Production in the forward region

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on behalf of the LHCb Collaboration

LISHEP 2013

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Brazil - Rio de Janeiro

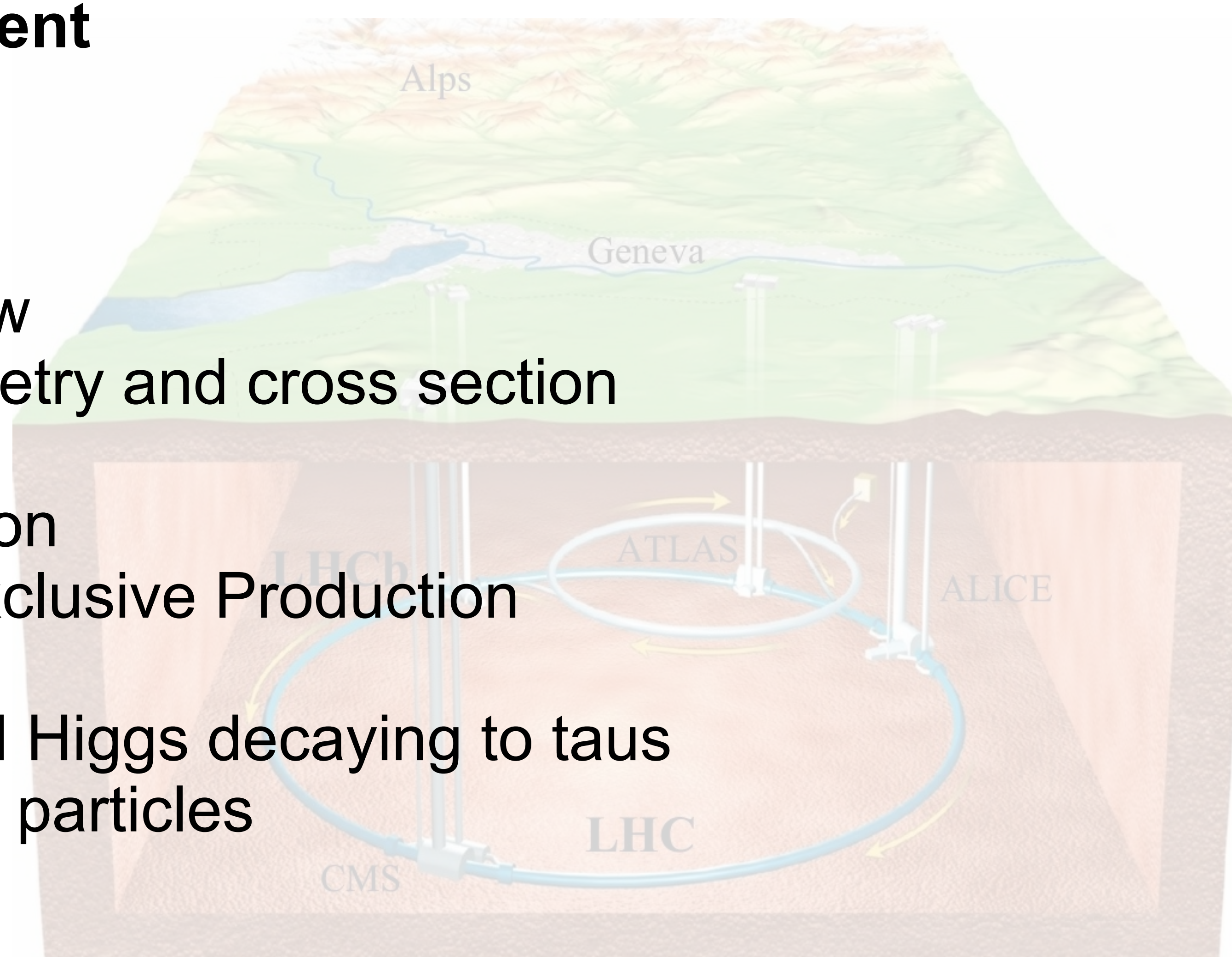
Brazil/East timezone

Outline

→ **LHCb Experiment**

→ **Results**
- QCD
  - energy flow
  - $b\bar{b}$ asymmetry and cross section
- EW
  - Z production
  - Central Exclusive Production
- Searches
  - SM/MSSM Higgs decaying to taus
  - Long-lived particles

→ **Summary**



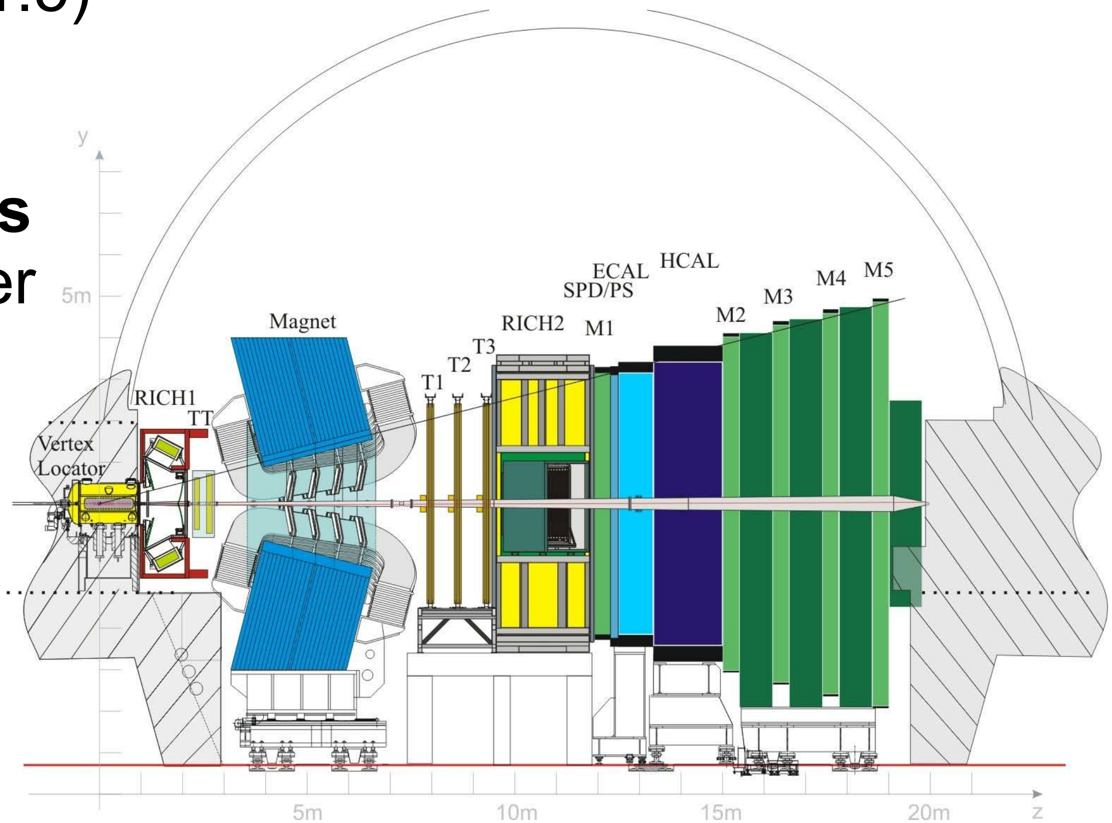
The detector is a single arm spectrometer fully instrumented in the forward region ($2.0 < \eta < 5.0$) → Unique coverage at LHC

Excellent Vertex Resolution and Tracking
→ Vertex Locator (also for $\eta < -1.5$)
→ Tracking Stations

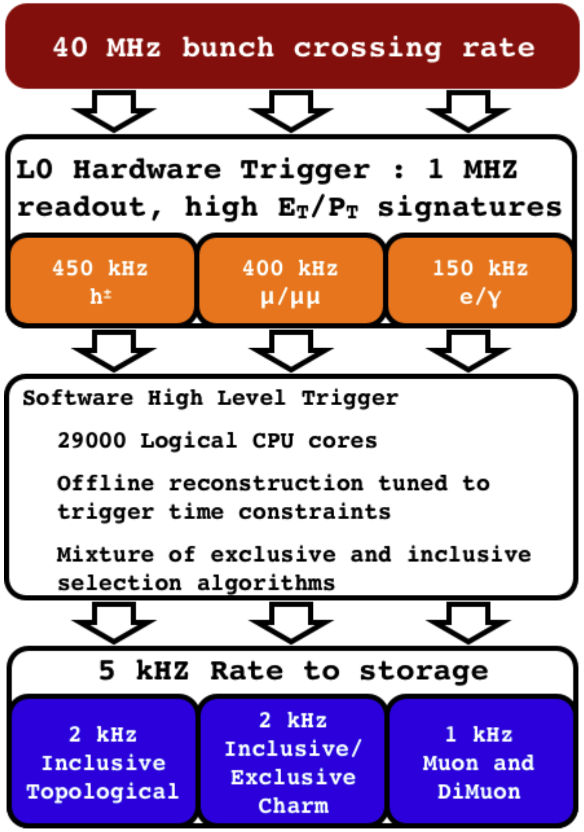
Neutral Energy Measurements
→ EM and Hadronic Calorimeter

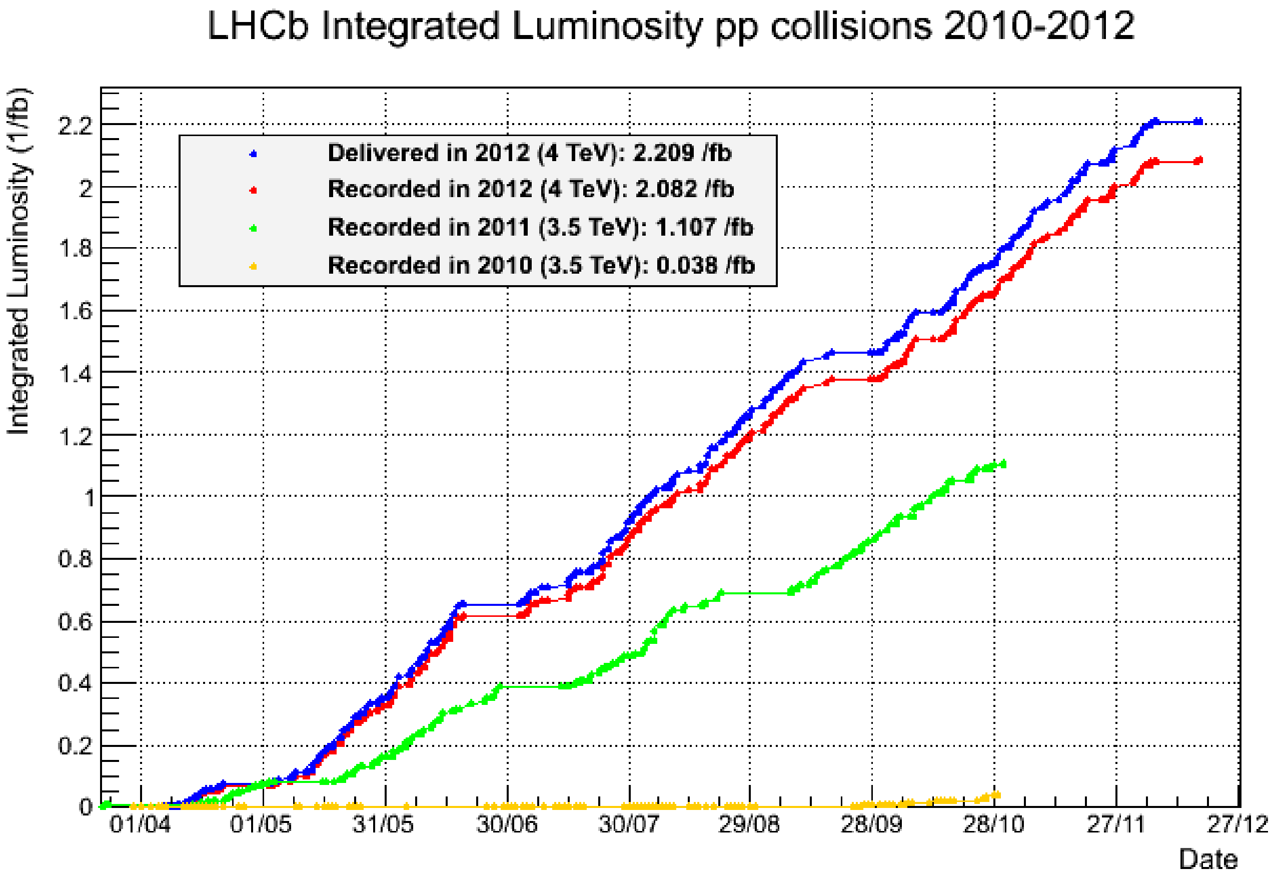
Particle Identification
→ Rich detectors
→ Muon Stations

Trigger
→ Ability to go low in muon p_T



LHCb Data





>90% data taking efficiency

>99% DQ efficiency

2010 → 37/pb at √s = 7 TeV

2011 → 1.0/fb at at √s = 7 TeV

2012 → 2/fb at at √s = 8 TeV

Thanks to LHC team!

Energy Flow Measurement

arXiv:1212.4755

Motivation

- Sensitive to parton radiation and multiple-parton interaction
- Tests of event generators – collider and cosmic ray models

Integrated Luminosity 0.1/nb – low pile-up data (2010)

Trigger

- At least one track reconstructed

Selections

- Inclusive minimum bias
- Hard-scattering (p_T>3 GeV)
- Diffractive enriched (no tracks $\eta<0$)
- Non-diffractive enriched (1 or more tracks $\eta<0$)

Analysis

- Measurement with tracks 2 GeV<p<1 TeV
- Corrected to particle level

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

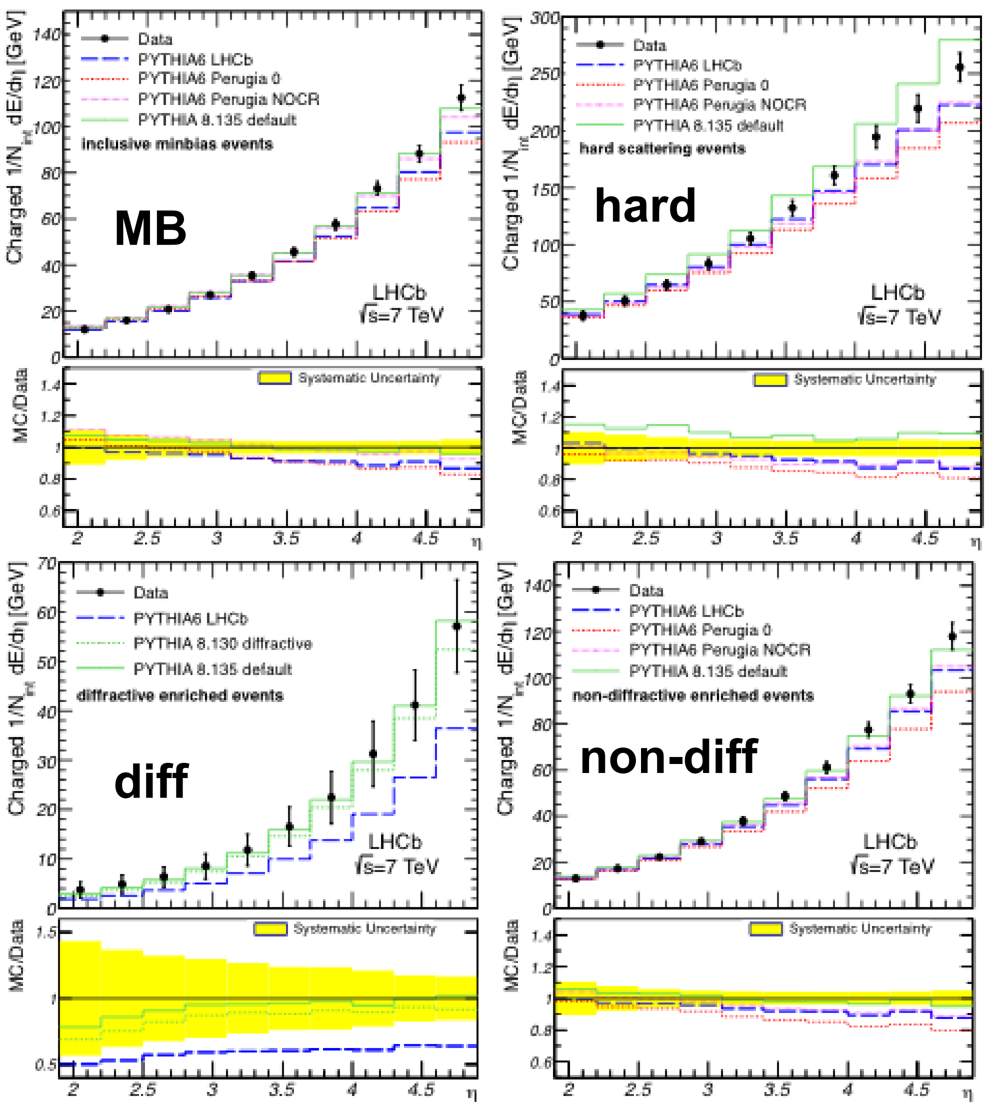
Main uncertainties

- model uncertainty, selection cuts

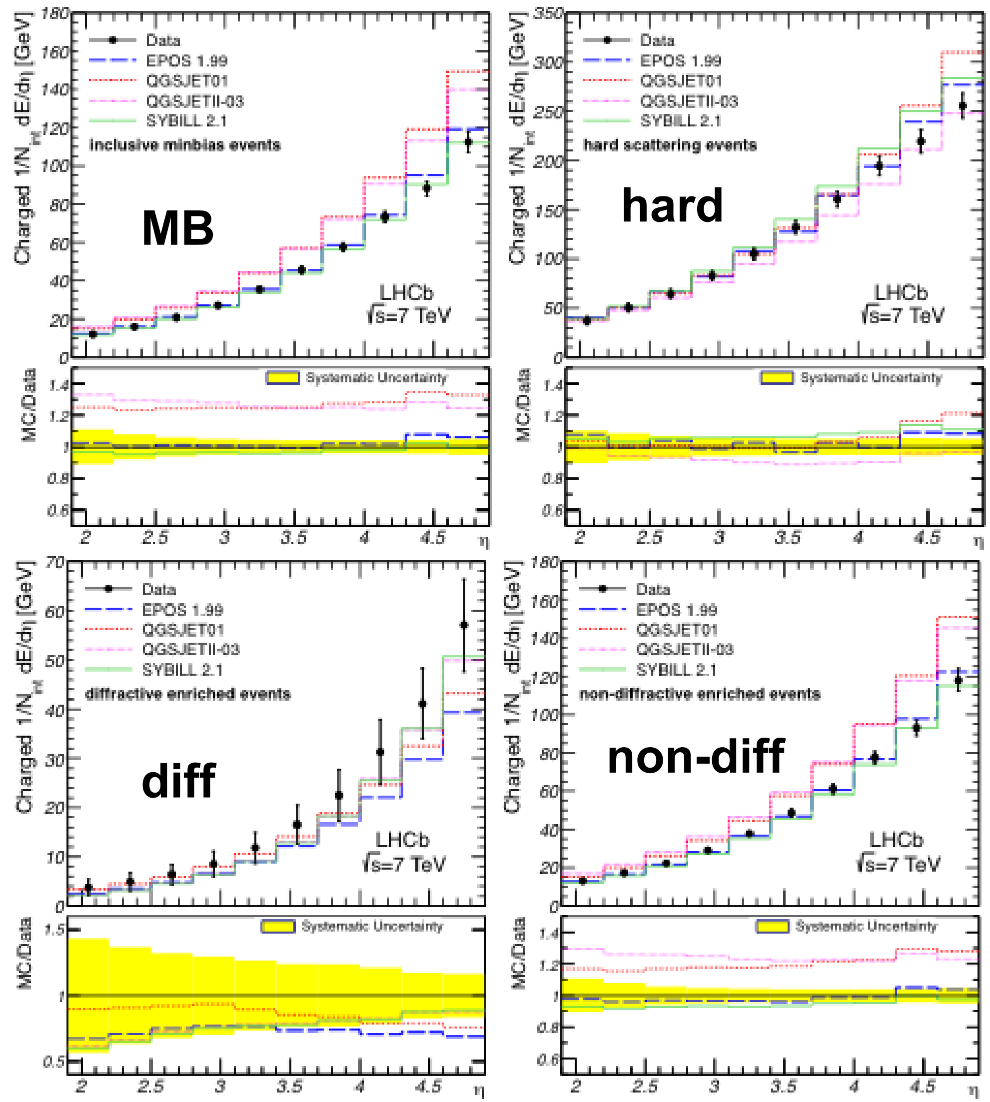
Energy Flow Measurement

arXiv:1212.4755

PYTHIA PREDICTIONS



COSMIC RAY PREDICTIONS



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

$b\bar{b}$ cross section

LHCB-CONF-2013-002

Integrated Luminosity: 18/pb (2010)

Trigger

B-hadron candidate using high p_T hadrons/electrons or muons from secondary vertex – efficiency = (10.2 $\pm$ 0.2)%

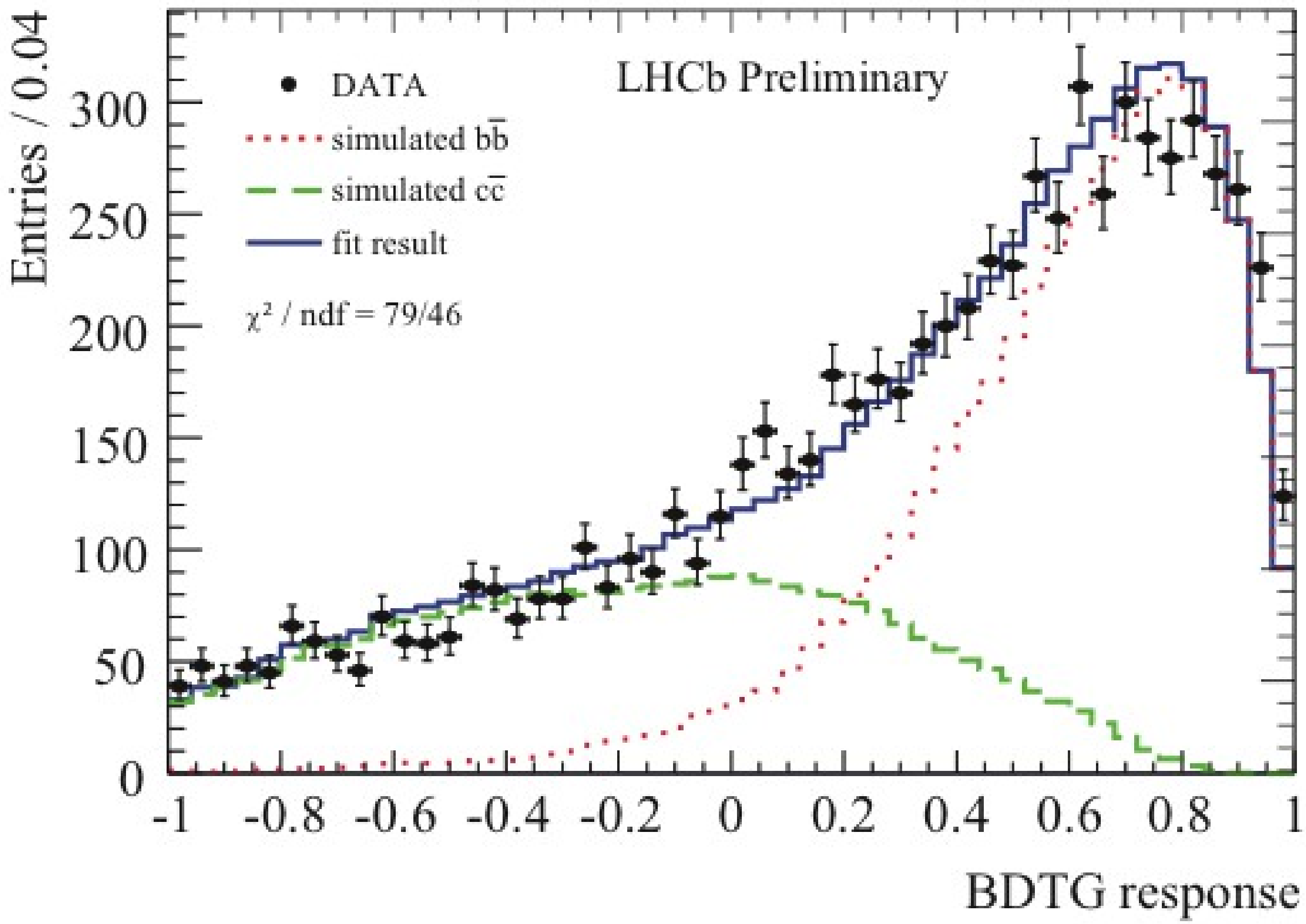
Selection Two B-hadron candidates from b-seed algorithm

– secondary vertex reconstructed from two or three tracks
– efficiency ~ 80%
– energy calibration derived from simulation
– η = [2.5 - 4.0] and p_T > 5 GeV

Analysis

Decomposition of $c\bar{c}$ and $b\bar{b}$ using fit template of a BDT using 4 variables: seed p, seed mass, sum of IP significances and scalar sum of track p_T wrt seed direction

Main uncertainties Luminosity, simulation dependence (~10%)



$$\sigma^{b\bar{b}} = 7.7 \pm 0.12\ (\text{stat}) \pm 0.84\ (\text{syst})\ \mu\text{b}$$

NLO PowHeg → σ = 5.3 ± 2.1 μb *

$$\sigma^{c\bar{c}} = 104.6 \pm 2.7\ (\text{stat}) \pm 11.4\ (\text{syst})\ \mu\text{b}.$$

FONLL → σ = [170,300] μb *

*Phys. Rev. Lett. 89 (2002) 122003.

$b\bar{b}$ forward-central asymmetry A_{FC}

LHCB-CONF-2013-001

Motivation

CDF/D0 measures larger $t\bar{t}$ A_{FB} than SM prediction

Atlas/CMS measurements are in agreement with SM

$b\bar{b}$ A_{FC} can constrain models (SM A_{FC}<1%)

$$A_{FC}^{b\bar{b}} = \frac{N(\Delta y > 0) - N(\Delta y < 0)}{N(\Delta y > 0) + N(\Delta y < 0)} \qquad \Delta y = y_{\bar{b}} - y_b$$

Integrated Luminosity 1.0/fb (2011)

Trigger B-hadron candidates – BDT discrimination at HLT

Selection

2 jets (η = [2. - 4.2] and p_T > 15 GeV) back-to-back

Flavor tagging with muon (purity ~ 70%)

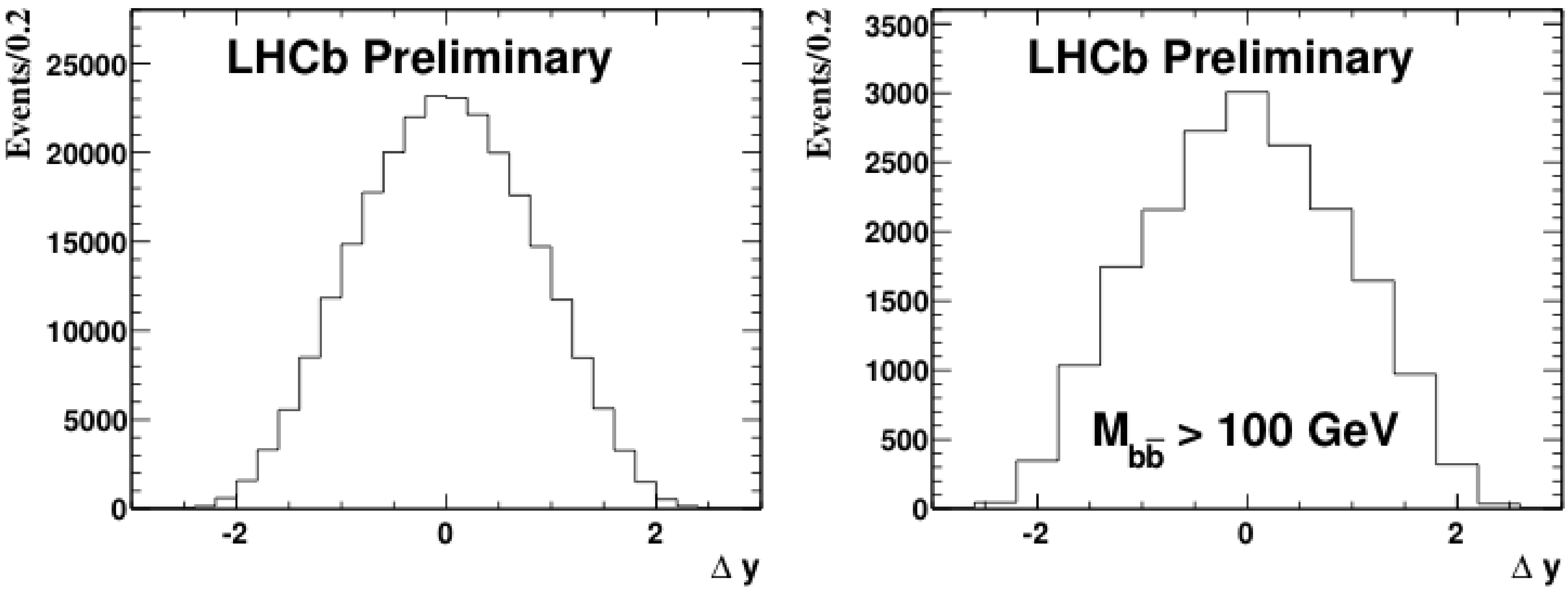
Jet to quark correction derived in simulation

Main uncertainties

flavor tagging, detector asymmetry

$b\bar{b}$ forward-central asymmetry A_{FC}

LHCB-CONF-2013-001



$$A_{\mathrm{FC}}^{b\bar{b}} = (-0.5 \pm 0.5\ (\mathrm{stat}) \pm 0.5\ (\mathrm{syst}))\%,$$
$$A_{\mathrm{FC}}^{b\bar{b}}(M_{b\bar{b}} > 100\ \mathrm{GeV}) = (-4.3 \pm 1.7\ (\mathrm{stat}) \pm 2.4\ (\mathrm{syst}))\%.$$

preliminary

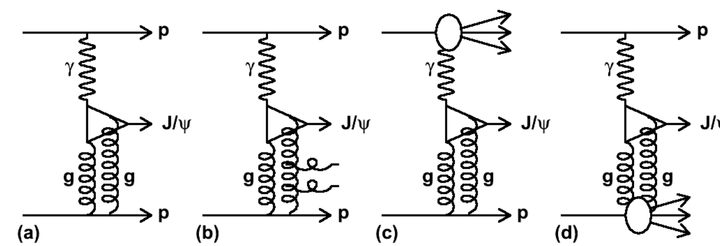
So far, measurement agrees with SM
NB, di-jet mass not unfolded (resolution ~20%)
Next, unfolding mass and study 2012 data

Central exclusive J/ψ and ψ(2S)

J.P.G40 (2013) 045001

Motivation

Testing ground for QCD



Integrated Luminosity 36/pb (2010)

Selection

Two muons and nothing else in the forward region (η = [2.0 , 4.5])

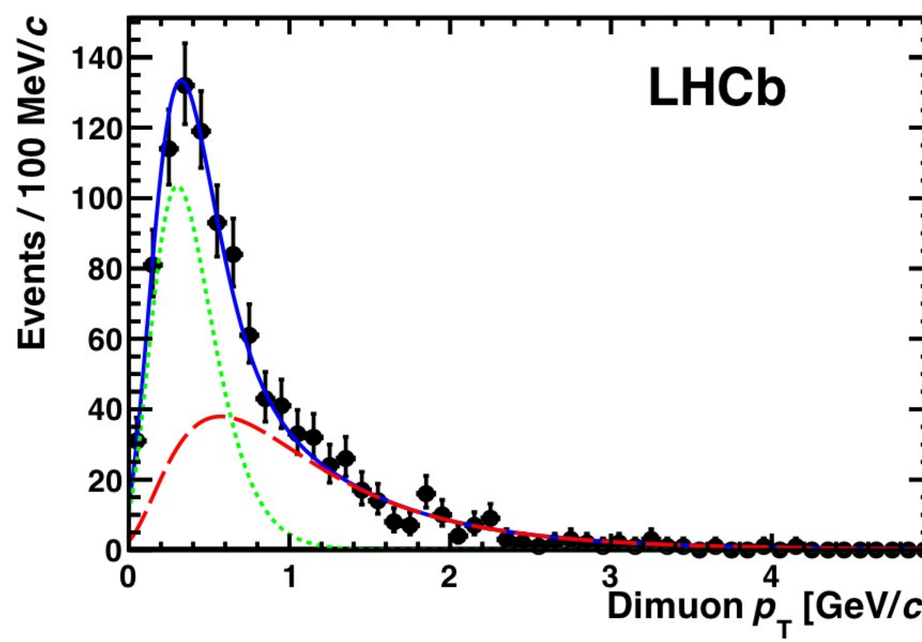
No backward tracks (η = [-3.5 , -1.5])

Analysis

Signal shape from SuperChic

Background shape from data

Template fit to Dimuon p_T



Main uncertainties

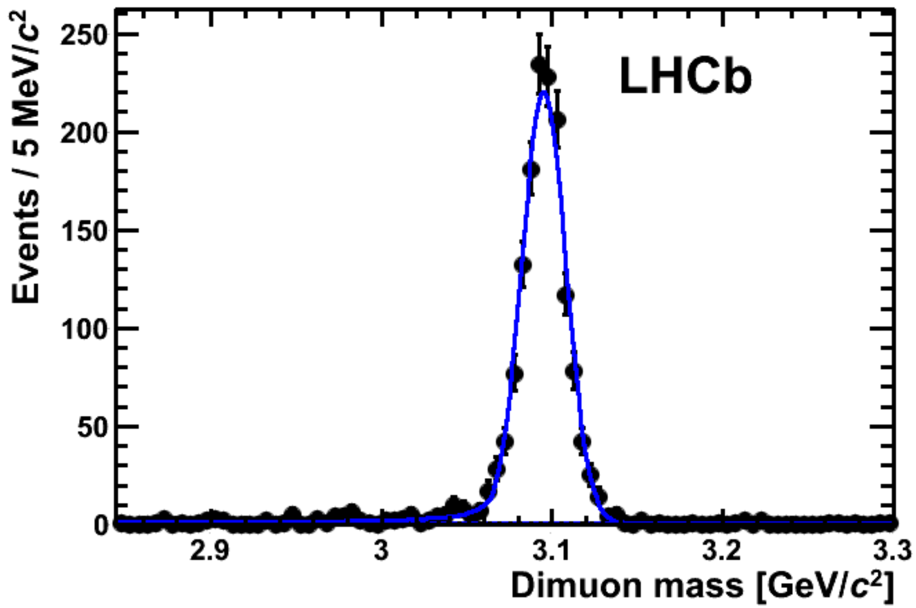
Trigger efficiency

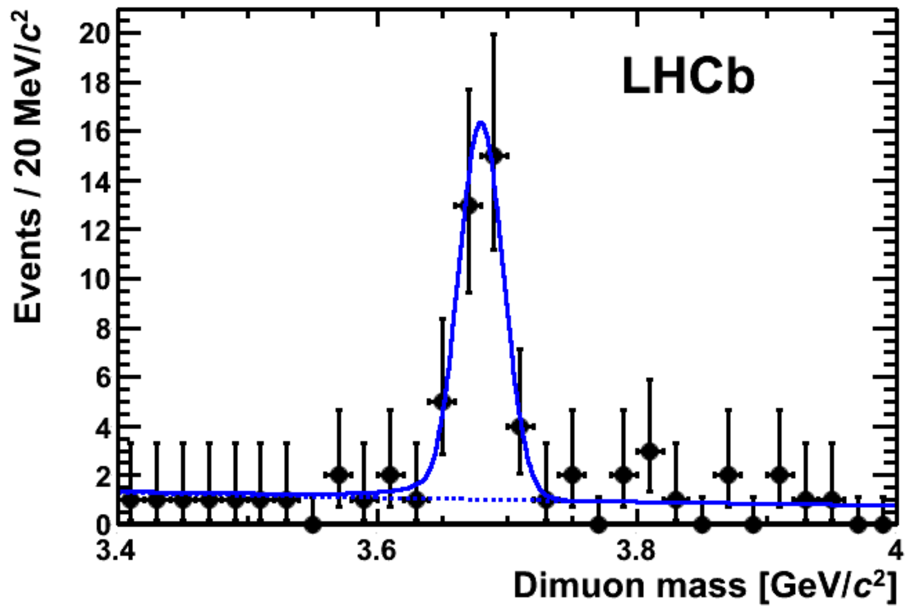
Luminosity

Signal/background shapes

Central exclusive J/ψ and ψ(2S)

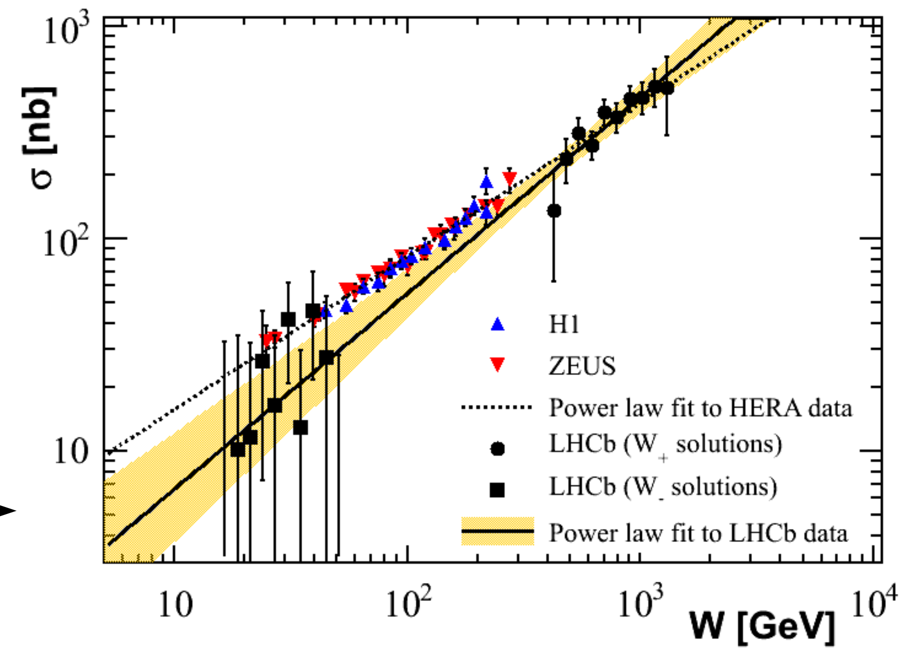
J.P.G40 (2013) 045001



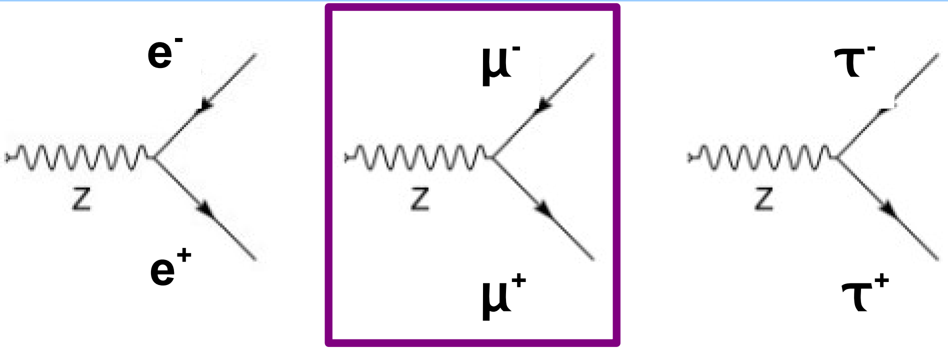


Predictions **[pb]**	$\sigma_{pp\to J/\psi(\to\mu^+\mu^-)}$	$\sigma_{pp\to\psi(2S)(\to\mu^+\mu^-)}$
Gonçalves and Machado	275	
STARLIGHT	292	6.1
Motyka and Watt	334	
SUPERCHIC	396	
Schäfer and Szczurek	710	17
LHCb measured value	$307 \pm 21 \pm 36$	$7.8 \pm 1.3 \pm 1.0$

$$\sigma_{\gamma p\to Vp}(W_\pm) = \frac{1/r(y)\frac{d\sigma}{dy}_{pp\to pVp} - k_\mp \frac{dn}{dk_\mp}\sigma_{\gamma p\to Vp}(W_\mp)}{k_\pm \frac{dn}{dk_\pm}}.$$



Integrated Luminosity 1.0/fb (2011)



JHEP 1206 (2012) 058

Trigger

Single electron/muon trigger

Selection

$Z \rightarrow e^+e^-$

Two electrons - p_T > 20 GeV and $2.0 < \eta < 4.5$

40 GeV < M_{ee} < 120 GeV

$Z \rightarrow \tau^+\tau^-$

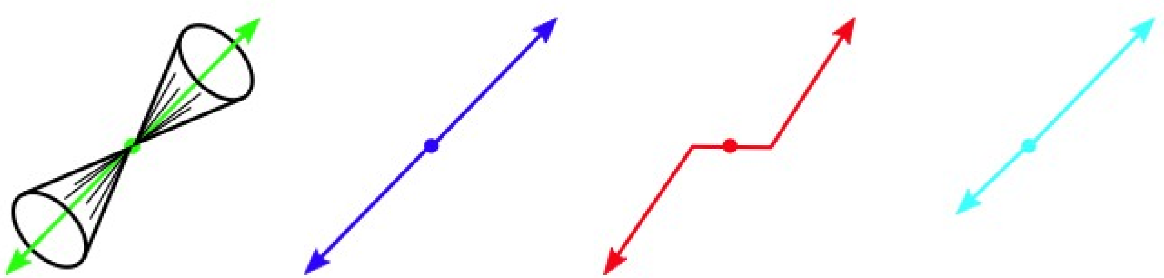
Channels - $\mu\mu$, μe, he, $h\mu$

One lepton with p_T > 20 GeV, second particle with p_T > 5 GeV

Isolated particles, back-to-back, displaced from primary vertex

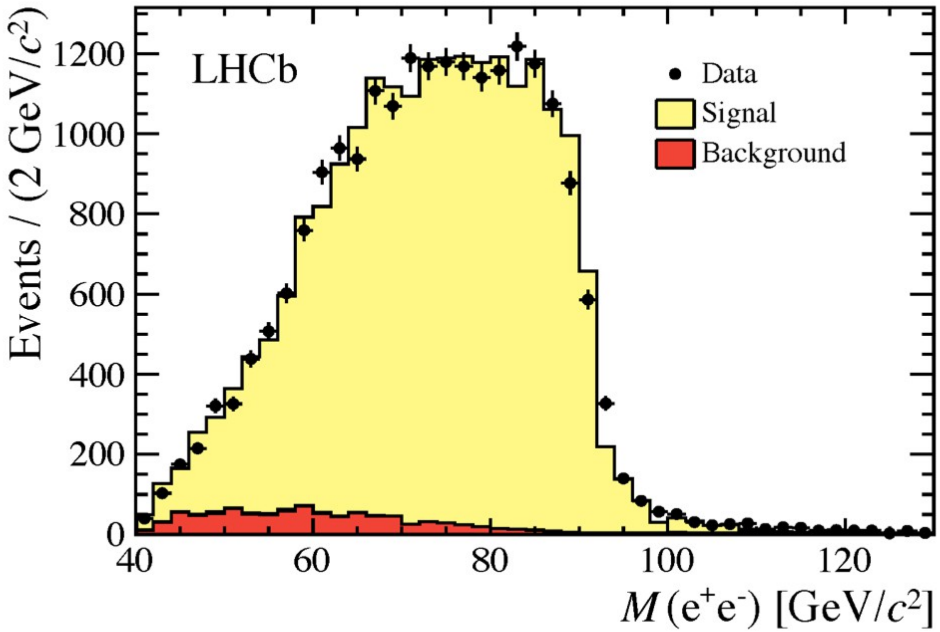
p_T asymmetry > 0.3 for $\mu\mu$ channel

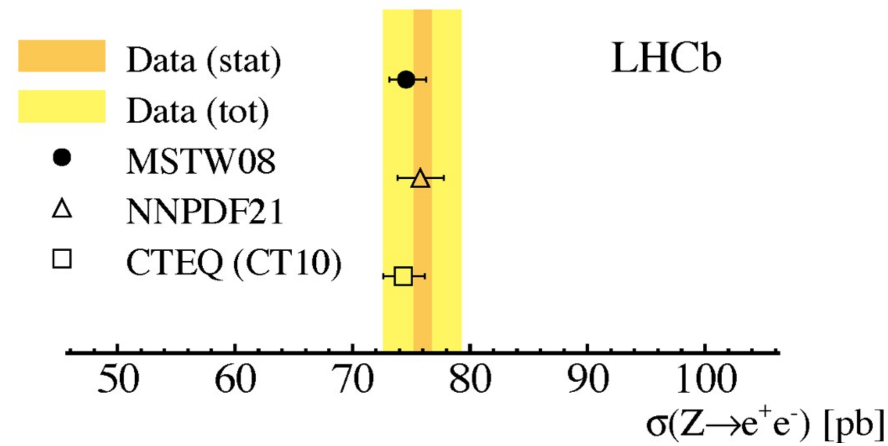
QCD / EW backgrounds estimated from data

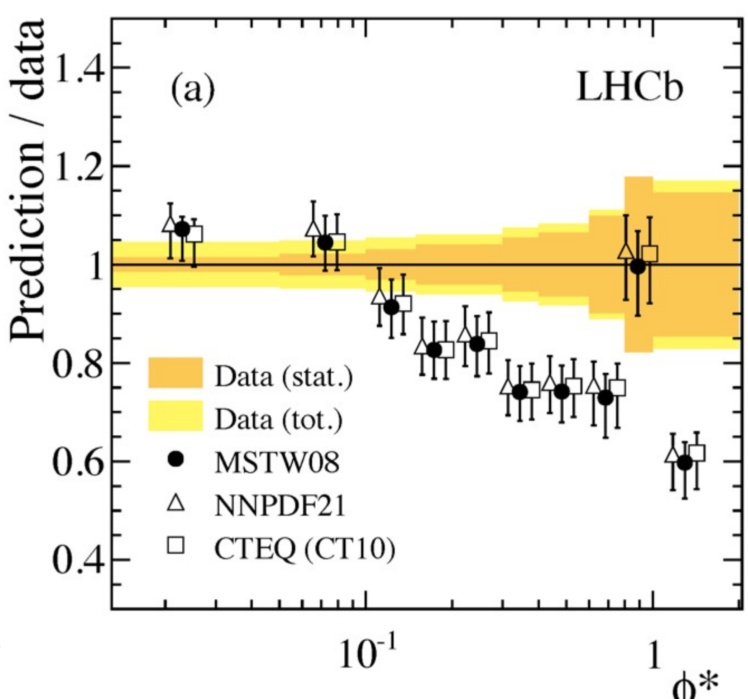


Inclusive Z production

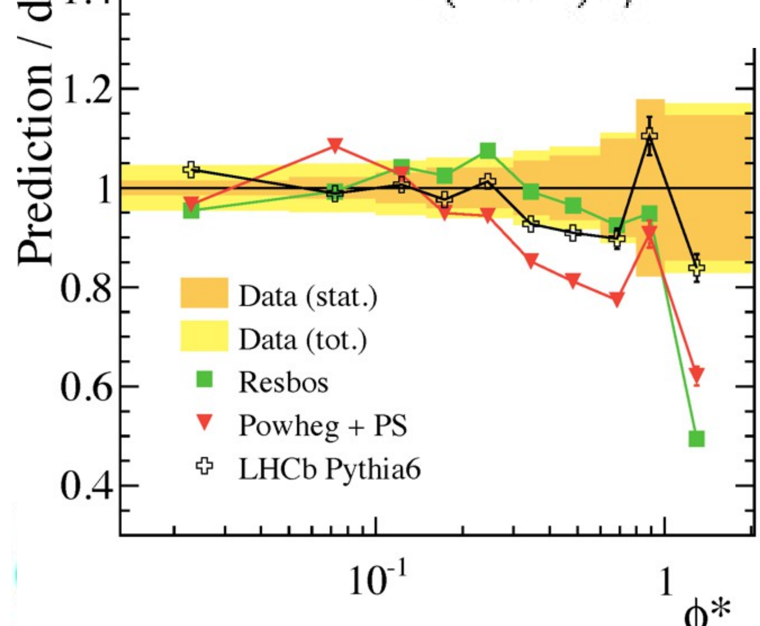
JHEP02(2013)106

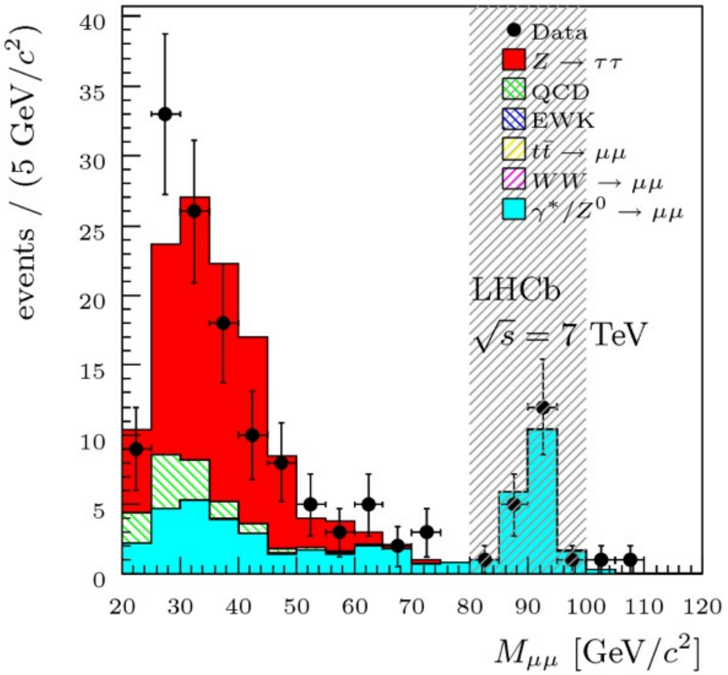


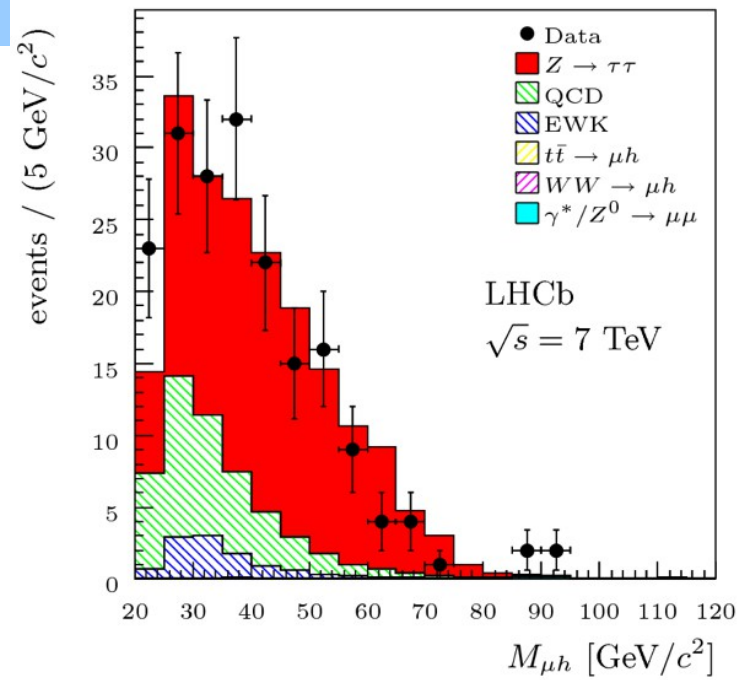




$$\phi^* \equiv \tan\left(\frac{\phi_{\rm acop}}{2}\right) \Big/ \cosh\left(\frac{\Delta\eta}{2}\right) \approx \frac{p_{\rm T}}{Mc}$$




Data
$Z \to \tau\tau$
QCD
EWK
$t\bar{t} \to \mu\mu$
$WW \to \mu\mu$
$\gamma^*/Z^0 \to \mu\mu$
LHCb
$\sqrt{s} = 7$ TeV
events / (5 GeV/c^2)
$M_{\mu\mu}$ [GeV/c^2]


Data
$Z \to \tau\tau$
QCD
EWK
$t\bar{t} \to \mu h$
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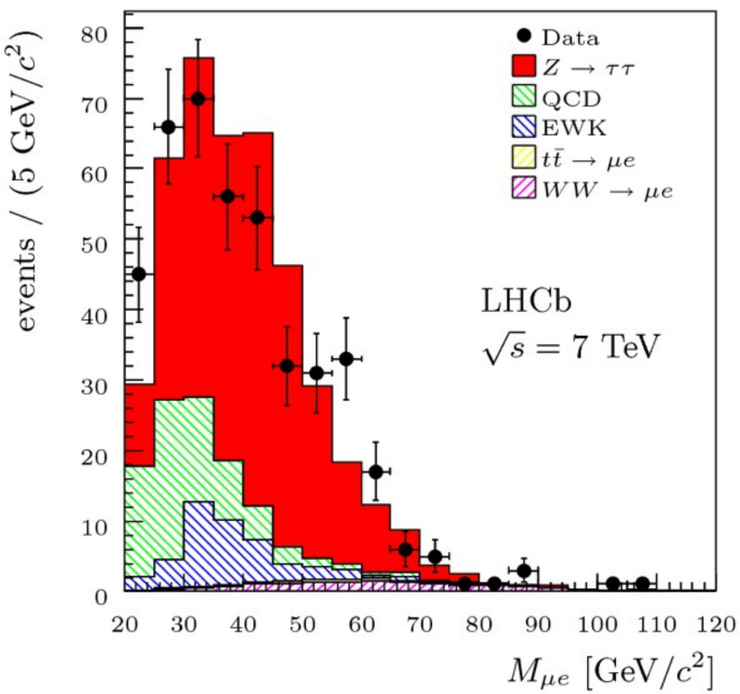
Data
$Z \to \tau\tau$
QCD
EWK
$t\bar{t} \to \mu e$
$WW \to \mu e$
LHCb
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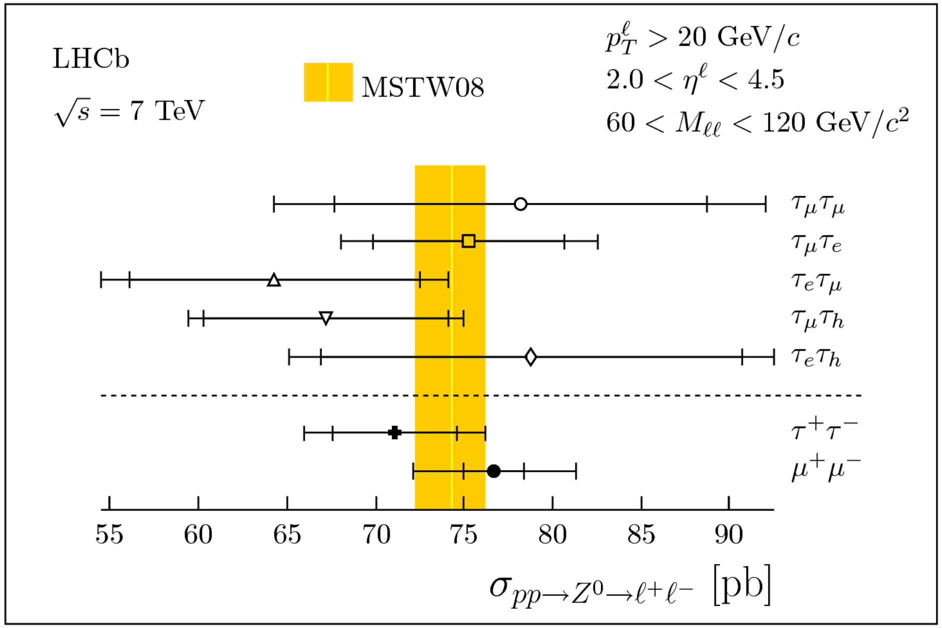
events / (5 GeV/c^2)
$M_{\mu e}$ [GeV/c^2]


LHCb
$\sqrt{s} = 7$ TeV
MSTW08
$p_T^\ell > 20$ GeV/c
$2.0 < \eta^\ell < 4.5$
$60 < M_{\ell\ell} < 120$ GeV/c^2
$\tau_\mu\tau_\mu$
$\tau_\mu\tau_e$
$\tau_e\tau_\mu$
$\tau_\mu\tau_h$
$\tau_e\tau_h$
$\tau^+\tau^-$
$\mu^+\mu^-$
$\sigma_{pp\to Z^0\to\ell^+\ell^-}$ [pb]

Motivation

limits to neutral Higgs – SM and MSSM

Integrated Luminosity 1.0/fb (2011)

Selection

same as $Z \rightarrow \tau^+\tau^-$ measurement

Backgrounds

QCD, W/Z, top/diboson

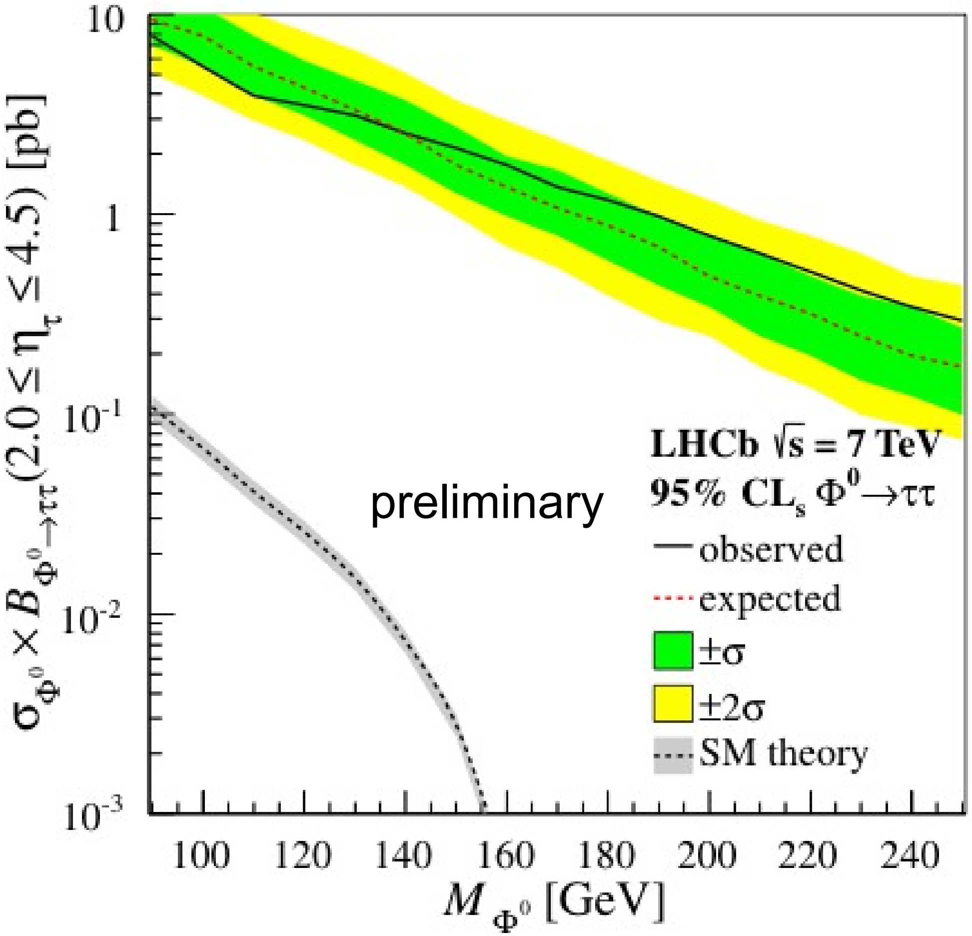
Signals

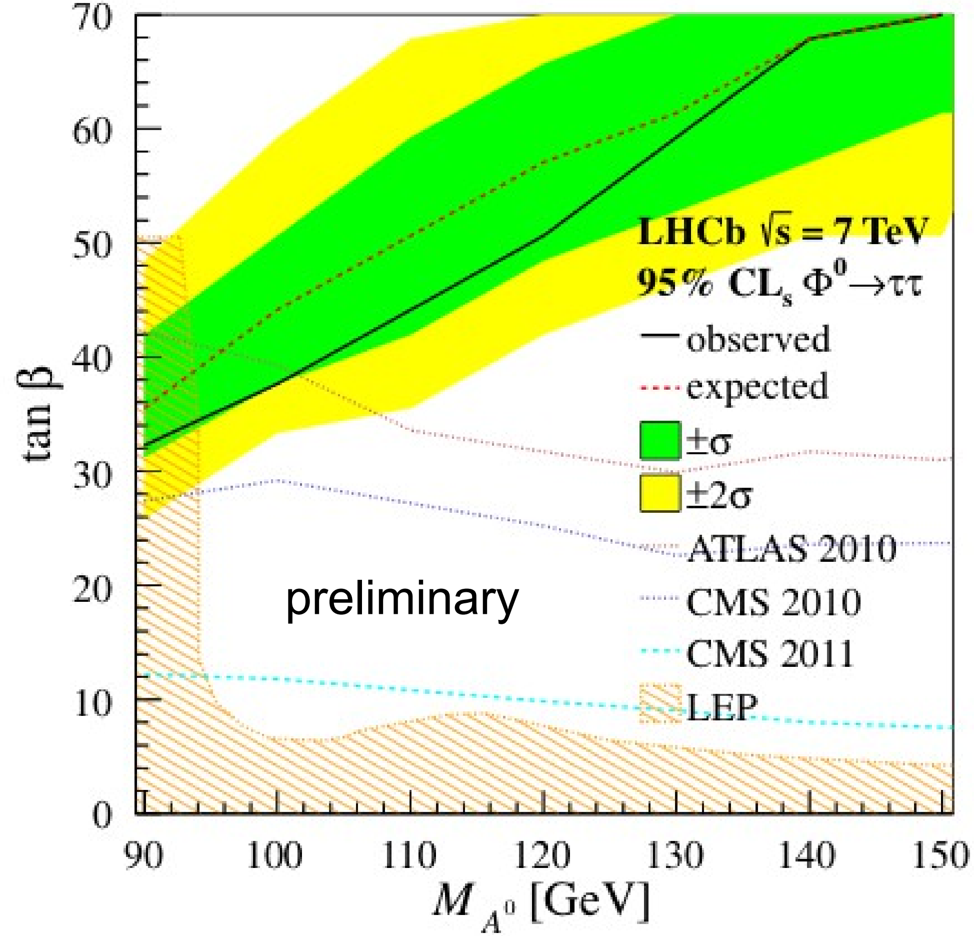
SM – dFG

MSSM – HIGLU, GGH@NNLO, BBH@NNLO

Search for SM / MSSM Higgs decaying in taus

LHCB-PAPER-2013-009

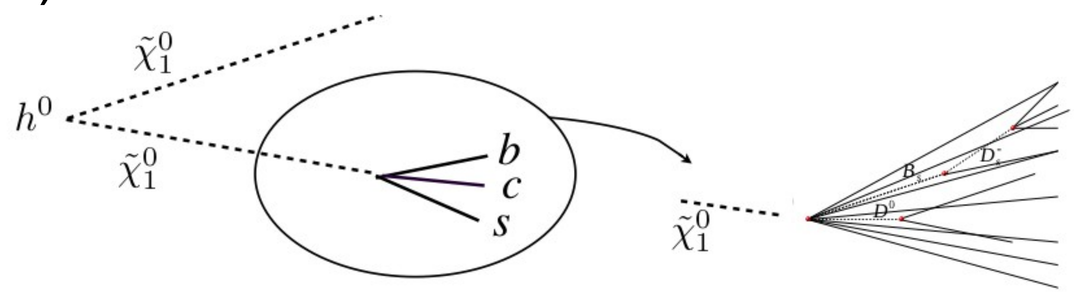




Motivation

SUSY with R-parity violation – Lightest Superpartner is unstable
Hidden Valley

Integrated Luminosity 35.8/pb (2010)

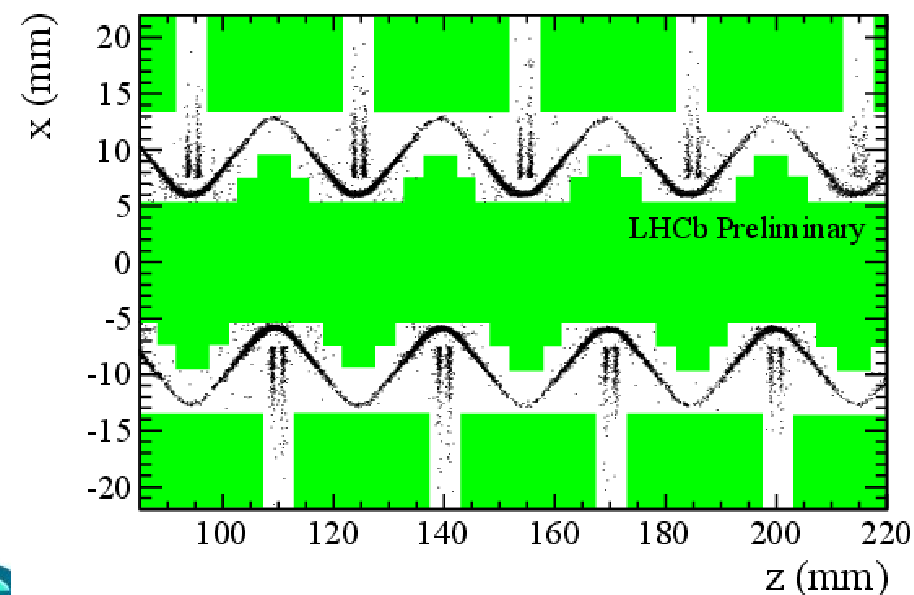


Loose Selection

One LLP candidate
- # of tracks > 4
- mass > 3 GeV
- radial distance from beam line > 0.4 mm

Backgrounds

Interaction with matter and QCD

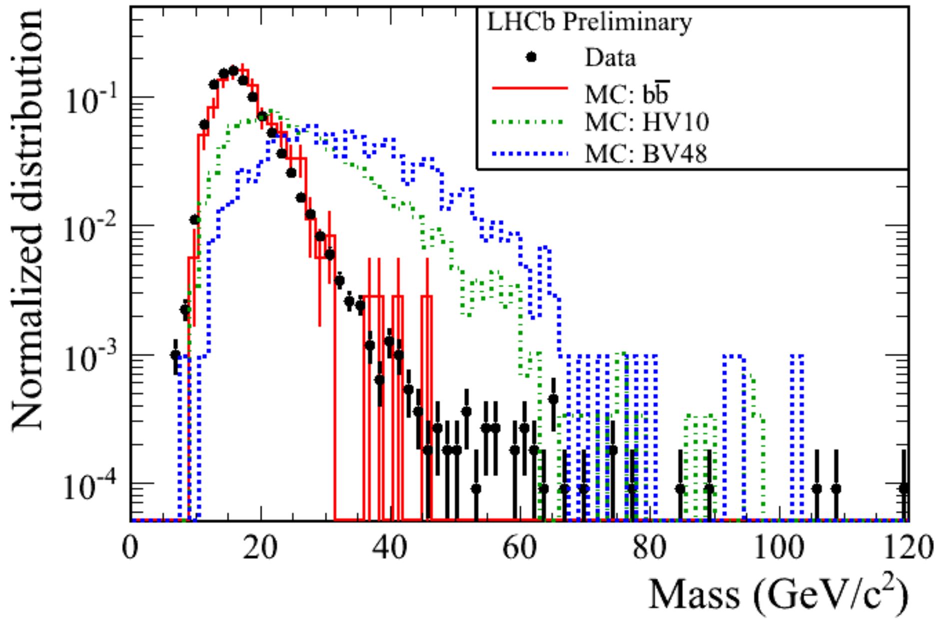


Final Selection

Require 2 LLPs back-to-back
- # of tracks > 6
- mass > 6 GeV

Search for Long-Lived Particles

LHCb-CONF-2012-014



m_{LLP}	30	35	40	48	55
m_{h^0}					
100	101	58	44	58	
105	100	75	44	39	
110	132	75	56	34	
114	128	91	47	32	46
120	148	93	58	34	31
125	179	90	61	41	29

m_{LLP}	30	35	40	48	55
τ_{LLP}					
3	210	156	136	168	410
5	145	101	68	58	137
10	129	91	47	32	46
15	155	90	49	31	33
20	131	93	63	32	31
25	142	100	61	34	25

Table 5: 95 % CL upper limits on the cross-section for the production of a Higgs boson in the BV model, as a function of the LLP and Higgs masses for a LLP lifetime of 10 ps (left), and as a function of the LLP mass and lifetime for a Higgs mass of 114 GeV/c^2 (right). Cross-sections, masses and lifetimes are given in pb, GeV/c^2 and ps, respectively.

Summary

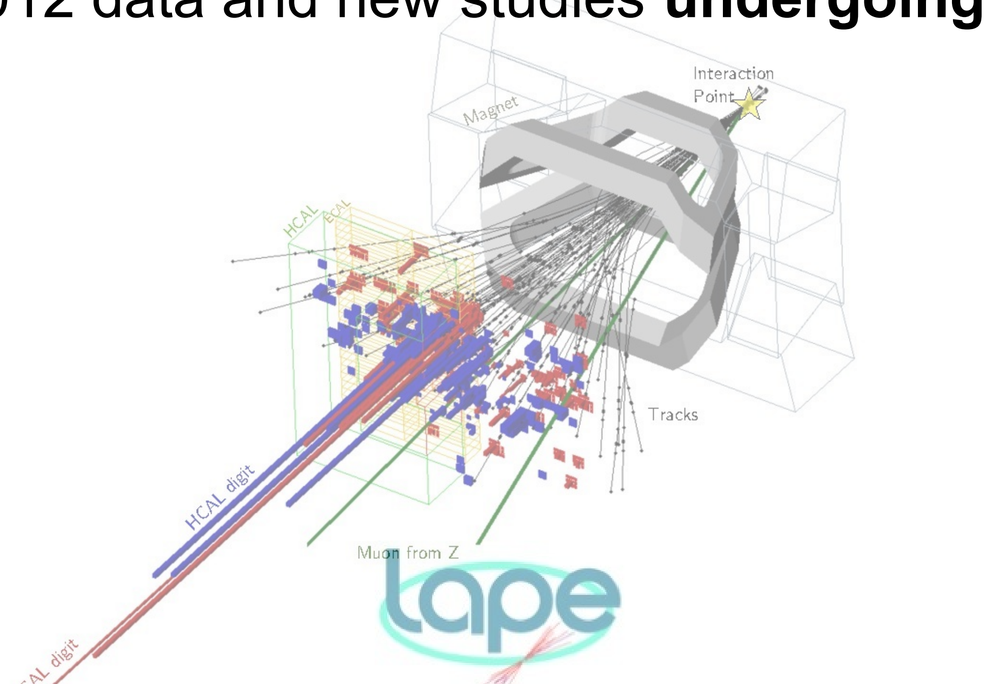
→ LHCb probes a unique coverage in η and low p_T reach at LHC

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

→ New limits of direct searches in the forward region

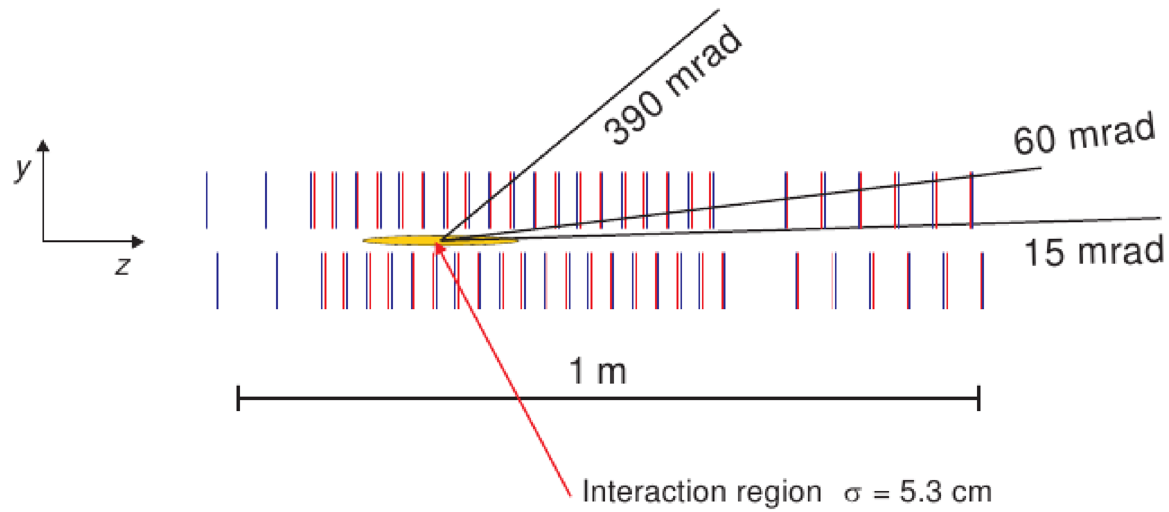
→ Many other results not covered in this talk are available here
LHCb Results

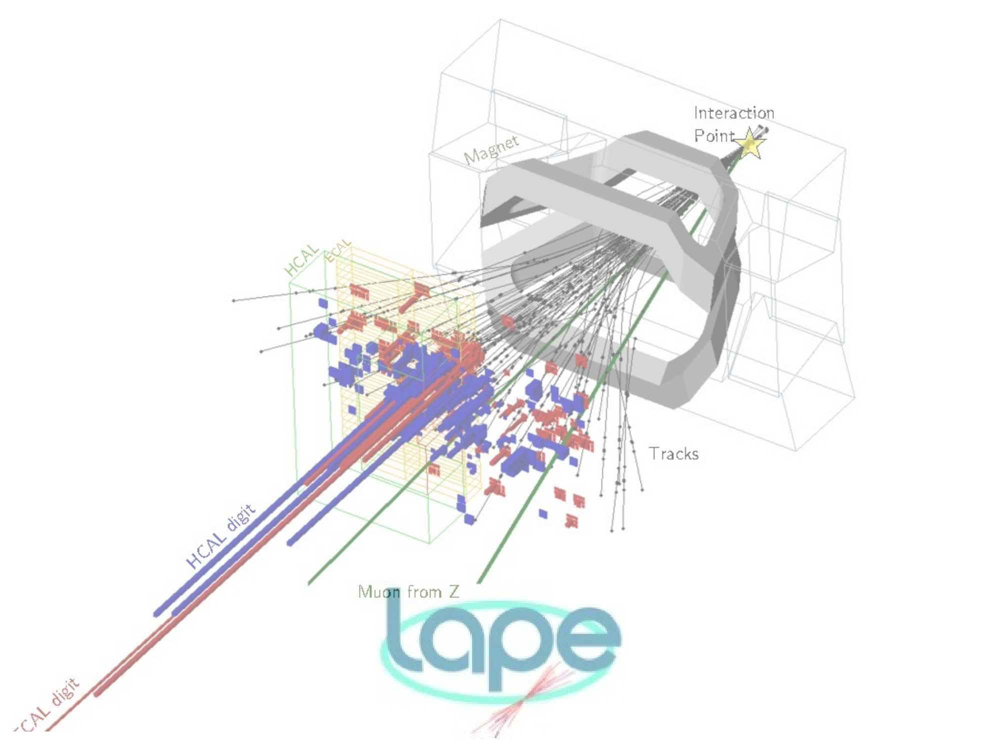
→ Update with 2012 data and new studies **undergoing**!



VELO acceptance

cross section at $x=0$:





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J.P.G40 (2013) 045001

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Inclusive Z production

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