Exclusive Production at LHCb

LHCb Implications Workshop

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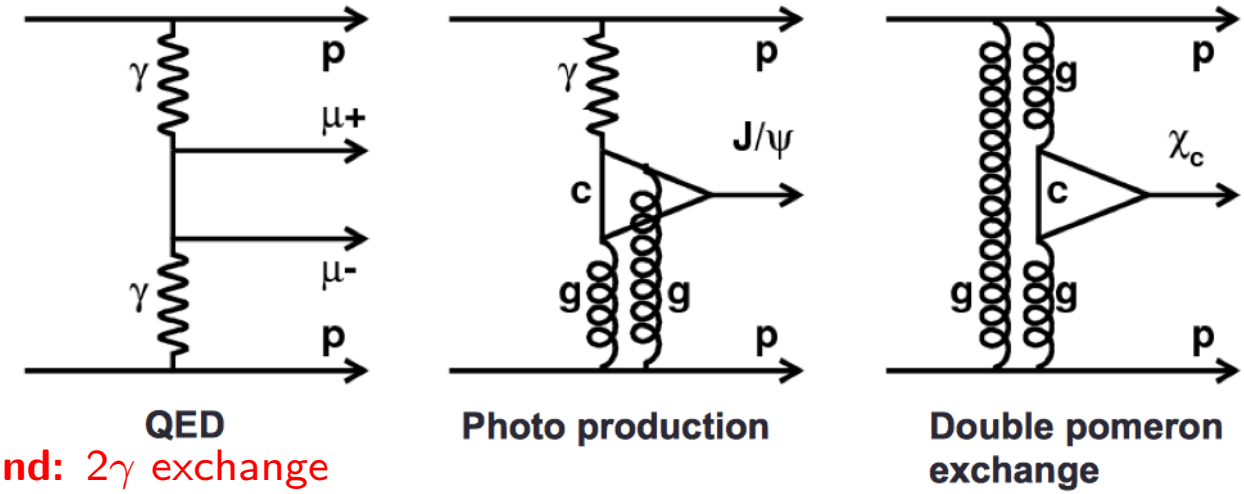
Overview

1. Central Exclusive Production (CEP) at LHCb
2. Results from run 1
3. Prospects for run 1 data
4. Extending LHCb's rapidity coverage for next year

CEP at LHC

Interactions of the form $pp \to pEp$



QED background: 2γ exchange

- QED process with small proton form-factor corrections

Pomeron exchange:

- Pomeron is, at leading order, a pair of gluons in $++$ state

- **Photoproduction:** Photon-pomeron fusion

- Probes gluon density at small values of proton's momentum fraction, x
- Perturbative calculations accessible for higher mass of E

- **Double pomeron exchange:** Pomeron-pomeron fusion

- E must be neutral $PC = ++$, no net flavour: $f_{0,2}, \chi_{c,b}, \gamma\gamma, JJ, H$
- Low $M(E)$: spectroscopy studies. High $M(E)$: QCD and the pomeron

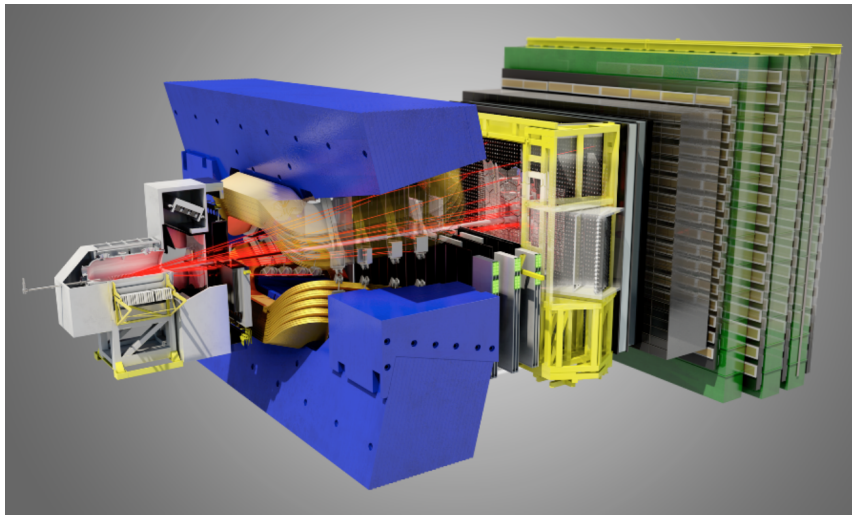
CEP at LHCb

Experimental signature:

- 'Exclusive' candidate (e.g. $J/\psi \to \mu^+\mu^-$) large rapidity gaps with respect to beam

At LHCb:

- Low pile-up
- Detection in pseudorapidity range $2 \to 5$
- Fully reconstruct and identify tracks from exclusive candidate
- Require no other detector activity
  - Implicitly require only one pp interaction
  - Run 1 effective $\mathcal{L}_{\text{int}}$: $\sim$600 pb^{-1}



Establishing the rapidity gap

- Require no other tracks reconstructed
- Require no γ or π^0 activity in calorimeter
- Even beyond LHCb acceptance: exclusive candidate p_T^2 distribution
  - Regge theory implies exclusive candidate $\frac{d\sigma}{dt} \approx \exp(b_s t)$, where $t \approx -p_T^2 c^2$
  - Proton-dissociative background: similar exponential but with harder p_T^2

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1) Exclusive J/ψ and $\psi(2S)$ production

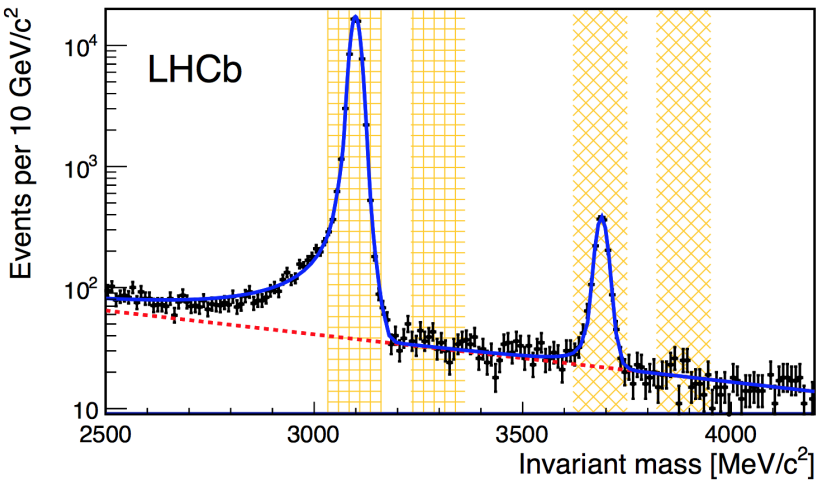
Measurement: differential production cross-section (J Phys G41 055002)

$pp \to p(J/\psi \text{ or } \psi(2S) \to \mu^+\mu^-)p$

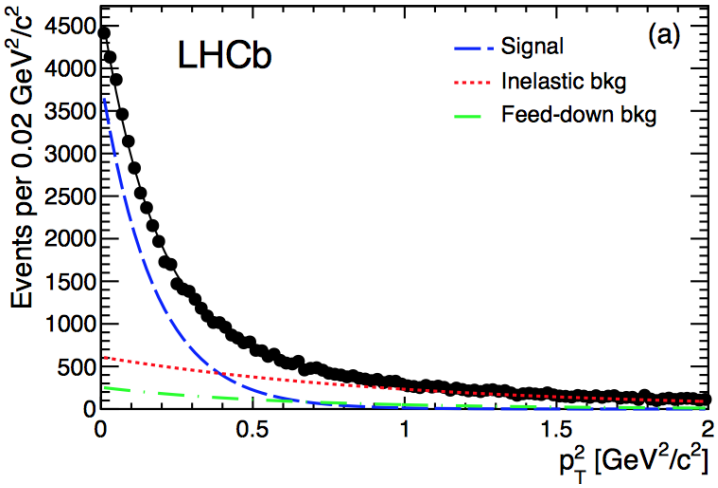
Motivation

- Exchange of a photon and pomeron
- Calculable using pQCD, depends on gluon PDFs
- In LHCb rapidity range, probe x down to 5×10^{-6}
- Sensitive to saturation effects
- Sensitive to odd-parity pomeron partner, 'odderon' (replacing photon)

'Empty-detector' signal and estimate of exclusivity



(a) Dimuon mass fit

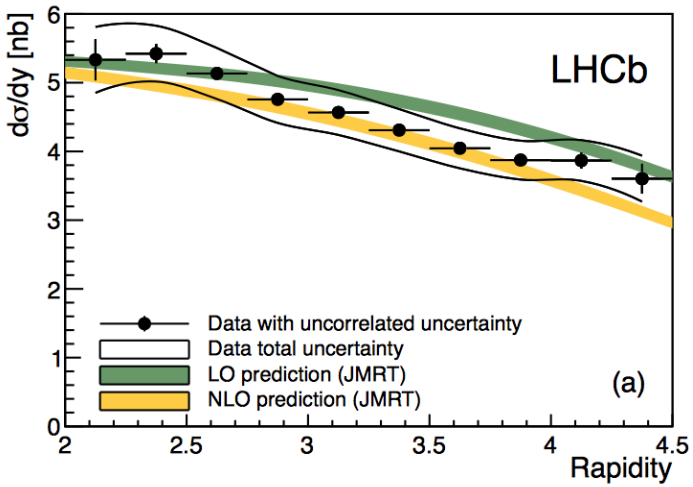


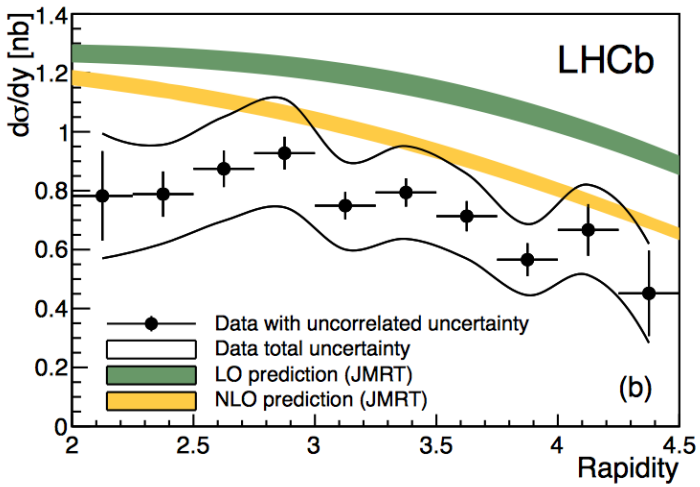
(b) Example J/ψ p_T^2 fit

1) Exclusive J/ψ and $\psi(2S)$ production

Interpretation

- LO and NLO extrapolations from HERA data have been performed [1]
- J/ψ (left) and $\psi(2S)$ (right) data are superimposed: good agreement with NLO





[1] JHEP 1311 (2013) 08

2) Double charmonium production

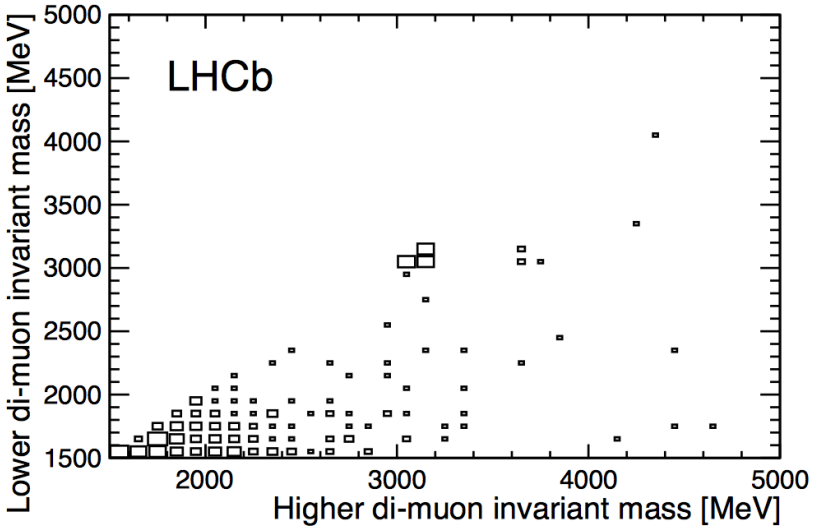
Measurement: production cross-section (J Phys G41 115002)

$pp \to p(X)p,\ X = \{J/\psi J/\psi, J/\psi\psi(2S), \psi(2S)\psi(2S), \chi_{ci}\chi_{ci}\}$

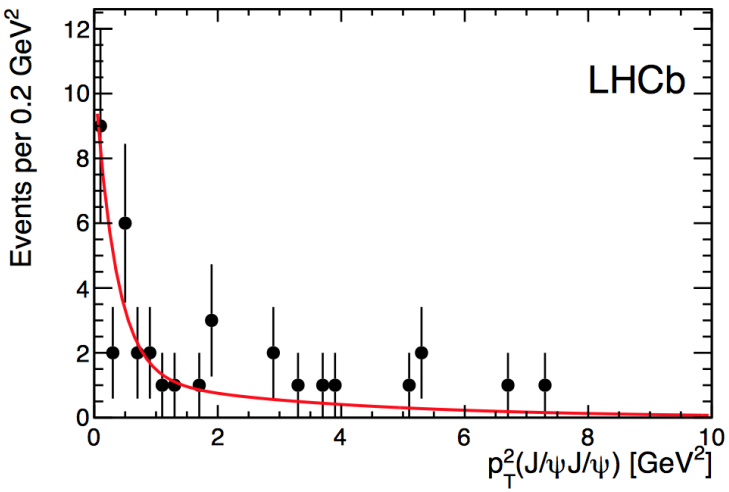
Motivation

- Exchange of two pomerons
- Cross-section and mass spectrum sensitive to exotics: e.g. glueballs or tetraquarks
- Relate cross section to calculated $\sigma(gg \to J/\psi J/\psi)$ using Durham model

'Empty-detector' signal



(c) Dimuon mass fit

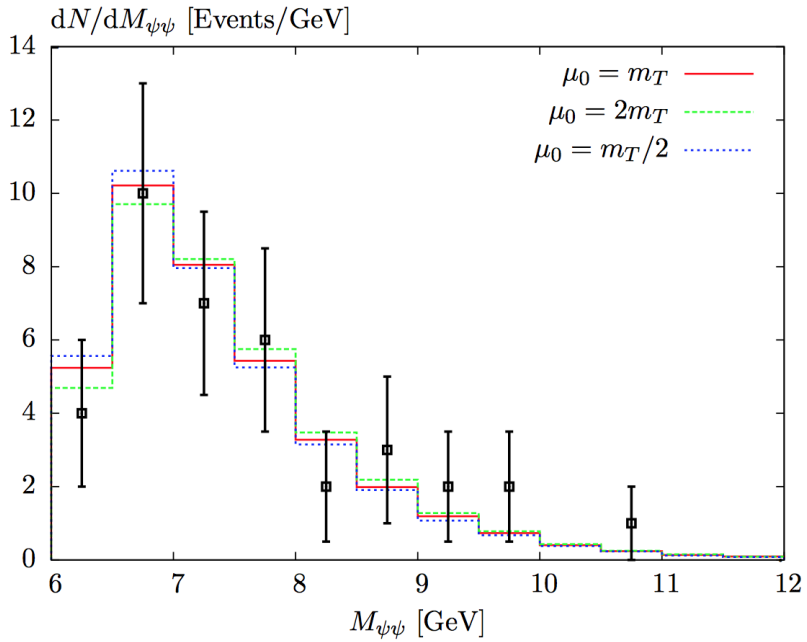


(d) Example: $J/\psi J\psi$ p_T^2 fit

2) Double charmonium production

Interpretation

- First observation of CEP for pairs of charmonium mesons
- Estimate of exclusive component in 'empty-detector' signal is $42 \pm 13\%$
- Measurement of $\sigma(J/\psi J/\psi) = 24 \pm 9 pb$ and $\frac{\sigma(J/\psi\psi(2S))}{\sigma(J/\psi J/\psi)} = 1.1^{+0.5}_{-0.4}$ in reasonably good agreement with subsequent theoretical calculation[2]
- Observed $J/\psi J/\psi$ mass spectrum in good agreement with shape (independent of renormalisation/factorisation scales) from MSTW08LO (cf inclusive $J/\psi J/\psi$ mass spectrum[3]).



[2] arXiv:1409.4785

[3] PLB 707 52

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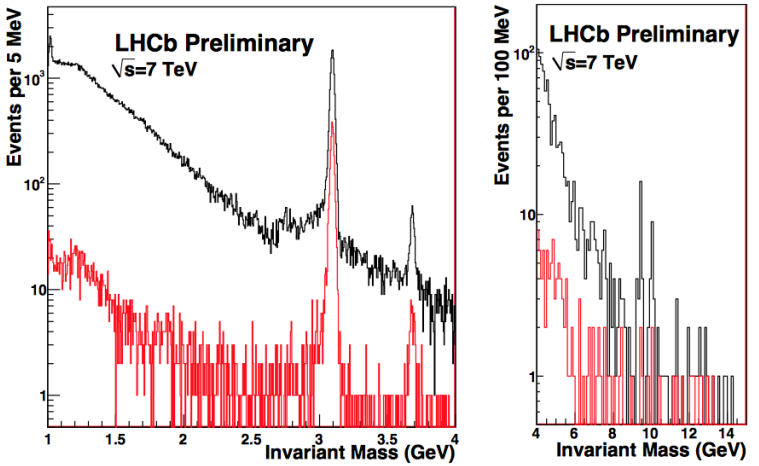
Ongoing analyses

Young field in LHCb, but maturing rapidly

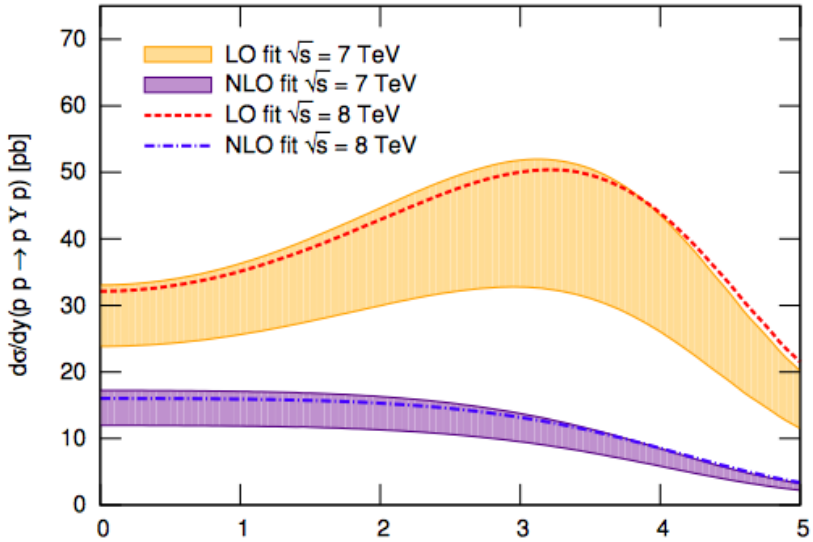
Photoproduction

- Gluon PDF: natural to extend dimuon mass range (e.g. $\Upsilon(1S, 2S, 3S)$) where:
  - Heavier central system $\Rightarrow$ pQCD
  - Probe very low x



(e) 37pb^{-1} dimuon mass spectrum

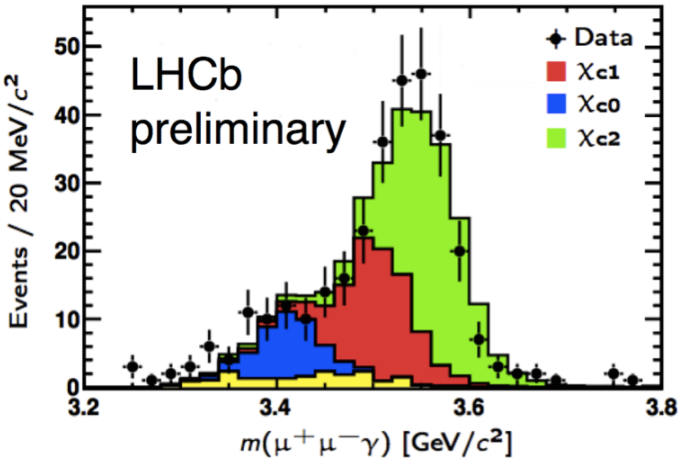
Predictions exist for the Υ CEP differential cross section:



Ongoing analyses

Pomeron pomeron fusion

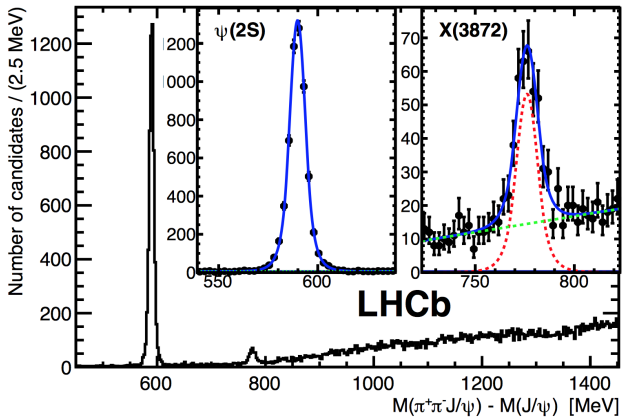
- Di-meson production(e.g. $\pi\pi, KK, D\bar{D}$?)
- Heavy quark systems $(\chi_c, \chi_b, ...)$
  - Decaying to $\mu^+\mu^-\gamma$
  - Expect separation of $\chi_{c0,1,2}$ states using converted photons



(f) $\mu^+\mu^-\gamma$ spectrum in 37pb^{-1}

Spectroscopy studies: $X(3872)$

- LHCb observed 1^{++} inclusively
- Can it be seen exclusively?



(g) Inclusive $X(3872)$

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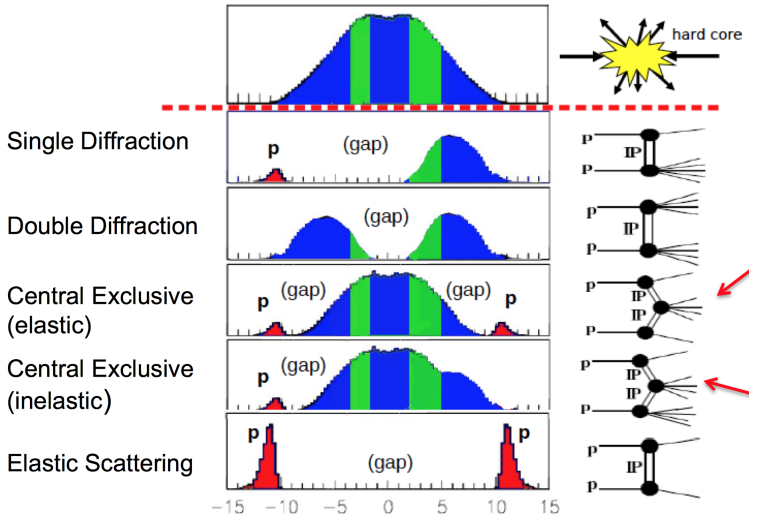
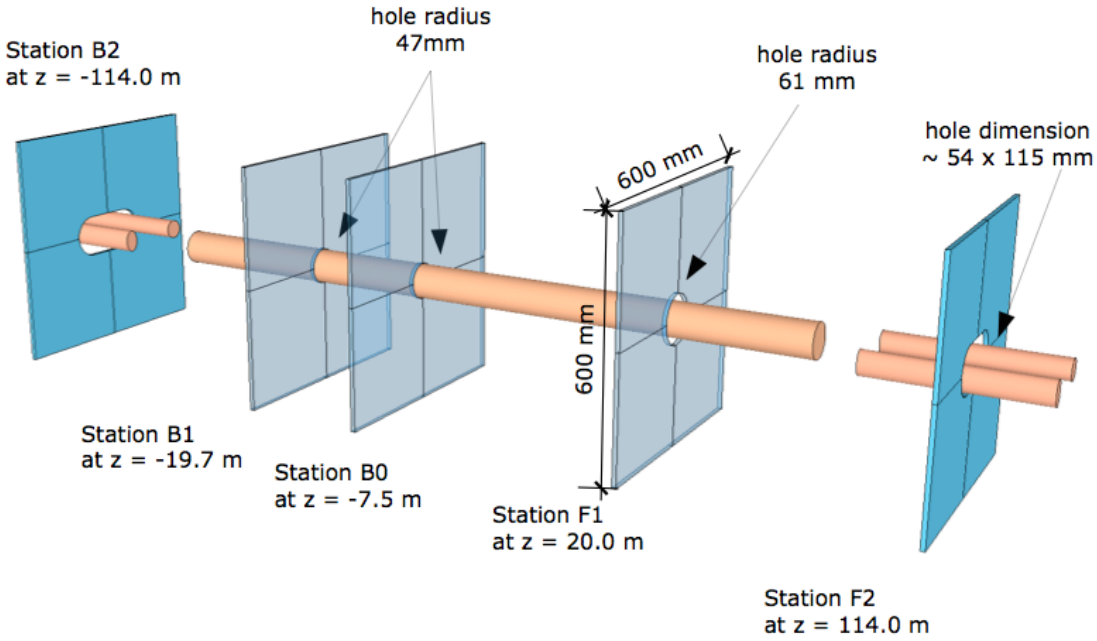
Concept

- Biggest challenge currently is to establish the rapidity gap
- High proportion (50% for $J\psi J\psi$ CEP) of 'empty-detector' signal where proton dissociation escapes down the beampipe
- LHCb hopes for $\sim 5\text{fb}^{-1}$ during run II at low pile-up



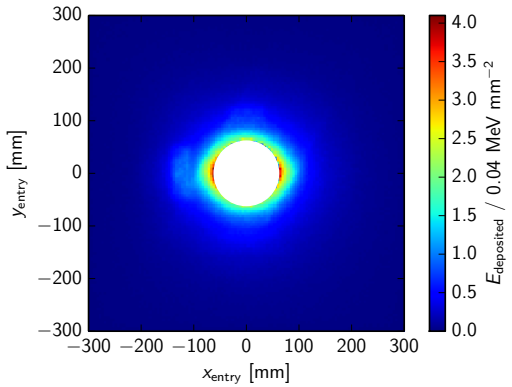
Install scintillators either side of LHCb

- Veto showers from high rapidity particles interacting with the beam-pipe elements

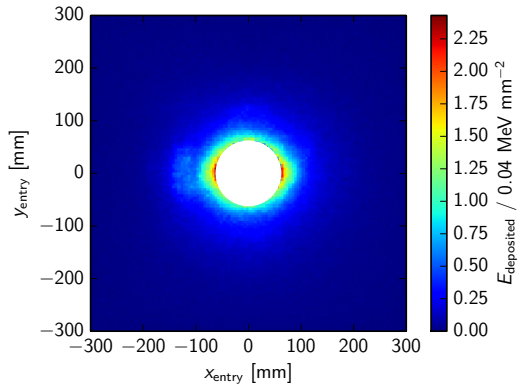


Simulation

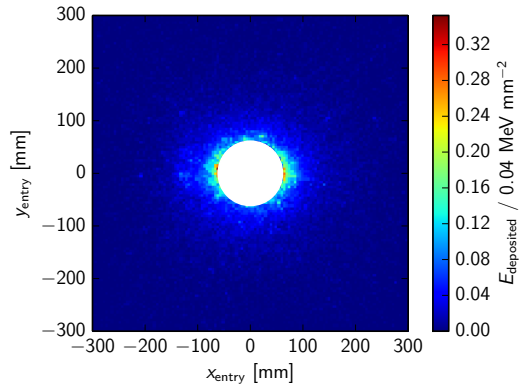
Simulated energy densities in first scintillator station



(h) Min-bias



(i) Single-diffractive

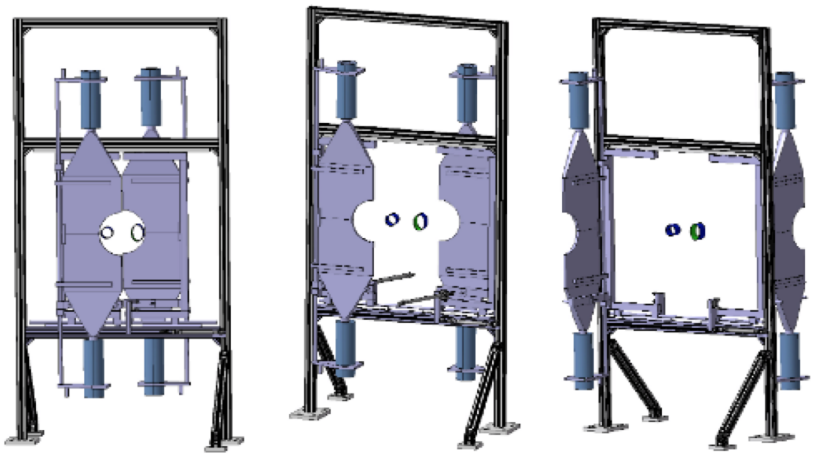


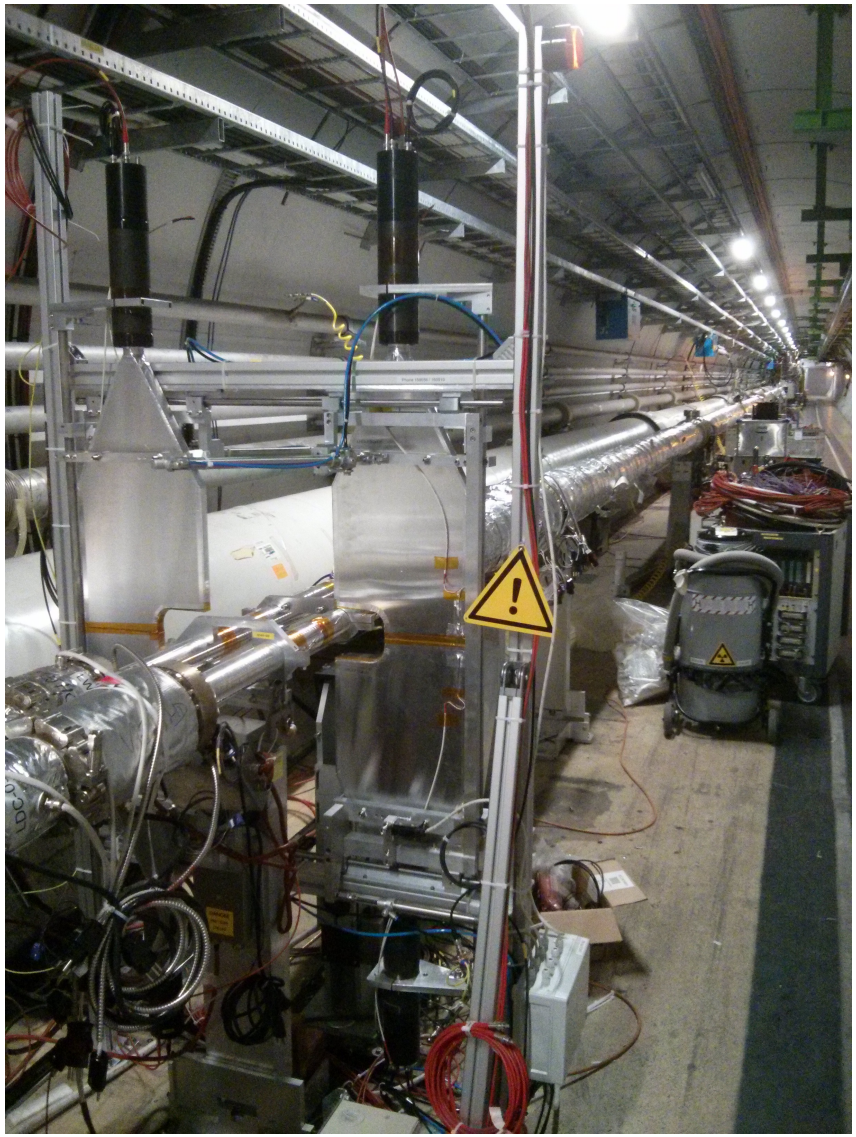
(j) CEP-like

- Each station must be sensitive to ~ 100 hits to effectively veto single diffractive events, while tolerating ~ 2500 hits/event in minimum bias operating conditions
- Efficiency is good even for low energy particles, beyond geometric acceptance due to showering

Installation and commissioning status

- Four of five stations installed and cabled
- Commissioning tests underway
- Read-out chain maturing





Summary

Exciting opportunities for CEP studies at LHCb

- **LHCb's forward acceptance** provides unique window on CEP
- **Spectroscopy** in a very clean environment
- **QCD studies**
  - very low-x gluon PDF
    - increased $\sqrt{s}$ allows probing of even lower x (CEP $J/\psi \rightarrow x = 2 \times 10^{-6}$)
  - nature of pomeron
  - sensitivity to glueballs, odderons, tetraquarks
- **Run 1**:
  - published analyses: $J\psi/\psi(2S)$ and double-charmonium CEP
  - many more analyses anticipated
- **Introduction of FSCs** for 2015 will greatly enhance LHCb's CEP programme