The Hagedorn birthday symposium in Divonne

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Event by event analysis of ultrarelativistic nuclear collisions: A new method to search for critical fluctuations

R. Stock (Frankfurt U.)

1994

In *Divonne 1994, Hot hadronic matter* 507-518
Prepared for Conference: C94-06-27.5
Proceedings

Keyword(s): INSPIRE: talk: Divonne 1994/06/27 | scattering: heavy ion | hadron: multiple production | multiplicity: high | critical phenomena | data analysis method: fluctuation | transverse momentum: spectrum | yield: (K pi) | momentum: correlation | correlation: two-pion | hadron: multiplicity | data analysis method | interpretation of experiments

Record added 1999-09-16, last modified 2015-04-24

http://inspirehep.net/record/387583

Introduction: Analysis of individual collision events

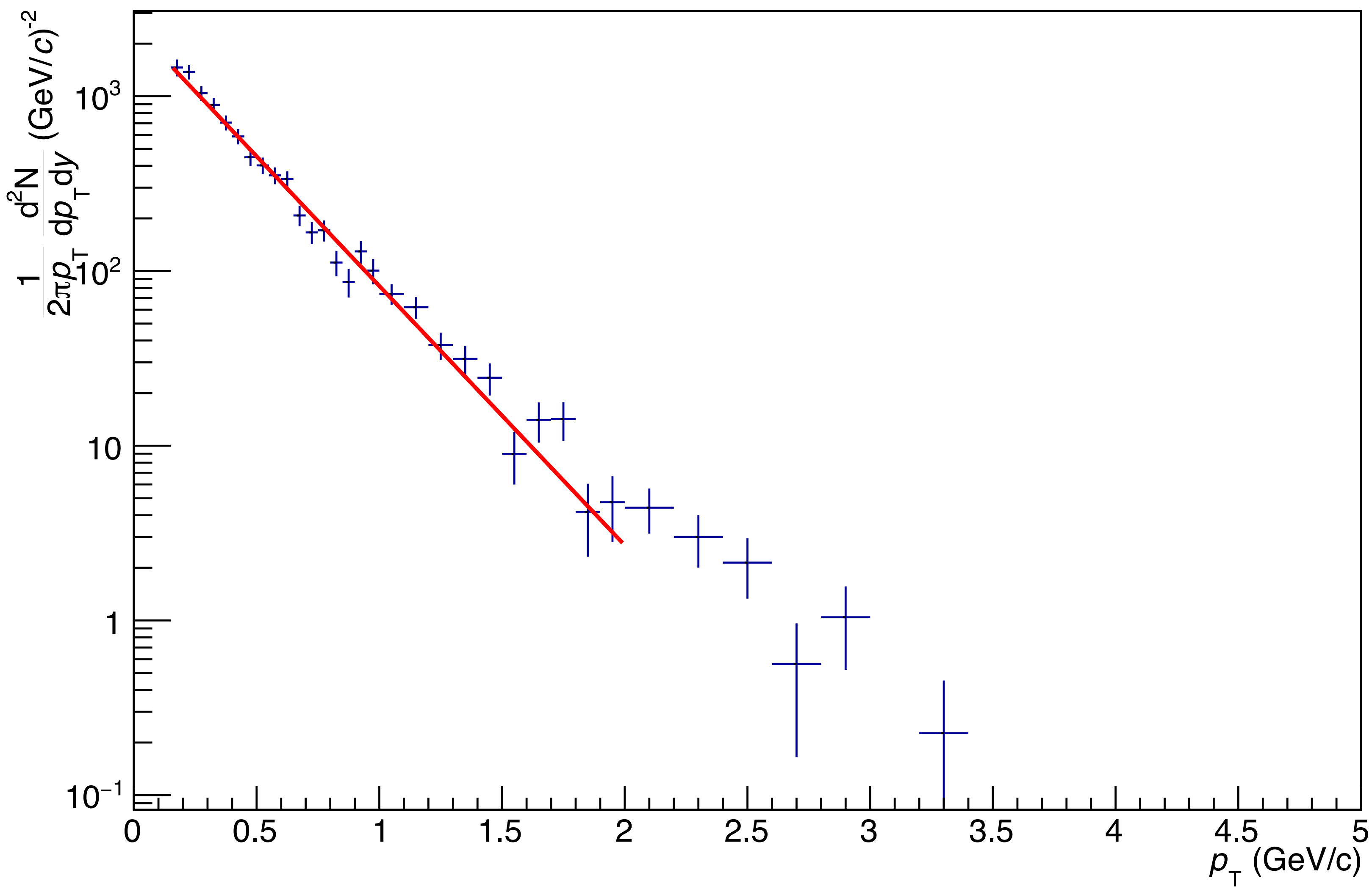
- Origin:
  topology analysis of jets in e^+e^- and ppbar by observables like thrust, sphericity, triaxiality
  From the 1980's until today

- New Aspect:
  Relativistic A+A collisions
  produce hundred (Bevalac 1983) to thousand (SPS) to thousands (RHIC, LHC) of charged particles

- analysed "exclusively" in large acceptance tracking detector systems employing TPC's (NA49, STAR, ALICE)

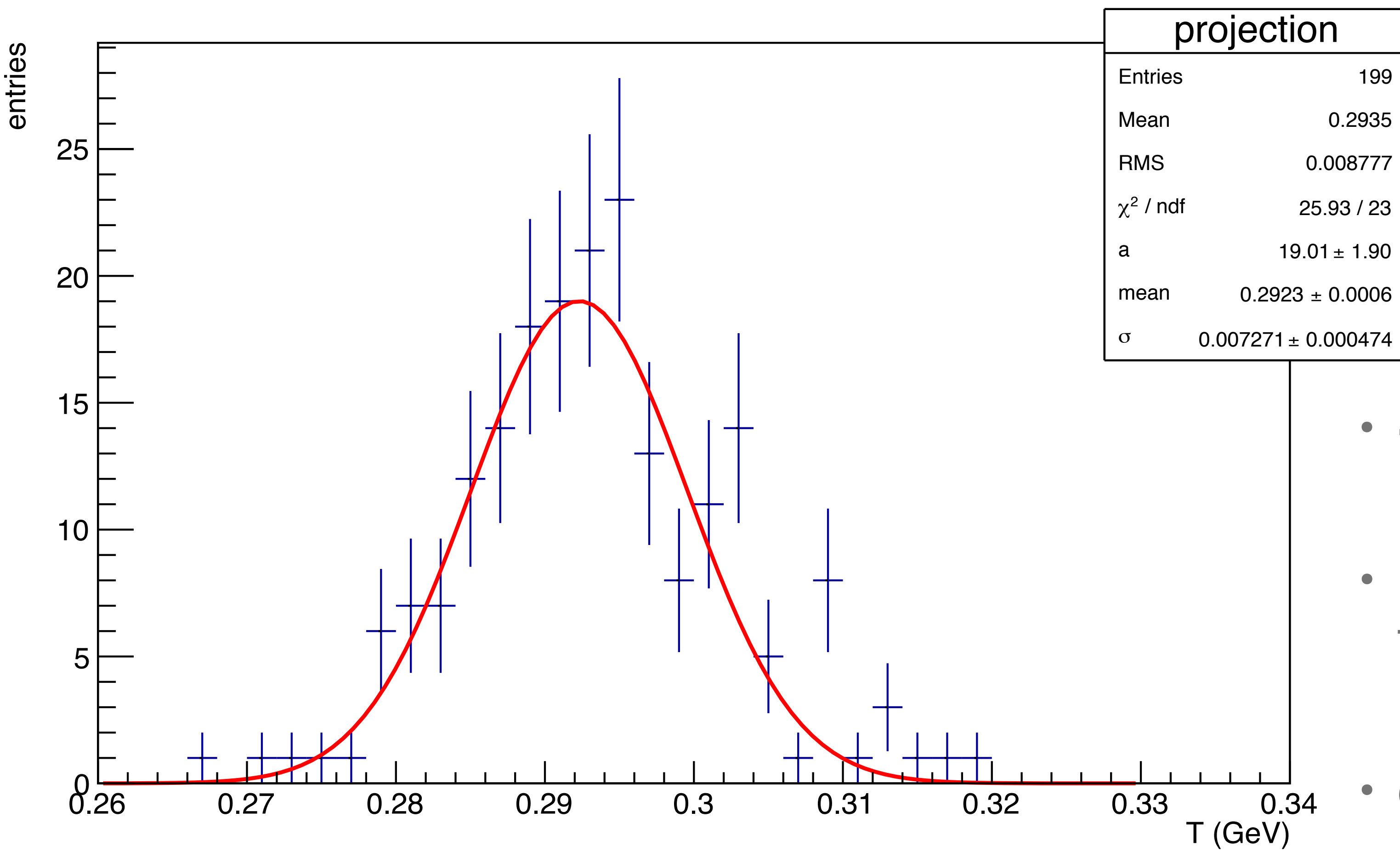
- Significant pion, kaon and p , pbar multiplicities with statistical significance

A first example: charge hadron p(T) spectrum in ALICE central Pb+Pb collisions at LHC 2.76 TeV



- a significant Maxwell-Boltzmann fit revealing an "inverse slope temperature" parameter T

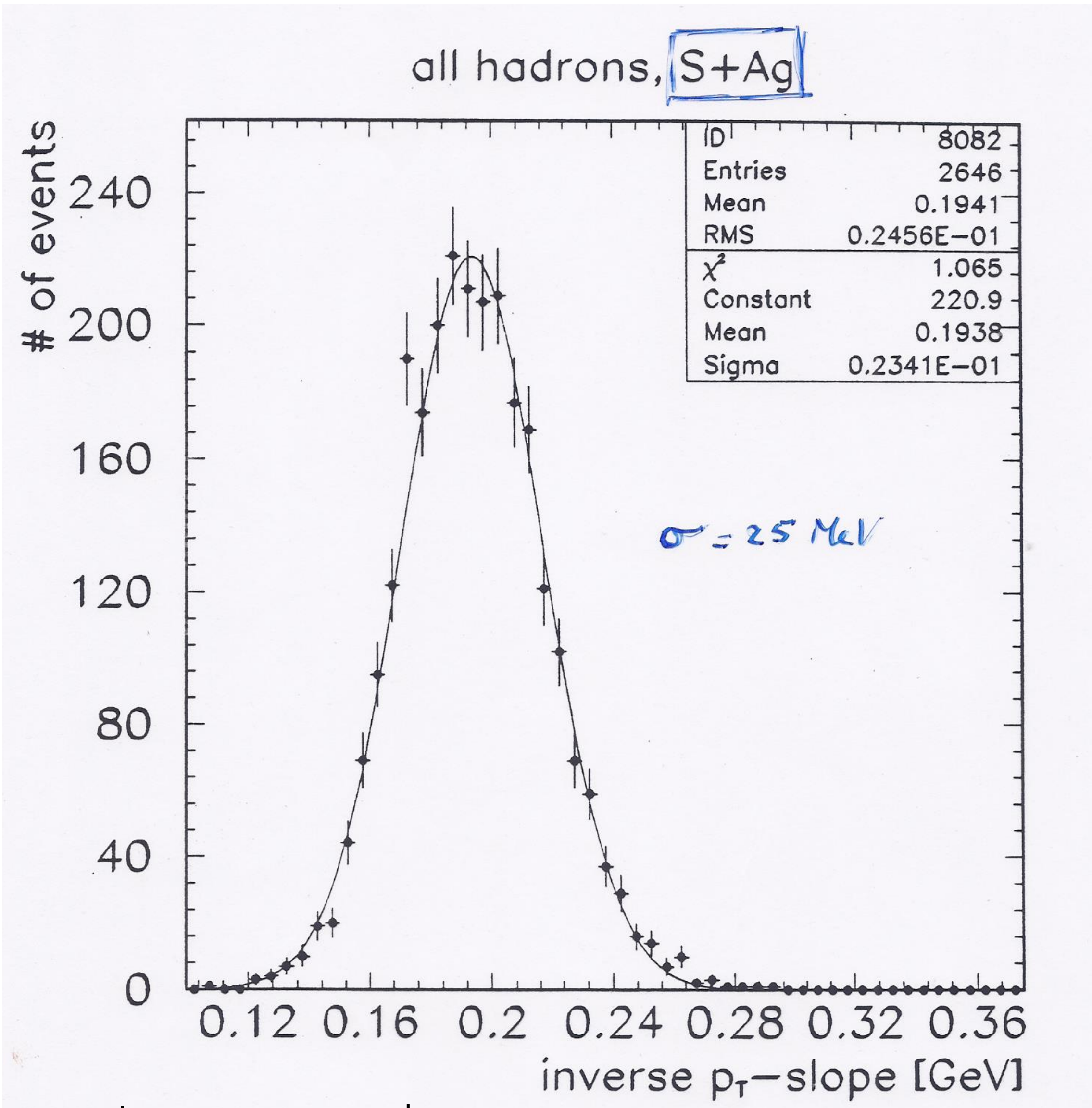
Histogram of 200 ALICE event “temperatures”



note: suppressed zero

- **<T> = 294 ± 8 MeV**
- NOT a “Hagedorn” temperature
- caused by hydrodynamic radial expansion flow of the collision volume

A similar example at SPS, NA49 S+Ag 20 GeV



note: suppressed zero

- **<T> = 194 ± 24 MeV much lower!**
- **charged hadron multiplicity 350**

The Physics behind e-by-e Analysis: Fluctuation of collective, global event properties

- Initial conditions: primordial gluon saturation & Color Glass Condensate
  see: F. Gelis Nucl. Phys. A 931 (2014) 73

  ➡ higher Fourier Moments of event p(T) anisotropy: v2, v3, v4 ...

- Critical fluctuations: critical “point”, first order phase transition
  see M. A. Stephanov et al. PRL 81 (1998) 4816
  V. Koch arXiv: 0810.2520

  ➡ Hadronic freeze-out temperature T_f

  ➡ Hadron ratio fluctuations
  Strangeness to entropy K/π
  Strangeness to baryon number K/p

Physics of e-by-e Analysis continued

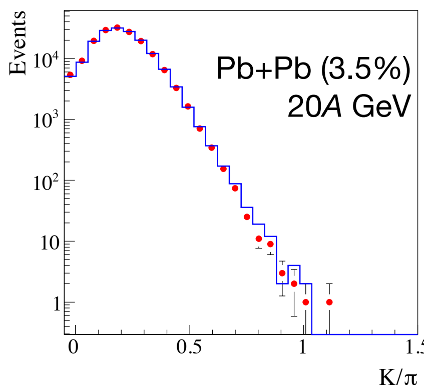
- Hydrodynamic fluctuations: initialization of flow
  η/s damping
  cavitation etc.

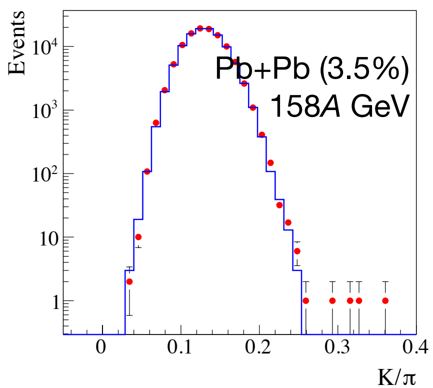
  ➡ Hadronic freeze-out configuration(s?)
  Clumping in final hadron source ?
  p(T) spectrum & radial expansion flow
  freeze-out source surface & size: Bose-Einstein Correl.

- A new technique: “event shape engineering”
  J. Schukraft, A. Timmins and S. A. Voloshin arXiv:1208.4563

Hadron Ratio-Fluctuation Introduction

- Extract event-by-event hadron ratios (e.g. K/π) from
  - real measured events (●)
  - mixed events (–)





- Extract *dynamical* fluctuations as quadratic difference of relative widths:

$$\sigma_{\mathrm{dyn}} = \mathrm{sign}\,(\sigma^2_{\mathrm{data}} - \sigma^2_{\mathrm{mix}})\sqrt{|\,\sigma^2_{\mathrm{data}} - \sigma^2_{\mathrm{mix}}\,|}$$

$$= \sqrt{\nu_{\mathrm{dyn}}} \qquad \text{(STAR)}$$

- T. Anticic et al. NA49, PRC 83 (2011) 061902
- A new further method: “Identity Method”
  T. Anticic et al., PRC 89 (2014) 054902
  without mixed background!

K/p: Strangeness to Baryon Correlation

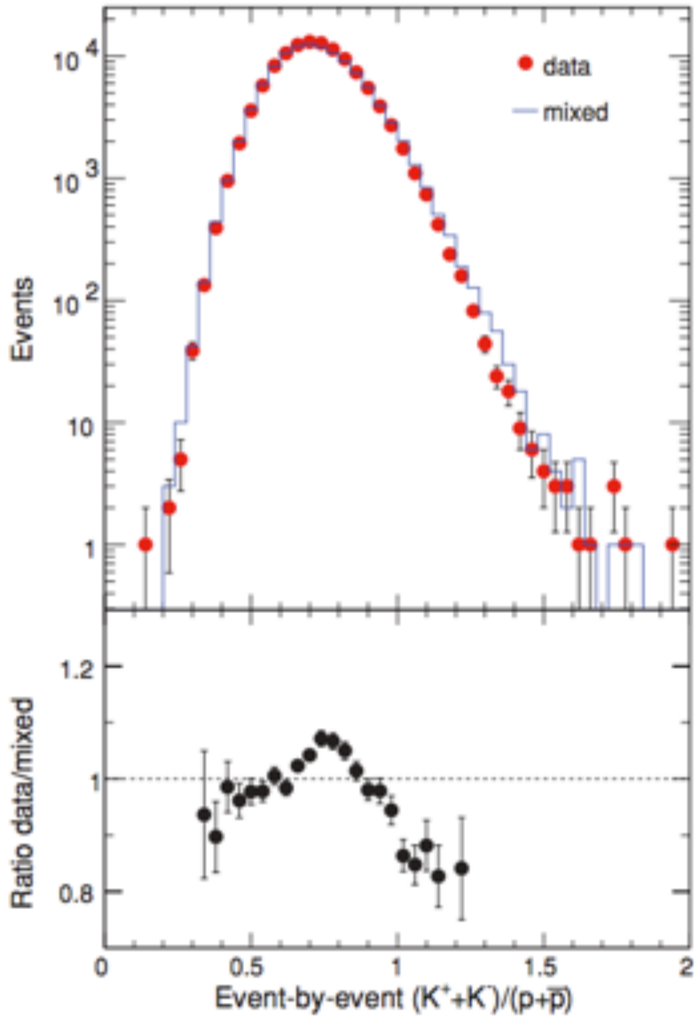


FIG. 2. (Color online) (Top) Event-by-event distribution of the $(K^+ + K^-)/(p + \bar{p})$ ratio at $\sqrt{s_{NN}} = 17.3$ GeV for real data events compared to the mixed event reference. (Bottom) The ratio data/mixed, where the convex shape indicates negative dynamical fluctuations. Only in the ratio plot, for better readability, statistically insignificant bins are not shown.

PHYSICAL REVIEW C **83**, 061902(R) (2011)

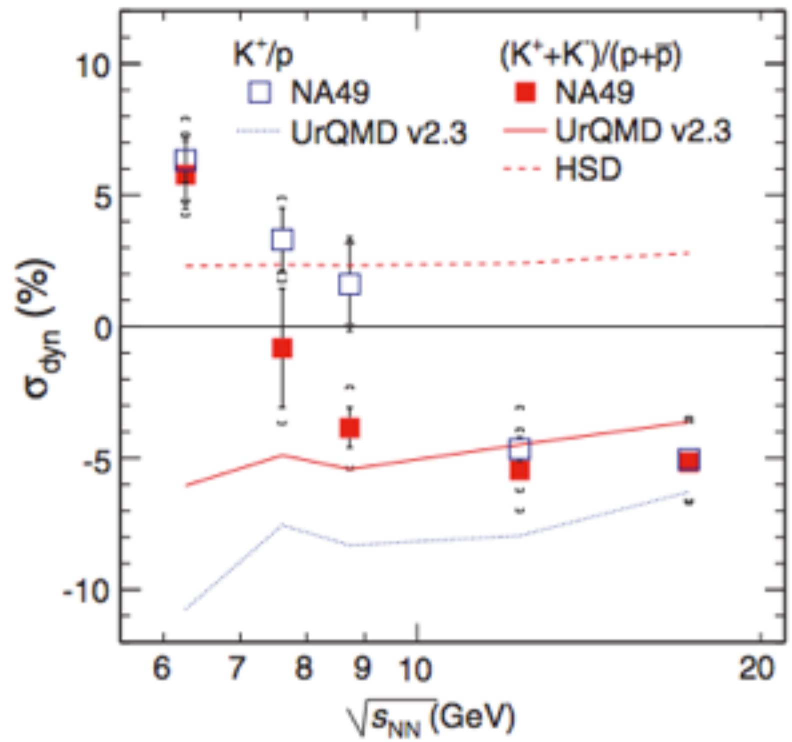
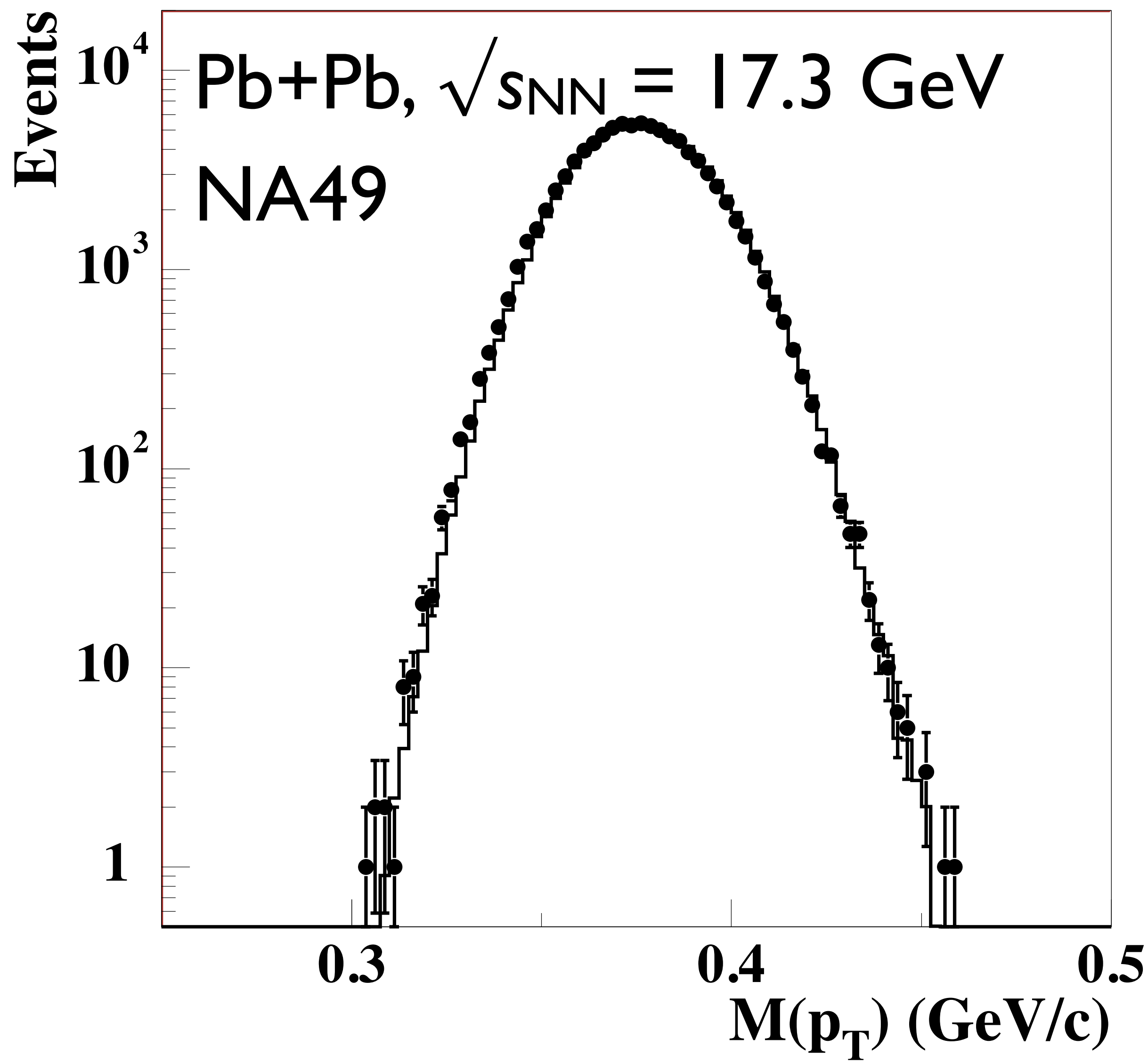


FIG. 4. (Color online) Energy dependence of the event-by-event dynamical fluctuations of the $(K^+ + K^-)/(p + \bar{p})$ and the K^+/p ratios. Symbols represent the NA49 measurements with statistical and systematic (brackets) uncertainties. Calculations within the UrQMD and Hadron-String Dynamics transport models, processed through an NA49 acceptance filter, are represented by lines. The statistical errors on the model results decrease from approximately 1.5% at 6.3 GeV to 0.5% at 17.3 GeV.

Global event mean p(T) e-by-e

The most expensive measurement of a Gaussian in history!



Phys.Lett.B459, 1999.

Hadronic p(T) spectra and radial hydro flow

- **Recall:**

  The p(T) spectrum reflects **two** freeze-out quantities:

  1. Thermal kinetic energy characterized by T_f

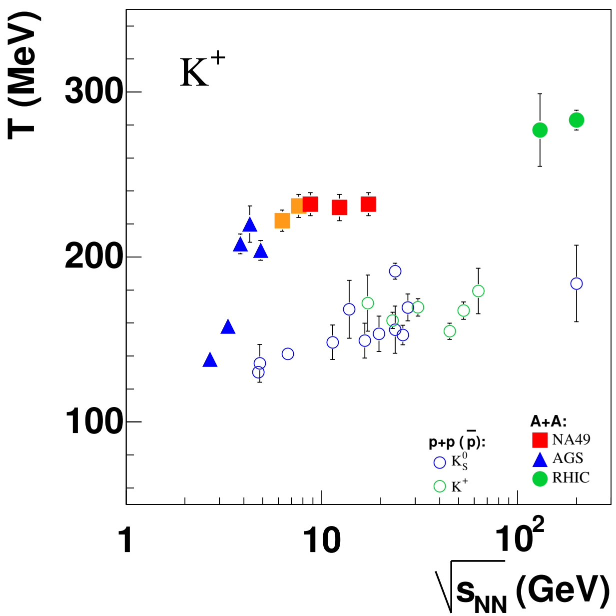
  2. Radial expansion flow kinetic energy flow in a transverse velocity field $<\beta(r)>$

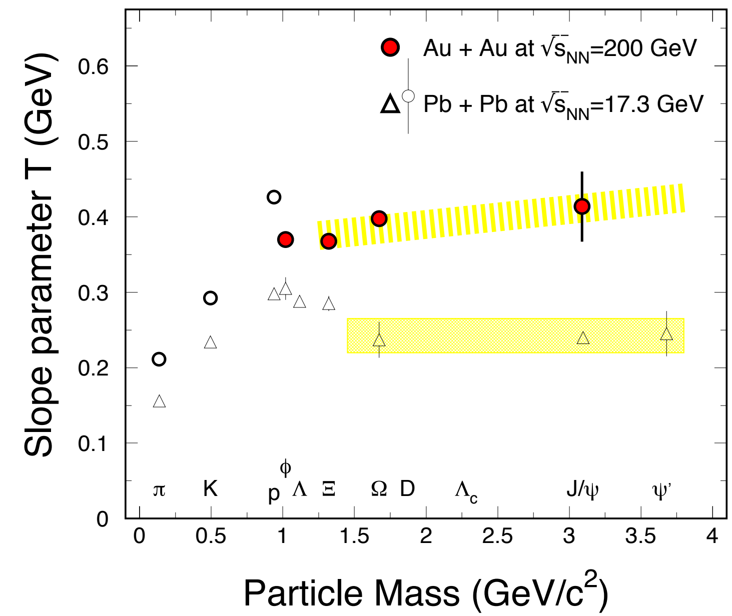
  Thus, $T = T_f + m_i <\beta_T>^2$

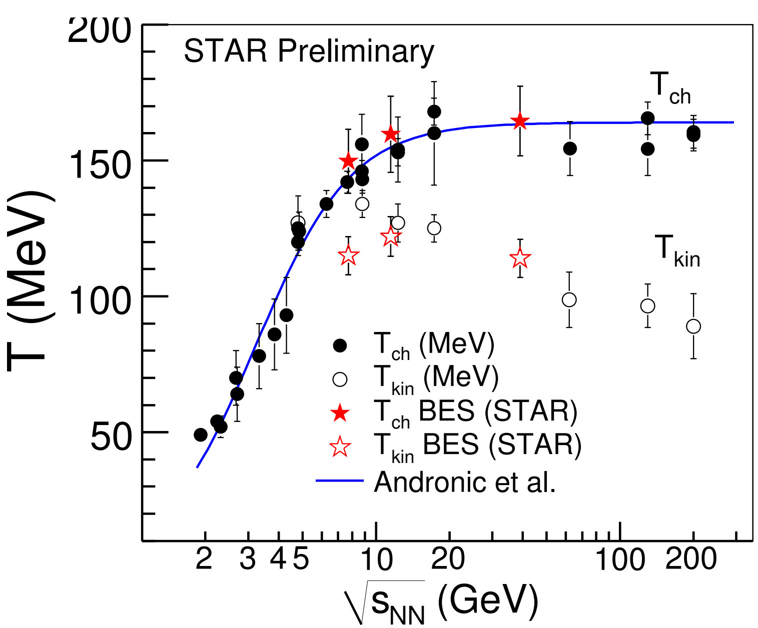
  superposition in Maxwell-Bolzmann fit $\frac{1}{p_T}\frac{d^2N}{dpdy} = const \cdot exp(-p_T/T)$

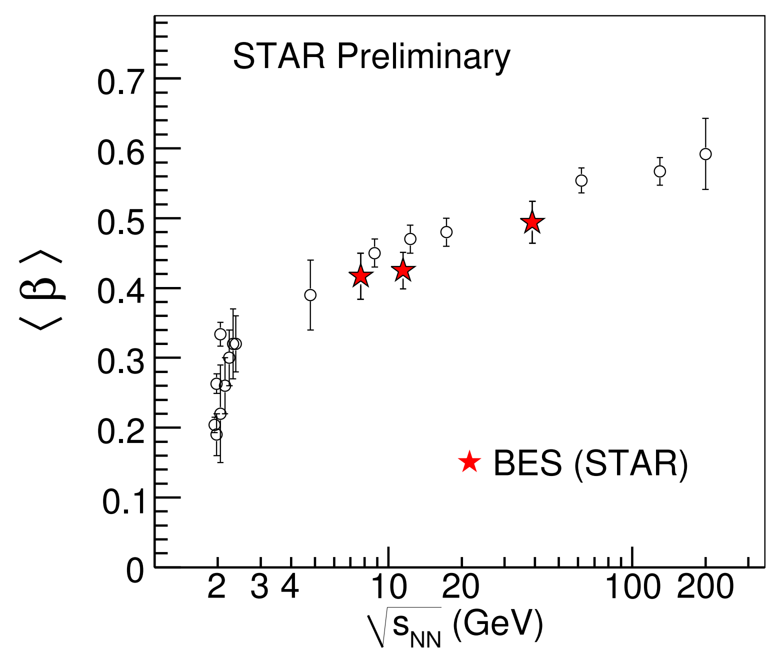
  Disentangle T_f and $<\beta_T>$ by "Blast wave" fit
  Schnedermann and Heinz PRC 48 (1993) 2462

Radial flow: ensemble data

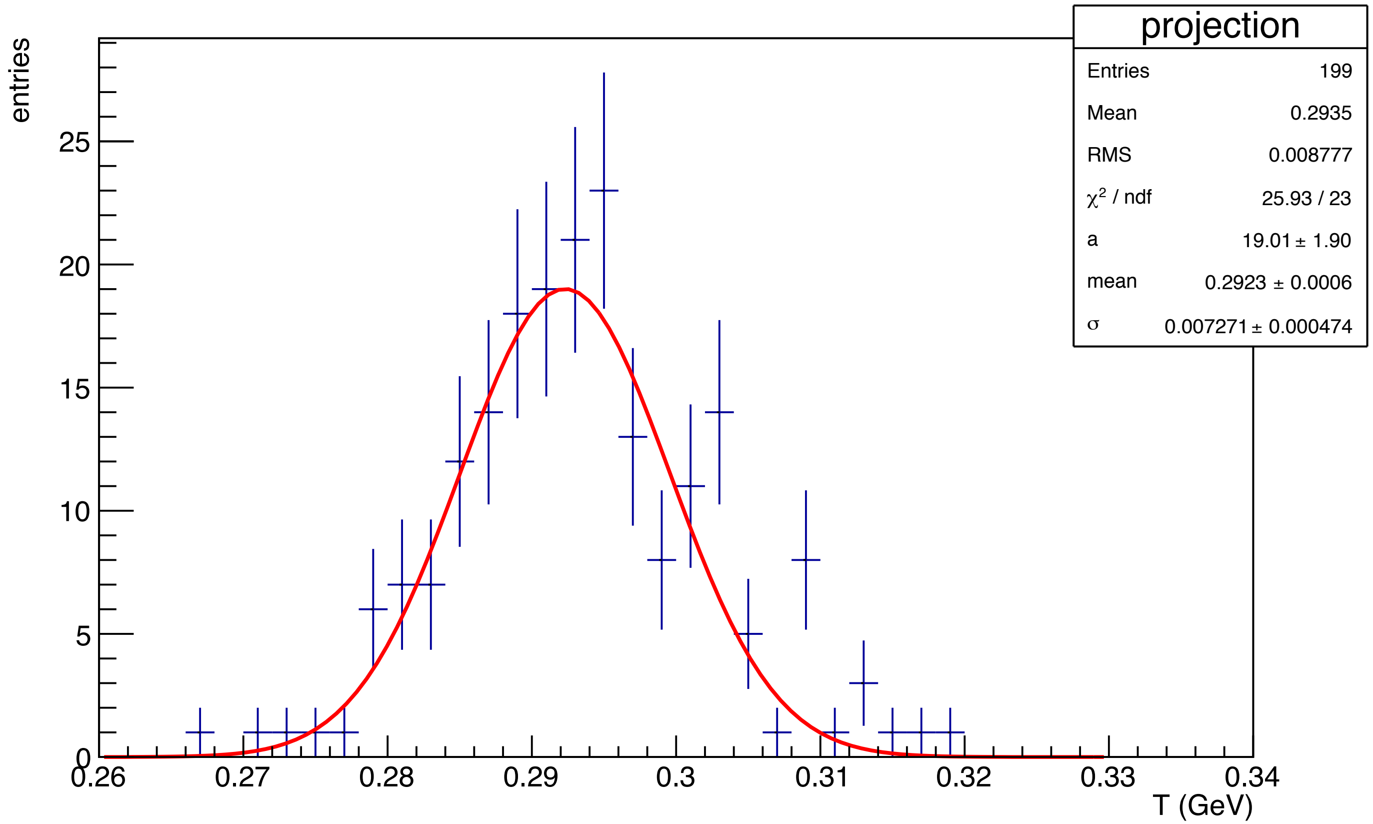








Histogram of 200 ALICE event "temperatures"



- **<T> = 294 ± 8 MeV**
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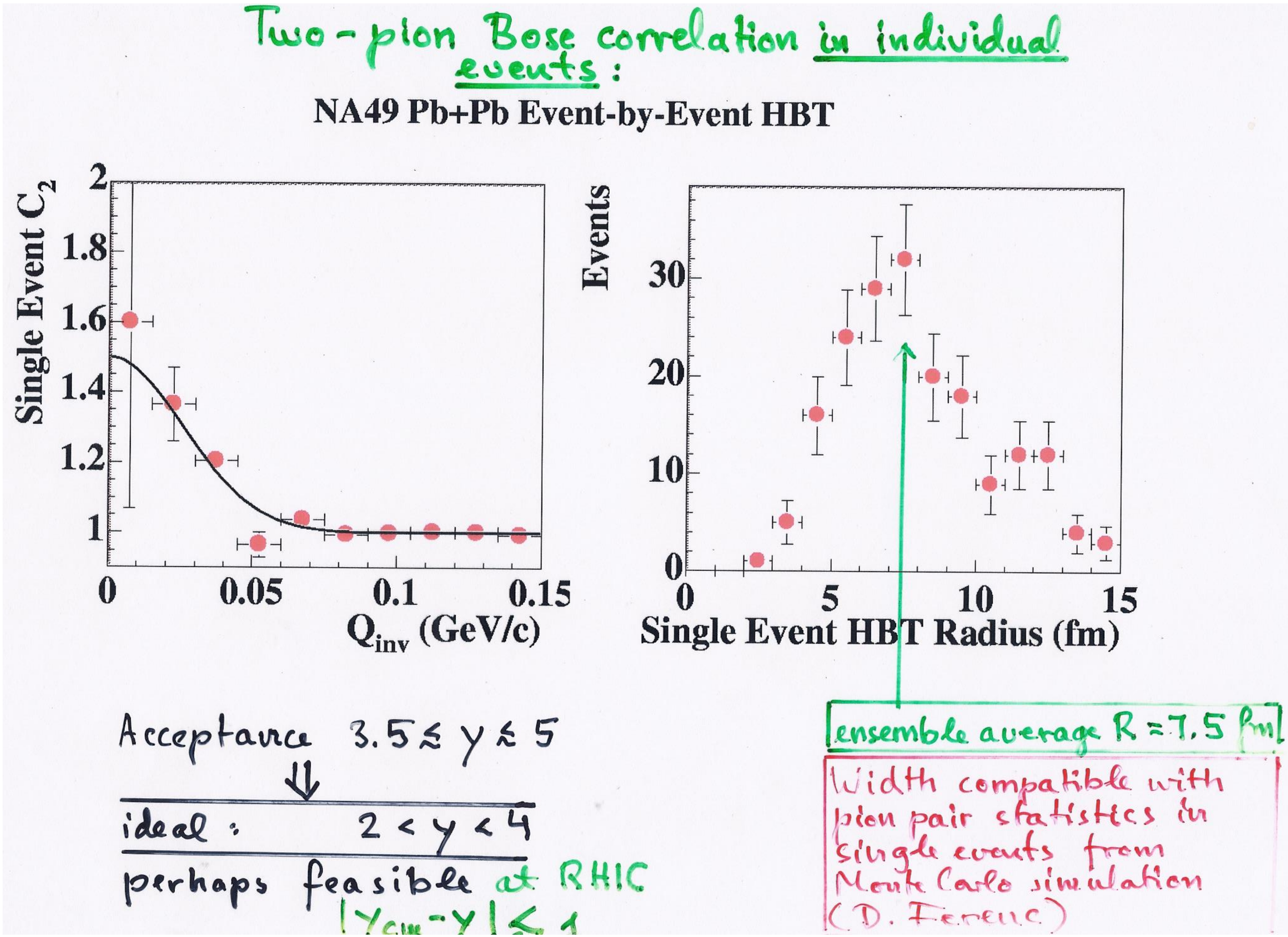
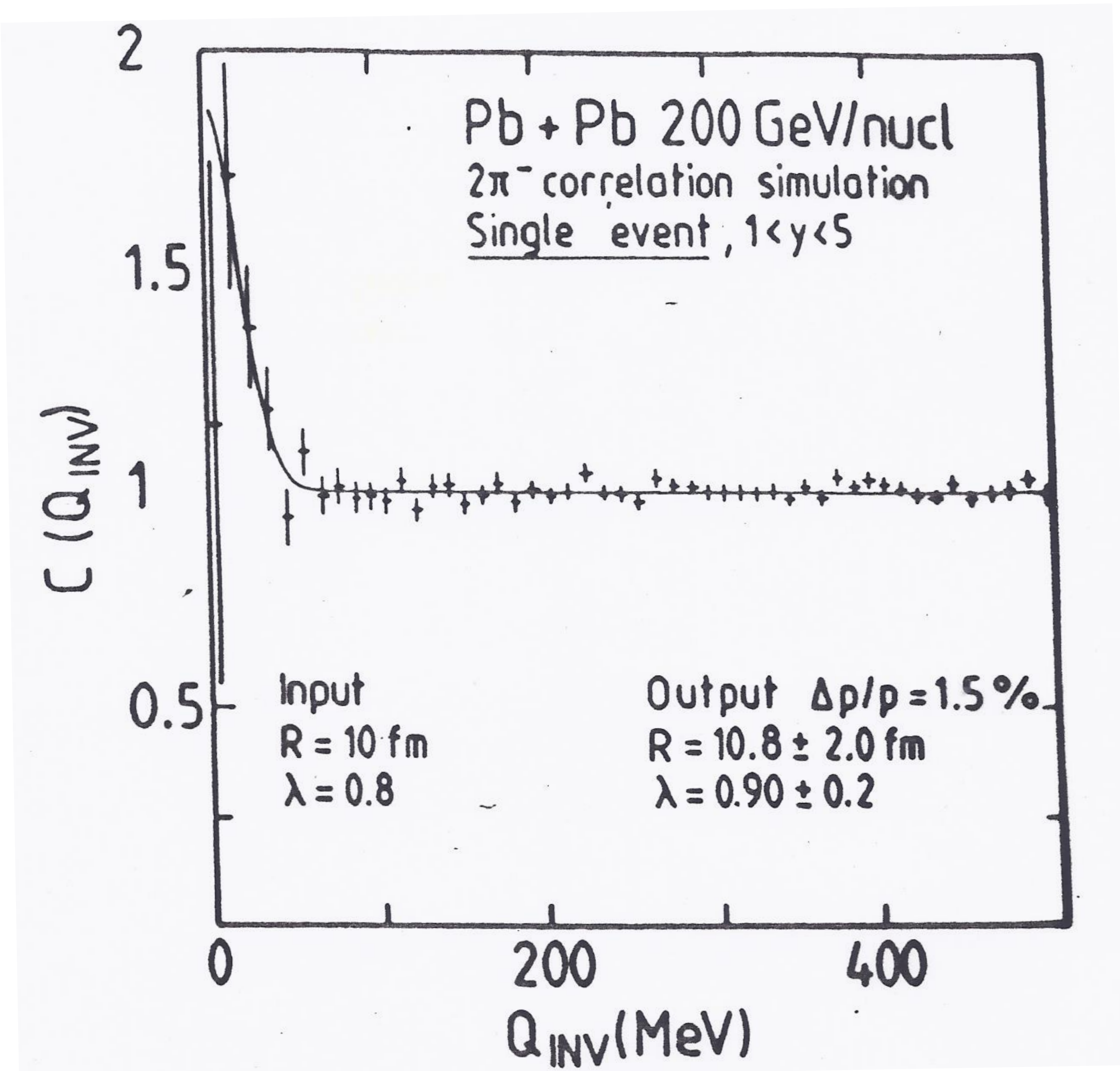
Unexplored: is this mere statistics
or also influenced by radial flow fluctuations **?**

One could than proceed with event engineering: high/low flow selection **!**

One step further:
2 Pion Bose-Einstein Correlation - HBT e-by-e



HBT simulation at 1000 π- per event

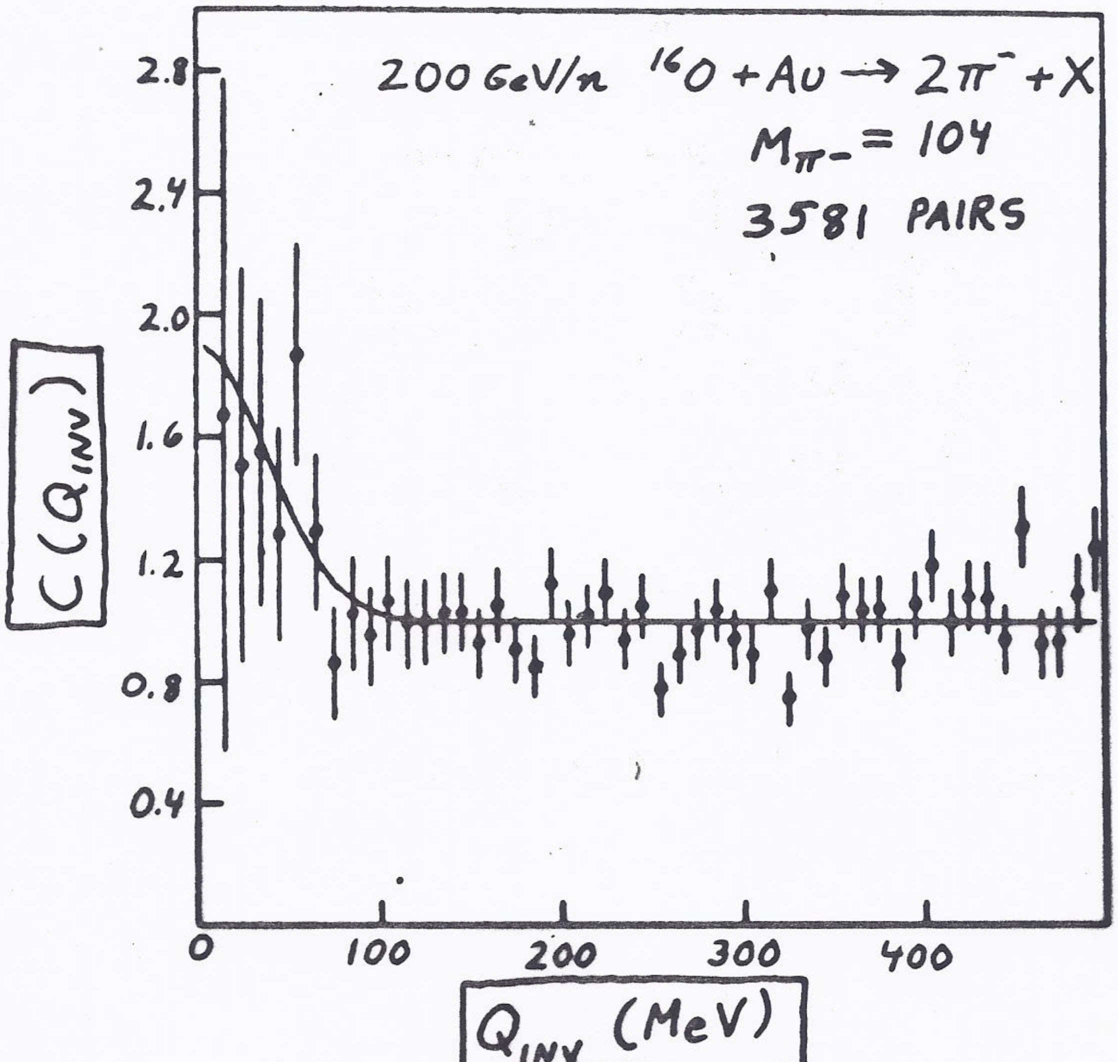


Fit to Q_{INV} correlation function yields invariant radius R_{inv}

Not measured in NA49 but in ALICE!

SINGLE - EVENT PION INTERFEROMETRY

NA35



$$C(Q_{INV}) \propto 1 + \lambda e^{-Q_{INV}^2 R^2/2} \leftarrow$$

$$\left(Q_{INV}^2 = Q^2 - Q_0^2, \quad Q = |\vec{p}_1 - \vec{p}_2|, \quad Q_0 = |E_1 - E_2|\right)$$

$R = 5.2 \pm 1.3$ fm
$\lambda = 0.90 \pm 0.45$

Summary Event by Event Physics in A+A

- Well explored with higher Fourier Harmonics for Hydro flow
  v2, v3, v4, ...

- **Unexplored** for:

- P(T) spectral inverse slope ➤➤ Radial Flow (“zeroth” harmonic)

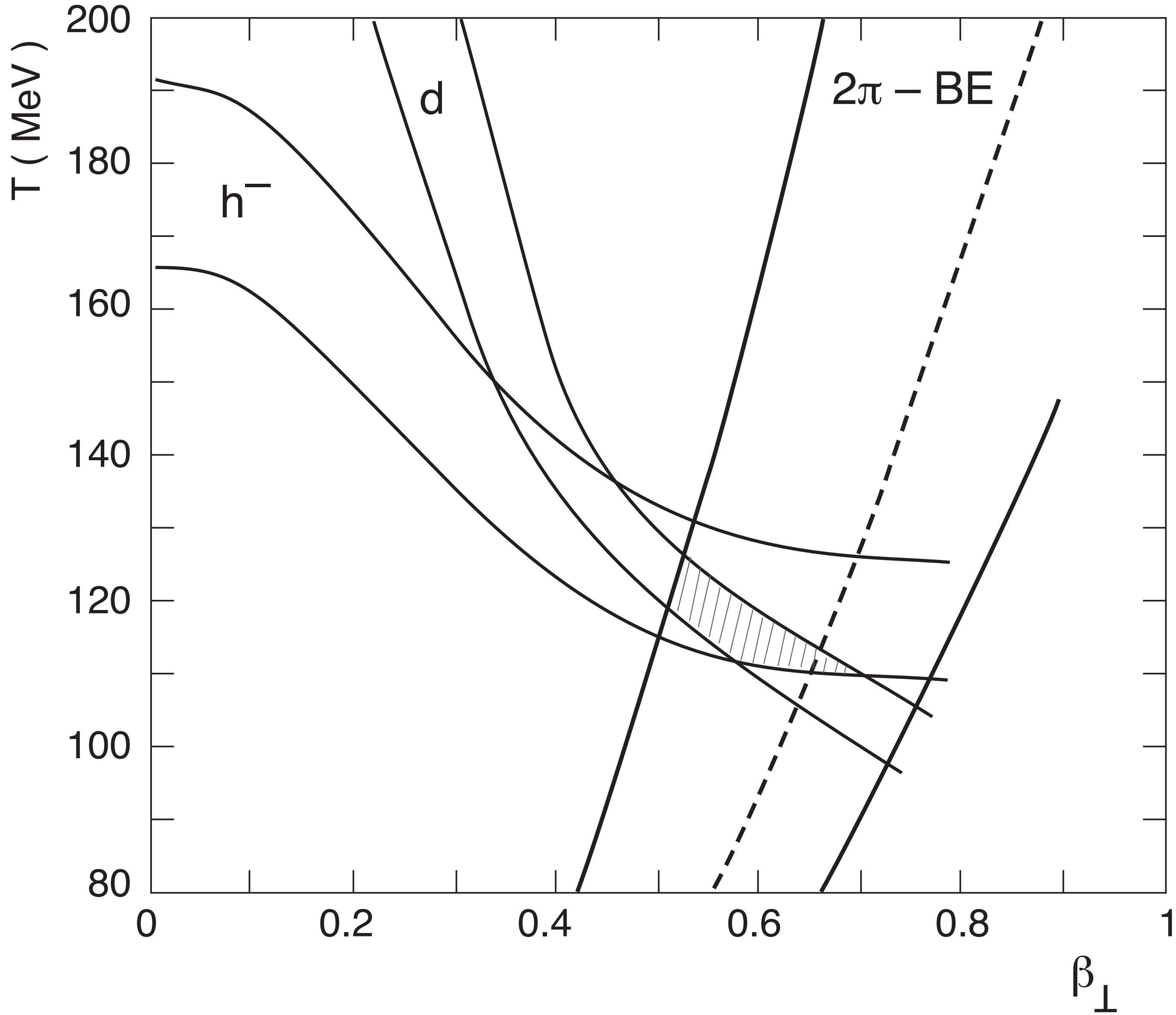
- 2 Pion BE correlation ➤➤ Fireball freeze-out shape / size

- New event energieering?

- First Results for Hadron-Ratio fluctuation ➤➤ Critical point search

Backup

Combined P(T) and BE Analysis NA49



Blast wave model fits