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Search for Deconfinement in NA49 at the CERN SPS

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Introduction

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

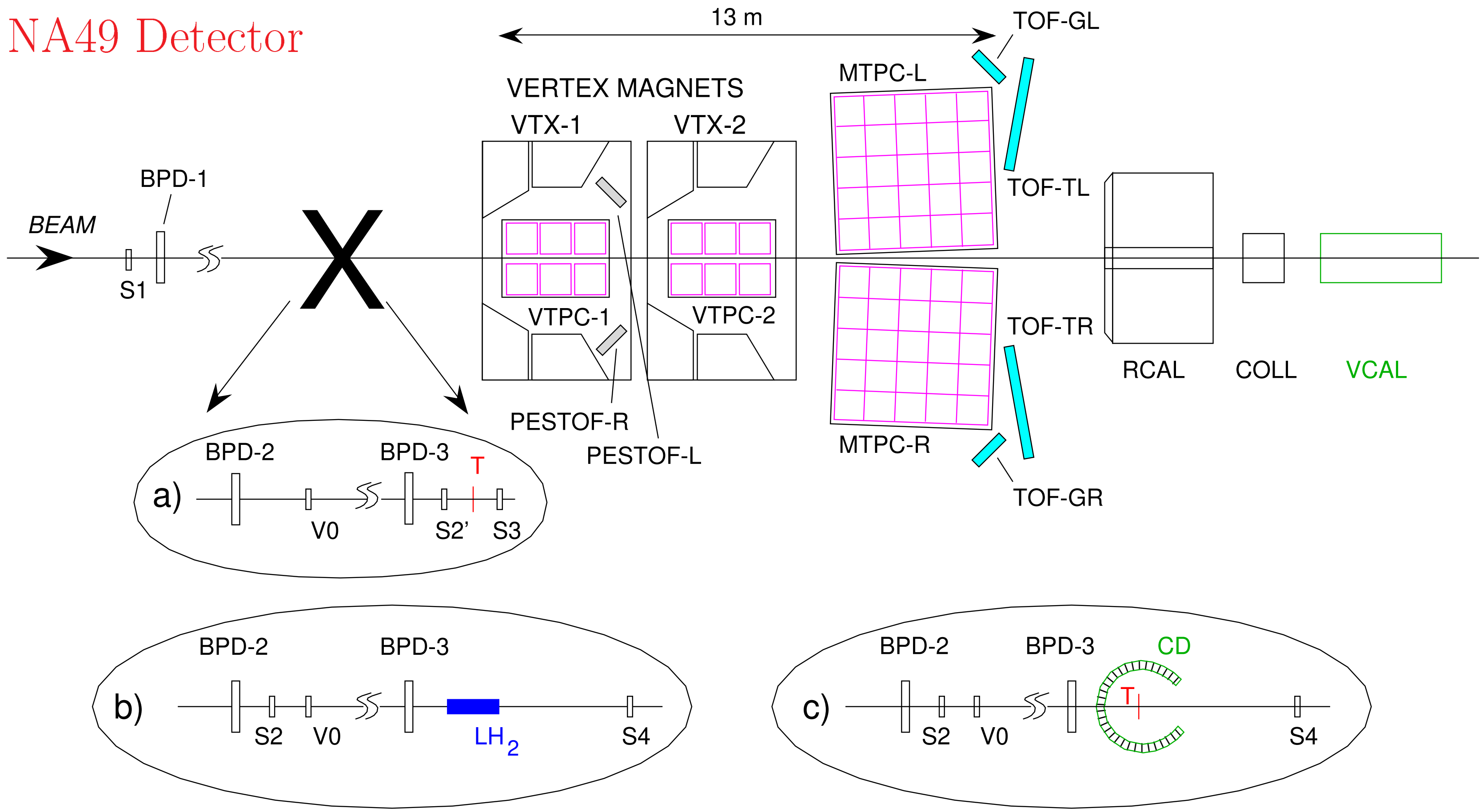
- within most model scenarios the data imply that the initial energy density exceeds the critical value of deconfinement
- originally proposed signatures of the QGP were observed (J/Ψ suppression, strangeness enhancement, ...), but their significance is under renewed discussion
- no observational evidence 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



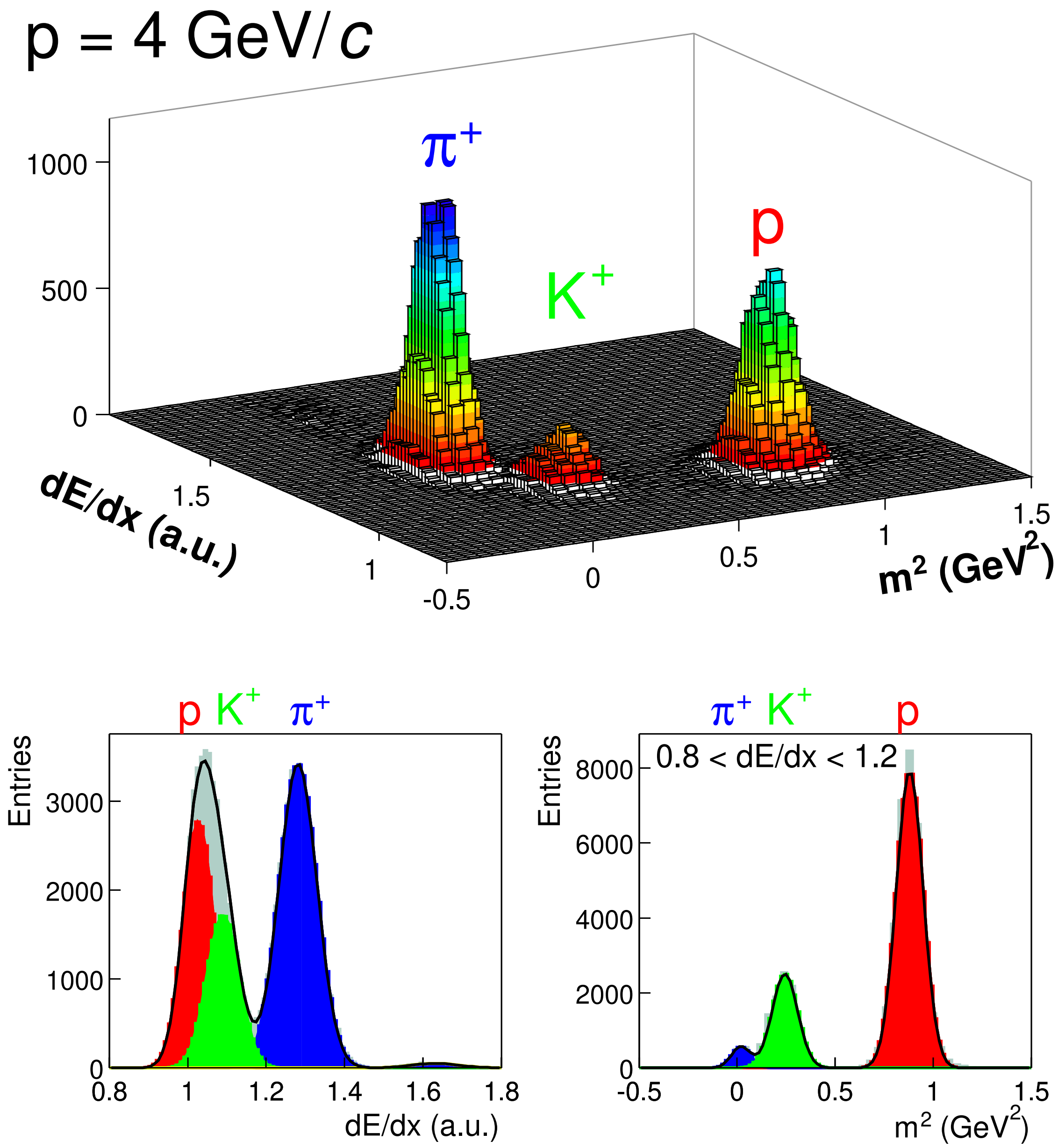
- large acceptance hadron spectrometer
- tracking (TPCs), particle identification (dE/dx,TOF)
- centrality selection (VCAL, CD - slow proton detecor)

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

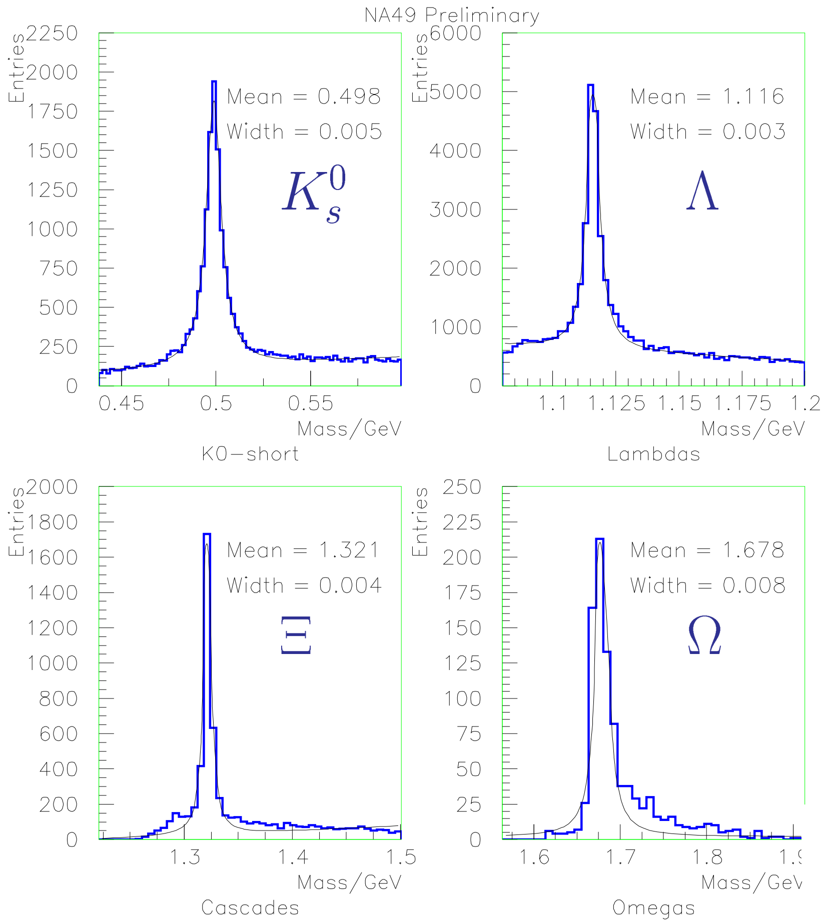
- dE/dx measurement in TPCs for $Y > Y_{CM}$
  resolution 3-4 %
- TOF measurement around midrapidity
  resolution 60 ps

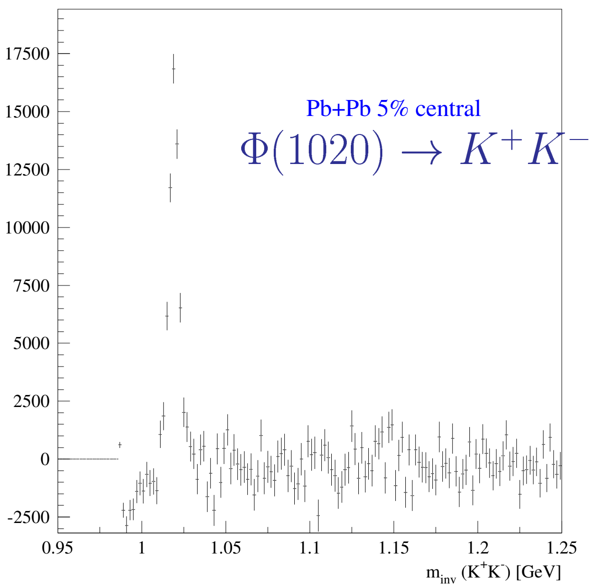
example at 40 A·GeV :

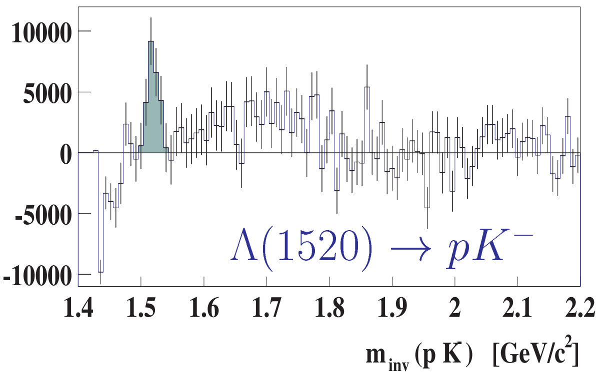


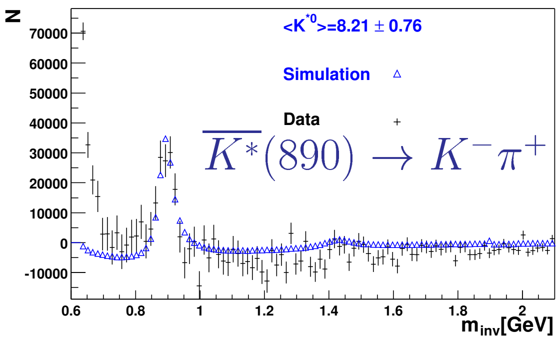
identification from decay topology and invariant mass

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

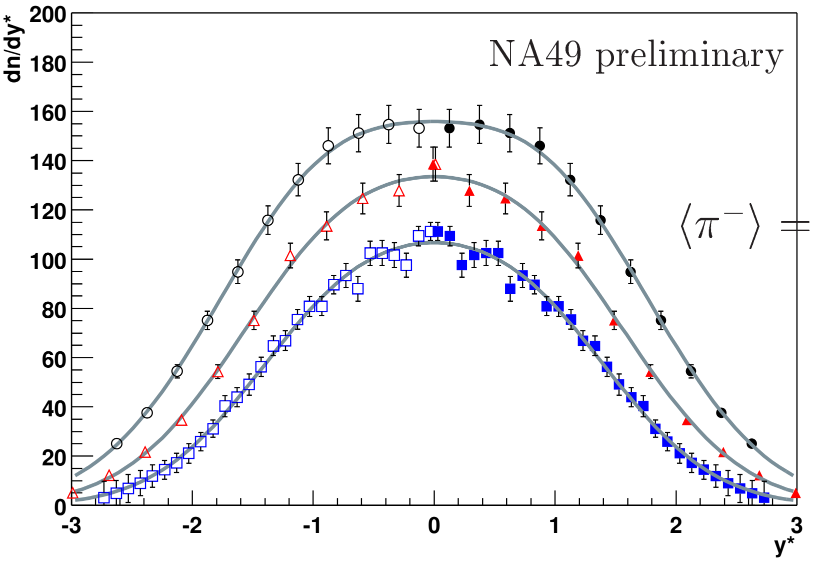








Pion Production in central PbPb collisions



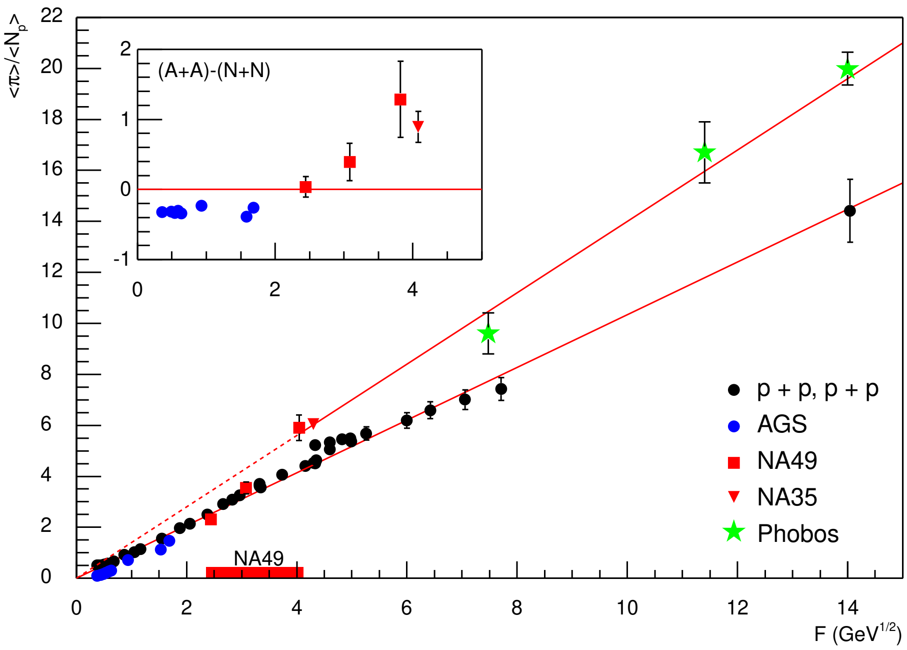
$\langle \pi^- \rangle = 610 \pm 30$ at 158 A·GeV

445 ± 22 80

312 ± 15 40

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

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



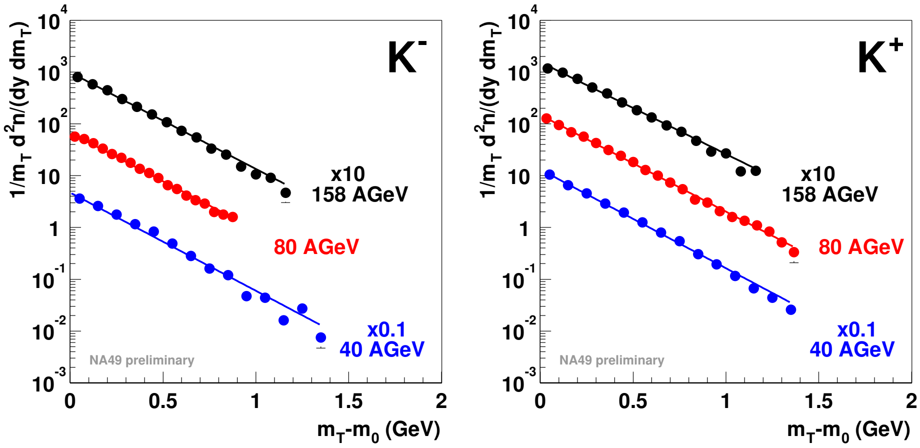
$$F = (\sqrt{s} - 2m_p)^{\frac{3}{4}} / (\sqrt{s})^{\frac{1}{4}} \approx s^{\frac{1}{4}}$$

change from pion suppression to pion enhancement
at low SPS energies

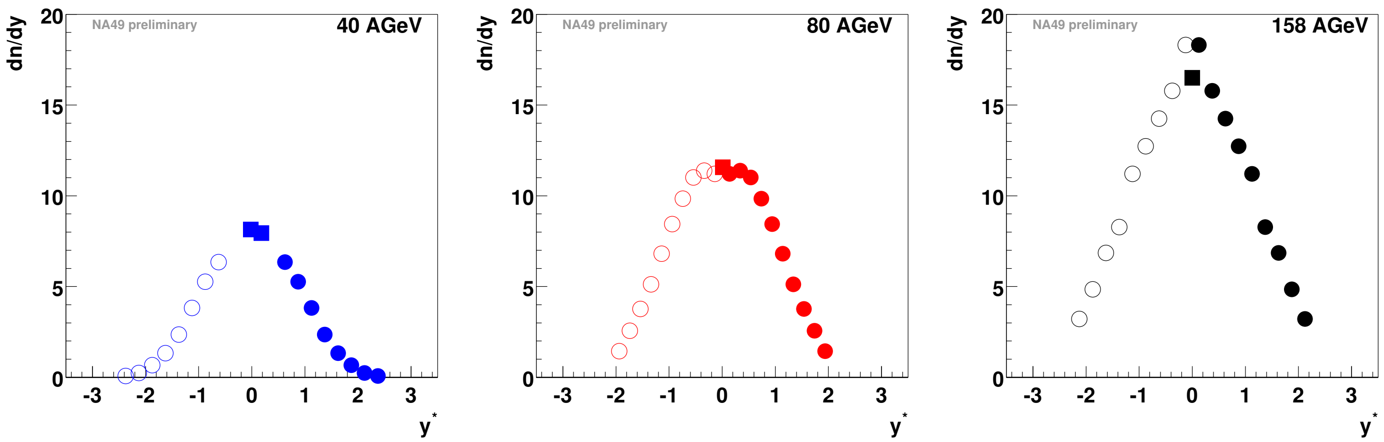
Kaon Production in central PbPb collisions

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

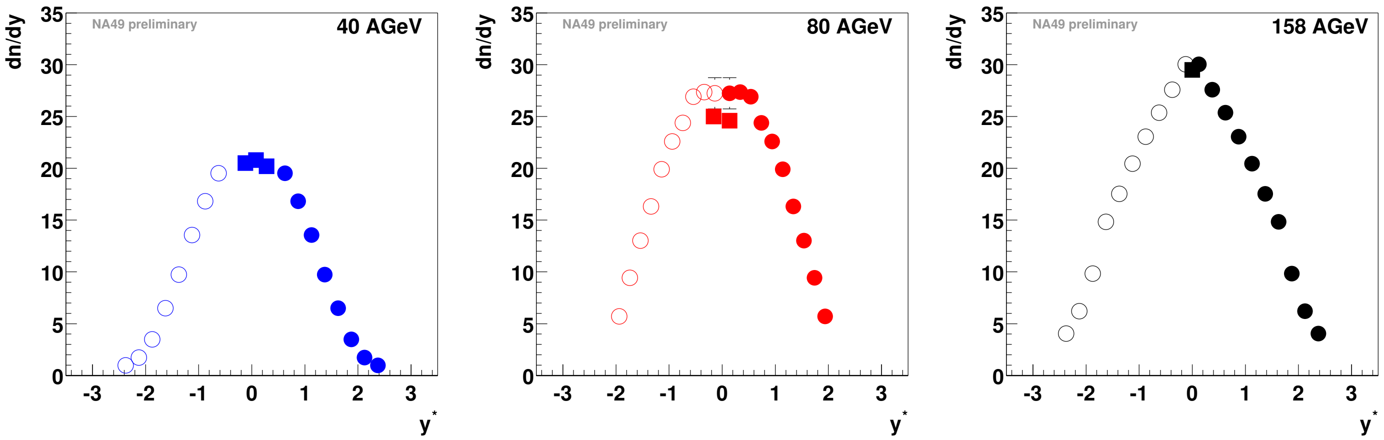
inverse slopes T = 220 – 240 MeV



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

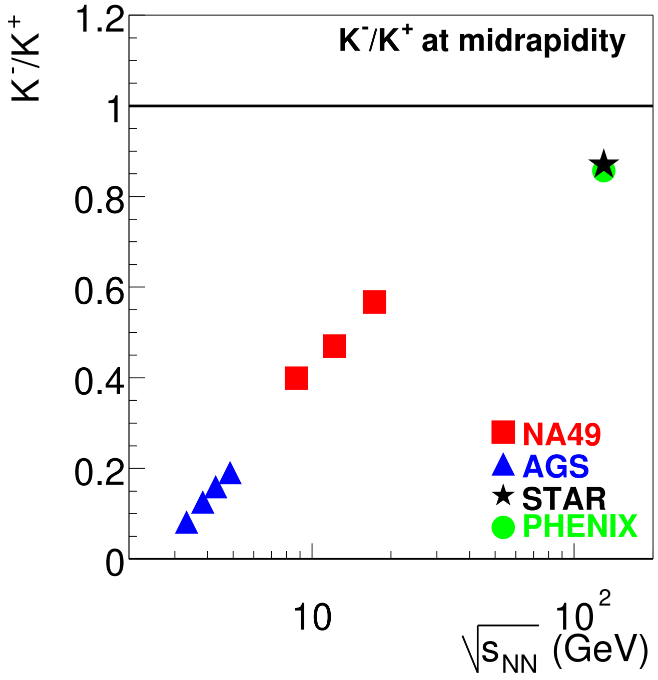


$\langle K^+ \rangle = 56 \pm 3$ $\quad 79 \pm 5$ $\quad 95 \pm 9$



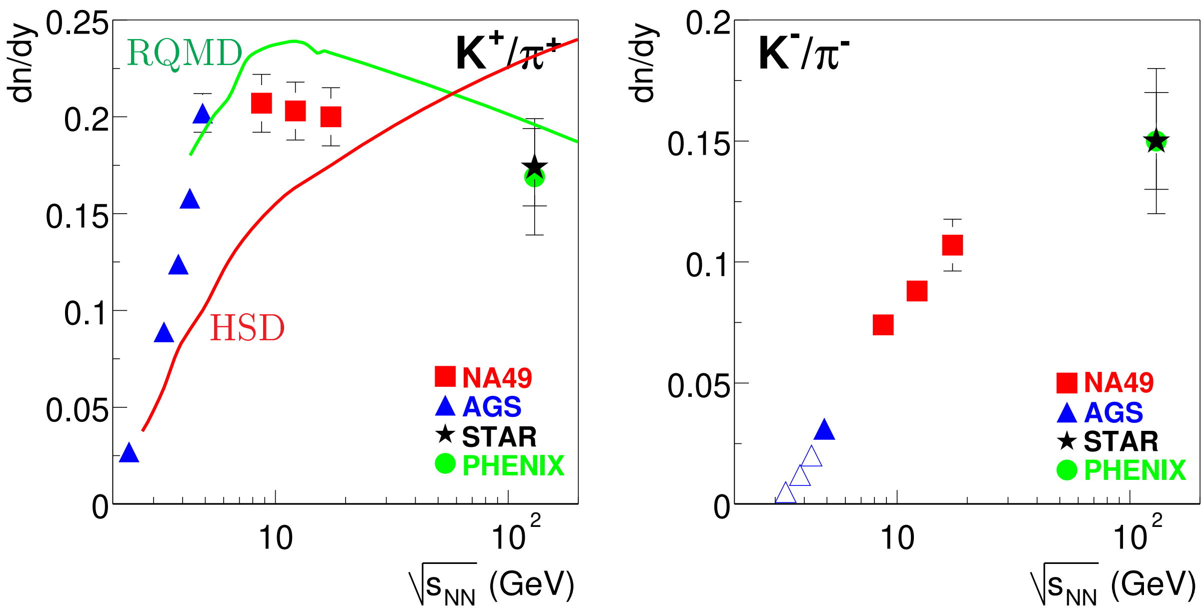
Energy dependence of Kaon Production

increase of the K^-/K^+ ratio reflects the decreasing baryon density



at midrapidity :

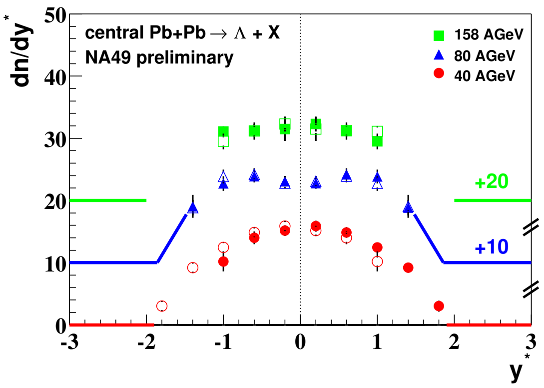
- K^+/π^+ seems to go through a maximum
- K^-/π^- increases monotonically

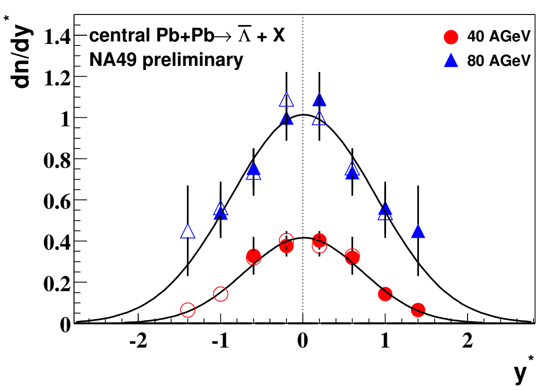


$\Lambda, \bar{\Lambda}$ Production in central PbPb collisions

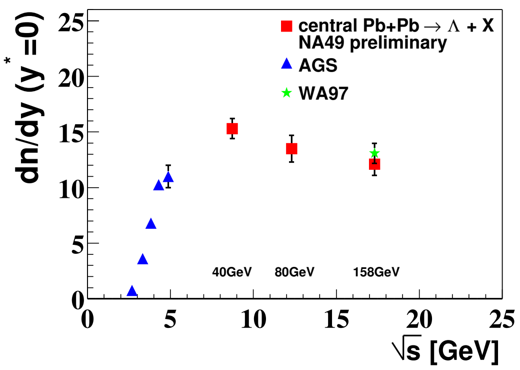
- rapidity distributions:

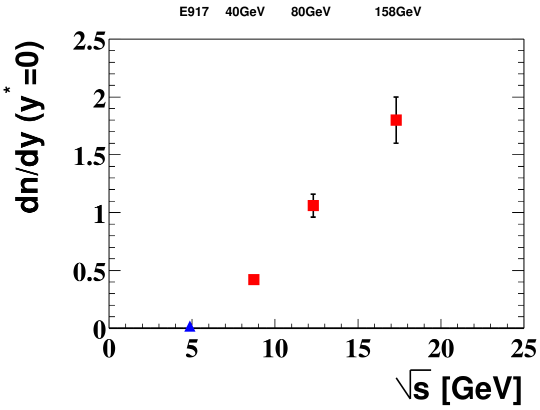
Λ $\qquad\qquad\qquad\qquad$ $\bar{\Lambda}$



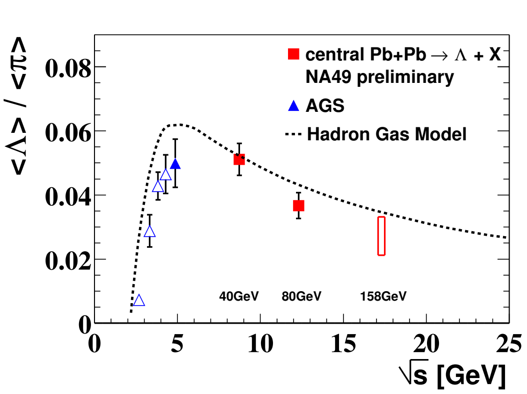


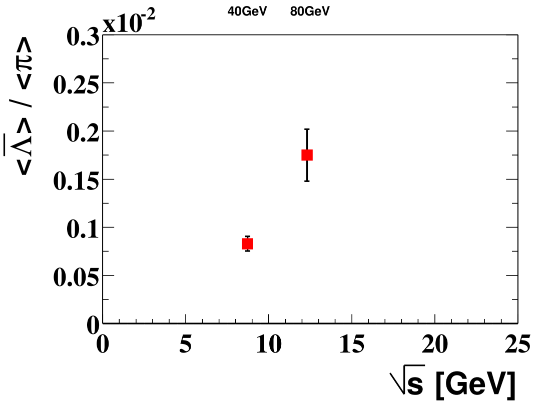
- midrapidity yields:





- 4π multiplicity ratios:



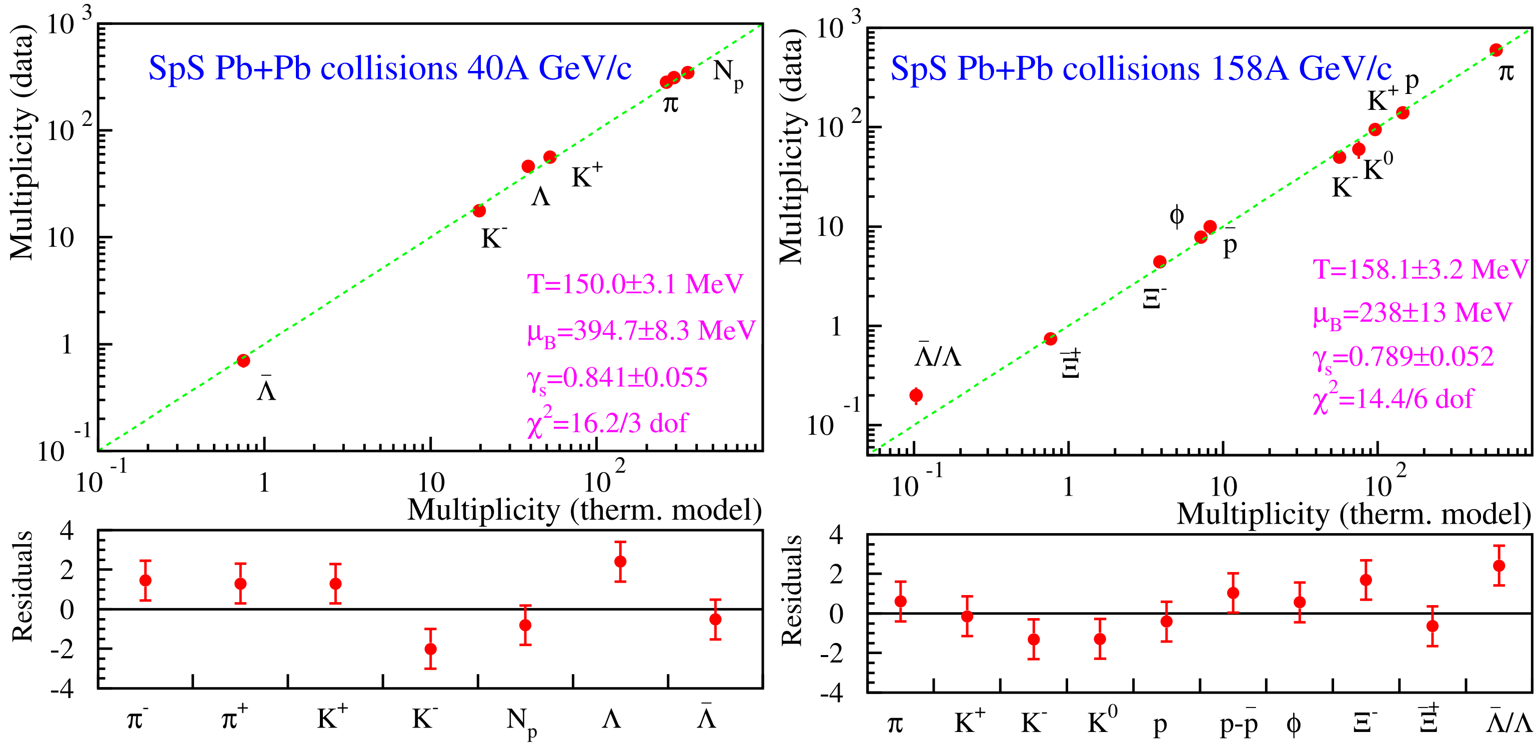


- $\langle\Lambda\rangle/\langle\pi\rangle$ shows maximum related to ρ_B
- $\langle\bar{\Lambda}\rangle/\langle\pi\rangle$ increases steeply due to $B\bar{B}$ production threshold

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, thus $\langle K^+ \rangle$ measures nearly half of all produced $\bar{s}$ quarks since baryon-antibaryon production is small at the SPS

models:

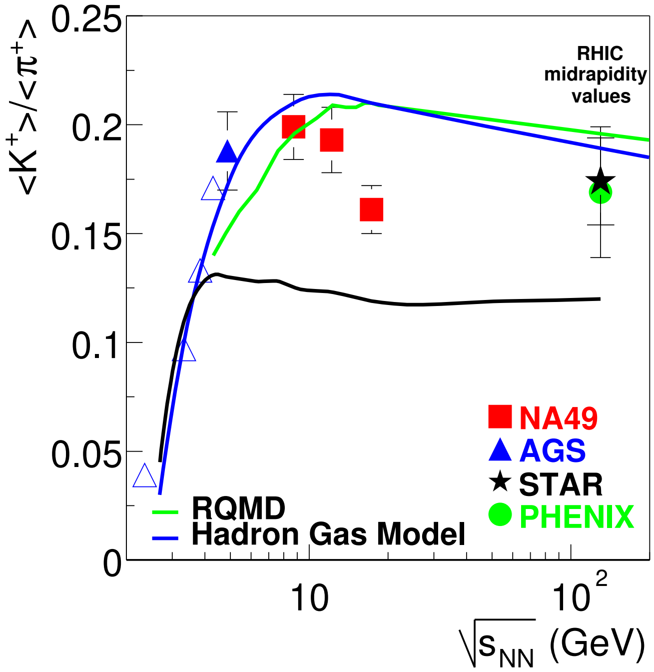
RQMD, UrQMD : strings + fusion + rescattering

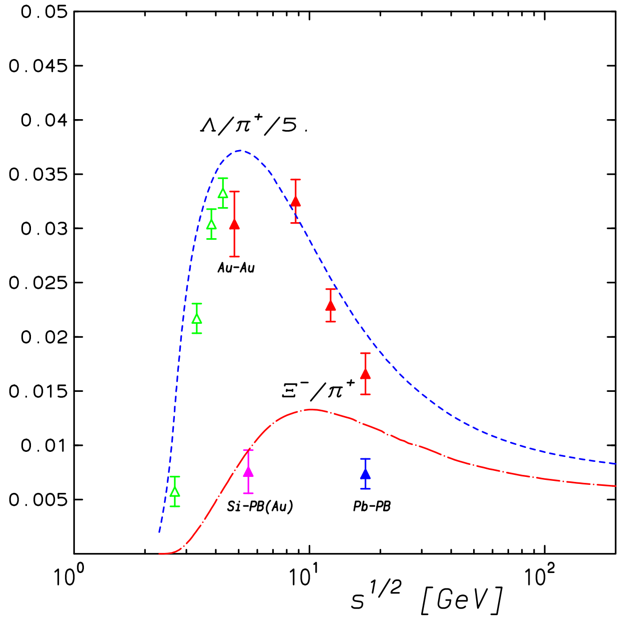
statistical model: (Braun-Munzinger,Cleymans,Oeschler,Redlich)

μ_B from parameterised energy dependence

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

4π multiplicities



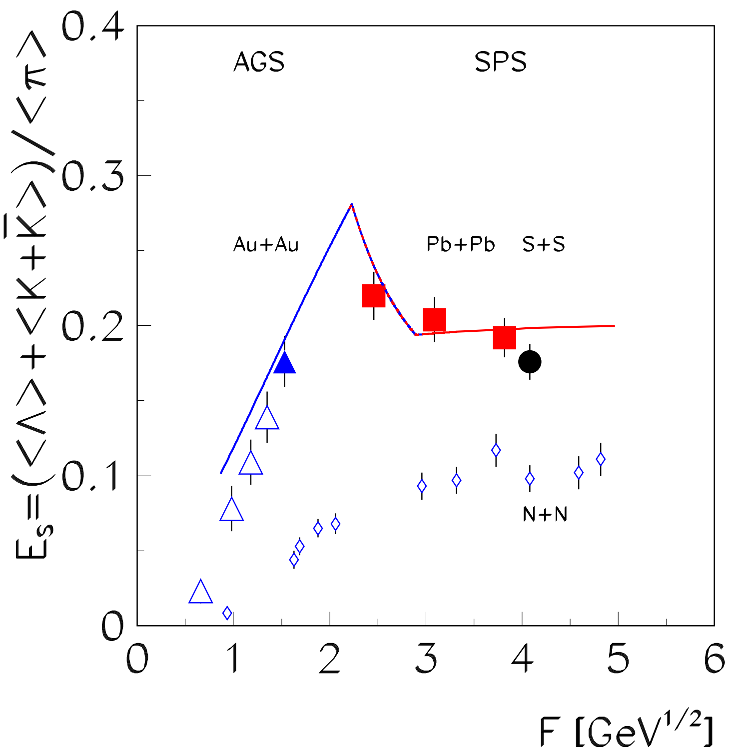


- strangeness undersaturation (K^+, Ξ^-) at top SPS energy not well reproduced
- strong peak in Λ/π caused by interplay of production threshold and decreasing μ_B

Comparison with Current Models (II)

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

- strangeness to entropy ratio established in the deconfined phase (below value for hadron gas of same T)
- saturation of E_s a generic feature when $T > m_s, m_q$



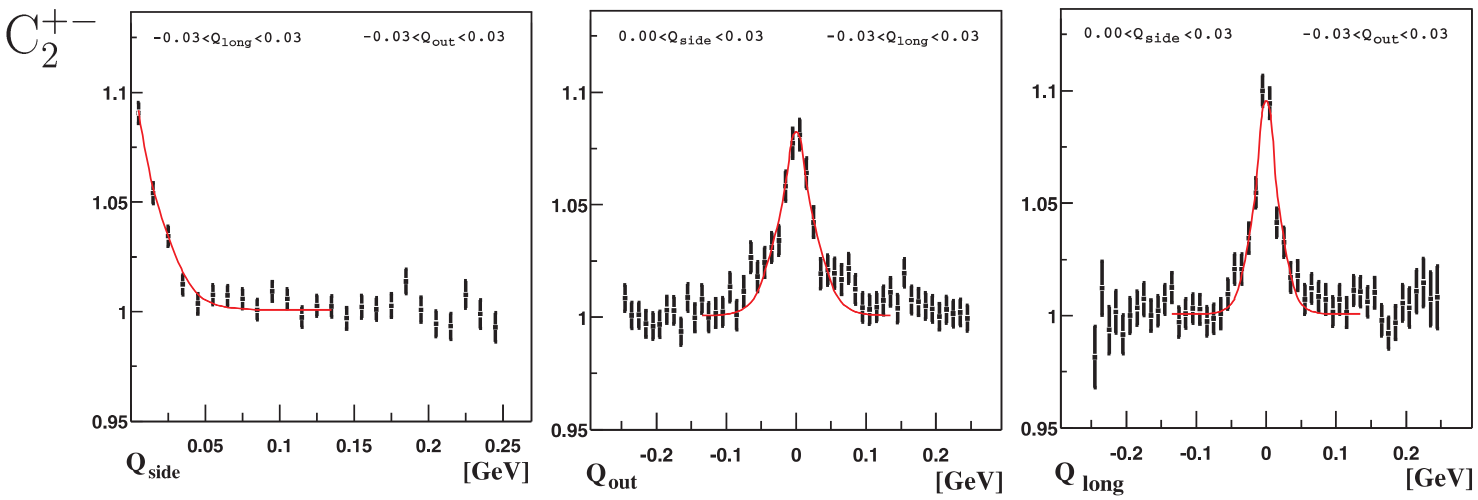
starting in the SPS energy range the NA49 data indicate the strangeness to entropy ratio of deconfined matter

Bose-Einstein Correlations of negative Pion Pairs

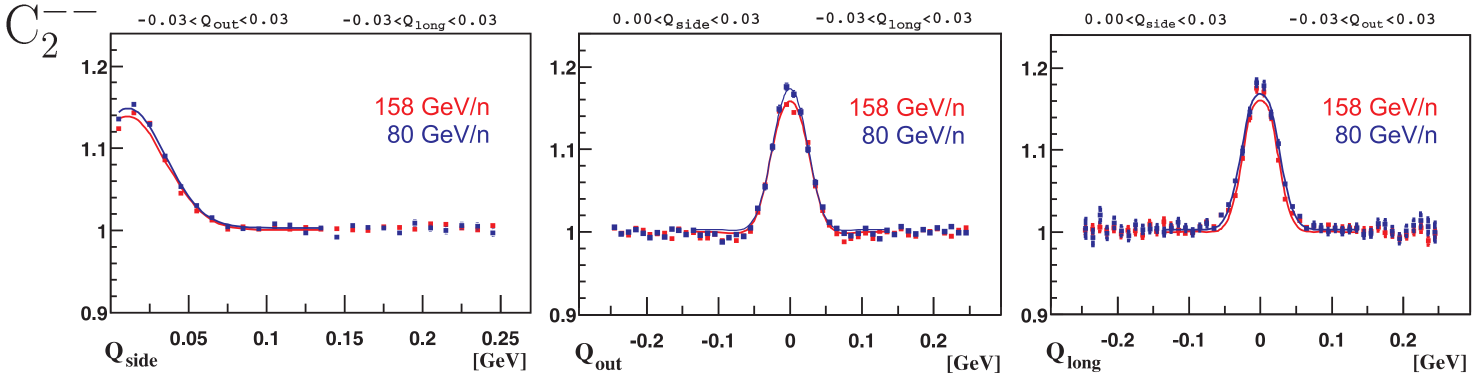
provide information on the size and internal dynamics
of the fireball at freezeout

- cartesian decomposition of $Q = p_1 - p_2$
  $$C_2 = 1 + \lambda \cdot exp(-R^2_{side}Q^2_{side} - R^2_{out}Q^2_{out} - R^2_{long}Q^2_{long} - 2R_{out,long}Q_{out}Q_{long})$$
- resolution $\sigma_{Q_i} \approx 4MeV$
- finite source size Coulomb correction
  (Sinyukov et al.,Phys.Lett.B432(1998),248)

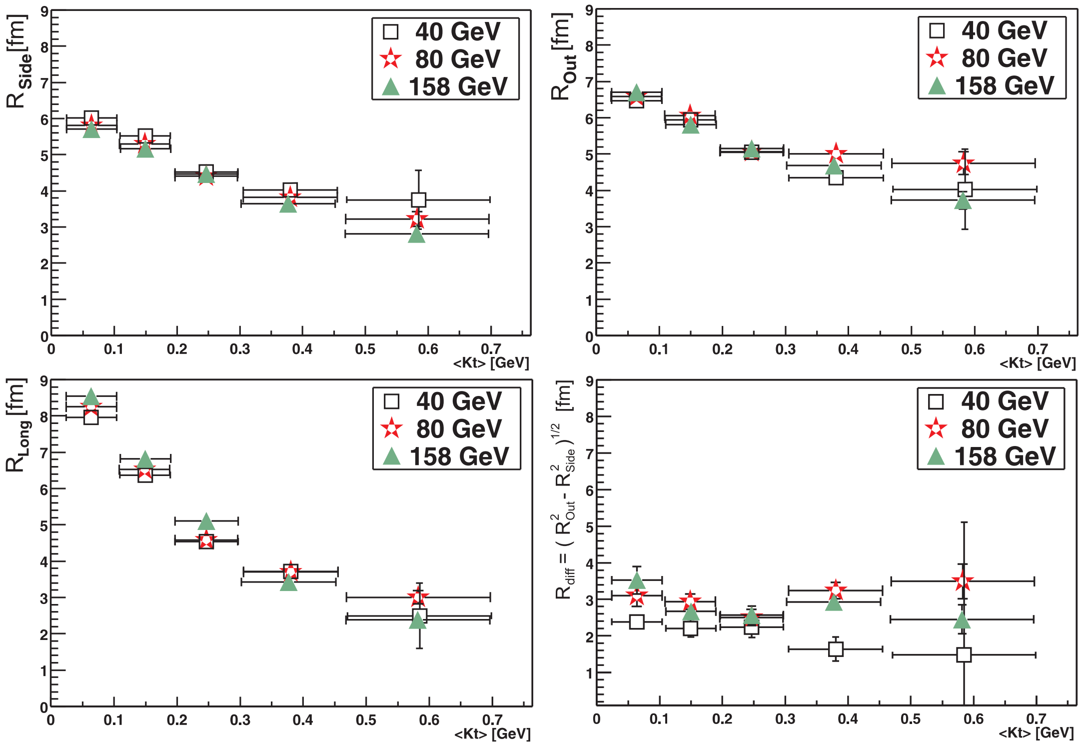
$\pi^+\pi^-$ Coulomb correlation (40 A·GeV, 0.1≤ K_T ≤0.2 GeV/c)



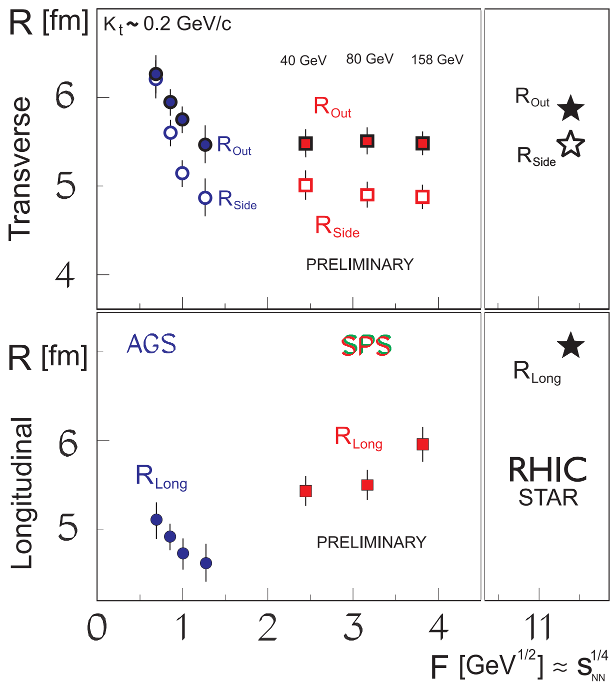
$\pi^-\pi^-$ BE+Coulomb correlation ($y_{cm} \leq y \leq y_{cm}$+0.5 , 0.1≤ K_T ≤0.2 GeV/c)



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



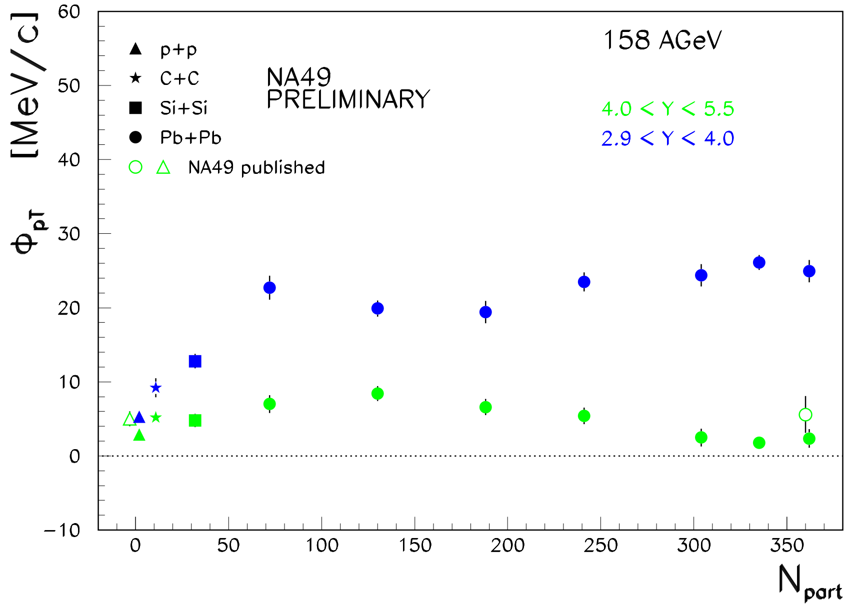
- $R_{long} \approx \tau \sqrt{\frac{T}{M_T}}$ (τ lifetime of fireball) increases with $\sqrt{s}$

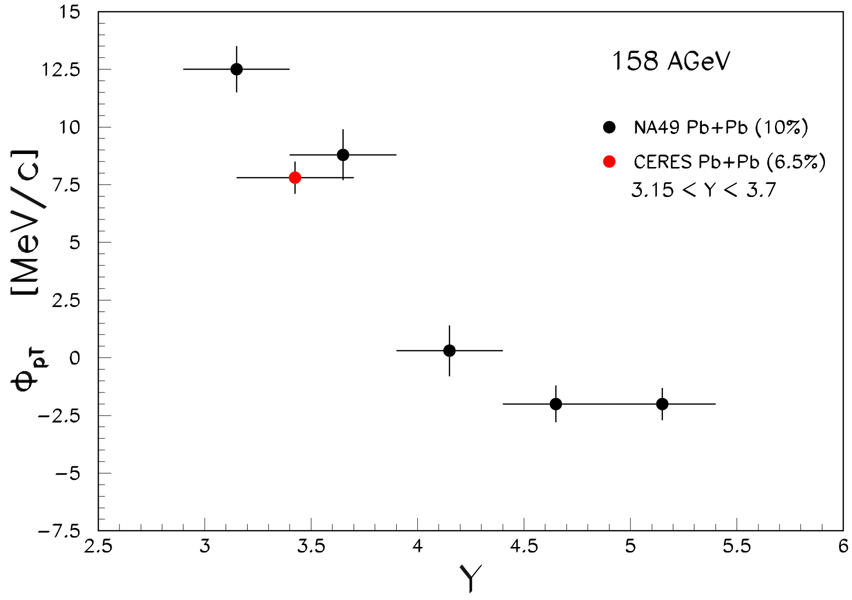
Fluctuations of $\langle p_T \rangle$

$$\Phi_{p_T} = \sqrt{\frac{\langle Z^2 \rangle}{\langle N_{ch} \rangle}} - \sqrt{\overline{z^2}} \qquad \text{(Gazdzicki,Mrowczynski)}$$

$$Z = \sum_{i=1}^{N_{ch}^{event}} p_{T,i} - \overline{p_T} \ , \ z_i = p_{T,i} - \overline{p_T} \ , \ \overline{p_T} \text{ inclusive average}$$

- independent of number of superimposed particle sources
- vanishes for independent particle emission



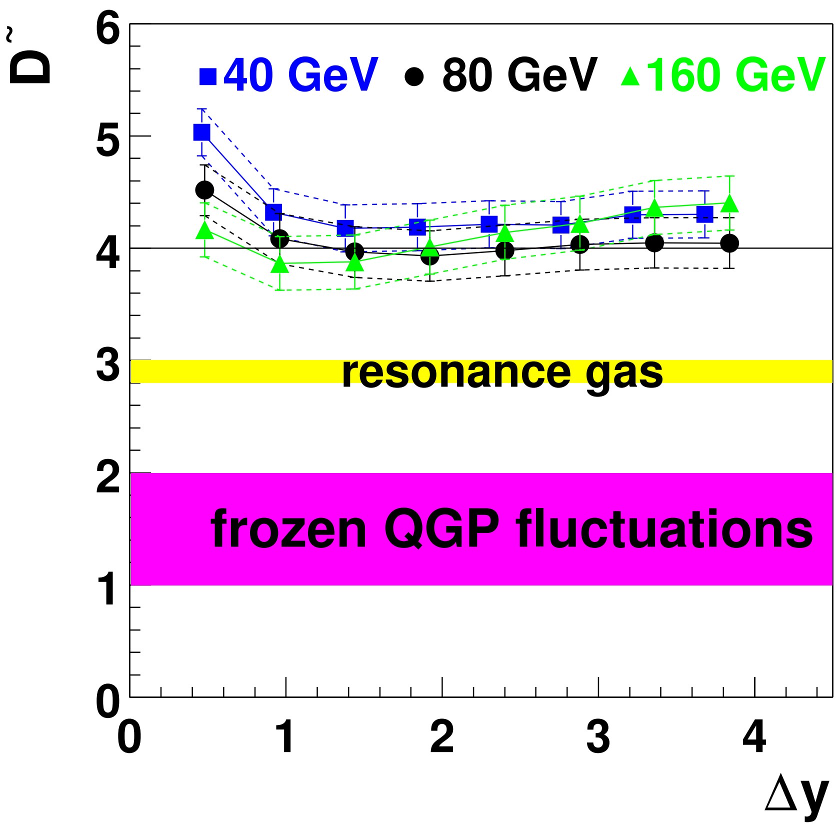


- value small, consistent with zero for rapidity > 4
- surprising increase towards mid rapidity

Charge Fluctuations (I)

- 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 : $C_y = 1 - \langle N_{ch} \rangle / \langle N_{ch} \rangle_{total}$

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



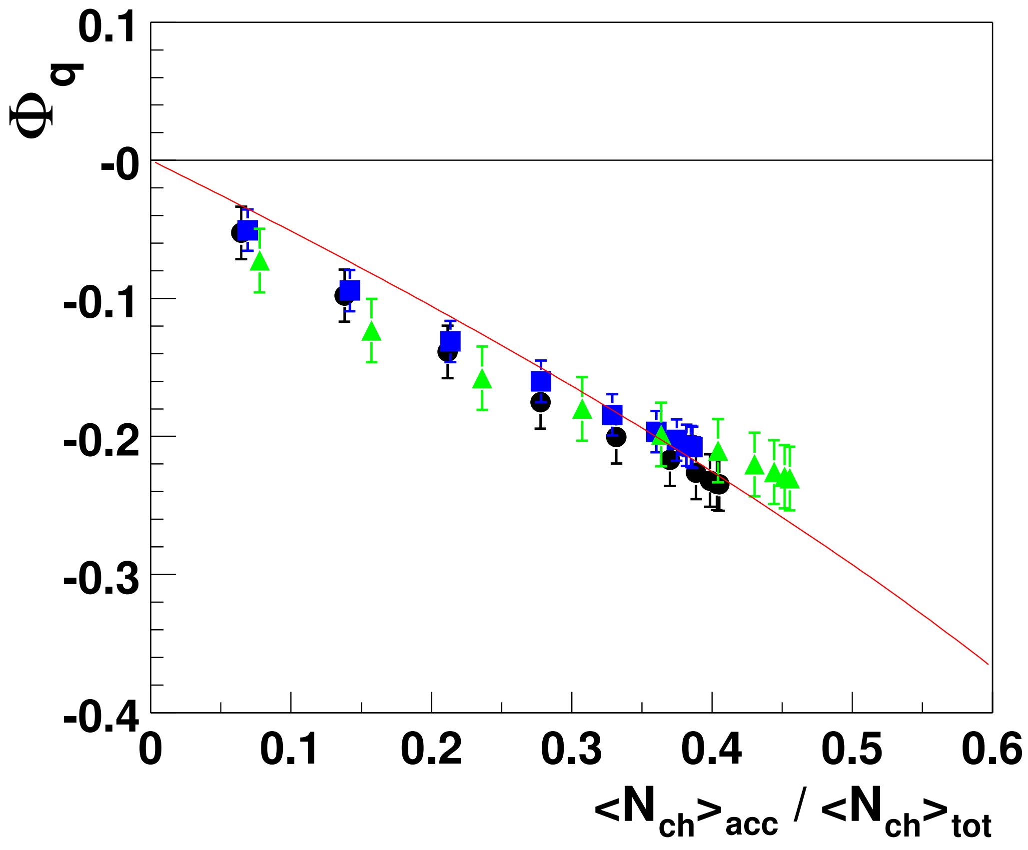
- no significant change in the SPS energy range
- consistent with independent particle emission + global charge conservation
- predicted reduction due to resonances ??
- can small QGP fluctuations survive hadronisation ?

Charge Fluctuations (II)

$$\Phi_q = \sqrt{\frac{\langle Z^2 \rangle}{\langle N_{ch} \rangle}} - \sqrt{1 - \frac{\langle Q \rangle^2}{\langle N_{ch} \rangle^2}}$$ (Gazdzicki,Mrowczynski)

$Z = \sum_{i=1}^{N_{ch}^{event}} Q_i - \overline{Q}$, $\overline{Q}$ inclusive mean charge

- independent of number of superimposed particle sources
- vanishes for independent particle emission
- local charge conservation $\rightarrow \Phi_q \approx$ -1



- no significant energy dependence
- consistent with independent pion emission + global charge conservation (see curve)

Anisotropic Flow in non-central Collisions

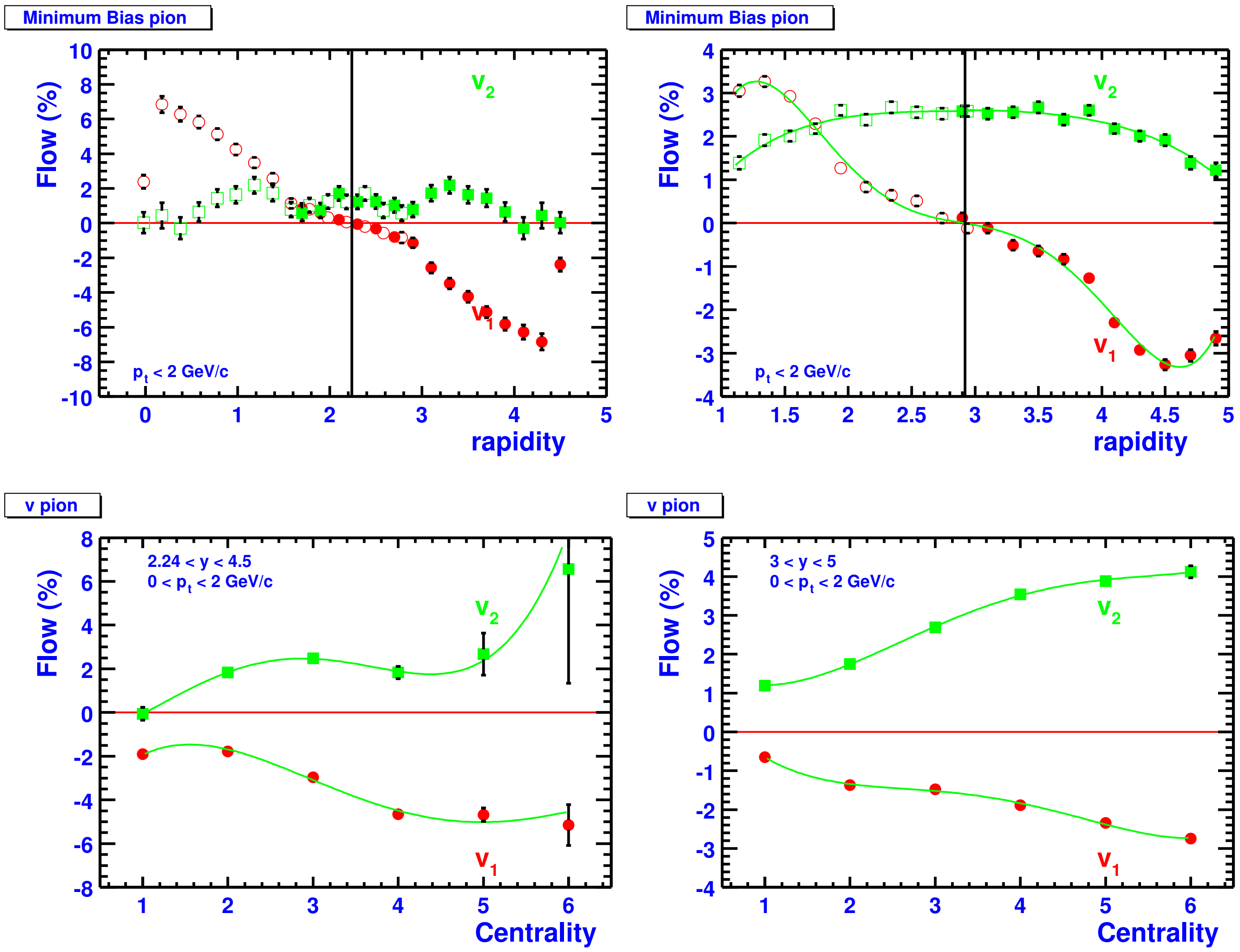
sensitive to pressure in the early stage of the reaction, self quenching

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

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)

Conclusions

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

Future

- further data taking in 2002 at lowest SPS energies : 20, 30 A·GeV central PbPb collisions
- complete the analysis
  - hadrochemical analysis : $p, \bar{p}, \Xi, \Omega, \Phi(1020), K^*(890), \Lambda^*(1520)$
  - elliptic flow
  - event-by-event $\langle p_T \rangle$, charge fluctuations
- evolution pp $\rightarrow$ pA $\rightarrow$ AA

  (was not discussed here)

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