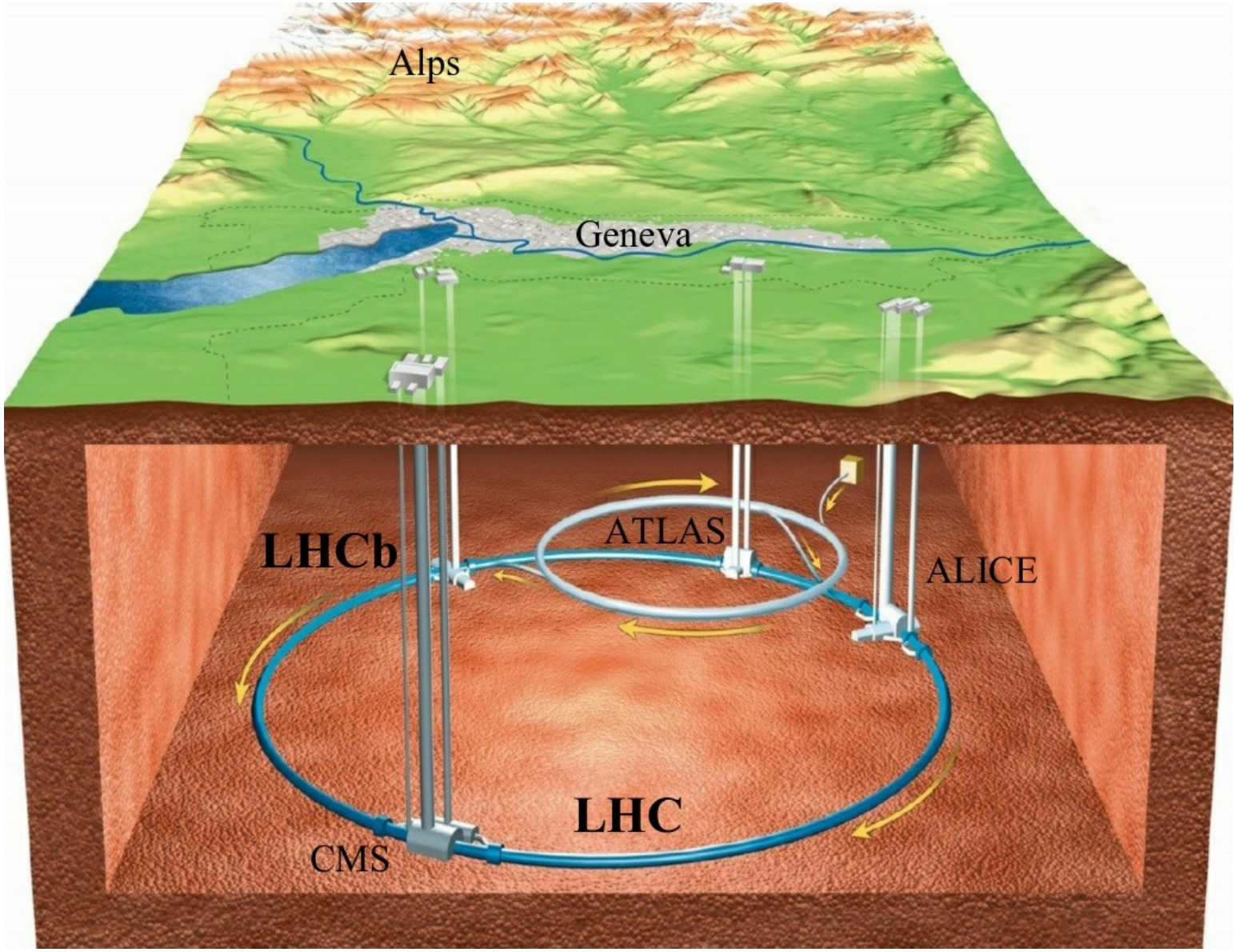
QCD Measurements at LHCb

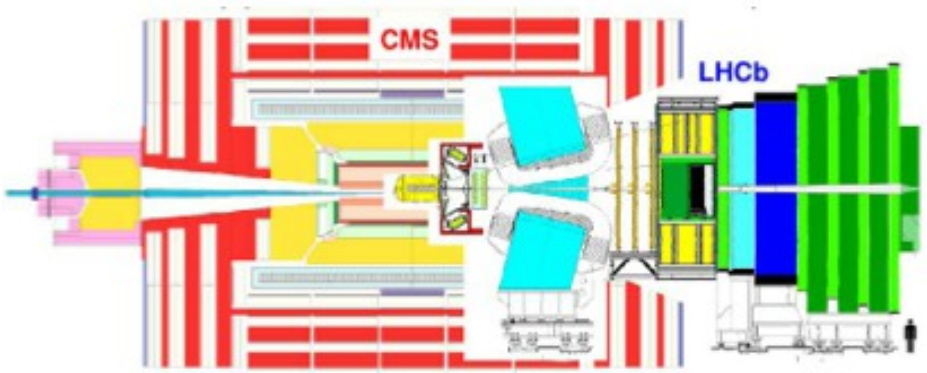
Murilo Rangel
on behalf of the LHCb Collaboration

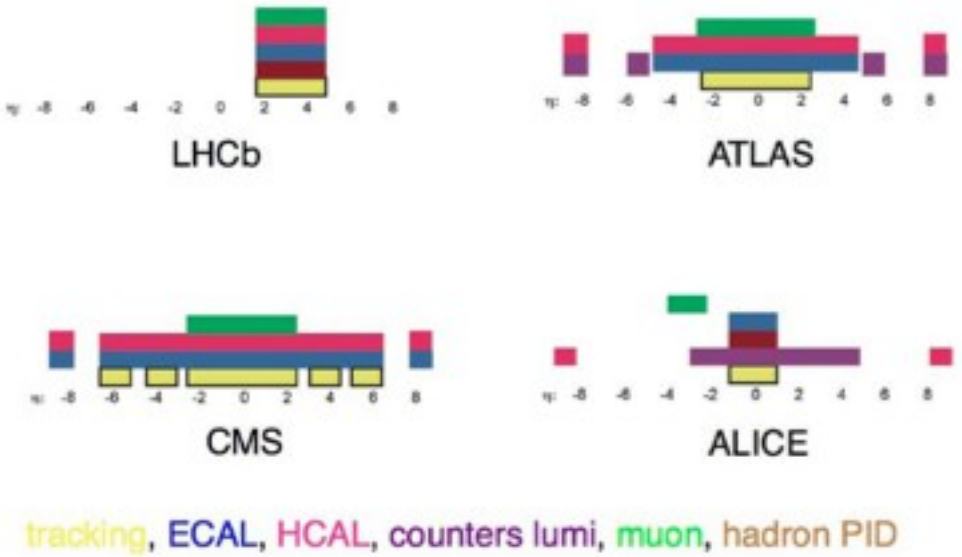
Introduction



Introduction

→ LHCb experiment covers an unique region of rapidity 2<y<5



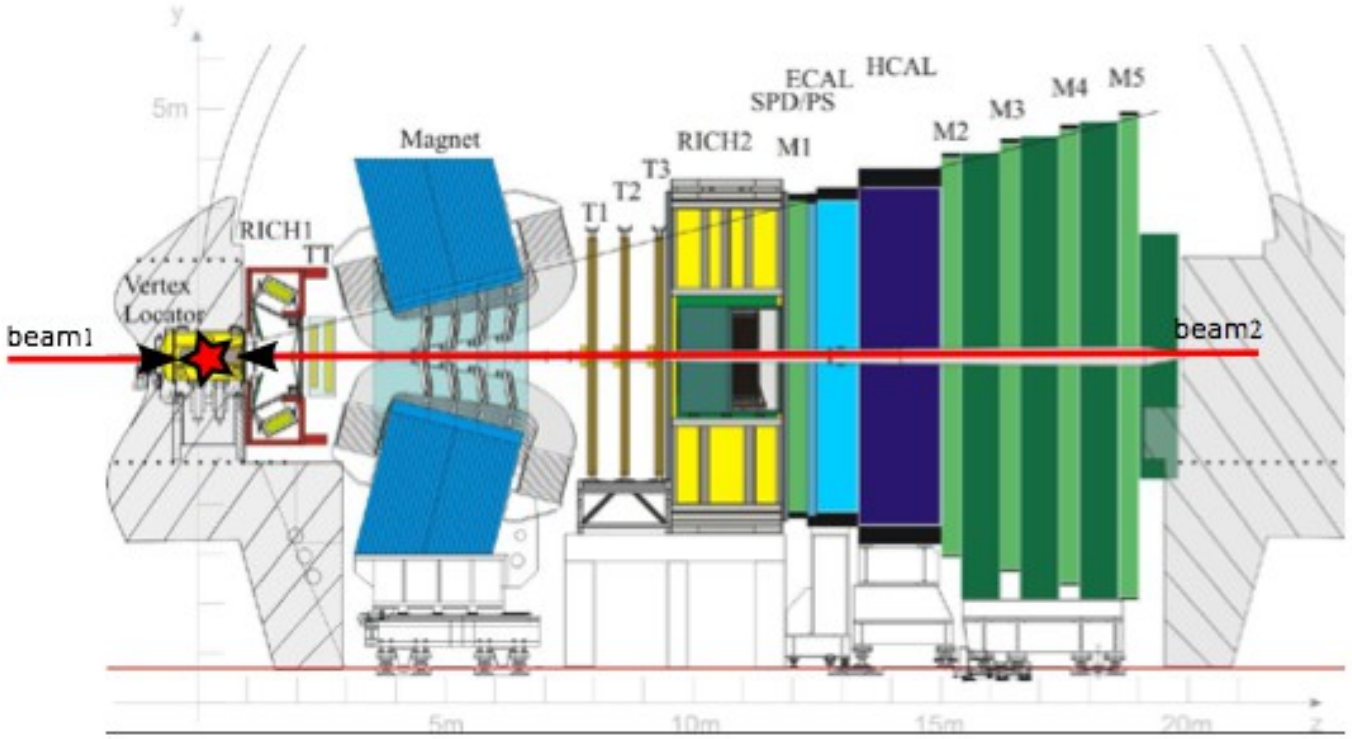


→ Forward region provides interesting tests of non-perturbative regime:
- particle production
- hadronization models
- collective effects

→ Precision tests to theoretical models

LHCb Experiment

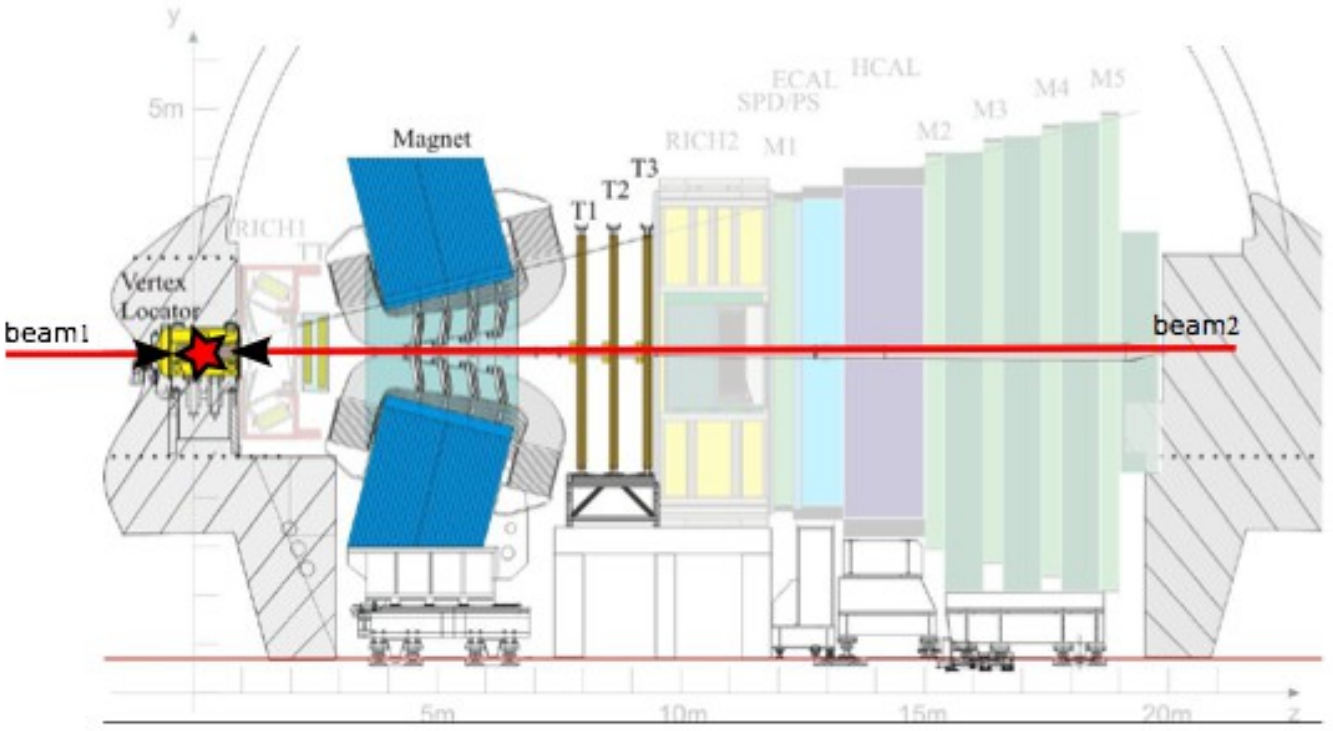
2008 JINST 3 S08005



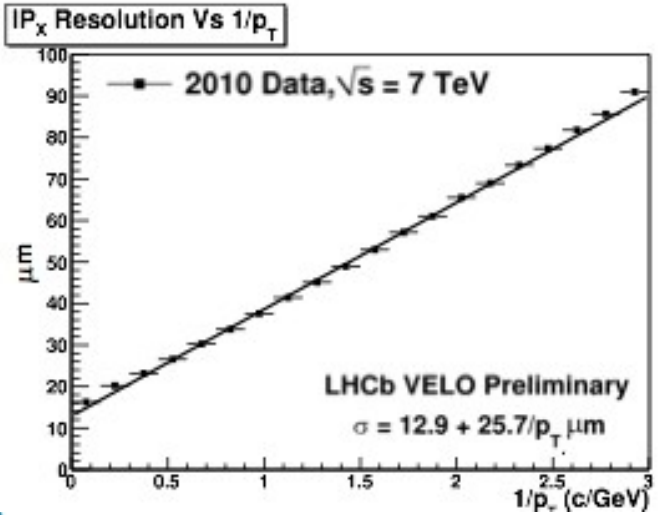
- Designed for CP violation studies in B decay and rare decays.
- Single arm spectrometer, $\sim 30\%$ of $b\bar{b}$ pairs produce in the acceptance.
- So far $\sim 0.3 nb^{-1}$ recorded at $\sqrt{s} = 900 GeV$ and $\sim 1.1 fb^{-1}$ $\sqrt{s} = 7 TeV$.

LHCb - Tracking

2008 JINST 3 S08005

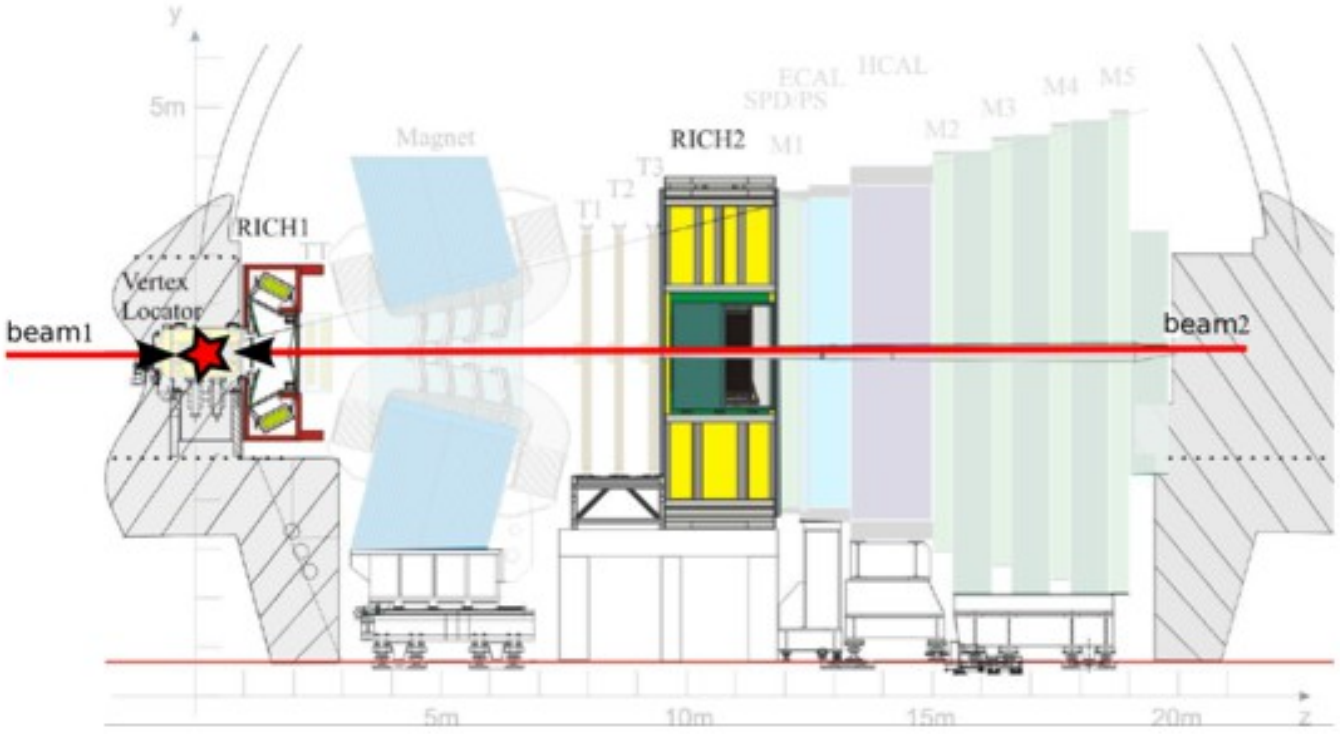


- Tracking efficiency $\sim 95\%$
- $\delta p/p \sim 0.5\%$
- Primary vertex resolution $50\mu m$
- VELO partially open at $\sqrt{s} = 900 GeV$

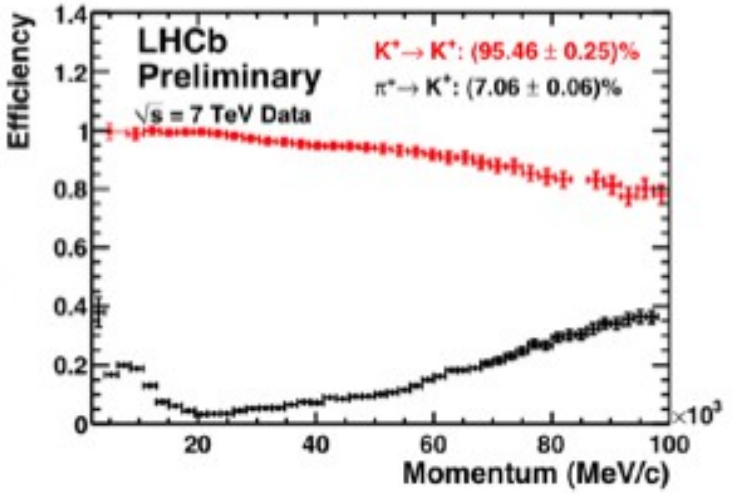


LHCb – Particle Identification

2008 JINST 3 S08005



- RICH1 cover momentums from 2 to 60 GeV/c
- RICH2 cover momentums from 20 to 100 GeV/c



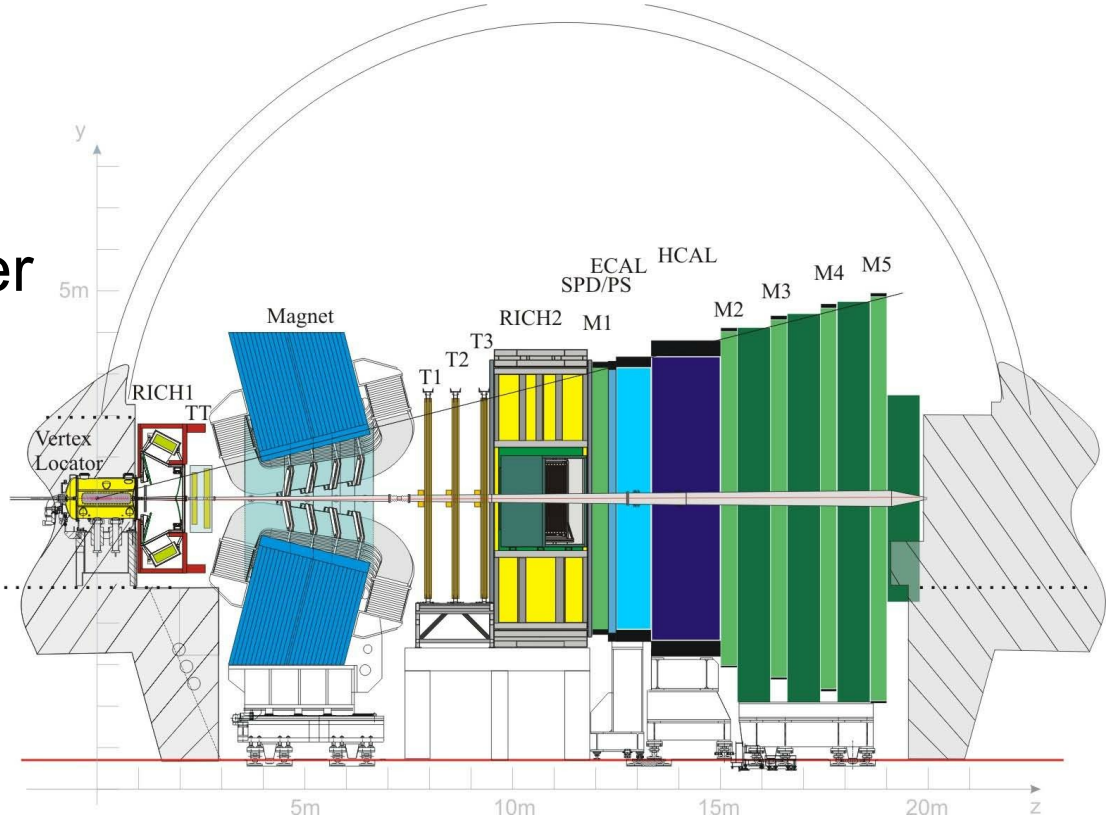
The detector is a single arm spectrometer fully instrumented in the forward region ($2.0 < \eta < 5.0$) → Unique coverage at LHC

Excellent Vertex Resolution and Tracking
→ Vertex Locator
→ Tracking Stations

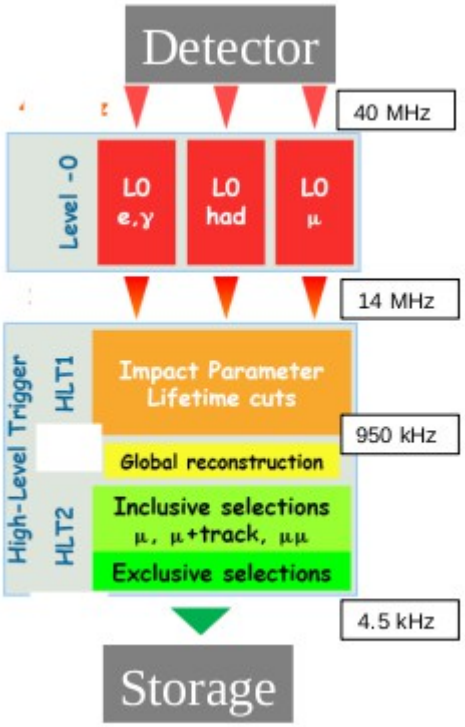
Energy Measurements
→ EM and Hadronic Calorimeter

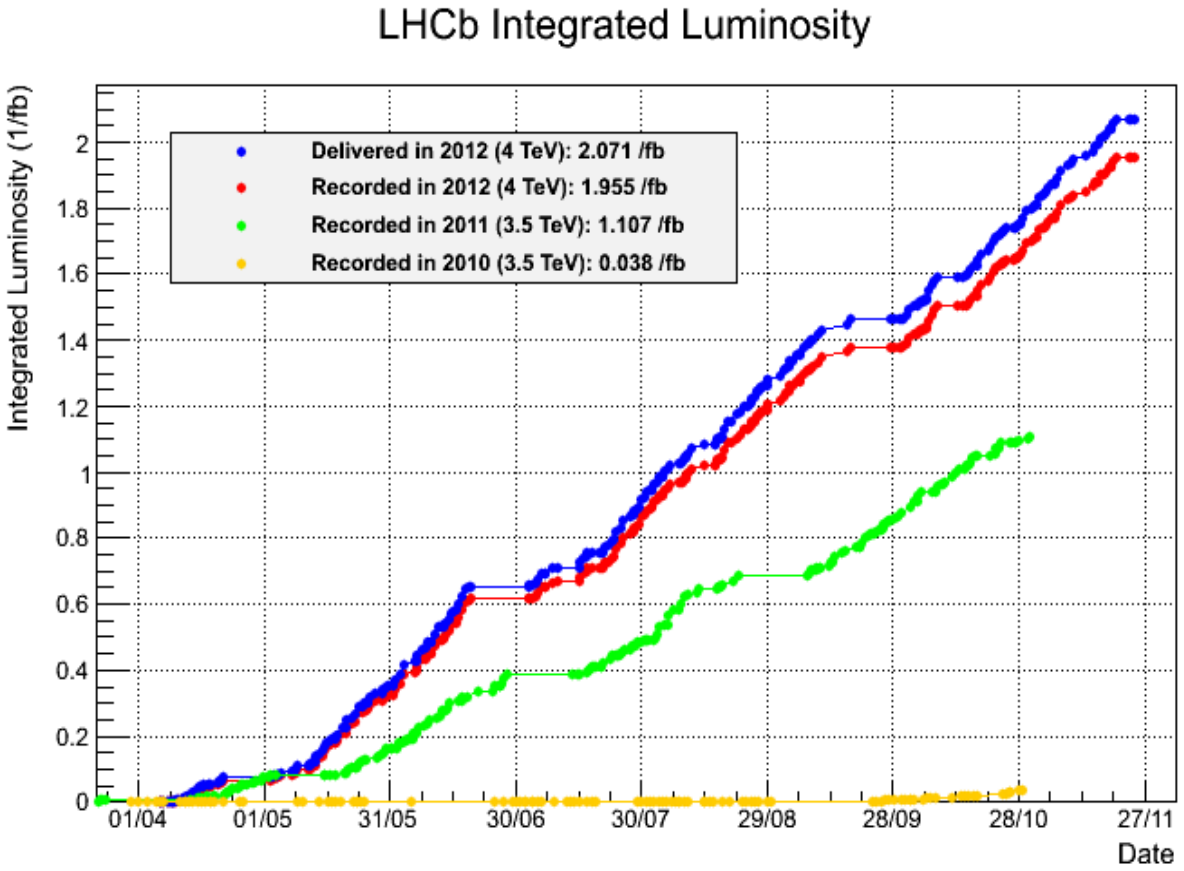
Particle Identification
→ Rich detectors
→ Muon Stations

Trigger
→ Ability to go low in muon p_T



LHCb Data





>90% data taking efficiency

2010 → 37/pb at $\sqrt{s}$ = 7 TeV

2011 → 1/fb at at $\sqrt{s}$ = 7 TeV

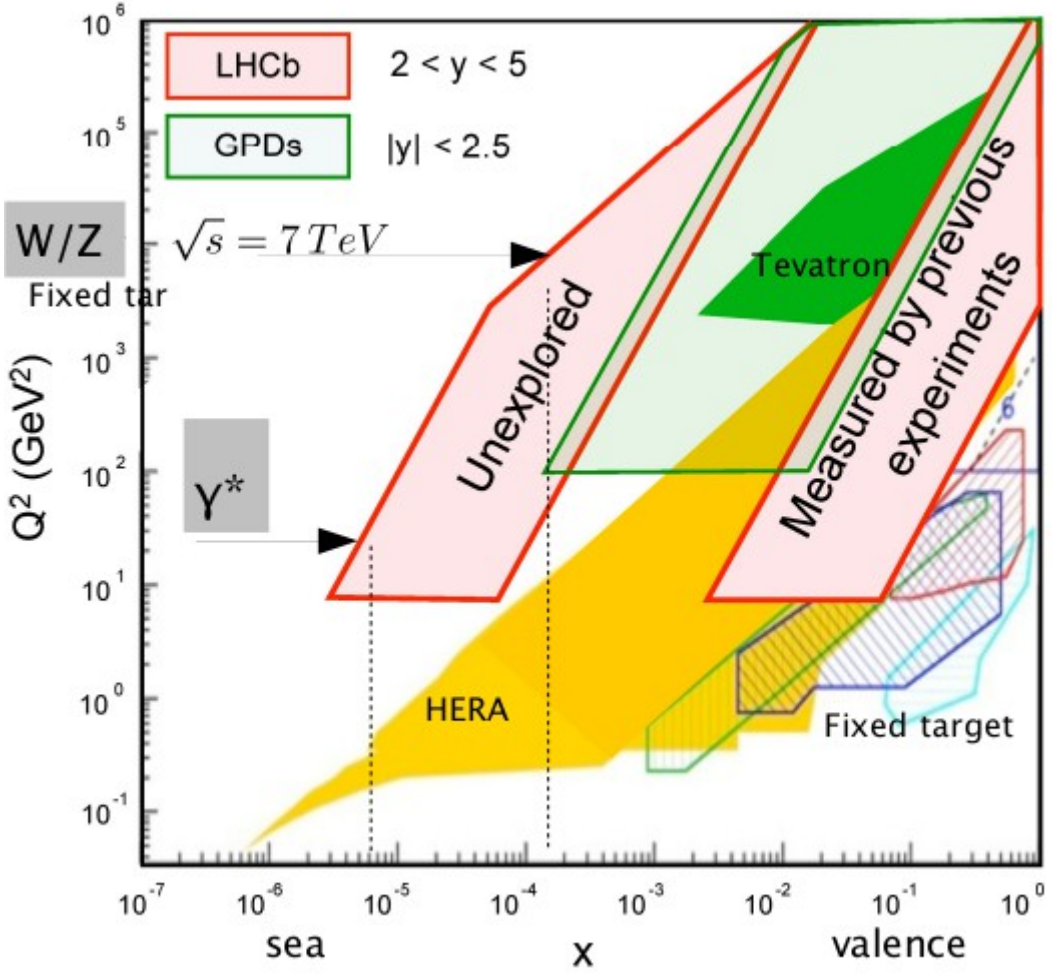
Thanks to LHC team!

Cross sections

$$\underbrace{\sigma(x,Q^2)}_{hadronic\ x-sec.} = \sum_{a,b} \int_0^1 dx_1\, dx_2 \underbrace{f_a(x_1 Q^2) f_b(x_2 Q^2)}_{PDFs\ 2-8\%} \underbrace{\hat{\sigma}(x_1, x_2, Q^2)}_{partonic\ x-sec.:\ NNLO\ 1\%}$$

LHCb is sensitive to low-x and a high-x parton collisions.

Two different regions are probed
→ inputs for PDF fits



Data

→ 2011 - 1/fb

→ same trigger and event selection for ($Z \rightarrow \mu^+\mu^-$)

Jet Selection

→ Particle Flow method

- tracks, γ, calorimeter clusters, V0s

→ anti-kt (R=0.5) reconstruction

→ Jet Identification cuts

→ Jet Energy Correction (MC)

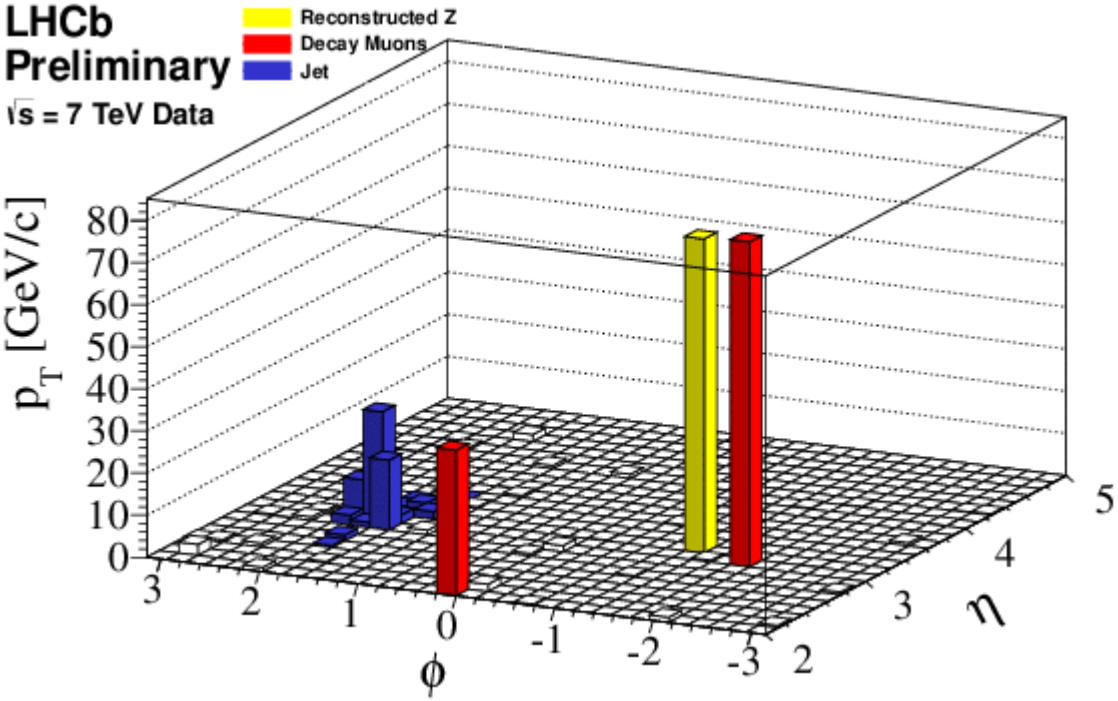
→ $p_T > 10$ GeV and $2.0 < \eta < 4.5$

→ DR(jet,μ)>0.4

Measurements

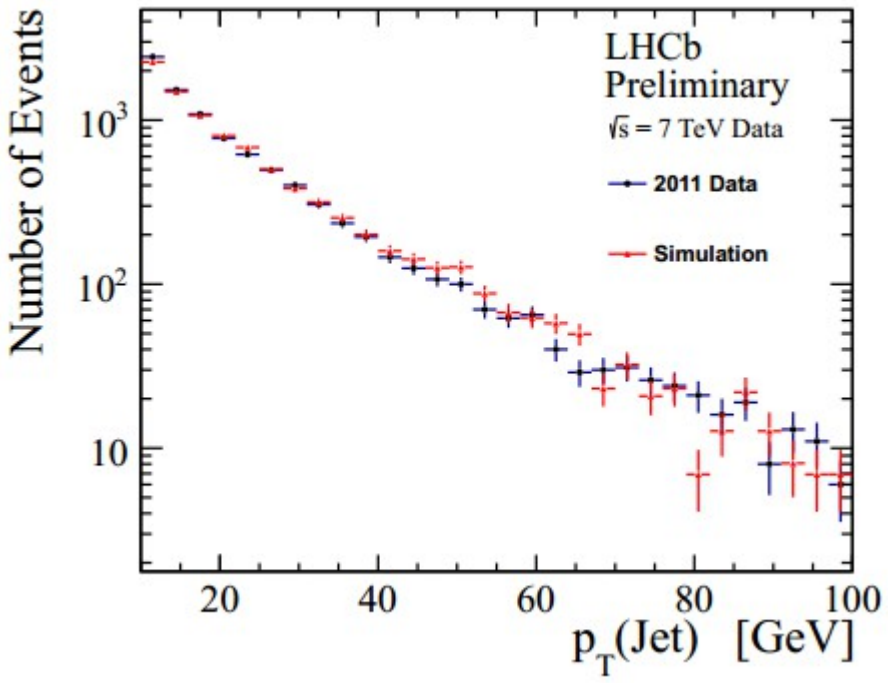
→ Differential Cross Section

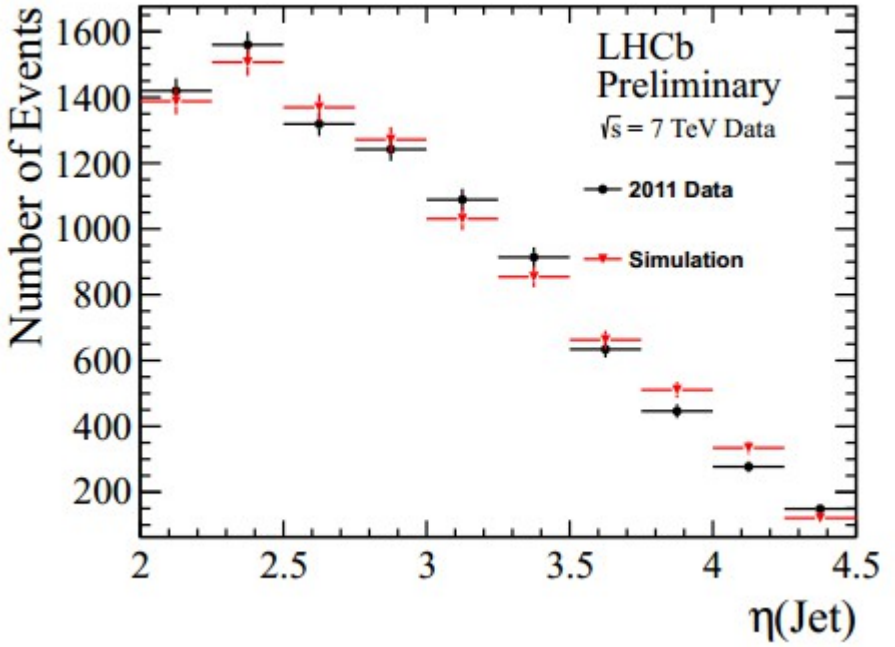
→ Jet Multiplicity

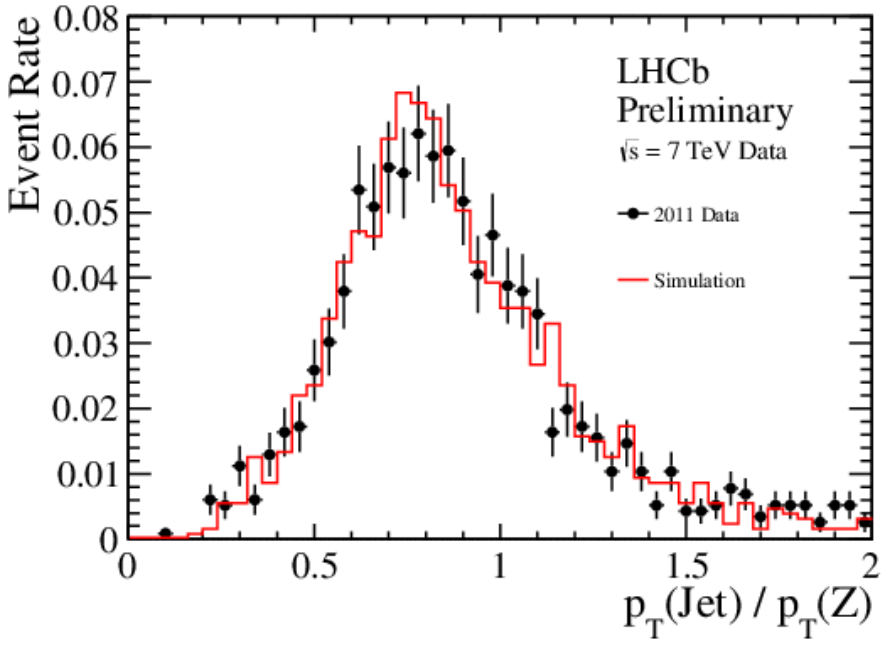


Control Plots

LHCb-CONF-2012-016



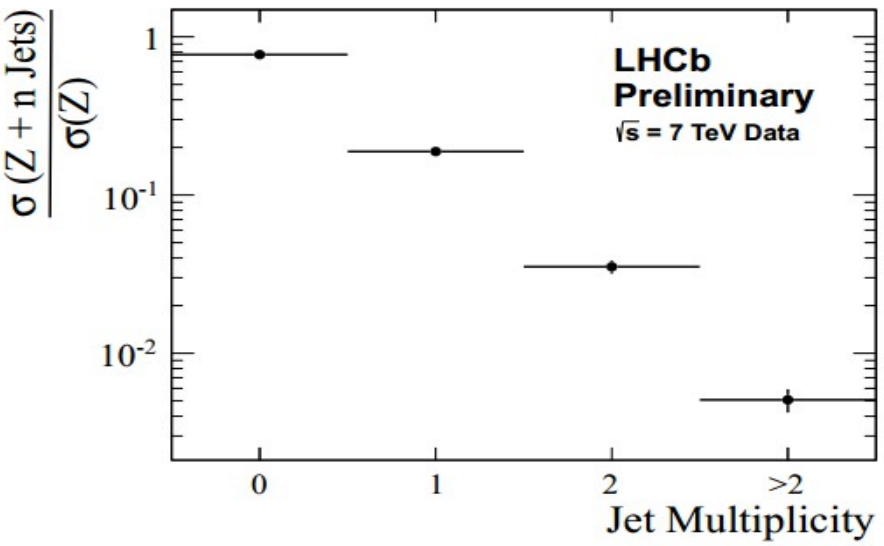


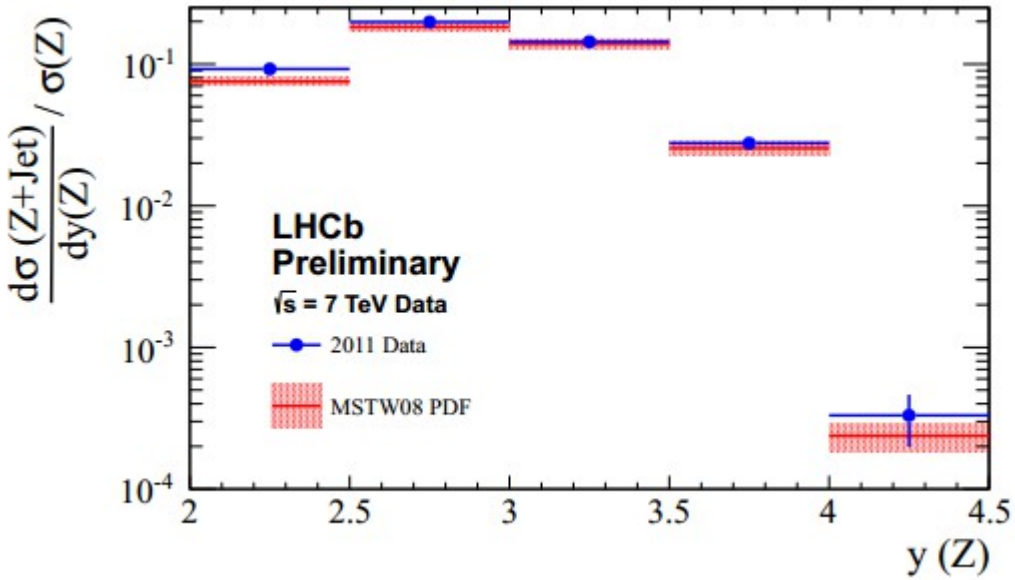


- Simulation and data agrees well at detector level
- JEC is validated in data
- 1st step for jet measurements at LHCb

Results

LHCb-CONF-2012-016

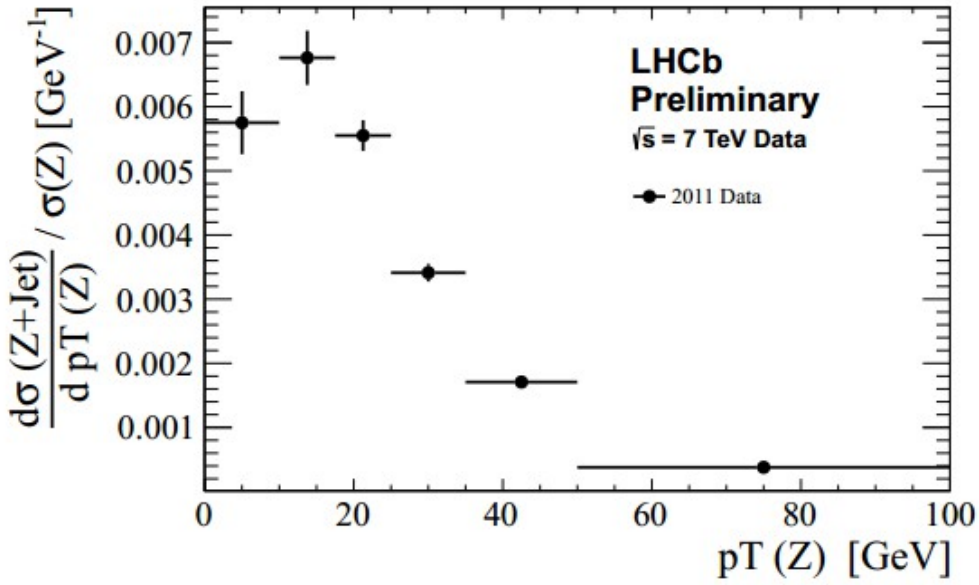




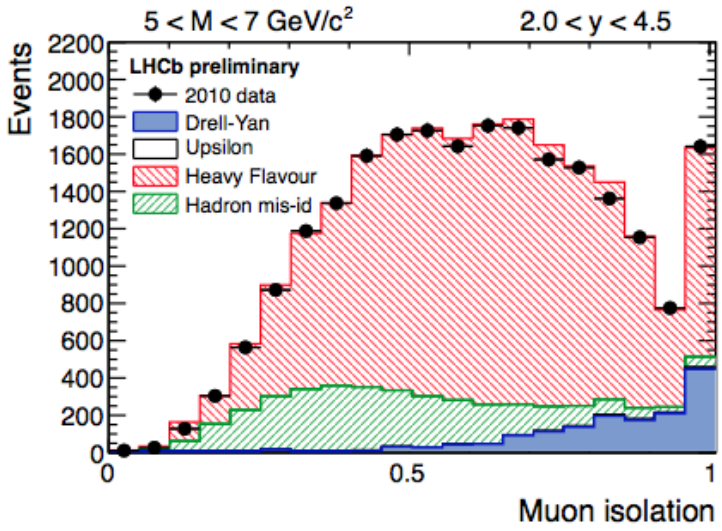
Fraction of events with at least one jet:

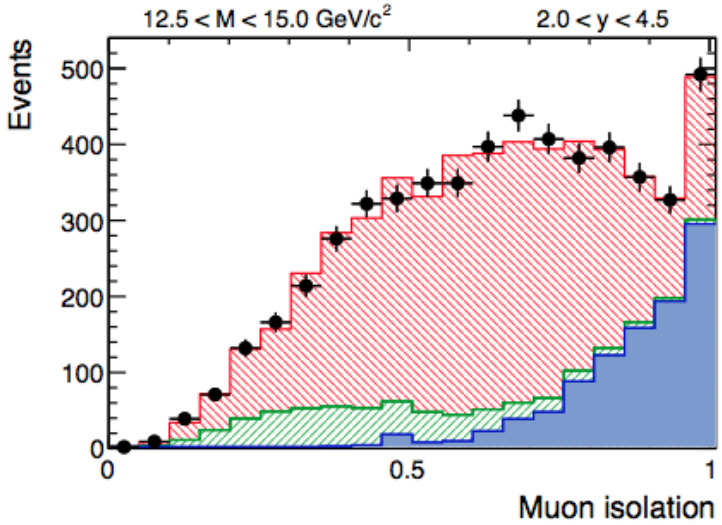
LHCb preliminary:
0.229 ±0.006(stat) ±0.009(syst)

NLO: FEWZ with MSTW0 (parton level)
$0.212\ ^{+0.006}_{-0.009}$ (PDF) ±0.016 (scale)



LHCb-CONF-2012-013





Data

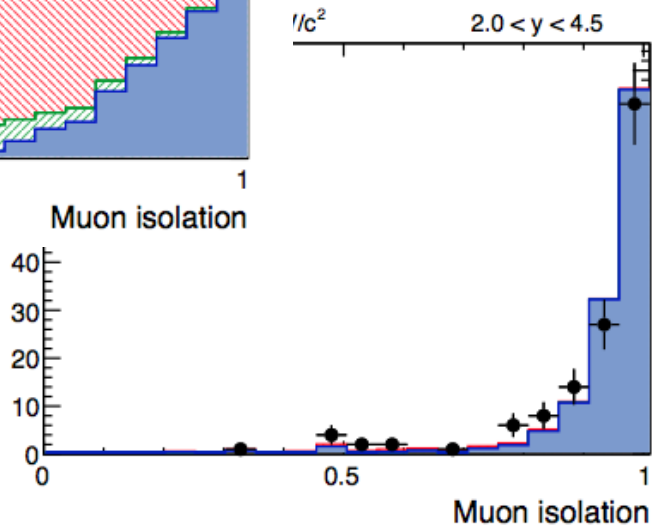
→ 2010 – 37/pb

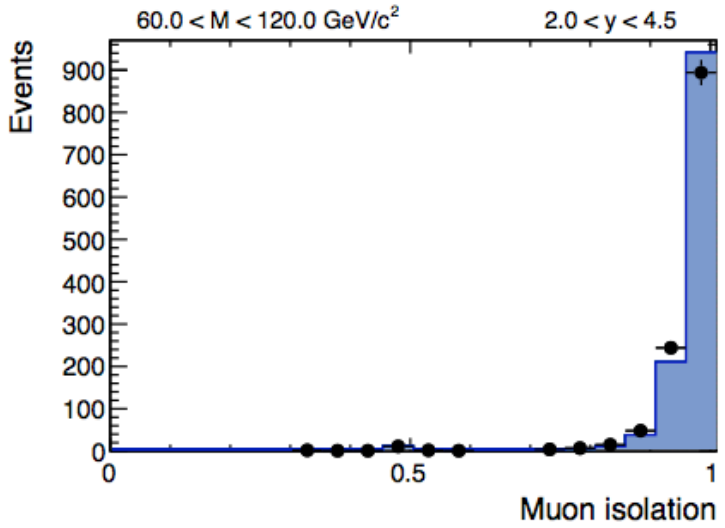
→ di-muon trigger $p_T > 2.5$ GeV

Selection

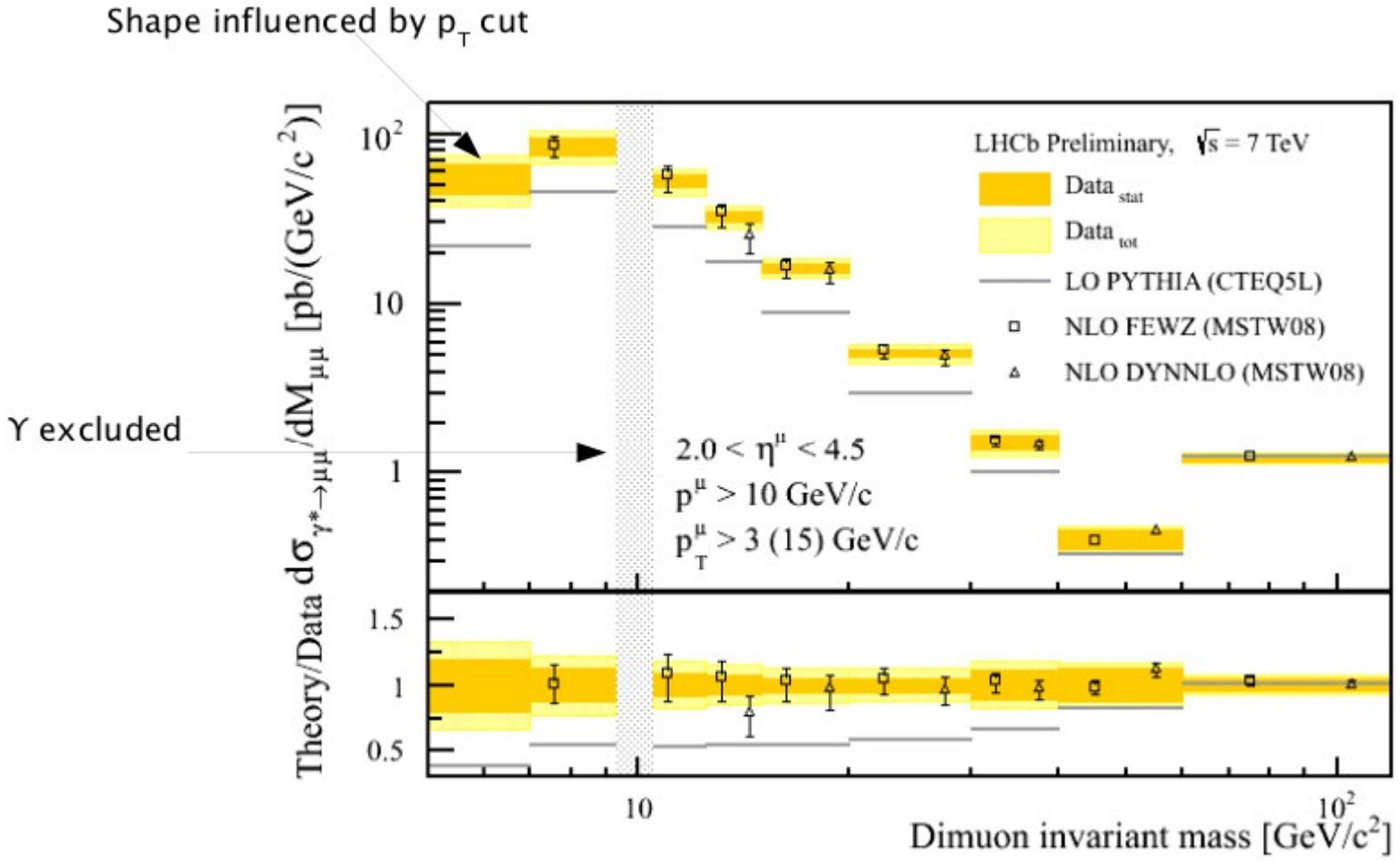
→ 2 muons - $5 < M_{\mu\mu} < 120$ GeV

- Signal extracted from template fits
- **9** mass bins
- **5** η bins in **2** mass regions





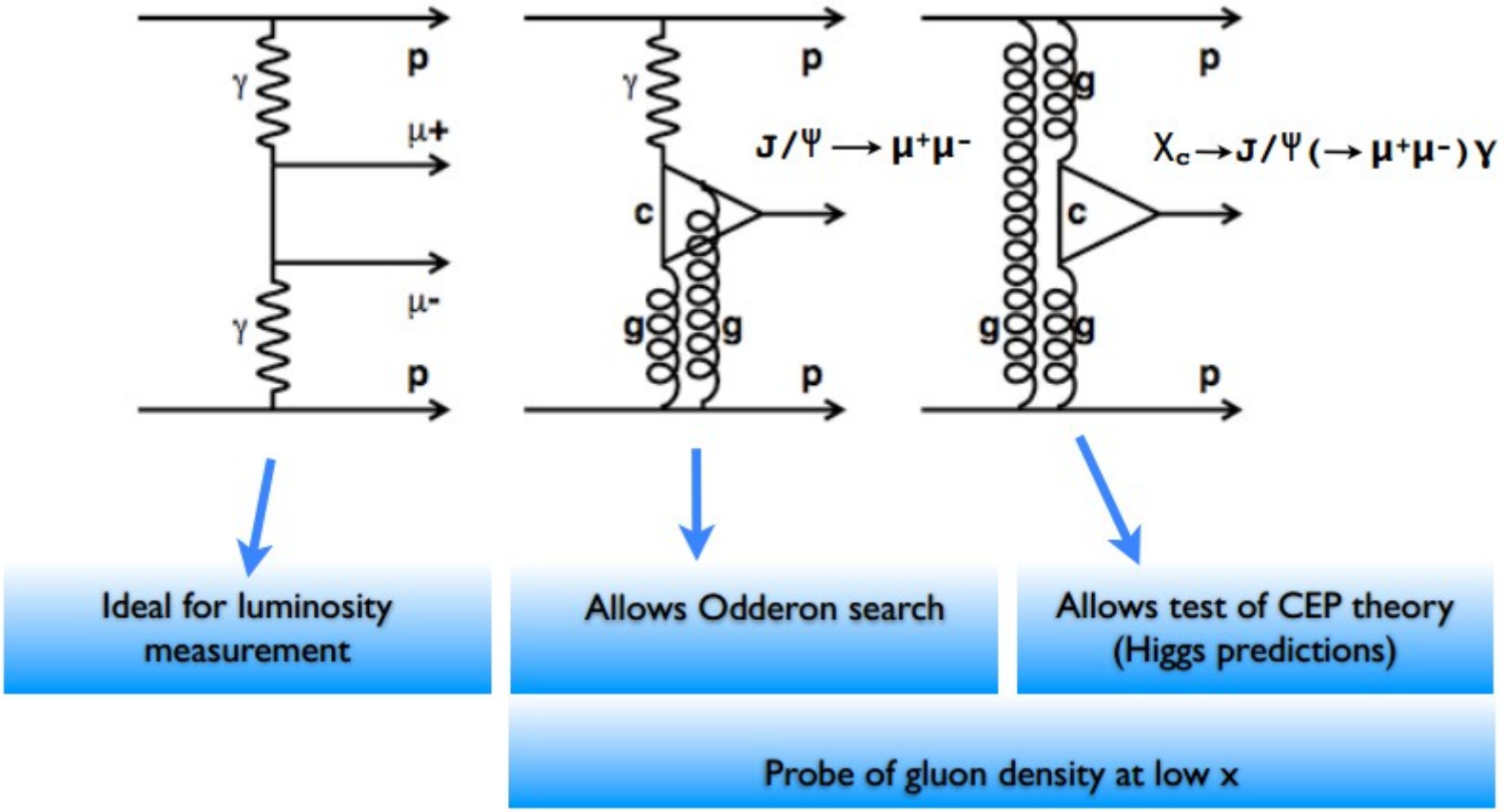
LHCb-CONF-2012-013



Compared to NLO predictions (FEWZ and DYNNLO) and PYTHIA
FEWZ predictions above 7 GeV/c^2, DYNNLO above 12.5 GeV/c^2

Central Exclusive DiMuon

LHCb-CONF-2011-022



Data

→ 2010 – 37/pb

→ di-muon + low multiplicity

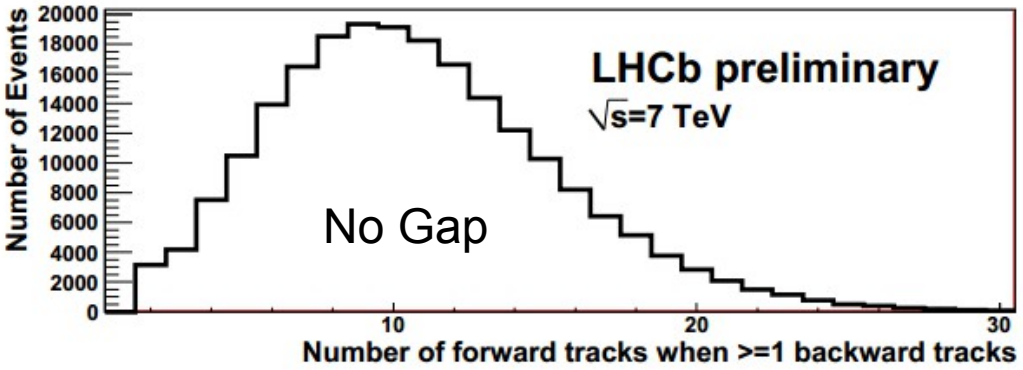
Selection

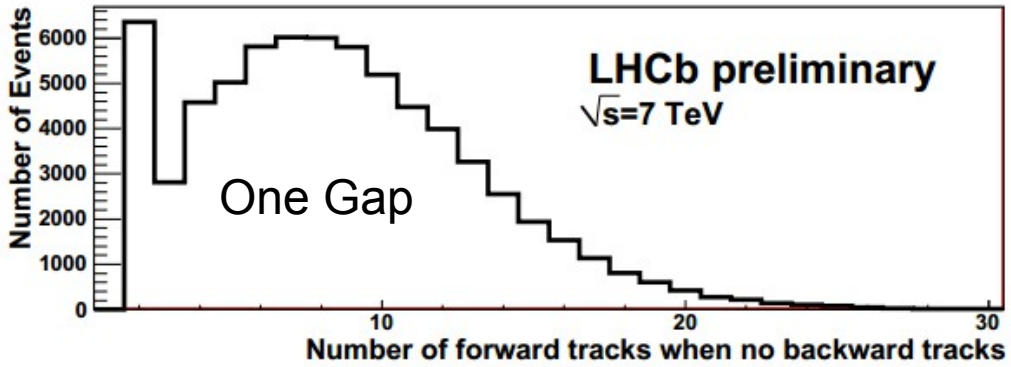
→ Rapidity Gap

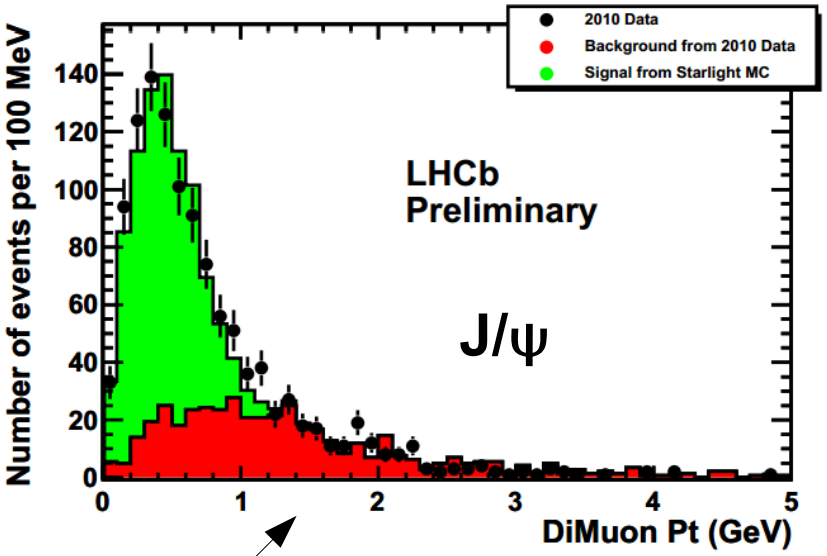
→ $M_{\mu\mu} > 2.9$ GeV or $p_{T\mu\mu} < 900$ MeV

Central Exclusive DiMuon

LHCb-CONF-2011-022

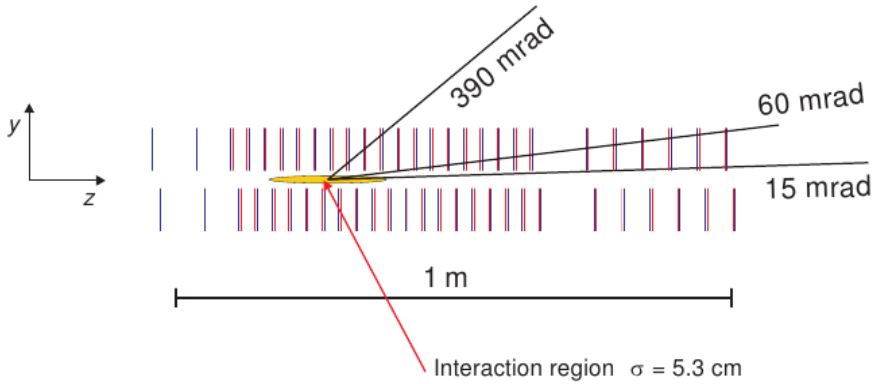


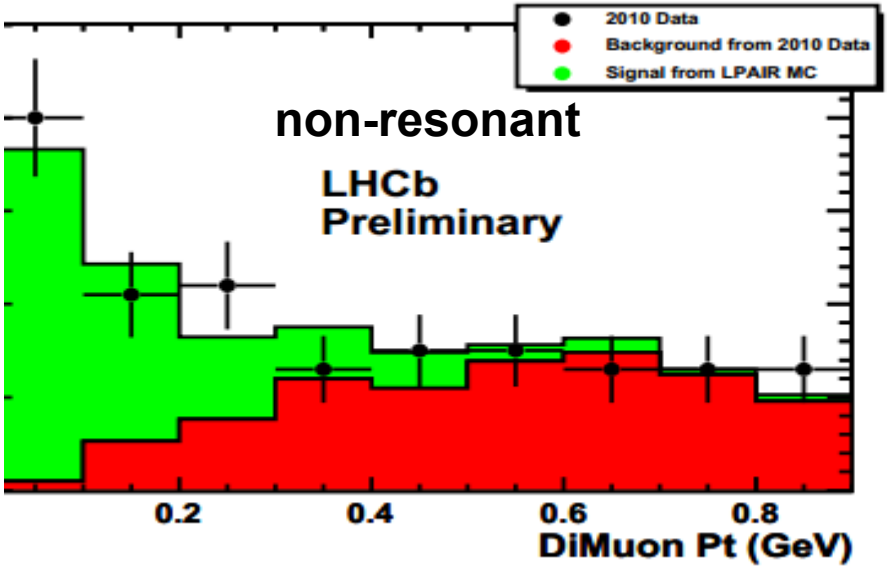




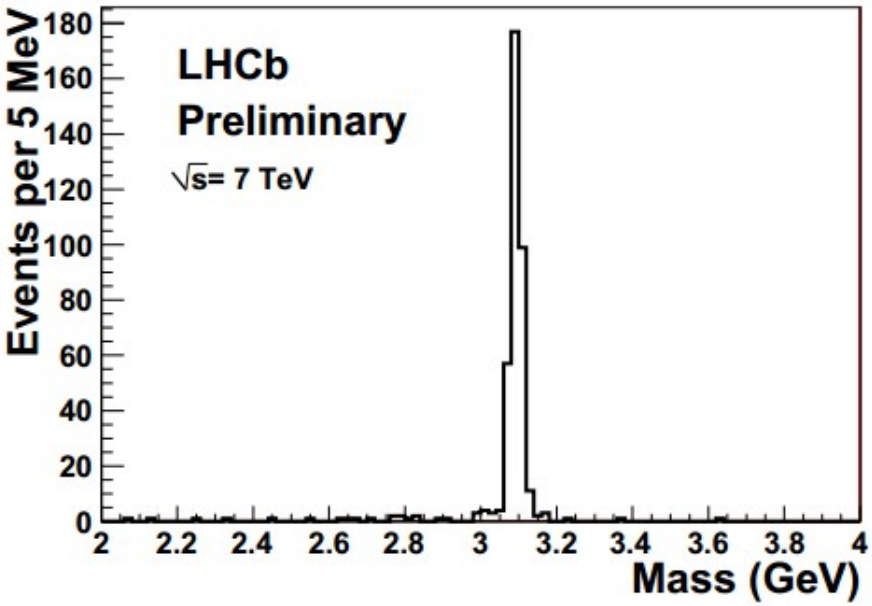
Requiring only 2 tracks

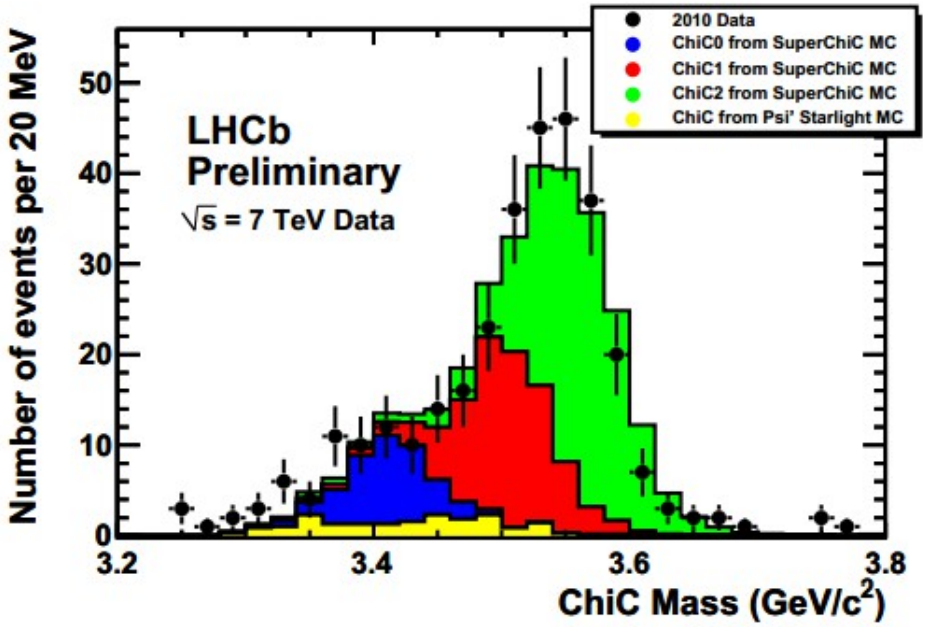
cross section at $x=0$:





.. and requiring 2 tracks and 1 photon





Preliminary Results

$\sigma_{J/\psi\to\mu^+\mu^-}\ (2<\eta_{\mu+},\eta_{\mu-}<4.5) = 474\pm12\pm51\pm92$ pb

$\sigma_{\psi(2S)\to\mu^+\mu^-}\ (2<\eta_{\mu+},\eta_{\mu-}<4.5) = 12.2\pm1.8\pm1.3\pm2.4$ pb

$\sigma_{\chi_c^0\to\mu^+\mu^-\gamma}\ (2<\eta_{\mu+},\eta_{\mu-},\eta_\gamma<4.5) = 9.3\pm2.2\pm3.5\pm1.8$ pb

$\sigma_{\chi_c^1\to\mu^+\mu^-\gamma}\ (2<\eta_{\mu+},\eta_{\mu-},\eta_\gamma<4.5) = 16.4\pm5.3\pm5.8\pm3.2$ pb

$\sigma_{\chi_c^2\to\mu^+\mu^-\gamma}\ (2<\eta_{\mu+},\eta_{\mu-},\eta_\gamma<4.5) = 28.0\pm5.4\pm9.7\pm5.4$ pb

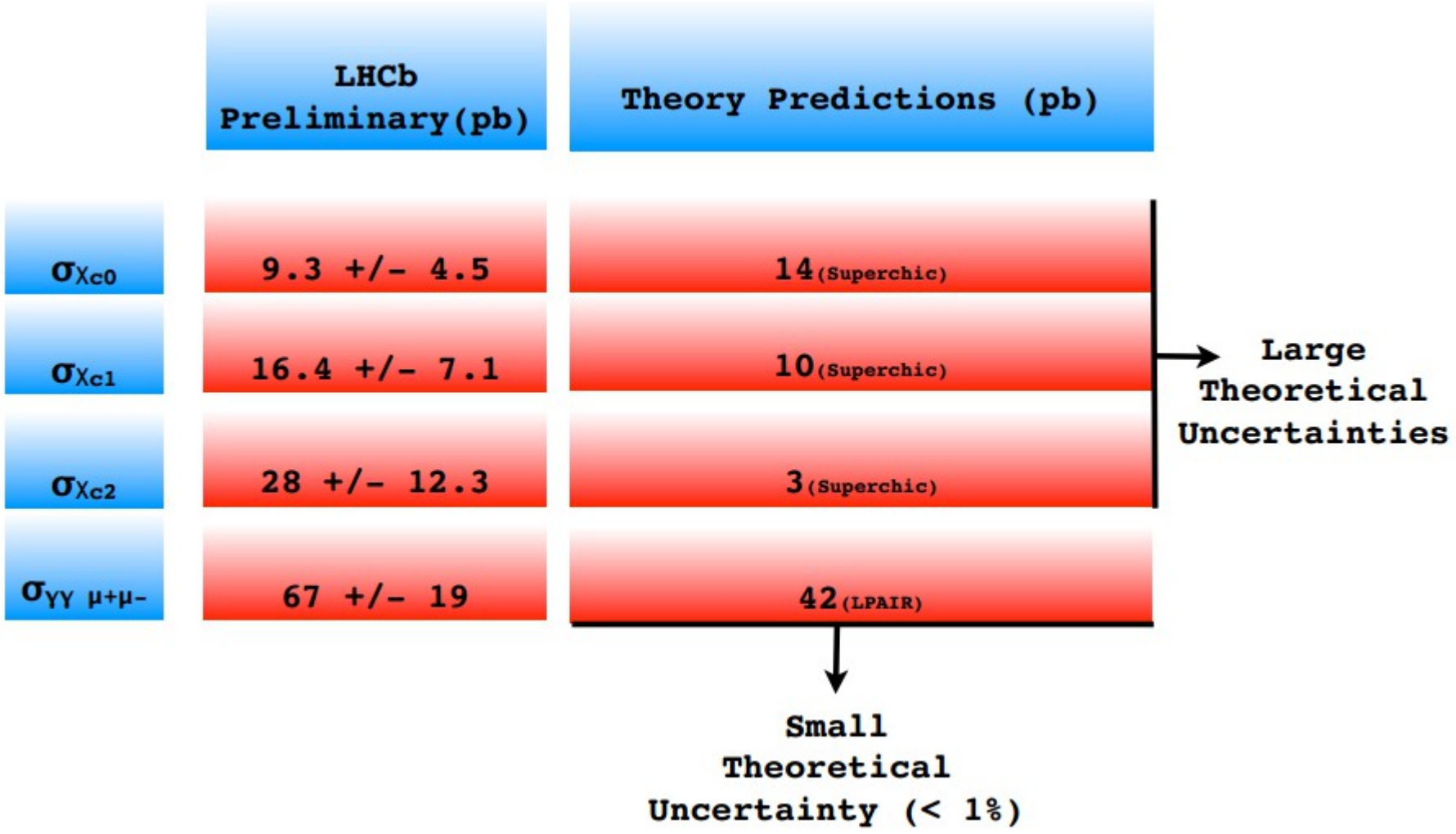
$\sigma_{\gamma\gamma\to\mu^+\mu^-}\ (2<\eta_{\mu+},\eta_{\mu-}<4.5;\ m_{\mu+\mu-}>2.5\ \mathrm{GeV}/c^2) = 67\pm10\pm7\pm15$ pb

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

	LHCb Preliminary(pb)	Theory Predictions (pb)
$\sigma_{J/\Psi}$	474 +/- 106	292 (Starlight) 330 (Superchic) 430 (Motyka&Watt)[5] 710 (Schafer&Szczurek)[6]
$\sigma_{\Psi(2S)}$	12.2 +/- 3.2	6.1 (Starlight) 17 (Schafer&Szczurek)
$J/\Psi/\Psi(2S)$	0.2 +/- 0.03	0.16 (Starlight) 0.2 (Schafer&Szczurek)

Also Measured at CDF: 0.14 +/-.05
and Hera: 0.17 +/-.01

[5]L. Motyka, G. Watt,, Phys. Rev. D 78, 014023 (2008).
[6]W. Schäfer, A. Szczurek, Phys.Rev. D76:094014,2007. arXiv:0811.2488.


LHCb Preliminary(pb)
Theory Predictions (pb)
σ_{Xc0}
9.3 +/- 4.5
14 (Superchic)
σ_{Xc1}
16.4 +/- 7.1
10 (Superchic)
σ_{Xc2}
28 +/- 12.3
3 (Superchic)
$\sigma_{\gamma\gamma\ \mu+\mu-}$
67 +/- 19
42 (LPAIR)
Large Theoretical Uncertainties
Small Theoretical Uncertainty (< 1%)

LHCb-CONF-2012-012

Energy flow (EF) at high η is useful to study parton radiation and multi-parton interaction (MPI)
Test of collision physics and cosmic ray models

$$\text{EF}: \frac{1}{N_{int}}\frac{dE_{tot}}{d\eta} \qquad \text{Experimentally}: \frac{1}{\Delta\eta}\left(\frac{1}{N_{int}}\sum_{i=1}^{N_{part,\eta}} E_{i,\eta}\right) \quad \Delta\eta = 0.3$$

N_{int} = number of inelastic pp collisions

Data: $0.1\,\text{nb}^{-1}$ 2010 run at $7\,\text{TeV}$ - no pile up
Trigger: events with at least one track segment in VELO, unbiased

Event categories:

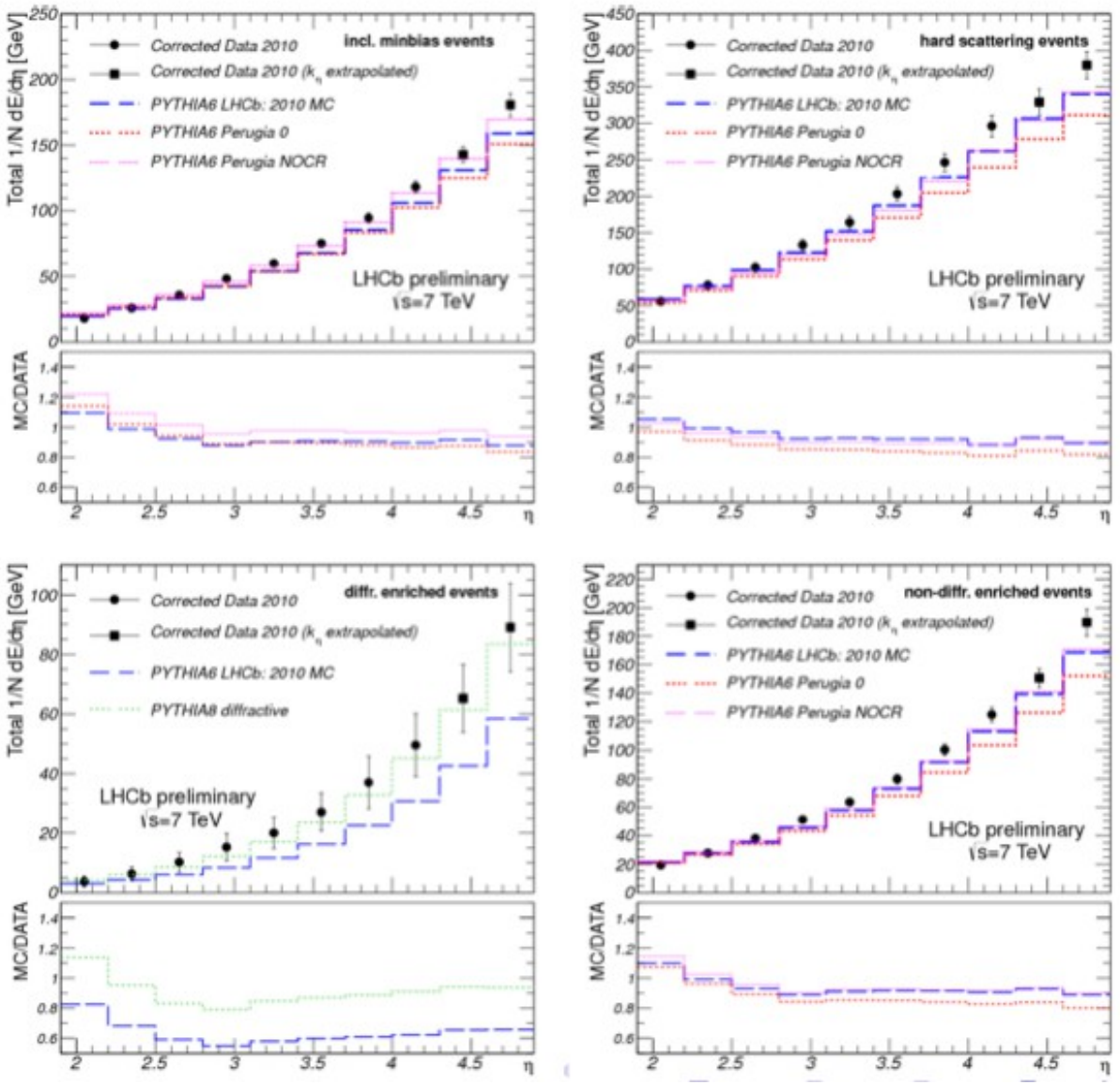
- **Inclusive MB**: at least one well reconstructed track with $p > 2\,\text{GeV}/c$
- **Hard Scattering**: at least one well reconstructed track with $p_T > 3\,\text{GeV}/c$
- **Diffractive enriched**: inclusive MB without tracks in $-3.5 < \eta < -.1.5$
- **Non-diffractive enriched**: inclusive MB with at least one track in $-3.5 < \eta < -.1.5$

Forward Energy Flow

Total EF compared to predictions of PYTHIA tunings.

All PYTHIA 6 tunings underestimate total EF at high η.

Best agreement for PYTHIA 8 in diffractive enriched events



Forward Energy Flow

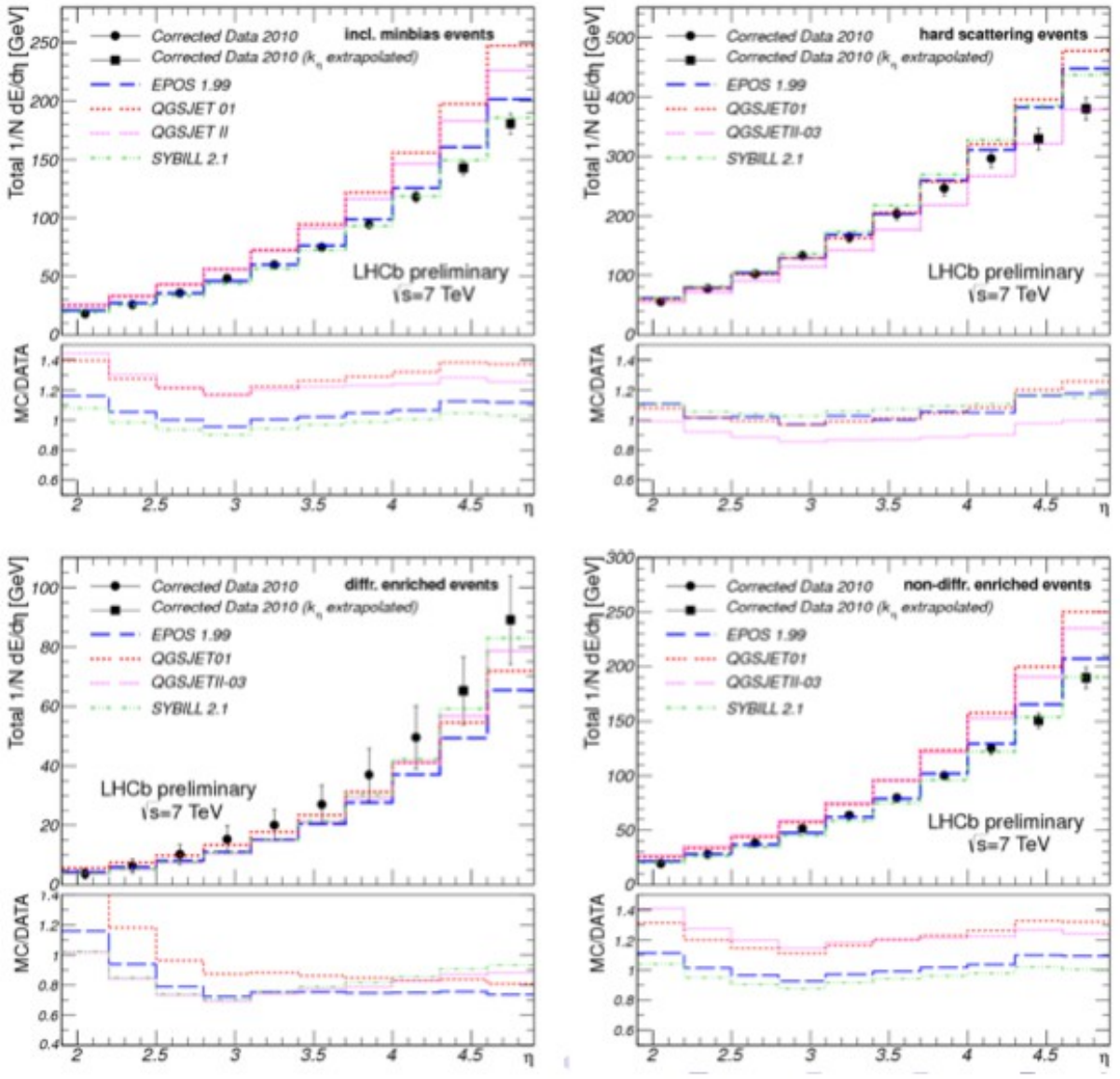
Total EF compared to predictions of cosmic ray generators predictions.

Total EF is overestimated.

Best agreement for SYBILL/EPOS in inclusive MB.

QGSJETII-03 reliable for hard scattering events.

Diffractive part is generally underestimated by all models.

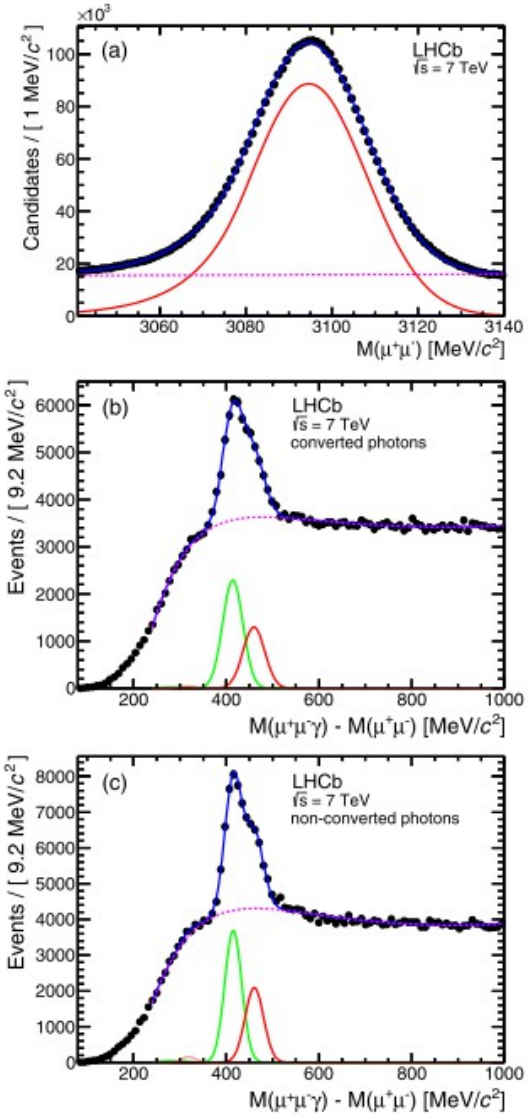


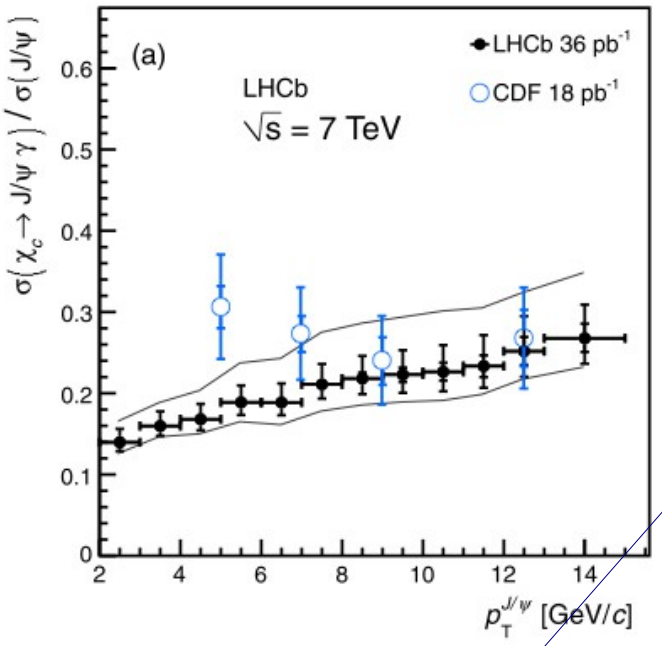
PLB 718 (2012) 431–440

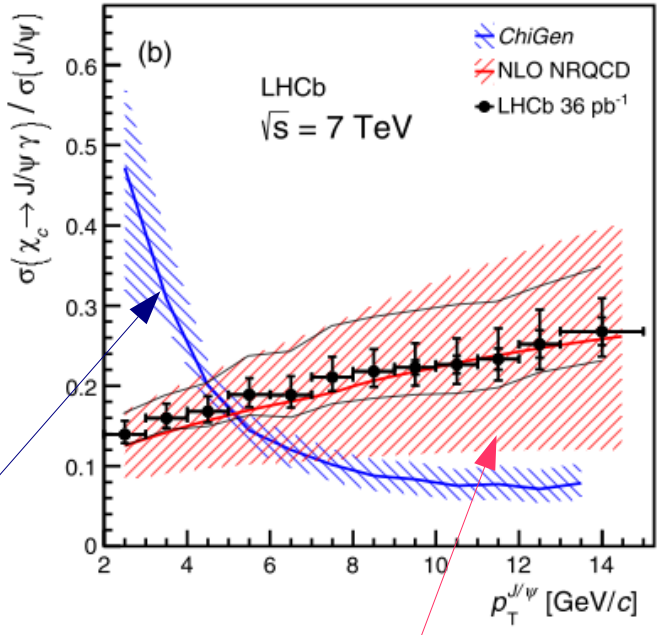
Data

→ 2010 - 36/pb

→ trigger by 2 oppositely charged muons







LO color-singlet

NLO Non-Relativistic QCD
color-singlet+color-octet

$D^{\pm}$ asymmetry

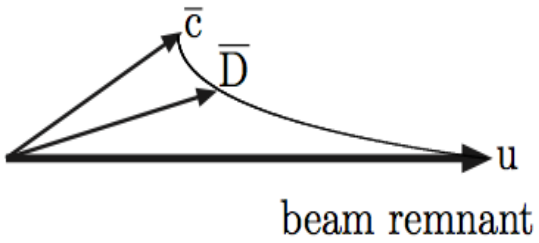
Data

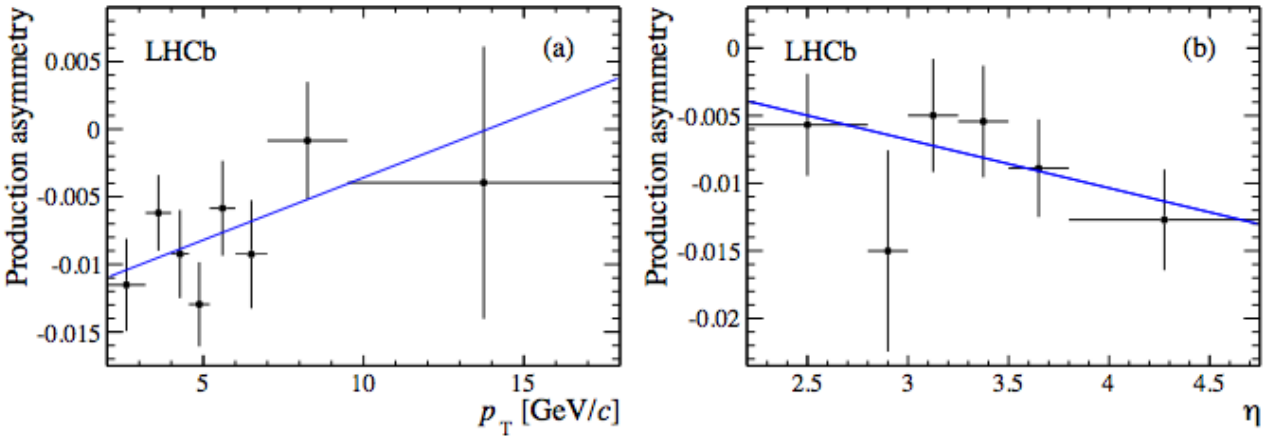
→ 2011 – 1/fb

→ trigger based in the D daughters avoiding charge bias

$$D^+ \to K^0_S\pi^+,\ K^0_S \to \pi^-\pi^+ \qquad A_P = \frac{\sigma(D^+) - \sigma(D^-)}{\sigma(D^+) + \sigma(D^-)}$$

Sensitivity to hadronization models that discriminate between $c\bar{c}$





$$A_P = (-0.96 \pm 0.26 \pm 0.18)\%$$

– measurement is so far compatible with expectations

$Ds^{\pm}$ asymmetry

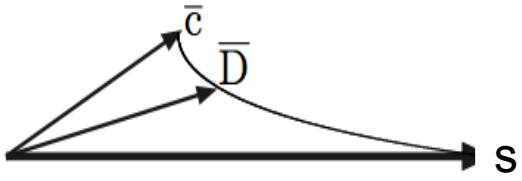
Data

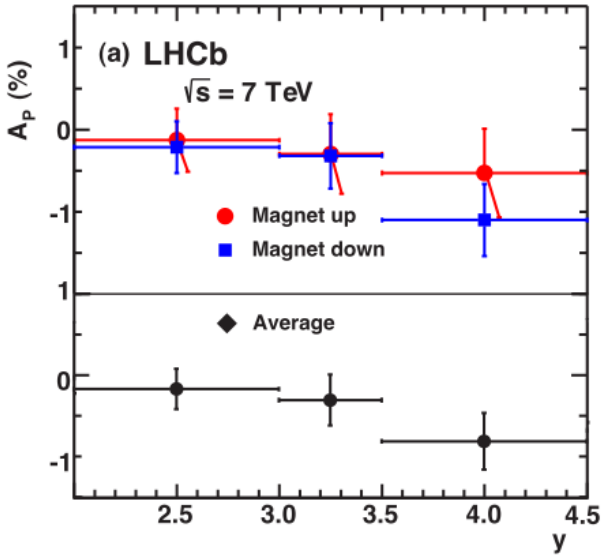
→ 2011 – 1/fb

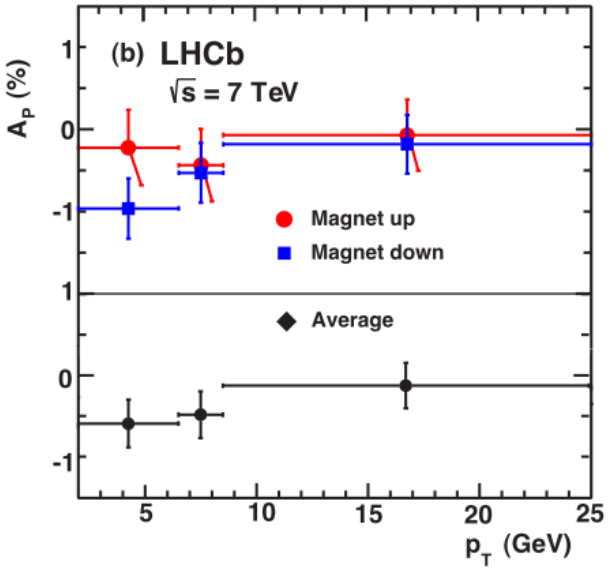
→ trigger based in the D daughters avoiding charge bias

$D_s^{\pm} \to \phi\pi^{\pm}$ decays, where $\phi \to K^+K^-$ $\qquad A_P = \dfrac{\sigma(D_s^+) - \sigma(D_s^-)}{\sigma(D_s^+) + \sigma(D_s^-)}$

Sensitivity to hadronization models that discriminate between $s\bar{s}$ or $c\bar{c}$







– measurement is so far compatible with expectations

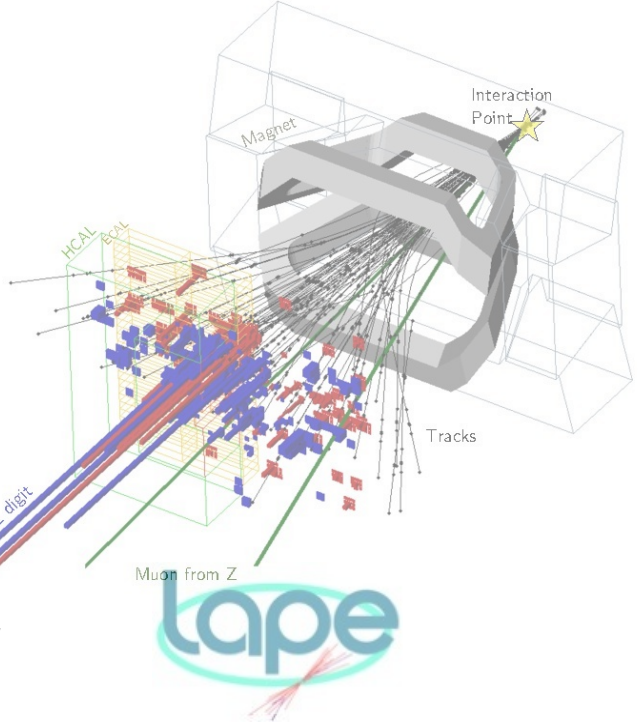
Summary

→ LHCb probes an unique range down to $x=8\times10^{-6}$

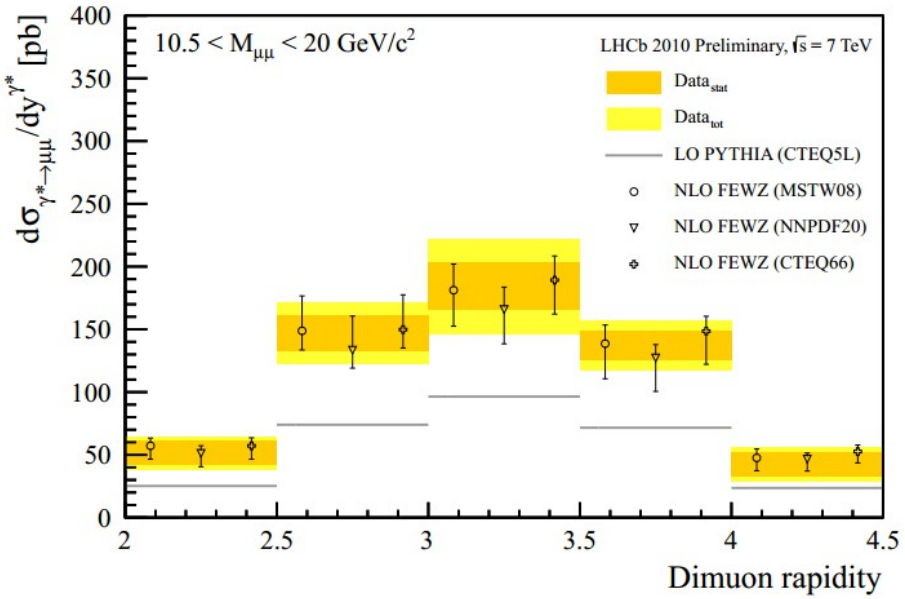
→ Measurements are in agreement with theoretical predictions and few of them already have precision comparable with theoretical uncertainties

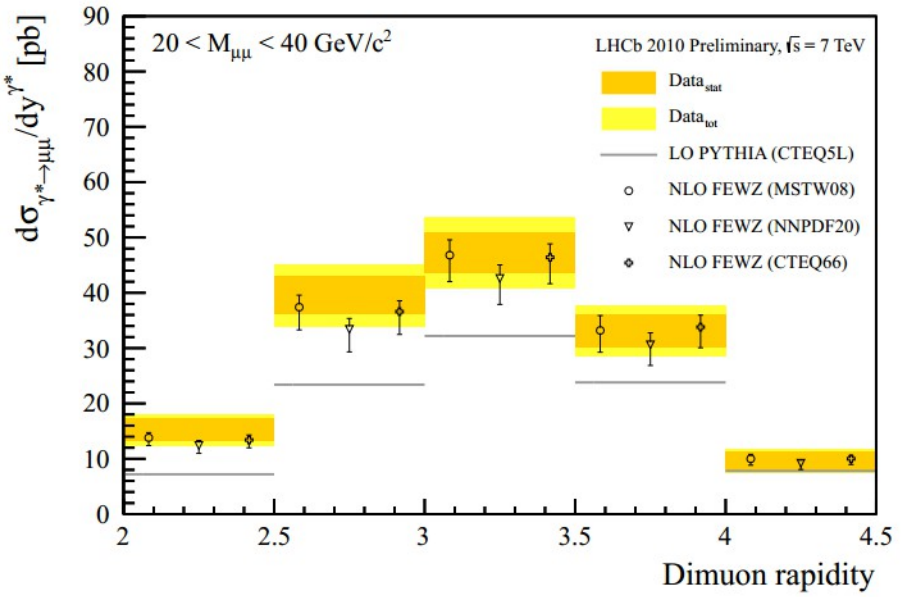
→ Many other measurements not covered in this talk → LHCb Results

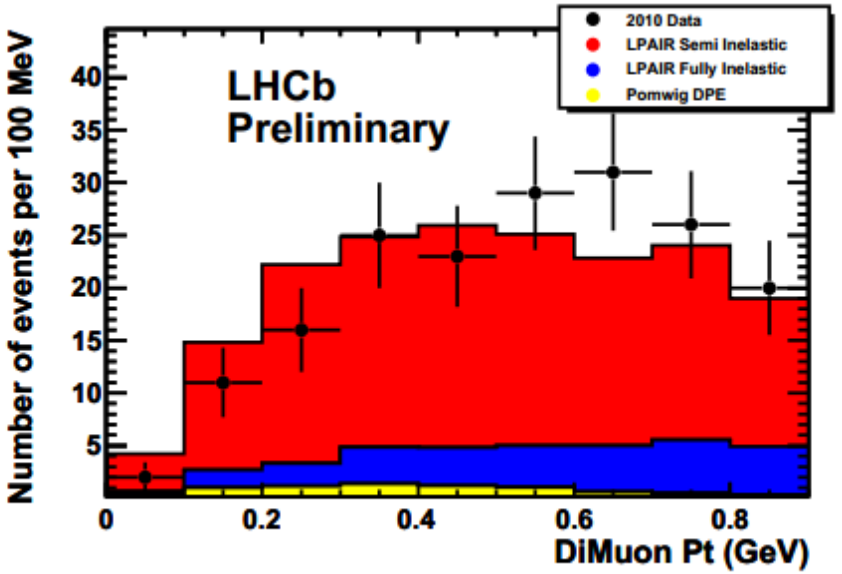
→ Update with **2011 (7 TeV) / 2012 (8 TeV)** data will improve experimental precisions and will allow other studies

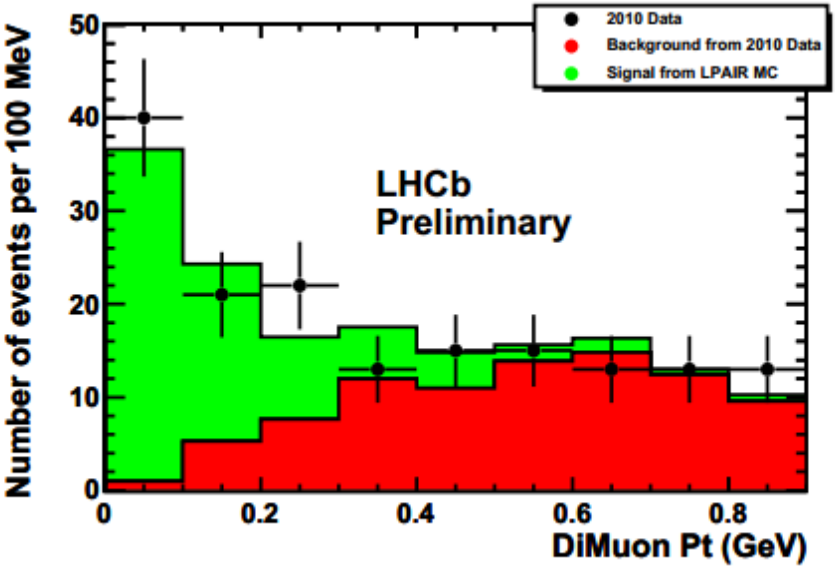


Low Mass Drell-Yan Production - Backup






2010 Data
LPAIR Semi Inelastic
LPAIR Fully Inelastic
Pomwig DPE
LHCb
Preliminary
Number of events per 100 MeV
DiMuon Pt (GeV)


2010 Data
Background from 2010 Data
Signal from LPAIR MC
LHCb
Preliminary
Number of events per 100 MeV
DiMuon Pt (GeV)