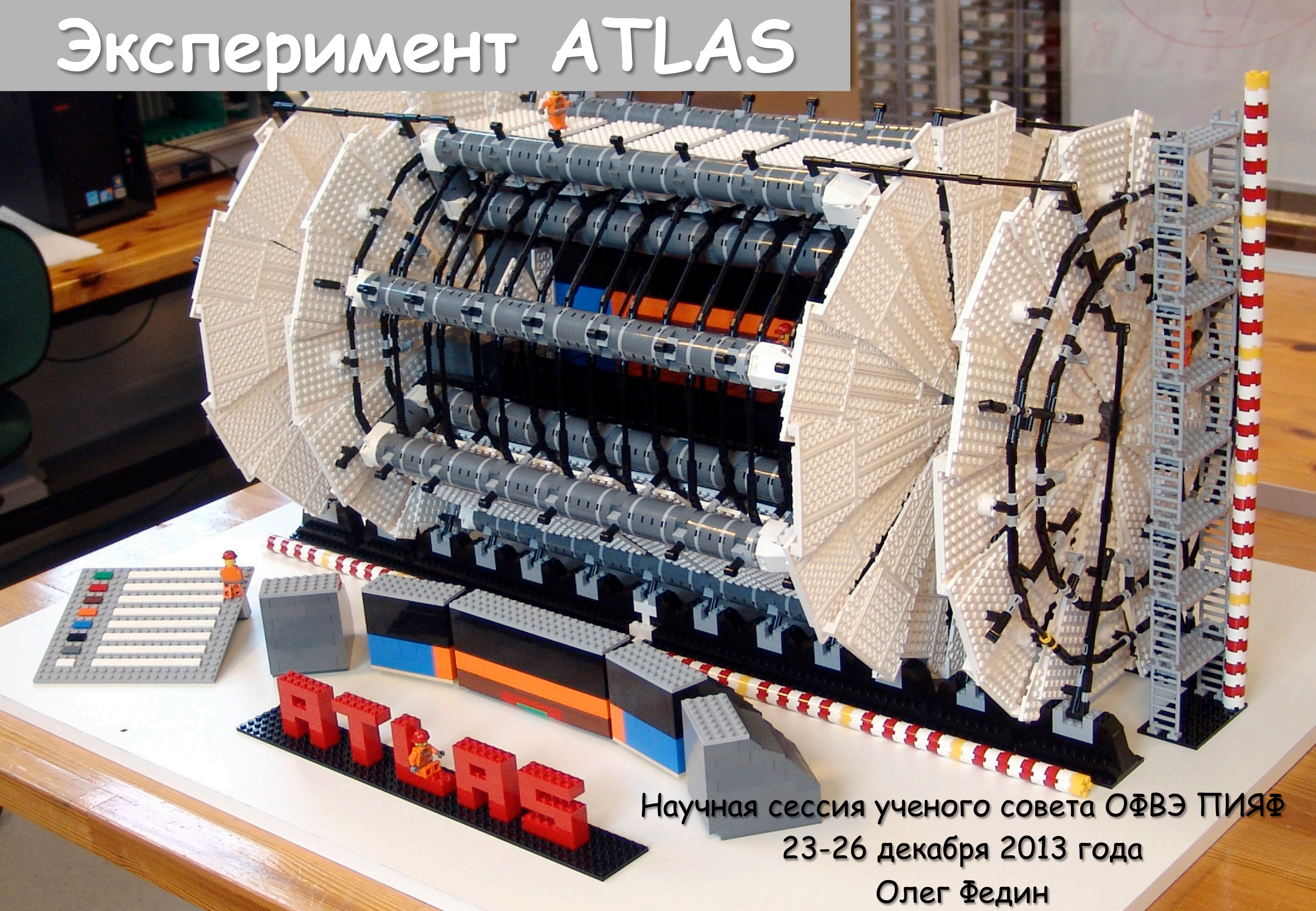
Эксперимент ATLAS



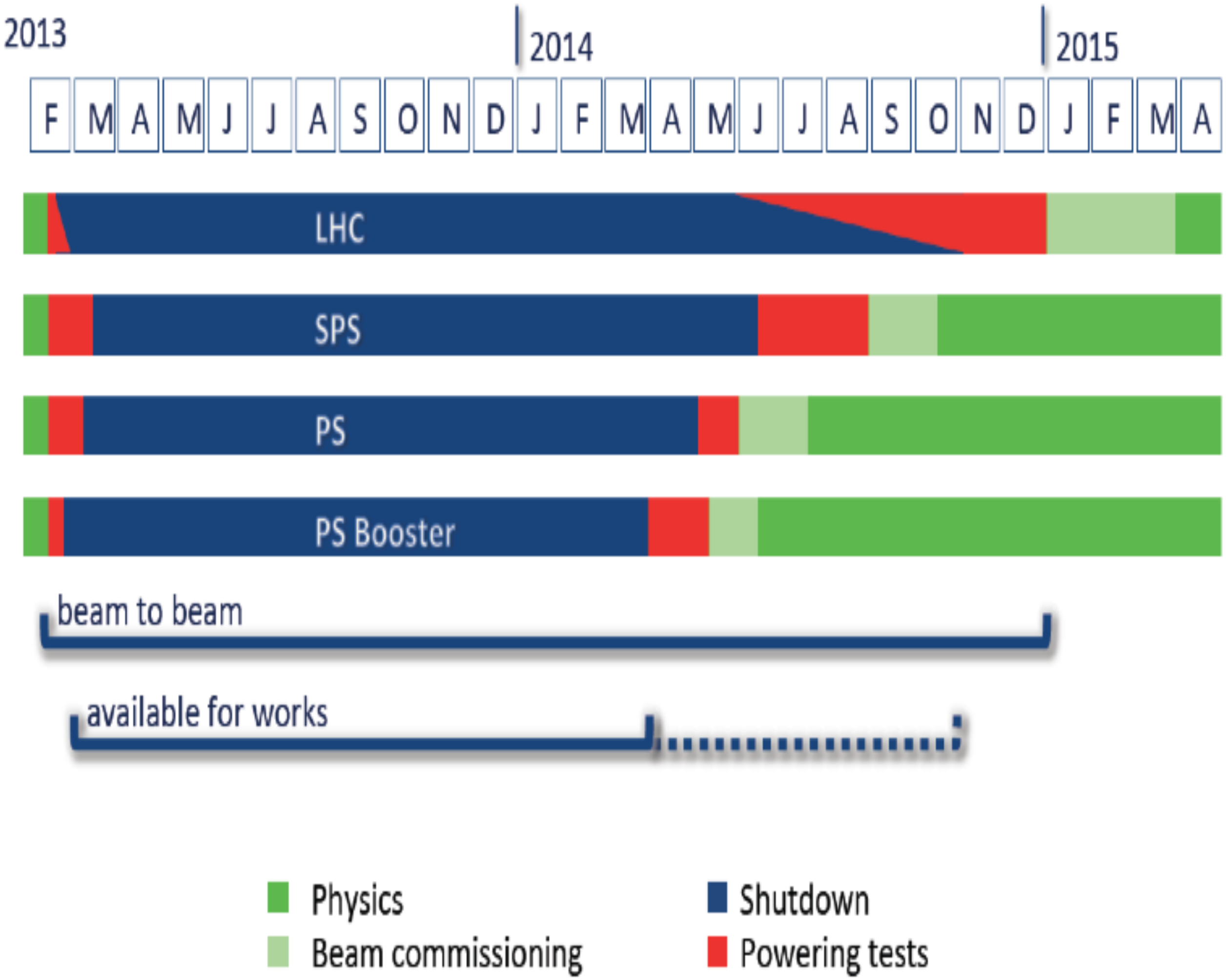
Научная сессия ученого совета ОФВЭ ПИЯФ

23-26 декабря 2013 года

Олег Федин

LHC shutdown LS1

LHC back for physics in April 2015 with most probably 13 TeV, i.e. 1.6 times enlarged energy

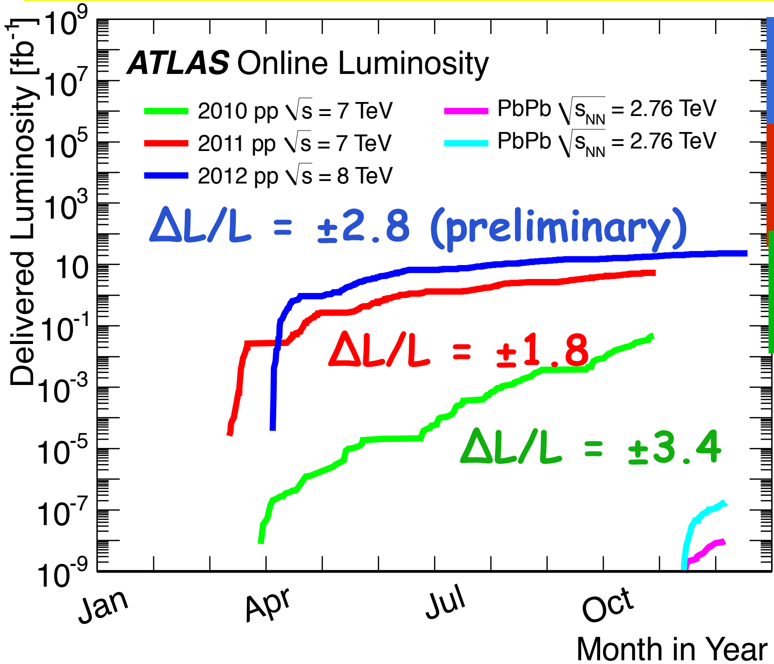


ATLAS LS1 activities:

- ✧ repair and revision of all ATLAS sub-systems.
- ✧ installation of the Pixel IBL.
- ✧ Analysis of data accumulated during RUN-I.
- ✧ Preparation for the ATLAS detector upgrade in Phase-I (2018).

RUN-I: ATLAS Luminosity & Data taking

Outstanding performance of LHC !



2012 – 8 TeV
L ~ 23 fb^{-1}

2011 – 7 TeV
L ~ 5 fb^{-1}

2010 – 7 TeV
L ~ 0.05 fb^{-1}

Number of events in RUN-I dataset (~ 28 fb^{-1}) after all selection cuts:

W → lν ~ 100 M (LEP2: 0.2M pair W^+/W^-)
Z→ ll ~ 10 M (LEP 16M)
tt → l+X ~ 0.4 M
SM Higgs ~ 400
[~1 H→ γγ (~1 H→ 4l) produced every 50' (14h) at 7x 10^{33}]

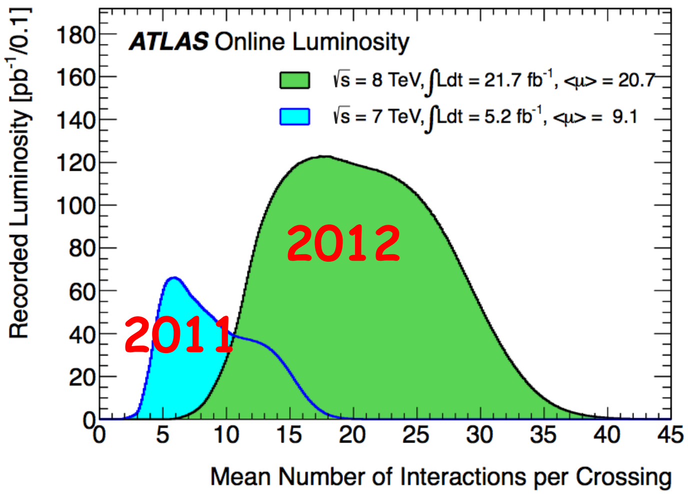
- **Data-taking efficiency = (recorded lumi)/(delivered lumi): ~ 93.7%**
- **Fraction of data after data quality cuts used for analysis: ~ 94%**
- **Fraction of delivery luminosity used for physics: ~ 90%**

→ **excellent performance of data taking and data quality**

Inner tracking Detectors			Calorimeters				Muon Detectors				Magnets	
Pixel	SCT	TRT	LAr EM	LAr HAD	LAr FWD	Tile	MDT	RPC	CSC	TGC	Solenoid	Toroid
99.8	99.6	99.2	97.5	99.2	99.5	99.2	99.4	98.8	99.4	99.1	99.8	99.3

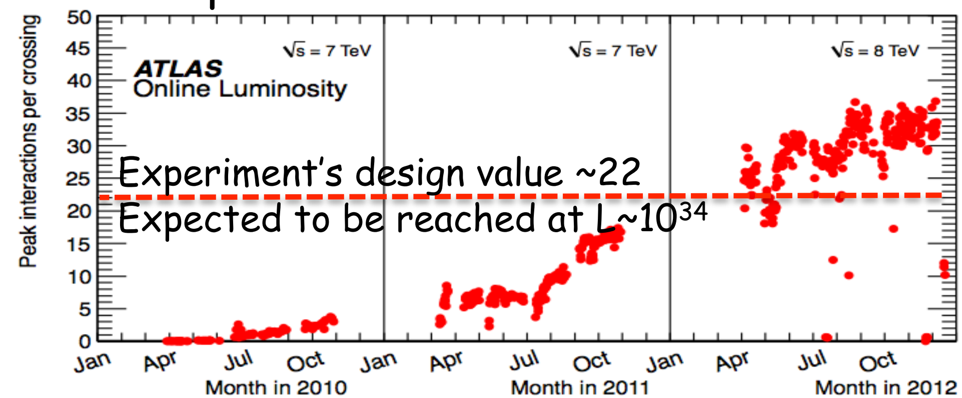
A challenge in RUN-I - pile up events

Numbers of interactions per bunch crossing



Huge efforts invested over the RUN-I to minimise the impact of pile-up on physics

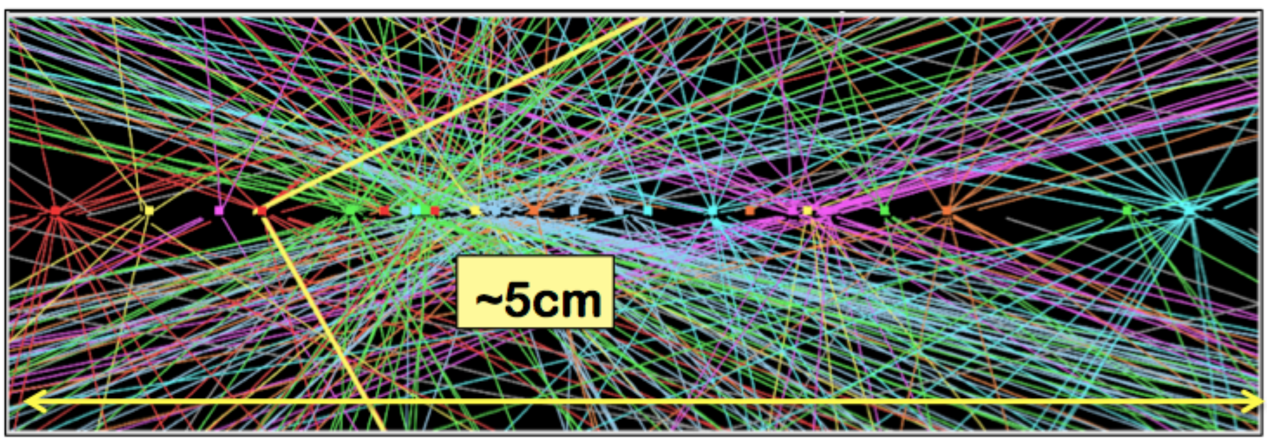
peak # collisions vs time



Peak Luminosity: $7.73 \times 10^{33}\ cm^{-2}\ s^{-1}$

$$\mu = L \times \sigma_{inel} / (n_{bunch} \times f_r)$$

Z→μμ event from 2012 data with 25 reconstructed vertices



Strategy:

- Developed pile-up robust fast triggers;
- Optimized reconstruction and identification of physics objects;
- Precise modeling of in-time and out-of-time pile-up in simulation;
- Flexible computing model to handle x2 trigger rate and x2 event size.

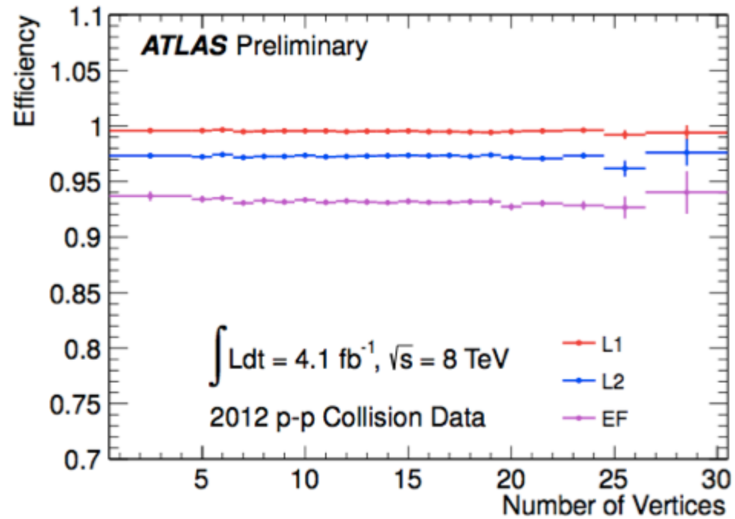
Trigger in 2012

Trigger Menu optimized for $7x10^{33}cm^{-2}s^{-1}$ at 8 TeV:
- ✧ improvement of object selection, e.g. isolation to keep single lepton threshold low (in-spite of 2 x lumi and 2 x pile-up with respect 2011)
- ✧ pile-up robust algorithms close to offline selections

Operations in 2012 show trigger is coping very well (in terms of rates, efficiencies, robustness,...) with harsh conditions while meeting physics requirements

Trigger rates:
- Level 1 rates ~ 65 kHz
- Level 2 rates ~ 5 kHz
- Event Filter(EF) rates ~ 400 Hz

Efficiency of inclusive single electron trigger as a function of pile-up



Main triggers at 7×10^{33} $cm^{-2}s^{-1}$

Offline (GeV)	L1 thr (GeV)	L1 rate (kHz)	EF thr (GeV)	EF rate (Hz) @5 10^{33}
e > 25	18	17	24	70
μ > 25	15	8	24	45
dilepton	10-15	15	8-18	21
2γ 25-40	10-16	12	20-35	17
2τ 30-45	11-15	12	20-29	12
Jet > 360	75	2	2	5
MET 120	40	2	80	17

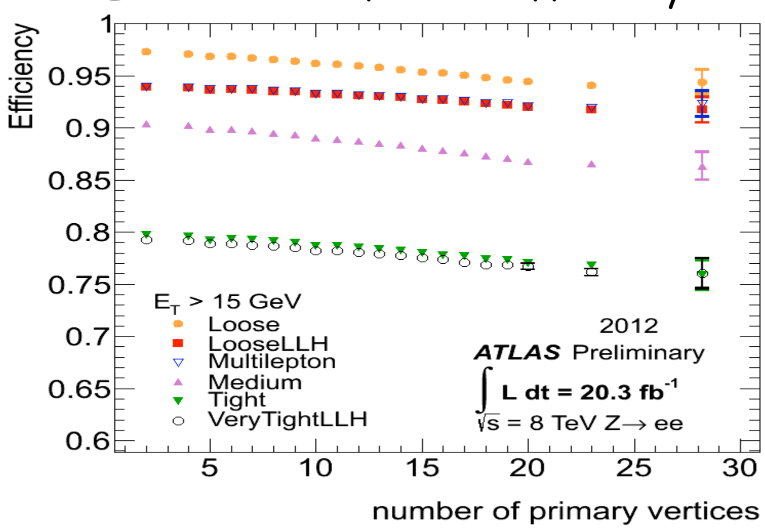
PNPI contribution :
- E_T^{miss} trigger optimization for 2012 data;
- optimization of single electron trigger for RUN-II (efficiency and rate) using 2012;

Electron Performance

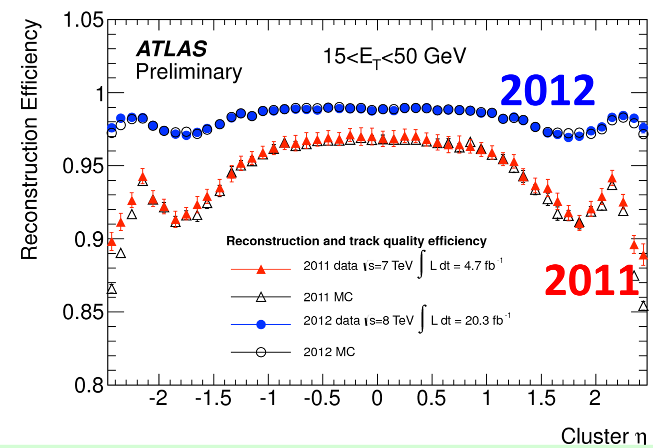
Electron reconstruction improved
- ✧ More performing track cluster matching
- ✧ Track pattern recognition takes in account of bremsstrahlung losses
- ✧ Achieved ~ 98% reconstruction efficiency, ~ flat vs η and ET

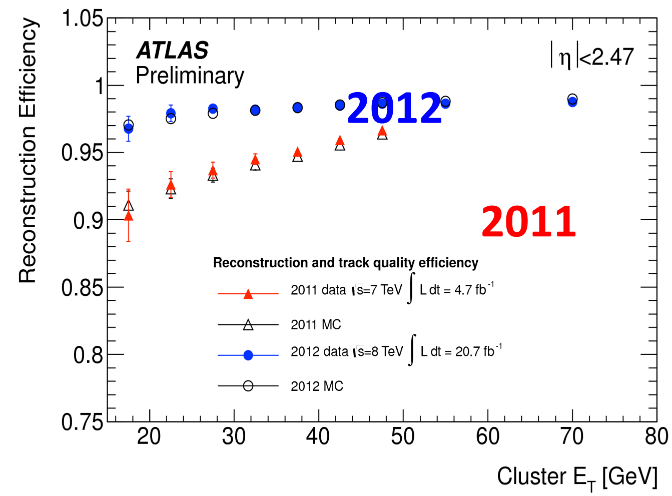
Retuning of cuts (shower shape) Identification efficiency achieved ~ 95%, ~ flat vs pile-up

Electron identification efficiency



Results are from Z→ee data and MC tag-and-probe





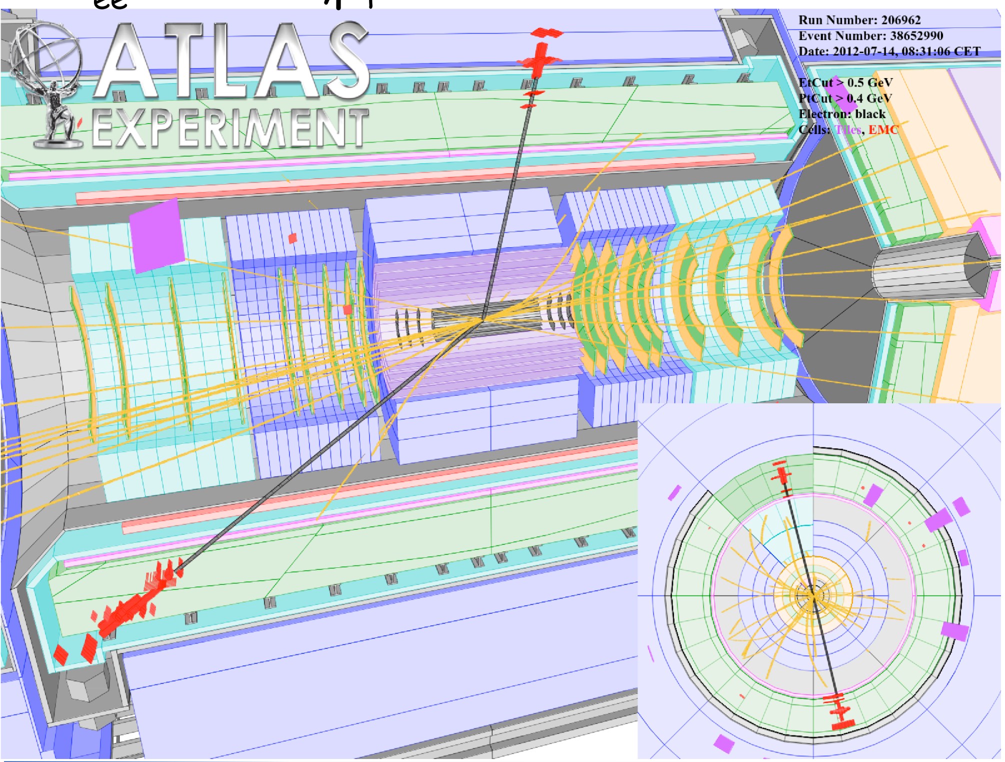
PNPI contribution :
- s/w development for the tracks refit to account lost of the energy due to brem;
- measuring electron efficiencies in 2012 data and define SF in Z→ee and ϒ→ee channels;
- validation of egamma s/w;
- The work supported by RFBR.

Search for high mass di-lepton resonances

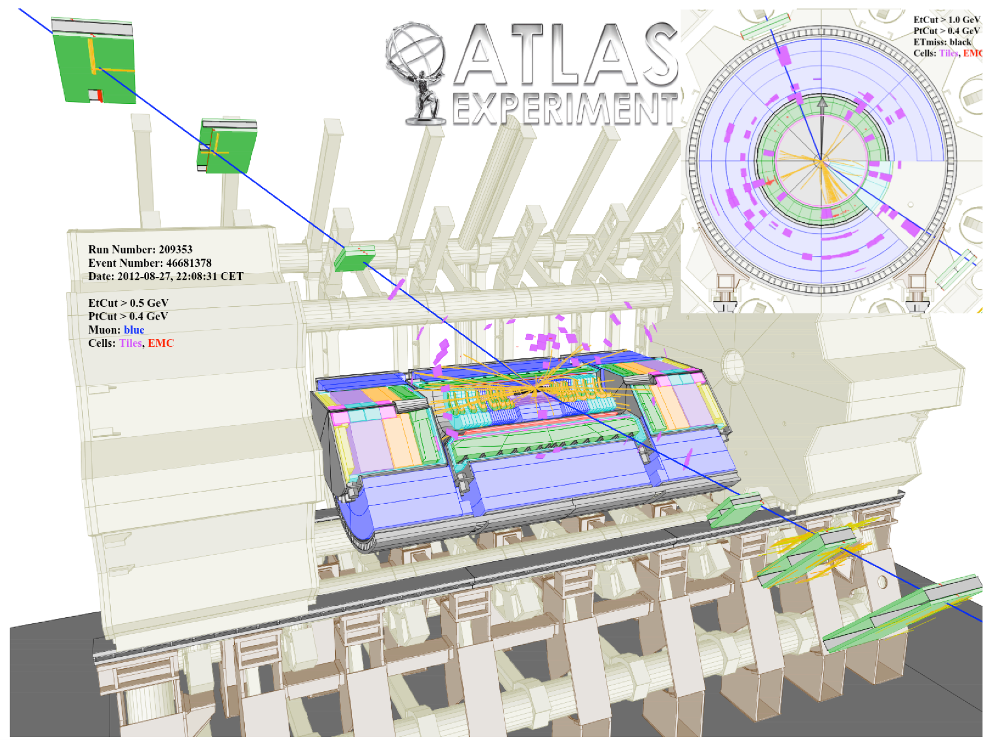
Models: Z′(SSM,E6), Z*, G*(RS) etc
- Signature: l^+l^- (with l=e,μ)
  - ✧ two electrons |η|<2.47 E_T >40/30GeV
  - ✧ two muons |η|<2.4 E >25 GeV

Benchmark model: Sequential Standard Model (SSM) in which Z′ has the same coupling to fermions as SM Z.

Highest invariant mass dielectron event
m_{ee} =1.5TeV,p_T=0.59/0.58 TeV

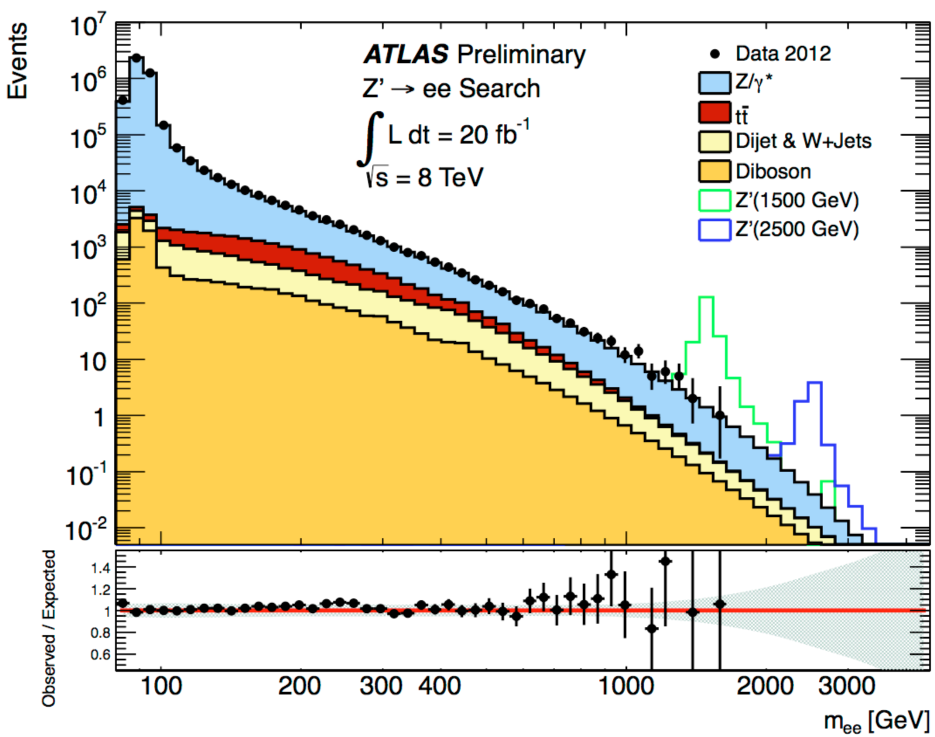


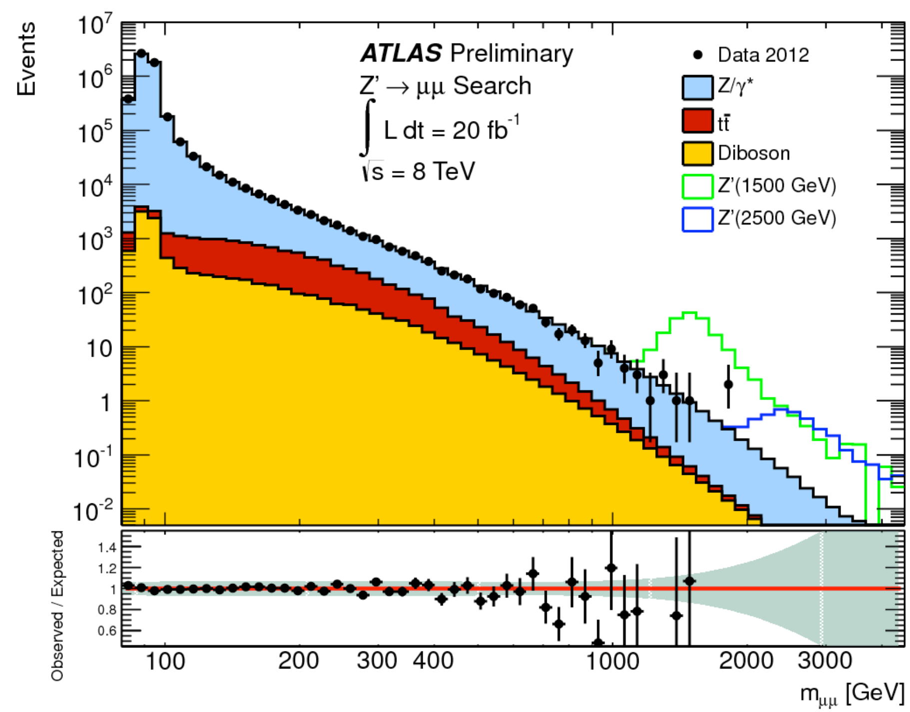
Highest invariant mass dimuon event
$m_{\mu\mu}$ =1.8TeV,p_T=0.65/0.65TeV



Search for high mass di-lepton resonances

- Observable is mass of di-lepton pair normalized to Z-peak
- Dominant background is $Z/\gamma^* \rightarrow ll$
- Backgrounds:
  - ✧ From simulation: Drell-Yan, diboson and ttbar
  - ✧ Data-driven estimation : W+jet and dijet
- Signals: From LO simulation





Search for high mass di-lepton resonances

In the absence of any significant signal 95% C.L. limits were set using Bayesian approach on cross section time branching ration

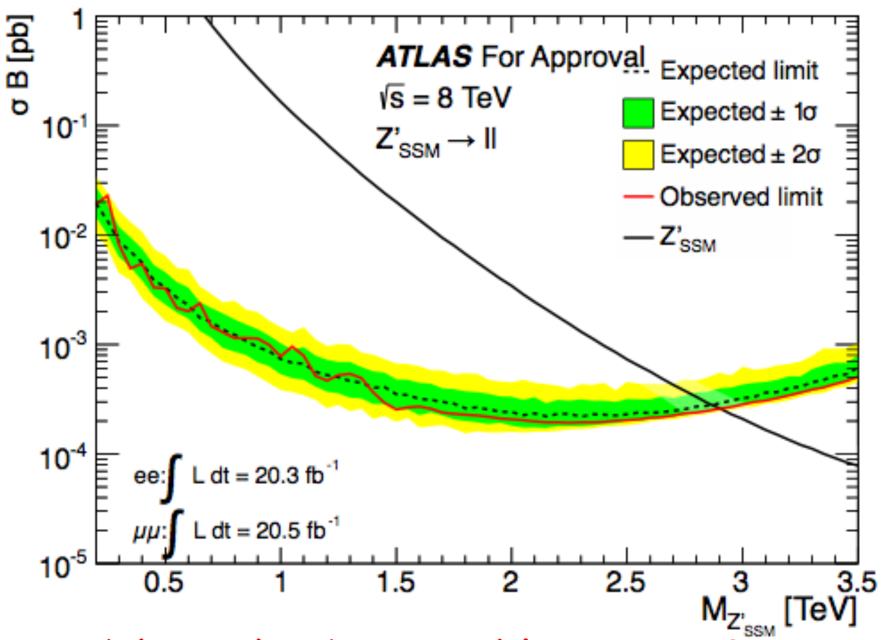
PNPI contribution :

- electron channel analysis: cut flow, QCD bkg. estimation, SF for electon efficiencies, Z* MC production and validation, CL for Z* channel.

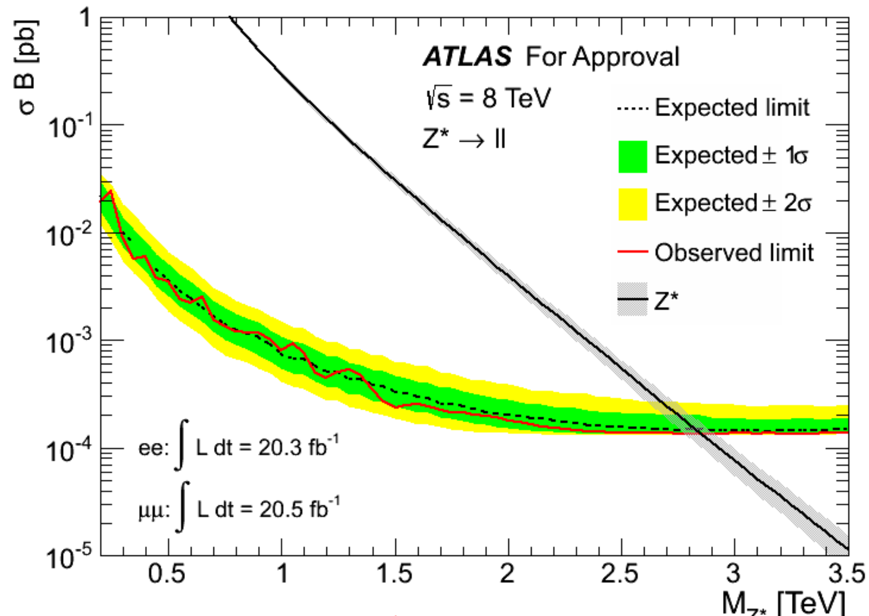
$$\mathcal{L}(\lambda, \boldsymbol{\nu}) = \prod_{i}^{N_{\rm bins}} \frac{e^{-\bar{n}_i} \bar{n}^{d_i}}{d_i!} G(\boldsymbol{\nu}).$$

$$\mathrm{LLR} = -2 \ln \frac{\mathcal{L}(\mathrm{data} \mid \hat{n}_{Z'}, \hat{M}_{Z'}, \hat{\boldsymbol{\nu}})}{\mathcal{L}(\mathrm{data} \mid (\hat{n}_{Z'} = 0), \hat{\hat{\boldsymbol{\nu}}})},$$

Model	Z'		Z^*	
Year	Obs. [TeV]	Exp.[TeV]	Obs. [TeV]	Exp. [TeV]
2010	1.048	1.088	1.152	1.185
2011	2.22	2.25	2.20	2.22
2012	2.90	2.87	2.85	2.82



Z' (SSM) observed limit: 2.90 TeV



Z* observed limit: 2.85 TeV

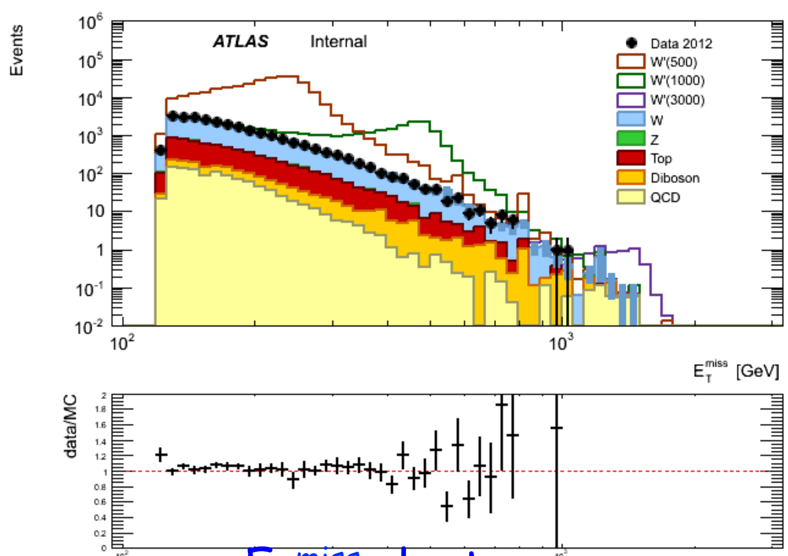
Search for heavy bosons decaying to lepton and neutrino

- Many models predict additional heavy bosons that decay to lepton and neutrino
- Use Sequential Standard Model (SSM) W' as benchmark model
- Search for high mass states with lepton plus missing ET
- The observable is transverse mass

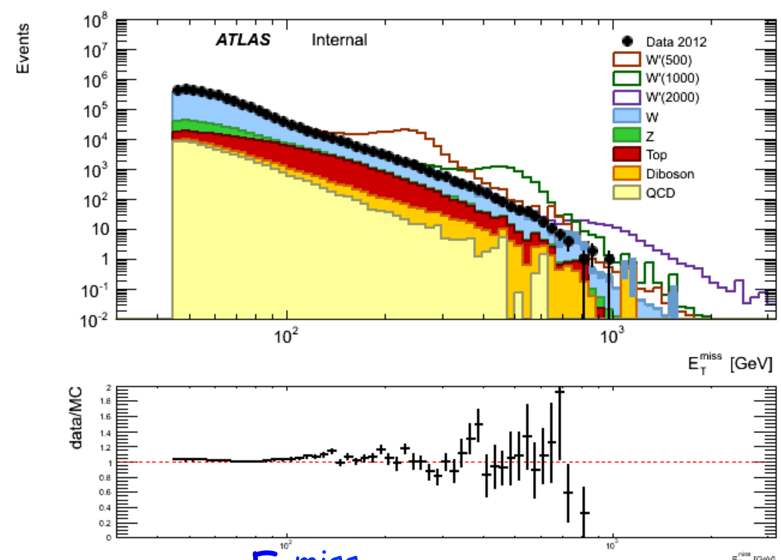
$$m_T = \sqrt{2 p_T^l E_T^{miss} (1 - \cos\varphi_{l\nu})}$$

- Look for excess above background – counting experiment!!

- Signature: lν (with l=e,μ)
  - ✧ one electron |η|<2.47 E_T >125 GeV and missing E_T> 125 GeV
  - ✧ one muon |η|<2.4 E_T >45 GeV and missing E_T > 45 GeV

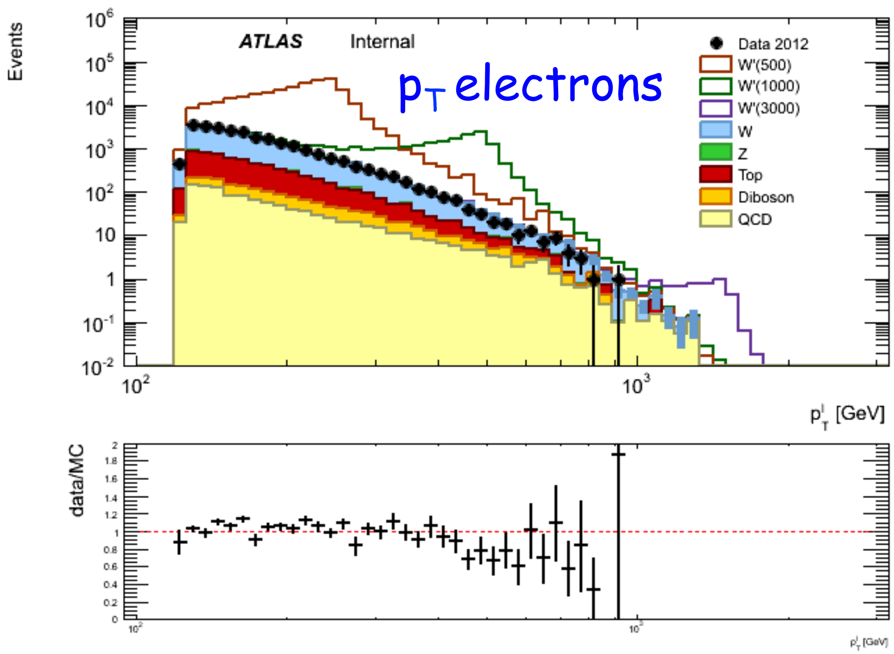


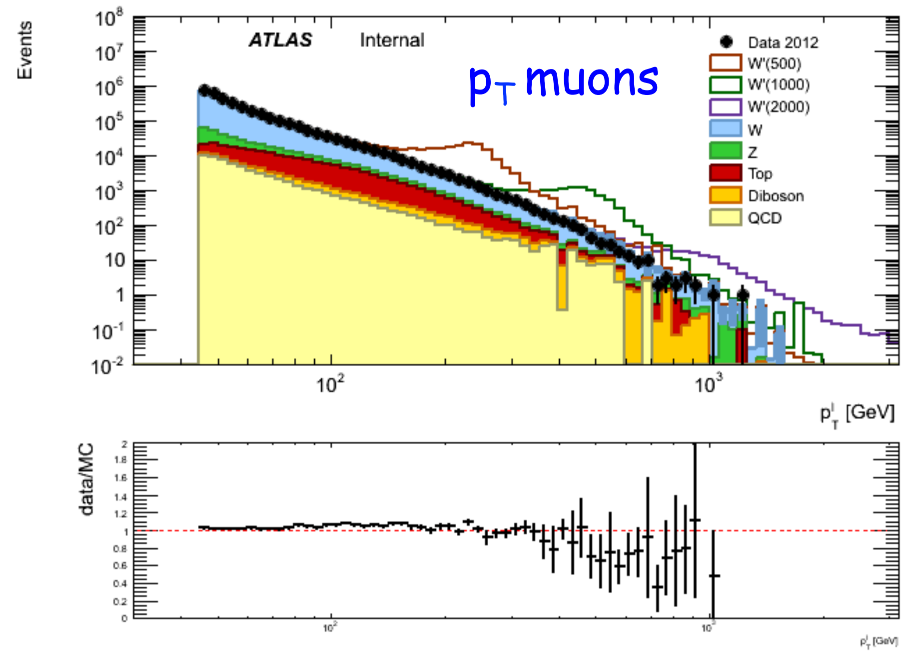
E_T^{miss} electrons



E_T^{miss} muons

Search for heavy bosons decaying to lepton and neutrino





Observed in both channels that MC overestimates data at high p_T
Should be resolved to be able to unblind

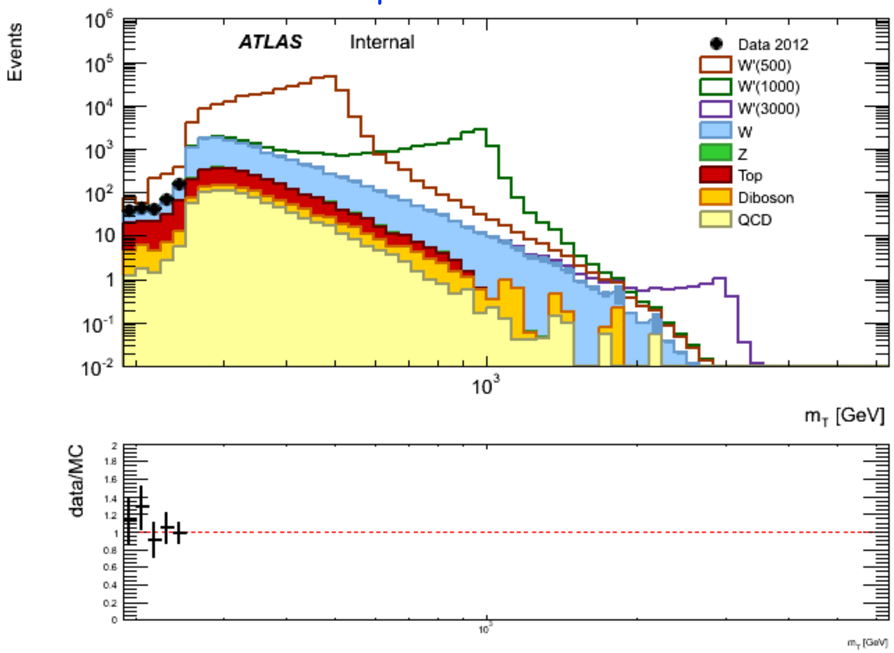
Background:

- $W \rightarrow l\nu$ most dominant and irreducible
- $Z \rightarrow ll$ when one lepton is not reconstructed mimicking real missing E_T
- Dibosons (WW,WZ,ZZ) + ttbar+ single top production are the next largest that have real missing ET
- QCD multi-jet estimated from data

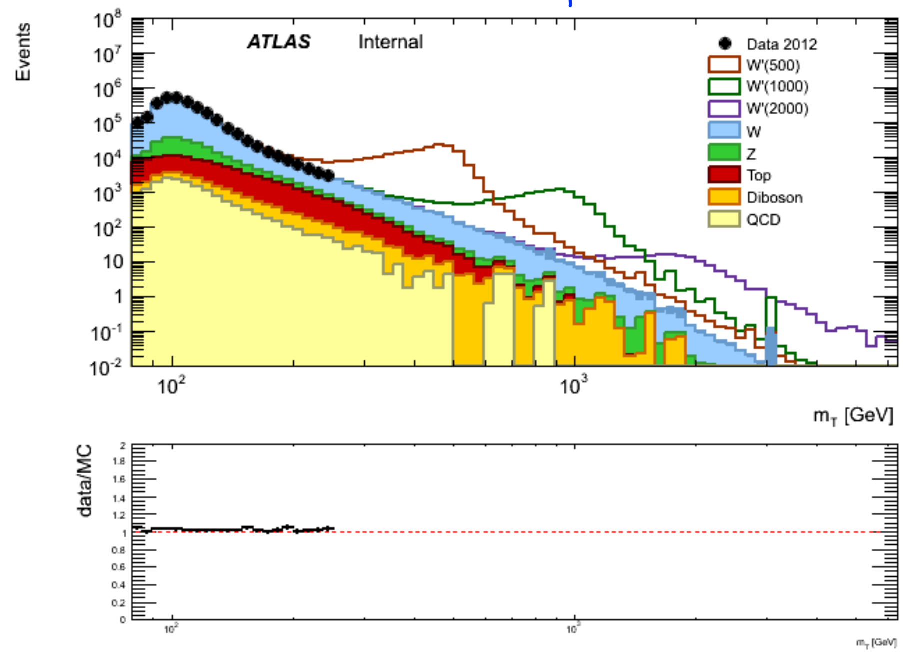
Search for heavy bosons decaying to lepton and neutrino

Analysis is still blind: data above 252 GeV (in the limit setting region) is not shown on plots

m_T electrons



m_T muons

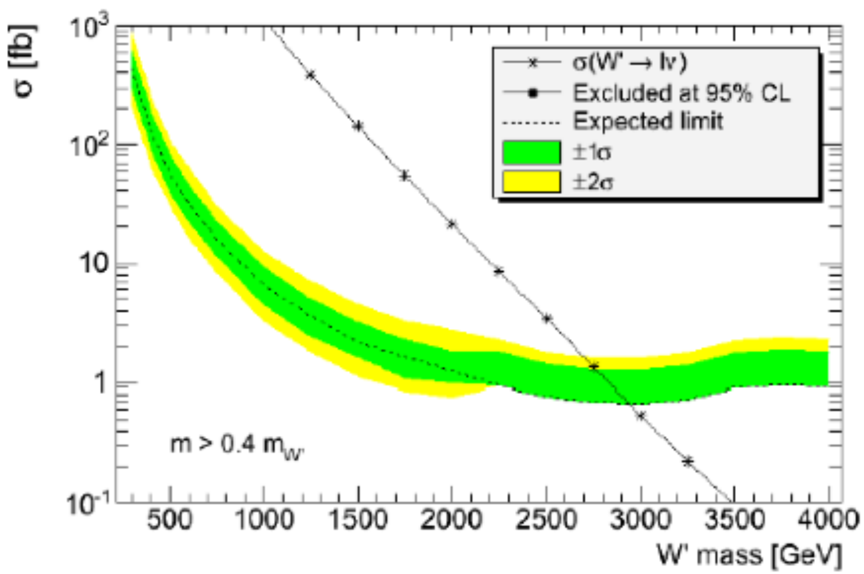


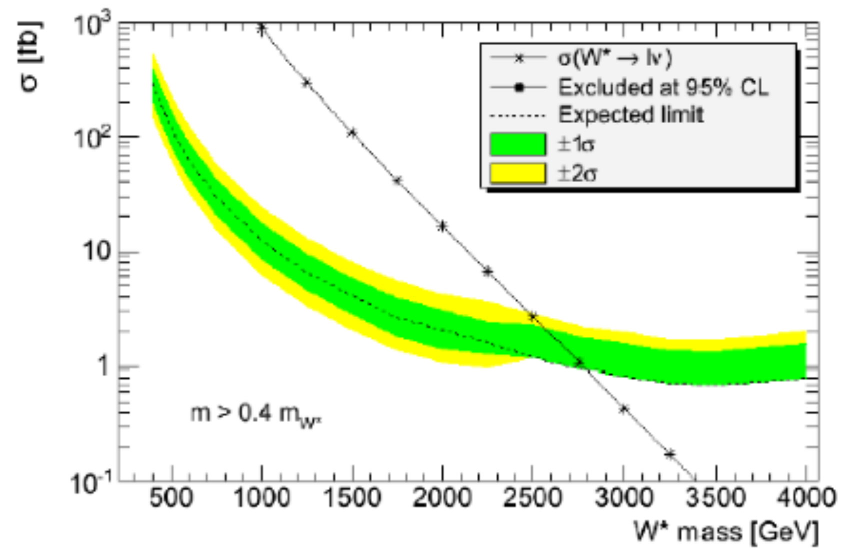
Search for heavy bosons decaying to lepton and neutrino

PNPI contribution :

- electron cahnnel analysis: cut flow, QCD bkg. estimation, SF for electon efficiencies, W* MC production and validation, CL for W* channel.

Model	W'		W^*	
Year	Obs. [TeV]	Exp.[TeV]	Obs. [TeV]	Exp. [TeV]
2010	1.49	1.45	1.35	1.32
2011	2.55	2.55	2.42	2.42
2012		2.95		2.80





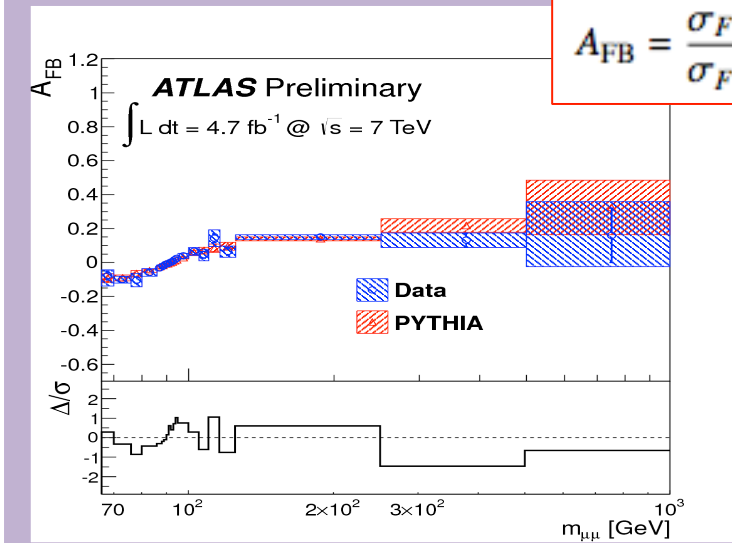
W' (SSM) expected limit: 2.95 TeV

W* expected limit: 2.80 TeV

Forward-backward asymmetry in Z→ll

Due to the V-A nature of the electroweak interaction, the leptons produced in the annihilation process qq→ Z/γ*→ l⁺l⁻ present a forward-backward asymmetry (A_{FB}) with respect to the quark direction in the rest frame of the dilepton system.

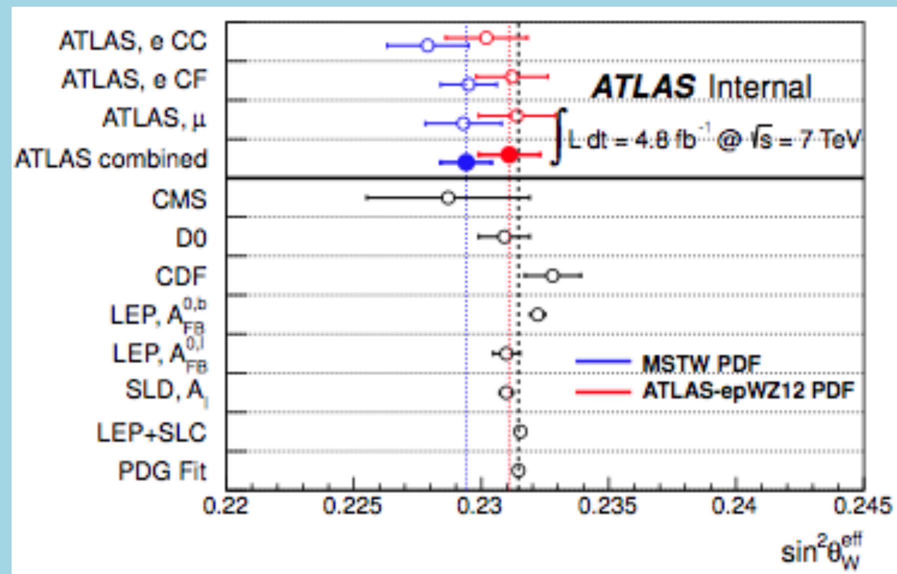
$$A_{FB} = \frac{\sigma_F - \sigma_B}{\sigma_F + \sigma_B}$$



$$\frac{d\sigma}{d\cos\theta} = \frac{4\pi\alpha^2}{3\hat{s}}\left[\frac{3}{8}A(1+\cos^2\theta) + B\cos\theta\right]$$

Several Standard Model parameters can be extracted from the A_{FB} measurement. One of these is the electroweak mixing angle, $\sin^2\theta_W$. At tree level, this is expressed by the ratio of the vector and axial-vector couplings of the fermions

$$\frac{g^f_{V,tree}}{g^f_{A,tree}} = 1 - 4|Q_f|\sin^2\theta_W$$



Z-boson polarization

Differential cross-section represented as of nine helicity cross-sections multiplied by harmonic polynomials in θ,φ angles of lepton in the Collins-Soper frame:

$$\frac{d\sigma}{dp_T^2 dy d\cos\vartheta d\varphi} = \frac{3}{16\pi}\frac{d\sigma^{U+L}}{dp_T^2 dy}\Big\{(1+\cos^2\vartheta) + \frac{1}{2}A_0(1-3\cos^2\vartheta) + \frac{1}{2}A_1\sin 2\vartheta\cos\varphi$$

$$+\frac{1}{2}A_2\sin^2\vartheta\cos 2\varphi + A_3\sin\vartheta\cos\varphi + A_4\cos\vartheta$$

$$+A_5\sin^2\vartheta\sin 2\varphi + A_6\sin 2\vartheta\sin\varphi + A_7\sin\vartheta\sin\varphi\Big\}$$

LO term ($(1+\cos^2\vartheta)$)

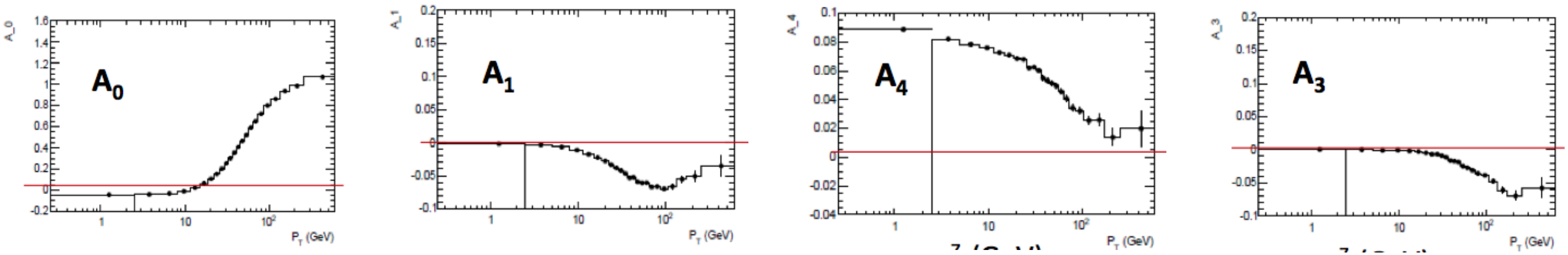
LO term ($A_4\cos\vartheta$)

A3, A4, A5, A6 - parity conserving
A0, A1, A2, A7 - parity violating
A4 - related to AFB

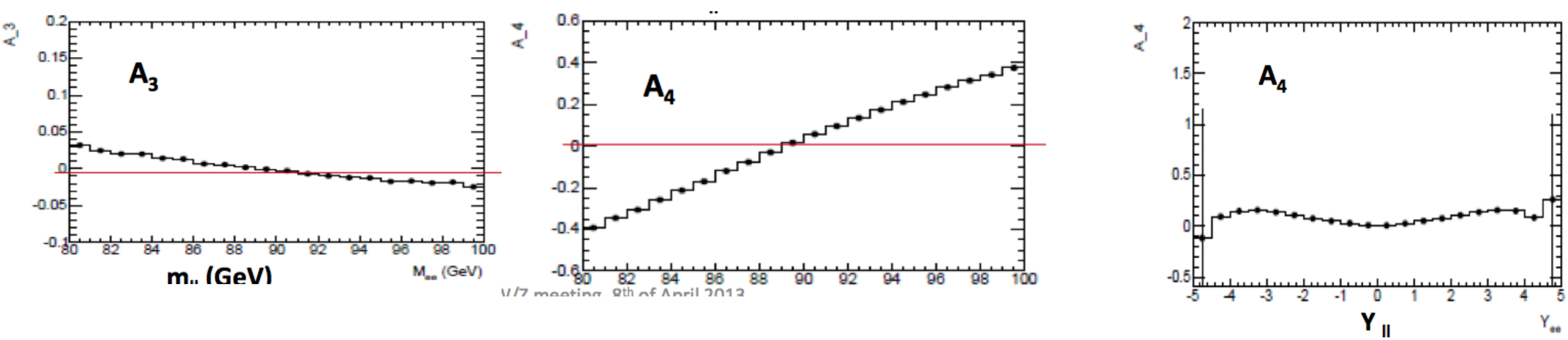
- Angular coefficients Ai are functions of lepton-pair kinematics: p_T^{ll}, y_{ll}, m_{ll}. Contain information about underlying QCD - dynamics, subject to modifications from higher order perturbative and non-perturbative corrections, structure functions, renormalisation/factorisation scale, underlying event, dependent on the subprocess type: annihilation or Compton scattering. => QCD dynamics can be probed.
- Aim is to measure all 8 coefficients A0 -A7, which requires simultaneous 2D fitting in ($\cos\theta_{CS}$,φ_{CS}) parameter space.
- May be used to compare MC generator implementations of hard scatter/parton shower
- Not explored in TH papers since almost 20 years, last published results on NLO corrections for Tevatron from `94.

Z-boson polarization

Angular coefficients are not expressed by analytical formulae (usually). Some expected to be small: A1,A3,A4, or close to zero: A5,A6,A7. At large p_T, A0 and A2 grow and saturate at 1.



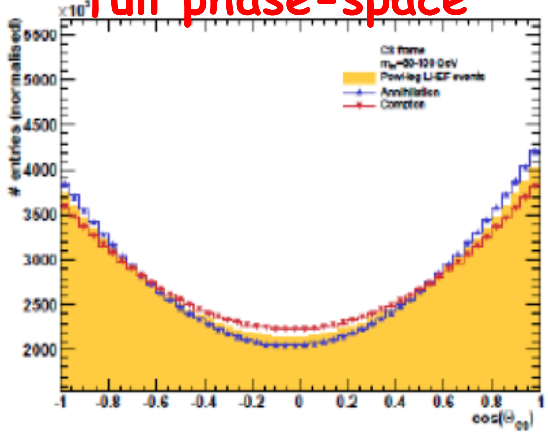
Only A3 and A4 show some dependence on m_{ll} and Y_{ll} .



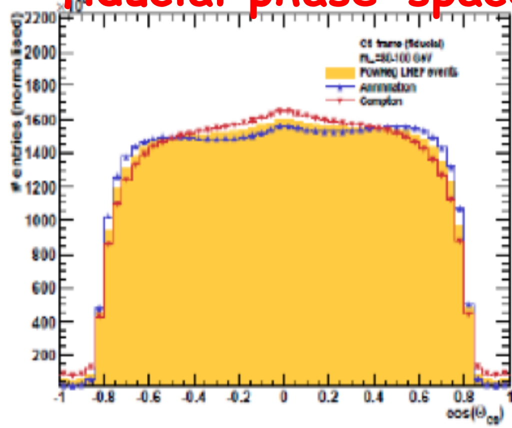
Z-boson polarization: analysis strategy

- ✧ Standard data analysis in the fiducial volume, after background subtraction and unfolded to the particle level (from detector effects and QED FSR: use Born-level leptons).
- ✧ Monte Carlo templates (particle level) propagated to the fiducial volume; use reweighting to isotropic events.
- ✧ 2D fit in ($\cos\theta_{CS}$,φ_{CS}) distributions in p_T bins, coefficients A0-A7 extracted from the fits.
- ✧ Comparison of measured coefficients with different MC predictions and different PDFs.
  - Interpretation in language of QCD dynamics.
  - Relation between A4 and $\sin^2\theta_W$.
- ✧ Prediction power for other observables (e.g. φ^*) At this point, we have a handle (in principle) on infinite order QCD in Collins-Soper frame!

full phase-space

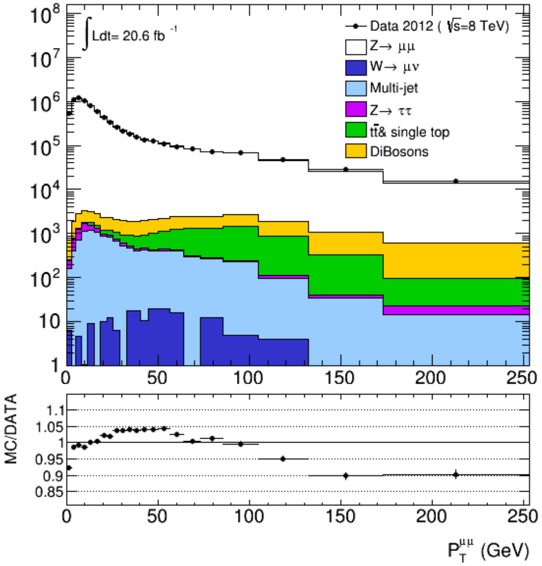


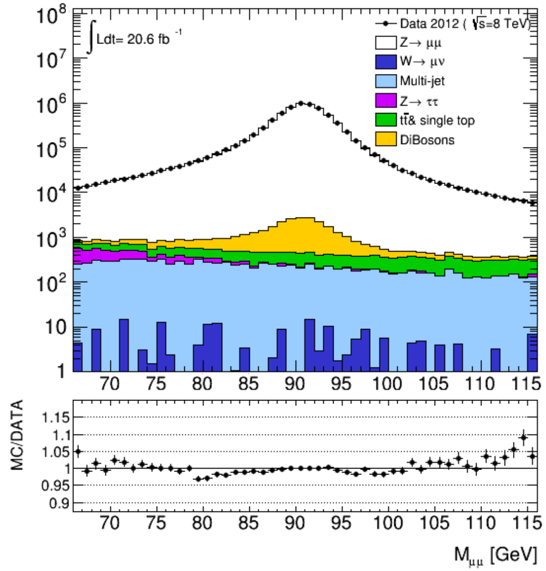
fiducial phase-space

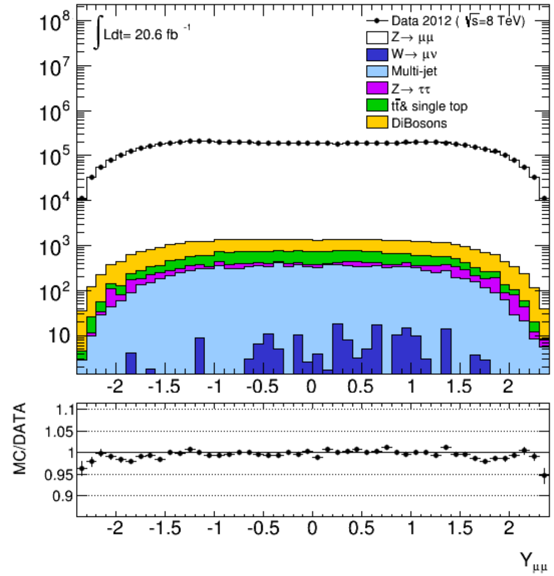


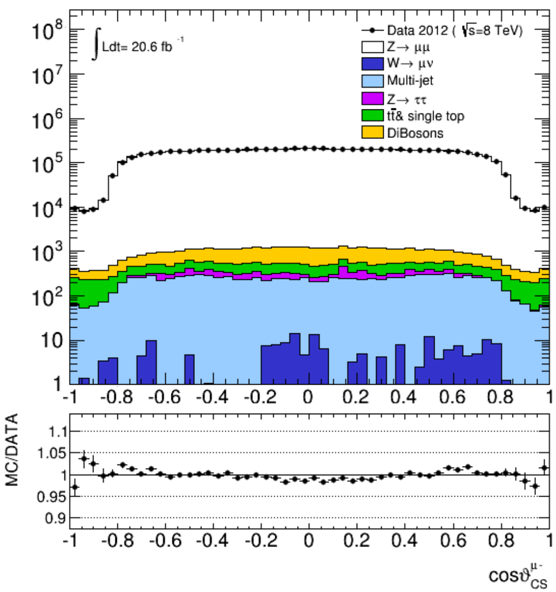
Distributions are sensitive to the production sub-process, and the shapes change rapidly with p_T^Z. In fiducial volume, the shapes are dominated by kinematic effects

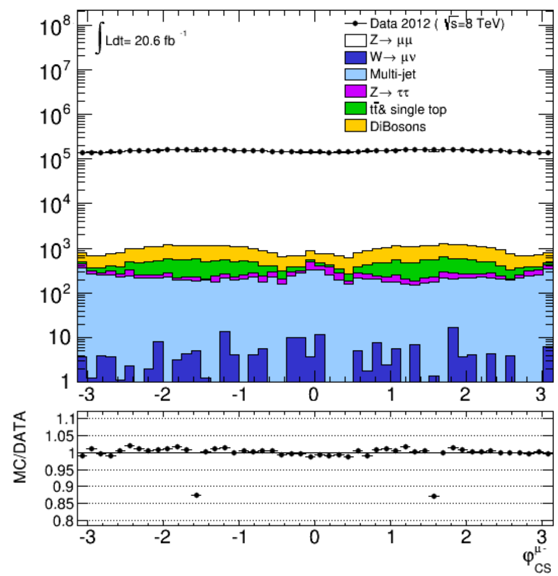
Z-boson polarization: QCD background estimation







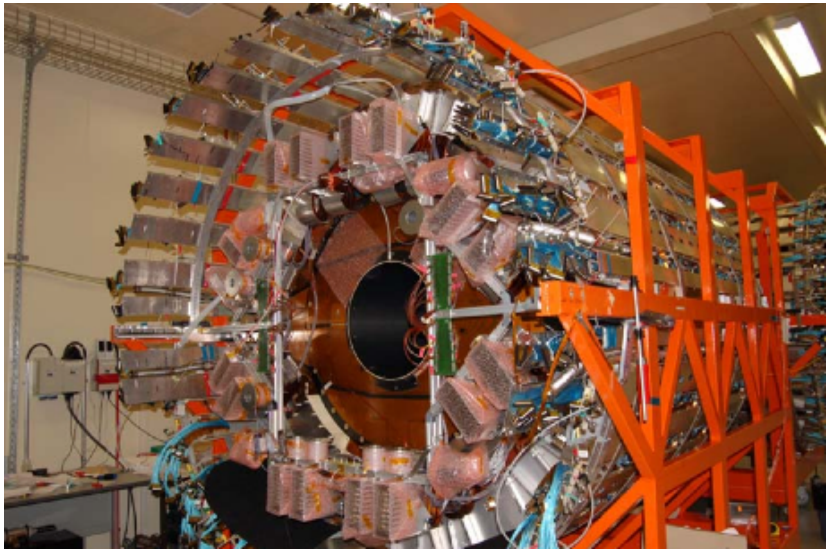




PNPI contribution :

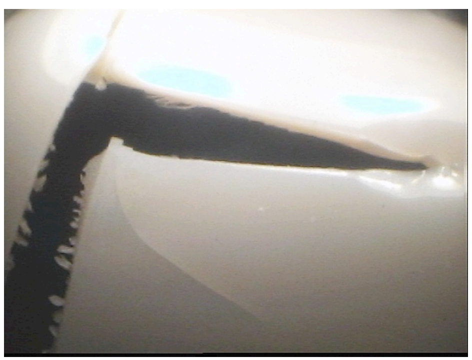
- *muon channel analysis: cut flow, QCD bkg. estimation, unfolding, closure for unfolding, reweightnig reco to data, template from different MC and fit in 2D space to extract coefficients*

TRT detector

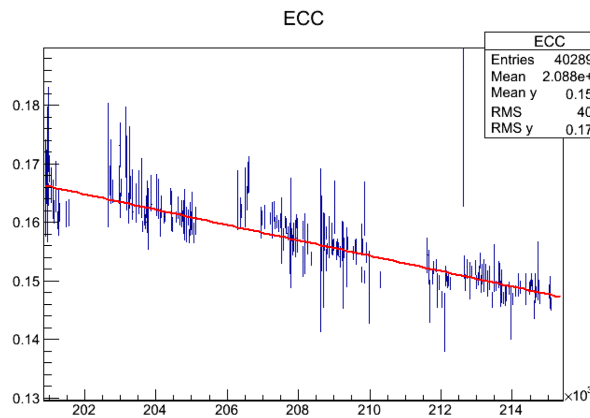


Сторона A			Сторона C		
	Утечка л/час			Утечка л/час	
Модуль	До ремонта	После ремонта	Модуль	До ремонта	После ремонта
A1	0	0	A1	HUGE	40
A2	0	0	A2	5	0
A3	0.06	0	A3	0.25	0.1
A4	0.8	0.9	A4	HUGE	260
A5	0.3	0.1	A5	0	0
A6	4.5	3	A6	HUGE	18
B1	75	0.1	B1	0	0
B2	0	0	B2	0	0
B3	0	0	B3	2.5	2.4
B4	0	0	B4	0.1	0
B5	9	0.04	B5	0.26	0.2
B6	0	0	B6	0.01	0.07
B7	0	0	B7	0.01	0.08
B8	0	0	B8	0.02	0

Фотография одной из трубок для подачи газовой смеси в детектор TRT, сделанная с помощью эндоскопа, на которой видно ее повреждения в месте изгиба под воздействием озона.



TR ratio vs # run



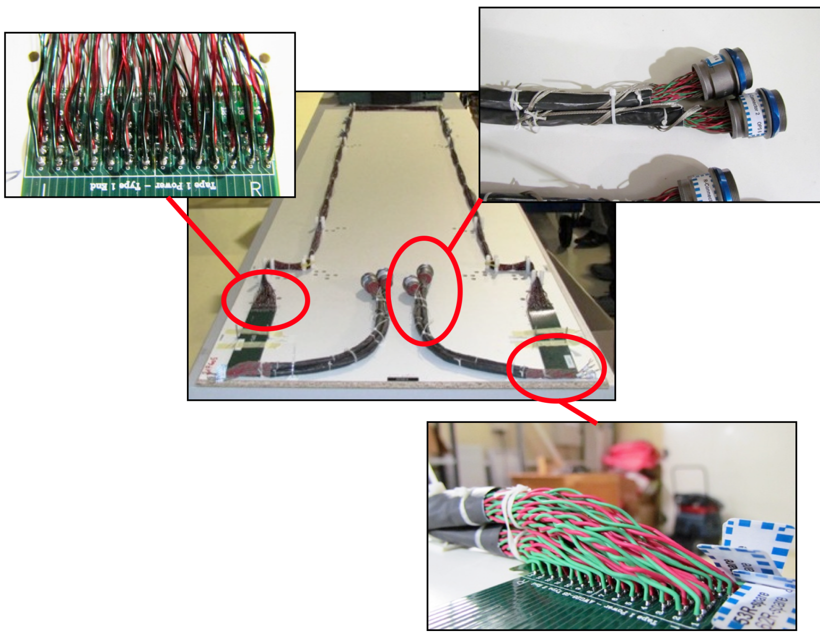
PNPI contribution :
- repairing of TRT detector;
- TRT s/w development

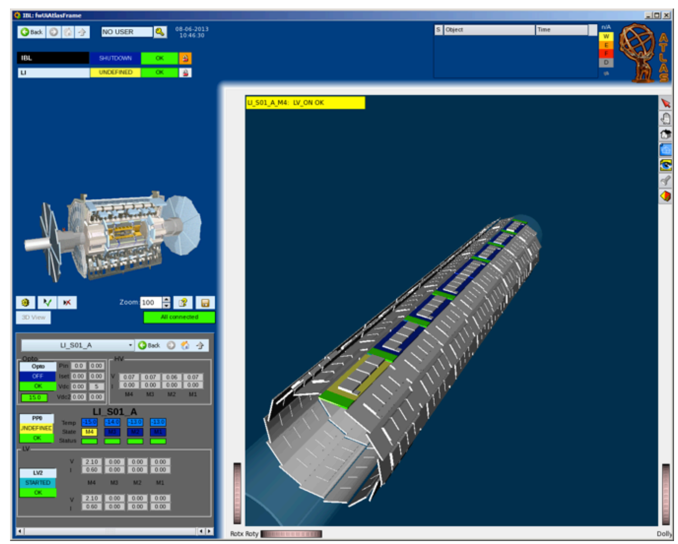
Pixel New Service Quarter Panels (nSQP) and IBL

- Transfer services from outside world to pixel detectors
- Problematic opto-couplers on SQP
- To replace these need new infrastructure and electronics
- New electronics will allow greater readout bandwidth for > 10^{34} operation

PNPI contribution :

- creation and assembly cables for the nSQP (technicians and engineers);
- installation of cables and temperature sensors for the Pixel evaporative cooling systev
- s/w developing for the Pixel DCS.





TDAQ/DCS

Отдел информационных технологий проф. Рябов Ю.Ф.

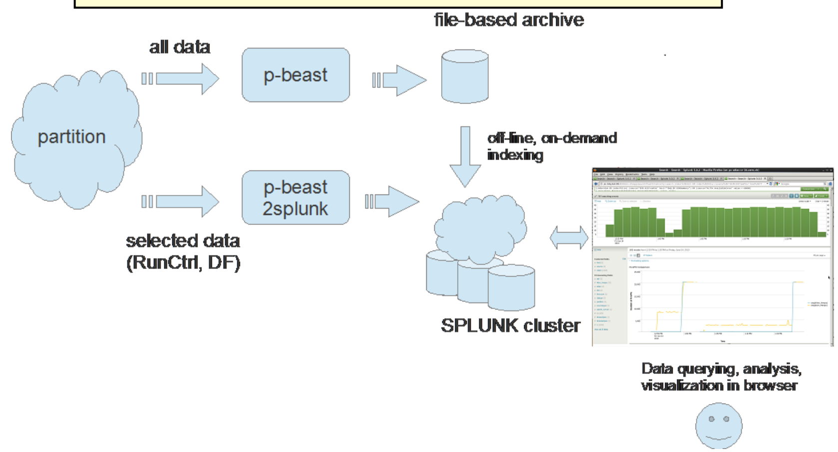
PNPI contribution to DCS:

- Upgrade computers, operating systems and base SCADA system of central DCS (11 PC)
- Development, testing and put in production of new CANOpen OPC server in advanced standard OPC UA.
- Upgrade and improvements of:
  –Rack Control system,
  –DCS Access Control (including remote access),
  –ATLAS – LHC Communication
  –Interface to Condition Database
  –Calorimeters' Cooling package
- DCS Expert on-call (7/7,24/24) > 20 weeks.

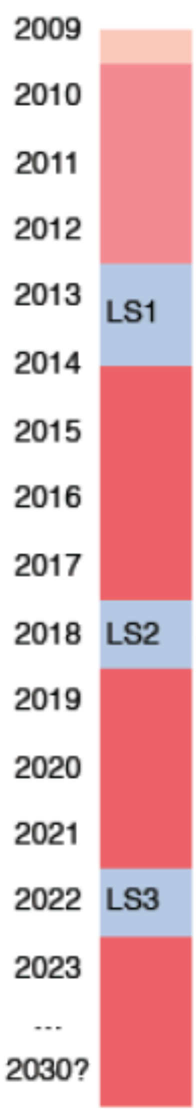
PNPI contribution to TDAQ:

- Software development of the system of control, configuration and monitoring of ATLAS DAQ – 4 new versions have been issued.
- Improvement of web interface of the "Shifter Assistant" system for the expert support of operational control of DAQ and detectors.
- Development of new tools of archiving and graphical representation of operational monitoring information.

Scheme of archiving & representation of data of TDAQ operational monitoring



План модернизации (upgrade) LHC



✧ LHC startup, √s = 900 GeV

√s=7~8 TeV, L=6x10^{33} cm^{-2} s^{-1}, bunch spacing 50 ns

Peak luminosity observed in ATLAS in 2012 - 7.7 10^{33} cm^{2}s^{-1}

Go to design energy, nominal luminosity

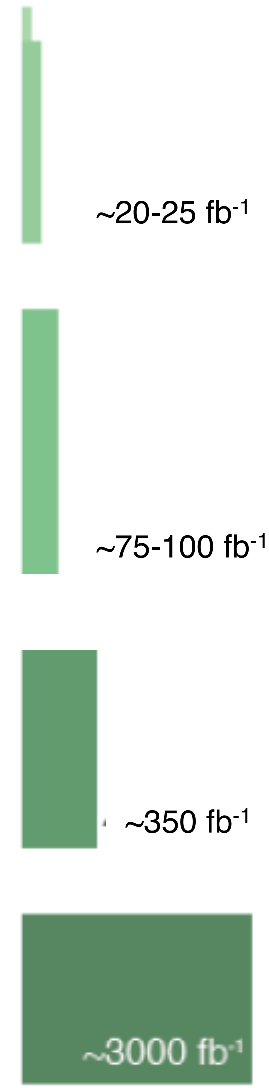
√s=13~14 TeV, L~1x10^{34} cm^{-2} s^{-1}, bunch spacing 25 ns

Injector and LHC Phase-1 upgrade to ultimate design luminosity

√s=14 TeV, L~2x10^{34} cm^{-2} s^{-1}, bunch spacing 25 ns

HL-LHC Phase-2 upgrade, IR, crab cavities?

√s=14 TeV, L=5x10^{34} cm^{-2} s^{-1}, luminosity leveling

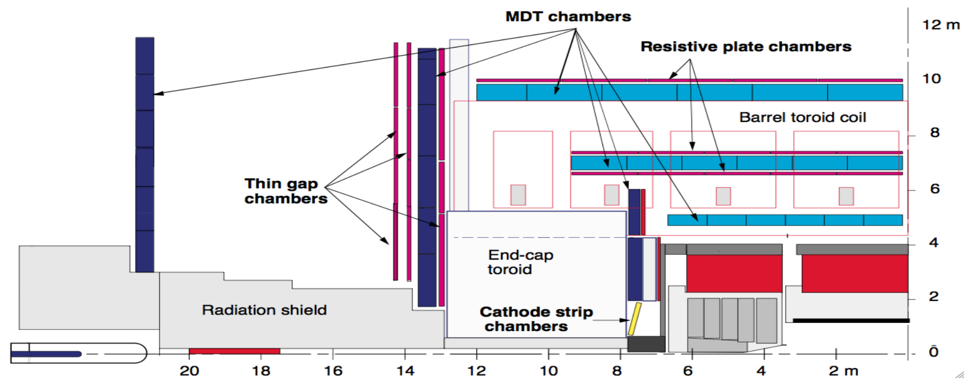


Towards to High Energy LHC (HE-LHC) -√s=33 TeV

PNPI @ ATLAS upgrade - Phase I

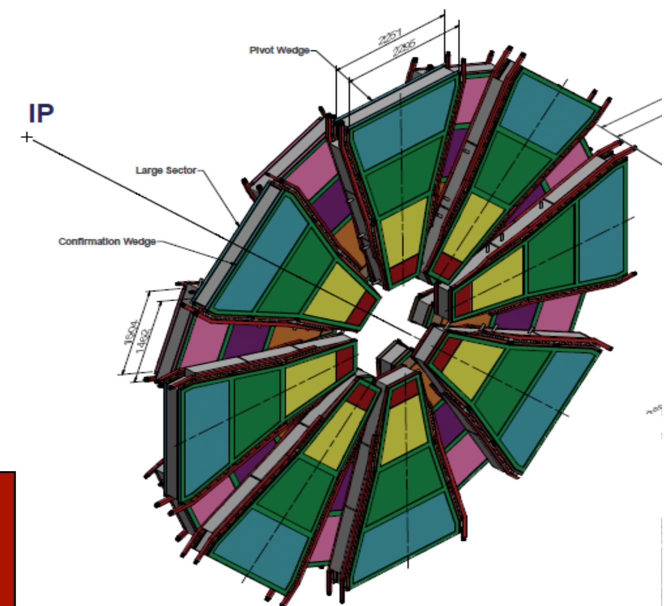
Новые детекторы в NSW должны:

- ❑ выдерживать загрузки до 15 кГц/см^2
- ❑ On-line (триггер)
  - ➢ Эффективность 99%
  - ➢ Обеспечить набор измерений с точностями R~100 мкм, φ~2-3 мрад, dθ~1 мрад;
- ❑ Off-line реконструкция
  - ➢ обеспечивать трековое разрешение ≈60 мкм в плоскости R-φ;
  - ➢ угловое разрешение ≈0.3 мрад;
  - ➢ эффективность восстановления сегмента трека не хуже 97%;
  - ➢ сохранять работоспособность до 1 К/см^2 накопленной дозы облучения (предполагая 10 лет работы в условиях sLHC).



В качестве новых детекторов были выбраны:

- ❑ TGC камеры хорошо, зарекомендовавшие себя в эксперименте ATLAS;
- ❑ новая технология MM (Micro Megas).



Possible participation of PNPI :

- Construction and assembly of sTGC chambers.
- Development of fast simulation for nSMW;
- Development trigger s/w and h/w for nSMW.