Angular Correlations of High-p_T Charged Hadrons at the CERN SPS

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Overview

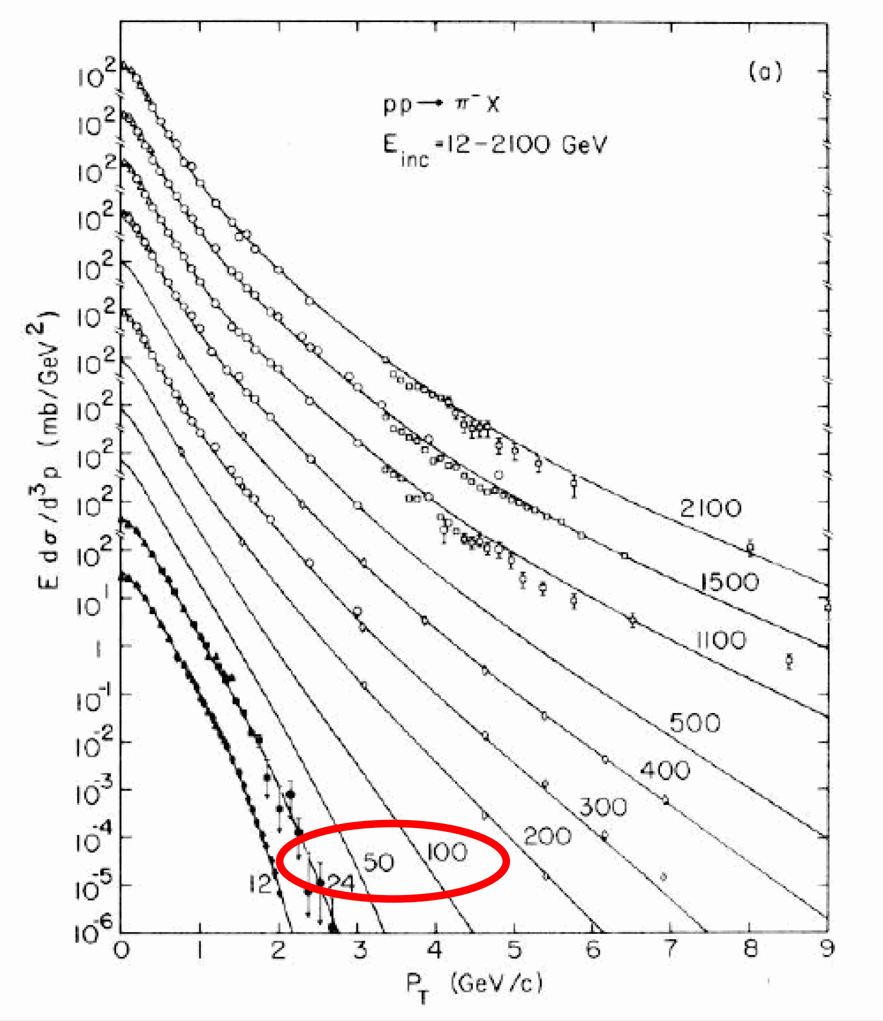
- Jets as a QGP probe; angular correlations
- NA49
- Two-particle azimuthal correlations
  - Pb+Pb at 158*A* GeV
  - other systems (p+p, Si+Si at 158*A* GeV)
  - lower energies (Pb+Pb at 20*A*, 30*A*, 40*A*, 30*A* GeV)
  - comparison with UrQMD
- *Two-particle* $(\Delta\eta,\Delta\phi)$ *correlations*
- *Three-particle azimuthal correlations*
- Summary

Jets as a QGP Probe

- Jets
  - originate in hard scattering
  - interact with hot, dense medium
- Angular correlations
  - observation of (di-)jets without reconstruction
  - two-particle $\Delta\phi$: detect away-side jet
  - three-particle $\Delta\phi$: shape of away-side jet
  - two-particle $(\Delta\eta,\Delta\phi)$: examine the ridge
- Significant results from RHIC

High-p_T Physics and SPS

Why is it difficult at $\sqrt{s_{NN}} \approx$ 20 GeV ?

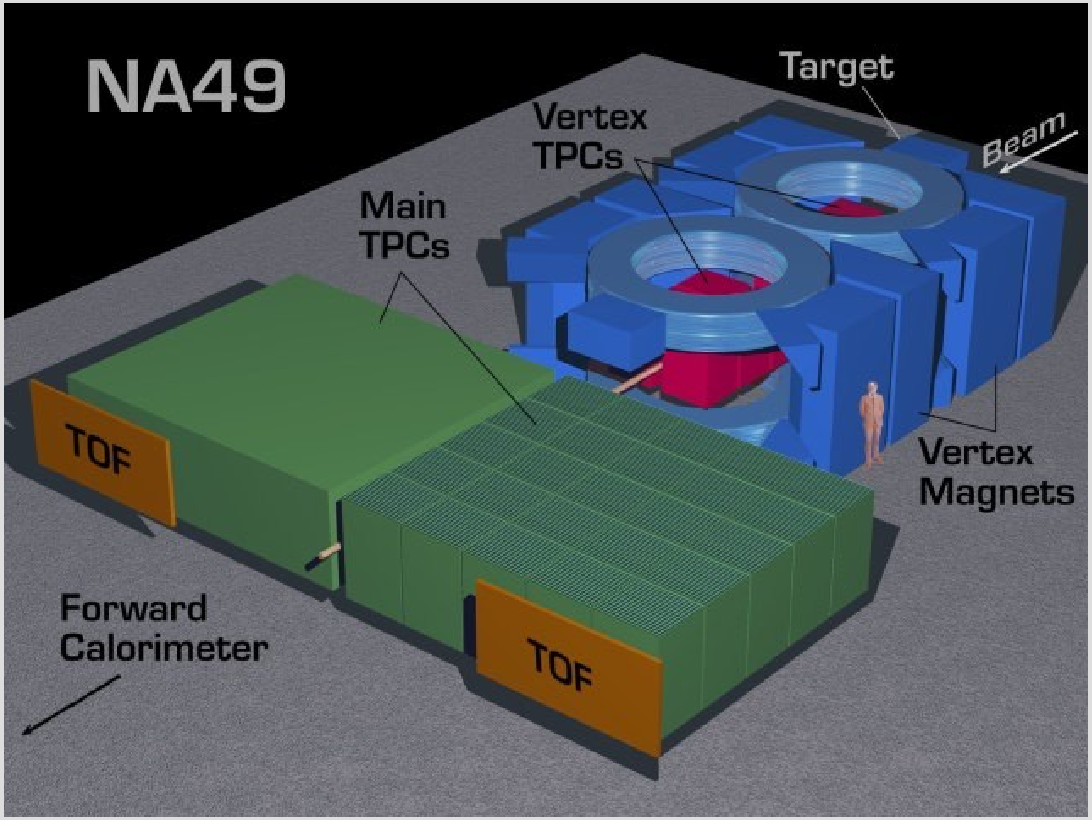


- Small hadron yields at high p_T due to steeply-falling spectra
- Transition from soft to hard physics unknown
- Effect of Cronin enhancement unknown, expected to be strong
- Theory: large uncertainties in perturbative-QCD calculations

E. W. Beier et al., Phys.Rev.D18:2235,1978

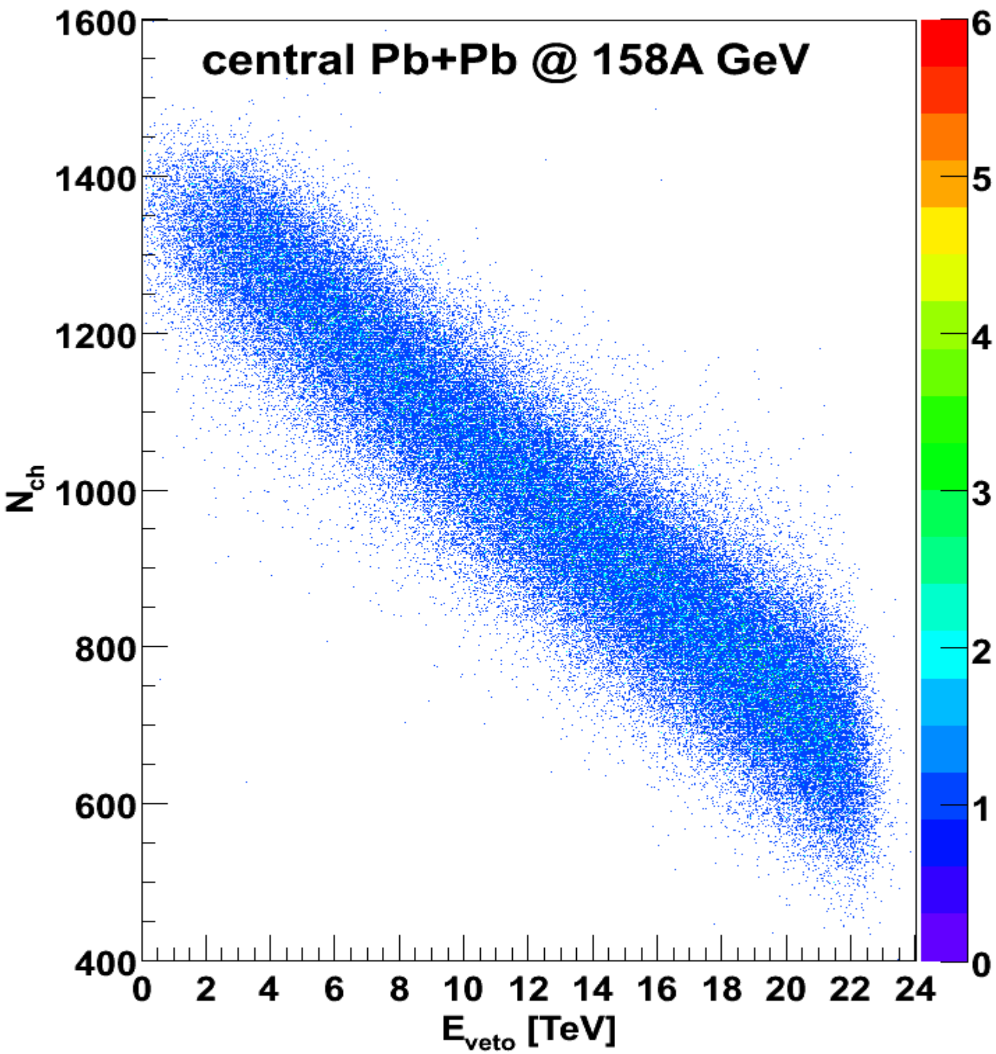
NA49

- Large-acceptance hadronic spectrometer
- Four large-volume TPCs
- Two ToF walls
- Beam/trigger detectors
- Veto Calorimeter
- Momentum resolution: $\sigma(p)/p^2 = (0.3-7) \cdot 10^{-4}\ (\mathrm{GeV}/c)^{-1}$



NA49

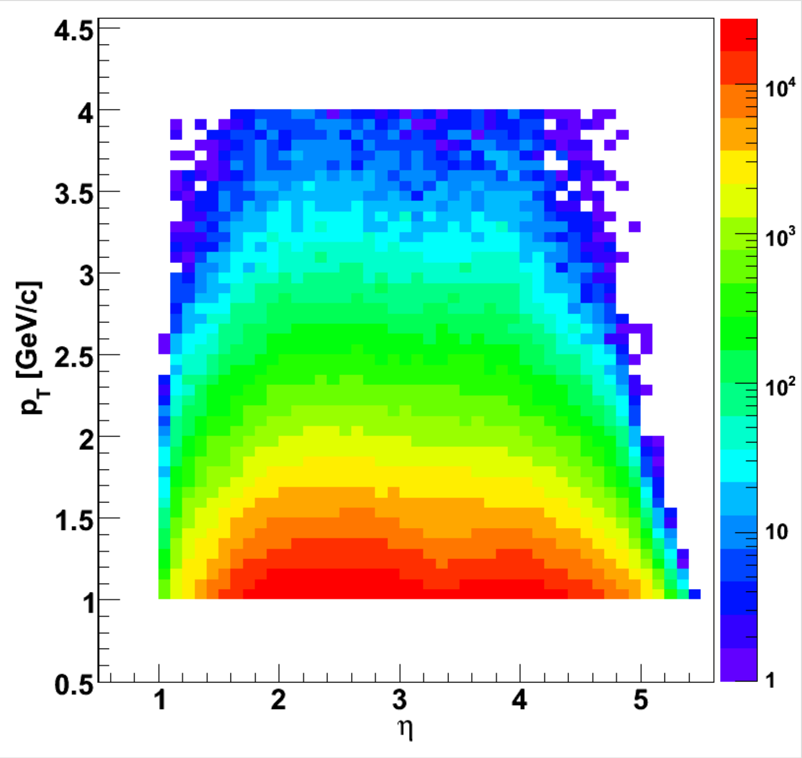
- Data sets
  - central Pb+Pb:
    - 158*A* GeV (2.4 M), 0-22 %
    - 80*A* GeV (265 k), 0-7 %
    - 40*A* GeV (530 k), 0-7 %
    - 30*A* GeV (445 k), 0-7 %
    - 20*A* GeV (370 k), 0-7 %
  - central Si+Si:
    - 158*A* GeV (220 k), 0-12 %
  - p+p, ≈90 % inelastic:
    - 158*A* GeV (1.5 M)
- Centrality selection: spectator energy in VCAL

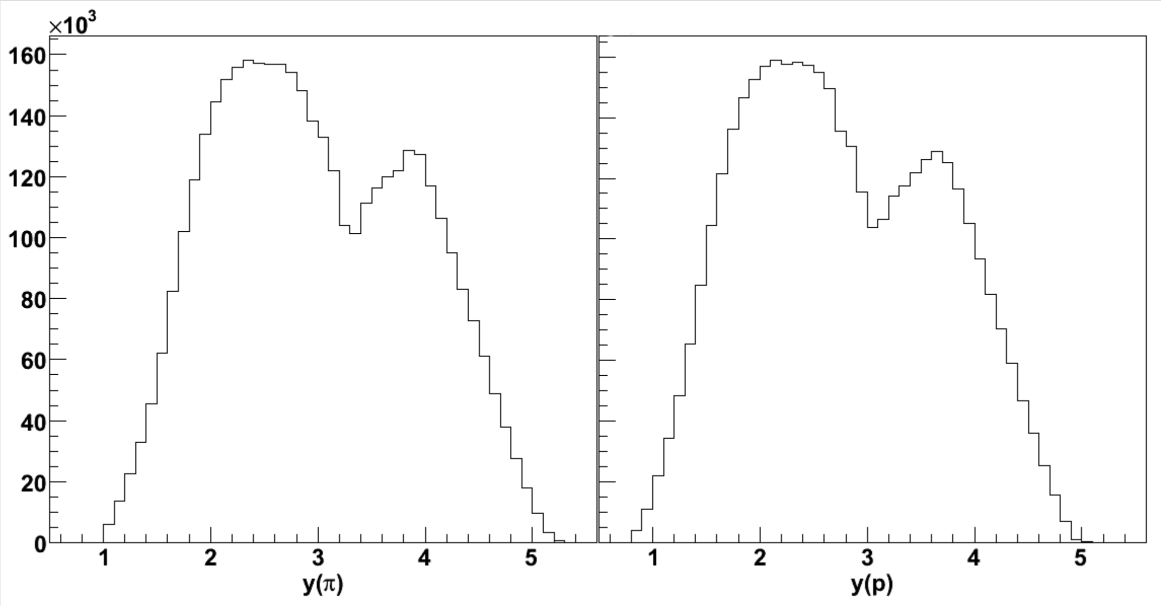


Two-particle Δϕ Correlations

Acceptance:

- $\eta \in [1;6]$
- $p_T^{trg} \in [2.5;4.0]$ GeV/c
- $p_T^{asc} \in [1.0;2.5]$ GeV/c



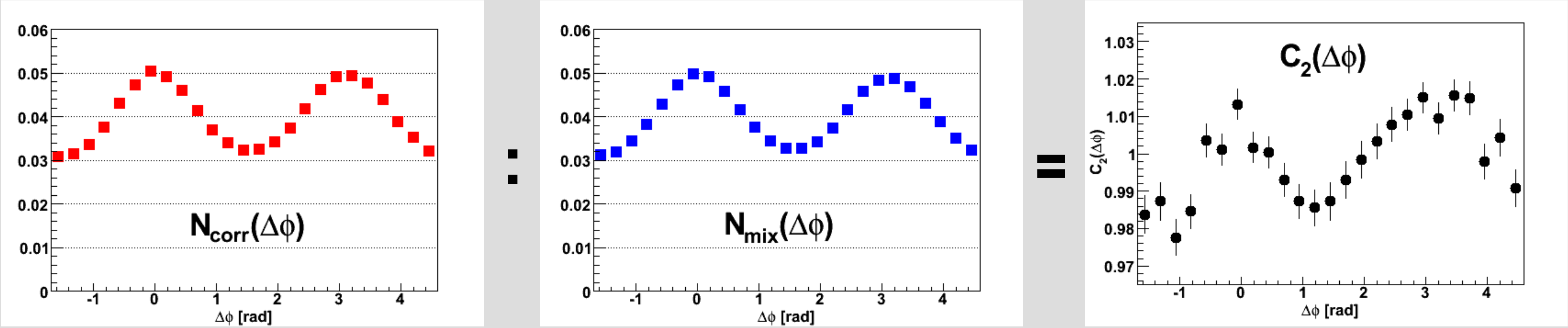


Data set: Pb+Pb at 158*A* GeV

Two-particle Δϕ Correlations

Correlation function defined as

$$C_2(\Delta\phi) = \frac{N_{corr}(\Delta\phi)}{N_{mix}(\Delta\phi)} \frac{\int N_{mix}(\Delta\phi')d(\Delta\phi')}{\int N_{corr}(\Delta\phi')d(\Delta\phi')}$$



* only statistical errors from now on

Two-particle $\Delta\phi$ Correlations

- Signal extraction: two-source model

  C_2 = hard + soft

  $C_2^{jet} = C_2 - aB_2$

  $B_2 = 1 + 2\langle v_2^T\rangle\langle v_2^A\rangle\cos(2\Delta\phi) + 2\langle v_4^T\rangle\langle v_4^A\rangle\cos(4\Delta\phi)$
- v_2, v_4 – reaction-plane analysis by D. Kikoła
- a: Zero Yield At Minimum assumption
  - $C_2^{jet}(\Delta\phi_{min}) = 0$
- Normalised to per-trigger conditional yield:

$$J_2(\Delta\phi) = \frac{1}{N^T}\frac{dN^{TA}}{d(\Delta\phi)} = \frac{C_2^{jet}(\Delta\phi)}{\int C_2(\Delta\phi')d(\Delta\phi')}\frac{N^{TA}}{N^T}$$

Ajitanand et al., Phys.Rev.C72:011902,2005

Miklos Gyulassy:

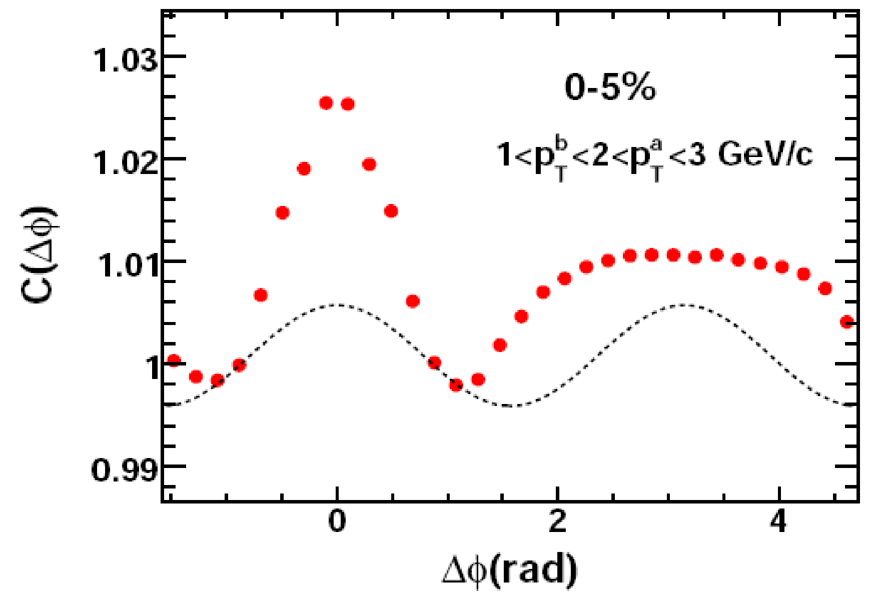
I am unhappy with ZYAM (assumed Zero Yield At Minimum)

Because 1% errors on the magnitude of an assumed independent "Background" (*The* sQGP signal !!)

produces a factor of 2 variation of the azimuthal correlations shape relative to a flat $C(\Delta\phi)$ near $\Delta\phi = \pi$

The "Mach" signal is tiny ~ 1% in correlation func

Systematic errors need To be much better controlled



Recent progress by McCumber (PHENIX) is an attempt to measure background level, but even then the Assumption of two independent Jet+QGP sources is dubious

Two-particle Δϕ Correlations

- Signal extraction: two-source model

C_2 = hard + soft

$C_2^{jet} = C_2 - aB_2$

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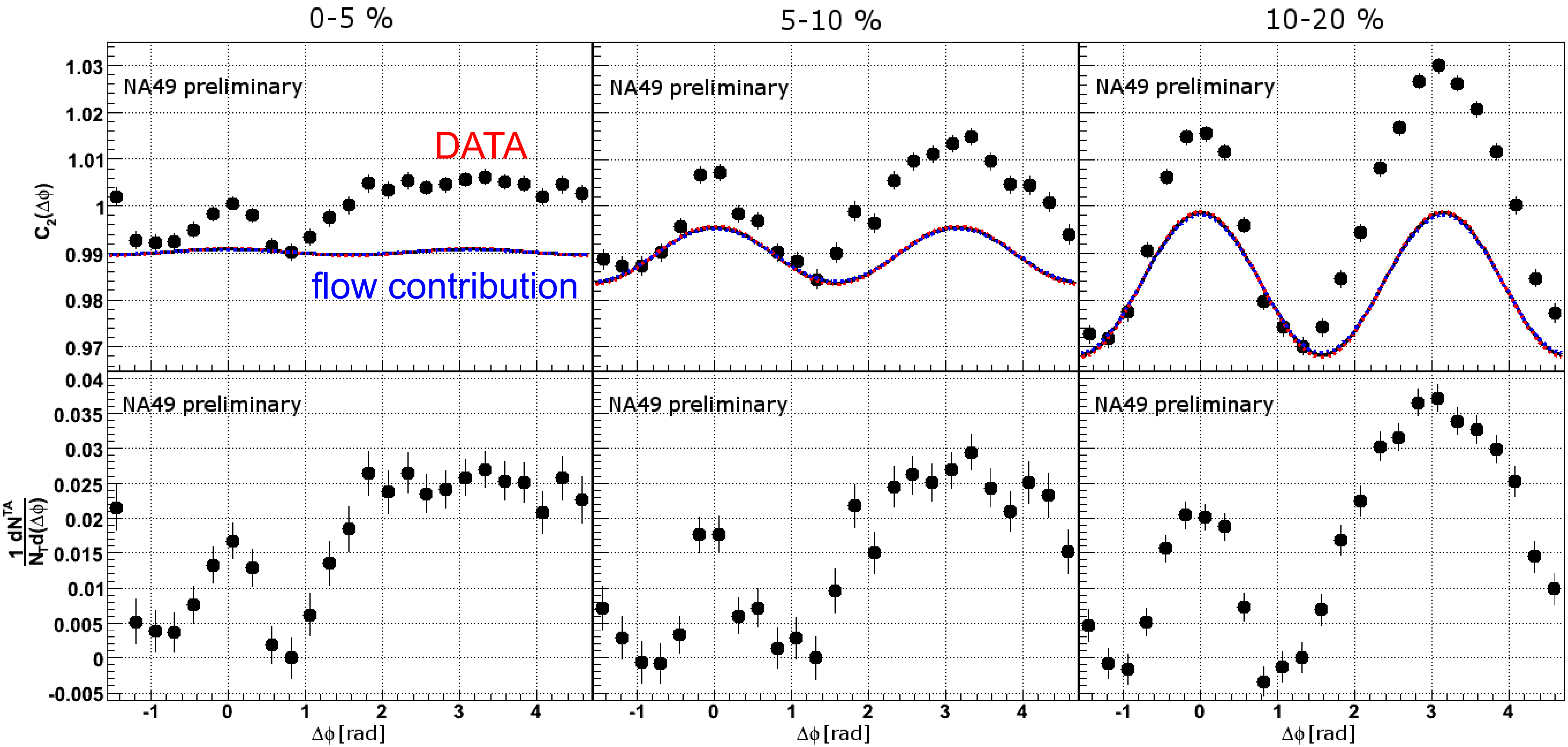
In light of possible problems with the two-source model and ZYAM, we concentrate on most central collisions.

Ajitanand et al., Phys.Rev.C72:011902,2005

Two-particle $\Delta\phi$ Correlations
Pb+Pb at 158*A* GeV

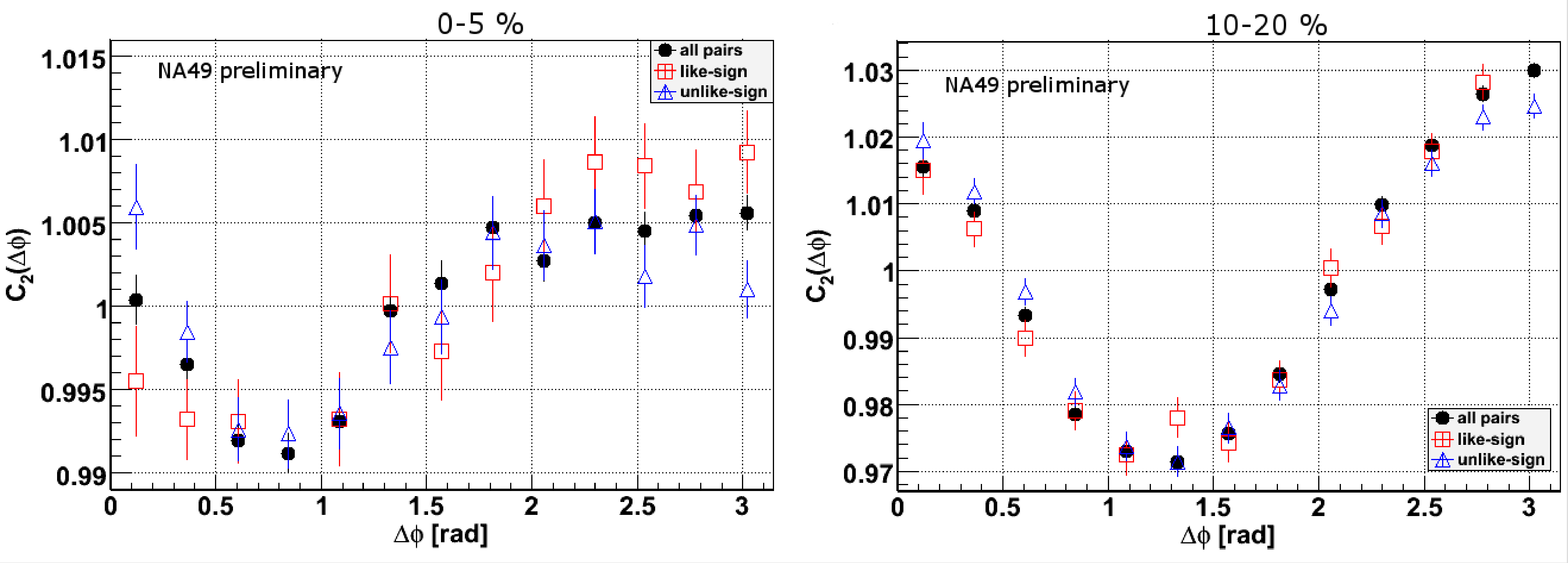


Flattened away side in most central collisions

Two-particle Δϕ Correlations

Pb+Pb at 158*A* GeV

- Near-side amplitude of $C_2(\Delta\phi)$ depends on charge of triggers and associates



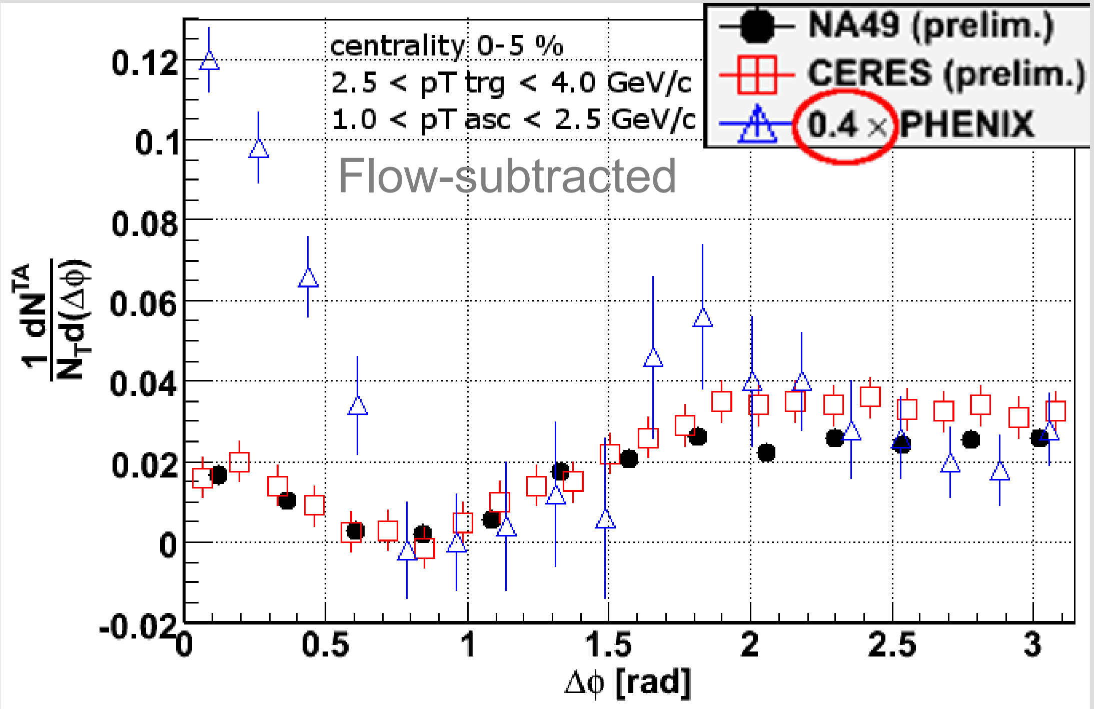
- Difference in like- vs. unlike-sign: consistent with local charge conservation

Two-particle Δϕ Correlations

Pb+Pb at 158*A* GeV

Comparison with CERES and PHENIX

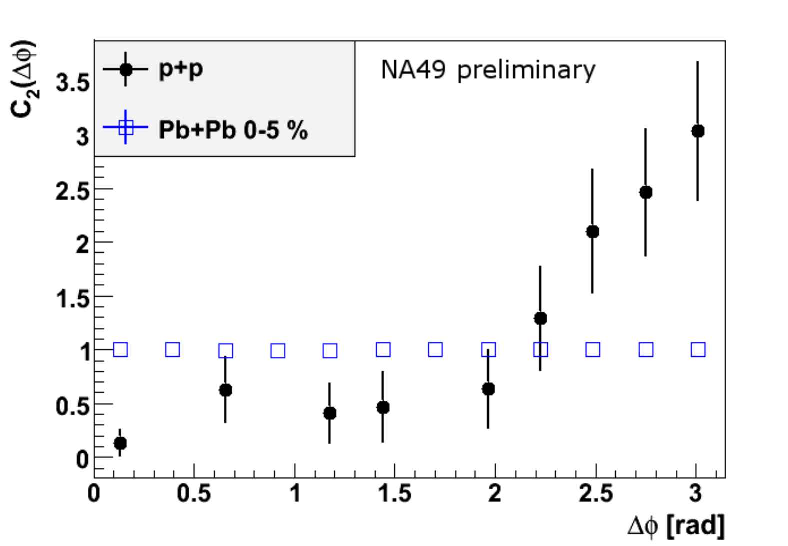
- RHIC yields much higher than at SPS
- Away-side shape similar
- Near-to-away-side yield ratio larger at RHIC
- Good agreement between SPS experiments

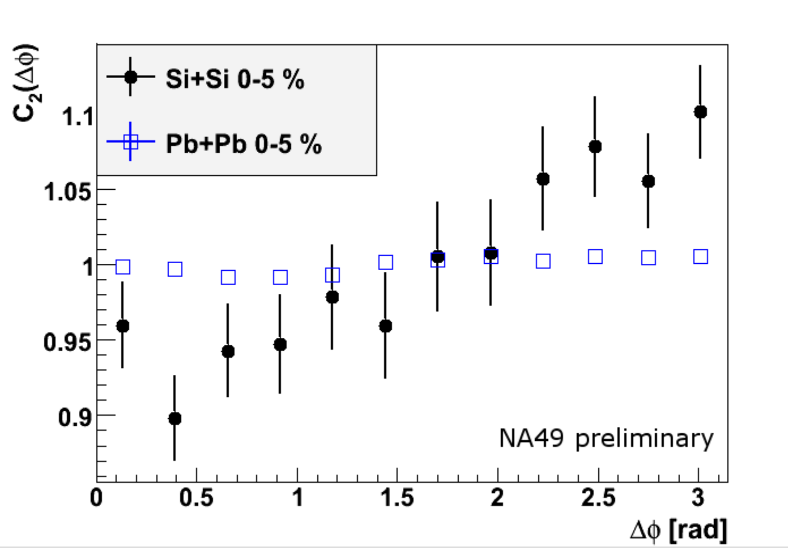


S. Kniege for CERES, talk at ISMD 2007
PHENIX, Phys.Rev.Lett.97:052301,2006

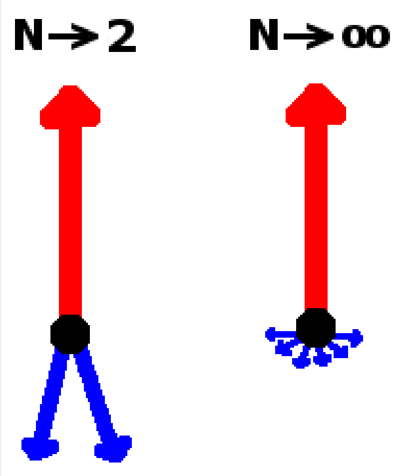
Two-particle Δϕ Correlations

Other Systems

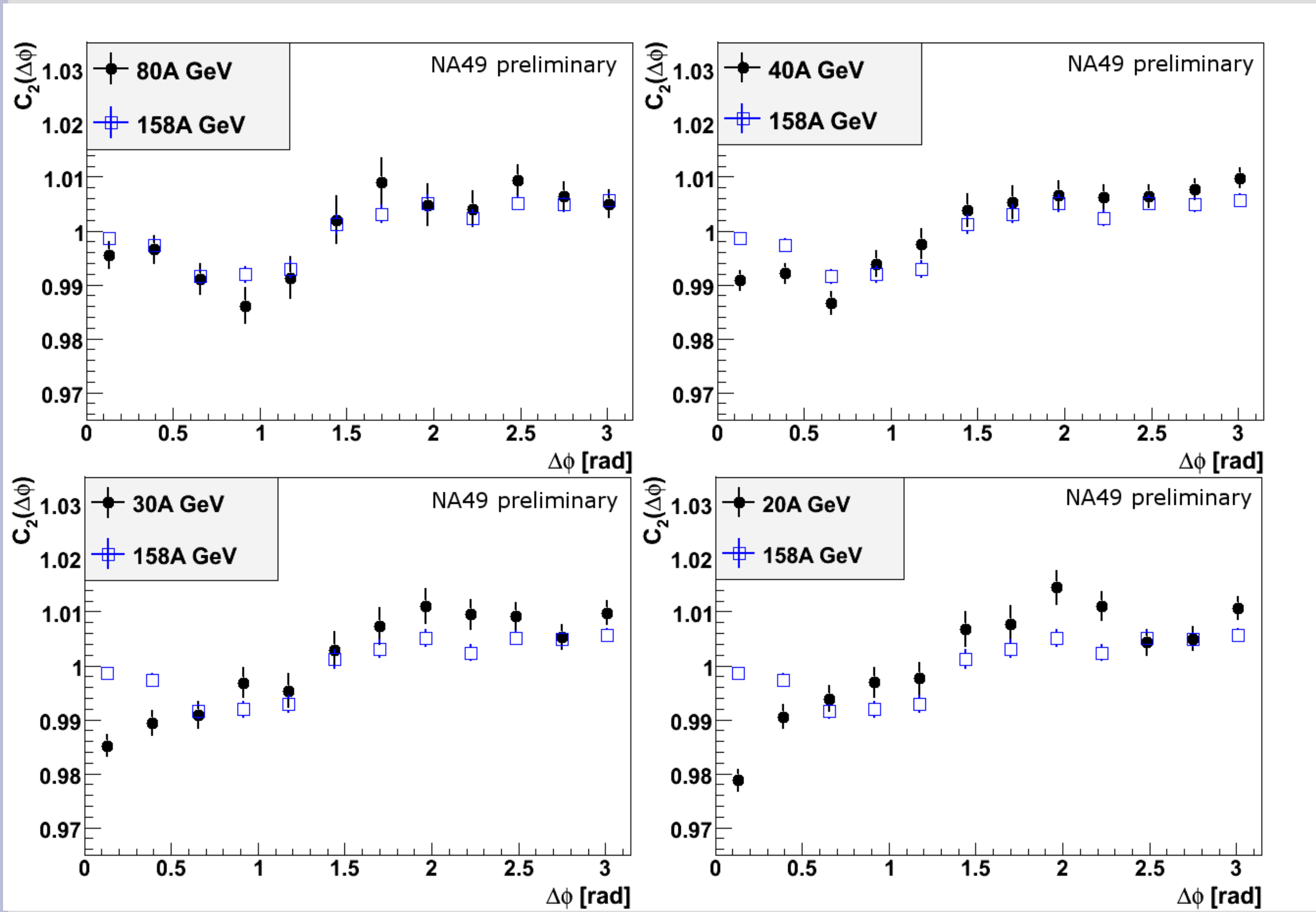




- Correlation stronger in smaller systems
- Away side: steeper peak in smaller systems
- Consistent with global momentum conservation



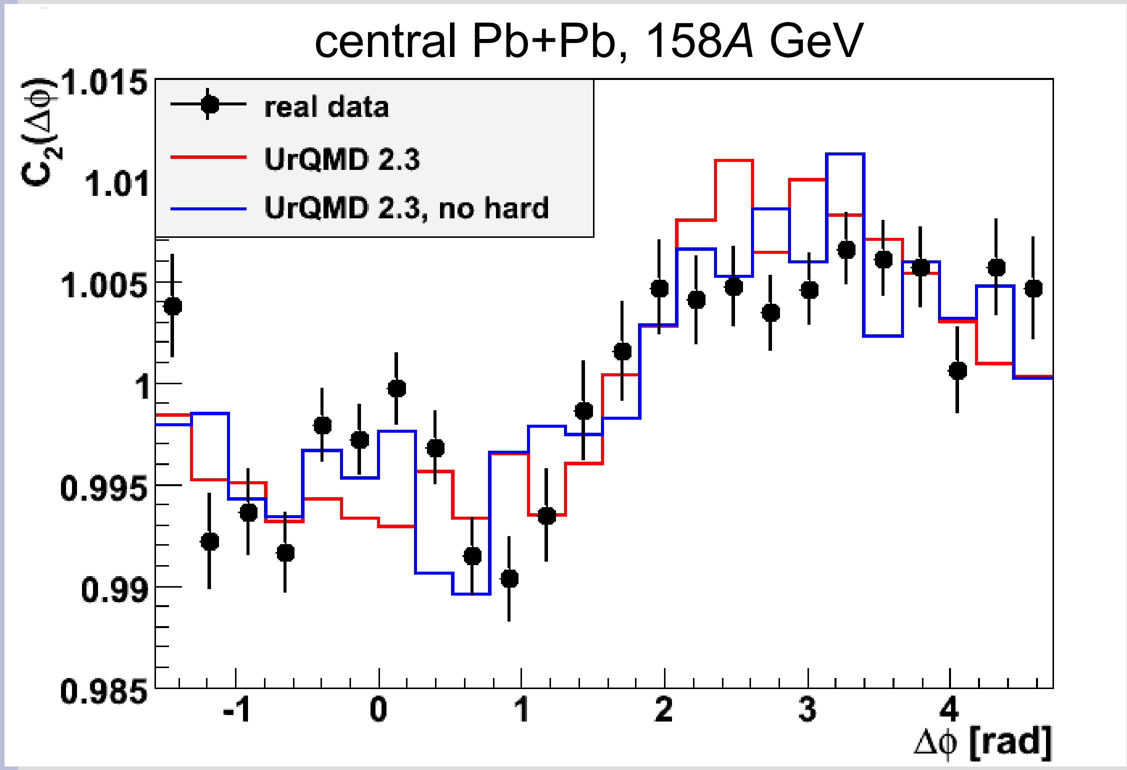
Two-particle Δϕ Correlations
Pb+Pb 0-5 % at lower energies



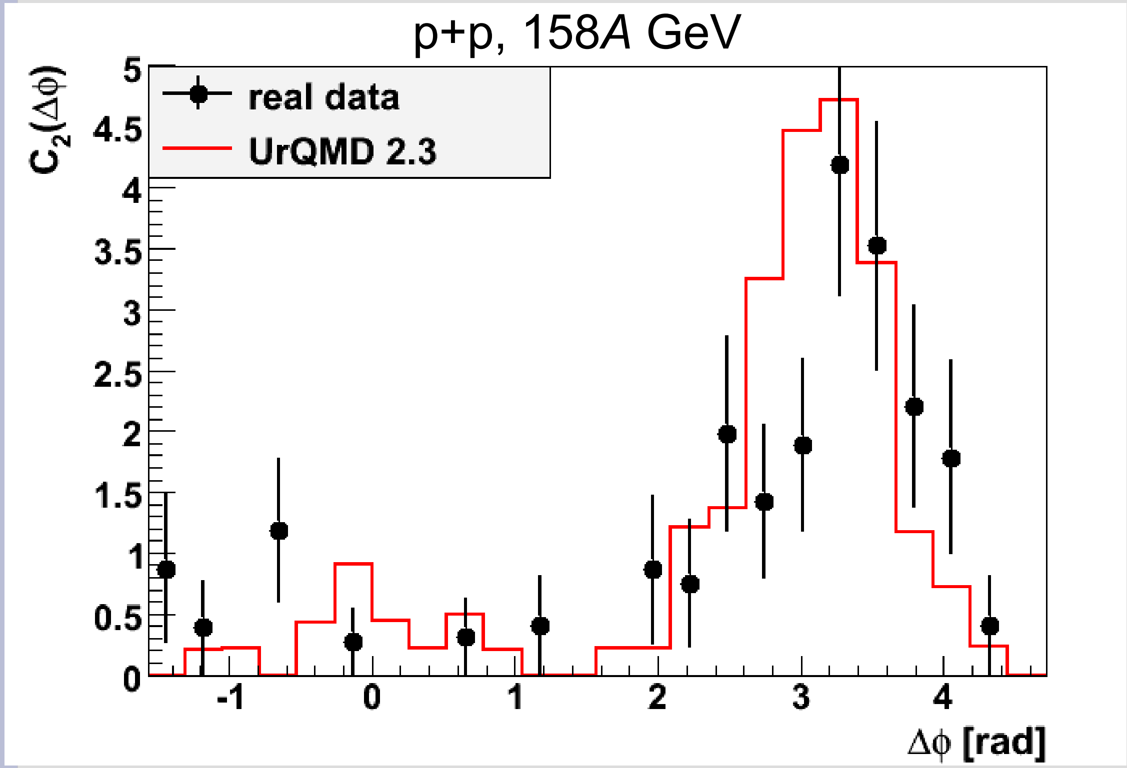
- Near side: yield seems to drop with decreasing energy
- Away side: weak or no energy dependence!
- Consistent with global momentum conservation?

Two-particle Δφ Correlations

Comparison with UrQMD



Two-particle Δφ Correlations
Comparison with UrQMD



- Good agreement with data
- Small hard contribution
- Consistent with (global?) momentum conservation

Summary

- Energy, system-size dependence of two-particle azimuthal correlations measured by NA49 at SPS
- Near side:
  - central Pb+Pb collisions: yield decreasing with energy
  - Pb+Pb 158*A* GeV: agreement with CERES
  - RHIC vs. SPS: higher yields and near-to-away-yield ratio
  - charge selection: consistent with parton fragmentation

Summary

- Away side:
  - stronger correlation in smaller systems
  - peak broadens with growing system size
  - (global) momentum conservation?
  - central Pb+Pb collisions: weak or no energy dependence
  - good agreement with UrQMD
  - Pb+Pb 158*A* GeV: agreement with CERES
  - SPS *vs.* RHIC: similar shape, RHIC yields larger

THANK YOU

BACKUP SLIDES

Event and Track Cuts

- Mixing: 50 last events
- Centrality bins: 0-5 %, 5-10 %, 10-20 %
- Reconstructed position of the primary vertex
- Track impact parameter (B)
- TPC N_{points}/N_{max} ratio
- TPC N_{max} for $N_{point} = 0$
- $2.5 \leq p_T^{trg} \leq 4.0$ GeV/c
- $1.0 \leq p_T^{asc} \leq 2.5$ GeV/c