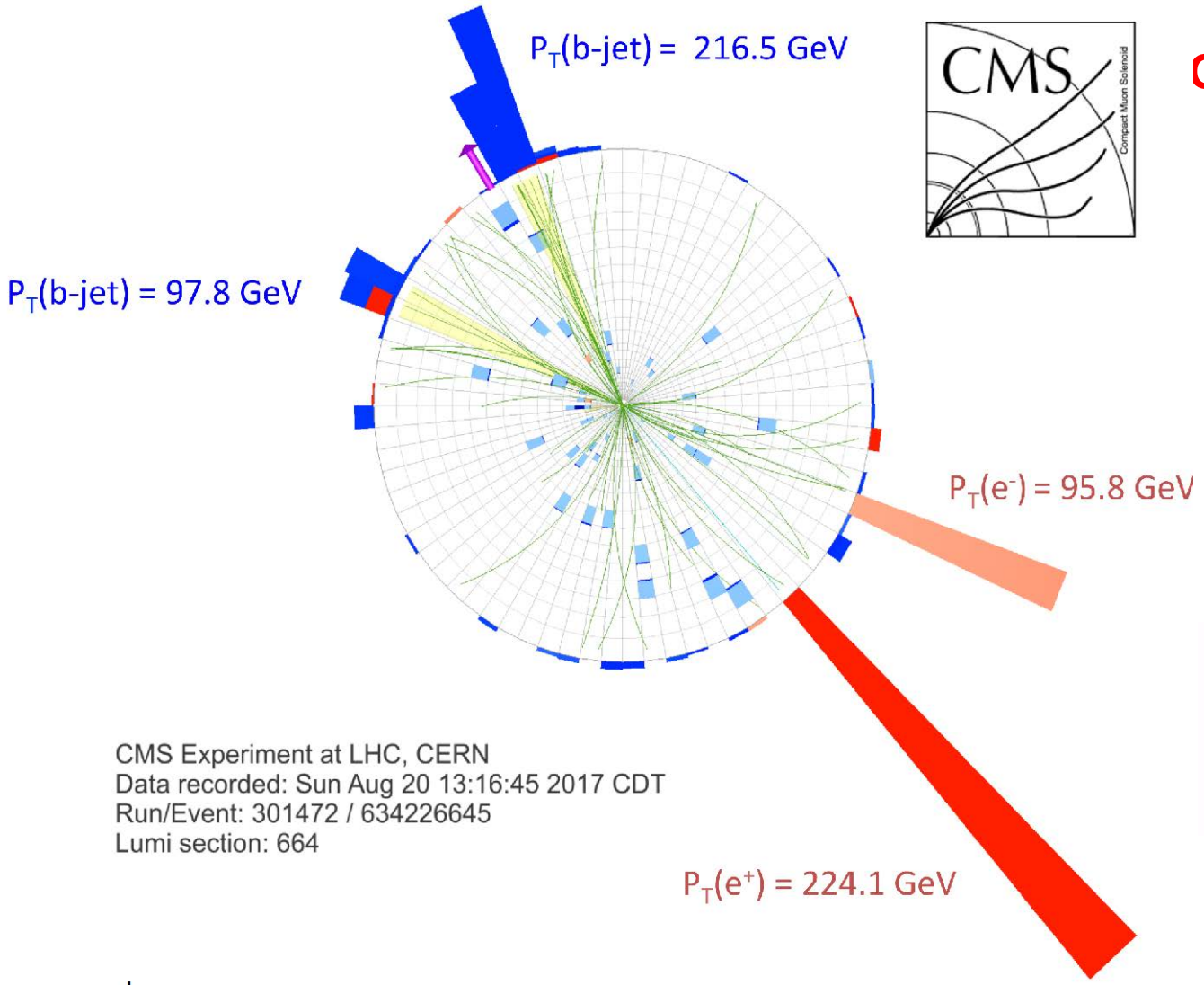
ПИЯФ: физика @CMS

В.Т. Ким

ОФВЭ НИЦ КИ - ПИЯФ

Сессия Ученого Совета
24-27 декабря 2018



$pp \rightarrow ZH$

$b + \bar{b}$

$e^+ + e^-$

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ПИЯФ @CMS

А.А. Воробьев

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Г.Е. Гаврилов
…

ПИЯФ: основные направления в CMS

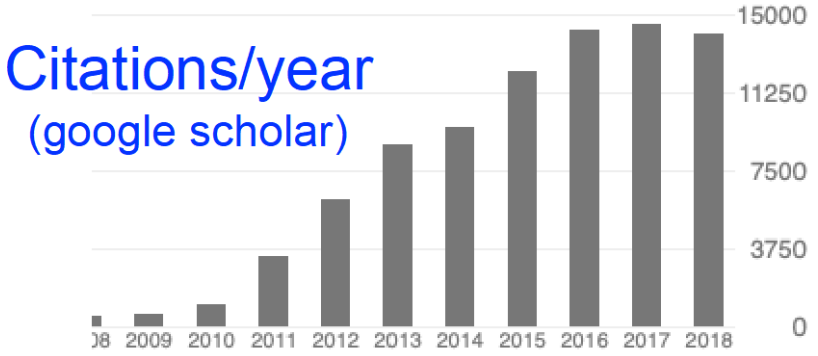
- асимптотические БФКЛ-эффекты в струйных процессах
- бозон Хиггса при больших pT
- электрослабое образование резонансов (VBF)
- тяжелые резонансы в многоструйных событиях
- дифракционные процессы

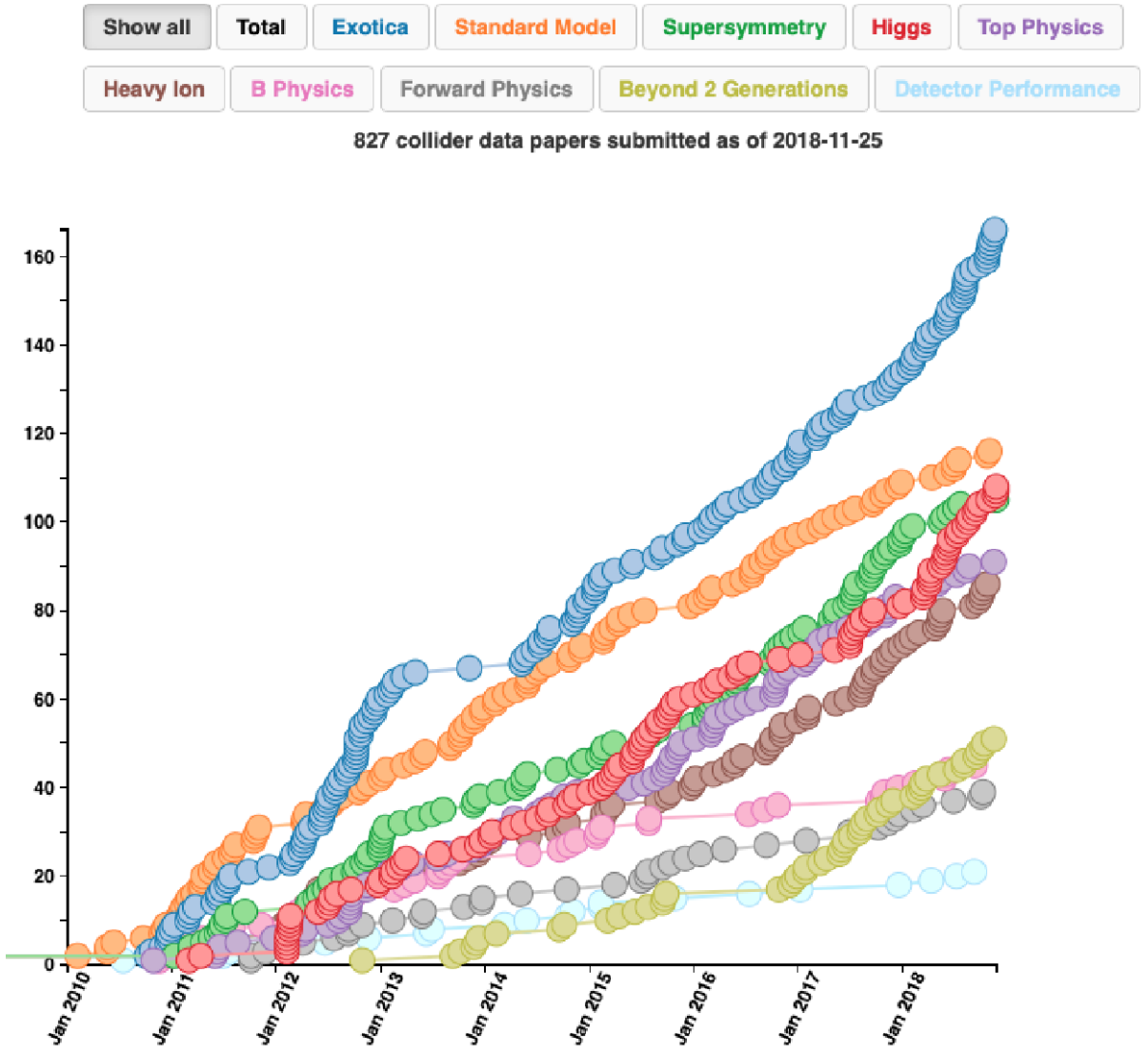
CMS: публикации

1.01.2010 - 30.11.2018

CMS:
827 статей по физике направлено в печать

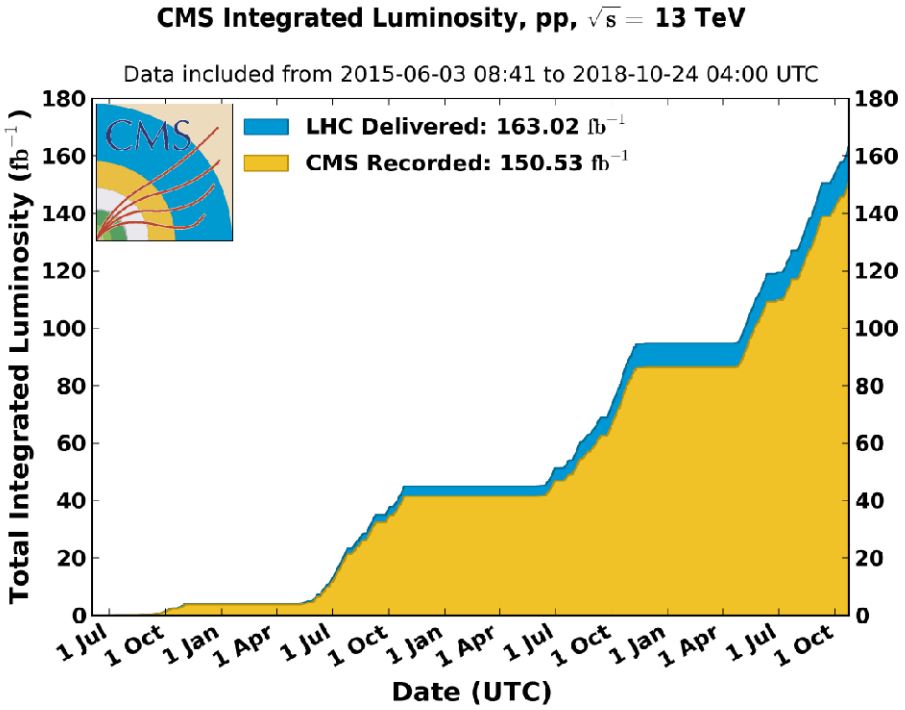
RUN 2: > 260 статей

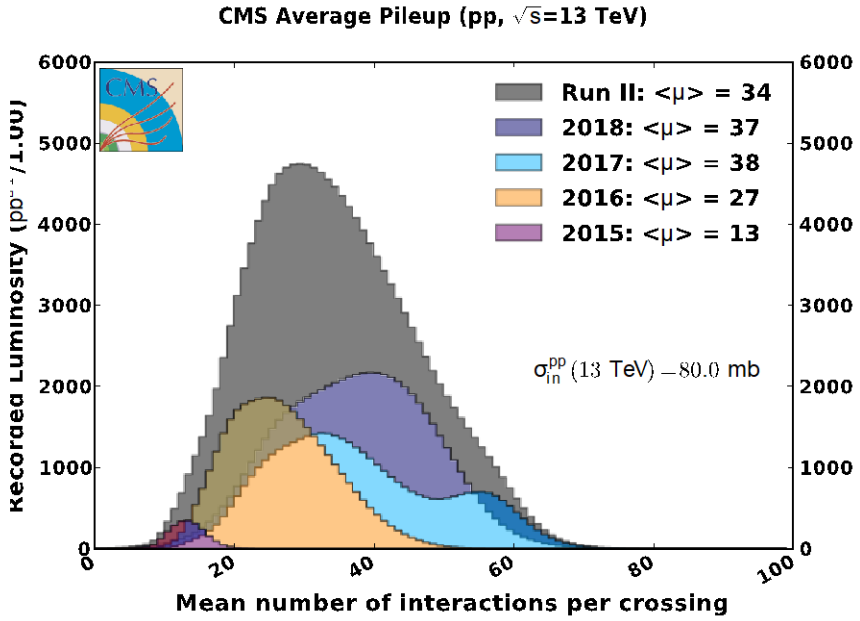




CMS: набор данных в 2018 г

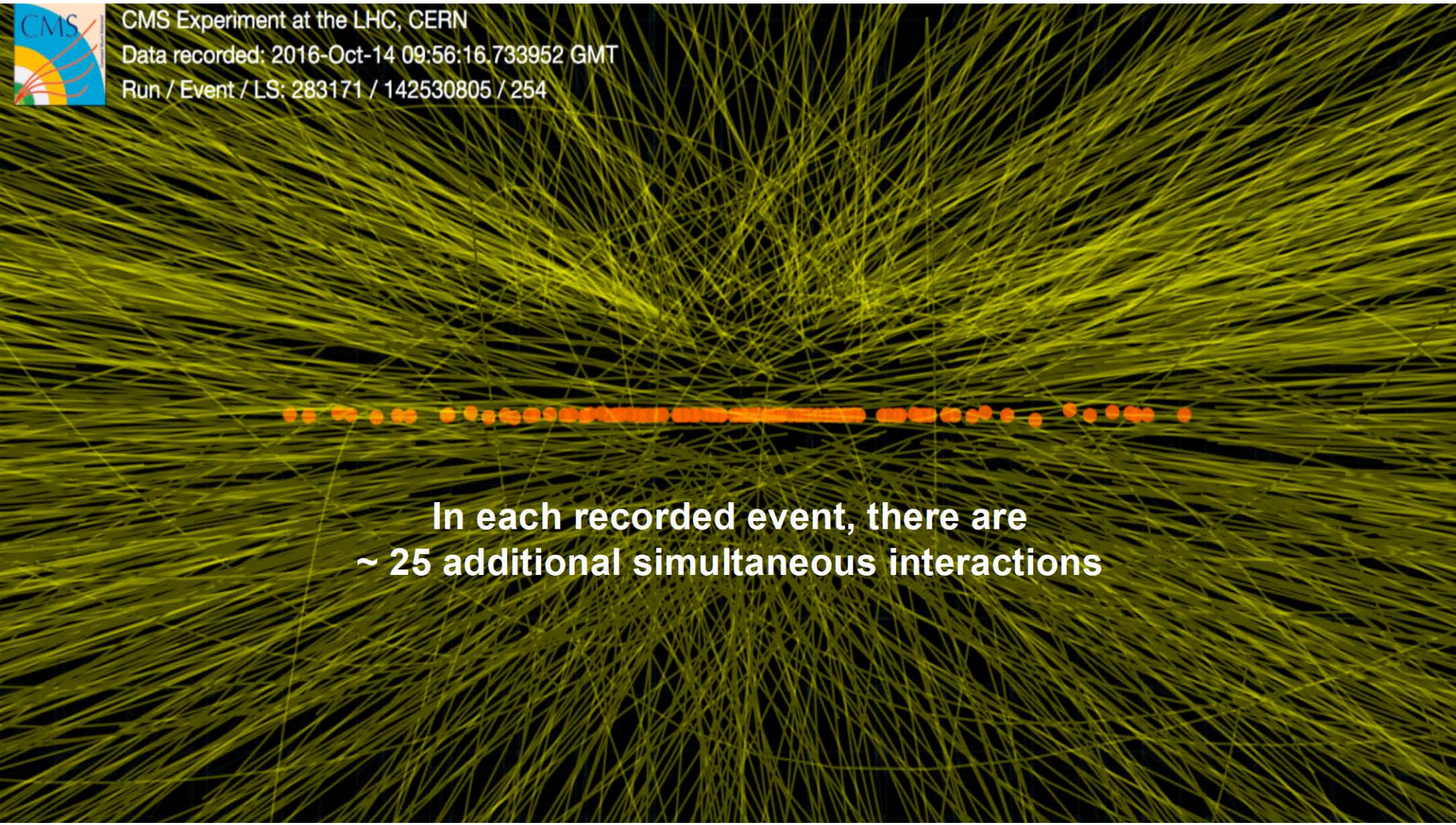
- 64/fb collected in 2018 (preliminary offline value)
  - ~94% of the delivered luminosity
    - Record for CMS!
  - ~58/fb recorded with Roman Pots inserted and Precision Proton Spectrometer detectors operating
- In total 150/fb collected in Run2
  - overall data-taking efficiency ~92%



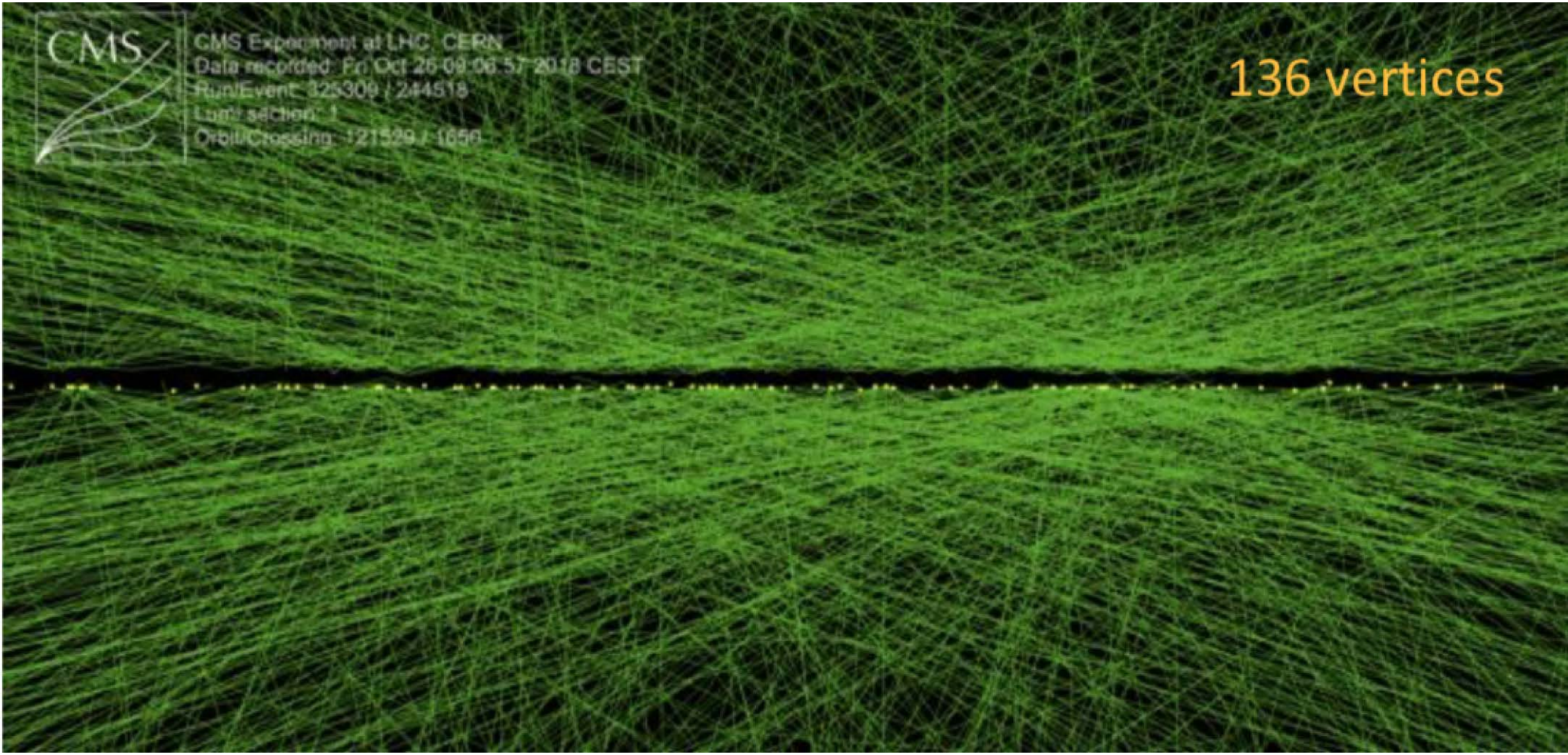


Simone.Gennai@cern.ch

CMS 2016: <pileup> ~ 27

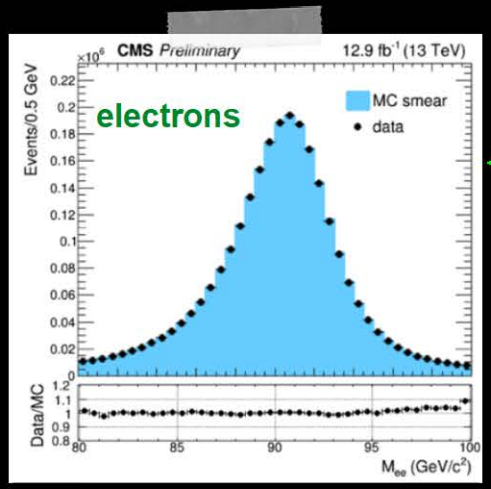


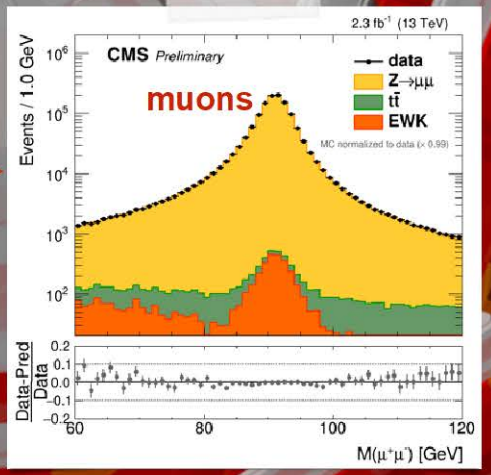
CMS 2018: <pileup> ~ 37



CMS: великолепный прибор!

CMS Experiment at the LHC, CERN
Data recorded: 2016-Jul-08 28:47:39.259242 GMT
Run / Event / LS: 276525 / 2665335317 / 1561



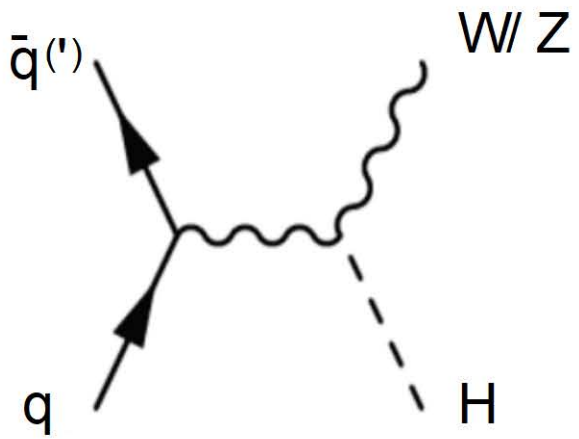


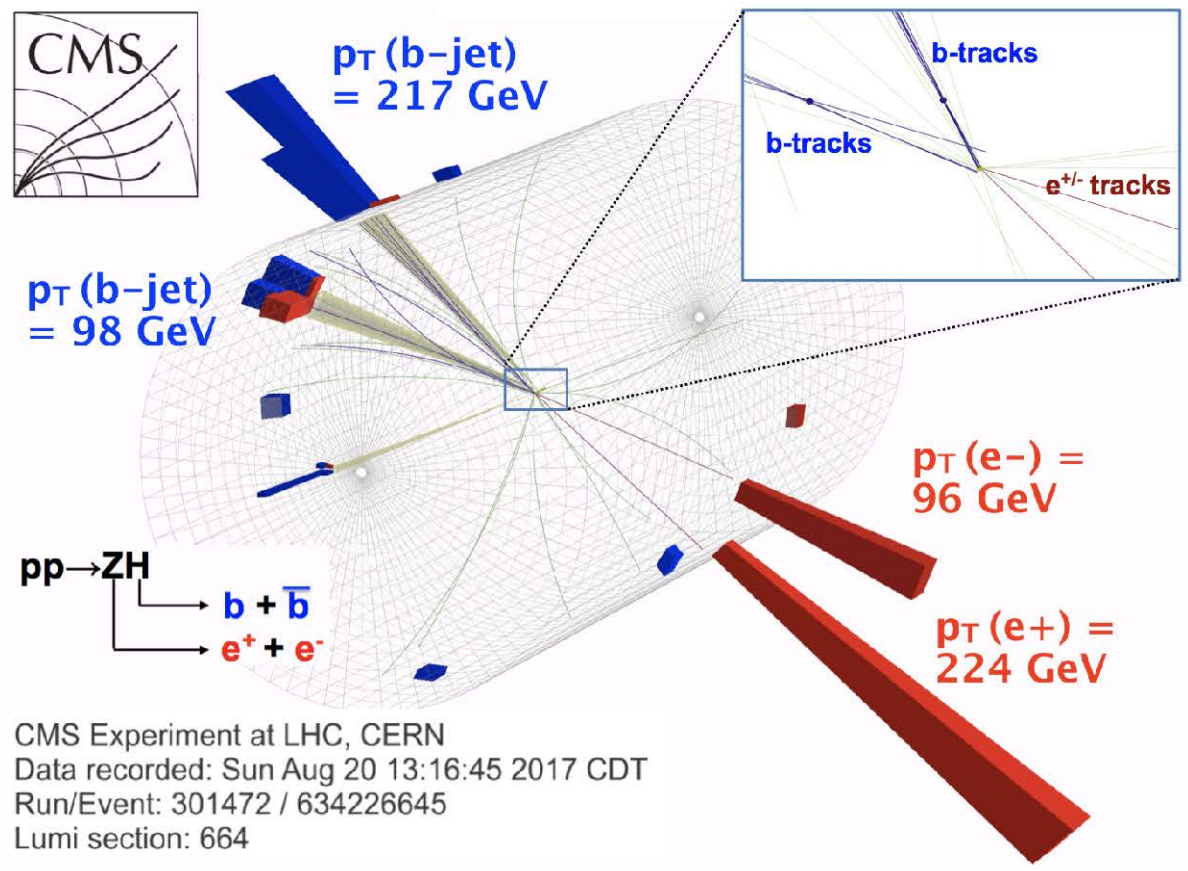
Extremely well calibrated detector.

Excellent agreement in simulation and data.

CMS: связь бозона Хиггса с тяжелыми фермионами

Channel	Date
H ττ	May 2017
pp ttH	Apr 2018
H bb, pp VH	**Aug 2018**



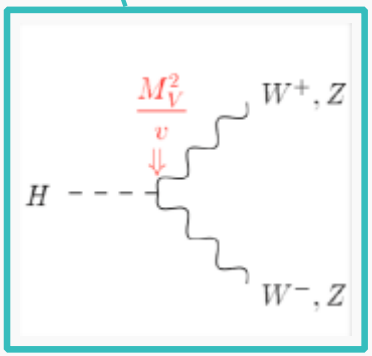


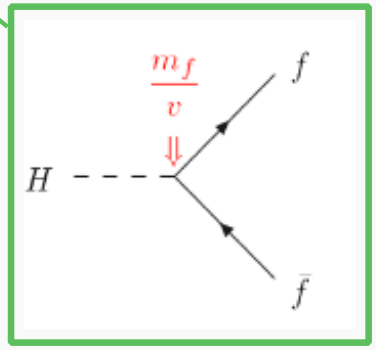
Higgs boson decay to b-quarks: Motivation

$$\mathcal{L} = -\frac{1}{4} F_{\mu\nu} F^{\mu\nu} + i\bar{\psi}\not{D}\psi + h.c.$$

$$+ \bar{\psi}_i y_{ij} \psi_j \phi + h.c.$$

$$+ |D_\mu \phi|^2 - V(\phi)$$





In the SM, the Higgs mechanism provides masses to bosons and fermions

- Higgs boson discovery in 2012 opens a whole new sector of the Lagrangian
- Yukawa couplings not required by EWSB

$\Rightarrow$ ad-hoc solution to generate fermion masses

Main questions to answer

- Is the SM structure of the Lagrangian correct ?
- Are the values of the couplings as predicted in the SM ?

$\Rightarrow$ Broad programme at the LHC

SM Higgs boson decay @LHC

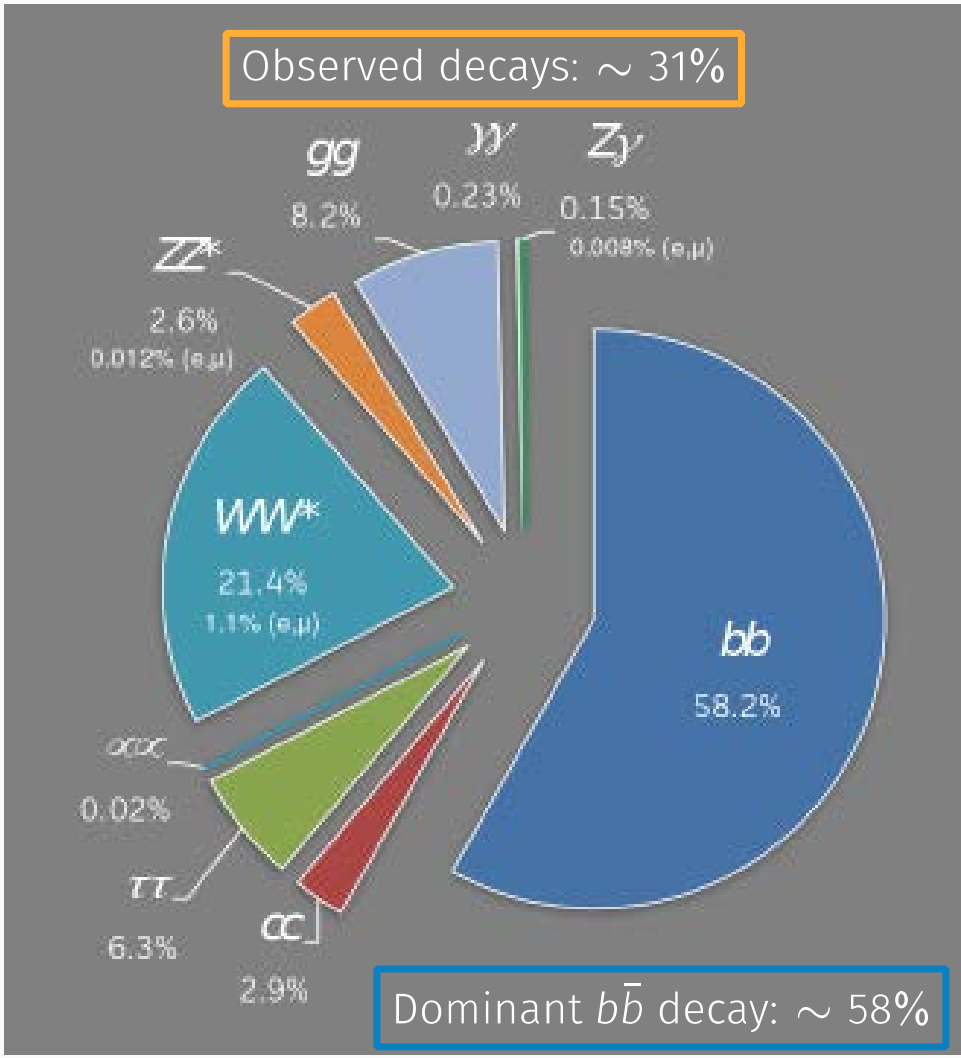
Higgs boson branching ratios

The Higgs boson couples to mass

⇒ Many decay modes accessible at the LHC

⇒ $b\bar{b}$ largest BR $\sim$ 58%

⇒ Coupling to $\gamma\gamma$ or gg through loops



$H \to b\bar{b}$ and Higgs boson couplings

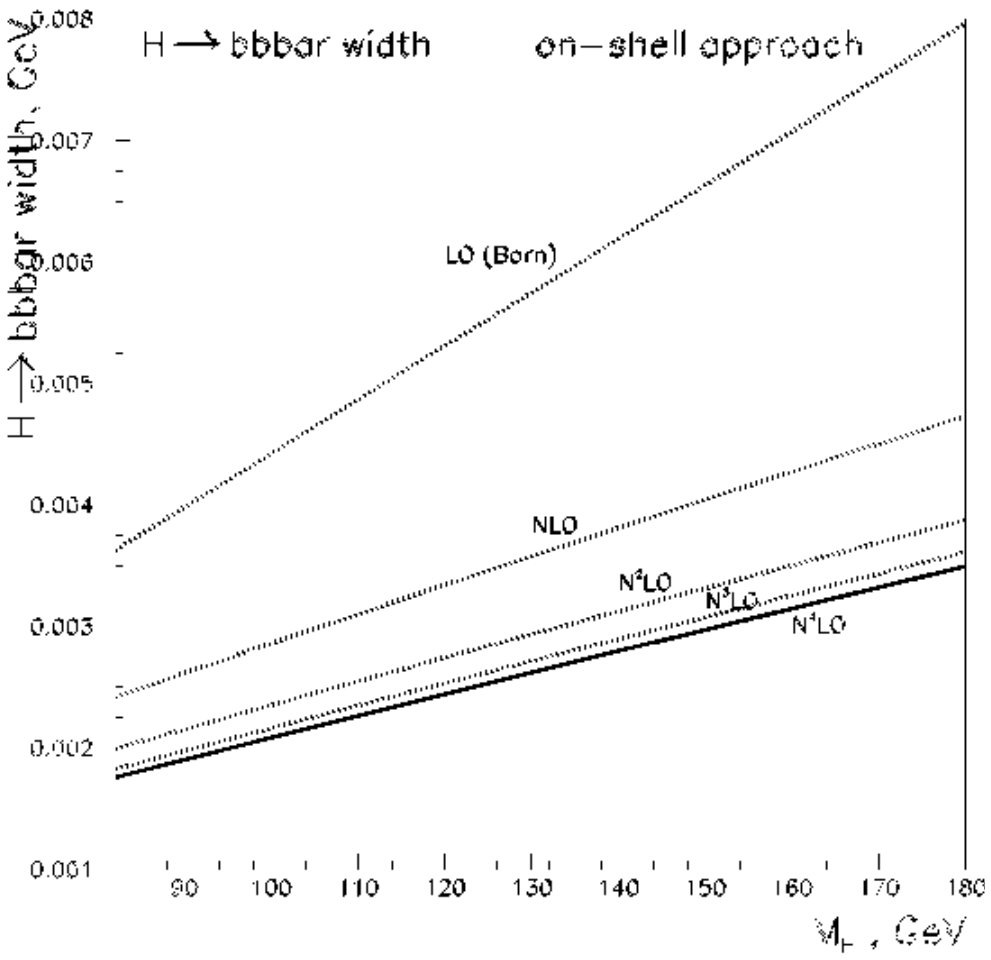
- Total width not directly measurable at the LHC
  - ⇒ Only coupling ratios truly model-independent
- Hypothesis of SM structure of the loops and no BSM decays
  - ⇒ $b\bar{b}$ largest BR: drives total width, thus measurements of absolute couplings
- If BSM particles allowed in loops and decays
  - ⇒ Measuring $H \to b\bar{b}$ limits BSM branching fraction allowed

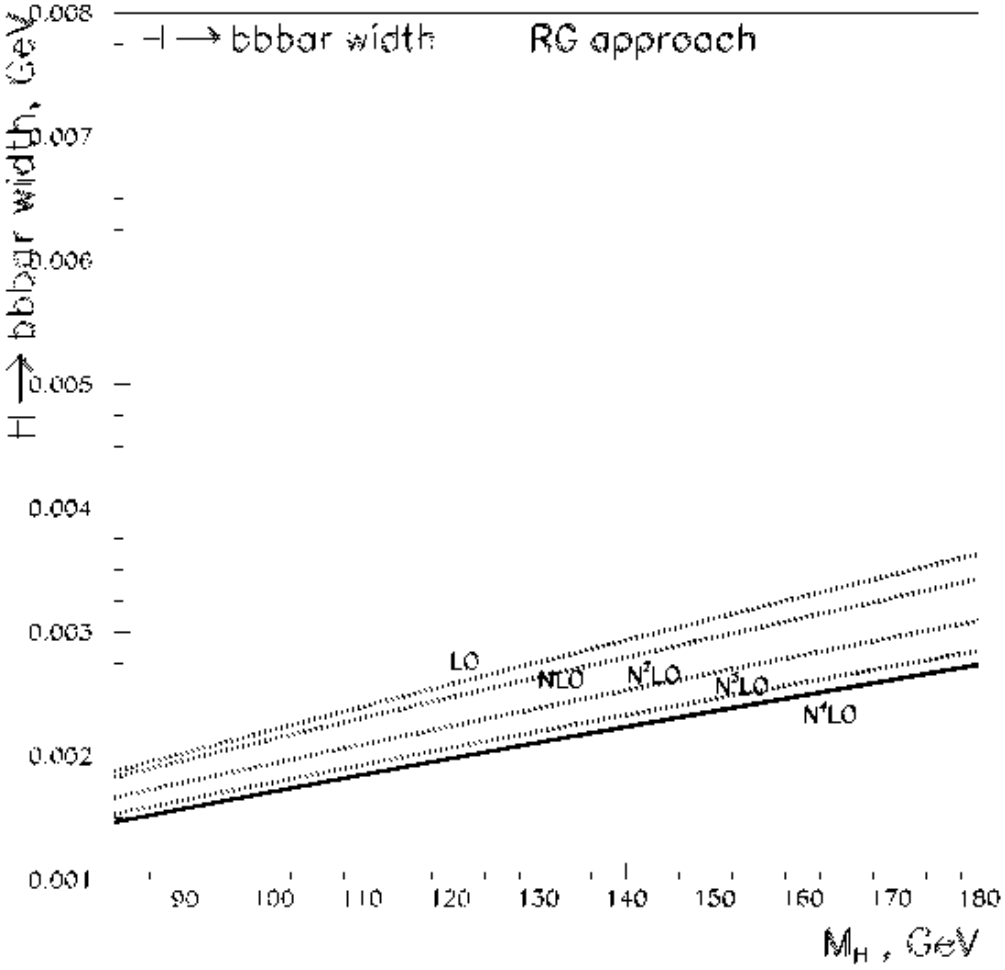
Higgs boson width to b-quarks upto N^{4}LO

P. Baikov, K. Chetyrkin, J. Kuhn (2006)
A. Kataev, V. Kim (2008)

$$\Gamma_{H\bar{b}b} = \Gamma_0^b \frac{\overline{m}_b^2(M_H)}{m_b^2}\left[1 + \sum_{i\geq 1} \Delta\Gamma_i\, a_s^i(M_H)\right]$$

$$\Gamma_0^b = 3\sqrt{2}/8\pi G_F M_H m_b^2$$



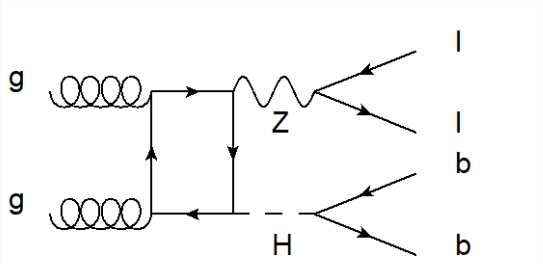


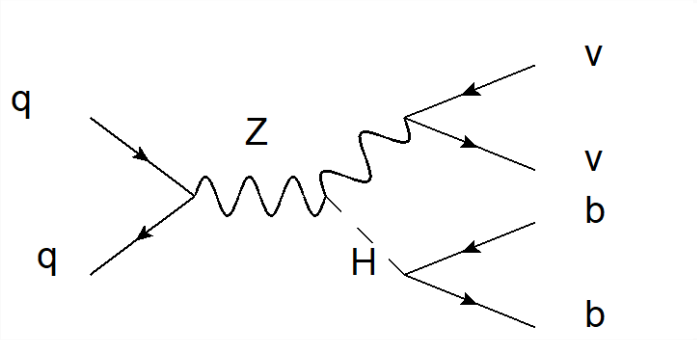
VH(bb) @LHC: search modes

Processes

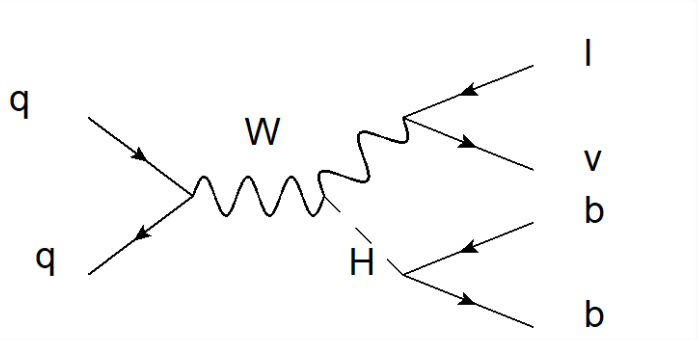
- *ZH* and *WH* production
  - Leptonic decays of *Z*/ *W* for bkg rejection and trigger
  - 3 channels: 0, 1, 2 electrons or muons
- *H* ! $b\bar{b}$ decays
  - 2 high-p_T *b*-jets
- Possibly additional jets

- *ZH* has additional *gg* induced diagrams

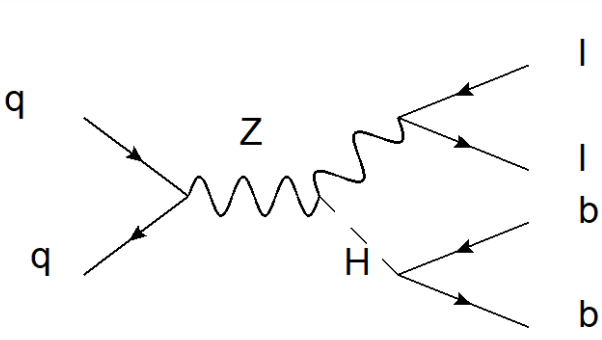




0-lepton



1-lepton

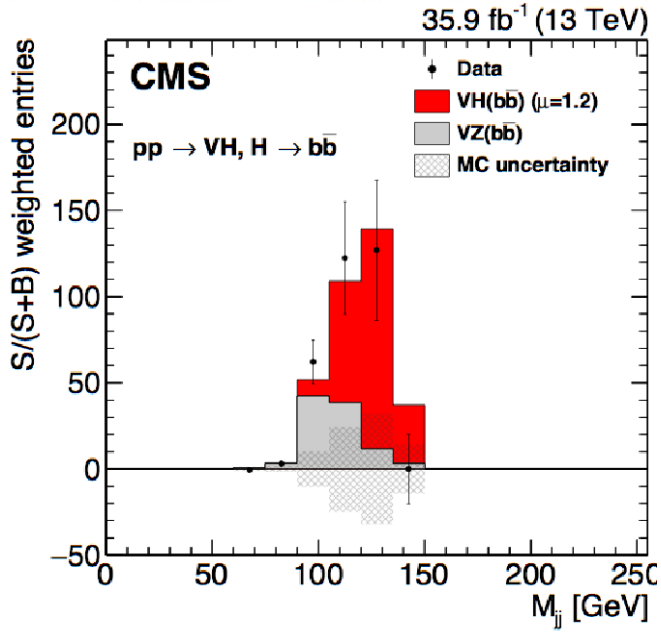


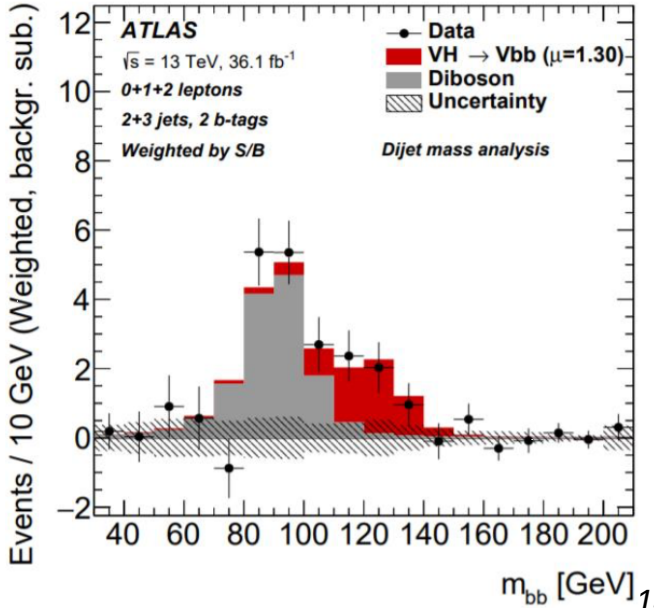
2-leptons

VH(bb) results @LHC with 2016 data

- **VH(bb) evidence at LHC established with 2016 data by both ATLAS and CMS**
  - Detectors clearly demonstrated ability to deal with very high pile-up for such complex analysis
- **Signal strength uncertainty ~40%**

	signal strength	significance (exp)	significance (obs)
ATLAS Run 1 [1]	$0.52^{+0.40}_{-0.37}$	2.6σ	1.4σ
CMS Run 1 [2]	$0.89^{+0.47}_{-0.44}$	2.5σ	2.1σ
ATLAS+CMS Run 1 [3]	$0.79^{+0.29}_{-0.27}$	3.7σ	2.6σ
ATLAS 2015+2016 [4]	$1.20^{+0.42}_{-0.36}$	3.0σ	**3.5σ**
CMS 2016 [5]	$1.19^{+0.40}_{-0.38}$	2.8σ	**3.3σ**





[1] JHEP 01 (2015) 069
[2] JHEP 08 (2016) 045
[3] JHEP 08 (2016) 045
[4] JHEP 12 (2017) 024
[5] PLB 780 (2018) 501

New H->bb analysis: key elements

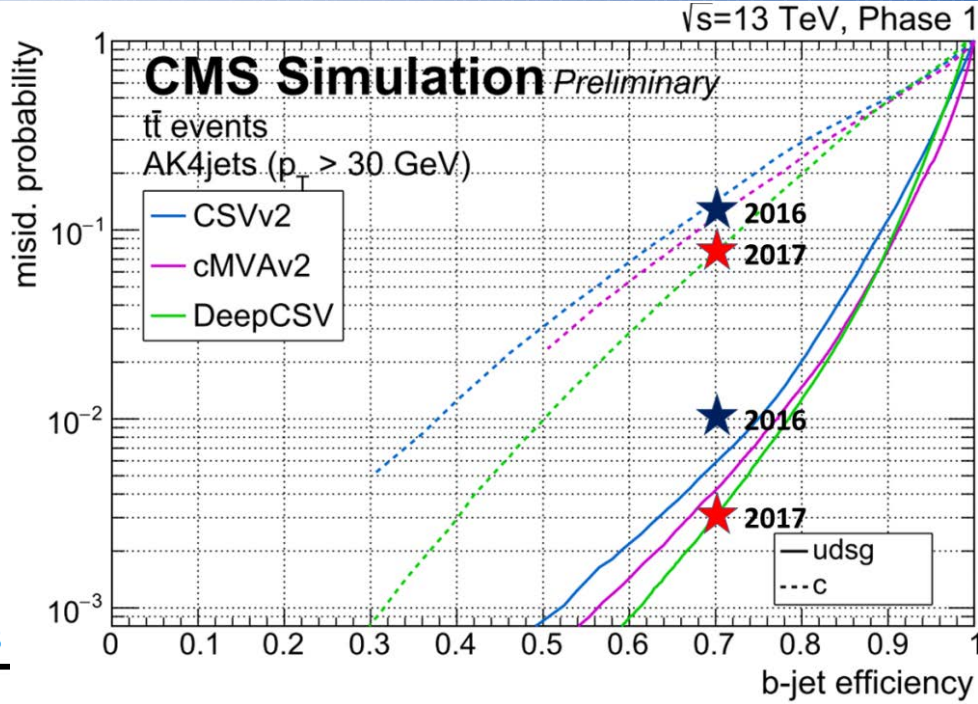
- increased datasets

- improved b-tagging

- improved dijet invariant mass resolution m_{bb}

- high pT-kinematics

b-tagging: CMS

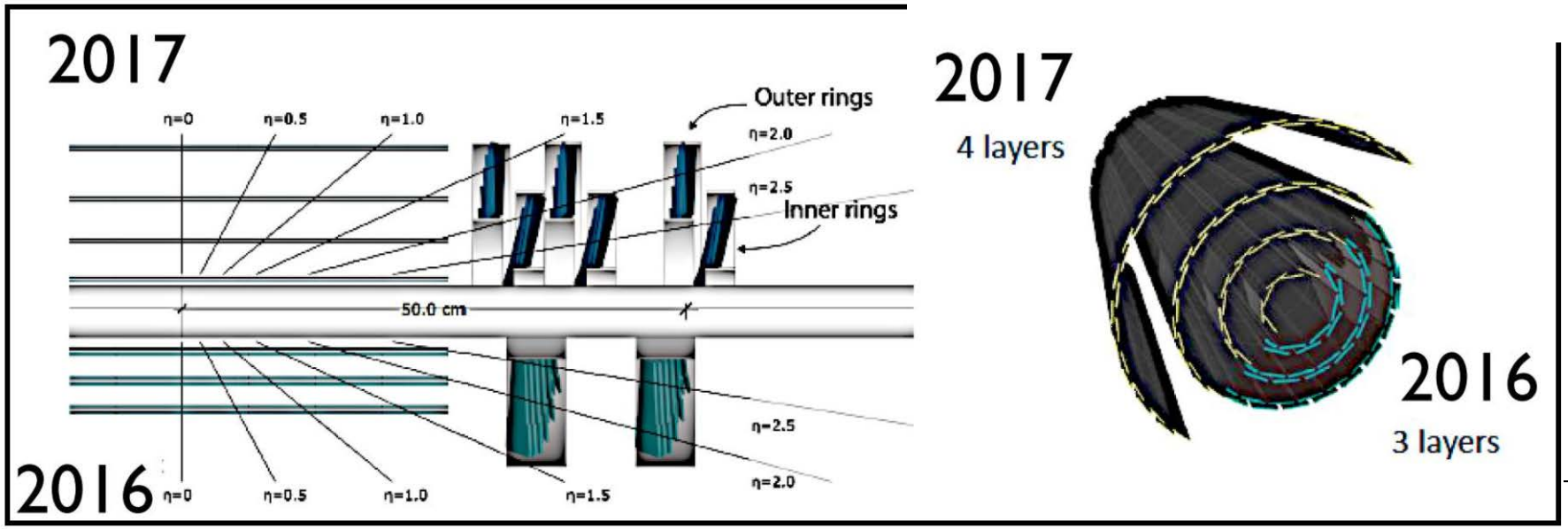


Continuous effort to improve b-tagging at CMS

- **New pixel detector** (4 layers)
- **DNN algorithm (DeepCSV) with additional per-track information**
- **Contamination from q/g < 1% for efficiency ~70%**

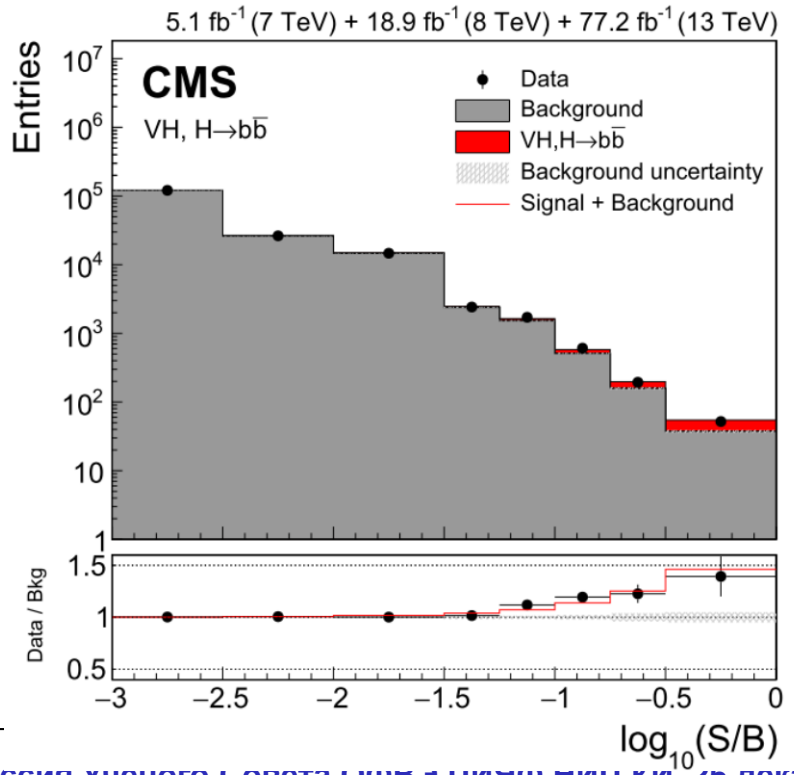
MC corrections derived on data with tt̄ events

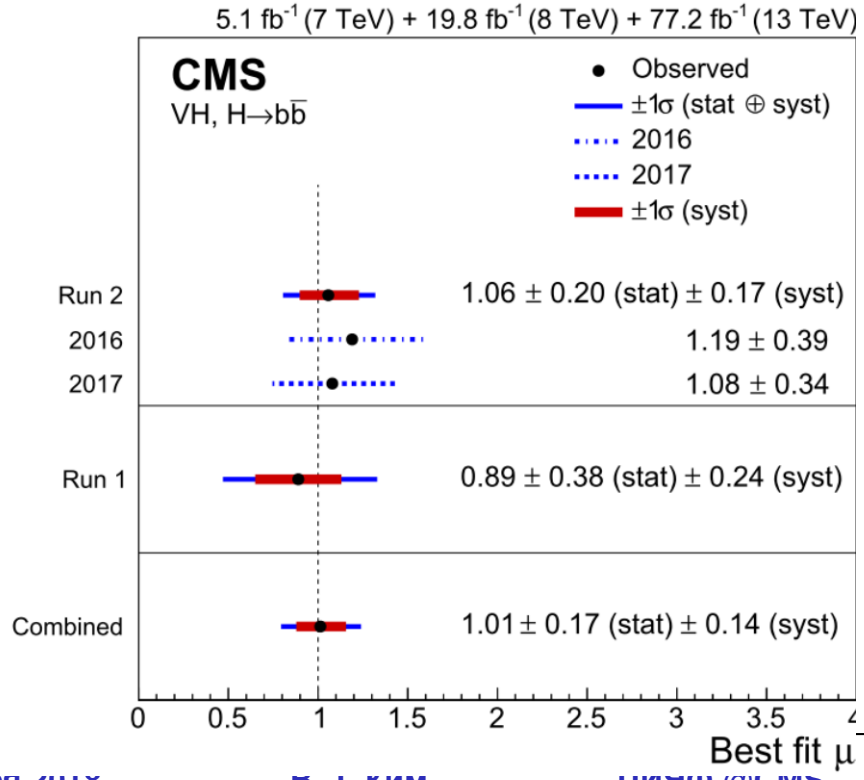
Good agreement between data and MC verified in all analysis regions



VH(bb): Run 1 + Run 2 combination @CMS

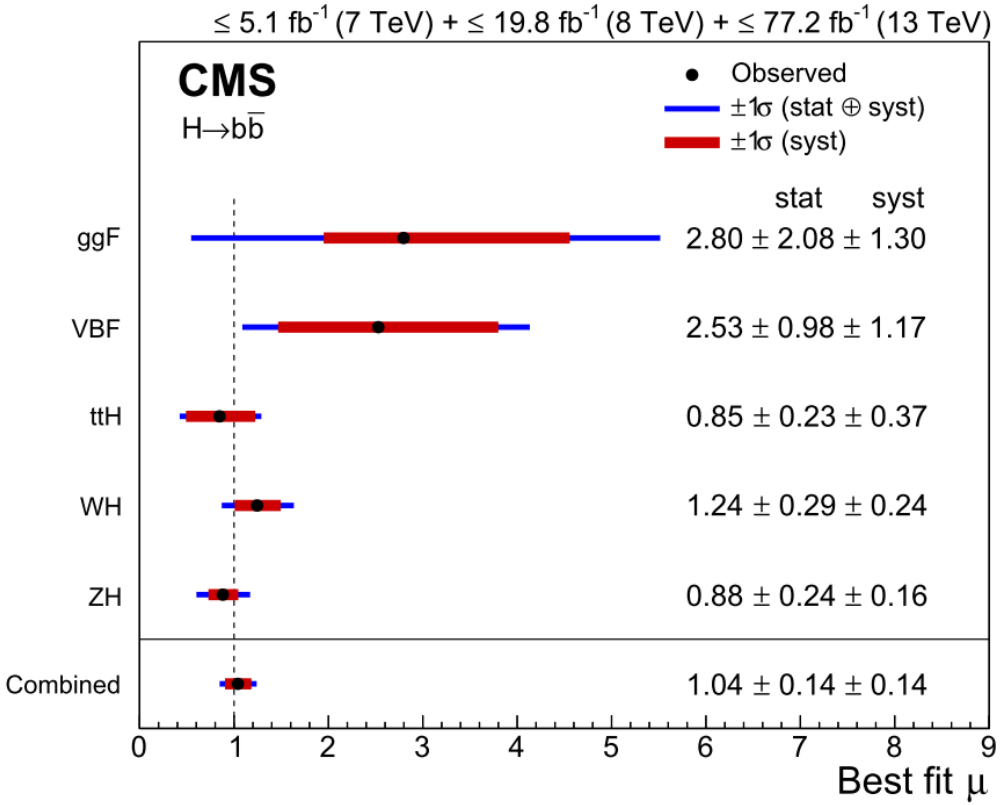
Data set	Significance (σ) Expected	Observed	Signal strength
2017	3.1	3.3	1.08 ± 0.34
Run 2 (2016+2017)	4.2	4.4	1.06 ± 0.26
Run 1 + Run 2	4.9	4.8	1.01 ± 0.23





H(bb): production mode combination @CMS

- **Combination of CMS H→bb measurements : VH, boosted ggH, VBF, ttH**
- **Most sources of systematic uncertainty are treated as uncorrelated**
  - Theory uncertainties are correlated between all processes and data sets
- **Measured signal strength is μ = 1.04 ± 0.20**



Significance

5.5σ expected

5.6σ observed

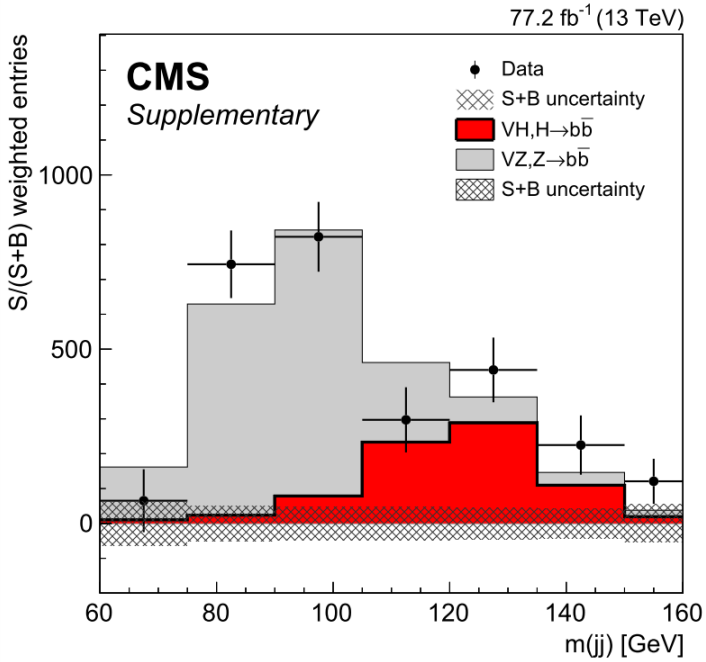
Observation of the H→bb decay by the CMS Collaboration

Higgs boson decay to b-quarks

- **CMS has reached a 5.6σ observation of the H→bb decay, with signal strength μ = 1.04 ± 0.20**
  - Combination of several production channels, dominated by VH(bb)
  - Result contained in **arXiv:1808.08242** and **provisionally accepted for publication in PRL**
    - Thank you to PRL and its referees for their impressive turn-around in reviewing the paper!

Published 17 Sep 2018 in PRL 121 (2018) 121801

- **Standard Model** assumption on **Yukawa coupling to b's confirmed** within the present uncertainty



- This result is the **culmination of H→bb searches** that started at LEP, continued at Tevatron and at the LHC

- Achievement possible only thanks to the **fantastic run of the LHC, and the CMS detector performance**
  - But is only a step towards the ultimate H→bb precision at LHC

Dijets with large rapidity separation:

- LHC 7 **ТэВ**:
CMS: Eur. Phys. J. C 72 (2012) 2216 – **первое измерение отношение сечений струй при больших интервалах быстроты** > 9.4

- LHC 7 **ТэВ**:
CMS: JHEP 08 (2016) 139 – **первое измерение азимутальных декорреляций струй при больших интервалах быстроты** > 9.4

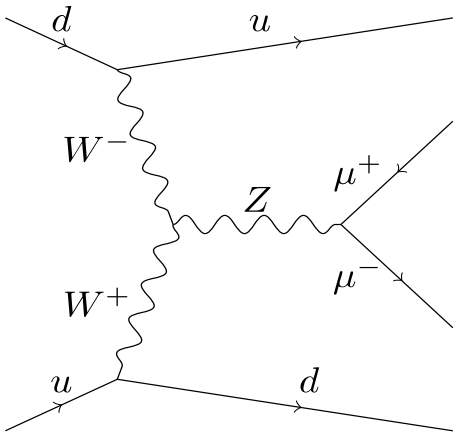
Electroweak Z boson production with two forward jets:

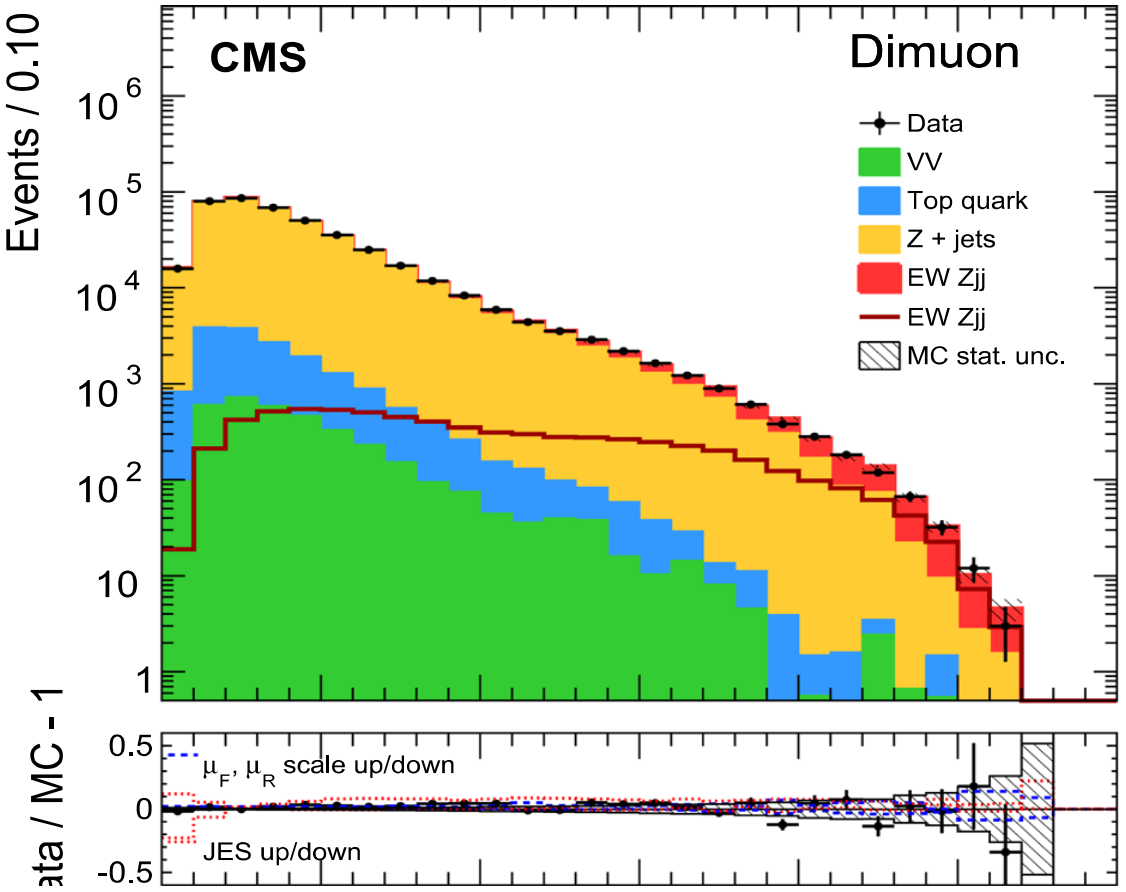
- LHC 7 **ТэВ**:
CMS: JHEP 1310 (2013) 062 – **первое наблюдение в адронных соударениях процесса электрослабого образования** Z-**бозона**
конечное состояние: **два лептона и две адронные струи вперед**

- LHC 8 **ТэВ**:
CMS: Eur. Phys. J. C 72 (2012) 2216 - **измерение в адронных соударениях сечение процесса электрослабого образования** Z-**бозона при** 8 **ТэВ**
σ(llJJ) = 174 ± 15 (**стат**.) ± 40 (**сист**.) **Фб**, mJJ > 120 **ГэВ,** 8 **ТэВ**

- LHC 13 **ТэВ**:
CMS: Eur. Phys. J. C 78 (2018) 589 **измерение в адронных соударениях сечение процесса электрослабого образования** Z-**бозона при** 13 **ТэВ**
σ(llJJ) = 534 ± 20 (**стат**.) ± 57 (**сист**.) **Фб**, mJJ > 120 **ГэВ,** 13 **ТэВ**

CMS 13 ТэВ: Электрослабый процесс Z + 2 струи





CMS Collaboration
Eur.Phys.J. C78 (2018) 589
CERN-EP-2017-328

$$\sigma(\text{EW } \ell\ell\text{jj}) = 534 \pm 20\,(\text{stat}) \pm 57\,(\text{syst})\,\text{fb} = 534 \pm 60\,(\text{total})\,\text{fb}$$

$$\text{SM prediction } \sigma_{\text{LO}}(\text{EW } \ell\ell\text{jj}) = 543 \pm 24\,\text{fb}$$

Дифракционные процессы на ядрах при энергиях LHC

CMS+TOTEM pA data 2016 8 ТэВ NN c.m.s.

CMS+TOTEM/PPS: дифракция

Total of ~110/fb collected in Run 2 !

Several analyses ongoing:

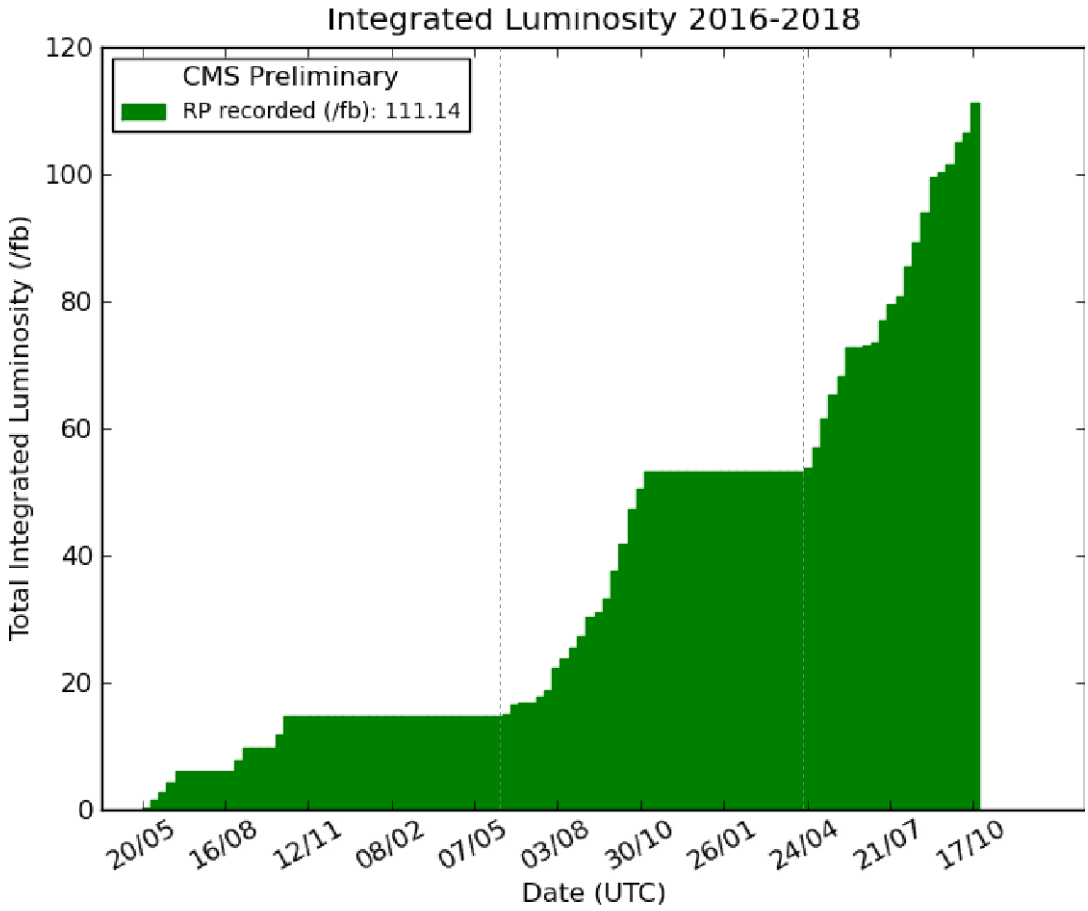
Central (semi)exclusive production of high mass lepton pairs

Anomalous Quartic Gauge Couplings

Central production of γγ, WW, ZZ, γZ, $t\bar{t}$

Missing mass searches

Search for axion-like particles



Заключение

ПИЯФ@CMS physics

- **Dijets:**

  К-фактор — **7 ТэВ: EPJ C 72 (2012) 22**

  К-фактор с вето — **2.76 ТэВ: завершение анализ**
  8 ТэВ: завершение анализа
  13 ТэВ: продолжается анализ

  азимутальные декорреляции — **7 ТэВ: JHEP 08 (2016) 139**
  13 ТэВ: продолжается анализ

- **EWK Z** — **7 ТэВ: JHEP 10 (2013) 062**
  8 ТэВ: EPJ C 75 (2015) 066
  13 ТэВ: EPJ C 78 (2018) 589
  полные данные Run2: продолжается анализ

- **CMS+TOTEM/PPS**

  дифракция в pA — **8 ТэВ: завершение анализа**


С Новым
годом!