Soft-QCD measurements at LHCb

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On behalf of the LHCb collaboration

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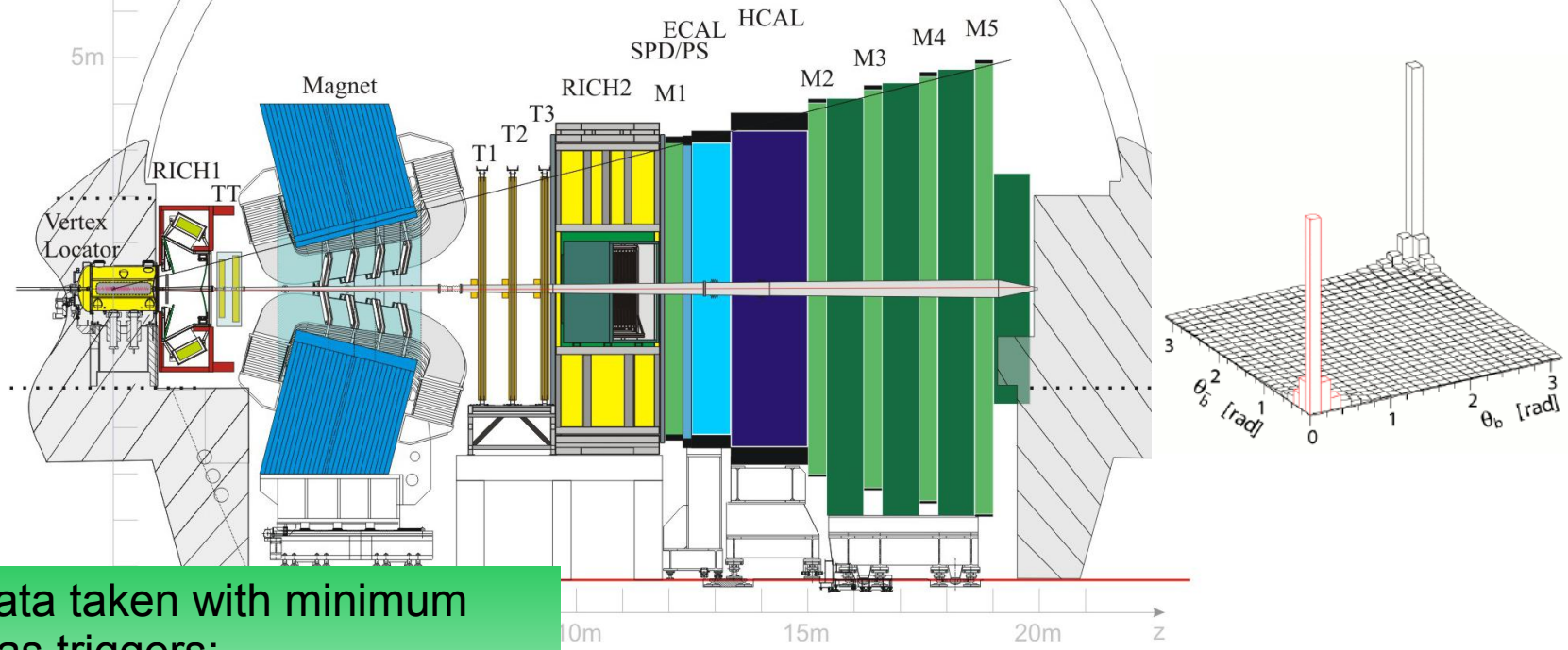
The LHCb Experiment

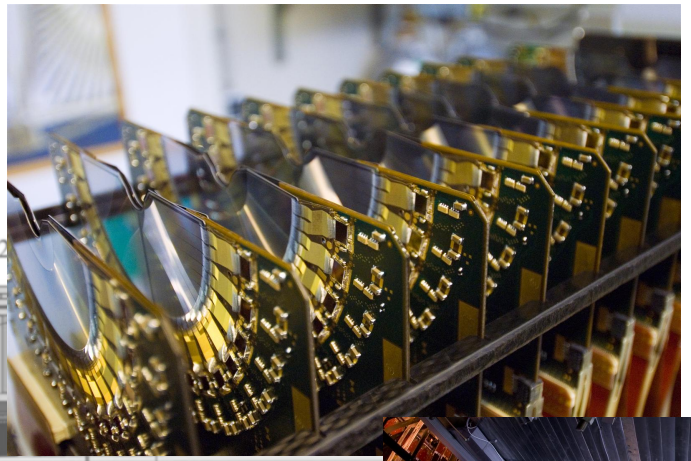
Single arm spectrometer (2<η<5) for precision measurements of CP violation and rare B decays

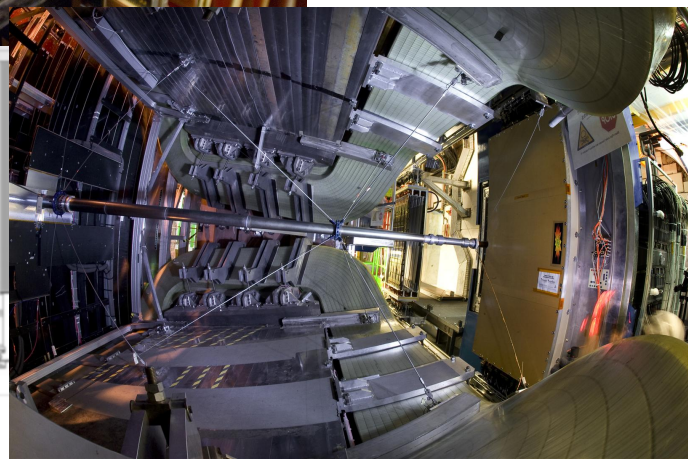


Data taken with minimum bias triggers:
2009: Calo ($7\mu b^{-1}$)
2010: 1 or more reconstructed tracks ($14nb^{-1}$)

Provides measurements in a region of phase space complementary to GP detectors

Tracking system





Tracking stations

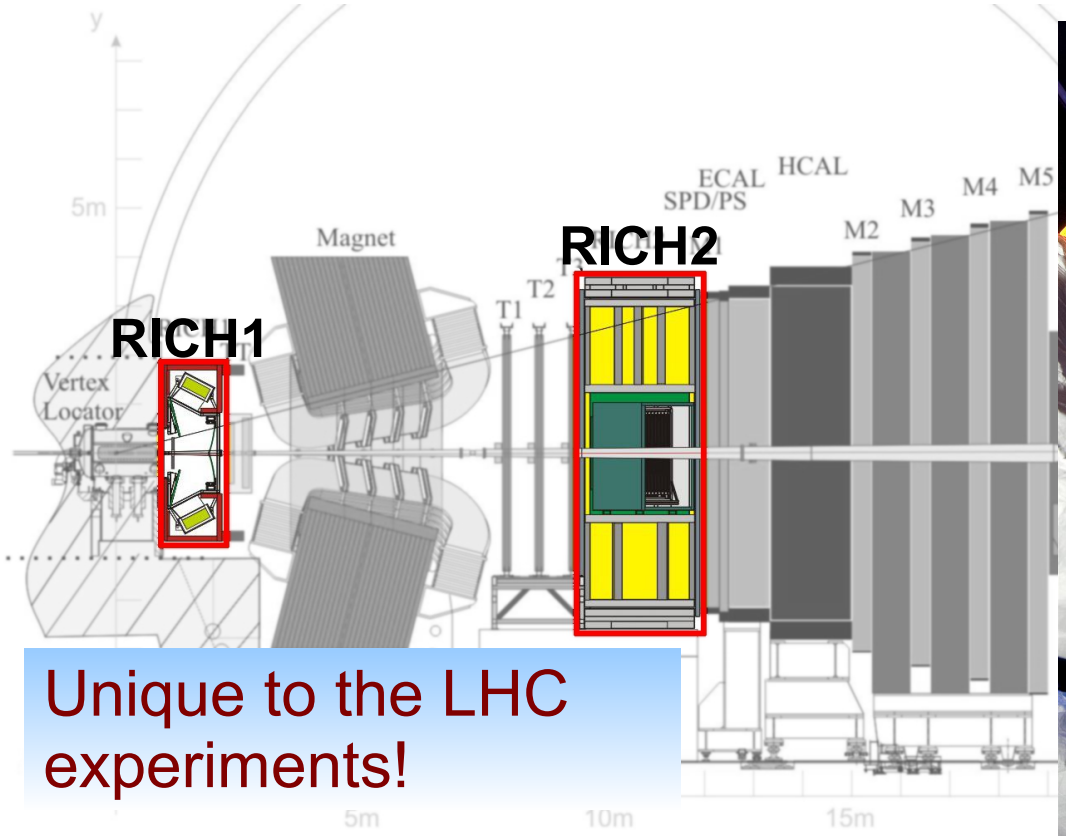
VErtex LOcator (VELO)

VELO was partially opened at $\sqrt{s}$=0.9 TeV due to beam size and extreme crossing angle at low energy

$\delta p/p \sim 0.5\%$ - reconstruction efficiency ~95%

Resolution for primary(secondary) vertices is σ_z~50(150) μm

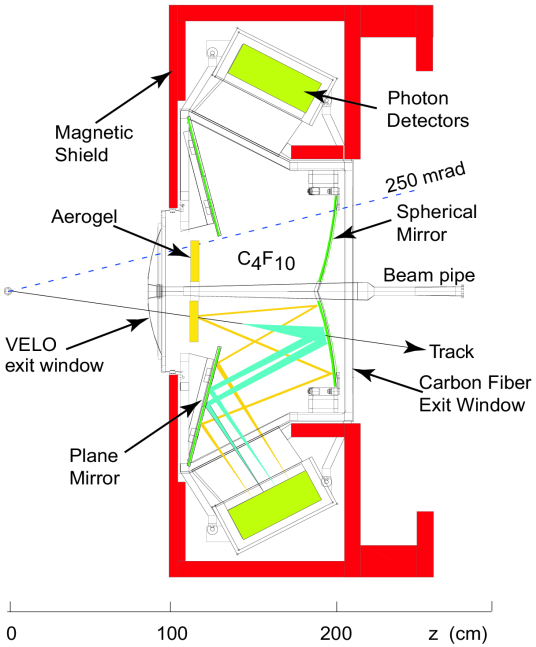
RICH Detectors

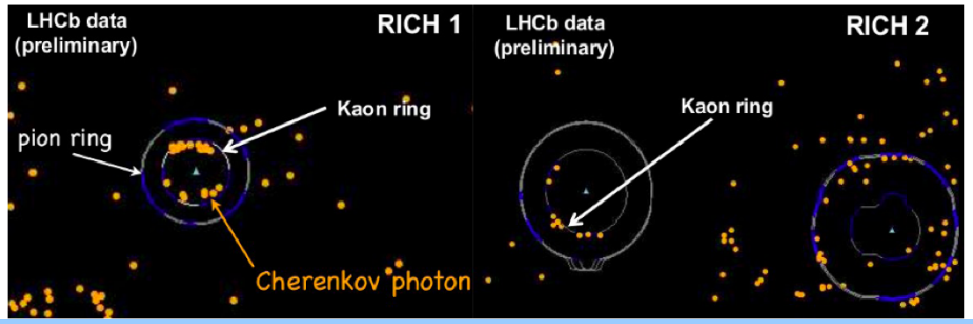


Unique to the LHC experiments!

2 Ring Imaging CHerenkov (RICH) detectors provide charged particle identification in a momentum range of 2 - 100 GeV

RICH Detectors & PID



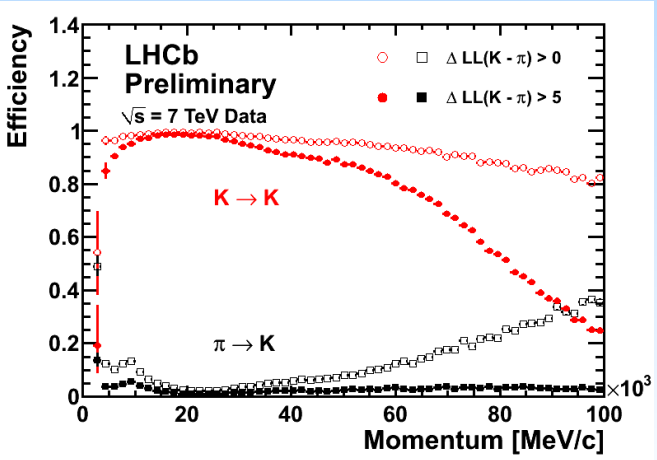


A ΔLL(x-y)* is constructed to discriminate between *p*, *K* and *π*.
PID efficiencies and *mis*ID rates vs ΔLL cuts are calculated from data using dedicated calibration samples

Protons: $\Lambda \to p\pi$

Kaons: $\Phi \to KK$, $D^* \to D(K\pi)\pi$

Pions: $K_s \to \pi\pi$



3 Radiators needed
RICH1 (2<p<60 GeV):
- Aerogel, n~1.03
- C_4F_{10}, n~1.0014

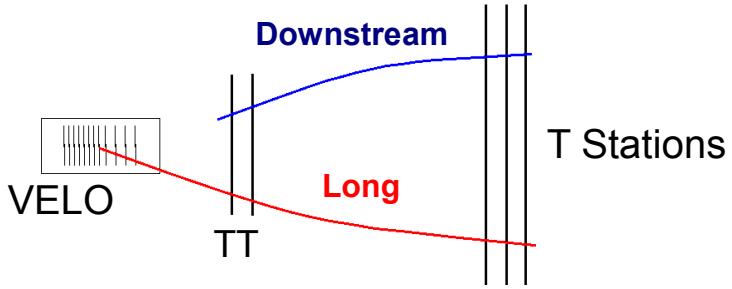
RICH2 (p>20 GeV)
- CF_4, n~1.0005

*Delta Log Likelihood between x and y particle hypotheses

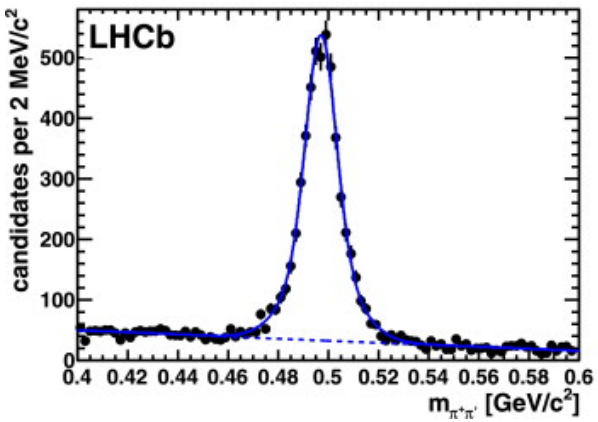
K_s Production Cross Section

- First measurement for LHCb with 2009 pilot run data
- $K_s \rightarrow \pi\pi$ selection based on tracking and impact parameters
- Two selections with long and downstream tracks
- First test for detector calibration

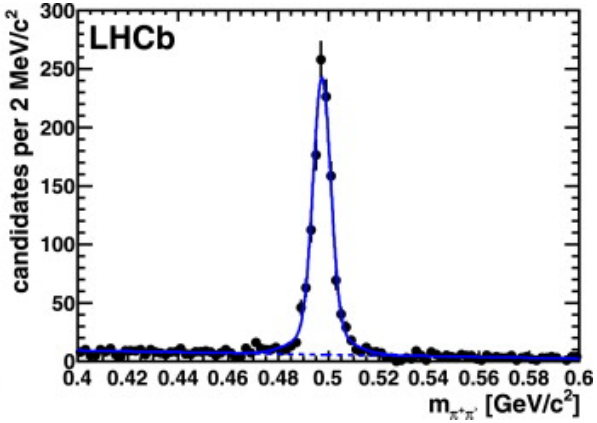
Published in: Phys. Lett. B 693 (2010) 69-80



Downstream-tracks

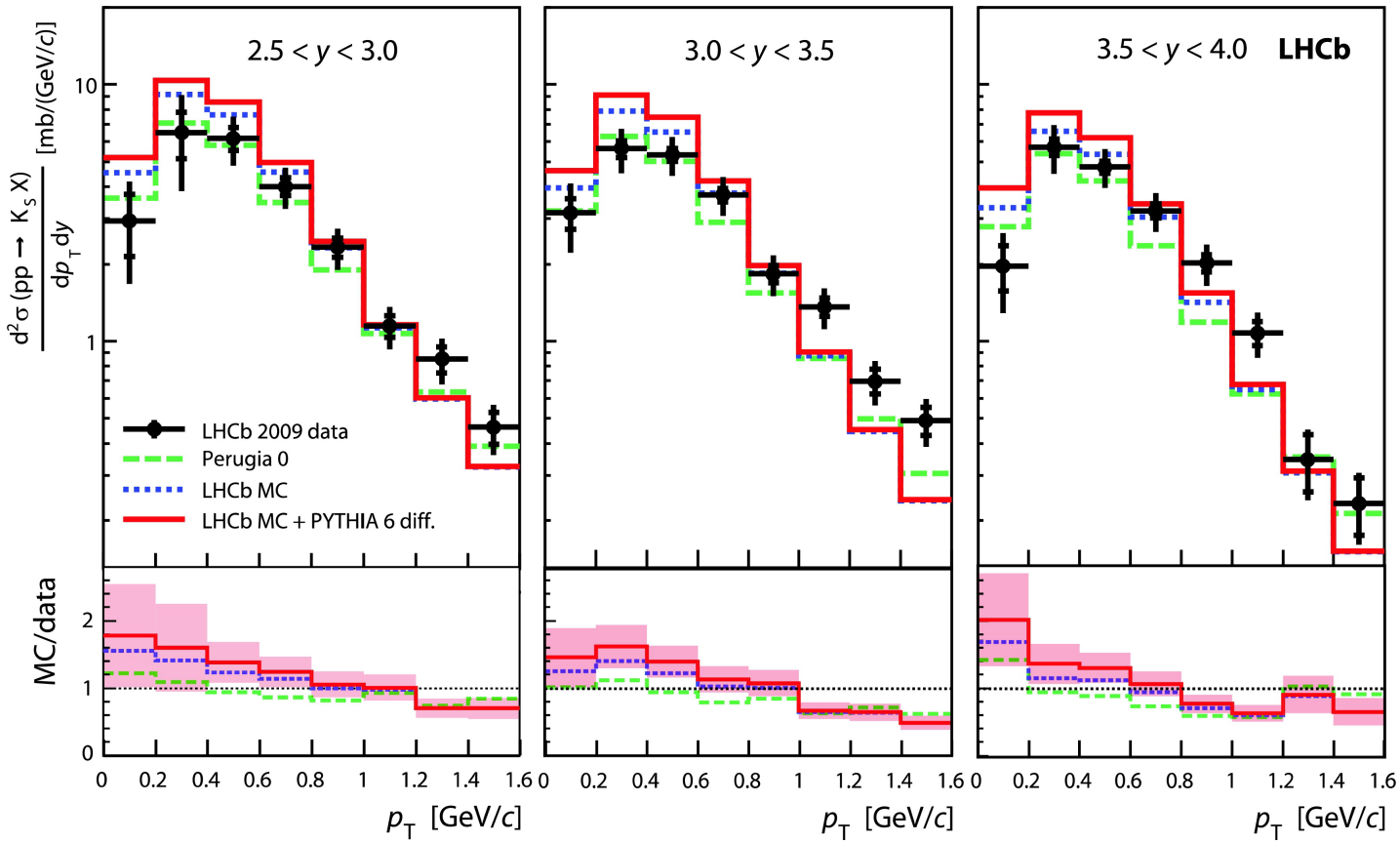


Long-tracks



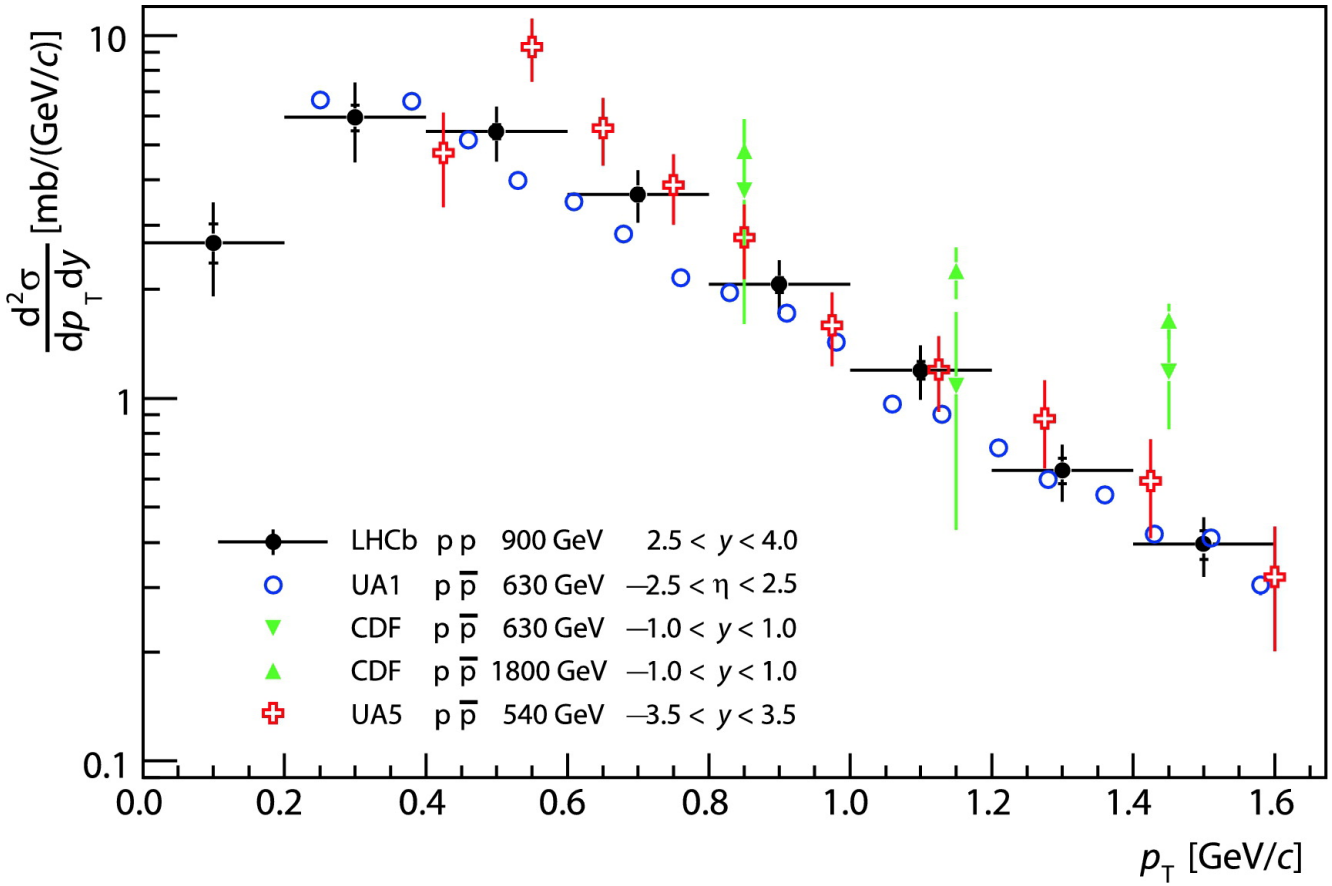
K_s Production Cross Section

Good consistency with PYTHIA expectations
P_T spectra slightly harder



K_s Production Cross Section

Comparison with other experiments



Unique measurement at high rapidity and low P_T

Hadron Production Ratios

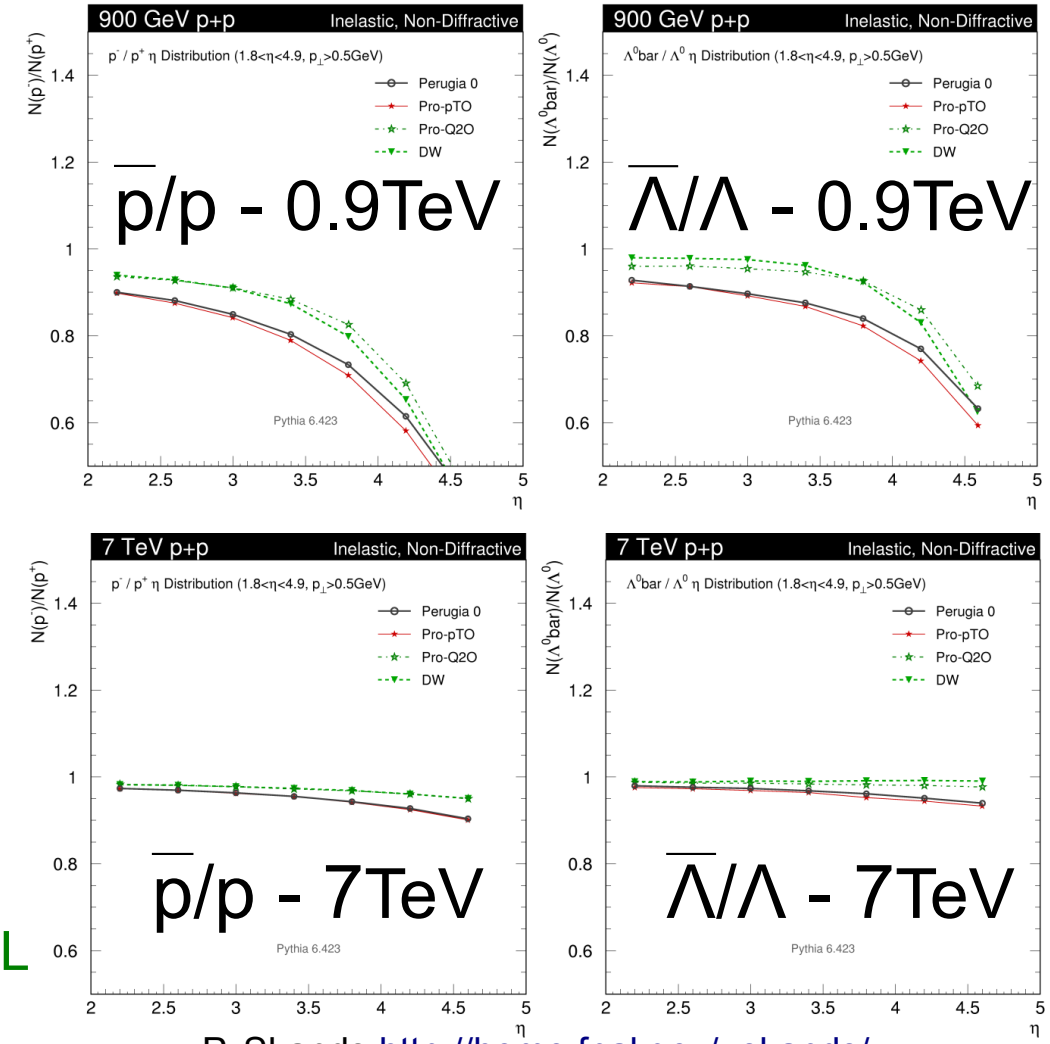
Motivation:

- Baryon number transport
- Hadronisation
- MC tuning

2 analyses:

- V^0 ratios (tracking & vertexing only)
- $\bar{p}/p$ (+ RICH PID)

Use minimum bias data
No need to know absolute L

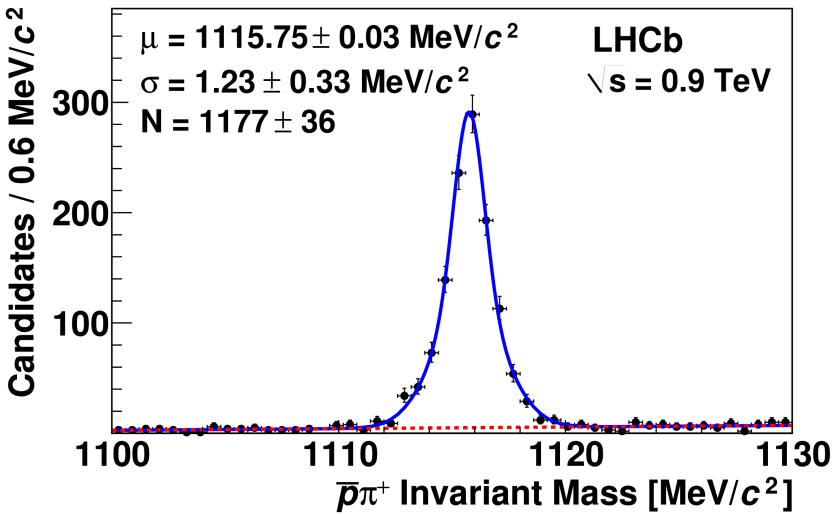


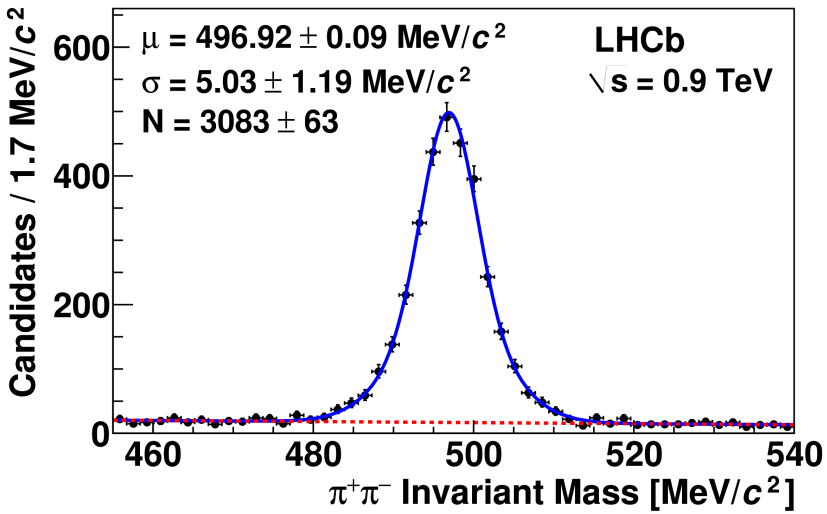
P. Skands http://home.fnal.gov/~skands/

V^0 Ratios

Analysis outline

- Long tracks
- Purely kinematic PID (Armenteros-Podolanski)
- $K_s \rightarrow \pi\pi$ and $\Lambda \rightarrow p\pi$ selection based on impact parameters
- Systematics partially cancel

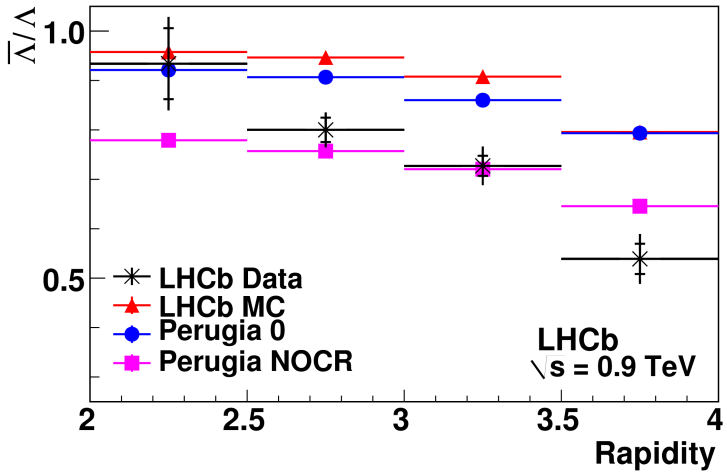


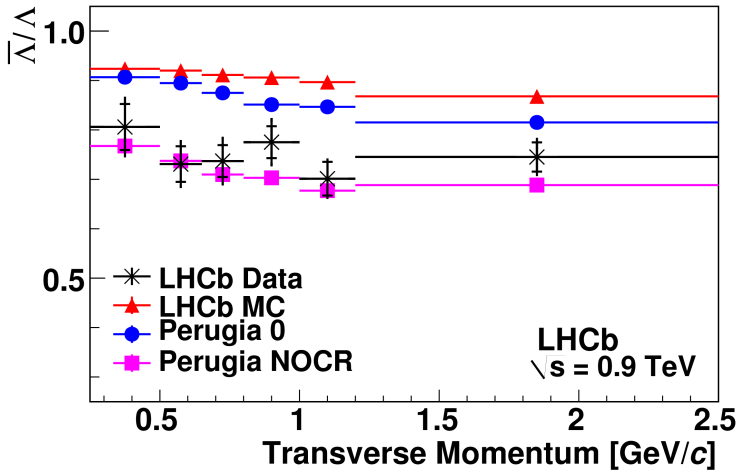


Published in: JHEP08(2011)034

V^0 Ratios – $\bar{\Lambda}/\Lambda$ Results

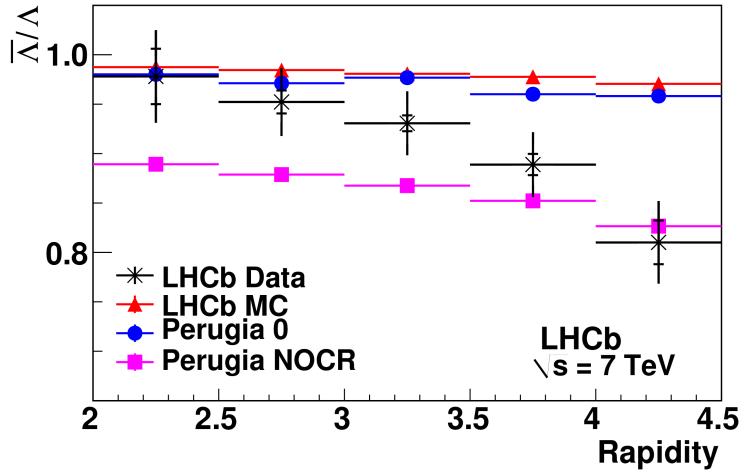
0.9 TeV

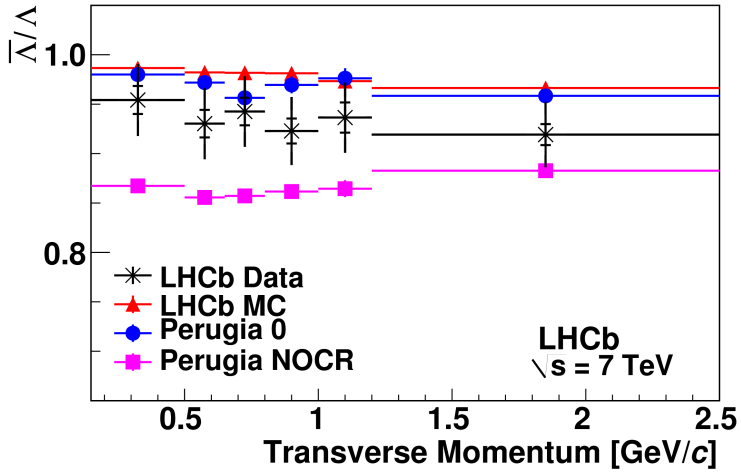




Baryon transport higher than predicted by LHCb MC or Perugia0, especially at 0.9 TeV

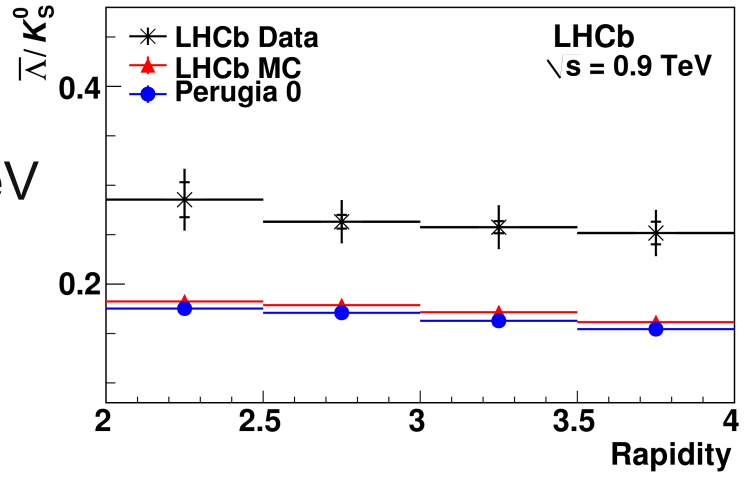
7 TeV

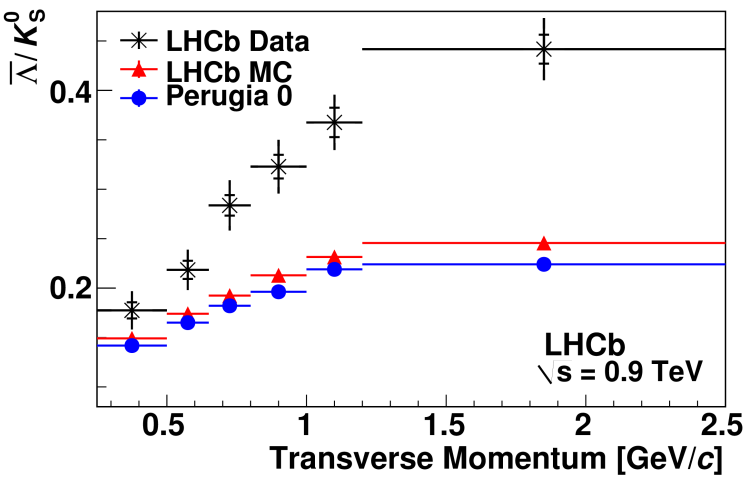




V^0 Ratios – $\bar{\Lambda}/K_s$ Results

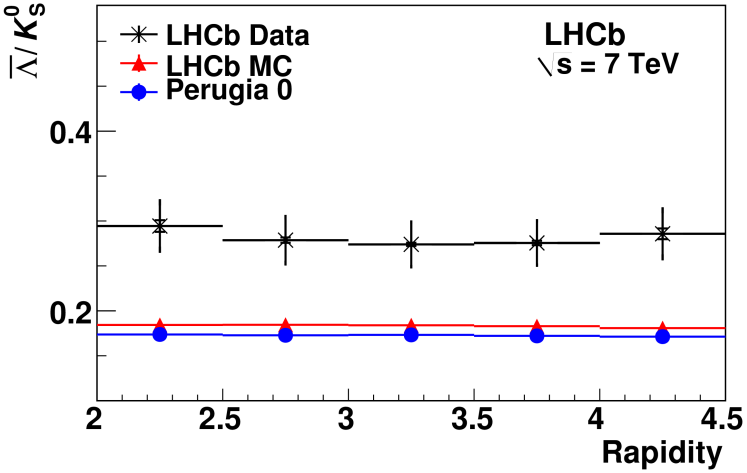
0.9 TeV

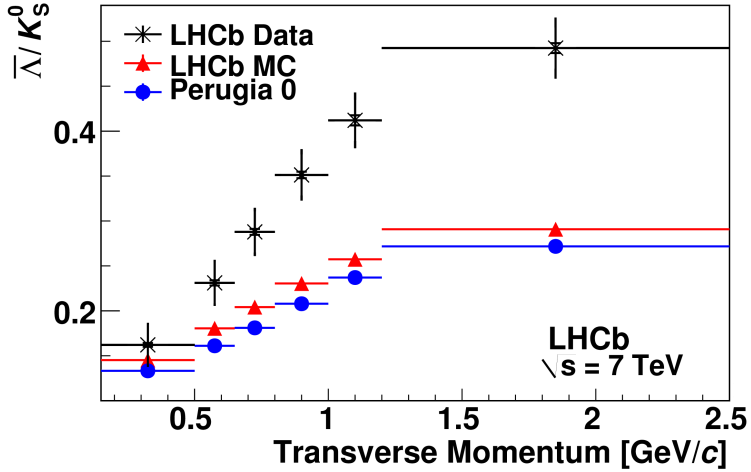




Baryon/meson suppression significantly lower than predicted

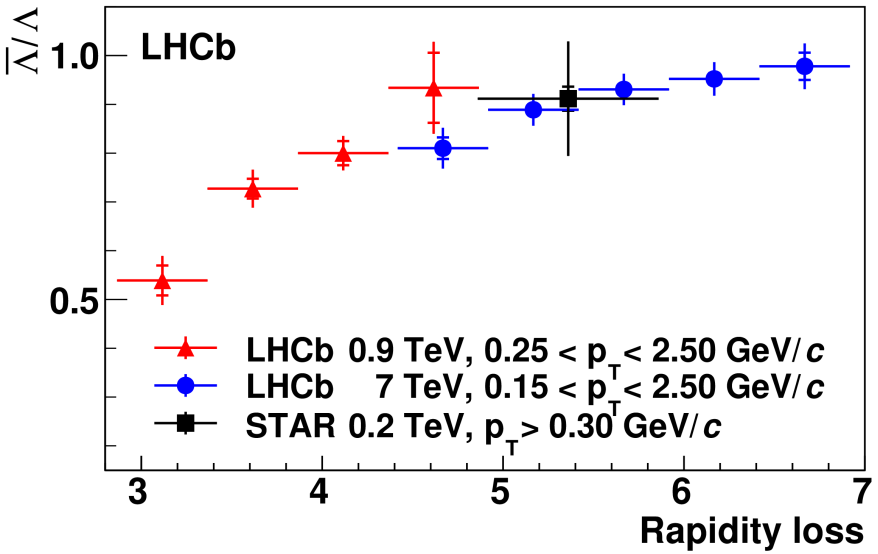
7 TeV

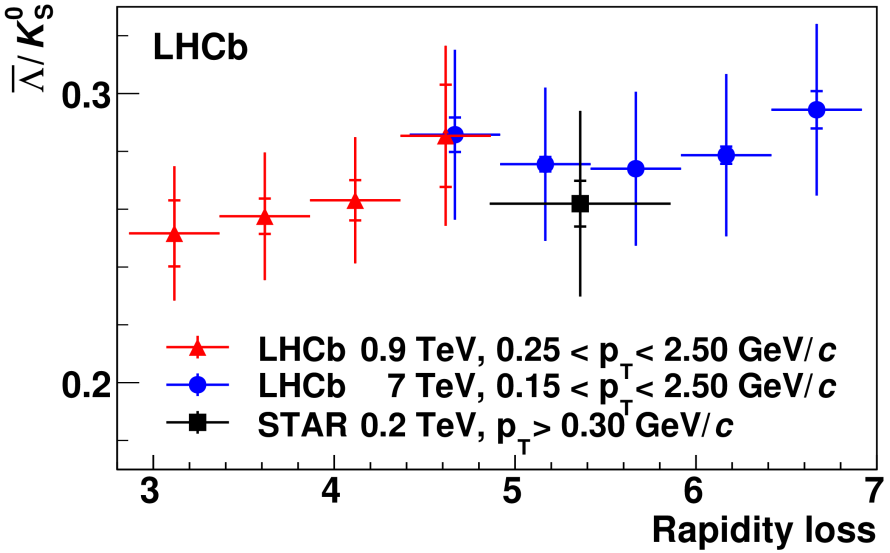




V^0 Ratios – Summary

Rapidity Loss $\Delta y = y_{beam} - y_{baryon}$



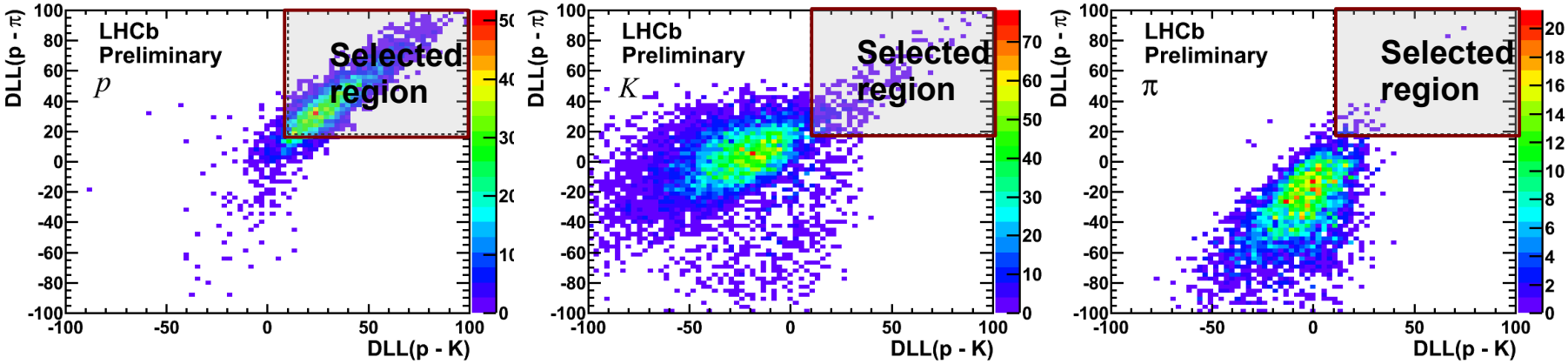


Good consistency with previous measurement

$\bar{p}/p$ ratio

- Pure samples of protons, kaons and pions selected with RICH particle ID
- PID efficiencies and *mis*ID are extracted from data using calibration samples of Λ, Φ, K_s

CERN-LHCb-CONF-2010-009



The analysis has been extended to provide further ratios such as K^-/K^+, π^-/π^+, p/π, K/π, p/K and results will be public soon

$\bar{p}/p$ ratio – Analysis strategy

Contamination correction

All corrections are applied independently for each (P_T,η) bin and particle charge

From data

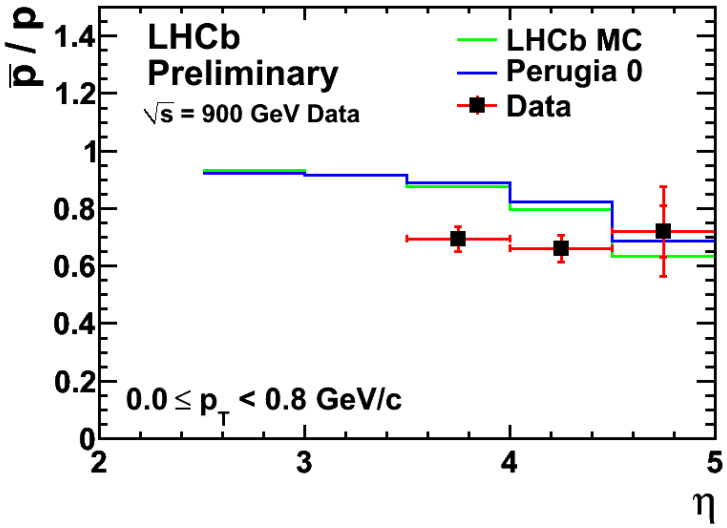
$$\begin{pmatrix} p_{Sel} \\ K_{Sel} \\ \pi_{Sel} \end{pmatrix} = \begin{pmatrix} p \to p & K \to p & \pi \to p \\ p \to K & K \to K & p \to K \\ p \to \pi & K \to p & \pi \to \pi \end{pmatrix} \begin{pmatrix} p_{True} \\ K_{True} \\ \pi_{True} \end{pmatrix}$$

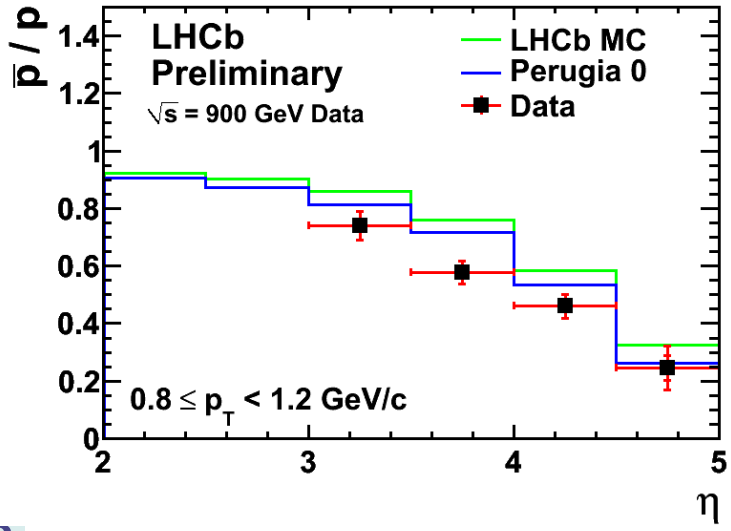
$$\begin{pmatrix} p_{True} \\ K_{True} \\ \pi_{True} \end{pmatrix} = \begin{pmatrix} p \to p & K \to p & \pi \to p \\ p \to K & K \to K & p \to K \\ p \to \pi & K \to p & \pi \to \pi \end{pmatrix}^{-1} \begin{pmatrix} p_{Sel} \\ K_{Sel} \\ \pi_{Sel} \end{pmatrix}$$

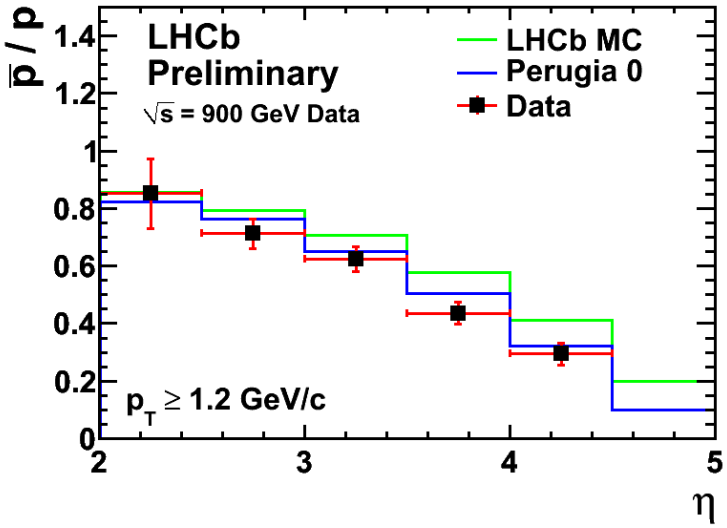
Different interaction cross-sections in the material between p and $\bar{p}$, particularly at low momentum
Therefore limit analysis to tracks with P > 5 GeV and correct using MC

$\bar{p}/p$ Ratio – Results 0.9 TeV

Baryon transport higher than predictions and consistent with $\bar{\Lambda}/\Lambda$



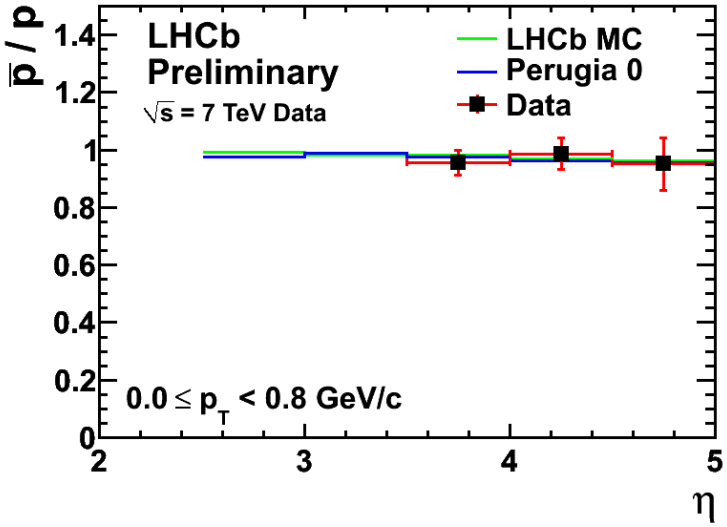


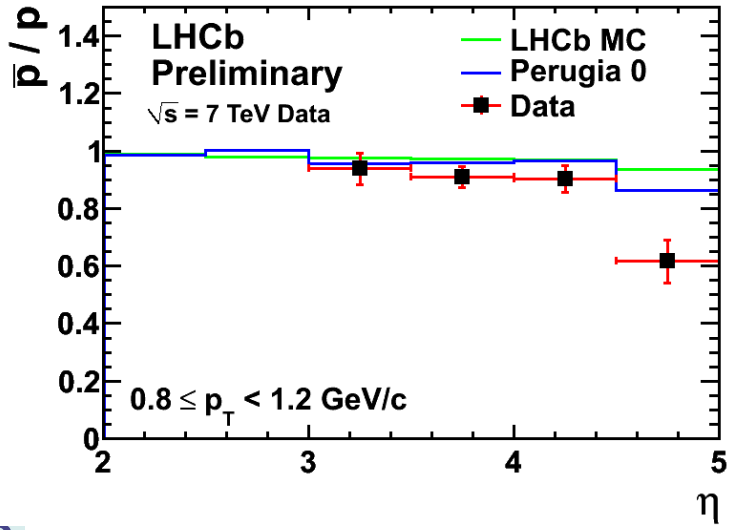


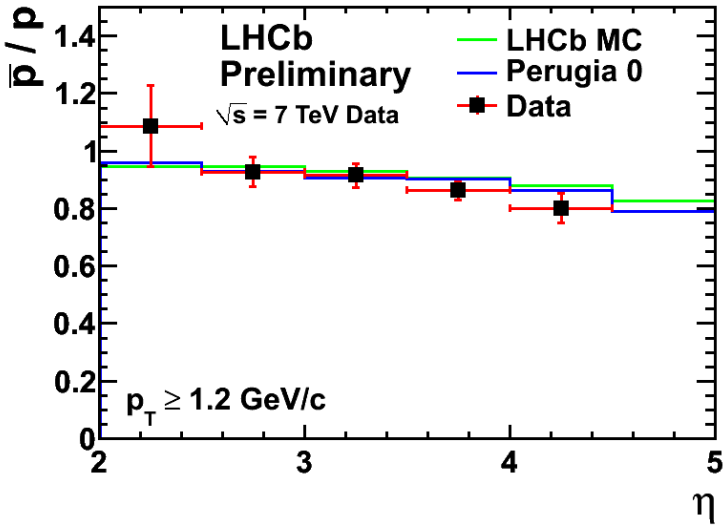
$\bar{p}/p$ Ratio – Results 7 TeV

Ratios become flatter as predicted by models

Better agreement with MC





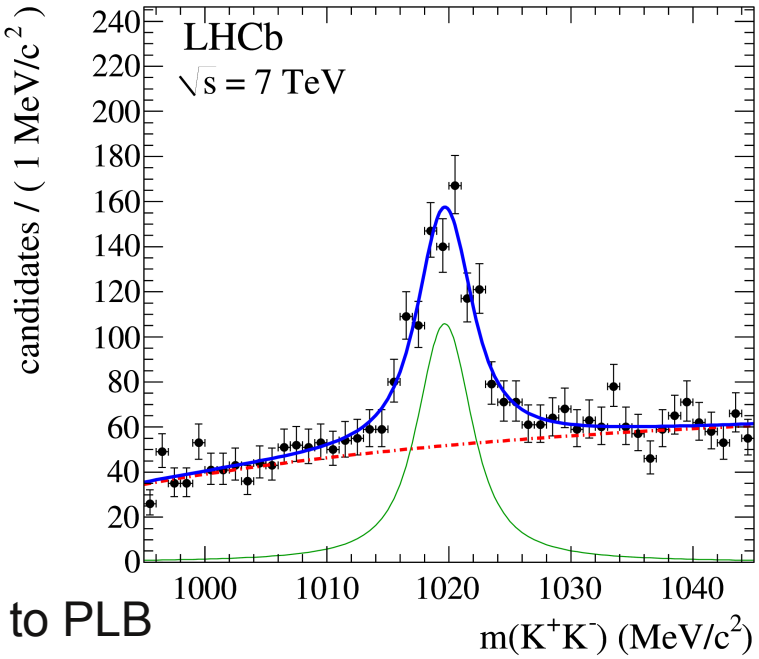


Inclusive Φ Cross Section

Unique way to study strangeness production

- Discrepancies from MC seen by other major LHC experiments
- Test QCD fragmentation models in *pp* interactions in LHCb's kinematic region

$\Phi \rightarrow K^+K^-$ candidates selection requires RICH PID information



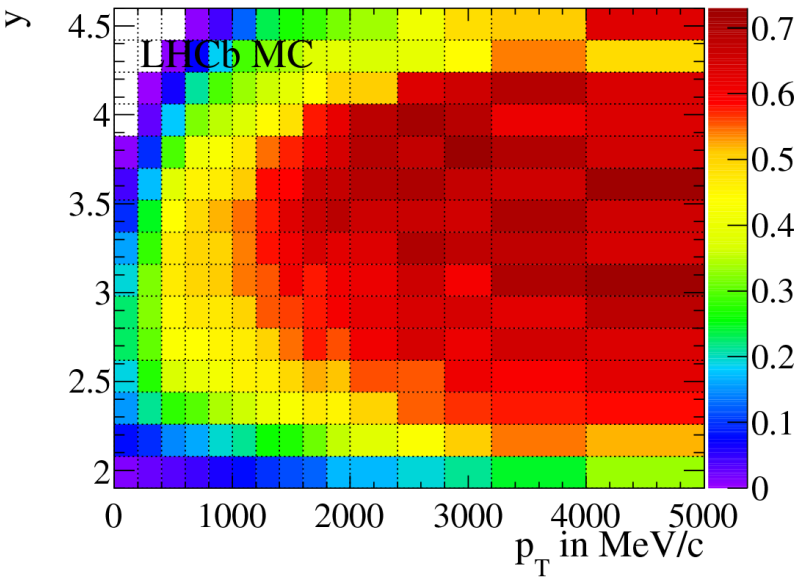
arXiv:1107.3935 , submitted to PLB

Inclusive Φ Cross Section

Cross section measurement is performed in bins of P_T and Y

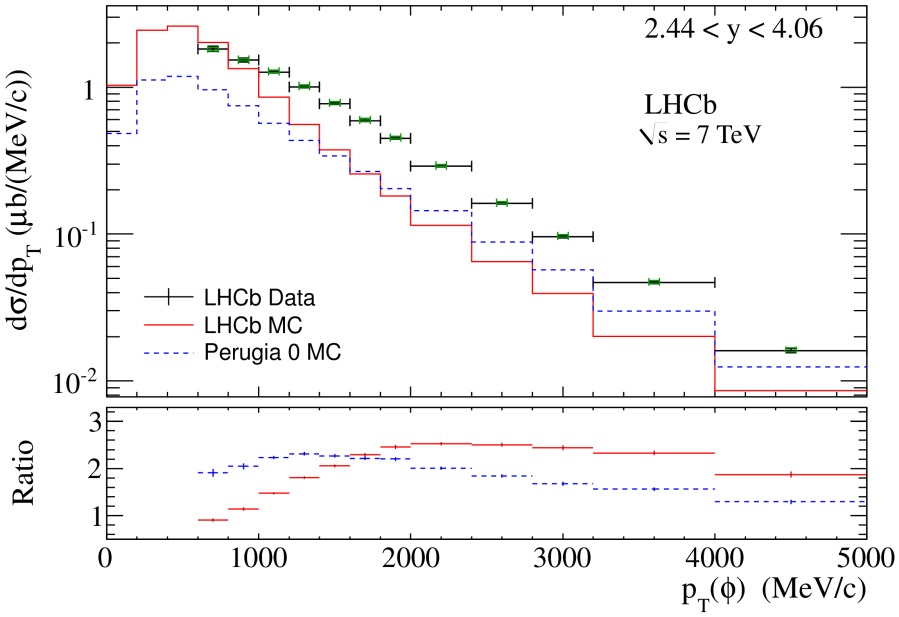
$$\sigma = \frac{N}{L \cdot B(\Phi \to KK) \cdot \epsilon_{REC+PID}}$$

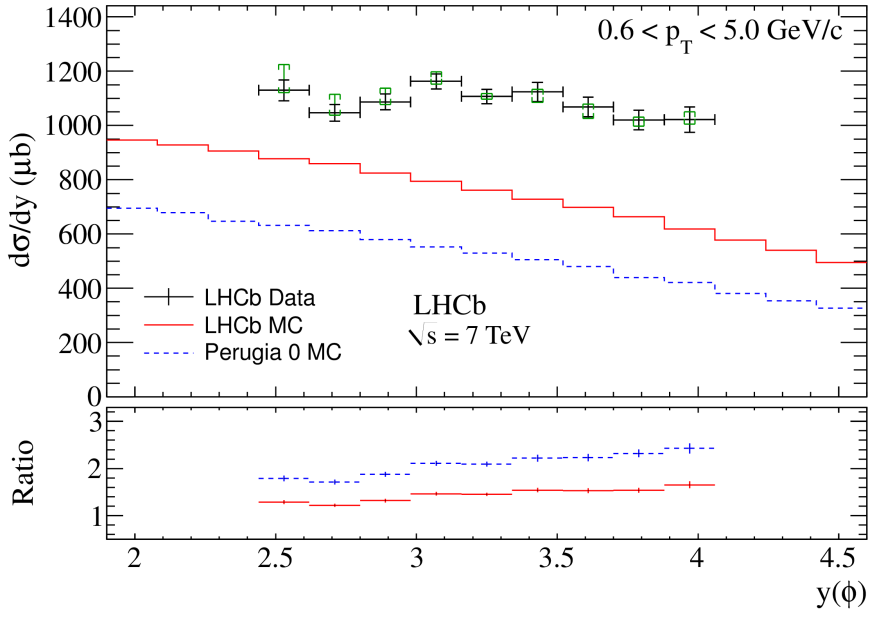
PID cuts efficiency estimated from data using tag&probe technique



Major systematics uncertainties	(%)
Tracking efficiency	8
Track Multiplicity	4
Reconstruction and PID (bin dependent)	3-7
Fit systematics	3
Luminosity (Normalisation)	4

Inclusive Φ Cross Section

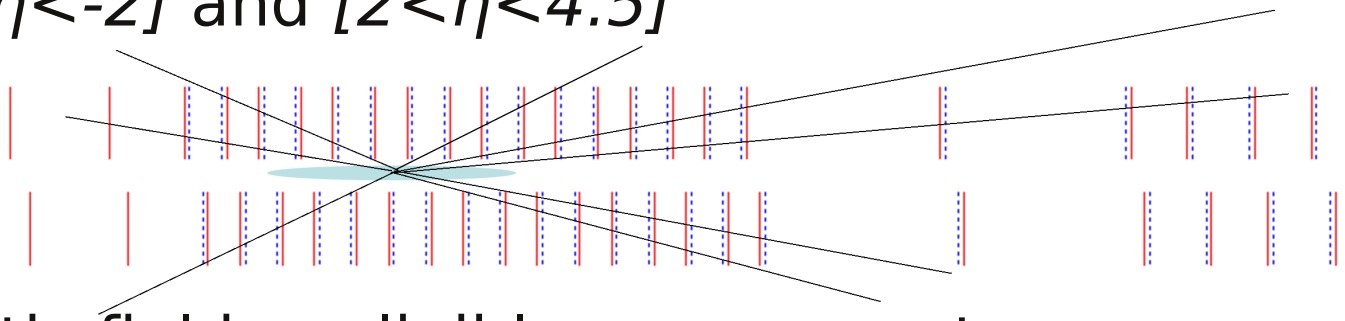




Φ production is underestimated in the measured kinematic range by both tunings

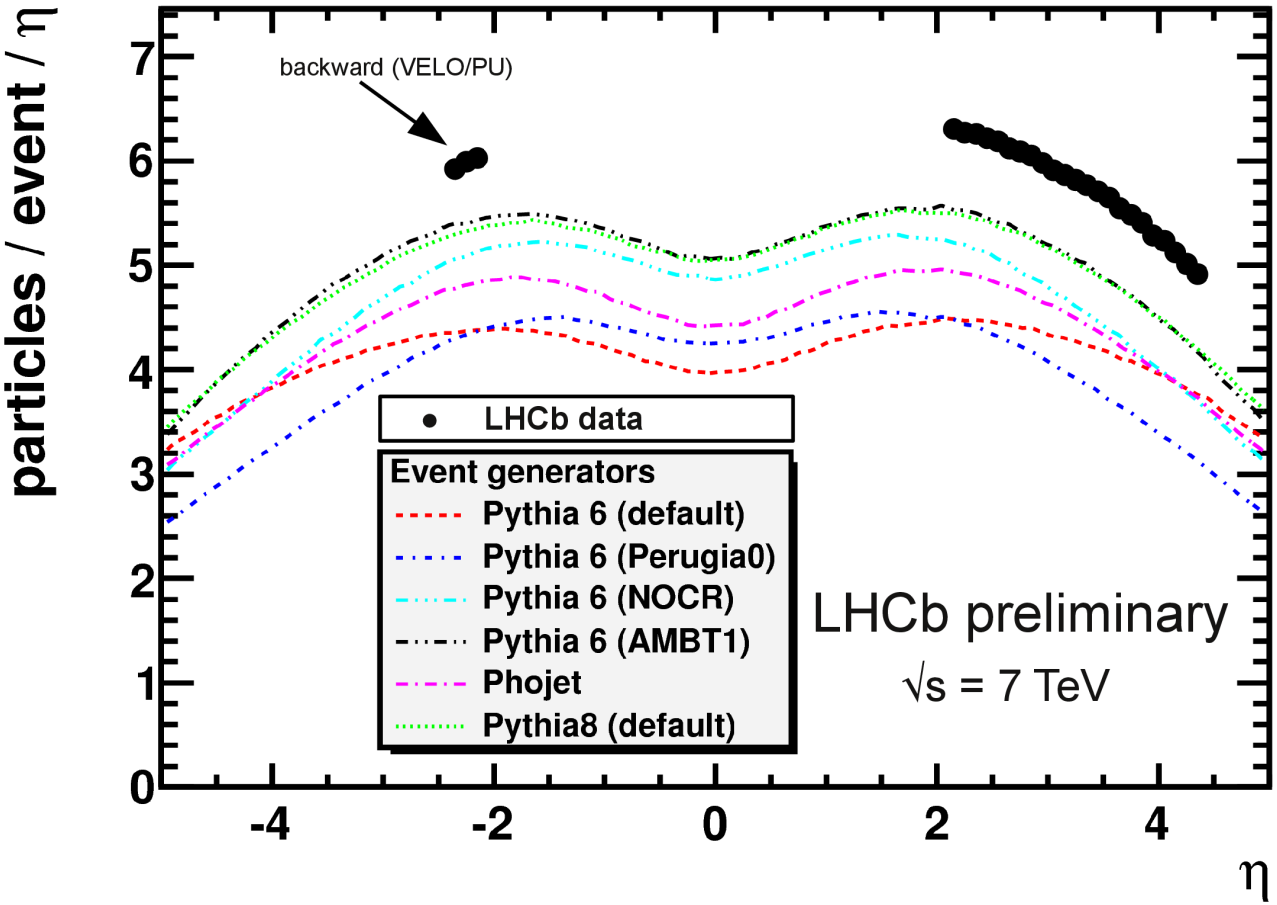
Charged Track Multiplicity

- Sensitive to low-x QCD dynamics and MPI
- Counting reconstructed tracks in VELO detector, high efficiency in the η ranges *[-2.5<η<-2]* and *[2<η<4.5]*



- Magnetic field negligible, no momentum measurement, tracks are straight lines
- The multiplicity distribution is determined using an unfolding technique
- Systematics (efficiency, ghosts, non-prompt and pile-up) are in general ~few%.

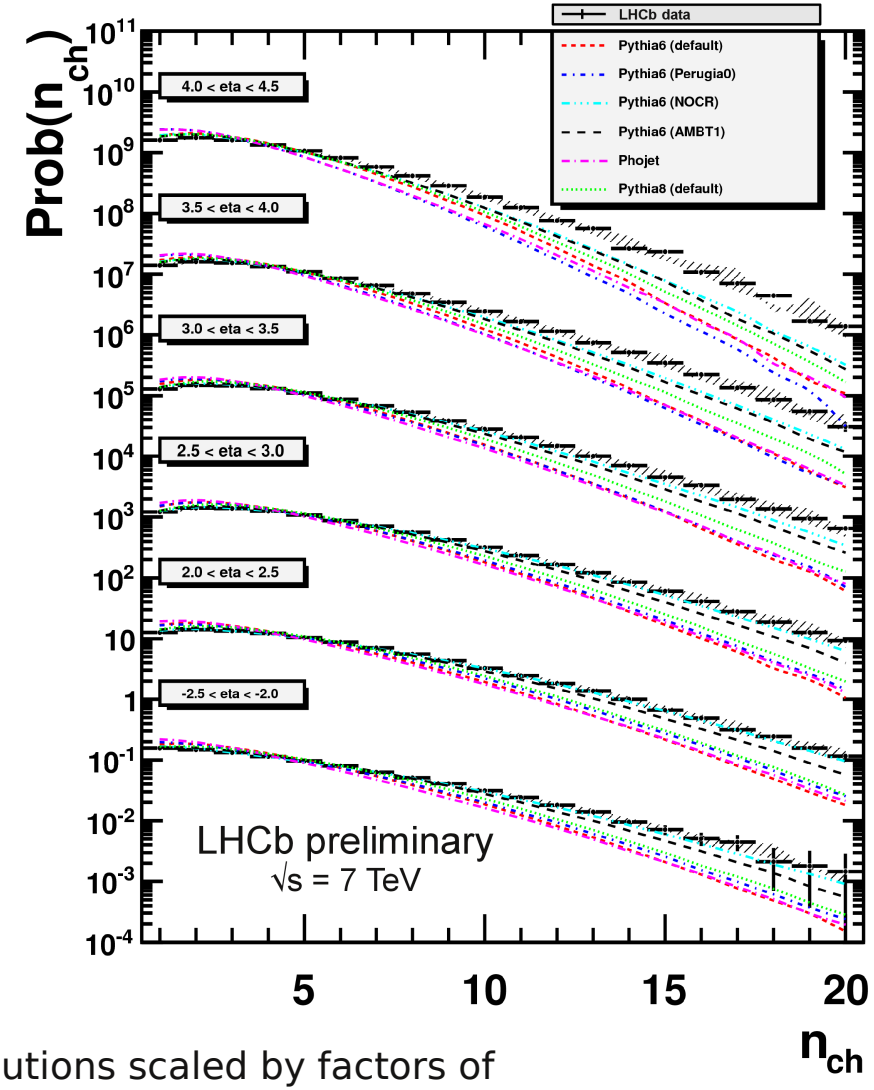
Charged Track Multiplicity



Normalised to events with at least one charged particle in the forward acceptance

Charged Track Multiplicity

Normalised to events with at least one track in the forward acceptance having $p_T > 1$GeV to enhance *hard interactions*



Different η-distributions scaled by factors of 10 to fit in one plot

Conclusions

LHCb has explored a unique kinematic region at low p_T and high rapidity

- Several analyses investigated hadron production and provide valuable input for QCD models and the LHCb MC retuning
- Proton analysis has been extended and improved to provide further ratios (K^-/K^+, π^-/π^+, p/π, K/π, p/K), results will be ready soon

Results compared to models indicate:

- Higher baryon transport
- Harder P_T spectra
- Underestimated strangeness production
- Underestimated charged particle multiplicity

Backup - LHCb MC

LHCb MC is based on Pythia v6.418

Non default Pythia parameters

Parameter	Value	Parameter	Value
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
parp(85)	0.33		

Minimum Bias definition

Processes included

Process Number	Description
11	f + f' → f + f' (QCD)
12	f + fbar → f' + fbar'
13	f + fbar -> g + g
28	f + g → f + g
53	g + g → f + fbar
68	g + g → g + g
91	Elastic scattering
92	Single diffractive (AB → XB)
93	Single diffractive (AB → AX)
94	Double diffractive
95	Low-pT scattering
412-439	Prompt charmonium
461-479	Prompt bottomonium