Predictions for hadronic observables from

Pb + Pb collisions at sqrt(s_{NN}) = 2.76 TeV

from a simple kinematic model

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WPCF-Kiev September 14, 2010

Outline

- Motivation & goals of the model
- Brief description of the model
- Comparison of model calculations with RHIC experiments STAR, PHENIX, and PHOBOS
- Predictions for LHC

  ➔ **Pb+Pb, sqrt(s_{NN}) = 2.76 TeV**

Motivation and goals of this work

The LHC will be giving us Pb + Pb collisions at sqrt(s_{NN}) = 2.76 TeV in November, 2010 !!

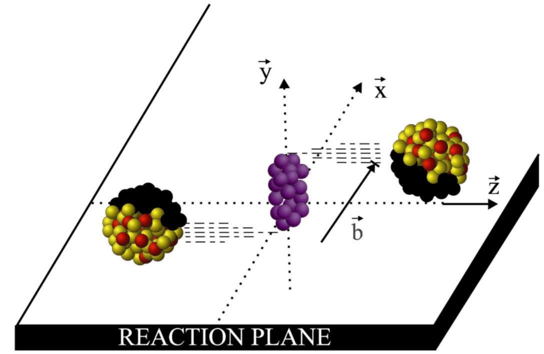
Make predictions for common hadronic observables which will be initially measured by experiments for LHC Pb + Pb collisions.

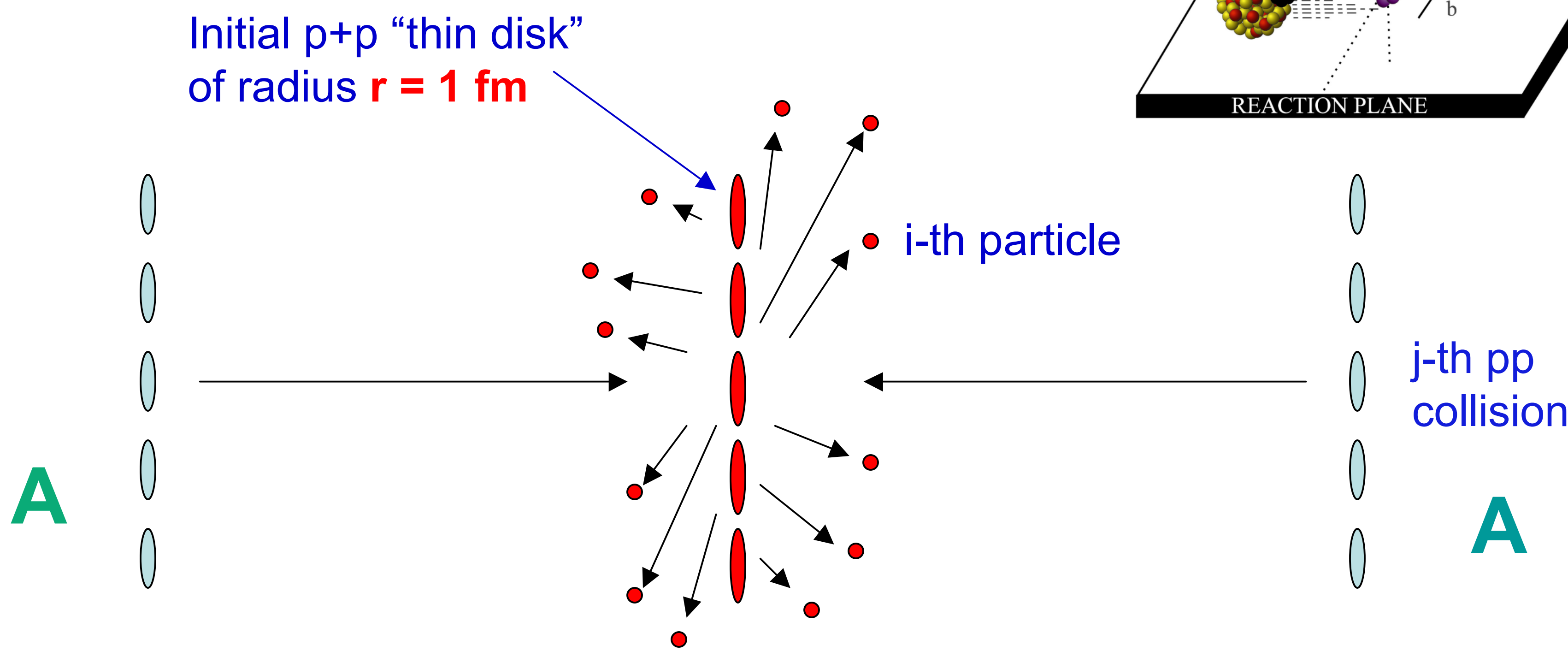
Use a model which has been shown to describe the overall trends of the main hadronic observables of the RHIC data and which can be easily scaled up to give predictions for these hadronic observables for LHC Pb + Pb collisions.

A simple hadronic rescattering model satisfies these requirements. The picture behind it is to use only hadrons as degrees of freedom in a Monte Carlo calculation to obtain a “limiting case scenario.”

Study the successes and failures of this picture @LHC when the predictions are eventually compared with data ➔ may already see this in December 2010 !!

Simple superposition-rescattering model for A+A collision



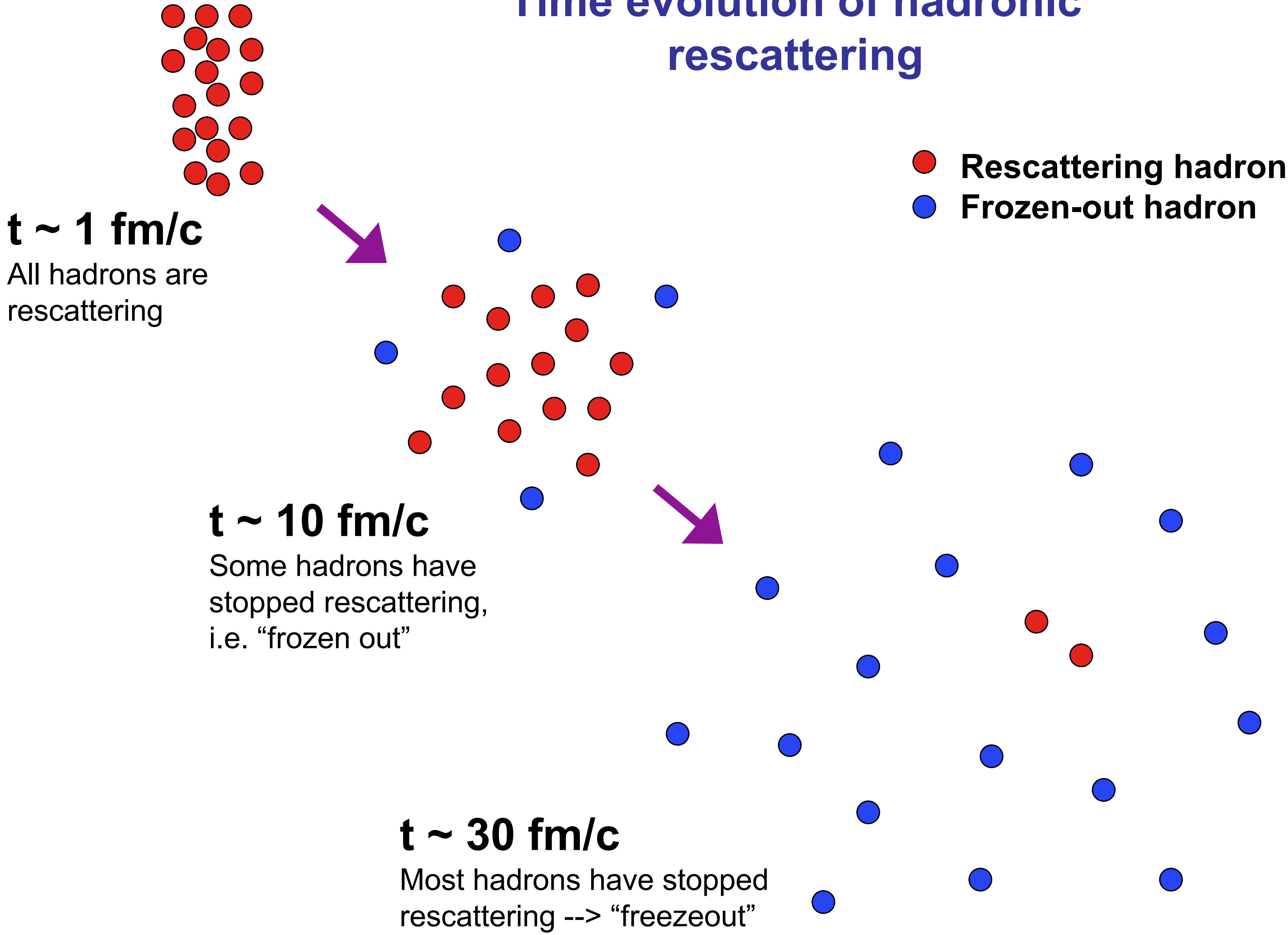


* Superimpose f*A PYTHIA pp events, where f=overlap fraction for impact param.
* Assume all particles have the same proper time for hadronization, τ, so that the hadronization space-time for each particle is given by "geometry+causality", i.e.

$$t_i = \tau E_i/m_i \;;\; x_i = x_{oi} + \tau p_{xi}/m_i \;;\; y_i = y_{oi} + \tau p_{yi}/m_i \;;\; z_i = \tau p_{zi}/m_i$$

* Perform hadronic rescattering using a "full" Monte Carlo rescattering calculation

Time evolution of hadronic rescattering



Other details of the model….

- Use PYTHIA v.6409 to generate hadrons for 200 GeV and 2.76 TeV p+p "minimum bias" (non-elastic and non-diffractive) events
  "final" hadrons from PYTHIA to use: → π, K, N, Δ , Λ , ω, ρ, K*, ϕ, η, η'

- Use mult > 20 or 34 (RHIC or LHC) cut on p+p events --> cuts out ~ 20-25% of events and helps dn/dη agree better with PHOBOS 200 GeV/n Au+Au

- Monte Carlo hadronic rescattering calculation:
  Let hadrons undergo strong binary collisions (elastic and inelastic) until the system gets so dilute that all collisions cease. Use 0.5 fm/c timesteps to 200 or 400 fm/c (RHIC or LHC)
  --> isospin-averaged σ(i,j) from Prakash, etc..
  Record the time, mass, position, and momentum of each hadron when it no longer scatters. → freezout condition

- Take τ = 0.1 fm/c for all calculations --> found to agree with Tevatron HBT data (T.J.H., Phys.Rev.C76, 025205 (2007))

- Model results for RHIC published in T.J.H., Phys.Rev.C79, 044902 (2009)

Comparisons with RHIC experiments

- Made a 90K event 200 GeV/n Au+Au minimum bias run with model --> apply centrality cuts (via multiplicity cuts) and kinematic cuts to this run to make "absolute comparisons" with experiments
- Comparisons made with published 200 GeV/n Au+Au experimental results:

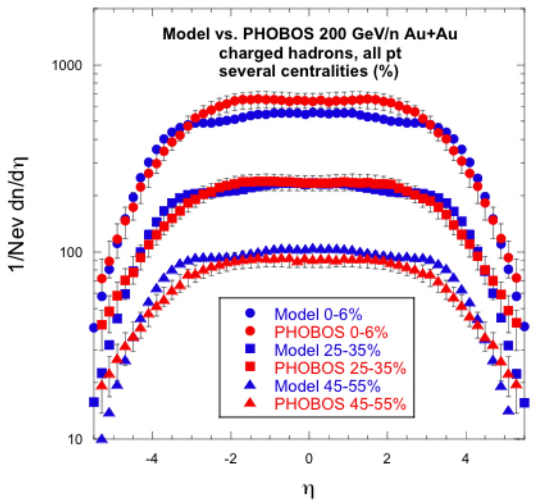
  - spectra with PHENIX, PHOBOS and STAR

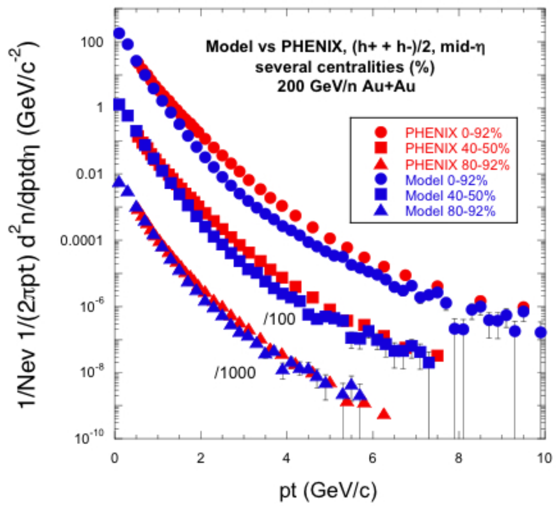
  - V_2 with PHENIX, PHOBOS and STAR

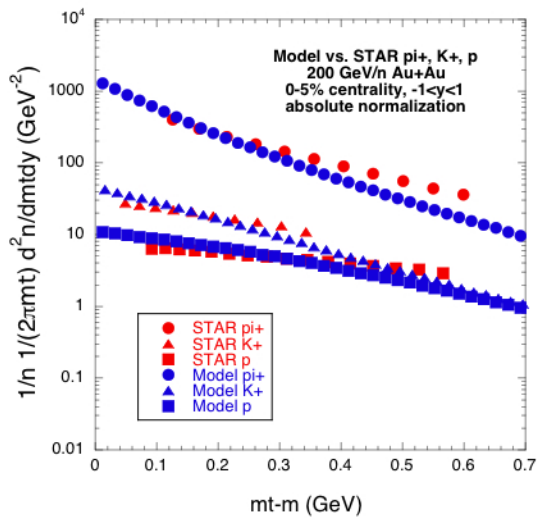
  - HBT with STAR

  - R_{AA} with PHENIX

Spectra: Model vs PHOBOS, PHENIX, and STAR

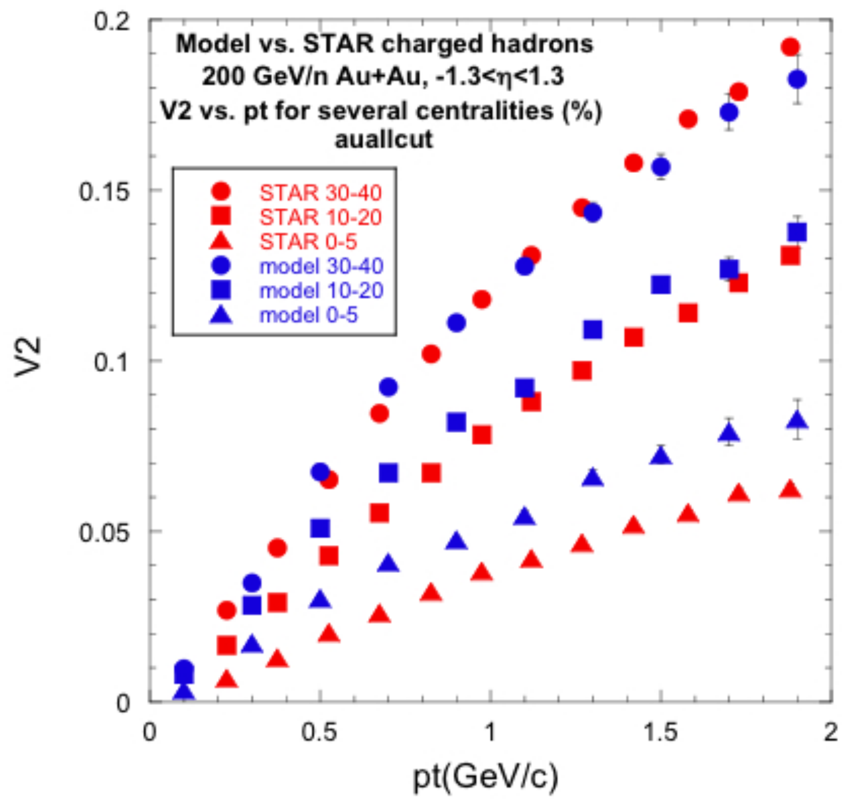


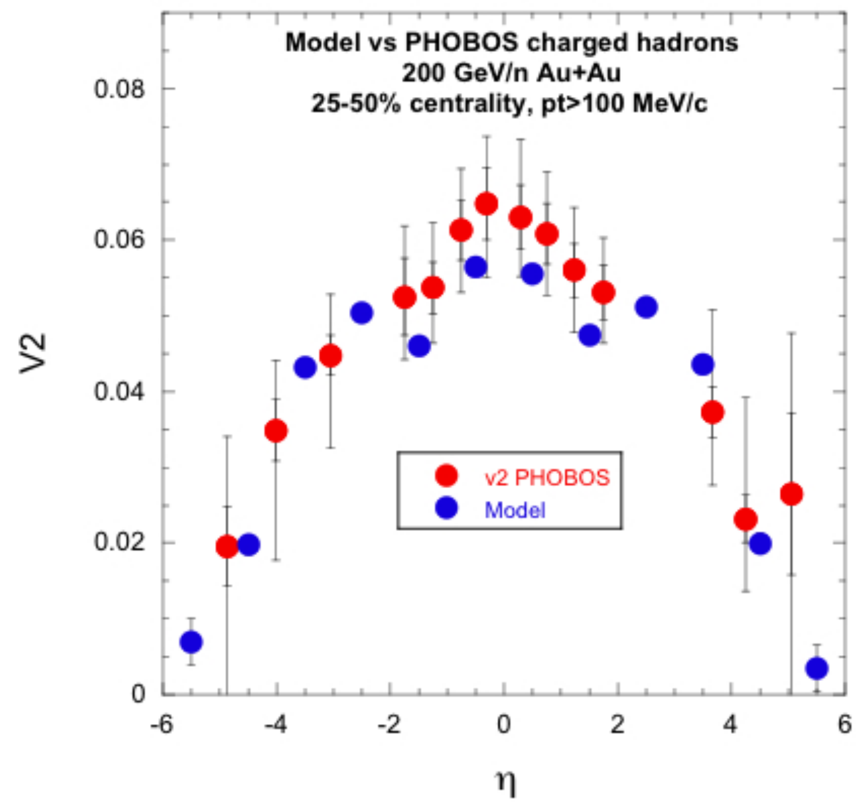




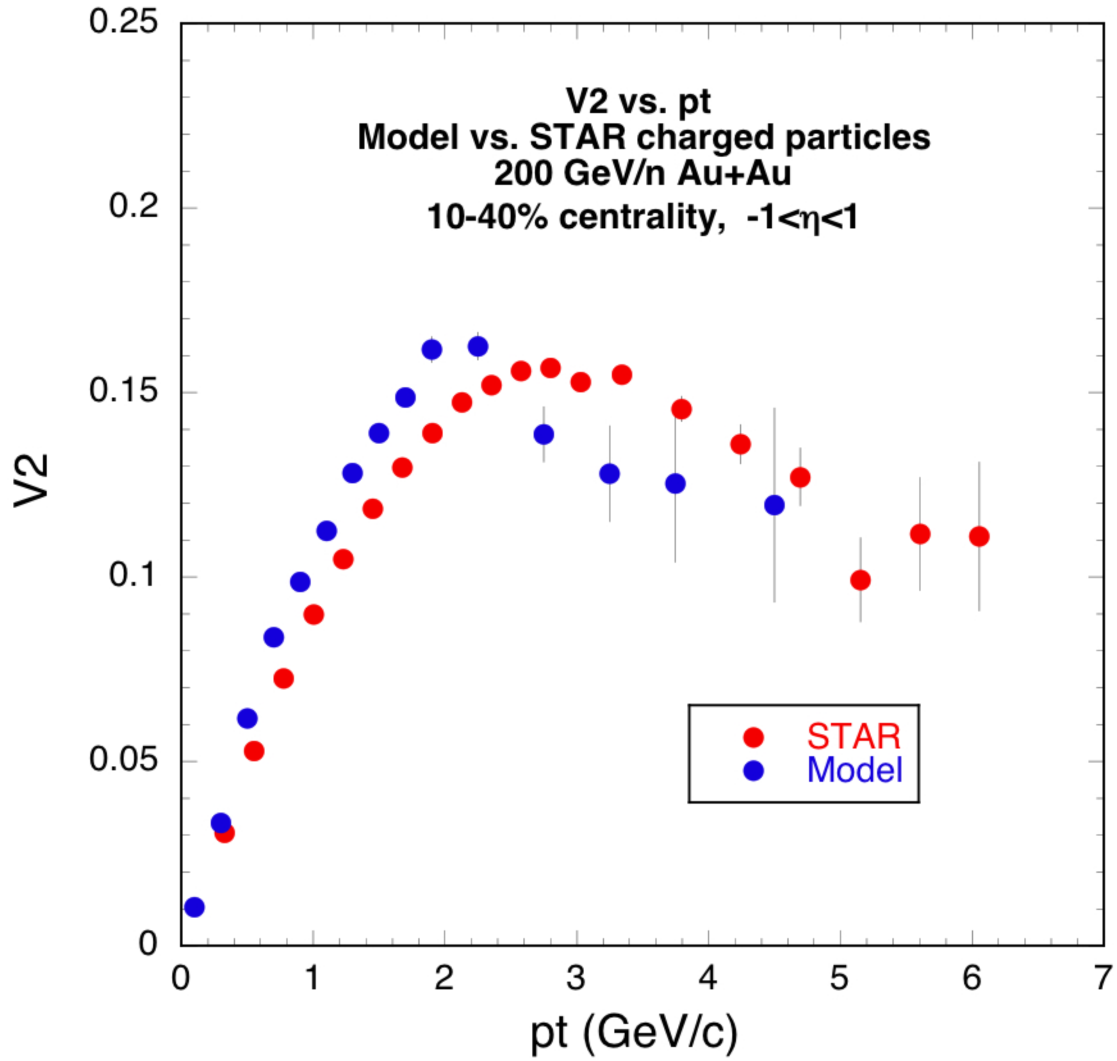
Elliptic flow vs. centrality, p_T, and η
Model vs. STAR and PHOBOS

$$V_2 = \langle \cos(2\phi) \rangle , \ \phi = \arctan(p_y/p_x)$$

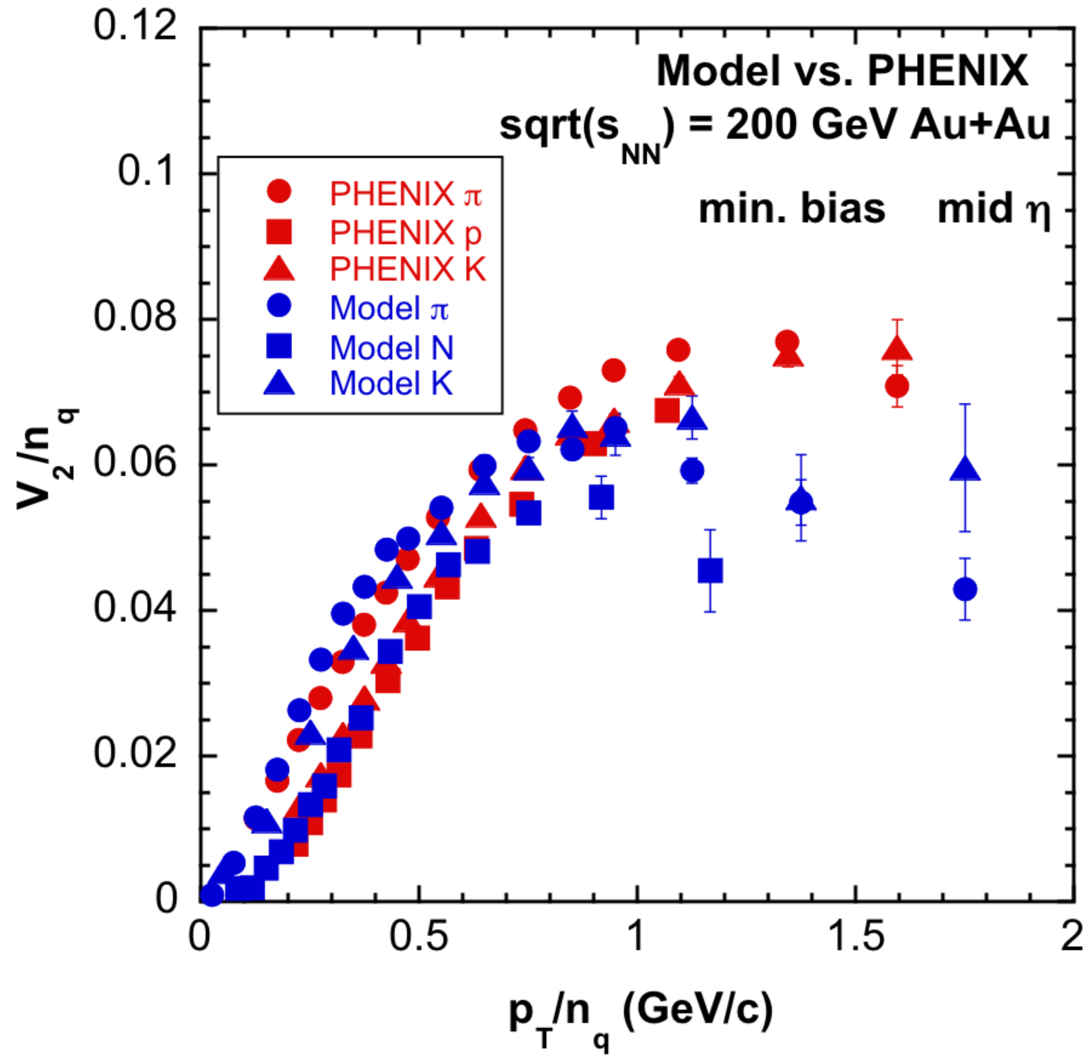




V_2 vs. p_T --> large p_T: Model vs. STAR



V_2/n_q vs. p_T/n_q for Model vs. PHENIX
For pions, kaons, and protons.



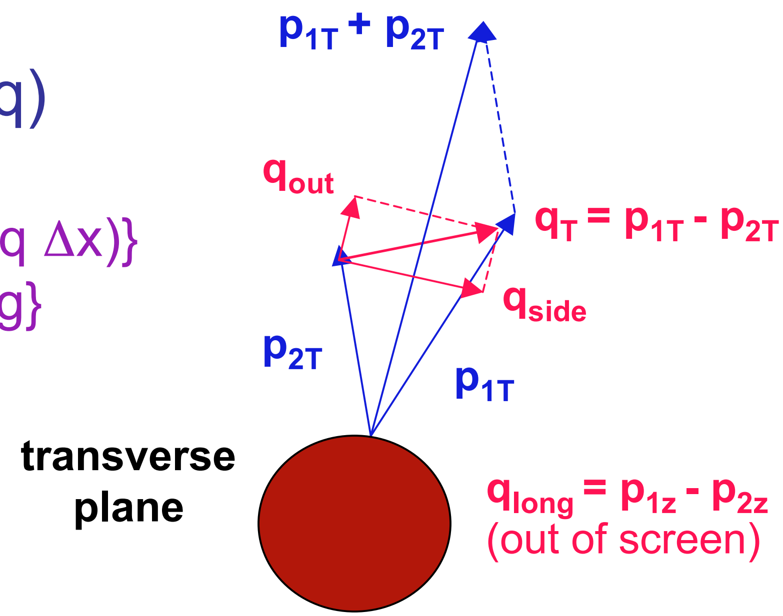
Model V_2 shows scaling with quark number like exp.

HBT/Femto - how implemented in model

* Form two-boson correlation function from the model:

$$C(q)=A(q)/B(q)$$

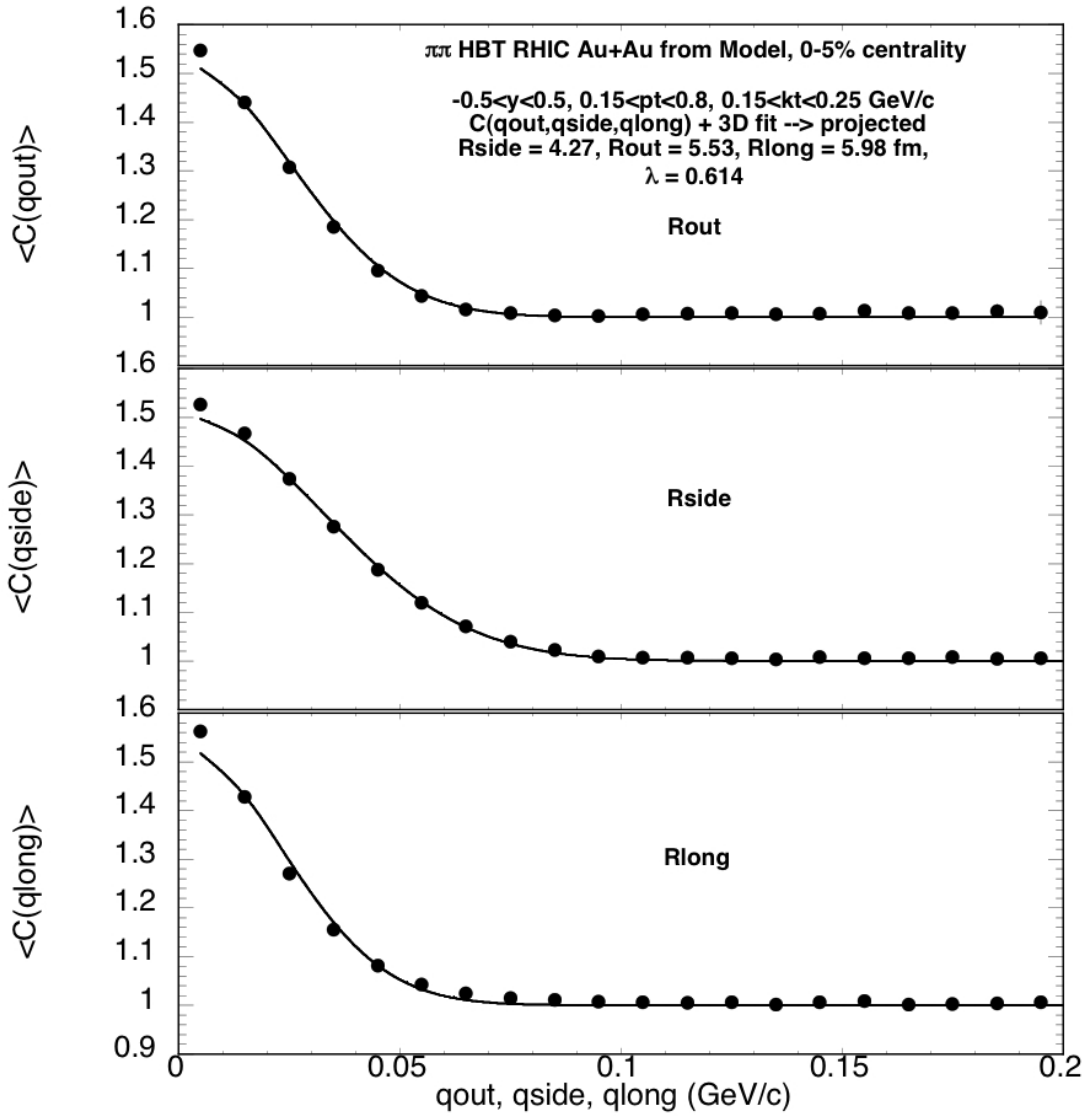
$A(q) = \Sigma\{$real pairs weighted by $1+\cos(q\,\Delta x)\}$
$B(q) = \Sigma\{$backg. pairs from event mixing$\}$
$q = p_1 - p_2 \quad \Delta x = x_1 - x_2$ (4-vectors)



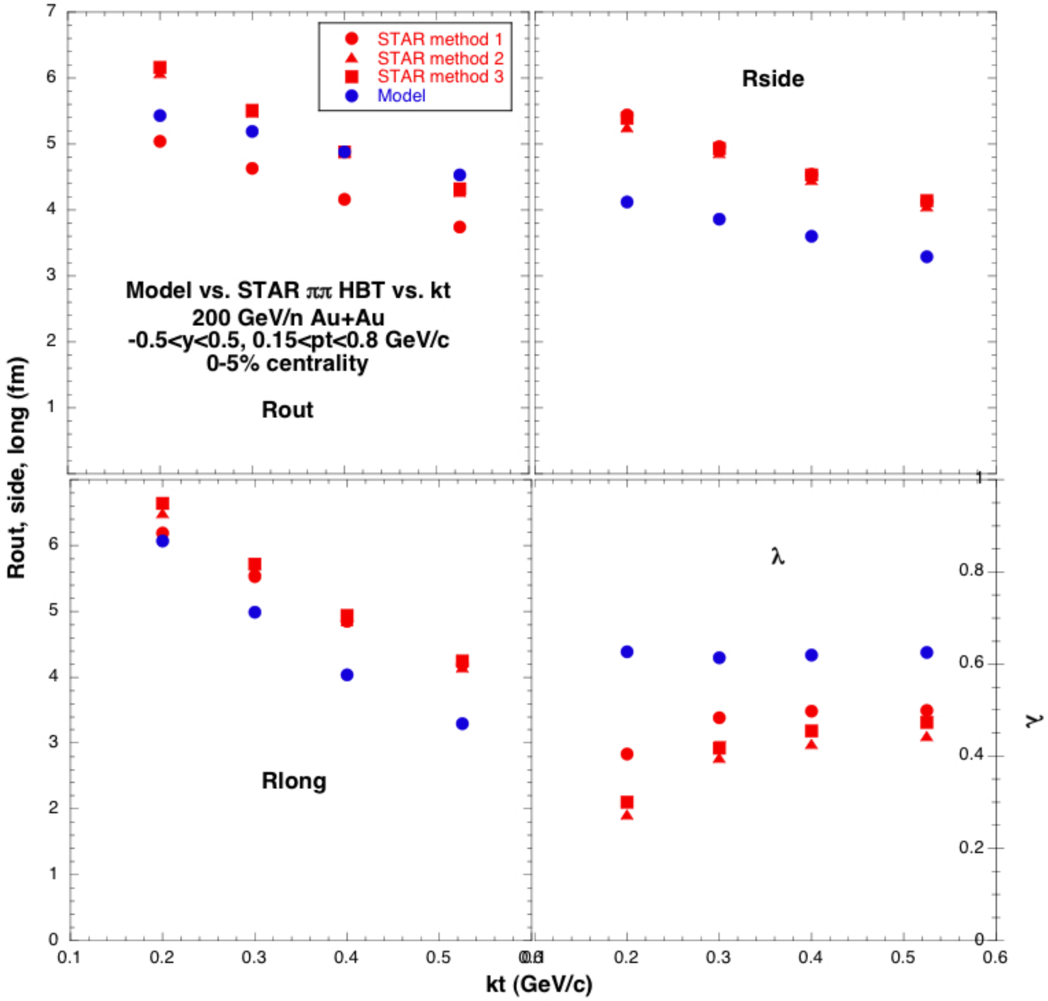
* Fit Gaussian function to $C(q) = C(q_{out},q_{side},q_{long})$ to extract pion source param. R_{out}, R_{side}, R_{long}, λ

$$C(q_o,q_s,q_l) = 1 + \lambda \exp[-(q_oR_o)^2-(q_sR_s)^2-(q_lR_l)^2]$$

ππ HBT from Model: projections --> q_{out}, q_{side}, q_{long}



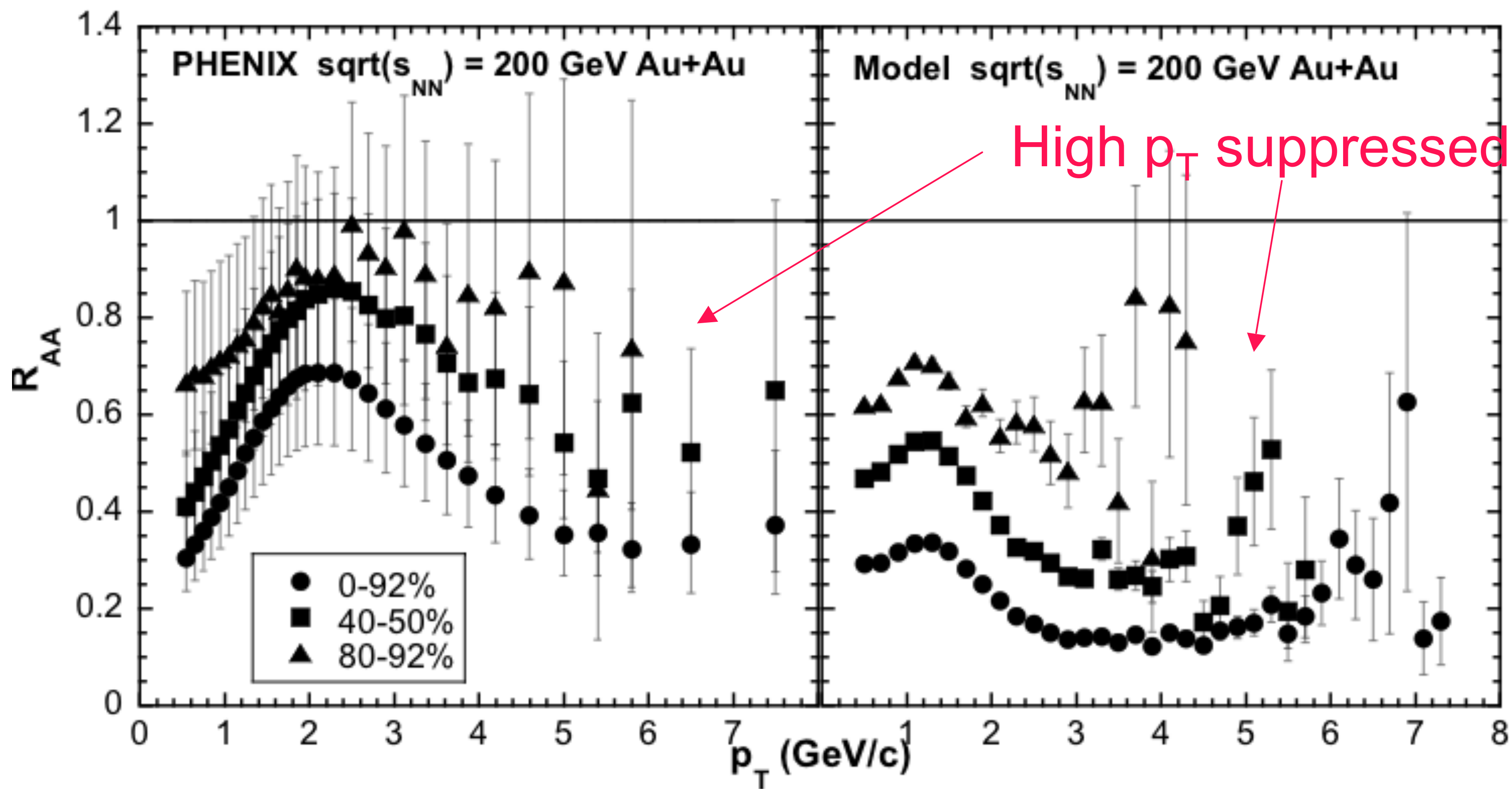
$\pi\pi$ HBT vs. k_T: Model vs. STAR



R_{AA} vs. p_T: Model vs. PHENIX

$$R_{AA} = (1/N_{ev})\ (d^2N_{AuAu}/dp_T d\eta)\ /\ (T_{AuAu}\ d^2\sigma_{pp}/dp_T d\eta)$$

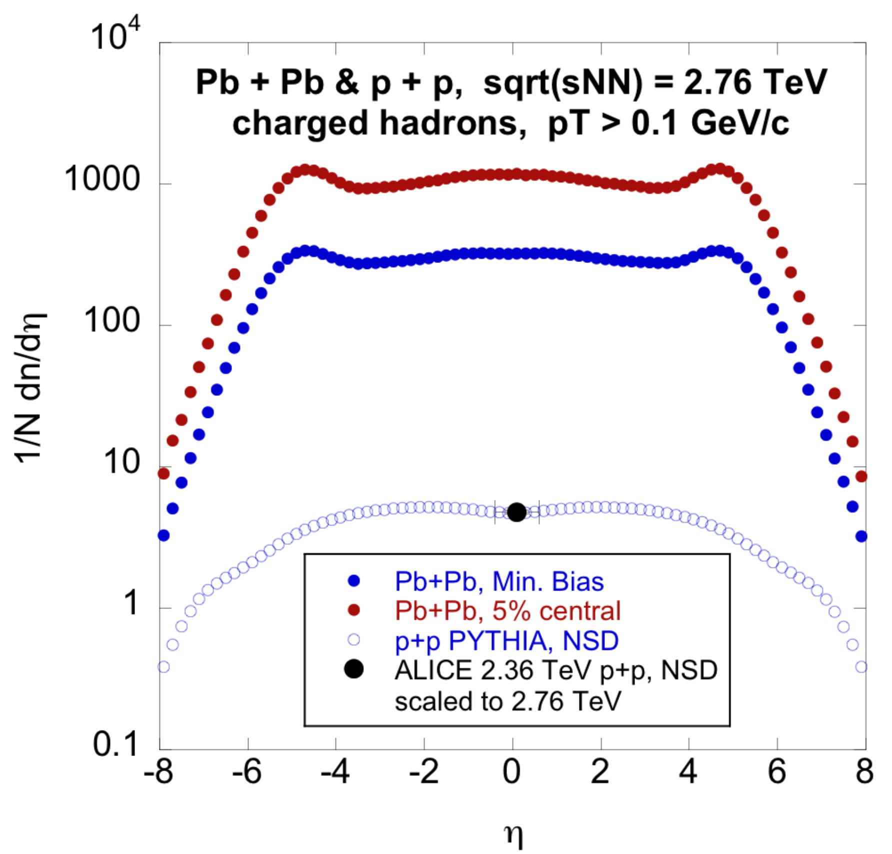
T_{AuAu} -- Glauber overlap function
(use PHENIX values for each centrality cut)

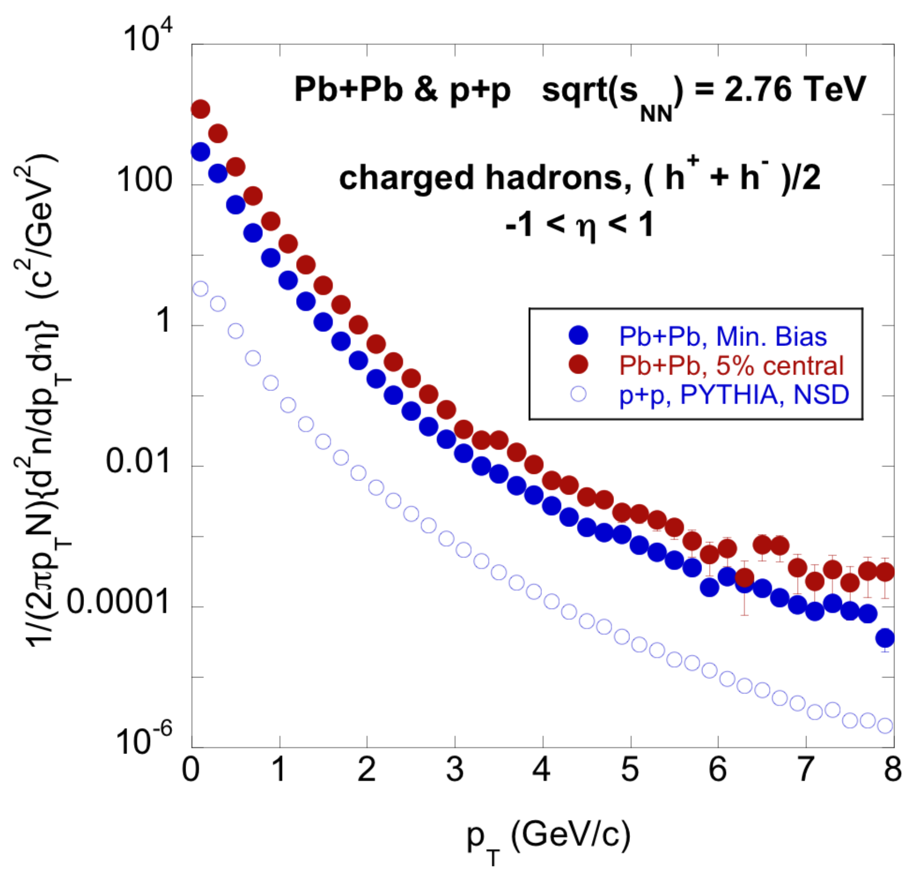


LHC Pb+Pb, sqrt(s_{NN}) = 2.76 TeV predictions from this model

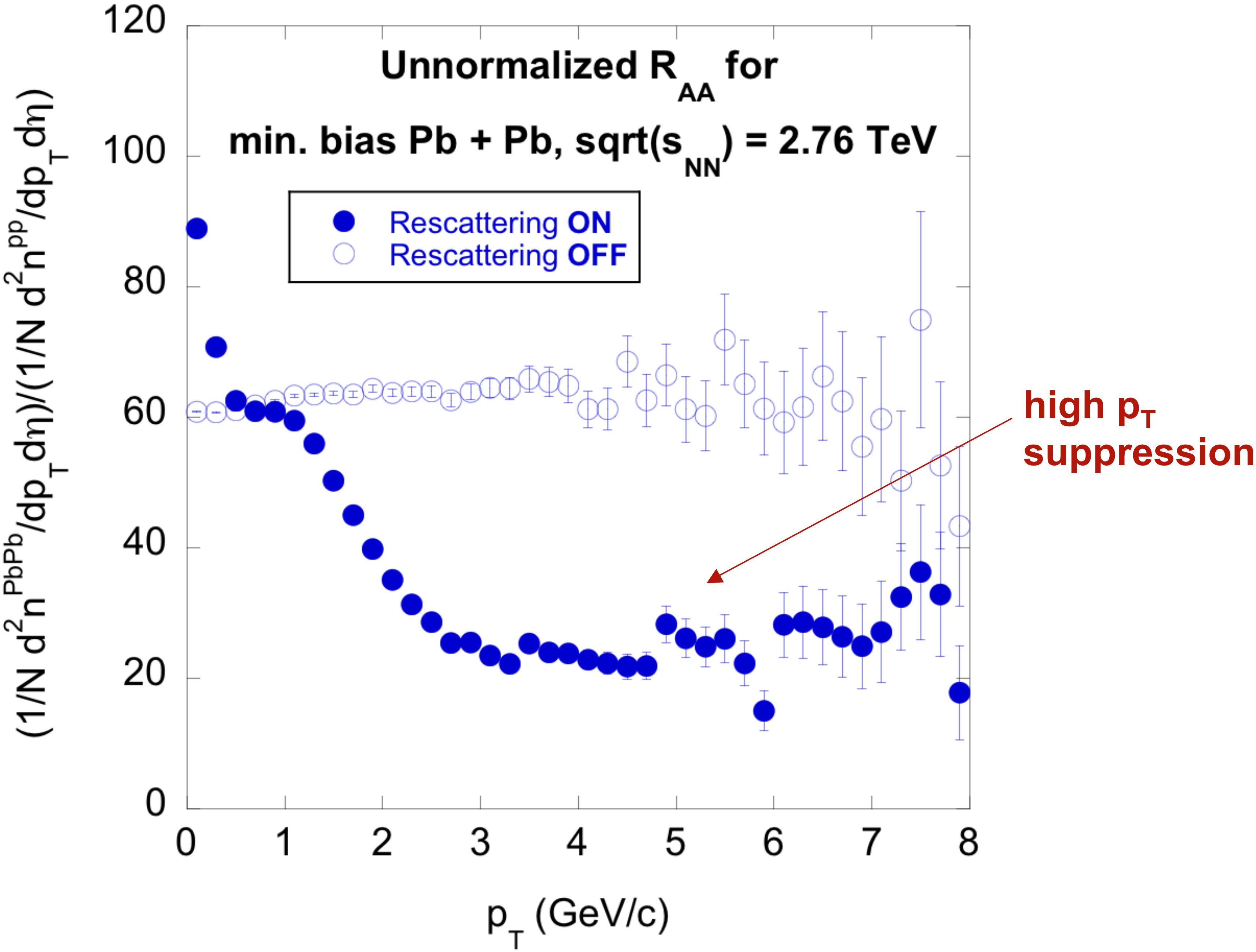
- Use PYTHIA 2.76 TeV p+p collisions as input
- Make multiplicity cut on p+p collisions > 34, cuts out ~20% of p+p events (comparable to multiplicity cut used for RHIC Au+Au)
- Substitute 197 --> 208
- Make a minimum bias run with model for 3200 Pb+Pb events
- Show predictions for spectra, R_{AA}, V_2, and HBT

Spectra for Pb + Pb, sqrt(sNN) = 2.76 TeV



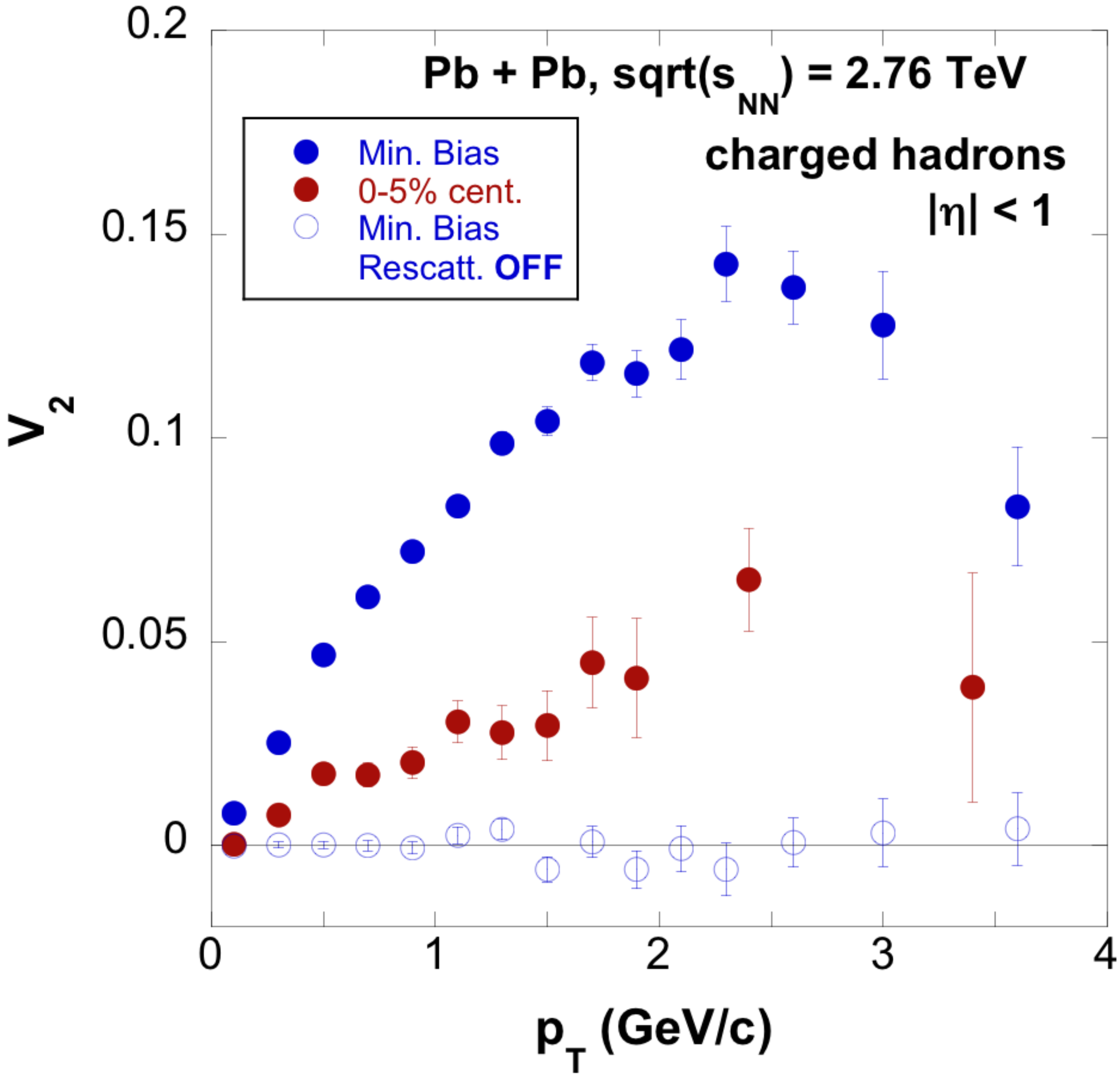


1/N dn/dη (0-5%, η=0) ➔ ~1200



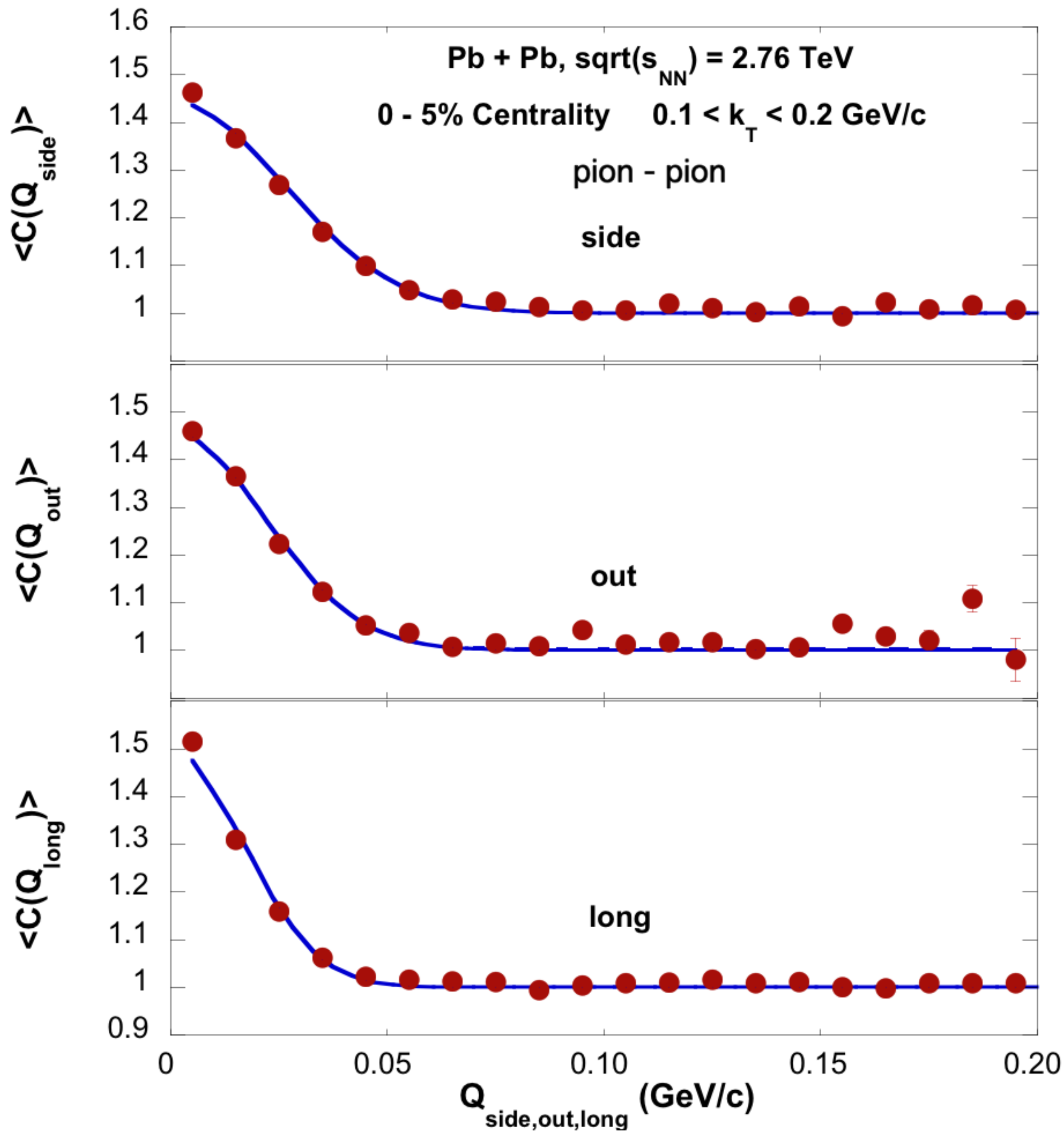
Unnormalized R_AA for
min. bias Pb + Pb, sqrt(s_NN) = 2.76 TeV
Rescattering ON
Rescattering OFF
high p_T suppression
(1/N d²n^PbPb/dp_T dη)/(1/N d²n^pp/dp_T dη)
p_T (GeV/c)
0
20
40
60
80
100
120
0
1
2
3
4
5
6
7
8

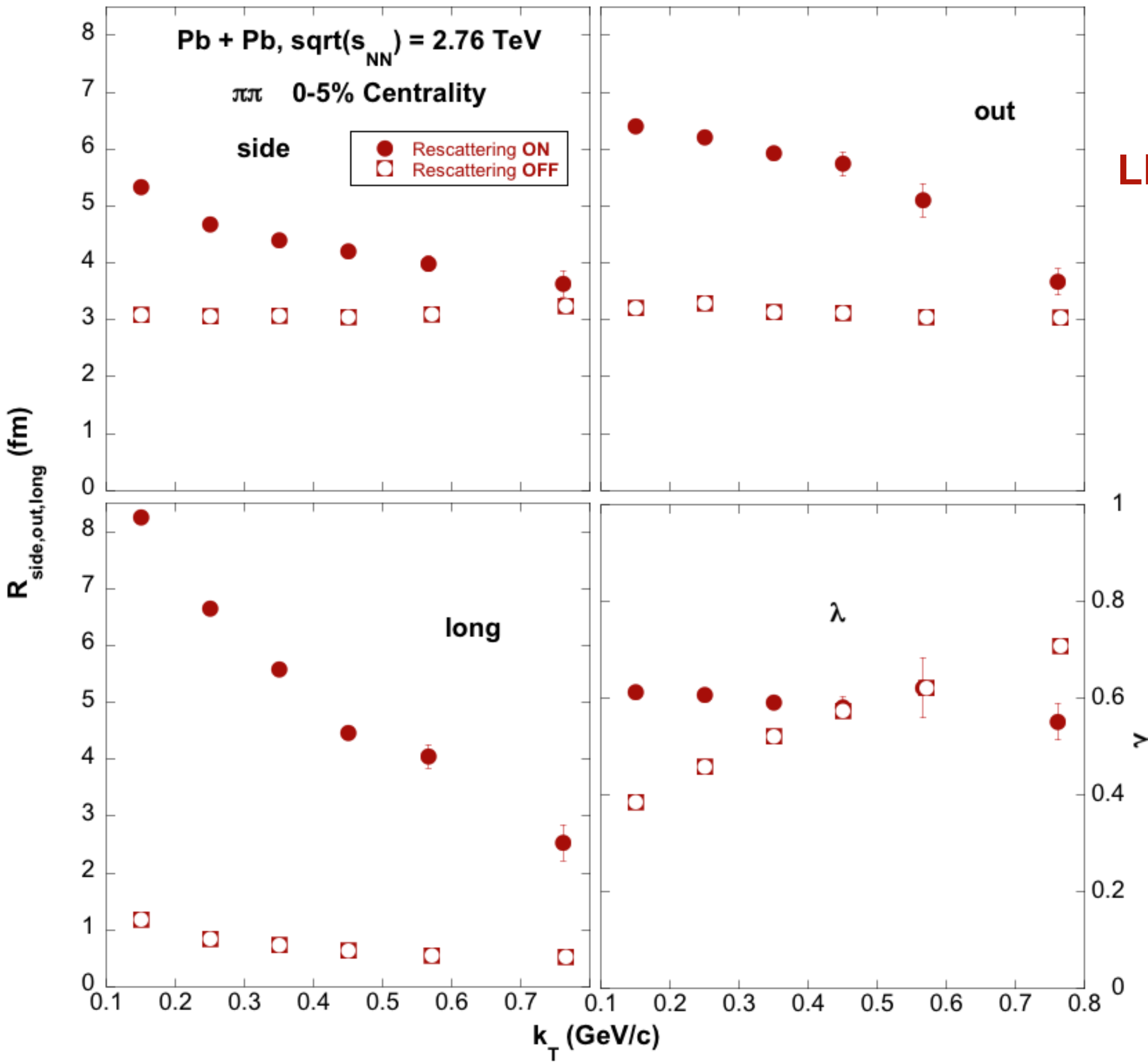
Elliptic flow for Pb + Pb, $\sqrt{s_{NN}}$ = 2.76 TeV



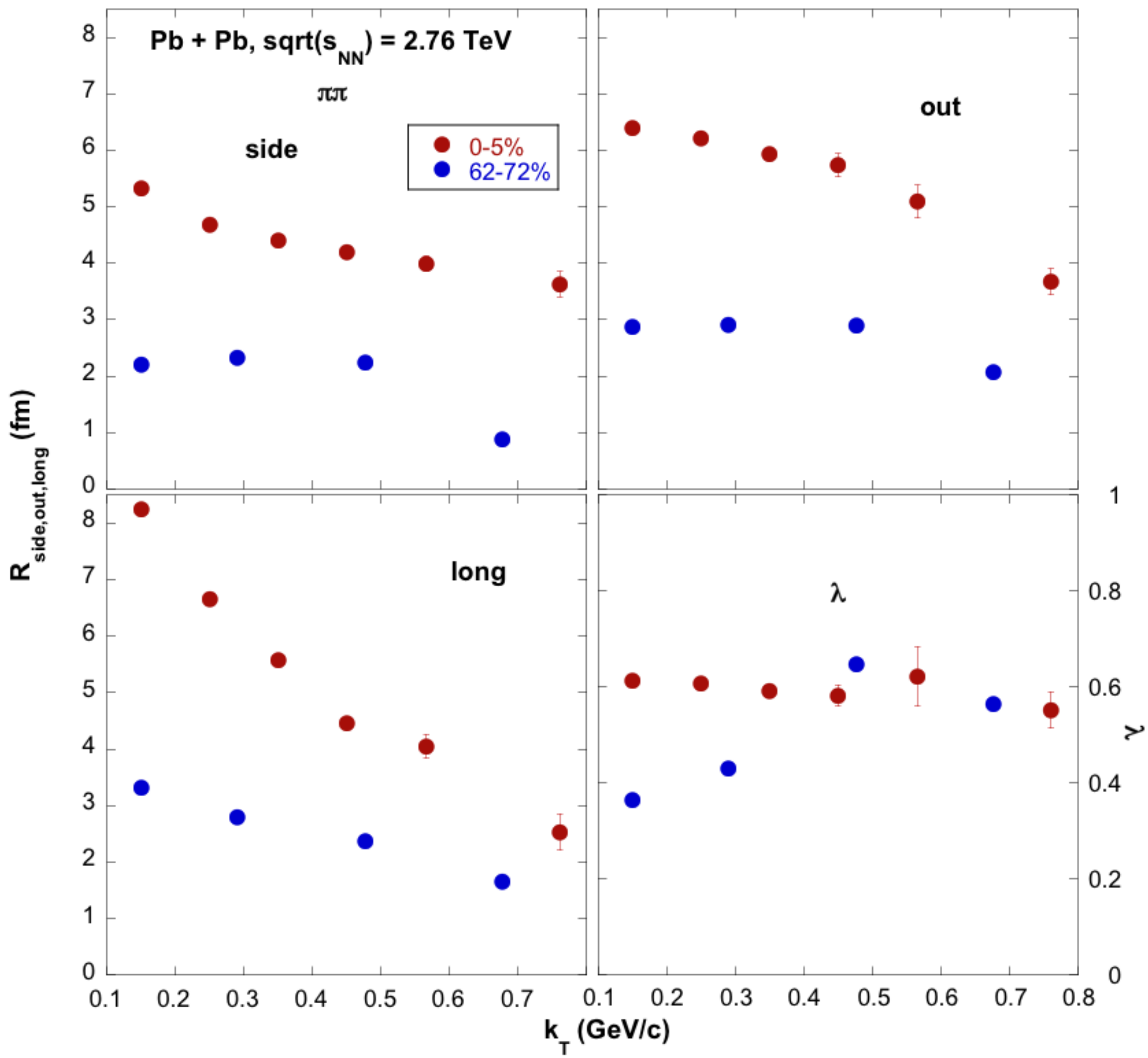
LHC V_2 ~ RHIC V_2

π–π HBT/Femto for Pb + Pb, sqrt(sNN) = 2.76 TeV



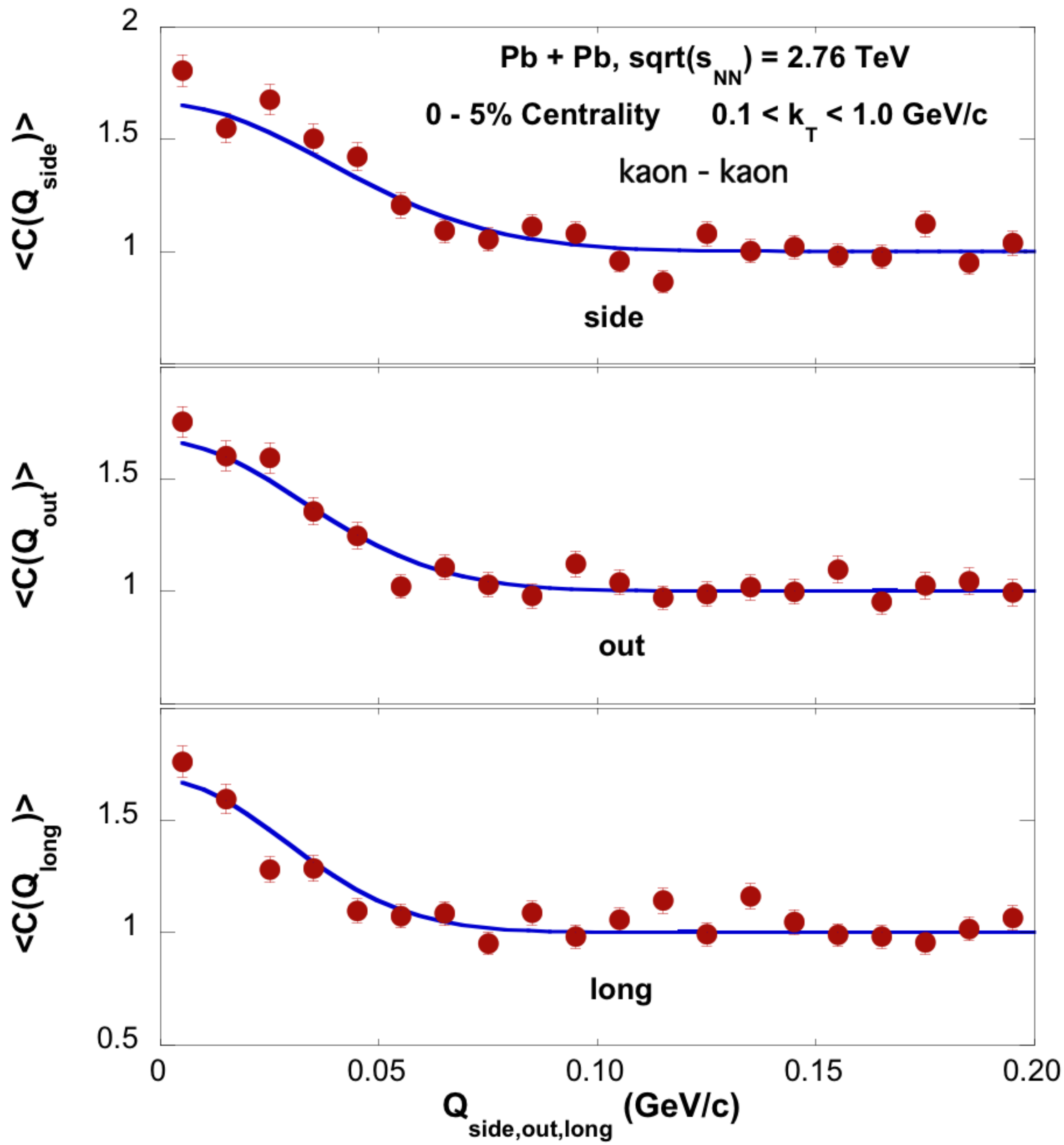


LHC R's
~ 1.2 RHIC R's

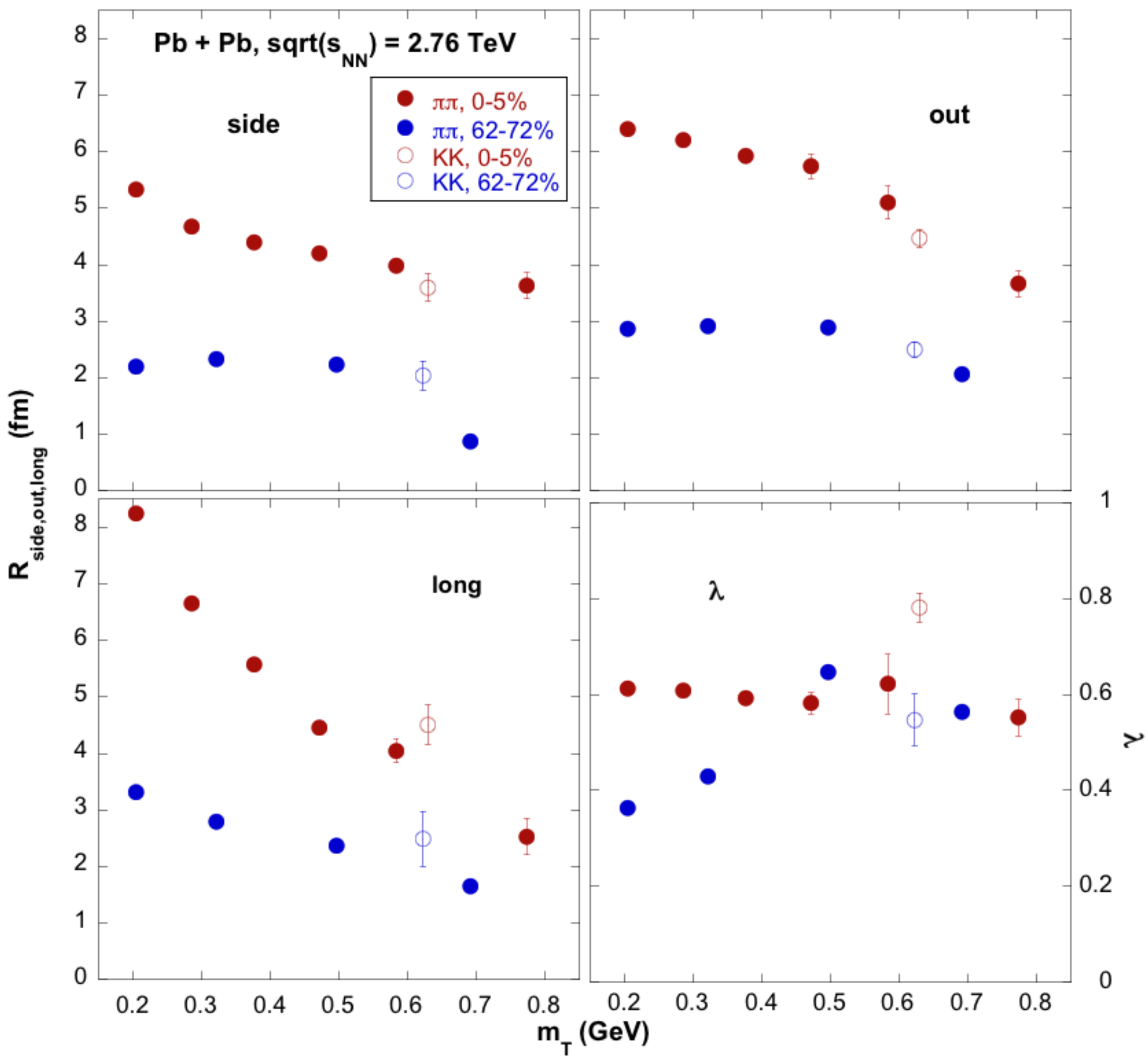


Pb + Pb, sqrt(s_NN) = 2.76 TeV
ππ
side
out
long
λ
0-5%
62-72%
R_side,out,long (fm)
λ
k_T (GeV/c)
0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8
0 1 2 3 4 5 6 7 8
0 0.2 0.4 0.6 0.8 1

K-K HBT/Femto for Pb + Pb, sqrt(sNN) = 2.76 TeV



R_{out}, R_{side}, R_{long} and λ for $\pi\pi$ and KK vs. m_T



KK R's show ~ m_T scaling

Conclusions

- The present simple hadronic rescattering model qualitatively describes the trends for a range of experimental results for 200 GeV/n Au+Au collisions at RHIC
- This suggests that the hadronization proper time in these collisions is short, ~ 0.1 fm/c
- Predictions from this model for LHC Pb+Pb collisions at sqrt(s_{NN}) = 2.76 TeV suggest:

  * $dn/d\eta$ ~ 1200 for charged hadrons at mid-rapidity for central collisions

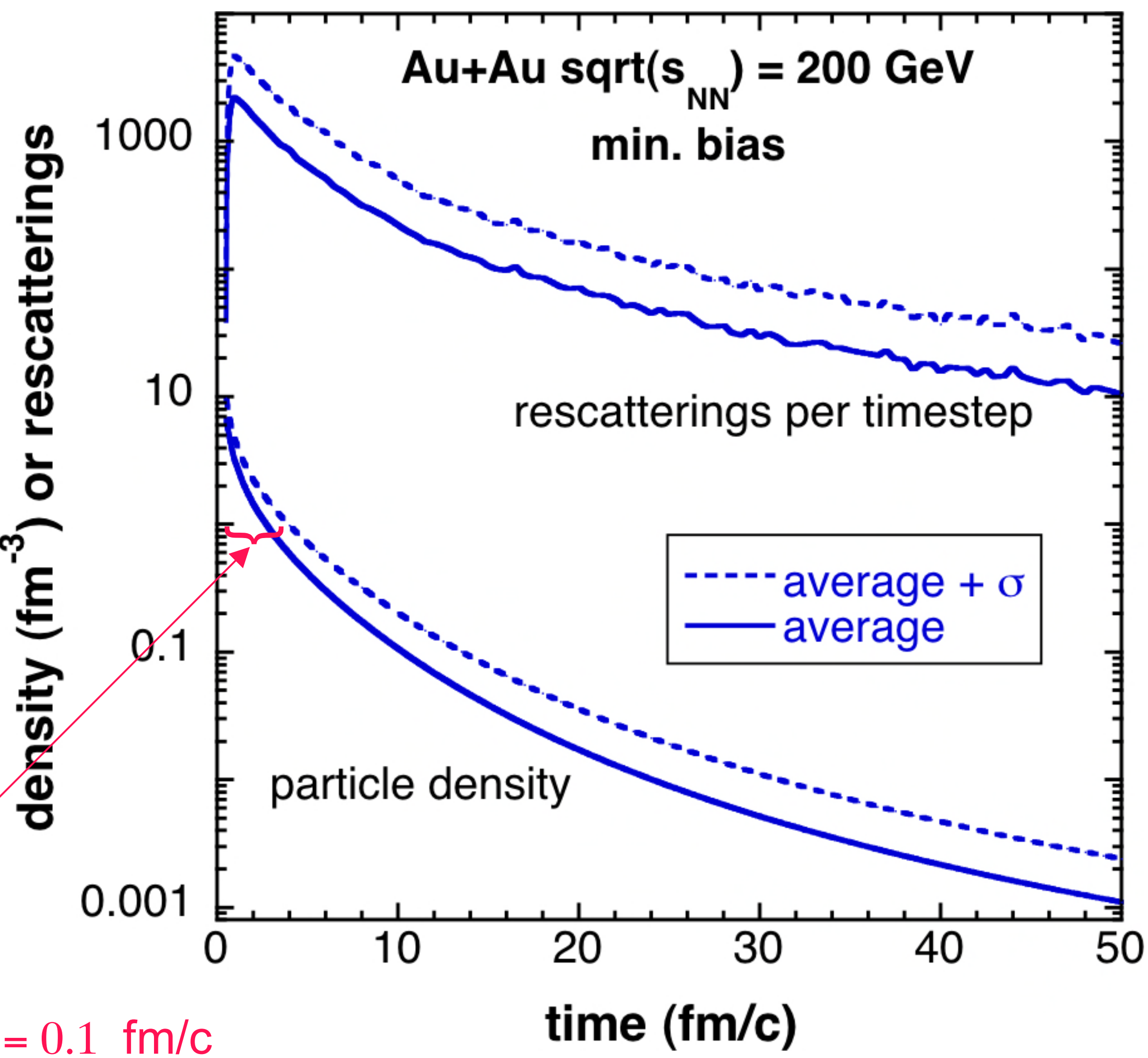
  * High-p_T suppression of R_{AA} should still be present

  * V_2 appears to be comparable to that at RHIC

  * $\pi\pi$ HBT should give ~ 20% higher radius parameters compared to RHIC…….KK HBT shows m_T scaling

Backup slides

Time evolution up to 50 fm/c of the particle density calculated at mid-rapidity ($-1 < y < 1$) and the number of rescatterings per time step from the model for minimum bias sqrt(s_{NN})=200 GeVAu+Au collisions.



→ 200

Big assumption:
binary collisions
of hadrons
or hadron-like
particles
here, too!! ↔ $\tau = 0.1$ fm/c

Advantages of this model

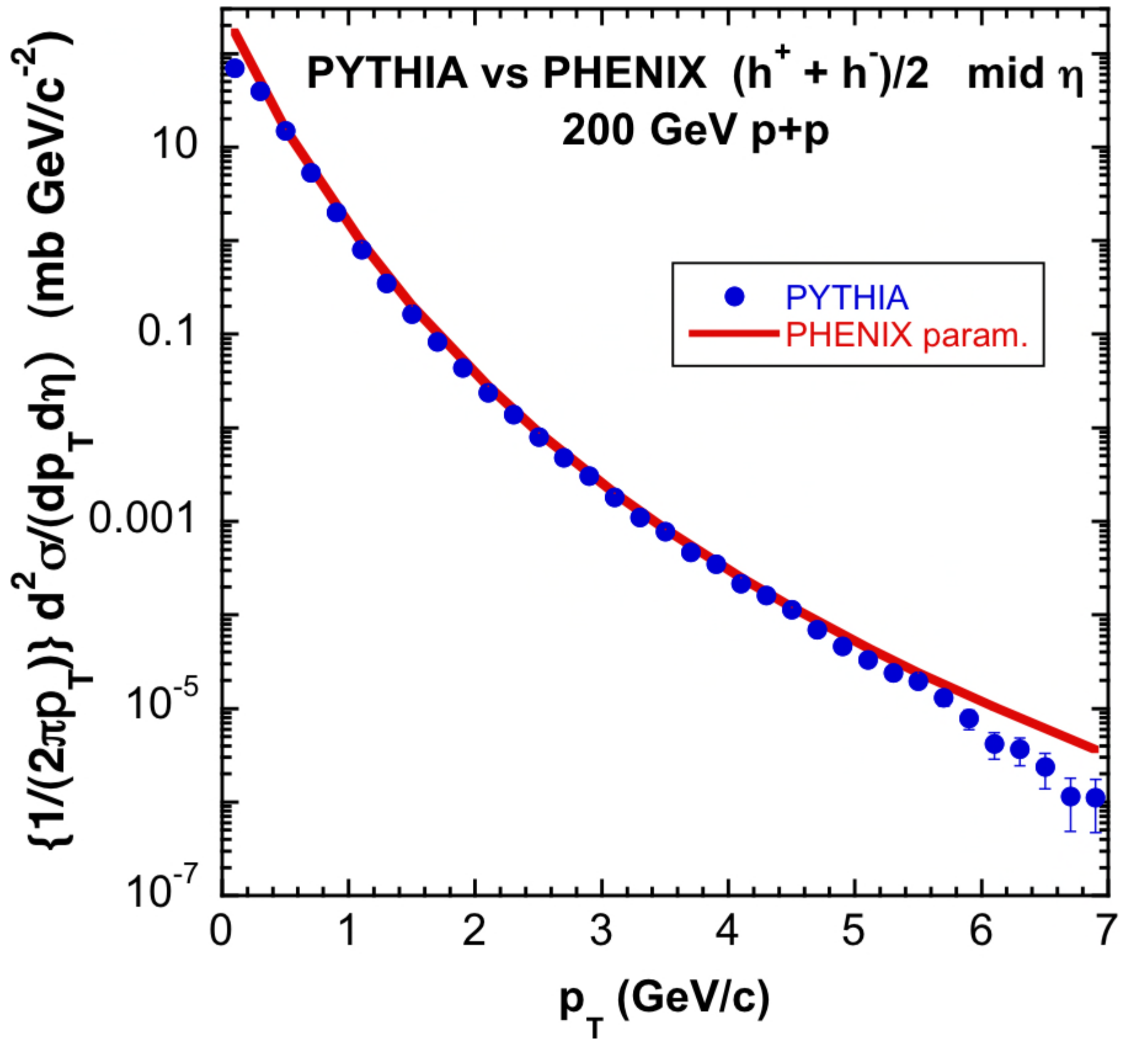
- Well-defined initial conditions: PYTHIA for kinematics and causality for geometry
- Jets are built into the model via PYTHIA so high-p_T observables can be studied
- Initial conditions easily scalable to LHC energies for predictions there
- Simplicity -- hadrons+geometry+rescattering with a few well-defined parameters

Disadvantages of this model

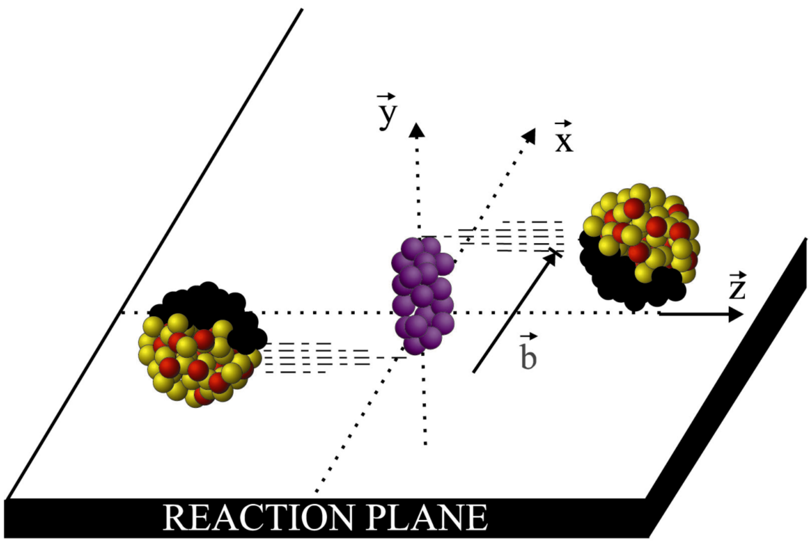
• Simplicity -- Surely leaves out some early-phase physics, e.g. quark and gluon degrees of freedom

• Therefore, will be satisfied to get a qualitative description of trends of at least some experimental observables

$d\sigma/dp_T$ from PYTHIA compared with a PHENIX parameterization for 200 GeV p+p collisions (absolute normalizations)



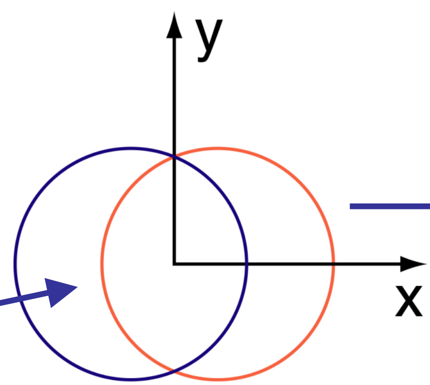
Elliptic Flow --> V_2

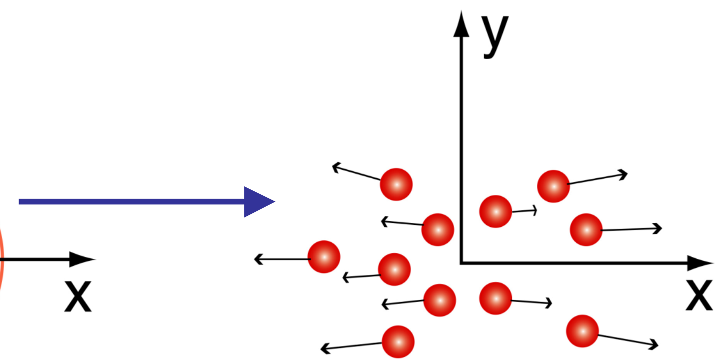


Origin: spatial anisotropy of the system when created and rescattering of evolving system

→probe of the early stage of the collision

Almond shape overlap region in coordinate space





$$\varepsilon = \frac{\langle y^2 - x^2 \rangle}{\langle y^2 + x^2 \rangle}$$

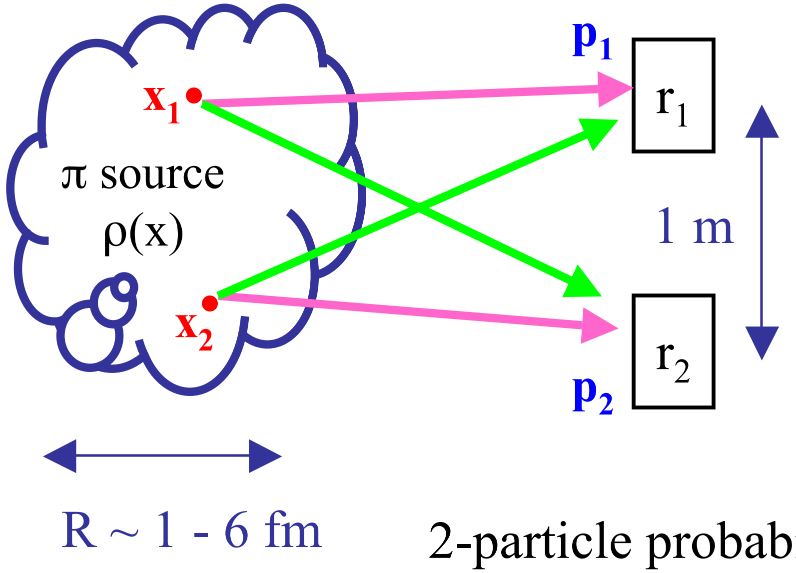
$$v_2 = \langle \cos 2\phi \rangle$$

$$\phi = \operatorname{atan} \frac{p_y}{p_x}$$

Spatial anisotropy

Momentum anisotropy

HBT* -- probing source geometry with boson pairs



$$\Psi = U(x_1,p_1)\exp\{i(r_1-x_1)p_1\}U(x_2,p_2)\exp\{i(r_2-x_2)p_2\}$$

$$+ U(x_1,p_2)\exp\{i(r_2-x_1)p_2\}U(x_2,p_1)\exp\{i(r_1-x_2)p_1\}$$

$$\Psi^*\Psi = (U_1^*U_1)(U_2^*U_2)[1+\cos(q\,\Delta x)]$$

2-particle probability

1-particle probability

$P(x_1,p_1)$

$q = p_1 - p_2$

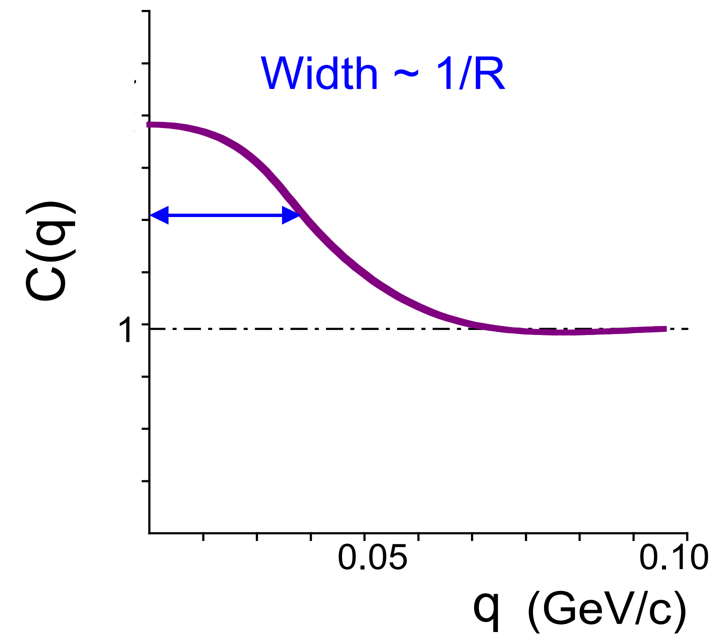
$\Delta x = x_1 - x_2$

Integrate $\Psi^*\Psi$ over $\rho(x)$

$$C(p_1,p_2) = \frac{P(p_1,p_2)}{P(p_1)P(p_2)} = 1 + |\tilde{\rho}(q)|^2$$

Measurable!

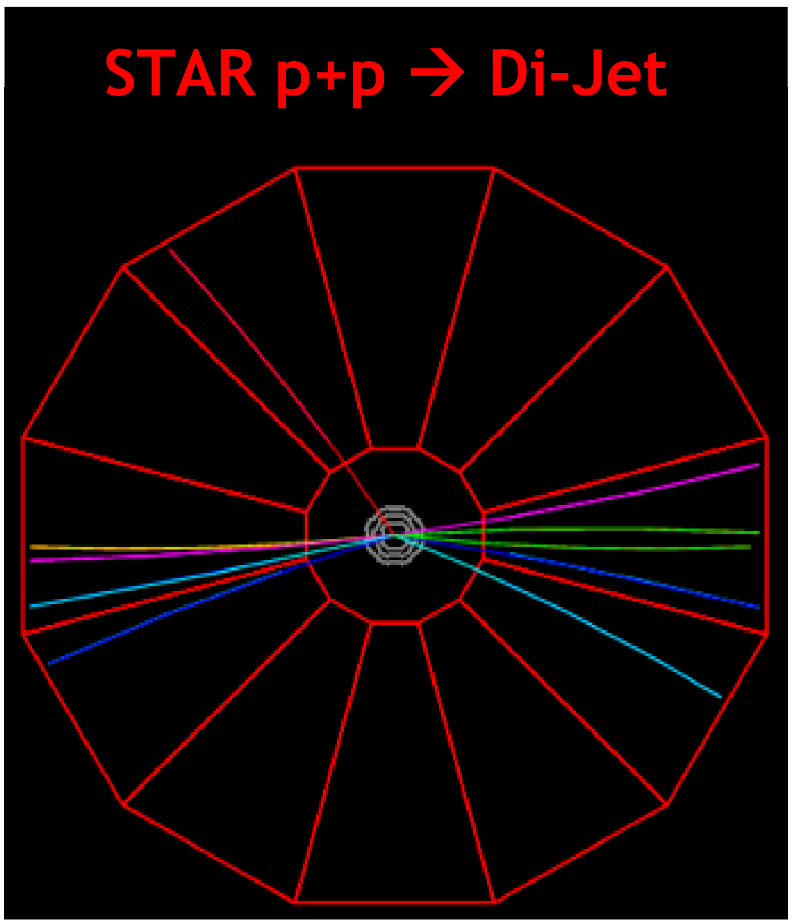
F.T. of pion source

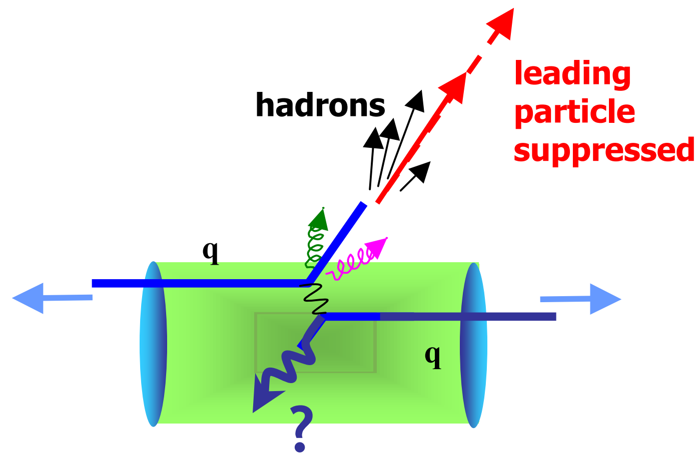


* Hanbury-Brown-Twiss interferometry

Jets in heavy-ion collisions

Goal: Use jets to probe properties of medium





Some Basic Observables:

-R_{AA} (nuclear modification factor)

leading jet particles suppressed?

-$\Delta\phi$ Azimuthal Correlations of di-jets

backward jet suppressed?

Motivation & Goal of the present work

Motivation:

* RHIC experiments have produced many interesting studies of hadronic observables from A+A collisions over the past six or so years.

* general categories of hadronic observables:
Spectra -- e.g. $dn/d\eta$, dn/dp_T, and dn/dm_T distributions
Elliptic flow (V_2) -- e.g. V_2 vs. η and V_2 vs. p_T distributions
Femtoscopy (HBT) -- e.g. $\pi\pi$ correlation studies vs. p_T and azimuthal angle
High p_T -- targeted as sensitive to jet effects, e.g. R_{AA} vs. p_T and $dn/d\Delta\phi$ distributions

* Models which describe the early stages of the collision in terms of partonic degrees of freedom, e.g. parton cascade or hydrodynamics, have been successful in describing the experimental systematics of some of these observables in some kinematic ranges, but no single model has thus far succeeded (to my knowledge) in making an adequate overall description of the systematics of all of these observables in a wide kinematical range

Goal of the present work:

To see how far one can get in describing the experimental systematics of all of the observables mentioned above in a wide kinematical range for $\sqrt{s_{NN}}$=200 GeV Au+Au collisions using a simple kinematic model with hadronic degrees of freedom (which a simple experimentalist can put together), **and make predictions for LHC Pb+Pb collisions**.

V_2 vs p_T --> pi, K, p: Model vs. PHENIX