LHCb

First look at 13 TeV and highlights from the most recent analyses

Anton Poluektov

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Budker Institute of Nuclear Physics, Novosibirsk, Russia

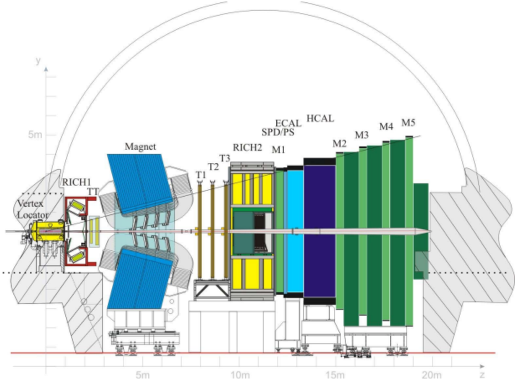
31 August 2015

On behalf of the LHCb collaboration

LHCb: beauty and charm in *pp* collisions

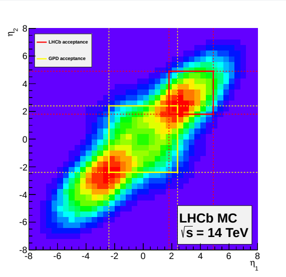
Rembrandt, Flora,
Hermitage (St. Petersburg)

One-arm spectrometer optimised for studies of beauty and charm decays



Angular acceptance

$$2 < \eta < 5$$



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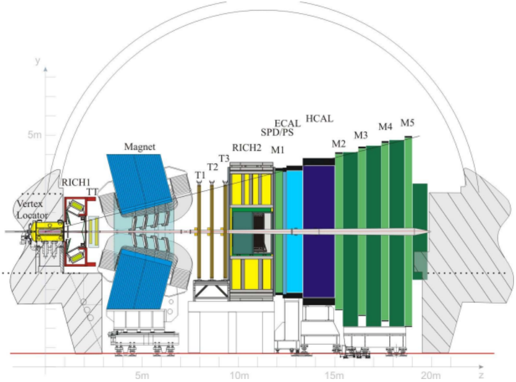
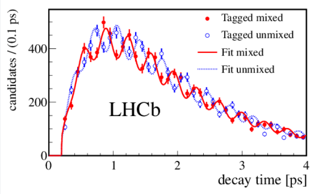


Vertexing

B_s^0 oscillations with $B_s^0 \to D_s\pi$



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

- Good vertexing: measure B^0 and B_s^0 oscillations, reject prompt background

LHCb

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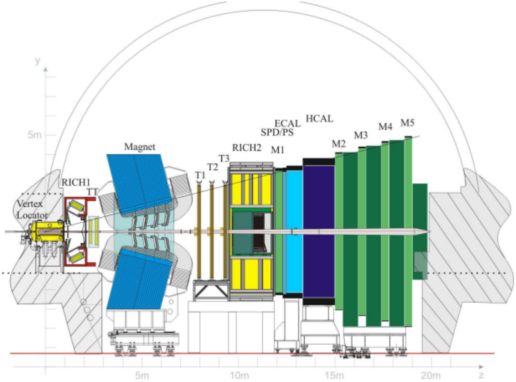
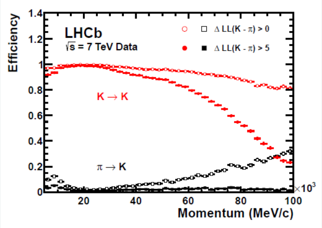


PID

K/π ID efficiency and misID rate



[EPJ C73 (2013) 2431]

- Good vertexing: measure B^0 and B_s^0 oscillations, reject prompt background
- Particle identification: flavour tagging, misID background

LHCb

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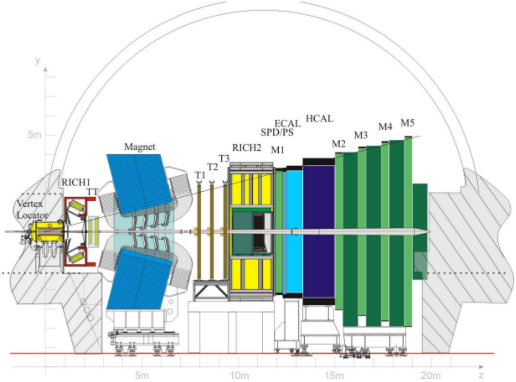
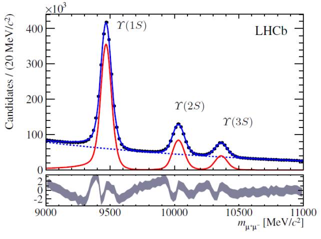


Tracking

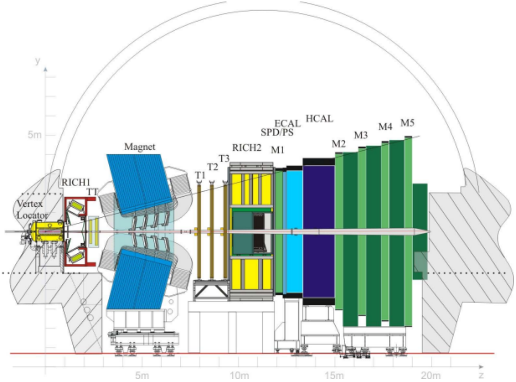
$\mu^+\mu^-$ mass spectrum



[PRL 111 (2013) 101805]

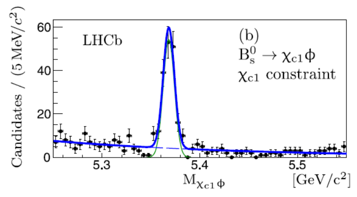
- Good vertexing: measure B^0 and B_s^0 oscillations, reject prompt background
- Particle identification: flavour tagging, misID background
- High-resolution tracking

One-arm spectrometer optimised for studies of beauty and charm decays



Calorimetry

$B_s^0 \to \chi_{c1}\phi$, $\chi_{c1} \to J/\psi\gamma$



[Nucl. Phys. B874 (2013) 663]

- Good vertexing: measure B^0 and B_s^0 oscillations, reject prompt background
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LHCb

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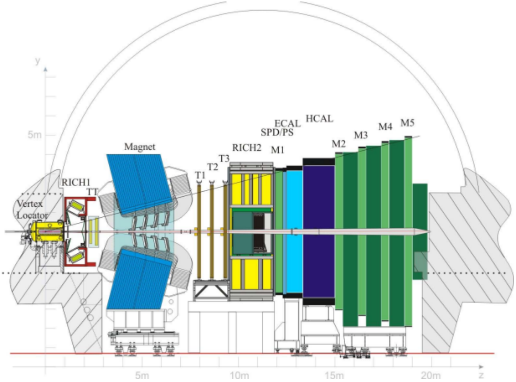

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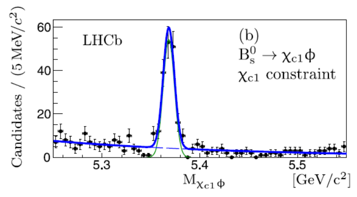

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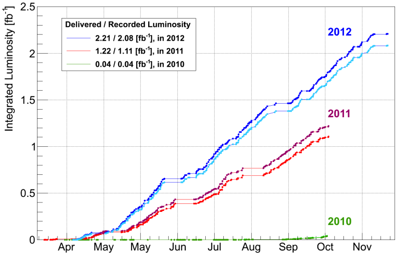
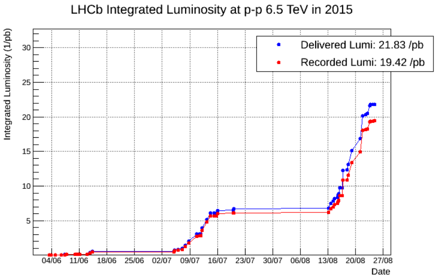
- Good vertexing: measure B^0 and B_s^0 oscillations, reject prompt background
- Particle identification: flavour tagging, misID background
- High-resolution tracking
- Calorimetry: reconstruct neutrals (π^0, γ) in the final state
- Efficient trigger, including fully hadronic modes

LHCb in Run 1 and Run 2

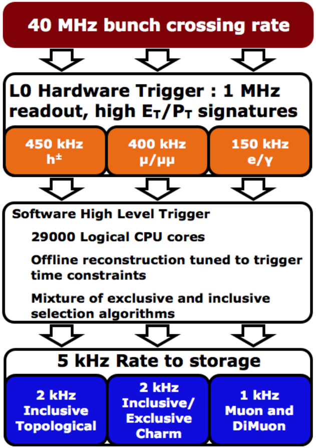




$3\,\mathrm{fb}^{-1}$ in 2011 and 2012
$>$250 papers published (and counting)
Many analyses still ongoing

Around $20\,\mathrm{pb}^{-1}$ so far in 2015
Early production measurements

Significant changes introduced this year in the LHCb trigger:



- 2011 and early 2012: increased trigger bandwidth (compared to design 2 kHz) to accommodate charm

LHCb trigger

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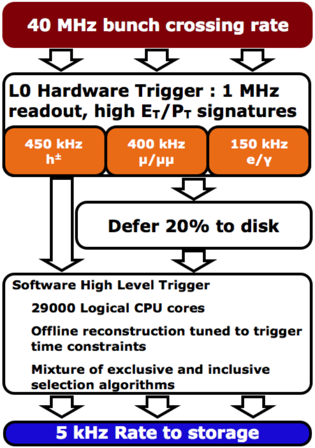

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- 2012: *deferred trigger* configuration: keep the trigger farm busy between fills

LHCb trigger

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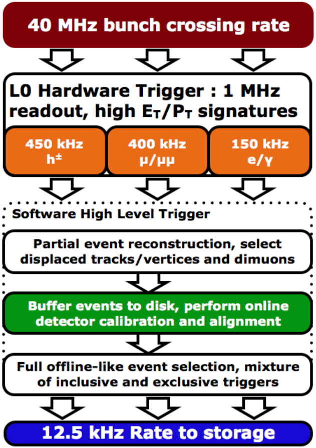


- 2011 and early 2012: increased trigger bandwidth (compared to design 2 kHz) to accommodate charm
- 2012: *deferred trigger* configuration: keep the trigger farm busy between fills
- 2015: *split trigger*
  - All 1st stage (HLT1) output stored on disk
  - Used for real-time calibration and alignment
  - 2nd stage (HLT2) uses offline-quality calibration
  - 5 kHz of 12 kHz to Turbo stream:
    - Candidates produced by trigger are stored
    - No raw event $\Rightarrow$ smaller event size
    - Used for high-yield channels (charm, J/ψ, ...)

Early measurements with 13 TeV

See also: talk by Alex PEARCE, HF section today

Rembrandt, The Return of the Prodigal Son, Hermitage (St. Petersburg)

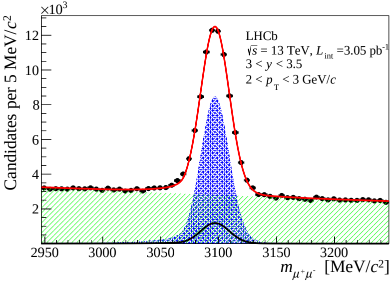
J/ψ production in $\sqrt{s} = 13\,\mathrm{TeV}$ data

LHCb-PAPER-2015-037, $\int Ldt = 3.05 \pm 0.12\,\mathrm{pb}^{-1}$

Motivation:

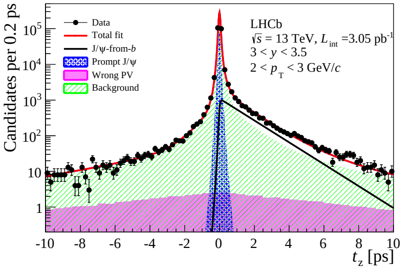
- Test QCD in both the perturbative ($q\bar{q}$ production) and non-perturbative ($q\bar{q}$ hadronisation) regimes
- Provide reliable estimates for B physics prospects in the coming $13\,\mathrm{TeV}$ run.

The first LHCb analysis using online reconstruction



$J/\psi \to \mu^+\mu^-$ invariant mass

Signal yield: $\sim 10^6$ events



Prompt and secondary (from B) J/ψ are distinguished using decay time distribution.

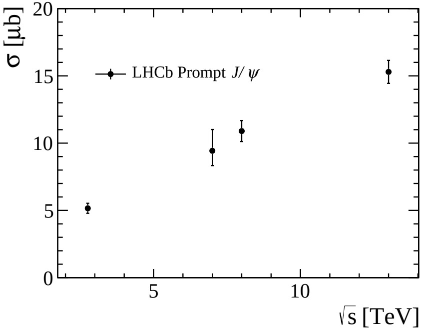
J/ψ production in $\sqrt{s} = 13\,\mathrm{TeV}$ data

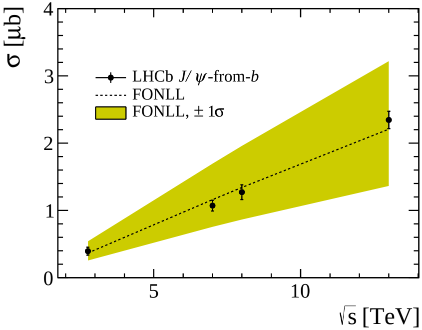
LHCb-PAPER-2015-037, $\int Ldt = 3.05 \pm 0.12\,\mathrm{pb}^{-1}$

Integrated J/ψ cross-sections in acceptance $p_{\mathrm{T}} < 14\,\mathrm{GeV}$, $2 < y < 4.5$

$$\sigma(\text{prompt}) = 15.30 \pm 0.03 \pm 0.86\,\mu\mathrm{b},$$
$$\sigma(\text{from } b) = 2.34 \pm 0.01 \pm 0.13\,\mu\mathrm{b}.$$

Total $\sigma(pp \to b\bar{b}X) = 515 \pm 2 \pm 53\,\mu\mathrm{b}$ (using $\mathcal{B}(b \to J/\psi X) = 1.16 \pm 0.10\%$).



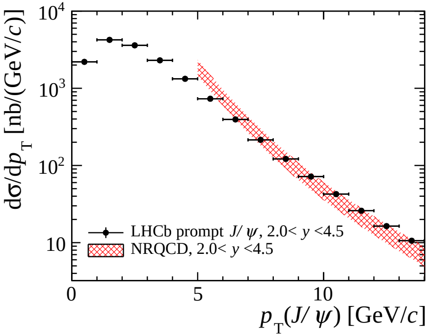


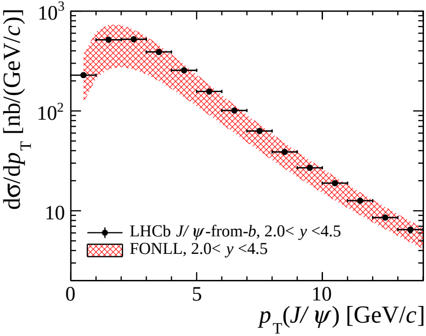
FONLL: M.Cacciari, M.Greco, P.Nason, JHEP 9805 (1998) 007

J/ψ production in $\sqrt{s} = 13\,\mathrm{TeV}$ data

LHCb-PAPER-2015-037, $\int Ldt = 3.05 \pm 0.12\,\mathrm{pb}^{-1}$

Differential cross-section and comparison with theory





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NRQCD: H.-S. Shao, H.Han, Y.-Q. Ma, C. Meng, Y.-J. Zhang, K.-T. Chao, JHEP 1505 (2015) 103

J/ψ production in $\sqrt{s} = 13\,\mathrm{TeV}$ data

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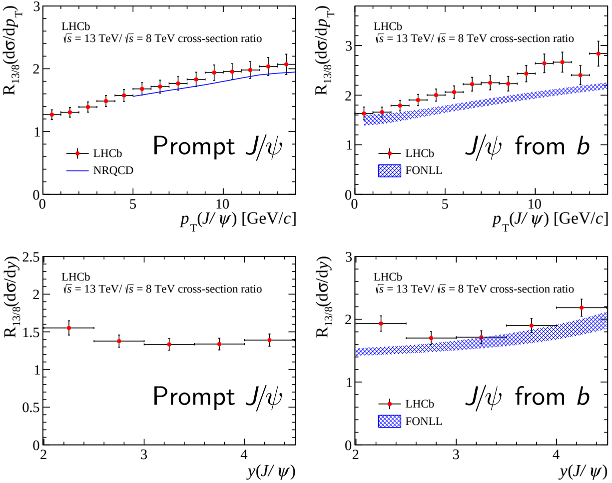

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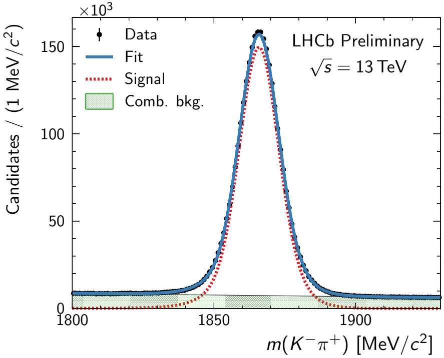
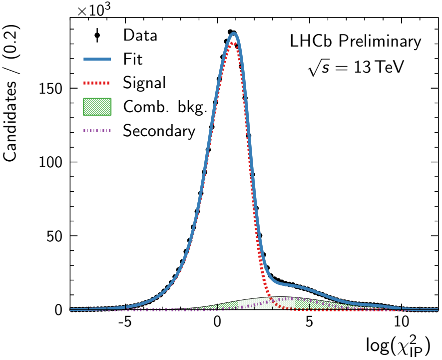
Prompt charm production in $\sqrt{s} = 13\,\mathrm{TeV}$ data New!

LHCb-PAPER-2015-041, $\int Ldt = 4.98 \pm 0.19\,\mathrm{pb}^{-1}$

Measure prompt production of D^0, $D^\pm$, $D_s^\pm$, $D^{*\pm}$



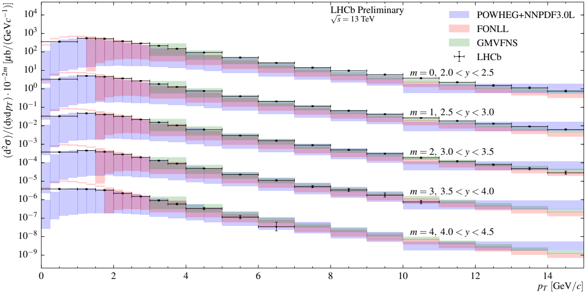
Invariant mass of $D^0 \to K^-\pi^+$

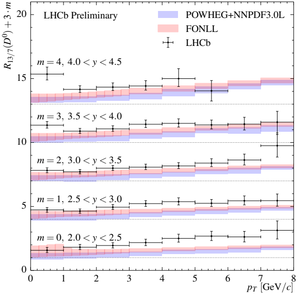


Prompt component is selected using impact parameter (χ^2_{IP}) distribution

LHCb-PAPER-2015-041, $\int Ldt = 4.98 \pm 0.19\,\text{pb}^{-1}$

D^0 double-differential cross-section in p_T, y (using $D^0 \to K^-\pi^+$)

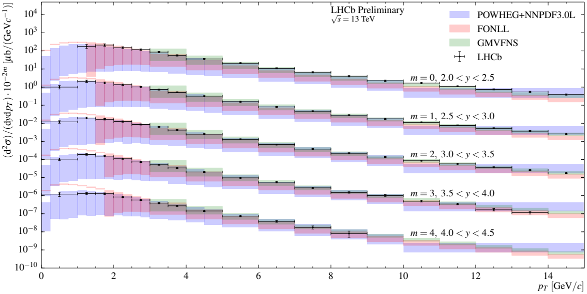


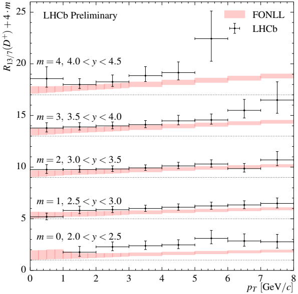


FONLL: M. Cacciari, M. Mangano, P. Nason, arXiv:1506.08025
POWHEG+NNPDF3.0L: R. Gauld, j. Rojo, L. Rottoli, J. Talbert, arXiv:1507.06197
GMVFNS: B. Kniel, G. Kramer, I. Schienbein, H. Spiesberger, EPJ C72 (2012) 2082

LHCb-PAPER-2015-041, $\int Ldt = 4.98 \pm 0.19\,\mathrm{pb}^{-1}$

$D^{\pm}$ double-differential cross-section in p_T, y (using $D^+ \to K^-\pi^+\pi^+$)





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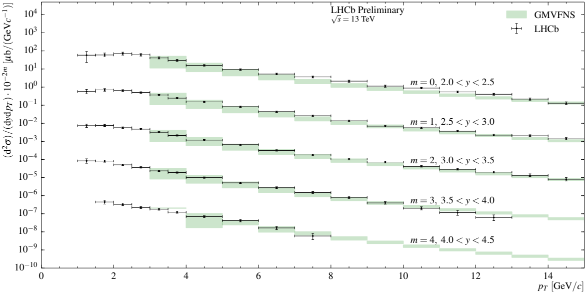
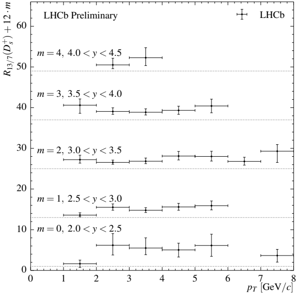
 New!

LHCb-PAPER-2015-041, $\int Ldt = 4.98 \pm 0.19\,\mathrm{pb}^{-1}$

$D_s^{\pm}$ double-differential cross-section in p_{T}, y (using $D_s^+ \to \phi\pi^+$)





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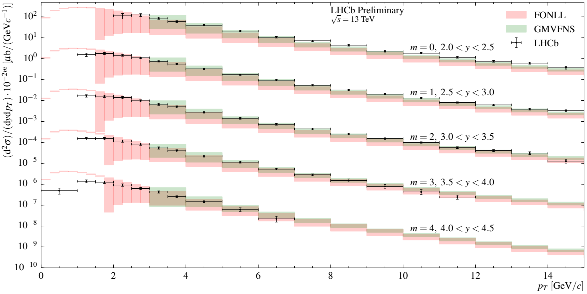
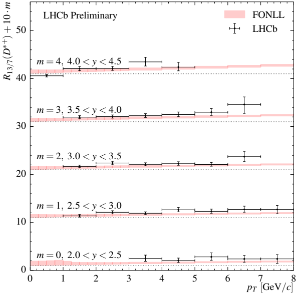
Prompt charm production in $\sqrt{s} = 13\,\mathrm{TeV}$ data New!

LHCb-PAPER-2015-041, $\int Ldt = 4.98 \pm 0.19\,\mathrm{pb}^{-1}$

$D^{*\pm}$ double-differential cross-section in p_{T}, y (using $D^{*+} \to D^0\pi^+$)





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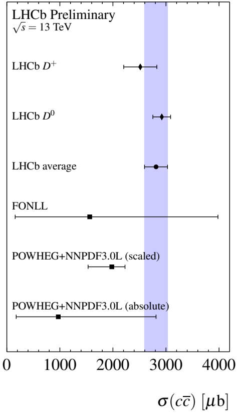


D^0 and $D^{\pm}$ cross-sections are recalculated to total $c\bar{c}$ cross-section using $c\bar{c} \to D^0$ and $c\bar{c} \to D^{\pm}$ fragmentation fractions measured in e^+e^- data [PDG].

Excellent agreement between D^0 and $D^{\pm}$

Integrated $c\bar{c}$ cross-section in acceptance $p_{\mathrm{T}} < 8\,\mathrm{GeV}$, $2 < y < 4.5$

$$\sigma(pp \to c\bar{c}X) = 2.72 \pm 0.01(\mathrm{stat}) \pm 0.18(\mathrm{syst}) \pm 0.14(\mathrm{FF})\,\mathrm{mb}$$

Observation of pentaquark states

See also: talk by Mikhail SHAPKIN, HF section on Friday

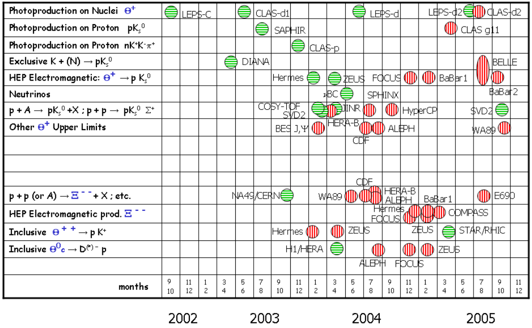
Henri Matisse, The Dance, Hermitage (St. Petersburg)

Exotic hadrons so far

- Theorists have thought about exotic (beyond $q\bar{q}$, qqq) hadrons since the early days of quark model
- Experimental evidence for 4-quark mesons started to appear only recently.
  - $X(3872)$ (Belle, BaBar, CDF)
  - $Z_b(10610)$ and $Z_b(10650)$ (Belle)
  - $Z(4430)$ (Belle, LHCb)
  - $Z_c(3900)$ (BES-III)

- Pentaquark: discoveries and undiscoveries
- Now: first conclusive observation of pentaquark-like structure from LHCb

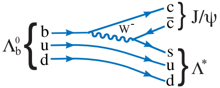
[R.A. Schumacher, nucl-ex/0512042]

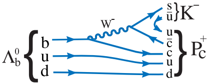


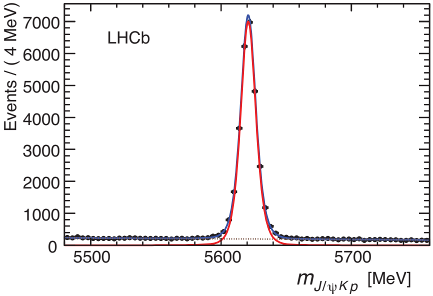
$\Lambda_b^0 \to J/\psi\, pK^-$ decay

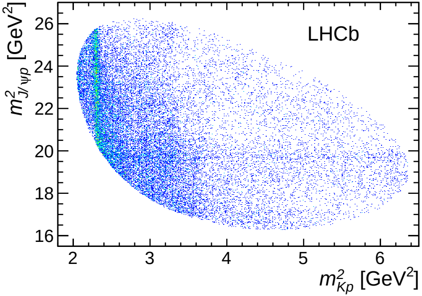
PRL 115, 072001 (2015), $\int L dt = 3.0\,\text{fb}^{-1}$

Conventional contributions only in pK^- spectrum (Λ^* states).







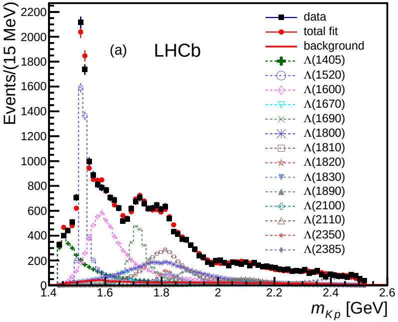


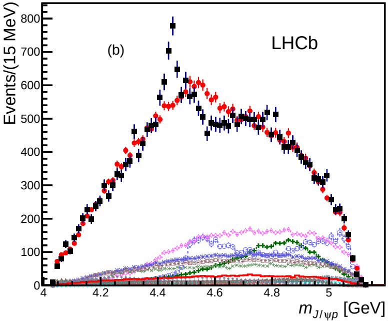
Event yield: 26007 ± 166 events
Low background (5.4%)

Dalitz distribution shows an unexpected narrow feature in $J/\psi\, p$ mass.

PRL 115, 072001 (2015), $\int L dt = 3.0\,\text{fb}^{-1}$

Full amplitude analysis of the $\Lambda_b^0 \to J/\psi\, pK^-$ decay to understand its dynamics.





Admixture of all known Λ^* states does not reproduce the feature at $m_{J/\psi\, p} = 4450\,\mathrm{MeV}$.

[PRL 115, 072001 (2015)](), $\int L dt = 3.0\,\text{fb}^{-1}$

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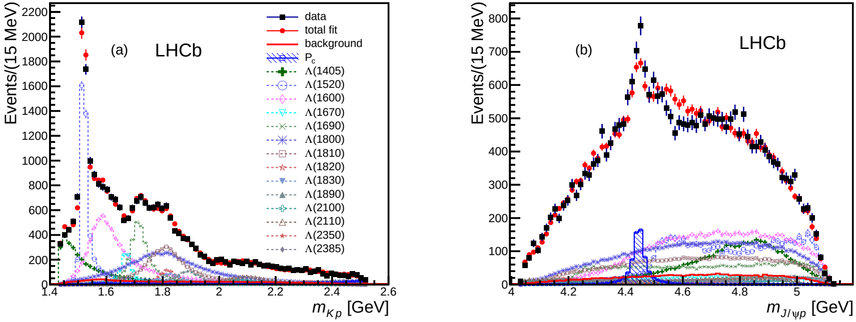
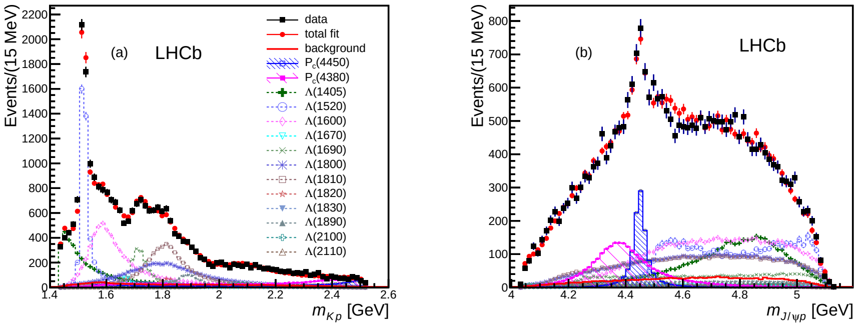


Inclusion of the exotic $J/\psi\, p$ state improves the fit, best $J^P = 5/2^{\pm}$

PRL 115, 072001 (2015), $\int Ldt = 3.0\,\text{fb}^{-1}$

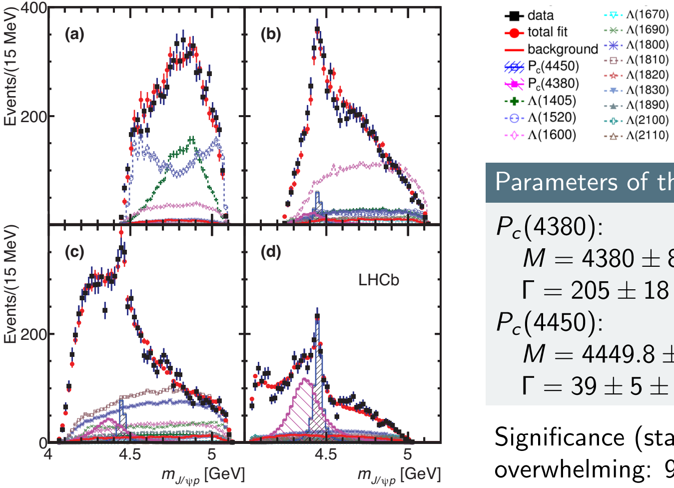
Full amplitude analysis of the $\Lambda_b^0 \to J/\psi\, pK^-$ decay to understand its dynamics.



Two $J/\psi\, p$ states give the best fit, $J = 3/2$ and $5/2$ with opposite parities

Observation of pentaquark states

PRL 115, 072001 (2015), $\int L dt = 3.0\,\mathrm{fb}^{-1}$



Parameters of the pentaquark states

$P_c(4380)$:
$M = 4380 \pm 8 \pm 29\,\mathrm{MeV}$,
$\Gamma = 205 \pm 18 \pm 86\,\mathrm{MeV}$
$P_c(4450)$:
$M = 4449.8 \pm 1.7 \pm 2.5\,\mathrm{MeV}$
$\Gamma = 39 \pm 5 \pm 19\,\mathrm{MeV}$

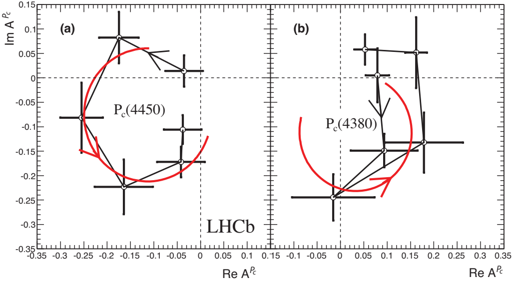
Significance (stat+syst) is overwhelming: 9σ and 12σ

Apparent need for 2nd wider $J/\psi\, p$ state

Observation of pentaquark states

PRL 115, 072001 (2015), $\int L dt = 3.0\,\text{fb}^{-1}$

Argand plots: model-independent confirmation of the resonant character of the exotic states.
Interference with Λ^* states allows to extract the phase in bins of $m_{J/\psi\, p}$.



Clear phase rotation for $P_c(4450)$, direction consistent with Breit-Wigner amplitude
Not conclusive for $P_c(4380)$, need more statistics.

Summary

- LHCb is taking 13 TeV data.
- First analyses using 13 TeV are completed. Using the new split trigger configuration and Turbo stream.
  - Prompt and secondary J/ψ production $\Rightarrow$ $b\bar{b}$ cross-section in 13 TeV pp collisions
  - Prompt charm production with 13 TeV
- Most recent highlight: observation of pentaquark-like states
  - $P_c \to J/\psi\, p$, minimum quark content $c\bar{c}uud$
  - Clearly resonant behaviour (phase rotation)
  - Need studies in other channels and by other experiments for firm confirmation. More results to come with Run I, Run II and LHCb upgrade.

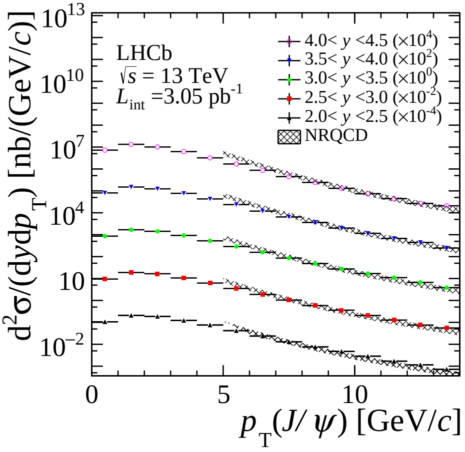
Backup

Frans Snyders, Fish Market, Hermitage (St. Petersburg)

J/ψ production in $\sqrt{s} = 13\,\mathrm{TeV}$ data

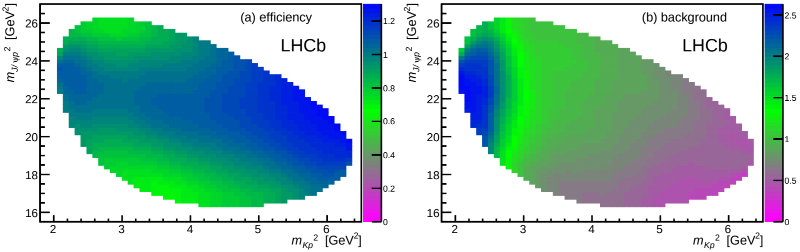
LHCb-PAPER-2015-037, $\int Ldt = 3.05 \pm 0.12\,\mathrm{pb}^{-1}$

Double differential cross-section of prompt J/ψ



PRL 115, 072001 (2015), $\int L dt = 3.0\,\mathrm{fb}^{-1}$

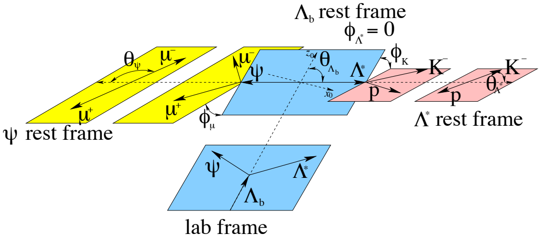
Efficiency and background distributions



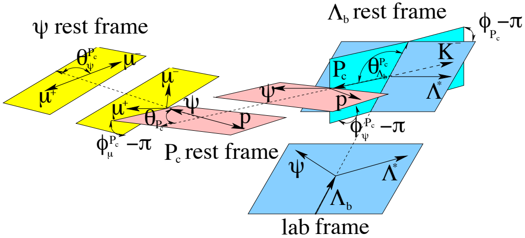
PRL 115, 072001 (2015), $\int L dt = 3.0\,\mathrm{fb}^{-1}$

Definition of angles

Λ^* angles:



P_c angles:



Observation of pentaquark states

PRL 115, 072001 (2015), $\int L dt = 3.0\,\mathrm{fb}^{-1}$

Angular distributions