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Experiments NA49 at the CERN SPS and STAR at RHIC

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Study of Ultrarelativistic Nucleus–Nucleus Collisions

- production of a droplet of superdense matter (several hundred fm^3 size, $\approx 10^{-22}$ sec lifetime)
- search for onset of deconfinement in PbPb collisions at CERN–SPS energies
- study of properties of deconfined matter in AuAu collisions at RHIC

present conclusions from SPS experiments:

In central Pb+Pb collisions at the top SPS energy:

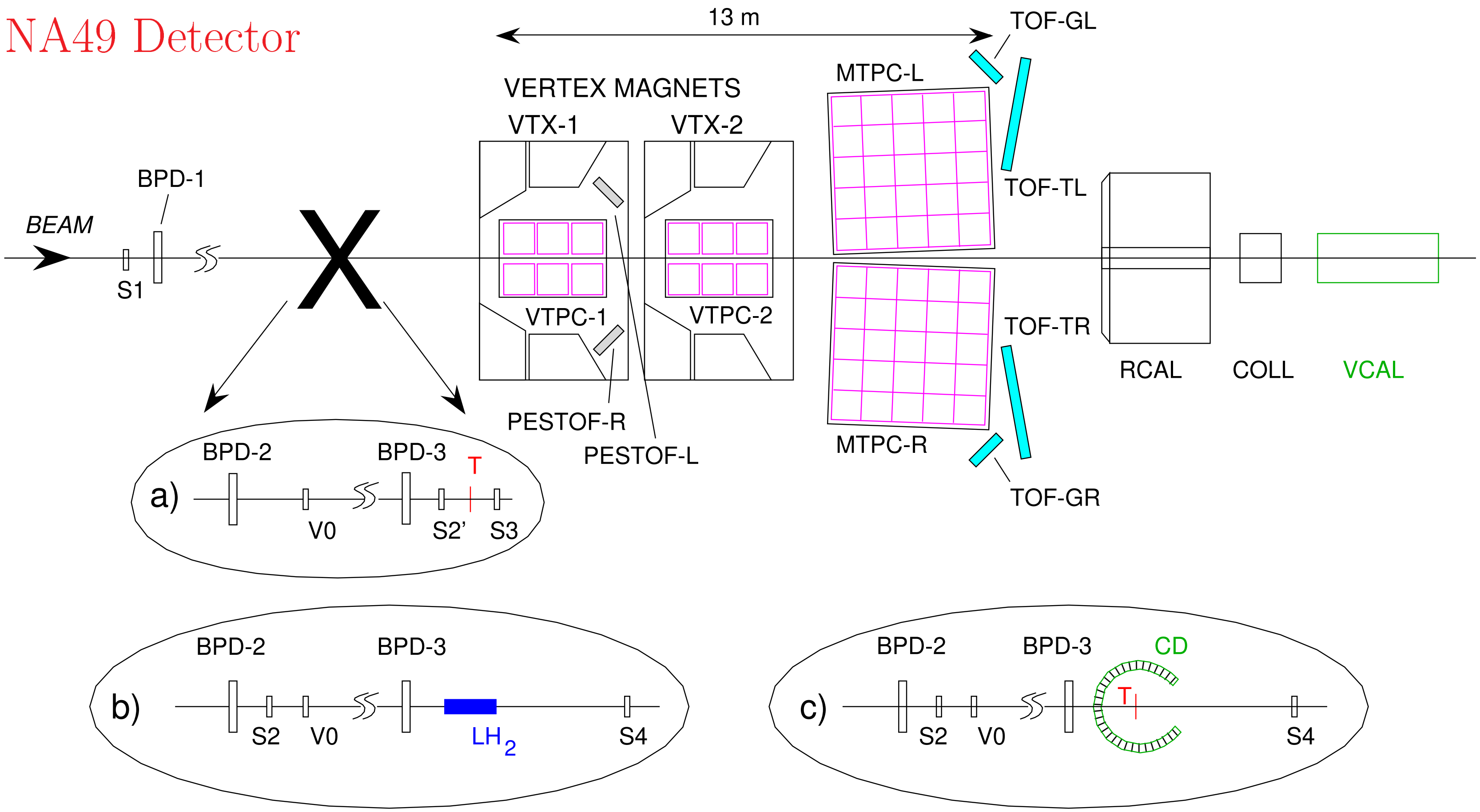
- within most model scenarios the data imply that the initial energy density exceeds the critical value of deconfinement
- strong indications of rapid flavor and kinetic equilibration
- originally proposed signatures of the QGP were observed (J/Ψ suppression, strangeness enhancement, ...), but their significance is under renewed discussion
- no observational evidence for a sharp QGP $\rightarrow$ hadron phase transition (mixed phase, critical fluctuations, DCC, parity violation, ...)

have we really achieved deconfinement at the SPS ?

try to locate the onset of deconfinement at the SPS

- energy scan between 20 - 158 A·GeV
- centrality and system size dependence of observables
- evolution pp $\rightarrow$ pPb $\rightarrow$ PbPb

The NA49 Detector



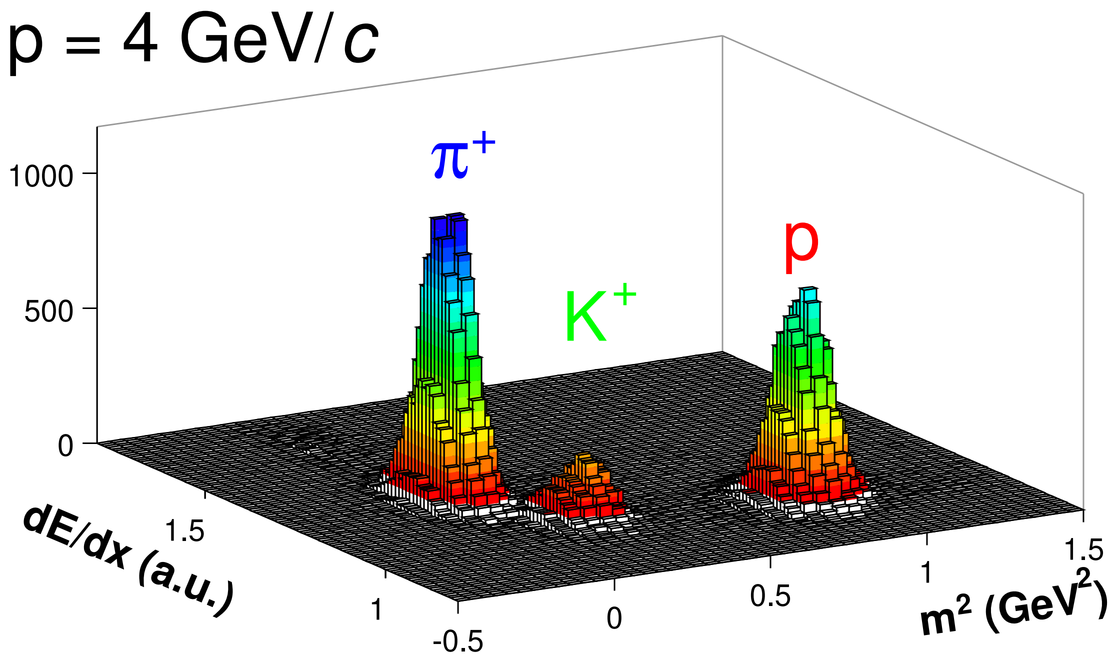
- large acceptance hadron spectrometer
- tracking (TPCs), particle identification (dE/dx,TOF)
- centrality selection (VCAL, CD - slow proton detecor)

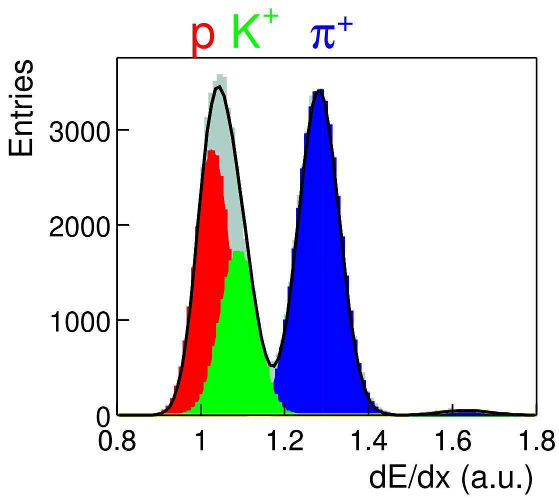
energy	centrality	$\langle N_{part} \rangle$
40 A·GeV	7.2%	349±5
80 A·GeV	7.2%	349±5
158 A·GeV	5.0%	362±5

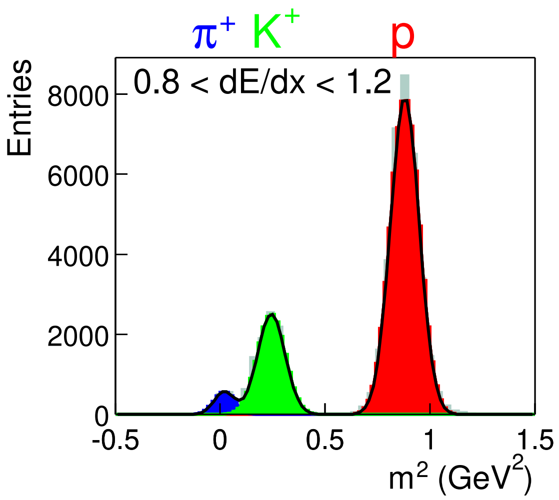
particle identification by dE/dx and TOF

- dE/dx measurement in TPCs for $Y > Y_{CM}$
  resolution 3-4 %
- TOF measurement around midrapidity
  resolution 60 ps

example at 40 A·GeV :

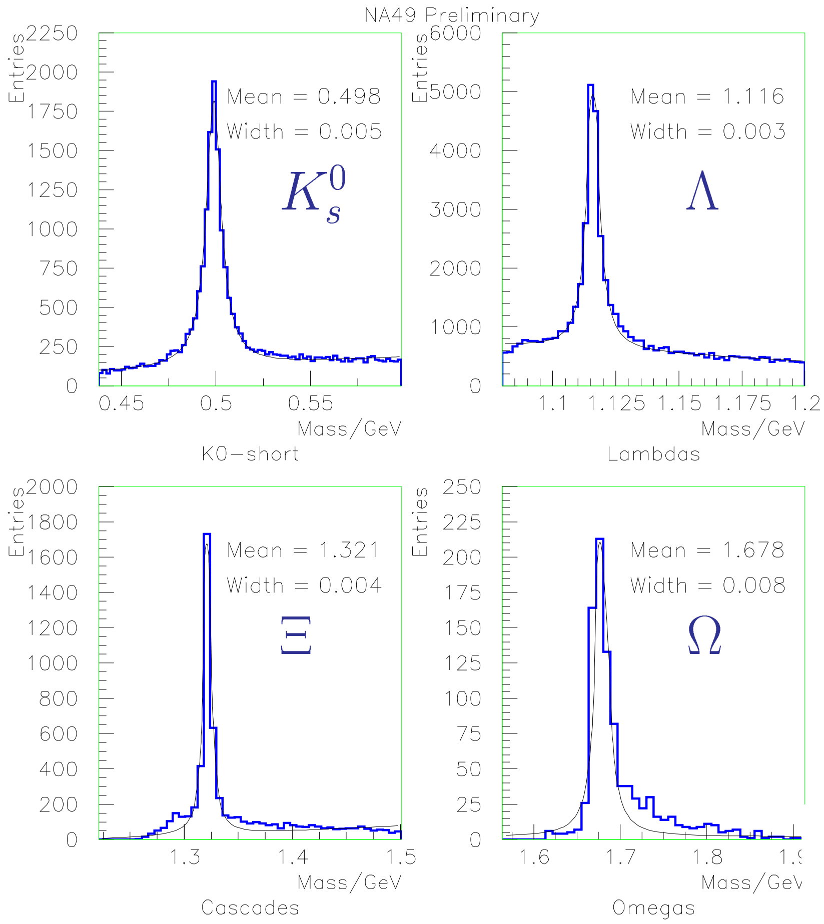


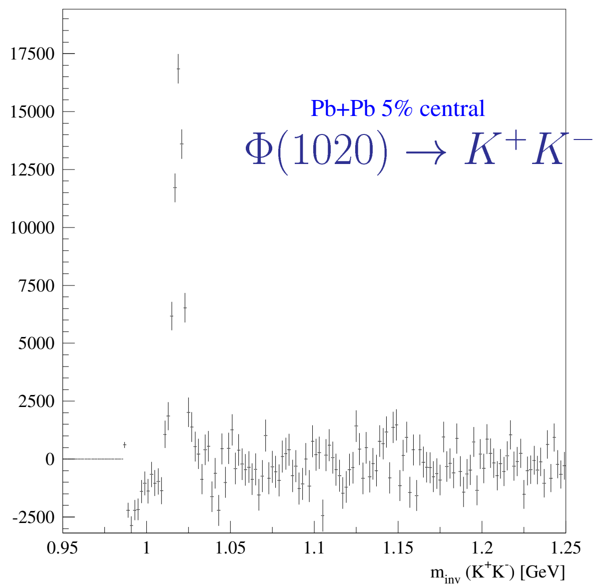


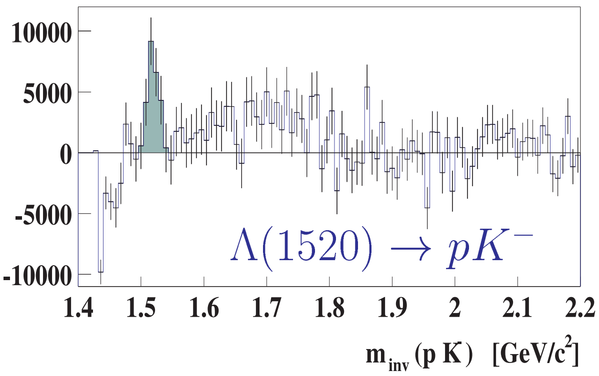


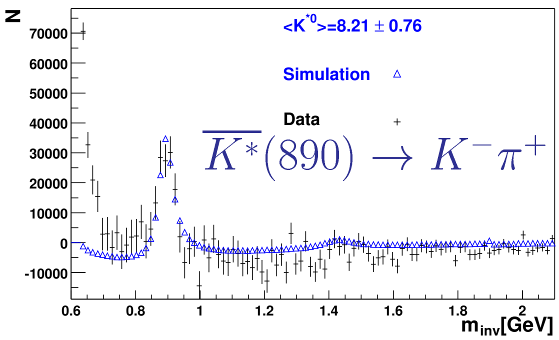
identification from decay topology and invariant mass

- excellent momentum resolution $\Delta p/p^2 \approx 3{\cdot}10^{-5}(GeV/c)^{-1}$

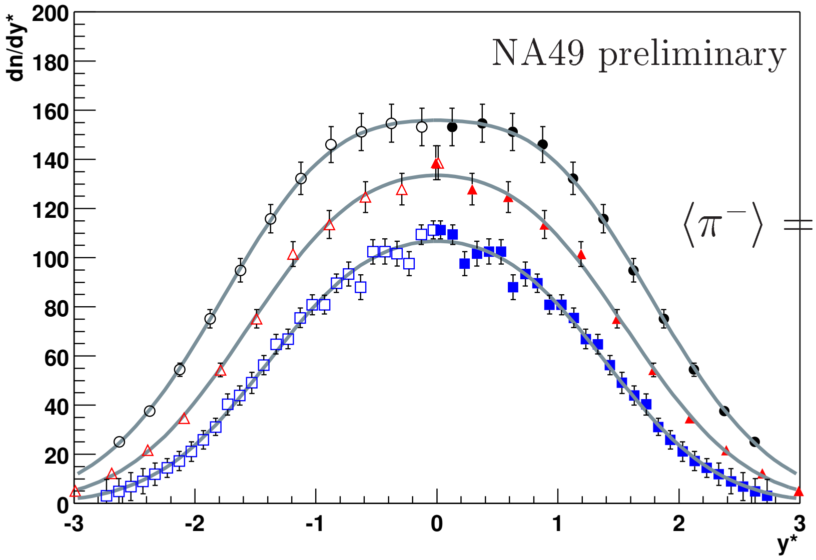








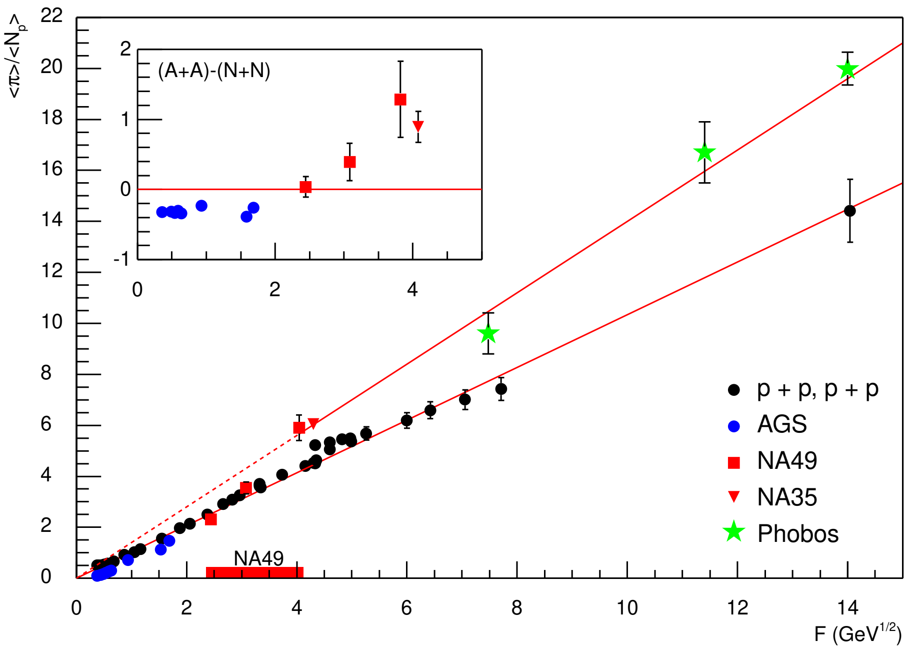
Pion Production in central PbPb collisions



$$\langle \pi^- \rangle = 610 \pm 30 \text{ at } 158 \text{ A}\cdot\text{GeV}$$
$$445 \pm 22 \qquad 80$$
$$312 \pm 15 \qquad 40$$

- dominant produced particle species at SPS, RHIC
- measure of entropy in a statistical model description

$$\frac{\langle \pi \rangle}{N_{part}}$$



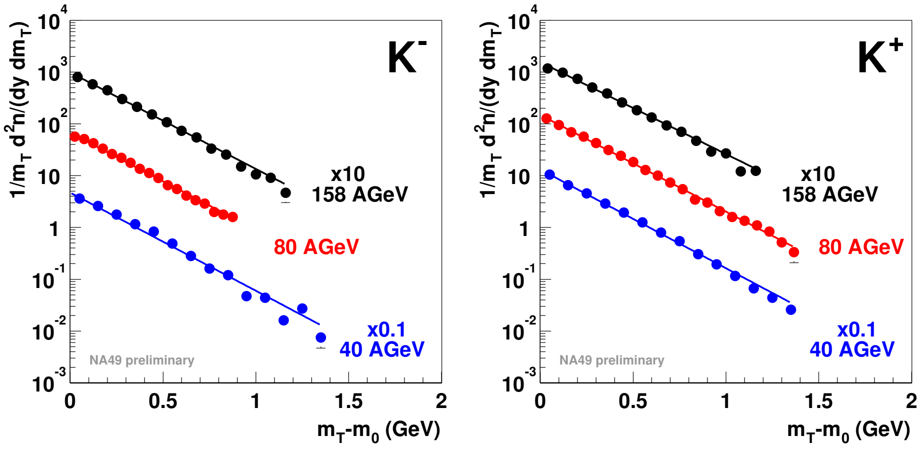
$$F = (\sqrt{s} - 2m_p)^{\frac{3}{4}} / (\sqrt{s})^{\frac{1}{4}} \approx s^{\frac{1}{4}}$$

change from pion suppression to pion enhancement
at low SPS energies

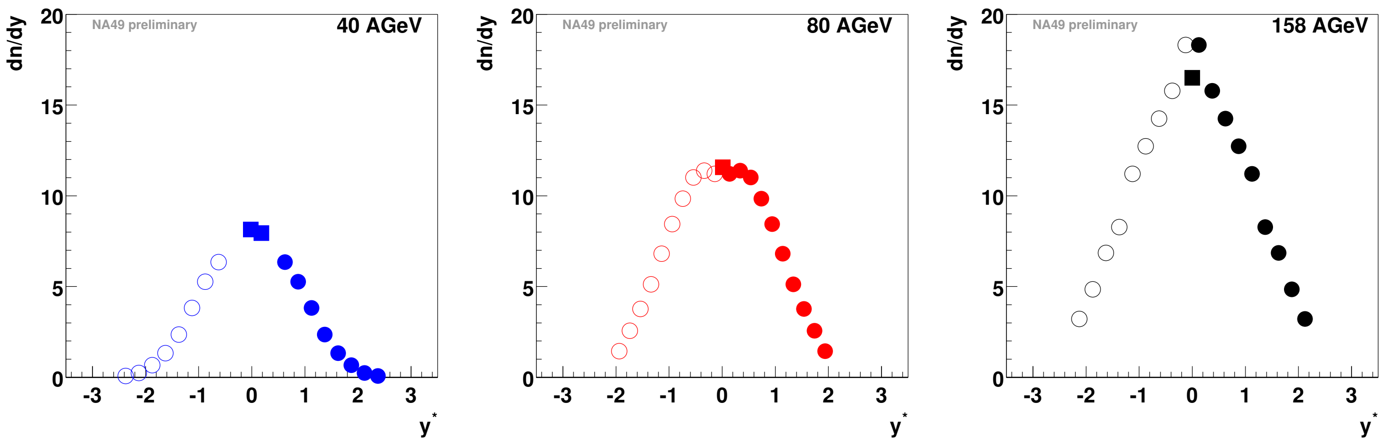
Kaon Production in central PbPb collisions

- Kaons contain 75 % of $s, \bar{s}$ quarks at SPS energies
- provide a measure of the total strangeness content

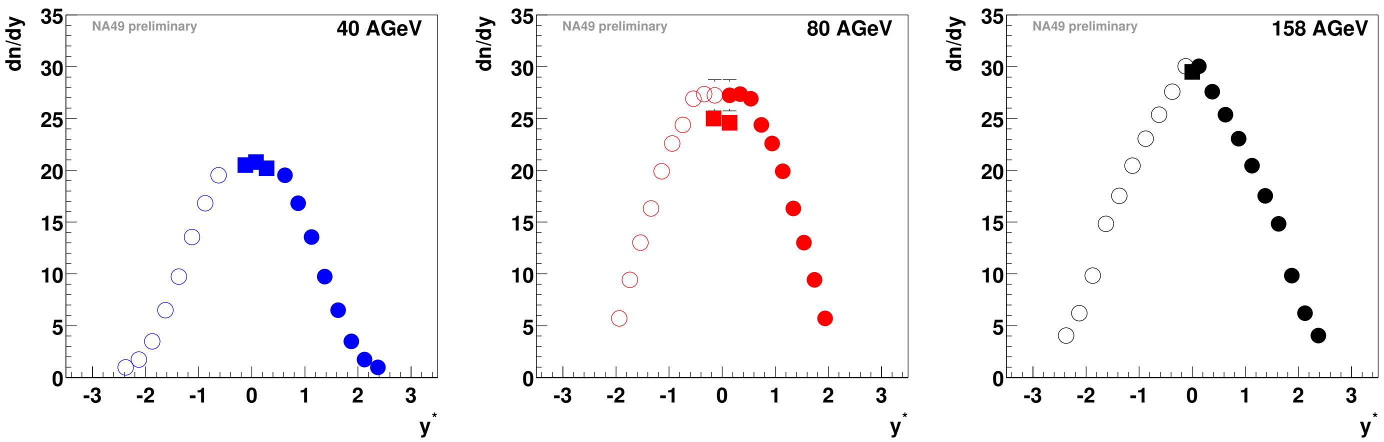
inverse slopes T = 220 – 240 MeV



$\langle K^- \rangle = 18 \pm 1$ $\quad 29 \pm 2$ $\quad 50 \pm 5$



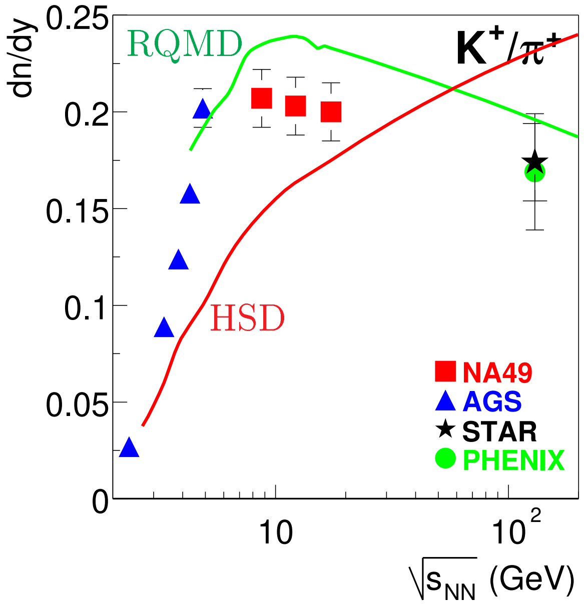
$\langle K^+ \rangle = 56 \pm 3$ $\quad 79 \pm 5$ $\quad 95 \pm 9$

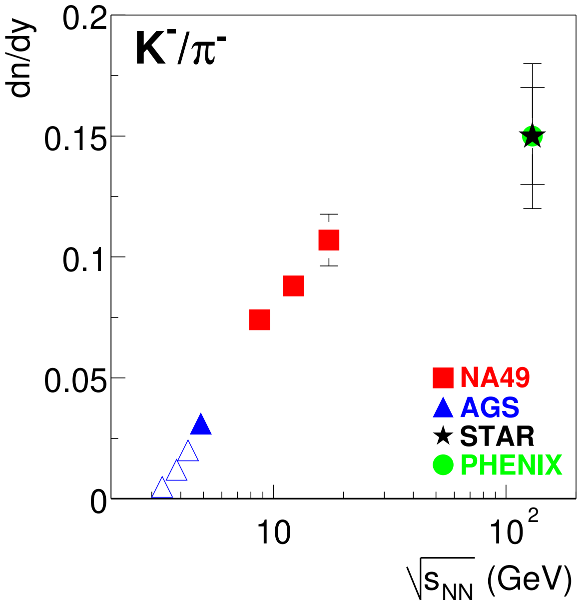


Energy dependence of Kaon Production

ratio of kaon to pion production at midrapidity :

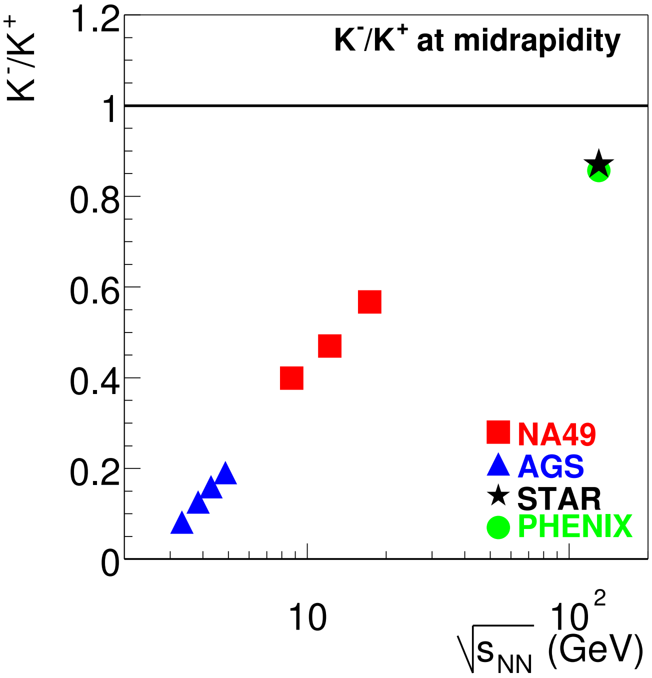
- K^+/π^+ seems to go through a maximum
- K^-/π^- increases monotonically





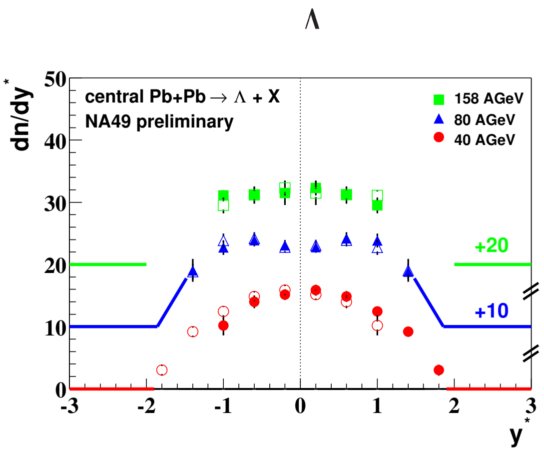
K^-/K^+ ratio at midrapidity :

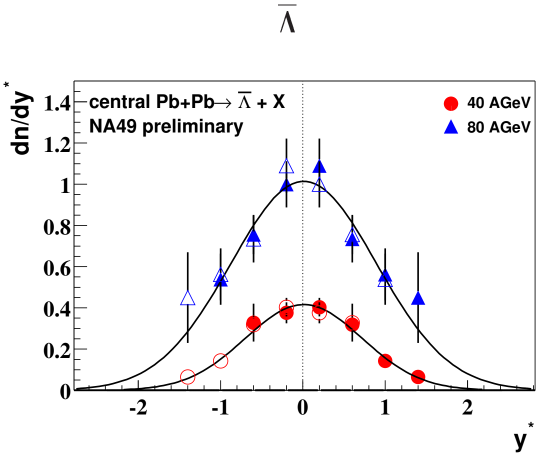
- increase reflects the decreasing baryon density



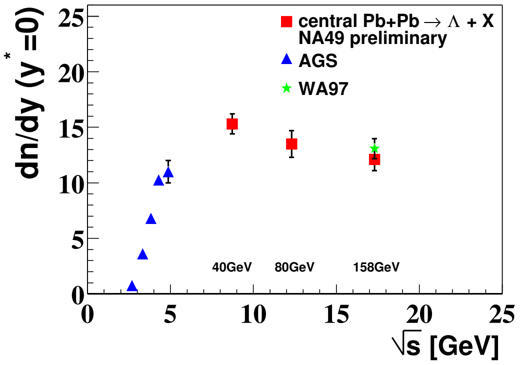
$\Lambda, \bar{\Lambda}$ Production in central PbPb collisions

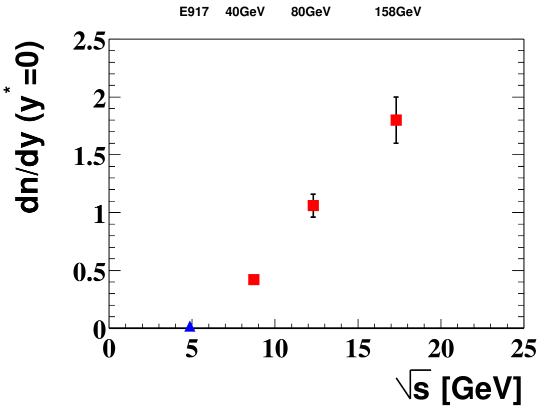
- rapidity distributions:



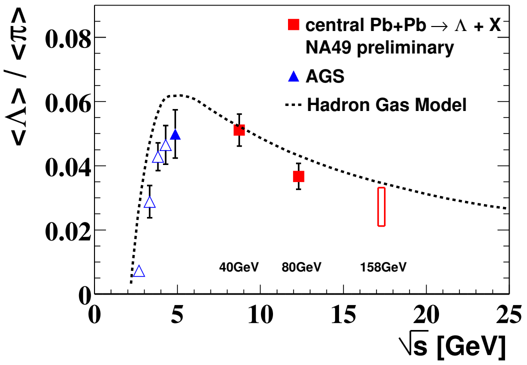


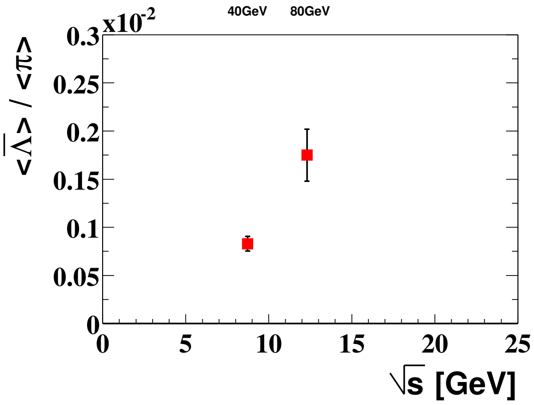
- midrapidity yields:





- 4π multiplicity ratios:



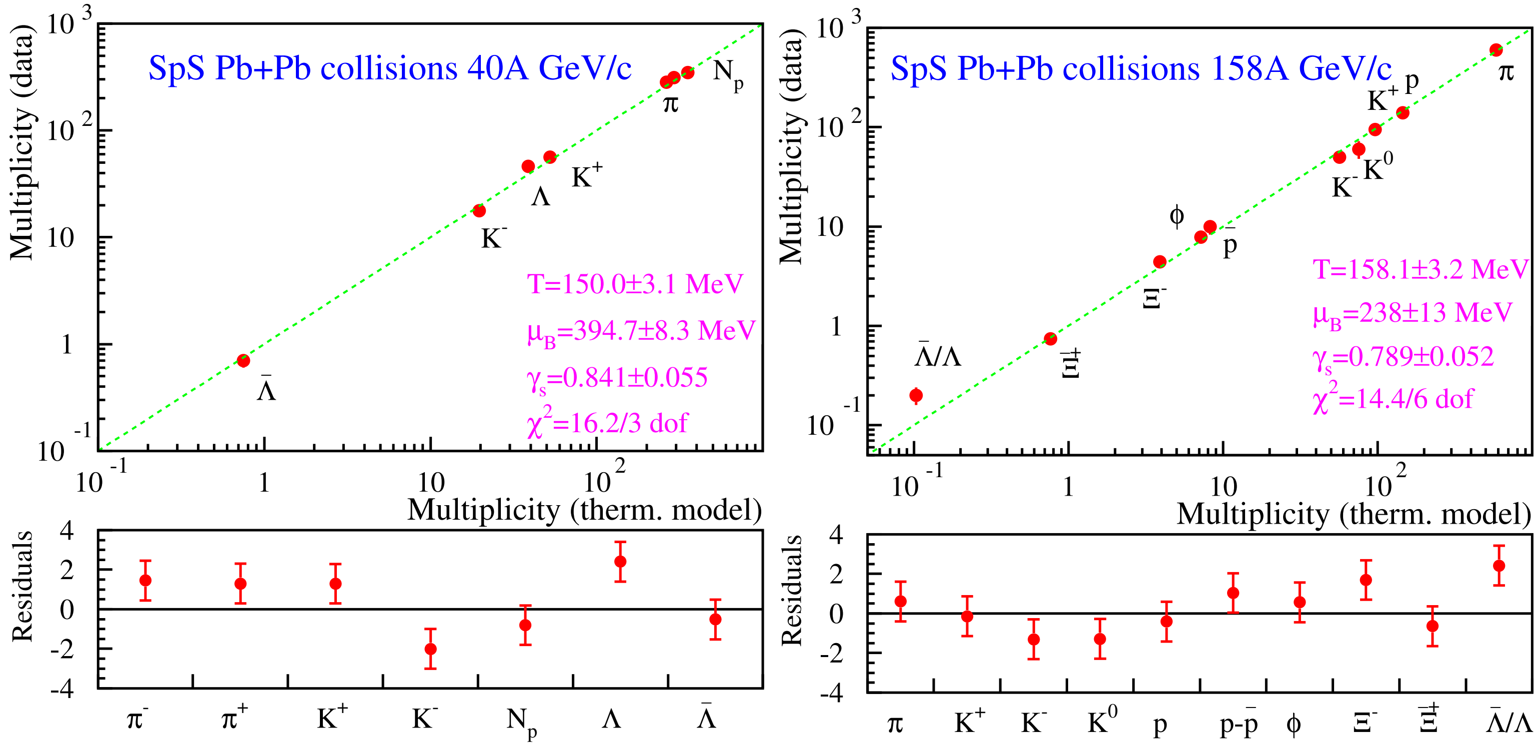


- $\langle \Lambda \rangle / \langle \pi \rangle$ shows maximum related to ρ_B
- $\langle \bar{\Lambda} \rangle / \langle \pi \rangle$ increases steeply due to $B\bar{B}$ production threshold

Statistical Analysis of 4π Particle Yields

parameters of the statistical model: T, μ_B, V

fit by Becattini et al. to (partly preliminary) NA49 data :



- reasonable fit, plausible parameters: $T \approx 150/160 MeV, \mu_B \approx 395/240 MeV$
- strangeness content below hadron gas level

Comparison with Current Models (I)

K^+ contains an $\bar{s}$ quark
$\langle K^+ \rangle \approx \langle K_s^0 \rangle$ $\quad \Rightarrow \quad \langle K^+ \rangle \approx \frac{1}{4} \cdot (\langle s \rangle + \langle \bar{s} \rangle)$
$Y\bar{Y}$ production small at SPS

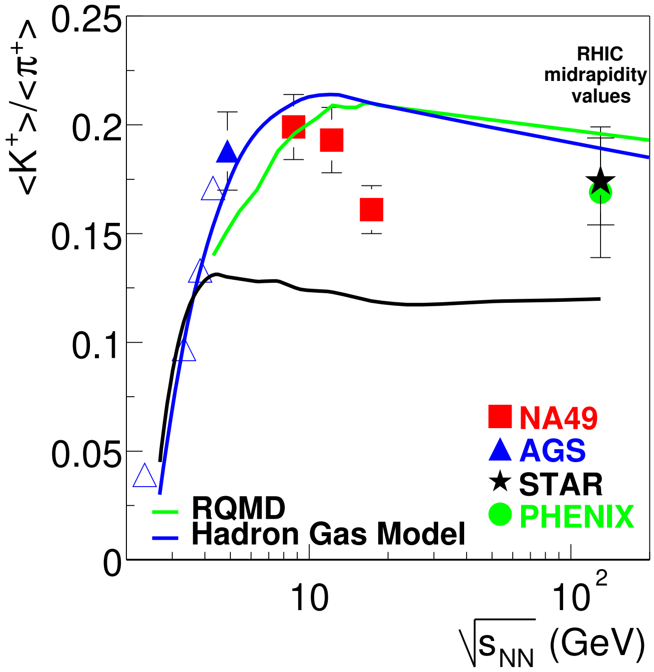
models:

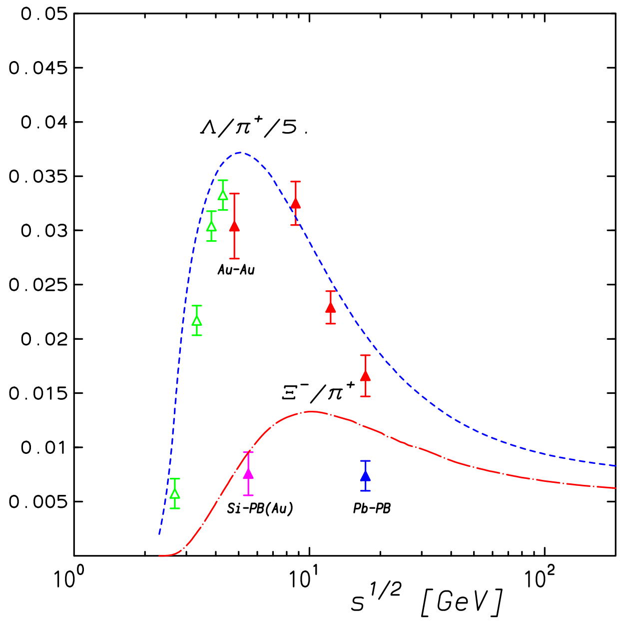
RQMD, UrQMD : strings + fusion + rescattering

statistical model: (Braun-Munzinger,Cleymans,Oeschler,Redlich)

μ_B from parameterised energy dependence
T from universal (μ_B,T) relation $\langle E \rangle / \langle N \rangle \approx 1$ GeV

4π multiplicities



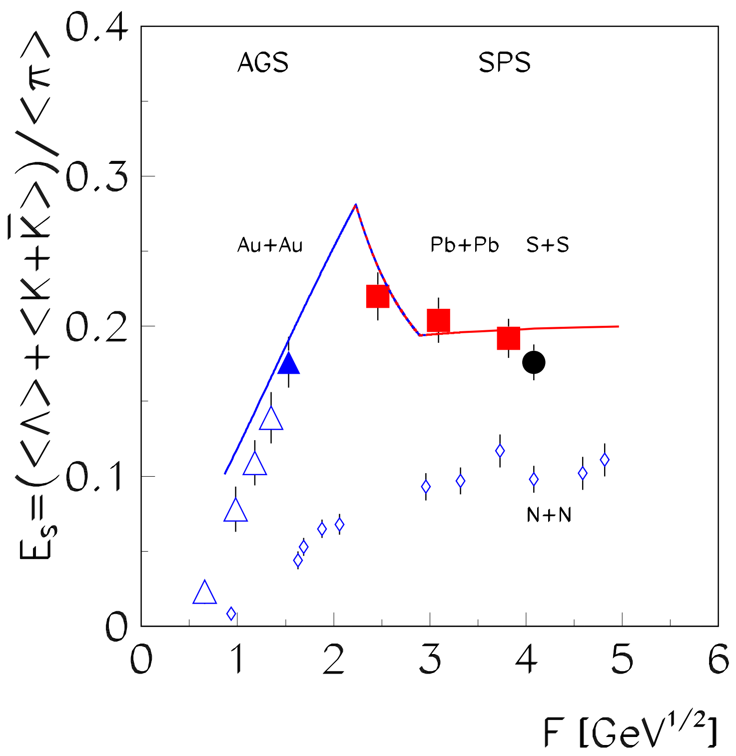


- strangeness undersaturation (K^+, Ξ^-) at top SPS energy not well reproduced
- strong peak in Λ/π caused by interplay of production threshold and decreasing μ_B

Comparison with Current Models (II)

Statistical model of the early stage: (Gazdzicki,Gorenstein)

- strangeness to entropy ratio established in the initial stage of the reaction (for deconfinement below the value for hadron gas of same temperature)
- assuming entropy conservation this ratio can be measured via E_s at the end of the reaction
- saturation of E_s a generic feature of deconfinement when T $> m_s, m_q$



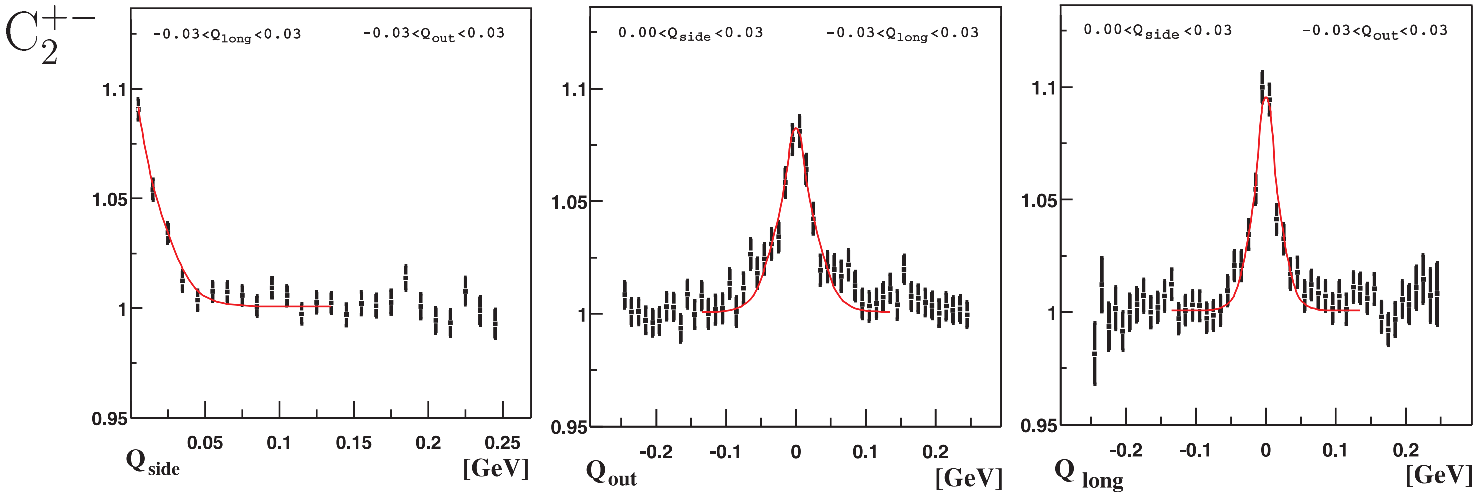
starting in the SPS energy range the NA49 data indicate the strangeness to entropy ratio of deconfined matter

Correlations of Pion Pairs

provide information on the size and internal dynamics
of the fireball at freezeout

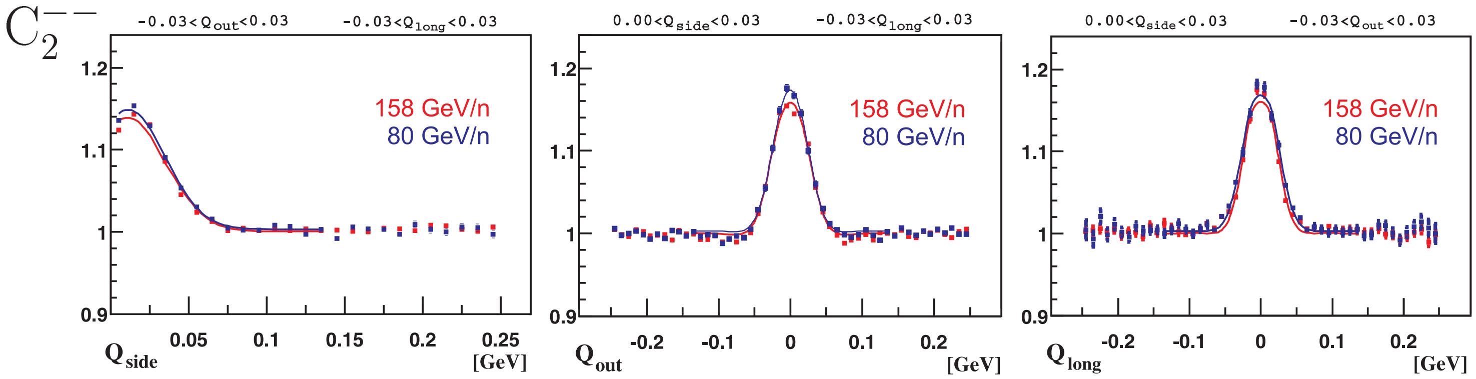
cartesian decomposition of $Q = p_1 - p_2$ into longitudinal(beam), side(transverse) and out(pair momentum) components

$\pi^+\pi^-$ Coulomb correlation (40 A·GeV, 0.1$\leq K_T \leq$0.2 GeV/c)



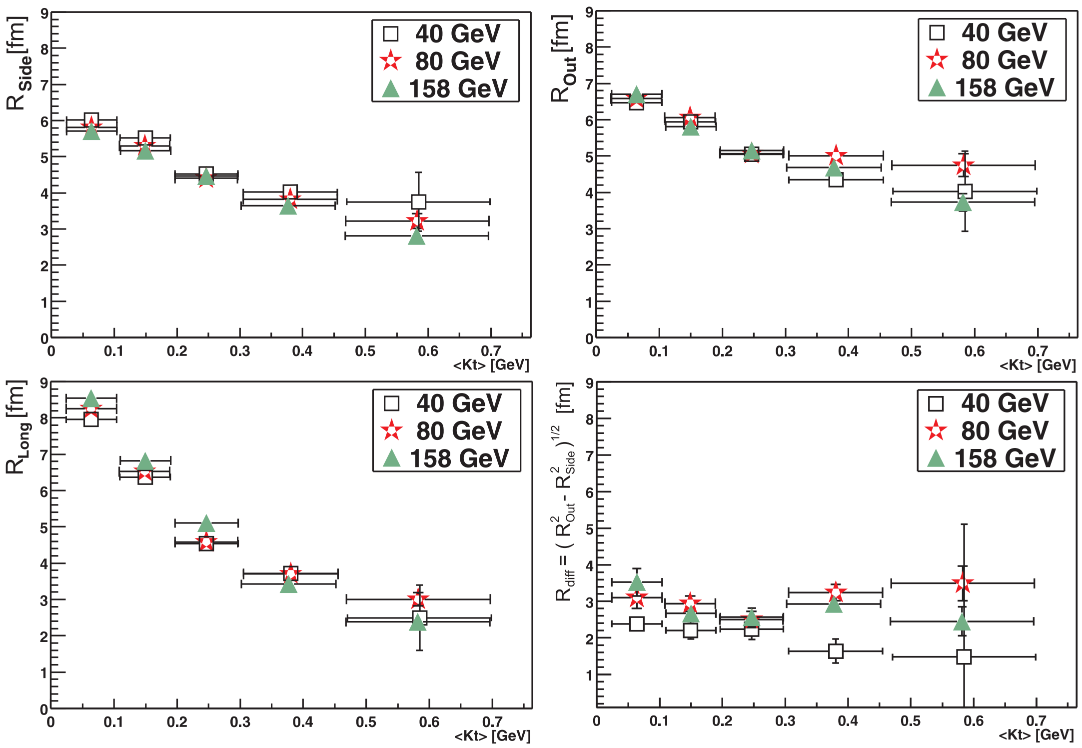
finite source size Coulomb wave calculation fits
$\pi^+\pi^-$ correlation (Sinyukov et al.,Phys.Lett.B432(1998),248)

$\pi^-\pi^-$ BE+Coulomb correlation ($y_{cm} \leq y \leq y_{cm}$+0.5 , 0.1$\leq K_T \leq$0.2 GeV/c)

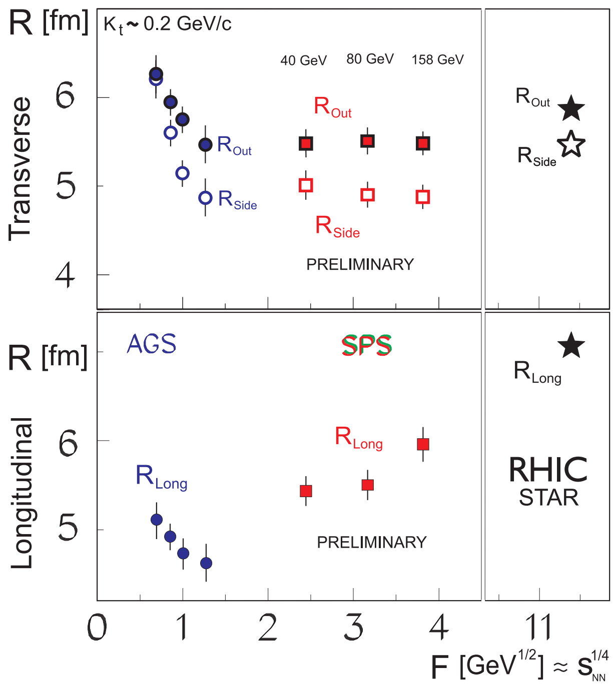


$$C_2 = C_{coul} \cdot \{1 + \lambda \cdot exp(-R^2_{side}Q^2_{side} - R^2_{out}Q^2_{out} - R^2_{long}Q^2_{long}$$
$$-2R_{out,long}Q_{out}Q_{long})\}$$

fitted radius parameters at midrapidity: (NA49 preliminary)



- similar values at 40, 80, 158 A·GeV (syst.err.≈ 0.5 fm)
- $R_{diff} \approx \Delta\tau \frac{T}{\sqrt{2M_T}}$ small → no long-lived mixed phase

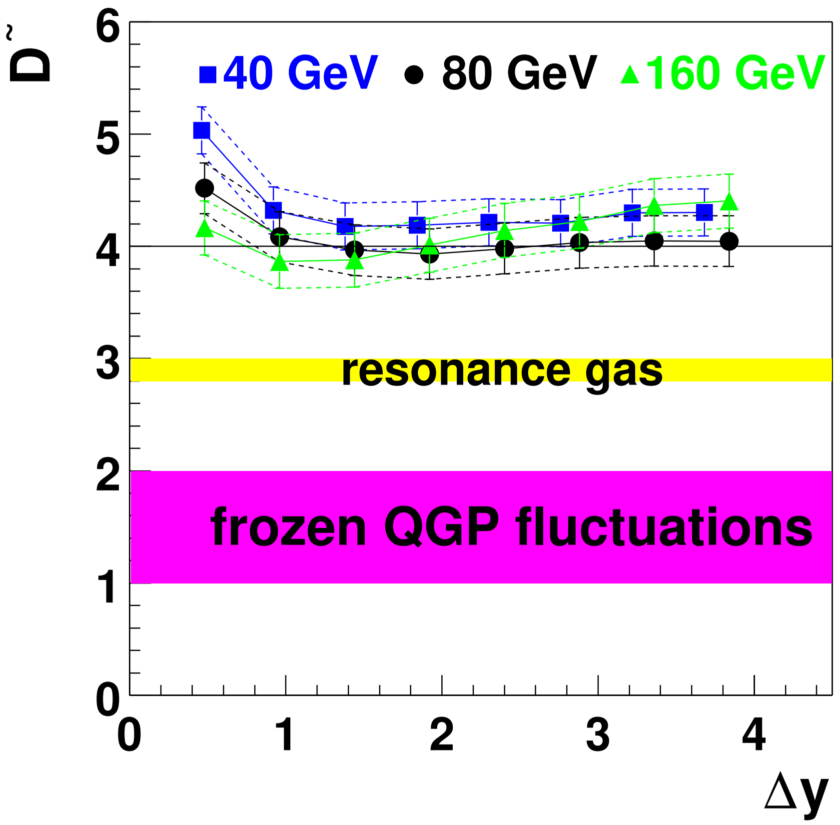


- $R_{long} \approx \tau\sqrt{\frac{T}{M_T}}$ (τ lifetime of fireball) increases with $\sqrt{s}$

Charge Fluctuations

- proposal of S.Jeon and V.Koch PRL 85(2000) 2076
  fluctuations of $R = N_+/N_-$ defined via
  $$D = (\langle R^2\rangle - \langle R\rangle^2) \cdot \langle N_{ch}\rangle$$
- corrections for residual charge : $C_\mu = \langle N_+\rangle^2/\langle N_-\rangle^2$
  global charge conservation : $C_y = 1 - \langle N_{ch}\rangle/\langle N_{ch}\rangle_{total}$

$$\tilde{D} = \frac{\langle \delta R^2\rangle \cdot \langle N_{ch}\rangle}{C_\mu \cdot C_y}$$



- no significant change in the SPS energy range
- consistent with independent particle emission + global charge conservation
- predicted reduction due to resonances ??
- can small QGP fluctuations survive hadronisation ?

Anisotropic Flow in non-central Collisions

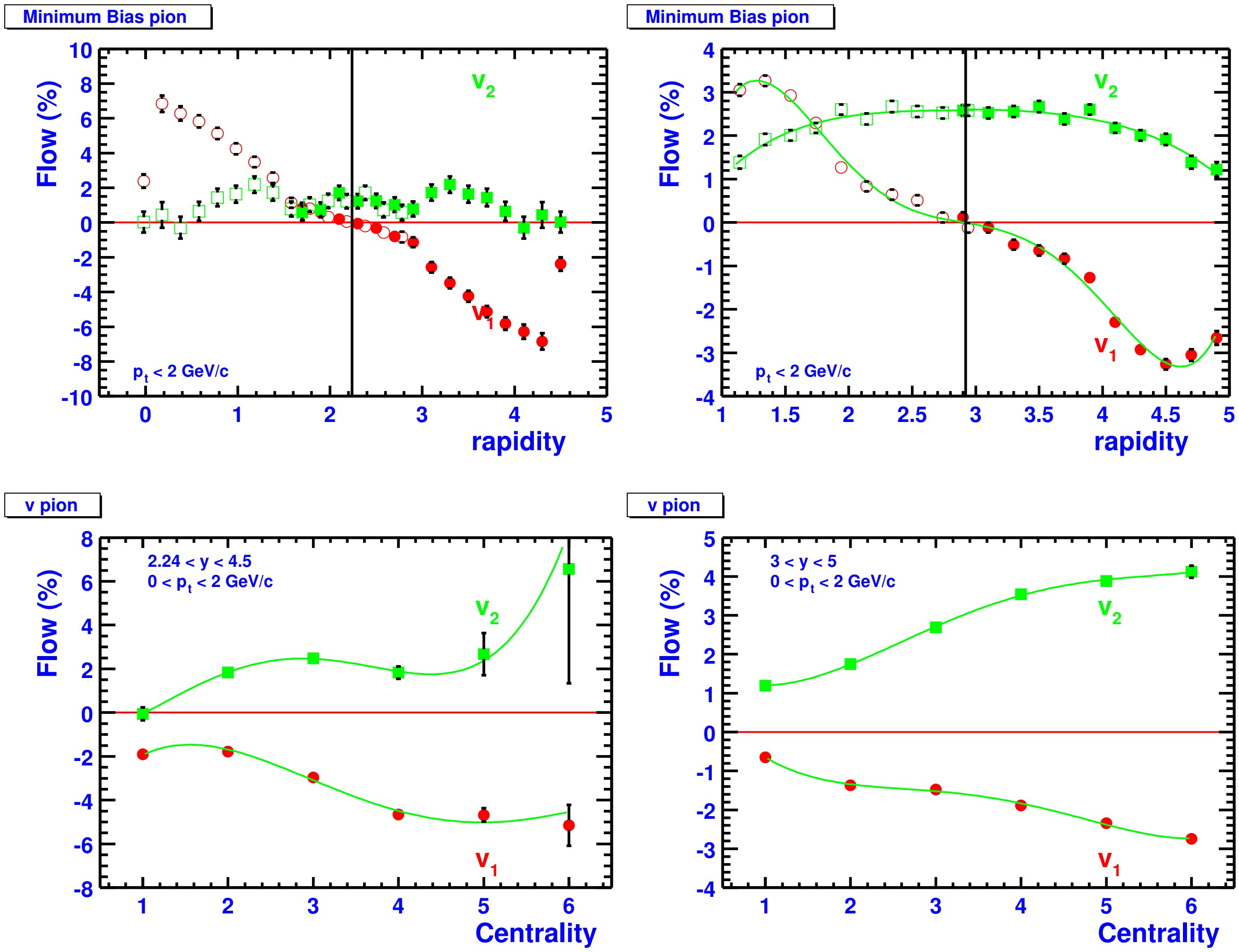
sensitive to pressure in the early stage of the reaction, self quenching

$$v_n = \langle cos(n(\Phi_i - \Psi_n)) \rangle = \sqrt{2} \langle sin(n \cdot \Phi_i) \cdot sin(n \cdot \Psi_n) \rangle$$

Φ_i particle azimuthal angle, Ψ_n angle of reaction plane

corrections for: reaction plane resolution (Poskanzer,Voloshin)
momentum conservation

40 A·GeV (preliminary) 158 A·GeV



- v_1 decreases 40 $\rightarrow$ 158 A·GeV
- no significant energy dependence for v_2

(factor 2 statistics available at 40 A·GeV)

STAR experiment at RHIC

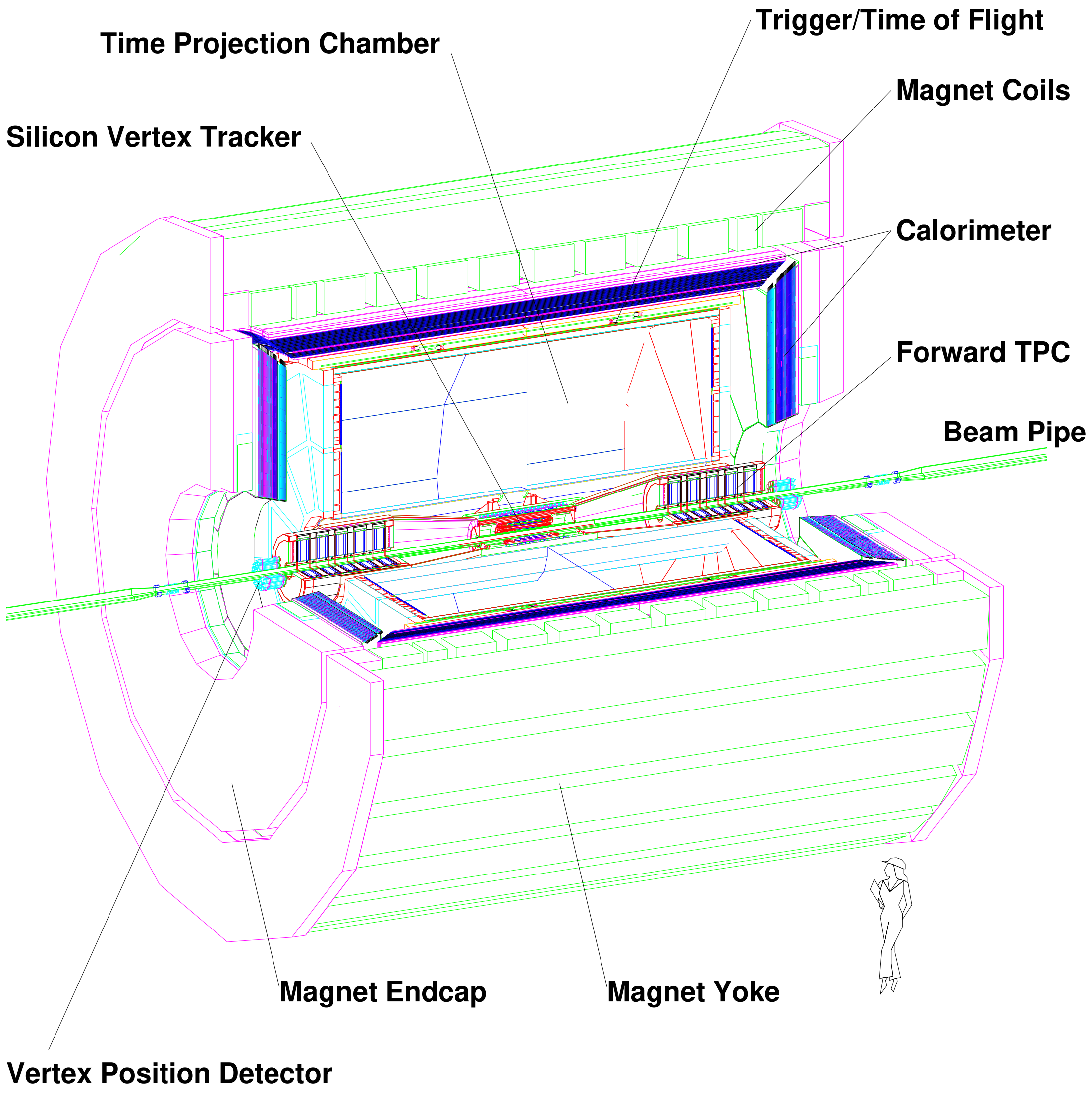
Study of deconfined matter in AuAu collisions

- initial energy density above 6 Gev/fm^3, longer lifetime of fireball
- study of parton energy loss in dense matter

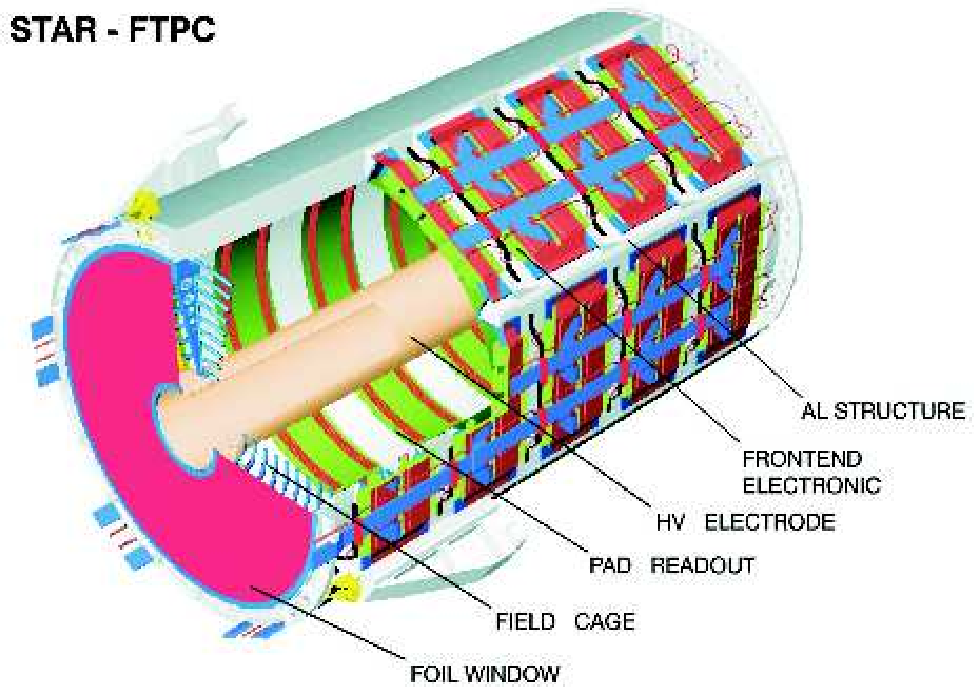
Study of polarised proton collisions

- contribution of gluons, sea quarks to the proton spin:

$$q + g \to q + \gamma \qquad u + \bar{d} \to W^+ \to l^+ + \nu$$



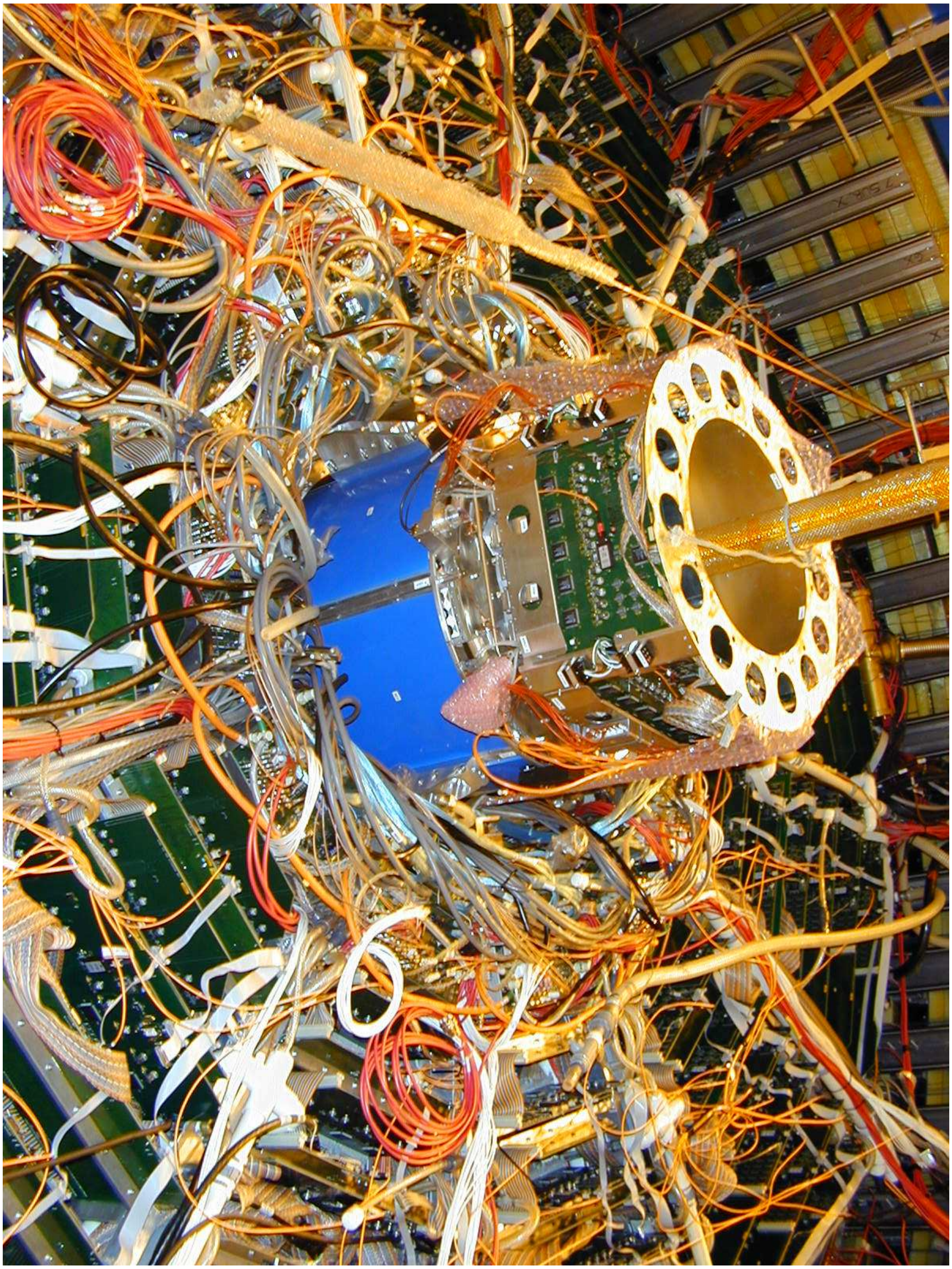
MPI contribution – 2 forward TPC detectors



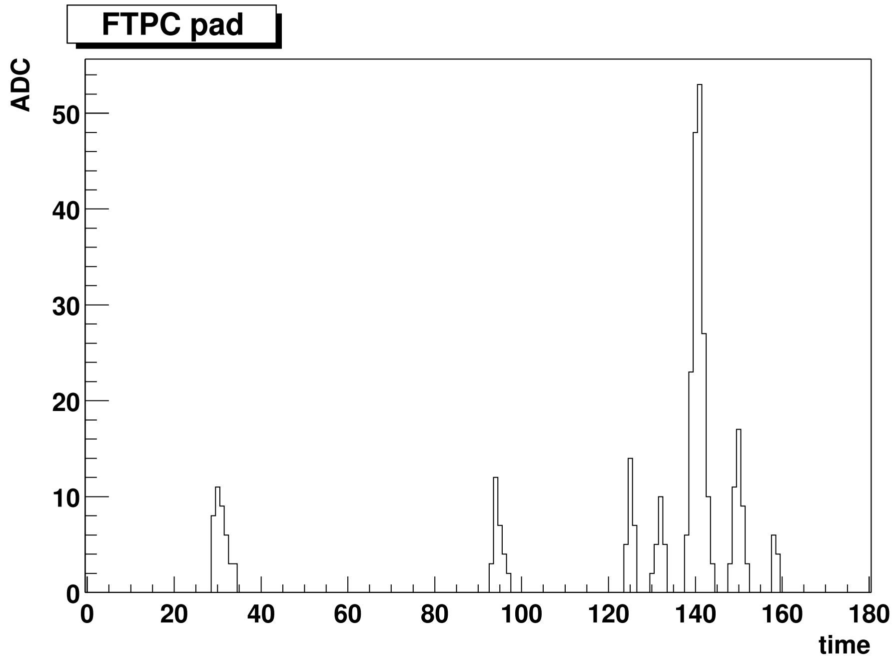
- extend STAR charged particle acceptance by region $2.5 < |\eta| < 4.0$
- charged particle and net proton $(h^+ - h^-)$ spectra, K_s^0 and Λ production, anisotropic flow, fluctuations of $\langle P_T \rangle$, DCC search
- radial electron drift perpendicular to magnetic field
- optimization of 2–track resolution
  - requires cool gas Ar/CO_2 (50%/50%)
  - small readout pads (1.6×20 mm^2), 1 mm gap between anode wires and pad plane
  - 2–track separation of 1-2 mm expected, order of magnitude improvement

design, prototyping and manufacture of detectors
development of calibration and reconstruction software

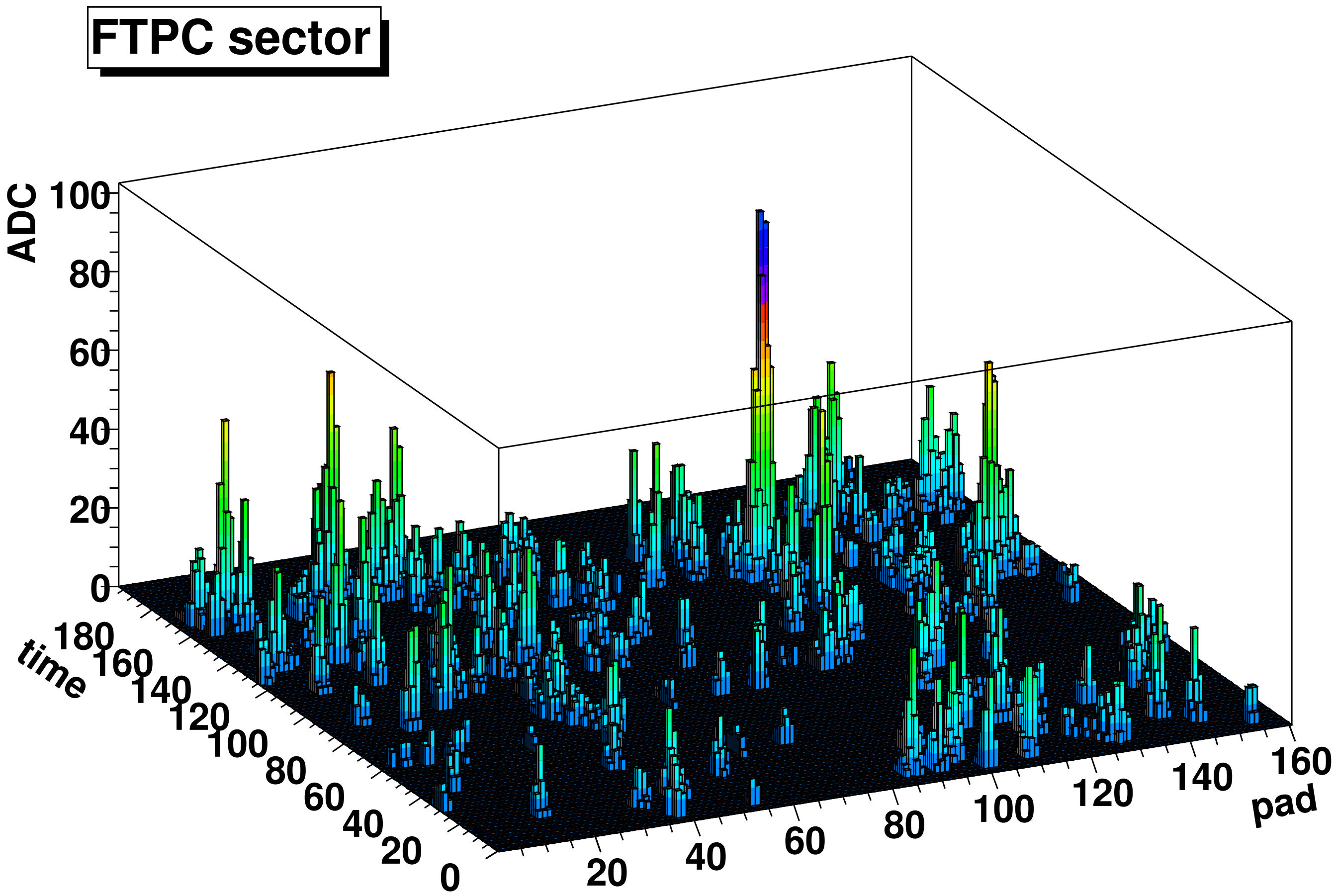
FTPC mounted in the STAR detector



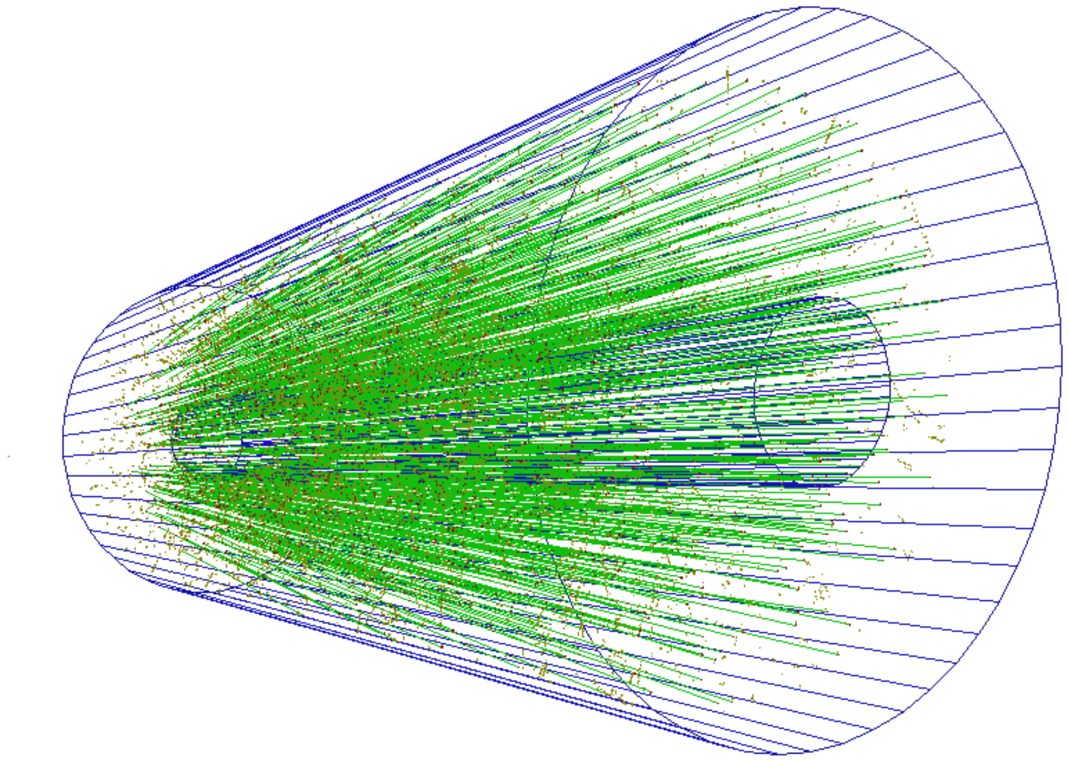
track signals on one pad



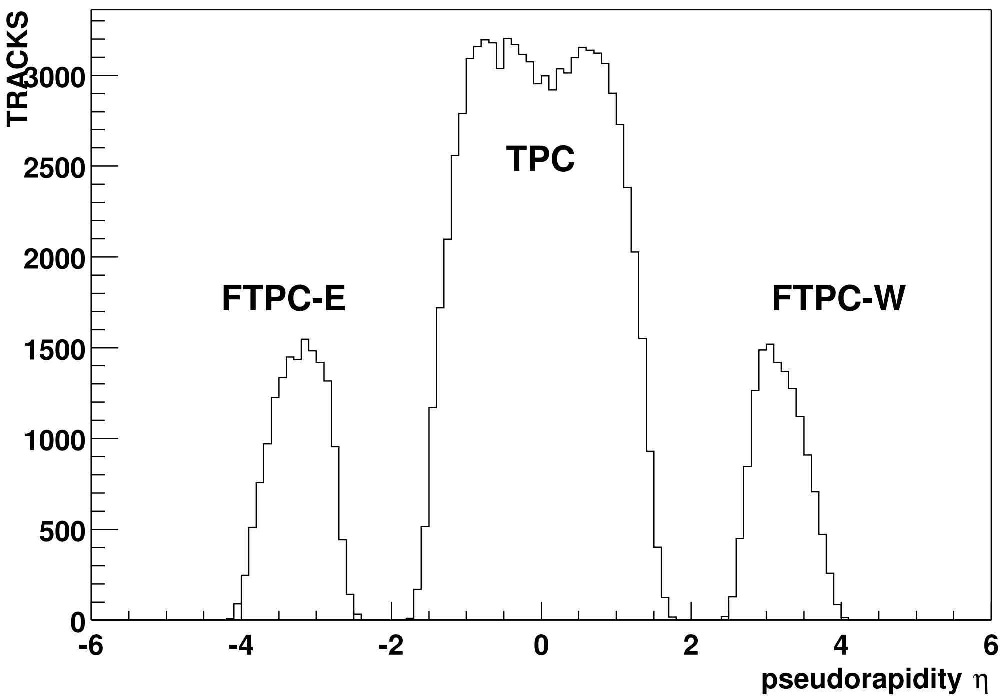
track signals in 1/6 of pad ring



reconstructed FTPC tracks in a central PbPb collision
($\approx$ 500 per FTPC)

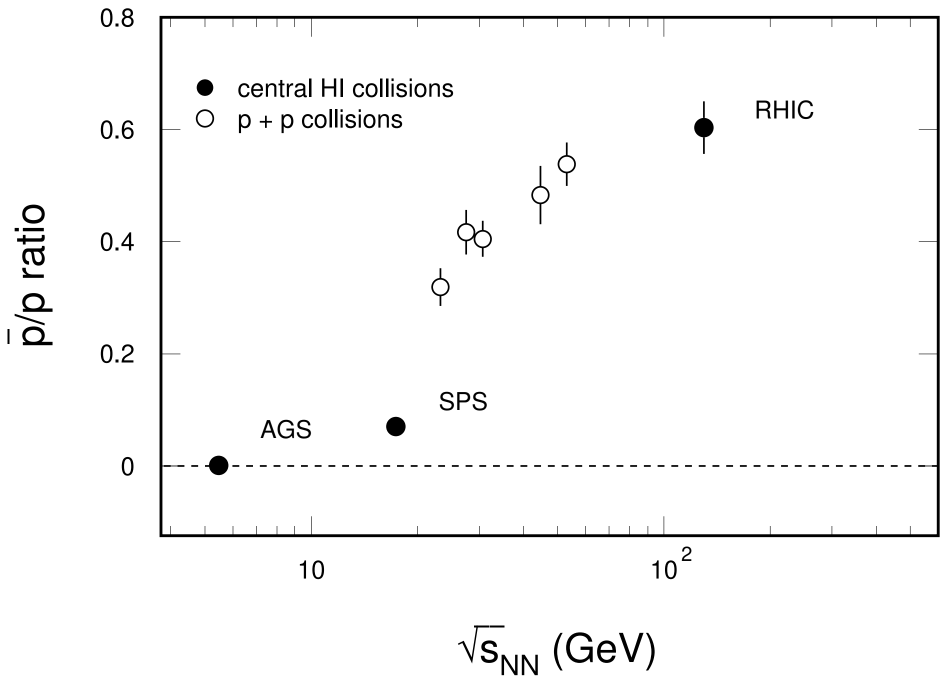


pseudorapidity distribution (very preliminary)



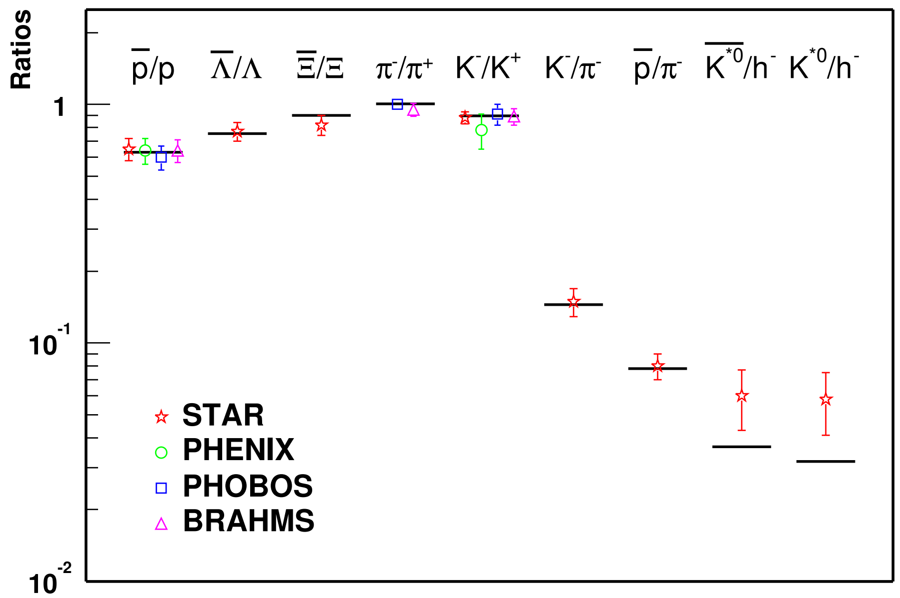
First results from STAR (2 week run in 2000)

$\bar{p}/p$ ratio at midrapidity increases tenfold



small $\mathrm{dN}^{p-\bar{p}}/\mathrm{dy}$, but $\mathrm{dN}^{p+\bar{p}}/\mathrm{dy}$ increases by factor 2

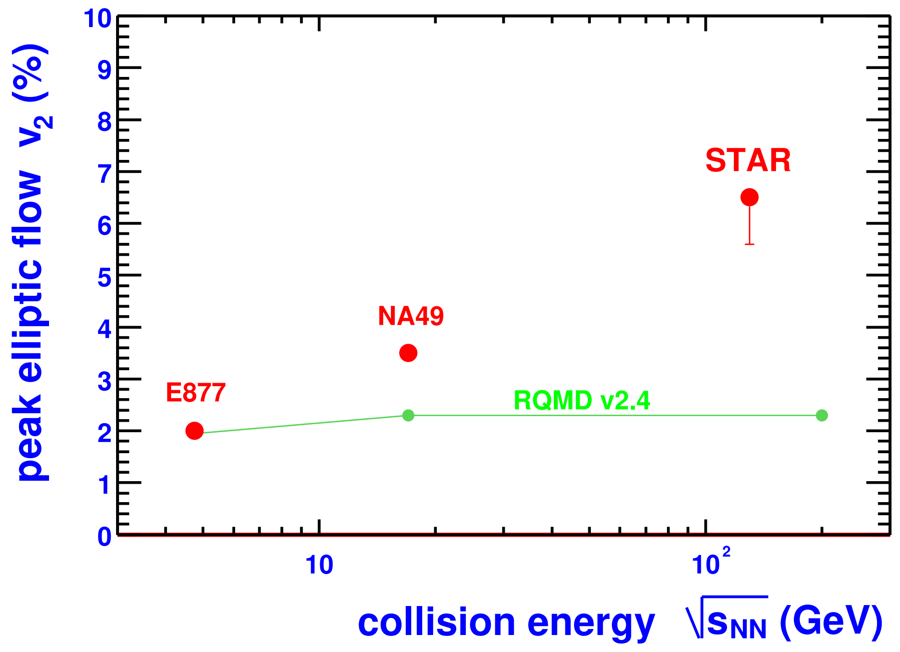
statistical hadronisation model also fits at RHIC



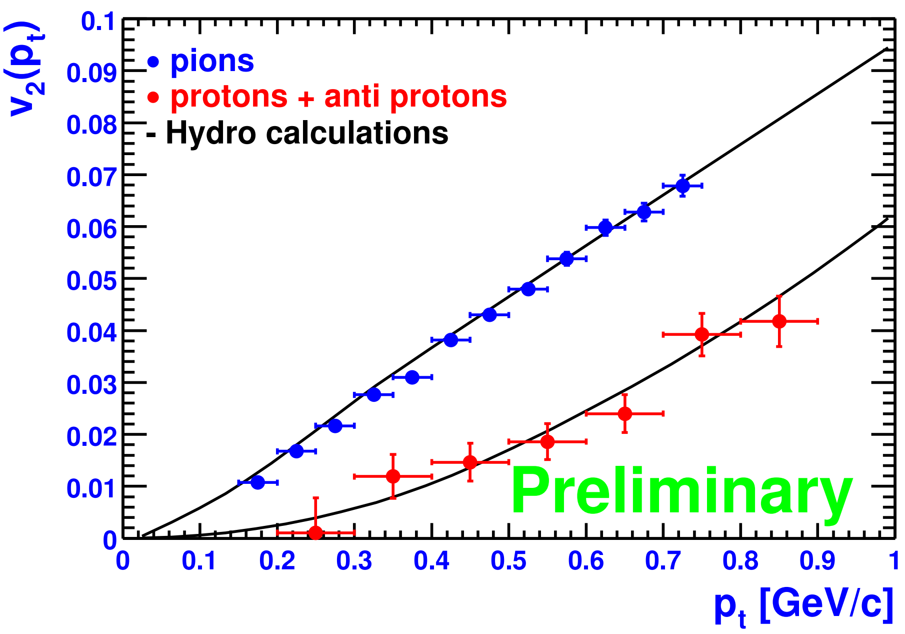
$T = 174$ MeV similar to SPS,

$\mu_B = 46$ MeV factor 5 smaller

elliptic flow in non–central collisions increases with $\sqrt{s}$



agreement with hydrodynamic model indicates early thermalisation and is consistent with hard QGP equation of state



Conclusion

NA49 studied central PbPb collisions at 40, 80, 158 A·GeV

- pion suppression (compared to pp reactions) changes to pion enhancement
- fraction of strange particles passes through a maximum
- strangeness production starts to be undersaturated at SPS energies, at a level consistent with the deconfinement hypothesis
- no unusual features are found in the evolution of the produced hadron system
- energy scan to be completed in 2002 with 20, 30 A·GeV central PbPb collisions

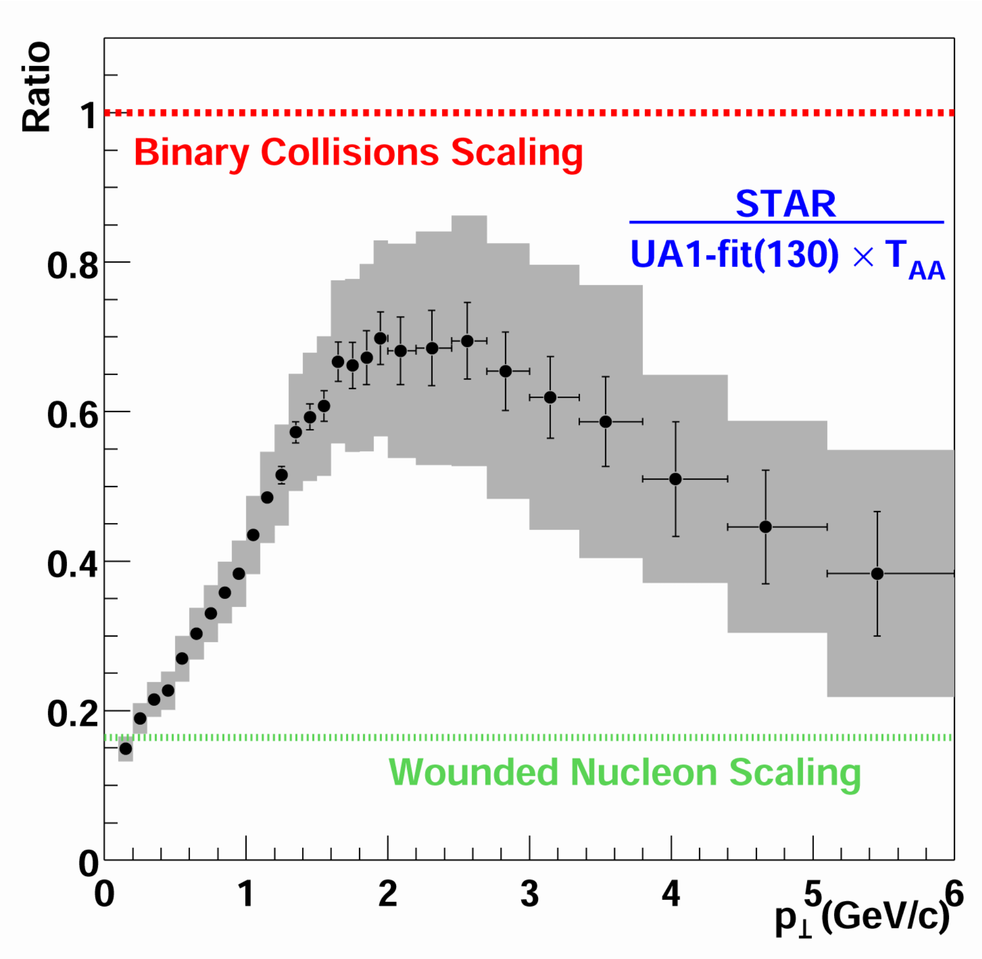
First STAR results from AuAu collisions at RHIC

- moderate multiplicity increase suggests saturation in the initial gluon cascade
- low but non-vanishing net baryon density at midrapidity
- strong collective and elliptic flow indicates early thermalisation and stiff QGP–like equation of state
- scaling behavior of particle yields at high P_T is suggestive of parton energy loss in the dense hadronic medium
- high statistics data of 100 + 100 A·GeV AuAu collisions on tape, data taking on pp collisions in progress
  (FTPC operational)
- completion of calorimetry by 2003
  (spin program, parton energy loss)

scaling of particle yields from pp to AuAu collisions

- proportional to N_{part} for soft production processes
- proportional to N_{coll} for products from hard processes, e.g. leading particles from jets

(STAR preliminary, negative hadrons)



failure to reach N_{coll} scaling at large P_T may indicate energy loss of the scattered parton in the dense hadronic medium