# LHCb status report

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23rd September 2015
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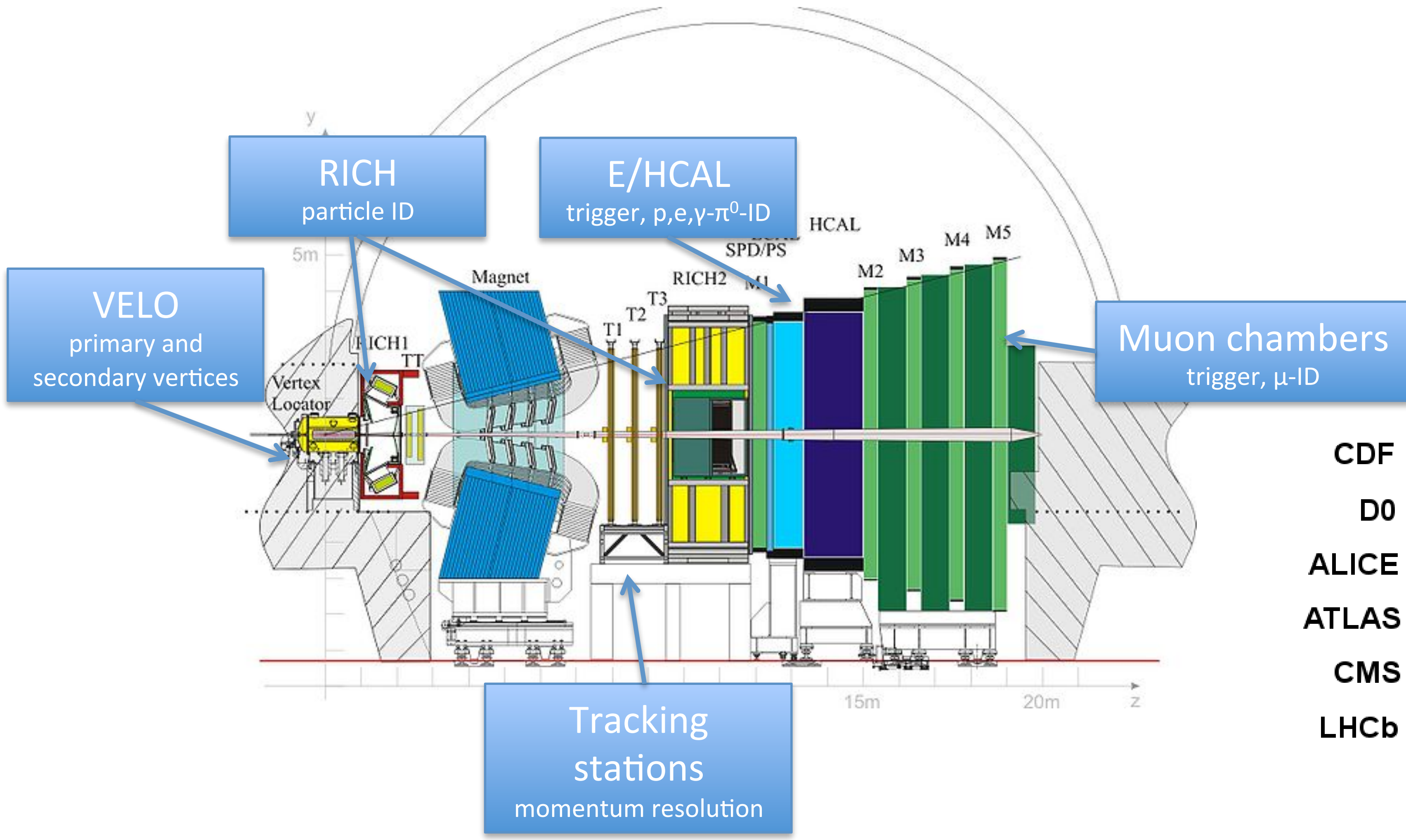
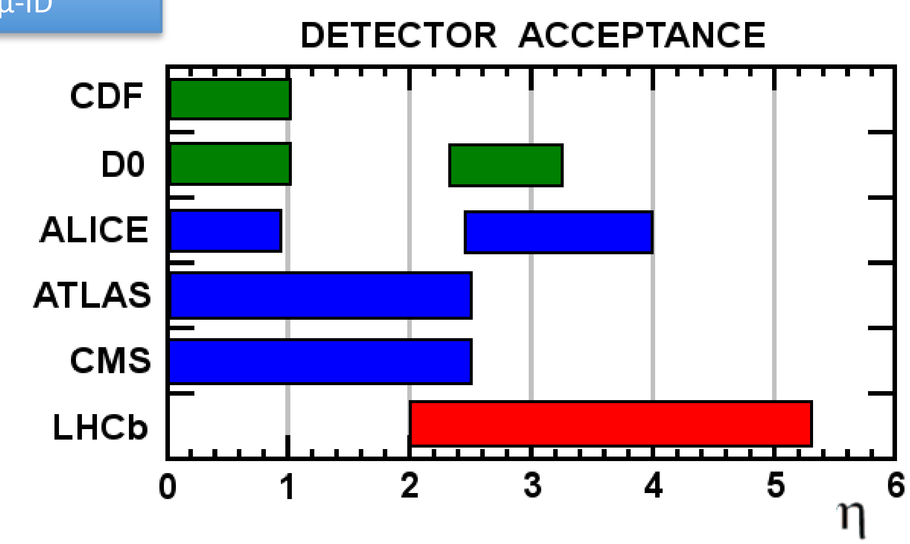
# Outline

- Introduction
- Physics highlights from Run 1 analyses
  - Pentaquarks in $\Lambda_b \to J/\psi K^- p$ (briefly)
  - Measurement of $\Lambda_b$ and $B^0$ production
  - Measurement of the forward-backward asymmetry and $\sin^2\theta_W$ in $Z/\gamma^* \to \mu\mu$ decays
  - Search for hidden sector bosons in $B^0 \to K^*\chi(\to \mu\mu)$
  - $\Delta m_d$ in semi-leptonic decays
  - Analysis of $B \to \pi\mu\mu$
  - Two particle correlations in p-Pb collisions
- Run 2 commissioning and physics results
- Upgrade status
- Conclusions

# LHCb Detector




LHCb is a forward arm spectrometer (pseudo-rapidity range: $2 < \eta < 5$),

Accurate resolutions through vertex locator and tracking stations ($\Delta p/p \sim 0.4\%$, $\sigma(IP) \sim 20\mu m$),

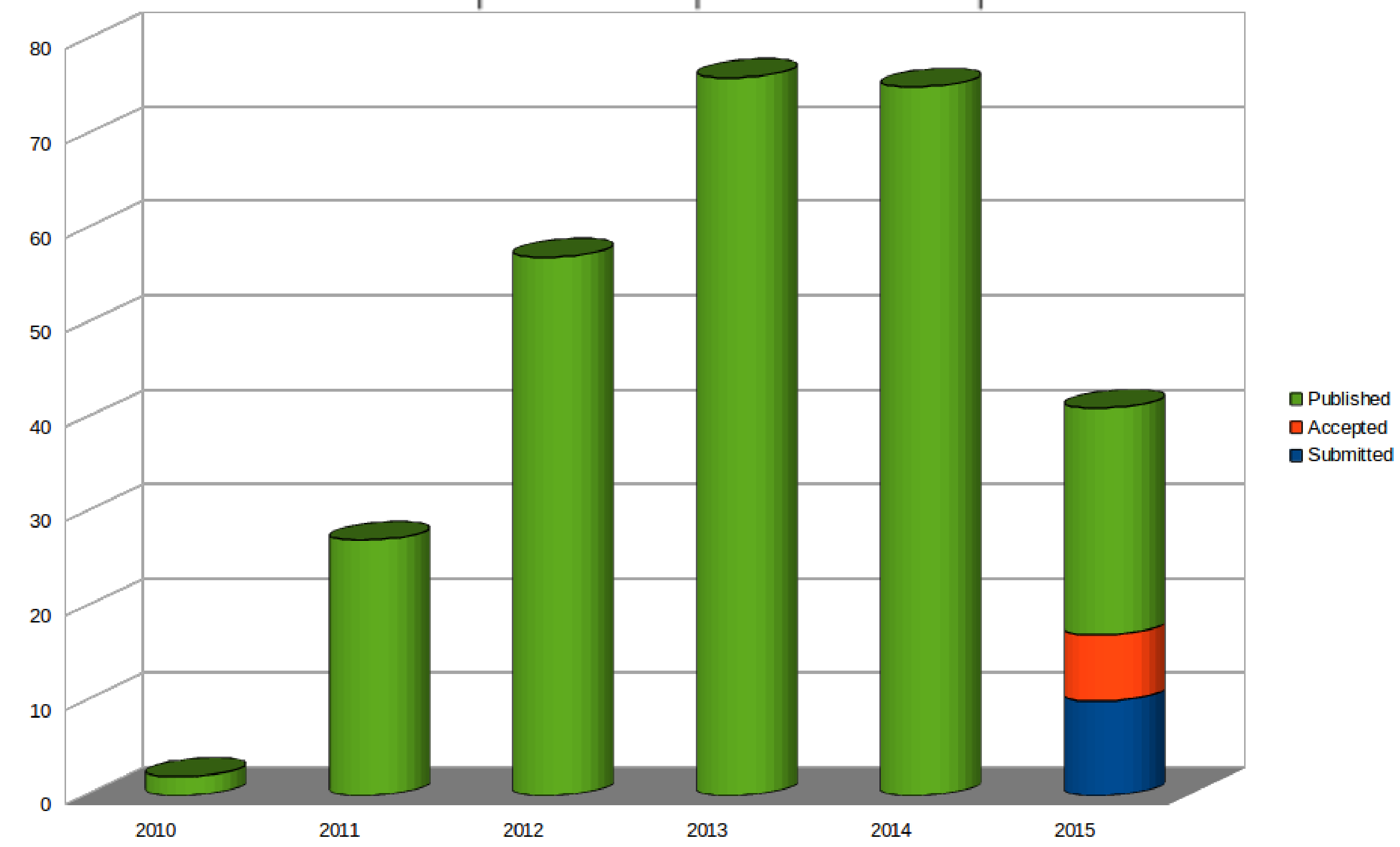
Accurate particle ID provided by RICH detectors,

High muon identification efficiency from muon stations.

# Publication output by year

| Year | Submitted | Accepted | Published | Total | Integral | CONF |
|---|---|---|---|---|---|---|
| 2010 | | | 2 | 2 | 2 | 7 |
| 2011 | | | 27 | 27 | 29 | 61 |
| 2012 | | | 57 | 57 | 86 | 22 |
| 2013 | | | 76 | 76 | 162 | 17 |
| 2014 | | | 75 | 75 | 237 | 4 |
| 2015 | 11 | 6 | 25 | 42 | 279 | 4 |
| Total | 11 | 6 | 262 | 279 | | 115 |

+23 published since last LHCC



# Physics papers submitted since last open session

**Measurement of the forward-backward charge asymmetry in $Z/\gamma^*$ decays into muon pairs and determination of the effective weak mixing angle [to be submitted to JHEP and the arXiv today]**

Studies of the resonance structure in $D^0 \to K_S K \pi$ decays [submitted to PRD, arXiv:1509.06628]

Forward production of Υ mesons in pp collisions at $\sqrt{s}$ = 7 and 8 TeV [submitted to JHEP, arXiv:1509.02372]

Measurement of forward J/ψ production cross-sections in pp collisions at $\sqrt{s}$ = 13 TeV [submitted to JHEP, arXiv:1509.00771]

Measurement of CP violation parameters and polarisation fractions in $B_s \to J/\psi K^{*0}$ decays [submitted to JHEP, arXiv:1509.00400]

**First measurement of the differential branching fraction and CP asymmetry of the $B \to \pi\mu\mu$ decay [submitted to JHEP, arXiv:1509.00414]**

**Study of the production of $\Lambda_b$ and $B^0$ hadrons in pp collisions and first measurement of the $\Lambda_b \to J/\psi p K^-$ branching fraction [submitted to Chin. Phys. C., arXiv:1509.00292]**

Measurement of the time-integrated CP asymmetry in $D^0 \to K_S K_S$ decays [submitted to JHEP, arXiv:1508.06087]

**Search for hidden-sector bosons in $B^0 \to K^{*0} \chi(\to \mu\mu)$ decays [submitted to PRL, arXiv:1508.04094]**

Measurement of the $B_s \to \phi\phi$ branching fraction [submitted to JHEP, arXiv:1508.00788]

Measurement of the branching fraction ratio $\mathfrak{B}(B_c^+ \to \psi(2S)\pi^+)/\mathfrak{B}(B_c^+ \to J/\psi\pi^+)$
[submitted to Phys.Rev.D., arXiv:1507.03516]

**Observation of J/ψp resonances consistent with pentaquark states in $\Lambda_b \to J/\psi K^- p$ decays [PRL 115 072001, arXiv:1507.03414]**

Search for long-lived heavy charged particles using a ring-imaging Cherenkov technique at LHCb [submitted to JHEP, arXiv:1506.09173]

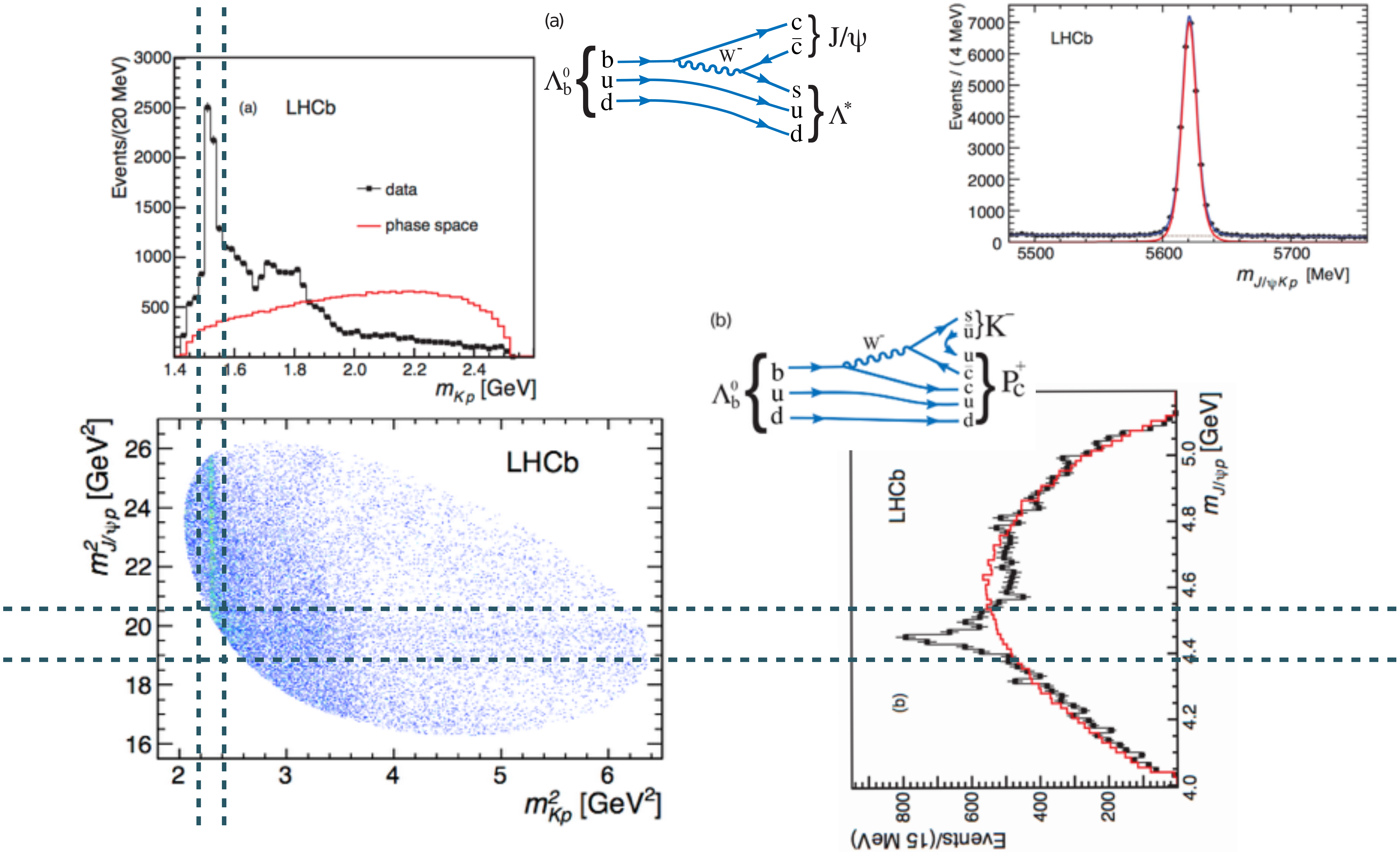
Angular analysis and differential branching fraction of the decay $B_s \to \phi\mu\mu$ [submitted to JHEP, arXiv:1506.08777]

Observation of the decay $B_s \to K_S K^{*0}$ [submitted to JHEP, arXiv:1506.08634]

Measurement of the ratio of branching fractions $\mathfrak{B}(B \to D^{*+}\tau^-\upsilon)/\mathfrak{B}(B \to D^{*+}\tau^-\upsilon)$ [PRL 115 112001, arXiv:1506.08614]

# Run 1 physics highlights…

# Observation of states consistent with pentaquarks in $\Lambda_b \to J/\psi K^- p$, arXiv:1507.03414, PRL 115 072001



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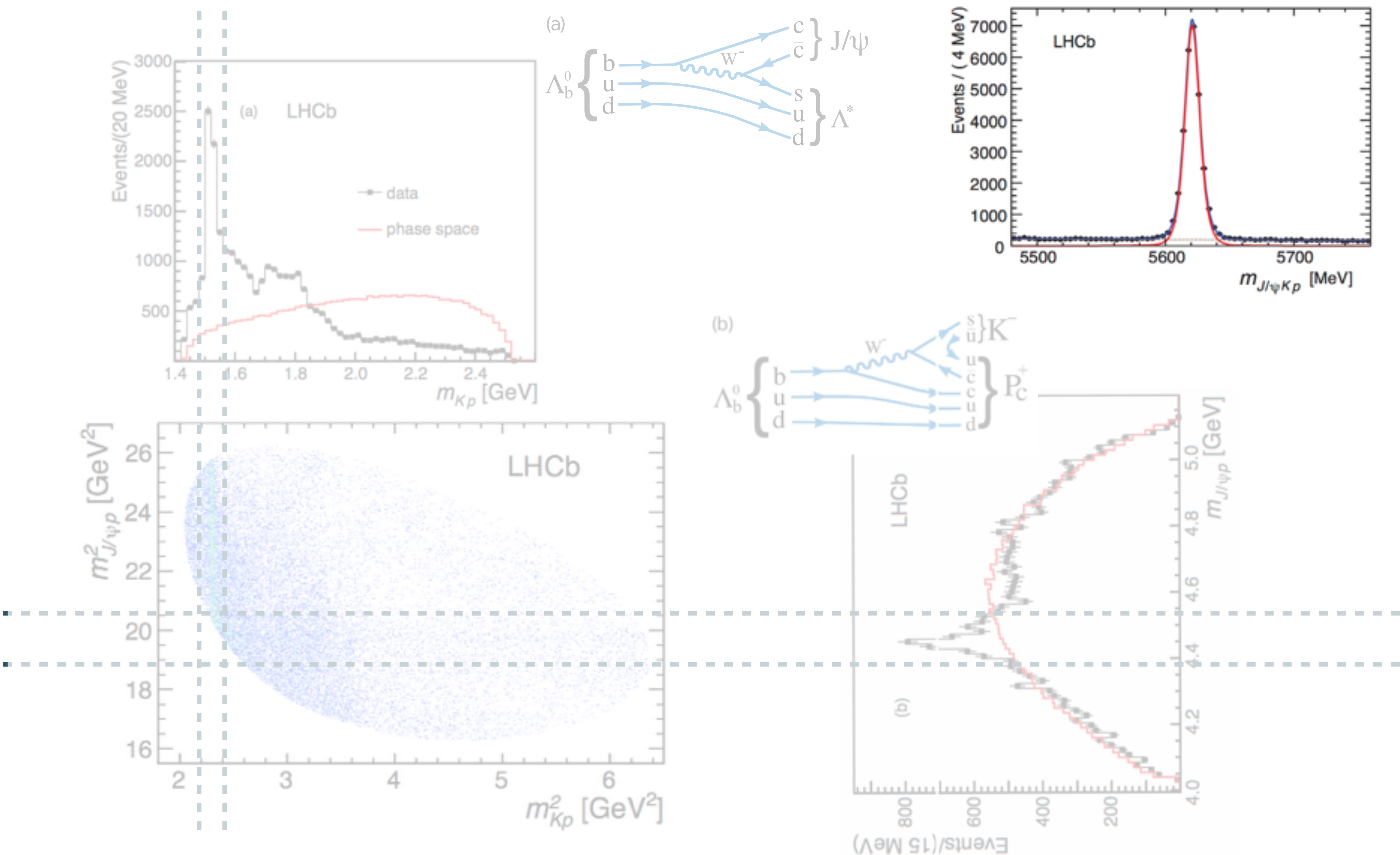

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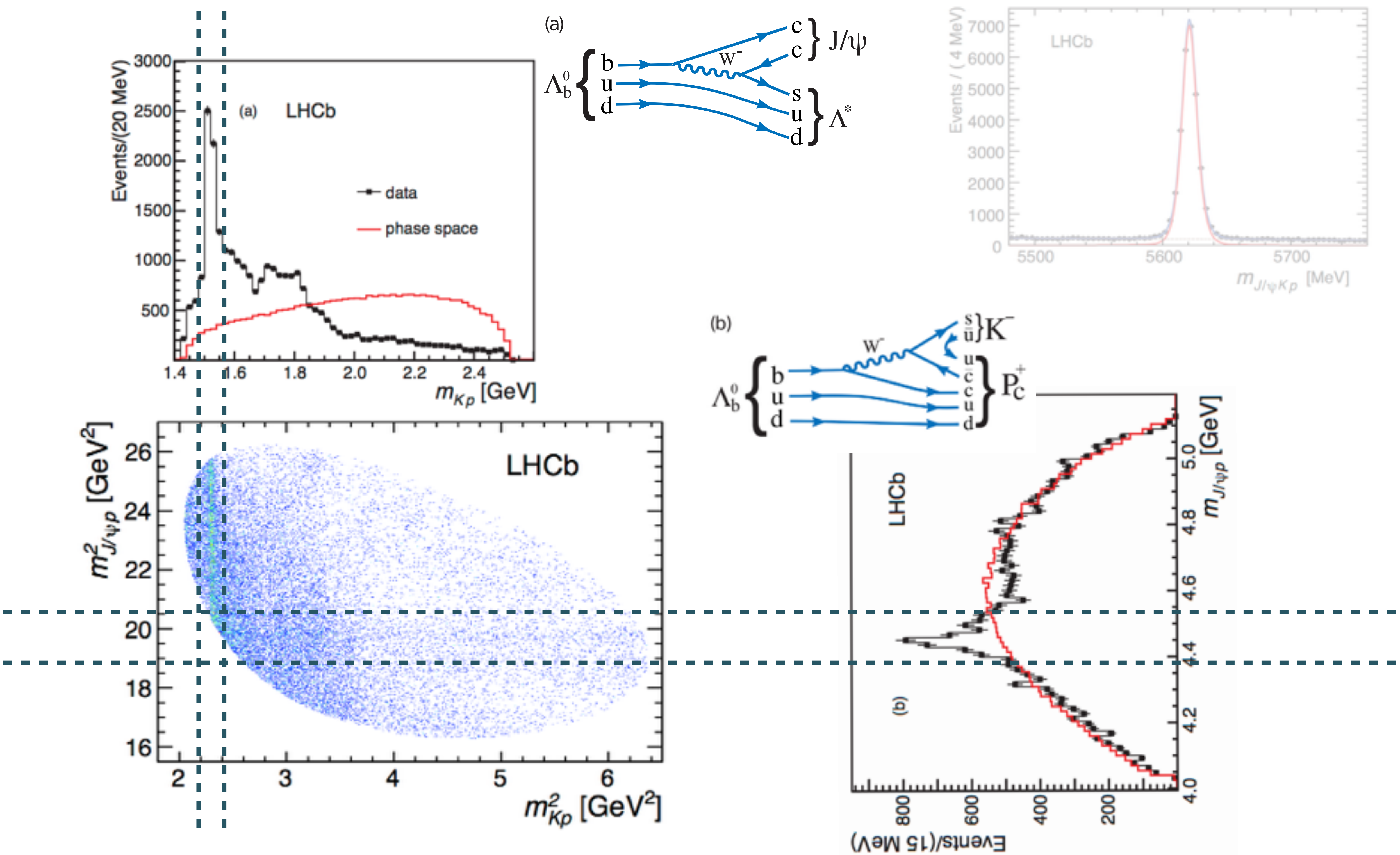
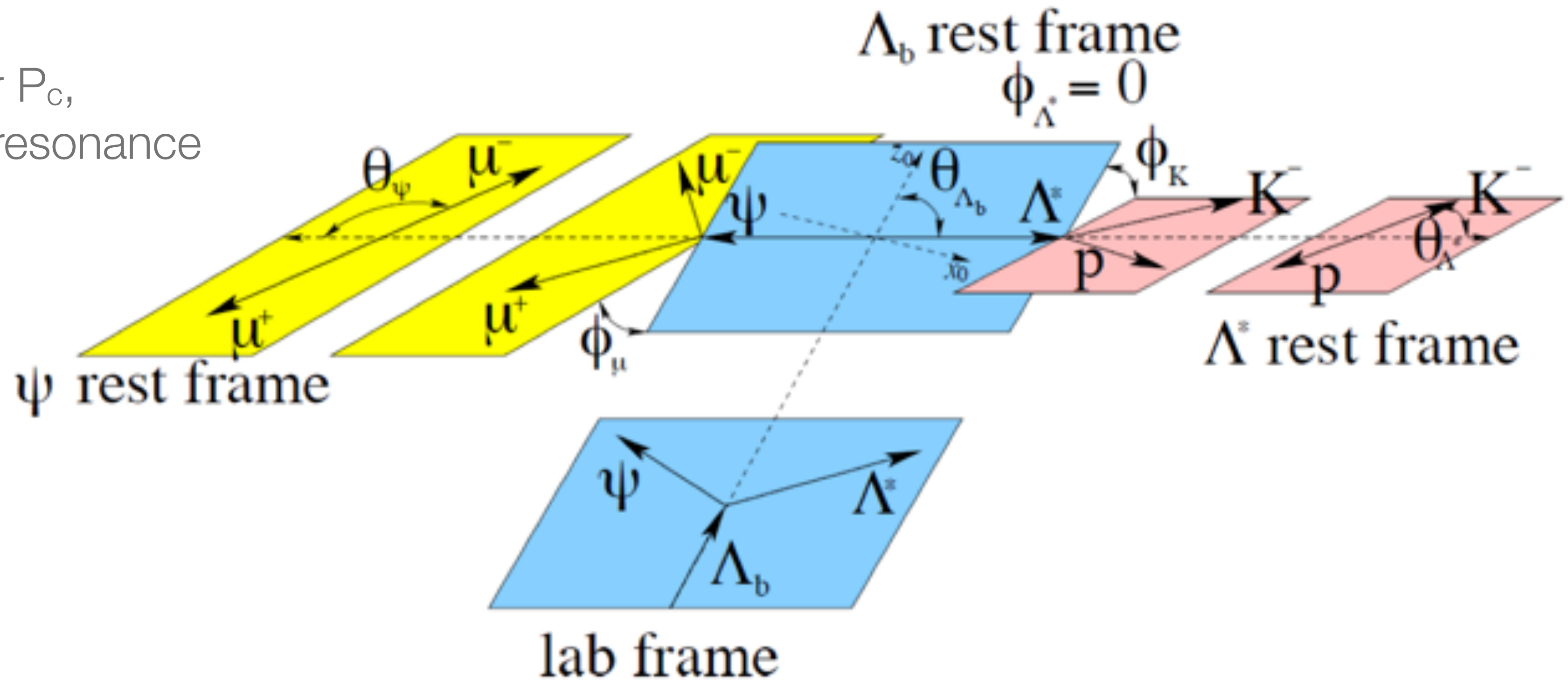


# Spectrum investigation

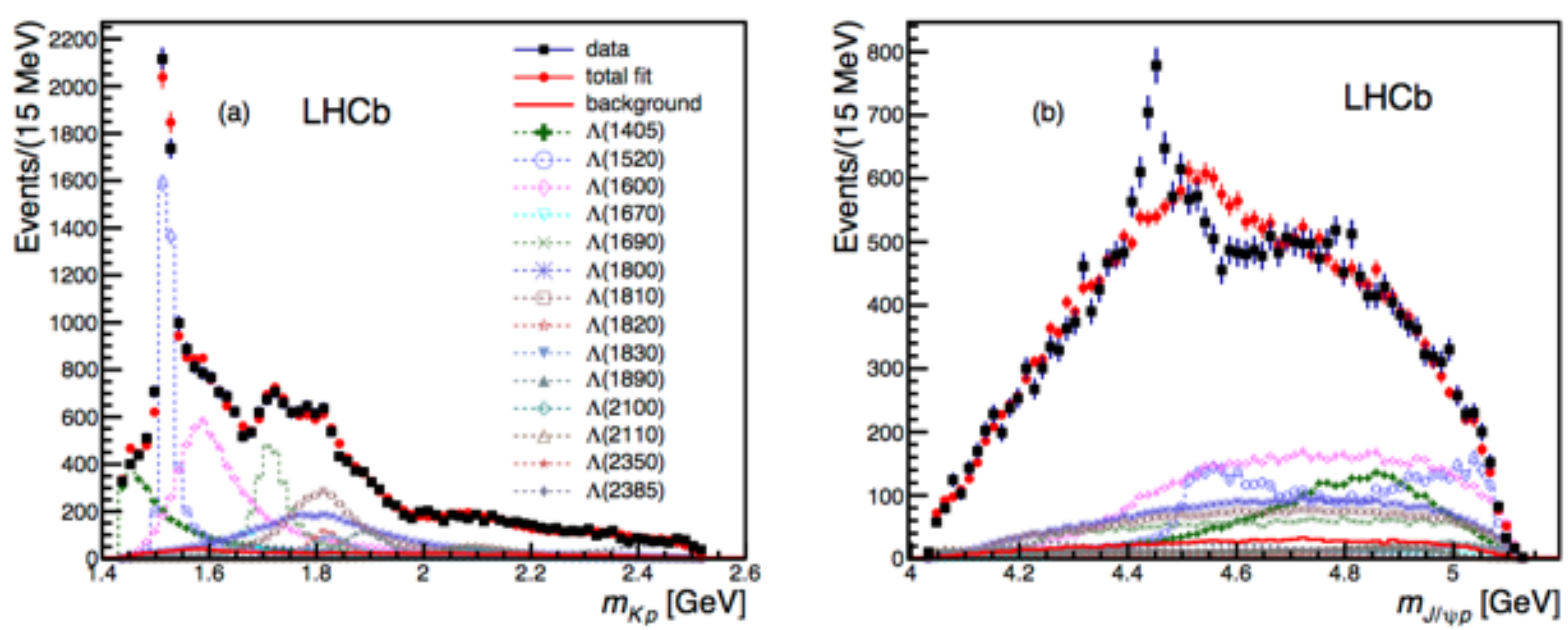
- Analyze all dimensions of the $\Lambda_b \to J/\psi K^- p$ decay kinematics.
  - to avoid biases due to averaging over some dimensions in presence of the non-uniform detector efficiency
  - For each matrix element $\Lambda^*$ or $P_c$, parametrise by 5 angles and resonance mass.




Veto $B_s \to J/\psi KK$ and $B^0 \to J/\psi K\pi$ decays

Exclude $\Xi_b$ and suppress fake tracks

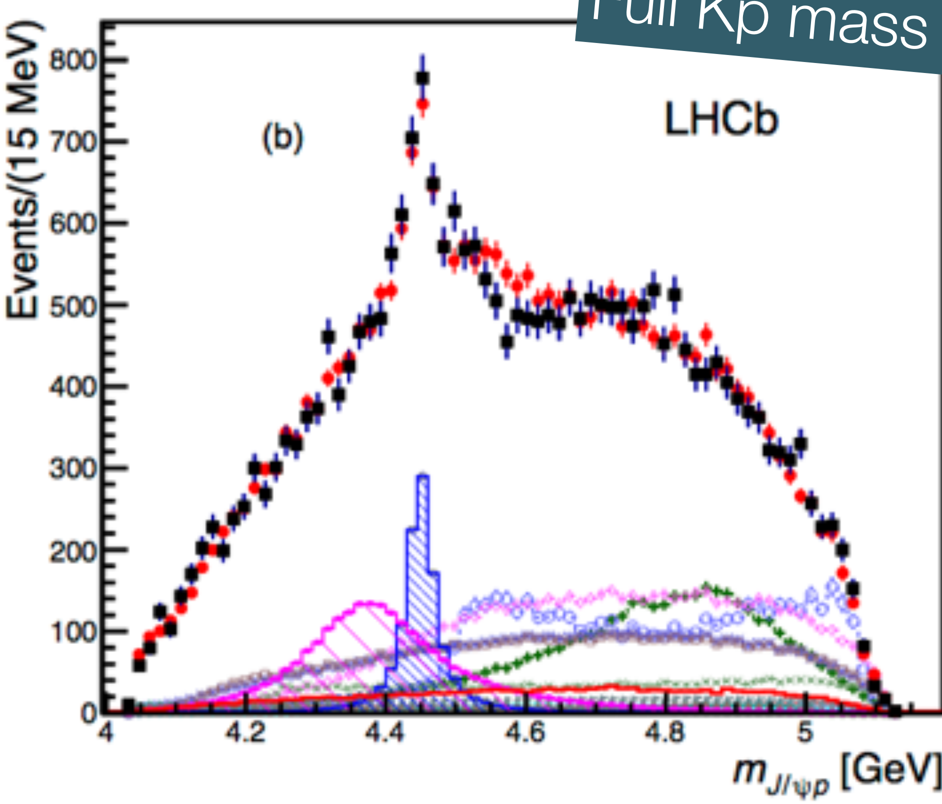
First thing is to try adding all known PDG contributions



# Spectrum investigation

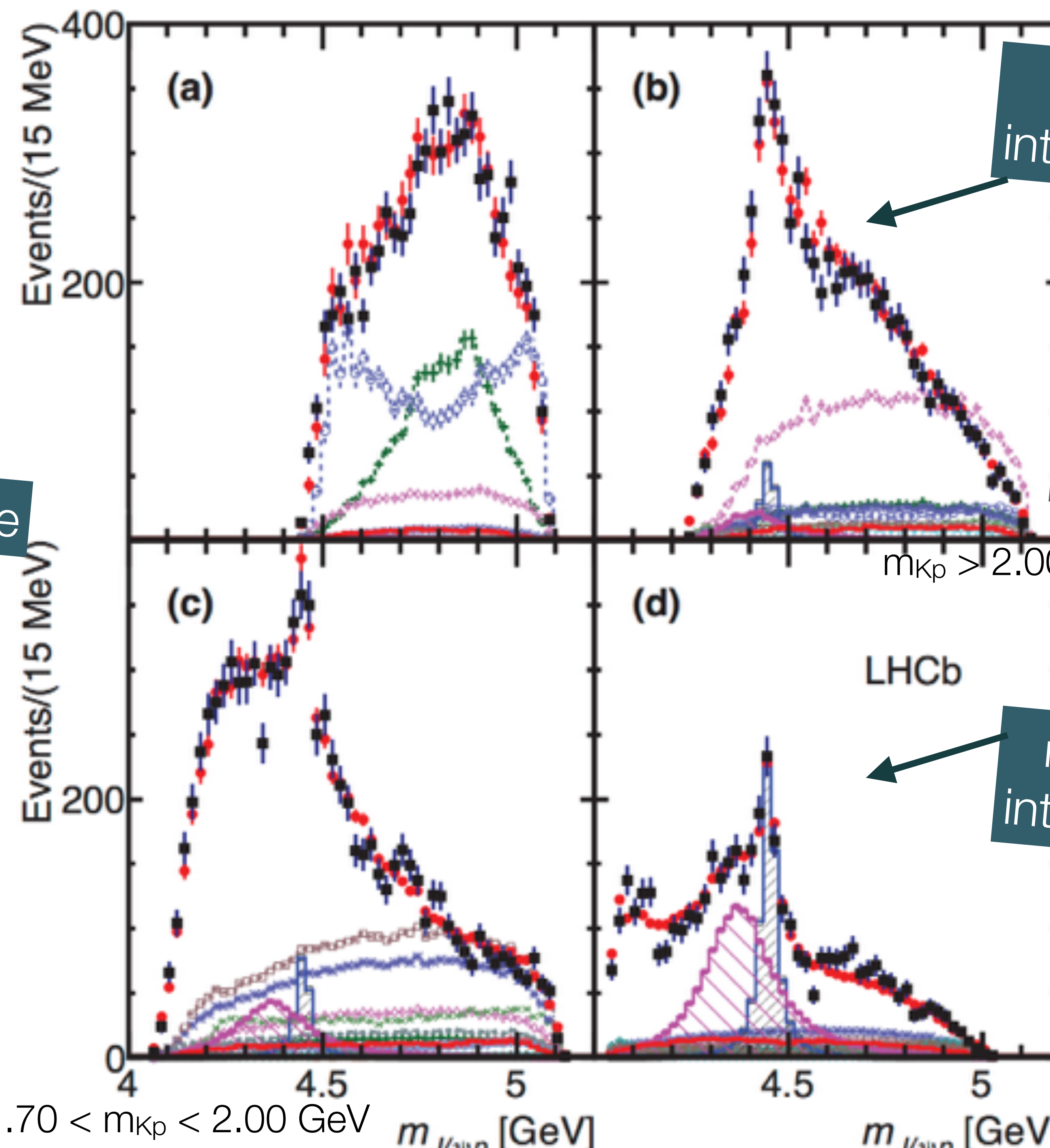
Best fit with 2 pentaquark states:
$J^P=(3/2^-, 5/2^+)$,
also $(3/2^+, 5/2^-)$
& $(5/2^+, 3/2^-)$ are preferred

Full Kp mass range




$m_{Kp}$<1.55GeV

$1.55 < m_{Kp} < 1.70$ GeV




$m_{Kp} > 2.00$ GeV

$1.70 < m_{Kp} < 2.00$ GeV

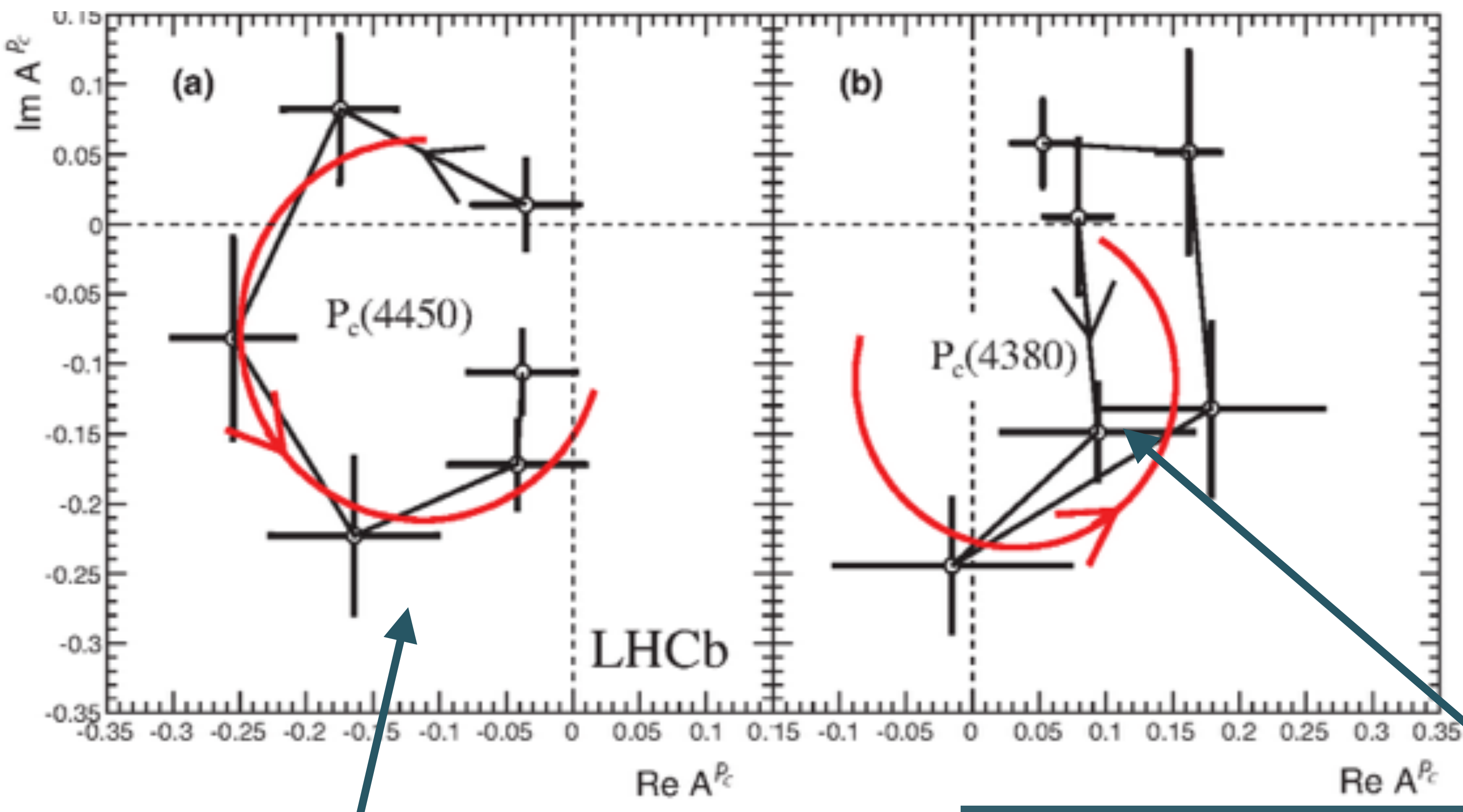
positive interference

Indicates opposite parity

negative interference

# Investigating the resonance character

By replacing the Breit-Wigner line shape for the individual $P_C$s with 6 complex amplitudes, can show the resonance structure on the Argand diagram.

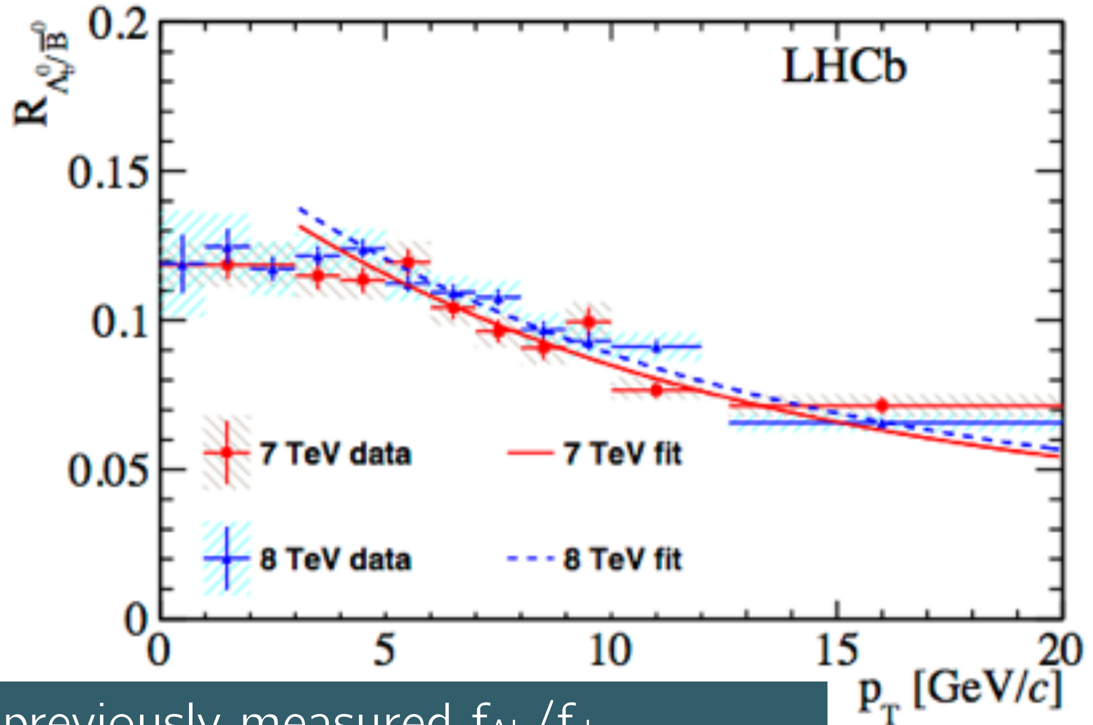



Resonance behaviour: rapid counter-clockwise phase change

Large phase change, require larger dataset to be sure of resonance behaviour

# Measurement of $\Lambda_b$ and $B^0$ production, arXiv:1509.00292

$$R_{\Lambda_b^0/\bar{B}^0}(p_T) = \frac{\mathcal{B}(\Lambda_b^0 \to J/\psi\, p K^-)}{\mathcal{B}(\bar{B}^0 \to J/\psi\, \bar{K}^{*0})} f_{\Lambda_b^0}/f_d(p_T)$$




LHCb has previously measured $f_{\Lambda b}/f_d$ (Phys. Rev. D 85, 032008)⇒ means with the results of this analysis, LHCb can measure absolute BFs without PDG input

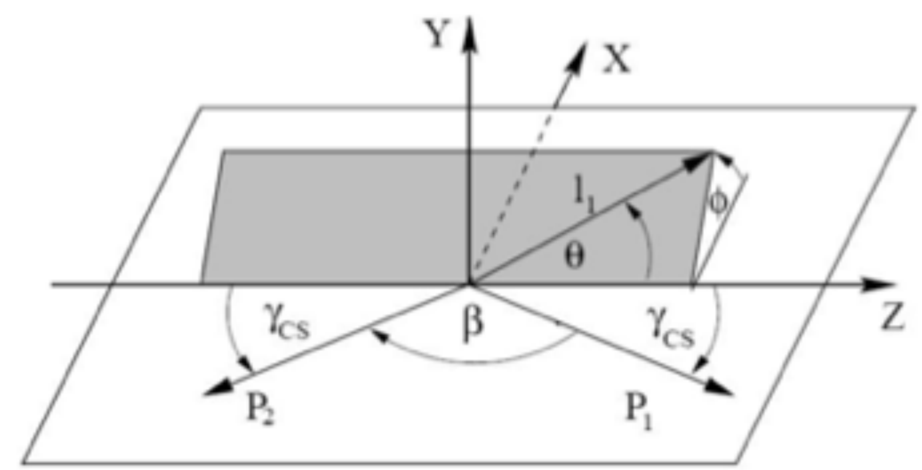
- Can determine the ratio of BFs and thus:
  $\mathfrak{B}(\Lambda_b \to J/\psi K^- p) = (3.04 \pm 0.04 \pm 0.06 \pm 0.33(\mathfrak{B})^{+0.43}_{-0.27}(f_{\Lambda b}/f_d)) \times 10^{-4}$

- From this results can measure:
  $\mathfrak{B}(\Lambda_b \to P_c^+(4380)K^-)\, \mathfrak{B}(P_c^+ \to J/\psi p) = (2.56 \pm 0.22 \pm 1.28^{+0.46}_{-0.36}(f_{\Lambda b}/f_d)) \times 10^{-5}$
- $\mathfrak{B}(\Lambda_b \to P_c^+(4450)K^-)\, \mathfrak{B}(P_c^+ \to J/\psi p) = (1.25 \pm 0.15 \pm 0.33^{+0.22}_{-0.18}(f_{\Lambda b}/f_d)) \times 10^{-5}$

# Measurement of the forward-backward asymmetry and $\sin\theta_W$ in $Z/\gamma^* \to \mu\mu$ decays (LHCb-PAPER-2015-039)

- SM Z couplings to left and right handed fermions differ
  ⇒leads to differences in the polar angle distribution of positive and negative muons from Z decays.
- In the SM, differential cross-section at leading order given by:

$$\frac{d\sigma}{d\cos\theta^*} = A(1+\cos^2\theta^*) + B\cos\theta^*$$




- $\theta^*$ is the polar angle of the +ve muon in the Collins-Soper frame (Phys. Rev. D 16 2219).
- A, B coefficients a function of the dimuon invariant mass, the colour charge of the quarks and the vector and axial-vector couplings.
- Forward-backward asymmetry:

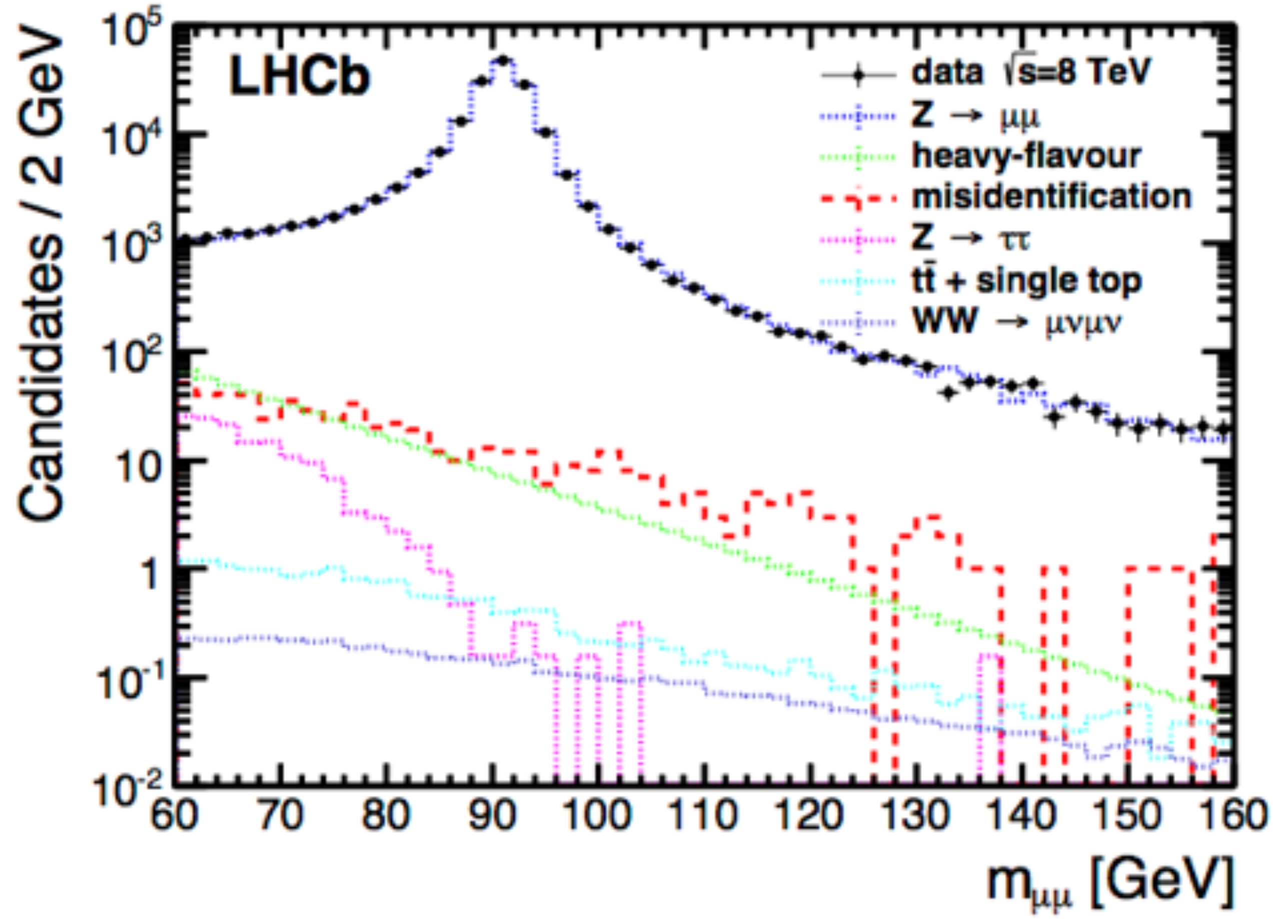
$$A_{FB} \equiv \frac{N_F - N_B}{N_F + N_B},$$

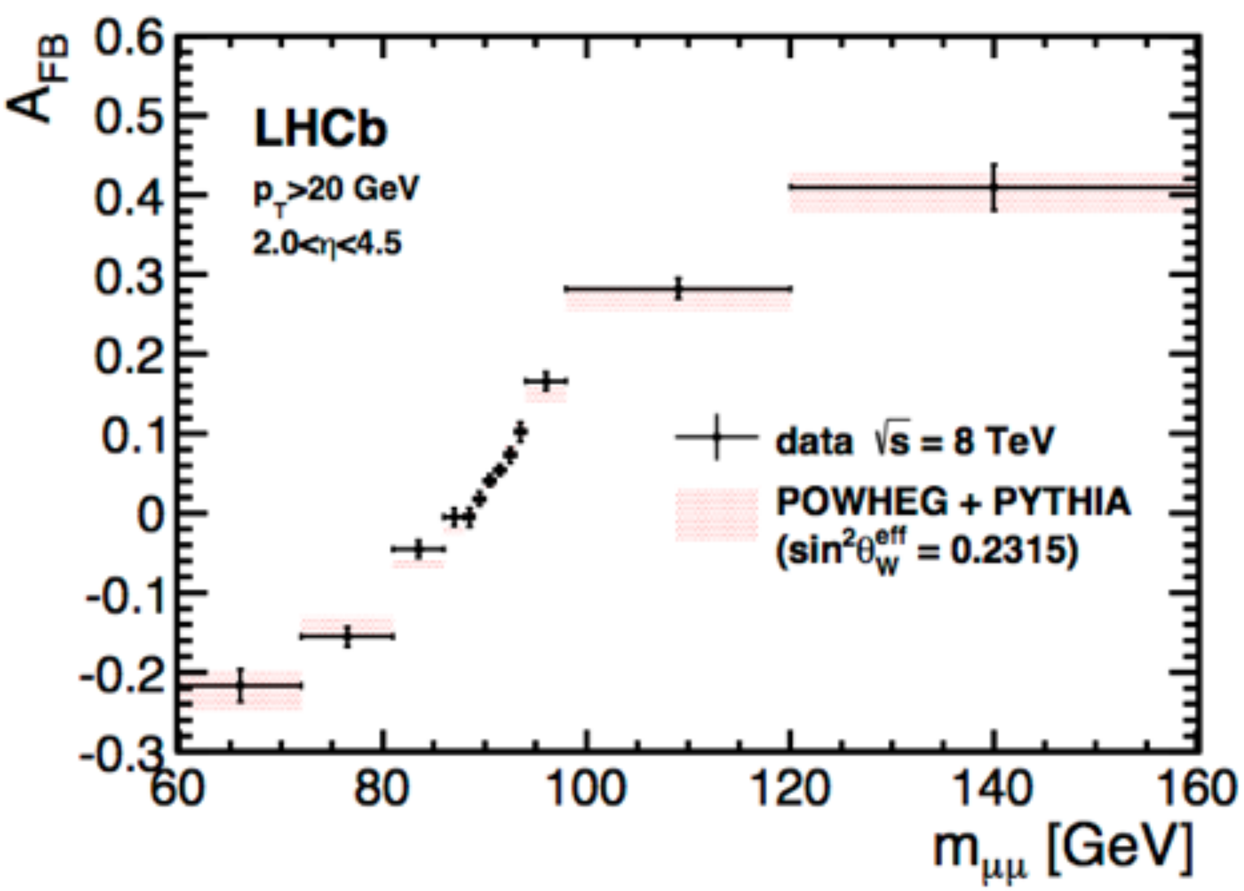
  where F means $\cos\theta^*>0$ and B $\cos\theta^*<0$
- Asymmetry depends on weak mixing angle $\theta_W$.

Forward acceptance has reduced dilution of ambiguity from knowledge of the incoming fermion direction

# Di-muon signals and $A_{FB}$

Simulated signal and backgrounds describe the observed distributions well.

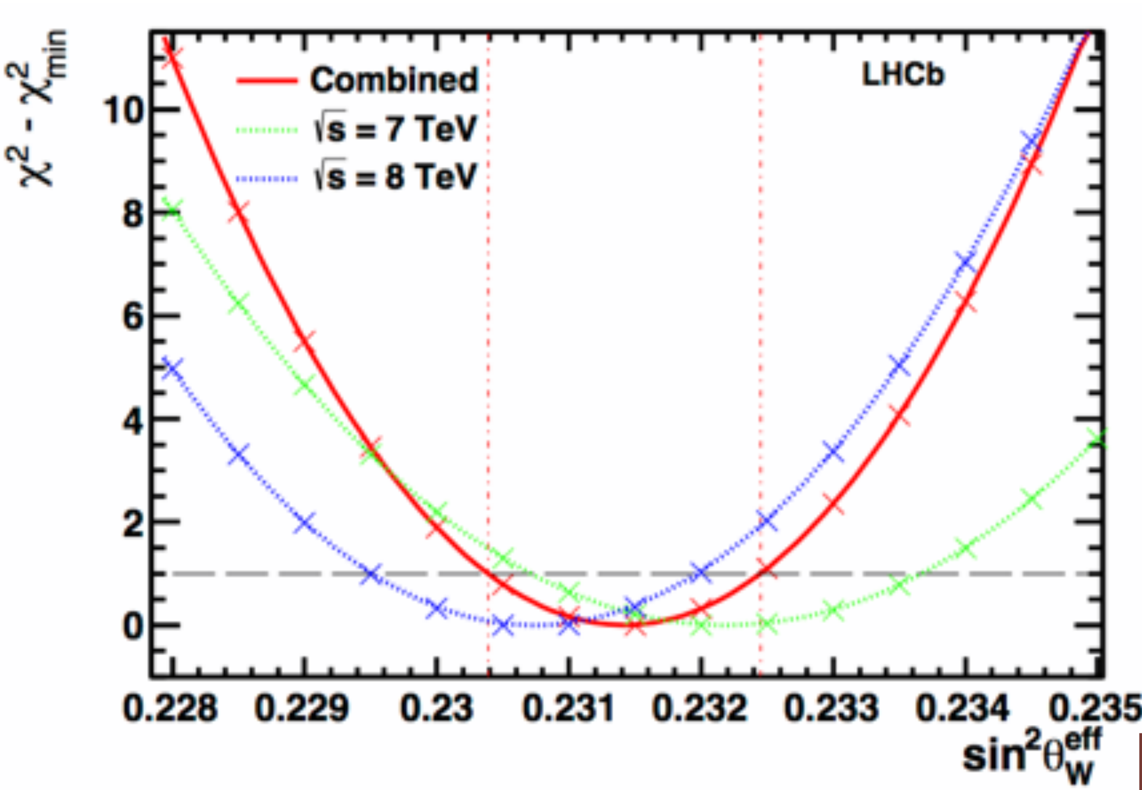


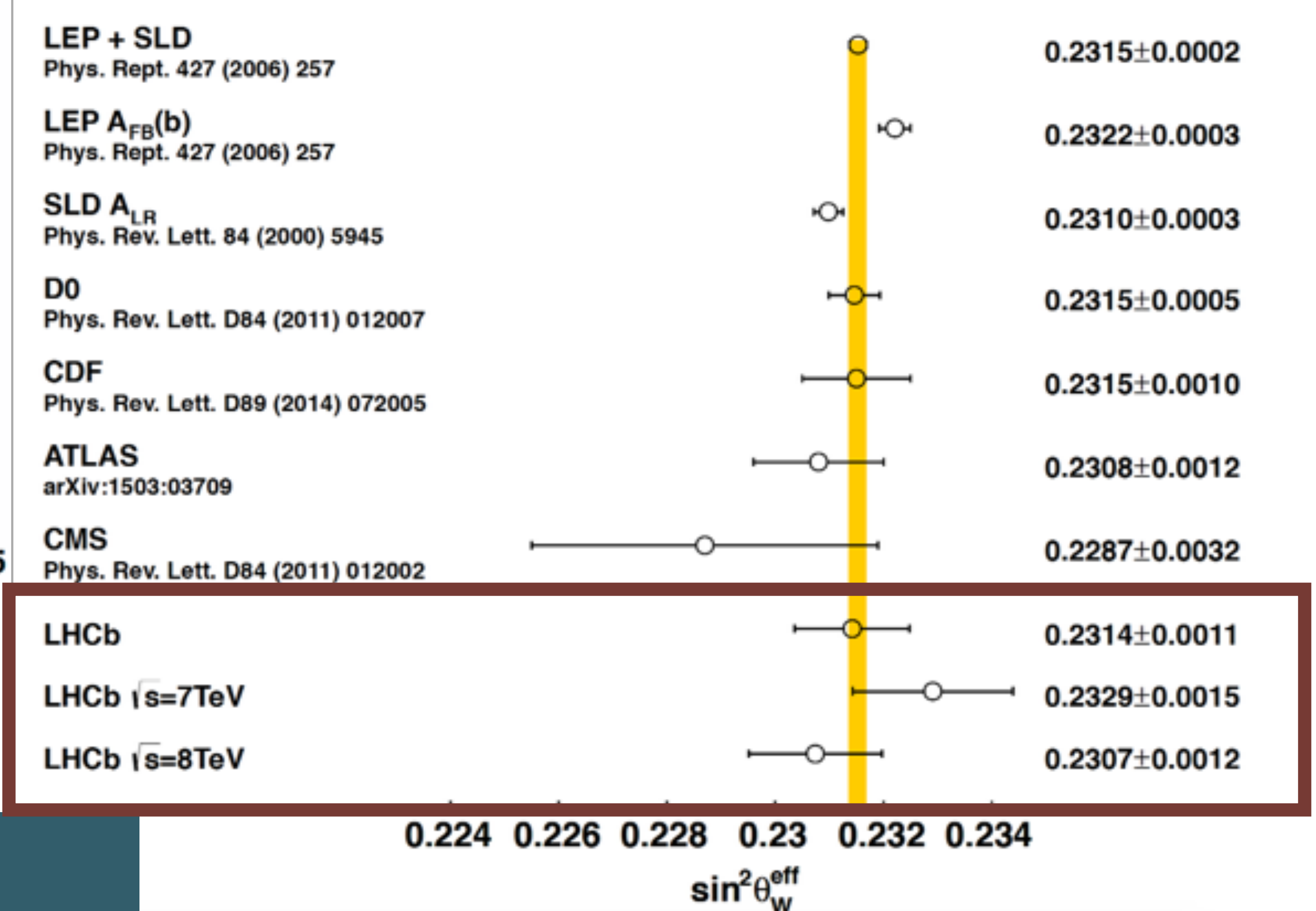

Measurements of the asymmetry show good agreement with simulation

# $\sin^2\theta_W$

Most precise of LHC results




$$\sin^2\theta_W^{\rm eff} = 0.23142 \pm 0.00073 \pm 0.00052 \pm 0.00056$$

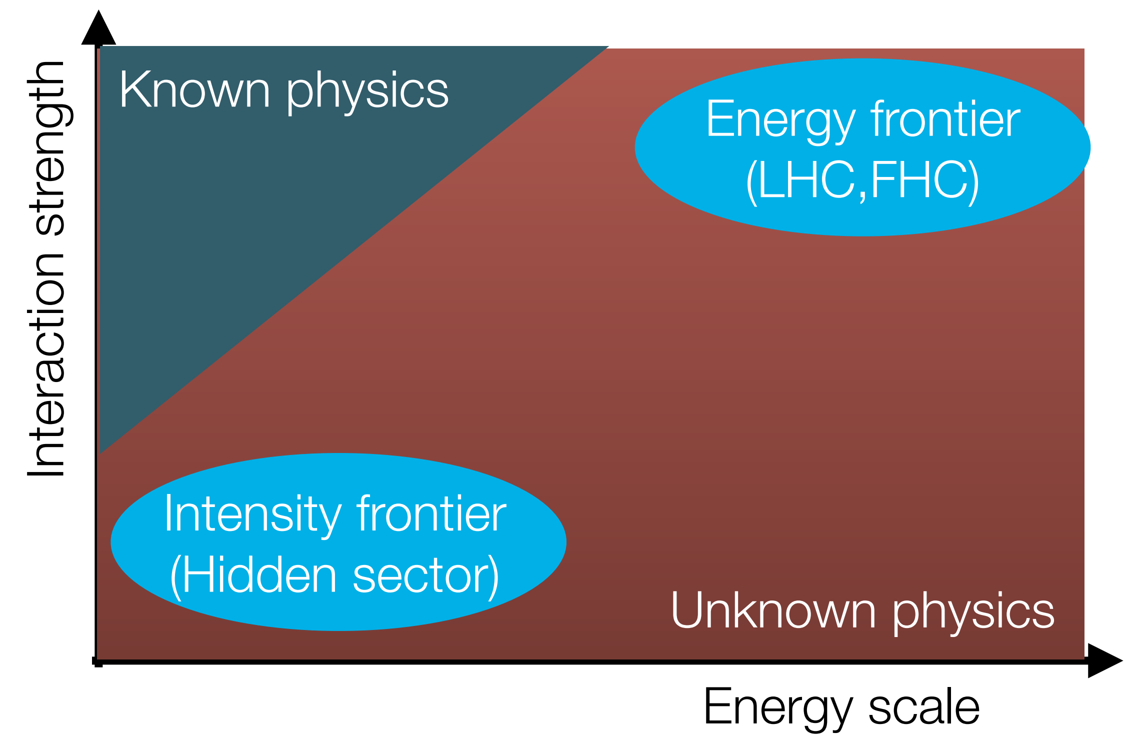



- $A_{FB}$ generated with a range of $\sin^2\theta_W$ using POWHEG-BOX.
- $\chi^2$ with data calculated for each.
- Fit to the distribution of $\chi^2$ to determine minimum and error.

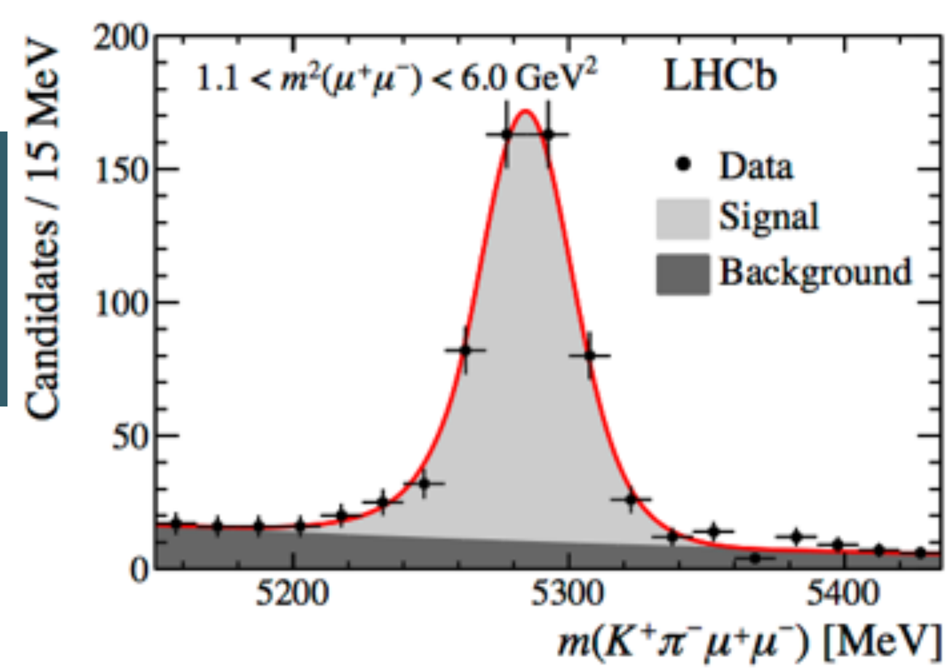
Largest theoretical uncertainties from PDFs renormalisation and factorisation scales

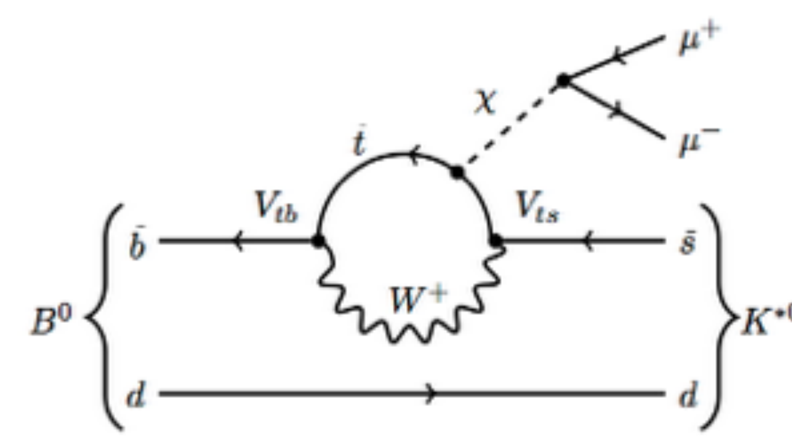
# Search for hidden sector bosons in $B^0 \to K^{*0}\chi(\to \mu\mu)$ (arXiv:1508.04094, accepted by PRL)

- Idea that new particles are not at ever increasing mass scales, but instead have low interaction strength.
- Many BSM theories predict TeV scale DM interacting via GeV scale bosons (arXiv:0810.0713)
- Summary of previous searches (arXiv:1504.04855).




$B^0 \to K^{*0}\mu\mu$ has a well studied selection strategy, gives clean signal.



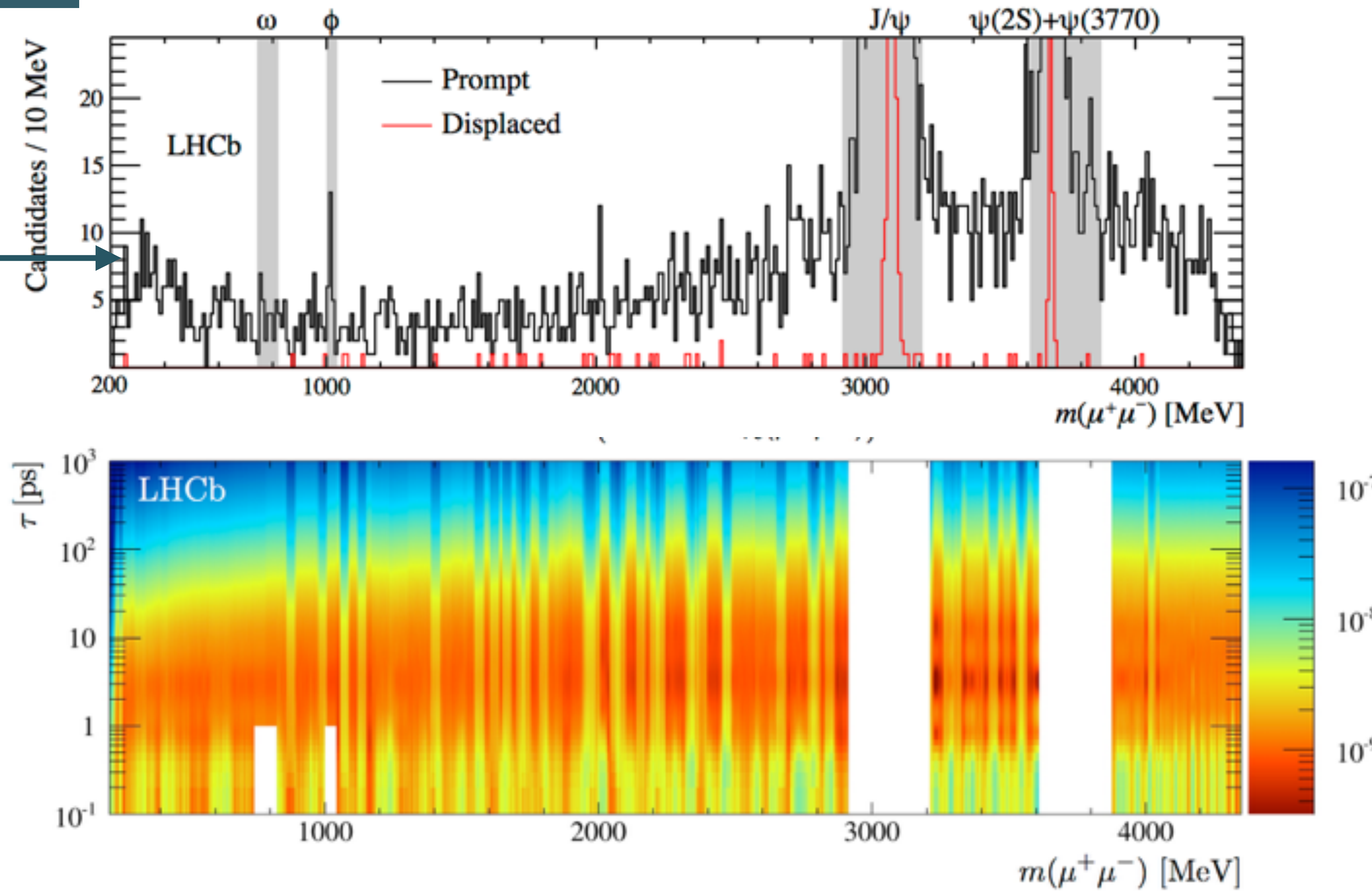



# μμ spectrum

Study the μμ spectrum within 50 MeV/$c^2$ of the $B^0$ mass

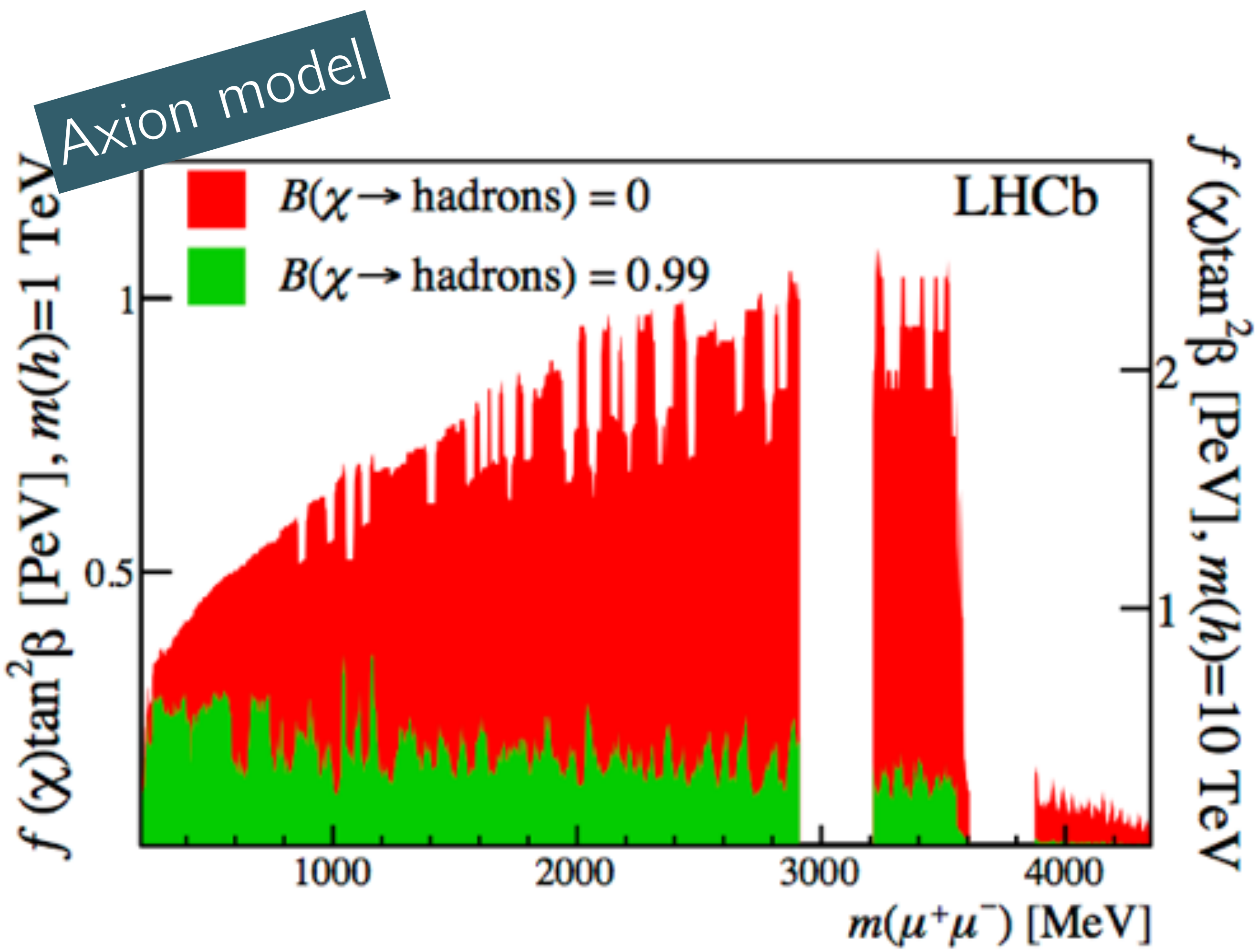
most significant local excess

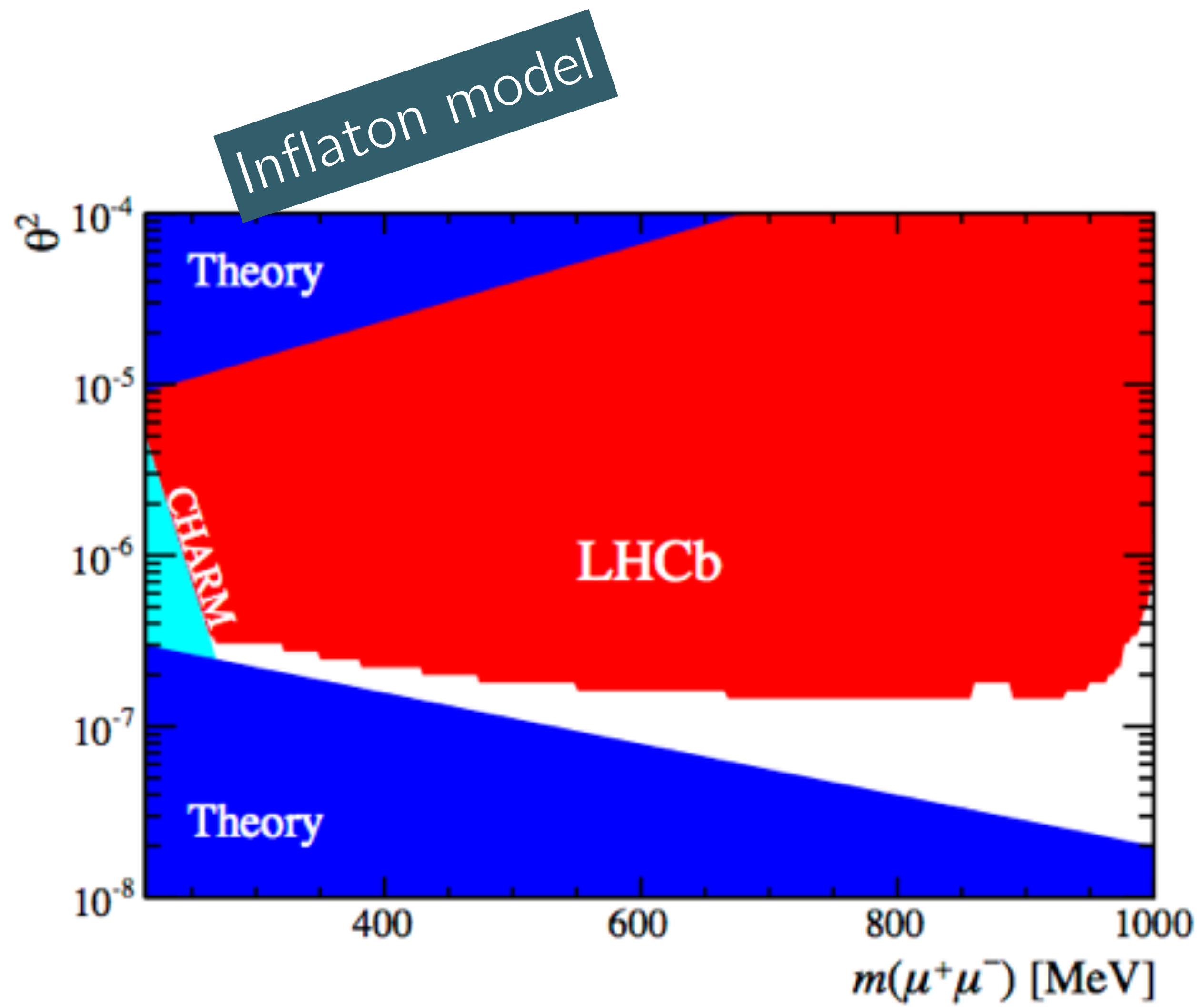
p-value of the no signal hypothesis is 80%



# Implications

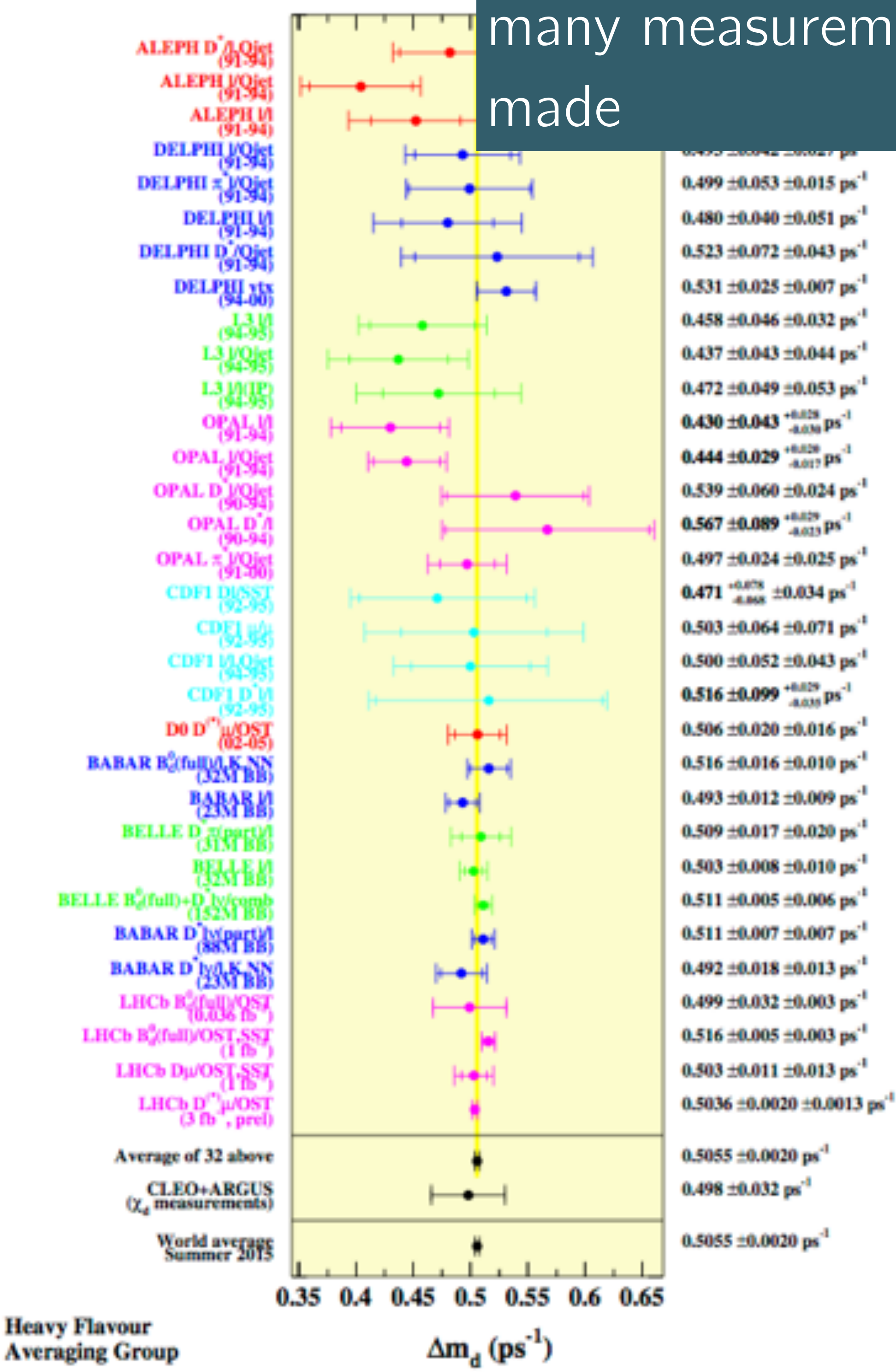
- Can use upper limits to exclude regions of parameter space given various models.
- 2 chosen are :
  - Axion model of Freytsis, Ligeti, and Thaler (arXiv:0911.5355)
  - Inflaton model of Bezrukov and Gorbunov (arXiv:1403.4638)



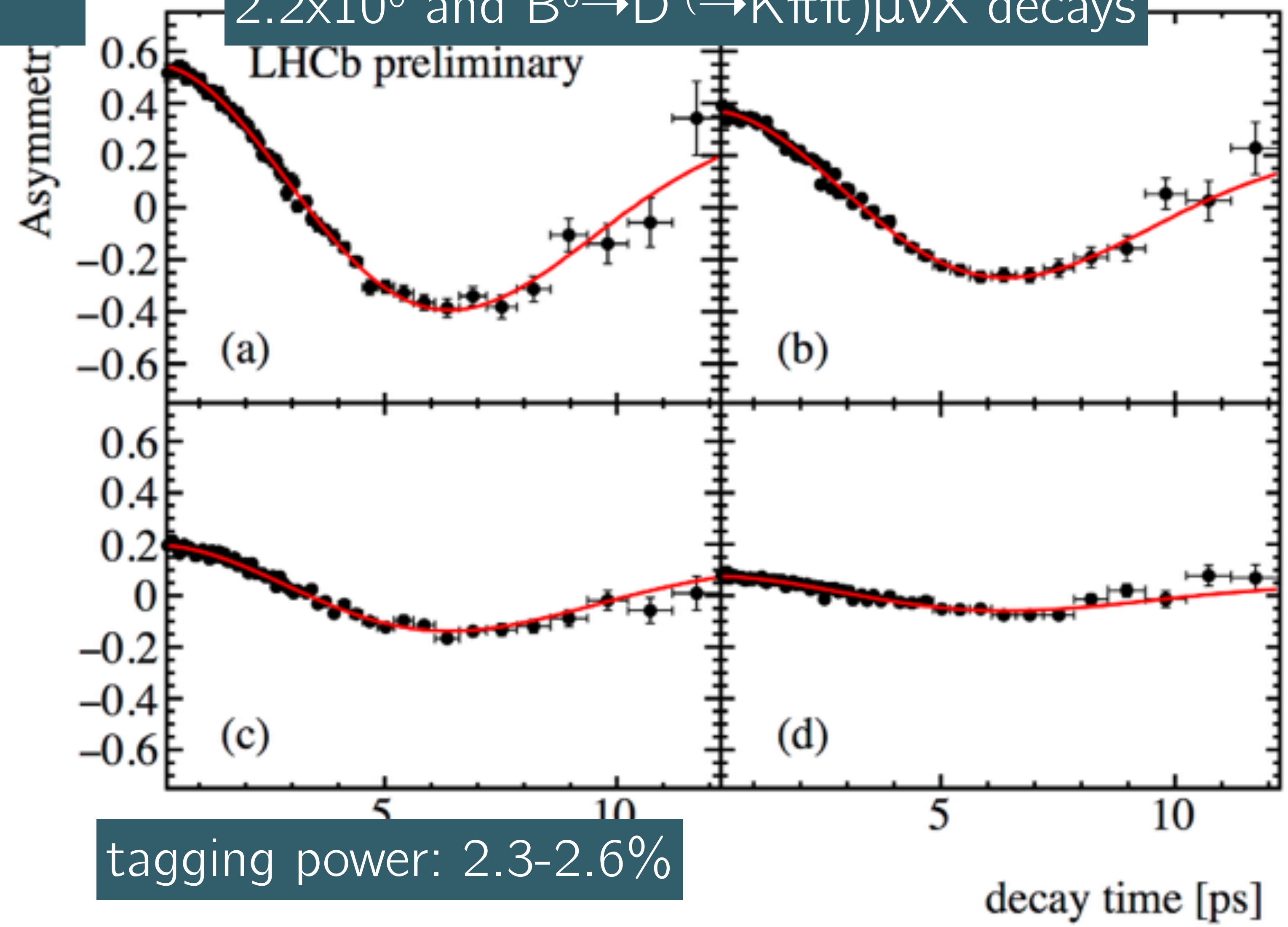



# Measurement of $\Delta m_d$ in semi-leptonic decays, LHCb-CONF-2015-003, LHCb-PAPER-2015-031 in preparation

many measurements made




Use $8.2\times10^5$ $B^0\to D^{*-}(\to D^0\pi^-)\mu\nu X$ and $2.2\times10^6$ and $B^0\to D^-(\to K\pi\pi)\mu\nu X$ decays




tagging power: 2.3-2.6%

Work ongoing to improve systematic uncertainties, expect improvements.

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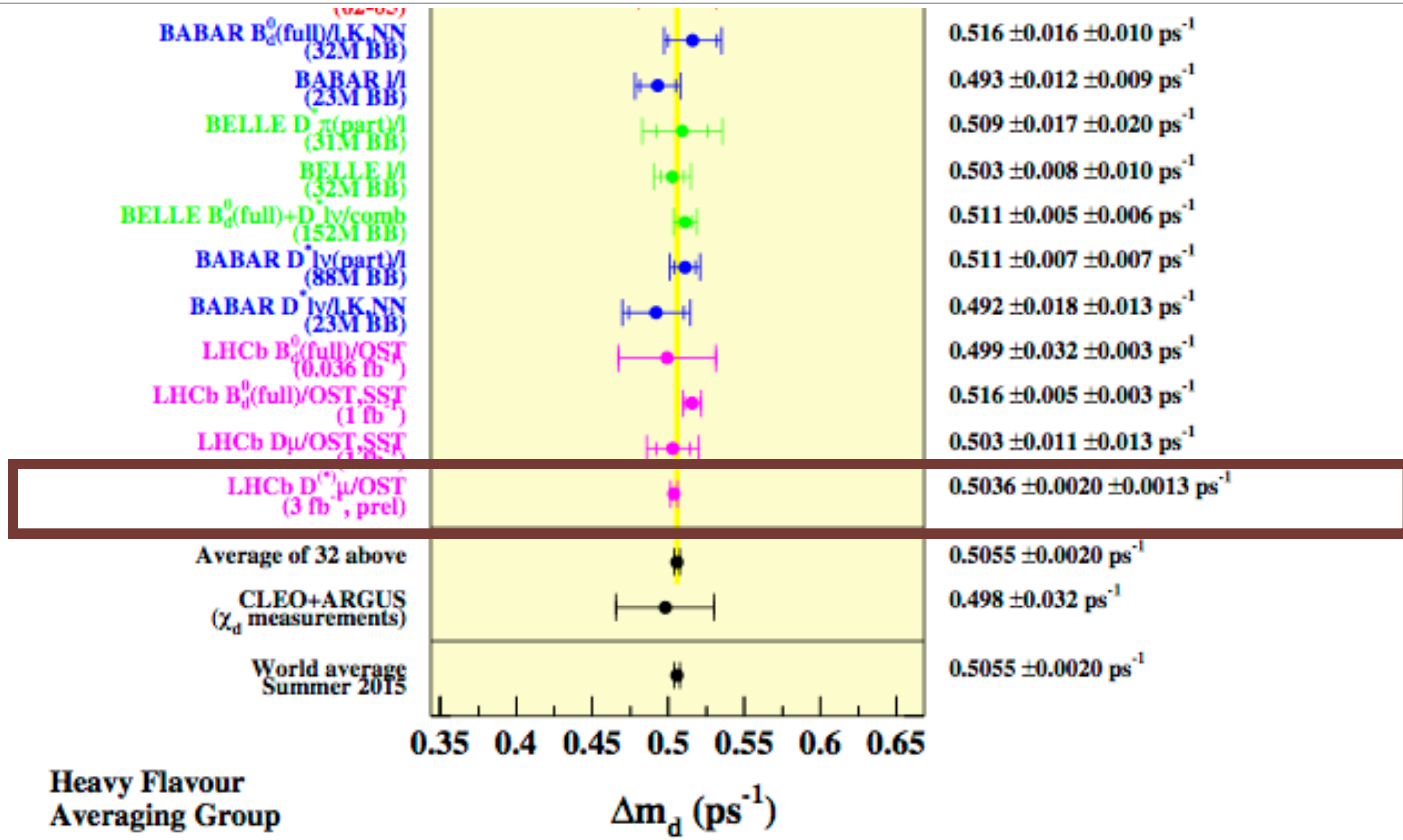



Preliminary result:
$\Delta m_d = (503.6 \pm 2.0 \pm 1.3)\ ns^{-1}$

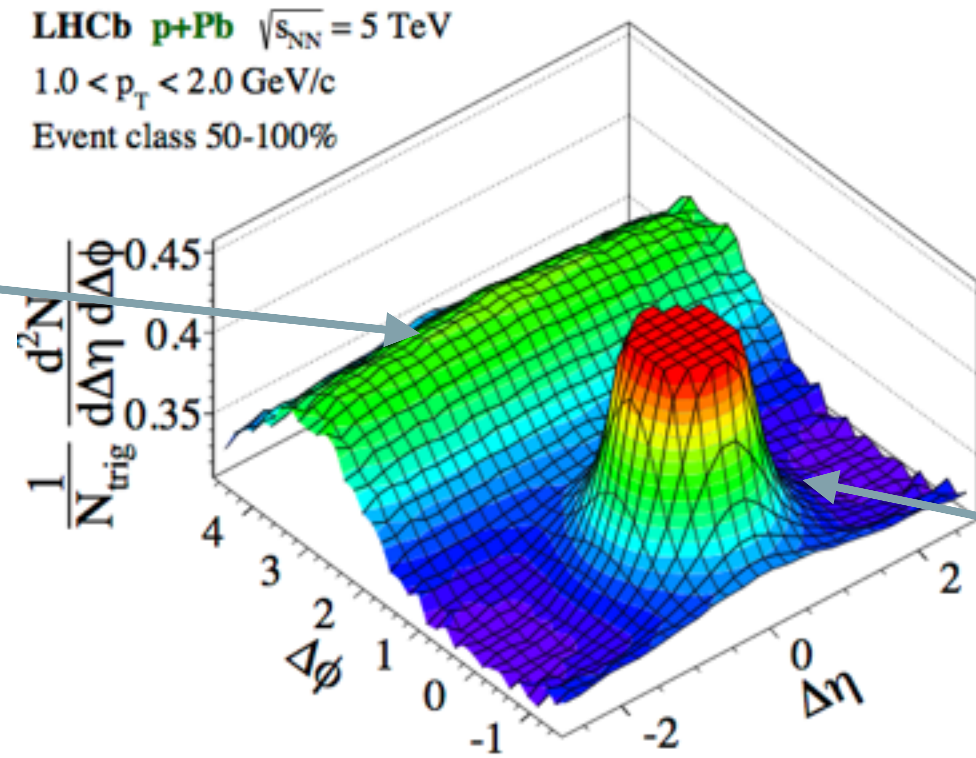
Most accurate single measurement
PDG average without: $\Delta m_d = (510 \pm 3)\ ns^{-1}$
PDG average with: $\Delta m_d = (505.5 \pm 2.0)\ ns^{-1}$

# Two particle correlations in p-Pb collisions at 5TeV, LHCb-CONF-2015-004

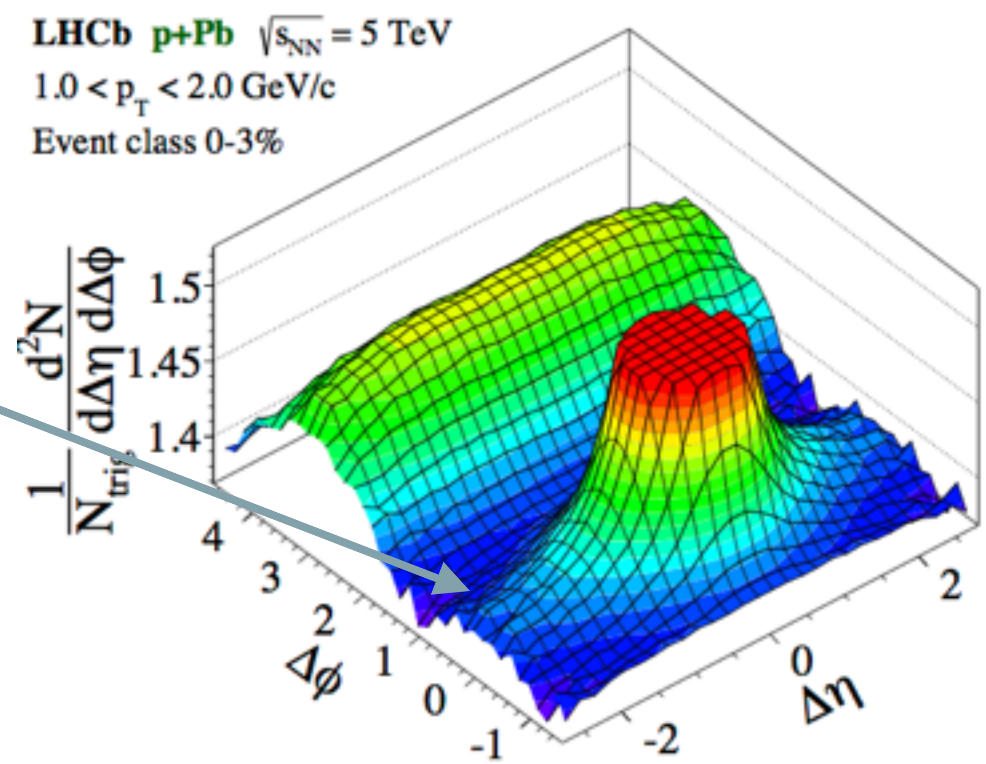
Study Δη and Δϕ in pPb collisions to probe collective effects

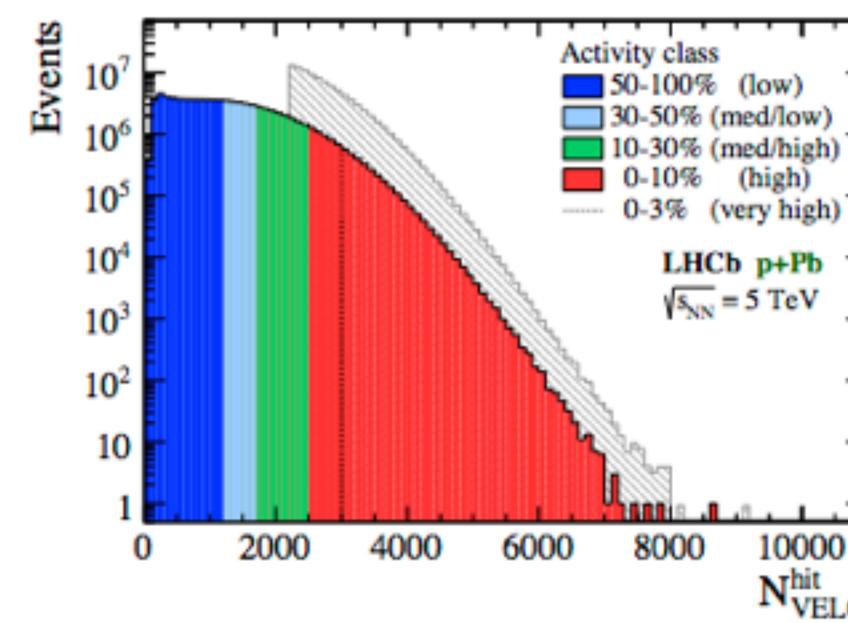
Conservation of momentum so corresponding far side ridge

Isolated structure dominates at (0,0) due to fragmentation around the initial parton



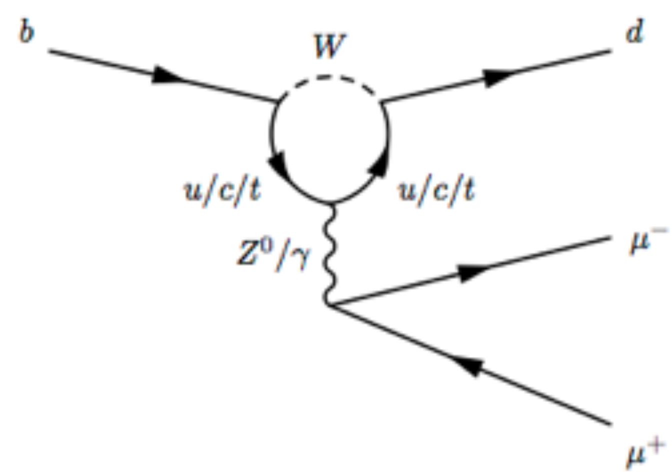

In large events, strong interactions with the media cause near-side ridge

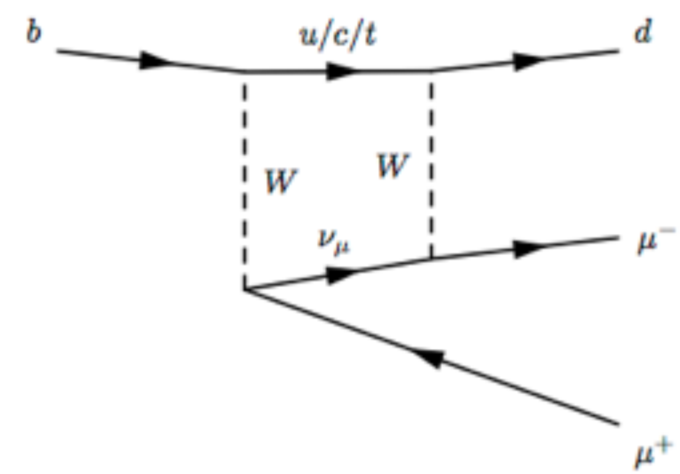


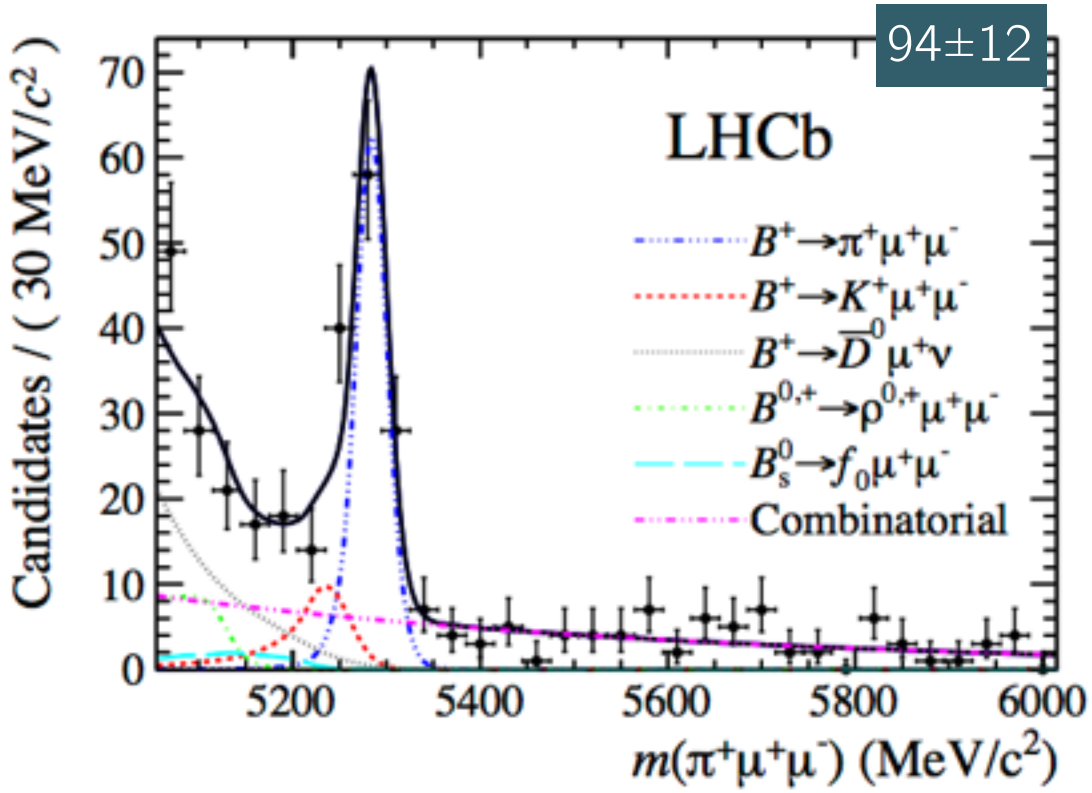



# Analysis of B→πμμ, arXiv:1509.00414

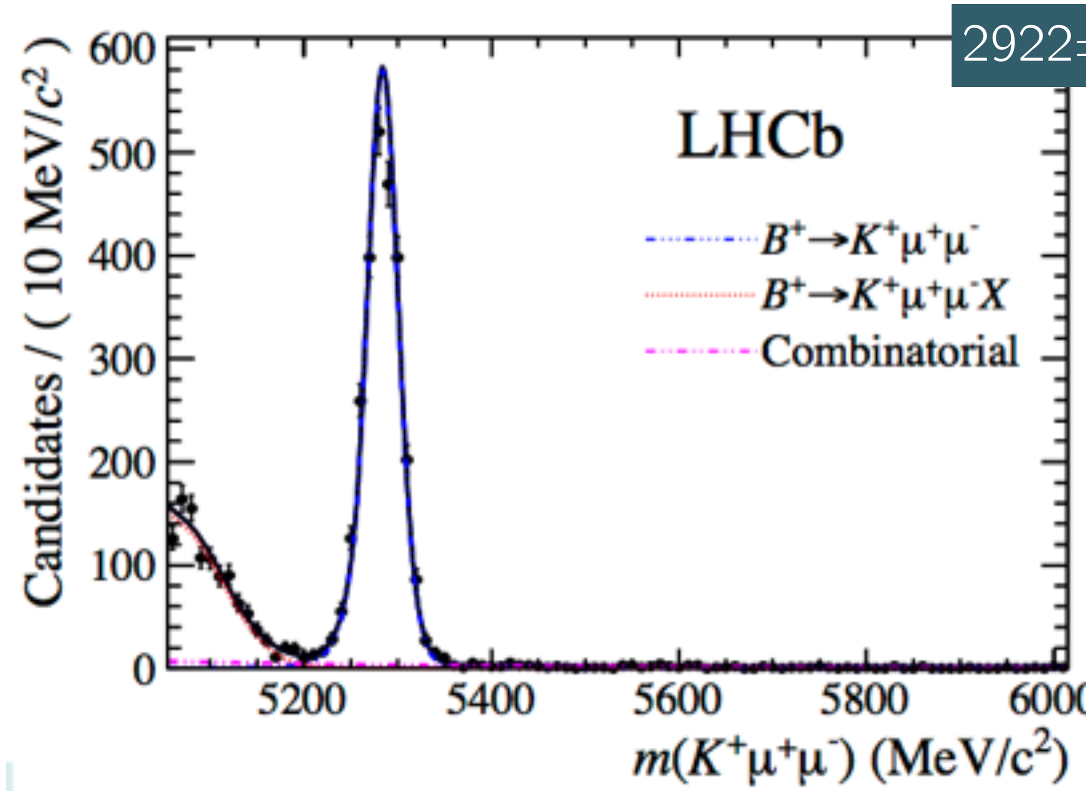
b→d FCNC transition




94±12




2922±55

$\mathfrak{B}(B\to\pi\mu\mu) = (1.83\pm0.24\pm0.05)\times10^{-8}$

Relative BF gives access to:
$|V_{td}|/|V_{ts}| = 0.24^{+0.05}_{-0.04}$

# Not finished…

- Lots more analyses still to come from Run 1 data.
- New ideas for analyses being thought of continually.
  - Inclusive trigger strategy and lots of collision data.

Electroweak cross-sections

$B_s \to \varphi\gamma$

Analyses of LFV

Many charm CP violation measurements, more $\gamma$ measurements

$B^0 \to K^*\mu\mu$

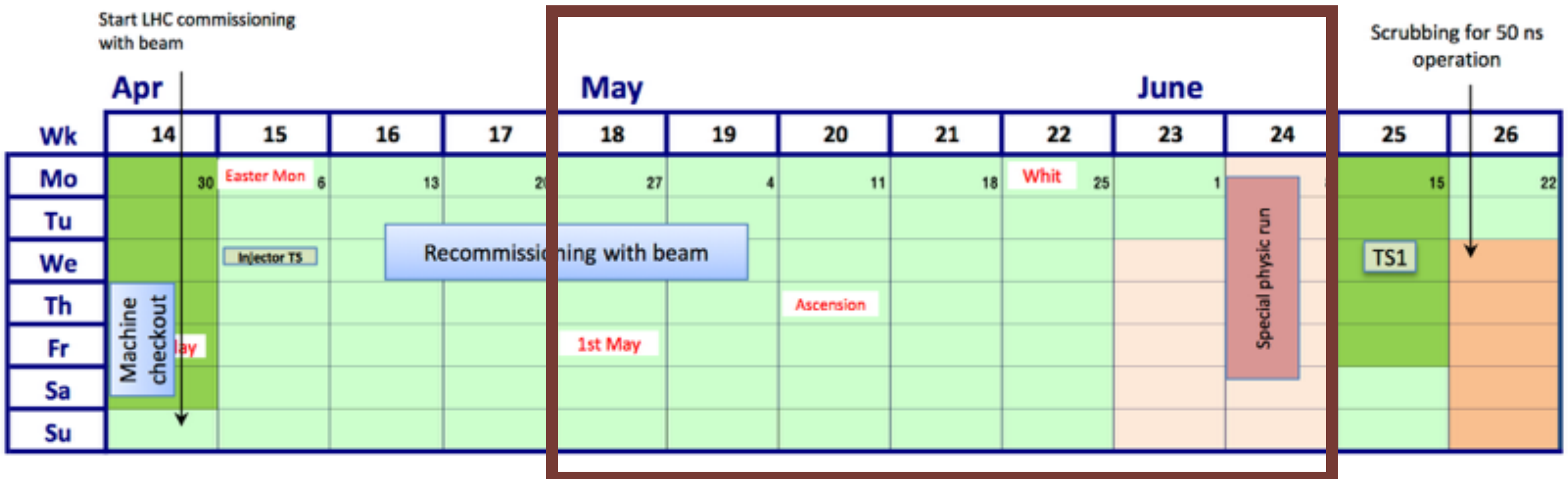
Charm spectroscopy

Electroweak cross-sections

many others…

# Run 2 commissioning and first results…

# Timeline so far this year…




- 21st May: First 13 TeV collisions delivered.
- June: Detector commissioning with data begins. Calibration runs taken.

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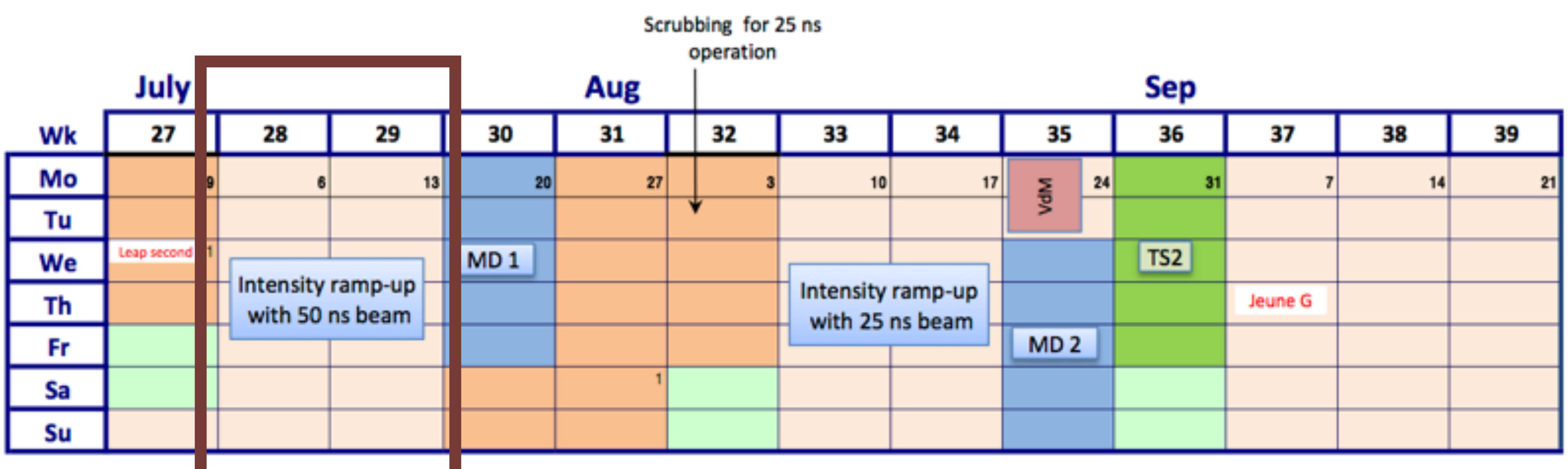


- Early July: 50ns ramp, early measurements data-taking period.

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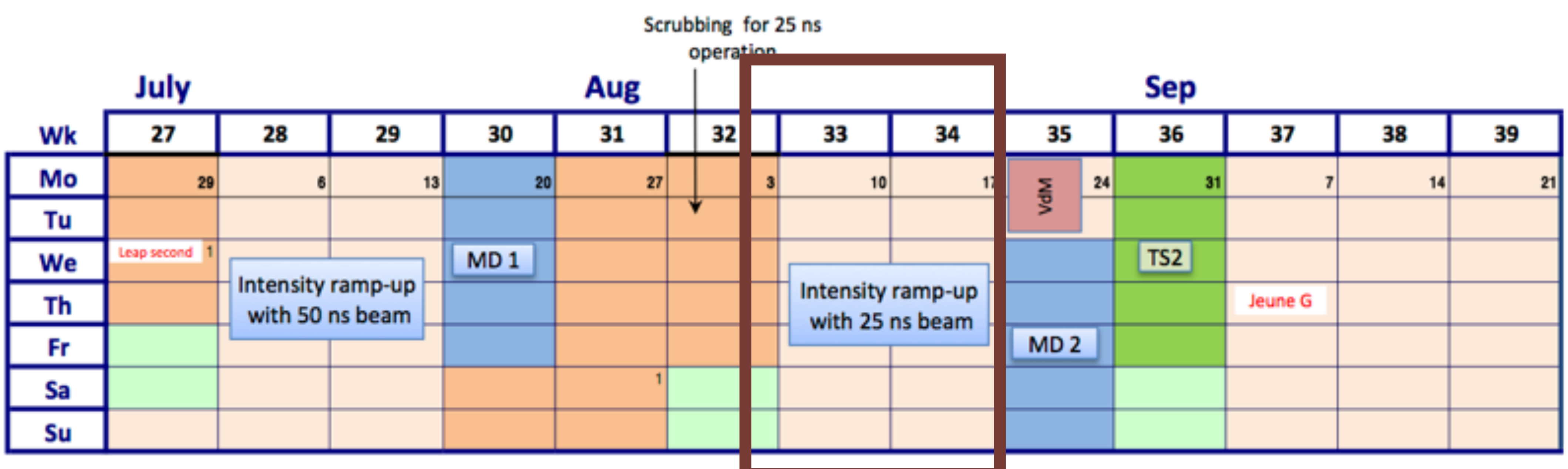


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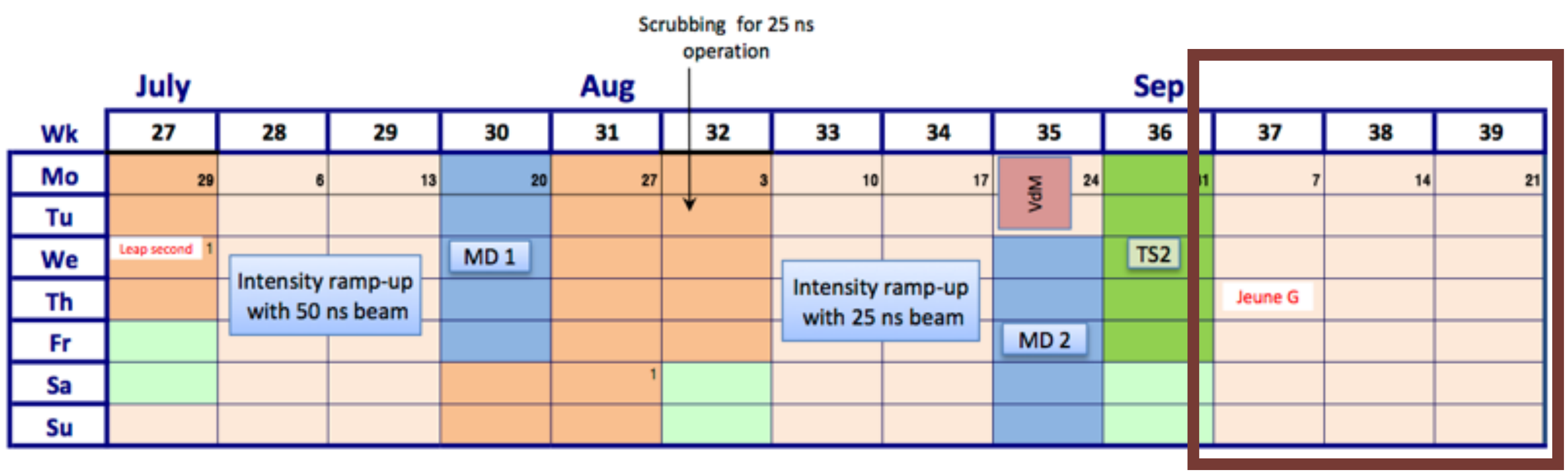


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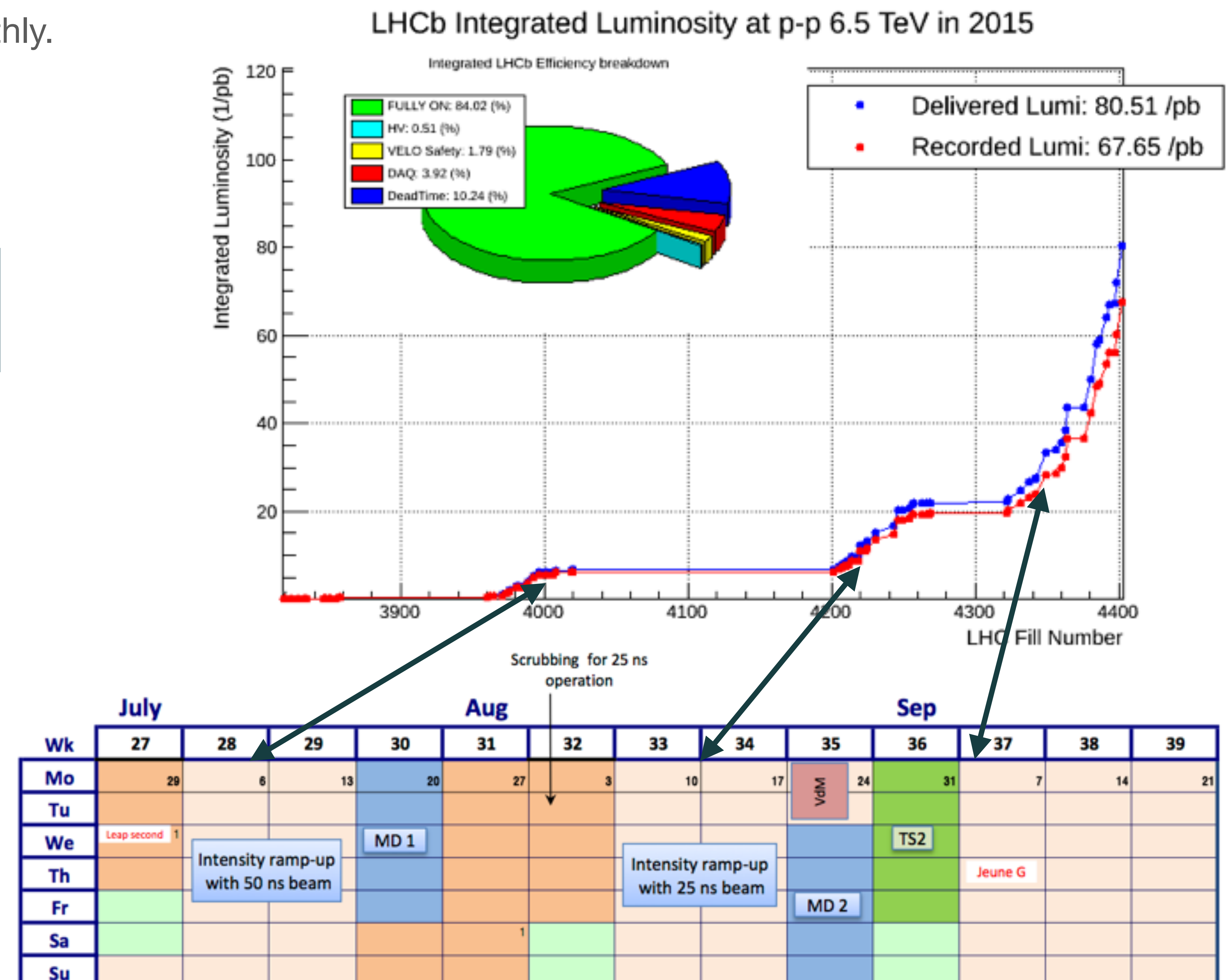
- Mid-August: End early measurements data-taking and move to 25ns core physics program in 25ns ramp.
- Early September: New tunings implemented, stable core physics data-taking.

# Run 2 data taking

- Data taking running smoothly.

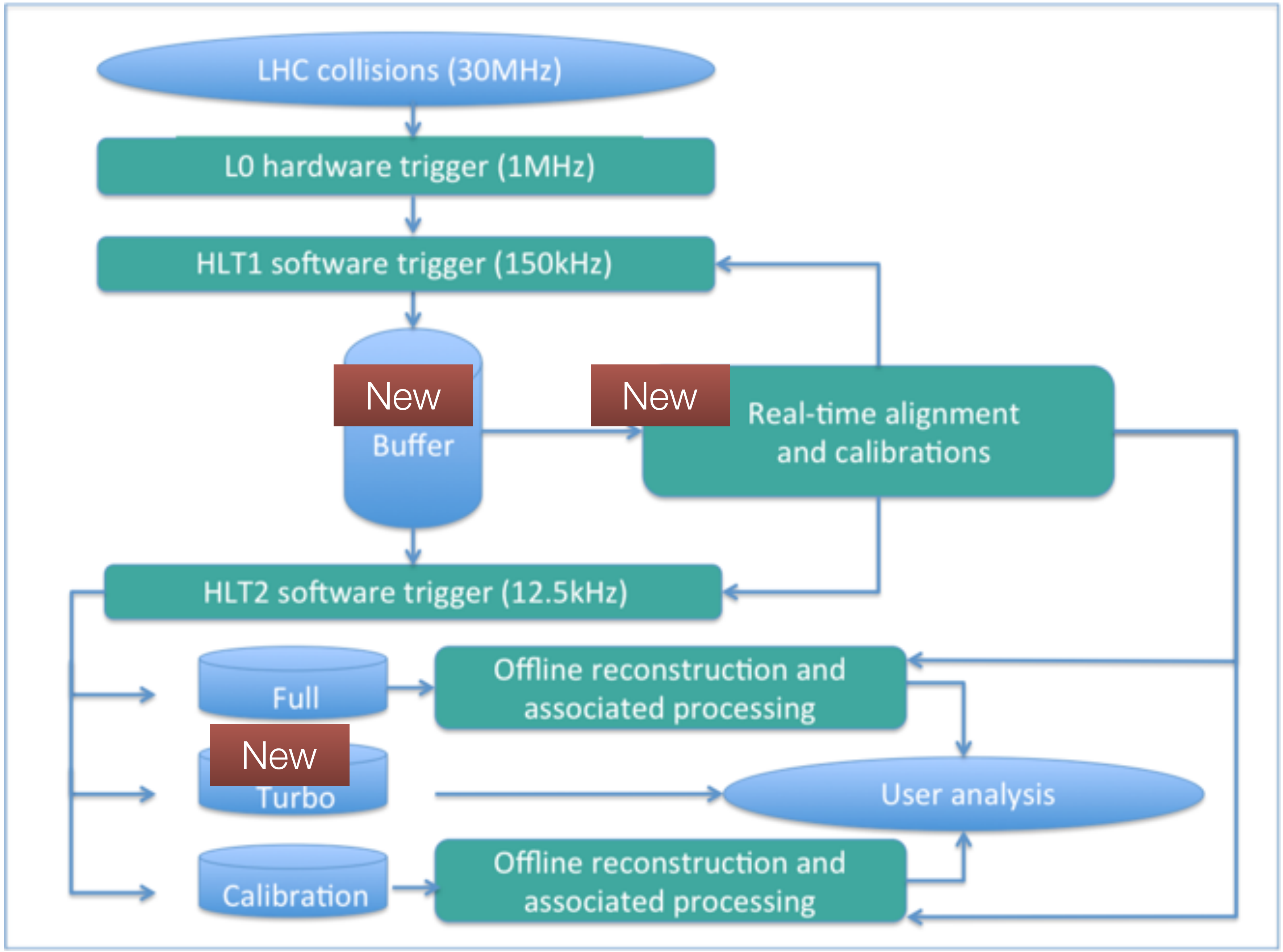
- Luminosity levelling at fixed pileup: μ=1.1

- Early measurements for 50ns ramp and part of 25ns ramp.
- Core physics program from end of August onwards.



# What's new in Run 2

- New strategy in Run 2 - upgrade to the Event Filter Farm gives us 27k physical cores (~55k logical cores) in the HLT and ~5PB disk space.
- Upgraded farm nodes 2x more powerful than those used in Run 1.

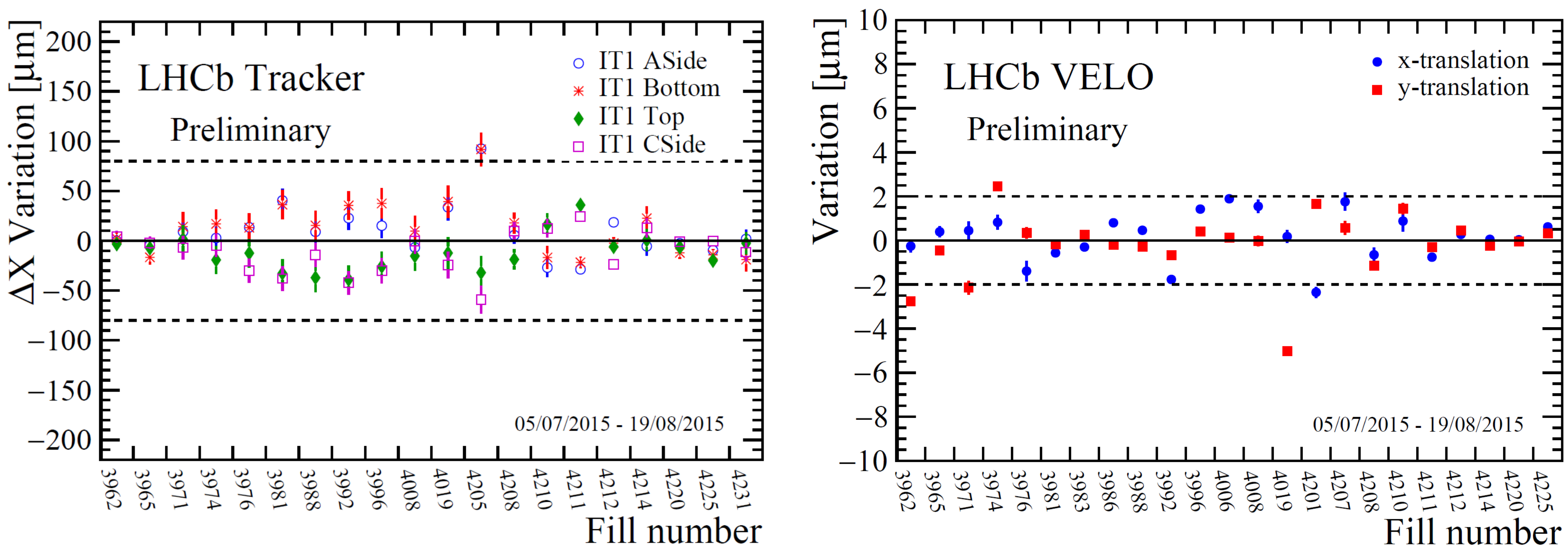


# Real-time alignment and calibrations

- Calibration and alignment performed at each fill (updated written when needed)
  - VELO and tracking alignment
  - OT $t_0$ calibration
  - RICH refractive index calibration
  - RICH mirror alignment
  - Automatic voltage adjustment in the CALO to correct for detector ageing
  - …

aligns 1700 detector components and computes almost 2000 calibration constants (not including CALO)

VELO and tracking station alignment



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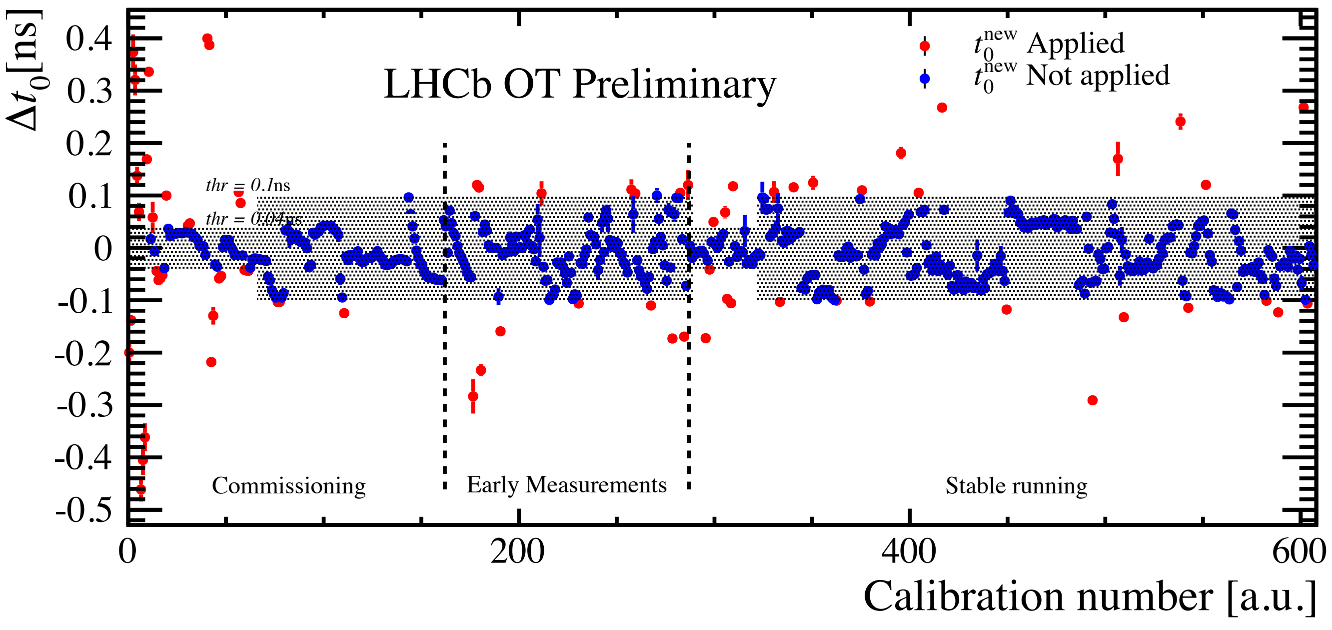
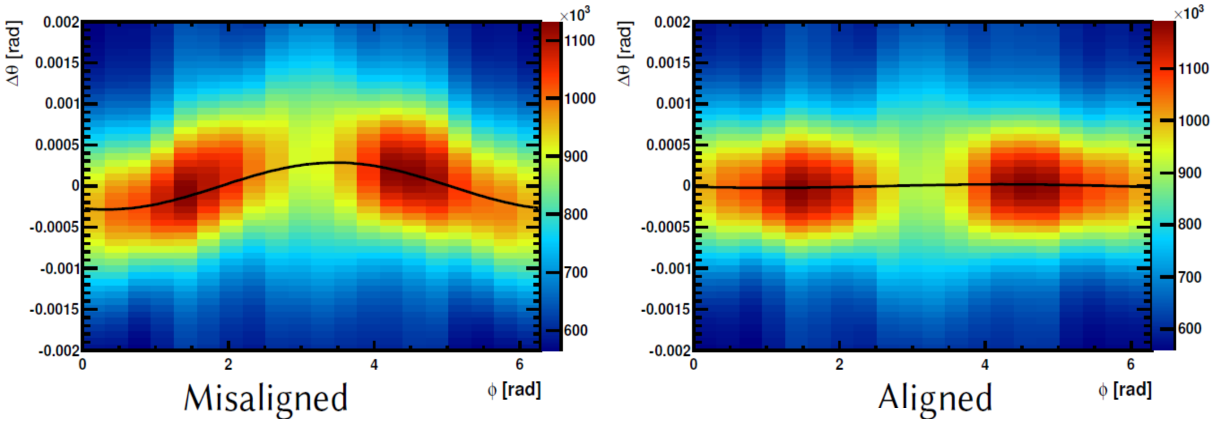
  - …

**Outer tracker $t_0$ calibration**



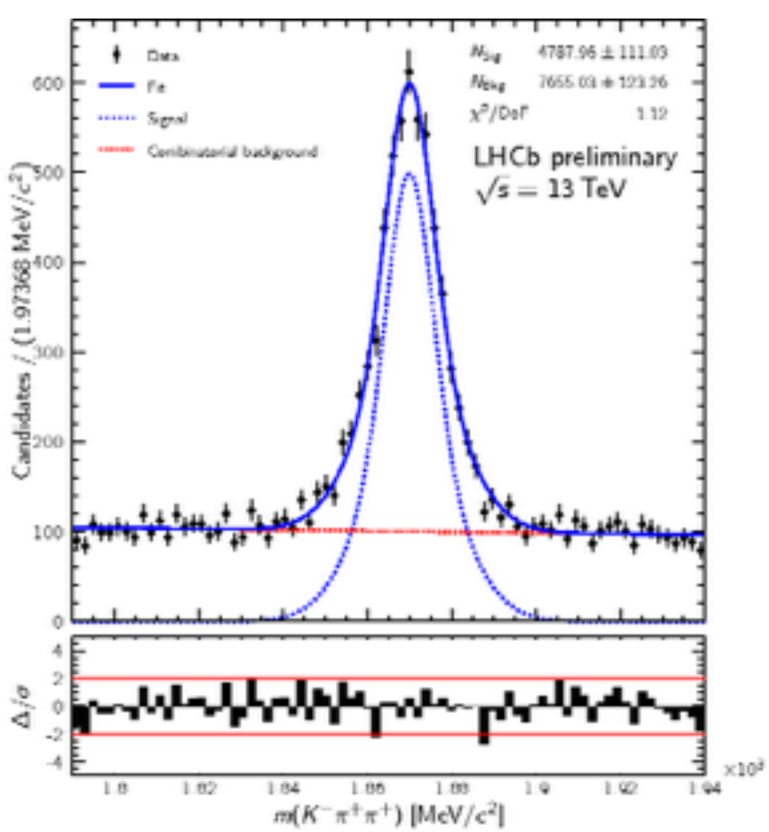

**RICH mirror alignment**



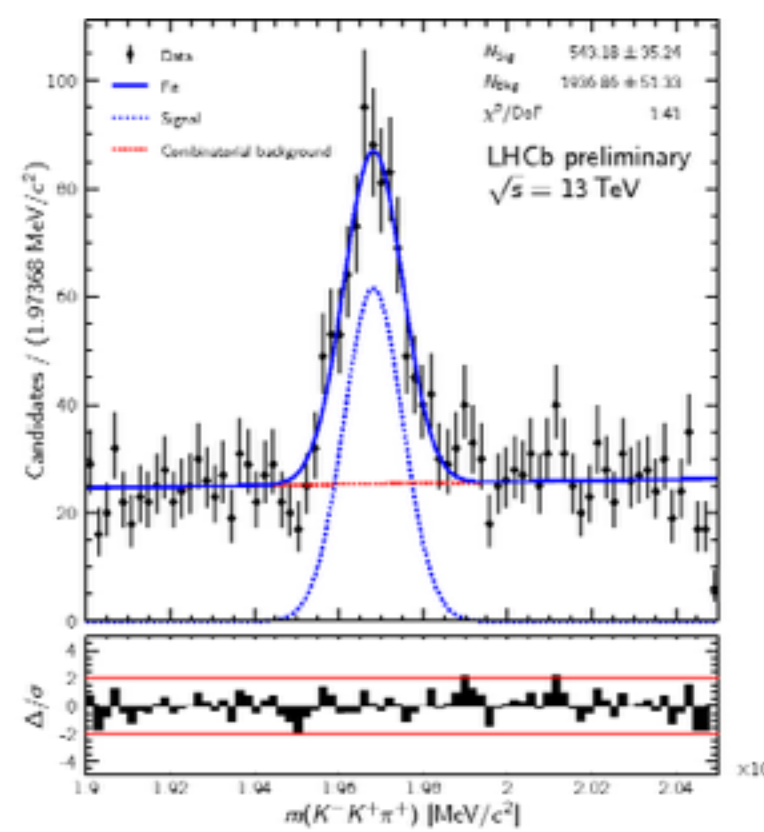
# Real-time alignment and calibrations

- Calibration and alignment performed at each fill (updated written when needed)
  - VELO and tracking alignment
  - OT $t_0$ calibration
  - RICH refractive index calibration
  - RICH mirror alignment
  - Automatic voltage adjustment in the CALO to correct for detector ageing
  - …

Direct HLT2 output



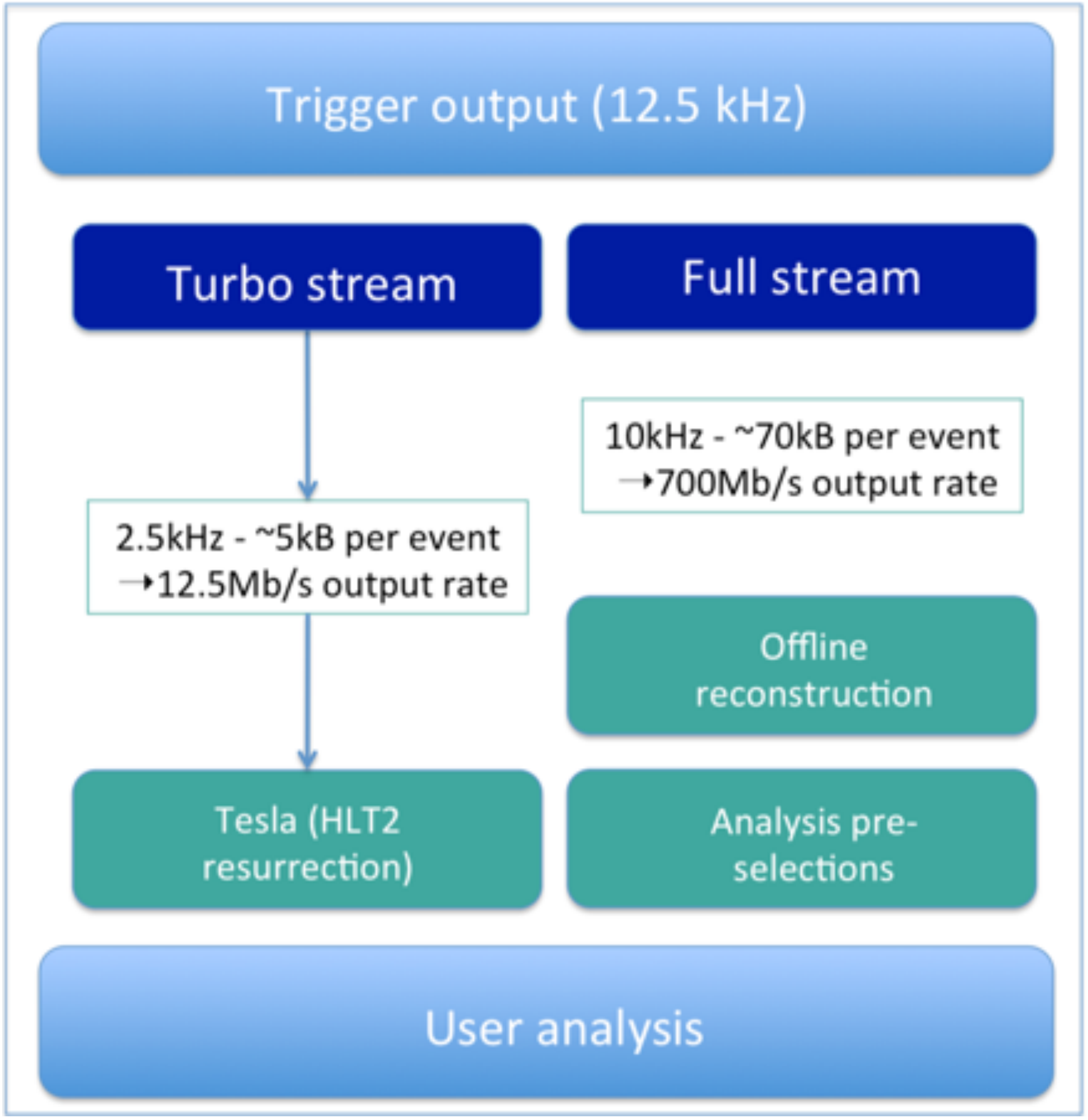

$D^+ \to K^-\pi^+\pi^+$




$D_s^+ \to K^-K^+\pi^+$

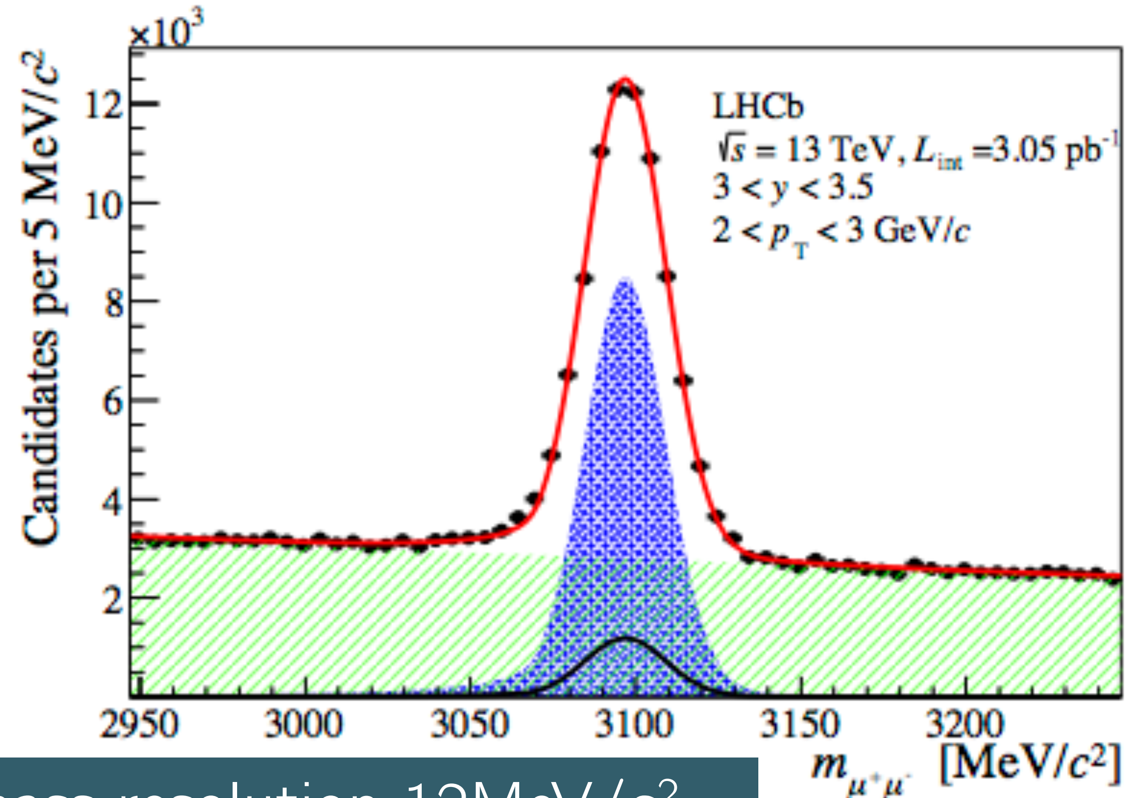
# The Turbo stream

- HLT reconstruction much closer to offline
- Offline quality particle identification in HLT2
- Introduced Turbo stream to saves HLT candidates only to reduce event size
- Turbo stream output does not need offline reconstruction and can be used directly to perform analysis.
- Lower bandwidth, lower waiting time…
- Made possible by real-time alignment




Of the 374 HLT2 lines in the 25ns core physics programme, 185 choose Turbo

# Turbo stream physics analysis - J/ψ production at 13TeV (arXiv:1509.00771)



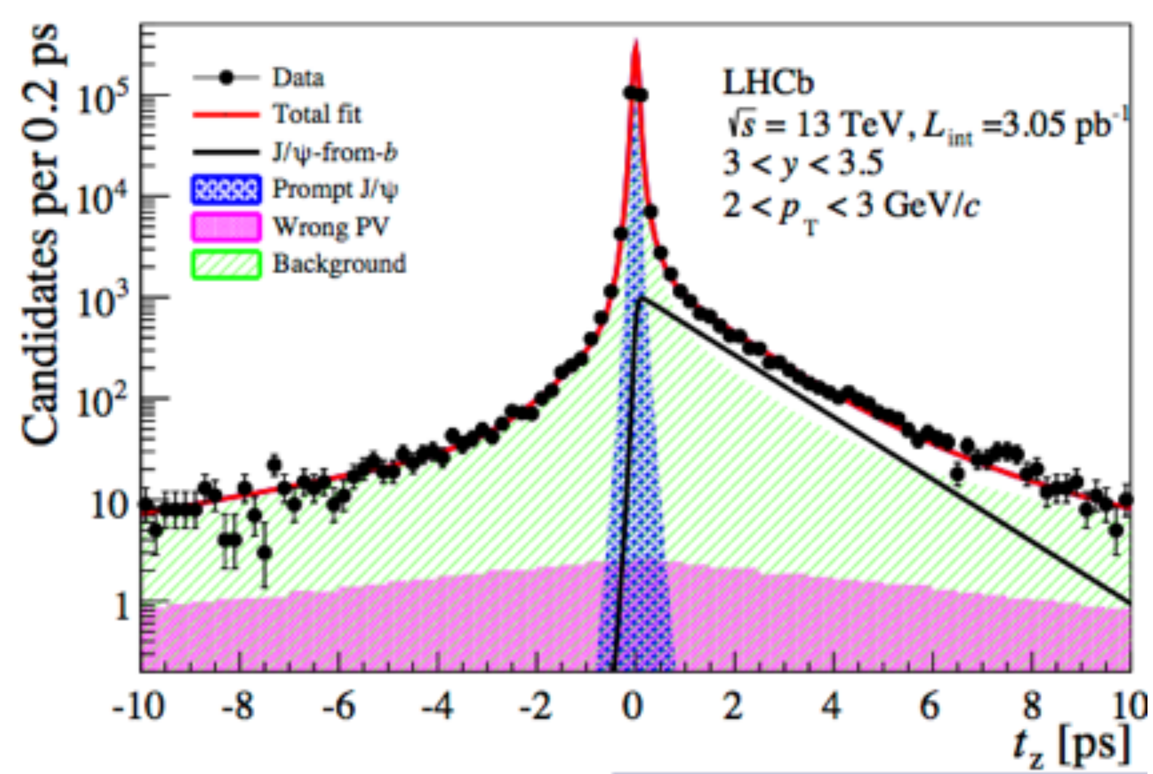

mass resolution 12MeV/c$^2$ consistent with Run 1 offline

Analysis finds ~$10^6$ candidates directly from the trigger.

No further reconstruction, all necessary information is persisted from the trigger

Component from B decays found from $t_z$ distribution

$$t_z = \frac{(z_{J/\psi} - z_{PV}) M_{J/\psi}}{p_z}$$



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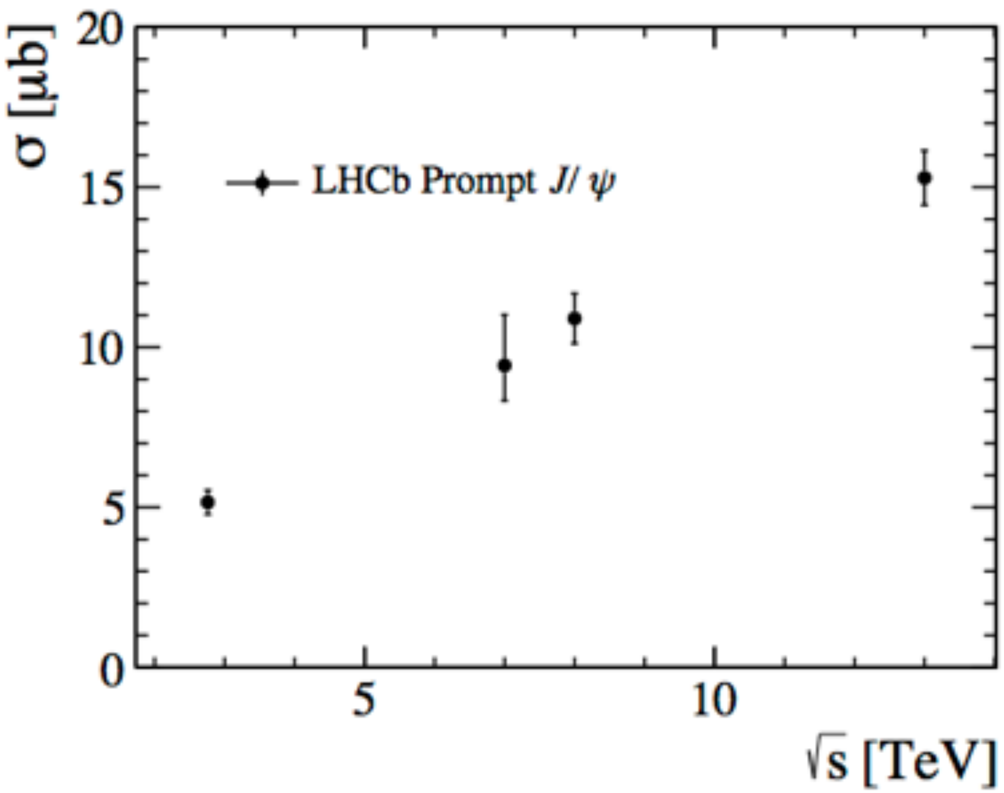
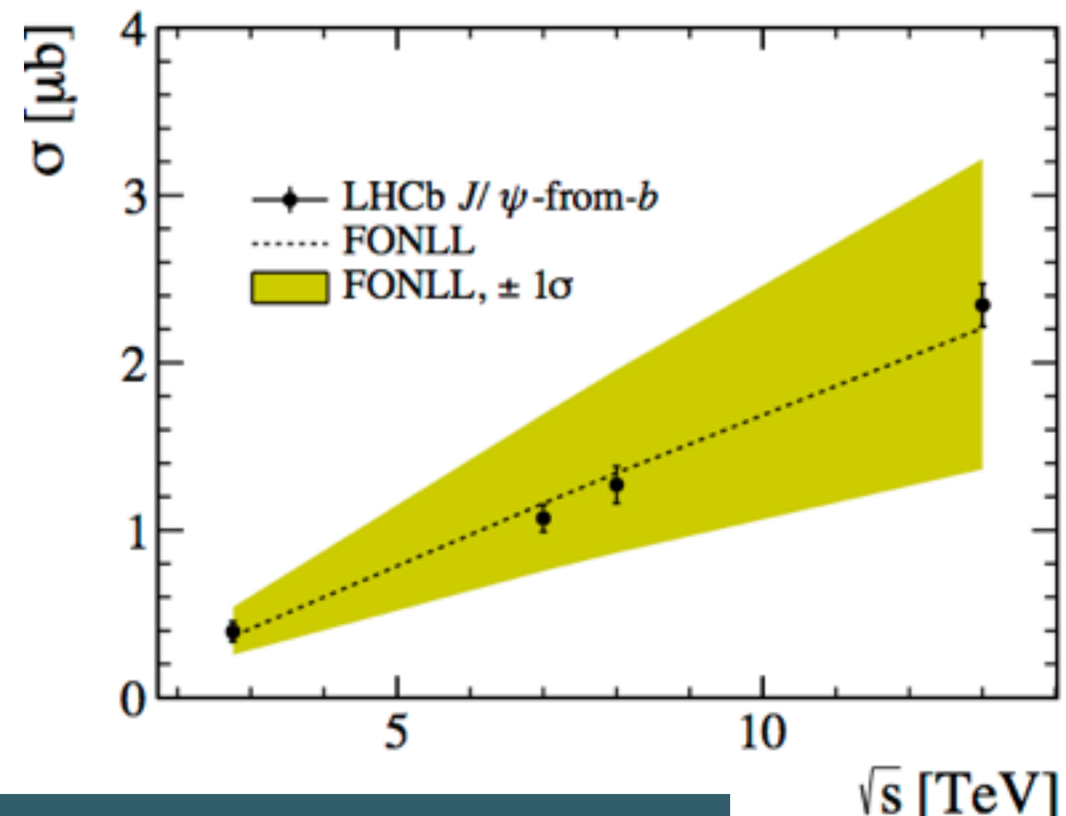



Total cross-sections:

$\sigma(J/\psi) = 15.30 \pm 0.03 \pm 0.86\ \mu b$

$\sigma(J/\psi\text{ from } b) = 2.34 \pm 0.01 \pm 0.13\ \mu b$

- Applying naive scaling factor from Pythia of 5.2 provides: $\sigma_{b\bar{b}}(4\pi) = 515 \pm 2 \pm 53\ \mu b$

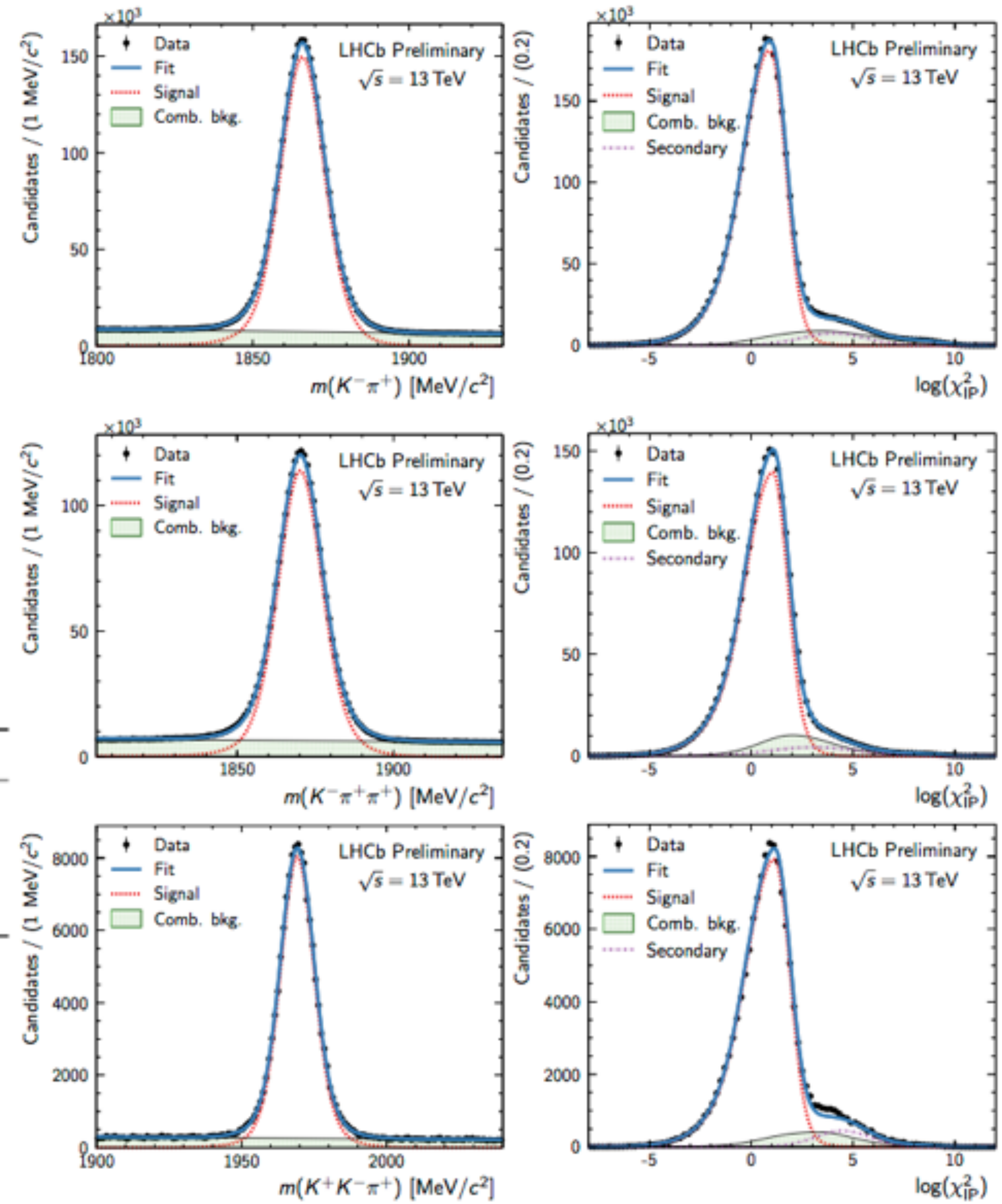
c.f. Yellow report of the 1999 workshop on Standard Model physics at the LHC (hep-ph/0003238) assumed 500μb (14TeV)

# Turbo stream physics analysis - Charm production at 13TeV (LHCb-PAPER-2015-041, in preparation)

- Analysis uses 5pb$^{-1}$ collected in July.
- Minimum bias trigger at L0 combined with Turbo Hlt2.
- $D^0 \to K^-\pi^+$, $D^+ \to K^-\pi^+\pi^+$, $D_s^+ \to \varphi\pi^+$ and $D^{*+} \to D^0\pi^+$ used to measure cross-sections.
- Integrated cross-section are determined in fiducial range

| | | | Extrapolation factor | Cross-section (μb) |
|---|---|---|---|---|
| $D^0$ | $0 < p_T < 8\,\text{GeV}$ | $2 < y < 4.5$ | $1.0005 \pm 0.0009$ | $2920 \pm 3 \pm 158 \pm 166$ |
| $D^+$ | $0 < p_T < 8\,\text{GeV}$ | $2 < y < 4.5$ | $1.058 \pm 0.033$ | $2516 \pm 11 \pm 228 \pm 213$ |
| $D_s^+$ | $1 < p_T < 8\,\text{GeV}$ | $2 < y < 4.5$ | - | $2490 \pm 31 \pm 265 \pm 700$ |
| $D^{*+}$ | $1 < p_T < 8\,\text{GeV}$ | $2 < y < 4.5$ | $1.0004 \pm 0.0023$ | $1897 \pm 13 \pm 187 \pm 254$ |

- $c\bar{c}$ cross-section measured to be $2.72 \pm 0.01 \pm 0.18 \pm 0.14$mb



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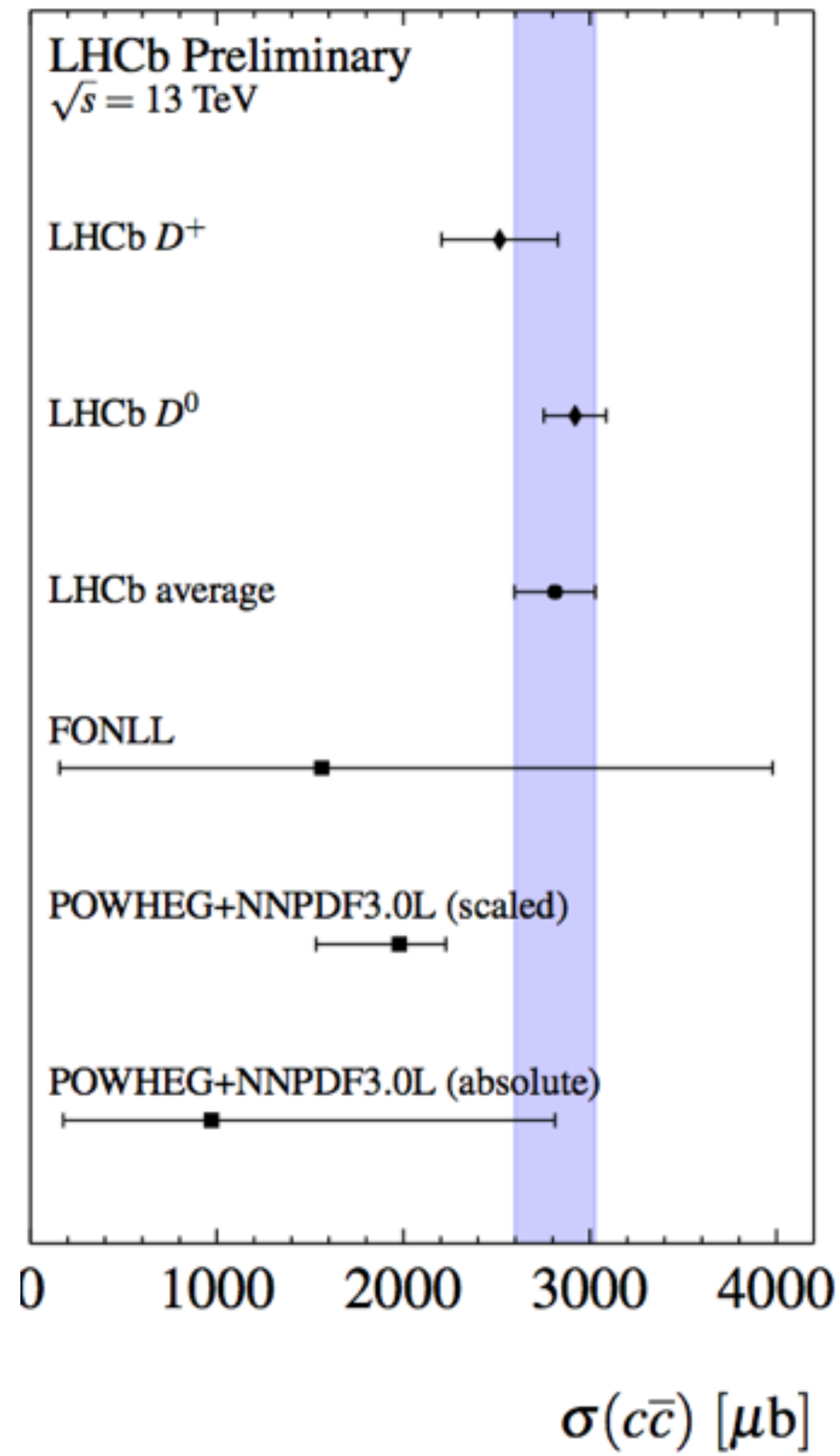
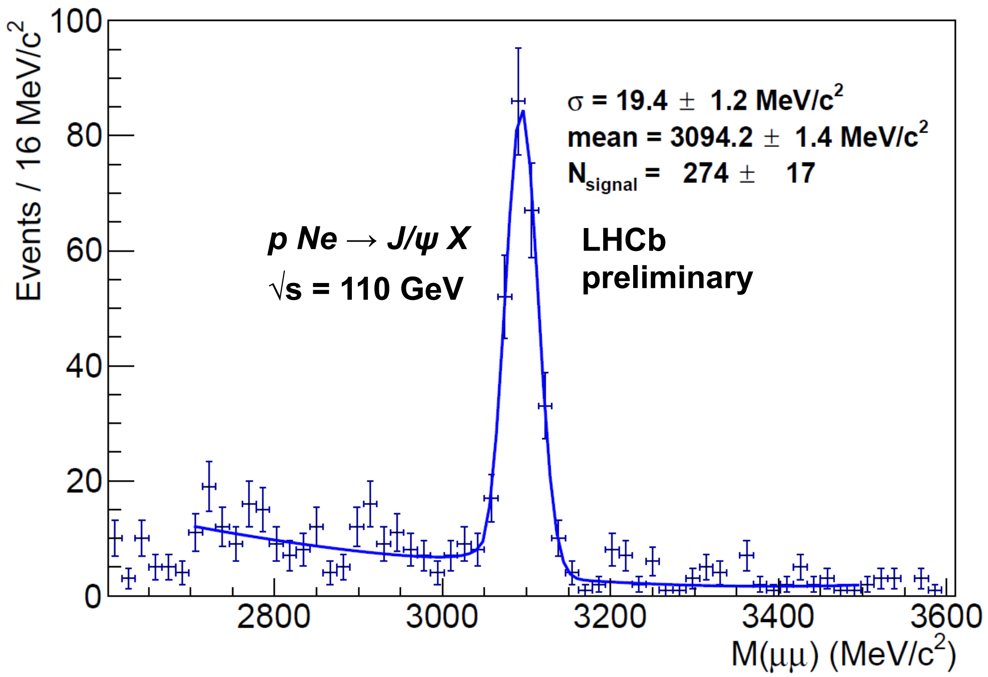
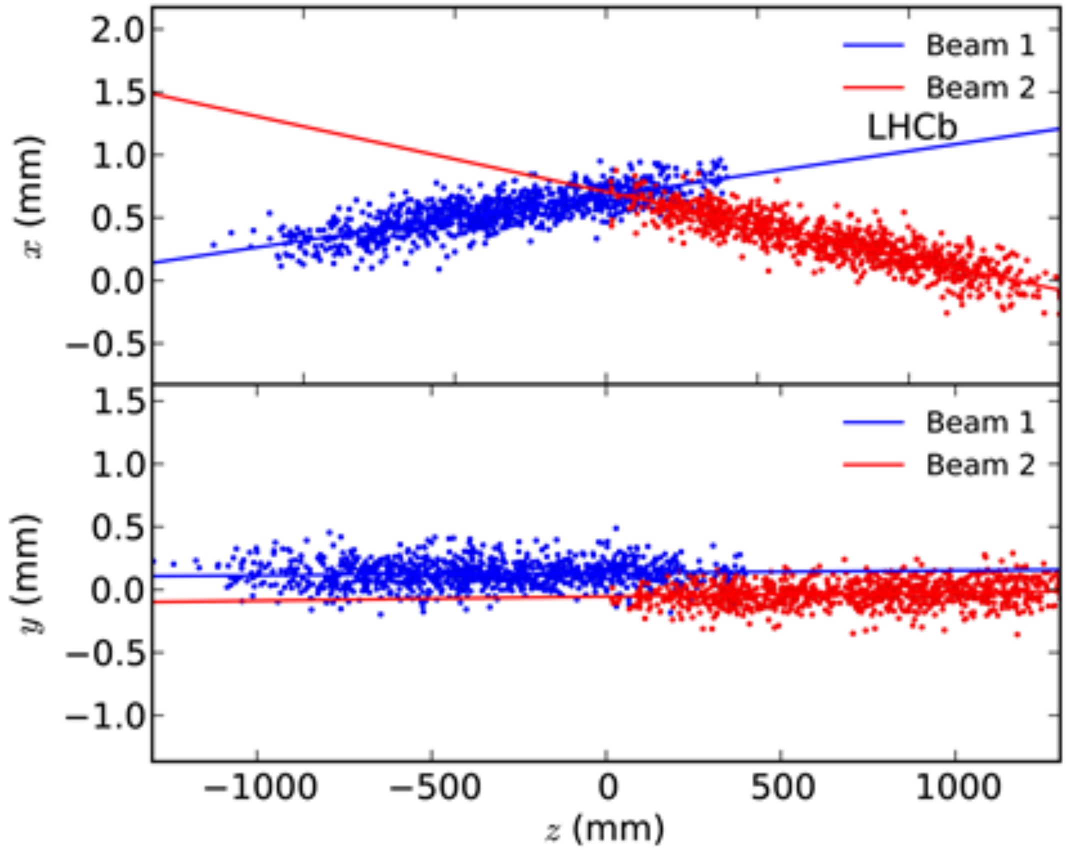


# SMOG

- J/ψ and prompt charm cross-sections calculated using luminosity determination from LHCb SMOG system, which injects gas and allows beam profiles to be imaged.
- Used also for dedicated fixed target measurements:

In Run 1, combined SMOG + Van der Meer scan gave lumi uncertainty of 1.1%



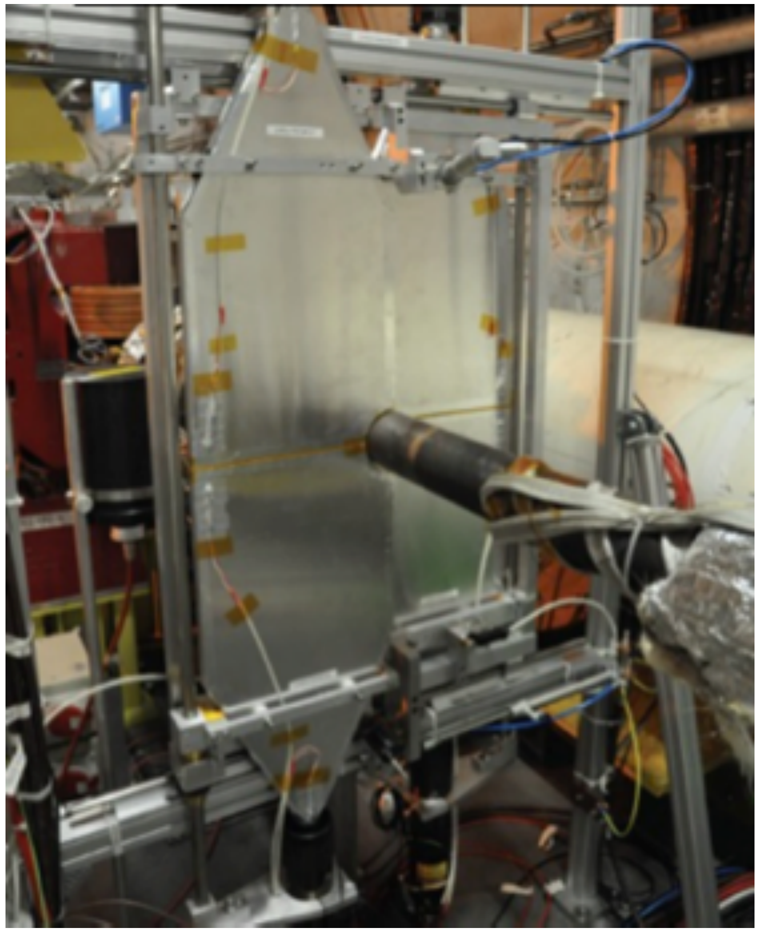

No Van der Meer in early 2015, SMOG alone gives 3.8% uncertainty

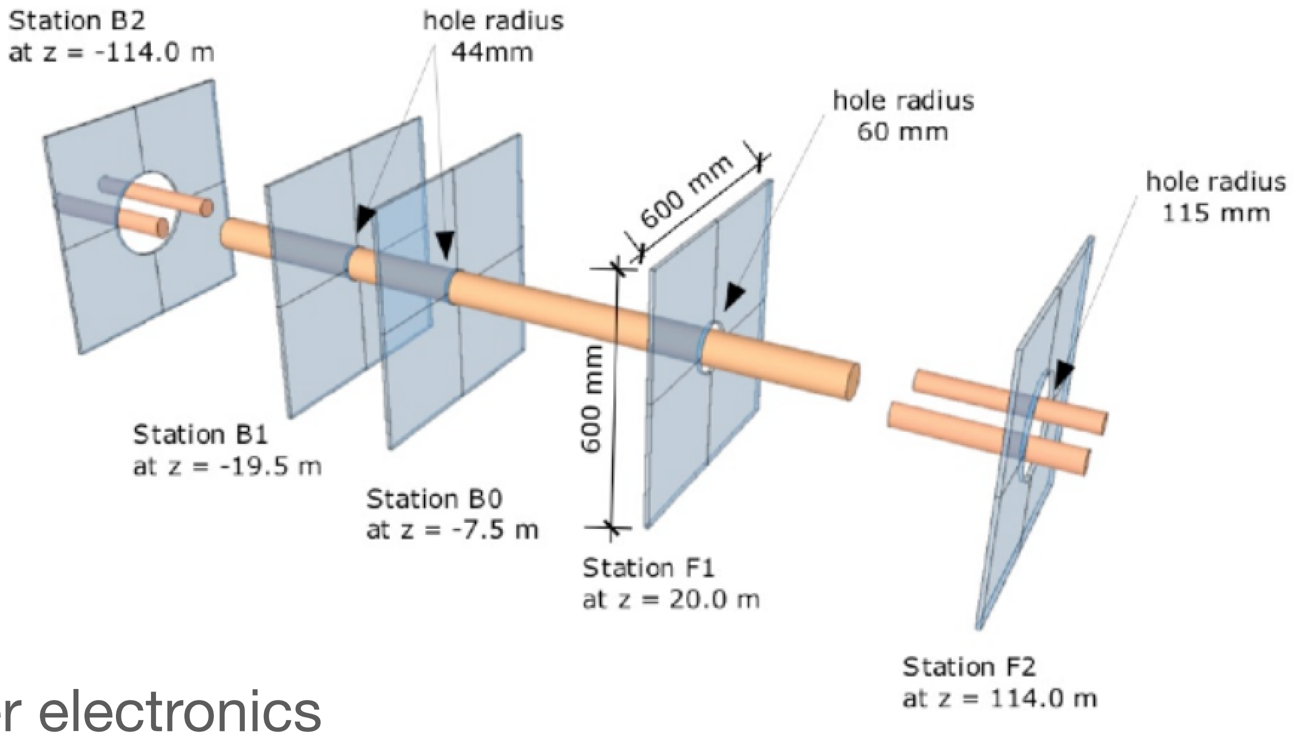
- Valuable ion physics measurements.
- LHCb participation in Pb-Pb collisions this year

Data also taken for p-He collisions, measuring σ (p He→ pbarX), which will be important as SM background to AMS/PAMELA antiproton ‘excess’

# Herschel

- Opportunity to study Central Exclusive Production (CEP) in Run II
- Need to tag background at very high rapidity ($5 < |\eta| < 8$)





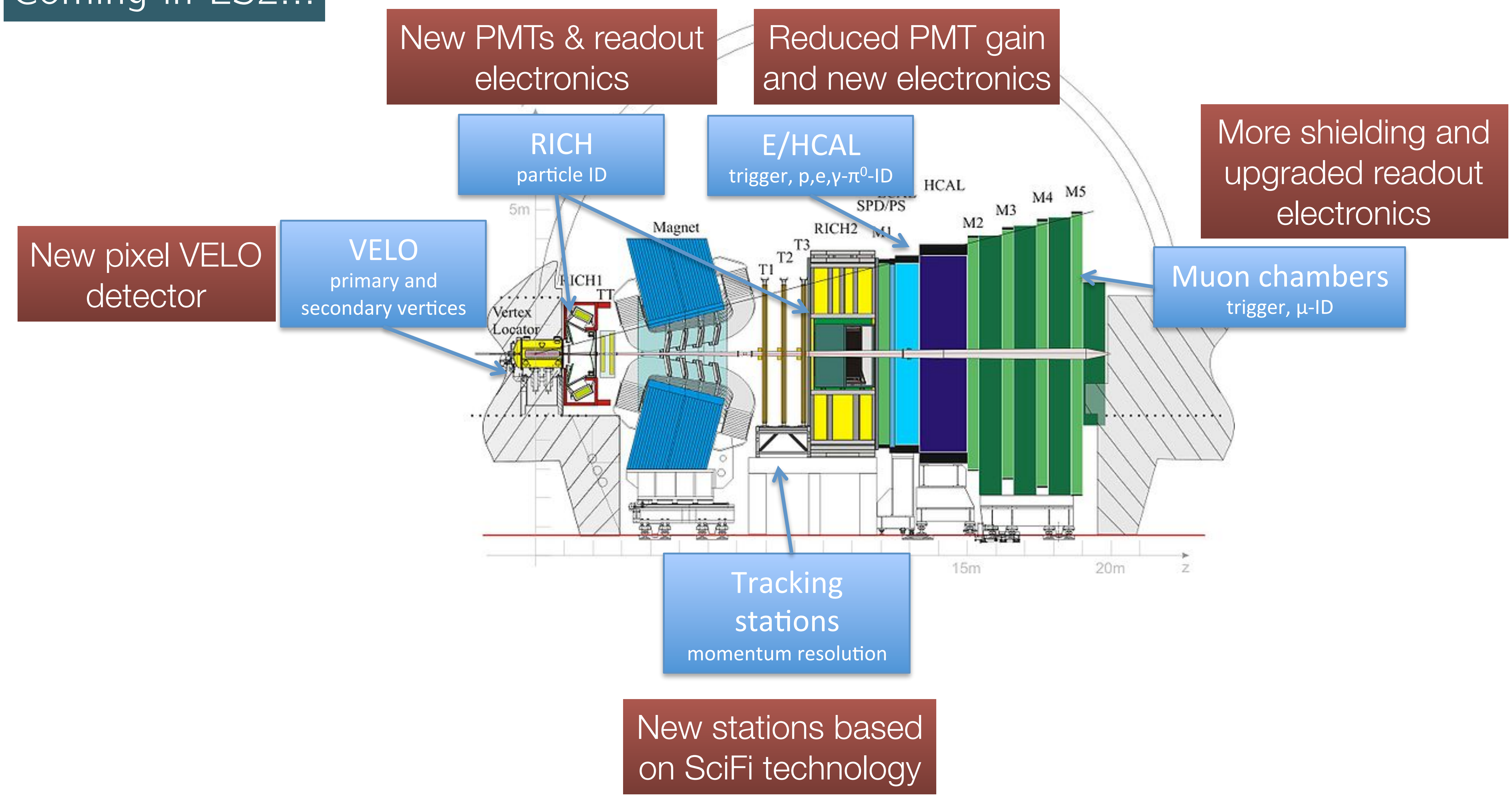

- Stations >100m from interaction region
- Detector installation completed
- Now taking collision data
- Final commissioning of readout and trigger electronics

# Upgrade status…

# LHCb upgrade reminder

40MHz readout of all sub-detectors and data processed with software triggers

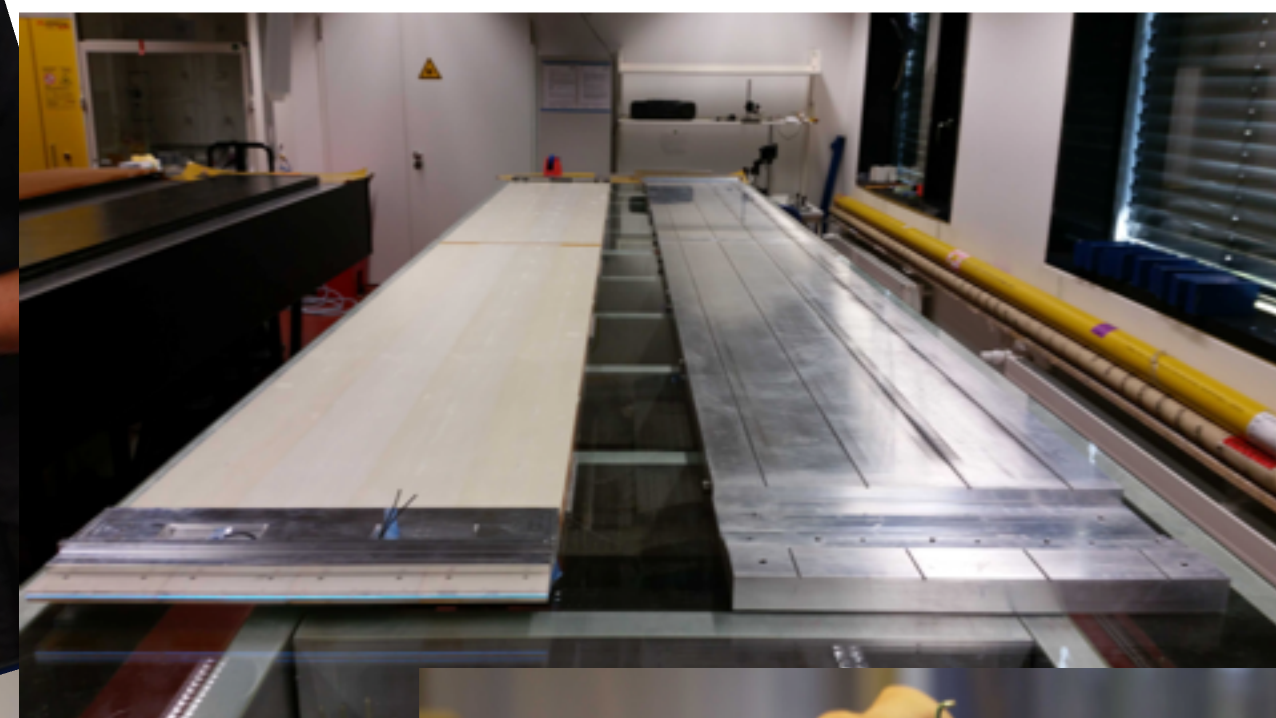
Coming in LS2…




will take data at luminosity of $2x10^{33}$ $cm^{-2}s^{-1}$

# Hard at work…

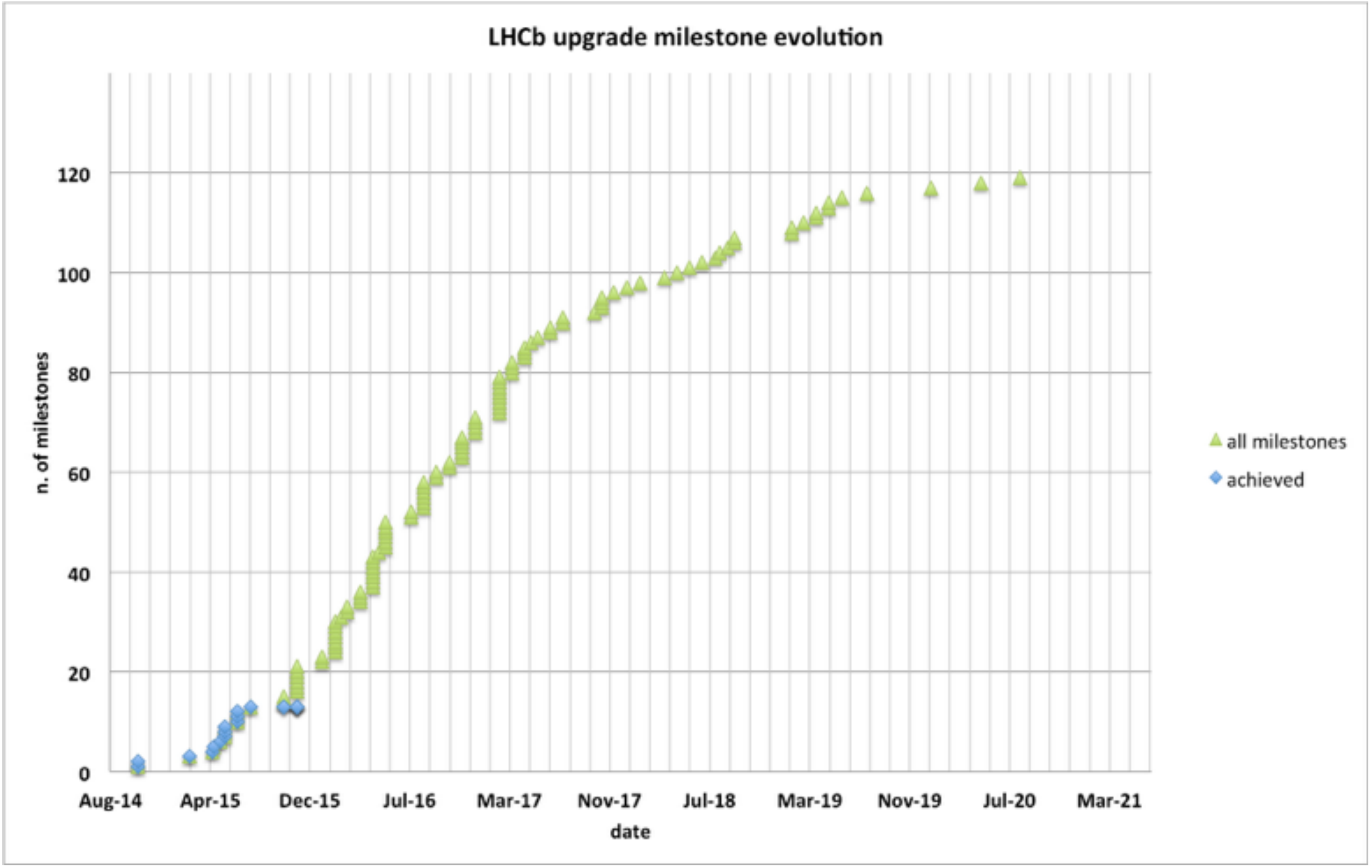
Engineering design reviews performed for SciFi tracker and UT…



Construction of a 5m SciFi module has been completed for test beam studies

# LHCb upgrade reminder

Progressing well, achieving milestones on schedule…



# Conclusions

- High quality paper output continues (+23 since last session).
- Wide range of physics scope, from pentaquark observation, to improved limits on hidden sectors, to most accurate flavour physics limits.

- Detector performing well in Run 2.
- Ambitious programme of improvements including automated alignment and calibrations, along with analyses direct from the trigger has been validated using early measurements.
- Offline processing working well analysts already looking at data.
- Many thanks to the LHC.

- Ambition continues with the LHCb Upgrade.
- Hard at work, studies and construction proceeding on schedule.


There is more to come…

Thank you for listening.

# Backup

# Backup

Table 1: Values of the mGMSB $\Lambda$ parameters in the SPS7 scenario used in this study, the corresponding masses of the $\widetilde{\tau}$, $m_{\widetilde{\tau}}$, and the cross-section of the pair production at next-to-leading order. The last two columns give the detector acceptance $A$.

| $\Lambda$ | $m_{\widetilde{\tau}}$ | $\sigma$ (fb) | | $A$ (%) | |
|---|---|---|---|---|---|
| (TeV) | (GeV/c$^2$) | 7 TeV | 8 TeV | 7 TeV | 8 TeV |
| 40 | 124 | 16.90 ± 0.79 | 21.20 ± 0.91 | 8.3 | 9.5 |
| 50 | 154 | 7.19 ± 0.38 | 9.20 ± 0.46 | 6.5 | 7.7 |
| 60 | 185 | 3.44 ± 0.20 | 4.50 ± 0.24 | 5.2 | 6.1 |
| 70 | 216 | 1.79 ± 0.11 | 2.39 ± 0.14 | 4.3 | 5.0 |
| 80 | 247 | 1.00 ± 0.07 | 1.35 ± 0.08 | 3.4 | 4.1 |
| 90 | 278 | 0.57 ± 0.04 | 0.80 ± 0.05 | 2.8 | 3.4 |
| 100 | 309 | 0.34 ± 0.02 | 0.49 ± 0.03 | 2.3 | 2.9 |

- $\Lambda$ = SUSY breaking scale.