LHCb 2016 performance and highlights
& Status of MoEDAL

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On behalf of the LHCb and
MoEDAL collaborations

LABORATOIRE
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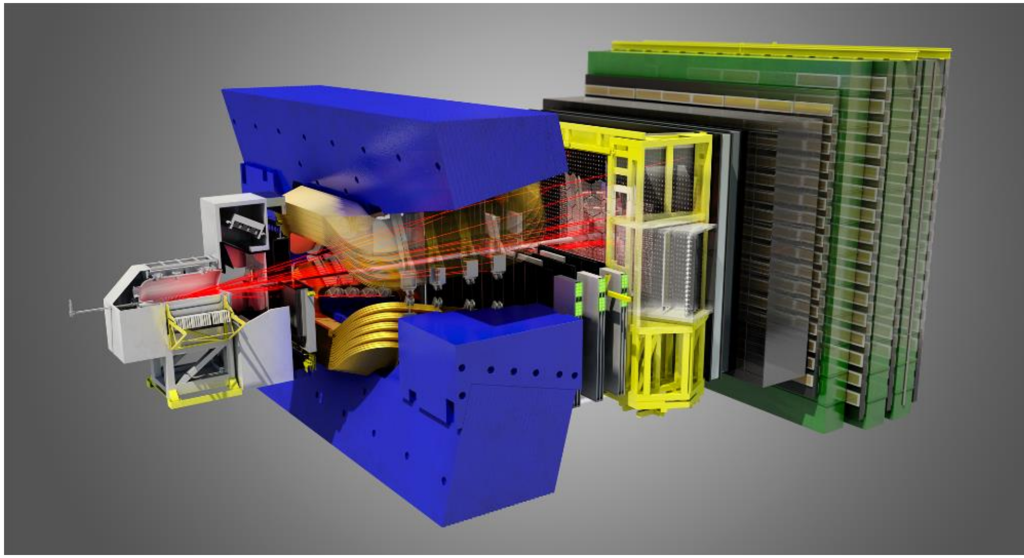
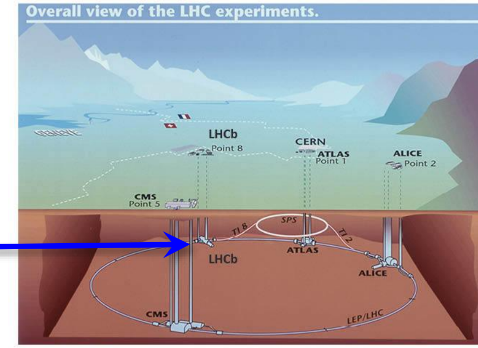
Open session of CERN council, 16/12/2016

Content

- LHCb
  - 2016 operation
  - Physics highlights
  - Upgrade
- MoEDAL

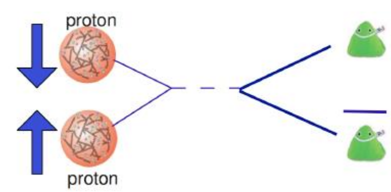
LHCb



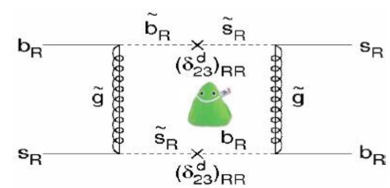


- A precision experiment for heavy flavour physics
- Core physics programme: *Study of the matter-antimatter asymmetry in beauty and charm decays*
- General purpose detector in the forward region: *spectroscopy, QCD, heavy ion physics …*
- 1151 members, 69 institutes, 16 countries

Why heavy flavour?

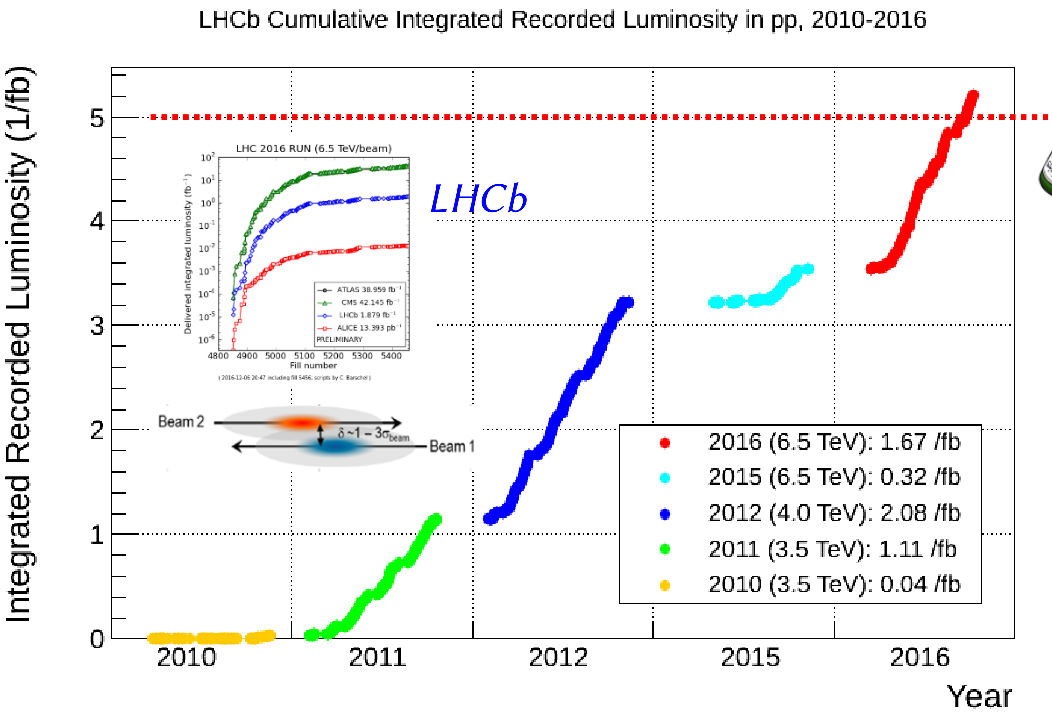


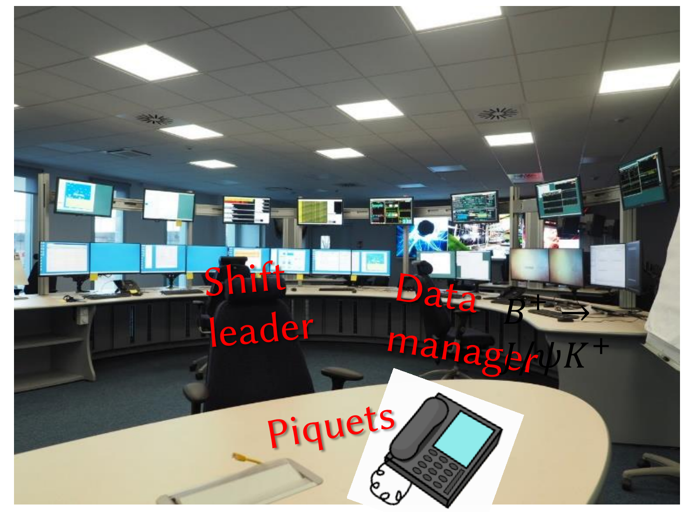
At high energy new particles can be produced directly



In the quantum loop of heavy flavour (b/c) decays we can indirectly probe effects of new physics at much higher energy scale

2016 : a year of harvest





- Successful *pp* data-taking
  - 1.7 fb^{-1} recorded with ~ 96% operation efficiency
  - A cumulative of **5 fb^{-1}** reached since LHC start!

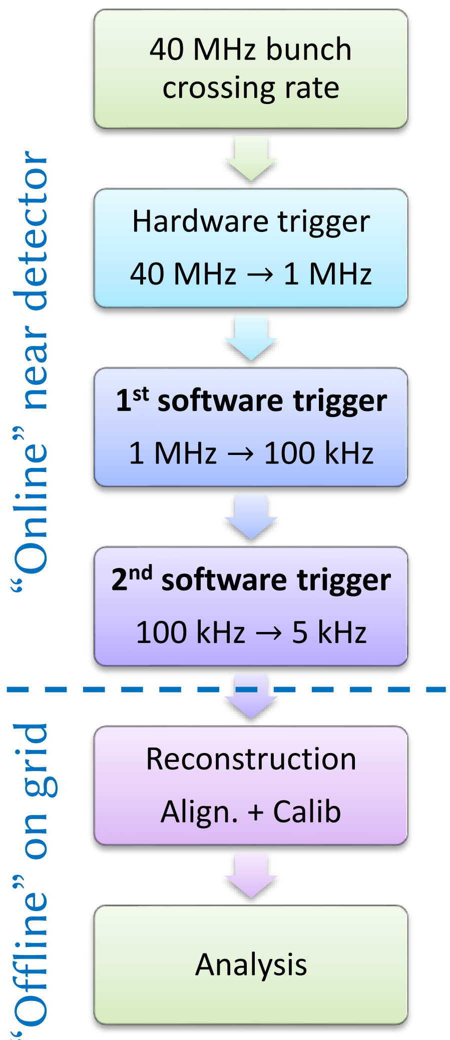
Data-taking with high levels of automation, in the new control room

NB: Beams not colliding head-to-head to maintain an optimal interaction rate

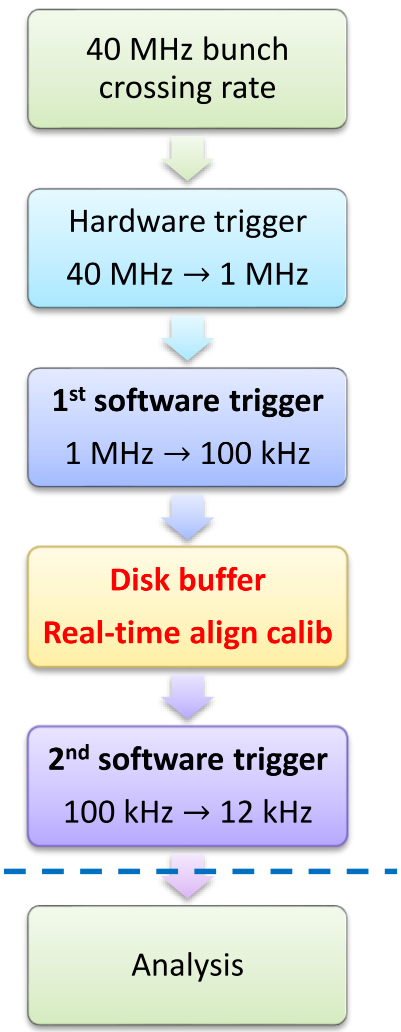
Many thanks to excellent performance of LHC and the accelerator experts!

A clearer way of data-taking

Run I



Run II

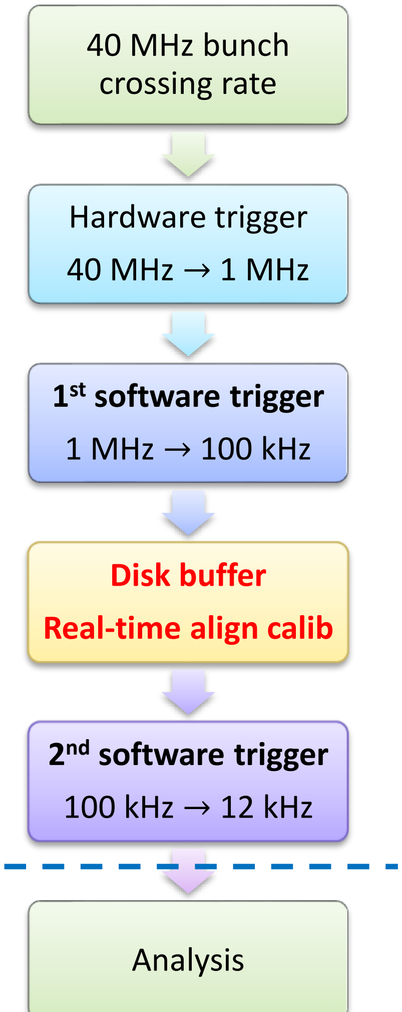


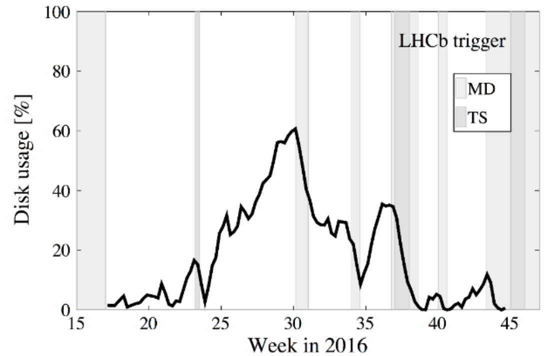
LHCb is pioneering a flexible & efficient online system, which

- allows real-time calibration and alignment
- maximises the usage of computing resources
- and delivers physics data of good quality at a high rate

To prove the point …

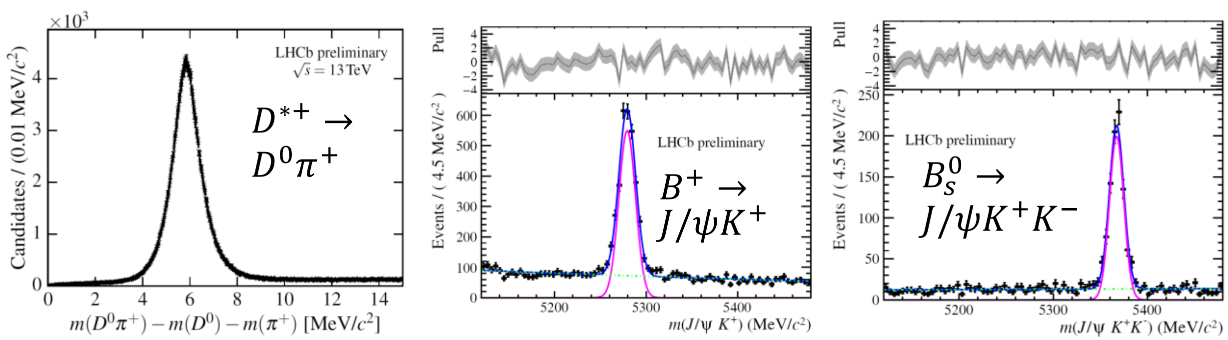
Efficient use of resources & better physics!





When there is no beam for physics, data stored on disk are processed
→ online farm always busy!

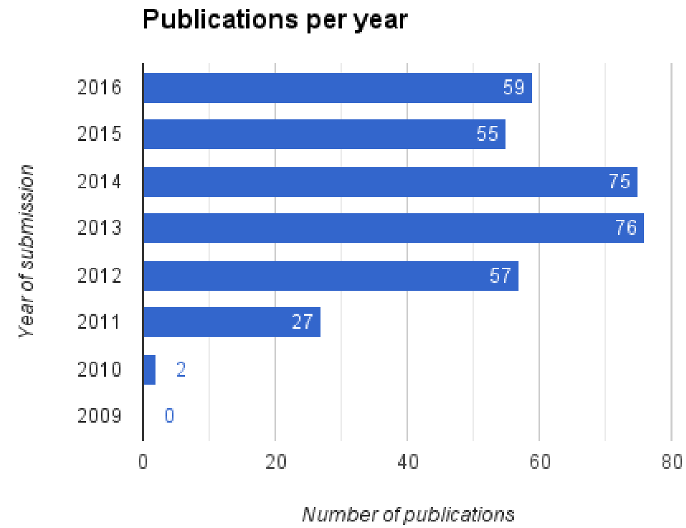
- Full event reconstruction, real-time alignment & calibration ⇒ improved resolution & lower background in 2nd software trigger
- Even better, the trigger output can be directly streamed out for physics analysis

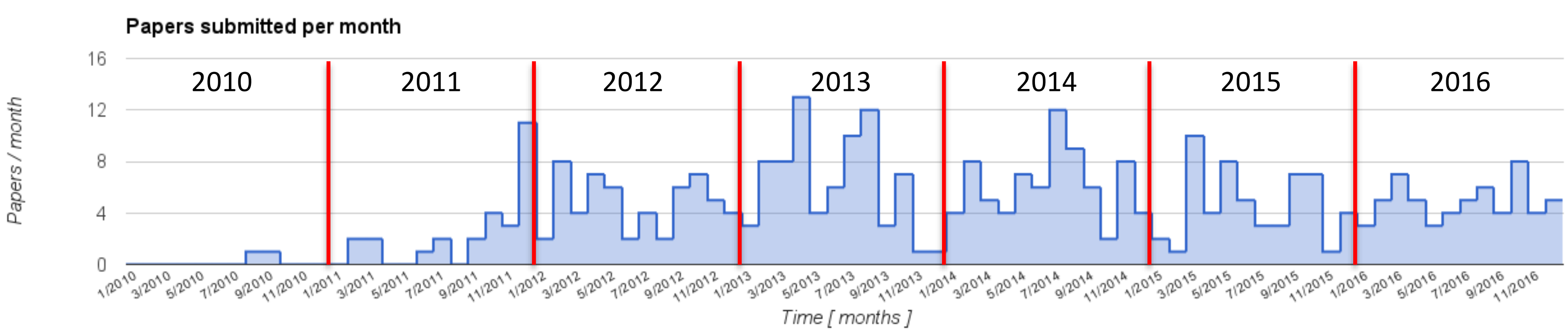


A year of harvest … in physics

- **351** papers submitted, 59 this year
- 16 with Editorial Board
- 17 CONF notes
- 40 analyses under review

- Still many interesting results out of Run I; while Run II are being used





A wide range of physics topics

CP violation

$B \to f$ not the same rate as $\bar{B} \to \bar{f}$?
Could the matter – antimatter asymmetry reveal effects beyond the Standard Model?

Rare decays

Some decays predicted to occur very rarely in the SM, if a higher rate observed new mechanism must come into play

QCD

How & how much beauty & charm produced in pp collisions?
Basis of understanding any signals at the LHC

Spectroscopy

Meson = $(q\bar{q})$,
Baryon = (qqq) or $(\bar{q}\bar{q}\bar{q})$
*How are quarks combined to form bound states?
*Any possibilities other than $q\bar{q}$ or qqq?

Electroweak

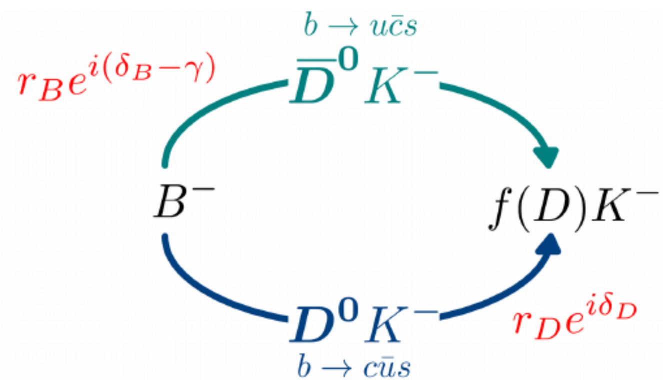
Ion & fix-target

While pursuing the core physics programme, LHCb is becoming a general purpose detector

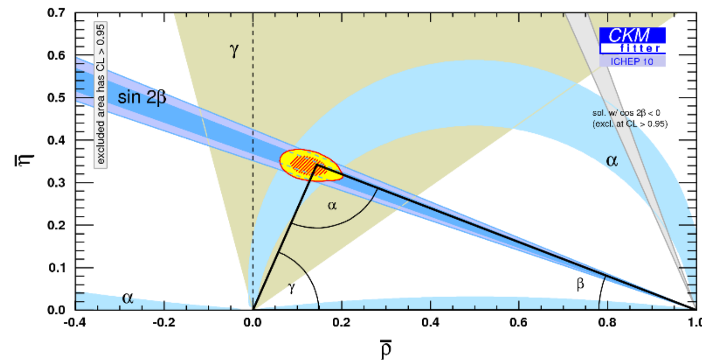
The γ angle

- The CKM unitary triangle contains information on how quarks change flavour in weak interactions, and the source of CP violation
- The γ angle is the least well known
- It can be measured in B decays

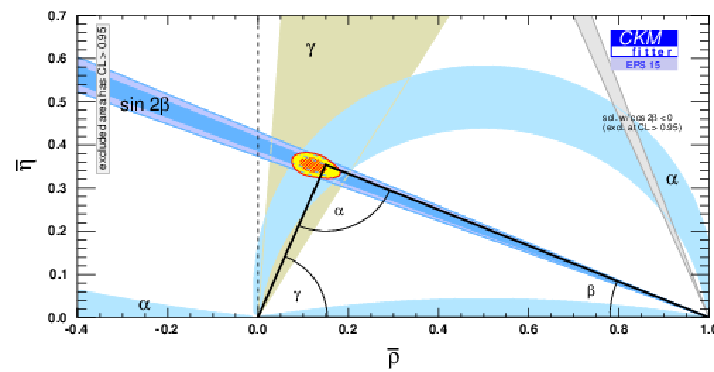
LHCb has been already making impact



World average
Before LHCb (2010)

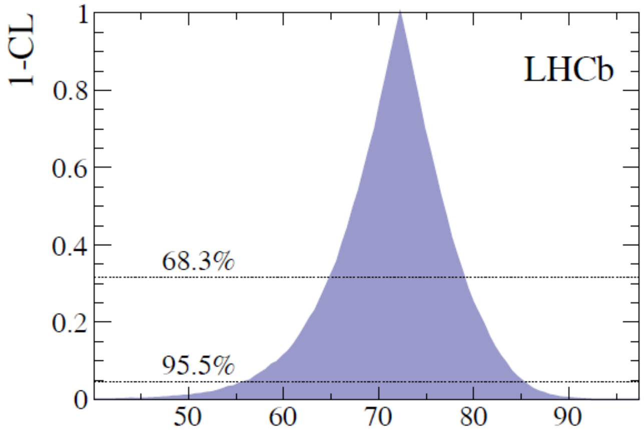


2015 (including LHCb measurements)



CKMfitter collaboration

All roads lead to γ

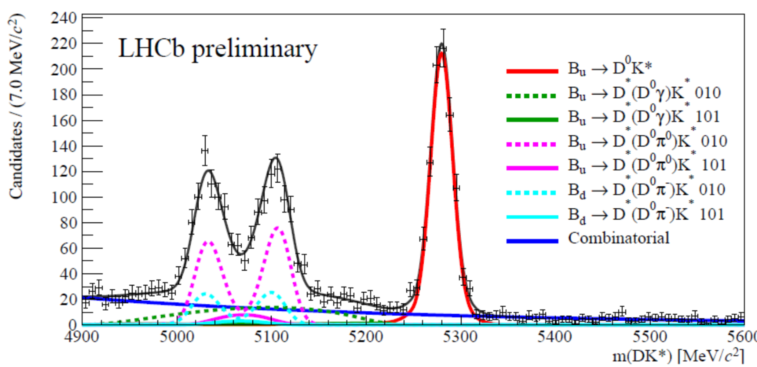


$$\gamma = (72.2^{+6.8}_{-7.3})^{\circ}$$

arXiv: 1611.03076

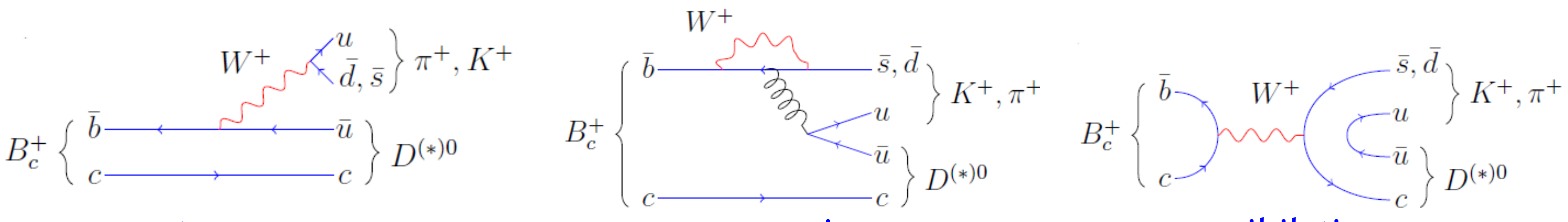
- Combination of numerous $B \to DK$ decay results from Run I continues to improve the γ precision
- Result significantly more precise than from the ensemble of all previous experiments!

- $B^{\pm} \to DK^{*\pm}$
  - 3 fb^{-1} Run I + 1 fb^{-1} Run II
- A bright prospect for Run II to further reducing γ uncertainty



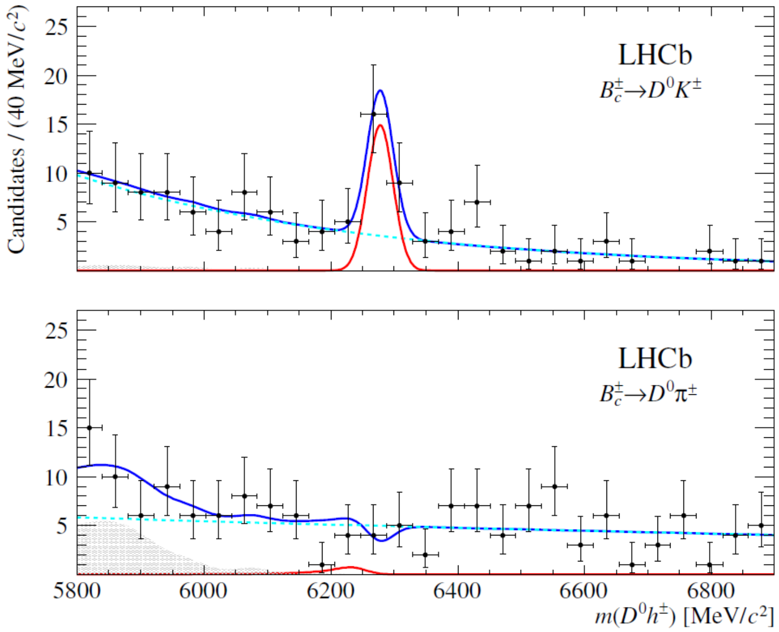
LHCb-CONF-2016-014

An unexpected B_c^+ decay



(Almost all known B_c decays so far)

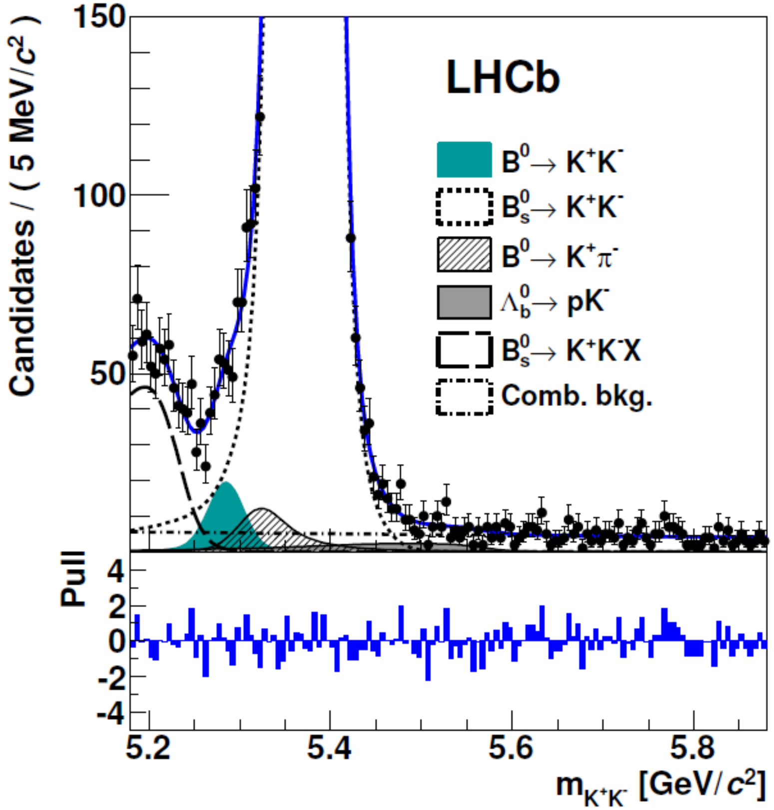
- B_c is very difficult to produce thus much less studied, most of its experimental knowledge from LHCb
  - For every ~200 B^+ only 1 B_c^+
- $B_c^+ \to D^0\pi^+$ is favoured decay, so is expected to appear first …
- … but it is not seen. In contrast the suppressed $B_c^+ \to D^0K^+$ shows a very clean signal (5.1σ)!



LHCb-PAPER-2016-058, in prep.

An intriguing result that requires theoretical explanation!

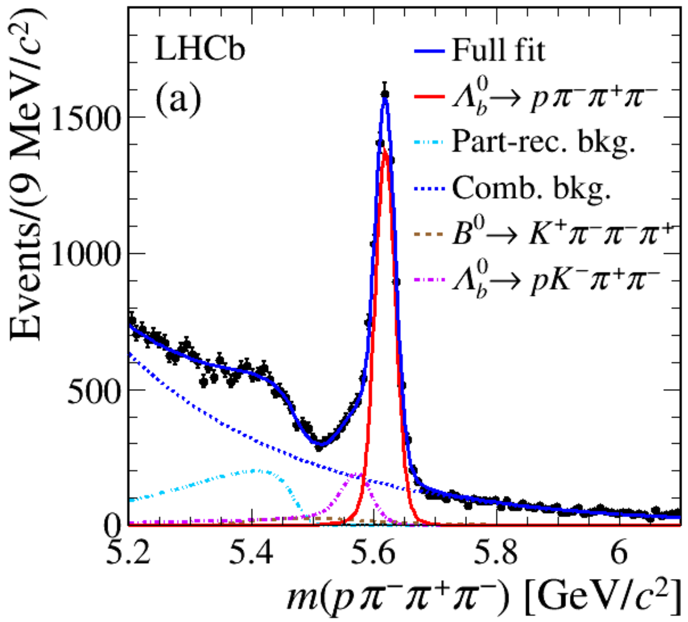
A very rare decay of $B^0 \to K^+K^-$



- $B^0 \to K^+K^-$ observed (5.8σ) after years' search
- The rarest B meson decay into fully hadronic final states
  - *Only 1 in ~12 million*

arXiv: 1610.08288

CP violation with baryons



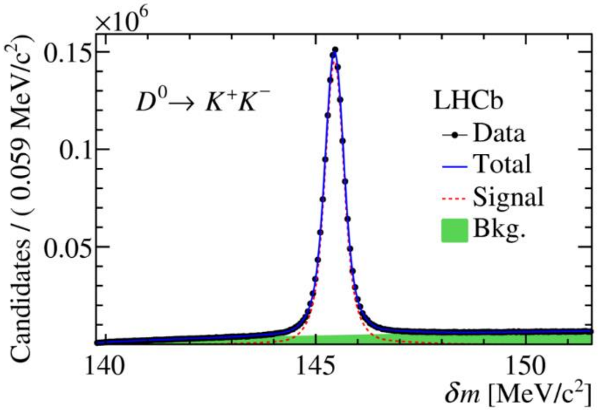
- Evidence (3.3 σ) for CP violation in $\Lambda_b^0 \to p\pi^+\pi^-\pi^+$ decay found
- First evidence of CP violation in baryon sector!

arXiv:1609.05216

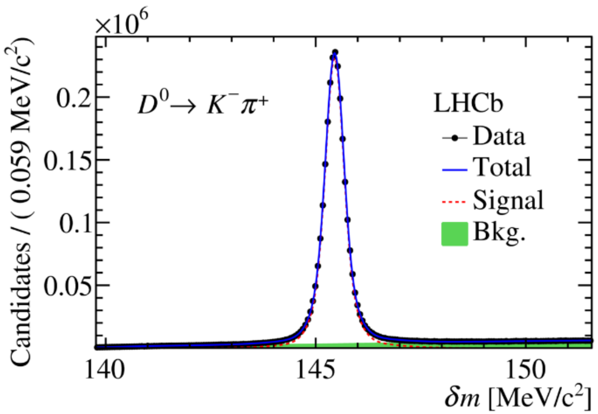
- A new gate opens for studying CP violation in baryons, since LHCb records large amount of Λ_b and other beauty baryons

Chin.Phys.C 40, 1 (2016) 011001

CP violation in charm



← ~ 6 million $D^0 \rightarrow K^+K^-$ *candidates*



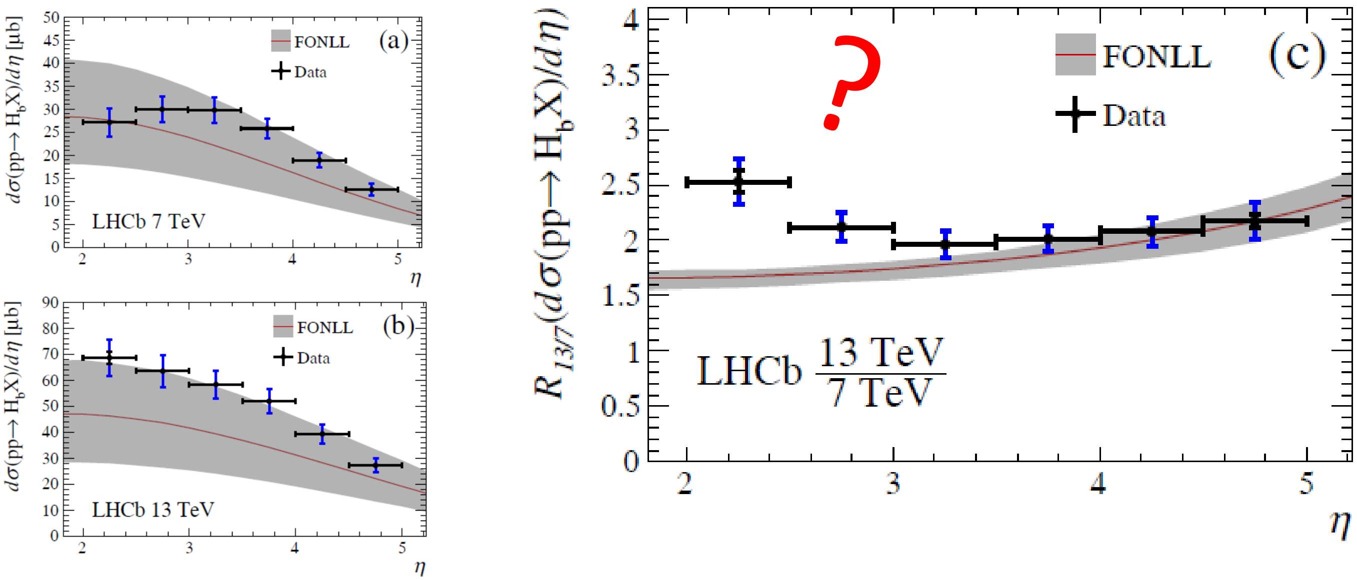
← ~ 32 million $D^0 \rightarrow K^+\pi^-$ *candidates*

- LHCb not only for beauty! Huge yield of charm mesons, with very clean background
- Sensitivity for CP violation reaches 0.1% in a single D decay, pushing towards the level predicted in the Standard Model

arXiv: 1610.09476

b quark production cross-section

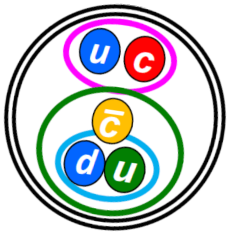
- Many searches for new physics at LHC reply on a good understanding of the b quark background
- Results comparing 13 TeV and 7 TeV are in tension with prediction by a widely used model → will surely attract a lot theorists' attention



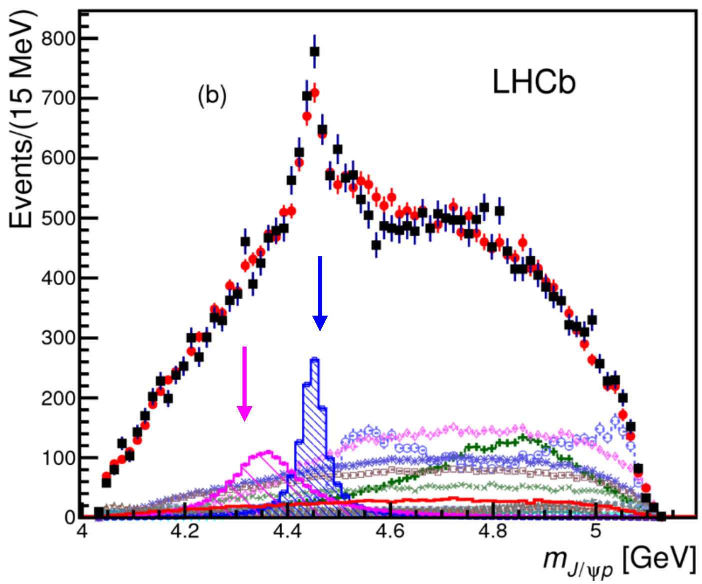
arXiv: 1612.05140

Pentaquark

- In the limelight 2015: observation of 2 pentaquark states in the $\Lambda_b^0 \to J/\psi p K^-$ decay
- Search in a similar yet rarer decay $\Lambda_b^0 \to J/\psi p \pi^+$ confirms these two states (>3σ)!
- Truly extending our view on how quarks form bound states

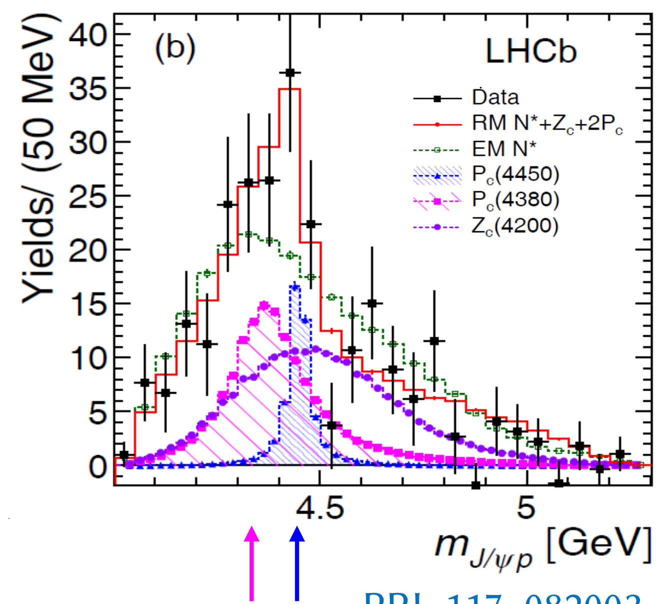


2015 discovery



PRL 115, 072001 (2015)

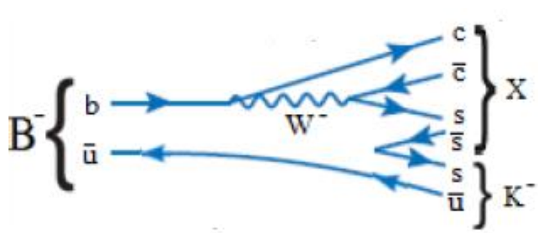
recent confirmation



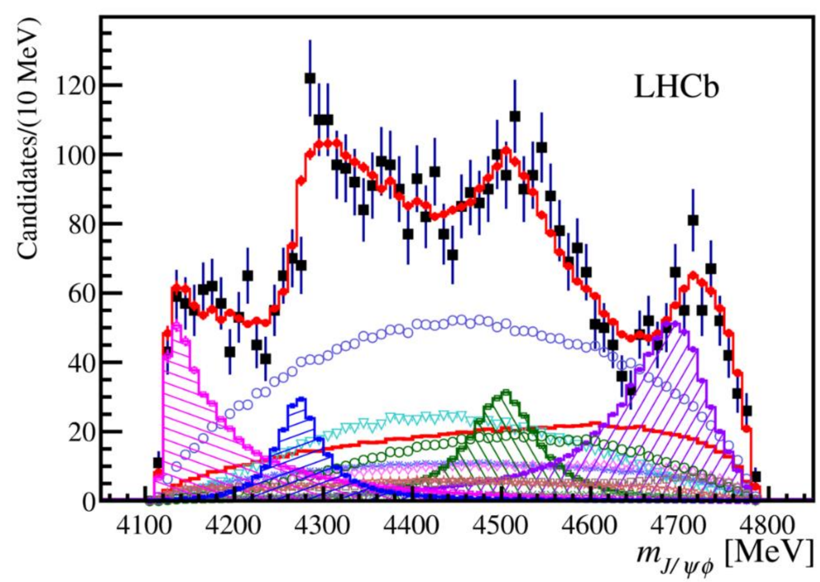
PRL 117, 082003 (2016)

Tetraquark-like states

- In $B^+ \to J/\psi\phi K^+$ decay
- Some experiments saw narrow X(4140), some didn't
- With large yield of the signal, and sophisticated analysis technique, LHCb find there are 4 such tetraquark-like states → controversy settled
- The quantum numbers are measured, a significant step towards understanding their nature



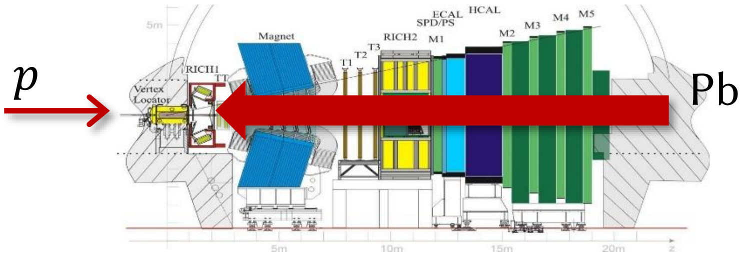
arXiv: 1606.07895
arXiv: 1606.07898

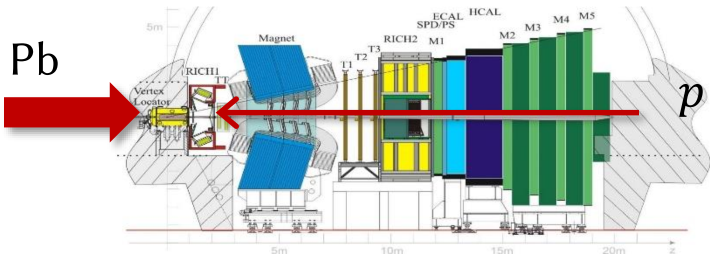


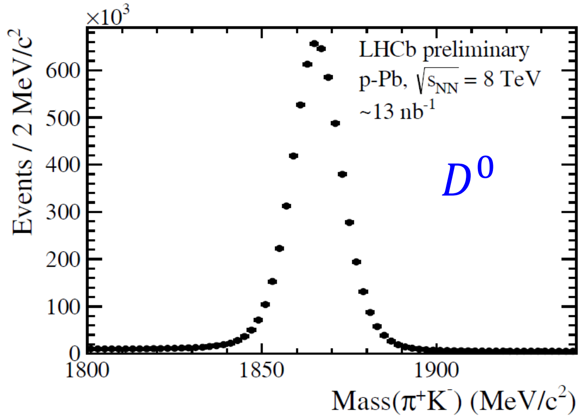
Not only *pp*!

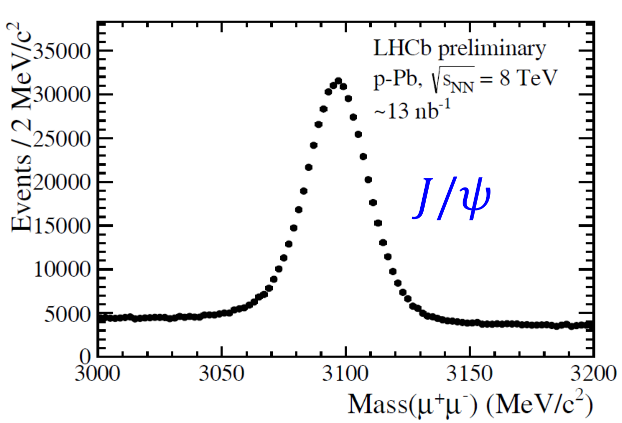
- Data taking in *p*Pb/Pb*p*
- ~ 30 nb^{-1} collected
  - 5, 8 TeV *p*Pb
  - 8 TeV Pb*p*

Thanks again to LHC for accepting our requests, and providing a lot of luminosity





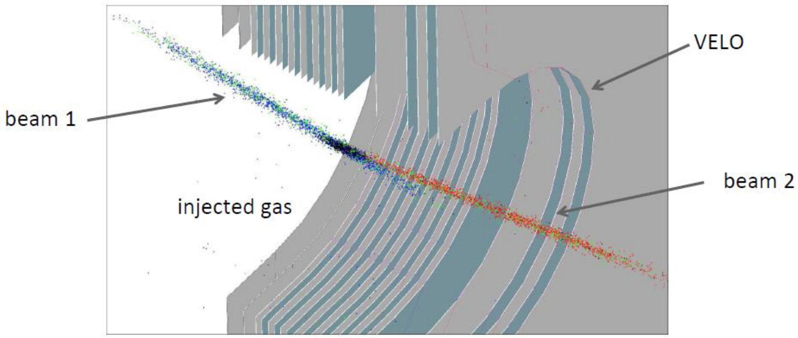


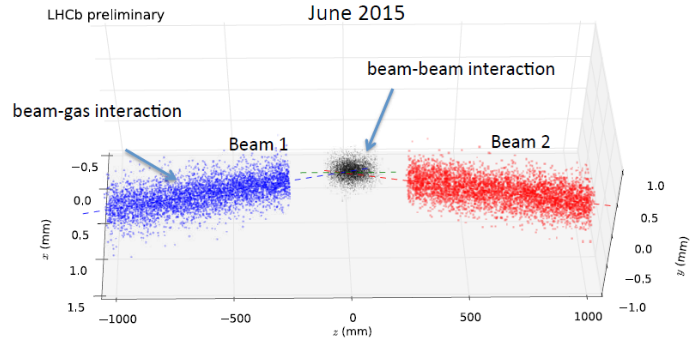


Already set off for physics in this years' data

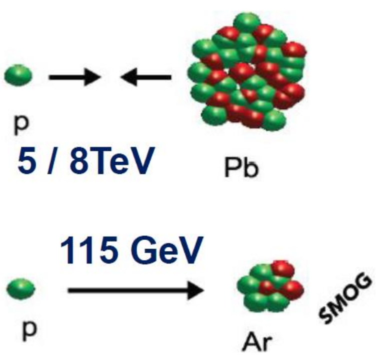
Fixed target data-taking

- Nobel gas injected in the beampipe, initially for beam imaging
  - Beam profiles pictured in the silicon vertex detector, giving precise luminosity measurement → unique in LHCb! JINST 9 P12005



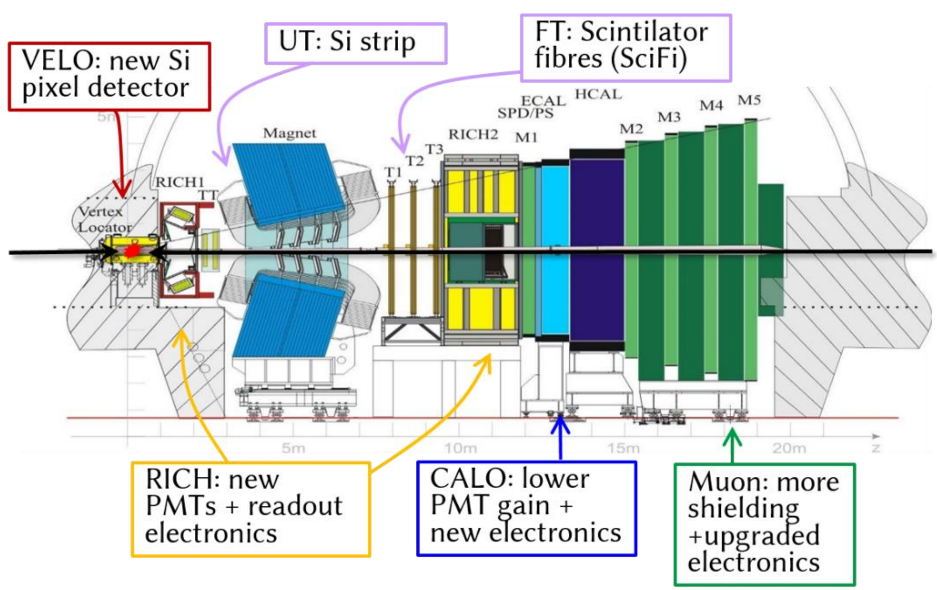


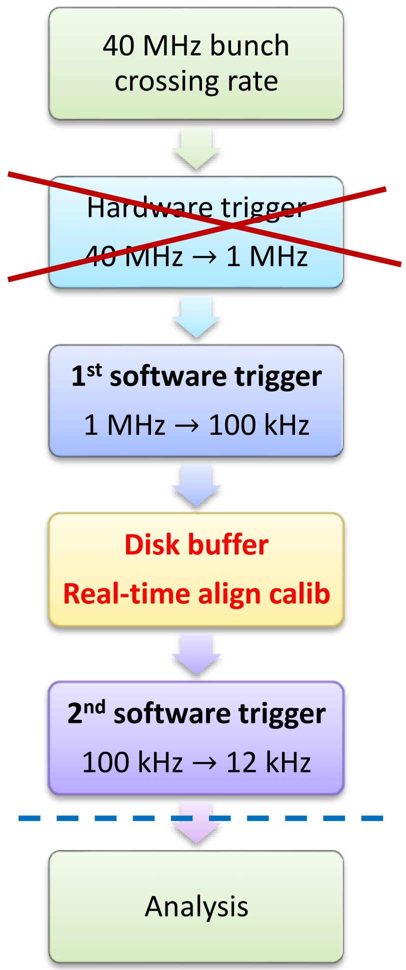
- The gas can serve as a fixed target!
  - *Bridging the energy gap between SPS and LHC*
  - *Beam-beam and beam-gas collisions for physics at the same time*



Upgrade

- After the next LHC long shutdown, LHCb will be upgraded for more physics!
  - 50 fb^{-1} luminosity in ~10 years time
  - More efficient trigger for hadronic final states
- This requires
  - Removing the hardware trigger ⇒ 40 MHz readout!
  - Improved sub-systems

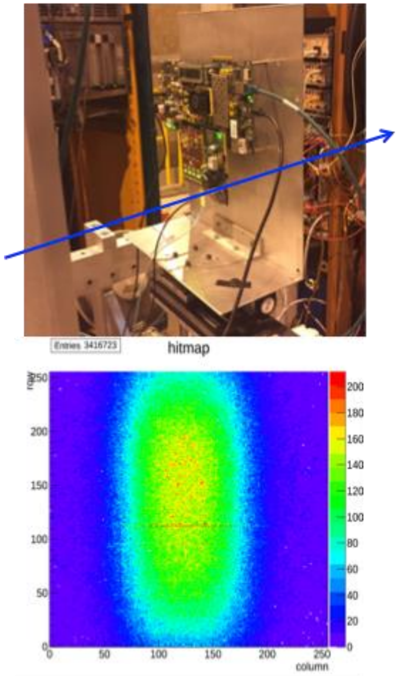




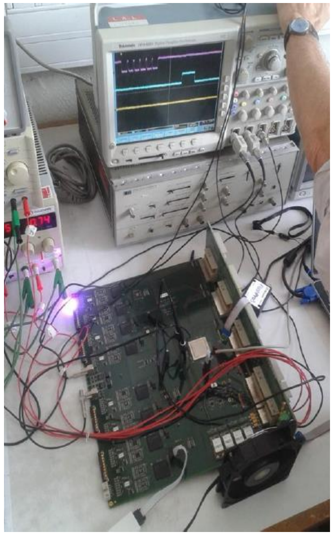
Upgrade progress

- Generally good progress
  - *Construction phase started*
- Current long technical stop is fully exploited
  - *Eg. Installation of CO_2 transfer lines for upgrade cooling*

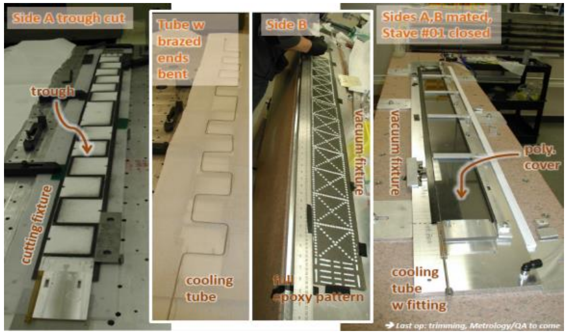
VELO readout chip in testbeam



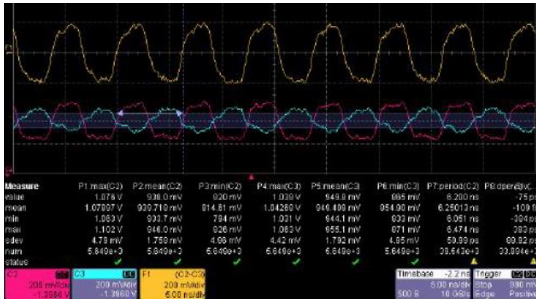
CALO Front-end board



UT stave construction

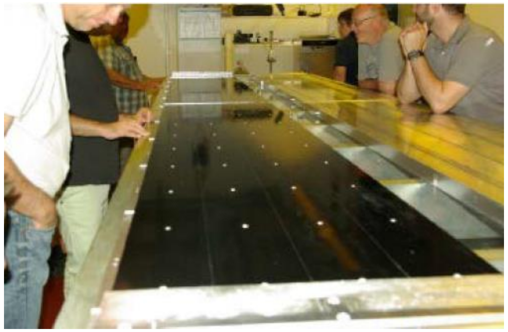


Test on MUON electronics



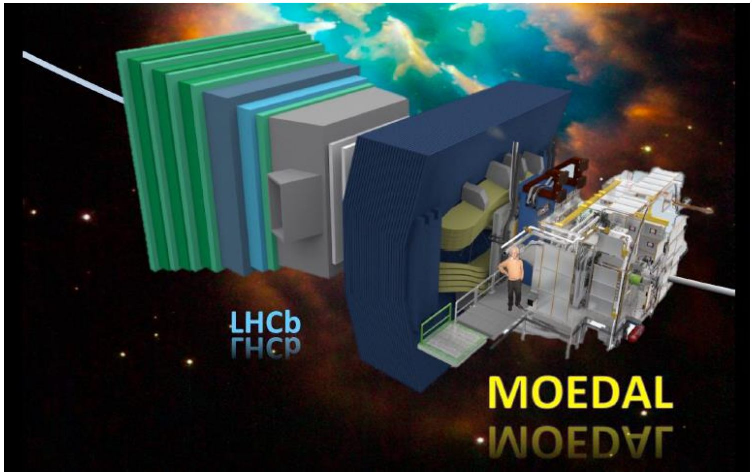
RICH digital board

SciFi module



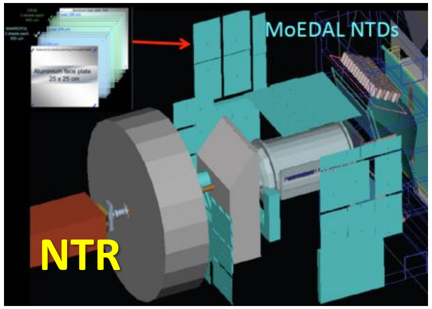
Monopole & Exotics Detector At the LHC

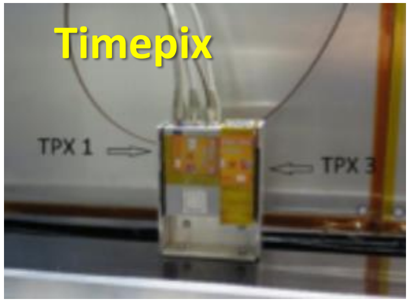
MoEDAL



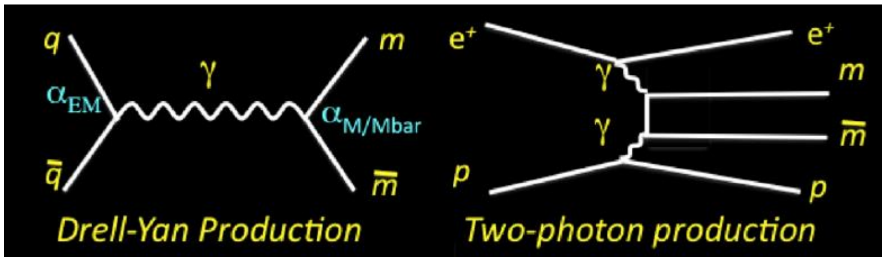
- Searching for the passage of highly ionizing particles as messengers of new physics, eg. magnetic monopole
- Ionization increases with magnetic charge $g = ng_d$, decreases with velocity
  → a unique signature

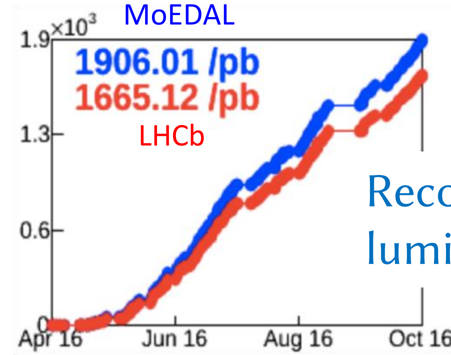
- A detector system mainly passive:
  - Nuclear track detector (NTR): plastic array
  - Trapping detector: a tonne of Alumnium
  - Timepix array: real time radiation monitoring





Search for magnetic monopole



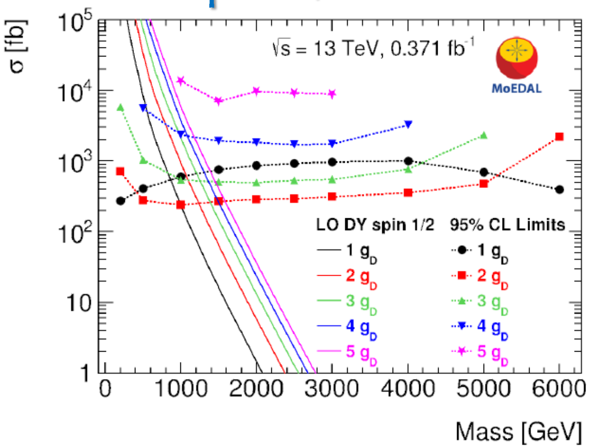


MoEDAL

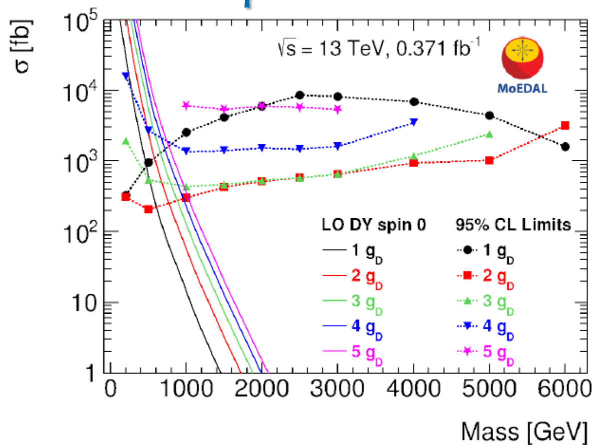
Recored luminosity

8 TeV result: JHEP 1608 (2016) 067; **13 TeV result**: arXiv: 1611.06817, submitted to PRL

Spin 1/2



Spin 0



Cross-section upper limit @ 95% C.L. for Drell-Yan monopole production in 13 TeV pp collisions.

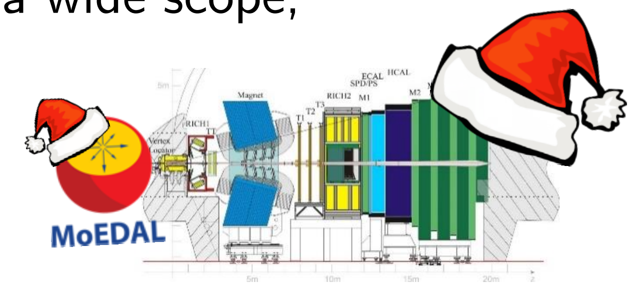
mass limits [GeV]	$1g_D$	$2g_D$	$3g_D$	$4g_D$
MoEDAL 13 TeV (this result)				
DY spin-1/2	890	1250	1260	1100
DY spin-0	460	760	800	650
MoEDAL 8 TeV				
DY spin-1/2	700	920	840	–
DY spin-0	420	600	560	–
ATLAS 8 TeV				
DY spin-1/2	1340	–	–	–
DY spin-0	1050	–	–	–

Monopole lower mass limit set for charge up to $4g_D$

Dirac charge: $g_D = \frac{1}{2\alpha_{em}} \sim 68.5$

Summary

- A great year for LHCb:
  - Successful data-taking for pp and pPb
  - Plenty of interesting physics results in a wide scope, with both Run I and Run II
  - Upgrade preparation well on track



- Also an excellent year for MoEDAL
  - Search for magnetic monopole with 8 and 13 TeV data

- A big thank you to the LHC, CERN, funding agencies, and all who support and help
- Wish you a nice xmas break, and look forward to an exciting 2017!