

# LHCb - Minimum Bias physics plans and MC framework

*7th Meeting of the*

*MCnet European Network, CERN January 2010*

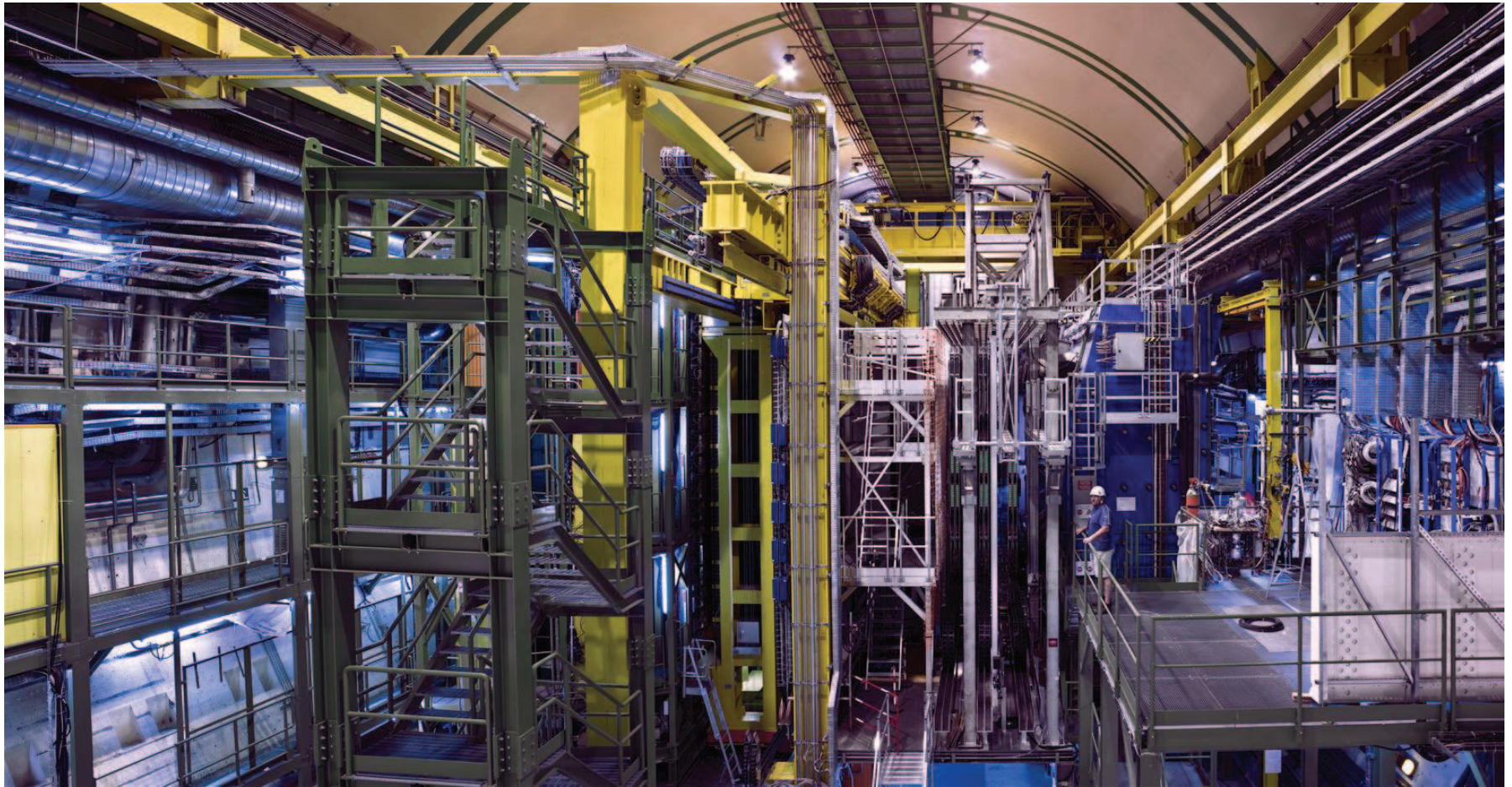
Raluca Mureşan

EPFL

on behalf of the LHCb collaboration

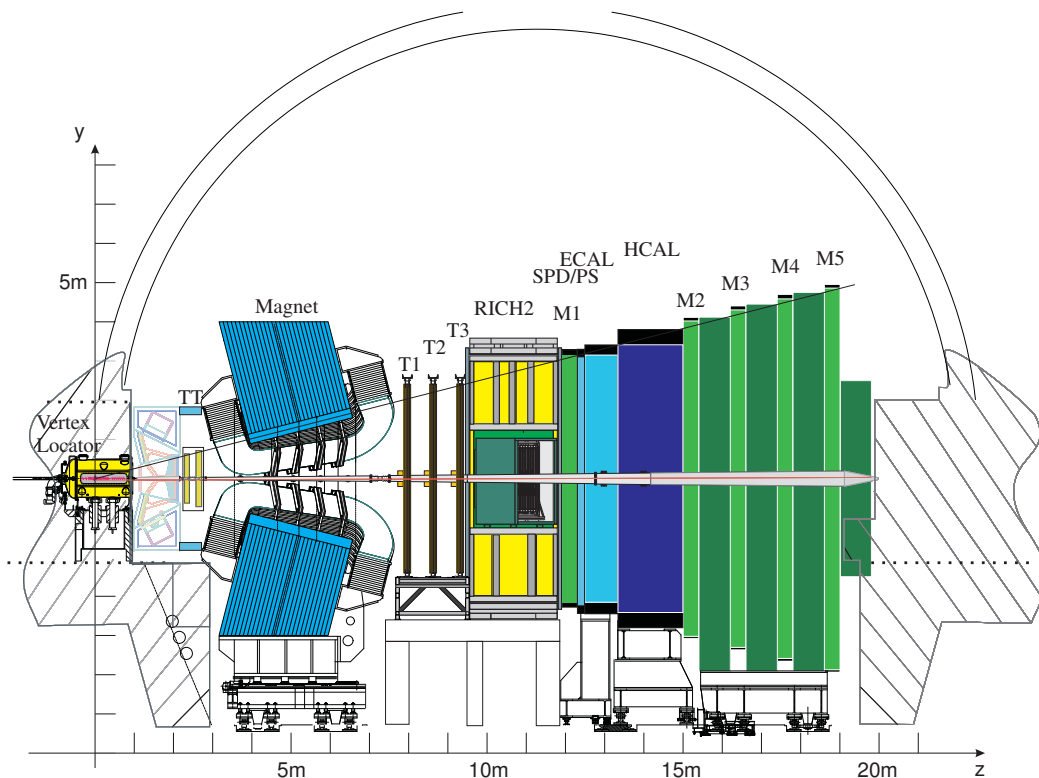
- LHCb detector and rapidity coverage
- Plans for Minimum Bias studies
- MC framework and generators @ LHCb
- Summary

LHCb detector is fully installed, first data were recorded and the analysis is ongoing.

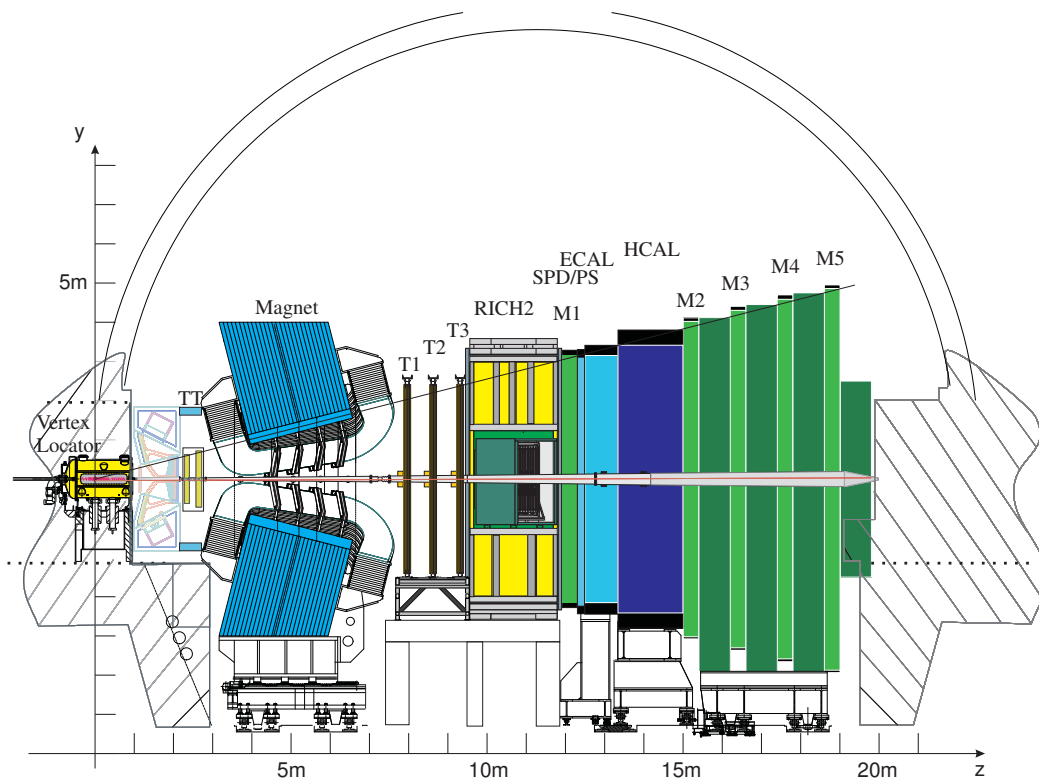


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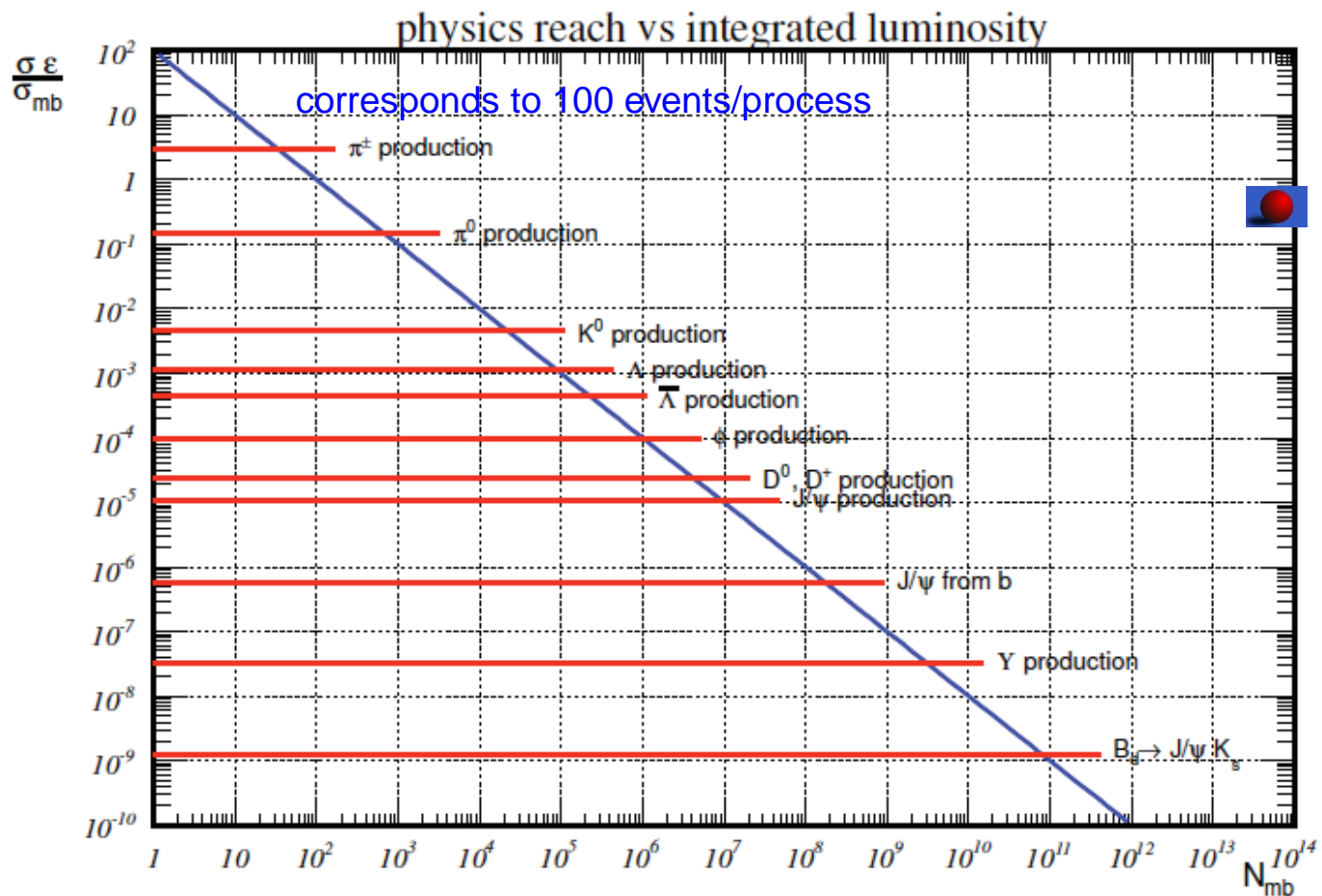




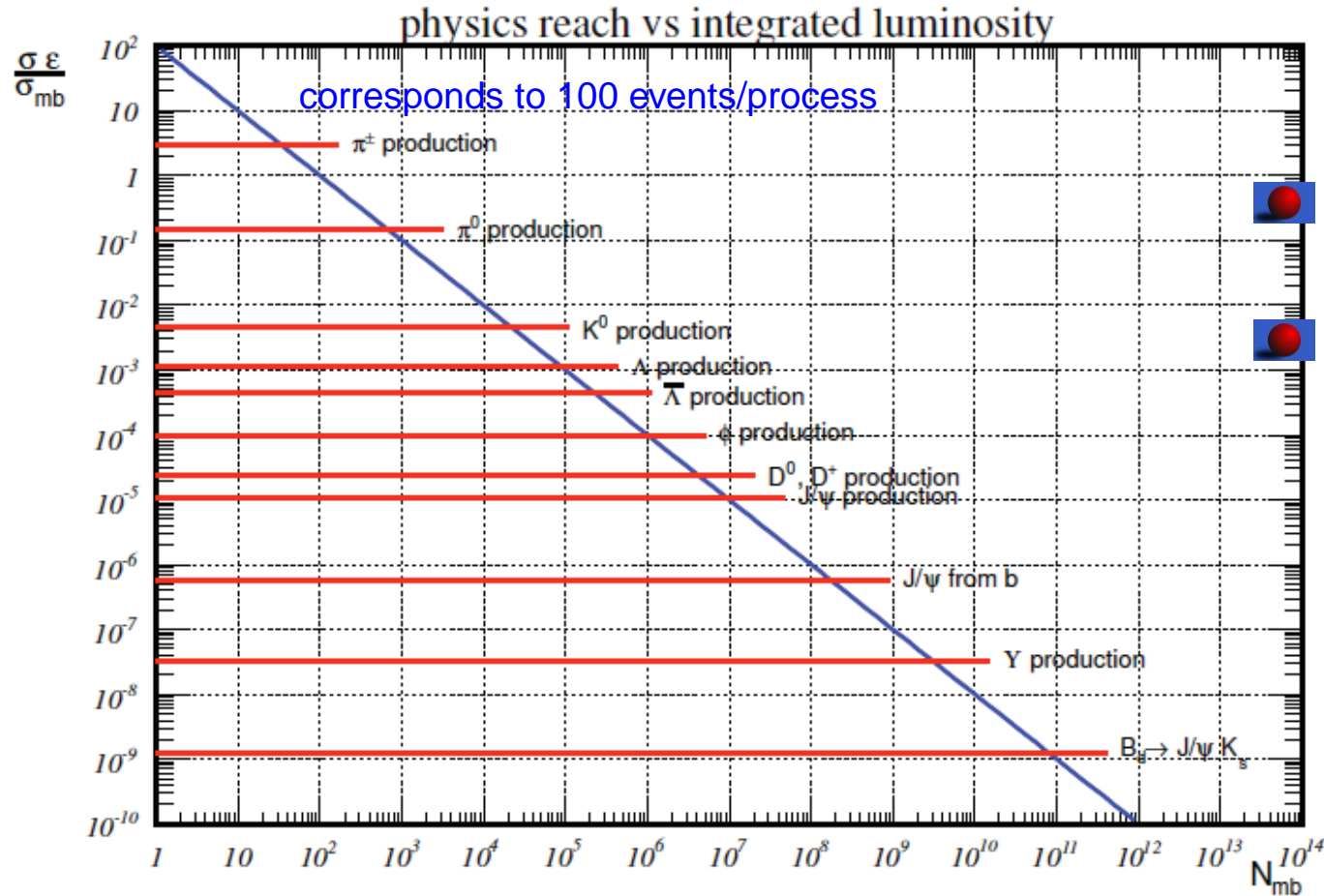
- Dedicated b-physics experiment: CP violation and rare decays
- Forward single arm spectrometer - large and correlated  $b\bar{b}$  quark production in the forward region.
- Coverage: 15-300(250) mrad



- For the first analysis we rely on the tracking detectors.
- Same data will be used for PID calibration using very clean samples of  $D^*$ ,  $\Lambda$  and  $K_S$ , reconstructed using only tracking information.

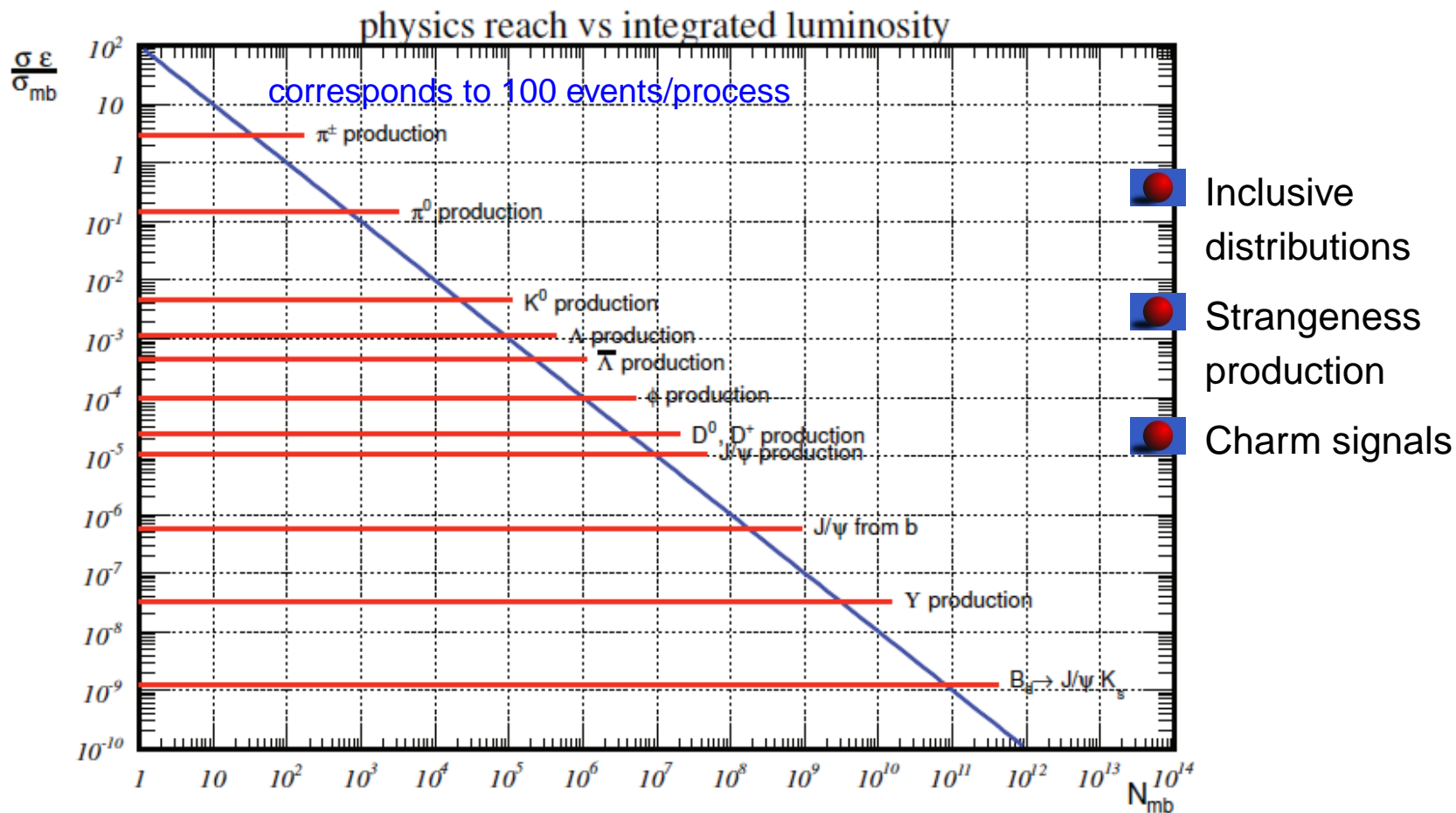


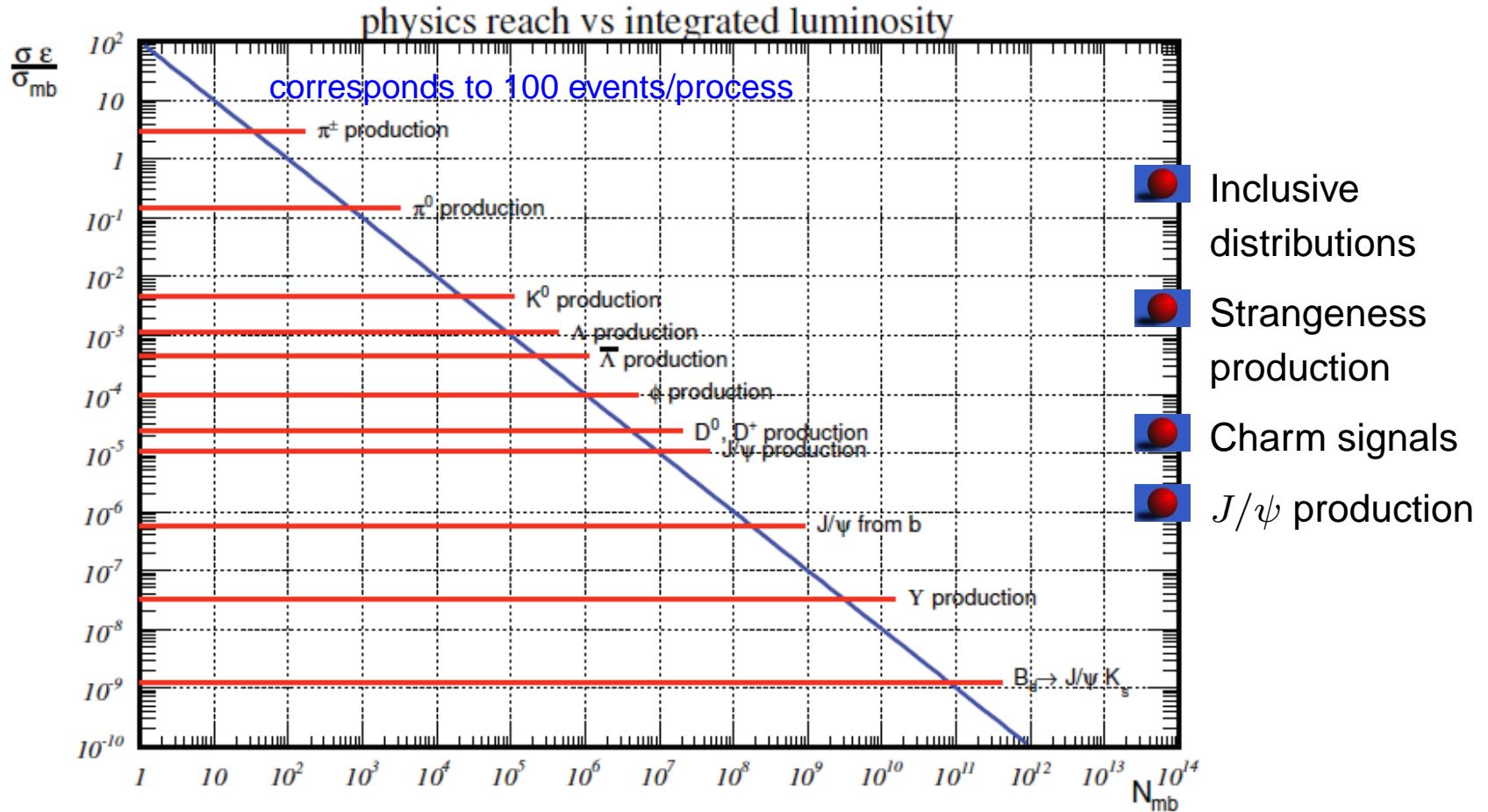
Inclusive  
distributions

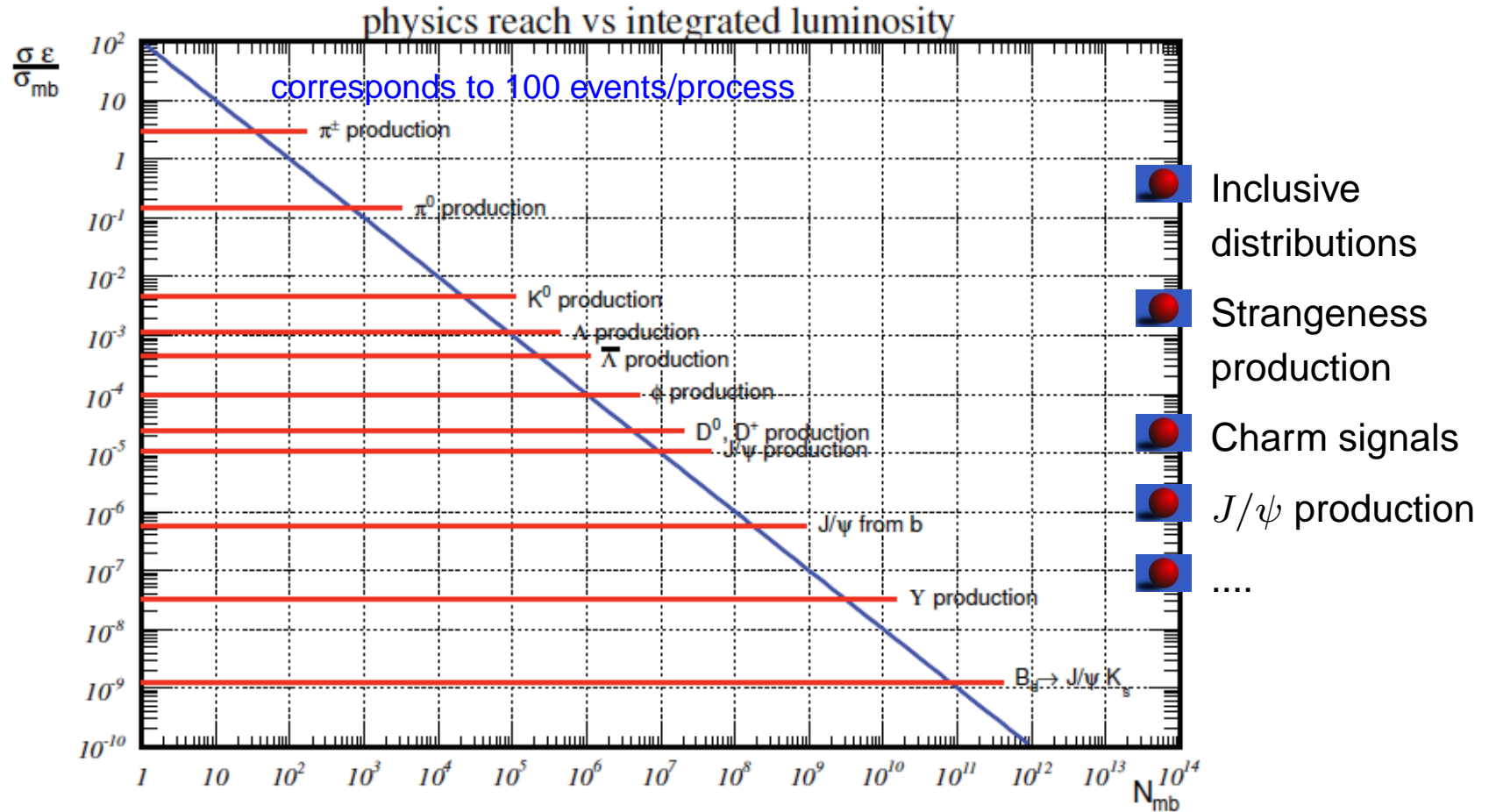


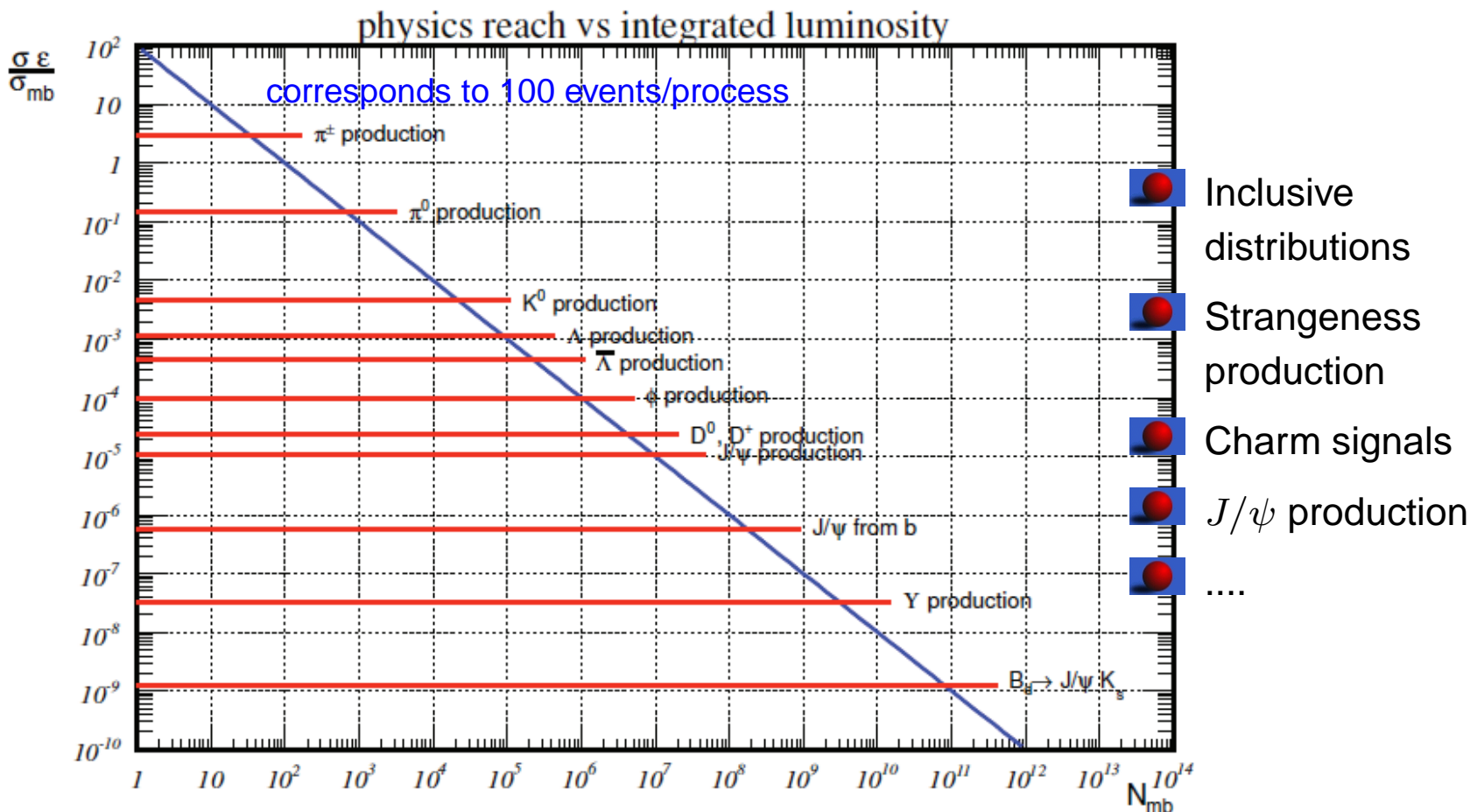
- Inclusive distributions
- Strangeness production







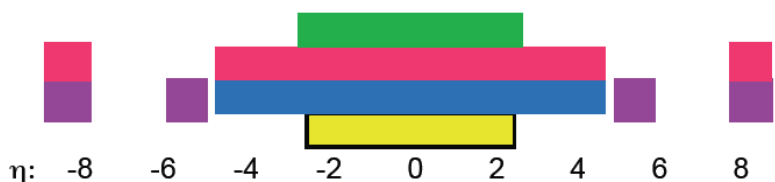




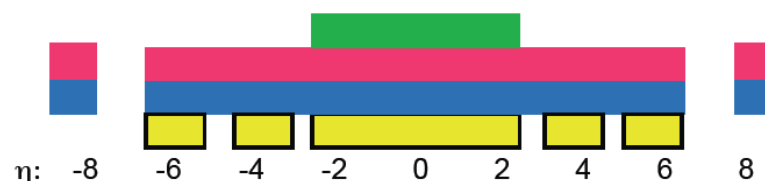
- Understanding and calibrating our detector
- MC tuning and validation
- QCD physics studies

Stepping stone towards reconstruction of interesting charm and beauty hadrons that have as daughters  $K_S, \Lambda, J/\psi, D^0, \dots$ , in particular for charm and beauty baryon studies ( $\Lambda$ )

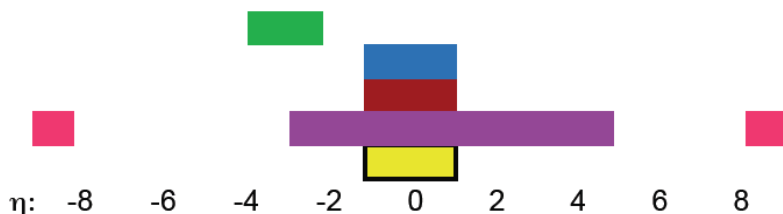
Studies of the inclusive distributions at LHCb particularly interesting because of the unique rapidity range coverage.



ATLAS



CMS+TOTEM



ALICE



LHCb

tracking, ECAL, HCAL, counters lumi, muon, hadron PID

- Models used by Pythia and other generators were tuned mainly on Tevatron data (LEP and SPS also used).
- The agreement between models is broken at LHC, due to different energy extrapolations. The models disagree even more in the LHCb kinematical region, also  $\eta$  extrapolation.
- Even basic distributions such as charged particle multiplicity can help for the MC tuning, e.g. collection of minimum bias distributions of interest: <http://home.fnal.gov/skands/leshouches-plots/qcdplots-houches.pdf>.
- The benchmark distributions variation range is constrained  
→ “New (QCD) physics” see Rick Field *Introduction to UE and MB studies*.

■ Particle ratios:  $\frac{dn^+ / d\eta}{dn^- / d\eta}$ ,  $\frac{dn^+ / dp_T}{dn^- / dp_T}$  .....

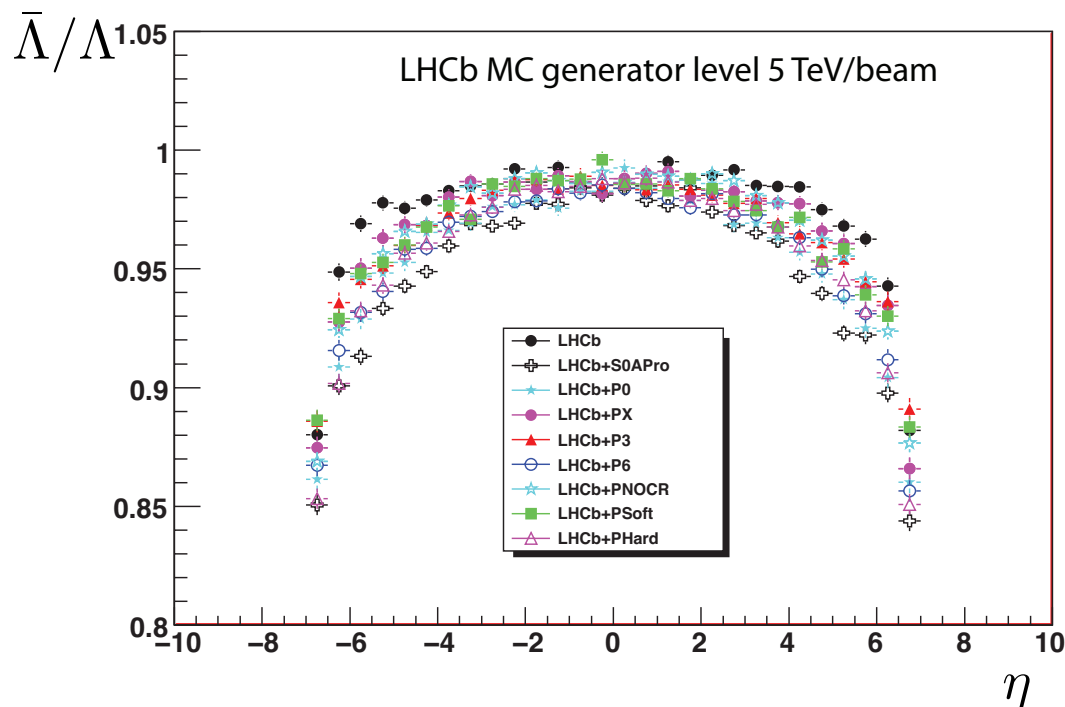
- can be done with very low integrated luminosity;
- vital for understanding charge asymmetries;


■ Inclusive distributions:  $\frac{dn}{dX}$ ,  $\frac{d^2n}{dXdY}$  with  $X, Y = p_T, \eta, \phi \dots$   
distribution to be measured for: all charged particles,  
separately for positives and negatives;

- essential for the understanding of our detector;
- important input for tuning of (MB) Monte Carlo generators;
- joining the efforts of all LHC communities.

No valence strange quarks in the initial state, strangeness probes fragmentation field in a unique way.

Non-diff, prompt  $\Lambda$  and  $\bar{\Lambda}$ .

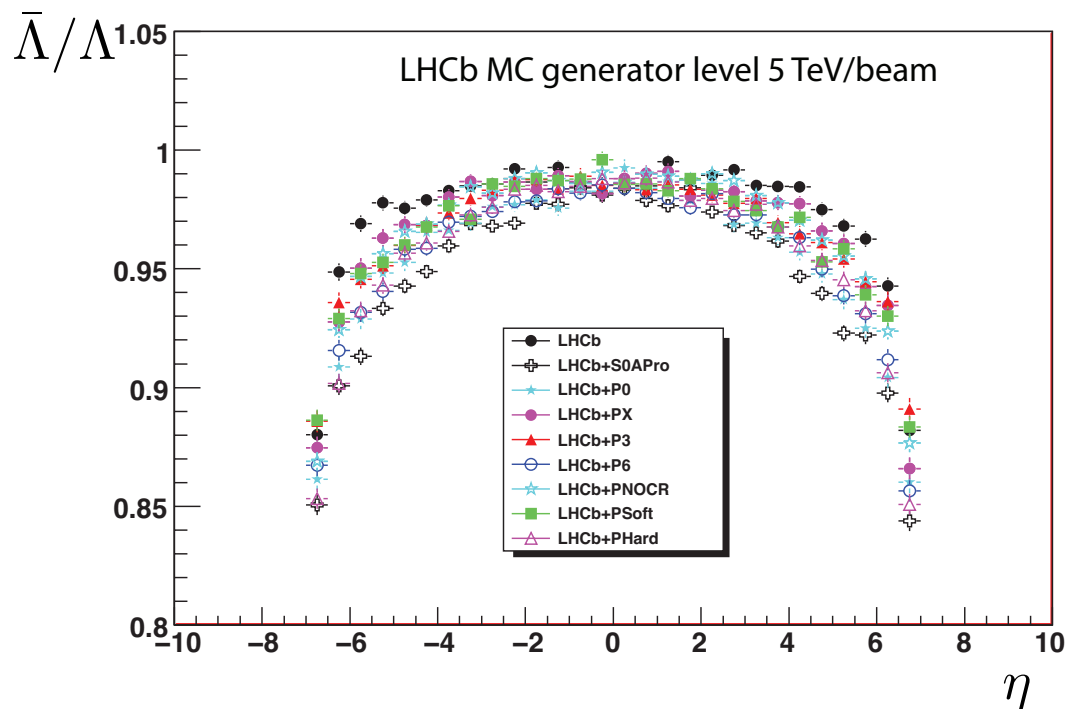





 The distributions were obtained by varying consistently PYTHIA parameters related to: parton distribution functions, initial state radiation, final state radiation, beam remnant, hadronization, underlying event, color reconnection see [P. Skands on Perugia tunes](#) on top of LHCb specific MC tunings.



No valence strange quarks in the initial state, strangeness probes fragmentation field in a unique way.

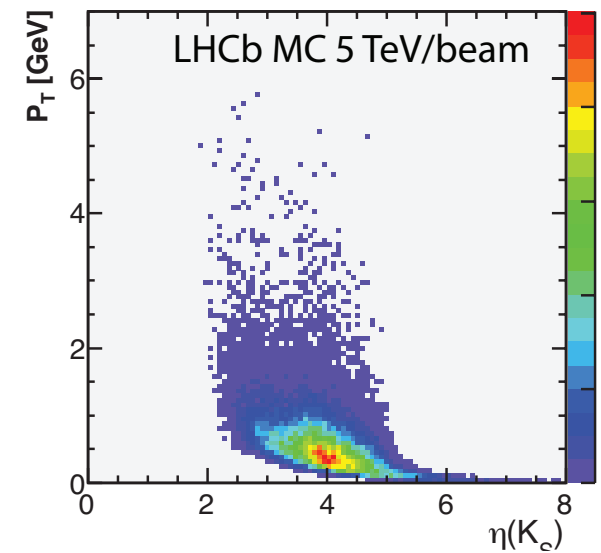
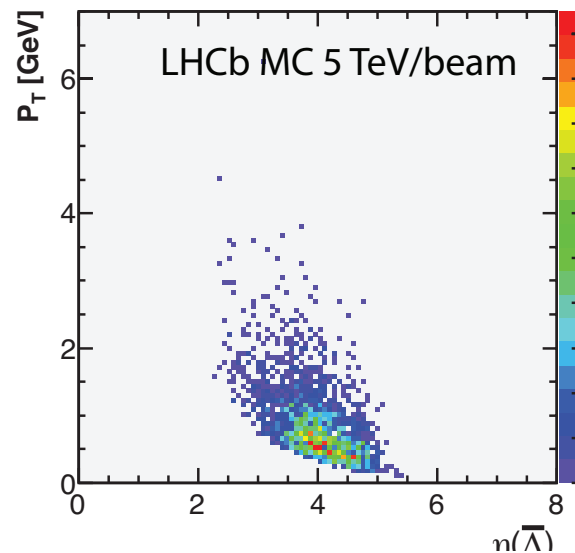
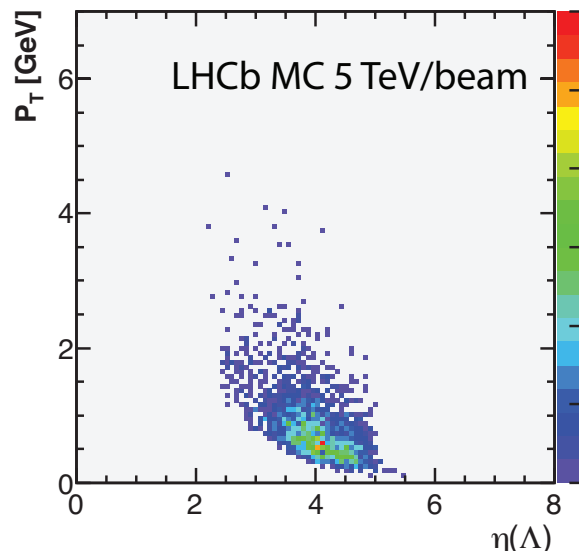
Non-diff, prompt  $\Lambda$  and  $\bar{\Lambda}$ .



-  Up to 5% difference in the LHCb kinematic region, only 1% for the central detectors;
-  Baryon number transport: get as close to the beam as possible!
-  And this is only what (a bunch of) theorists thought of → **“New physics” might be round the corner**

- Look to the prompt  $\Lambda$ ,  $\bar{\Lambda}$ ,  $K_S$  (i.e. produced at the primary vertex or coming from the electromagnetic or a strong decay of a prompt particle in non-diffractive events);
- Use only tracking information (no PID) and very well measured long tracks that are leaving signal in VELO, TT and T1-T3.

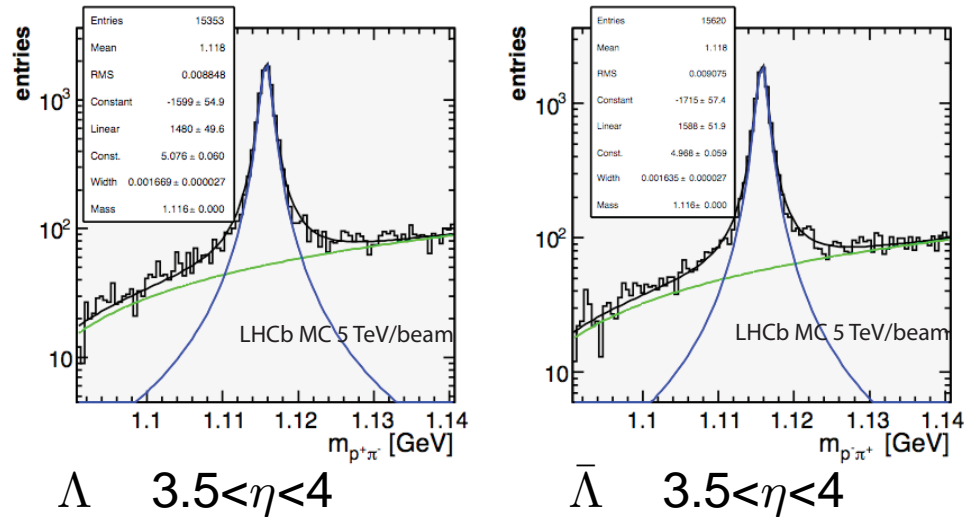
## Selected $V^0$ kinematic range



- $\eta$ ,  $y$  and  $p_T$  distributions of  $V^0$ , since models generally agree on the total amount of strangeness but do not agree on its distribution.
- nr of  $K_S$ /charged particle multiplicity
- meson/baryon ratio  $p_T$  distributions
- antibaryon/baryon ratio  $\eta$ ,  $y$  distributions.
- ...

Ratios are good candidates for first measurements: most systematics cancel, no luminosity measurement needed

Fit of the mass plots in each  $\eta$  bin  $\rightarrow$  nr. the signal and background events;



Statistical error on  $\bar{\Lambda}/\Lambda$  (9 M events, extrapolated to  $10^8$  events - first data)

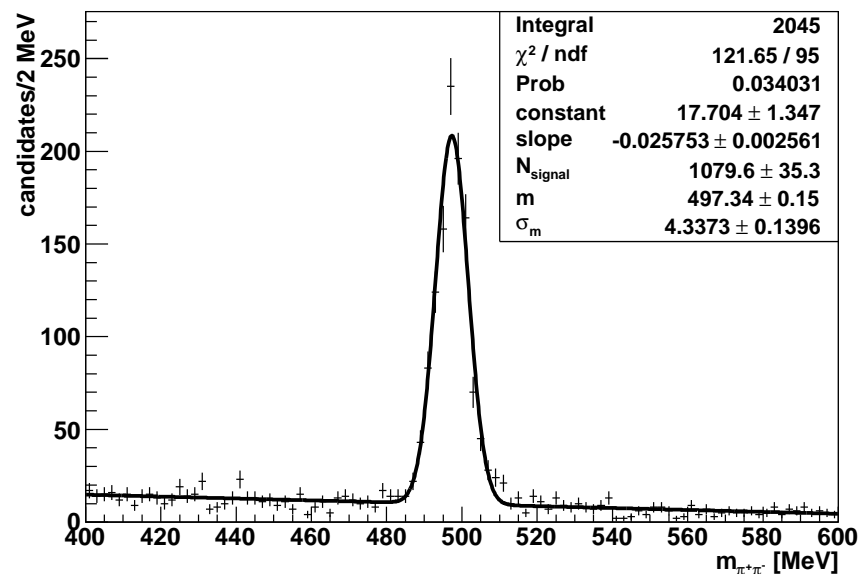
$\eta$ bin	stat. errors	$\eta$ bin	stat errors
(2.5, 3.0)	1.4%	(4.0, 4.5)	0.5%
(3.0, 3.5)	0.8%	(4.5, 5.0)	1.1%
(3.5, 4.0)	0.5%		

*LHCb can discriminate between the models.*

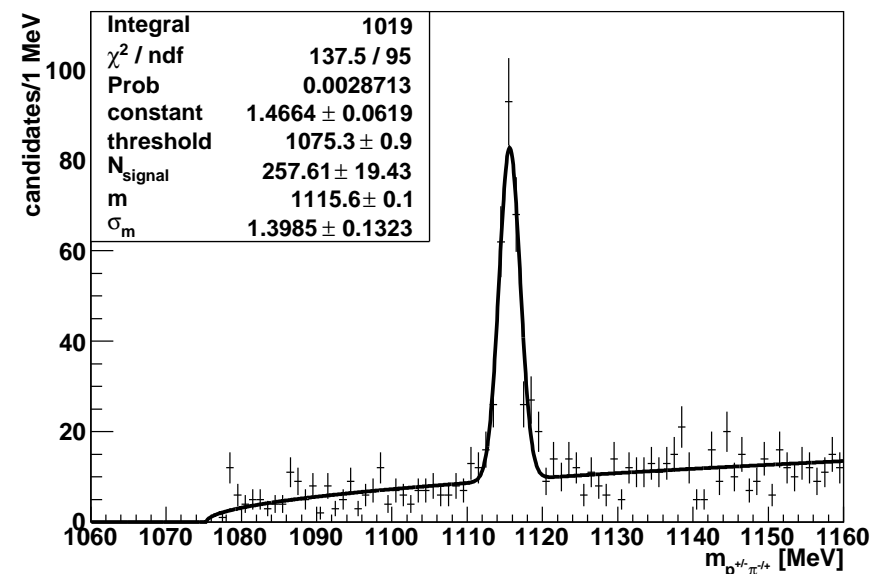
Systematics under study

LHCb very preliminary —  $K_s$  and  $\Lambda$  450 GeV/beam

$m_{\pi^+\pi^-}$  (LHCb 2009 data, preliminary)



$m_{\rho^+\pi^-\pi^+}$  (LHCb 2009 data, preliminary)

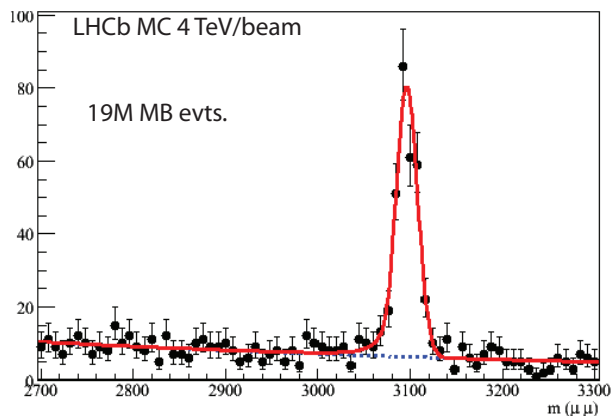
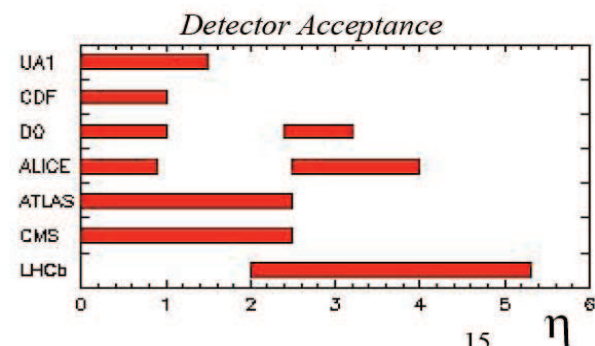


Ready for exciting physics results in 2010.

- Given the large cross-section of  $J/\psi$  production large data samples will be available already in the first days of LHC running.
- Use the  $J/\psi$  sample to measure the cross section for prompt and bb production:
  - $pp \rightarrow X + (\psi(2S), \chi_{c0,1,2}, \dots \rightarrow X) J/\psi$
  - $pp \rightarrow X + bb(b/b \rightarrow J/\psi X)$
- These cross-sections are important for later analysis steps in LHCb:
  - Assess event yields,
  - Understand muon trigger rates,
  - Necessary input for branching fraction measurements.

- $J/\psi$  prompt production not completely understood
- The Colour Octet Model reproduces the  $p_T$  spectrum measured at Tevatron, but not the production polarization ( $\nearrow p_T$  not observed). Other models also predict the same  $p_T$  spectrum but no polarization.

Unique LHCb  $\eta$  coverage where theoretical predictions are less accurate.



- $5 \text{ pb}^{-1}$  at  $\sqrt{s} = 8 \text{ TeV}$ ,  
3M reco  $J/\psi$  expected

LHCb geometry will induce a fake  $J/\psi$  pol.

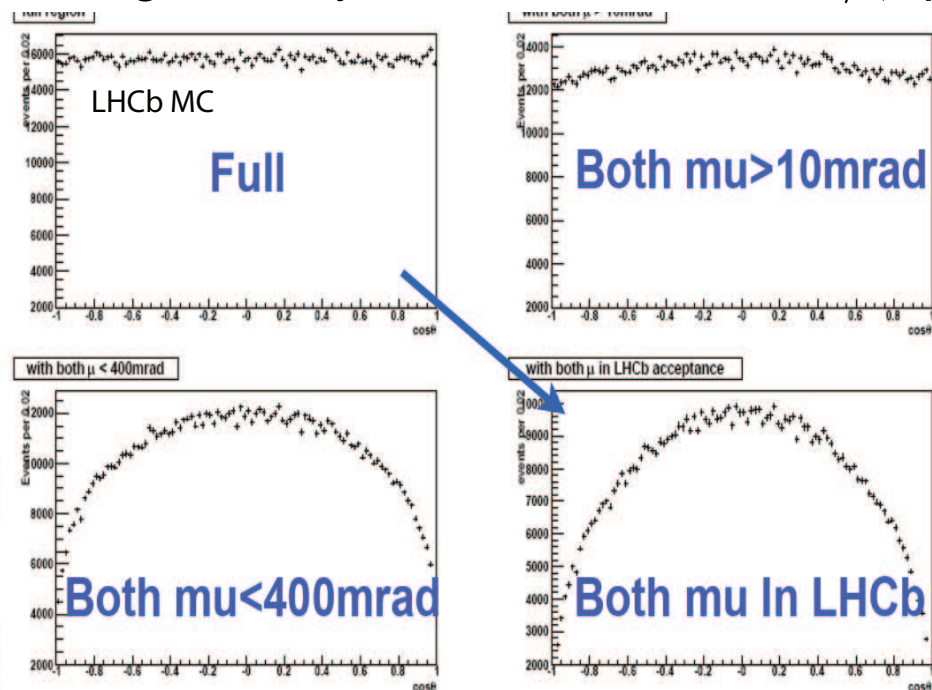
$$\frac{dN}{d\cos(\theta)} \propto 1 + \alpha \cos^2(\theta)$$

$$\theta \angle (p_{\mu^+}^{CM}, p_{J/\psi}^{SL}).$$

$\alpha=+1$  transverse pol;

$\alpha=-1$  longitudinal pol;

$\alpha=0$  no polarization



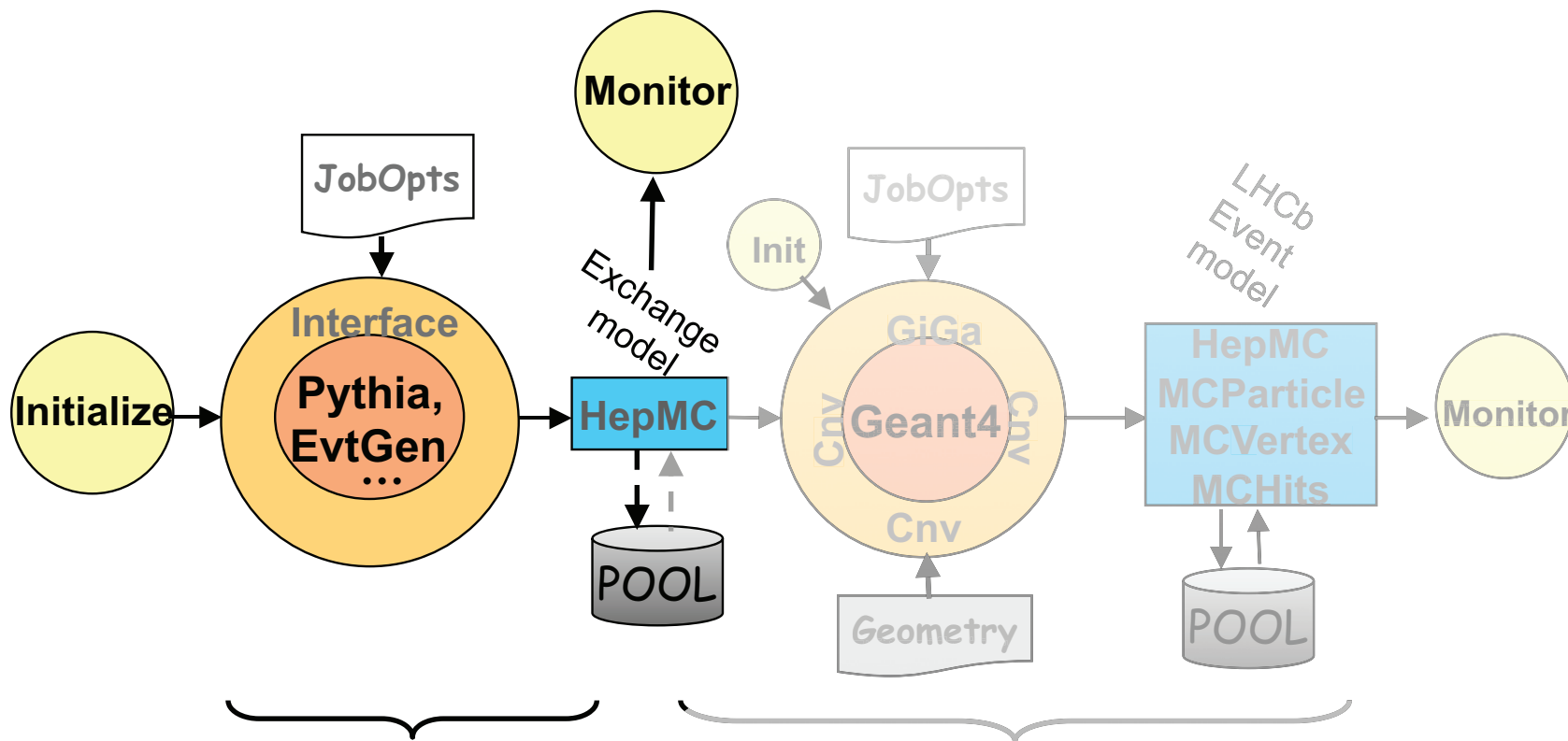
input $\alpha$	input $\sigma(nb)$	$\sigma(nb)$ measured for $\alpha=0$
0	4340	$4337.3 \pm 7.7$
+1	4909	$4305.4 \pm 7.7$
-1	3518	$4383.0 \pm 7.9$

Syst. error up to 25 % if ignoring polarization.



- The simulation application, Gauss, is a collection of “User Code” specialized for physics simulation based on the underlying OO software framework (Gaudi) used by all LHCb event processing software;
- Specialized algorithms and tools for generators (PYTHIA, EvtGen, ...) and detector simulation (Geant4);
- All generators “wrapped” into C++ code to make them “callable and controllable” from within the framework at run time.









Two INDEPENDENT phases normally run in sequence as in production, but generator phase can and it is run by itself.



**Event Generation**  
 primary event generator  
 specialized decay package  
 pile-up generation

**Detector Simulation**  
 geometry of the detector (LHCb → Geant4)  
 tracking through materials (Geant4)  
 hit creation and MC truth information (Geant4 → LHCb)

The generation algorithm uses tools, i.e. pieces of code realizing specific actions of the generation sequence:

-  **PileUpTool** - Generation of number of pile-up events
-  **SampleGenerationTool** - generate a given sample of events (minimum bias, inclusive, signal, ...)
-  **ProductionTool** - Generation of one p-p interaction
-  **BeamTool** - Generation of beam parameters (3 momentum)
-  **DecayTool** - Decay of unstable particles,
-  **CutTool** - Cut at generator level,
-  **FullGenEventCutTool** - Cut on full event properties,
-  **VertexSmearingTool** - Smearing of primary vertex.

Each tool has a generic interface and (at least) one specific implementation. This allows to use different methods to realize each action. For example, generation of p-p interactions can be done with PYTHIA or HERWIG, without changing the rest.

The functionality of Production and Decay tools is implemented using external generator libraries

- **PYTHIA6** to generate pp interactions up to hadronization - LHAPDF for PDF
- **EvtGen** to generate the decay and evolution of all particles, B hadrons, generic and user/signal.
  - delegate to PYTHIA when decay not present in decay table (called internally)
  - delegate to Photos for QED radiative corrections (called internally)

Ensure both production and decay use the same particle properties (masses, lifetimes, ...) via Gaudi particle property service;

HepMC used not only to save the events on output but also as exchange format between production and decay.

- PYTHIA 6.421.(2)
- LHAPDF 5.7.1
- Photos 215.(5)
  - Called inside the EvtGen package.
  - Used to generate radiative corrections for every decay modes.
  - We follow the updates. If the C++ version will be available, we are interested to test it.
- EvtGen - v11r6: version obtained by merging in 2009 the contributions from Babar, Belle, CDF, LHCb (A. Rys), with additional LHCb changes, models and updated decay files
  - $B^0, B_s$  mixing
  - $B_s \rightarrow J/\psi\Phi$  correct time dependant angular distributions
  - rare semileptonic decay model using Wilson coefficients ( e.g.  $B \rightarrow K^* \mu\mu$ )
- HEPMC 2.03.(1)

Libraries linked directly from LCG builds

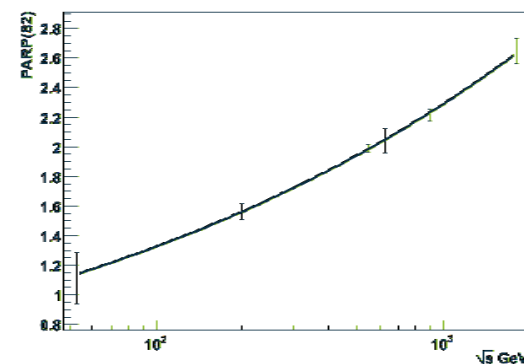
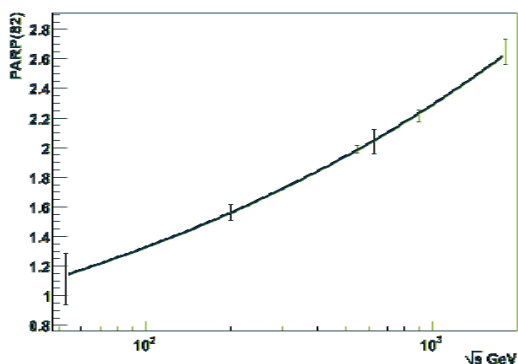
**Minimum Bias:** Keep all events generated by PYTHIA: elastic, diffractive, inelastic.

**Inclusive:** Extract events generated by PYTHIA with at least one b-(or c) hadron in 400 mrad w/r to the z axis. If all of these hadrons have  $p_z < 0$ , flip the whole event.

**Signal:** Extract events generated by PYTHIA containing one  $B^\pm$  (or one  $B^0/\bar{B}^0$ ,  $J/\psi$ ,  $D_s^+/D_s^-$ , e.t.c.) in 400 mrad. If there are several candidates, choose randomly one. If it has  $p_z < 0$ , flip the whole event. To speed up generation, if the interaction contains a b quark, repeat the hadronization process of PYTHIA until the interaction contains the  $B^+/B^-$ . Decay the signal candidate according to a forced channel with EvtGen. Decay  $B^{**}$  and B mixing with EvtGen.

**Special**(Higgs, top, W, Z, ...): Keep all events generated by PYTHIA with special settings and passing specific generator level cuts ( $p_T(\text{lepton}) > 4 \text{ GeV}$ ). Decay Higgs, top, W, Z, ... with PYTHIA, all other particles with EvtGen.





- PYTHIA 6.4 (LHAPDF-CTEQL61) with Interleaved Multiple Interaction (MI) model tuned to agree with experiments measured particle multiplicities;
- Retune  $p_{T,min}$  (done in the past for PYTHIA 6.2 with old MI model)
- Tune to central charge particle densities from UA5 and CDF
- Find PARP(82) value for new MI model at each energy
- PARP(82) extrapolated to LHC energy using equation (suggested by PYTHIA)



$$p_{\perp} = p_{\perp min}^{LHC} \left( \frac{\sqrt{s}}{14TeV} \right)^{2\epsilon}$$




- Included in the retune are the PARJ(11 - 17) settings tuned to correctly reproduce excited meson states important for us relative fraction of B mesons

Introduce Color Octet Model for Quarkonia production:

-  only prompt  $J/\psi$  was generated in the past with color-singlet model
-  known not to reproduce correctly production at Tevatron, now generate prompt  $J/\psi$  with also color-octet production (available in PYTHIA 6.4)
-  larger cross section + harder spectrum
-  add possibility to produce simultaneously  $\psi(2S)$ ,  $\psi(3770)$ ,  $\Upsilon(1S)$ ,  $\Upsilon(2S)$ ,  $\Upsilon(3S)$ ,  $\Upsilon(4S)$  and  $\Upsilon(5S)$ .

LHCb-2007-042

## PYTHIA 8

-  not yet used for production but integrated in GAUSS, consistency checks with PYTHIA 6, working and giving reasonable results; the integration rather easy.
-  Still details to study: status code of particles, repeated hadronization method, use of user processes, ...
-  validation work discontinued two years ago due to the lack of manpower although latest version available in Gauss.



Gauss allows to use other production and decay engine than the default ones

- HERWIG 6.510.(3) + Jimmy 4.31.(3) + MC@NLO
- Hijing 1.383.bs.2 for beam-gas events
- HiddenValley HV 0.403
- AlpGen 2.1.2

Gauss allows to use other production and decay engine than the default ones

## HERWIG 6.510.(3) + Jimmy 4.31.(3) + MC@NLO

- A  $b\bar{b}$  event generator different from PYTHIA useful for estimates of systematic uncertainties.
- Work in progress to resolve some outstanding issues: correct handling of MC@NLO negative weights; correct behaviour for pile-up; checking/optimisation of tunable parameters.
- Interfacing to MC@NLO is difficult: implemented as a standalone program rather than as a library of routines; designed so that results need to be written to file for rereading, and can't be passed directly to a showering routine.
- Limited support for further development in this area at present. In future may move to HERWIG++, and use POWHEG instead of MC@NLO.

## Hijing 1.383.bs.2 for beam-gas events

## HiddenValley HV 0.403

## AlpGen 2.1.2

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- Code embedded into LHCb framework and run inside Gauss generator step.
- The update of the code, built within the LHCb environment (to e.g. newer version of original HV), is not trivial task.

- AlpGen 2.1.2

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HiddenValley HV 0.403



AlpGen 2.1.2

- used it to simulate 4b, 4c and 2b2c-events, which are considered as one of the major background for Hidden Valley and other high-pt physics.
- work has been done with large help of theory people from John Hopkins University
- not working within new Gauss versions, recommissioning phase.

 BCVEGPY

 SHERPA 1.3.

## BCVEGPY

-  extension to PYTHIA
-  for Bc production, private build

## SHERPA 1.3.

## BCVEGPY

## SHERPA 1.3.

- Sherpa as ProductionTool with EvtGen as well as PYTHIA with Sherpa as DecayTool.
- Sherpa as DecayTool: Signal decays are possible, but CP-violation does not work when using signal decays. Mass smearing still complicated, as PYTHIA particles have to come on-shell. Work in progress.
- Sherpa as ProductionTool: Incl.  $b\bar{b}$  is possible but need to use PYTHIA for Pile-Up, as Sherpa can not produce Minimum Bias. Inclusion of Minimum Bias, would be a feature we would be happy to see in near future.
- Sherpa as Production+DecayTool: Is planned, as it would help us to benefit from the spin correlations used in Sherpa. As long as no Minimum Bias is available in Sherpa, we will have to use PYTHIA for Pile-up.
- Wish list: We would really appreciate if signal decays would become standard in Sherpa, e.g. part of the Run.dat steering files. Most important topic for us is correct simulation of CP violation when using signal decays as well as the correct simulation of the influences of CP violation on the angular distributions, e.g. in  $B_s \rightarrow J/\psi\Phi$  or  $B_s \rightarrow \Phi\Phi$  etc.



 BCVEGPY

 SHERPA 1.3.

*Small experiment, not infinite amount of people, hard to find people to integrate the generators in our framework, but ...*

*Gauss is able to read the "external" events produced by any generator in LHA format both as parton-level "hard" event, where Gauss will perform the subsequent hadronization, and as "final hadronized" event.*

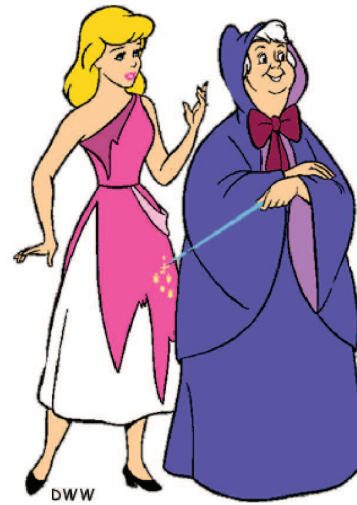
*We can study practically all generators if one offers as input LHA-xml or HepMC Ascii files . For production through full simulation chain, on the Grid, one needs though to interface them to Gauss*

- LHCb started exploiting the very first minimum bias data
- In parallel to detector calibration, Monte Carlo tuning and tests of future charm and beauty physics analysis, very interesting physics studies are planned using the first  $10\text{-}20 \text{ pb}^{-1}$ : strangeness production,  $J/\psi$  production and polarization ...
- Our detector covers a unique kinematical range offering a wonderful ground for testing different models, generators, tunings.
- In LHCb simulation framework we can use practically all generators.

*Inclusive production*



*Inclusive production*    QCD



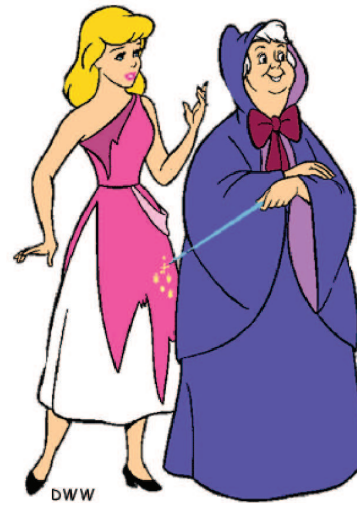
*Inclusive production*



*Inclusive production*



*Inclusive production* QCD



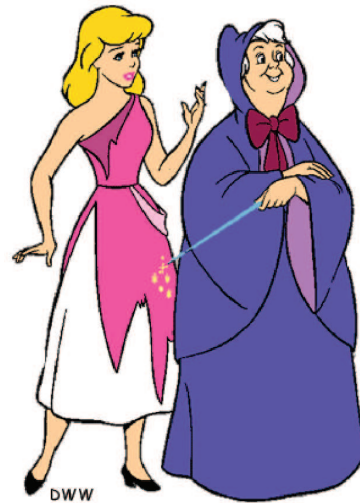
*Inclusive production*



*Inclusive production*



*Inclusive production* QCD



*Inclusive production*



# Thanks

Several people helped me to put together the information for the second part of the talk

G. Corti, P. Robbe, K. Harrison, V. Belyaev, M. Kucharczyk, V. Coco, J. He, J. Wishahi ...

Thanks a lot!