Статус детектора LHCb @ LS2

Семинар ОФВЭ ПИЯФ

Итоги модернизации LHCb:

Декабрь 2018 – апрель 2022

12.04.2022

Олег Маев (ЛБФ ОФВЭ) on behalf of cavemans

План доклада

- ***LHCb детектор и его текущая модернизация.***
- ***Краткий обзор по статусу субдетекторов.***
- ***Роль ОФВЭ ПИЯФ в LHCb. Мюонный детектор. Вклад ПИЯФ.***
- ***Перспективы участия ПИЯФ в следующей модернизации.***

LHCb до U1 (RUN1 & RUN2)

А.А. Воробьёв был одним из тех, кто заложил основные принципы и идеи конструкции LHCb детектора в целом и Мюонной системы как она есть сейчас и вероятно будет.

The history of LHCb

https://link.springer.com/article/10.1140/epjh/s13129-021-00002-z

По физике LHCb ~30 заметок на сайте новостей науки ПИЯФ подготовил Алексей Дзюба!

https://hepd.pnpi.spb.ru/hepd/structure/div/lbp/LHCb-news.pdf

an excellent performance of LHCb detectors

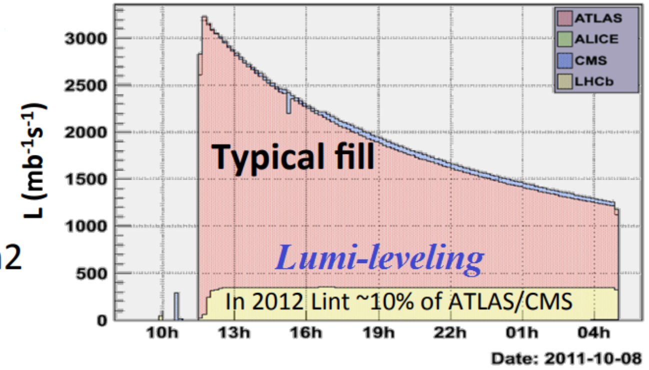
+ Lumi-leveling
+ deffered HLT (RUN1)
--> "TURBO" in RUN2

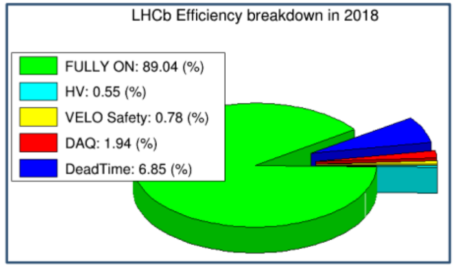
~ 10 fb^{-1} delivered Run1+ Run2

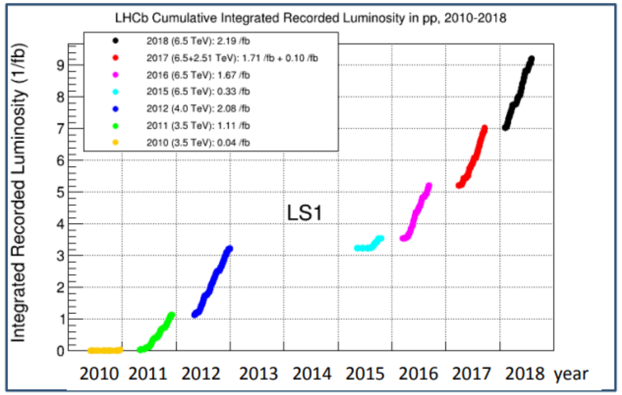
- 9 fb^{-1} recorded

Run1: 3fb^{-1} @7-8TeV.

Run2: 6fb^{-1} @13TeV.

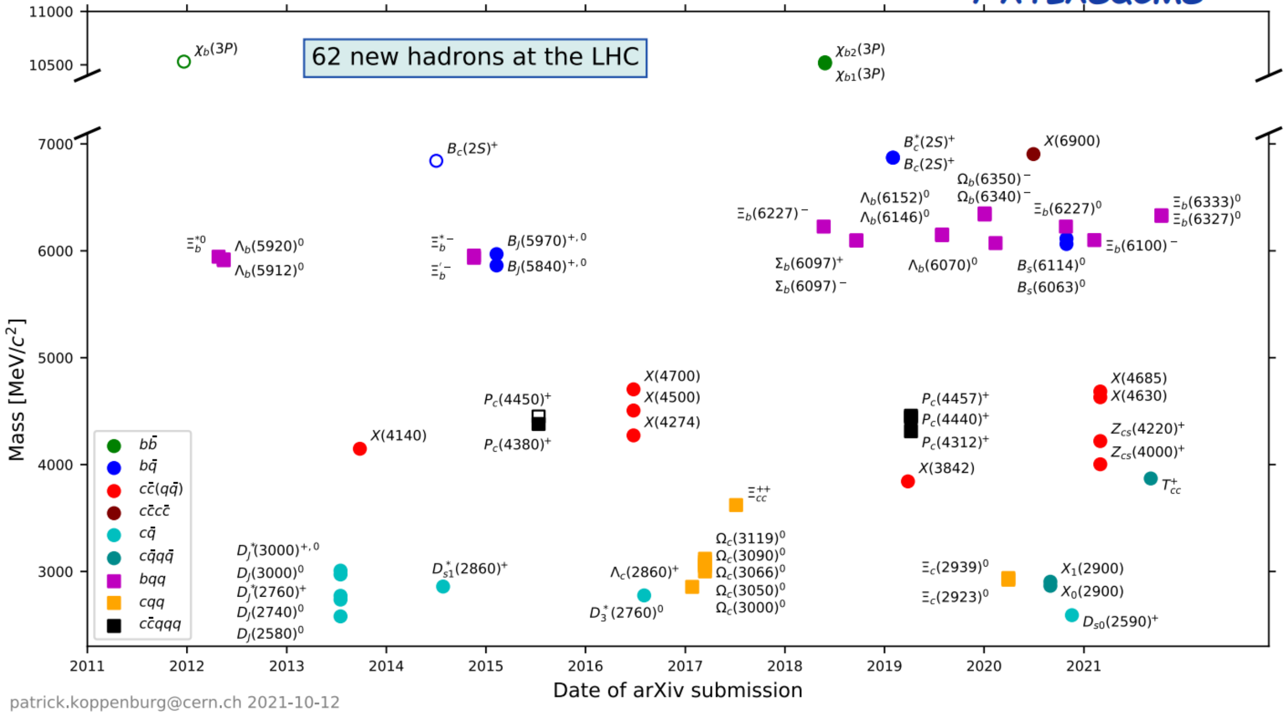






https://www.nikhef.nl/~pkoppenb/particles.html

55 LHCb
7 ATLAS&CMS

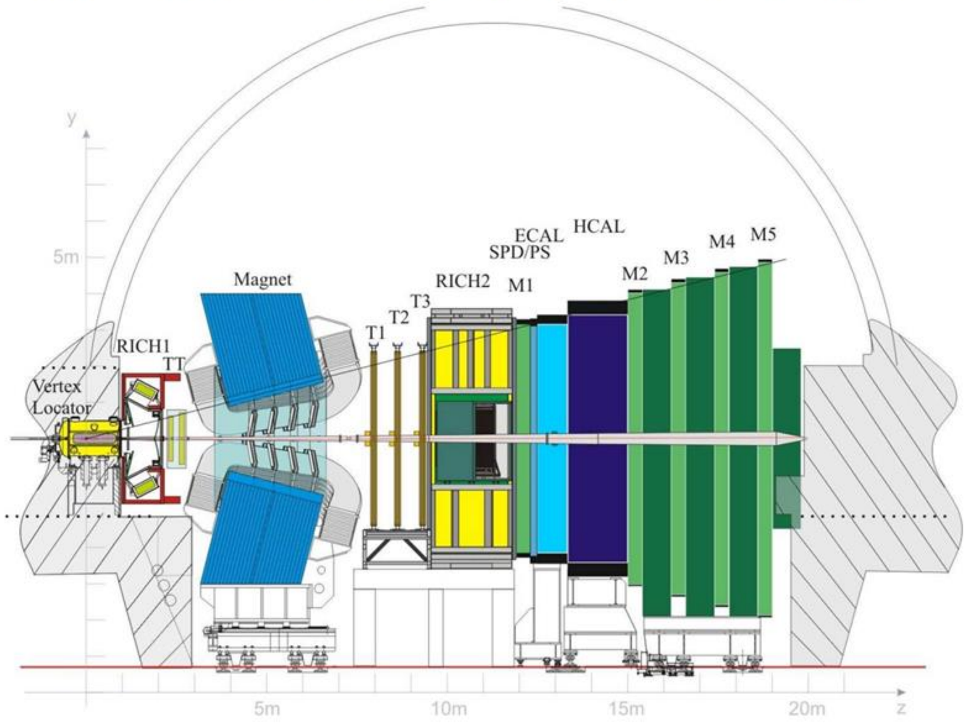


LHCb до и после LS2(U1)

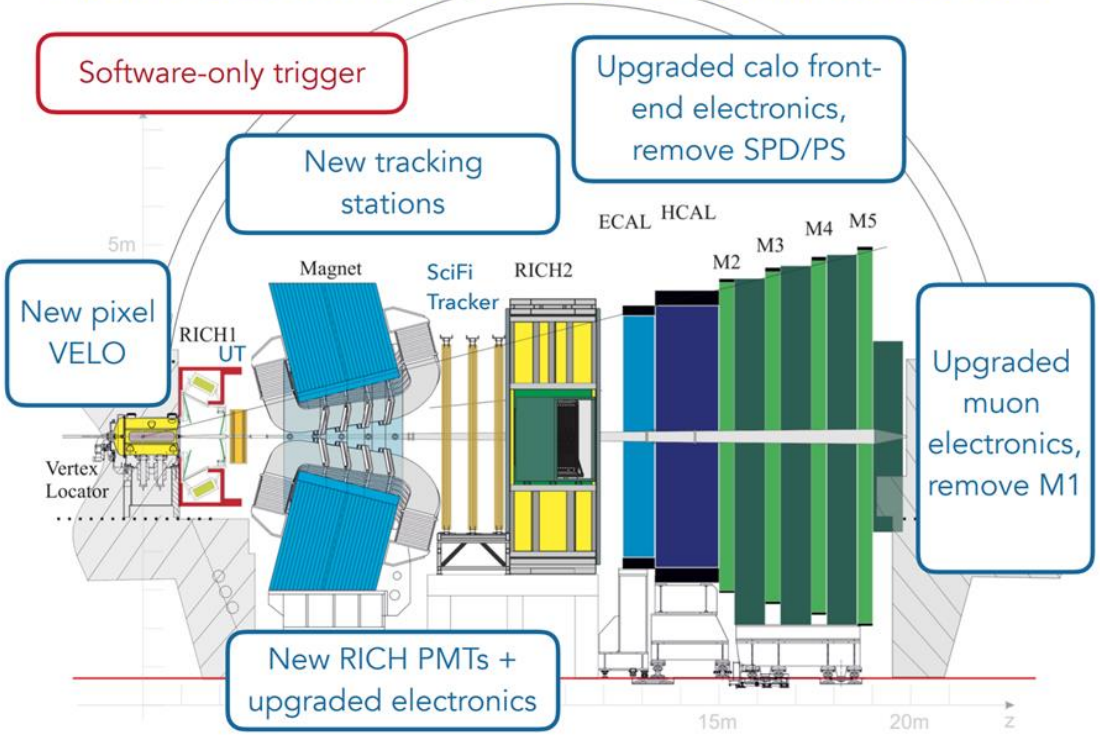
- ***LHCb детектор** (${L_{max}}$~4x10^{32}cm^{-2}s^{-1}, Rtr$_{max}$~1.1 MHz) **и текущая модернизация** (L_{max}~2x10^{33}cm^{-2}s^{-1}, Rtr$_{max}$~40MHz)*

Precision experiment studying b and c quark decays at the LHC

single arm spectrometer covering the pseudo-rapidity region $2 < \eta < 5$



Upgrade U1:
all detectors new but RICH2, CALOs and MUON



Детектор LHCb. Упрощённая схема. Слева в период RUN1 и RUN2. Справа после модернизации. В обоих случаях показан вид сбоку, в разрезе в плоскости оси пучка, проходящий сквозь детектор посередине. Светло-зелёным цветом обозначены мюонные станции.

Основная цель текущего U1

Многократное ускорение набора статистики:

- ***RUN1 & RUN2:** L_{max}~$4x10^{32}cm^{-2}s^{-1}$, Rtr_{max}~1.1 MHz → RUN3 & RUN4: L_{max}~$2x10^{33}cm^{-2}s^{-1}$, Rtr_{max}~40MHz*
- ***μ~1.1 → ~5 – число видимых детектором LHCb событий на одно столкновение пучков***

Данная задача достигается:

1. Увеличением гранулярности детекторов где это необходимо и возможно.

- ***В LHCb заменяются все детекторы на новые, кроме RICH2 (хотя вся инфраструктура детектора фактически обновляется), ECAL, HCAL (защитный кожух пучковой трубы был заменён на свинцовый, также центральные ячейки калориметра были замещены экраном из вольфрама для уменьшения фоновых загрузок в MUON) и MUON (в мюонном детекторе будут заменяться три центральных региона (всего 16) в станциях M2 и M3 (камеры производятся в ПИЯФ)***
- ***Несколько детекторов: M1, PS/SPD (из калориметрической системы) удаляется вообще.***

2. Полная замена считывающей электроники и систем сбора данных, а также всех компьютерных мощностей.

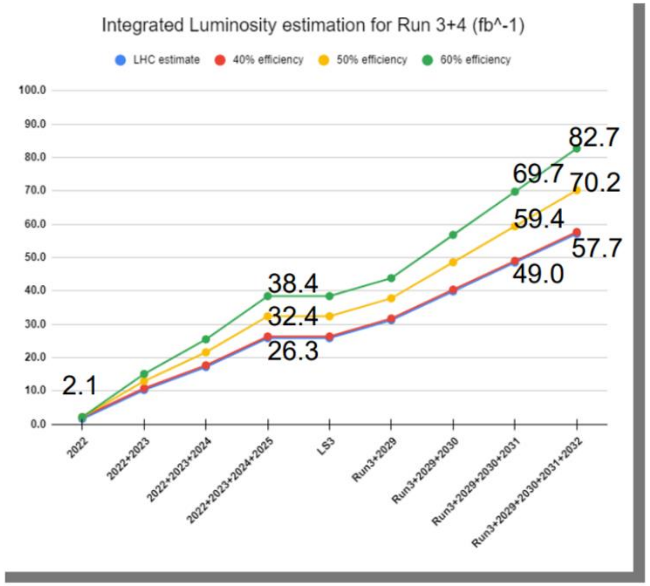
Luminosity perspectives in Run3 and Run4

Proposed changes (to be ratified)
- Run3 is 2022-2025 (+1 years) ✓
- LS3 is 2026-2028 (+6 months) ✓
- Run4 is 2029-2031(2032)
  (possibly 4 years to exploit HL-LHC as 1st is commissioning)

LHCb estimates based on:

- 2022: 75 days @ efficiency 33% (600h), leveling at 1×10^{33} cm^{-2} s^{-1} → 2.1 fb^{-1}
- 2024: 100 days**, extra EYETS, leveling at 2×10^{33} cm^{-2} s^{-1}
- 2023+2025: 125 days, leveling at 2×10^{33} cm^{-2} s^{-1}
  → Variable efficiency 40-60% every year gives between total integrated 26.3 and 38.4 fb^{-1}
- 2029: 1200h in SB out of 125 days, eff 25%, leveling at 2×10^{33} cm^{-2} s^{-1} → 5.4 fb^{-1}/y
- 2030++: SB of 125 days, leveling at 2×10^{33} cm^{-2} s^{-1}
  → Variable efficiency 40-60% every year gives between total integrated Run3+Run4 57.7 and

* SB=stable beam



https://arxiv.org/pdf/1808.08865.pdf

LHCb physics reach with the Upgrade-I and Upgrade-II

Aim at collecting 50 fb^{-1} in Run3-4 and 300 fb^{-1} in Run5-6

✓ Collected ~9 fb^{-1} of data in Run1-2

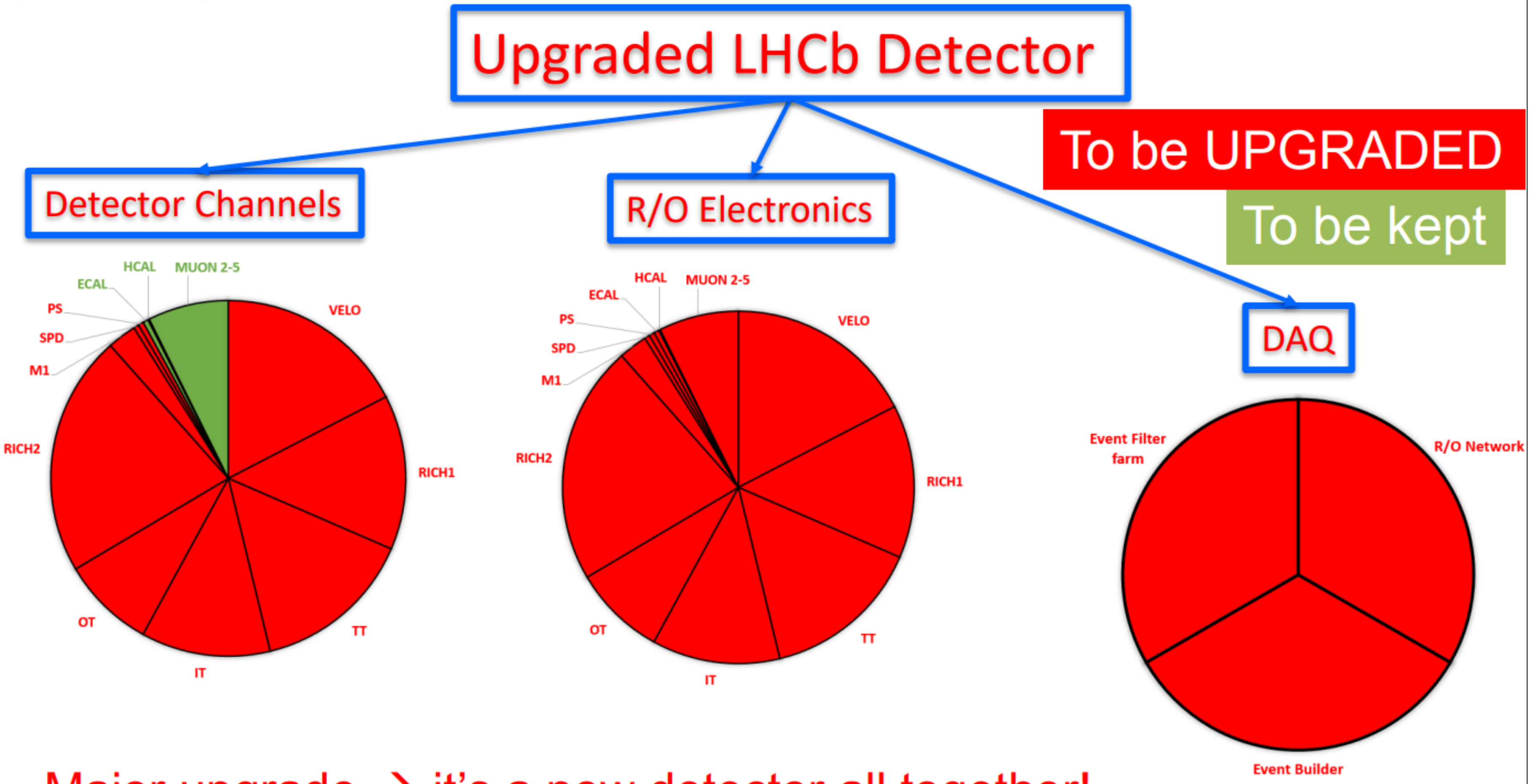
Table 10.1: Summary of prospects for future measurements of selected flavour observables for LHCb, Belle II and Phase-II ATLAS and CMS. The projected LHCb sensitivities take no account of potential detector improvements, apart from in the trigger. The Belle-II sensitivities are taken from Ref. [608].

Observable	Current LHCb	LHCb 2025	Belle II	Upgrade II	ATLAS & CMS
EW Penguins					
R_K $(1 < q^2 < 6\,\text{GeV}^2c^4)$	0.1 [274]	0.025	0.036	0.007	–
R_{K^*} $(1 < q^2 < 6\,\text{GeV}^2c^4)$	0.1 [275]	0.031	0.032	0.008	–
R_ϕ, R_{pK}, R_π	–	0.08, 0.06, 0.18	–	0.02, 0.02, 0.05	–
CKM tests					
γ, with $B_s^0 \to D_s^+ K^-$	$(^{+17}_{-22})^\circ$ [136]	4°	–	1°	–
γ, all modes	$(^{+5.0}_{-5.8})^\circ$ [167]	1.5°	1.5°	0.35°	–
$\sin 2\beta$, with $B^0 \to J/\psi K_S^0$	0.04 [609]	0.011	0.005	0.003	–
ϕ_s, with $B_s^0 \to J/\psi\phi$	49 mrad [44]	14 mrad	–	4 mrad	22 mrad [610]
ϕ_s, with $B_s^0 \to D_s^+ D_s^-$	170 mrad [49]	35 mrad	–	9 mrad	–
$\phi_s^{s\bar{s}s}$, with $B_s^0 \to \phi\phi$	154 mrad [94]	39 mrad	–	11 mrad	Under study [611]
a_{sl}^s	33×10^{-4} [211]	10×10^{-4}	–	3×10^{-4}	–
$\lvert V_{ub}\rvert/\lvert V_{cb}\rvert$	6% [201]	3%	1%	1%	–
$\boldsymbol{B_s^0, B^0 \to \mu^+\mu^-}$					
$\mathcal{B}(B^0 \to \mu^+\mu^-)/\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	90% [264]	34%	–	10%	21% [612]
$\tau_{B_s^0 \to \mu^+\mu^-}$	22% [264]	8%	–	2%	–
$S_{\mu\mu}$	–	–	–	0.2	–
$\boldsymbol{b \to c\ell^-\bar{\nu}_l}$ **LUV studies**					
$R(D^*)$	0.026 [215, 217]	0.0072	0.005	0.002	–
$R(J/\psi)$	0.24 [220]	0.071	–	0.02	–
Charm					
$\Delta A_{CP}(KK - \pi\pi)$	8.5×10^{-4} [613]	1.7×10^{-4}	5.4×10^{-4}	3.0×10^{-5}	–
A_Γ $(\approx x \sin\phi)$	2.8×10^{-4} [240]	4.3×10^{-5}	3.5×10^{-4}	1.0×10^{-5}	–
$x \sin\phi$ from $D^0 \to K^+\pi^-$	13×10^{-4} [228]	3.2×10^{-4}	4.6×10^{-4}	8.0×10^{-5}	–
$x \sin\phi$ from multibody decays	–	$(K3\pi)$ 4.0×10^{-5}	$(K_S^0\pi\pi)$ 1.2×10^{-4}	$(K3\pi)$ 8.0×10^{-6}	–

U1 - Новый детектор LHCb!

Upgrade-I for Run 3

CERN-LHCC-2012-007



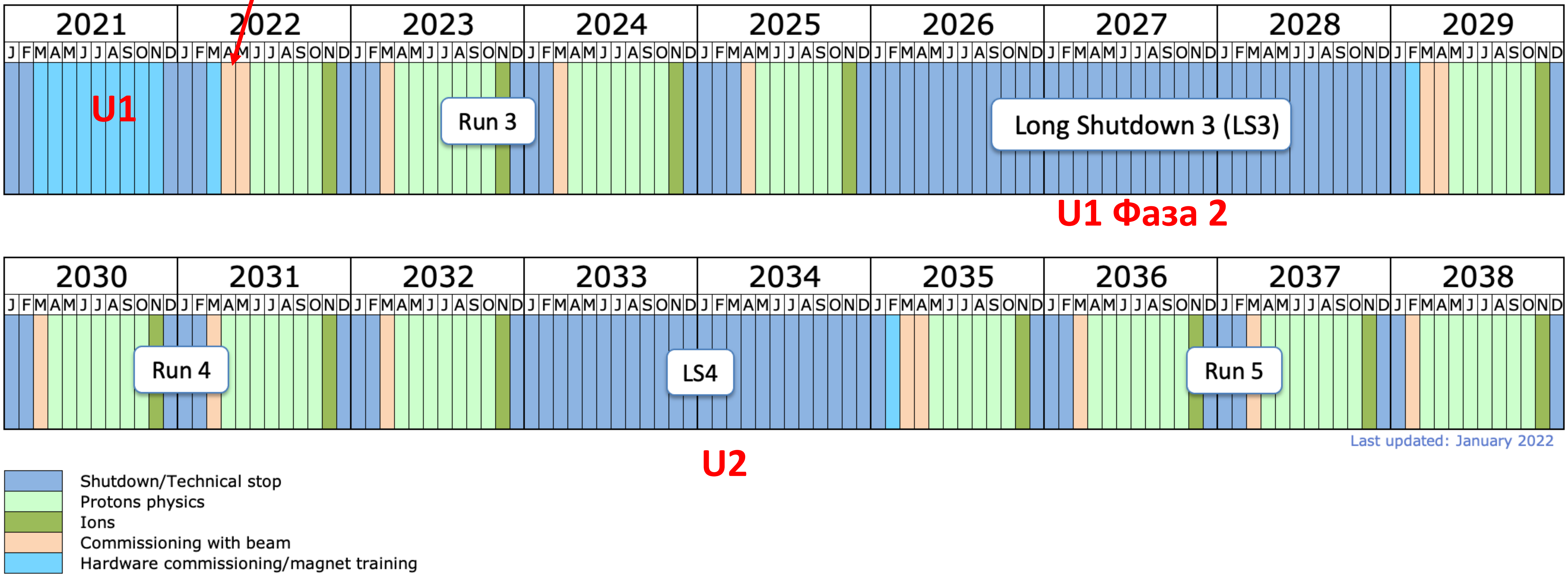
Major upgrade → it's a new detector all together!

LHC календарь

Сейчас

Longer term LHC schedule

In January 2022, the schedule was updated with long shutdown 3 (LS3) to start in 2026 and to last for 3 years.



LHC official schedule in 2022

First beams in the LHC around ~~13th~~ of April **24th**

First Stable Beams expected around 15th June

https://indico.cern.ch/event/1100341/contributions/4629160/attachments/2356849/4022146/rs20211130_2022-DraftLHCSchedule.pdf

2022 – Q1

- **LHC tunnel and experimental caverns closed Thursday afternoon 24.03** to enable DSO test on 25.03
- Interleaved magnet training and machine check-out starts Thu. evening 24.03
- Vacuum valves open, except S23 to allow for cold check-out activities on 28.03
- **During week 13 punctual access to experimental caverns possible** – *coordinated by BE-OP*
- **Large uncertainty on duration of the magnet training** – *potential to start beam commissioning earlier*

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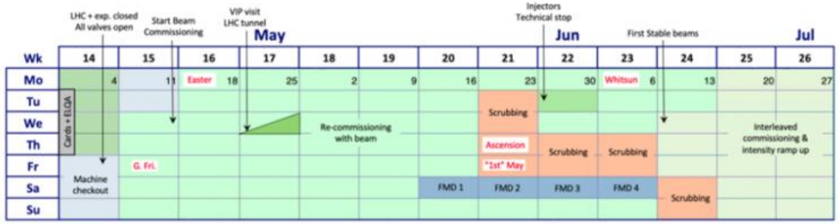
2022 – Q2



- **Tue. 05.04 until Wed. 07.04 incl. re-installation of original QPS boards and ELQA**
- **LHC tunnel and Experimental caverns closed and all vacuum valves open on Fri. 08.04**
- Start of beam commissioning Wed. 13.04
- Four floating MDs that removed the MD block initially scheduled in week 40

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2022 – Q3

- Collisions with >1200 bunches Mon. 18.07
- **Beam stop for FASER and SND to install emulsion not yet included**
- **A long stable running period with 25 ns beam during the summer**
- **Wk 36 - wk 38: Special Runs, MD block 1, Technical stop**

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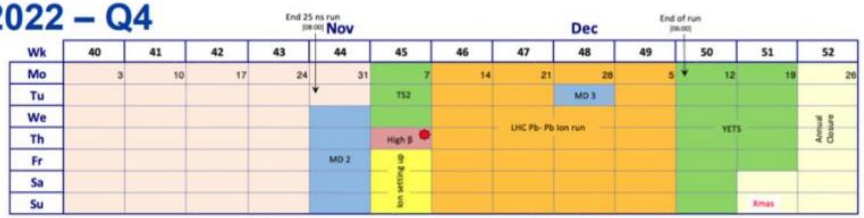
2022 – Q4



- **Wk 44: MD block 2**
- **Wk 45**
  - Technical stop – mainly for experiment reconfiguration for Pb-Pb ions run
  - High beta run
  - Setting up of Pb ion beam in the LHC
- **Details of the Pb-Pb ion run to be defined – *modalities of the p-p reference run (LPC)***
- **Wk 48 MD block 3 (ions)**
- **Mon. 12.12 end of 2022 run**

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LHCb:

1. ***Шахта была закрыта для постоянного доступа 24-ого марта 2022 (сейчас снова открыта до 18.04)***
2. ***Первые столкновения – середина мая***
3. ***Первый пучок для физики ожидается в июне***
4. ***Техническая остановка***

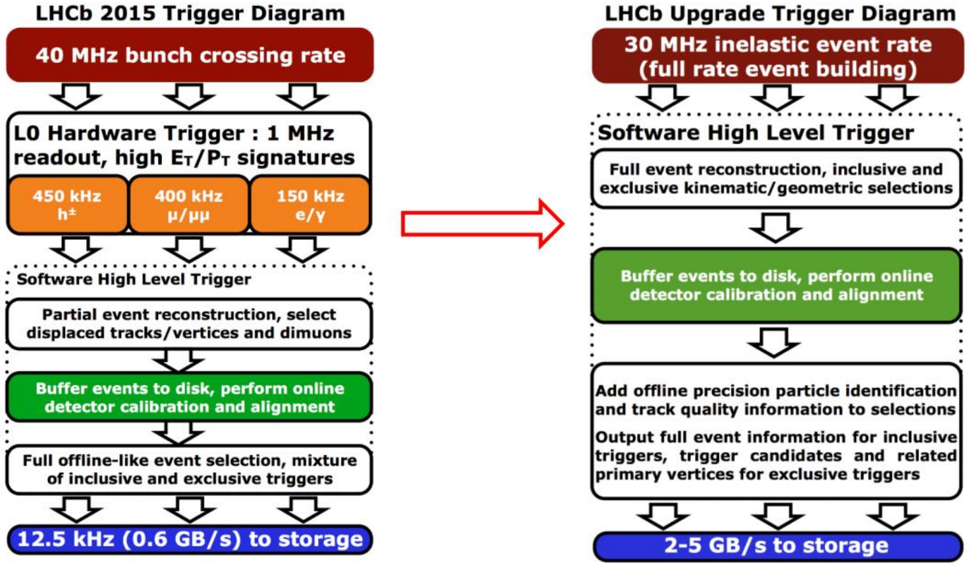
Trigger

Статус: ввод в эксплуатацию.

LHCb Upgrade-I challenges

Remove L0 trigger!

Achieve same reconstruction performance in harsher environment
Record all bunch crossings with fully software trigger



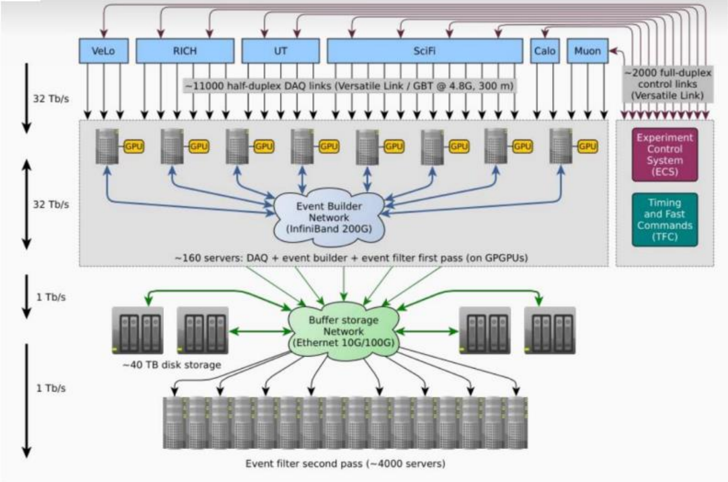
L0 trigger	E_T/p_T threshold			SPD threshold
	2015	2016	2017	
Hadron	> 3.6 GeV	> 3.7 GeV	> 3.46 GeV	< 450
Photon	> 2.7 GeV	> 2.78 GeV	> 2.47 GeV	< 450
Electron	> 2.7 GeV	> 2.4 GeV	> 2.11 GeV	< 450
Muon	> 2.8 GeV	> 1.8 GeV	> 1.35 GeV	< 450
Muon high p_T	> 6.0 GeV	> 6.0 GeV	> 6.0 GeV	none
Dimuon	> 1.69 GeV^2	> 2.25 GeV^2	> 1.69 GeV^2	< 900

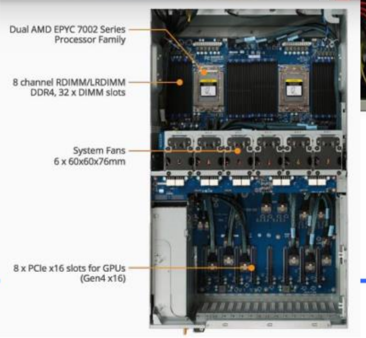
Table 1. The L0 thresholds for the different trigger lines used to take the majority of the data for each indicated year. Technical trigger lines and those used for special areas of the physics programme are excluded for brevity. The Hadron, Photon, and Electron trigger lines select events based on the E_T of reconstructed ECAL and HCAL clusters. The Muon, Muon High, and Dimon trigger lines select events based on the p_T reconstructed MUON stubs, where the Dimuon selection is based on the product of the largest and second largest p_T stubs found in the event. As some of the subdetectors also read out hits associated to other bunch crossings, the use of bandwidth is further optimised in most of the L0 lines by rejecting events with a large E_T (> 24 GeV) for the previous bunch crossing [19].

https://arxiv.org/abs/1812.10790

CERN-LHCC-2014-016

Trigger-less readout system





PCIe40+ GPU server

- Back-End electronics on surface in data center
- ~19000 long distance optical fibers (99.75% yield)
- Common Back-End boards (PCIe40)
  - ✓ Large FPGA and optical links (48 x 10 Gbps)
  - ✓ Flavor of firmware defines functionality
- Total effective bandwidth of 32 Tbps

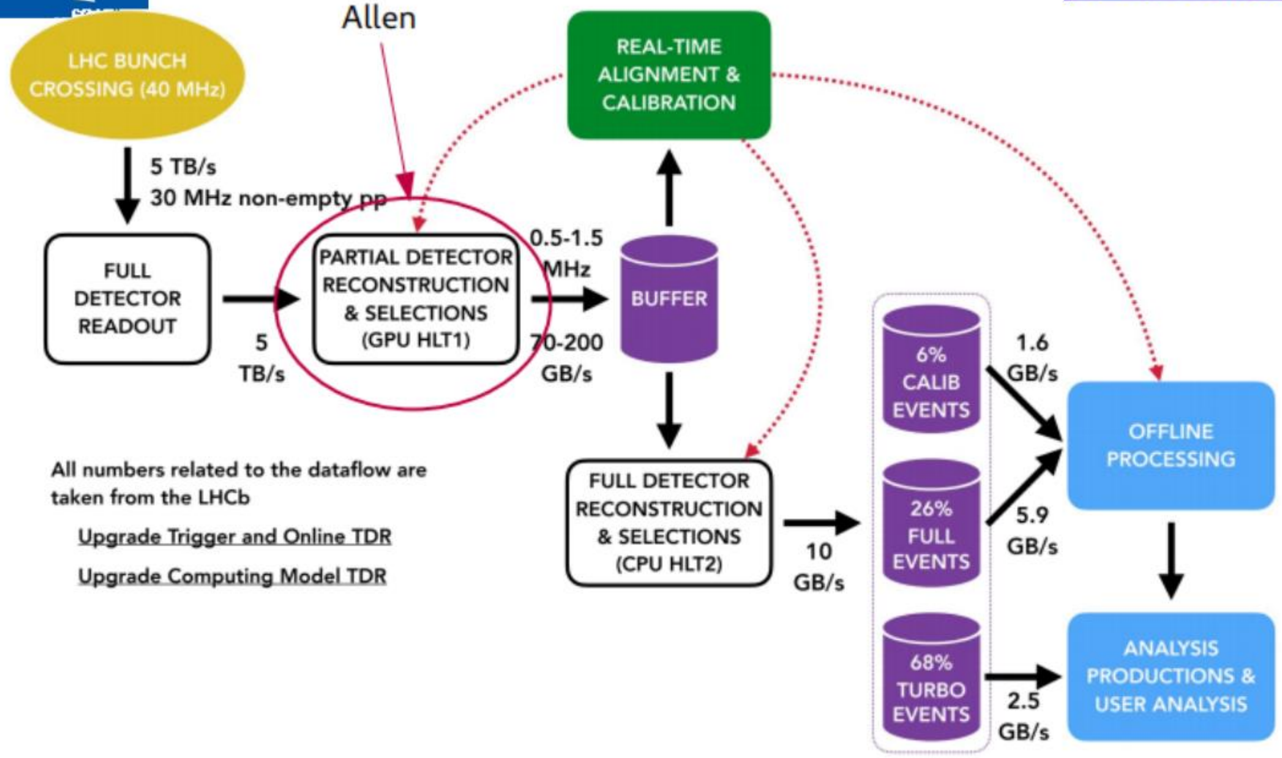
7

Статус: ввод в эксплуатацию.

Trigger

Data processing and trigger

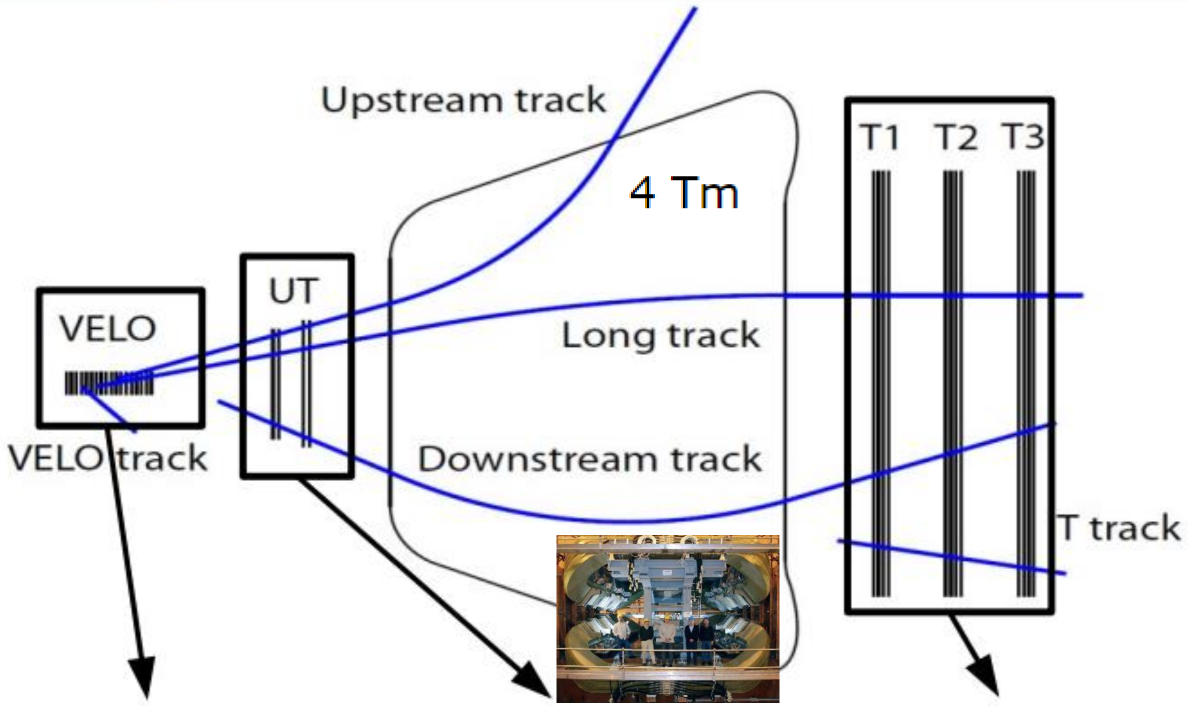
CERN-LHCC-2018-007



- HLT1 reconstruction in GPUs
- Offline reconstruction in HLT2
- TURBO model for exclusive selections

Comput. Phys. Commun. **208** 35-42
Run 2: 2019 *JINST* **14** P04013
GPU: Comput Softw Big Sci 4, 7 (2020)
TURBO: 2019 *JINST* **14** P04006

LHCb Tracking System Upgrade



$\sigma(IP) \approx 20\mu m$
$\delta p/p = 0.4 - 0.6\ \%$
$\epsilon_{track} > 96\ \%$

VELO
Vertex Locator
Silicon strips
⇩ **Upgrade**
PIXEL VELO
Vertex Locator
Silicon pixel

TT
Tracker Turicensis
Silicon strips
⇩ **Upgrade**
UT
Upstream Tracker
Silicon strips

IT + OT
Downstream tracking
Silicon strips + straw tubes
⇩ **Upgrade**
SciFi
Downstream tracking
Scintillating fibers

LHCb tracking system

Tracks reconstructed by linking segments from one or more detectors

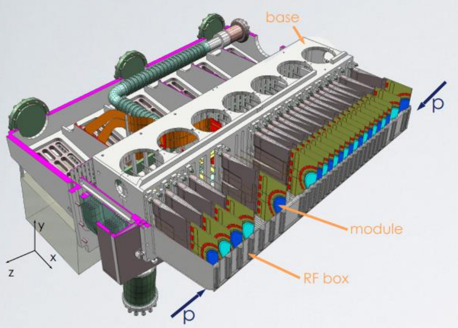
Three tracking detectors:

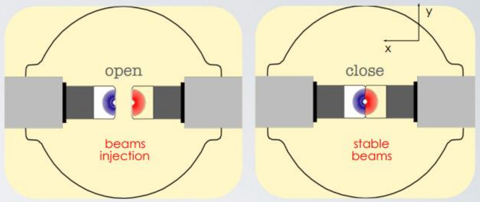
- **Vertex Locator**
  Precision tracking near the interaction region
- **TT → UT**
  Track reconstruction before the magnet
- **IT+OT → SciFi**
  Track reconstruction after the magnet. Important for recconstructing long lived particles

All the tracking detectors will be upgraded after LS2

VELO

Старый детектор: ***JINST*** **3 (2008) S08005, 2014** ***JINST*** **9 P09007**





- 2 retractable detector halves at 5 (30) mm from beam when closed (open).
- 21 stations per half with an R and φ sensor.
- First active strip @ 8 mm from the beam.
- Operates in secondary vacuum.
- 300 μm Al foil separates detector from beam vacuum.
- CO_2 cooling system (operates @ -30°C, sensors @ -10°C).

39th International Conference on High Energy Physics 4 July 7th, 2018

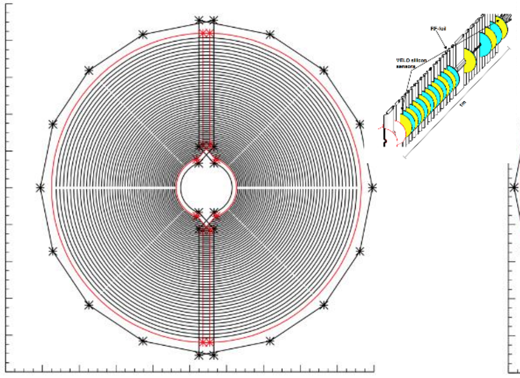


Figure 2: The layout of the R sensor strips showing two sensors on opposite sides of the detector, for clarity only every 10th strip is drawn. The outline of the silicon sensor is marked, as is the outline of the sensitive area of the sensor. The scale has major tick marks at 1 cm intervals.

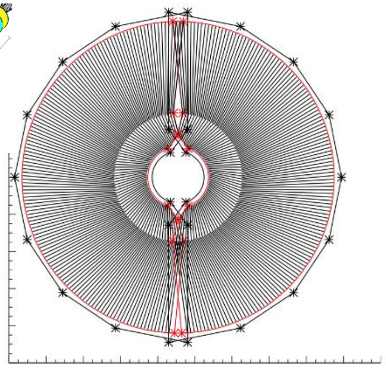
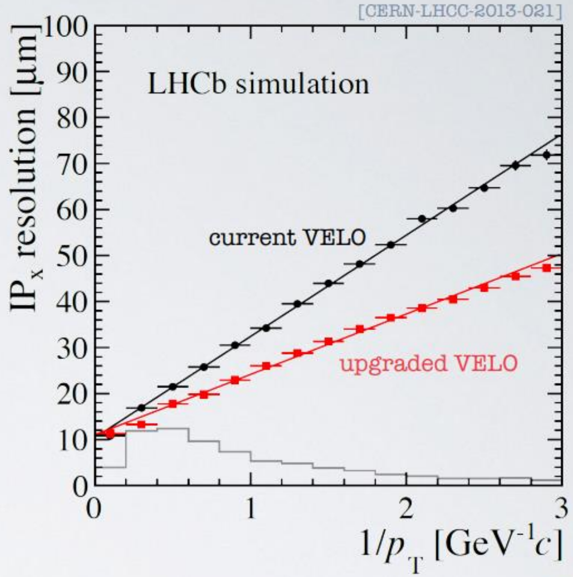
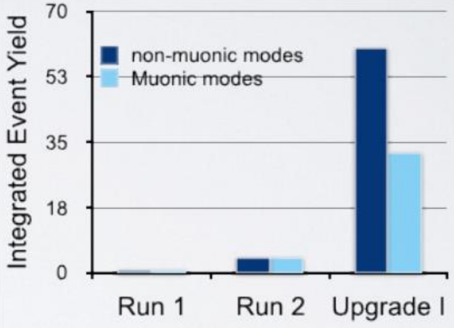


Figure 3: The layout of the Phi sensor strips showing two sensors on opposite sides of the detector, for clarity only every 10th strip is drawn. The outline of the silicon sensor is marked, as is the outline of the sensitive area of the sensor. The scale has major tick marks at 1 cm intervals.

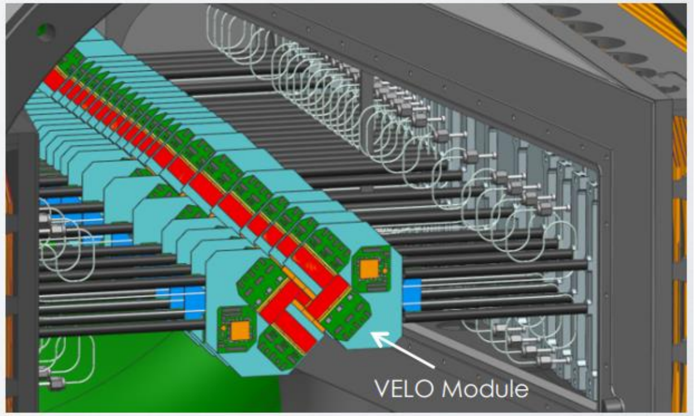
LHCb Upgrade motivation

- To be operated @ 40 MHz and 2×10^{33} $cm^{-2}s^{-1}$ and at 3.5 mm from the beams
  - 2.8 Tb/s data rates
  - 8×10^{15} 1 MeV n_{eq} cm^{-2} max fluence
  - sensors to be kept < -20 °C
- Improve detector performance
  - track reconstruction
  - resolution
- The plan:
  - new pixel detector
    - no ghost tracks
    - faster reco algorithm
  - new front-end electronics
  - thinner RF-foil
  - more efficient cooling interface





many hadronic channels saturate, due to energy cuts in the trigger



Статус: ввод в эксплуатацию первой установленной половинки. Может быть вторая появится в Мае.

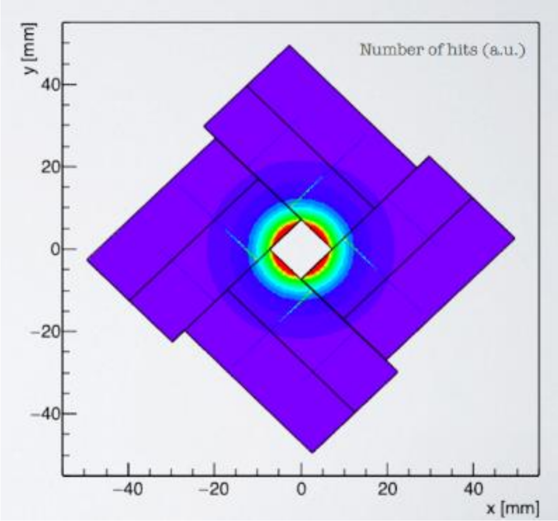
VELO

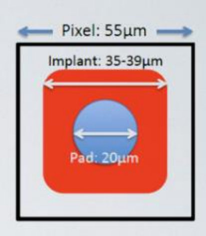
Upgraded Vertex Detector

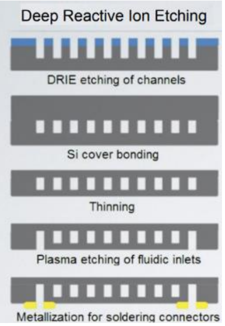
CERN-LHCC-2013-021

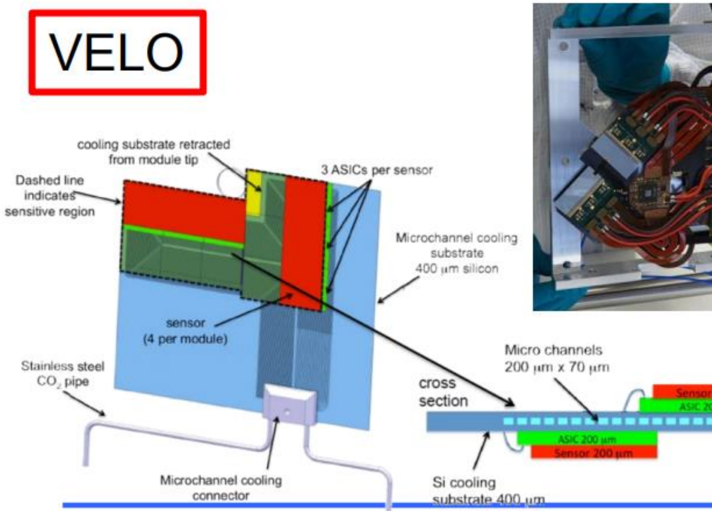
- Two movable halves: get closer to beam (5mm to 3.5mm) to improve IP resolution
  - ✓ 52 modules for a total of 41M pixels covering total area ~ 1.2 m^2
- Hybrid Pixel Silicon detector modules cooled down with fluid (bi-phase CO_2) which passes under the chips in etched micro-channels (T < - 20 C)
  - ✓ 200 µm n-on-p sensor tiles
- New ASIC VeloPix, ~20 Gbps in hottest ASIC and total of ~3 Tbps

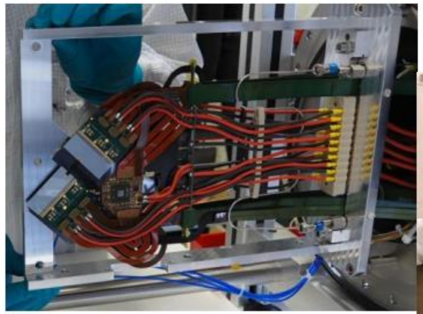
Feature	old VELO	VELO Upgrade I
operation	2010 – 2019	2021 – 2030
Sensors	R, ϕ strips, semicircular	pixels, L shaped geometry
	173,032 strips (~0.2 M)	41 M pixels
Distance From Beam	8.2 mm	5.1 mm
Maximum Fluence	4.3×10^{14} 1 MeV neq cm^{-2}	8×10^{15} 1 MeV neq cm^{-2}
HV Tolerance	500 V	1000 V
ASIC Readout Rate	1 MHz	40 MHz
Total Data Rate	~150 Gb/sec	2.8 Tb/sec
Power Consumption	~ 0.8 kW	~ 1.6 kW
Operating Temperature	~ -8 °C	~ -25 °C

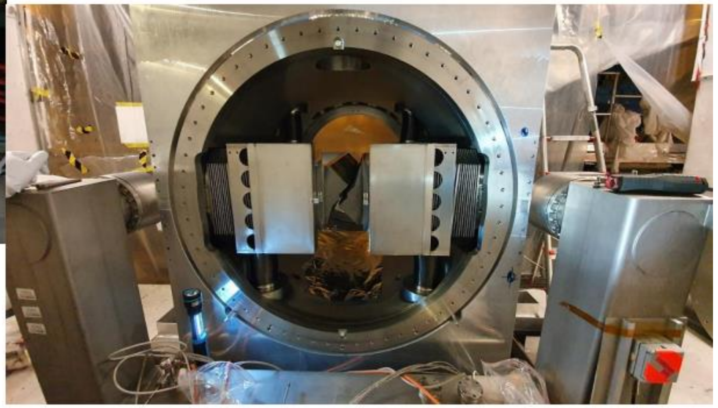










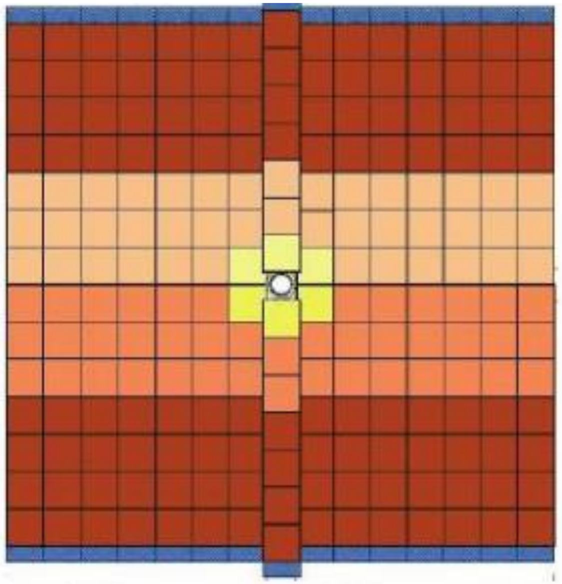


Статус: не готов

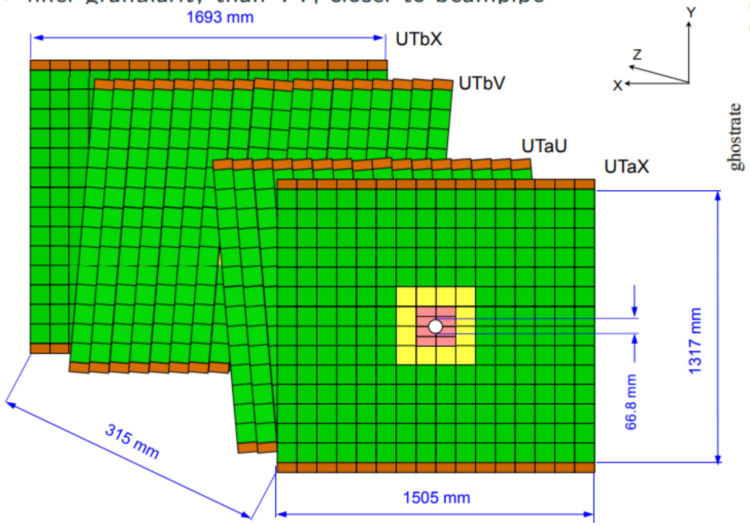
TT (Tracker Turicensis) → UT

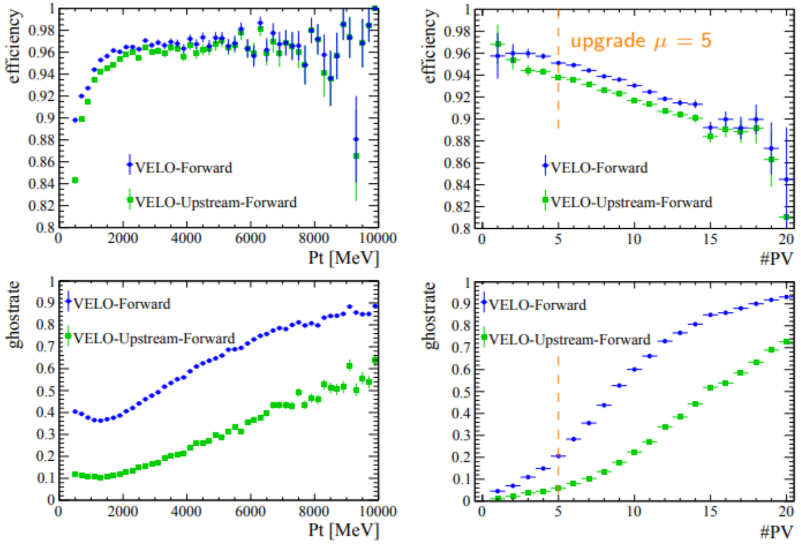
- improve p_T resolution and suppress ghost tracks
- trigger speed up: using Velo+UT matching, very low-p_T tracks can be removed ($p_T < 0.4$ GeV) and search window in SciFi tightened

TT



- four detection planes, $\sim 2\ m^2$ each
- two planes with vertical strips, two rotated by $\pm 5°$
- finer granularity than TT, closer to beampipe

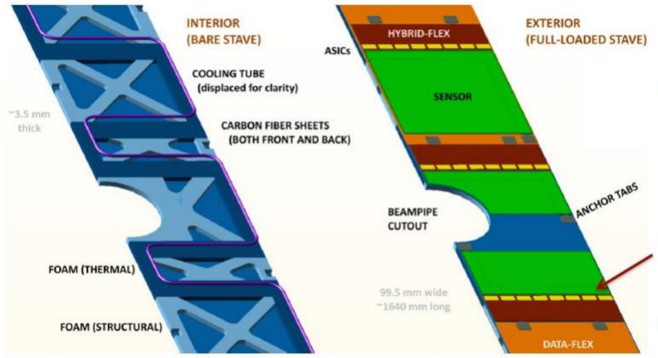




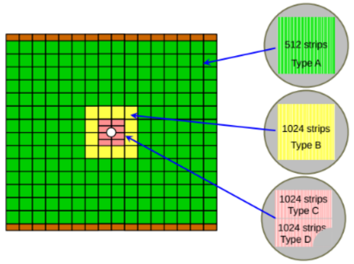
Sensor	Type	Thickness	Pitch	Length	Strips	# sensors
A	p-in-n	320 μm	187.5 μm	99.5 mm	512	888
B	n-in-p	250 μm	93.5 μm	99.5 mm	1024	48
C	n-in-p	250 μm	93.5 μm	50 mm	1024	16
D	n-in-p	250 μm	93.5 μm	50 mm	1024	16

- ❑ Current detector – TT
- ❑ Four planes of silicon strip detectors vital for reconstructing tracks outside VELO
- ❑ Not radiation hard enough for the upgrade
- ❑ New front-end read-out electronics needed for 40 MHz trigger
- ❑ Need finer granularity to cope with higher occupancies

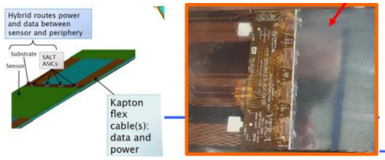
❑ Stave design well advanced – now switching to construction phase



- ❑ Staves provide support for 14 or 16 hybrid modules, data flex connectors and CO_2 cooling tubes
- ❑ Staves are $\sim 10\ cm$ wide and $\sim 1.6\ m$ long



- ❑ Dedicated read-out ASIC chip SALT (**S**ilicon **A**SIC for **L**HCb **T**racking) is being extensively tested
- ❑ Second engineering run before summer



IT(ST)+OT → SciFi

Статус: установлен
2017 JINST 12 P11016

Gaseous straw tube detector and covers an area of 5 x 6 m^2
12 double layers of straw tubes (3 stations, each station consists of 4 module layers)

Each module consists of 2 staggered straw tube monolayers

Number of straws in monolayer: 64

Total number of straws: 53760

Inner diameter of straw tubes: 4.9mm

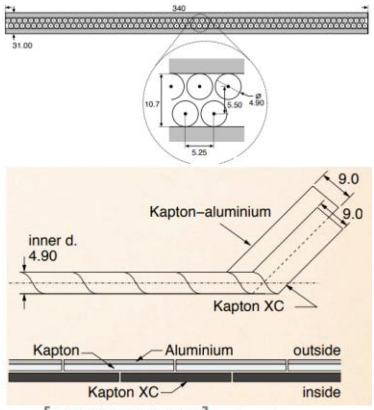
Straw tube length: 2.4m

Glue: Araldite Epoxy AY103-1

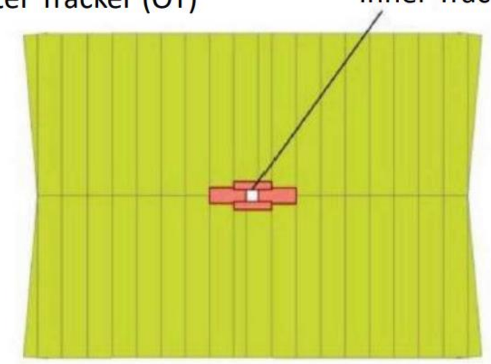
Cathode: Kapton XC

Anode: Gold+Tungsten (HV: +1550V)

Gas: Ar/CO_2/O_2 : 70/28.5/1.5 %



[LHCB-TDR-015]



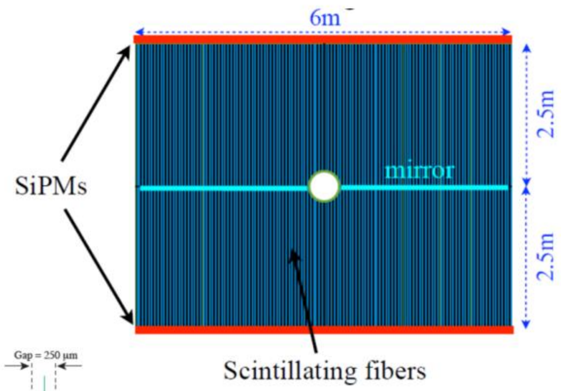
- ❑ Current detector – IT and OT
- ❑ Four planes of silicon sensors close to the beam (high η tracks)
- ❑ Four planes of straw tube gas detectors outside
- ❑ New read-out electronics needed in both cases
- ❑ Cannot cope with high occupancies

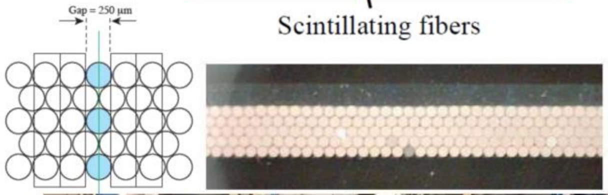
CERN-LHCC-2014-001

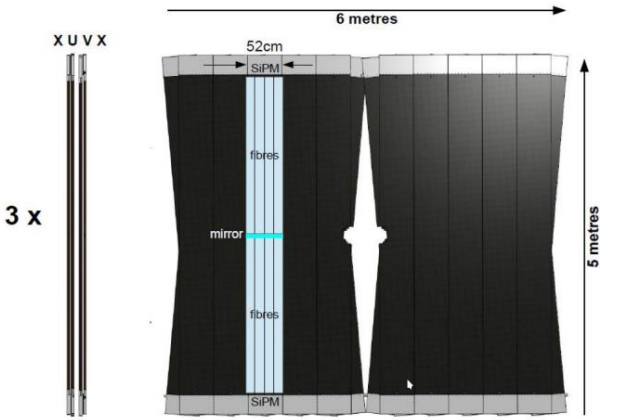
Scintillating Fibers (SciFi)

Completely new detector based on Scintillating Thin Fibers

- blue-emitting multi clad fibers, laid down as a mat
- 2.4m long, 250 um diameter (2.8 ns decay time)
- 12 layers of modules in different layout 3 x (x-u-v-x)
- read out with SiPM at -40C
- new ASIC, 64 channels 130 nm CMOS
  - ADC with 3 hardware thresholds
- FPGA on FE cluster board







Schematic yz- and xy-view of one SciFi tracking station. It is composed out of 4 layers with vertical (x) and rotated (u,v) fibre orientations.
Each layer is made of 10 or 12 individual fibre modules.

Статус: готовы

RICH1 & RICH2

Заменили всё, кроме зеркал в RICH2

In order to allow operation of the RICH detector system at the upgrade luminosity the RICH 1 optical system is being redesigned: in particular the focal length of the spherical mirrors will be increased from 2.7 m to 3.7 m to reduce the hit occupancy on the photodetectors. The cooling system and the support mechanics will also be modified, with the goal of allowing stable operation and easier access to the detector during maintenance.

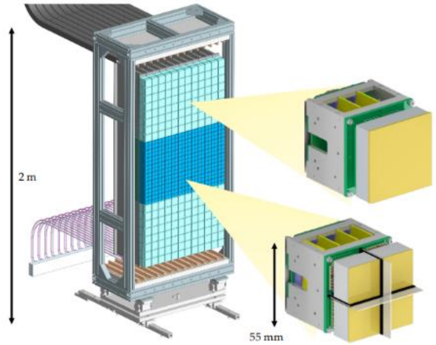


Figure 1: CAD model of the RICH 2 photodetector plane. The two types of elementary cell described in the text are shown.

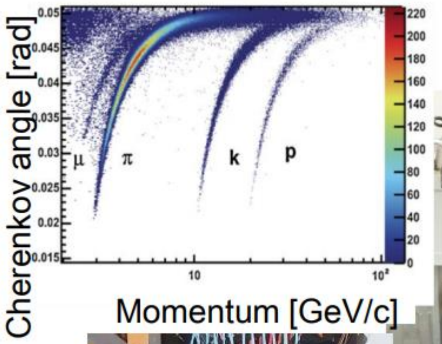
Upgraded Particle ID

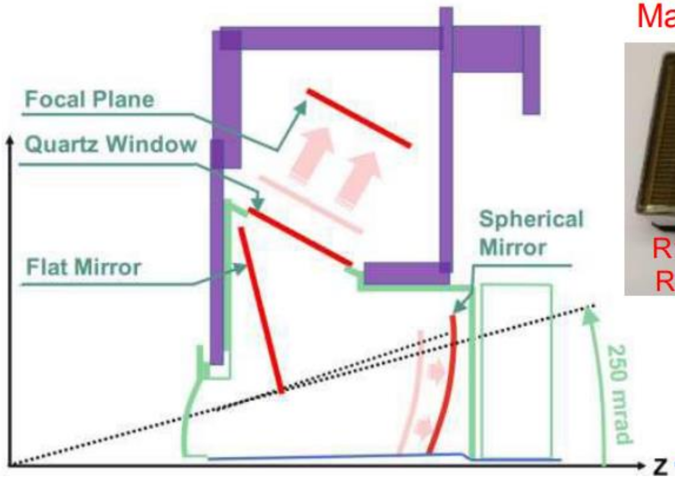
CERN-LHCC-2013-022

Ring-Imaging Cherenkov (RICH)

Maintain excellent Particle ID:

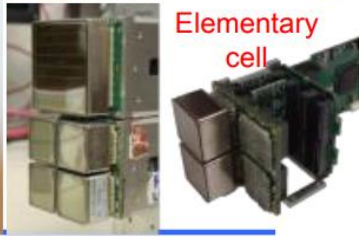
- RICH1 with C_4F_{10} (10-65 GeV/c)
- RICH2 with CF_4 (15-100 GeV/c)
  - ✓ Replace HPDs with MaPMTs
  - ✓ New Readout ASIC (CLARO)
  - ✓ FPGA on FE boards for serialization and latching of signal





MaPMTs (Hamamatsu)

RICH2



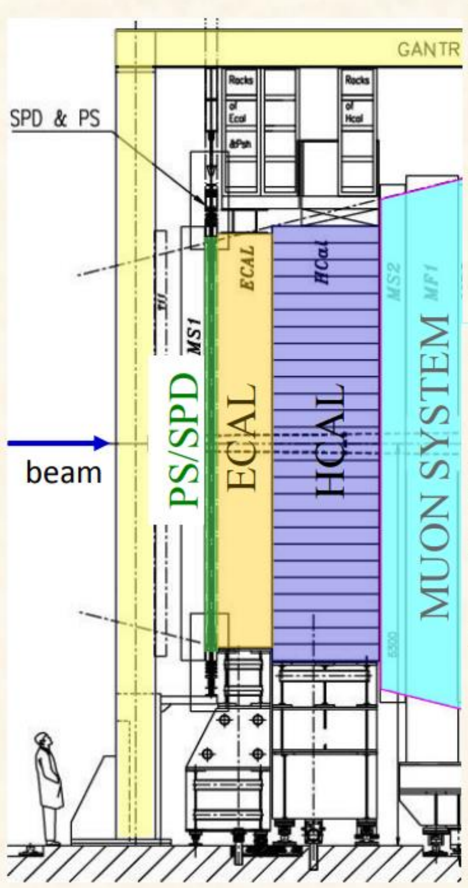
PS/SPD + ECAL + HCAL → ECAL + HCAL

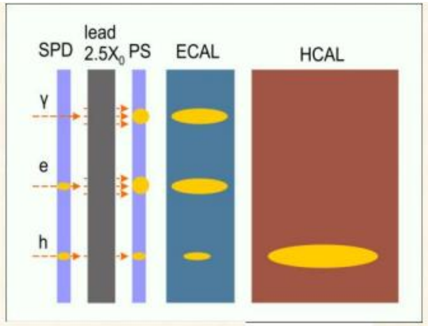
Purpose of the calorimeter system:

- Provide E_T measurement to level-0 trigger → readout every 25 ns
- Provide EM nature of trigger candidates (h,e,γ) → SPD, PS, ECAL & HCAL

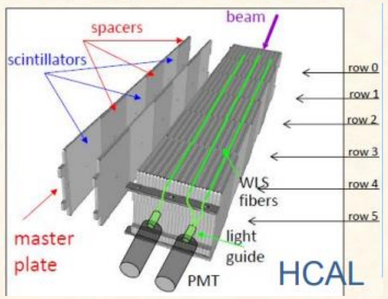
Choice of technology

- ECAL: good EM resolution (10%/√E + 1%), fast response (25 ns), rad. hardness of 250 krad/year in inner, small segmentation (energetic π^0 & minimal pile-up), cost effective.
- HCAL: moderate resolution (80%/√E + 10%), fast, 50 krad/year in inner, cost effective.





- Hardware Level-0 trigger
  - SPD multiplicity ← CALORIMETRY
  - search for a highest ET object:
    - E_T (e±/γ) > 2.7 GeV ← CALORIMETRY
    - E_T (hadr.) > 3.6 GeV ← CALORIMETRY
    - p_T (μ) > 1.4 GeV/c ← MUON ID system



- solid angle coverage 300x250 mrad
- distance from IP: ~12.5 m
- four subdetectors: SPD,PS,ECAL,HCAL
- based on scint./WLS technique, light readout with PMT
- provides:
  - L0 trigger on high p_T $e^{\pm}$, π^0, γ, hadron
  - precise energy measurement of $e^{\pm}$ and γ
  - particle identification: $e^{\pm}$/γ/hadron; contributes to Muon ID (HCAL).

Yu. Guz CHEF2017 Upgrade of the LHCb Calorimeter system

Статус: готовы

LHCb Upgrade EoI: CERN-LHCC-2008-007
LHCb Upgrade LoI: CERN-LHCC-2011-001
LHCb Upgrade Framework TDR: CERN-LHCC-2012-007
LHCb Phase-2 Upgrade EoI: CERN-LHCC-2017-003

ECAL + HCAL

Present Calorimeter detectors will be kept:

- ECAL (Shashlik 25 X_0 Pb + scintillator)
- HCAL (TileCal Fe + scintillator)
  - ✓ PS/SPD removed
- PMT gain reduced by a factor 5
- Front-End electronics redeveloped
  - For trigger-less readout and sending Non-Zero Suppressed data

MUON

U1: LS2 (phase 1)

- ***Замена всей контрольной и считывающей электроники (и всего что с ней связано) в детекторе для обеспечения перехода на передачу данных с частотой 40МГц.***

- ***M1 полностью удалена, поскольку в ней заметно теряется потребность в условиях 5-ого увеличения загрузок на физические каналы, т.е. станция будет перегружена физическими сигналами. Кроме того, полный отказ от HW триггера и, соответственно, роль мюонной системы в измерении поперечного импульса мюонов для триггера L0MUON, где наличие M1 обеспечивало 25-35% в эффективности разрешения по p_t . Новые трековые станции должны гарантировать полное и качественное замещение мюонной системы в этой роли.***

U1 (phase 2): RUN3 - LS3

- ***Замена камер в трёх центральных регионах в станциях M2 и M3 (M2R1, M2R2 и M3R1) на падовые камеры повышенной гранулярности. Разработка, конструкция, изготовление и ввод в эксплуатацию данных камер полностью лежит на ПИЯФ.***
- ***Замена HCAL на стенку из железа, бетона и вольфрама***

MUON. New Electronics.

На данный момент все работы в шахте успешно завершены.

Вся новая электроника установлена и введена в эксплуатацию на уровне детектора.

Сейчас отлаживаются все цепочки в новом Data center:

22 TELL40s (control and DAQ) – data servers – HLT – EB etc.

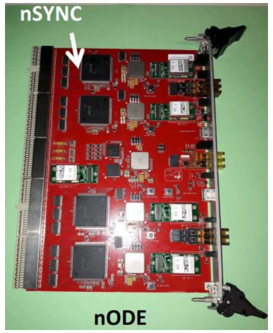
DCS – контроль над LV, HV, Gas, Temperature – в порядке (А. Чубыкин)

Самые большие проблемы остаются в ECS (контроль над FEE и DAQ).

nODE: 40 MHz readout board; each nODE equipped with 4 custom ASICS (nSYNC)

nSB, nPDM: system configuration and pulsing boards

nBP: custom Back Plane for nPDM/nSB crates



Board Type	Needed (+spares)	Produced	Tested	Installed	Installation completion percentage	Expected delivery and installation time	Comments
nODE	144(+46)	185/190	182	**144/144**	**100%**	Completed	All stations ok
nSB	120(+30)	150	150	**120/120**	**100%**	Completed	All stations ok
nPDM	8(+6)	14	14	**8/8**	**100%**	Completed	All stations ok
nBP	8(+6)	14	14	**8/8**	**100%**	Completed	All stations ok

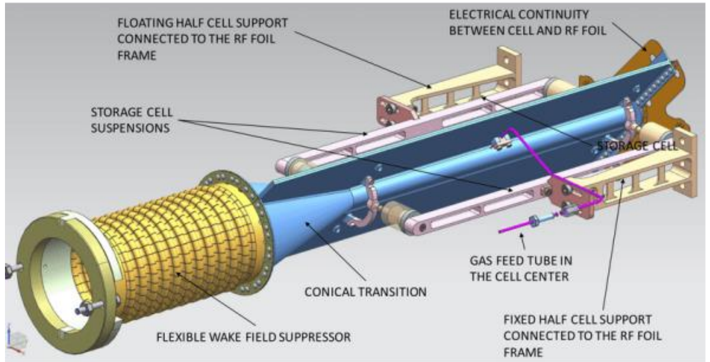
Статус: готов к установке

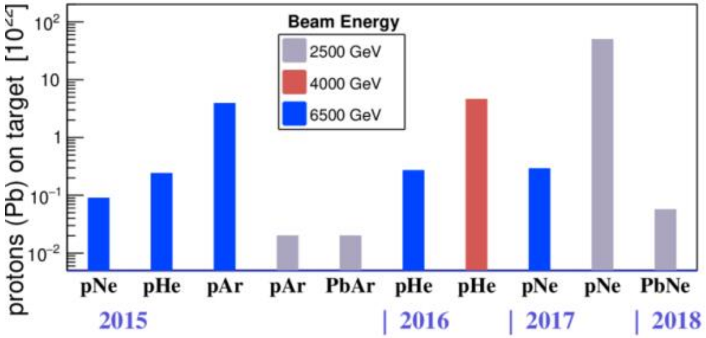
SMOG2

SMOG2 and Fixed Target physics

CERN-LHCC-2019-005

New SMOG2 system installed to inject various gas species in the LHCb IP
- Fixed Target physics at the LHC collider: in // with pp data taking
- Gas cell attached to VELO, displaced p-gas IP for easy distinction from pp data





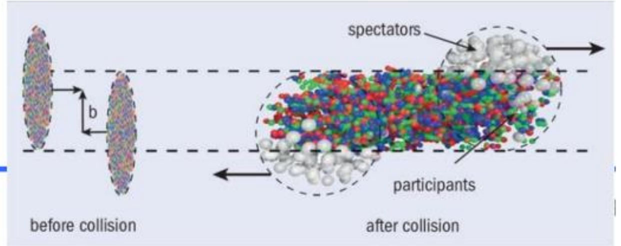
http://cds.cern.ch/record/2649878/

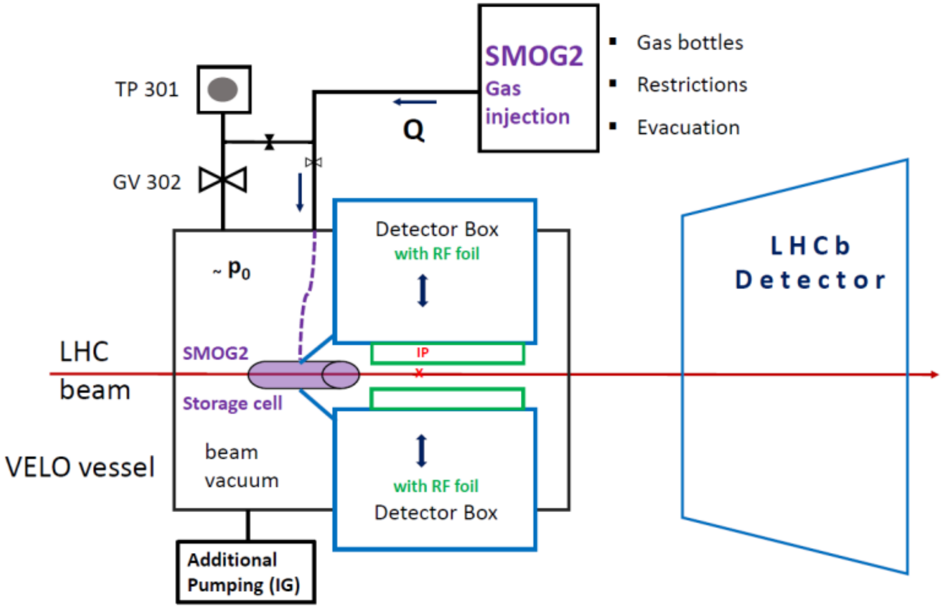
Physics program spans over:

- anti-proton production
- Central exclusive production
- X(3872)/ψ(2S)
- ψ(2S) / J/ψ
- Strangeness production
- Λc → pKπ

+ LHCb participation in Heavy Ion runs (PbPb and pPb data taking)

✓ Down to 30% centrality in LHCb in Run3!





Sketch of the SMOG2 system.
The gas is injected via capillary at the center of the storage cell.

Table 1: Typical SMOG2 areal densities θ_{SMOG2} for different gas species and the resulting target parameters (intensity and flow rate). For comparison, the corresponding SMOG densities θ_{SMOG} are also reported, assuming the same flow rate, a pumping speed on the VELO vessel of 500 l/s and a fiducial region of 0.8 m (as in Ref. [6]).

Gas species	He	Ne	Ar	Kr	Xe	H_2	D_2	N_2	O_2
θ_{SMOG2} (10^{12} cm^{-2})	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Intensity (10^{15} particles/s)	5.80	2.58	1.82	1.36	1.01	4.08	2.89	1.09	1.03
Flow rate (10^{-5} mbar l/s)	21.4	9.6	6.8	4.68	3.75	15.02	10.07	4.05	3.83
θ_{SMOG} (10^{12} cm^{-2})	0.92	0.41	0.29	0.20	0.16	1.30	0.92	0.35	0.33
$\theta_{SMOG2}/\theta_{SMOG}$)	10.9	24.4	34.5	25.0	31.3	7.7	10.9	28.6	30.3

An improved design for the gas target, called SMOG2, has been recently proposed [12] and approved by the LHCb collaboration to be integrated in the design of the upgraded VELO detector [13]. In this new design, the gas would be contained in a storage cell, illustrated in Figure 3. The cell consists of a 20 cm long tube with a diameter of 1 cm, fed by a capillary tube. The target is placed 40 ± 10 cm upstream of the nominal LHCb collision point. The cell is made from two halves which, as the rest of the VELO detector, can be retracted from their operating position while the LHC beams are being injected and tuned, and closed when stable beams are declared. Outside the open ends of the cell, the gas density is suppressed by the VELO vacuum pumps, so that the beam-gas collisions occur mostly inside the cell. This allows to increase the effective areal density in the target by up to two orders of magnitudes with respect to SMOG for the same gas flow. Even higher densities could be considered if compatible with the spectrometer occupancy and machine operation.

Статус LHCb на сегодня

*1. VELO – одна половинка установлена в этом году, **второй ещё нет даже в ЦЕРНе**, может быть будет установлена в Мае. Если нет, то в сентябре.*
*2. UT – **не готов, планируется к установке в сентябре**, если TS позволит по времени.*
3. SciFi – полностью установлен, вводится в работу.
4. RICH1&RICH2 – в порядке
5. CALOs - в порядке на уровне детекторной части
6. MUON - в порядке на уровне детекторной части
*7 Trigger – ждёт LHC и детекторы, **несколько месяцев на настройку.***

Все установленные детекторы заняты вводом в эксплуатацию новой электроники, DAQ, …, и программной частью (контроль, мониторинг, …)

В 2022-м году качественного набора данных для физики не ожидается совсем или почти совсем.
Если удастся поставить VELO, без UT, эфф. LHCb “оптимистично” оценивается на уровне ~80%

U1 Работа над ошибками

Взгляд из LHCb:

«The overall schedule sees installation of the upgraded experiment in the second long shutdown of the LHC in **2018**, to be ready for data taking in **2019**.» - FTDR - CERN-LHCC-2012-007 ; LHCb-TDR-12, 25 May 2012.
Сейчас **апрель 2022** и мы ещё не готовы…, при хорошем раскладе набор качественных данных начнётся в **2023**…
Т.е. вместо ~1.5 лет, потребовалось 3.5, на самом деле ~4.5 года.

- ***Фактор пандемии конечно присутствует, но он измеряется месяцами задержки, никак не годами…***
- ***Дьявол он как всегда в деталях. Прочность цепи определяется прочностью самого слабого ее звена.***

1. ***За ~10 лет в период RUN1&RUN2 произошло значительное, и по многим направлением безвозвратное, вымывание реальных экспертов из практической работы. В результате, многие ответственные работы выполнялись и даже велись неопытными сотрудниками и студентами, зачастую вообще без серьёзного контроля.***
2. ***Делегирование большого объёма «деликатных» работ в коммерческие фирмы, что повлекло дополнительный отток практических специалистов из данного проекта уже на моменте начального планирования. В результате коммуникация с фирмами и контроль заказов, также оказался «неидеальным».***
3. ***Во многих случаях, координация работ на всех уровнях осуществлялась людьми, не имеющими достаточного практического опыта в создании детекторов.***

Резюме: серьёзность поставленной задачи адекватно не воспринималась как на моменте планирования, так и на всём промежутке реализации.

Работа над ошибками. Что дальше.

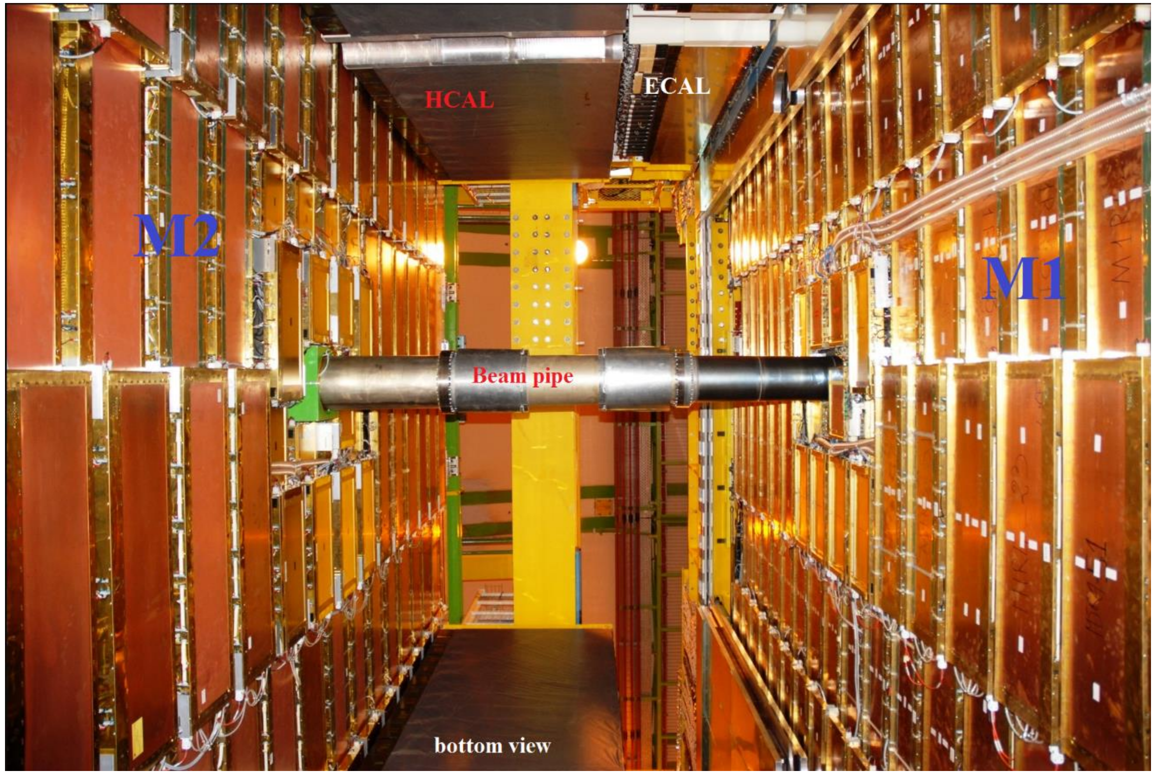
- ***Дьявол он как всегда в деталях. Прочность цепи определяется прочностью самого слабого ее звена.***

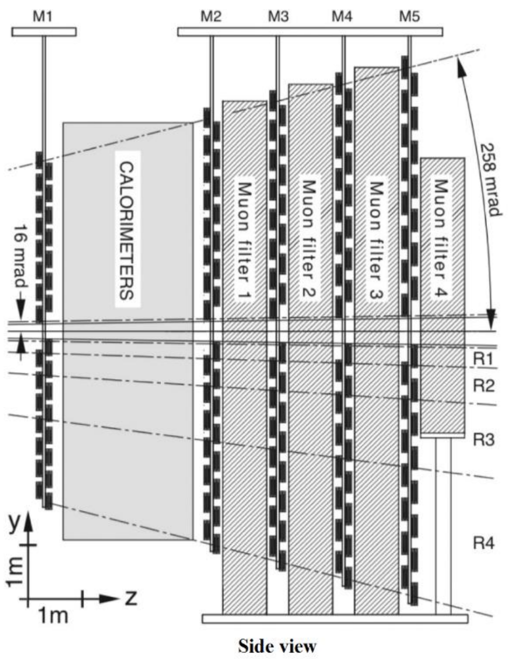
Мой личный взгляд на всё это:

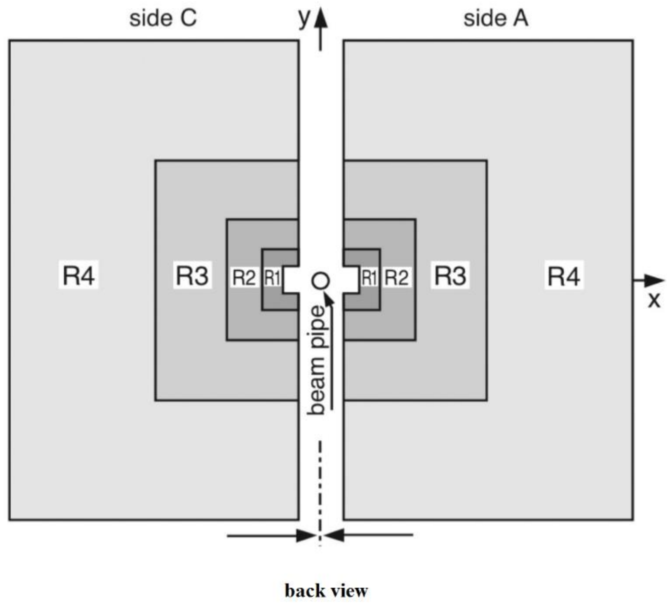
- Всё что написано ниже звучит привычно и банально, но это уже не слова а выход в новую реальность.

1. ***Идея максимального вовлечения коммерческих фирм в создание экспериментальных установок несостоятельна и опасна.***
2. ***Во многих научных центрах (и не только за рубежом) научно-производственная база полностью уничтожена или находится в крайней стадии деградации, причём самым тяжёлым последствием является потеря специалистов, фактически традиционных школ по созданию детекторов.***
3. ***Без восстановления полноценной инженерной и производственно-технической базы внутри институтов по всем направлениям, создание крупных экспериментальных установок скоро станет практически невозможным.***
4. ***Кроме пункта 3., необходимо восстановление системного продуктивного формата работы, где физики, инженеры, механики и студенты работают в реальном тесном взаимодействии над установкой от дизайна до запуска и набора данных, плотно включая во всё это образовательный процесс. Я имею в виду, что такой формат должен вернуться в рамки «необходимого и обязательного», и если какое-то звено выпадает, то это должно сразу считаться проблемой и решаться.***

Мюонный детектор. Вклад ПИЯФ.







Основным вкладом ПИЯФ в эксперимент LHCb является участие в создании и непрерывного поддержания в рабочем состоянии Мюонного детектора.

- На начальном этапе это было производство камер для трёх периферийных регионов детектора, M2-M4 R4 (установлено по 192 камеры в каждой станции, всего произведено более 650 камер) и системы подачи высокого напряжения для R3-R4 в станциях M2-M5 – установлено 3840 каналов в системе, всего произведено более 4500 каналов.

Кроме того, были произведены дополнительные запасные камеры для третьего региона (R3), в станциях M2 и M3

Мюонный детектор. Вклад ПИЯФ.

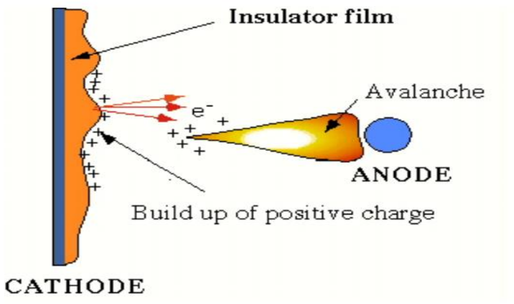
В период RUN1&RUN2:

1. *Управление детектором в период набора данных – непрерывно, основная реальная ответственность на ПИЯФ.*
2. *Поддержка детектора в целом (устранение всех видов неполадок) – 100%*
3. *Устранение проблем в мюонных камерах во время набора данных (Мальтер эффект и тп.) – 100%*
4. *Поддержка инфраструктуры (запасные камеры, HV (при участии МГУ), LV, контроль газа, электроника, тестовые программы): RUN1 ~80%, RUN2 ~100%*
5. *Поддержка SW по контролю и DAQ (DCS & ECS): RUN1 - ~100% Италия, RUN2 - ~80% перетекло на ПИЯФ (что будет в RUN3 оценим в сл. году)*
6. ***ПИЯФ пока почти не задействован в практической работе по мониторингу данных (SW), реконструкции треков и идентификации частиц, симуляциям, контролю за геометрией детектора по данным.***
7. *Постоянное активное участие в анализе данных*

Н.Ф. Бондарь
Б.В. Бочин
С.С. Волков
А.А. Воробьёв
С.А. Гец
А.Г. Граник
А.А. Дзюба
Д.С. Ильин
В.С. Козлов
С.Н. Котряхова
О.Е. Маев
П.В. Неустроев
Н.Р. Сагидова
А.Д. Чубыкин
В.В. Чуликов
Ю.А. Щеглов

Коллективы ОРЭ, ОМК и ещё очень много сотрудников ПИЯФ, участвовавших в создании детектора

Мюонный детектор. Вклад ПИЯФ.



Обеспечение стабильности работы камер. Мальтер эффект.
Разработана методика “лечения” камер без ущерба для эффективности и все необходимые инструменты для её успешного применения.

F.P. Albicocco et al., Long-term and efficient operation of the MWPC muon detector at LHCb, JINST (14) 2019 P11031, http://arxiv.org/abs/1908.02178

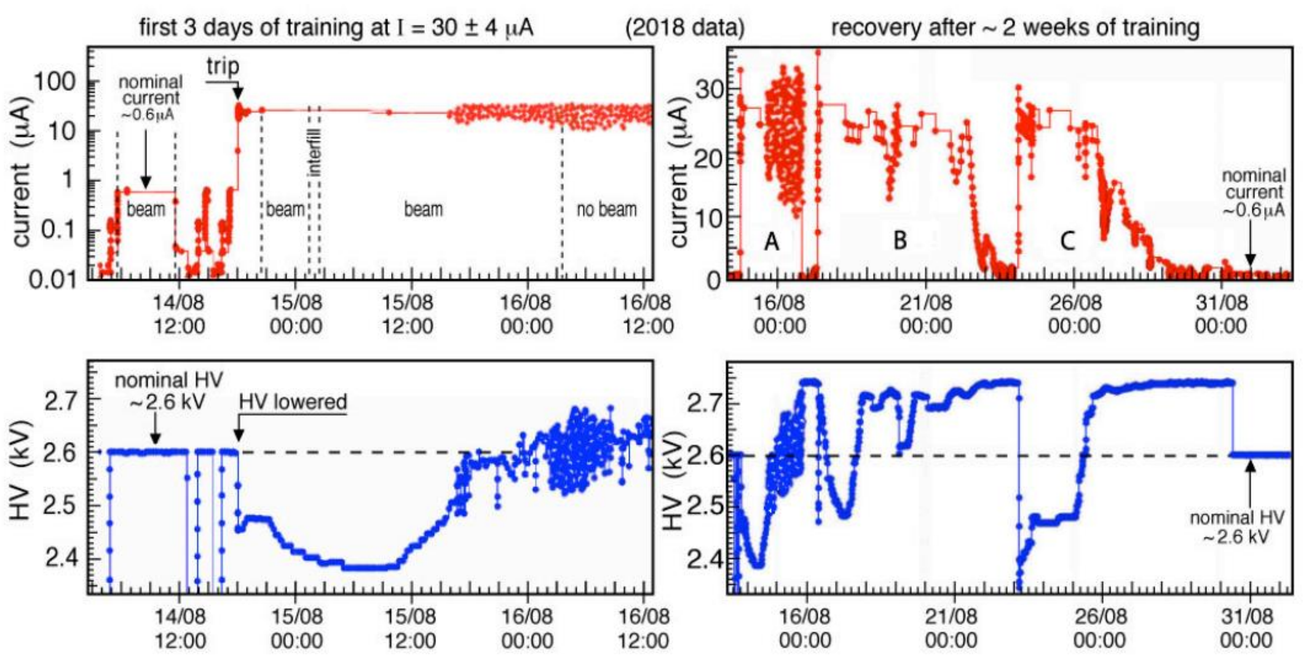


Figure 4. A typical example of the appearance of a self-sustained current and of the recovery procedure during normal LHCb operation with beams. The data refer to a gap in region M5R3. The plots on the left show the current (top) and HV setting (bottom) during a period of about 3 days around the first appearance of the HV trip and the subsequent start of HV training. The plots on the right show the current (top) and HV setting (bottom) during the full recovery procedure, which lasted about two weeks. The nominal HV setting for this gap is 2600 V; the average current in presence of colliding beams is about 0.6 μA.

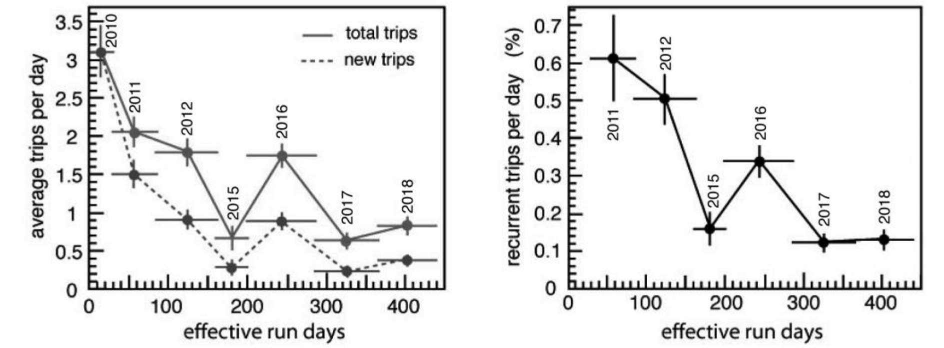
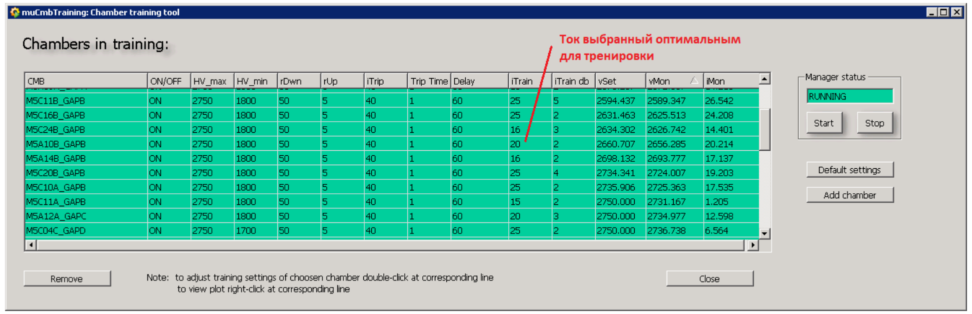


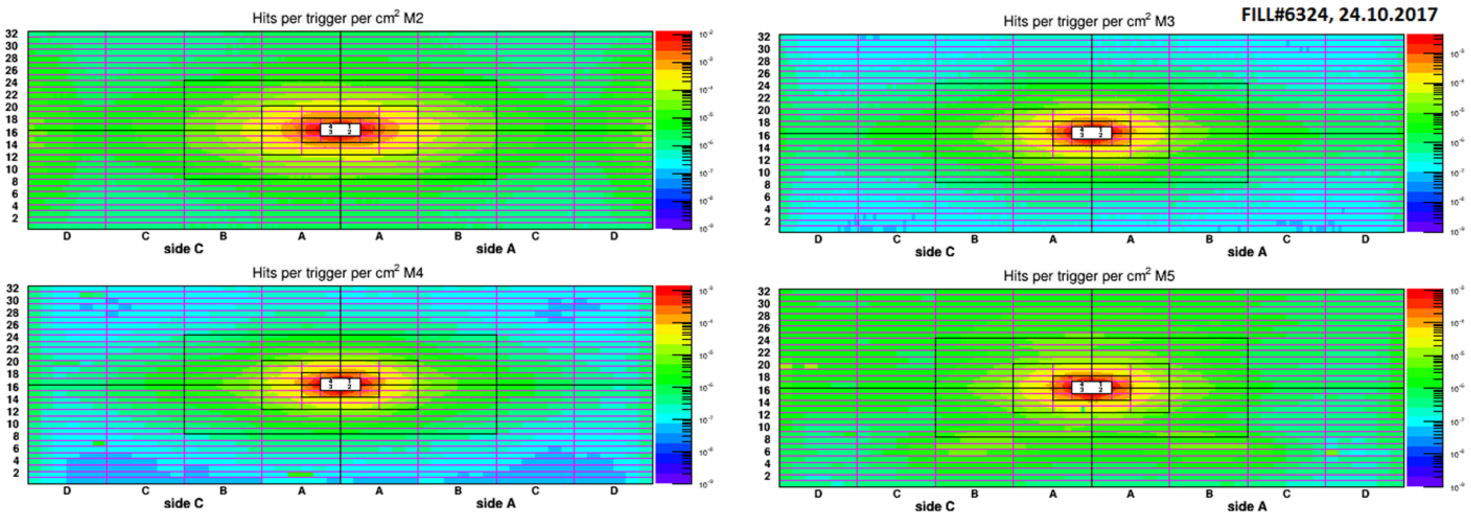
Figure 6. Left: Average number of trips per day observed during each year of data taking, as a function of the total number of effective run days integrated between 2010 and 2018; the total number of trips is shown in red (full line), the number of new trips in blue (dotted line). Right: Average number of recurrent trips per day observed during each year of data taking normalized to the total number of gaps already tripped in the past. Points are evaluated starting from 2011. Errors are statistical.



CMB	ON/OFF	HV_max	HV_min	rDwn	rUp	iTrip	Trip Time	Delay	iTrain	iTrain db	vSet	vMon	iMon
M5C11B_GAPB	ON	2750	1800	50	5	40	1	60	25	5	2594.437	2589.347	26.542
M5C16B_GAPB	ON	2750	1800	50	5	40	1	60	25	2	2631.463	2625.513	24.208
M5C24B_GAPB	ON	2750	1800	50	5	40	1	60	16	3	2634.302	2626.742	14.401
M5A10B_GAPB	ON	2750	1800	50	5	40	1	60	20	2	2660.707	2656.285	20.214
M5A14B_GAPB	ON	2750	1800	50	5	40	1	60	16	2	2698.132	2693.777	17.137
M5C20B_GAPB	ON	2750	1800	50	5	40	1	60	25	4	2734.341	2724.007	19.203
M5C10A_GAPB	ON	2750	1800	50	5	40	1	60	25	2	2735.906	2725.363	17.535
M5C11A_GAPB	ON	2750	1800	50	5	40	1	60	15	2	2750.000	2731.167	1.205
M5A12A_GAPC	ON	2750	1800	50	5	40	1	60	20	3	2750.000	2734.977	12.598
M5C04C_GAPD	ON	2750	1700	50	5	40	1	60	25	2	2750.000	2736.738	6.564

Модернизация MUON. Вклад ПИЯФ.

Создание камер повышенной гранулярности для трёх внутренних регионов детектора. Установка: RUN3 - LS3.



Геометрическое распределение загрузок в плоскости XY в Мюонной системе при каждом срабатывании триггера.

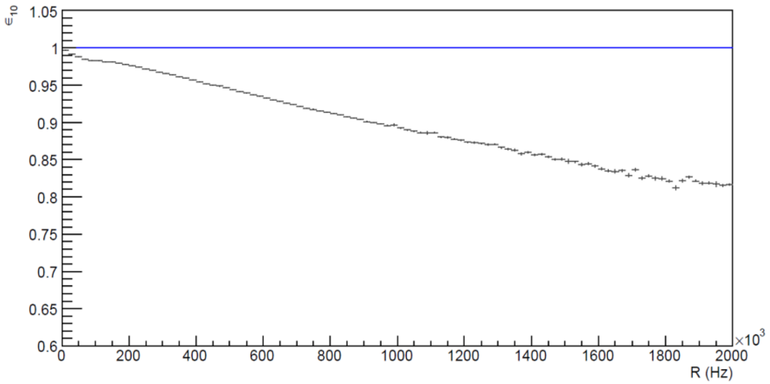
Inefficiencies reported in the TDR

Region	Inefficiency at 10^{33} cm^{-2}s^{-1}	Inefficiency at 2×10^{33} cm^{-2}s^{-1}
M2R1	3.2 ± 1.2 %	7.1 ± 2.8 %
M2R2	2.0 ± 0.5 %	4.1 ± 1.1 %
M2R3	1.3 ± 0.2 %	2.6 ± 0.4 %
M2R4	0.9 ± 0.2 %	1.7 ± 0.3 %
M3R1	1.5 ± 0.4 %	3.3 ± 1.1 %
M3R2	0.6 ± 0.1 %	1.2 ± 0.3 %
M3R3	0.4 ± 0.1 %	0.9 ± 0.1 %
M3R4	0.3 ± 0.1 %	0.6 ± 0.1 %
M4R1	0.5 ± 0.2 %	1.1 ± 0.3 %
M4R2	0.6 ± 0.1 %	1.3 ± 0.2 %
M4R3	0.5 ± 0.1 %	0.9 ± 0.2 %
M4R4	0.3 ± 0.1 %	0.6 ± 0.1 %
M5R1	0.6 ± 0.2 %	1.3 ± 0.5 %
M5R2	0.7 ± 0.2 %	1.4 ± 0.3 %
M5R3	0.6 ± 0.1 %	1.2 ± 0.2 %
M5R4	1.2 ± 0.2 %	2.3 ± 0.3 %

inefficiency from CARIOCA
inefficiency mainly from DIALOG

Following my simulation DIALOG inefficiency is underestimated

Таблица 2. Прогнозируемая (расчёты на 2012 год) неэффективность только от «мертвого» времени, усреднённая по камерам региона, в станциях M2-M5. Стрелками, в сочетаниях синего (время формирования выходного сигнала в 18нс) и красного («мертвое» время усилителя – была использована величина в 75 нс) цветов в стрелках, отражён вклад каждого из факторов, образующих «эффективное» мертвое время фронт-энд электроники.



Измеренная эффективность регистрации физического канала считывающей электроники в зависимости от загрузки, с учётом неэффективности только от мёртвого времени.

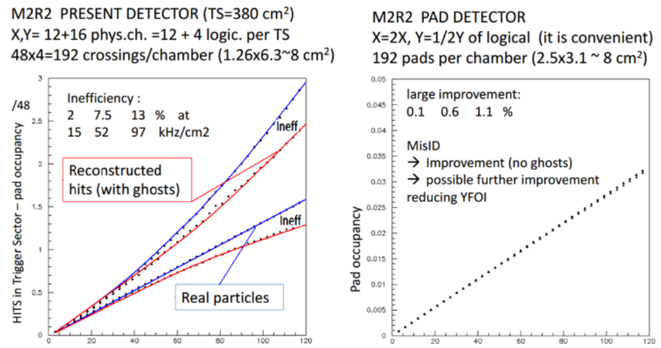
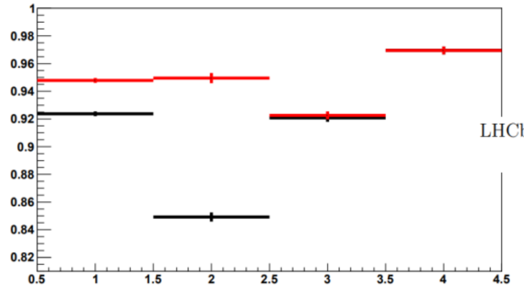


Рис. 36. Слева расчёты Монте-Карло числа ожидаемых (синяя кривая) и зарегистрированных (красная кривая) событий в одном тригерном секторе (48 логических падов, образованных пересечением X и Y логических каналов) в зависимости от физической загрузки в существующем мюонном детекторе, справа загруженность на один логический пад в зависимости от физической загрузки для одного из предлагаемых вариантов будущего падового детектора для региона M2R2.

These calculations are based on the deadtime maps prepared for the PID-TDR, convoluted with MC events after stripping and selection.



LHCb-INT-2017-019
August 7, 2017

Figure 3: Efficiency drop of $B_s^0 \to \mu^+\mu^-$ events for different event topologies: all events in bin 1, events with at least one muon passing through M2R1 or at least one muon passing through M2R2 in bin 2 and 3, respectively, all other events in bin 4; black points are results without PAD chambers, red with 24 PAD chambers installed in M2R1 and M3R1; the fraction of events populating bin 2,3,4 is 0.234, 0.362 and 0.404, respectively.

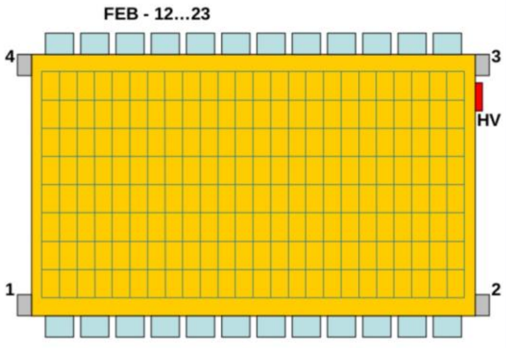
Prototypes and M23/R1 production

Boris Bochin, Stanislav Gets, Nikolai Bondar, Dmitrii Ilin, Vladimir Kozlov and many other people at PNPI.

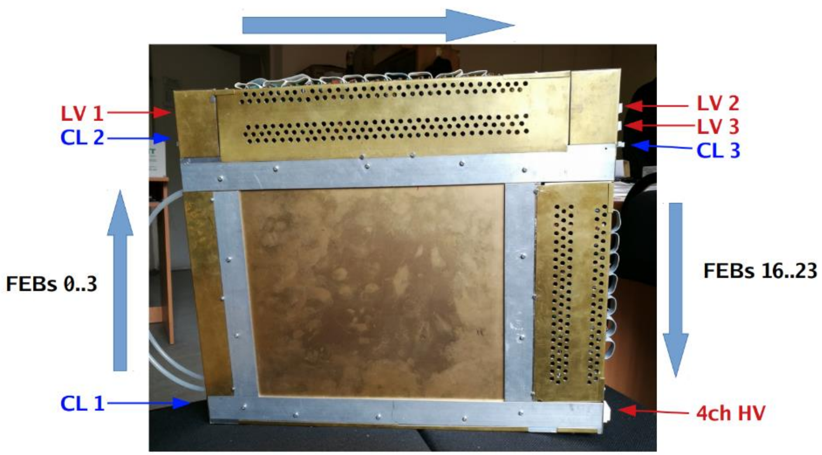
1. M2R2 made in April of 2016 at PNPI, successfully tested with 1 GeV proton beam at PNPI and on GIF++ at CERN at very high rates conditions.
2. M2R1 made in spring of 2020 at PNPI, successfully tested on cosmics only (beam was not available last year) and delivered at CERN in Nov. 2020. It is fully dressed with electronics and trained with HV.
- all tests planned on GIF++ were postponed because lack of manpower
https://indico.cern.ch/event/951553/contributions/3997791/attachments/2097783/3526230/M2R2M2R1_tests_7Sept.pdf
Production of the (12 + 3 spares) M2R1 CMBs is ongoing at PNPI.
3. Building a prototype for M3R1 was skipped because it almost same as M2R1 - small difference in pad size only
PCBs for M3R1 are under production.

M2R2 prototype (2017)

Chamber layout

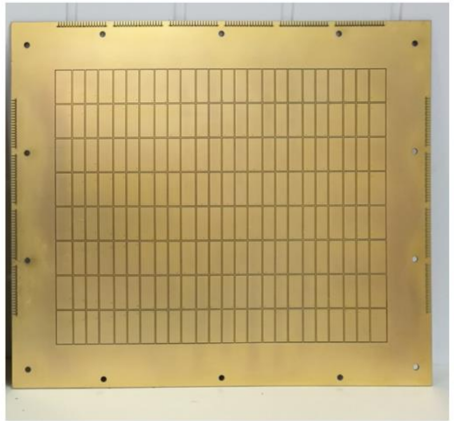


M2R1 Chamber prototype

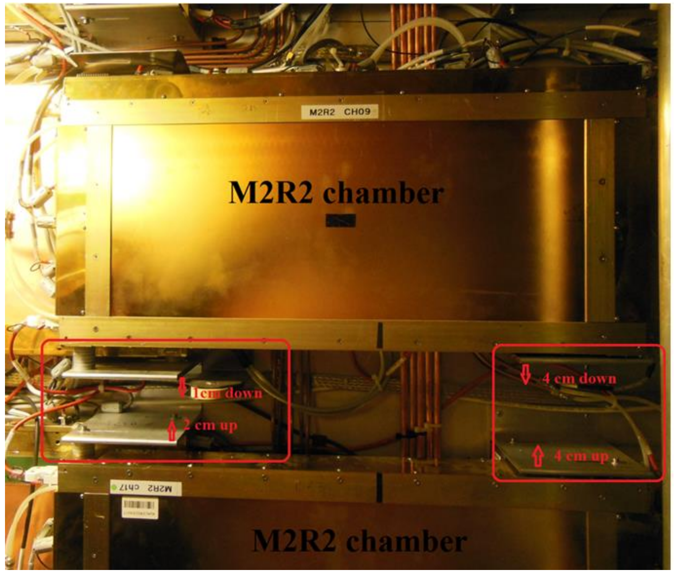


CL — Control Line. One per 8 FEBs
LV — Low Voltage supply
FEB — 16ch Frondend board (Carioca/Dialog)

cathode PCB



Infrastructure for the new pad CMBs



Status:

Infrastructure for the new pad chambers in regions M2R1, M2R2 and M3R1.

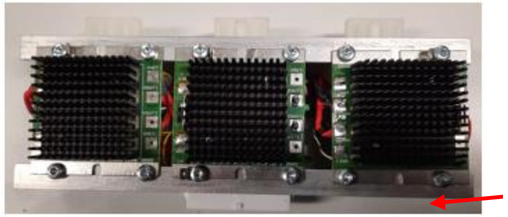
1. Additional signal cables (576 cables): all cables installed on the wall.

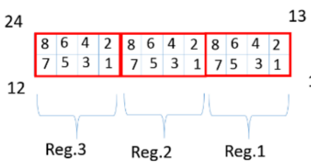
576 connectors on rack side – done

2. Chamber supports (balconies) repositioned on the walls according to the new CMB dimensions.

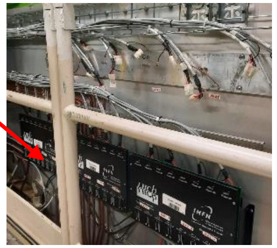
3. LV-system. Installation - done

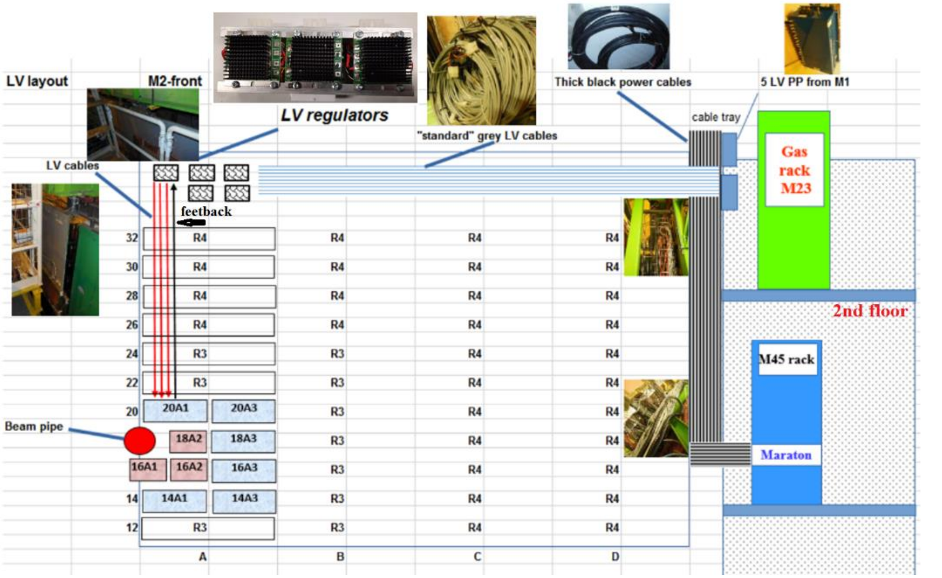
- ***Modification of the nominal LV-regulators – done***
  (enough only for M3R1, for M2R2 – will be removed from replaced cmbs. 96 regulators needed in total)
- ***M2R1+4CMBs M2R2 – equipped with GEMs regulators – done***





Pin 1 – feed back positive
Pin 2 – feed back GND
Pin 3 – LV out channel 1
Pin 4 – GND channel 1
Pin 7 – feed back positive
Pin 8 – feed back GND
Pin 5 – LV out channel 2
Pin 6 – GND channel 2

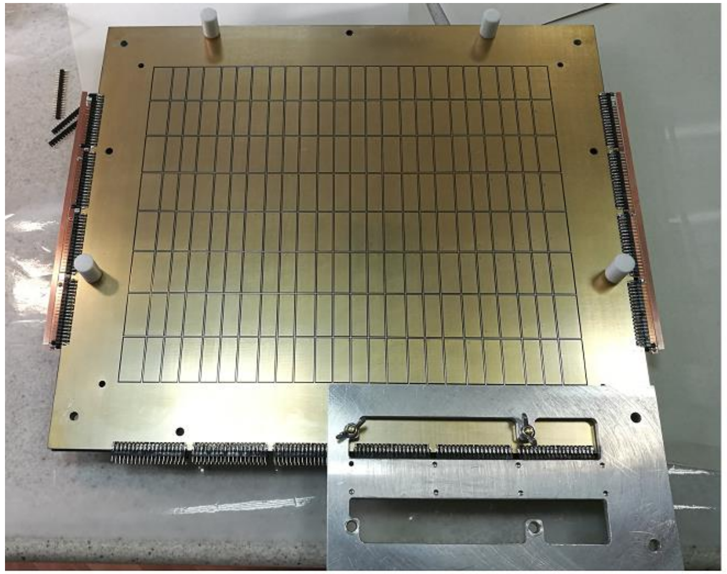
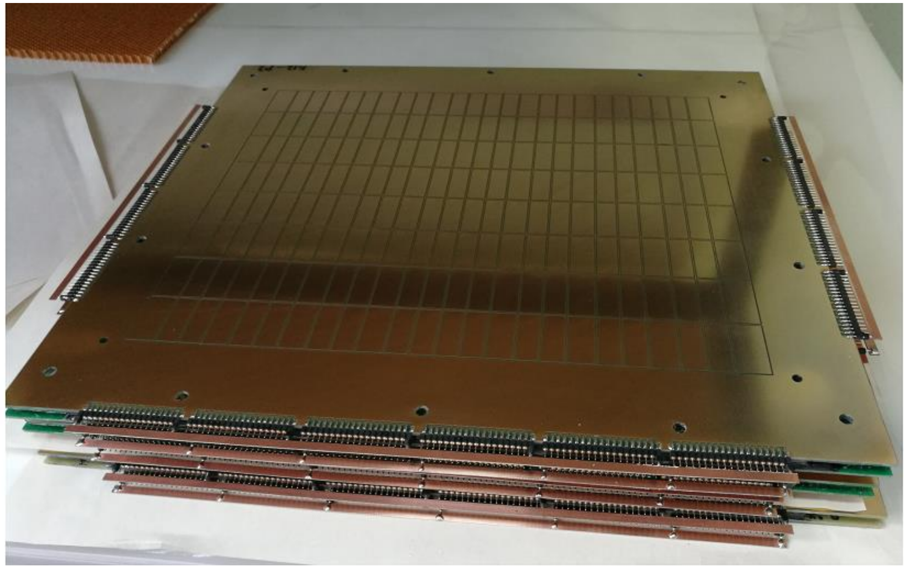




- ***two MARATONs for FEBs (one per side) installed in M45 racks in Q1 and Q4, also 2 AC/DC PS and 2 RCMs in B1 + cables, conn., DSS, etc.***
- ***16 power cables (2x16mm^2) and PPs from M1 are installed on both sides.***
- ***work (cabling etc.) is ongoing on the walls ((3x2)x24=288 LV-cables)***

4. Thermo-switches for higher temperature (60 °C) in M2/3 – installed.

Производство M2R1 в ПИЯФ

Boris Bochin, Stanislav Gets, Nikolai Bondar, Dmitrii Ilin, Vladimir Kozlov and many other people at PNPI.

2 камеры уже собраны

В этом году мы должны полностью сделать M2R1 и M3R1.

M2R1 – крайний срок в июле должны быть в ЦЕРНе и к концу года быть полностью подготовлены к установке в детектор.

M3R1 – можно позже, но в связи с реорганизацией в ПИЯФ производство должно быть завершено в этом году.

Перспективы.

CERN-LHCC-2021-012 ; LHCB-TDR-02

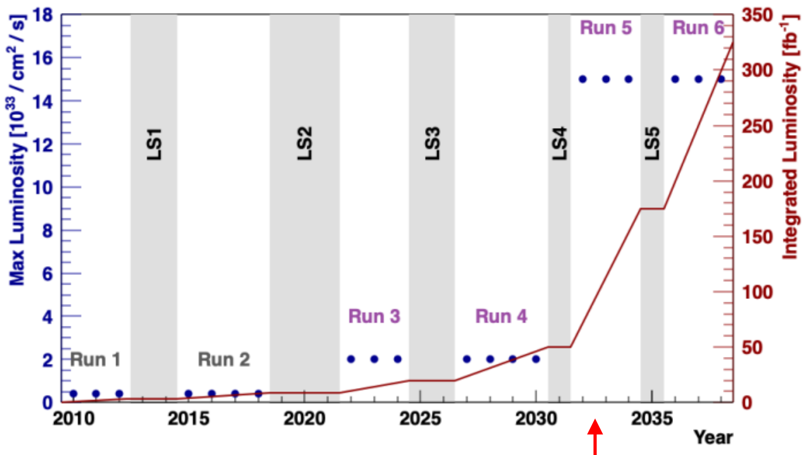
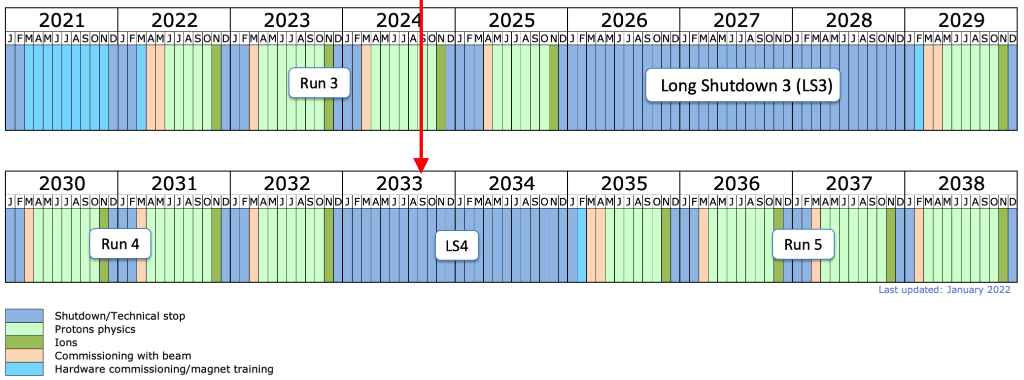


Figure 1.1: Integrated luminosity profile for the original LHCb, Upgrade I (Run 3 and 4) and Upgrade II (Run 5 and 6) experiments, in the context of the official LHC schedule of 2021 (extensions of Run 3 and LS3 by one year and six months, respectively, have been deliberated in January 2022). The blue points and the left scale indicate the anticipated maximum instantaneous luminosity whilst the red line and right scale indicate the accumulated integrated luminosity.

Longer term LHC schedule

In January 2022, the schedule was updated with long shutdown 3 (LS3) to start in 2026 and to last for 3 years.



Перспективы.

CERN-LHCC-2021-012 ; LHCB-TDR-023

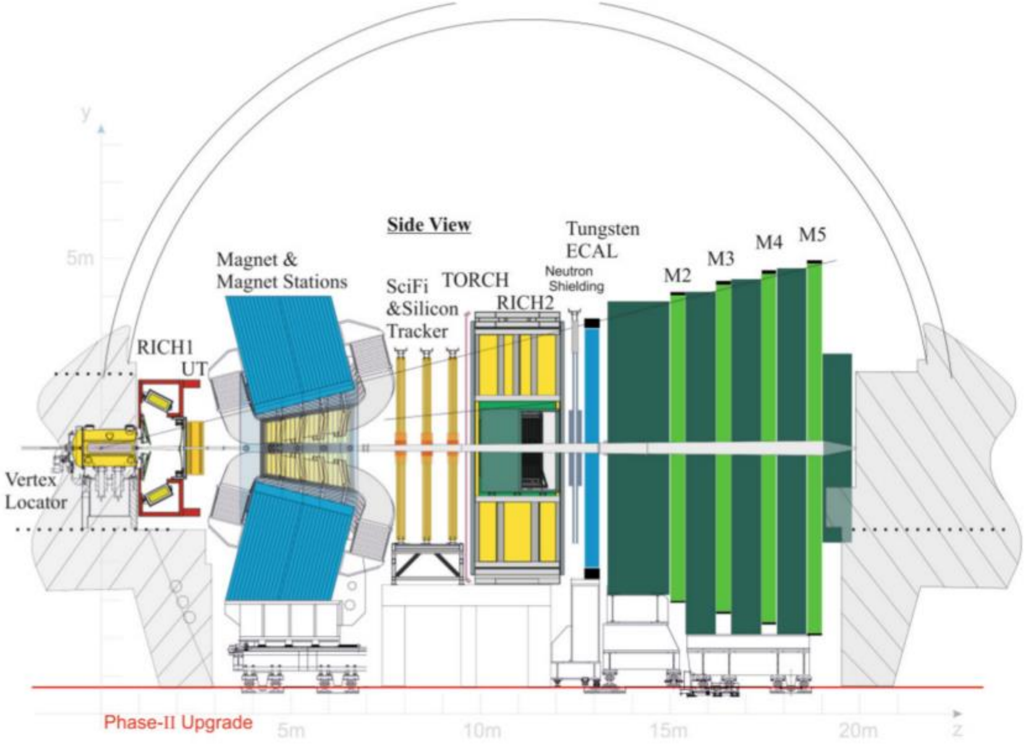


Figure 1.2: Schematic side-view of the Upgrade II detector.

L_{max}~$(1.5 – 2)x10^{34}cm^{-2}s^{-1}$

In this proposal the detector challenges are met while keeping the existing footprint of the spectrometer, and largely maintaining the current arrangement of sub-systems, as shown in Fig. 1.2. The tracking system will consist of a Vertex Locator (VELO) and tracking stations placed upstream (Upstream Tracker, UT) and downstream the magnet (Mighty Tracker, MT). The Mighty Tracker will be split in an Silicon Tracker covering the inner region, and a Scintillating Fiber Tracker (SciFi) covering the outer region. As a new feature with respect to Upgrade I, additional tracking stations (Magnet Stations, MS) will cover the magnet side walls. The particle identification (PID) system will consist of a RICH system composed by RICH1 and RICH2 detectors placed upstream and downstream the magnet, respectively, an electromagnetic calorimeter (ECAL), and 4 muon stations (M2–M5). The baseline design will not include anymore an hadron calorimeter in front of the muon detector, replaced by additional shielding, and will feature instead a time-of-flight detector (TORCH) in front of RICH2.

TORCH: A large area time-of-flight detector for particle identification [arXiv:1810.06658]

MUON: Mu-RWELLs & MWPCs

Перспективы для ПИЯФ в LHCb MUON на U2

Границы применимости:

Главный фактор потери эффективности – мёртвое время фронт-энд электроники (~100 нс), определяемой входной загрузкой.

Уменьшается с площадью считывающего электрода. Лимит для камер MUON MWPC ~ 2-3см^2.

MUON detector at UPGRADE II.
Option with MWPCs

CERN-LHCC-2021-012 ; LHCB-TDR-023

Proposal based on two sets of facts:

- objective

1. No any sign of aging in MUON MWPCs after ~9 years of operation (about 450 effective days irradiation with LHC-beam) even where the collected charge was ~0.6-0.7C/cm of wire. Same for FE-electronics.
2. MWPC remains still one of the most efficient, robust and same time simple and cheap detector for MIP particles.
3. One of the main factor of expected inefficiency at HL (means high rate) conditions is a dead time of FE-electronics which could be reduced by increasing the granularity of the pad MWPCs and with new redout electronics which should be designed and produced at any case.
4. Second factor of expected inefficiency due to so-called "ghosts" in double-redout MWPCs in (M2M3/R1R2) could be fully vanished by replacement double redout MWPCs with high granularity pad chambers.
5. HW-trigger gone. No needs to keep fixed granularity of the physical pads in chambers and granularity of regions themselves as before.

- subjective (practical/realistic)

1. *Most of the existing MWPCs and significant part of infrastructure could be either fully reused from the present MUON detector either with some minor upgrade.*
2. *About 200 same type or higher granularity but with same geometrical size pad MWPCs should be produced, installed and commissioned for U2 and it looks feasible for MUON collaboration.*
3. *About 200 kchs of new redout electronics for MWPCs should be designed and produced and it again looks feasible for experts within MUON collaboration. New collaborators are welcome for sure! See Nikolai's slides with details.*
4. *Option with MWPCs allows greatly reduce an amount of funding and human resources required on the stages of production, installation and commissioning of U2 MUON detector.*
5. *Cost estimation for option with reuse present MWPCs is limited by ~5-6 MEUR in total what looks reasonable for U2*

Перспективы для ПИЯФ в LHCb MUON на U2

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Present detector

M1 removed already, but with new PAD CMBs it will be quite similar with M2

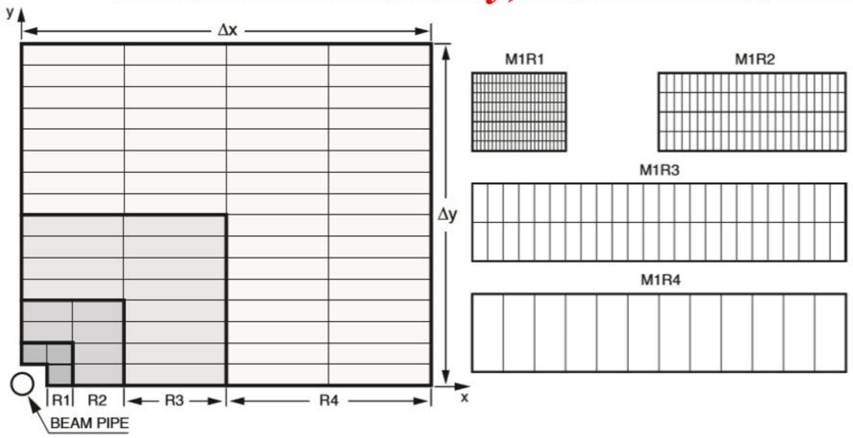
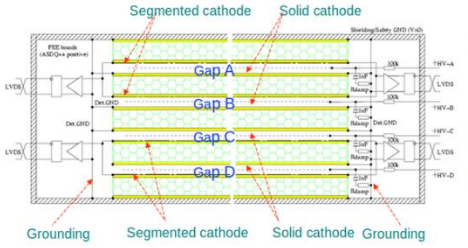


Figure 6.47: Left: front view of a quadrant of a muon station. Each rectangle represents one chamber. Each station contains 276 chambers. Right: division into logical pads of four chambers belonging to the four regions of station M1. In each region of stations M2-M3 (M4-M5) the number of pad columns per chamber is double (half) the number in the corresponding region of station M1, while the number of pad rows per chamber is the same (see table 6.5).

Table 6.5: Basic information for the five stations M1–M5 and the four regions R1–R4. All dimensions in cm. z: distance of the stations from the IP; Δx and Δy: dimensions of a quadrant in each station (see figure 6.47). Rows R1-R4: granularity of the different regions of the muon detector as seen by trigger and DAQ. Number of logical pads per chamber (in brackets) and size of the logical pads, along x and y. In parentheses: size of the logical pads projected onto station M1.

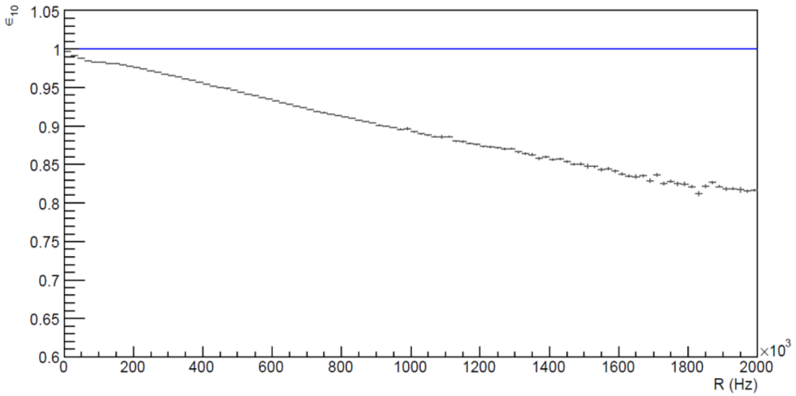
	M1	M2	M3	M4	M5
z	1210	1527	1647	1767	1887
Δx	384	480	518	556	594
Δy	320	400	432	464	495
R1	[24 × 8] 1 × 2.5	[48 × 8] 0.63 × 3.1 (0.5 × 2.5)	[48 × 8] 0.67 × 3.4 (0.5 × 2.5)	[12 × 8] 2.9 × 3.6 (2 × 2.5)	[12 × 8] 3.1 × 3.9 (2 × 2.5)
R2	[24 × 4] 2 × 5	[48 × 4] 1.25 × 6.3 (1 × 5)	[48 × 4] 1.35 × 6.8 (1 × 5)	[12 × 4] 5.8 × 7.3 (4 × 5)	[12 × 4] 6.2 × 7.7 (4 × 5)
R3	[24 × 2] 4 × 10	[48 × 2] 2.5 × 12.5 (2 × 10)	[48 × 2] 2.7 × 13.5 (2 × 10)	[12 × 2] 11.6 × 14.5 (8 × 10)	[12 × 2] 12.4 × 15.5 (8 × 10)
R4	[12 × 1] 8 × 20	[24 × 1] 5 × 25 (4 × 20)	[24 × 1] 5.4 × 27 (4 × 20)	[6 × 1] 23.1 × 29 (16 × 20)	[6 × 1] 24.8 × 30.9 (16 × 20)



Gas mixture	40% Ar + 55% CO2 + 5% CF4
Anode-cath gap	2.5mm
Anode wire diameter	30 um
Anode wire step	2mm
Operating voltage	2.5-2.8 kV (2.65 kV - working voltage)
MWPC readout type	- Wire pads (R4) - Anode & cathode pads (R1-R2 in M2-M3) - Cathode pads (everywhere else)
Hit efficiency	99% (in 25ns time window)
Time resolution	2.5-4 ns

Figure 3. Cross section of a MWPC with the four gaps indicated by A, B, C and D jointed in the common gas circuit, is shown on the left. Each gap is supplied with an independent HV-line. Corresponding readout pads in contiguous layers (bi-gaps) A&B and C&D are galvanically OR-ed. The most significant parameters of MWPC are presented in the table on the right.

Сигналы с пар (A&B, B&C) проективных падов в газовых промежутках объединяются по .ИЛИ. на входе FEE, затем ещё раз объединяются по .ИЛИ. на выходе.



Измеренная эффективность регистрации физического канала считывающей электроники в зависимости от загрузки, с учётом неэффективности только от мёртвого времени.

Перспективы для ПИЯФ в LHCb MUON на U2

CERN-LHCC-2021-012 ; LHCB-TDR-023

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Proposal on application of the multi-wire proportional chambers of the LHCb MUON Detector at very high rates for the future upgrades

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ABSTRACT: The MUON Detector (MD) of LHCb is one of the largest instruments of this kind worldwide, and one of the most irradiated. It has performed exceptionally well during the RUN1 and RUN2 of the LHC at an instantaneous luminosity of 4×10^{32} cm^{-2}s^{-1}, with tracking inefficiencies at the level of 1% and 2.6%, respectively.

Looking forward for the future LHCb Upgrade 2 (U2) planned in 2031 and aiming in running the detector at increased luminosity by factor ~ 50, and at the same time keeping a very high (~ 99%) detection efficiency, an option with reuse significant part of the present Multi Wire Proportional Chambers (MWPC) in a new Muon System is presented. In addition, the first idea of new Front End Electronics (FEE) and an existing test setup applicable for designing both: new MWPCs with higher granularity of the cathode readout pads and new FEE are described.

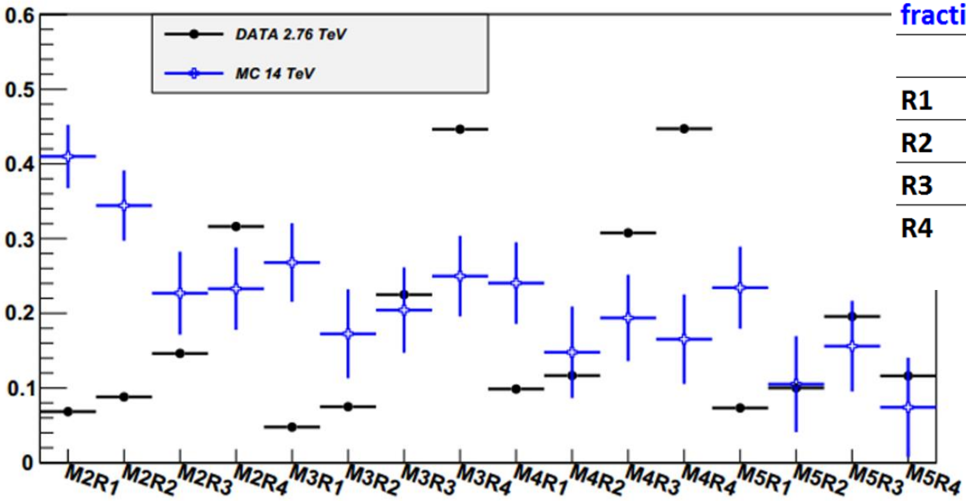
KEYWORDS: Muon spectrometers; Radiation damage to detector materials (gas detectors); Wire chambers (MWPC, Thin-gap chambers, drift chambers, drift tubes, proportional chambers etc)

[1]Corresponding author.

https://doi.org/10.1088/1748-0221/15/07/C07001

Fraction of correlated hits in 4 gaps in .OR.

From 2012 data, to be checked with rates from bi-gaps in .AND. taken at the end of 2018.
To be mentioned, that this feature really helped MUON to be efficient in some areas with very high occupancy during RUN1&RUN2.



fraction of correlated hits (%)

	M2	M3	M4	M5
R1	7	5	10	8
R2	9	8	12	10
R3	15	22	30	20
R4	32	45	45	12

Фракция сигналов от LEB (низкоэнергетичного фона) огромна.
Основная черта – сигнал появляется только в одном промежутке – треков нет.

Перспективы для ПИЯФ в LHCb MUON на U2

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M2 (Q2), four gaps readout + gate

All what was done before including readout from all four gaps in R1-R3 with .AND. at list in two projective gaps.
Fraction of correlated hits:
*Input rate: R1*0.565, R2*0.583, R3*0.630, (R4->R3)*0.742. Bigaps in R4 – not possible to separate.*
*Output rate: R1*0.231, R2*0.283, R3*0.414, (R4->R3)*0.653.*
Max. Input rates per FE-ch.: ~4.4MHz (uncor. new pad cmbs M2R1) – Max. Output rate ~1MHz (tracks, new pad cmbs M2R1)

INPUT

R(1gap) = R(2gaps)(1+3*fcor)/(1+fcor)/2*

new granularity, new FEBs (4 gaps redout)

M2: R1*0.565, R2*0.583, R3*0.630, (R4->R3)*0.742

	D	C	B	A / A3	A2	A1
16	684847	329684	584791	1648110	4395531	beam pipe
15	426302	300706	467131	1098586	2094599	4117610
14	536286	264059	376976	614844	982298	
13	316082	204576	250214	350912	466263	
12	722541	450906	362176	446825		
11	445159	350004	191109	260459		
10	546221	286492	177932	331111		
9	505476	210973	114094	184792		
8	258686	182499	470646	670442		
7	316199	136223	281437	424047		
6	315781	112926	249034	320772		
5	204917	85489	166407	204181		
4	678158	58138	138715	165998		
3	450413	66191	98443	112448		
2	419367	70018	100360	119324		
1	214900	84401	90257	113213		

fraction of correlated hits (%)

M2	fcor(%) 4 Gaps	reduction input	reduction output
R1	7	0,565	0,231
R2	9	0,583	0,283
R3	15	0,630	0,414
R4	32	0,742	0,653

R12-> new detectors (RWELLs)
R1 ~1 MHz/cm^2 (gap)
R2 ~ 0.3 MHz/cm^2 (gap)

present R4 cmbs (only 128, 192 now)
24chs

present M2R3 CMBs, now 48 installed
needed: 72-> 24 M2R3 to be produced
96chs

size of M2R3 but 2 times higher granularity
40 new cmbs to be designed and produced
192chs

Nphys.ch(UPGRADE I)=

R4	R3	R2	R1	total
9216	9216	9216	4608	32256

Nphys.ch(UPGRADE II)=

R4	R3	R2(RWELL)	R1(RWELL)	total	MWPCs
6144	58368	73728	36864	175104	64512

36 NEW detectors, 40 NEW M2M3
and 24 present M2R3 to be designed and produced

OUTPUT

R(out) = R(1gap)(4*fcor)/(1+3*fcor)*

output rate

M2: R1*0.231, R2*0.283, R3*0.414, (R4->R3)*0.653

	D	C	B	A / A3	A2	A1
16	447205	215284	242104	466415	1015368	beam pipe
15	278375	196361	193392	310900	483852	951168
14	350195	172430	156068	174001	277990	
13	206402	133588	103588	99308	131952	
12	471819	450906	149941	184986		
11	290689	350004	79119	107830		
10	356682	286492	73664	137080		
9	330076	210973	47235	76504		
8	168922	182499	470646	429083		
7	206478	136223	281437	424047		
6	206205	112926	249034	320772		
5	133811	85489	166407	204181		
4	678158	58138	138715	165998		
3	450413	66191	98443	112448		
2	419367	70018	100360	119324		
1	214900	84401	90257	113213		

	R4	R3a	R3b	R2	R1
Rmax	678158	471819	447205	466415	1015368
Rmax_av	229421	191438	227015	243428	816796

Перспективы для ПИЯФ в LHCb MUON на U2

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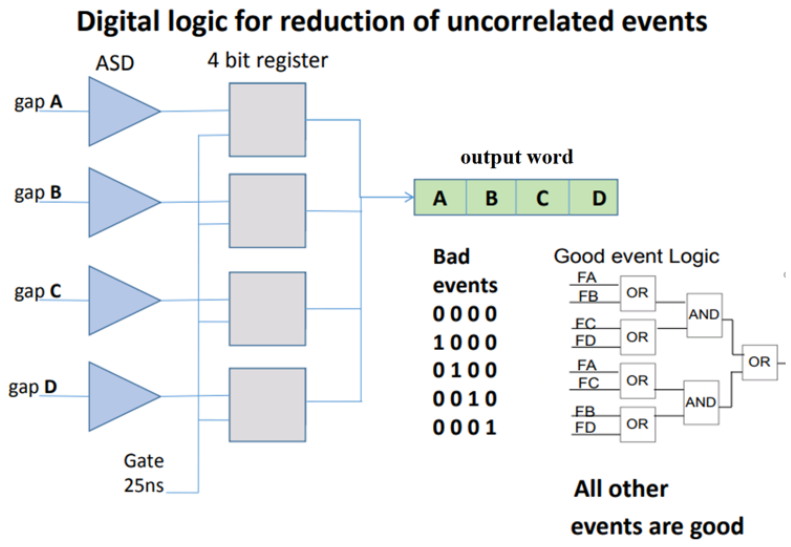
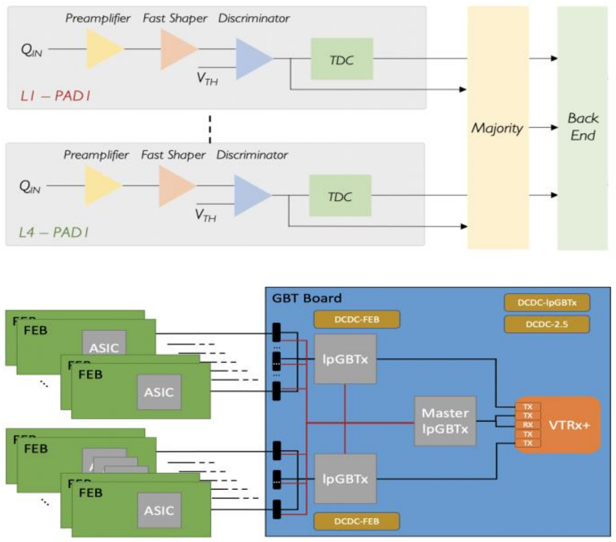
Option with new FEBs

1. *Readout of all four gaps separately immediately gives reduction in the rate per physical channel. It could be realized only in R1-R3 in all stations and in M5R4, where signals combined on the level of OPB/SPB boards. In R4 regions in M2-M4 channels in bi-gaps combined galvanically inside the chambers and there is no way to separate them.*
2. *Implementing a smart logic on FEB-level to reject signals from low energy background, so-called uncorrelated hits. It gives a hit only in one of consecutive pads.*
   As a first proposal: adding a gate opening an .OR. of all four gaps which is formed as requirement of at least one .AND. in the projective gaps.

See Nikolai's presentation for details. Here is a one of simplified version of new FEB.
https://indico.cern.ch/event/967781/contributions/4081323/attachments/2130405/3587643/N-front-end-V2.pdf





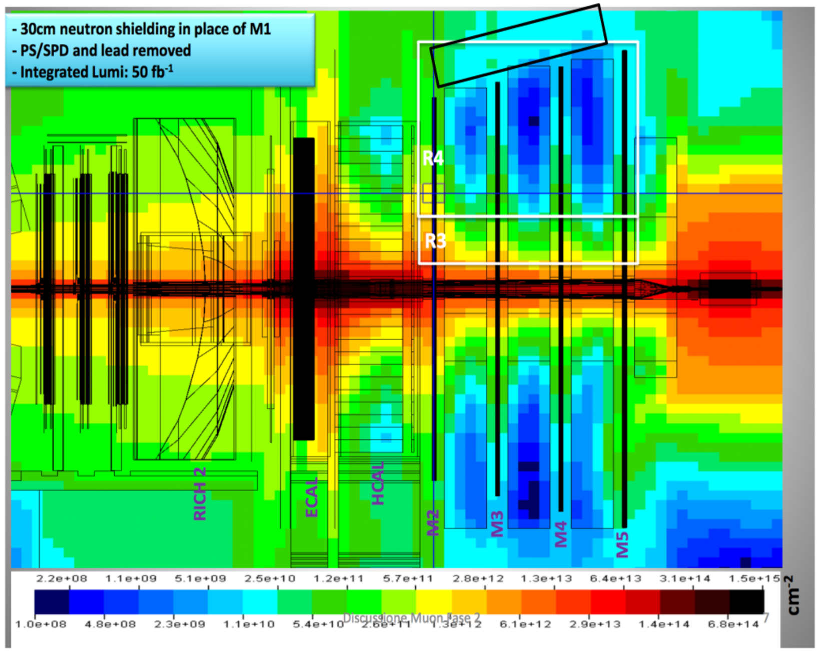
Schematic views of the proposed FE channel (top) and data readout architecture (bottom).

The proposed FE scheme foresees a single front-end ASIC per FE board (FEB), directly installed on the chamber, as in the present muon electronics, and the lpGBTx installed in a separate data concentrator board (GBTboard), as shown in Fig. 4.35 (bottom). The latter could also be mounted on the same chamber. Since the number of FEBs per chamber is very different from inner to outer regions (e.g. 56 FEBs/chamber in R1 ad R2, only 3 FEBs/chamber in R4) the number of FEBs connected to each lpGBTx could be further optimized by using different types of GBTboards, with an optimal number of lpGBTx installed for each type. The data bandwidth and the total number of optical links needed for each detector region is given in Tab. 4.11, together with the number of PCIe40 boards.

Neutron shielding

What we don't know precisely - a fraction in the LEB hitting MWPCs which is coming from thermal neutrons!

Distribution of the integrated (50 fb^{-1}) neutron flux in the upgraded LHCb from Matthias Karacson



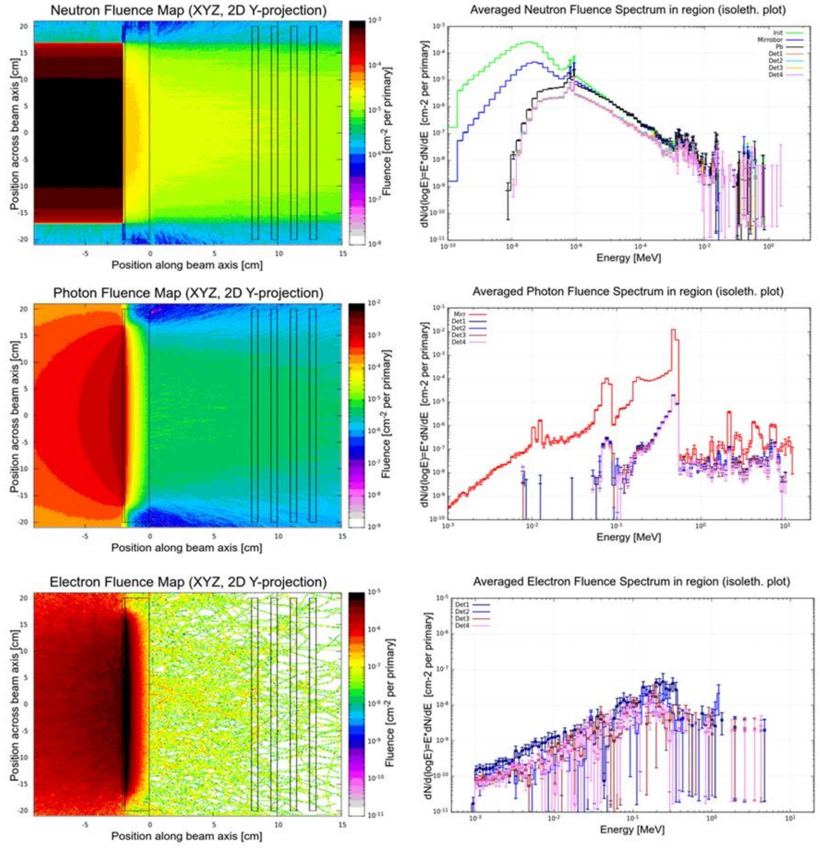
Fluka simulations with Mirrobor (borated "rubber", 20%) from Dmitrii Ilin

$^{10}B + n \rightarrow \alpha\ (0.83\ MeV) + {}^{7}Li\ (1.47\ MeV) + \gamma\ (0.48\ MeV)\ (93\%)$

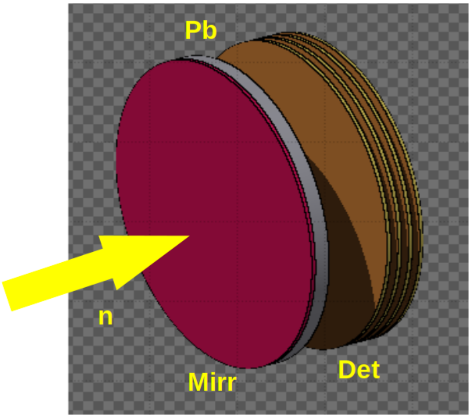
$\rightarrow \alpha\ (1.8\ MeV) + {}^{7}Li\ (1.0\ MeV)\ (7\%)$

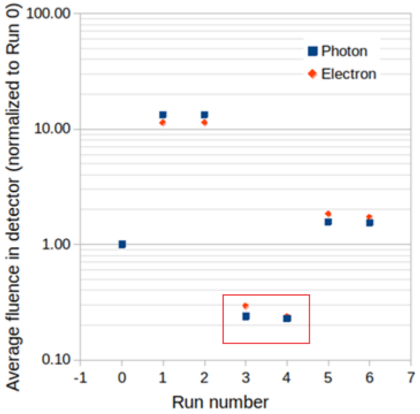
Mirrobor - это композитный гибкий материал на основе порошка карбида бора B_4C и связующего акрилатного клея. Массовое содержание B_4C в материале около 80% (с природным содержанием B^{10} - ~20%), что примерно соответствует концентрации атомов B^{10} на уровне 9.4×10^{21} ат/см^3 (по данным производителя).

Результат с одной из наиболее приемлемой для мюонного детектора композицией материалов, включающей в себя слои толщиной 19мм свинца и 2мм Mirrobor представлен на Рисунке.



Слева представлены 2D-проекции потоков части, сверху – вниз: нейтронов, фотонов от фотоядерных реакций и вторичных электронов, справа, в том же порядке – энергетические спектры частиц,



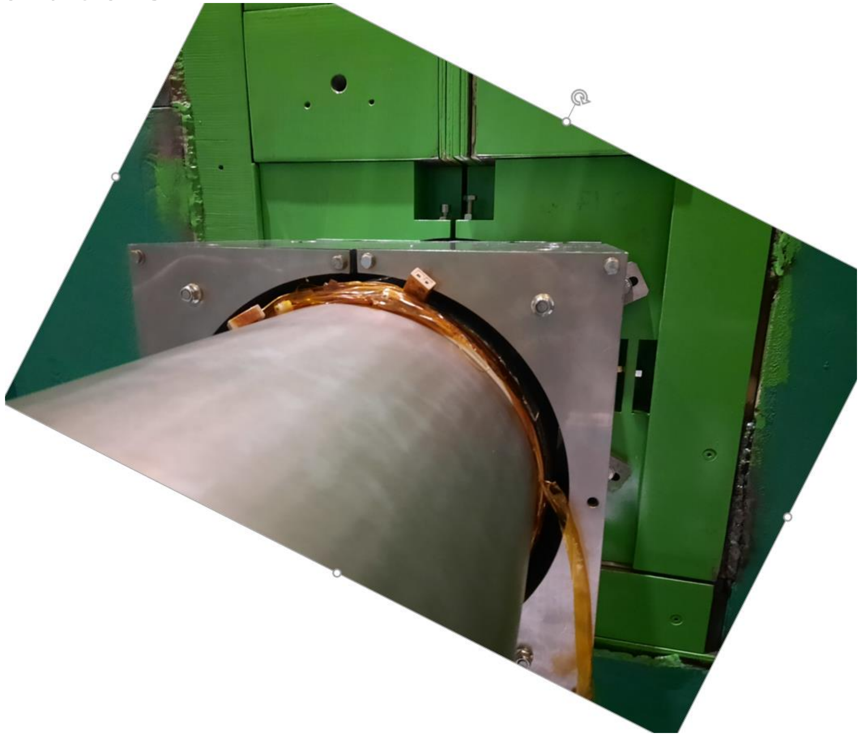


fluxs normalized to no shields

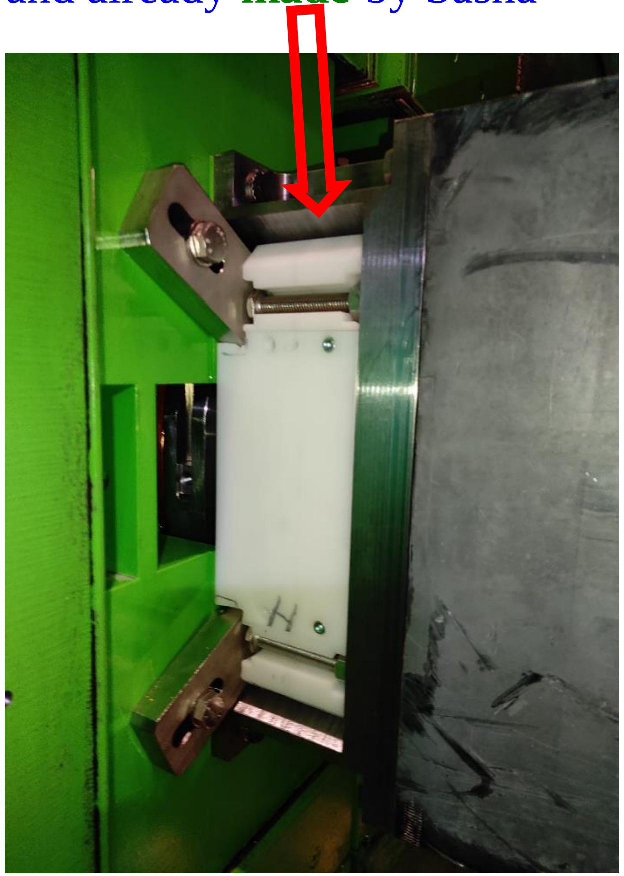
	Photon	Electron	
Run0	1.00	1.00	Plain
Run1	13.22	11.27	2mm Mirr
Run2	13.26	11.36	5mm Mirr
Run3	0.24	0.29	2mm+19mmPb
Run4	0.23	0.24	5mm+19mmPb
Run5	1.57	1.83	2mm+10mmPb
Run6	1.53	1.72	5mm+10mmPb

Neutron shielding

Idea is an installation few pieces of the flexible borated plastic "Mirrobor" in front of muon chambers on M2-front and inside new M2 beam plug in order to measure a reduction (if it is) of the rates directly with comparing the rates on symmetrical chambers on A and C-sides and also comparing the rates on shielded and not shielded neighbor FEB-channels where ratio bw rates on channels is well known at nominal conditions.



Insertions in M2 beam plug (lead + Mirrobor) to be made on external firm. Work with lead is forbidden at CERN. Mockup has been designed and already **made** by Sasha



Final drawings of the lead parts including:

1. ***Sandwich plates for M2-front (two samples)***
2. ***Insertions in M2 beam plug – 16 pieces in total***

have been finished by Alessandro Saputi and already sent or will be sent next days for the request an invoice.

Заключение

1. ***LHCb в качестве фактически НОВОГО детектора начнёт качественный набор данных для физики не позднее следующего года.***

2. ***Есть над чем задуматься, при планировании строительства новых крупных экспериментальных установок.***

3. ***Вклад ОФВЭ ПИЯФ в LHCb в целом и в Мюонный детектор в частности остаётся на высоком уровне.***

4. ***Есть хорошие идеи по использованию пропорциональных камер для следующей модернизации и для крупных экспериментов в будущем.***