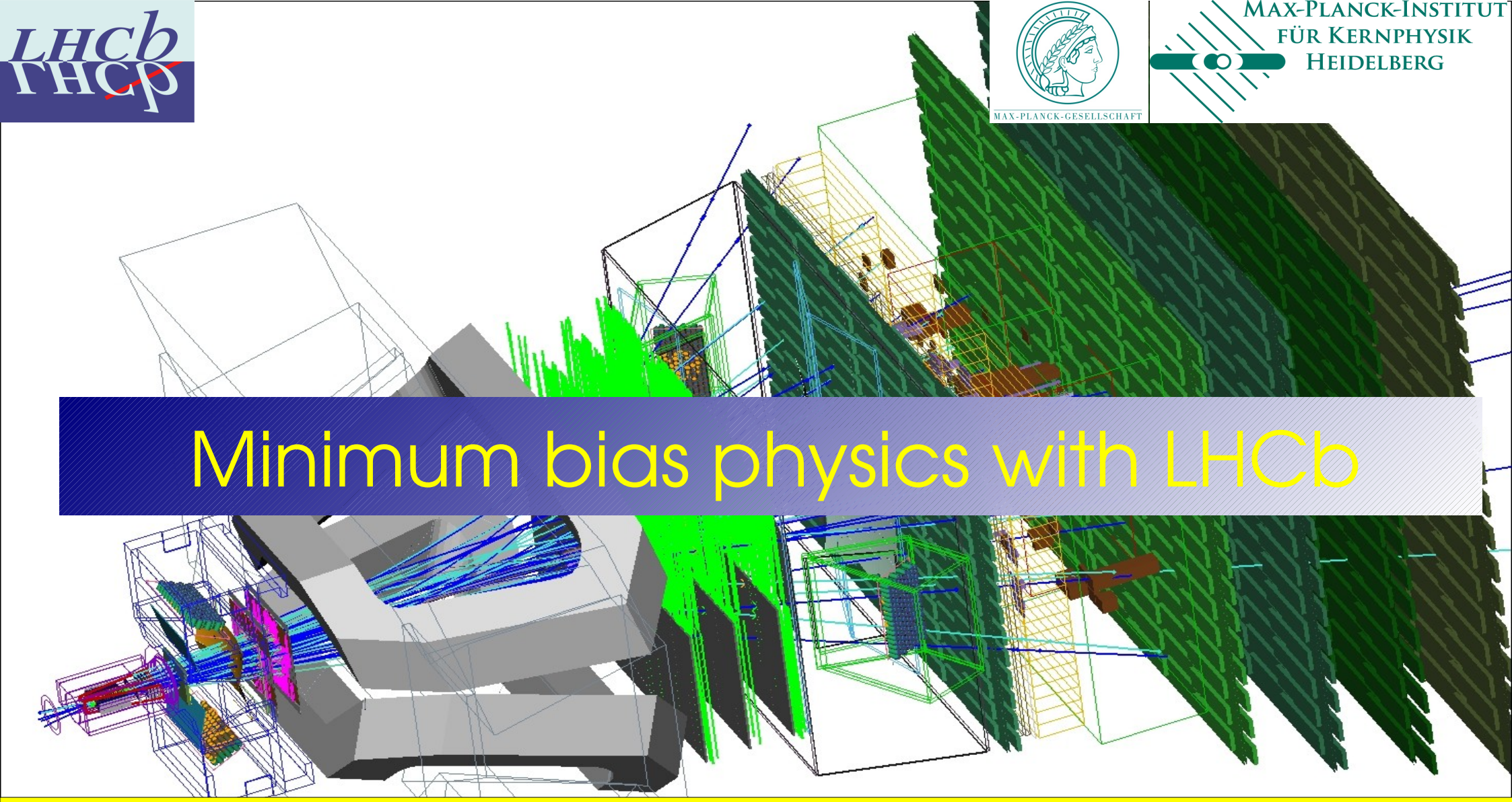


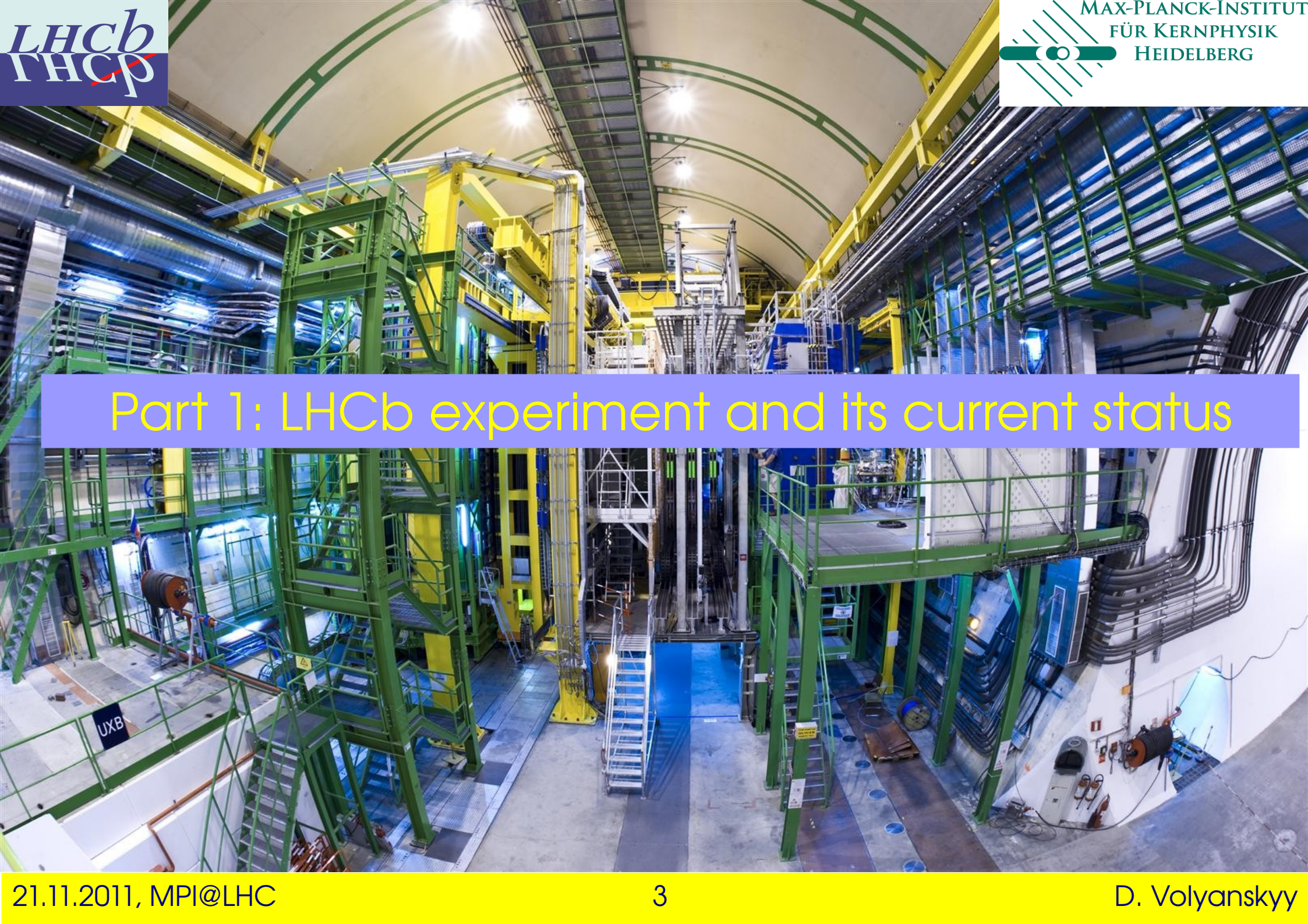
Minimum bias physics with LHCb

Dmytro Volyanskyy
Max-Planck-Institut für Kernphysik (Heidelberg, Germany)
on behalf of the LHCb collaboration

3rd International Workshop on Multiple Partonic Interactions at the LHC
November 21st –25th, 2011, Hamburg, Germany

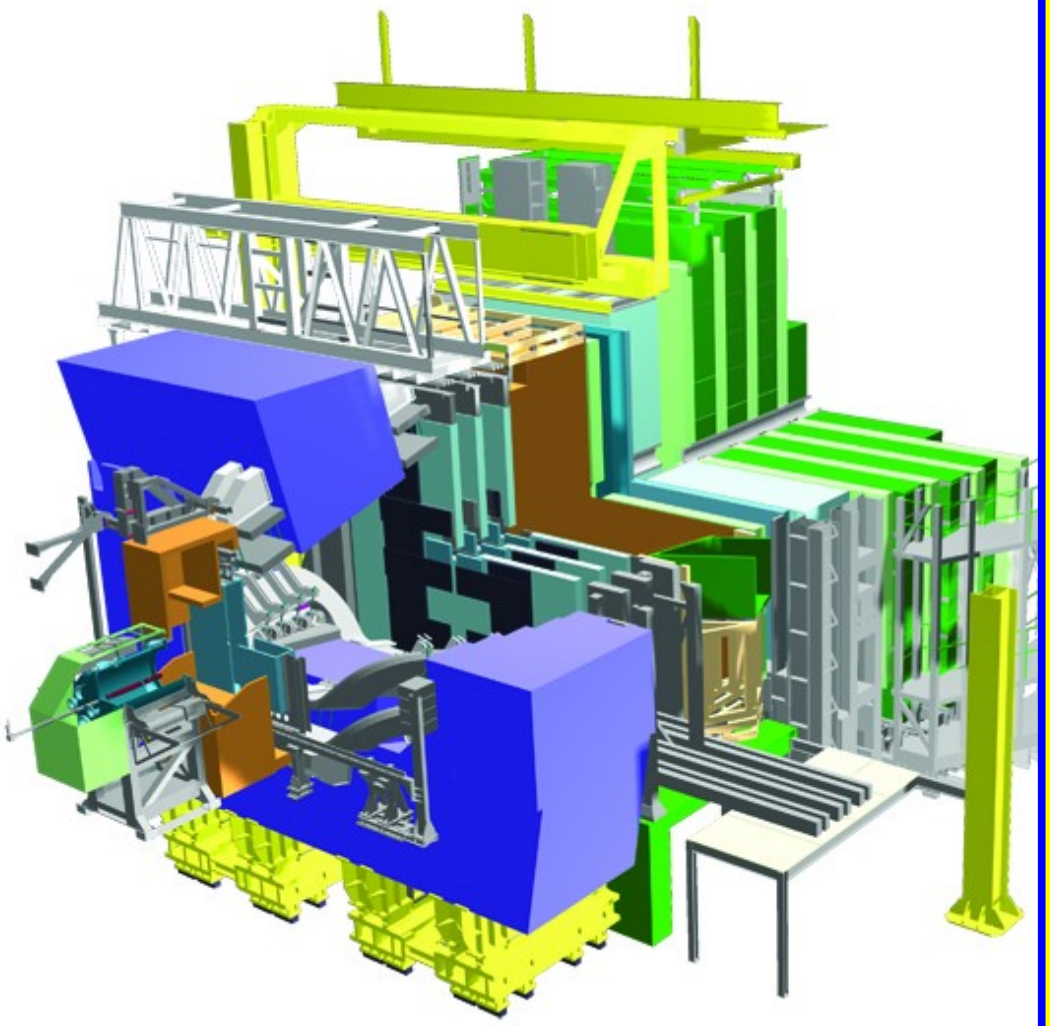
Outline

=> LHCb experiment and its current status
=> Overview of minimum bias physics results
=> Prospects for diffractive physics at LHCb
=> Outlook



Part 1: LHCb experiment and its current status

LHCb overview (1)

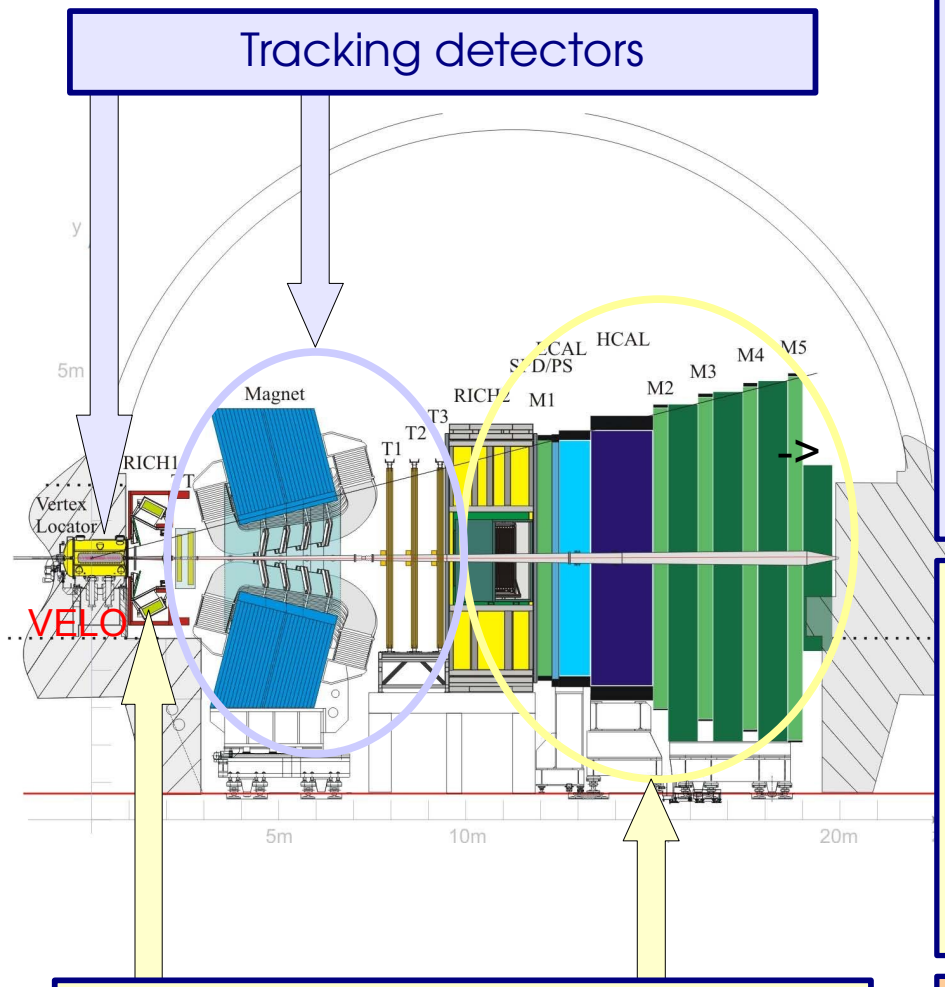


LHCb key facts:

- One of the 4 main experiments at the LHC
- Major Purpose: investigation of the Matter-Antimatter asymmetry via studies of CP violation in the B meson sector, studies of rare B decays and search for New Physics
- Forward spectrometer with planar detectors: B hadrons at the LHC are predominately produced at low polar angles in the same forward cone
- Angular coverage: 10-300 (250) mrad in the horizontal (vertical) plane
- Pseudorapidity coverage: $1.9<\eta<4.9$
- Size: 10m high, 13m wide, 21m long
- Weight: ~5600 tons
- Number of r/o channels: ~10^6
- Designed to run at a moderate luminosity: large pile-up complicates identification of the B decay vertex and flavor tagging

LHCb overview (2)

=> LHCb spectrometer: combination of tracking and PID detectors covering the full detector acceptance



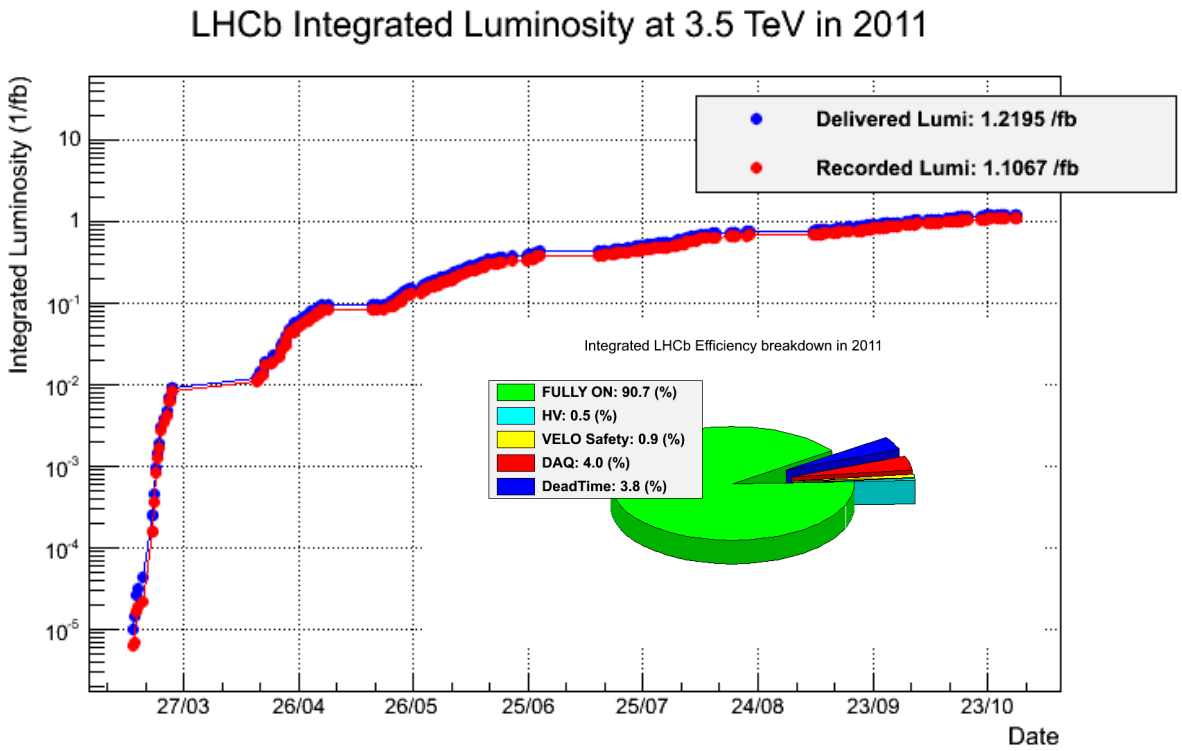
- Excellent tracking performance:
  - -> momentum resolution of tracks $\delta p/p$ ~ 0.3-0.5% depending on p
  - -> invariant mass resolution of ~10-20 MeV/c^2 depending on the B decay channel
  - -> precise vertex reconstruction: proper time resolution for B hadrons <50 fs
  - -> tracking detector hardware: SiStrip, StrawTubes

CERN-LHCb-PROC-2010-008

- High quality particle identification:
  - -> RICH system: efficient π/K, K/p separation
  - -> SPD: e/γ separation PS: e/hadrons separation
  - -> ECAL: e and γ energy measurements
  - -> HCAL: π, K, p energy measurements
  - -> MUON: μ identification

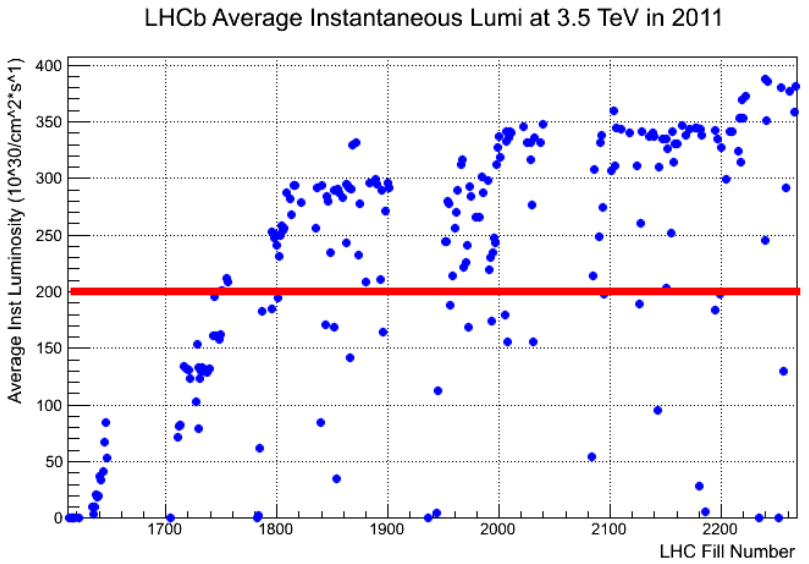
- Selective and flexible trigger system

LHCb overview (3)



year	luminosity	energy (TeV)
2009	6.8 μb^{-1}	0.9
2010	0.3 nb^{-1}	0.9
2010	37 pb^{-1}	7
2011	0.1 pb^{-1}	2.76
2011	1.1 fb^{-1}	7

- Good quality of recorded data:
  - -> >95% of r/o channels are operational
- Data taking efficiency: 91%



=> Running challenges:

- Luminosities up to 3.9× 10^{32} cm^{-2} s^{-1} were achieved in 2011
- LHCb design luminosity: 2.0 × 10^{32} cm^{-2} s^{-1}
- Strong challenge for the trigger, offline reconstruction and data processing
- LHCb successfully copes with these extreme running conditions !

LHCb Potential

- LHCb, due to its rapidity coverage, explores particle production in an unique kinematic range:

  -> probes of PDFs at very low and at high values of x and low-Q^2

  -> measurements of the low-mass (up to 2.5 GeV) Drell-Yan cross-section are possible with LHCb – probe x values down to 1.5×10^{-6}

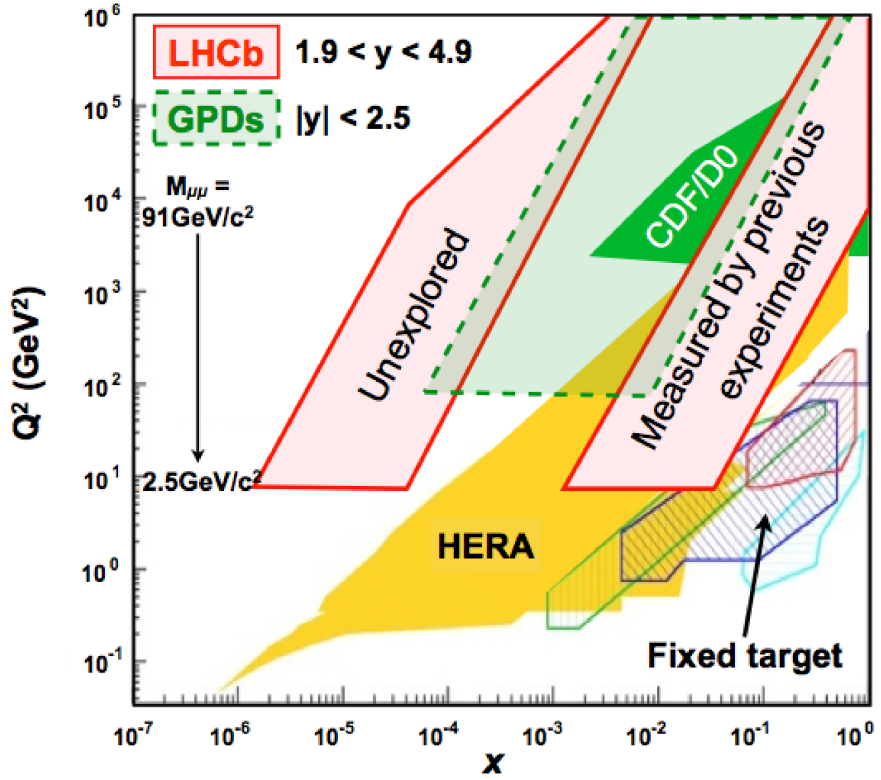
- Ability to investigate low-p_T region (<0.5 GeV/c) at large η(>4)

  -> the only one LHC experiment that can investigate this region of the phase space

  -> great potential to study soft QCD physics

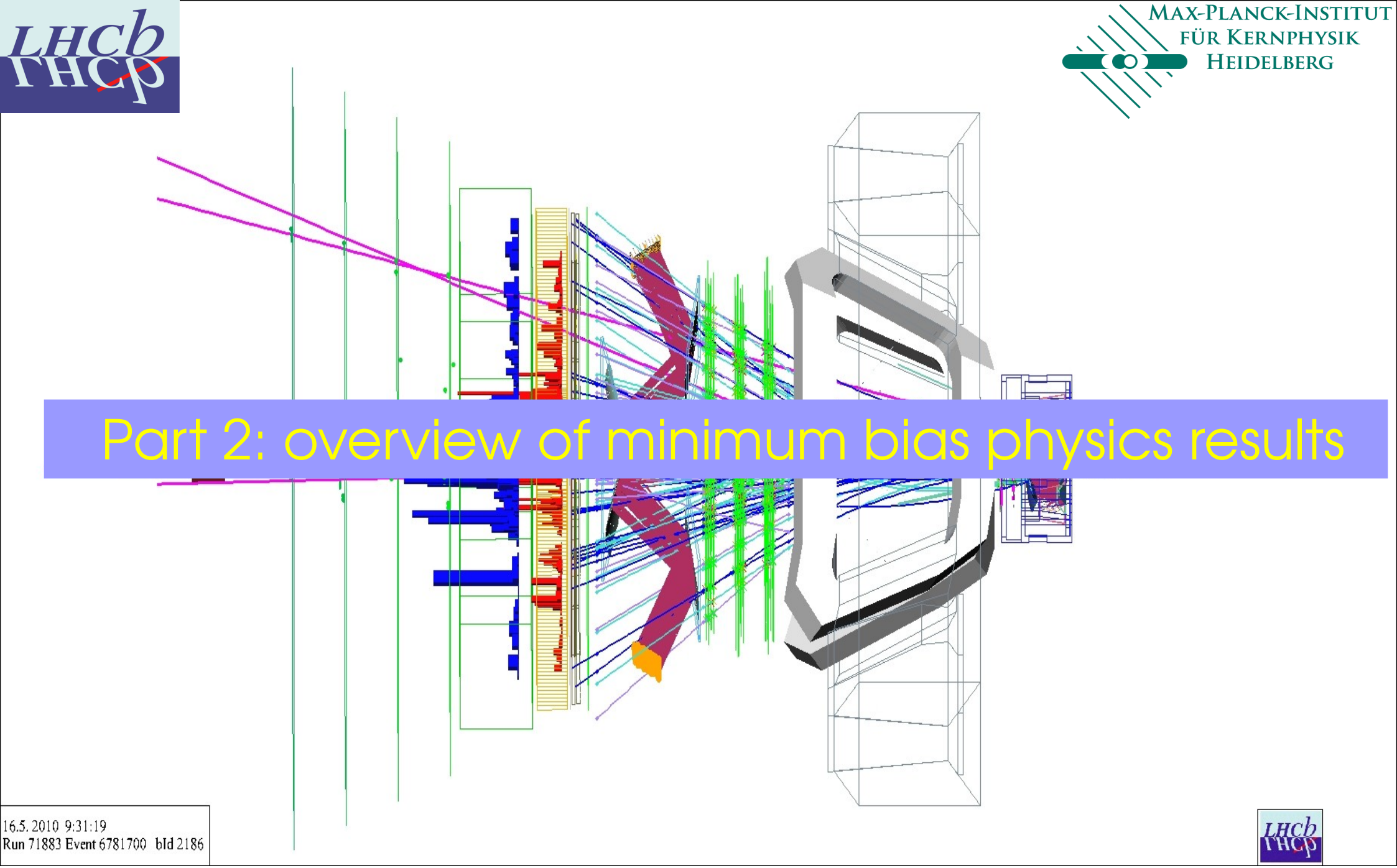
- Minimum Bias (MB) data dominated by soft QCD processes

arXiv:0808.1847v1 [hep-ph]
LHCb-CONF-2009-014



- LHCb 2010/2011 MB Trigger:

  -> at least 1 track-segment in VELO or in the main tracker



Part 2: overview of minimum bias physics results

MB approved results

=> Strangeness production:

- Ks cross-section at 0.9 TeV and ϕ cross-section at 7.0 TeV
  - -> sensitive tests of soft hadronic interactions (strange quark mass is of the order of Λ_{QCD})
  - -> large uncertainties for QCD predictions in this region
  - -> explore uncovered regions – current models have been tuned to describe SPS and Tevatron data (central rapidity and $p_T > 0.5$GeV)

=> Baryon Number Transport and Baryon Suppression:

- V^0 ratios ($\overline{\Lambda}/\Lambda$ and $\overline{\Lambda}$/Ks) $\overline{p}/p$ production ratios at 0.9 TeV and 7.0 TeV
  - -> antibaryon-baryon production ratio: direct measurement of the baryon transport from the beam particles to the fragmented final states
  - -> baryon-meson ratio: good test of fragmentation models probing baryon/meson production suppression
  - -> N.B. production ratios cancel many systematic uncertainties

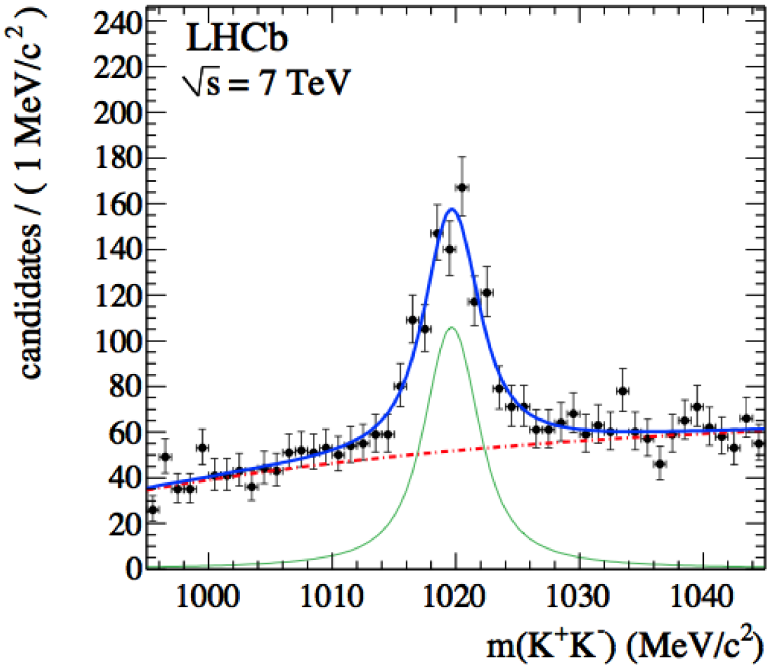
=> Charged particle multiplicities at 7 TeV:

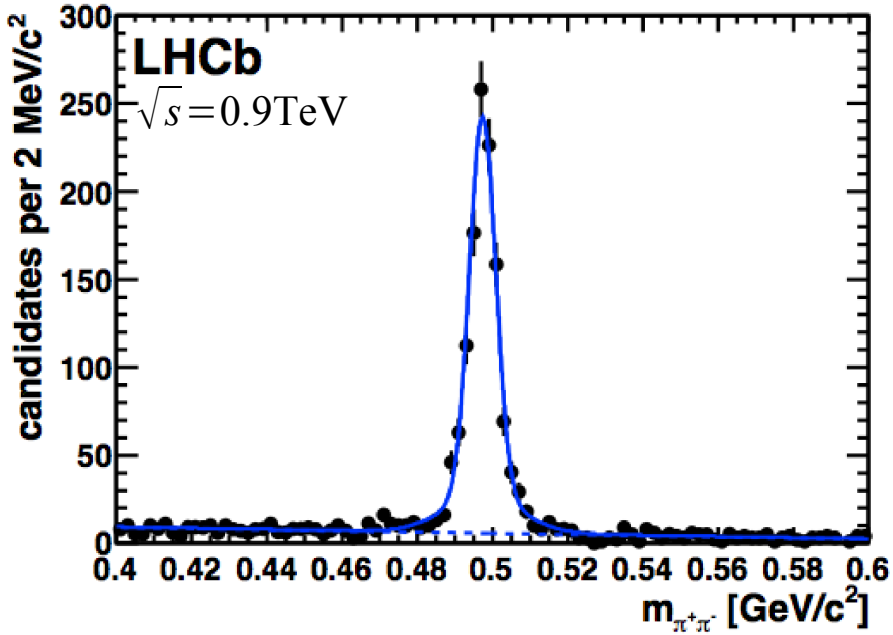
- -> valuable input for MC tuning and modeling of the underlying event

Strangeness Production

- Ks production cross-section:
  - -> differential xsections: $0<p_T<1.6$ GeV/c, $2.5<y<4.0$
  - -> 2009 MB data: 6.8 μb^{-1}@0.9 TeV (calo-based MB trigger)
  - -> prompt Ks reconstructed via $Ks \rightarrow \pi^+\pi^-$ mode

Physics Letters B 693 (2010) 69-80
arXiv:1008.3105v2 [hep-ex]



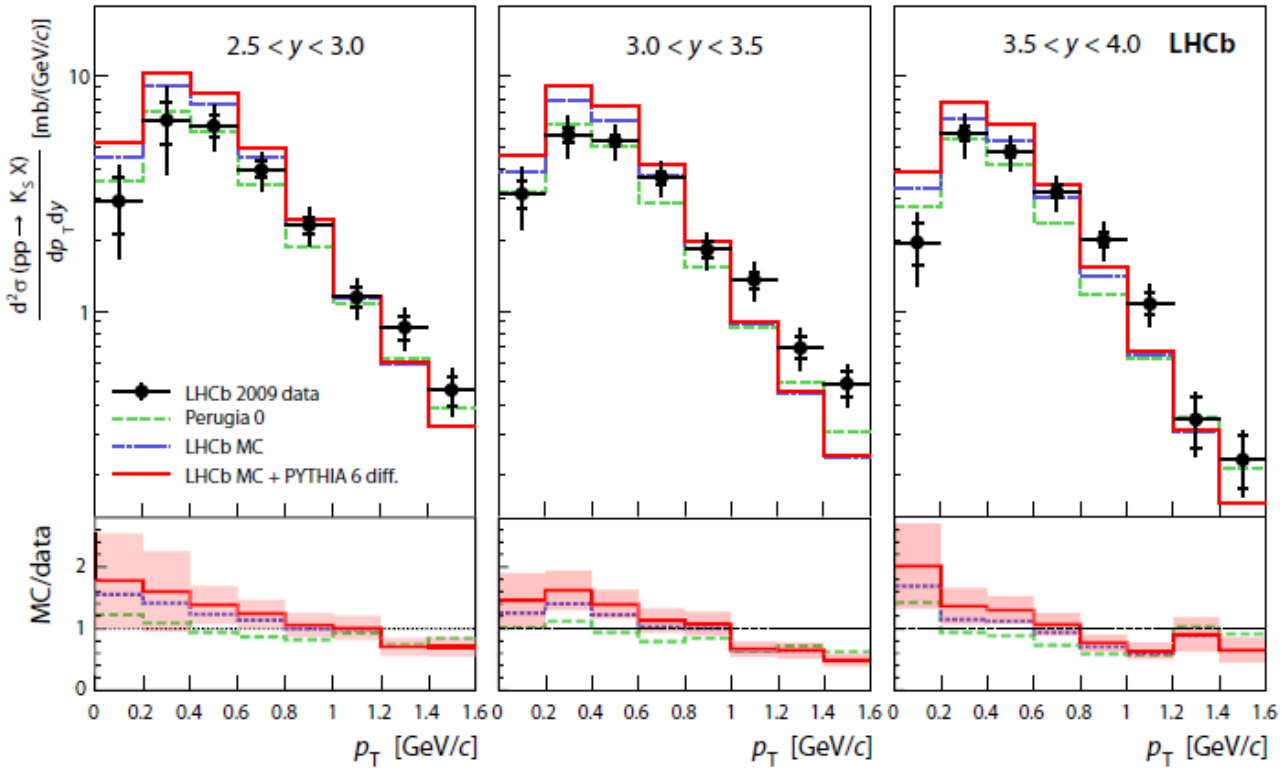


- ϕ production cross-section:
  - -> differential xsections: $0.6<p_T<5.0$ GeV/c, $2.44<y<4.06$
  - -> 2010 MB data: 14.7 nb^{-1}@7.0 TeV (track-based MB trigger)
  - -> both prompt and non-prompt ϕ reconstructed via $\phi \rightarrow K^+K^-$ mode

Physics Letters B 703 (2011) 267-273
arXiv:1107.3935v1 [hep-ex]

Ks cross-section (1)

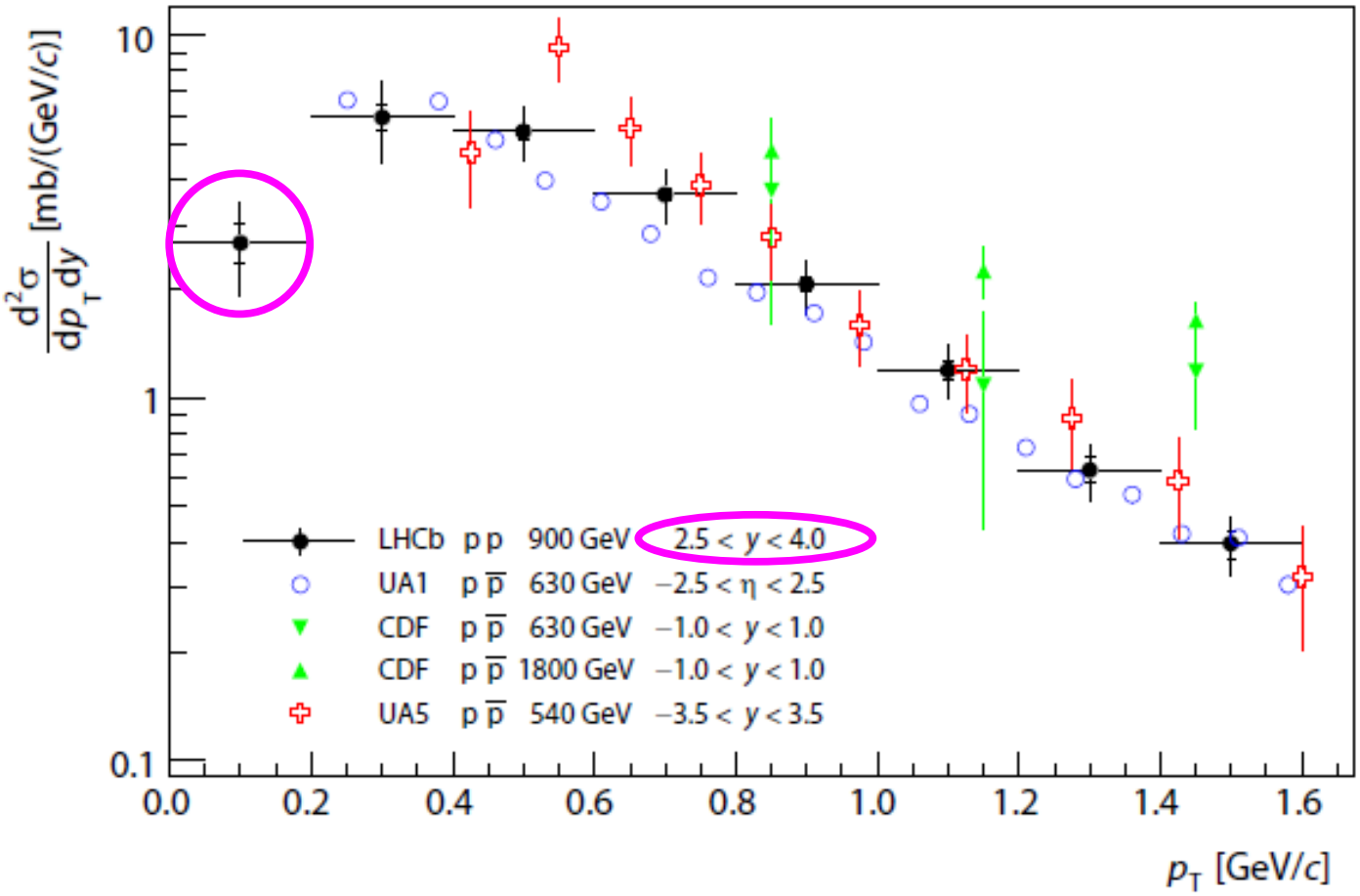
- for every (p_T,y) bin the Ks production cross-section is estimated as: $\sigma_i = \frac{N_i^{\rm obs}}{\epsilon_i^{\rm trig/sel}\ \epsilon_i^{\rm sel}\ L_{\rm int}}$
- $N_{\rm obs}$ obtained from the mass distributions, efficiencies estimated using MC
- $L_{\rm int}$ estimation: novel technique based on the beam currents, sizes and positions



- p_T spectrum is harder in data than in MC
- best description given by Perugia0 tune
- largest systematics from luminosity estimation (beam currents uncertainty)

Ks cross-section (2)

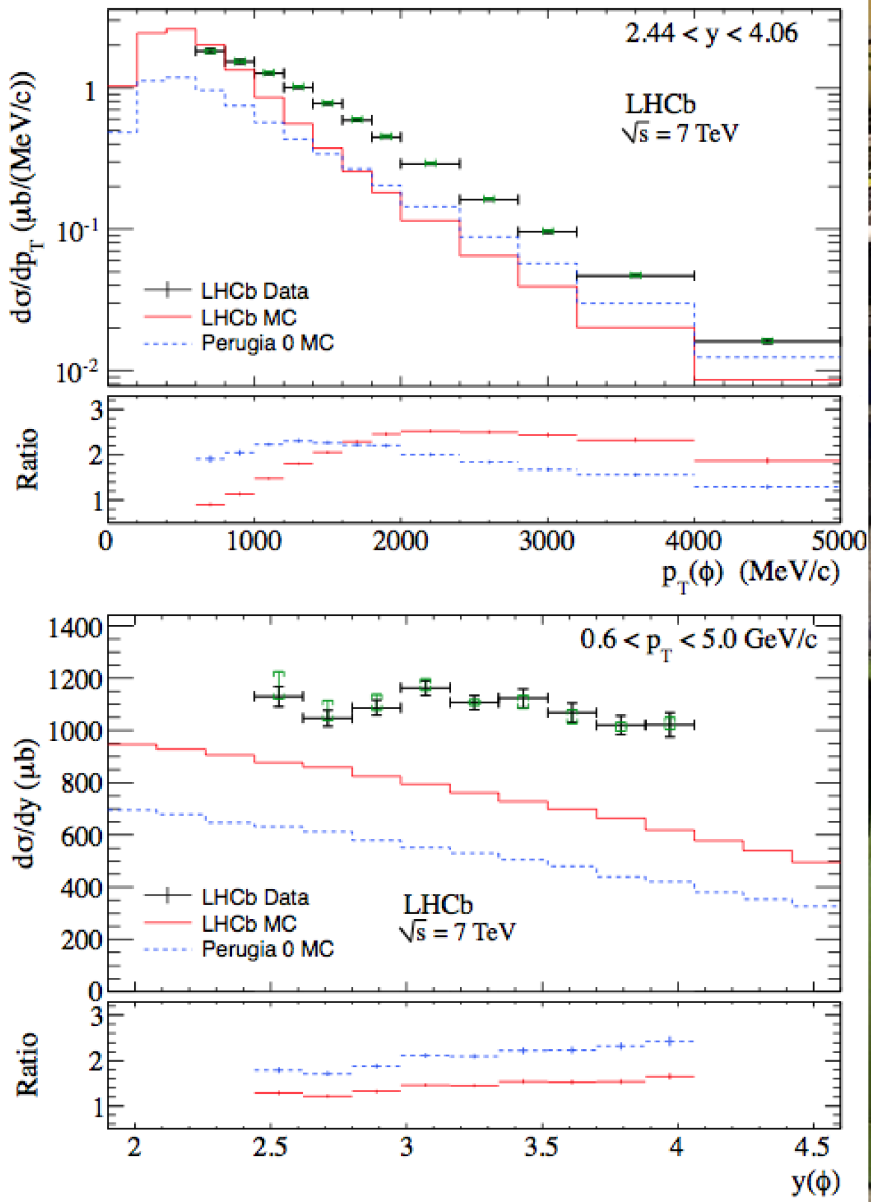
- Comparison with other experiments having different collision energies and rapidity coverage:



- LHCb does extend the measurements towards low-p_T and large y
- good consistency with other experiments !

ϕ cross-section

- Differential cross-sections:
- Discrepancy between data and MC models used in this study is observed
  - -> cross-section is underestimated by MC
  - -> more strange mesons produced in the forward direction than expected by the current models
- Largest systematics from the tracking efficiency and luminosity estimation
  - -> total systematic uncertainty ~10%

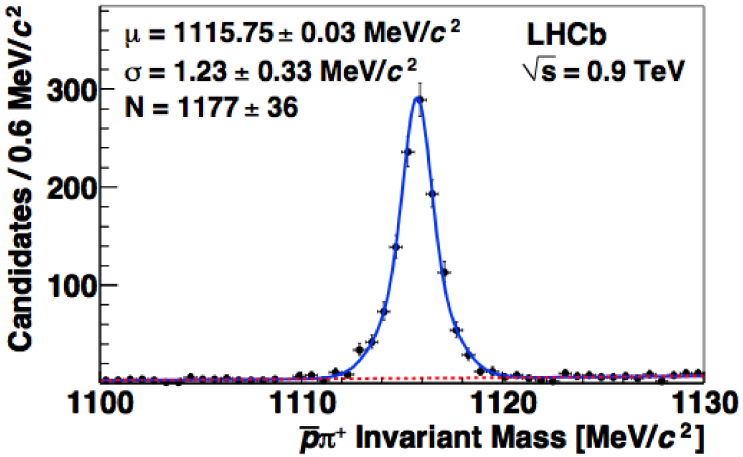


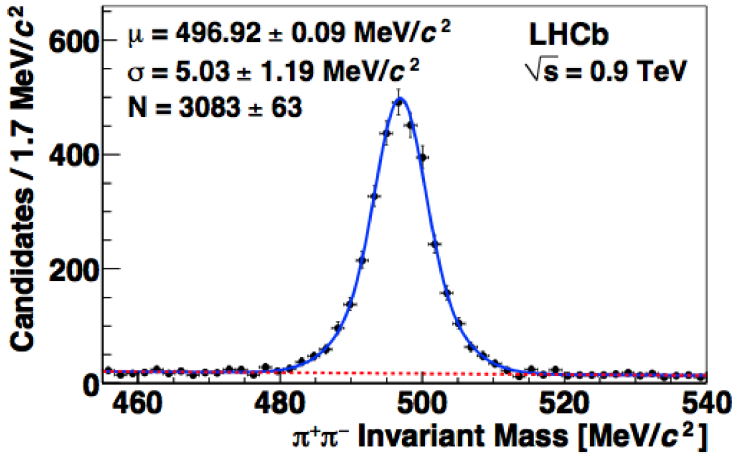
V^0 production ratios

- Focus on $\overline{\Lambda}/\Lambda$ and $\overline{\Lambda}$/Ks production ratios at 0.9 TeV and 7.0 TeV to probe baryon number transport and baryon/meson production suppression

$$\frac{\overline{\Lambda}}{\Lambda} = \frac{\sigma(pp \to \overline{\Lambda} X)}{\sigma(pp \to \Lambda X)} \qquad \frac{\overline{\Lambda}}{K_s^0} = \frac{\sigma(pp \to \overline{\Lambda} X)}{\sigma(pp \to K_s^0 X)}$$

- Reconstruction via $\Lambda \to \pi p$ and $Ks \to \pi\pi$ modes
  - -> cuts on track χ^2, reconstructed PV, invariant mass + microbias trigger



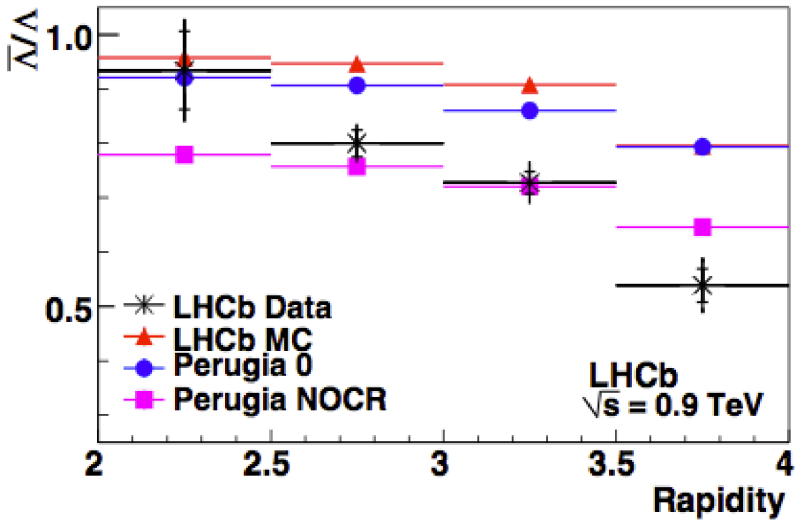


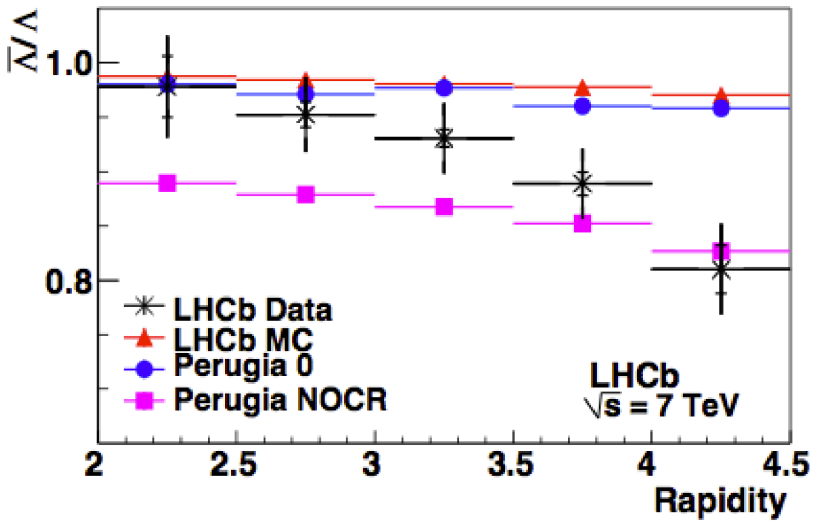
- Prompt Λ and Ks selected using a Fisher discriminant based on the mother and daughters impact parameter

J. High Energy Phys 08 (2011) 034
arXiv:1107.0882v2 [hep-ex]

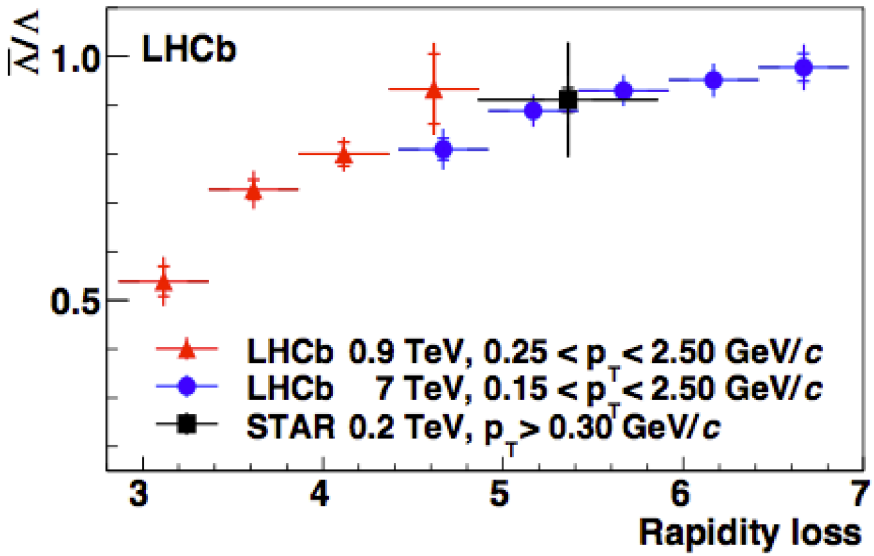
- Significantly reduced systematic uncertainty (many errors cancel out)

$\bar{\Lambda}/\Lambda$ production ratio vs rapidity

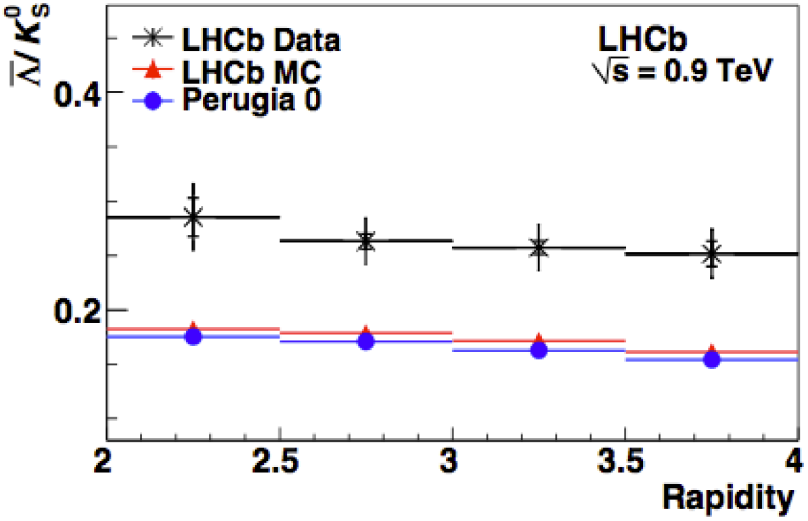


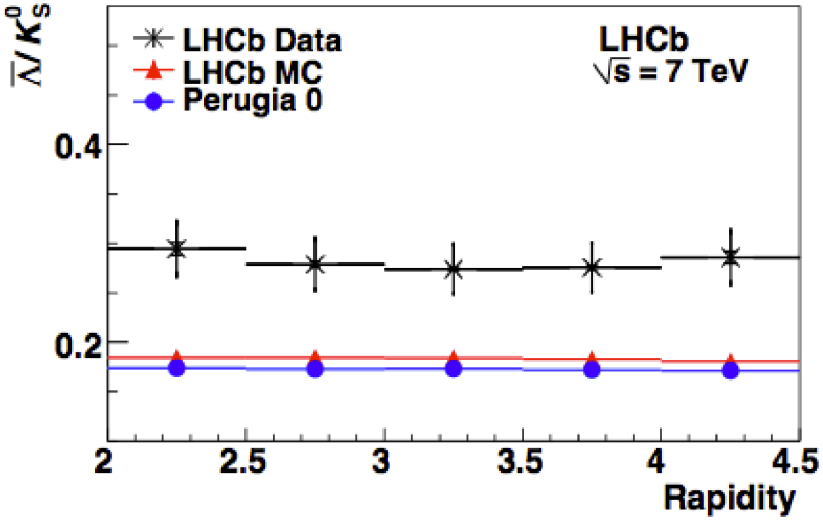


- Large discrepancy between data and MC
- Baryon number transport is higher than expected by MC models (except Perugia NOCR)
- Production ratio vs $\Delta y = y_{beam} - y$ consistency with STAR measurement

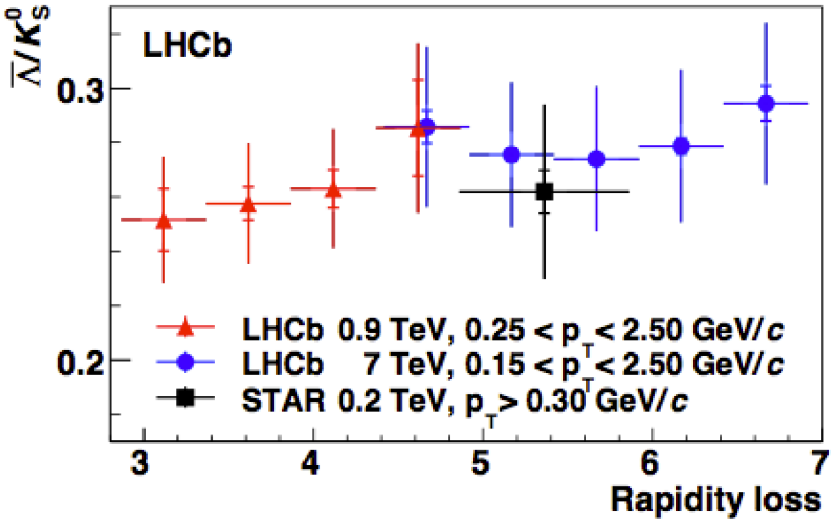


$\bar{\Lambda}/K_S$ production ratio vs rapidity



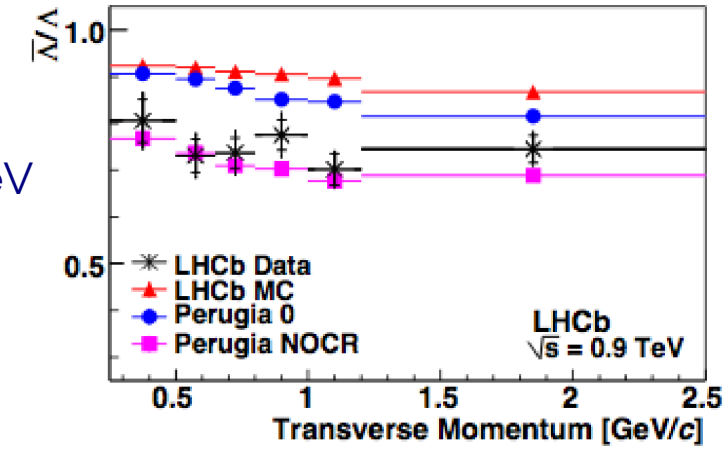


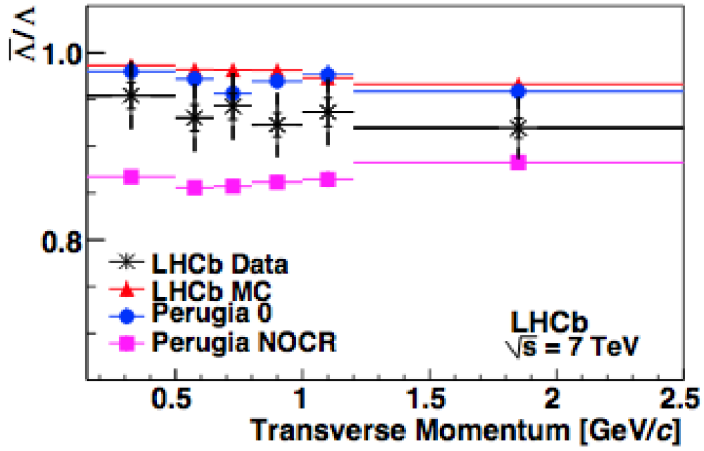
- Good agreement between 0.9 & 7.0 TeV
- Large discrepancy between data and MC at both collision energies
- Baryon/Meson suppression is much lower than expected by MC models
- Production ratio vs $\Delta y = y_{beam} - y$ consistency with STAR measurement

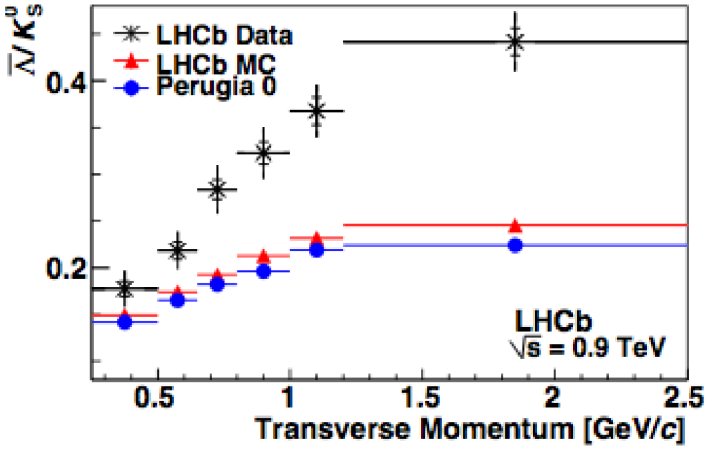


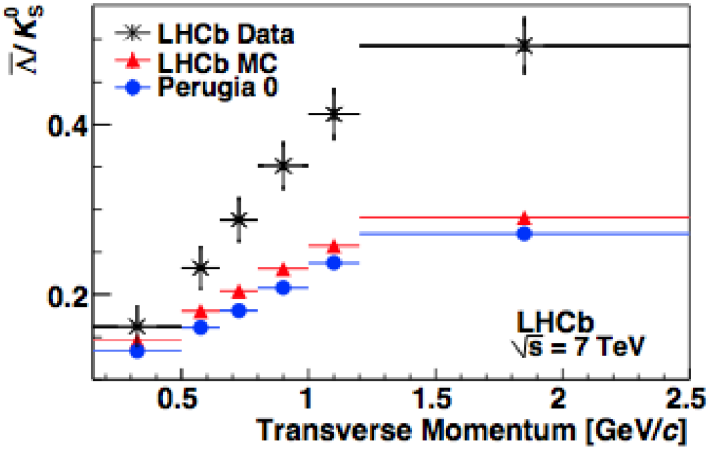
$\bar{\Lambda}/\Lambda$ and $\bar{\Lambda}/K_S$ ratios vs p_T

- $\bar{\Lambda}/\Lambda$:
  - -> PerugiaNOCR gives best description of data @0.9 TeV Perugia0 @7TeV
- $\bar{\Lambda}/K_S$:
  - -> Large discrepancy between data and MC at high p_T



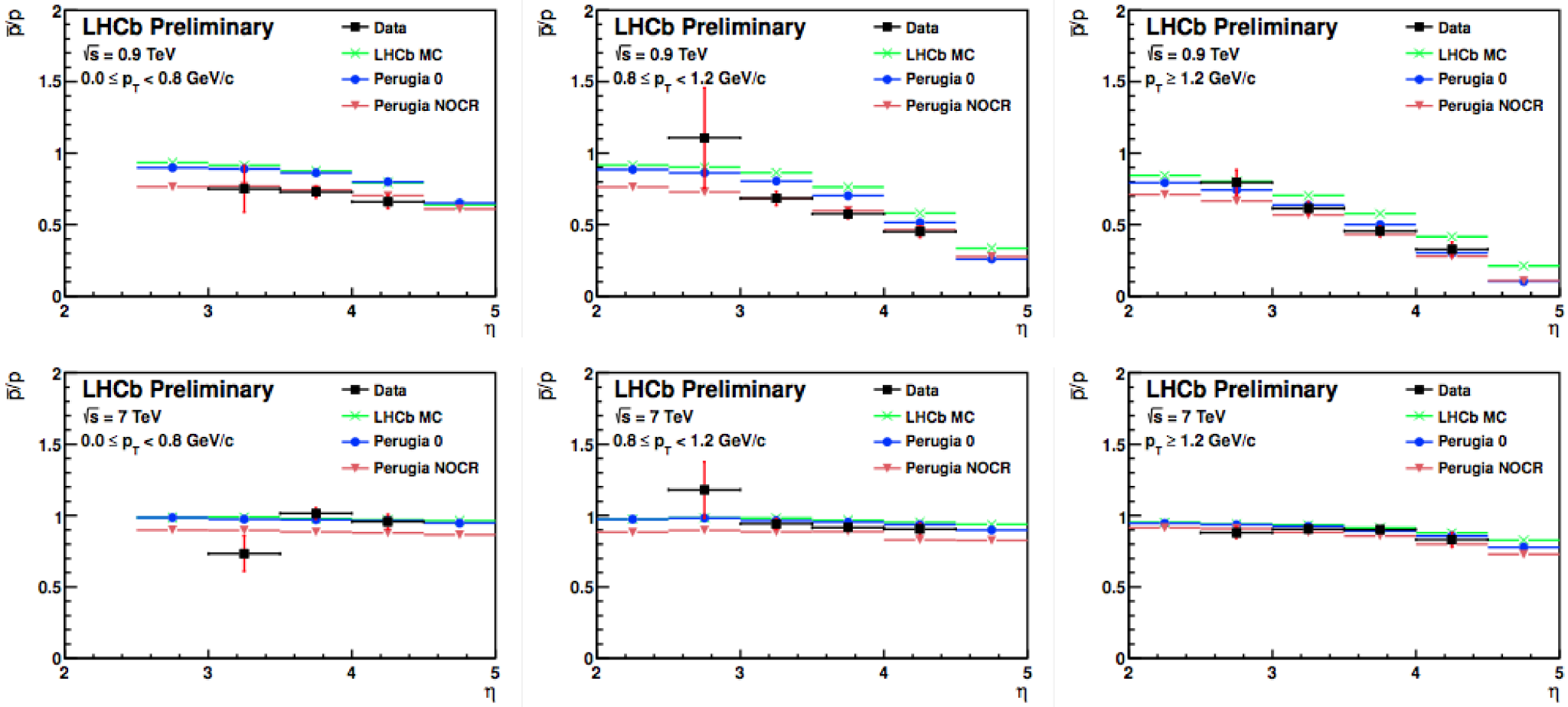






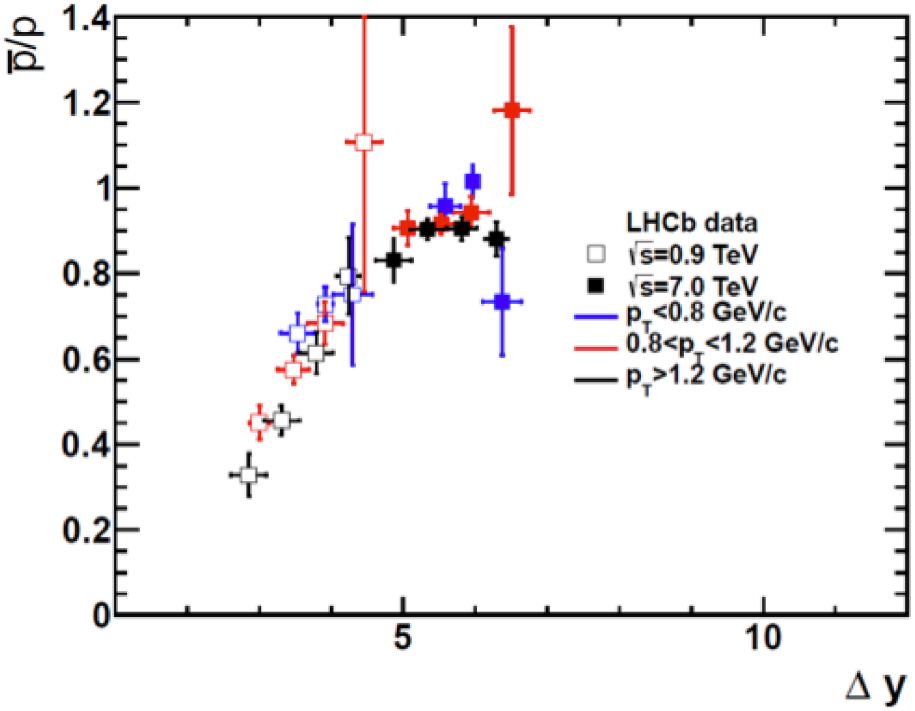
$\bar{p}/p$ production ratio (1)

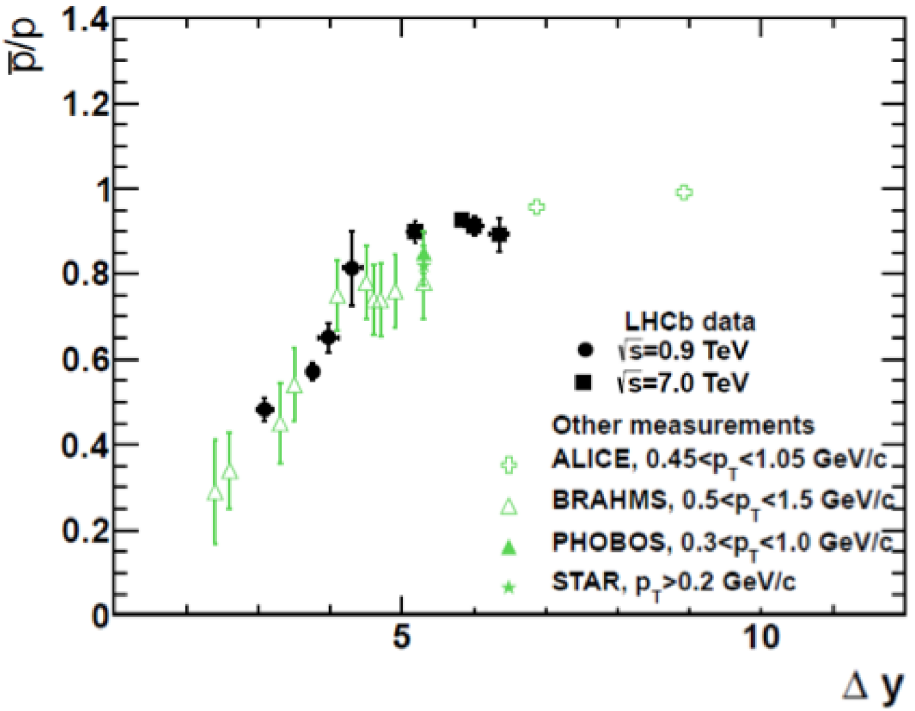
- $\bar{p}/p$ production ratios at 0.9 TeV and 7.0 TeV to probe baryon number transport
  - -> rapidity and p_T dependence is investigated
- Selection of prompt protons:
  - -> tight PID requirements, cuts on track χ^2, P, reconstructed PV + microbias trigger



$\bar{p}/p$ production ratio (2)

- production ratio vs rapidity loss :





- -> no evidence of a strong p_T dependence
- -> consistency with results of other experiments
- -> much precise measurements performed by LHCb
- -> analysis is extended to probe hadronization mechanism via K^-/K^+, π^-/π^+, $(K^- + K^+)/(\pi^- + \pi^+)$ and other ratios
  - reasonable agreement between data and MC

Charged particle multiplicities (1)

- Analysis Outline:

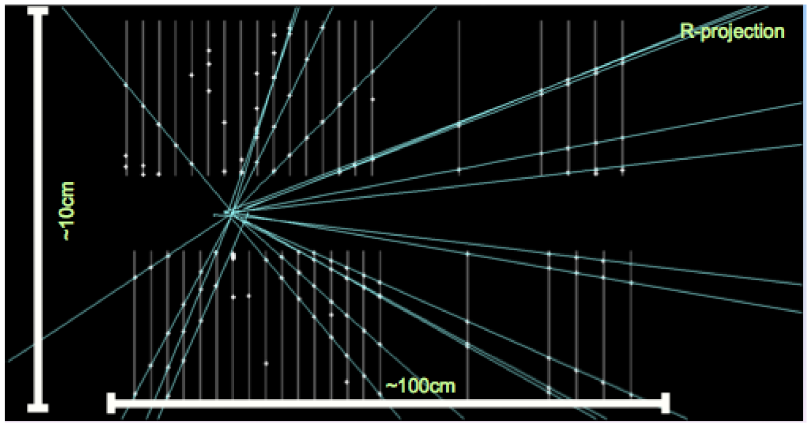
-> done with low pile-up 2010 MB dataset
  – (3.7±0.4)% of the events have more than one interaction – distributions corrected accordingly

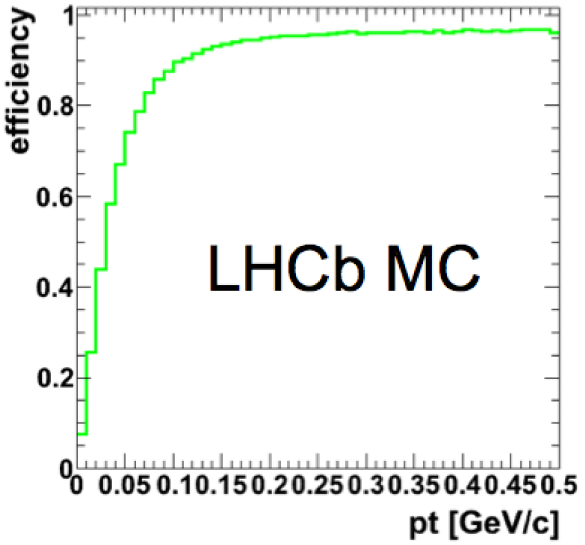
-> particles are counted using the reconstructed tracks in the LHCb VELO

-> no momentum measurements: VELO located outside the main magnetic field

-> no explicit cut on the reconstructed momentum
  – according to MC, trajectories of ~1% of particles are not reconstructed by VELO due to multiple scattering and residual magnetic field. Efficiency drops towards very low momentum.
  – included in the efficiency correction

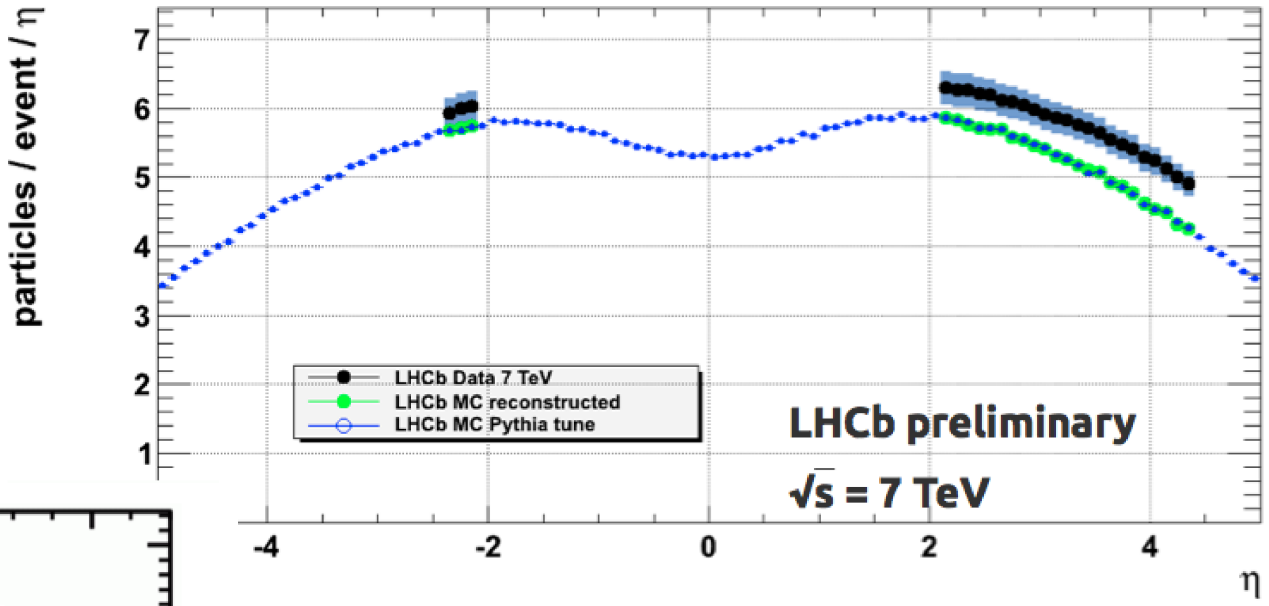
-> reconstructed tracks required to originate from the luminous region:
  – according to MC non-prompt particle contamination is ~5-10% (mainly tracks from converted photons)
  – distributions corrected accordingly

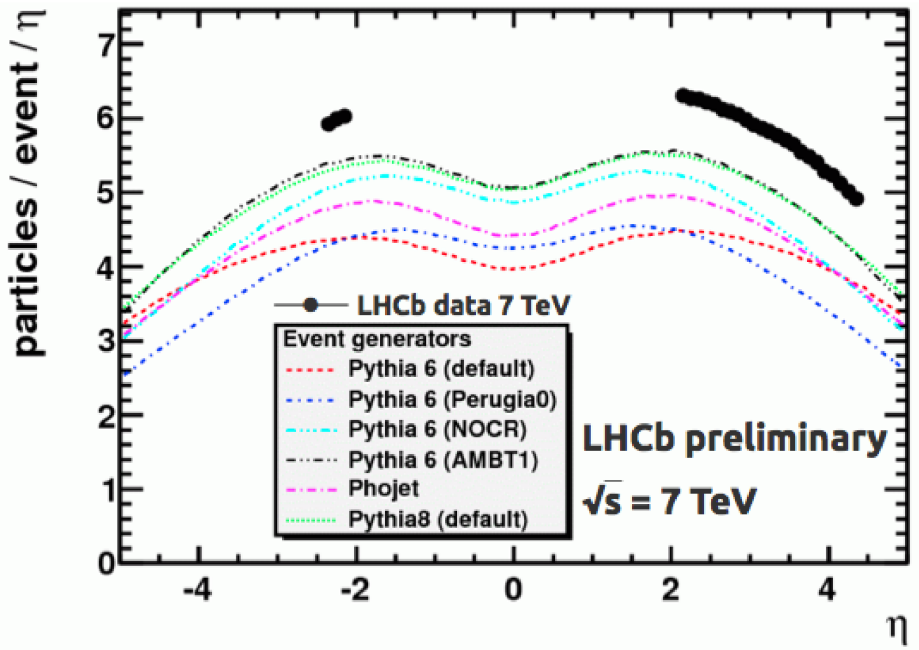




Charged particle multiplicities (2)

- normalized to events with at least 1 charged particle in the forward acceptance
- Multiplicity vs η dependence is similar in data and MC
- LHCb Pythia tune gives best description of data

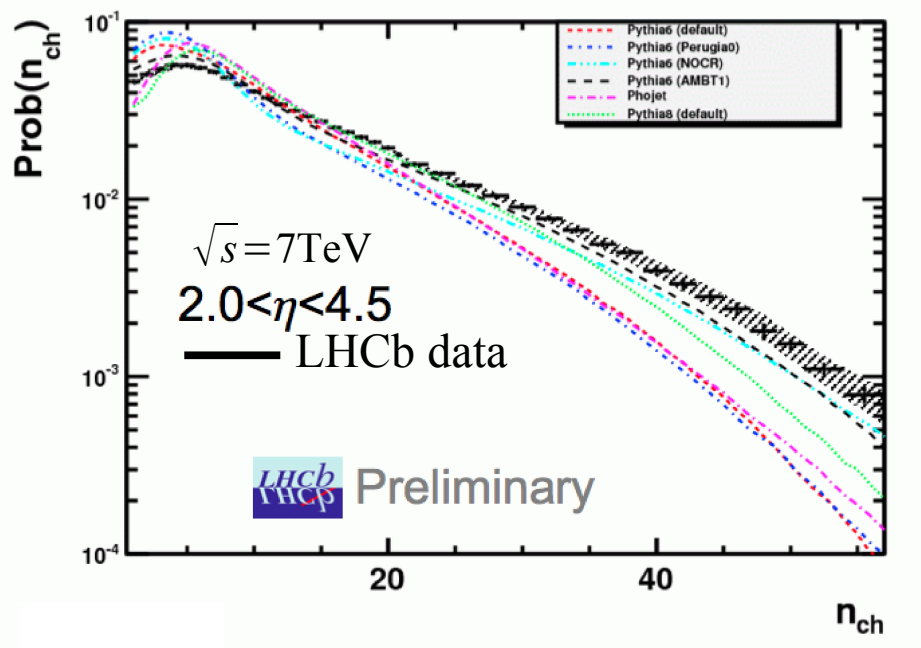




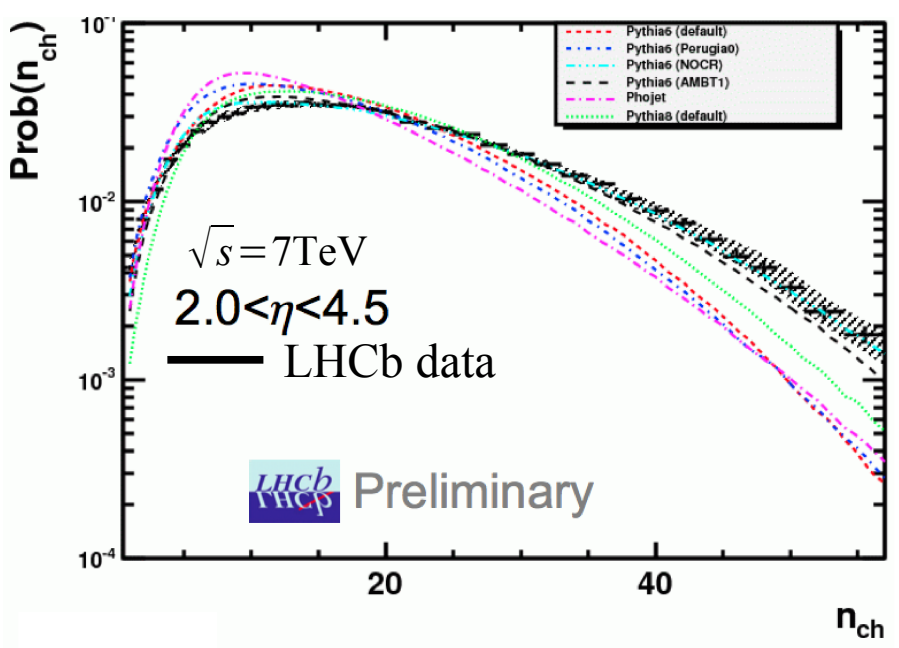
- Large discrepancy between data and MC: valuable input for MC tuning and underlying event models

Charged particle multiplicities (3)

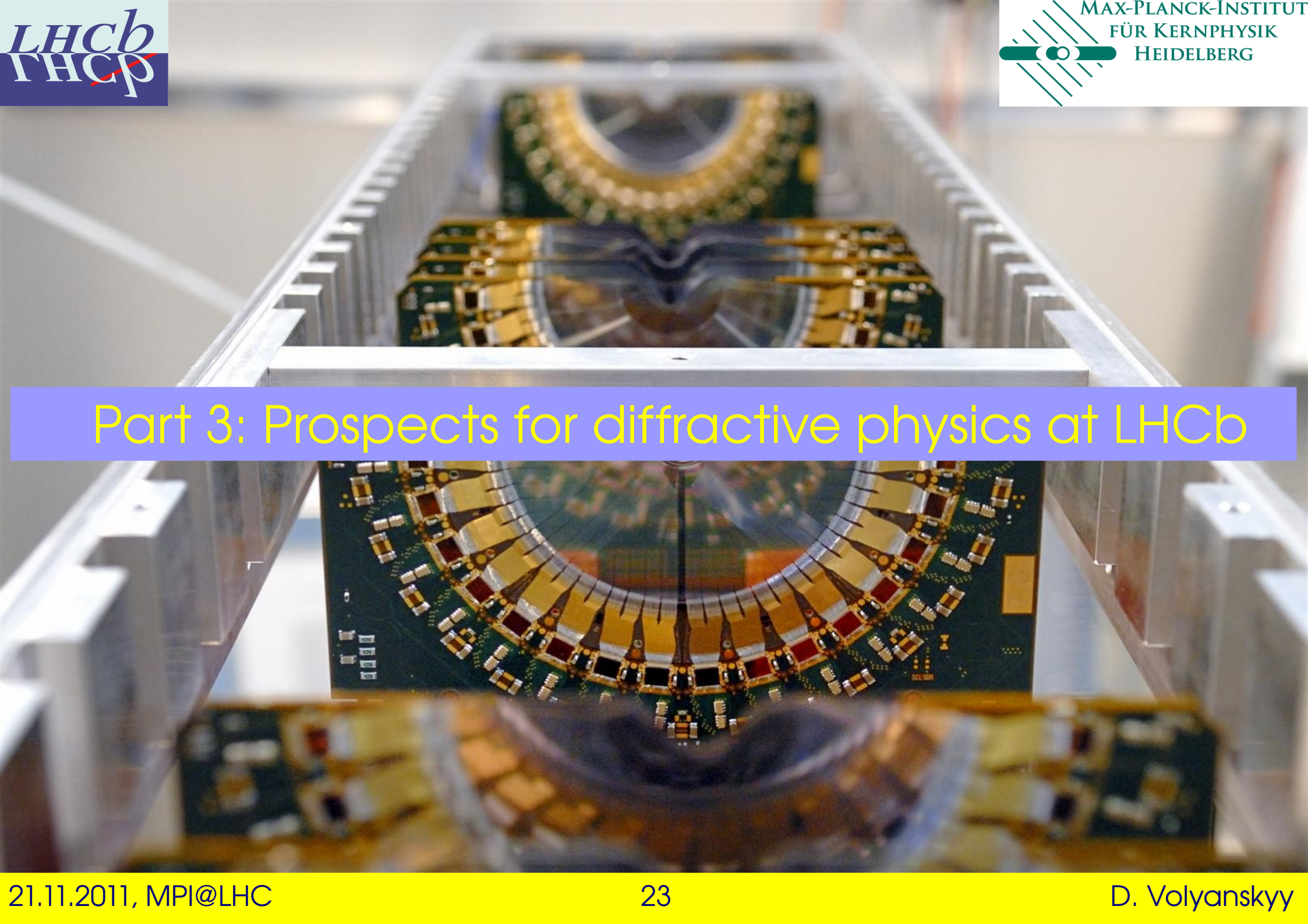
- probability to have n_{ch} in an unbiased event



- probability to have n_{ch} in a hard interaction event (at least one track with p_T > 1 GeV)



- good agreement between Perugia NOCR prediction and real data (black solid line)



Part 3: Prospects for diffractive physics at LHCb

Diffraction with LHCb (1)

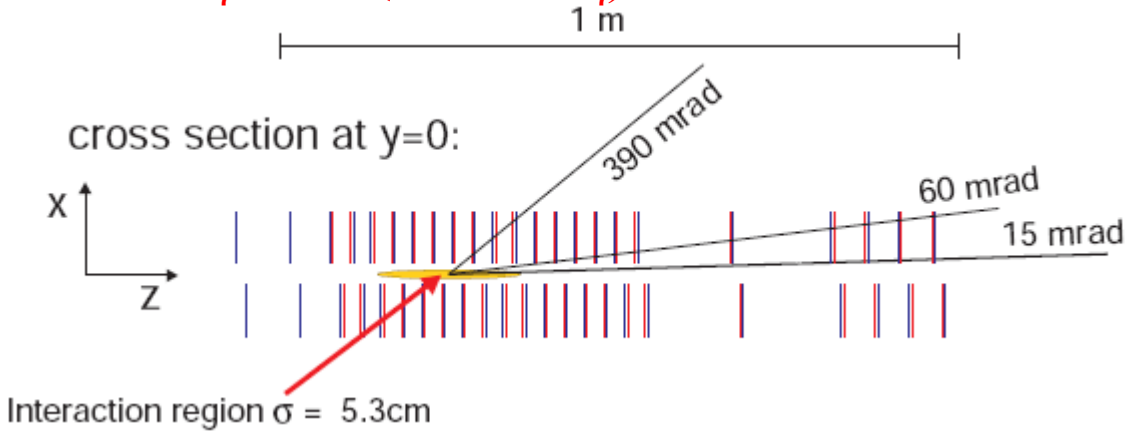
=> LHCb is able to measure diffractive processes using MB data

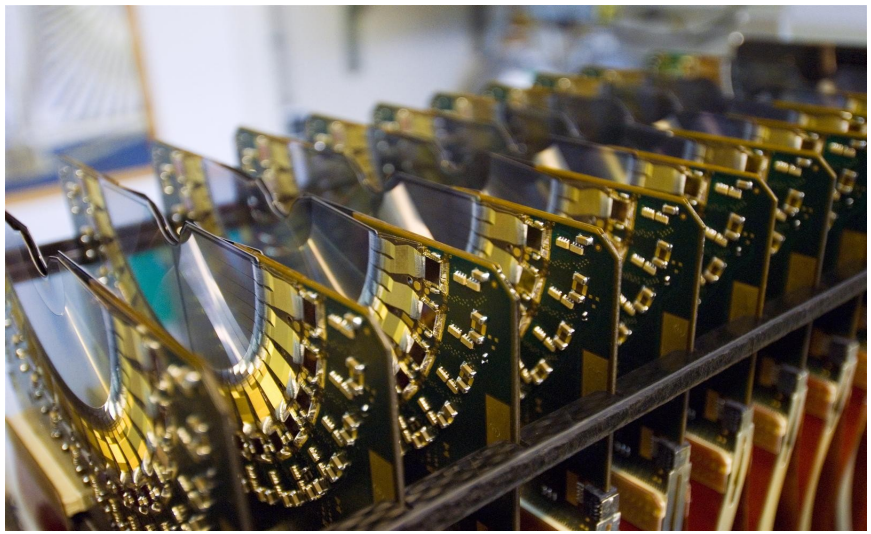
- MB trigger (at least 1 track segment in VELO or main tracker) is very tolerant to diffractive events
- VELO is a crucial component to detect events with Large Rapidity Gaps (LRG)
  - -> LRG: total absence of particles in a particular η interval, unique feature of diffractive events
  - -> 21 SiStrip stations measuring r and phi hit positions + 2 radial-only stations
  - -> excellent performance during data taking: (>99.8% hit finding efficiency)
  - -> surrounds IP being outside magnetic field, just 8 mm away from the beam line
  - -> largest angular coverage among LHCb subcomponents
  - -> detection coverage: 1.5< η <5.0 , -4< η <-1.5

- LRG definitions in LHCb:

– $3.5 < \eta < -1.5$ (2 units of η)

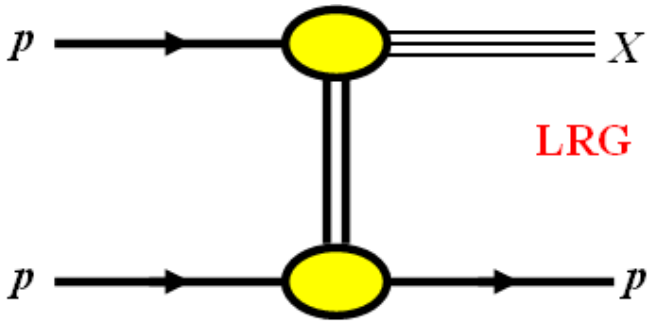
$1.9 < \eta < 4.9$ (3 units of η)



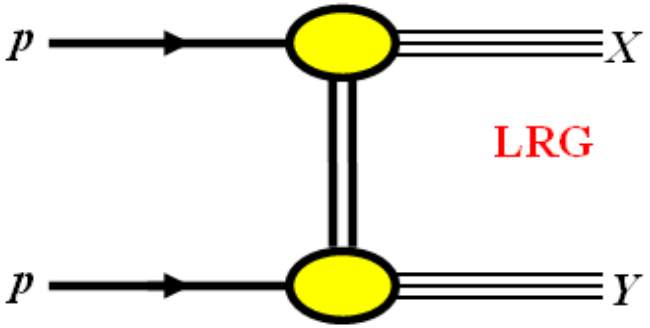


Diffraction with LHCb (2)

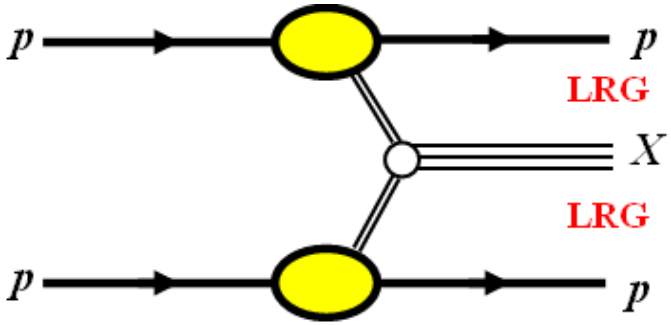
Single-Diffractive Dissociation



Double-Diffractive Dissociation



Double-Pomeron Exchange



- SD events ($pp \to Xp$ or $pp \to pX$) can easily be identified as those having only the forward or backward-going tracks
- DD events ($pp \to XY$) either have the activity on both sides of VELO or the activity on one side only (hard to distinguish from ND and SD)
- DPE events ($pp \to pXp$) can be identified similarly to SD ones. However, X is expected to be produced mainly in the central region

Diffraction with LHCb (3)

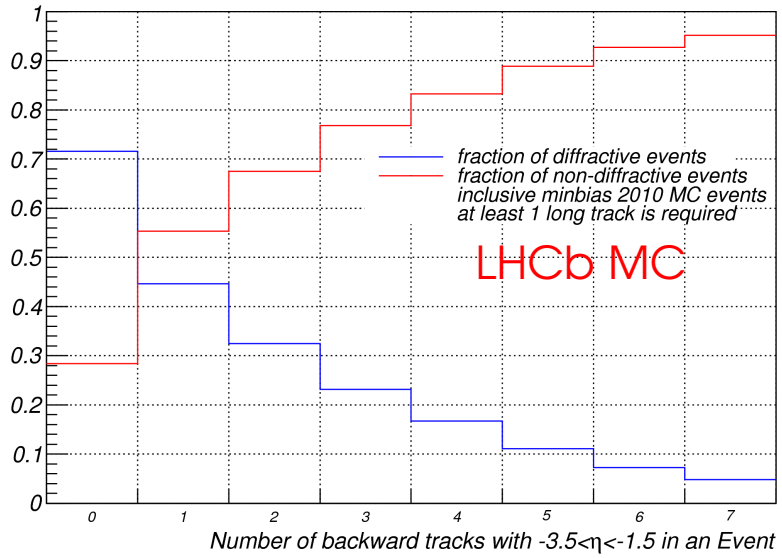
- Possible selection approaches (exploiting LRG):

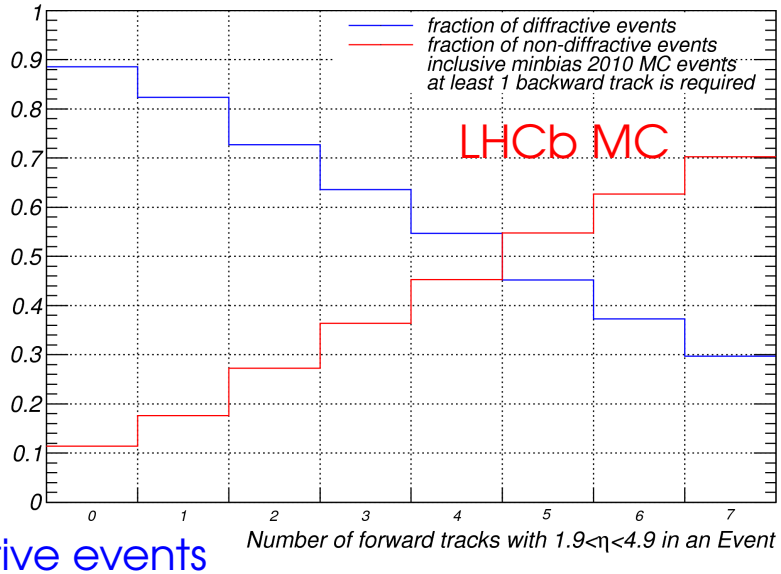
-> Upstream diffractive candidate:
- no tracks reconstructed in $1.9 < \eta < 4.9$
- at least 1 track reconstructed in $-3.5 < \eta < -1.5$

-> Downstream diffractive candidate:
- at least 1 long track reconstructed in $1.9 < \eta < 4.9$
- no tracks reconstructed in $-3.5 < \eta < -1.5$

-> Non-diffractive candidate:
- at least 1 long track reconstructed in $1.9 < \eta < 4.9$
- at least 1 track reconstructed in $-3.5 < \eta < -1.5$

-> background source: beam gas interactions
- long track (traversing all tracking stations/P>2GeV) + originating from the beam line - good evidence of an inelastic pp interaction
- upstream diffractive candidates may be affected





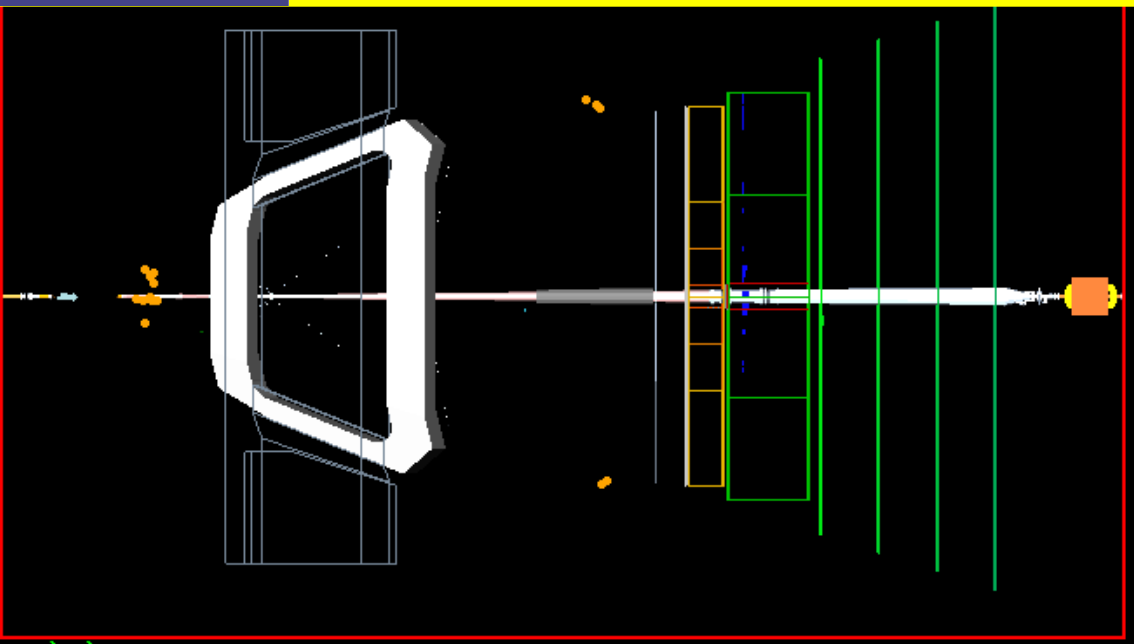
- Study with PYTHIA6 LHCb Tune/MB data:

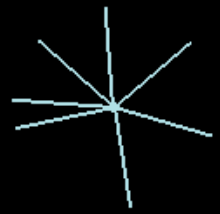
-> retrieving PYTHIA process ID for every selected diffractive and non-diffractive candidate

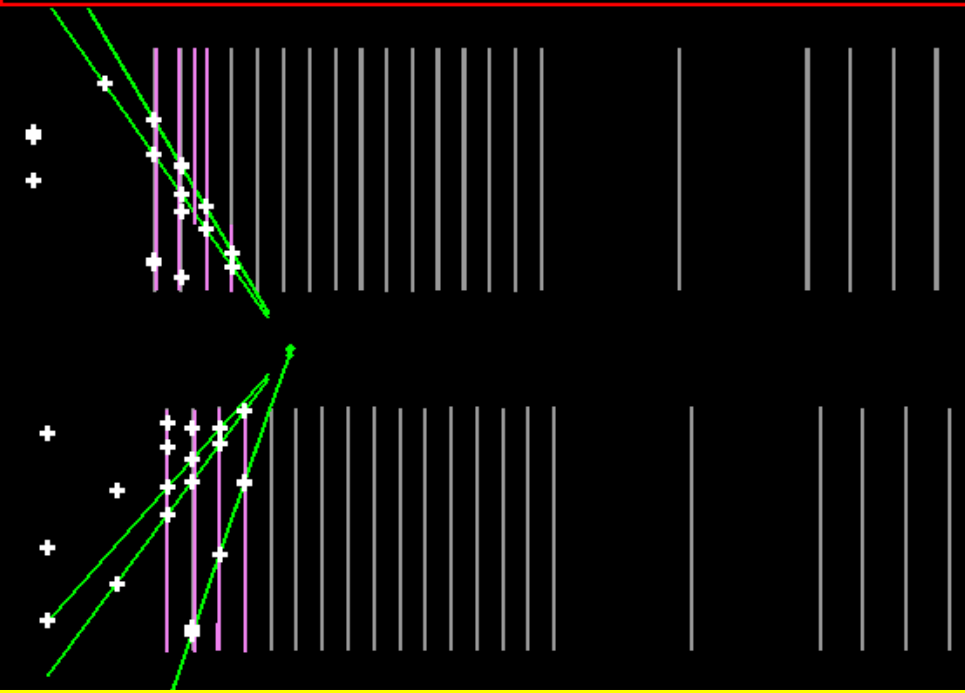
-> ~90% of upstream diffractive and ~70% of downstream diffractive candidates are indeed diffractive events

-> ~90% of non-diffractive candidates are indeed non-diffractive events

Upstream Diffractive Candidate



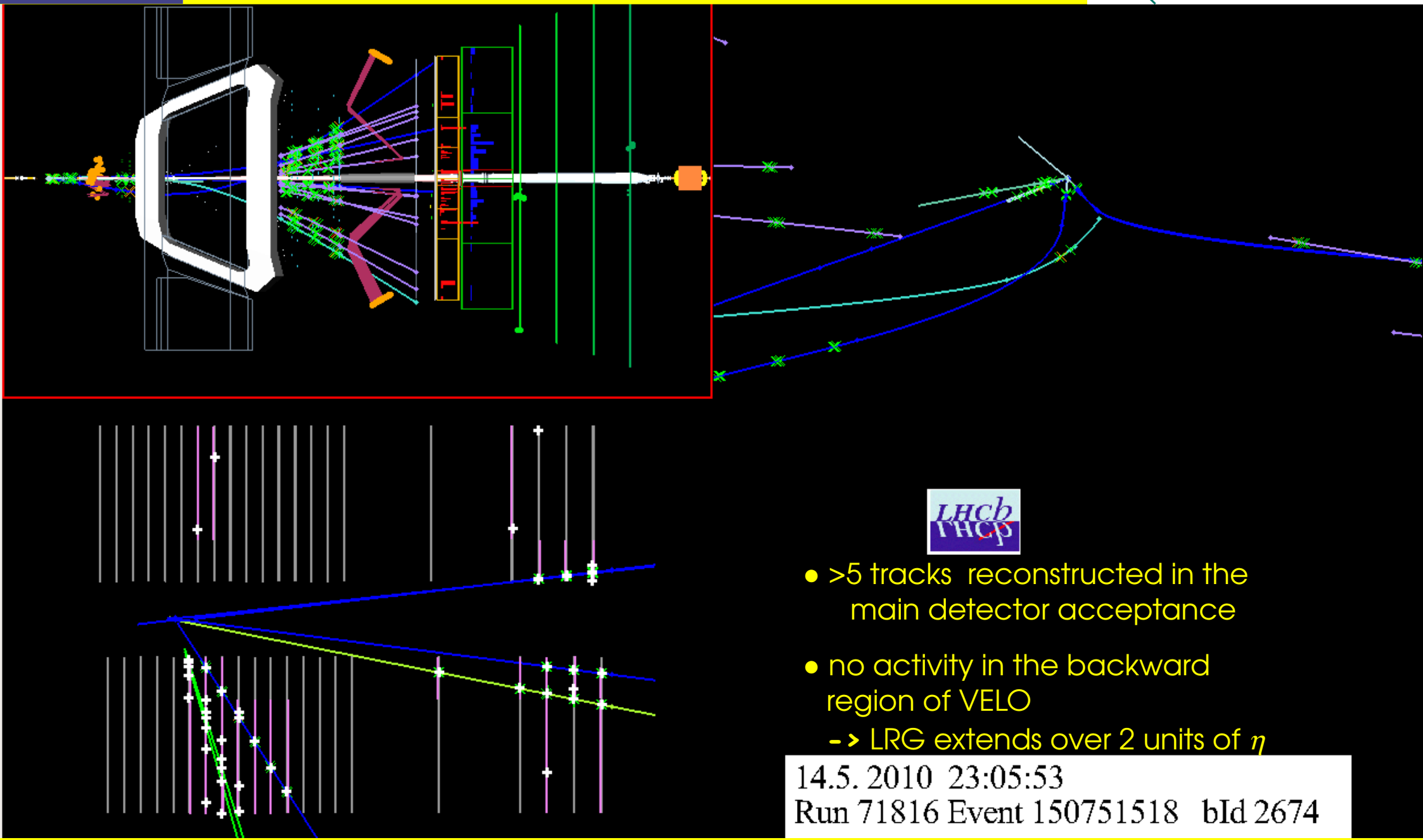




- quite a few backward tracks reconstructed
- no activity in the main detector acceptance
  -> LRG extends over 3 units of η

14.5. 2010 23:05:53
Run 71816 Event 150752285 bId 2674

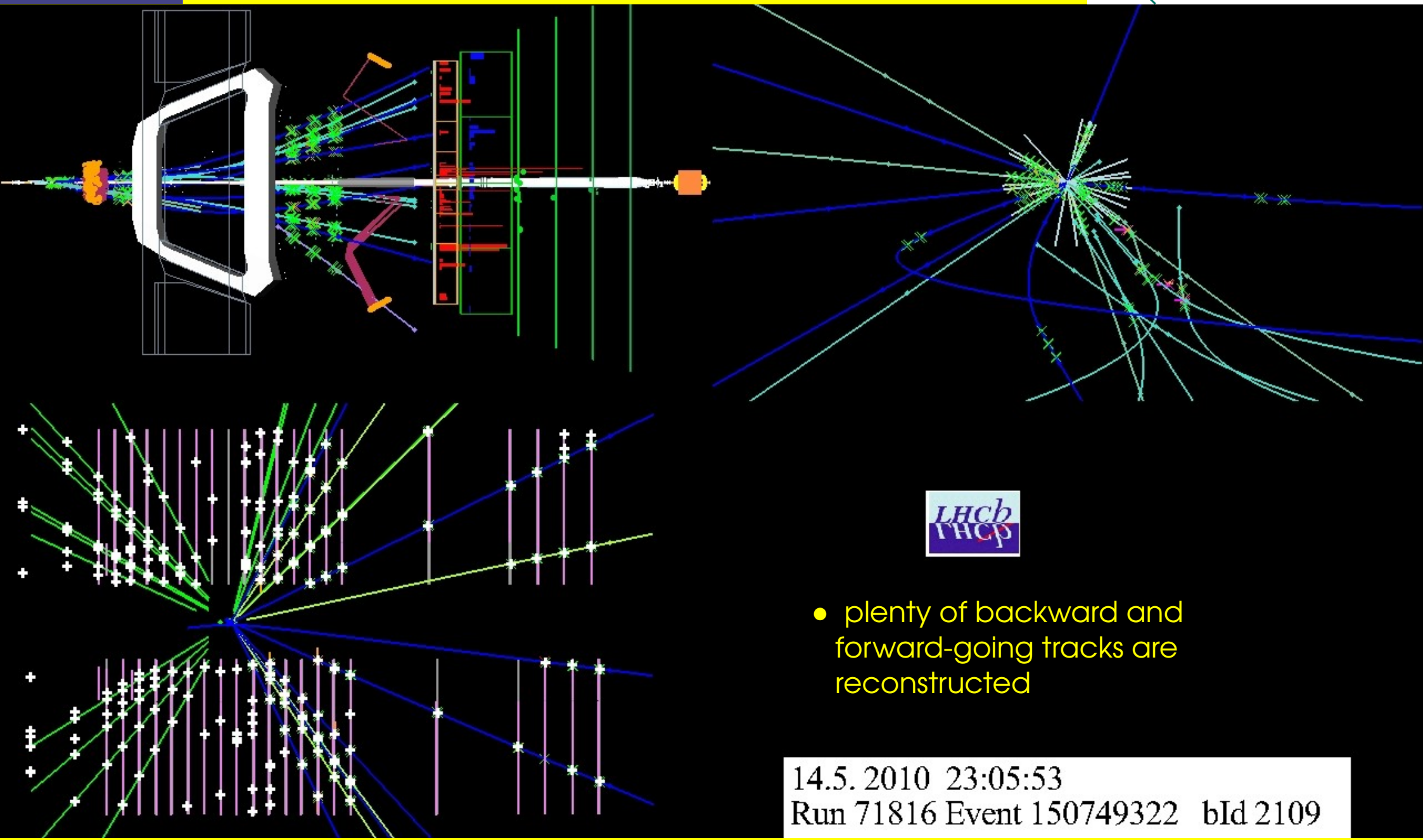
Downstream Diffractive Candidate



- >5 tracks reconstructed in the main detector acceptance
- no activity in the backward region of VELO
  -> LRG extends over 2 units of η

14.5. 2010 23:05:53
Run 71816 Event 150751518 bId 2674

Non-Diffractive Candidate



- plenty of backward and forward-going tracks are reconstructed

14.5. 2010 23:05:53
Run 71816 Event 150749322 bId 2109

Summary

- LHCb is running smoothly taking data of high quality
- Excellent detector performance allows to perform high-precision measurements in a unique rapidity and transverse momentum range

  -> great potential to study wide range of QCD topics (incl. diffraction, UE)

- First MB results from LHCb deliver much input to the theory:

  -> higher baryon number transport, charged particle multiplicities and ϕ production cross-section, lower baryon/meson suppression, harder p_T distributions are observed in data compared to current models

- More results are on the way