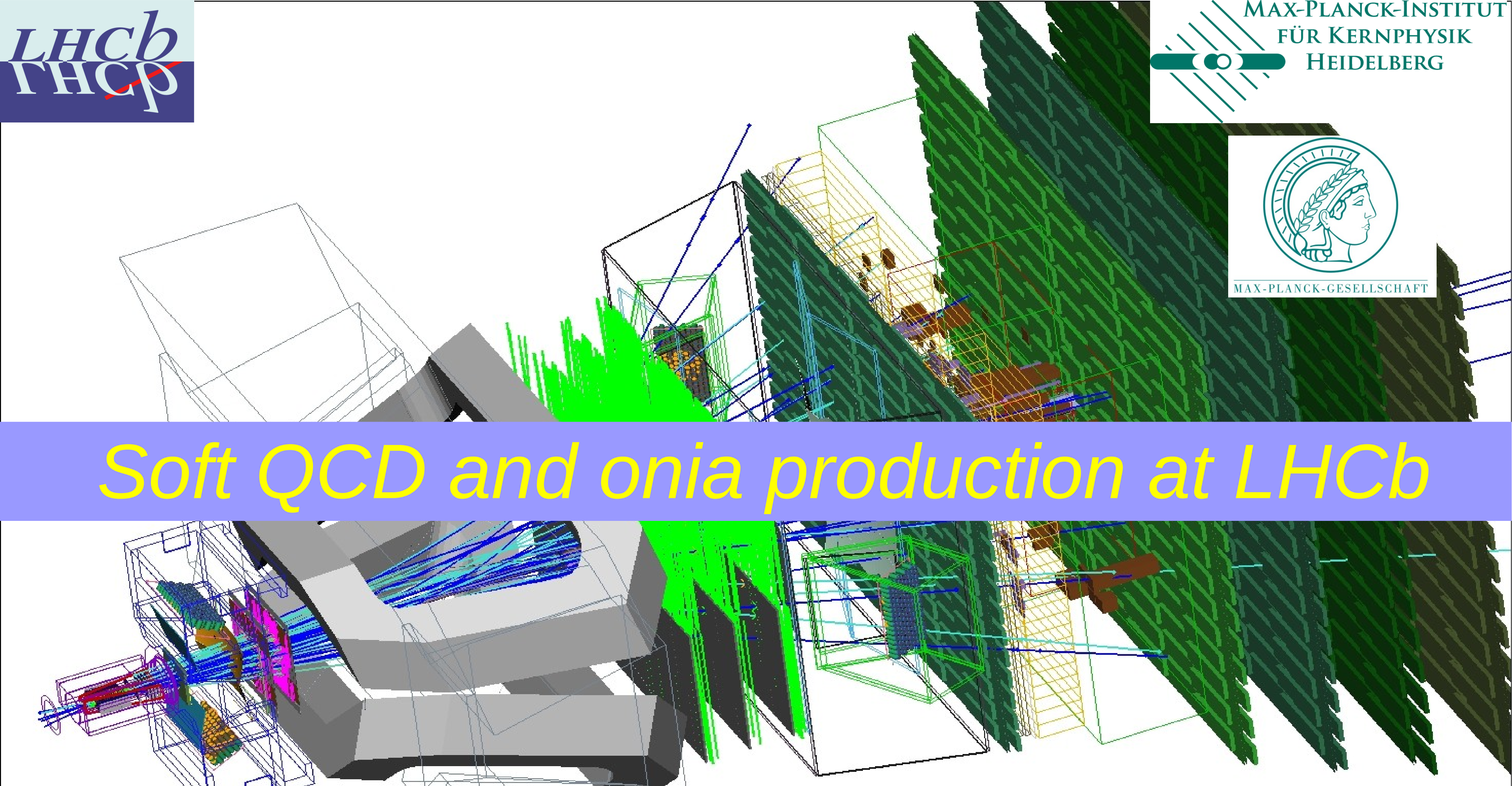


Soft QCD and onia production at LHCb

Dmytro Volyanskyy
Max-Planck-Institut für Kernphysik (Heidelberg, Germany)
on behalf of the LHCb collaboration

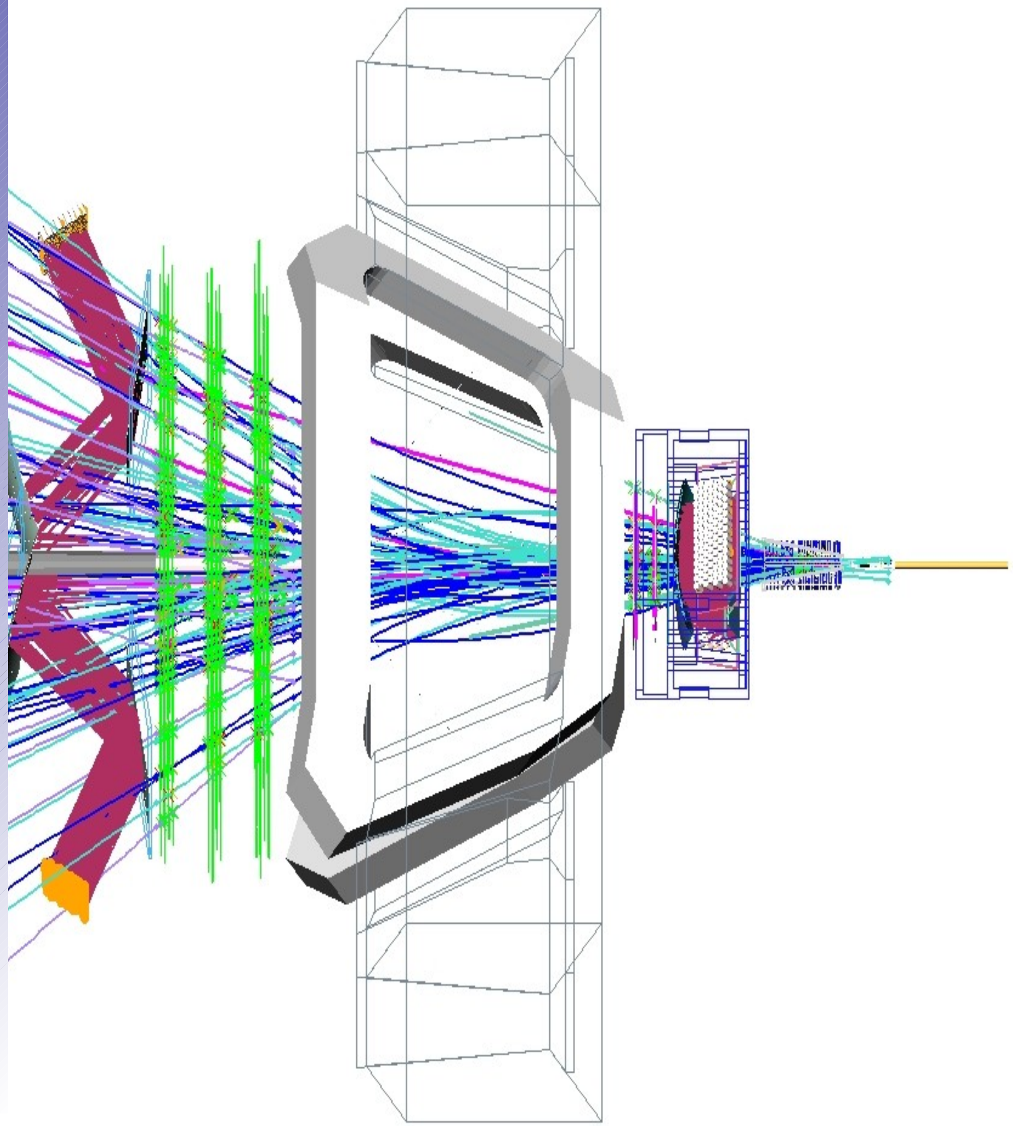
6th International Workshop on Quantum Chromodynamics – Theory and Experiment (QCD@Work 2012), 18–21 June 2012, Lecce, Italy

Outline

- *LHCb and its current status*
- *Selected results:*

  → energy flow measurements
  → charged particle multiplicities
  → charmonia production
  → double J/ψ and J/ψ+open charm
  → χ_c and B_c production
  → excited Λ_b^0 baryons

- *Summary*



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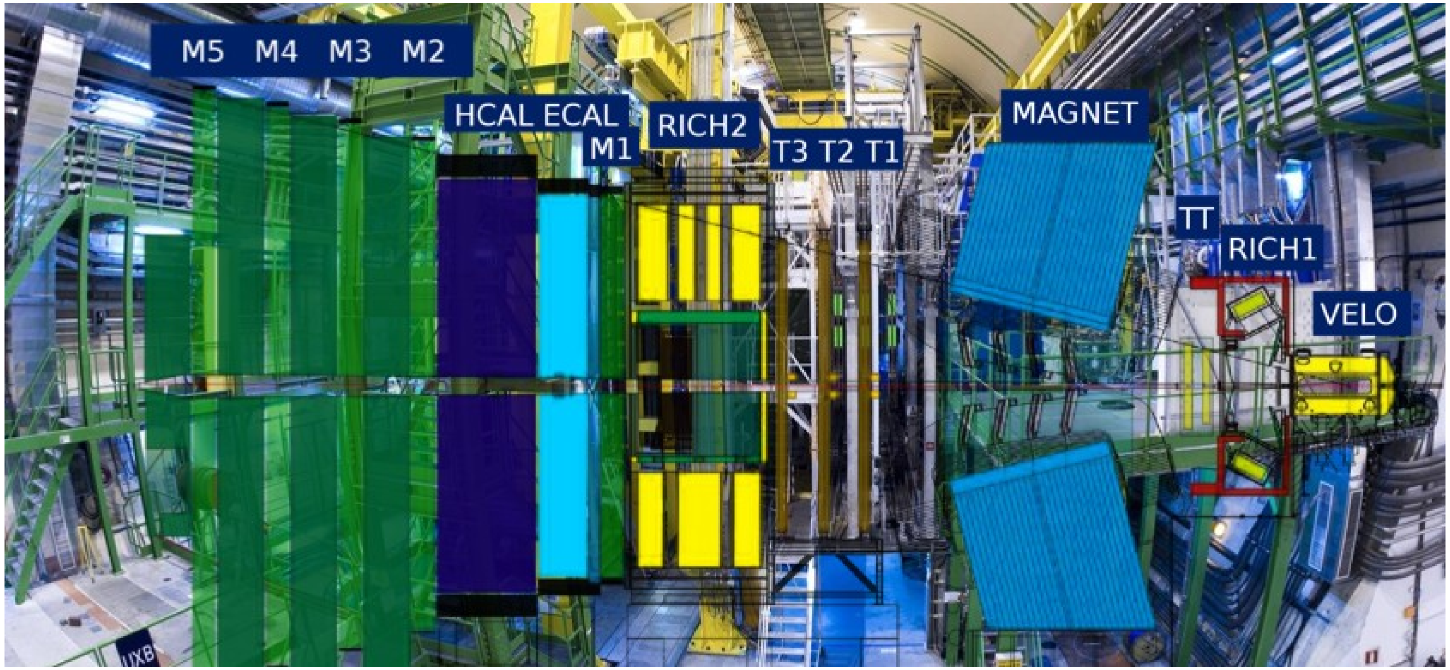
Run 71883 Event 6781700 bId 2186

LHCb experiment

- *One of the 4 main detectors at the LHC:*
  - → *CP violation, rare decays, New Physics searches*
- *Forward spectrometer with planar detectors:*
  - → *B hadrons at the LHC are produced at low polar angles*
  - → *angular coverage: $2 < \eta < 5$*
  - → *combination of PID and tracking detectors covering the full acceptance: unique@LHC*

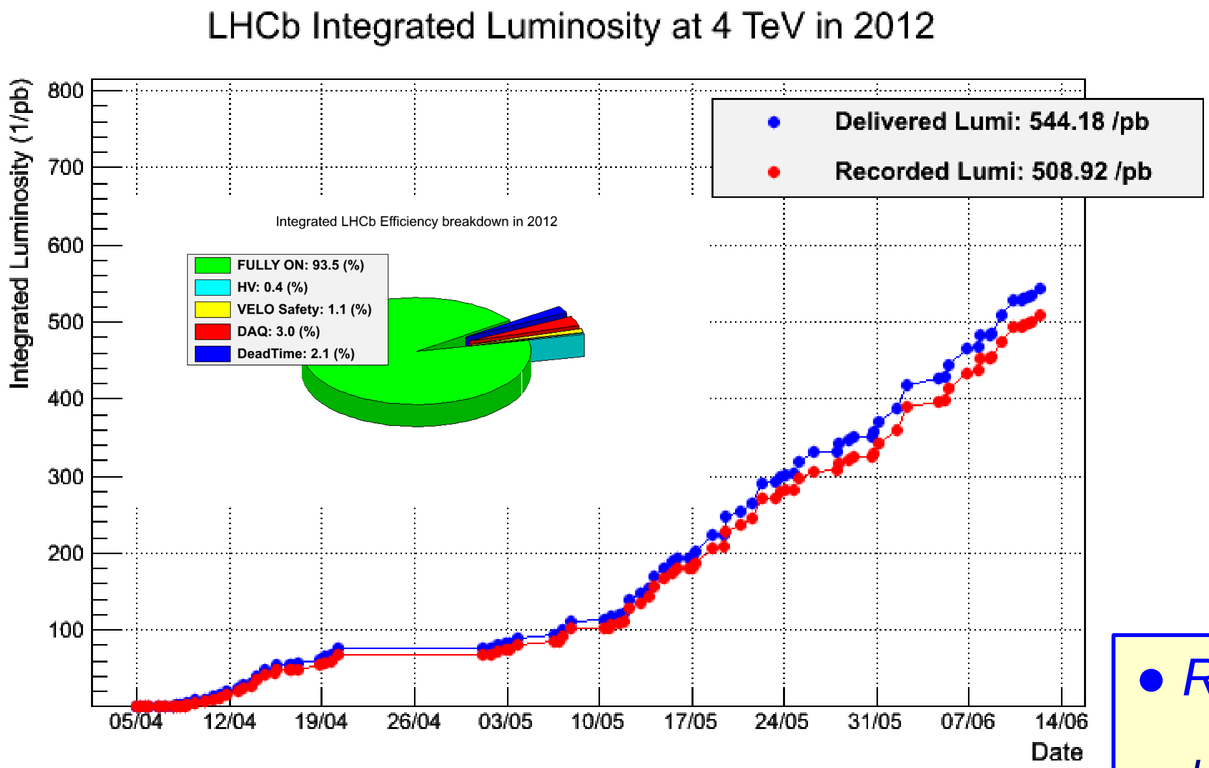


- *Excellent tracking performance:*
  - → *momentum resolution of long tracks traversing the full tracking setup $\delta p/p \sim$ 0.35–0.55%*
  - → *invariant mass resolution of ~10–20 MeV/c^2 depending on the B decay channel*
  - → *precise vertex reconstruction: proper time resolution for B hadrons < 50 fs*
- *Selective and flexible trigger system*

- *High quality particle identification:*
  - → *RICH system: efficient hadron ID over the wide momentum range – unique@LHC*
  - → *SPD/PS: robust e/γ and e/hadrons separation*
  - → *ECAL: e, γ energy measurements + trigger*
  - → *HCAL: hadron energies + trigger*
  - → *MUON: μ identification + trigger*

more info in Antonio Pellegrino's talk tomorrow

Data taking: 2009-2012



year	luminosity	energy (TeV)
2009	6.8 μb^{-1}	0.9
2010	0.3 nb^{-1}	0.9
2010	37 pb^{-1}	7
2011	0.1 pb^{-1}	2.76
2011	1.0 fb^{-1}	7
2012	1.5 fb^{-1} (exp.)	8

- *Good quality of recorded data:*
  → >95% of r/o channels are operational
- *Data taking efficiency > 90%*

- *Running challenges:*

→ *L_{ins} up to 4× 10^{32} cm^{-2} s^{-1} achieved in 2011 and 2012*

→ *LHCb design luminosity: L_{ins}=2.0 × 10^{32} cm^{-2} s^{-1}*

→ *Strong challenge for the trigger, offline reconstruction and data processing*

→ *LHCb successfully copes with these extreme running conditions*

- *LHCb, due to its rapidity coverage, explores particle production in an unique kinematic range:*

  → probes of PDFs at very low and at high values of x and low-Q^2

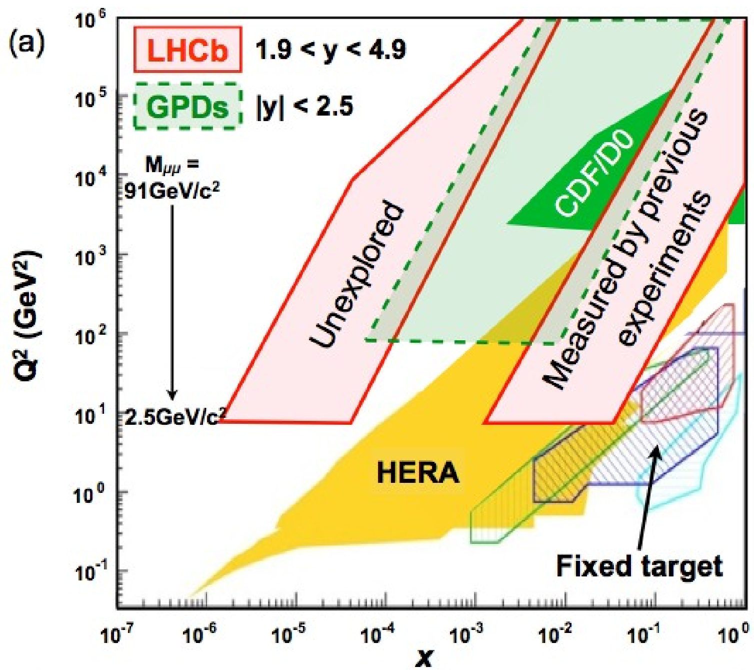
- *Ability to study low-p_T region (<0.5 GeV/c) at large η(>4)*

  → the only one LHC experiment that can investigate this region of the phase space

  → great potential to study soft QCD physics

- *Minimum Bias (MB) data dominated by soft QCD processes:*

  → LHCb MB trigger: at least 1 track-segment in the detector – 100% efficient for the majority of physics processes of interest



- *Onia production: Motivation*

  → robust test of pQCD, Color Octet & Color Singlet production mechanisms and MC generators

  → combination of Color Octet and Color Singlet describes p_T and cross sections measured at Tevatron, but the polarization remains an issue

  → Double-charm and high mass onia production studies should help

Forward Energy Flow: outline

- *Energy Flow (EF) :*

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

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average energy created in a particular η interval per inelastic pp interaction and normalized to the η bin size

- *EF directly sensitive to the amount of parton radiation and multi-parton interactions (MPI) at large η*
  - → *MPI features are still not well known: strongly needed for a precise description of the UE*
  - → *possibility to discriminate between MPI models and determine important parameters*
  - → *great input for MC tuning*
- *improve the existing constraints on ultra high energy cosmic-ray interaction models:*
  - → *LHC provides first possibility to compare cosmic-ray showering models at E_{lab} of up to ~10^{17}eV*
- *it has never been measured at a hadron collider in the pre-LHC era*

- *EF is measured in 1.9<η<4.9 with low pile-up pp MB data at 7 TeV for the following event classes:*
  - → *inclusive MB: at least 1 long track in 1.9<η<4.9 with p > 2 GeV/c*
  - → *hard scattering: at least 1 long track in 1.9<η<4.9 with p_T > 3 GeV/c*
  - → *diffractive enriched: inclusive MB with no backward tracks in −3.5<η<−1.5*
  - → *non-diffractive enriched: inclusive MB with at least 1 backward track in −3.5<η<−1.5*
- *Data corrected for detector effects & compared to the generator level predictions (PYTHIA-based and cosmic-ray models)*
- *Systematic effects: tracking related factors, model dependency, pile-up contamination*

Total EF vs PYTHIA tunes

- *EF increases with the momentum transfer in an underlying pp process:*
  $EF_{hard} > EF_{non\text{-}diffr} > EF_{incl} > EF_{diffr}$
- *PYTHIA tunes reproduce the EF evolution as a function of η*
- *PYTHIA-based models underestimate EF at large η and overestimate it at low η in case of all event classes:*
- *PYTHIA LHCb tune and Perugia NOCR predictions for the selected inclusive and non-diffractive enriched events are similar*
- *Perugia 0 significantly underestimates EF at large η in case of all event classes*
- *PYTHIA8 describes the diffractive enriched EF much better than PYTHIA6*

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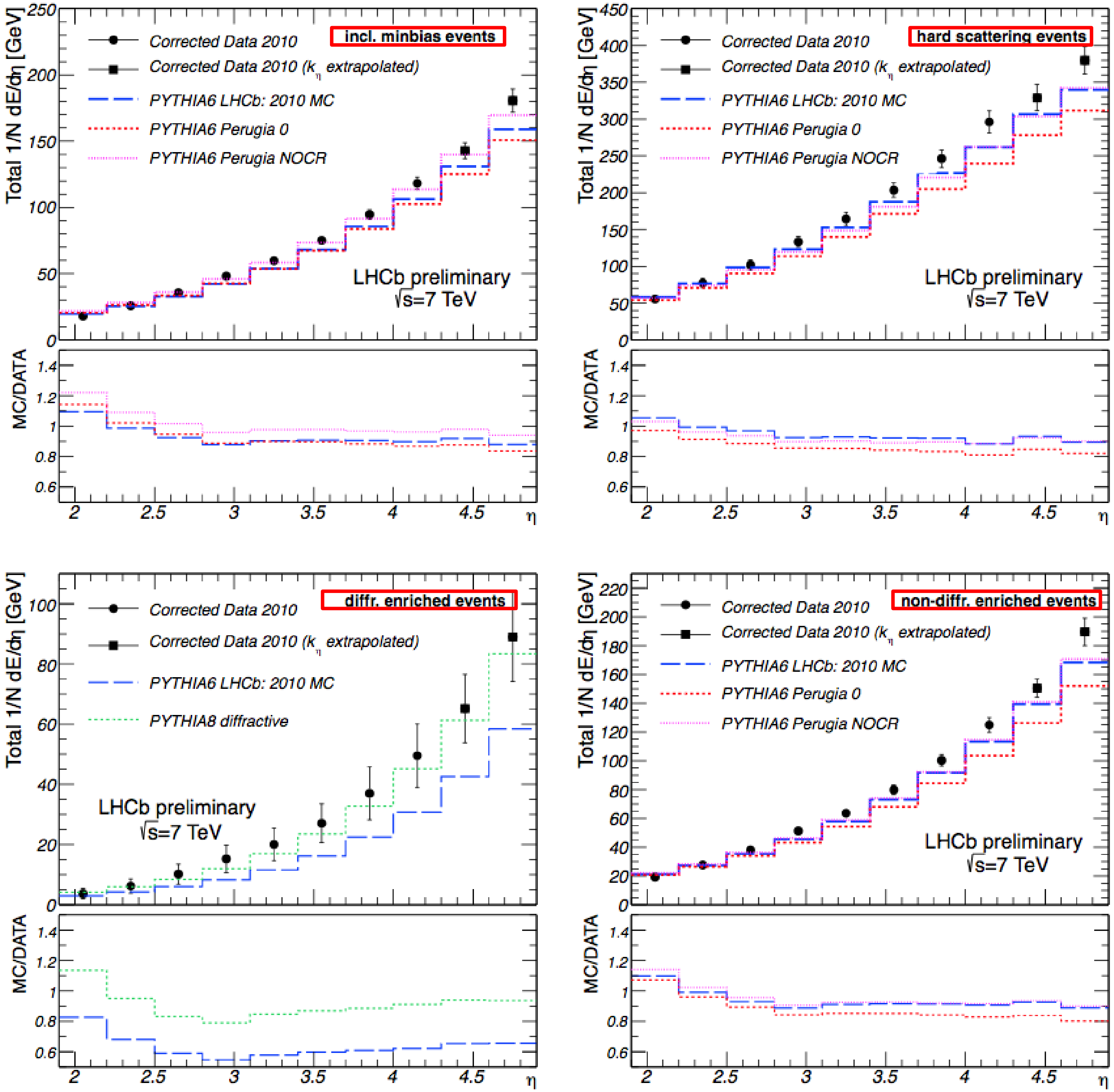

Total EF vs cosmic-ray models

- *EPOS 1.99, SYBILL 2.1, QGSJET01, QGSJETII cosmic ray interaction models*
  - → *soft processes via Pomeron exchanges (Gribov's Reggeon Field Theory)*
  - → *hard processes: pQCD or exchanges of semi-hard Pomerons*
  - → *models are not tuned to LHC data*
- *Good agreement between the data and QGSJETII prediction for the hard scattering EF at large η*
- *SYBILL 2.1 gives the best description of the inclusive and non-diffractive EF*
- *None of the models are able to describe the EF measurements for all event classes:*
  - → *valuable input for MC tuning and MPI/UE models*

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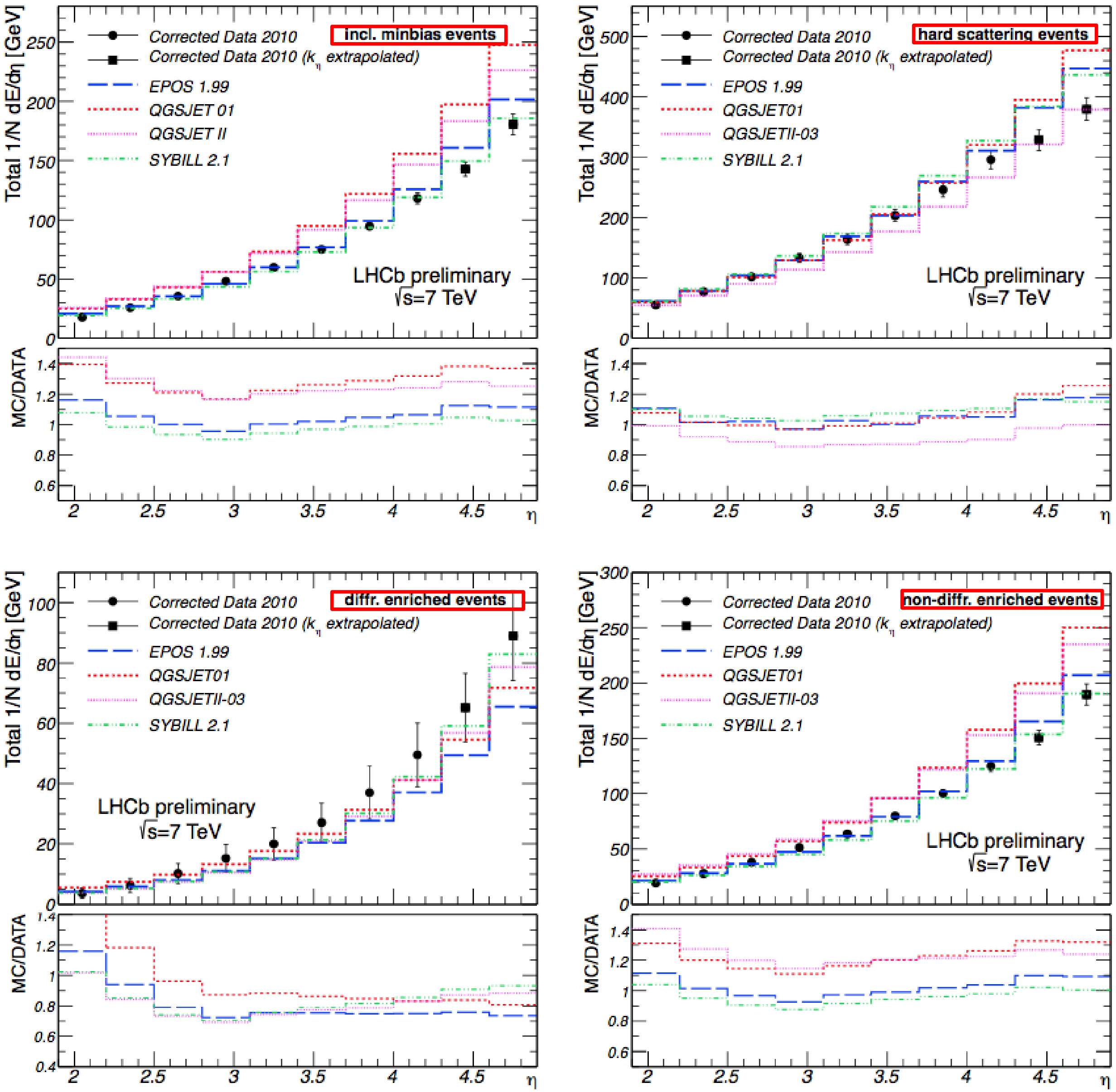
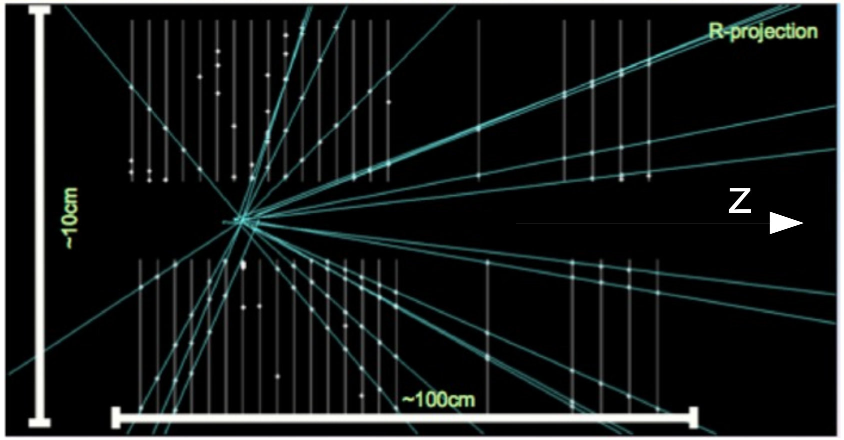


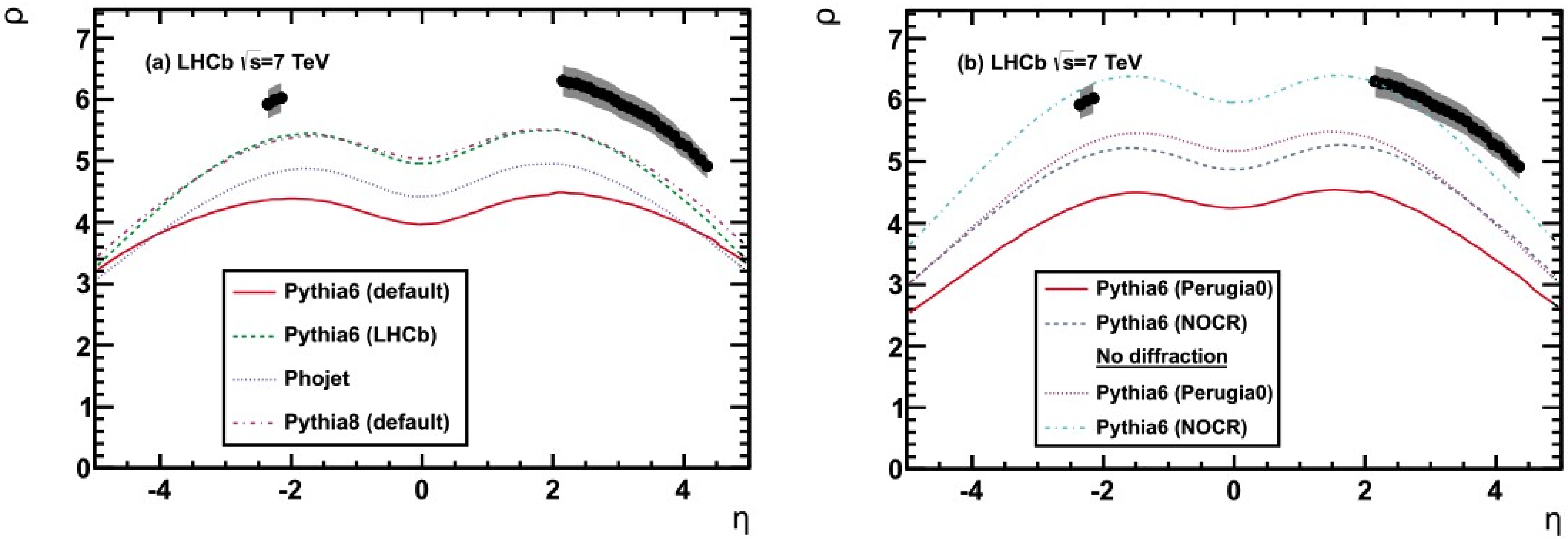
Charged Particle Multiplicities (1)

- *Measurement of the charged particle multiplicities :*
  - → *sensitivity to the underlying QCD dynamics*
  - → *charged particles counted using reconstructed tracks in the LHCb VELO:*
    - – *high detection efficiency for 2.0<η<4.5 and –2.5<η<–2.0*
    - – *tracks are straight lines in the VELO as no magnetic field there – no momentum measurements*
  - → *measurements with inclusive MB and hard QCD (at least 1 long track with p_T>1 GeV/c) events*



- *Charged particle density per event vs η for the data and models:*
  - → *normalized to events with at least 1 charged particle in the forward acceptance*

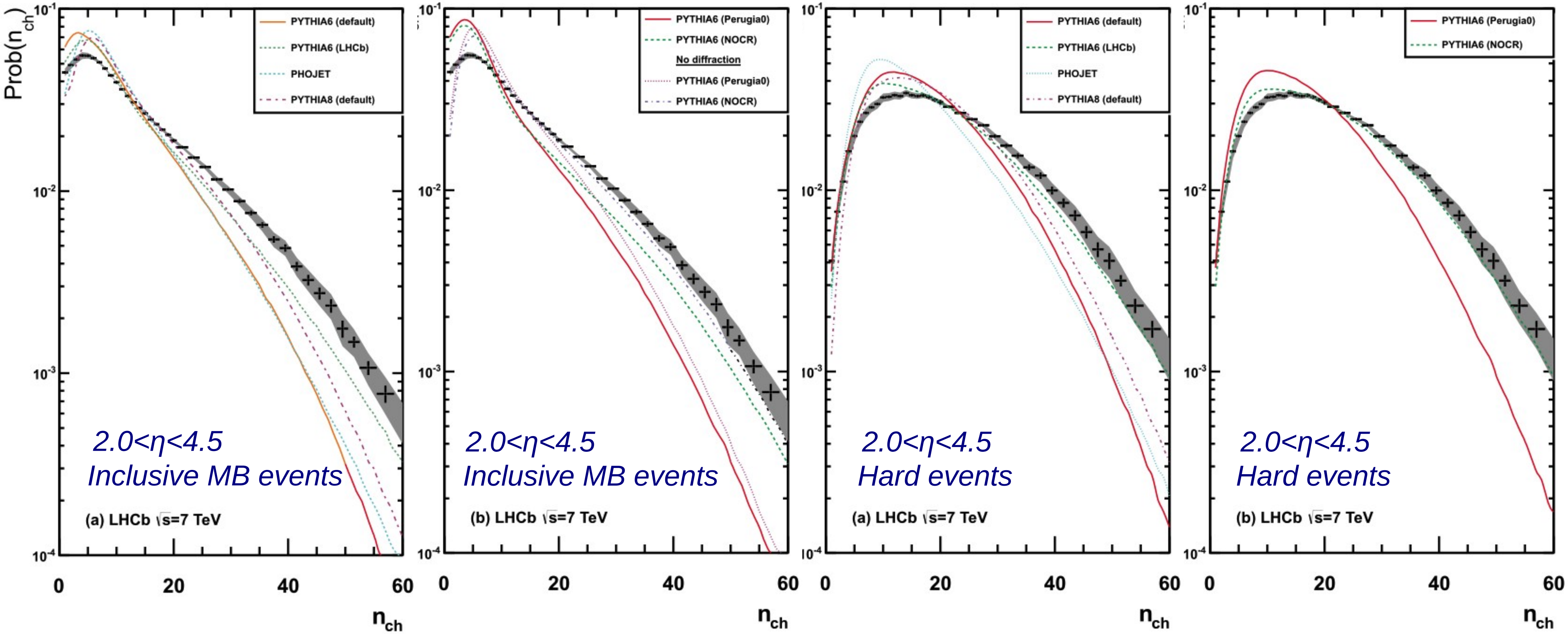
Eur. Phys. J. C 72 (2012) 1947



→ *large discrepancy between the data and model predictions: Perugia NOCR without diffraction gives the best description of the measurements*

Charged Particle Multiplicities (2)

- *multiplicity distributions for inclusive MB and hard events vs generator level predictions:*



Eur. Phys. J. C 72 (2012) 1947

- *none of the generators are fully able to describe the multiplicity distributions or the charged density distribution as a function of η in the LHCb acceptance*

- *models underestimate the charged particle production in the forward region*
  → valuable input for MC tuning and UE models

Other results on soft QCD: Highlights

- *Prompt Ks production in pp collisions at 0.9 TeV* — *Phys. Lett. B 693 (2010) 69-80*
  - → *differential cross-section measured for 2.5<y<4 and 0<p_T<1.6 GeV/c*
  - → *performed with 2009 data*
  - → *reasonable consistency with the predictions given by the PYTHIA-based models*

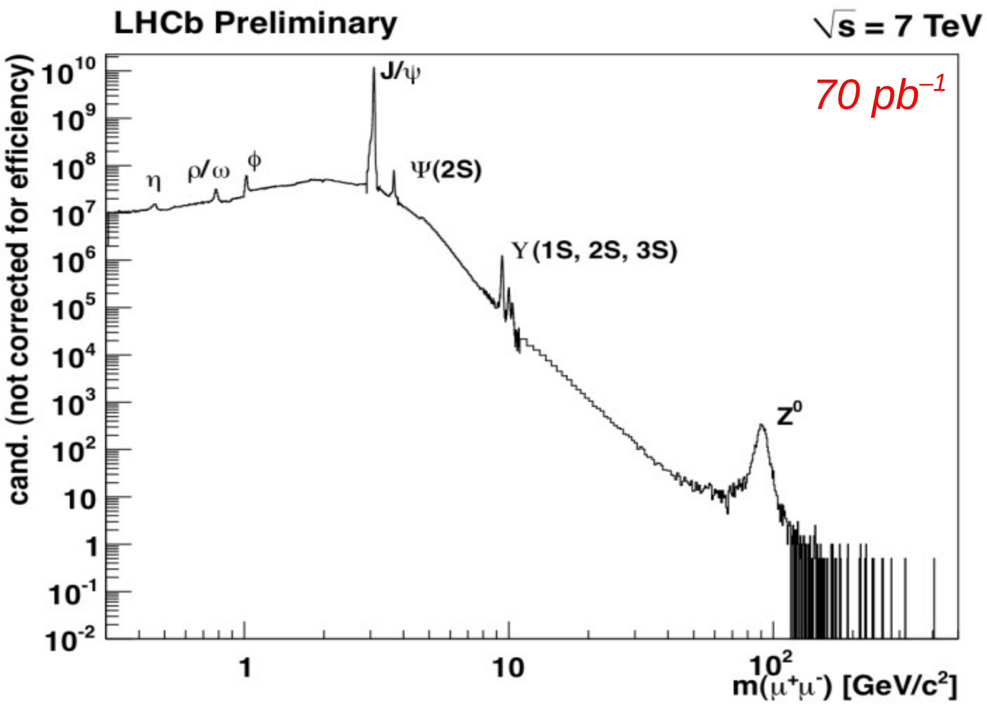
- *Inclusive ϕ cross-section in pp collisions at 7 TeV* — *Phys. Lett. B 703 (2011) 267-273*
  - → *differential cross-section measured for 2.44<y<4.06 and 0.6<p_T<5.0 GeV/c*
  - → *cross-section is significantly underestimated by the PYTHIA tunes across the entire phase space !*

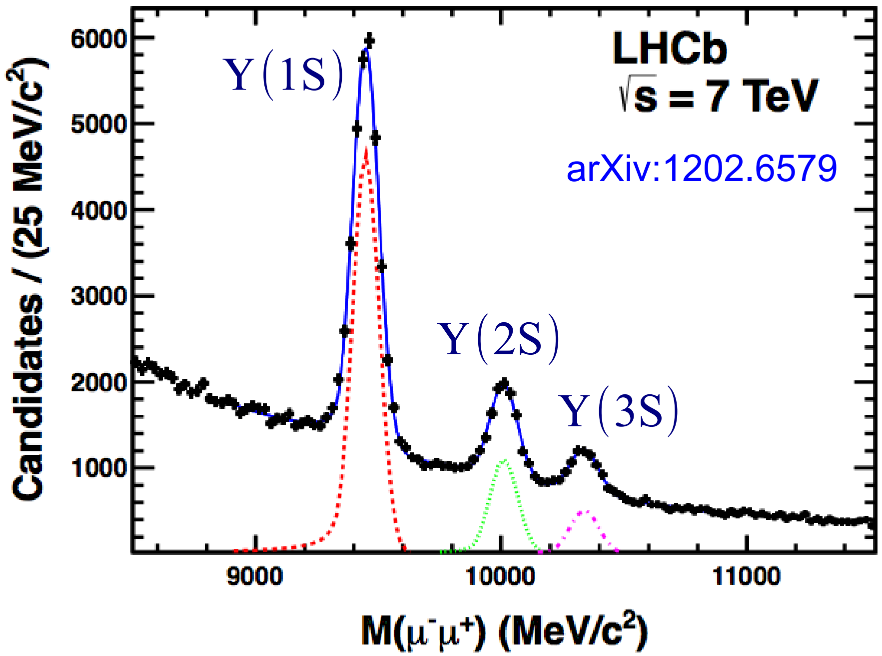
- *V0 production ratios in pp collisions at 0.9 and 7 TeV* — *J. High Energy Phys. 08 (2011) 034*
  - → *ratios measured for 2.0<y<4.5 and 0.15<p_T<2.5 GeV/c*
  - → *large discrepancy between the data and PYTHIA-based models*

- *Prompt hadron production ratios in pp collisions at 7 TeV* — *LHCb-PAPER-2011-037 (in preparation)*
  - → *ratios measured for 2.5<y<4.5 and p_T<1.2 GeV/c*
  - → *none of the PYTHIA-based models are able to describe all the measurements*

Charmonium to $\mu^+\mu^-$

- *dimuon mass spectra:*





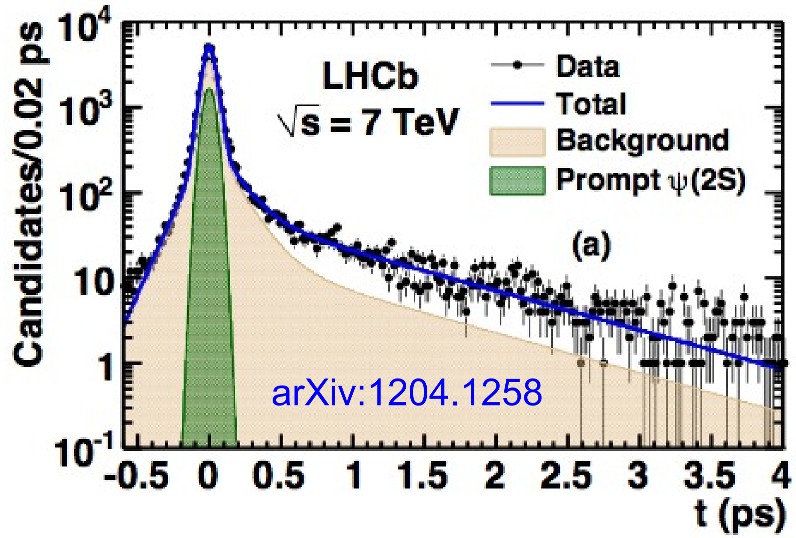
→ *mass resolutions:*

$J/\psi:\sim 12\,MeV/c^2 \quad \psi(2S):\sim 16\,MeV/c^2 \quad \Upsilon(1S):\sim 54\,MeV/c^2$

→ *total efficiency for dimuon channels at LHCb > 40%*

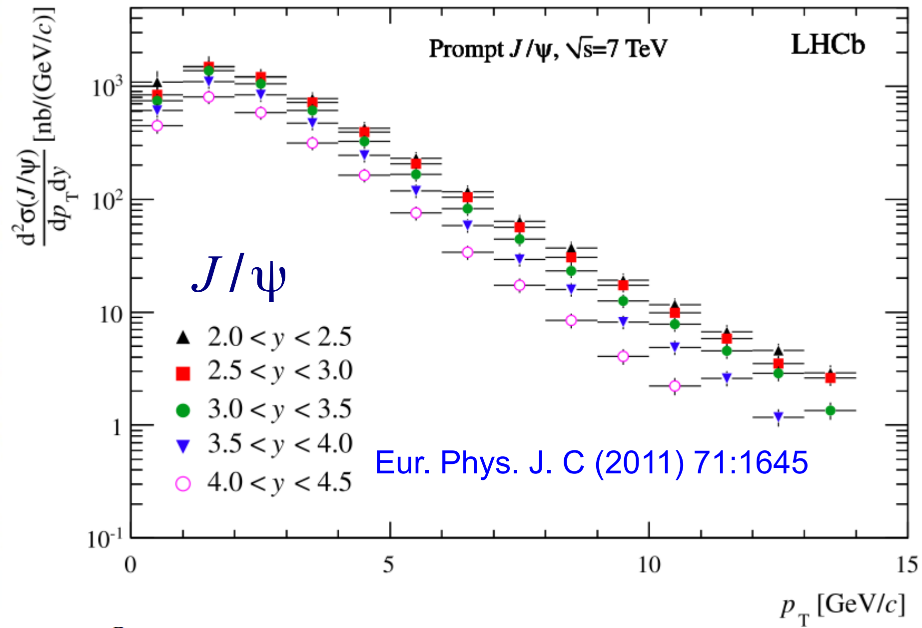
→ *promptly produced charmonia distinguished from the b-hadron decay products using:*

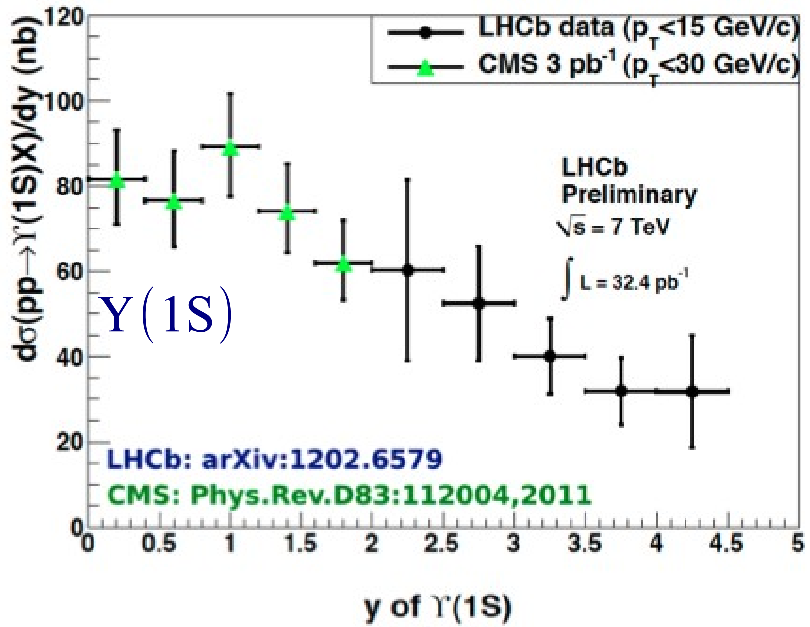
$$t=\frac{(z_{charm}-z_{PV})\,m_{charm}}{p_z}$$

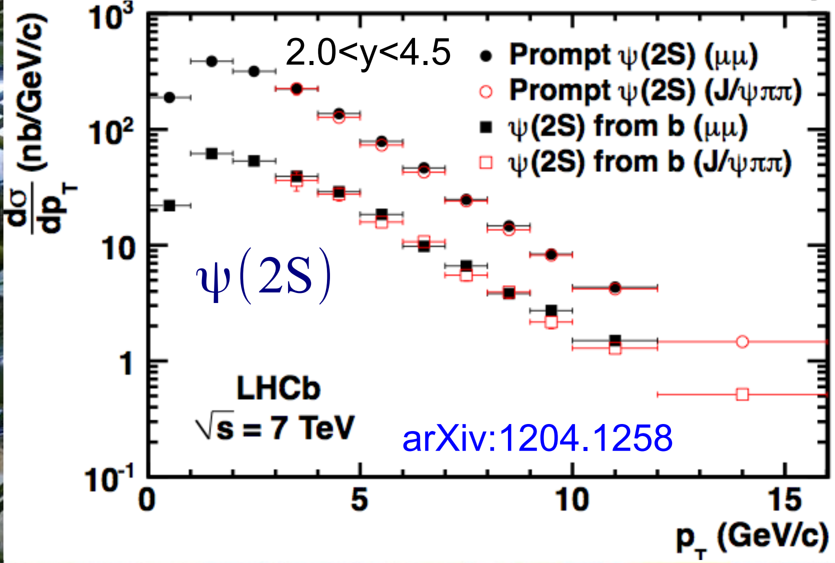


Charmonia production

- *Production cross sections assuming unpolarized states*

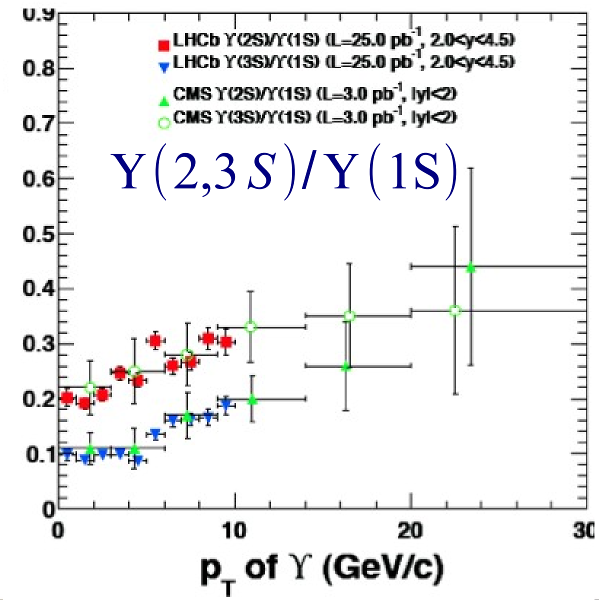




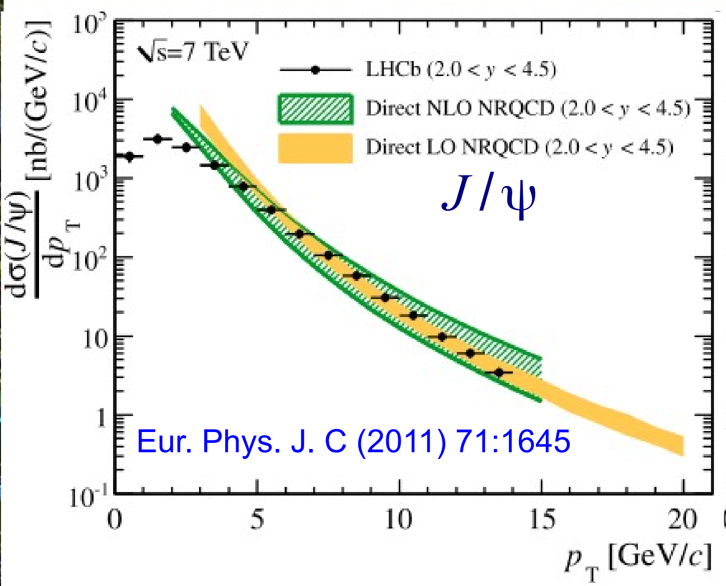


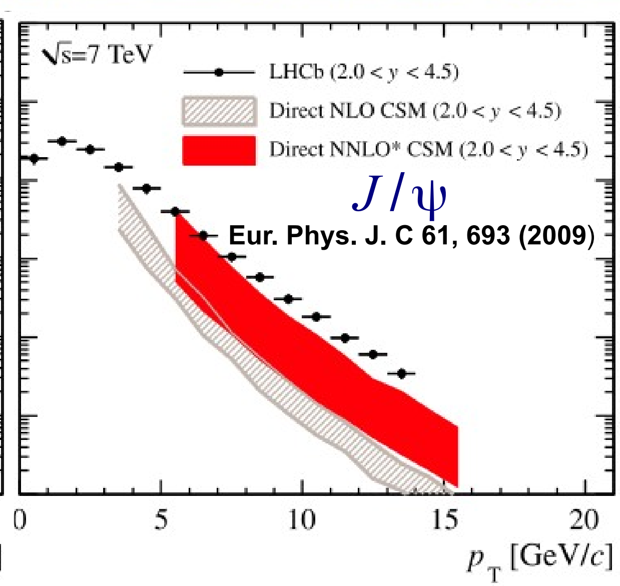
→ *good consistency between different decay channels of* $\psi(2S)$

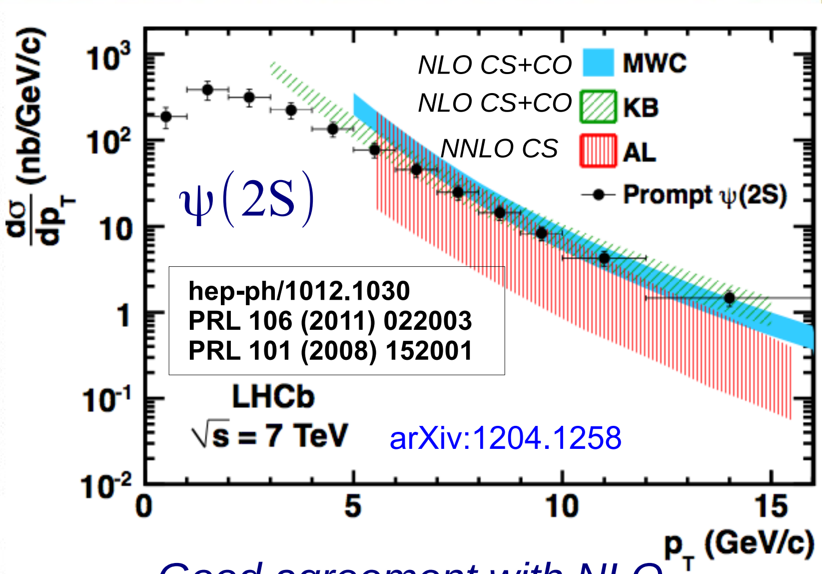
→ *LHCb and CMS results agree well for* $\Upsilon(nS)$



Charmonia production vs Theory



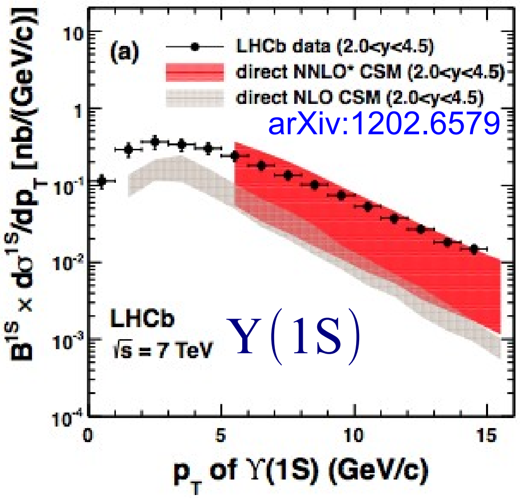


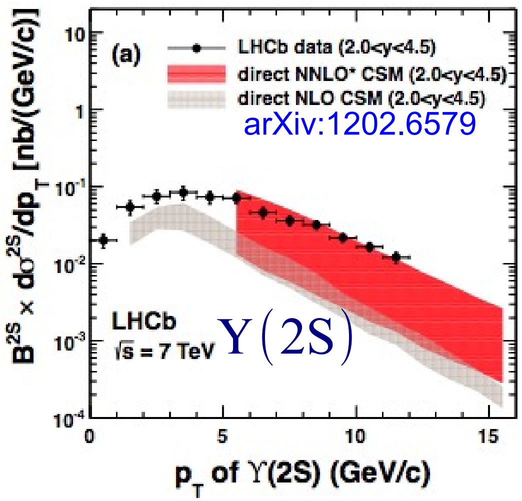


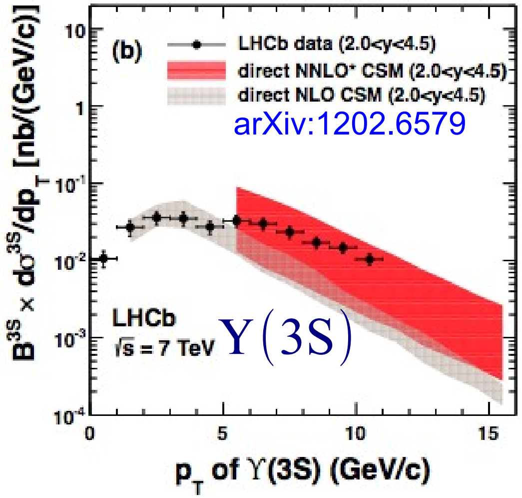
→ *(N)LO NRQCD describe the J/ψ cross section rather well (not the case for the (N)NLO CSM)*

→ *Good agreement with NLO calculations with color-singlet and color-octet contributions at large p_T*

→ *Reasonable agreement with NNLO CSM calculations for $\Upsilon(nS)$ states*







Double J/ψ production

- *$\sigma(J/\psi J/\psi)$ measured with 37.5 pb^{-1} for 2.0<y<4.5 and p_T< 10GeV/c*
  - *→ 2 J/ψ from a common vertex*
  - *→ 141 ± 19 events observed*
  - *→ statistical significance >6σ*

- *Potential enhancement of pp → J/ψJ/ψ+X from Double Parton Scattering (DPS) mechanism and intrinsic charm model (IC)*

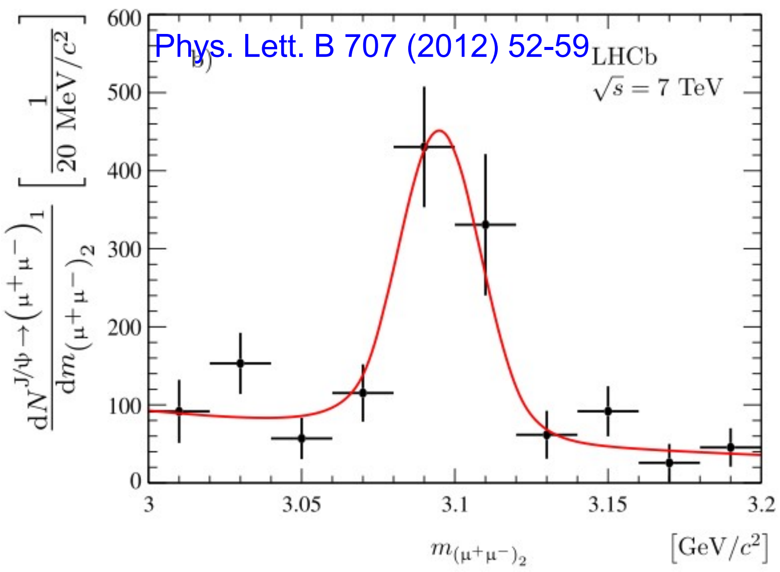
- *Results at 7 TeV for 2.0<y<4.5 and p_T< 10GeV/c*

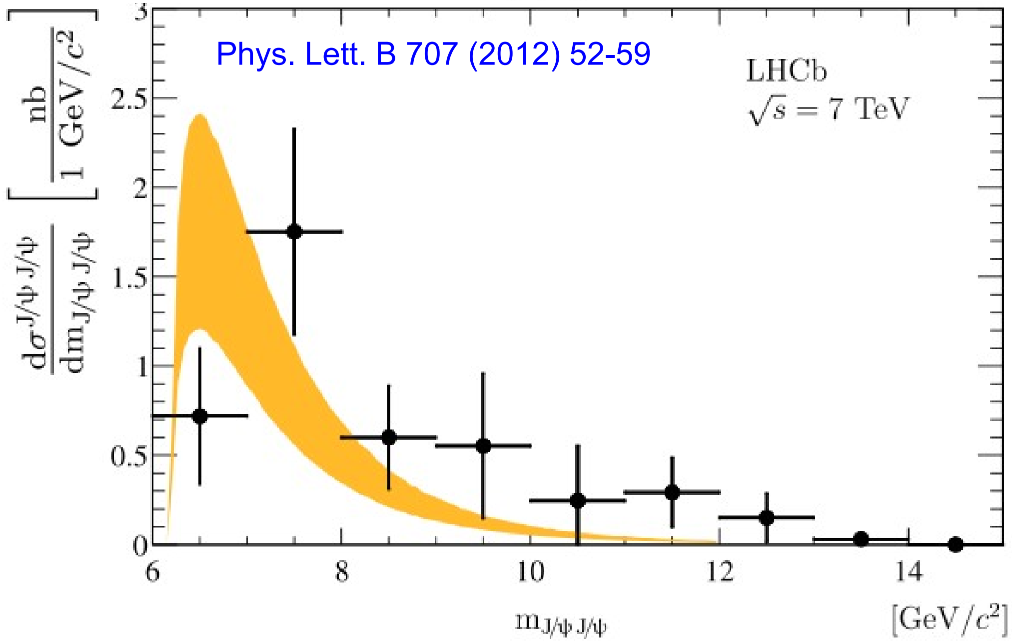
$$\sigma(J/\psi J/\psi) = 5.1 \pm 1.0(\text{stat}) \pm 1.1(\text{syst})\ \text{nb}$$

$$\frac{\sigma(J/\psi J/\psi)}{\sigma(J/\psi)} = [5.1 \pm 1.0(\text{stat}) \pm 0.6^{+1.2}_{-1.0}(\text{syst+polar})] \times 10^{-4}$$

→ Theory predictions:
L0 CS: $\sigma(J/\psi J/\psi)$ = 4 nb (arXiv:1204.1058)
DPS contribution: 2 nb (arXiv:1106.2184)

- *$\sigma(J/\psi J/\psi)$ vs invariant mass of both J/ψ: data vs theory:*
  - *→ more statistics is needed*



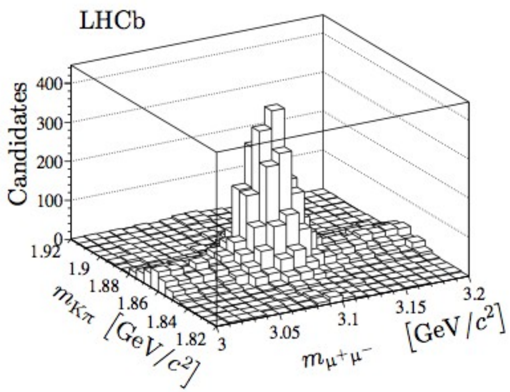


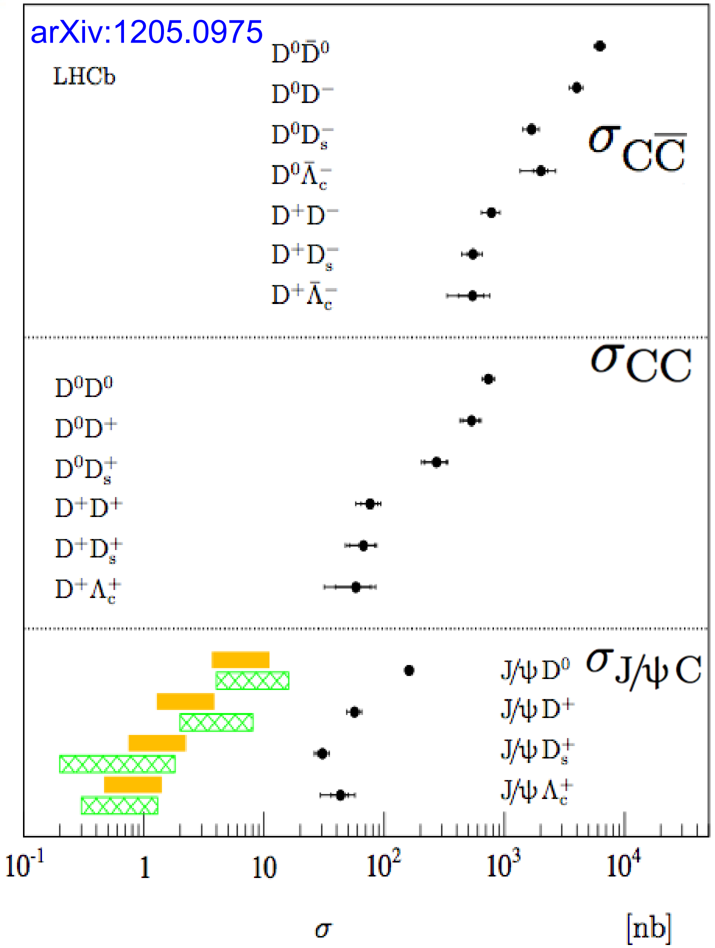
J/ψ+open charm production

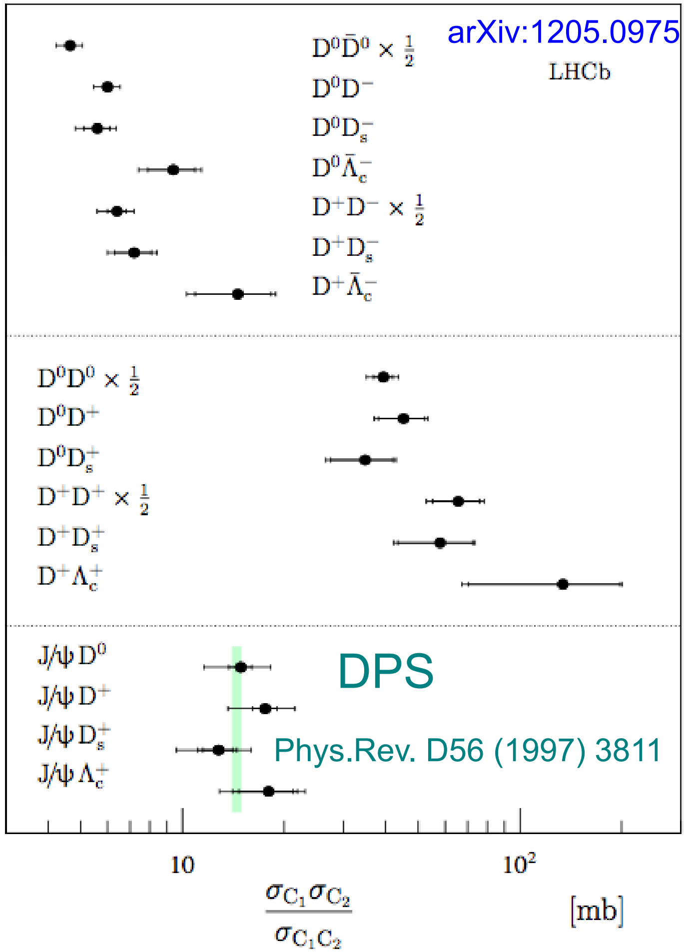
- *First observation of $J/\psi C(\bar{C})$ and CC open charm states in hadronic collisions performed with 0.36 fb^{-1}@7TeV*
- *predictions from DPS and IC larger by one order of magnitude than the LO CSM calculations*
- *In case DPS dominates*

$$\frac{\sigma_{C_1}\sigma_{C_2}}{\sigma_{C_1C_2}} \sim 15\,mb$$

from the cross-sections measured at Tevatron for multi-jet events
→ PDR 56 3811 (1997)







→ *LO predictions*
Phys.Rev. D57 (1998) 4385
Eur. Phys. J C61 (2009) 693
significantly underestimate the cross-sections

→ *Good consistency between DPS prediction and the results for J/ψC modes, whereas 2-3 times lower for CC states*

χ_c production

- χ_c production studies provide important test of NRQCD and CS/CO mechanisms:

→ prompt χ_c give substantial feed-down to J/ψ production: crucial for polarization studies

- $\sigma(\chi_c \to J/\psi\gamma)/\sigma(J/\psi)$ (arXiv:1204.1462)

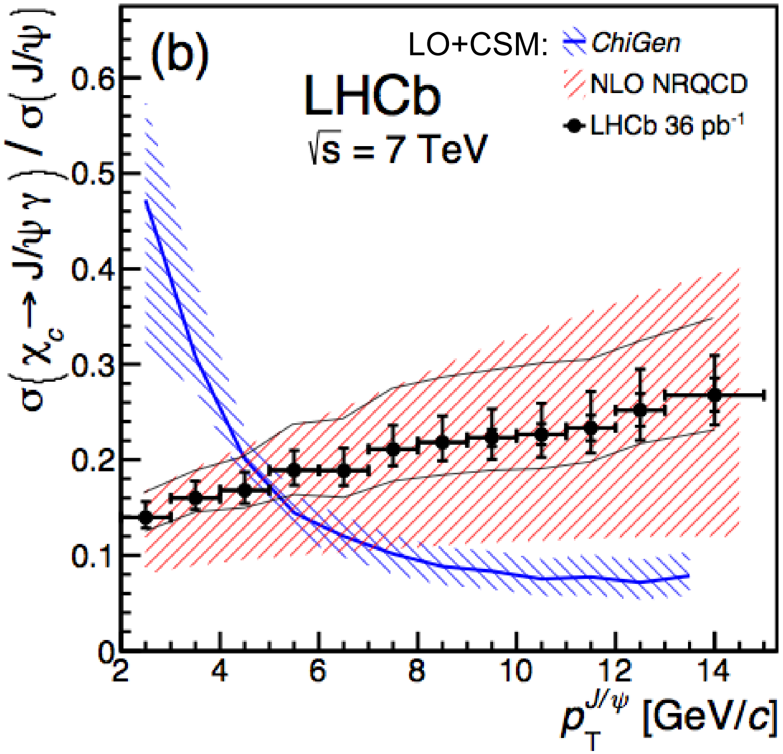
  $\sigma(\chi_{c2})/\sigma(\chi_{c1})$ (arXiv:1202.1080)

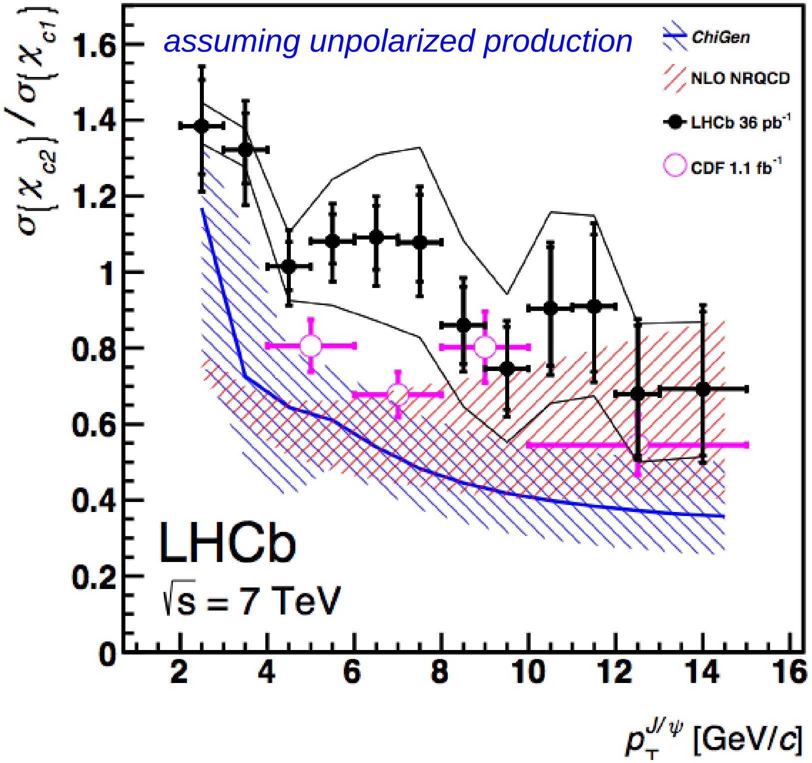
  measured by LHCb using 36 pb^{-1}@7TeV for 2< p_T< 15 GeV/c

- Converted **after the magnet** and non-converted photons are detected in the ECAL

- Results for $\sigma(\chi_c \to J/\psi\gamma)/\sigma(J/\psi)$ in agreement with NLO NRQCD

- $\sigma(\chi_{c2})/\sigma(\chi_{c1})$ is found to be larger than any prediction and CDF measurement





B_c production

- *only the ground state of B_c is observed so far*
  → great spectroscopy potential

- *LHCb has performed the world's best measurement of the B_c mass with 2010 data @ 7TeV:*

$$M\left(B_c^+\right) = 6268.0 \pm 4.0 \pm 0.6\,\mathrm{MeV}/c^2$$

$$using\ B_c^+ \to J/\psi\pi^+$$

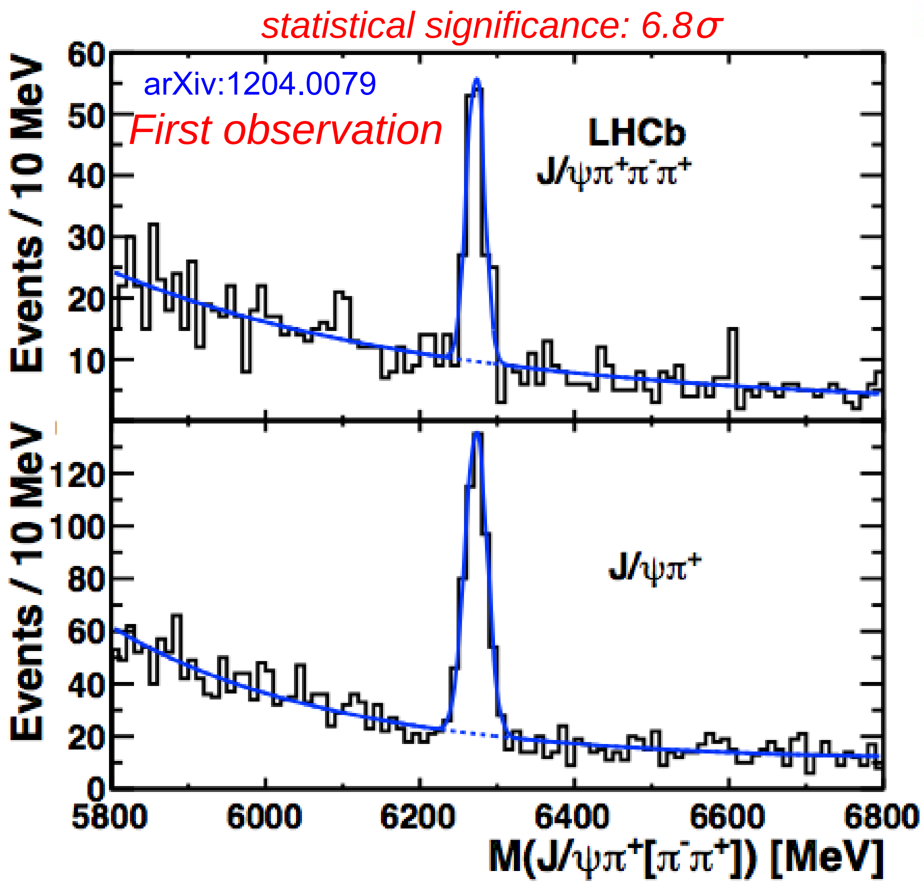
- *Ratio measured for p_T>4 GeV/c and 2.5<y<4.5* (CERN-LHCb-CONF-2011-017)

$$R_{c+} = \frac{\sigma(B_c^+) \times \mathcal{B}(B_c^+ \to J/\psi\pi^+)}{\sigma(B^+) \times \mathcal{B}(B^+ \to J/\psi K^+)} = (2.2 \pm 0.8 \pm 0.2)\%$$

- *First observation of $B_c^+ \to J/\psi\pi^+\pi^-\pi^+$ using 2011 data* (arXiv:1204.0079)

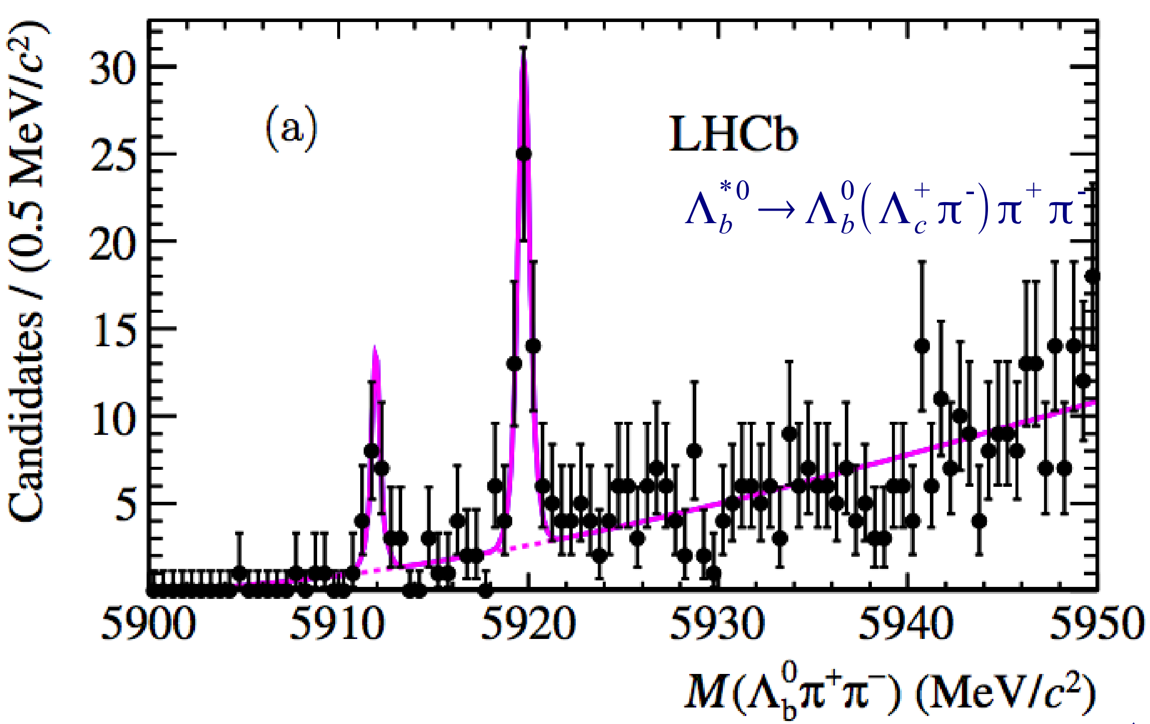
$$\frac{\mathcal{B}(B_c^+ \to J/\psi\pi^+\pi^-\pi^+)}{\mathcal{B}(B_c^+ \to J/\psi\pi^+)} = 2.41 \pm 0.30 \pm 0.33$$

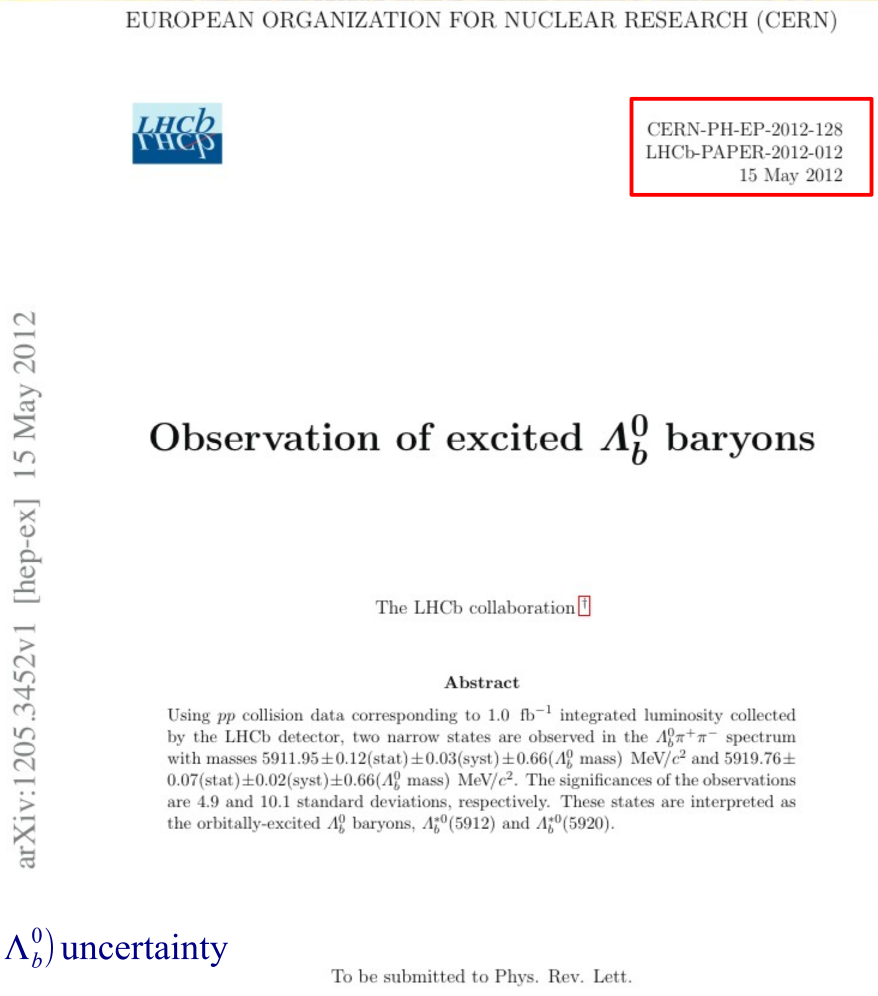
→ theory predictions: 1.5 – 2.3



First observation of $\Lambda_b^{*0}(5912)$ and $\Lambda_b^{*0}(5920)$

- *Quark models predicts* Λ_b^{*0} *with* $J^P = 1/2^-, 3/2^-$ *decaying into* $\Lambda_b^{*0} \to \Lambda_b^0 \pi^+ \pi^-$
- *Two orbitally excited* Λ_b^{*0} *states are observed for the first time using 1 fb^{-1} of data at 7 TeV*




EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)

CERN-PH-EP-2012-128
LHCb-PAPER-2012-012
15 May 2012

arXiv:1205.3452v1 [hep-ex] 15 May 2012

Observation of excited Λ_b^0 baryons

The LHCb collaboration[†]

Abstract

Using pp collision data corresponding to 1.0 fb^{-1} integrated luminosity collected by the LHCb detector, two narrow states are observed in the $\Lambda_b^0\pi^+\pi^-$ spectrum with masses $5911.95 \pm 0.12(\text{stat}) \pm 0.03(\text{syst}) \pm 0.66(\Lambda_b^0 \text{ mass})$ MeV/c^2 and $5919.76 \pm 0.07(\text{stat}) \pm 0.02(\text{syst}) \pm 0.66(\Lambda_b^0 \text{ mass})$ MeV/c^2. The significances of the observations are 4.9 and 10.1 standard deviations, respectively. These states are interpreted as the orbitally-excited Λ_b^0 baryons, $\Lambda_b^{*0}(5912)$ and $\Lambda_b^{*0}(5920)$.

To be submitted to Phys. Rev. Lett.

$M(\Lambda_b^0)$ uncertainty

$$M_{\Lambda_b^{*0}(5912)} = 5911.95 \pm 0.12 \pm 0.03 \pm 0.66 \text{ MeV}/c^2 \quad \Gamma_{\Lambda_b^{*0}(5912)} < 0.82 \text{ MeV}$$

@95 CL

$$M_{\Lambda_b^{*0}(5920)} = 5919.76 \pm 0.07 \pm 0.02 \pm 0.66 \text{ MeV}/c^2 \quad \Gamma_{\Lambda_b^{*0}(5920)} < 0.71 \text{ MeV}$$

Summary

LHCb detector achievements:

- *Excellent vertex resolutions*
- *Great tracking performance*
- *Robust particle identification*
- *Selective and flexible trigger system*

→ *Great conditions to deliver high-quality physics results*

Just do it :-)

…and LHCb does it indeed :

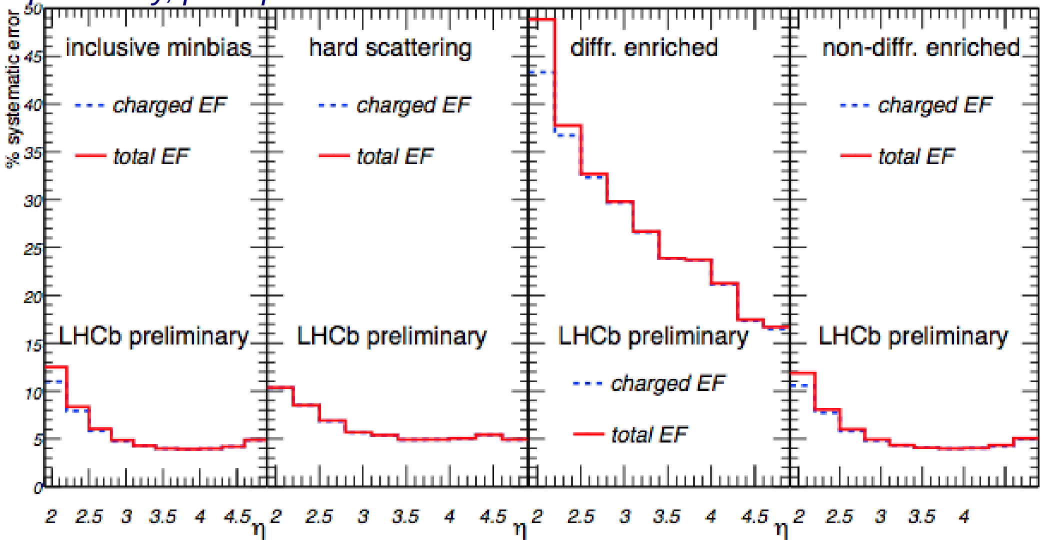
- *57 papers submitted to journals so far, a lot more in the pipeline*
- *world's best measurements of many important physics parameters and first observations of very rare processes !*
- *LHCb is much more than just a beauty experiment :-)*

  → *a lot of measurements in the quarkonia and soft QCD sector were performed bringing much input for theoreticians*

  → *stay tuned for further results in particular obtained at 8 TeV !*

Backup: systematics

- ***Energy Flow systematics:*** *tracking related factors, model dependency, pile-up contamination*



Relative systematic uncertainties (%) for the D^0C cross-sections. The uncertainties for CC and $C\overline{C}$ are equal.

Source		D^0D^0	D^0D^+	$D^0D_s^+$	$D^0\Lambda_c^+$
D^0C reconstruction	$\varepsilon_1^{reco} \times \varepsilon_2^{reco}$	1.4	1.4	2.3	3.6
Hadron ID	ε_{had}^{ID}	1.2	1.8	1.6	2.4
Tracking	ξ^{trk}	8.5	10.7	10.6	10.6
Trigger	$\varepsilon_{CC,C\overline{C}}^{trg}$	1.8	2.5	3.9	5.2
Global event cuts	ε^{GEC}	1.0	1.0	1.0	1.0
Luminosity	$\mathcal{L}$	3.7	3.7	3.7	3.7
$\mathcal{B}(D^0 \to K^-\pi^+)$	$\mathcal{B}_1$	1.3	1.3	1.3	1.3
C branching fractions	$\mathcal{B}_2$	1.3	4.3	6.0	26
Total		10	12	14	30

Relative systematic uncertainties (%) for the D^+C cross-sections. The uncertainties for the CC and $C\overline{C}$ are equal.

Source		D^+D^+	$D^+D_s^+$	$D^+\Lambda_c^+$
D^+C reconstruction	$\varepsilon_1^{reco} \times \varepsilon_2^{reco}$	1.4	2.2	4.0
Hadron ID	ε_{had}^{ID}	2.3	2.4	3.0
Tracking	ξ^{trk}	12.8	12.8	12.8
Trigger	$\varepsilon_{CC,C\overline{C}}^{trg}$	3.7	5.8	5.0
Global event cuts	ε^{GEC}	1.0	1.0	1.0
Luminosity	$\mathcal{L}$	3.7	3.7	3.7
$\mathcal{B}(D^+ \to K^-\pi^+\pi^+)$	$\mathcal{B}_1$	4.3	4.3	4.3
C branching fractions	$\mathcal{B}_2$	4.3	6.0	26
Total		17	17	31

Relative systematic uncertainties (%) for the $J/\psi C$ cross-sections.

Source		$J/\psi D^0$	$J/\psi D^+$	$J/\psi D_s^+$	$J/\psi \Lambda_c^+$
J/ψ reconstruction	ε_1^{reco}	1.3	1.3	1.3	1.3
C reconstruction	ε_2^{reco}	0.7	0.8	1.7	3.3
Muon ID	$\varepsilon_{J/\psi}^{ID}$	1.1	1.1	1.1	1.1
Hadron ID	ε_{had}^{ID}	1.1	1.9	1.1	1.5
Tracking	ξ^{trk}	4.9	7.0	7.0	7.0
Trigger	$\varepsilon_{J/\psi C}^{trg}$	3.0	3.0	3.0	3.0
J/ψ polarization	$\varepsilon_{J/\psi}^{reco}$	3.0	3.0	3.0	3.0
Global event cuts	ε^{GEC}	0.7	0.7	0.7	0.7
Luminosity	$\mathcal{L}$	3.7	3.7	3.7	3.7
$\mathcal{B}(J/\psi \to \mu^+\mu^-)$	$\mathcal{B}_1$	1.0	1.0	1.0	1.0
C branching fractions	$\mathcal{B}_2$	1.3	4.3	6.0	26
Total		8	10	11	28

Backup: systematics

→ double J/ψ production

Relative systematic uncertainties on the cross-section measurement. The total uncertainty is calculated as the quadratic sum of the individual components.

Source	Systematic uncertainty [%]
Track-finding efficiency	4×4
Trigger efficiency	8
Per-event efficiency	3
J/ψ polarisation	2×5
Data/simulation difference for χ^2/ndf	3
Global event cuts	2
Muon identification	2×1.1
Luminosity	3.5
$J/\psi \to \mu^+\mu^-$ branching ratio	2×1
Total	21

ψ(2S)

Systematic uncertainties included in the measurement of the cross-section. Uncertainties labelled with a are correlated between the $\mu^+\mu^-$ and $J/\psi\pi^+\pi^-$ mode, while b indicates a correlation between $\psi(2S) \to \mu^+\mu^-$ and the $J/\psi \to \mu^+\mu^-$ uncertainties [8].

Uncertainty source	$\mu^+\mu^-$(%)	$J/\psi\pi^+\pi^-$(%)
Luminosity^{a,b}	3.5	3.5
Trigger efficiency^{a}	1–8	1–7
Total efficiency	0.4–2.2	0.6–1.0
Global event cuts^{a,b}	2.1	2.1
Muon identification^{a,b}	1.1	1.1
Tracking efficiency^{a}	3.5	7.3
Track $\chi^{2\,a,b}$	1	2
Vertex fit^{b}	0.8	1.3
Hadron identification	–	0.5
Unknown polarization^{a}	15–26	15–26
$\mathcal{B}(\psi(2S) \to e^+e^-)$	2.2	–
$\mathcal{B}(\psi(2S) \to J/\psi\pi^+\pi^-)$	–	1.2
$\mathcal{B}(J/\psi \to \mu^+\mu^-)$	–	1.0
Mass fit function	1.1	0.5
Pseudo-decay-time fits	2.7	2.7

Summary of the relative systematic uncertainties on the cross-section measurements. Ranges indicate variations depending on the (p_T, y) bin and the Υ state. All uncertainties are fully correlated among the bins.

Source	Uncertainty (%)
Unknown Υ polarisation	0.3–41.0
Trigger	3.0
Track reconstruction	2.4
Track quality requirement	0.5
Vertexing requirement	1.0
Muon identification	1.1
Global event selection requirements	0.6
p_T binning effect	1.0
Fit function	1.1–2.1
Luminosity	3.5

B_c^+

Summary of systematic uncertainties.

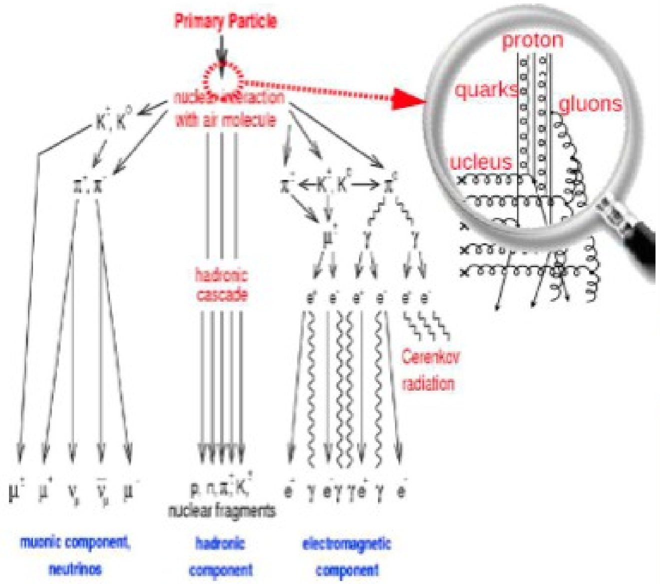
Source	Systematic error (%)
B_c^+ lifetime	6.0
J/ψ vertexing	1.6
Track χ^2	3.0
Trigger	3.0
Tracking	1.0
Weighting procedure	2.3
Total	7.9

Backup: cosmic-ray models

Max-Planck-Institut für Kernphysik Heidelberg

Modelling Interactions in Extensive Air Showers

by Ralf Ulrich



Requirements and Problems:

- Interactions up to $\sqrt{s} \sim 500$ TeV
  → Far beyond accelerator energies...
- Mainly soft physics + diffraction: **forward region**
  → Difficult to instrument...
  → Only fixed target at lower energies...
- Target is **air**: p-air, π-air, K-air, A-air, . . .
  → Typical target very different from **air**:
  Nuclear effects must be considered...

Ingredients:

- Theory: pQCD (hard) + Gribov-Regge (soft)
- A lot of phenomenology: Diffraction, String fragmentation, Saturation, Remnants, Nuclear effects, ...

Older models:

Glauber based, different mostly in remnants+diffraction, for example:
QGSJet01 *(Kalmykov, Ostapchenko)*
SIBYLL *(Engel, Gaisser, Lipari, Stanev)*

Recent models:

QGSJetII *(Ostapchenko)*
Theory++, Optimized for cosmic rays

EPOS *(Werner, Pierog)*
Phenomenology++
Optimized for LHC, RHIC (and cosmic rays)

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