ALICE on the eve of first collisions

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JZJ ou les 2 infinis - Journee Jean Zinn-Justin

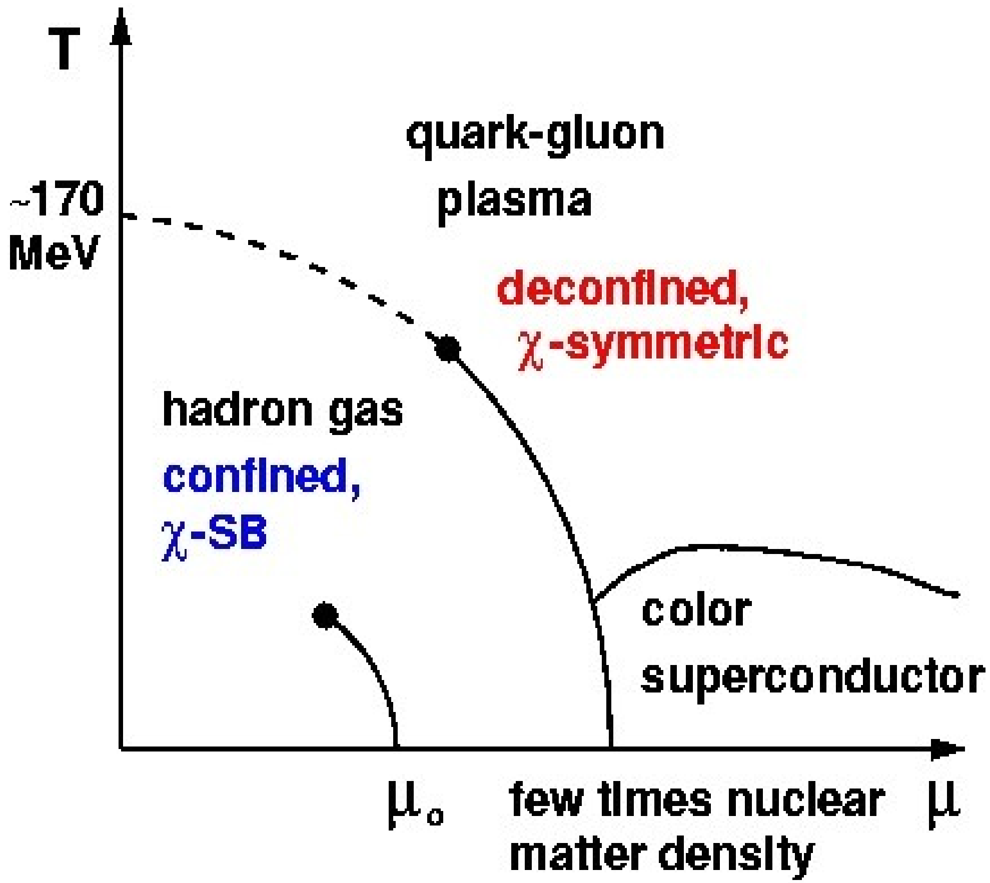
September 29, 2008 Irfu, CEA Saclay

the phase diagram of strongly interacting matter

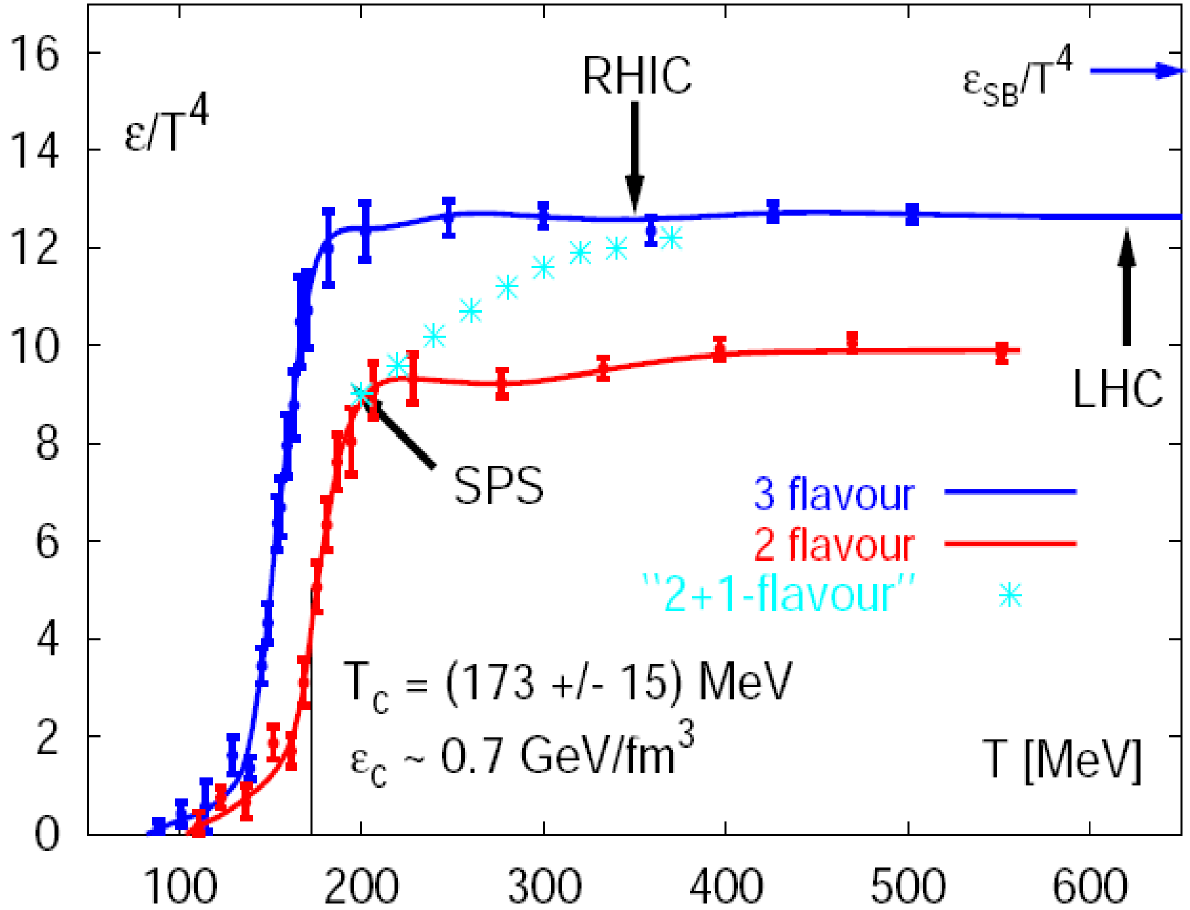
at low temperature and normal density
quarks and gluons are bound in hadrons
color is confined and chiral symmetry is spontaneously broken (generating 99% of proton mass e.g.) 1972

at high temperature and/or high density
quarks and gluons freed from confinement
-> new state of strongly interacting matter
1975

temperature for phase transition about
T=170 MeV at mu_b=0
note: T stands for kT, so 170 MeV ≙ 2 10^{12}K



phase transition between hadrons and deconfined quark gluon matter in Lattice QCD



Lattice QCD calculations for $\mu_b = 0$

Karsch & Laermann, hep-lat/0305025

$T_c = 173$ +- 12 MeV

$\varepsilon_c = 700$ +- 200 MeV/fm^3

for the (2 + 1) flavor case:

the phase transition to the QGP and its parameters are quantitative predictions of QCD.

The order of the transition is not yet definitively determined

most likely continuous cross over

SPS : 1986 - 2003

- S and Pb ; up to $\sqrt{s}$ =20 GeV/nucl pair

E_{cm}* = 3200 GeV - 2500 prod. hadrons

LHC : starting 2008

- Pb ; up to $\sqrt{s}$ = 5.5 TeV/nucl pair

E_{cm}* = 1150 TeV - 40000? prod. hadrons

AGS : 1986 - 2000

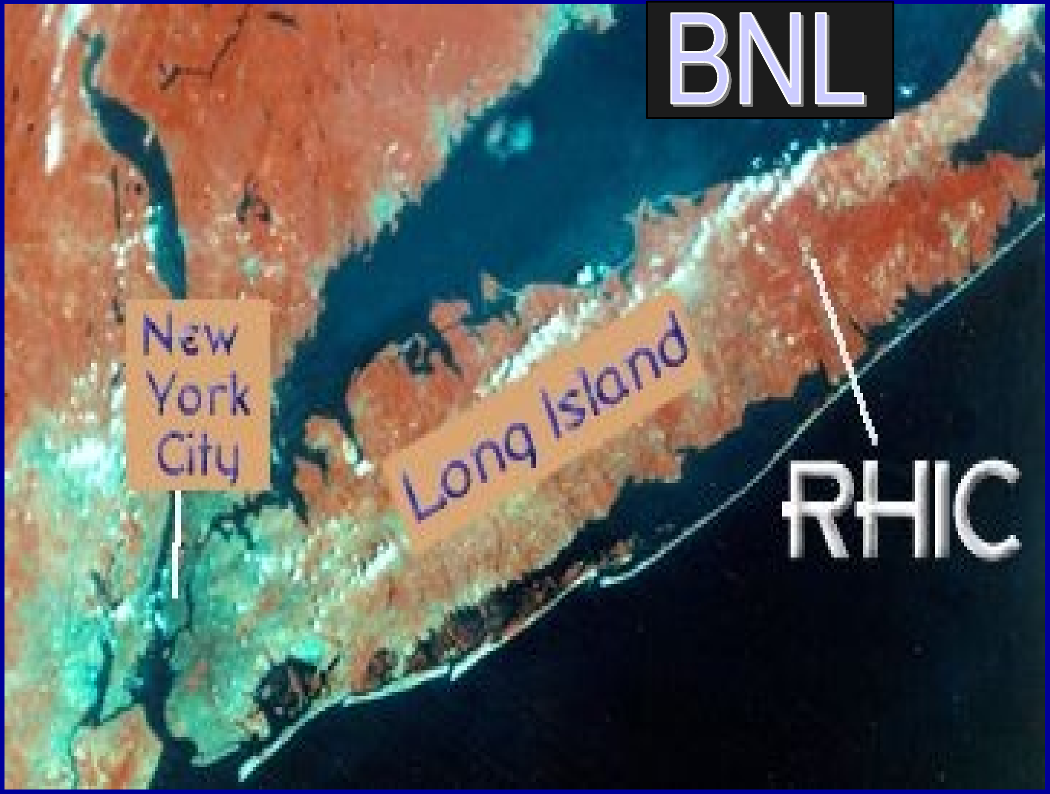
- Si and Au ; up to $\sqrt{\mathbf{s}}$ =5 GeV /nucl pair

E_{cm}* = 600 GeV - 1000 produced hadrons

RHIC : 2000

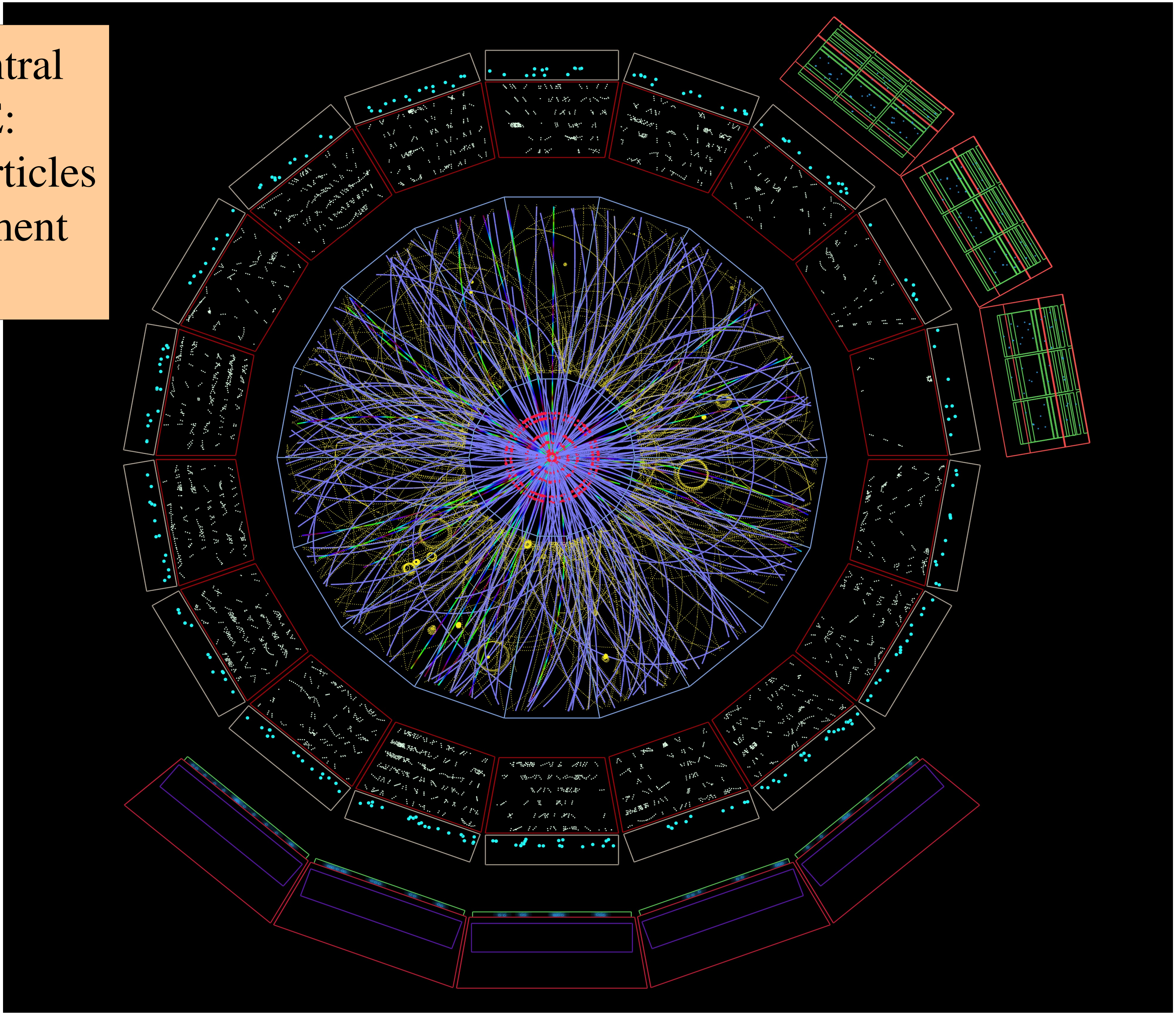
- Au ; up to $\sqrt{\mathbf{s}}$ = 200 GeV /nucl pair

E_{cm}* = 40 TeV - 7500 prod. hadrons



the challenge of LHC: identification and reconstruction of 5000 (up to 15000) tracks of charged particles

cut through the central barrel of ALICE: tracks of charged particles in a 1 degree segment (1% of tracks)



Experimental determination of the critical temperature for the quark-hadron phase transition

the hadro-chemical composition of the fireball or
what are the 7500 hadrons observed in final state at RHIC?

Analysis of yields of produced hadronic species in statistical model – grand canonical

partition function: $\ln Z_i = \frac{V g_i}{2\pi^2} \int_0^\infty \pm p^2 dp \ln(1 \pm \exp(-(E_i - \mu_i)/T))$

particle densities: $n_i = N/V = -\frac{T}{V}\frac{\partial \ln Z_i}{\partial \mu} = \frac{g_i}{2\pi^2}\int_0^\infty \frac{p^2\,\mathrm{d}p}{\exp((E_i-\mu_i)/T) \pm 1}$

for every conserved quantum number there is a chemical potential:

$$\mu_i = \mu_B B_i + \mu_S S_i + \mu_{I_3} I_i^3$$

but can use conservation laws to constrain V, μ_S, μ_{I_3} → **Fit at each energy provides values for T and μ_b**

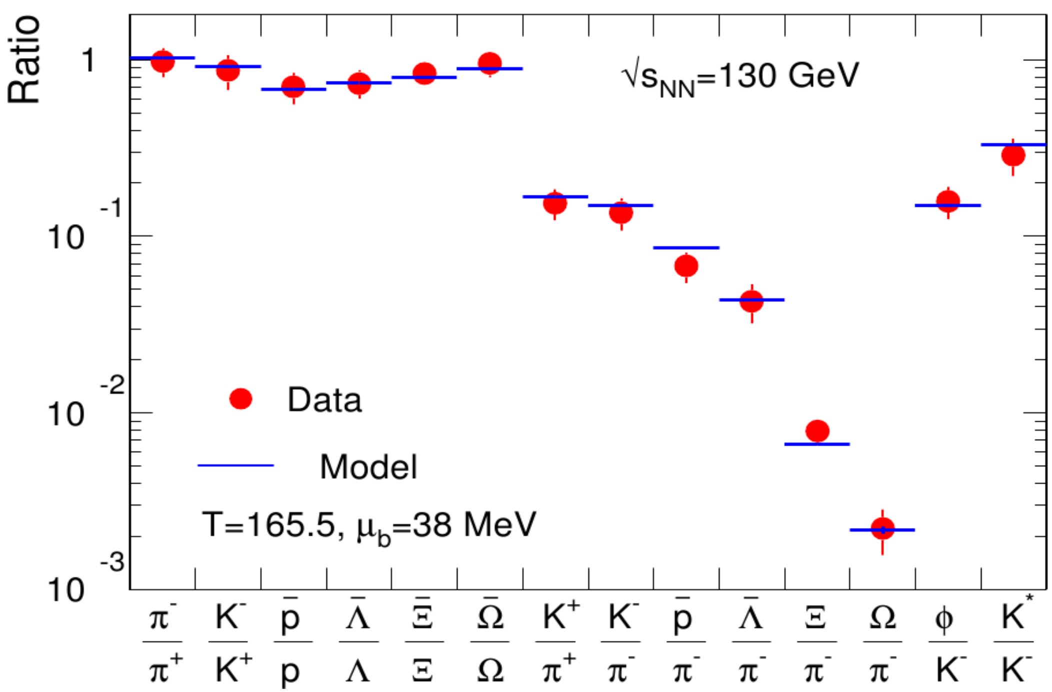
- from AGS energy upwards all hadron yields in central collisions of heavy nuclei reflect grand canonical equilibration
- strangeness suppression known from pp and e^+e^- is lifted

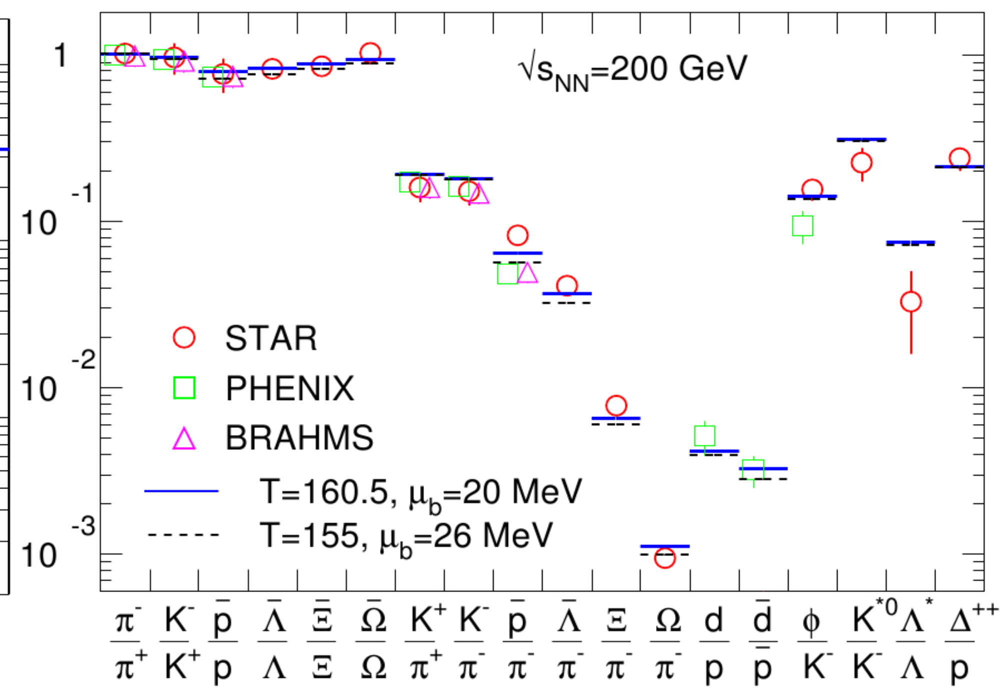
for a review: Braun-Munzinger, Stachel, Redlich, QGP3, R. Hwa, ed. (Singapore 2004) nucl-th/0304013

hadron yields at RHIC compared to statistical model (GC)

130 GeV data in excellent agreement
with thermal model predictions

prel. 200 GeV data fully in line
still some experimental discrepancies



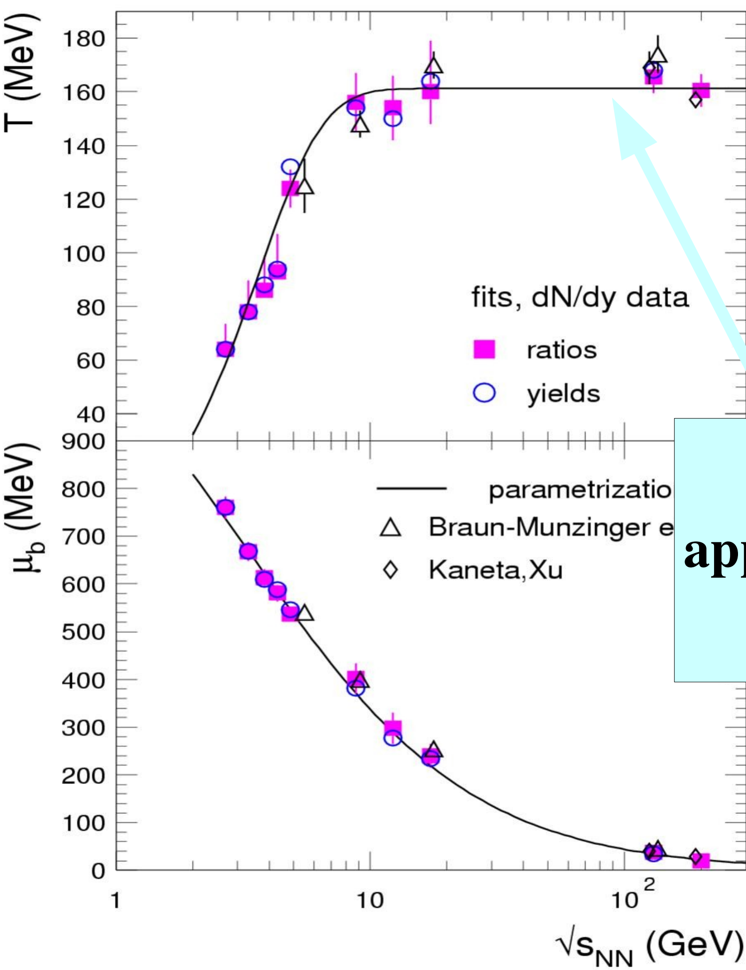


chemical freeze-out at: T = 165 ± 5 MeV

P. Braun-Munzinger, D. Magestro, K. Redlich, J. Stachel, Phys. Lett. B518 (2001) 41
A. Andronic, P. Braun-Munzinger, J. Stachel, Nucl. Phys. A772 (2006) 167

hadrochemical freeze-out points and the phase diagram

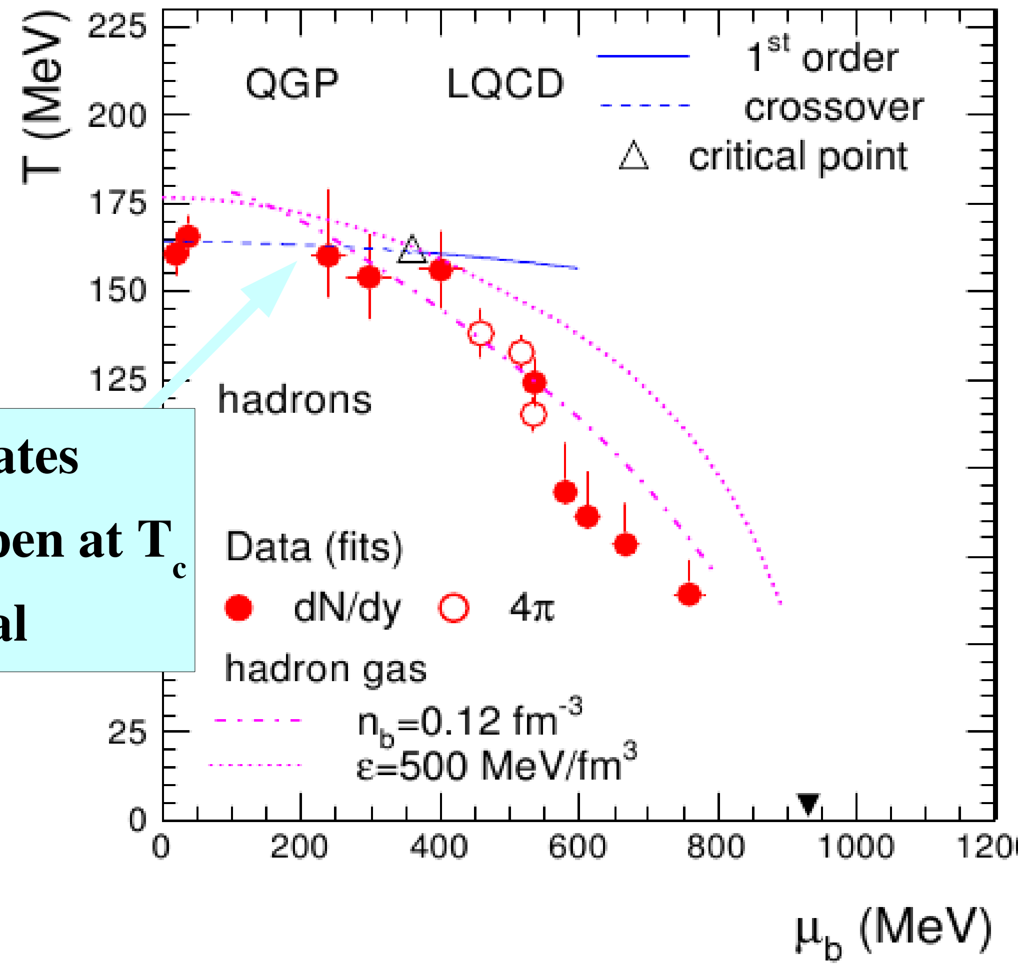
A. Andronic, P. Braun-Munzinger, J. Stachel, Nucl. Phys. A772 (2006) 167



T_{chem} saturates

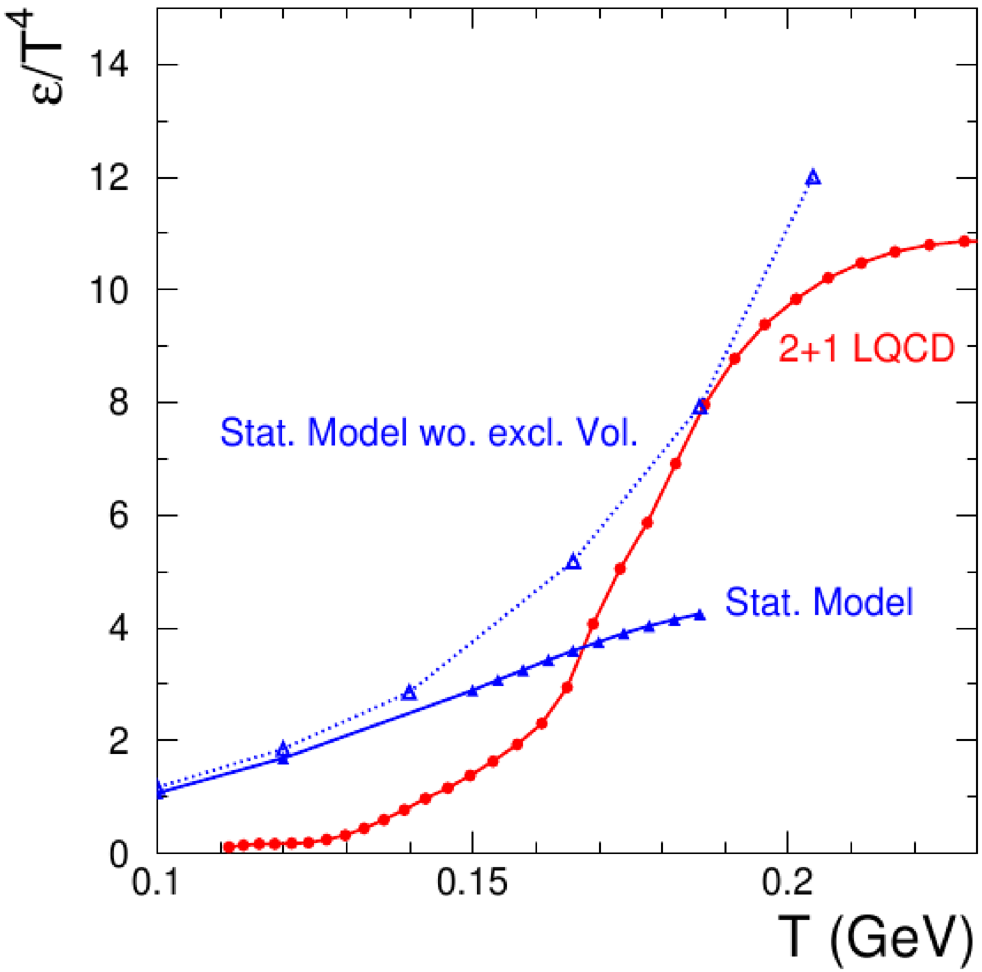
appears to happen at T_c

not trivial



why do all particle yields show one common freeze-out T?

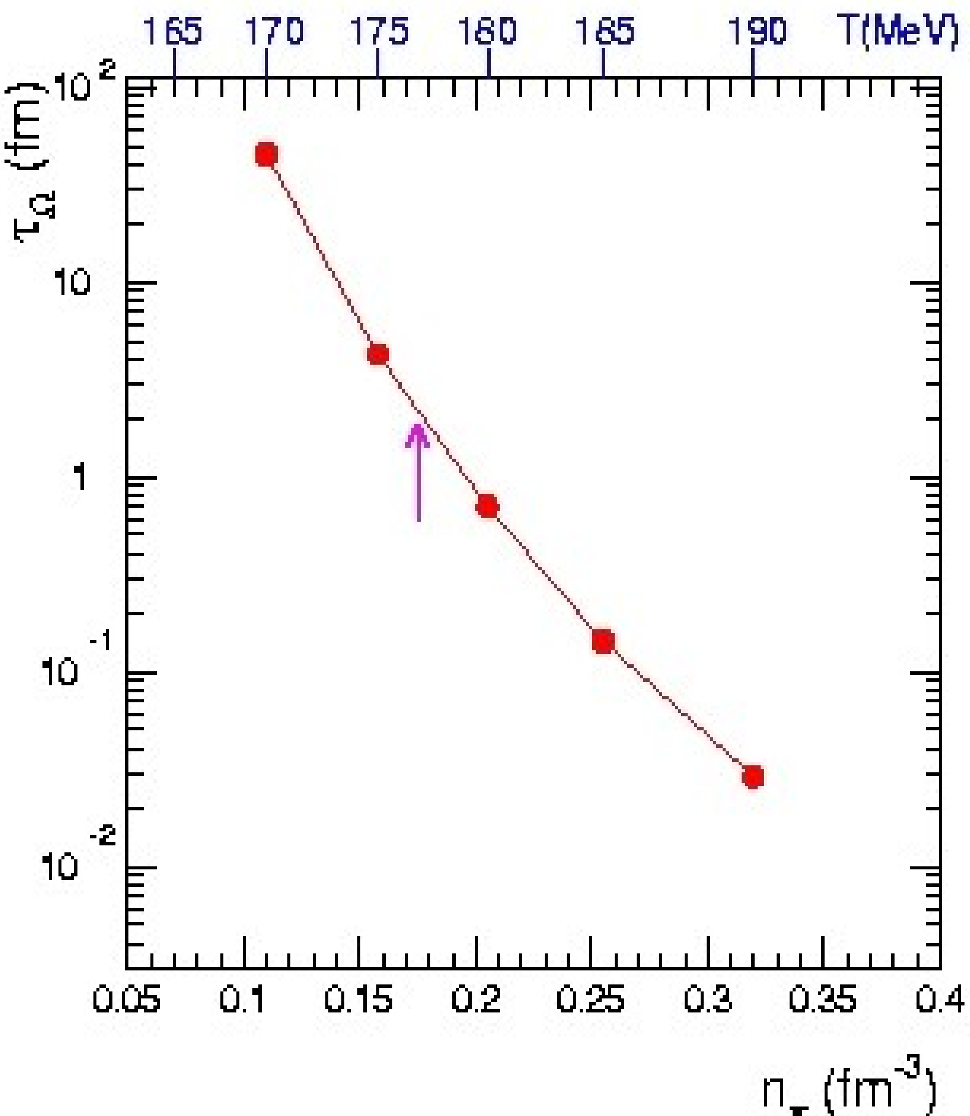
- The density of particles varies rapidly (factor 2 within 8 MeV) with T near the phase transition due to increase in degrees of freedom.
- also: system spends time at Tc -> volume has to triple (entropy cons.)
- Multi-particle collisions are strongly enhanced at high density and lead to chem. equilibrium very near to T_c



Lattice QCD by F. Karsch et al.

P. Braun-Munzinger, J. Stachel, C. Wetterich, Phys. Lett. B596 (2004)61

Density dependence of characteristic time for strange baryon production



P. Braun-Munzinger, J. Stachel, C. Wetterich, Phys. Lett. B596 (2004)61

- For small mu_b, reactions such as $2\pi + KKK \rightarrow \Omega$ Nbar bring multi-strange baryons close to equilibrium.
- in region around T_c equilibration time $\tau_\Omega \propto T^{-60}$!
- increase ρ_π by 1/3 or 8 MeV: $\tau = 0.2$ fm/c

  decrease ρ_π by 1/3: $\tau = 27$ fm/c

  i.e. rate change by 3 oom with density change of 2

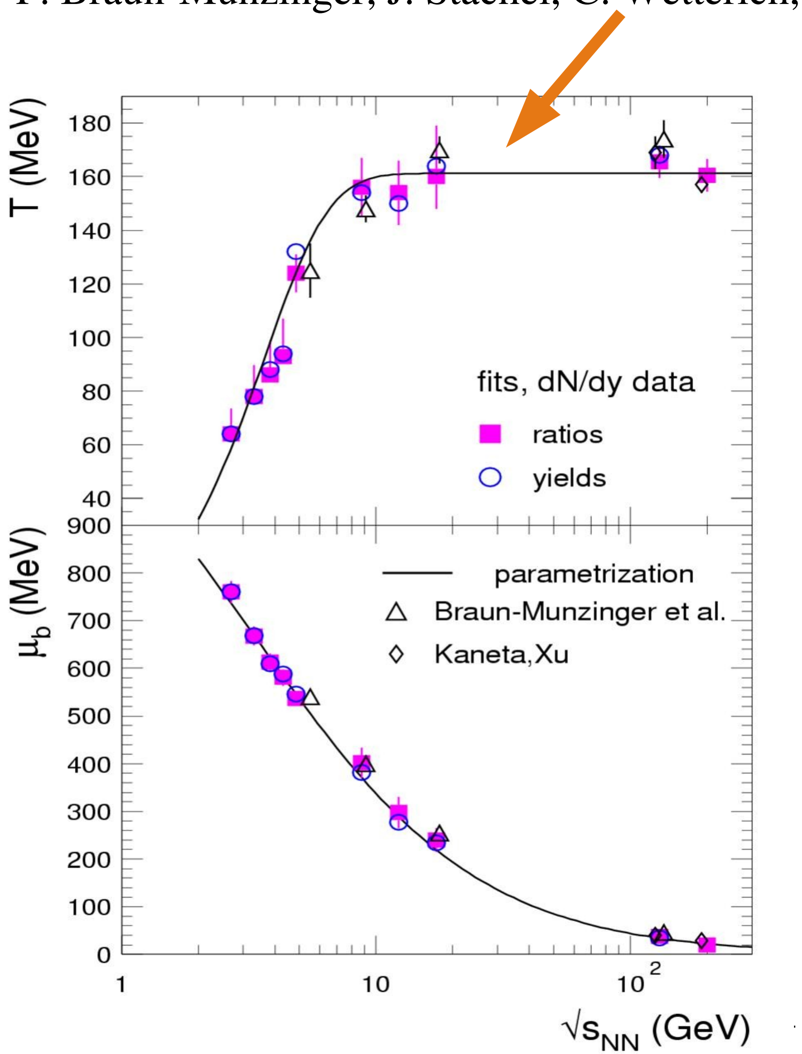
natural consequence that chemical freeze-out takes place at T_c!

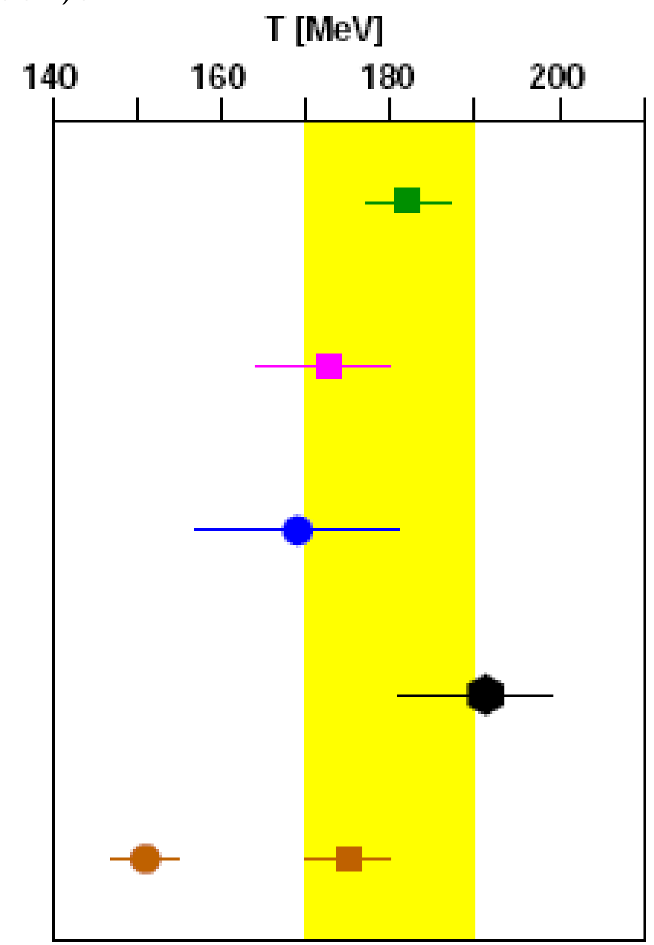
equilibration driven by high densities near T_c

rapid equilibration within a narrow temperature interval around T_c by multiparticle collisions

requires $T_c \approx 170$ MeV

P. Braun-Munzinger, J. Stachel, C. Wetterich, Phys. Lett. B596 (2004)61





synopsis of different lattice QCD results
F.Karsch, Erice, Sept. 2008

Charmonia: towards an unambiguous signature for deconfinement at the LHC

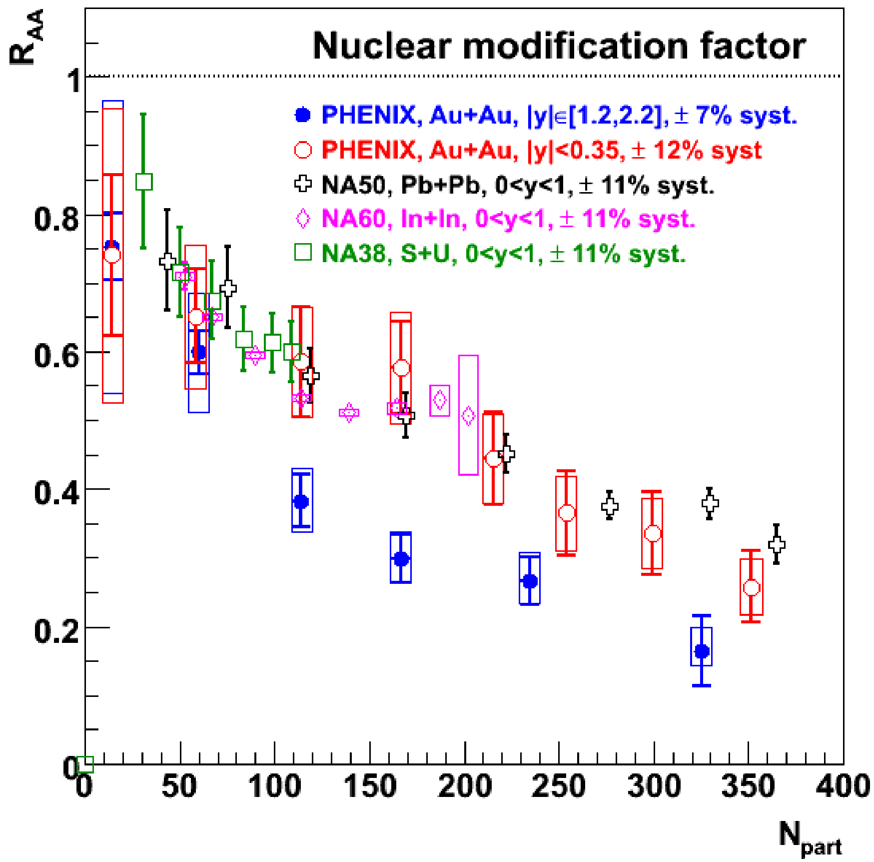
- T. Matsui and H. Satz (PLB178 (1986) 416) predict J/ψ suppression in QGP due to Debye screening

J/ψ 1 s state of ccbar
mass 3.1 GeV
radius 0.45 fm

- significant suppression seen in central PbPb at top SPS energy (NA50) in line with QGP expectations

J/ψ production in AuAu collisions at RHIC

PRL 98 (2007) 232301



R_{AA}: J/ψ yield in AuAu / J/ψ yield in pp times N_{coll}

at mid-rapidity suppression at RHIC very similar to SPS

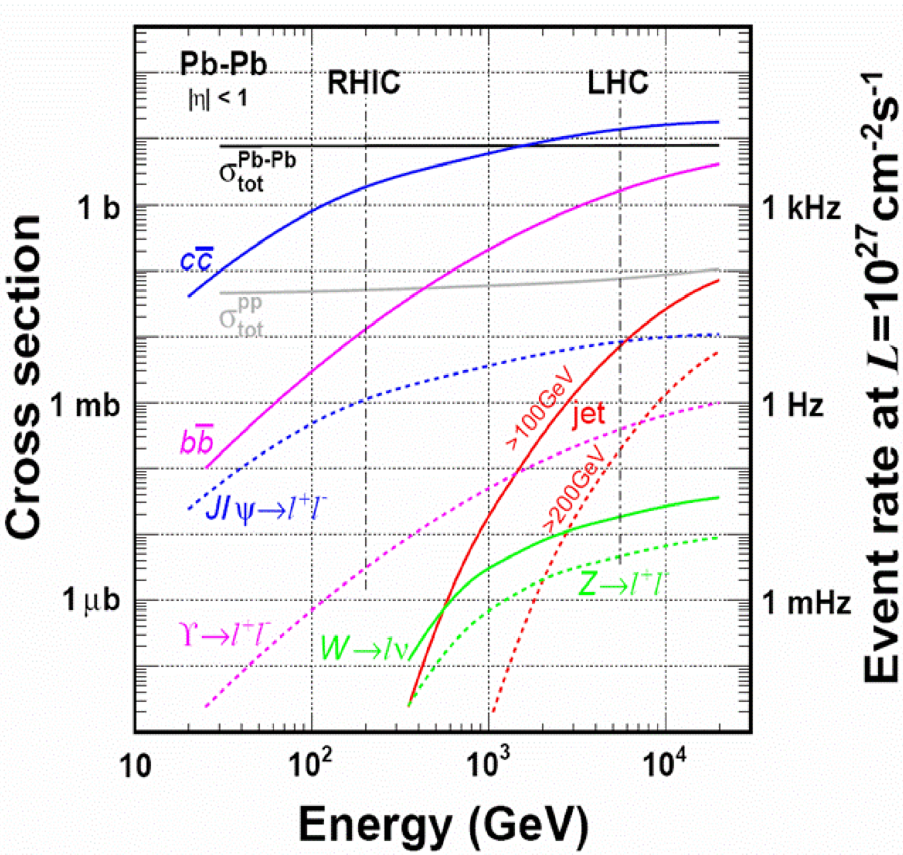
suppression at forward/backward rapidity stronger!

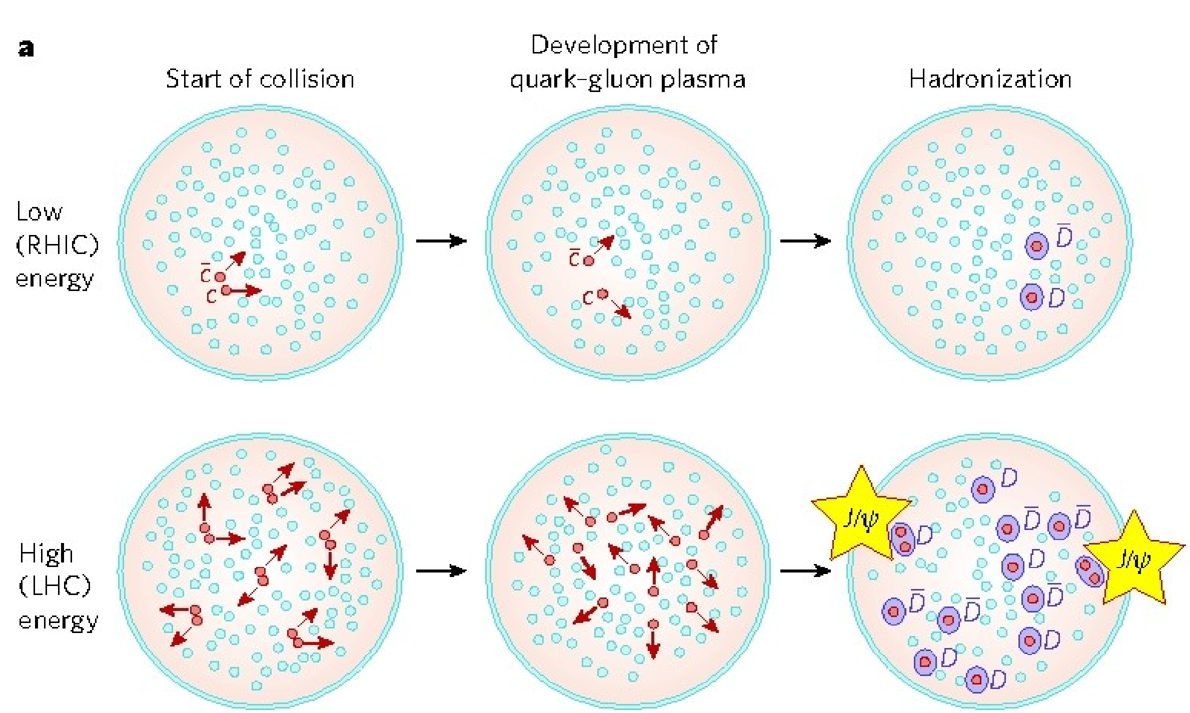
- but prediction:
  at hadronization of QGP
  J/ψ can form again
  from deconfined quarks,
  in particular if number of
  ccbar pairs is large

$$N_{J/\psi} \propto N_{cc}^{2}$$

(P. Braun-Munzinger and J.Stachel, PLB490 (2000) 196)

what happens at higher beam energy when more and more charm-anticharm quark pairs are produced?





low energy: few c-quarks per collision → **suppression** of J/ψ
high energy: many “ “ → **enhancement** “
unambiguous signature for QGP!

quarkonium production through statistical hadronization

- assume: all charm quarks are produced in initial hard scattering; number not changed in QGP
- hadronization at T_c following grand canonical statistical model used for hadrons with light valence quarks (fugacity g_c to fix number of charm quarks)

$$N_{c\bar{c}}^{direct} = \frac{1}{2} g_c V \left(\sum_i n_{D_i}^{therm} + n_{\Lambda_i}^{therm}\right) + g_c^2 V \left(\sum_i n_{\psi_i}^{therm}\right) + \ldots$$

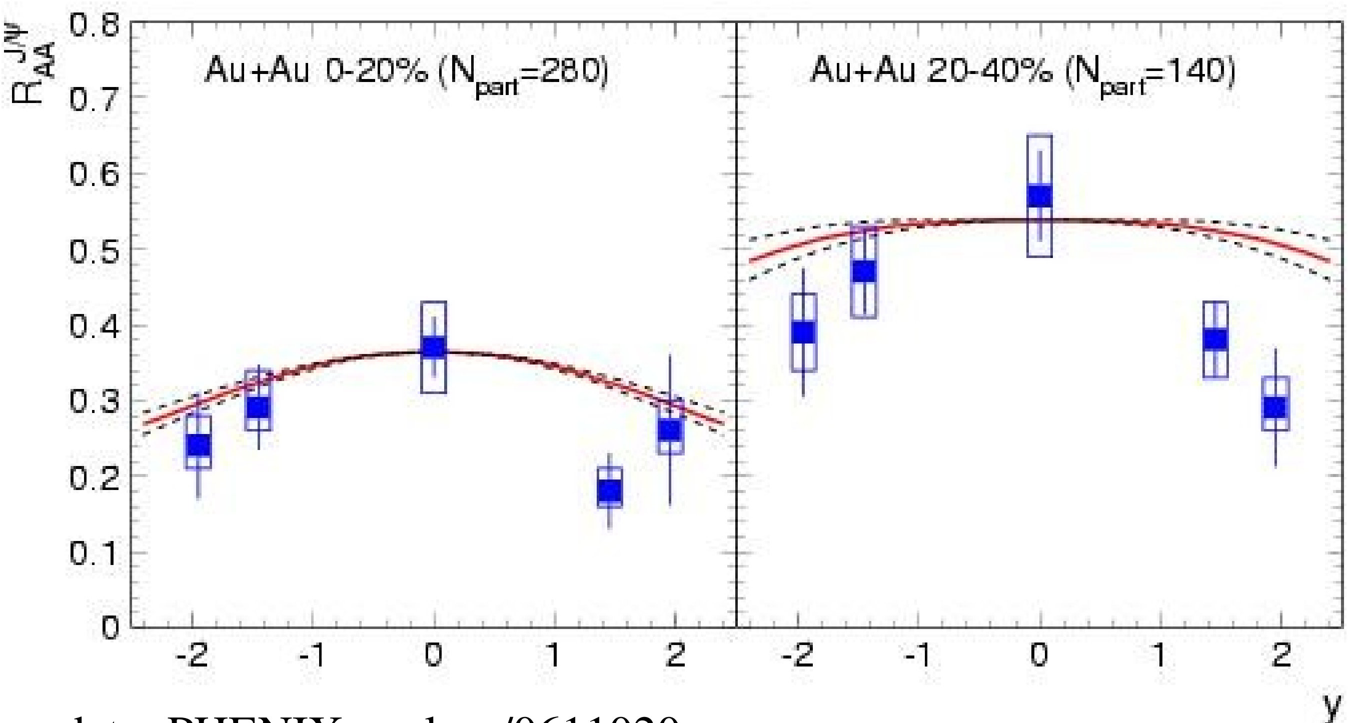
and for $N_{c,\bar{c}} << 1 \rightarrow$ canonical: $N_{c\bar{c}}^{dir} = \frac{1}{2} g_c N_{oc}^{therm} \frac{I_1(g_c N_{oc}^{therm})}{I_0(g_c N_{oc}^{therm})}$

obtain: $N_D = N_D^{therm} \cdot g_c \cdot \frac{I_1}{I_0}$ and $N_{J/\psi} = N_{J/\psi}^{therm} \cdot g_c^2$ and all other charmed hadrons

additional input parameters: $V, N_{c\bar{c}}^{dir}(pQCD)$

comparison of model predictions to RHIC data:

R_{AA}: J/ψ yield in AuAu / J/ψ yield in pp times N_{coll}



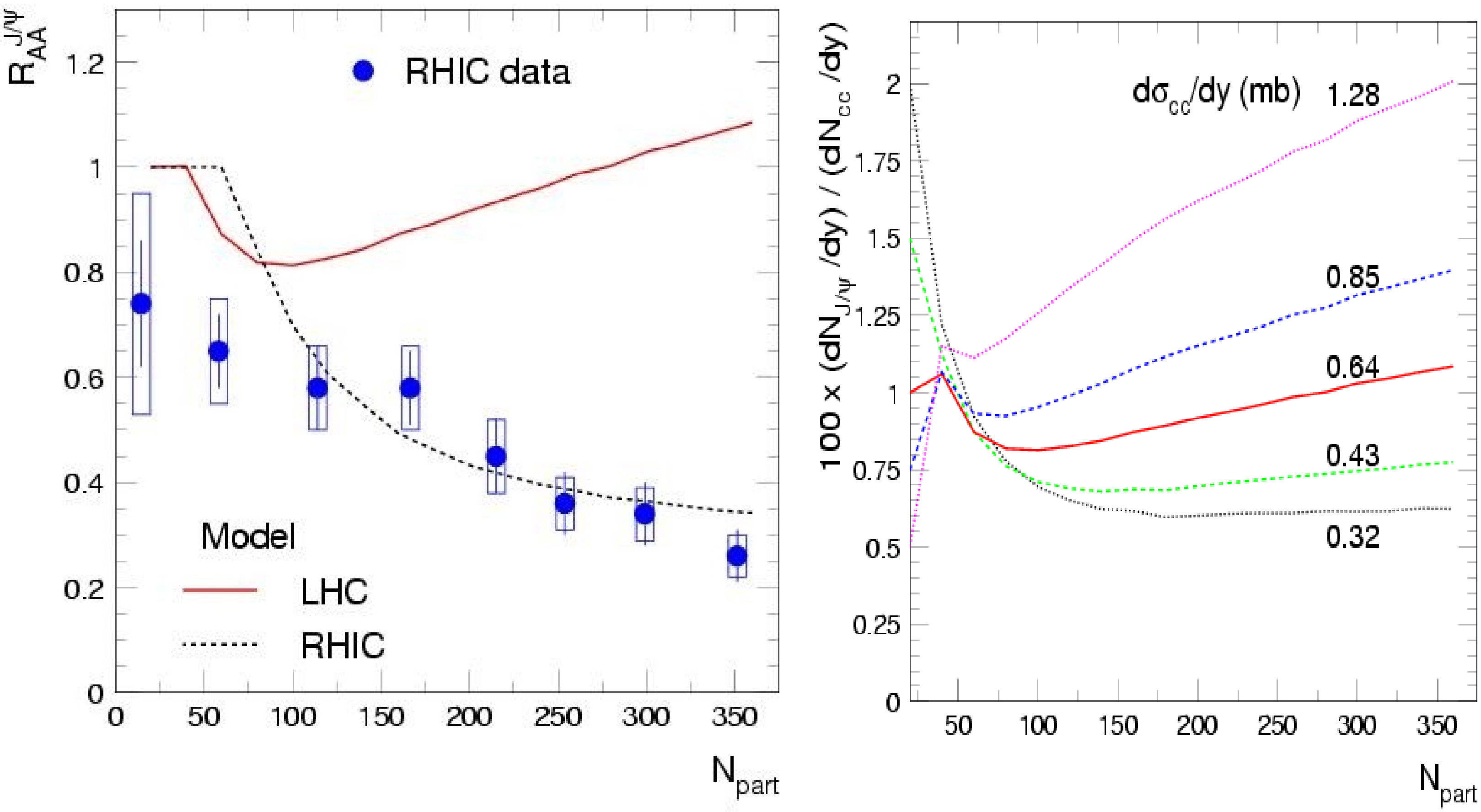
good agreement, no free parameters

data: PHENIX nucl-ex/0611020
additional 14% syst error beyond shown
model: A. Andronic, P. Braun-Munzinger, K. Redlich, J. Stachel Phys. Lett. B652 (2007) 259

remark: y-dep opposite in 'normal Debye screening' picture; suppression strongest at midrapidity (largest density of color charges)

energy dependence of quarkonium production in statistical hadronization model

A. Andronic, P. Braun-Munzinger, K. Redlich, J. Stachel Phys. Lett. B652 (2007) 259

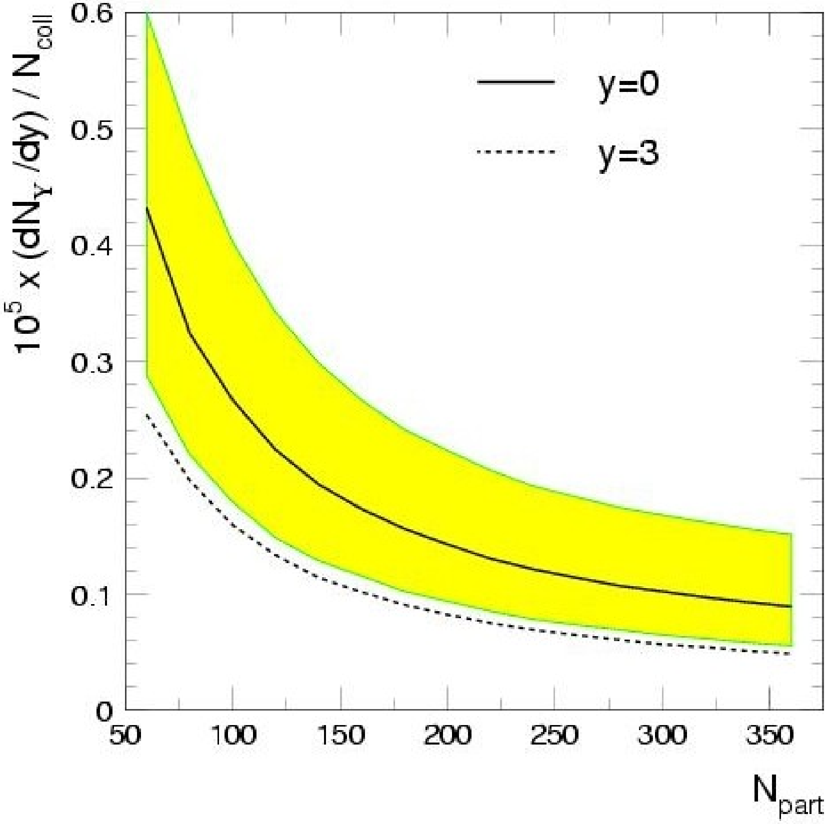


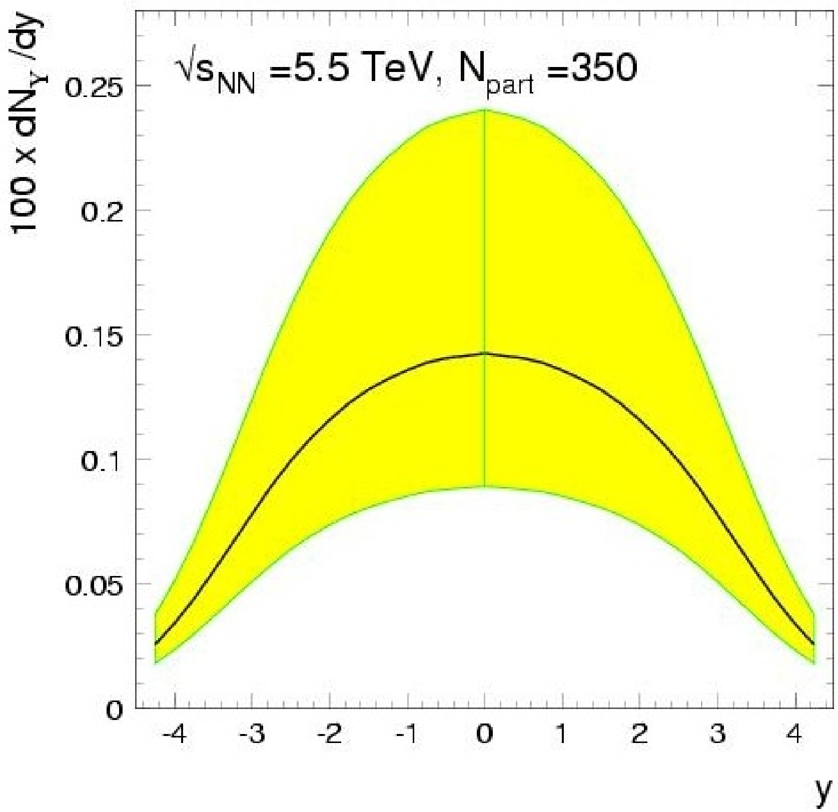
centrality dependence and enhancement beyond pp value will be fingerprint of statistical hadronization at LHC

-> direct signal for deconfinement

bottomonium at LHC

predictions with statistical hadronization model





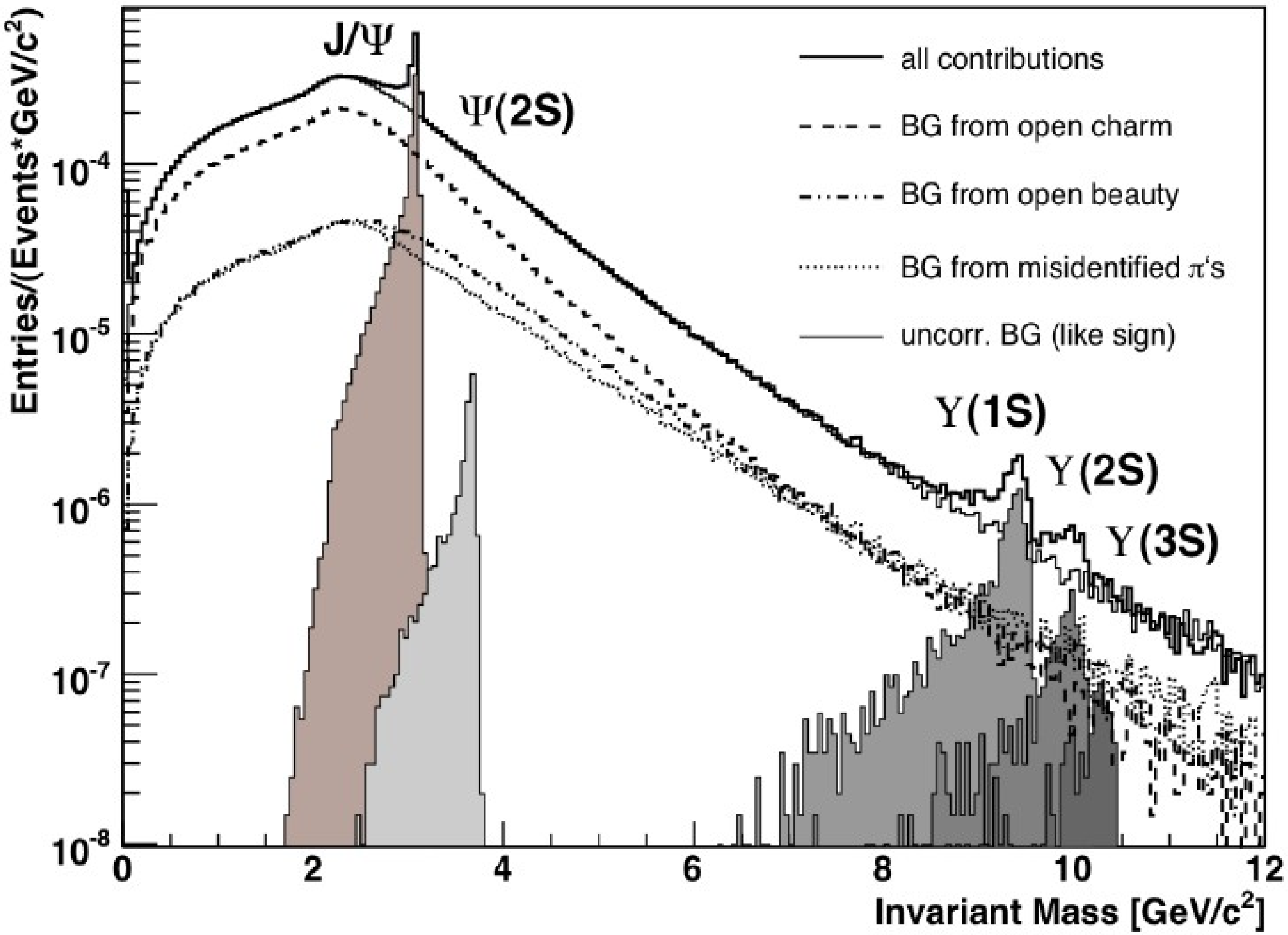
in terms of number of produced quarks, beauty at LHC like charm at RHIC

do they thermalize and hadronize statistically??

if yes, population of 2s and 3s states completely negligible (exp-Δm/T)

charmonia in the di-electron channel at mid-rapidity

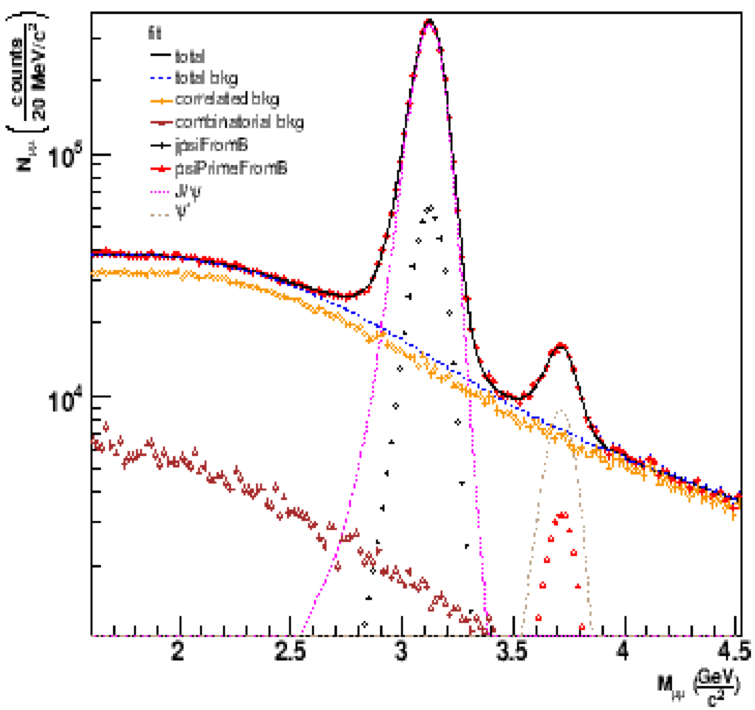
electron identification with TPC and TRD



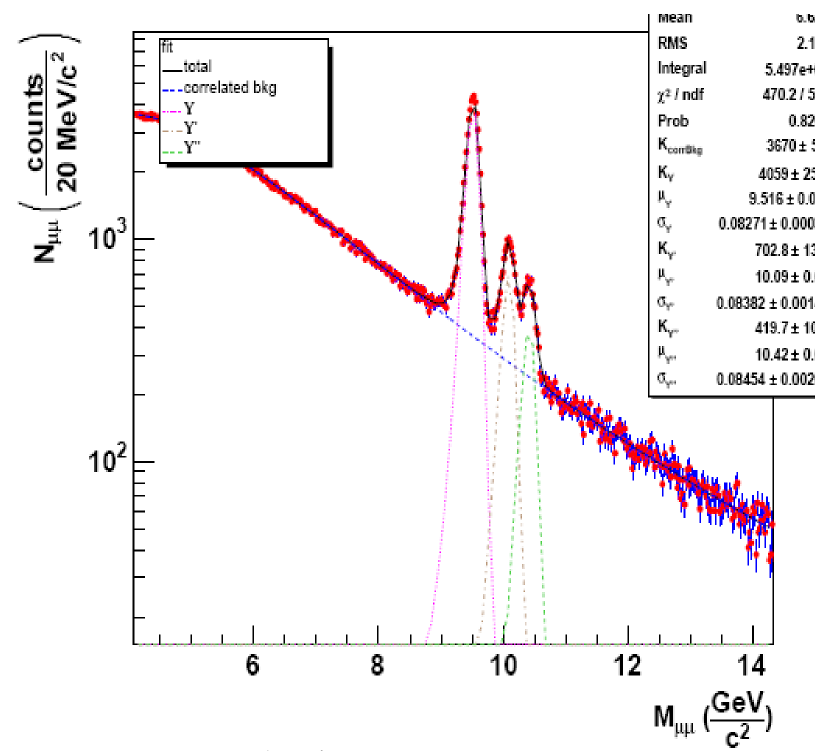
Simulation: W. Sommer (Frankfurt) $2 \cdot 10^8$ central PbPb coll.
corresponding to 1 year of LHC heavy ion running

Charmonia in the di-muon channel at y=2.4-4.0

700 000 J/psi and 6800 Upsilon for 2 10^8 PbPb collisions (1 month)



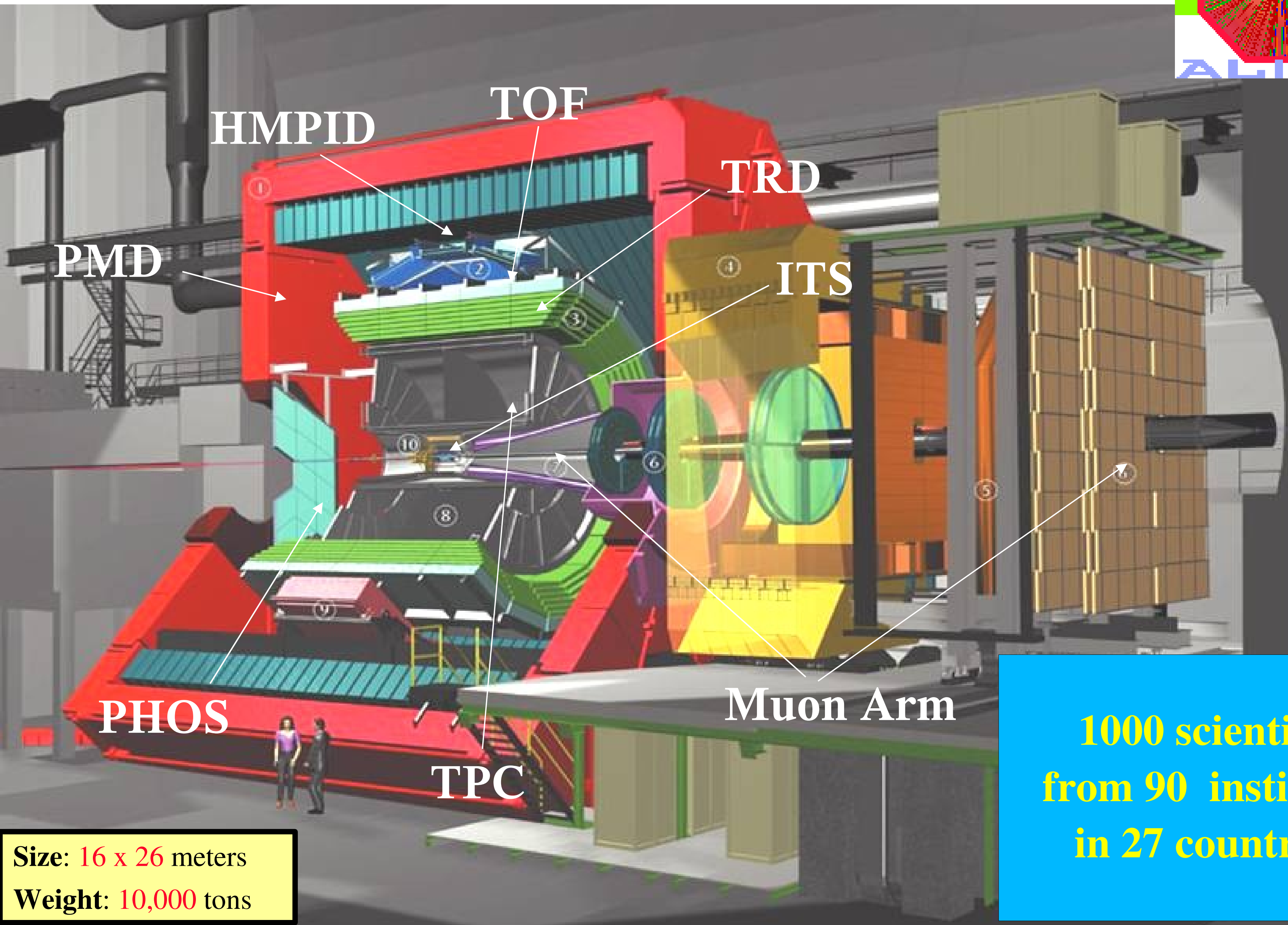
resolution 74 MeV



resolution 109 MeV

Visit of Alain Bugat, Administrateur General de l'Energie Atomic France, at ALICE February 2004

ALICE



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

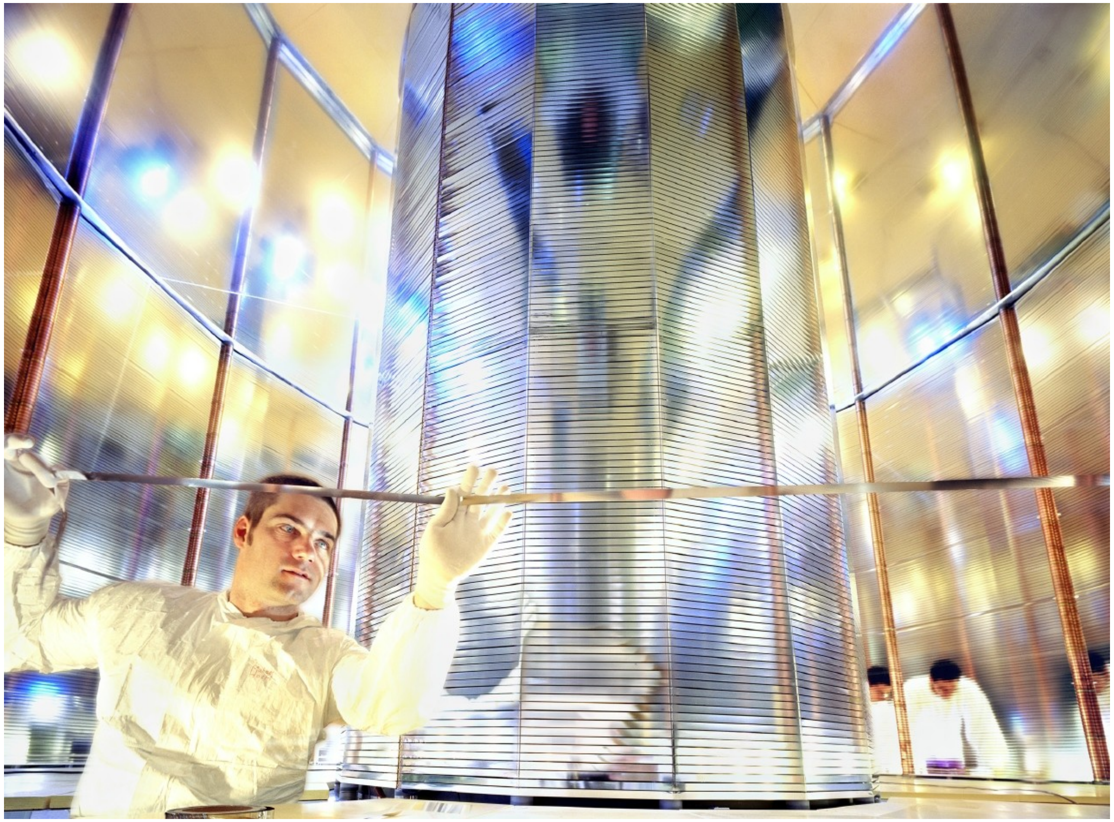
1000 scientists from 90 institutes in 27 countries

Start-up Configuration 2008

- complete - fully installed & commissioned
  - ITS, TPC, TOF, HMPID, MUONS, PMD, V0, T0, FMD, ZDC, ACORDE, DA
- partially completed
  - TRD (25%) to be completed by 2009
  - PHOS (60%) to be completed by 2010
  - HLT (30%) to be completed by 2009
  - EMCAL (0%) to be completed by 2010/11
- at start-up full hadron and muon capabilities
- partial electron and photon capabilities

the TPC (Time Projection Chamber) - 3D reconstruction of up to 15 000 tracks of charged particles per event

with 95 m^3 the largest TPC ever



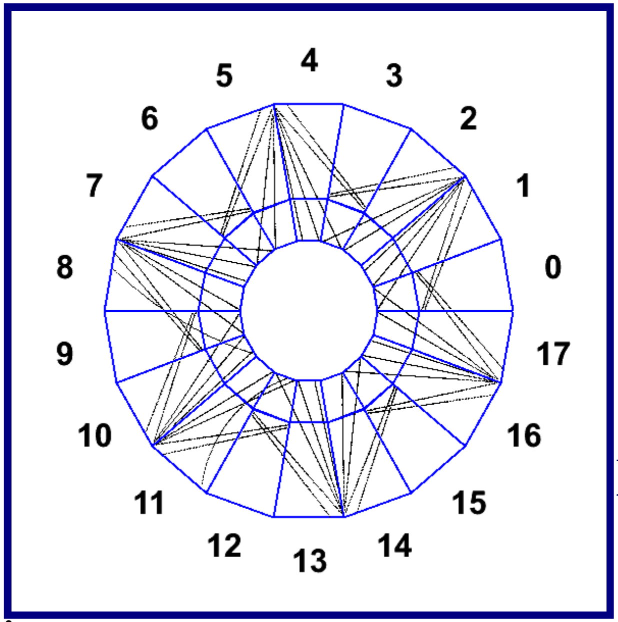
560 million read-out pixels!

precision better than 500 μm in all 3 dim.

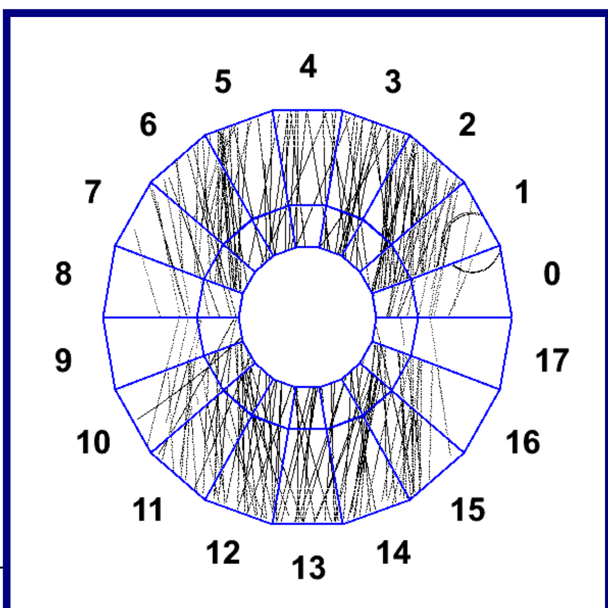
180 space and charge points per track

TPC calibration and alignment

laser system

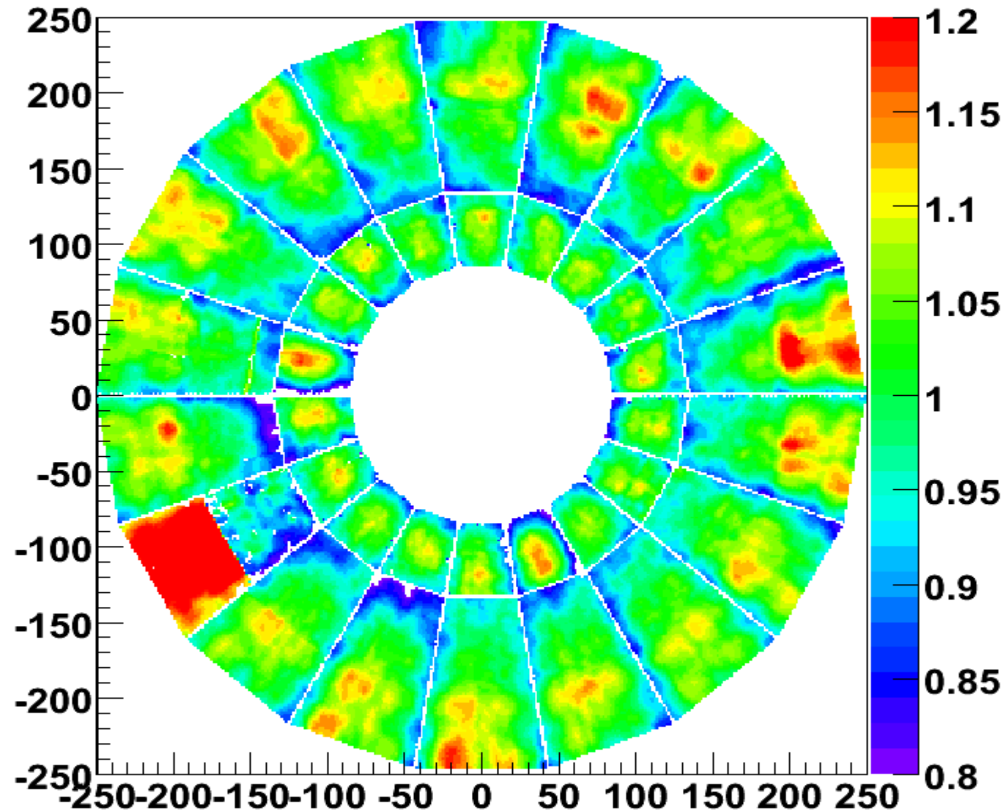


cosmic radiation

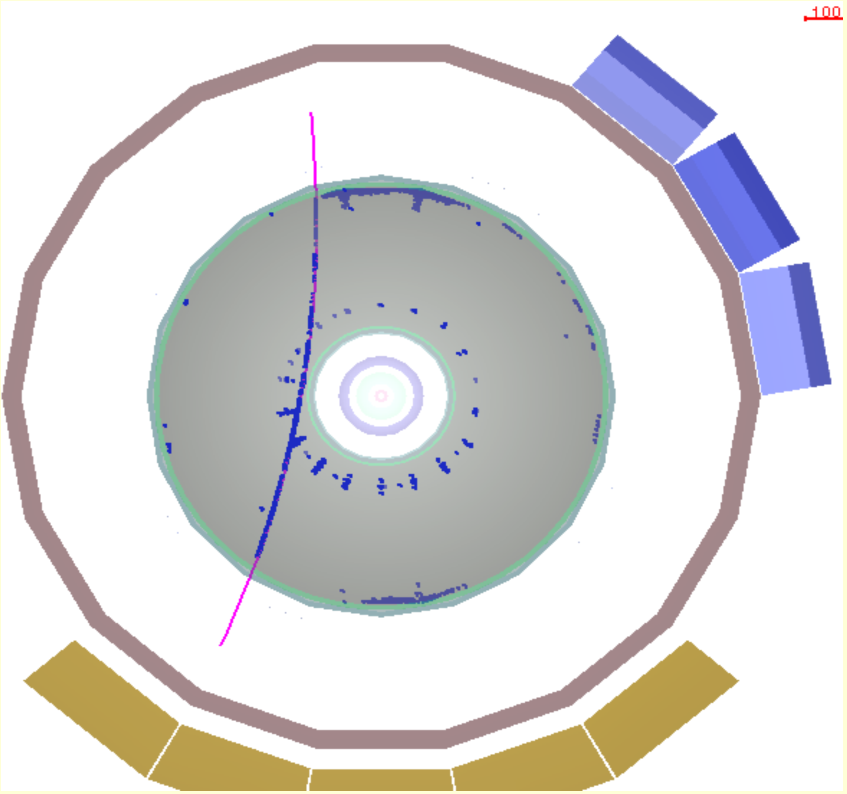


L

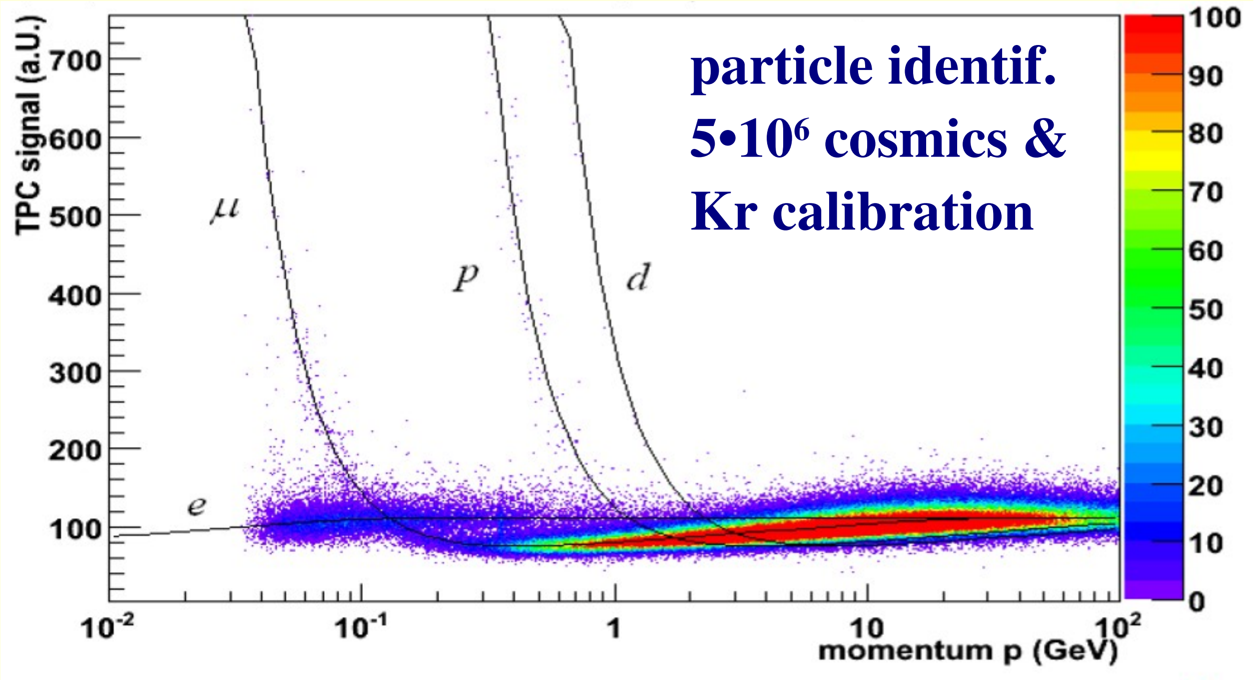
Krypton gain calibration

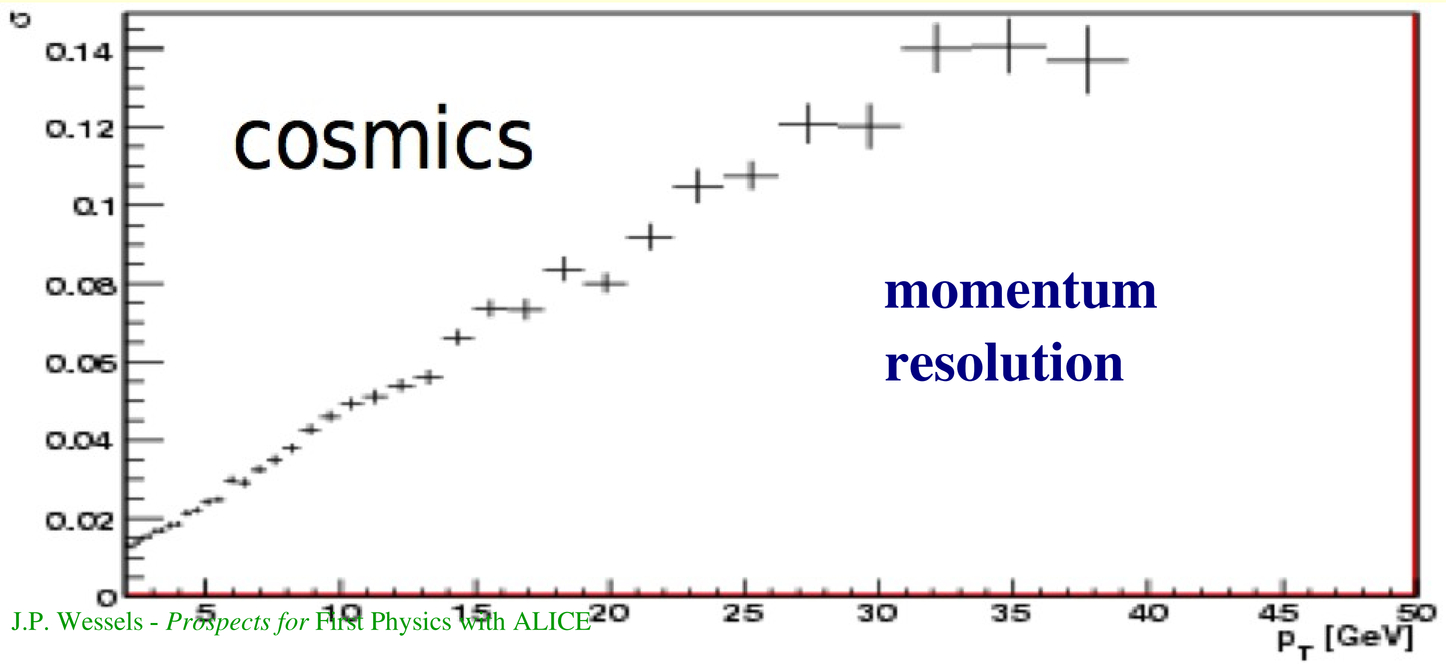


tracking cosmic rays in magnetic field

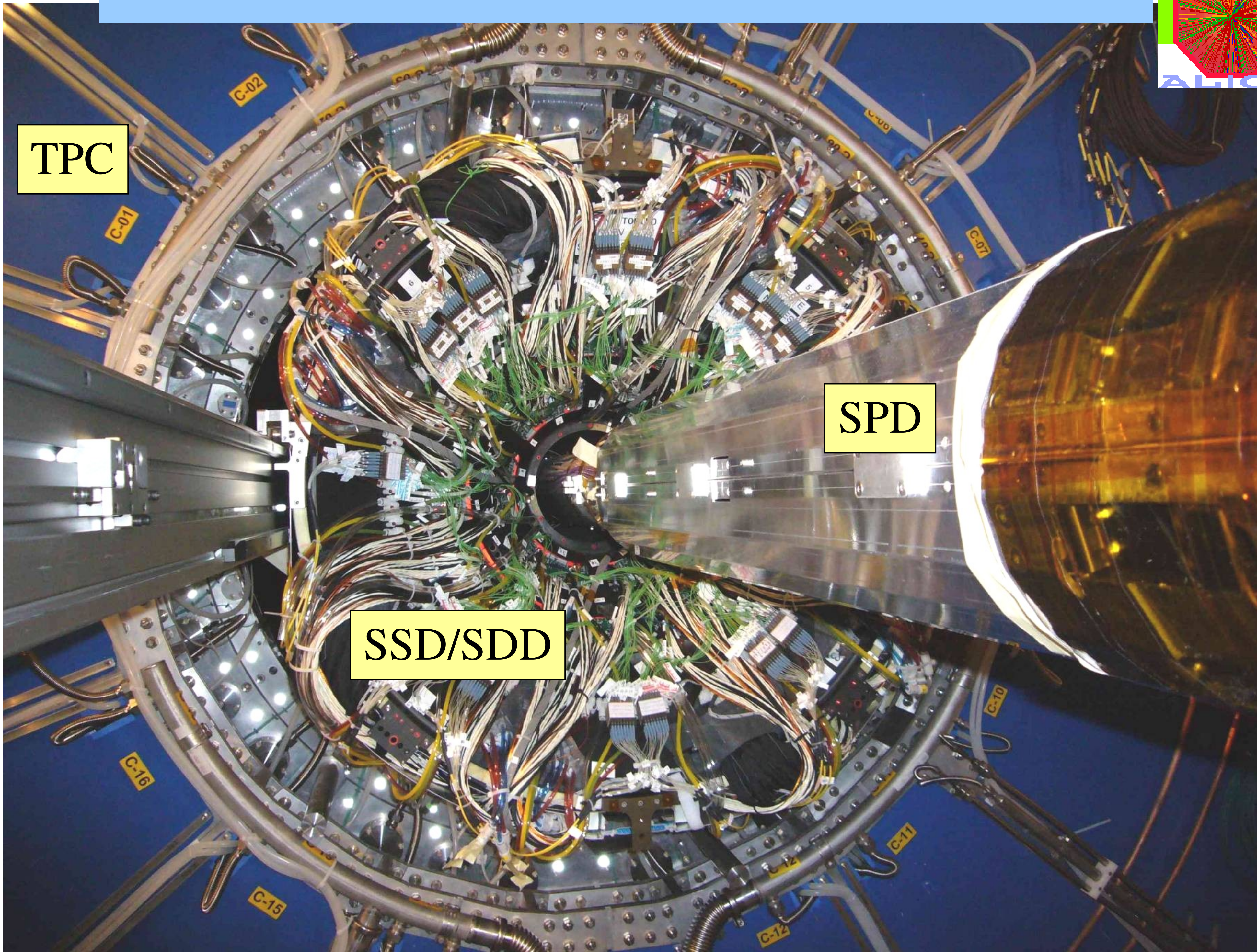


M. Ivanov, A. Kalweit





ITS Russian Dolls - Sliding the SSD/SDD over the SPD



ALICE Inner Tracking System alignment with cosmics

Silicon Pixel Detector (SPD):
- ~10M channels
- 240 sensitive vol. (60 ladders)

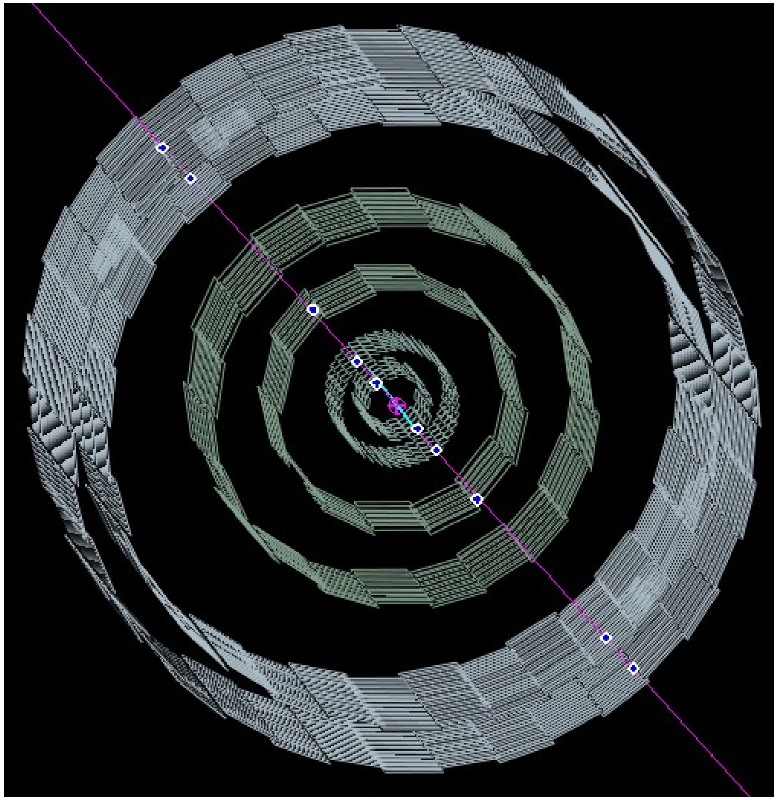
Silicon Drift Detector (SDD):
- ~133k channels
- 260 sensitive vol. (36 ladders)

Silicon Strip Detector (SSD):
- ~2.6M channels
- 1698 sensitive vol. (72 ladders)

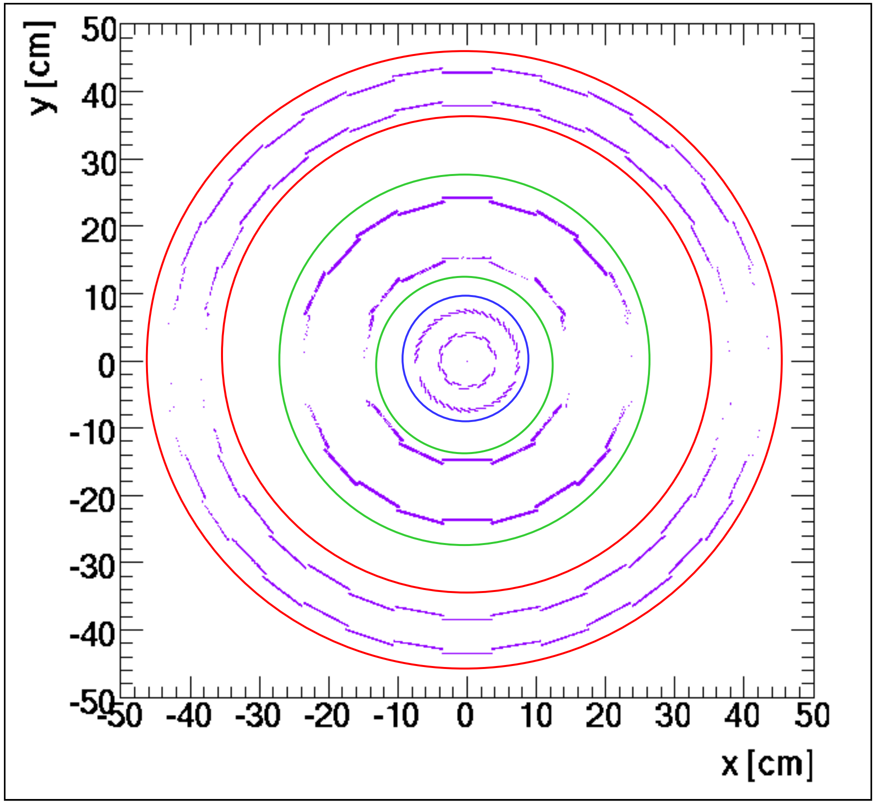
ITS total: 2.2k alignable sensitive volumes   13k degrees of freedom

- ~50k cosmic μ for alignment collected since end of May, using Pixel trigger

Typical event display



Distribution of **clusters** in the 6 layers

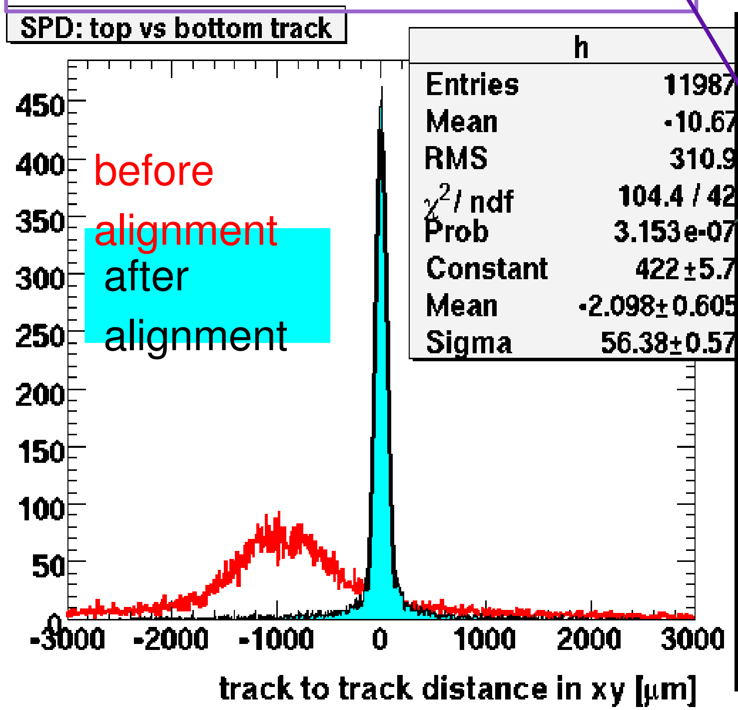


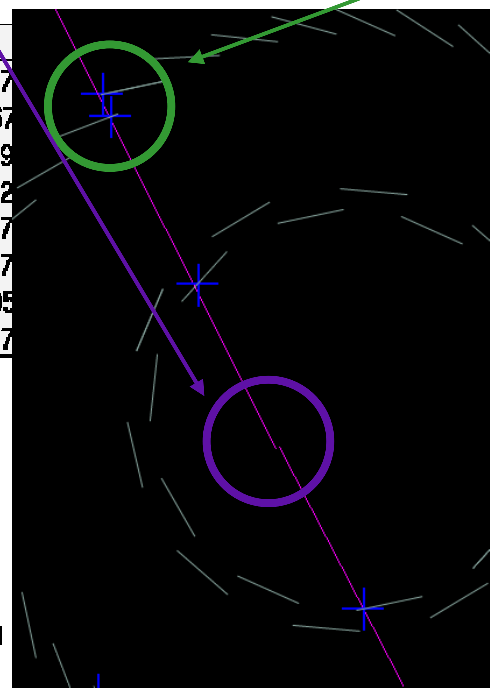
ALICE Inner Tracking System alignment with cosmics

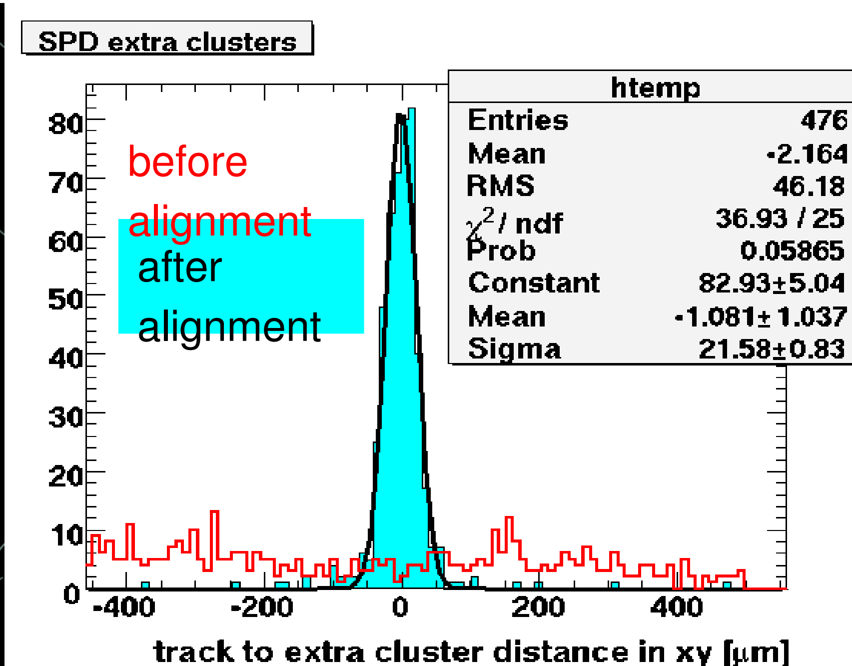
- Preliminary results for SPD (Pixels):

Track-to-track (top vs bottom) distance in transv. plane

Track-to-“extra clusters” distance in transv. plane





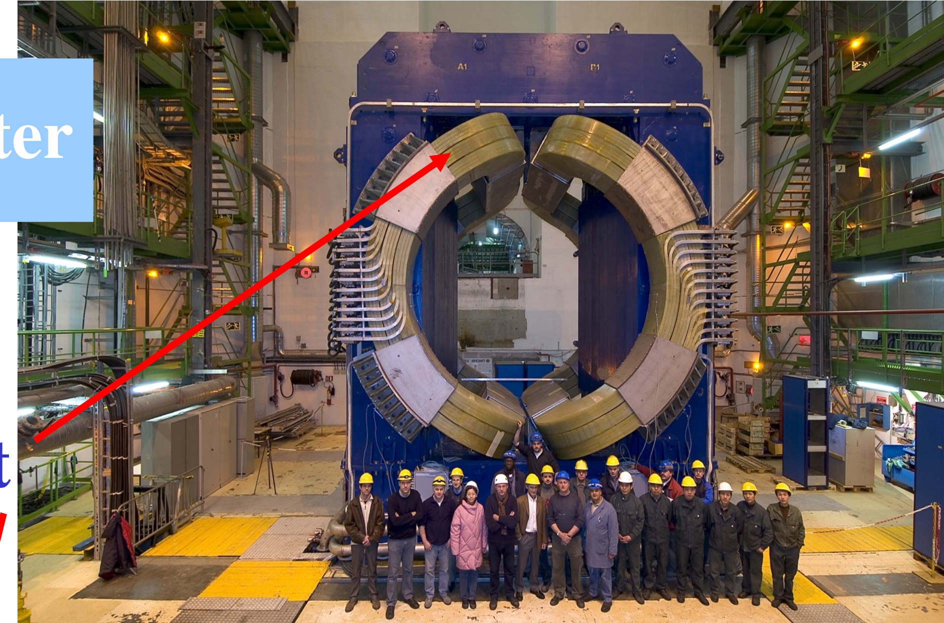


σ = 55 μm (vs 40 μm in simul. without misalignment)

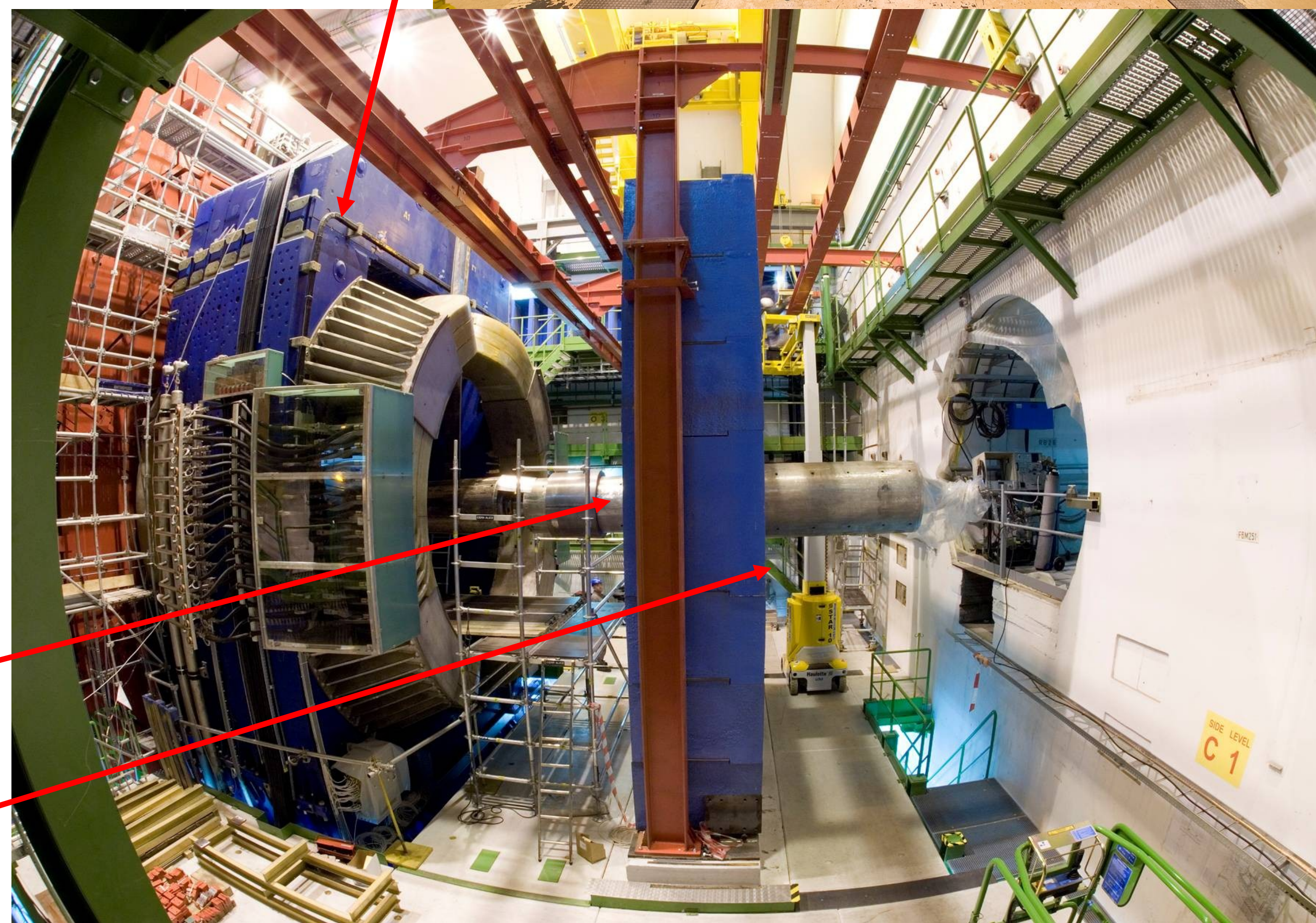
σ = 21 μm (vs 15 μm in simul. without misalignment)

- **These results indicate a residual misalignment (after realignment with cosmics) of < 10 μm, to be compared to a detector position resolution of 12 μm in rϕ**

ALICE (Di)-Muon Spectrometer



dipole magnet



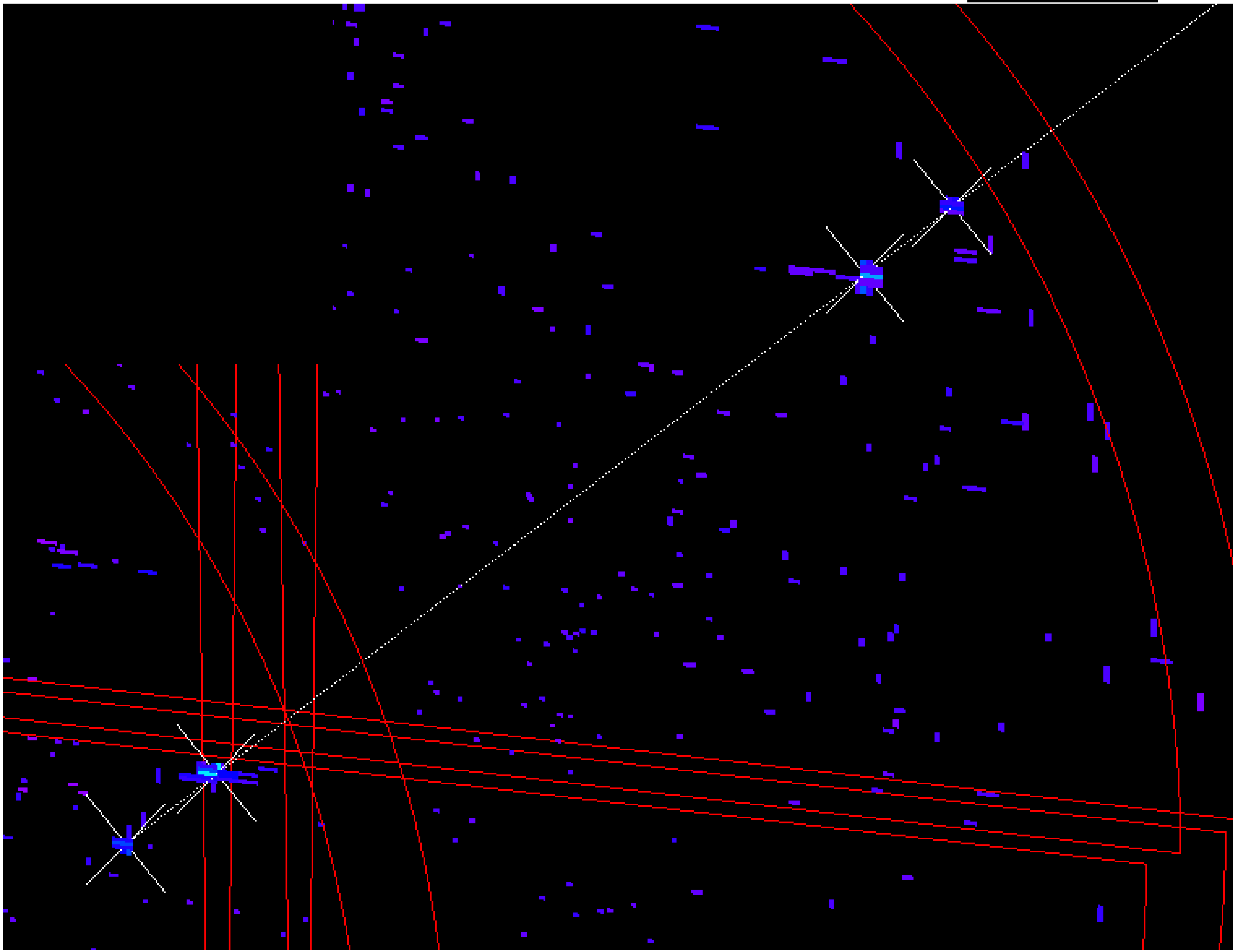
muon chambers

muon absorber

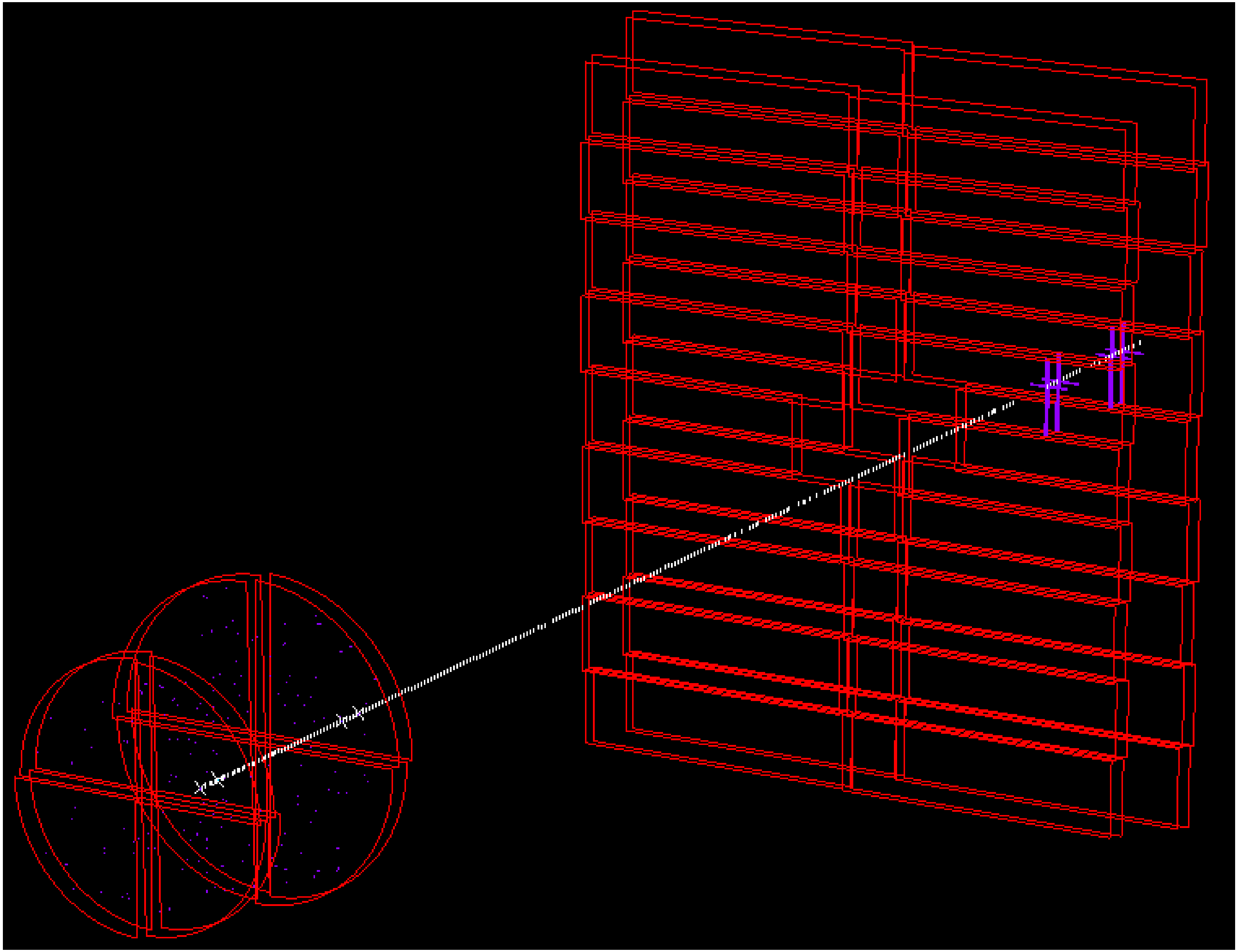
muon filter

First hits and tracks in ALICE muon arm June 2008

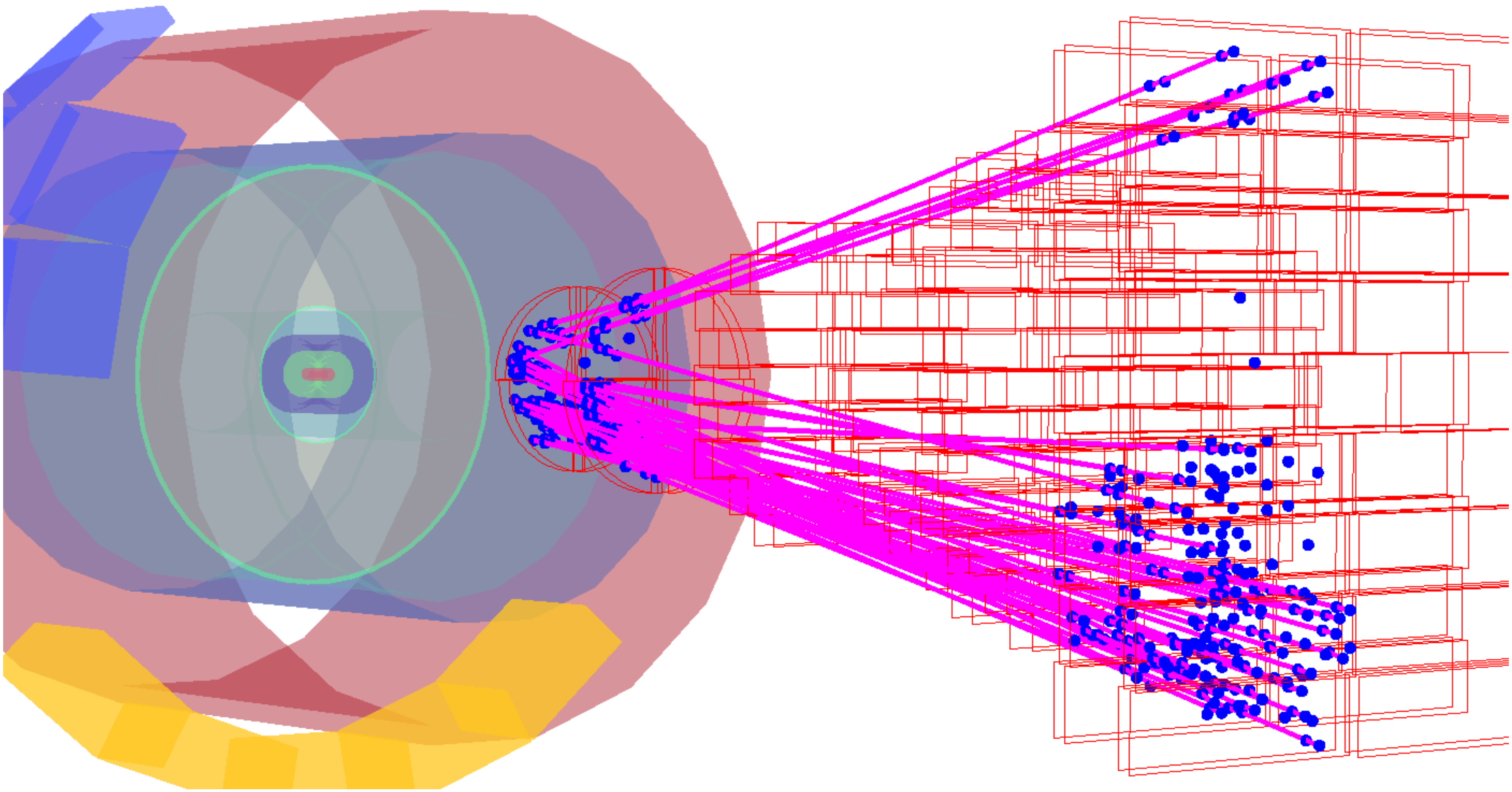
vulpescu@clermont.in2p3.fr



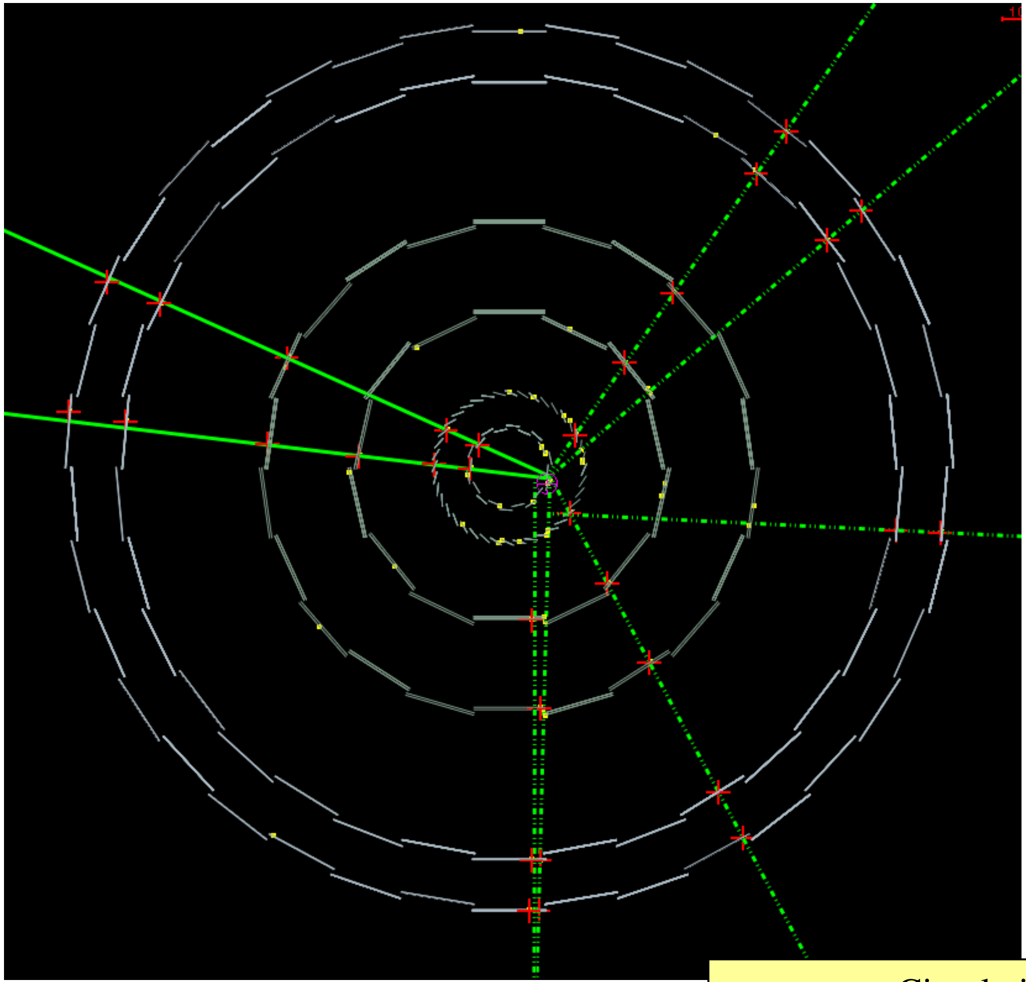
First hits and tracks

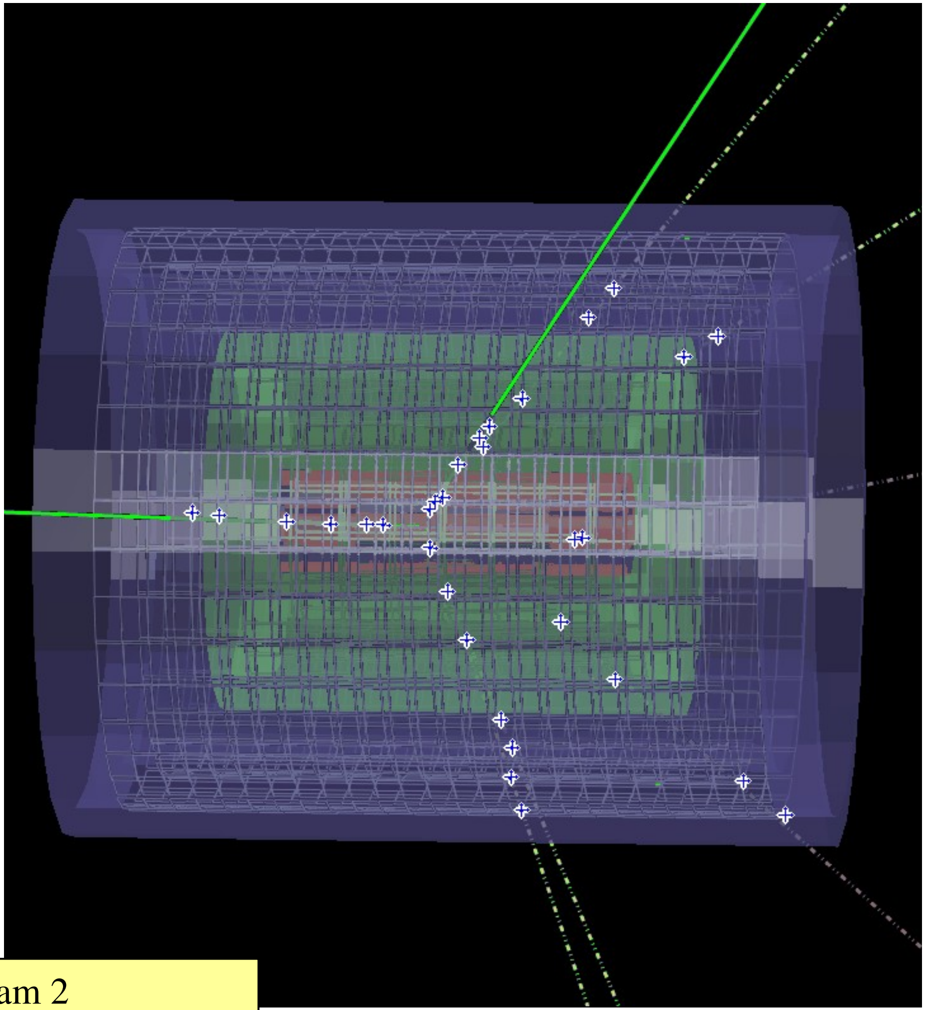


All cosmic tracks



First interactions on Sept 12





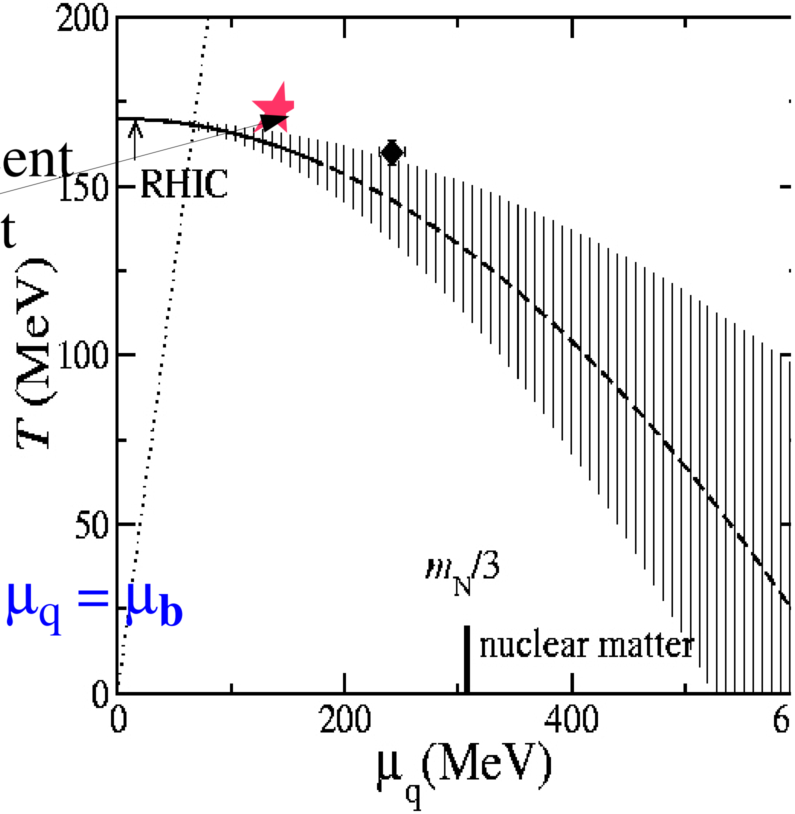
Circulating beam 2
stray particle causing an interaction in the ITS

conclusion

dear Jean,
thank you for your continued support
have some fun with physics in the time to come
and maybe see you again at Heidelberg

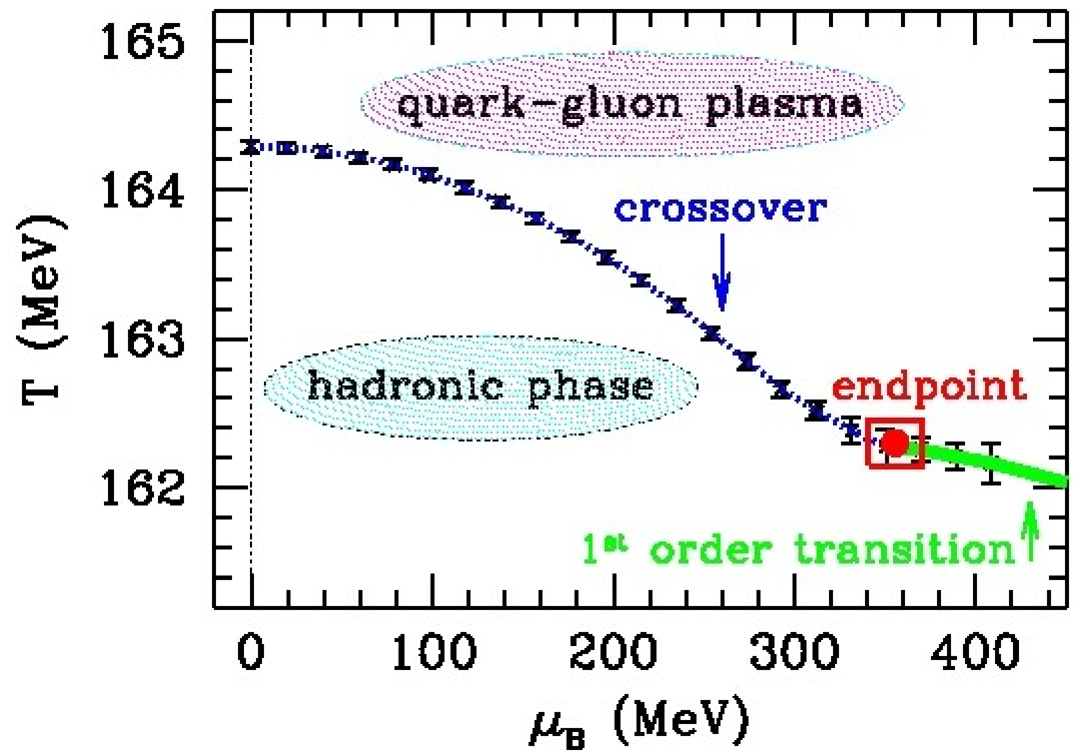
The QCD phase boundary at finite baryon density from lattice QCD

more recent end point



Note: $3\ \mu_q = \mu_b$

S. Ejiri et al, hep-lat/0312006



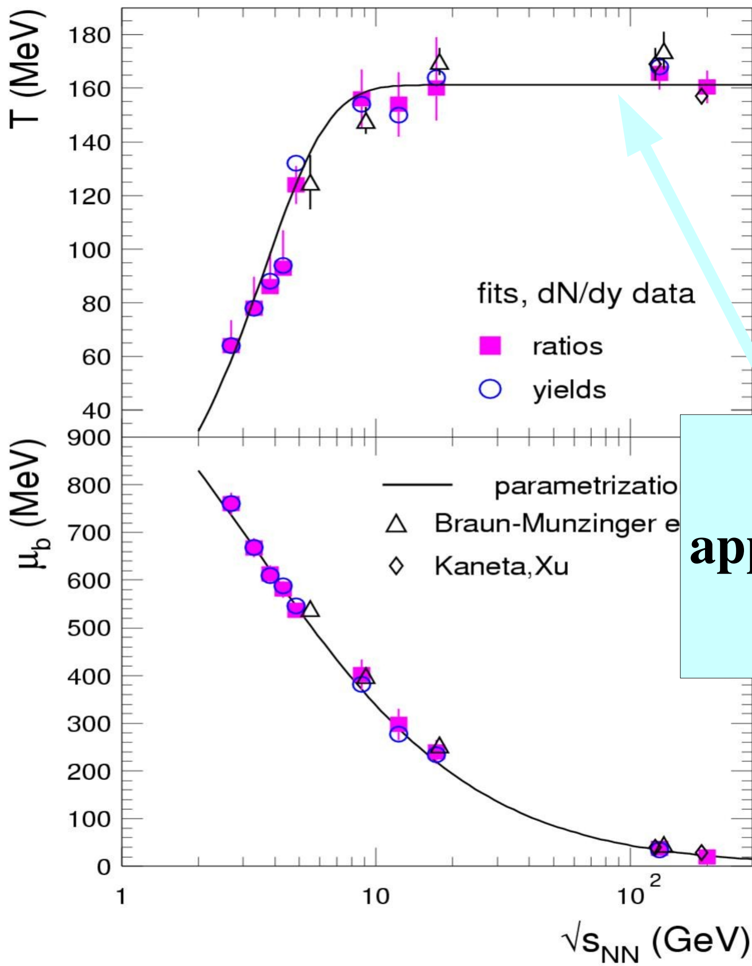
Z. Fodor, S. Katz, JHEP0404, (2004) 050

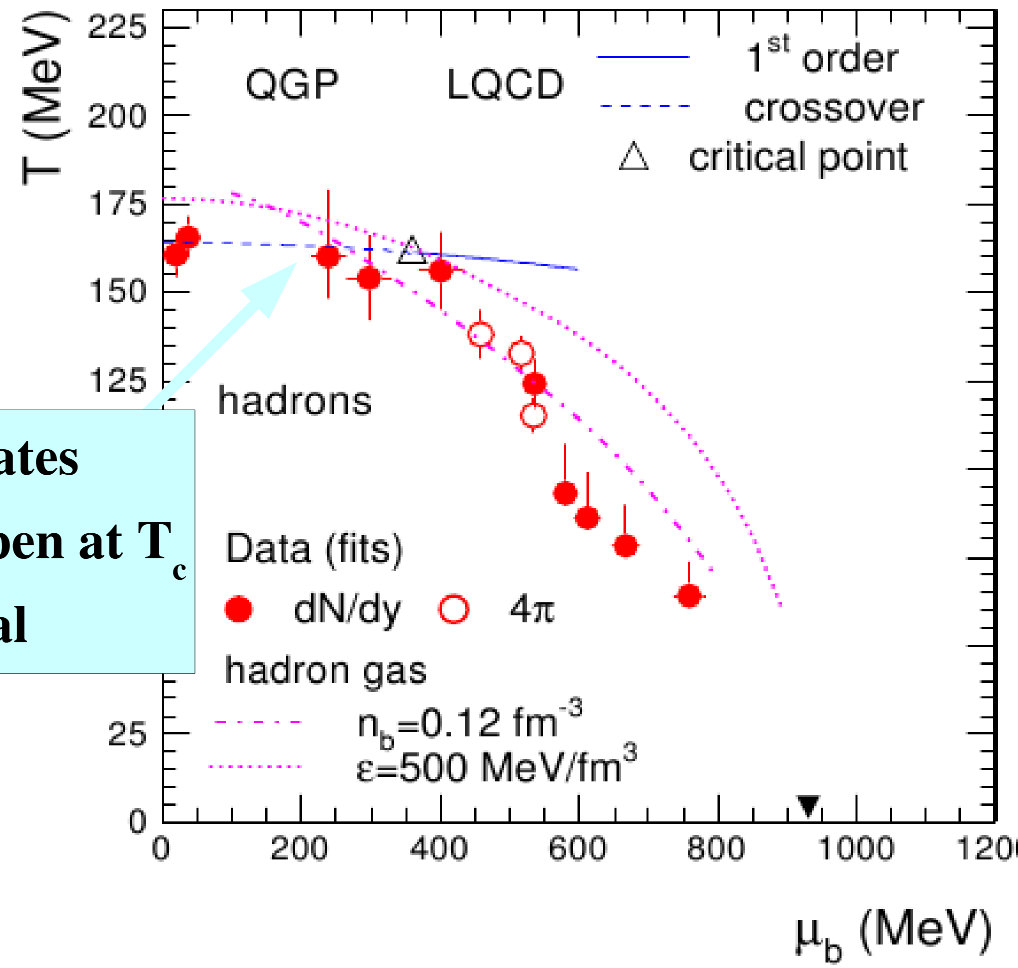
Tri-critical point not (yet) well determined theoretically

Forcrand, Philipsen hep-lat/0607017: maybe no critical end point

hadrochemical freeze-out points and the phase diagram

A. Andronic, P. Braun-Munzinger, J. Stachel, Nucl. Phys. A772 (2006) 167



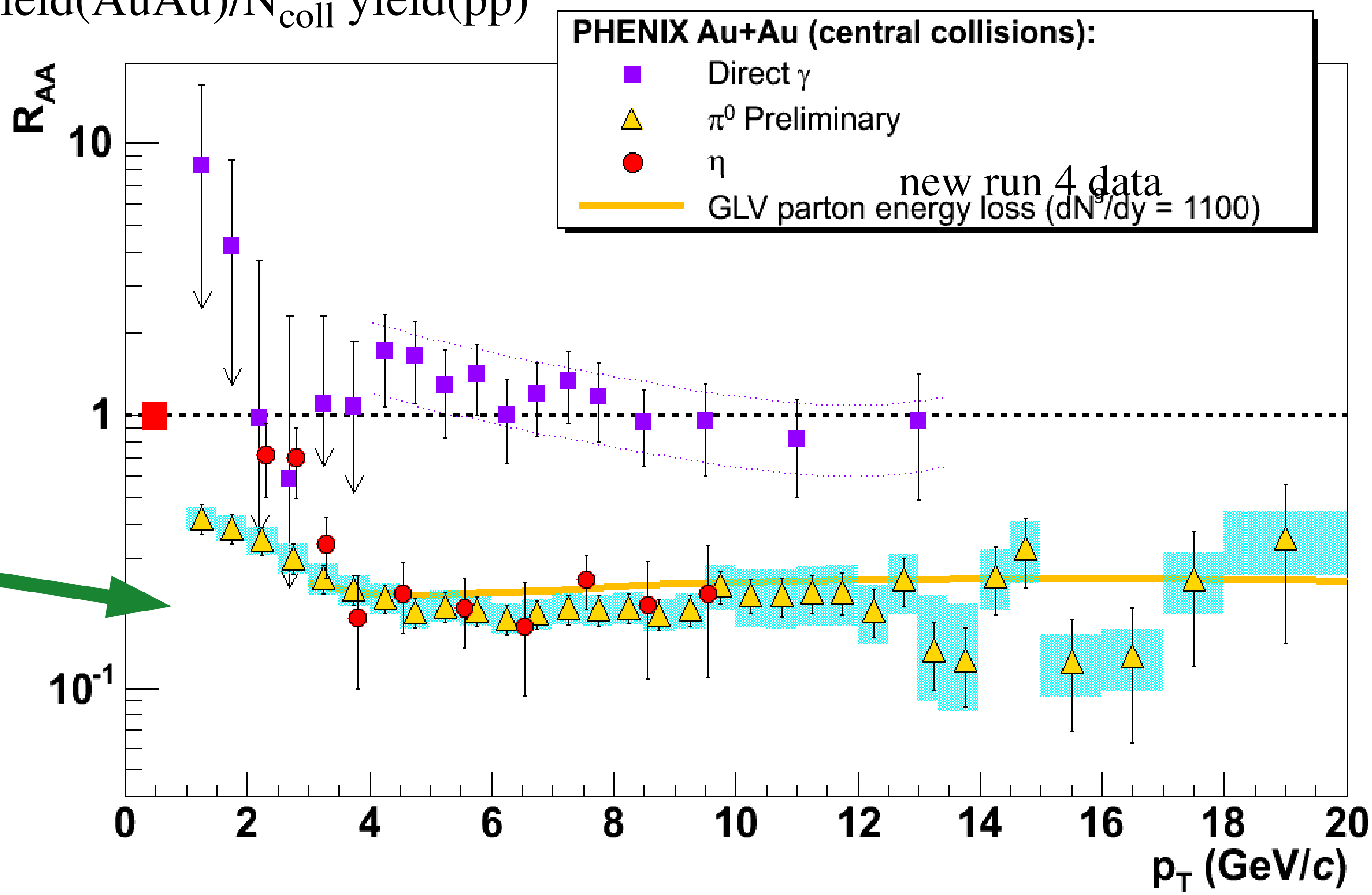


T_{chem} saturates appears to happen at T_c not trivial

expectations for LHC: again equilibrium, same $T=T_c$=165 MeV, very small μ_b
interesting question: what about strongly decaying resonances –
sensitive to existence of hadronic fireball after hadronization of QGP

RHIC result: jet quenching

R_{AA}=yield(AuAu)/N_{coll} yield(pp)



high gluon density of the plasma induces energy loss of partons most calculations based on radiation

photons: $R_{AA} \simeq 1$ initial hard interactions understood

jet quenching indicative of high gluon rapidity density

I. Vitev, JPG 30 (2004) S791

	$\tau_0[fm]$	$T[MeV]$	$\varepsilon[GeV/fm^3]$	$\tau_{tot}[fm]$	dN^g/dy
SPS	**0.8**	**210-240**	**1.5-2.5**	**1.4-2**	**200-350**
RHIC	**0.6**	**380-400**	**14-20**	**6-7**	**800-1200**
LHC	**0.2**	**710-850**	**190-400**	**18-23**	**2000-3500**

- **Consistent estimate with hydrodynamic analysis**

several mechanisms describe jet quenching at RHIC -> predictions for LHC span very wide range

- R_{AA} stays at 0.2 out to 100 GeV or so
- R_{AA} rises slowly toward high pt
- R_{AA} much smaller than at RHIC

need to cover large p_t range

go beyond leading particle analysis

identified jets, frag. function, ...