Central Exclusive DiMuon Production

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On behalf of the LHCb collaboration

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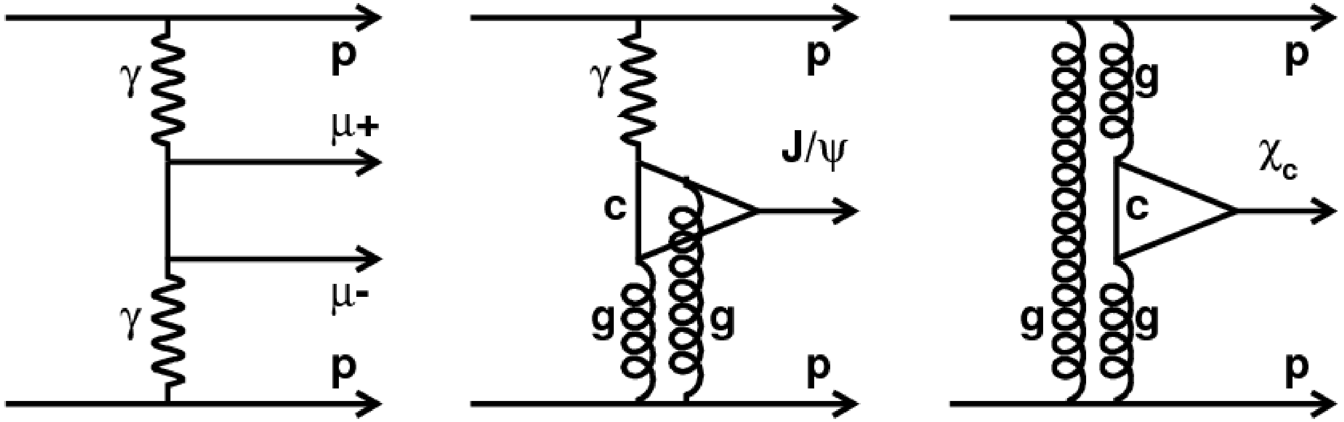
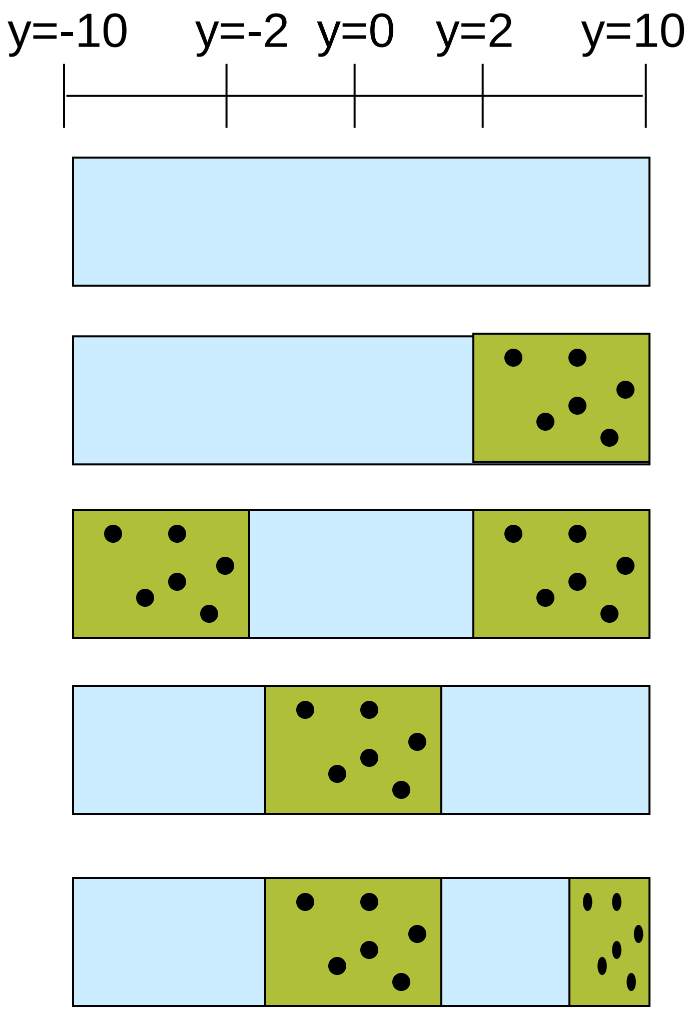
Motivation

Usually proton collisions produce very many final state particle because the gluon is a coloured object.
But if a **colourless** object is exchanged…..



- Results can be related to HERA and Tevatron
- Understand QCD in a clean environment
- Unambiguous evidence for pomeron. Search for odderon
- Constrain unintegrated parton distributions at very small *x (2x10^{-6})*
- Search for saturation effects

Central Exclusive Production



Elastic Scattering

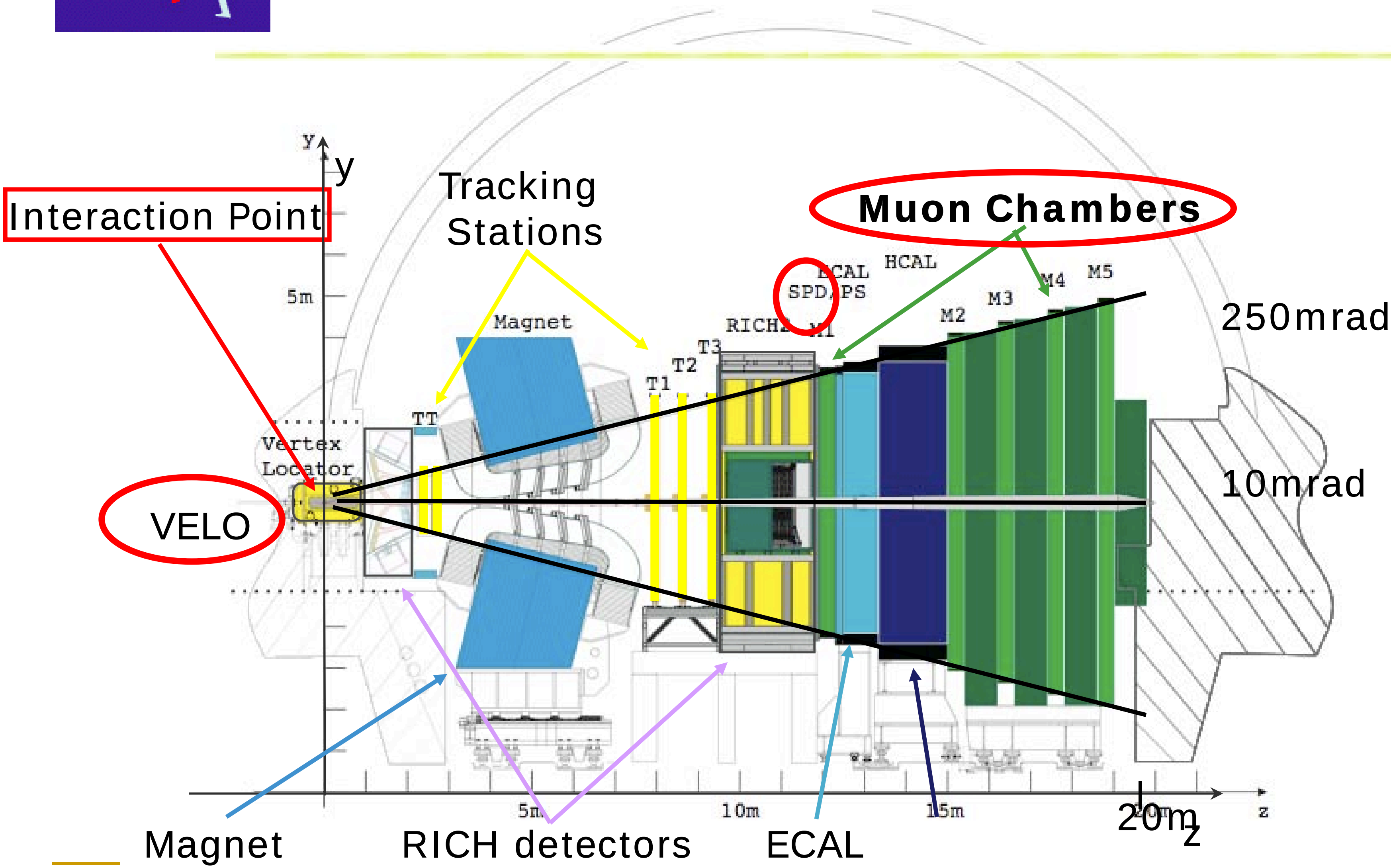
Single Diffraction

Double Diffraction

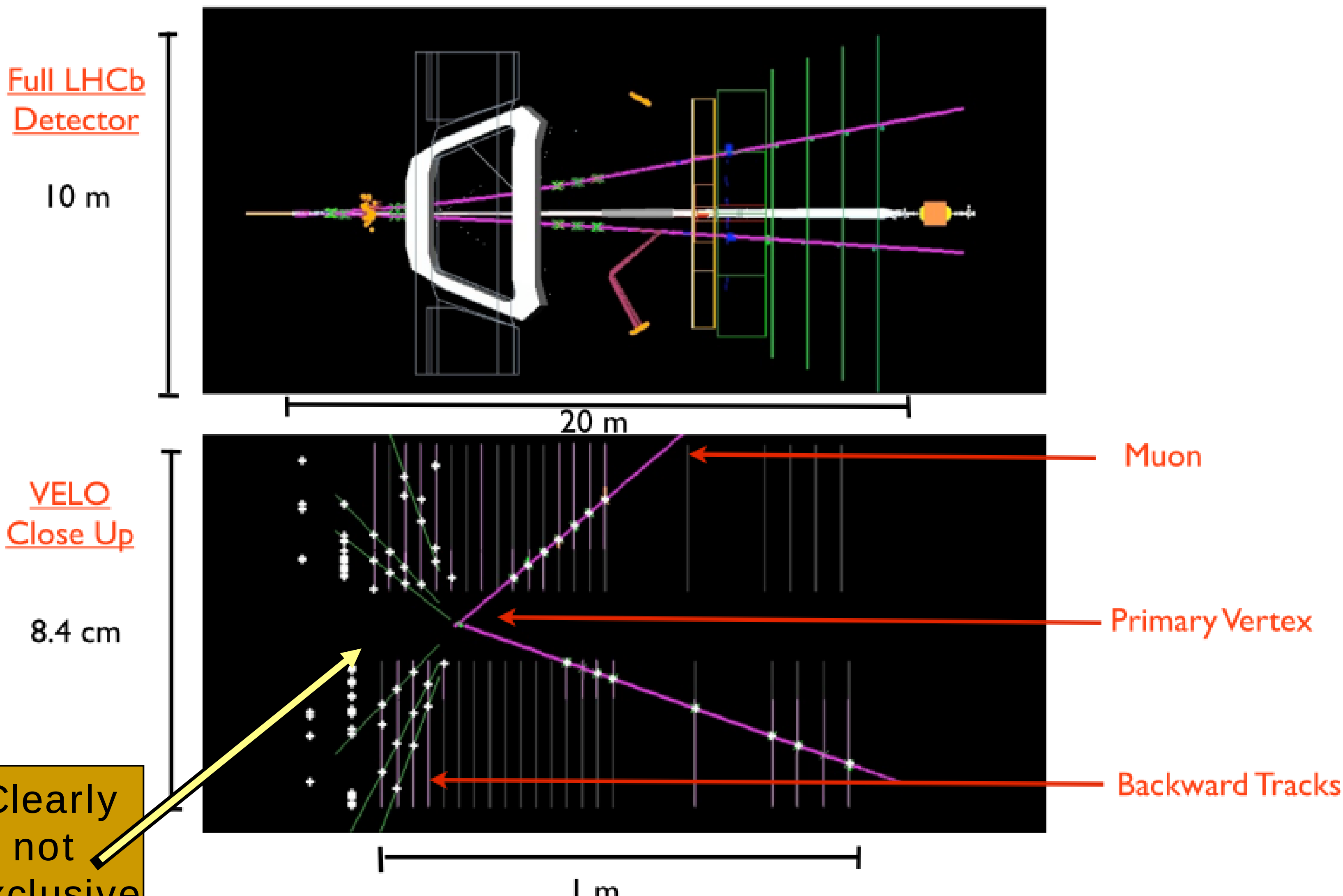
Central Exclusive Production (elastic)

Central Exclusive Production (inelastic)

LHCb: a forward spectrometer

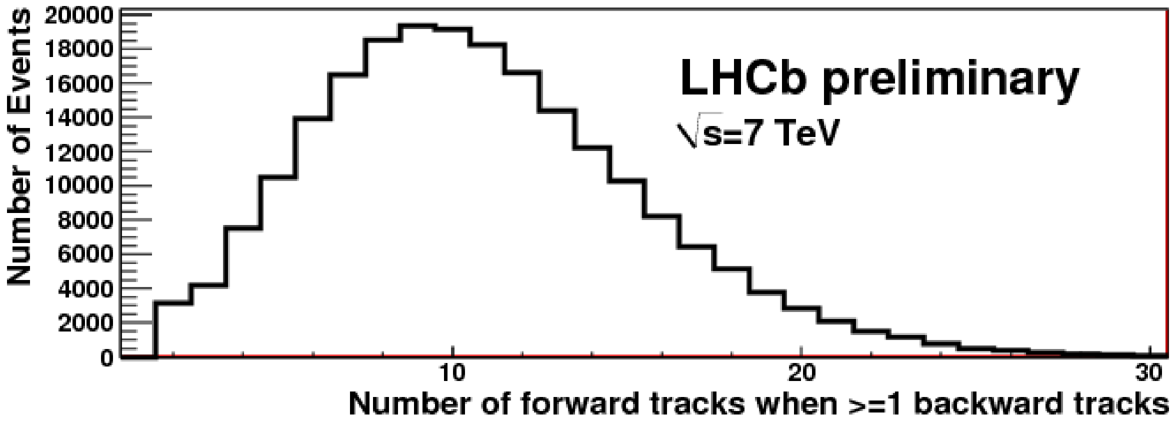


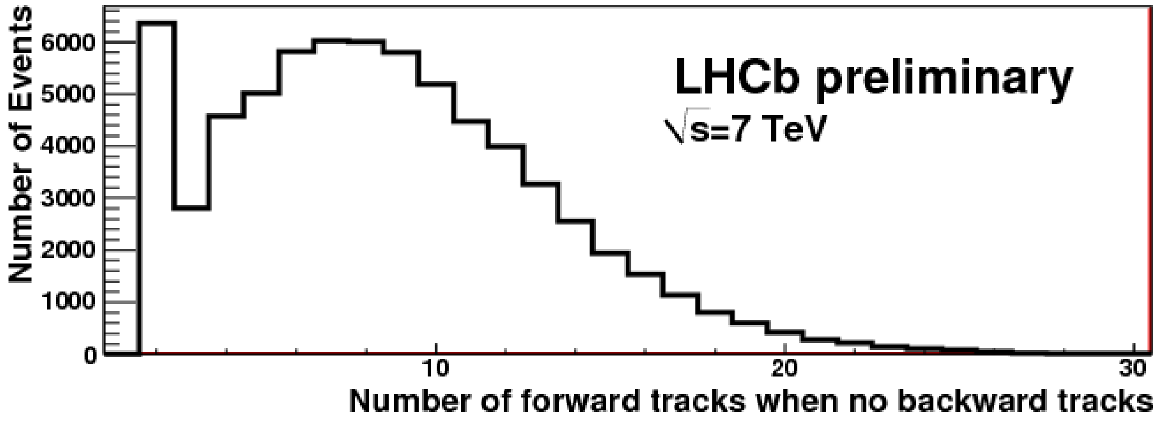
Use of backwards tracks



Clearly not exclusive

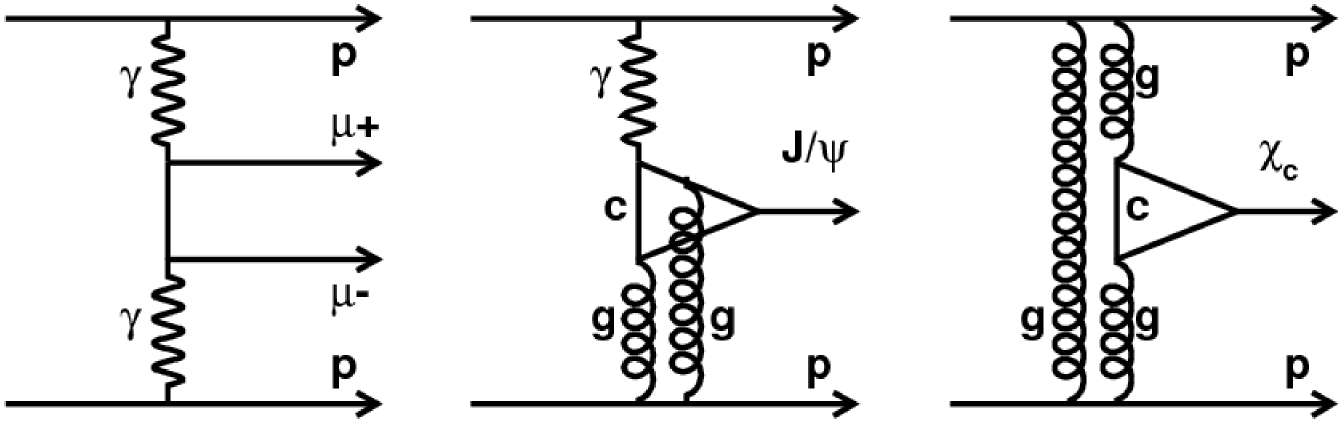
Trigger on two muons and <20 SPD hits





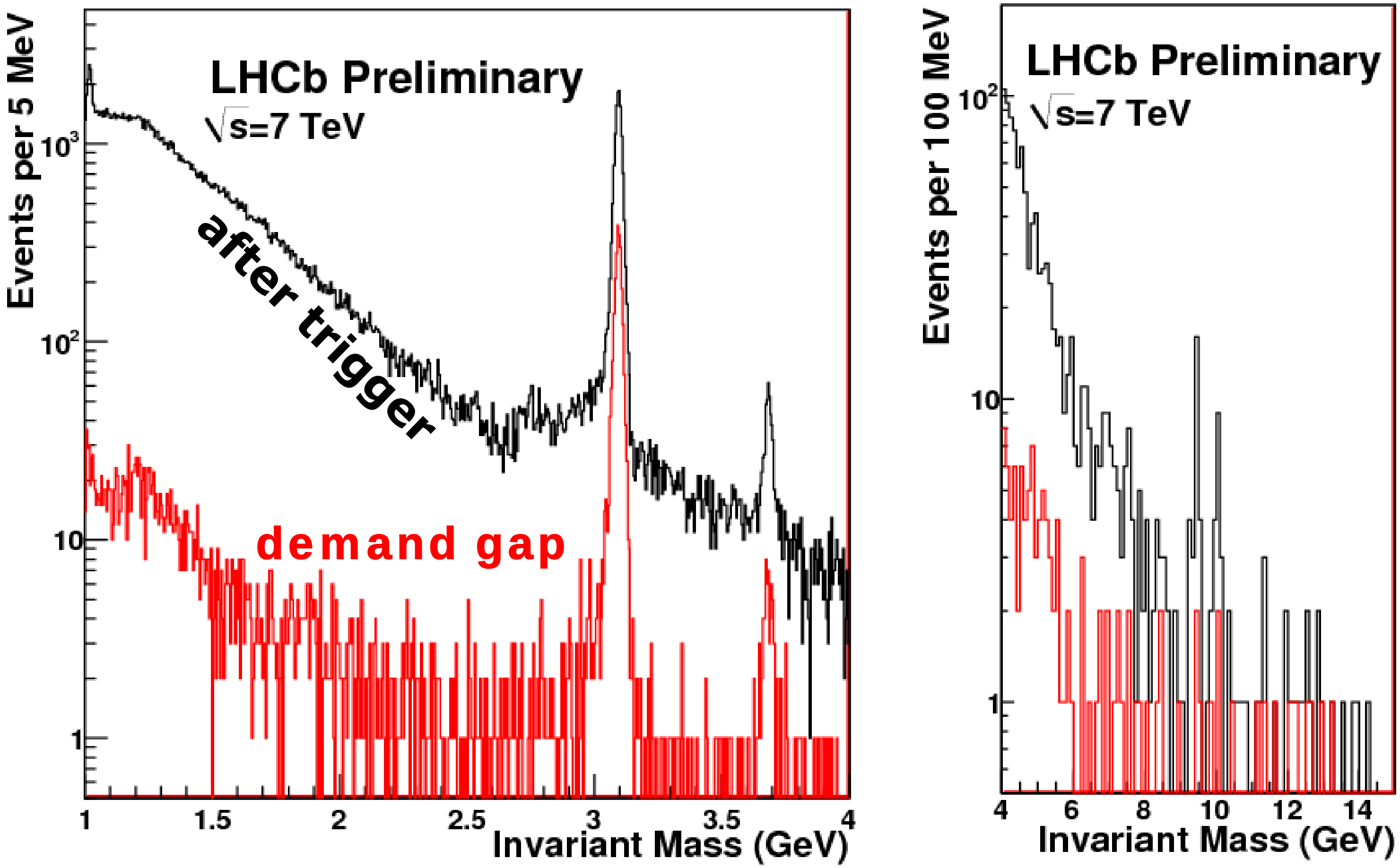
Requiring a gap, there is evidence for central exclusive production decaying to two muons.

Simple Selection Criteria



- **No backward tracks (gap of ~2 units of rapidity)**
- **Precisely two forward muons**
- No photons (for J/psi and diphoton process)
- One photon (for ChiC analysis)
- p_T of dimuon <900 MeV (<100MeV for pμμp).

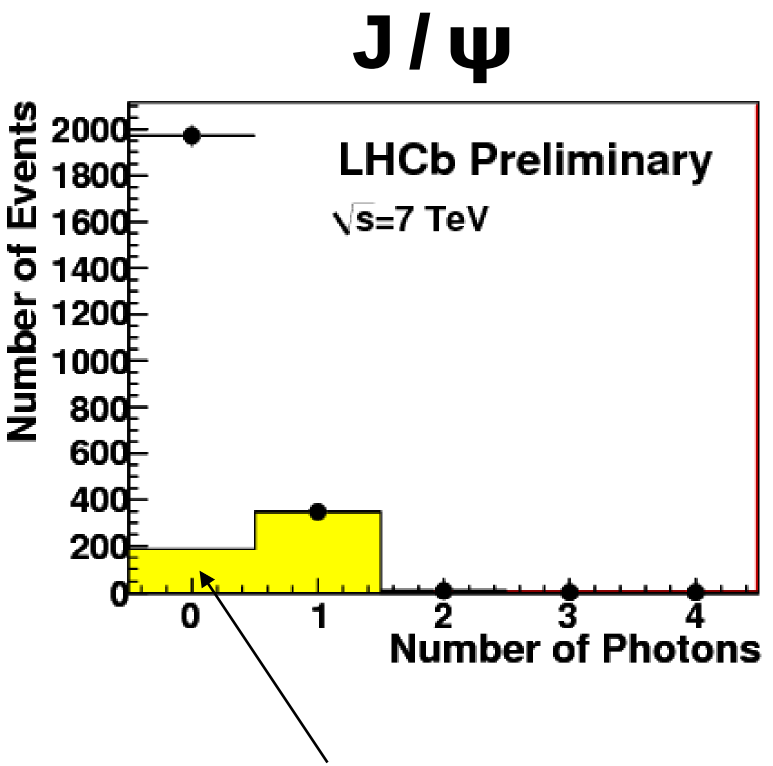
Dimuon Mass Spectrum

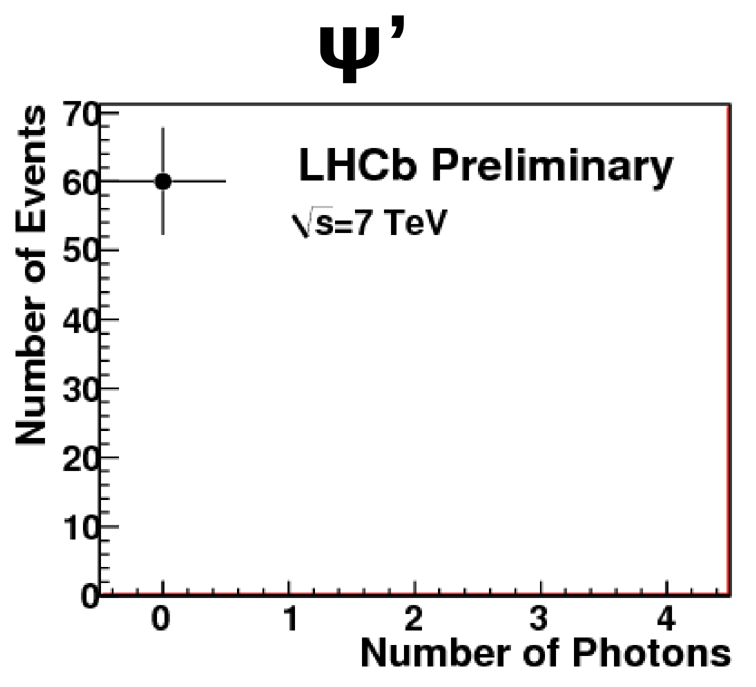


J/ψ and ψ’

- No backward tracks
- Precisely two forward muons
- No photons

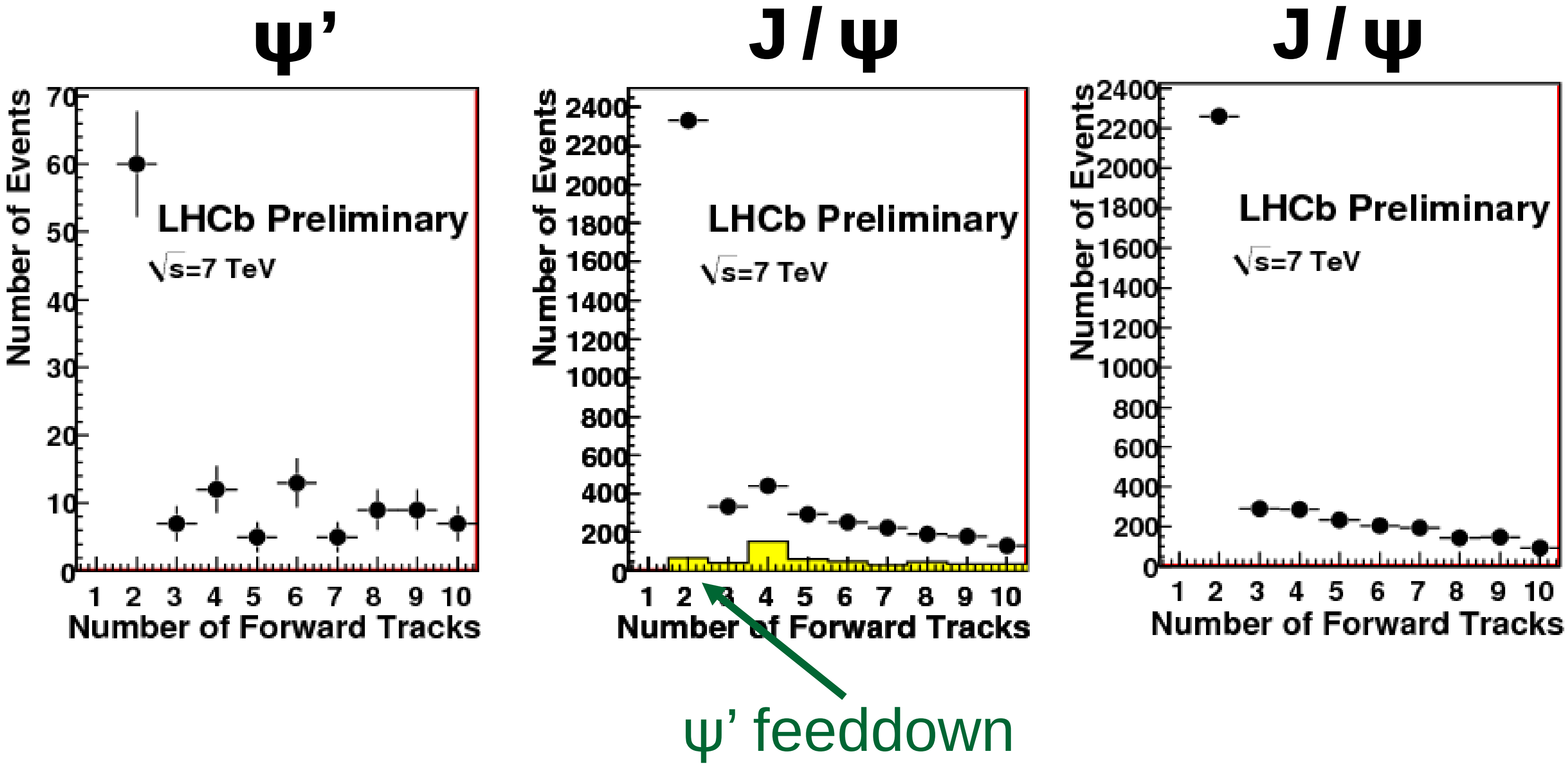
J/ψ and ψ': Number of Photons





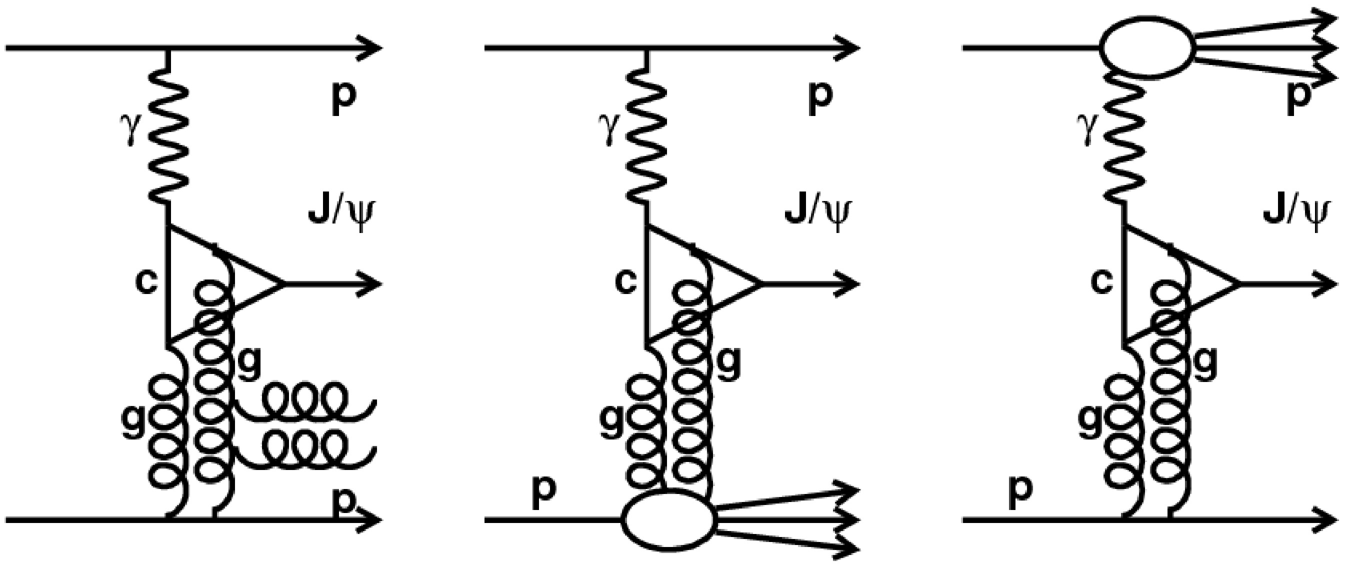
Estimated feeddown from Chi_c

J/ψ and ψ': Number of Tracks

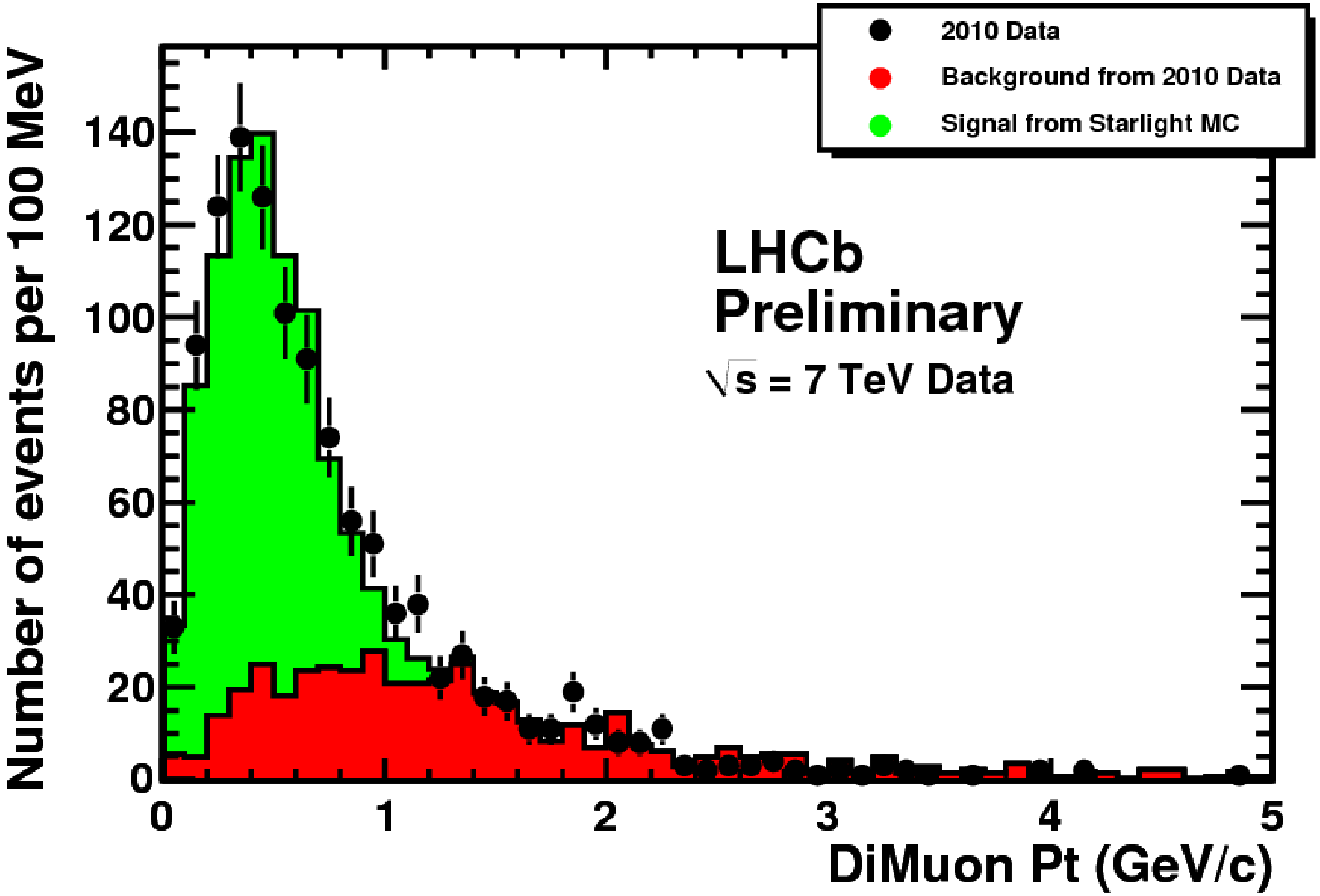


Tempting to fit the background under the peak using straight line/exponential. Better if we can understand the physics giving background.

Inelastic backgrounds

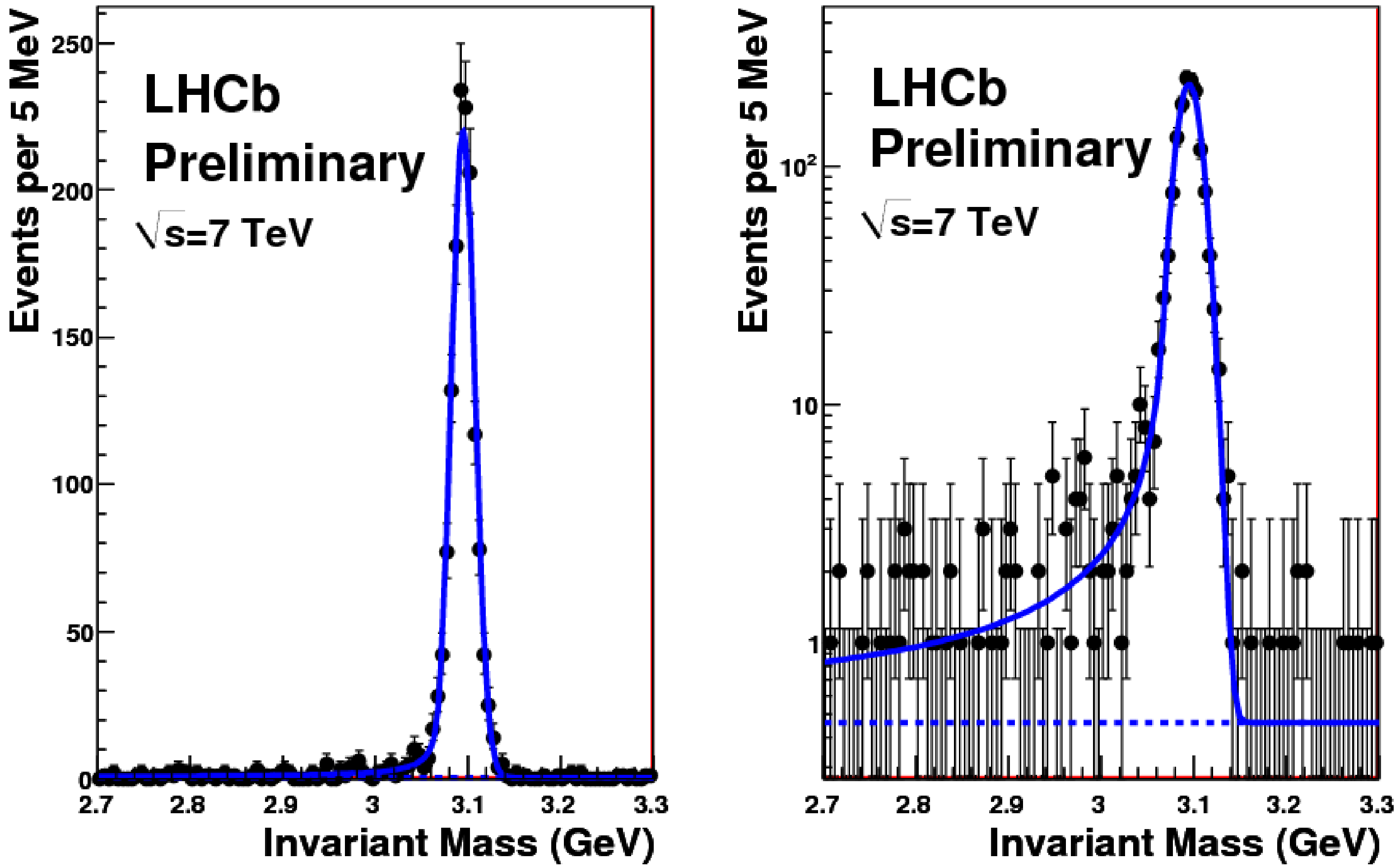


Fit elastic and inelastic components



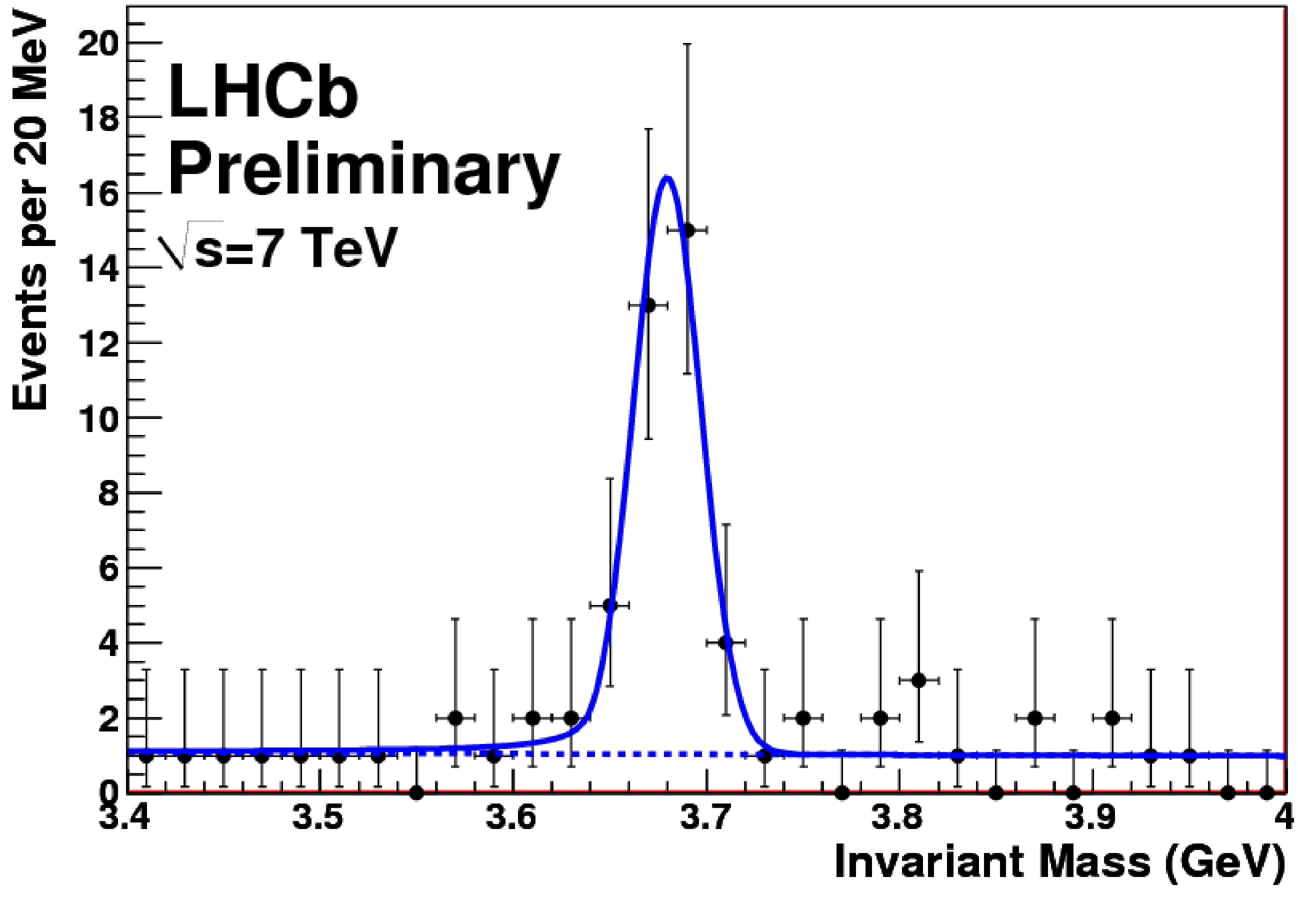
Estimate purity below 900 MeV to be 80+-3 %

J/ψ Non-resonant background & misid



This is not background subtracted !

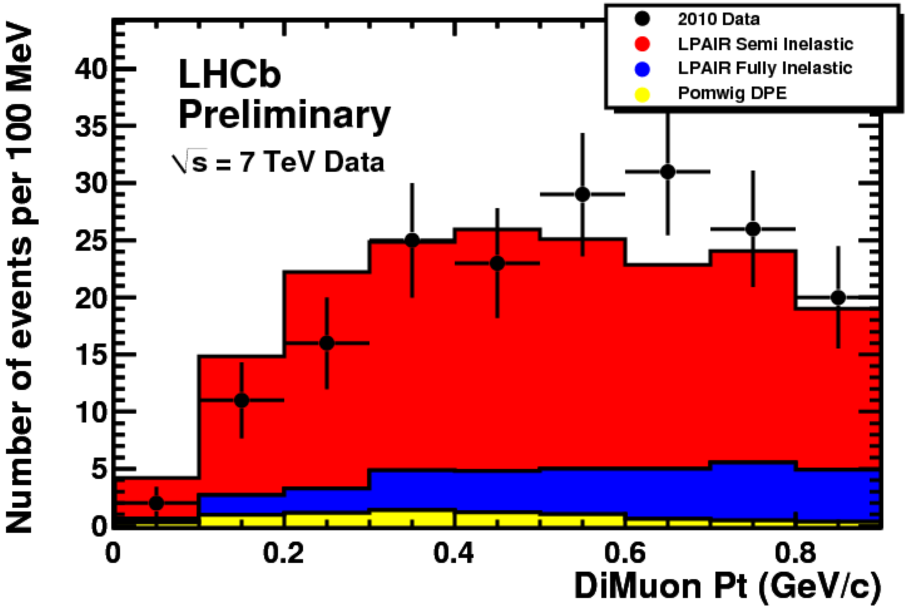
ψ': Non-resonant backgrounds & misid

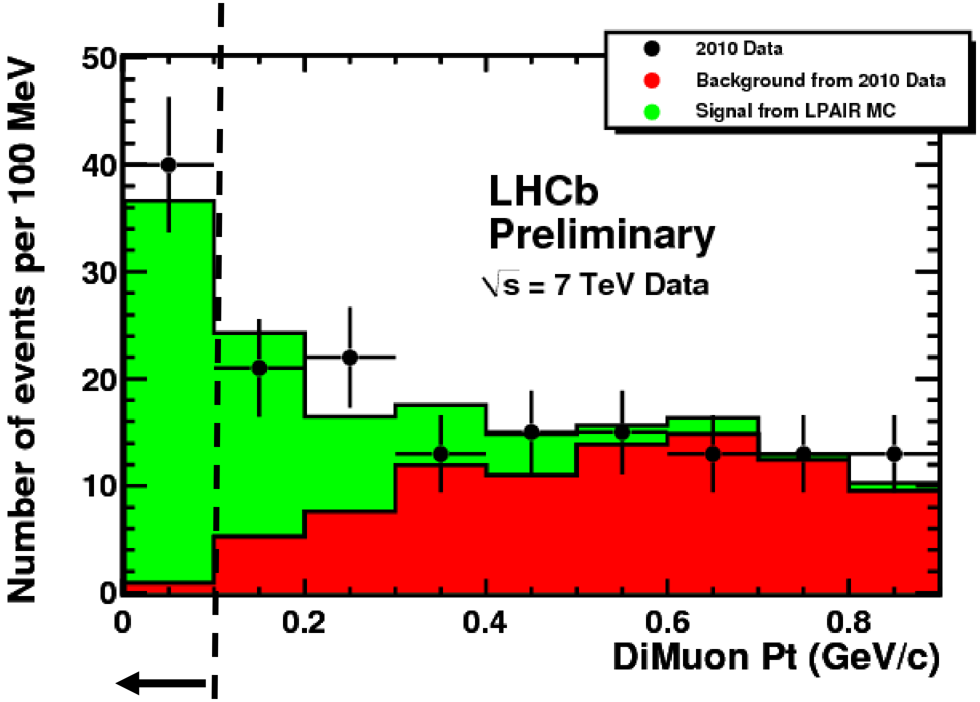


pp->pμμp

- No backward tracks
- Precisely two forward muons. $m_{\mu\mu}$>2.5 GeV
- No photons

Fit elastic and inelastic components





Shape for inelastic events

Note: this time we have simulation that predicts the shape for the three contributions.

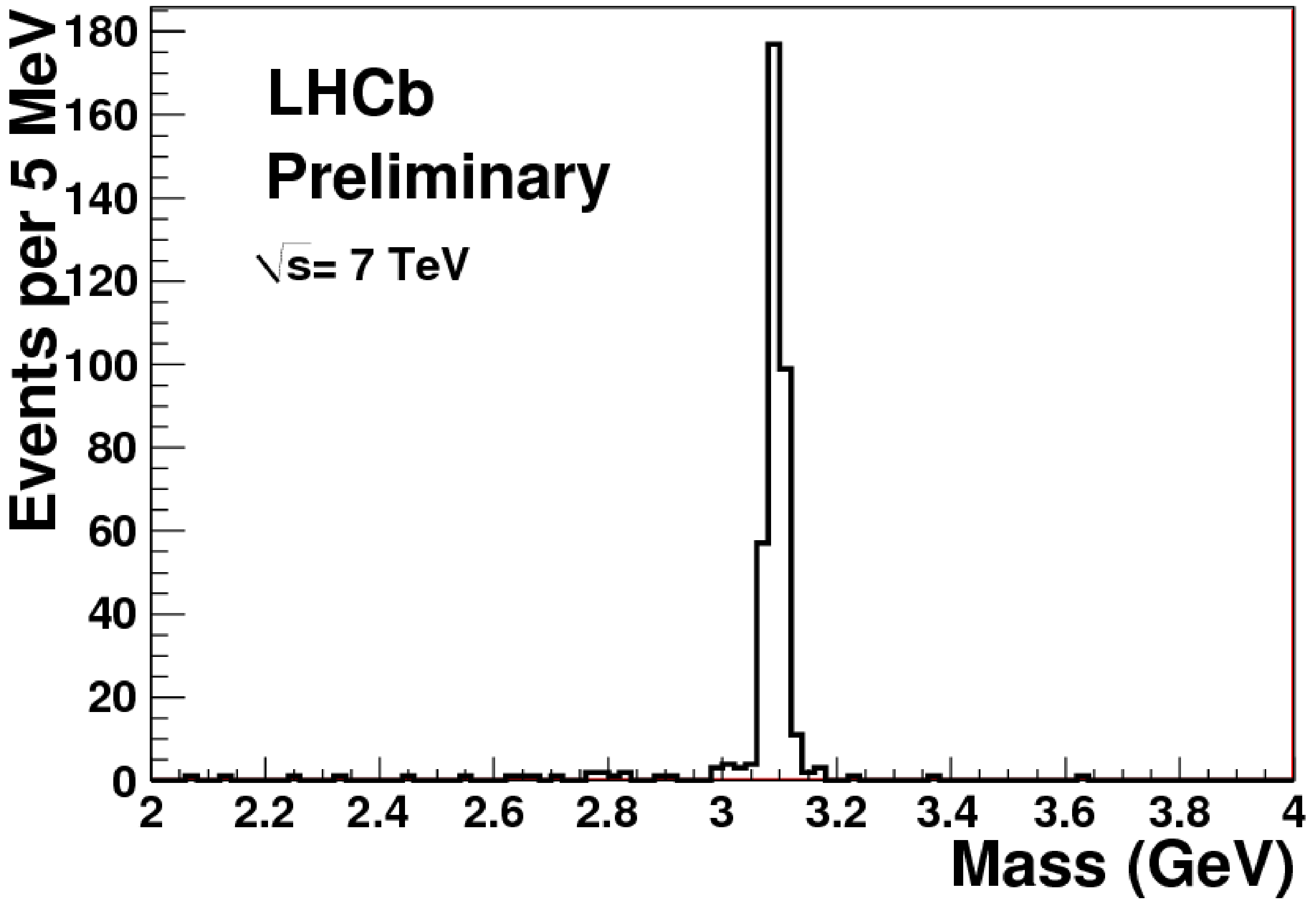
Fit to signal events

Background shape from data
Signal shape from simulation.

χ_c

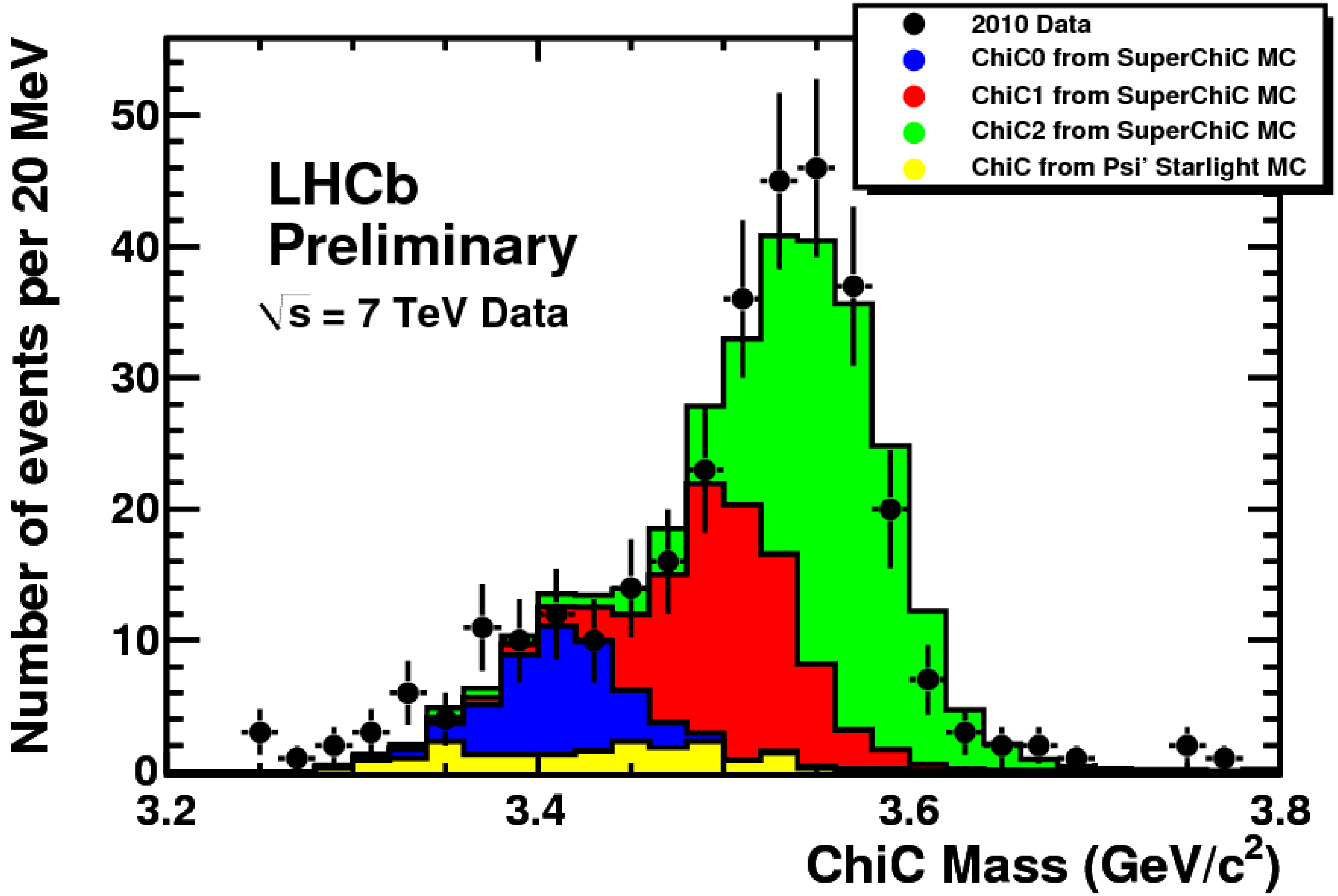
- No backward tracks
- Precisely two forward muons
- Precisely one photon

χ_c: DiMuon Invariant Mass



About half the background that was observed in the exclusive J/ψ analysis (since no continuum process).

χ_c: DiMuon+Photon Invariant Mass



(Caveat: Inelastic contribution appears to be much larger than for J/ψ)

Cross-section calculations

- **$\sigma=(pN/\varepsilon)$ / L**

- **ε:** Trigger, tracking, photon & selection efficiencies are estimated from simulation, with size of systematics taken from data/simulation agreement.

- **p:** Feed-down for ψ', χ_c subtracted. Uncertainty on fit to p_T spectrum taken as systematic on inelastic contribution.

- **L:** Analysis only uses **single-interaction** events. Need to know average number of pile-up interactions. Currently translates into 20% uncertainty on L.

Summary

	J/ψ	ψ'	χ_{c0}	χ_{c1}	χ_{c2}	diphoton
ϵ_{track} $\epsilon_{\mu id}$ ϵ_{γ} ϵ_{sel}	0.97 ± 0.03 0.89 ± 0.03 0.95	0.97 ± 0.03 0.89 ± 0.03 0.95	0.97 ± 0.03 0.89 ± 0.03 0.61 ± 0.08 0.76	0.97 ± 0.03 0.89 ± 0.03 0.75 ± 0.05 0.76	0.97 ± 0.03 0.89 ± 0.03 0.78 ± 0.04 0.76	0.96 ± 0.03 0.89 ± 0.03 0.35
Efficiency	0.71 ± 0.06	0.71 ± 0.06	0.34 ± 0.06	0.43 ± 0.05	0.44 ± 0.04	0.25 ± 0.02
# Events	1468 ± 38	40 ± 6	25 ± 6	56 ± 18	99 ± 29	40 ± 6
Purity	0.71 ± 0.03	0.67 ± 0.03	0.39 ± 0.13	0.39 ± 0.13	0.39 ± 0.13	0.97 ± 0.01
L_{eff} (pb^{-1})	3.1 ± 0.6	3.1 ± 0.6	3.1 ± 0.6	3.1 ± 0.6	3.1 ± 0.6	2.3 ± 0.5
Cross-section $\times BR$ (pb)	474 ± 12 $\pm 45 \pm 92$	12.2 ± 1.8 $\pm 1.2 \pm 2.4$	9.3 ± 2.2 $\pm 3.5 \pm 1.8$	16.4 ± 5.3 $\pm 5.8 \pm 3.2$	28.0 ± 5.4 $\pm 9.7 \pm 5.4$	67 ± 10 $\pm 5 \pm 15$

$$\sigma_{J\psi \to \mu^+\mu^-}(2 < \eta_{\mu+}, \eta_{\mu-} < 4.5) = 474 \pm 12 \pm 45 \pm 92 \text{ pb}$$

$$\sigma_{\psi' \to \mu^+\mu^-}(2 < \eta_{\mu+}, \eta_{\mu-} < 4.5) = 12.2 \pm 1.8 \pm 1.2 \pm 2.4 \text{ pb}$$

$$\sigma_{\chi_0 \to J\psi\gamma \to \mu^+\mu^-\gamma}(2 < \eta_{\mu+}, \eta_{\mu-}, \eta_\gamma < 4.5) = 9.3 \pm 2.2 \pm 3.5 \pm 1.8 \text{ pb}$$

$$\sigma_{\chi_1 \to J\psi\gamma \to \mu^+\mu^-\gamma}(2 < \eta_{\mu+}, \eta_{\mu-}, \eta_\gamma < 4.5) = 16.4 \pm 5.3 \pm 5.8 \pm 3.2 \text{ pb}$$

$$\sigma_{\chi_2 \to J\psi\gamma \to \mu^+\mu^-\gamma}(2 < \eta_{\mu+}, \eta_{\mu-}, \eta_\gamma < 4.5) = 28.0 \pm 5.4 \pm 9.7 \pm 5.4 \text{ pb}$$

$$\sigma_{pp \to p\mu^+\mu^-p}(2 < \eta_{\mu+}, \eta_{\mu-} < 4.5; m_{\mu+\mu-} > 2.5GeV) = 67 \pm 10 \pm 5 \pm 15 \text{ pb}$$

Comparison to Theory

J/ψ:
474 +-103 pb

Starlight (Klein & Nystrand) 292 pb
SuperChic (Harland-Lang, Khoze, Ryskin, Stirlin) 330 pb
Motyka & Watt 330 pb
Schäfer & Szczurek 710 pb

ψ':
12.2 +- 3.2 pb

Starlight (Klein & Nystrand) 6 pb
Schäfer & Szczurek ~ 17 pb

σ(ψ')/σ(J/ψ):
0.20 +- 0.03

Starlight (Klein & Nystrand) 0.16
Schäfer & Szczurek ~ 0.2
HERA: 0.166 +- 0.012 (lower $\sqrt{(\gamma p)}$)
CDF: 0.14 +- 0.05 (lower $\sqrt{(\gamma p)}$)

	χ_0: 9.3 +- 4.5 pb	χ_1: 16.4 +- 7.1 pb	χ_2: 28.0 +-12.3 pb
SuperChic:	14 pb	10 pb	3 pb

pμμp: 67 +- 19 pb

LPAIR (J. Vermaseren) 42 pb

Summary

- First Observation of CEP at LHC
- First separation of χ_c spin states in CEP
- Good agreement with theory predictions
- Consistency with HERA and CDF results.