Are the away-side jets disappearing at RHIC?

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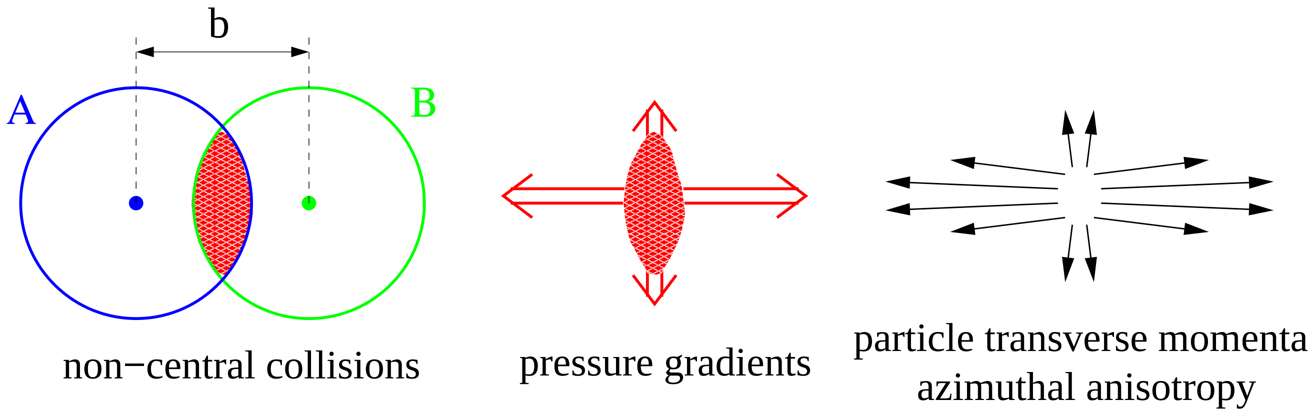
SUMMARY

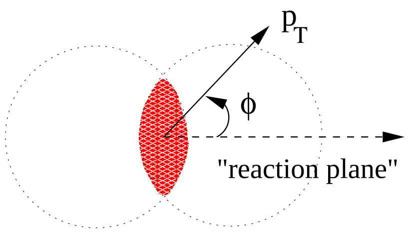


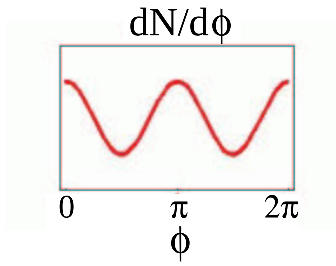
- INTRODUCTION
  - Flow and non-flow correlations (CERES, STAR)
  - Semihard processes (qualitative)
- MINIJET (PARTON) PRODUCTION in pQCD
  - Semihard parton rescatterings
  - Single- and double-minijet inclusive production
- NON-FLOW TWO-PARTICLE CORRELATIONS
  - "Broadening of π-peak" at CERES
  - "Disappearance of back-to-back jet" at STAR
  - Surface emission vs. semihard decorrelations
- ANSWER (?) AND CONCLUSIONS

Two-particle correlations

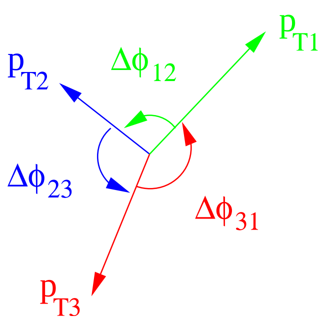
Elliptic flow and azimuthal distributions

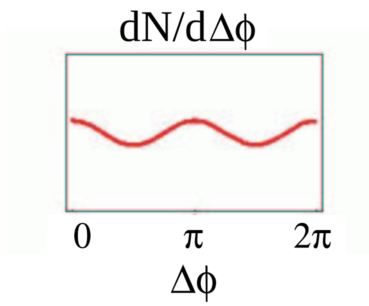
- Single particle: $$\frac{dN^{(1)}}{d\phi} = C\,[1 + 2\,v_2\cos(2\phi) + \ldots]$$





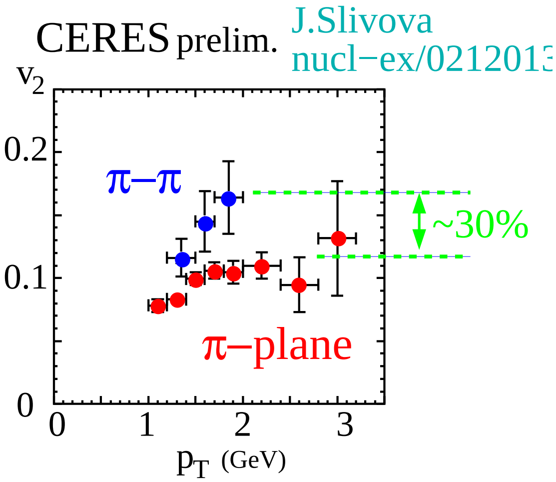
- Two-particle: $$\frac{dN^{(2)}}{d\Delta\phi} = D\,\left[1 + 2\,w_2^2\cos(2\Delta\phi) + \ldots\right]$$

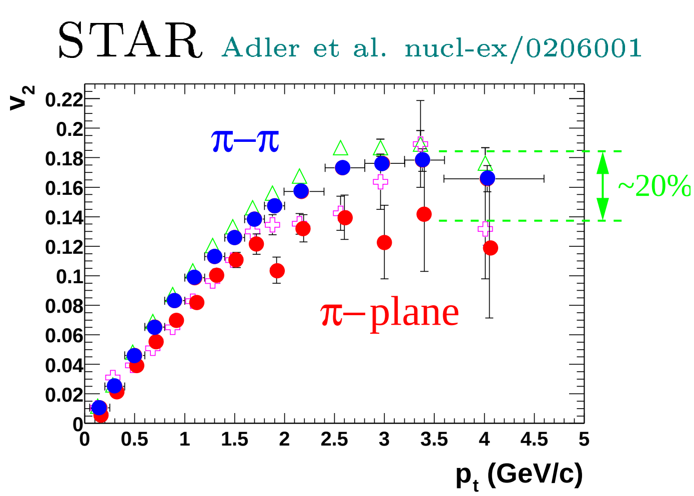




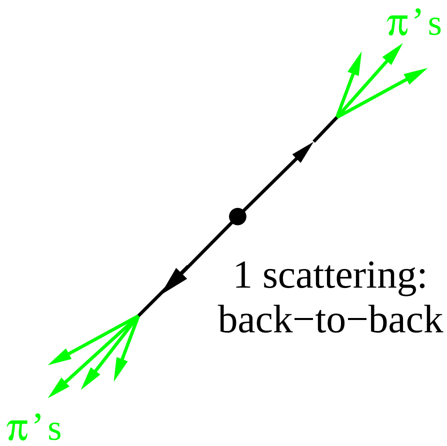
without other effects $\boxed{w_2 = v_2}$

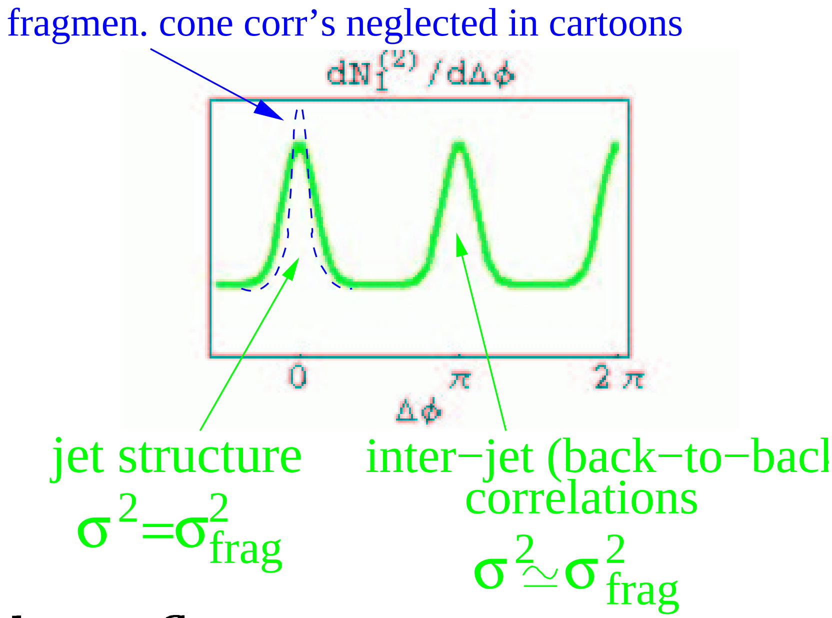
Non flow correlations



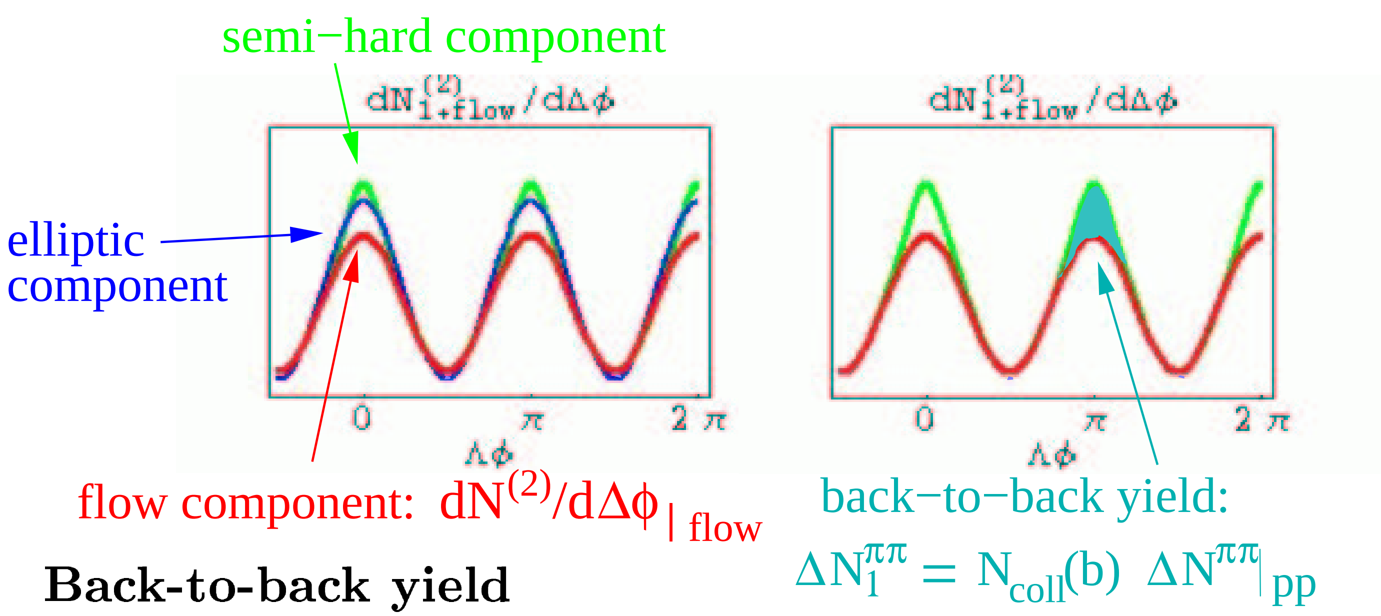


"Semihard" correlations: 1 scattering





Combining flow and non-flow:

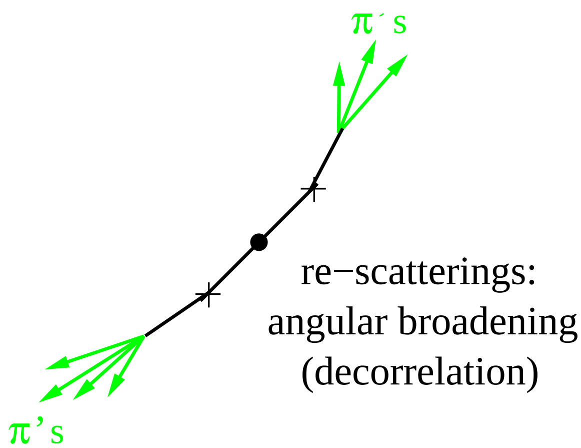


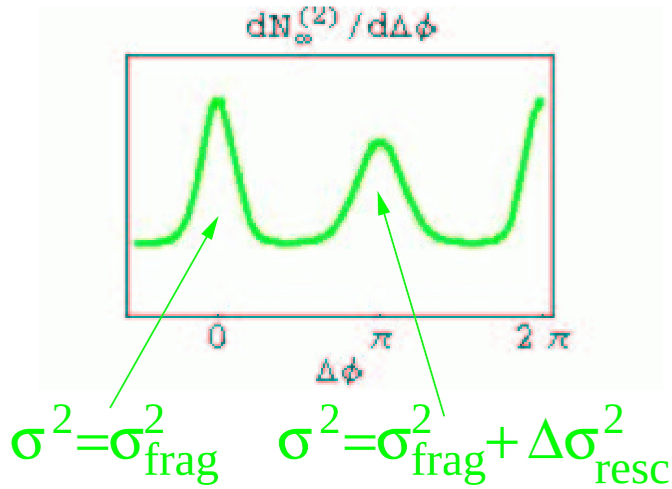
Back-to-back yield

The area between the two curves around $\Delta\phi = \pi$ gives the average number of π pairs correlated by semihard parton interactions:

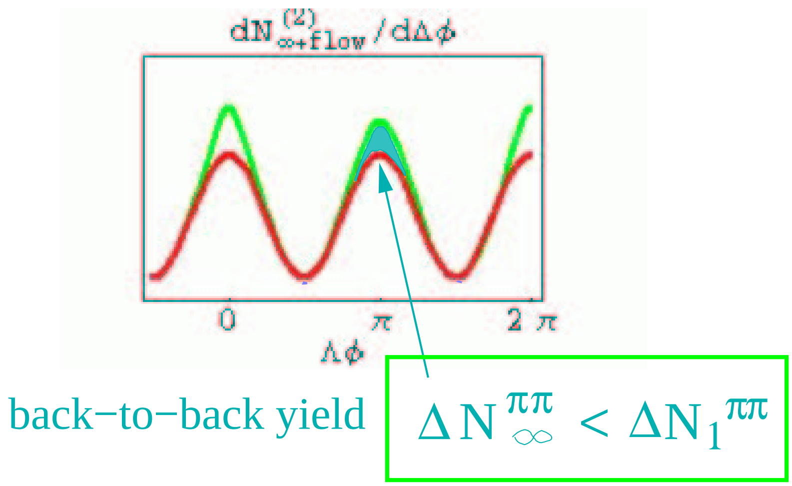
$$\Delta N^{\pi\pi}(b) = \int_{\Delta\phi=\frac{\pi}{2}}^{\Delta\phi=\frac{3}{2}\pi} d\Delta\phi \left[\frac{dN^{(2)}}{d\Delta\phi} - \left.\frac{dN^{(2)}}{d\Delta\phi}\right|_{flow} \right]$$

“Semihard” correlations: rescatterings





Combining flow and non-flow:

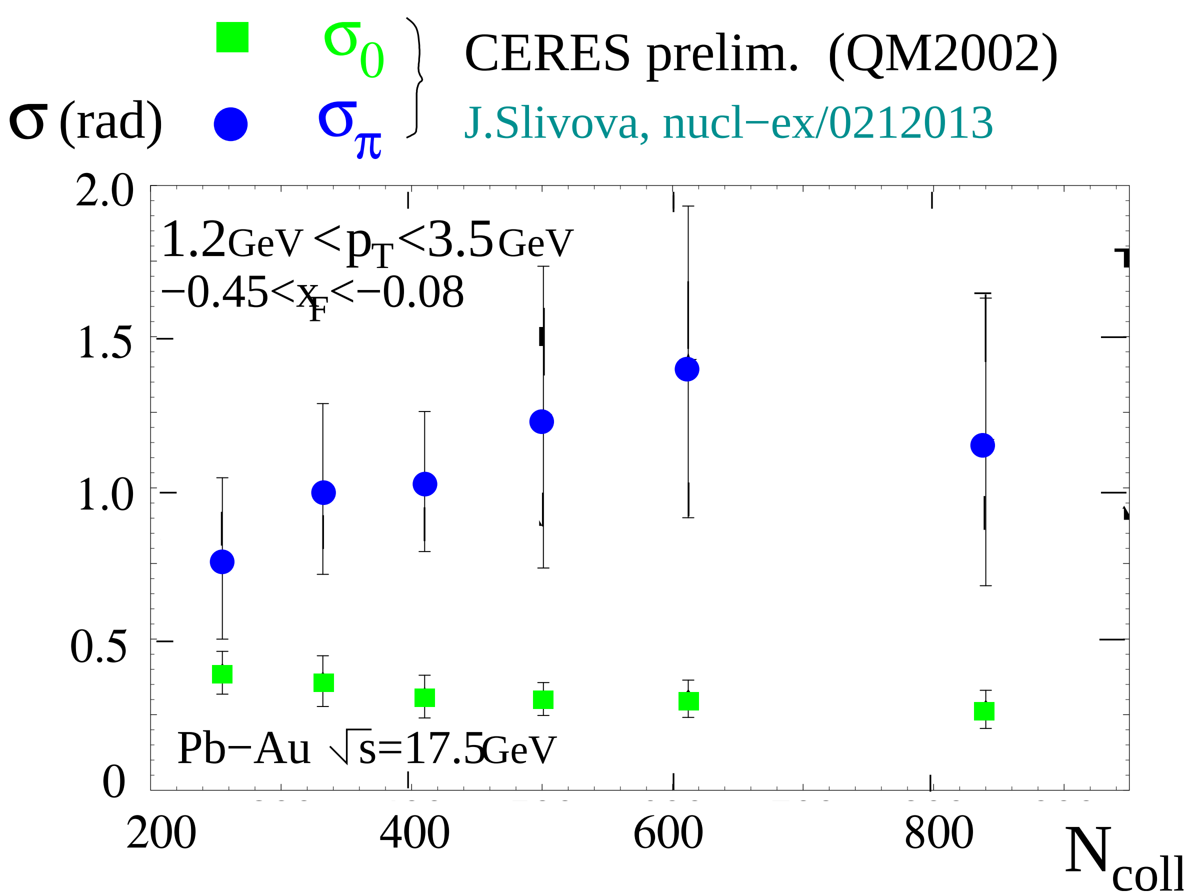


Parton rescatterings
broaden the peak at $\Delta\phi = \pi$
and reduce the back-to-back yield

Peak widths at $\Delta\phi = 0$ and $\Delta\phi = \pi$

Observable: The width of the peak at $\Delta\phi = 0$ and $\Delta\phi = \pi$ after subtraction of the flow component

Energy: $\sqrt{s} = 17.5$ GeV



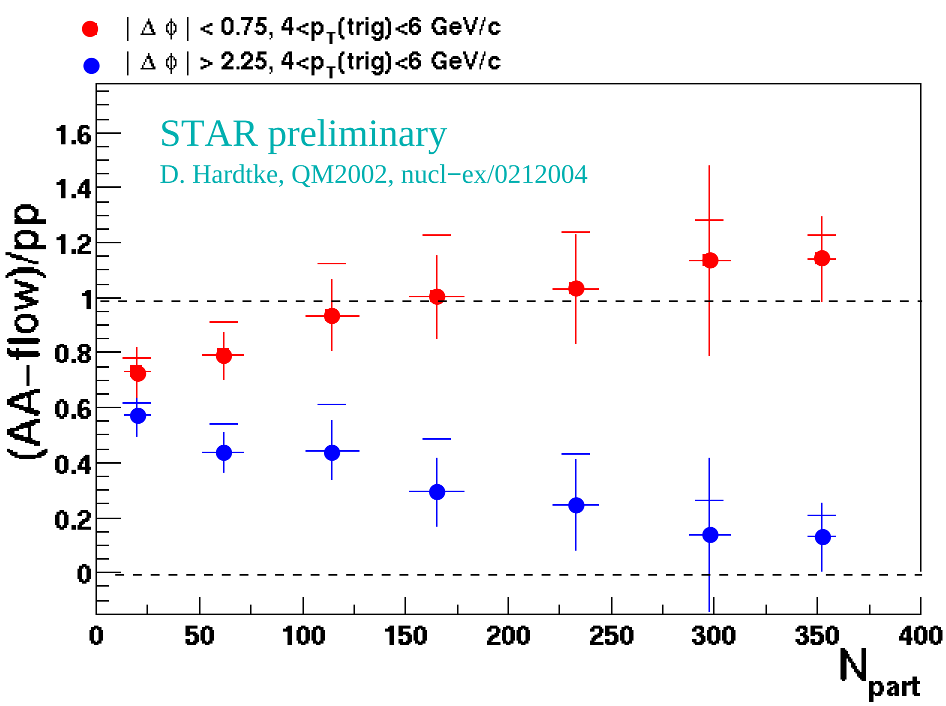
- Peak at $\Delta\phi = \pi$ broader than at $\Delta\phi = 0$
  Caveat: intra-jet correlations not subtracted)
- The broadening seems to increase with centrality
  $\Longrightarrow$ supports the rescattering picture

Suppression of b-t-b particles

Observable: Ratio of pion "back-to-back yield" at $\Delta\phi = \pi$ to the scaled pp data:

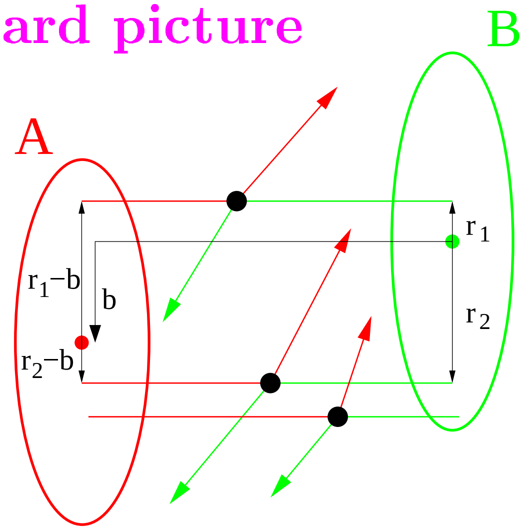
$$\frac{\Delta N^{\pi\pi}(b) \,/\, N^{trig}}{\Delta N^{\pi\pi}\big|_{pp} \,/\, N^{trig}_{pp}} \equiv \frac{AA - \text{flow}}{pp}$$

Energy: $\sqrt{s} = 200$ GeV



- Back-to-back particles are suppressed in peripheral collisions and "disappear" in central collisions.
- Same effect expected with semihard parton rescatterings

Semihard interactions - standard picture



- Nucleus–nucleus cross-section by eikonalizing *pp* cross-section
- It includes only *disconnected collisions* between partons:

$$\sigma_{mj} = \int d^2b \left(1 - e^{-\sigma_J T_{AB}(b)}\right)$$

$$N_{jet} = 2N_{\text{collisions}}$$

where: $\sigma_J = \int dx\, dx'\, G(x)\, \sigma_H(xx')\, G(x') \propto 1/p_0^n$

x, x' = parton fractional momenta

$G(x)$ = Parton Distribution Function (PDF)

$\sigma_H(xx')$ = pQCD parton-parton cross-section

p_0 = IR regulator

$T_{AB}(b) = \int \tau_A(b-r)\, \tau_B(r)\, d^2r$ = nuclear overlap

$\tau_A(r)$ = nuclear thickness function

- Minijet cross-section is unitarized: $\sigma_{mj} \xrightarrow[p_0 \to 0]{} \pi(R_A + R_B)^2$
- BUT energy conservation is violated: E_T diverges as $p_0 \to 0$

$$N_{jet}^{eik}(b) = 2\sigma_J T_{AB}(b) \propto 1/p_0^2$$

$$E_{T\,jet}^{\,eik}(b) \approx p_0 N_{jet}^{eik} \propto 1/p_0$$

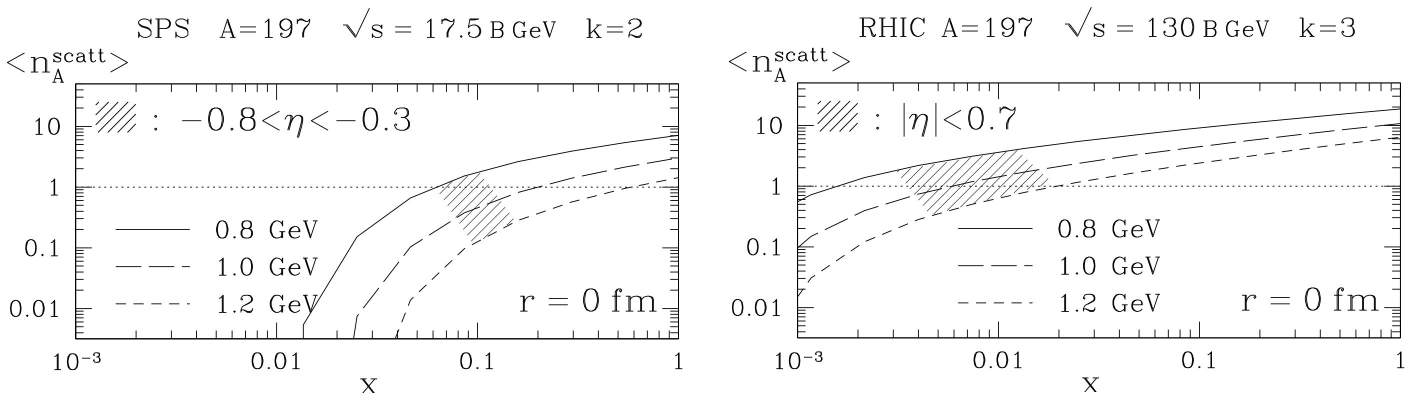
$\Longrightarrow$ some dynamics is missing

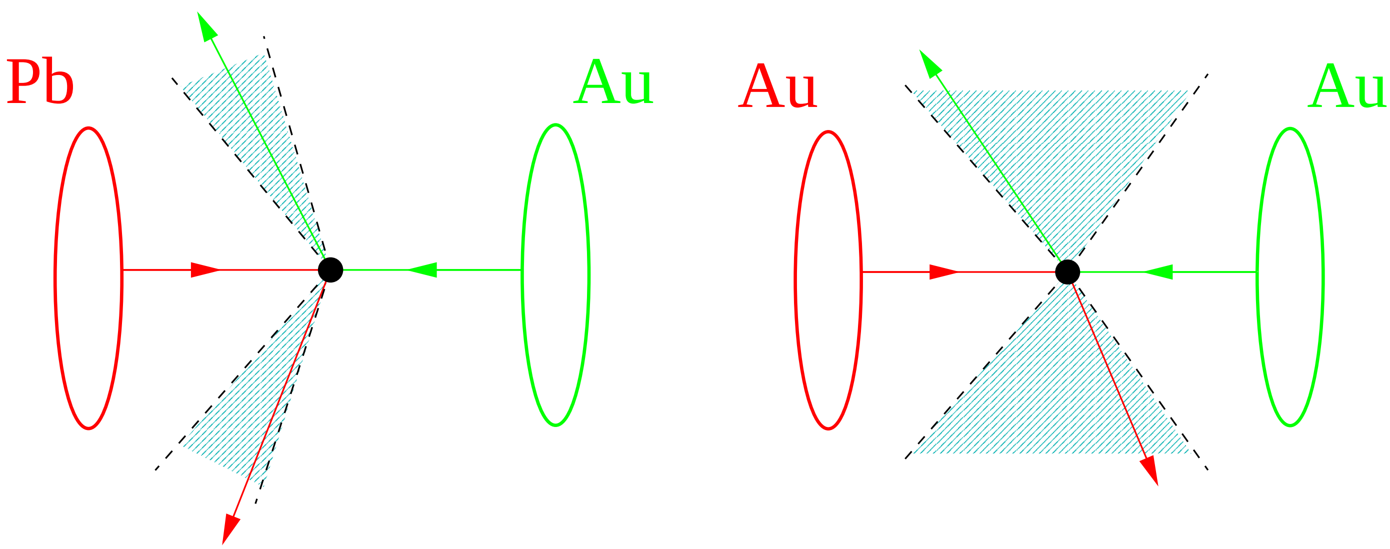
Average number of minijets

$$N^{eik}_{jet}(b) = 2\int d^2r\,dx\,\underbrace{G(x)\tau_A(b-r)}_{\text{proj. parton flux}}\underbrace{\int dx'\,\sigma_H(xx')\,G(x')\tau_B(r)}_{\text{average no. of scatterings}}$$

Number of scatterings of one incoming parton

$$\langle n_A^{scat}(x,b)\rangle = \int dx'\,\sigma_H(xx')\,G(x')\,\tau_B(b)$$





WE NEED TO INCLUDE THE RESCATTERINGS

Semihard interactions: rescatterings

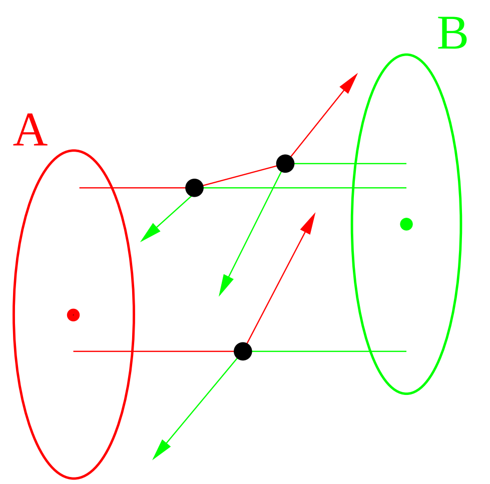
Calucci, Treleani, PRD41(90)3367, PRD44(91)2746
Braun et al., hep-ph/0207303

Def. minijet = parton with at at least 1 semi-hard scattering

Def. semi-hard scattering = $p_{exch} > p_0$

Assumptions:

- QCD generalized factorization
- independent scatterings



$N_{jet} \leq 2 N_{collisions}$

Multiparton distributions:

$$D_A^n = \frac{1}{n!} \underbrace{G\,\tau_A \ldots G\,\tau_A}_{n \text{ times}} e^{-\int G\,\tau_A}$$

Probability of at least 1 semi-hard interaction

$$P_{nm} = 1 - \prod_{i=1}^{n} \prod_{j=1}^{m} (1 - \hat\sigma_{ij})$$

where $\hat\sigma_{ij}(x_i x'_j, r_i - r'_j) = \sigma_H(x_i x'_j) \delta^{(2)}(r_i - r'_j)$ is the probability of a semi-hard parton-parton scattering

Average number of minijets:

$$N_{jet} = \sum_{n,m=1}^{\infty} n \int D_A^n \, P_{nm} \, D_B^m \; + \; \{n \leftrightarrow m\}$$

Average number of minijets

$$\frac{dN^A_{jet}}{dx}(b) = \int d^2r \overbrace{G(x)\tau_A(b-r)}^{\text{density of projectiles}} \underbrace{\left(1 - e^{-\overbrace{\int dx'\sigma_H(xx')G(x')\tau_B(r)}^{\langle n_B^{\text{scat}}\rangle}}\right)}_{\text{prob. of at least 1 scatt.}}$$

Expansion in the no. of scatterings

$$\frac{dN^A_{jet}}{dx}(b) = \int d^2r\, G(x)\tau_A(b-r)$$

$$\times \sum_{n=1}^{\infty} \underbrace{\frac{1}{n!}\left[\int dx'\sigma_H(xx')G(x')\tau_B(r)\right]^n \overbrace{e^{-\int dx'\sigma_H(xx')G(x')\tau_B(r)}}^{\substack{\text{absorption factor}\\ \text{(prob. conservation)}}}}_{\text{PROBABILITY of } n \text{ scatterings}}$$

Two remarkable limits

$$\frac{dN_{jet}}{dx}(b) \longrightarrow \begin{cases} 2\int G\,\tau_A\,\sigma_H\,G\,\tau_B = \dfrac{dN^{eik}_{jet}}{dx}(b) & \dfrac{p_0}{\sqrt{s}}\to 1 \\ \int G\,\tau_A + \int G\,\tau_B \overset{def.}{=} \dfrac{dN_{lim}}{dx}(b) & \dfrac{p_0}{\sqrt{s}}\to 0 \end{cases}$$

"black-disc limit"

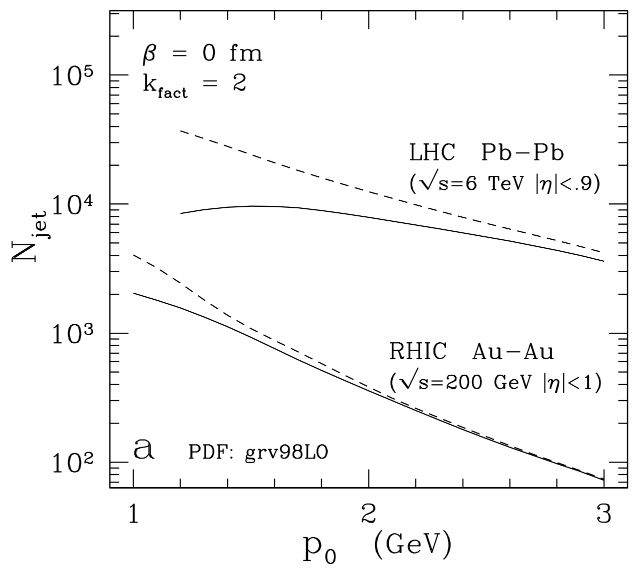
Remarks

- finite limit at low cutoff:
  "Elastic semihard collisions cannot free more partons than those inside the incoming nucleus"
- at high cutoff disconnected collisions dominate

Minijet multiplicity A.A., D.Treleani, Phys.Rev.D 63(2001)116002

$$N_{jet}(b) = \int d^2r dx\, G(x)\tau_A(b-r) \left(1 - e^{-\int dx'\sigma_H(xx')G(x')\tau_B(r)}\right) + A \leftrightarrow B$$

NOTE: in all computations we set the scale $Q = p_0$.



Rescatterings vs. single-scattering:

- Less sensitive on p_0
- Minijet multiplicity is suppressed

Initial conditions: with $p_0 = 1\text{GeV}$ at RHIC
and $p_0 = 2\text{GeV}$ at LHC

$$\left.\frac{dN}{dy}\right|_{y=0} \approx 1000 \text{ (RHIC)},\ 5000 \text{ (LHC)}$$

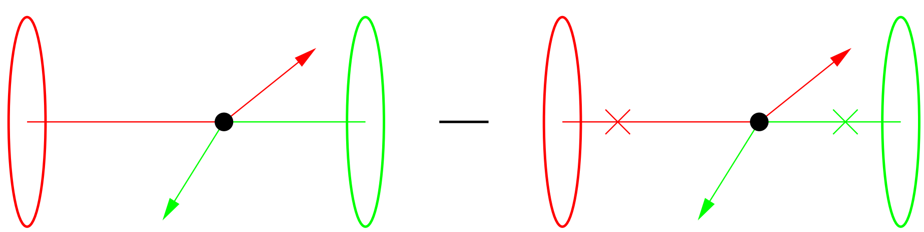
Back-to-back minijet yield

In our multiple semihard scattering model:

$$\underbrace{\Delta N^{JJ}_\infty(b)}_{\text{b.t.b jet yield}} = \overbrace{2\int d^2r\, dx_1\, dx_2\; G(x_1)\,\tau_A(b-r)\,\sigma_H(x_1x_2)\,G(x_2)\,\tau_B(r)}^{\equiv \Delta N_1^{JJ}(b)} \underbrace{- 2\int d^2r\, dx_1\, dx_2\; \frac{dN^A_{jet}}{dx_1}(b,r)\,\sigma_H(x_1x_2)\,\frac{dN^B_{jet}}{dx_2}(r)}_{\text{decorrelation term}}$$

where $\frac{dN^A_{jet}}{dx}(b,r) = G(x)\,\tau_A(b-r)\big[1 - \exp(-\int dx' G(x')\,\tau_B(r)\sigma_H(xx'))\big]$

Diagrammatically:



Two remarkable limits

$$\Delta N^{JJ}(b) \longrightarrow \begin{cases} \Delta N_1^{JJ}(b) = T_{AB}(b)\Delta^{\pi\pi}\big|_{pp} & \frac{p_0}{\sqrt{s}} \longrightarrow 1 \\ 0 & \frac{p_0}{\sqrt{s}} \longrightarrow 0 \end{cases}$$

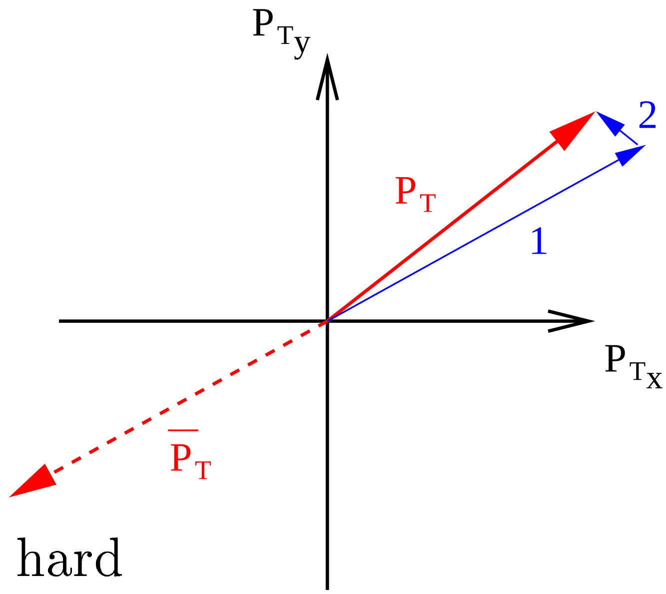
Double differential distribution also computable:

$$\frac{dN^{JJ}_\infty(b)}{dp_1\, dp_2\, d\Delta\phi}$$

Picture of the interaction

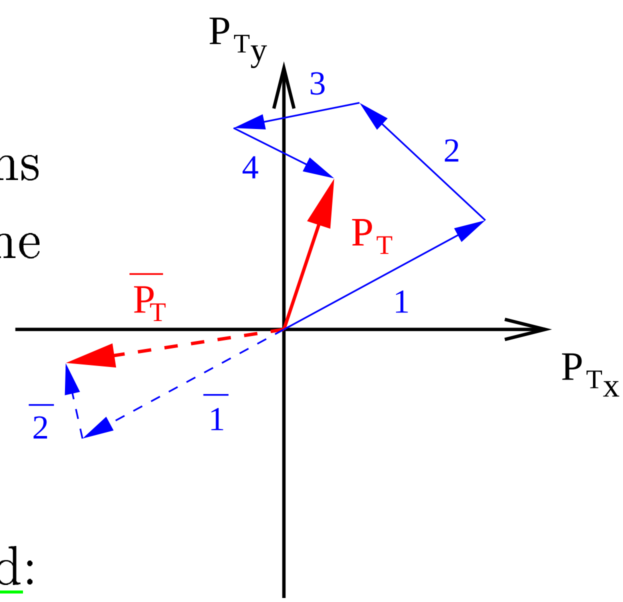
(fixed $\sqrt{s}$)

Large b (high $\mathbf{p}_T$)



- very few rescatterings: disconnected collisions dominate
- tr. spectrum $\propto 1/p_T^4$
- strong correlations due to hard back-to-back scatterings

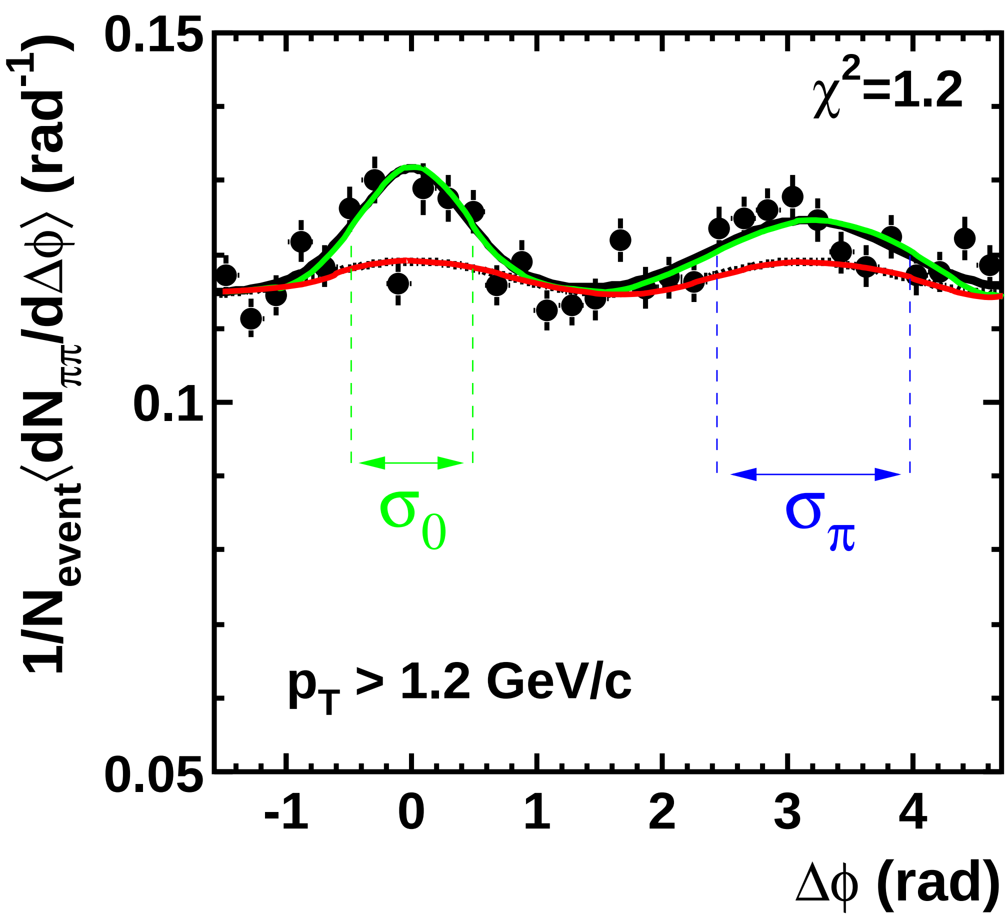
Small b (low $\mathbf{p}_T$)



- a lot of rescatterings: partons do a random-like walk in the p_T plane
- Cronin effect (deformation of the p_T spectrum)
- more and more uncorrelated: they loose memory of their targets

Broadening of peak at $\Delta\phi = \pi$

- **CERES analysis** J.Slivova, QM2002



(red line) $= A\left[1 + 2v_2^2\cos(2\Delta\phi)\right]$

(green line) $=$ (red line) $+ \, B\, e^{-\Delta\phi^2/(2\sigma_0^2)} + C\, e^{-(\Delta\phi-\pi)^2/(2\sigma_\pi^2)}$

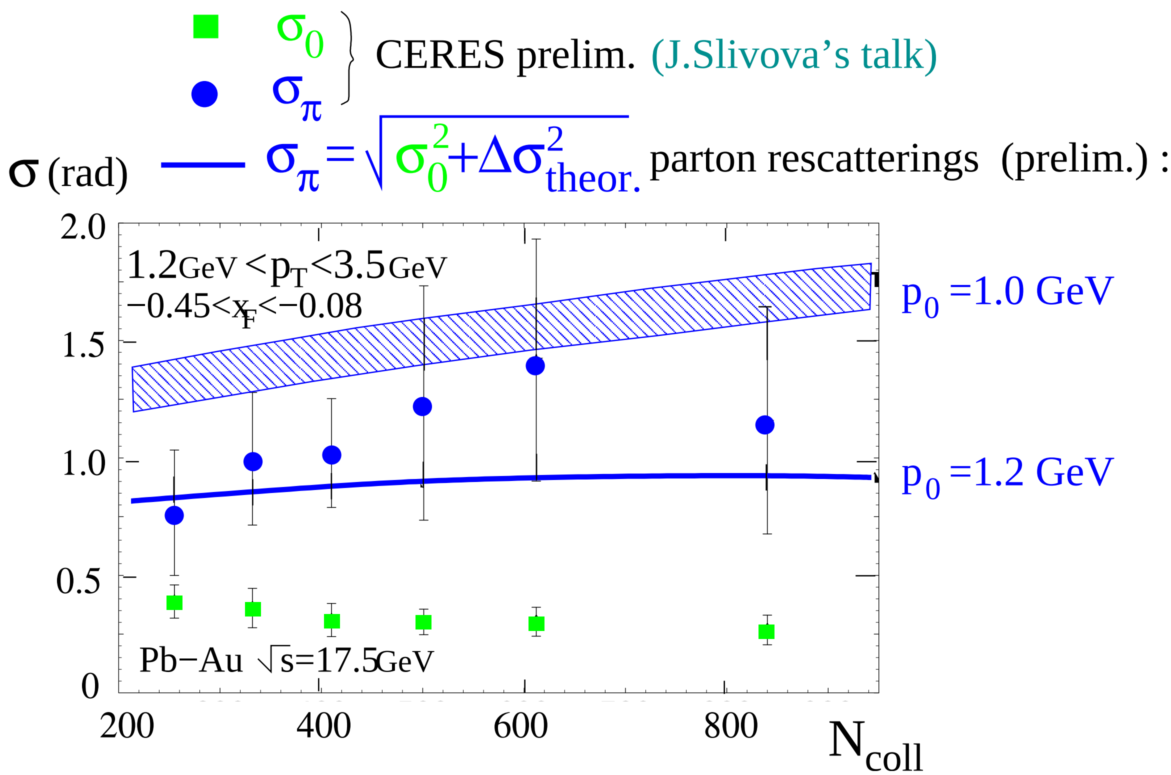
- $v_2 = (9.0 \pm 0.2)\%$ rom reaction plane analysis
- $A, B, C, \sigma_0, \sigma_\pi$ fitted to data

- **Effect of semihard rescatterings** AA, Pirner - in progress

$$\Delta\sigma^2_{\rm theor.} = \frac{\langle \sin^2(\Delta\phi - \pi)\rangle}{\langle 1\rangle} \underset{\substack{\Delta\phi-\pi \\ \text{small}}}{\approx} \frac{\langle (\Delta\phi-\pi)^2\rangle}{\langle 1\rangle}$$

where $\langle \mathcal{F}(\Delta\phi)\rangle = \int_{\rm exp.cuts} dp_1\, dp_2\, d\Delta\phi\ \mathcal{F}(\Delta\phi) \frac{dN^{JJ}_{\infty}}{dp_1\, dp_2\, d\Delta\phi} \otimes D_1^{\pi\pm} \otimes D_2^{\pi\pm}$

NOTE: $\Delta\phi - \pi \sim 1 \Longrightarrow$ corrections applied to compare with data. This introduces some theoretical errors, see plot.

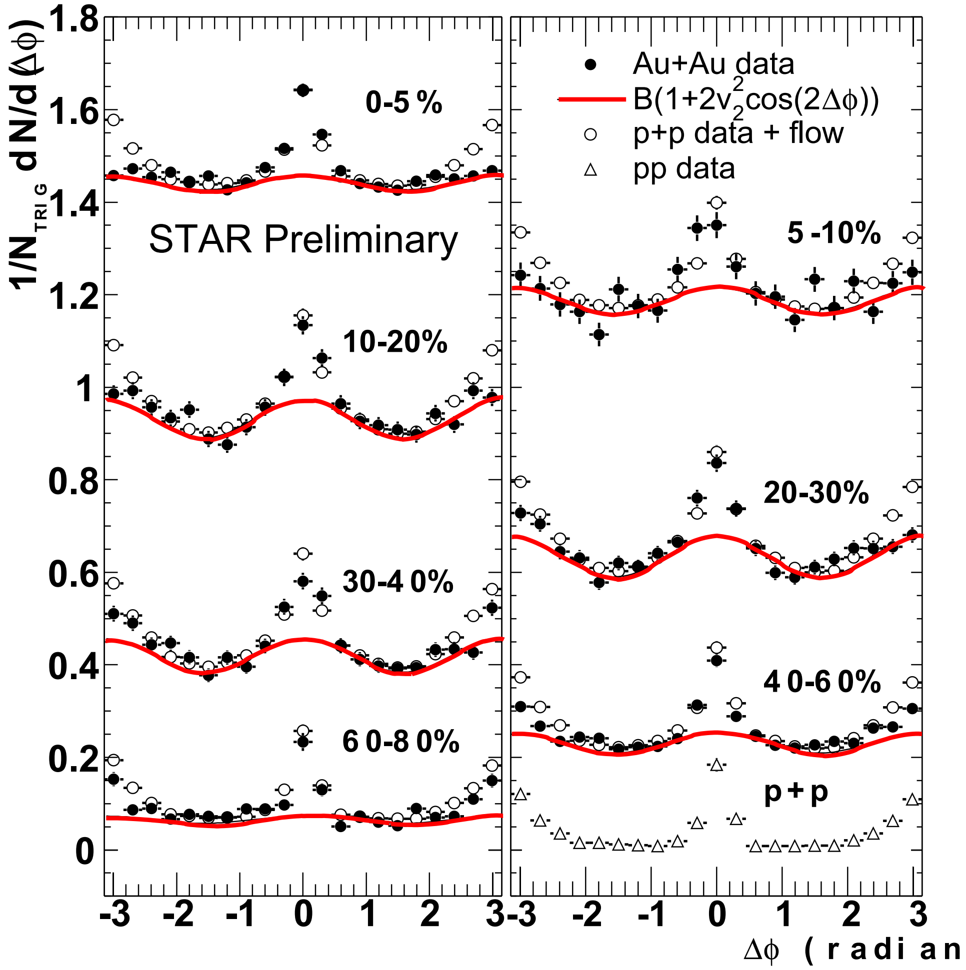


- Peak at $\Delta\phi = \pi$ broader than at $\Delta\phi = 0$ (**Remember:** intrajet dynamic correlations not considered)

- The broadening seem to increase with centrality $\rightsquigarrow$ described by semihard rescatterings

Back-to-back pion yield at STAR

Star analysis: D.Hardtke, nucl-ex/0212004



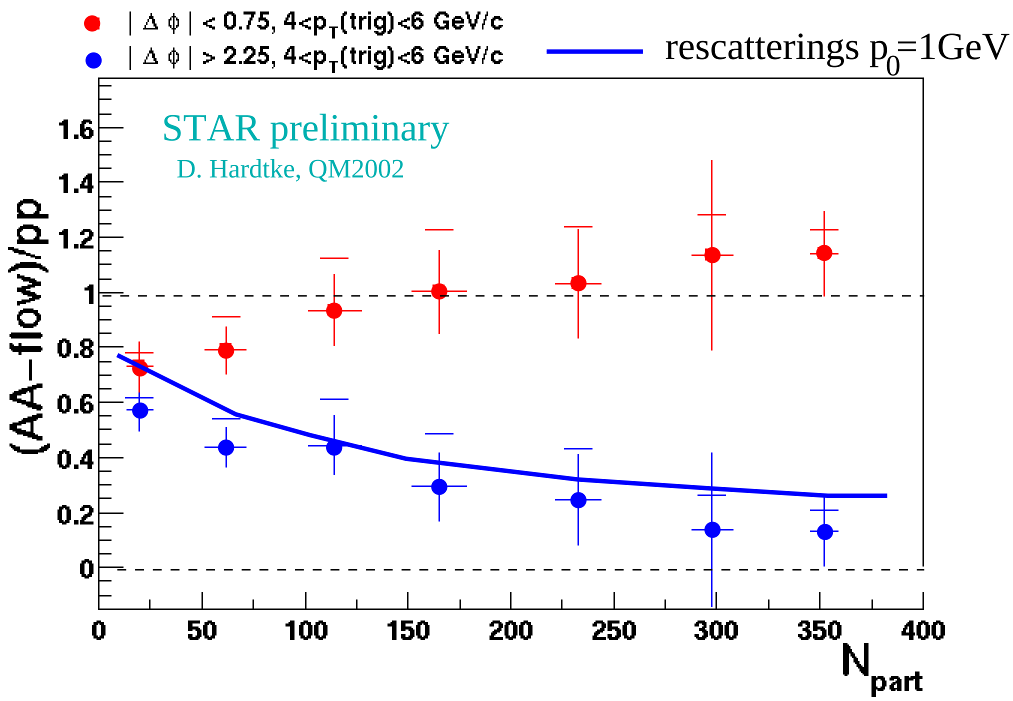
- v_2 from reaction plane analysis
- back-to-back yield in AA: $\Delta N^{\pi\pi}|_{AA} = \mathrm{data_{AA}} - \mathrm{flow}$
- direct comparison to *pp* data for b-t-b $\Delta N^{\pi\pi}|_{pp}$ (same energy, same detector)

⇝ No problems with fragmentation cone correlations or detector-induced correlations

⇝ Systematic errors cancel in the ratio AA/pp

Ratio of yield at π to scaled pp data:

$$R(b) = \frac{\Delta N_\infty^{JJ}(b)}{\Delta N_1^{JJ}(b)} \quad \textbf{vs.} \quad R_{\rm exp}(b) = \frac{\Delta N^{\pi\pi}(b) \,/\, N^{\rm trig}}{\Delta N^{\pi\pi}|_{pp} \,/\, N_{pp}^{\rm trig}}$$



NOTE: • hadronization and p_T cuts not included in this computation (tempus fugit...)

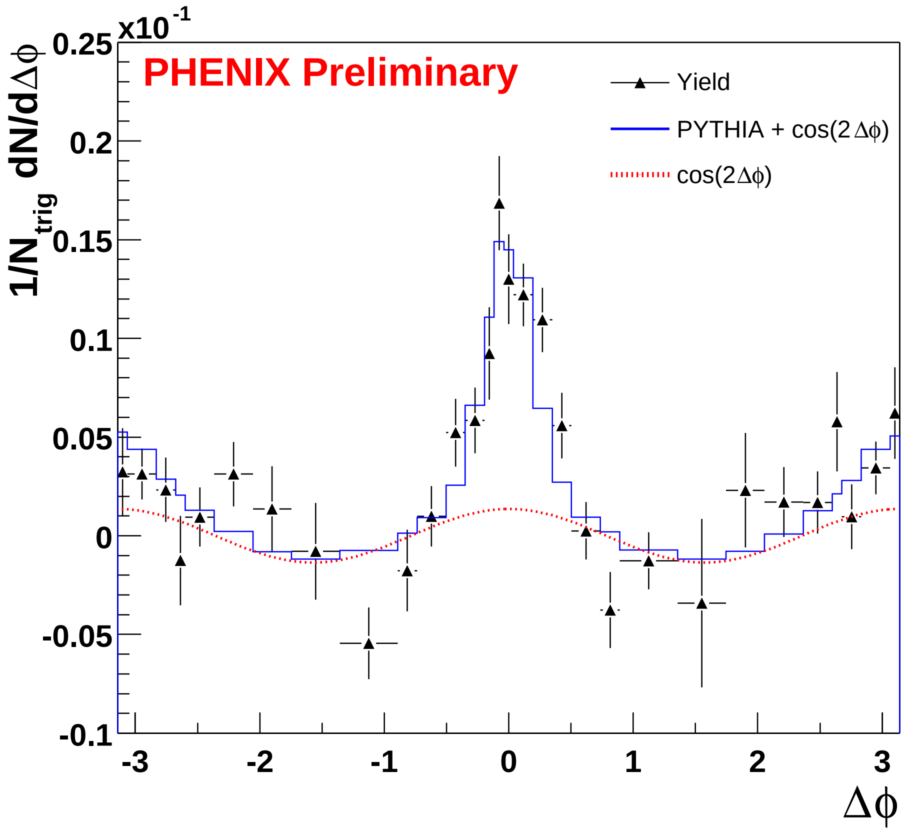
• hadronization effects partly cancel in the ratio

$\Longrightarrow$ Rescatterings have good chances to account for the observed effect

COMING SOON: p_T-cuts and hadronization

Caveat: If you don't ask you will not obtain...

- **PHENIX analysis** M.Chiu, QM2002, nucl-ex/0211008



$$\text{——} = A\left[1 + 2 v_2^2 \cos(2\Delta\phi)\right]$$

$$\text{——} = \text{——} + a_{\text{pythia}} \frac{1}{N_{\text{pythia}}} \frac{dN^{\text{ch}}_{\text{pythia}}}{d\Delta\phi}$$

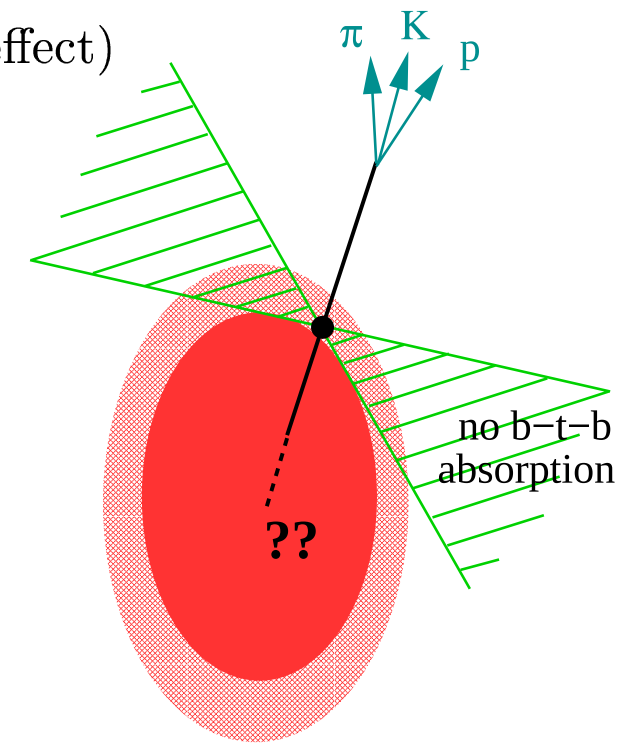
- Both v_2 and jet peaks fitted at the same time
- Fit doesn't allow for a suppression of away-side jets:

  $\Longrightarrow$ they see fully the away-side jets!

  but underestimate v_2.

Surface emission vs. semihard decorrelation

- **Surface emission:** (final state effect)



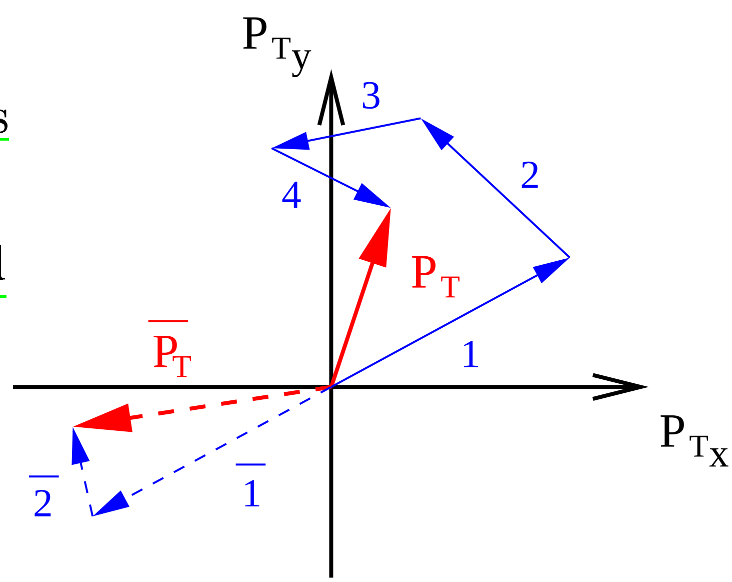
The away-side jet is absorbed by the medium ⇒ disappears

BUT

absorption-free azimuthal region
⇒ can't explain total suppression
(unless infinitely thin surface)

- **Semihard decorrelations:** (initial state effect)

The away-side jet survives
but uncorrelated
⇒ part of the background



Both effects may be at work at the same time
⇝ look at dA collisions !!

CONCLUSIONS

- **Semihard decorrelations** are **non negligibe**
  - account for broadening of π-peak at CERES
  - good chances for suppression of b-t-b yield at STAR
  - explain qualitatively why $\mathrm{STAR}_{\mathrm{non-flow}} < \mathrm{CERES}_{\mathrm{non-flow}}$

- **Are the away-side jets disappearing?**

Maybe not!

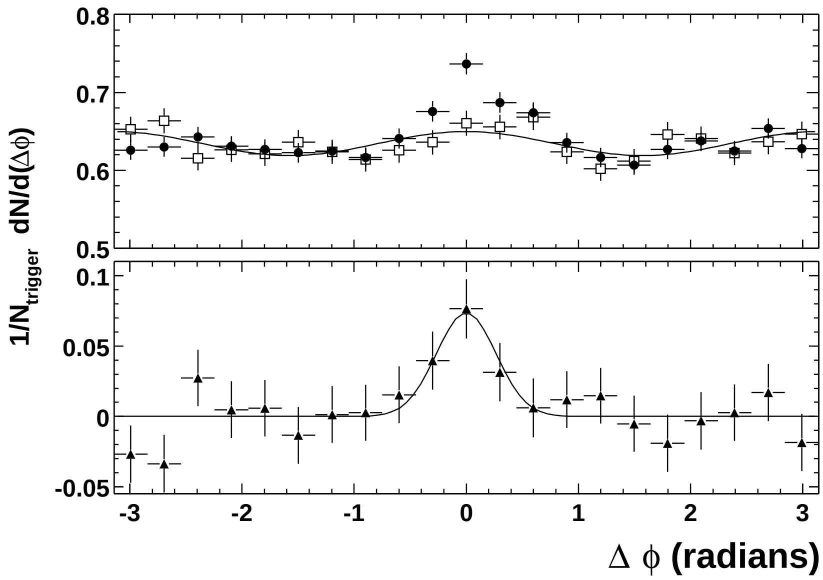
$\Longrightarrow$ look at dA collisions!
(no "QGP" is formed $\Rightarrow$ no absorption)

$\Longrightarrow$ η- (and p_T-) systematics
($\langle N_{\mathrm{scatt}} \rangle$ increases with η, decreases with p_T)

EXTRA SLIDES

Evidence for minijets at STAR

Adler et al., nucle-ex/0206006



● : $|\eta_2 - \eta_1| < 0.5$

○ : $|\eta_2 - \eta_1| > 0.5$

△ = ● − ○

Gaussian fit:

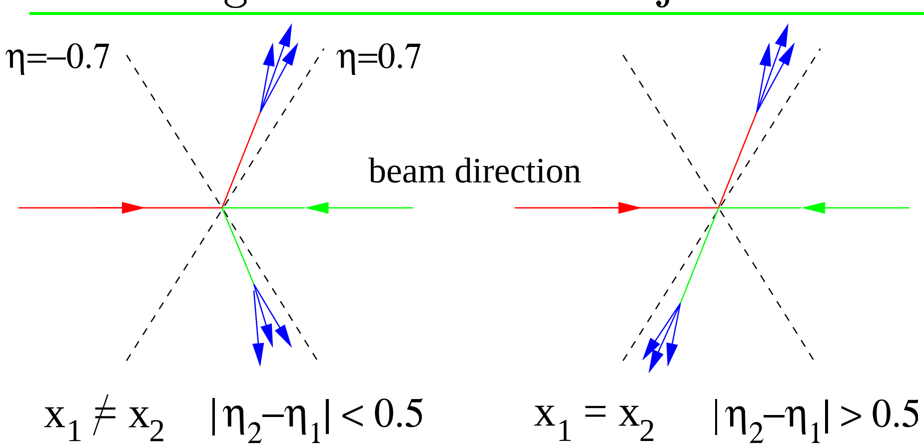
$\sigma = 0.27 \pm 0.09$ rad

trigger particle	:	$4 < p_T < 6$	} $\lvert\eta\rvert < 0.7$
2nd particle	:	$2 < p_T < 6$	

Remarks:

– In ●, hadrons from the same minijet are included (but also part of back-to-back minijet)

– In ○, hadrons from the same minijet are excluded (but the remaining back-to-back minijet are included)

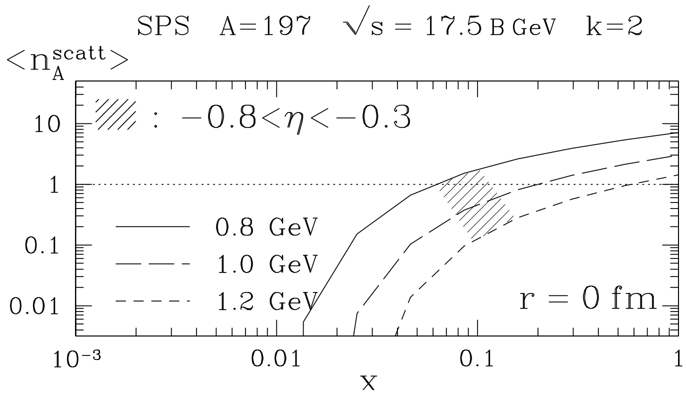


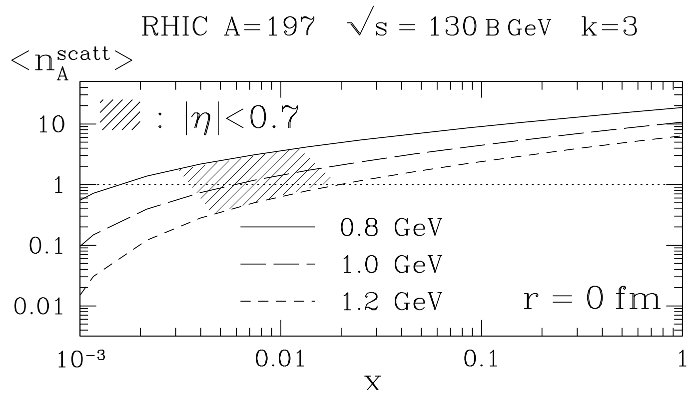
⇒ Back-to-back minijets almost cancel out in this observable

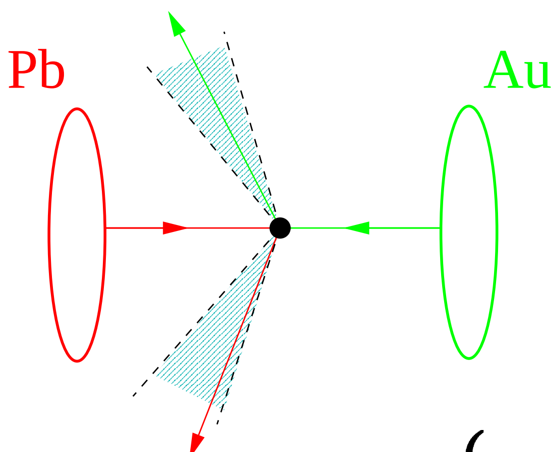
From SPS to RHIC

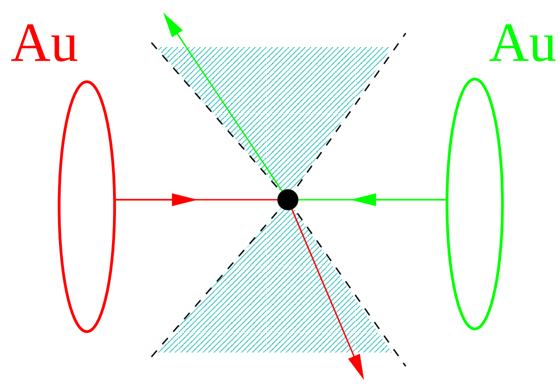
- Effects of rescatterings governed by the average no. of scatterings of one incoming parton:

$$\langle n_A^{scat}(x,b)\rangle = \int dx'\, \sigma_H(xx')\, G(x')\, \tau_B(b)$$









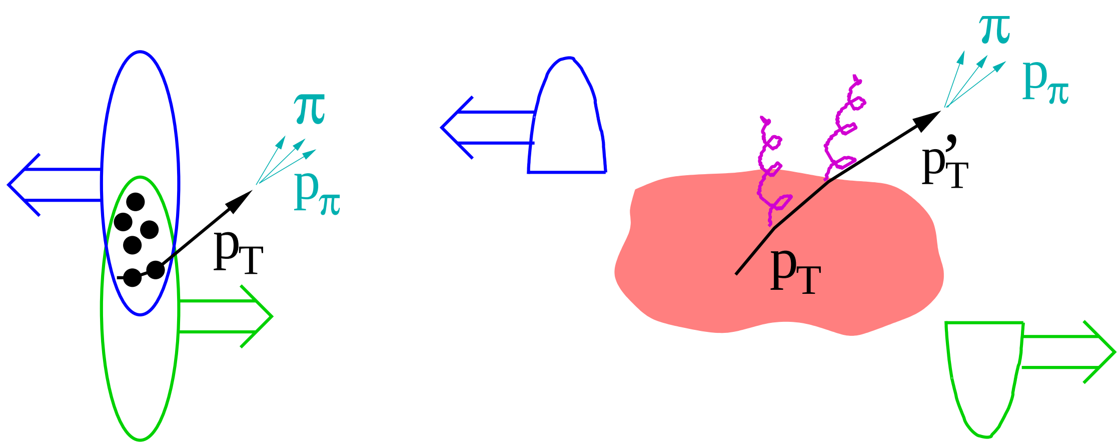
$\langle n_A^{scat}(x,b)\rangle$ { increases with $\sqrt{s}$; decreases as $p_T^{\rm jet}$ increases }

- At RHIC, in absence of other effects (e.g., jet quenching)

  $\Longrightarrow$ Semihard correlations at larger p_T than at SPS

  $\Longrightarrow$ Larger π-peak broadening than at SPS

Rescatterings vs. quenching



"initial state": rescatterings

"final state": jet quenching

In presence of quenching, and fixing the pion transverse momentum p_T^π, the jet must exit the initial state rescattering with a higher transverse momentum p_T:

$$p_T|_{\text{quench.}} > p_T|_{\text{no quench.}}$$

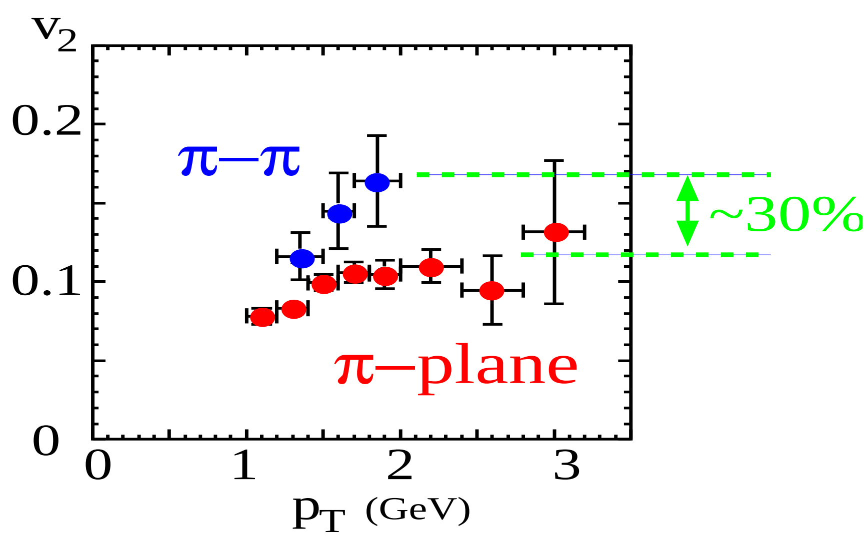
$\Longrightarrow$ Less rescatterings than without quenching
$\Longrightarrow$ Some correlations at low p_T may survive
$\Longrightarrow$ Extra broadening due to gluon radiation

Jet-quenching delays the disappearance of correlations at high-$\sqrt{s}$

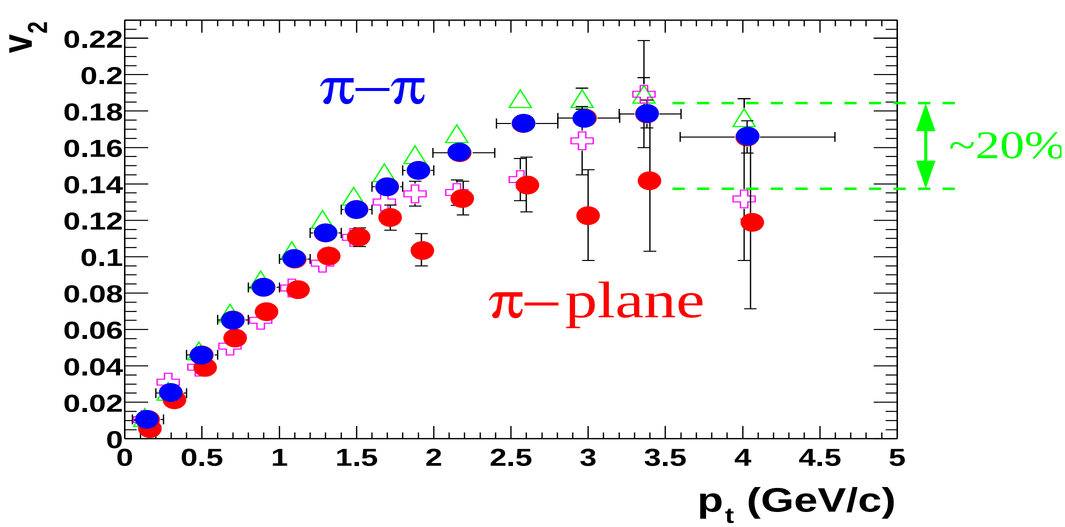
The interplay of rescatterings and jet-quenching must be carefully studied.

Elliptic flow vs. energy

CERES preliminary data J.Slivova's talk



STAR data (min. bias) Adler et al., nucle-ex/0206001



- Non-flow correlations appear at larger p_T at RHIC

  $\Longrightarrow$ as expected from semi-hard rescatterings

Non-flow correlations vs. centrality

STAR data Adler et al., nucle-ex/0206001