

Impact of LHCb results on the tuning of Monte Carlo generators

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*on behalf of the **LHCb** collaboration

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*QCD@LHC, ETH & University of Zürich
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Outline

- ◆ The LHCb Detector at the LHC
- ◆ Monte Carlo (MC) Event Generators
- ◆ What and How to Tune
- ◆ LHCb Experimental Input to Generator Tuning
- ◆ Conclusions & Outlook

The LHCb detector at the LHC *

JINST 3 (2008) S080005; IJMP A30 (2015) 1530022

Fully instrumented single-arm spectrometer.

Unique pseudorapidity range:

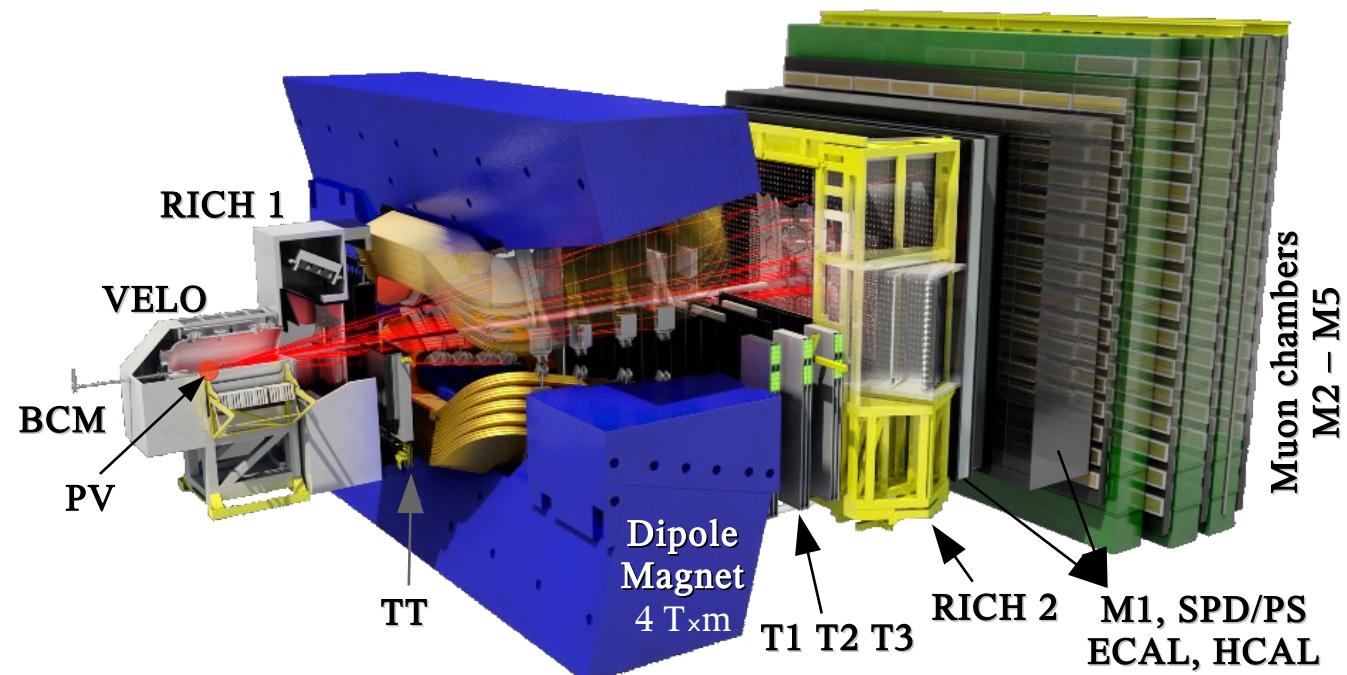
- ★ forward: $2 < \eta < 5$
- ★ backward: $-3.5 < \eta < -1.5$ (PV in VErtex Locator; no momentum measurement)

High precision tracking & vertexing: Impact Parameter (IP) resolution $\sim 20 \mu\text{m}$ at high- p_T

Momentum resolution ($\Delta p / p$): from 0.5 % below 20 GeV/c to 1.0 % @ 200 GeV/c

Good PID efficiency:

- π , p, K: RICH 1,2
- e, γ , μ : CALO/M1-M5

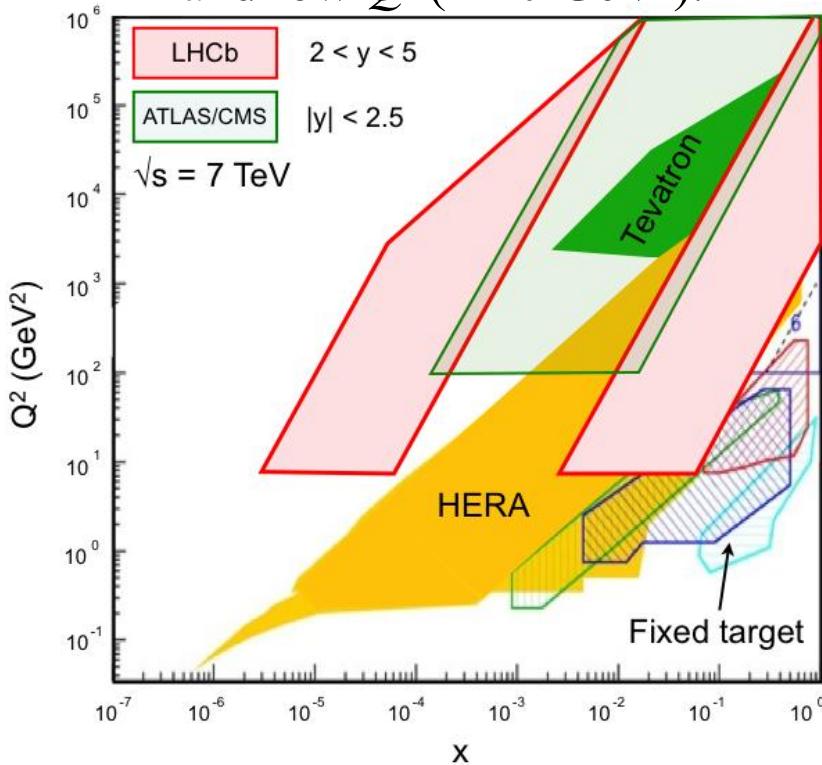


* more details in back-ups

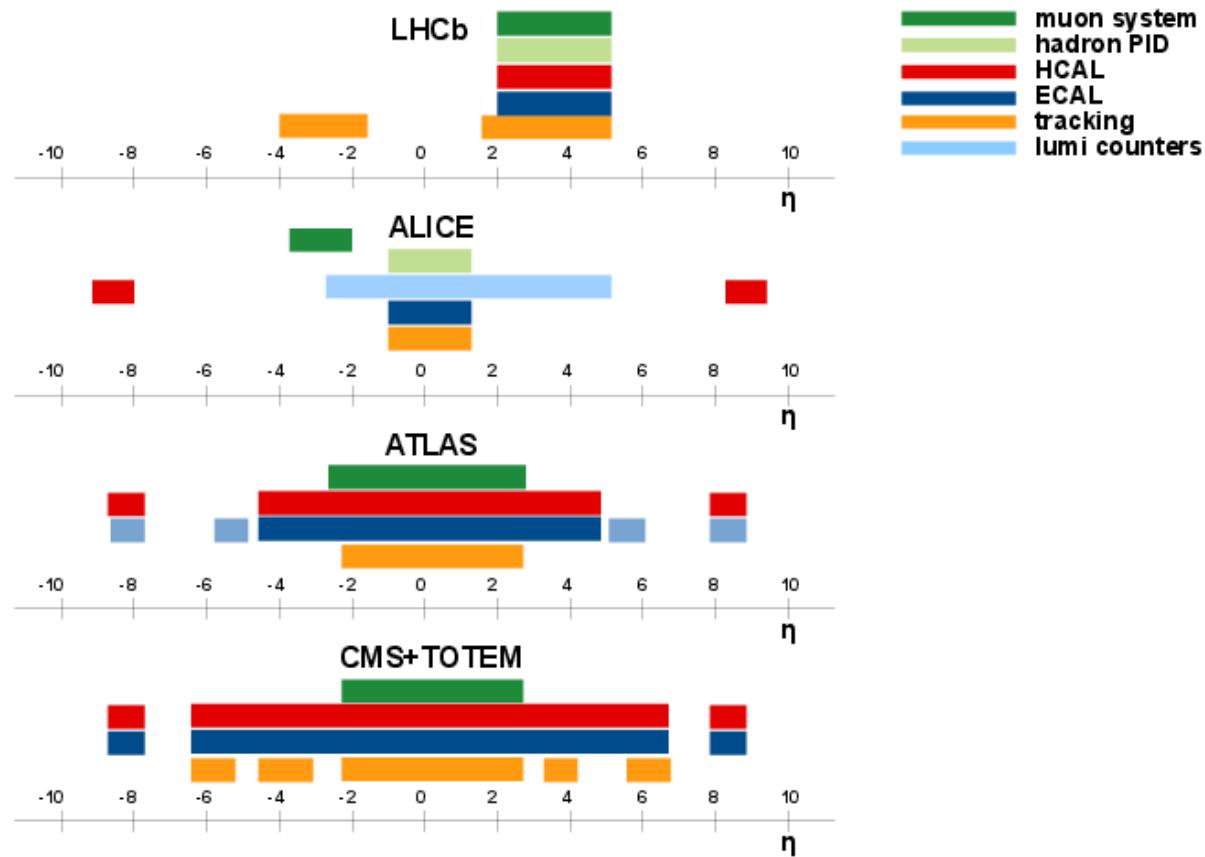
The LHCb detector at the LHC

JINST 3 (2008) S080005; IJMP A30 (2015) 1530022

Also access low x_{Bj} ($\sim 10^{-6}$)
and low Q^2 ($> 10 \text{ GeV}^2$).



LHCb covered phase-space region
complementary to other detectors at LHC



Recorded data samples in back-ups

MC Event Generators

- General Purpose Event Generators (GPEG) – compromise QCD, global description of whole event
 - ◆ **PYTHIA 8** – successor to JETSET (since 1978)
 - ◆ **HERWIG** – successor to EARWIG (since 1984)
 - ◆ **SHERPA** – developed since 2000s
 - ◆ Experiment specific cocktails of generators with full detector simulation
- Specialized Generators – provide in detail specific aspects of generated event; sometimes pluggable into GPEGs
 - ◆ **ALPGEN**, **MADGRAPH**, **VINCIA**, **MC@NLO**, **POWHEG**, **HEJ**, **BLACKHAT**, **MINLO**, **UNLOPS**, **Geneva**
 - ◆ **HIJING**, **CRMC**: (PHOJET, EPOS, QGSJET, SIBYLL), DPMJET,
 - ◆ **CASCADE**, **EvtGen**, **GenXicc**, **SuperChic**, **BCVEGPY**, ...

Detailed talks during Monte Carlo sessions this week.

Generators* characteristics: shower model, higher order matrix element (ME) corrections and hadronisation model

- **Showering** models implementing colour coherence: HERWIG (angular ordering), PYTHIA (angular vetoes) or VINCIA, ARIADNE, SHERPA (coherent dipoles/antennae)
- Order of ME correction**: LO (PYTHIA), NLO (POWHEG) and multi-leg (N)LO (VINCIA, MiNLO, UNLOPS); merge showers using matching schema (avoid double counting).
- **Hadronisation** is either based on Lund string model (PYTHIA) or cluster models (HERWIG, SHERPA)

* examples are generic and not limited to the given list of generators

** see P. Skands' [talk @ CERN-Fermilab HCP Summer School 2015](#); arXiv: 1207.2389

What and How to Tune

- **Matrix Elements** – NO, but precise measurements may provide new/better values.
 - **Hadronisation** – many parameters for flavour selection including b and c fragmentation functions, some for kinematics
 - **Showers** – very sensitive in some generators. Optimize cut-off scale and coupling constant(s).
 - **Multiple Parton Interactions (MPI)** – last before completing a tune to give as strict boundaries as possible
-
- **LHCb Approach to Tuning**
 - Limited by available measurements: use as many compatible sets as possible from different experiments at multiple energies; weight to favour data to describe
 - Start from existing (global) tunes
 - Keep in mind tunes in central region may not be best for forward region and vice versa
 - Preliminary re-tune of light flavour production – better match underlying event (UE)
 - Tune hadronisation of heavy flavour
 - Re-tune non-perturbative QCD sector
 - Hope for a quick convergence if not repeat

LHCb Approach to MC Event Generator Tuning

- Lots of correlated steering params: coupling/scale constants and cut-offs; hadronisation params, fragmentation function, flavour selection; MPI cut-off, matter overlap parametrisation, colour reconnection and energy dependence.
- 100 k – 10 M events/run: time/resource costly
- **Methods/Tools:**
 - **By eye** – painful, non-optimal, unstable results
 - **Brute force** – computationally intensive even for optimized scanning grid; may end in local minima
 - **Parametrisation** – Hamacher & Weierstall (1995) quadratic interpolation; re-implemented as **Professor** & **RIVET**
(arXiv:hep-ph/1003.0694; EPJ C65 (2010) 331)

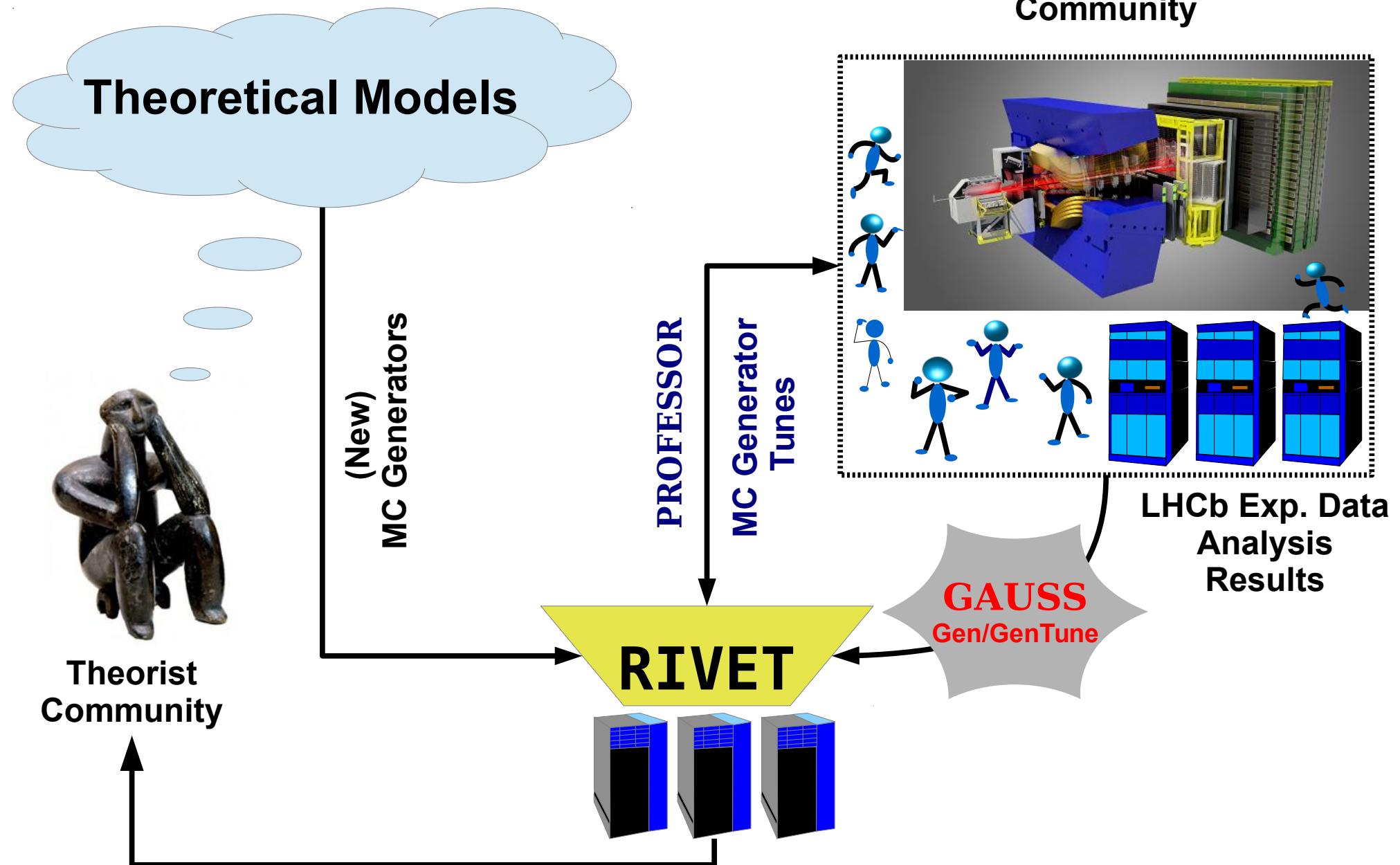
LHCb Approach to Tuning - A Word of Warning

Must understand a measurement before using it in tuning:

- Cross-sections in fiducial region depend slightly on MC models used to derive efficiencies
- Avoid extrapolated measurements which clearly depend on models for full phase-space evaluation (mind LHCb's narrow coverage)
- Bias from MC input in evaluation of correction factors and unfolding for production measurements → possible solution would be to consider detector response matrix (weaker dependence) – publish in HepData?

In back-ups: Growing table of LHCb measurements useful for tuning indicating HepData record and RIVET analysis module status.

Only CDS links given on these slides.



Light Flavour Production*

→ K_s production:

- 0.9 [PLB 693 (2010) 69]
- 7 & 8 (limited by data sample)
- 13 (on-going)

→ V^0 ratios:

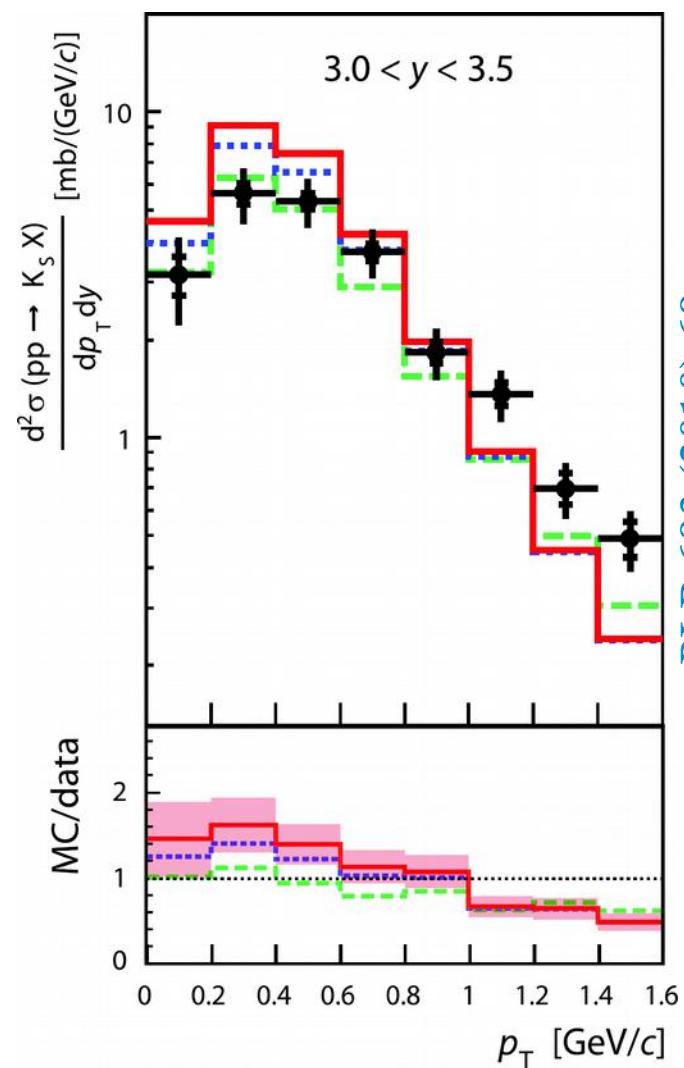
- 0.9 & 7** [JHEP 08 (2011) 034]
- 2.76, 13 (on-going)

→ Φ production:

- 7** [PLB 703 (2011) 267]
- 13 (planned)

→ Prompt light hadron:

- 0.9 & 7** [EPJ C72 (2012) 2168]
- 2.76, 13 (planned)



PLB 693 (2010) 69

* numbers represent \sqrt{s} in TeV for pp collisions

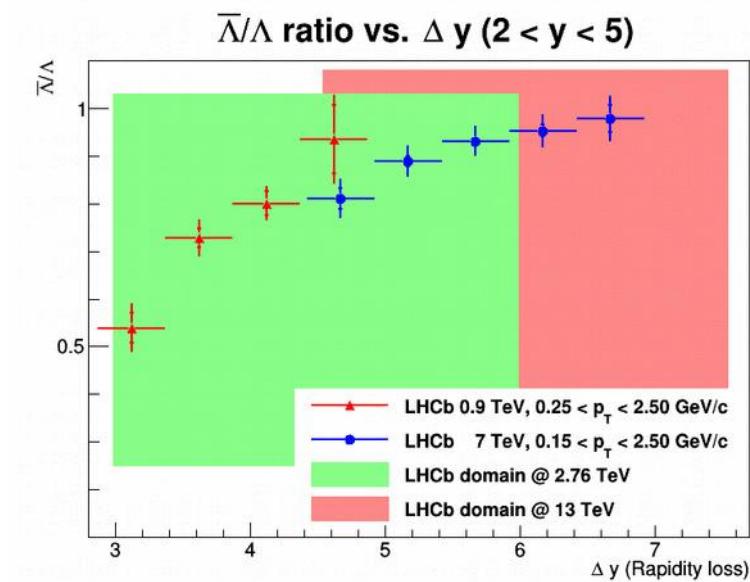
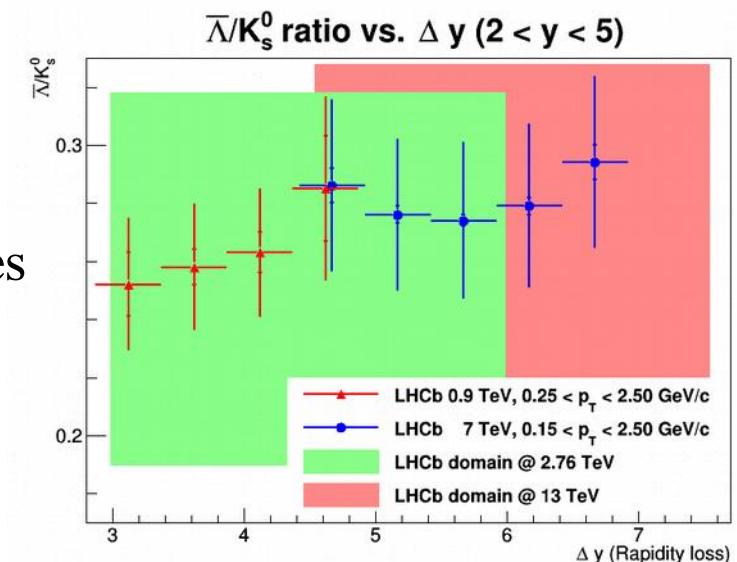
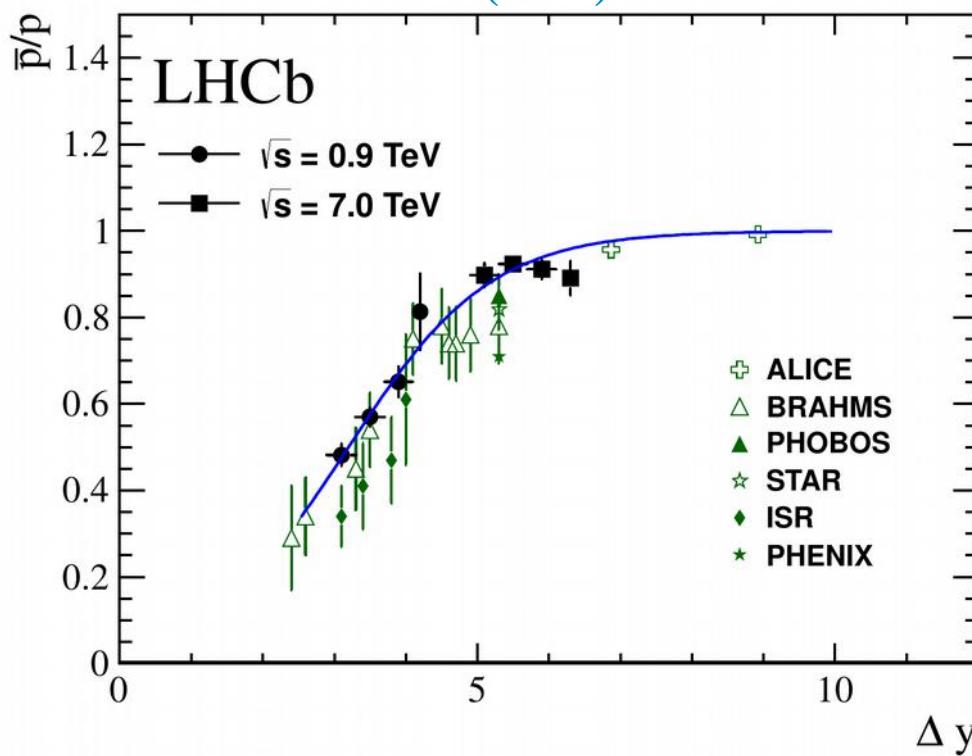
** used in first PYTHIA8 tuning in the forward region

→ Many more measurements on-going; different \sqrt{s} ; comparison to newer tunes from LHC data

Light Flavour Production

- (LHCb) prompt light particles include products of heavy hadron decays.
- Optimize baryon number transport (\bar{p}/p , $\bar{\Lambda}/\Lambda$), baryon suppression ($\bar{\Lambda}/K_s$, $(p+p)/(\pi^+ + \pi^-)$, ...), strangeness production
- Further constraints from charged particle multiplicities

EPJ C72 (2012) 2168



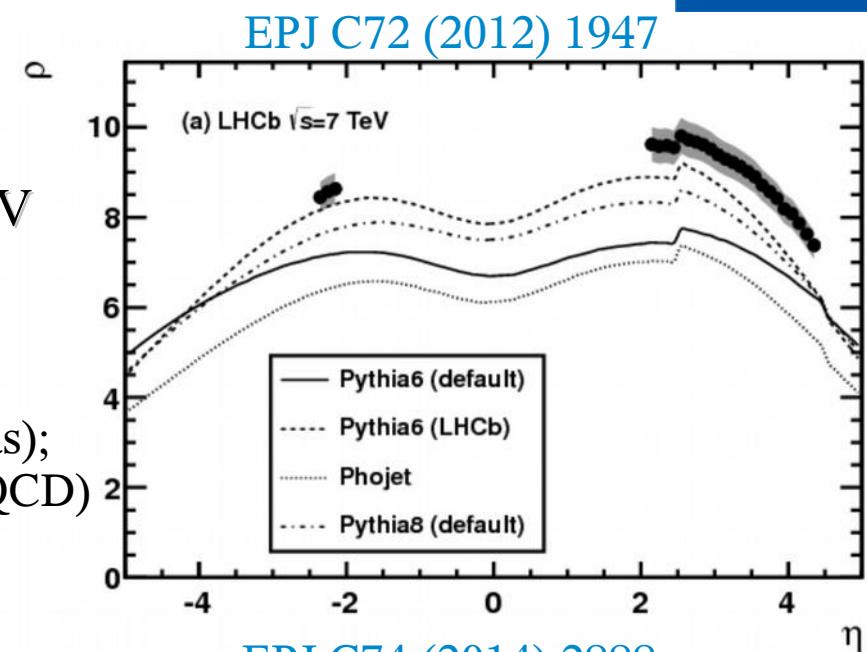
Global Event Characteristics

Charged particle multiplicities in pp collisions at 7 TeV

EPJ C72 (2012) 1947

Selection: at least 1 trk in $2 < \eta < 5$

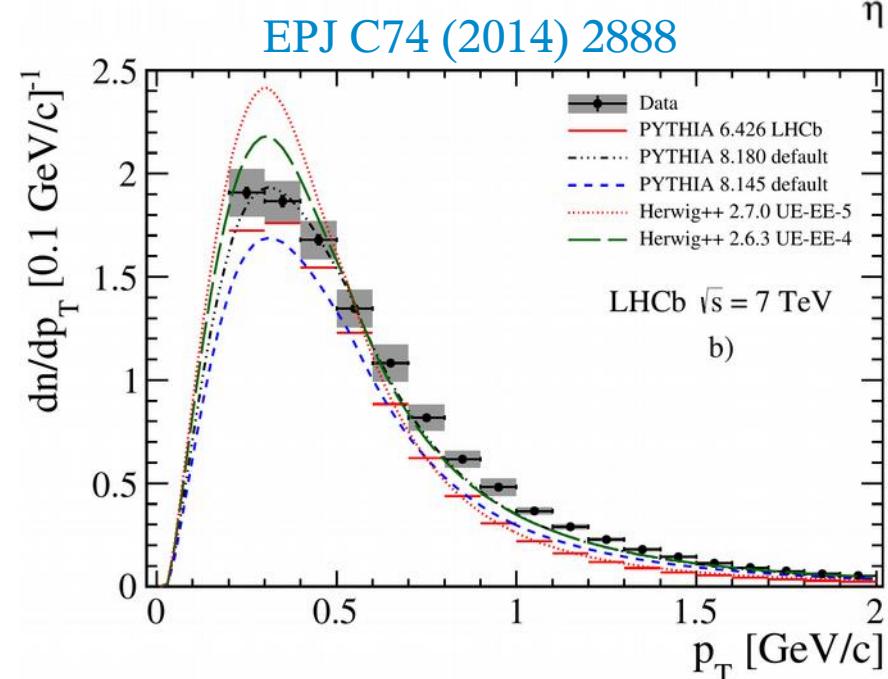
Kinematic range: $-2.5 < \eta < -2.0$, $2.0 < \eta < 4.5$ (minbias);
 $p_T > 1 \text{ GeV}/c$, $2.5 < \eta < 4.5$ (hard QCD)



EPJ C74 (2014) 2888

Selection: $p_T > 0.2 \text{ GeV}/c$, $p > 2 \text{ GeV}/c$, $2.0 < \eta < 4.8$

Kinematic range: $0.2 < p_T < 2.0 \text{ GeV}/c$; $2.0 < \eta < 4.5$



13 TeV measurement on-going

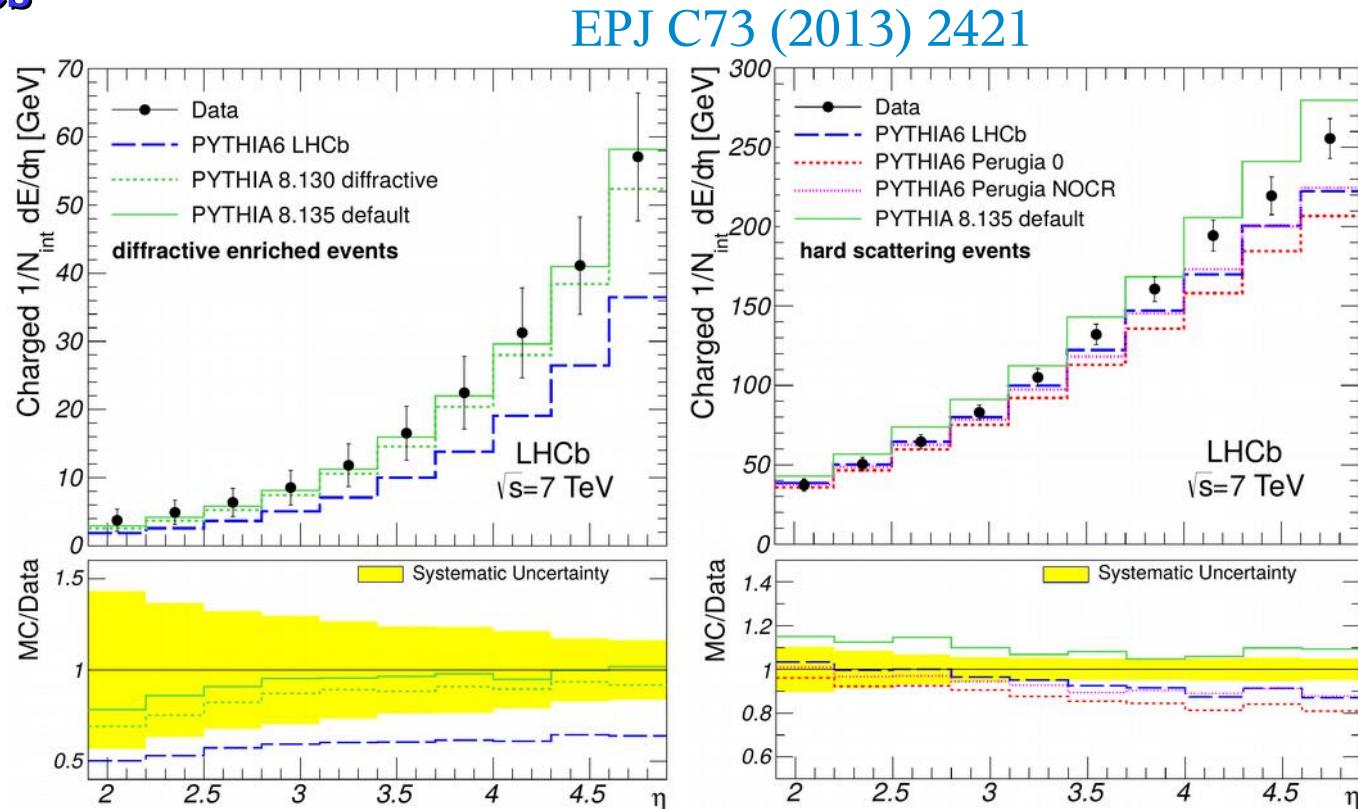
Global Event Characteristics

Energy Flow at 7 TeV

Selection: at least 1 trk from PV

Event classes:

- minbias $1.9 < \eta < 4.9$,
 $2 < p < 10^3 \text{ GeV}/c$
- hard scattering
 $p_T > 3 \text{ GeV}/c$
- diffractive enriched
no trk. in $-3.5 < \eta < -1.5$
- non-diffractive enriched
at least 1 trk. $-3.5 < \eta < -1.5$



→ Largest divergence between models in forward region where LHCb data has smallest uncertainties. Reference for tuning both MC and cosmic ray generators.

- Important input to constrain MPI in the light flavour sector
- 13 TeV measurement on-going

Global Event – Total Cross-sections

Inelastic pp cross-section @ 7 TeV

$$\sigma_{\text{inel}}^{\text{acc}} = 55.0 \pm 2.4 \text{ mb}$$

- prompt charged parts., $p_T > 0.2 \text{ GeV}/c$, $2.0 < \eta < 4.5$
- main uncertainty from luminosity
- 13 TeV measurement is on-going

→ Preliminary tune of total cross-sections separately from rest of steering parameters; rely on other LHC measurements:

- ATLAS

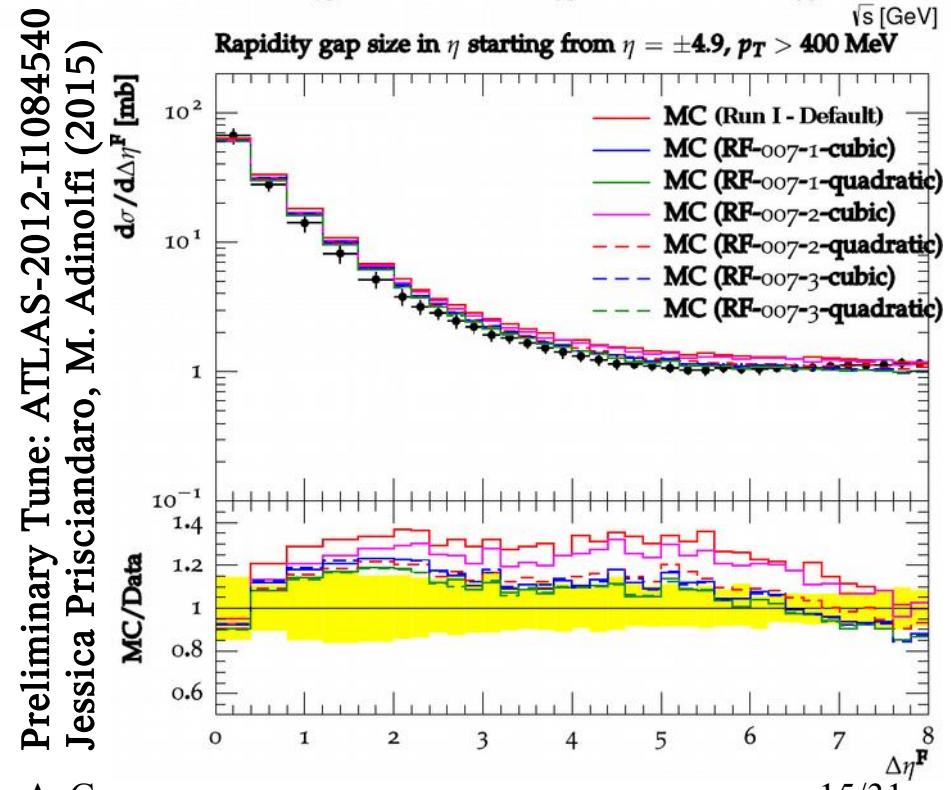
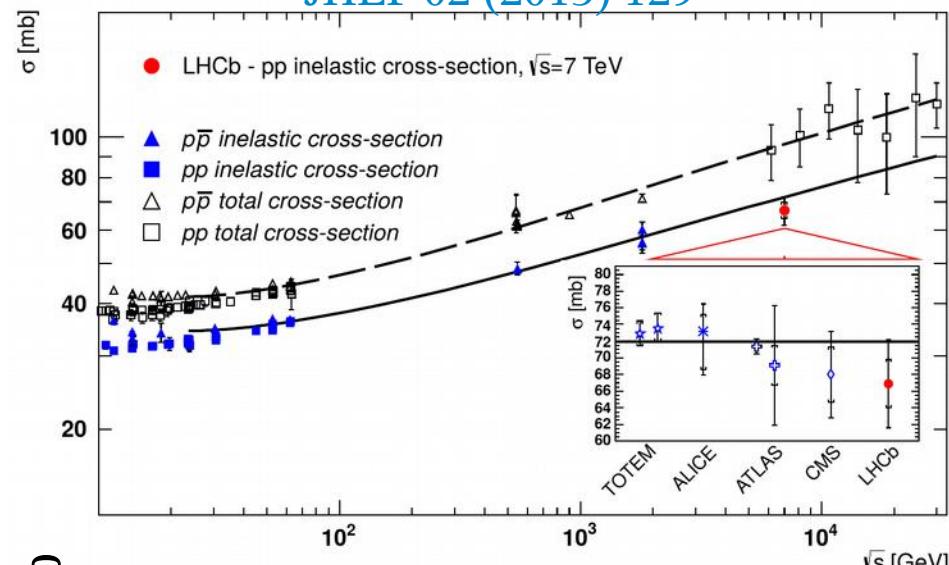
Nature Com. 2 (2011) 463, EJP C72 (2012) 1926;

- CMS

PLB 722 (2013) 5, PRD 92 (2015) 012003 [new!];

- TOTEM

EPL 101 (2013) 21002



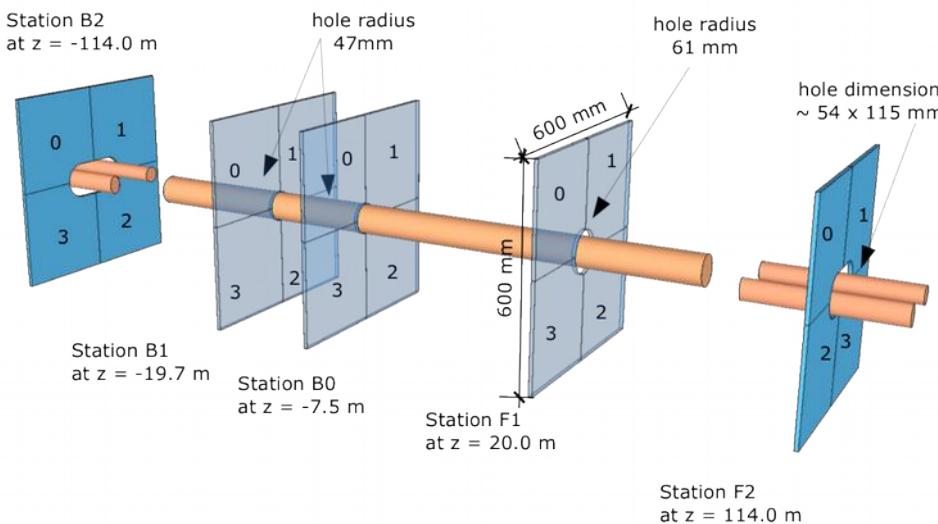
Global Event – Total Cross-sections

Central diffraction not covered by tune.

Possible input in high mass domain (pomeron PDFs) from central exclusive production measurements:

[JPG 40 \(2013\) 045001](#), [JPG 41 \(2014\) 055002](#),
[JHEP 09 \(2015\) 084](#)

Dedicated sub-system in Run II
 HeRSChel – High Rapidity Shower Counters for LHCb

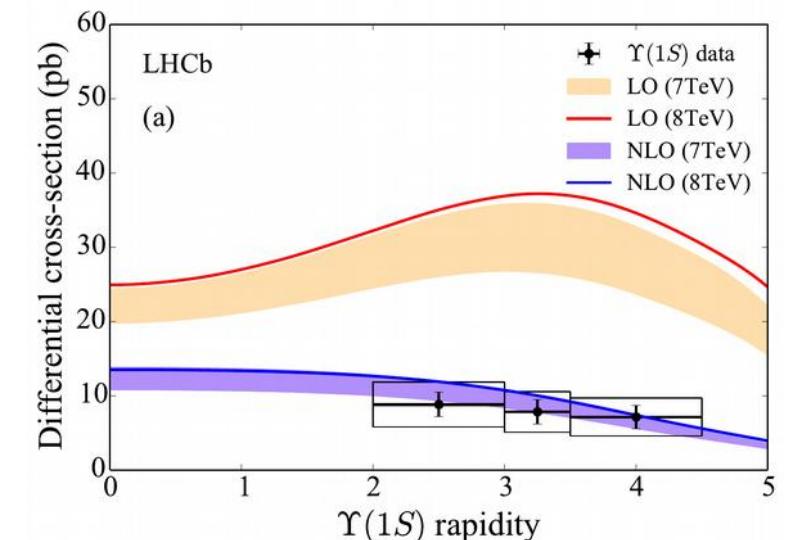


reduce background from non-elastic events outside LHCb acceptance.

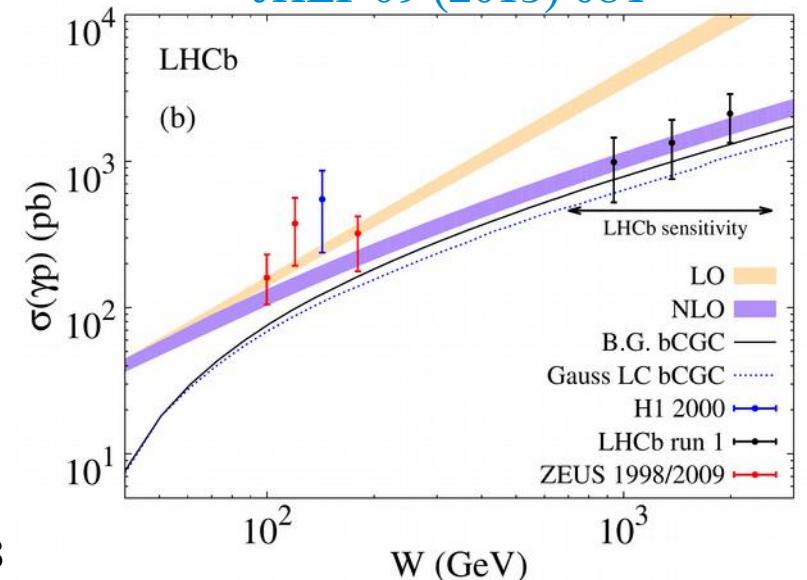
Dedicated talk by Tomasz Szumlak in Hard QCD+EW on Thu, 25.08

QCD@LHC: August 22nd, 2016

Parallel: Monte Carlo, A. Grecu



[JHEP 09 \(2015\) 084](#)

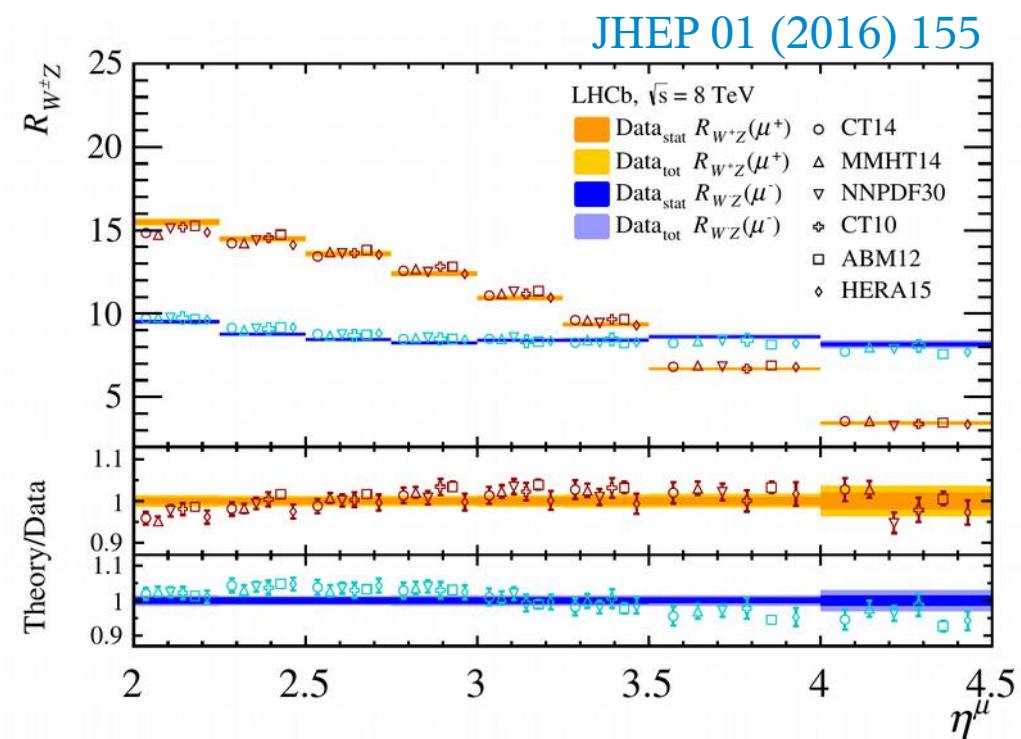
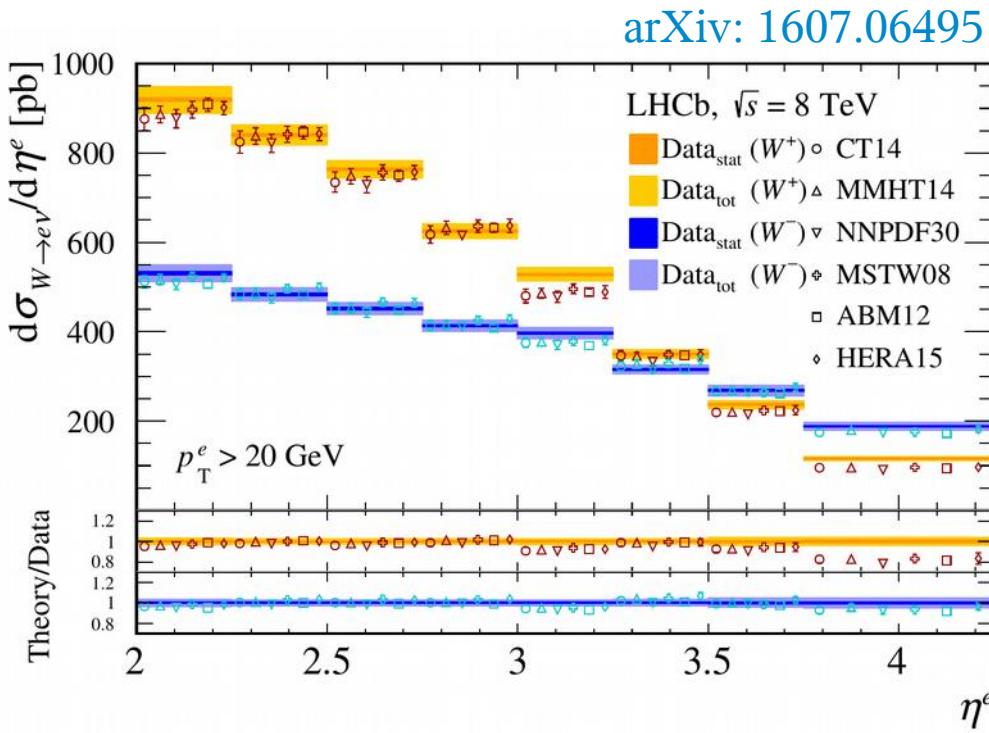


Input to PDF Tuning*

- EW boson production cross-sections and ratios**
 - $Z \rightarrow \ell\ell$ @ 7, 8, 13 TeV + $W \rightarrow \mu\nu$ @ 7, 8 TeV (on-going $W \rightarrow e\nu$)

JHEP 08 (2015) 039, JHEP 01 (2016) 155, arXiv: 1607.06495, JHEP 02 (2013) 106, JHEP 05 (2015) 109

- Good agreement with NNLO predictions; Ratios and double ratios limit PDFs' uncertainties at high lepton pseudorapidity



* Talks by Katharina Müller and Voica Rădescu in plenary session tomorrow morning.

** More details: Previous Hard QCD+EW parallel session, A. Grecu's talk

Parallel: Monte Carlo, A. Grecu

Measuring SM Free Parameters

- Most precise measurement of the effective weak mixing (Weinberg) angle at hadron colliders.

JHEP 11 (2015) 190

LEP + SLD
Phys. Rept. 427 (2006) 257

LEP A_{FB}(b)
Phys. Rept. 427 (2006) 257

SLD A_{LR}
Phys. Rev. Lett. 84 (2000) 5945

D0
Phys. Rev. Lett. 115 (2015) 041801

CDF
arXiv:1605.02719

CMS
Phys. Rev. D 84 (2011) 112002

ATLAS
JHEP 09 (2015) 049

LHCb
JHEP 11 (2015) 190

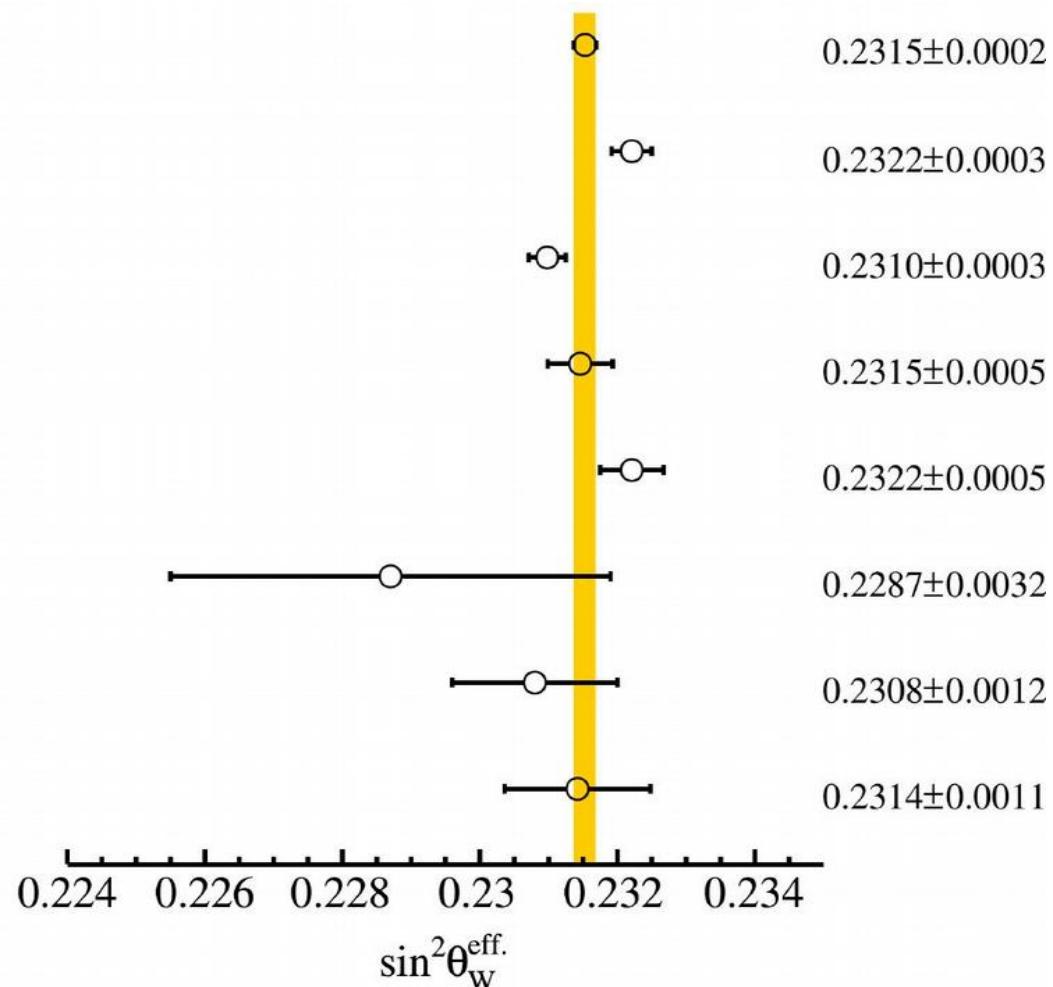


Fig. 4 – Update by Will Barter

Input to PDF Tuning

- Probing flavour PDFs in proton – measurements of EW boson + flavour quark jet.

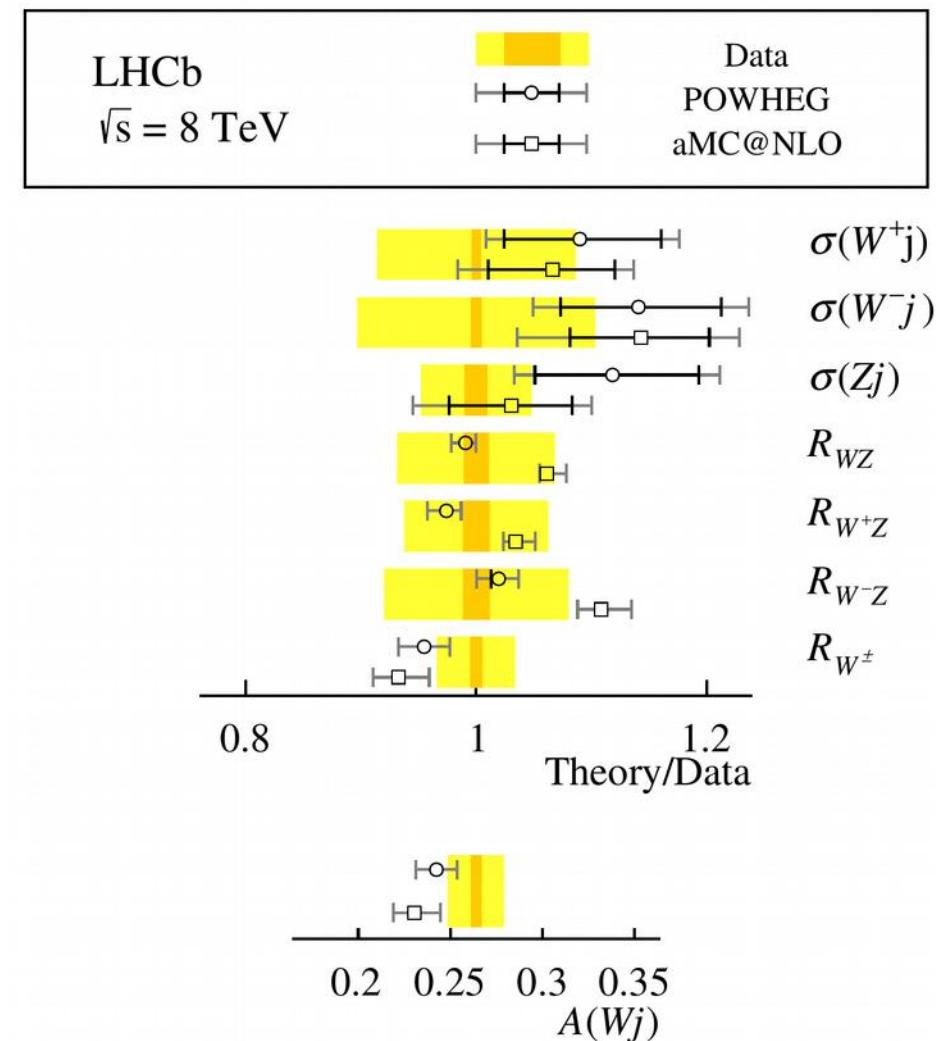
Z + b-jet @ 7 TeV JHEP 01 (2015) 064

W + b/c @ 8 TeV PRD 92 (2015) 052001

W/Z + jets @ 8 TeV JHEP 05 (2016) 131

- Limits on u/d PDFs at high x-Björken

More details in Wouter Hulsbergen's talk
during Hard QCD+EW parallel session
tomorrow afternoon.



JHEP 05 (2016) 131

Heavy Flavour* Production

- Charmonium
 - J/ ψ @ 2.76, 7, 8, 13 TeV
 - $\psi(2S)$ @ 7 TeV
 - $\sigma(\chi_{c2})/\sigma(\chi_{c1})$, χ_c :J/ ψ , $\eta_c(1S)$:J/ ψ ,
 - $\chi_{c0}:\chi_{c1}:\chi_{c2}$
 -
 - J/ ψ , $\psi(2S)$ polarisations @ 7 TeV, but not supported by current colour-octet models

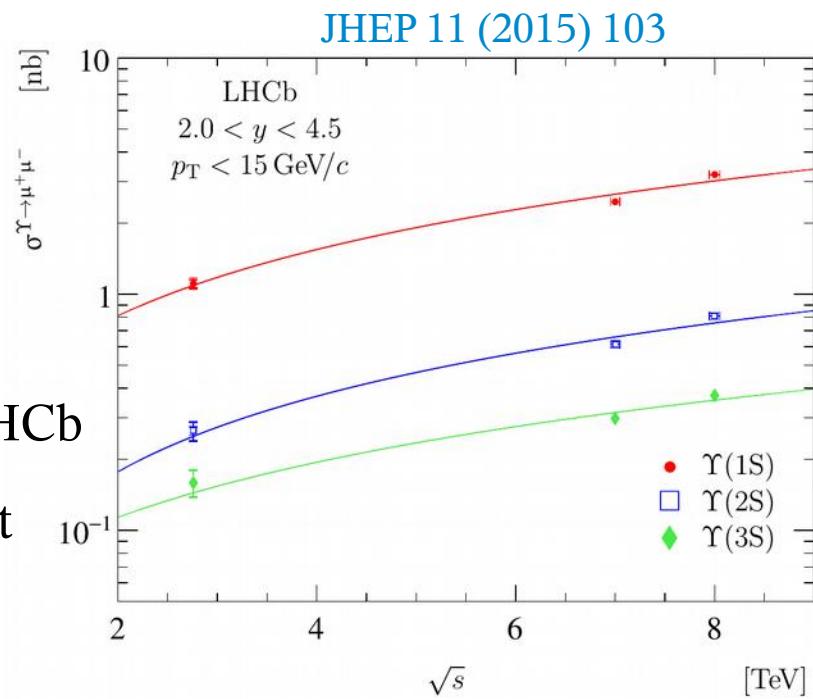
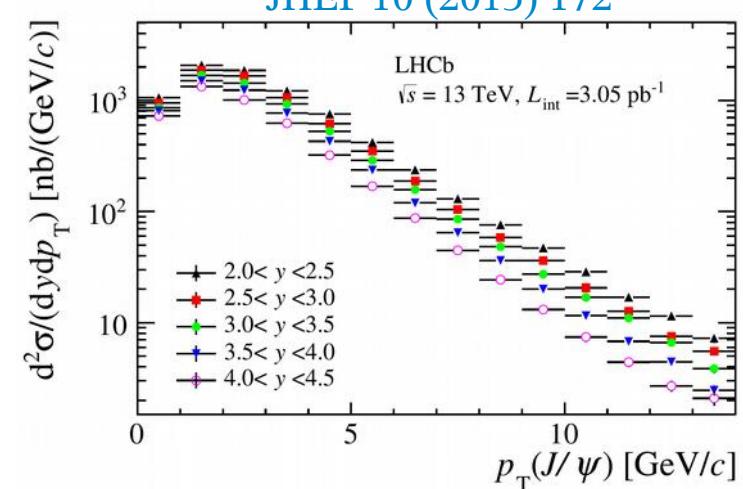
- Bottomonium
 - $\Upsilon(n\text{ S})$ @ 2.76, 7, 8 TeV;
 - $\sigma(\chi_{c2})/\sigma(\chi_{c1})$ @ 7 TeV

- Problems describing full phase-space, especially in forward/central regions → input from LHCb

- Optimize quarkonia NRQCD matrix elements in event generators (altering inclusion in MPI framework, e.g. PYTHIA 8).

- EPJ C74 (2014) 2835
 EJP C71 (2011) 1645
 JHEP 06 (2013) 064
 JHEP 10 (2015) 172
 PLB 714 (2012) 215
 PLB 718 (2012) 431
 EPJ C75 (2015) 311
 JHEP 10 (2013) 115
-
- EPJ C73 (2013) 2631
 EPJ C74 (2014) 2872

- EPJ C74 (2014) 2835
 EPJ C72 (2012) 2025
 JHEP 11 (2015) 103
 JHEP 10 (2014) 088



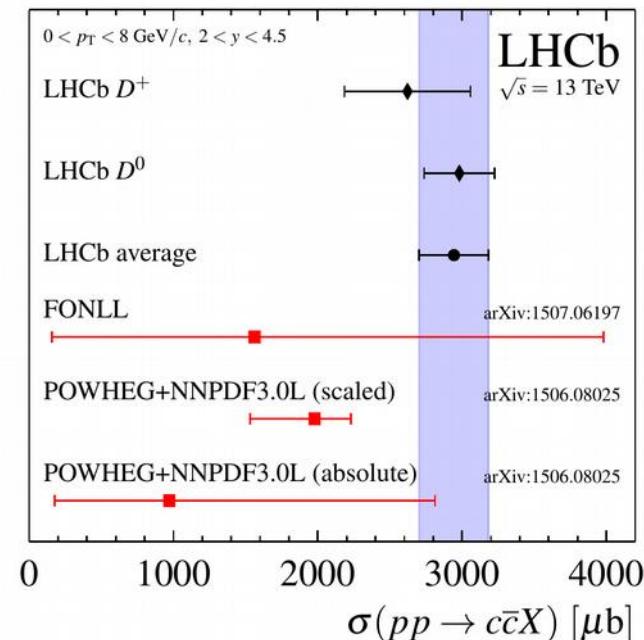
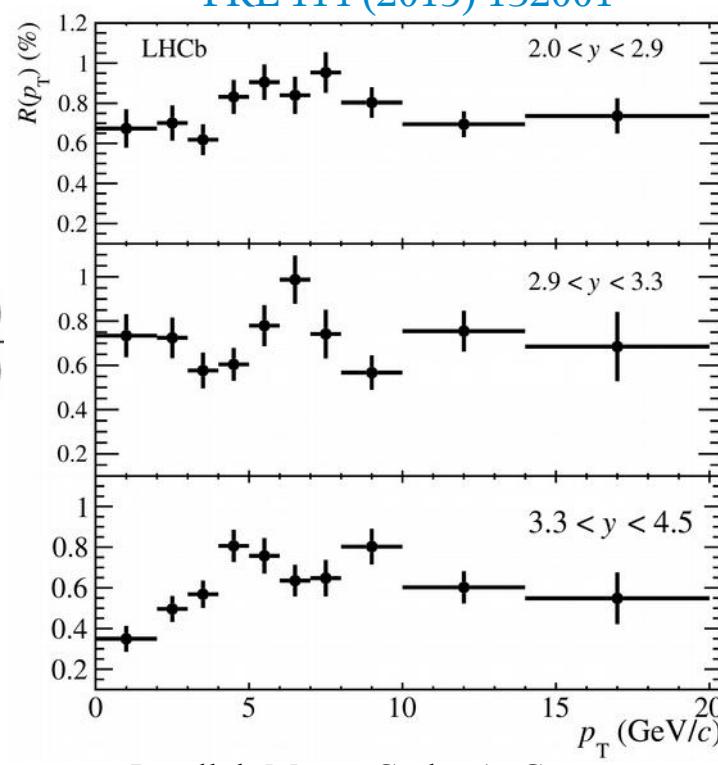
*To be presented in detail in “Heavy quarks” dedicated session in the following days.
 Parallel: Monte Carlo, A. Grecu

LHCb Experimental Input to Generator Tuning

Heavy Flavour Production

- Prompt c -hadrons ($D^0, D^+, D_s^+, D^{*+}, \Lambda_c$) @ 7, 13 TeV
- b -hadrons
 B^\pm, B^0, B_s^0 @ 7 TeV
 $B_c^+:B^+$ @ 8 TeV
 - JHEP 04 (2012) 093
 - JHEP 08 (2013) 117
 - PRL 114 (2015) 132001
- ▶ Constrain parameters of b and c fragmentation functions

$$R(p_T, y) = \frac{N_{B_c^+}(p_T, y)}{N_{B^+}(p_T, y)} \frac{\epsilon_{B^+}(p_T, y)}{\epsilon_{B_c^+}(p_T, y)}$$

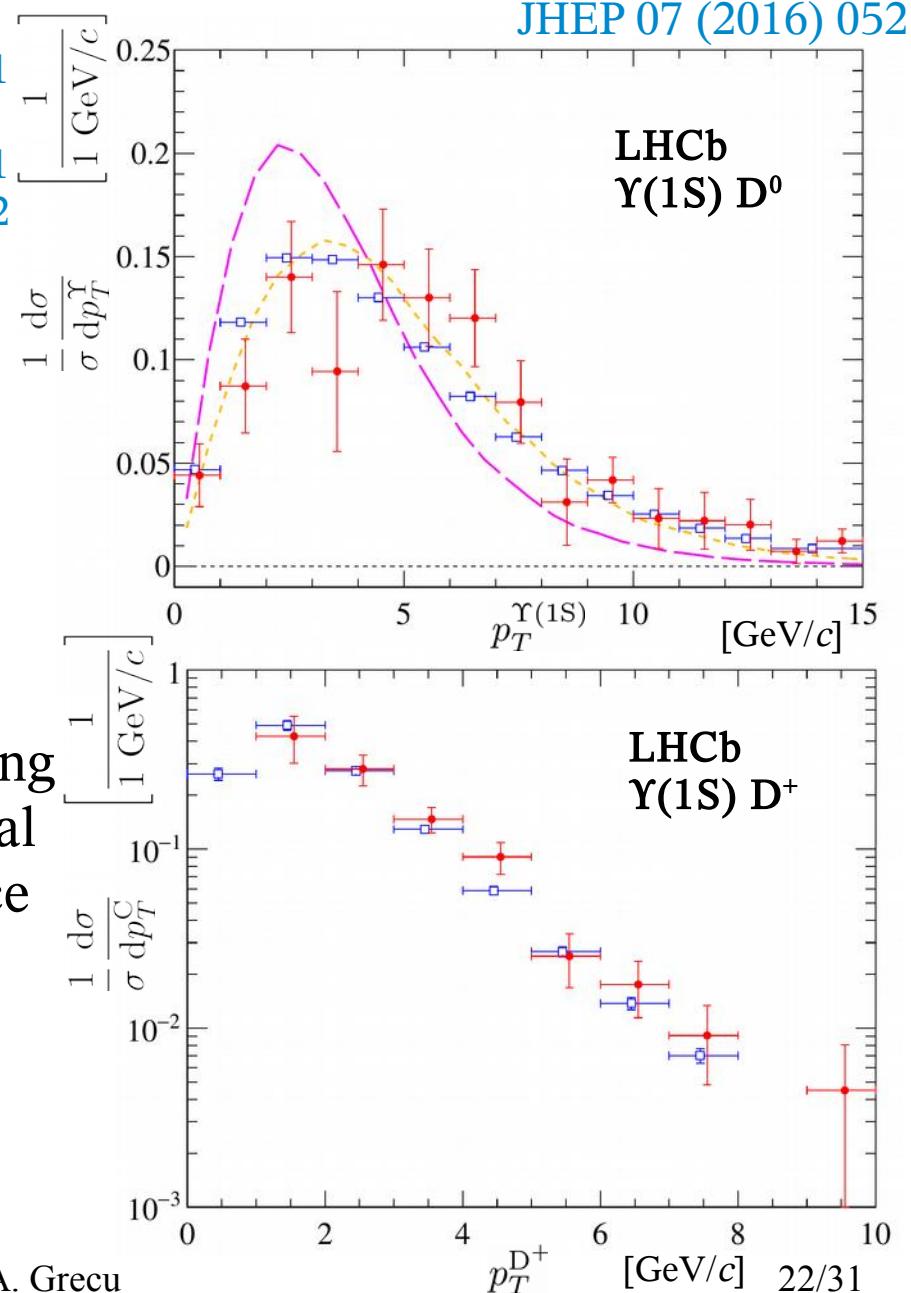


Heavy Flavour – Associated Production

- Z boson + D meson @ 7 TeV JHEP 04 (2014) 091
PLB 707 (2012) 52
- J/ ψ pair @ 7 TeV JHEP 06 (2012) 141
JHEP 07 (2016) 052
- Charmonium + open charm hadron @ 7 TeV
- Υ + open charm hadron @ 7 & 8 TeV

- Measurements support double parton scattering (DPS) production mechanisms over traditional single parton scattering (SPS) ones. Reference for validating implementation of DPS production mechanisms.

[blue dots – DPS, curves – SPS predictions]



Conclusions & Outlook

- Unique fiducial volume at LHC experiments
- Plethora of measurements to be used as reference in event generator tuning
- Future measurements in the light and heavy flavour sectors – ensure a better description of flavour production in the forward region
- Strong program of precise EW measurements providing stricter limits on proton PDFs at low/high x -Björken
- LHCb heavy flavour production measurements provide valuable input in optimizing and developing fragmentation and hadronisation models in this sector. Tunes may be specific to forward region (due to model implementation).
- More measurements to follow:
 - inclusive b-hadron production @ 7 and 13 TeV
 - prompt charm production @ 5 TeV
 - central exclusive production of J/ψ and $\psi(2S)$ @ 13 TeV
- ...

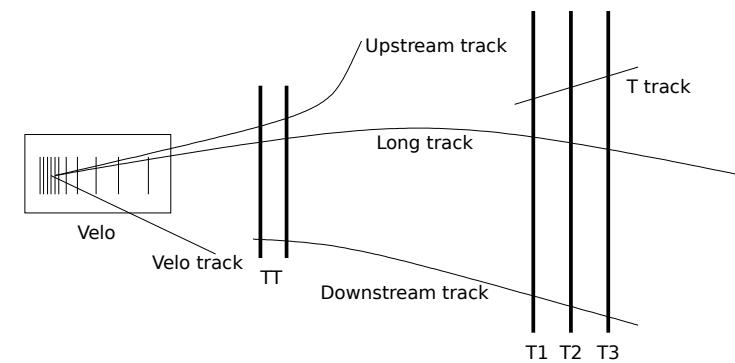
Thank you!

BACKUPS

The LHCb Detector Performance

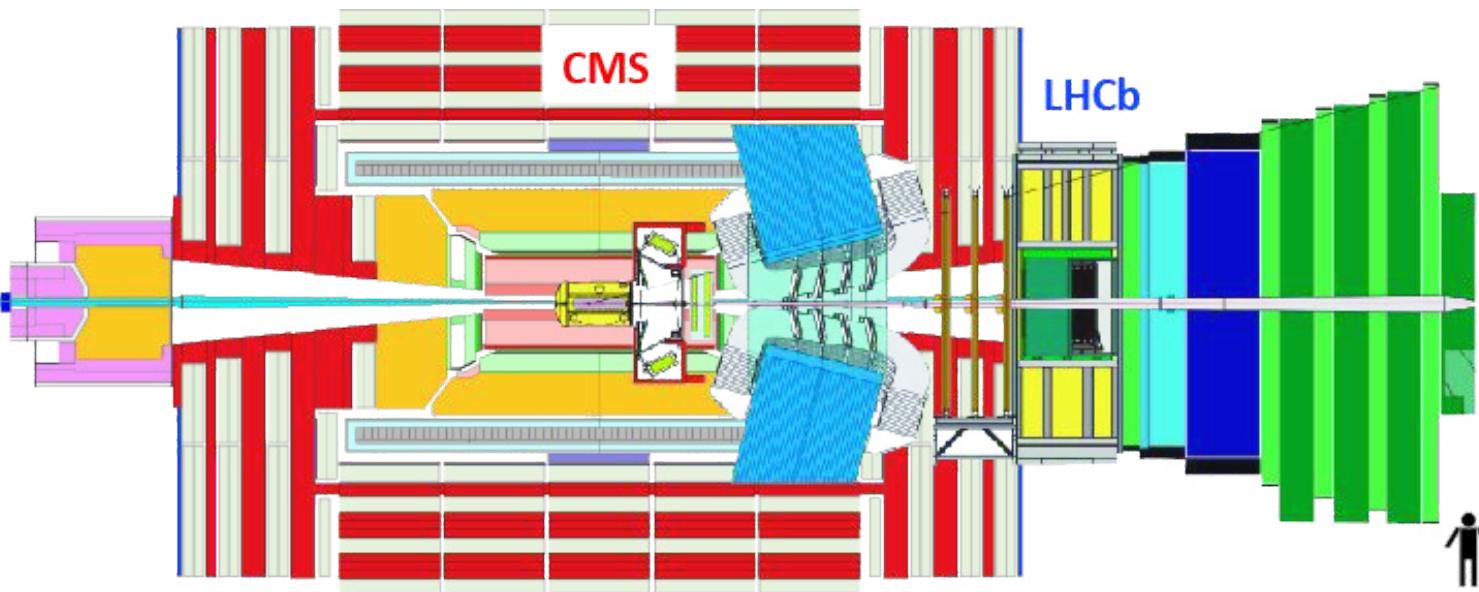
IJMP A30 (2015) 1530022

- Impact Parameter (IP) resolution: $(15 + 29/p_T[\text{GeV}/c]) \mu\text{m}$, i.e., $\sim 20 \mu\text{m}$ at high p_T
- Momentum resolution: $\Delta p/p \sim 0.5\%$ ($p < 20 \text{ GeV}/c$) $\rightarrow 1.0\%$ ($p \sim 200 \text{ GeV}/c$)
- ECAL resolution (nominal): $1\% + 10\%/\sqrt{E[\text{GeV}]}$
- Invariant mass resolution:
 - $\sim 8 \text{ MeV}/c^2$ for $B \rightarrow J/\psi X$ decays with constraint on J/ψ mass
 - $\sim 22 \text{ MeV}/c^2$ for two-body B decays
 - $\sim 100 \text{ MeV}/c^2$ for $B_s \rightarrow \phi \gamma$, dominated by photon contribution
- Trigger efficiencies:
 - $\sim 90\%$ for dimuon channels
 - $\sim 30\%$ for multi-body hadronic final states
- Track reconstruction efficiency: $\sim 96\%$ for Long Tracks
- Particle ID efficiency:
 - Electron ID $\sim 90\%$ for $\sim 5\%$ $e \rightarrow h$ mis-id probability
 - Kaon ID $\sim 95\%$ for $\sim 5\%$ $\pi \rightarrow K$ mis-id probability
 - Muon ID $\sim 97\%$ for 1-3% $\pi \rightarrow \mu$ mis-id probability
- Integrated luminosity for datasets:
 - 7 TeV (2011): $1.0/\text{fb} \pm 1.7\%$
 - 8 TeV (2012): $2.0/\text{fb} \pm 1.2\%$
 - 13 TeV (2015): $0.3/\text{fb} \pm 3.9\%$ (to improve in 2016)
- Data taking efficiency: 90% (99% good for physics analyses)



The LHCb Detector & Data Samples

Extends central detectors phase coverage at LHC.



Integrated luminosity

LHC Run I

2010: 37 pb^{-1} 2011: 1.0 fb^{-1} 2012: 2 fb^{-1}

LHC Run II

2015: 1.0 fb^{-1} 2016: $>250 \text{ pb}^{-1}$

Event Generator Tunes & Theoretical Models

★ PYTHIA 6.4

T. Sjöstrand, S. Mrenna, P. Skands, JHEP **05** (2006) 026

LHCb MC tune (GAUSS: PYTHIA6.4+EVTGEN+PHOTOS)

I. Belyaev *et al.*, Nuclear Science Symposium Conference Record (NSS/MIC)
(IEEE, New York 2010), p. 1155

Perugia0, PerugiaNOCR, Perugia 2010 tunes

P. Z. Skands, Phys. Rev. D **82** (Oct, 2010) 074018

★ PYTHIA 8.1

T. Sjöstrand, S. Mrenna, P. Skands, Comput. Phys. Commun. **178** (2008) 850

★ Cosmic-ray models:

EPOS:

T. Pierog and K. Werner, Nucl. Phys. Proc. Suppl. **196** (2009) 102

QGSJET:

S. Ostapchenko, Status of QGSJET, AIP Conf. Proc. **928** (2007) 118

SYBILL:

E.-J. Ahn *et al.*, Phys. Rev. D **80** (2009) 094003

★ Other Monte Carlo Event Generators and Theoretical Models:

PHOJET:

R. Engel, Z. Phys. C **66** (1995) 203; doi

HERWIG++:

M. Bahr *et al.*, Eur. Phys. J. C **58** (2008) 639-707; doi

SUPERCHIC:

L.A. Harland-Lang, V.A. Khoze, M.G. Ryskin, W.J. Stirling,
Eur. Phys. J. C **65** (2010) 433

STARLIGHT:

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

G&M model: V.P. Gonçalves and M.V.T. Machado, Phys. Rev. C **84** (2011) 011902; arXiv:1106.3036

Sch&S model: W. Schäfer and A. Szczerba, Phys. Rev. D **76** (2007) 094014; arXiv:0705:2887

JMRT model: Jones S., Martin A., Ryskin M. and Teubner T., JHEP **11** (2013) 085

RIVET/HEPData – LHCb Measurements I

Legend:

- **text** - record/AM exists
- **text** - possible RIVET code name for AM

Nr.	Title	HepData	RIVET AM
1	Prompt K_s^0 production in pp collisions at $\sqrt{s} = 0.9$ TeV [PLB 693 (2010) 69-80]	0k	LHCB-2010-S8758301
2	Measurement of $\sigma(pp \rightarrow b\bar{b}X)$ at $\sqrt{s} = 7$ TeV in the forward region [PLB 694 (2010) 209-216]	0k	LHCB-2010-I867355
3	Measurement of J/ψ production in pp collisions at $\sqrt{s} = 7$ TeV [EPJ C71 (2011) 1645]	0k	LHCB-2011-I891233
4	Measurement of V^0 production ratios in pp collisions at $\sqrt{s} = 0.9$ and 7 TeV [JHEP 08 (2011) 034]	0k	LHCB-2011-I917009
5	Measurement of the inclusive ϕ cross-section in pp collisions at $\sqrt{s} = 7$ TeV [PLB 703 (2011) 267-273]	0k	LHCB-2011-I919315
6	Measurement of charged particle multiplicities in pp collisions at $\sqrt{s} = 7$ TeV in the forward region [EPJ C72 (2012) 1947]	0k	LHCB-2012-I1082369
7	Observation of J/ψ pair production in pp collisions at $\sqrt{s} = 7$ TeV [PLB 707 (2012) 52-59]	0k	LHCB-2012-I926280
8	Measurement of the cross-section ratio $\sigma(\chi_{c2})/\sigma(\chi_{c1})$ for prompt χ_c production at $\sqrt{s} = 7$ TeV [PLB 714 (2012) 215-223]	0k	LHCB-2012-I1087907
9	Measurement of the ratio of prompt χ_c to J/ψ production in pp collisions at $\sqrt{s} = 7$ TeV [PLB 718 (2012) 431-440]	0k	LHCB-2012-I1107645
10	Measurement of Upsilon production in pp collisions at $\sqrt{s} = 7$ TeV [EPJ C72 (2012) 2025]	0k	LHCB-2012-I1091071
11	Measurement of prompt hadron production ratios in pp collisions at $\sqrt{s} = 0.9$ and 7 TeV [EPJ C72 (2012) 2168]	0k	LHCB-2012-I1119400
12	Measurement of the B^\pm production cross-section in pp collisions at $\sqrt{s} = 7$ TeV [JHEP 04 (2012) 093]	0k	LHCB-2012-I1089993
14	Measurement of the forward energy flow in pp collisions at $\sqrt{s} = 7$ TeV [EPJ C73 (2013) 2421]	0k	LHCB-2013-I1208105
15	Measurement of the cross-section for $Z \rightarrow e^+ e^-$ production in pp collisions at $\sqrt{s} = 7$ TeV [JHEP 02 (2013) 106]	0k	LHCB-2012-I1208102

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RIVET/HEPData – LHCb Measurements II

Nr.	Title	HepData	RIVET AM
16	Prompt charm production in pp collisions at $\text{sqrt}(s)=7 \text{ TeV}$ [NPB 871 (2013) 1-20]	0k	LHCb-2013-I1218996
17	Exclusive J/ψ and $\psi(2S)$ production in pp collisions at $\sqrt{s} = 7 \text{ TeV}$ [JPG 40 (2013) 045001]	0k	LHCb-2013-I1216886
18	Measurement of B meson production cross-sections in proton-proton collisions at $\sqrt{s} = 7 \text{ TeV}$ [JHEP 08 (2013) 117]	0k	LHCb-2013-I1238809
19	Measurement of J/ψ polarization in pp collisions at $\sqrt{s} = 7 \text{ TeV}$ [EPJ C73 (2013) 2631]	0k	LHCb-2013-I1244315
20	Production of J/ψ and Υ mesons in pp collisions at $\sqrt{s} = 8 \text{ TeV}$ [JHEP 06 (2013) 064]	0k	LHCb-2013-I1230344
21	Measurement of the relative rate of prompt χ_{c0} , χ_{c1} and χ_{c2} production at $\sqrt{s} = 7 \text{ TeV}$ [JHEP 10 (2013) 115]	0k	LHCb-2013-I1242869
22	Study of J/ψ production and cold nuclear matter effects in pPb collisions at $\sqrt{s_{NN}} = 5 \text{ TeV}$ [JHEP 02 (2014) 072]	0k	LHCb-2014-I1251899
23	Updated measurements of exclusive J/ψ and $\psi(2S)$ production cross-sections in pp collisions at $\sqrt{s} = 7 \text{ TeV}$ [JPG 41 (2014) 055002]	0k	LHCb-2014-I1277076
24	Observation of associated production of a Z boson with a D meson in the forward region [JHEP 04 (2014) 091]	0k	LHCb-2014-I1277075
25	Measurement of Υ production in pp collisions at $\sqrt{s} = 2.76 \text{ TeV}$ [EPJ C74 (2014) 2835]	0k	LHCb-2014-I1280929
26	Measurement of $\psi(2S)$ polarisation in pp collisions at $\sqrt{s} = 7 \text{ TeV}$ [EPJ C74 (2014) 2872]	0k	LHCb-2014-I1283844
27	Measurement of charged particle multiplicities and densities in pp collisions at $\sqrt{s} = 7 \text{ TeV}$ in the forward region [EPJ C74 (2014) 2888]	0k	LHCb-2014-I1281685
28	Study of Υ production and cold nuclear matter effects in pPb collisions at $\sqrt{s_{NN}}=5 \text{ TeV}$ [JHEP 07 (2014) 094]	0k	LHCb-2014-I1297230
29	Observation of Z production in proton-lead collisions at LHCb [JHEP 09 (2014) 030]	0k	LHCb-2014-I1300150
30	Measurement of B_c^+ production in proton-proton collisions at $\sqrt{s} = 8 \text{ TeV}$ [PRL 114 (2015) 132001]	0k	LHCb-2015-I1327230
31	Measurement of the inelastic pp cross-section at a centre-of-mass energy of $\sqrt{s} = 7 \text{ TeV}$ [JHEP 02 (2015) 129]	0k	LHCb-2015-I1333223
32	Measurement of the exclusive Υ production cross-section in pp collisions at $\sqrt{s} = 7 \text{ TeV}$ and 8 TeV [JHEP 09 (2015) 084]	0k	LHCb-2015-I1373746
34	Measurement of forward J/ψ production cross-sections in pp collisions at $\sqrt{s} = 13 \text{ TeV}$ [JHEP 10 (2015) 172]	0k	LHCb-2015-I1391511

RIVET/HEPData – LHCb Measurements III

Nr.	Title	HepData	RIVET AM
35	Measurements of prompt charm production cross-sections in pp collisions at $\sqrt{s} = 13$ TeV [JHEP 03 (2016) 159]	0k	LHCb-2016-I1396331
36	Forward production of Υ mesons in pp collisions at $\sqrt{s} = 7$ and 8TeV [JHEP 11 (2015) 103]	0k	LHCb-2015-I1392456
37	Production of associated Υ and open charm hadrons in pp collisions at $\sqrt{s} = 7$ and 8 TeV via double parton scattering [JHEP 07 (2016) 052]	0k	LHCb-2016-I1399056
38	Measurement of forward W and Z boson production in pp collisions at $\sqrt{s} = 8$ TeV [JHEP 01 (2016) 155]	0k	LHCb-2016-I1406555
40	Measurement of the forward Z boson production cross-section in pp collisions at $\sqrt{s} = 13$ TeV [arXiv:1607.06495]	no	LHCb-2016-I1477581
41	Measurement of the forward Z boson production cross-section in pp collisions at $\sqrt{s} = 7$ TeV [JHEP 08 (2015) 039]	0k	LHCb-2015-I1373300
42	Measurement of forward $Z \rightarrow e^+e^-$ production at $\sqrt{s} = 8$ TeV [JHEP 05 (2015) 109]	0k	LHCb-2015-I1347133