From pp to heavy-ion collisions at LHC: ALICE experimental programme

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Outlook

- Motivation to collide heavy ions
- LHC experimental programme
- ALICE experiment
- pp collisions
- Heavy-ion collisions
- First measurement

Vacuum

- **Energy of pair created from vacuum:**

$$E_{kin} = p \sim 1/r \qquad (p \times r \geq 1)$$

$$E_{pot} = -\, q^2/(4\pi r) \qquad (q = e \text{ or } q = g_s)$$

$$E = E_{kin} + E_{pot} = (1/r)\times(1 - q^2/4\pi) = (1/r)\times(1 - \alpha_{em,s})$$

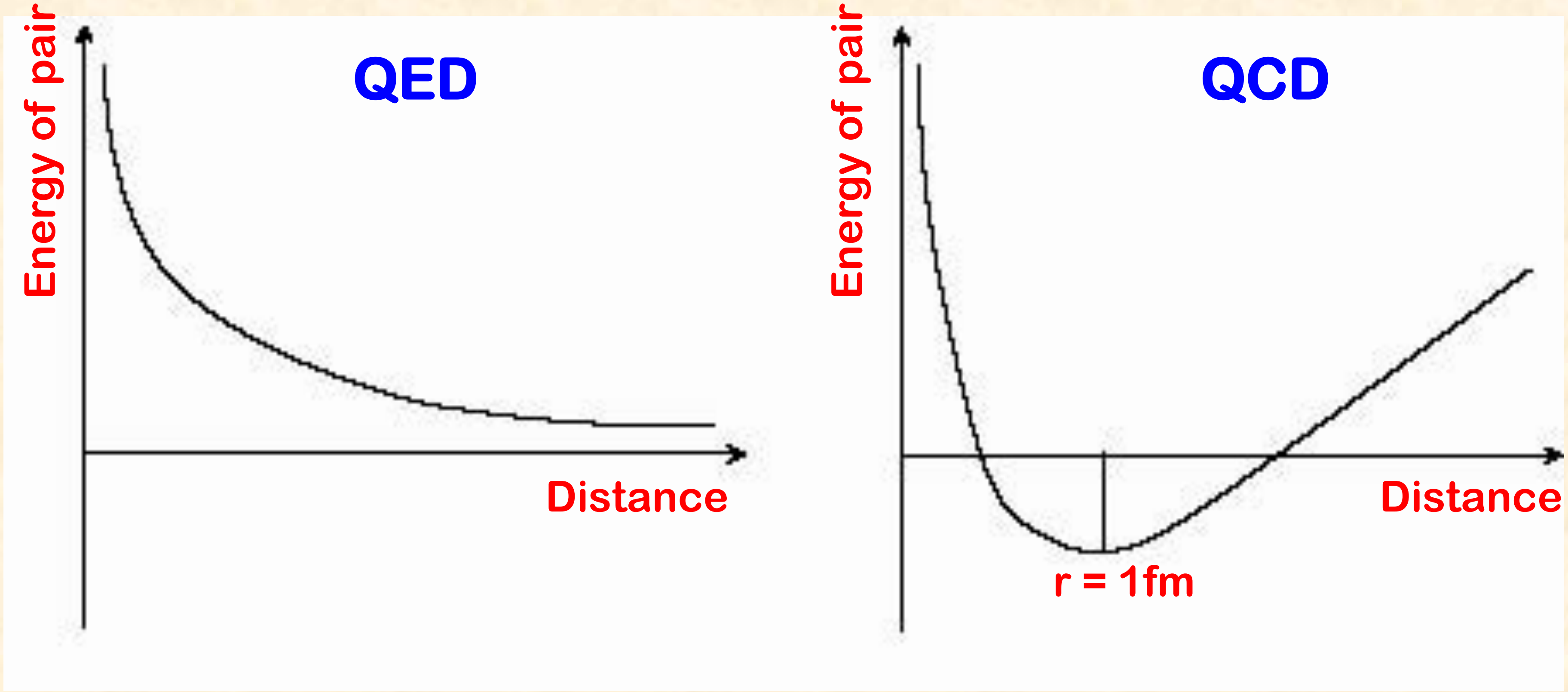
- **in QED this is true for any distance (down to Planck scale 10^{-20} fm)**

- **in QCD it's restricted to small distances, up to few fm at most**

QED vs. QCD

- **in QED**
  - **for large distances** $\alpha_{em} = 1/137$
  - **at EW scale (r = 2×10^{-3} fm)** $\alpha_{em} = 1/128$
  - **at Planck scale (r = 10^{-20} fm)** $\alpha_{em} = 1/76$
- **numerical factor in energy** $(1 - \alpha_{em})$ **varies**
  - **between 0.987 – 0.993 (i.e. 0.6%) changing the pair separation from Planck scale to infinity**
- **in QCD**
  - α_s **decreases for small distances (asymptotic freedom)**
  - **at $\Lambda_{QCD} \approx$ 0.2GeV (r ≈ 1 fm)** $\alpha_s \approx 1$
  - **at EW scale** $\alpha_s = 0.118$
  - **at Planck scale** $\alpha_s = 0.04$
- **numerical factor in energy** $(1 - \alpha_s)$
  - **decreases with distance, at Planck scale 0.96**
  - **however, at r ≈ 1 fm it became negative !**
- **at even larger separation** $E = \sigma \times r$ $(\sigma \approx 1\ \text{GeV/fm})$
  - **and became again positive**

QED vs. QCD



Kinetic energy always dominates over potential energy (weak field)
virtual pairs

Energy stored in field overcomes kinetic energy at some distance
real pairs – vacuum condensate

QCD symmetries

- **QCD Lagrangian has two approximate symmetries**
  - Z_3–(centre) symmetry (for pure guage, i.e. in the limit $m_q \rightarrow \infty$)
  - chiral–symmetry (restored with vanishing masses, i.e. $m_q \rightarrow 0$)

- **At high density and temperature eventually**
  - Z_3–symmetry destroyed (confinement—deconfinement transition)
  - chiral–symmetry restored (chiral phase transition)
  - responsible: vacuum condensate

- **Questions:**
  - is there one phase transition for both or two ?
  - what is the order of the phase transition(s)
    - is it first order (it has a latent heat) ?
    - is it second order (is just a \`kink’) ?
    - is just cross-over transition ?

Confinement

- **massive quark in purely gluonic vacuum at zero temperature**
  - **not seen by detector due destructive inference**
  - **expectation value for trace of quark propagator – 3–valued path integral with different phases**

    exp (i × 2πj/3), j=1,2,3 (generators of Z_3)
  - **increasing the temperature** T **until some value this will stay**
    - **till gluon field will have enough time to follow (re-arrange coherently) our shaking test charge**
  - **increasing temperature further (above some critical value) gluon field will have not time enough**
    - **interference of 3 paths will be destroyed**
    - **test colour charge will became detectable, will be deconfined**
  - **to calculate this we have to continue analytically the quark propagator over complex time (**$t = +i/T$**) – Polyakov loop – which will became non-zero for** $T > T_c$
    - **Polyakov loop is the order parameter**

Chiral symmetry

- **For $m_q \rightarrow 0$ quark helicity will be conserved**
  - **because gluons have helicity ±1 QCD Lagrangian in this limit has $SU(3)_L \times SU(3)_R$ symmetry**
    - **QCD world decayed into two worlds which do not communicate – left-handed and right-handed**
  - **when we put into QCD vacuum massless left-handed quark it can annihilate with left-handed anti-quark from vacuum condensate – liberating thus right-handed quark**
    - **for an outside observer our test quark changed spontaneously its helicity and therefore it has to acquire some dynamic mass !**
    - **QCD quark—anti-quark condensate generates dynamic quark masses and chiral symmetry is destroyed**
  - **when we rise temperature kinetic energy term of the pair energy will above some value overcome potential energy**
    - **quark—anti-quark condensate will disappear from vacuum**
    - **chiral symmetry is restored above some critical temperature**
    - **value of $\langle 0|\bar{q}q|0\rangle$ is the order parameter**

QCD symmetries

- **Both symmetries are broken dynamically**
  - **Z_3 symmetry is broken by kinetic energy (at high T)**
    - **order parameter (Polyakov loop) is zero below T_c and non-zero above**
    - **it is a order – disorder phase transition, Z_3 is restored below T_c**
  - **chiral symmetry is broken by potential energy (at low T)**
    - **order parameter (quark—anti-quark condensate) is non-zero below T_c and zero above**
    - **it is a disorder – order phase transition, chiral symmetry is restored above T_c**
- **Both are broken also explicitly – by mass term**
  - **because of smallness of m_q it's reasonable to expect that the scenario concerning chiral symmetry will be a good approximation**
  - **what about Z_3 symmetry, why it's not completely destroyed by small m_q ?**

Confinement restoration

- **When we try to drop m_q from infinity down its bare (small) value what happen will depend on temperature**
  - at low temperature m_q will effectively stop decreasing when we go below quark dynamic mass $M_q \approx 350$ MeV because chiral symmetry is broken
  - Z_3 symmetry remains an approximate symmetry at low temperature even after this severe explicit breaking attempt
  - chiral symmetry breaking effectively increases quark masses and therefore drives the Z_3 symmetry restoration
  - this is an argument that the two phase transition might occur at the same point

QCD Phases – Toy Model

- **consider**
  - **confined phase (hadron gas, HG) made of pions**
  - **deconfined phase (quark—gluon plasma, QGP) made of gluons and two flavor of quarks**
  - **ideal-gas equation of state**

$$\varepsilon = (g/30)\,\pi^2 T^4\,,\quad p = \varepsilon/3 = (g/90)\,\pi^2 T^4$$

where $g = n_b + (7/8)\,n_f$

- **for HG** $n_b = 3$, $n_f = 0$

$$p_{HG} = (1/30)\,\pi^2 T^4$$

- **for QGP:** $n_b = 16$, $n_f = 24$ **but now we have also an external pressure from QCD vacuum** B

$$p_{QGP} = (37/90)\,\pi^2 T^4 - B$$

- **at phase boundary – pressures have to be equal**

$T_c = (90B/34\pi^2)^{1/4} = 144$ MeV **for** $B^{1/4} = 200$ MeV (**MIT bag model**)

QCD Phases – Perturbation Theory

- **at non-zero baryon density – first order p-QCD**

$$\varepsilon = [16(1 - 15\alpha_s/4\pi) + (7/8)12n_q(1 - 50\alpha_s/21\pi)]\ (1/30)\ \pi^2T^4 +$$

$$+ \Sigma_q\ 16(1 - 15\alpha_s/2\pi)\ (3/\ \pi^2)\mu_q^2(\pi^2T^4 + \mu_q^2(\ /2)$$

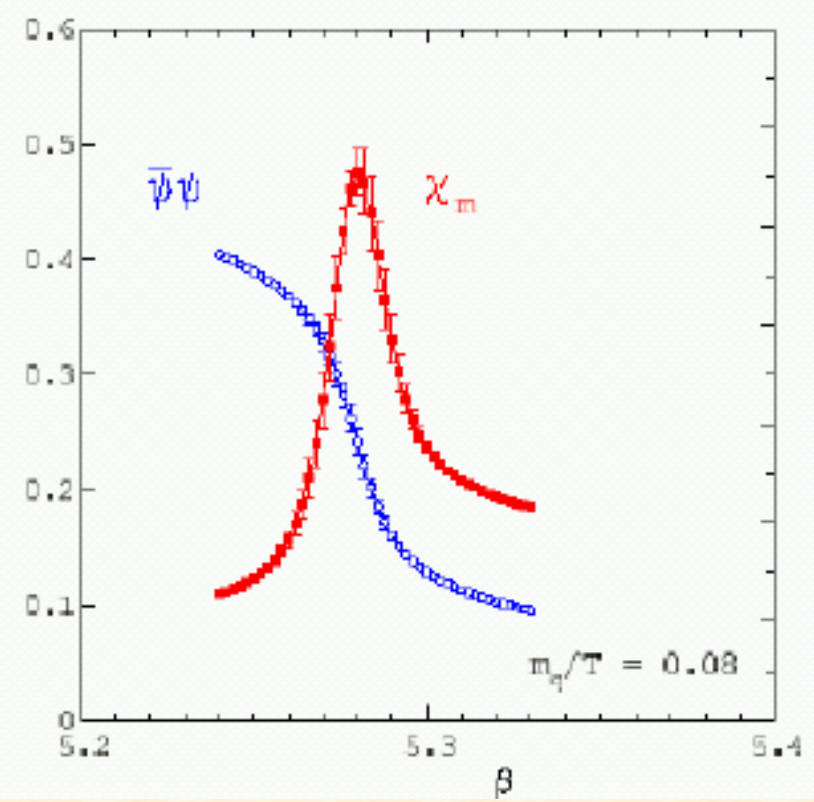
(for $\mu_q = 0$, $\alpha_s = 0$, **and** $n_q = 2$ **we get our toy model)**

using $\alpha_s = 0.4$ **the same way we estimate** $T_c = 164$ MeV

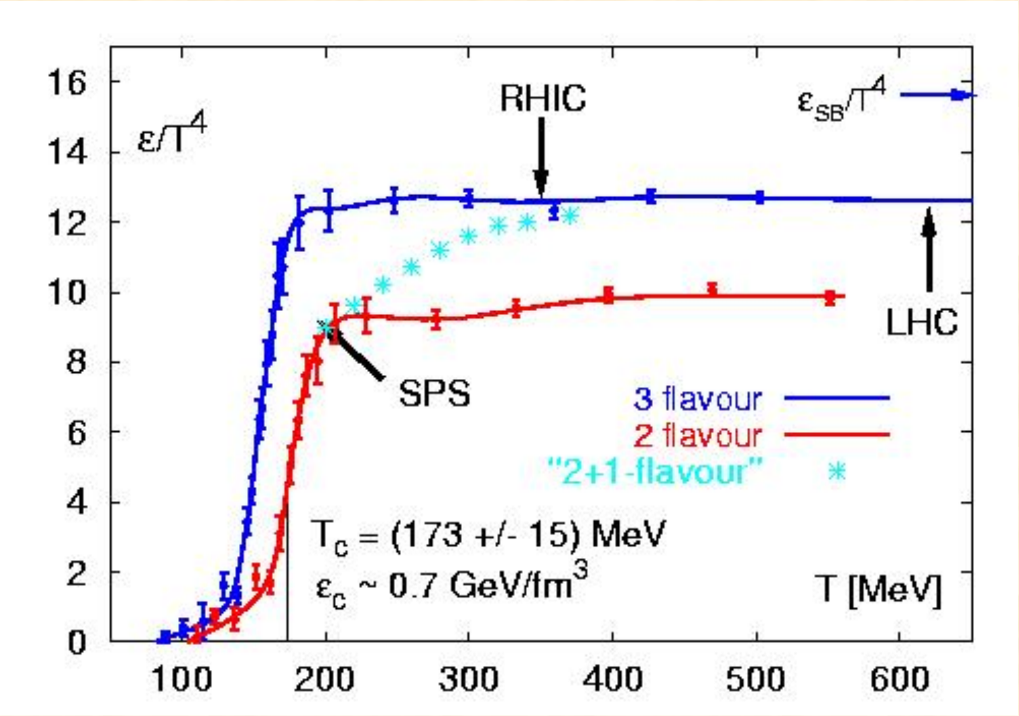
- today analytical calculations exist for higher orders

Lattice QCD

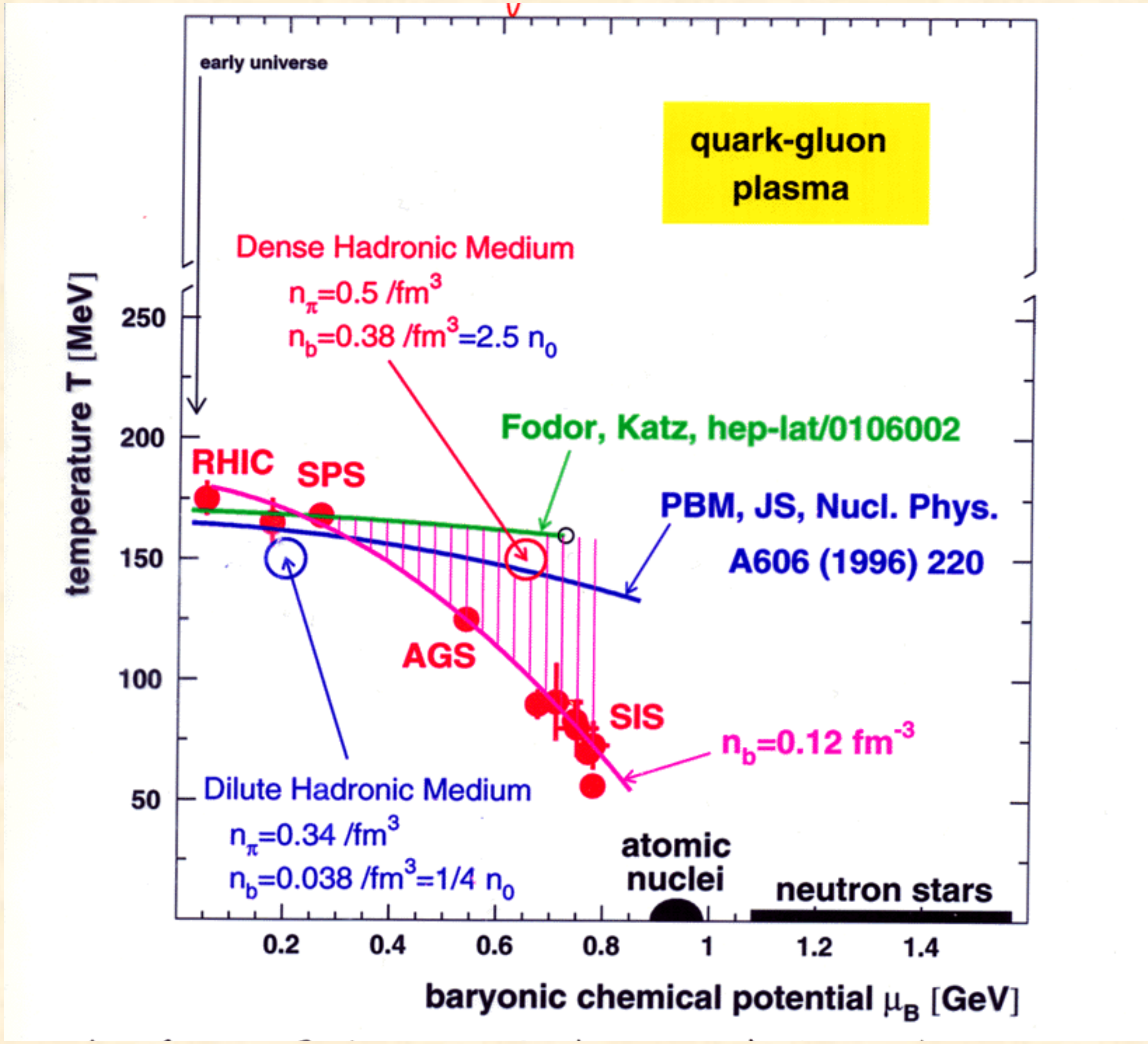
Quark—anti-quark vacuum condensate as function of temperature



QCD equation of state

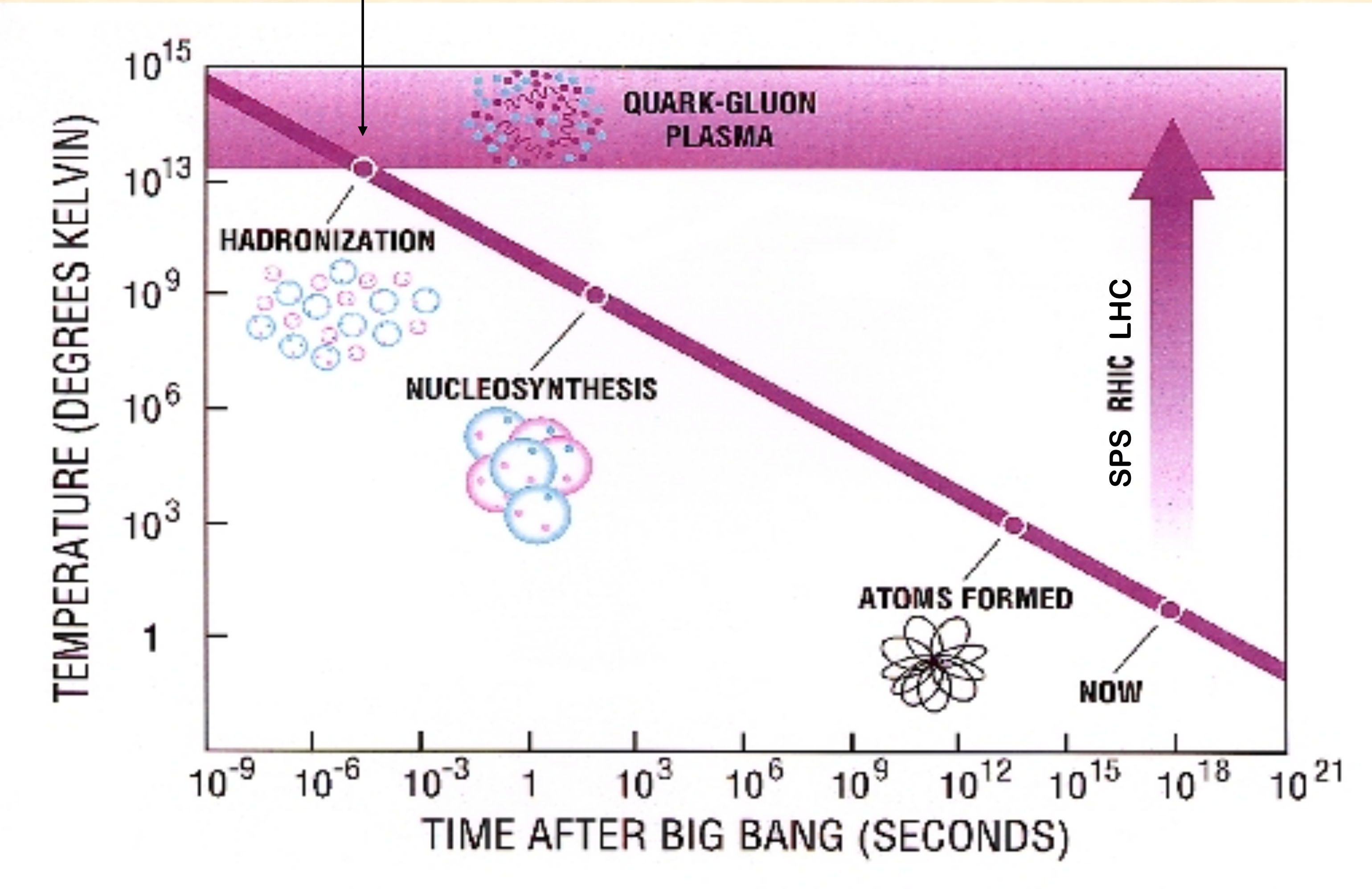


Phase Diagram of QCD

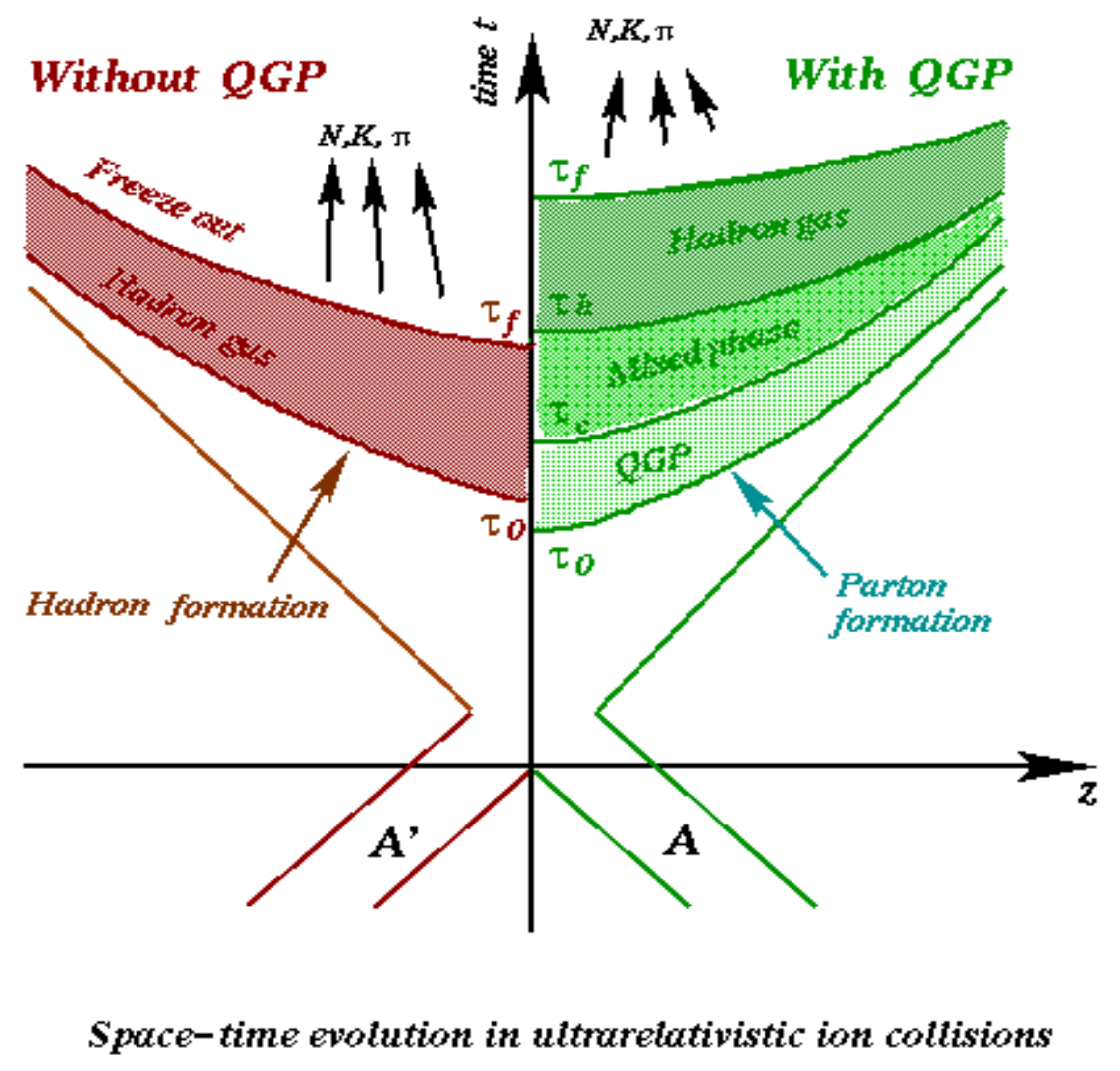


Phase transition in early Universe

10 – 100 μs

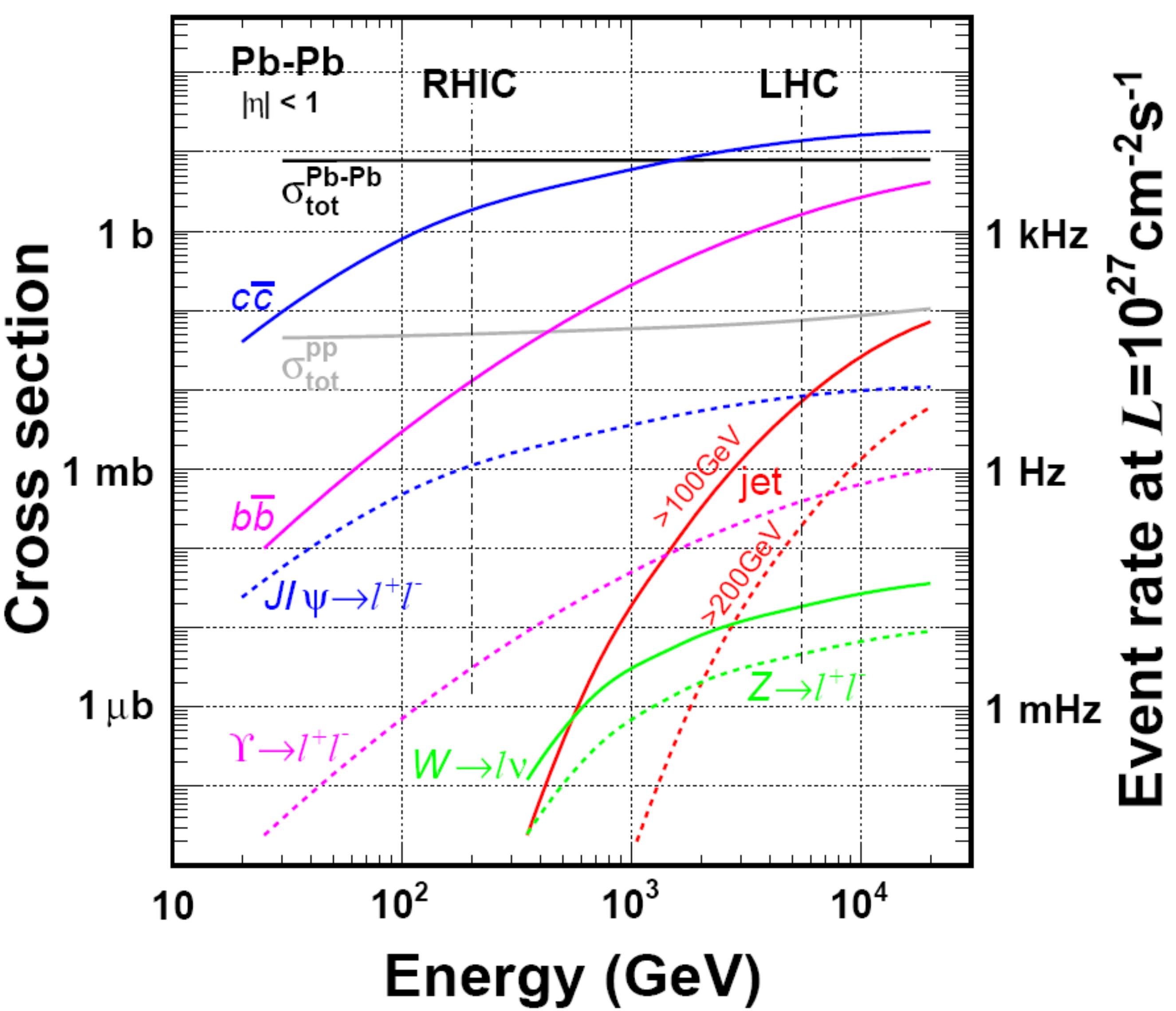


Space-time evolution



Space−time evolution in ultrarelativistic ion collisions

Cross sections at LHC



From RHIC to LHC

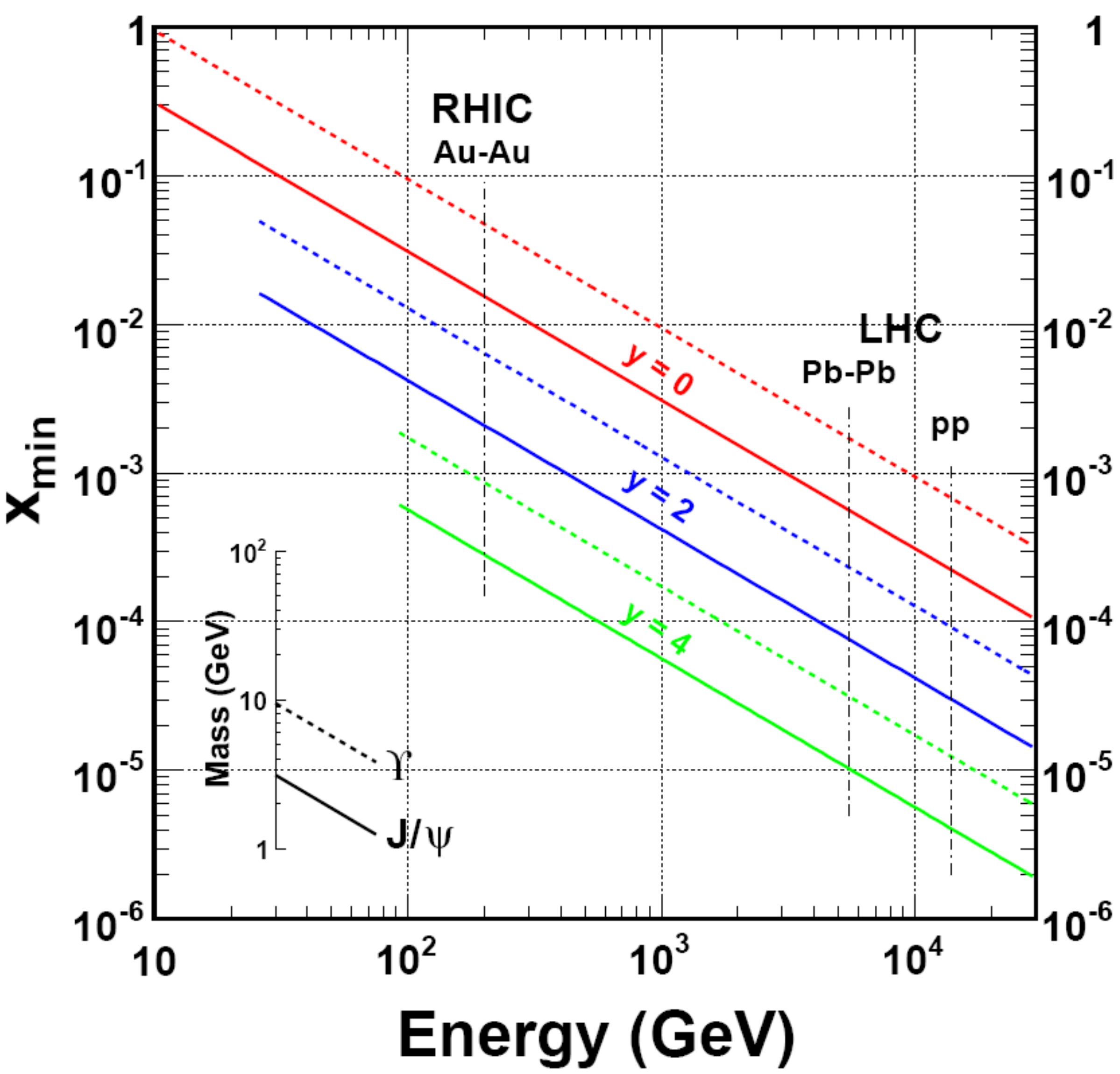
$\sigma_{cc} \rightarrow \sim 10$

$\sigma_{bb} \rightarrow \sim 100$

$\sigma_{jet>100GeV} \rightarrow \sim \infty$

$\sigma_{RHIC}(\Upsilon \rightarrow \ell\ell) \sim \sigma_{LHC}(Z \rightarrow \ell\ell)$

New low-x regime



From RHIC to LHC

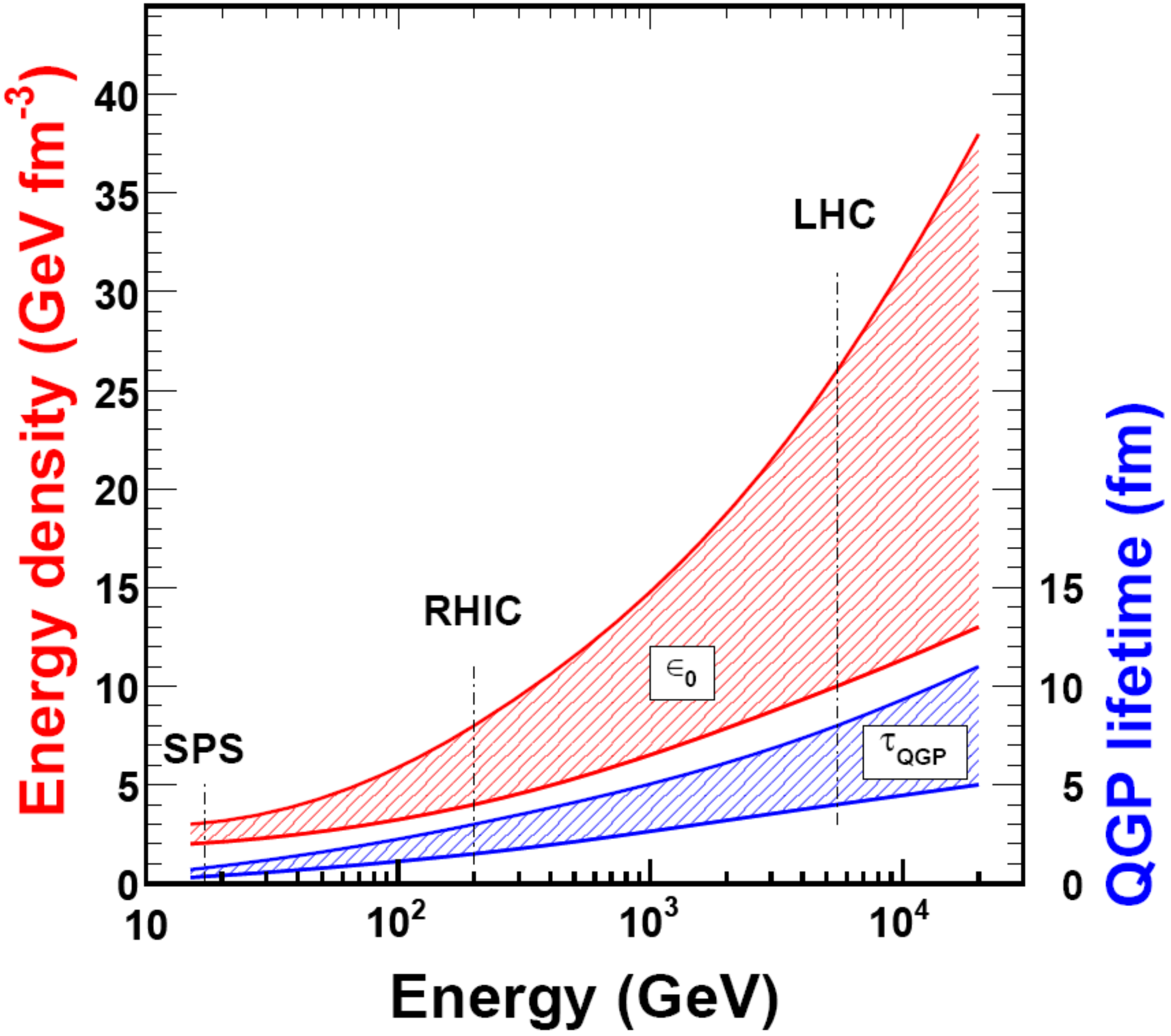
x_{min} ↘ ~ 10^{-2}

- factor 1/30 due to energy
- factor 1/3 larger rapidity

With J/ψ at rapidity 4

- Pb-Pb collisions $x_{min} \sim 10^{-5}$
- pp collisions $x_{min} \sim 3\times10^{-6}$

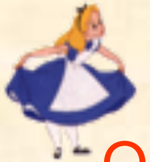
Energy density



From RHIC to LHC

$\varepsilon_0 = dN/dy \langle E_\perp \rangle / \tau_0\, 4\pi R^2$
– increase by factor 2–3

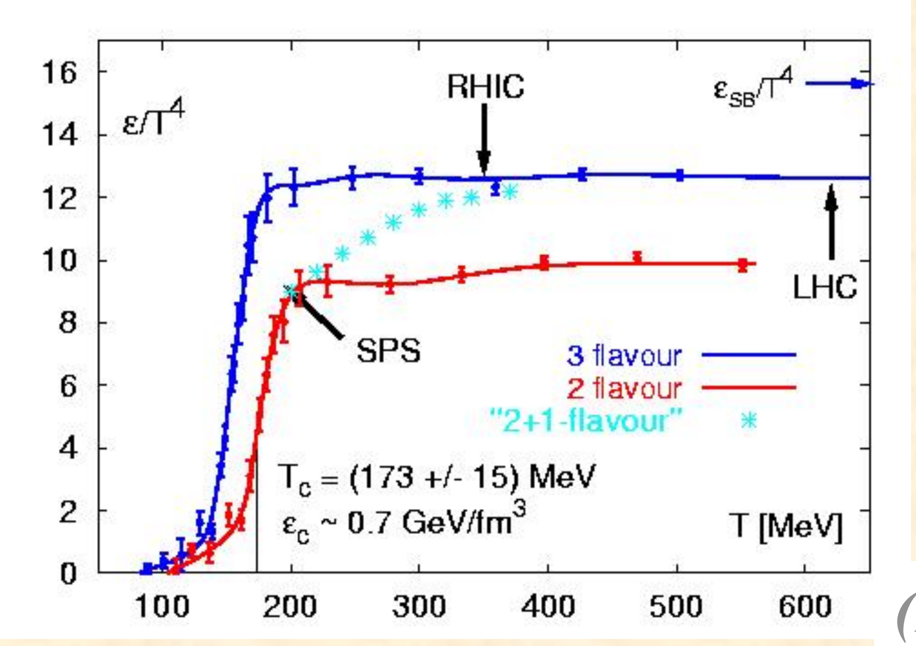
QGP lifetime
– increase by factor 2–3



Moreover

Qualitative improvements:

- Vanishing net baryon density ($\mu_B \rightarrow 0$):
  - closer to early Universe, closer to Lattice QCD
- High energy density → approaching the limit of an “ideal” gas of QCD quanta



(F.Karsch)

- Stronger thermal radiation
- Hard probes:
  - ✓Heavy flavours
  - ✓Jets and jet quenching

Dominant processes in particle production

SPS: soft

RHIC: soft and semi-hard

LHC: semi-hard and hard

Experimental conditions @ LHC

- pp commissioning start April 2009

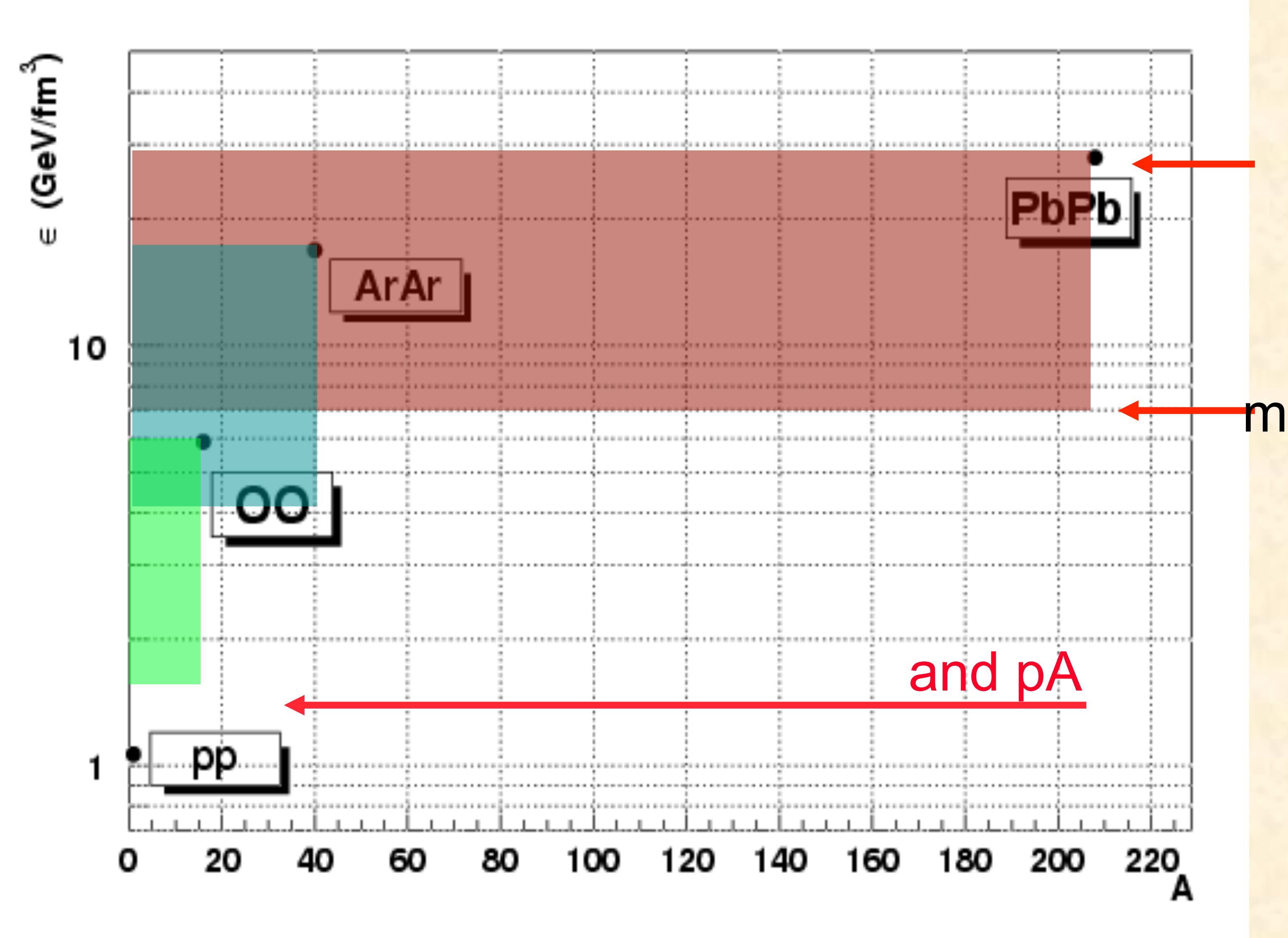
- Agreed initial Heavy-Ion programme at LHC

  - **Initial few years** (1HI ‘year’ = 10^6 effective s, ~like at SPS)
    - 2 - 3 years Pb-Pb $\mathcal{L} \sim 10^{27}$ cm^{-2}s^{-1}
    - 1 year p - Pb ‘like’ (p, d or α) $\mathcal{L} \sim 10^{29}$ cm^{-2}s^{-1}
    - 1 year light ions (eg Ar-Ar) $\mathcal{L} \sim$ few 10^{27} to 10^{29} cm^{-2}s^{-1}

      plus, for ALICE (limited by pileup in TPC):
    - reg. pp run at $\sqrt{s} = 14$ TeV $\mathcal{L} \sim 10^{29}$ and < 3×10^{30} cm^{-2}s^{-1}
  - **Later: different options depending on Physics results**

- Heavy Ion running part of LHC initial program, early pilot run expected by end of 2010

Use different Ion species to vary the energy density

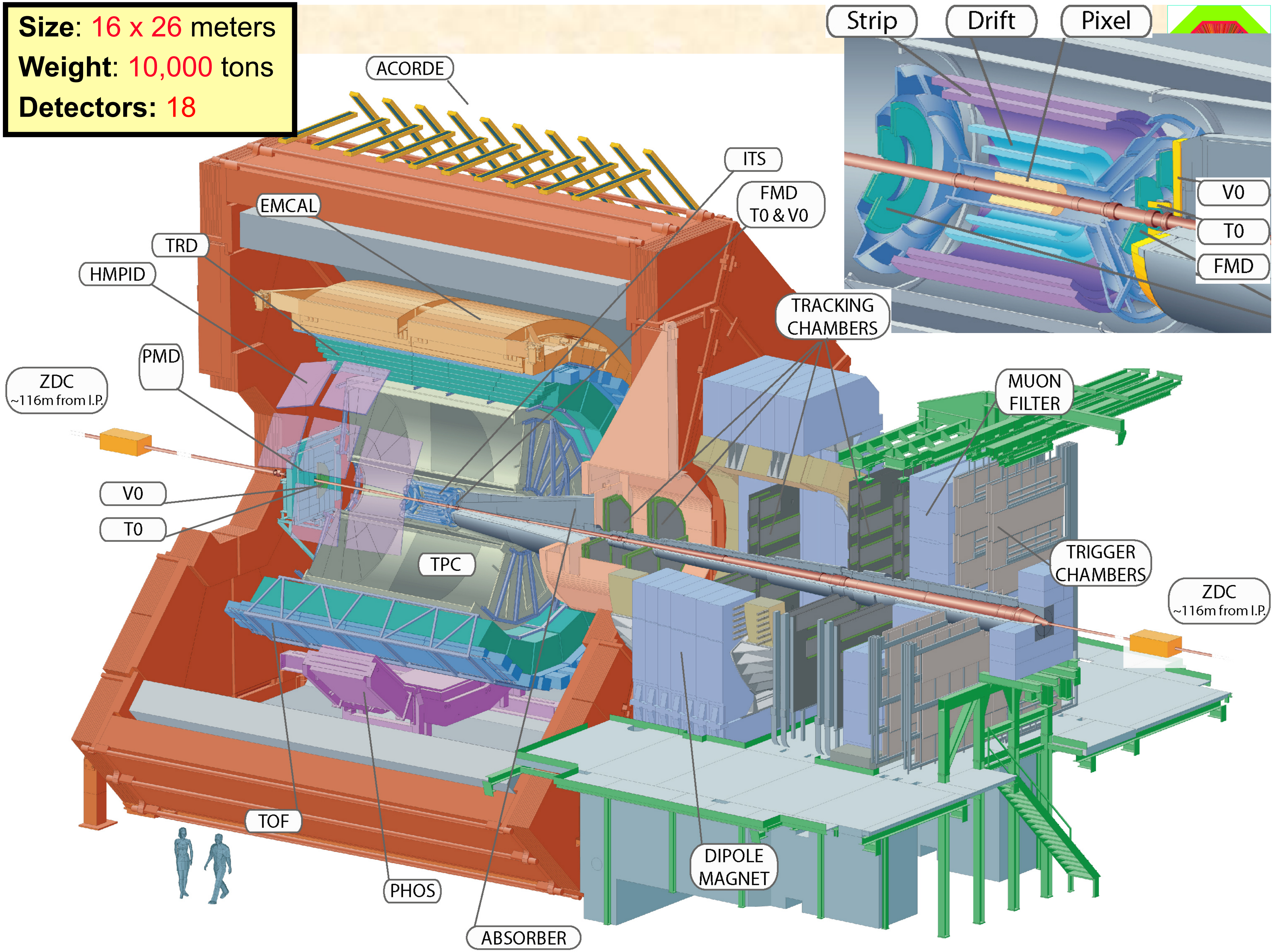


central

minimum bias

and pA

Size: 16 x 26 meters
Weight: 10,000 tons
Detectors: 18



ALICE Collaboration

~ 1000 Members

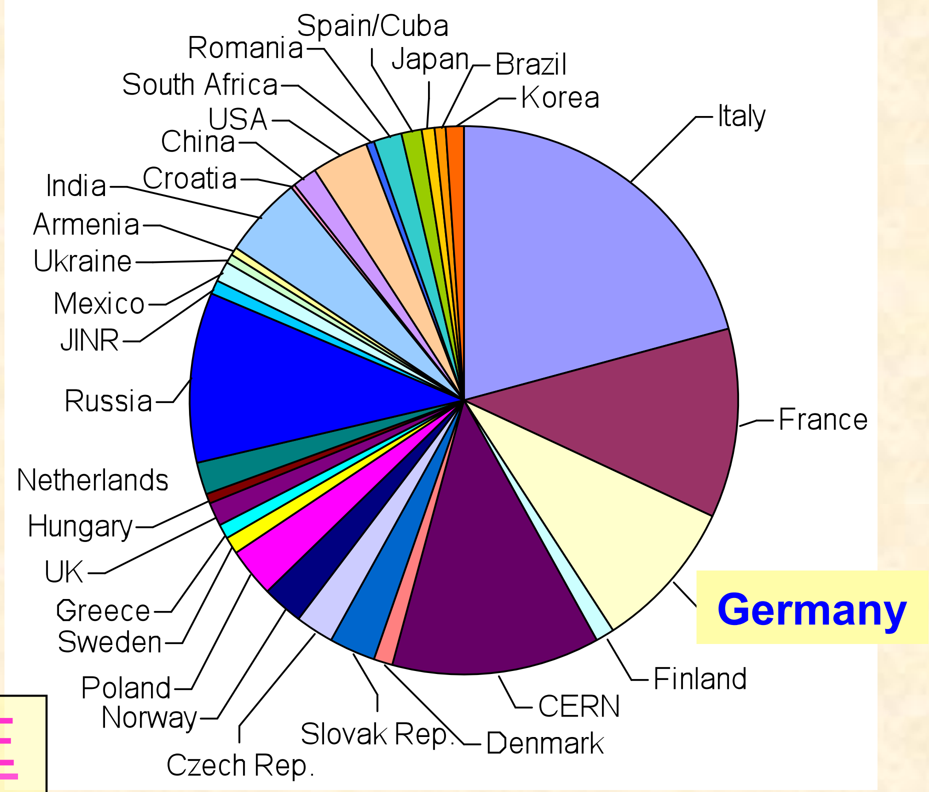
(63% from CERN MS)

~30 Countries

~100 Institutes

~150 MCHF capital cost

(+ inherited magnet)



A brief history of ALICE

1990-1996: Design

1992-2002: R&D

2000-2010: Construction

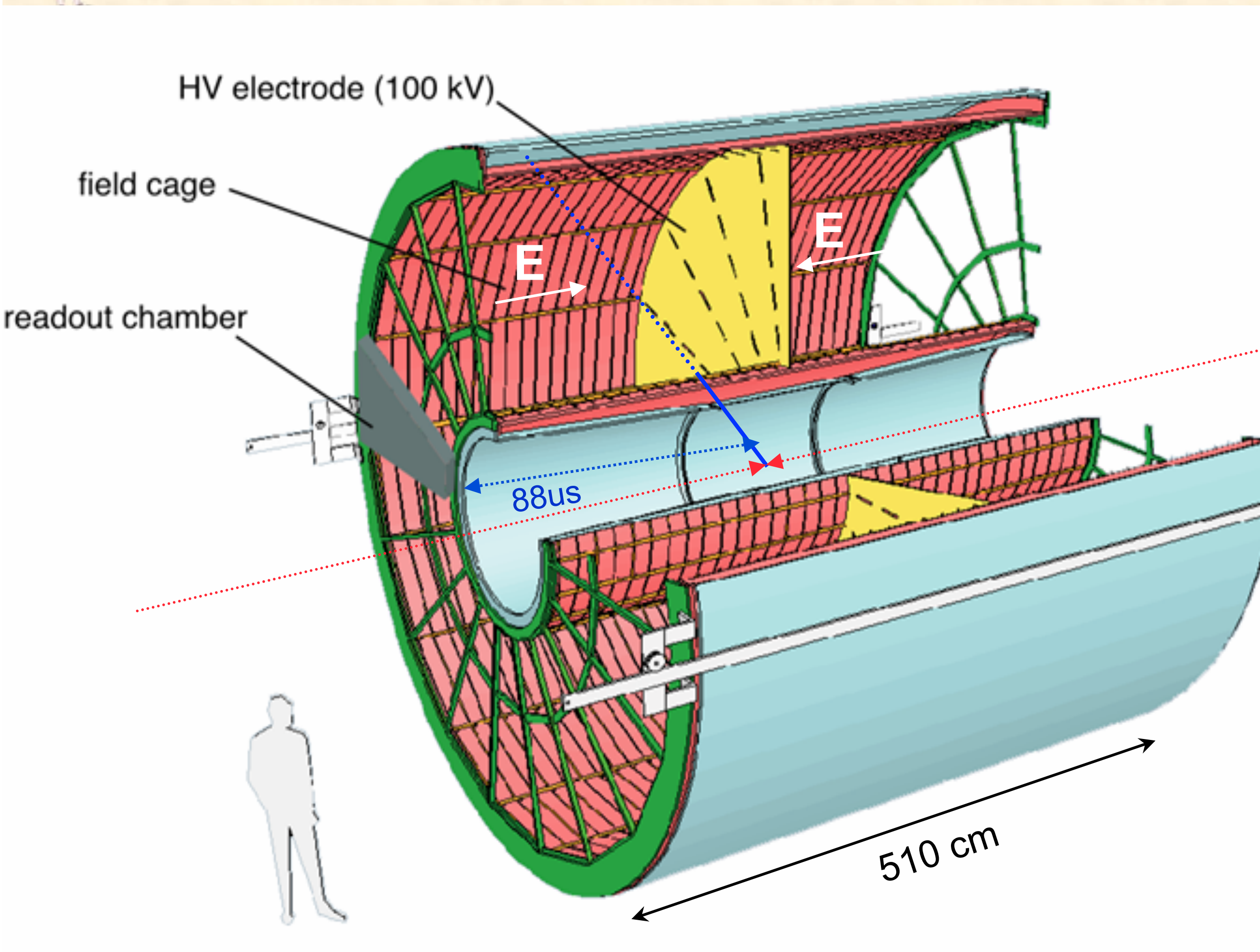
2002-2007: Installation

2008 -> : Commissioning

The ALICE
Magnet in 2000:

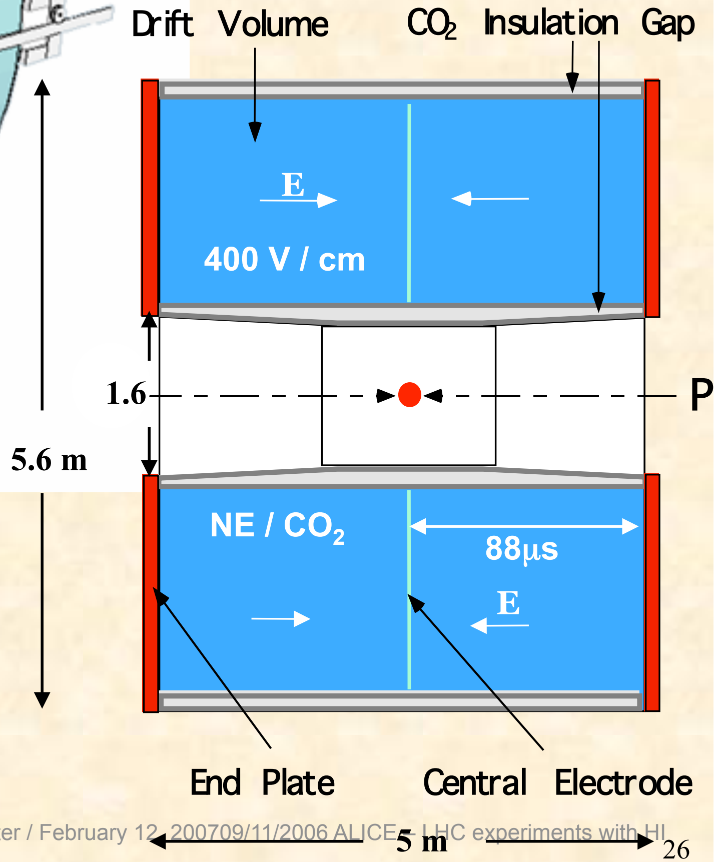
ready for the experiment to move in!

TPC layout



GAS VOLUME
88 m^3

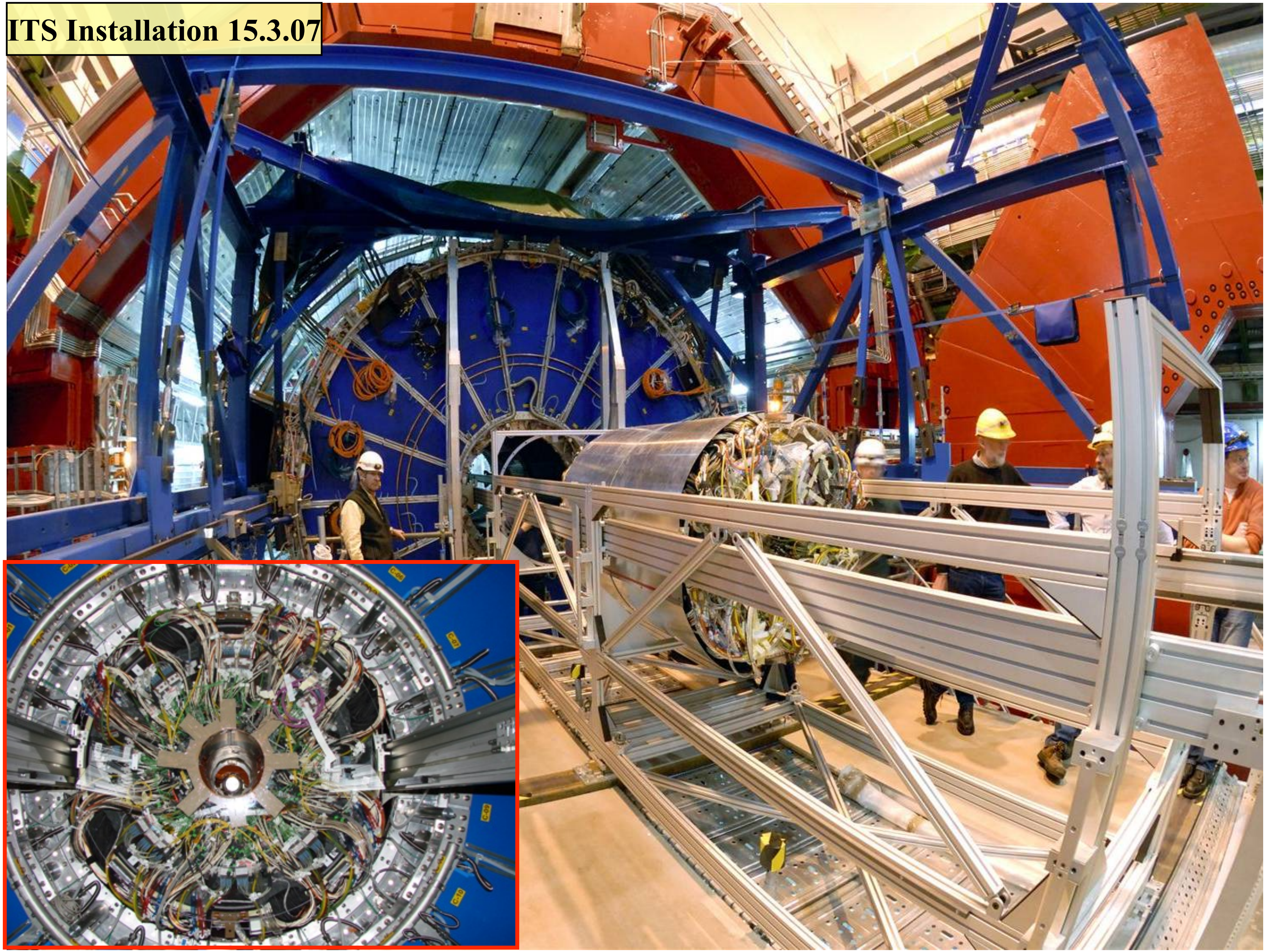
DRIFT GAS
90% Ne - 10%CO$_2$



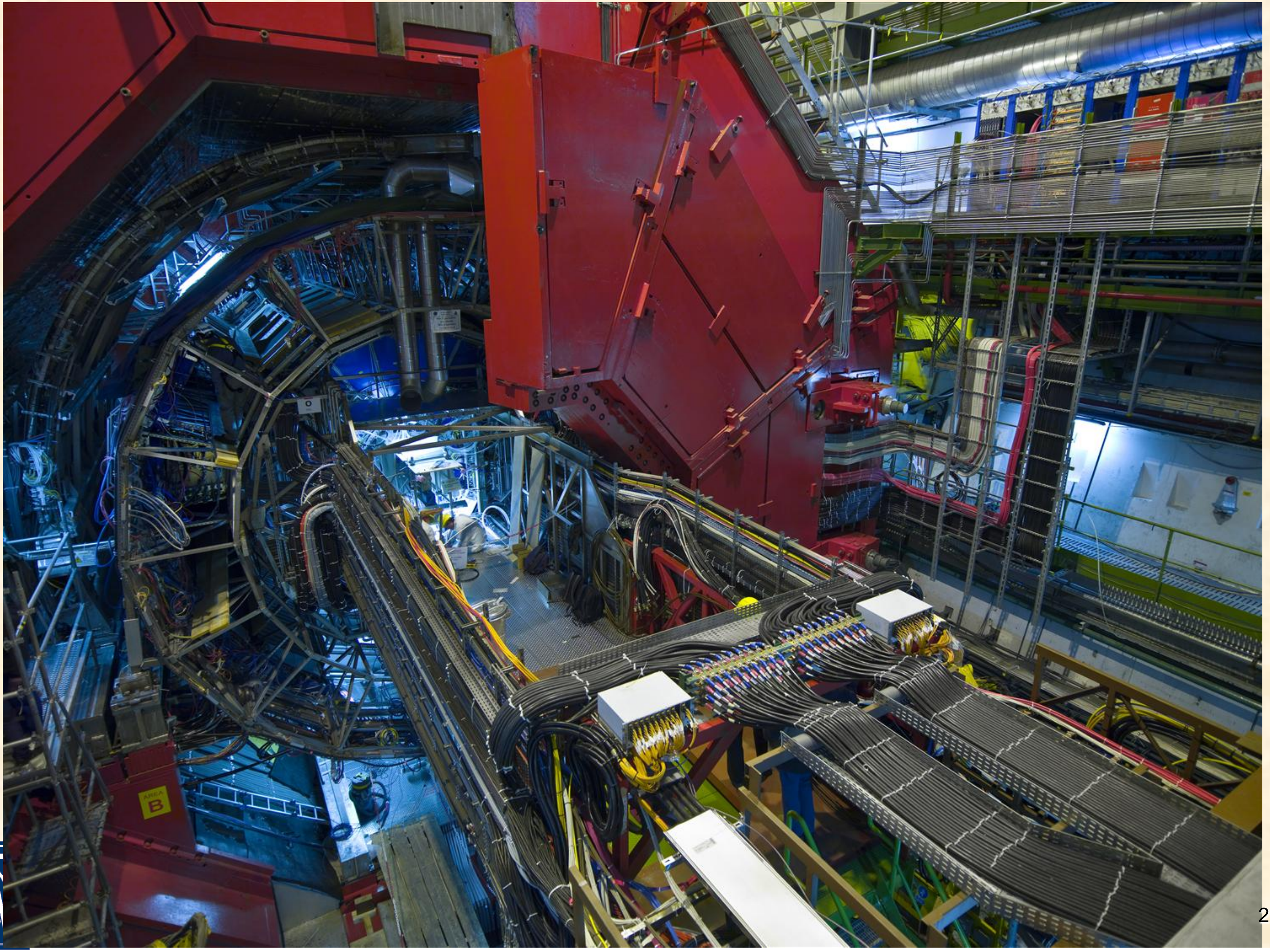
Readout plane segmentation

18 trapezoidal sectors
each covering 20 degrees in azimuth

ITS Installation 15.3.07



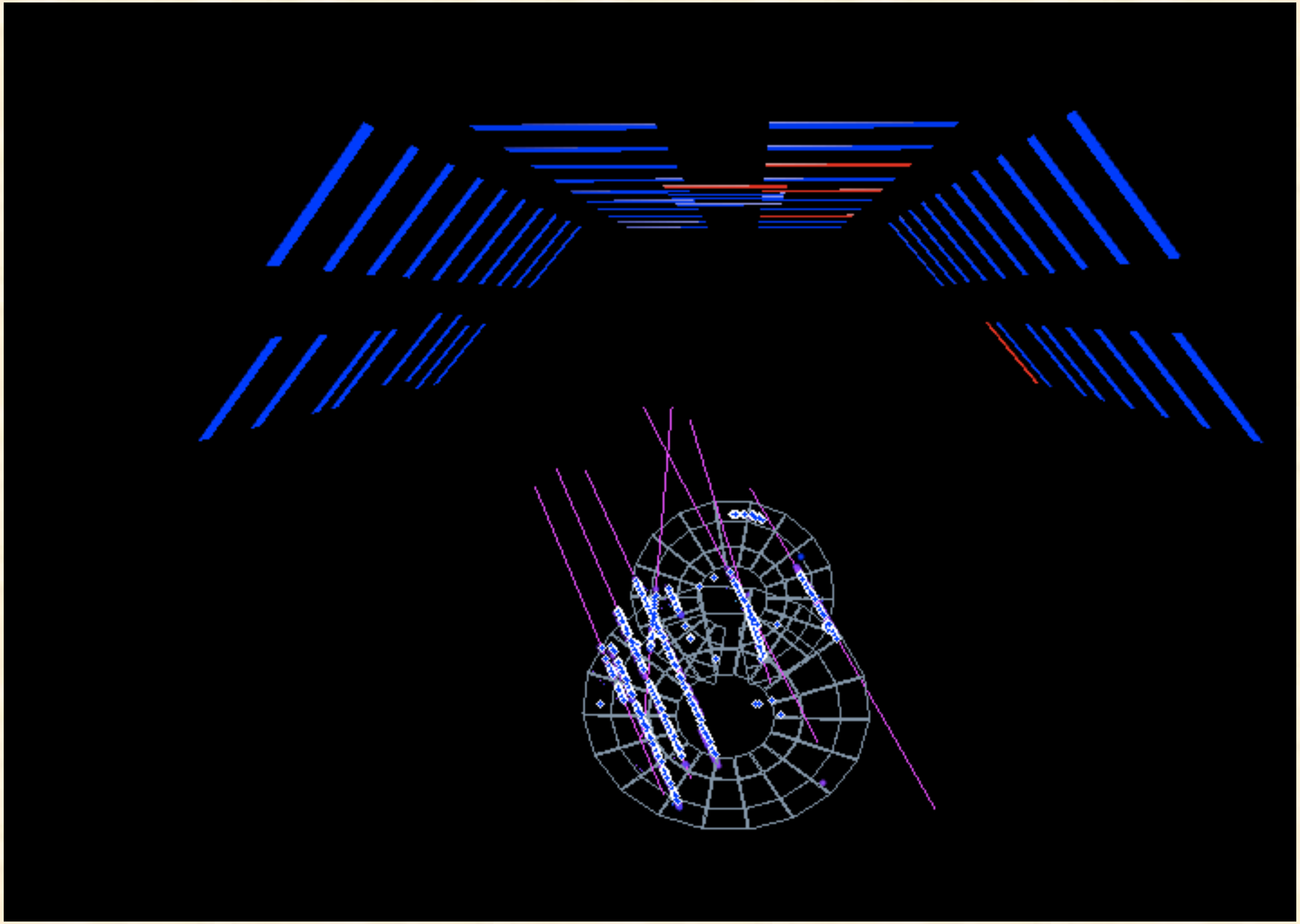
ALICE



Start-up configuration in 2009

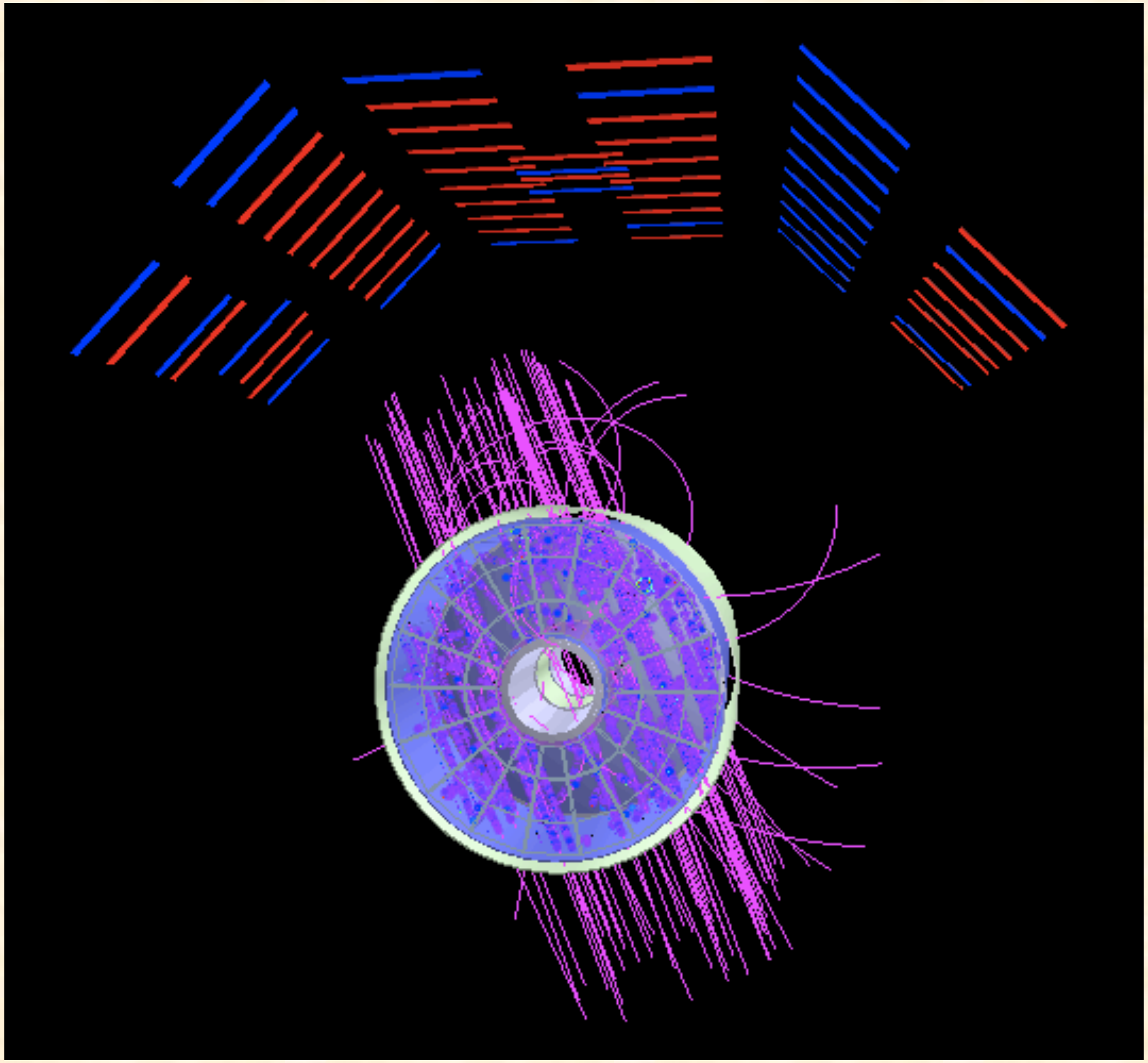
- **complete – fully installed & commissioned**
  - ITS, TPC, TOF, HMPID, MUONS, PMD, V0, T0, FMD, ZDC, ACORDE, DAQ, HLT
- **partially completed**
  - TRD (40%) to be completed by 2010
  - PHOS (60%) to be completed by 2010
  - EMCAL (20%) to be completed by 2010/11
- **at start-up full hadron and muon capabilities**
- **partial electron and photon capabilities**

Cosmic physics with ALICE



Event
9161

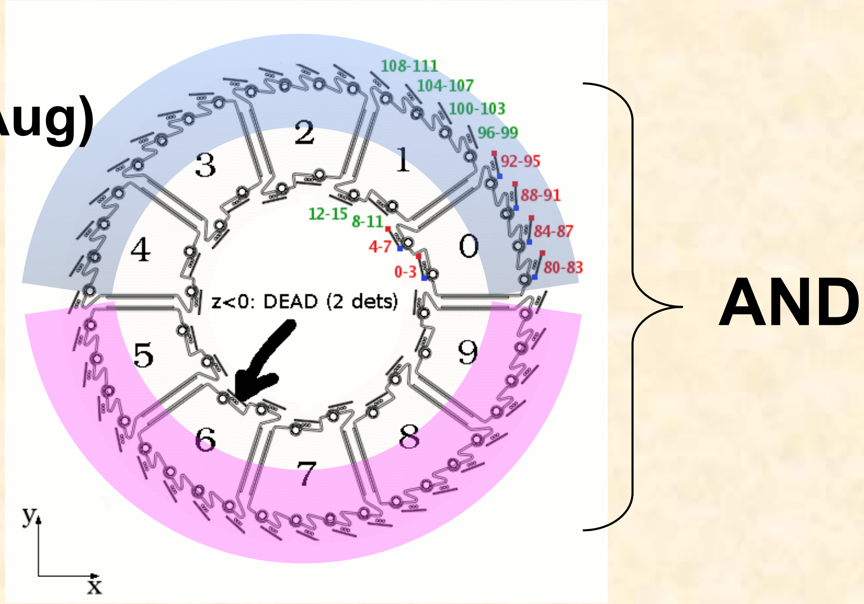
High multiplicity in ACORDE and TPC



File:/Volumes/MRC/RunsAliEn/Run62107/08000062107000.460/AliESDs.root, N. of Event:8560, ACORDE Multiplicity:35, No. of ESD's tracks:148

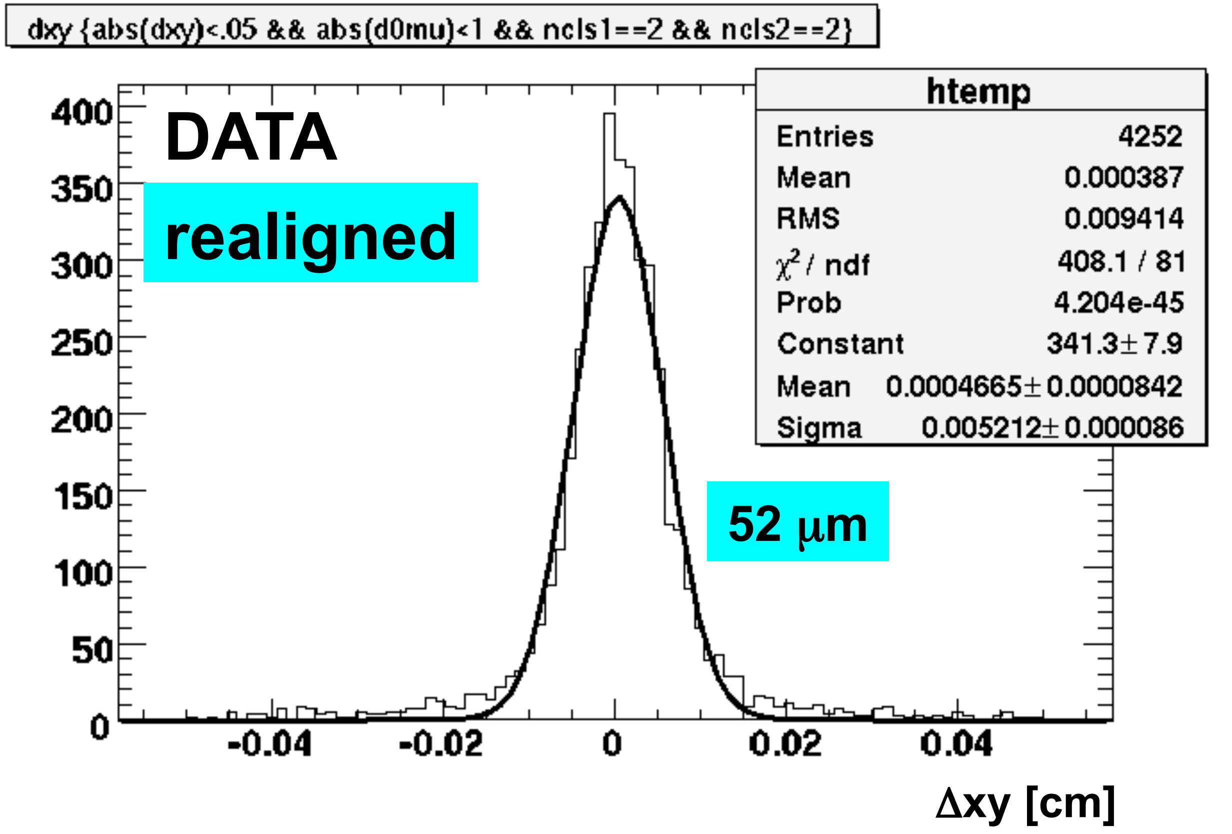
Cosmics with SPD trigger

- Pixel FastOR trigger since May 25: first side C, then also side A
- Trigger configuration:
  - ⇨ rate: 0.05 Hz (June) → 0.18 Hz (Aug)
  - ⇨ purity (reconstructed with 3-4 cls/triggered): about 30%
  - ⇨ about 85% of SPD taking data in August

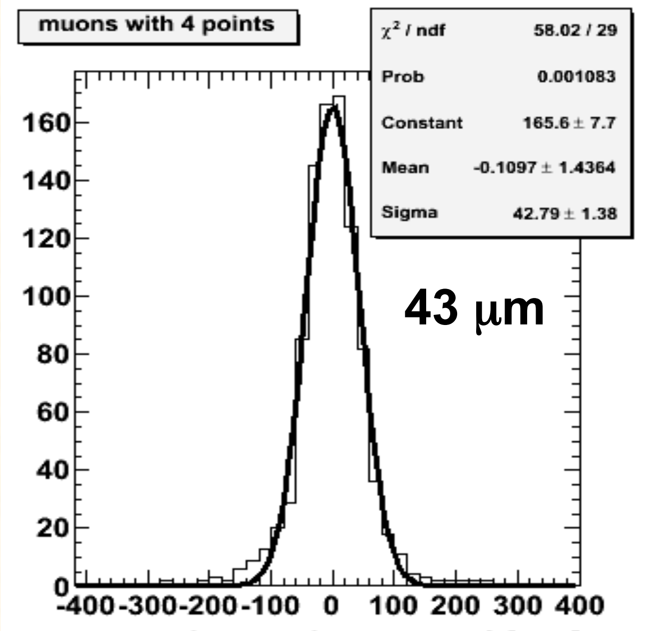


- Statistics collected: about 10^5 good events
  - ⇨ events with 4-cls in SPD: 45k
  - ⇨ events with 3-cls in SPD: 55k

Millepede SPD realignment: Δxy at y=0



Sim, ideal geom:



Expected spread

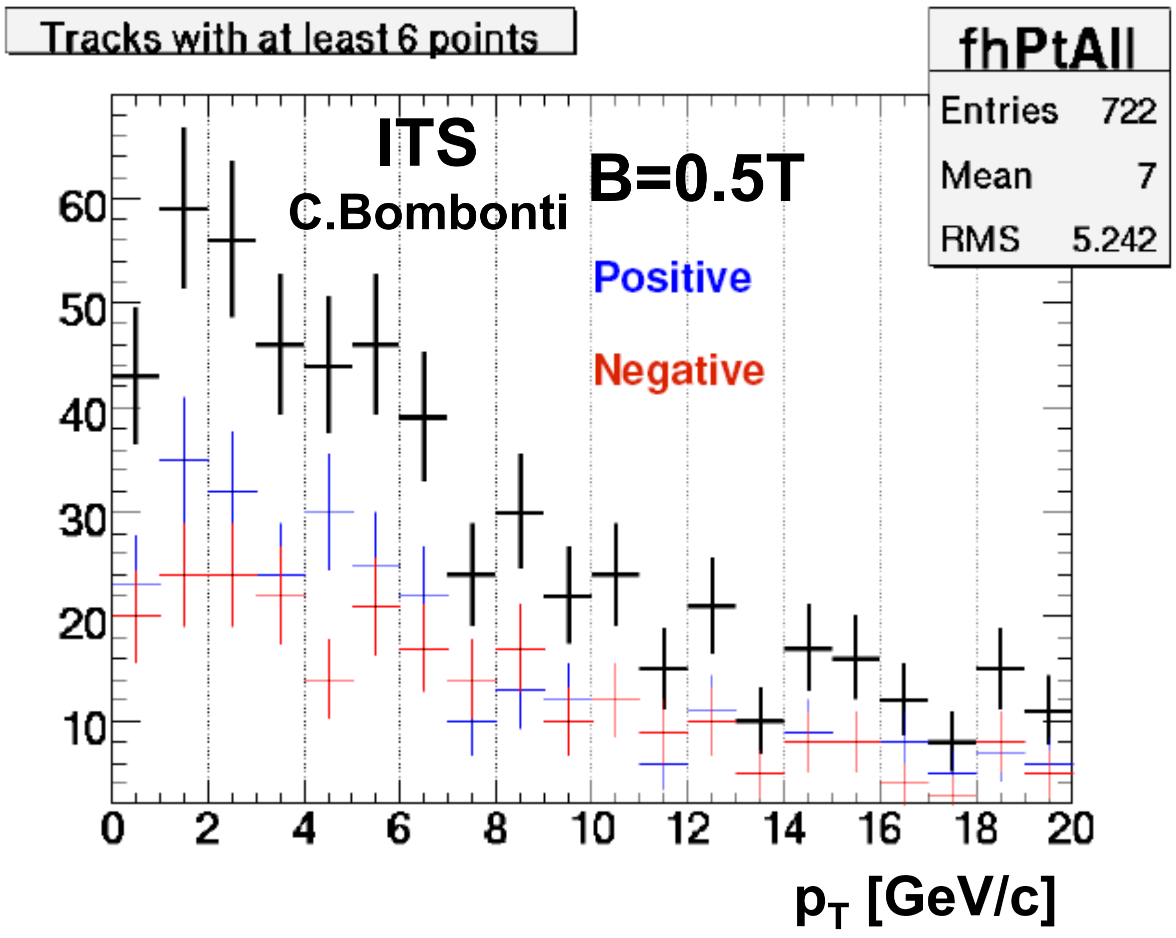
$$\sigma^2_{\Delta x}=2*(r^2_{SPD2}+r^2_{SPD1})/(r_{SPD2}-r_{SPD1})^2*\sigma^2_{spatial}$$

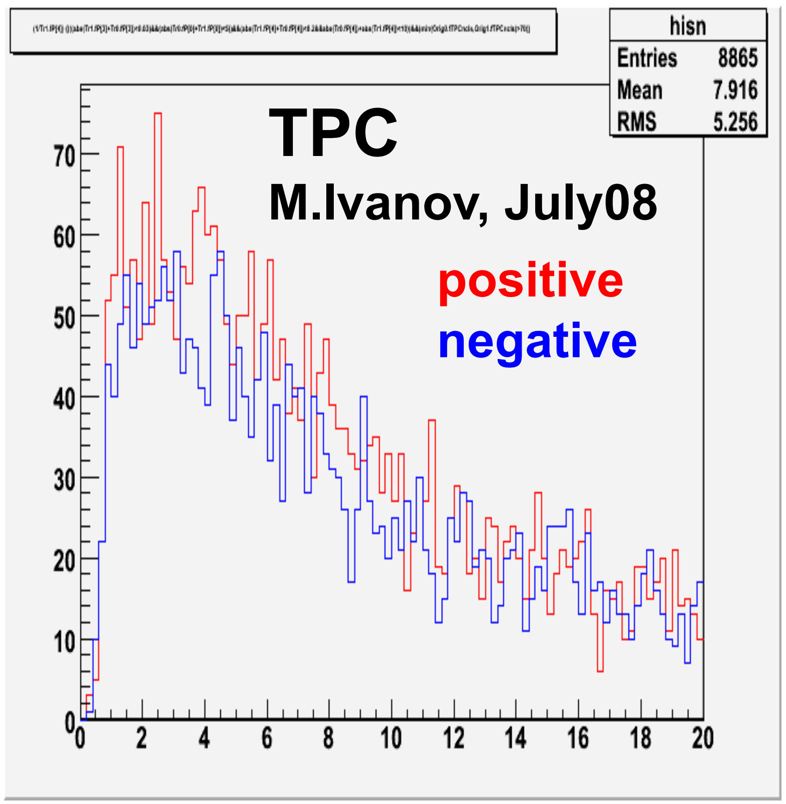
→ $\sigma_{spatial}$=14 μm

→ $\sigma_{spatial}$=11 μm (Sim)

M.Lunardon, S.Moretto

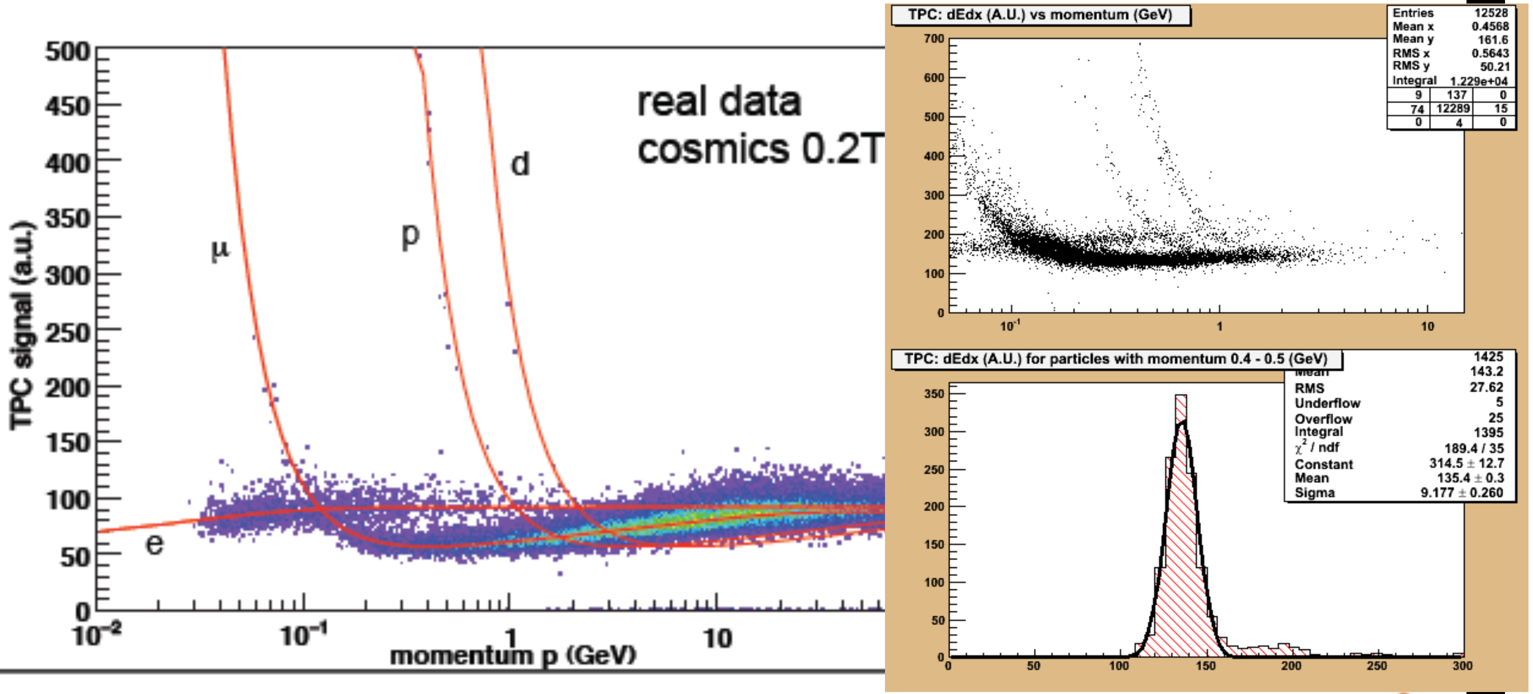
Cosmic p_T-spectra and charge



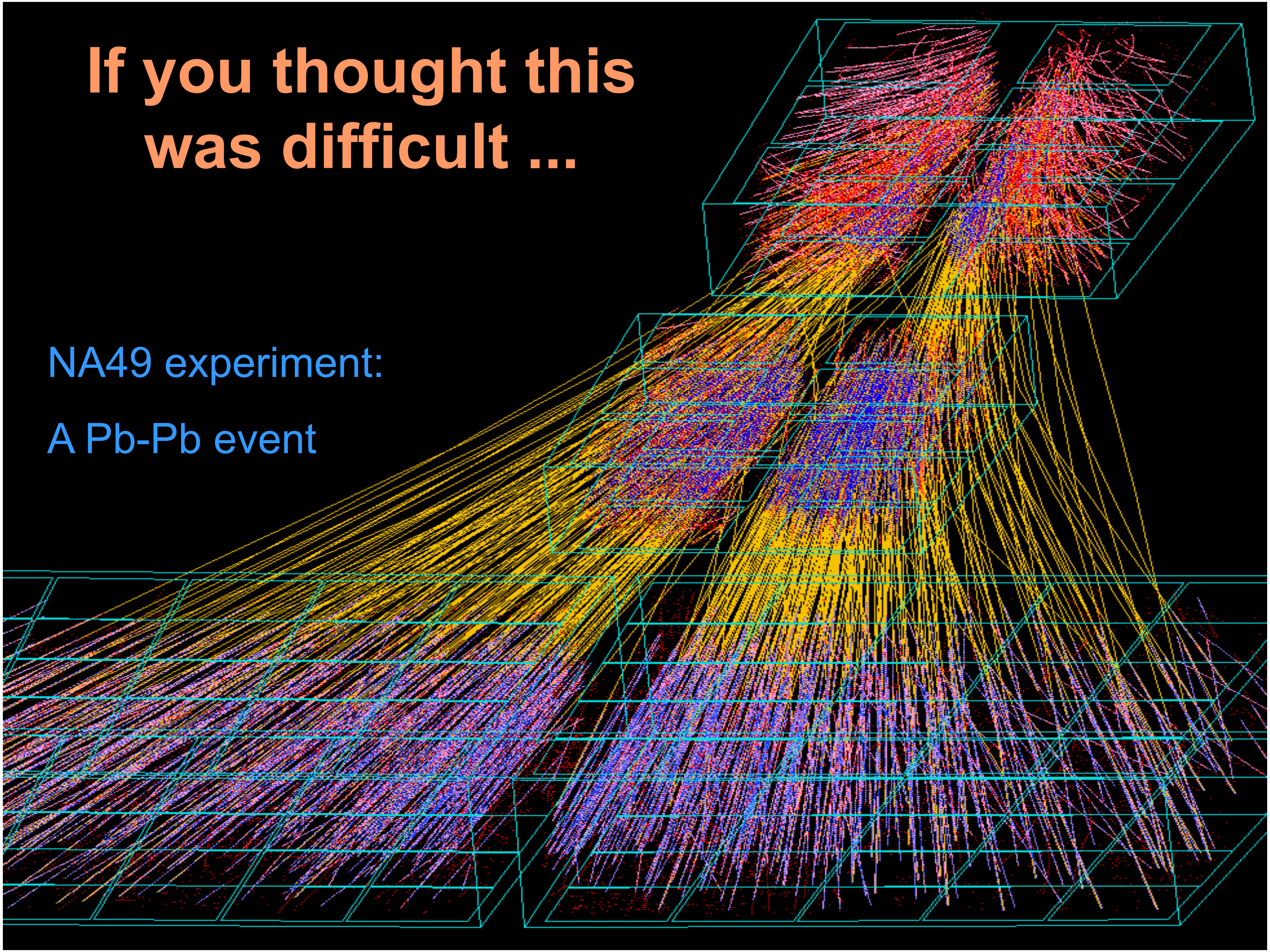


TPC calibration status

- The TPC is sufficiently calibrated for this measurement and will be further improved
    - pT resolution: focus on pT < 3 GeV, σ ≈ 1..2%
    - dE/dx resolution: 4.5 - 6%
    - ALEPH parametrisation of the Bethe-Bloch curve describes the data



28.10.2008 | A.Kalweit@GSI.de

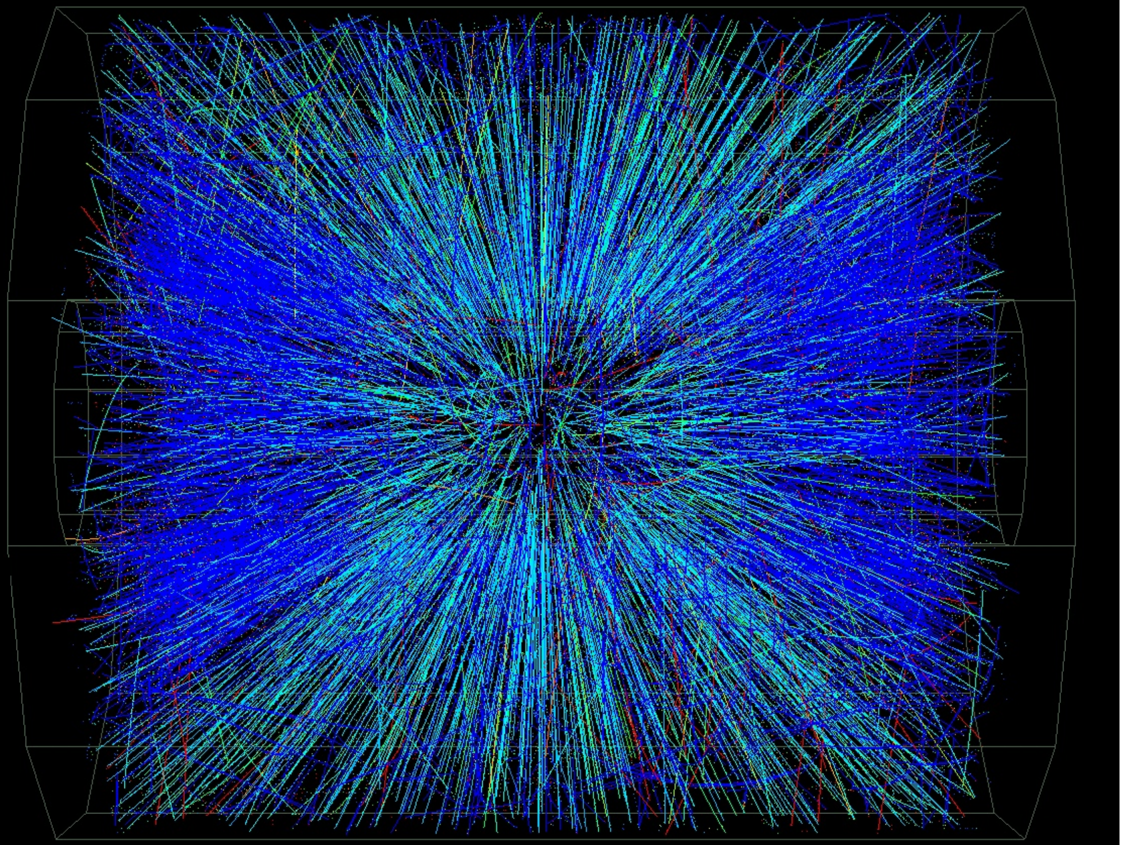


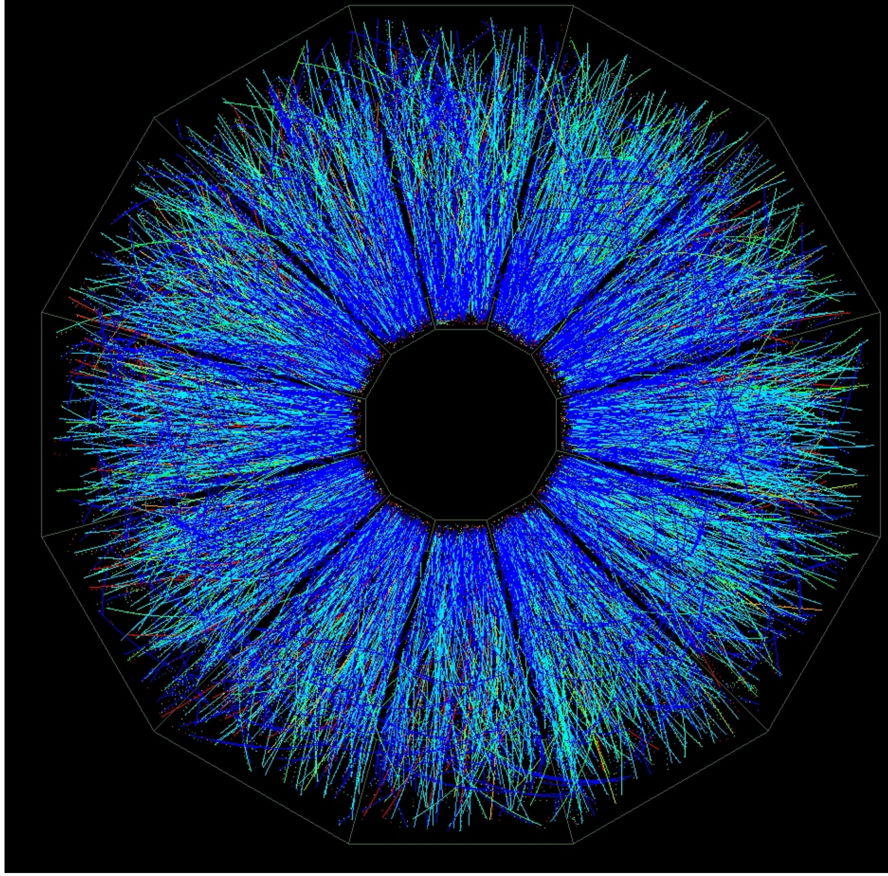
If you thought this was difficult ...

NA49 experiment:

A Pb-Pb event

and this was even more difficult ...



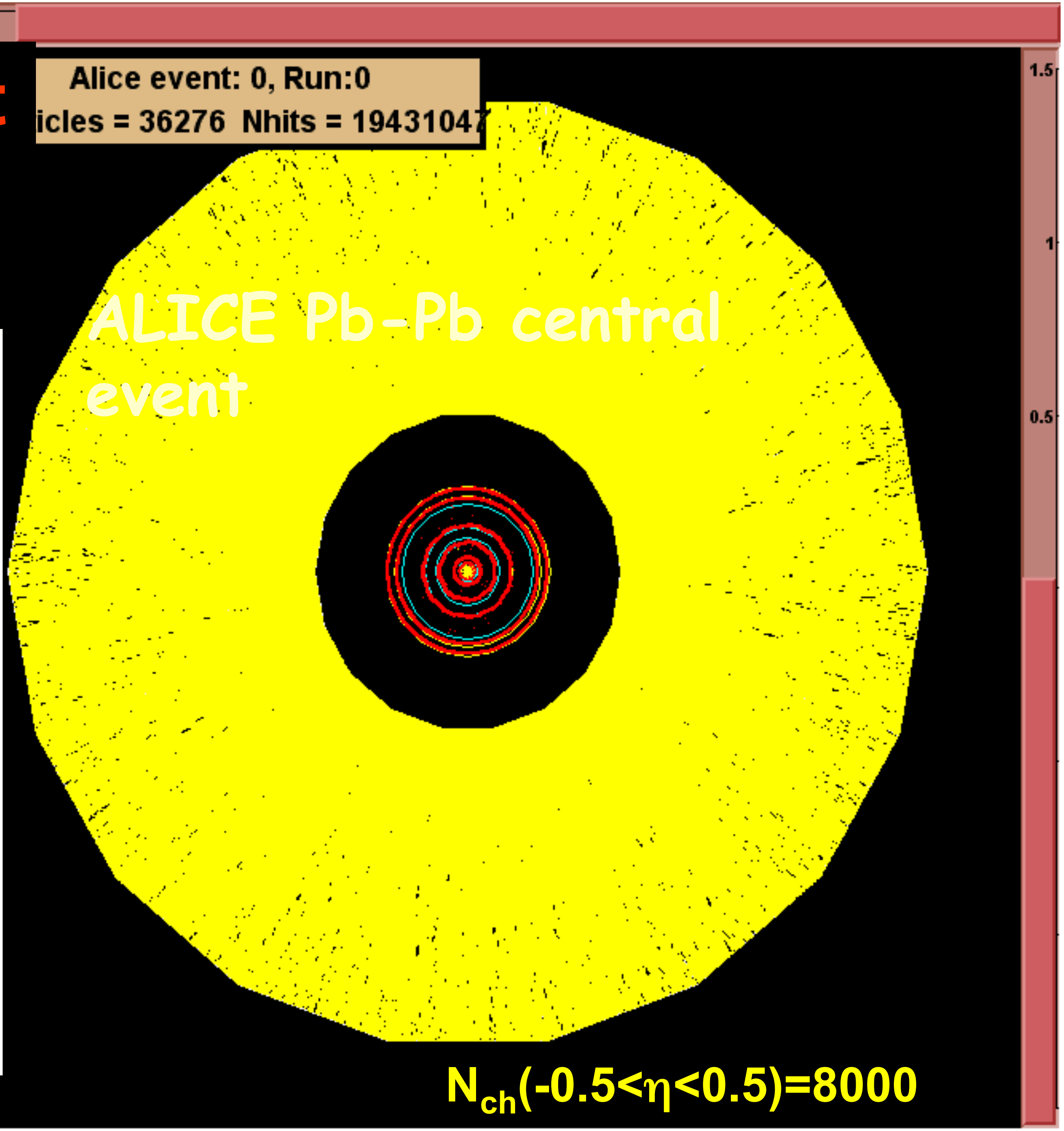


STAR

A central Au-Au event

@ ~130 GeV/nucleon

… then what about this!



Alice event: 0, Run:0
icles = 36276 Nhits = 19431047

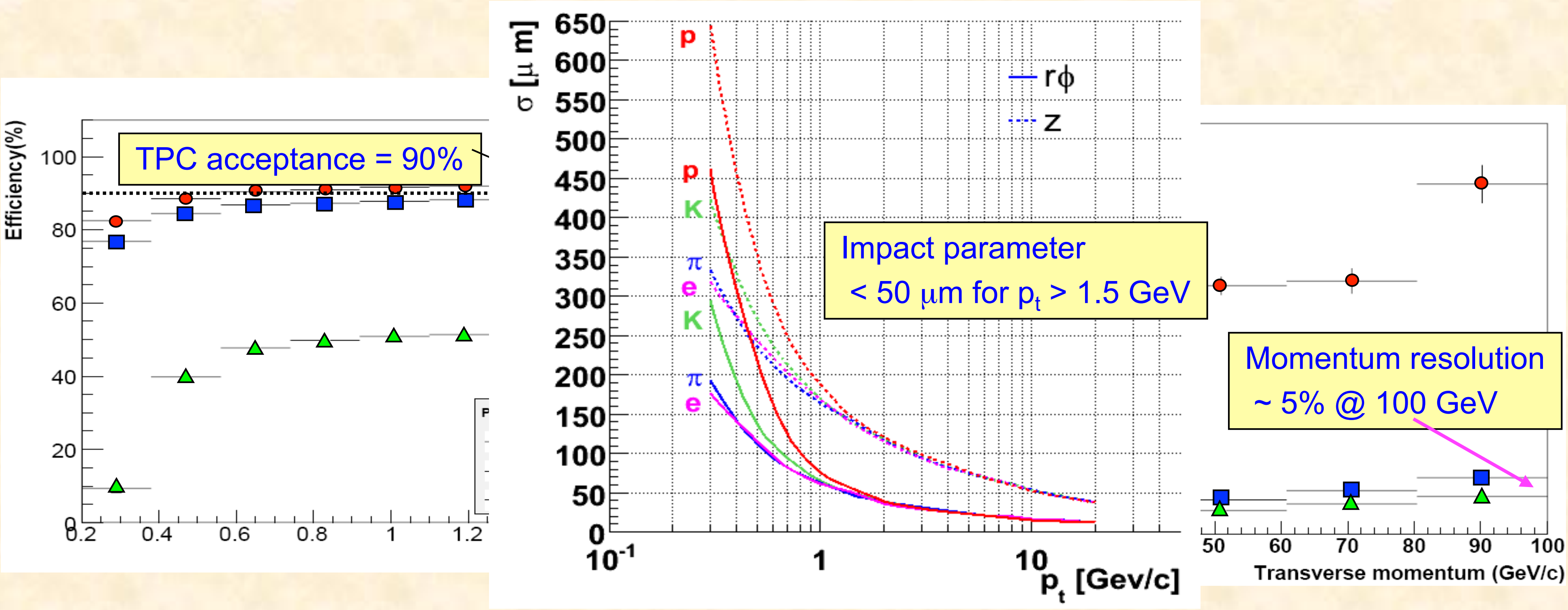
ALICE Pb-Pb central event

$N_{ch}(-0.5<\eta<0.5)=8000$

ALICE Tracking Performance

Robust, redundant tracking from < 100 MeV/c to > 100 GeV/c

Very little dependence on dN/dy up to dN/dy ≈ 8000



TPC acceptance = 90%

Impact parameter

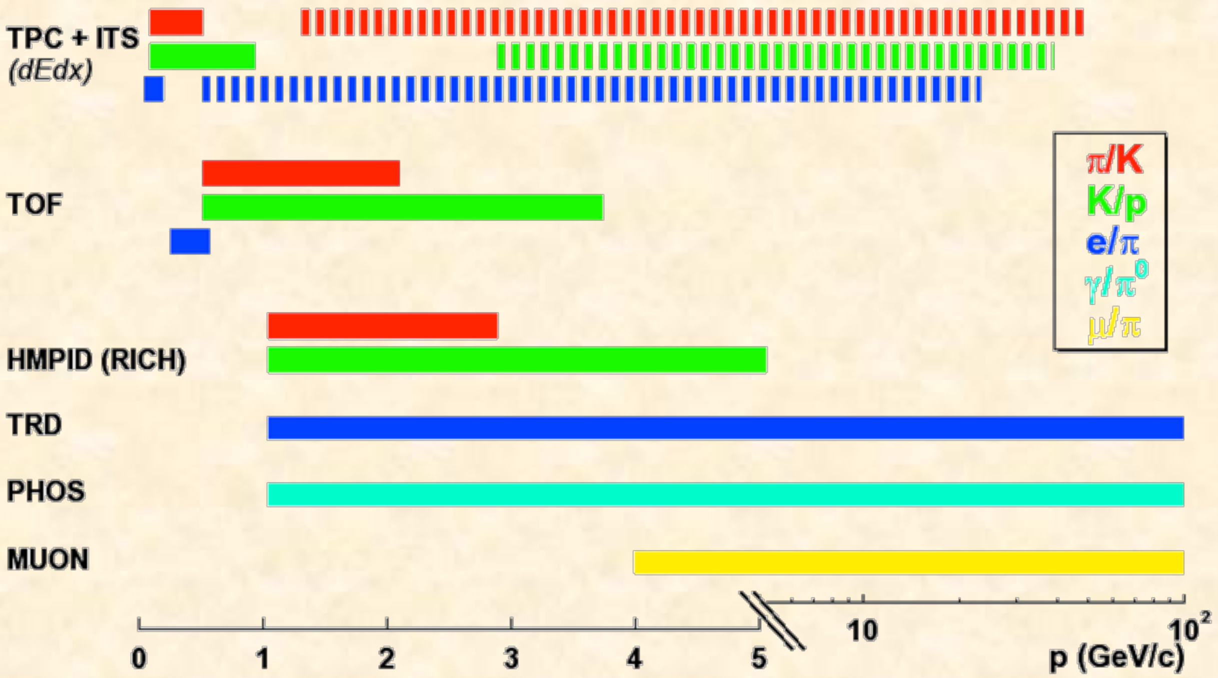
< 50 μm for p_t > 1.5 GeV

Momentum resolution

~ 5% @ 100 GeV

- **δp/p < 5% at 100 GeV with careful control of systematics**

Particle Identification in ALICE



- 'stable' hadrons (π, K, p): 100 MeV/c < p < 5 GeV/c; (π and p with ~ 80 % purity to ~ 60 GeV/c)
  - dE/dx in silicon (ITS) and gas (TPC) + time-of-flight (TOF) + Cherenkov (RICH)
- decay topologies (K^0, K^+, K^-, Λ, D)
  - K and L decays beyond 10 GeV/c
- leptons (e,μ), photons, π^0
  - electrons TRD: p > 1 GeV/c, muons: p > 5 GeV/c, π^0 in PHOS: 1 < p < 80 GeV/c

- excellent particle ID up to ~ 50 to 60 GeV/c

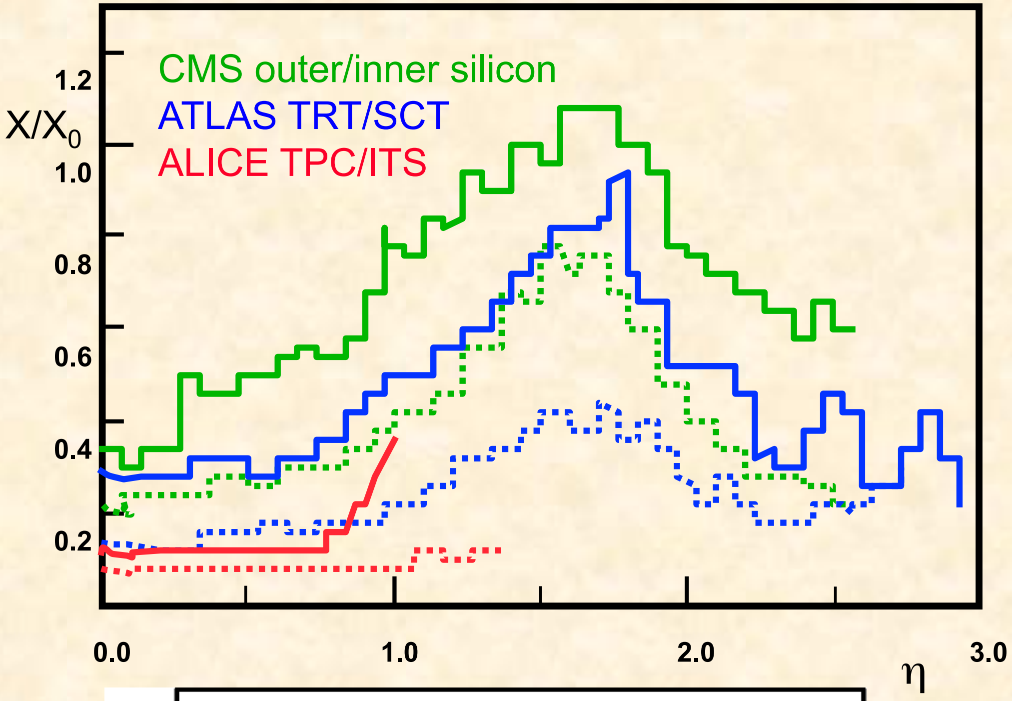
Low momentum cut-off

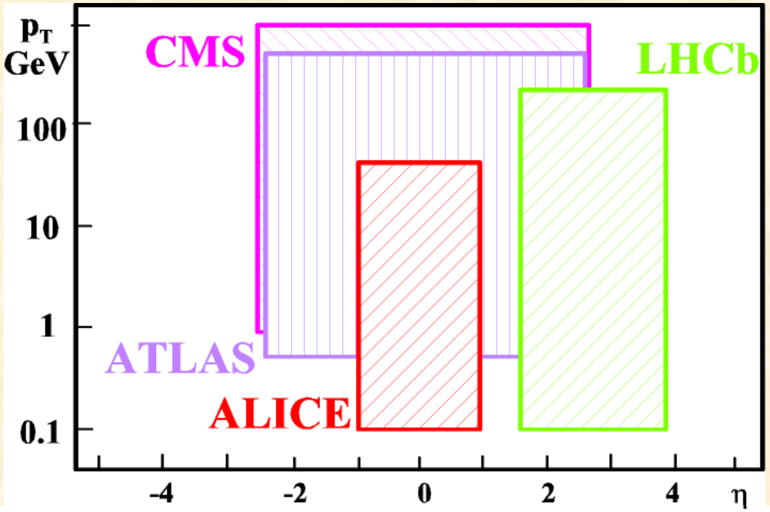
ALICE compared to other LHC detectors

Relatively low magnetic field

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

Ultimate cut-off – the amount of material in the tracker





First Physics with ALICE
From pp to Pb–Pb

- **first pp run (starting this summer)**
  - ⇨ important pp reference data for heavy ions
  - ⇨ minimum bias running
  - ⇨ unique pp physics with ALICE
- **early heavy-ion run (10^6 s @ 1/20 nominal luminosity in 2009)**
  - ⇨ establish global event characteristics
  - ⇨ bulk properties (thermodynamics, hydrodynamics…)
  - ⇨ start of hard probe measurements

pp Physics with ALICE

- ALICE detector performs very well in pp
  - very low-momentum cutoff (<100 MeV/c) new x_T-regime (down to 4×10^{-6})
  - p_t-reach up to 100 GeV/c
  - excellent particle identification
  - efficient minimum-bias trigger
  - additional triggers

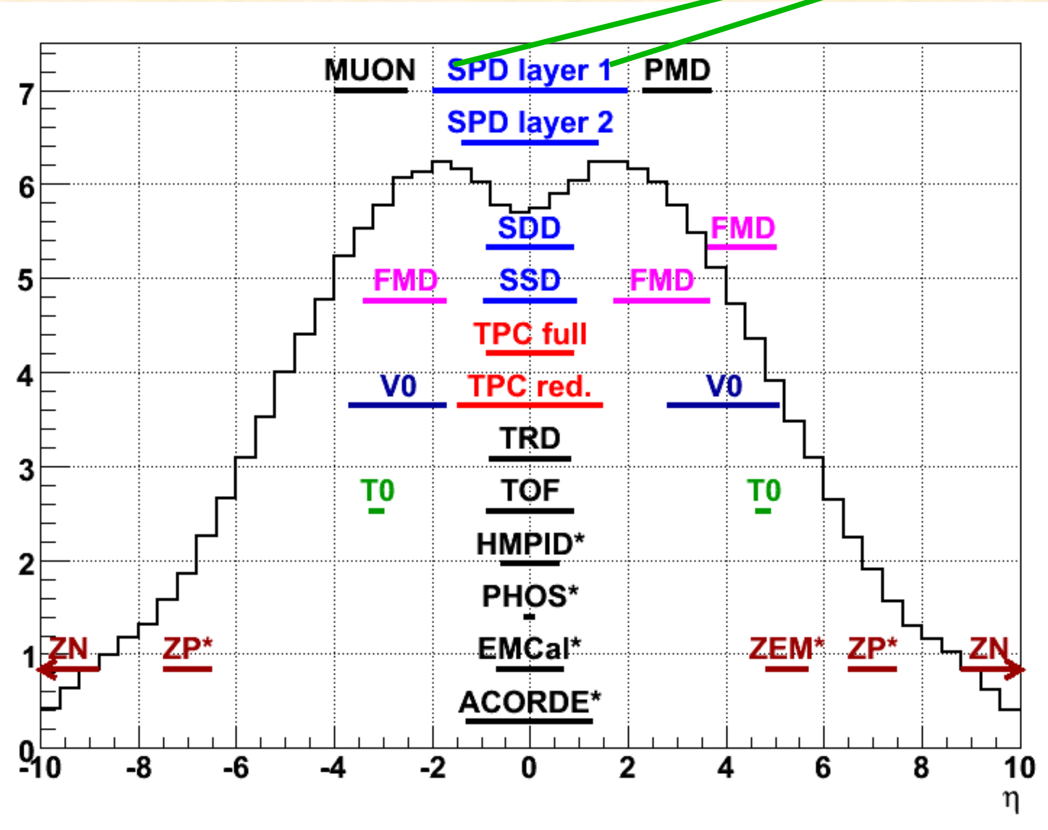
- first physics in ALICE will be pp
  - provides important reference data for heavy-ion programme
- unique pp physics in ALICE e.g.
  - multiplicity distribution
  - baryon transport
  - measurement of charm cross section major input to pp QCD physics

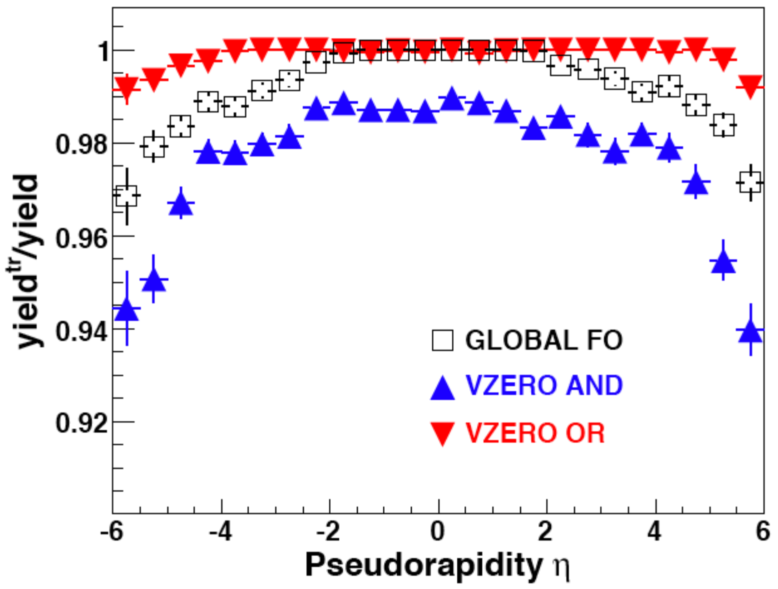
- **start-up**
  - some collisions at 900 GeV
    → connect to existing systematics
- **pp nominal run**
  - $\int Ldt = 3\cdot10^{30}$ cm^{-2} s^{-1} x 10^{7} s
    30 pb^{-1} for pp run at 14 TeV
    $N_{\text{pp collisions}} = 2\cdot10^{12}$ collisions
  - minimum-bias triggers:
    20 events pile-up (TPC)
    $N_{\text{pp minb}} = 10^{9}$ collisions
  - high-multiplicity trigger:
    reserved bandwidth ~ 10Hz
  - muon triggers:
    ~ 100% efficiency, < 1kHz
  - electron trigger:
    ~ 25% efficiency of TRD L1

Charged Particle Acceptance

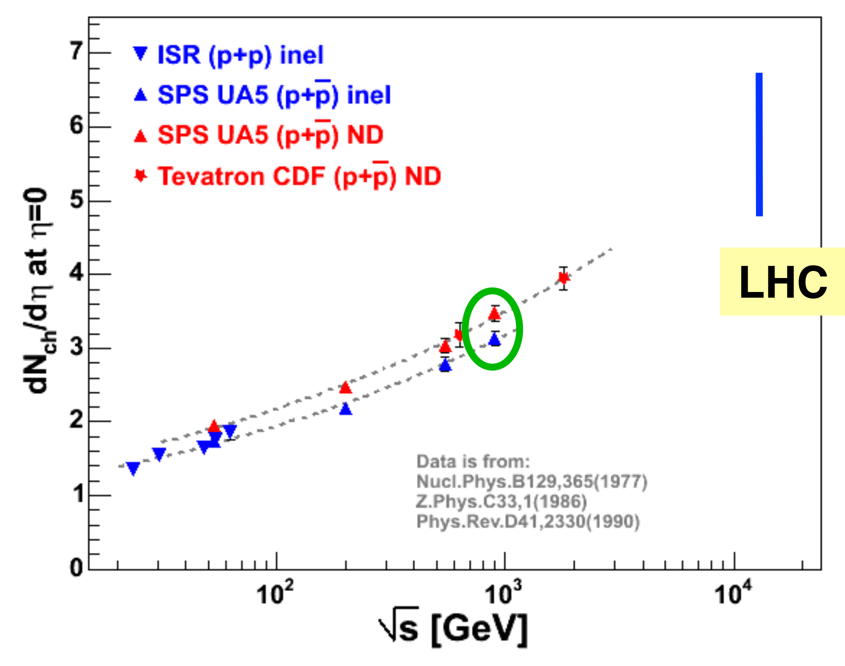
- operating with fast multiplicity trigger L0 from Silicon Pixels
- efficiency studied for
- single diffractive
- double diffractive
- non-diffractive

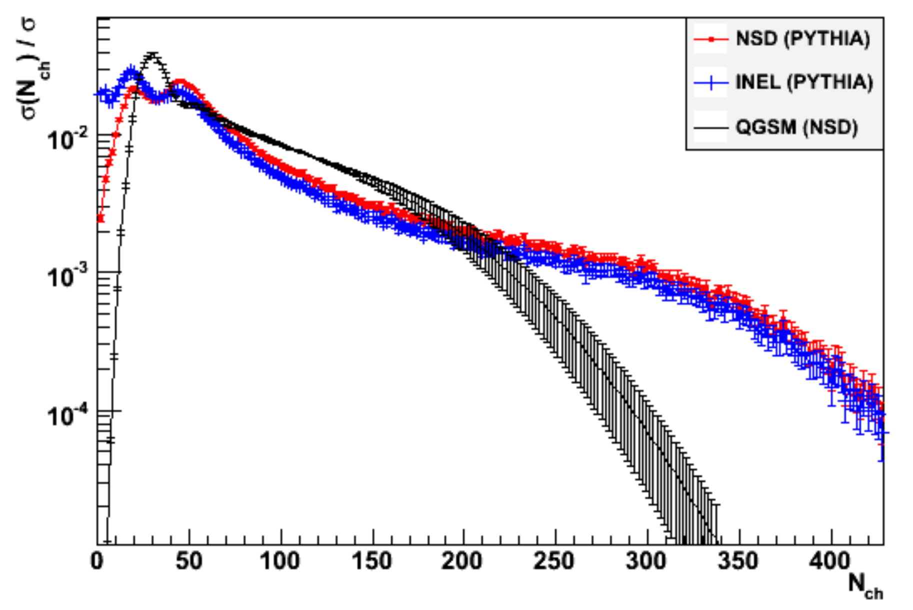
events





Charged Particle Multiplicity





- extend existing energy dependence
- unique SPD trigger (L0) for minimum-bias precision measurement
- completely new look at fluctuations in pp (neg. binomials, KNO…)

trigger efficiency	
ND-INEL	98%
SD	55%
DD	58%

J F Grosse-Oetringhaus

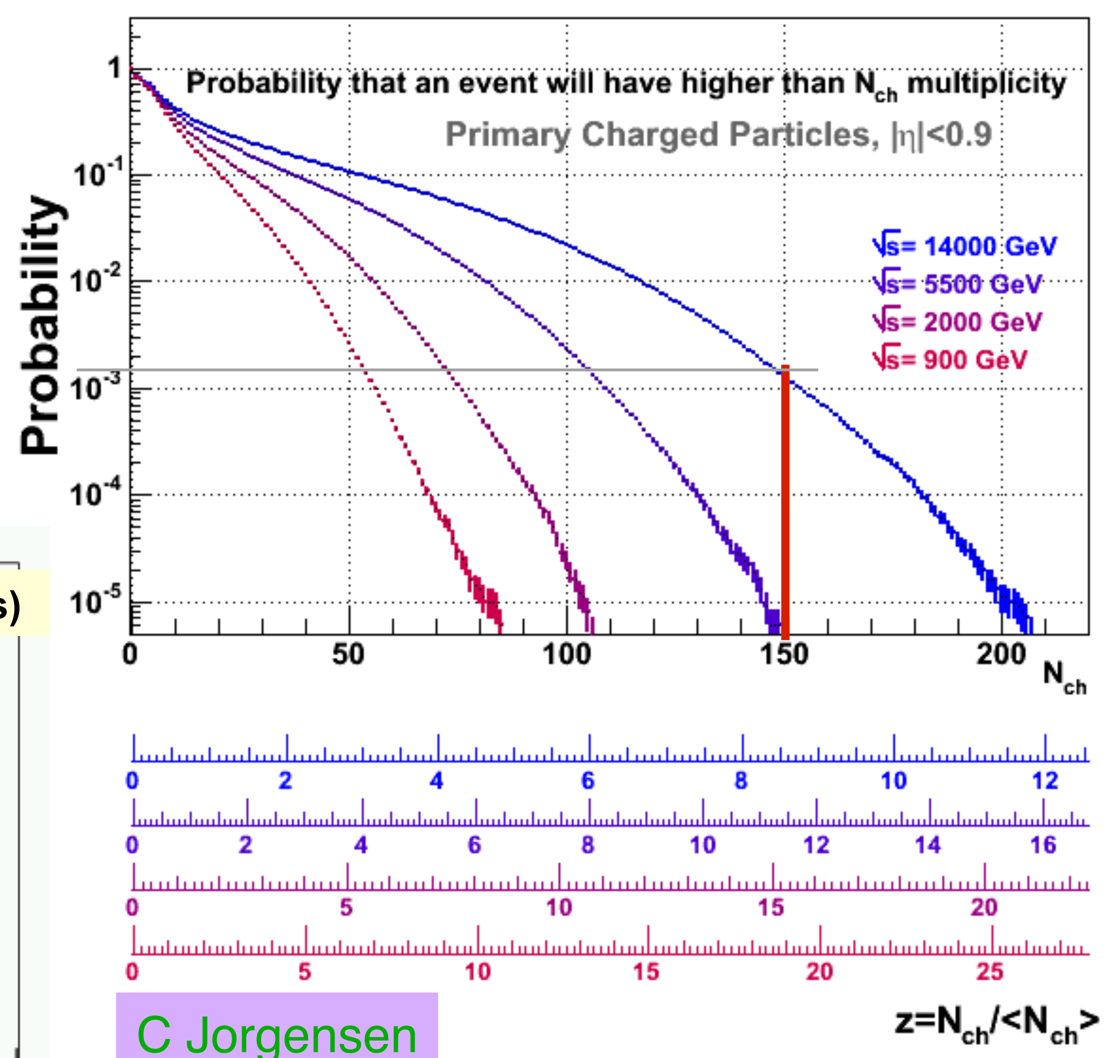
Initial multiplicity reach

with 20k minimum bias pp events up to multiplicity ~ 8 times the average
(30 events beyond)

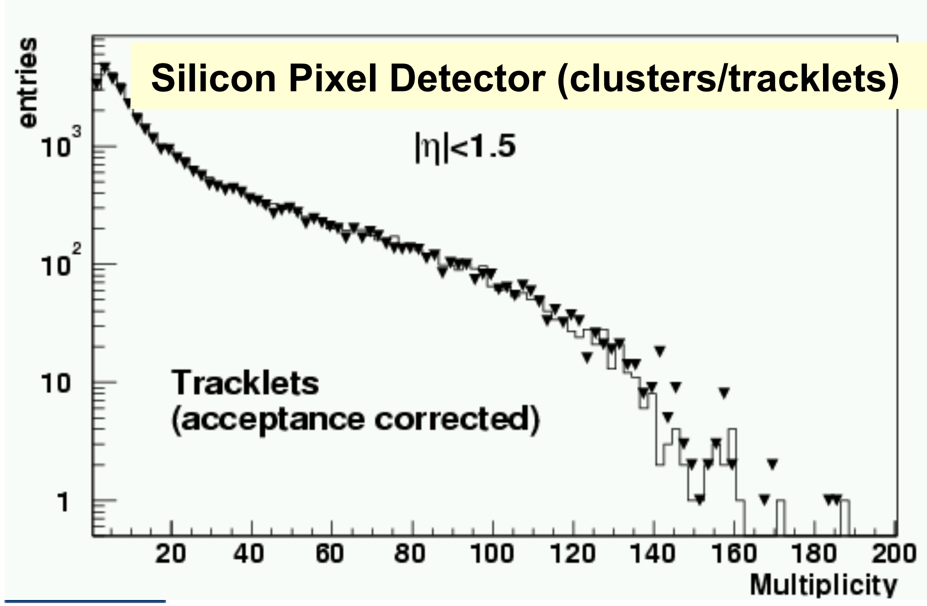
multiplicity trigger
to enrich the high-multiplicity

energy density in high-multiplicity pp events (Bjorken formula)
- dN/dy few (2–4) 10^2 smaller
- increase ~ 30 (smaller size)

⇨ at 10 times the mean multiplicity energy density as with heavy ions



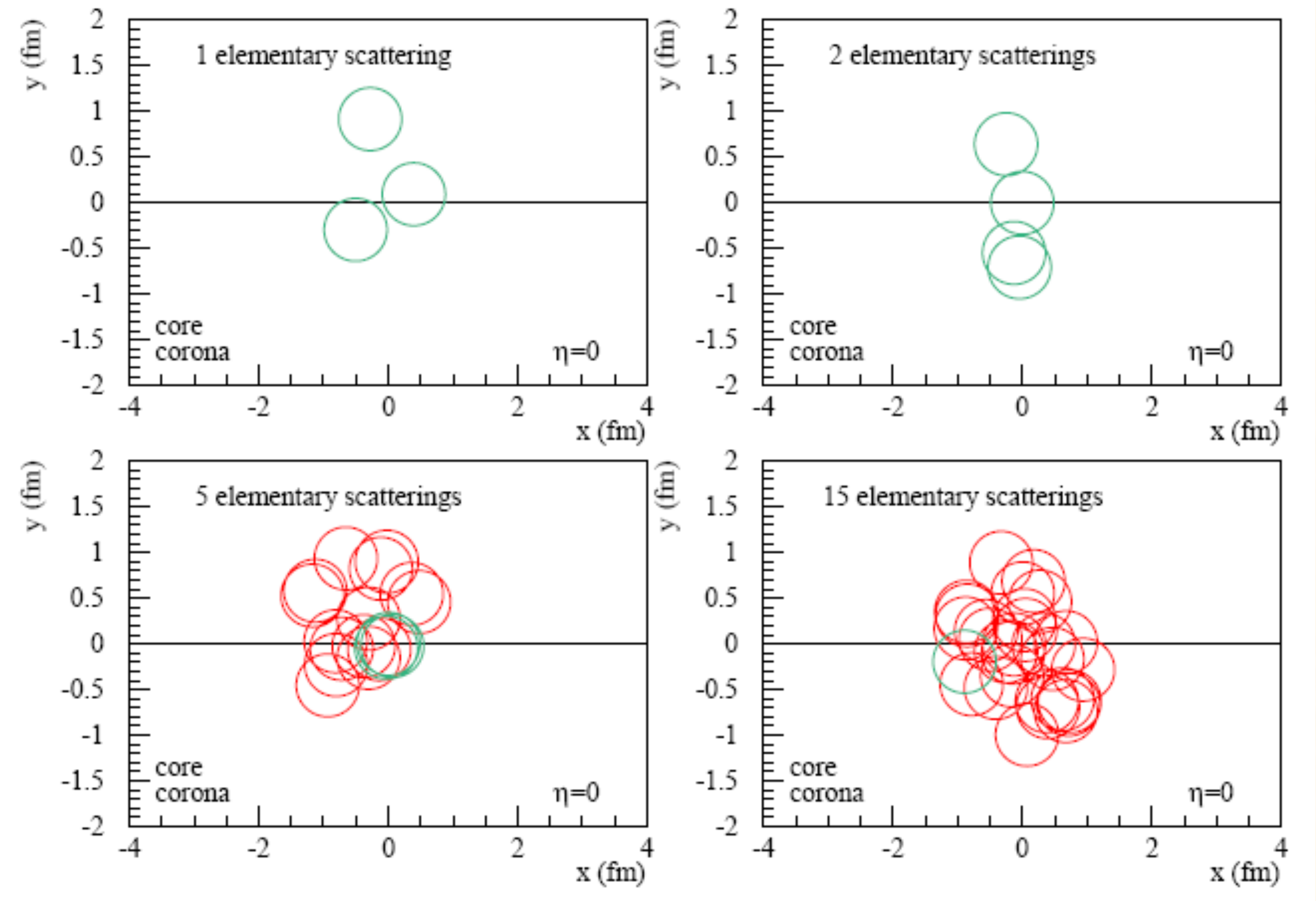
C Jorgensen



Density in pp

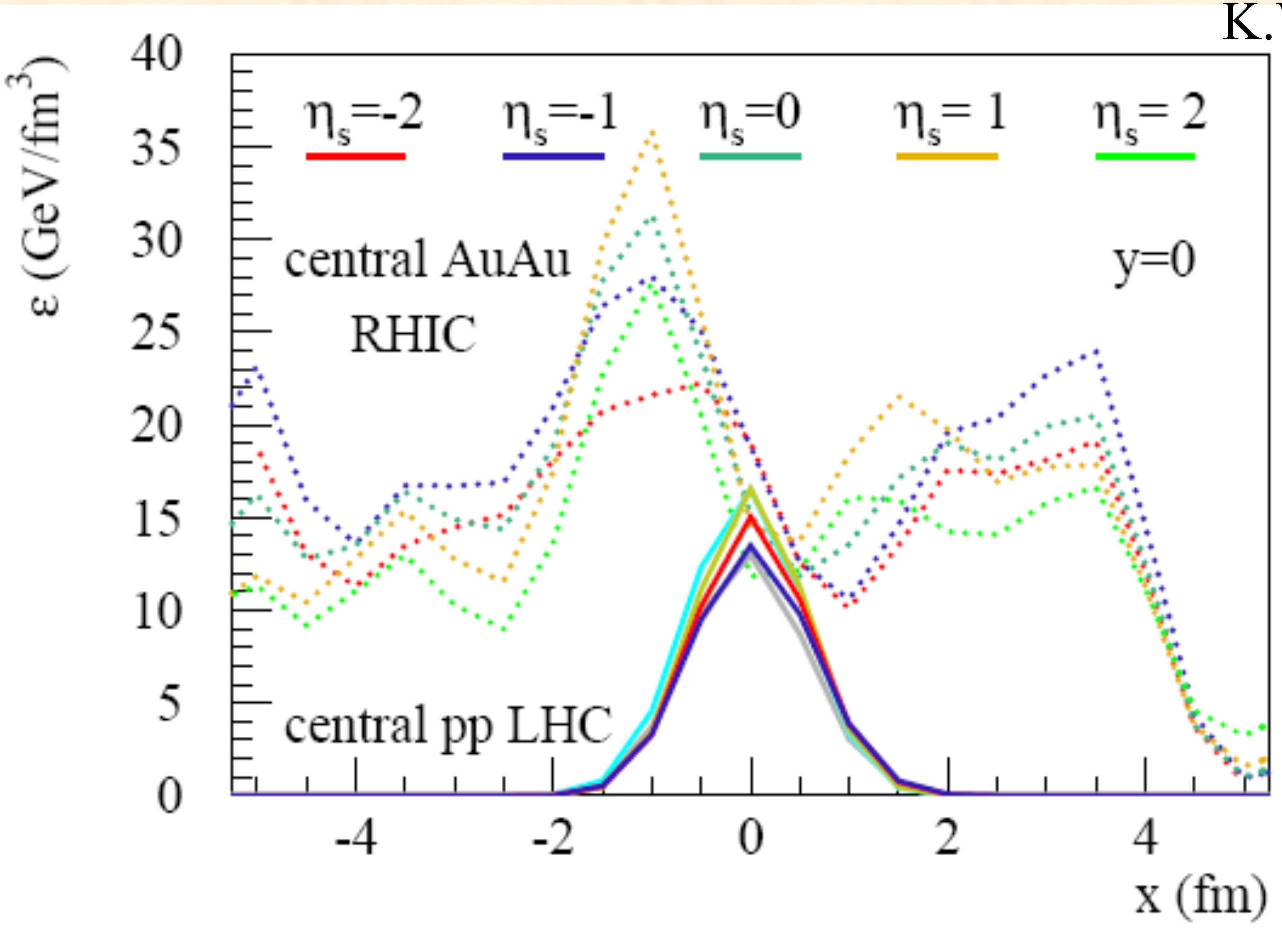
Energy density in high-momentum pp collisions can be as high as in HI

K.Werner, EPOS model

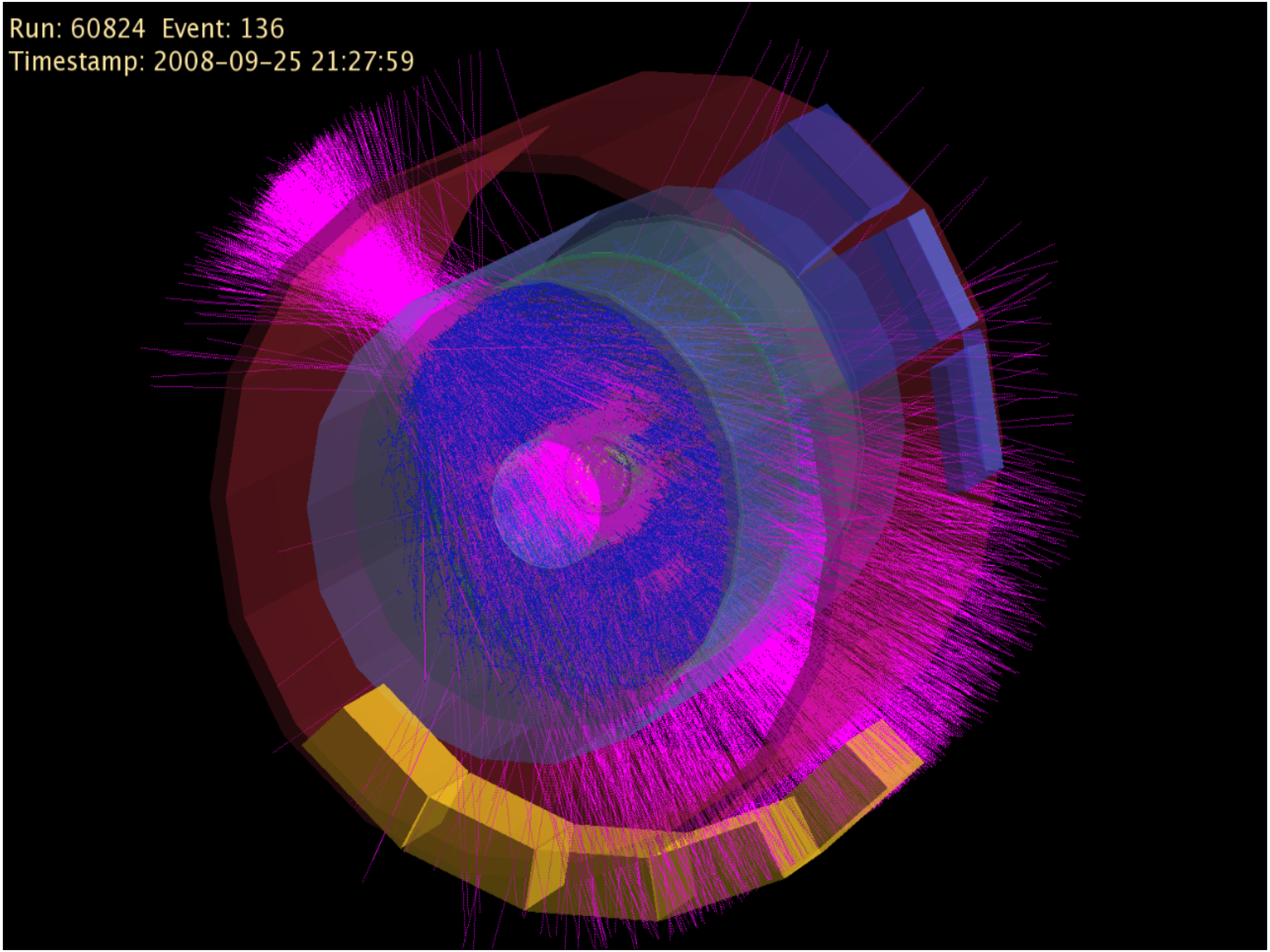


Density in pp vs. HI

K.Werner, EPOS model



The widths of the sub-flux in AuAu tubes are of the order of 2fm … like the flux tubes for "central" pp scatterings!


Run: 60824 Event: 136
Timestamp: 2008-09-25 21:27:59

High-multiplicity trigger

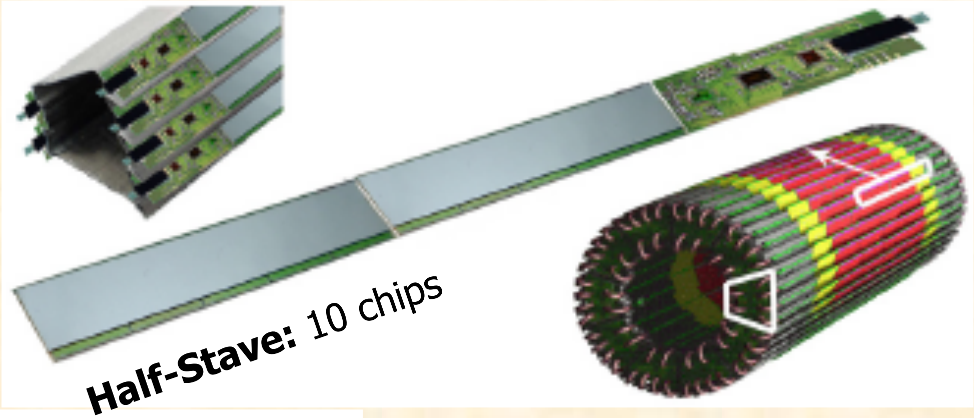
Silicon pixel detector

- fast-OR trigger at Level-0

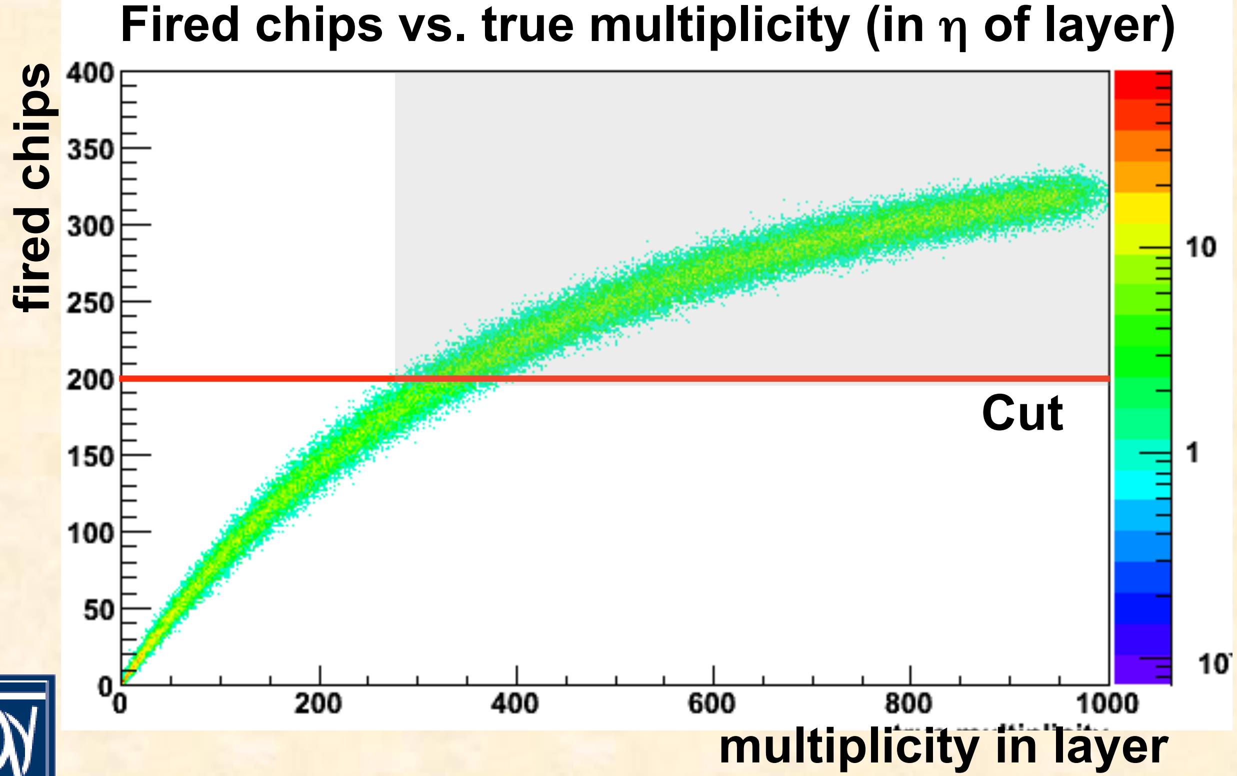
  OR signal from each pixel chip
- two layers of pixel detectors

  400 chips layer 1; 800 layer 2
- trigger on chip-multiplicity per layer

Sector: 4 (outer) + 2 (inner) staves



SPD: 10 sectors (1200 chips)


Fired chips vs. true multiplicity (in η of layer)

Few trigger thresholds

- tuned with different downscaling factors
- maximum threshold determined by
  - event rate
  - background
  - double interactions

High-multiplicity trigger – example

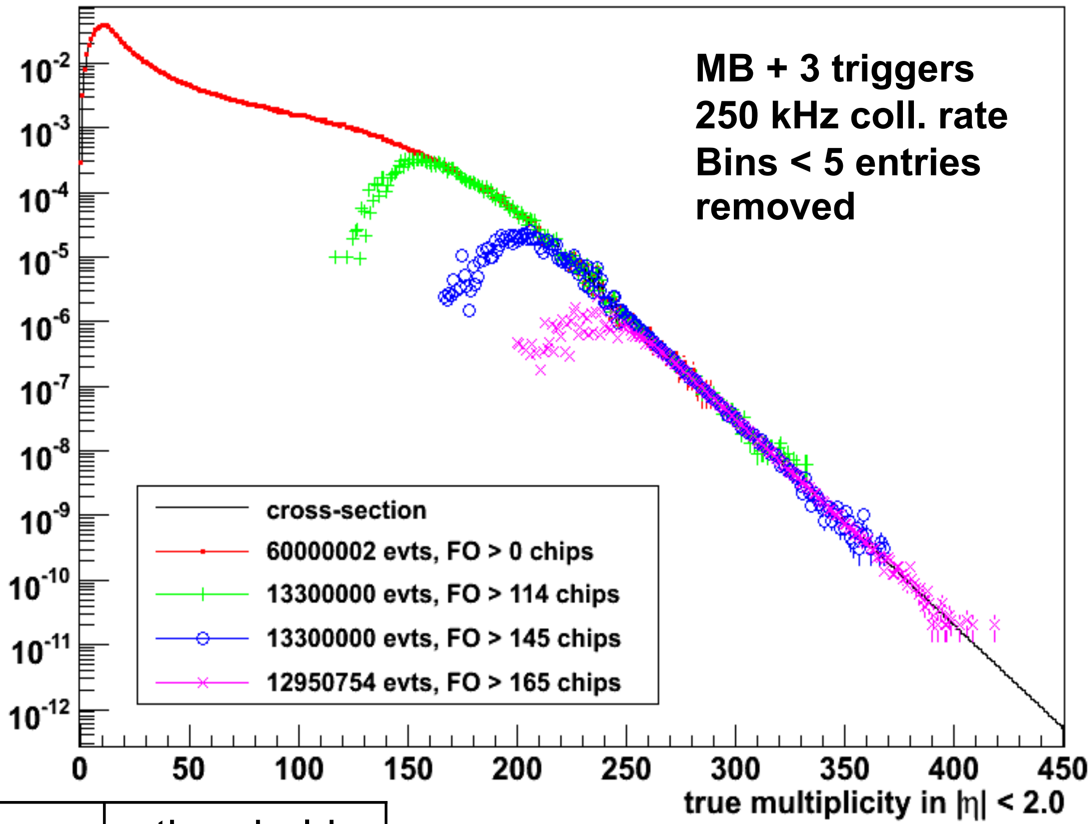
Example of threshold tuning:

MB and 3 high-mult. triggers

250 kHz collision rate
recording rate 100 Hz

MB 60%

3 HM triggers: 40%

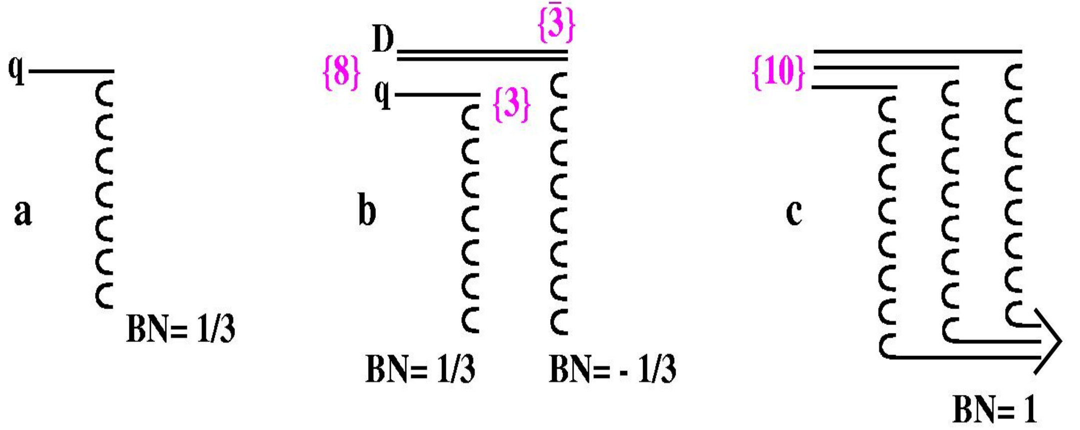


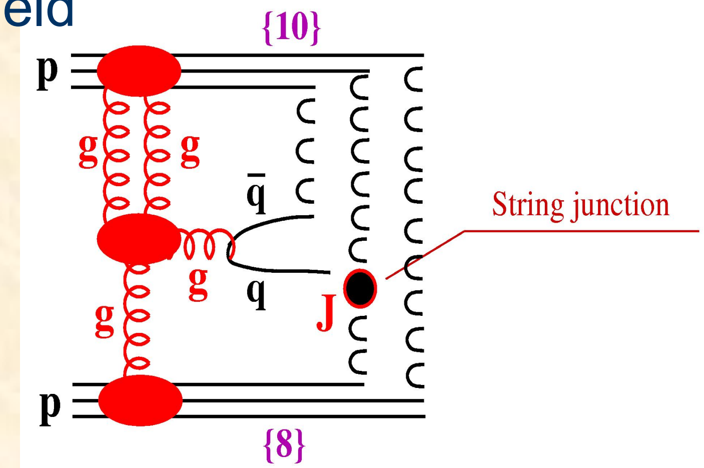
trigger rate Hz	scaling	raw rate	threshold layer 1
60.0	4167	250000	min. bias
13.3	259	3453.3	114
13.3	16	213.3	145
13.3	1	13.3	165

J F Grosse-Oetringhaus

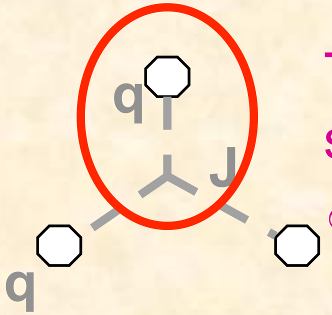
Baryon number transfer in rapidity

- When original baryon changes its colour configuration (by gluon exchange) it can transfer its baryon number to low-x without valence quarks – by specific configuration of gluon field





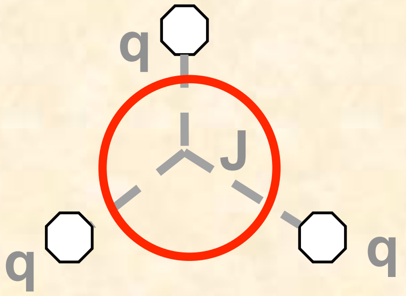
Standard case – quark exchange



This exchanged is suppressed

$\propto \exp(-1/2\ \Delta y)$

Gluon mechanism



Different prediction for junction exchange:

$\propto \exp(-\alpha_J\ \Delta y)$

α_J **= 0.5 Veneziano, Rossi**

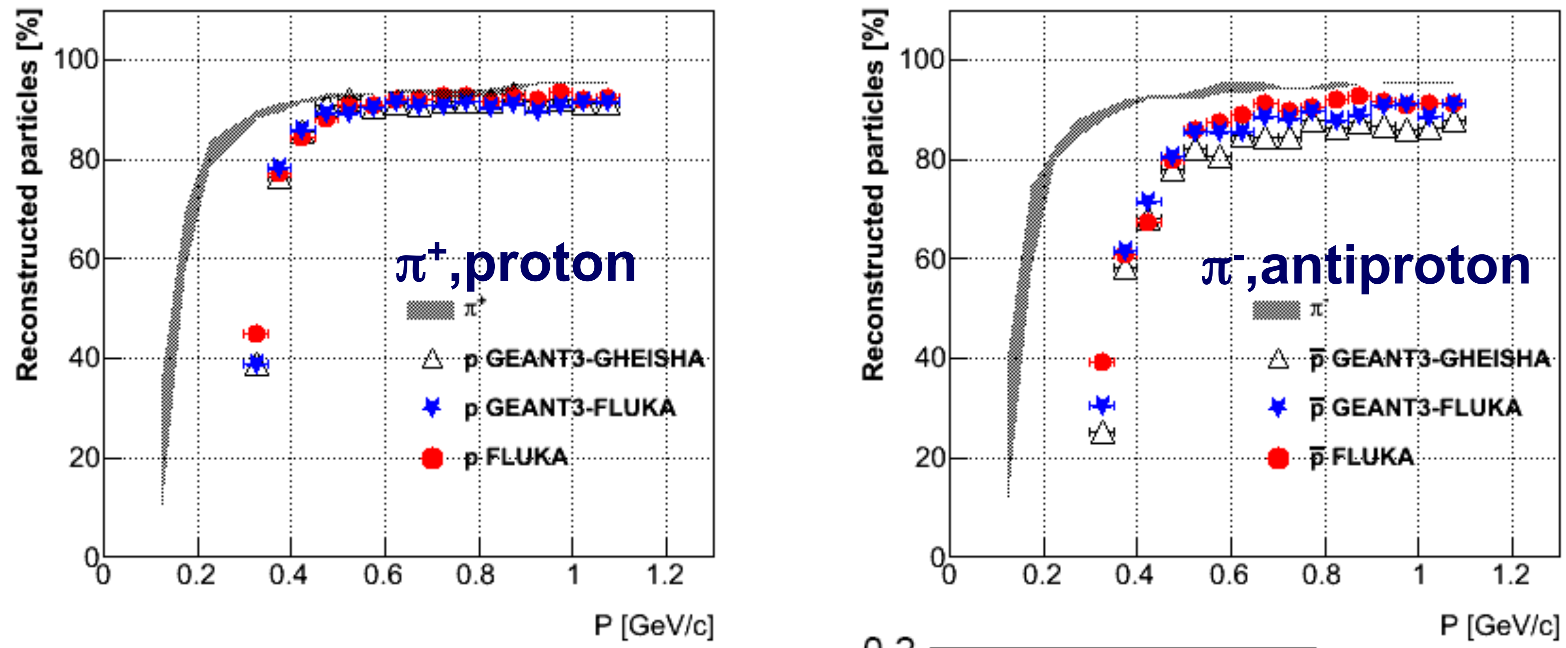
α_J **= 0 Kopeliovich**

- experimentally we measure baryon – antibaryon asymmetry
- largest rapidity gap at LHC (> 9 units)
- predicted absolute value for protons ~ 2-7%

$$\boxed{A = 2 \cdot \frac{N_B - N_{\bar{B}}}{N_B + N_{\bar{B}}}}$$

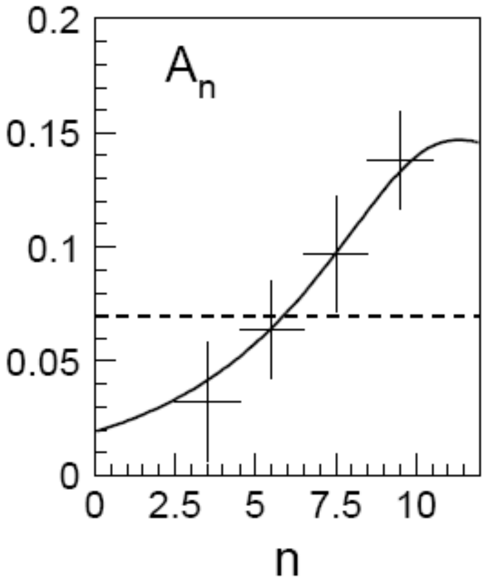
Asymmetry measurement

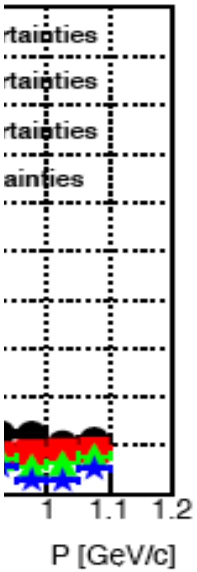
reconstruction efficiencies



- systematic error of asymmetry below 1% for p > 0.5 GeV/c: contributions from uncertainties in the cross sections, material budget, beam gas events
- statistical error < 1% for 10^6 pp events (< 1 day)

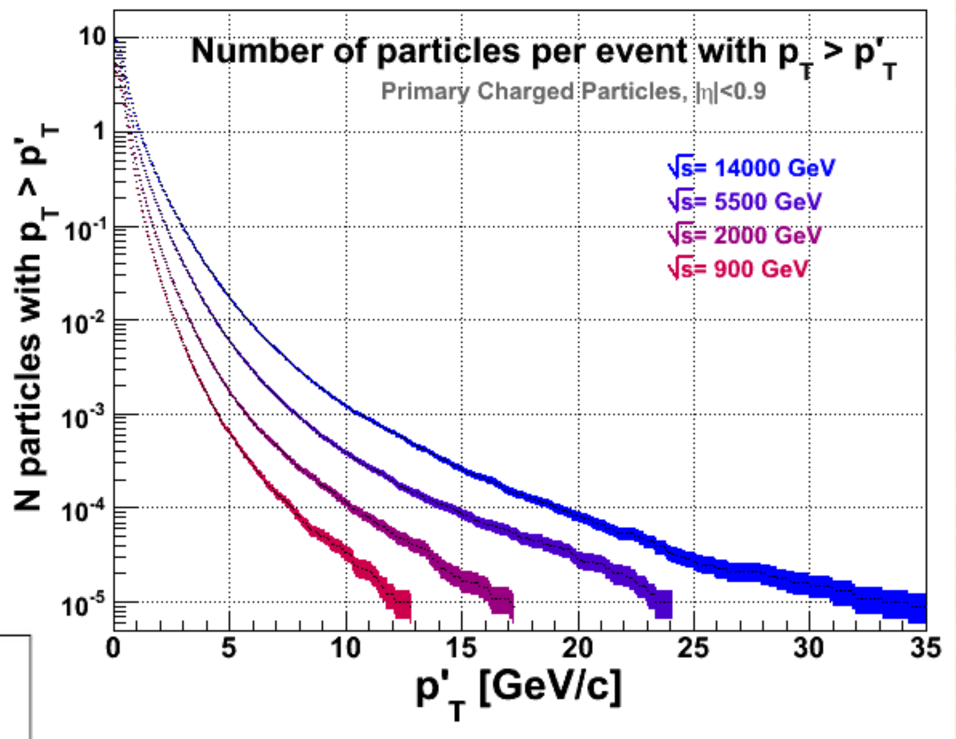
- additional prediction asymmetry increases with multiplicity
- will be extended to $\Lambda,\bar{\Lambda}$ (asymmetry larger)

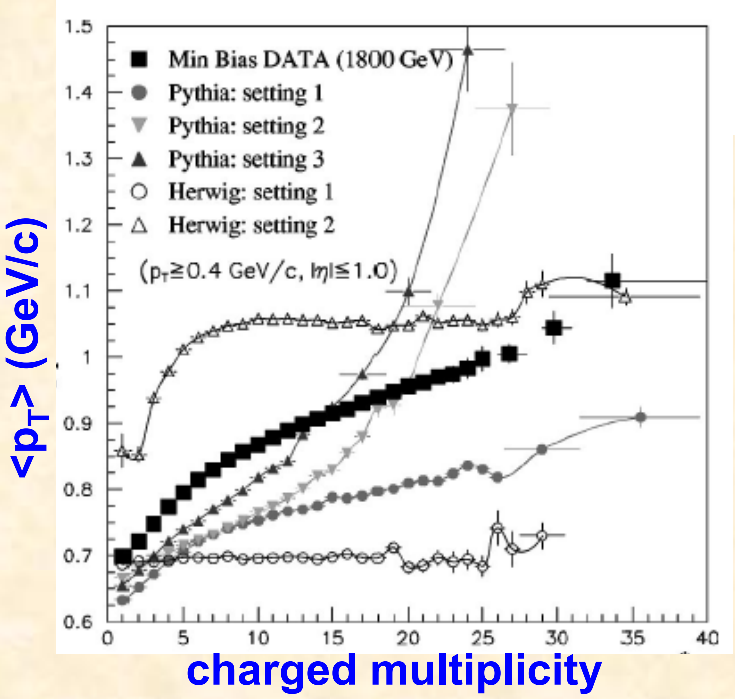




Transverse momentum

- ⇨ with 20k events we reach (first few days)
  - ✪ **5 GeV (at 0.9 TeV)**
  - ✪ **10 GeV (at 14 TeV)**
- ⇨ with O(10^8) events we reach (first month)
  - ✪ **15 GeV (at 0.9 TeV)**
  - ✪ **50 GeV (at 14 TeV)**

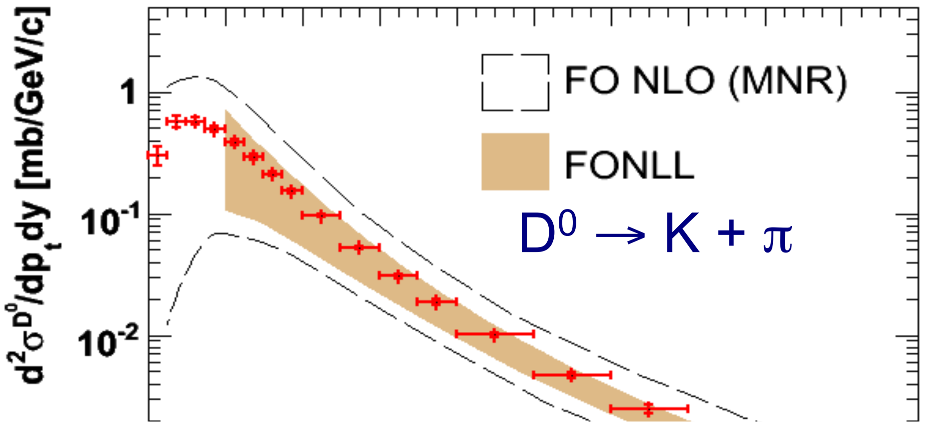


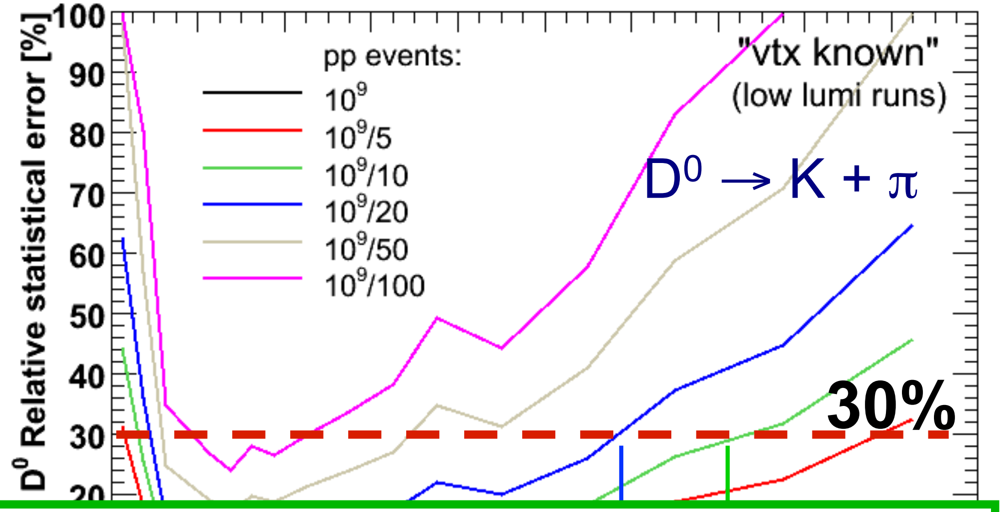


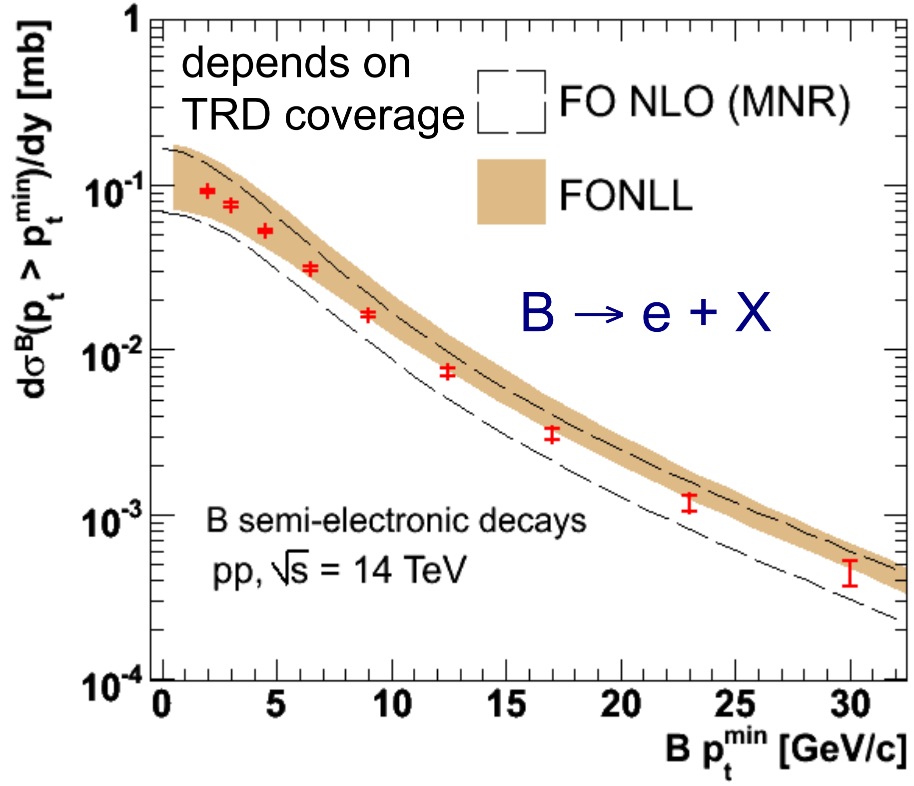
mean transverse momentum vs. multiplicity

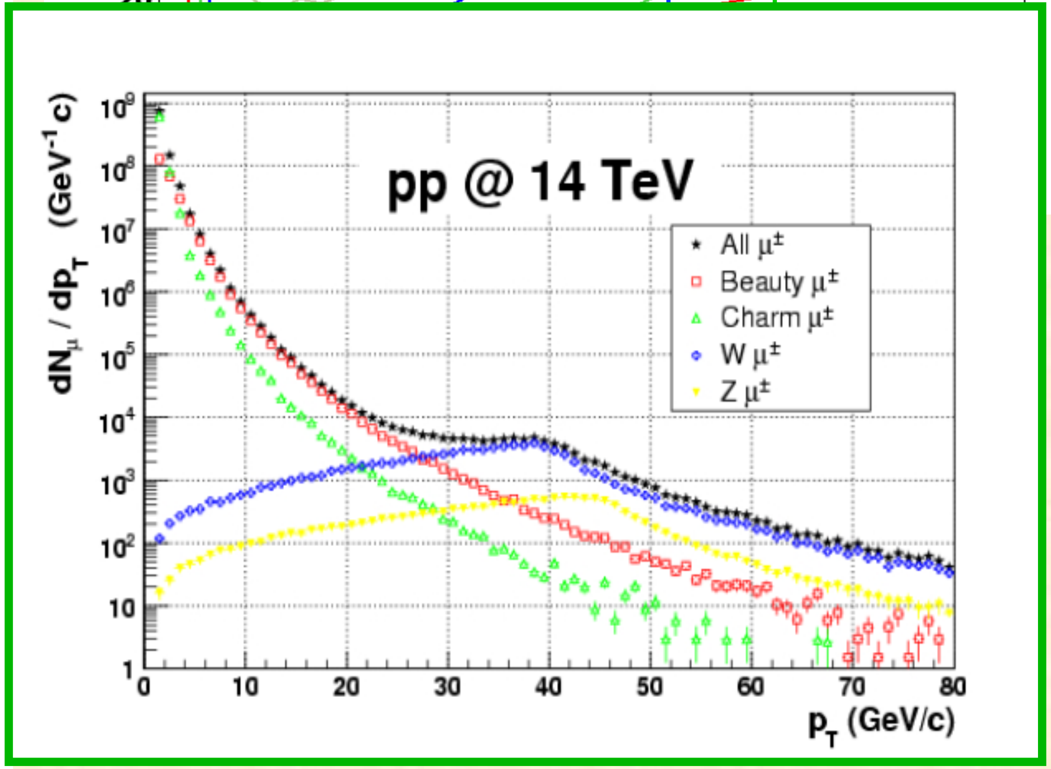
Heavy-flavour physics

for 10^9 pp events Andrea Dainese









LHC as Ion Collider

- **Running conditions for ‘typical’ Alice year:**

Collision system	$\sqrt{s_{NN}}$ (TeV)	L_0 ($cm^{-2}s^{-1}$)	$\langle L\rangle/L_0$ (%)	Run time (s/year)	σ_{inel} (b)
pp	14.0	10^{31*}		10^7	0.07
PbPb	5.5	10^{27}	70-50	$10^{6\,**}$	7.7

- **+ other collision systems: pA, lighter ions (Sn, Kr, Ar, O)**
- **& energies (pp @ 5.5 TeV)**

* L_{max} (ALICE) = 10^{31}

** $\int L\,dt$ (ALICE) ~ 0.7 nb^{-1}/year

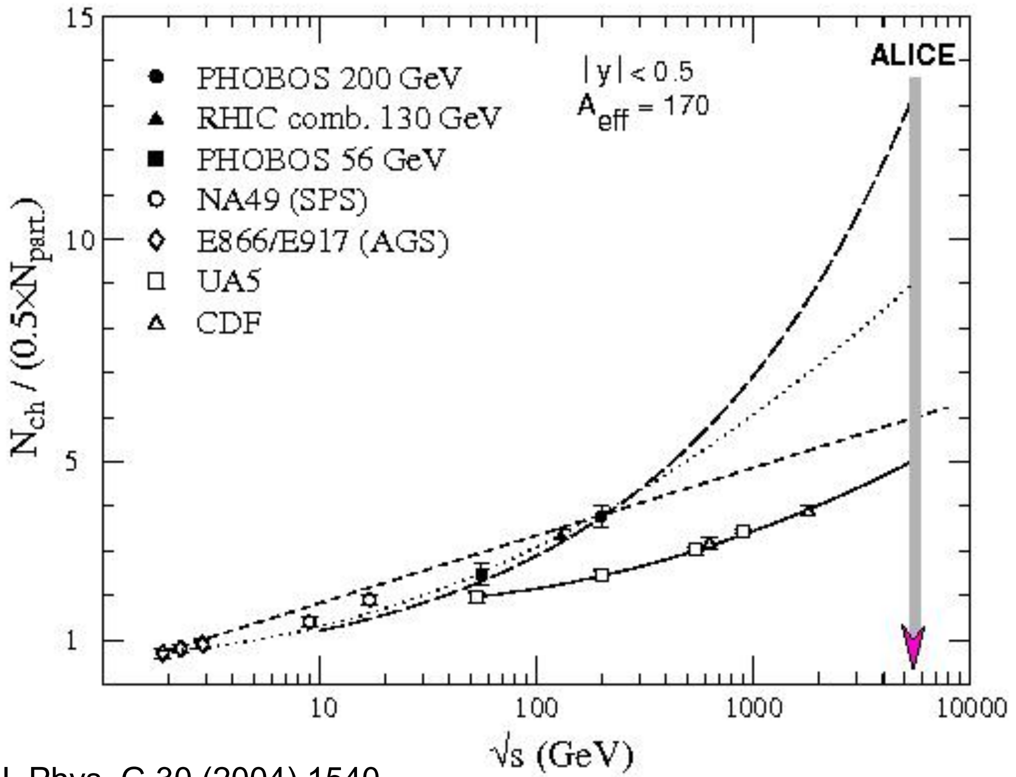
Heavy-ion physics with ALICE

- **fully commissioned detector & trigger**
  - alignment, calibration available from pp
- **first 10^5 events:** global event properties
  - multiplicity, rapidity density
  - elliptic flow
- **first 10^6 events:** source characteristics
  - particle spectra, resonances
  - differential flow analysis
  - interferometry
- **first 10^7 events:** high-p_t, heavy flavours
  - jet quenching, heavy-flavour energy loss
  - charmonium production
- yield bulk properties of created medium
  - energy density, temperature, pressure
  - heat capacity/entropy, viscosity, sound velocity, opacity
  - susceptibilities, order of phase transition

- **early ion scheme**
  - 1/20 of nominal luminosity
  - $\int L dt = 5 \cdot 10^{25}$ cm^{-2} s^{-1} x 10^6 s
    0.05 nb^{-1} for PbPb at 5.5 TeV
    $N_{\text{pp collisions}} = 2 \cdot 10^8$ collisions
    400 Hz minimum-bias rate
    20 Hz central (5%)
  - muon triggers:
    ~ 100% efficiency, < 1kHz
  - centrality triggers:
    bandwidth limited
    $N_{\text{PbPbminb}} = 10^7$ events (10Hz)
    $N_{\text{PbPbcentral}} = 10^7$ events (10Hz)

Charged-particle Multiplicity Density

integrated multiplicity distributions from Au-Au/Pb-Pb collisions
and scaled pp collisions



J. Phys. G 30 (2004) 1540

$dN_{ch}/dy = 2600$

saturation model

Eskola hep-ph/050649

$dN_{ch}/dy = 1200$

ln(√s) extrapolation

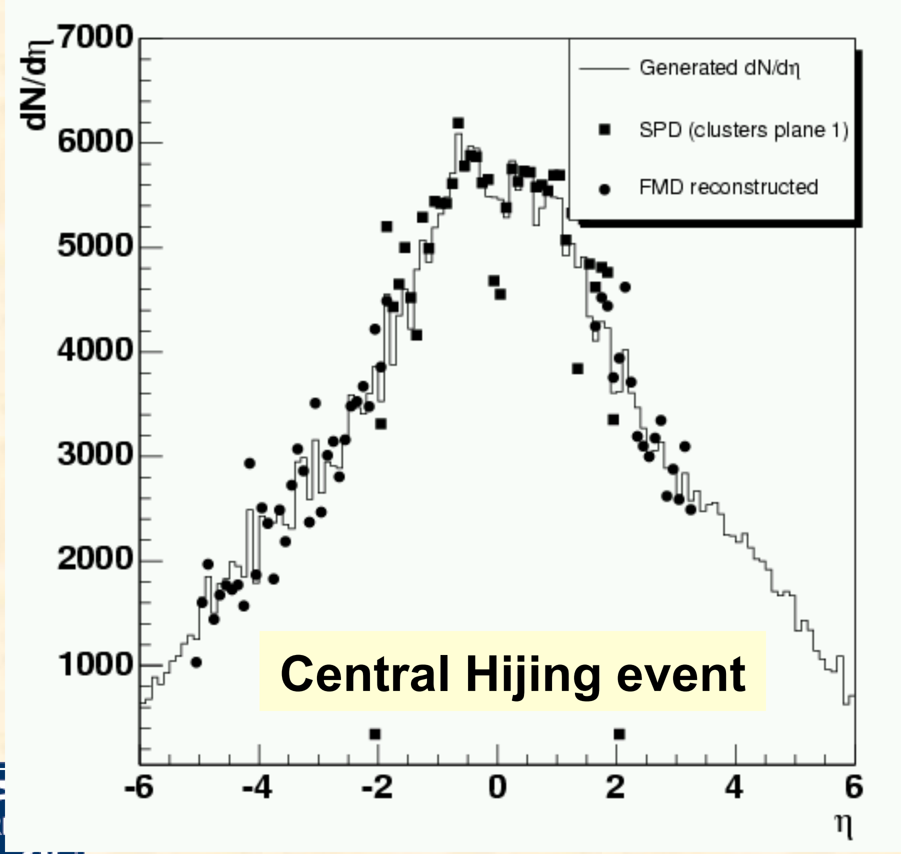
- **ALICE designed (before RHIC) for $dN_{ch}/dy = 3500$**
  design checked up to $dN_{ch}/dy = 7000$

Global event properties in Pb-Pb

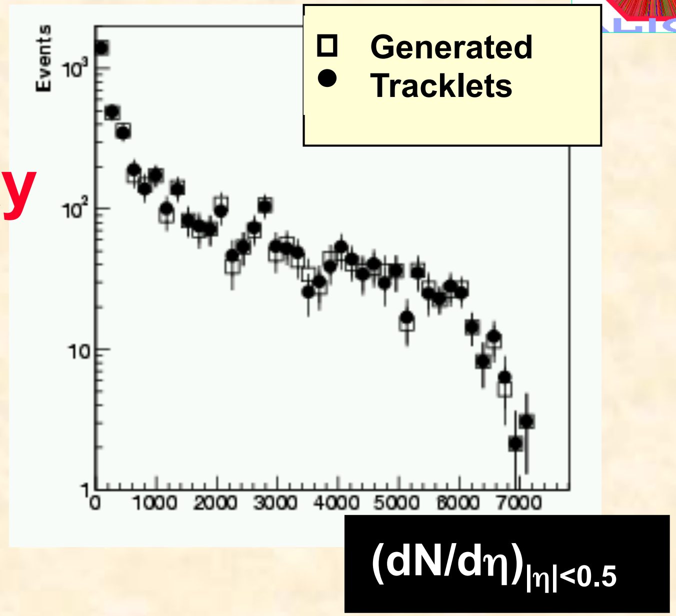
Multiplicity distribution ($dN_{ch}/d\eta$) in Pb-Pb

➡ **First estimate of energy density**
Saturation, CGC ?

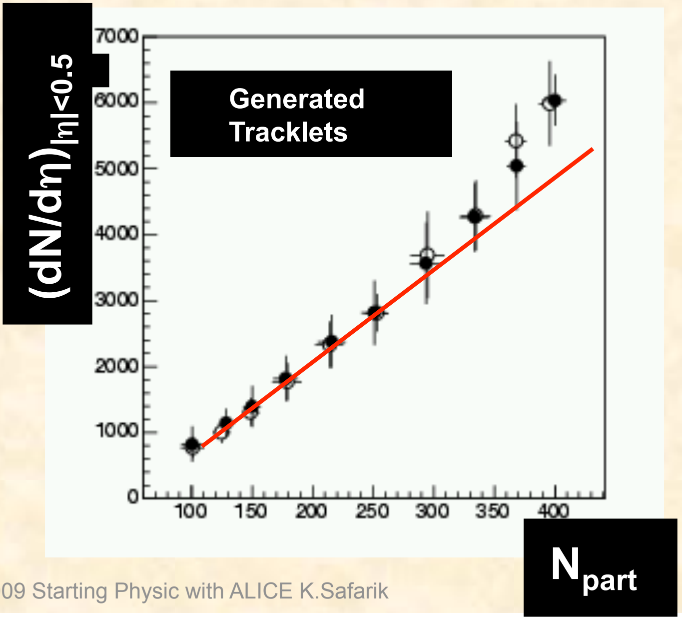
Silicon Pixel Detector: $-1.6 < \eta < +1.6$
+ Forward Multiplicity Detectors: $\eta \longrightarrow -5, +3.5$



Central Hijing event



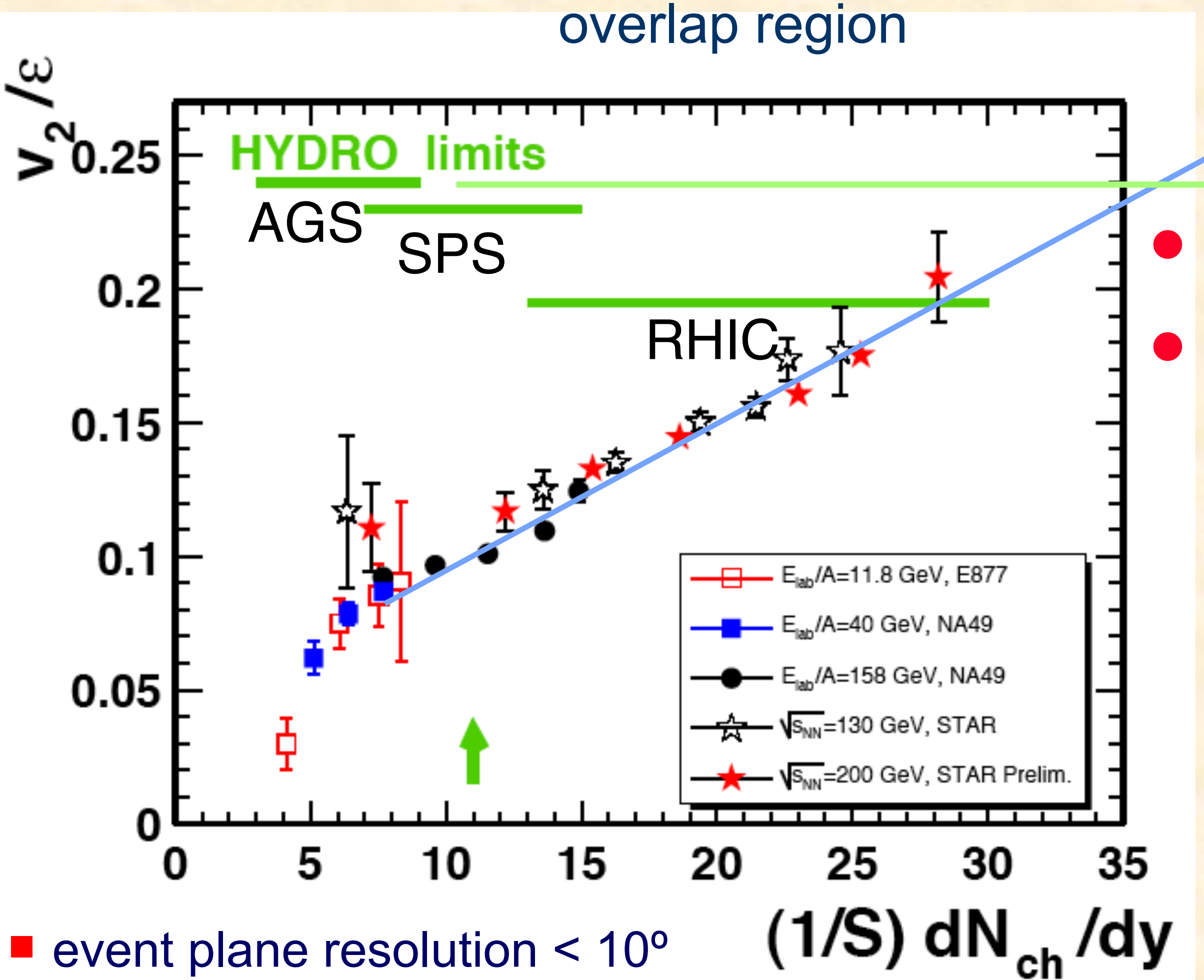
$dN/d\eta$ % centrality (N_{part}) ➡ Fraction of particles produced in hard processes



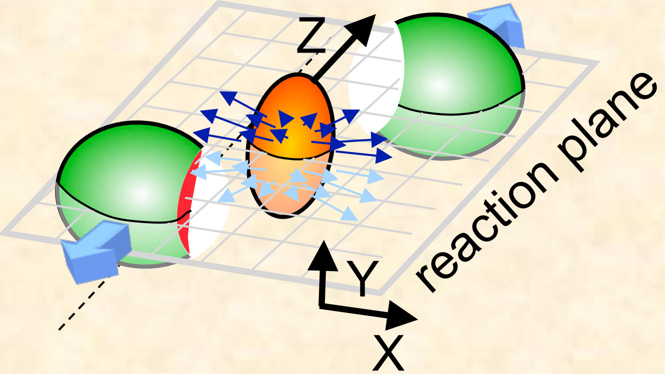
Elliptical Flow - Day 1 Physics

- data increase linearly
- hydrodynamical limit reached at RHIC → ‘ideal fluid’

excentricity vs. particle multiplicity in overlap region



- clear predictions from hydrodynamics
- sensitive to equation-of-state

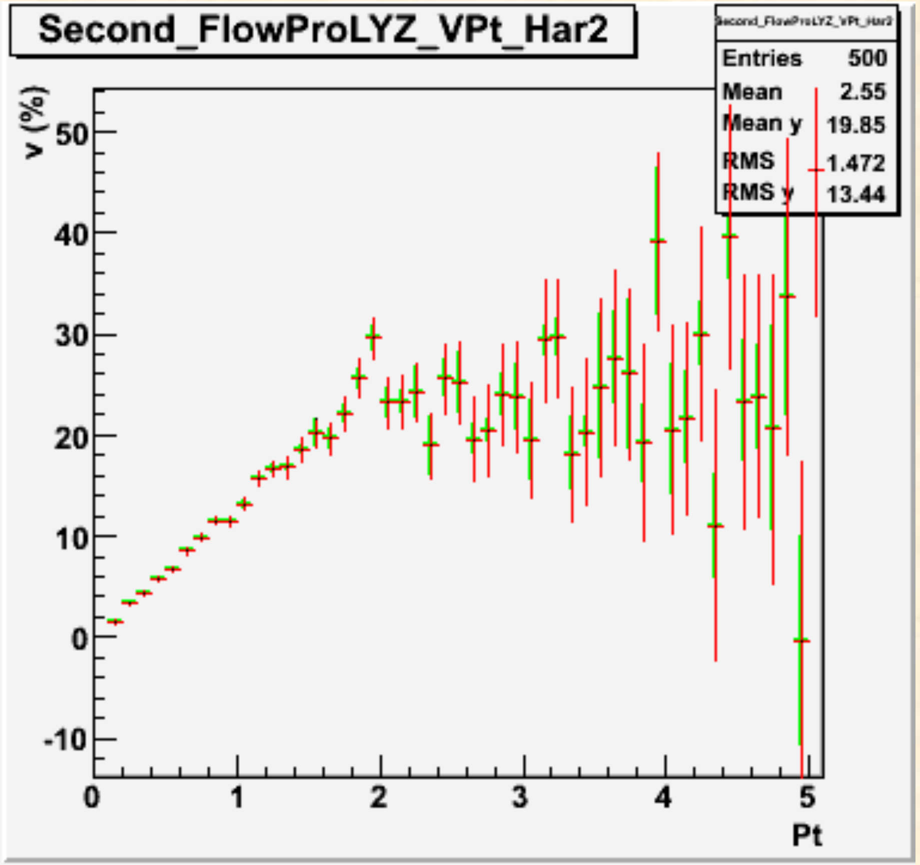


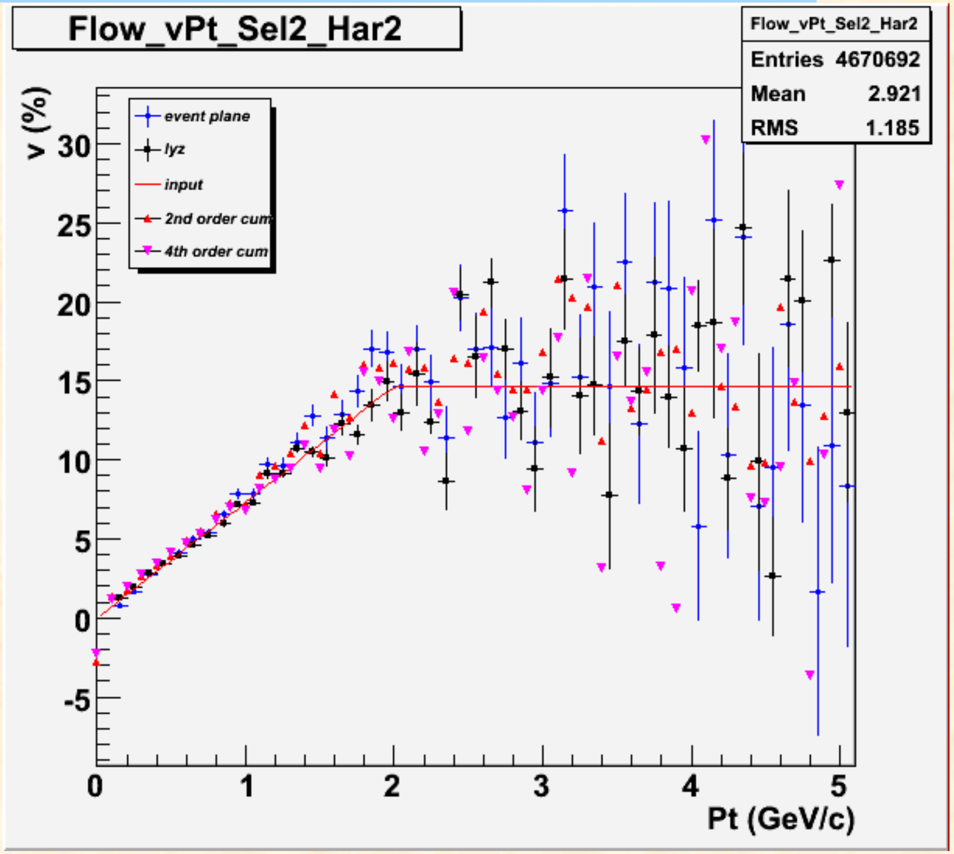
- event plane resolution < 10º
- very robust signal - no PID necessary

v_2 measurement studies

Standard event-plane method

500 HIJING event
centrality b = 8fm
multiplicity <M> = 1900
integrated v_2 = 3.3%





Lee-Yang Zero method

1100 HIJING event
centrality b = 9fm
multiplicity <M> = 1200
integrated v_2 = 6%

red – modified LYZ method (J-Y Ollitrault)

N van der Kolk

Identified particle spectra in Pb-Pb

Excitation functions of bulk observables for identified hadrons

New regime at LHC: strong influence of hard processes

Chemical composition

Equilibrium vs non equilibrium stat. models ? **Jet propagation vs thermalization ?**

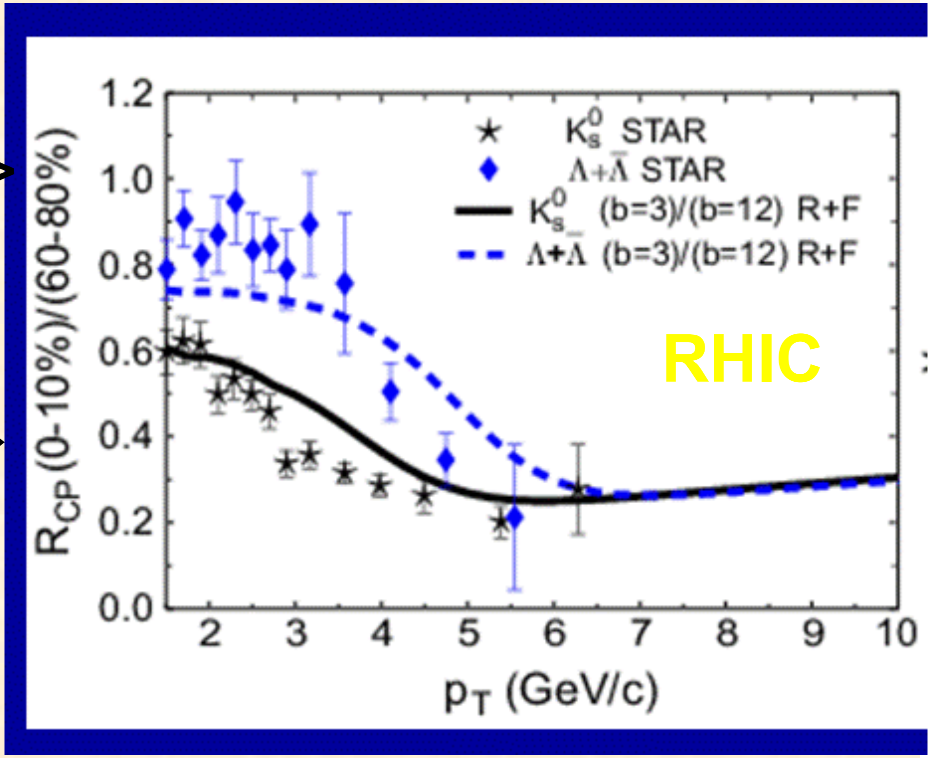
Strangeness production : correlation volume (N_{part} → GC, N_{bin} → hard processes) ?

Interplay between hard and soft processes at intermediate p_T

- → **R_{cp}: central over peripheral yields/<Nbin>**
- → **Baryon/meson ratio**
- → **Elliptic flow**

Parton recombination + fragmentation ?

or soft (hydro -> flow) + quenching ?
or … ?



Production mechanisms versus hadron species in pp

Topological identification of strange particles

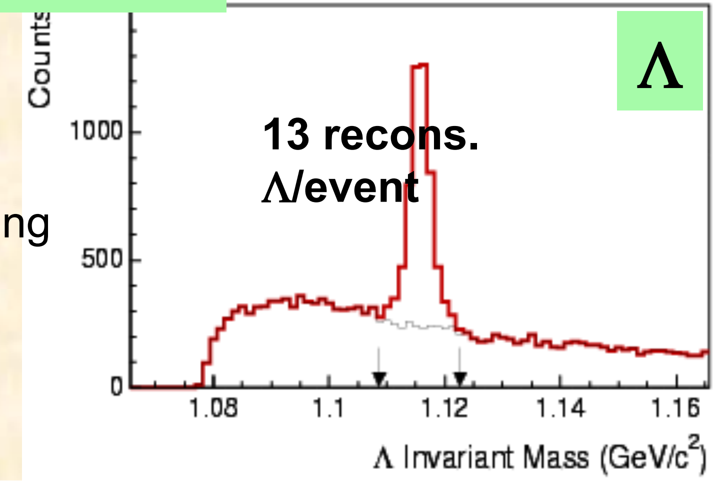
Statistical limit : p_T ~8 - 10 GeV for K^+, K^-, K^0_s, Λ, 3 - 6 GeV for Ξ, Ω

Secondary vertex and cascade finding

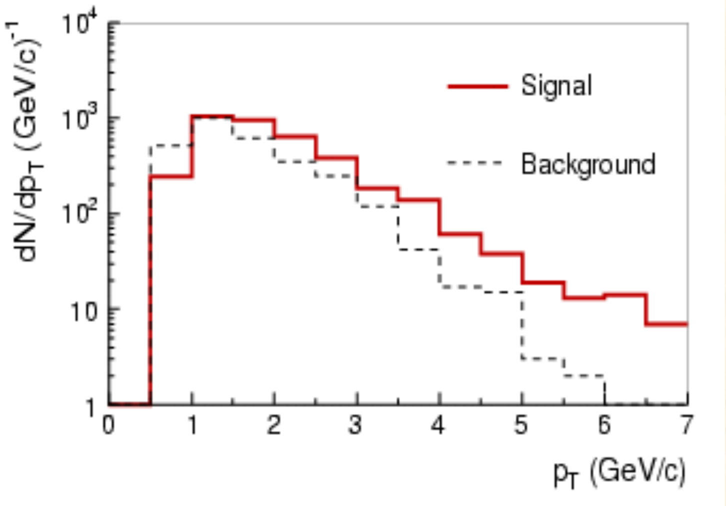
p_T dependent cuts -> optimize efficiency over the whole p_T range

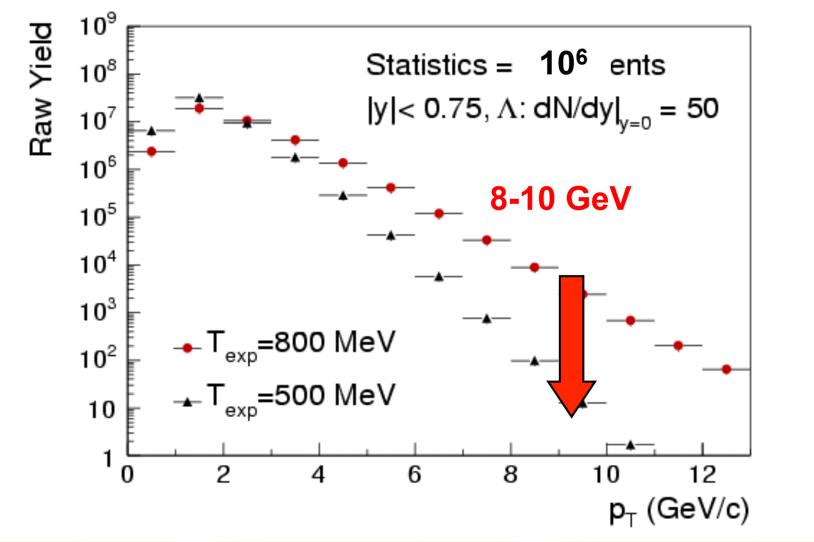
Pb-Pb central

300 Hijing events



13 recons. Λ/event





8-10 GeV

Reconst. rates:

Ξ: 0.1/event

Ω: 0.01/event

p_T: 1 to 3-6 GeV

ρ, ϕ, K^*, K^0_s, Λ, Ξ, Ω…

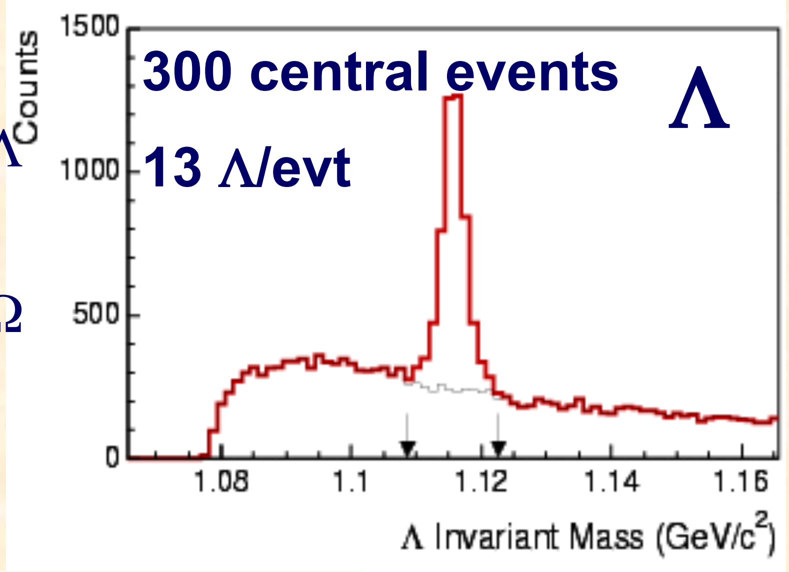
10^7 events:

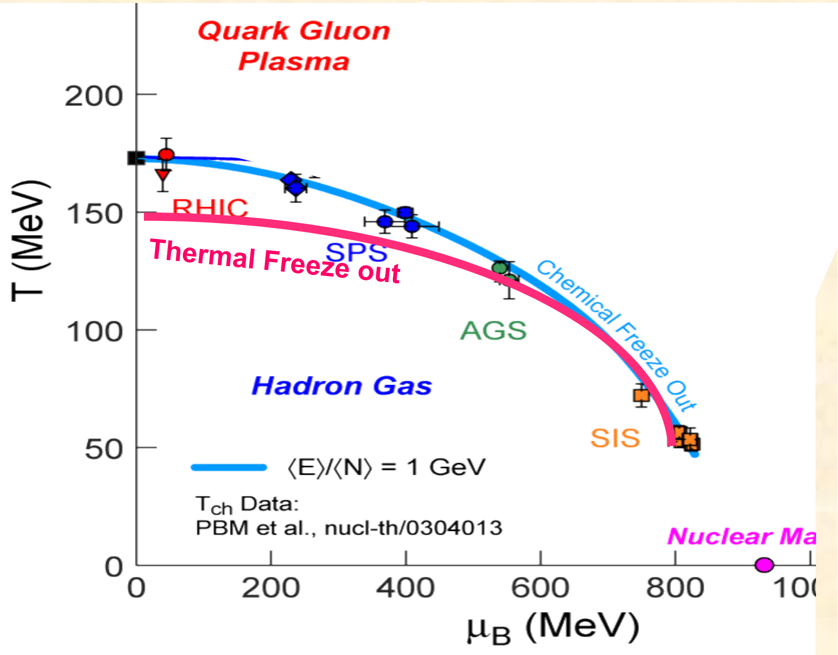
p_t reach ϕ,K,Λ

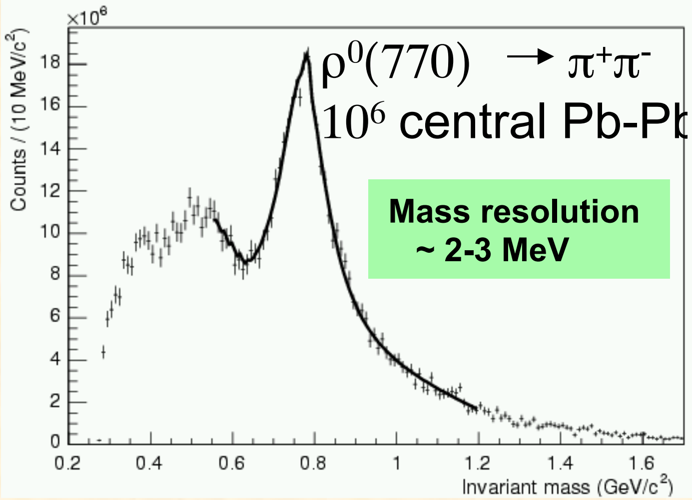
~ 13-15 GeV

p_t reach ρ,Ξ,Ω

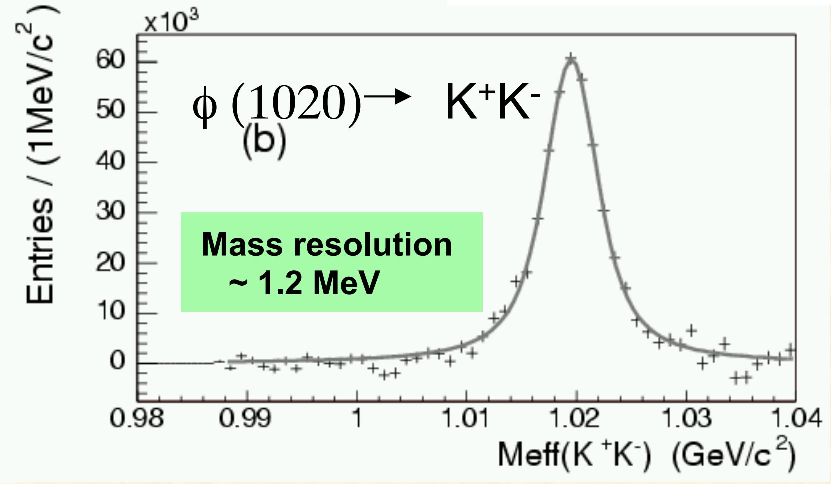
~ 9-12 GeV







Mass resolution
~ 2-3 MeV



Mass resolution
~ 1.2 MeV

- **hadrochemical analysis**
- **chemical/kinetic freeze-out**
- **medium modifications of mass, widths**

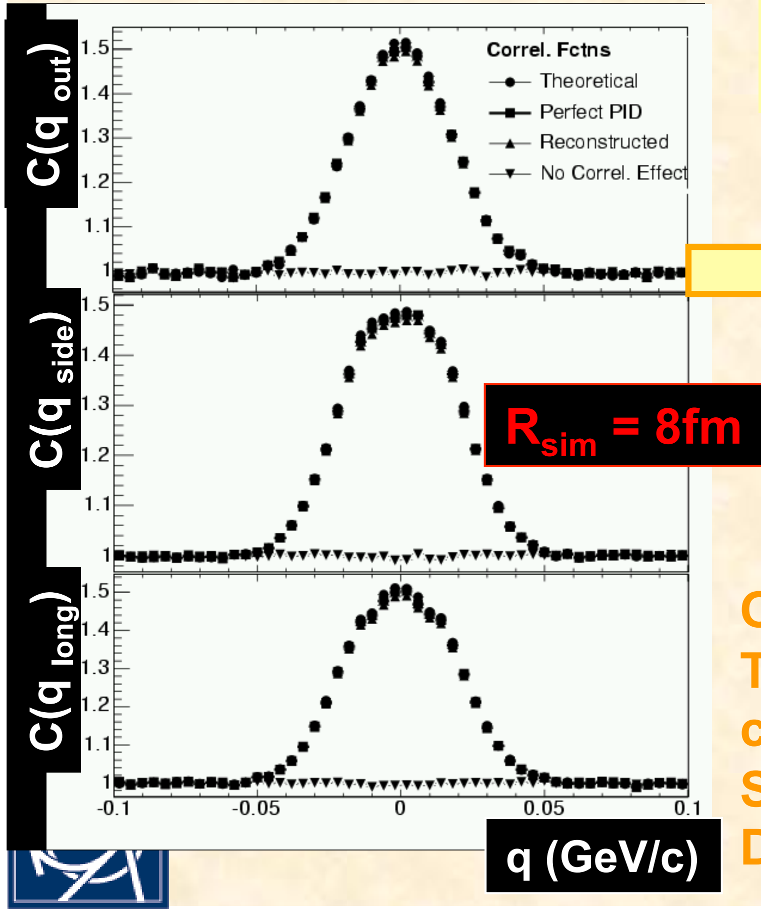
Particle correlations

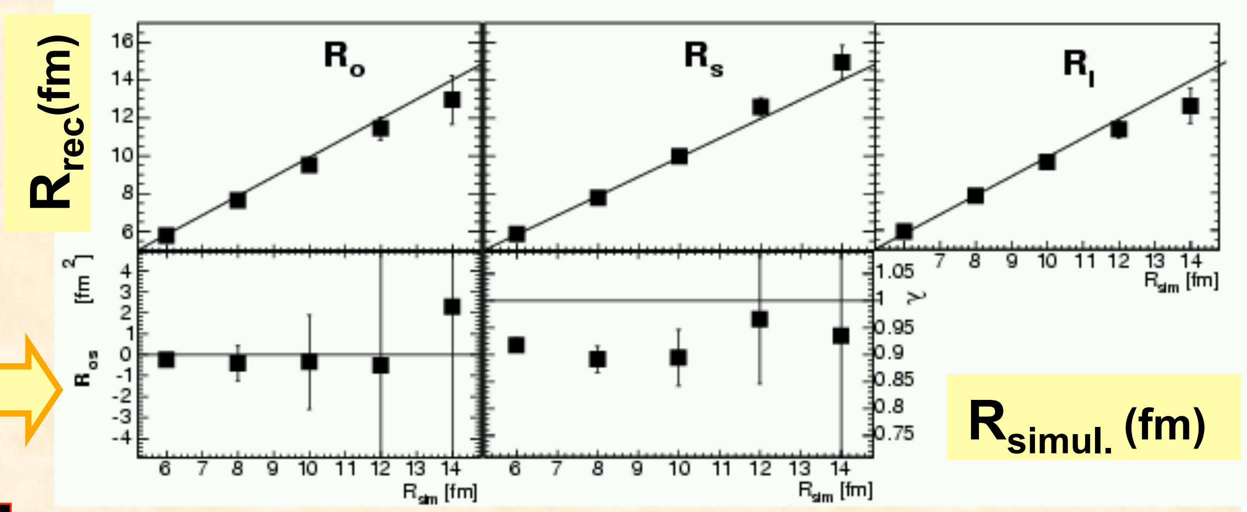
Two pion momentum correlation analysis

Study of event mixing, two track resolutions, track splitting/merging, pair purity, Coulomb interactions, momentum resolution corrections, PID corrections

Central Pb-Pb events (0-2 fm) with dN/dy = 6000 (MeVSim + QS & FSI weights)

Correlations fonctions



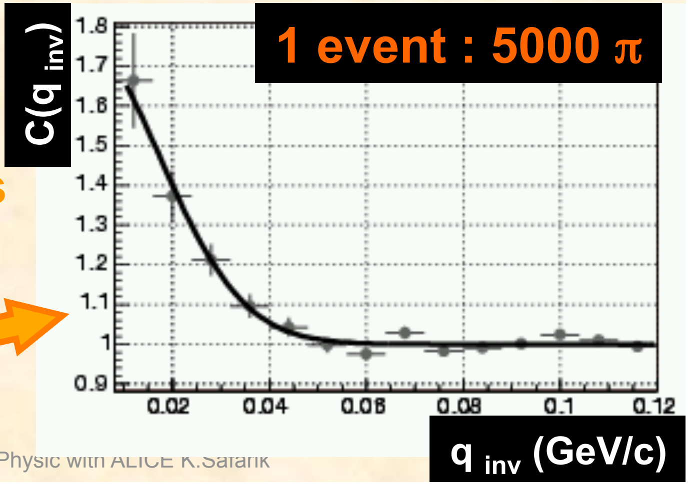


Other potential analyses

Two kaon & two proton correlations

Single event HBT

Direct photon HBT, …



Heavy Quarks – dead cone

- Heavy quarks **with momenta < 20–30 GeV/*c*** → ***v* << *c***

- Gluon radiation is suppressed at angles < m_Q/E_Q

  → “dead-cone” effect

  ⇨ **Due to destructive interference**

  ⇨ **Contributes to the harder fragmentation of heavy quarks**

- **Yu.L.Dokshitzer and D.E.Kharzeev:** *dead cone implies lower energy loss*

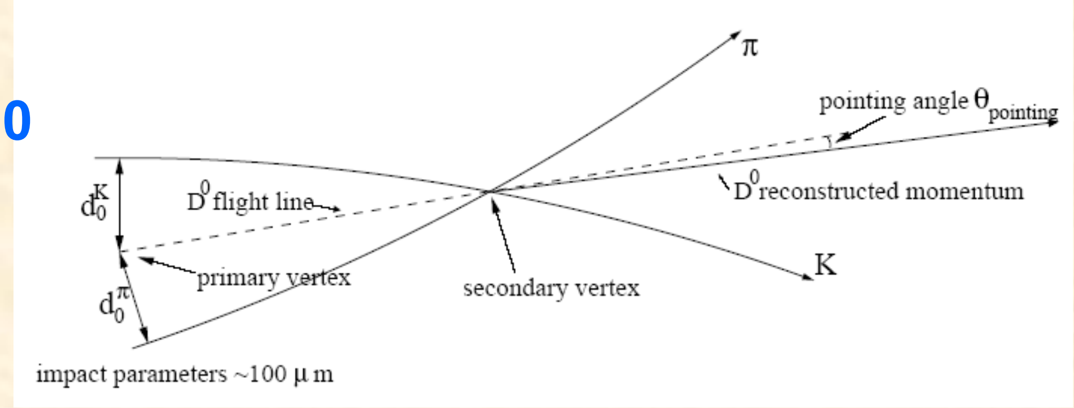
⇒ **D mesons quenching reduced**

⇒ **Ratio D/hadrons (or D/π^0) enhanced and sensitive to medium properties**

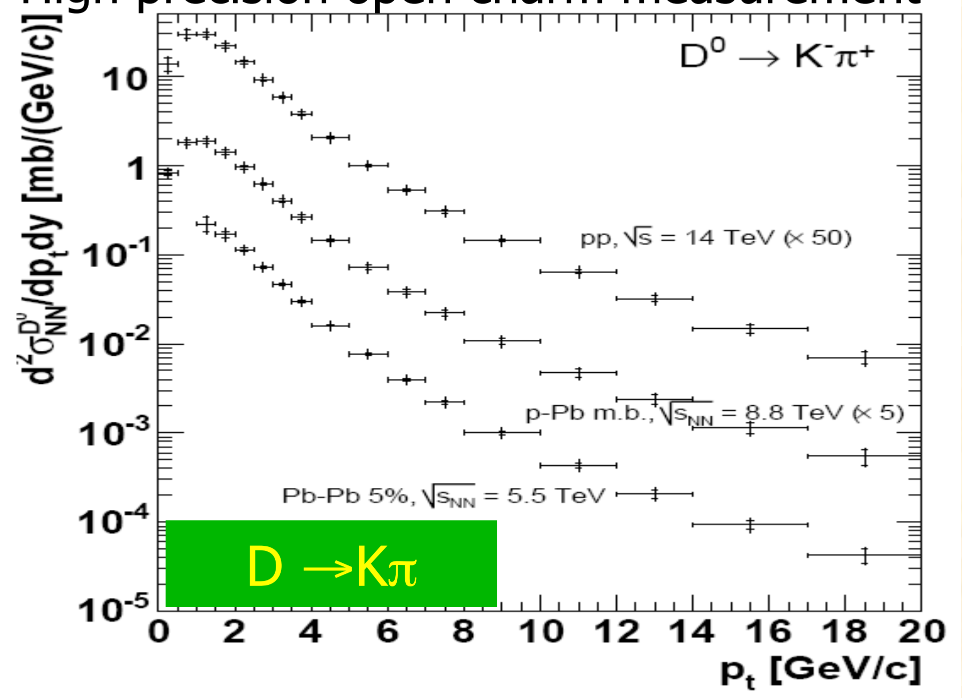
Yu.L.Dokshitzer and D.E.Kharzeev, Phys. Lett. **B519** (2001) 199 [arXiv:hep-ph/0106202].

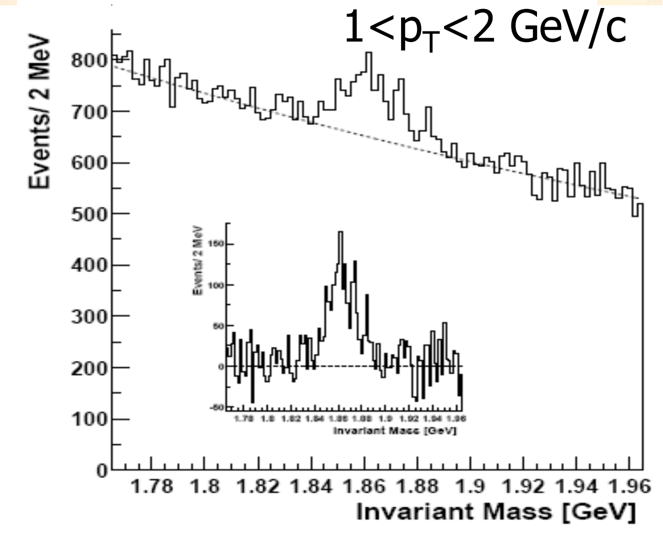
$D^0 \rightarrow K\pi$ channel

- **High precision vertexing, σ~100 μm (ITS)**
- **High precision tracking (ITS +TPC+TRD)**
- **K and/or π identification (TOF)**
- **Overall significance for 10^6 events ~10**



High precision open charm measurement



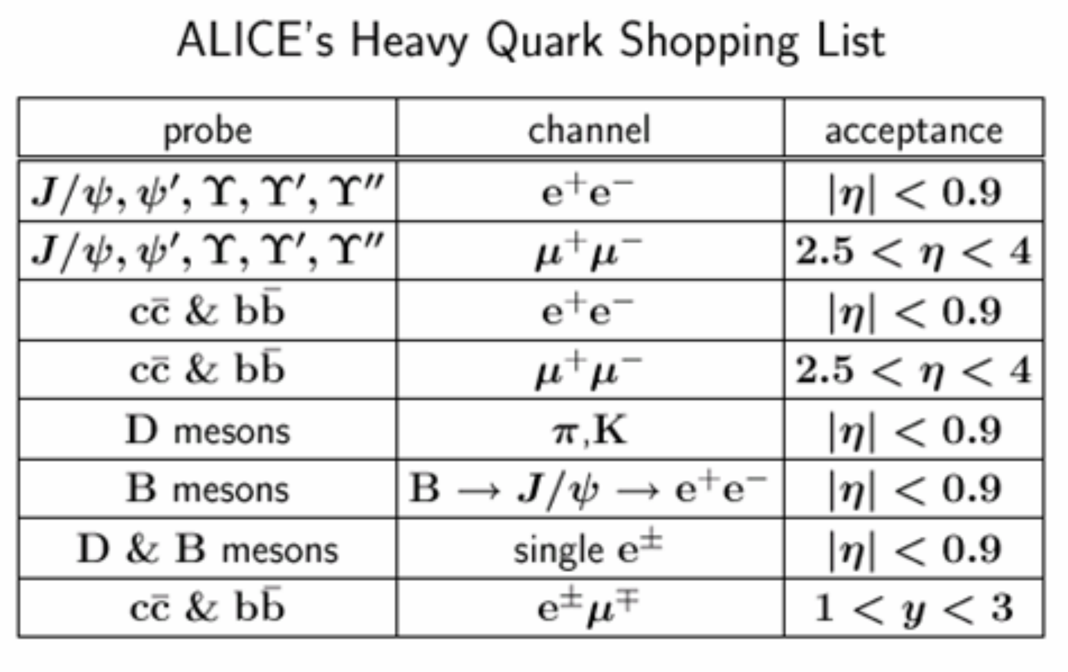


10 times lower statistics ~factor 3 in the significance, we can measure D^0 in the pilot run

Heavy-quarks and quarkonia

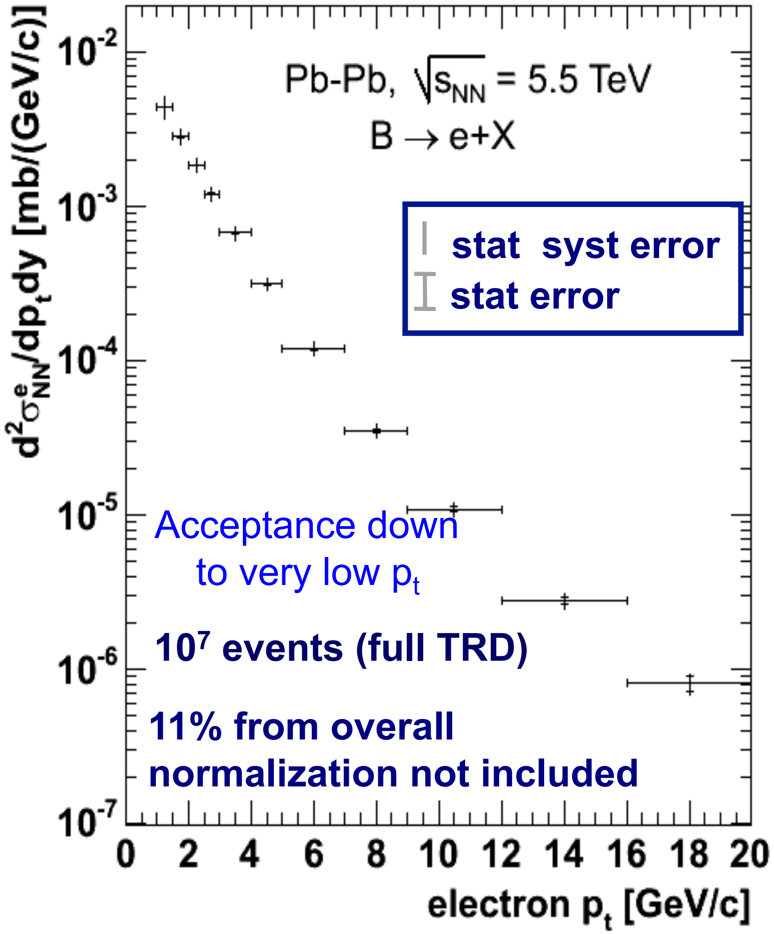
N($q\bar{q}$) per central PbPb collision

	SPS	RHIC	LHC
charm	0.2	10	200
bottom	-	0.05	6



ALICE's Heavy Quark Shopping List

probe	channel	acceptance
$J/\psi, \psi', \Upsilon, \Upsilon', \Upsilon''$	e^+e^-	$\|\eta\| < 0.9$
$J/\psi, \psi', \Upsilon, \Upsilon', \Upsilon''$	$\mu^+\mu^-$	$2.5 < \eta < 4$
$c\bar{c}$ & $b\bar{b}$	e^+e^-	$\|\eta\| < 0.9$
$c\bar{c}$ & $b\bar{b}$	$\mu^+\mu^-$	$2.5 < \eta < 4$
D mesons	π,K	$\|\eta\| < 0.9$
B mesons	$B \to J/\psi \to e^+e^-$	$\|\eta\| < 0.9$
D & B mesons	single $e^\pm$	$\|\eta\| < 0.9$
$c\bar{c}$ & $b\bar{b}$	$e^\pm\mu^\mp$	$1 < y < 3$



Acceptance down to very low p_t

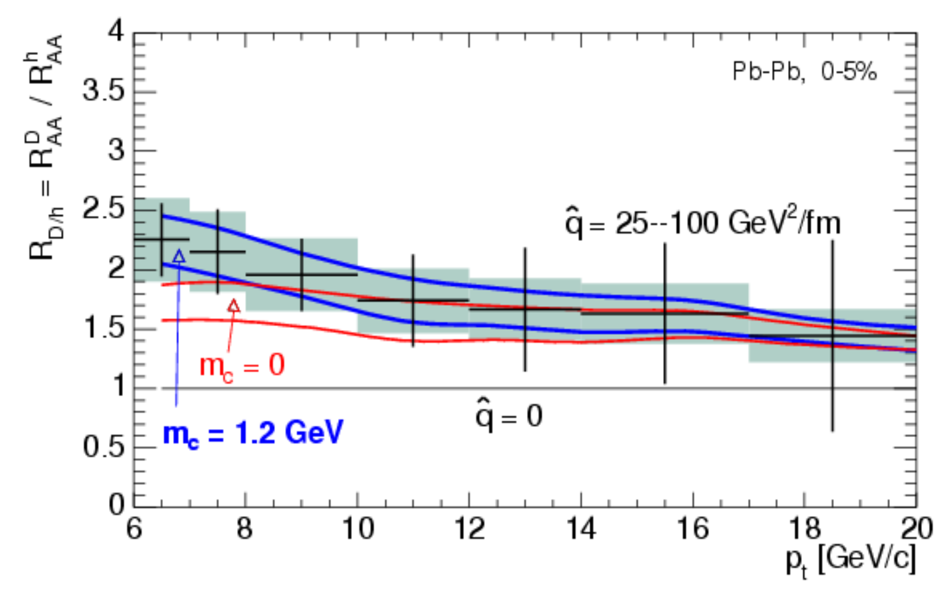
10^7 events (full TRD)

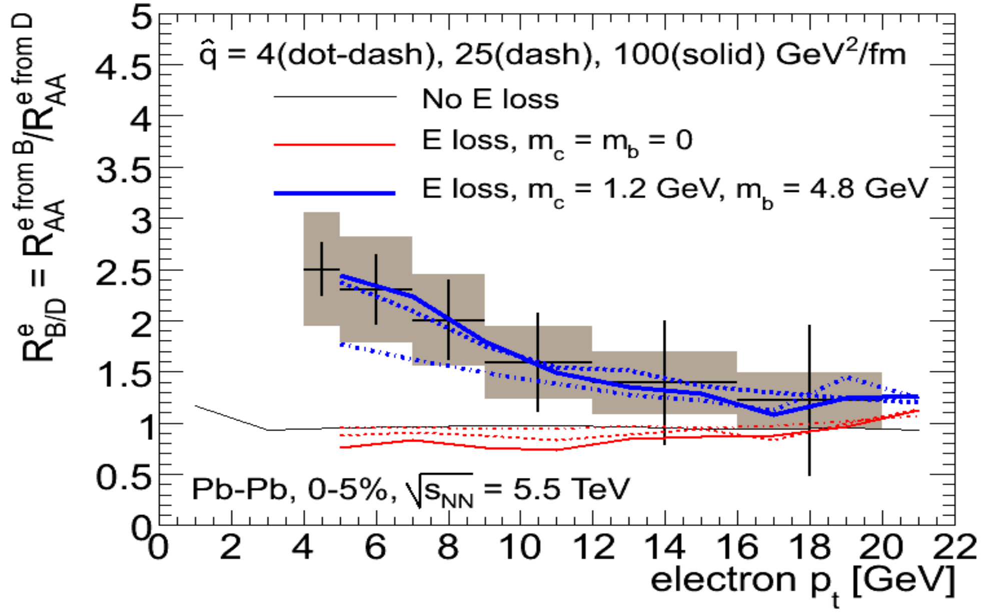
11% from overall normalization not included

Heavy-flavour quenching: R_{AA}

One year at nominal luminosity: 10^9 pp events; 10^7 central PbPb events

$$R_{D/h}(p_t) = R_{AA}^{D}(p_t) \Big/ R_{AA}^{h}(p_t) \qquad R_{B/D}(p_t) = R_{AA}^{\text{e from B}}(p_t) \Big/ R_{AA}^{\text{e from D}}(p_t)$$



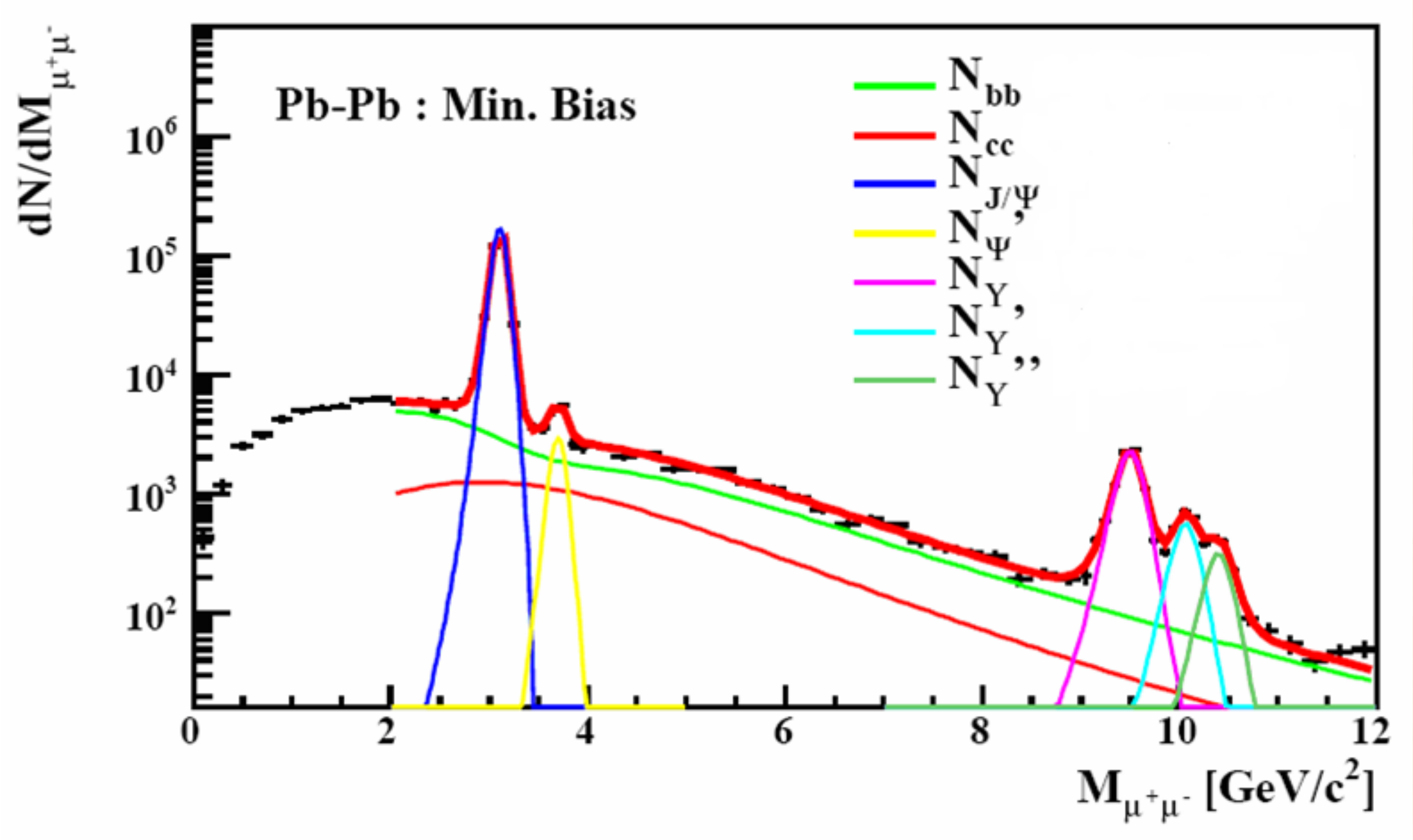


Probes colour charge dependence

Probes mass dependence

Di-muon mass spectrum

- One month (10^6 sec) Pb-Pb collisions at nominal luminosity
- Adequate statistics to study Y- family and quench-scenarios



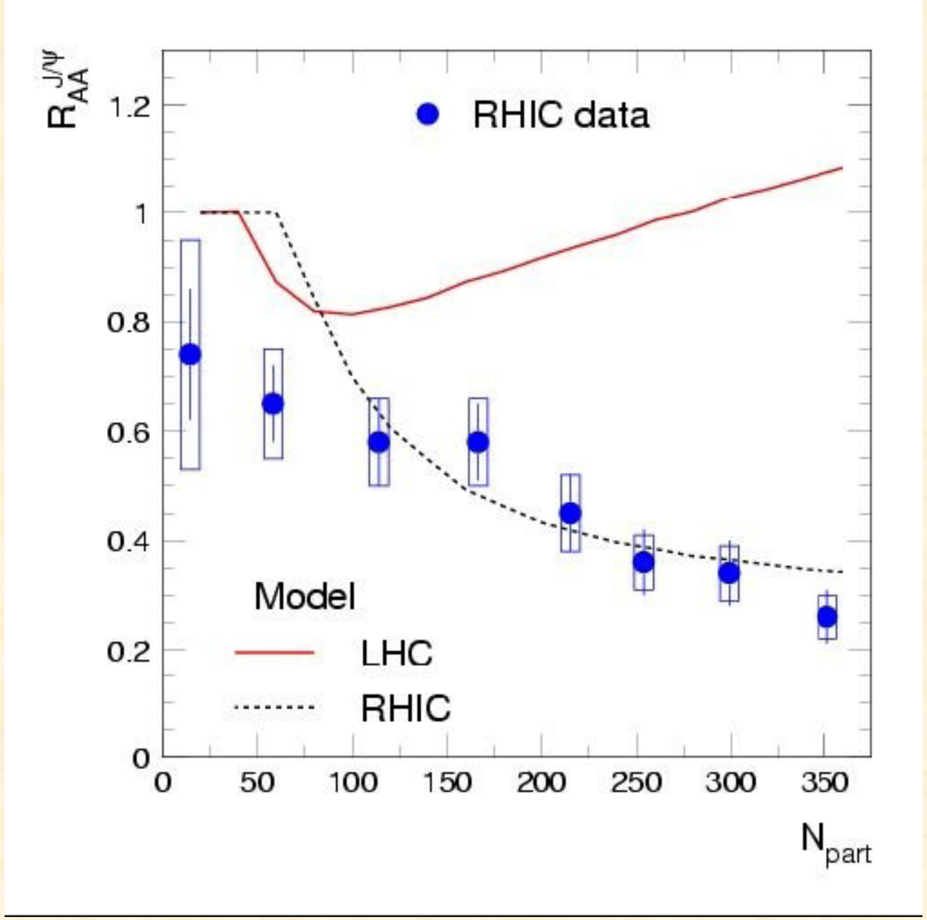
J/Ψ ~ $3*10^5$

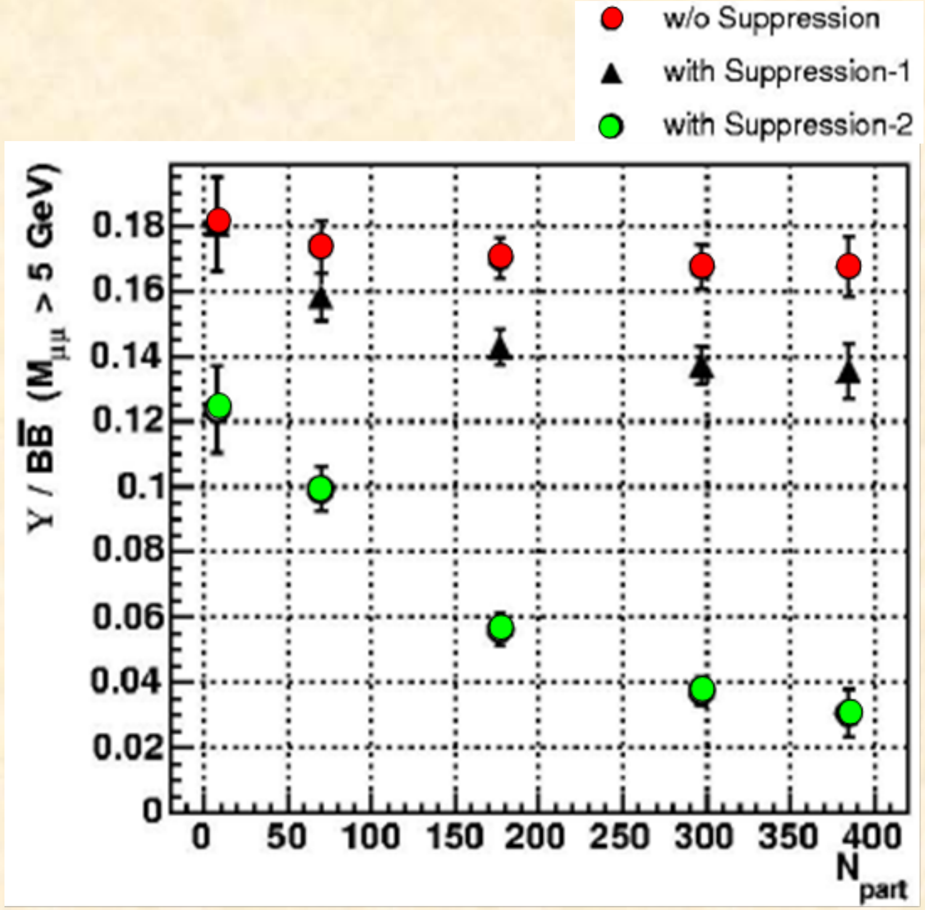
Y ~ 8000

Quarkonia production

- J/Ψ ~ 3*10^5
- Suppression vs recombination

study suppression scenarios
Υ ~ 8000



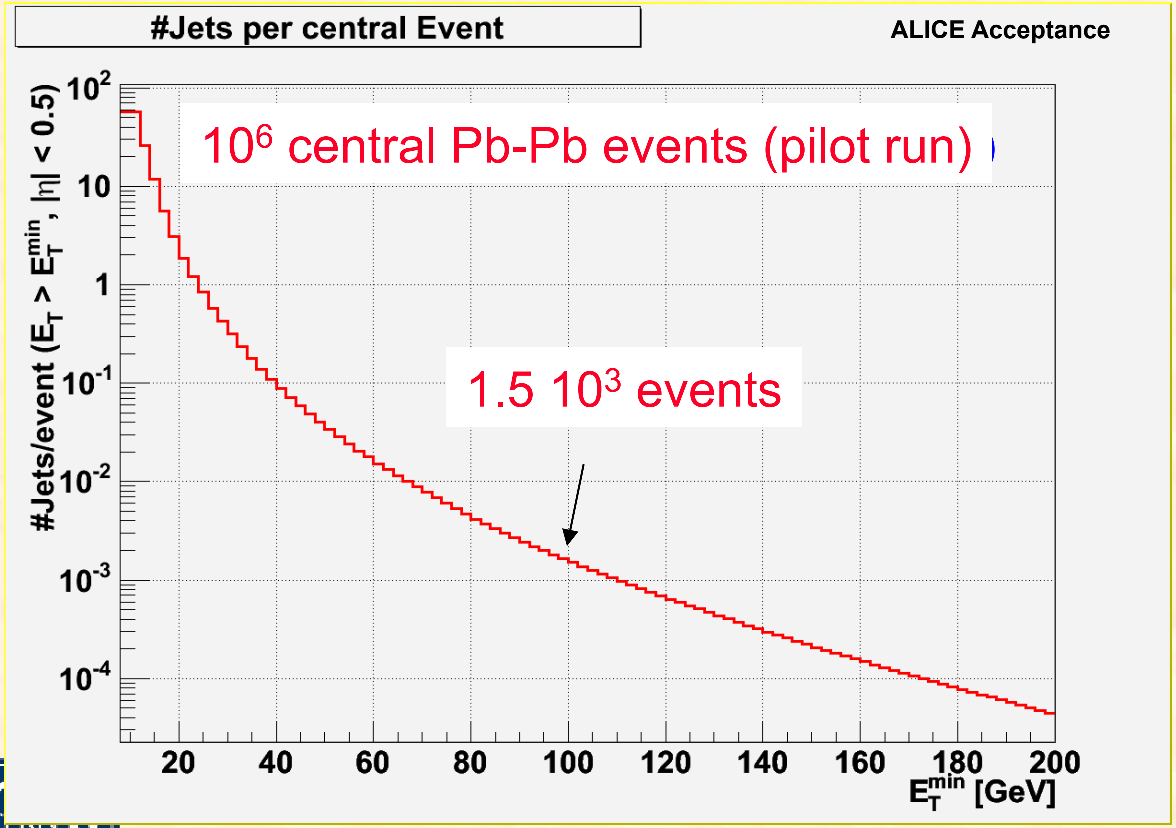


Jet statistics in pilot Pb run

Jets are produced copiously

2 20 100 200 p_t (GeV)

100/event 1/event 10^3 in first 10^6 Pb-Pb events


#Jets per central Event

ALICE Acceptance

10^6 central Pb-Pb events (pilot run)

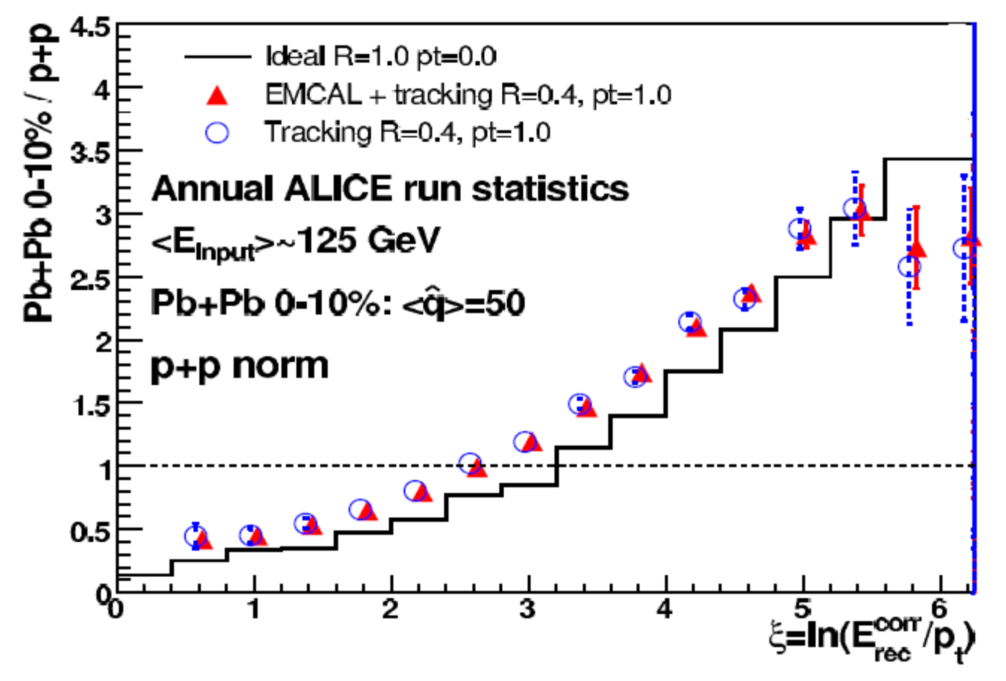
1.5 10^3 events

10^6 central PbPb collisions

E_T threshold	N_{jets}
50 GeV	5×10^4
100 GeV	1.5×10^3
150 GeV	300
200 GeV	50

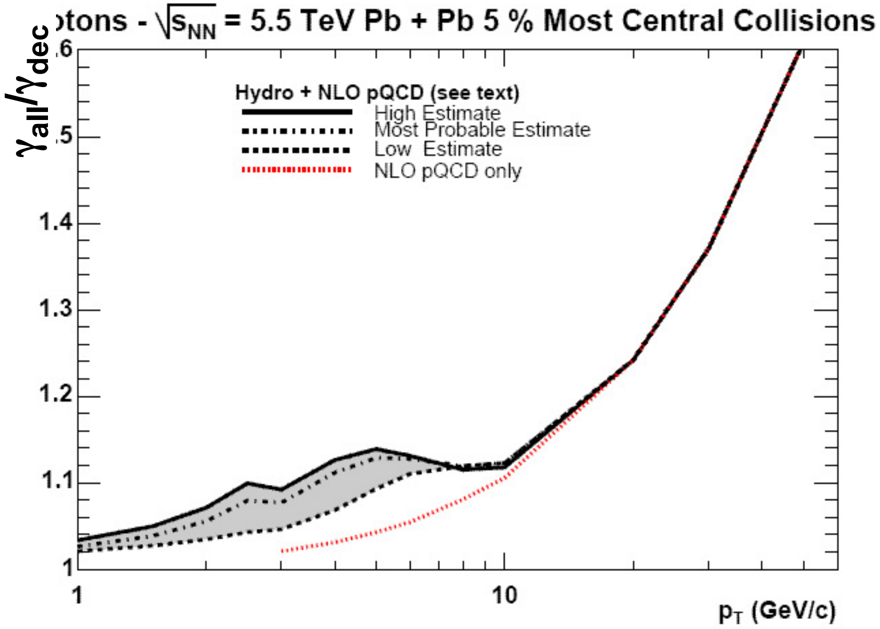
Jet Production at LHC

- Initial measurements up to 100 GeV (untriggered charged jets only)
- Detailed study of fragmentation possible
- Sensitive to energy loss mechanism
- Accuracy on transport coefficient < $\hat{q}$ > ~20%

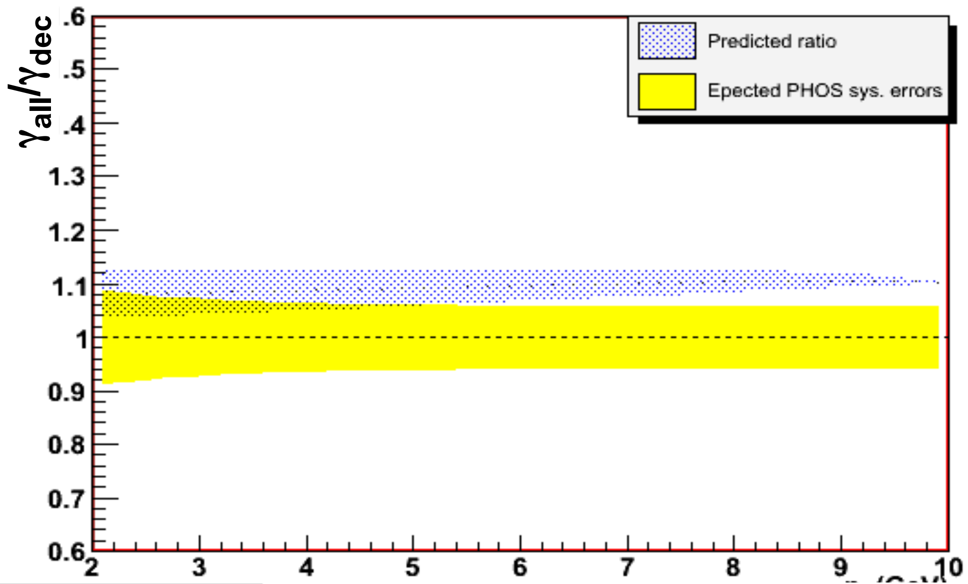


p_t jet > (GeV/c)	jets/event Pb+Pb	accepted jets/ month
5	3.5 10^2	4.9 10^{10}
50	7.7 10^{-2}	1.5 10^7
100	3.5 10^{-3}	8.1 10^5
150	4.8 10^{-4}	1.2 10^5
200	1.1 10^{-4}	2.8 10^4

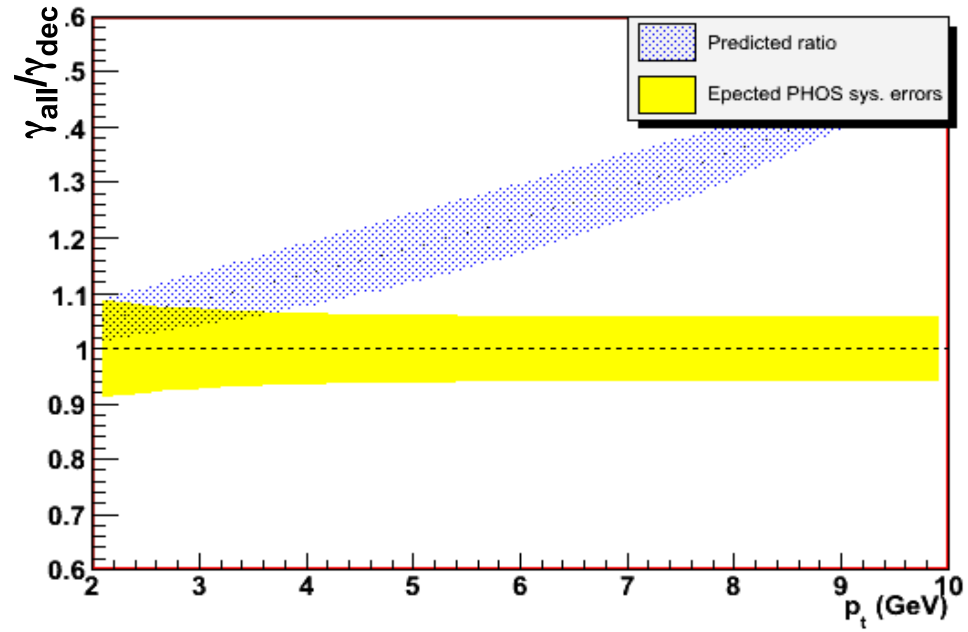
Thermal and hard photons



Without quenching



With quenching

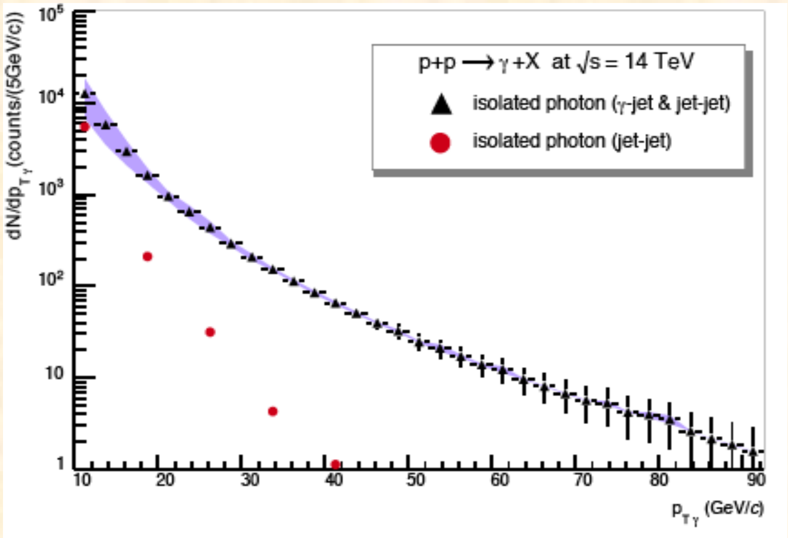


ALICE sensitivity to thermal radiation without and with quenching of the away jet, measured relative to all Gammas (basically gammas from π^0)

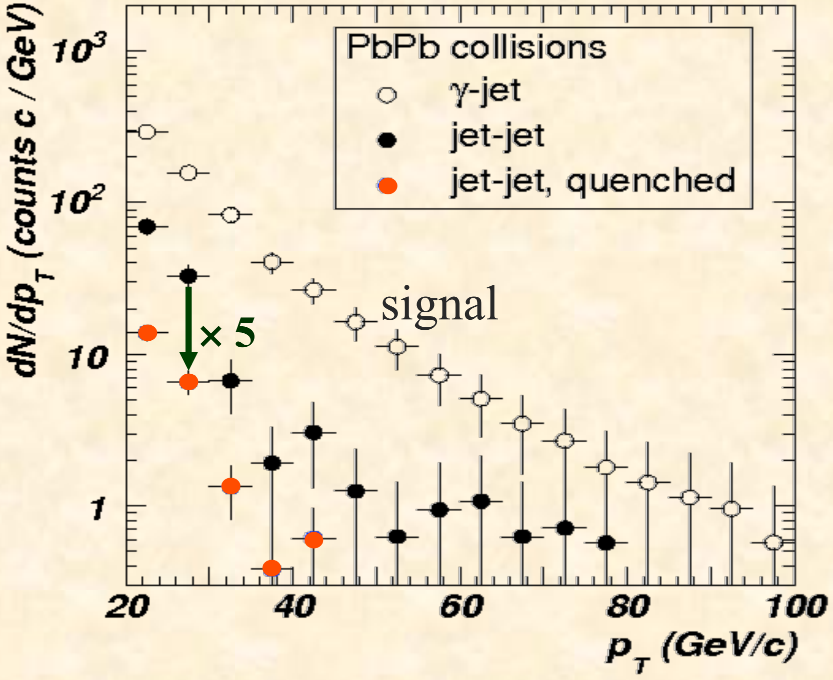
Thermal photons above 3- 4 GeV expected to be measurable

Identifying prompt γ in ALICE

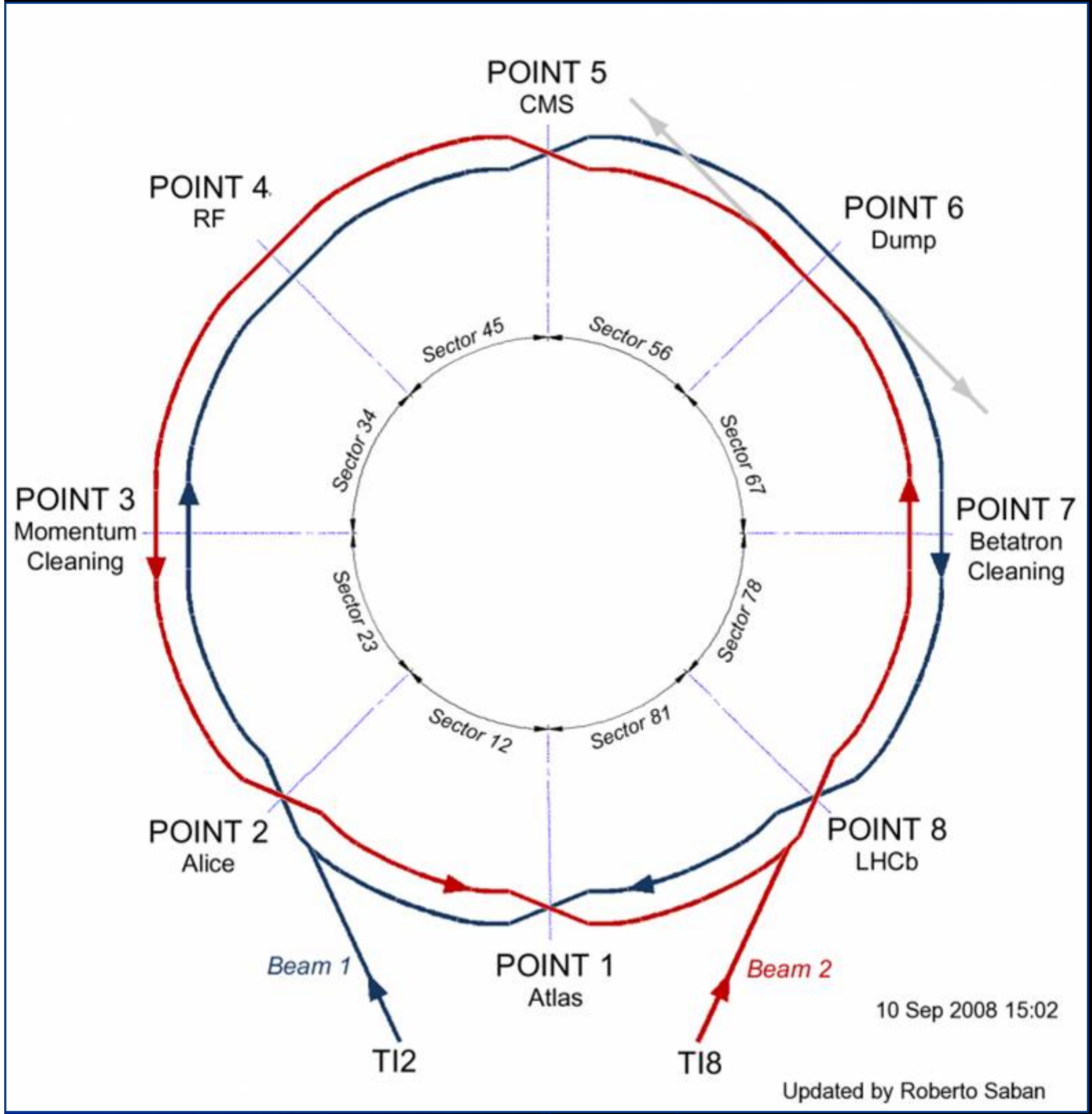
- **pp**
  - ⇨ **R = 0.3, Σp_T < 2 GeV/c**
  - ⇨ **Efficiency: 69%**
  - ⇨ **Background rejection: 1/170**
  - ⇨ **First year (10 pb^{-1})**
    - ✪ **3000 γ (E_γ > 20 GeV)**



- **PbPb**
  - ⇨ **R = 0.2, p_T^{thresh} = 2 GeV/c**
  - ⇨ **Efficiency: 50%**
  - ⇨ **Background rejection: 1/14**
  - ⇨ **One month of running**
    - ✪ **2000 γ (E_γ > 20 GeV)**
    - ✪ **Increases to 40 GeV with EMCal**



Particles in the LHC

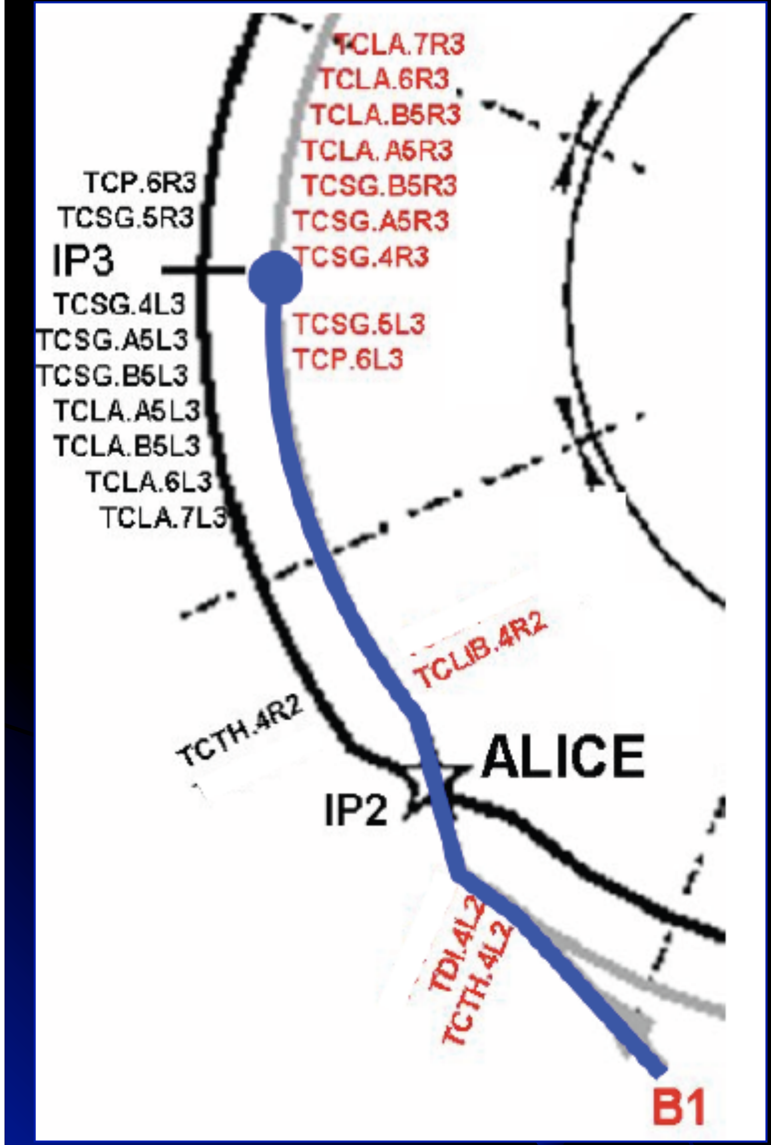


10 Sep 2008 15:02

Updated by Roberto Saban

- first signs of life…
  - 14-15 June
  - extraction in TI2 and dump
- injection tests
  1) 8-11 August
     - first injection in LHC (beam 1)
  2) 22-24 August
     - first injection of beam 2
  3) 5-7 September
- circulating beams
  - 10 September

08.08.08: First Injection in LHC !

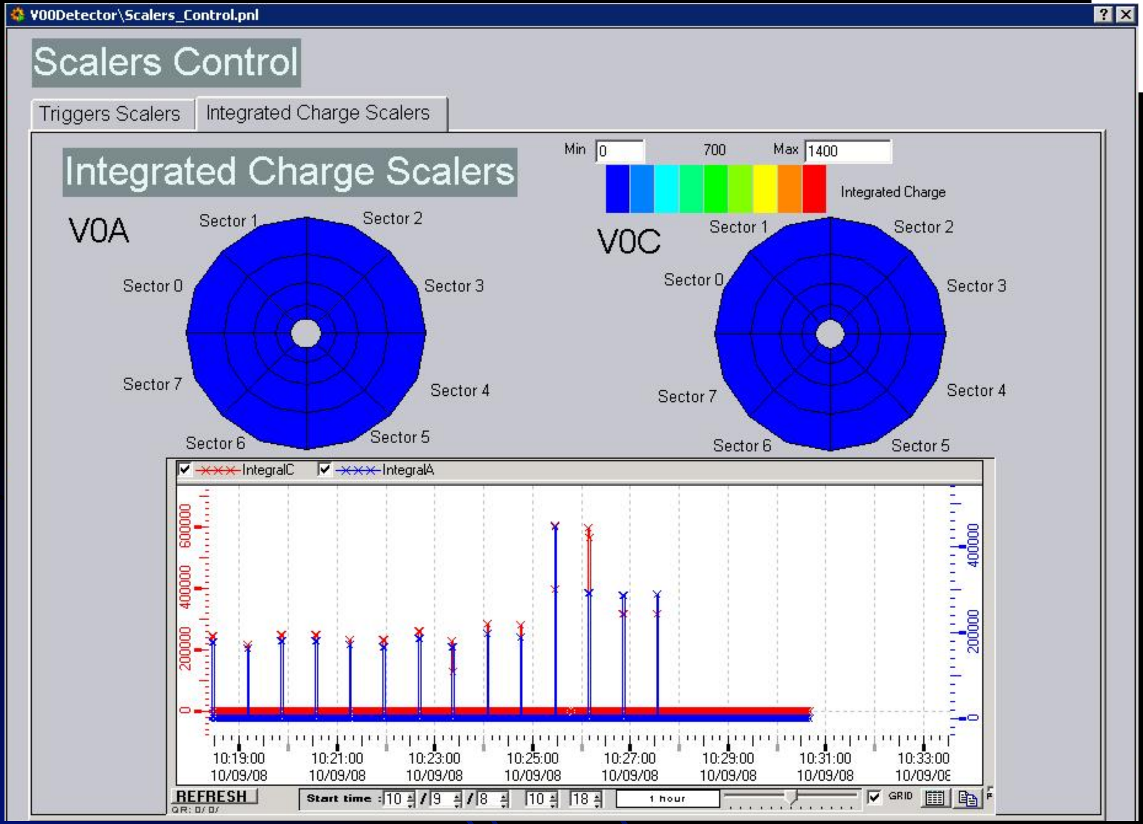


同一个世界 同一个梦想

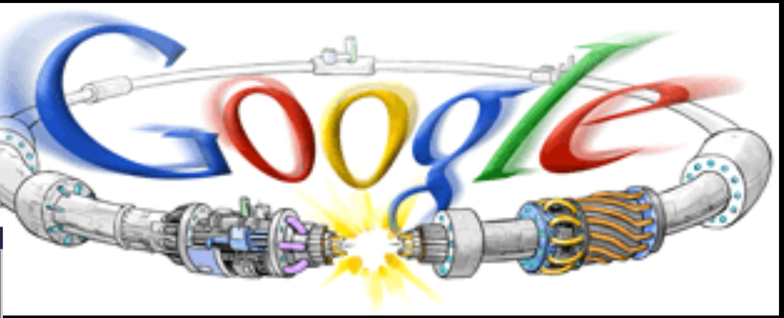
One World One Dream

10 September: circulating beams!

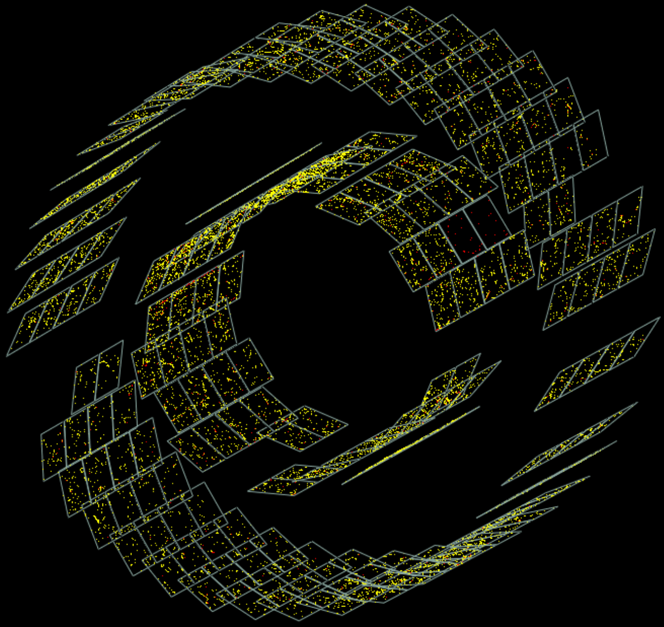
- beam 1: 1st complete orbit ~ 10:30



- beam 2: 1st complete orbit ~ 15:00



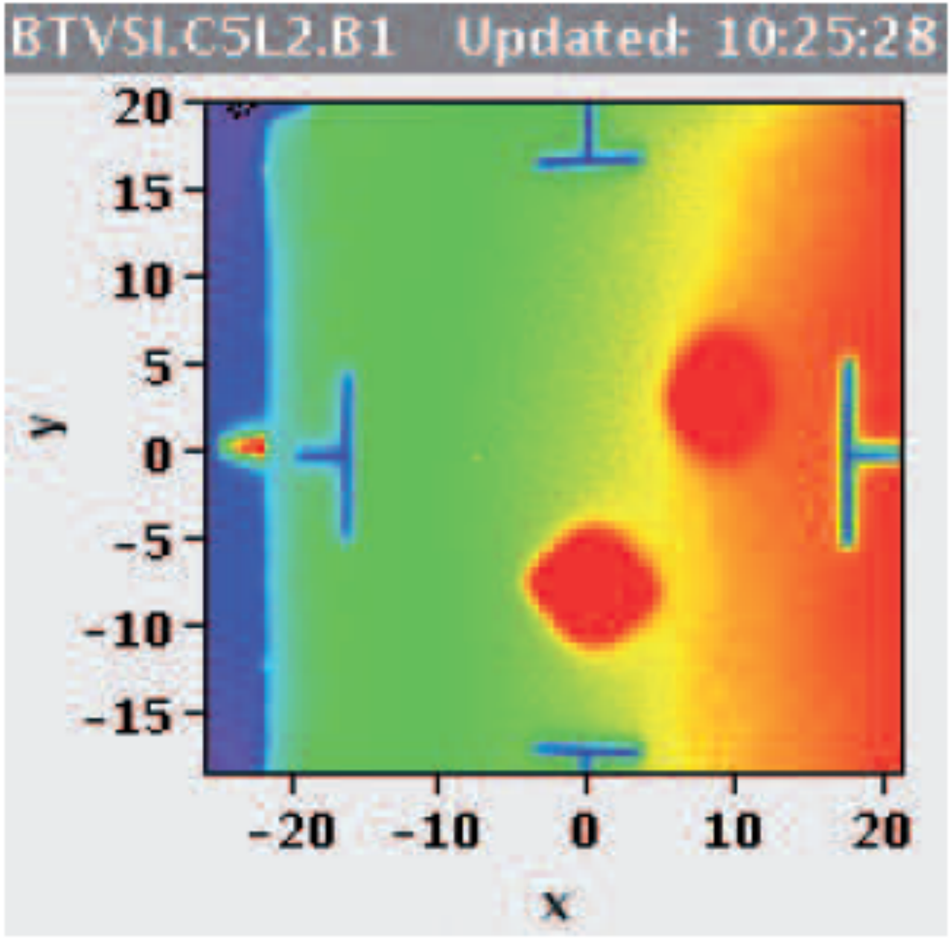
- first signals from ALICE

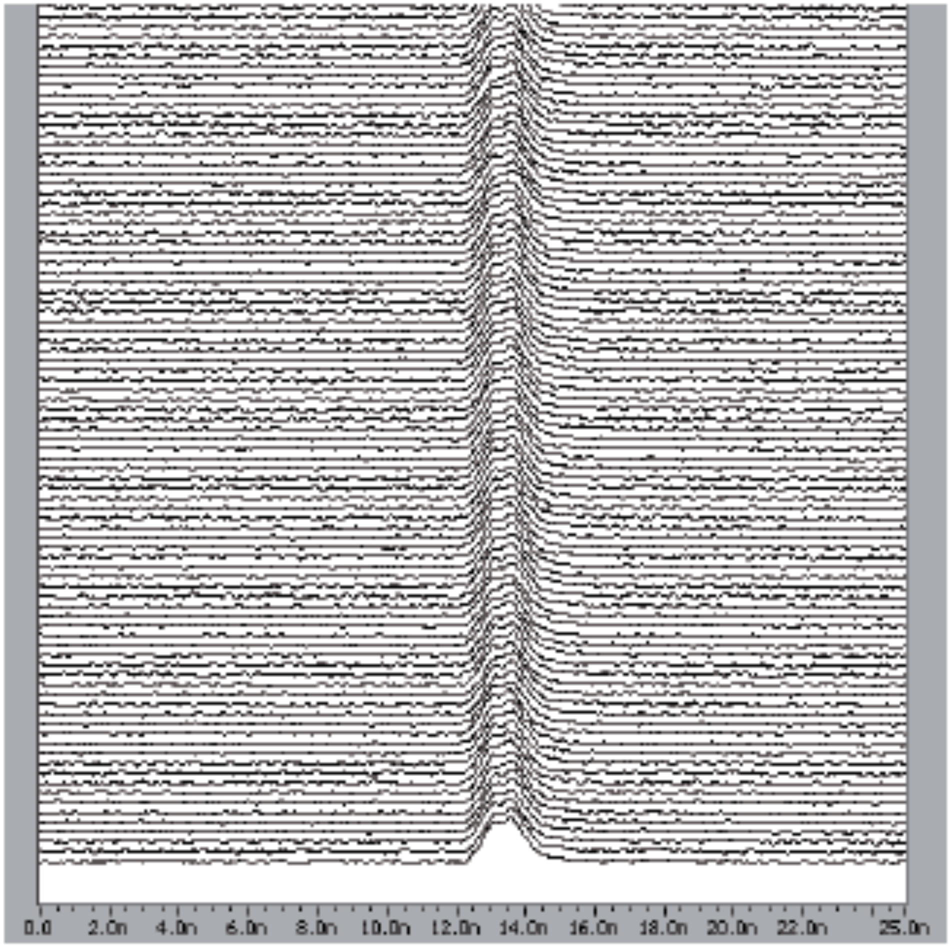


LHC operation 10 – 11 September

First orbit

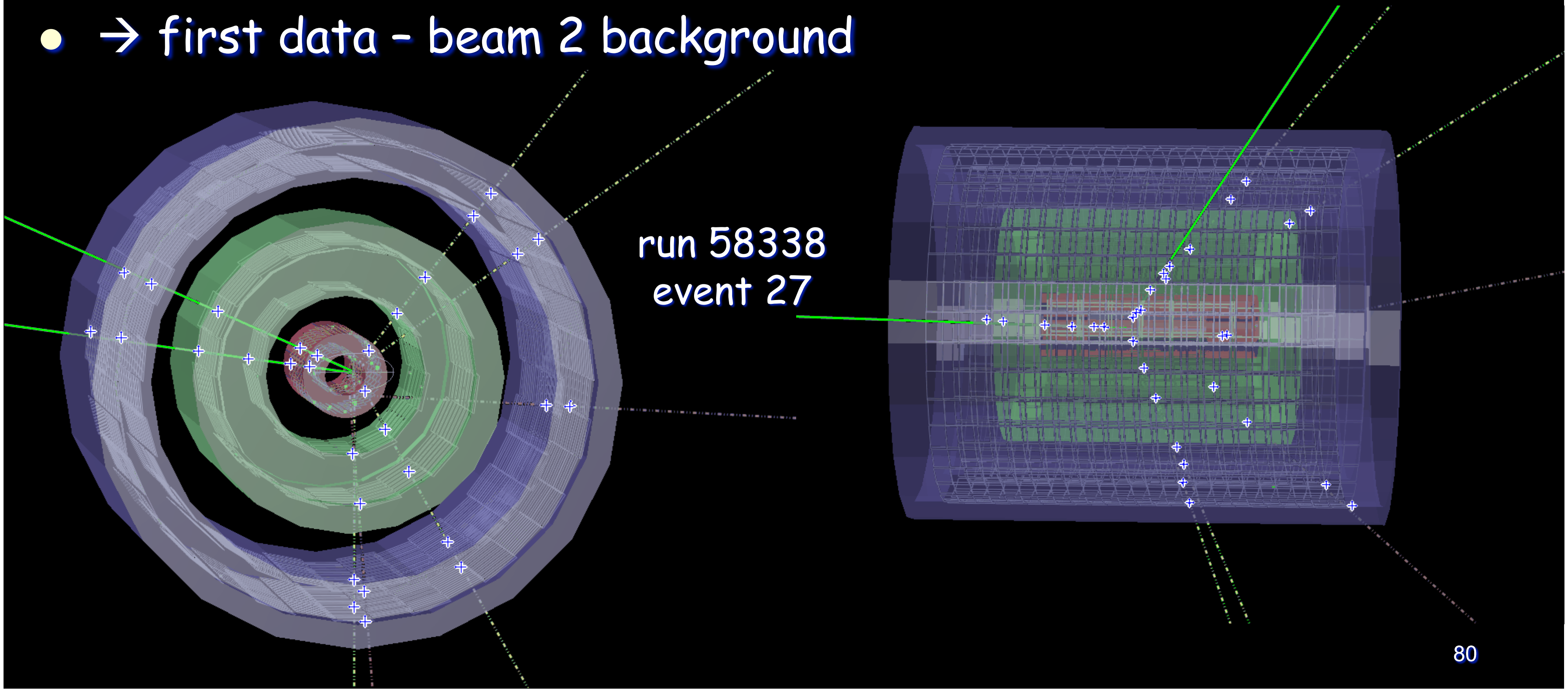
RF capture



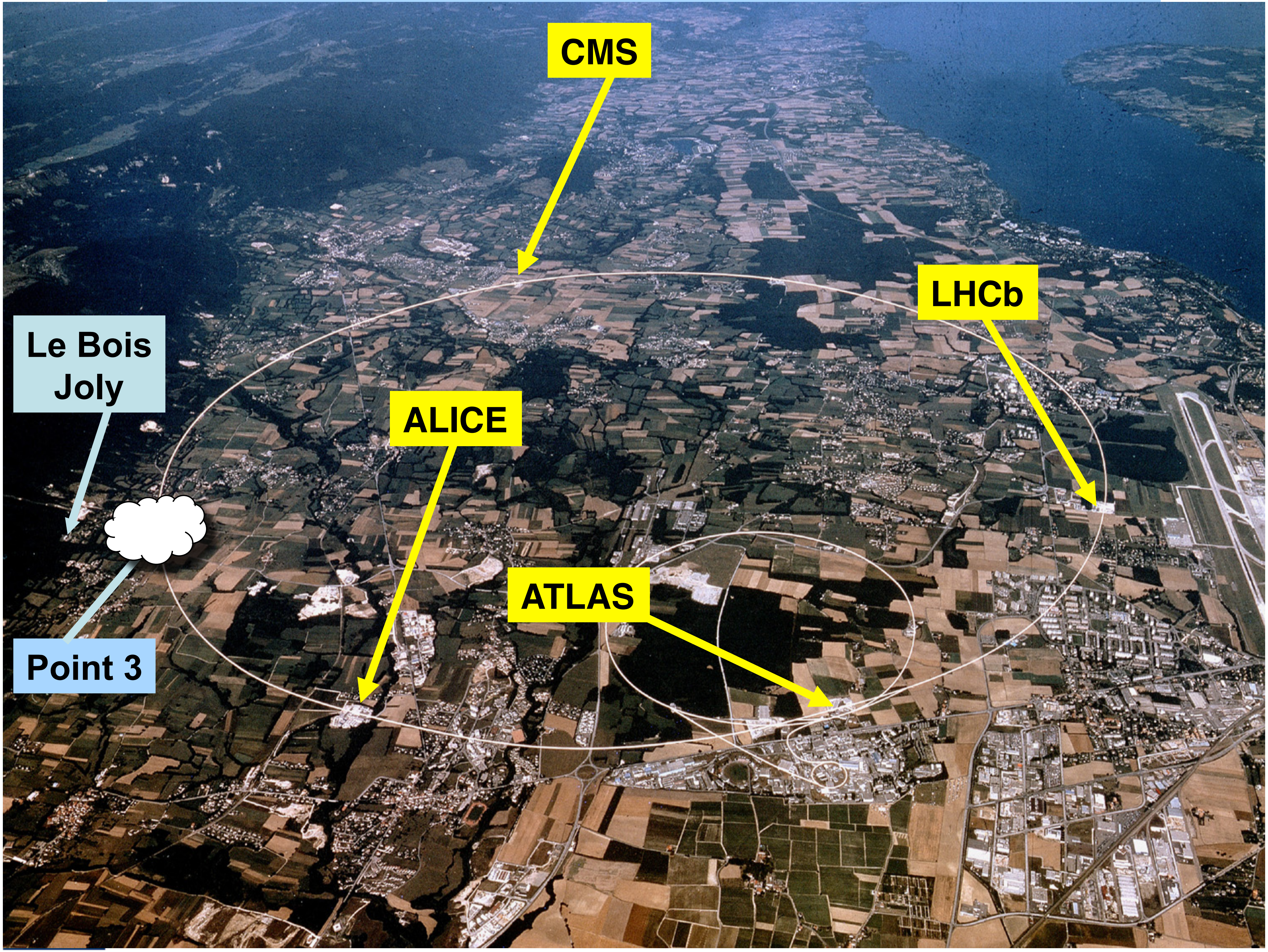


11 September: RF capture (beam bkg data)

- 11 September, ~ 22:35 first capture
  - beam 2 kept in orbit for over 10 minutes!
- series of injections with tens of mins RF capture during night
  - in ALICE: 673 events in total
- → first data – beam 2 background

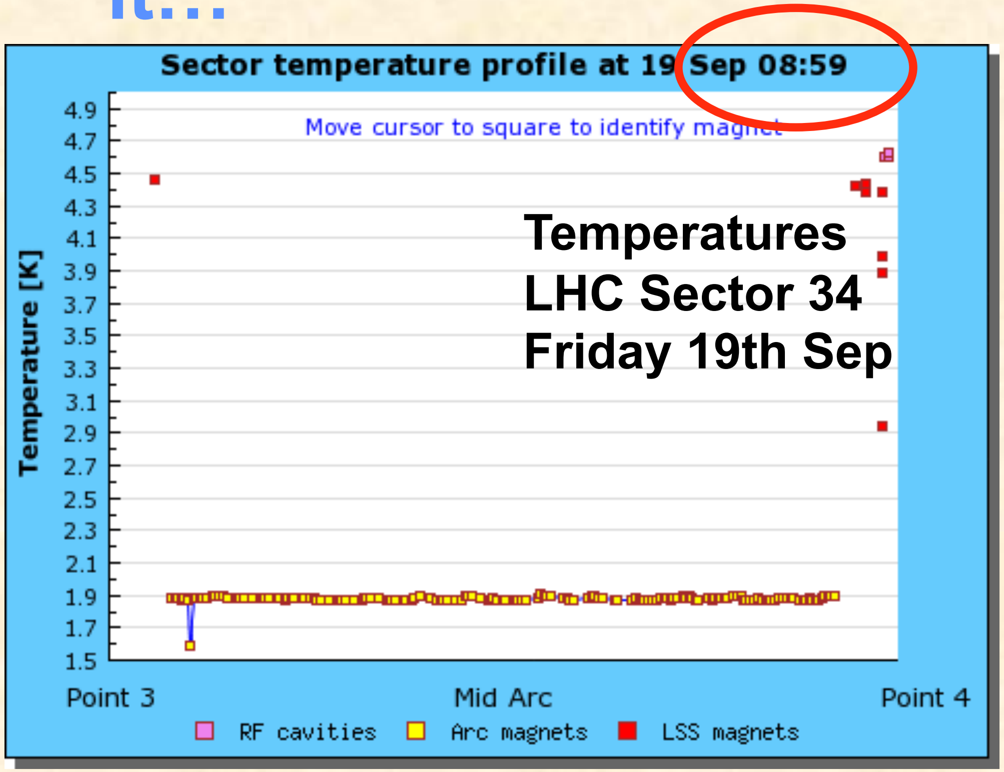


run 58338
event 27


CMS
LHCb
Le Bois Joly
ALICE
ATLAS
Point 3

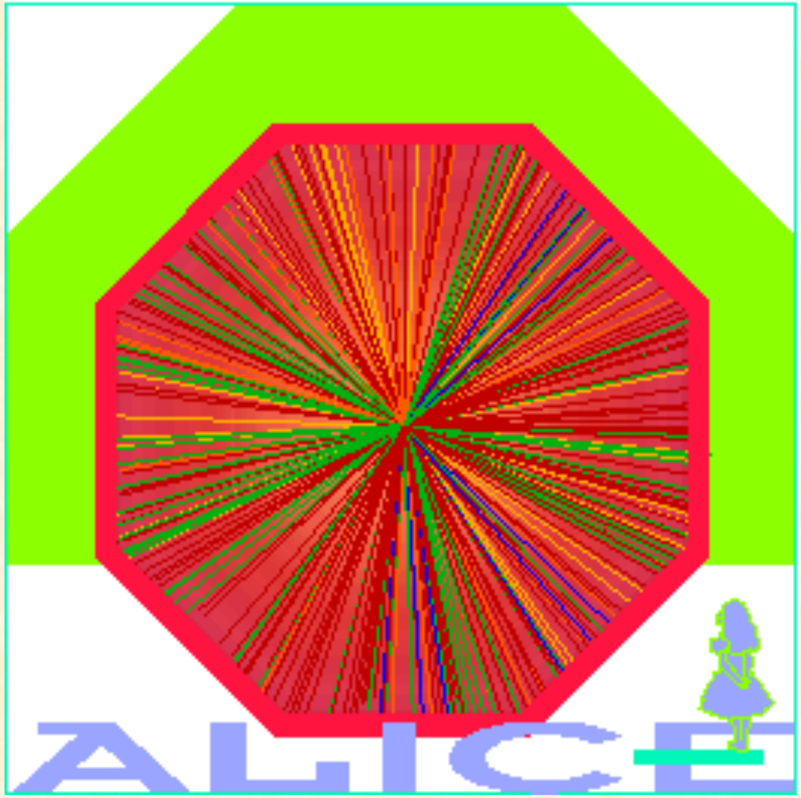
Fate of 2008 physics at LHC

- …and we were 5’ from it…


Sector temperature profile at 19 Sep 08:59

Move cursor to square to identify magnet

Temperatures
LHC Sector 34
Friday 19th Sep



Jan Fiete Grosse-Oetringhaus

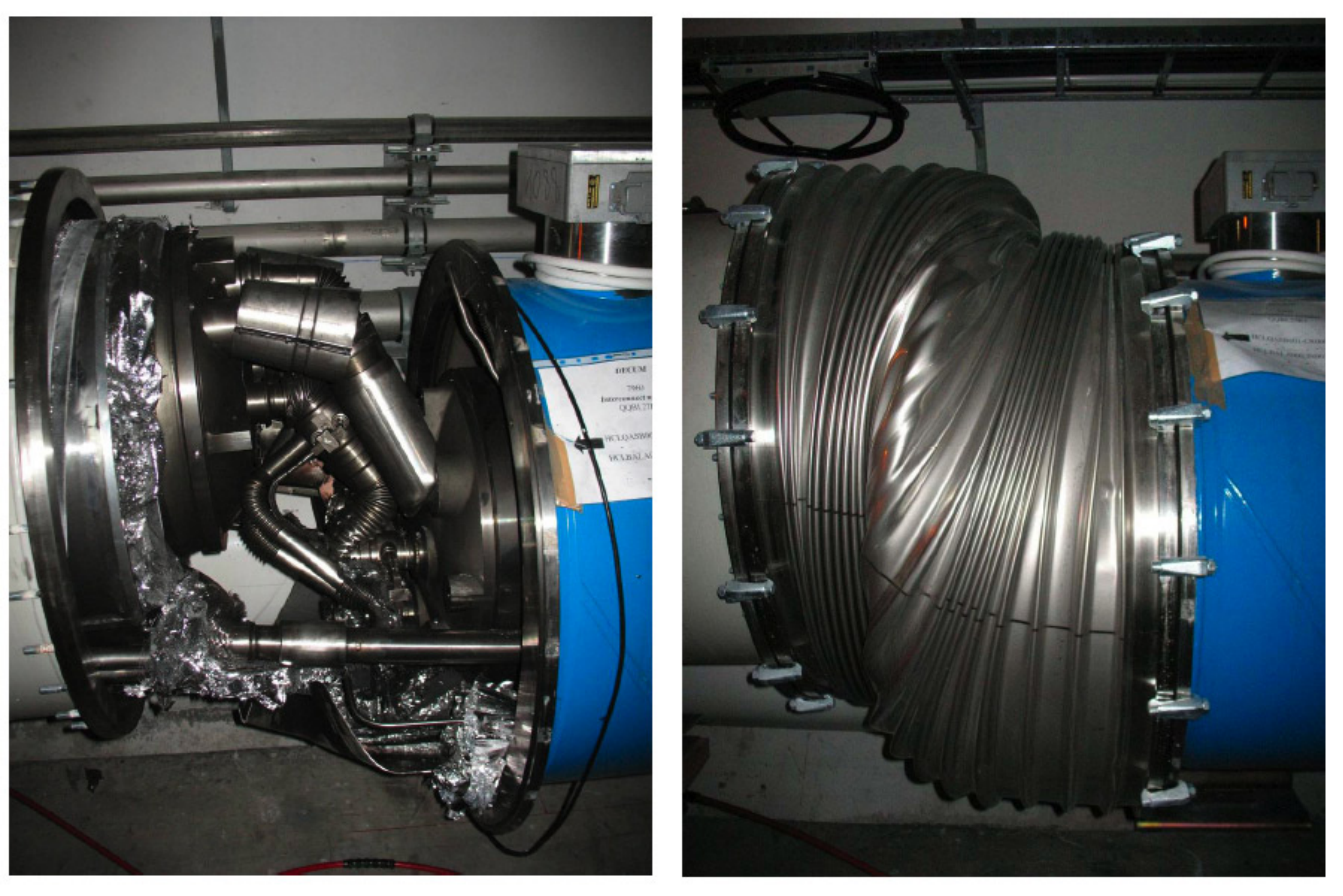
So: what happened on 19 Sept?

- 19 September, ~ 11:30: large helium leak in sector 34
  - helium escaped in the tunnel
  - insulation vacuum broken
  - beam vacuum broken (up to sector valves)

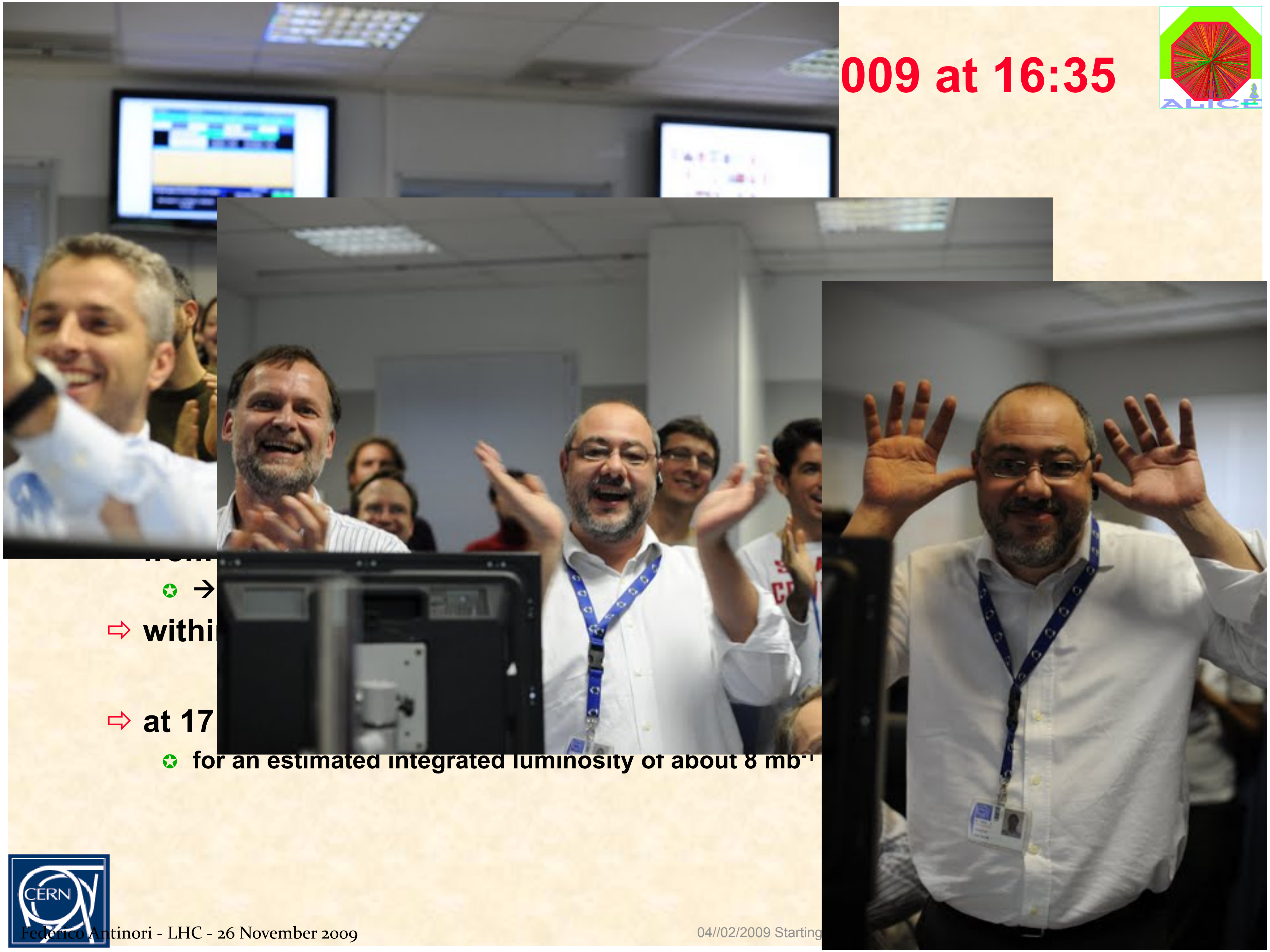
- confirmed: due to electrical fault
  - resistive splice in interconnect

- magnets in sector 34 were being commissioned to 5 TeV (10kA)
  - at 450 GeV (1kA) worked well
  - incident occurred at ~9kA
  - all other (7) sectors had been commissioned to 5 TeV (and above) without problems

Dipole – quadruple interconnection



009 at 16:35



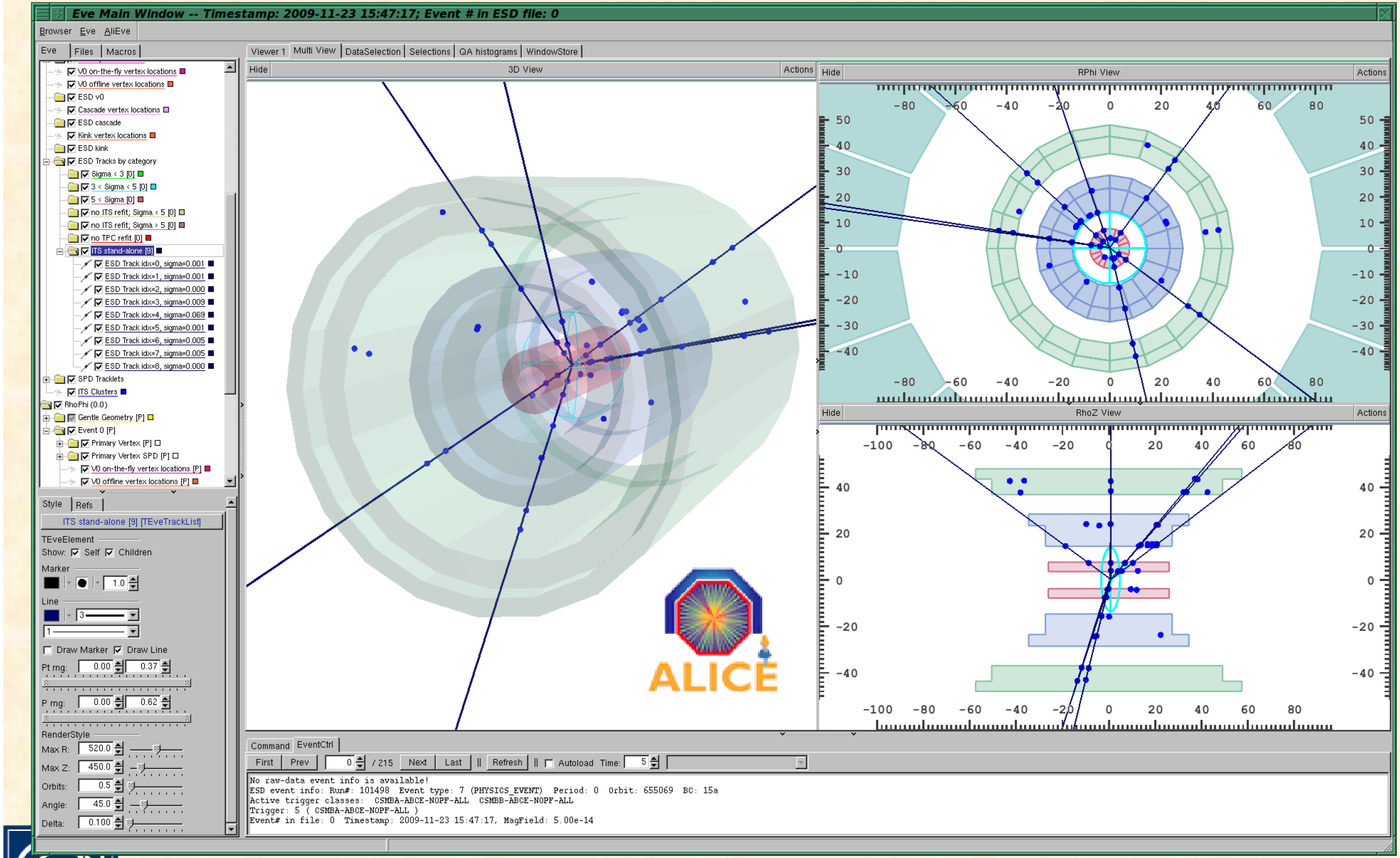
- ✪ →

⇨ withi

⇨ at 17

- ✪ for an estimated integrated luminosity of about 8 mb^{-1}

The first event



TEveElement
Show: ☑ Self ☑ Children
Marker 1.0
Line 3 1
☐ Draw Marker ☑ Draw Line
Pt rng: 0.00 0.37
P rng: 0.00 0.62
RenderStyle
Max R: 520.0
Max Z: 450.0
Orbits: 0.5
Angle: 45.0
Delta: 0.100

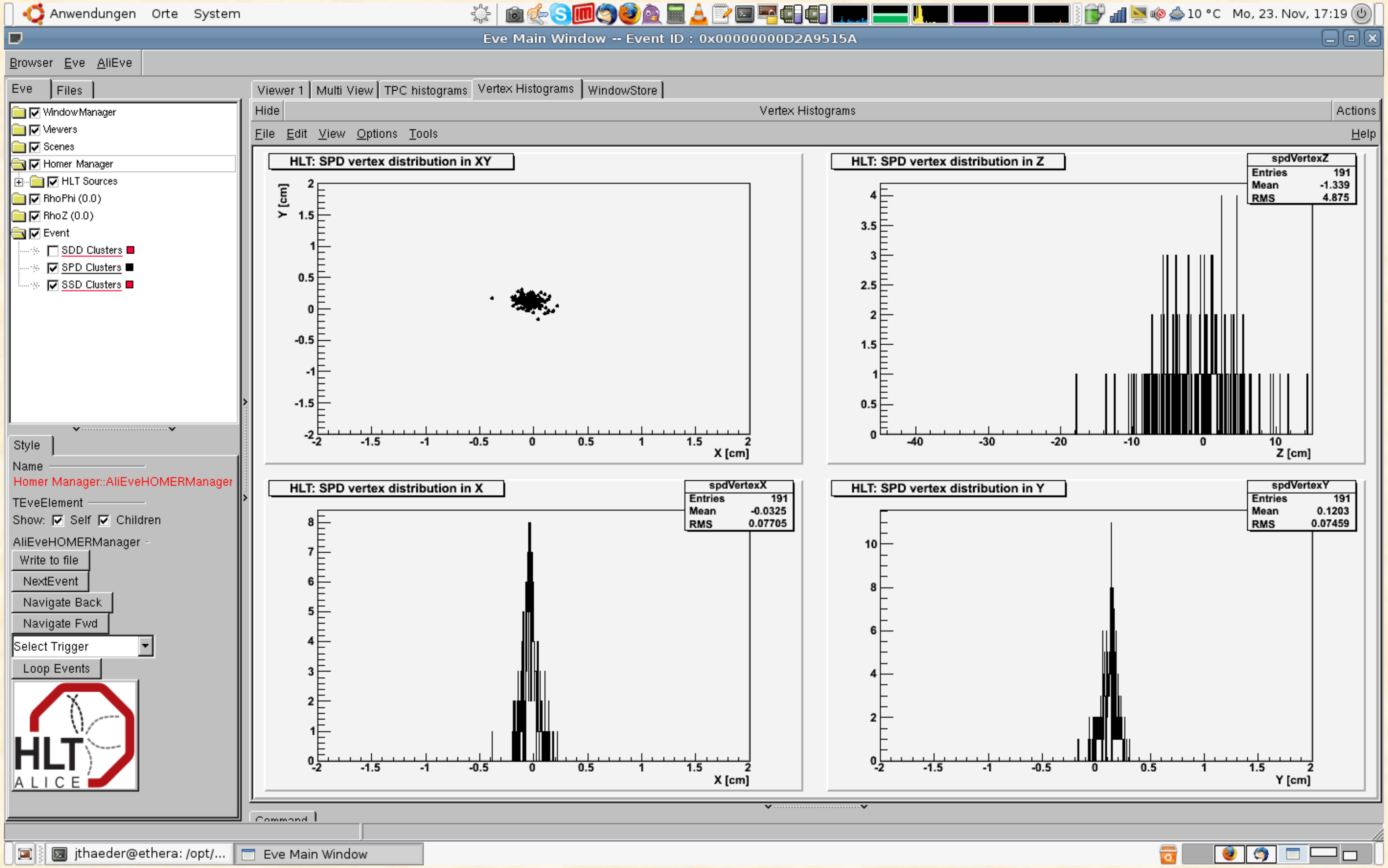
Event: 0 / 215 ☐ Autoload Time: 5

```
No raw-data event info is available!
ESD event info: Run#: 101498  Event type: 7 (PHYSICS_EVENT)  Period: 0  Orbit: 655069  BC: 15a
Active trigger classes:  CSMBA-ABCE-NOPF-ALL  CSMBB-ABCE-NOPF-ALL
Trigger: 5 ( CSMBA-ABCE-NOPF-ALL )
Event# in file: 0  Timestamp: 2009-11-23 15:47:17, MagField: 5.00e-14
```

86

Vertex distribution – online

- **Calculated by High Level Trigger from tracklets in Silicon Pixel Detector**



spdVertexZ	
Entries	191
Mean	-1.339
RMS	4.875

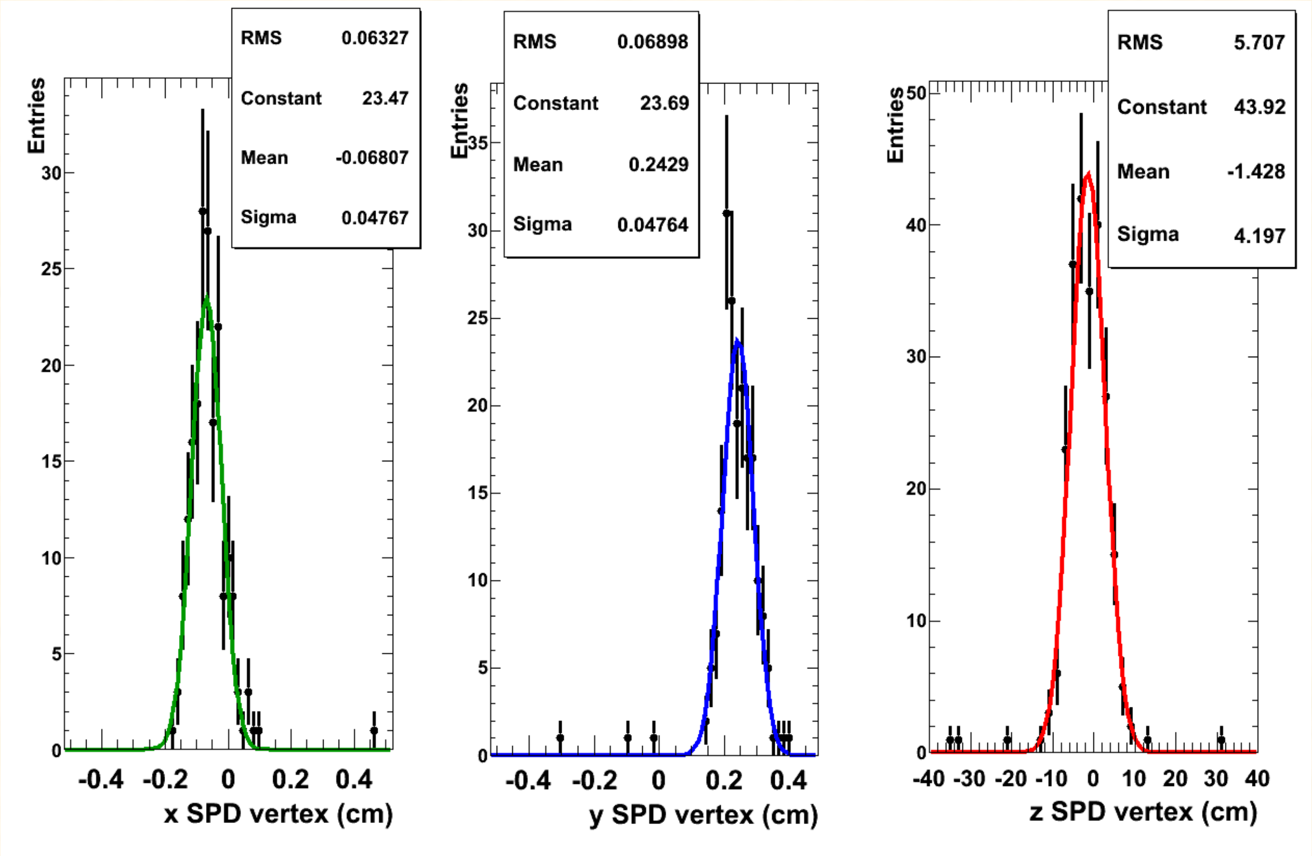
spdVertexX	
Entries	191
Mean	-0.0325
RMS	0.07705

spdVertexY	
Entries	191
Mean	0.1203
RMS	0.07459

87

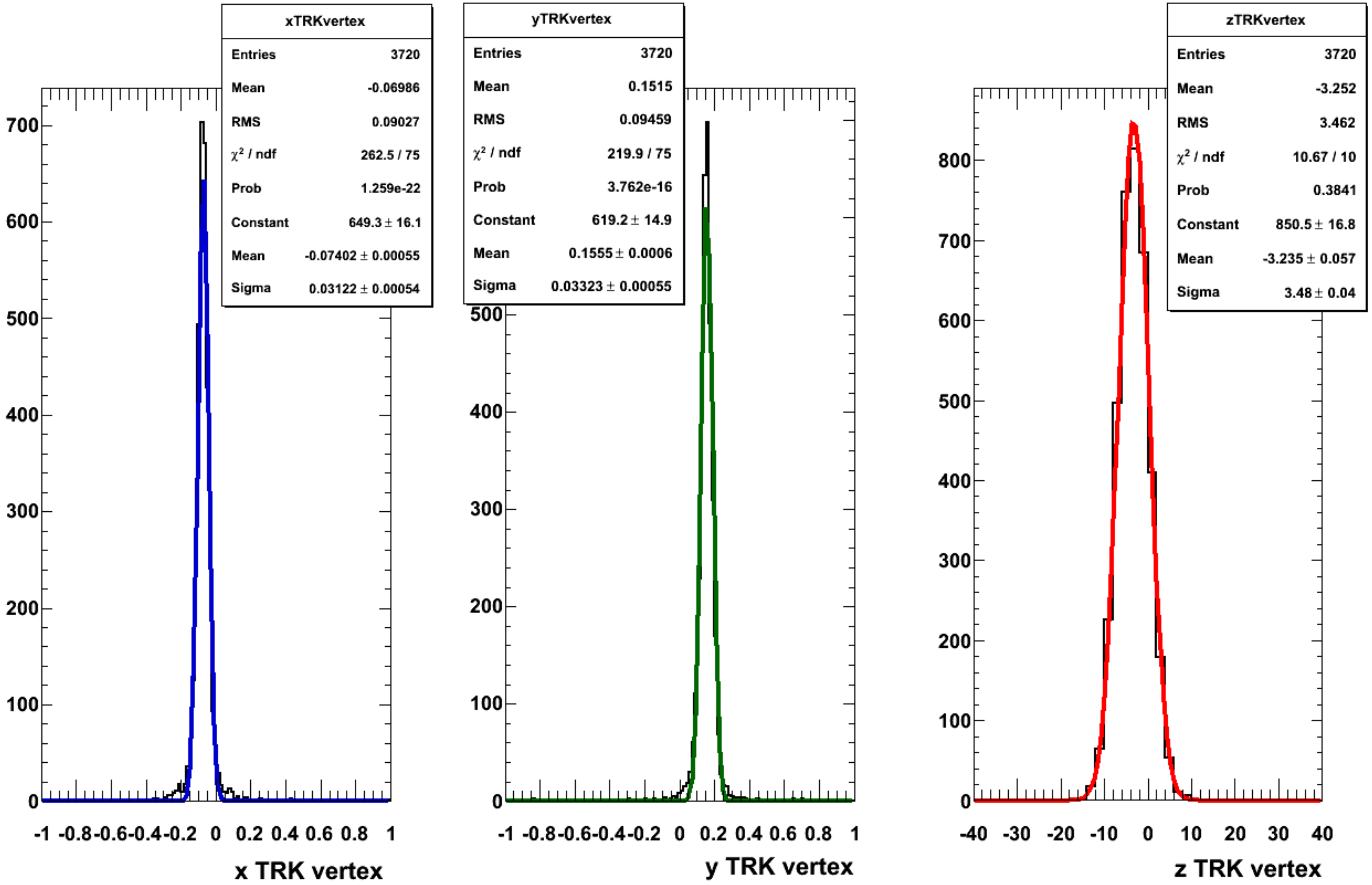
Vertex distribution – offline

- **Calculated in Offline from tracklets in Silicon Pixel Detector:**



$\sigma_x \sim 475\ \mu m$ $\sigma_y \sim 475\ \mu m$ $\sigma_z \sim 4.2$ cm

Vertex from last weekend



X: mean - 740 µm
sigma 312 µm

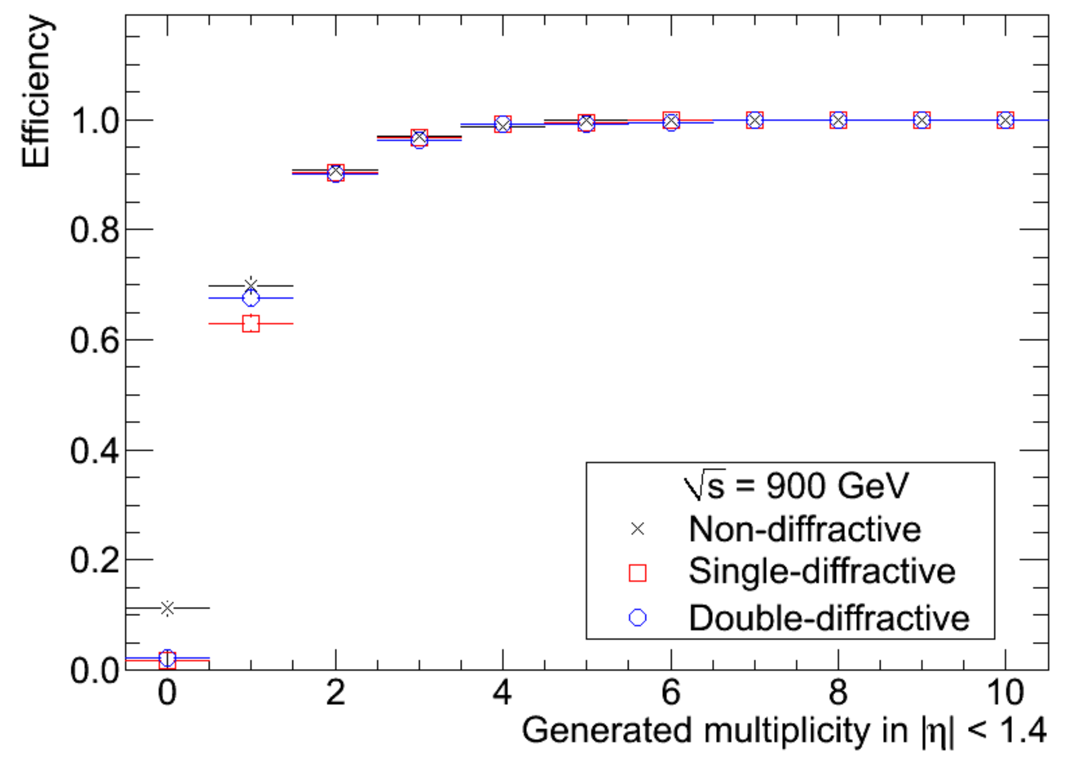
Y: mean + 0.16 cm
sigma 332 µm

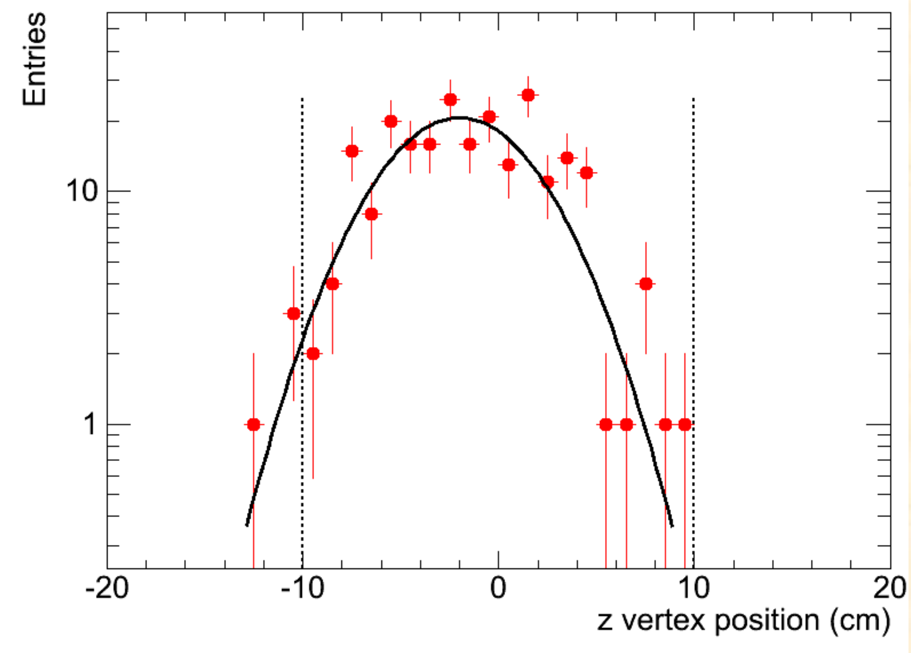
Z: mean - 3.2 cm
sigma 3.5 cm

First measurement

- Charged particle pseudorapidity density in pp at 900 GeV
- Using the tracklets reconstructed in Silicon Pixel Detector

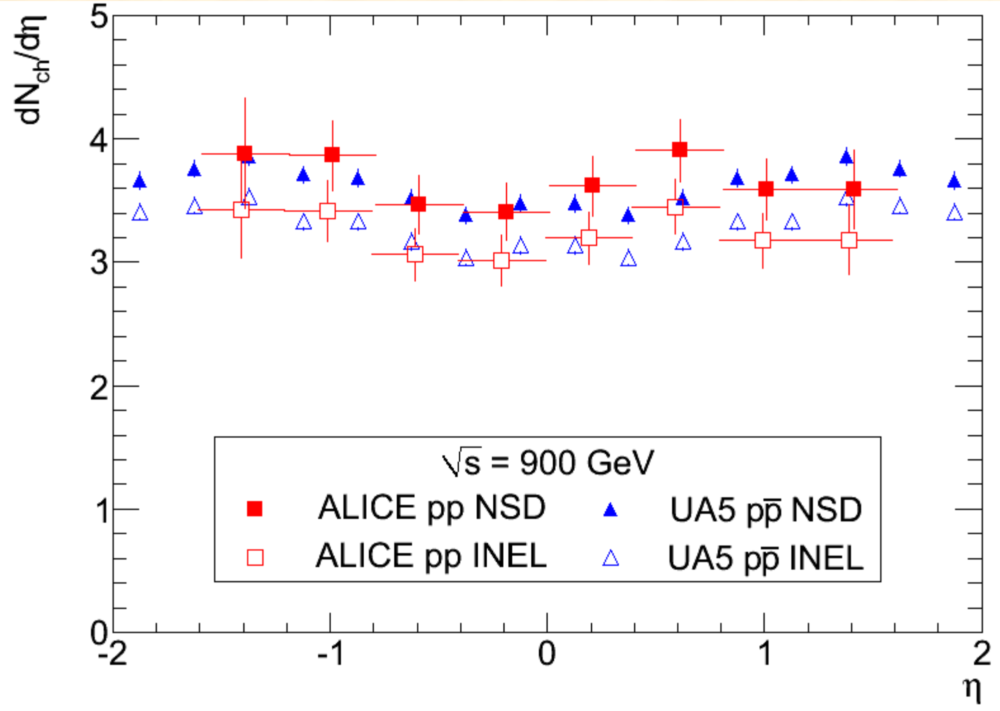
arXiv:0911.5430 [hep-ex]

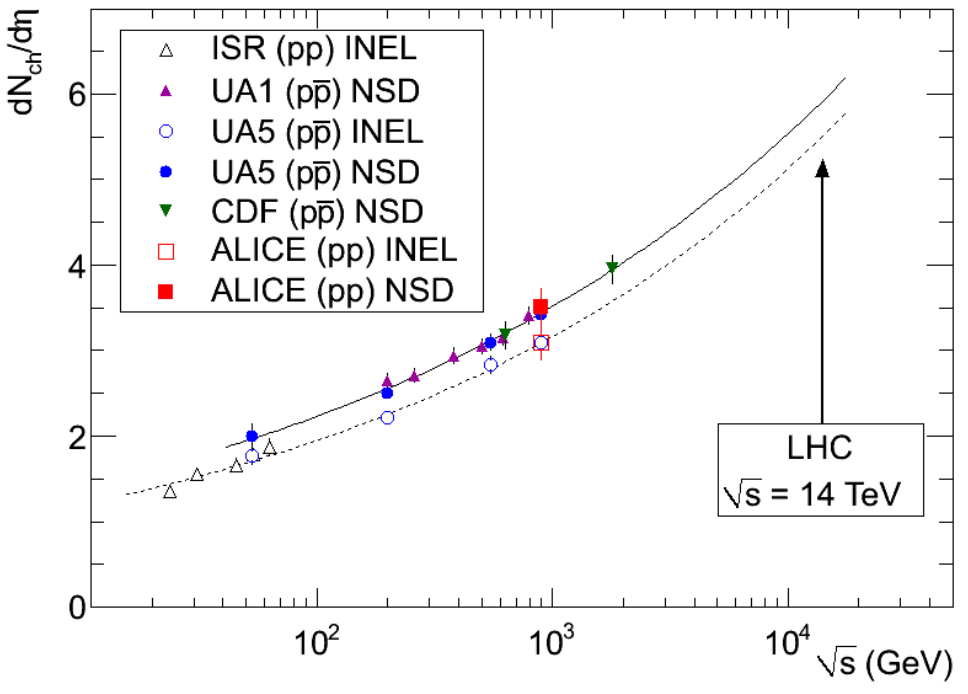




Result

- **Data presented in two normalizations**
  - ⇨ **inelastic collisions** **3.10 +- 0.13 +- 0.22**
  - ⇨ **non-single-diffractive collisions** **3.52 +- 0.15 +- 0.25**
- **Comparison proton-proton vs. antiproton-proton (UA5)**
  - ⇨ **possible difference due to C=-1 (odderon) exchange**
- **Pseudorapidity densities in proton-proton and antiproton-proton are compatible**





Summary & Outlook

- **first pp run**
  - ⇨ important pp reference data for heavy ions
  - ⇨ unique physics to ALICE
    - ✪ minimum-bias running
    - ✪ fragmentation studies
    - ✪ baryon-number transport
    - ✪ heavy-flavour cross sections
- **first few heavy-ion collisions**
  - ⇨ establish global event characteristics
  - ⇨ important bulk properties
- **first long heavy-ion run**
  - ⇨ quarkonia measurements
  - ⇨ Jet-suppression studies
  - ⇨ flavour dependences

Outlook

- **high luminosity heavy ion running (1nb^{-1})**
  - ⇨ dedicated high p_t electron triggers
  - ⇨ jets > 100 GeV (EMCAL)
  - ⇨ Y - states
  - ⇨ γ - jet correlations
  - ⇨ …
- **pA & light ion running**