13 TeV x-sections measurements

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on behalf of the LHCb Collaboration

AGH-UST

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Outline

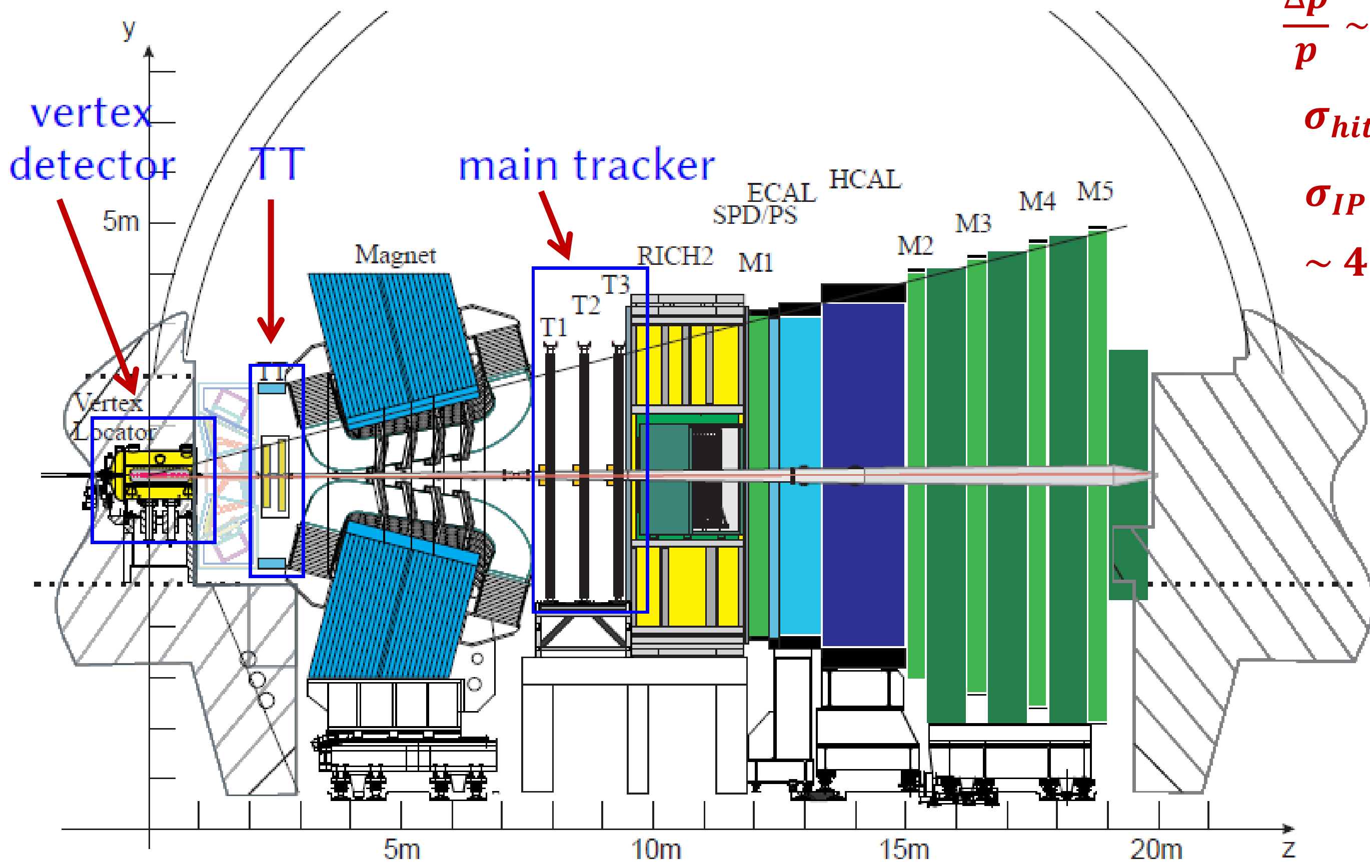
- ❑ LHCb Detector
- ❑ Detector on-line calibration and alignment
- ❑ Enhanced Trigger in RUN II
- ❑ 13 TeV x-sections measurements
- ❑ Summary

Introduction – LHCb detector

- **LHCb** is dedicated for studying **heavy quark flavour physics**
- It is a **single arm forward spectrometer** (**$2 < \eta < 5$**)
- Excellent tracking capabilities provided by:
  - Vertex detector **VELO**
  - Upstream and downstream tracking stations
  - 4 Tm warm dipole magnet
- Particle identification done by:
  - RICH detectors
  - Calorimeters
  - Muon stations
- Partial information from calorimeters and muon system contribute to **L0 trigger** (hardware) that works at LHC clock – **40 MHz**
- **Full** detector readout at **1 MHz**

Introduction – LHCb detector

- ❑ Tracking system – precise momentum reconstruction, vertexing, decay time resolution
- ❑ Excellent PID using RICH detectors (cover different momentum range), calorimeters and muon chambers in concert



$\frac{\Delta p}{p} \sim 0.5 - 1.0\,\%$

$\sigma_{hit} \approx 4\ \mu m$

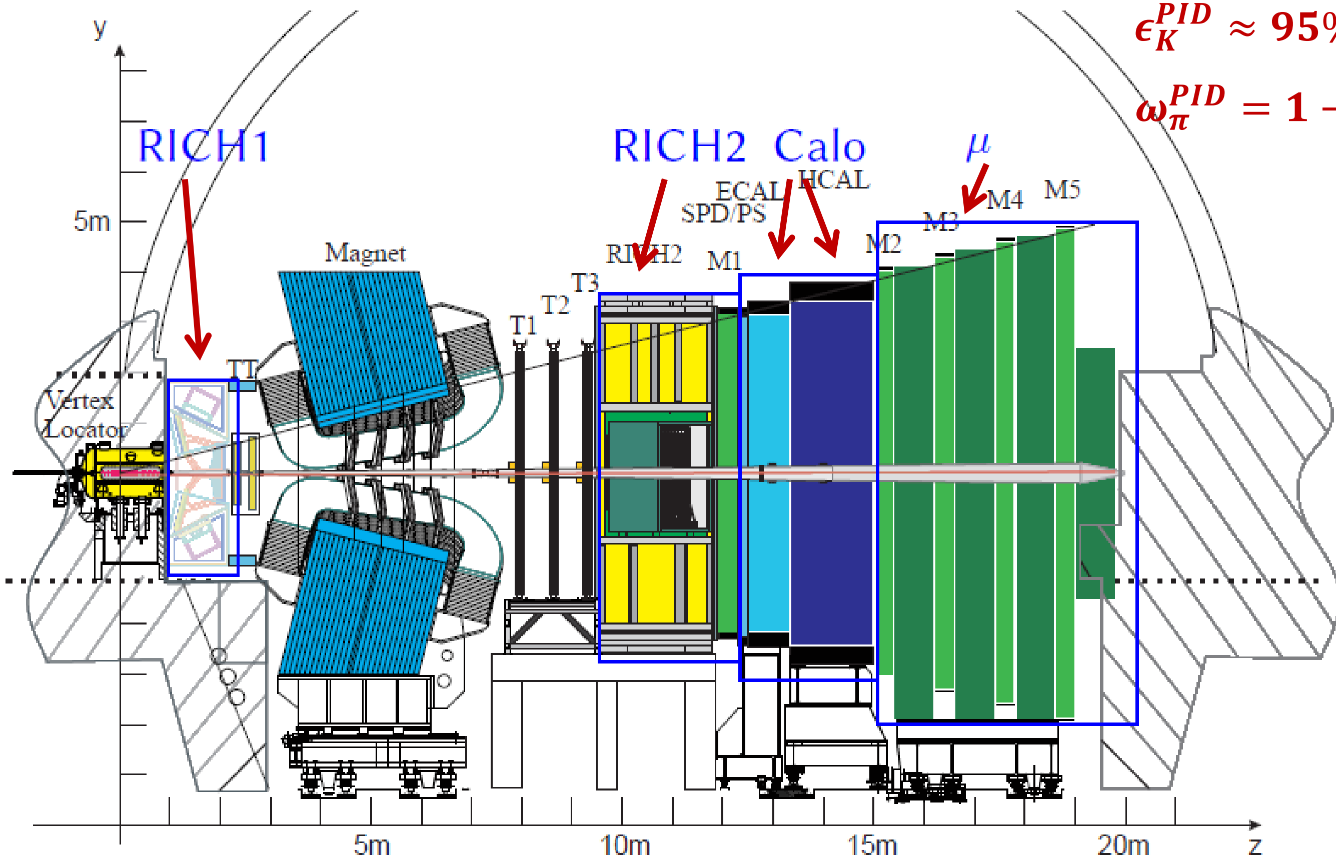
$\sigma_{IP} \approx 13\ \mu m$

$\sim 40 - 50\ fs$

[JINST 3 (2008) S08005]

Introduction – LHCb detector

- ❑ Tracking system – precise momentum reconstruction, vertexing, decay time resolution
- ❑ Excellent PID using RICH detectors (cover different momentum range), calorimeters and muon chambers in concert



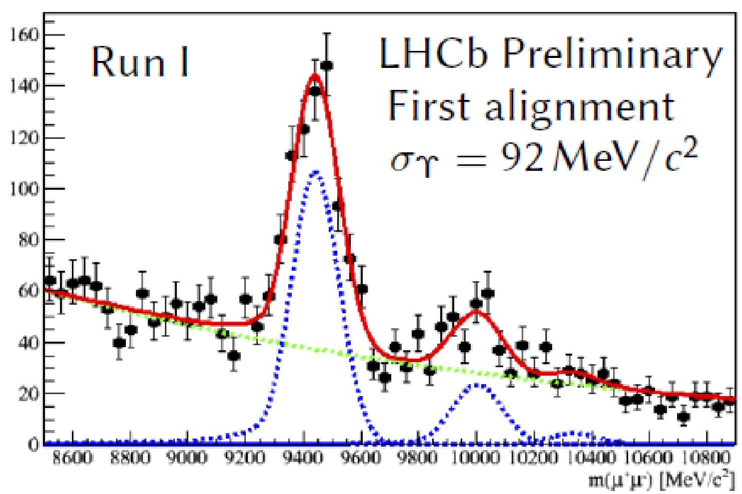
$\epsilon_K^{PID} \approx 95\%$

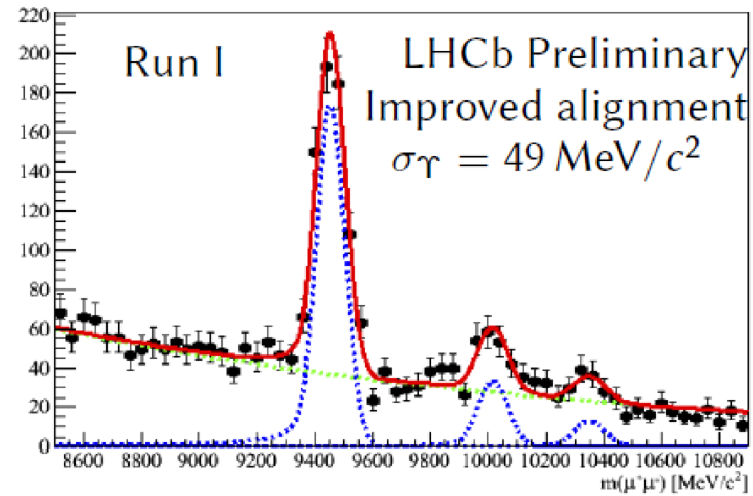
$\omega_\pi^{PID} = 1 - \epsilon_\pi^{PID} \approx 10\%$

[JINST 3 (2008) S08005]

Real-time detector alignment and calibration

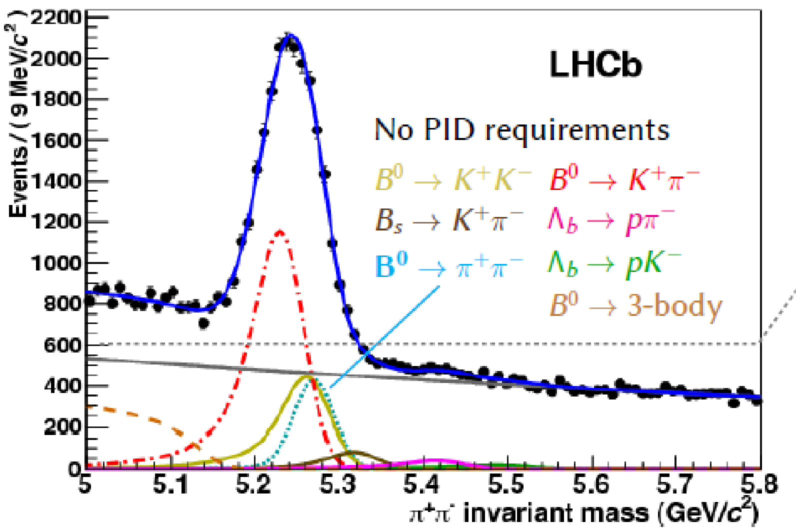
- **Novel** approach to on-line trigger system for a HEP experiment
  - Provide **off-line quality** tracking in real-time
  - Need to have robust and reliable procedure that can accommodate **fill-by-fill calibration and alignment**
- Detector alignment has critical impact on physics performance of the experiment
  - Topological trigger (separation of beauty and charm)
  - Momentum resolution $\frac{\Delta p}{p}$

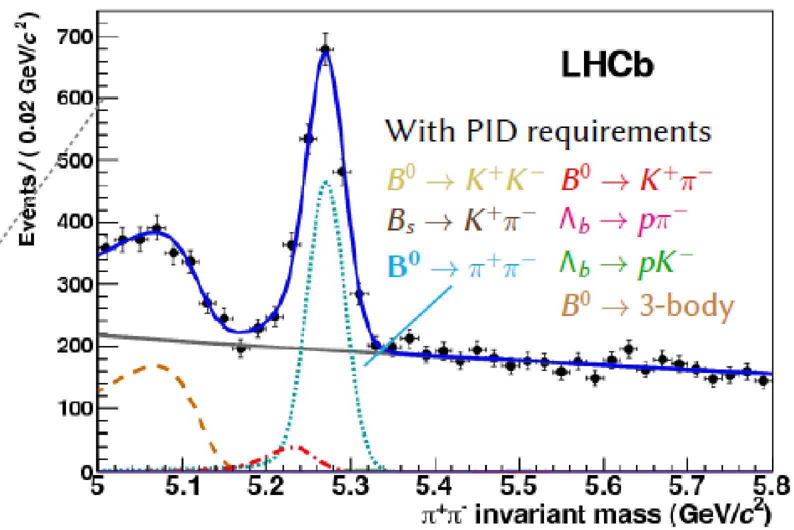




Real-time detector alignment and calibration

- Harsh hadronic environment
- Selection criteria must be **tight** in order to select required signal samples containing hadronic decays, but must **not reject** to many events on the other hand
- Must provide excellent RICH calibration

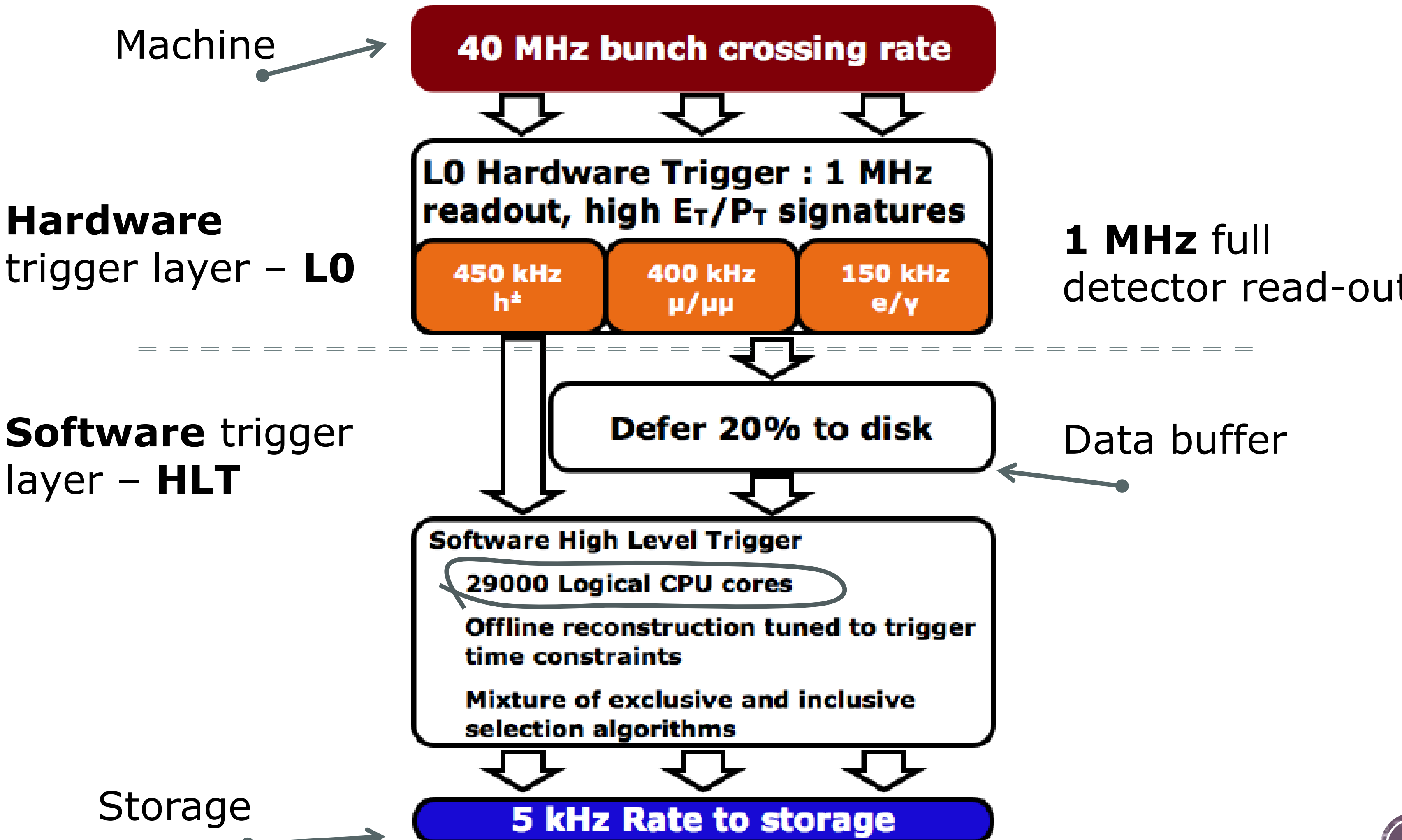




[Eur. Phys. J. C 73 (2013) 2431]

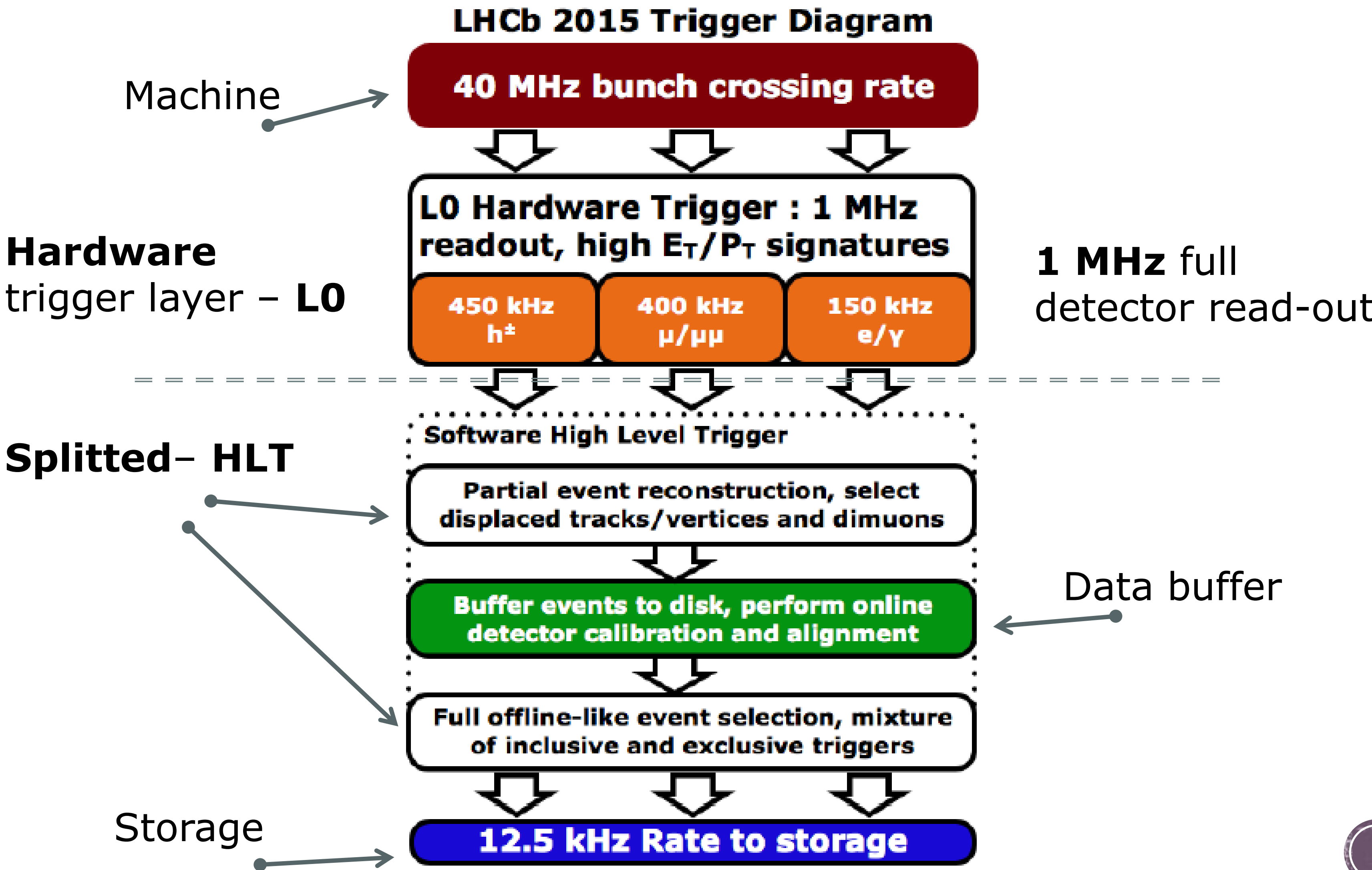
LHCb Trigger - Introduction

- **RUN I** (evolution from the nominal design $2\ kHz \rightarrow 5kHz$)



Enhanced trigger for RUN II

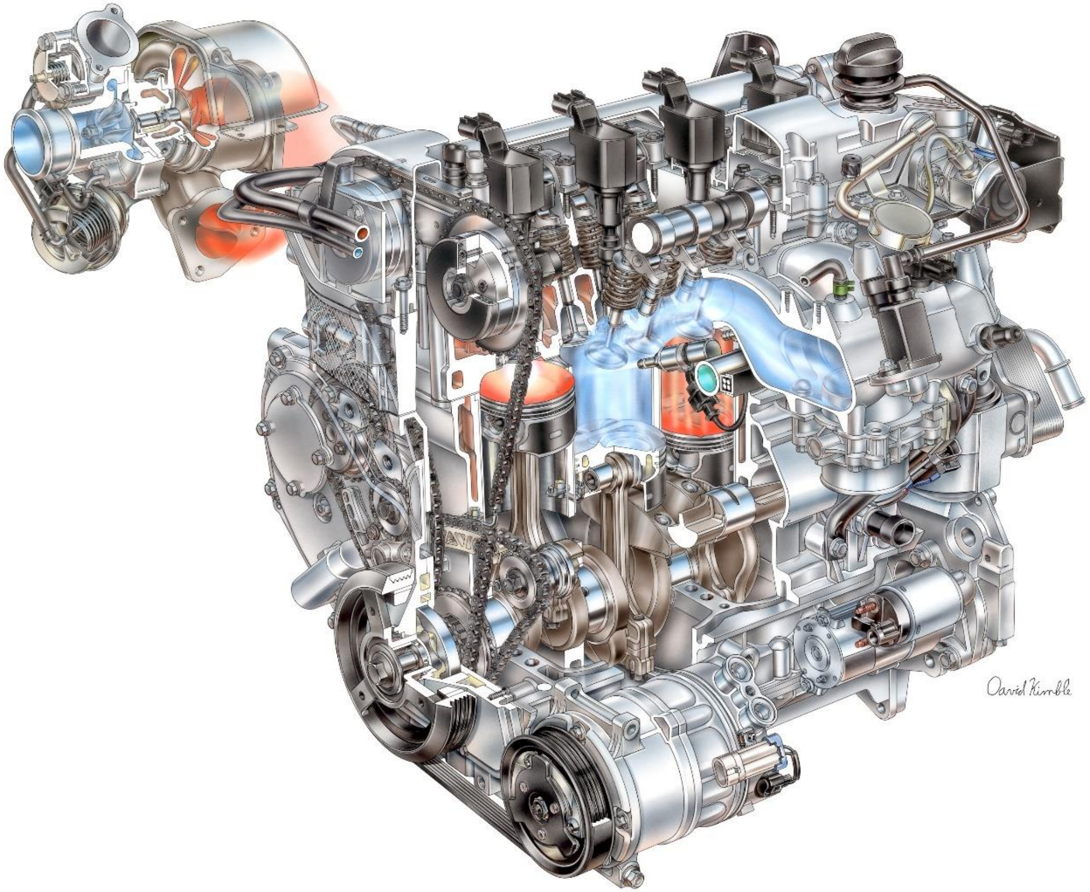
- **RUN II** (major revision of the trigger $5\ kHz \rightarrow 12\ kHz$)



Enhanced trigger for RUN II – alignment & calibration

- The procedure uses **tracks reconstructed** in the LHCb tracker and muon stations
- New set of parameters are ready for HLT2 processing **after several minutes**
- The most sensitive part is the **vertex detector** – new parameters are calculated for **each fill**
- Other tracking detectors much more stable (new consts. needed every few weeks)
- **RICH** mirrors alignment and refractive index calculations are included in this framework
- Drift time in **gaseous tracking** detectors
- **Calorimeter** calibration

That’s not all – introducing TURBO

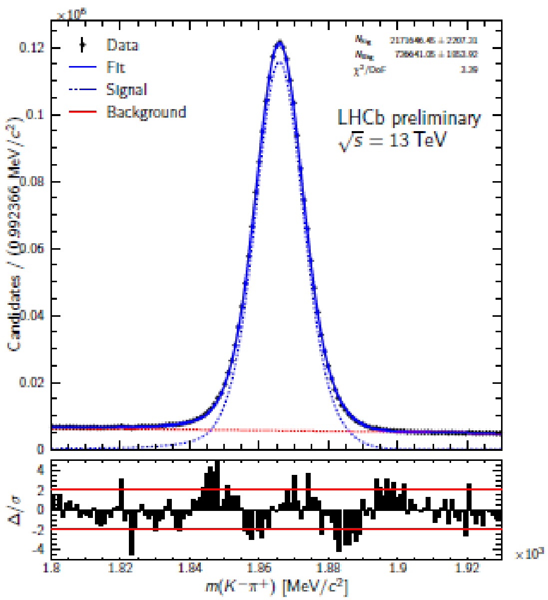


That’s not all – introducing TURBO

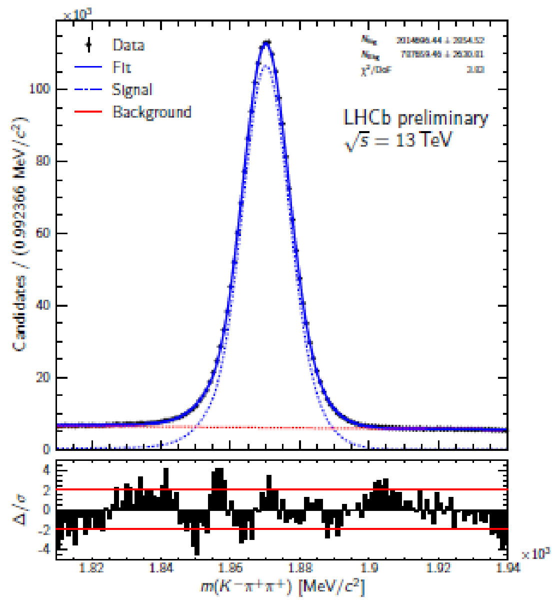
- **This idea is quite amazing!**
- Out of the $12.5\ kHz$ of the output stream $\sim \mathbf{5}\ \boldsymbol{kHz}$ is dedicated to so called **TURBO stream**
- The central idea is to save only the **trigger level objects** that caused it to „**fire**”
  - **Tracks** and **vertices**
  - **No raw data** is stored for the TURBO
- Huge gain
  - The event size is **much smaller**
  - **No** reprocessing
  - Analysis much faster
- Used for **high yield** exclusive modes (charm)

That's not all – introducing TURBO

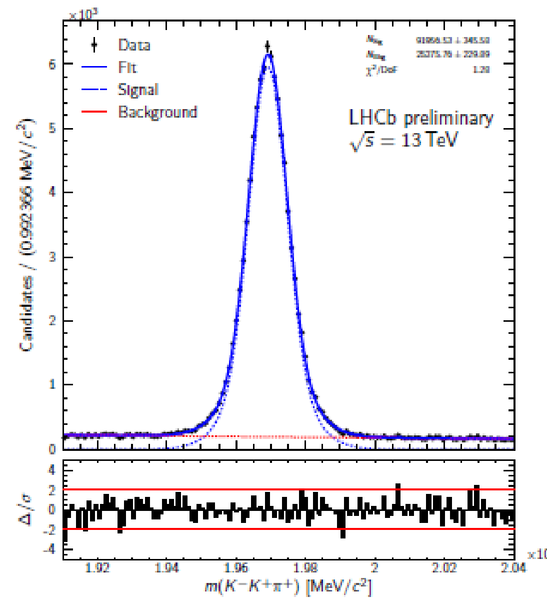
- **The TURBO** stream has been commissioning this year and is performing superbly
- Below plots obtained directly after the HLT



$D^0 \rightarrow K^- \pi^+$



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



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

- Background almost non existent – tribute for the excellent LHCb tracking performance – off-line tracking quality in the HLT
- The number of events is much higher than that in RUN I

Selected resuts for the RUN II data

- The LHCb detector started to collect data at $\sqrt{s} = 13\ TeV$
- Thanks to excellent performance of the tracking and PID LHCb is well suited for contributing to various QCD tests in the forward direction
  - Unique kinematical coverage at LHC
- Will present cross-section measurements for:
  - prompt J/ψ mesons
  - J/ψ mesons from b-hadrons
  - prompt charm mesons
  - Z^0 production x-section (not shown here see Katharina's talk)
- Previously performed for $\sqrt{s} = 2.76\ TeV, 7\ \mathrm{TeV}$ and $8\ TeV$

Selected resuts for the RUN II data

- **The measurement technique**
  - The double-differential cross-section expressed as a function of the transverse momentum and rapidity

$$\frac{\mathrm{d}^2\sigma_i(H)}{\mathrm{d}p_\mathrm{T}\mathrm{d}y} = \frac{1}{\Delta p_\mathrm{T}\Delta y} \cdot \frac{N_i(H \to f + \text{c.c.})}{\varepsilon_{i,\mathrm{tot}}(H \to f) \cdot \Gamma(H \to f) \cdot \mathcal{L}_\mathrm{int}}$$

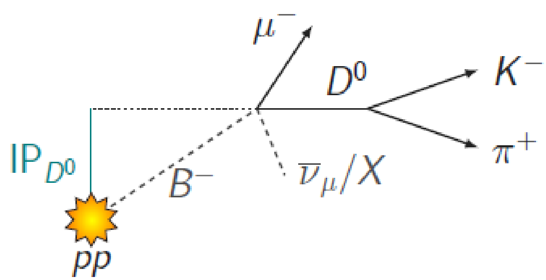
  - Count events N_i decaying to a given final state f
  - The main experimental difficulty is to distinguish prompt decays coming from the PV from the secondary signal
    - use **pseudo-lifetime** for J/ψ
    - and **impact parameter significance** for open charm decays
  - Luminosity – precise measurement thanks to the **SMOG**
    - $\mathcal{L}_{int}^{J/\psi,b\bar{b}} = (3.05 \pm 0.12)\ pb^{-1}$
    - $\mathcal{L}_{int}^{c\bar{c}} = (4.98 \pm 0.19)\ pb^{-1}$

Selected resuts for the RUN II data

- **Signal extraction**
  - J/ψ meson production studied using the $\boldsymbol{J/\psi \rightarrow \mu^{+}\mu^{-}}$ decay mode
  - The fraction of J/ψ's originating from b-hadron decays estimated using **pseudo-lifetime** variable

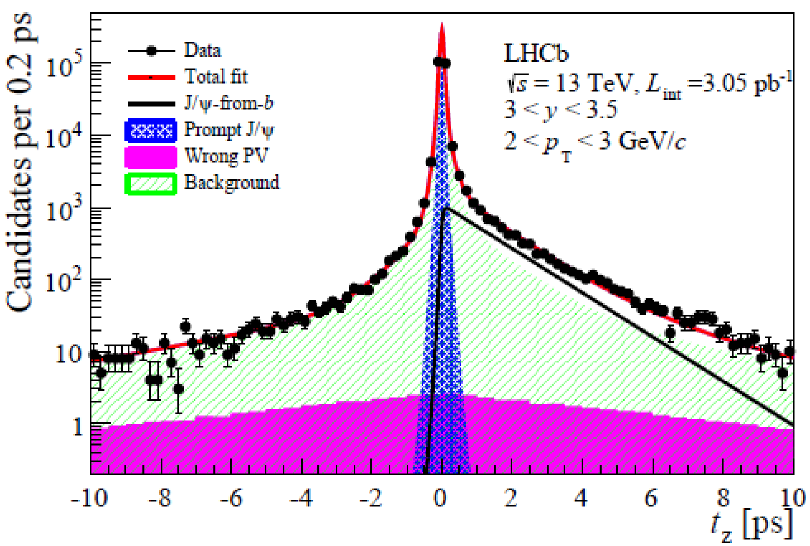
$$t_z = \frac{(z_{J/\psi} - z_{PV}) \cdot M_{J/\psi}}{p_z}$$

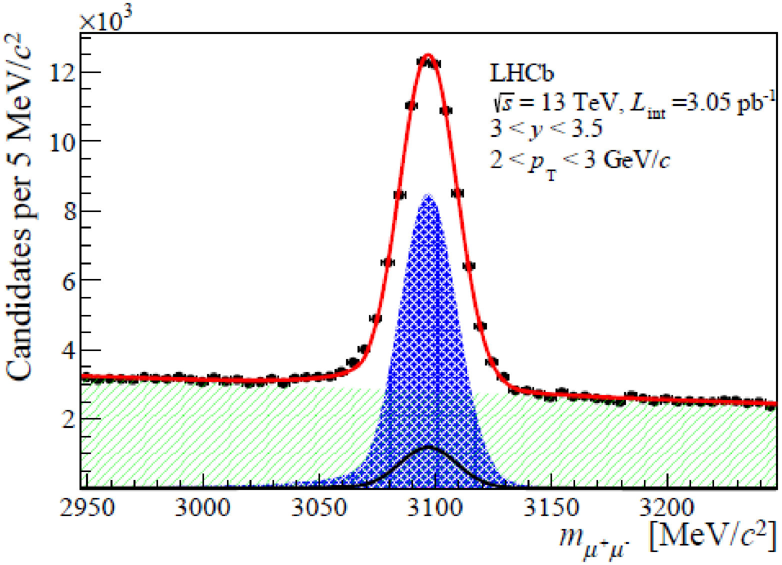
  - For the charm mesons studies the following decay modes were used: $\boldsymbol{D^0 \rightarrow K^-\pi^+}$, $\boldsymbol{D^+ \rightarrow K^-\pi^+\pi^+}$, $\boldsymbol{D_s^+ \rightarrow K^-K^+\pi^+}$ and $\boldsymbol{D^{*+} \rightarrow D^0\pi^+}$
  - Use **impact parameter** significance, χ^2_{IP}, to separate the secondary charm mesons



Selected resuts for the RUN II data

❑ Signal extraction J/ψ





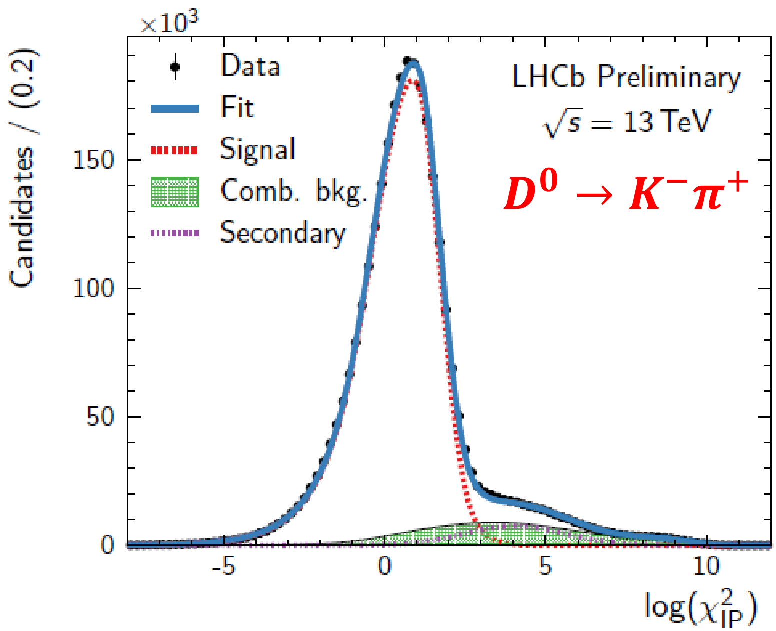
Separate secondary J/ψ mesons

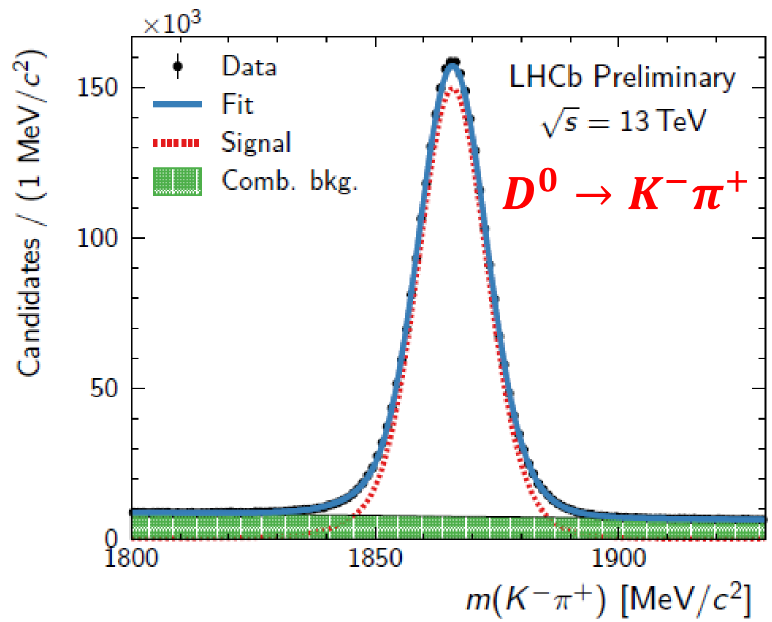
Distinguish signal and bkg. by fitting the mass $m_{\mu^+\mu^-}$

[arXiv:1509.00771]

Selected resuts for the RUN II data

❑ Signal extraction charm





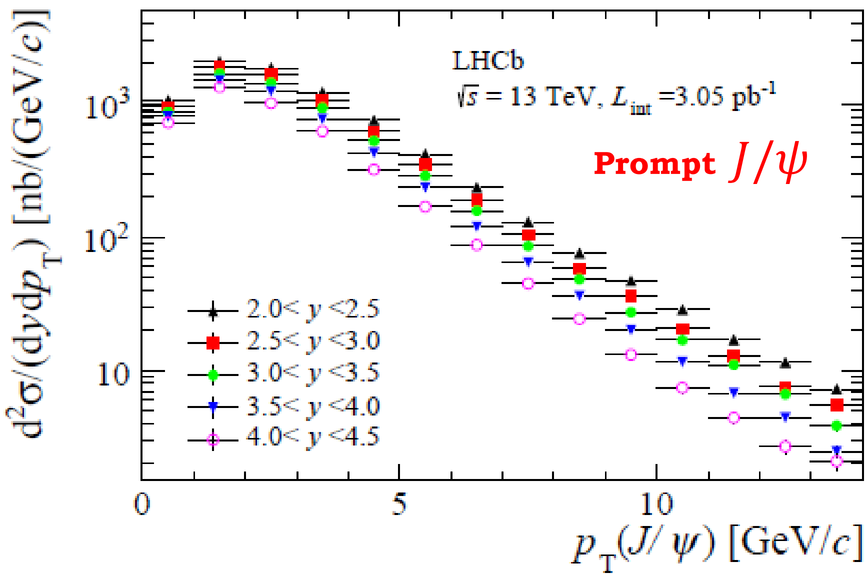
Separate secondary mesons using χ^2_{IP}

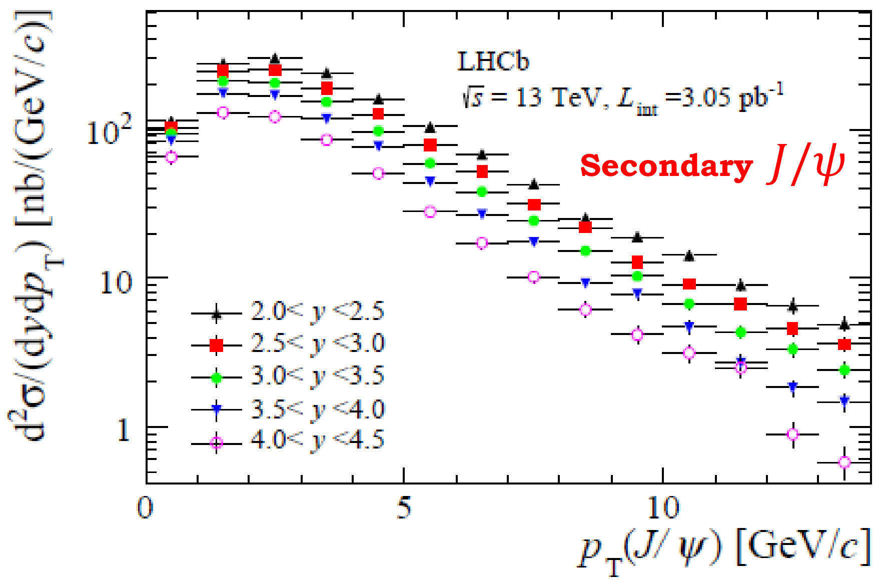
Separate signal and bkg. by fitting the mass of a given decaying hadron

[ArXiV:1510.01707]

Selected resuts for the RUN II data

- J/ψ cross-section measurement (prompt and secondary)





$$\sigma^{J/\psi}_{prompt} = 15.30 \pm 0.03\ (stat) \pm 0.86\ (sys)\ \mu b$$

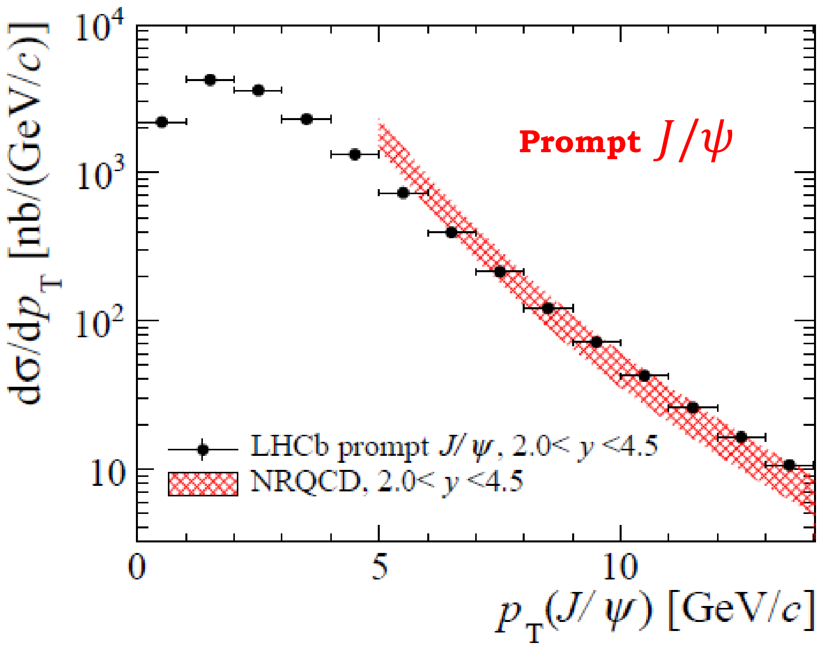
$$\sigma^{J/\psi}_{from-B} = 2.34 \pm 0.01\ (stat) \pm 0.13\ (sys)\ \mu b$$

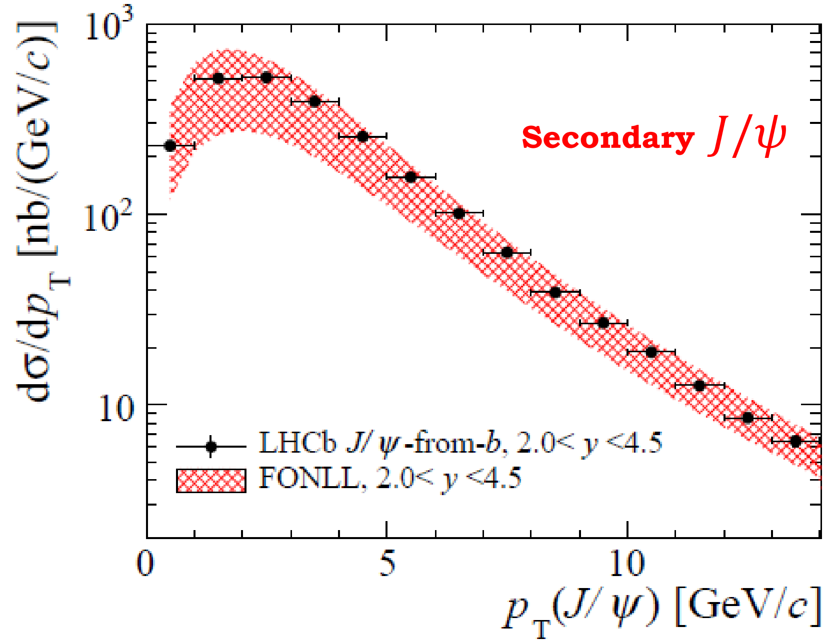
$$\sigma^{b\bar{b}} = 515.0 \pm 2.0\ (stat) \pm 53.0\ (sys)\ \mu b$$

[arXiv:1509.00771]

Selected resuts for the RUN II data

- ❑ Comparison with theory - J/ψ production
  - ❑ cross sections integrated over rapidity - $2 < y < 4.5$





NRQCD model for the prompt J/ψ production

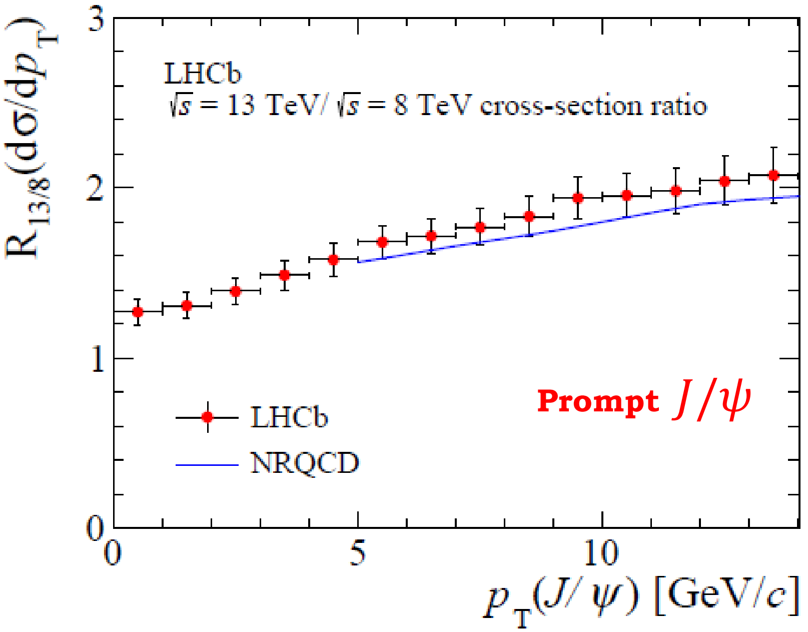
[Shao et al., JHEP 1505 (2015) 103]

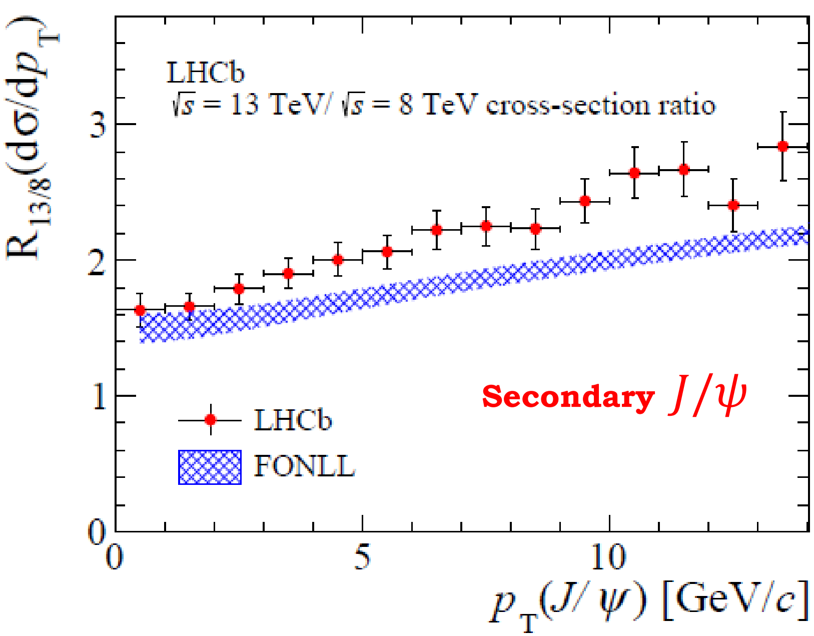
FONLL model for the b-hadron J/ψ production

[Cacciari et al., JHEP 1210 (2012) 137]

Selected resuts for the RUN II data

- Can also compare the results from $13\,TeV$ data sample with the previously measured cross-sections at $8\,TeV$





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[Shao et al., JHEP 1505 (2015) 103]

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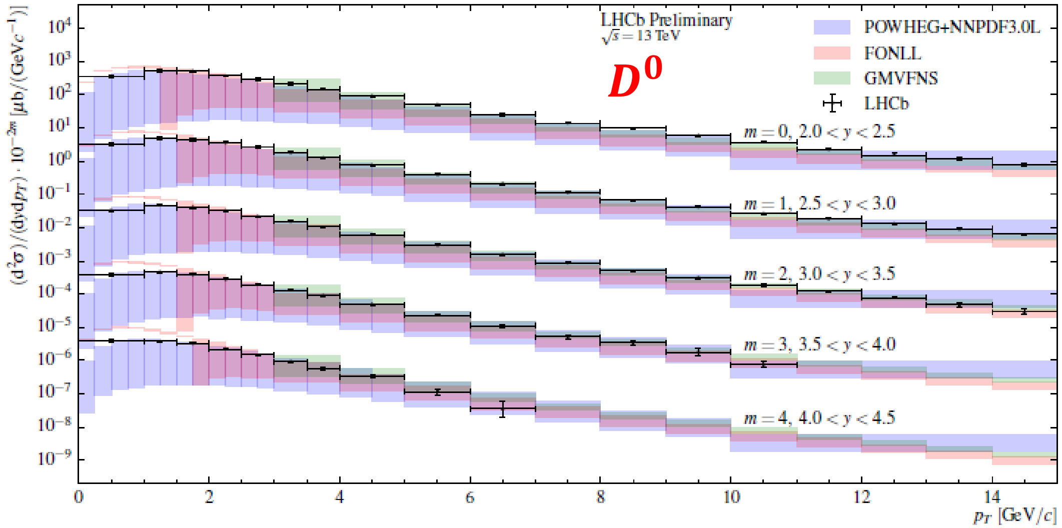
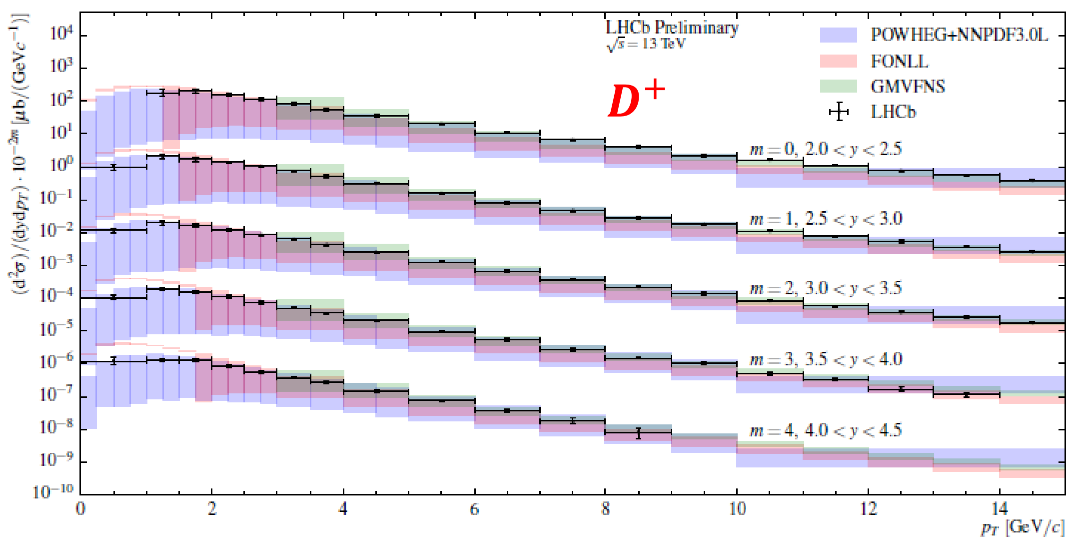
Selected resuts for the RUN II data

- Charm meson cross-sections (the same for the rest of them)





[ArXiV:1510.01707]

Selected resuts for the RUN II data

- Measured values for respective charm mesons (μb)

$$\sigma_{prompt}^{D^0} = 3370 \pm 4\,(stat) \pm 200\,(sys)\ \mu b$$

$$\sigma_{prompt}^{D^+} = 1280 \pm 8\,(stat) \pm 190\,(sys)\ \mu b$$

$$\sigma_{prompt}^{D_s^+} = 460 \pm 13\,(stat) \pm 100\,(sys)\ \mu b$$

$$\sigma_{prompt}^{D^{*+}} = 880 \pm 5\,(stat) \pm 140\,(sys)\ \mu b$$

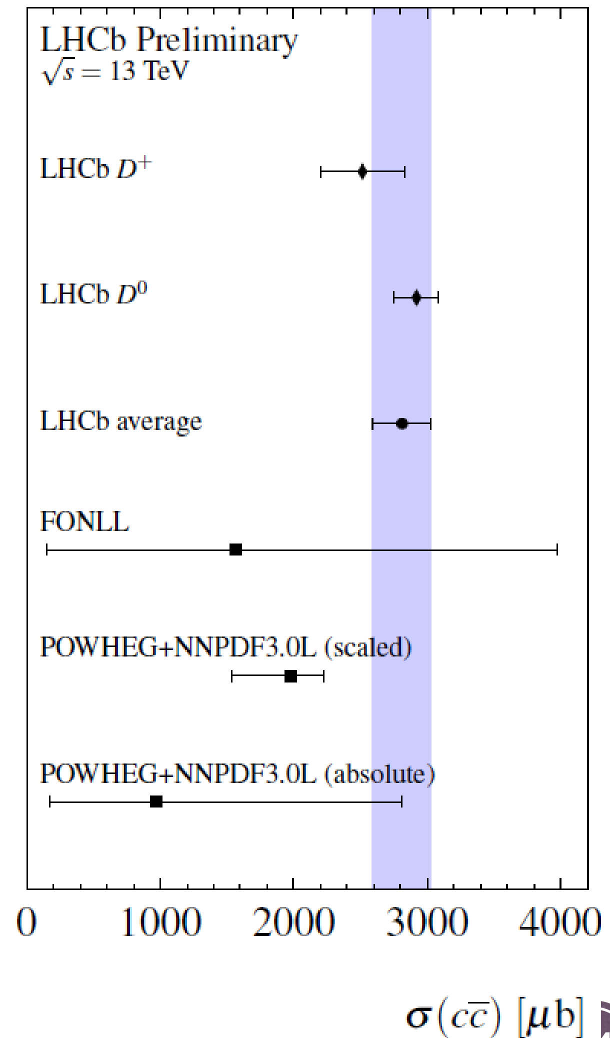
- The integrated cross-sections are given in the LHCb acceptance that is defined as follow
  - rapidity range $2 < y < 4.5$
  - transverse momentum of charm meson $0 < p_T < 8\ GeV$

[ArXiV:1510.01707]

Selected resuts for the RUN II data

- Evaluate total $c\bar{c}$ production cross-section
  - use fragmentation fractions from electron colliders
  - include D^0 and D^+ results only (D_s^* and D^{*+} much smaller)

$$\sigma^{c\bar{c}} = 2940 \pm 3(stat) \pm 180(sys) \pm 160(frag)$$



Summary

- First data taken at $13\,TeV$ after the LS1
- Revised „upgrade-like" trigger works perfectly
- Measured various cross-sections using new TURBO stream (selection done at the trigger level)
  - prompt J/ψ
  - J/ψ from b-hadrons
  - total $b\bar{b}$
  - charm mesons D^0, D^+, D_s^+, D^{*+}
  - total $c\bar{c}$
- Two papers pertaining to the above studies

[**arXiv:1509.00771** for J/ψ and $b\bar{b}$]

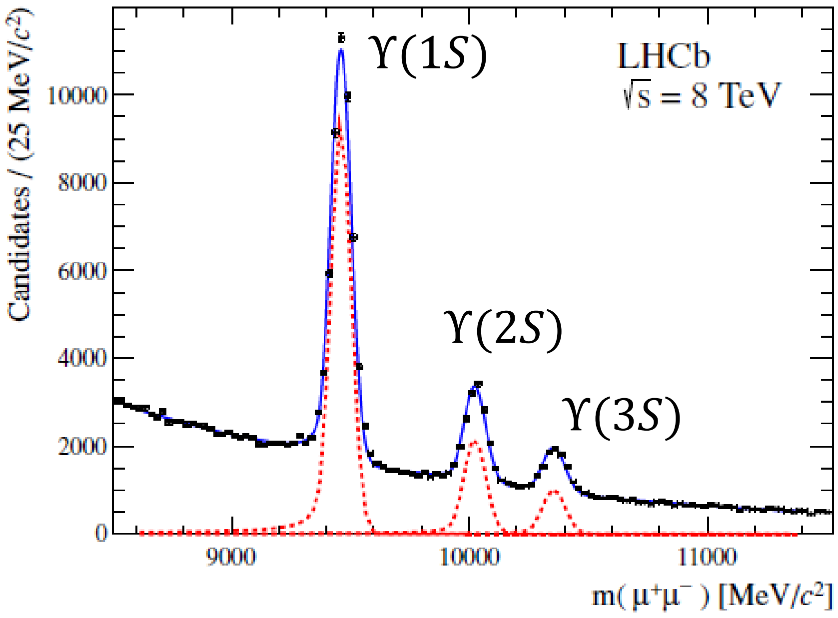
[**arXiv:1510.01707** $c\bar{c}$]

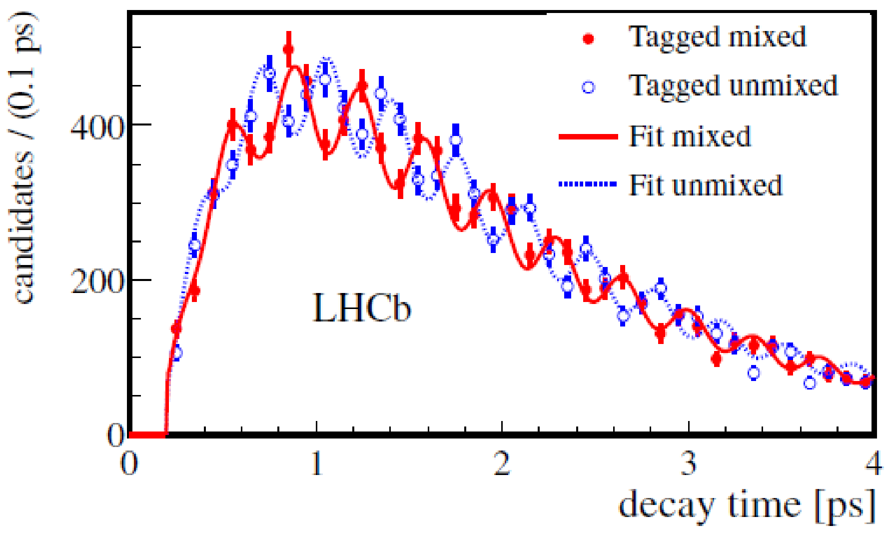
Introduction – LHCb detector

- Although LHCb became a versatile general purpose forward physics experiment its main goal is **precise flavour physics**
- **Complementary** approach w.r.t. Atlas and CMS
  - **Indirect** searches for New Physics using **quantum loops**
- Performance of our spectrometer **exceeded** any predictions!
  - superb **tracking** with momentum resolution $\frac{\Delta p}{p} \sim \mathbf{0.5 - 1.0\ \%}$
  - excellent **vertexing** (primary and secondary) and geometrical **impact parameter** resolutions - $\sigma_{hit} \approx 4\ \mu m$ and $\sigma_{IP} \approx 13\ \mu m$
  - **decay time resolution** $\sim 40 - 50\ fs$ (depending on the decay mode)
  - excellent **PID** (Particle IDentification)
    - Kaon PID $\epsilon_K^{PID} \approx 95\%$
    - Pion mis-identification ($p_\pi \to$ 2-100 GeV) $\omega_\pi^{PID} = 1 - \epsilon_\pi^{PID} \approx 10\%$

LHCb detector performance

- The **wellbeing** of the LHCb detector is constantly checked – its performance has a direct impact on physics results!
- **Mass resolution and decay time**





[J. High Energy Phys. 06 (2013) 064]

[New J. Phys. 15 (2013) 053021]