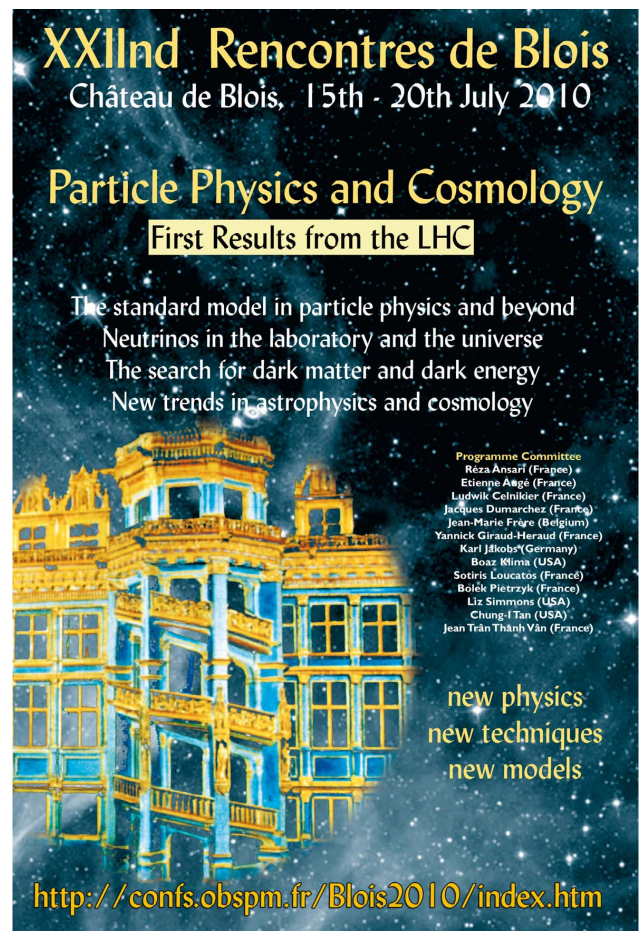
Luminosity measurement and K-short production with first LHCb data



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for the LHCb collaboration

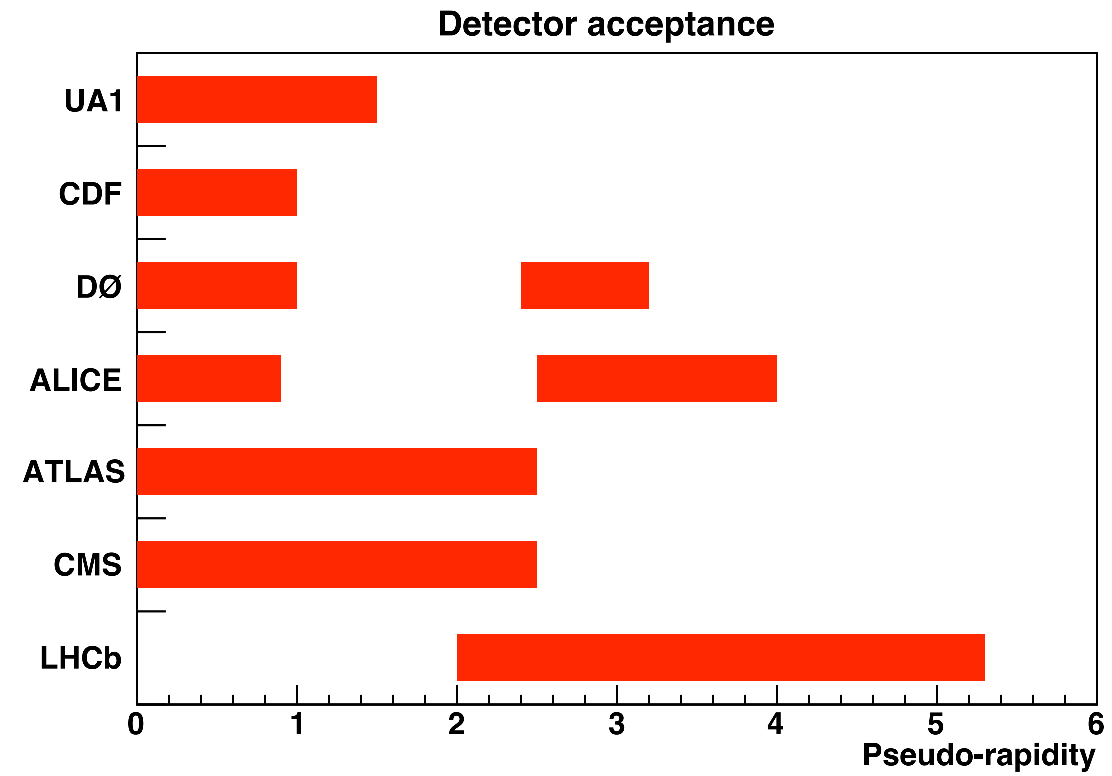
Introduction

- Measurement of the prompt K_s production
- Using data collected during 2009 LHC pilot runs, $\sqrt{s}$ = 0.9 TeV
- Prompt: if the K_s is produced directly in the pp interaction, or in the EM or strong decay of a resonance, eg. K^*
- Direct determination of luminosity delivered in 2009, measured from beam parameters
- Luminosity normalises the production measurement, giving K_s cross-section

Motivation for K_s analysis

Theoretical motivation:

- New regime:
  - $\sqrt{s}$ = 0.9 TeV
  - pp collisions
  - coverage in the forward region

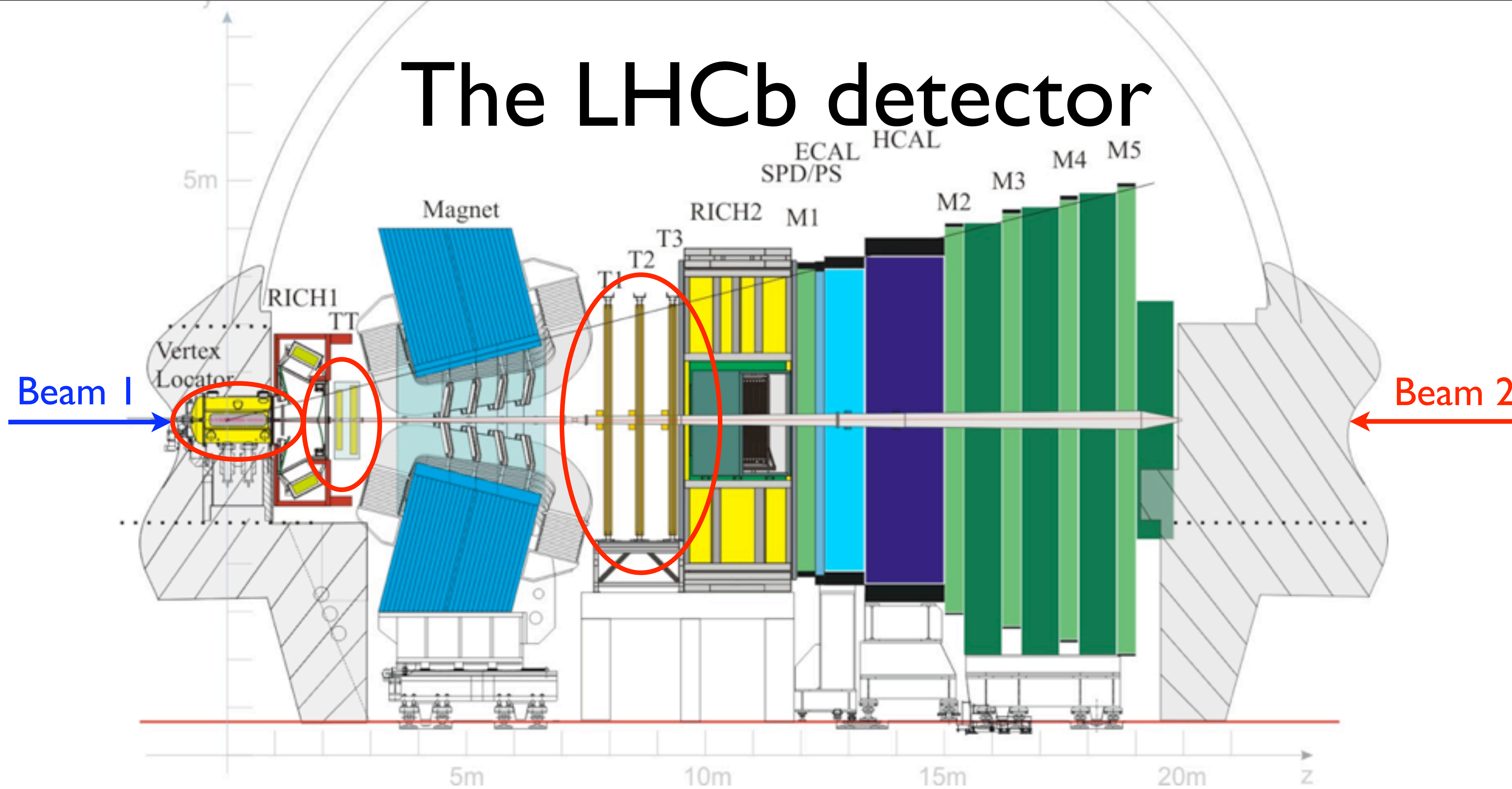


- Models tuned for central rapidity and p_T > 0.4-5 GeV/c. Check the model extrapolation to forward region and down to p_T = 0
- Strangeness production is of interest in heavy ion physics, we can provide an important reference point

Experimental motivation, an ‘early’ result:

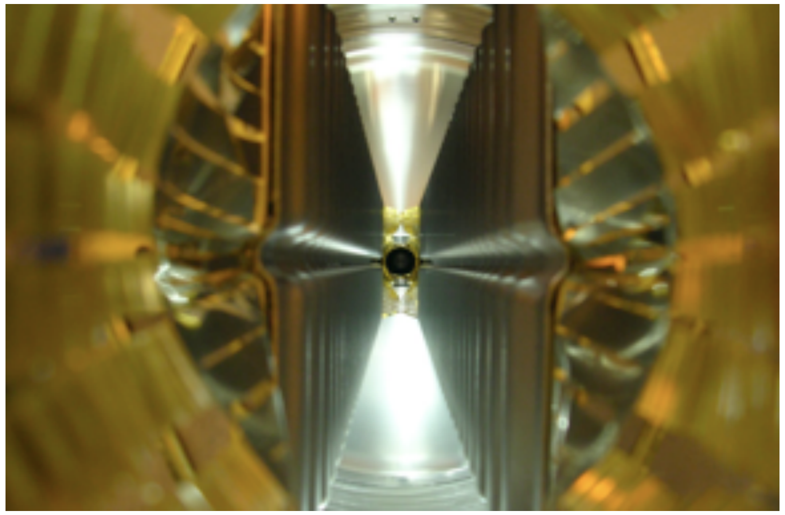
- Only vertex locator and tracking required in analysis
- Simple minimum bias trigger
- Gain knowledge of alignment, calibration, magnetic field strength

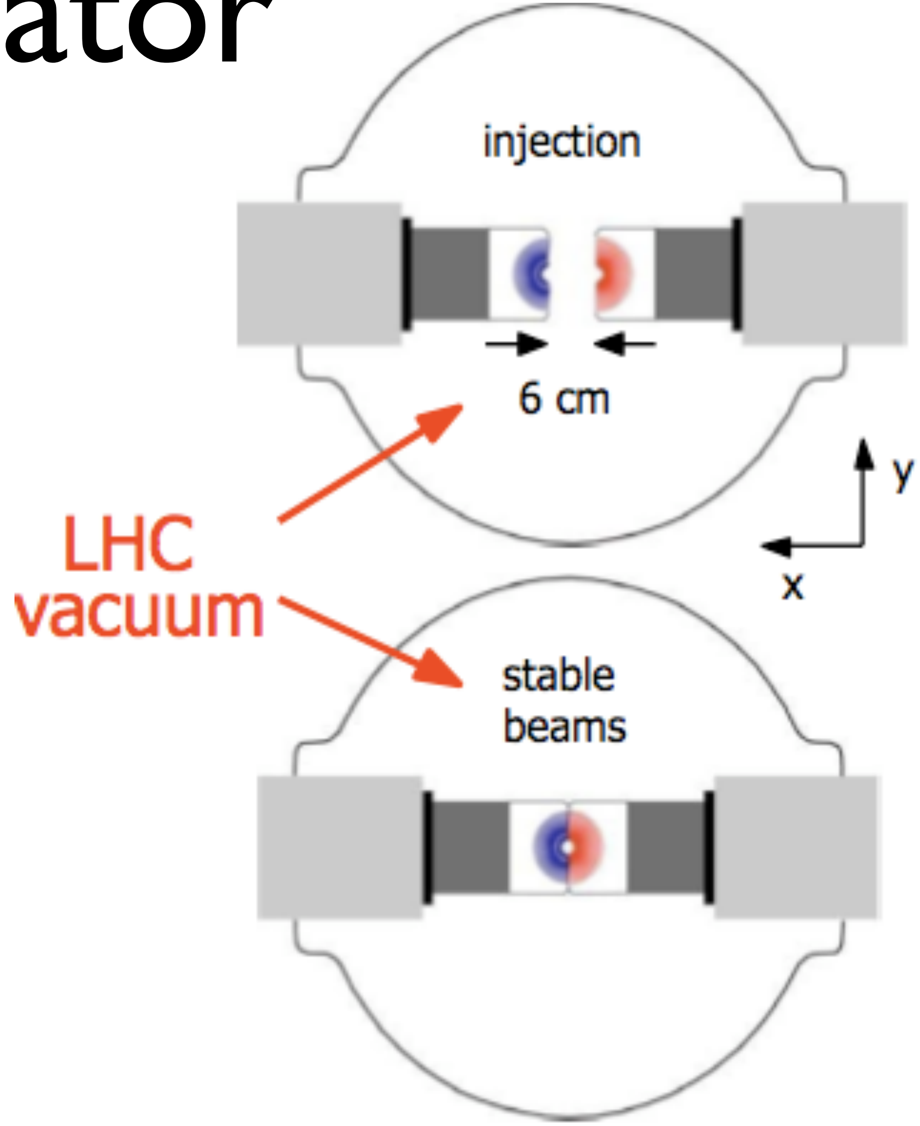
The LHCb detector



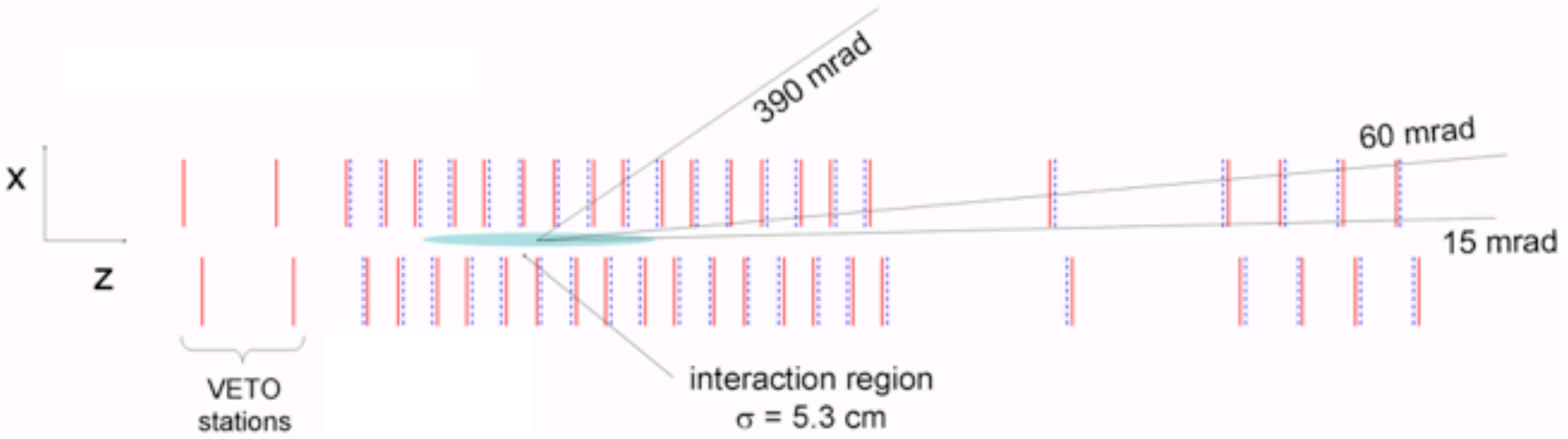
- Single-arm spectrometer, covering 15 - 300 (250) mrad in the (non) bending plane
- Silicon micro-strip VELO and TT stations, straw tubes in T1-3
- In 2009 VELO was "half open" at ±15 mm due to larger beam size and crossing angle
- Tracking stations both before and after 3.7 Tm dipole magnet

The VErtex LOcator

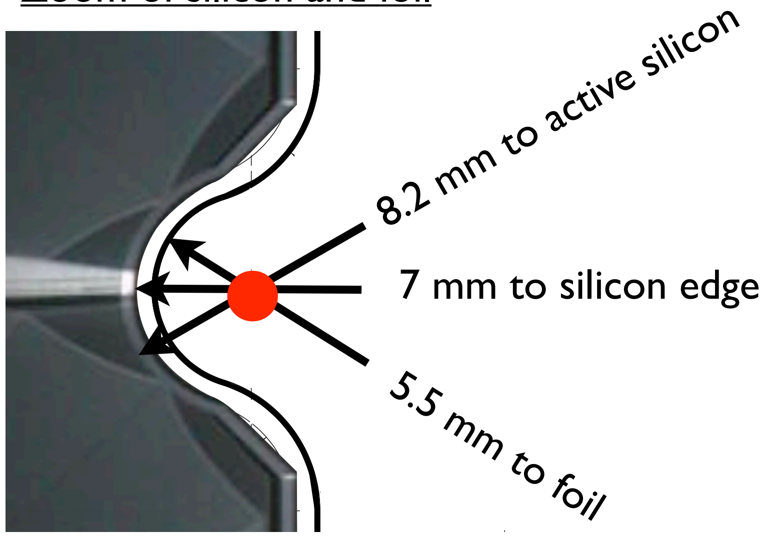




- VELO made in two halves which move in x, y
- Retracts during injection, closes upon stable beams
- Normally: active silicon 8 mm from beam
- 2009: larger beam sizes and crossing angle so for safety, only 'half-closed' to 15 mm



Zoom of silicon and foil



Analysis strategy

- $K_S^0 \rightarrow \pi^+\pi^-$ with 70 % branching fraction
- Take every combination of two oppositely charged tracks which satisfy selections
- Boost to rest frame of pp collision to get K_s 4-momentum (E,p)
- Measure the K_s production in bins of transverse momentum (p_T) and rapidity (y):

$$\begin{aligned} p_{\mathrm{T}} &= \sqrt{p_x^2 + p_y^2} \\ y &= \frac{1}{2} \ln \frac{E + p_z}{E - p_z} \end{aligned}$$

- For each bin, the cross section is:

Observed signal decays

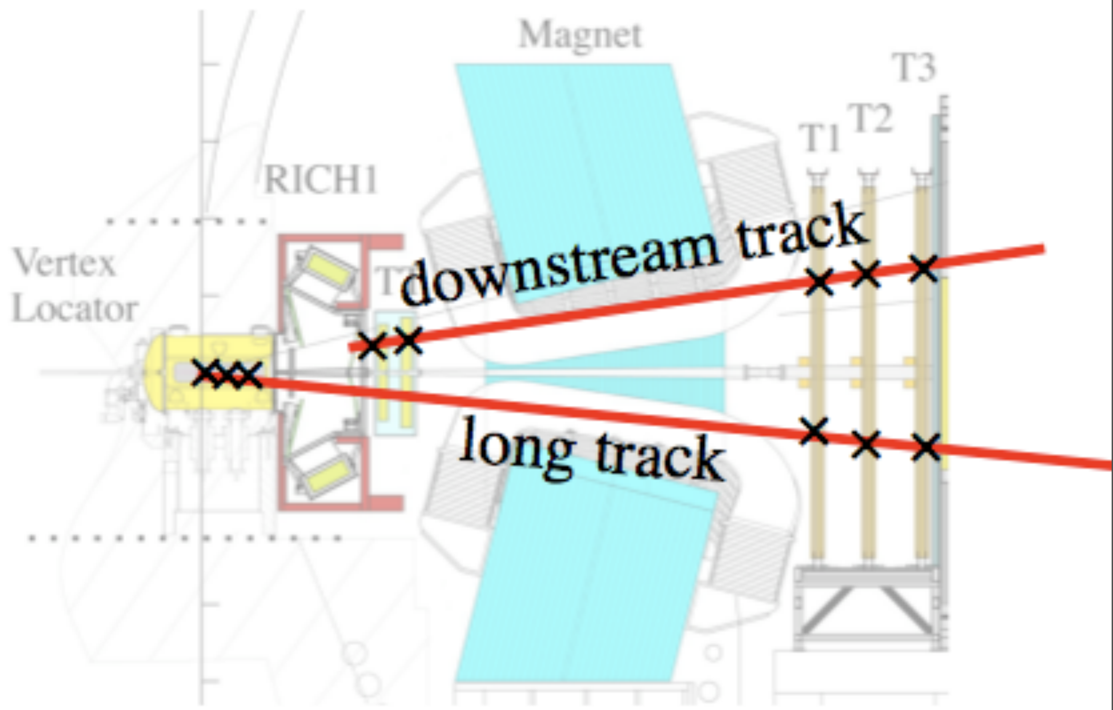
$$\sigma_i = \frac{N_i^{obs}}{\epsilon_i^{trig/sel} \times \epsilon_i^{sel} \times L_{int}}$$

Trigger efficiency

Integrated luminosity

Reconstruction and selection efficiency

Dual analysis



Two independent, complementary analyses performed:

Downstream track analysis:

- No VELO hits used in reconstruction
- High statistics
- Wider mass resolution, more background

Long track analysis:

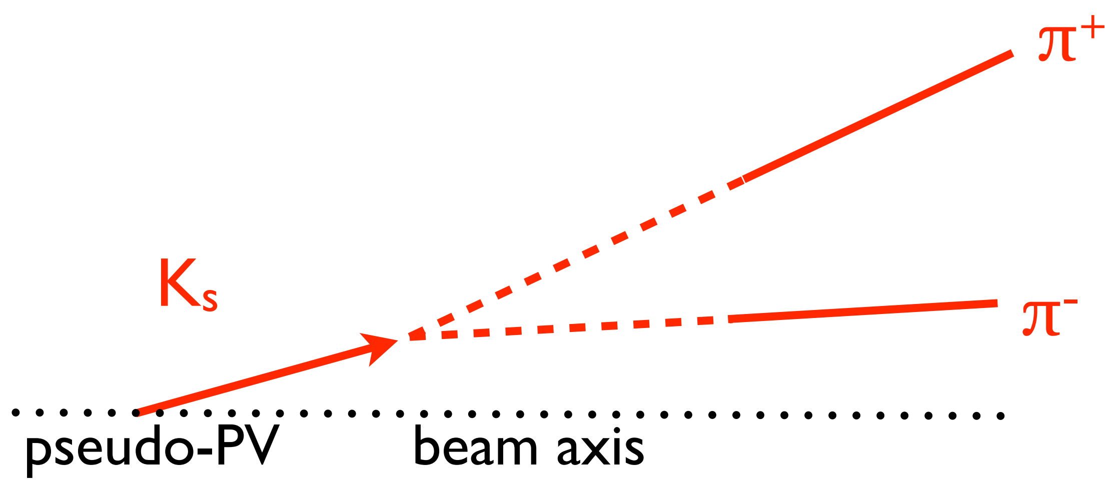
- Tracks require VELO hits
- Low statistics due to K_s boost and open VELO
- Good background rejection, good mass resolution

Choose not to combine the results since the systematic uncertainties are correlated

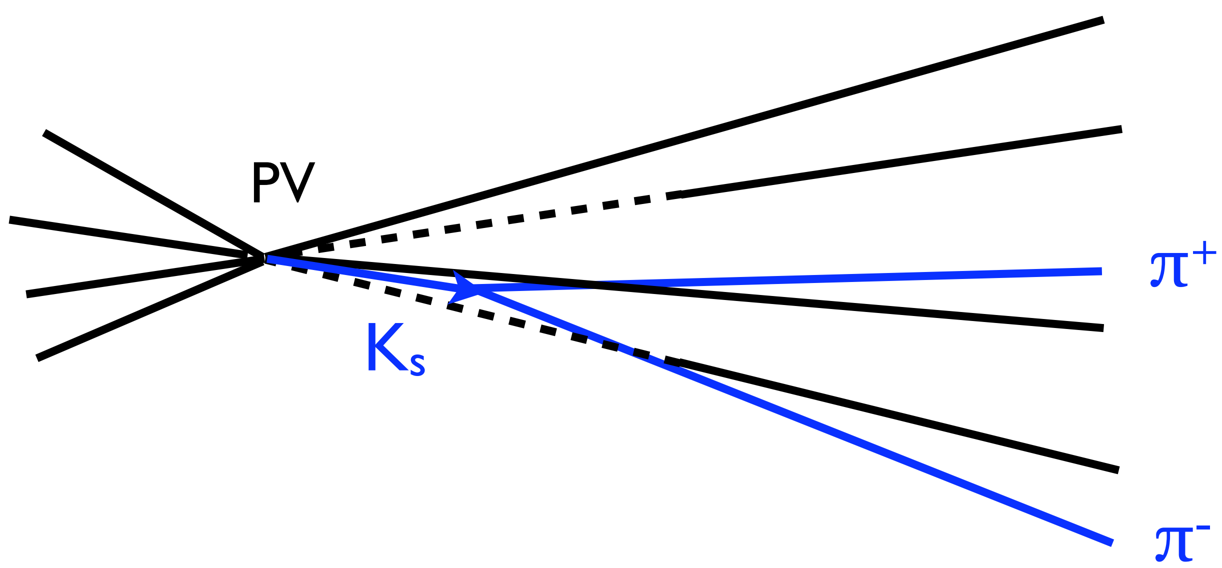
Used the most precise measurement for each phase-space bin

Event reconstruction and selection

Downstream track analysis



Long track analysis



- Require good track and vertex fits
- Require that the K_s flies, and points back to the PV or beam axis
- Topological and kinematic cuts to reduce downstream background
- Reduce background in the long analysis with an impact parameter requirement:

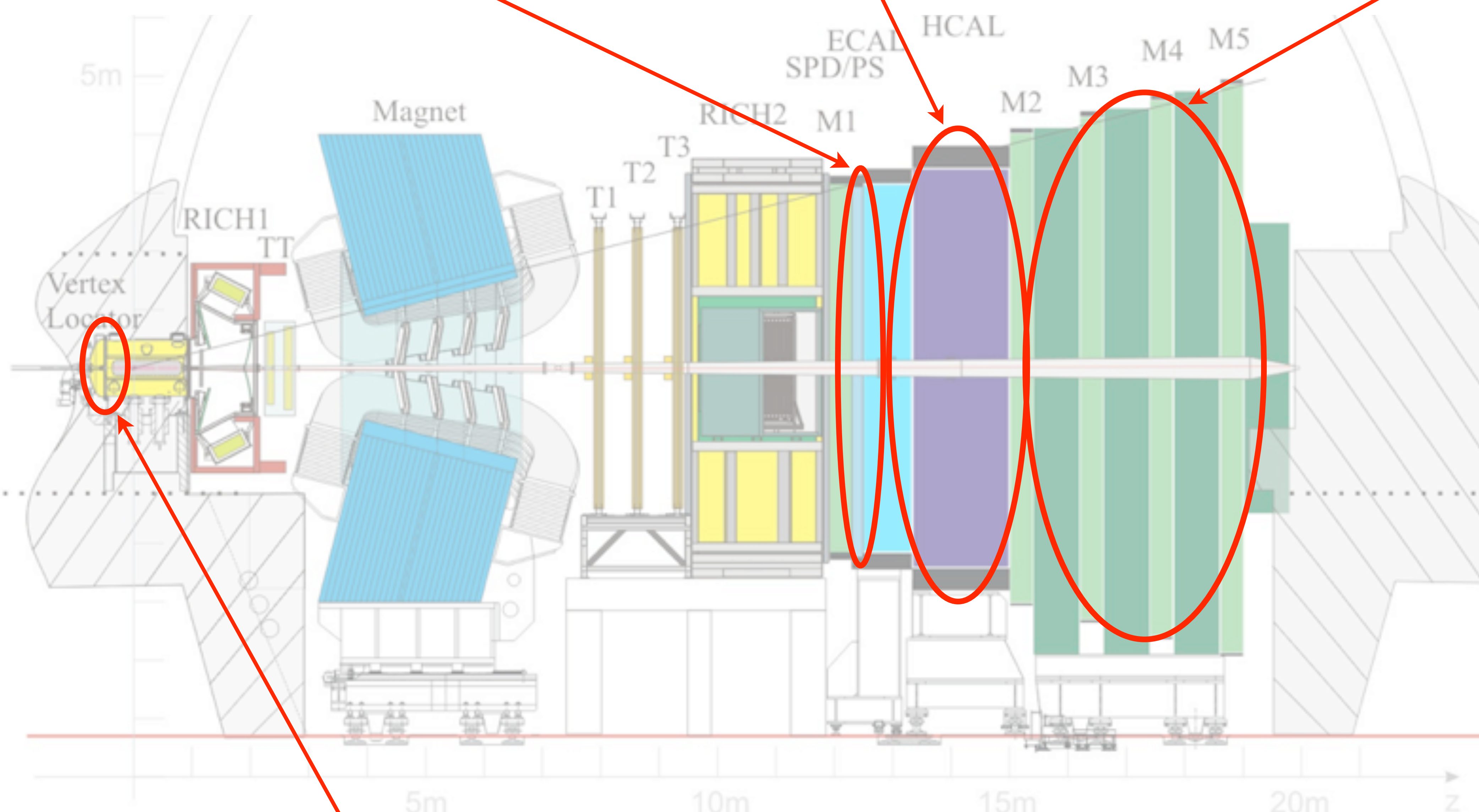
$$\nu = \ln \frac{I_{\pi^+} \times I_{\pi^-}}{I_{K_s} \times I_1}, \; I_1 = 1\,\mathrm{mm}$$

Downstream track:

Long track:

Trigger

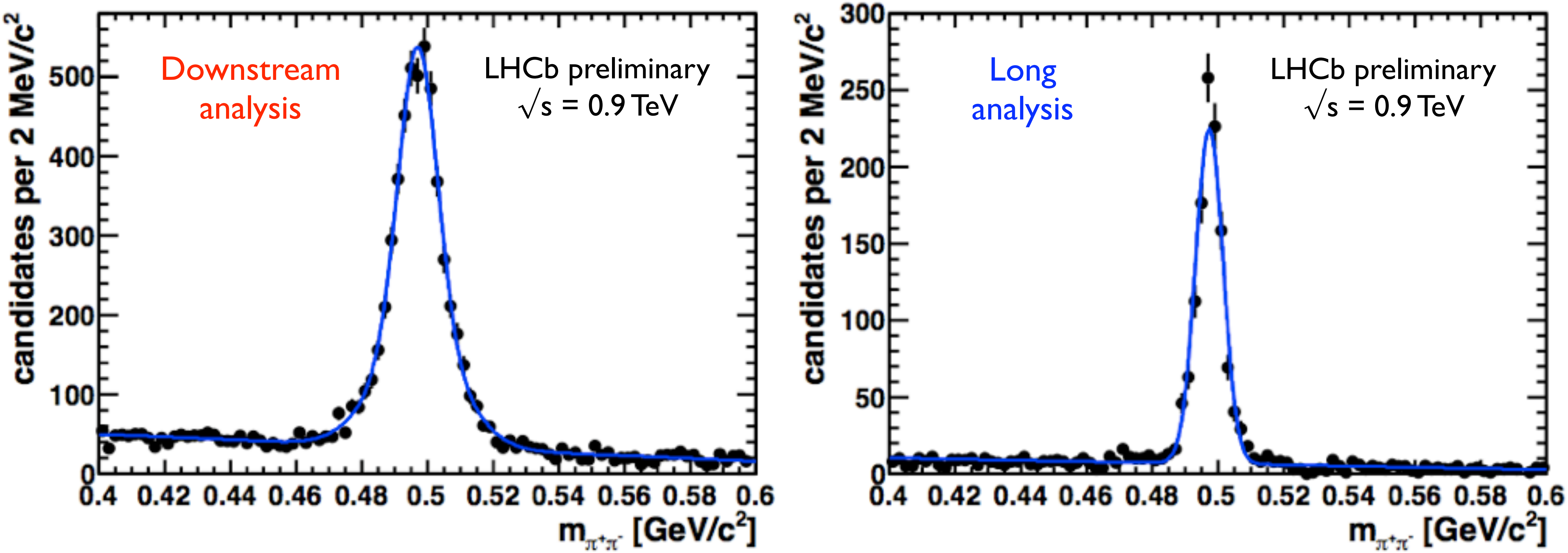
For beam-beam and beam1-gas: (Scintillator pixel detector Triggers if hits > 2 AND Hadron calorimeter Triggers if 2x2 cluster has p_T > 240 MeV) OR Muon detector Triggers if 1 track has p_T > 480 MeV



For beam2-gas: Pile-up detector Triggers if hits > 7

K_s signal extraction

The beam-gas subtracted mass distributions of all selected events



	Downstream	Long	
Beam-gas subtracted yield in beam-beam	4801 ± 84	1182 ± 36	
Mean mass (MeV/c^2)	497.12 ± 0.14	497.31 ± 0.13	(PDG: 497.61 ± 0.02)
Mass resolution (MeV/c^2)	9.2	4.0	
Total yield in beam-gas	56 ± 10	15 ± 6	

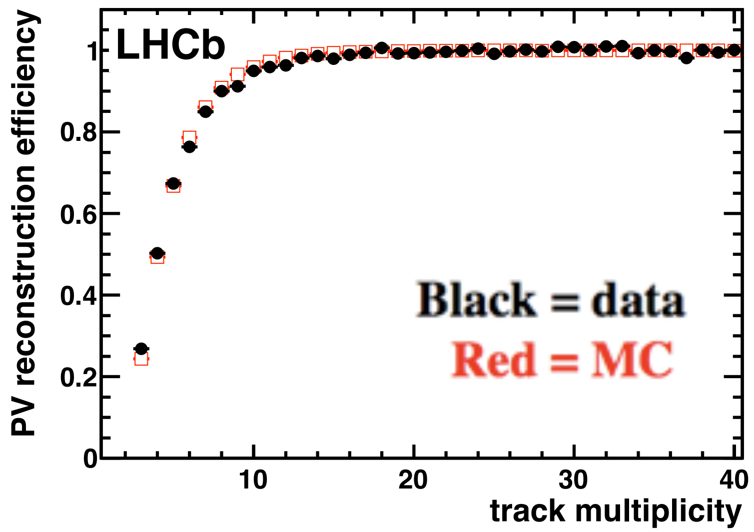
Efficiency corrections

Efficiencies are corrected per bin of p_T and y:

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

Reconstruction and selection efficiency ε^{sel}:

- Selection efficiency estimated in MC, includes geometric acceptance, reconstruction efficiency:
    - Tracking efficiency
    - Primary vertexing efficiency (for the long analysis only)

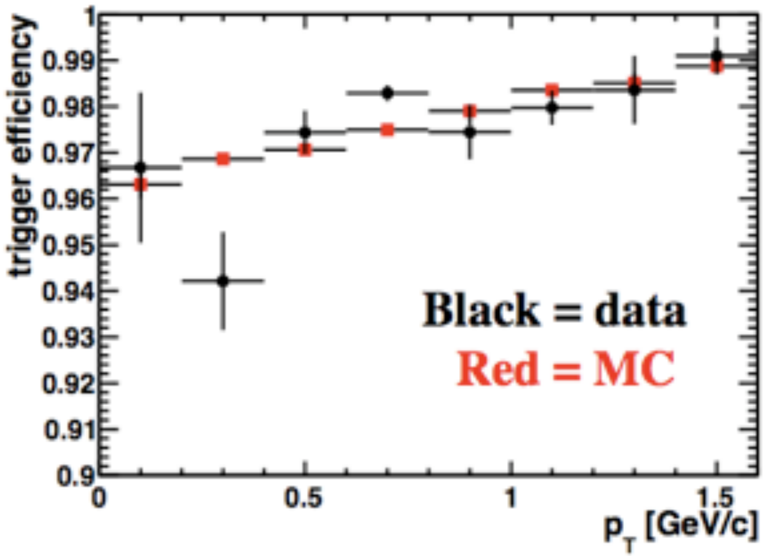


Trigger efficiency $\varepsilon^{trig/sel}$:

- Calculate ratio of triggered, selected events and selected events in MC

Total efficiency

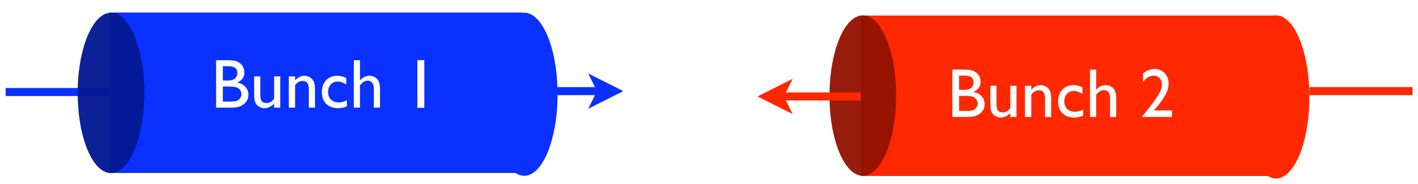
- 3 - 20 % depending on bin (geometric acceptance)

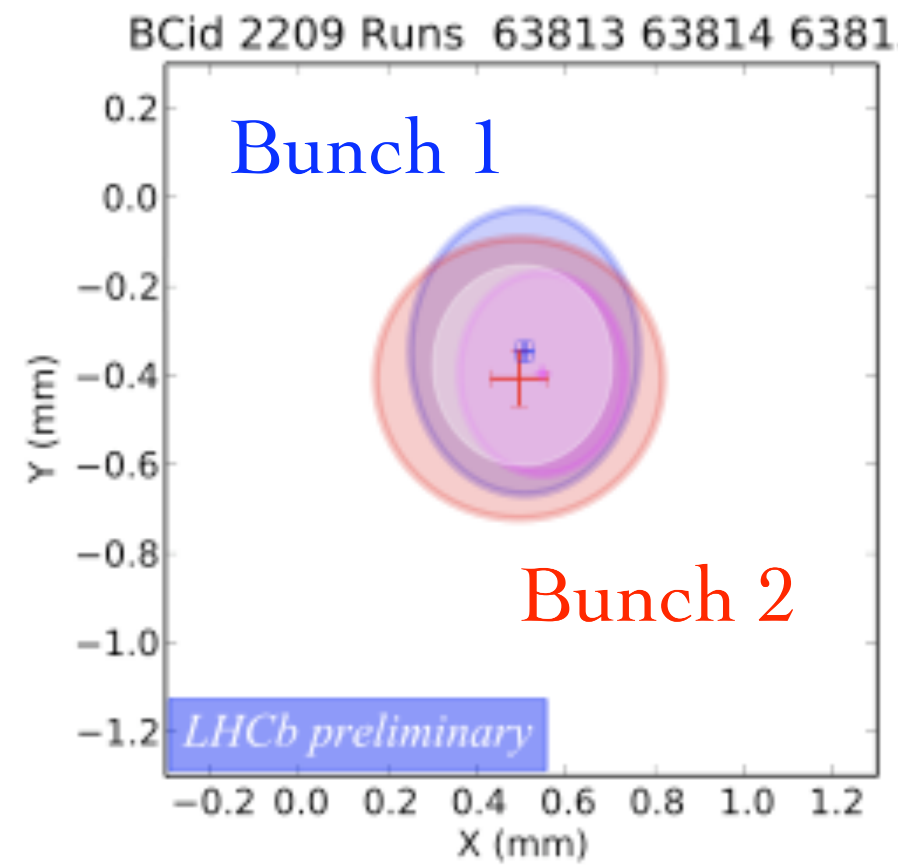


	Efficiency	Systematic uncertainty
Tracking	85-100%	6-17%
Primary Vertex	91%	1.5%
Trigger	> 95% in every bin	2.5%

Luminosity method

- For 2009 runs, luminosity was calculated directly from beam parameters





- Luminosity for N pairs of colliding bunches:

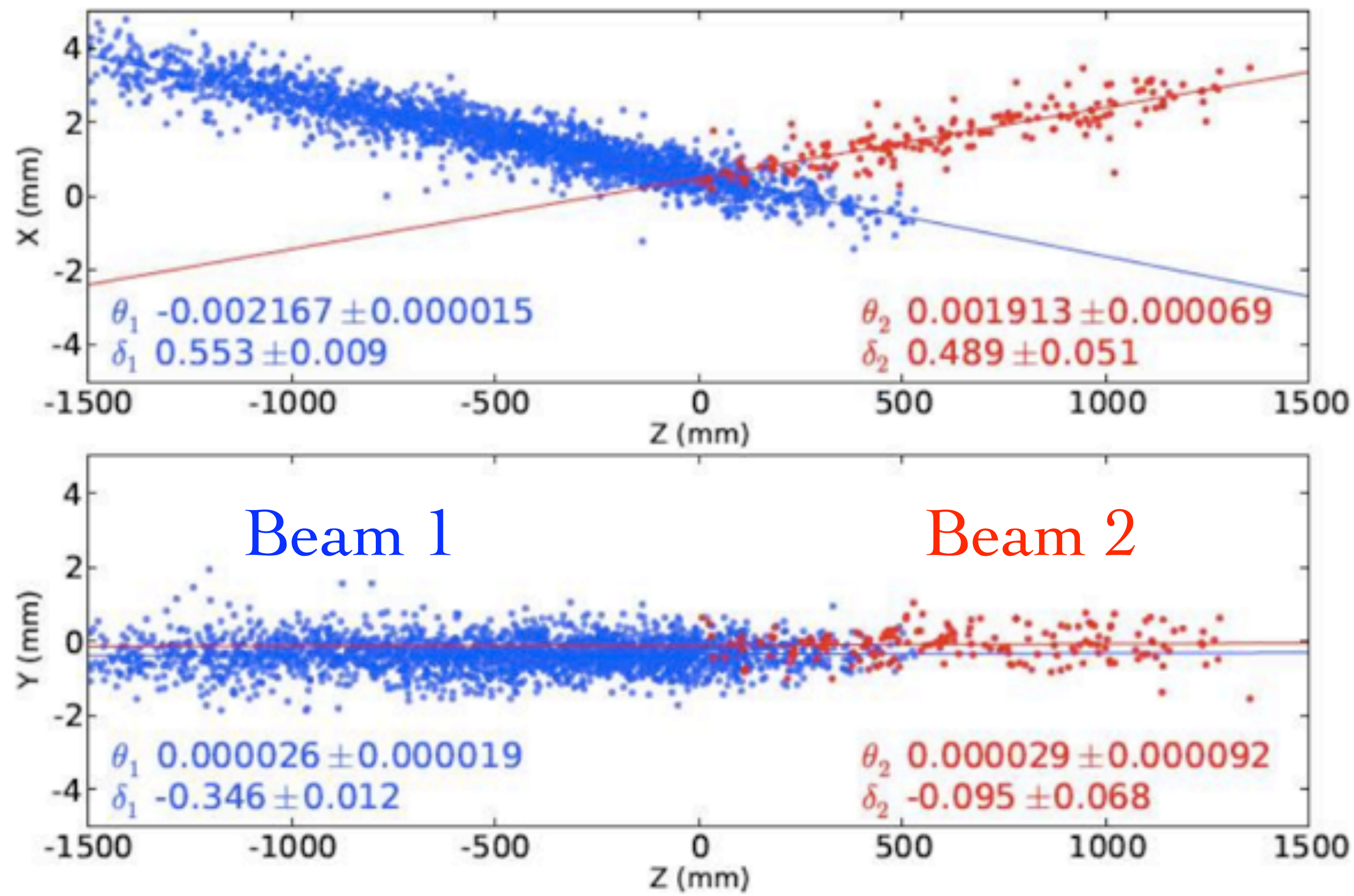
$$L = f \sum_{i=1}^{N} \frac{n_{1i} n_{2i}}{A_{\mathrm{eff}\,i}}$$

$$\begin{aligned} f &= 11.245\ \mathrm{kHz};\ \text{revolution freq.} \\ n_{1i}, n_{2i} &= \text{number of protons in bunch} \\ A_{\mathrm{eff}\,i} &= \text{effective collision area} \end{aligned}$$

- Get bunch currents from the LHC machine measurements
- Use VELO to image beams by reconstructing vertices from beam-gas interactions. Gives the beam sizes, positions and angles for effective area calculation

Beam-gas reconstruction

- VELO can reconstruct the two beams separately using beam-gas events
- Gas pressure in beam-pipe is around 10^{-9} millibar and uniform
- Acceptance up to |z| ~ 1.5 m
- Crossing angle flips as we reverse the polarity of the LHCb dipole magnet
- All possible due to how closely the VELO approaches the beam



Vertex resolution in beam-gas events

- We measure a convolution of the bare beam size with the vertex resolution
- Resolution must be measured and removed
- Resolution parametrised as a function of number of tracks and z position of the vertex:

As a function of tracks:

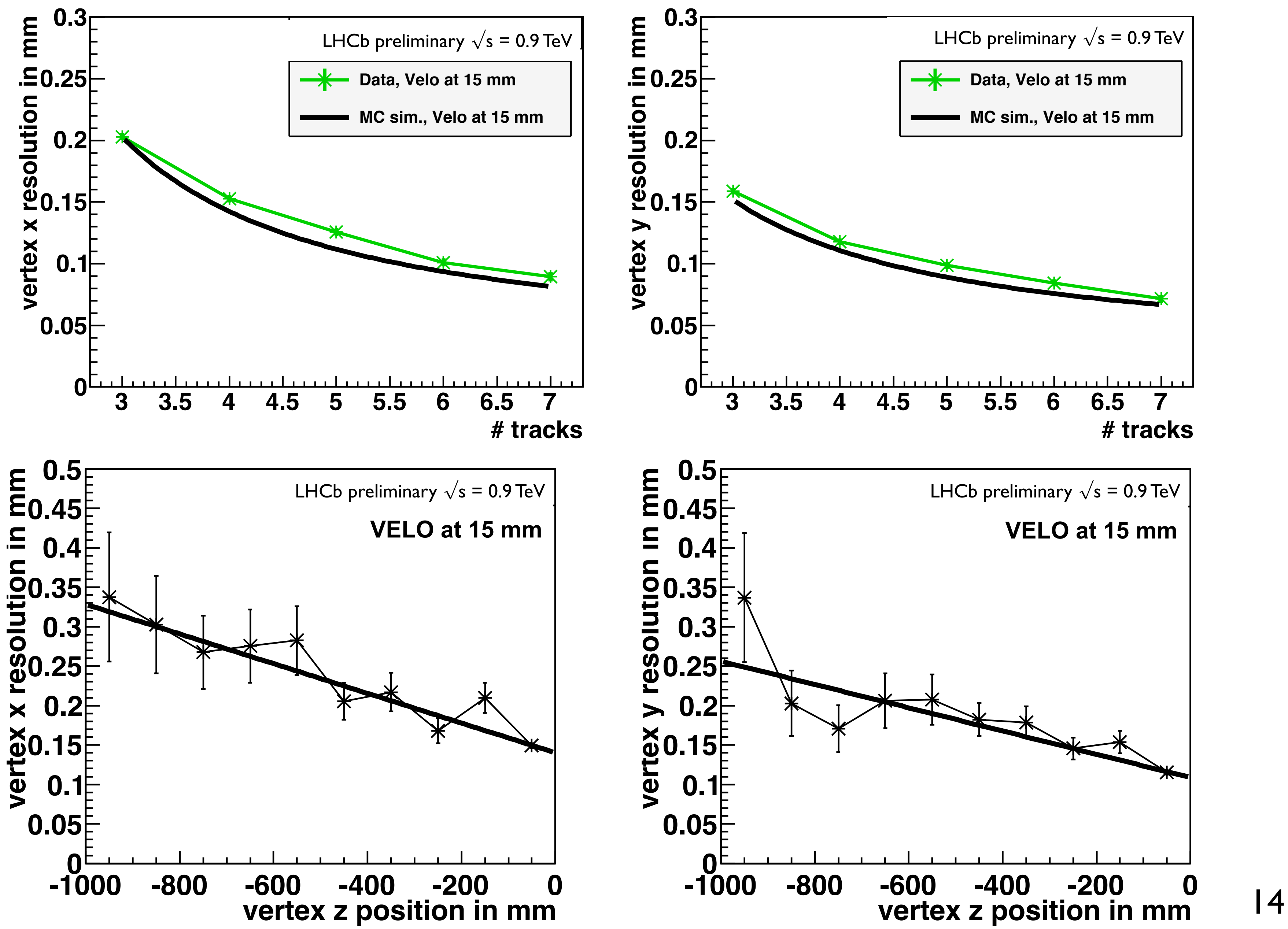
Resolution better in y than x, due to VELO-beam distance.

Dependence ~1/√N

As a function of z position:

Resolution worse at large |z| due to extrapolation distance.

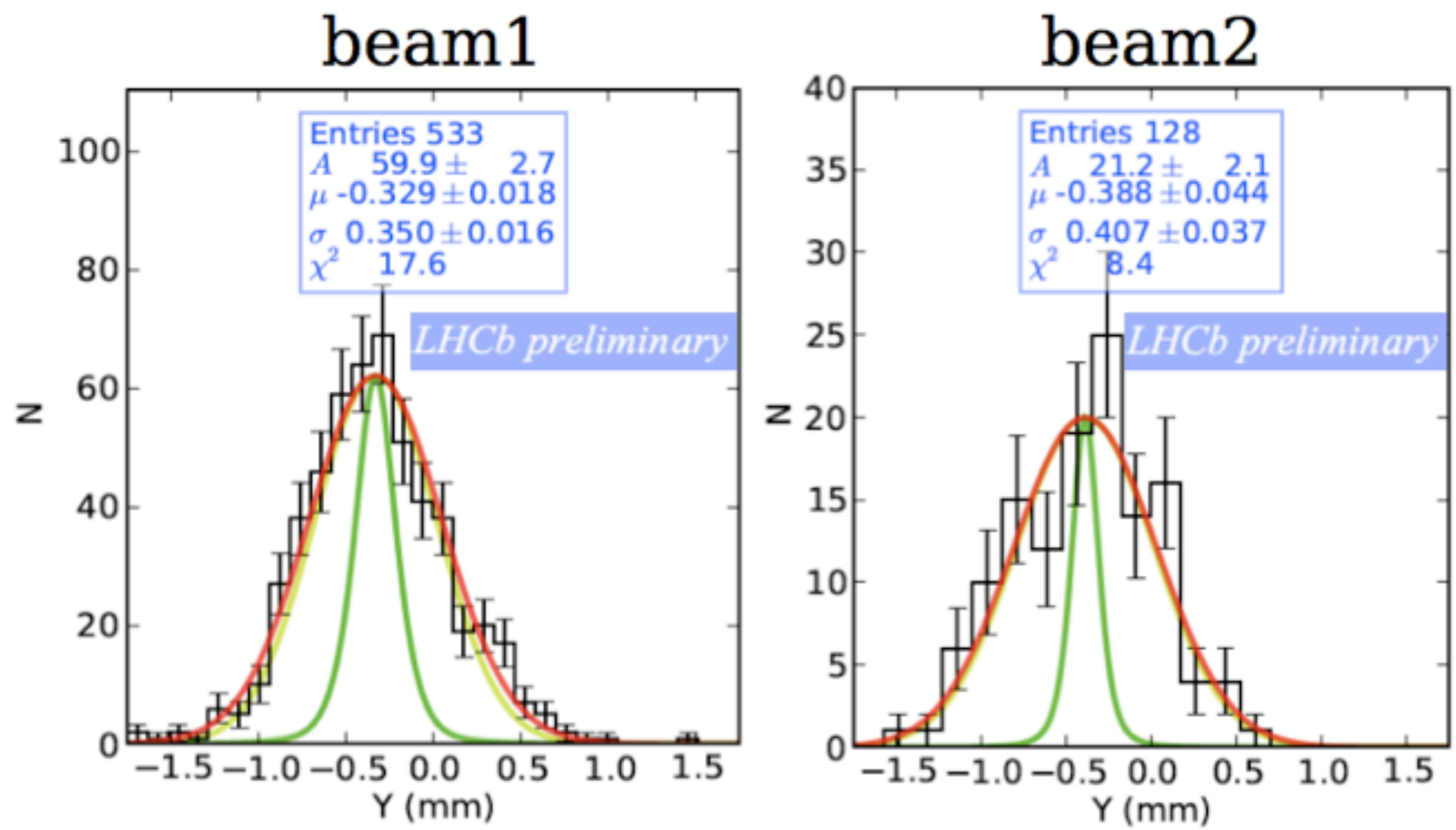
Dependence linear



Luminosity results

- Vertex resolutions are deconvoluted from the measured beam size
- Bare beam sizes then used to calculate the effective crossing-area

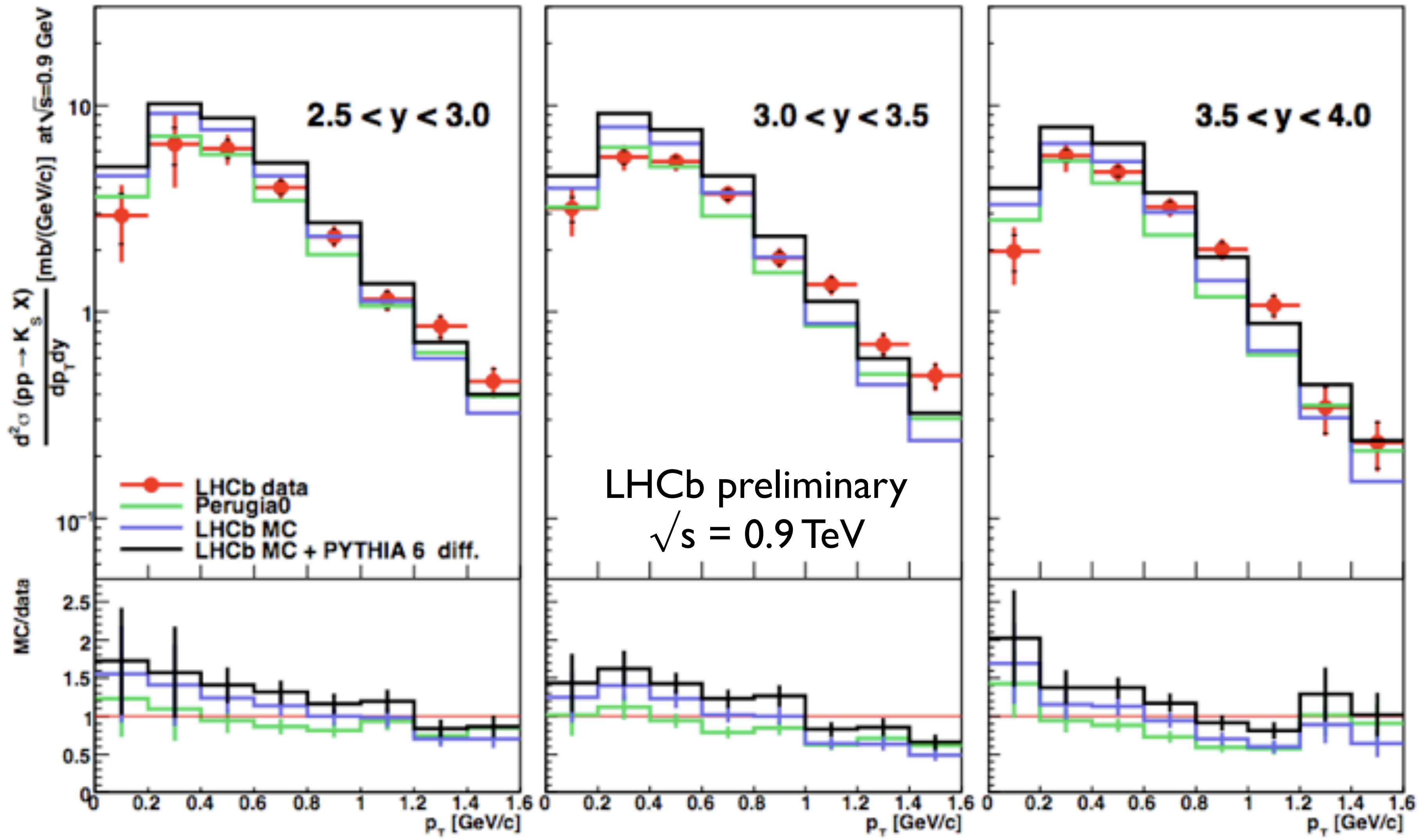
Vertex resolution
Measured size
Bare beam size, after de-convoluting the resolution



- Luminosity delivered during 2009 and used for Ks analysis: 6.8 ± 1 μb^{-1}

Beam currents	Widths	Positions	Angles		Luminosity total
12%	5%	3%	1%	=	15%

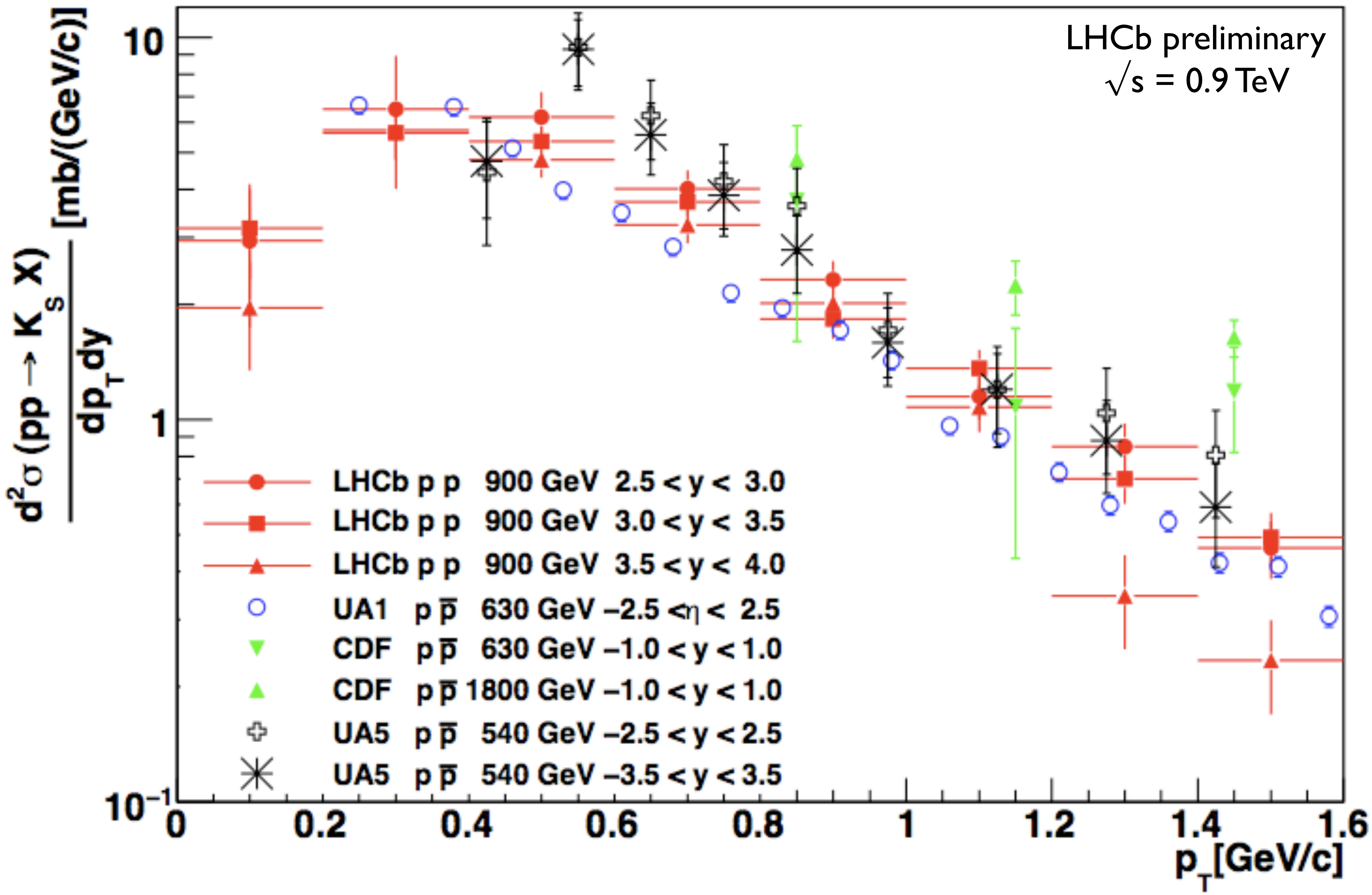
Prompt σ (K_s) results



- LHCb data - includes both diffractive and non-diffractive K_s production
- Perugia0 - the "Perugia 0" settings, which exclude diffraction
- LHCb MC - standard LHCb MC, with no diffractive processes
- LHCb MC + PYTHIA 6 diff.- standard LHCb MC including soft diffraction

- Lowest two p_T bins in $2.5 < y < 3$ from long analysis, rest from downstream
- Data tend to be harder in p_T than PYTHIA

Prompt σ (K_s) results



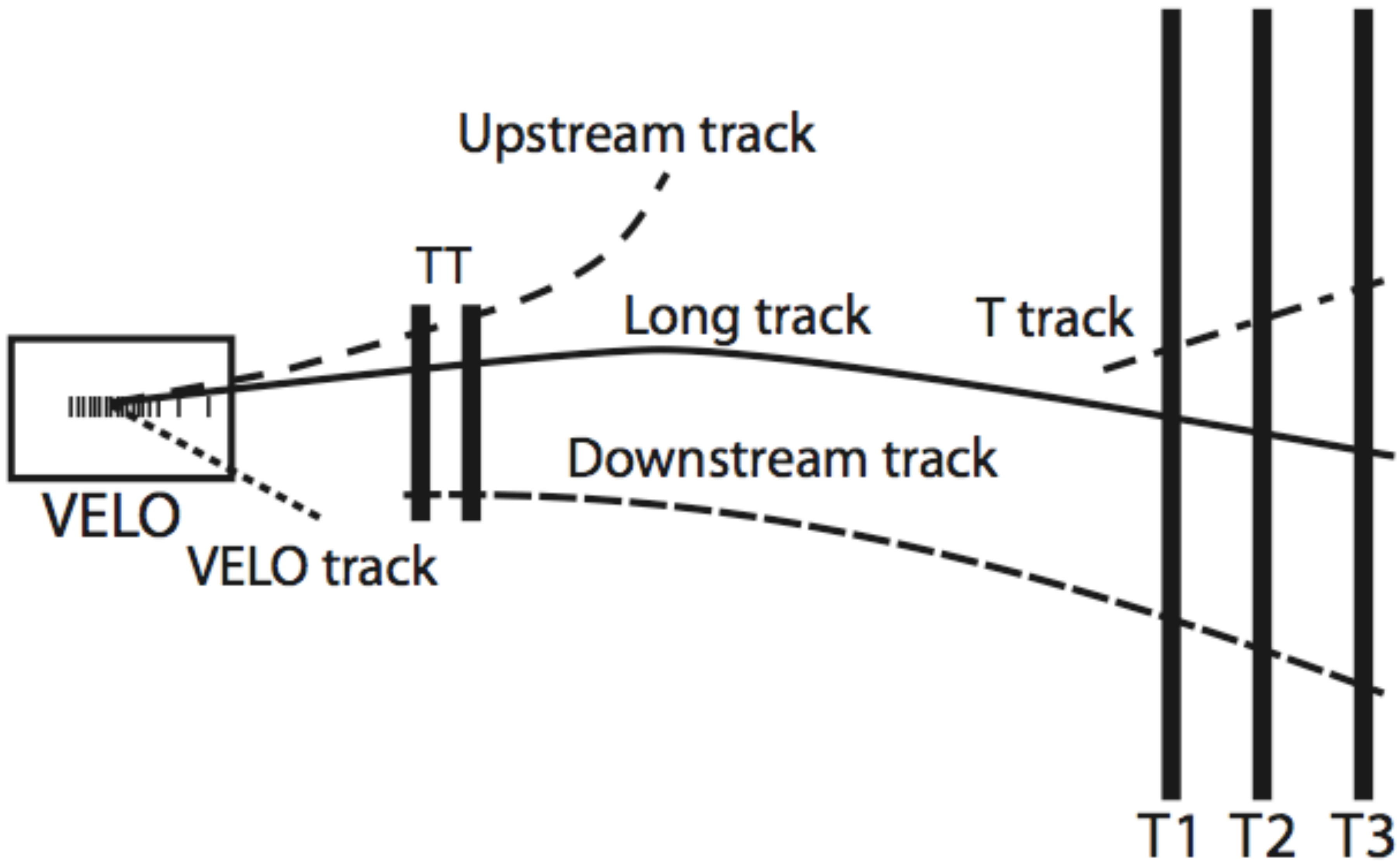
- Expectations broadly supported by data:
  - steepening of p_T spectrum at increasing rapidity
  - more abundant production with increasing energy
- LHCb uniquely providing measurements at high rapidity, and down to $p_T = 0$

Conclusions

- First physics paper from LHCb - draft currently in collaboration review
- Prompt K_s cross-section at $\sqrt{s}$ = 0.9 TeV
- Including a direct luminosity determination of 2009 runs: 6.8 ± 1 μb^{-1}
- Cross section measurement done in bins of p_T and y
- Extended measurement range down to p_T = 0 and very forward rapidity
- Data-MC in broad agreement
- p_T spectra tend to be slightly harder than PYTHIA predictions

Backup slides

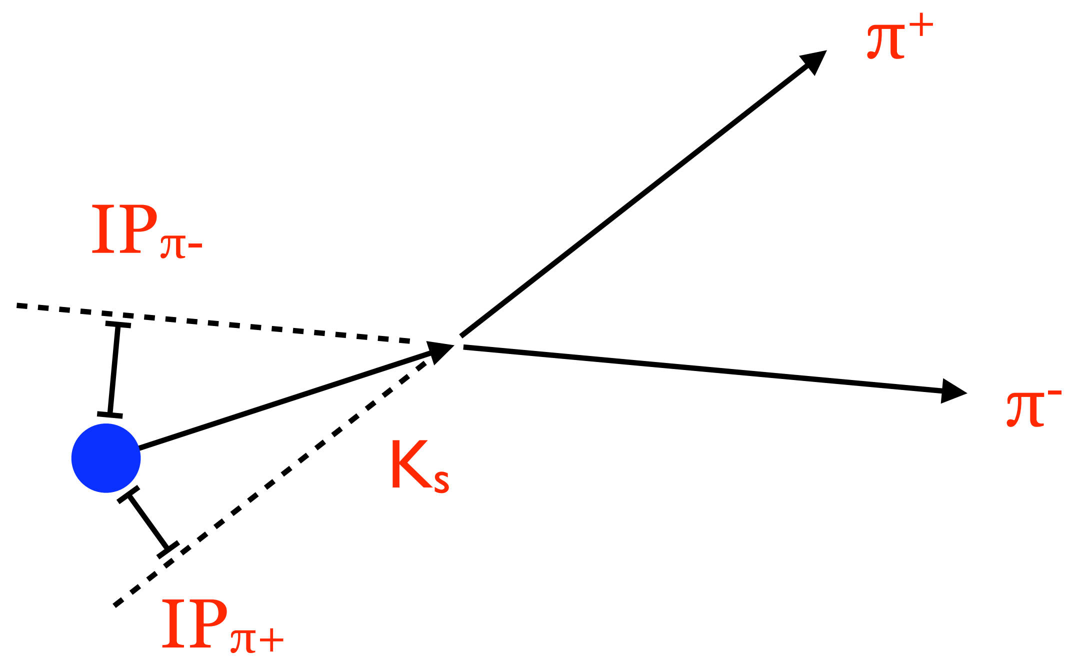
Tracks in LHCb



Selections

Downstream track analysis

Each π momentum	> 2 GeV/c
Each π transverse momentum	> 0.05 GeV/c
Each track χ^2/ndf	< 25
π distance of closest approach to z axis	> 3 mm
K_s decay vertex χ^2/ndf	< 25
z of K_s decay vertex	< 2200 mm
|z| of pseudo-PV	< 150 mm
cos $\theta_{pointing}$	> 0.99995
K_s proper time ($c\tau$)	> 5 mm



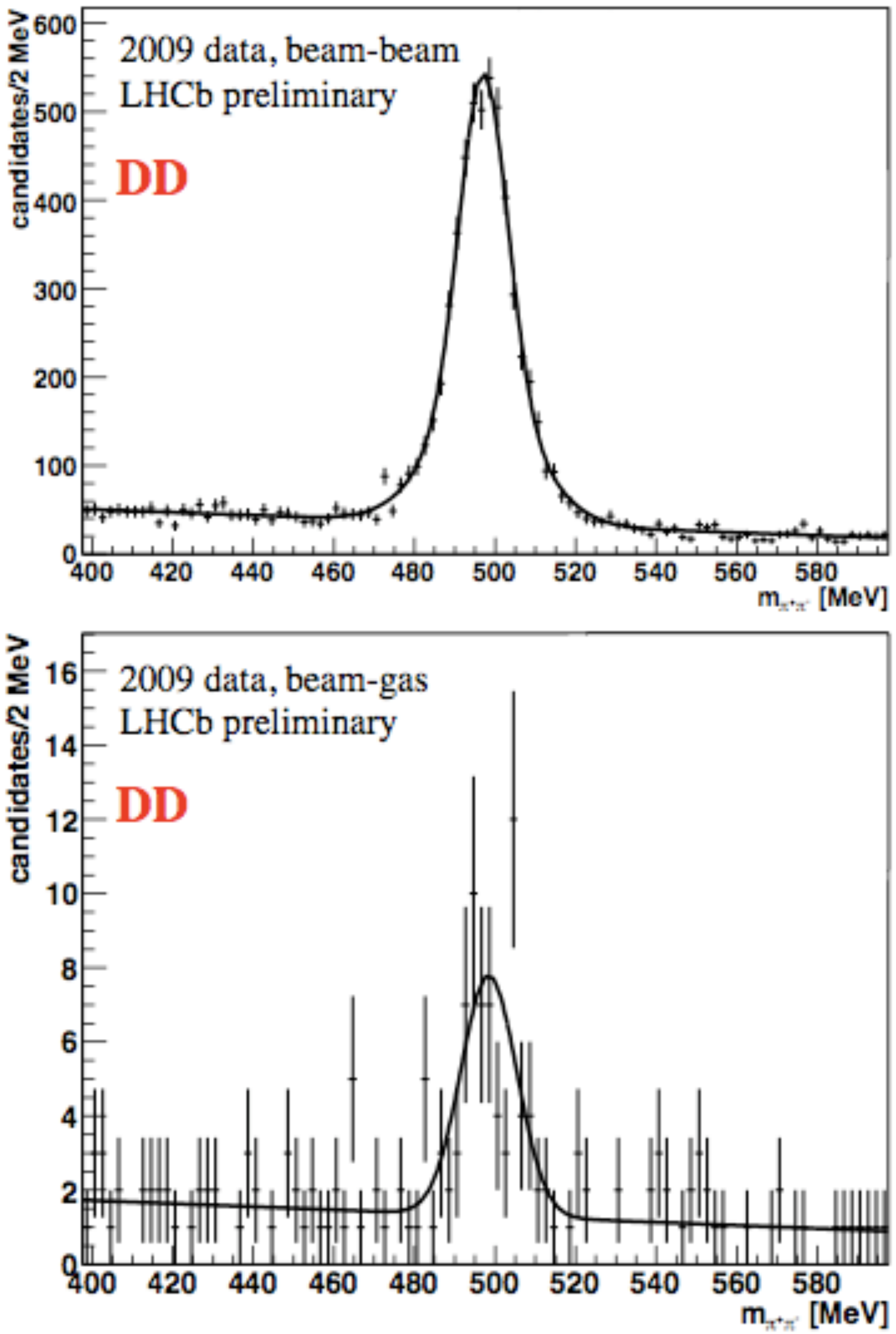
$$\nu = \ln \frac{I_{\pi^+} \times I_{\pi^-}}{I_{K_s} \times I_1}, \ I_1 = 1\,\mathrm{mm}$$

Long track analysis

|z| of associated PV	< 200 mm
Each track χ^2/ndf	< 25
K_s decay vertex χ^2/ndf	< 100
$z(K_s)$ - z(PV)	> 0
IP-related variable ν	> 2

Beam-gas subtraction

- Beam1-gas contributes < 1.5%
- Plot mass peak for bb, and be
- Normalise, because different bunches have different number of protons (could have used beam currents but this is more accurate)
- Normalisation factor 0.9, found by looking at z < -200 mm
- Beam-gas collisions can make K-shorts!



Full table of systematics

Source of uncertainty	Downstream analysis		Long analysis	
	uncorrelated	correlated	uncorrelated	correlated
Yields N_i^{obs}:				
– Data statistics	$5 - 25\,\%$		$9 - 38\,\%$	
– Signal extraction	$1 - 5\,\%$		$0 - 21\,\%$	
– Beam-gas subtraction		negligible		negligible
Quadratic sum of above 3	$6 - 25\,\%$		$9 - 38\,\%$	
Eff. correction $(\epsilon_i^{\text{trig/sel}} \times \epsilon_i^{\text{sel}})^{-1}$:				
– MC statistics	$1 - 5\,\%$		$2 - 9\,\%$	
– Track finding		$6 - 17\,\%$		$4 - 27\,\%$
– PV reconstruction				$1.5\,\%$
– Selection		$4\,\%$		$5\,\%$
– Trigger		$2.5\,\%$		$1.5\,\%$
– p_{T} and y shape within bin	$0 - 20\,\%$		$0 - 25\,\%$	
– Diffraction modelling		$0 - 1\,\%$		$1 - 6\,\%$
– Non-prompt contamination		$< 1\,\%$		$< 1\,\%$
– Material interactions		$< 1\,\%$		$< 1\,\%$
Quadratic sum of above 9	$1 - 20\,\%$	$7 - 18\,\%$	$2 - 25\,\%$	$5 - 21\,\%$
Normalisation $(L_{\text{int}})^{-1}$:				
– Bunch currents		$12\,\%$		$12\,\%$
– Beam widths		$5\,\%$		$5\,\%$
– Beam positions		$3\,\%$		$3\,\%$
– Beam angles		$1\,\%$		$1\,\%$
Quadratic sum of above 4		$14\,\%$		$14\,\%$
Quadratic sum of all above	$6 - 28\,\%$	$16 - 23\,\%$	$9 - 39\,\%$	$15 - 25\,\%$