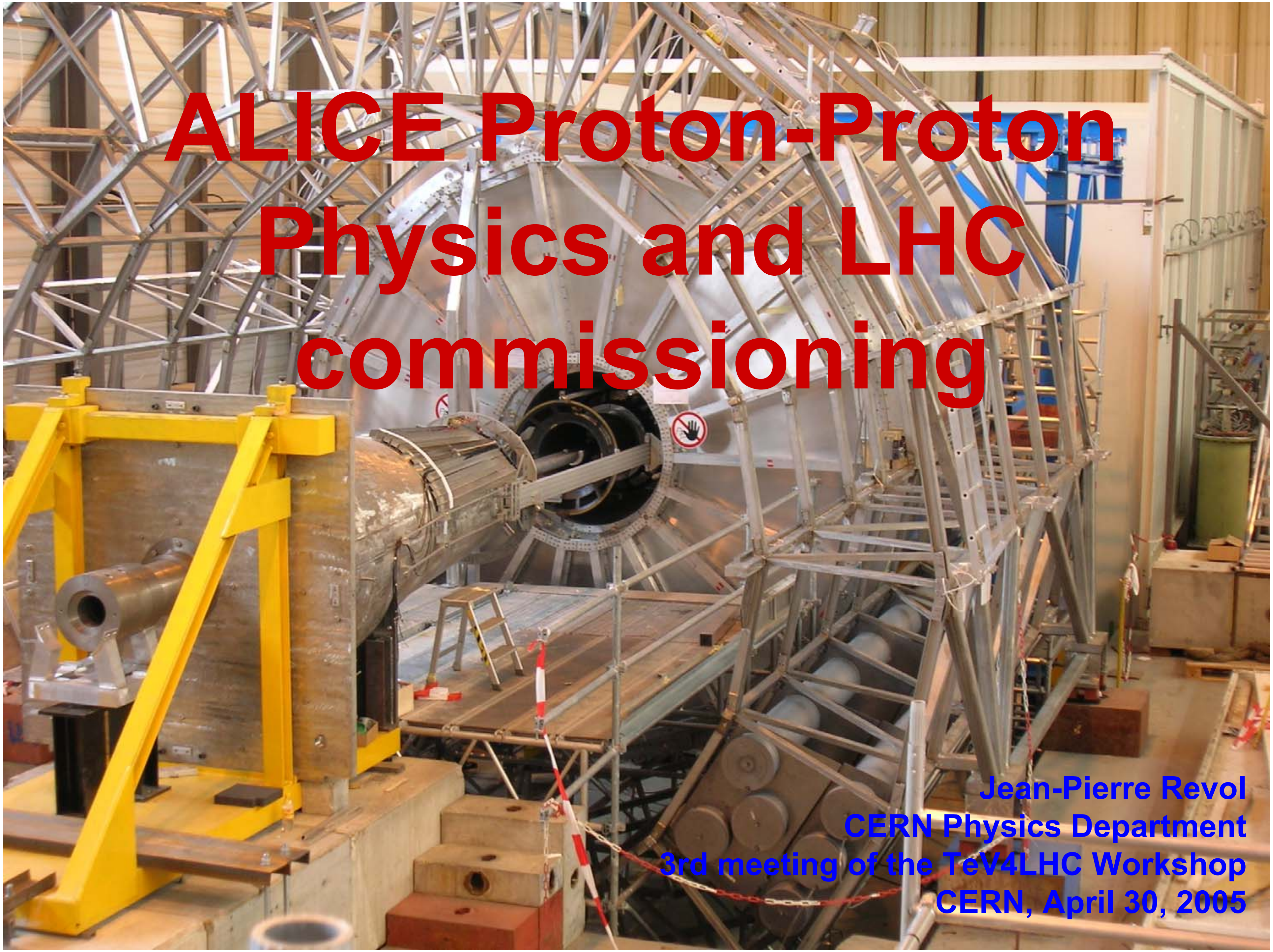
ALICE Proton-Proton Physics and LHC commissioning



Jean-Pierre Revol
CERN Physics Department
3rd meeting of the TeV4LHC Workshop
CERN, April 30, 2005

ALICE is optimized for low p_T proton-proton physics

- Complete understanding of the physics of colliding protons at LHC requires the study of all phenomena, including those with large cross-sections, even though they were not the driving motivation for building the LHC.

- Those phenomena with cross-sections ranging probably between 100 mb(σ_{tot}), 60 mb($\sigma_{inel.}$) and 12 mb($\sigma_{diff.}$) [cf. A. Kaidalov] represent the bulk of the events at LHC. They are generally characterized by low p_T.

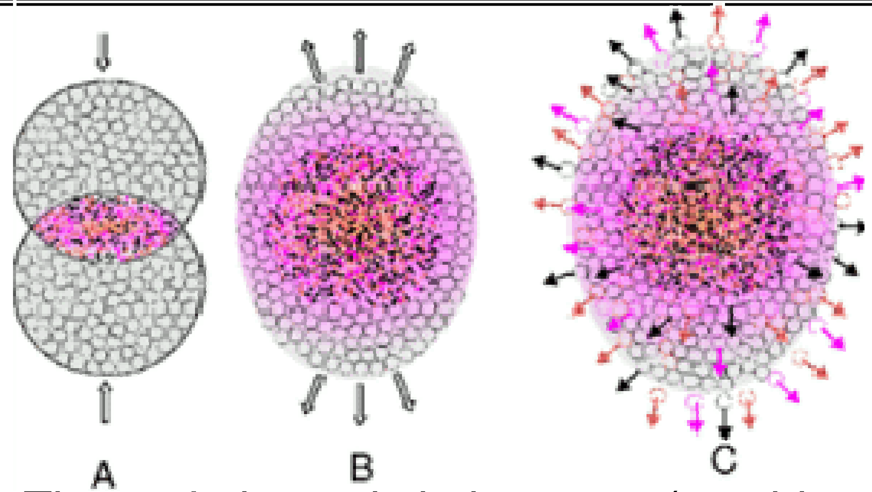
- As new kinematic domains are investigated, new physics could be present. Therefore, low p_T phenomena should not be neglected:
  - they will contribute to our understanding of the strong interaction, at the frontier between perturbative and non-perturbative QCD (a most challenging domain) - Access to a much smaller x range => many more higher orders to calculate!
  - they are inescapable at LHC, as they will be first to be observed in the commissioning phase of the machine and of the detectors.

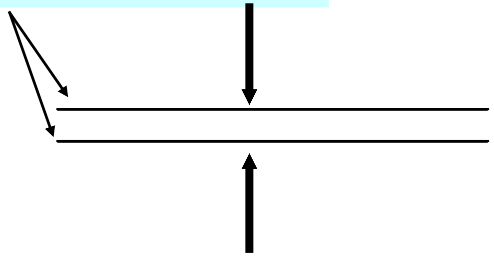
Low p_T proton-proton physics with ALICE

- Low p_T proton-proton studies represent a major part of the ALICE programme for several reasons:
  - to provide "reference" data to understand heavy ion collisions. In a new energy domain, each signal in HI has to be compared to pp;
  - Genuine proton-proton physics when unique or competitive; note that ALICE can reach rather "high" p_T, up to ~ 100 GeV/c, ensuring an overlap range with other LHC experiments;
  - Detector commissioning (will be carried out with pp data (simpler): the first ALICE paper will be a paper on proton-proton collisions).

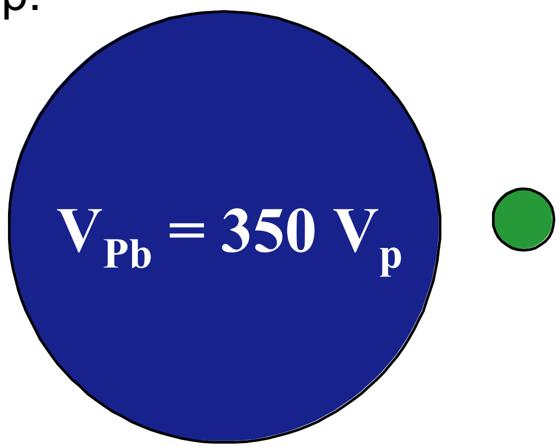
- Low p_T proton-proton collisions are also of interest in the search for rare phenomena as they contribute to the background (Higgs, SUSY, etc.):
  - Minumum bias event pile-up;
  - Underlying event [a large fraction of particles in high-p_T events is at low p_T].

pp and HI collisions





- The real picture is in between (combined effect of the Lorentz boost (γ = 2750), of a distribution of low x partons and of the uncertainty principle).
- Is there a difference between Pb ions and protons? Within a factor 2 at most, same structure functions; parton saturation (gg$\rightarrow$ g ~ $A^{1/6}$) is also present in pp.



What changes really is the volume

$$\langle r^2 \rangle_{lead}^{\frac{1}{2}} \approx 0.97 \times A^{\frac{1}{3}} \approx 5.7\,fm$$

$$\langle r^2 \rangle_{proton}^{\frac{1}{2}} \approx 0.81\,fm$$

pp and HI collisions

- Proton-proton collisions at LHC will reach initial energy densities comparable to those available in gold-gold collisions at RHIC. Therefore, they represent considerable interest for the study of high energy densities, going from small volumes with pp to large volumes with Heavy Ion collisions. (In addition, it is important to have pp and HI in same detector!)

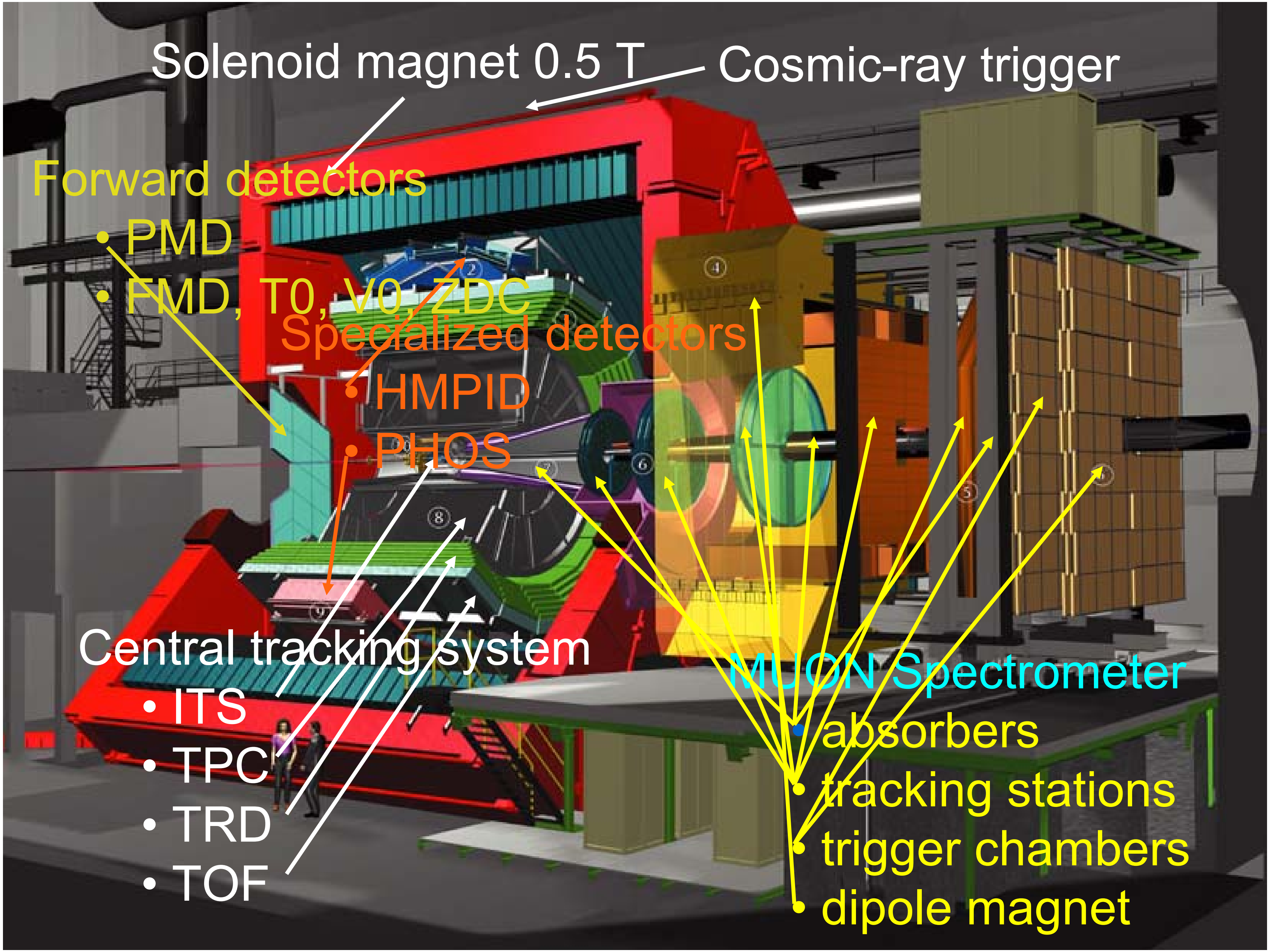
	<E> (MeV)	dN_{ch}/dy	V_i (fm^3)	ε_i (GeV/fm^3)
$p\bar{p}$ ($\sqrt{s}$ = 630 GeV)	400	4	4.5	0.5
$p\bar{p}$ ($\sqrt{s}$ = 1.8 TeV)	400	5.3	4.5	0.7
pp ($\sqrt{s}$ = 14 TeV)	500	7	4.5	1.2
Au-Au (RHIC) ($\sqrt{s}$ = 200 GeV)	500	700	153	5.5
Pb-Pb (LHC) ($\sqrt{s}$ = 5500 GeV)	500	3000-8000	159	15-40

$$\varepsilon_i = \frac{3}{2} \frac{\langle E \rangle}{\pi R_N^2 A^{\frac{2}{3}}} \frac{dN_{Ch.}}{dy}$$

→ 12 GeV/fm^3

(10^9 events)

- Can QGP be produced in pp collisions? These ideas have been already explored at the Tevatron, with intriguing results (T. Alexopoulos et al., E-735 : "Evidence for hadron deconfinement in proton-antiproton collisions at 1.8 TeV"). Why are system parameters thermal? Maximum entropy?

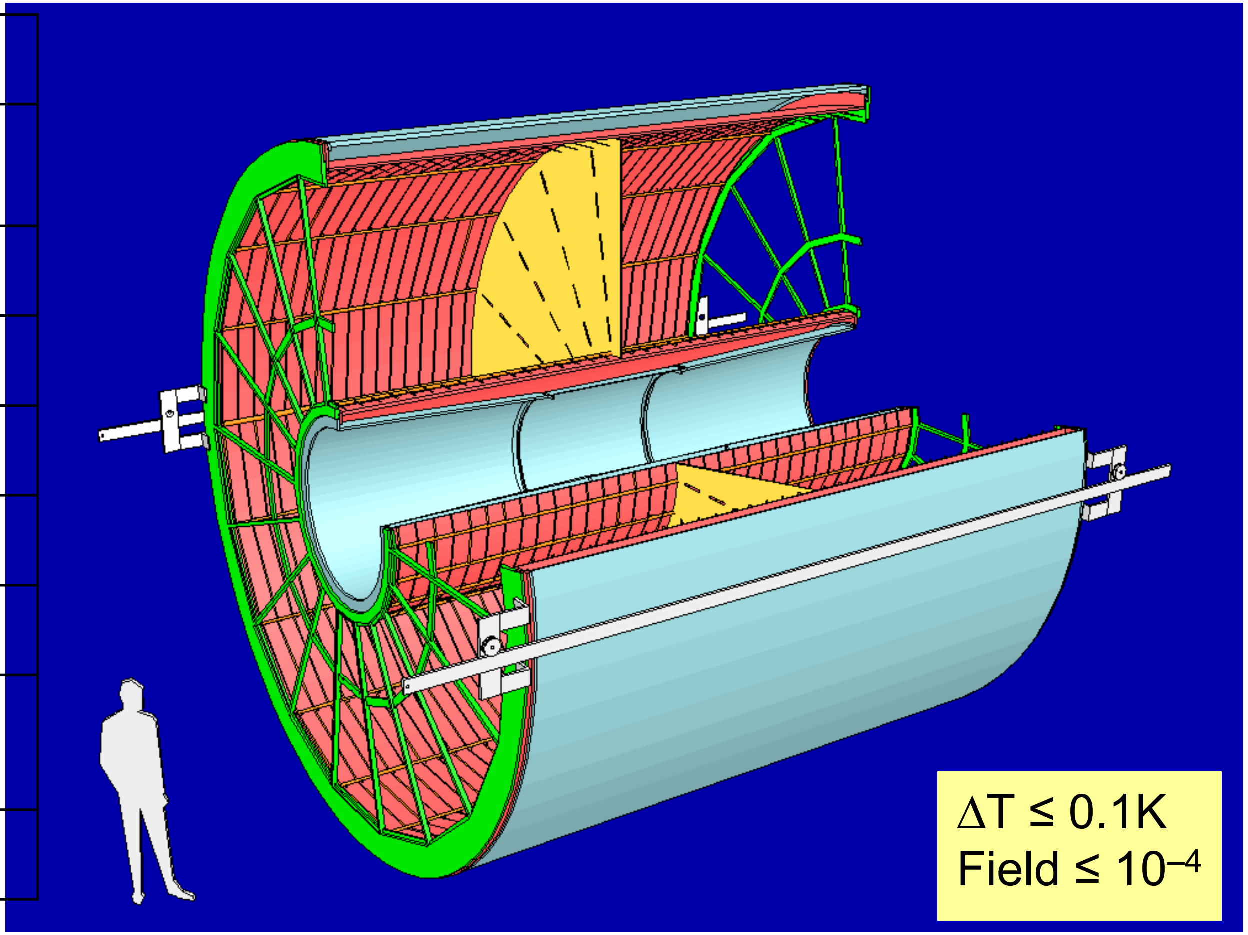


Solenoid magnet 0.5 T
Cosmic-ray trigger
Forward detectors
• PMD
• FMD, T0, V0, ZDC
Specialized detectors
• HMPID
• PHOS
Central tracking system
• ITS
• TPC
• TRD
• TOF
MUON Spectrometer
• absorbers
• tracking stations
• trigger chambers
• dipole magnet

ALICE Time Projection Chamber

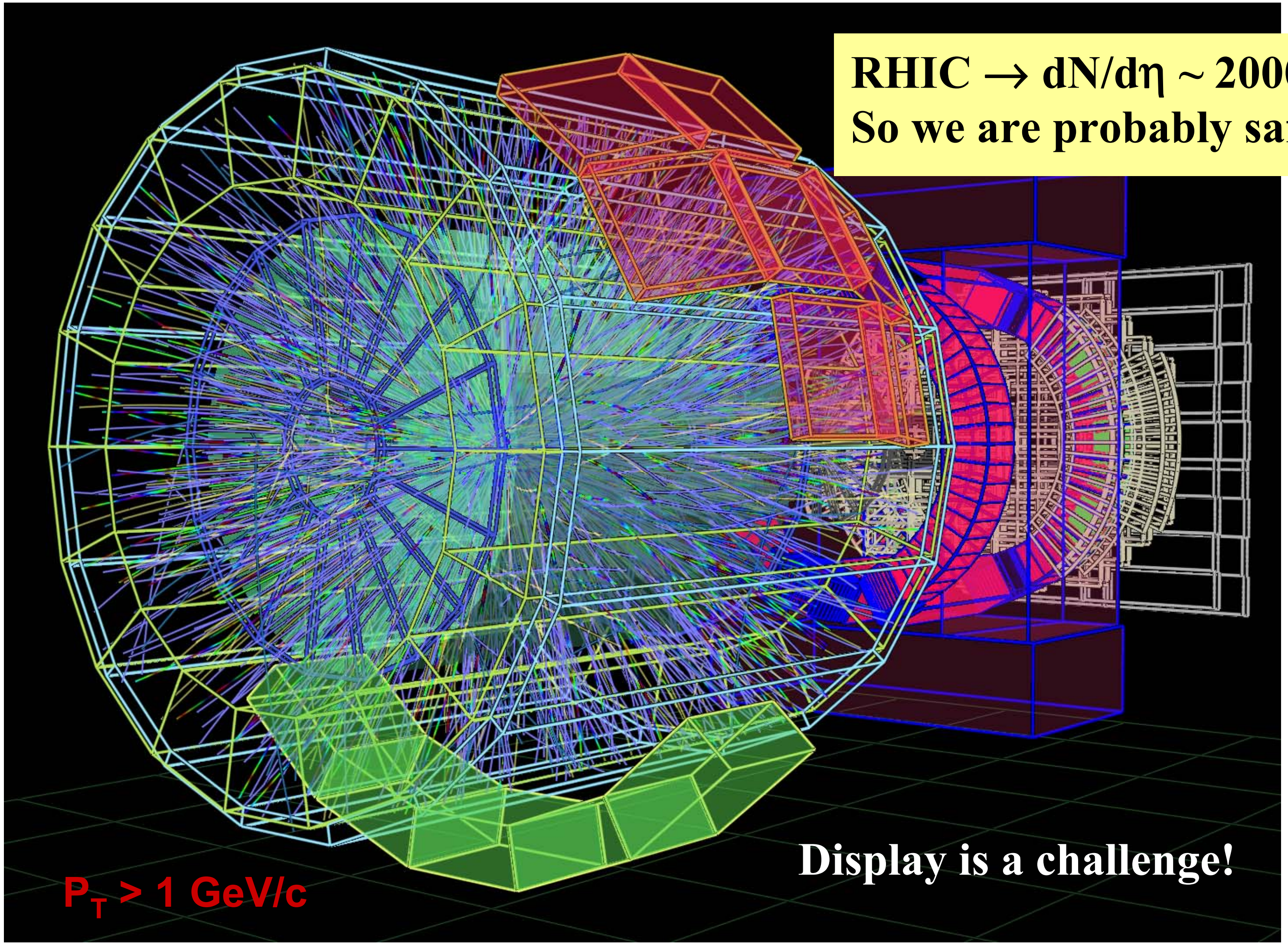
- The TPC plays a crucial role in ALICE. It provides information to all other detectors in the central region ($-1.5 < \eta < 1.5$). (most challenging TPC)

Channels	557 568
Gas	Ne/CO_2 90/10 or + 5%N_2
Volume	88 m^3
Drift length	2.5 m
Drift field	400 V/cm
Drift velocity	2.84 cm/μs
Max drift time	88 μs
Diffusion	$D_L = D_T = 220$ μm $cm^{-1/2}$
X/X_0	3.5% at $\eta = 0$



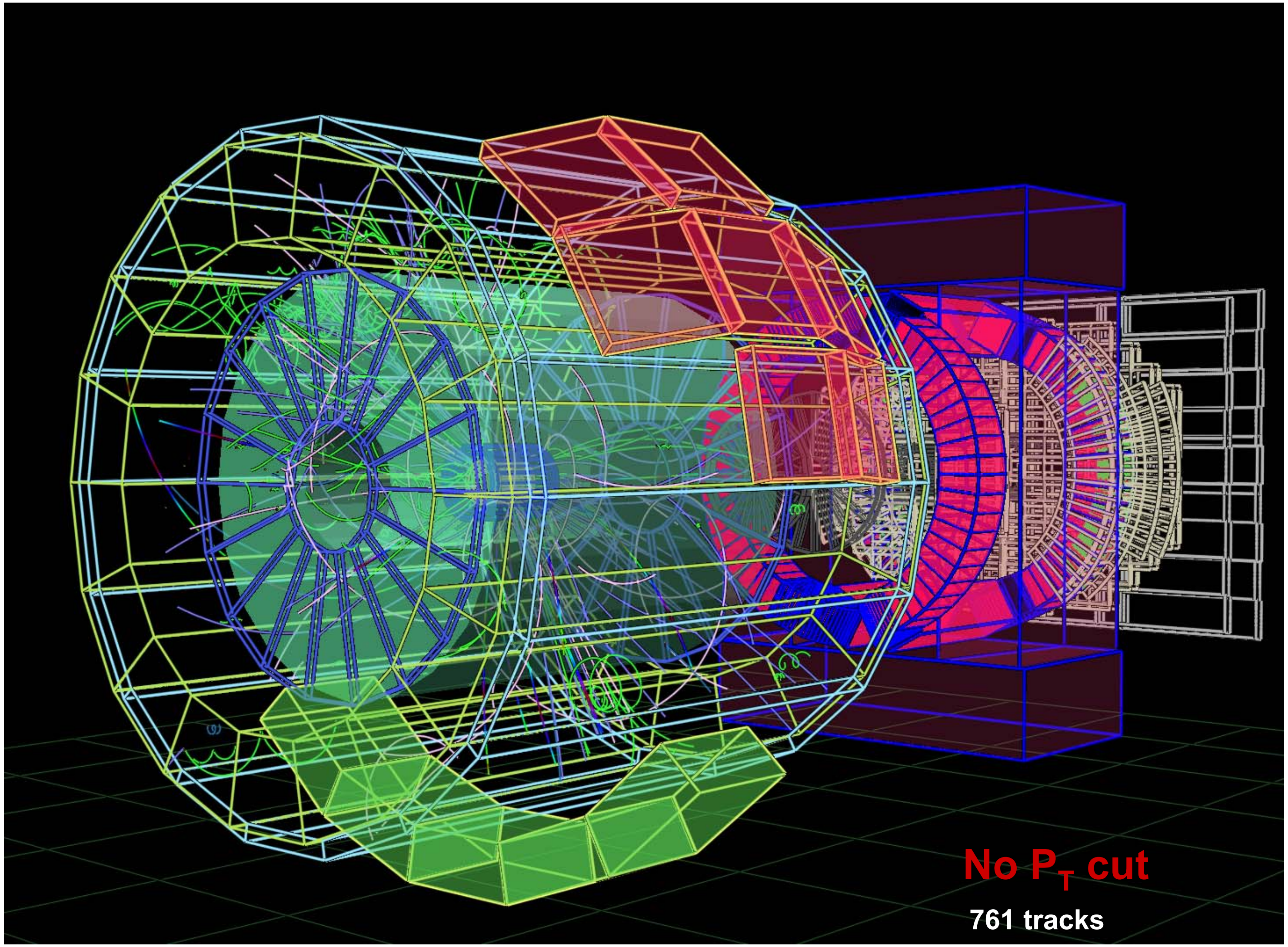
ALICE is optimized for lead-lead collisions at LHC

- The TPC is designed to work up to 8000 tracks per unit of rapidity.



Proton-proton event in ALICE

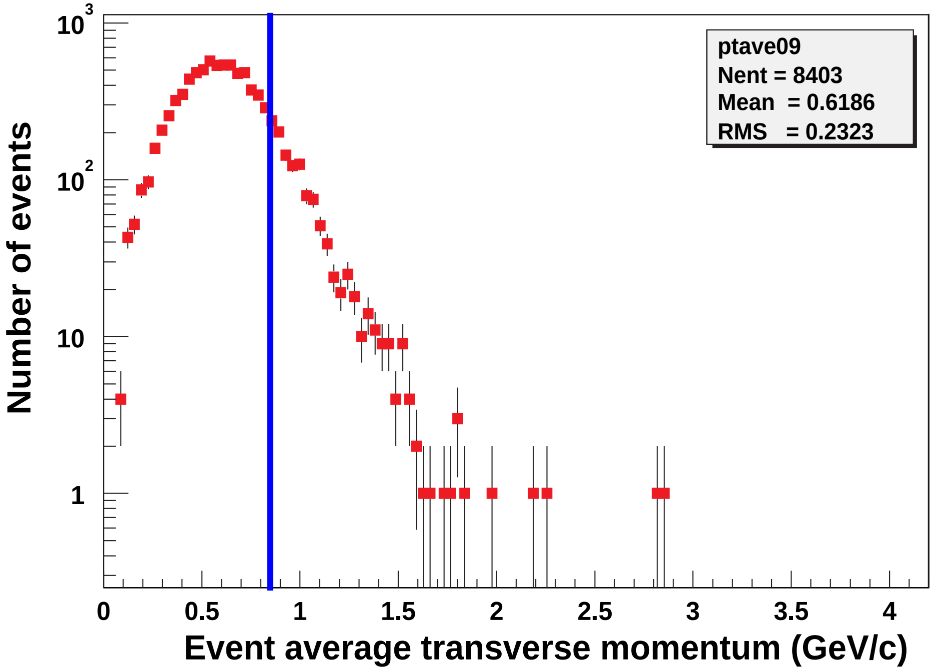
- With $dN/d\eta \sim 7$, pp events will be studied under ideal conditions of momentum and dE/dx resolution, thanks to low occupancy ~ few 10^{-4}



Tracking in central region

☐ **ALICE** optimized for low p_T (small material budget, low B field) and high multiplicity (high granularity); Vertex detectors (ITS), TPC and TRD, are used for tracking in central region.

	Magnetic field (T)	Material thickness: X/X0 (%)	P_T cutoff (GeV/c)
ALICE	**02.-0.5**	**7**	**0.1–0.25**
ATLAS	**2.0**	**30**	**0.5**
CMS	**4.0**	**20**	**0.75**
LHCb	**4Tm**	**3.2**	**0.1***

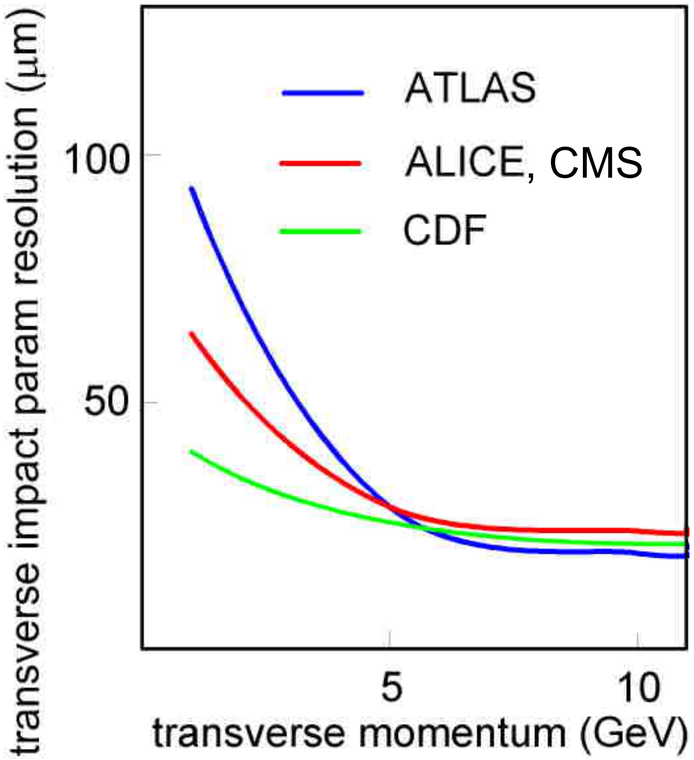


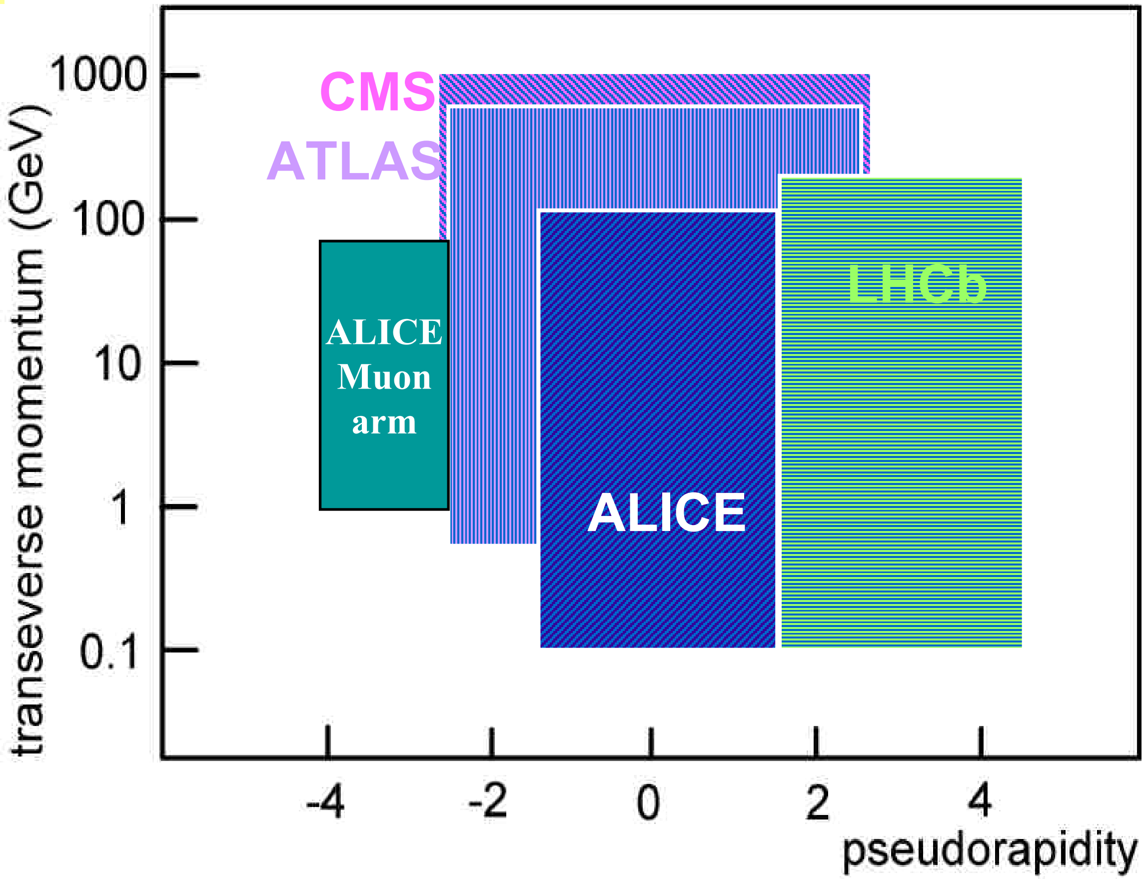
* Minimum momentum is 1 GeV, while for ALICE p ~ p_T

☐ Beam pipe Φ = 59.6 mm pushes the first Si pixel layer to 3.9 cm from the beam axis. Thickness = 0.8 mm Be (0.23% X_0). Competitive at LHC but **not very daring! Improvement should be part of the upgrade (follow CDF! Be with R = 1.313 cm; thickness = 0.58 mm)**

Comparison with other LHC experiments

Vertex detectors resolution

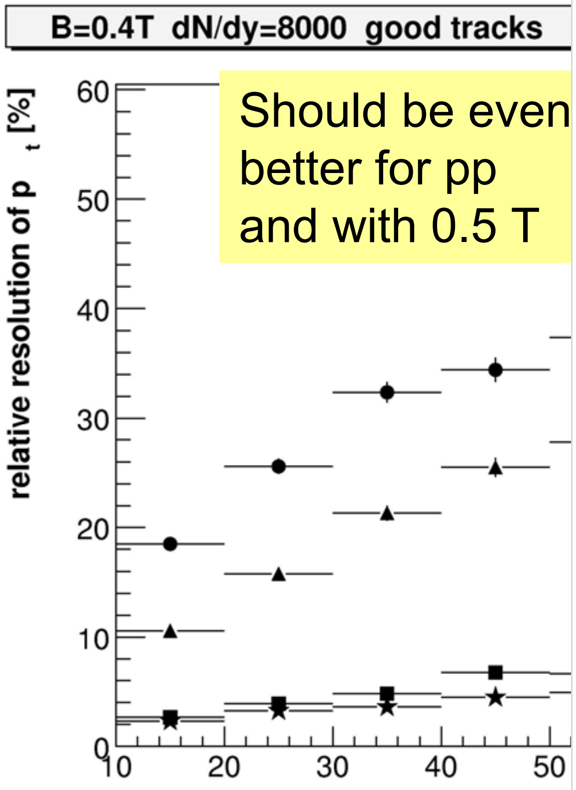


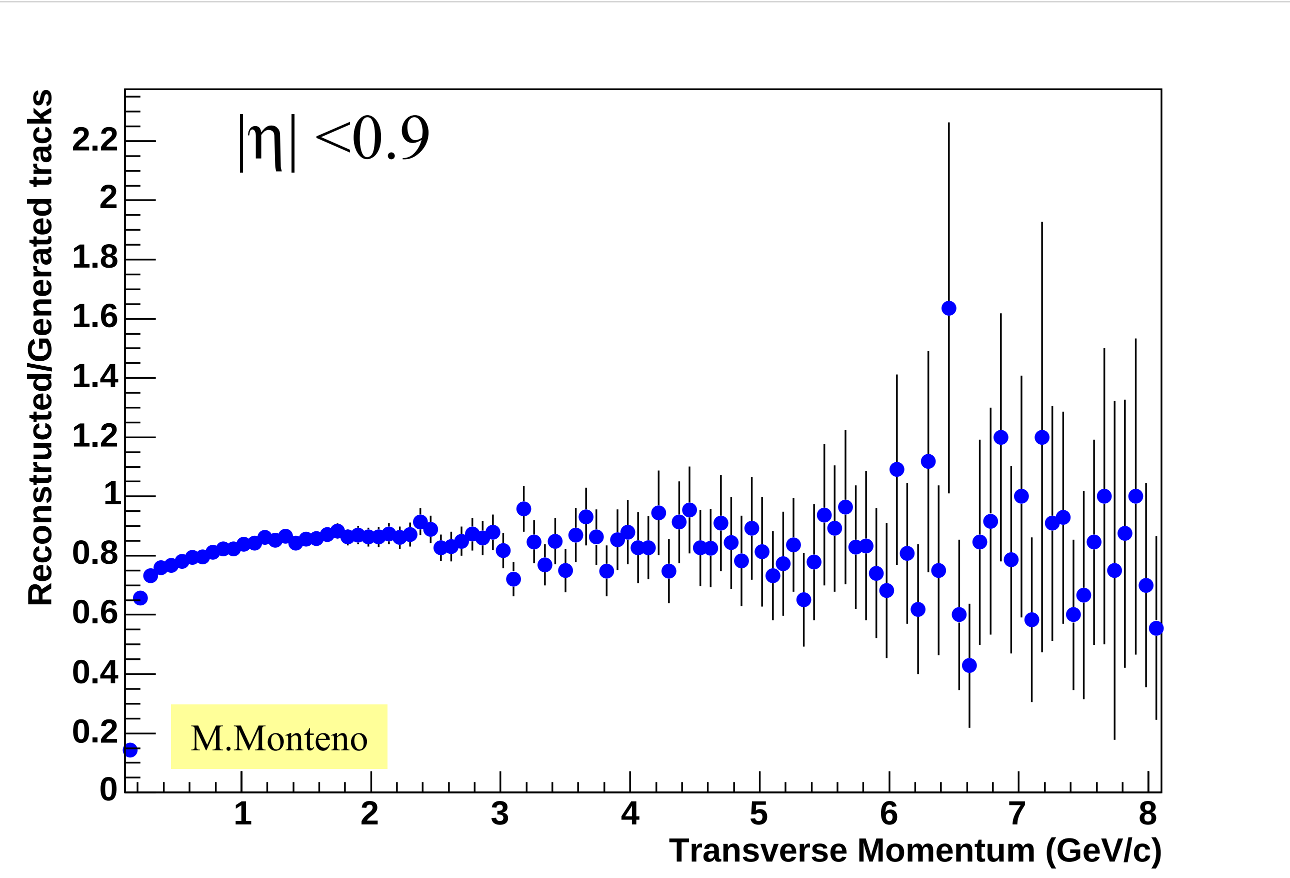


Charged particles not including muons

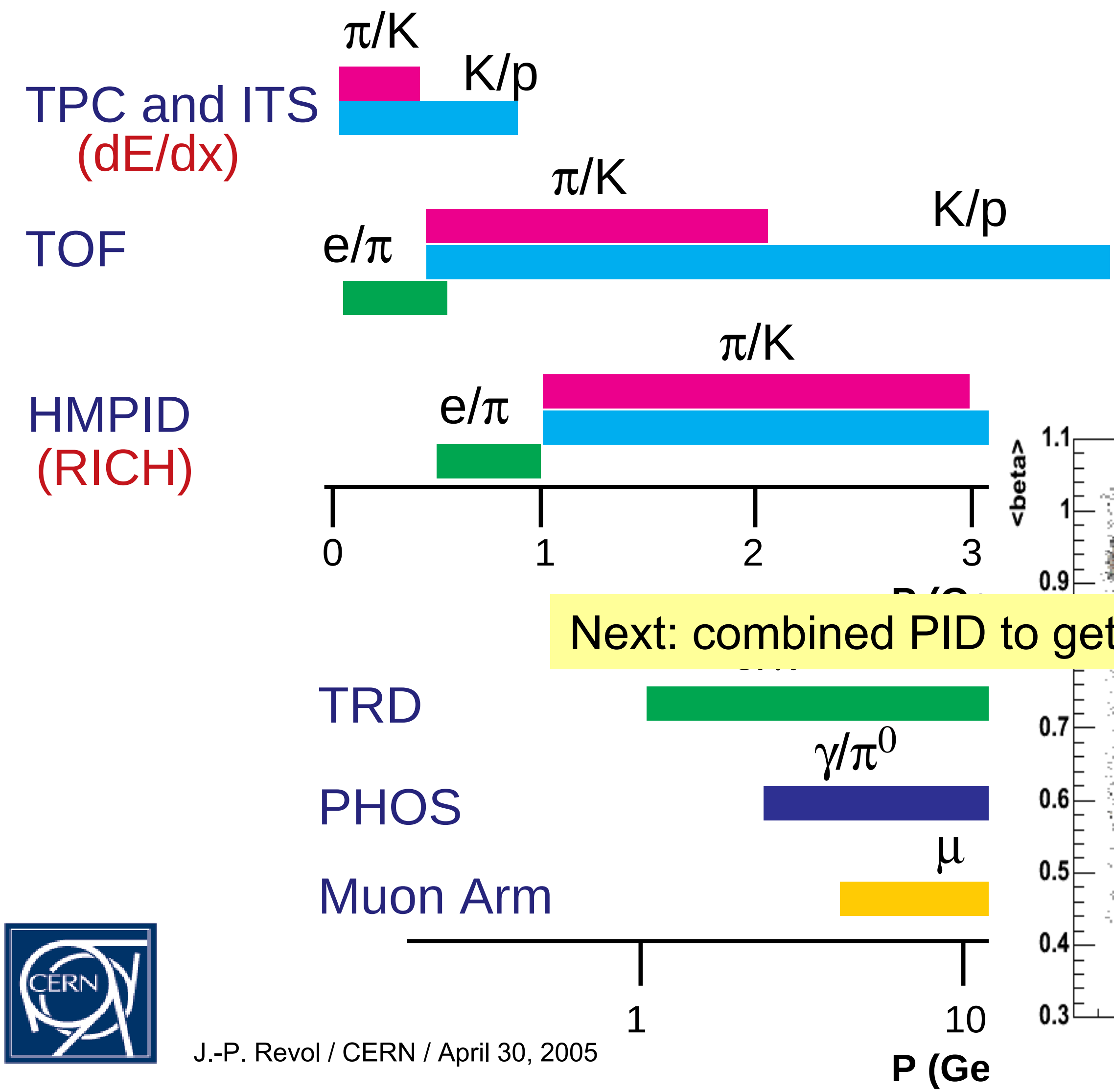
Tracking performance: momentum resolution

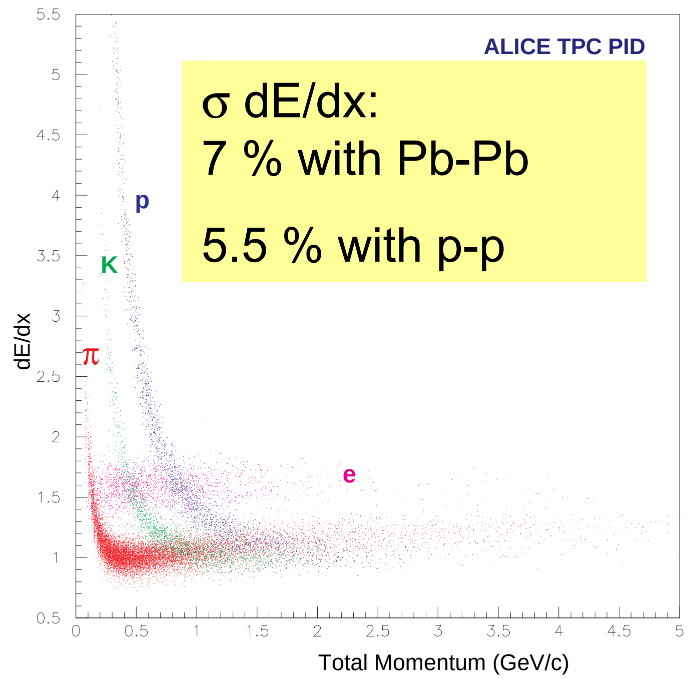
- The detector simulation and reconstruction work. They are being used for a detailed evaluation of the detector performance, in various configurations.
- The momentum resolution is excellent up to high P_T region: with 0.4T, 9% at 100 GeV/c. Will be ~ 20% better at 0.5T.

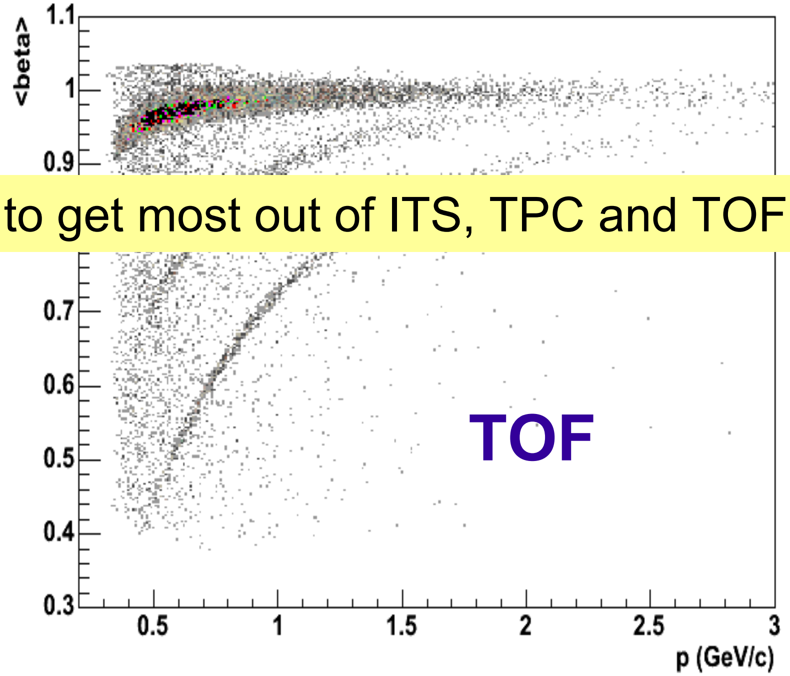




ALICE has unique particle identification

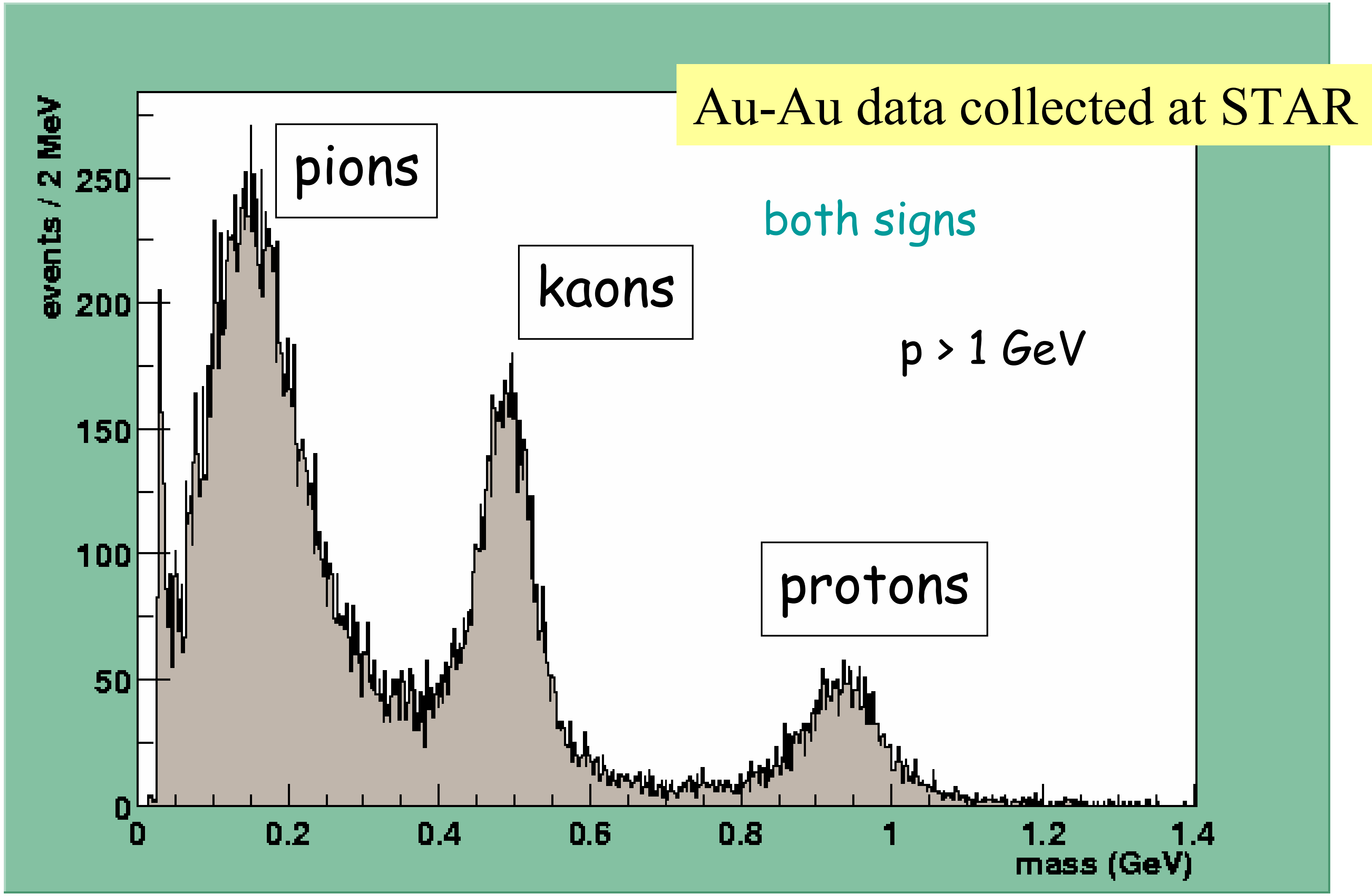






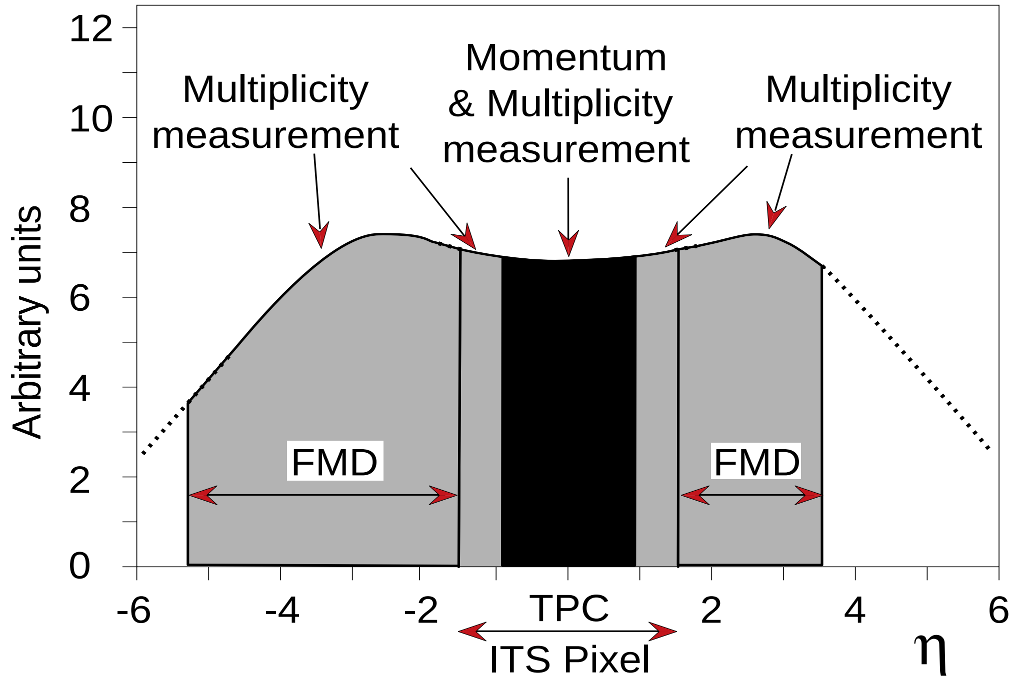
Next: combined PID to get most out of ITS, TPC and TOF

First data from the ALICE detector: HMPID at RHIC



First ALICE physics: Study of Global Event Properties

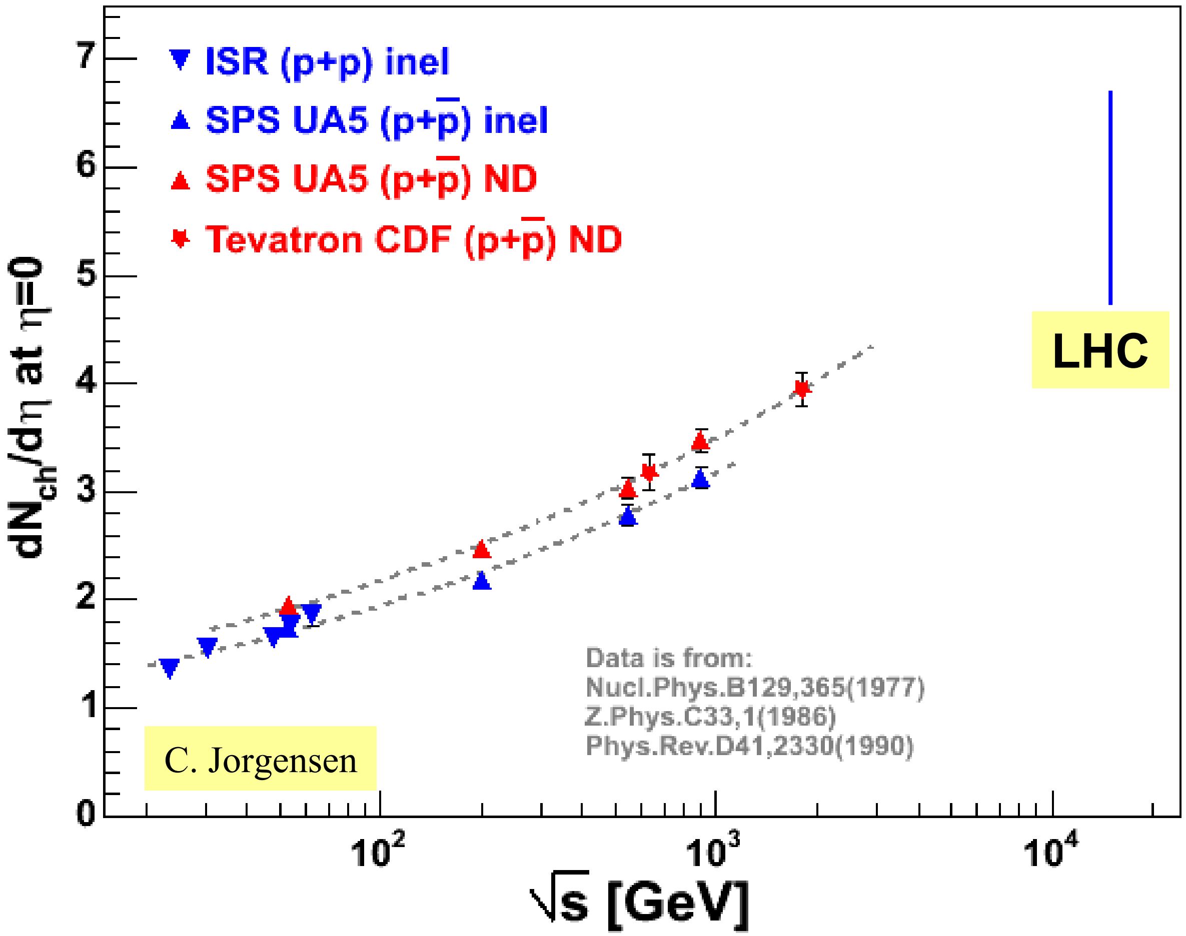
- **Charged particle multiplicity**: The Minimum Bias trigger is provided by a coincidence between V0 counters covering a pseudorapidity range from -1.7 to -3.7 and from 2.8 to 5.1. This corresponds to a visible non-elastic cross-section of ~ 67 mb.



- Charged particle multiplicity is measured over 8.8 units of rapidity, momentum is measured in the TPC and the Inner Tracking System (ITS) over 1.8 units of rapidity for optimal resolution and up to 3 units in total. (ATLAS and CMS have a better rapidity coverage)

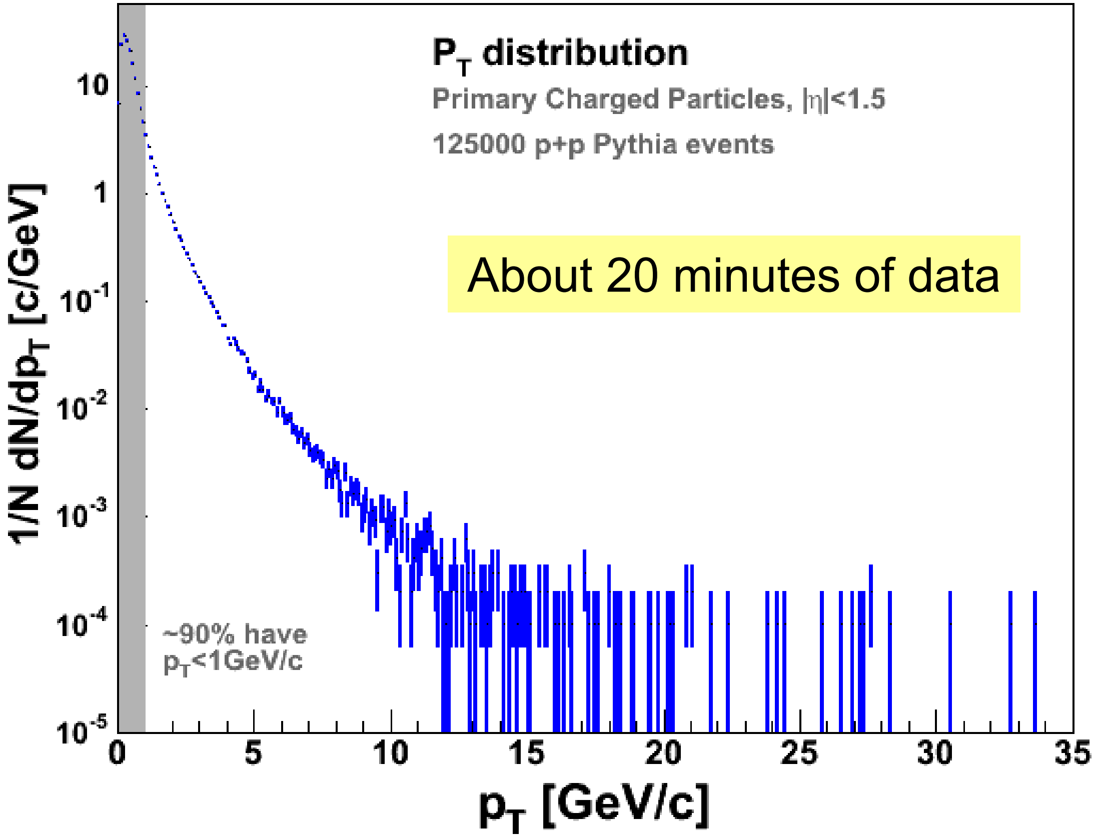
Charged track density

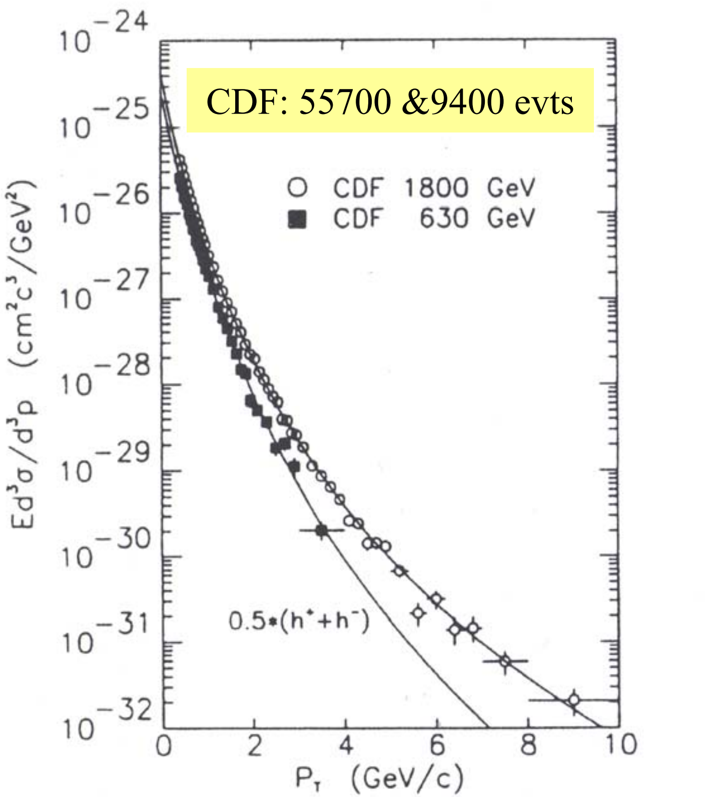
- ALICE will make a precise measurement of charged track multiplicity at 14000 GeV.



Measurement of the charged track momentum distribution

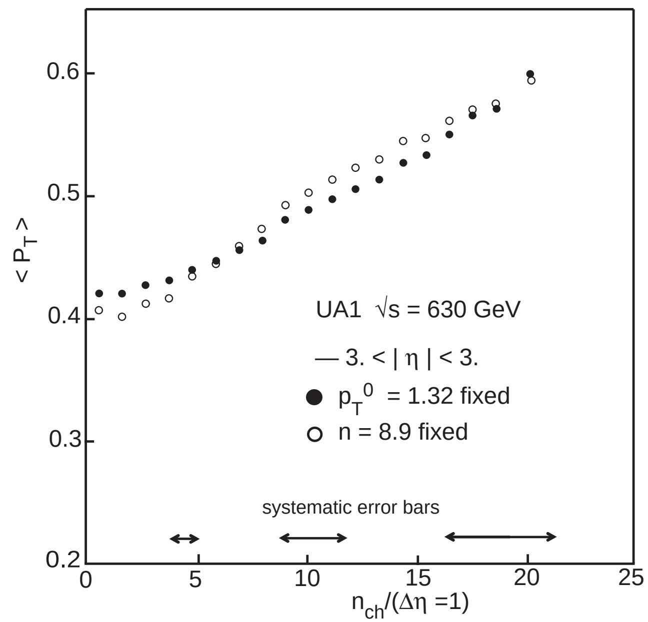
- At 3×10^{30} cm^{-2} s^{-1} the MB event rate is 2×10^{5} Hz. In ALICE, the event size is 1 Mbyte and 10^{9} events could be collected in one year (10^{7} s) with a rate of 100 Hz, or 100 Mbytes/s, reaching a momentum of 50 GeV/c. The statistics are not limited by genuine event rate!

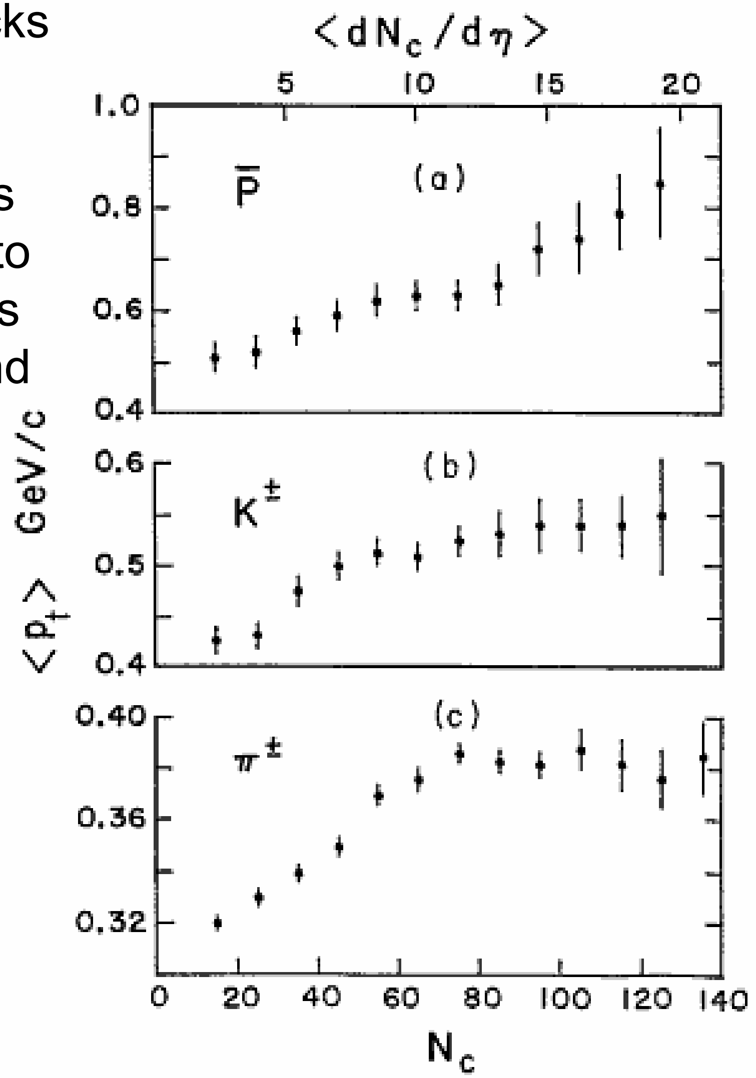




Global Event Properties (cont.)

- One interesting issue is the study of charged tracks $<p_T>$ as a function of multiplicity. The correlation discovered by UA1, also observed by CDF for exclusive states, is still not well understood and is a diagnostic for new physics. Correlations seem to depend on the type of particle. While DPMJET fits the pion data, it does not fit the kaon data well and completely misses for antiprotons.

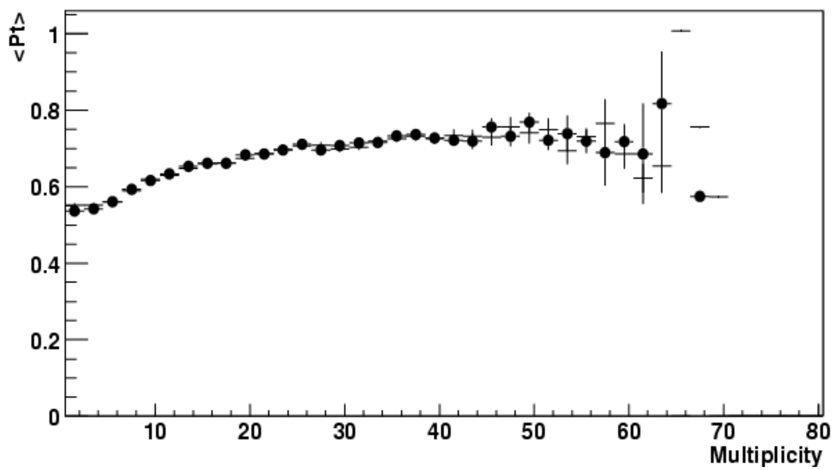




Global Event Properties (cont.)

- Will the correlation look like the Pythia prediction at LHC?
- Next step: study the correlation $<p_T>$ vs N_{ch} separately for pions, kaons and protons/antiprotons, etc. (as in E735 at Tevatron) using some PID "global" algorithm to span over a rather large p_T range (0.2 – 5 GeV/c).
- With 10^9 events one can collect substantial samples of identified particles.

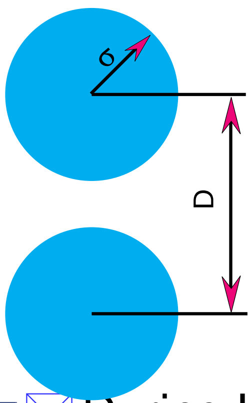
Fully simulated and reconstructed Pythia events



	K_S^0	Λ	Ξ	Ω	P	$\bar{P}$
Yield per event	0.1	0.01	2×10^{-4}	10^{-5}	0.4	0.4
Statistics needed	10^4	10^4	10^4	10^4	10^4	10^4
PP events needed	10^5	10^6	10^8	10^9	10^4	10^4

Commissioning LHC and ALICE

- ALICE could not run usefully much above a luminosity of 5×10^{30} cm^{-2} s^{-1} (events pile up in the 88 μs maximum drift time of the TPC).
- How will ALICE get low luminosity conditions?
  - By using special beam optics at Point 2:
    - The reduction factor is $\beta^*/\beta_{nom.} = \beta^* / 0.5$ m. Under nominal conditions, maximum $\beta^* = 35$ m, which gives reduction-factor 70;
  - In special runs at low luminosity, when detector is complete, to take data with negligible event overlap, and if possible a small enough β*, so that the transverse vertex spread is minimized, in view of heavy flavour physics;
  - By displacing the beam, whenever the above conditions are not sufficient:



$$Luminosity : L(D) = L_0 \exp\left(-\frac{D^2}{4\sigma^2}\right)$$

for D/σ = 4.5, the additional reduction factor is ~ 160.

⇒ $L_{ALICE} = 3\times10^{30}$ $cm^{-2}s^{-1}$ for $L_{max} = 10^{34}$ $cm^{-2}s^{-1}$

  - During LHC commissioning!

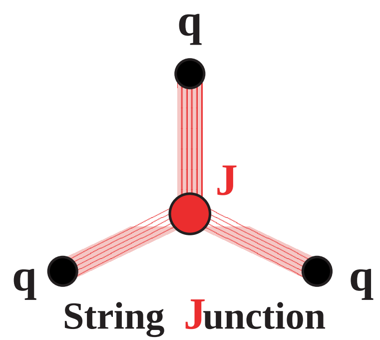
Beam characteristics (LHC-OP-BCP-0001 rev 1.)

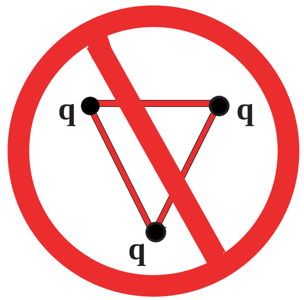
- LHC commissioning time will be ideal for ALICE. $L = f \times N_b \frac{N_1 N_2}{\pi(4\sigma_x\sigma_y)}$

Beam Energy (TeV)	**0.9**	**2.0**	**5.5**	**6 to 7**	**6 to 7**	**6 to 7**
Number of bunches	**43**	**43**	**43**	**43**	43	156
β^* [m]	**10**	**10**	**10**	**10**	10	10
Crossing Angle [μrad]	**0**	**0**	**0**	**0**	0	0
Transverse emittance [μm]	**3.75**	**3.75**	**3.75**	**3.75**	3.75	3.75
Bunch spacing [ns]	**2025**	**2025**	**2025**	**2025**	2025	525
Bunch Intensity	**$1x10^{10}$**	**$1x10^{10}$**	**$1x10^{10}$**	**$1x10^{10}$**	$4x10^{10}$	$4x10^{10}$
Luminosity [cm^{-2} s^{-1}]	**$4x10^{27}$**	**$9x10^{27}$**	**$2.4x10^{28}$**	**$6x10^{28}$**	$1x10^{30}$	$3.5x10^{30}$
Inelastic Rate [Hz]	**144**	**369**	**1128**	**3600**	57600	201600
Time to collect $2x10^4$ events →	140s	60s	20s	5s		

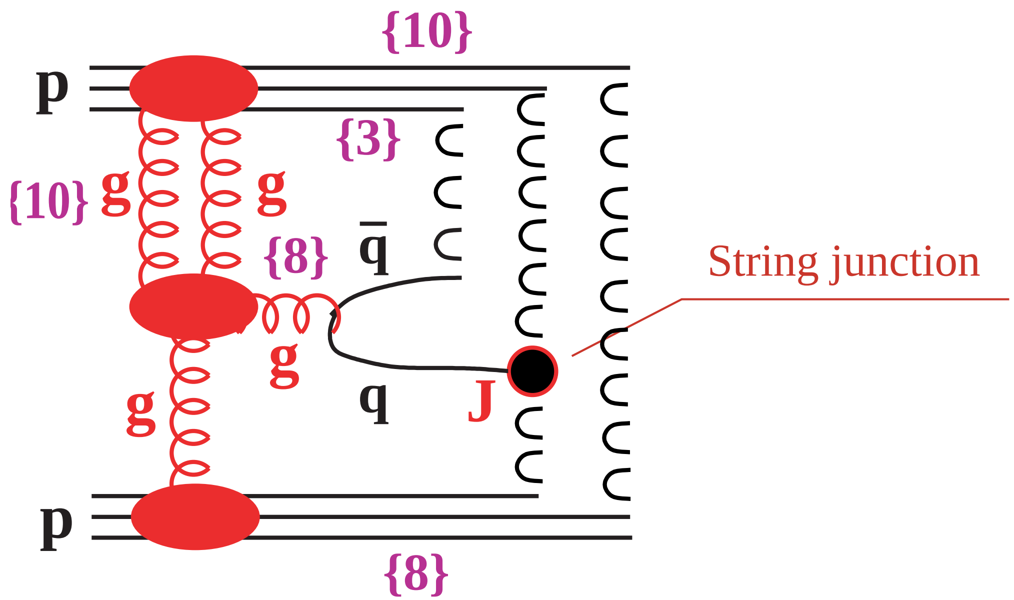
Baryon Production in Central Rapidity Region

- Can gluons carry baryon number? (Rossi, Veneziano String Junction)





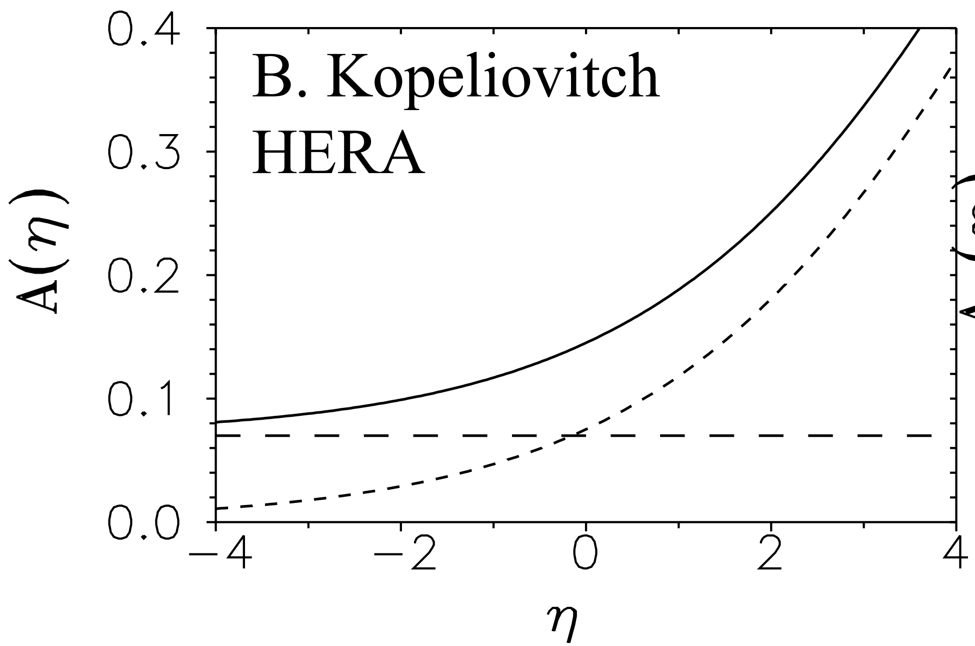
  - Baryon number can be transferred by specific configuration of the gluon field: (B. Z. Kopeliovitch and B. Zakharov Z. Phys. C43 (1989) 241).
  - This would result in substantial baryon production in central rapidity region

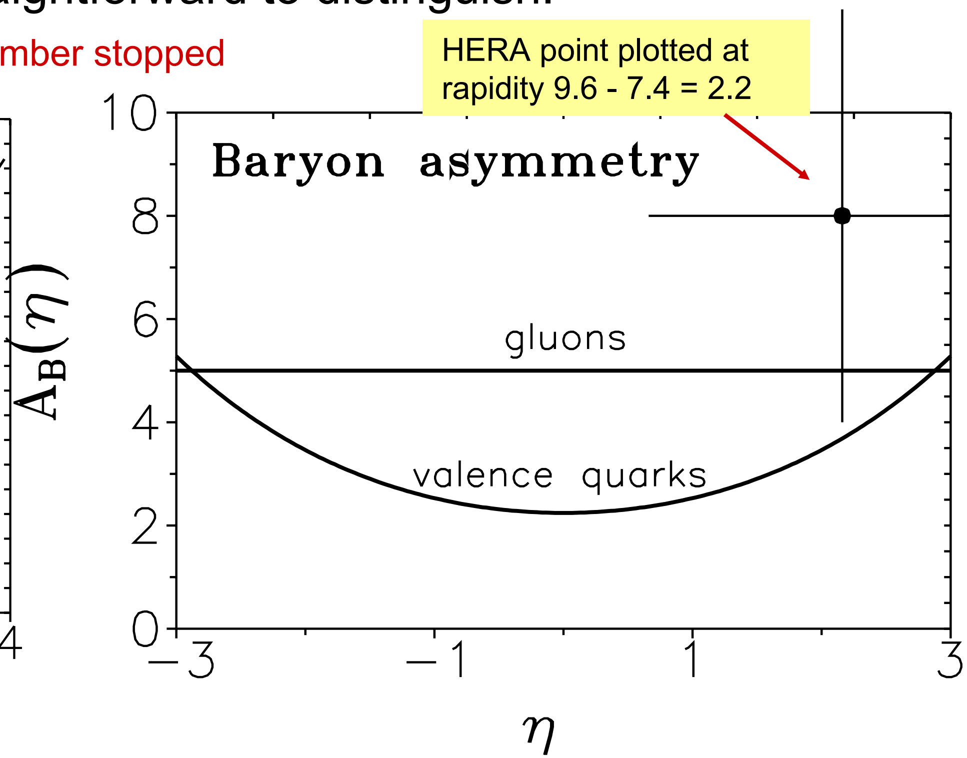


Baryon Production in Central Rapidity Region (cont.)

- At LHC huge rapidity gap between incoming protons ($y_p = \pm 9.6$) and central rapidity ($y = 0$) would allow contribution from valence quarks to be (probably) negligible (constant baryon density as opposed to models where stopping is a "mechanical*" phenomenon and the density decreases as $\exp(-0.5\Delta y) = 1/120$. Should be straightforward to distinguish.

* "mechanical" = both energy and baryon number stopped





- At HERA, the valence quark contribution is still relatively large

Baryon Production in Central Rapidity Region (cont.)

- ALICE will be able to measure $p, \overline{p}, \Lambda$, Ξ, and Ω. The idea is to measure the asymmetry between baryons and anti-baryons (B. Kopeliovitch):

$$A_p \equiv 2\times\frac{p-\overline{p}}{p+\overline{p}} \sim 5\%\, at\ LHC$$

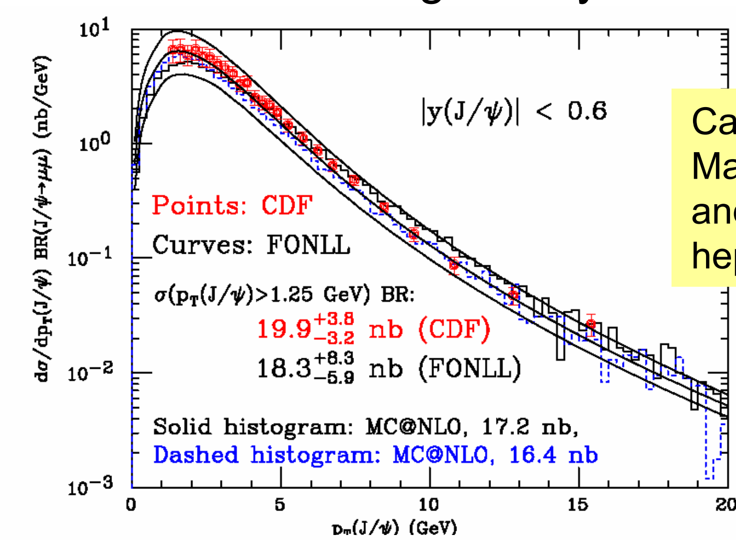
$$A_\Lambda \equiv 2\times\frac{\Lambda-\overline{\Lambda}}{\Lambda+\overline{\Lambda}} \approx 30\%\, at\ LHC$$

Systematics ≤ 2% (Beam-Gas, antiproton absorption, secondary protons)

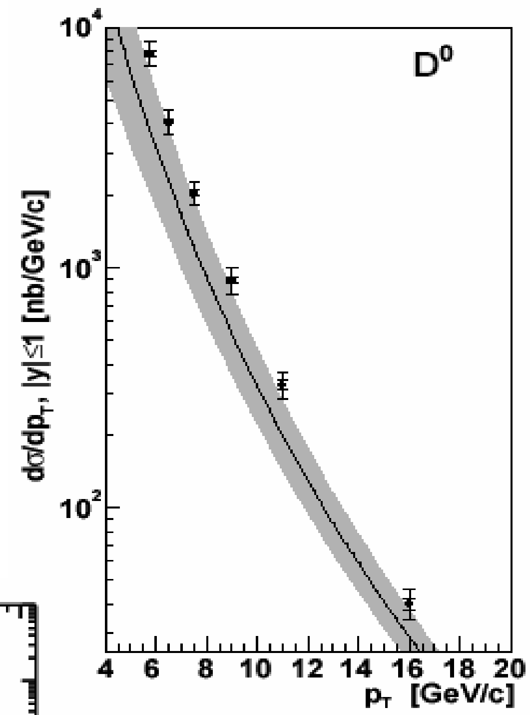
- 10^9 MB events $\Rightarrow$ 1.4×10^{10} pions, $7\times10^8\,\overline{p}$, $10^7\ \Lambda$, $2\times10^5\ \Xi$ and $10^4\ \Omega$.
- Since baryon stopping implies more strings to exchange, it is expected that those events have higher particle multiplicities, hence a measurement of the asymmetry as a function of multiplicity is needed.
- Such measurements will be relevant to heavy ion collisions where baryon stopping should be dramatically enhanced.
- ALICE can also study heavy flavor baryons (Λ_b, Ξ_b, Ω_b, ...) which are poorly known. With Br.($\Lambda_b \to J/\psi\Lambda$) = $(4.7 \pm 2.8)\times10^{-4}$, 10^9 events, triggered on J/ψ using the TRD detector, should produce a few thousand Λ_bs. What's more, there is a chance to observe Ξ_b and Ω_b

Heavy flavour production at LHC

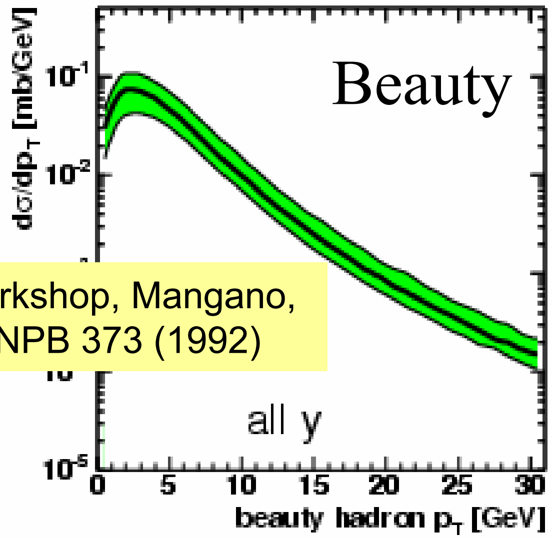
- Important test of pQCD requiring both B and C studies. Large uncertainties on NLO predictions for LHC. Probe of small x gluon dynamics.

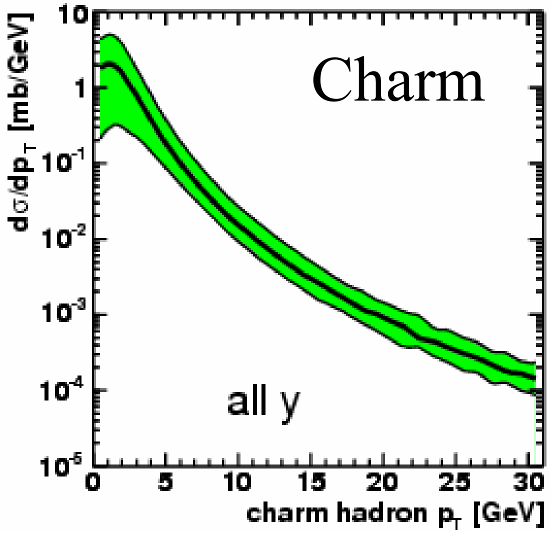


Cacciari, Frixione, Mangano, Nason and Ridolfi, hep-ph/0312132



CDF, hep-ex/0307080
FONLL: Cacciari, Nason

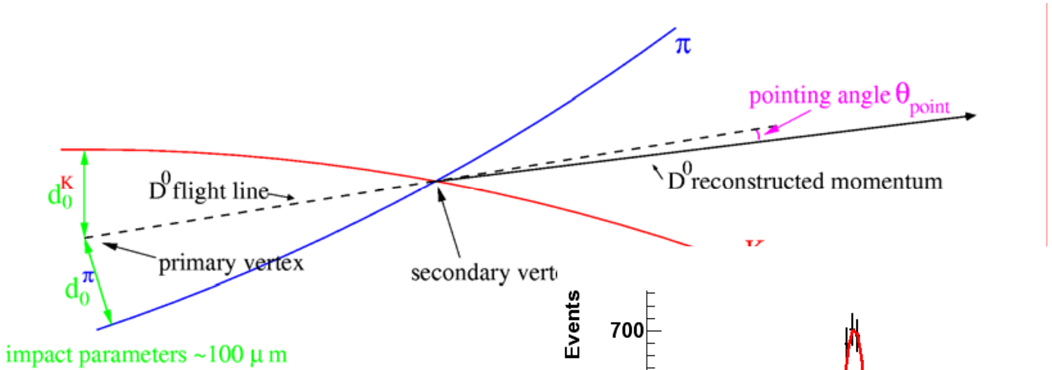


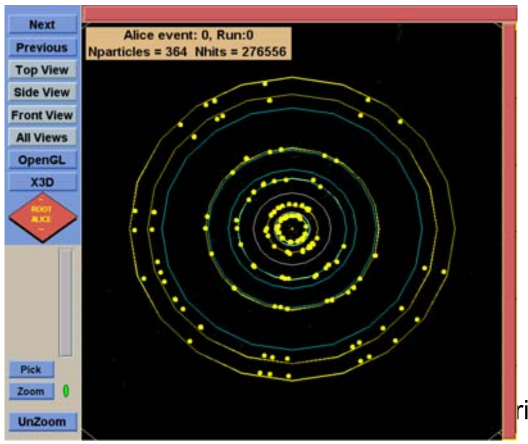


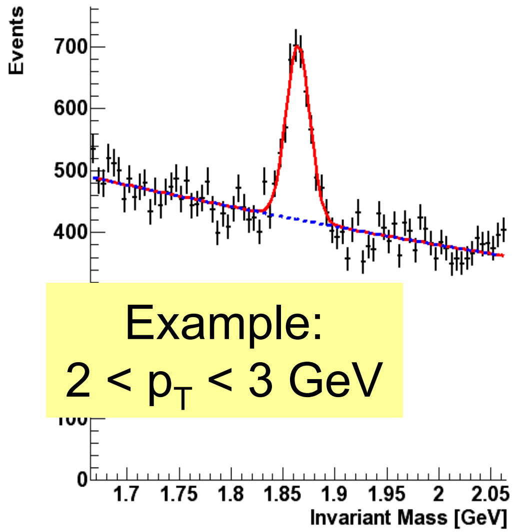
HERA-LHC Workshop, Mangano, Nason, Ridolfi, NPB 373 (1992)

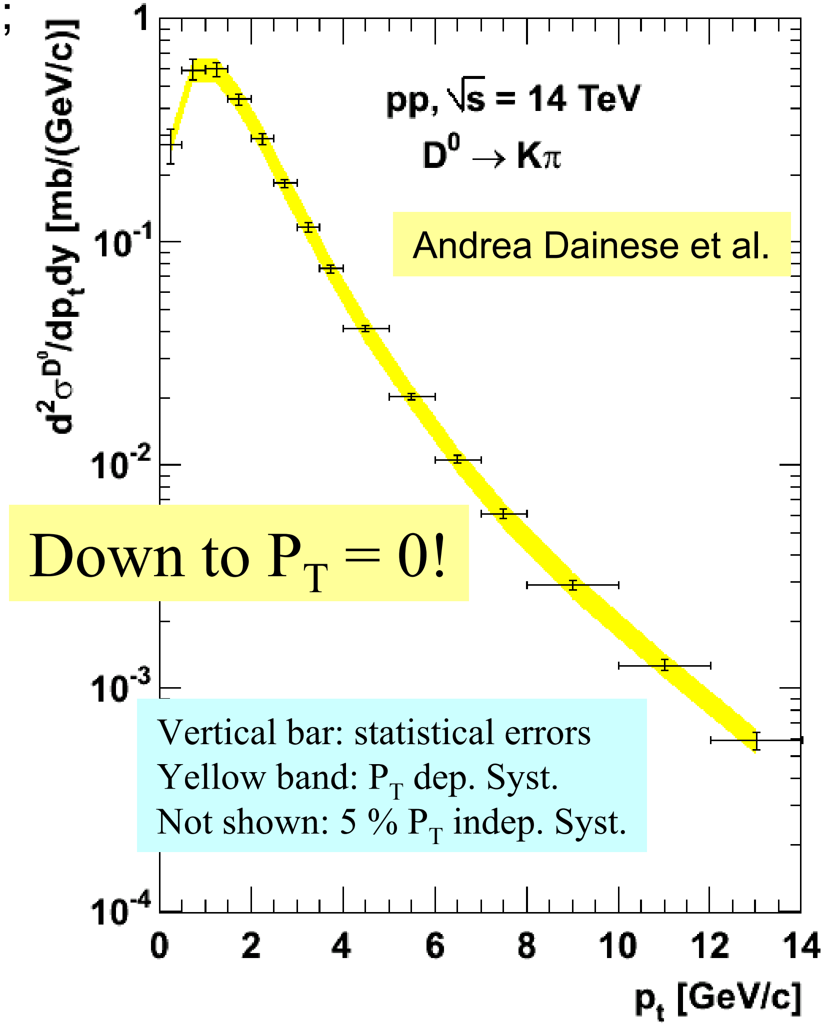
Charm production measurement

- Charm quark in **hadronic** ($D^0 \rightarrow \pi^+K^-$) and in **semileptonic** channels: TRD with P_T(electron) > 1 GeV/c
- Benchmark channel for ALICE: $D^0 \rightarrow \pi^+ K^-$ [$c\tau(D^0)$ = 124 μm] (**fully simulated**)
  - Reconstruct primary vertex using all tracks;
  - Select displaced topologies;
  - $K^\pm$ ID via TOF crucial at low P_T







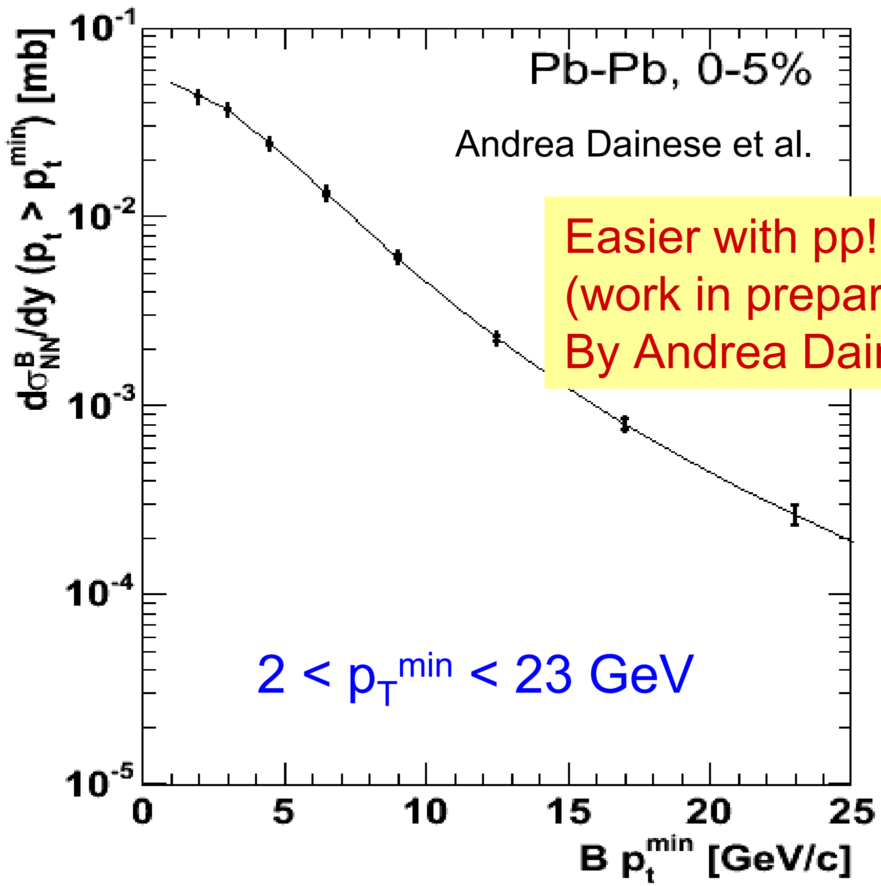


Beauty and Charm physics

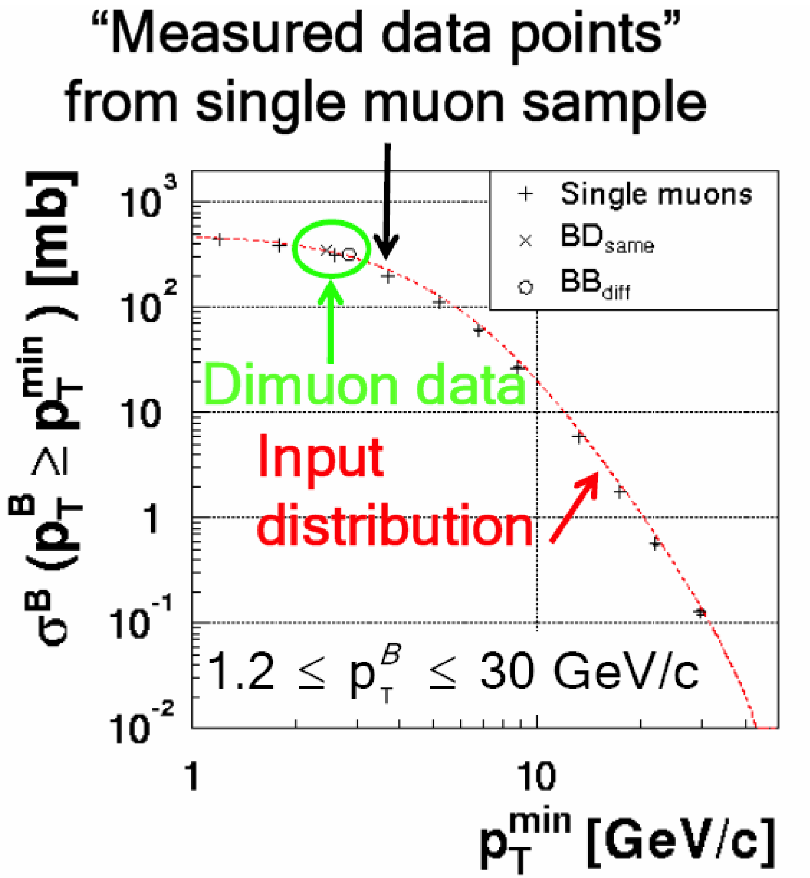
- At LHC energies $\sigma_{b\bar{b}} / \sigma_{c\bar{c}} \sim 5\%$ D⁰'s from **b → B⁰/B⁺ → D⁰** not negligible.
- From "Standard" NLO pQCD + Pythia fragmentation + PDG:

$$\frac{dN/dy(b \to D^0)}{dN/dy(c \to D^0)} = \frac{\overbrace{dN/dy(b \to B^0/B^+)}^{0.0017} \times \overbrace{BR(B^0/B^+ \to D^0 + X)}^{0.64}}{\underbrace{dN/dy(c \to D^0)}_{0.0196}} = 5.5\%$$

- Use excellent lepton ID: B → (μ±)e± + X, J/Psi + X (muon arm, TRD)

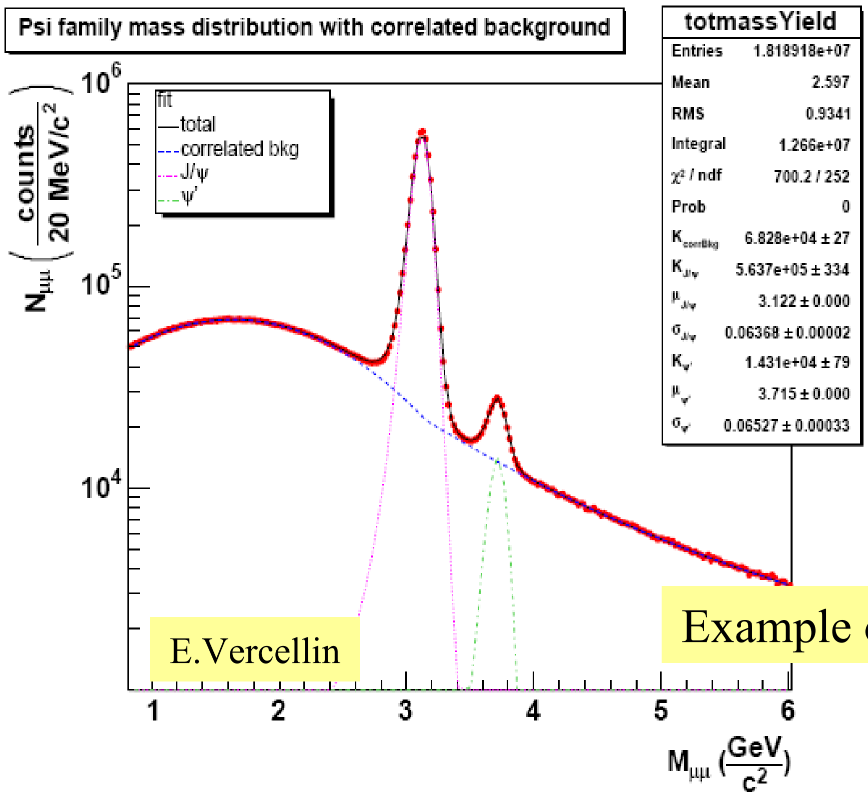


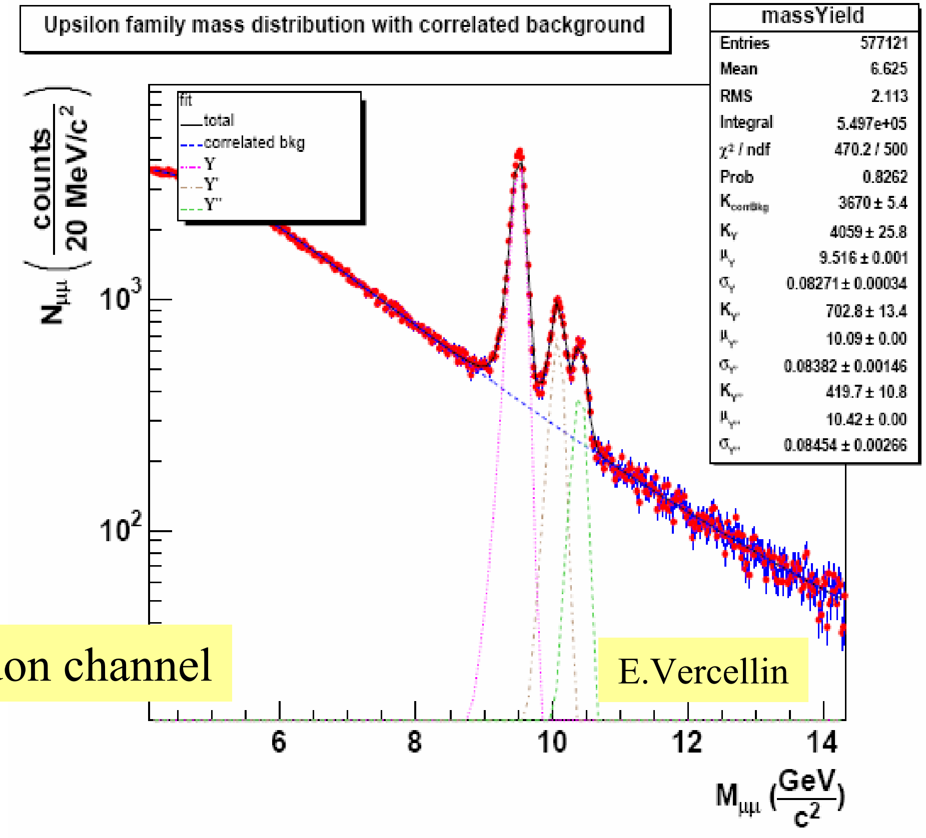
Easier with pp!
(work in preparation,
By Andrea Dainese)



Quarkonia physics

- **Muon channel** (2.5 <y< 4) ΔM = 90 MeV at the Υ. In one year of data: 8.5×10^5 J/Ψ with a S/B ratio of 13 and 6.5×10^3 Υ with a S/B ratio of 16.
- **Electron channel** (-1<y<1), with a mass resolution of ΔM = 70 MeV, and statistics of 5×10^5 J/Ψ in one year and S/B > 10. The mass resolution for Y is ≤ 100 MeV. Acceptance down to P_T ~ 0.

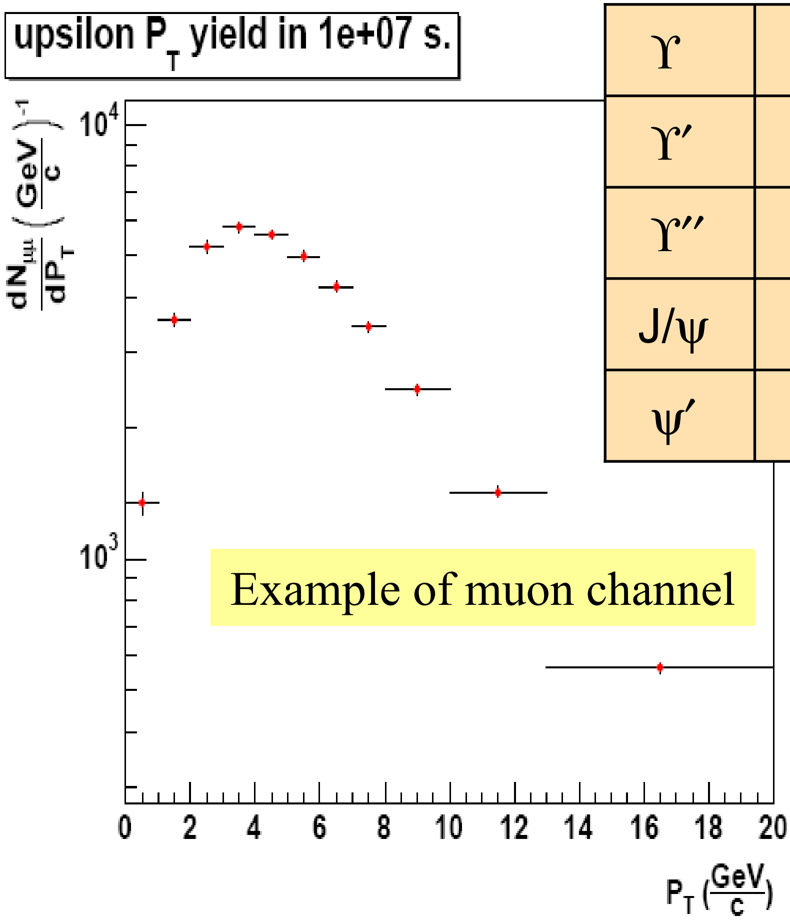




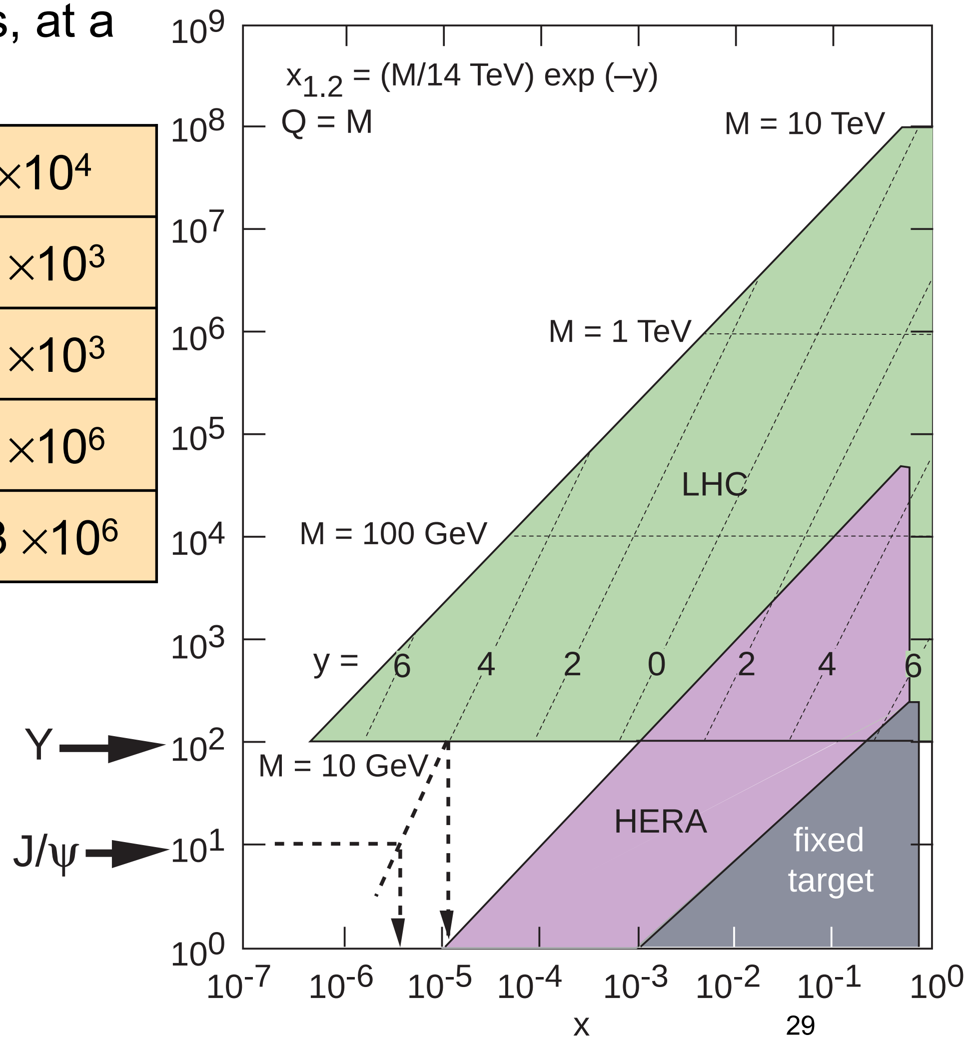
Example of muon channel

Kinematic range at LHC

- The quarkonia studies will cover an entirely new kinematic domain at LHC, where both gluon saturation and non-perturbative QCD will play a role.
- Data taking scenario: 10^7 seconds, at a luminosity of 5×10^{30} cm^{-2} s^{-1}

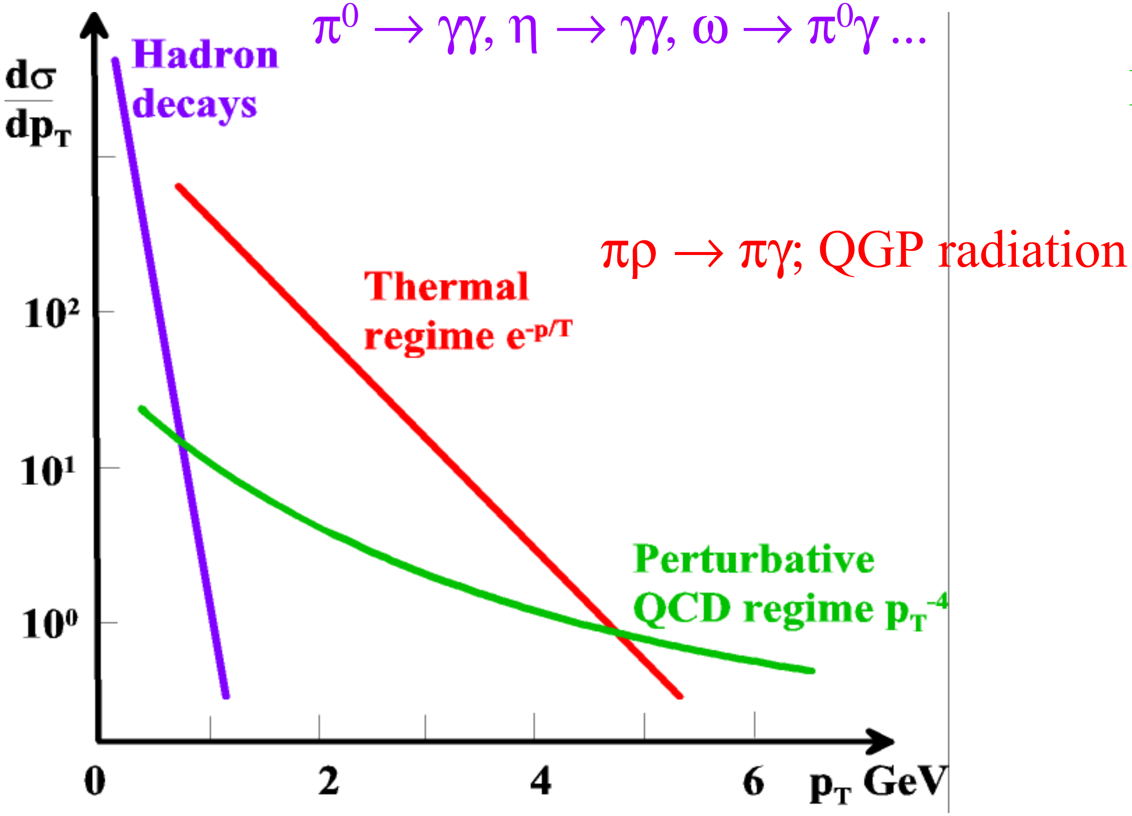


Υ	4.8×10^4
Υ'	8.7×10^3
Υ''	5.3×10^3
J/ψ	5.0×10^6
ψ'	0.13×10^6

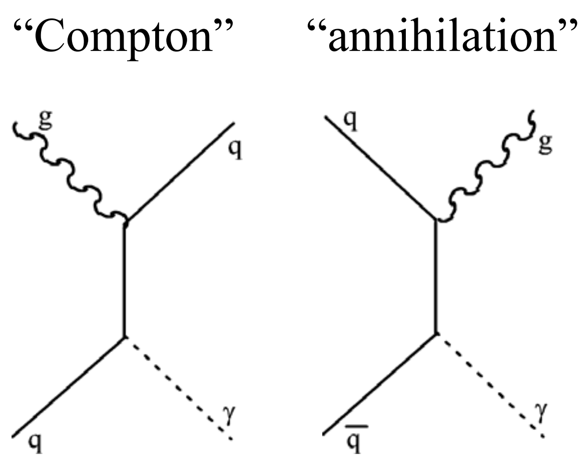


Photon Physics in ALICE

- Two main motivations:
  - Calibrate photon production in pp to subtract NN contribution in Heavy Ion collisions, in search for thermal photon signal from QGP, and study jet quenching (longer lifetime at LHC)
  - Perform high P_T QCD tests (γ, π^0 cross-section, jet fragmentation, etc.)

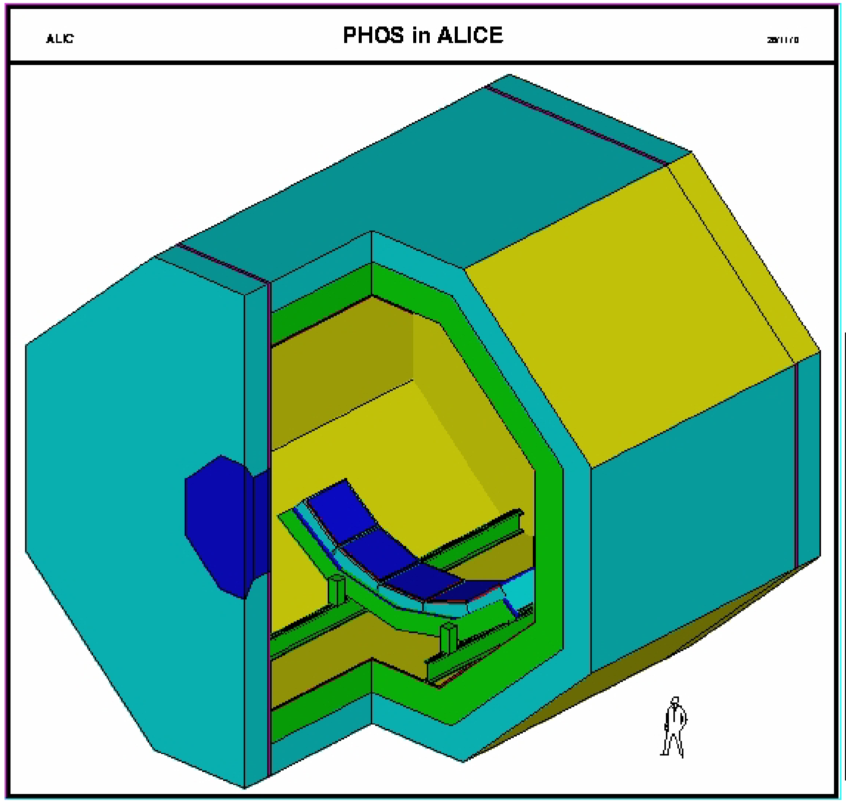


Perturbative QCD contribution

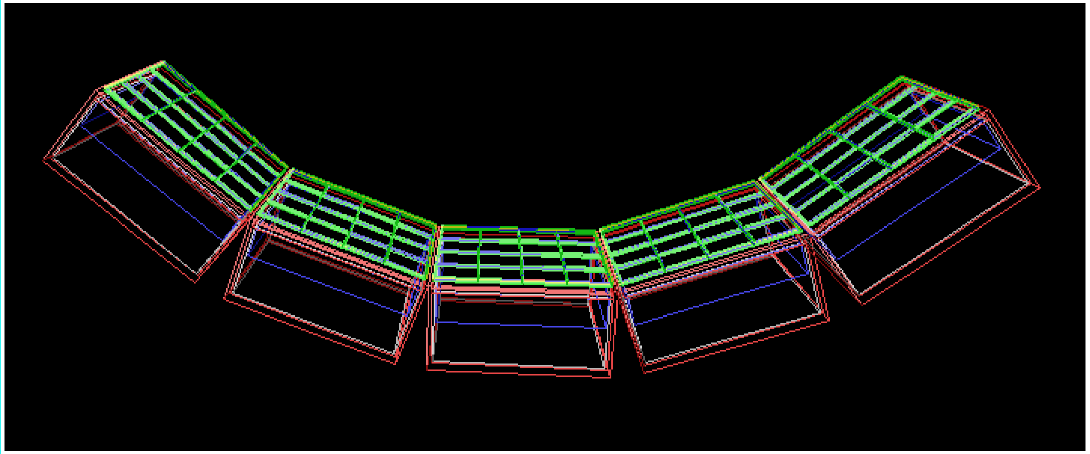


ALICE Photon Spectrometer (PHOS)

- Dimensions: $\eta \sim \pm 0.12$, $\varphi \sim 100°$ ($1 \times 8\ m^2$) at radius $R \sim 4.6$ m
$PbWO_4$ crystals, $X_0 = 0.89$ cm, $\lambda_{int} = 19.5$ cm, Moliere radius: 2.0 cm
- Granularity: $2.2 \times 2.2\ cm^2$ ($\Delta\eta \times \Delta\varphi \sim 0.005 \times 0.005$), length: 18 cm



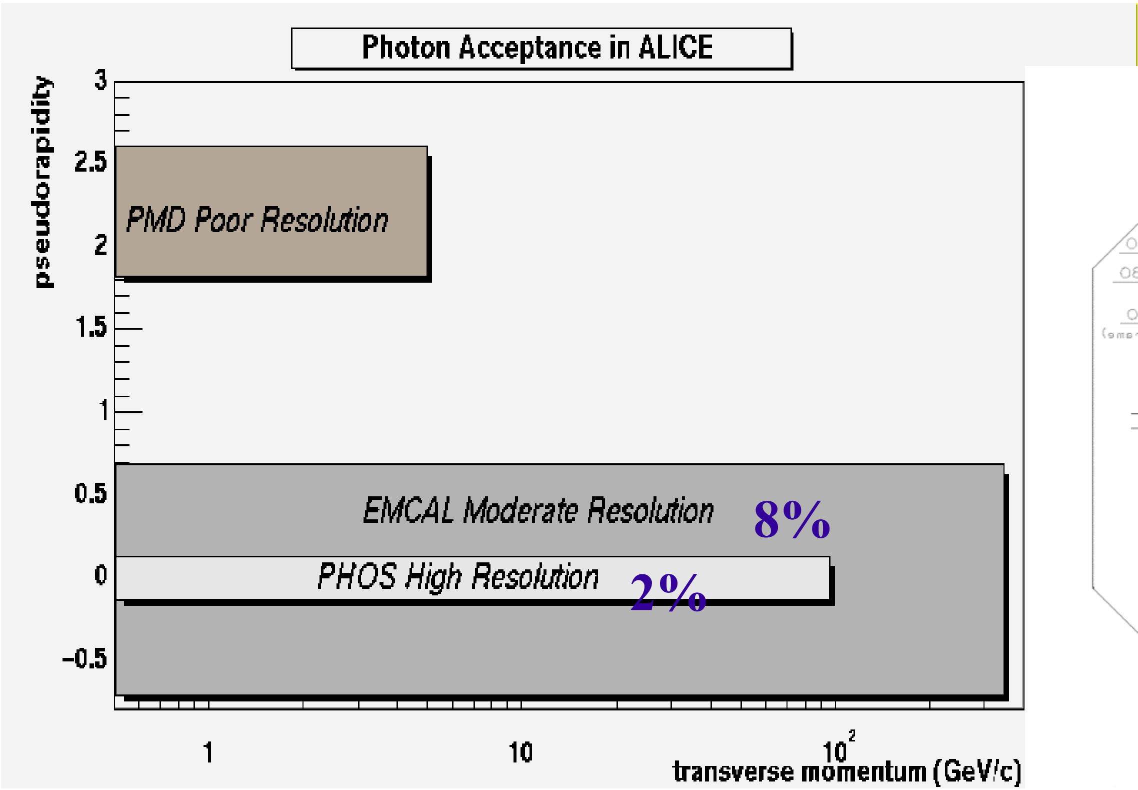
- The granularity is the same as CMS but the distance from the interaction point is 3 times that of CMS
- π^0 identified from 1 to 80 GeV/c
- Energy resolution 2% above 3 GeV/c



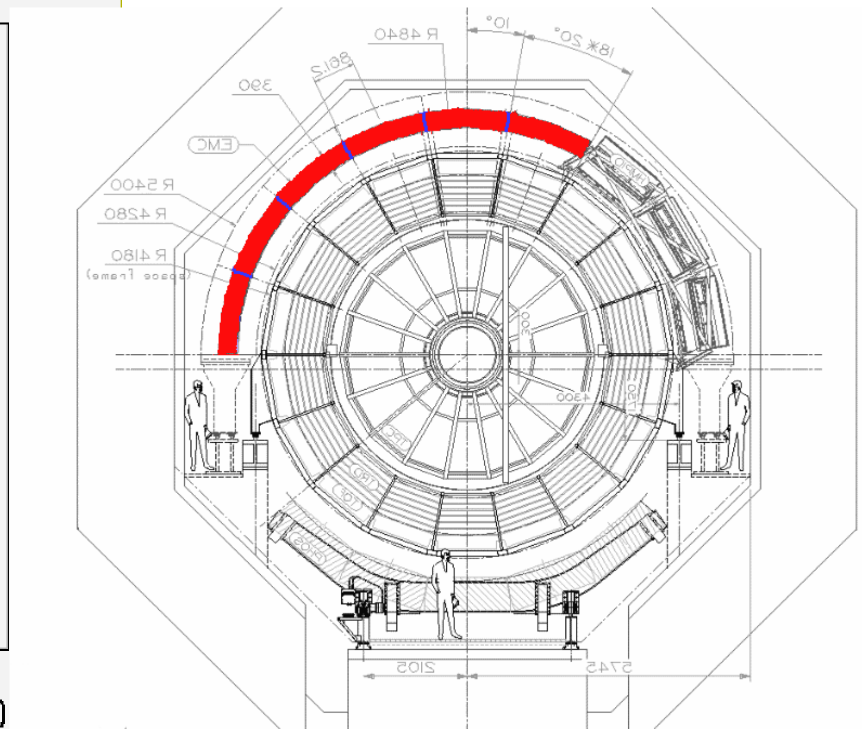
Jet physics in ALICE

- ALICE is considering the possibility to construct an electromagnetic calorimeter (USA EMCAL project); Most likely not ready at start of LHC.
- In the mean time, jet studies will be carried out using charged tracks only.

Jet fragmentation using identified particles, and PHOS for γ tagging



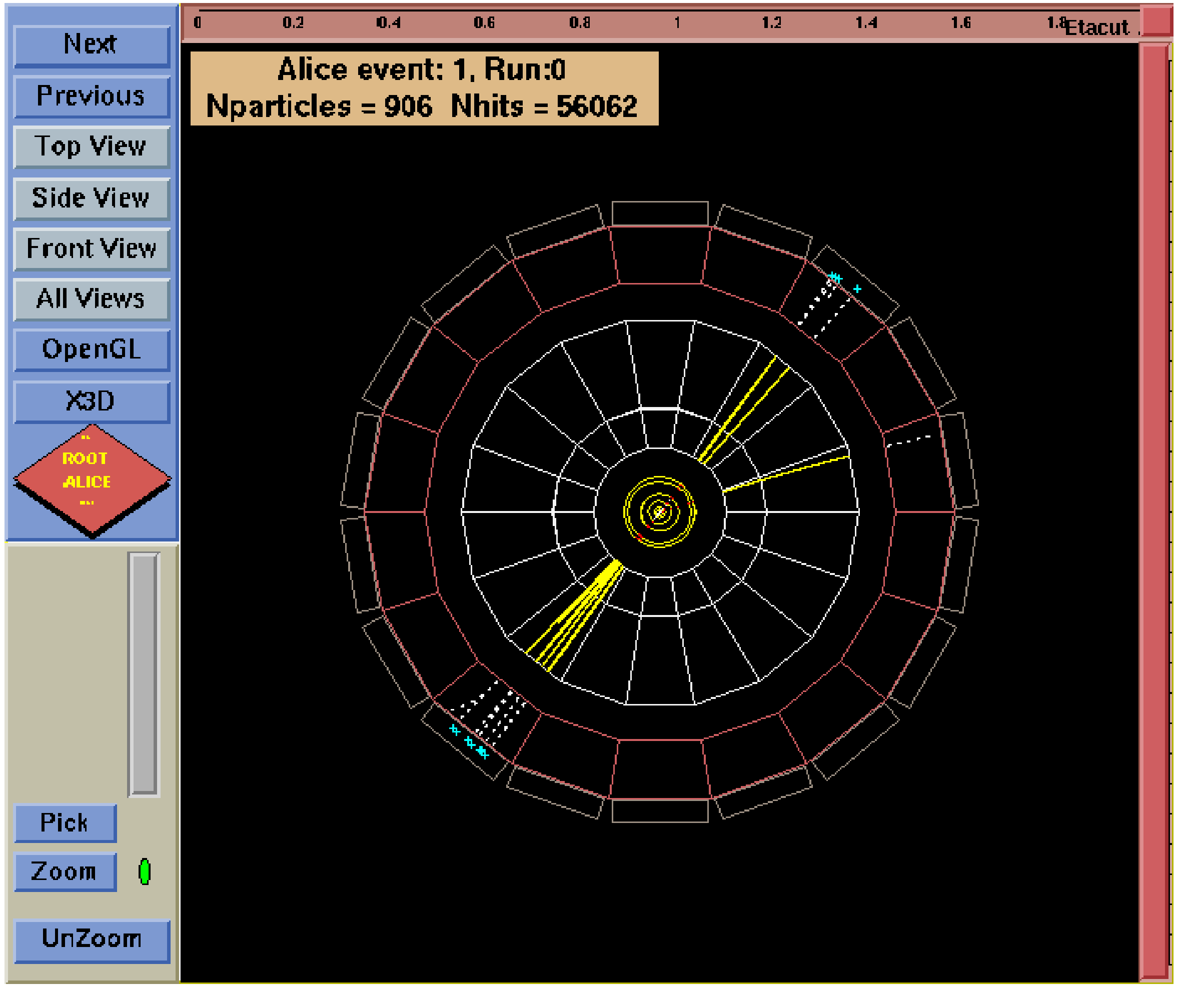
EMCAL



Jet physics in ALICE

- Jet rates:
  - P_T>100 GeV: 10^7/year @ L = 10^{30} cm^{-2} s^{-1} in ALICE acceptance
- Jet Reconstruction:
  - Limited to charge particles (2/3 of the energy)
- Physics topics:
  - Correlation between leading particles
  - Jet-Jet Correlation
  - Jet fragmentation properties

    ⇒ all of this relevant to jet quenching studies in Pb-Pb collisions



ALICE simulated proton-proton event with two jets with a cut of 2 GeV/c on track momenta

Conclusion

- Many items not covered here (strangeness production, B production, π^0 production with PHOS, Diffractive events, Cosmic ray related physics, etc.).
  *ALICE Collaboration, J. Physics G: Nucl. Part. Phys. **30** (2004) 1517-1753*
- Low P_T proton-proton phenomena studies at LHC are mandatory:
  - Necessity to explore in detail and fully a new domain of physics;
  - Contribute to a better understanding of the strong interaction in a challenging kinematic domain;
  - Needed for the study of heavy ion collisions and has therefore always been part of the ALICE programme;
  - Some of it (Minimum Bias and underlying event properties) is relevant to the understanding of the background to high P_T signals.
- ALICE is complementary to the other LHC detectors, because it is optimized for low p_T physics, and because of its unique Particle Identification capabilities.
- ALICE will be ready in April 2007 and will be commissioned with pp collisions.
- Physics with ALICE will start with the first few minutes of collision at LHC.

CR 5 installation schedule