LHCb Report
at the LHCC Open Session

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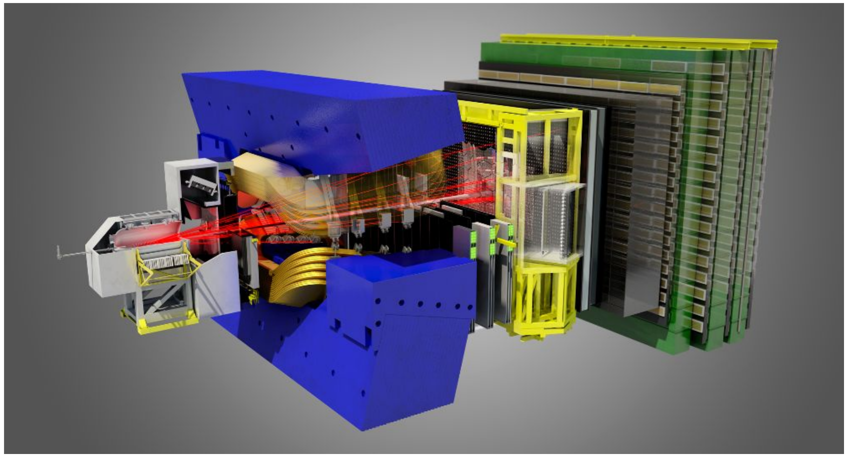
Sezione di Firenze



March 2nd, 2016 CERN, Geneva

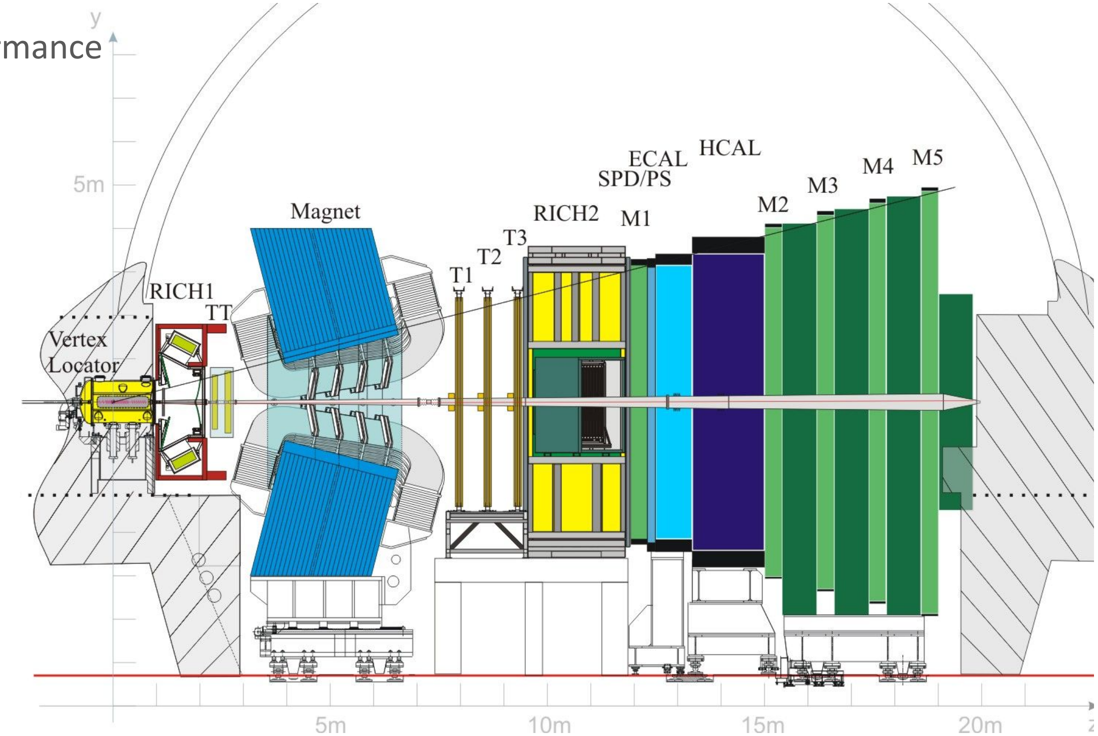
Outline

- **Introduction**
  - The LHCb experiment
  - Papers & Conferences
- **Results since the last LHCC**
  - CP violation and the γ measurement
  - CP violation and **charmless** *b* decays
  - **Charm** mixing and CP violation
- **Analysing the special runs**
  - Physics in *pA* collisions
- **Physics Tools *and* Data Science**
  - Flavour Tagging
  - Muon identification for the upgrade
- **Trigger and online processing**
- **Preparation for the 2016 data taking**
- **Upgrade**
- **Summary**

Introduction: the LHCb experiment

Originally designed to search indirect evidence of new physics in CP violating a rare *b* and *c* decays, LHCb is today a general purpose detector in the forward region.

- ➔ unique geometrical coverage
- ➔ outstanding track momentum and vertex resolution
- ➔ excellent Particle Identification performance
- ➔ unique trigger strategy



Tracking efficiency	> 96 %
Decay time resolution	45 fs
Momentum resolution	0.5 - 1.0 %
Software trigger input	10^6 events / s

Introduction: Published papers

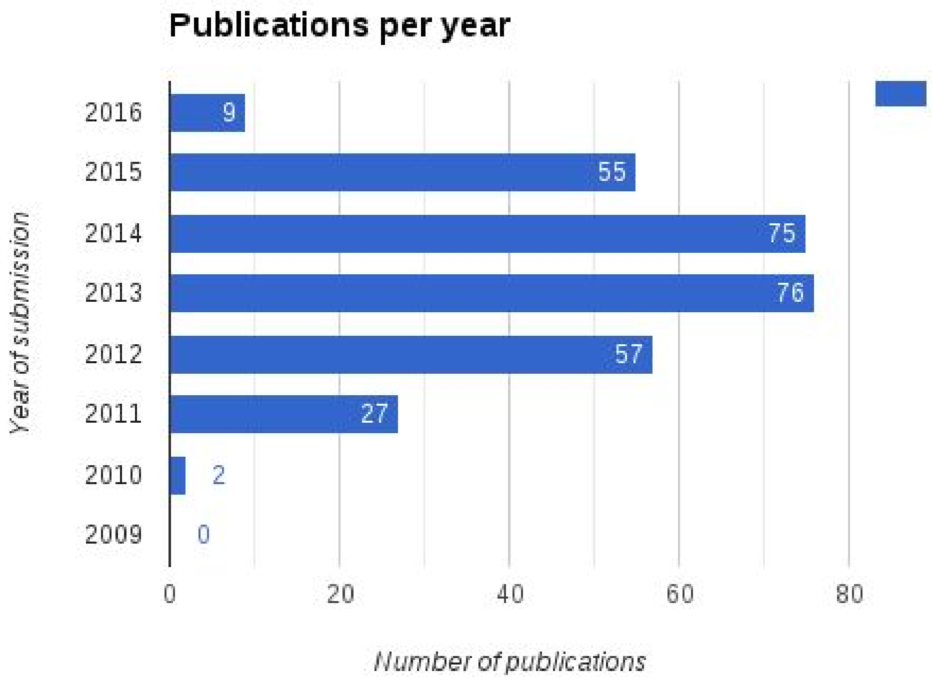
301 submitted Physics papers

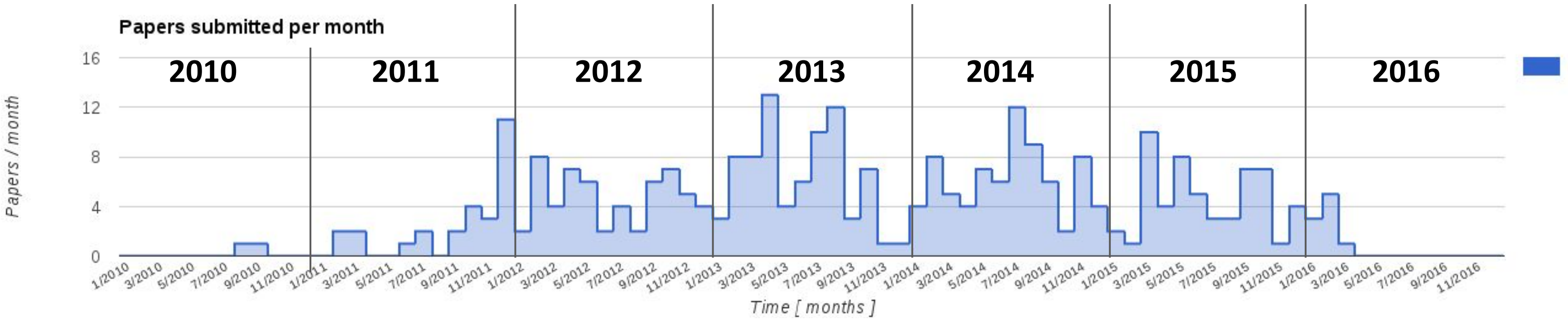
21 conference-reports
(not in statistics)

14 detector performance papers
(not in statistics)

Still a lot to do with Run-1 data!

Too many exciting results to be shown today.

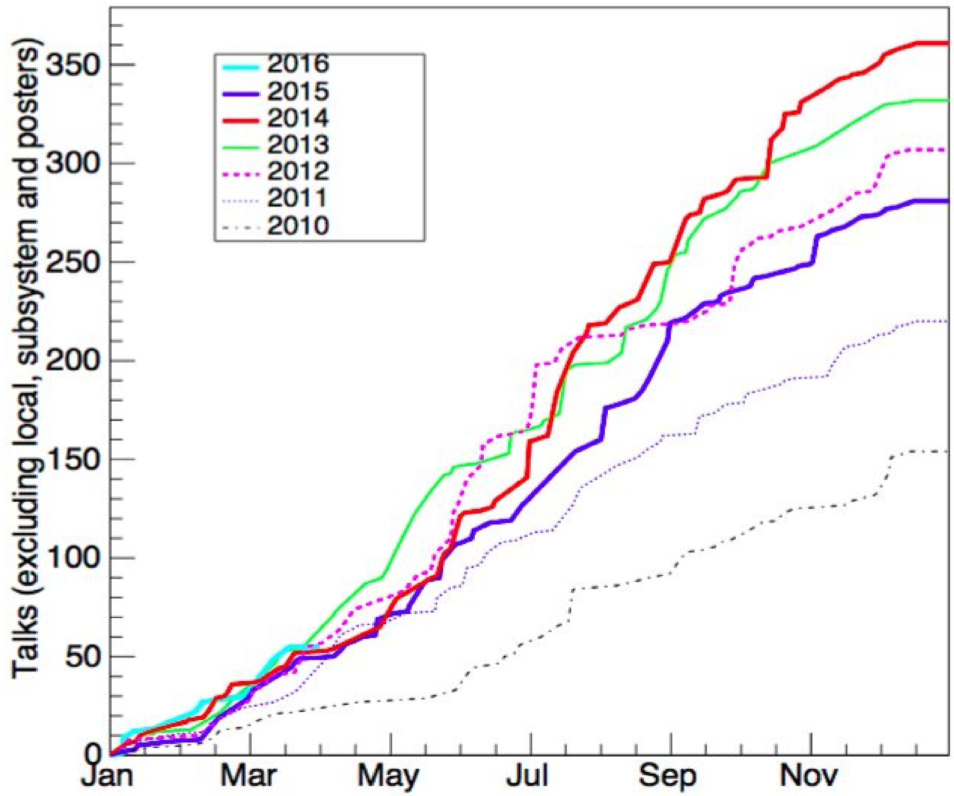


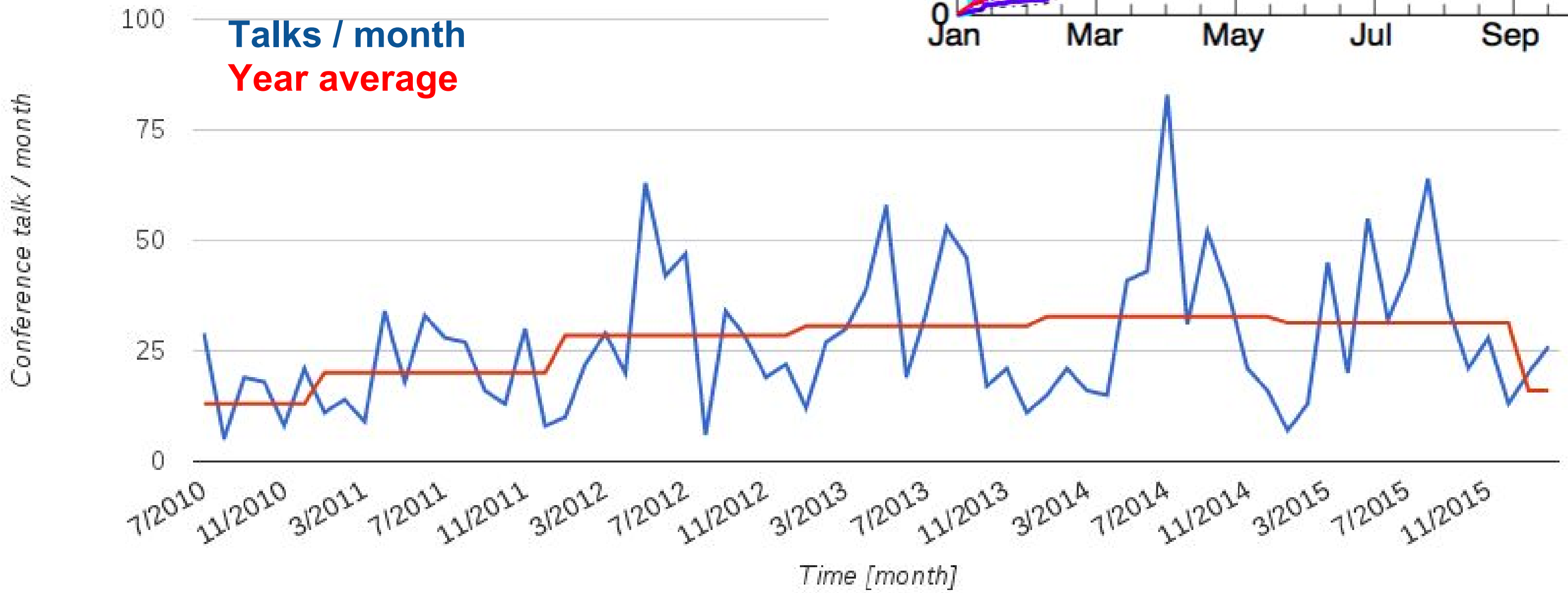


Introduction:
Conference talks

2436 talks at conferences since 1995

About 30 talks/month since 2012.





New results since last LHCC meeting

First observation of the rare $B^+ \to D^+ K^+ \pi^-$ decay	PAPER-2015-054	PRD	arXiv:1512.02494	08 Dec 2015
Angular analysis of the $B^0 \to K^{*0} \mu^+ \mu^-$ decay	PAPER-2015-051	JHEP 02 (2016) 104	arXiv:1512.04442	14 Dec 2015
Study of $D_{sJ}^{(*)+}$ mesons decaying to $D^{*+} K_S^0$ and $D^{*0} K^+$ final states	PAPER-2015-052	JHEP 02 (2016) 133	arXiv:1601.01495	07 Jan 2016
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A new algorithm for identifying the flavour of B0sBs0 mesons at LHCb	PAPER-2015-056	JINST	arXiv:1602.07252	23 Feb 2016

New results since last LHCC meeting

Observation of new *b*-hadron decays

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New constraints on the CKM model from Amplitude and Dalitz Plot analyses

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World leading **charm** results
with *high-precision, high-statistics* measurements

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Competitive measurements from *special-runs*
with unique inputs from secondary vertex resolution

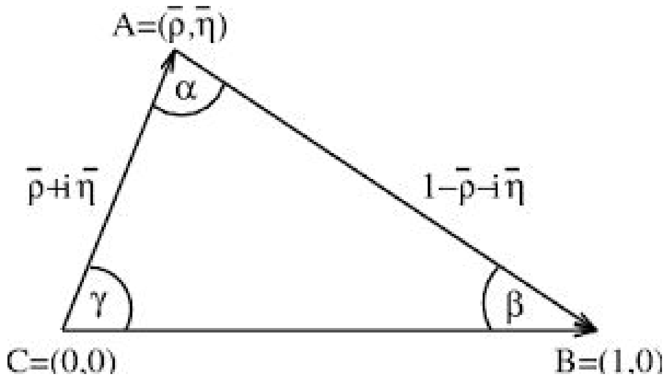
Physics Data Analyses:
CP violation & the measurement of γ

CKM metrology: measuring γ

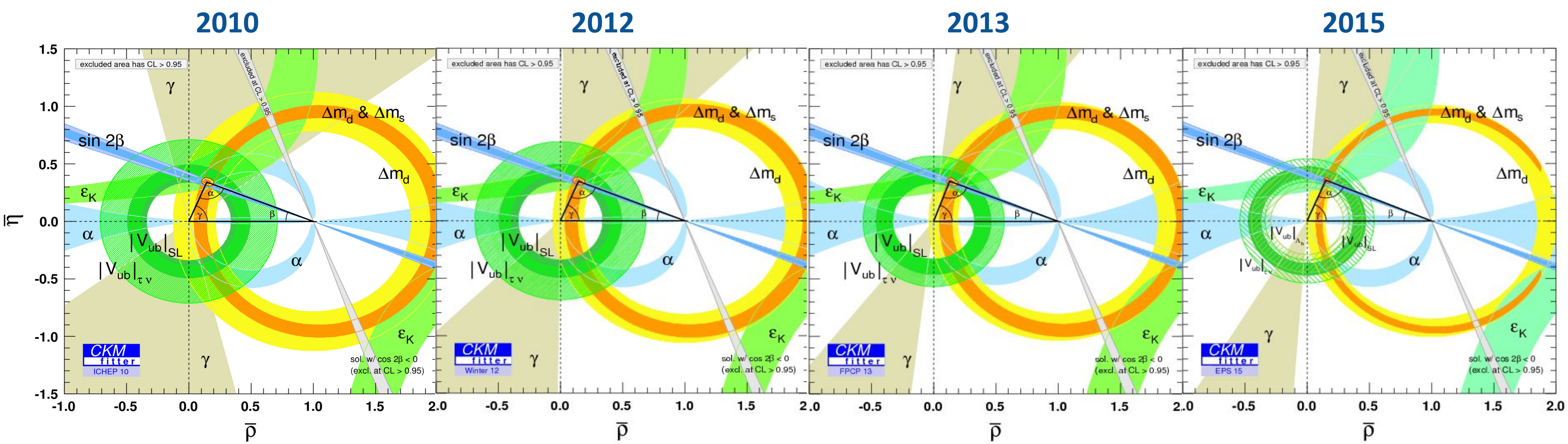
The Cabibbo-Kobayashi-Maskawa matrix, describing quark mixing, is expected to be unitary in the Standard Model.

Unitarity is translated into triangular relations between complex amplitudes.

One of these triangles is special: it has all sides of the same order of magnitude, it is named the *bd*-triangle.



LHCb is among the major contributors (in the last few years) constraining the parameters, angles and sides, of the *bd*-triangle, as evident from the evolution of the global fit (taken here from CKM fitter)



The constraint on the angle γ was improved significantly, but it is still the less stringent.

Constraining γ with the $B^0 \rightarrow D^0 K^- \pi^+$ decay mode

3.0 fb^{-1} collected in Run1

Constraints on γ from pure tree *beauty-to-charm* decays are robustly **free from contributions from *New Physics*.**

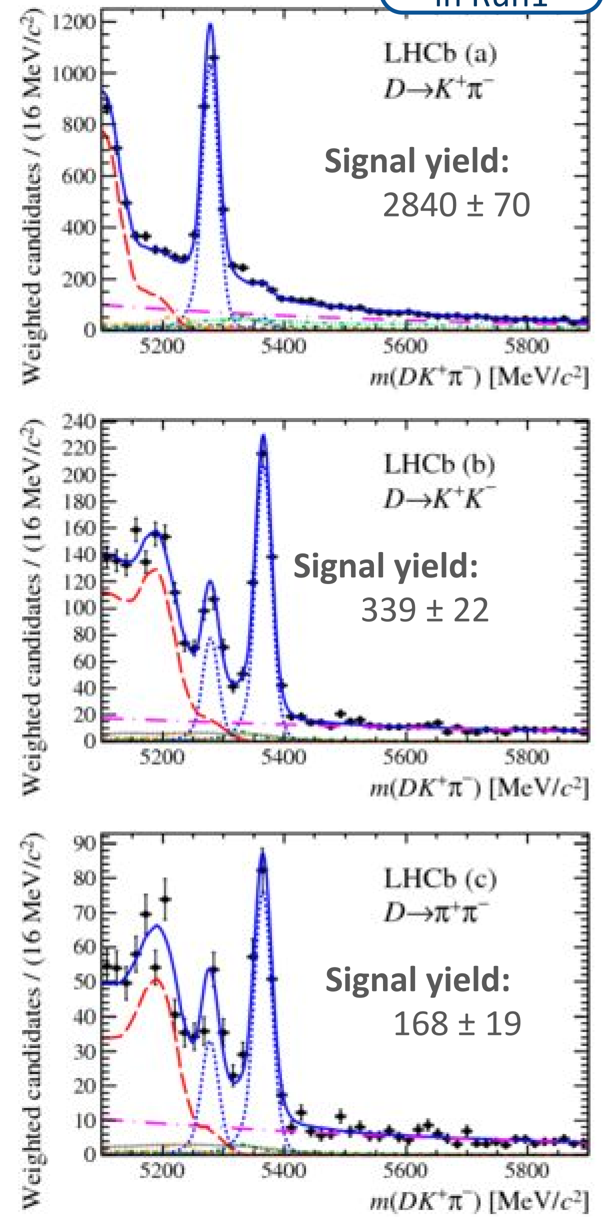
The uncertainties on γ are mainly statistical: better measurements combining constraining by more decays.

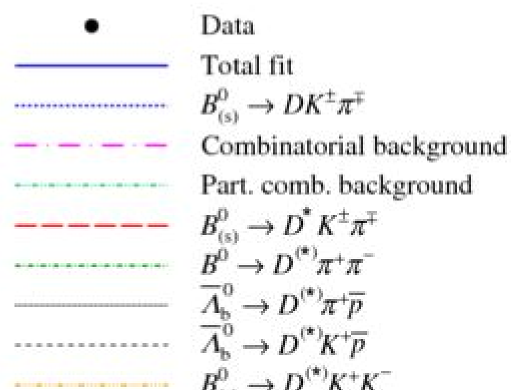
Last LHCb γ combination: $\gamma = (73^{+9}_{-10})°$

LHCb-CONF-2014-004

Decays used to measure γ so far include

- *$B^\pm \rightarrow D^0 h^\pm$ (hh)*
  - *with $D^0 \rightarrow KK$ or $D^0 \rightarrow \pi\pi$* (GLW method)
  - *with $D^0 \rightarrow K\pi$ (doubly Cabibbo-suppressed)* (ADS method)
  - *with $D^0 \rightarrow K_S^0\pi\pi$* (GGSZ method)
- time dependent using $B_s^0 \rightarrow D_s K$



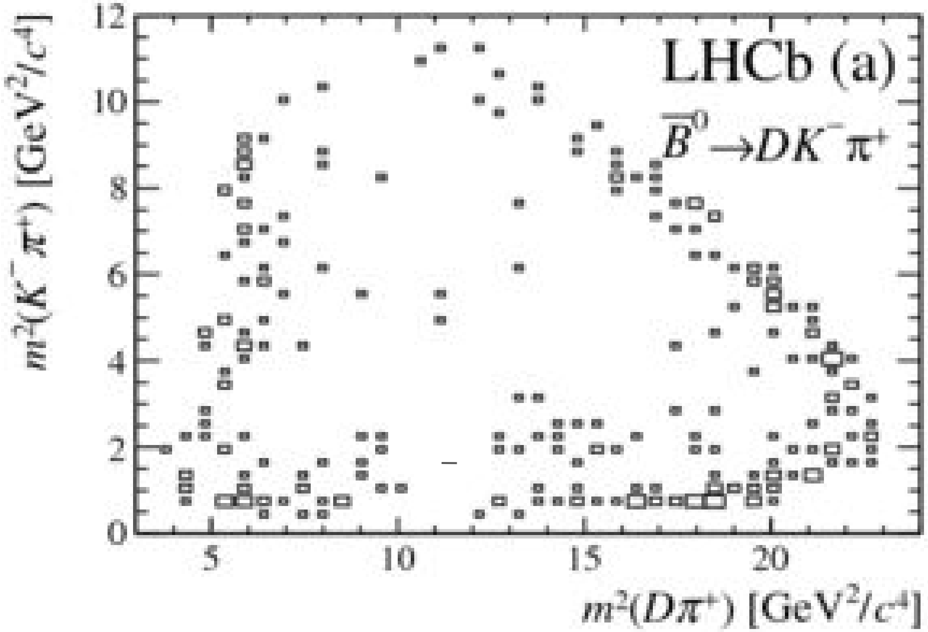


Despite the low statistics, the decay $B^0 \rightarrow D^0 K^- \pi^+$ offers a new opportunity of constraining γ.

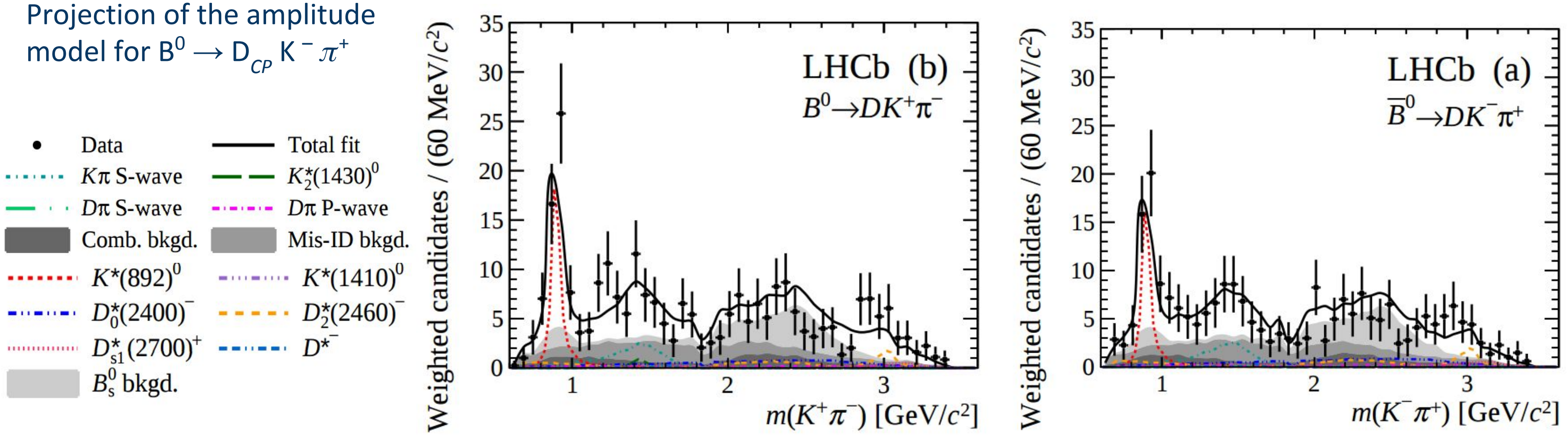
Dalitz Plot analysis of $B^0 \rightarrow D^0 K^- \pi^+$ decays

Extracting γ from an analysis of the *Dalitz Plot.*

In particular from the contribution $B^0 \rightarrow D^0 K^*(892)^0$



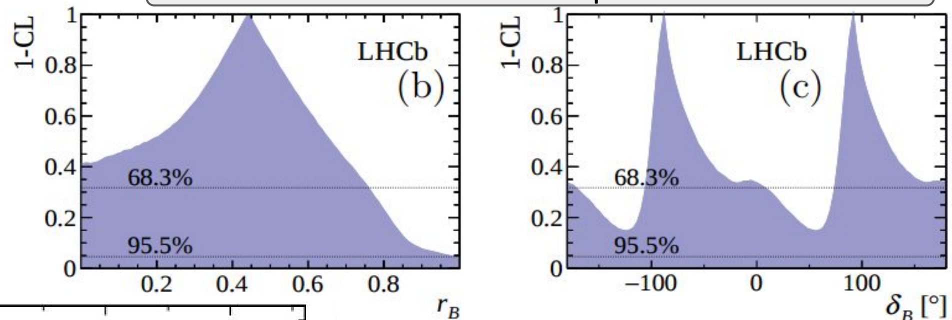
Projection of the amplitude model for $B^0 \rightarrow D_{CP} K^- \pi^+$

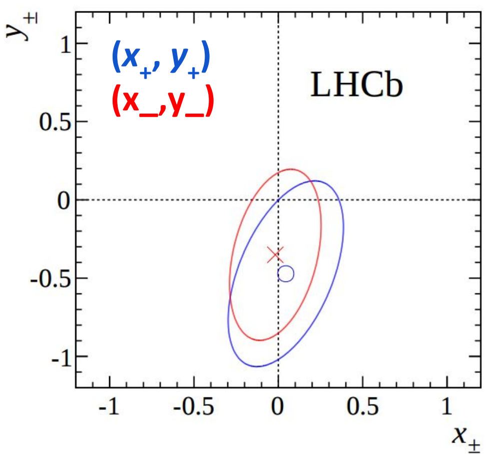


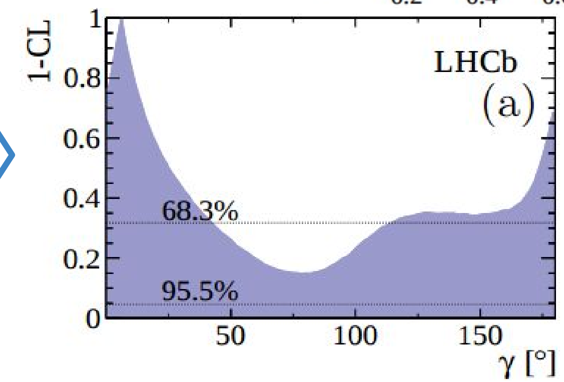
Using $B^0 \rightarrow D^0 K^*(892)^0$ to constrain the CKM angle γ

The observables *x* and *y*, which depend on γ (but also the hadronic nuisance parameters r_B and δ_B) are measured separately:
a discrepancy would be evidence of CP violation.

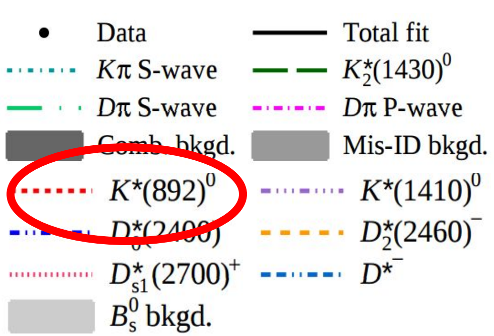
Hadronic nuisance parameters.

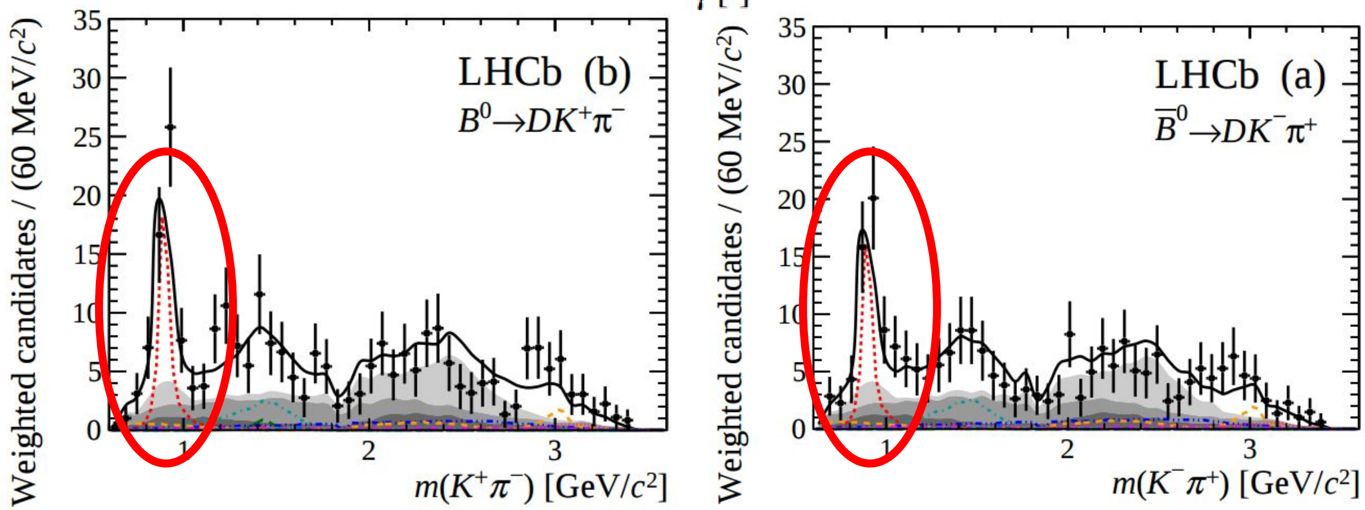






While no value of γ is excluded at 95% C.L., this is a powerful new method to measure γ which will be very important in Run 2 and beyond!





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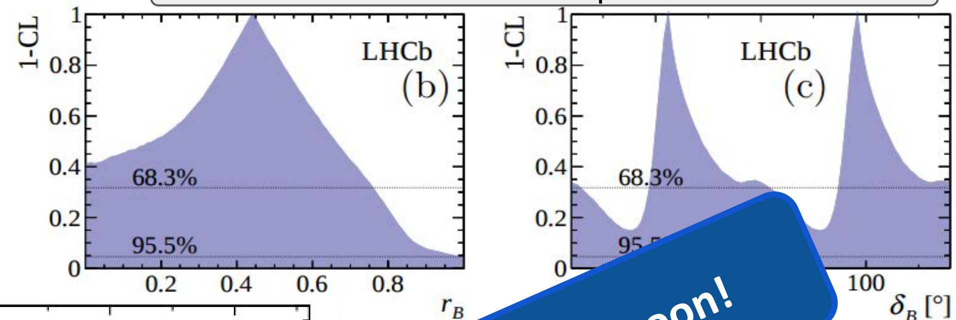

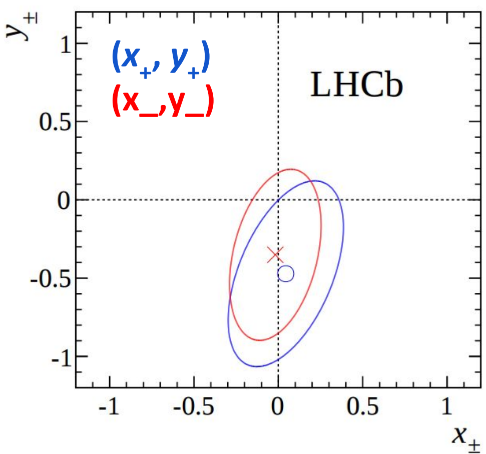

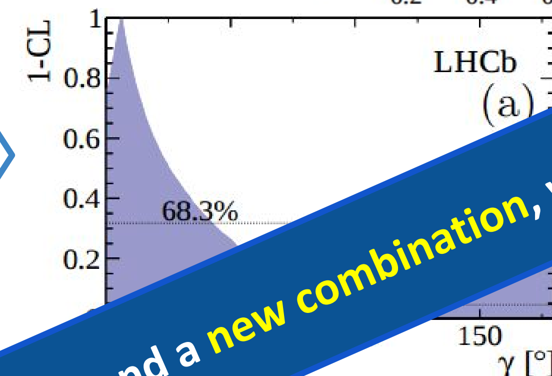

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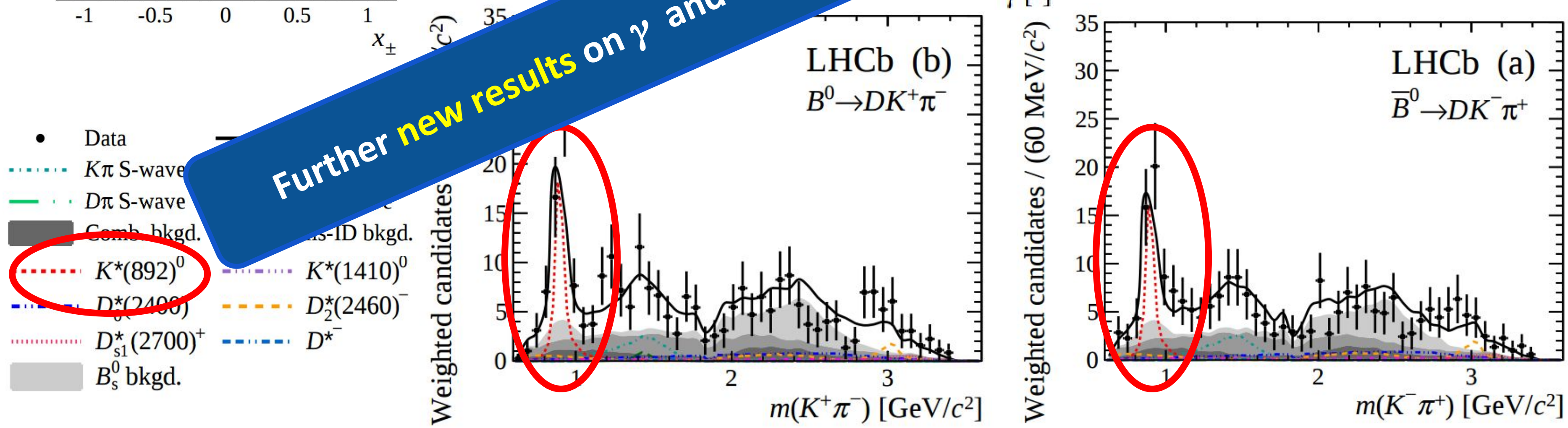
Further **new results** on γ and a **new combination**, will be presented soon!



Physics Data Analyses:
CP violating charmless b decays

The importance of being *charmless*

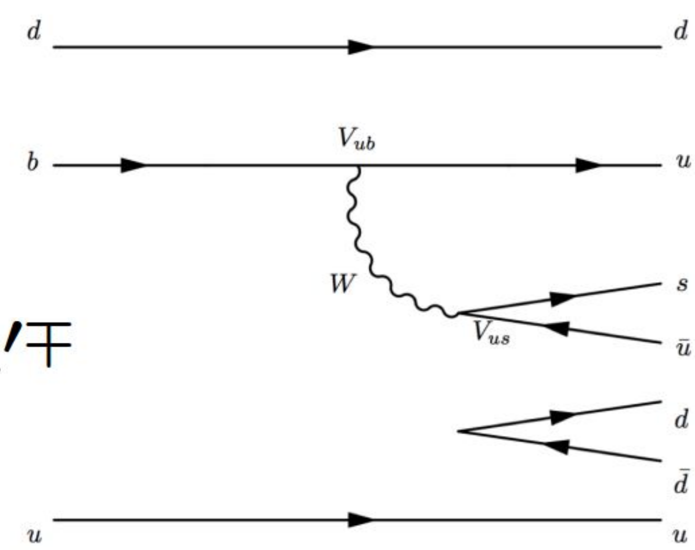
Charmless *b* decays often present decay amplitudes with important interference of *tree* and *loop* processes.

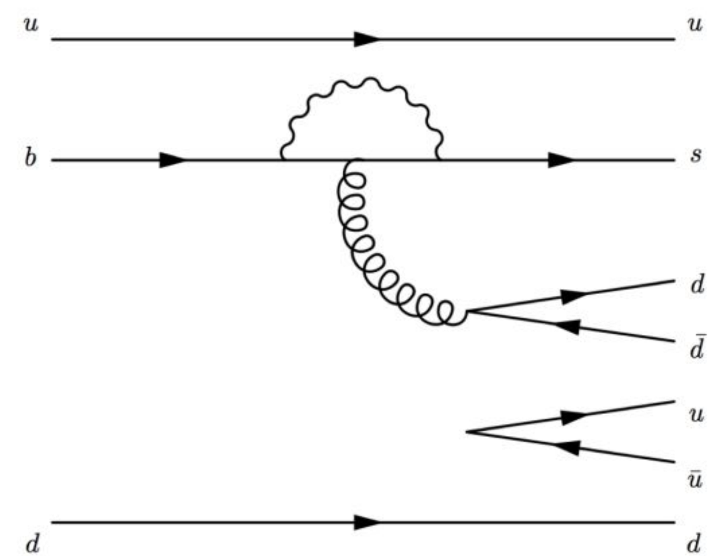
Inconsistency of the CP violating effects in charmless *b* decays, with measurements based on pure-tree decays, would be **indirect evidence for new physics** arising as *new CP-violating contribution* in the loops.

LHCb did it with **baryons**!

Unexplored field at *b* factories.

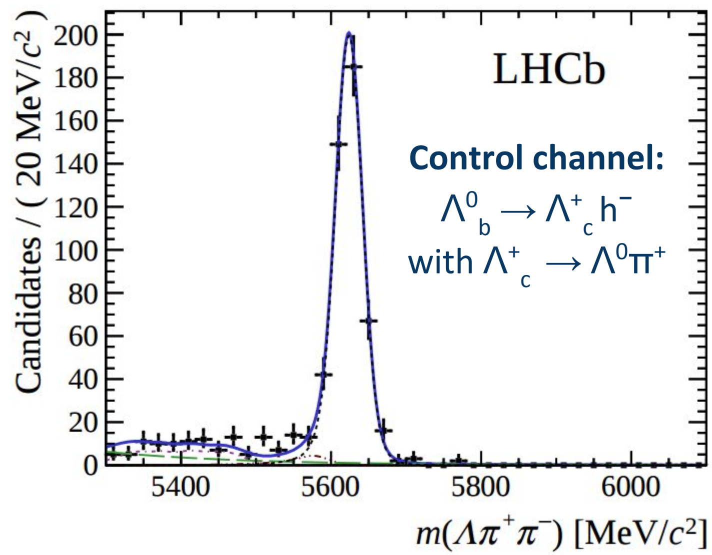
$$\Lambda_b^0 \to \Lambda h^{\pm} h'^{\mp}$$





Looking for the first time at Λ^0_b charmless decays: $\Lambda^0_b \to \Lambda^0 h^+ h^-$

Using 3.0 fb^{-1} collected in Run 1, and the control channel $\Lambda^0_b \to \Lambda^+_c h^-$, LHCb measured:

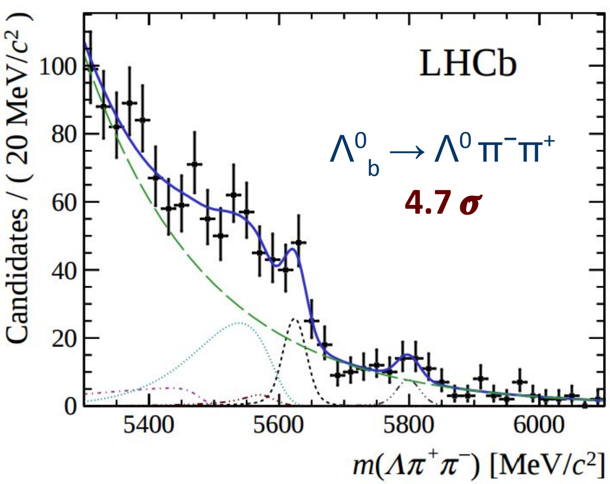


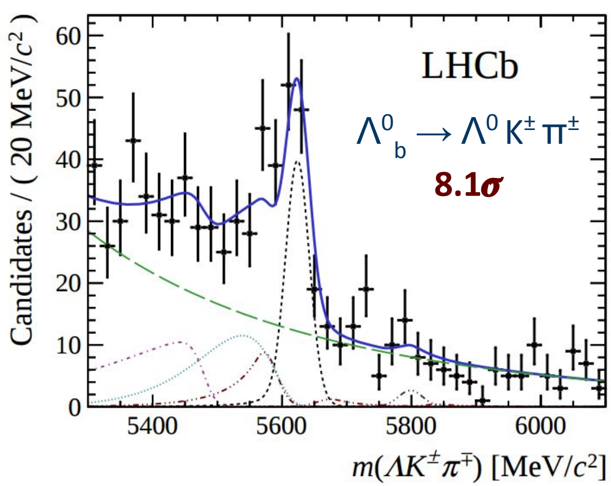
$$\frac{\mathcal{B}(\Lambda_b^0 \to \Lambda\pi^+\pi^-)}{\mathcal{B}(\Lambda_b^0 \to (\Lambda\pi^+)_{\Lambda_c^+}\,\pi^-)} = (7.3 \pm 1.9\,(\text{stat}) \pm 2.2\,(\text{syst})) \times 10^{-2},$$

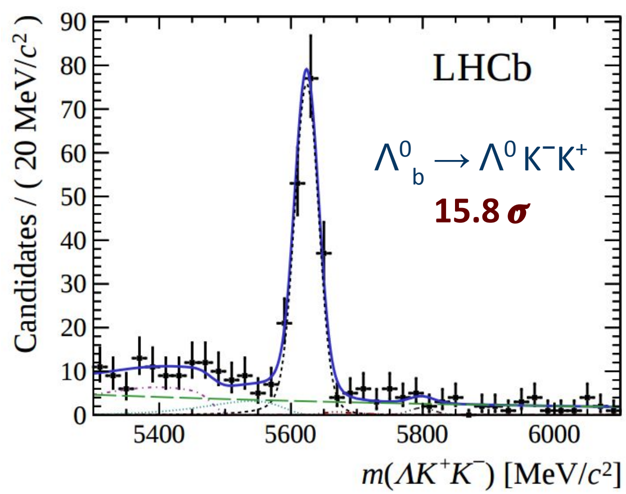
$$\frac{\mathcal{B}(\Lambda_b^0 \to \Lambda K^+\pi^-)}{\mathcal{B}(\Lambda_b^0 \to (\Lambda\pi^+)_{\Lambda_c^+}\,\pi^-)} = (8.9 \pm 1.2\,(\text{stat}) \pm 1.3\,(\text{syst})) \times 10^{-2},$$

$$\frac{\mathcal{B}(\Lambda_b^0 \to \Lambda K^+K^-)}{\mathcal{B}(\Lambda_b^0 \to (\Lambda\pi^+)_{\Lambda_c^+}\,\pi^-)} = (25.3 \pm 1.9\,(\text{stat}) \pm 1.9\,(\text{syst})) \times 10^{-2},$$

And upper limits set on Ξ_b decays to the same final states







Testing CP symmetry *(where only direct violation would be possible)*

The statistics in KK and Kπ channels is enough to measure **the time-integrated CP asymmetry**, correcting effects of asymmetries in the **detector**, **reconstruction** and and **production** (initial state *pp* is asymmetric) with the **control channel** $\Lambda^0_b \rightarrow \Lambda^+_c h^-$:

$$\mathcal{A}_{CP}^{\rm raw} = \frac{N_f^{\rm corr} - N_{\bar{f}}^{\rm corr}}{N_f^{\rm corr} + N_{\bar{f}}^{\rm corr}}$$

$$\mathcal{A}_{CP}(\Lambda_b^0 \to \Lambda h^+ h'^-) = \mathcal{A}_{CP}^{\rm raw}(\Lambda_b^0 \to \Lambda h^+ h'^-) - \mathcal{A}_{CP}^{\rm raw}(\Lambda_b^0 \to (\Lambda\pi^+)_{\Lambda_c^+}\pi^-)\,.$$

$$\begin{aligned}
\mathcal{A}_{CP}(\Lambda_b^0 \to \Lambda K^+\pi^-) &= -0.53 \pm 0.23\,({\rm stat}) \pm 0.11\,({\rm syst})\,,\\
\mathcal{A}_{CP}(\Lambda_b^0 \to \Lambda K^+K^-) &= -0.28 \pm 0.10\,({\rm stat}) \pm 0.07\,({\rm syst})\,.
\end{aligned}$$

No evidence yet of CP violation, but will be very interesting to revisit with Run 2 data

About systematic uncertainties.

The statistical error on the normalization channel dominates the systematic uncertainty on the asymmetry.
Enhancing the statistics with the new data, will also reduce the systematic error!

Physics Data Analyses:
Mixing and CP violation with charm

Measuring D^0 oscillations with $D^0 \longrightarrow K^+ \pi^- \pi^+ \pi^-$ decays

The oscillation is the transition

$$D^0 \longrightarrow \overline{D}^0 \quad (\text{and } \overline{D}^0 \longrightarrow D^0)$$

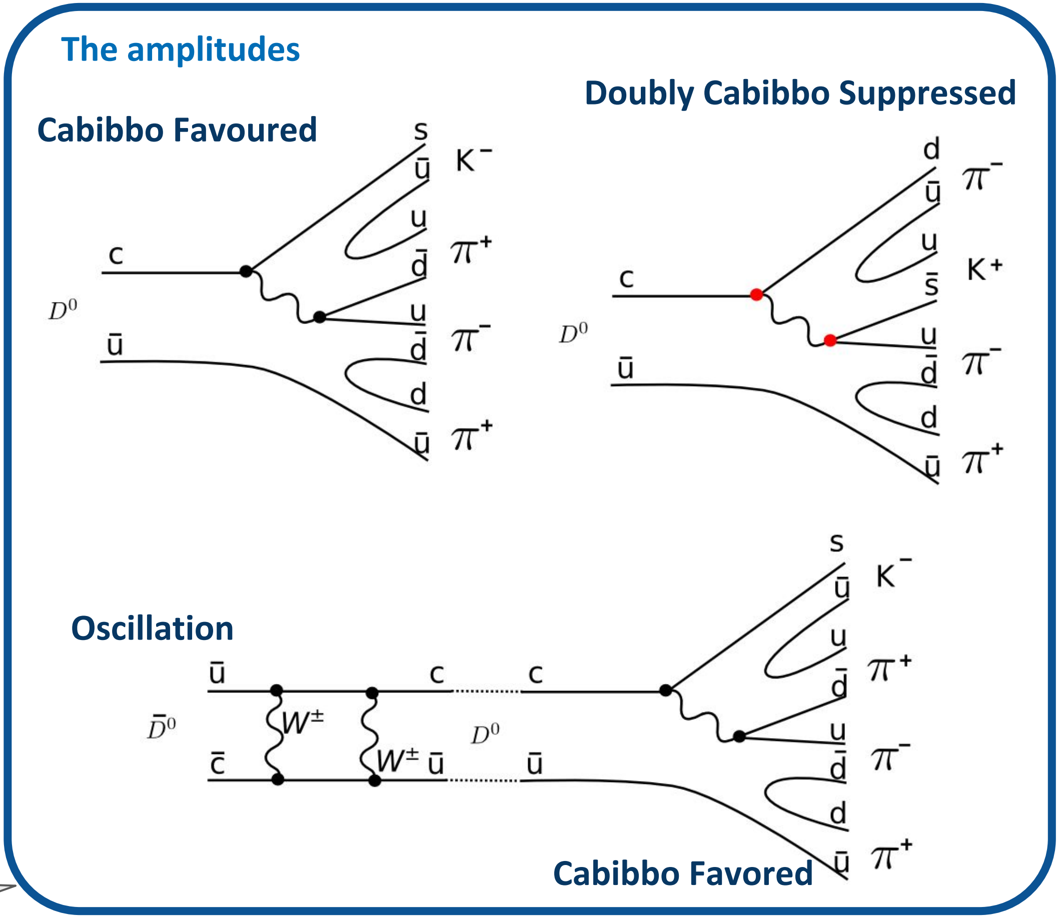
during time evolution.

LHCb was the **first experiment to unambiguously observe *D^0* oscillation** studying $D^0 \longrightarrow K\,\pi$ decays.

LHCb-PAPER-2012-038

Now, using 3.0 fb^{-1} of data, LHCb measures for **the first time the oscillation of *D^0*** mesons using another decay channel:
$D^0 \longrightarrow K^+ \pi^- \pi^+ \pi^-$.

NEW



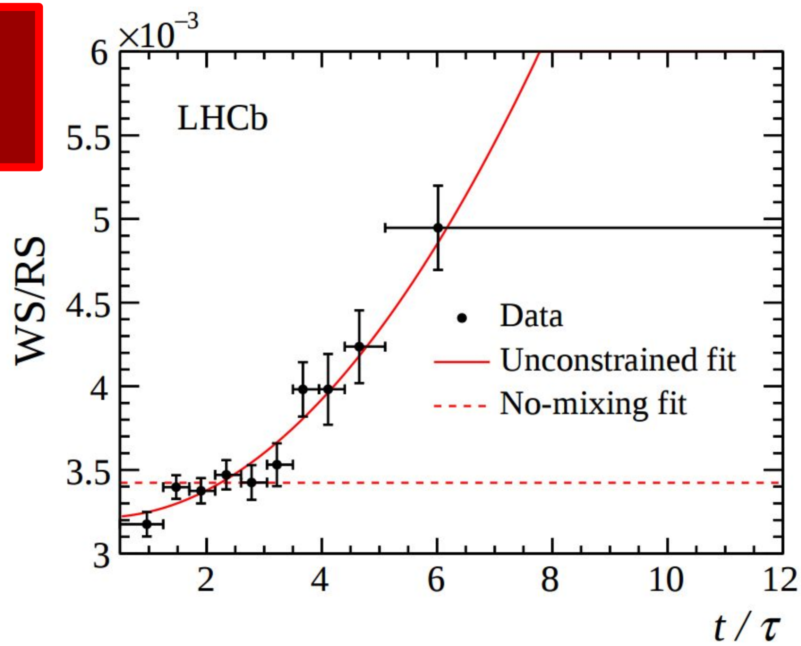
Fitting the time-dependent asymmetry

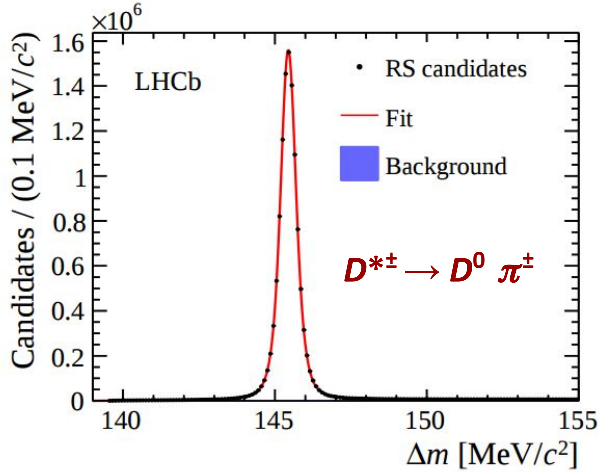
11.4 M events

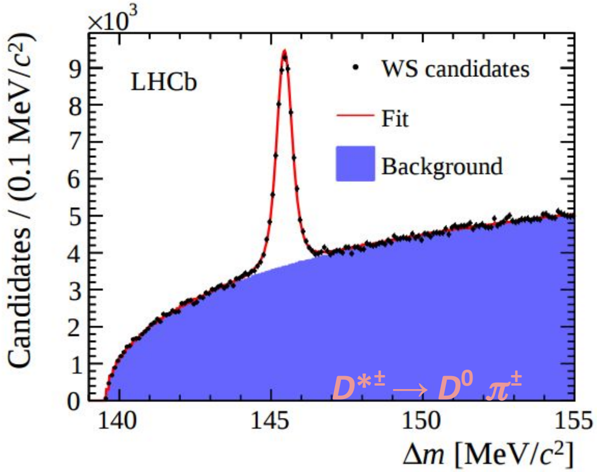
100% efficient flavour tagging, using $D^{*\pm} \to D^0 \pi^\pm$ to determine the *initial flavour* of the D^0 candidate, defining

- ***Right Sign:*** $D^{*\pm} \to D^0 \pi^\pm$ with $D^0 \to K^\mp \pi^\pm \pi^\mp \pi^\pm$
  soft pion and kaon have ***opposite*** *charge*
- ***Wrong Sign:*** $D^{*\pm} \to D^0 \pi^\pm$ with $D^0 \to K^\pm \pi^\mp \pi^\pm \pi^\mp$
  soft pion and kaon have ***same*** *charge*

Dominant uncertainty: **statistical**







Oscillation has a statistical significance of **8.2 σ**

Provides also world's best measurements of hadronic parameters that are important inputs for γ

Fitting the time-dependent asymmetry

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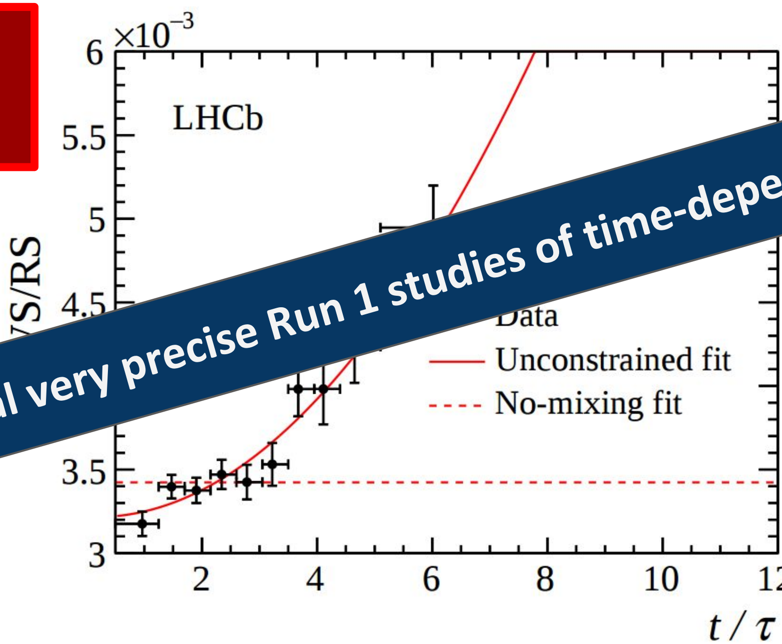
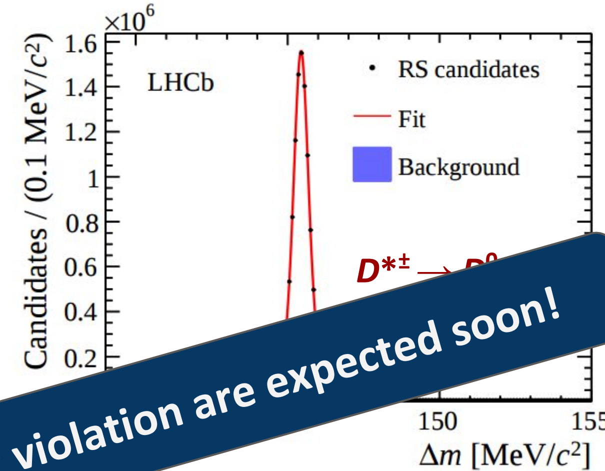
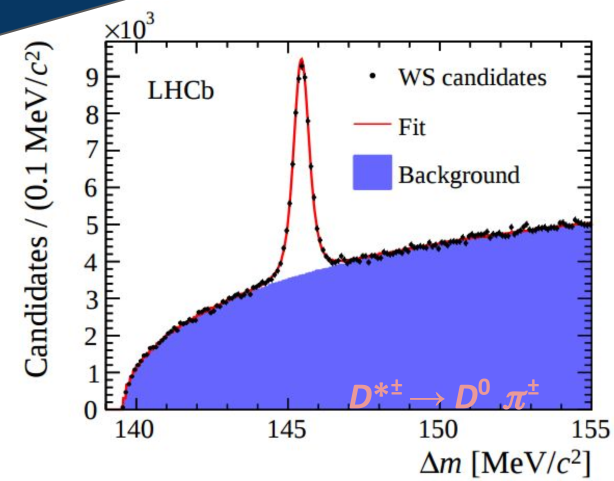






Additional very precise Run 1 studies of time-dependent CP violation are expected soon!

Oscillation has a statistical significance of **8.2 σ**

Provides also world's best measurements of hadronic parameters that are important inputs for gamma

Measurement of ΔA_{CP}: difference of time-integrated CP asymmetry in $D^0 \rightarrow K^+K^-$ and $D^0 \rightarrow \pi^+\pi^-$

Measuring the difference of CP asymmetries allows to cancel contributions of most systematic uncertainties,

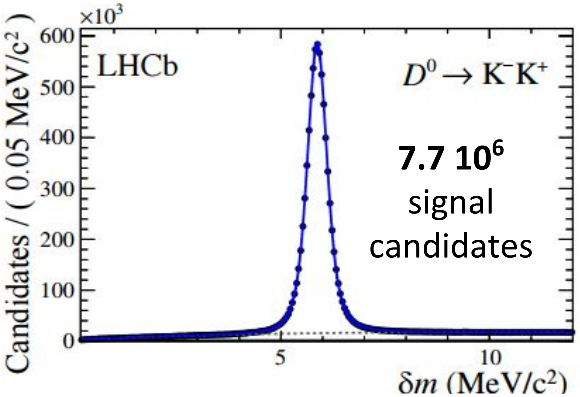
$$A_{\text{raw}} = \frac{N_f - N_{\bar{f}}}{N_f + N_{\bar{f}}} \Rightarrow \Delta A_{CP} = A_{\text{raw}}(K^-K^+) - A_{\text{raw}}(\pi^-\pi^+).$$

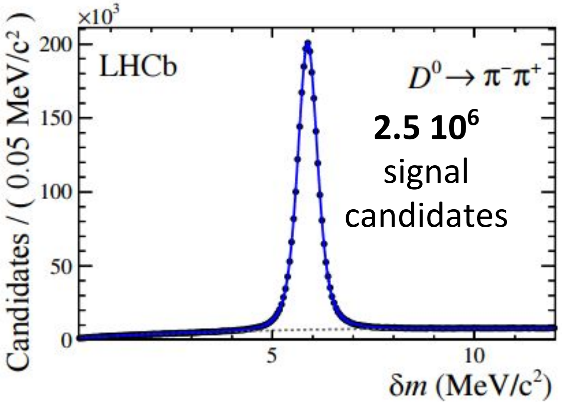
Original flavour of the D^0 meson is tagged with $D^{*+} \rightarrow D^0 \pi^+$ decays.

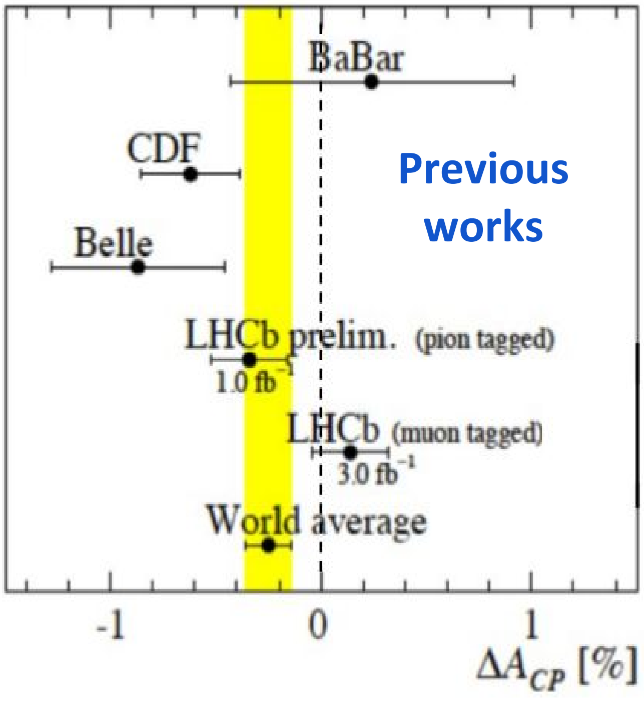
The result,

$$\Delta A_{CP} = (-0.10 \pm 0.08\ (\text{stat}) \pm 0.03\ (\text{syst}))\,\%,$$

is the **world's best measurement** of a time-integrated asymmetry in the charm sector from a single experiment, and is **consistent** with the **Standard Model**.



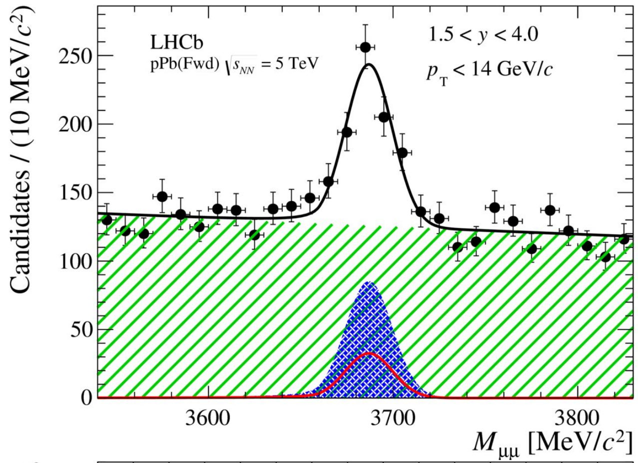




Previous works

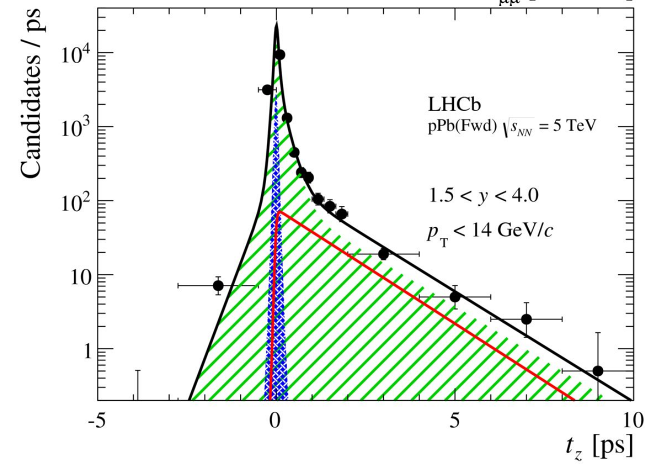
Beyond *pp* collisions

ψ(2S) in pA collisions



Analysing **1.6 nb^{-1}** of data collected in *p*Pb collisions at $\sqrt{s_{NN}}$ = 5 TeV, LHCb has measured the production cross-section of the charmonium state ψ(2S).

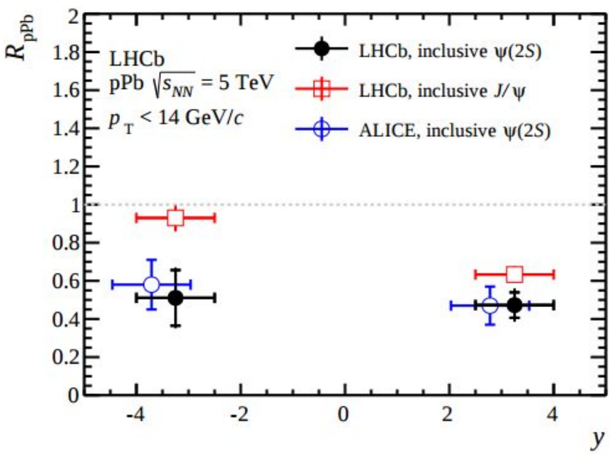
When studying ***Quark Gluon Plasma*** (QGP) in PbPb collisions, it is important to distinguish effects of nuclear physics *(**Cold Nuclear Matter**)* from those genuinely caused by the asymptotically freedom of partons in QGP.



Nuclear effects are characterized from

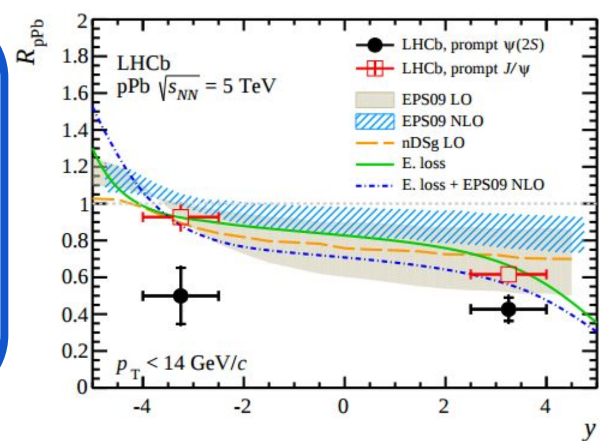
$$R_{pA}(y, p_T, \sqrt{s_{NN}}) \equiv \frac{1}{A}\frac{d^2\sigma_{pA}(y, p_T, \sqrt{s_{NN}})/dydp_T}{d^2\sigma_{pp}(y, p_T, \sqrt{s_{NN}})/dydp_T},$$

Cross-section in *pp* at the same $\sqrt{s_{NN}}$: extrapolated, not measured yet



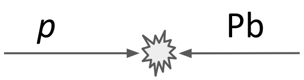
Exploiting the outstanding resolution of the VELO,
LHCb measured of R_{pA} for *prompt* and ψ(2S) *from b*.

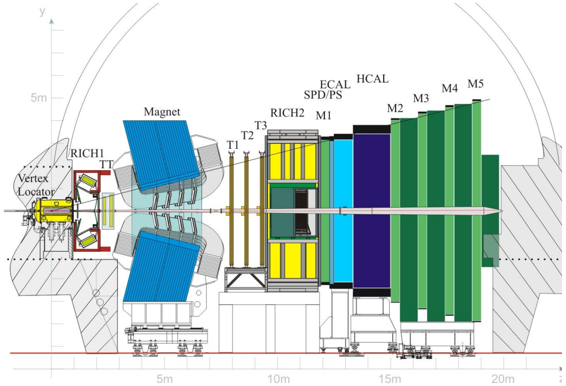
Observed unpredicted suppression of prompt ψ(2S) wrt. J/ψ



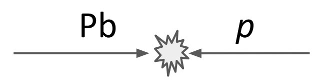
Forward and backward *pA* collisions

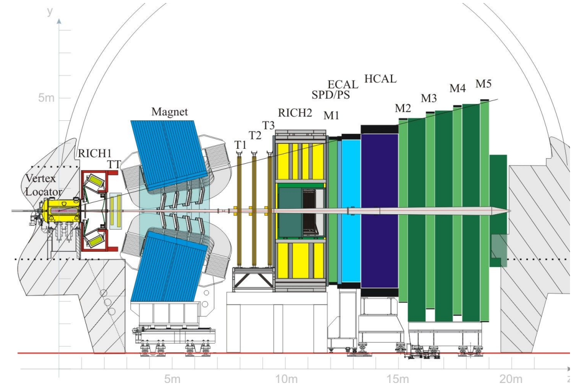
Forward





Backward



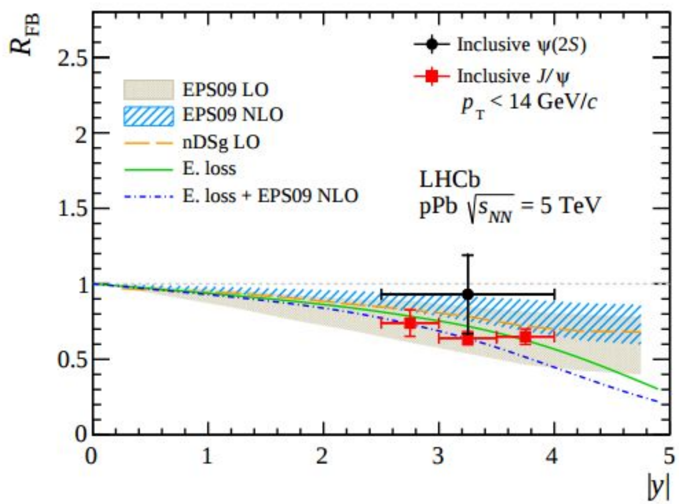


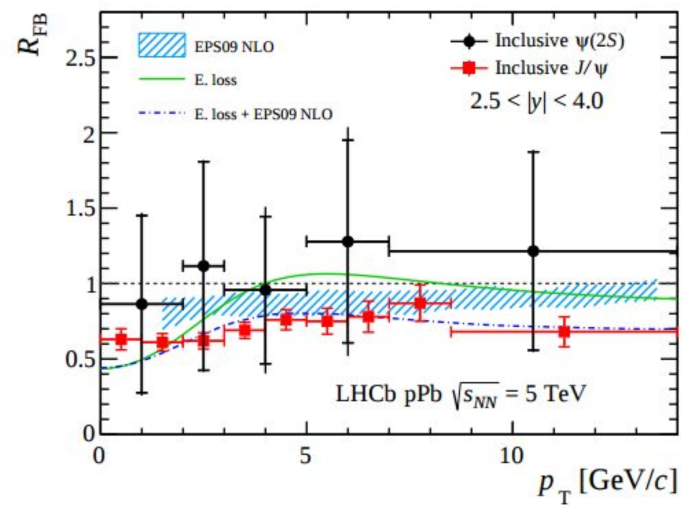
The measured ratio

$$R_{\mathrm{FB}}(y, p_{\mathrm{T}}, \sqrt{s_{NN}}) \equiv \frac{\sigma_{p\mathrm{Pb}}(+|y|, p_{\mathrm{T}}, \sqrt{s_{NN}})}{\sigma_{p\mathrm{Pb}}(-|y|, p_{\mathrm{T}}, \sqrt{s_{NN}})}.$$

can be compared to theoretical predictions, without assumptions on the production cross-section in *pp* collisions.

Agreement with predictions within uncertainties



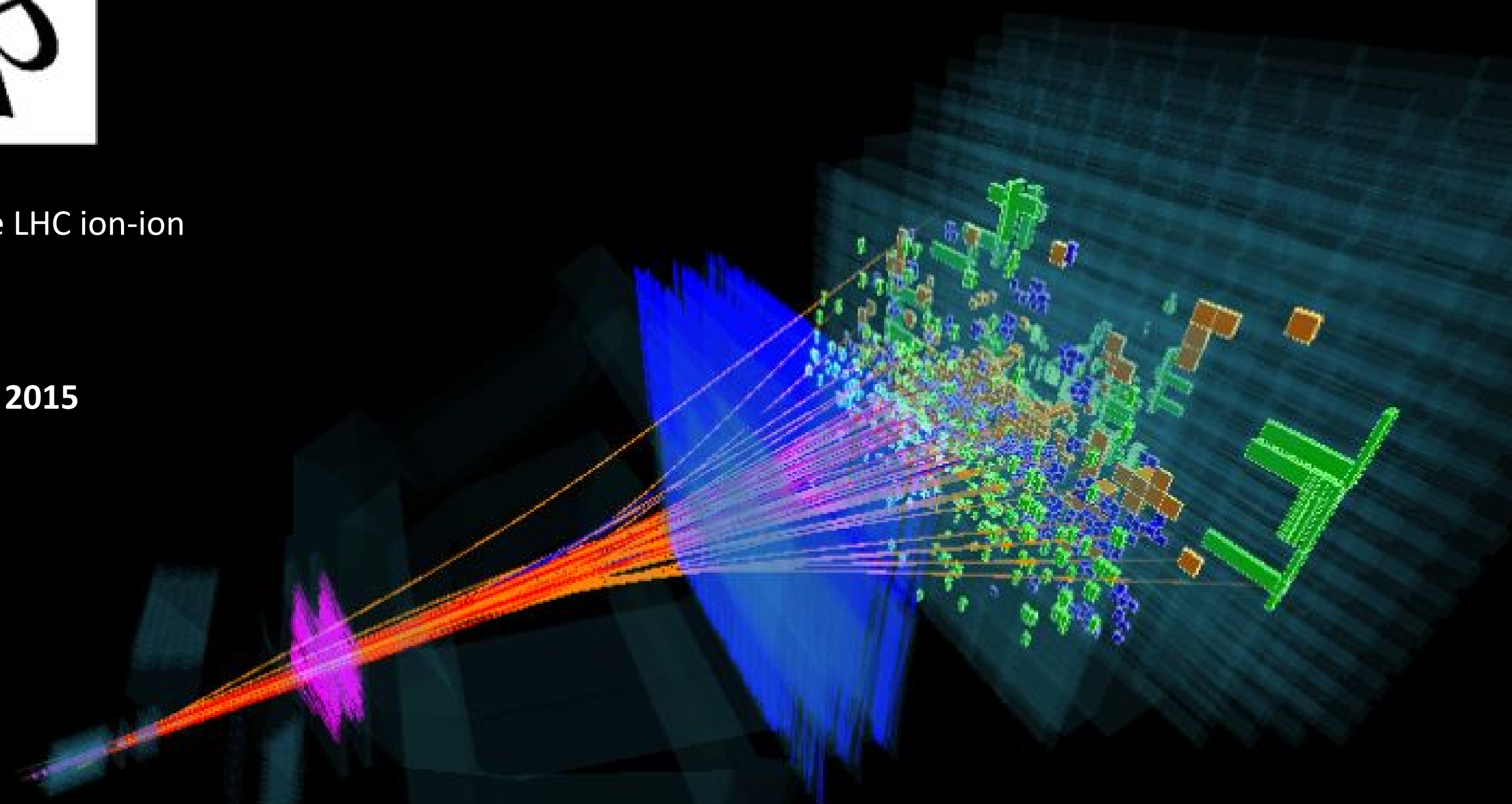


PbPb - facing the challenge of the high occupancy

PbPb collisions

LHCb participate at the LHC ion-ion programme!

24 days data-taking in 2015



Tracking is challenging,
some systems reached the **maximal** design **throughput** (additional deadtime)

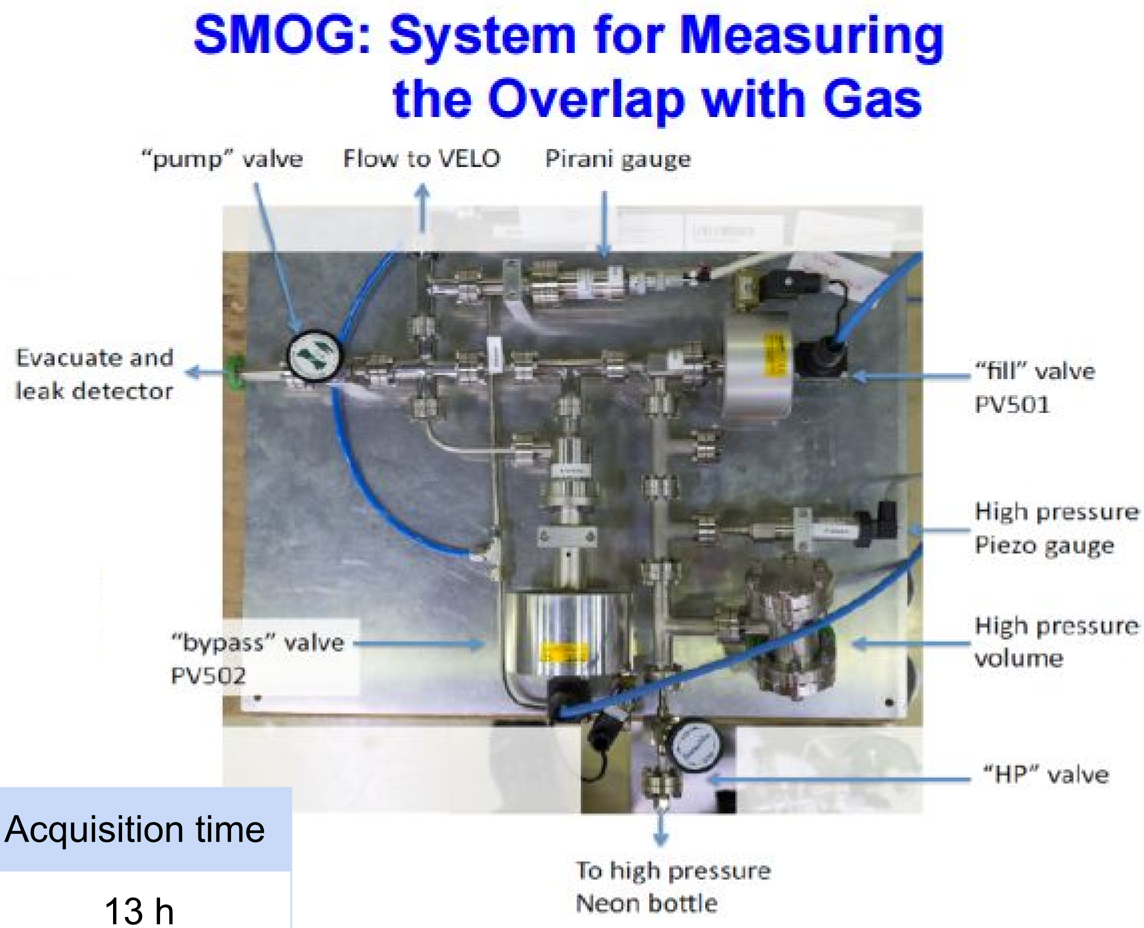
Online data reconstruction impossible: using minimum bias triggers.

LHCb as fixed-target experiment: SMOG

SMOG allows to inject gas in the beam-pipe close to the VELO region.

Scientific motivation:

- Sensitive probes of nuclear structure
- Cross-section measurement of $pHe \rightarrow \bar{p}X$, dominant systematic uncertainty in dark matter searches with antimatter in cosmic rays.



	$\sqrt{s}$ [GeV]	Date	Acquisition time
pNe	110.4	Aug. 25/26	13 h
pHe	110.4	Sept. 8	8 h
pAr	110.4	Oct. 15-18	29 h

Physics Tools & Data Science

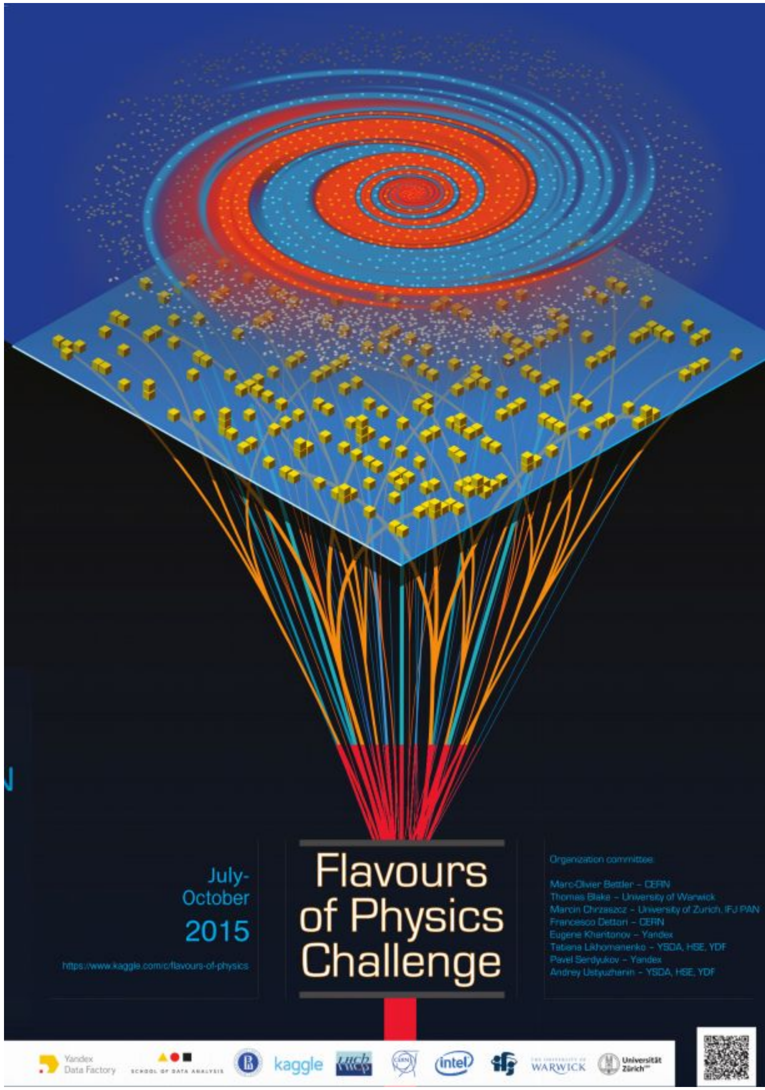
Data Science @ LHCb: *The Kaggle Challenge*

LHCb took part to the *Kaggle Challenge*

- An online, world-wide, rewarded competition in solving *data-science problems.*
- Proposed a problem with **real physics data** in the context of the search for *lepton-flavour-violating* $\tau \to \mu\mu\mu$

The goal is *outreach* and *cross-fertilization* with ideas, technologies and techniques used in other fields.

Some of the methods used in the competitions are now under evaluation for ongoing physics analyses.



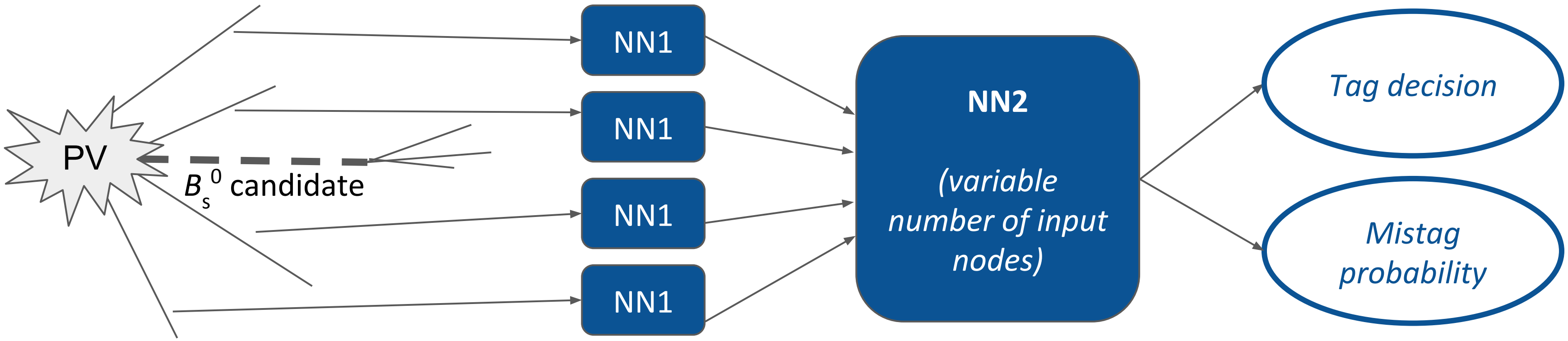
Flavour tagging

(see also the poster in the LHCC Students' session)

Measuring flavour oscillations and time-dependent CP violation in neutral *B* mesons requires defining (*tagging*) the initial flavour of the reconstructed $B^0_{(s)}$ meson (***flavour tagging***).
This can be done exploiting:

- *the other b-hadron produced in the pp collision* ***(Opposite-Side Tagging)***
- *the light hadrons in the "b-jet", produced in the hadronization of the b-quark* ***(Same-Side Tagging)***

LHCb has recently developed a ***new Same-Side Flavour Tagging Algorithm*** for B_s^0 mesons , based on the combination of **two Neural Network** classifiers trained to decide the flavour of the reconstructed B_s^0 the estimated probability of *mistag*.



The algorithm was calibrated on 3 fb^{-1} of data collected in Run 1, resolving the oscillation with the $B_s^0 \to D_s^- \pi^+$ decays, and through the production (and strong-decay) of the excited state $B_s^*(5840)^+ \to B^+ K^-$ (**for the first time**).

This + 50% improvement in the tagging power (1.2 % ➡ 1.80 ± 0.19 ± 0.18 %) in $B_s^0 \to D_s^- \pi^+$ was exploited in leading to publications of world leading measurements of CP-violation parameters in B_s^0 decays (*e.g.* arxiv:1411.3104).

Studies for the Muon Identification for the LHCb Upgrade

Exploring *Machine Learning* algorithms also in the reconstruction, already at trigger level, **combining in fast multivariate classifiers low-level detector quantities.**

For example, a *Boosted Decision Tree* was developed for the muon identification combining

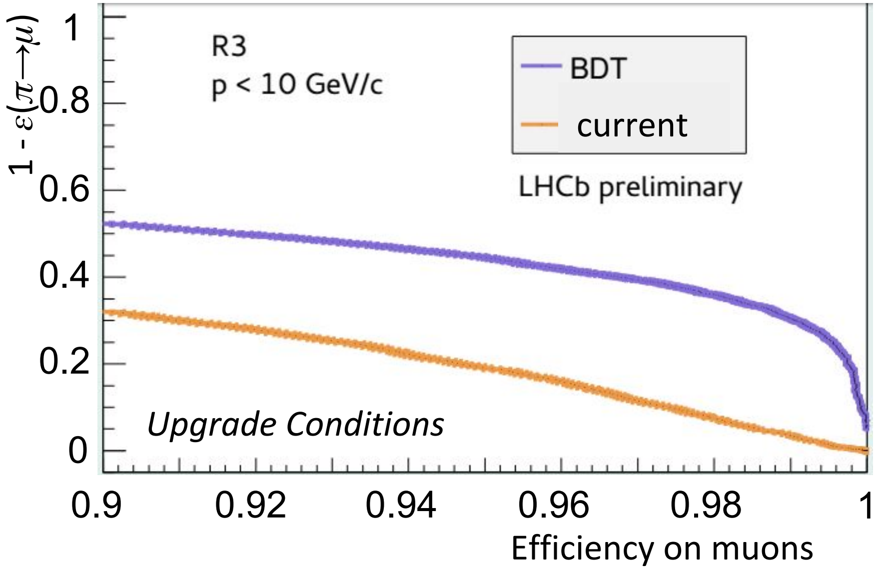
- discrepancy between measured hits and extrapolated tracks *(variable already used in current algorithms)*
- number of extrapolated tracks consistent with the hits relevant to the muon identification *(isolation)*
- **TDC of the electronic channels recording the hits** *(reject electronic noise)*

Algorithm designed to cope with the high-occupancy of the upgraded LHCb detector.

Under evaluation for Run2!

For details, refer to the LHCb Posters in the Students' Poster Session.

Results relative to muon preselection



Trigger & Online Processing

Novel data-taking strategy

As already discussed at previous LHCC meetings, since 2015 the LHCb High-Level Trigger performs a complete, off-line quality reconstruction, including real-time alignment and calibrations.

Turbo

- Part of the physics programme needs **billions of recorded candidates** (e.g. charm measurements): but with no need for the rest of the event.

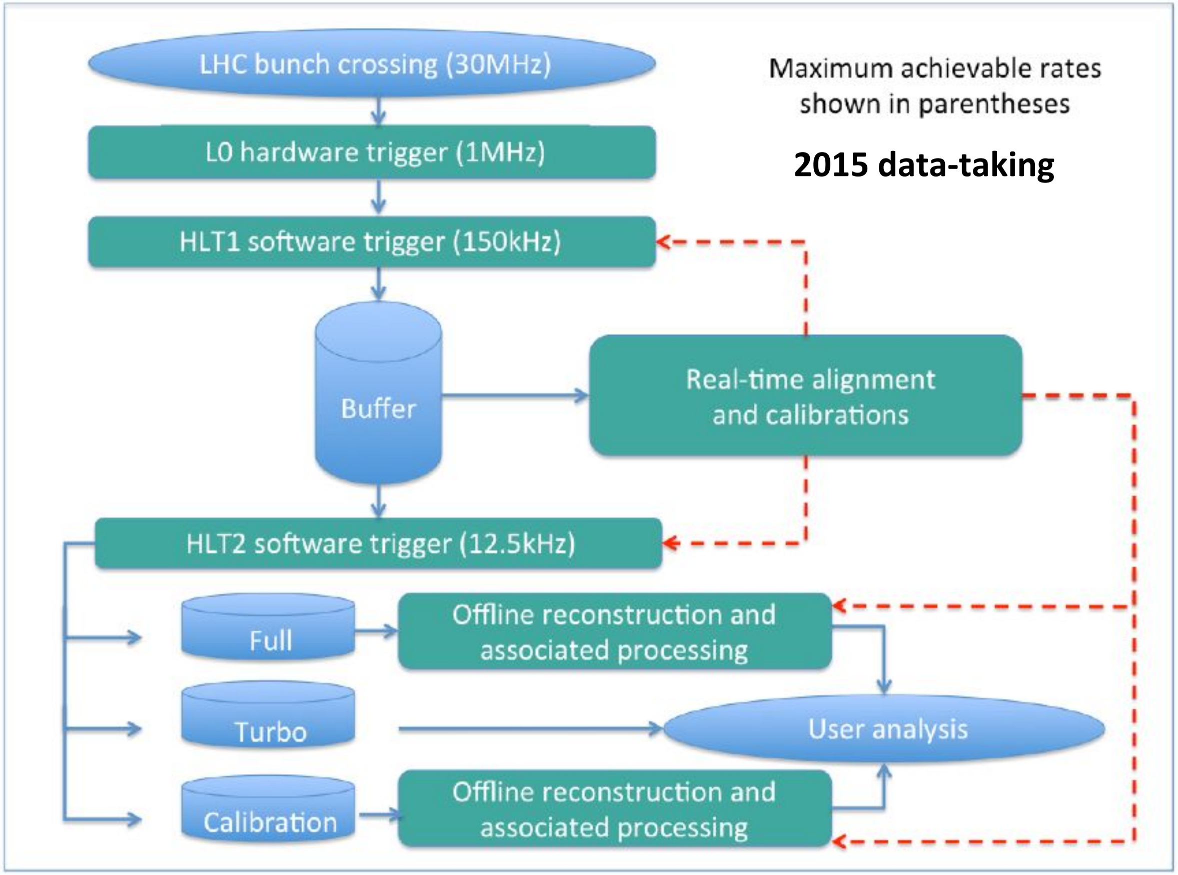
FULL

- Searches for rare states and rare decays still need the FULL event to take advantage of *new algorithms* (e.g. new MuonId)

Calibration

- New algorithms have to be **developed and calibrated**, online performance (efficiency, rejection power) has to be measured.

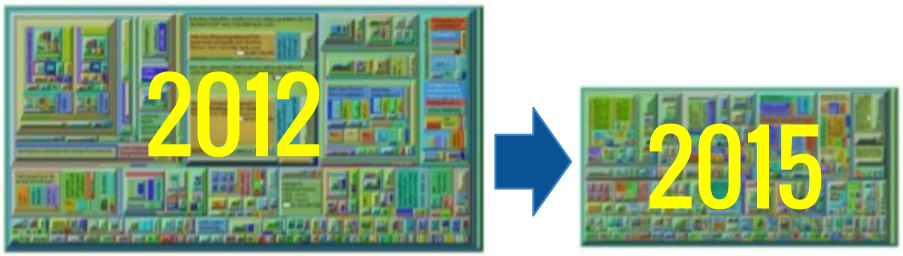
See the poster in Students' Poster Session for details!



Improvements in the *High Level Trigger*

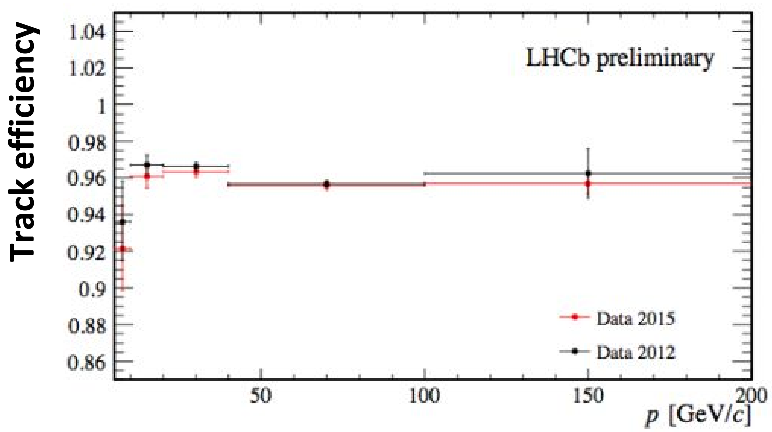
50% overall speed-up of the reconstruction software

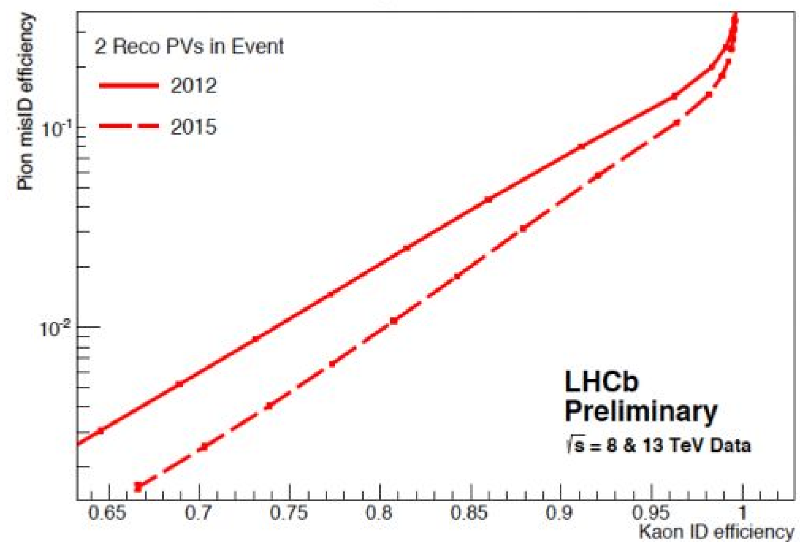
(more to come for 2016 data-taking)



(Area ∝ CPU time)

~50% increase in the selection efficiency
for most *b* and *c* decays





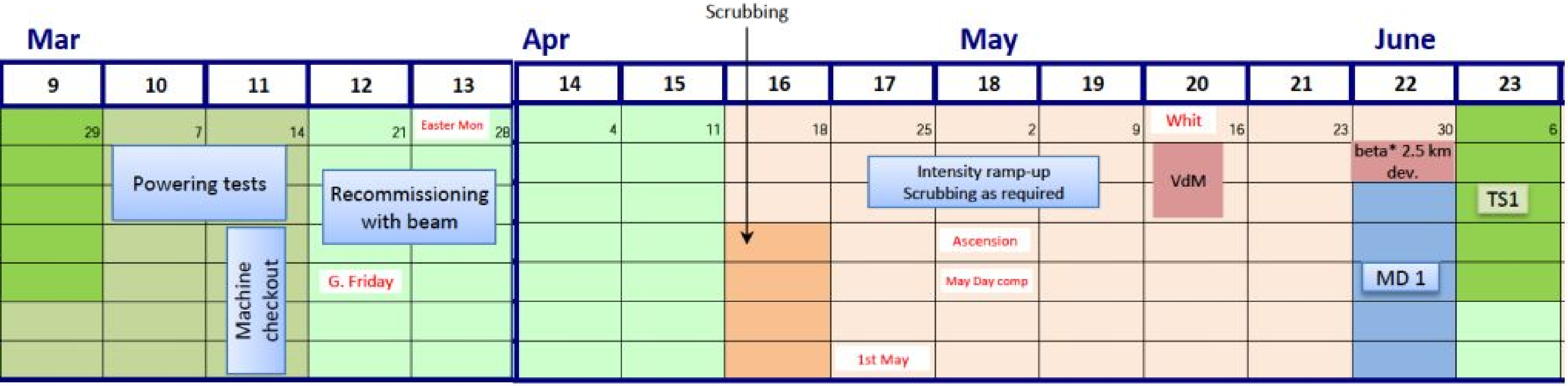
Advanced Tracking Ghost Rejection

Innovative Neural Network algorithm combining inputs from different tracking detectors.

Particle Identification in the trigger

Including full RICH reconstruction and statistical combination with CALO and MUON systems.

Getting ready for 2016 data-taking



Migration to the new Control Room

and Meeting Room

Detector activities and readiness for 2016

LHCb is ready for the restart of the data-taking!

VELO

Planned improvements for 2016:
more automation of scanning procedures

RICH detectors

Improved performance wrt. Run 1
Very few hardware failures & operational issues
For 2016: *improve spare situation*

Inner tracker (Silicon Tracker)

Brand new Experiment Control System and Cooling plants.
For 2016: *Increase resilience at safety breaks*

CALO

LED-based high-voltage tuning & online π^0 calibration; automatic occupancy monitoring
For 2016: *improve π^0 procedure & monitoring*

Outer tracker (straw tubes)

Developed a technique to deal with high occupancy (e.g. PbPb runs)
For 2016: *keep monitoring aging with scans*

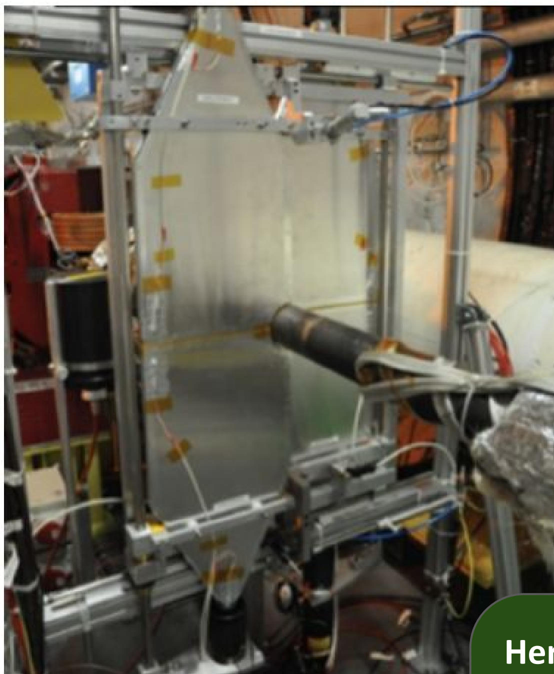
Muon

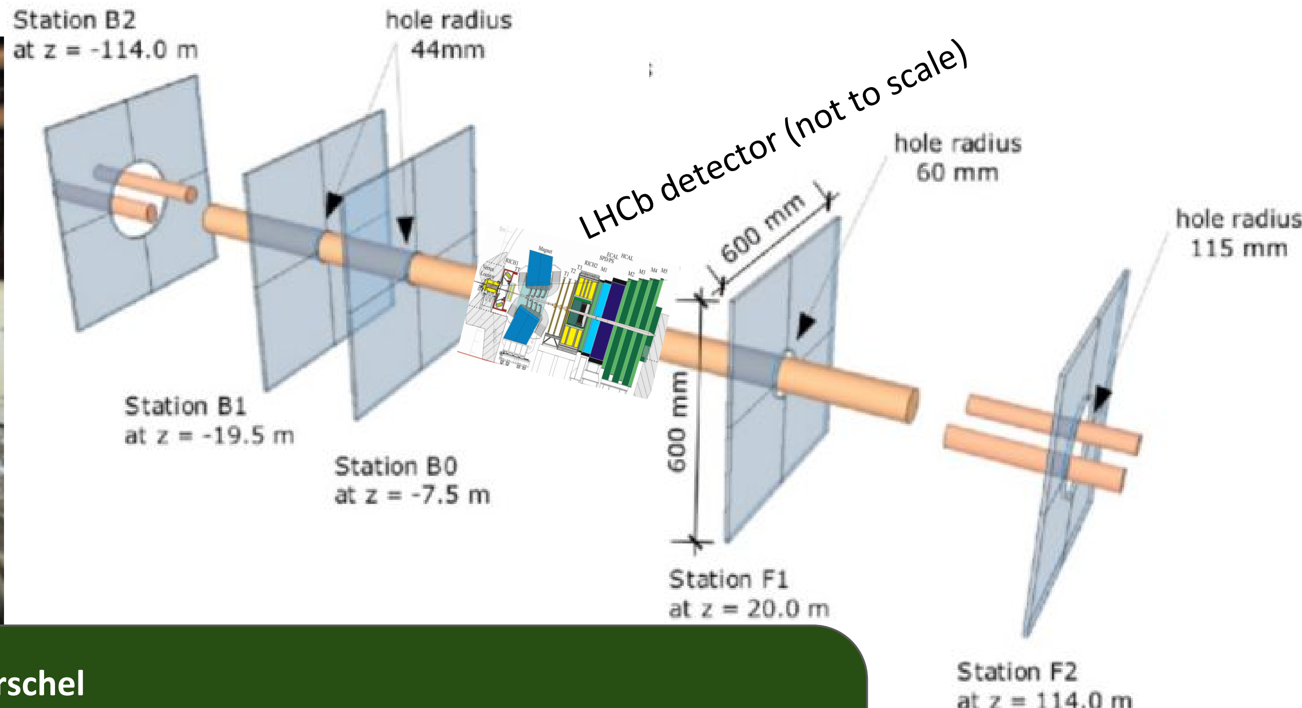
Chamber efficiency 98-99% across the detector
Reached occupancy limits with special runs
For 2016: *a new GEM closed loop gas system*

Herschel: *a new entry*

Five planes of scintillators, instrumented with phototubes, placed in the tunnel at 5 < $|\eta|$ < 8.

Enhances LHCb efficiency in tagging rapidity gaps and improve experiment's performance in Central Exclusive Production (CEP) measurements.





Herschel

2015 was a year of commissioning & physics

Included in 90% of the data-taking
For 2016: *more automated scans, enhanced electronic stability and S/B ratio.*

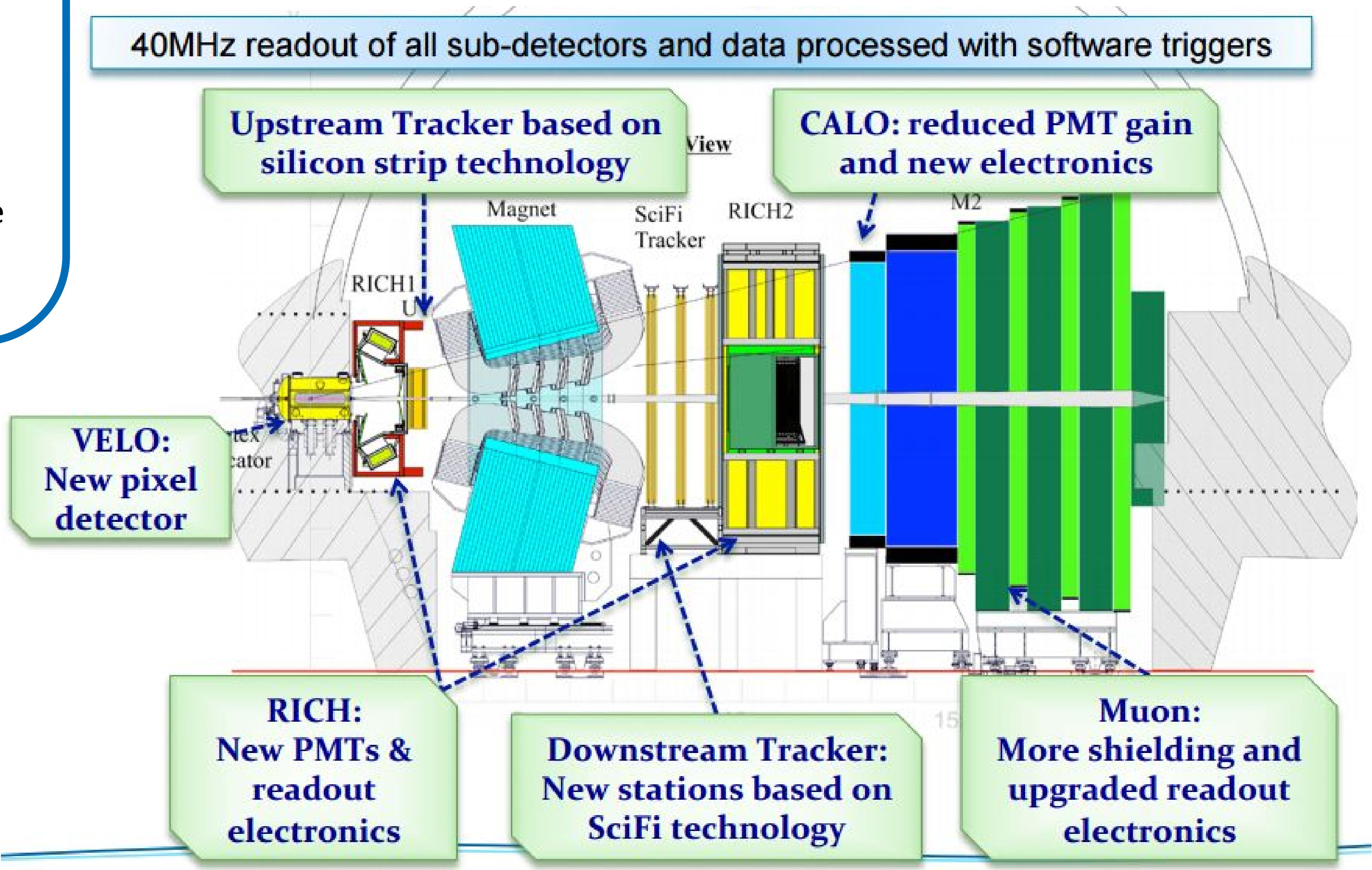
The LHCb Upgrade

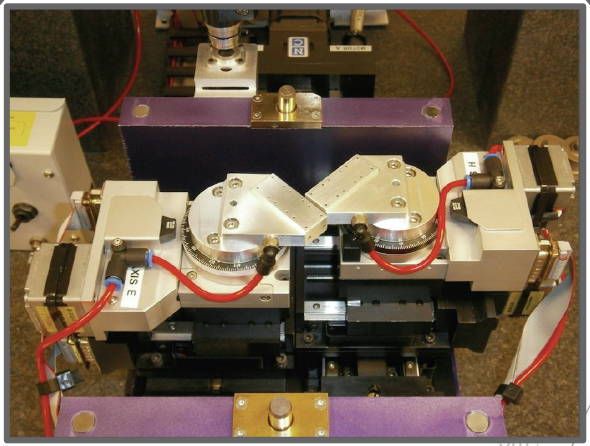
Overview of the detector upgrade

By 2015 a first round of **Engineering Reviews** (EDR) was **completed**.

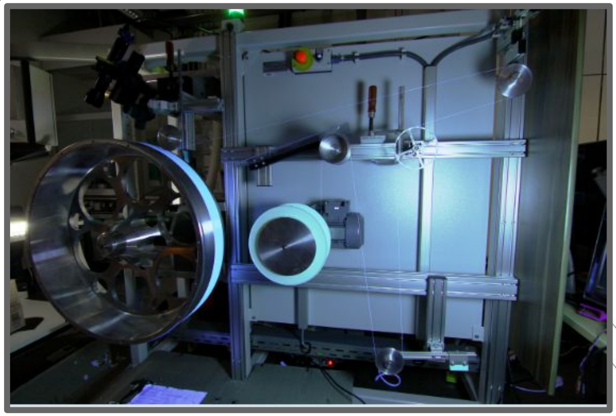
All subdetectors are now moving towards the **construction phase**.

Important procurement contracts have been or are about to be signed.

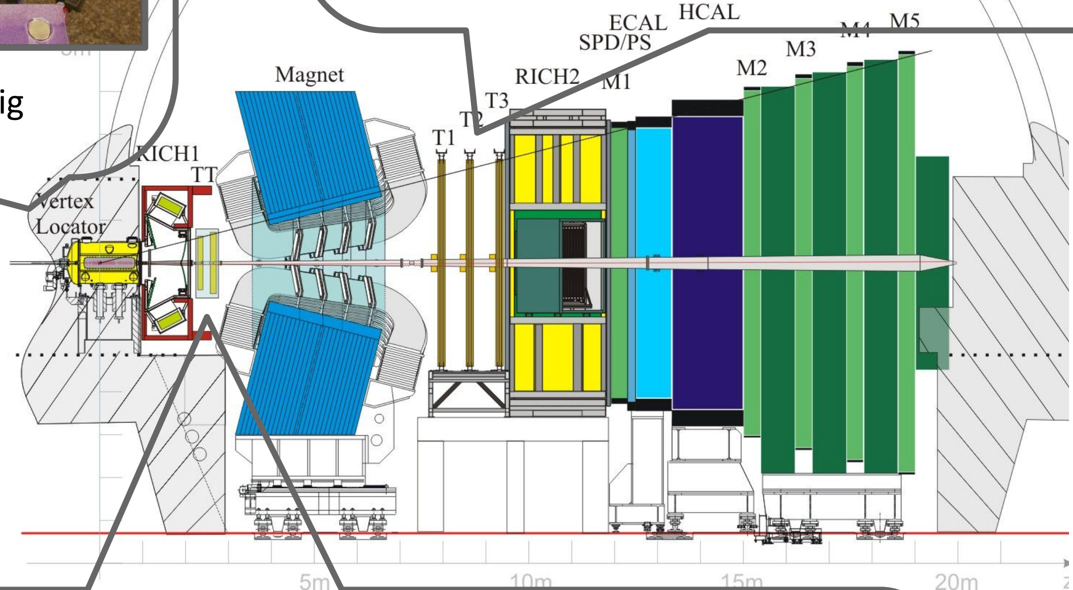


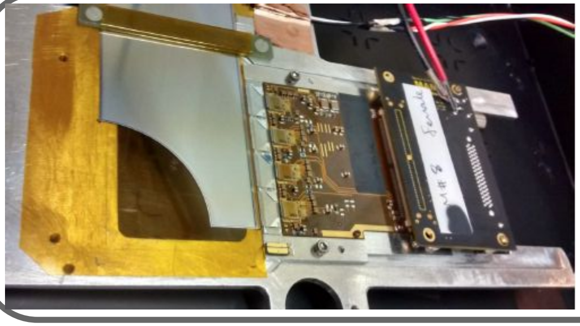


Velo module mounting jig



Scintillating fiber winding machine in Dortmund





UT sensor under test

Evolving the computing towards the upgrade

With the **kick-off meeting** at the 6th ***LHCb Computing Workshop*** November 16-20, 2015, the LHCb Collaboration has started a collaboration-wide review of the needs and possible strategies for upgrade of the LHCb Computing.

A first document, the ***roadmap for the upgrade*****,** is going to be presented at the Collaboration next week.

Most likely, the evolution of the computing model will happen ***during*** Run2, to take advantage of the new developments as soon as they are available!

Summary

Summary 1/2

LHCb physics programme is wide and vast!

Quark mixing, CP violation, in the *b* and *c sector*, heavy flavour spectroscopy, *lepton flavour violation*, *lepton flavour universality tests*, heavy-ion physics, auxiliary measurements for dark matter searches in cosmic rays.

thanks to a new programme including special runs (pA, Ap, PbPb, SMOG)

Many active analyses with results expected soon…

- **beauty baryon spectroscopy:** *mass* and *lifetime* measurements
- new precise measurements and combination of the angle γ
- new *CP* asymmetries in the *charm* and *beauty* sectors
- further studies of the P_c **pentaquarks**
- electroweak bosons **cross-section measurements**
- charmless decays of the B_c^+ meson
- new studies on lepton universality
- precise measurements of ***B^0* oscillations**
- ***and many others…***

Summary 2/2

Many contributions in the field of technologies and techniques for *Data Analysis*

Flavour tagging and new muon identification algorithms based on machine learning, *Kaggle challenge*, new ideas, innovative trigger and online processing techniques .

Getting ready for the 2016 data-taking

During the *year-end technical stop*, implemented in our detector & software the lessons learned in 2015.
2015 was successful year for data-taking, main improvements in the monitoring and data quality procedure.

Looking forward to increasing our data samples with SMOG and with *p*Pb collisions!

Many thanks to the LHC!

Activities on the upgrade are proceeding well

Detector developments for the LHCb upgrade are ongoing! Achievements in the software and computing technologies will be exploited (and tested) already during Run 2 as soon as they are ready!

LHCb posters at the LHCC Students' poster session

LHCb measurements of J/psi and open charm cross-sections at 13 TeV
Dominik Muller, Illya Komarov

Soft QCD and pA physics, with a focus on the ridge at LHCb
Karlis Dreimanis

Bs semileptonic asymmetry at LHCb
Laurent Dufour

Bs2Ds(*)Ds(*) and outlook of B2DD/B2D*D at LHCb
Nicoletta Belloli

Constraints on the CKM angle gamma and extensions with B+->DK*+ at LHCb
Anita Katharine Nandi

Fundamental physics with semileptonic b-baryon decays at LHCb
Scott Edward Ely

Measurement of the $B_s \to \phi\phi$ branching fraction and angular analysis of $B_s \to \phi\pi\pi$ at LHCb
Adam Morris

Measurement of the branching fraction ratio Br(Bc -> Psi(2S) pi)/Br(Bc -> Jpsi pi) at LHCb
Liupan An

R(D*) and other tauonic decays at LHCb
Federico Betti

Jet flavor tagging and top x-section at LHCb
Chitsanu Khurewathanakul

Search for hidden-sector bosons at LHCb
Andrea Mauri

New algorithms for Flavour Tagging at the LHCb experiment
Davide Fazzini

Novel Muon Identification algorithms for the LHCb Upgrade
Violetta Cogoni

Novel real-time calibration and alignment procedure for LHCb Run II
Claire Prouve

The LHCb trigger in Run-II
Olli Lupton

Verification of Geant4 physics models for the LHCb simulation
Peter Noel Griffith

Prospects with Vub measurements at LHCb
Slavomira Stefkova

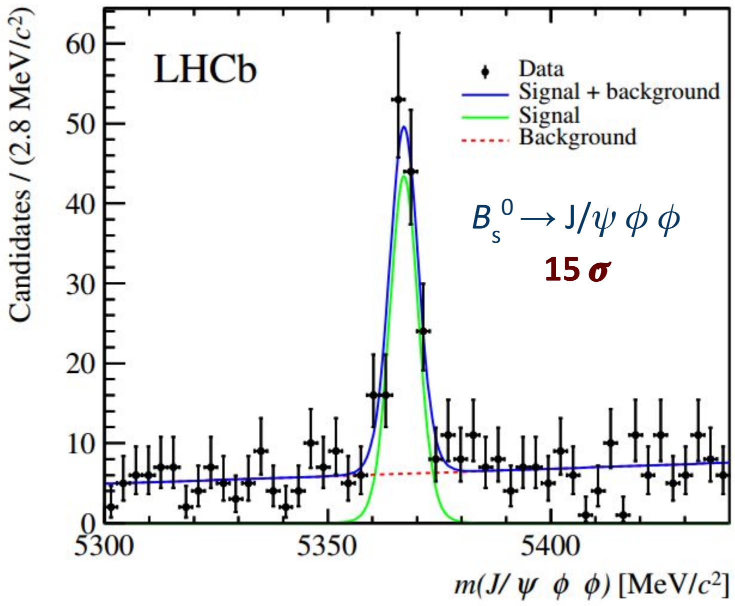
Additional slides

Physics Data Analyses:
b-hadron and quarkonia spectroscopy

First observation of the decay $B_s^0 \to J/\psi\,\phi\,\phi$

Using 3.0 fb^{-1} collected during Run 1,
it was possible to achieve the **first observation** of
$B_s^0 \to J/\psi\,\phi\,\phi$ decays.

$$\frac{\mathcal{B}(B_s^0 \to J/\psi\,\phi\,\phi)}{\mathcal{B}(B_s^0 \to J/\psi\,\phi)} = 0.0115 \pm 0.0012\ (\mathrm{stat})\ ^{+0.0005}_{-0.0009}\ (\mathrm{syst})\,.$$



The *Q-value* of the $B_s^0 \to J/\psi\,\phi\,\phi$ decay mode is small, this allows good B_s^0 mass measurements:

➔ improve the mass resolution,

➔ enhance control on the systematic uncertainties (**momentum scale**)

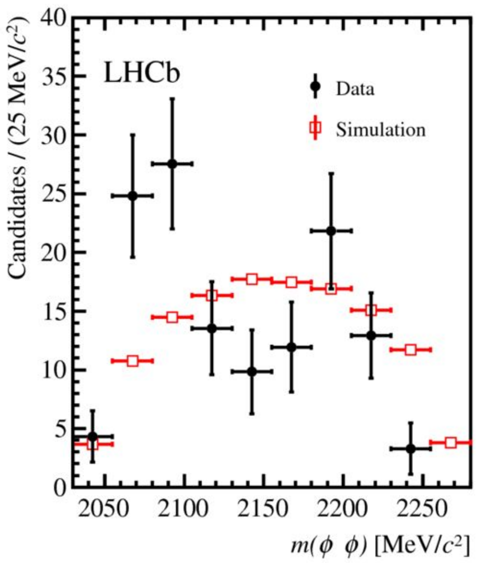
m(B_s^0) = 5367.08 ± 0.38 (stat) **± 0.15** (syst) **MeV/c^2**

overall uncertainty only **20% larger** than the current **world's best measurement**, and **statistics dominated**!

Hunting the mysterious $Y(4140)$ and $\eta(2225)$ states

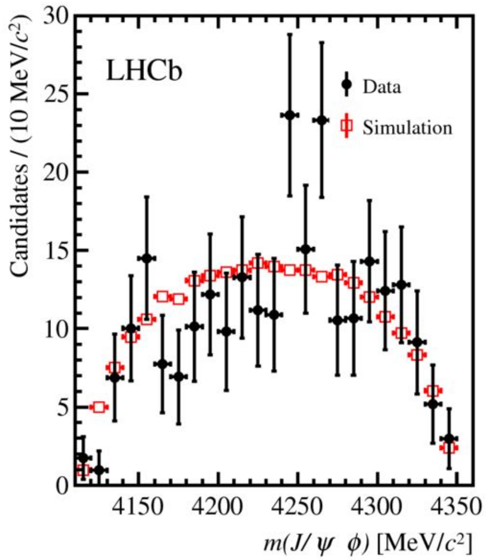
Y(4140) $\rightarrow J/\psi\, \phi$ transition were reported by CDF (arxiv:0903.2229), but was not found at *B* factories.

Hints at hadronic collider experiments (arxiv:1309.6580, arxiv:1309.6920) are in tension:
the existence of this state remains an open question.



Other experiments (*e.g. BES,* arxiv:0801.3885) reported a near threshold enhancement in the m($\phi\phi$) spectrum of J/$\psi \rightarrow \gamma\phi\phi$ decays.

Studying $B_s^0 \rightarrow J/\psi\, \phi\, \phi$ decays can shed light onto this controversial state, named **η(2225)**.



The limited statistics makes hard to draw conclusions, but we will double the statistics by the end of the year!

LHCb & antimatter in cosmic rays

LHCb and the antimatter searches

Recent **AMS** result show an antimatter excess in the flux of cosmic rays at Energy *O*(100 GeV)

Dark matter annihilation can be an exotic production measurement for cosmic anti-protons.

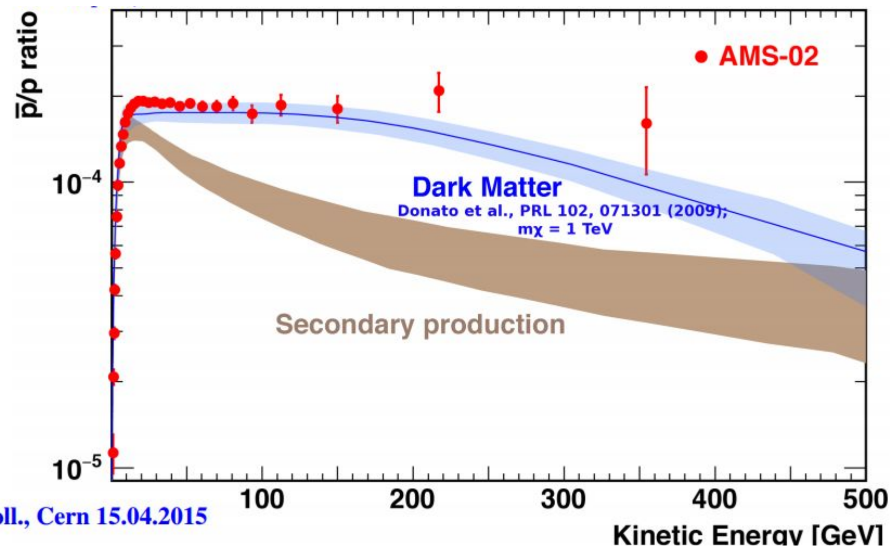
PAMELA confirmed the anti-proton excess.

Unfortunately the **production cross-section of cosmic anti-protons** in interactions with the Interstellar Medium (mainly Helium) are a **dominant source of systematic uncertainty**.

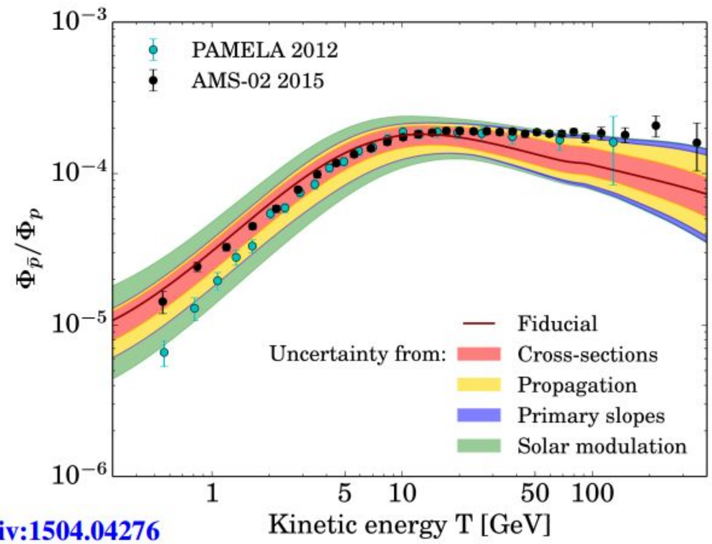
The pHe LHCb programme is conceived to measure the $pHe \rightarrow \bar{p} X$ at $\sqrt{s}$ = 110 GeV

Normalization channel: elastic scattering pe^{-}

Main challenge: He purity



AMS Coll., Cern 15.04.2015



Giesen et al., arXiv:1504.04276

LHCb and the antimatter searches

Recent **AMS** result show an antimatter excess in the flux of cosmic rays at Energy *O*(100 GeV)

Dark matter annihilation can be an exotic production measure... protons.

PAMELA confirmed...

Unfortunately the p... **cosmic anti-proton**... Interstellar Medium... **dominant source of**...

The pHe LHCb prog... measure the *p*He →...

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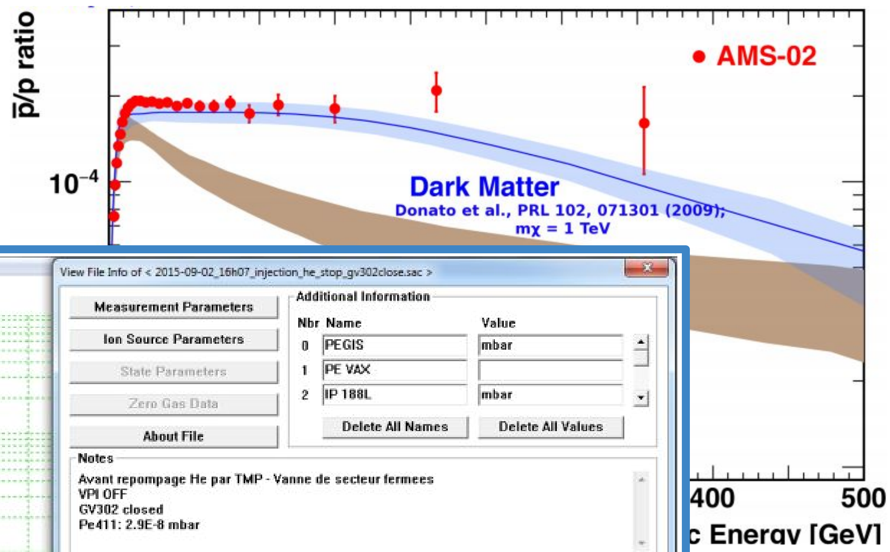
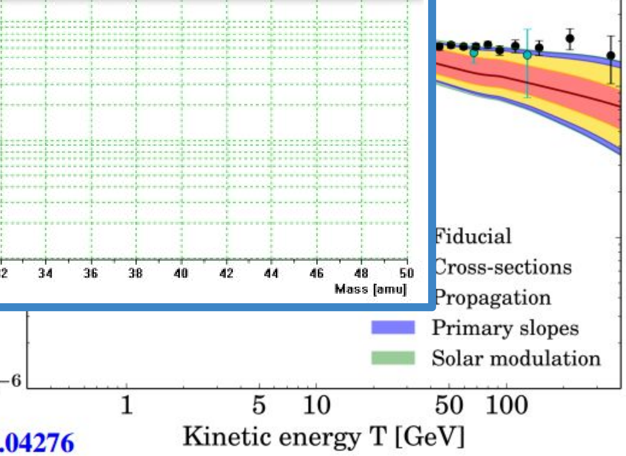
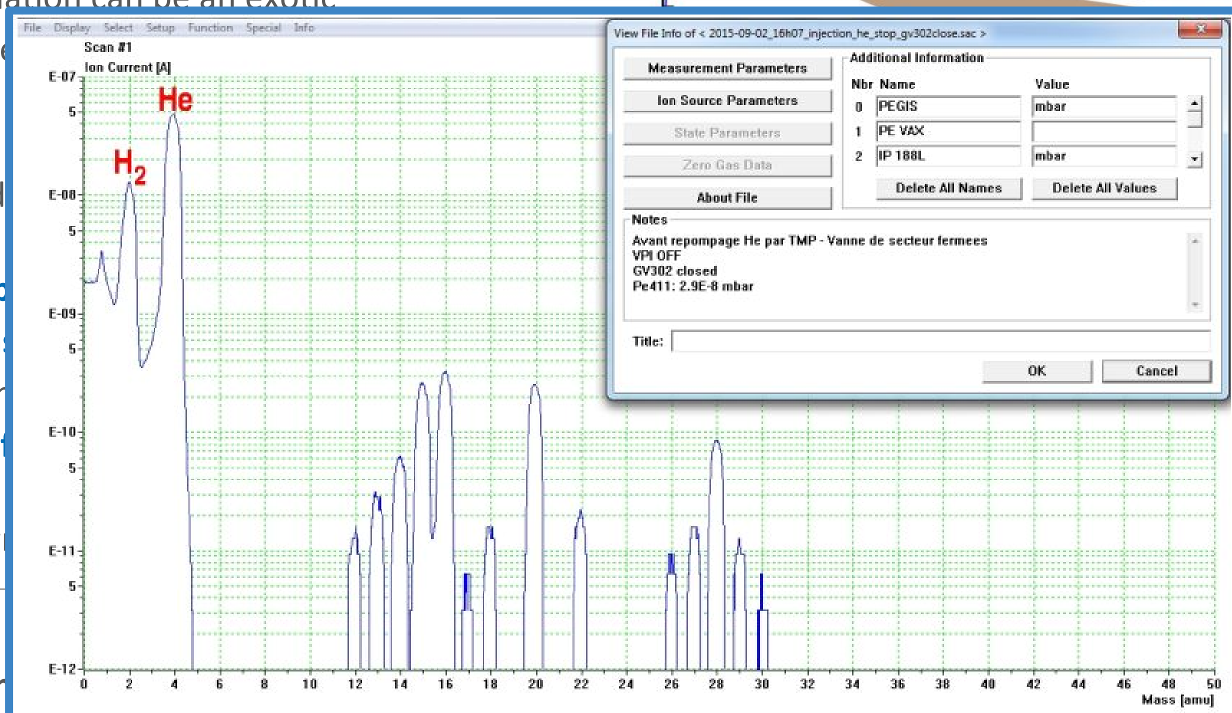




Giesen et al., arXiv:1504.04276



Software and computing

Simulation gets expensive

While moving the reconstruction online allows to select **huge and pure samples of beauty and charm hadrons**, the offline computing resources get overwhelmed of simulation jobs to get comparable statistics of simulated samples.

The current FULL simulation paradigm in use at LHCb (relying on GEANT for all interactions) is not sustainable.

➡ Need to focus on **fast simulations** techniques, splitting and combining the needs of

- huge-statistics analyses: fast simulation, *slimmed* output
- rare states & decays searches: detailed simulation of selected parts of the detector
- detector studies: full simulation including RAW event

Key words:

parametrization - to avoid simulating everything,

modularity - to fall back onto *full simulation* for crucial aspects of a physics analysis

flexibility - to handle different needs and requirements on a per-analysis basis.

The **LHCb Simulation Group** has started a collaboration with **FCC** on the Simulation and Fast Simulation Software.

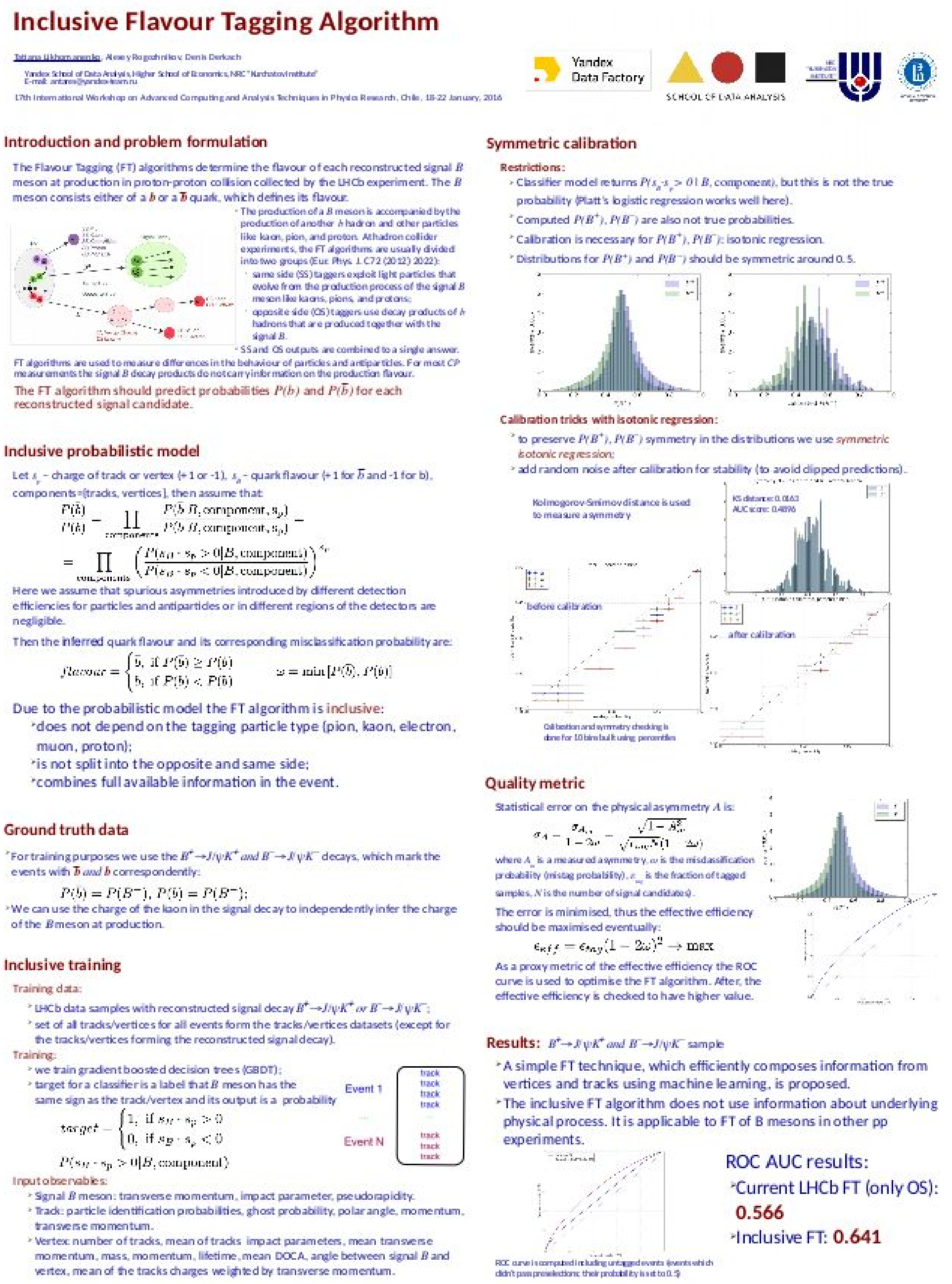
The aim is to develop an **experiment-independent Simulation software package based on Gaudi** architecture.

Flavour tagging

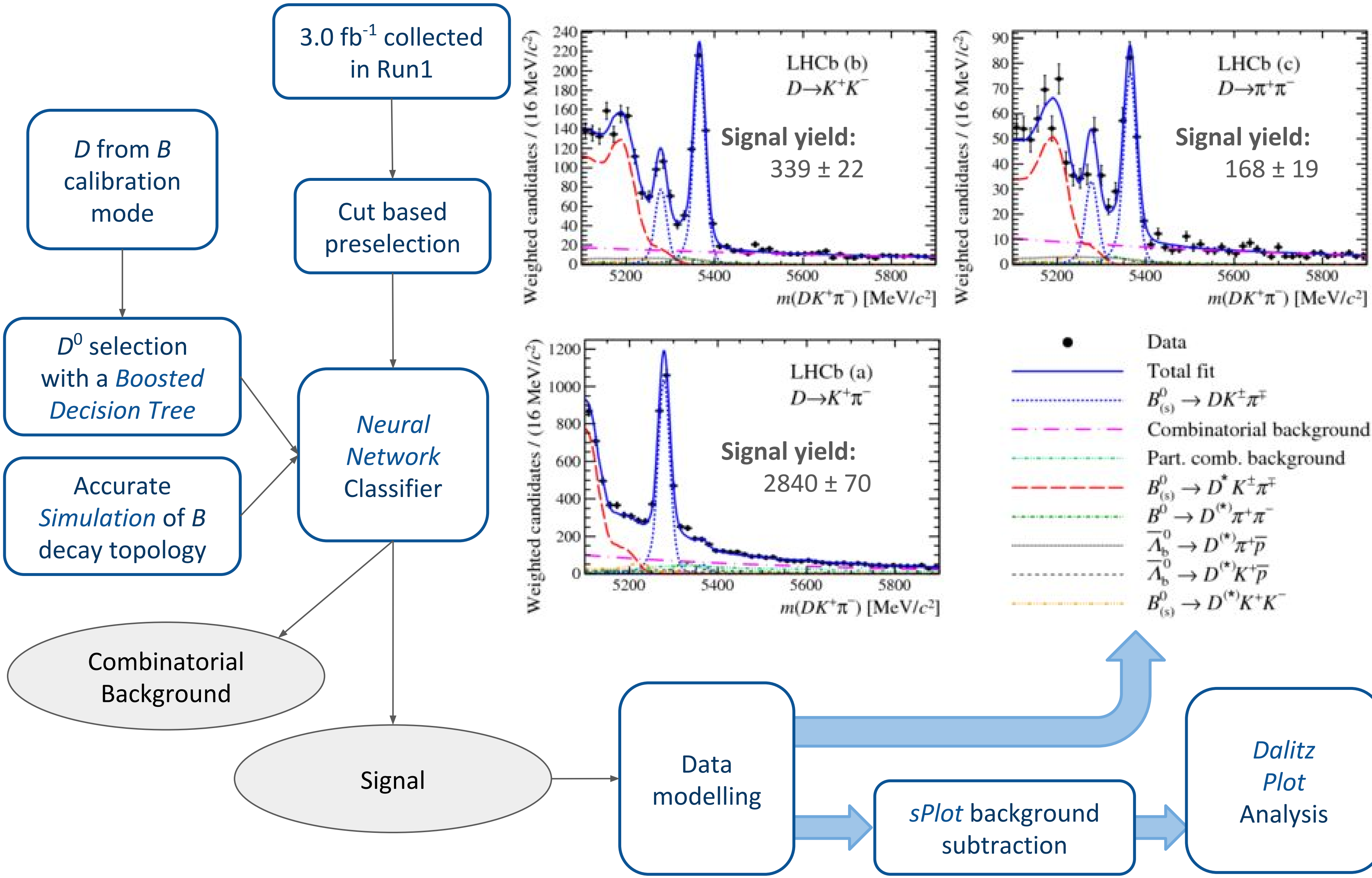
LHCb collaborates with institutes specifically interested in Data Science, doing research on classification and regression algorithms.

This is a poster presented at ACAT 2016 by the *Yandex School of Data Analysis* on a different approach to the **Flavour Tagging at LHCb**.

Without knowledge of the underlying physics.



Constraining γ with the $B^0 \rightarrow D^0 K^- \pi^+$ decay mode



Measuring D^0 oscillations with $D^0 \to K^+ \pi^- \pi^+ \pi^-$ decays

Using 3.0 fb^{-1} of data, LHCb measures for the first time the oscillation of D^0 mesons using the decay $D^0 \to K^+ \pi^- \pi^+ \pi^-$.

The oscillation is the transition

$$D^0 \to \overline{D}^0 \qquad (\text{and } \overline{D}^0 \to D^0)$$

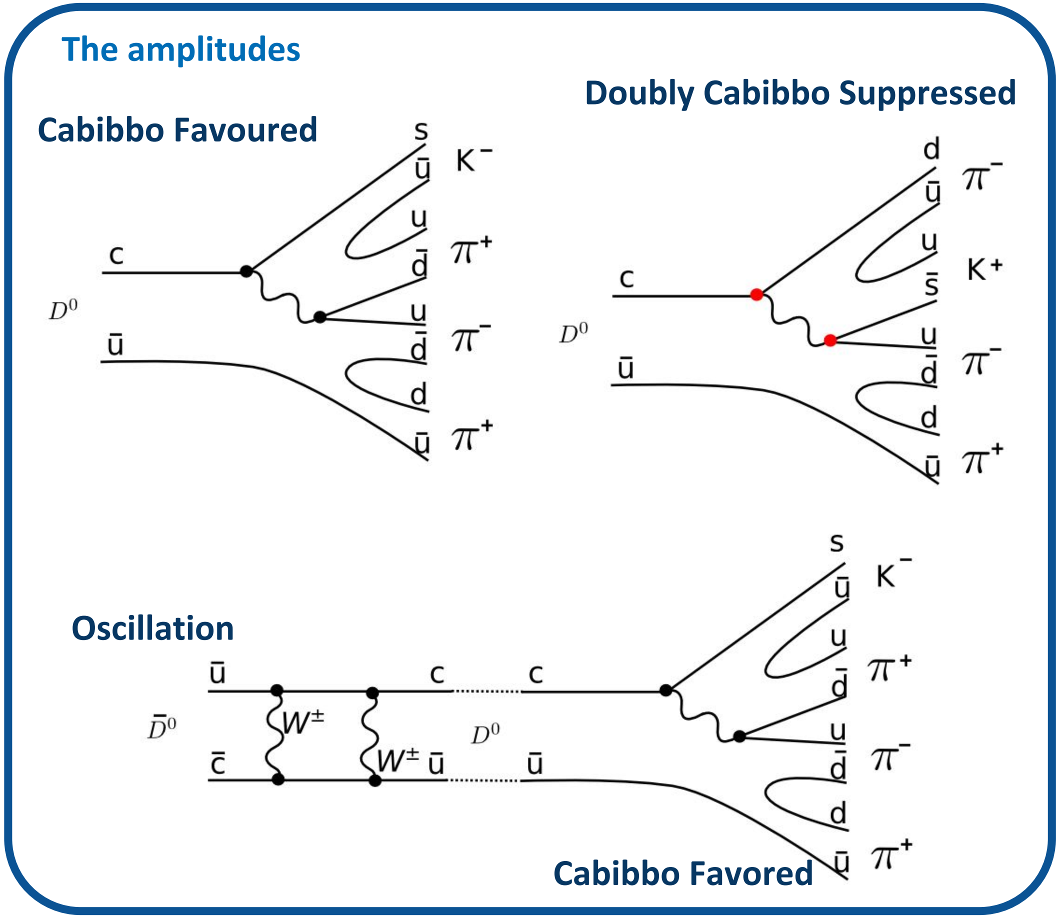
during time evolution.

Contribution of the DCS (independent of t)

Coherence factor, depending on the decay mode ($D^0 \to K^+ \pi^- \pi^+ \pi^-$)

$$R(t) \approx \left(r_D^{K3\pi}\right)^2 - r_D^{K3\pi} R_D^{K3\pi} \cdot y'_{K3\pi} \frac{t}{\tau} + \frac{x^2+y^2}{4}\left(\frac{t}{\tau}\right)^2$$

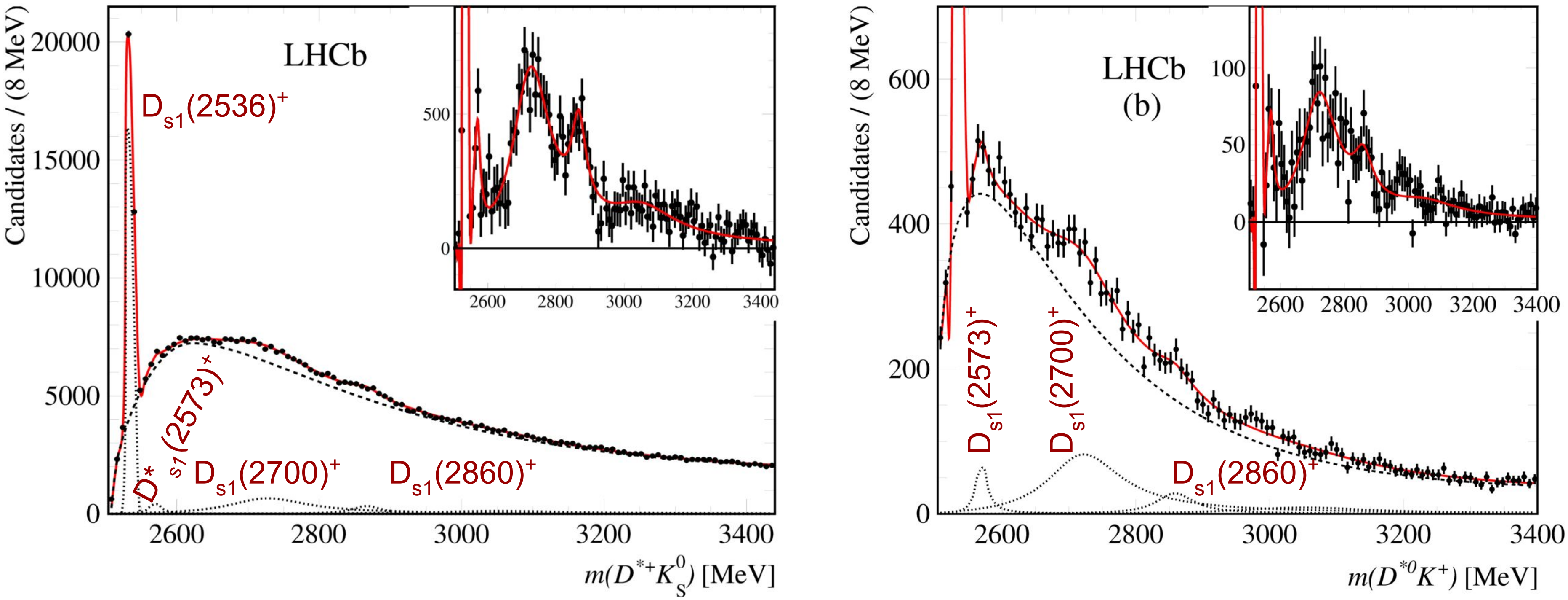
Mixing parameters of charm, independent of the decay mode!



Spectroscopy of D_{sJ} states over the D^*K threshold

Using 3.0 fb^{-1} of data collected in Run 1. LHCb has studied the combinations of ***prompt $D^{*+} K_S^0$ and $D^{*0} K^+$***

Broad peaking structures are interpreted as resonances, mass, width and spin-parity were also measured.



Properties of D^*_{sJ} states are predicted from molecular and standard quark models.

Note: *in this kind of analyses it is **impossible to distinguish signal and combinatorial background**: background need to be **modeled and subtracted**, which requires huge statistics.*

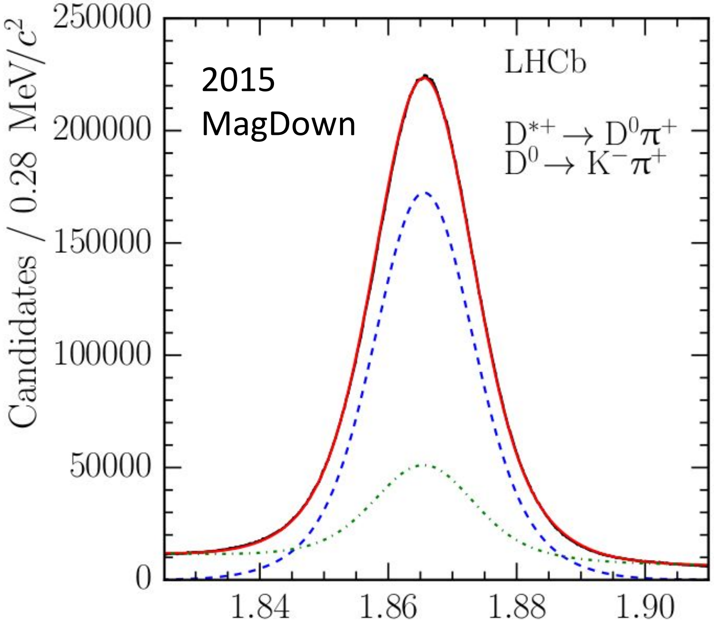
A dedicated processing for Calibration Samples

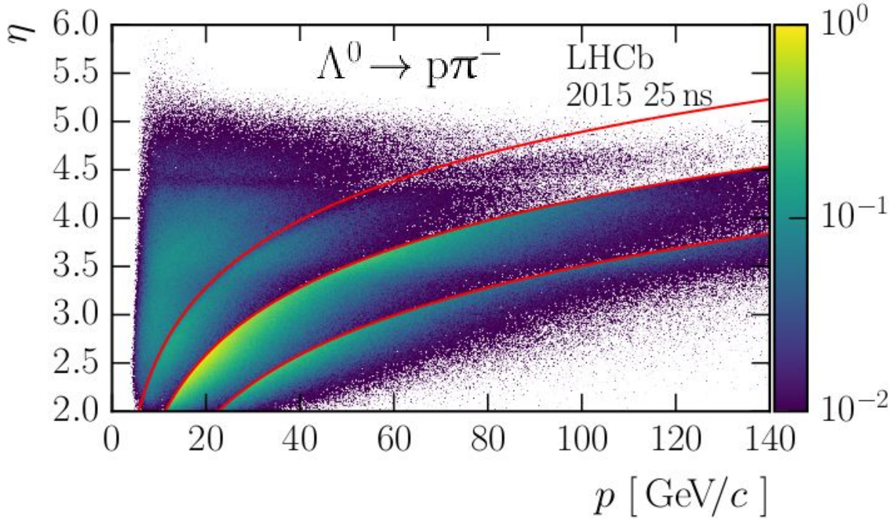
Calibrations samples: sets of candidates selected to be unbiased with respect to some part of the reconstruction (tracking, PID, trigger…)

PID and tracking calibration samples are:

- Selected defining *Turbo Candidates* in the HLT
- The full event is stored and sent offline
- Processed with the standard offline reconstruction (today: validation, tomorrow: reprocessing)
- Processed with analyst's own reco. algorithms
- *Trigger* and *offline* candidates matched

Because of **high correlation** between the **standard** algorithms used in the online selection and ***ad-hoc*** algorithms analysts run offline,
it is crucial to **process each single candidate twice** and measure the **efficiency of the combined selection requirement**.





Drawing conclusions from 2015...