Soft and diffractive physics at LHCb

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On behalf of the LHCb collaboration

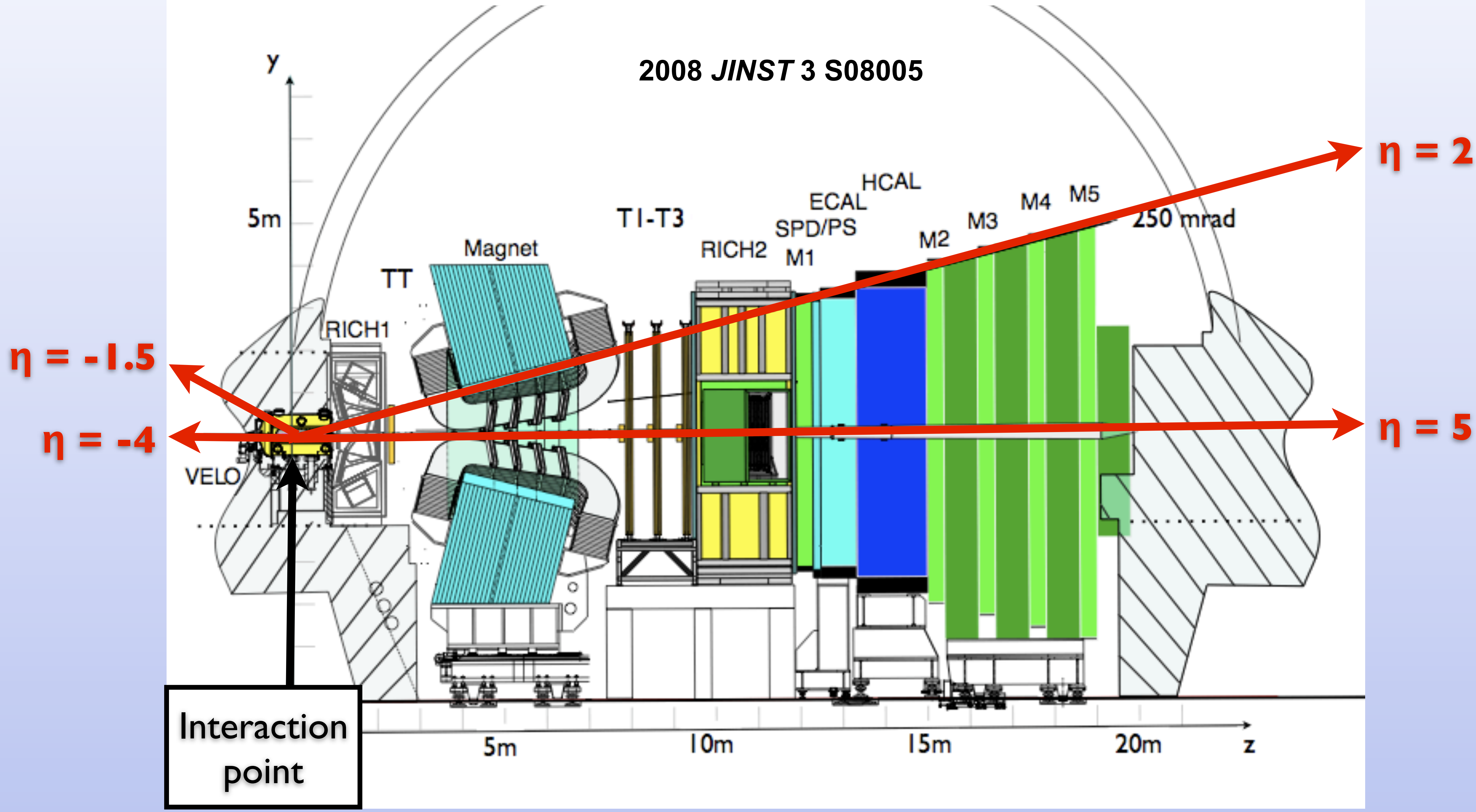
Multi-Parton Interactions at the LHC- CERN 3rd - 7th Dec 2012

Overview

- The LHCb detector
- Energy Flow (EF) definition and physics motivation
- Measurements of charged and total EF
- Central Exclusive Production (CEP) physics motivation
- Measurements of CEP in the dimuon channel
- Summary

The LHCb detector

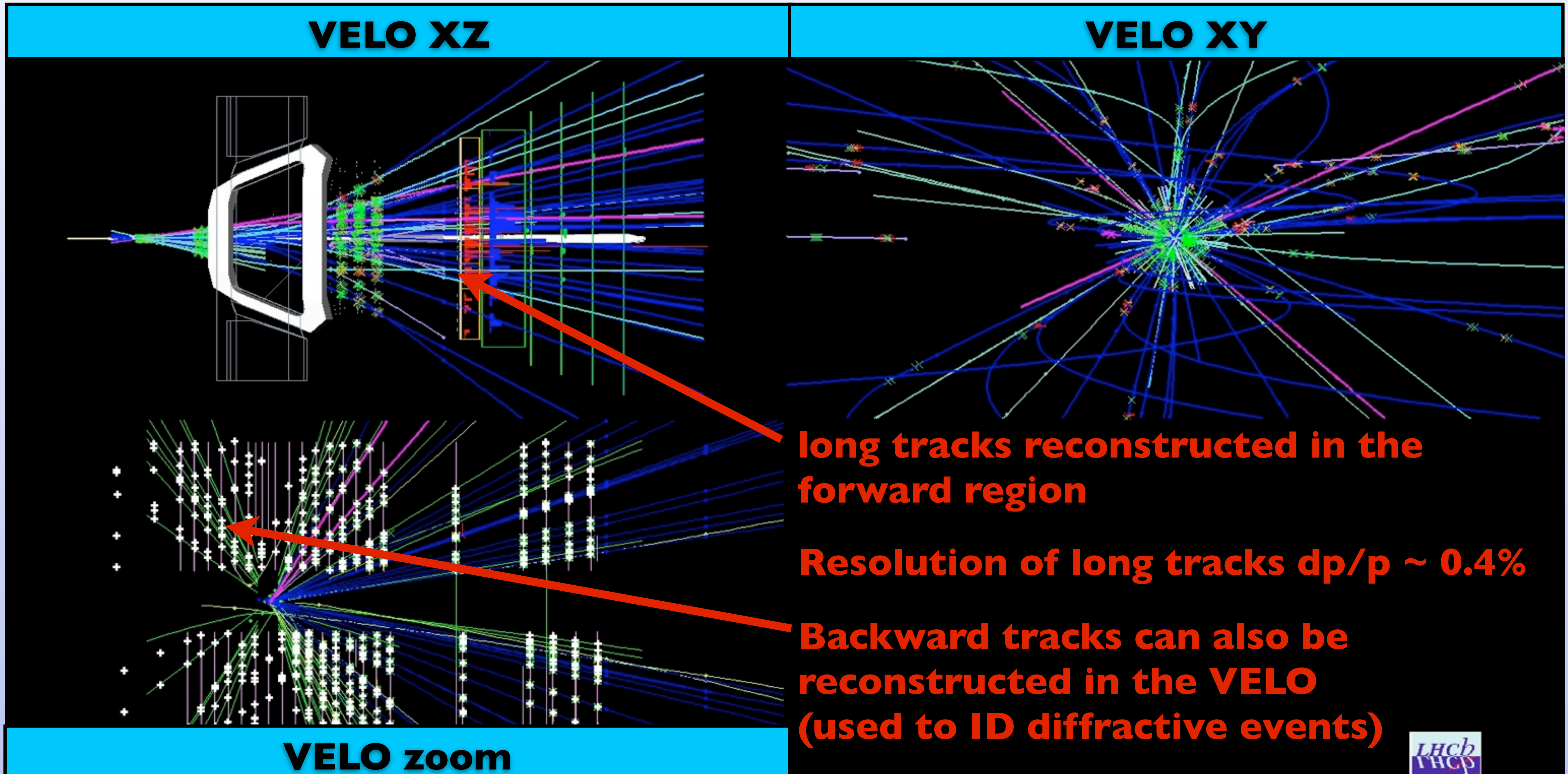
Forward arm spectrometer designed to study b physics



Operates in a low μ environment (~1.5 in 2010)

Possible to investigate low p_T process at high **η** (study soft QCD)

Typical event at LHCb



long tracks reconstructed in the forward region

Resolution of long tracks dp/p ~ 0.4%

Backward tracks can also be reconstructed in the VELO (used to ID diffractive events)

Energy flow: definition and physics motivation

Average energy created in a particular interval of η per inelastic pp collision

(normalised to the η bin size)

N_{int} = # Inelastic pp collisions
$N_{\text{part},\eta}$ = # Stable particles in η bin
$E_{i,\eta}$ = Energy of an individual particle

$$\frac{1}{N_{\text{int}}}\frac{dE_{tot}}{d\eta} = \frac{1}{\Delta\eta}\left(\frac{1}{N_{\text{int}}}\sum_{i=1}^{N_{part,\eta}} E_{i,\eta}\right)$$

Forward EF sensitive to the amount of parton radiation and Multi Parton Interactions (MPI)
MPI is predominant source of UE but not well understood
Measurement may allow discrimination between MPI models
+ determine important parameters for existing models

LHCb analysis uses reconstructed tracks and photons to measure EF
(LHCb-CONF-2012-012)

Energy Flow analysis outline

Charged EF measured with tracks (Primary measurement)

Use momentum of Long tracks with 2<P<1000 GeV/c

Approximation P = E used (PID not required)

Charged EF is corrected to account for detector effects

Ratio of MC predictions at generator and detector level

Neutral EF from Charged EF (data) and Neutral EF/Charged EF Ratio (MC)

Factor introduced to account for data MC mismatch

Total EF (Neutral+Charged) measured with low pile-up MB data at 7 TeV

(~ 6 million events, 5% pile-up)

4 event classes

Inclusive MB : at least 1 long track

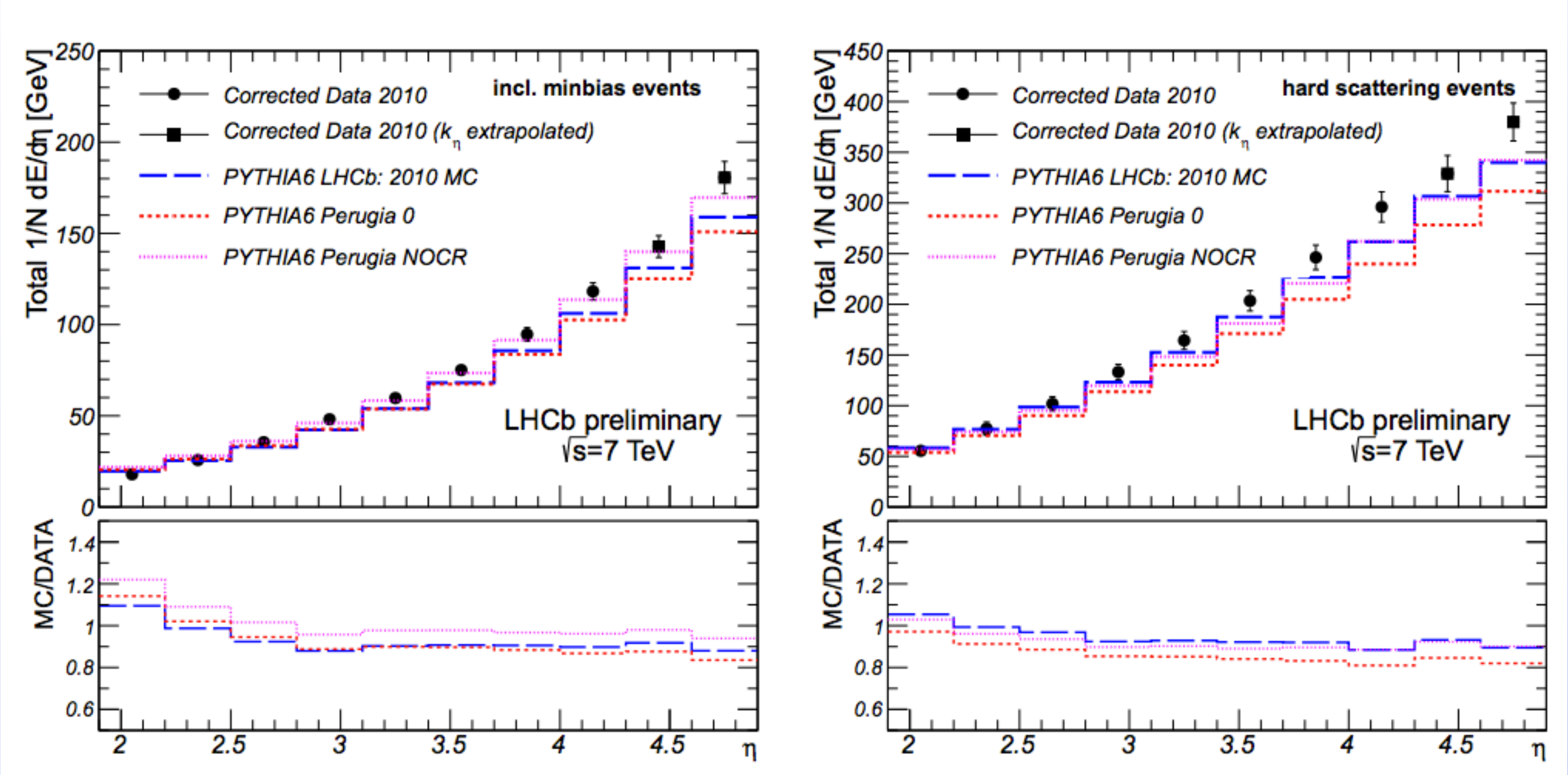
Hard scattering : MB with at least 1 long track with P_T>2 GeV/c

Diffractive enriched : MB with no backward tracks

Non-diffractive enriched : MB with at least 1 backward track

Total EF Vs. PYTHIA tunes

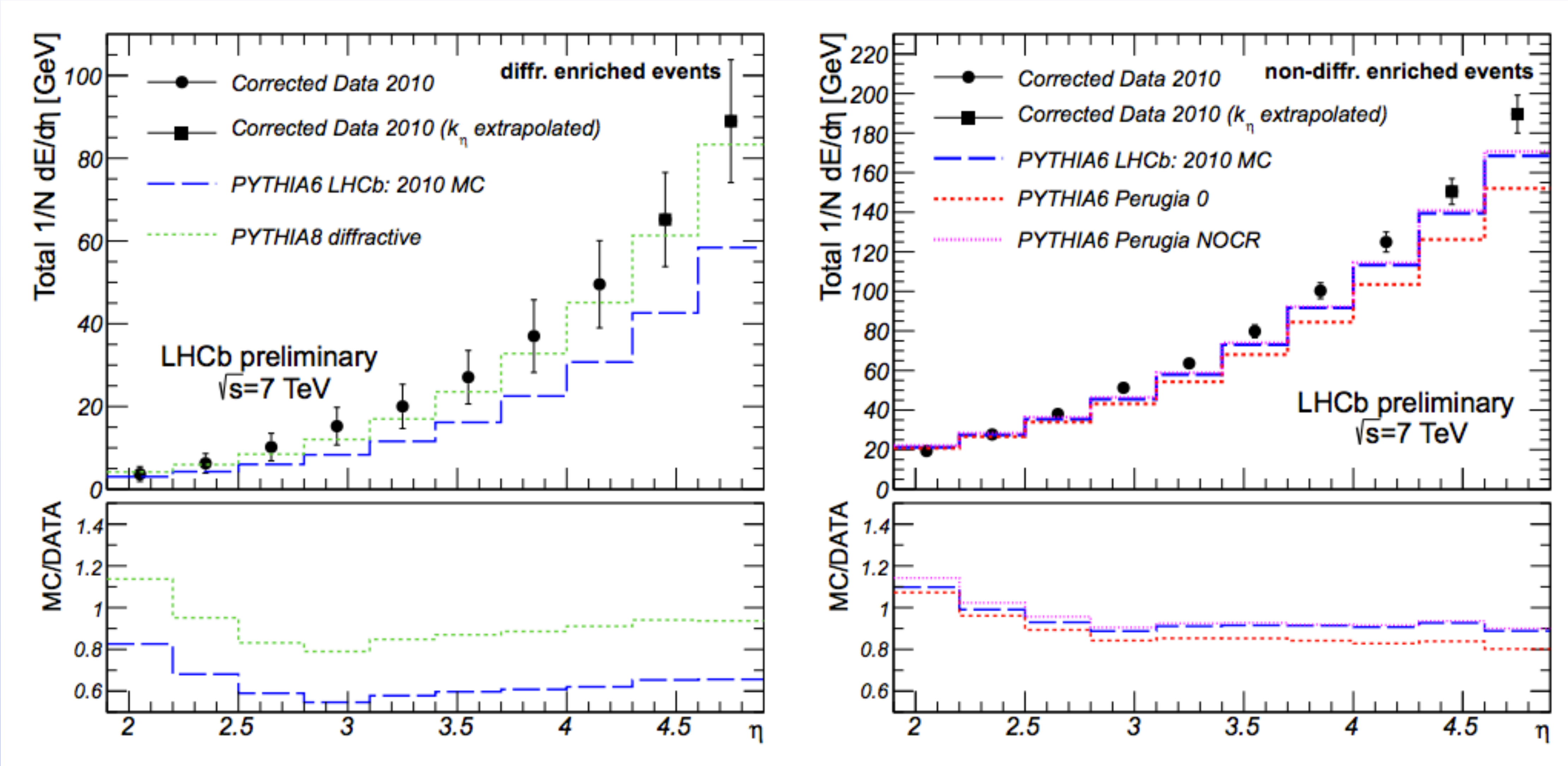
Error bars show systematic uncertainty
(Statistical uncertainties are negligible)



Pythia based models underestimate EF at large η and overestimate at low η

EF increases with momentum transfer of underlying pp prosess

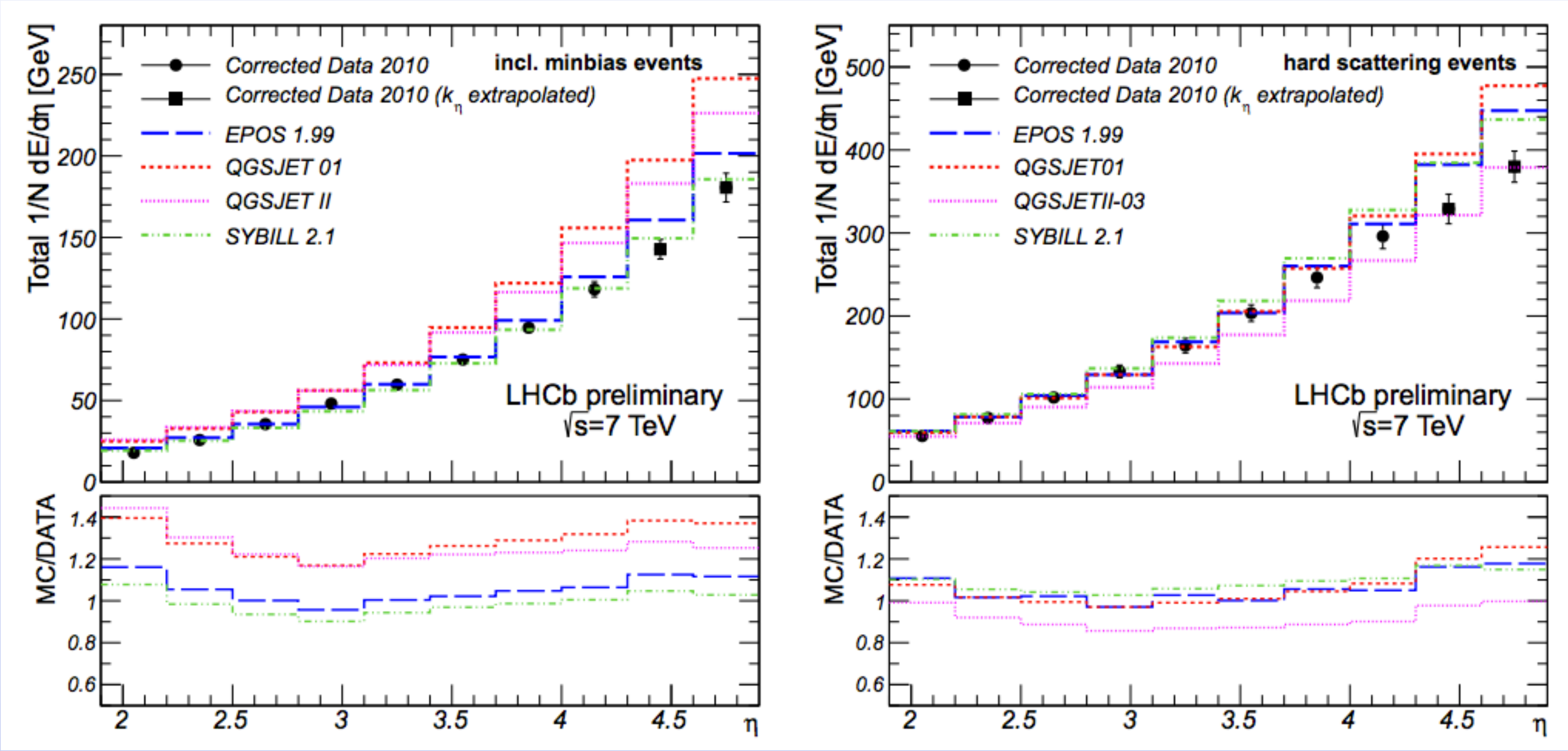
Total EF Vs. PYTHIA tunes



<u>Diffractive EF described best by PYTHIA 8</u>

<u>Non-diffractive and diffractive EF underestimated by PYTHIA models</u>

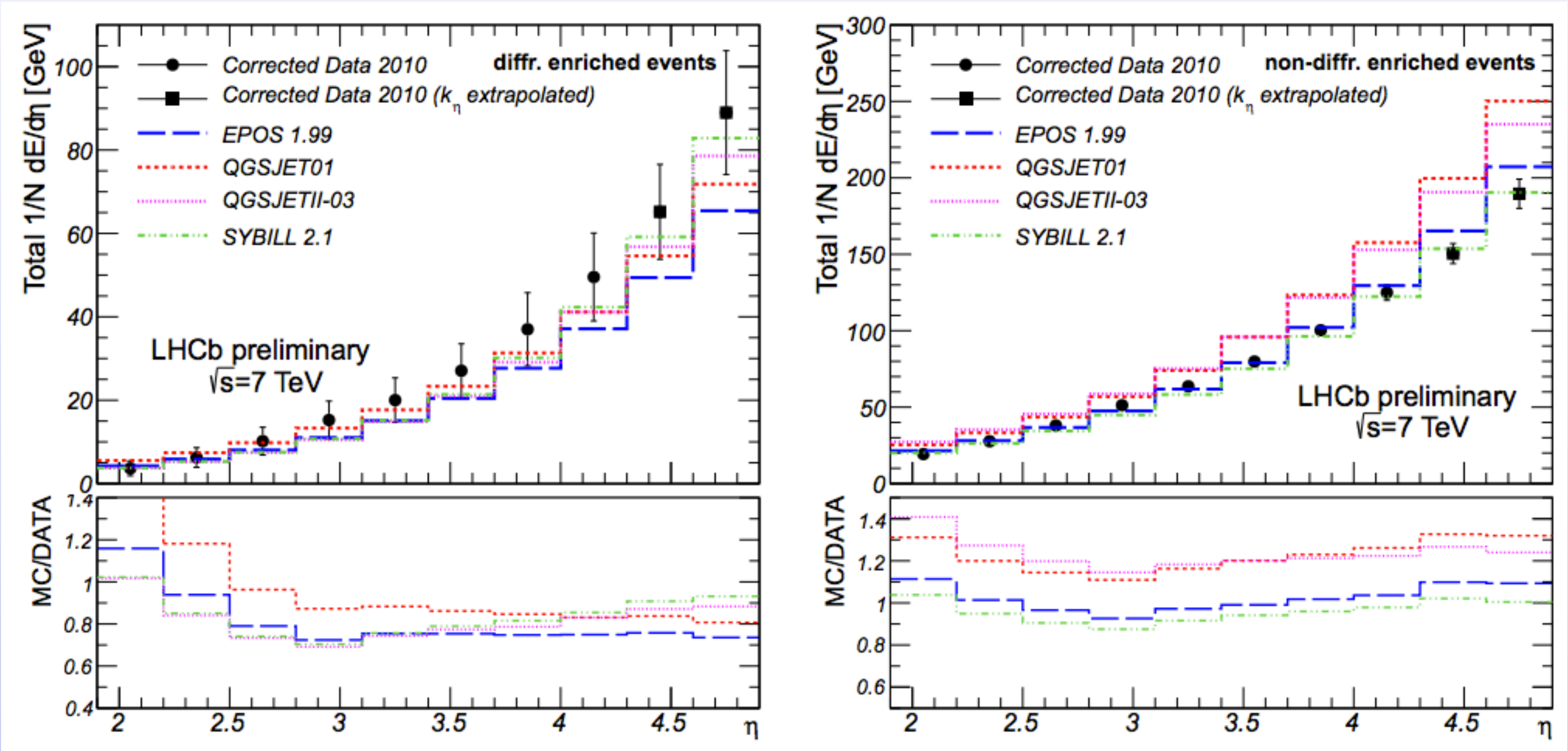
Total EF Vs. Cosmic-ray models



Inclusive MB EF best described by SYBILL (out of all models)

Hard scattering EF at large η best described by QGSJETII-03 (out of all models)

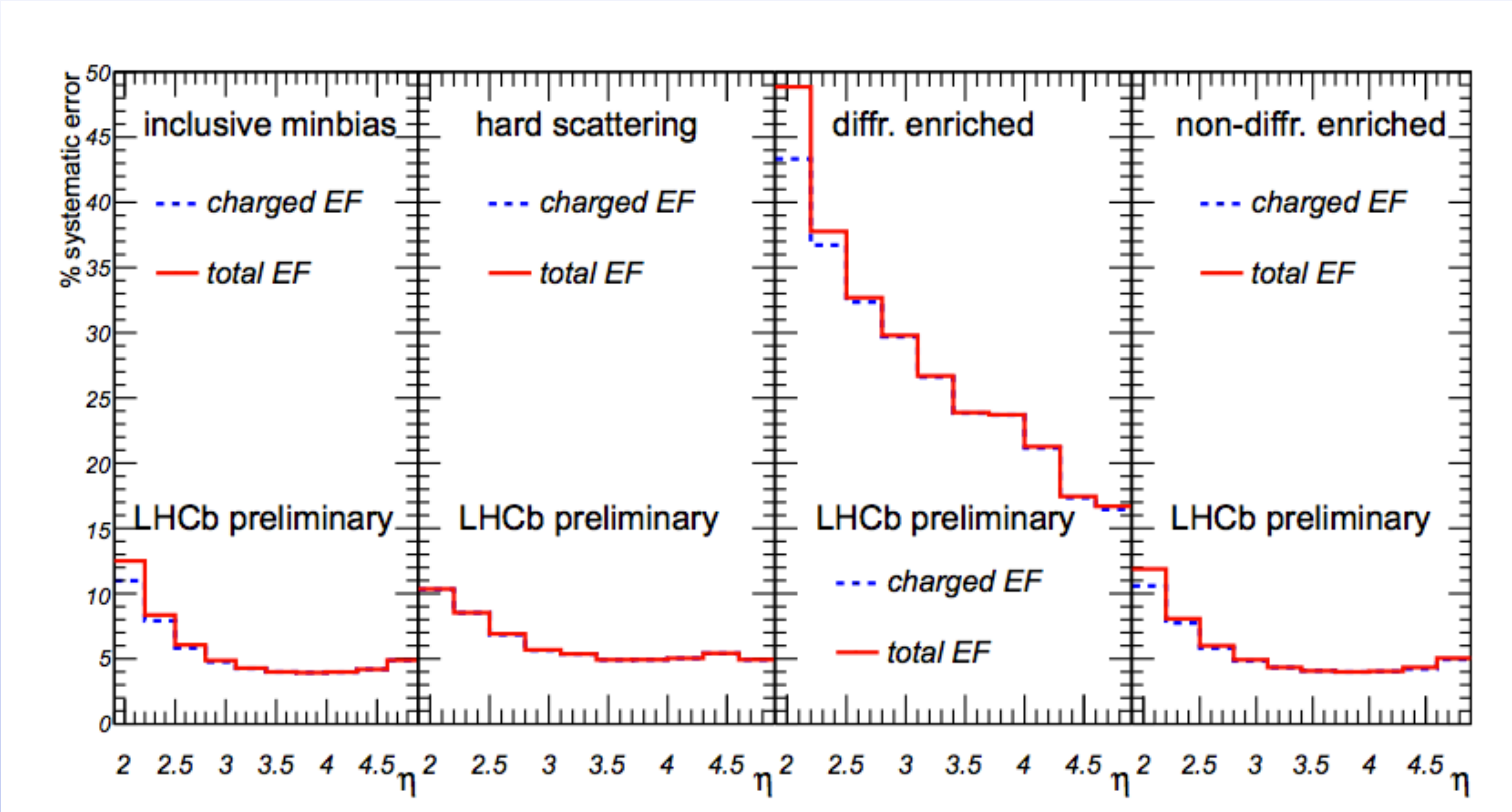
Total EF Vs. Cosmic-ray models



Diffractive EF description from SYBILL is competitive with PYTHIA 8

Non-diffractive EF is best described by SYBILL (out of all models)

Systematic uncertainties

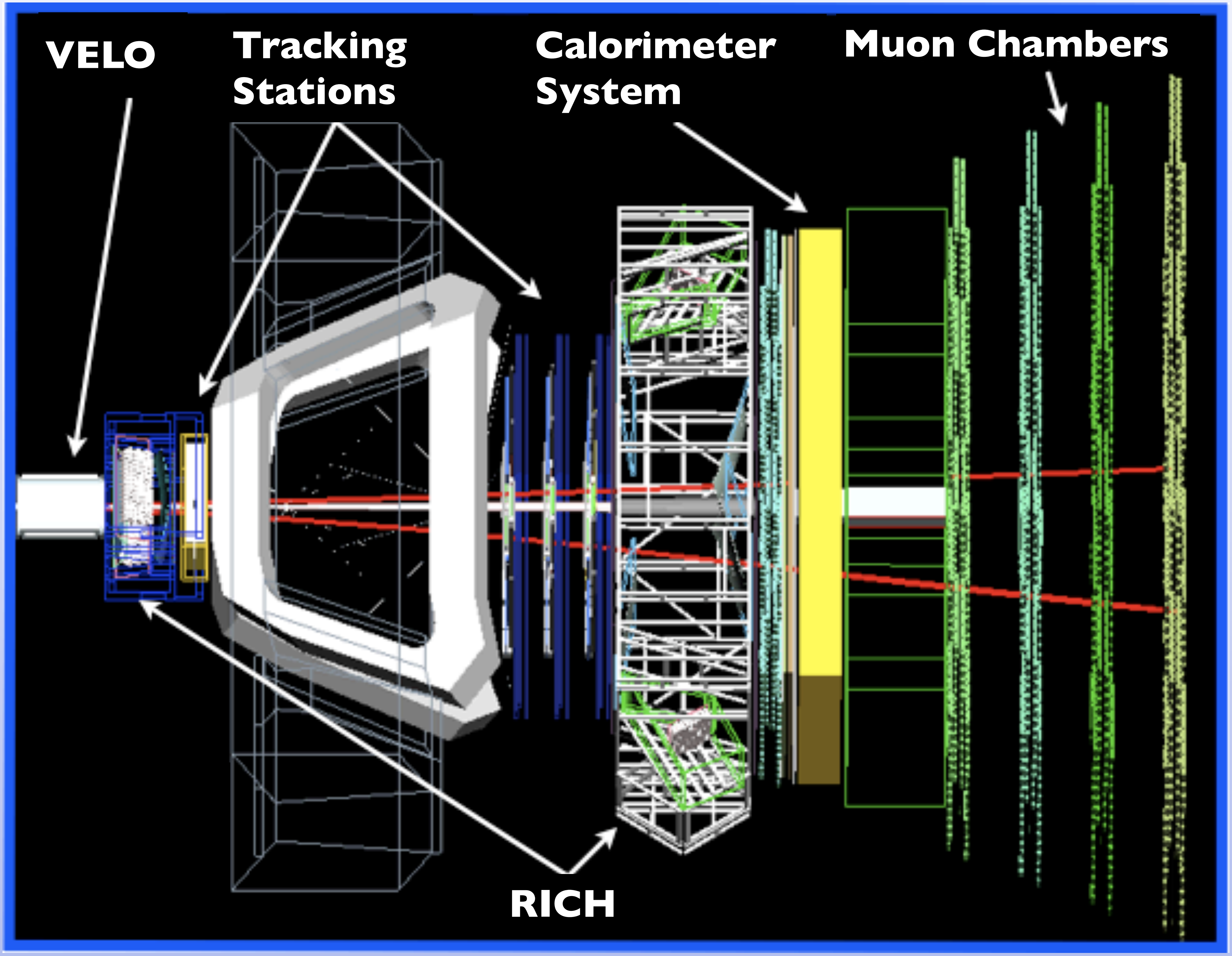


Model dependance of correction factors dominates systematic

Smallest uncertainty at high η where measurement is most sensitive to MPI

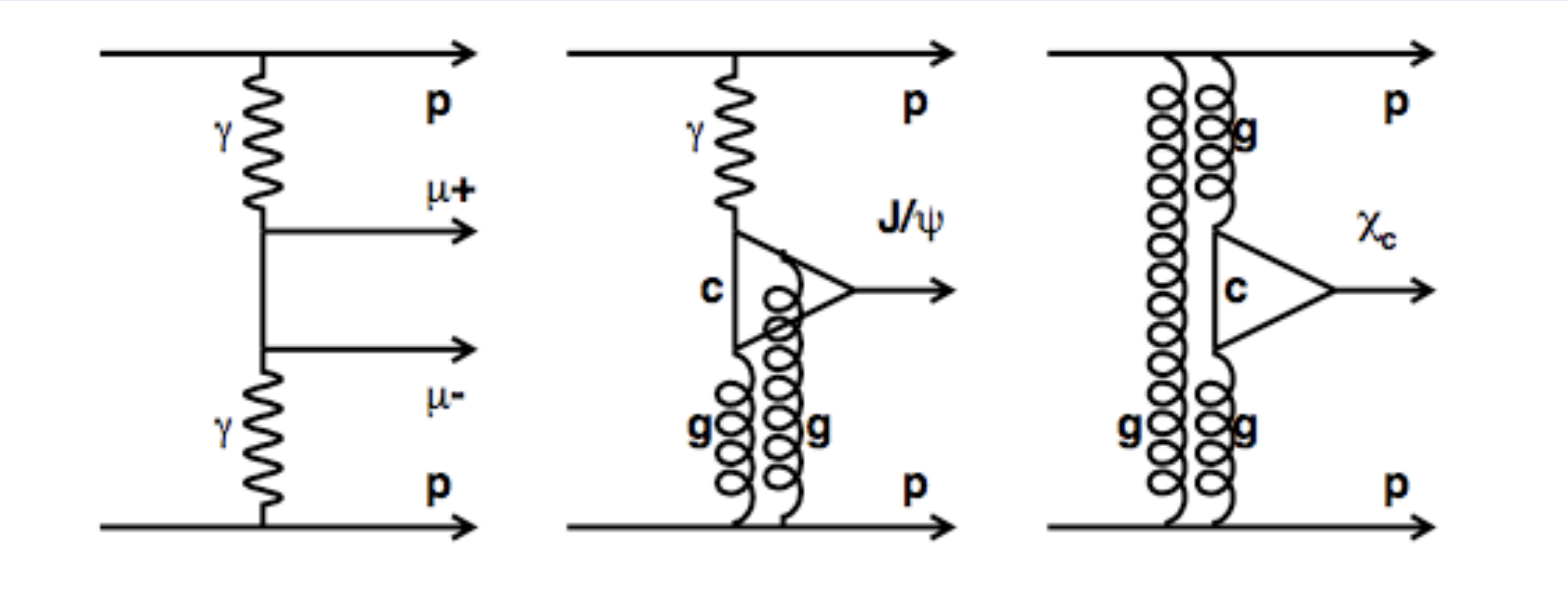
Exclusive dimuon candidate at LHCb

Just 2 long tracks (identified as muons) and no backward tracks



Exclusive dimuon physics motivation

Protons go down beam pipe so signal is 2 muons (+photon) and rapidity gaps



Diphoton dimuon production ideal for luminosity measurement

Exclusive J/Ψ measurement allows search for Odderon

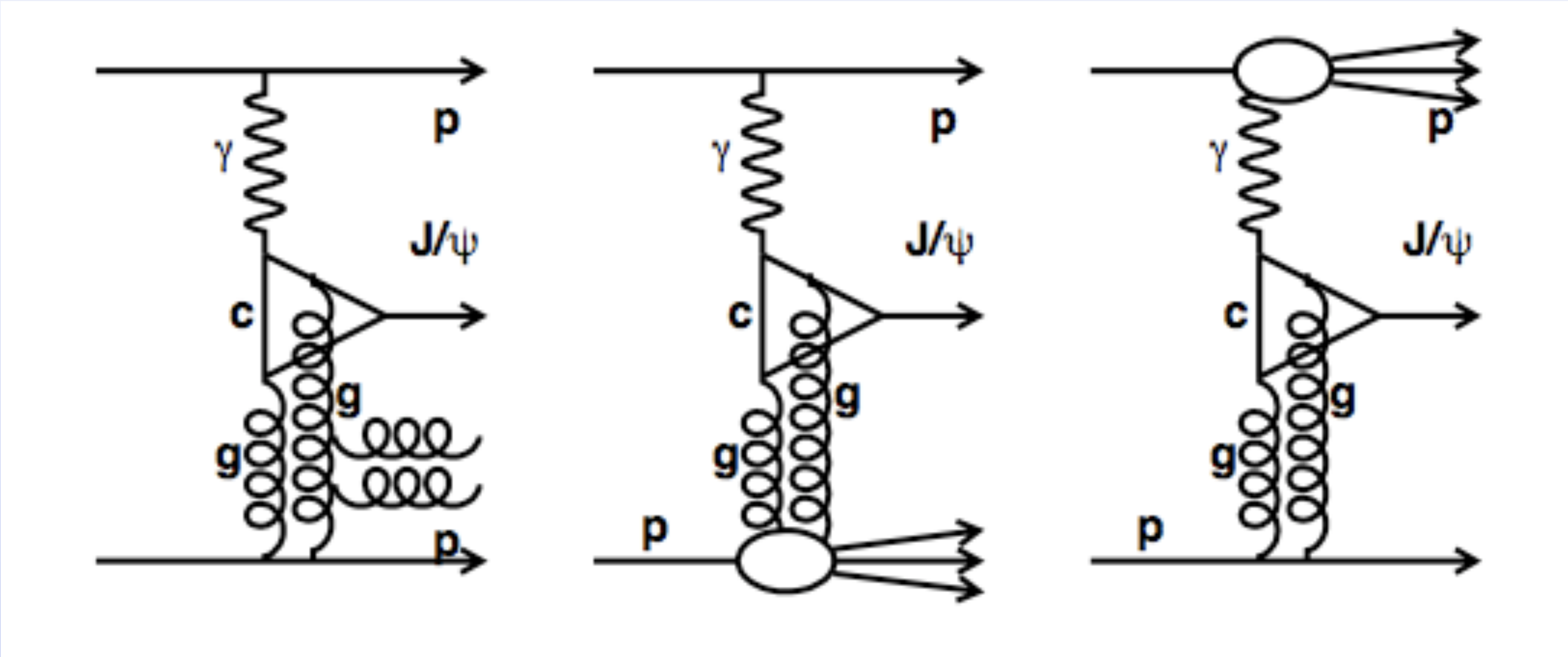
Exclusive Xc allows test of CEP Higgs predictions

Both J/Ψ and Xc measurements allow probe of gluon at low x

(LHCb-CONF-2011-022)

Inelastic background

Gluon emissions and proton dissociation

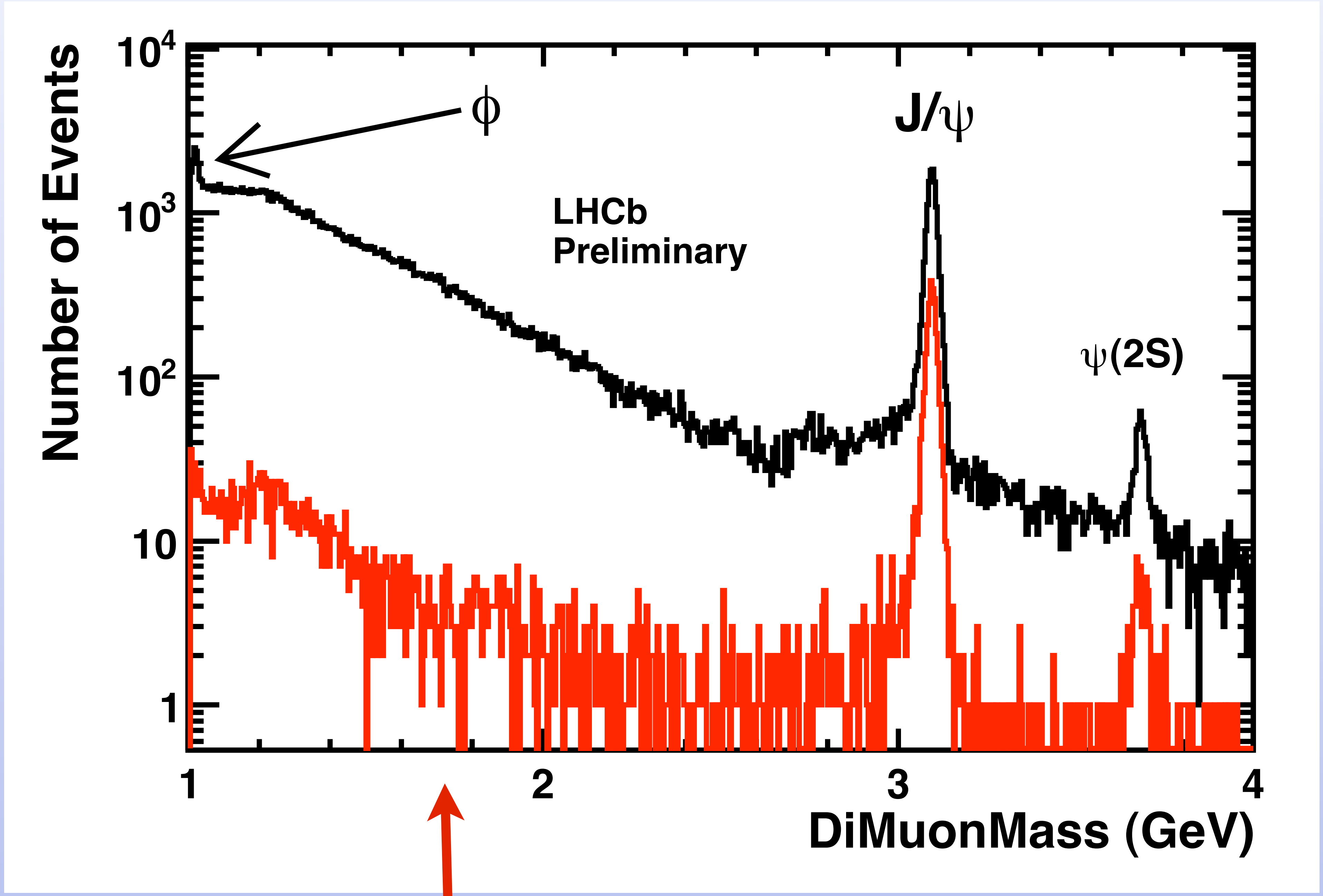


Additional particles may not be detected in LHCb
Central object generally has a higher Pt than for signal

Exclusive dimuon candidates at LHCb

Events passing low multiplicity dimuon trigger in 2010

(Total Lumi collected in 2010 = 37 pb^{-1})



Just 2 forward tracks and no backward tracks

Pile-up events rejected

J/Ψ inelastic background

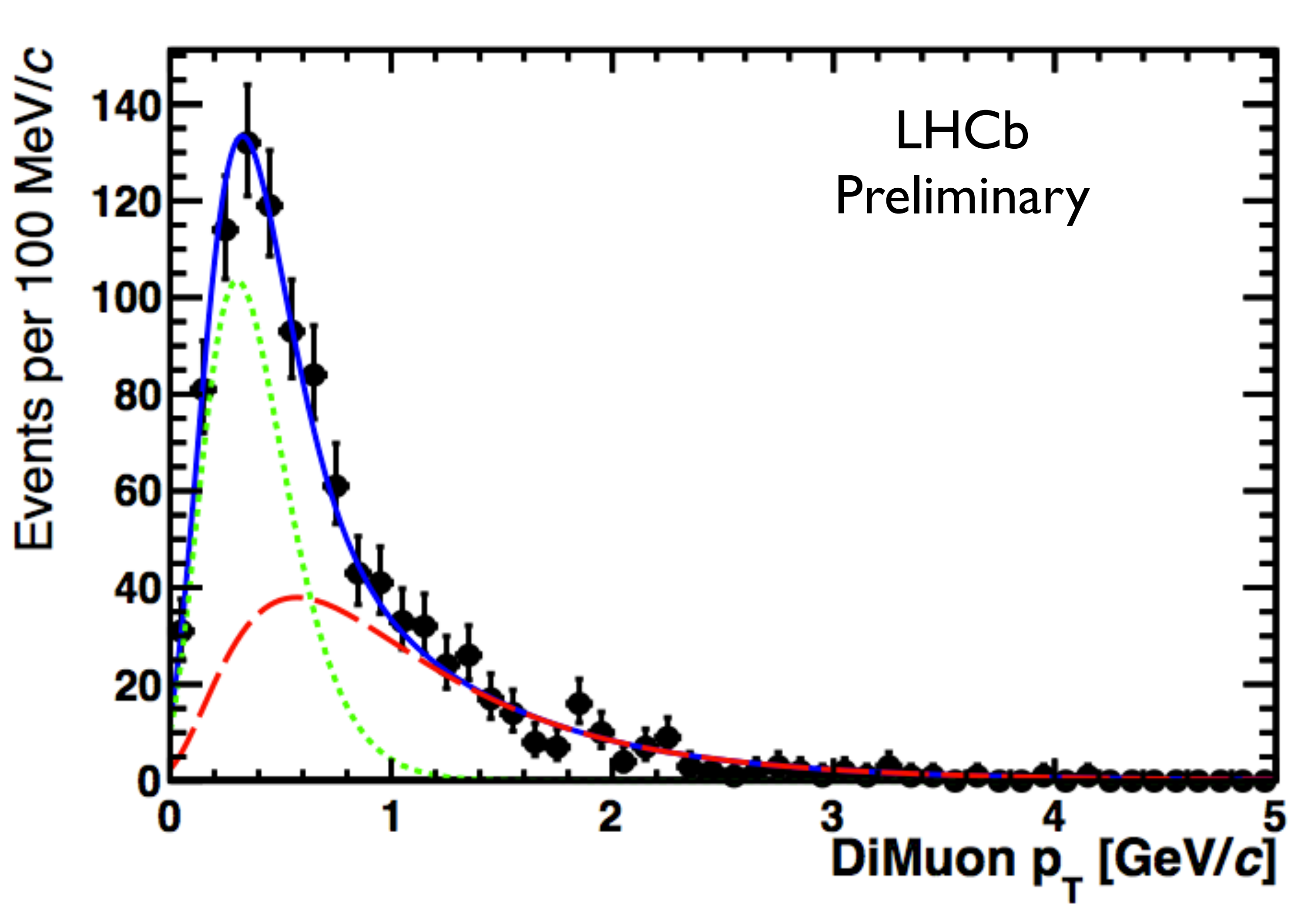
<u>Fit exclusive J/Ψ candidate P_T spectrum</u>

Inelastic background taken from data

Signal from Superchic which uses $\exp(-b\, p_T^2)$ form

Slope b estimated from explicit calculation using HERA data: 6.1 +/- 0.3 GeV^{-2}

Fit gives b = 5.8 +/- 1 GeV^{-2}



<u>Require DiMuon Pt < 900 MeV</u>

Exclusive J/Ψ and Ψ(2S) measurements

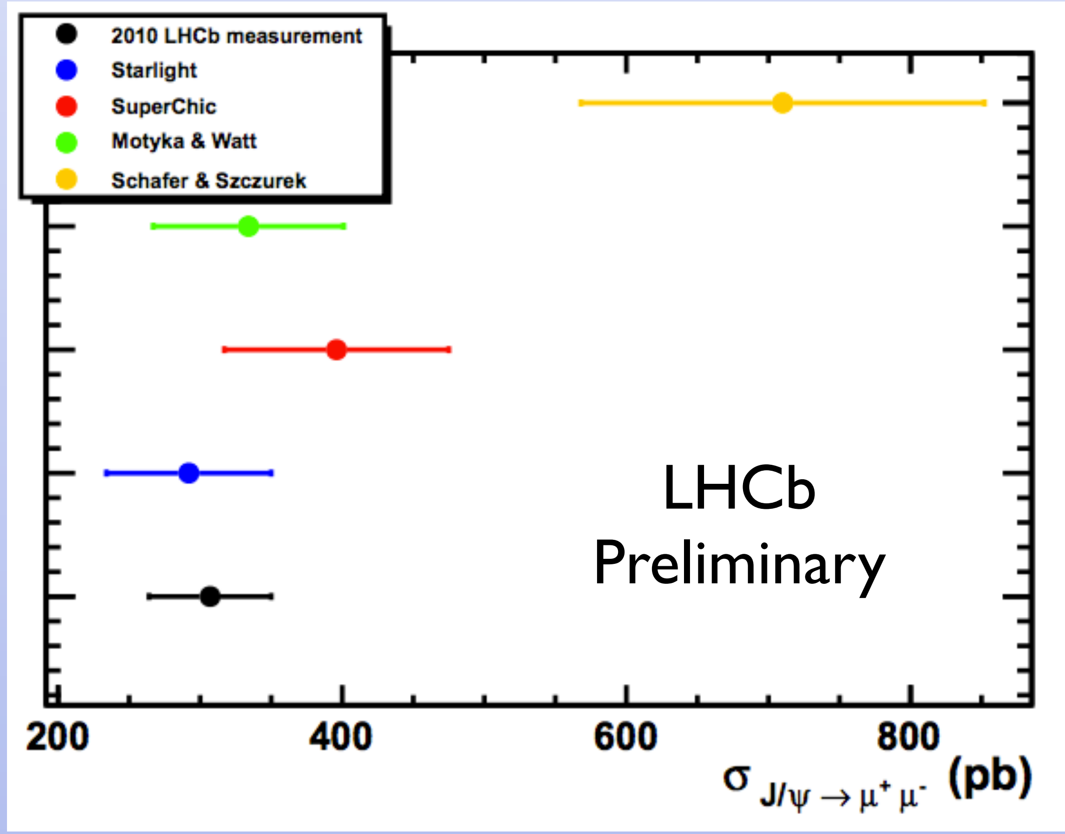
Measurements correspond to cross-section times branching ratio where the decay products are in the LHCb acceptance

$$\sigma_{J/\Psi \to \mu^+\mu^-} = 307 \pm 21 \pm 33 \pm 17 \text{ pb}$$

$$\sigma_{\Psi(2S) \to \mu^+\mu^-} = 7.8 \pm 1.3 \pm 1.0 \pm 0.4 \text{ pb}$$

Statistical + systematic + luminosity uncertainties are given

Measured cross-sections are consistent with theoretical predictions:
L. Motyka & G. Watt, W. Schäfer & A. Szczurek, SuperChic, Starlight



Ratio of Ψ(2S) to J/Ψ:	0.19 +/- .03
Starlight prediction :	0.16
Schafer & Szczurek prediction :	0.2
HERA :	0.166 +/- 0.012
CDF :	0.14 +/- .05

J/Ψ production σ as a function rapidity

Rapidity	2-2.25	2.25-2.5	2.5-2.75	2.75-3	3-3.25
$\frac{d\sigma}{dy}(J/\psi)$	$3.2 \pm 0.8 \pm 0.9$	$4.5 \pm 0.5 \pm 0.8$	$5.3 \pm 0.4 \pm 0.9$	$4.4 \pm 0.3 \pm 0.7$	$5.5 \pm 0.3 \pm 0.8$
Rapidity	3.25-3.5	3.5-3.75	3.75-4	4-4.25	4.25-4.5
$\frac{d\sigma}{dy}(J/\psi)$	$4.8 \pm 0.3 \pm 0.7$	$5.2 \pm 0.3 \pm 0.8$	$4.8 \pm 0.4 \pm 0.8$	$4.7 \pm 0.5 \pm 0.9$	$4.1 \pm 0.9 \pm 1.3$

$$\frac{d\sigma}{dy}_{pp\to pVp} = r(y)\left[k_+\frac{dn}{dk_+}\sigma_{\gamma p\to Vp}(W^+) + k_-\frac{dn}{dk_-}\sigma_{\gamma p\to Vp}(W^-)\right] \quad *$$

Absorptive correction

$$r(y) = 0.85 - \frac{0.1|y|}{3}$$

Photon Energy spectrum

$$\frac{dn}{dk} = \frac{\alpha_{em}}{2\pi k}\left[1+\left(1-\frac{2k}{\sqrt{s}}\right)^2\right]\left(\log A - \frac{11}{6} + \frac{3}{A} - \frac{3}{2A^2} + \frac{1}{3A^3}\right)$$

Assume power law behaviour for photoproduction $\sigma(W) = (aW^{\delta})$

Fit of * to the differential data gives :

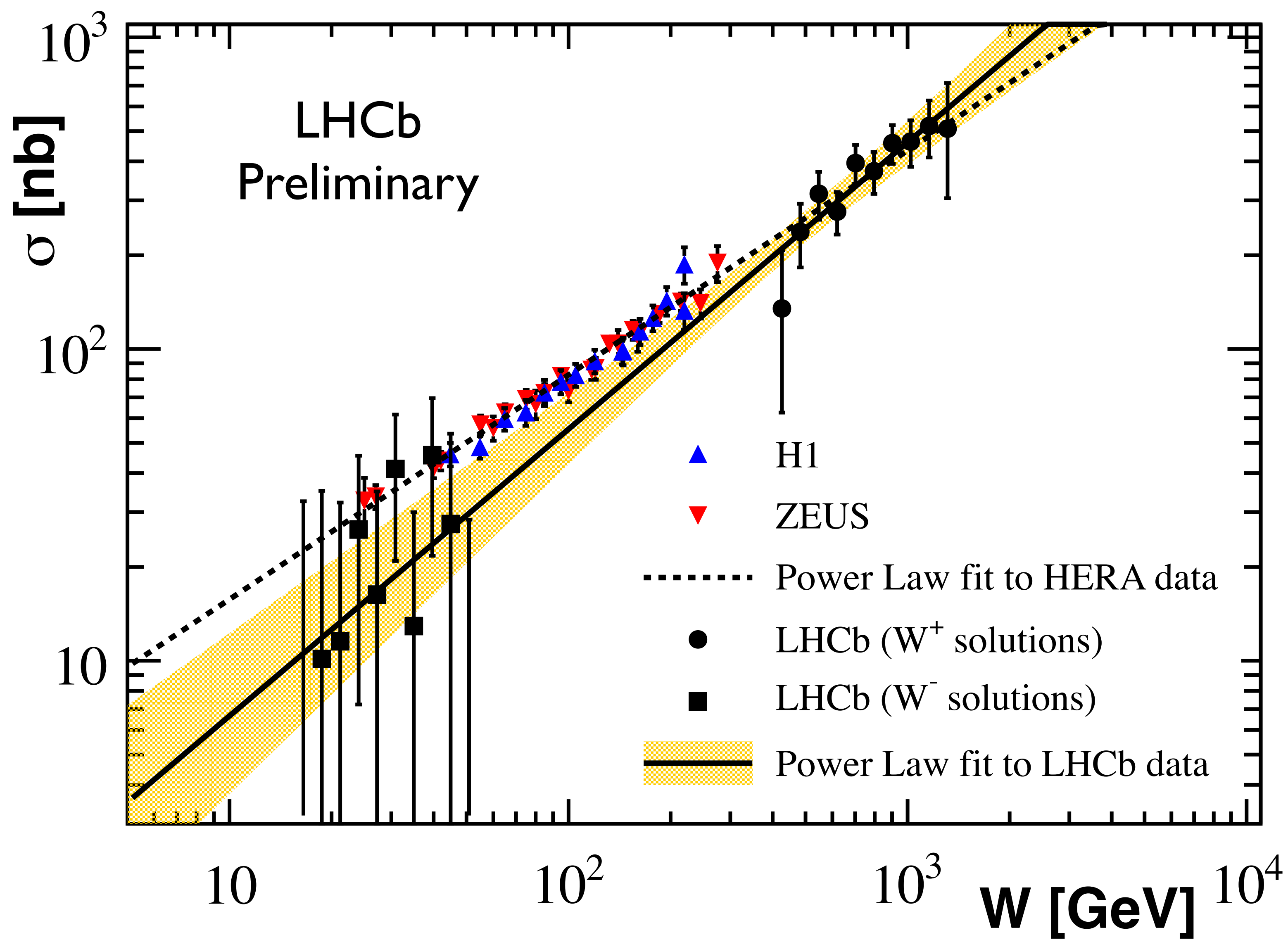
$a = 0.8^{+1.2}_{-0.5}$ nb $\quad \delta = 0.92 \pm 0.15$

Consistent with HERA data (a = 3 nb and δ = 0.72)

J/Ψ photoproduction σ

Differential cross-sections transformed into photoproduction cross-sections

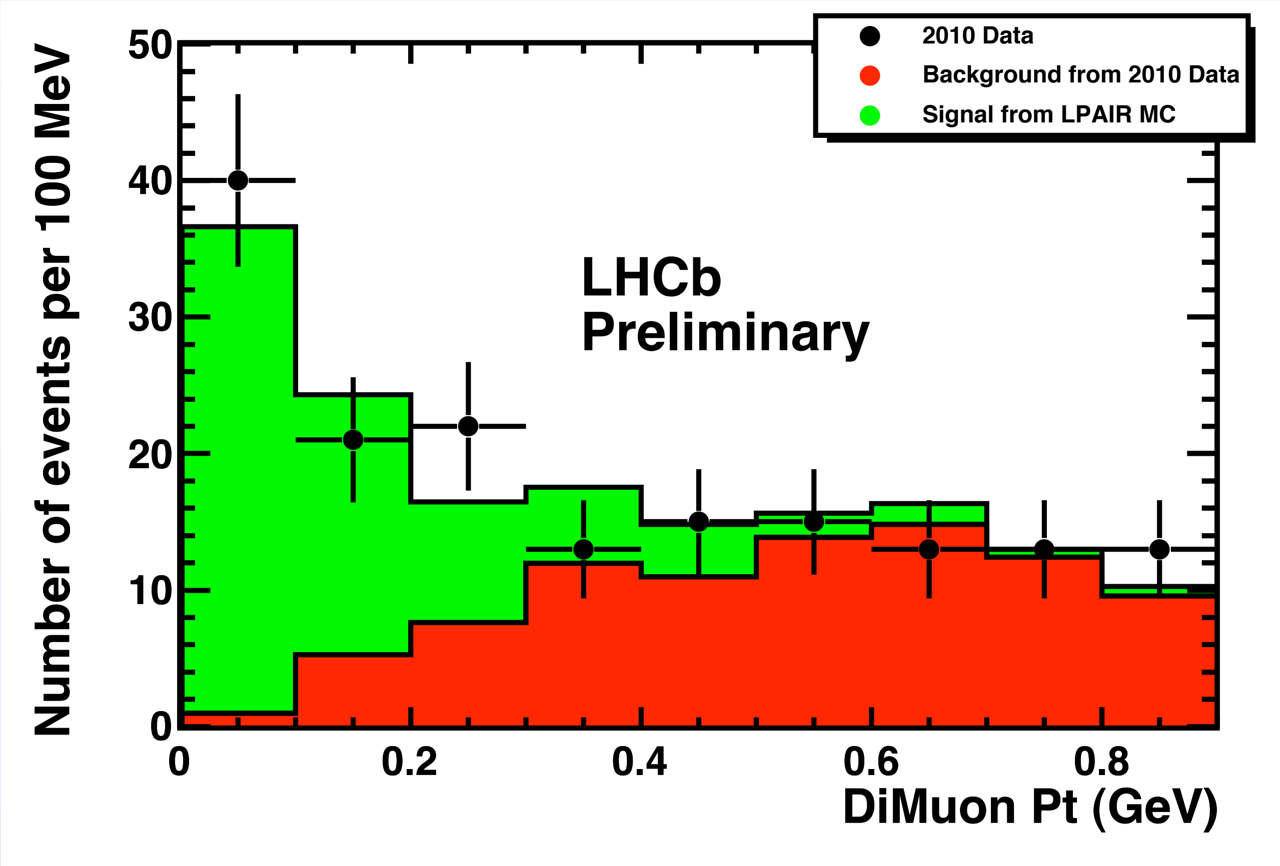
$$\sigma_{\gamma p \to Vp}(W^{\pm}) = \frac{1/r(y)\frac{\mathrm{d}\sigma}{\mathrm{d}y}_{pp\to pVp} - k_{\mp}\frac{\mathrm{d}n}{\mathrm{d}k_{\mp}}\sigma_{\gamma p\to Vp}(W^{\mp})}{k_{\pm}\frac{\mathrm{d}n}{\mathrm{d}k_{\pm}}}$$



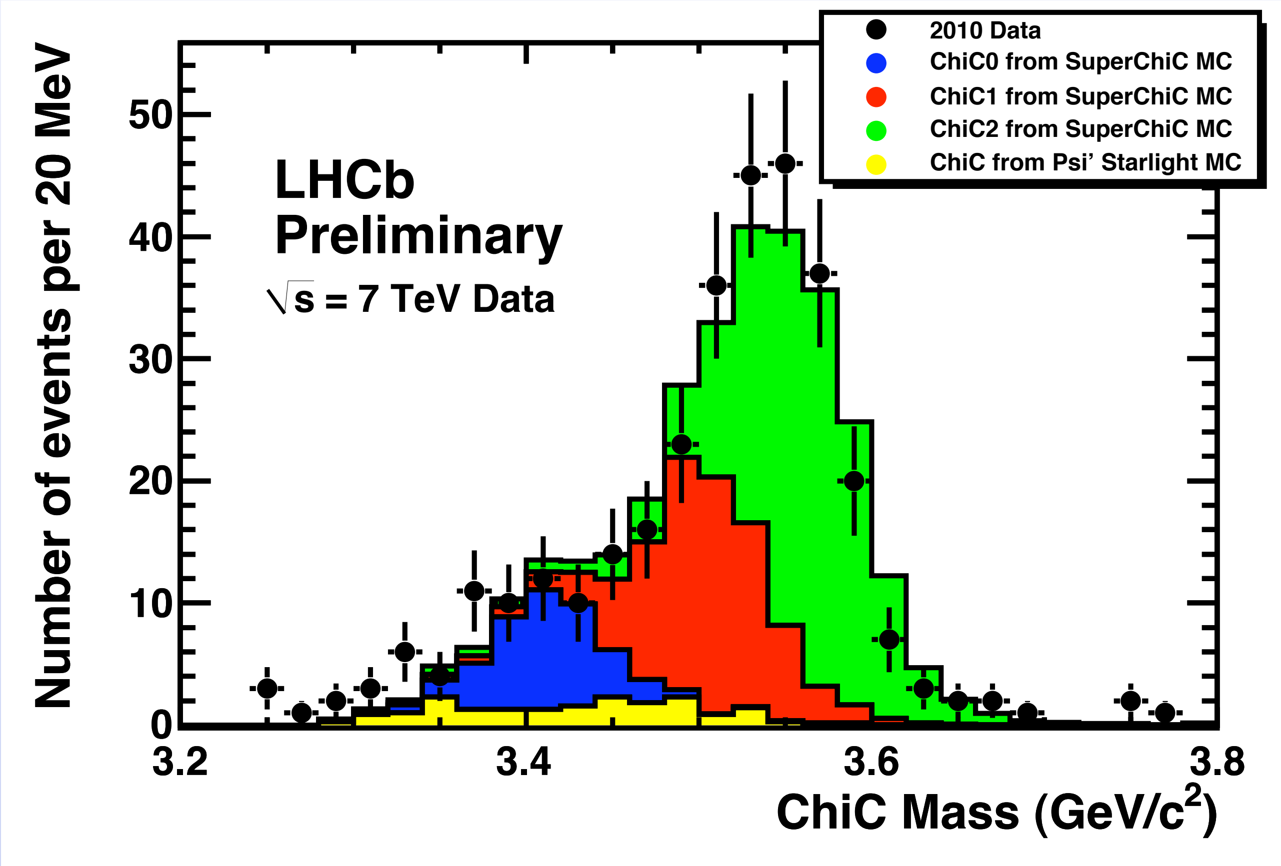
Exclusive diphoton dimuons and Xc measurements

Dimuons with mass > 2.5 GeV

+ mass cuts to remove J/Ψ and Ψ(2S)



J/Ψ + photon mass



$$\sigma_{\chi_{c0} \to \mu^+\mu^-\gamma} = 9.3 \pm 2.2 \pm 3.5 \pm 1.8 \text{ pb}$$

$$\sigma_{\chi_{c1} \to \mu^+\mu^-\gamma} = 16.4 \pm 5.3 \pm 5.8 \pm 3.2 \text{ pb}$$

$$\sigma_{\chi_{c2} \to \mu^+\mu^-\gamma} = 28.0 \pm 5.4 \pm 9.7 \pm 5.4 \text{ pb}$$

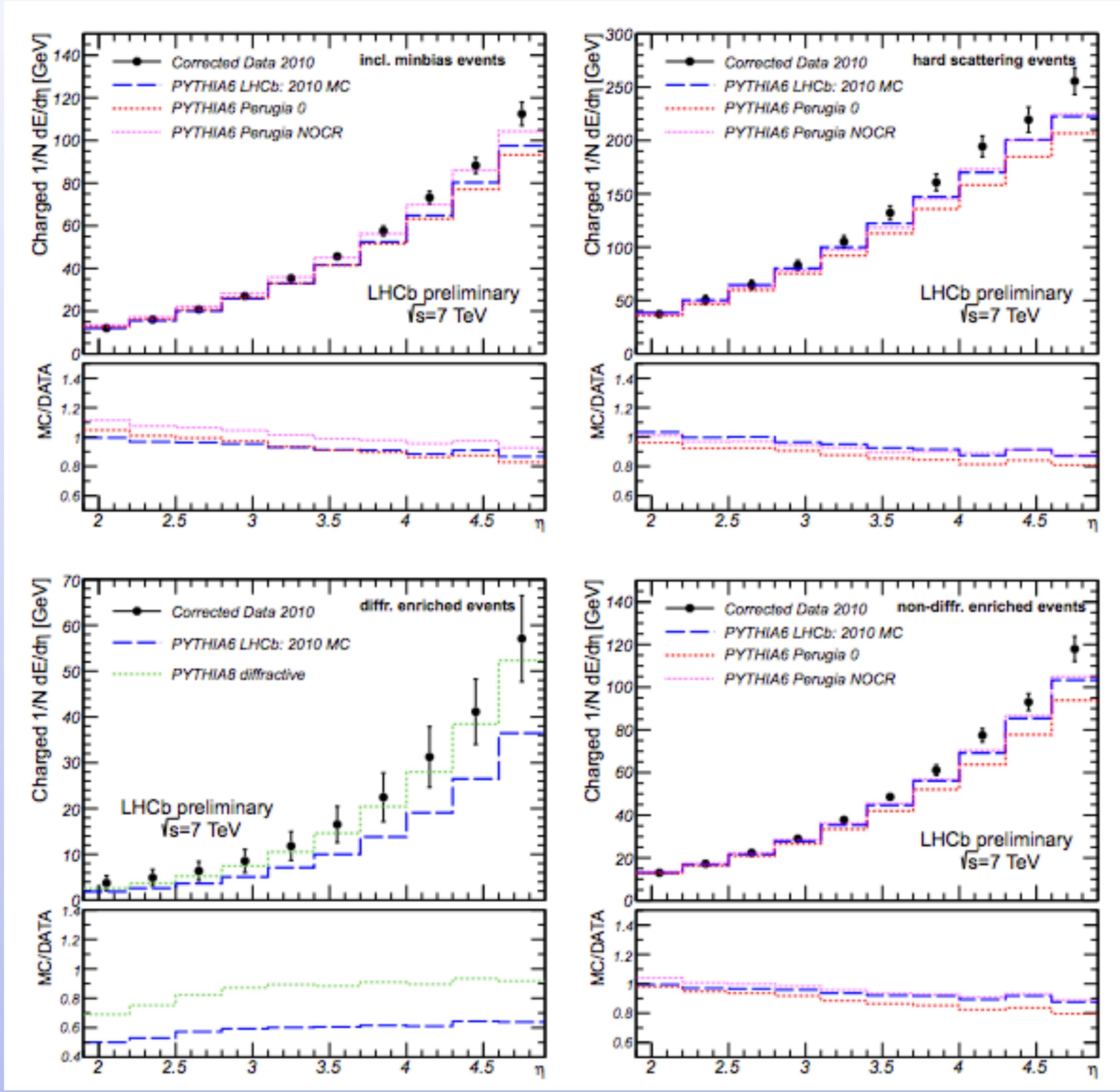
$$\sigma_{\gamma\gamma \to \mu^+\mu^-} = 67 \pm 10 \pm 5 \pm 15 \text{ pb}$$

Conclusions

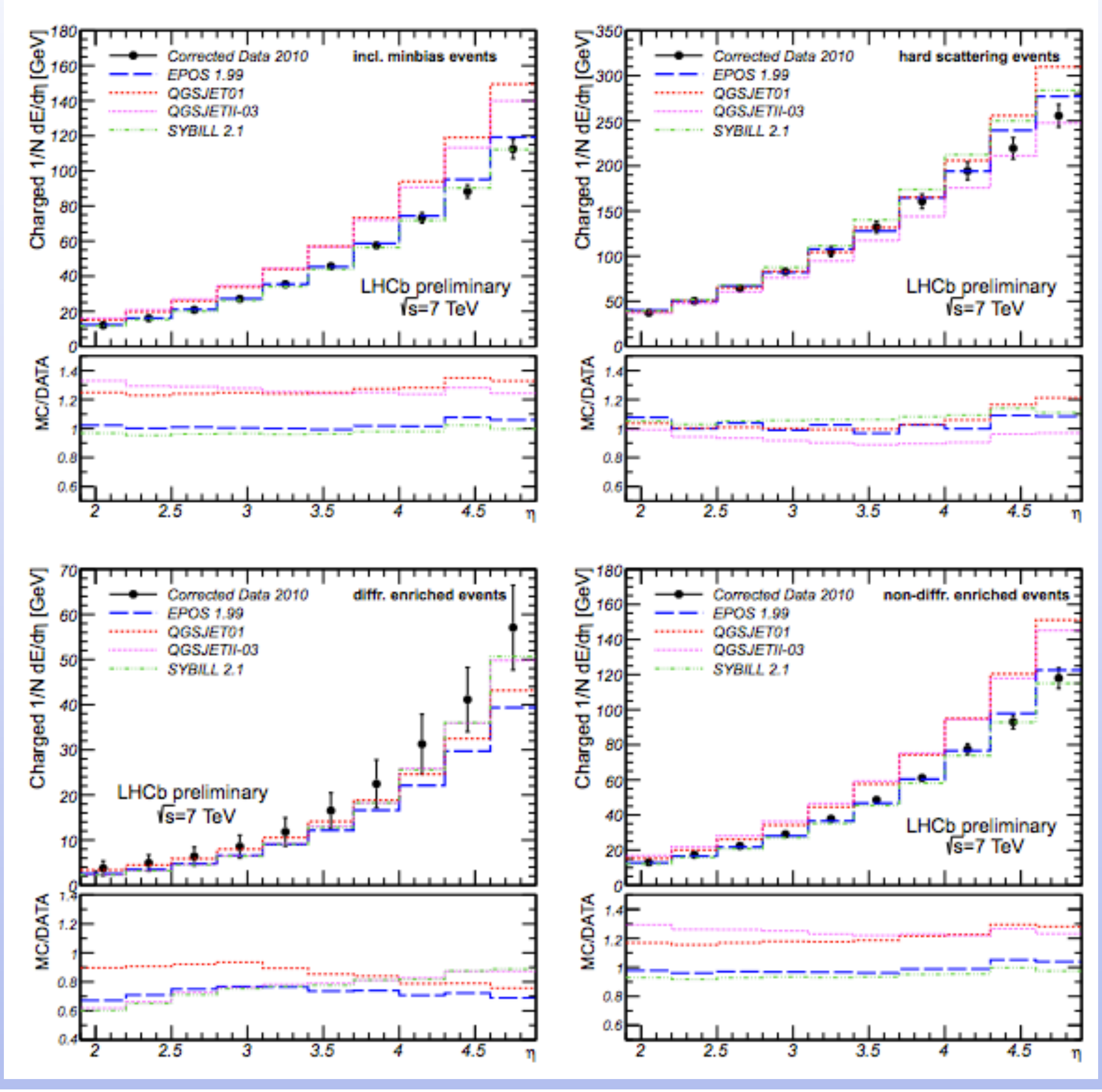
- Forward EF has been measured for inclusive MB, hard scattering, diffractive and non-diffractive enriched events
- PYTHIA based generators underestimate the data at large η while most of the cosmic-ray models overestimate it, except for diffractive events
- SYBILL gives best description of the inclusive MB and non-diffractive EF
- Exclusive J/Ψ, Ψ(2S), X_c and diphoton produced dimuons have been measured at LHCb
- Cross-sections are consistent with theoretical predictions
- J/Ψ photoproduction cross-section has been determined and is consistent with HERA

BACKUP

Charged EF Vs. PYTHIA tunes

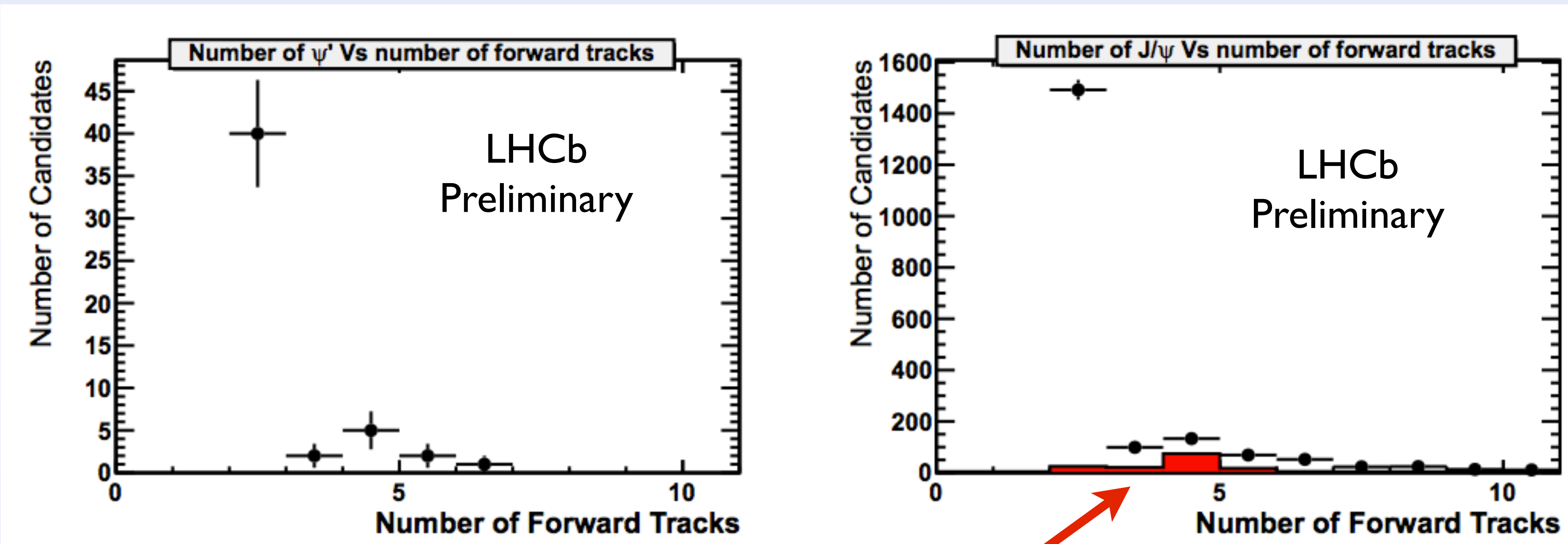


Charged EF Vs. Cosmic-ray models



J/Ψ and Ψ(2S) candidates

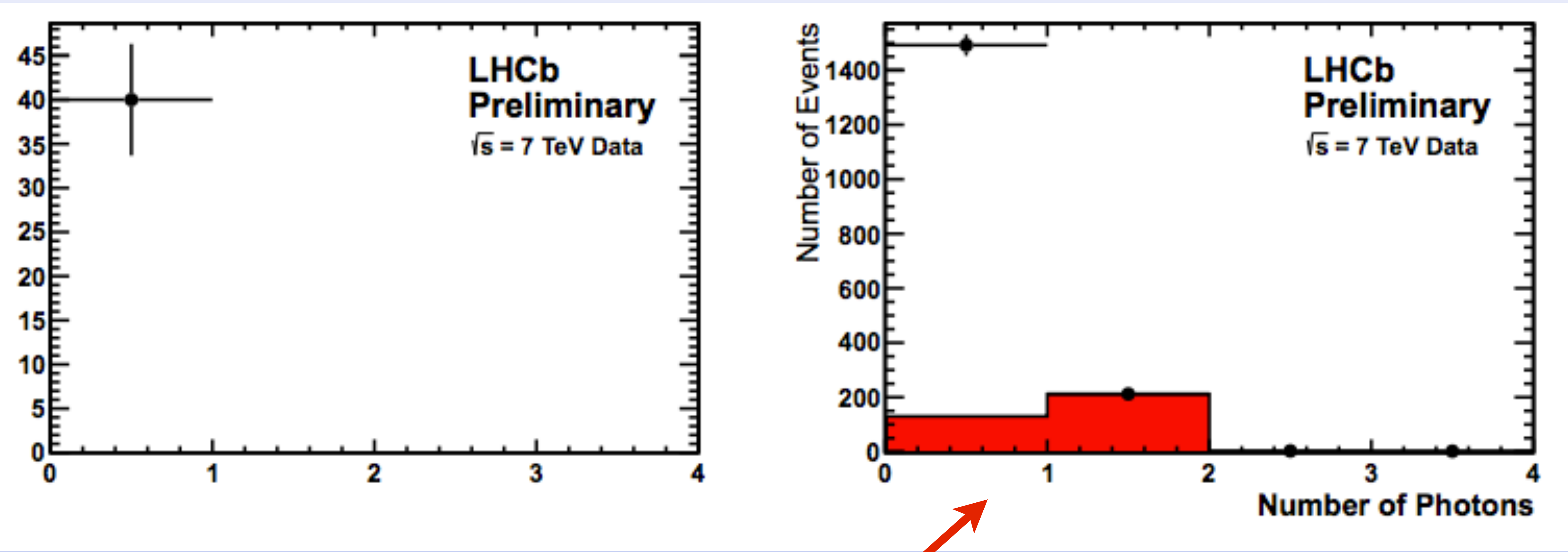
Number of forward tracks in events with no backward tracks



Ψ(2S) -> J/Ψ + X estimated from Superchic

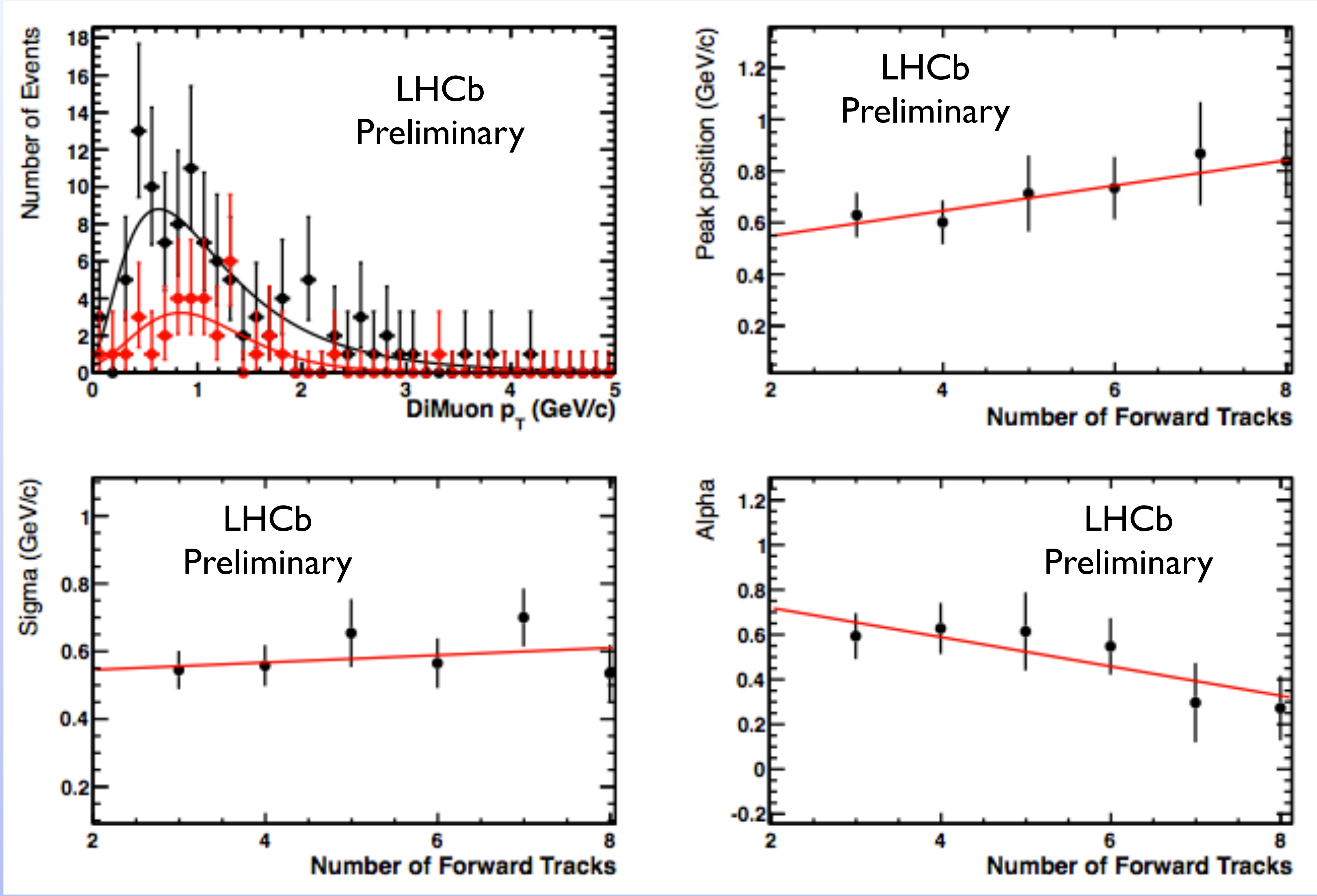
J/Ψ and Ψ(2S) candidates

Number of Photons in events with no backward tracks and 2 forward tracks



Xc -> J/Ψ + γ estimated from Superchic

Inelastic J/Ψ background



Exclusive J/Ψ b estimation

Regge Theory Prediction: b increases with W

$$b = b_0 + 4\alpha' \ln \frac{W}{W_0}$$

Measured at HERA

2 W values for each bin of rapidity

$$(W^{\pm})^2 = M\sqrt{s}\exp \pm y.$$

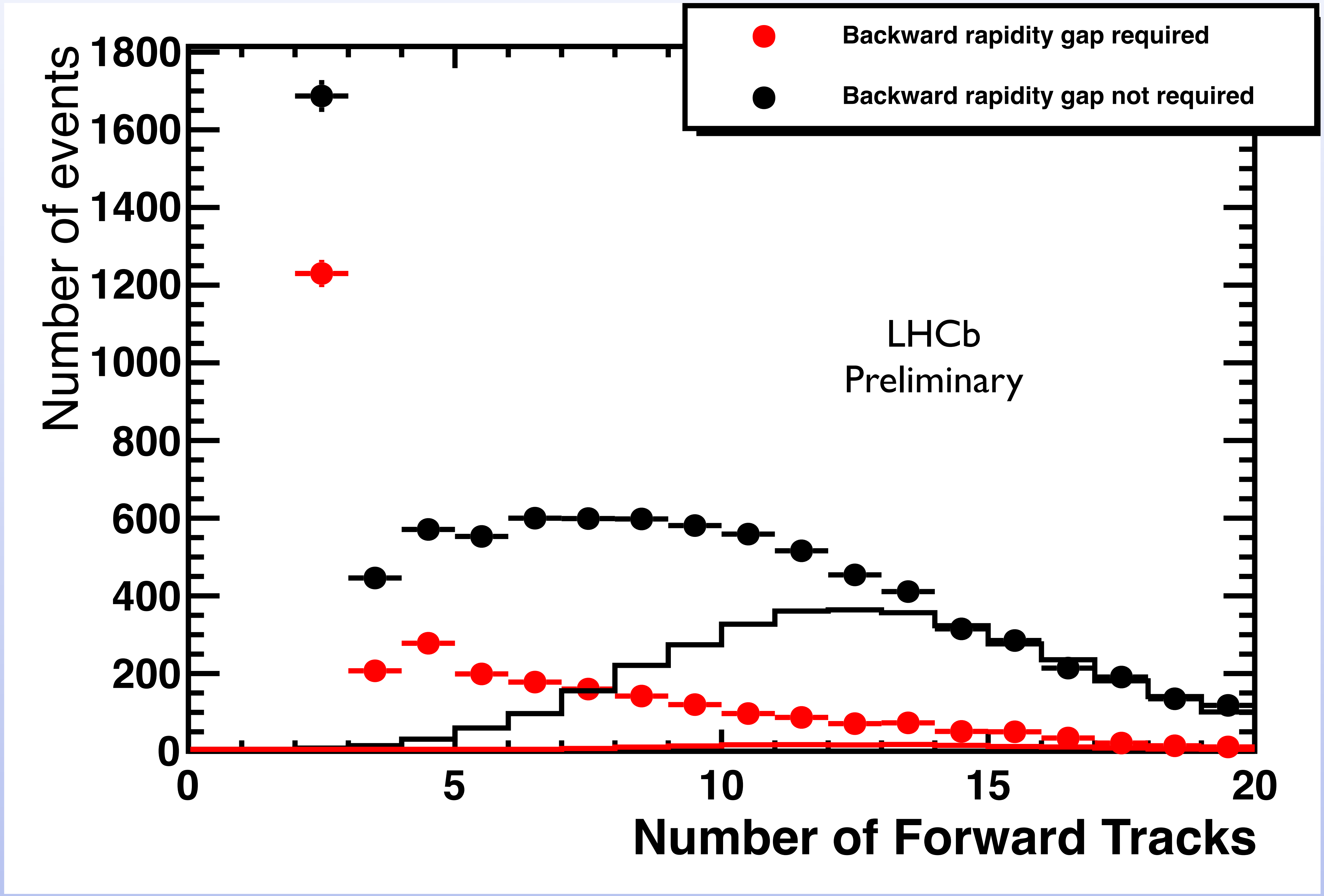
Weight b values (1 for each W) by photon flux

$$\frac{dn}{dk} = \frac{\alpha_{em}}{2\pi k}\left[1 + \left(1 - \frac{2k}{\sqrt{s}}\right)^2\right]\left(\log A - \frac{11}{6} + \frac{3}{A} - \frac{3}{2A^2} + \frac{1}{3A^3}\right)$$

y	W_1	W_2	b_1	b_2	weight 1	weight 2	$< b >$
2.125	426.0	50.9	6.2	4.5	0.70	0.30	5.73
2.375	482.8	44.9	6.3	4.4	0.72	0.28	5.81
2.625	547.1	39.6	6.4	4.3	0.74	0.26	5.89
2.875	619.9	35.0	6.5	4.2	0.75	0.25	5.98
3.125	702.4	30.9	6.6	4.1	0.77	0.23	6.06
3.375	796.0	27.2	6.7	4.0	0.78	0.22	6.15
3.625	901.9	24.0	6.8	3.9	0.79	0.211	6.24
3.875	1022.0	21.2	6.9	3.8	0.80	0.20	6.34
4.125	1158.1	18.7	7.0	3.7	0.81	0.19	6.42
4.375	1312.3	16.5	7.1	3.6	0.82	0.18	6.51

→ 6.1 +/- 0.3 GeV^{-2}

Inclusive J/Ψ background



Preliminary results

Efficiencies determined from Simulation

Effective Luminosity L_{eff} depends on trigger efficiencies and on the average number of interactions per beam crossing μ

	J/ψ	ψ'
#Events N	1492 ± 39	40 ± 6
Efficiency ϵ	0.71 ± 0.05	0.71 ± 0.05
Purity p	$0.62 \pm 0.04 \pm 0.05$	$0.59 \pm 0.04 \pm 0.05$
$L_{eff}(pb^{-1})$	4.24 ± 0.23	4.24 ± 0.23

Quantity	Systematic
Luminosity	3.5 %
μ	0.7 %
Trigger	4 %
Tracking ϵ	2 % (1% per μ)
Identification ϵ	5 % (2.5% per μ)
Selection ϵ	1%
Non resonant background ($\psi(2S)$ analysis)	3%
$\psi(2S)$ background (J/ψ analysis)	0.3%
χ_c background (J/ψ analysis)	0.8%
Precision of dimuon p_T fit	6 %
Signal shape of dimuon p_T fit	6 %
Background shape of dimuon $p_T$fit	6 %