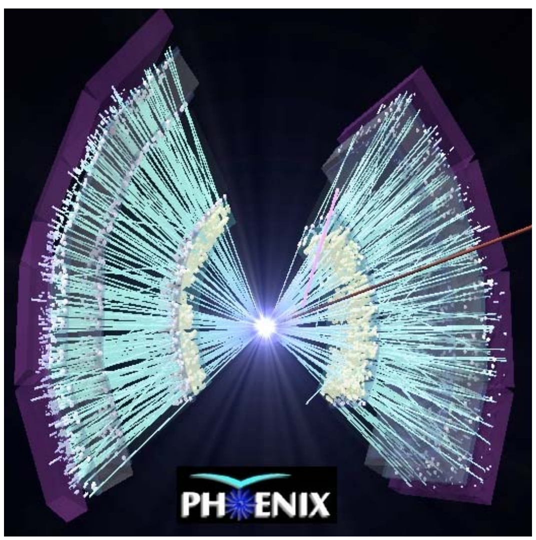
Radial Flow Study from Identified Hadron Spectra in Au+Au collisions at $\sqrt{s_{NN}} = 200\text{GeV}$



Akio Kiyomichi (RIKEN)
for the PHENIX Collaboration

DNP03 meeting at Tucson
November 1, 2003

Outline

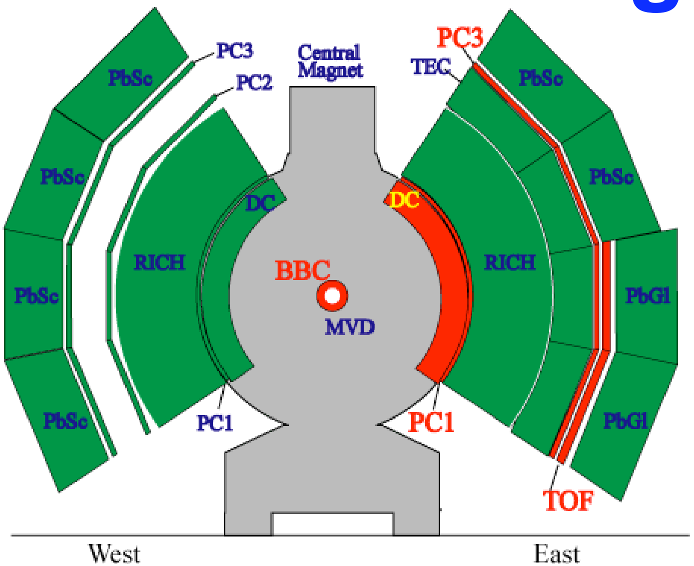
- **Identified charged hadron spectra at RHIC**
  - p_T spectra : Having the entire history of dynamical evolution of the system.
    - $\langle p_T \rangle$ vs. particle mass, centrality.
    - Centrality dependence of spectra shape.
    - Freeze-out temperature and expansion velocity.

- **In this presentation:**
  - Result of identified charged hadron p_T spectra in Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV from PHENIX.

    PHENIX Collaboration S.S.Adler et al., accepted to PRC, nucl-ex/0307022

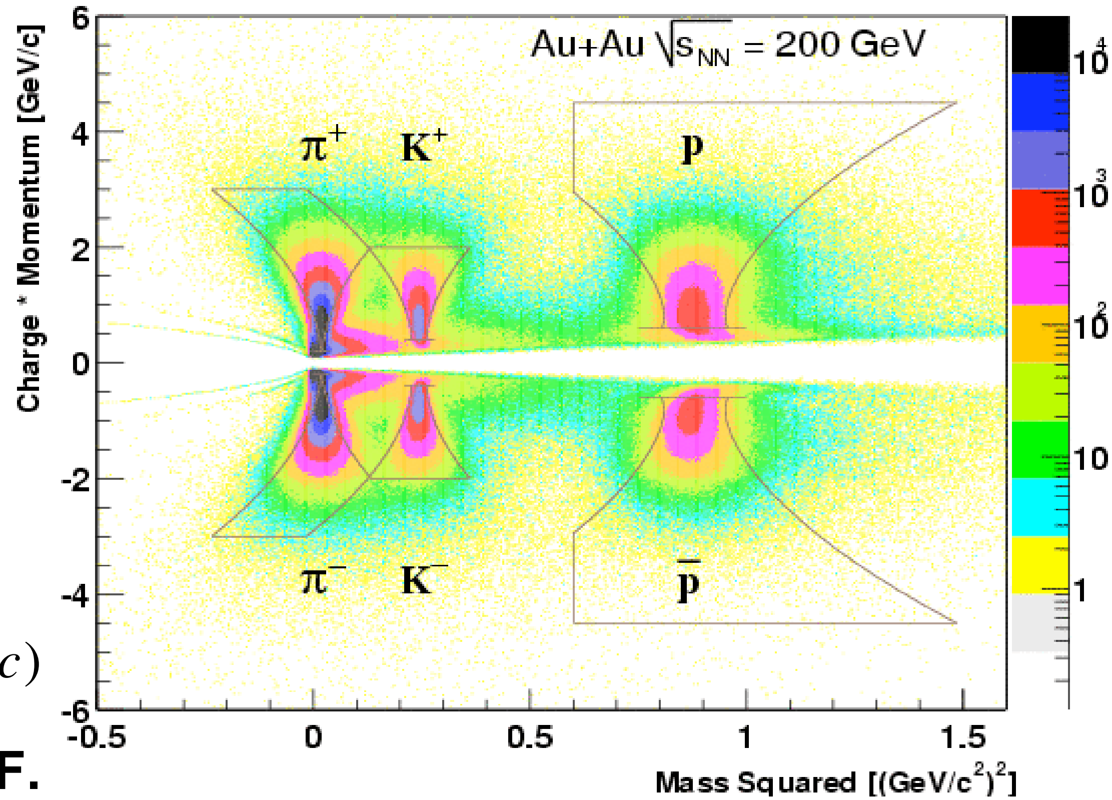
  - Freeze-out temperature and expansion velocity based on the hydro dynamical model (radial flow).

Charged Hadron PID



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

$$\delta p / p \approx 0.7\% \oplus 1.0\% \times p \ (\mathrm{GeV}/c)$$



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

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PID p_T Spectra

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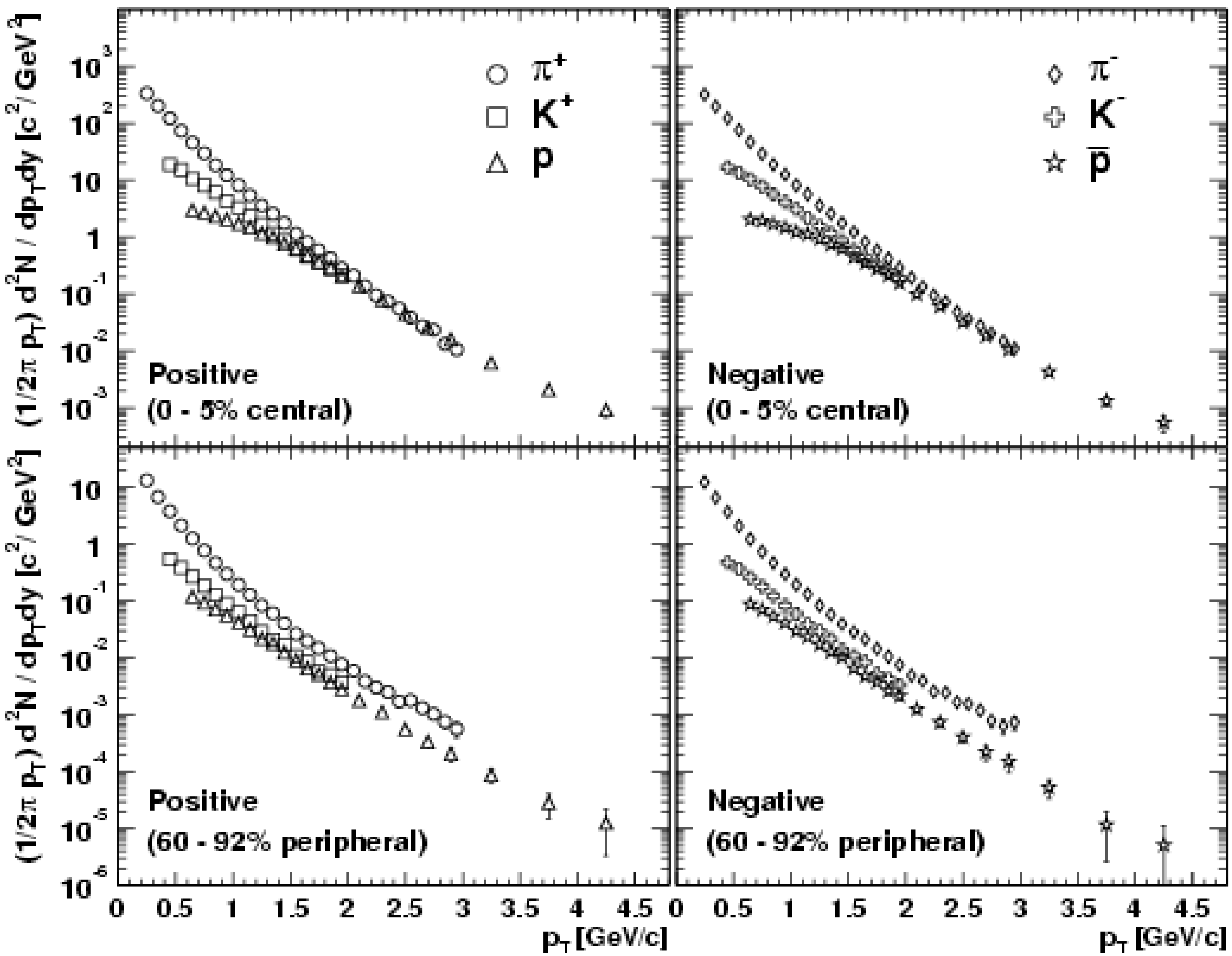

Central

- 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.

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Mean p_T vs. N_{part}

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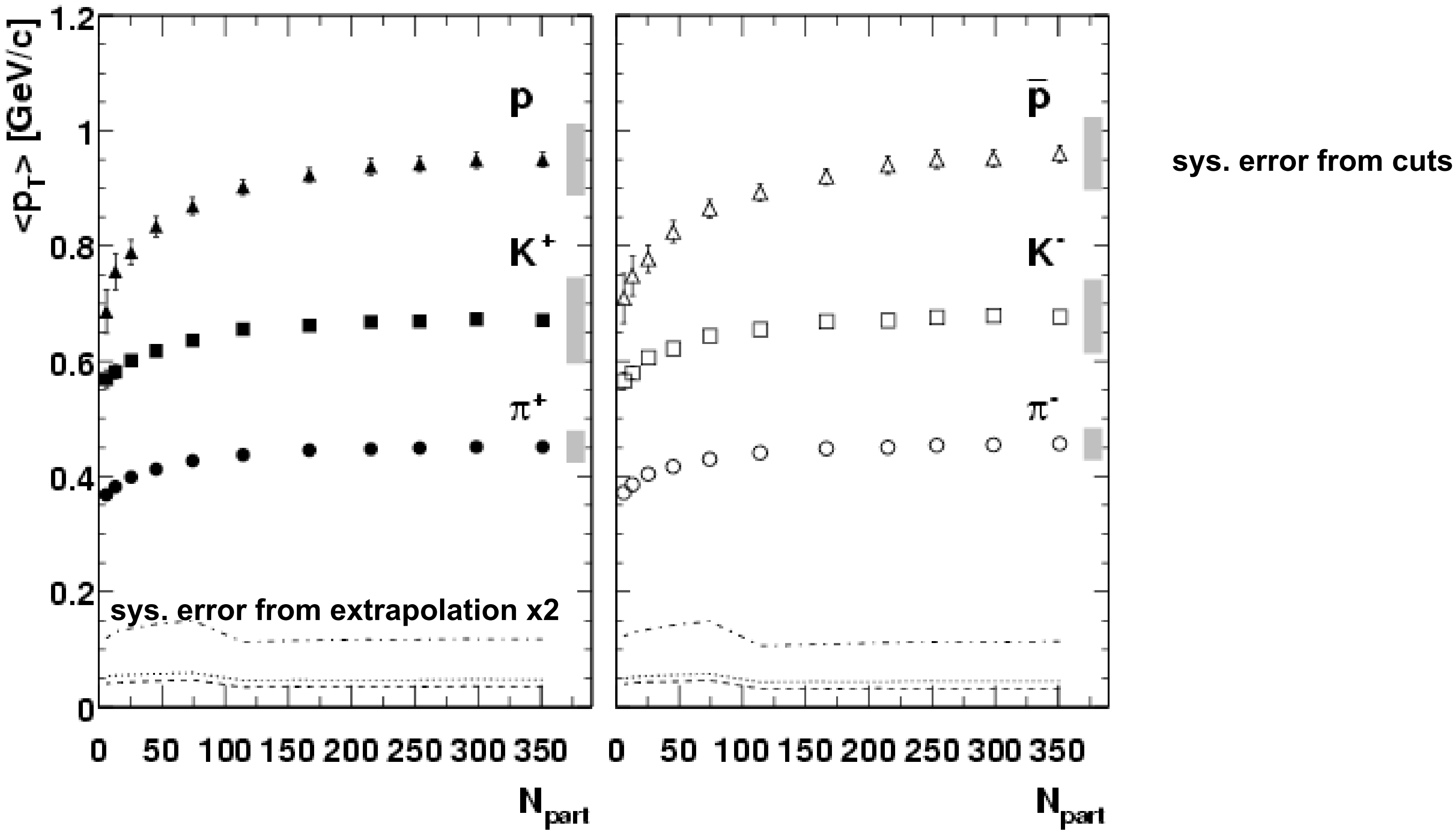

- Increase from peripheral to mid-central, and then saturate from mid-central to central for all particle species.
- Observed clear mass dependence.
- **Indicative radial expansion. (consistent with hydro picture)**

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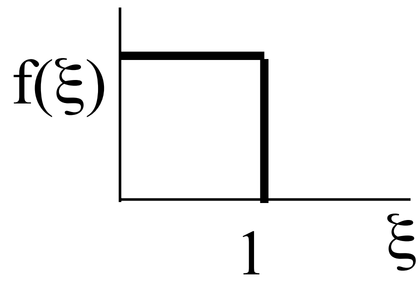
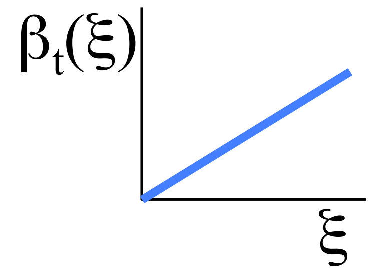
Blast-wave model Parameterization

$$\frac{1}{m_T}\frac{dN}{dm_T} = A\int f(\xi)\xi d\xi m_T \, I_0\left(\frac{p_T \sinh\rho}{T_{fo}}\right) K_1\left(\frac{m_T \cosh\rho}{T_{fo}}\right)$$

Parameters:

- normalization **A**
- freeze-out temperature $\mathbf{T_{fo}}$
- surface velocity $\boldsymbol{\beta_t}$





integration variable
$\xi \leftrightarrow$ radius r
$= r/R$
definite integral from 0 to 1
particle density distribution $f(\xi) \sim$ const

linear velocity profile $\beta_t(\xi) = \beta_t \xi$
surface velocity β_t
average velocity $<\beta_t> = 2/3\ \beta_t$
boost $\rho(\xi) = \mathrm{atanh}(\ \beta_t(\xi)\ )$

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

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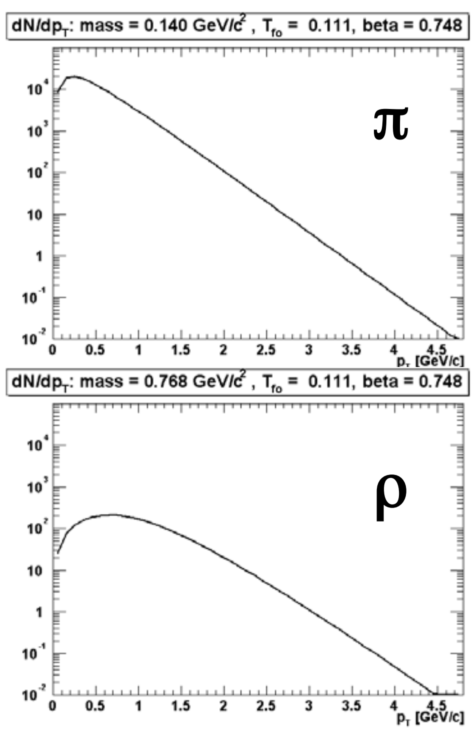
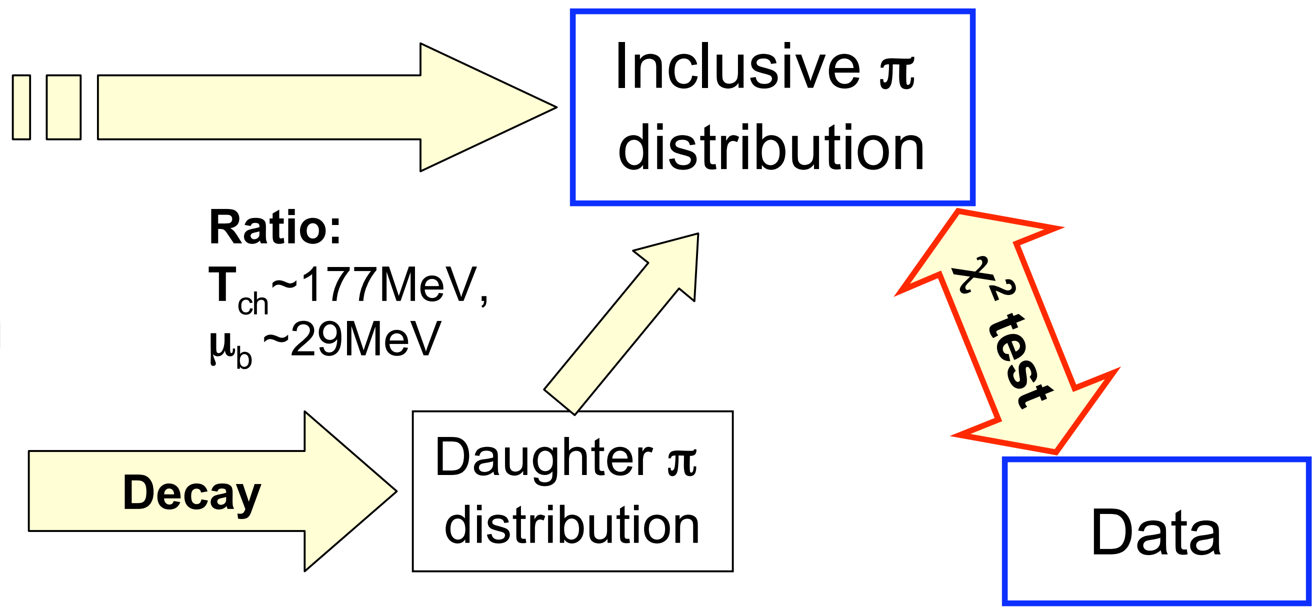
Model fit with resonance feed down

- Generate p_T distribution for each particle species by **(mass, T_{fo}, β_T)**.
- Decay and create p_T spectra of π,K,p.
- Chemical parameters : **T_{ch} = 177MeV, μ_B = 29MeV**

  [P.Braun-Munzinger et al,PLB518(2001)41]

  → determine initial particle ratio.
- Create inclusive p_T spectra. → χ^2 test





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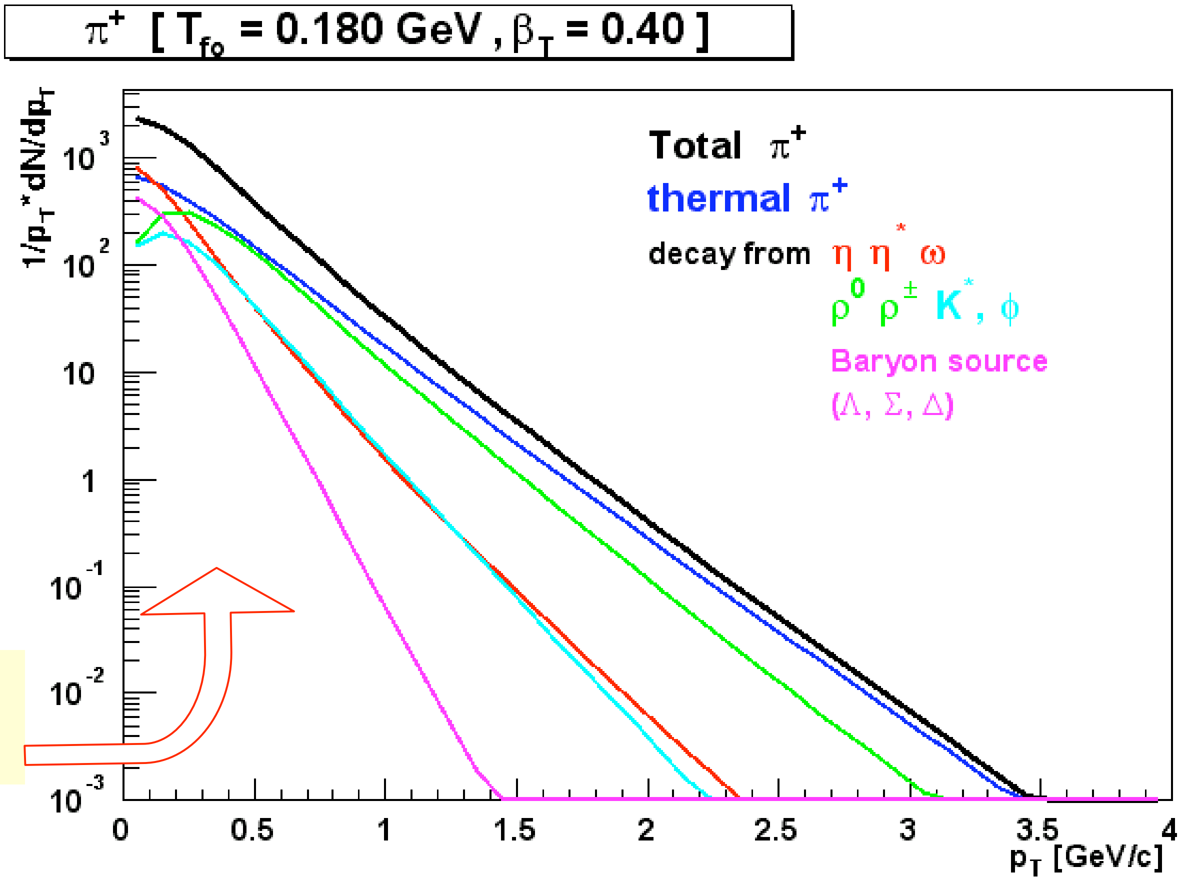
Inclusive p_T spectra

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)

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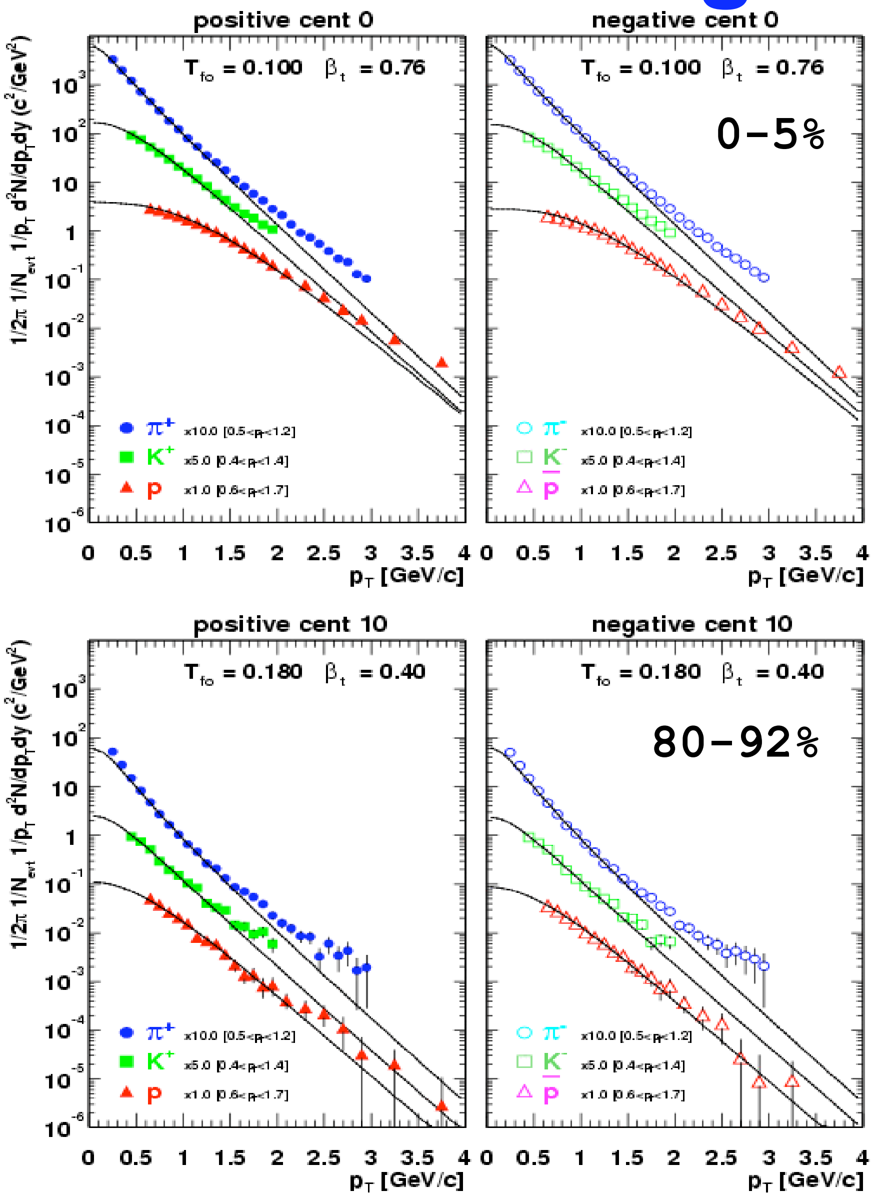
Fitting the p_T spectra



- Minimize contribution from hard process
  - $(m_T - m_0) < 1$GeV
- Exclude π resonance at very low pT region
  - π : $p_T > 0.5$GeV/c
- Simultaneous fit in mesh.
  - T_{fo}: 60~240MeV ,4MeV each
  - β_t : 0.1~0.9, 0.02 each

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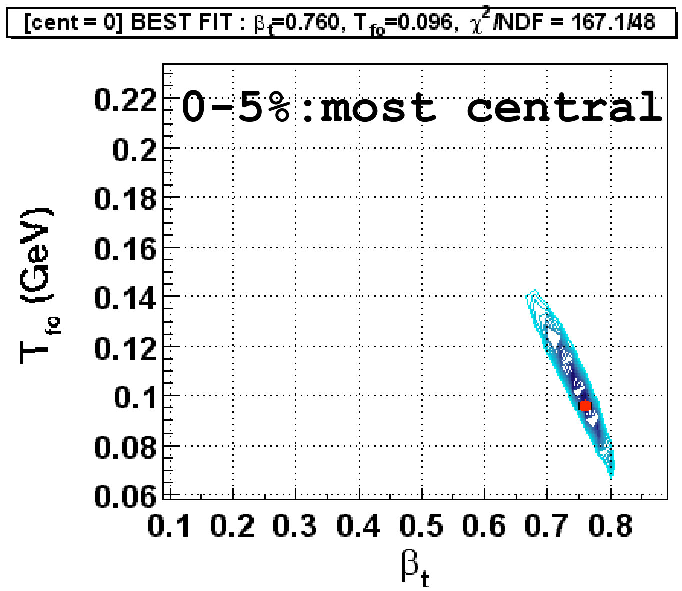
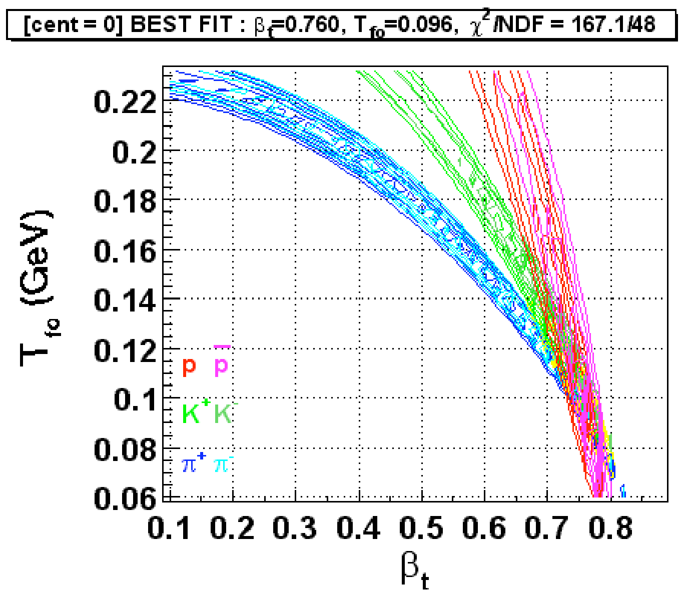
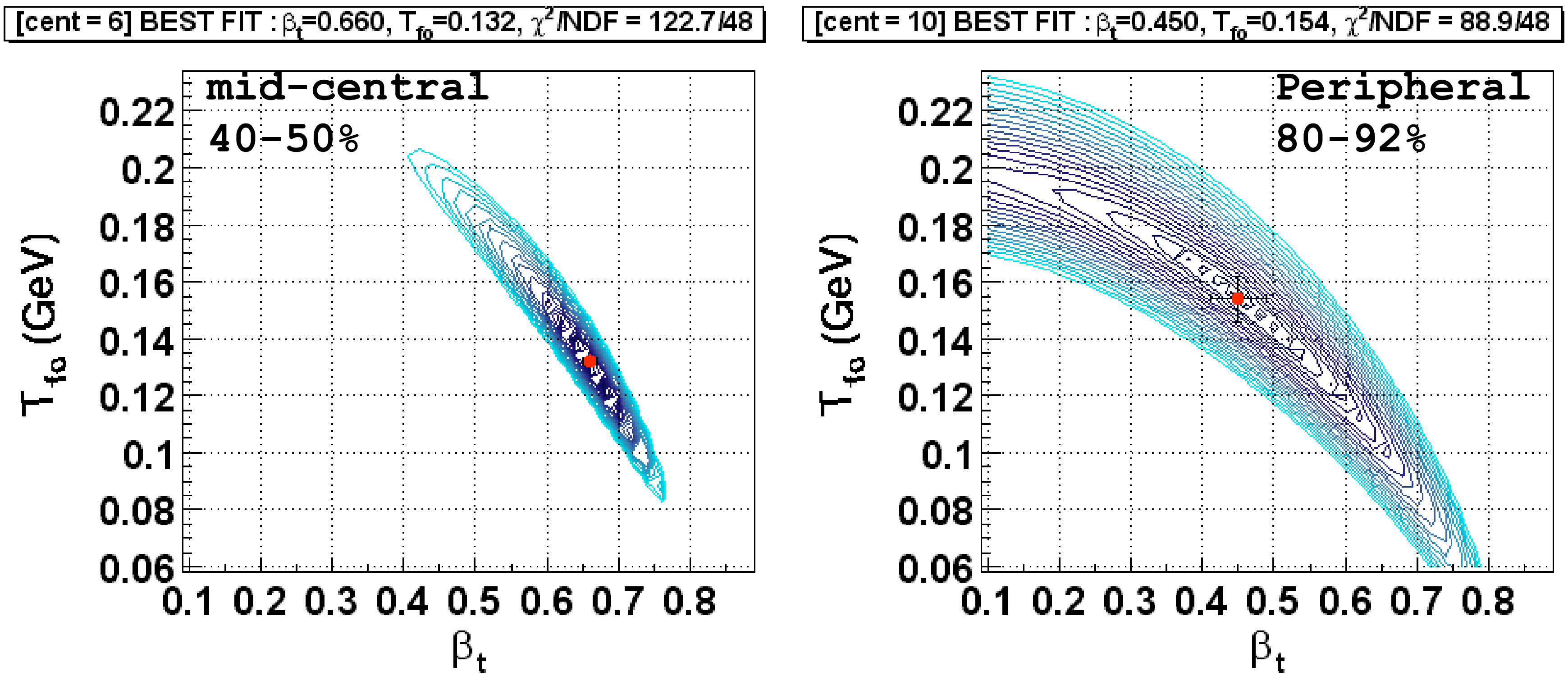
χ^2 Contours in parameter space T_{fo} and β_t

- The first 20 n-σ contour levels are shown in each centrality.
- Upper figure show the χ^2 test result of simultaneous fitting for most-central spectra.
- Lower figure show χ^2 contours for each particles.
- Due to large meshes, 1 sigma of χ^2 is not clearly determined.
  → need more smoothing.





χ^2 counters

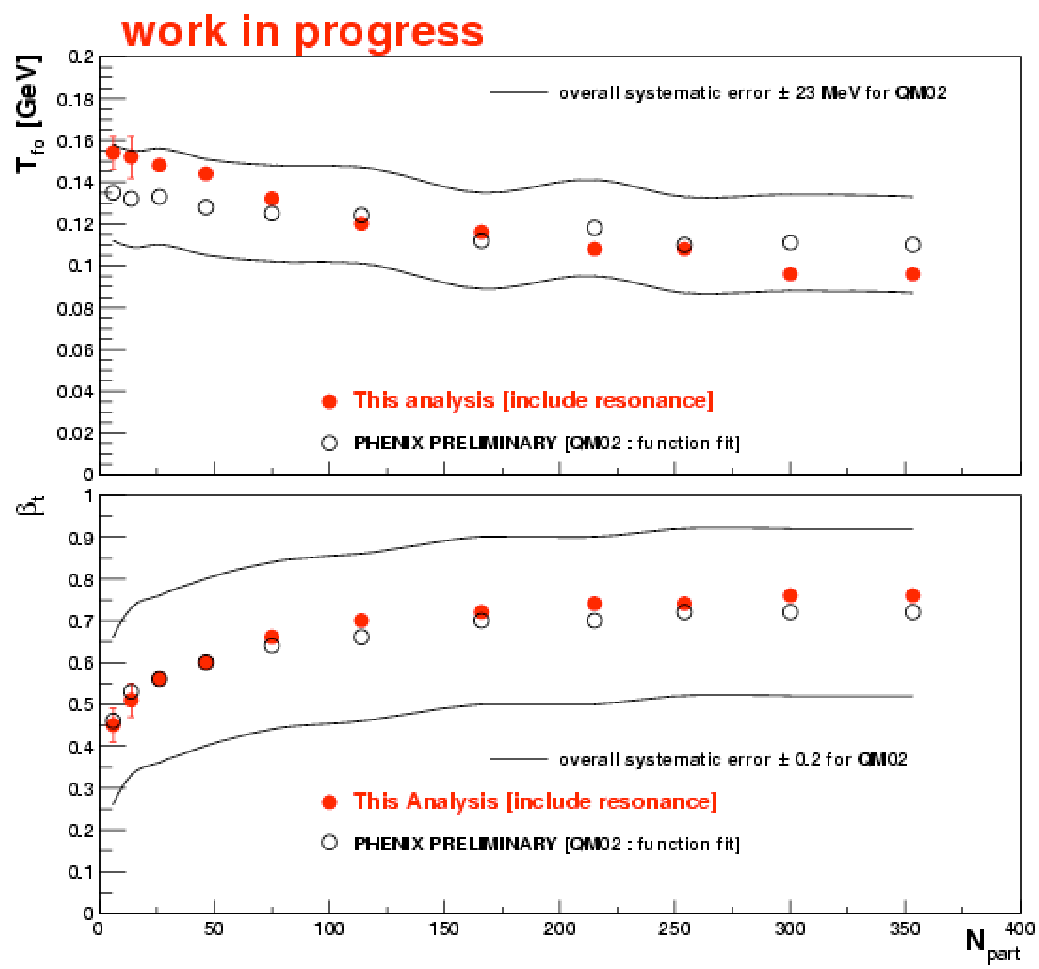


- χ^2 counters for the mid-central and most peripheral spectra

Centrality dependence of T_{fo} and β_t

- Expansion parameters in each centrality.
- Open circle and lines are PHENIX Preliminary at QM2002, which take blast-wave function fit.

- Red is this analysis, which include resonance effect.
- 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

- We present the final result of identified charged hadron p_T spectra in Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV from PHENIX.

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- Hydro-dynamical Collective Expansion.
  - Results of 200 GeV data indicate a strong collective expansion at central collisions.
  - $<p_T>$ vs. centrality : the heavier mass, the larger $<p_T>$, steep rise at peripheral to mid-central collisions.
  - 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, $\beta_t \rightarrow 0$**

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PHENIX

12 Countries; 57 Institutions; 460 Participants*

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
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	University of Tsukuba, Tsukuba
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	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
USA	Abilene Christian University, Abilene, TX
	Brookhaven National Laboratory, Upton, NY
	University of California - Riverside, Riverside, CA
	University of Colorado, Boulder, CO
	Columbia University, Nevis Laboratories, Irvington, NY
	Florida State University, Tallahassee, 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
	New Mexico State University, Las Cruces, NM
	Dept. of Chemistry, Stony Brook Univ., Stony Brook, NY
	Dept. Phys. and Astronomy, Stony Brook Univ., Stony Brook, NY
	Oak Ridge National Laboratory, Oak Ridge, TN
	University of Tennessee, Knoxville, TN
	Vanderbilt University, Nashville, TN

*as of July 2002

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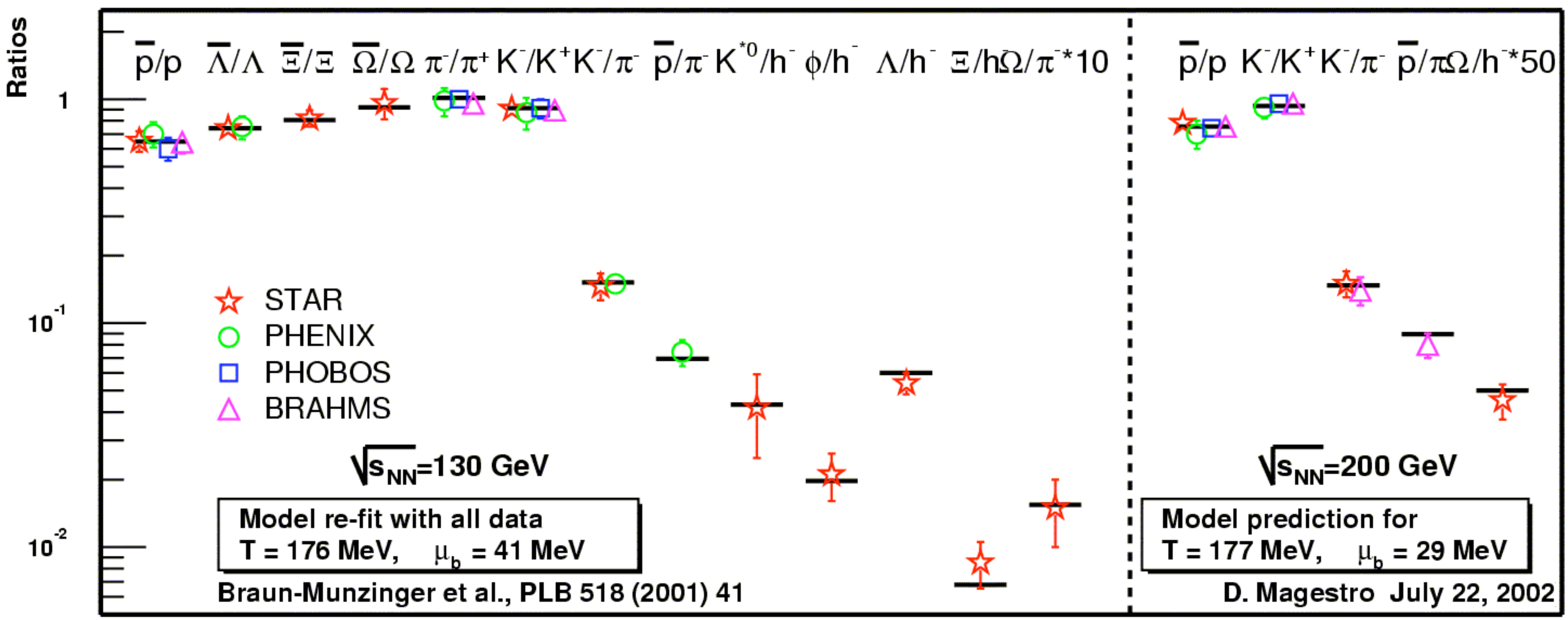
Evidence for equilibrated final state

- Almost complete reconstruction of hadronic state when system decouples by the statistical thermal model.

- Fit yields vs. mass (grand canonical ensemble)
  - T_{ch} = 177 MeV, μ_B = 29 MeV @ 200 GeV central AuAu.



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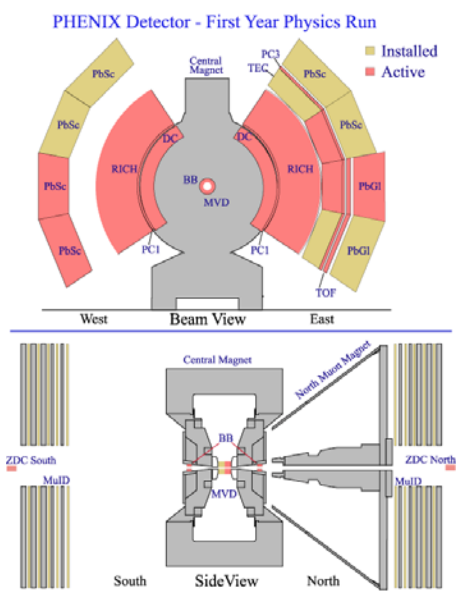
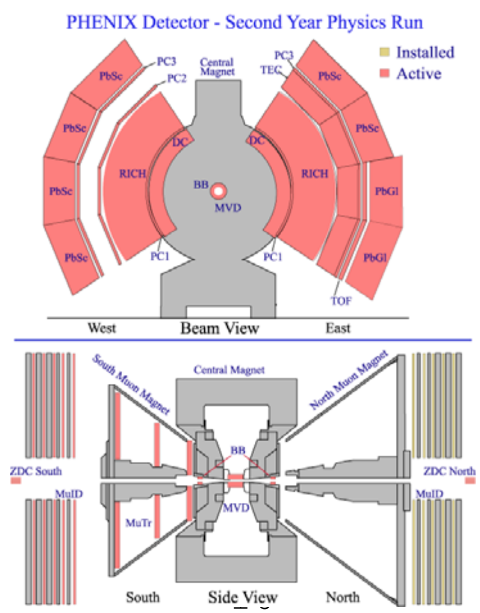
PHENIX Run History

Run	Year	Species	$s^{1/2}$ [GeV]	$\int Ldt$	N_{tot}	p-p Equivalent	Data Size
01	2000	Au-Au	130	1 μb^{-1}	10M	0.04 pb^{-1}	3 TB
02	2001/2002	Au-Au	200	24 μb^{-1}	170M	1.0 pb^{-1}	10 TB
		p-p	200	0.15 pb^{-1}	3.7G	0.15 pb^{-1}	20 TB
03	2002/2003	d-Au	200	2.74 nb^{-1}	5.5G	1.1 pb^{-1}	46 TB
		p-p	200	0.35 pb^{-1}	6.6G	0.35 pb^{-1}	35 TB

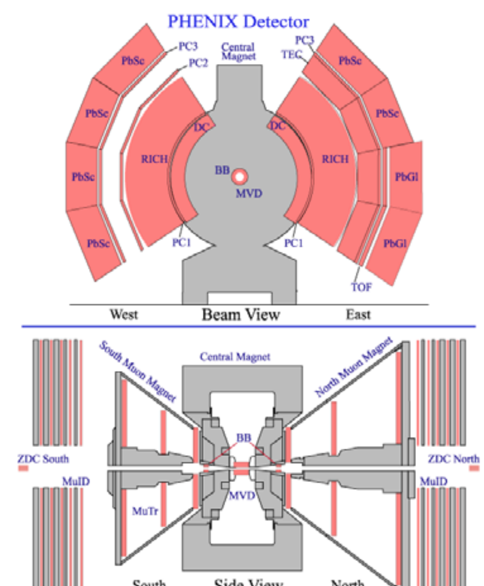
Run-1



Run-2



Run-3



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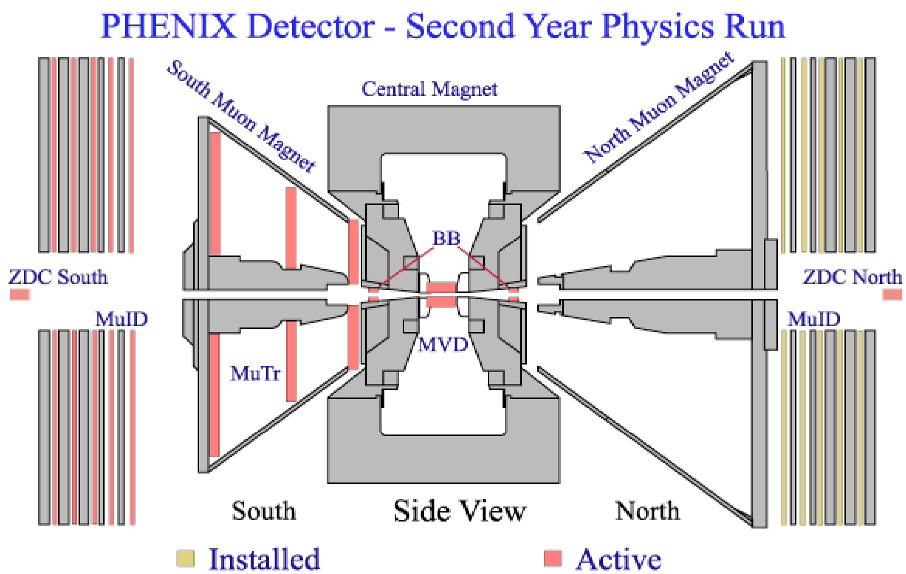
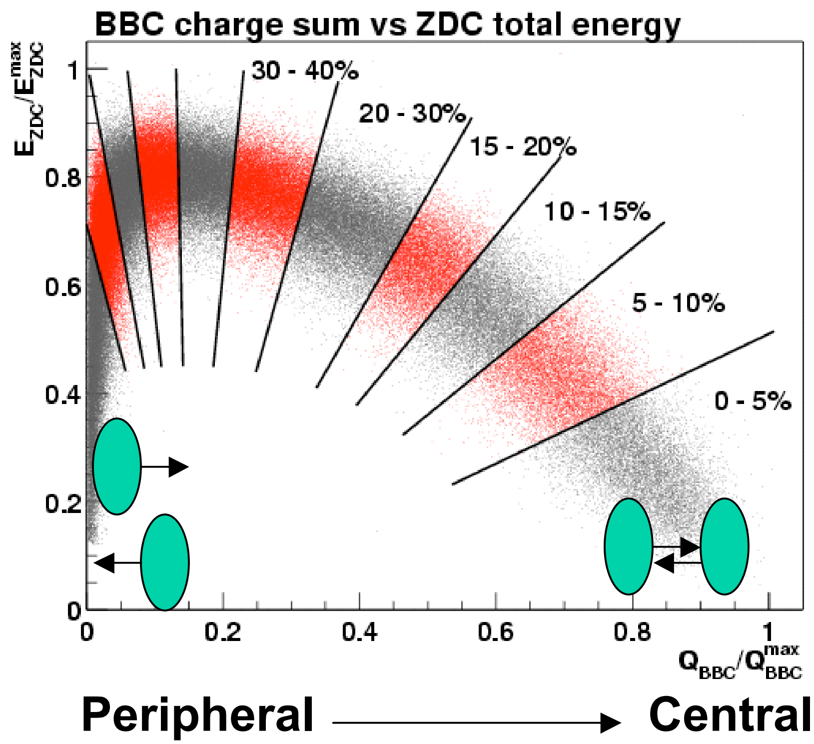
Event Characterization





- Centrality selection : Used charge sum of Beam-Beam Counter (**BBC**, |η|=3~4) and energy of Zero-degree calorimeter (**ZDC**) in minimum bias events (92% of total inelastic cross sections).
- Extracted $\mathbf{N_{coll}}$ and $\mathbf{N_{part}}$ based on Glauber model.

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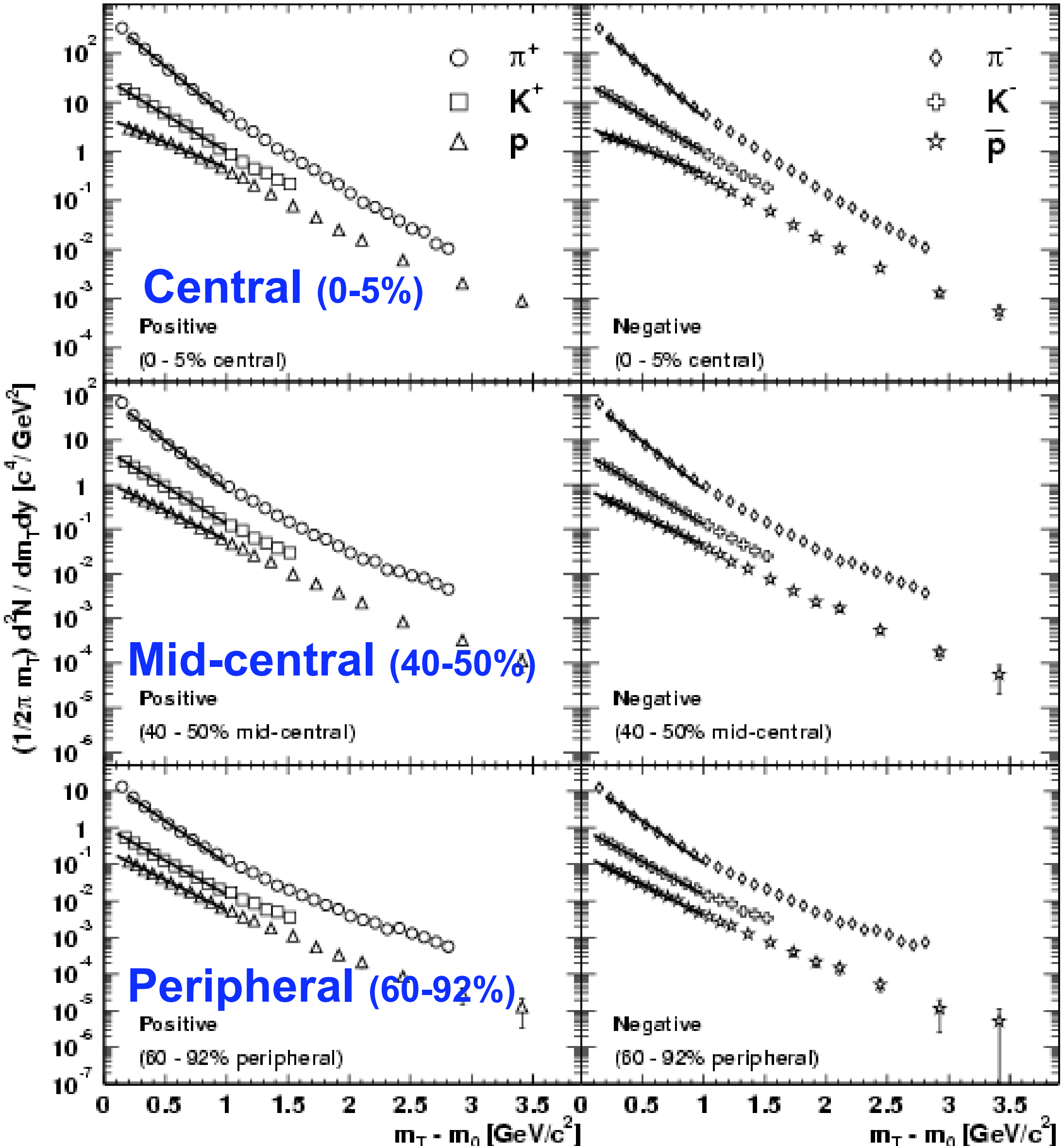
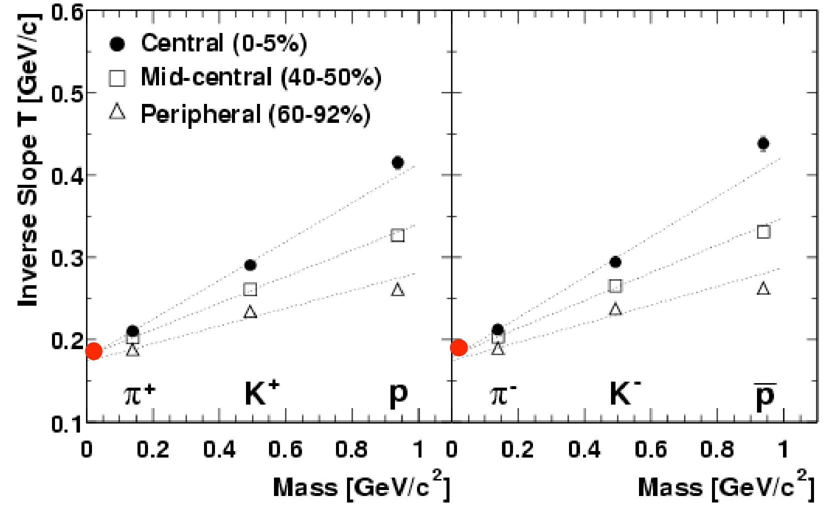
m_T - m_0 Spectra





- **Clear mass and centrality dep. in slope parameter T.**
- **Consistent with collective flow picture.**

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