



Exclusive DiMuon Production at LHCb

Dermot Moran on behalf of the LHCb collaboration

DIS 2011 - 11th-15th April 2011

Overview

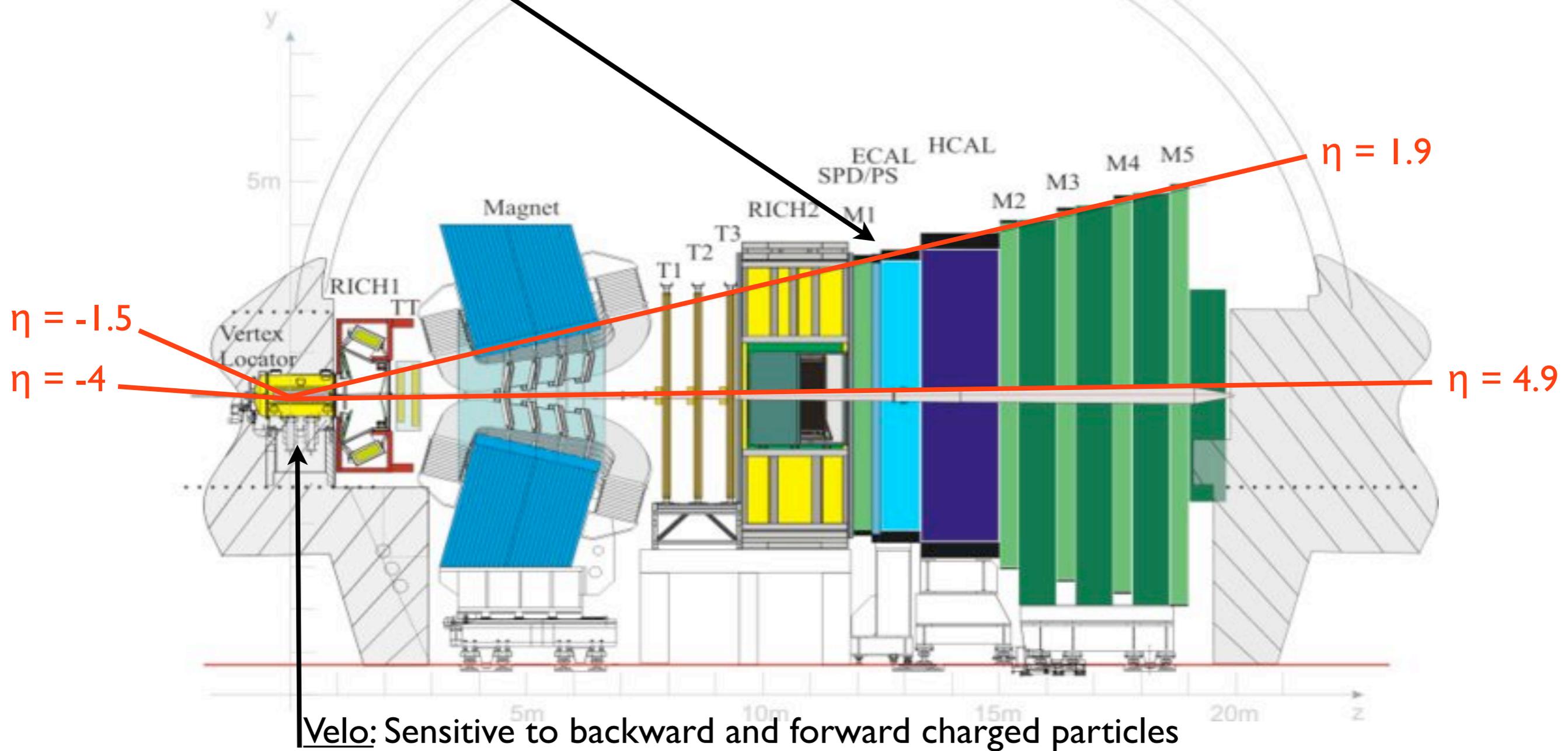
- LHCb Experiment
- Exclusive Search at LHCb
- Exclusive $J\psi \psi'$
- Exclusive DiPhoton DiMuons
- Exclusive χ_C
- Cross-section measurements
- Conclusion

LHCb experiment

- Dedicated b physics experiment
- Investigate CP violation and rare decays
- Forward arm spectrometer covers pseudorapidity $1.9 < \eta < 4.9$ with some backward sensitivity $-4 < \eta < -1.5$ to charged particles
- 7 TeV proton collisions
- 37 pb^{-1} of data used for this study (Interested in Single interaction events so effective Lumi depends on pile up)

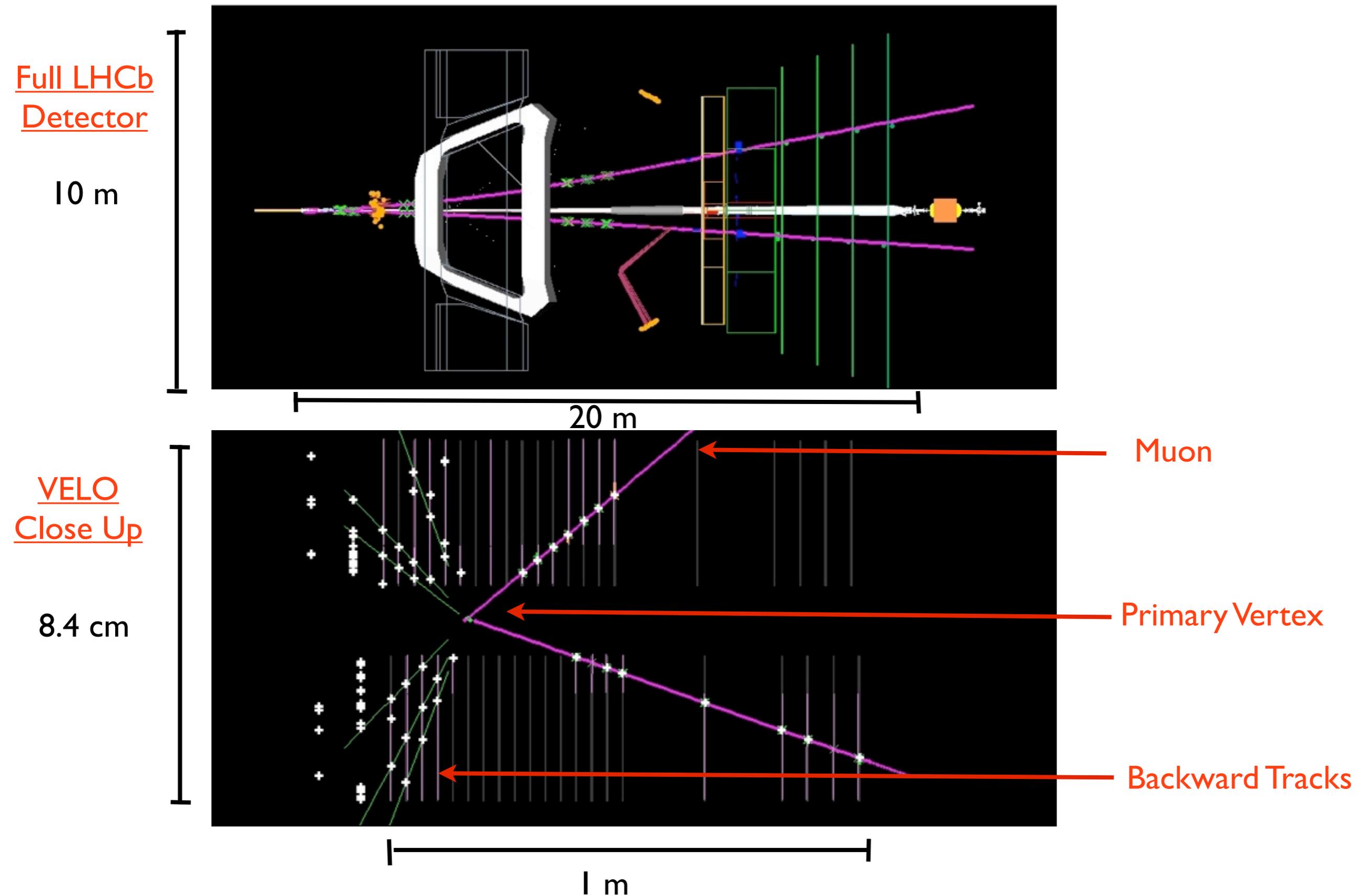
LHCb detector

Scintillation Pad Detector SPD: Counts number of charged particles



LHCb event display

Low Multiplicity Event (Non Exclusive)



Exclusive Processes Considered

Exclusive JPsi, Psi' (-> mu+mu-)

Produced by photon pomeron fusion

Starlight: Models diphoton and photon pomeron fusion

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

Exclusive ChiC (-> mu+mu- + gamma)

Produced by double pomeron exchange

SuperChiC: MC for central exclusive production

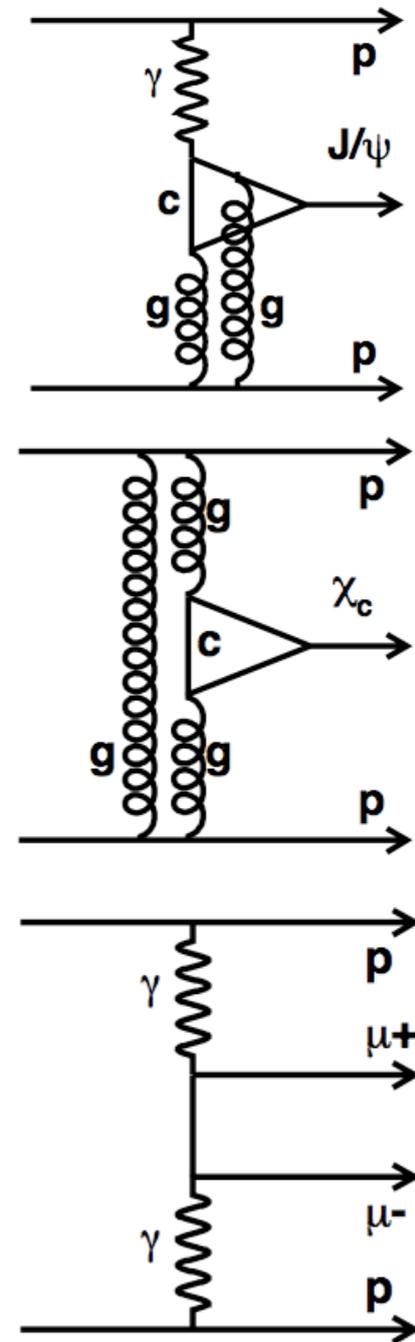
(L.A. Harland-Lang, V.A. Khoze, M.G. Ryskin, W.J. Stirling, arXiv:0909.4748 [hep-ph].).

Exclusive DiPhoton DiMuon

Produced by DiPhoton fusion

LPAIR: Models EM production of lepton pairs

(A.G.Shamov and V.I.Telnov, NIM A {\\bf 494} (2002) 51).



Elastic (Signal)

- Both Protons remain Intact
- Rapidity gaps
- Pt of central object is small

Inelastic (Background)

- Proton dissociation
- Rapidity gaps smaller than for elastic
- Pt of central object generally higher than for elastic

Exclusive Search Strategy

2 DiMuon Triggers Used

1) Exclusive DiMuon Trigger:

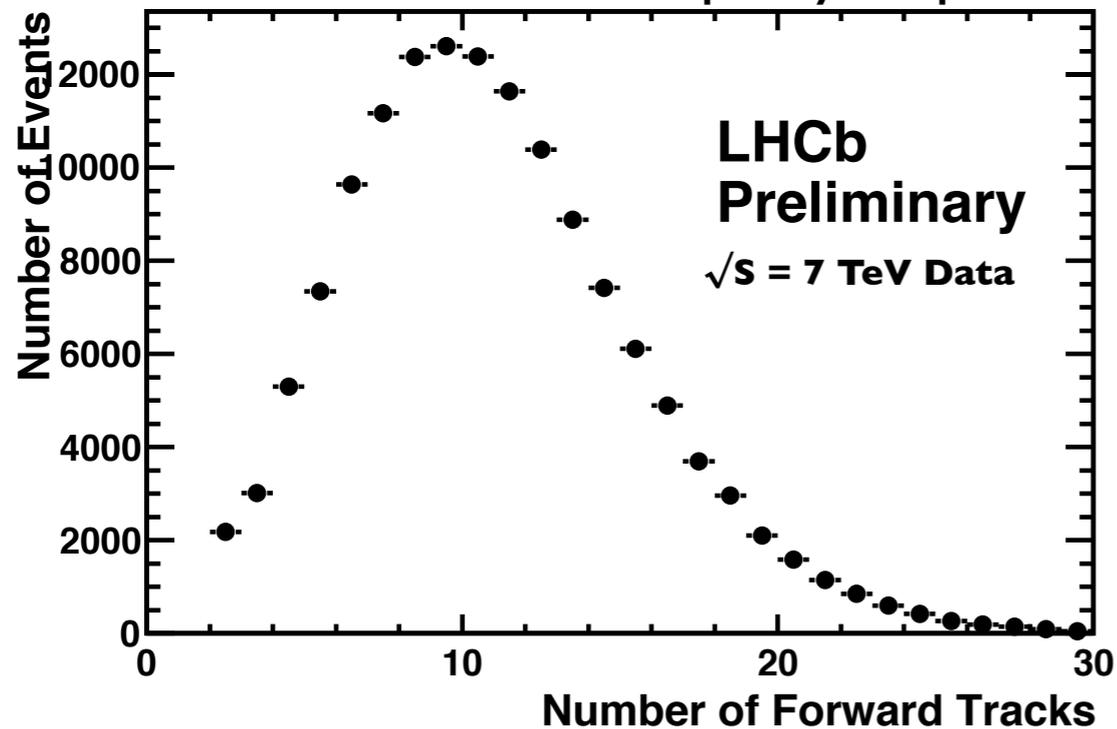
SPD Multiplicity < 20
DiMuon Mass > 1 GeV
DiMuon Pt < 0.9 GeV
Just 2 muons

2) Unbiased DiMuon Trigger:

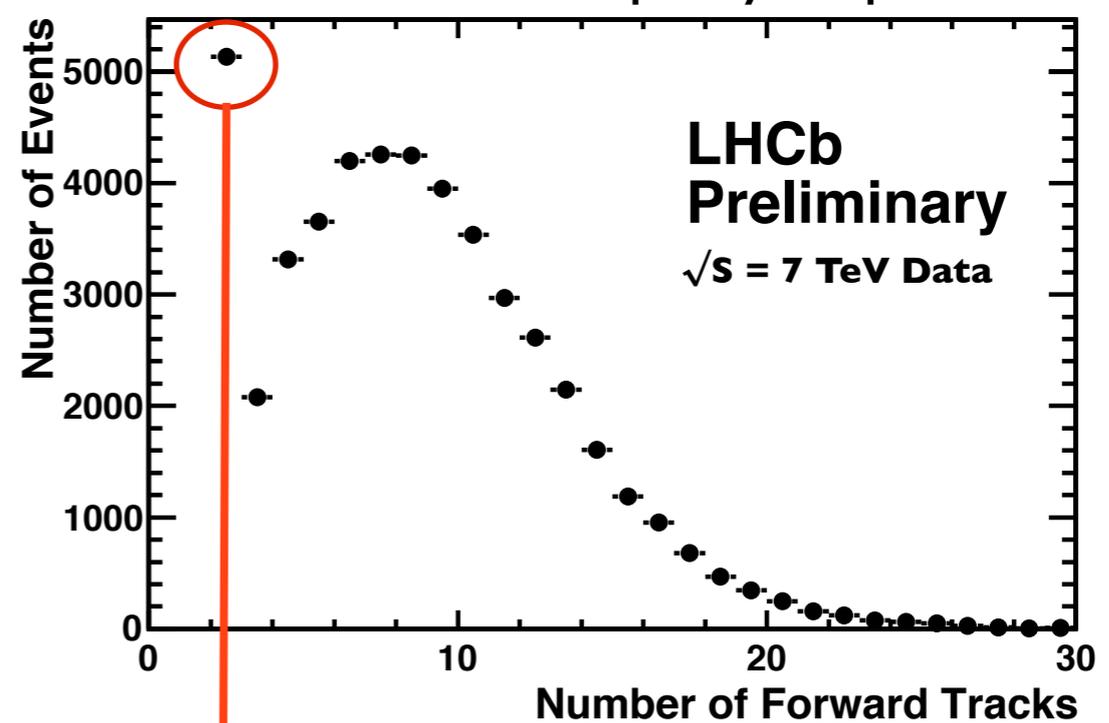
SPD Multiplicity < 20
DiMuon Mass > 2.7 GeV

Use VELO Backward Tracking to identify Rapidity gaps (2 units of rapidity)

Events with No Rapidity Gap



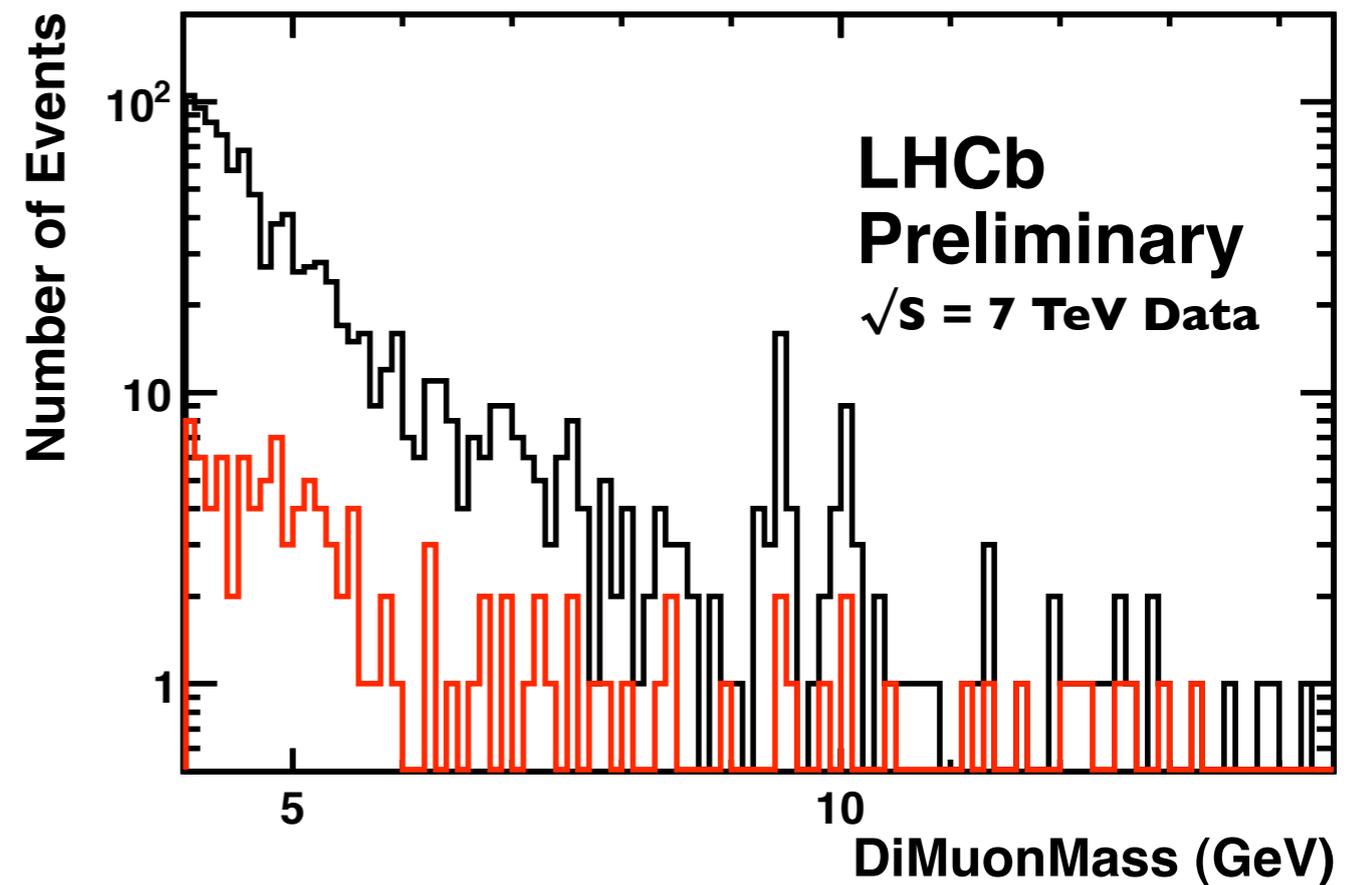
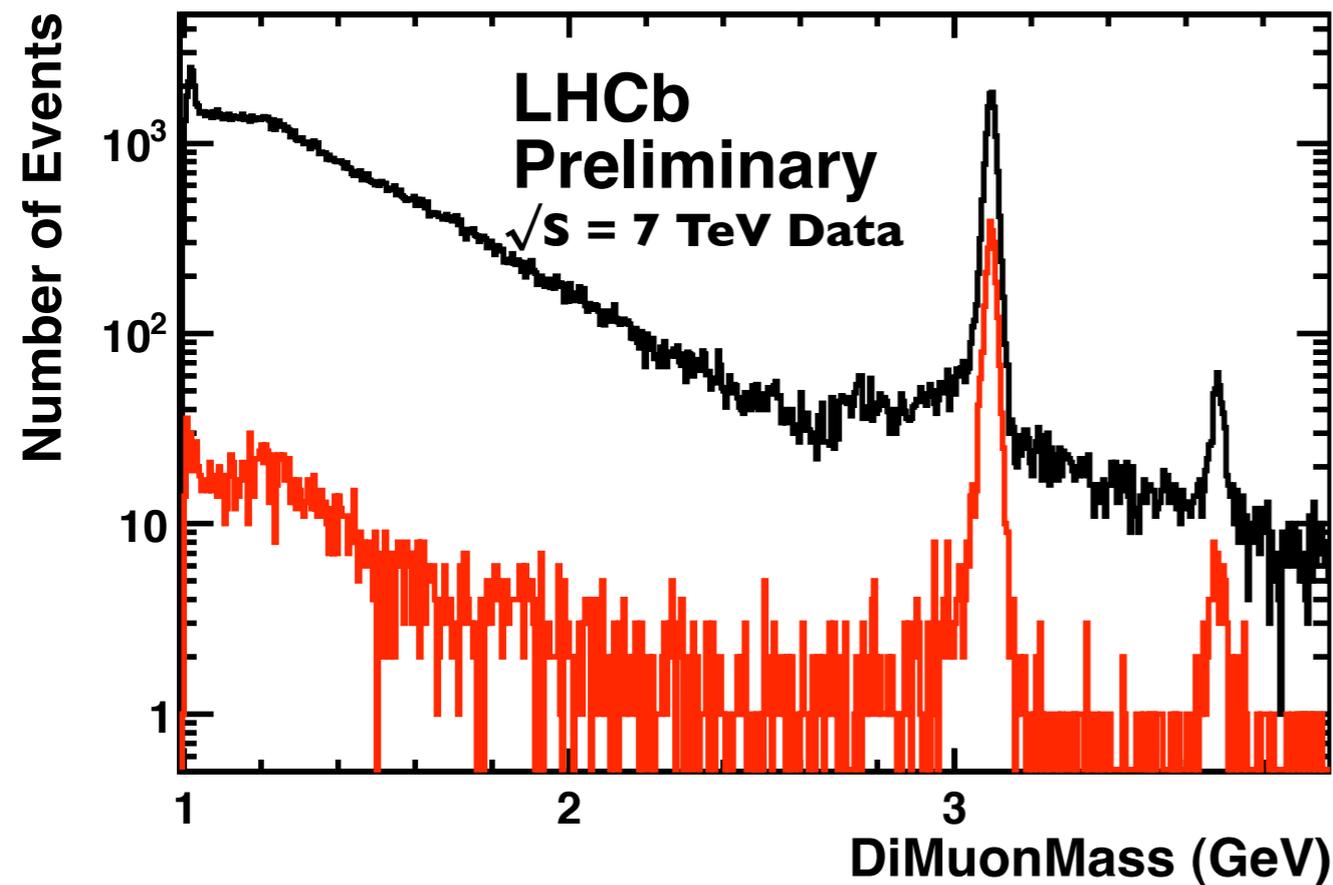
Events with Rapidity Gap



Clear peak at 2 Forward Tracks when rapidity gap requested
Candidates for Exclusive production

Exclusive Search Strategy

**DiMuon Mass Spectrum for Events Passing Trigger
+ No Backward Tracks + 2 Forward Tracks**



- Exclusive J/ψ , ψ' , DiPhoton DiMuon Candidates evident
- More stats required to investigate Exclusive Φ and Upsilon

Exclusive J/ψ & ψ'

Offline Selection

DiMuon Mass within 65 MeV of PDG Value

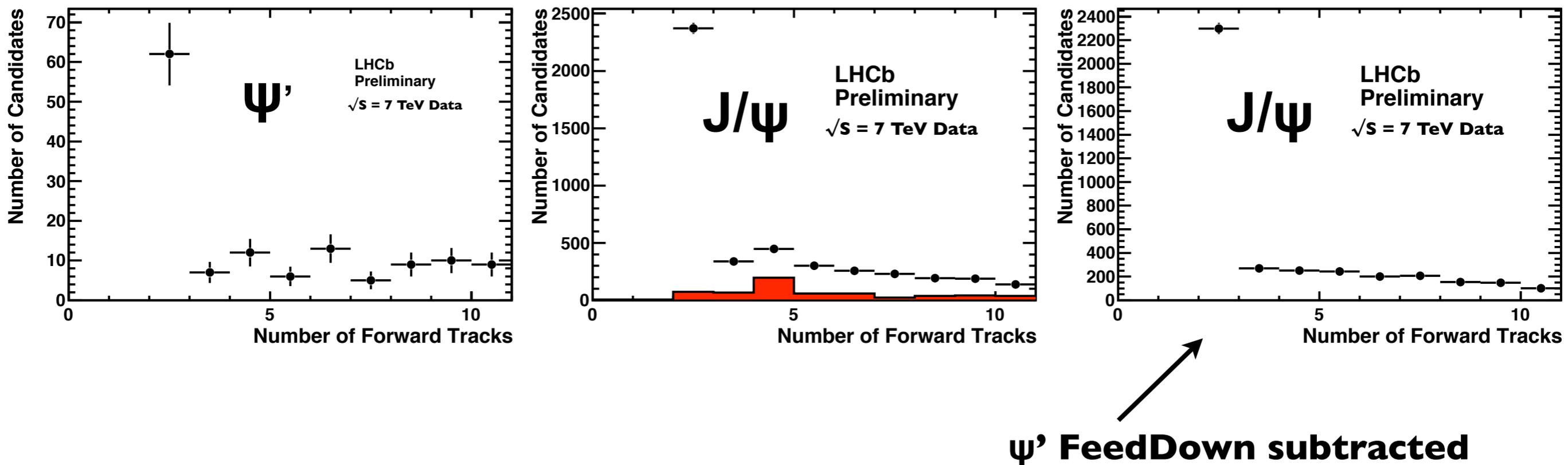
No Backward Tracks + 2 Forward Tracks

No Photons

DiMuon Pt < 900 MeV

Number of Forward Tracks

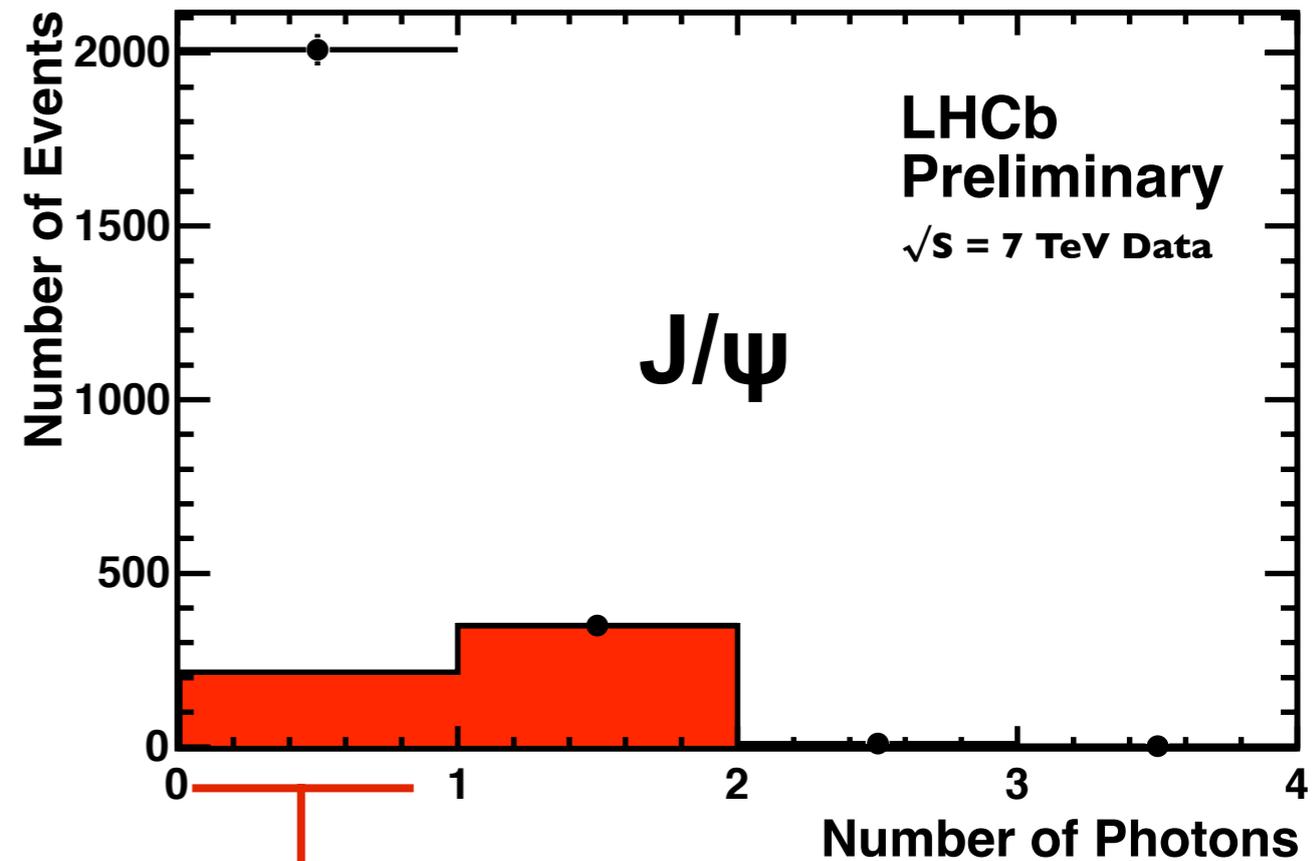
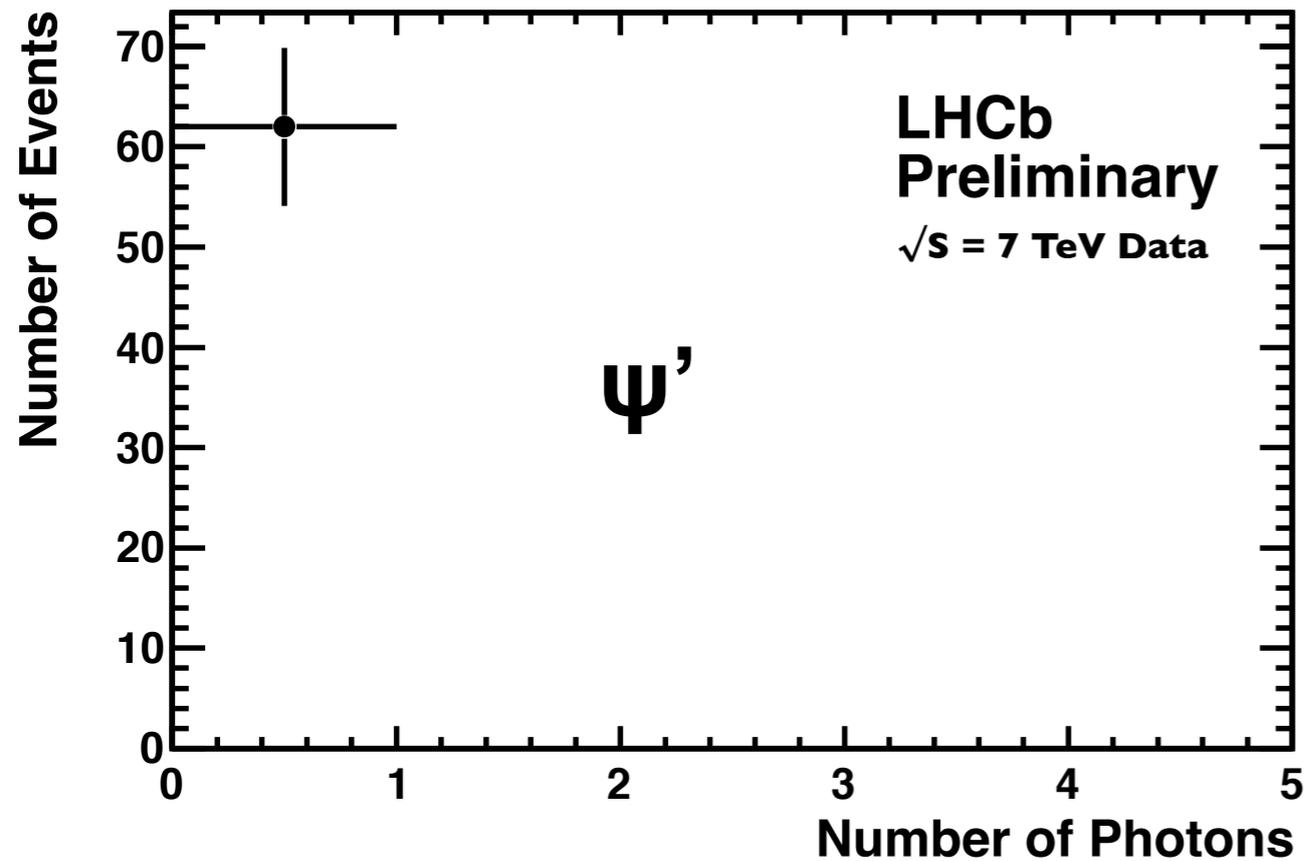
Number of Psi' and JPsi Candidates Vs Number of Forward Tracks



- $\Psi' \rightarrow J/\psi + X$ sample generated with Starlight MC + Full LHCb simulation
- Background from Ψ' Feeddown estimated to be $1.8 \pm 0.3 \%$

Number of Photons

Number of Psi' and JPsi Candidates Vs Number of Photons

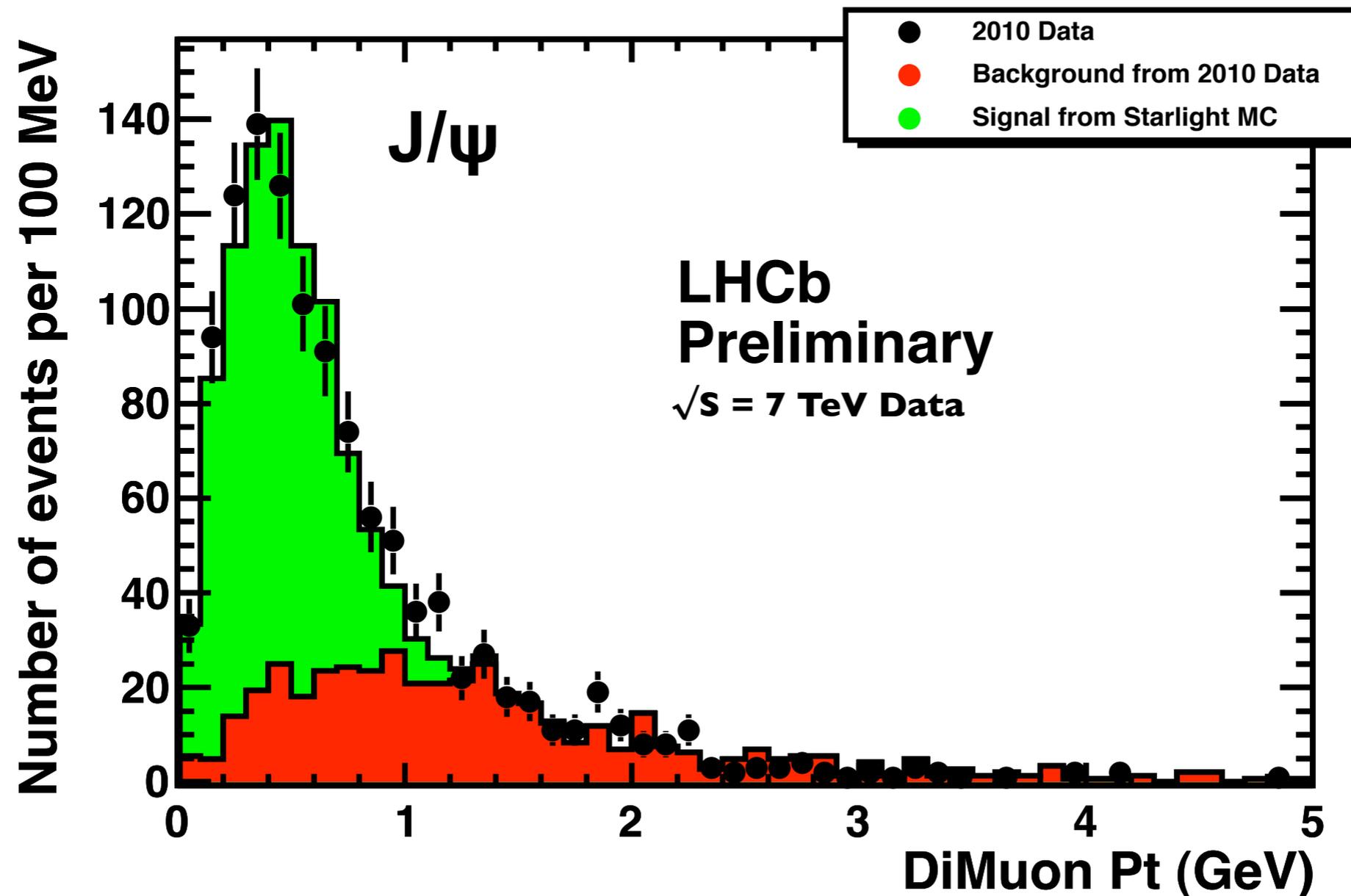


$X_c \rightarrow J/\psi + \gamma$ with γ outside acceptance or not reconstructed

- Additional Photons accompany some JPsi (Exclusive ChiC candidates)
- $X_c \rightarrow J/\psi + \gamma$ generated with SuperChiC MC + full LHCb simulation
- Background from X_c Feiddown estimated to be 9.0 +/- 0.5 %

Fit Elastic and Inelastic components

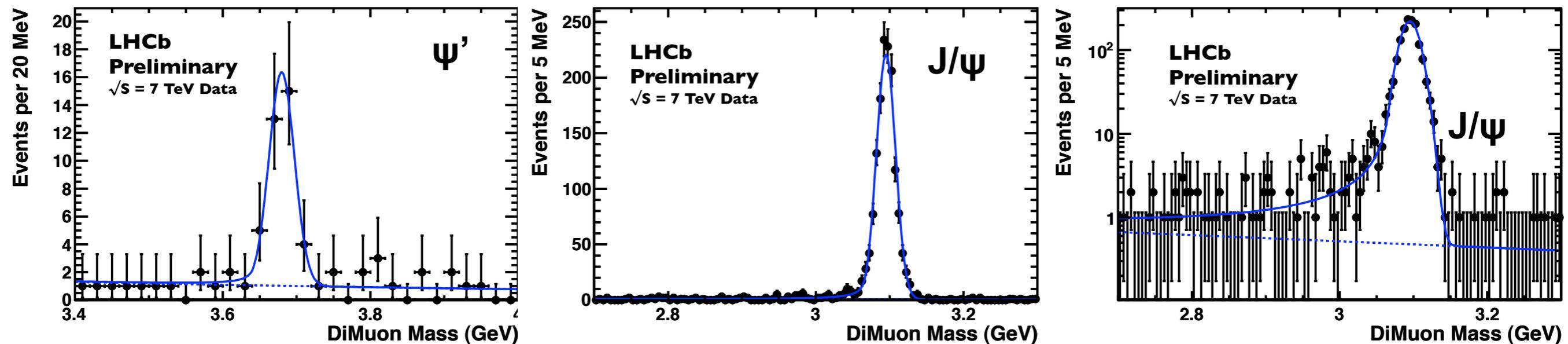
- **Inelastic Background** Pt Shape obtained from Data (no backward tracks, no photons and >2 Forward Tracks)
- **Elastic Signal** Pt Shape taken from Starlight MC and full LHCb simulation



- For J/ψ Pt < 900 MeV the Inelastic Background is estimated to be 20 +/- 3%

Non resonant Backgrounds

- Non Resonant backgrounds from DiPhoton DiMuons or Misidentified Pions and Kaons



- 40 Events between 3.615 and 3.745 GeV (Non Resonant Background = 16%)
- 1468 Events between 3.035 and 3.165 GeV (Non Resonant Background = 0.8%)

Exclusive DiPhoton DiMuons

Offline Selection

DiMuon Mass > 2.5 GeV

Cut at JPsi Psi' mass peaks

No Backward Tracks + 2 Forward Tracks

No Photons

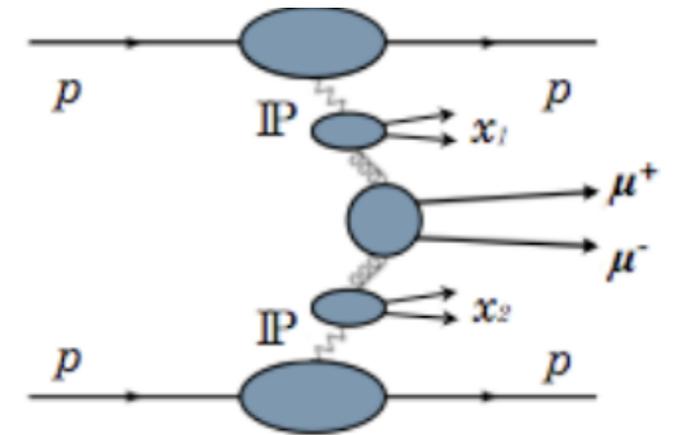
DiMuon Pt < 100 MeV

Backgrounds Considered

Dimuons from Double Pomeron Exchange (DPE)

Generated with Pomwig

HI pomeron PDFs (06 and 97 NLO) used

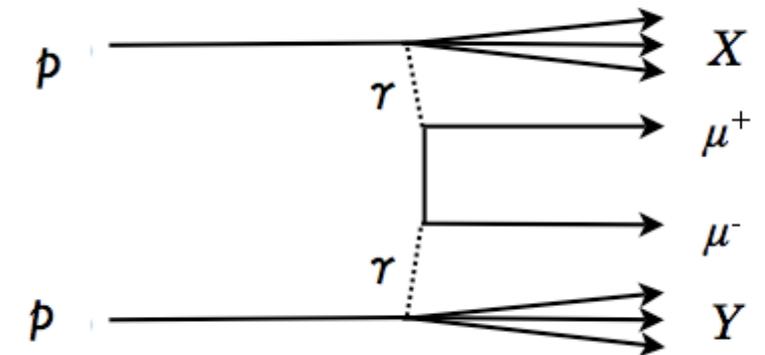


Dimuons from Inelastic diphoton fusion

One or both protons dissociate during interaction

Generated with LPAIR

A.Suri and D.R.Yennie Proton PDFs used



Mis-Id from Zero Bias Data

Zero Bias events dominated by pions and kaons

Apply all Exclusive cuts except requiring that the track is a muon

Scale by probability for pions/kaons to be identified as muons

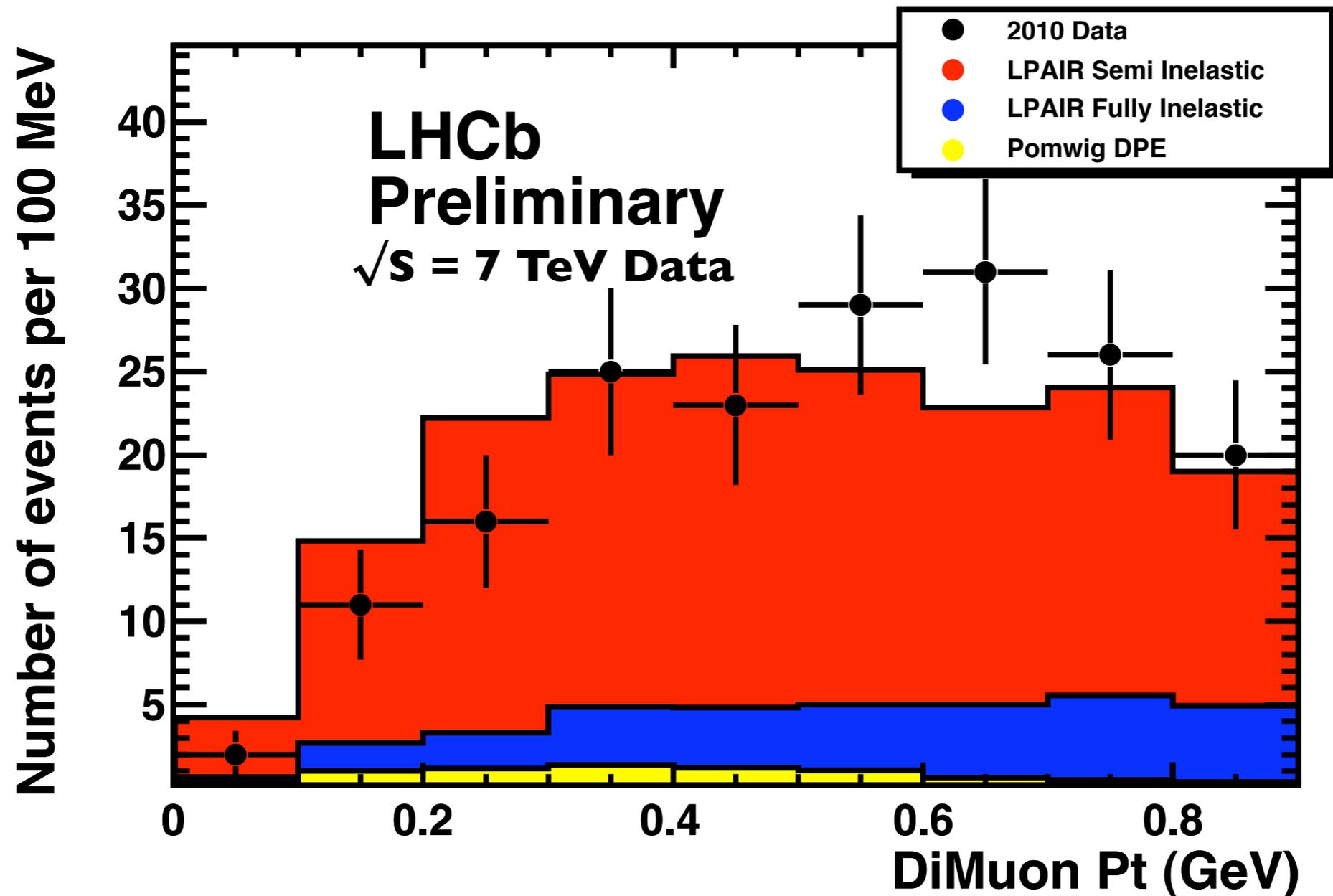
Significant background at low masses ($1 \text{ GeV} < \text{Mass} < 2.5 \text{ GeV}$)

Limited Statistics mean MisID Shapes cannot be determined for events passing Exclusive Cuts

For now using high Mass cut to suppress MisID background ($\text{Mass} > 2.5 \text{ GeV}$)

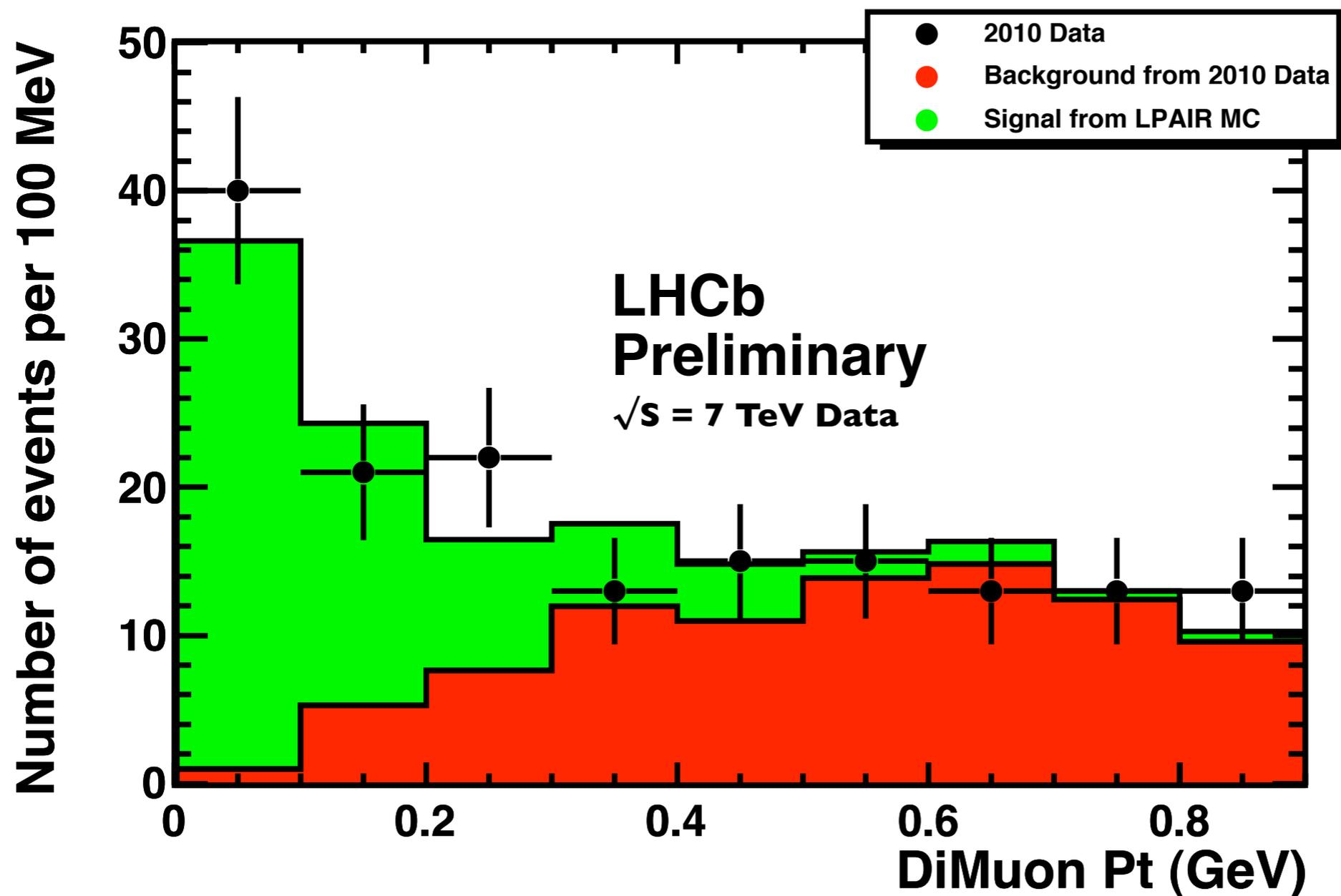
Inelastic Background

- Inelastic Background Pt Shape obtained from Data (no backward tracks, no photons and forward tracks > 2)
- Comparison with MC predictions of **Semi Inelastic** and **Fully Inelastic** DiPhoton DiMuon production from LPAIR and **Double Pomeron Exchange** from Pomwig (Normalized to number of events)



Fit Elastic and Inelastic components

- **Inelastic Background** Pt Shape obtained from Data (no backward tracks, no photons and >2 Forward Tracks)
- **Elastic Signal** Pt Shape taken from LPAIR MC and full LHCb simulation



- For DiMuon Pt < 100 MeV there is a Signal Purity of 97 +/- 1%

Exclusive ChiC

Offline Selection

DiMuon Mass within 65 MeV of PDG Value

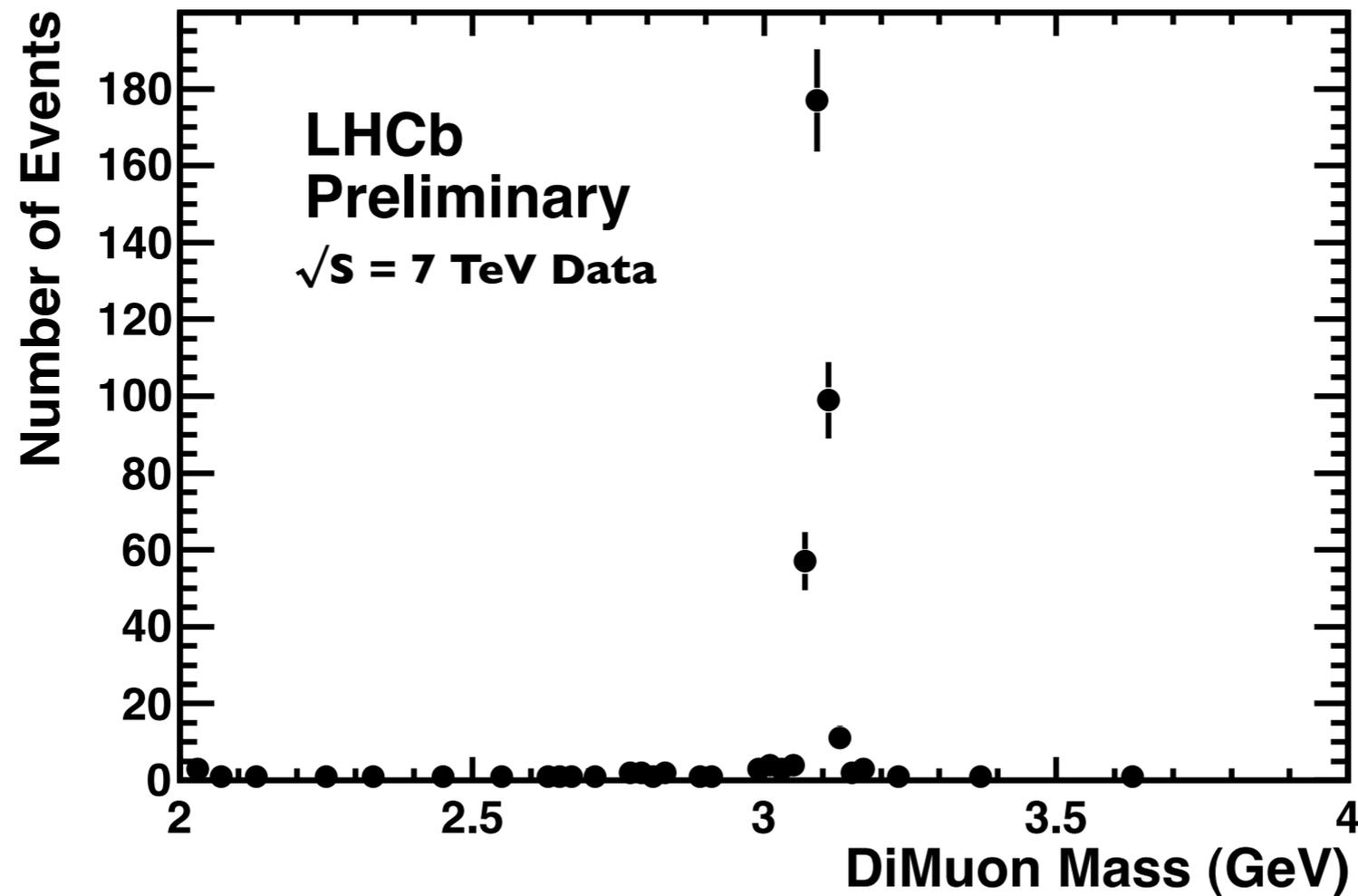
No Backward Tracks + 2 Forward Tracks

1 Photon

DiMuon Pt < 900 MeV

Exclusive ChiC

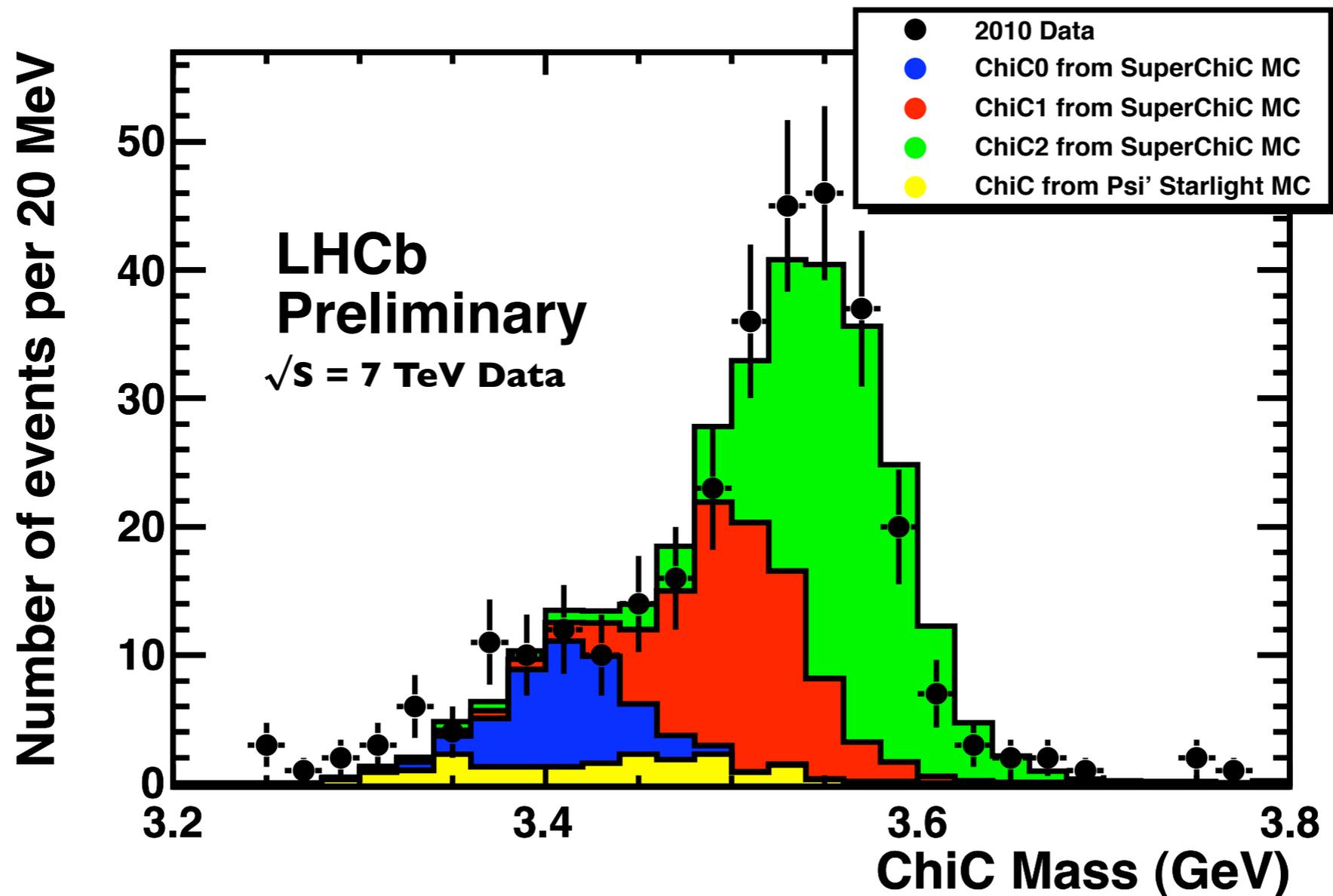
- Require No Backward Tracks, 2 Forward Tracks and 1 Photon



- Only 4% of events outside JPsi peak (9% outside JPsi and Psi' when 0 photons required)
- Exclusive ChiC candidates evident

Exclusive ChiC

- Shapes for **ChiC0**, **ChiC1** and **ChiC2** taken from SuperChiC MC + Full LHCb simulation
- Shape for **Psi'** taken from Starlight MC + full LHCb simulation



- Ratio of ChiC0 : ChiC1 : ChiC2 is 1 : 2.2 +/- 0.8 : 3.9 +/- 1.1

Cross section measurements

Cross-section Calculation

- Final state Muons and Photons required to have pseudorapidities between 2 and 4.5
- Efficiencies have been determined from Simulation
- Systematics applied based on MC/Data comparison studies

$$\text{Total Efficiency } \epsilon = \epsilon_{\text{Track}}^2 \epsilon_{\text{MuonID}}^2 \epsilon_{\text{Photon}} \epsilon_{\text{Selection}}$$

- Effective Luminosity L_{eff} depends on trigger efficiencies and on the average number of interactions per beam crossing μ (large Lumi uncertainty for this analysis)

$$\text{Cross-section} = \# \text{Events} * \text{Purity} / \epsilon * L_{\text{eff}}$$

	J/ψ	ψ'	χ_{c0}	χ_{c1}	χ_{c2}	diphoton
ϵ_{track}	0.97 ± 0.03	0.97 ± 0.03	0.97 ± 0.03	0.97 ± 0.03	0.97 ± 0.03	0.96 ± 0.03
$\epsilon_{\mu\text{id}}$	0.89 ± 0.03	0.89 ± 0.03	0.89 ± 0.03	0.89 ± 0.03	0.89 ± 0.03	0.89 ± 0.03
ϵ_{γ}			0.61 ± 0.08	0.75 ± 0.05	0.78 ± 0.04	
ϵ_{sel}	0.95	0.95	0.76	0.76	0.76	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
$L_{\text{eff}} (\text{pb}^{-1})$	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	474 ± 12	12.2 ± 1.8	9.3 ± 2.2	16.4 ± 5.3	28.0 ± 5.4	67 ± 10
$\times BR (\text{pb})$	$\pm 45 \pm 92$	$\pm 1.2 \pm 2.4$	$\pm 3.5 \pm 1.8$	$\pm 5.8 \pm 3.2$	$\pm 9.7 \pm 5.4$	$\pm 5 \pm 15$

CS +/- Stat +/- Sys +/- Lumi

Comparison with Theory

Experimental Results

Theory Predictions

$J/\psi \rightarrow \mu^+\mu^-$:	474 +/- 103 pb	→	292 pb (Starlight) 330 pb (SuperChic) 330 pb (Motyka&Watt) 710 pb (Schafer&Szcurek)
$\psi' \rightarrow \mu^+\mu^-$:	12.2 +/- 3.2 pb	→	6.1 pb (Starlight) 17 pb (Schafer&Szcurek)
$\chi_0 \rightarrow \mu^+\mu^-\gamma$:	9.3 +/- 4.5 pb	→	14 pb (SuperChic)
$\chi_1 \rightarrow \mu^+\mu^-\gamma$:	16.4 +/- 7.1 pb	→	10 pb (SuperChic)
$\chi_2 \rightarrow \mu^+\mu^-\gamma$:	28 +/- 12.3 pb	→	3 pb (SuperChic)
$\gamma\gamma \rightarrow \mu^+\mu^-$:	67 +/- 19 pb	→	42 pb (LPAIR)

- Large Theoretical uncertainties (Except DiPhoton DiMuon prediction, uncertainty ~ 1%)
- Predictions contain Rescattering Corrections
(Extra strong Interaction between protons alters cross-section by ~20%)
- Results are consistent with predictions

Conclusion

- **Clear Signals observed for Exclusive JPsi, Psi', DiPhoton DiMuons and Exclusive ChiC**
- **Cross-section measurements for resonances in agreement with MC predictions which have large uncertainties**
- **Cross-section measurement for DPDM agrees with theoretical estimate**
- **Expect to measure DPDM cross-section for DiMuons with Mass down to 1 GeV (Large increase in statistics)**
- **With more data plan to measure Exclusive Upsilon and Phi production**
- **Further studies on systematics required to reduce cross-section uncertainties (In particular systematic from determining average number of interactions per crossing)**