Minimum Bias Physics at LHCb

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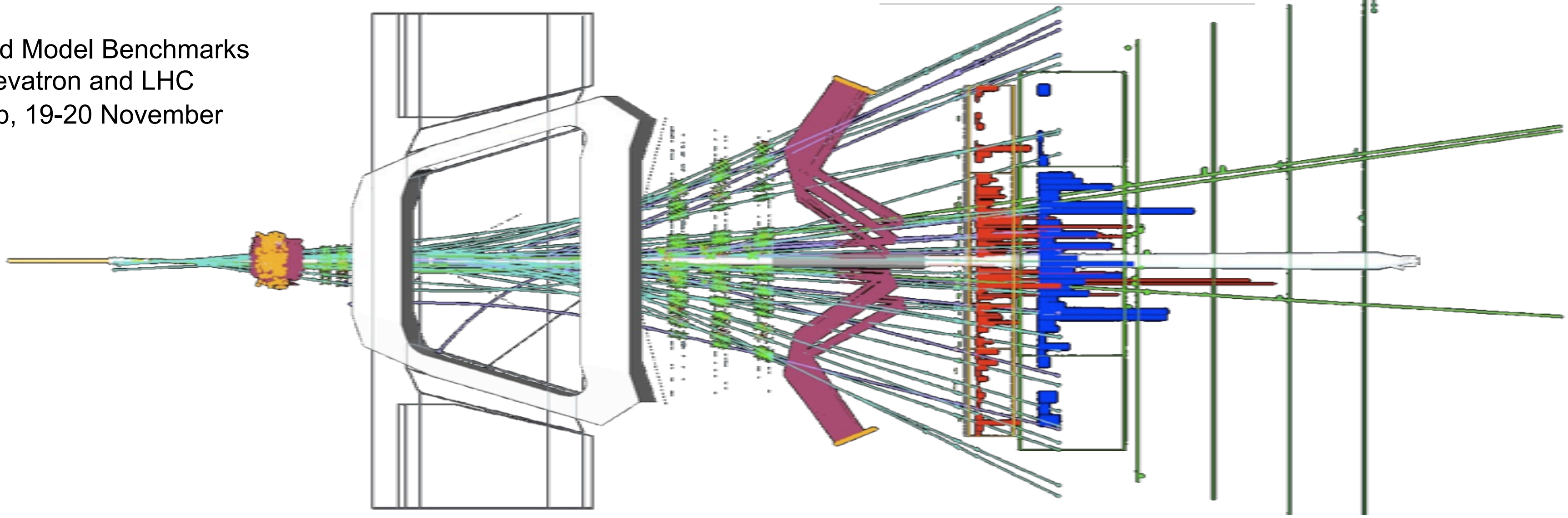
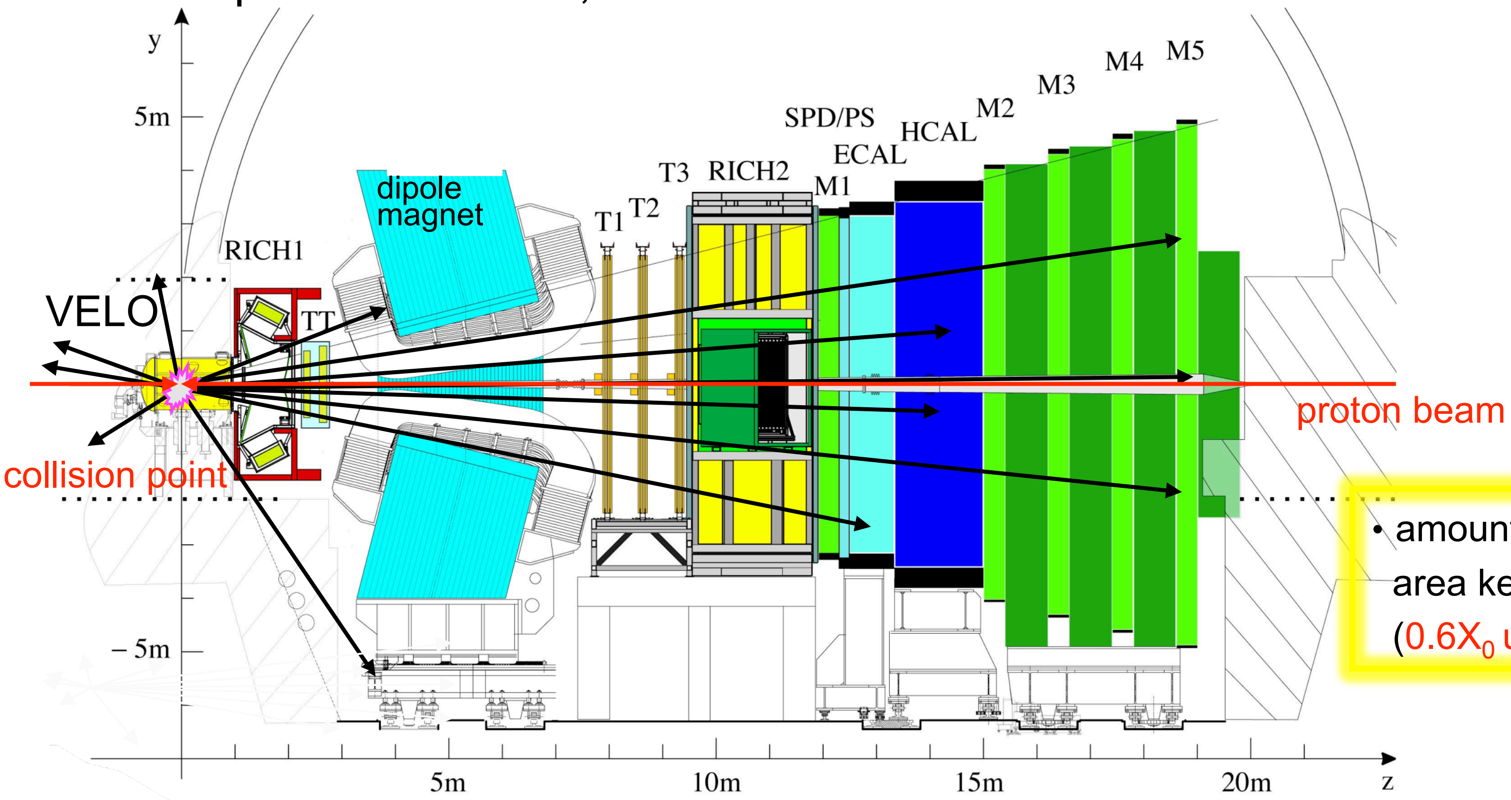
Standard Model Benchmarks
at the Tevatron and LHC
Fermilab, 19-20 November



LHCb

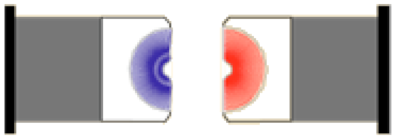
- single arm forward spectrometer (15 mrad < θ < 300 (250) mrad)
- designed to make precision measurement of CP violation and other rare phenomena in the b system at the LHC
- trigger and reconstruct many different B decay modes to make independent and complementary measurements
- forward production of $b\bar{b}$, correlated

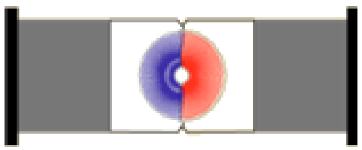


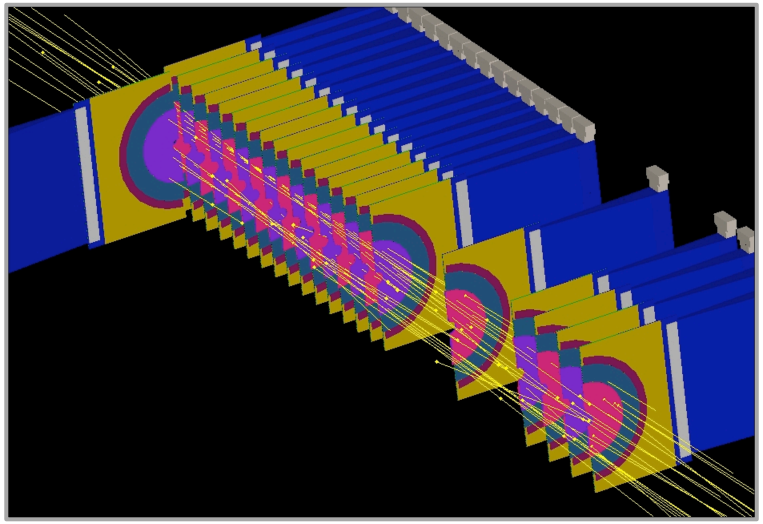
- amount of material in tracker area kept as low as possible ($0.6X_0$ up to RICH2)

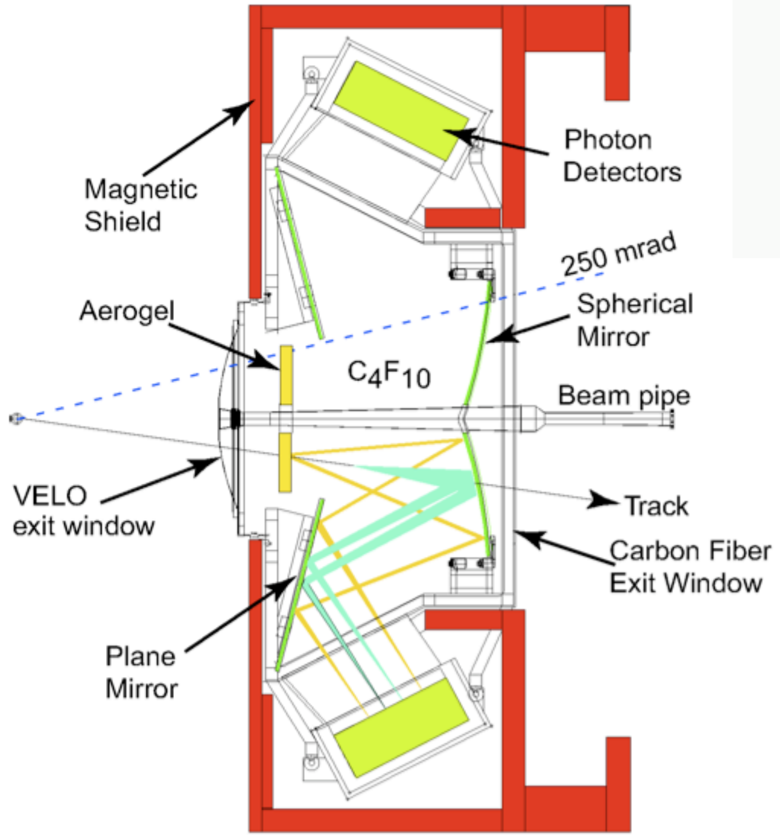
LHCb - VELO and RICH

- contains the pp-collision point
- precise determination of primary and secondary vertices
- 21 silicon μ-strip station with r-φ geometry
- 2 extra pile-up stations per half
  - recognition of multiple interaction collisions at the trigger level
- pitch= 40-100 μm
- 172k channels
- 2 retractable detector halves:
  - ~8 mm from beam when closed
  - retracted by 30mm during injection









- two Cherenkov detectors (RICH) for charged hadron identification
- excellent π/*K*/*p* separation for momenta in range 2-100 GeV/c
- two gaseous and one aerogel radiators

Silica Aerogel
n=1.03
1-10 GeV/c

C_4F_{10} gas
n=1.0014
Up to ~70 GeV/c

RICH1

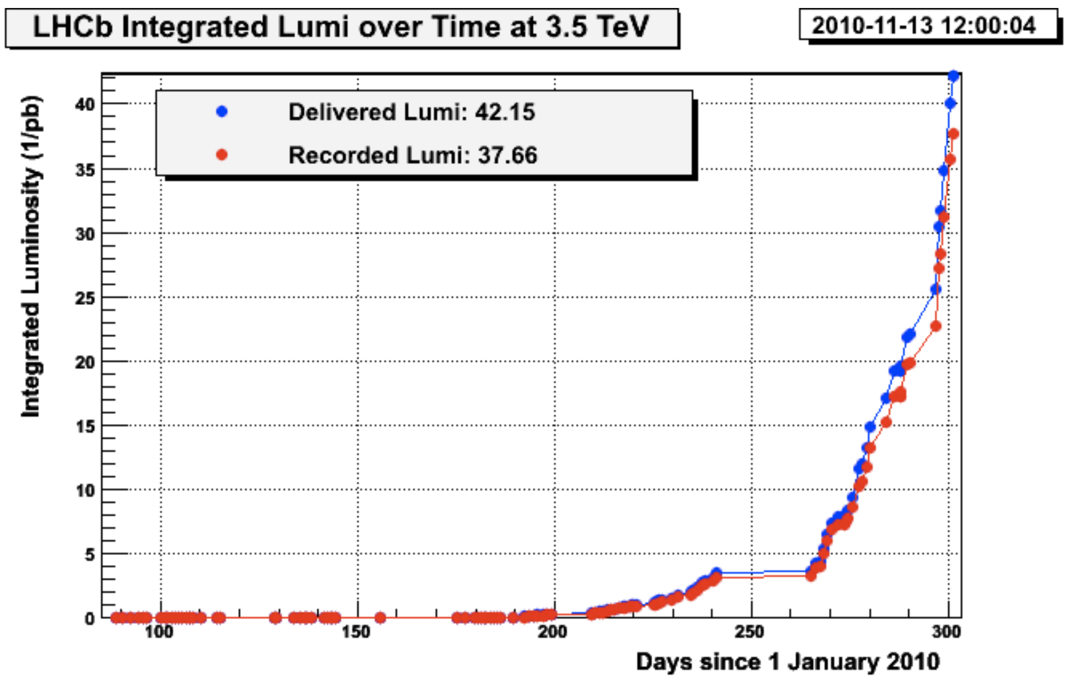
CF_4 gas
n=1.0005
beyond ~100 GeV/c

RICH2

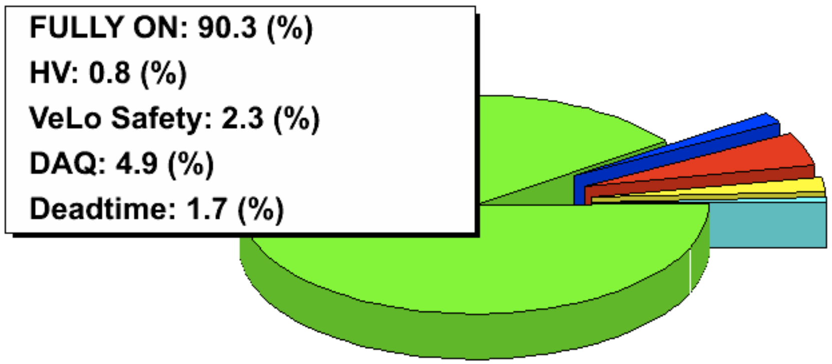
LHCb data

- 6.8 μb^{-1} at $\sqrt{s}$= 0.9 TeV in 2009
- 0.31 nb^{-1} at $\sqrt{s}$= 0.9 TeV in 2010
- 38 pb^{-1} at $\sqrt{s}$= 7 TeV in 2010

have been recorded
(~90% of delivered lumi)



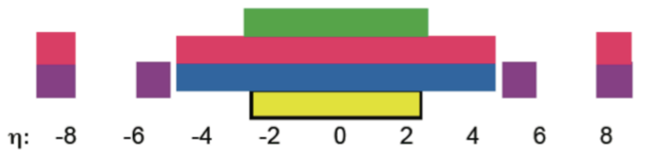
Integrated LHCb efficiency breakdown



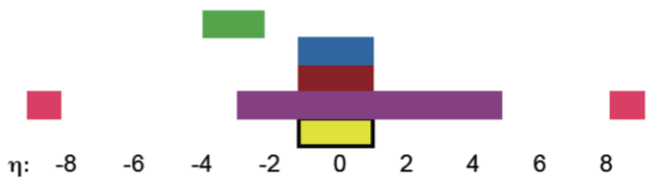
Physics reaches at LHCb with collected data include so far:

- inclusive distributions
- strangeness production
- first charm results
- Onia (J/ψ, ϒ, χ_c, …)
- first b results
- W,Z production

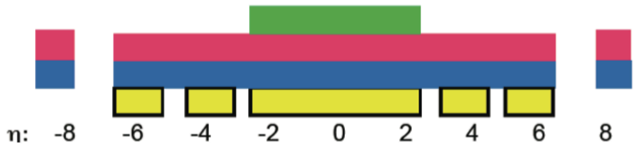
Angular coverage comparison



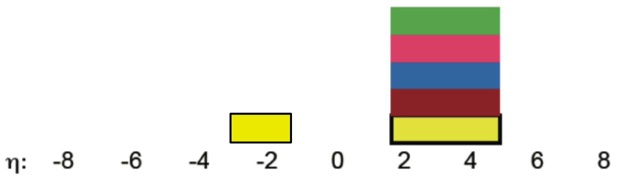
ATLAS



ALICE



CMS&TOTEM



LHCb

First LHCb public results – light hadron production – exploiting the interest for measurements in the forward region where production models were extrapolated not only in energy but also in rapidity

LHCb is the only experiment fully instrumented In the forward direction

strengths of LHCb:

- hadron PID
- tracking, PID and calorimetry in full acceptance

Pythia tunings

Results will be shown compared to Perugia0 tune (Phys.Rev.D82:074018,2010) and LHCb current tune

LHCb tune (PYTHIA 6.421)

LHAPDF-CTEQL61

Included process types:
11-13
28
53
68
91-95
421-439
461-479

Particles are decayed through EVTGEN

Non-default in LHCb tune		parp(85)	0.33
ckin(41)	3.0	parp(86)	0.66
mstp(2)	2	parp(91)	1.0
mstp(33)	3	parp(149)	0.02
mstp(128)	2	parp(150)	0.085
mstp(81)	21	parj(11)	0.5
mstp(82)	3	parj(12)	0.4
mstp(52)	2	parj(13)	0.79
mstp(51)	10042	parj(14)	0.0
mstp(142)	2	parj(15)	0.018
parp(67)	1.0	parj(16)	0.054
parp(82)	4.28	parj(17)	0.131
parp(89)	14000	mstj(26)	0
parp(90)	0.238	parj(33)	0.4

Studies with first data

First Physics at LHCb:

production measurements → K^0_s cross sections at 0.9 TeV

antiparticle-particle ratios → $\overline{\Lambda}/\Lambda$, $\overline{p}/p$ ratios at 0.9 and 7 TeV

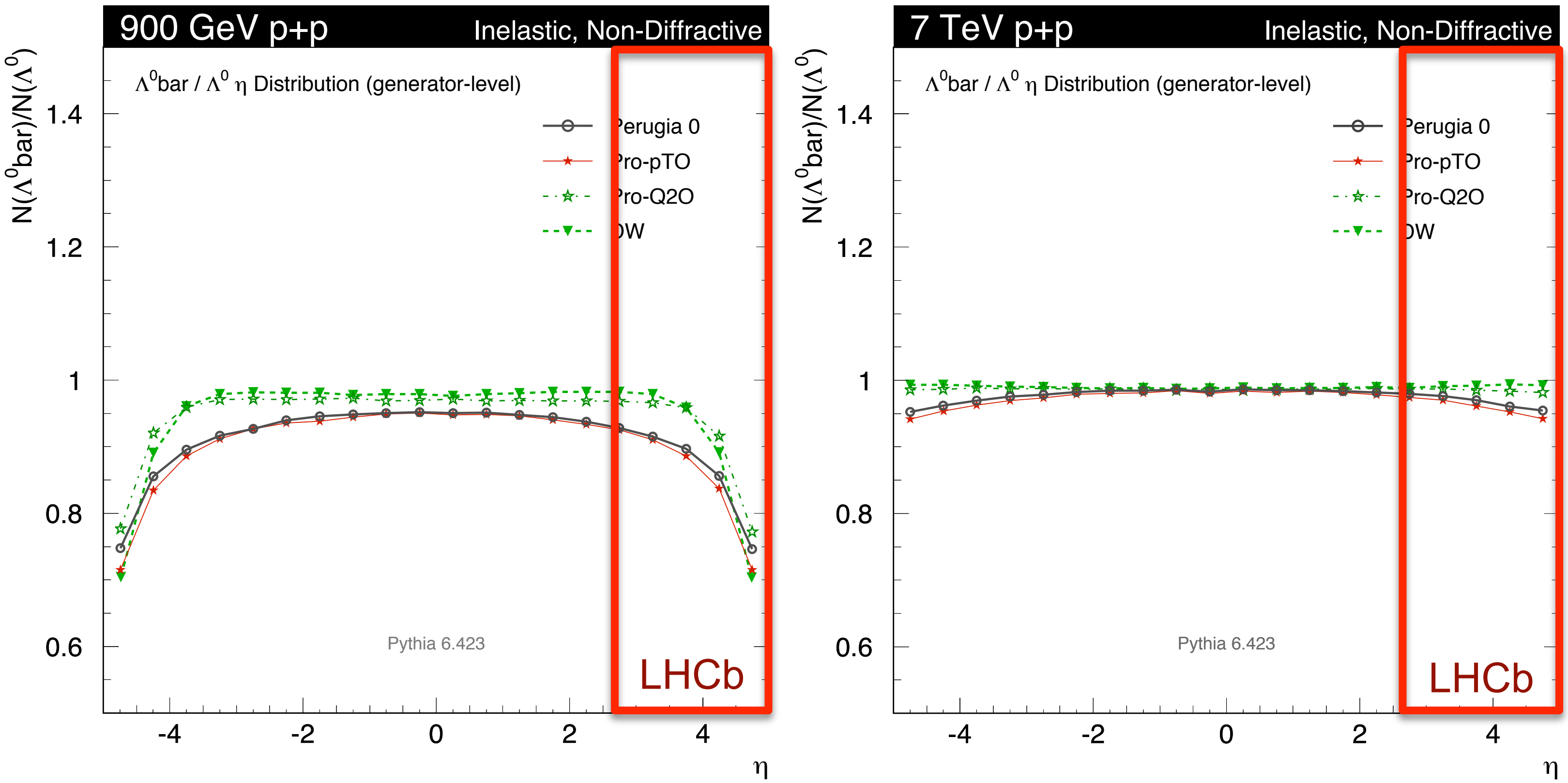
baryon-meson ratio → $\overline{\Lambda}/K^0_s$ ratio at 0.9 and 7 TeV

From theory point of view:

- hadronization still not well understood: at present different phenomenological models available but no theory can describe this process consistently
- since strange quarks are no valence quarks in the initial state:
  - good test for fragmentation models
- highest CM energy so far 1.96TeV at Tevatron (but ppbar, in pp 200 GeV)
- models have been tuned to SPS and Tevatron data (central rapidity and p_T>0.4GeV). LHCb can cover forward rapidity and provide measurements down to p_T~0

- antiparticle-particle ratio helps to understand:
  - which partons carry the baryon number
  - the baryon number flow in inelastic collisions
- baryon-meson ratio good test of fragmentation models

$\overline{\Lambda}/\Lambda$ LHCb coverage



http://home.fnal.gov/~skands/leshouches-plots

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From experimental point of view:

- minimal requirements for the detector: only tracking and vertexing are needed for V^0s
- simple minimum bias trigger
- momentum calibration cross-checks with mass distributions
- no PID required (except for proton results)
- preparation for more complex analyses (B_d -> J/ψ K_s, b-baryons, multistrange baryons…)

Prompt K^0_s production

Physics Letter B 693 (2010) pp. 69-80
arXiv:1008.3105v2

K^0_s cross-section is the first LHCb measurement to contribute to the understanding and tuning of hadronisation/fragmentation models.

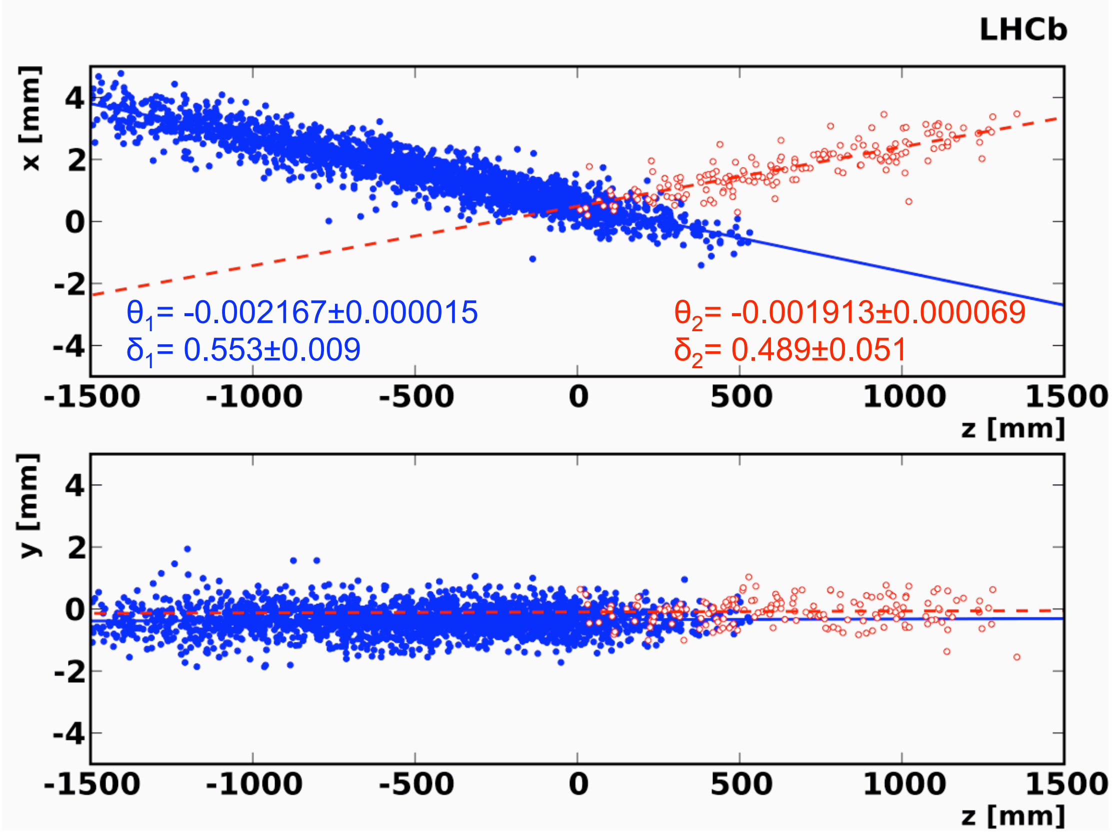
- 6.8 μb^{-1} recorded in the 2009 pilot run
- K^0_s reconstructed through: $K^0_s \rightarrow \pi^+\pi^-$
- high purity selection without requiring particle identification (ideal first measurement for LHCb)
- main systematic contributions:
  - -luminosity (~12%)
  - -tracking efficiencies (~10%)

Prompt K^0_s production – luminosity measurement

Direct measurement of luminosity based on knowledge of beam profiles:

$$\mathcal{L}_{int.} = f \cdot \sum_{i=0}^{N} \frac{n_{1;i} \cdot n_{2;i}}{4\pi \cdot \sigma_i^x \cdot \sigma_i^y}$$

$n_{1;i}$ $n_{2;i}$	Number of protons in bunch 1, 2
σ_i^x σ_i^y	Transverse bunch size
f	Revolution frequency



- bunch currents from the machine
- beam size, positions and angles measured with VELO using beam gas interactions

Integrated luminosity = (6.8 ±1.0) μb-1

15% tot uncertainty dominated by beam currents

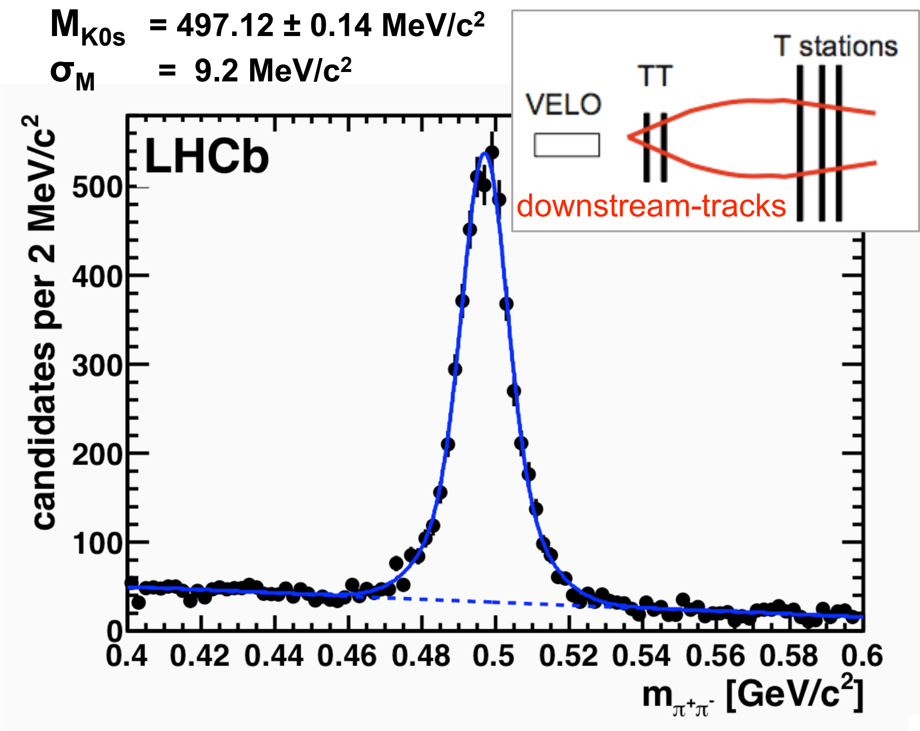
currents	widths	positions	angles
12%	5%	2%	1%

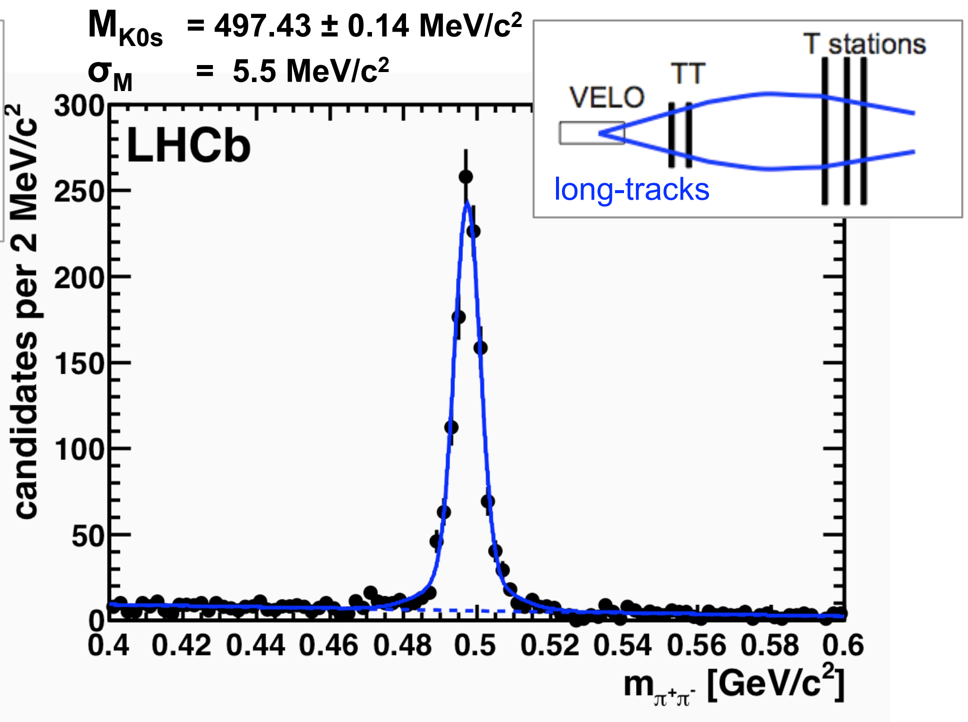
in latest measurements improved to ~5%

Prompt K^0_s production - tracking

Mass distributions of all selected K^0_s candidates

during 2009 pilot run beam size and crossing angles larger than design -> VELO not fully closed -> only limited coverage for long tracks compared to nominal configuration



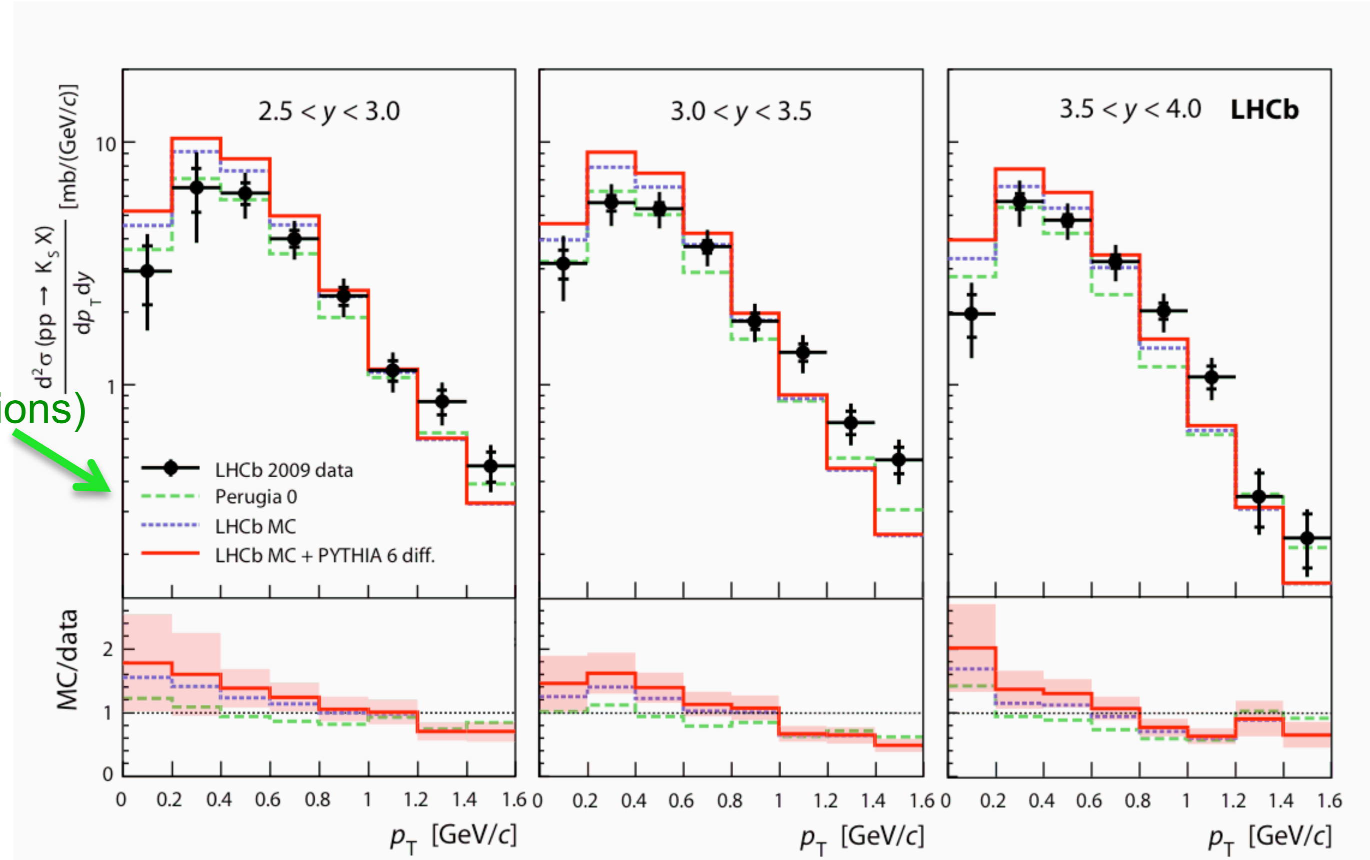


- signal extraction from fit
- cross-sections evaluated separately from both downstream and long track selection (consistent results)
- results not statistically independent → downstream-track measurements taken (except lowest p_T bins 2.5<y<3.0 from long-track selection)

Prompt K^0_s production

Measurements in bins of y and p_T and compared to LHCb MC (with and w/o diffraction) and Perugia0 Tuning

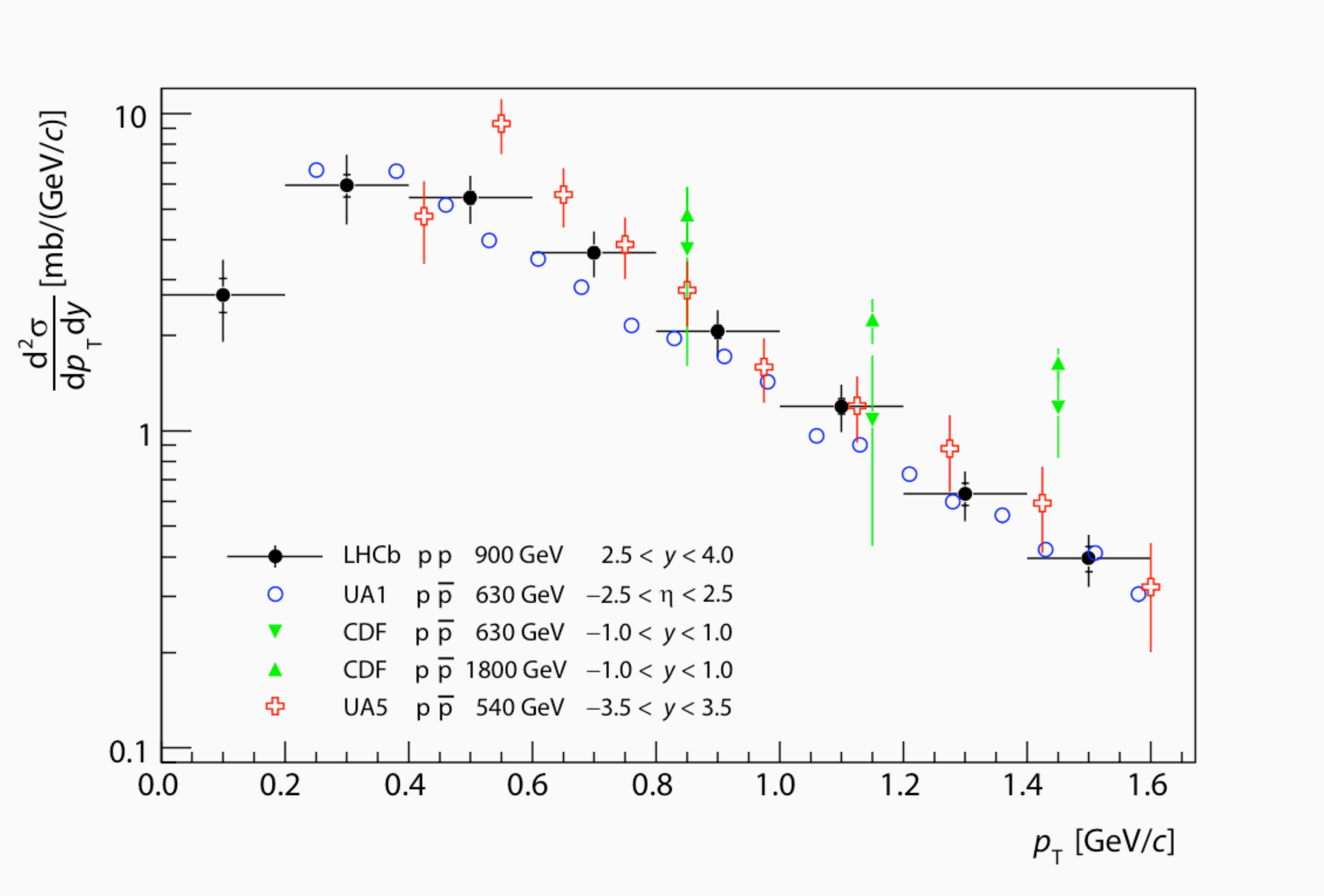
Perugia 0 tune
(no diffractive contributions)



• data favor harder p_T spectrum than MC predictions

Prompt K^0_s production

Comparing with other experiments…



- K^0_s cross-section not measured before at 0.9 TeV
- LHCb results reach larger rapidity values and lower p_T than previous experiments

Prompt K^0_s systematics

Source of Uncertainty	Errors
signal extraction	1-5%
beam-gas subtraction	<1%
MC statistics	1-5%
track finding	6-17%
selection	4%
trigger	2%
p_T and y shape within bin	0-20%
diffraction modeling	0-1%
non-prompt contamination	<1%
material interaction	<1%
luminosity	15%
Total systematic uncertainty	17-31%

V^0 ratio measurements

Interesting physics probed by strange particle ratios:

- Baryon Number Transport ($\bar{\Lambda} / \Lambda$)
  direct measurement of the baryon transport from the interacting beams to the fragmented final states.
  Various models of baryon number transport exist, measurements in the LHCb kinematic range could provide new info to distinguish between models.

- Baryon Suppression ($\bar{\Lambda} / K^0_s$)
  very sensitive test of fragmentation models since final states (meson and anti-baryon) different from initial state (two baryons).

- Both ratios very important input for tuning of fragmentation models

V^0 ratio measurements

LHCb preliminary
LHCb-CONF-2010-011

Measurement of $\bar{\Lambda}/\Lambda$ and $\bar{\Lambda}/K^0_s$ ratios using prompt particles with 2010 data:

- $\sqrt{s}$ = 0.9 TeV → 0.3 nb^{-1}
- $\sqrt{s}$ = 7 TeV → 0.2 nb^{-1}

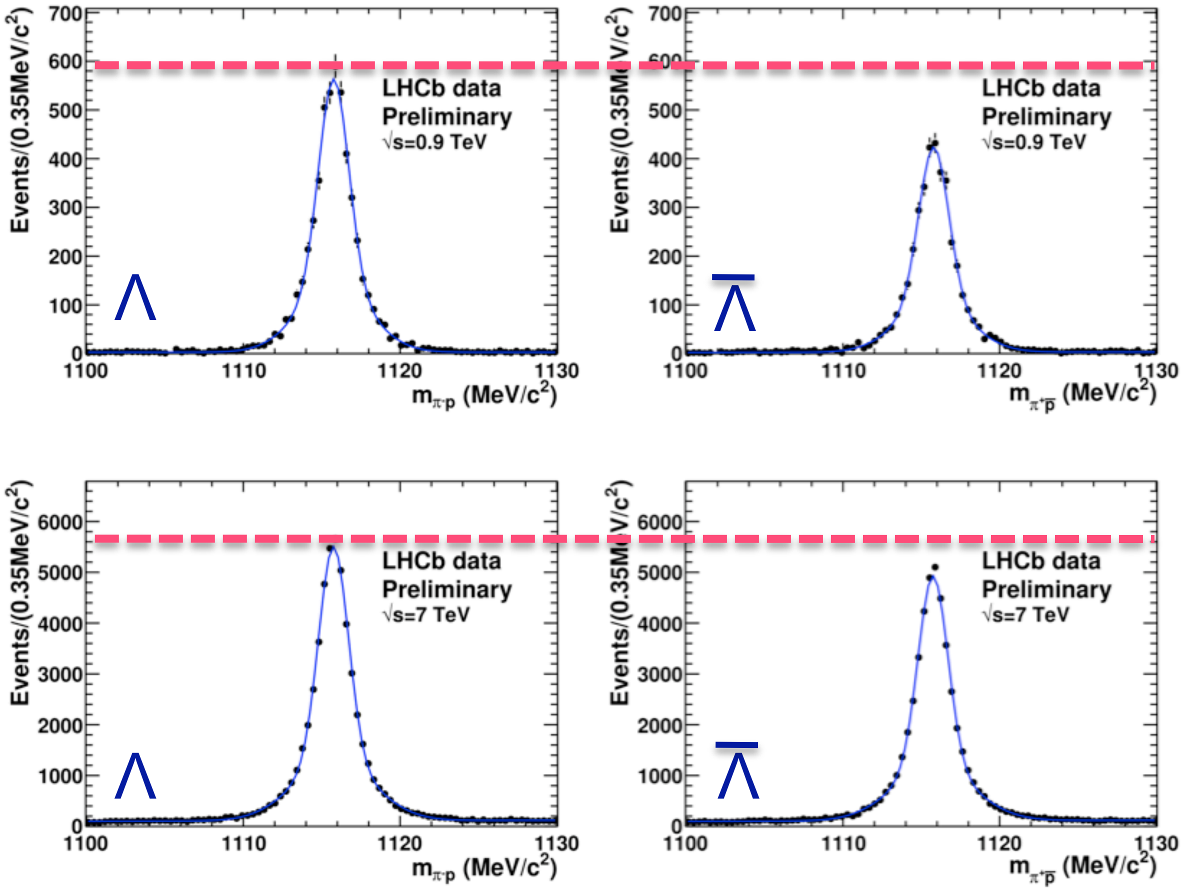
- $\bar{\Lambda}$, Λ and K^0_s identified through: $\Lambda \to p\,\pi^-$, $\bar{\Lambda} \to \bar{p}\,\pi^+$, $K^0_s \to \pi^+\pi^-$
- no PID info used, to get rid of cross feeds between K^0_s and Λ, the other resonance mass hypotheses were tried. If invariant mass range around the other resonance mass → candidate discarded.

Efficiencies from MC for prompt, non-diffractive events

Ratios benefit from reduced systematic uncertainties (errors cancel out, absolute luminosity not required): $\sigma(\bar{\Lambda}/\Lambda)$~2%, $\sigma(\bar{\Lambda}/K^0_s)$~2-12%

Strange Baryons Production

Baryon number conservation requires the destroyed beam particles in inelastic non-diffractive collisions must be balanced by creation of baryons elsewhere. How close baryon and anti-baryon are produced in the phase space?



0.9 TeV

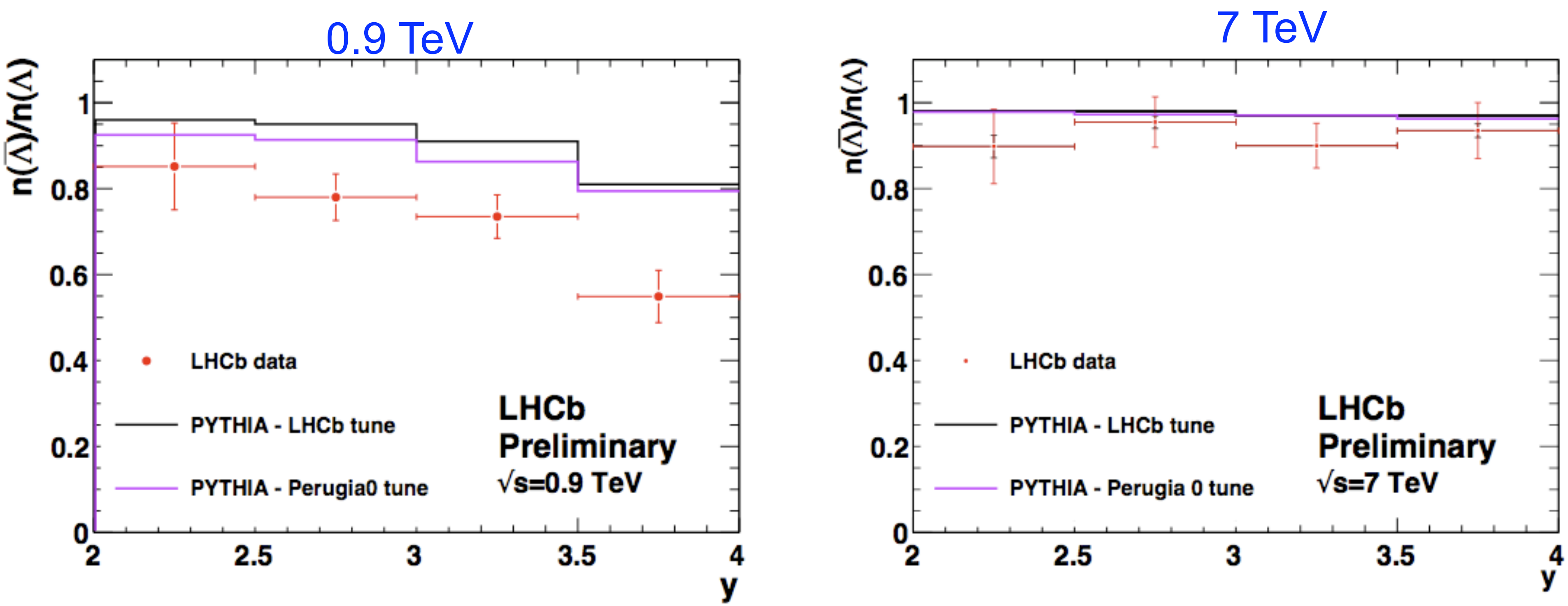
7 TeV

Evidence for energy dependence of production ratios

Baryon Number Transport

Measured n($\bar{\Lambda}$)/n(Λ) ratio:

- clear energy dependence seen
- measurements lie significantly under MC prediction at 0.9TeV
- reasonable agreement at 7 TeV where the ratio is expected to be close to unity

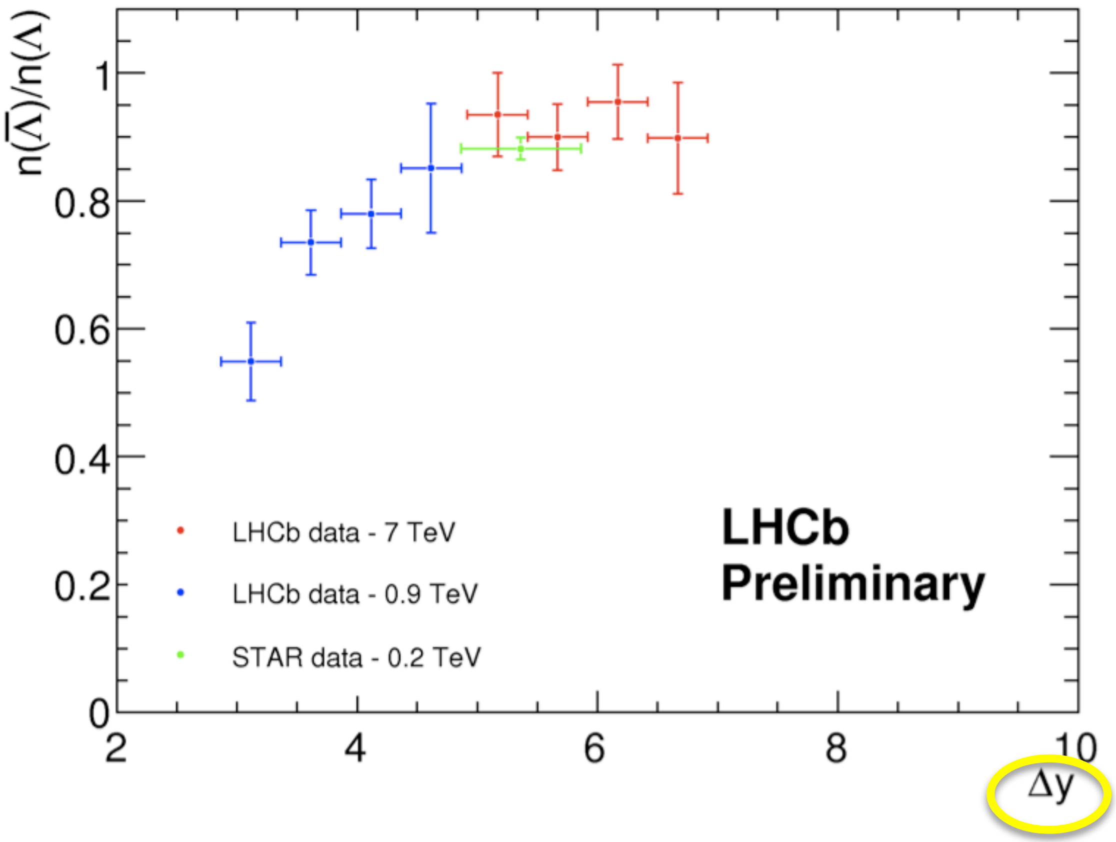


Baryon Number Transport

Comparing rapidity bins at the same distance from the beam:

$$y_1 = y_2 + \ln(E_{b1}/E_{b2})$$

allows to probe scaling violations

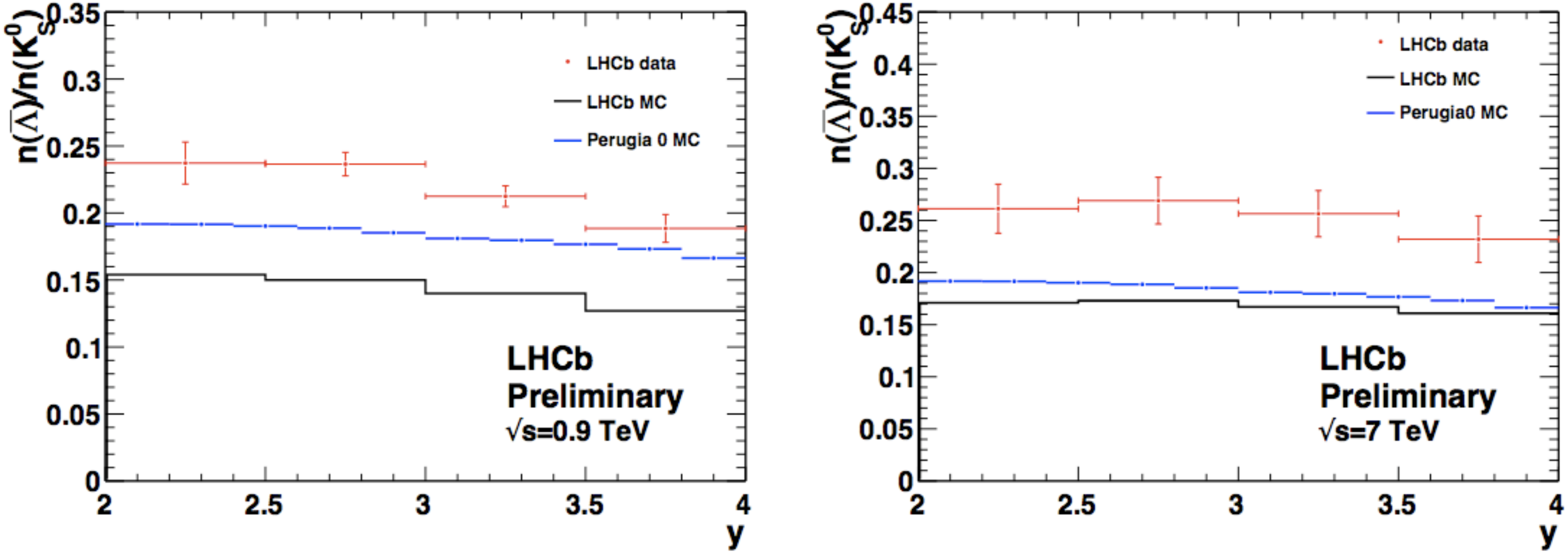


- dependence on difference to beam rapidity observed
- results consistent with STAR

$\Delta y = y_{beam} - y(\Lambda)$

Study of Baryon suppression

Measured $\overline{\Lambda}$ / K^0_s production ratio

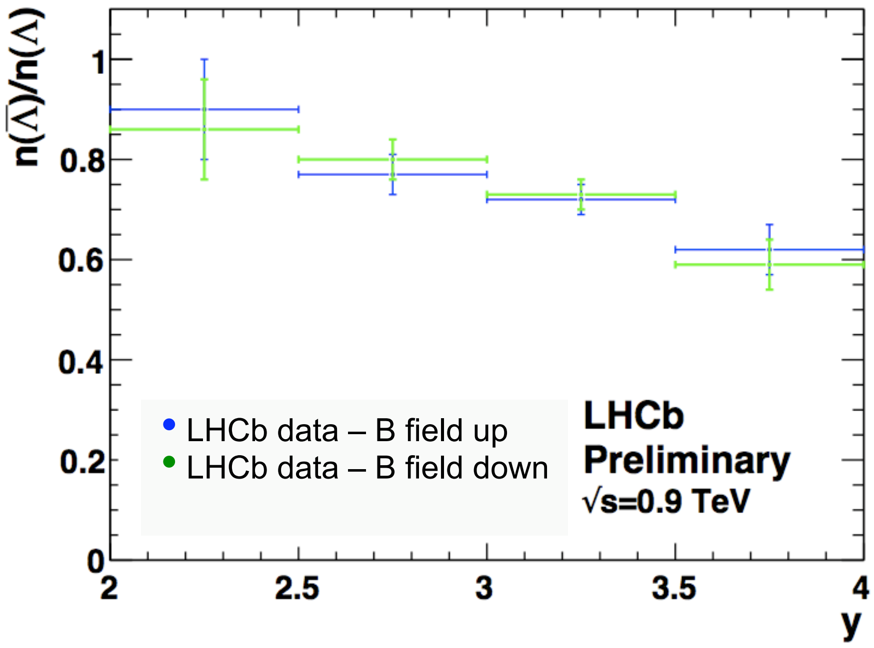


- significant differences data/MC
- forward region not well described by models
- sensitive observable for MC tuning

V^0 ratio systematics

Source of Uncertainty	Errors
MC modeling of diffractive contributions	1%
MC modeling of non-prompt contribution	1%
Variation of selection cuts	1%
$\Lambda - \overline{\Lambda}$ production and absorbtion along flight path	1%
Transverse polarization	-
p – $\overline{\text{p}}$ interactions in the detector	-
Azimuthal modeling of the acceptance	-
Total systematic uncertainty	**2%**

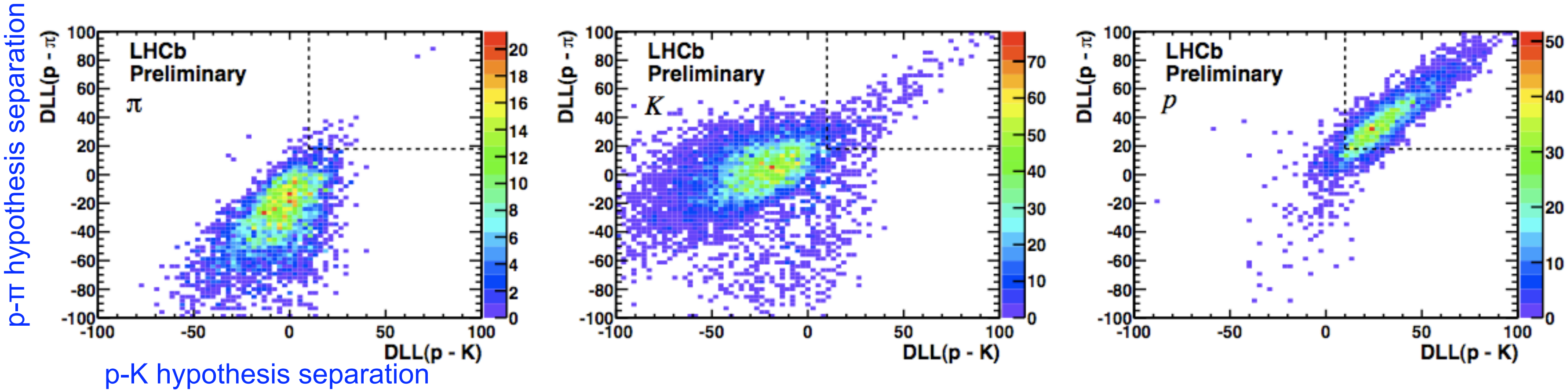
- different polarities data were analysed independently (good agreement)
- combined in a single measurement



Studies $\bar{p}$/p ratio

LHCb preliminary
LHCb-CONF-2010-009

- measurement of $\bar{p}$/p using prompt particles with 2010 data:
  - $\sqrt{s}$ = 0.9TeV -> 0.3nb^{-1} (15 Mevts)
  - $\sqrt{s}$ = 7TeV -> 0.2nb^{-1} (13 Mevts)
- largely independent systematics w.r.t. $\bar{\Lambda}/\Lambda$
- RICH Particle Identification DLL cut (*): DLL(A-B) = $\Delta\ln \mathcal{L}_{AB} = \ln(\mathcal{L}_A/\mathcal{L}_B)$ used to discriminate between hadron species
- PID calibrated in data:
  - π and p from $K^0_s \rightarrow \pi^+\pi^-$ and $\Lambda \rightarrow p\,\pi$
  - K from $\Phi \rightarrow K^+K^-$ with one track identified by RICH and the other one left unbiased for PID measurement

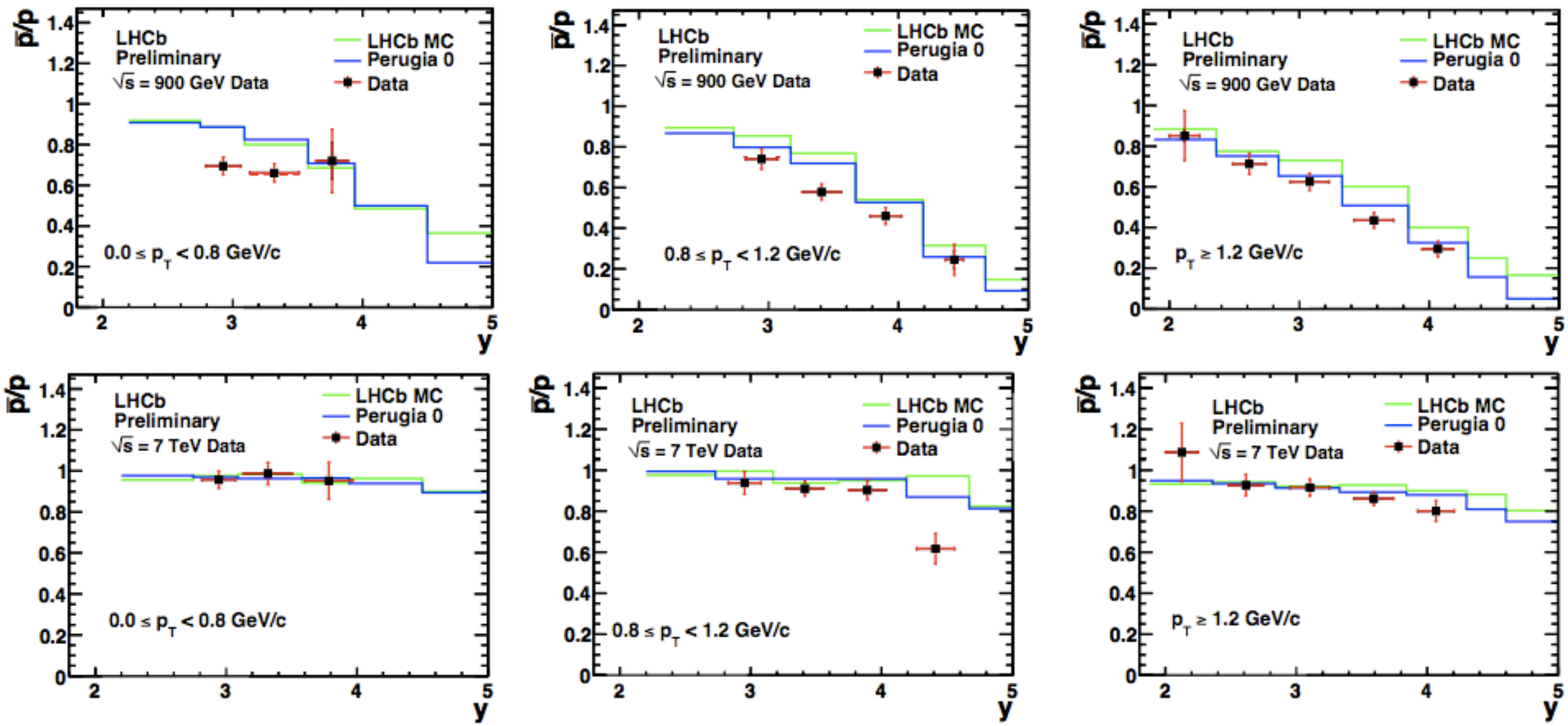


- high purity p($\bar{p}$) sample of 90-95% obtained over full LHCb acceptance

(*) the DLL(A-B) function tends to have +ve values for correctly A-type identified particles and –ve for correctly B-type identified particles.

Baryon number transport $\bar{p}/p$

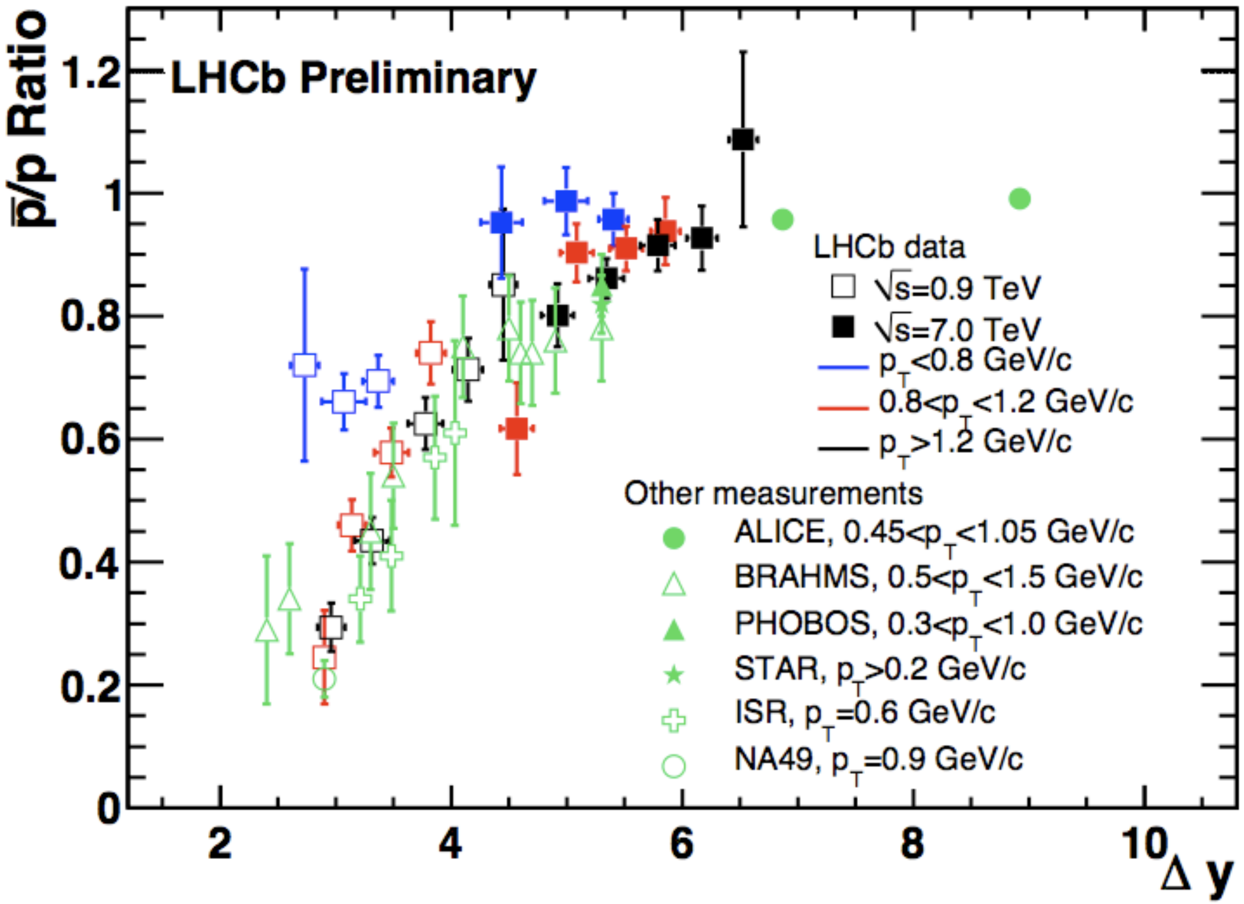
- enough statistics to make differential studies in p_T
- uncertainty dominated by finite statistics of RICH calibration sample



- similar energy dependence as in $\bar{\Lambda}/\Lambda$ case observed
- reasonable agreement with Perugia0

Baryon number transport $\bar{p}/p$

Ratio measured as a function of rapidity loss: $\Delta y = y_{beam} - y_{baryon}$



<y> of the tracks in the corresponding η bin

- scaling behaviour observed
- possibly slightly p_T dependence
- consistent with previous measurements

$\bar{p}/p$ ratio systematics

Systematic contributions (given for p_T> 1.2 GeV, 3.<η<3.5 at √s = 7TeV)

Source of Uncertainty	Err.
PID	3.6%
Ghost tracks	1%
MC detector description	<1%
Material interactions cross sections	<1%
Magnet Polarity	1.4%
Tracking Asymmetries	<2%
Non-prompt contamination	<1%
Crossing angle	<1%
Tot Systematic Uncertainty	4%
Tot Statistical Uncertainty	1%
Tot Uncertainty	4%

Summary

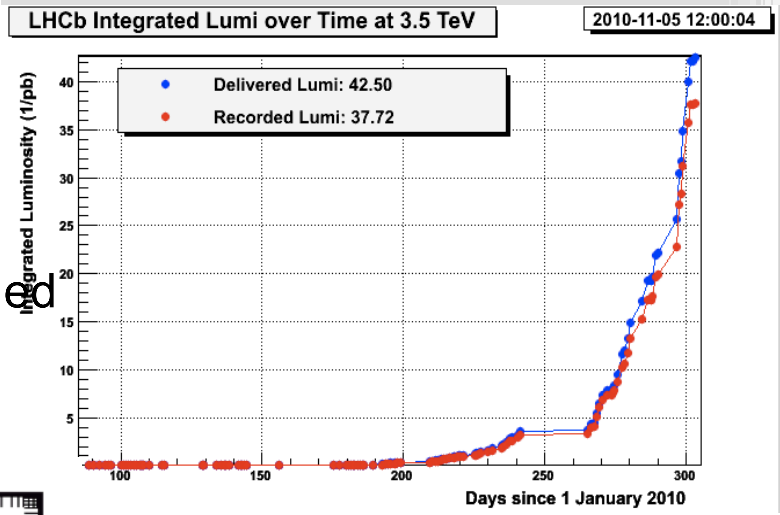
LHCb has produced Minimum Bias results in a unique rapidity and transverse momentum range

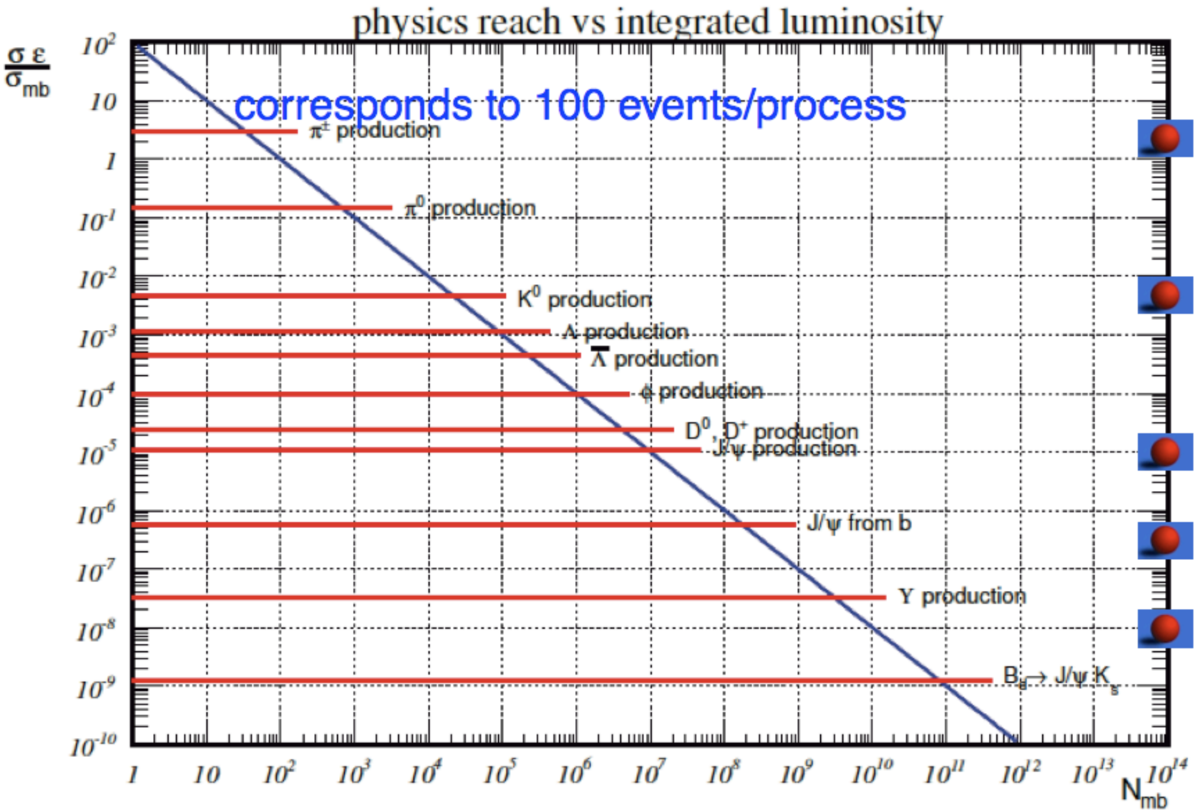
- prompt K^0_s absolute production cross section at $\sqrt{s}$ = 0.9TeV presented:
  - p_T spectra tend to be “harder” than PYTHIA predictions
  - extended measurement range to lower p_T and new y range
- prompt $\overline{\Lambda}$ / Λ ratio at $\sqrt{s}$ = 0.9TeV
  - tends to be lower than PYTHIA Perugia0 and LHCb tune, lower at larger y
- prompt $\overline{\Lambda}$ / Λ ratio at $\sqrt{s}$ = 7TeV
  - in fair agreement with PYTHIA LHCb tune, quite flat vs. y
- prompt $\overline{p}$ / p ratios at $\sqrt{s}$ = 0.9TeV and $\sqrt{s}$ = 7TeV
  - show similar energy dependence as Λ / Λ
- prompt $\overline{\Lambda}$ / K^0_s ratio at $\sqrt{s}$ = 0.9TeV and $\sqrt{s}$ = 7TeV
  - baryon suppression in hadronization is lower than predicted

More Minimum Bias studies are on the way (multiplicities, inclusive ϕ…)

LHCb data

- 6.8 μb^{-1} at √s= 0.9 TeV in the 2009 pilot run
- 0.31 nb^{-1} at √s= 0.9 TeV in 2010
- 38 pb^{-1} at √s= 7 TeV in 2010 have been recorded so far (~90% of delivered lumi)





- Inclusive distributions
- Strangeness production
- charm signals
- J/ψ production
- first b results – we are here

recorded MinBias events needed to observe 100 evts of process X

Prompt K^0_s production: selection

- 6.8 μb^{-1} recorded in the 2009 pilot run
- K^0_s reconstructed through: $K^0_s \rightarrow \pi^+\pi^-$
- differential cross section quoted for $0<p_T<1.6$ GeV/c, $2.5<y<4$
- VELO partially open (15mm)
- CALO trigger with 2x2 cluster with $E_t>240$MeV in HCAL and SPD hits >2

Table 2: $K^0_S \rightarrow \pi^+\pi^-$ selection requirements.

Variable	Requirement
Downstream-track selection	
Each π-track momentum	> 2 GeV/c
Each π-track transverse momentum	> 0.05 GeV/c
Each track fit χ^2/ndf	< 25
Distance of closest approach of each π-track to the z axis	> 3 mm
K^0_S decay vertex fit χ^2/ndf	< 25
z of K^0_S decay vertex	< 2200 mm
$\|z\|$ of pseudo-PV	< 150 mm
$\cos\theta_{\rm pointing}$	> 0.99995
K^0_S proper time ($c\tau$)	> 5 mm
Long-track selection	
$\|z\|$ of associated PV	< 200 mm
Each track fit χ^2/ndf	< 25
K^0_S decay vertex χ^2/ndf	< 100
$z(K^0_S) - z(\mathrm{PV})$	> 0 mm
Variable ν related to impact parameters	> 2

Prompt K^0_s production

- cross sections in bins of p_T and y of the K_S:

$N_{pp\text{-}coll} = N_{bb} - \beta N_{be}$
$\beta = 0.916 \pm 0.019$

$$\sigma_i = \frac{N_i^{\text{obs}}}{\epsilon_i^{\text{trig/sel}} \times \epsilon_i^{\text{sel}} \times L_{\text{int}}}$$

$K_S \rightarrow \pi^-\pi^+$ yield from beam-gas subtracted mass distribution of selected candidates

$$\epsilon_i^{\text{trig/sel}} = \frac{Y_i^{\text{trig/sel}}}{Y_i^{\text{sel}}}$$

$$\epsilon_i^{\text{sel}} = \frac{M_i^{\text{sel}}}{M_i^{\text{gen,prompt}}}$$

Trigger efficiency from reweighted MC reproducing track multiplicity in data

Reconstruction + selection efficiency from MC (includes acceptance, secondary interactions, branching ratio, non-prompt production, p_T and y resolution, …)

Luminosity from beam-gas method

V^0 ratio measurements

LHCb preliminary

Measurement of $\overline{\Lambda}/\Lambda$ and $\overline{\Lambda}/K^0_s$ ratios using prompt particles with 2010 data:

- $\sqrt{s}$ = 0.9 TeV → 0.3 nb^{-1}
- $\sqrt{s}$ = 7 TeV → 0.2 nb^{-1}

- $\overline{\Lambda}$, Λ and K^0_s identified through: $\Lambda \rightarrow p\,\pi^-$, $\overline{\Lambda} \rightarrow \overline{p}\,\pi^+$, $K^0_s \rightarrow \pi^+\pi^-$
- microbias trigger
- Long tracks used ($\chi 2$/ndof<20)
- >= 1 PV , cut on mother pointing angle to PV, cut on mother IP$\chi 2$ w.r.t. PV

- no PID info used, to get rid of cross feeds between K^0_s and Λ, the other resonance mass hypotheses were tried. If invariant mass range around the other resonance mass candidate discarded.

- high-purity K^0_s and Λ selection based on a combination of impact parameters (IP):

$$v = \log(IP_1) + \log(IP_2) - \log(IP_{V0})$$

Efficiencies from MC for prompt, non-diffractive events

Ratios benefit from reduced systematic uncertainties (errors cancel out, absolute luminosity not required): $\sigma(\Lambda/\Lambda)$~2%, $\sigma(\Lambda/K^0_s)$~2-12%

Studies $\bar{p}/p$ ratio

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  - $\sqrt{s}$ = 0.9TeV -> 0.3nb^{-1} (15 Mevts)
  - $\sqrt{s}$ = 7TeV -> 0.2nb^{-1} (13 Mevts)
- microBias trigger used (random L0.and.at least 1 VELO track segment in HLT1)
- >=1PV, $|z_{PV}|$ <200mm
- Long tracks used (χ2/ndof<10)
- IP quality cut, P>5GeV/c
- RICH Particle Identification DLL cut (*): DLL(A-B) = $\Delta \ln \mathcal{L}_{AB} = \ln(\mathcal{L}_A/\mathcal{L}_B)$ used to discriminate between hadron species
- PID calibrated in data:
  - π and p from $K^0_s \rightarrow \pi^+\pi^-$ and $\Lambda \rightarrow p\,\pi$
  - K from $\Phi \rightarrow K^+K^-$ with one track identified by RICH and the other one left unbiased for PID measurement

- high purity p($\bar{p}$) sample of 90-95% obtained over full LHCb acceptance

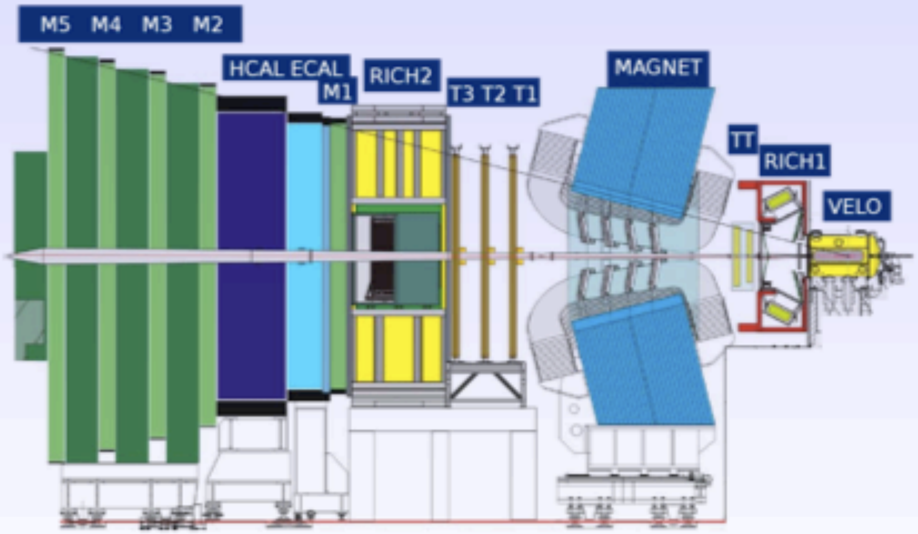
(*) the DLL(A-B) function tends to have +ve values for correctly A-type identified particles and –ve for correctly B-type identified particles.

Vertex Measurement

$\sigma(z) \sim 50[150]$ μm for the Primary [Secondary] Vertices
$\sigma(IP) \sim 14 + 35/p_T(\text{GeV})$ μm
$\sigma(t) \sim 40$ fs on b-hadrons decay times

Energy measurement

$\sigma_E/E \simeq 9\%/\sqrt{E} \oplus 0.8\%$ (ECAL)
$\sigma_E/E \simeq 69\%/\sqrt{E} \oplus 9\%$ (HCAL)



Tracking

$\varepsilon = 95\%$ for $p > 5$ GeV
$\sigma(p)/p \sim 0.4\%$
σ(b-hadrons mass) ~ 14 MeV

Particle Identification

$\varepsilon(K) \sim 95\%$ at 5% of π/K mis-id.
$\varepsilon(\mu) \sim 93\%$ at 1% of $\pi, K/\mu$ mis-id.

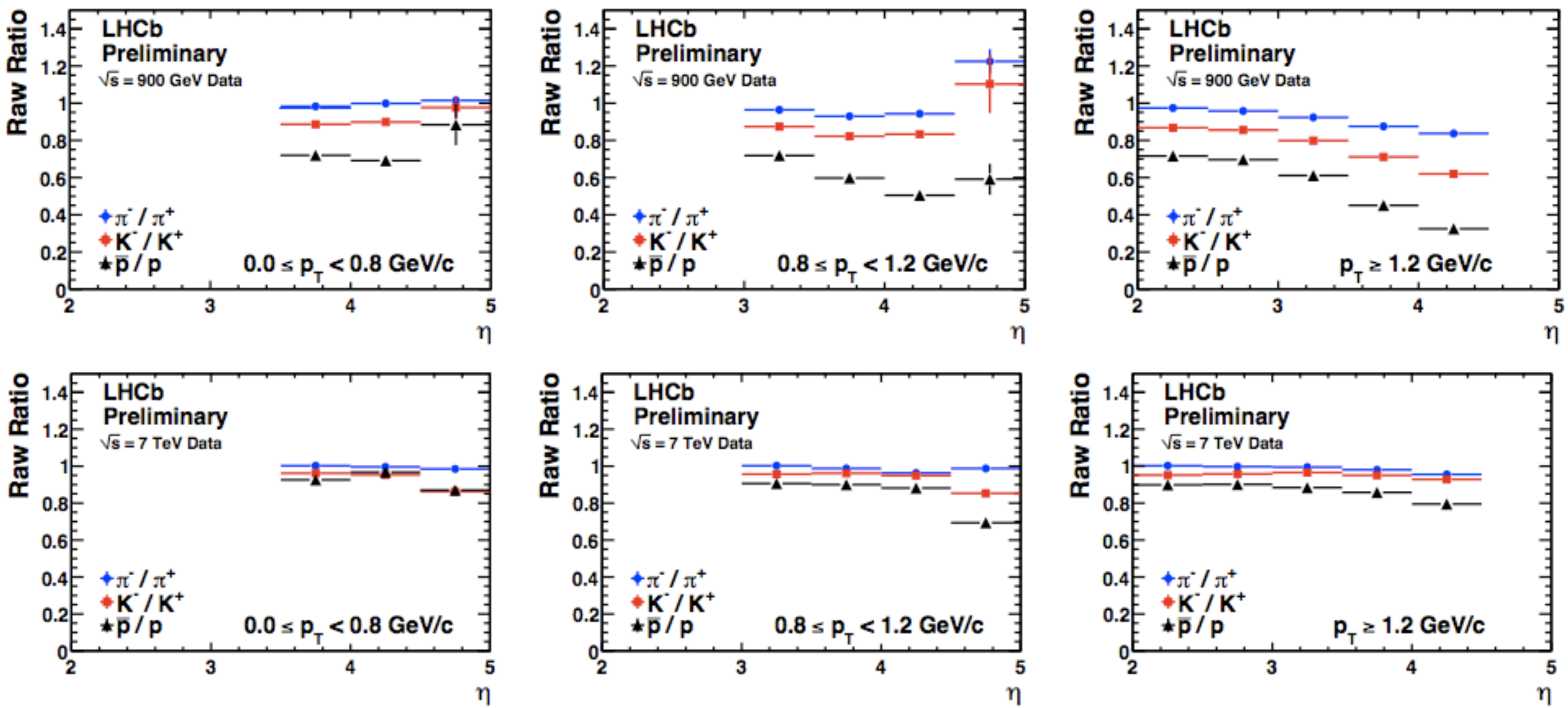
Trigger

L0 hardware: 40 MHz $\Rightarrow$ 1 MHz
$\longrightarrow$ Information from Muon Stations, Calorimeters and VELO
$\longrightarrow$ High p_T e, μ, γ

HLT High Level Trigger: 1 MHz $\Rightarrow$ 2 kHz
$\longrightarrow$ software
$\longrightarrow$ full detector information

Study of other particle ratios…

- strong energy dependence observed also for other particle types
- important input for MC tuning



***distributions after selection but prior to any correction for reconstruction biases