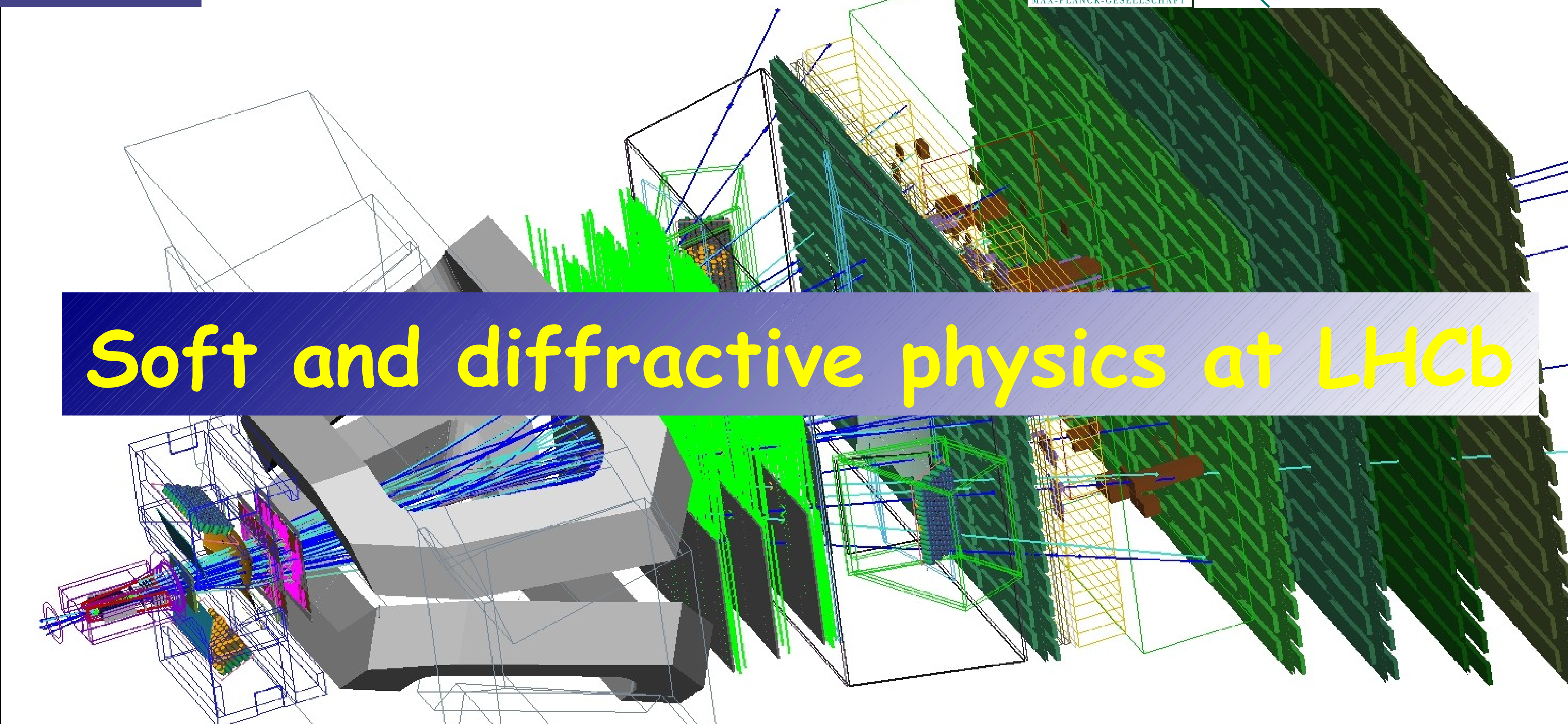


Soft and diffractive physics at LHCb

Dmytro Volyanskyy

Max-Planck-Institut für Kernphysik (Heidelberg, Germany)

on behalf of the LHCb collaboration

LISHEP 2011 Workshop on LHC (July 4th –10th, 2011) Rio De Janeiro, Brazil

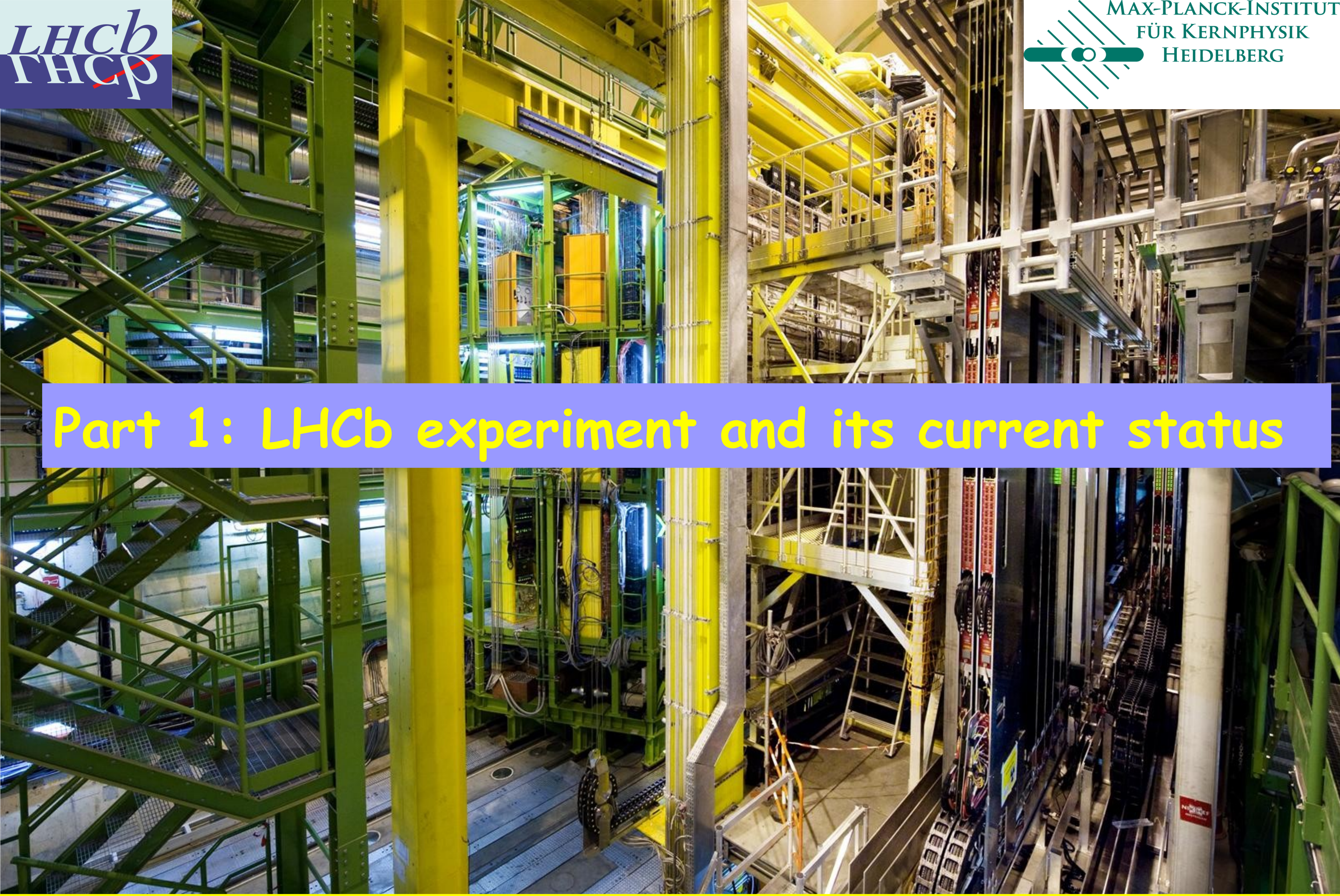
Outline

=> LHCb experiment and its current status

=> Prospects for diffractive physics at LHCb

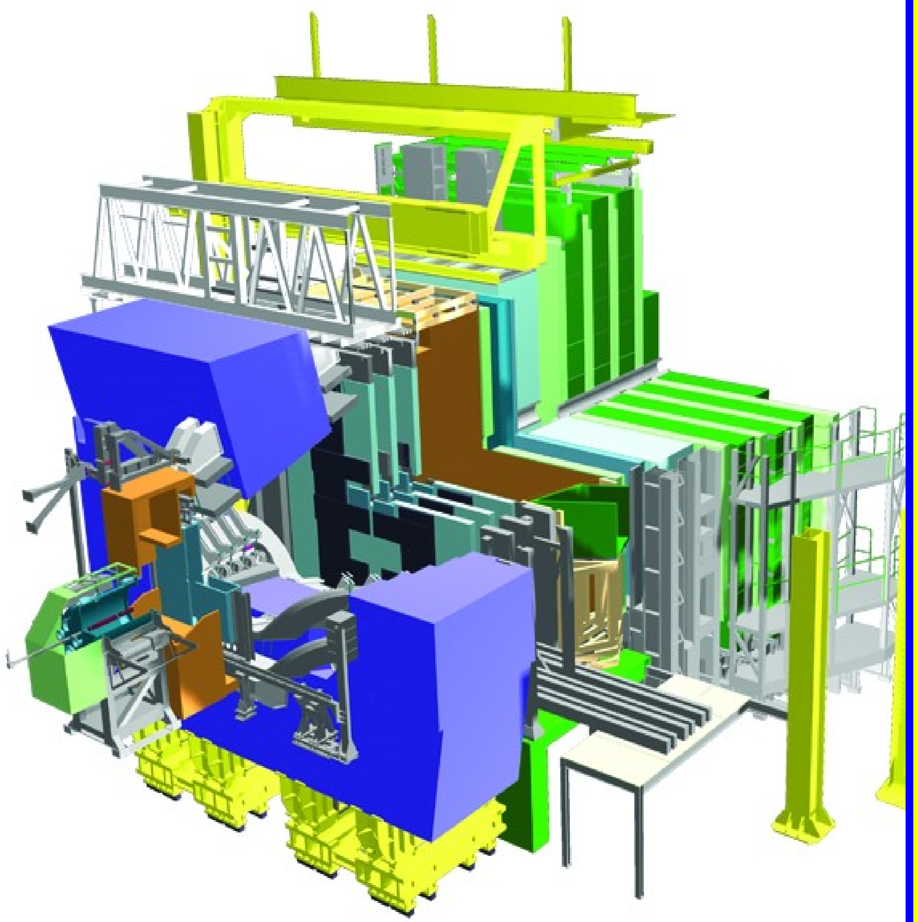
=> Overview of minimum bias physics results

=> 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: $\sim 10^6$
- Designed to run at a moderate luminosity: large pile-up complicates identification of the B decay vertex and flavor tagging

LHCb overview (2)

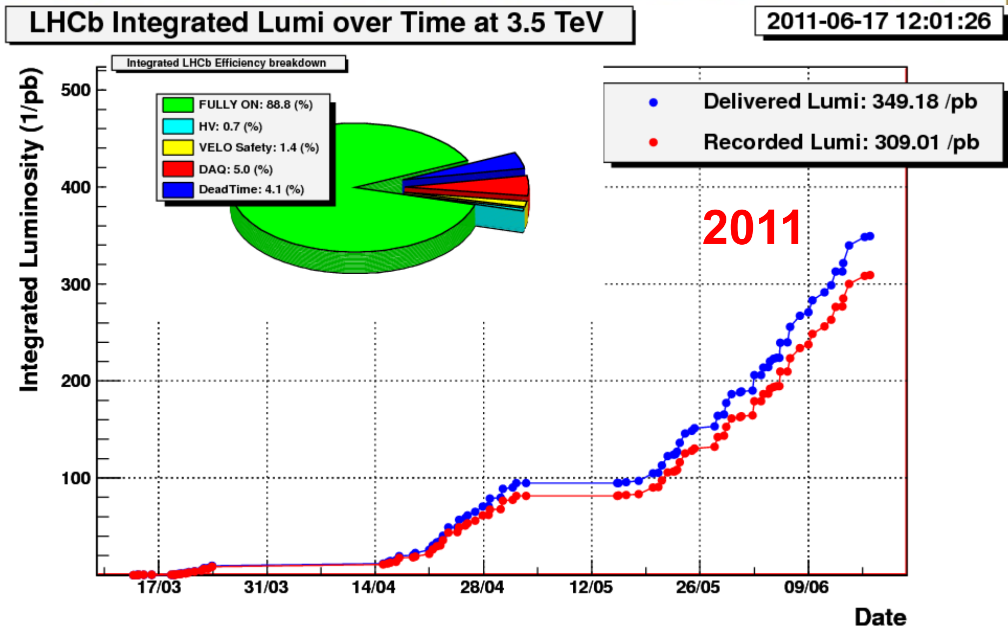
- First collision data taking 11/2009
- Collision data collected:

→ 2009: 6.8 μb^{-1} @ 0.9TeV
→ 2010: 0.3 nb^{-1} @ 0.9TeV, 37 pb^{-1} @ 7TeV
→ 2011: 309 pb^{-1} @ 7TeV (as of 17.06.2011)
~1 fb^{-1} is expected by the end of 2011

- Good quality of recorded data:

→ >95% of r/o channels are operational

- High data taking efficiency



Running challenges:

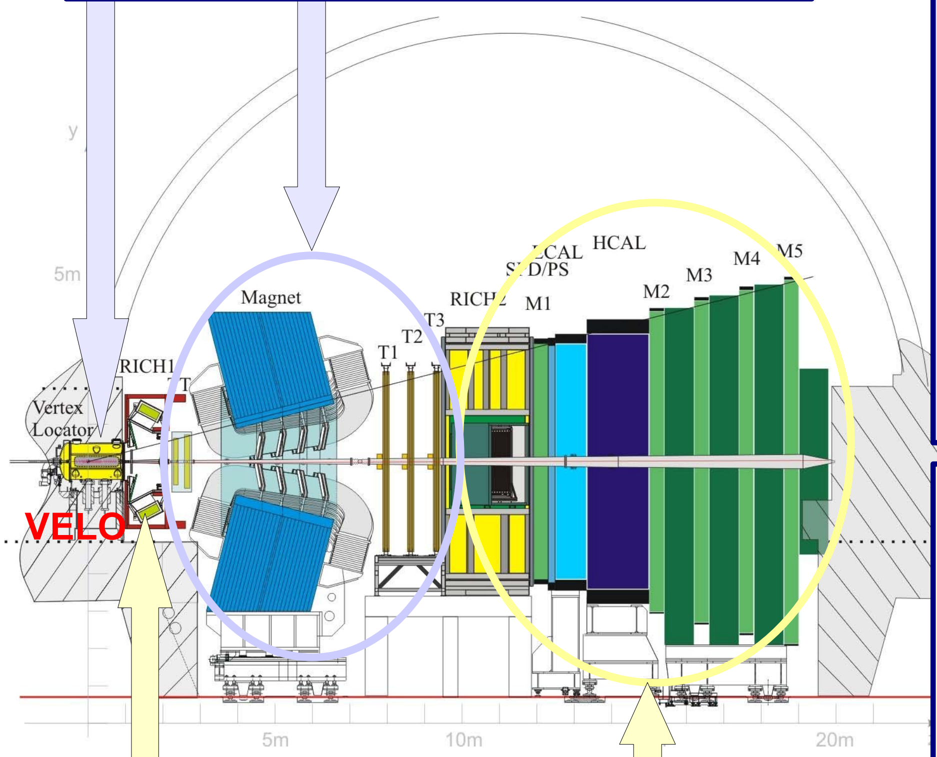
Outstanding beam characteristics (~10^{11} protons per bunch) achieved by the LHC at the end of 2010 implied μ~2.5 → factor of 5 above the LHCb design value !

- strong challenge for the trigger, offline reconstruction and data processing
- LHCb was and is successfully coping with these extreme running conditions

LHCb overview (3)

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

Tracking detectors



PID detectors

- Excellent tracking performance:

→ momentum resolution of tracks $\delta p/p \sim 0.3\text{-}0.5\%$ 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,StawTube

CERN-LHCb-PROC-2010-008

- High quality particle identification:

→ RICH system: efficient π/K, K/p separation

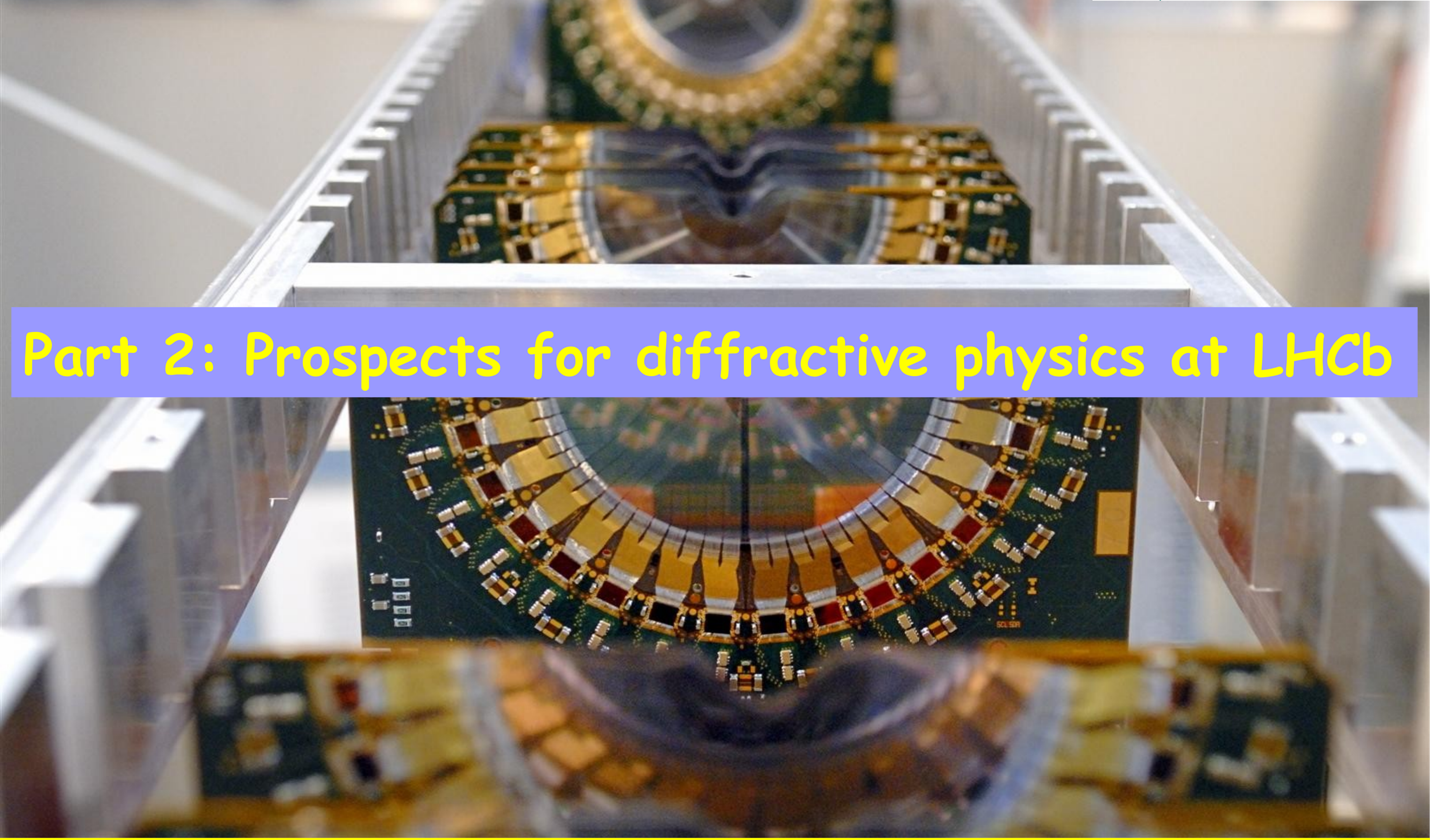
→ SPD: e/γ separation PS: e/hadrons separation

→ ECAL: e and γ energy measurements

→ HCAL: π,K,p energy measurements

→ MUON: μ identification

- Selective and flexible trigger system



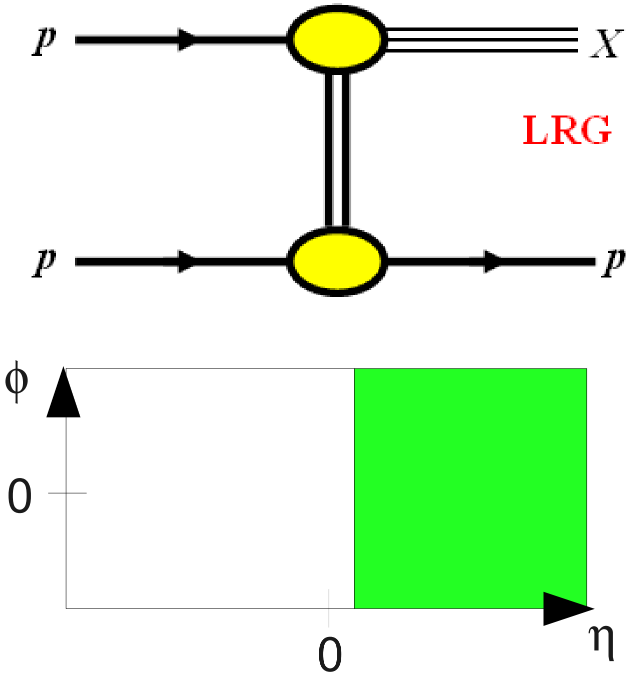
Part 2: Prospects for diffractive physics at LHCb

Physics Motivation (1)

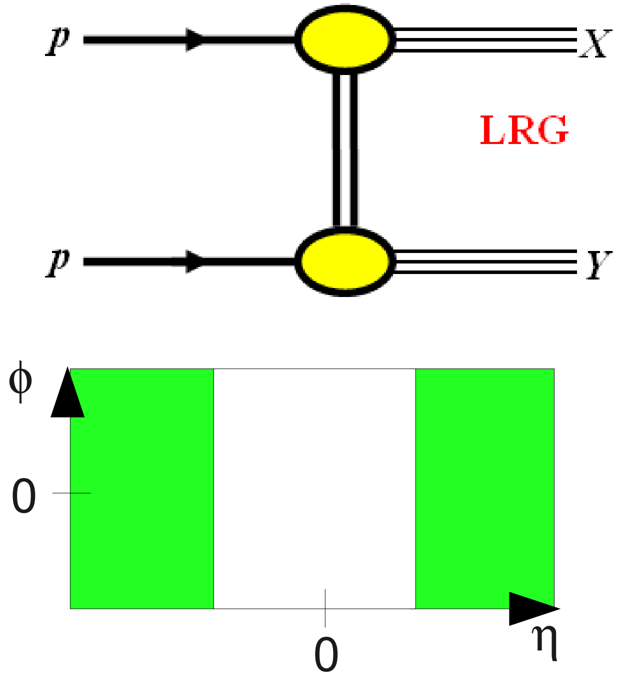
- Diffractive process in pp collisions: pp -> XY, pp->pXp reactions

→ X,Y: protons or low-mass systems (resonances or continuum states)
→ X and Y separated by LRG (colorless exchange), acquire energy of the incoming pp
→ Hard Diffraction: perturbative QCD => exchange of a colorless state of partons
→ Soft Diffraction: Regge Theory => colorless exchange mediated by the Pomeron

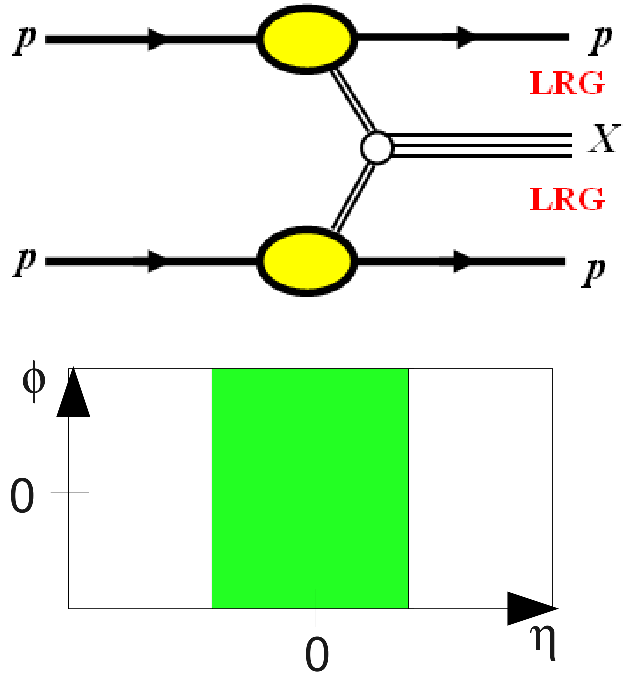
Single-Diffractive Dissociation



Double-Diffractive Dissociation

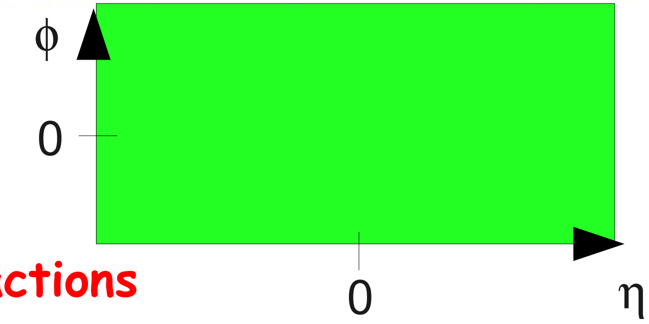


Central-Diffractive Dissociation



Physics Motivation (2)

Non-Diffractive pp interaction:
color exchange = no rapidity gaps



- Hard to distinguish between different inelastic pp interactions but <u>the LRG is a unique feature helping to identify the diffractive signal</u>
- Diffractive events contribute <u>significantly</u> to MB dataset:
  - → $\sigma_{TOT}=(\sigma_{el} + \sigma_{inel})$ ~100mb @ 7 TeV
  - → σ_{inel} ~70mb @ 7 TeV => confirmed by ATLAS and CMS
  - → diffractive contribution to σ_{inel} : $(\sigma_{SD} + \sigma_{DD} + \sigma_{CD})/\sigma_{inel}$ ~ 0.2-0.3
  - → on average, every 4th inelastic pp interaction at LHC is a diffractive one !
  - → theory predictions: σ_{SD} ~10mb, σ_{DD}~7mb, σ_{CD}~1mb

arXiv:1105.4916v1 [hep-ph] , arXiv:1002.3527v2 [hep-ph] , arXiv:hep-ex/0602021v1

- Constraint on diffractive contribution is <u>essential</u> to improve our understanding of collision data and pile up and tune the existing MC models

- Large differences between the models implemented in MC generators

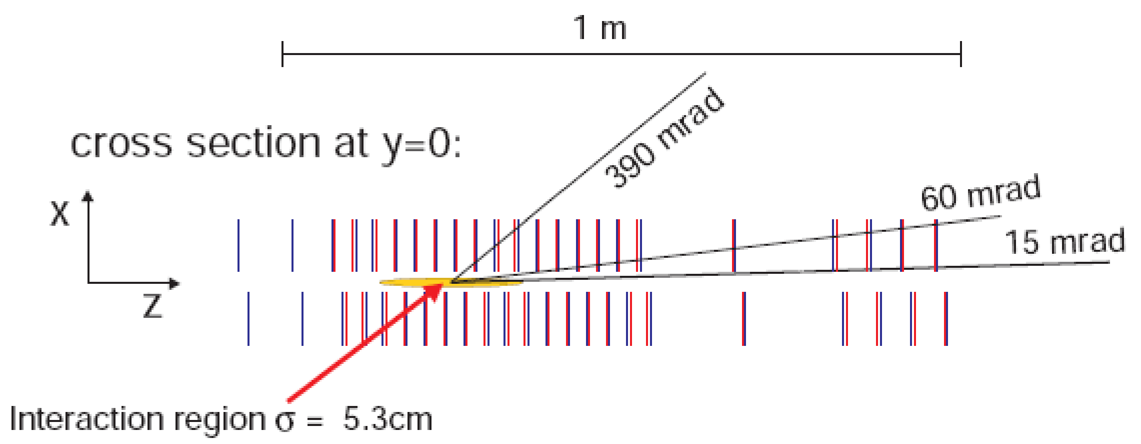
LHCb VErtex LOcator

- VELO is crucial element for detecting rapidity gap events

→ 21 SiStrip stations measuring r and ϕ hit positions + 2 radial-only stations

→ surrounds IP being outside magnetic field

→ just 8 mm away from the beams (halves kept open during the injection phase)



→ largest angular coverage among LHCb subcomponents

→ ability to reconstruct forward and backward going tracks: $1.5 < \eta < 5.0$, $-4 < \eta < -1.5$

=> no momentum measurements, but a sizeable rapidity gap is provided

=> multiplicity measurements done in the region $2.0 < \eta < 4.5$, $-2.5 < \eta < -2.0$

→ excellent performance during data taking:

=> 99.8% hit finding efficiency, great vertexing and proper time resolution achieved

Possible Selection Approaches

- Approach 1: events with a well reconstructed PV which has either no backward or no forward going tracks

→ exploiting the LRG feature of diffractive events

→ well reconstructed PV – warranty of dealing with an inelastic pp event, whose cost is an inefficient signal selection (losing diffractive events with small number of tracks)

- Approach 2: events with low-IP tracks w.r.t to the beam line

→ exploiting another diffractive signature

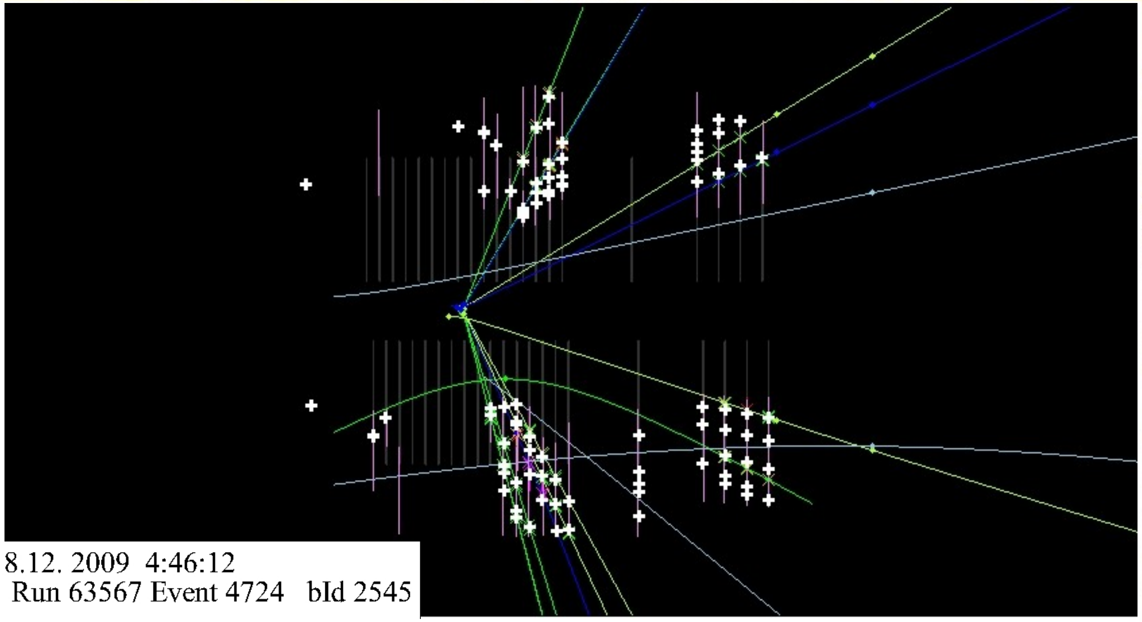
→ do not require PV to be reconstructed – maximize signal selection efficiency

→ cosmic and beam gas background should be negligible

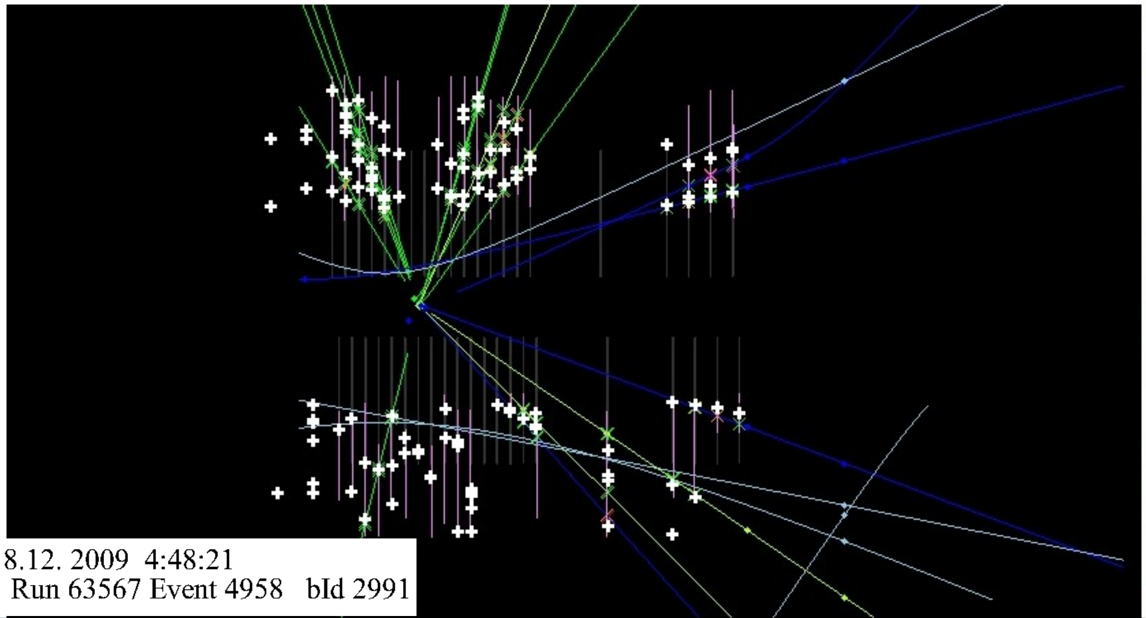
- Consider no pile-up events only

Some collision events

- **Diffractive candidate @ 0.9 TeV**
  → LRG extends over the backward region of VELO



- **Non-diffractive candidate @ 0.9TeV**
  → both forward and backward going tracks are reconstructed



MC Study

- **Generator level study** CERN-LHCb-PROC-2010-071

  → prospects for measuring the properties of events with dominantly diffractive contributions

- **PYTHIA 8.135: default settings**

  → much more accurate description of diffractive processes than in PYTHIA6

  arXiv:1005.3894v1 [hep-ph]

  → process selection: `pythia.readString("SoftQCD:all=on")`

  → no pile-up *pp* collisions @ 7 TeV

- **Toy-model detector simulation with VELO and main tracker only**

  → VELO nominal geometry

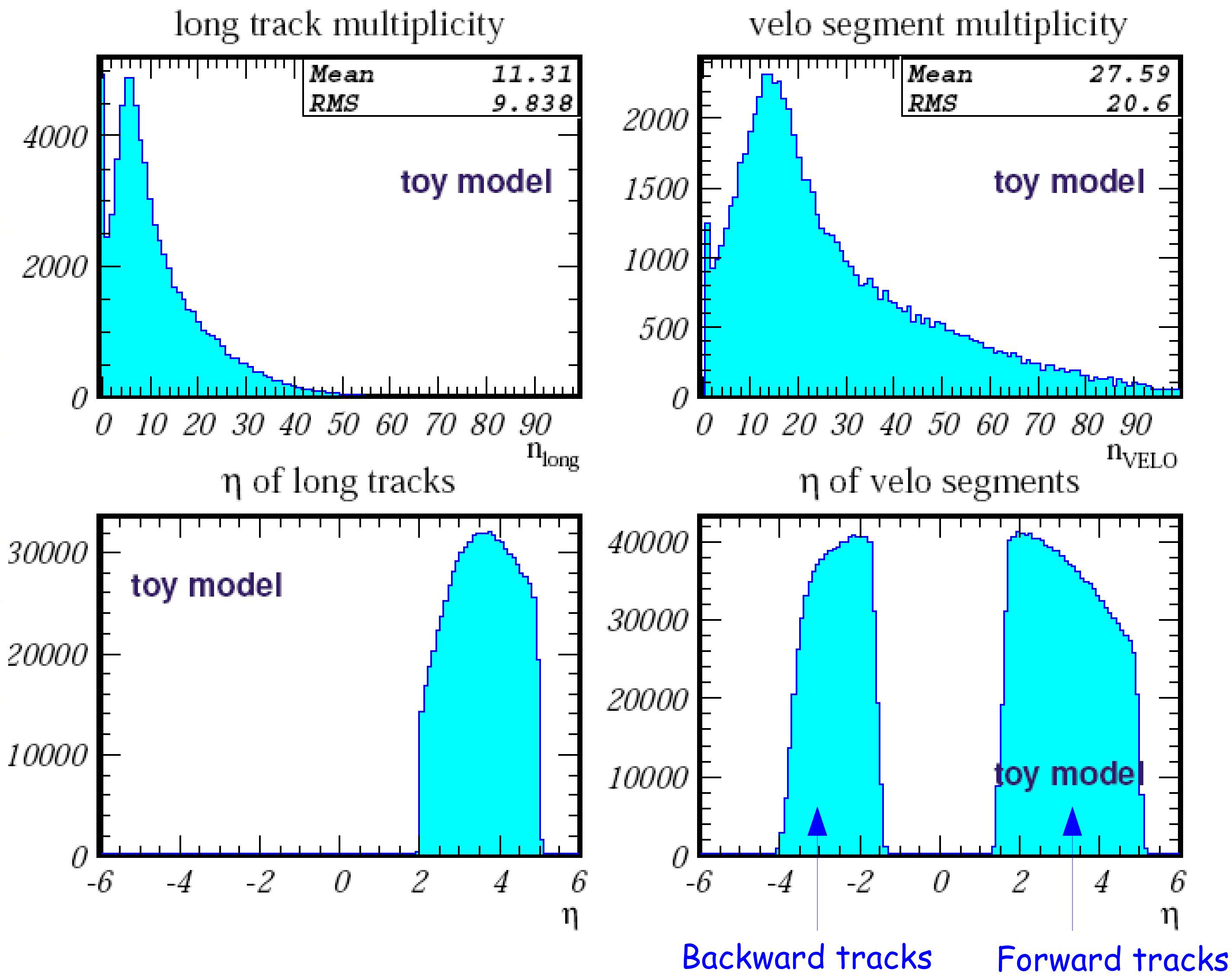
  → accept track if three stations are hit

  → acceptance of tracking system behind the magnet: $2 < \eta < 5$ and $p > 2$ GeV/c

  → VELO segments for long tracks

Multiplicity (1)

- **Track Multiplicities and Angular Coverage:**

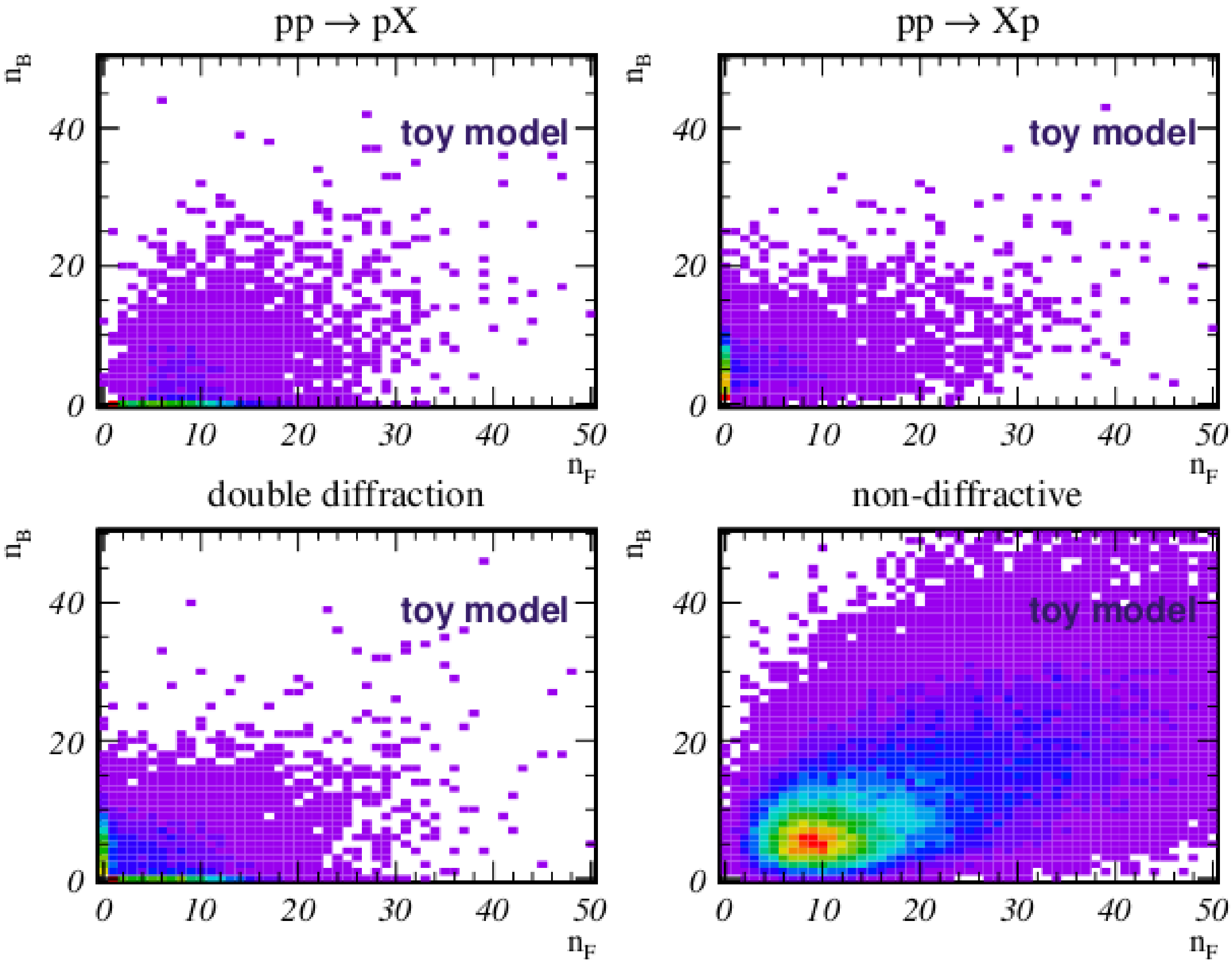


As expected:

- $n_{long} \ll n_{VELO}$
- no VELO measurements for $-1.5 < \eta < 1.5$

Multiplicity (2)

- Multiplicity of forward/backward VELO segments:



- n_B/n_F -number of forward/backward VELO track segments

As expected:

- $\overline{n}_B < \overline{n}_F$ for pp→pX, SD1
- $\overline{n}_B > \overline{n}_F$ for pp→Xp, SD2
- $\overline{n}_B \sim \overline{n}_F$ for pp→XY, DD
- much larger multiplicity for ND events

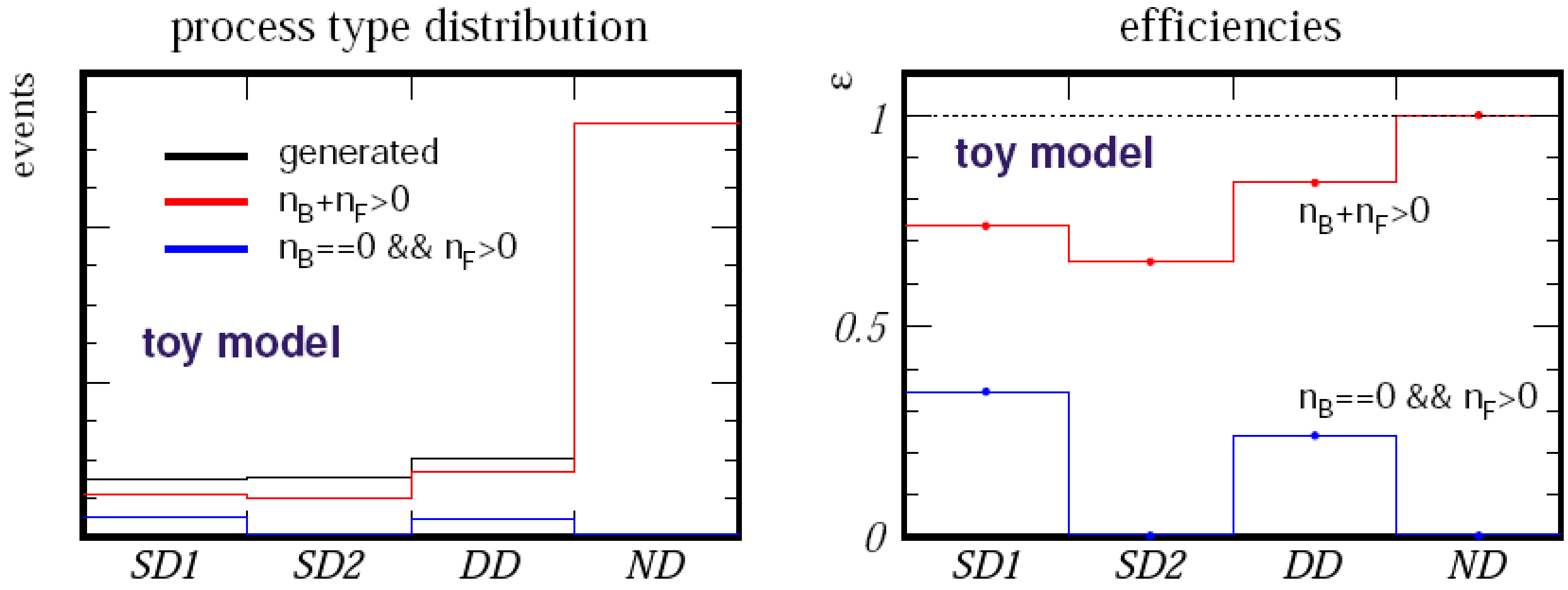
Selection Efficiency

- VELO multiplicity based event selection:

→ Selection A: $n_F + n_B > 0$

→ Selection B: $n_F > 0$ & $n_B = 0$ (equivalent to $\Delta\eta \geq 2.5$) => enhancing diffractive component

→ PYTHIA process type is retrieved for all events



→ Rapidity Gap requirement suppresses ND drastically, but removes quite a few SD1&&DD

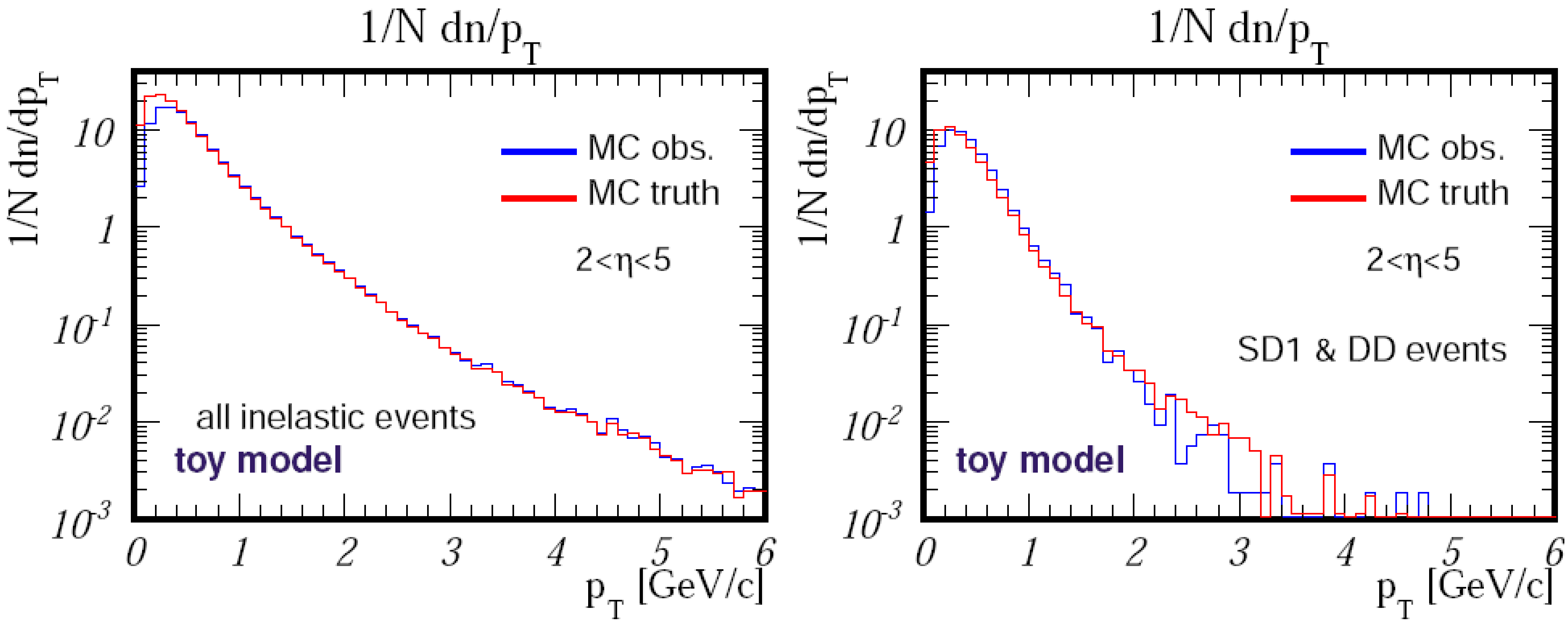
=> selection efficiencies for SD1 & DD at the order of 30%

→ N.B. the obtained fractions are model dependent !

p_T-distributions

- **Inclusive transverse momentum spectra:**

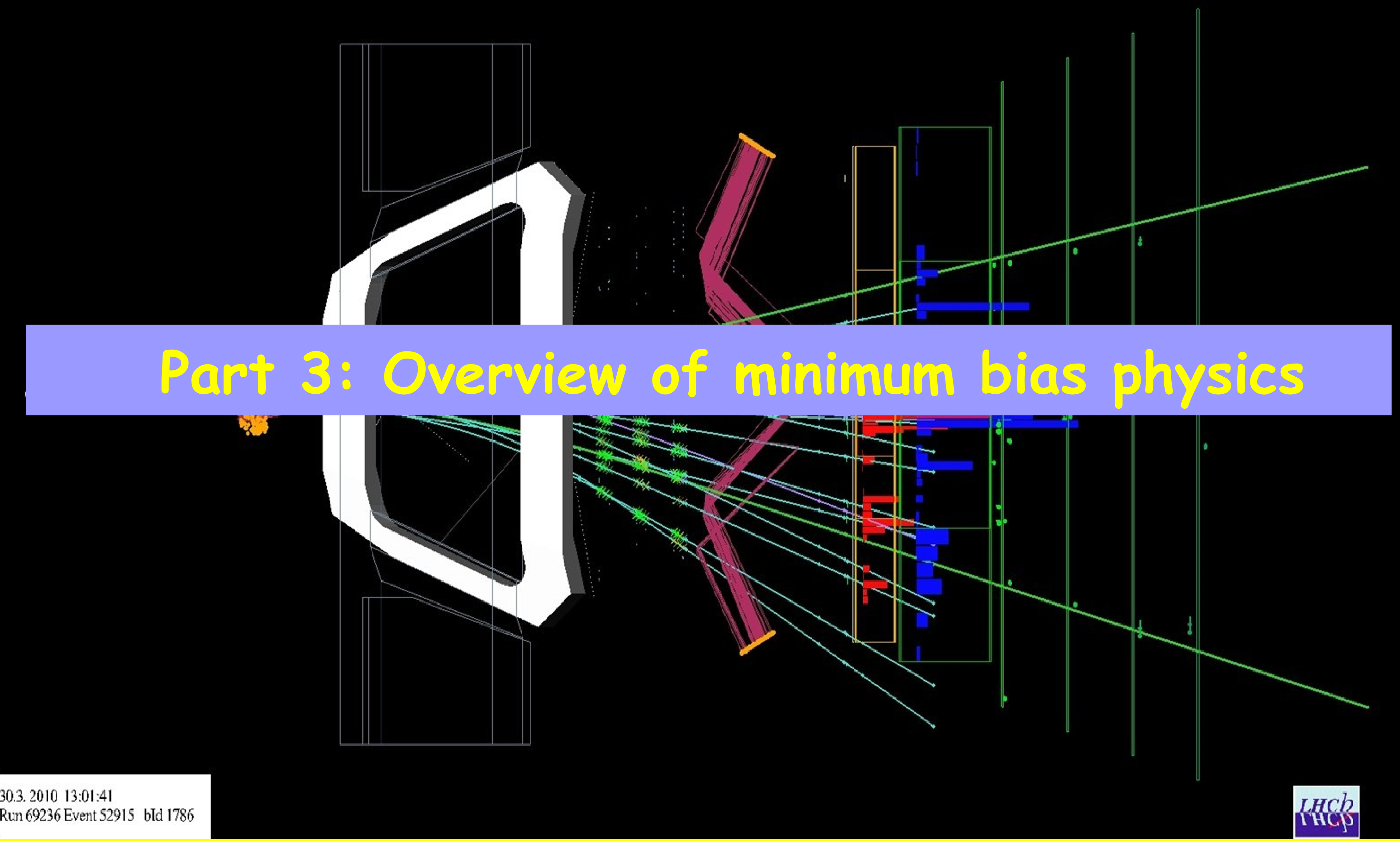
→ all tracks with VELO segments + within the main tracker acceptance



→ Good agreement between generated and observed distributions

→ As expected, the p_T spectrum is softer for diffractive events

LHCb Event Display



Part 3: Overview of minimum bias physics

Soft QCD

- Great potential to study soft (low-p_T) QCD physics with LHCb
- Ability to investigate low-p_T region (<0.5 GeV/c) at large η(>4), low-x at low Q^2
  => the only one LHC experiment that can do it
- Inelastic pp interactions => Minimum Bias (MB) data dominated by soft QCD processes
- MB Trigger at LHCb:
  => in 2009: provided by the calorimeter system
  => in 2010: at least 1 track-segment in VELO or in the main tracker

MB physics

What physics can be studied with MB data ?

1) Cross-sections and production ratios for identified particles
   => study the dynamics of particle production in high energy hadron collisions also as a function of kinematic variables
   => correlation studies (e.g. Bose-Einstein, kinematic etc.)

2) Underlying Event structure
   => includes particles from beam-beam remnants and MPI
   => unavoidable background to most collider observables
   => its understanding is essential for precise measurements at the LHC

3) Multiple Parton Interaction (MPI):
   => arises mainly in the region of low x
   => weakly known at the moment
   => can be studied via measurements of multiplicity and forward energy flow

4) Diffractive processes (see slides 9-10)

5) ...

Study strangeness production:

- **Ks cross-section at 0.9 TeV and ϕ cross-section at 7.0 TeV**

Motivation:

=> sensitive tests of soft hadronic interactions, Ms is of the order of Λ_{QCD}.

=> QCD predictions in this region have large uncertainties

=> explore uncovered regions - current models have been tuned to describe SPS and Tevatron data (central rapidity and p_T> 0.5GeV)

Baryon Number Transport and Baryon Suppression:

- **$\overline{\Lambda}/\Lambda$ and $\overline{\Lambda}$/Ks production ratios at 0.9 TeV and 7.0 TeV**

Motivation:

=> 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

Ks cross-section (1)

- **Analysis Outline:**

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

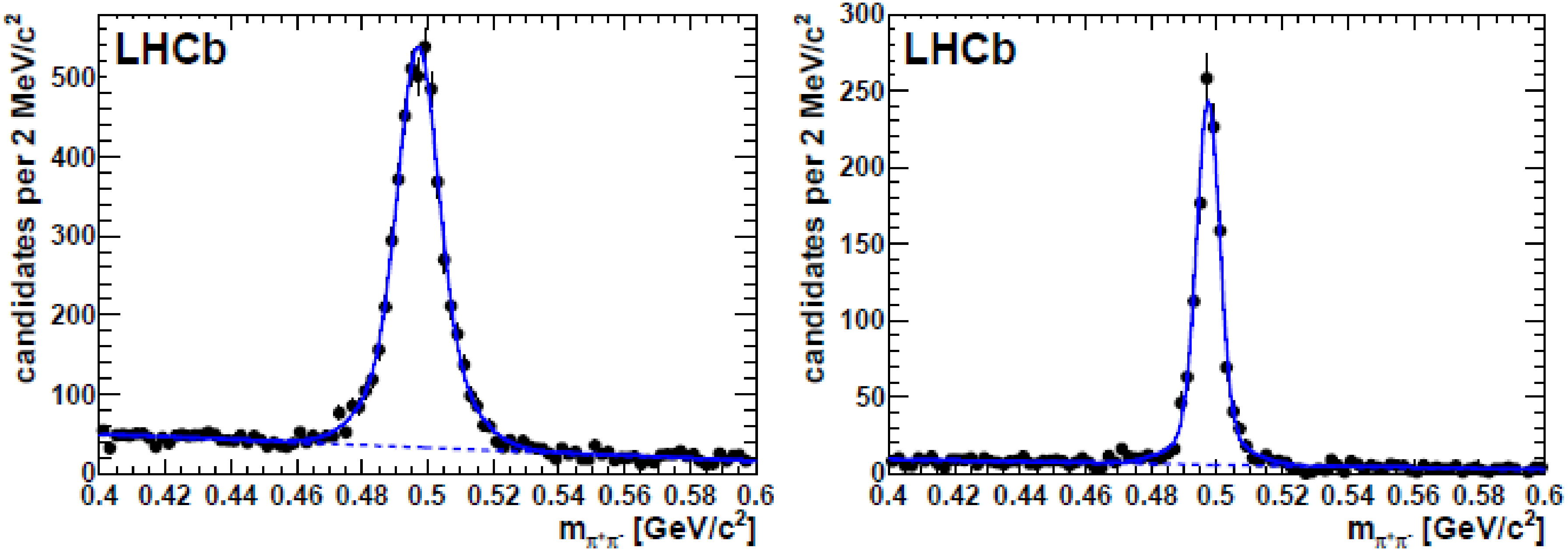
→ done with first 2009 MB data: 6.8 μb^{-1}@0.9 TeV (calo based MB trigger)

→ prompt Ks, reconstruction via Ks → $\pi^+\pi^-$ mode

→ two approaches: 1) long-track selection (tracks traversing all tracking stations)

2) downstream-track selection (tracks with no VELO segments)

downstream-track: σ~9.2 MeV/c² long-track: σ~5.5 MeV/c²



→ cross-sections evaluated separately from both downstream and long-track selections

=> consistency obtained

Ks cross-section (2)

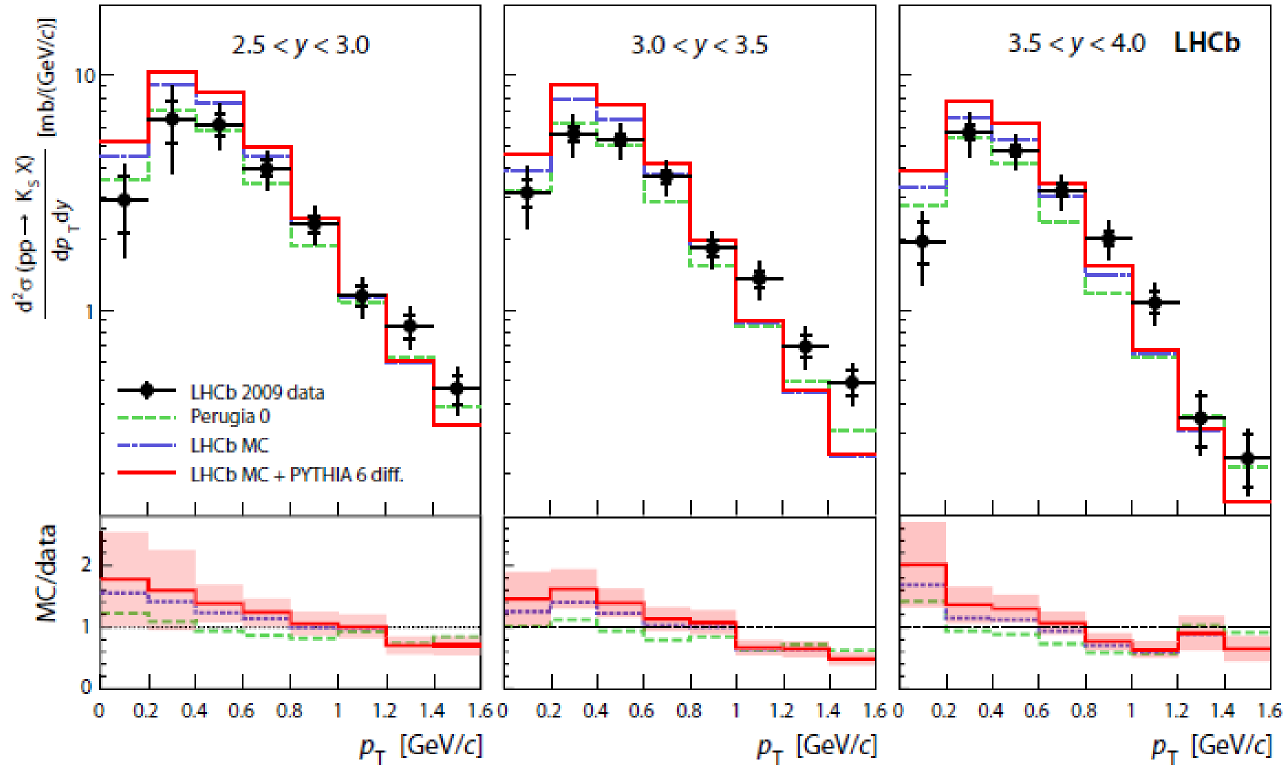
→ the cross-section is estimated in bins of p_T and y

→ for very bin the Ks production cross-section estimated as:

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

→ N_{obs} obtained from the mass distributions, efficiencies estimated using MC

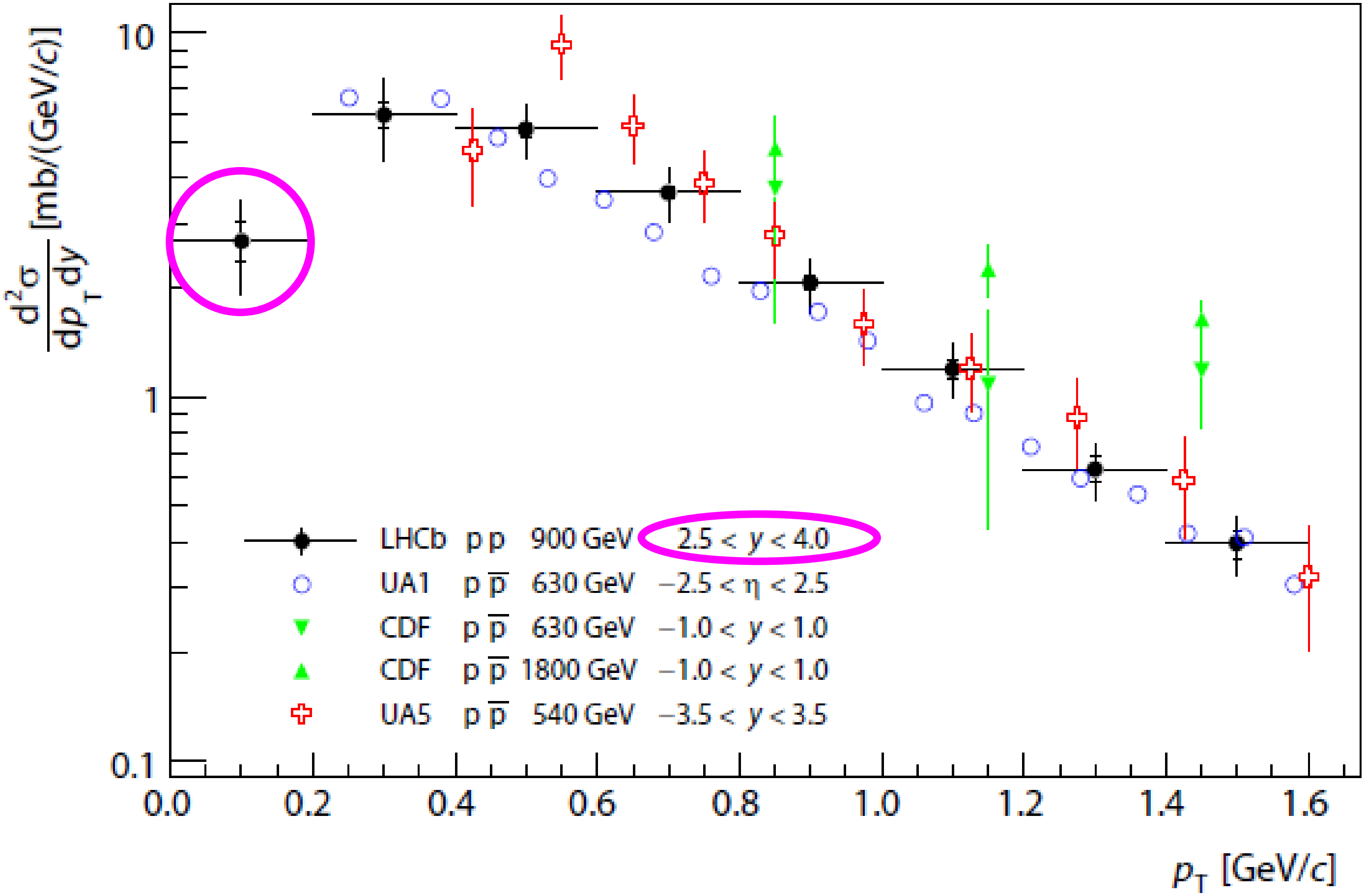
→ L_{int} estimation: a novel technique based on the beam currents, sizes and positions



- p_T spectrum is harder in data than in MC
- best description given by Perugia0 tune (no diffraction)
- largest systematics from lumi estimation (beam currents uncertainty)

Ks cross-section (3)

- 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 (1)

CERN-LHCb-CONF-2010-014

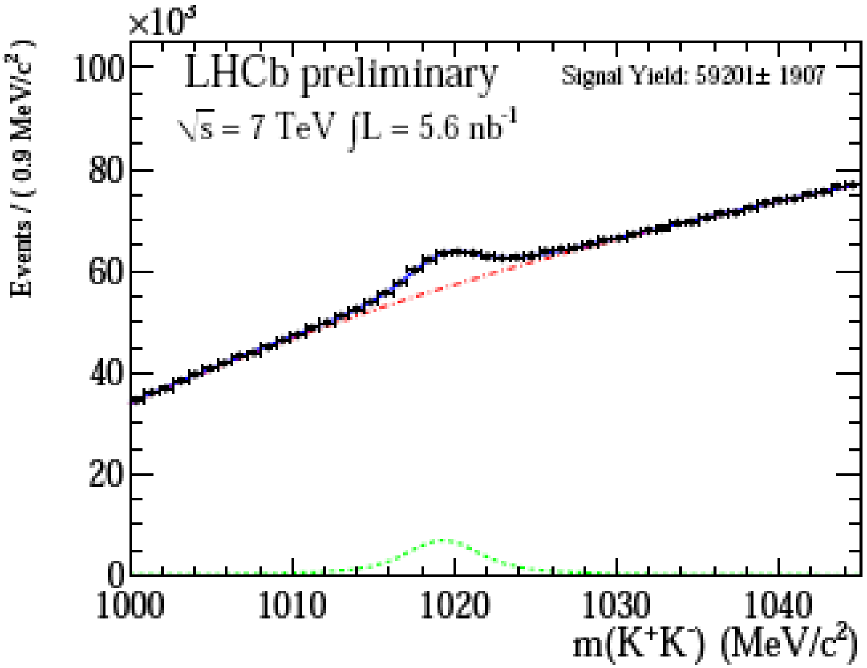
- **Analysis Outline:**

→ done with 2010 low pile-up data sample

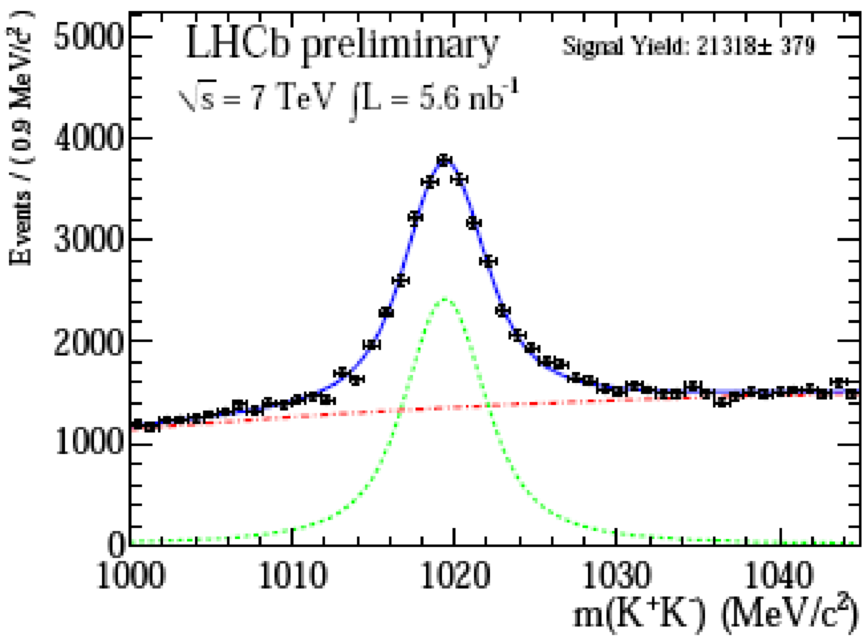
→ reconstruction via $\phi \rightarrow K^+K^-$ => rigorous test of RICH PID performance

→ two approaches: require at least one kaon/both kaons to pass tight PID cuts to evaluate PID efficiency

Tight PID on one kaon

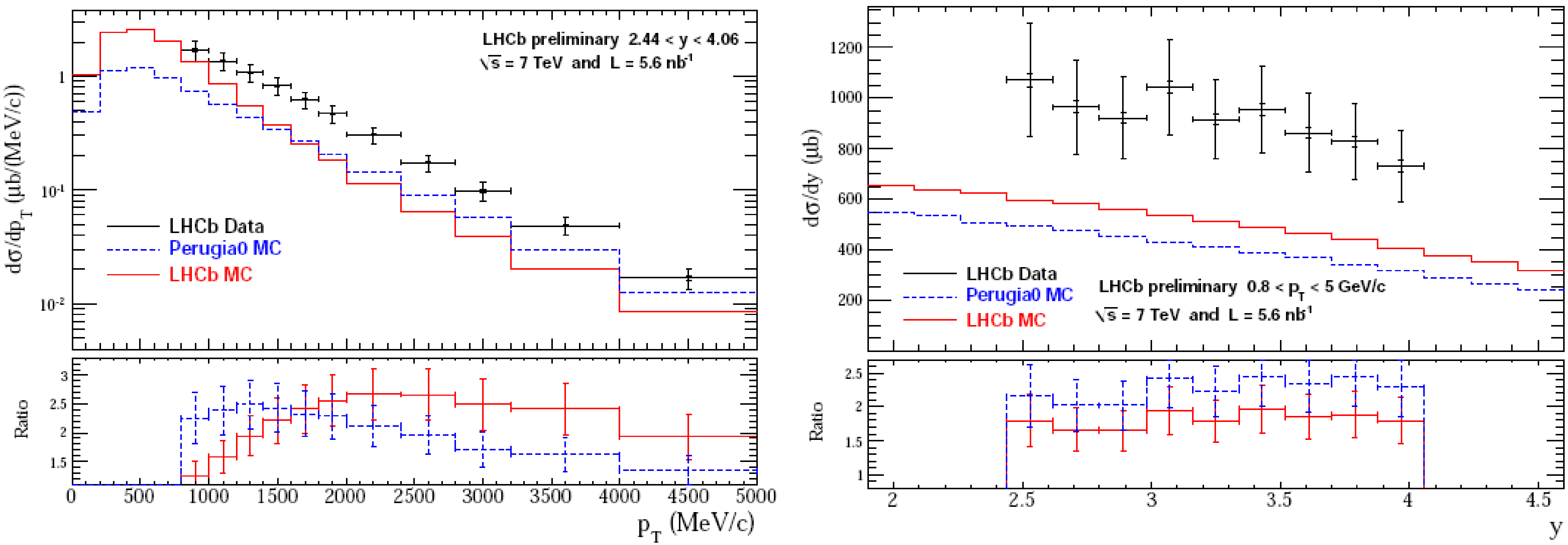


Tight PID on both kaons



ϕ cross-section (2)

→ the cross-section is estimated in bins of p_T and y:



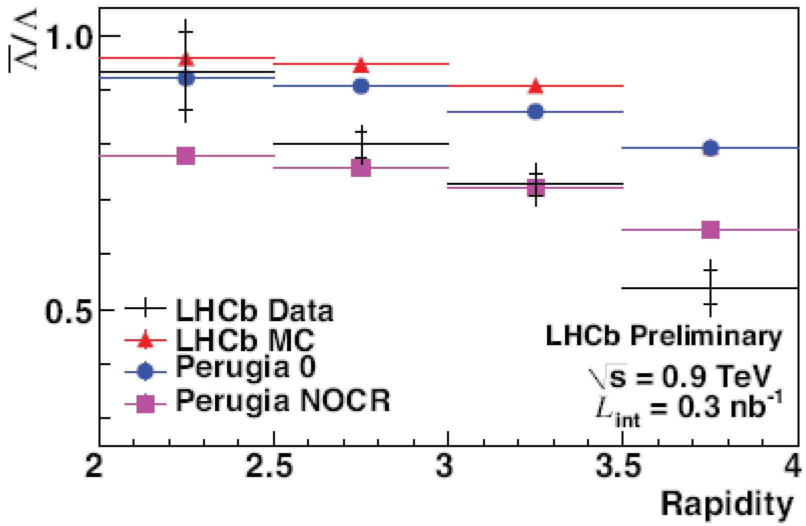
- Discrepancy between data and MC models used in this study is observed
- Error bars show total uncertainties including correlated systematics
- Largest systematics from luminosity estimation (beam currents uncertainty) ~10%

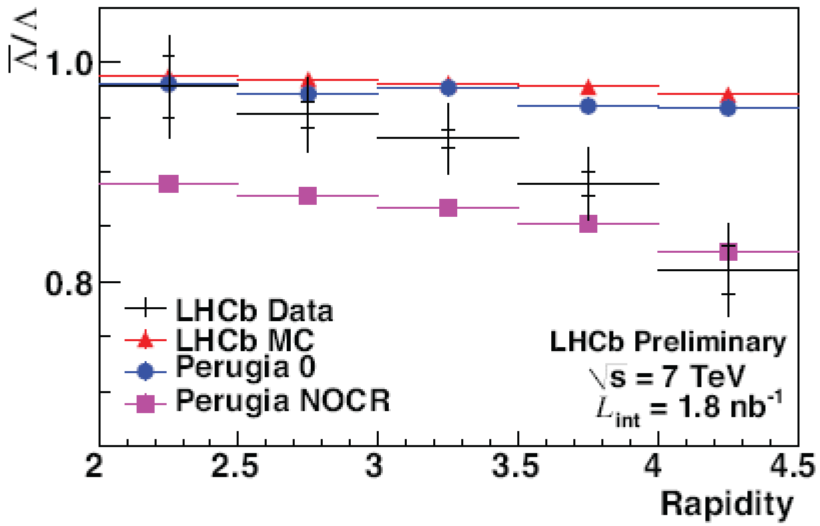
Particle production ratios

- 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
- Reconstruction via $\Lambda \to \pi p$ and $Ks \to \pi\pi$ modes, long tracks only, cuts on track χ^2 to remove fakes, microbias trigger, reconstructed PV, invariant mass requirements
- Prompt Λ and Ks selected using a Fisher discriminant based on the mother and daughters impact parameter.
- Significantly reduced systematic uncertainty (many errors cancel out)

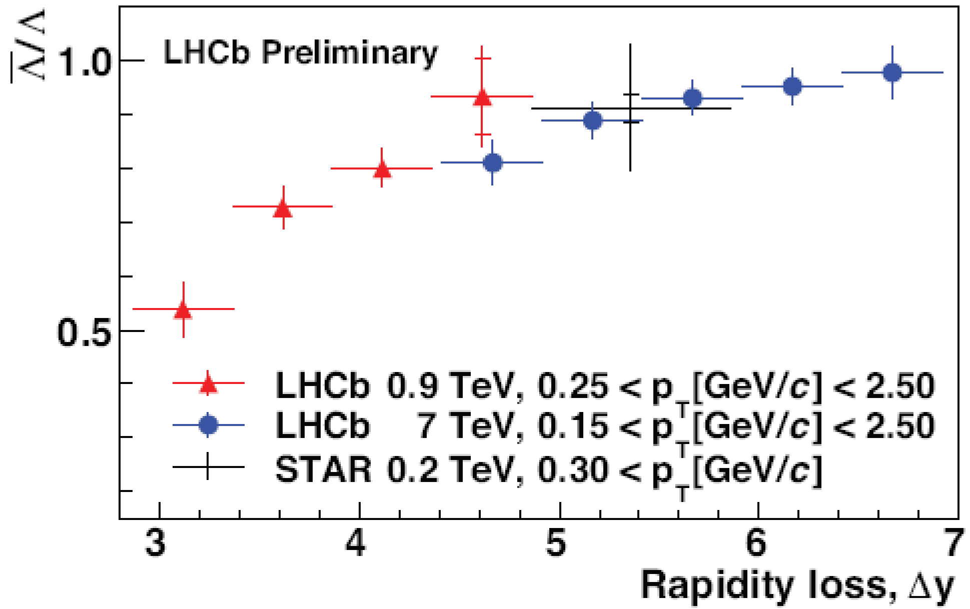
CERN-LHCb-CONF-2010-011

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

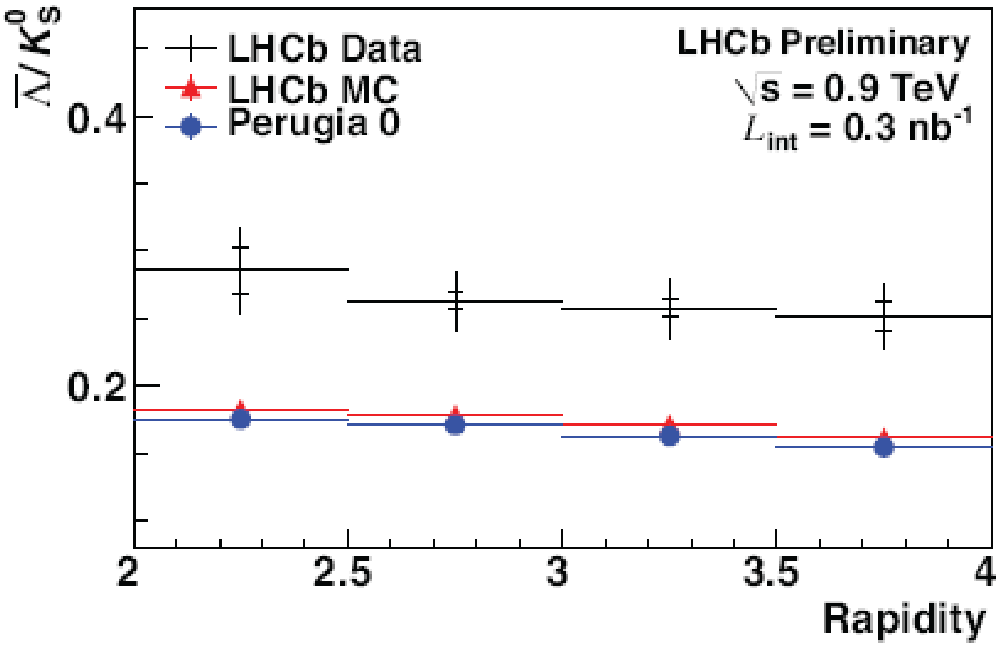


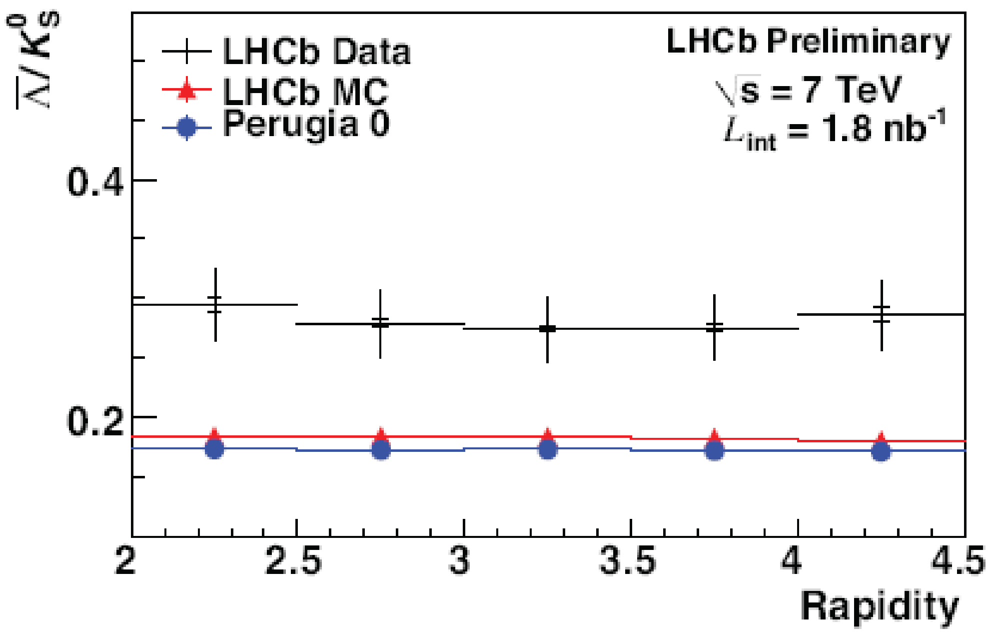


- Energy dependence is observed
- Discrepancy between data and MC
- Baryon number transport is higher than expected by MC models (except Perugia NOCR)
- production ratio vs $\Delta y = y_{beam} - y_{\Lambda}$ consistency with STAR measurement



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





- Large discrepancy between data and MC at both collision energies
- Baryon/Meson suppression is lower than expected by the models
- Important input for MC tuning

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
  => good conditions to study wide variety of QCD topics (inc. diffraction,UE)

- First soft QCD results from LHCb deliver much input to the theory
  => higher baryon number transport, lower baryon/meson suppression,
  harder p_T distributions are observed in data compared to current models

- More results are on the way