Minimum Bias at LHCb

Umberto Marconi,
INFN Sezione di Bologna

MPI@LHC 2008

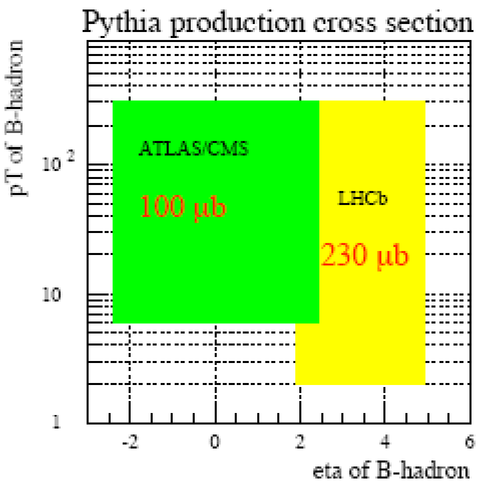
Perugia, October 2008

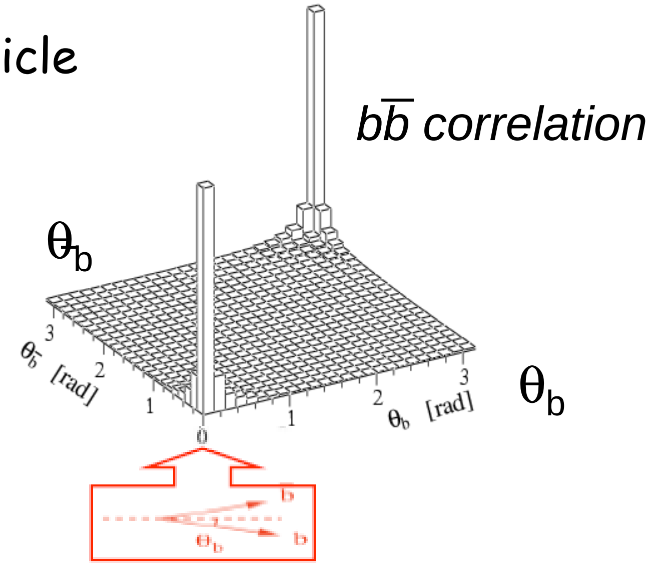
The LHCb Experiment.

- LHCb is a dedicated beauty physics experiment at LHC.
- Advantages of beauty physics at hadron colliders:
  - High value of the beauty cross section expected at 14 TeV: $\sigma_{bb} \sim 500\ \mu b$ (the e+e- cross section at $\Upsilon(4s)$ is 1 nb).
  - Access to all b-hadrons: B_d, B_u, B_s, b-baryons and B_c
- The challenge:
  - Multiplicity of tracks.
  - Rate of background events: $\sigma_{inel} \sim 80$ mb

The LHCb Detector.

- Spectrometer to cover the forward region: bb pair production peaks at small ϑ angles, with small relative opening angles.
- Selective and efficient trigger system, also on fully hadronic B decay modes.
- Tracking and vertex reconstruction for good mass resolution and proper time measurements of secondary vertices.
- PID capability to discriminate particle in the final states: μ, π, K



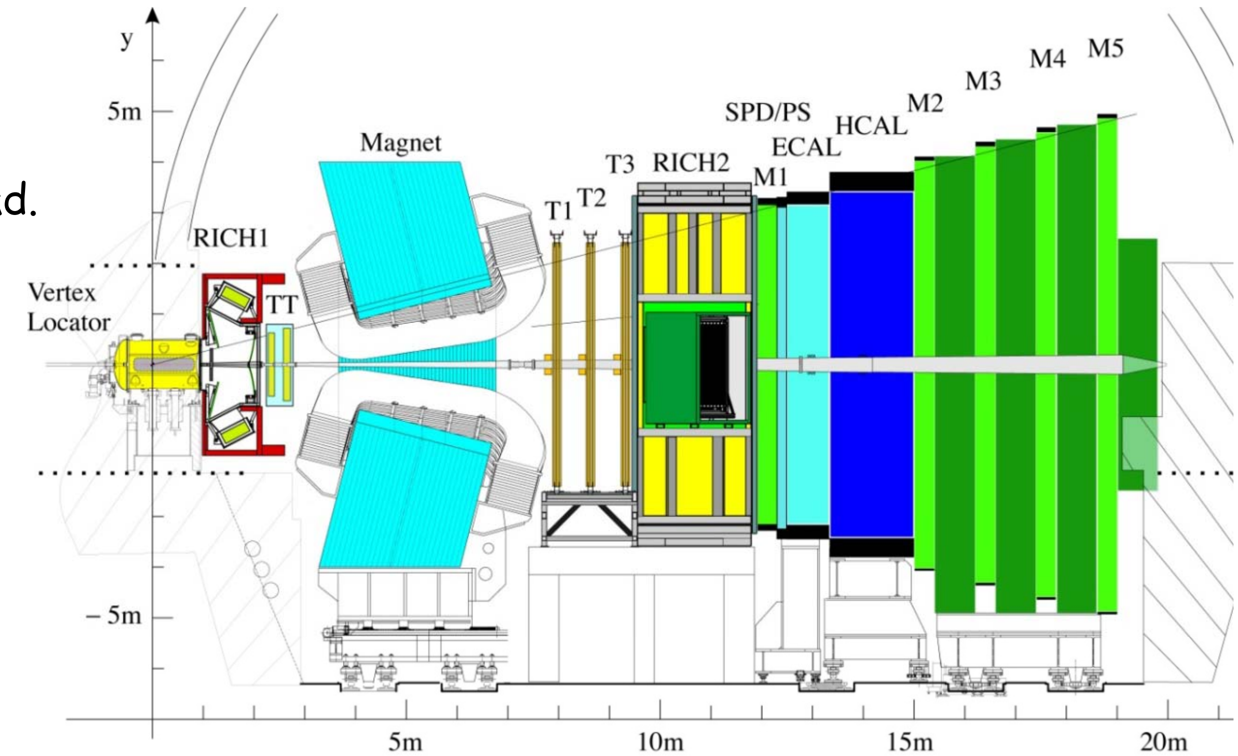


B meson average momentum p ~ 80 GeV/c

B meson average transverse momentum $p_\perp$ ~ 5 GeV/c

The LHCb Detector (II).

15 < ϑ < 300 mrad.



VELO: Silicon Strip detector for precise secondary vertex reconstruction.

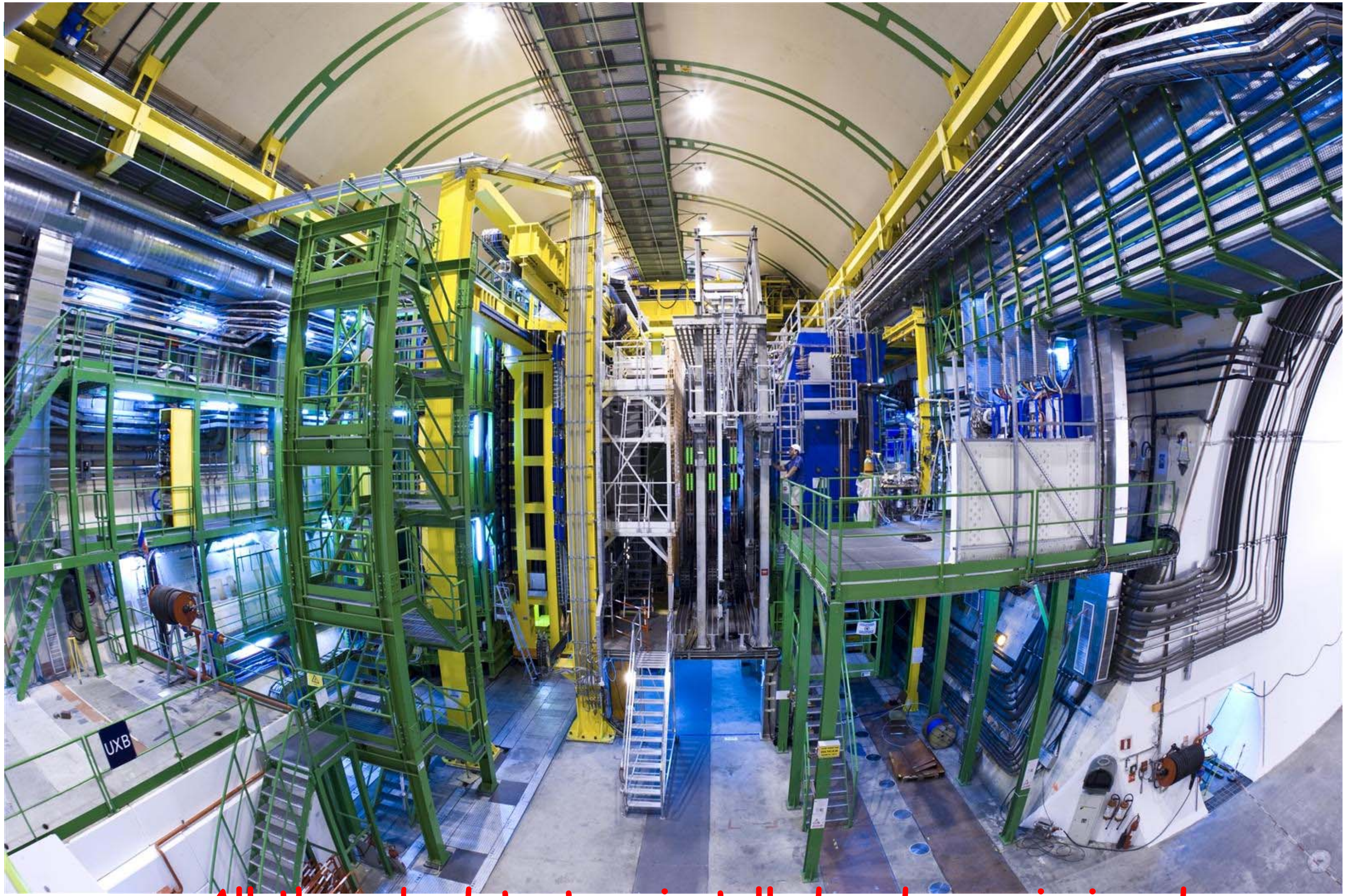
TT,T1,T2,T2: tracking stations, Silicon Strip and Straws to detect charged particles.

RICH1, RICH2: Ring Imaging Cherenkov detectors for π/K/p separation.

ECAL, HCAL: electromagnetic and hadronic calorimeters for trigger and energy flow.

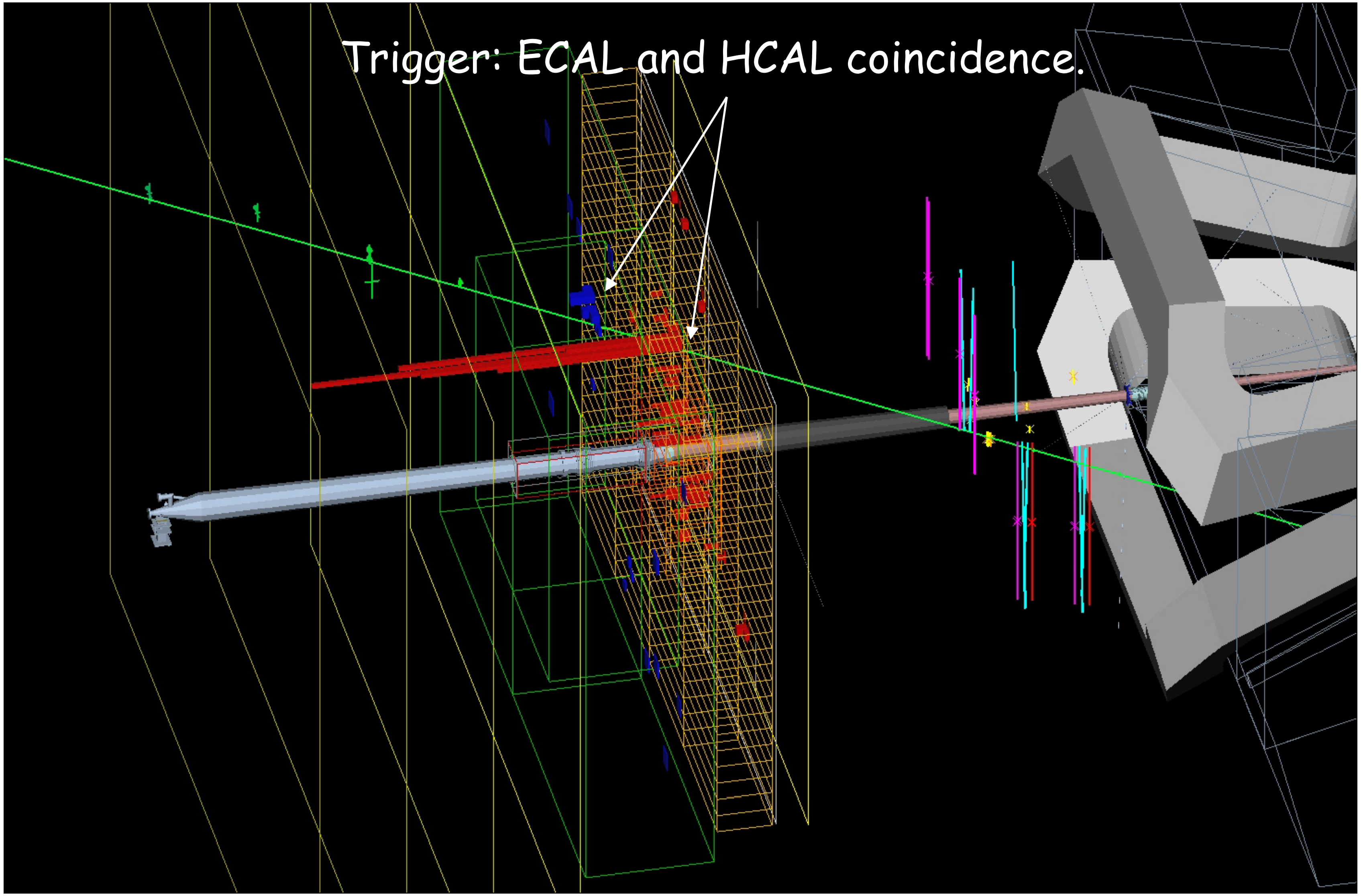
M1-M5: Muon stations for muon identication

The LHCb Detector.

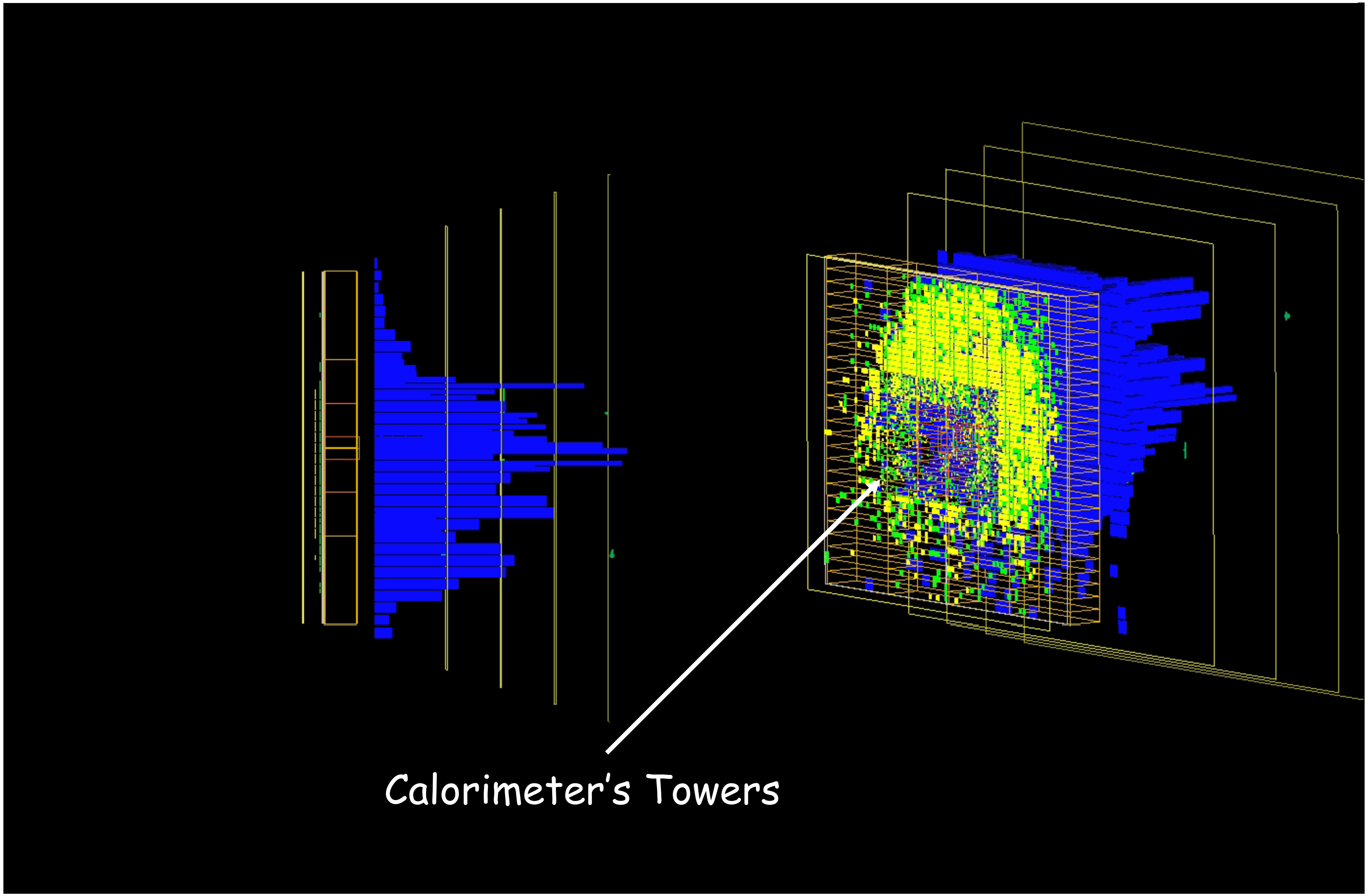


All the sub-detectors installed and commissioned

Detector Commissioning with Cosmics.

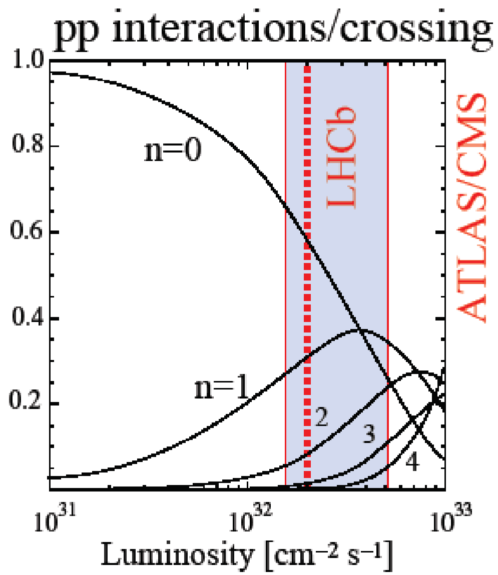


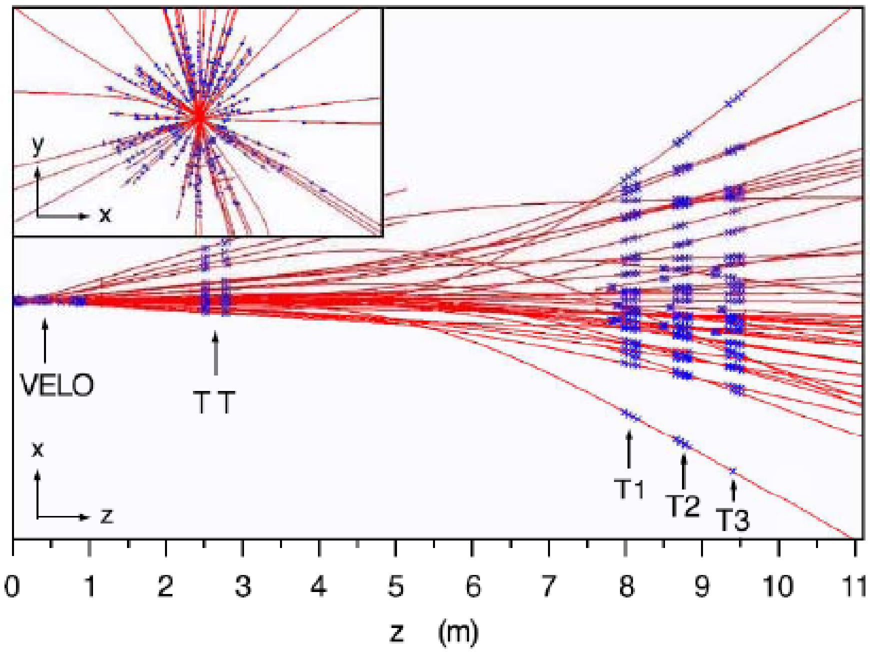
Particles Splash due to Beam Dumping



LHCb Running Conditions.

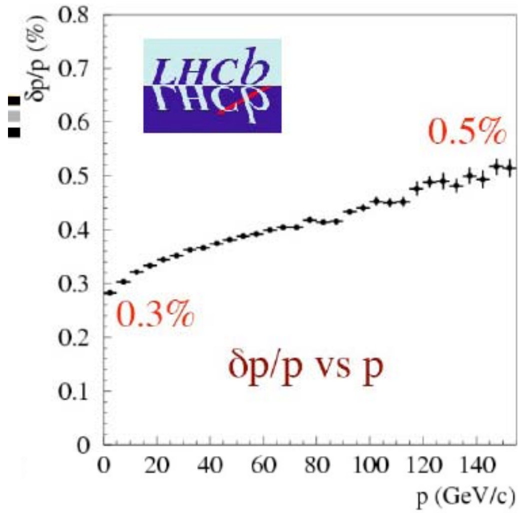
- Run at reduced luminosity with respect to the LHC capabilities: Average instantaneous luminosity $L = 2\times10^{32}\ cm^{-2}s^{-1}$.
- L value at the level of $2\times 10^{32}\ cm^{-2}s^{-1}$ favours the probability of small number of primary interactions per bunch crossing.
- At the average luminosity 10^{12} bb pairs produced per year of data taking (2 fb^{-1}).

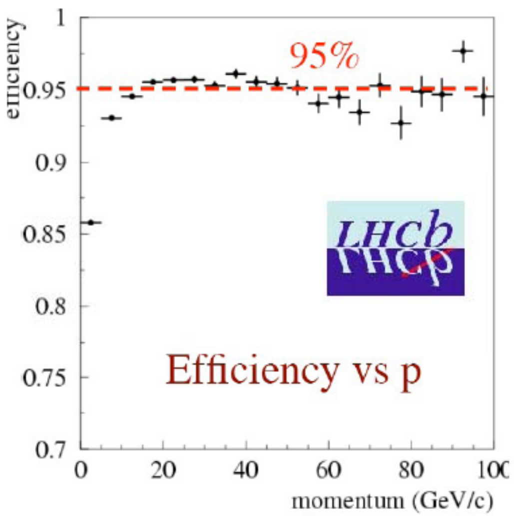


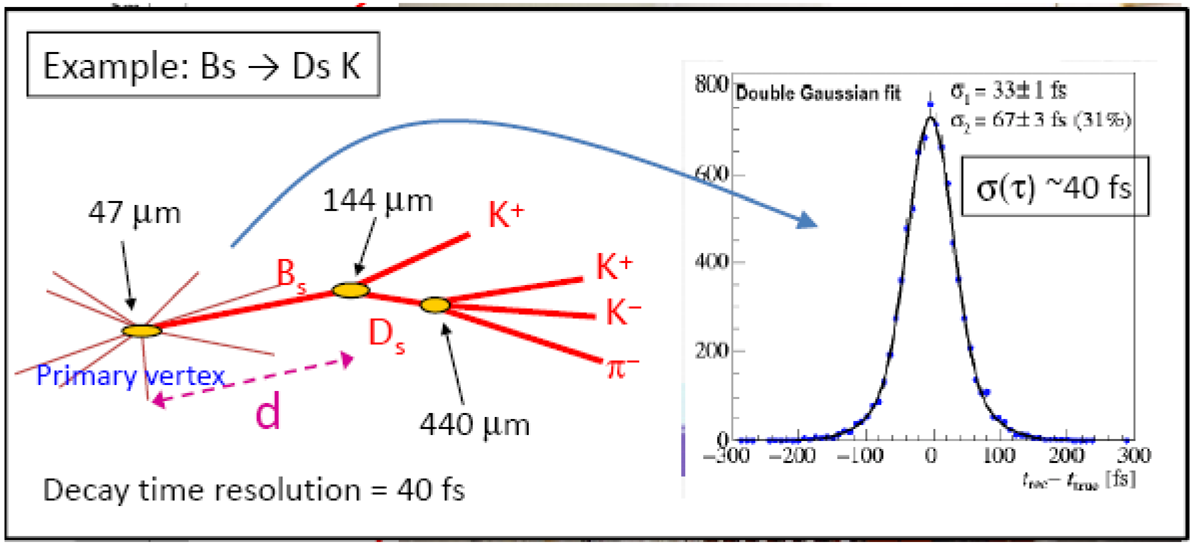


Detector Performances.

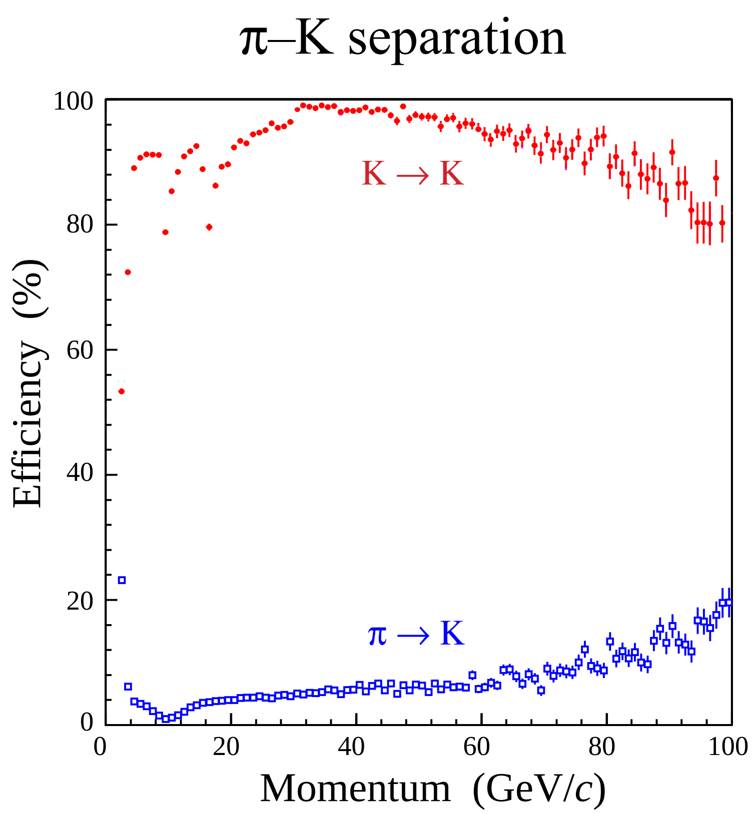
- $\delta p/p$, depending on p: 0.3% ÷ 0.5%.
- Mass resolution: 10÷20 MeV/c^2
- High efficiency on "long tracks" from B decays: 95%. 4% ghosts for tracks with p_T> 0.5 GeV/c.
- Impact parameter resolution: σ_{IP} ~ 30 μm
- Proper time resolution: 40 fs.

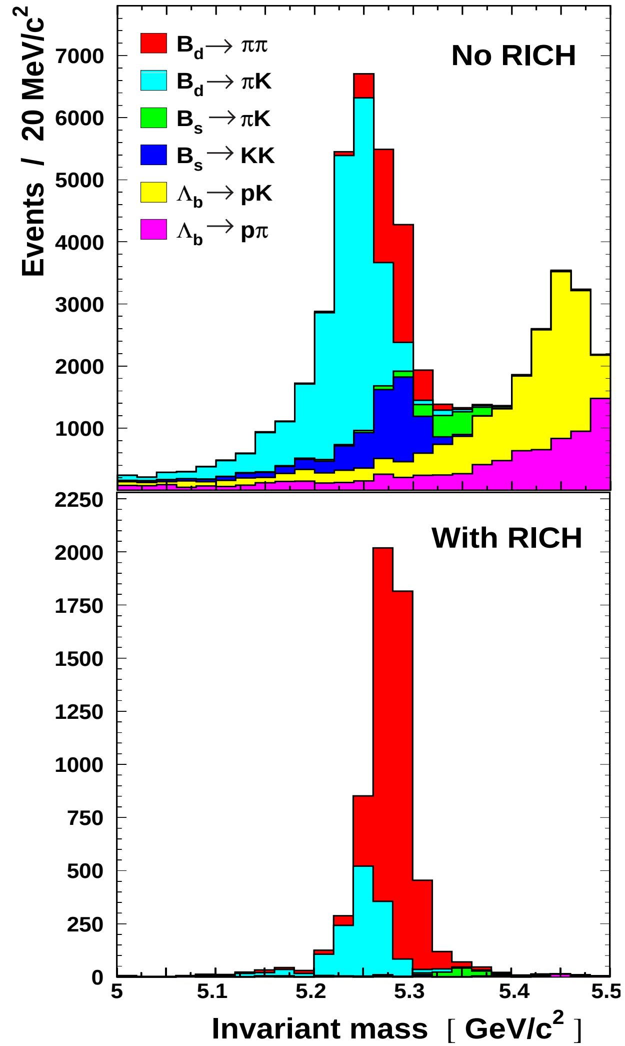






Particle ID





Kaon ID ~ 88%

Pion mis-ID ~ 3%

The LHCb Trigger

- LHCb needs a trigger system to select B events.
- The trigger system is organized in two layers.
  - The **L0 trigger** selects events with high p_T particles in the final state, detected with the Calorimeters and the Muon detectors, reducing the input rate from 40 MHz to **1 MHz**.
    - L0 is a hardware trigger, implemented on custom electronics.
  - The **High Level Trigger** selects exclusive B decay modes as well as auxiliary signals for systematic studies, like B inclusive decays.
    - HLT is a software trigger, implemented as selection algorithms running on a computing farm of about 2000 CPUs.
- The **DAQ rate**, after the HLT, is **2 kHz**.
- **MB events** can be recorded at the maximum rate of about **2 kHz** (max available bandwidth).
- **MB physics** can be performed on early data with large data samples.

MPI: “Hic Sunt Leones”

MPI: Multi Partonic Interactions

MPI in Pythia.

- The composite nature of the two colliding protons implies the possibility that several pairs of partons can enter into separate and simultaneous scatterings.
- Multiple interactions contribute to the overall event activity, in particular at **low $p_\perp$**.
- The total rate of parton-parton interactions is described by means of perturbative QCD. The perturbative parton-parton scattering framework is extended into the low-$p_\perp$ region.
- A **regularization** of the **divergence** in the cross section for $p_\perp \to 0$ has to be introduced. The cutoff $p_{\perp min}$ is the **main free parameter of the model**.

$$\sigma_{\rm hard}(p_{\perp\rm min}) = \int_{p^2_{\perp\rm min}}^{s/4} \frac{{\rm d}\sigma}{{\rm d}p^2_\perp}\,{\rm d}p^2_\perp$$

- The average number of interaction per collision $\langle n \rangle = \dfrac{\sigma_{hard}(p_{\perp\min})}{\sigma_{nd}(s)}$
- The probability for a parton collision to take place at $p_\perp$ $P(p_\perp) = \dfrac{1}{\sigma_{nd}(s)} \dfrac{d\sigma}{dp_\perp}$

Tuning of MPI.

- In LHCb tuning of the Multi Partonic Interactions parameters has been carried out using Pythia versions 6.1÷6.3.
- LHCb is currently using Pythia version 6.4, which provides a **new MPI model**.
- Amongst the MPI Model available LHCb uses Pythia **Model 3**: varying impact parameter and hadronic matter overlap consistent with a Gaussian matter distribution. Continuous turn-off of the cross-section at $p_{\perp min}$.
- $p_{\perp min}$ the cross-section parameter (scale of the cutoff) can be set through:

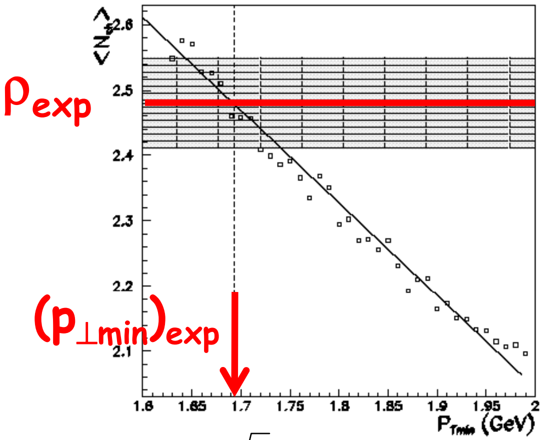
$$p_{\perp \min}(s) = A \times s^{\varepsilon} = PARP(82)\left(\frac{\sqrt{s}}{PARP(89)}\right)^{2\,PARP(90)}$$

$$\rho_{\exp} = \left.\frac{dN_{ch}}{d\eta}\right|_{|\eta|<0.25}$$

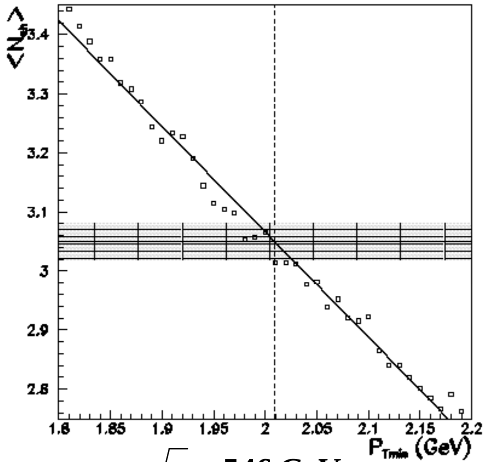
$\sqrt{s}$ (GeV)	ρ_{EXP}
53 [UA5]	1.96 ± 0.10
200 [UA5]	2.48 ± 0.06
546 [UA5]	3.05 ± 0.03
630 [CDF]	3.18 ± 0.12
900 [UA5]	3.46 ± 0.06
1800 [CDF]	3.95 ± 0.13

- Parton distribution functions to be chosen carefully.
  - CTEQ4L. Inclusion of energy dependent $p_{\perp}$ cut-off.
- Tuning of $p_{\perp min}$ on experimental data.
  - Charged particles densities ρ_{exp} produced in proton-antiproton collisions at the central region pseudo-rapidity η=0.

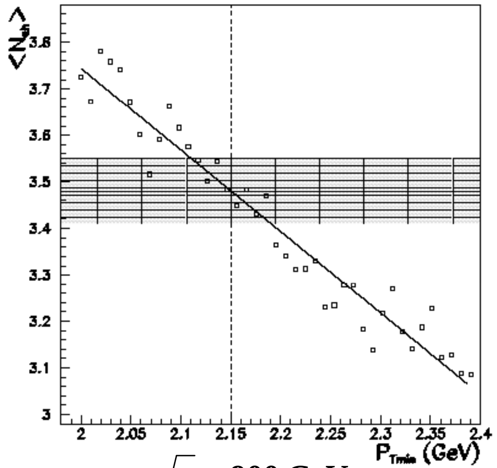
MPI $p_{\perp\min}(s)$



$\sqrt{s} = 200\,GeV$



$\sqrt{s} = 546\,GeV$

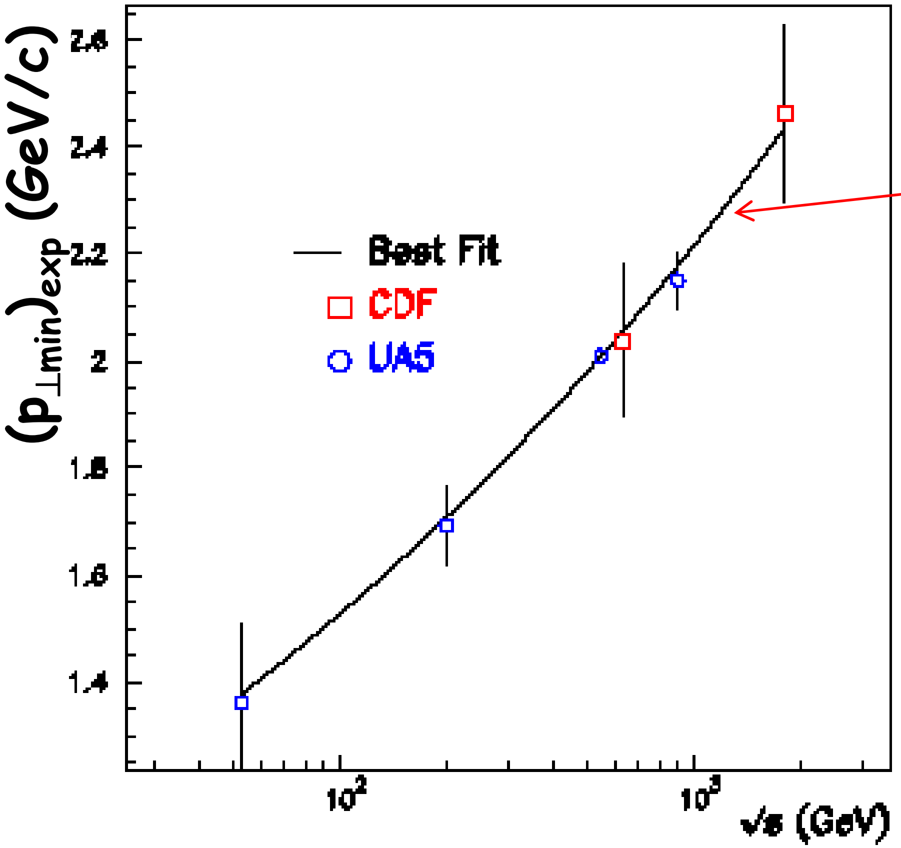


$\sqrt{s} = 900\,GeV$

$$\left\langle {dN_{ch}}/{d\eta} \right\rangle_{|\eta|<0.25}(s) = A(\ln s)^2 + B\ln s + C \Longrightarrow p_{\perp\min} = p_{\perp\min}(s)$$

- At a given $\sqrt{s}$ generate the density of charged particles varying the $p_{\perp\min}$ values.
- Generate 10^6 proton-antiproton collisions (non-diffractive) for each $p_{\perp\min}$ value.
  - Uncertainty on the fitted value is then unaffected by MC statistical errors.
- At the given $\sqrt{s}$ fit the $\rho(p_{\perp\min}) = A\, p_{\perp\min} + B$ dependence of simulated events.
- The solution for $p_{\perp\min}$ is: $(p_{\perp\min})_{exp} = A^{-1}(\rho_{exp} - B)$ with error $\Delta(p_{\perp\min})_{exp} = A^{-1}\Delta\rho_{exp}$

MPI $p_{\perp\min}^{LHC}$



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

Fit Results

$$p_{\perp\min}^{LHC} = (3.39 \pm 0.16)\ GeV/c$$

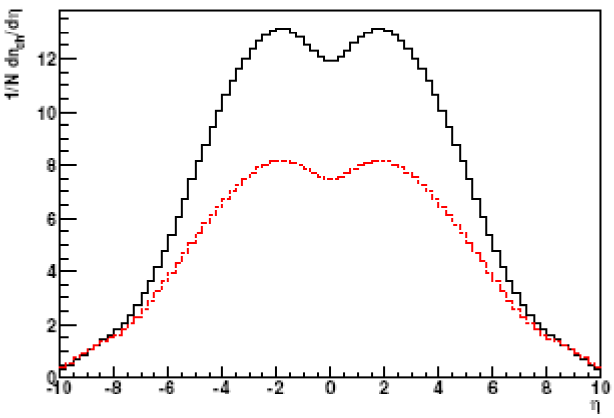
$$\varepsilon = 0.081 \pm 0.007$$

$$\frac{1}{N_{ch}}\frac{dN_{ch}}{d\eta}\bigg|\eta \leq 0.25 = 6.37 \pm 0.52$$

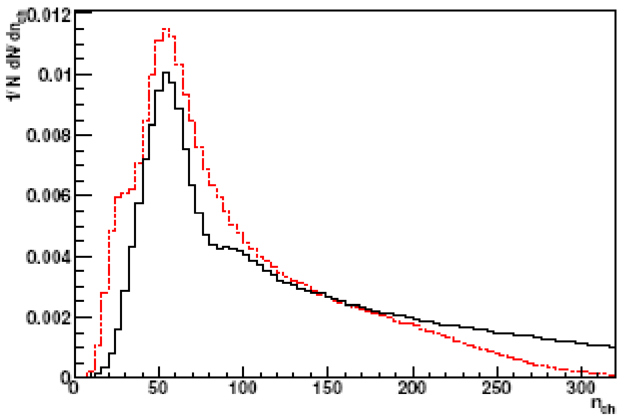
Pythia v6.226

MPI in Pythia 6.4

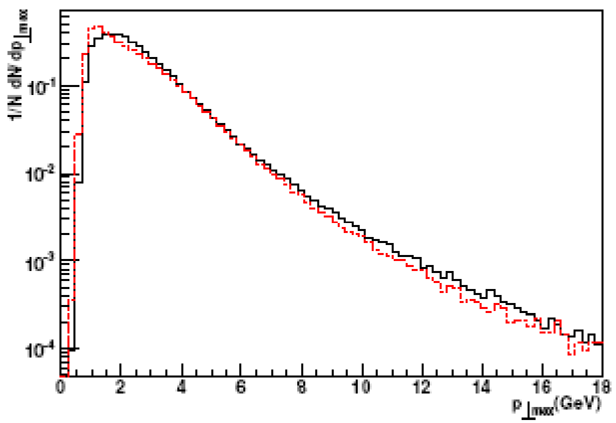
Pseudo-rapidity



Charged multiplicity



Maximum $p_\perp$



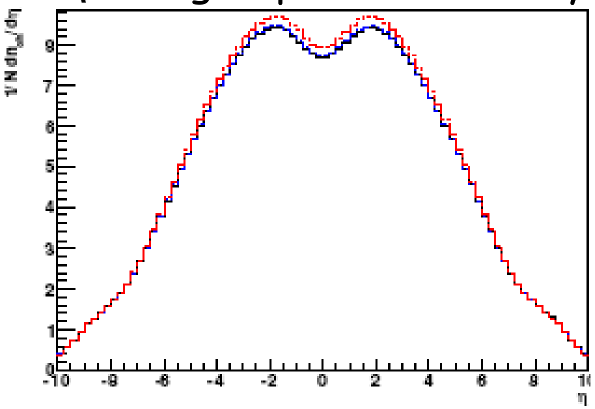
- Needs of retuning of the $p_{\perp min}$ value, moving to Pythia 6.4, due to the new available MPI model.
- Comparison of **Pythia 6.406** old-MPI model (red line) with **Pythia 6.406** new MPI model (black line) in the full solid angle acceptance, when using the same value of $p_{\perp min}$ = 3.41 GeV/c and ε=0.126, tuned for the old MPI model.
- The updated fit of MPI parameters tuned on Pythia 6.406 new MPI model gives:

$$p_{\perp \min}^{LHC} = (4.28 \pm 0.25)\, GeV/c \qquad \varepsilon = 0.119 \pm 0.009$$

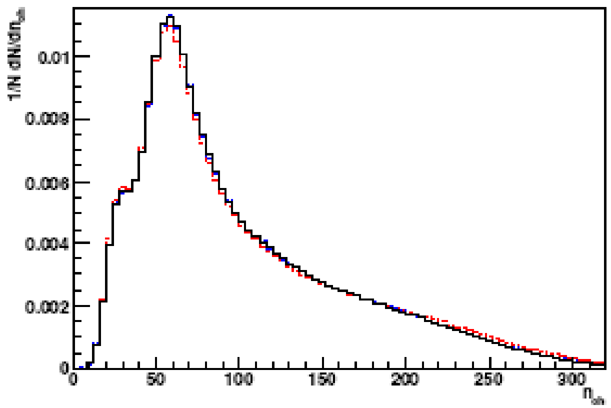
- Maximum $p_\perp$: charged stable particle with highest $p_\perp$

Tuning of MPI in Pythia.

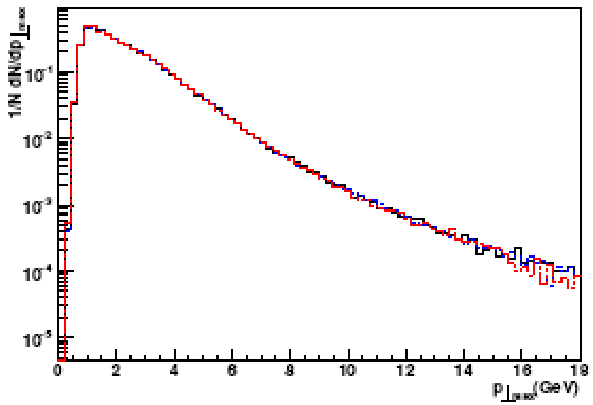
η charged particle density



Charged multiplicity



$p_{\perp max}$ distribution



- Distributions at LHC energy and full 4π acceptance.
- Comparison of different Pythia versions:

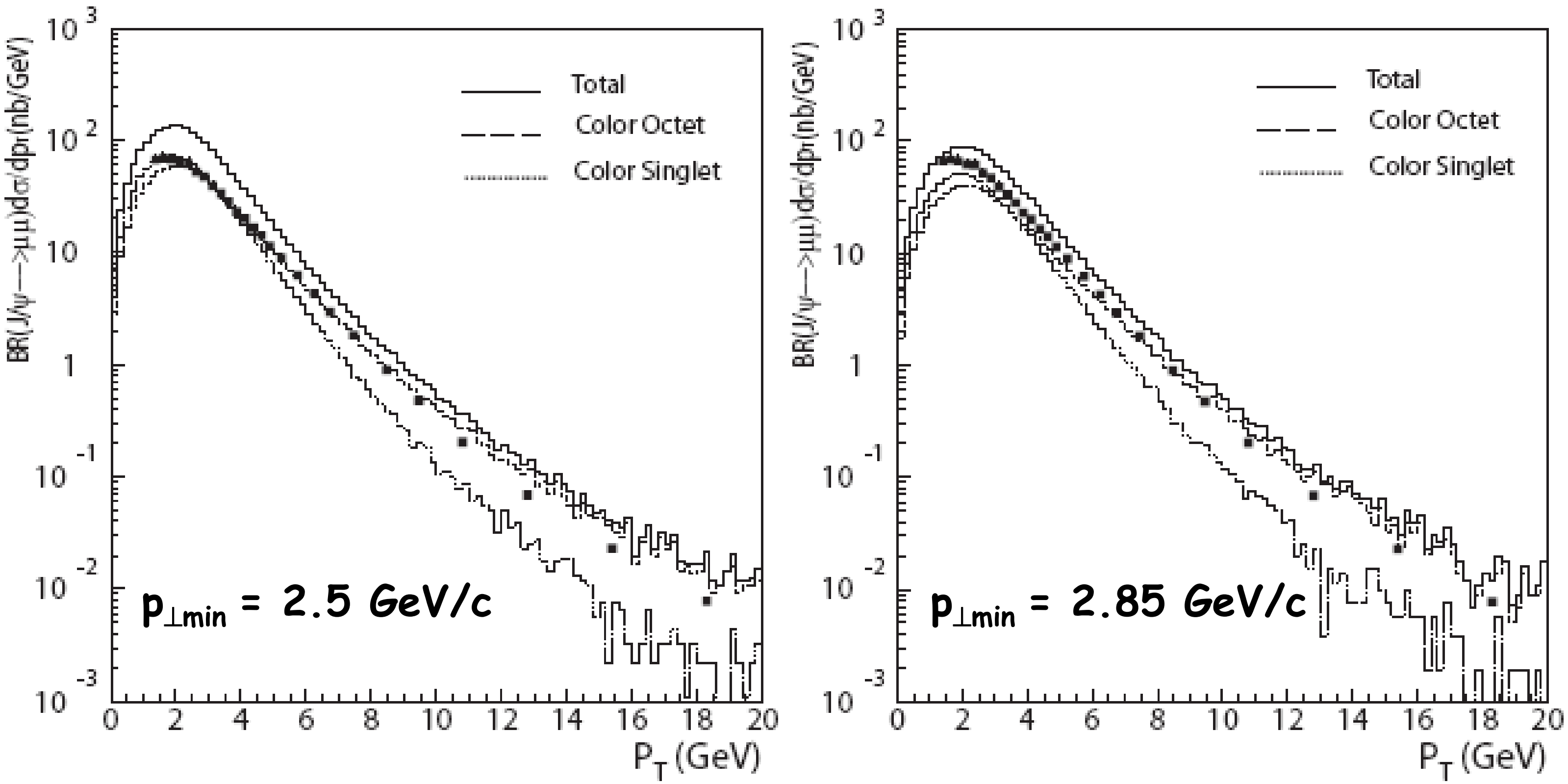
  Pythia 6.2 (black solid line), used for 2004 Detector re-optimization studies.
  Pythia 6.3 (blue dot-dashed), used for 2006 Monte Carlo data Production.
  Pythia 6.4 (red dashed), to be used for the next data production.

- Retuning was needed to include the generation of excited meson states B*,B** whilst retaining the spin counting rules, through Pythia PARJ(14÷17)
  - The inclusion of the primary excited meson states led to an increase in the average multiplicity.
- Retuning to correct the production rates of the generated ρ^0(770), ω(782), K*(892), etc.: through PARJ(11÷13).

Heavy Quarkonia Production in Pythia.

- Hidden charmonium production mechanism can be investigated at LHCb.
- In particular "prompt J/Ψ" signal is important in LHCb as it is a source of backgrounds for $B \to J/\Psi + X$ decays.
- NRQCD, implemented in Pythia since version 6.324, parametrizes the non-perturbative fragmentation of the q-qbar pair, extending Color Singlet Model to Color Octet Model.
  - COM implies 10 matrix elements $\left\langle Q\overline{Q}\left[{}^{2S+1}L_J^{(C)}\right]\right\rangle$ to be tuned: each representing the probability a q-qbar pair in a ${}^{2s+1}L_J{}^{(Color)}$ state builds up a given bound state.
- The first attempt to tune CSM and COM together with the $p_{\perp min}$ by the LHCb collaboration is documented in the LHCb note: LHCb-2007-042

Heavy Quarkonia Production in Pythia. (II)



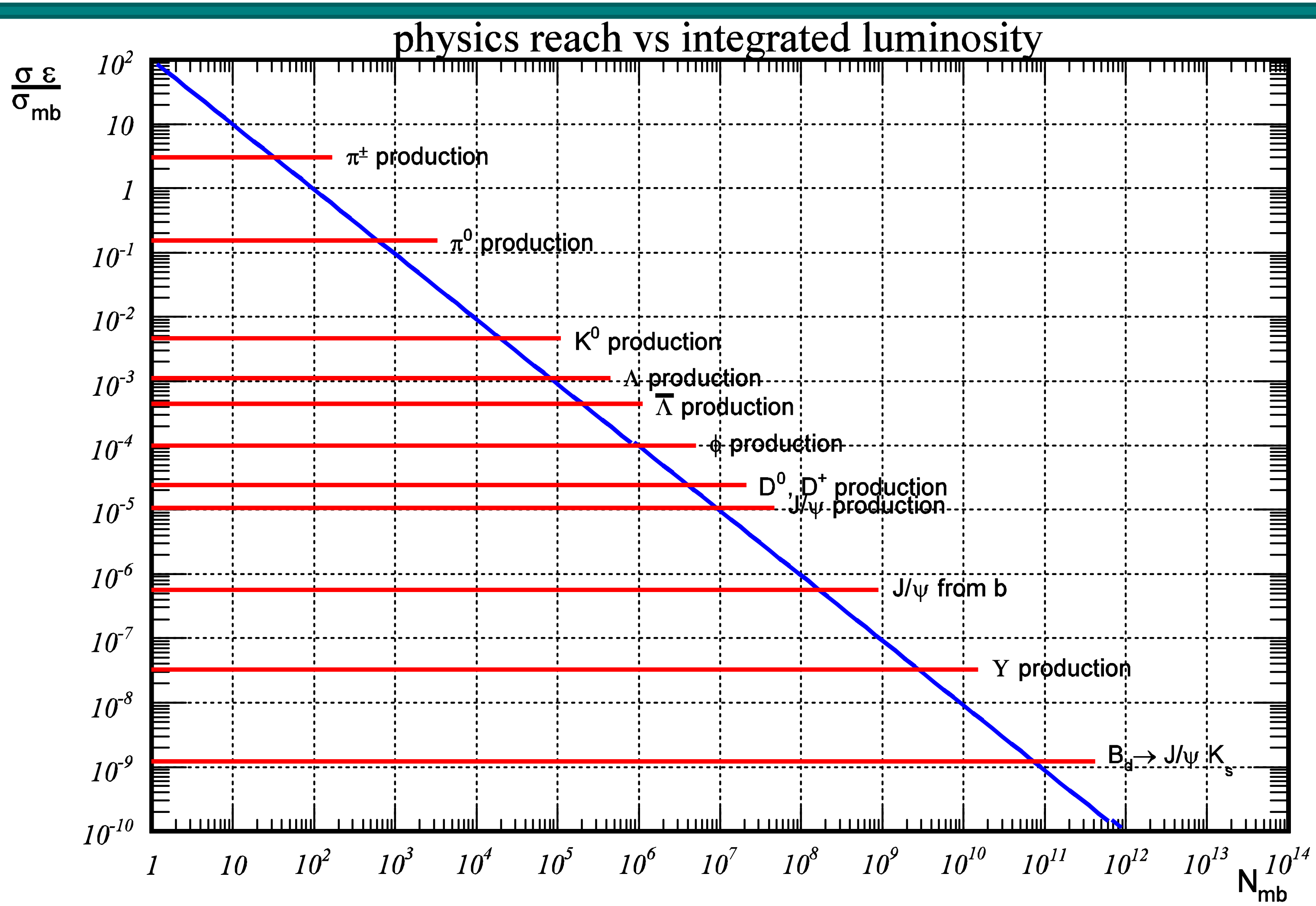
LHCb tuning of Pythia to fit the CDF measurements of **J/ψ→μ+μ-** $p_{\perp}$differential cross section. CDF Collaboration, Phys. ReV. D71 032001, 2005

CSM and COM and leading order regularization $p_{\perp min}$ cut-off tuned simultaneously.

Matrix elements values (*) extracted from: Nason P. et al. arXiv: hep-ph/0003142

(*) $\left\langle Q\overline{Q}\left[{}^{2S+1}L_J^{(C)}\right]\right\rangle$

Physics with MB Events.



Minimum Bias data taking can be performed at 2 kHz rate.

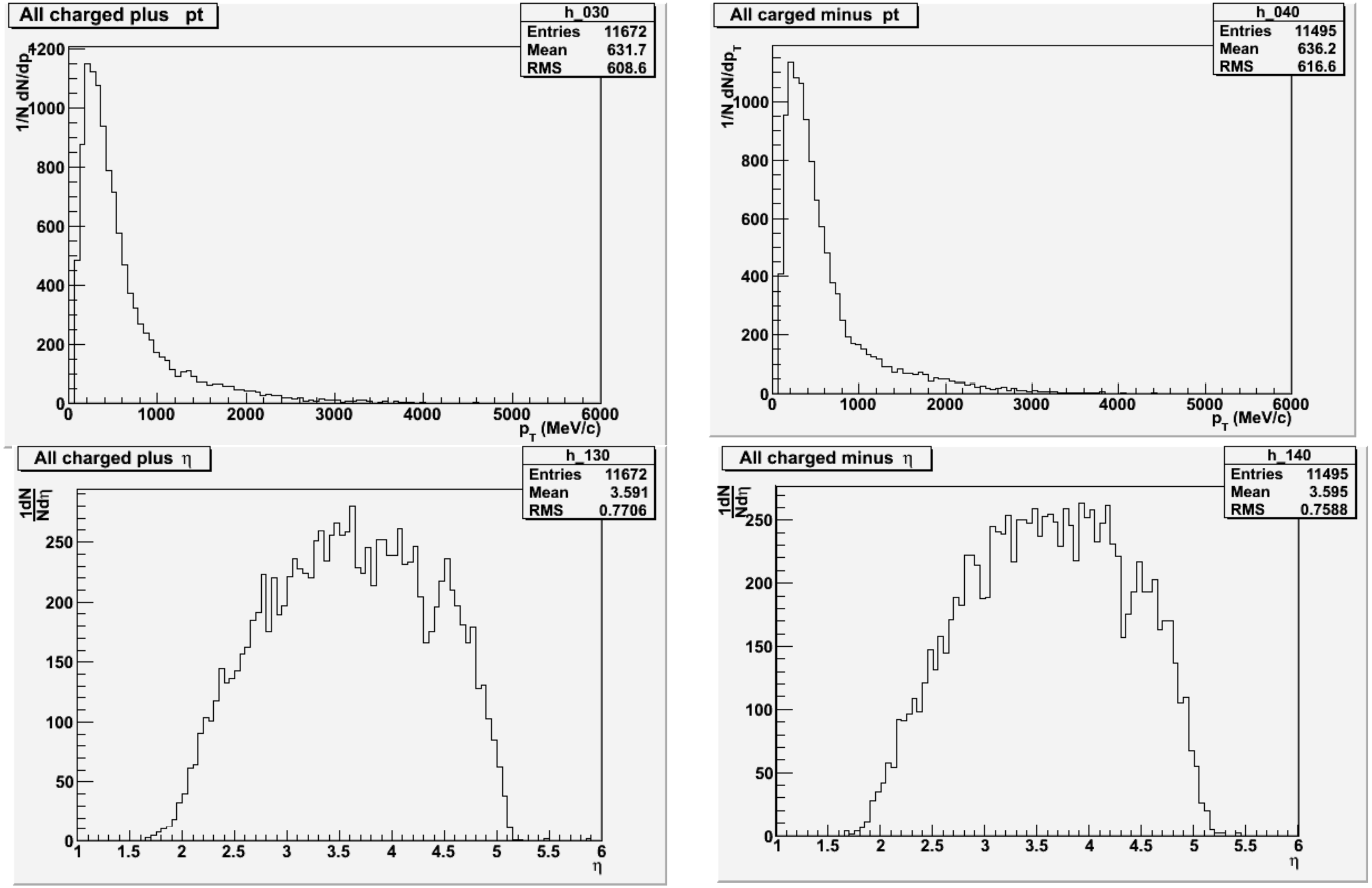
Measurements of Particle Ratios.

- Observables: pseudo-rapidity η, transverse momentum p_T, azimuthal angle ϕ.

$$R_\eta = \frac{dn^+ / d\eta}{dn^- / d\eta} \qquad R_{p_T} = \frac{dn^+ / dp_T^2}{dn^- / dp_T^2} \qquad R_\phi = \frac{dn^+ / d\phi}{dn^- / d\phi}$$

- Can be done even with very low integrated luminosity.
- Important for tuning of the Monte Carlo.
- Of high interest in HEP community: cosmic rays shower development.
- No data available on pp collision beyond $\sqrt{s} = 200$ GeV.

Distributions in the LHCb acceptance.



No PID on tracks requested.

Measurements with Strangeness.

Armenteros Podolansky Method to select Λ

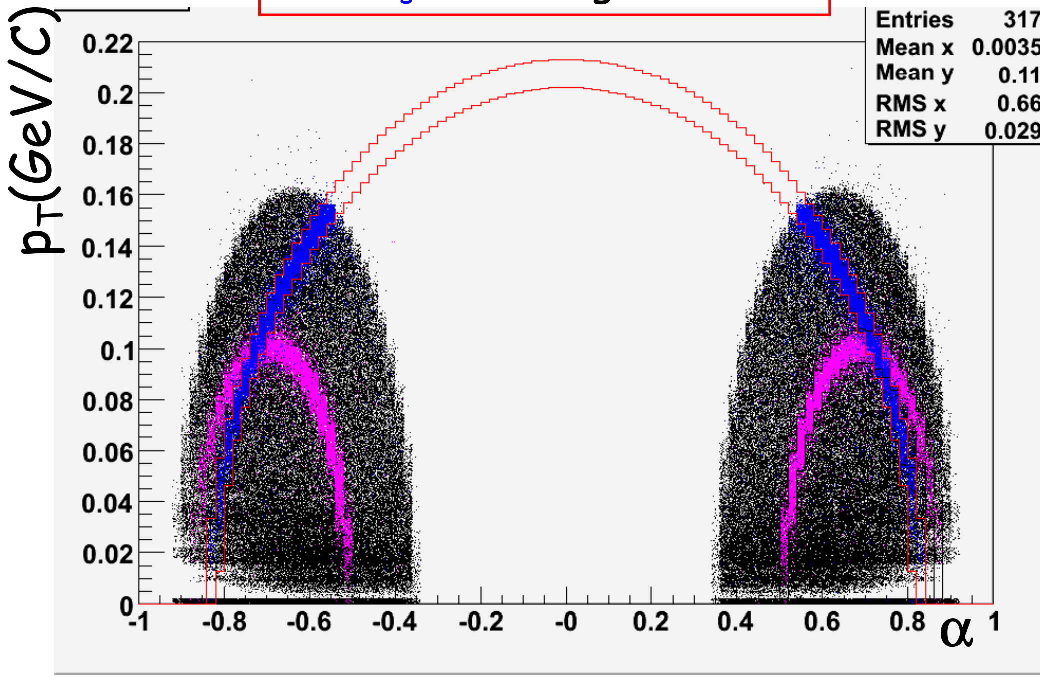
Plot: transverse momentum versus asymmetry of longitudinal momenta.

PID relies on relativistic decay kinematics.

Particles passing the pre-selection cuts: K_s , Λ, background

$$\alpha = \frac{p_L^+ - p_L^-}{p_L^+ + p_L^-}$$

	Preselection	Selection
PionMinIPS	3	13
ProtonMinIPS	3	6 (and <50)
PionMinPt(MeV/c)	100	100
ProtonMinPt(MeV/c)	400	500
MassWindow(MeV)	50	1.5
MotherFlightS	10	10
MotherMaxVertChi2	50	10
MotherMinPt(MeV/c)	500	500



$\overline{\Lambda} \rightarrow \overline{p}\, \pi^+$ $\Lambda \rightarrow p\, \pi^-$

Measurements with Strangeness. (II)

(1) Purity after selection
(2) Purity after selection and AP selection
(3) Purity after selection and AP selection and higher track quality.

(1)

Mother of	No MC	Λ	K_s^0	π^+	Υ	$\rho^0(770)$	$\rho^+(770)$	p	ω
π (%)	5.39	88.45	4.97	0.56	0.05	0.06	0.05	0.04	0.04
p (%)	5.06	88.35	5.27	0.36	0.05	0.12	0.10	0.08	0.07

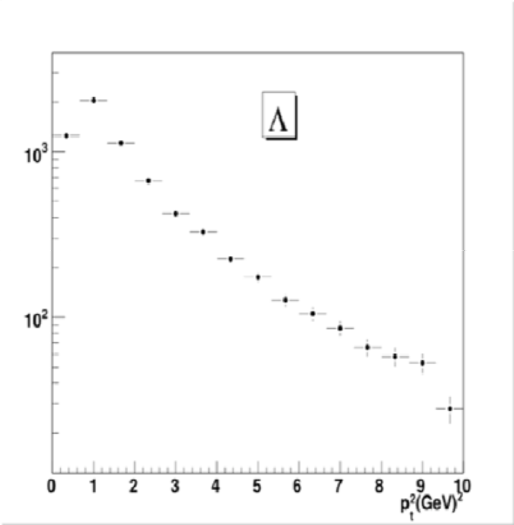
(2)

Mother of	No MC	Λ	K_s^0	π^+	Υ	$\rho^0(770)$	$\rho^+(770)$	p	ω
π(%)	4.77	94.08	0.94	0.59	0.04	0.06	0.05	0.05	0.05
p(%)	4.62	92.78	1.06	0.40	0.05	0.12	0.12	0.09	0.07

(3)

Mother of	No MC	Λ	K_s^0	π^+	Υ	$\rho^0(770)$	$\rho^+(770)$	p	ω
π(%)	1.72	96.58	0.74	0.43	0.03	0.05	0.05	0.05	0.04
p(%)	2.01	96.21	0.77	0.32	0.02	0.09	0.07	0.06	0.04

Measurements with Strangeness. (IIII)



For 10^8 MB events we expect ~ 10^5 Λ sample of 95% purity for Λ polarization studies.

Source of p and π for detector calibration.

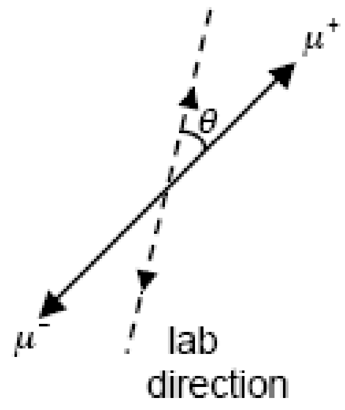
- Measure cross section ratios, which don't require luminosity.

$$\frac{d\sigma(\Lambda)}{d\sigma(\bar{\Lambda})}(y, p_T)$$

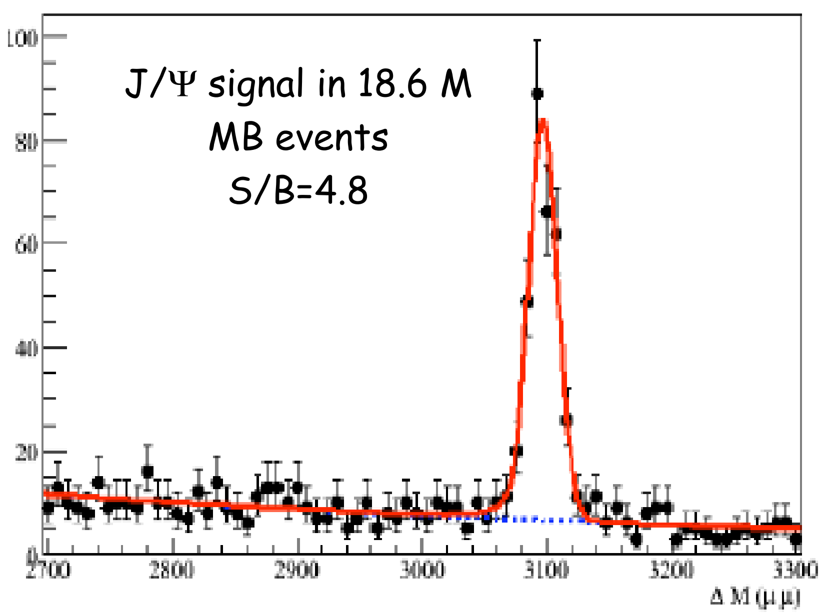
- Possible extension:
  - Hyperon production: $\Xi^- \to \Lambda\pi^-$, $\Omega^- \to \Lambda K^-$
  - Vector meson production : e. g. ϕ and K^*

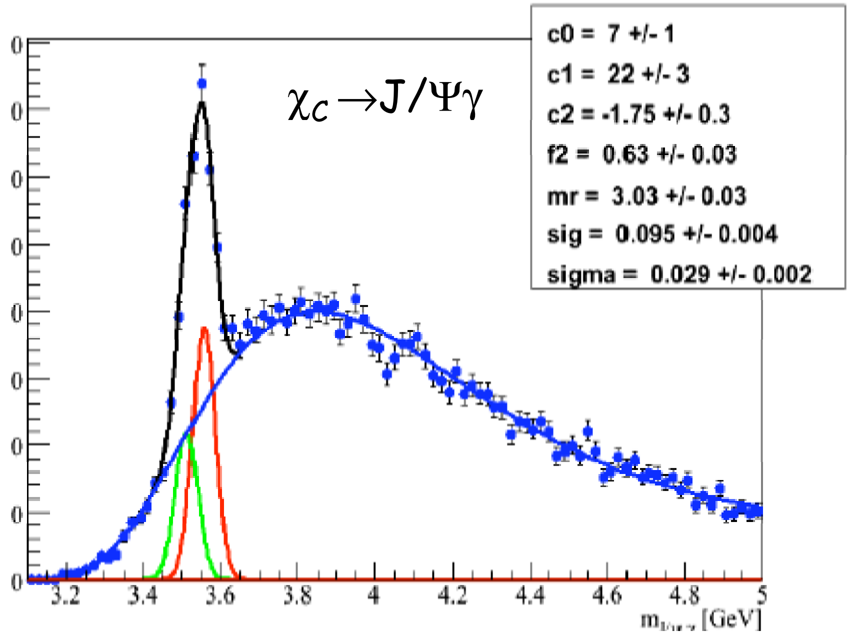
J/Ψ Production

- J/Ψ production is an important building block for many decays analysis.
- Prompt (direct & indirect) J/Ψ physics
  - pT spectra.
  - Polarization (spin alignment).
  - χ_C and Ψ(2s) productions.



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



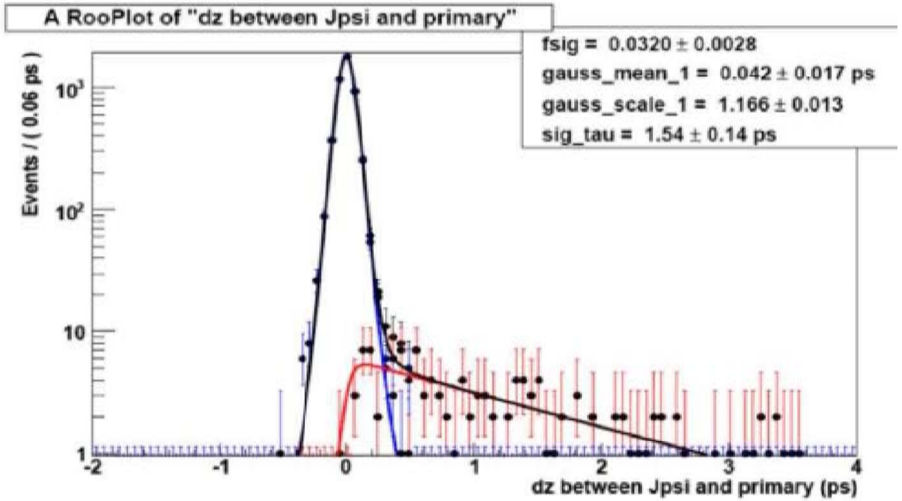


Prompt over Retarded J/Ψ Ratio.

Discriminating variable

$$t = \frac{dz}{p_z} \times M^{J/\Psi} \approx \frac{d}{p} \times M^{J/\Psi} = c\tau$$

$$BR(b \to J/\psi\ X) = (1.16 \pm 0.10)\,\%$$



- Retarded J/Ψ from B decays can be disentangled from prompt J/Ψ
- Estimates of the $\sigma_{J/\Psi}$ cross section in within the LHCb acceptance:

$$\sigma_{prompt} = (3101.0 \pm 5.5)\,nb \qquad \sigma_{retarded} = (235.7 \pm 1.6)\,nb$$

- Expected statistical error at the level of 10% in 1 month of data taking.

Conclusions.

- The LHCb detector is ready for data taking.
- LHCb relies on Pythia and the MPI model implemented therein for its simulations and feasibility studies.
- LHCb will take data at 2 KHz.
  Large MB data samples, collected in the forward region covered by the LHCb detector, will be therefore available as soon as LHC provides collisions.
- In the early phase efforts of the collaboration will be dedicated to Minimum Bias events analysis, for calibrations, MC tuning and for first physics measurements.