Central exclusive J/ψ and χ_c production at LHCb

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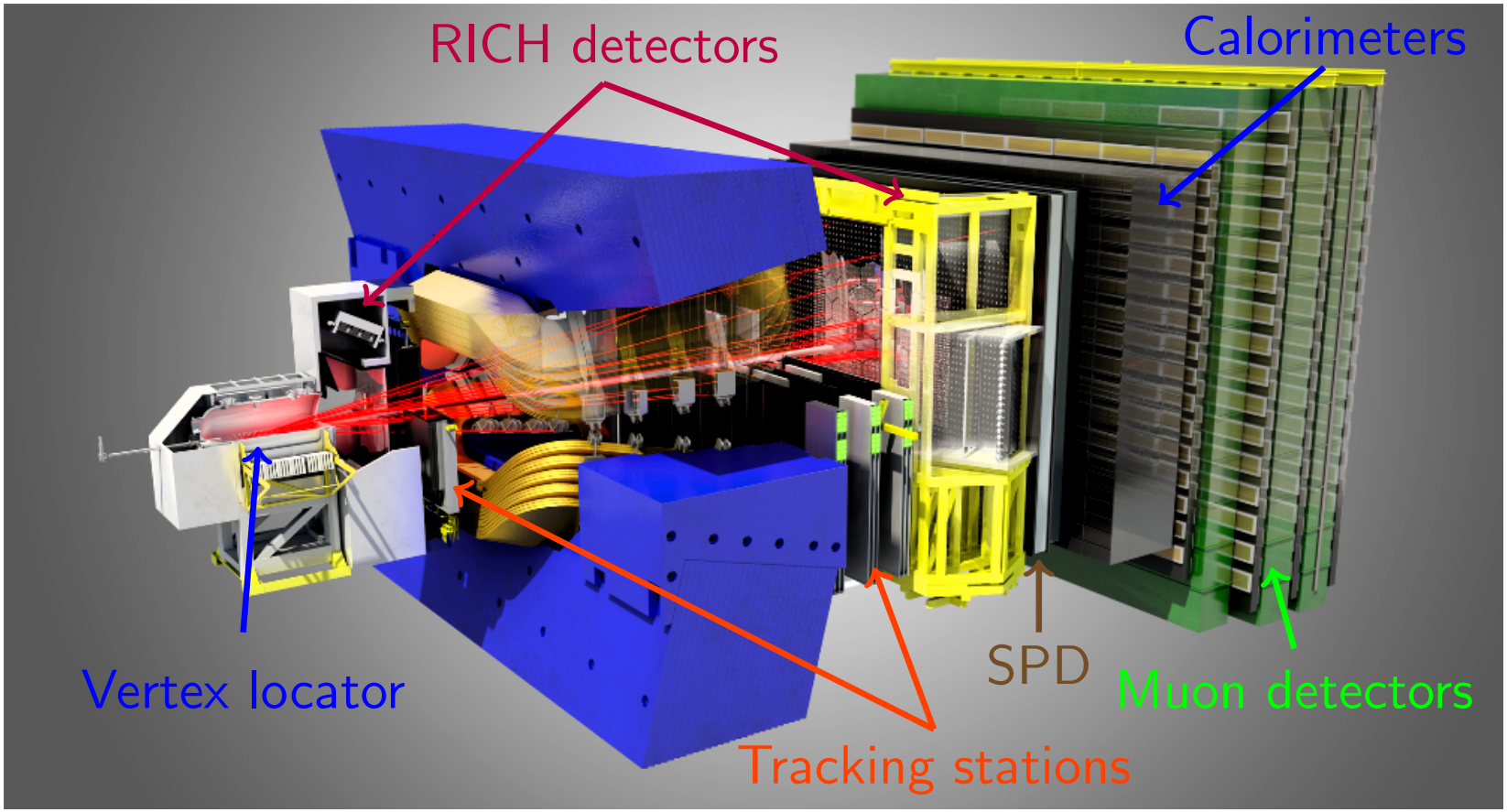
Outline

1. LHCb detector
2. Central exclusive production (CEP) at LHCb
3. CEP of dimuons
   - Event selection
   - Exclusive purity estimation
   - J/ψ and $\psi(2S)$ cross sections [J. Phys. G. 40 (2013) 045001]
   - χ_c cross sections [LHCb-CONF-2011-022]
4. Future prospects
5. Summary

LHCb detector



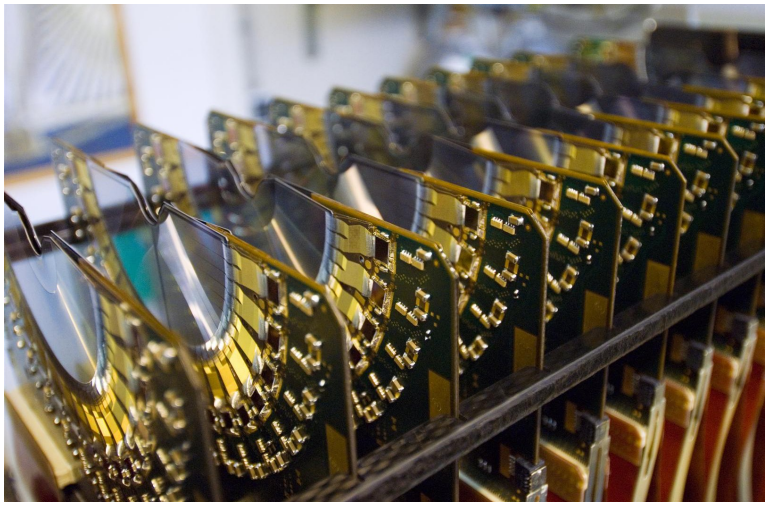
- Single arm spectrometer
- Fully instrumented in $2 < \eta < 5$
- Backward track reconstruction in $-4 < \eta < -1.5$

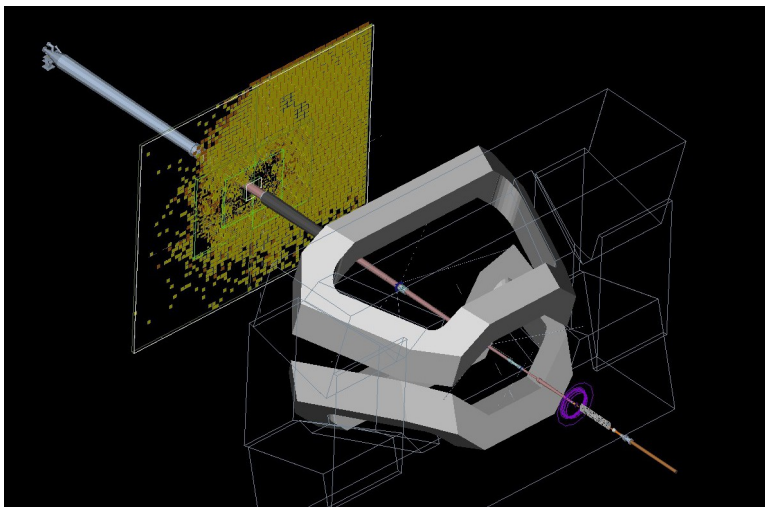
[JINST 3 (2008) S08005]

LHCb detector

Vertex Locator

- 42 silicon strip detectors surrounding interaction region
- Detectors upstream of IR allow reconstruction of backward tracks





Scintillator pad detector

- Segmented detector in front of calorimeters
- Measures charged particle multiplicity

CEP at LHCb

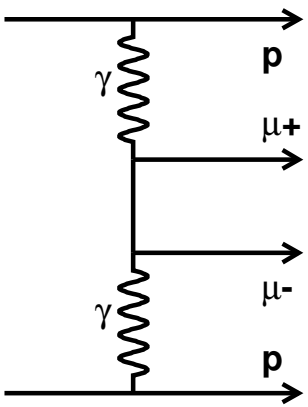
LHCb is well suited to measurements of CEP:

- Fully instrumented to high rapidity, $\eta = 5$
- Low pileup: simplify analysis by only using bunch crossings containing a single interaction (21% of luminosity)
- Flexible trigger
  - Muon detectors and calorimeters available in hardware trigger
  - Full event information available in software trigger
- Excellent particle identification, momentum and vertex resolution
- Sensitivity to low momentum particles, both for triggering and precise reconstruction

Central exclusive dimuon production

- Elastic process, intact protons continuing down beampipe
- Exchange of colourless objects (photon, pomeron)

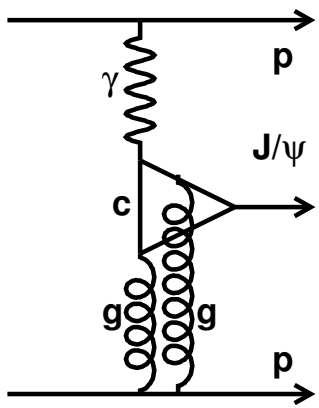
diphoton fusion



LPAIR

[A.G Shamov and V.I Telnov, NIM A, 494 (2002), 51]

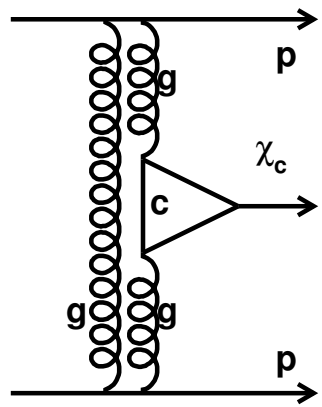
γ-pomeron fusion



STARlight

[S.R. Klein and J. Nystrand, Phys. Rev. Lett., 92 (2004), 142003]

dipomeron fusion



SuperCHIC

[L.A. Harland-Lang, V.A. Khoze, M.G. Ryskin and W.J. Stirling, Eur. Phys. J. C, 65 (2010), 433]

- Signature is isolated dimuon in LHCb with rapidity gaps
- Analyses use 36 pb^{-1} of $\sqrt{s} = 7$ TeV data from 2010

J/ψ and $\psi(2S)$ event selection

Hardware trigger

1. 1 muon, $p_\perp > 400$ MeV/c , or dimuon, each $p_\perp > 80$ MeV/c
2. < 20 hits in SPD

Software trigger

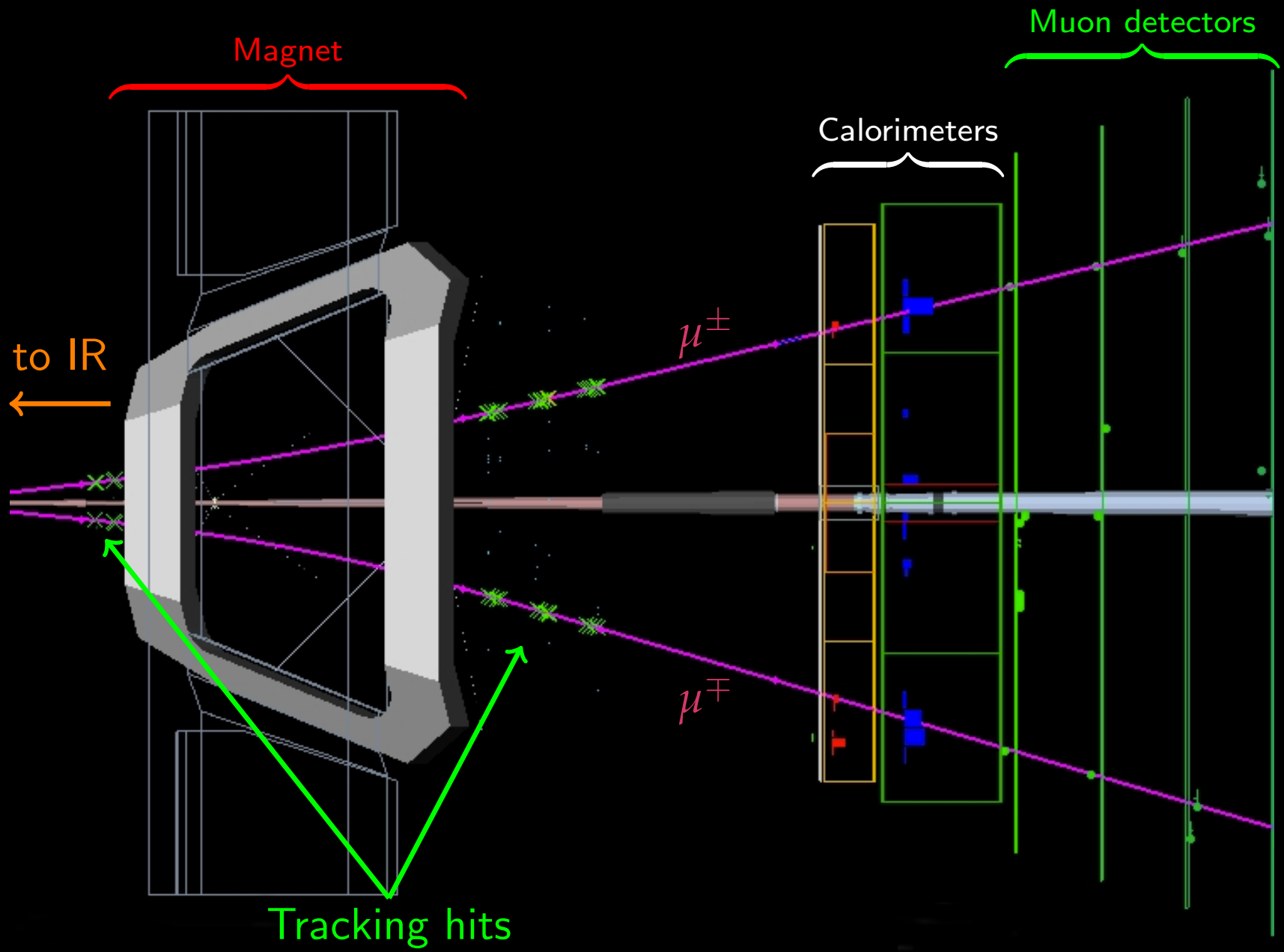
1. Dimuon, mass > 2.9 GeV/c^2 , or dimuon, mass > 1 GeV/c^2 , $p_\perp < 900$ MeV/c and closest approach < 150 µm

Offline selection

1. Two muon tracks with $2.0 < \eta_{\mu^\pm} < 4.5$
2. No photons or other tracks (including backward tracks)
3. Dimuon mass within 65 MeV/c^2 of J/ψ or $\psi(2S)$ mass

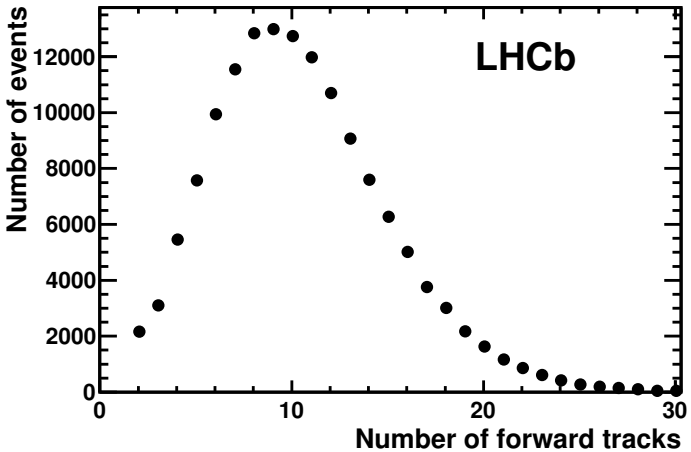
[J. Phys. G. 40 (2013) 045001]

Triggered dimuon candidate

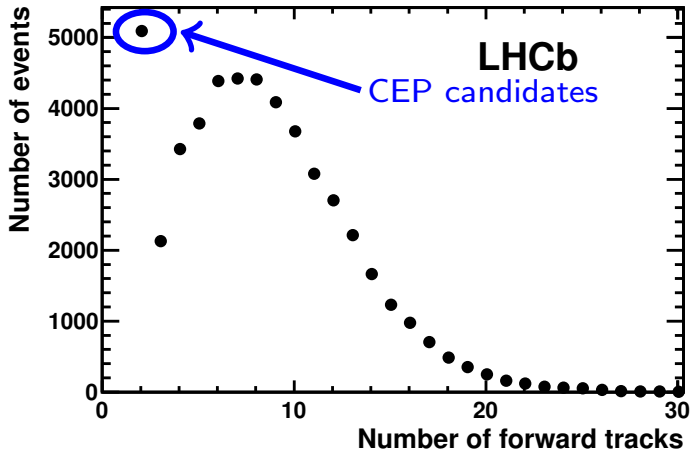


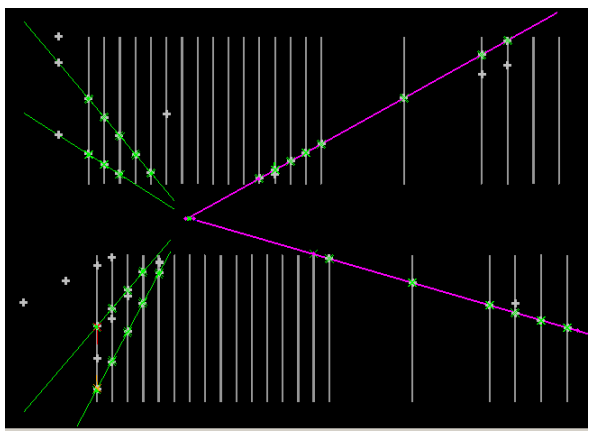
Backward tracks veto

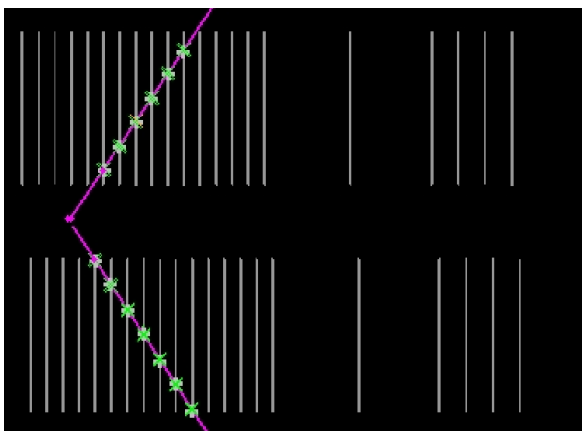
All triggered events



Triggered, no backward tracks



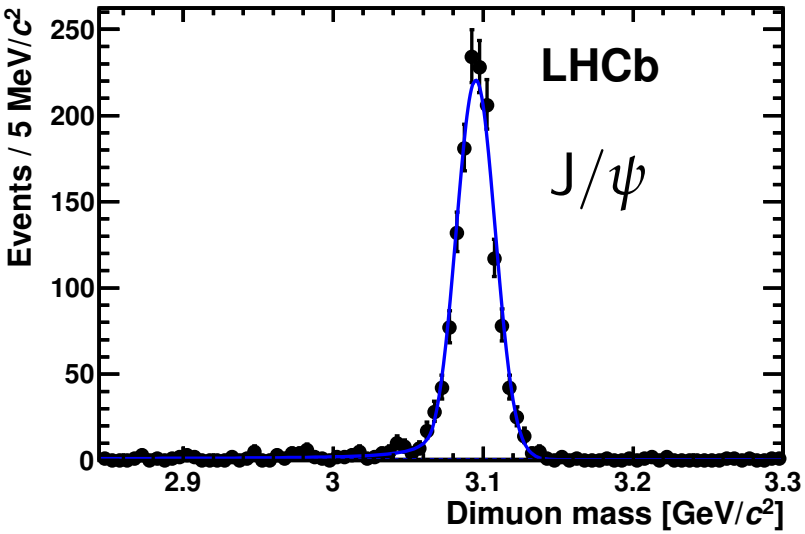


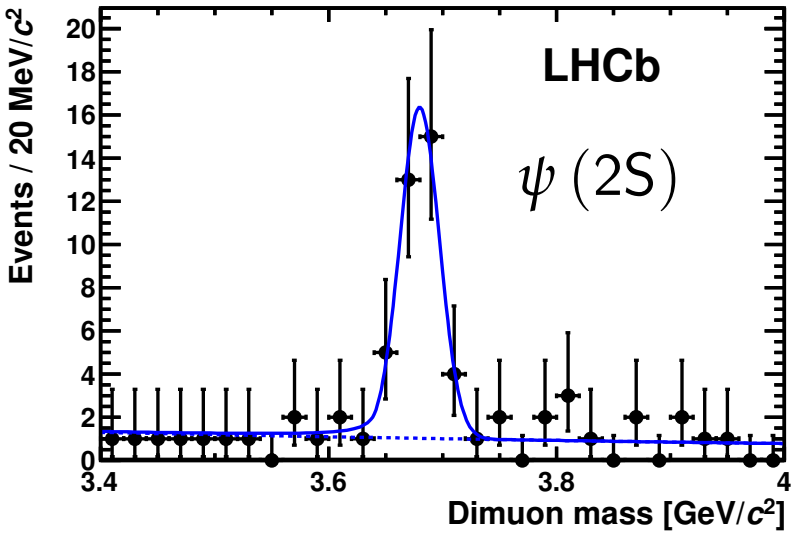


1492 exclusive J/ψ and 40 exclusive $\psi\,(2S)$ candidates in 2010

[J. Phys. G. 40 (2013) 045001]

Purity estimation: non-resonant background





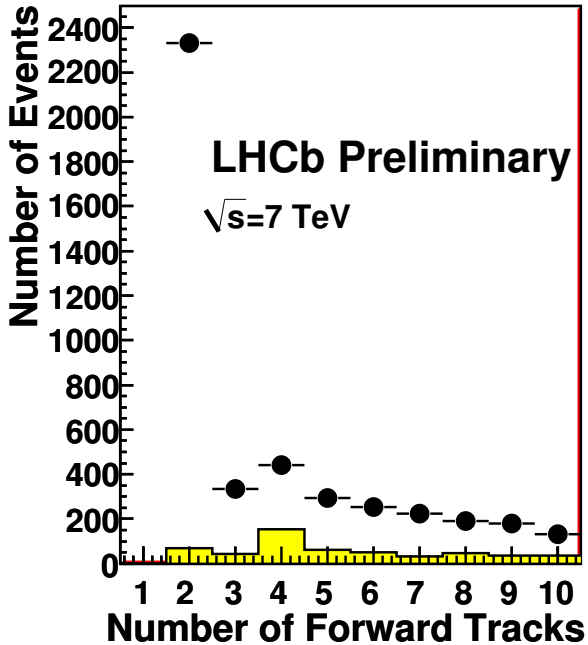
- Fit invariant mass spectra
  - Resonance modelled with Crystal ball function
  - Continuum modelled with exponential
- Non-resonant contribution:
  - $(0.8 \pm 0.1)\,\%$ of events within 65 MeV/c^2 of J/ψ mass
  - $(16 \pm 3)\,\%$ of events within 65 MeV/c^2 of $\psi\,(2S)$ mass

[J. Phys. G. 40 (2013) 045001]

Purity estimation: feed down to J/ψ

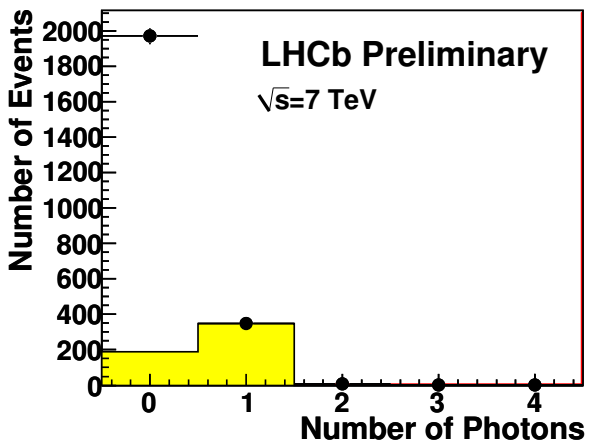
$\psi(2S) \to J/\psi X$, X undetected

- Suppressed by 2 track requirement
- Residual estimated by STARlight simulation, normalised to data
- $(1.8 \pm 0.3)\,\%$ of $J/\psi \to \mu\mu$



$\chi_c \to J/\psi\gamma$, γ undetected

- Suppressed by requiring no photons
- Residual estimated by SuperCHIC simulation, normalised to data
- $(9.0 \pm 0.8)\,\%$ of $J/\psi \to \mu\mu$

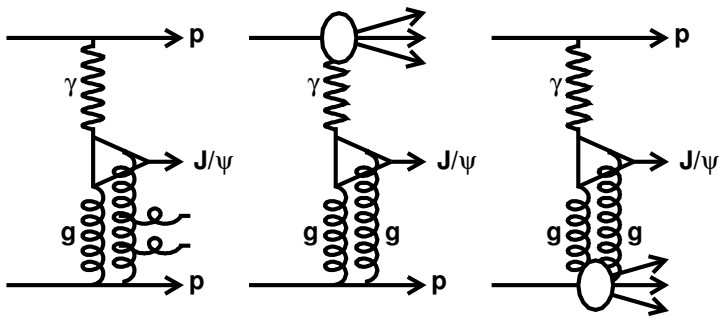


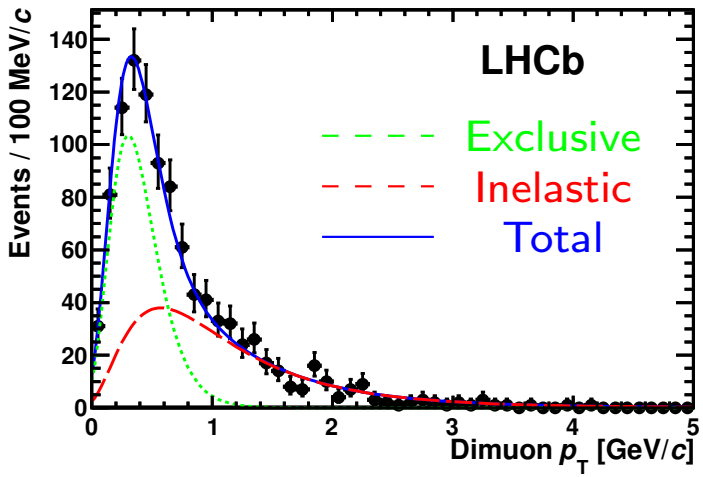
[J. Phys. G. 40 (2013) 045001]

[LHCb-CONF-2011-022]

Purity estimation: inelastic contributions

- Fit to dimuon $p_\perp$ distribution
- Novosibirsk background fit to 3–8 track events extrapolated to 2 track events
- Signal shape from SuperCHIC: $\exp\left(-bp_\perp^2\right)$
  - HERA extrapolation to LHCb: $b = (6.1 \pm 0.3)\ \text{GeV}^{-2}c^2$
  - Fit: $b = (5.8 \pm 1.0)\ \text{GeV}^{-2}c^2$
- J/ψ inelastic contribution: $(30 \pm 4 \pm 6)\,\%$ for $p_\perp < 900\ \text{MeV}/c$
- Same value assumed for $\psi\,(2\text{S})$





[J. Phys. G. 40 (2013) 045001]

Overall exclusive purities:

$(62 \pm 4 \pm 5)\,\%$ for J/ψ $\qquad$ $(59 \pm 4 \pm 5)\,\%$ for $\psi\,(2\text{S})$

Systematic uncertainties

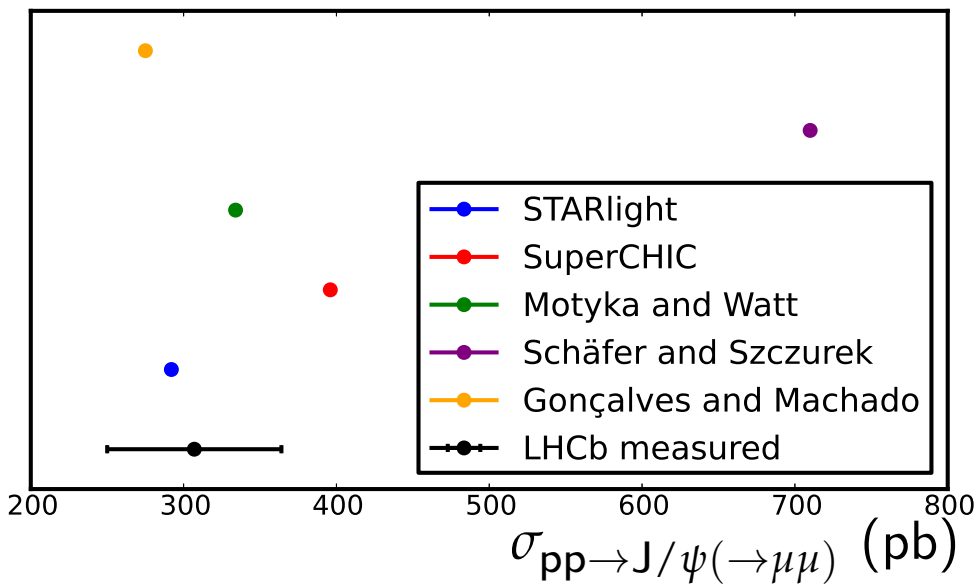
Source	Uncertainty (%)
Luminosity	3.5
Trigger efficiency	4
Tracking efficiency	2
Identification efficiency	5
Selection efficiency	1
Single interaction efficiency	0.7
$\psi(2S)$ background (J/ψ analysis)	0.3
χ_c background (J/ψ analysis)	0.8
Signal shape of dimuon $p_\perp$ fit	6
Background shape of dimuon $p_\perp$ fit	6
Total (J/ψ analysis)	**29.3**
Total ($\psi(2S)$ analysis)	**28.2**

[J. Phys. G. 40 (2013) 045001]

J/ψ and $\psi(2S)$ results

Cross section $\times$ branching fraction, $2.0 < \eta_{\mu^+,\mu^-} < 4.5$:

$$\sigma_{pp\to J/\psi(\to\mu\mu)} = (307 \pm 21 \pm 36) \text{ pb}$$
$$\sigma_{pp\to\psi(2S)(\to\mu\mu)} = (7.8 \pm 1.3 \pm 1.0) \text{ pb}$$

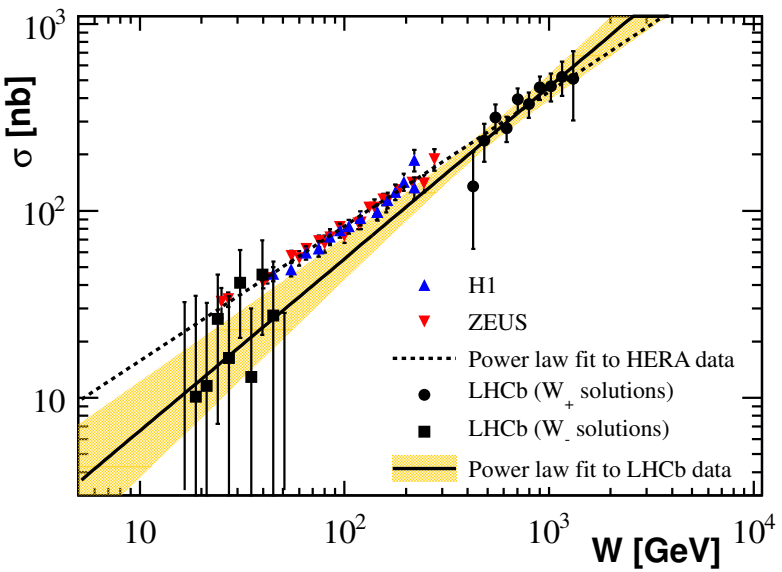


Consistent with theory predictions from Gonçalves and Machado, Motyka and Watt, SuperCHIC and STARlight [J. Phys. G. 40 (2013) 045001]

J/ψ cross section as a function of rapidity

- For comparison with HERA, differential cross section calculated in 10 rapidity bins and reweighted by photon flux

$$\frac{\mathrm{d}\sigma}{\mathrm{d}y}_{\mathrm{pp}\to\mathrm{p}V\mathrm{p}} = r(y)\left[k_+\frac{\mathrm{d}n}{\mathrm{d}k_+}\sigma_{\gamma\mathrm{p}\to V\mathrm{p}}(W_+) + k_-\frac{\mathrm{d}n}{\mathrm{d}k_-}\sigma_{\gamma\mathrm{p}\to V\mathrm{p}}(W_-)\right]$$



[J. Phys. G. 40 (2013) 045001]

- Two solutions for W in each rapidity bin
- Data fitted with power law $\sigma(W) = aW^{\delta}$:

$$a = 0.8^{+1.2}_{-0.5}\ \mathrm{nb}$$

$$\delta = 0.92 \pm 0.15$$

- Consistent with HERA data

χ_c production

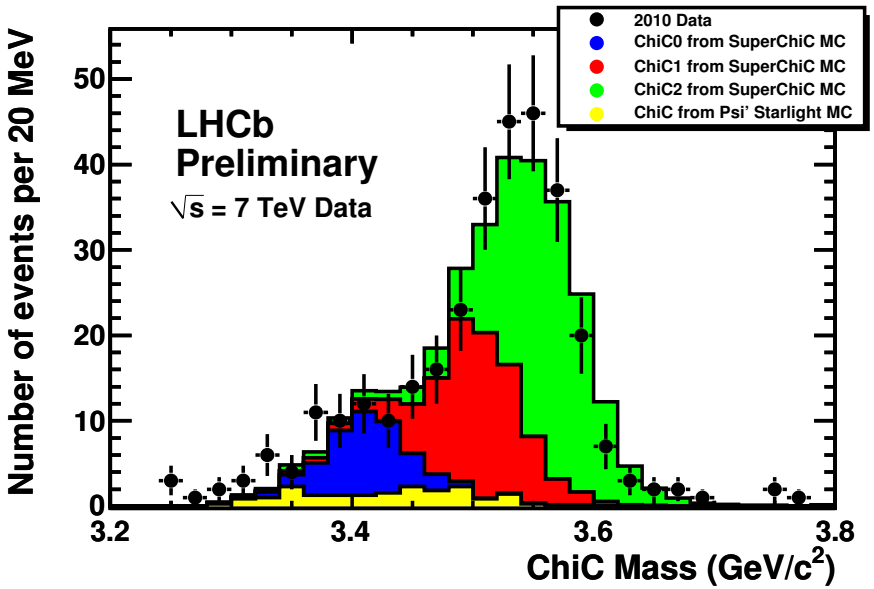
[LHCb-CONF-2011-022]

Selection

Dimuon, γ with $E_\perp > 200$ MeV, no extra tracks: 194 events.

Backgrounds

Inelastic contribution from dimuon $p_\perp$ fit, $\psi(2S)$ feed down from STARlight: $(39 \pm 13)\,\%$ purity for $p_\perp < 900$ MeV$/c$



Results

Mode	LHCb measured (pb)	SuperCHIC (pb)
$\sigma_{\chi_{c0}\to J/\psi\gamma\to\mu\mu}$	$9.3 \pm 2.2 \pm 3.5 \pm 1.8$	14
$\sigma_{\chi_{c1}\to J/\psi\gamma\to\mu\mu}$	$16.4 \pm 5.3 \pm 5.8 \pm 3.2$	10
$\sigma_{\chi_{c2}\to J/\psi\gamma\to\mu\mu}$	$28.0 \pm 5.4 \pm 9.7 \pm 5.4$	3

Future prospects

Improved statistics

80 times more luminosity in 2011–2012 dataset than 2010

Analysis techniques

Increased rapidity coverage for backward tracks

Hadronic final states

Hadronic final states, e.g. $\chi_c \to hh$, open charm

HERSCHEL: High Rapidity Shower Counters for LHCb

Potential installation in LS1 for increased inelastic background rejection

Reduced pileup

Move to 25 ns running doubles usable luminosity to 40%

Summary

Results

- Published J/ψ and $\psi(2S)$ results [J. Phys. G. 40 (2013) 045001]
  - Comparison with HERA J/ψ photoproduction results with extended W coverage
- Preliminary χ_c cross sections [LHCb-CONF-2011-022]

Outlook

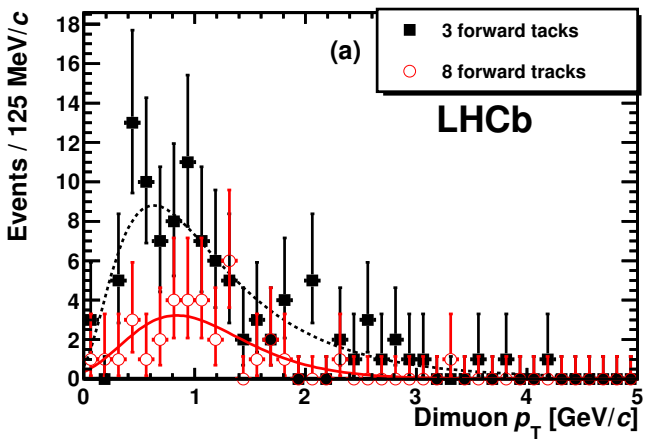
- Reduced uncertainties with greater statistics
- Improved backward track reconstruction
- Extensions of studies to hadronic final states
- Potential installation of forward shower counters
- Increased usable luminosity with move to 25 ns running

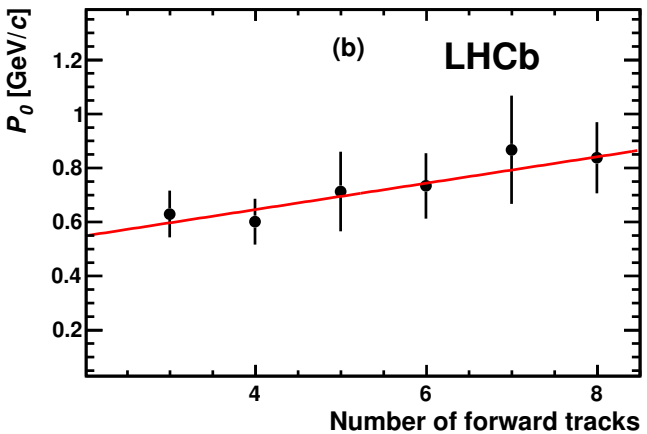
References

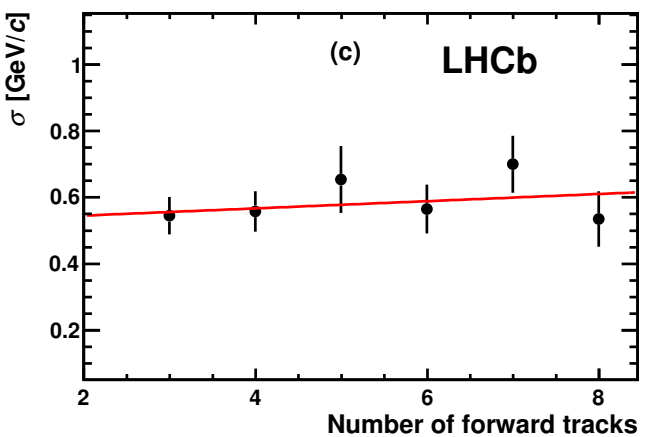
- A.A. Alves Jr. *et al* (LHCb Collaboration), *The LHCb detector at the LHC*, J. Instrum. 3 (2008) S08005
- R. Aaij *et al* (LHCb Collaboration), *Exclusive J/ψ and $\psi(2S)$ production in pp collisions at $\sqrt{s} = 7$ TeV*, J. Phys. G: Nucl. Part. Phys. 40 (2013) 045001
- The LHCb Collaboration, *Central Exclusive Dimuon Production at $\sqrt{s} = 7$ TeV*, LHCb-CONF-2011-022
- A.G Shamov and V.I Telnov, *Precision luminosity measurement at LHC using two-photon production of $\mu^+\mu^-$ pairs*, Nucl. Instr. Meth. Phys. Res. A 494 (2002) 51
- S.R. Klein and J. Nystrand, *Photoproduction of Quarkonium in Proton-Proton and Nucleus-Nucleus Collisions*, Phys. Rev. Lett. 92 (2004) 142003
- L.A. Harland-Lang, V.A. Khoze, M.G. Ryskin and W.J. Stirling, *Central exclusive χ_c meson production at the Tevatron revisited*, Eur. Phys. J. C 65 (2010) 433
- L. Motyka and G. Watt, *Exclusive photoproduction at the Fermilab Tevatron and CERN LHC within the dipole picture*, Phys. Rev. D 78 (2008) 014023
- V.P. Gonçalves and M.V.T. Machado, *Vector meson production in coherent hadronic interactions*, Phys. Rev. C 84 (2011) 011902(R)

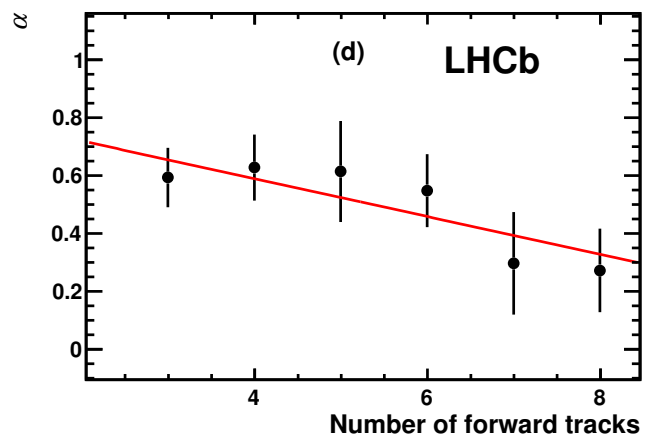
Supplementary: Dimuon $p_\perp$ fit for J/ψ

$$N\left(P; P_0, \sigma, \alpha\right) = A \exp\left(-0.5\left(\ln^2\left(1 + \Lambda\alpha\left(P - P_0\right)\right)/\alpha^2 + \alpha^2\right)\right)$$









[J. Phys. G. 40 (2013) 045001]