Inclusive particle production at LHCb

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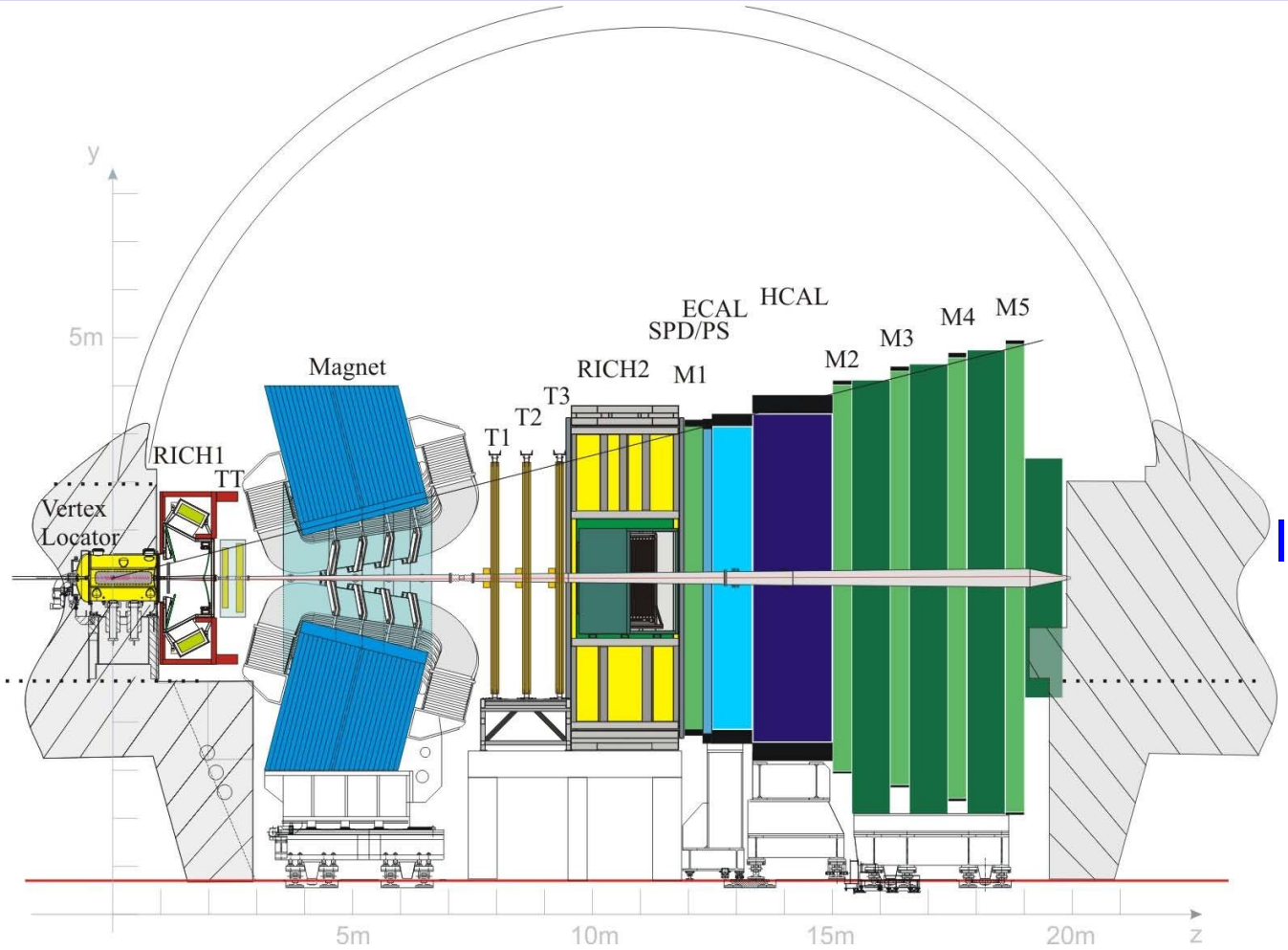
Outline

The LHCb detector



optimized for *b*-physics

excellent also for charm and light flavor physics

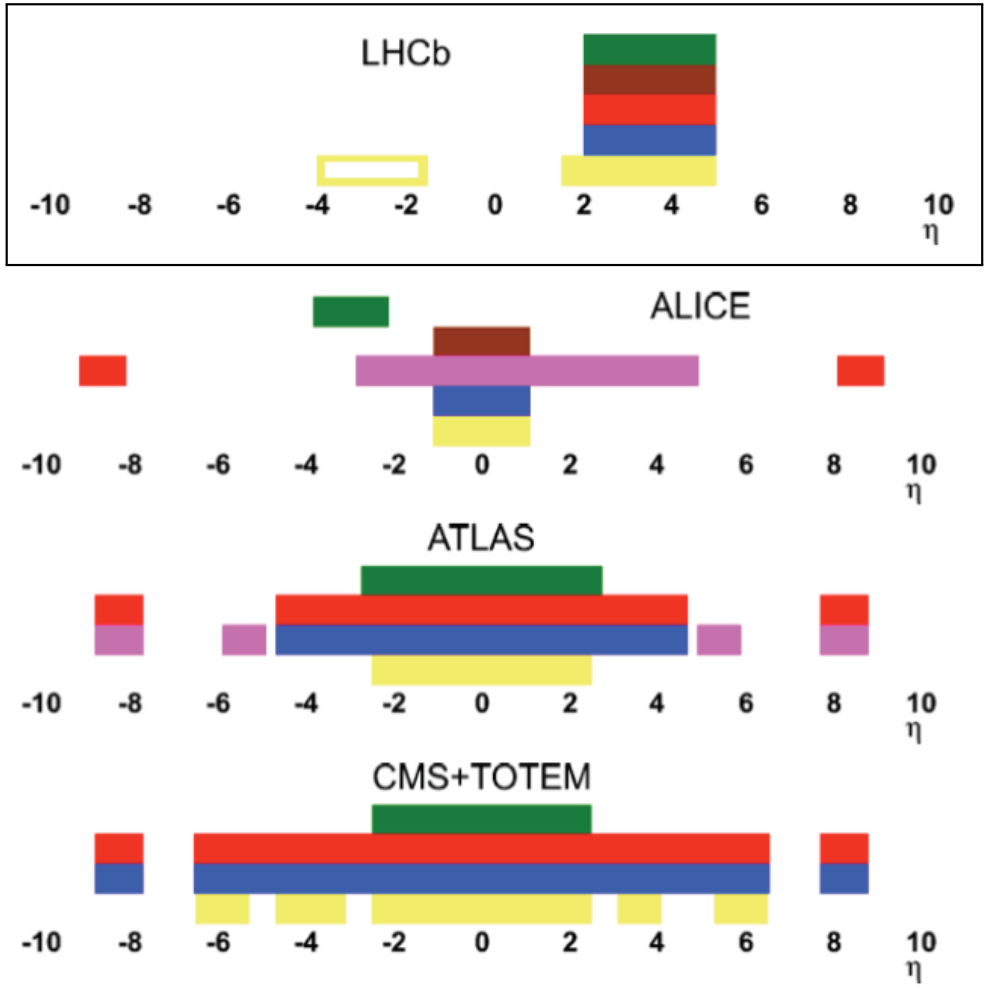
unique kinematic range: $2 < \eta < 5$, down to $p_T \approx 0$

- excellent vertex resolution (VELO)
- particle identification (RICH: $\pi/K/p$, ECAL: e/γ, MUON)
- trigger used in analyses in this talk: trigger with minimal bias

Inclusive particle production

Important input to models:

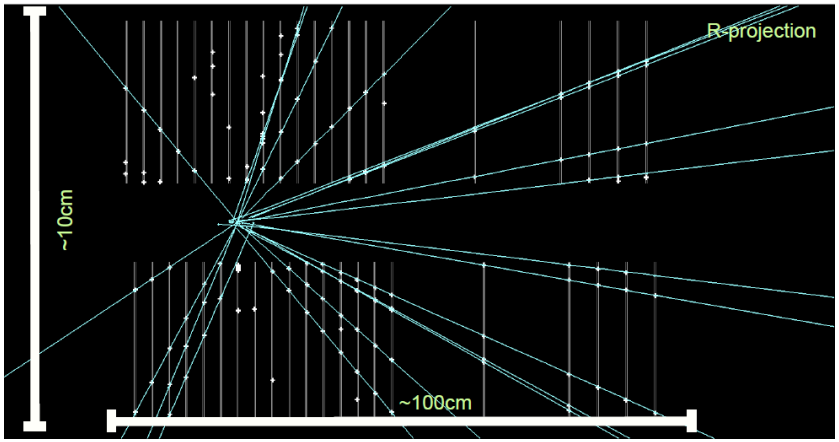
- tuning of event generators
- modeling of underlying event
- forward region
  especially interesting
- test of particle production
- test hadronization
- baryon number transport



Not covered here:
Heavy flavors, energy flow, electro-weak
Talks by: J. Anderson, A. Bursche, S. Farry, A. Moran, G. Sabatino, D. Volyanskyy, Z. Yang

Charged particle multiplicities, overview

- primary charged particles:
  directly produced in *pp*-collision, or from short lived decays
- use VELO (Silicon Vertex Detector)
  - uniform acceptance and high efficiency coverage:
    $2 < \eta < 4.5$ (forward)
    $-2.5 < \eta < -2$ (backward)
  - no magnetic field
    - tracks are straight lines
    - no explicit momentum cut
    - but no momentum measurement
  - low material budget



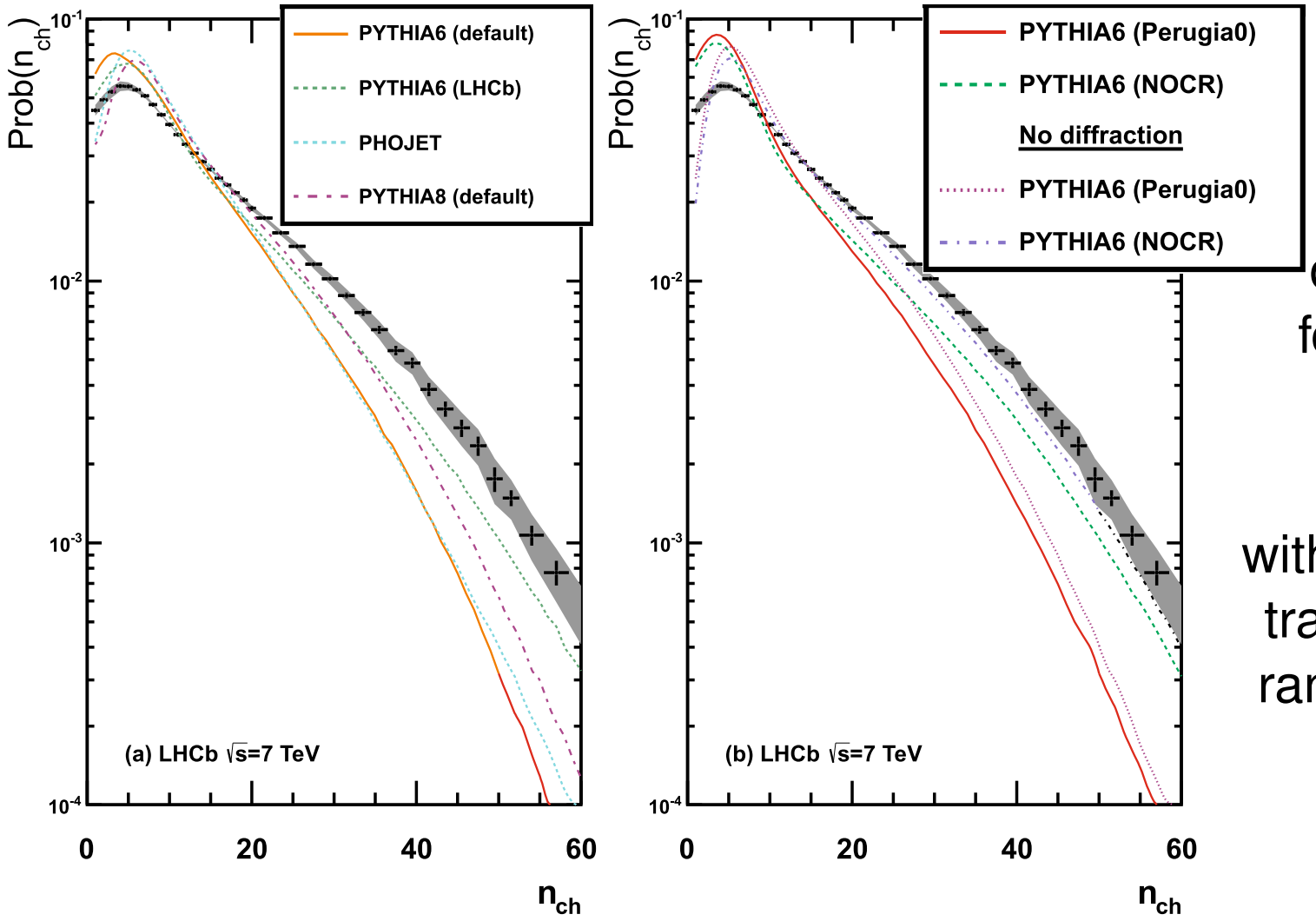
- dataset:
  - low luminosity running phase in 2010 $\rightarrow$ low pile up (3.7 %)
  - $1.5 \cdot 10^6$ *pp* events of each magnet polarity at $\sqrt{s} = 7$ TeV

Charged particle multiplicities, method

- to select primary particles from *pp*-collision:
  - cut on minimal track distance to beam line
  - particles from "luminous region" in beam line direction
- suppress fake tracks (ghosts & clone tracks) by track quality cuts
- corrections applied to data:
  - per event background correction:
    remaining fake tracks (linear dependency on occupancy)
    remaining non-prompt particles (gamma conversions, V^0s)
  - efficiency correction for particle multiplicity:
    unfolding to correct for migrations due to reconstruction efficiency
  - correct for the small pile up
- main systematics: tracking efficiencies (4 %)
  obtained by combining data and MC driven methods

Particle multiplicities

LHCb-PAPER-2011-011



Multiplicity distribution in forward range ($2 < \eta < 4.5$)

Only events with at least one track in forward range accepted

- all generators underestimate charged particle multiplicity
- excluding diffractive processes in PYTHIA improves result

Particle densities ρ per event versus pseudorapidity

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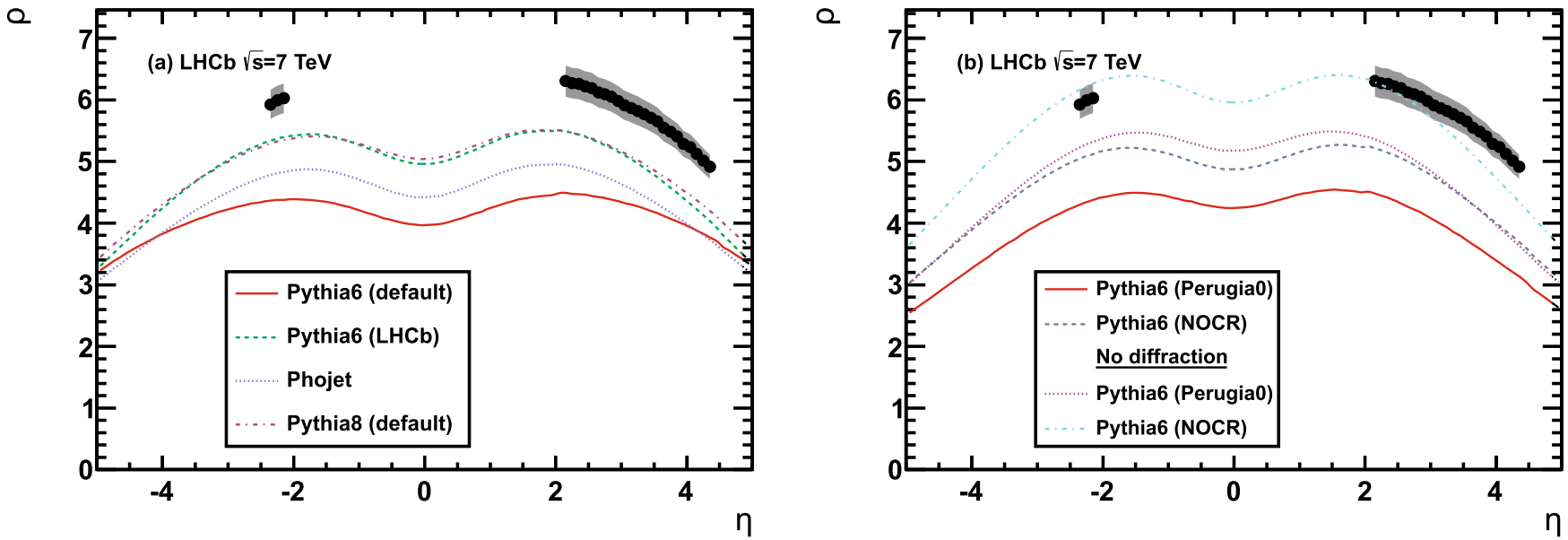
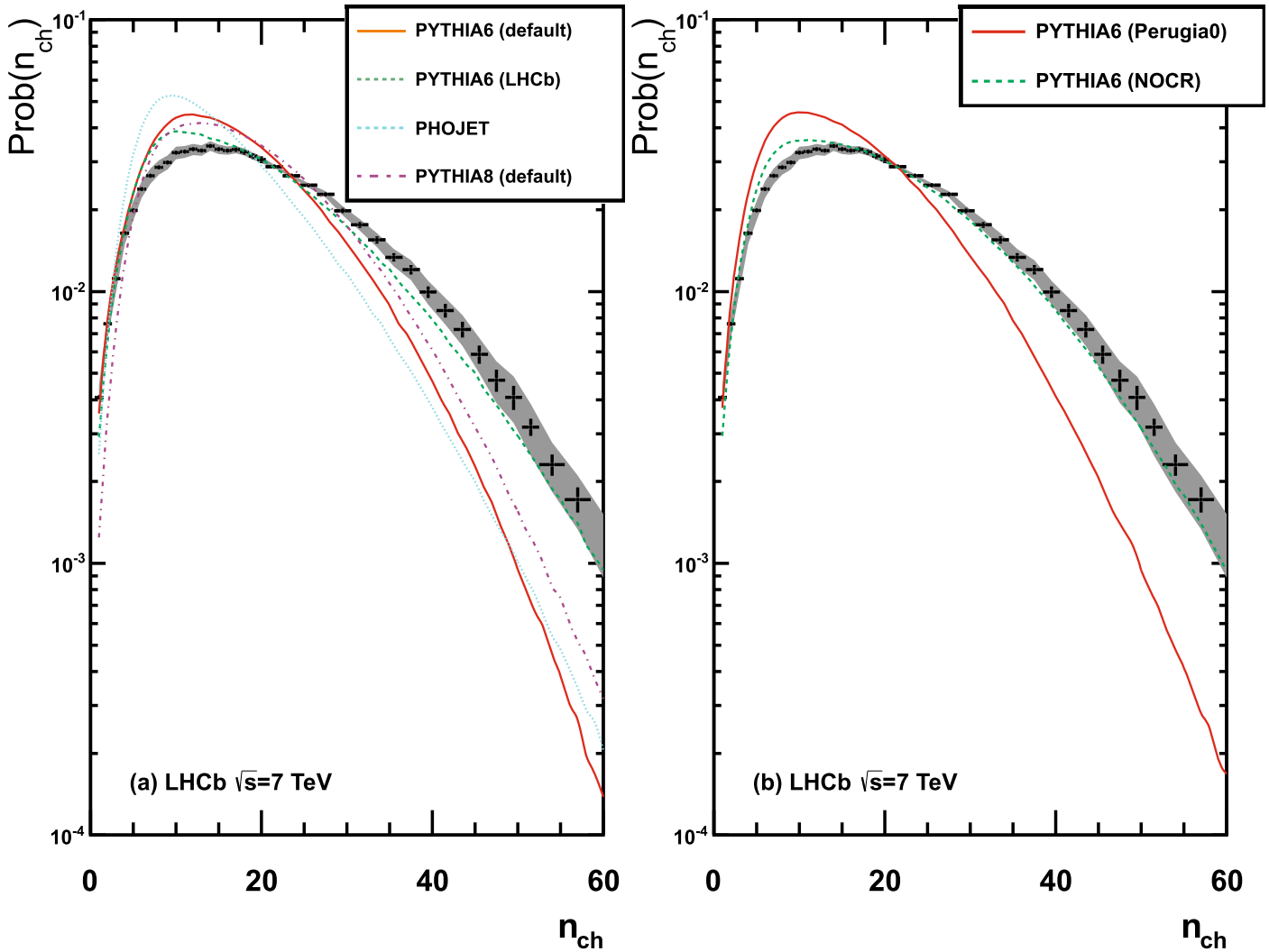
Only events with ≥ 1 tracks in forward direction accepted ($2 < \eta < 4.5$) (in data and MC)



- charged particle density larger than in standard MC prediction
- models without diffractive processes:
  better quantitative description but shape not well reproduced

Particle multiplicities – hard interactions

LHCb-PAPER-2011-011



Multiplicity distribution in forward range ($2 < \eta < 4.5$) for hard events

I.e., at least one high p_T-track w/ $p_T > 1$ GeV in forward range

- hard events better described by MC
- best agreement with PYTHIA in LHCb & NOCR tuning

Prompt hadron production ratios, method

Ratios like: $\frac{\overline{p}}{p}$, $\frac{K^-}{K^+}$, $\frac{\overline{p}+p}{K^-+K^+}$, $\frac{K^-+K^+}{\pi^-+\pi^+}$, ...

- probes baryon transport where protons are involved
- measurements performed at $\sqrt{s} = 900$ GeV (0.3 nb^{-1}) and $\sqrt{s} = 7$ TeV (1.8 nb^{-1})
- prompt particles with $p > 5$ GeV selected with PID requirements
- largest systematic error: PID efficiencies
- efficiency and purity of PID evaluated on data using tag and probe method on: $\phi \to K^+K^-$, $K^0_s \to \pi^+\pi^-$ and $\Lambda \to \pi p$

Measurements are done in 3 bins of p_T (0; 0.8; 1.2 GeV) and 4 equally sized bins of η in $2.5 < \eta < 4.5$ ($p_T < 0.8$: $3 < \eta < 4.5$)

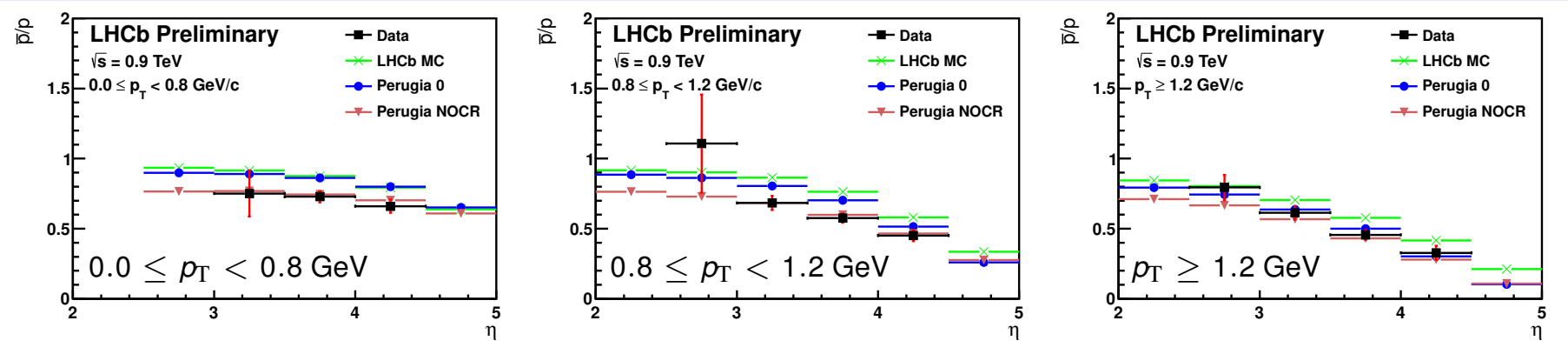
Prompt hadron production ratios, analysis

- cross contamination effect due to PID misidentification
  - taken from calibration sample
  - in bins of p_{T}, η
  - for each magnet polarity and particle/anti-particle separately
- PID efficiency reweighted according to track multiplicity
- *e.g.*, for $p_{\mathrm{T}} > 1.2$ GeV, $\eta > 3$:
  protons: purities $>$ 90 %, efficiencies $>$ 95 %
  kaons: purities $>$ 90 %, efficiencies $>$ 80 %
- correction of particle losses due to interaction with material
  - extracted from MC
  - in bins of p_{T}, η
  - for each magnet polarity and particle/anti-particle separately

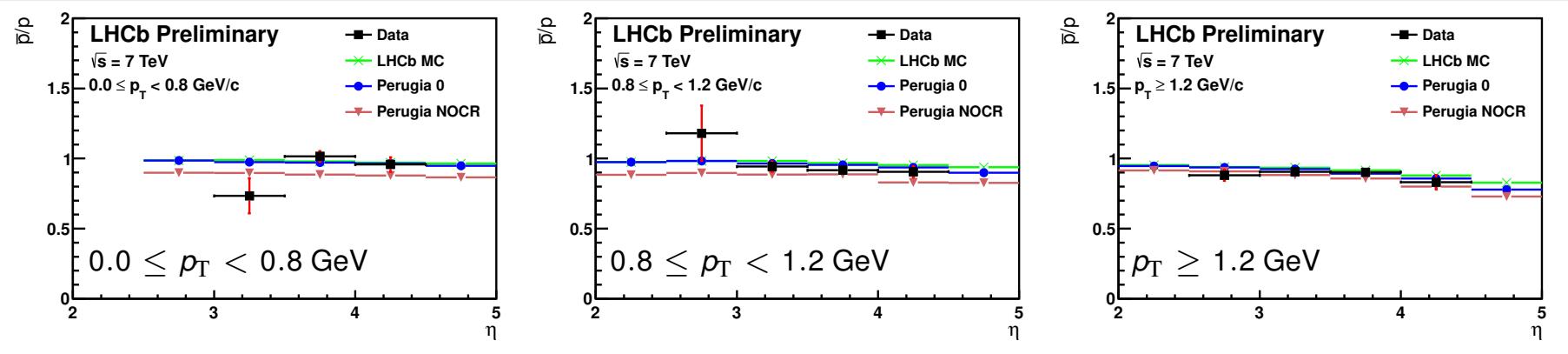
Prompt hadron production ratios

LHCb-PAPER-2011-037 (in preparation)

$\frac{\bar{p}}{p}$, $\sqrt{s} = 900$ GeV

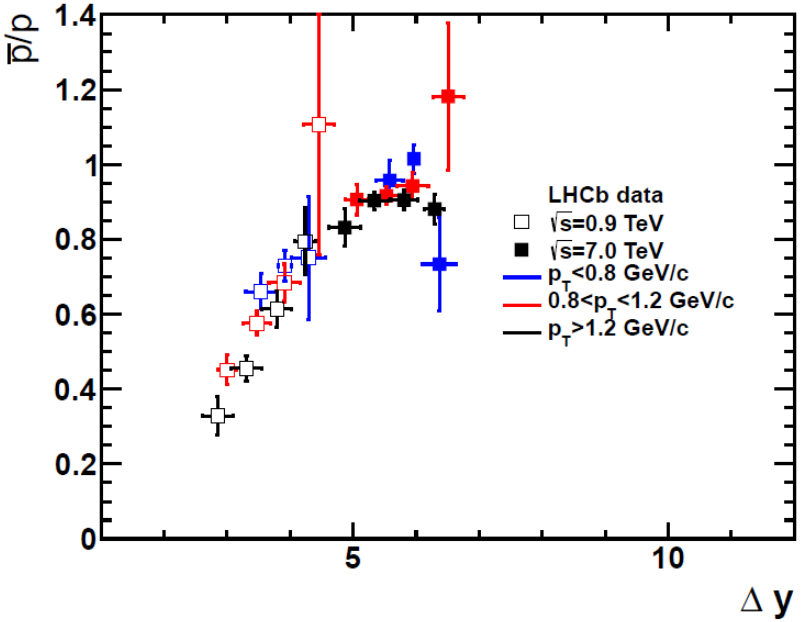


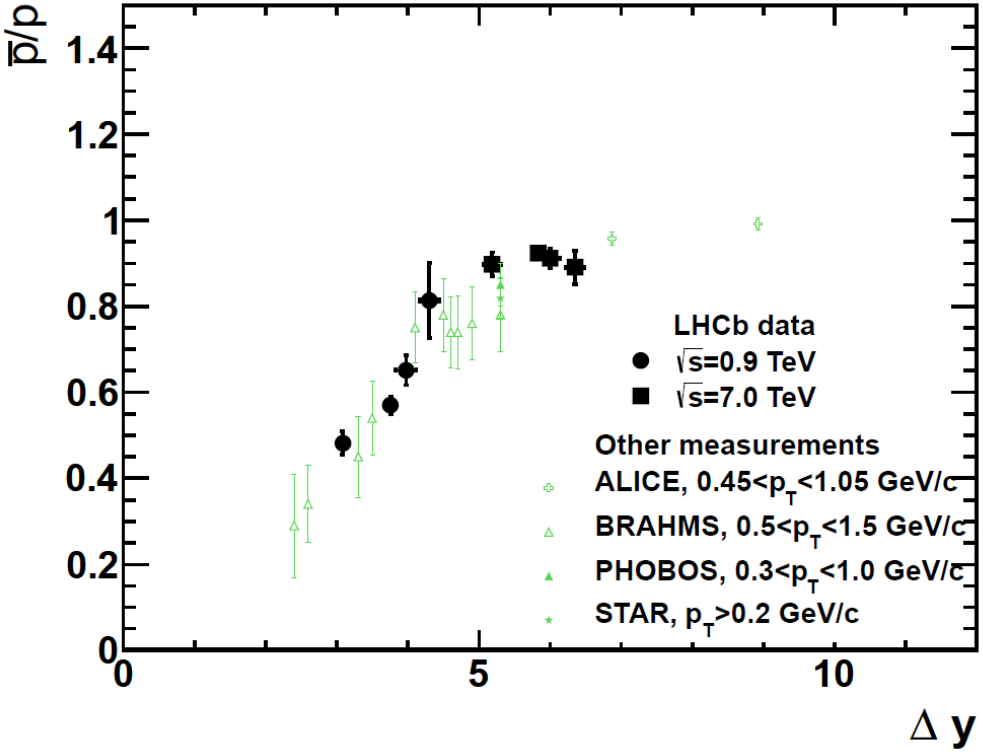
$\frac{\bar{p}}{p}$, $\sqrt{s} = 7$ TeV



Prompt hadron production ratios

LHCb-PAPER-2011-037 (in preparation)



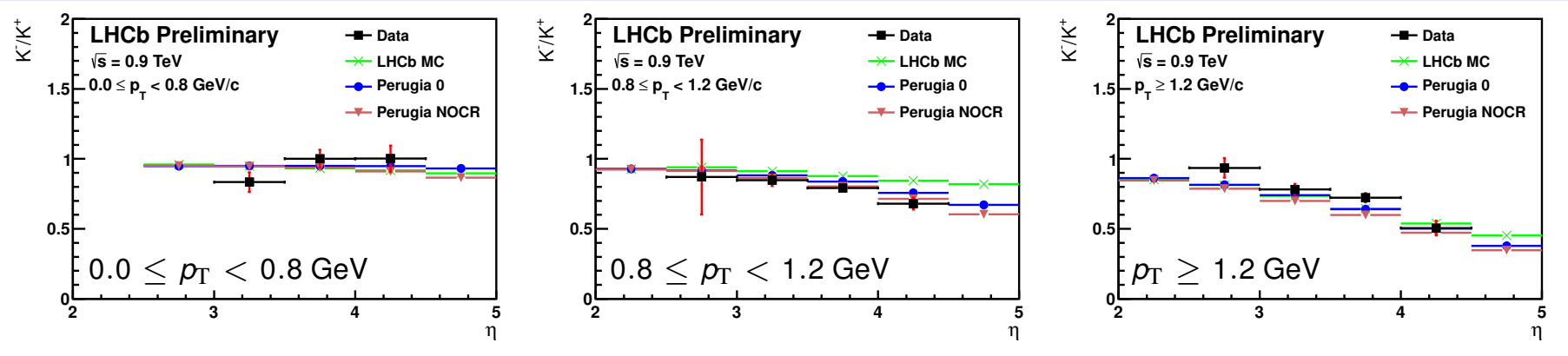


- rapidity loss $\Delta y = y_{\text{beam}} - y$, to compare data from different $\sqrt{s}$
- no evidence of significant p_{T} or $\sqrt{s}$ dependency
- consistent w/ previous experiments, significantly more precise

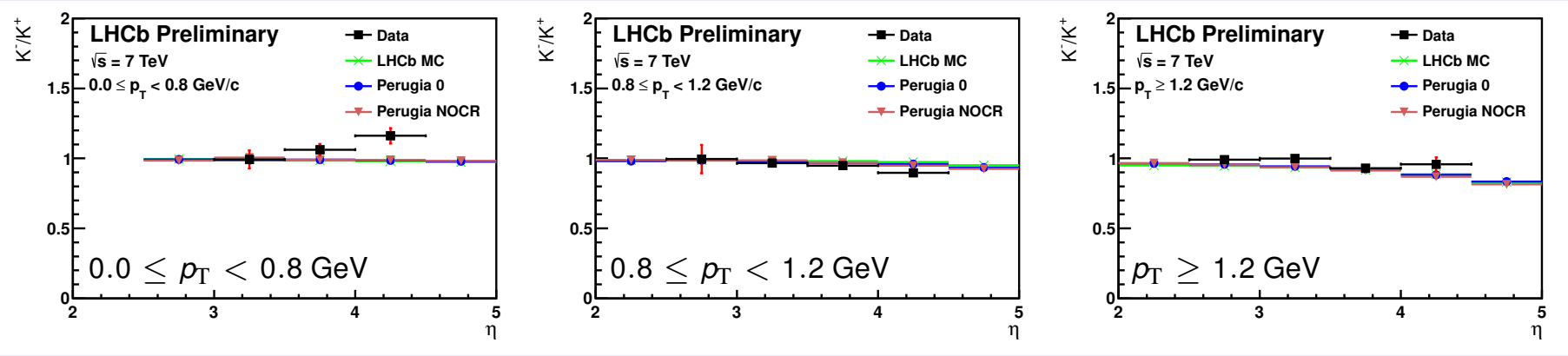
Prompt hadron production ratios

LHCb-PAPER-2011-037 (in preparation)

$\frac{K^-}{K^+}$, $\sqrt{s} = 900$ GeV



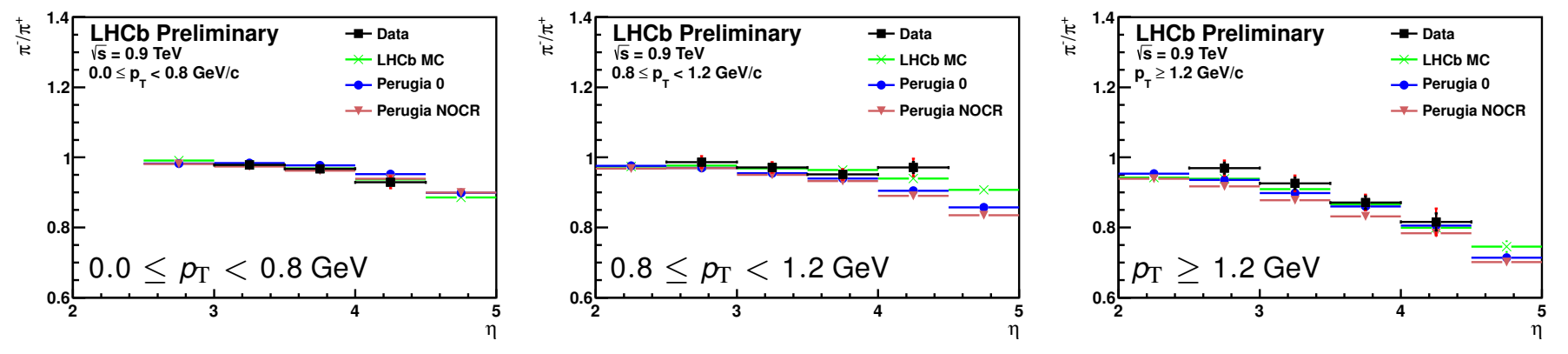
$\frac{K^-}{K^+}$, $\sqrt{s} = 7$ TeV



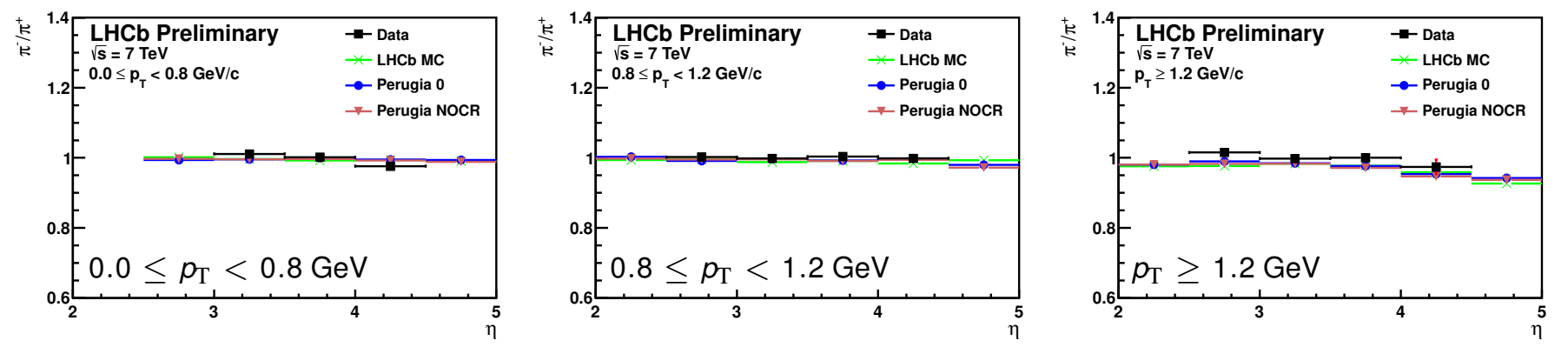
Prompt hadron production ratios

LHCb-PAPER-2011-037 (in preparation)

$\frac{\pi^-}{\pi^+}$, $\sqrt{s} = 900$ GeV



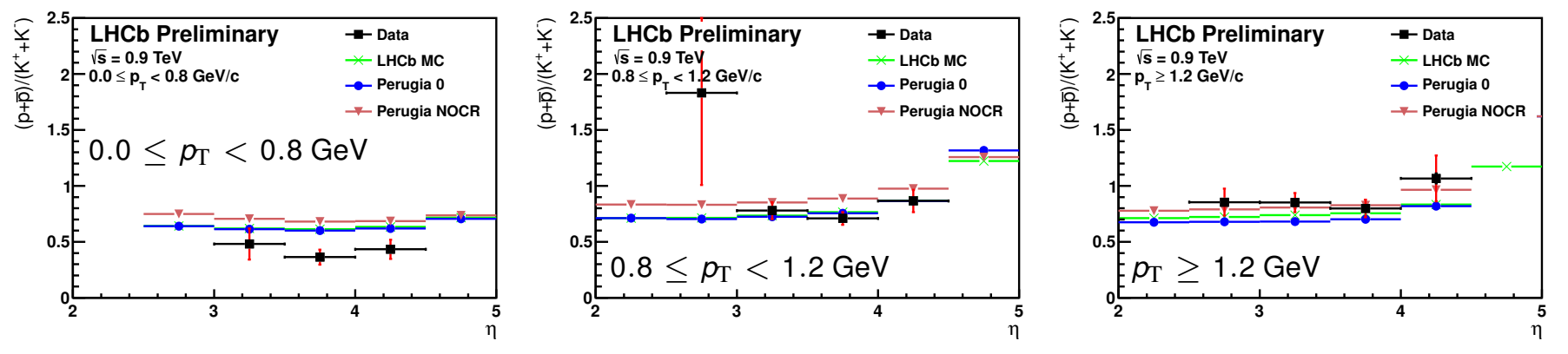
$\frac{\pi^-}{\pi^+}$, $\sqrt{s} = 7$ TeV



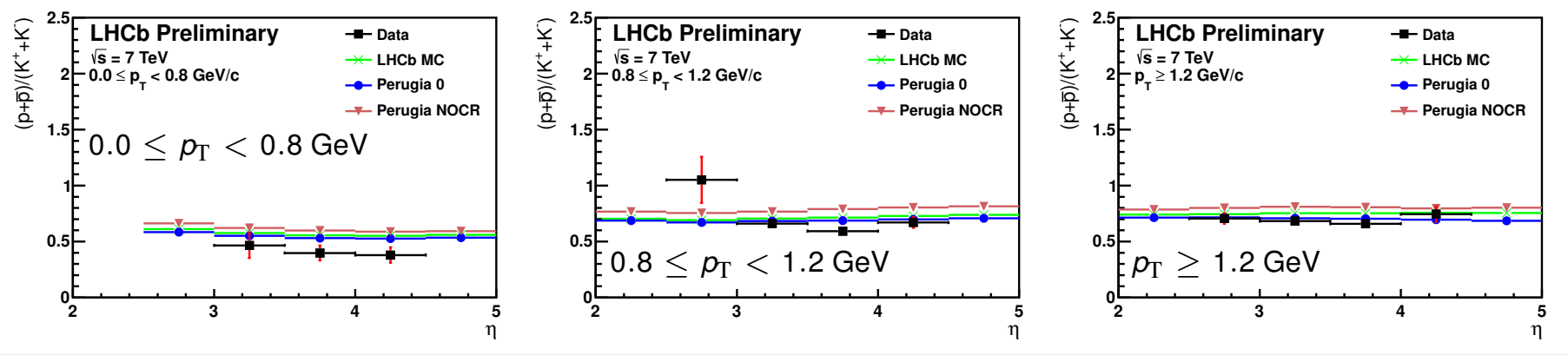
Prompt hadron production ratios

LHCb-PAPER-2011-037 (in preparation)

$\frac{\bar{p}+p}{K^-+K^+}$, $\sqrt{s} = 900$ GeV



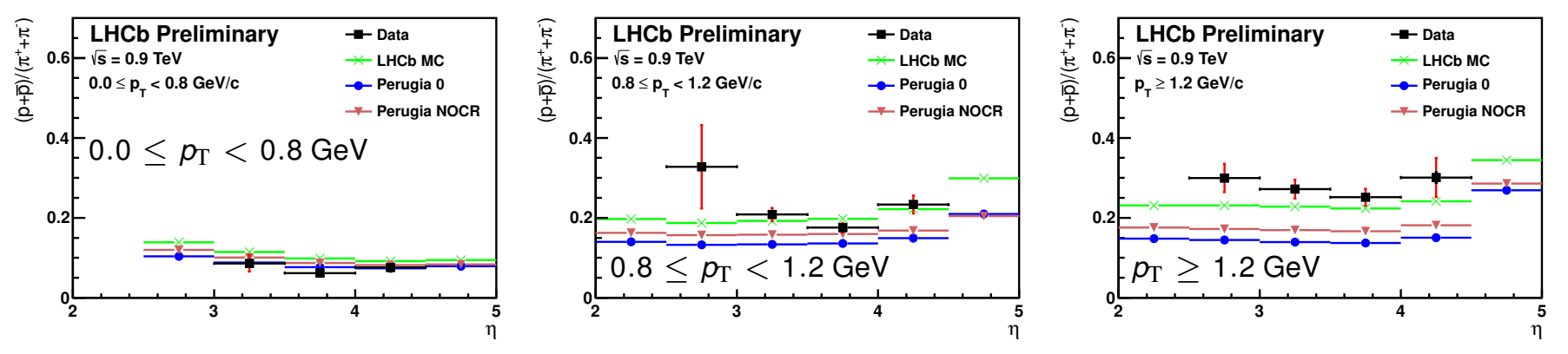
$\frac{\bar{p}+p}{K^-+K^+}$, $\sqrt{s} = 7$ TeV



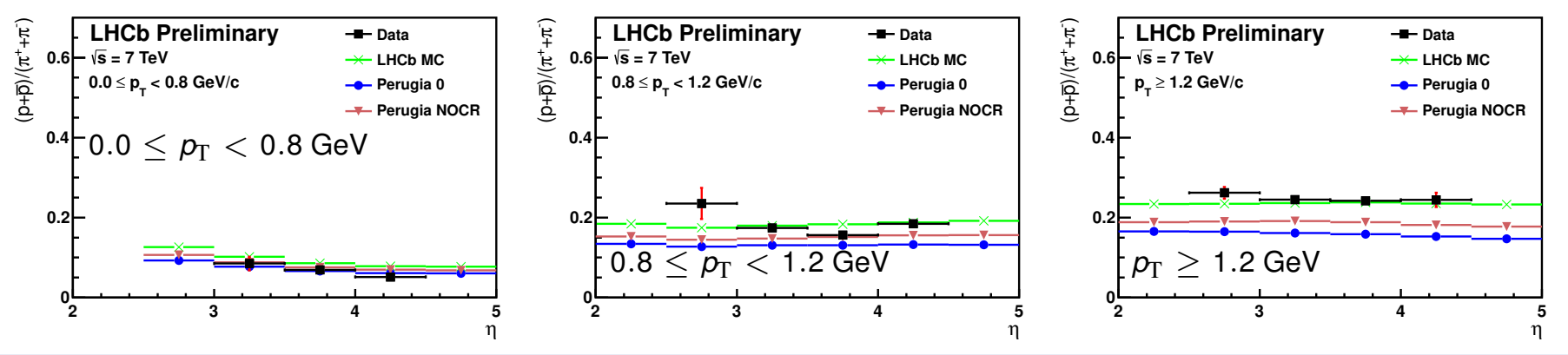
Prompt hadron production ratios

LHCb-PAPER-2011-037 (in preparation)

$\frac{\bar{p}+p}{\pi^-+\pi^+}$, $\sqrt{s} = 900$ GeV



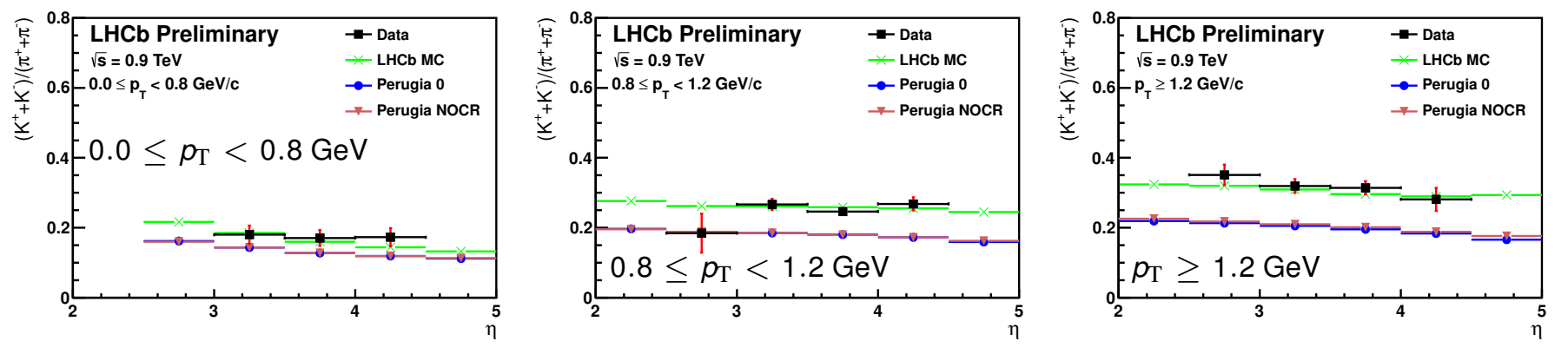
$\frac{\bar{p}+p}{\pi^-+\pi^+}$, $\sqrt{s} = 7$ TeV



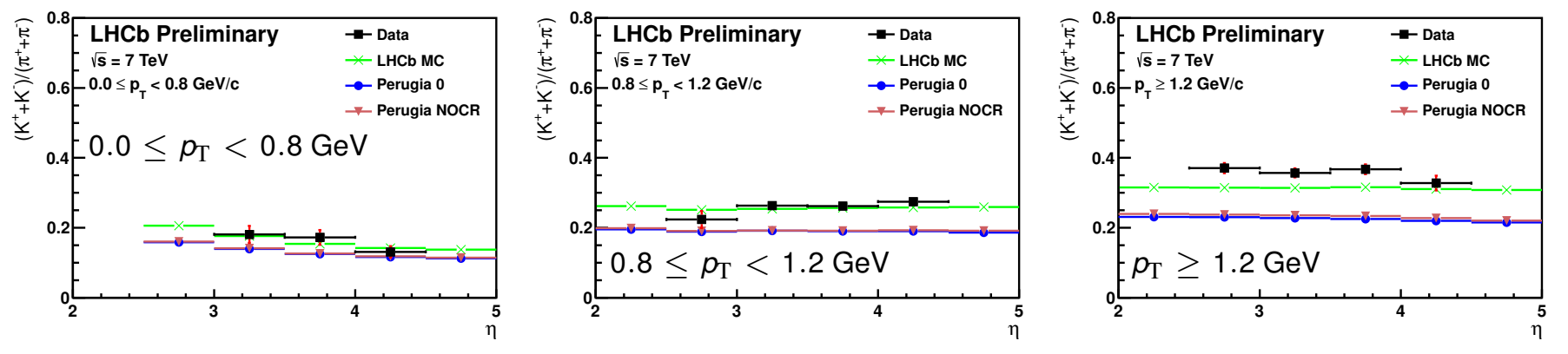
Prompt hadron production ratios

LHCb-PAPER-2011-037 (in preparation)

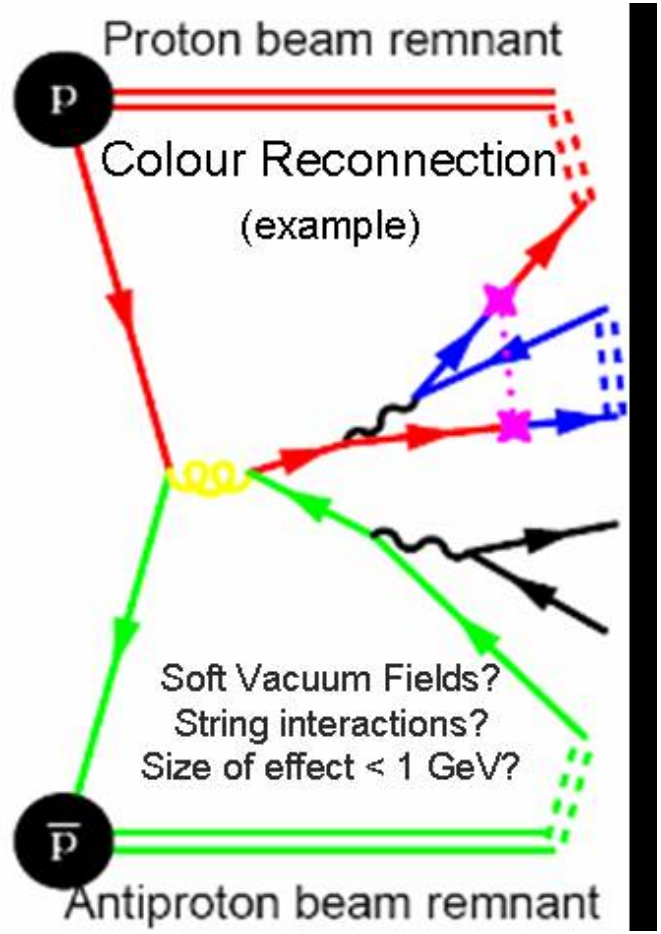
$\frac{K^- + K^+}{\pi^- + \pi^+}$, $\sqrt{s} = 900$ GeV



$\frac{K^- + K^+}{\pi^- + \pi^+}$, $\sqrt{s} = 7$ TeV

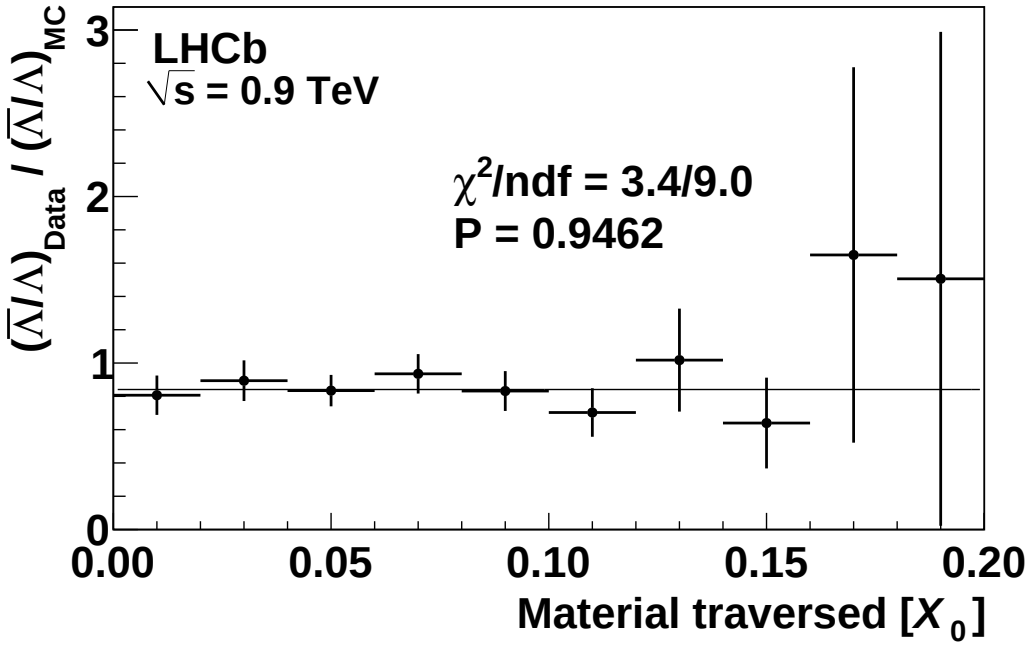


Strangeness – production ratios



Graph by Peter Skands

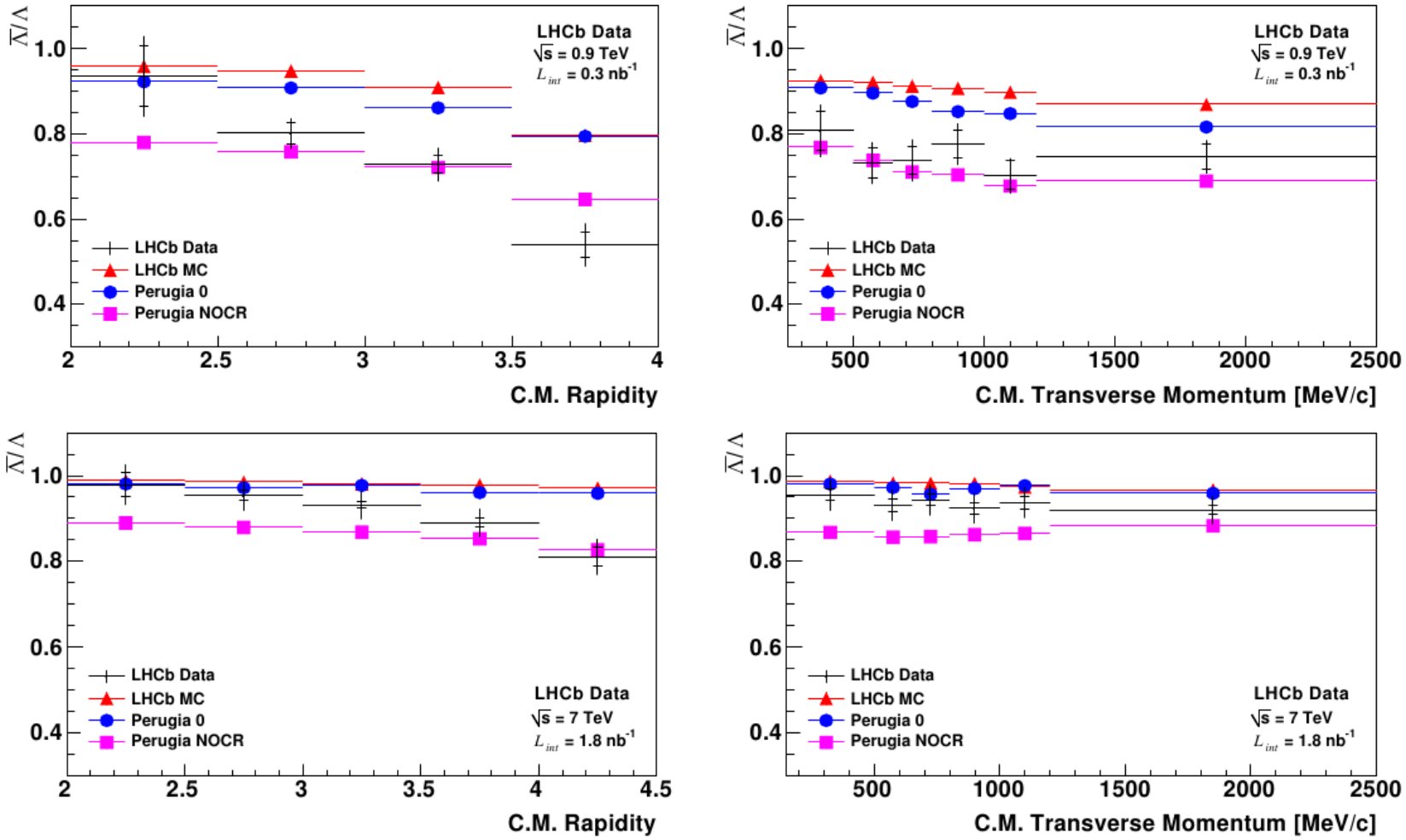
- testing baryon number transport from *pp* to final state
- same data used as in previous analysis
- no PID used
- largest systematic uncertainty: interaction with material



Strangeness – production ratio $\frac{\bar{\Lambda}}{\Lambda} = \frac{\sigma(pp \to \bar{\Lambda} X)}{\sigma(pp \to \Lambda X)}$

$\sqrt{s} = 900$ GeV

$\sqrt{s} = 7$ TeV



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- PV requirement results in small diffractive contribution in data
- only agreement with Monte Carlo at low rapidity
- larger rapidities: extreme baryon transport (NOCR) favored

Strangeness – production ratio $\frac{\bar{\Lambda}}{K_S^0} = \frac{\sigma(pp \to \bar{\Lambda} X)}{\sigma(pp \to K_S^0 X)}$

Baryon-to-meson suppression in strange quark hadronization

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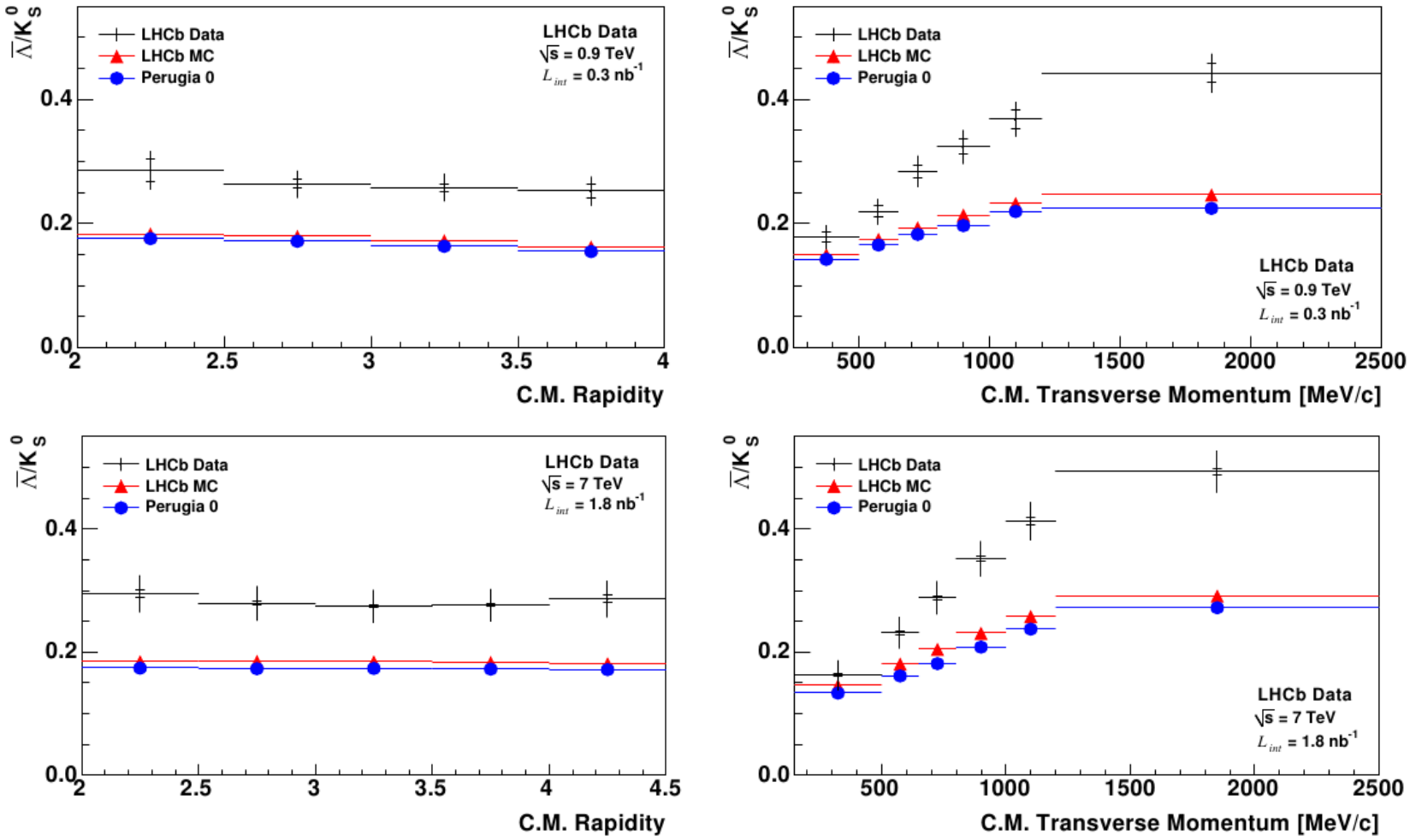
$\sqrt{s} = 900$ GeV

$\sqrt{s} = 7$ TeV



- both energies: production ratio much larger than in MC
- similar size of the effect in both energies

$\Rightarrow$ baryon/meson suppression lower than expected

Inclusive ϕ production

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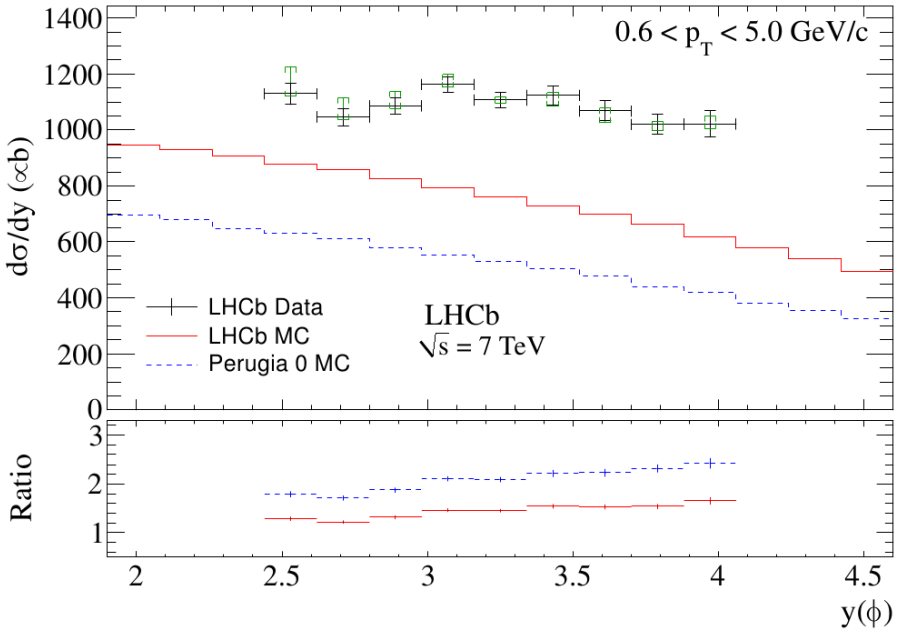
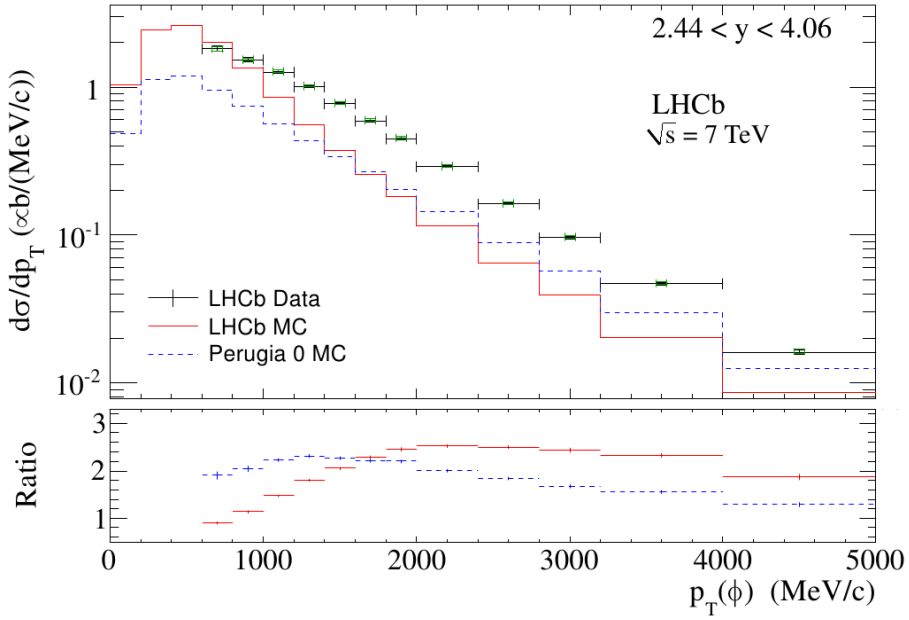
- measure ϕ meson cross-section in pp collisions at $\sqrt{s} = 7$ TeV
- dataset: 14.7 nb^{-1} collected
- $\phi \to K^+K^-$ mass window: $995\,\mathrm{MeV} < m_\phi < 1045\,\mathrm{MeV}$





$\Rightarrow$ simulations underestimate ϕ production in measured range

inclusive cross-section (0.6 GeV $< p_\mathrm{T} <$ 5.0 GeV, 2.44 $< y <$ 4.06):

$$\sigma_{pp\to\phi X} = 1758 \pm 19(\mathrm{stat})^{+43}_{-14}(\mathrm{syst}) \pm 182(\mathrm{scale})\,\mu\mathrm{b}$$

Summary and outlook

- LHCb is an excellent environment for particle production measurements in forward region
- charged particle multiplicities underestimated by MC generators, better description of hard events (esp. NOCR and LHCb tunes)
- particle production ratios not well described by simulations
  - light flavor hadron ratios need MC-tuning: best described by NOCR and LHCb tunes
  - models underestimate baryon number transport, esp. at 900 GeV: low η: standard tunes agree with data, high η: NOCR fits data better
  - baryon/meson suppression is much lower then expected
- ϕ meson production largely underestimated by models

Outlook:

- $\sqrt{s} = 2.76$ TeV data on disk
- $\sqrt{s} = 8$ TeV data to be taken soon

Start backup slides

Backup

Pythia tunes

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

Particle multiplicities: unfolding

Correct migrations due to reconstruction efficiency ε:

$$P_{\mathrm{obs}}(n_{\mathrm{obs}}) = \sum_{n_{\mathrm{true}}=0}^{\infty} P_{\mathrm{true}}(n_{\mathrm{true}}) \cdot f_{\mathrm{binomial}}(n_{\mathrm{obs}}; n_{\mathrm{true}}, \varepsilon)$$

unfold true particle multiplicity by fitting to observed multiplicity