2011 Europhysics Conference on High-Energy Physics, Grenoble

Measurements of Particle Production in pp-Collisions in the Forward Region at the LHC

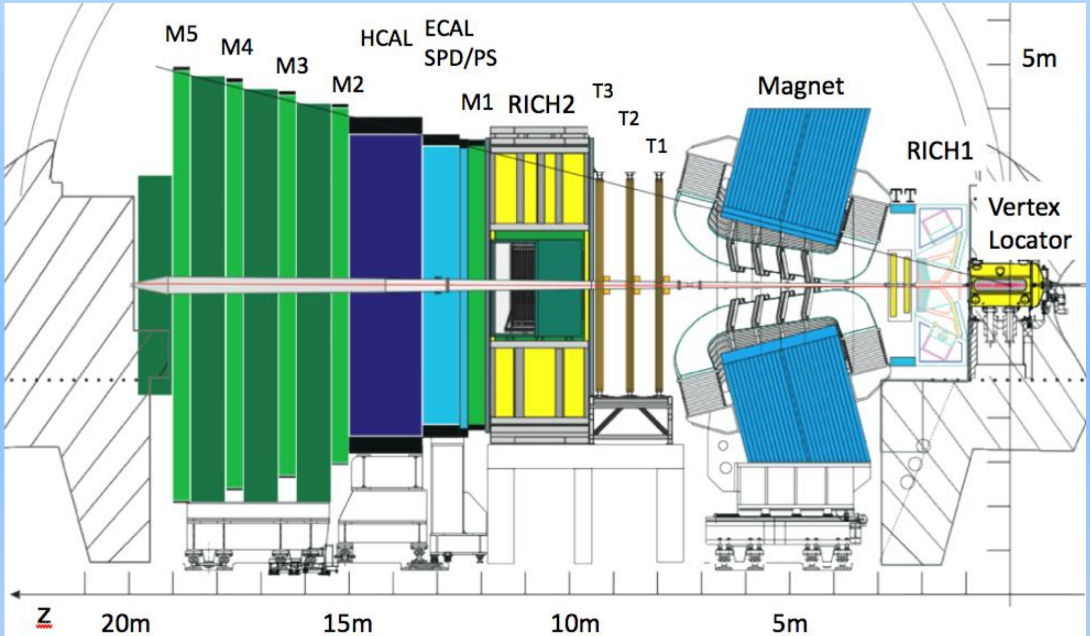
Thomas Ruf for the LHCb collaboration

- **Introduction**
- **Particle Multiplicities** Preliminary results New !
- **Particle Production** Final results
- **Summary**

Introduction

- **Particle multiplicities and particle production measurements are important input for tuning of event generators and modelling of the underlying event**
  - Good understanding of soft QCD processes is required for extracting many important measurements at the LHC
- **The LHCb detector has a unique forward coverage in the pseudorapidity range of $2<\eta<5$**
- **The LHCb measurements are compared to different event generators and tunings**

The LHCb Detector

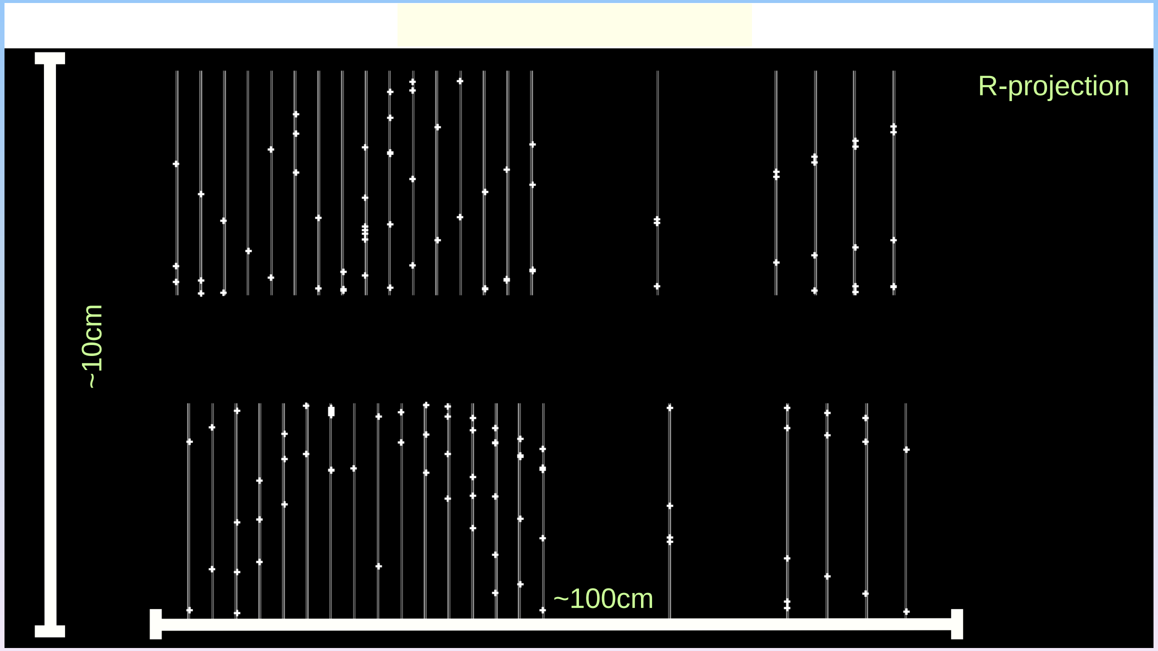


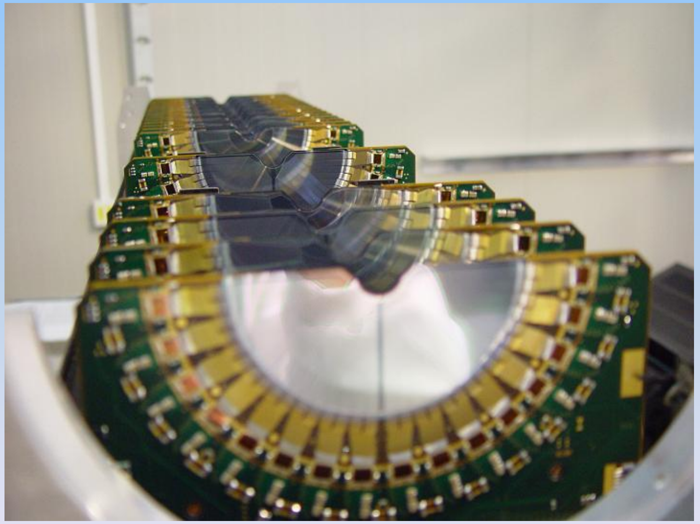
- **Single arm forward spectrometer made for high precision measurements of CP violation and rare decays in the beauty and charm sector**
- **Excellent tracking and vertexing**
  - VELO, 8mm distance to beam, impact parameter resolution ~15μm (high p_T)
- **Unique Hadron PID**
  - Two Rich detectors exploiting 3 radiators

- **Data: from early 2010, low luminosity running of LHC**
  - low pile-up
  - low trigger thresholds (at least one track reconstructed in the event)
    $\Rightarrow$ no or small corrections

Measurement of Particle Multiplicities

- **Particles are counted by reconstructing tracks in the VELO**
  - high and uniform efficiency, closest to interaction point (minimal material), partial backward coverage
  - outside main magnetic field, no momentum measurement





Measurement of Particle Multiplicities

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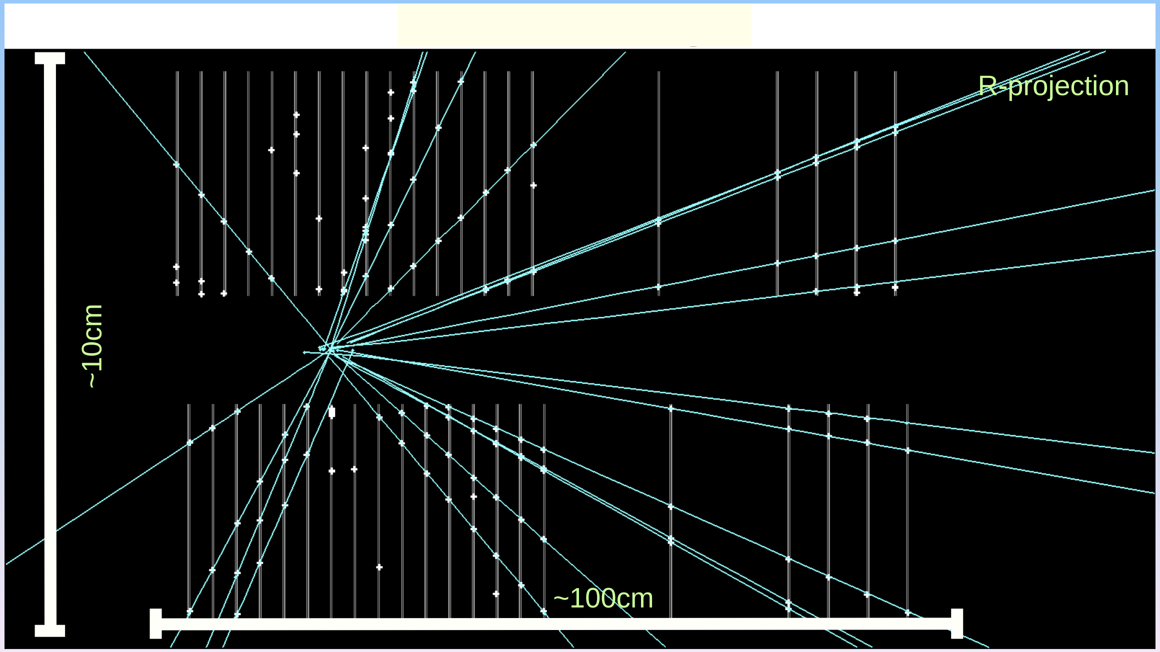
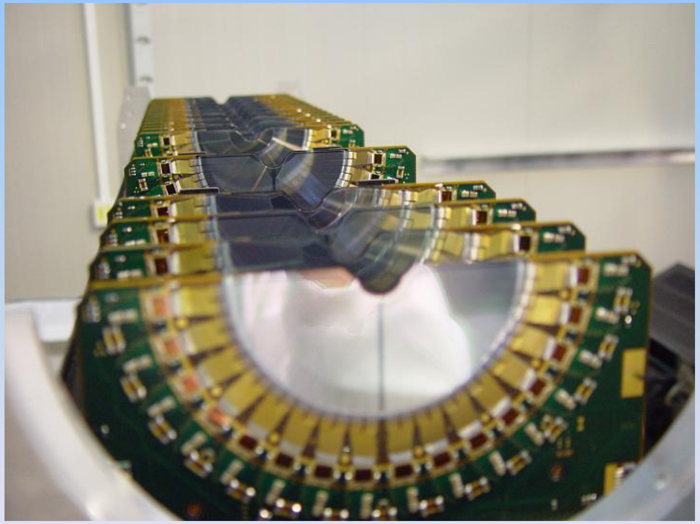
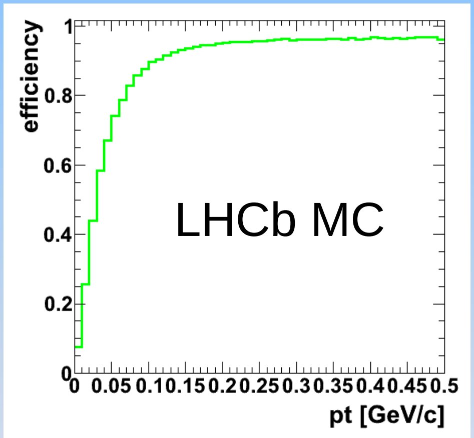




Overview of the Analysis

- **Definition of prompt charged particles at generator level:**
  - (e,μ,π,K,p) excluding particles from K_s or hyperon decays.
    - proper lifetimes of all mother particles $\sum\tau < 10$ps
- **Tracks are required to originate from luminous region.**
  - Correction for remaining non-prompt particle contamination, (5-10)%, mainly tracks from converted photons is taken from MC. Assume scaling with charged particle multiplicity, sys. error: 1%.
- **No explicit momentum cut**
  - Due to residual magnetic field and multiple scattering, efficiency drops towards very low momentum ⇒ Using predictions of different event generators, about ~1% of particles are lost. Contained in the efficiency correction



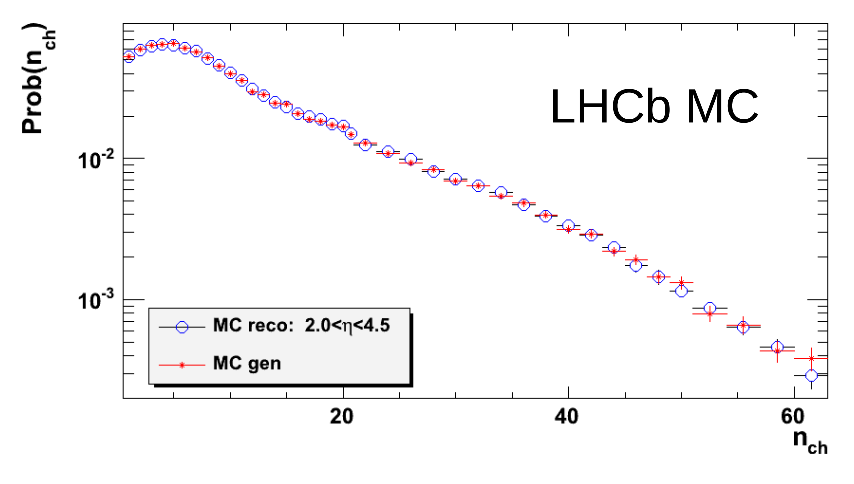
- **Distributions need to be corrected for a small pile-up contamination**
  - (3.7±0.4)% of the events have more than one interaction.

Unfolding

- **Event particle multiplicities are obtained by unfolding migrations due to reconstruction inefficiencies with fits to a sum of binomial distributions:**
  - Observed distribution: events with *k* tracks with probability f(k) :

$$\mathbf{f}(\boldsymbol{k}) = \sum_{i=0}^{\infty} \boldsymbol{a_i} \times \binom{N}{k} (1-\boldsymbol{\varepsilon})^{N-k} \boldsymbol{\varepsilon}^k$$

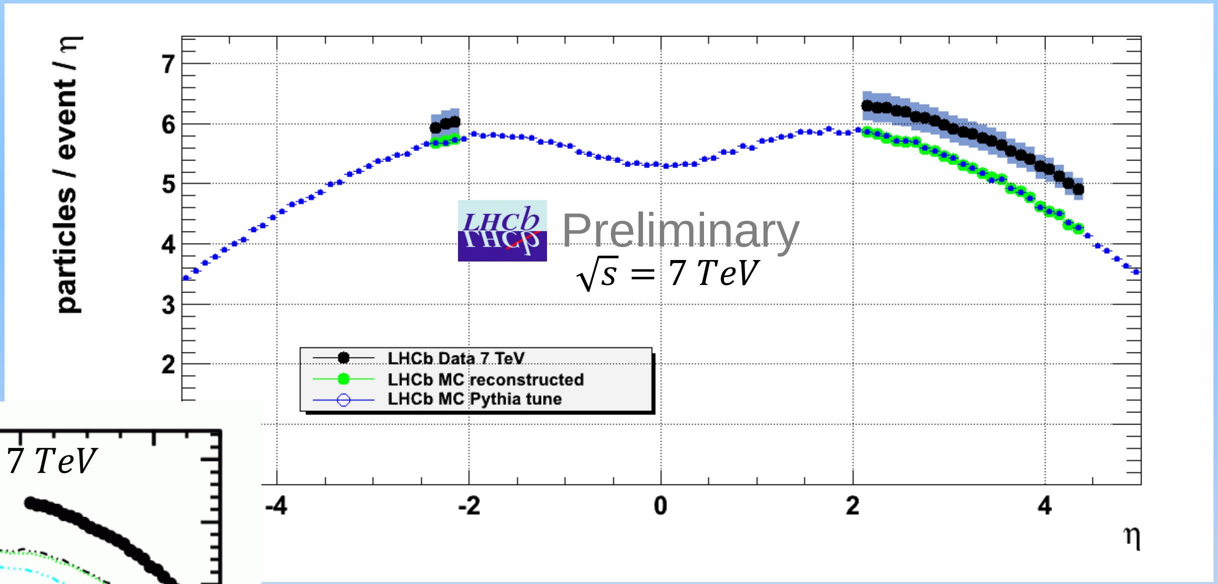
  - Weight $\boldsymbol{a_i}$ of each binomial distribution corresponds to the probability for the original particle multiplicity to occur. $\boldsymbol{\varepsilon}$ taken from MC and cross checked with data.
- **Procedure verified with MC simulations:**
  - Reconstructed and corrected particle multiplicity distribution reproduces generated distribution

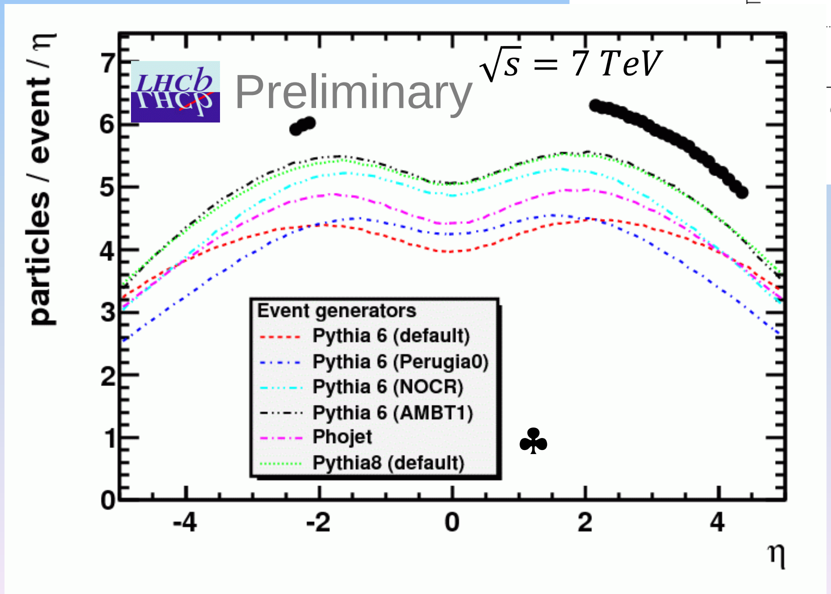


- **Systematic error:**
  - Change of $\boldsymbol{\varepsilon}$ by ±4%

Results: Charged Particles vs η

Normalized to events with with at least one charged particle in the forward acceptance, 2.0<η<4.5

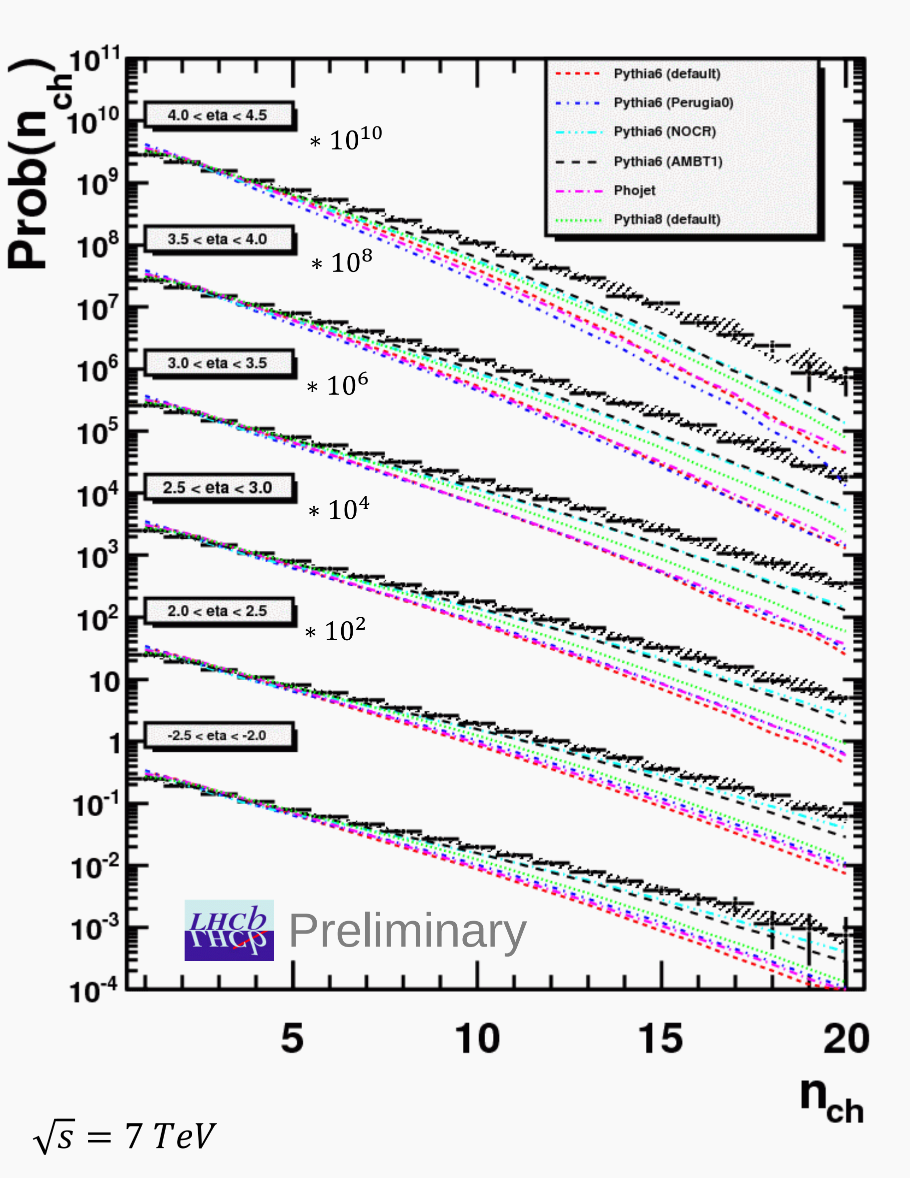




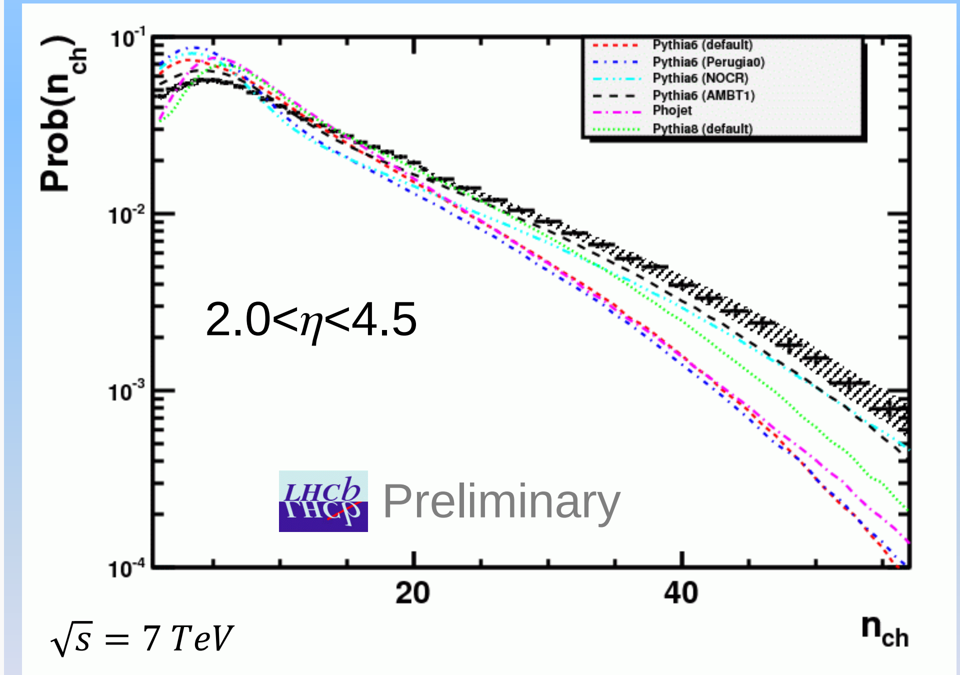
- **Data points systematically above generator predictions**
  - LHCb Pythias tune comes closest to data

♣ Monte Carlo Pythia tunes include diffractive processes

Charged Particle per Event Multiplicities

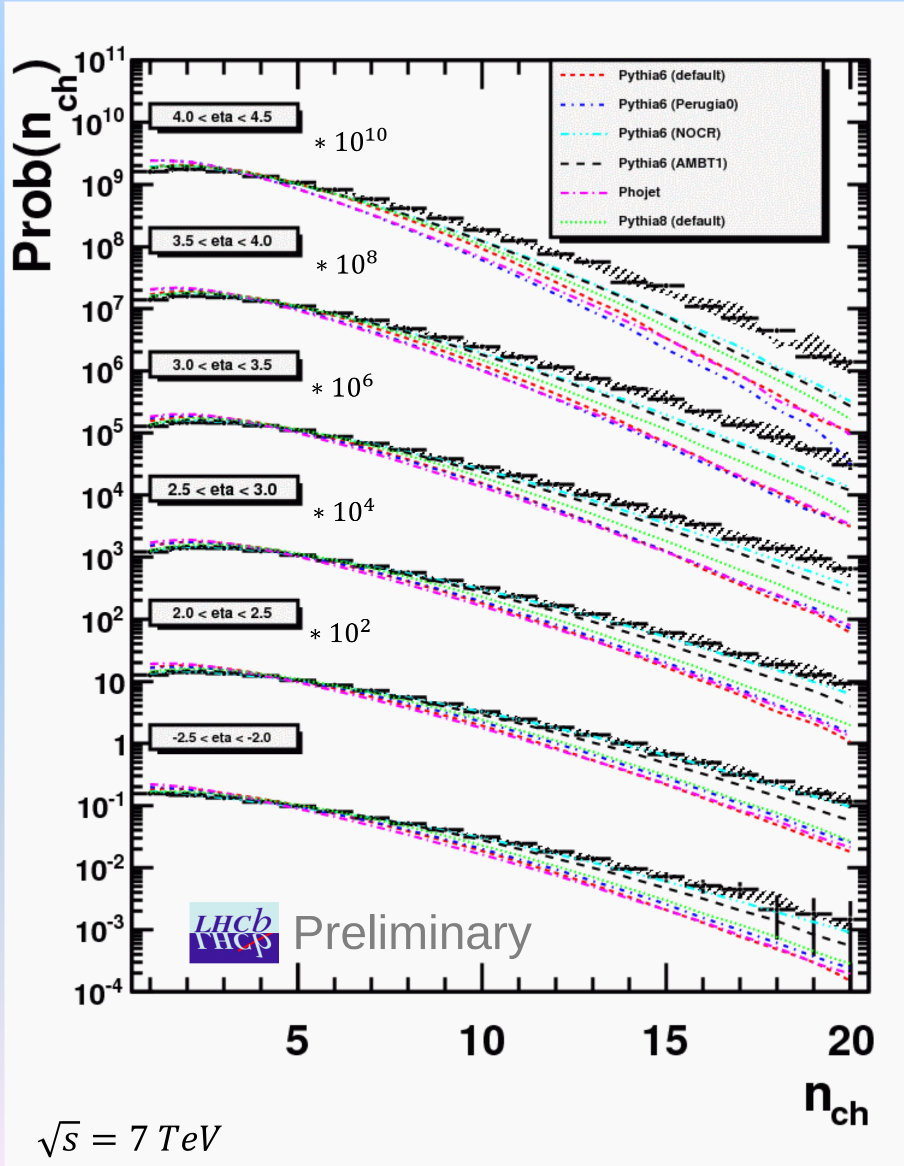


Normalized to number of events with with at least one charged particle in the related η range

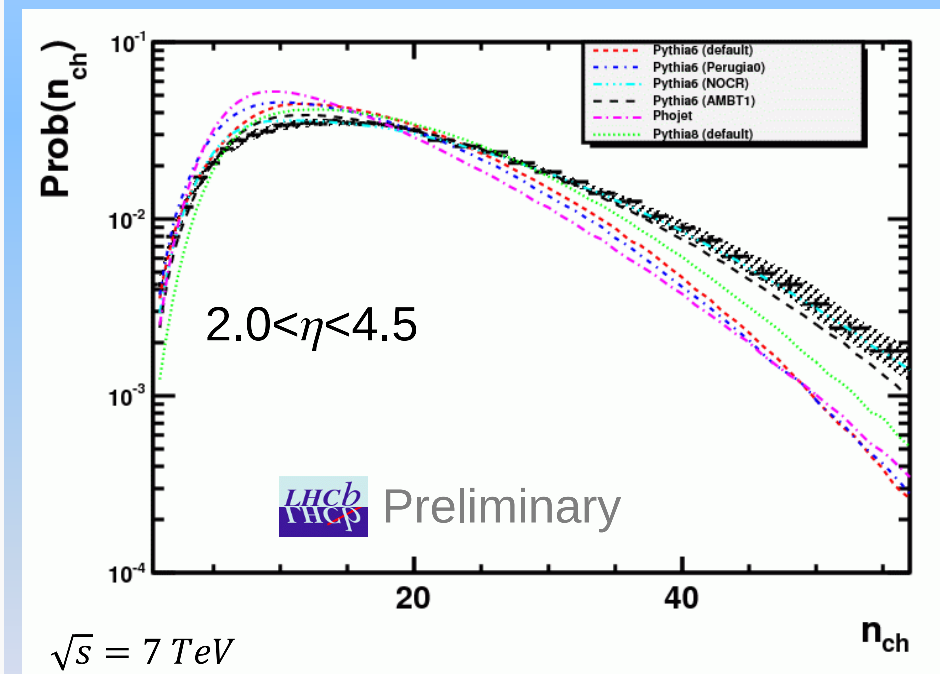


- Pythia6 default and Perugia0 are far off from the data points

Charged Particle per Event Multiplicities

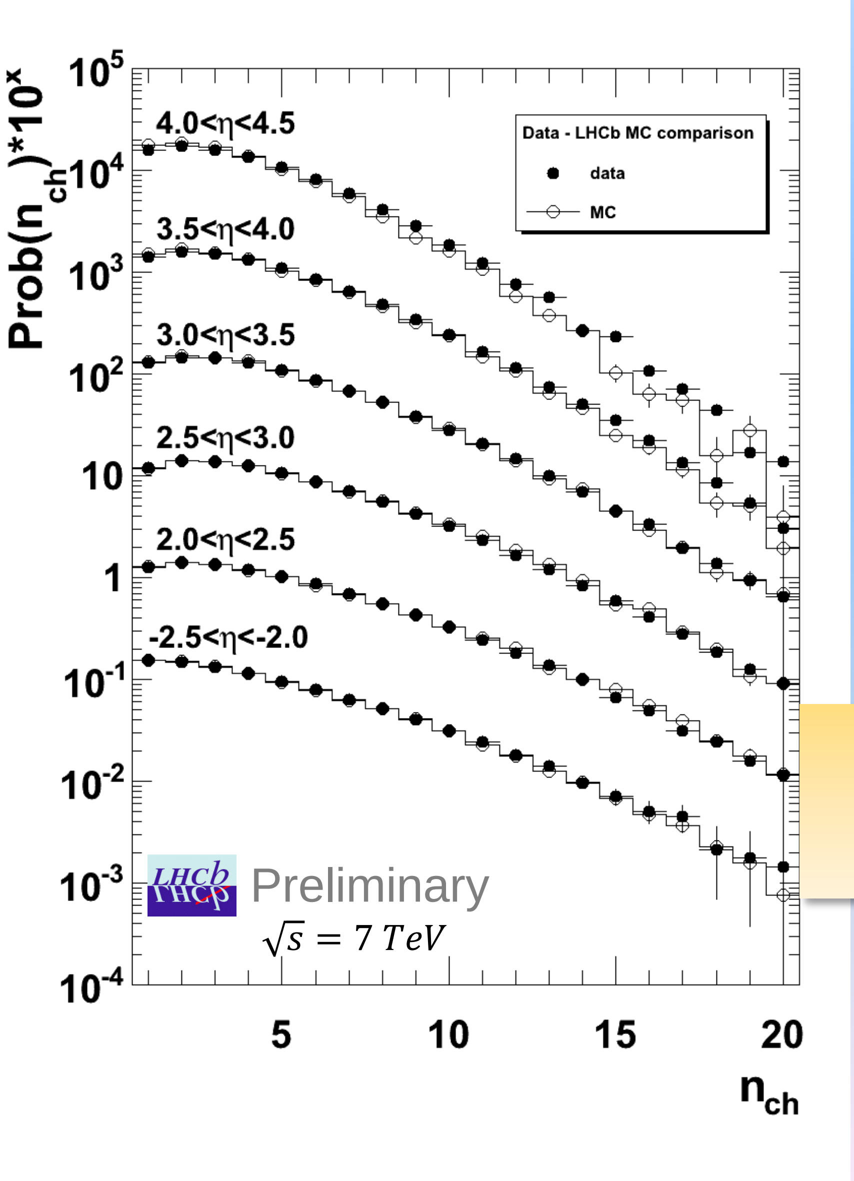


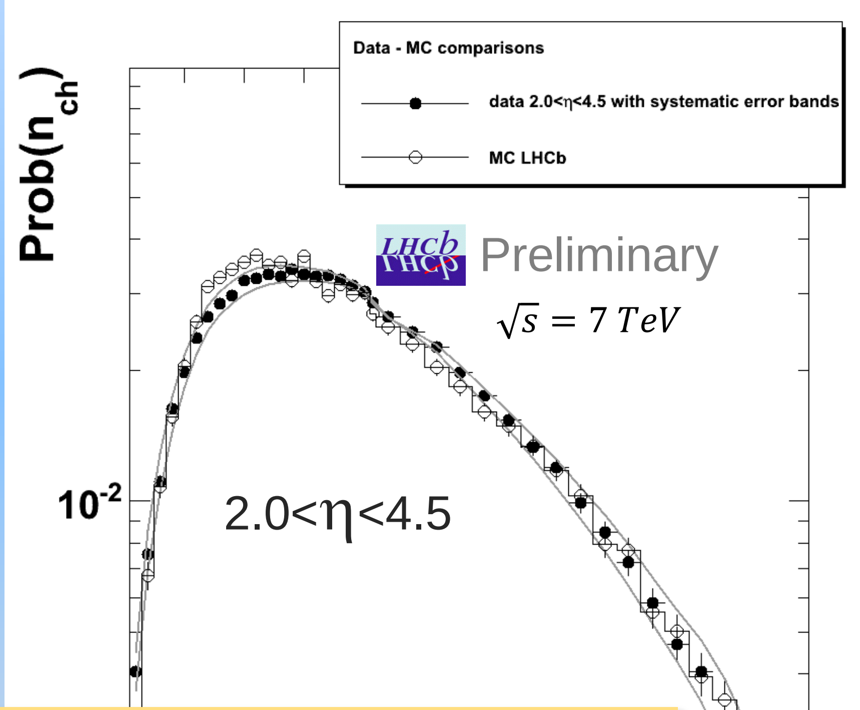
<u>Hard interactions</u>: require at least one charged particle with p_T>1GeV/c in 2.5<η<4.5



Good agreement between Pythia6 (NOCR, AMBT1) tune and data.

Results: Charged Particle Multiplicities



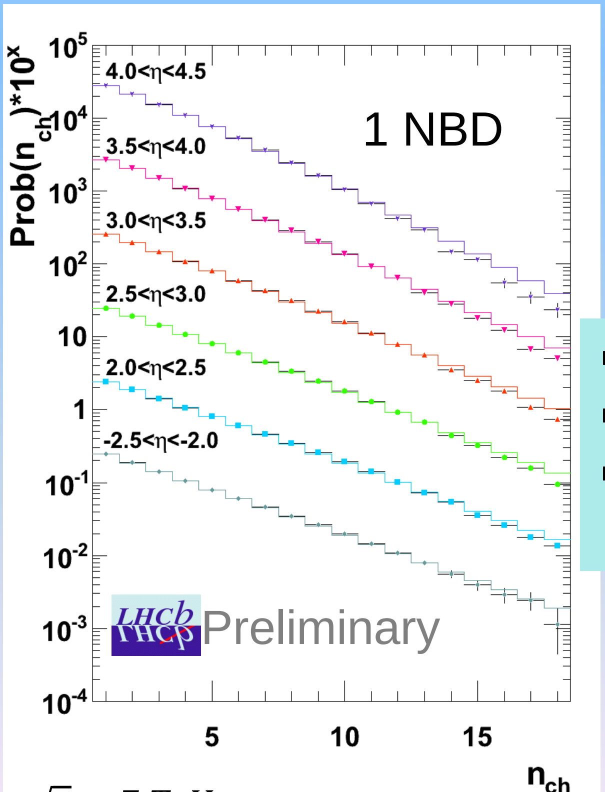


Data (hard events) compared to LHCb Pythia tune: Good agreement.

Fits to the Particle Multiplicity Distributions

- **Small η intervals fit well with single negative binomial function, full range requires 2 NBD.**

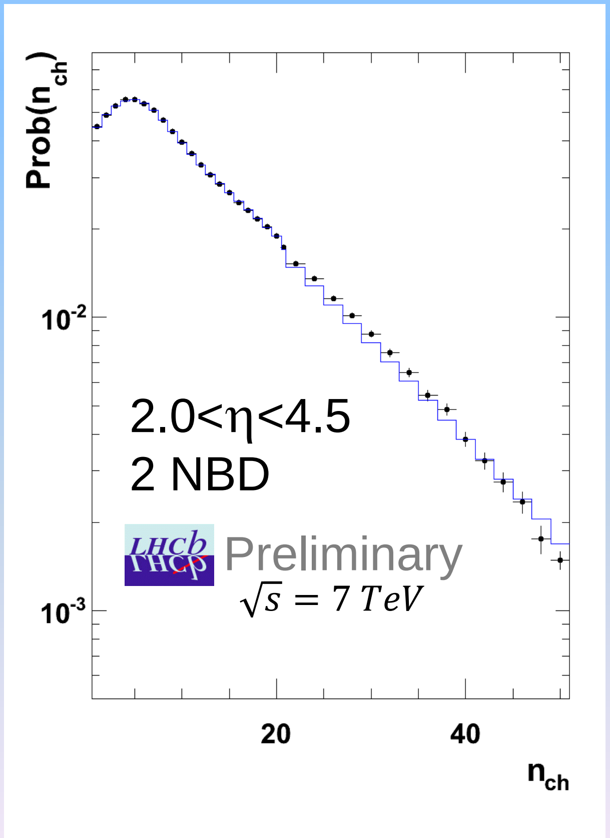
$$P(n) = \frac{(n+k-1)!}{n!(k-1)!} p^k (1-p)^n,\ p = \frac{k}{k+mean}$$



$\sqrt{s} = 7\ TeV$

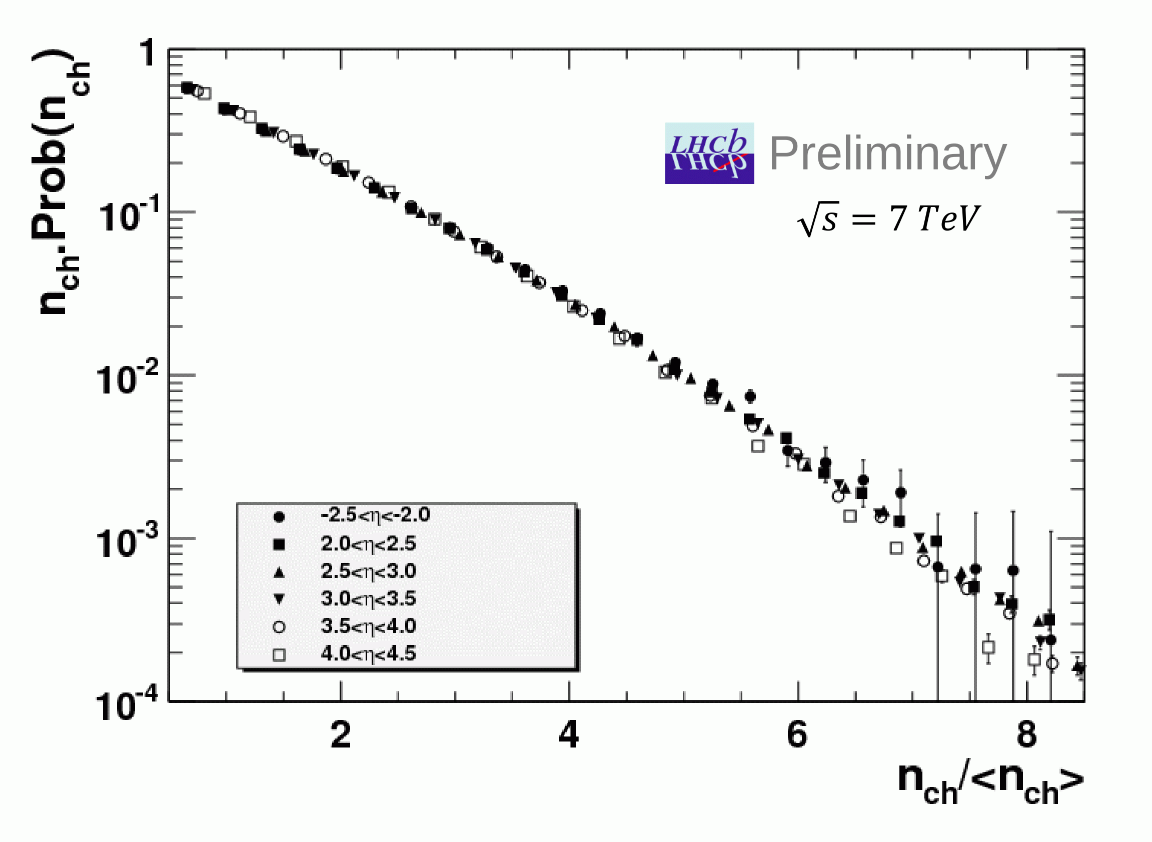
- η : 2.25 – 4.25
- k : 1.1 – 1.4
- $mean$: 3.1 – 2.5

  $k * mean \simeq 3.4$



KNO Distribution

- $z = n_{ch} / \langle n_{ch} \rangle$, expected to scale with energy. $\langle n_{ch} \rangle$ taken from negative binomial fit.
- Clearly shows that distributions in each η-range are self-consistent.
- Will be interesting to see these distributions at higher E_{cm}



Koba-Nielsen-Olesen

V^0 Production Studies

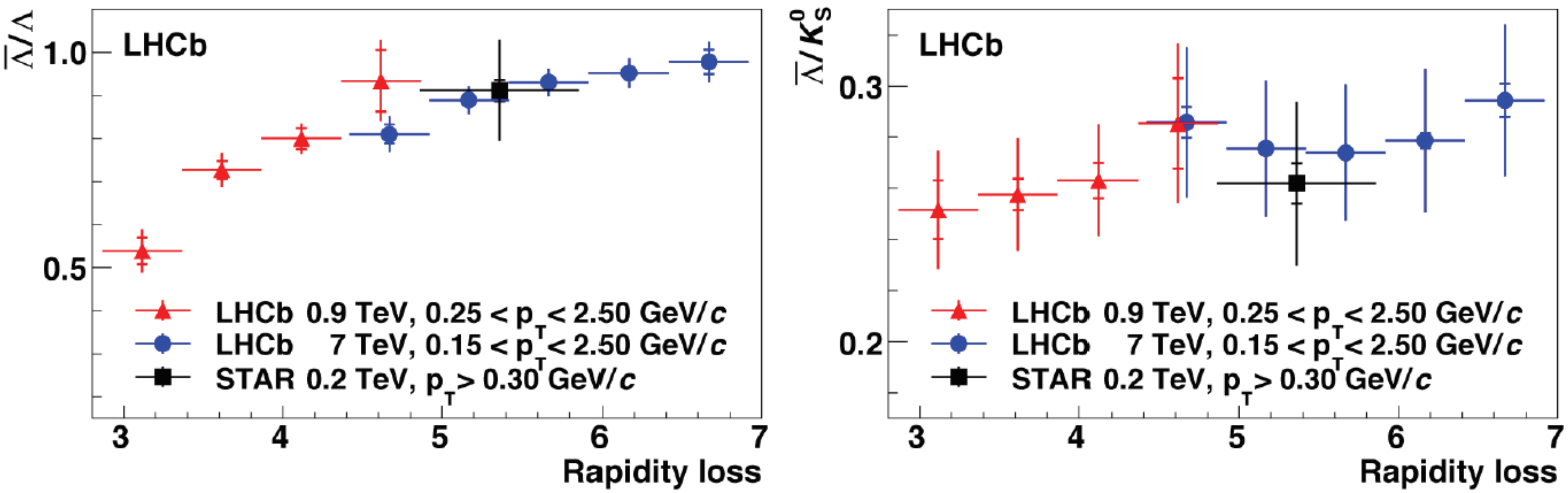
Particle Production, V^0 Ratios

submitted to JHEP
http://arxiv.org/abs/1107.0882

- **Study of baryon number transport in pp-collisions to final state hadrons and baryon vs. meson suppression in hadronization at two different energies:**

$$\frac{\bar{\Lambda}}{\Lambda} = \frac{\sigma(pp \to \bar{\Lambda}X)}{\sigma(pp \to \Lambda X)}$$

$$\frac{\bar{\Lambda}}{K^0_S} = \frac{\sigma(pp \to \bar{\Lambda}X)}{\sigma(pp \to K^0_S X)}$$



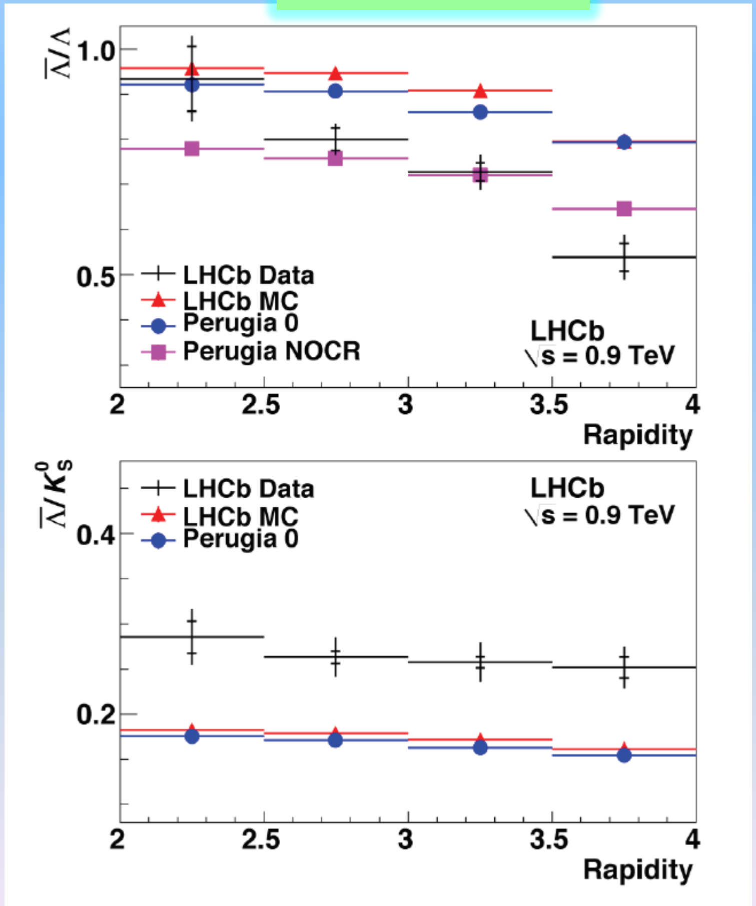
$\Delta y = y_{beam} - y$

$y_{beam} =$ 6.9 at 0.9 TeV; 8.9 at 7 TeV

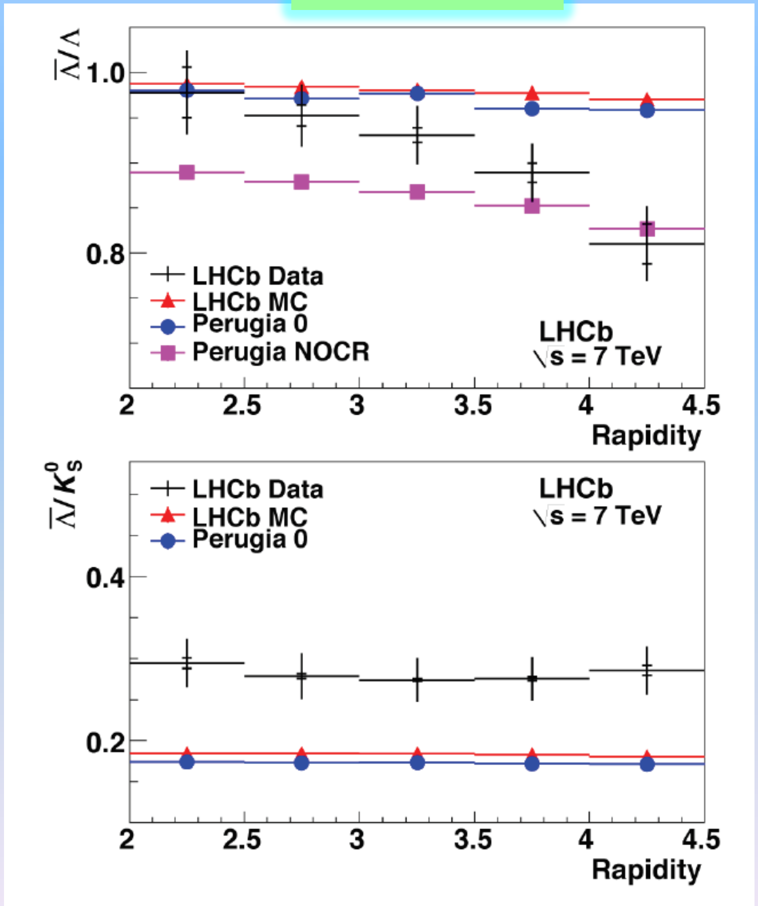
Comparison with Generators

- **Extreme Perugia NOCR favoured for $\bar{\Lambda}/\Lambda$ at high rapidity**

$\sqrt{s}$ = 0.9 TeV



$\sqrt{s}$ = 7 TeV

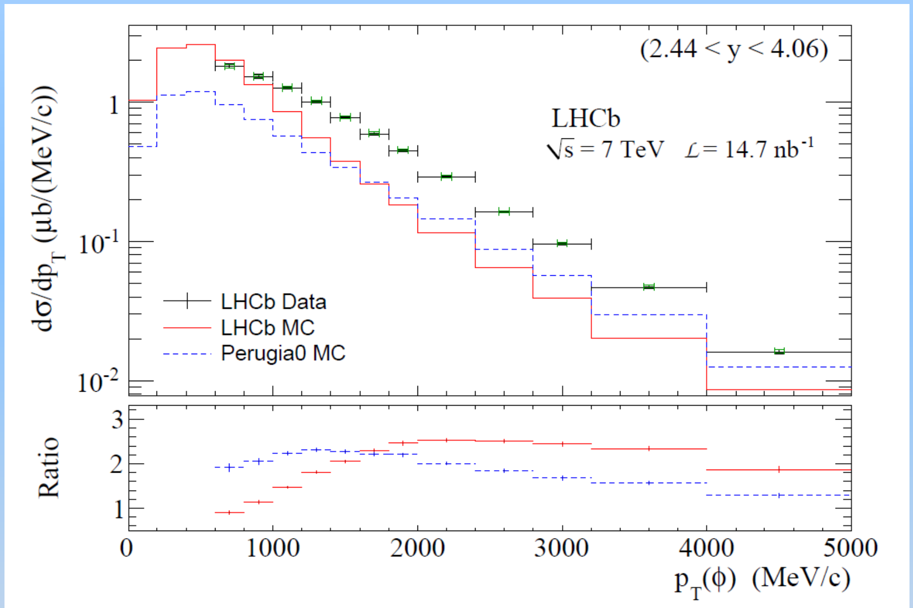


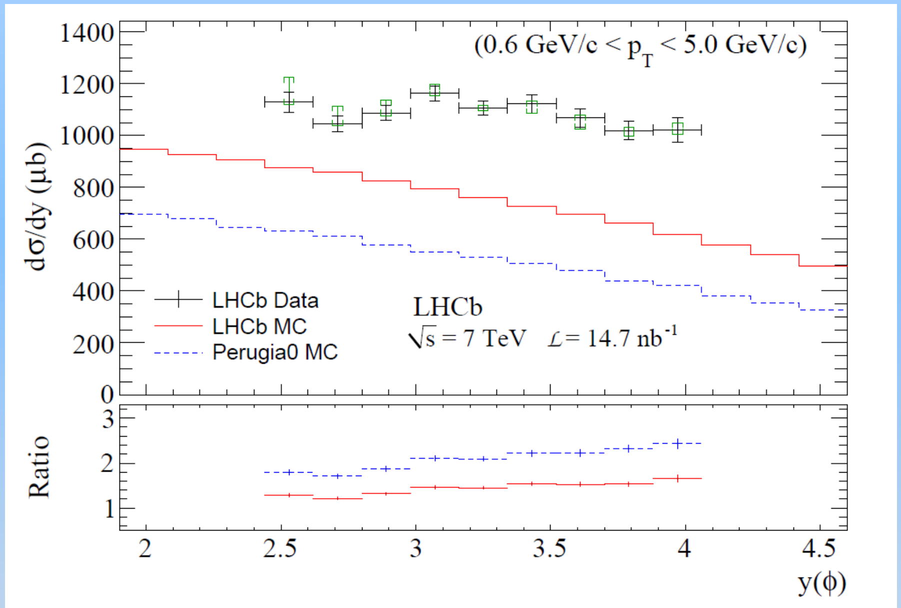
Inclusive ϕ Production

Inclusive ϕ Production

Submitted to Phys.Lett.B
http://arxiv.org/abs/1107.3935

- **Underestimated by Pythia Perugia 0 and LHCb tune**





Integrated cross section for (0.6 GeV/*c* < p_T < 5.0 GeV/*c*) and (2.44 < *y* < 4.06):

$$\sigma(pp \to \Phi X) = 1758 \pm 19_{stat} {}^{+43}_{-14}{}_{syst} \pm 182_{syst} \mu b$$

Mean p_T : 1.24 ± 0.01 GeV/*c* (data) ; 1.238 ± 0.002 GeV/*c* (Perugia 0 MC)

Summary

- **Particle multiplicities and particle production in the forward region are studied with the LHCb detector**
  - Charged particle production is underestimated in most generator tunings
    - The LHCb Pythia tune describes the observed particle multiplicities best
    - Differences become smaller for hard interactions
  - The ratio $\bar{\Lambda}/\Lambda$, measuring baryon number transport, is smaller in data than predicted in simulation, particularly at high rapidity.
  - The ratio $\bar{\Lambda}/K_S$, measuring baryon-to-meson suppression, is significantly larger than predicted at $\sqrt{S} = 0.9$ TeV and $\sqrt{S} = 7$ TeV
  - ϕ production is largely underestimated by the event generators

LHCb Pythia Tune

Non default PYTHIA parameters in the LHCb simulation software

Parameter	Value	Parameter	Value
CKIN(41)	3.0	PARP(86)	0.66
MSTP(2)	2	PARP(89)	14000
MSTP(33)	3	PARP(90)	0.238
MSTP(81)	21	PARP(91)	1.0
MSTP(82)	3	PARP(149)	0.02
MSTP(52)	2	PARP(150)	0.085
MSTP(51)	10042	PARJ(11)	0.5
MSTP(142)	2	PARJ(12)	0.4
PARP(67)	1	PARJ(13)	0.79
PARP(82)	4.28	PARJ(14)	0.0
PARP(85)	0.33	PARJ(15)	0.018
MSTJ(26)	0	PARJ(16)	0.054
PARJ(33)	0.4	PARJ(17)	0.131

Perugia0 corresponding PYTHIA parameters

Parameter	Value	Parameter	Value
CKIN(41)	12.	PARP(86)	0.95
MSTP(2)	1	PARP(89)	1800
MSTP(33)	0	PARP(90)	0.25
MSTP(81)	11	PARP(91)	2.0
MSTP(82)	4	PARP(149)	0.48
MSTP(52)	1	PARP(150)	0.09
MSTP(51)	7	PARJ(11)	0.5
MSTP(142)	0	PARJ(12)	0.56
PARP(67)	4	PARJ(13)	0.75
PARP(82)	2.0	PARJ(14)	0.0
PARP(85)	0.9	PARJ(15)	0.0
MSTJ(26)	2	PARJ(16)	0.0
PARJ(33)	0.8	PARJ(17)	0.0

PARP(82): UE IR cutoff at reference ecm, Pythia 0: 3.4 Pythia NOCR: 3.19
PARP(89): Reference ecm
PARp(90): UE IR cutoff ecm scaling power