Seminar class on RHIC Physics Lecture 4 – Basic Heavy Ion Collisions – Impact parameter, Npart and Nbin

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UCR

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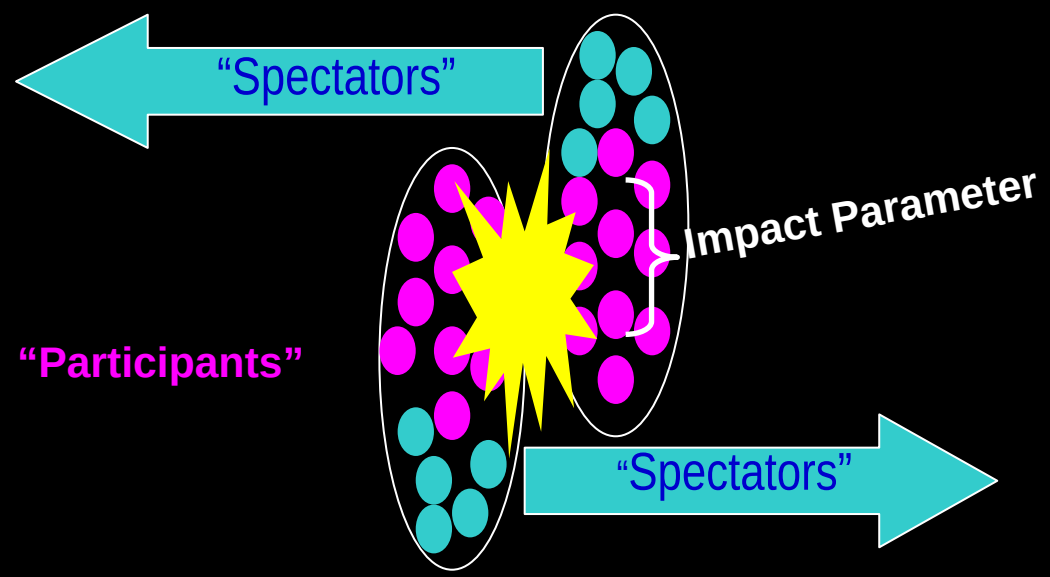
May 8, 2007 2PM BNL time 11AM UCR time

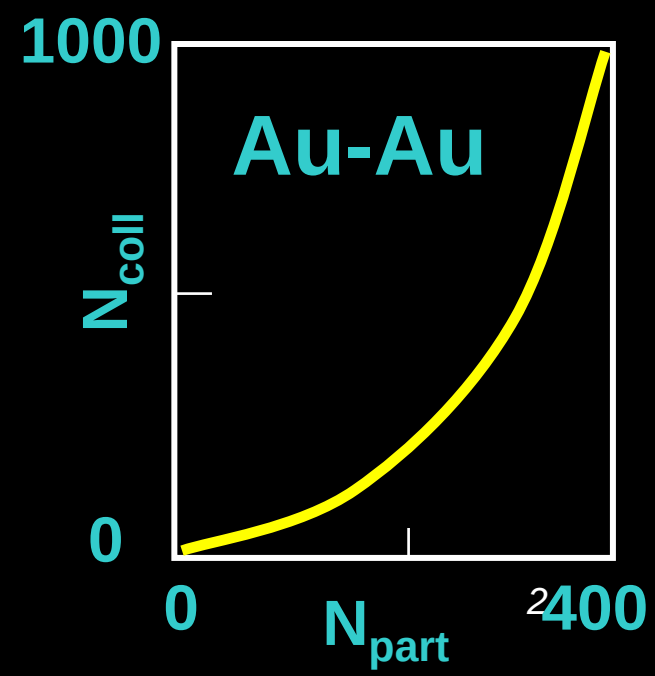
bridge line 631-344-6363 room 2-95

Website:https://www.phenix.bnl.gov/WWW/publish/seto/class/UCR%20RHIC%20seminar/

Centrality~impact parameter



Centrality def'n
0%: head on
90%: glancing

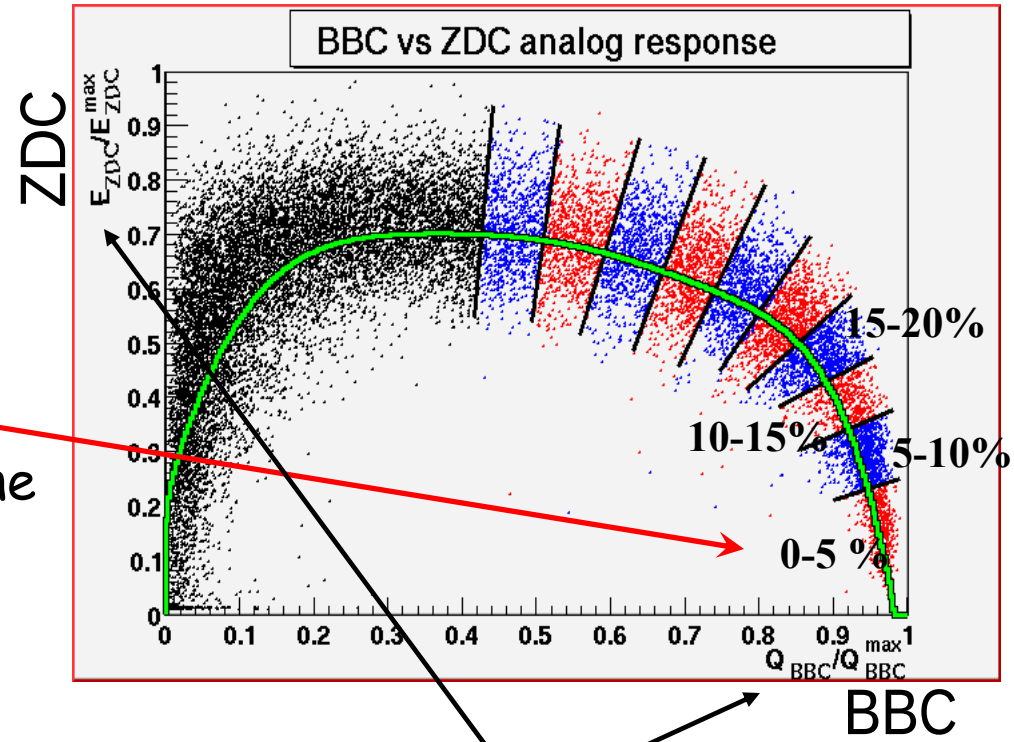


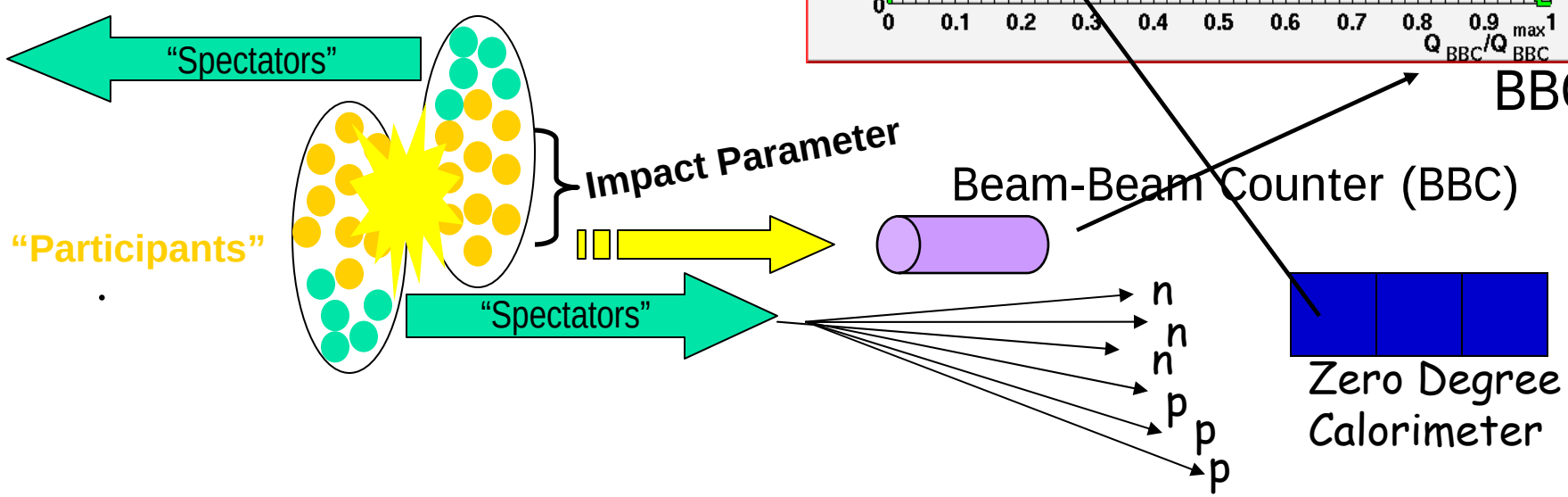
- Soft interactions ~ $N_{participants}$
- Hard interactions ~ $N_{collisions}$

A simple Glauber model gives
$N_{collisions}$ and $N_{participants}$

We need to worry about Geometry
Measuring Centrality (impact parameter)

- Zero Degree Calorimeters (ZDC)
  - Sensitive to spectator neutrons
  - common to all four RHIC experiments
- Beam Beam Counters (BBC)
- Using a combination of the ZDC's and BBC's we can define Centrality Classes



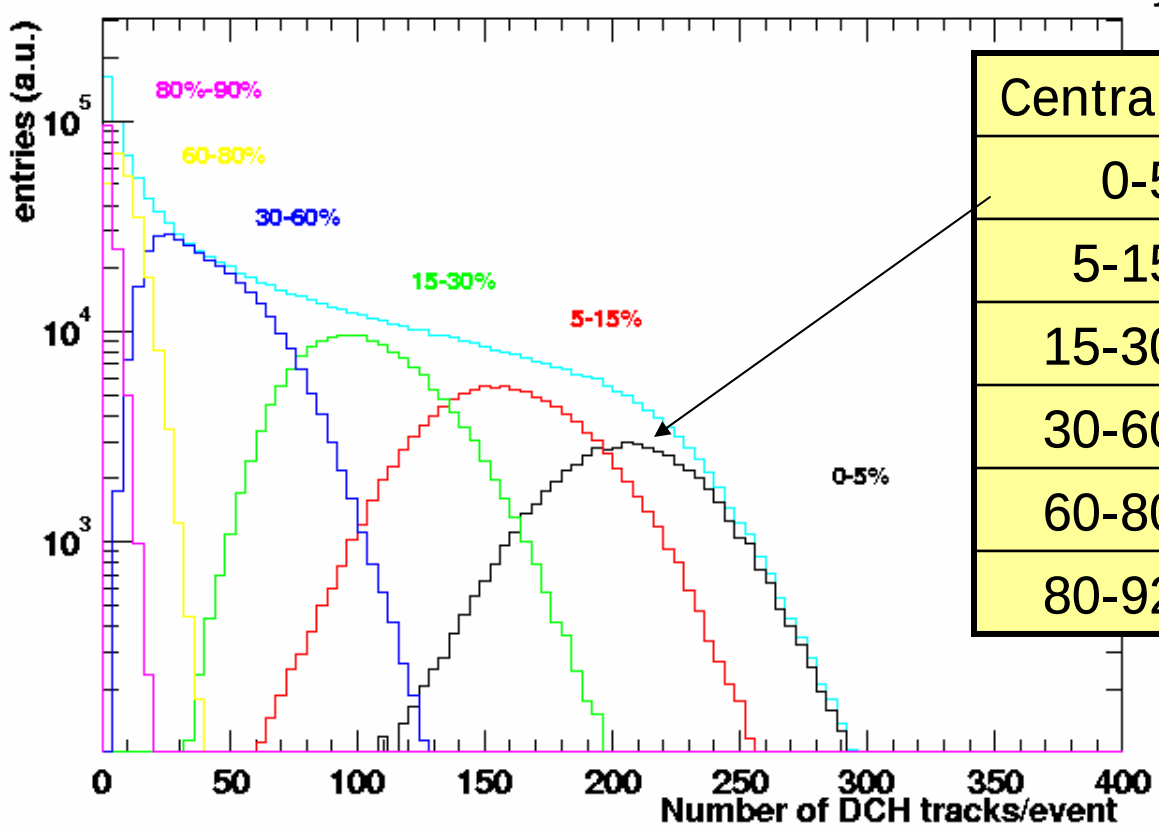


Conversion from Centrality to N_{binary} collisions and $N_{participants}$

- Many models of particle production identify two components.
  - Soft interactions where production scales with $N_{participants}$
  - Hard interactions where production scales with N_{binary}

$$dN_{ch}/d\eta\big|_{\eta=0} = Soft \times N_{part} + Hard \times N_{bin}$$

A simple Glauber model gives N_{binary} and $N_{participants}$



Centrality	Binary	Participants
0-5%	945 ± **15%**	347 ± **15%**
5-15%	673 ± **15%**	271 ± **15%**
15-30%	383 ± **15%**	178 ± **15%**
30-60%	123 ± **15%**	76 ± **15%**
60-80%	19 ± **60%**	19 ± **60%**
80-92%	3.7 ± **60%**	5 ± **60%**

Introduces systematic error
Large for peripheral events

pp collisions

EPS Figure

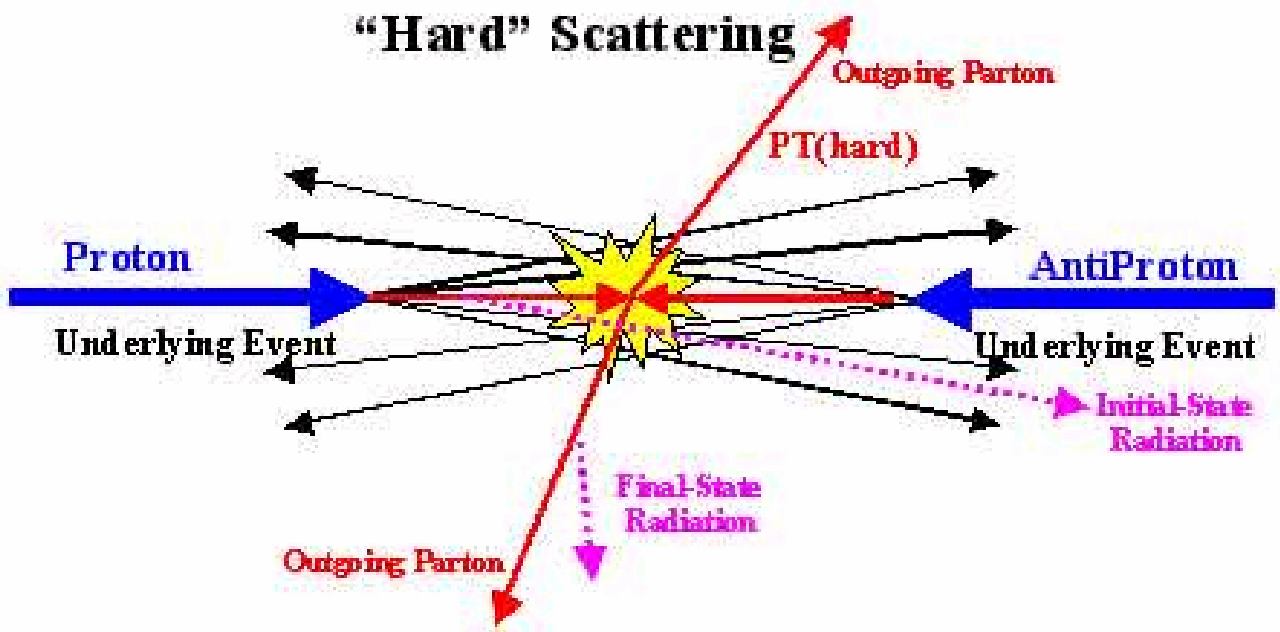
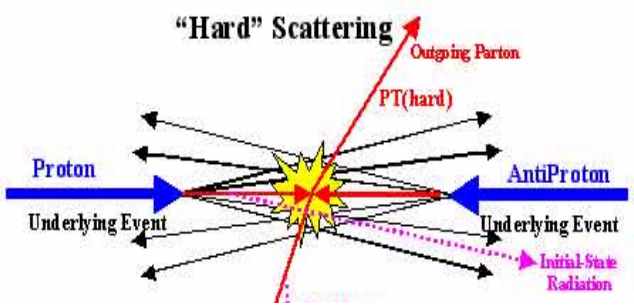


Illustration of the way the QCD Monte-Carlo models simulate a proton-antiproton collision in which a hard 2-to-2 parton scattering with transverse momentum, PT(hard), has occurred. The resulting event contains particles that originate from the two outgoing partons (*plus initial and final-state radiation*) and particles that come from the breakup of the proton and antiproton ("beam-beam remnants"). The "underlying event" is everything except the two outgoing hard scattered "jets" and consists of the "beam-beam remnants" plus initial and final-state radiation. The "hard scattering" component consists of the outgoing two "jets" plus initial and final-state radiation. (Return)

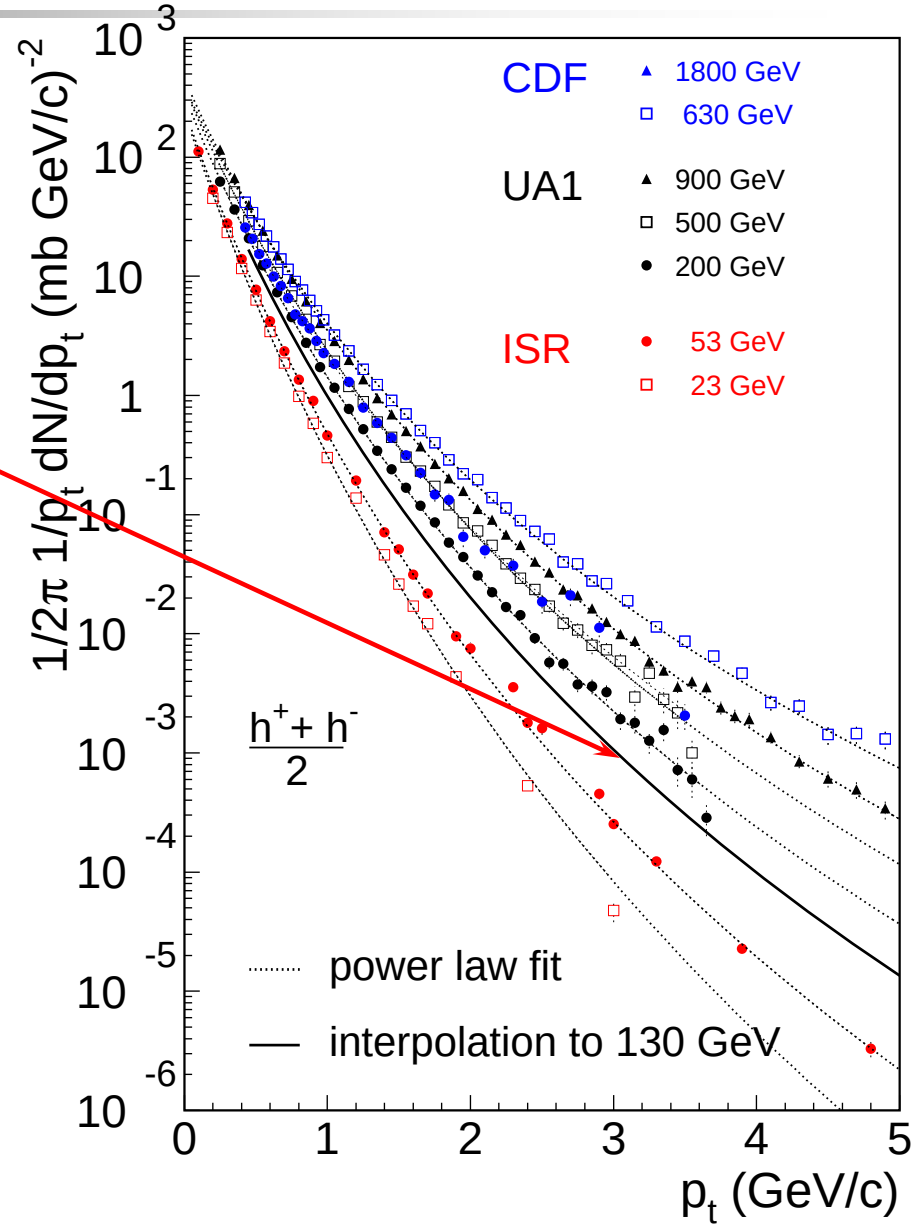
Setting the baseline

- Pp collisions scaled to √s = 130 GeV
  - Good fit to a power law
  - 1/pT dN/dpT~ $A(1+pT/p0)^{-n}$

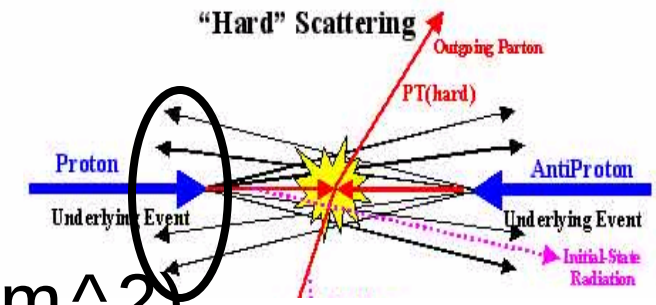
Especially at high pT



EPS Figure



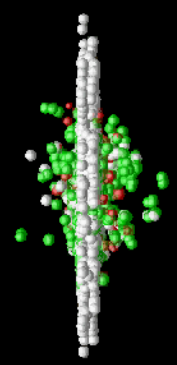
Soft Collisions

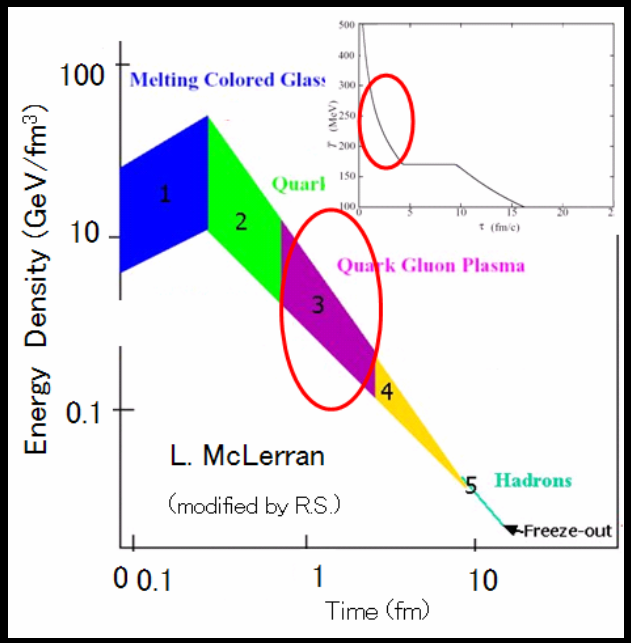


- AuAu collisions at Low PT
  - usual fit is to Mt=sqrt(pt^2+m^2)
  - Assume absence of flow
  - 1/Mt dN/dMT ~ Aexp(-(mt-m0)/T)

A, and T are fit. m0=mass

strongly interacting QGP???
partonic energy loss
Hard probes



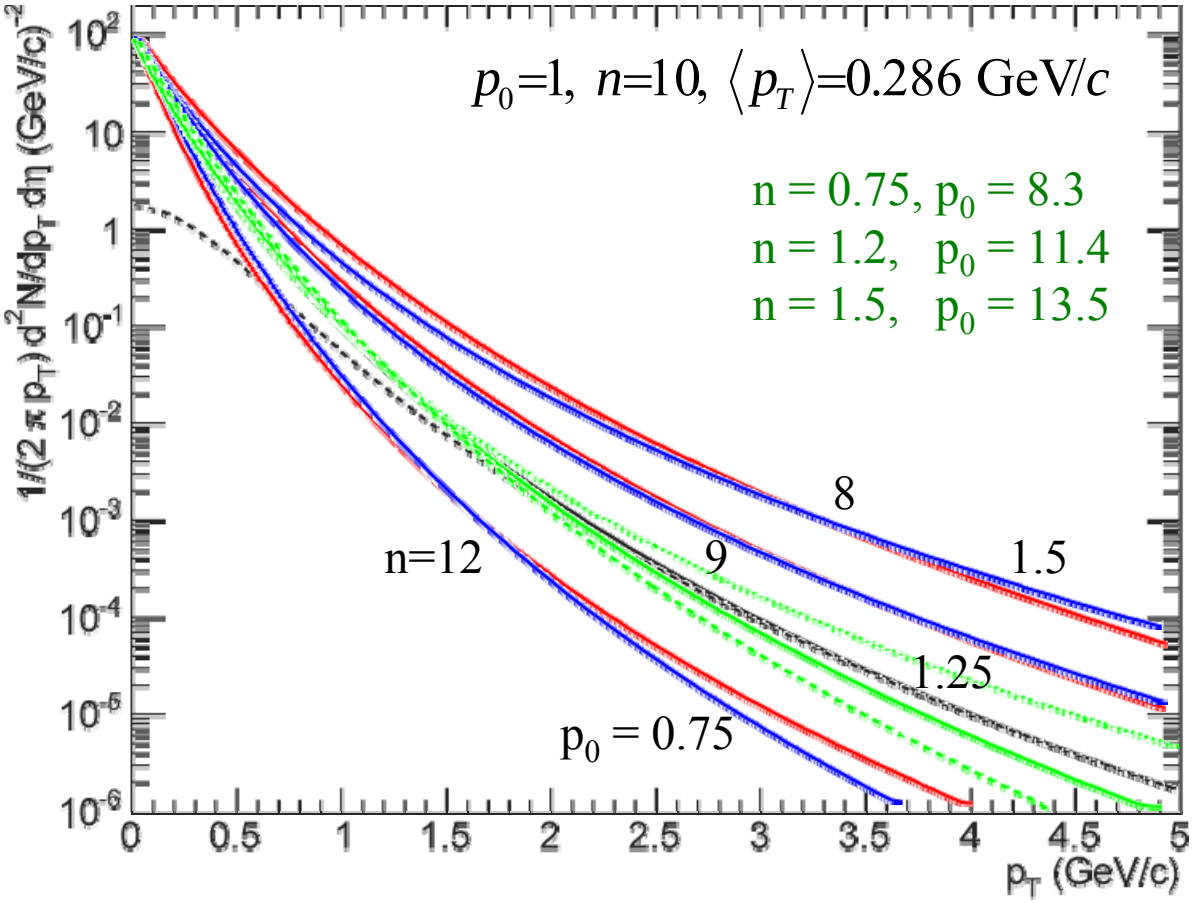


The Powerlaw Function

pQCD approach for $Ed^3\sigma/dp^3$

- Point-like scattering process a+b→c+d (via vector gluon exchange) (Berman, Bjorken, Kogut 1971)
  - $d\sigma/dt \sim 1/s^2$
  - $Ed^3\sigma/dp^3 \sim p_T^{-4}\ f(x_T,\theta)$
- "*Black Box model*" (Feynman, Field, Fox)
  - assume arbitrarily $d\sigma/dt \sim 1/(s\ t^3)$
  - $Ed^3\sigma/dp^3 \sim p_T^{-8}$
- *Constituent Interchange Model* and quark-fusion model
  - add other subprocesses (quark-meson,quark-diquark scattering)
  - n = 8 for pions
  - n = 12 for baryons
- Data (pp, $\bar{p}p$) appears to scale *approximately* like n=8 pions and kaons and n=10-12 for protons but only in *certain regions*

The Powerlaw Function



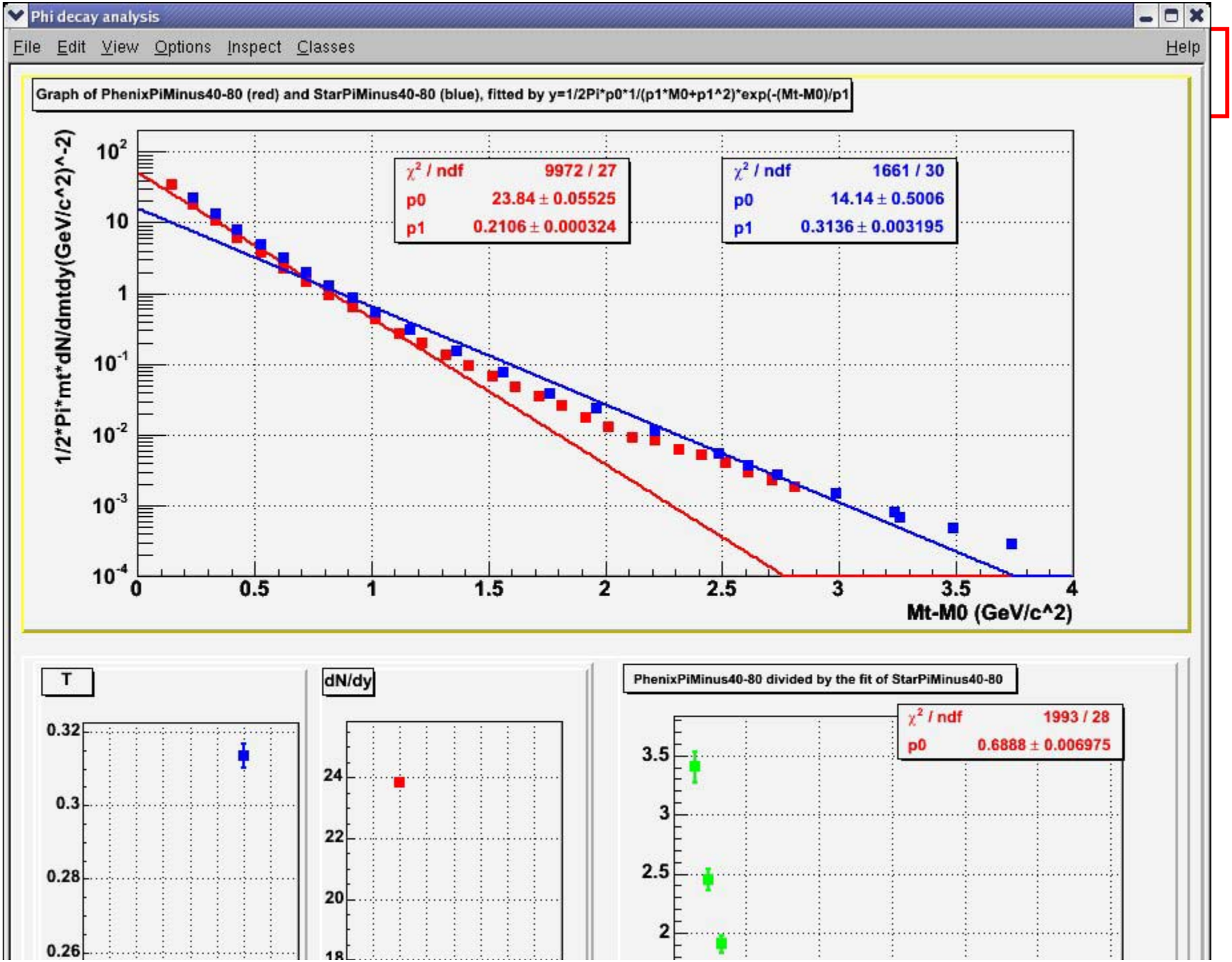
- $p_0 \uparrow \Rightarrow$ flattens spectra
- $p_0 \sim \langle p_T \rangle$
- $n \downarrow \Rightarrow$ lifts tail
- $n \sim 1/\langle p_T \rangle$
- n, p_0 strongly correlated

often:
use $\langle p_T \rangle$ directly in fit
Beware of extrapolations!

Powerlaw using m_T describes low p_T region usually better

$$\frac{d\sigma}{p_T dp_T d\eta} = A \cdot \left(1 + \frac{p_T}{p_0}\right)^{-n} \quad \text{and} \quad \langle p_T \rangle = \frac{2p_0}{n\text{-}3}$$

A pQCD inspired phenomenological approach


Phi decay analysis
File Edit View Options Inspect Classes
Help
Graph of PhenixPiMinus40-80 (red) and StarPiMinus40-80 (blue), fitted by y=1/2Pi*p0*1/(p1*M0+p1^2)*exp(-(Mt-M0)/p1
χ² / ndf 9972 / 27
p0 23.84 ± 0.05525
p1 0.2106 ± 0.000324
χ² / ndf 1661 / 30
p0 14.14 ± 0.5006
p1 0.3136 ± 0.003195
1/2*Pi*mt*dN/dmtdy(GeV/c^2)^-2)
Mt-M0 (GeV/c^2)
T
dN/dy
PhenixPiMinus40-80 divided by the fit of StarPiMinus40-80
χ² / ndf 1993 / 28
p0 0.6888 ± 0.006975

"Thermal" Spectra

Invariant spectrum of particles radiated by a thermal source:

$$E\frac{d^3N}{dp^3} = \frac{dN}{dy\, m_T\, dm_T\, d\phi} \propto Ee^{-(E-\mu)/T}$$

where:	$m_T = (m^2+p_T^2)^{1/2}$	transverse mass (Note: requires knowledge of mass)
	$\mu = b\,\mu_b + s\,\mu_s$	grand canonical chem. potential
	T	temperature of source

Neglect quantum statistics (small effect) and integrating over rapidity gives:

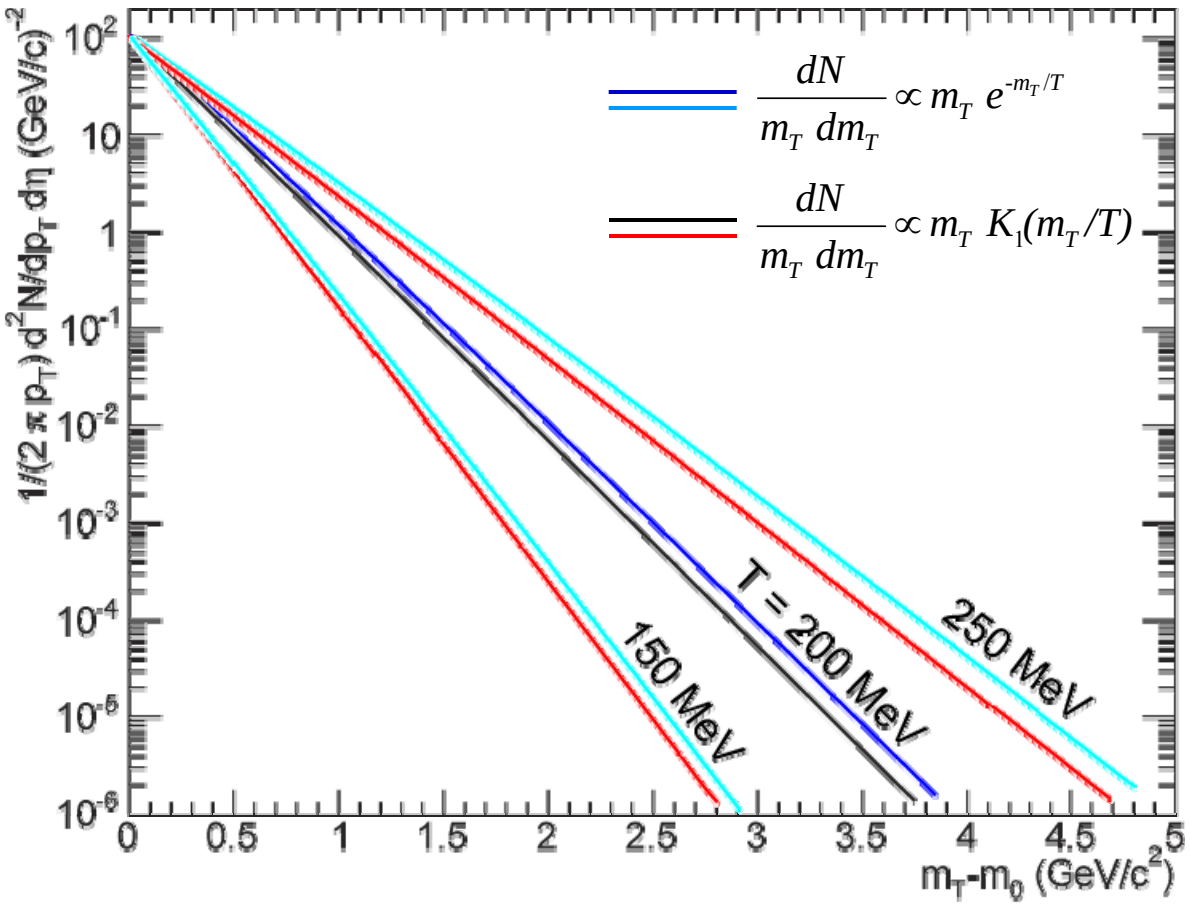
$$\frac{dN}{m_T\, dm_T} \propto m_T\, K_1(m_T/T) \xrightarrow{m_T >> T} \sqrt{m_T}\, e^{-m_T/T}$$

R. Hagedorn, Supplemento al Nuovo Cimento Vol. III, No.2 (1965)

At mid-rapidity $E = m_T \cosh y = m_T$ and hence: $\frac{dN}{m_T\, dm_T} \propto m_T\, e^{-m_T/T}$

"Boltzmann"

"Thermal" Spectra (flow aside)



Describes many spectra well over several orders of magnitude with almost uniform slope 1/T

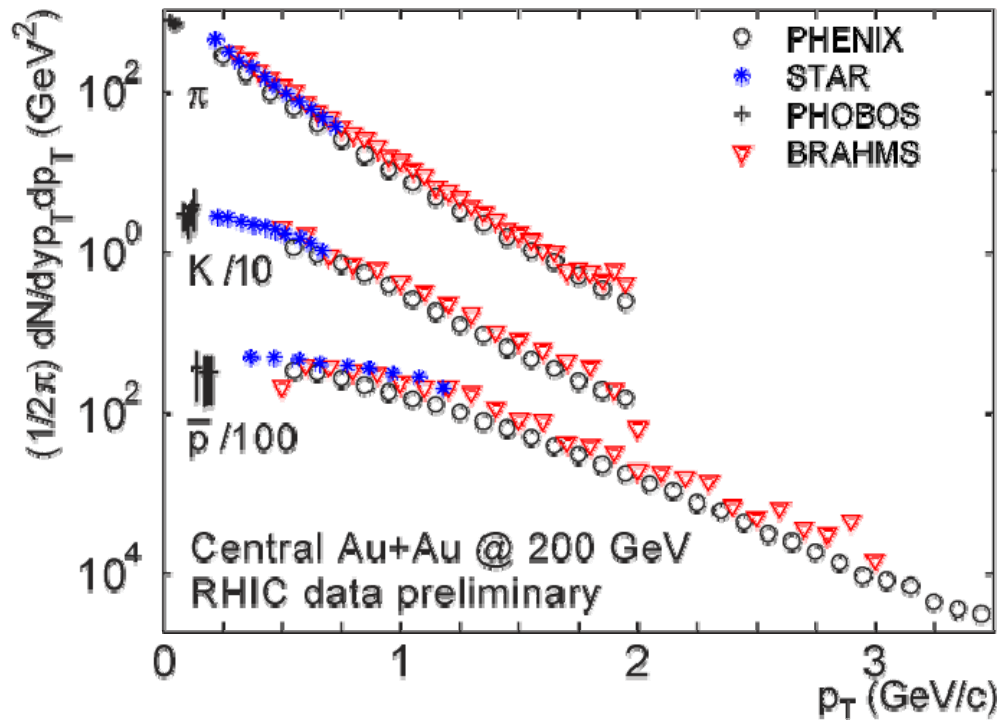
- usually fails at low-p_T ($\Rightarrow$ flow)
- most certainly will fail at high-p_T ($\Rightarrow$ power-law)

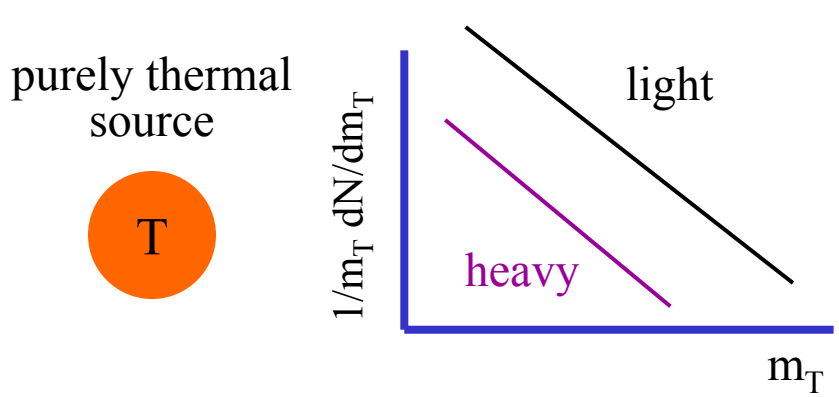
N.B. Constituent quark and parton recombination models yield exponential spectra with partons following a pQCD power-law distribution. (Biro, Müller, hep-ph/0309052)
$\Rightarrow$ T is not related to actual "temperature" but reflects pQCD parameter p_0 and n.

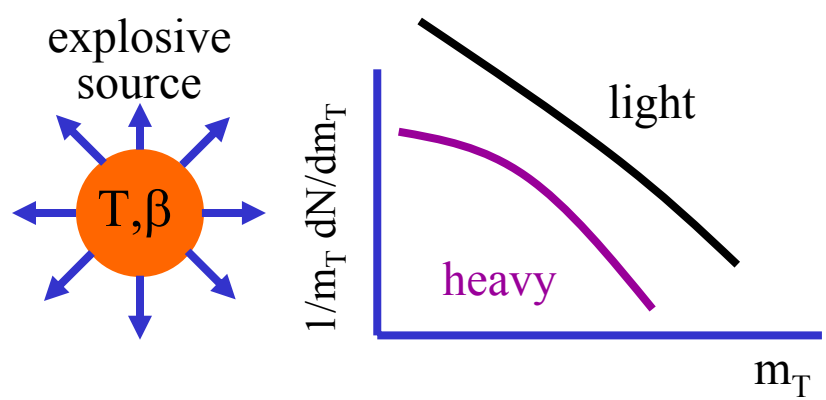
"Thermal" Spectra and Flow

- Different spectral shapes for particles of differing mass
  → strong collective radial flow

- Spectral shape is determined by more than a simple T
- at a minimum T, β_T





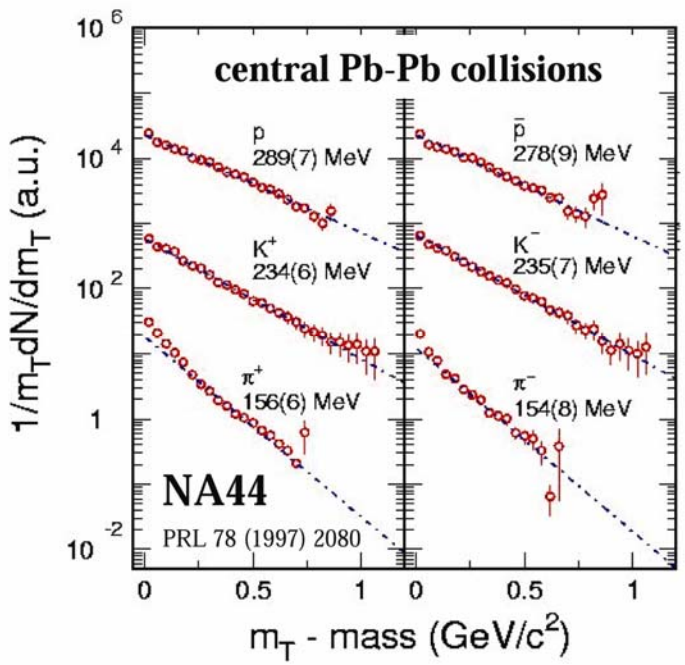


Thermal + Flow: "Traditional" Approach

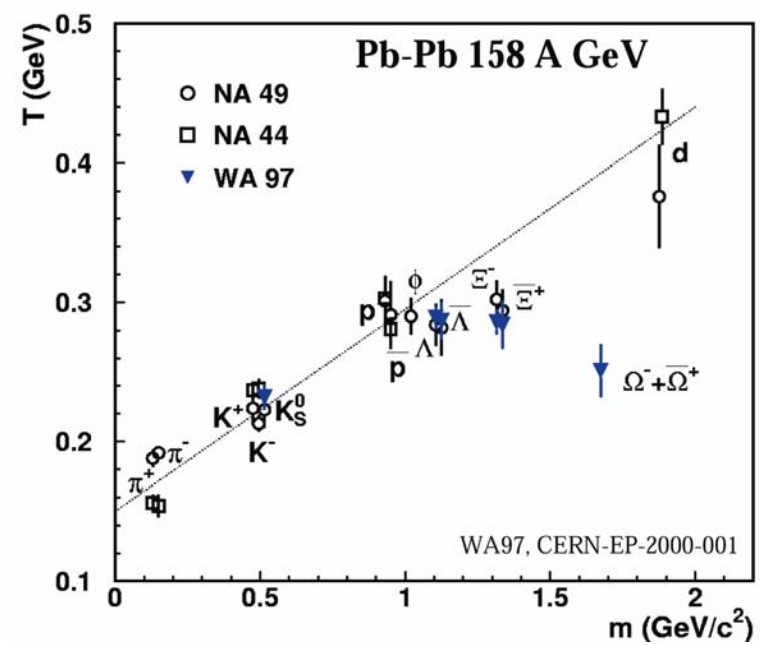
$$T_{measured} = \begin{cases} T_{th} + m\langle\beta_T\rangle^2 & \text{for} \quad p_T \le m \\ T_{th}\sqrt{\dfrac{1+\langle\beta_T\rangle}{1-\langle\beta_T\rangle}} & \text{for} \quad p_T >> m \quad \text{(blue shift)} \end{cases}$$

Assume ***common*** flow pattern and ***common*** temperature T_{th}

1. Fit Data $\Rightarrow T$



2. Plot $T(m) \Rightarrow T_{th}, \beta_T$



Problem: spectra are not exponential in the first place (fit range dependence)

Functions, Functions, …

$$\frac{dN}{p_T dp_T} \propto \left(1+\frac{p_0}{p_T}\right)^{-n}$$ power law (high-p_T)

$$\frac{dN}{m_T dm_T} \propto m_T \; K_1\left(\frac{m_T}{T}\right) \xrightarrow{m_T >> T} \sqrt{m_T}\, e^{-m_T/T}$$ thermal emission (4π)

$$\frac{dN}{m_T dm_T} \propto m_T e^{-m_T/T}$$ thermal emission (y=0)

$$\frac{dN}{m_T dm_T} \propto \int_0^{\mathrm{R}} r\, dr\, m_T \; I_0\left(\frac{p_T \sinh\rho}{T}\right) K_1\left(\frac{m_T \cosh\rho}{T}\right)$$ thermal + flow

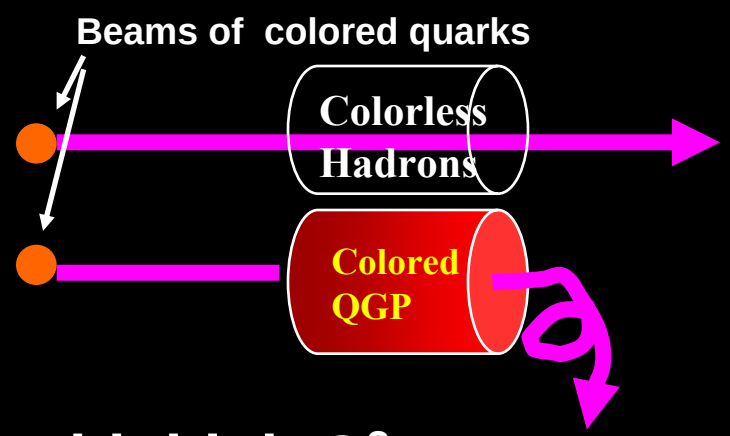
$$\frac{dN}{m_T dm_T} \propto e^{-m_T/T}$$ simple

$$\frac{dN}{m_T dm_T} \propto \frac{e^{-m_T/T}}{\mathrm{m_T}^{\lambda}}$$ Empirical parametrization from pp ($\mathrm{m_T}$-scaling)

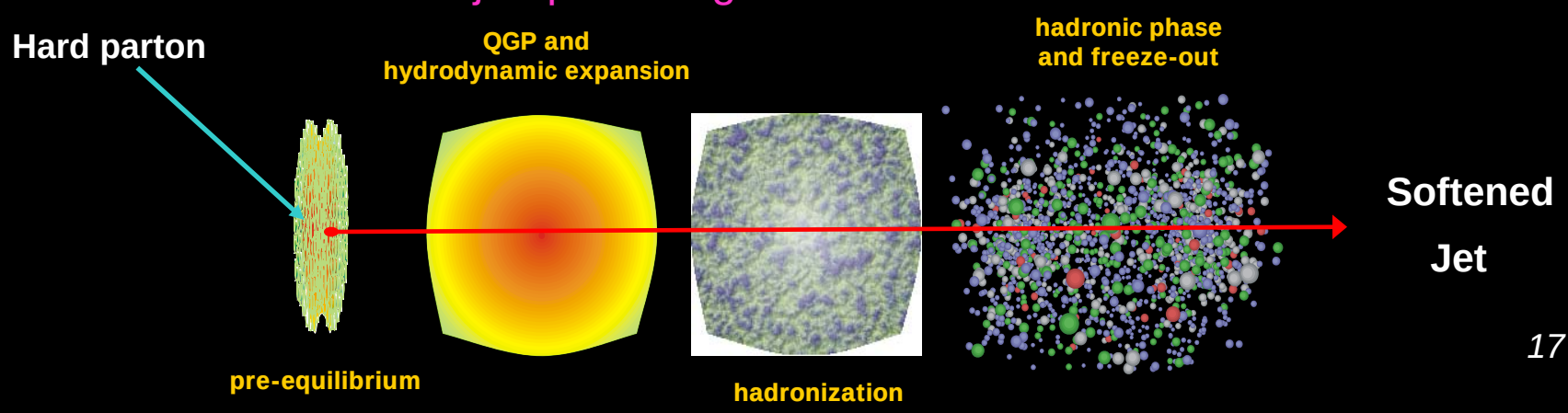
but also from theoretical model (flux-tube + Schwinger)
(Gatoff, Wong, PRD 46, 997 (1992)

Note: "T" depends on function used
in papers often more than one fit function quoted …

Hard Probes In Heavy Ion Collisions, aka Jet quenching

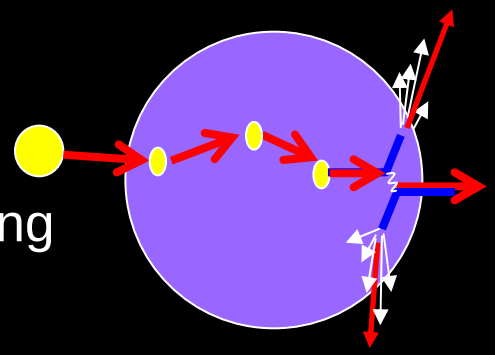


- The experiment we would like to do – Deep Inelastic Scattering of the QGP
- "hard" probes
  - **Formed in initial collision with high Q^2**
    - **penetrate hot and dense matter**
    - **sensitive to state of hot and dense matter**
      - dE/dx **by strong interaction**
      - ⇒ jet quenching



Models – scaling pp to AA

- How do we scale from pp to AA?
  - Nuclear Geometry
    - Scale Hard processes with N_{binary}
    - Scale soft processes with $N_{participants}$
      - Remember – N_{bin} and N_{part} taken from centrality measurement
  - pp effects
    - Intrinsic k_T
  - pp to pA effects
    - "Cronin effect", initial state quark scattering
      i.e. p_T broadening
      Enhances higher p_T
    - Nuclear shadowing
      - Gluon shadowing
        - is not measured
        - large role at RHIC

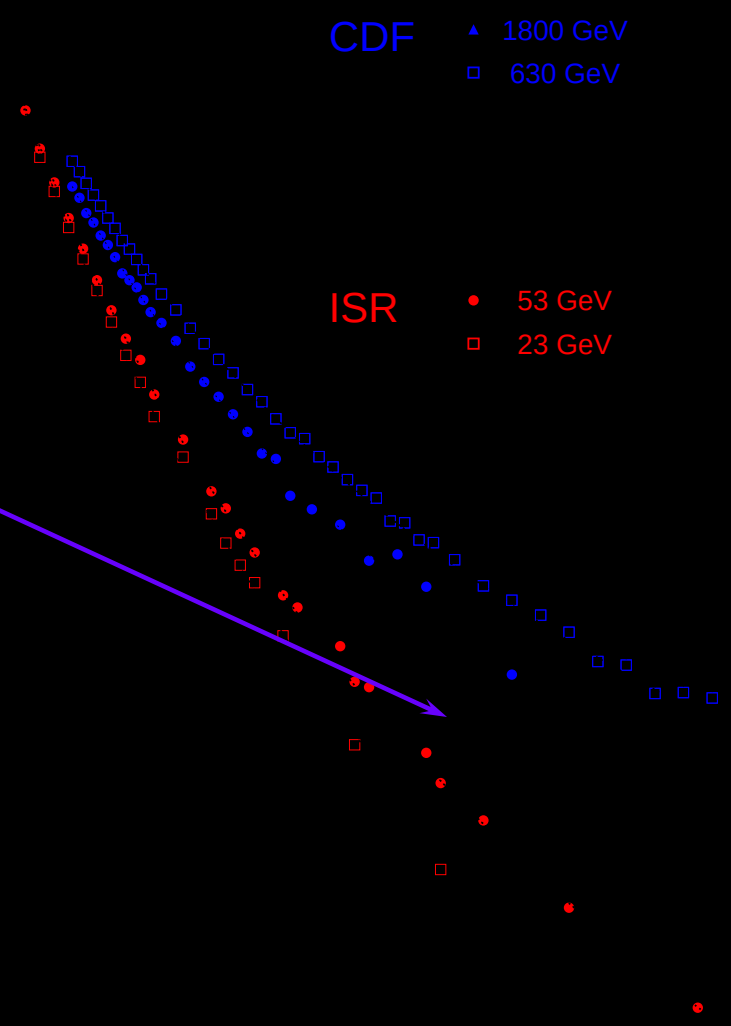


Measure pA at RHIC!

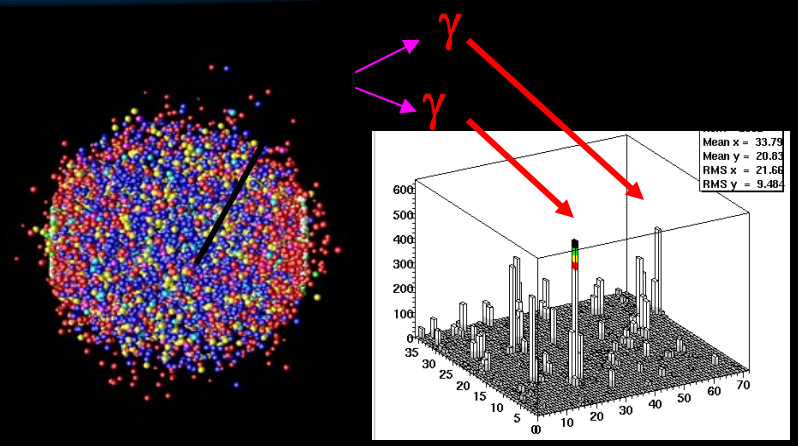
Setting the baseline

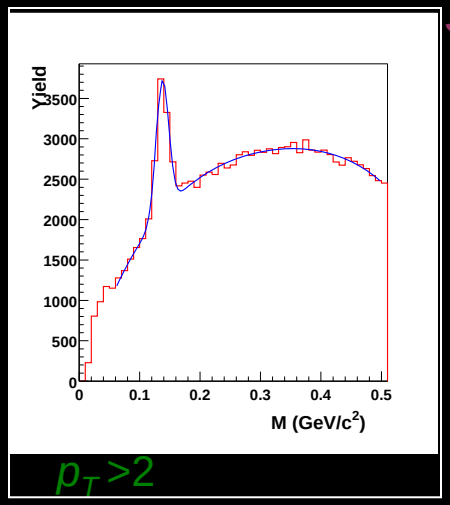
- To find jet suppression – compare to what?
  - Pp collisions scaled to √s = 130 GeV
    - Good fit to a power law
  - Peripheral collisions – an approximation to pp, or pA

    and
- pQCD Models – Hijing, VNI, etc. + jet dE/dx
  - Needed to make quantitative statements about energy loss
  - Some are extensions of standard Monte-Carlo's



PHENIX Data: π^0 spectra





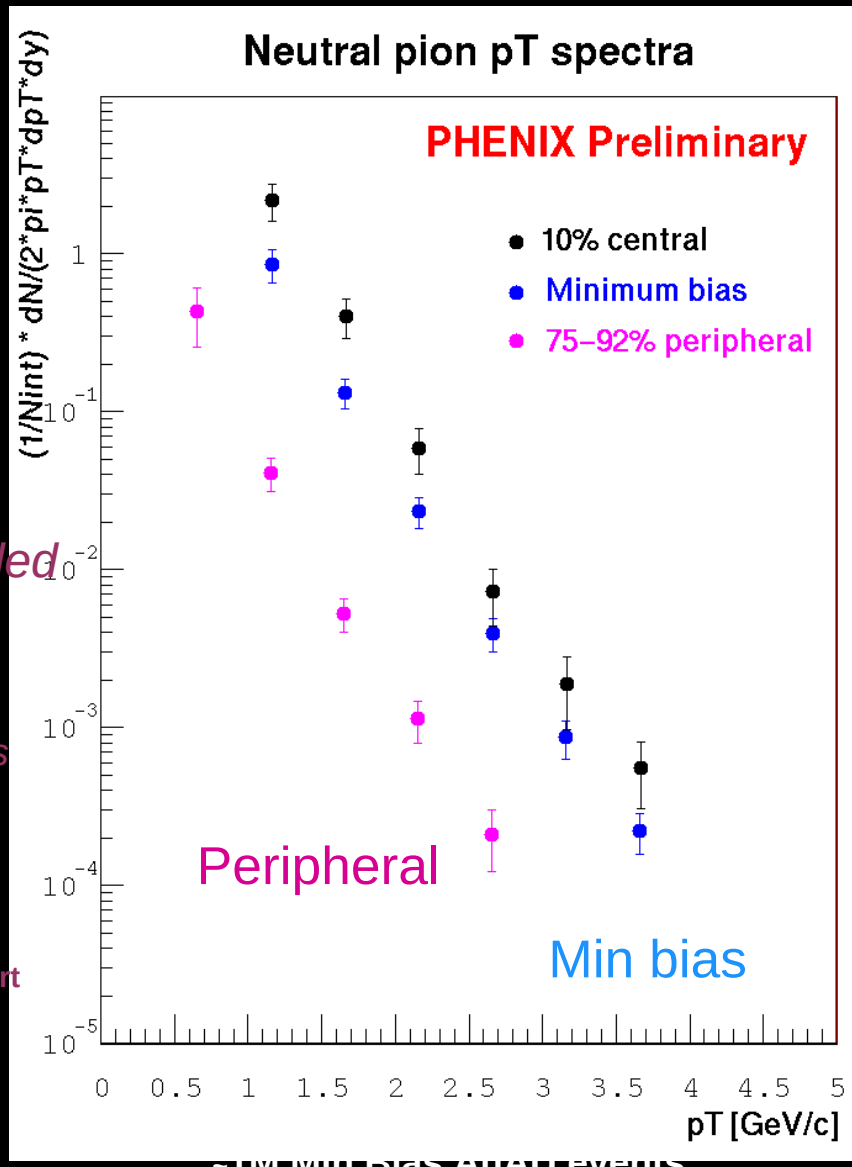
p_T>2 GeV,asym<0.8

Systematic errors included

Main sources:

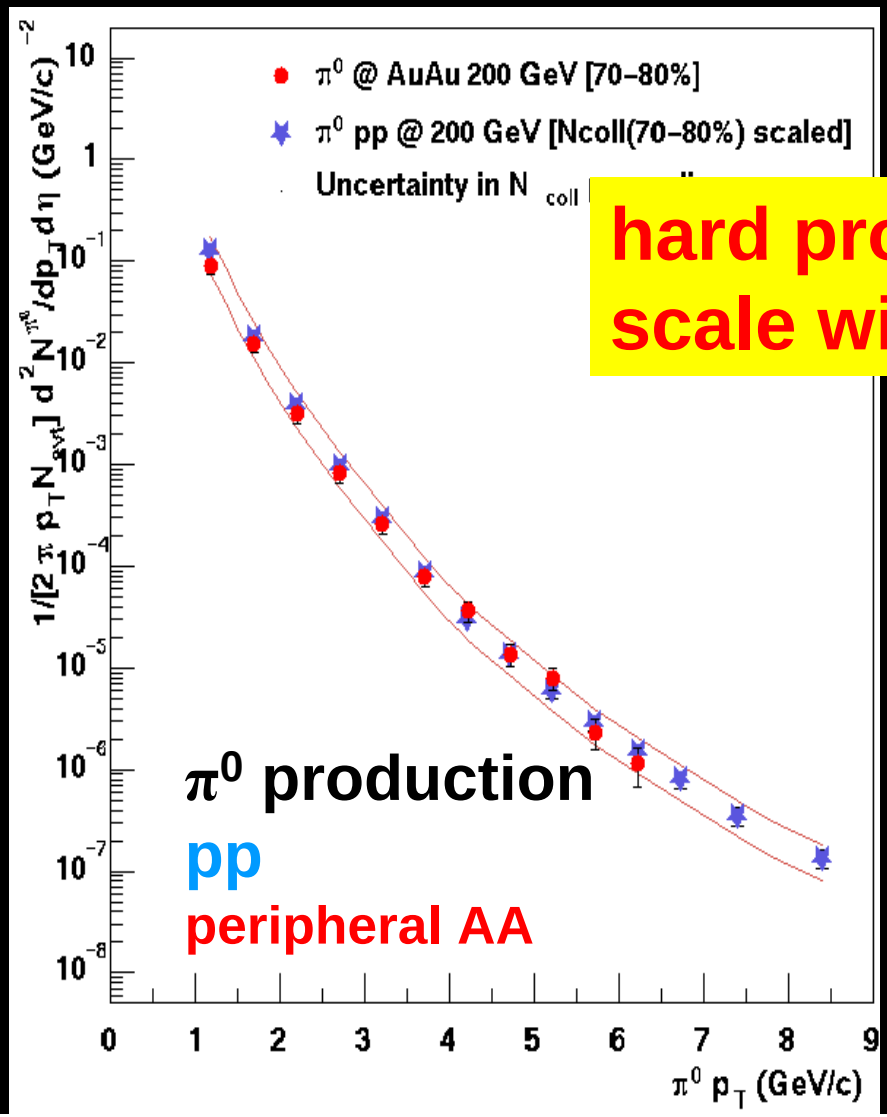
- *peak extraction*
- *PID loss*
- *efficiency calculations*
- *non-vertex pions*
- *pT scale*

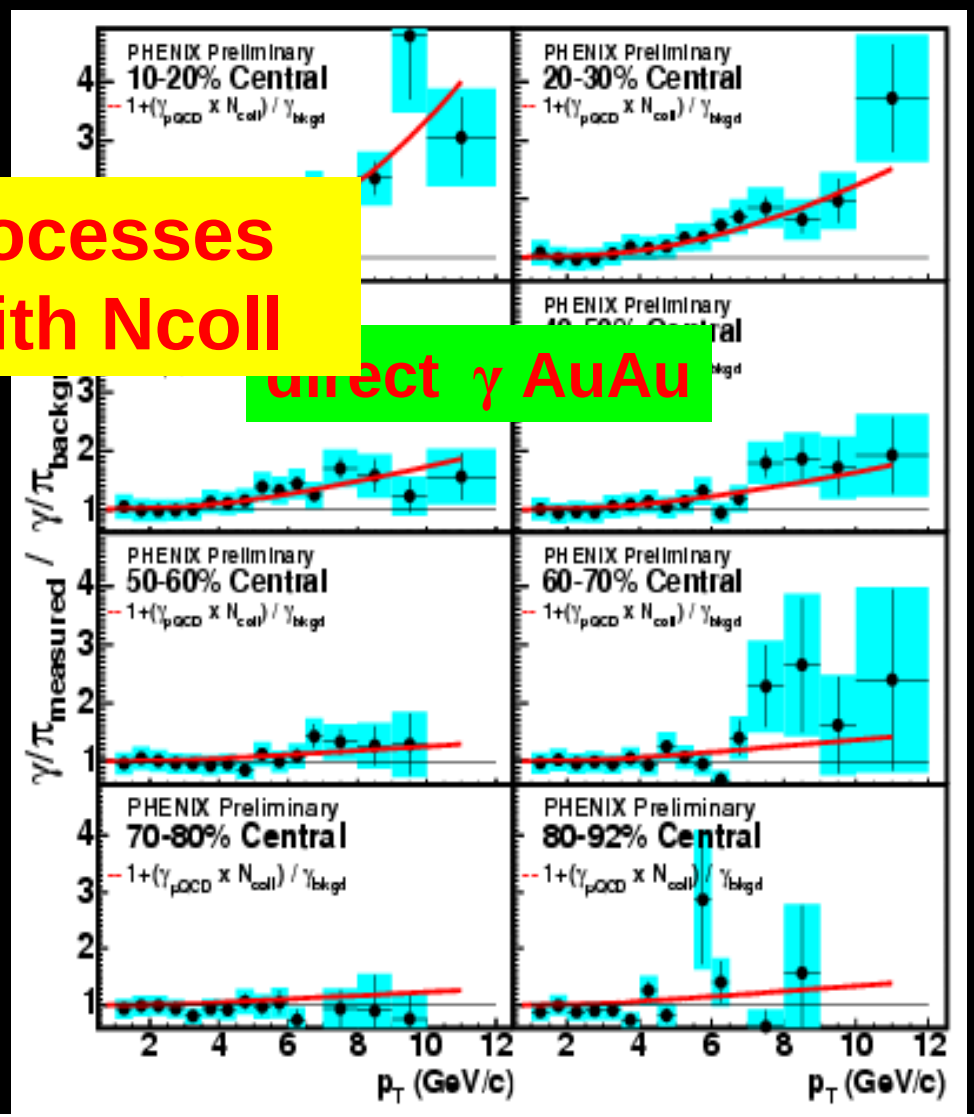
Centrality	~N_{bin}	~N_{part}
10%	860	300
M.B.	125	75
75-92%	6	6



~1M Min Bias AuAu events

the Validity of binary scaling



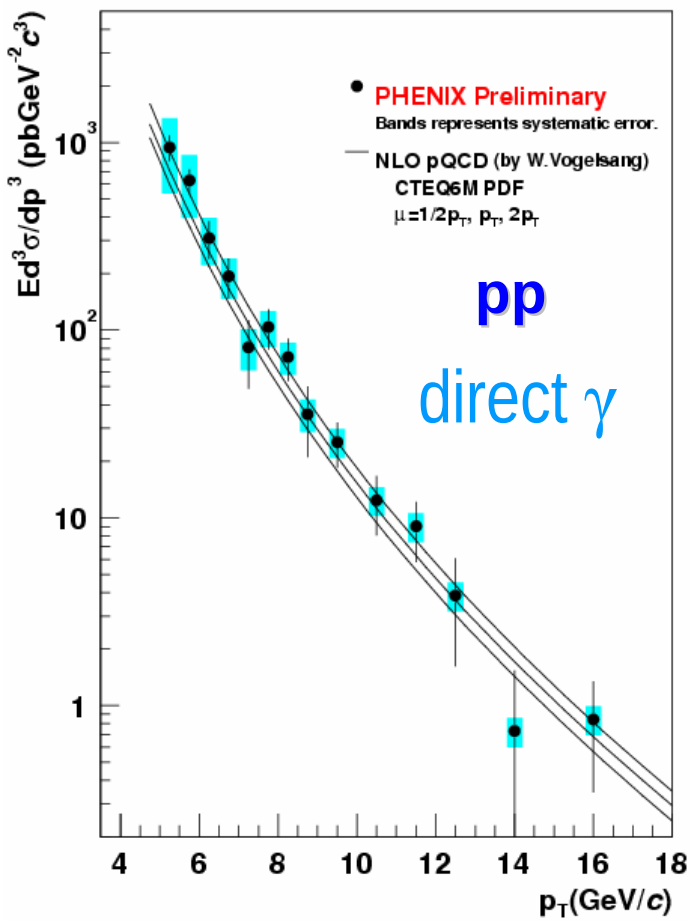


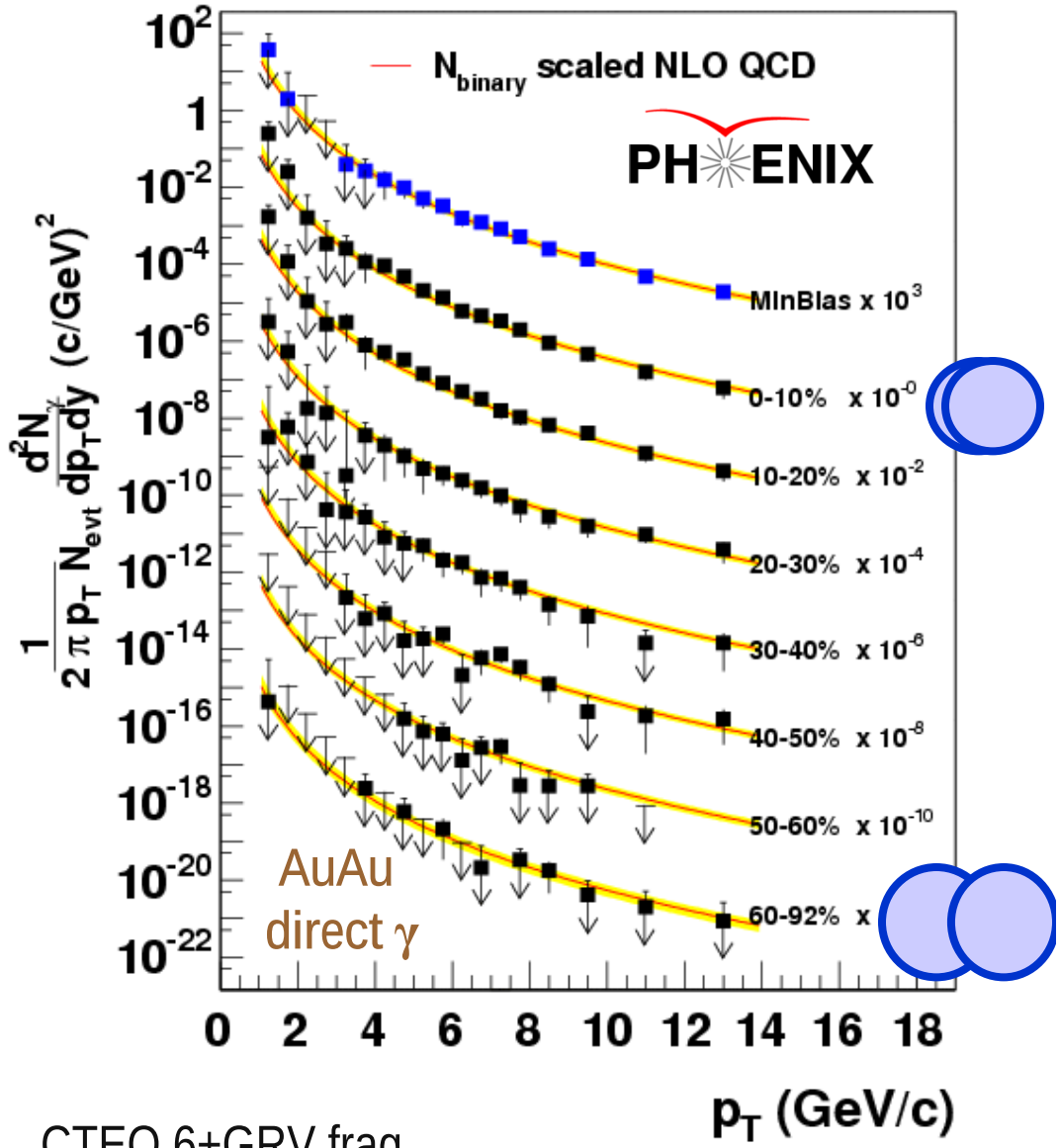
hard processes scale with Ncoll

direct γ AuAu

Calibrated Probe – direct photons

- (simple) p+p collisions
  - Supported by pQCD
- AuAu collisions
  - assumes binary scaling

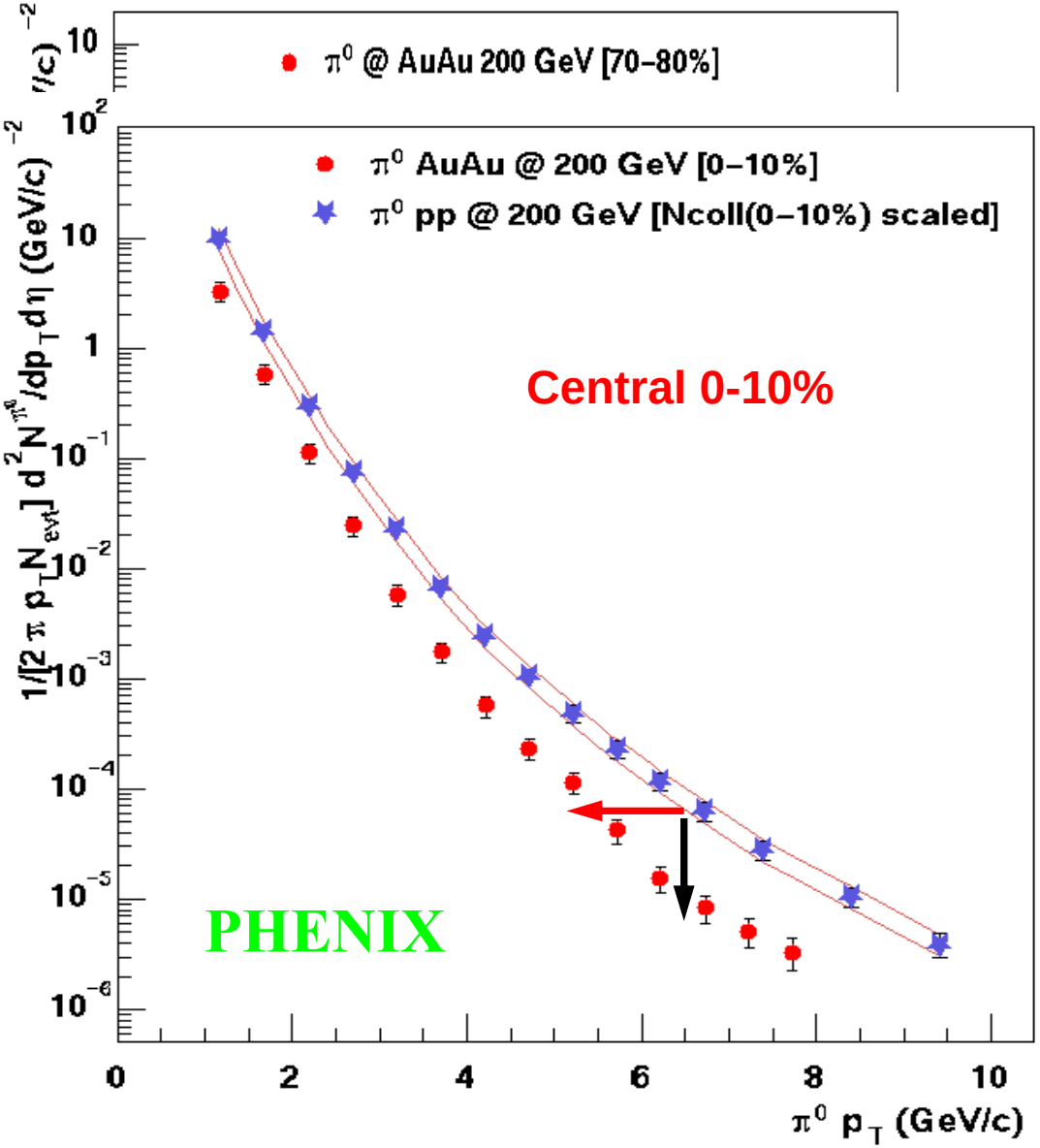




CTEQ 6+GRV frag

Parton Energy Loss – π^0 Production

- Calibrating the probes- pp reference data
  - -agrees with NLO pQCD
- Peripheral Collisions
  - -Scale with Ncoll
- Central Collisions
  - DO NOT SCALE!
- Is it
  - Suppression of low-x gluons in the initial state?
  - Energy loss in sQGP

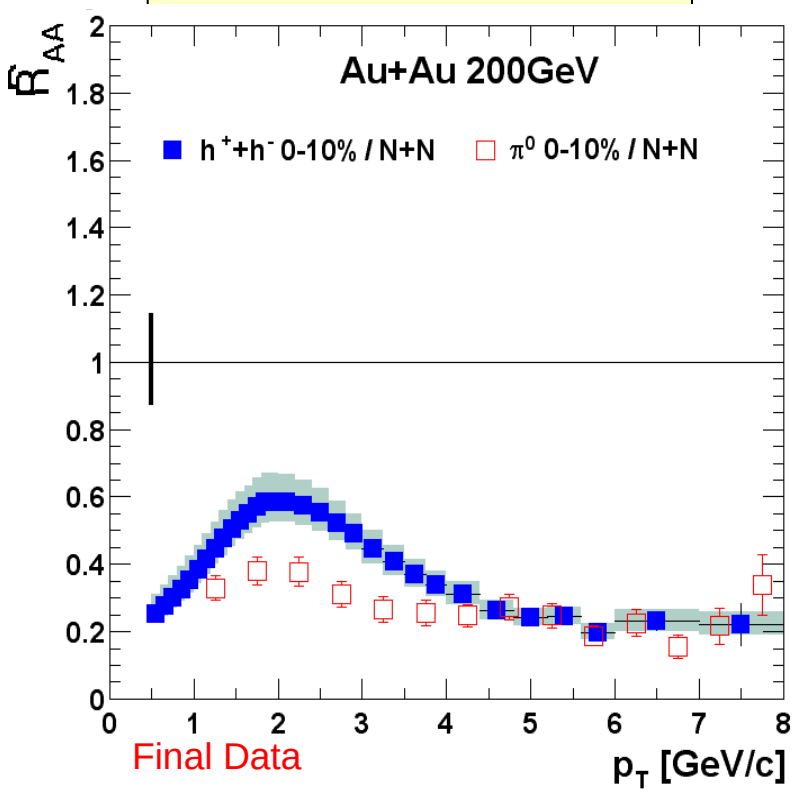


dA – the null experiment

- Its a final state thing!

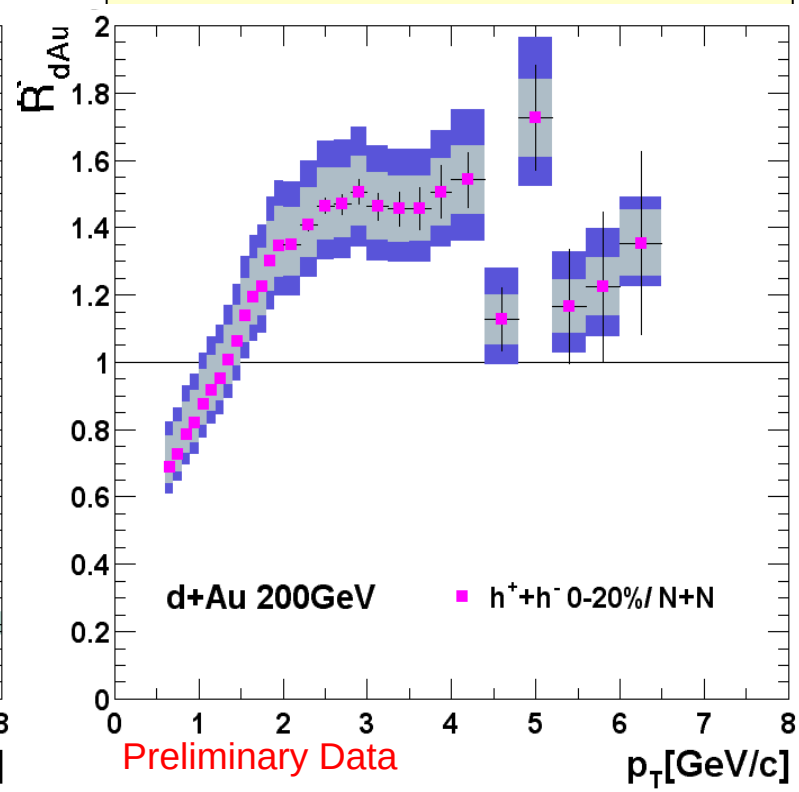
Central

Au + Au Experiment



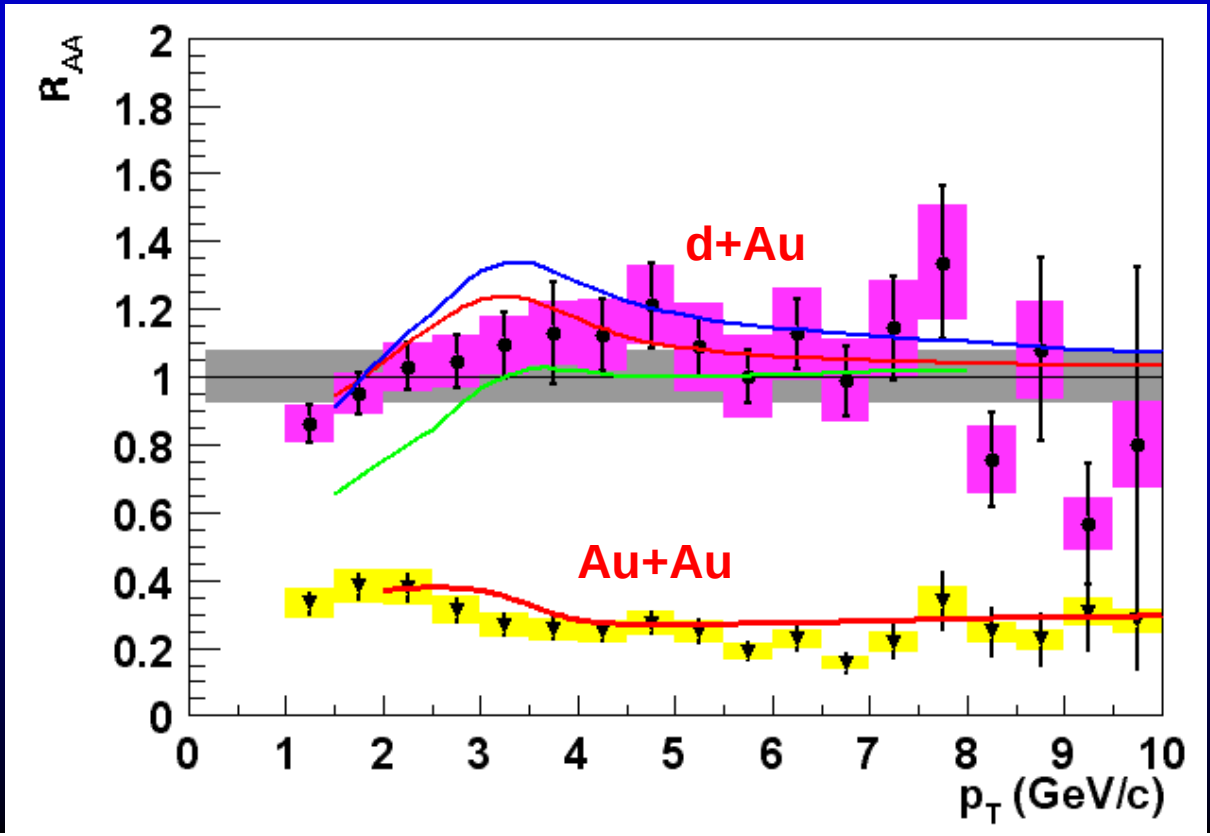
Final Data

d + Au Control Experiment



Preliminary Data

High Energy Densities?

- **A Calculation of energy loss**
  - **Au+Au suppression** (I. Vitev and M. Gyulassy, hep-ph/0208108)
  - **d+Au enhancement** (I. Vitev, nucl-th/0302002)
- **understood in an approach that combines multiple scattering with absorption in *a dense partonic medium***

- **$dN_g/dy \sim 1100$**
- **ε=15 GeV/fm^3**