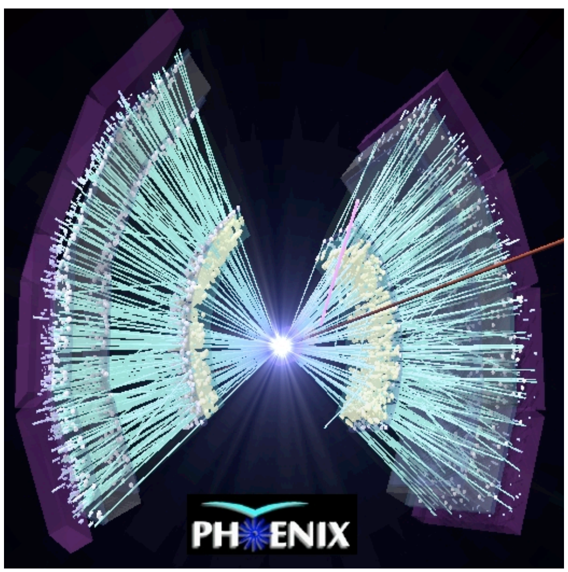
Radial Flow Study via Identified Hadron Spectra in Au+Au collisions



Akio Kiyomichi (RIKEN)
for the PHENIX Collaboration

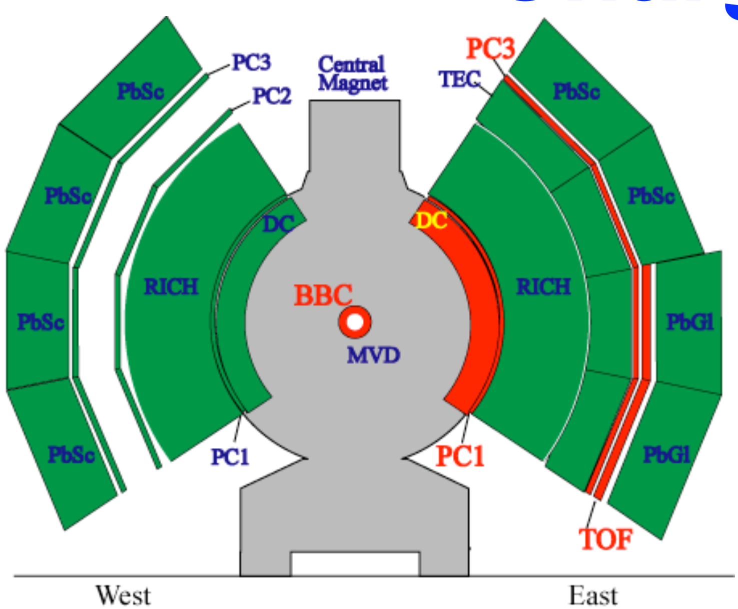
JPS fall Meeting at Kochi University
September 29, 2004

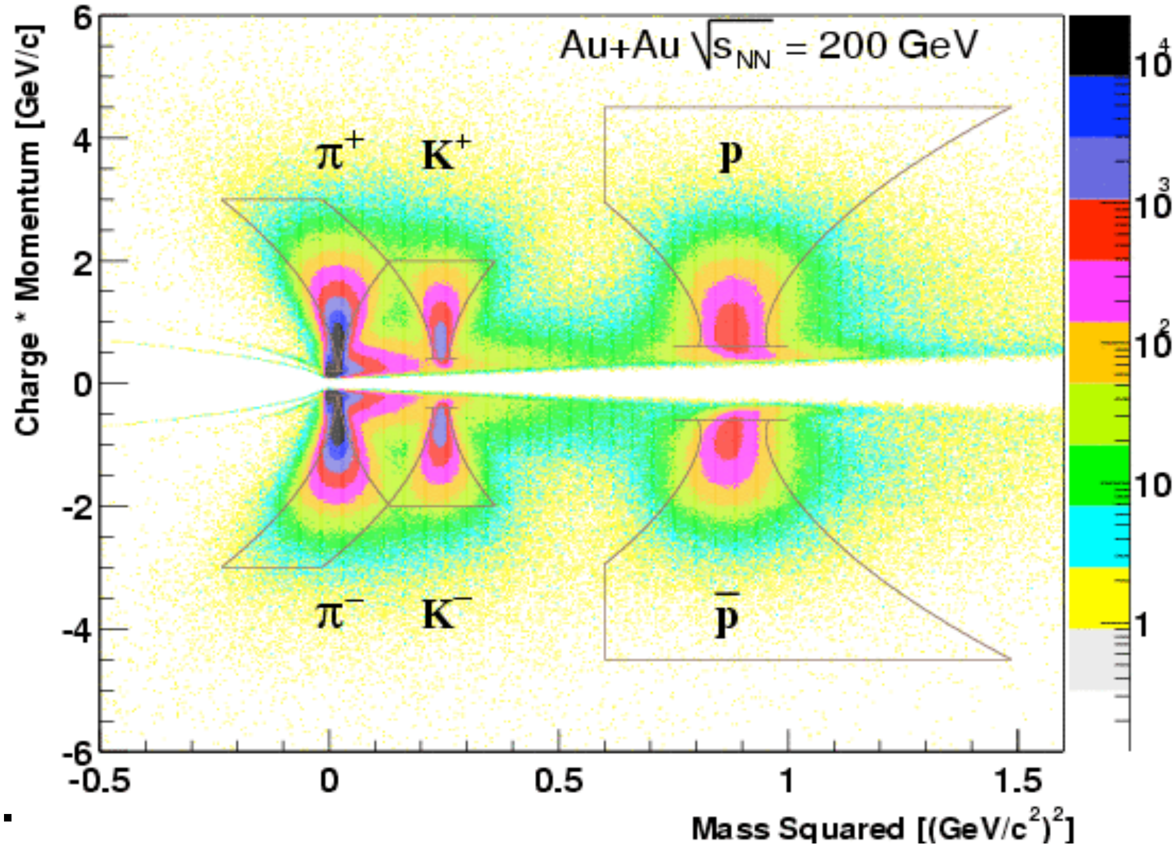
Outline

- **Identified charged hadron spectra at RHIC**
  - p_T spectra : Having the entire history of dynamical evolution of the system.
    - Centrality dependence of spectra shape.
    - $<p_T>$ vs. particle mass, centrality.
    - Freeze-out temperature and expansion velocity(radial flow).

- **In this presentation:**
  - Result of identified charged hadron p_T spectra in Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV (run-2) and 130 GeV(run-1) from PHENIX.
  - Freeze-out temperature and expansion velocity based on the hydro-dynamical model.
    - Single particle spectra of π,K,p are described by common temperature and velocity.
  - Centrality dependence, beam energy dependence.

Charged Hadron PID





- **Detectors for hadron measurement.**
  - DCH+PC1+TOF+BBC
  - $\Delta\phi = \pi/8$, $-0.35 < \eta < 0.35$

- **Charged Hadron PID by TOF.**
  - 0.2< π < 3.0 GeV/c
  - 0.4< K < 2.0 GeV/c
  - 0.6< p < 4.5 GeV/c

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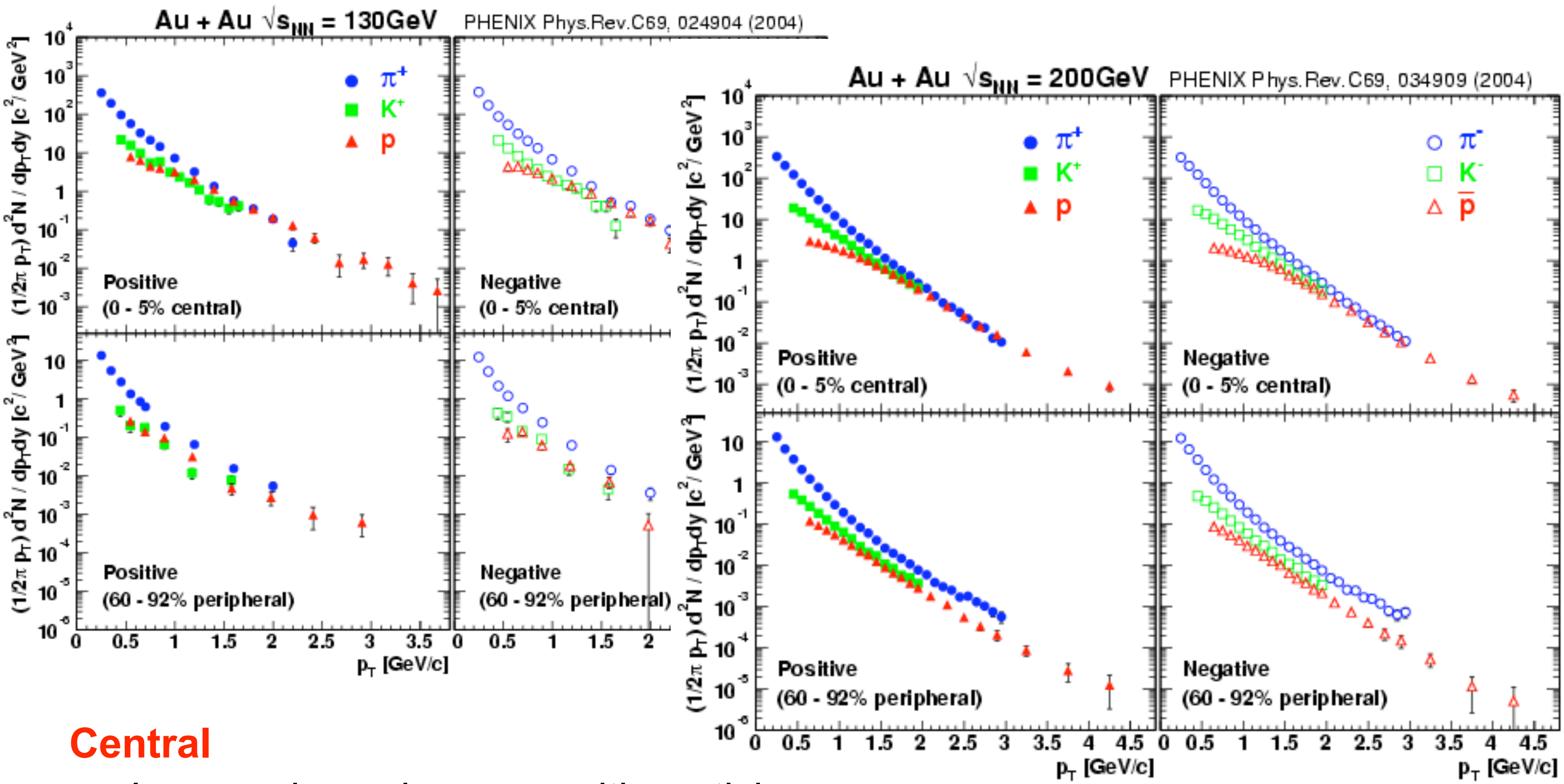
p_T Spectra



Central

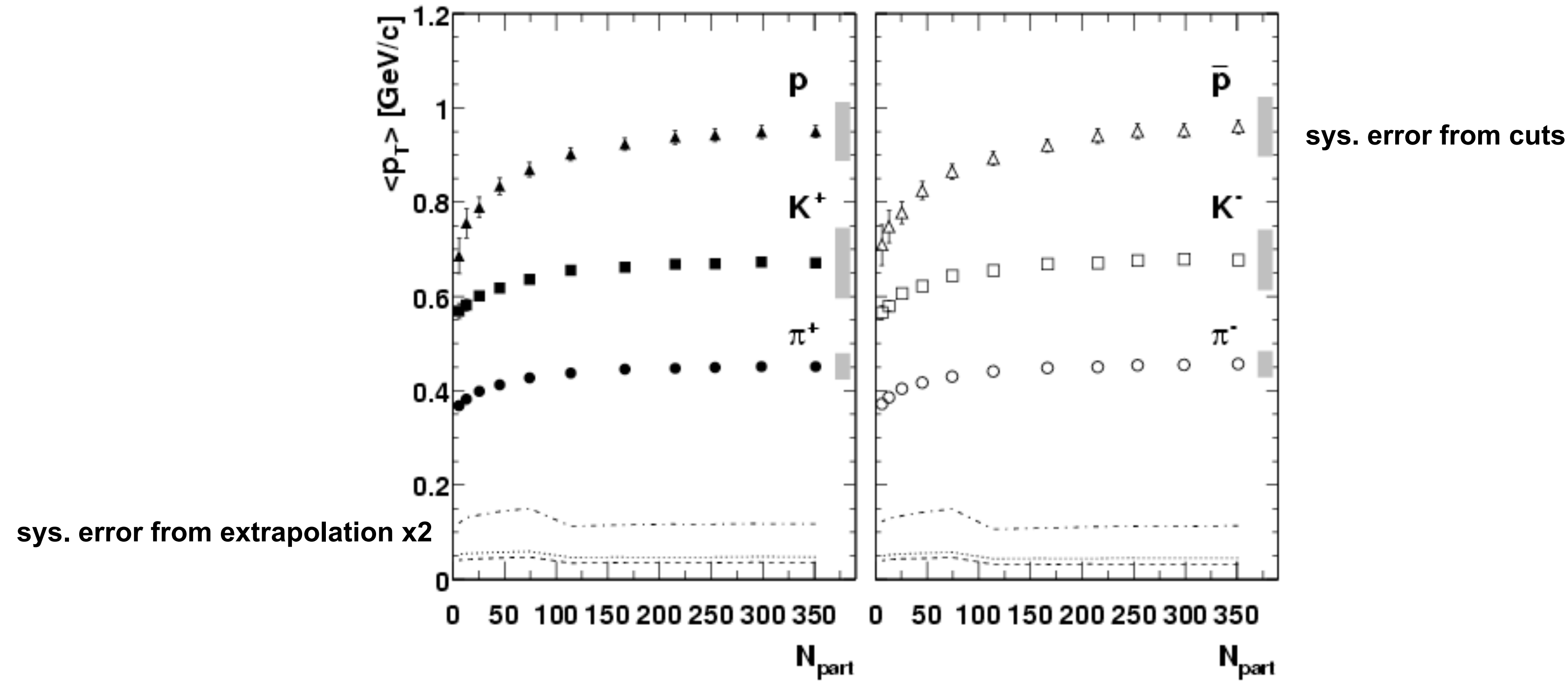
- Low p_T slopes increase with particle mass.
- Proton and anti-proton yields equal the pion yield at high p_T.

Peripheral

- Mass dependence is less pronounces.
- Similar to pp.

Mean p_T vs. N_{part}

Au+Au at $\sqrt{s_{NN}}$ = 200 GeV PHENIX:Phys.Rev.C69,034909(2004)



- Increase from peripheral to mid-central, and then saturate from mid-central to central for all particle species.
- Observed clear mass dependence.
- **Indicative radial expansion. (consistent with hydro picture)**

Blast-wave model Parameterization

$$\frac{1}{m_T}\frac{dN}{dm_T} = A\int_0^R f(r)rdrm_T \mathrm{I}_0\left(\frac{p_T \sinh\rho}{T_{fo}}\right)\mathrm{K}_1\left(\frac{m_T \cosh\rho}{T_{fo}}\right)$$

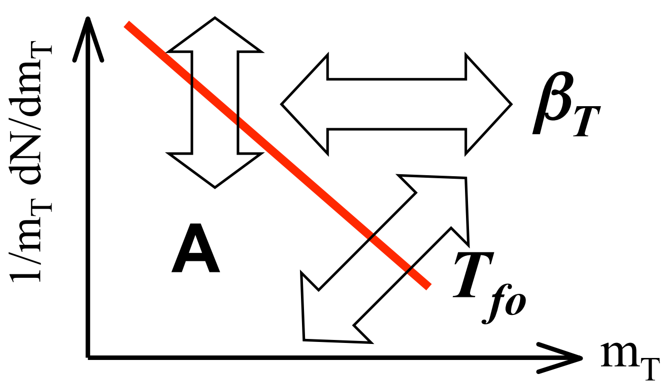
$$\rho(r) = \tanh^{-1}(\beta_T)\cdot r/R$$

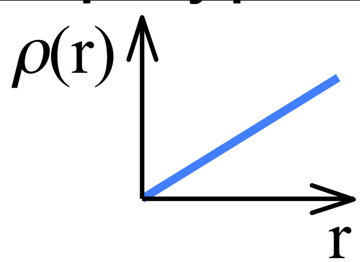
$\mathbf{I_0}$, $\mathbf{K_1}$: modified Bessel function

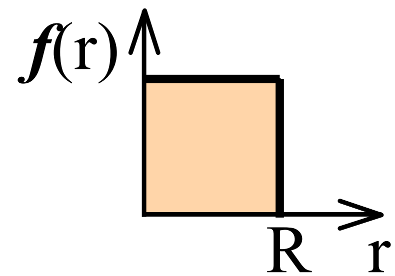
Ref:<u>**Sollfrank,Schnedermann,Heinz,PRC48(1993)2462.**</u>

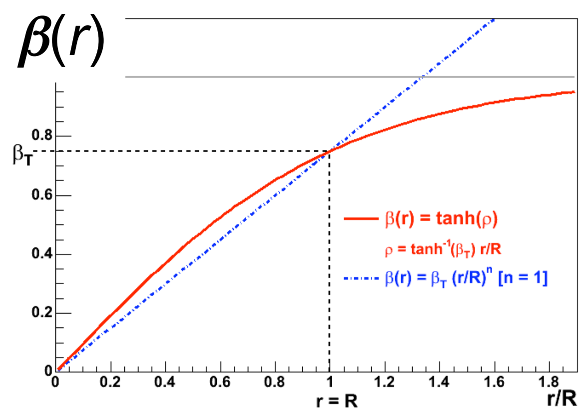
Use <u>**linear flow rapidity profile**</u> and <u>**constant particle density**</u>

Parameters:
- normalization **A**
- freeze-out temperature T_{fo}
- surface velocity β_T









Average flow velocity:

$$\langle\beta_T\rangle = \frac{\int_0^R \beta(r)rdr}{\int_0^R rdr}$$

$$\beta(r) = \tanh\rho(r)$$

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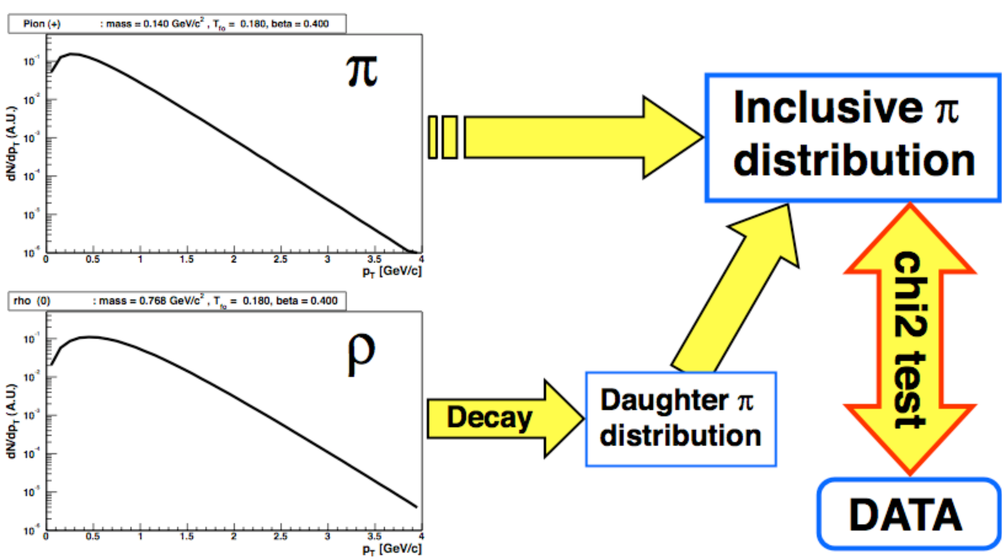
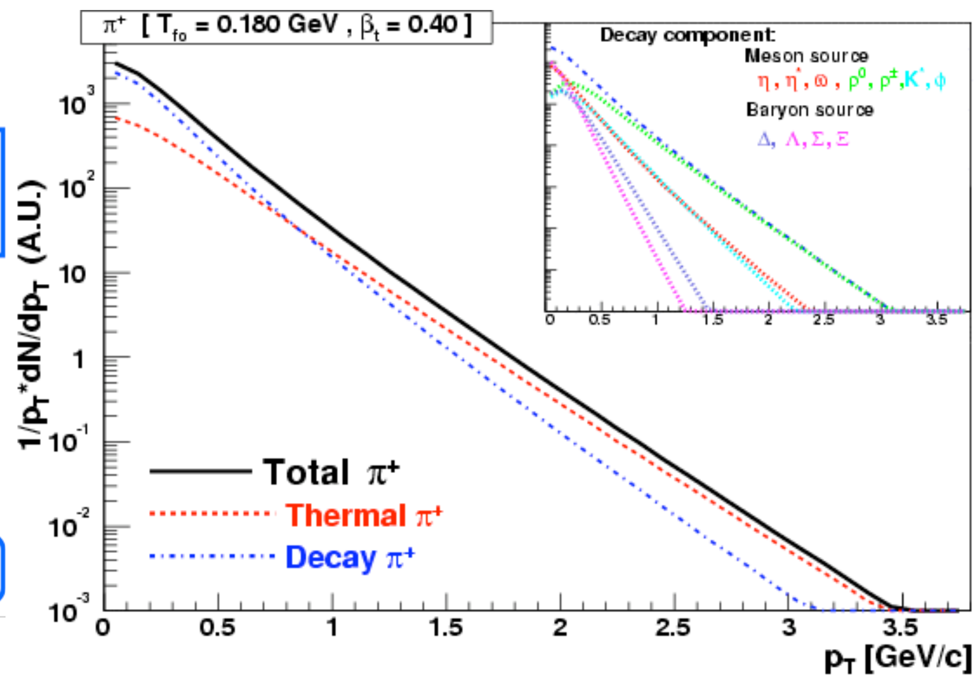
Model fit with resonance feed down

1. Generate resonances with p_T distribution determined by each combinations of T_{fo}, β_T.
2. Decay them and obtain p_T spectra of π,K,p.
3. Particle abundance calculated with chemical parameters
   T_{ch} = 177MeV, μ_B = 29MeV (200GeV), T_{ch} = 176MeV, μ_B = 41MeV(130GeV)
   Ref:P.Braun-Munzinger et al,PLB518(2001)41.
4. Merge and create inclusive p_T spectra. → χ^2 test





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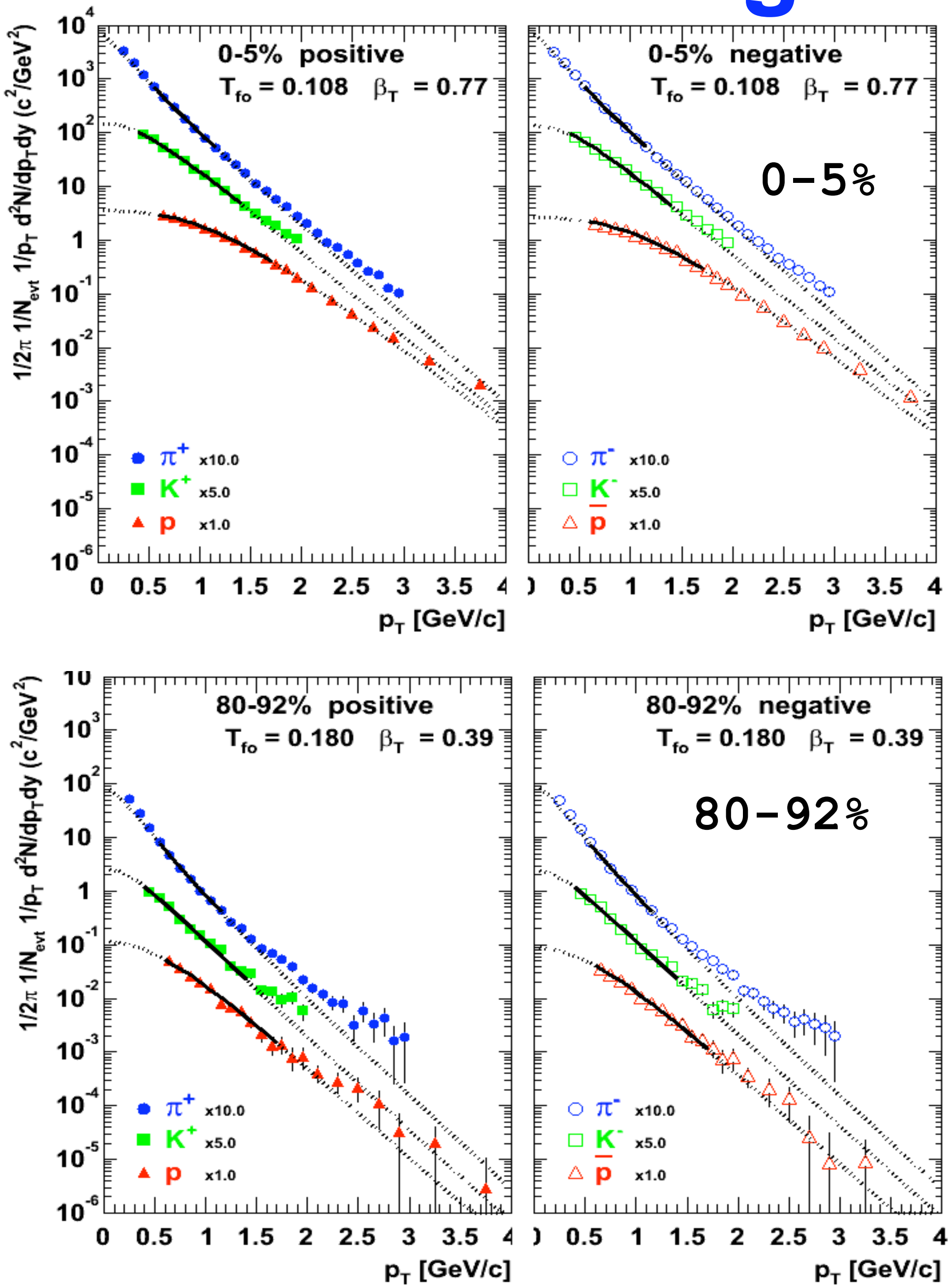
Fitting the p_T spectra



- Minimize contribution from hard process
  - $(m_T\text{-}m_0) < 1GeV$
  - → **π : p_T < 1.2GeV/c,**
    K : p_T < 1.4GeV/c,
    p : p_T < 1.7GeV/c
- Exclude large resonance for pion at very low p_T region
  - π : p_T>0.5GeV/c

- Simultaneous fit to spectra of π,K,p
  - T_{fo} : 60~240MeV , **2**MeV each
  - β_T : 0.00~0.90, **0.01** each
- More fine mesh in small region:
  - T_{fo} : 90~130MeV , **1**MeV each
  - β_T : 0.70~0.82, **0.002** each

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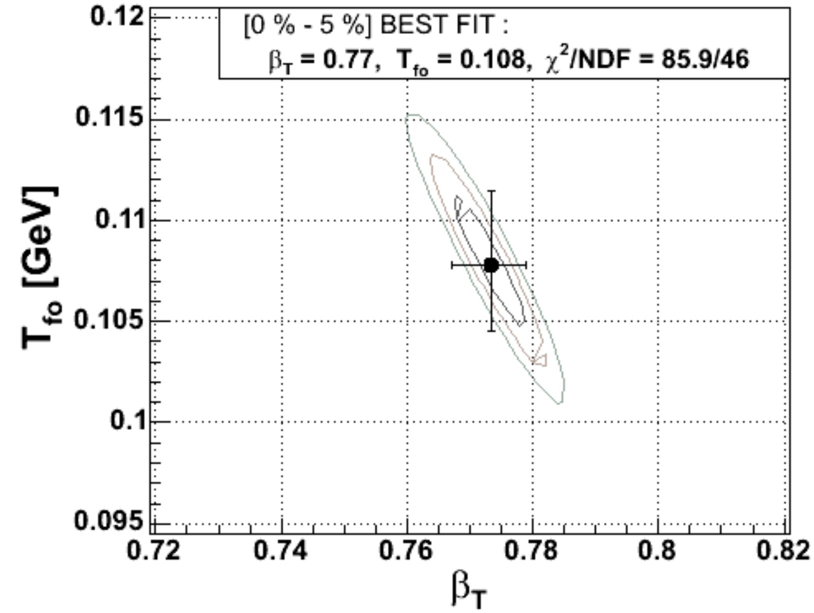
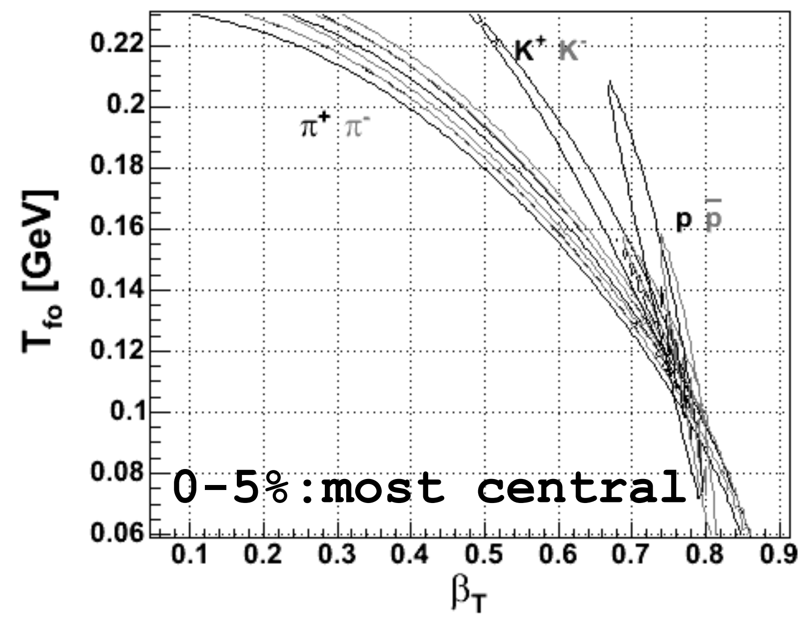
χ^2 contours in parameter space T_{fo} and β_T

- Upper figure show the χ^2 test result of simultaneous fitting for most-central spectra.
- Lower figure show χ^2 contours for each particles.
- There are strong anti-correlation between T_{fo} and β_T.

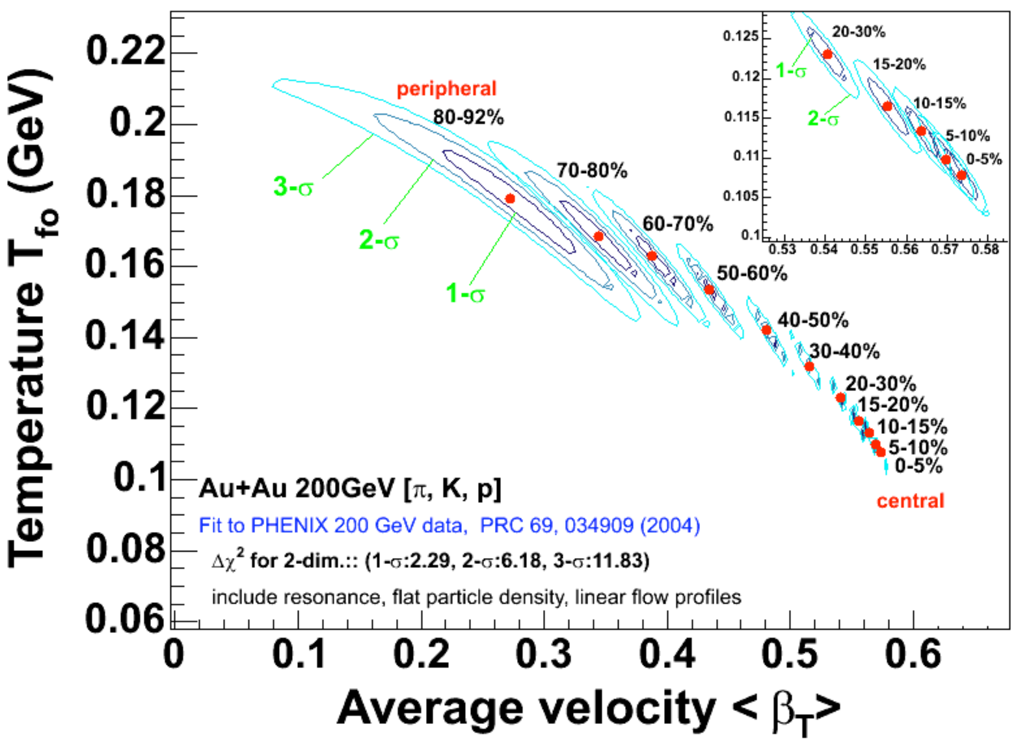


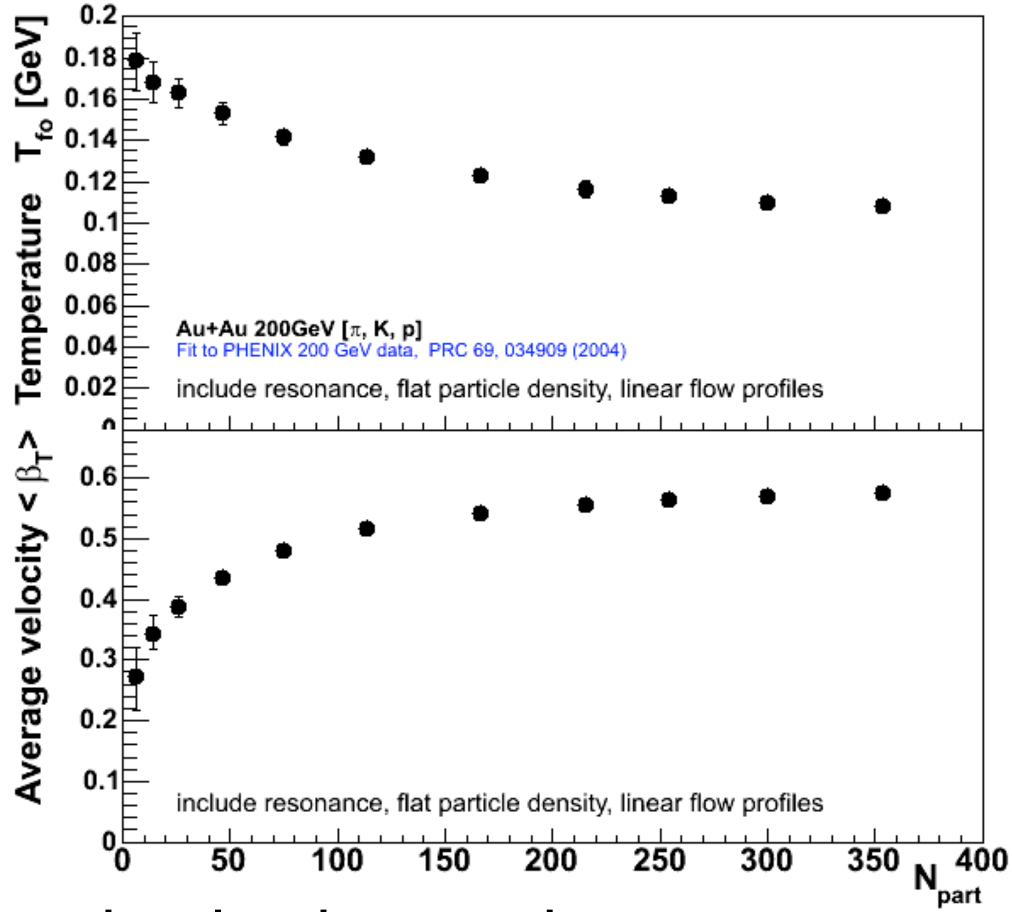


PHENIX Au+Au most central:

- **200GeV: T_{fo} = 108MeV, $<\beta_T>$ = 0.57**
- **130GeV: T_{fo} = 134MeV, $<\beta_T>$ = 0.48**

Centrality dependence of T_{fo} and $<\beta_T>$





- N_{part} dependence of expansion is observed:
  - @central: saturate
  - @peripheral : $N_{part} \rightarrow 0$, **T_{fo} increase, $<\beta_T> \rightarrow 0$**

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Conclusion

- Results of identified charged hadron spectra.
  - Au+Au 130GeV: Phys.Rev.C69 024904(2004)
  - Au+Au 200GeV: Phys.Rev.C69 034909(2004)
- Hydro-dynamical model fit to the spectra with resonance decay effect.
  - N_{part} dependence of expansion is observed
    - @central : saturate
    - @peripheral $N_{part} \rightarrow 0$: **T_{fo} increase, $\langle\beta_T\rangle \rightarrow 0$**
  - For the most central:
    - **Au+Au 200GeV: T_{fo} = 108MeV, $\langle\beta_T\rangle$ = 0.57**
    - **Au+Au 130GeV: T_{fo} = 134MeV, $\langle\beta_T\rangle$ = 0.48**

Next Step

- for Au+Au 62.4GeV, p+p 200GeV

PHENIX

Country	Institution
Brazil	University of São Paulo, São Paulo
China	Academia Sinica, Taipei, Taiwan
	China Institute of Atomic Energy, Beijing
	Peking University, Beijing
France	LPC, University de Clermont-Ferrand, Clermont-Ferrand
	Dapnia, CEA Saclay, Gif-sur-Yvette
	IPN-Orsay, Universite Paris Sud, CNRS-IN2P3, Orsay
	LLR, Ecòle Polytechnique, CNRS-IN2P3, Palaiseau
	SUBATECH, Ecòle des Mines at Nantes, Nantes
Germany	University of Münster, Münster
Hungary	Central Research Institute for Physics (KFKI), Budapest
	Debrecen University, Debrecen
	Eötvös Loránd University (ELTE), Budapest
India	Banaras Hindu University, Banaras
	Bhabha Atomic Research Centre, Bombay
Israel	Weizmann Institute, Rehovot
Japan	Center for Nuclear Study, University of Tokyo, Tokyo
	Hiroshima University, Higashi-Hiroshima
	KEK, Institute for High Energy Physics, Tsukuba
	Kyoto University, Kyoto
	Nagasaki Institute of Applied Science, Nagasaki
	RIKEN, Institute for Physical and Chemical Research, Wako
	RIKEN-BNL Research Center, Upton, NY
	Rikkyo University, Tokyo
	Tokyo Institute of Technology, Tokyo
	University of Tsukuba, Tsukuba
	Waseda University, Tokyo
S. Korea	Cyclotron Application Laboratory, KAERI, Seoul
	Kangnung National University, Kangnung
	Korea University, Seoul
	Myong Ji University, Yongin City
	System Electronics Laboratory, Seoul Nat. University, Seoul
	Yonsei University, Seoul
Russia	Institute of High Energy Physics, Protovino
	Joint Institute for Nuclear Research, Dubna
	Kurchatov Institute, Moscow
	PNPI, St. Petersburg Nuclear Physics Institute, St. Petersburg
	St. Petersburg State Technical University, St. Petersburg
Sweden	Lund University, Lund

12 Countries; 58 Institutions; 480 Participants*

Country	Institution
USA	Abilene Christian University, Abilene, TX
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	University of California - Riverside, Riverside, CA
	University of Colorado, Boulder, CO
	Columbia University, Nevis Laboratories, Irvington, NY
	Florida State University, Tallahassee, FL
	Florida Technical University, Melbourne, FL
	Georgia State University, Atlanta, GA
	University of Illinois Urbana Champaign, Urbana-Champaign, IL
	Iowa State University and Ames Laboratory, Ames, IA
	Los Alamos National Laboratory, Los Alamos, NM
	Lawrence Livermore National Laboratory, Livermore, Ca
	University of New Mexico, Albuquerque, NM
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	Dept. of Chemistry, Stony Brook Univ., Stony Brook, NY
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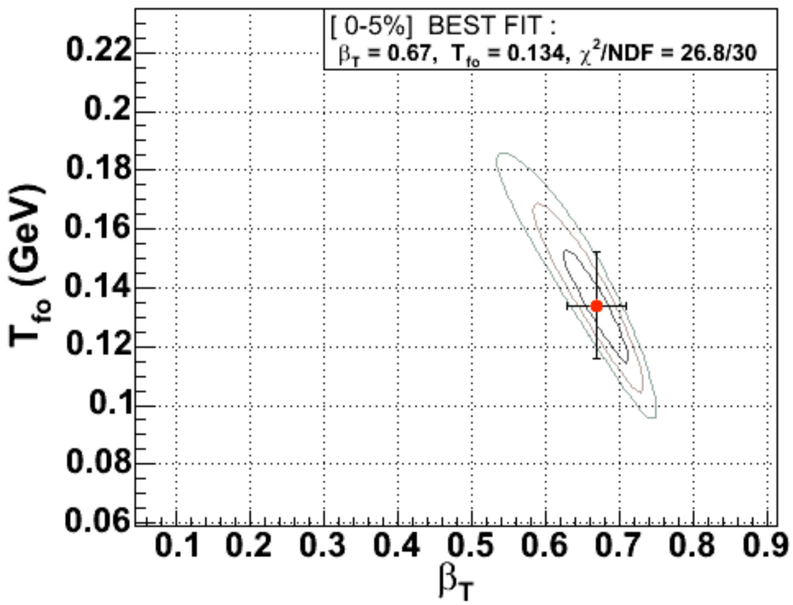
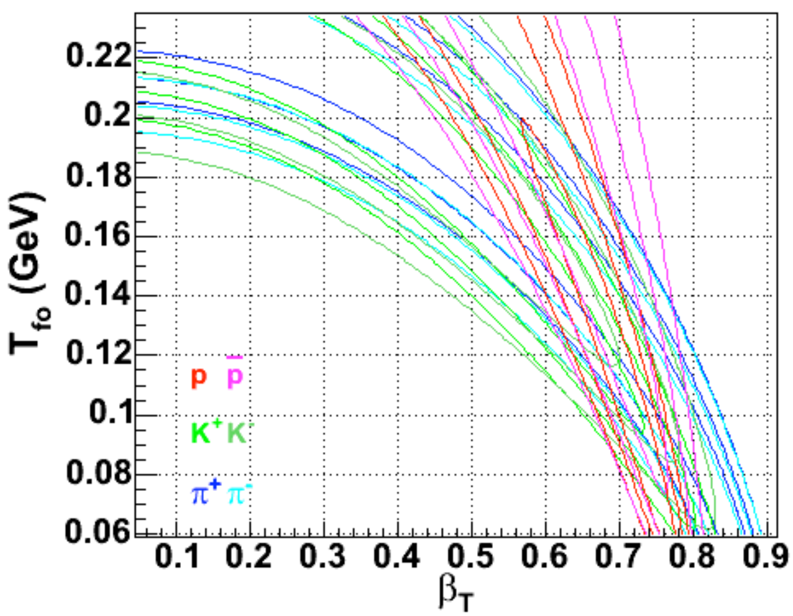
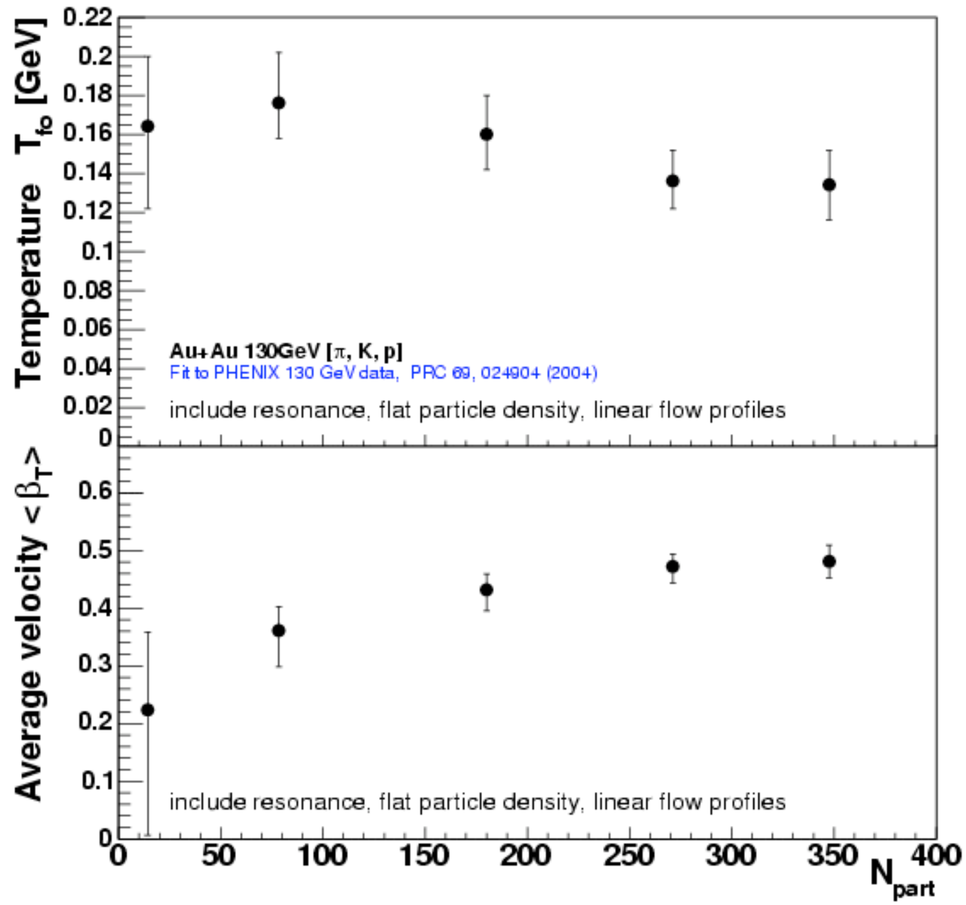
	Oak Ridge National Laboratory, Oak Ridge, TN
	University of Tennessee, Knoxville, TN
	Vanderbilt University, Nashville, TN

*as of January 2004

Au+Au 130GeV

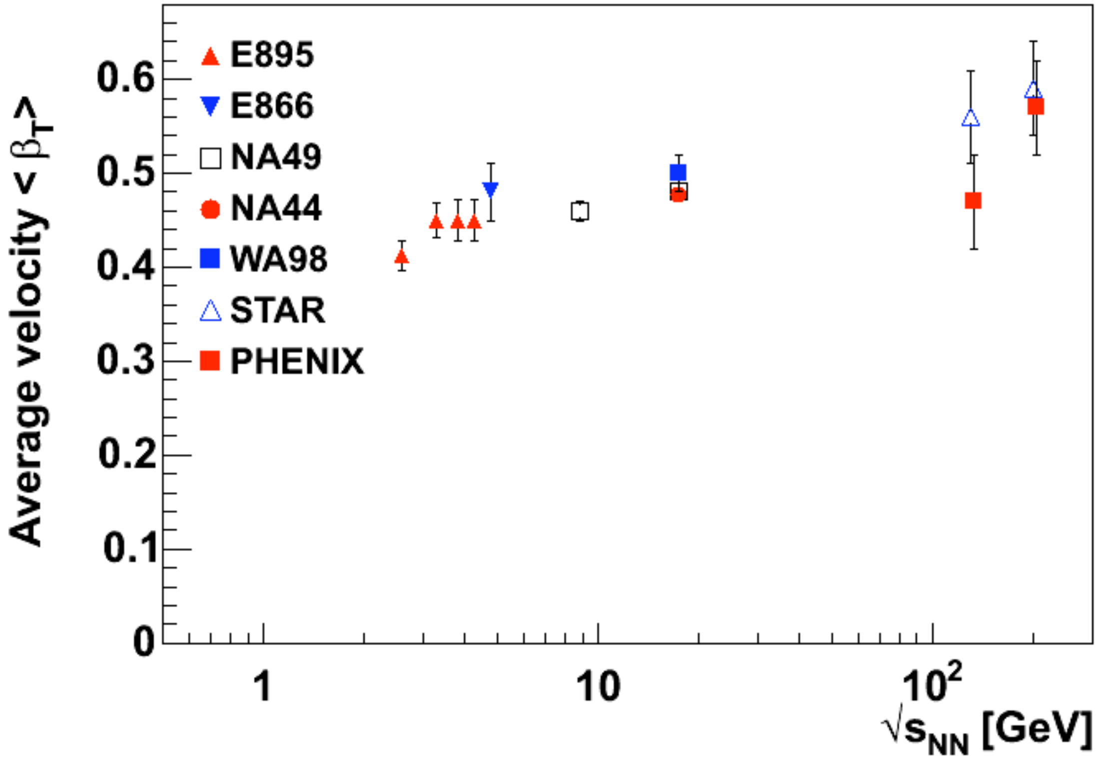


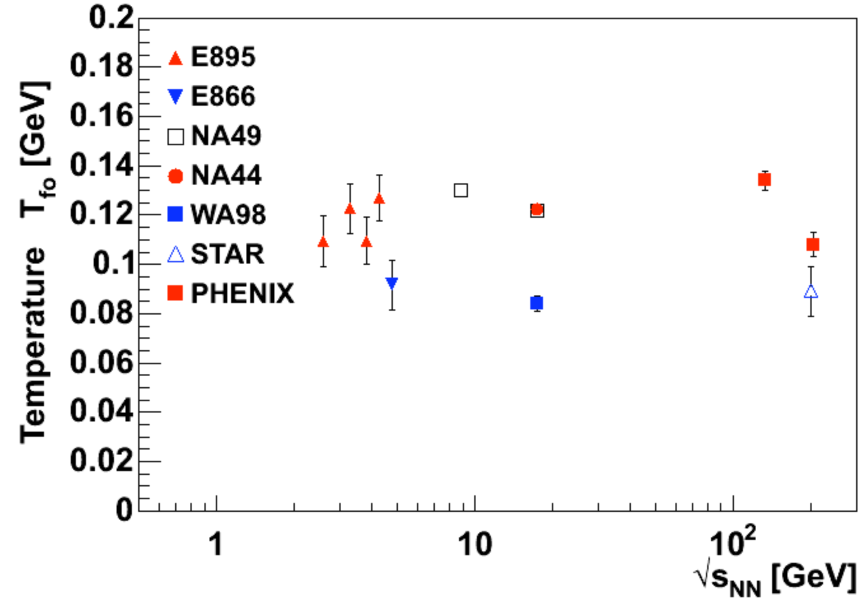




- Simultaneous fit to spectra of π,K,p (Au+Au 130GeV)

Beam energy dependence





- Most central event of Au+Au (AGS,RHIC) or Pb+Pb (SPS)
- Radial flow: Slightly increases from $<\beta_T>$~0.45 (AGS) to ~0.5 (SPS), ~0.55(RHIC) .
- Temperature: 100~120MeV

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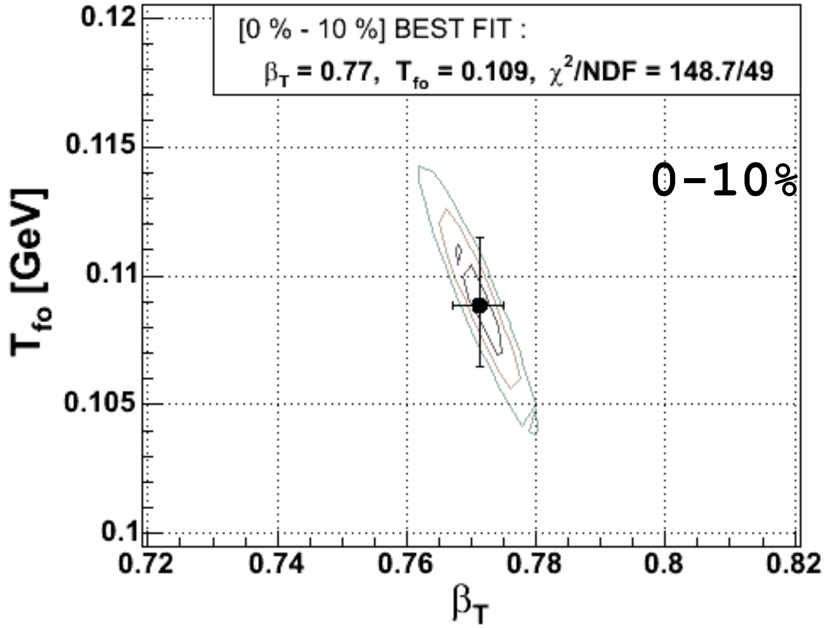
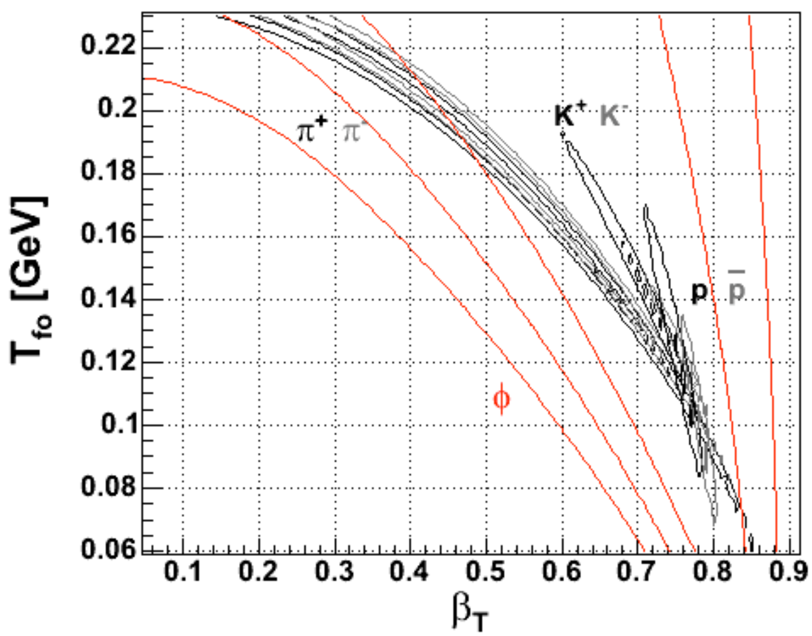
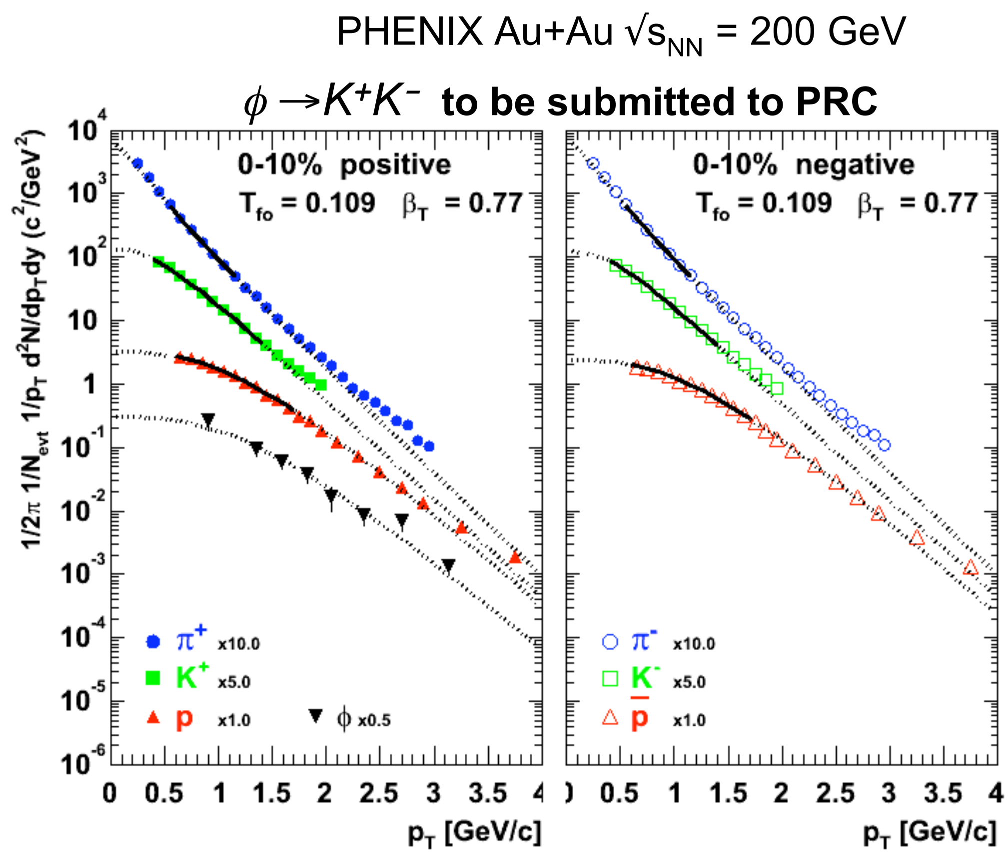
Fit with phi meson



- Simultaneous fit of π,K,p and ϕ.
- χ^2 contour for ϕ overlap with π,K,p.
- Seem to be common T_{fo} and $<\beta_T>$





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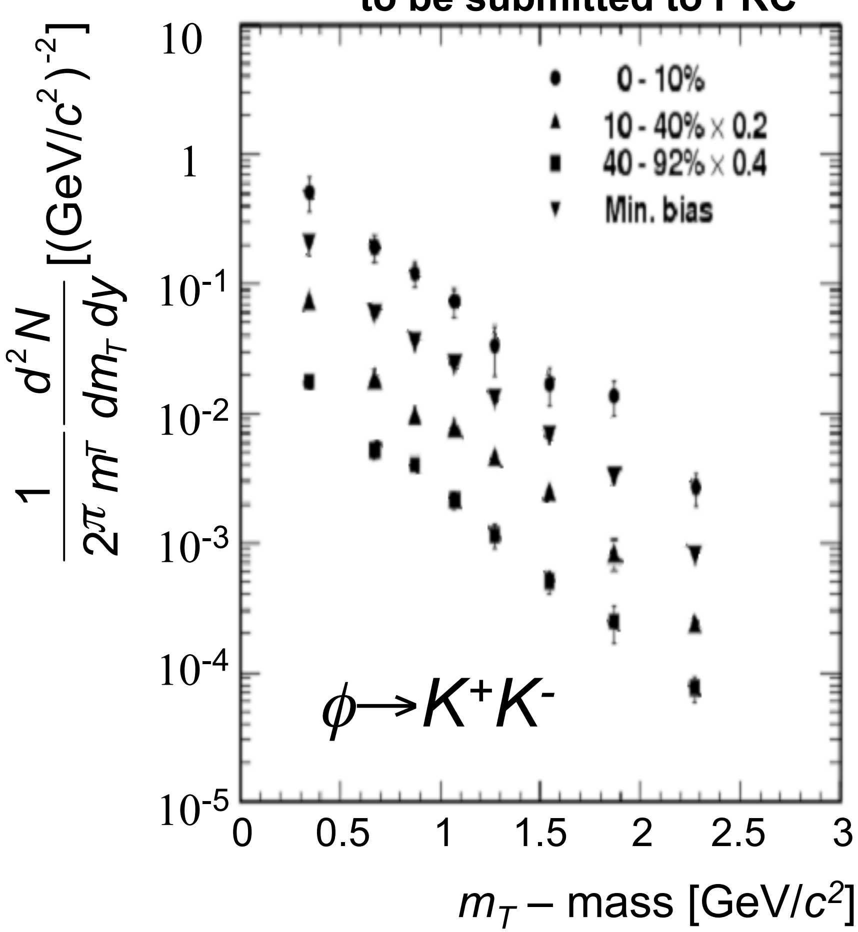
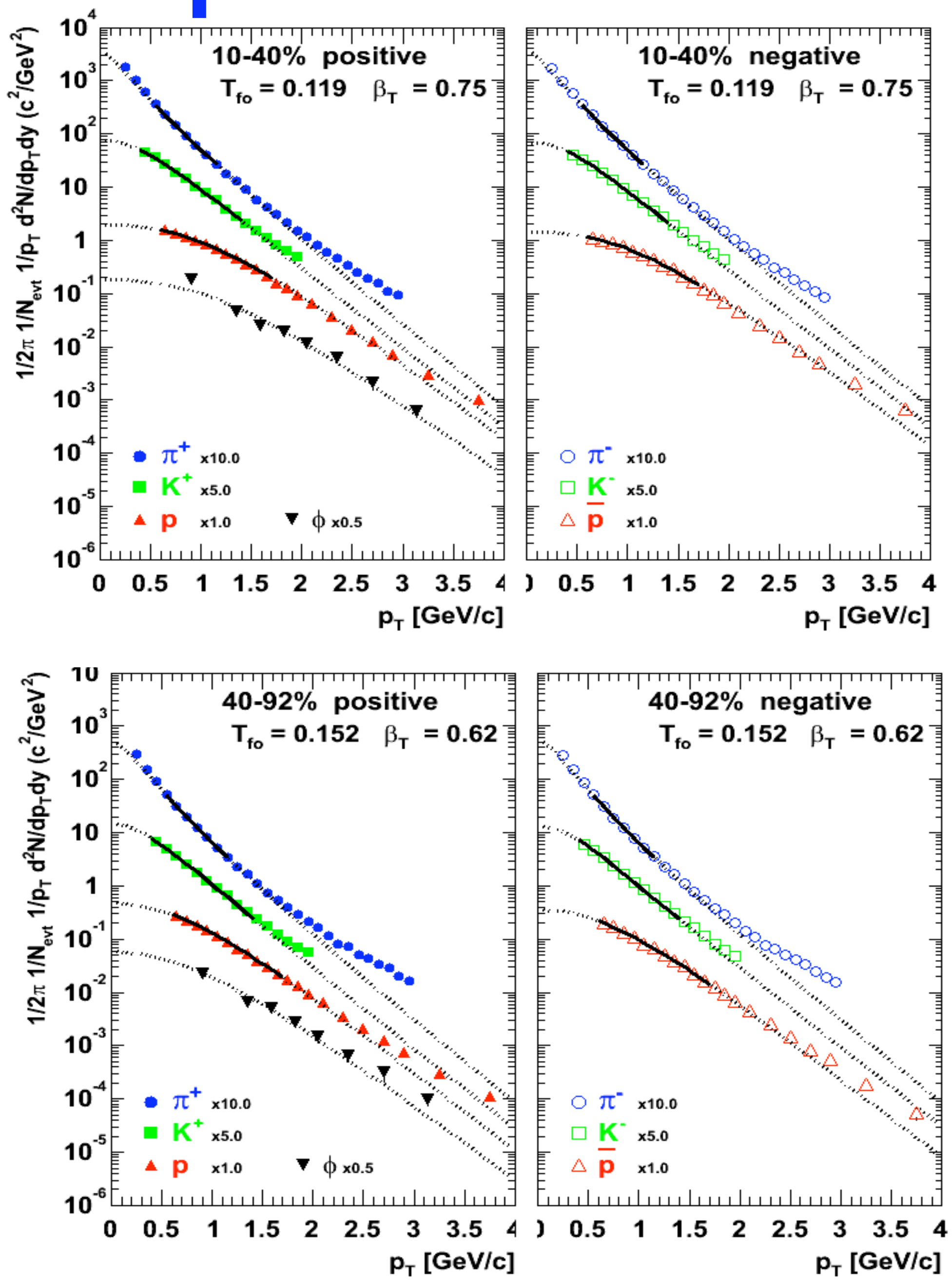
Fit with phi

PHENIX Au+Au $\sqrt{s_{NN}}$ = 200 GeV

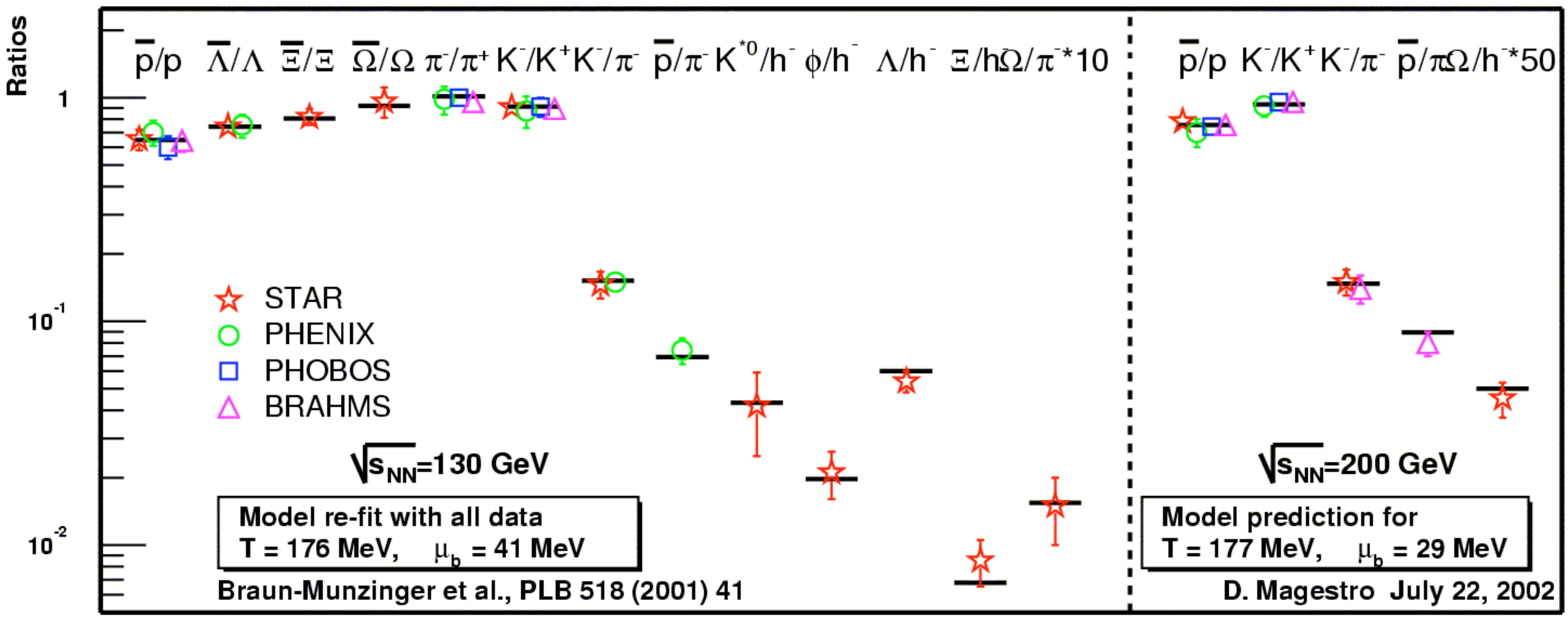
to be submitted to PRC





Evidence for equilibrated final state

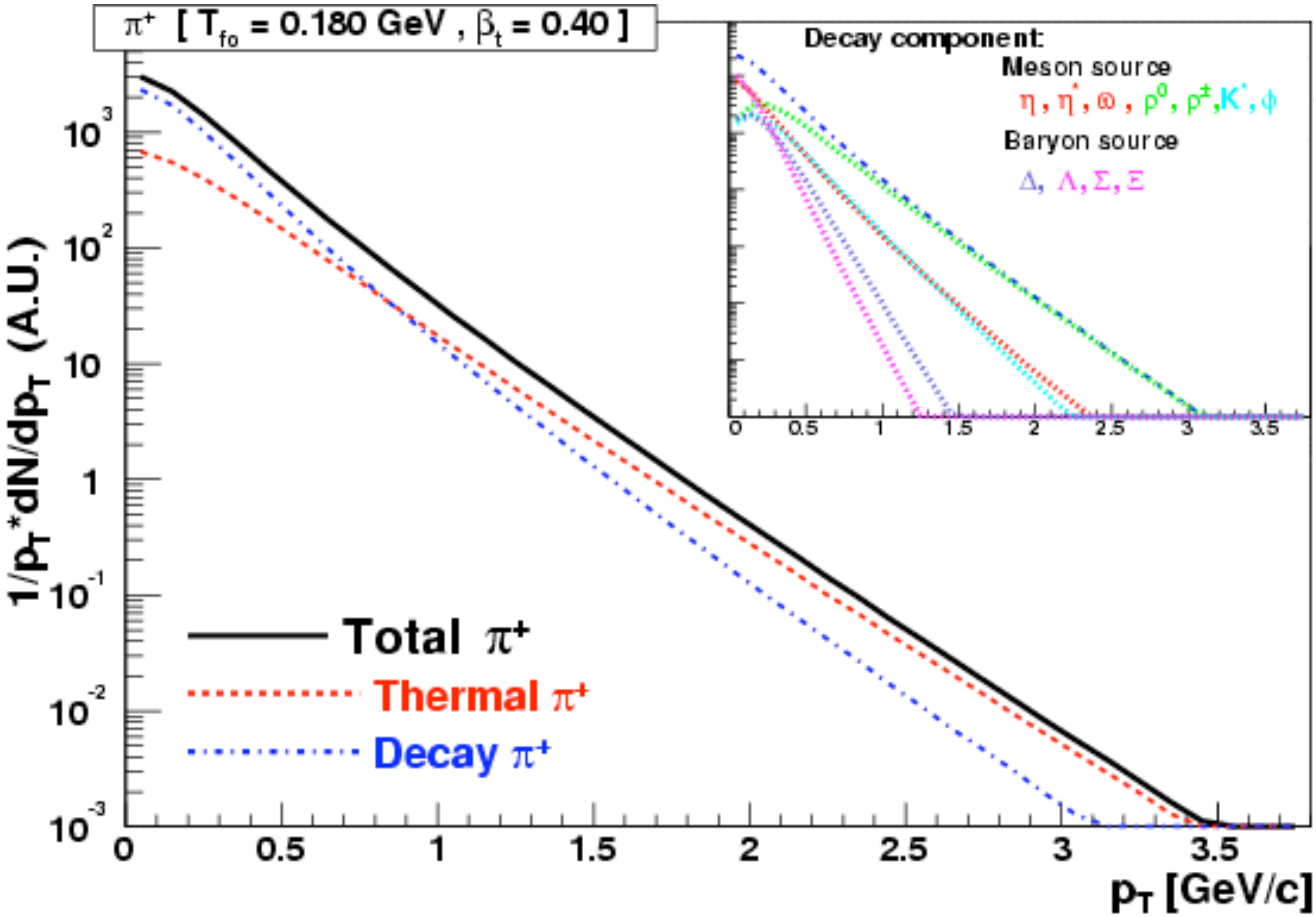
- Almost complete reconstruction of hadronic state when system decouples by the statistical thermal model.
- Fit yields vs. mass (grand canonical ensemble)
  Ø T_{ch} = 177 MeV, μ_B = 29 MeV @ 200 GeV central AuAu.



Inclusive p_T spectra

Resonance:

- $\pi^{\pm}$, $K^{\pm}$, p, anti-p
- ρ^0, $\rho^{\pm}$, η, ω
- $K^{*\pm}$, K^{*0}, anti-K^{*0}, ϕ
- Λ, $\Sigma^{\pm}$, Δ^0, $\Delta^{\pm}$, Δ^{++},anti-



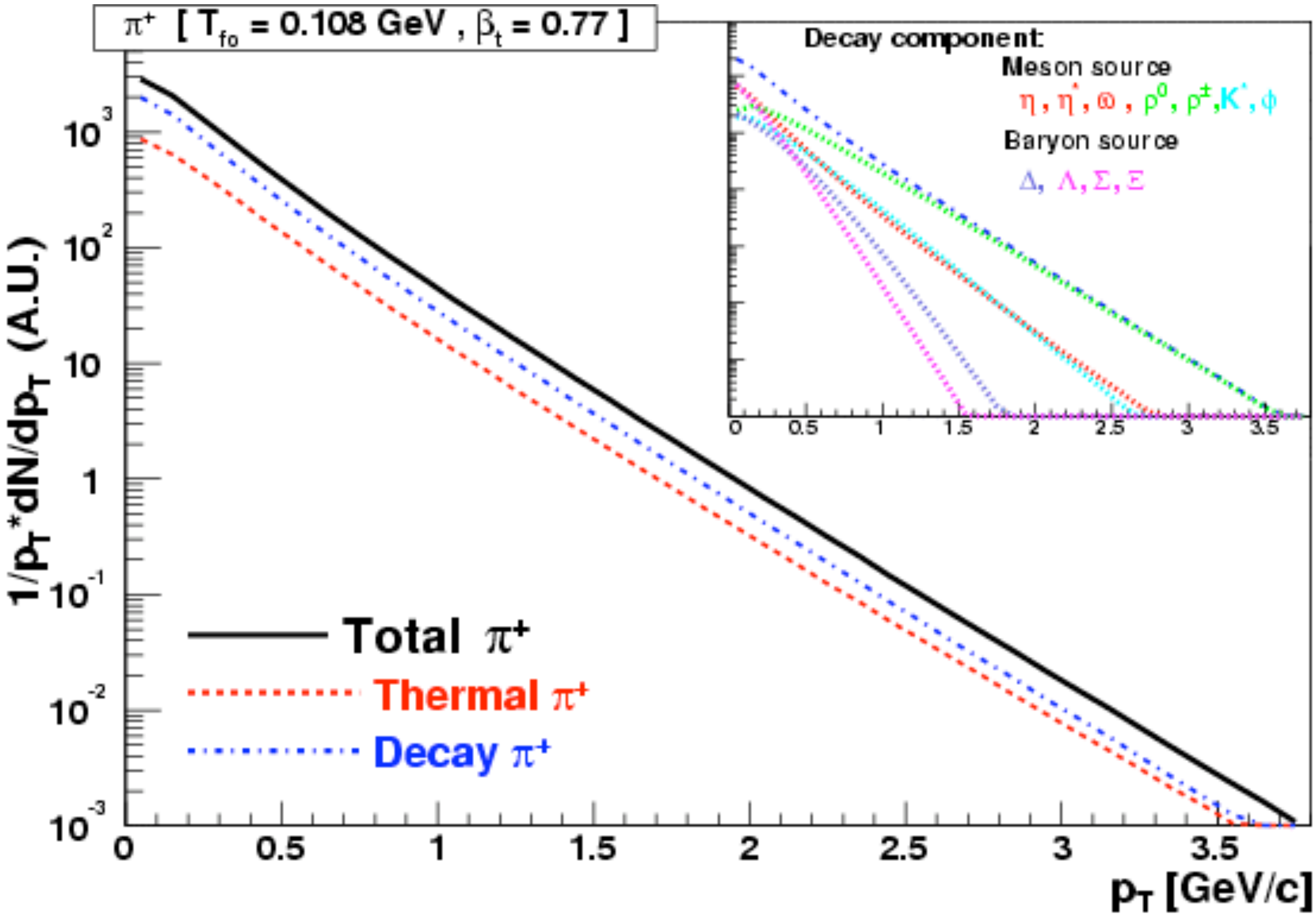
Create inclusive p_T spectra for each particles, each (T_{fo} , β_T)

Spare

Inclusive p_T spectra

Resonance:

- $\pi^{\pm}$, $K^{\pm}$, p, anti-p
- ρ^0, $\rho^{\pm}$, η, ω
- $K^{*\pm}$, K^{*0}, anti-K^{*0}, ϕ
- Λ, $\Sigma^{\pm}$, Δ^0, $\Delta^{\pm}$, Δ^{++},anti-



Create inclusive p_T spectra for each particles, each (T_{fo} , β_T)

Spare

T_{fo} vs. $<\beta_T>$