Nuovi risultati di NA60 sulla transizione di fase verso in QGP

- Introduction

- Low mass region
  - → medium modification of the ρ

- Intermediate mass region
  - → open charm and thermal dimuons

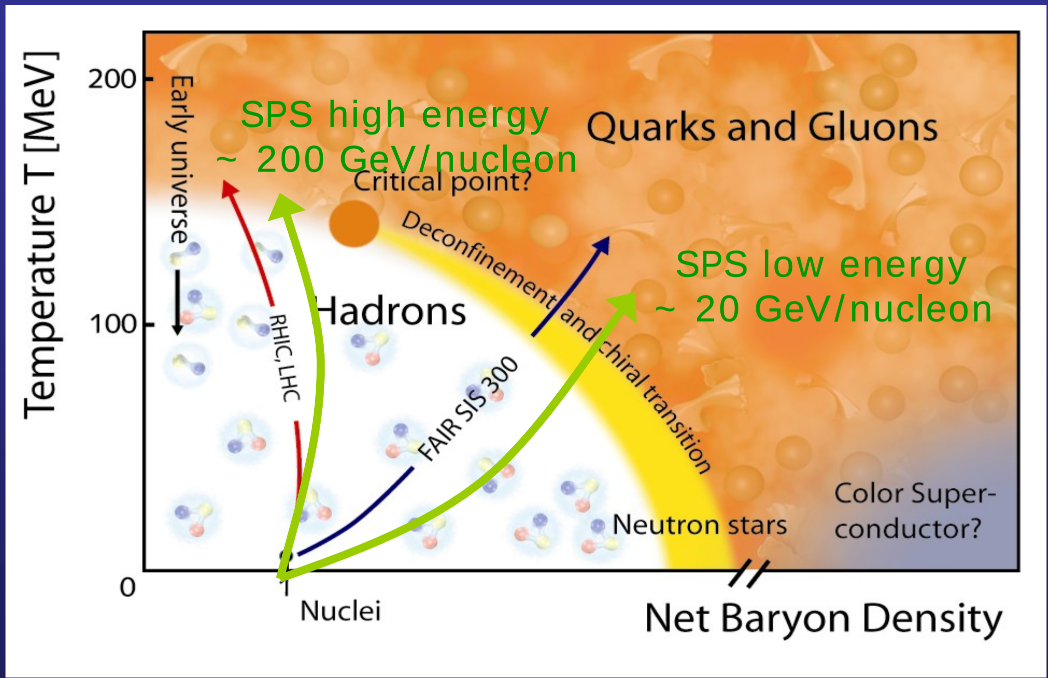
- High mass region
  - → centrality dependence of J/ψ and ψ' suppression
    - In-In collisions
    - p-A collisions
  - → J/ψ polarization, p_T and y distributions

R. Arnaldi – Collaborazione NA60

IV Congressino di Sezione, 23 Gennaio 2007

Heavy Ion Collisions

• QCD predicts a transition between nuclear matter and a deconfined state of quarks and gluons (QGP) at high temperature and density



SPS probably sitting in the region close to deconfinement threshold

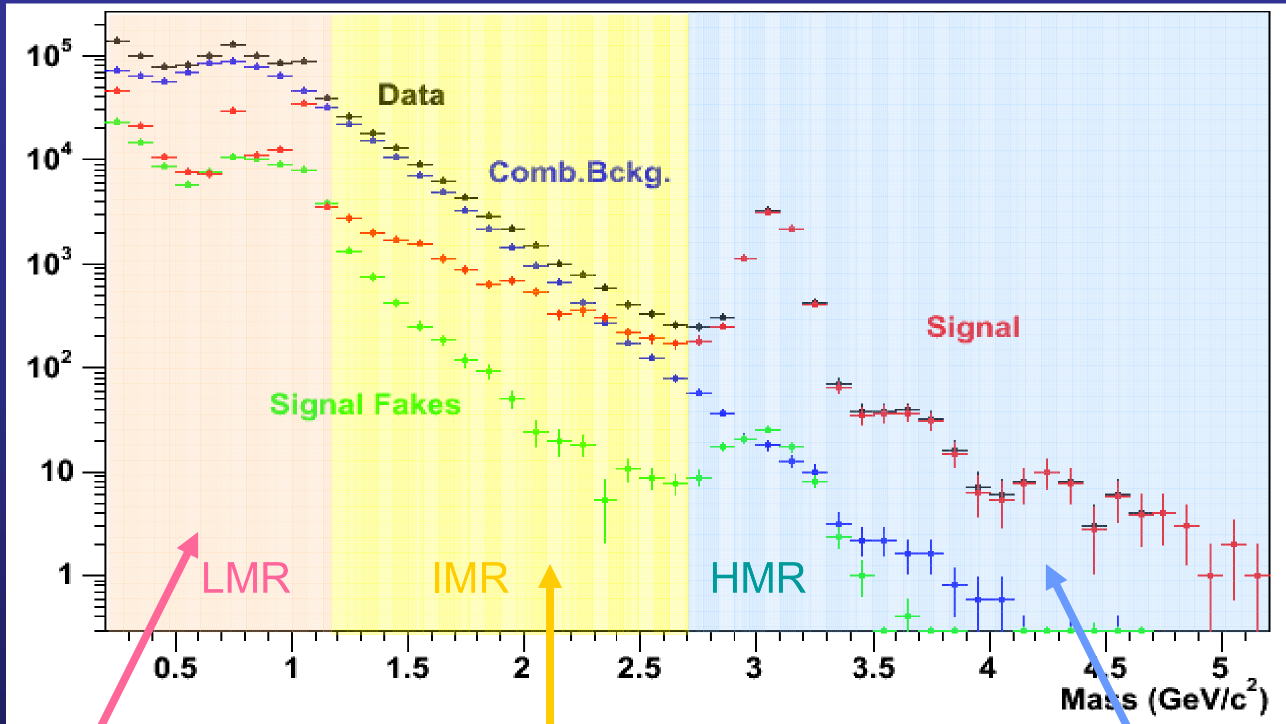
• Heavy ion collisions provide the way to search for this transition in the laboratory

• Dileptons are an ideal tool to probe the deconfined phase, since they are not subject to strong interactions → they exit from the medium without suffering final state interactions

NA60 at the CERN SPS

- Designed to reach unprecedented accuracy in the measurement of muon pair production in HI collisions
- Aim: answer specific questions left open, in the leptonic sector, by the previous SPS experiments, finished in 2000 (and that can hardly be addressed at RHIC and LHC)
- Data taking: 2003-2004 (In-In @ 158 GeV and p-A @ 158 and 400 GeV)

Physics topics

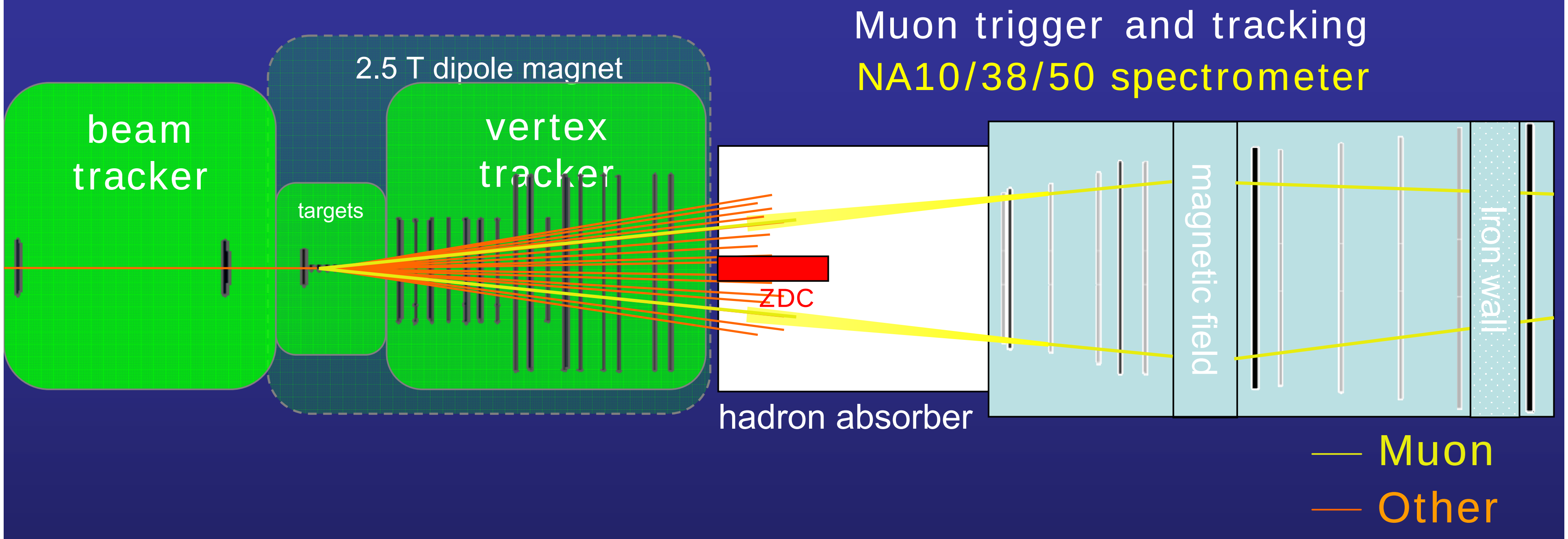


Determine the origin of the low-mass excess seen by CERES, possibly connected with chiral symmetry restoration

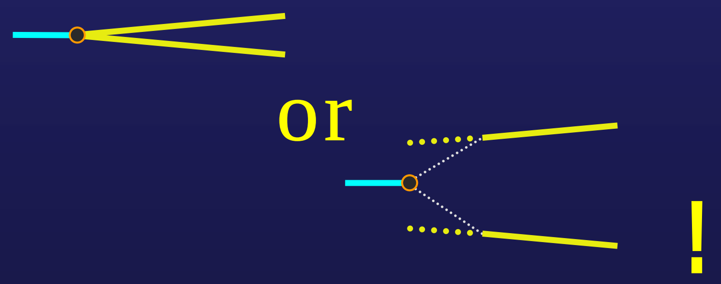
Study the origin of the intermediate mass excess seen by HELIOS-3, NA38, NA50, maybe connected with thermal dilepton production

Investigate the origin of the J/ψ suppression, by comparing NA50 Pb-Pb results with new data obtained with lighter ions

The NA60 experiment

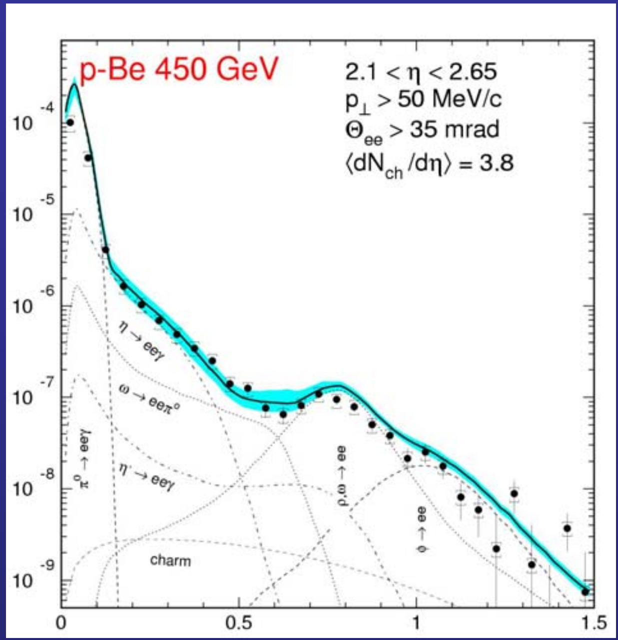


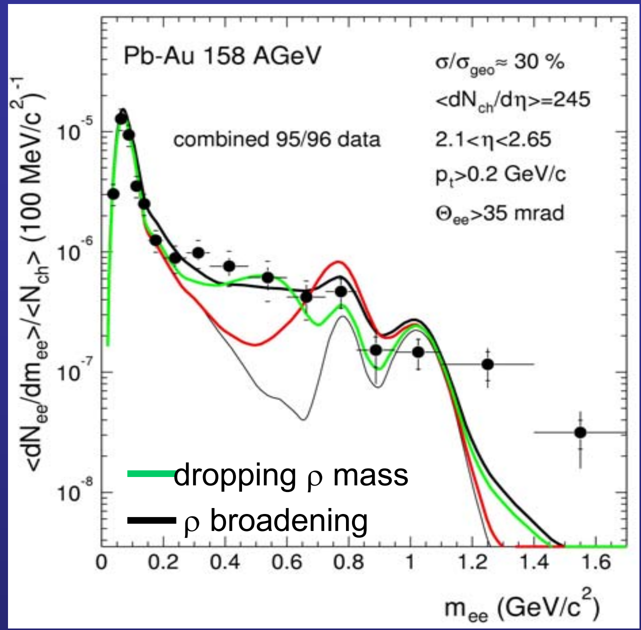
Matching in coordinate and momentum space



- Improved dimuon mass resolution
- Origin of muons can be accurately determined

Physics topic: low masses

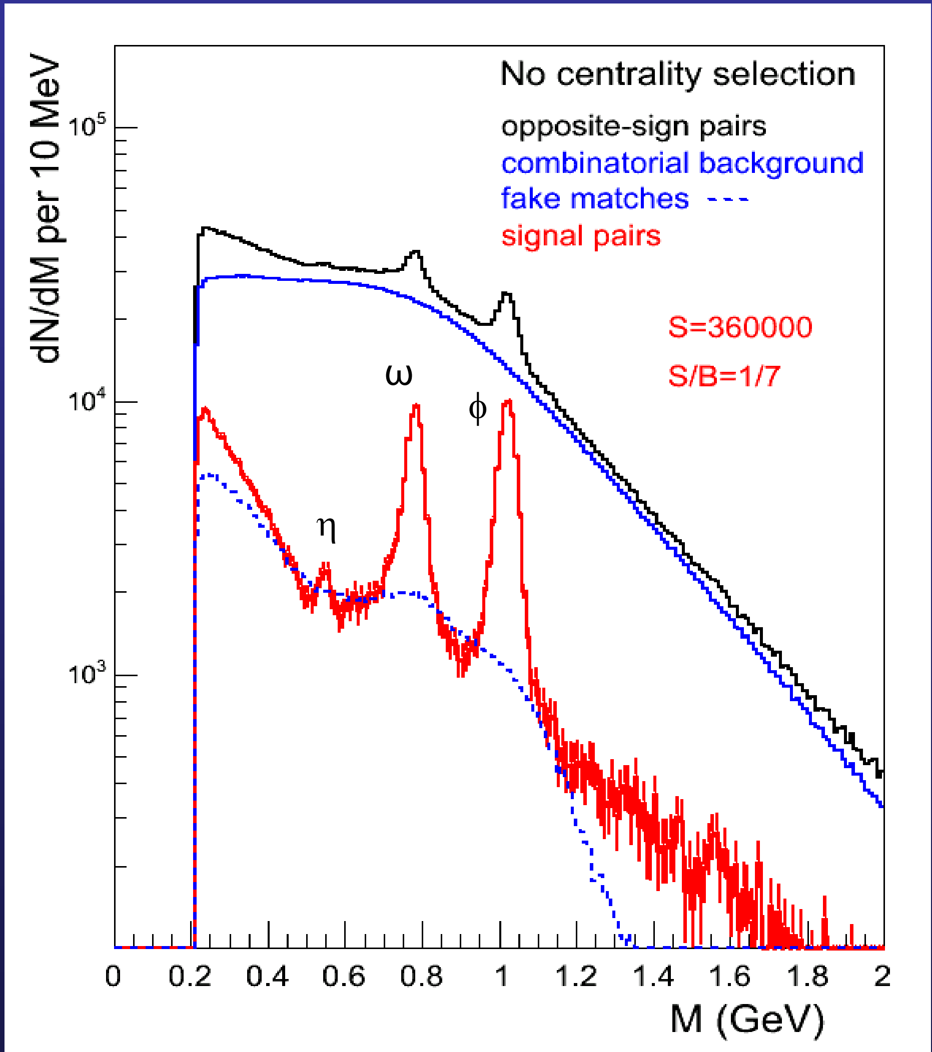




- CERES observed that in the LOW MASS region:
  - p-A data can be described by the sum of expected sources
  - A-A data show an excess with respect to expected sources
- Excess is interpreted as direct thermal radiation from the fireball, (occurring via the $\pi^+\pi^- \to \rho \to l^+l^-$ process, with a ρ modified by the medium)
- Still missing: discrimination between the various theoretical explanations

→ Good statistics and mass resolution are needed

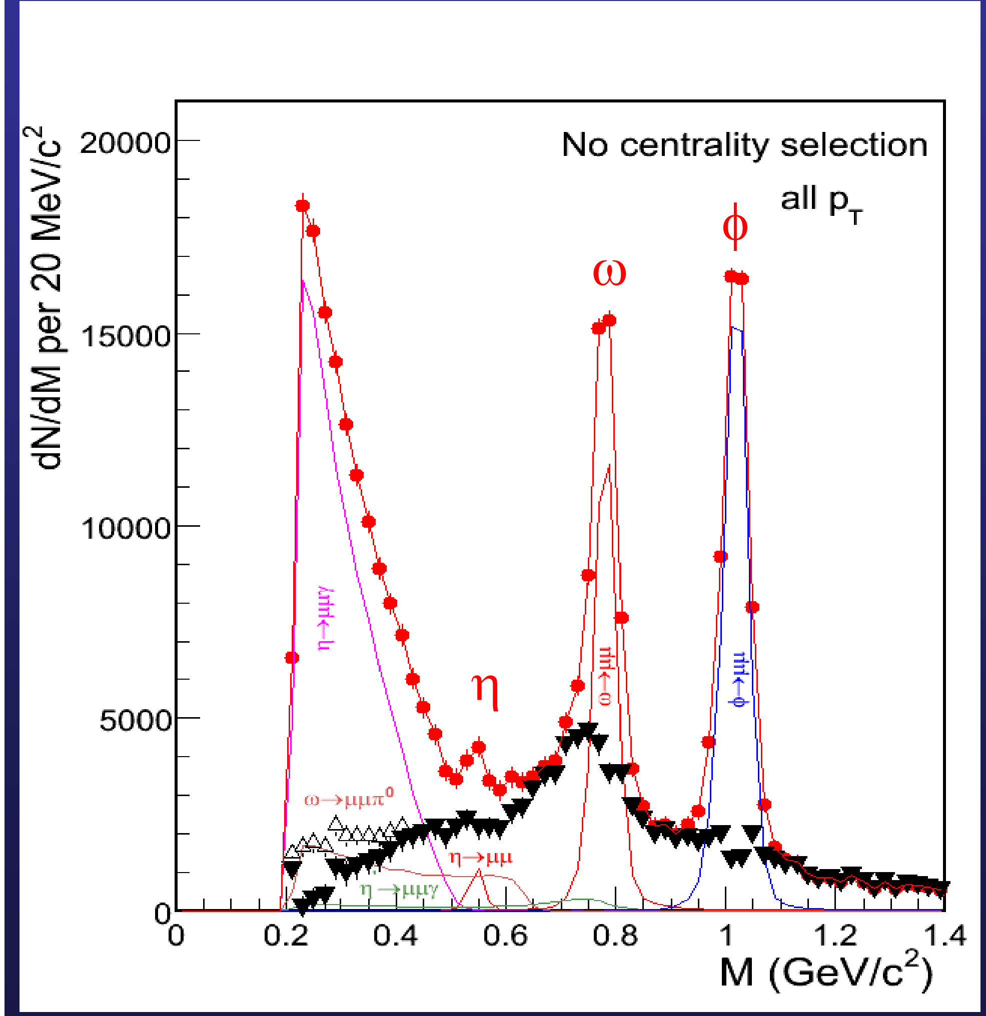
Low mass dimuons: NA60 In-In data



- Net data sample: 360 000 events
- Fakes / CB < 10 %
- ω and ϕ peaks clearly visible in dilepton channel; even $\eta \rightarrow \mu\mu$ seen
- Mass resolution: 23 MeV at the ϕ position
- Progress over CERES: statistics: factor >1000 resolution: factor 2-3

Low mass dimuons: NA60 In-In data (2)

• Search for in-medium modifications of vector mesons



Peripheral data: well reproduced by the hadronic cocktail

Central data: excess is isolated by subtracting the cocktail

Phys. Rev. Lett. 96 (2006) 162302

ω and ϕ:

fix yields to get, after subtraction, a smooth underlying continuum

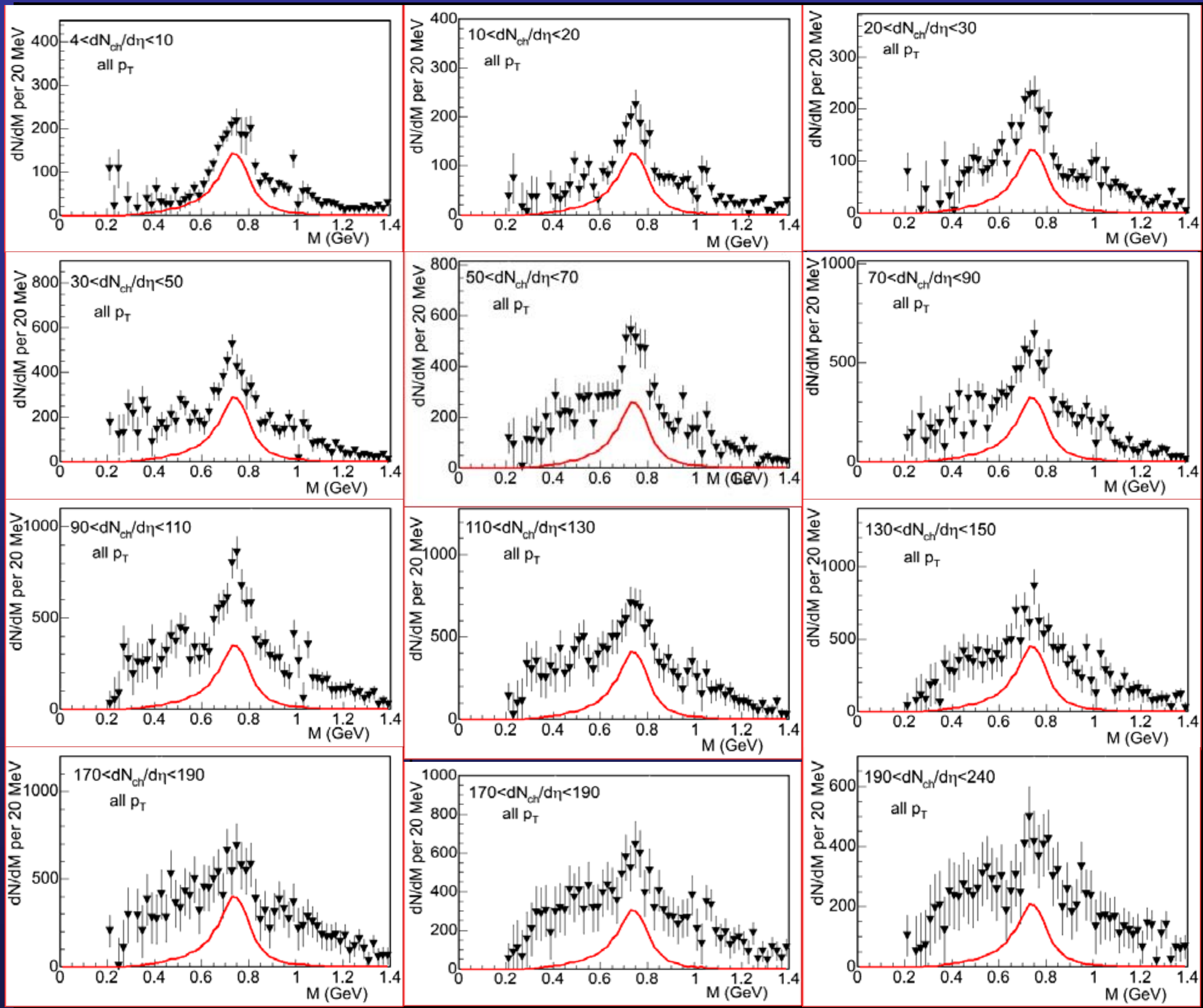
η:

▼ set upper limit, defined by saturating the measured yield in the mass region close to 0.2 GeV (lower limit for excess).

△ use yield measured for p_T>1.4 GeV/c

Excess spectra

• Fine analysis in 12 centrality bins



data – cocktail ($\text{all } p_T$)

• No cocktail ρ and no DD subtracted

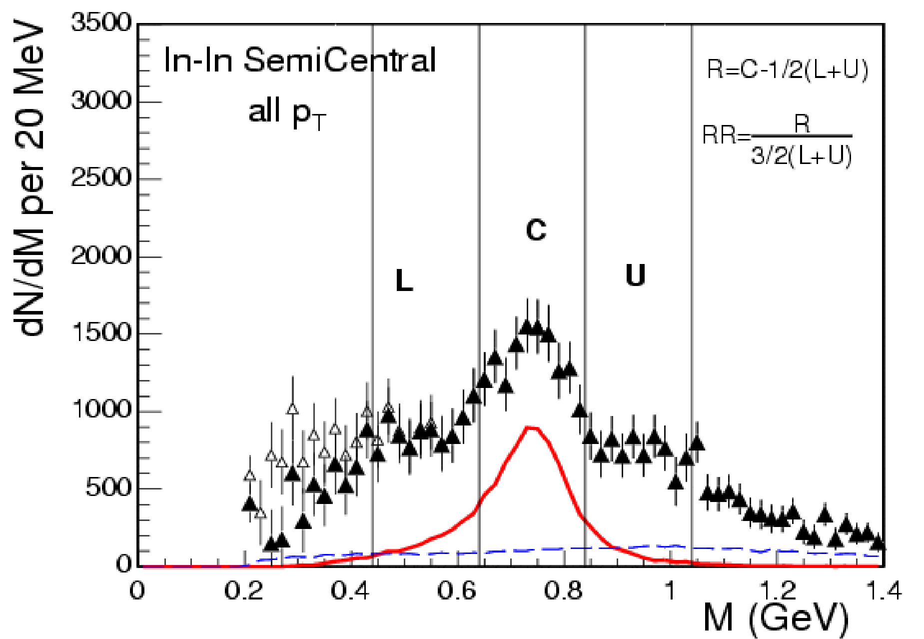
Clear excess above the cocktail ρ, centered at the nominal ρ pole and rising with centrality

• Excess even more pronounced at low p_T

cocktail ρ/ω =1.2

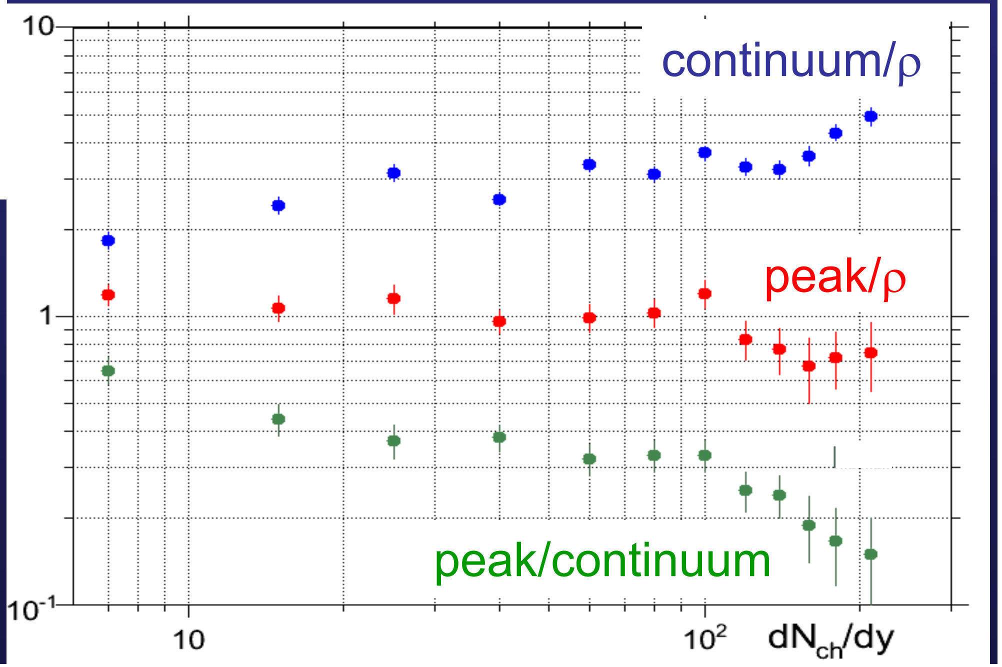
Evolution of the excess shape with centrality

Quantify the peak and the broad symmetric continuum with a mass interval C around the peak (0.64 <M<0.84 GeV) and two equal side bins L, U



"continuum" = 3/2(L+U)
"peak" = C-1/2(L+U)

Fine analysis in 12 centrality bins



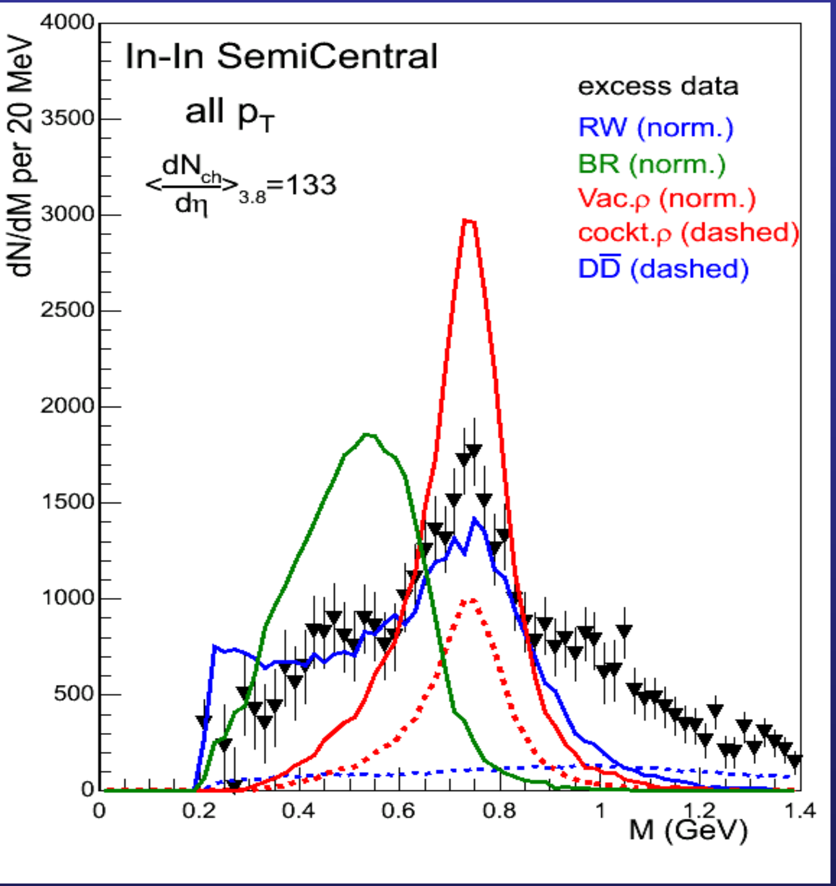
- Peak/cocktail ρ drops by a factor ~2 from peripheral to central:

the peak seen is not the cocktail ρ

- nontrivial changes of all three variables at $dN_{ch}/dy>100$?

Comparison to theory

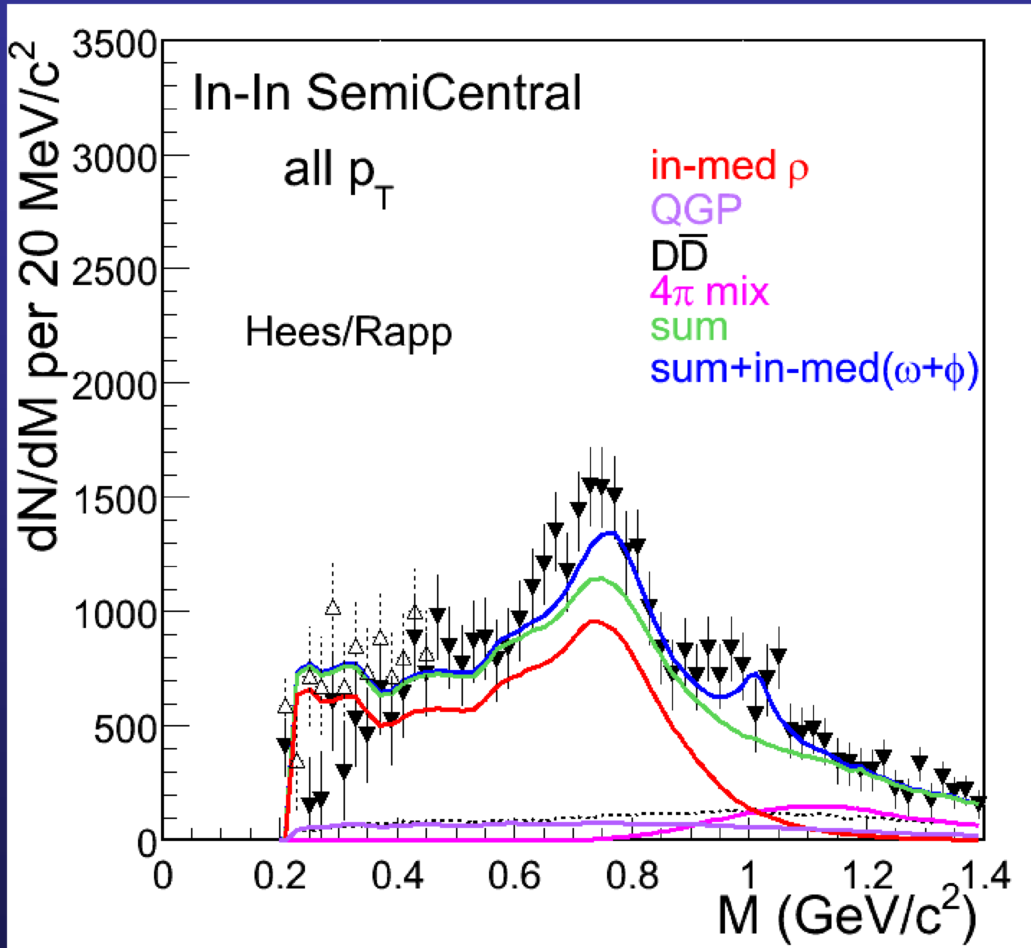
- Predictions for In-In by Rapp et al. (2003) for $\langle dN_{ch}/d\eta \rangle = 133$, covering all scenarios
- Data and predictions as shown, after acceptance filtering, roughly mirror the respective spectral functions, averaged over space-time and momenta
- Theoretical yields normalized to data in mass interval < 0.9 GeV/c^2



- Dropping ρ mass (BR) ruled out by data
- Hadronic models predicting strong broadening/no mass shift (RW) in fair agreement with data

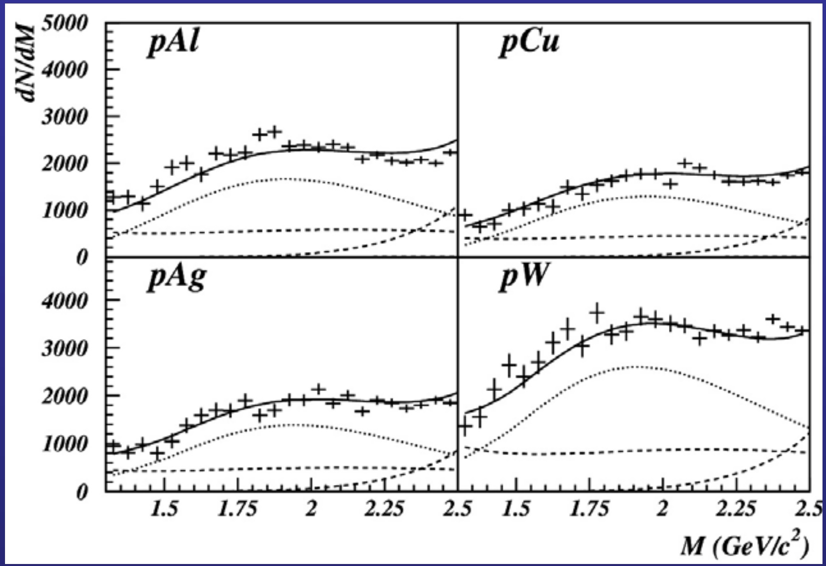
Description of the mass region above 1 GeV

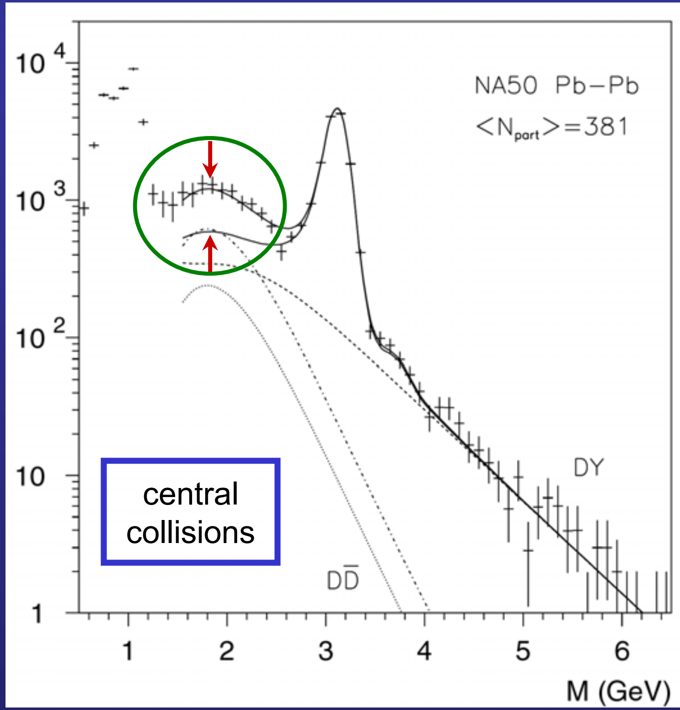
Rapp/Hees hep-ph/0604269 (2006)



Mass region above 1 GeV described in terms of hadronic processes, 4 π ..., sensitive to vector-axialvector mixing and therefore to chiral symmetry restoration!

Physics topic: Intermediate mass region

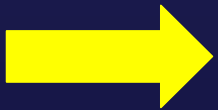




- NA38/NA50 and Helios-3:

IMR excess in S-U/S-W and Pb-Pb, with respect to p-A (described with open charm + Drell-Yan)

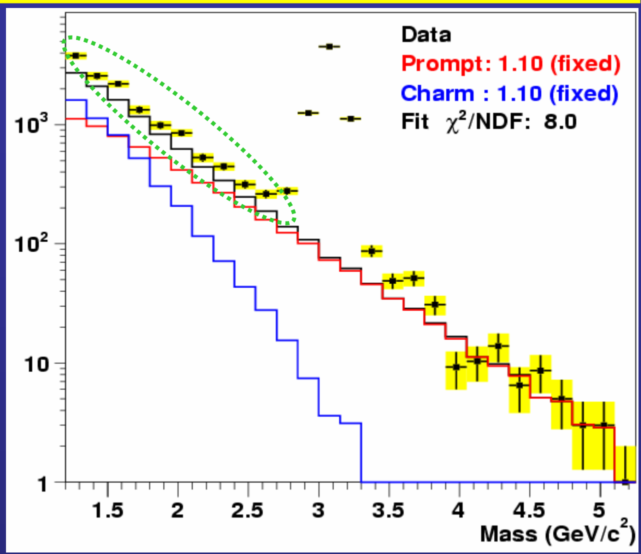
- Can be ascribed to both:
  - Anomalous open charm enhancement
  - Thermal dimuon production



need measurement of muon offsets to discriminate between the two explanations

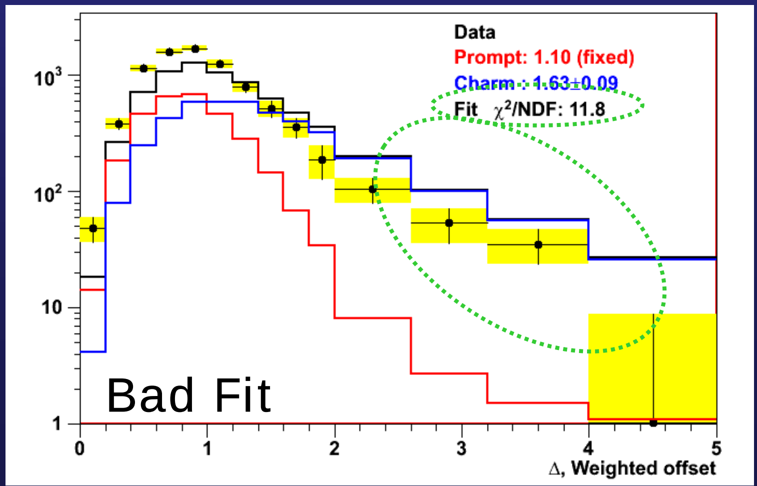
Intermediate masses in NA60

The fit to the mass spectra, with **Charm** and **Drell-Yan** contributions fixed to the expected yields shows an excess in IMR

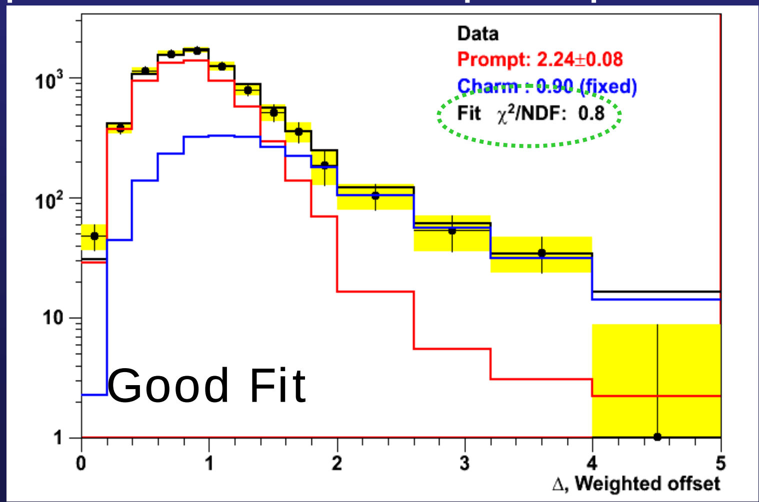


NA60 measures the muon offsets Δ_μ: distance between interaction vertex and track impact point

Fix prompt contribution to the expected DY – leave open charm free



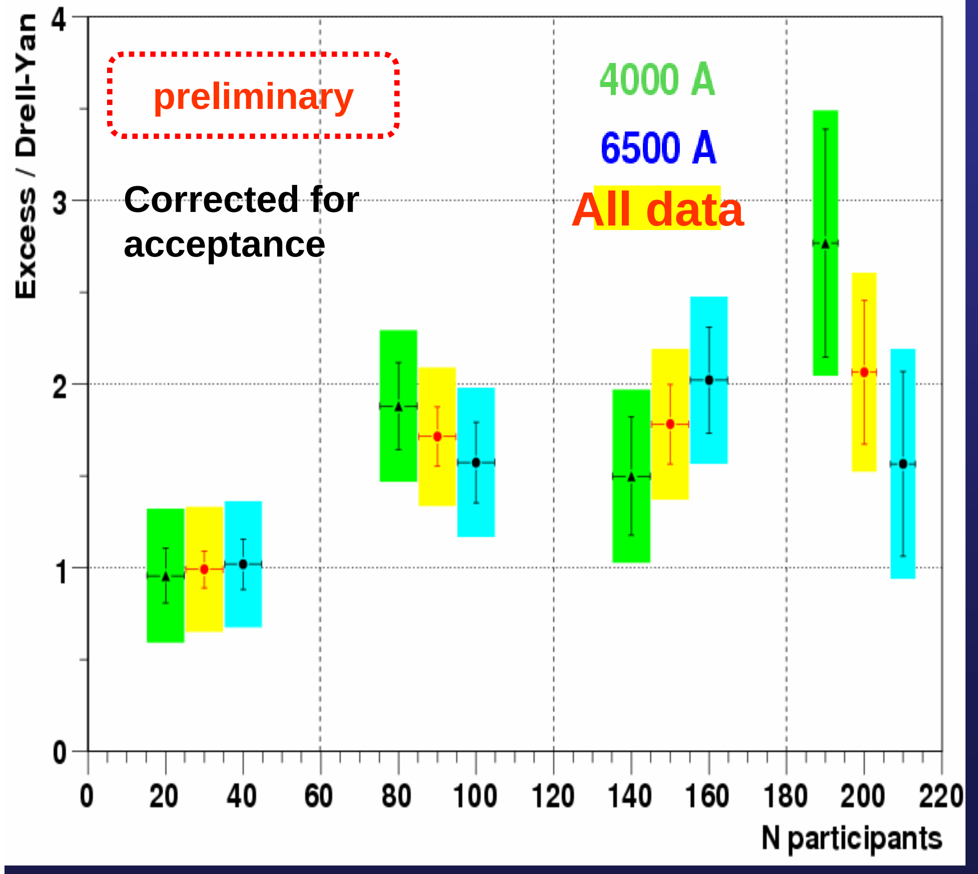
Fix charm contribution according to expectations – leave prompts free

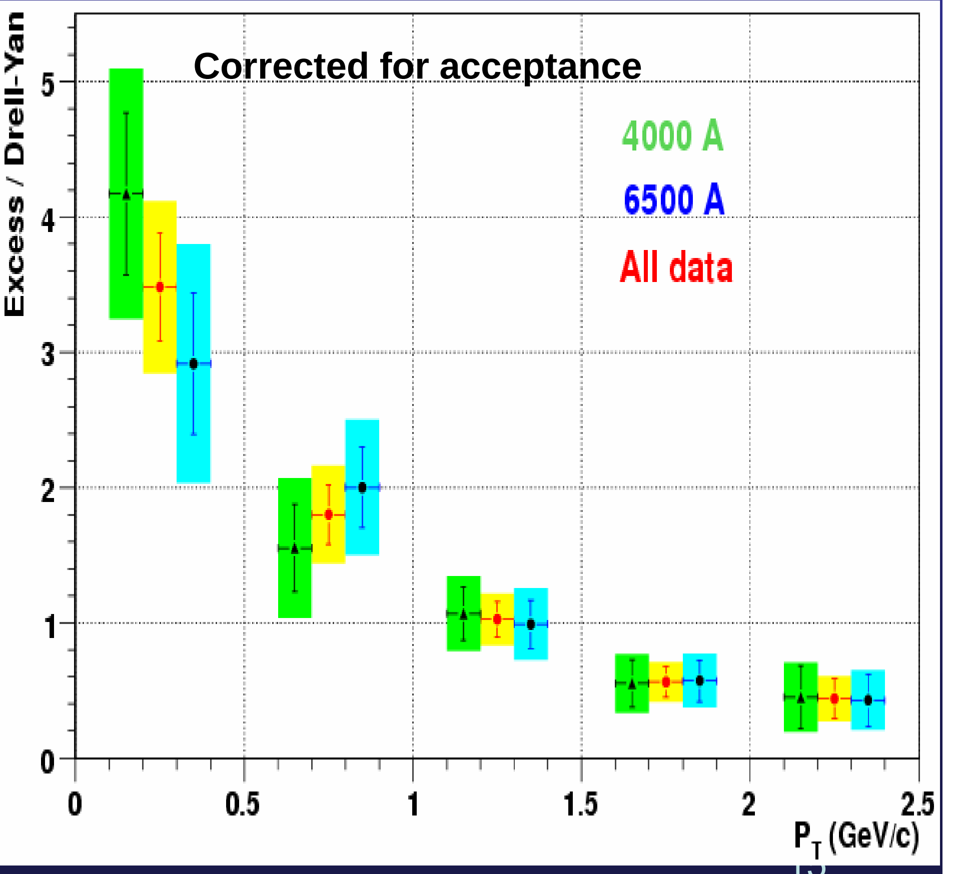


The excess is a prompt source 2.2 times higher than the expected DY

Centrality and p_T dependence of the excess

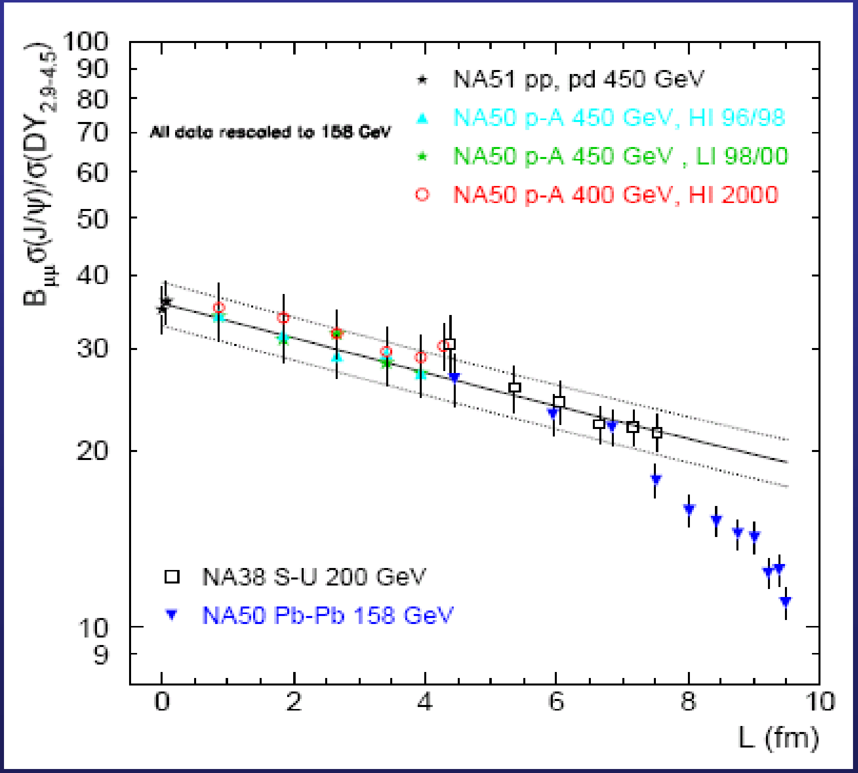
- Slight increase as a function of number of participant with respect to Drell-Yan
- Excess contribution is dominated by low P_T's, reaching a factor 3.5±0.4 for P_T<0.5 GeV/c





Physics topic: J/ψ suppression

- At CERN SPS energy ($\sqrt{s}$ ~ 20 GeV/nucleon)
  → Study the onset of deconfinement (Matsui and Satz, 1986)



NA38/NA50:

- p-A data define the expected J/ψ absorption in normal nuclear matter
- S-U and peripheral Pb-Pb data can be described by the normal nuclear absorption
- central Pb-Pb collisions show an anomalous J/ψ suppression

Main topics (to be) studied

- Normal vs anomalous suppression
  → needs accurate p-A data taken at the same energies as A-A data
- Scaling variables(s) for the onset of the anomaly
  → needs comparison between different colliding systems

Event selection

- 2 event selections have been used for J/ψ analysis

1)
- No matching required
- Extrapolation of muon tracks must lie in the target region

⇒ Higher statistics
Poor vertex resolution (~1 cm)

2)
- Matching between muon tracks and vertex spectrometer tracks
- Dimuon vertex in the most upstream interaction vertex
(MC correction to account for centrality bias due to fragment reinteraction)

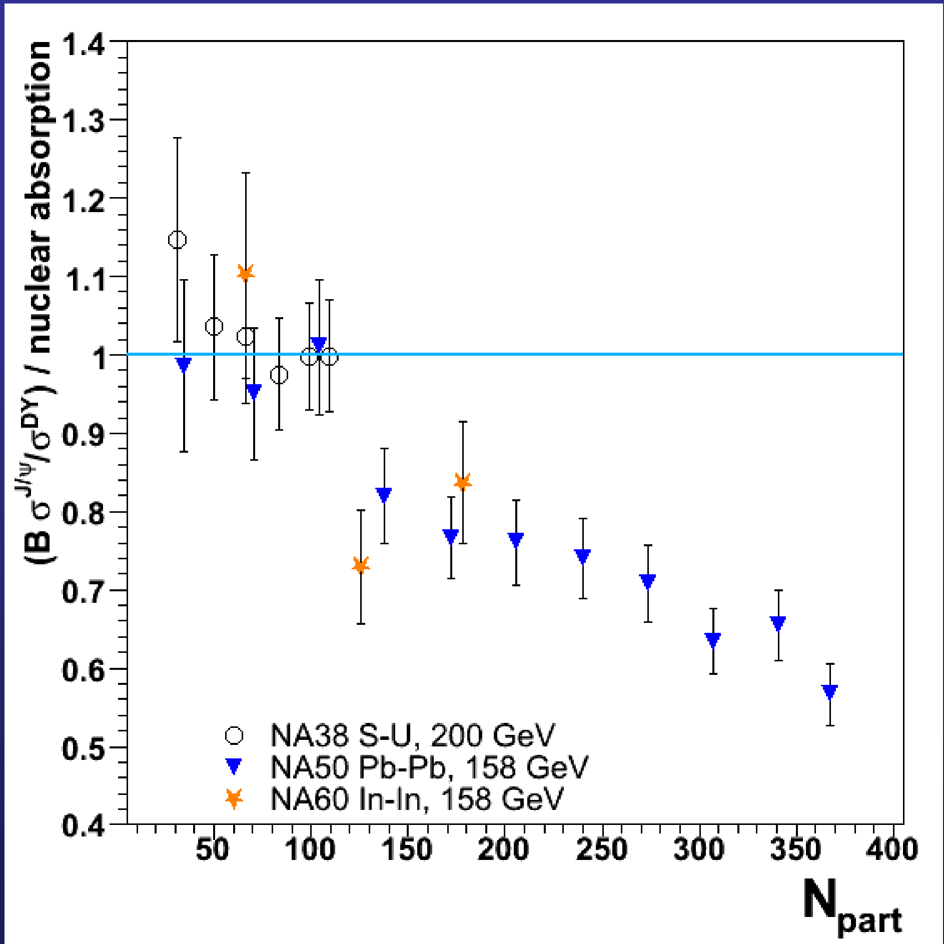
⇒ Better control of systematics
Good vertex resolution(~200μm)
Lose 40% of the statistics

- After quality cuts → $N_{J/\psi}$ ~ 45000 (1), 29000 (2)

- 2 analyses

a) Use selection 1 and normalize to Drell-Yan
b) Use selection 2 and normalize to calculated J/ψ nuclear absorption

J/ψ / DY vs. centrality (analysis a)



→ Anomalous suppression present in Indium-Indium

- Qualitative agreement with NA50 results plotted as a function of N_{part}

- Data points have been normalized to the expected J/ψ normal nuclear absorption, calculated with

$$\sigma^{J/\psi}_{abs} = 4.18 \pm 0.35 \text{ mb}$$

as measured with p-A NA50 data at 400 and 450 GeV

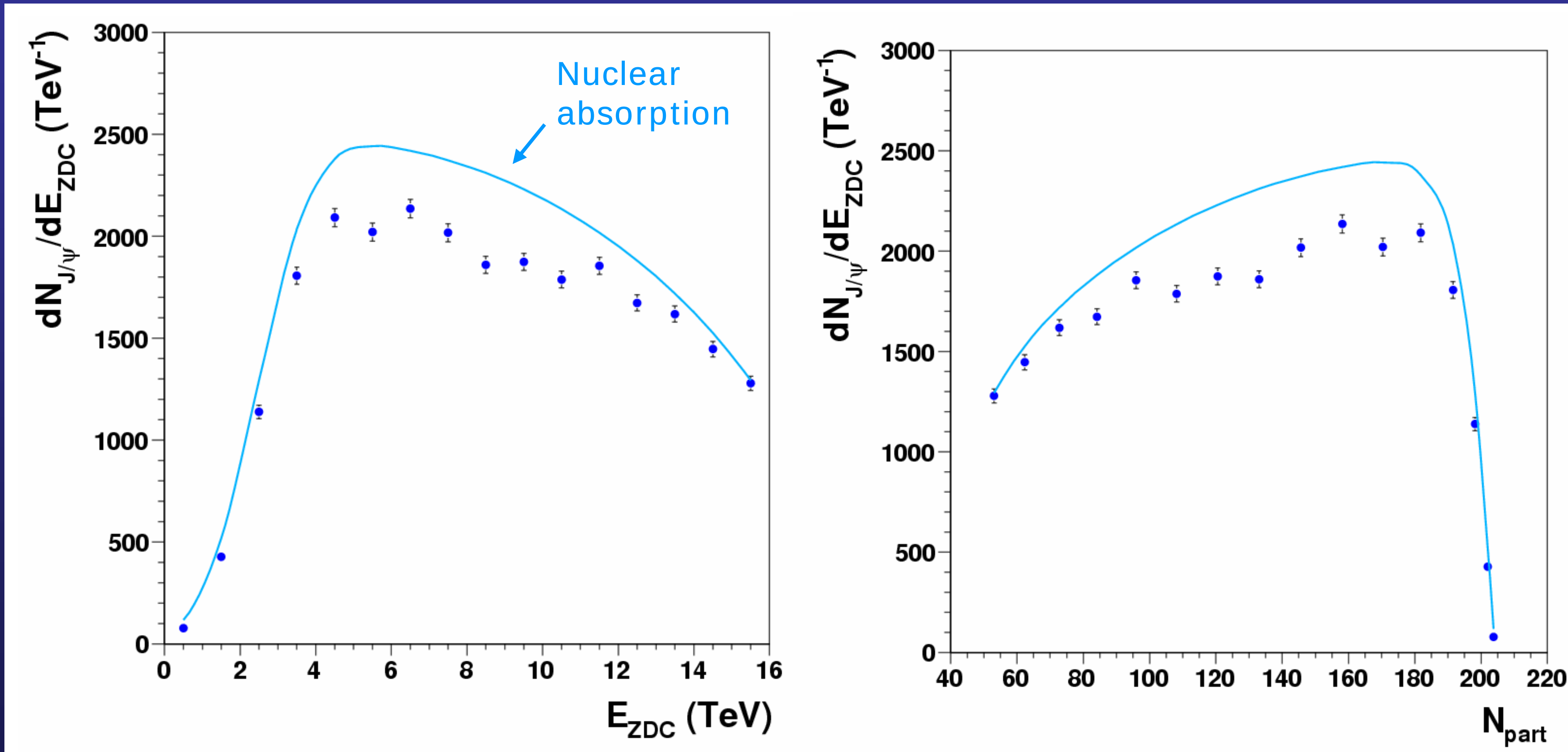
B. Alessandro et al., Eur. Phys. J. C39(2005) 335

3 centrality bins, defined through E_{ZDC}

- bin1 → $\langle N_{part}\rangle$ = 63 (E_{ZDC} > 11 TeV)
- bin2 → $\langle N_{part}\rangle$ = 123 (7 < E_{ZDC} < 11 TeV)
- bin3 → $\langle N_{part}\rangle$ = 175 (E_{ZDC} < 7 TeV)

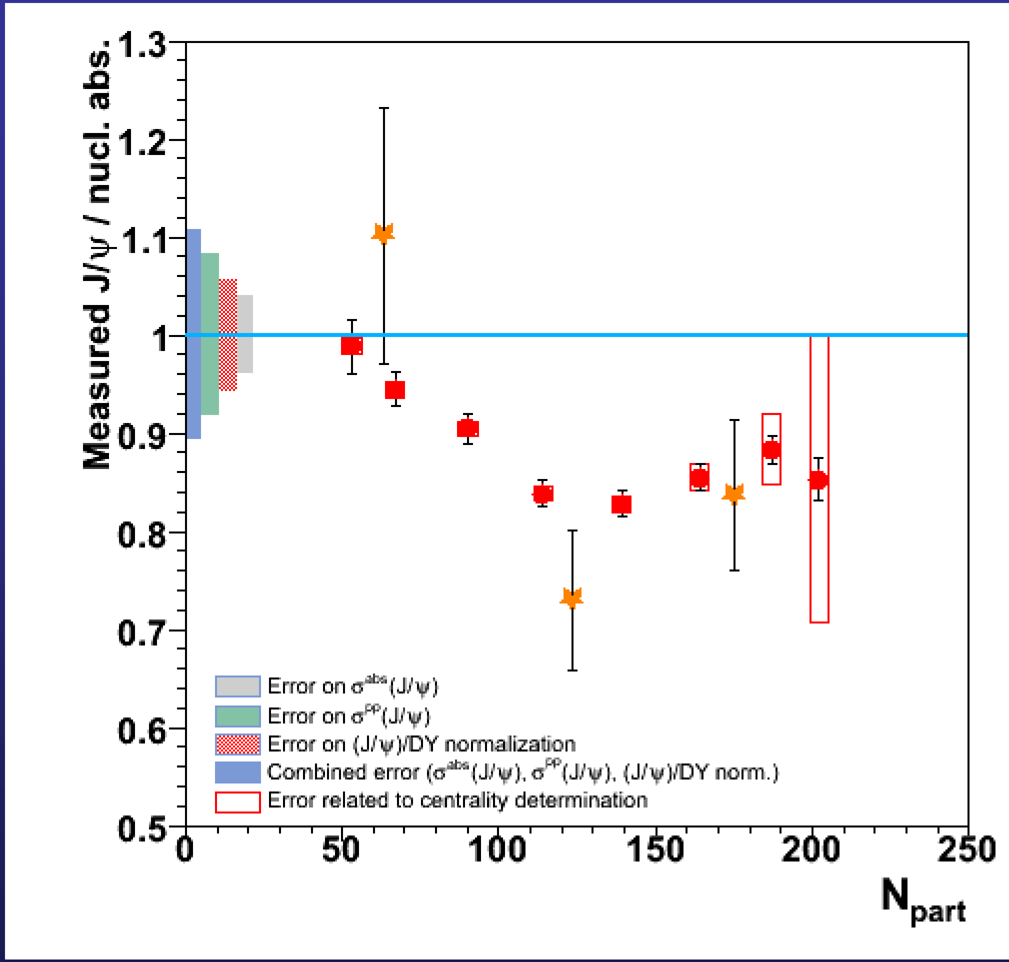
J/ψ yield vs. nuclear absorption (analysis b)

- Compare data to the expected J/ψ centrality distribution, calculated assuming nuclear absorption (with σ_{abs} =4.18 mb) as the only suppression source



Normalization of the nuclear absorption curve ➡ require the ratio measured/expected, integrated over centrality, to be equal to the same quantity from the (J/ψ)/DY analysis (0.87 ± 0.05)

Results and systematic errors



Small statistical errors

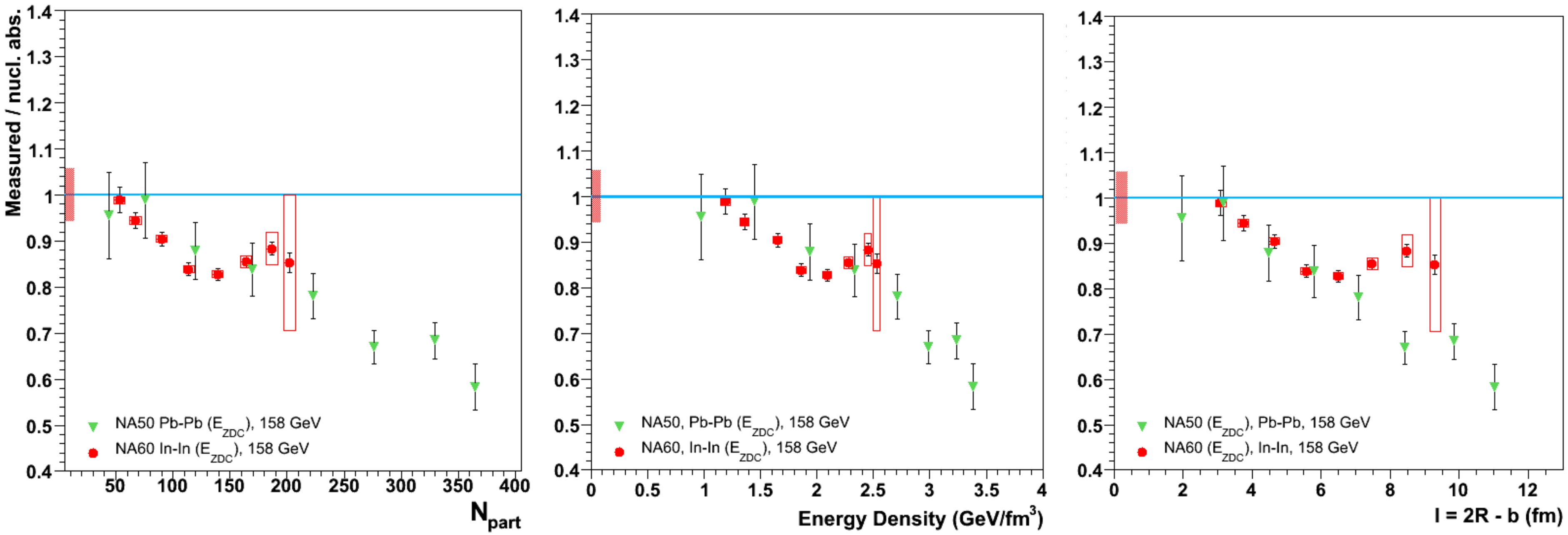
Careful study of systematic errors is needed

Sources:

- Uncertainty on normal nuclear absorption parameters ($\sigma^{abs}(J/\psi)$ and $\sigma^{pp}(J/\psi)$)
- Uncertainty on relative normalization between data and absorption curve
- Uncertainty on centrality determination (affects relative position of data and abs. curve)
  - Glauber model parameters
  - E_{ZDC} to N_{part}

- ~10% error centrality indep.→ does not affect shape of the distribution
- Partly common to analyses a and b
- (Most) Central points affected by a considerable error

Various centrality estimators

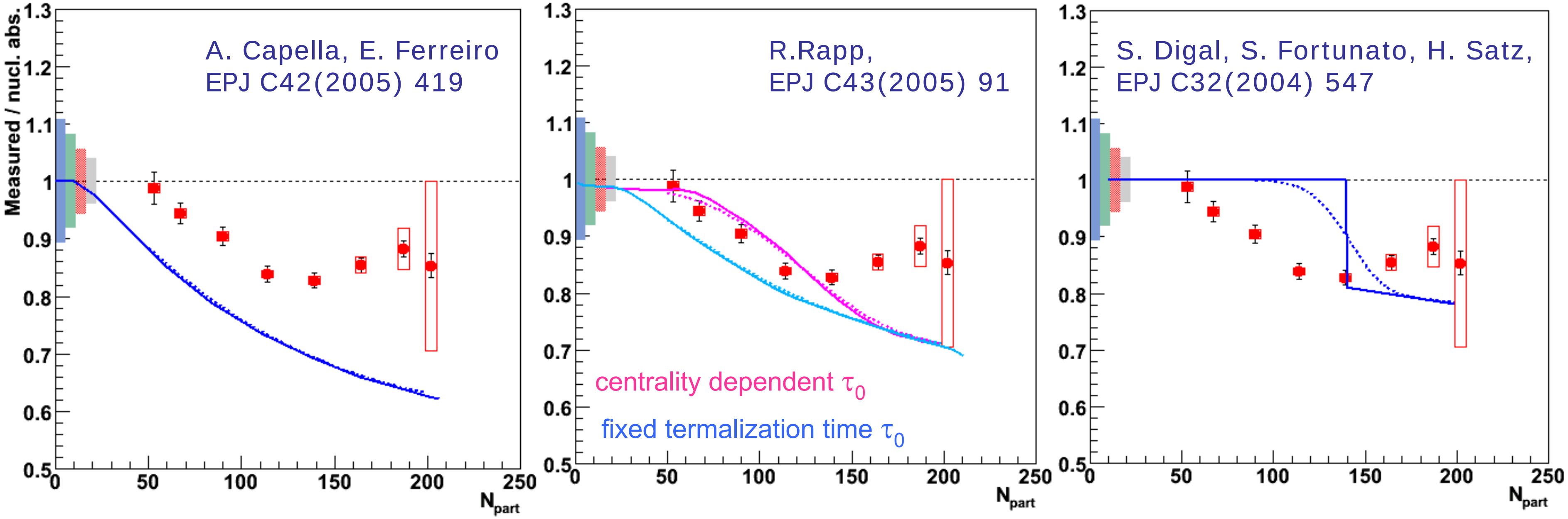


- Suppression vs
  - number of participants
  - energy density
  - fireball's transverse size

- Anomalous suppression sets in at $\varepsilon \sim 1.5$ GeV/fm^3 (τ_0=1 fm/c)
- What is the best scaling variable for the onset ?

  → Clear answer requires more accurate Pb-Pb suppression pattern

Comparison with theoretical predictions



Suppression by hadronic comovers (σ_{co} = 0.65 mb, tuned for Pb-Pb collisions)

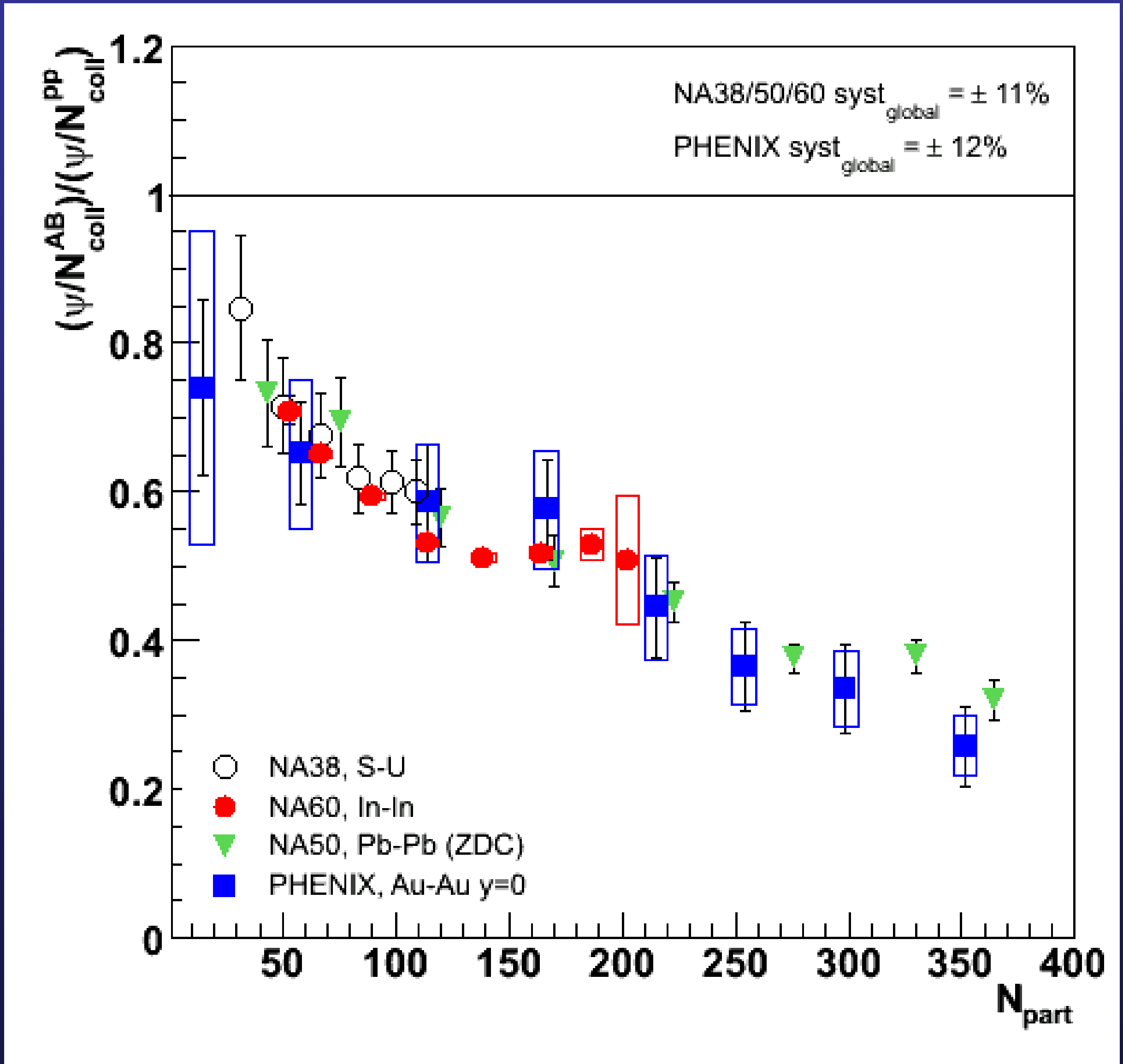
Dissociation and regeneration in QGP and hadron gas

Percolation, with onset of suppression at $N_{part}\sim 140$

- Size of the anomalous suppression reasonably reproduced
- Quantitative description not satisfactory

Comparison between SPS and RHIC

- Plot J/ψ yield vs N_{part} , normalized to collision scaling expectations



We see a nice scaling (really surprising....)

Coherent interpretation of SPS vs RHIC

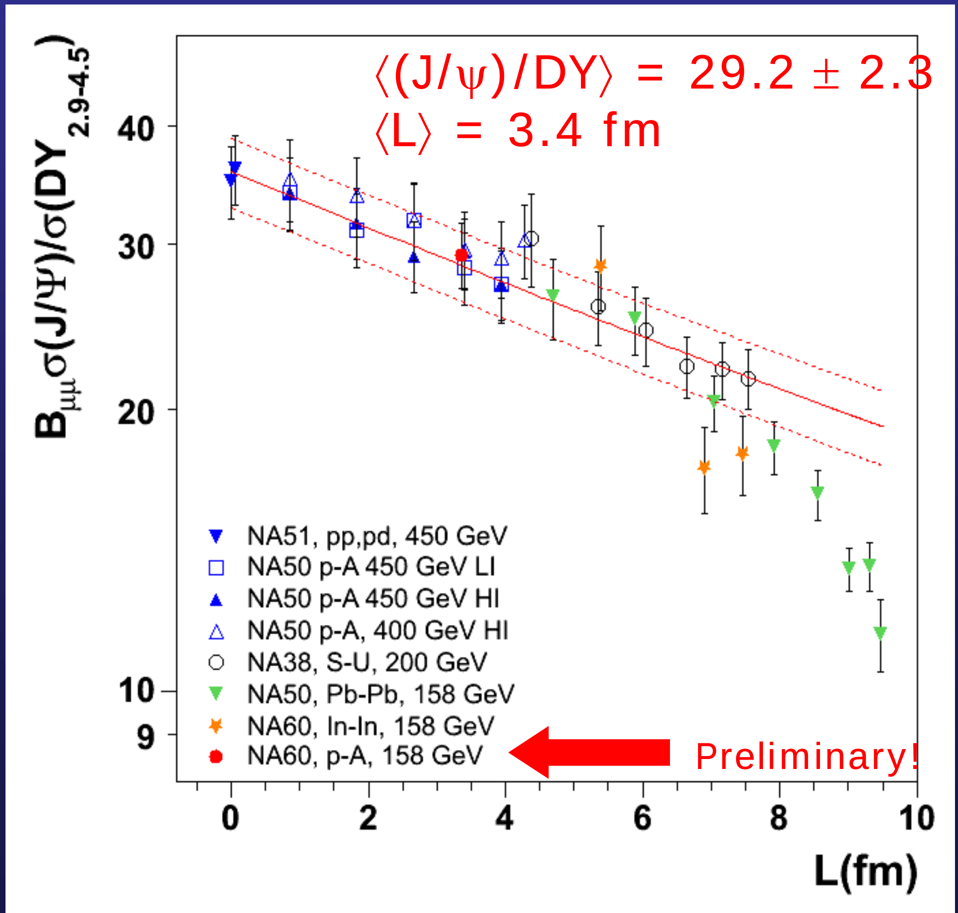
challenge for theorists

Work in this direction has already started (see e.g. Karsch, Kharzeev and Satz, PLB 637(2006) 75)

pA collisions @ 158 GeV

- Accurate proton data are an essential reference for A-A
- NA60 has taken p-A data at 158 GeV

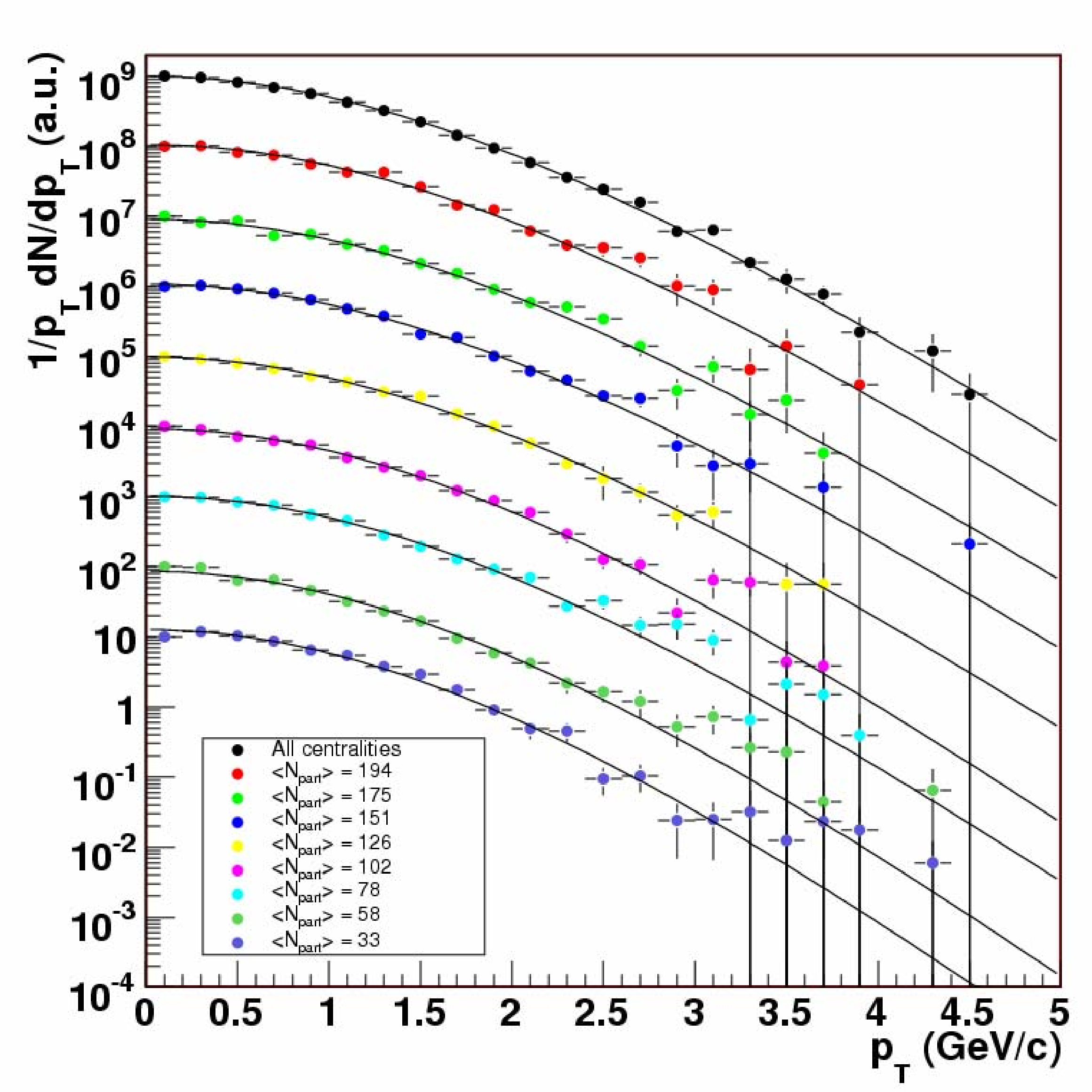
→ Obtain for the first time at SPS energy information on nuclear absorption and production yields at the same energy of A-A data



- Reduce systematic errors on the reference curve for A-A collisions, due to energy and kinematic rescaling

- Preliminary NA60 result shows that the rescaling of the J/ψ production cross section from 450(400) GeV to 158 GeV is correct !

J/ψ transverse momentum distributions



Kinematical region
$0.1 < y_{CM} < 0.9$
$-0.4 < \cos\theta_H < 0.4$

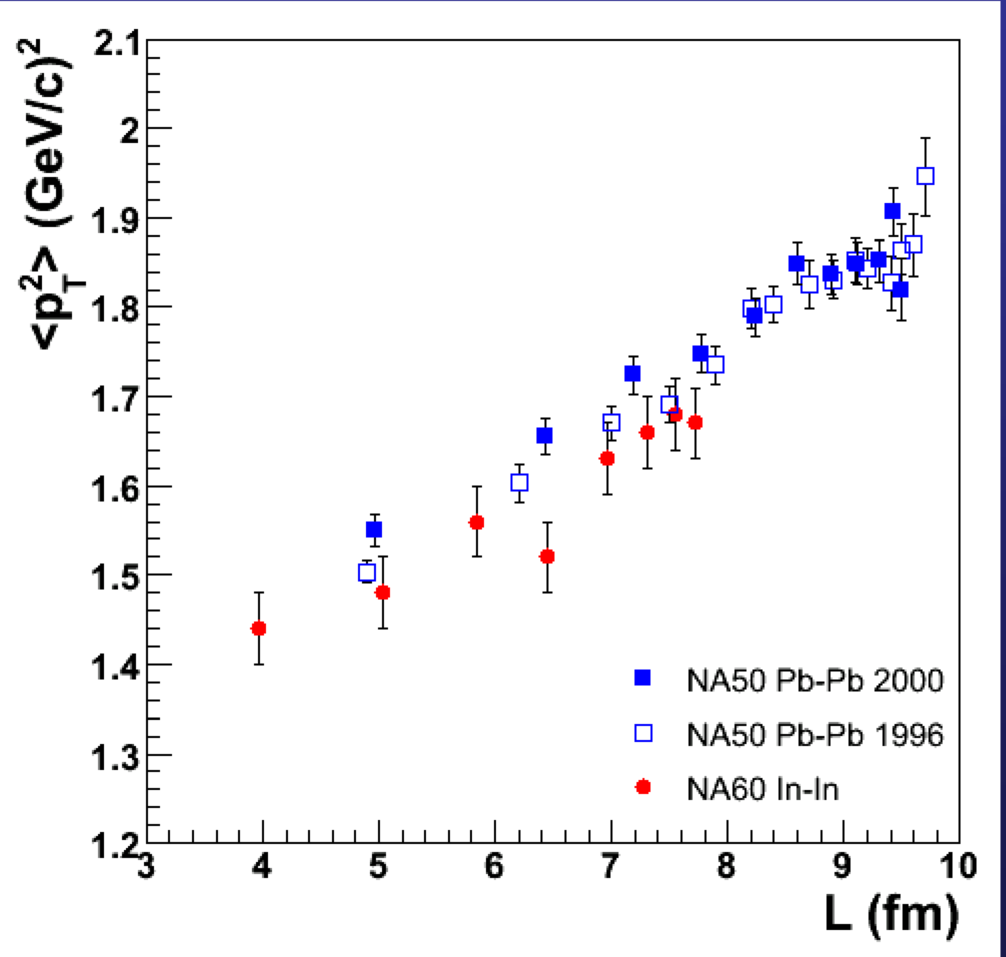
Transverse momentum distributions fitted with

$1/p_T \, dN/dp_T = e^{-mT/T}$

- Study evolution of T and $\langle p_T^2 \rangle$ with centrality

$\langle p_T^2 \rangle$ vs centrality

- If p_T broadening is due to gluon scattering in the initial state
  $\rightarrow \langle p_T^2 \rangle = \langle p_T^2 \rangle_{pp} + \alpha_{gN} \cdot L$



- NA60 In-In points are in fair agreement with Pb-Pb results

- We get

$\alpha_{gN}^{InIn} = 0.067 \pm 0.011$ (GeV/c)^2/fm
$\langle p_T^2 \rangle_{pp}^{InIn} = 1.15 \pm 0.07$ (GeV/c)^2
$\chi^2/ndf = 0.62$

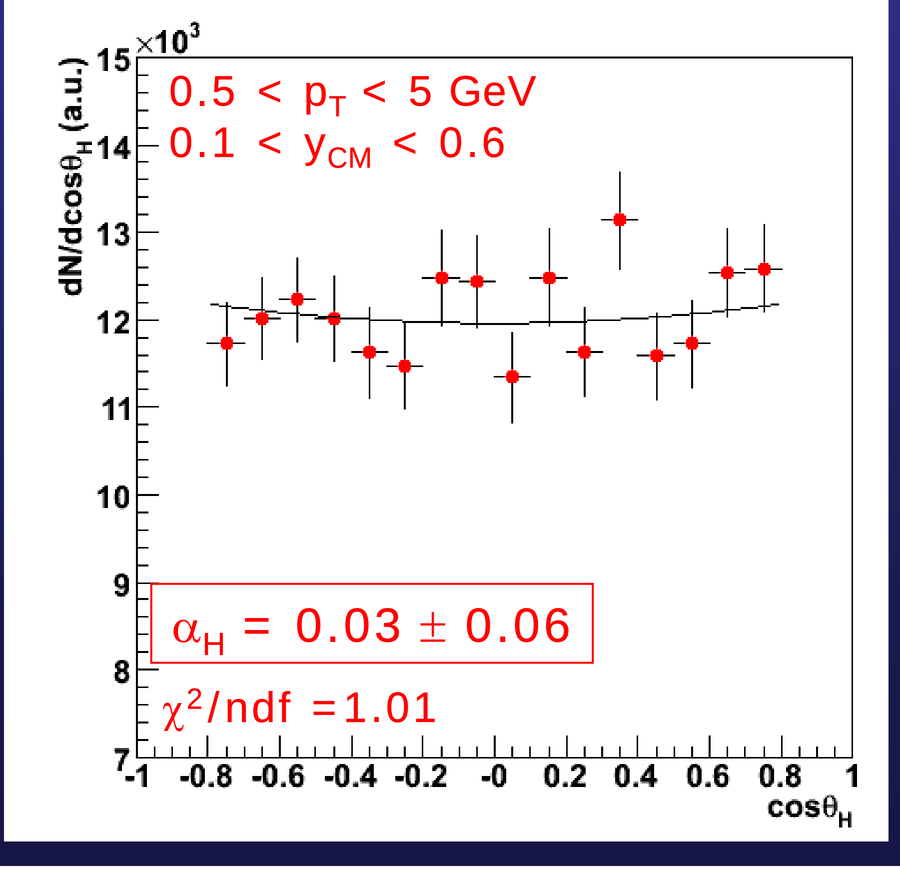
to be compared with

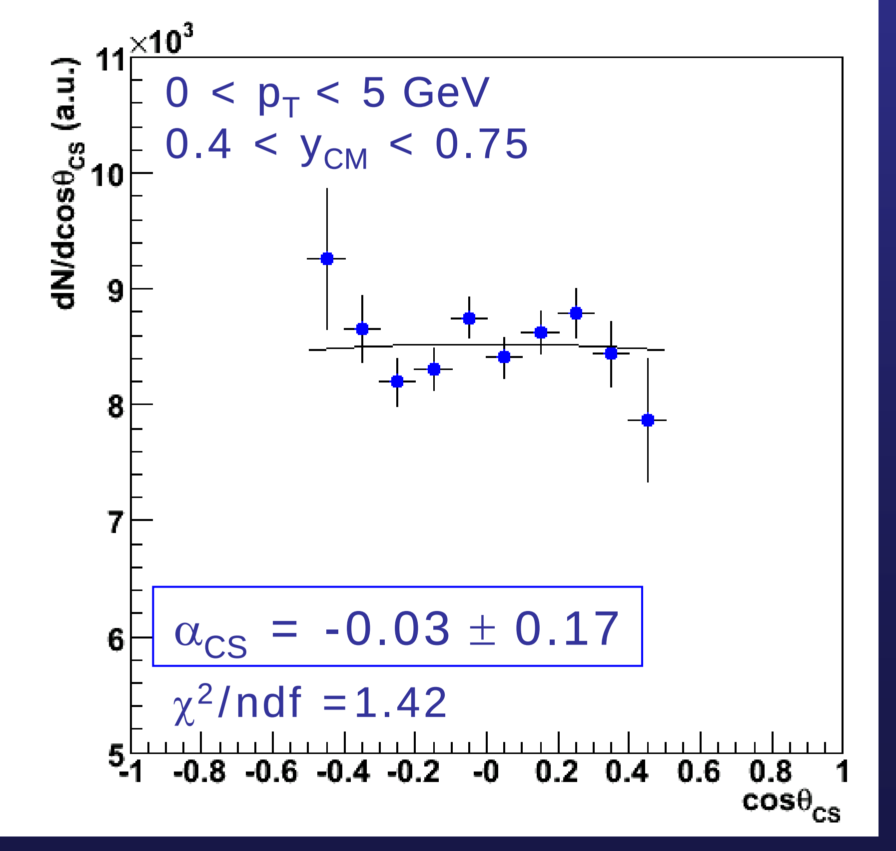
$\alpha_{gN}^{PbPb} = 0.073 \pm 0.005$ (GeV/c)^2/fm
$\langle p_T^2 \rangle_{pp}^{PbPb} = 1.19 \pm 0.04$ (GeV/c)^2
$\chi^2/ndf = 1.22$

(NA50 2000 event sample)

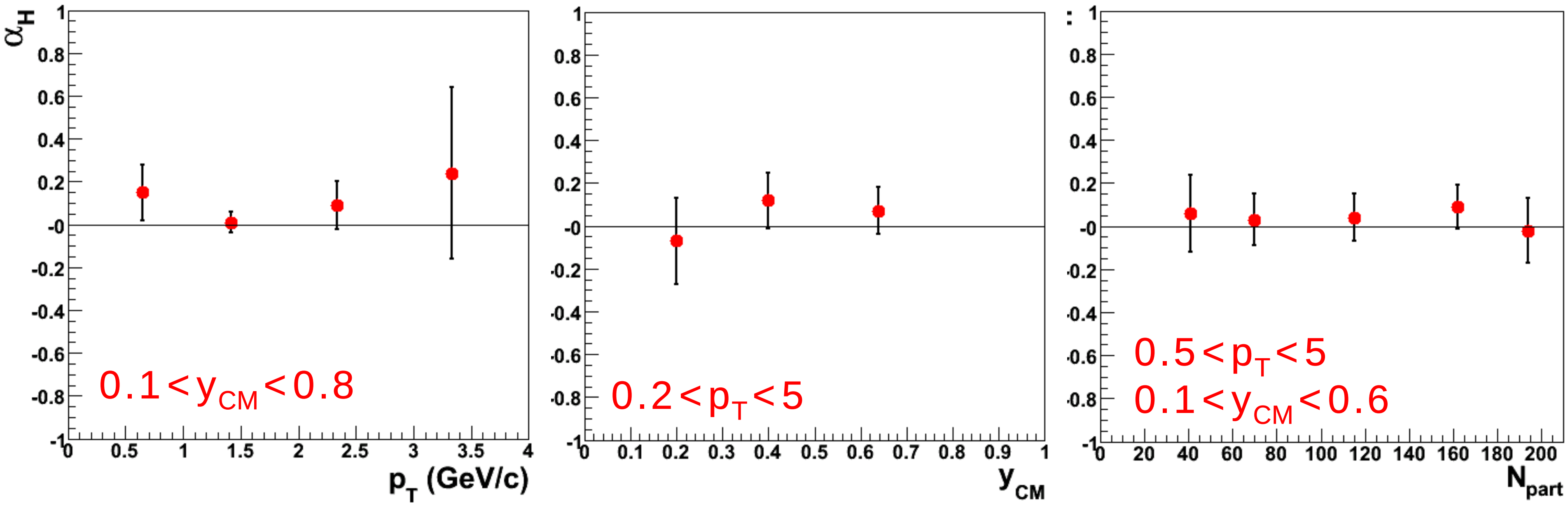
J/ψ polarization

- Quarkonium polarization → test of production models
  - CSM: transverse polarization
  - CEM: no polarization
  - NRQCD: transverse polarization at high p_T
- Deconfinement should lead to a higher degree of polarization
  (Ioffe,Kharzeev PRC 68(2003) 094013)





Polarization vs p_T, y, centrality



- Helicity reference system (good coverage in NA60, $-0.8<\cos\theta_H<0.8$)
- No significant polarization effects as a function of
  - Centrality
  - Kinematical region
- Similar results in the Collins-Soper reference frame, albeit with much narrower coverage ($-0.4<\cos\theta_{CS}<0.4$)

Conclusions and perspectives

- NA60 has performed a high-quality study of dimuon production in Indium-Indium collisions at the SPS

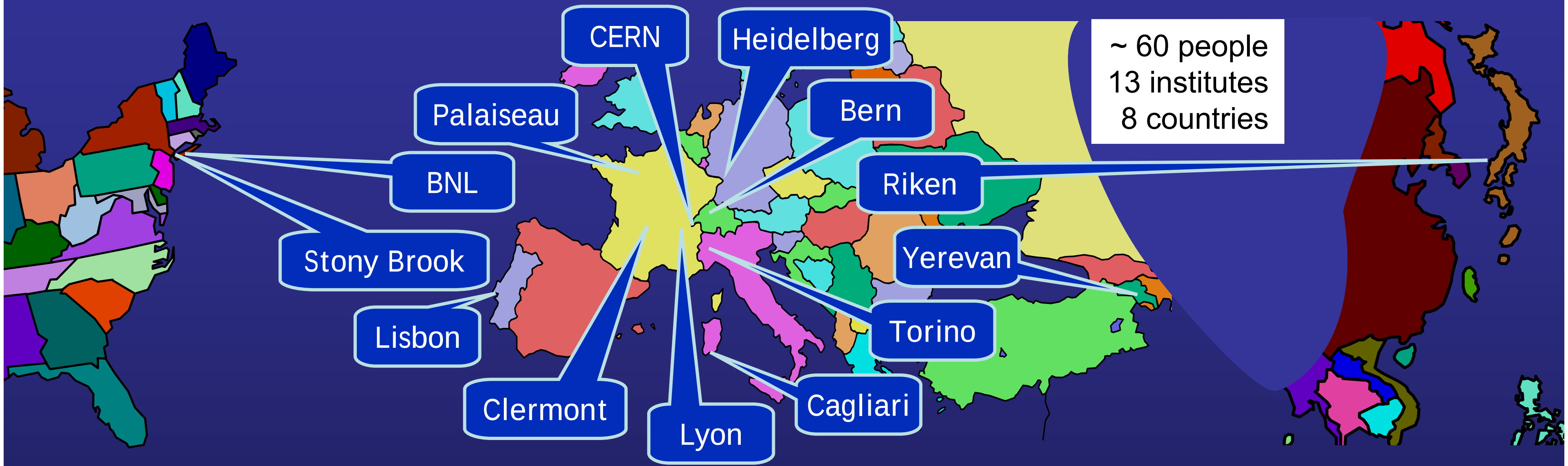
- Low masses
  - Strong broadening, but no significant mass shift of the intermediate ρ

- Intermediate masses
  - Excess is prompt, open charm production agrees with expectations
  - Excess dominated by low p_T (factor 3.5±0.4 for p_T<0.5 GeV/c)

- J/ψ
  - The anomalous suppression, seen in Pb-Pb collisions by NA50, is confirmed for a lighter system (onset at ε_{Bj} ~ 1.5 GeV/fm^3)
  - Preliminary results from p-A collisions at 158 GeV show that the normalization of the absorption curve is correct (peripheral In-In and Pb-Pb results are compatible with p-A)
  - No J/ψ polarization, p_T distributions sensitive to initial state effects

The NA60 collaboration

http://cern.ch/na60



R. Arnaldi, R. Averbeck, K. Banicz, K. Borer, J. Buytaert, J. Castor, B. Chaurand, W. Chen, B. Cheynis, C. Cicalò, A. Colla, P. Cortese, S. Damjanović, A. David, A. de Falco, N. de Marco, A. Devaux, A. Drees, L. Ducroux, H. En'yo, A. Ferretti, M. Floris, P. Force, A.A. Grigoryan, J.Y. Grossiord, N. Guettet, A. Guichard, H. Gulkanyan, J. Heuser, M. Keil, L. Kluberg, Z. Li, C. Lourenço, J. Lozano, F. Manso, P. Martins, A. Masoni, A. Neves, H. Ohnishi, C. Oppedisano, P. Parracho, P. Pillot, T. Poghosyan, G. Puddu, E. Radermacher, P. Ramalhete, P. Rosinsky, E. Scomparin, J. Seixas, S. Serci, R. Shahoyan,P. Sonderegger, H.J. Specht, R. Tieulent, E. Tveiten, G. Usai, H. Vardanyan, R. Veenhof and H. Wöhri

Backup slides

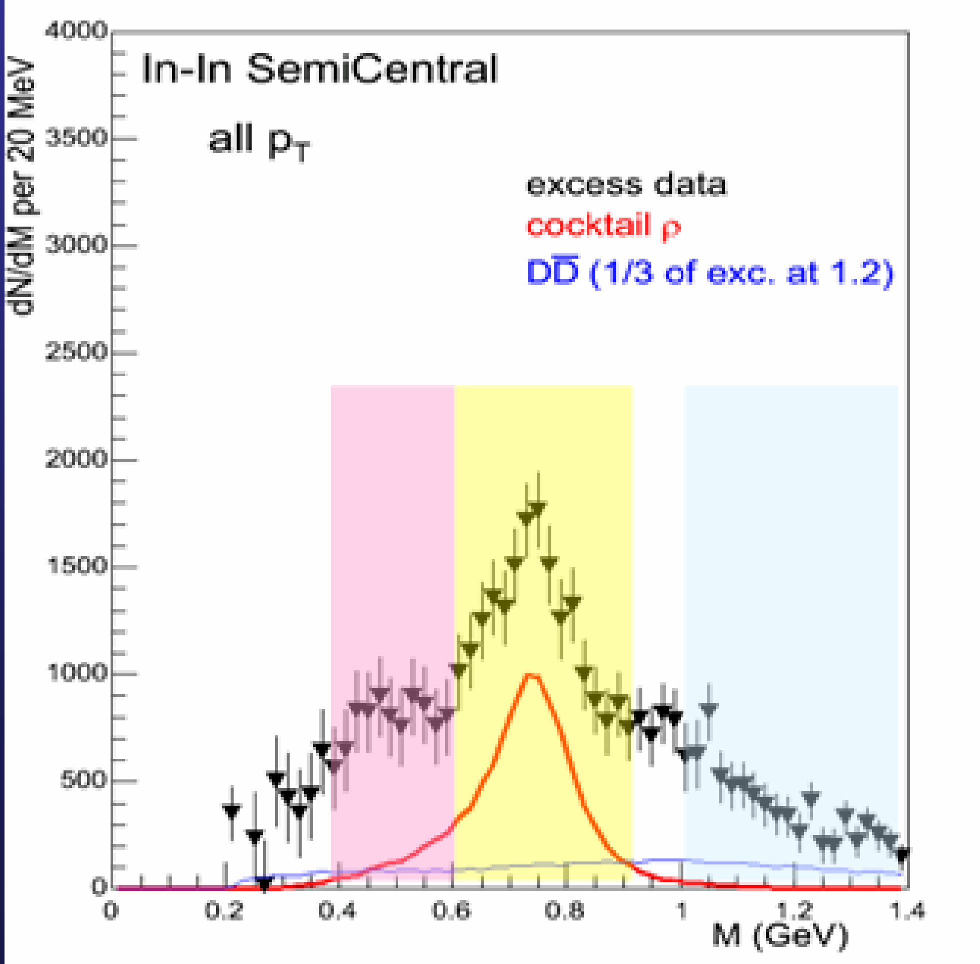
p_T spectra - acceptance correction

- Reduce 3-dimensional acceptance correction in M-p_T-y to a 2-dimensional correction in M-p_T, using measured y distribution as an input. Use ϕ for control
- Use slices of
  Δm = 0.1 GeV
  Δp_T = 0.2 GeV
- Check behaviour on 3 extended mass windows

  0.4<M<0.6 GeV

  0.6<M<0.9 GeV

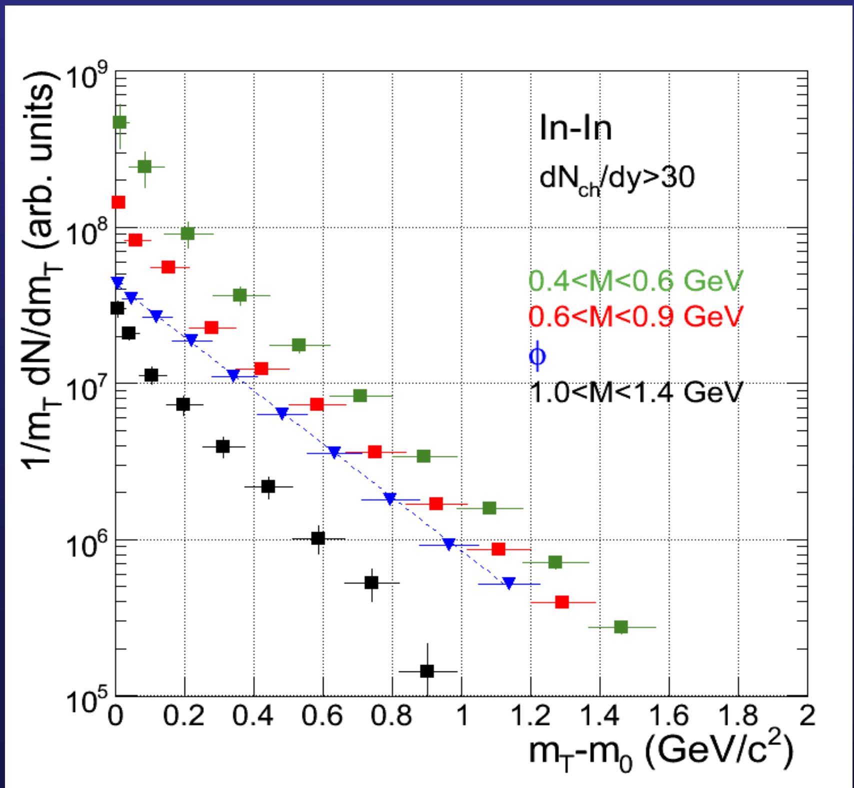
  1.0<M<1.4 GeV



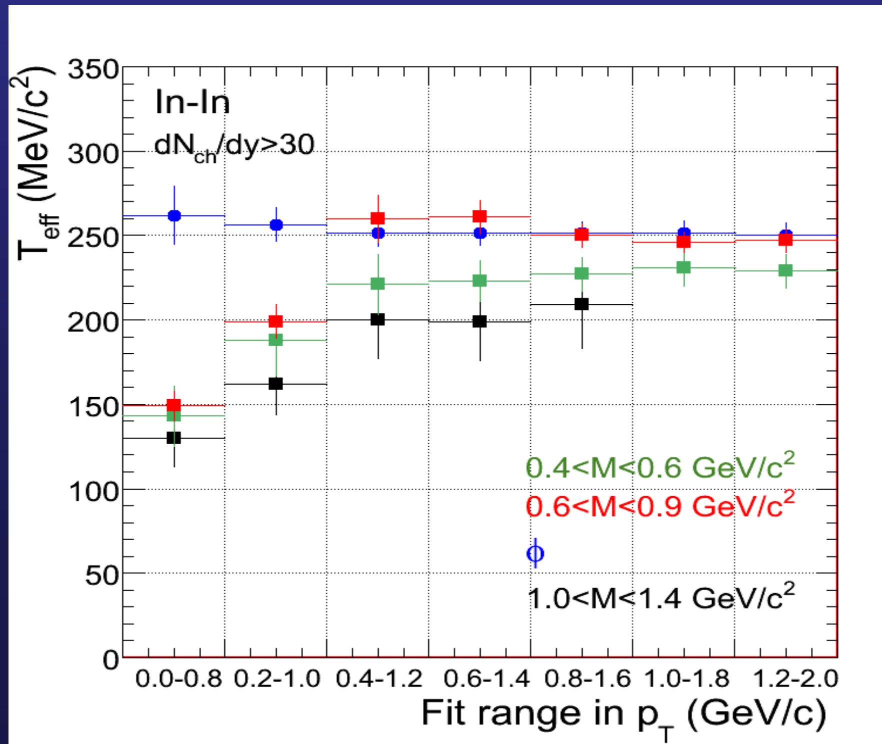
Subtract charm from the data (based on NA60 IMR results) before acceptance correction

First look to transverse momentum distributions

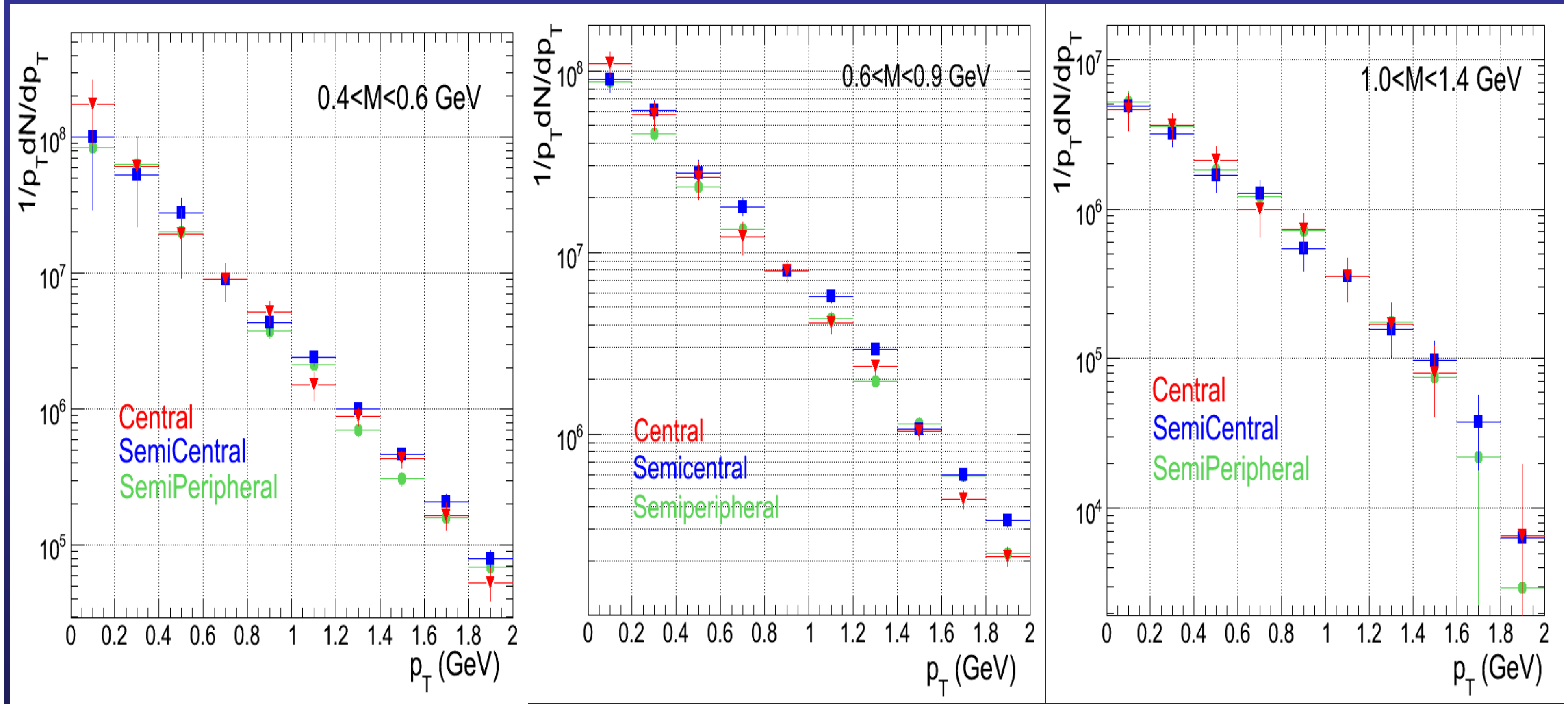
- Trend at small m_T opposite to what expected from radial flow
- High mass interval shows steepest slope $\rightarrow$ smaller T slope



- Differential fits with gliding windows of Δp_T=0.8 GeV $\rightarrow$ local slope T_{eff}
- At high p_T, ρ-like region hardest, high mass region softest!
- Not explained by theory



Excess p_T spectra: 3 centrality bins



Hardly any centrality dependence

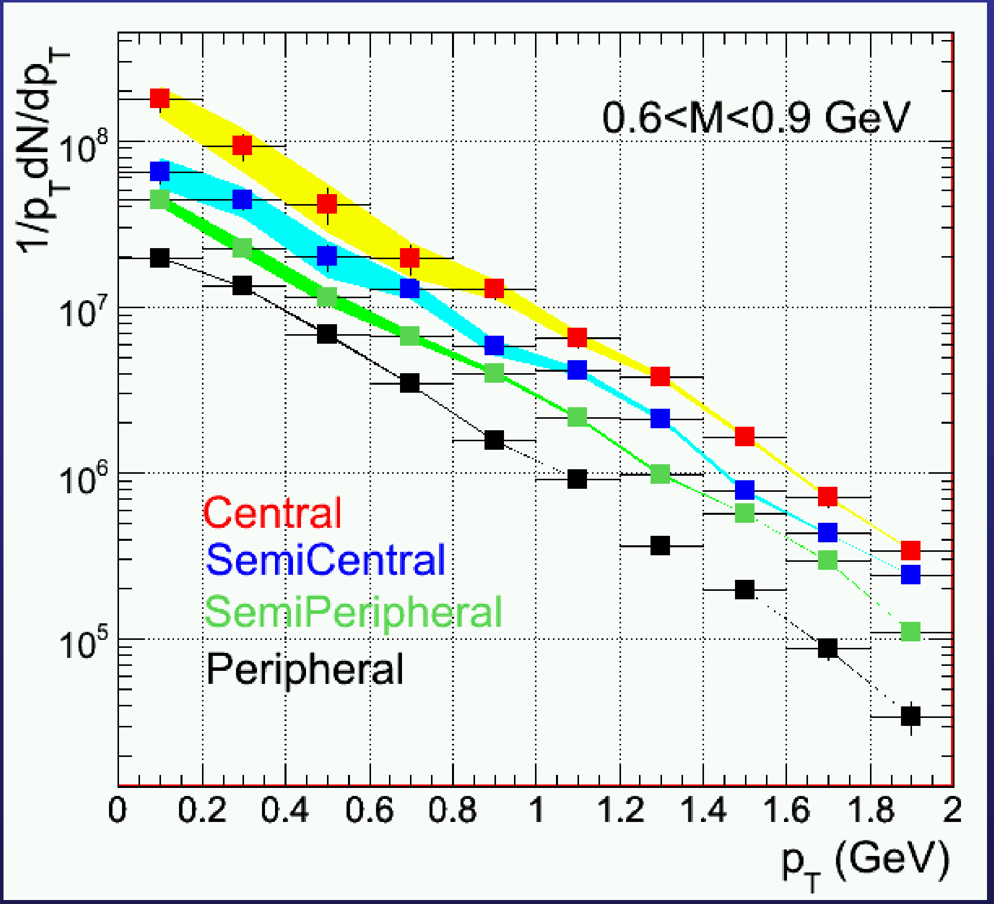
BUT

Significant mass dependence

Systematics of low-p_T data: combinatorial background

- Enhanced yield at low-p_T seen at all centralities, including the peripheral bin
- Errors at low p_T, due to subtraction of combinatorial background:

peripheral	1%
semiperipheral	10%
semicentral	20%
central	25%



Enhanced yield at low p_T not due to incorrect subtraction of combinatorial background

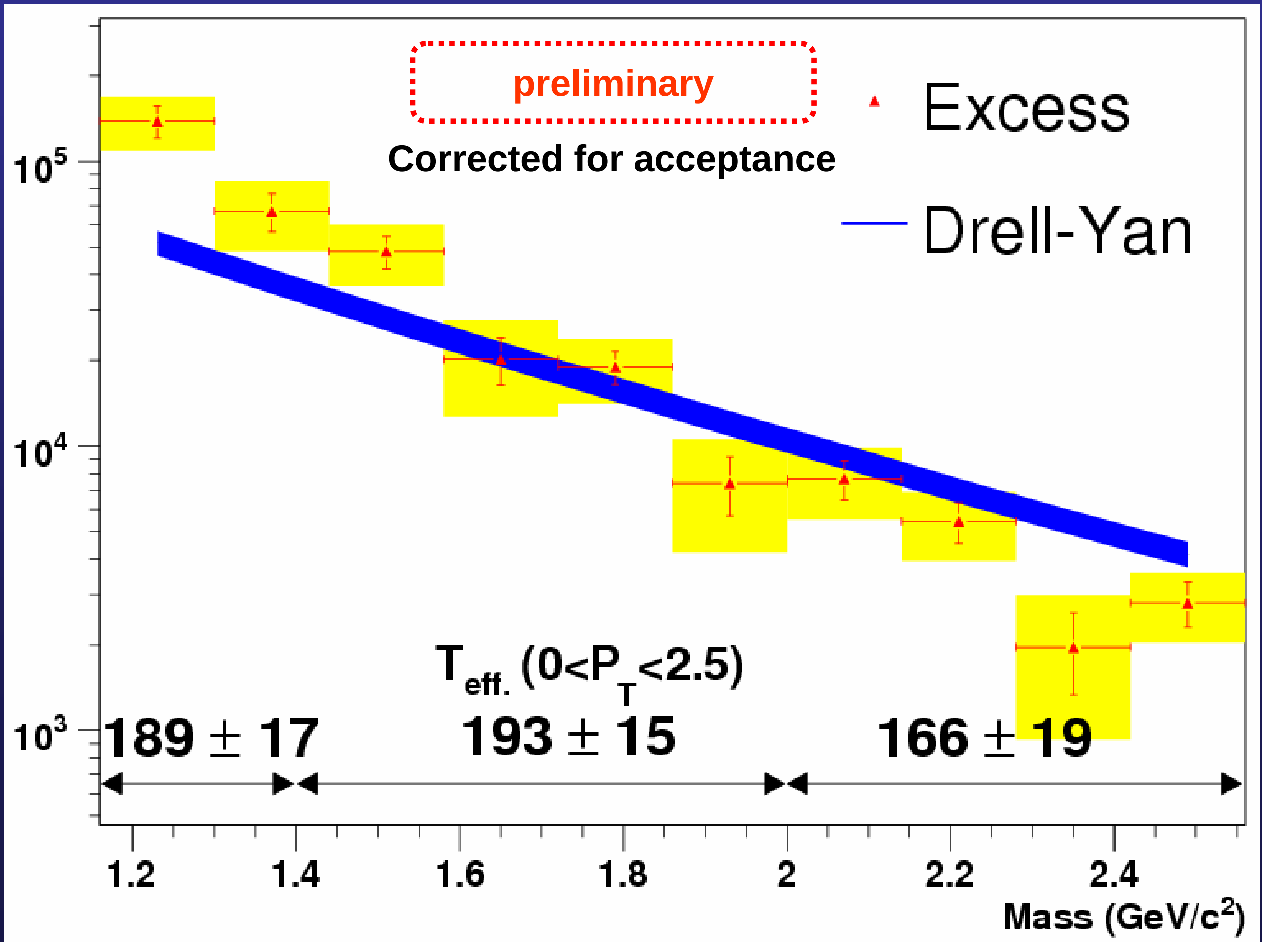
Mass spectrum ($1.16<M<2.56$ GeV/c^2)

Contributions to IMR corrected for the acceptance in

$-0.5 < \cos\theta < 0.5$

$2.92 < y_{lab} < 3.92$

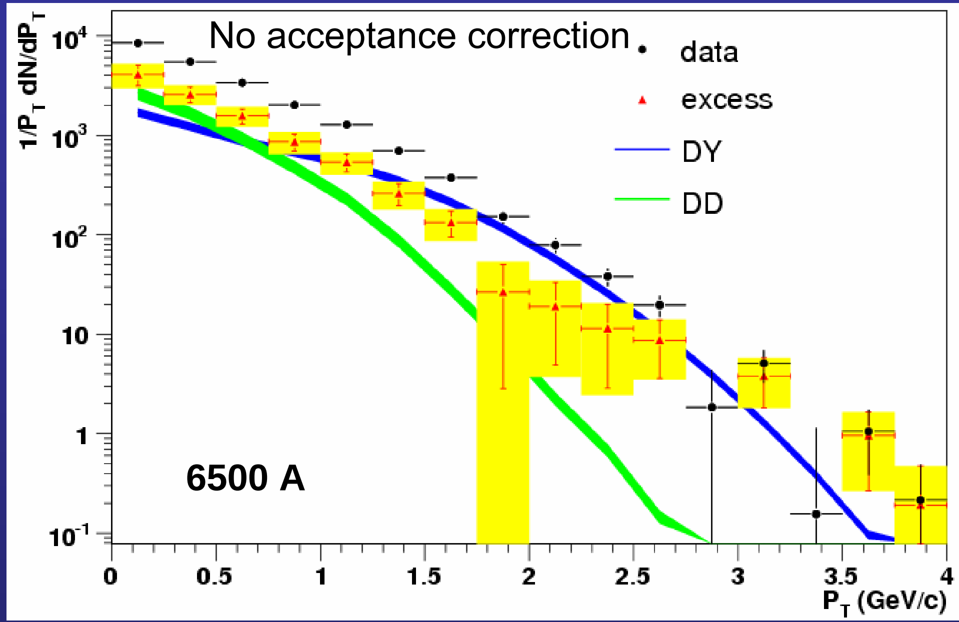
(both 4000 and 6500 A data sample used)



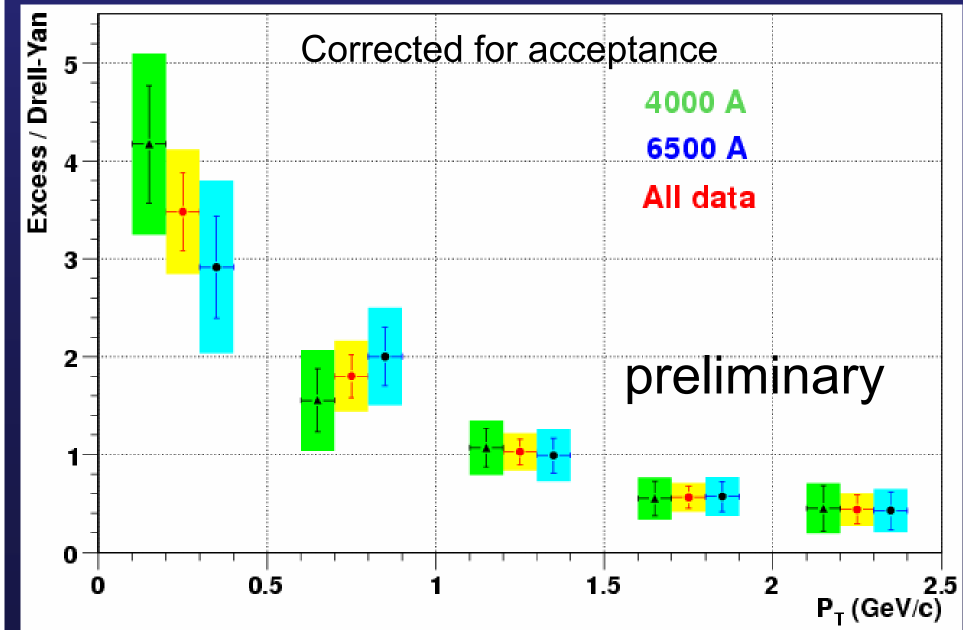
Estimates systematic errors on T_{eff} are ~ 20 MeV

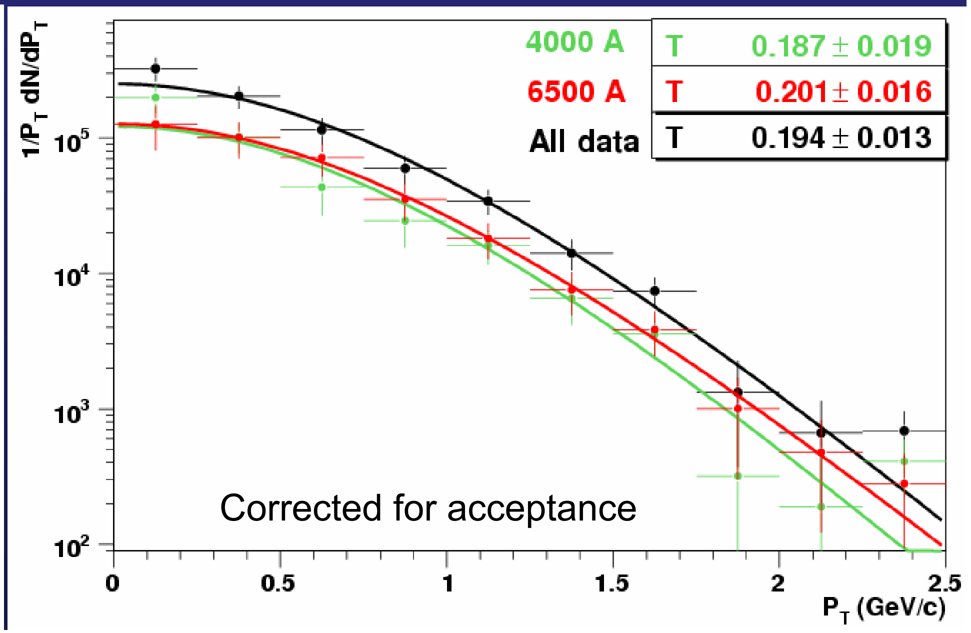
p_T dependence of the excess

High p_T tail strongly depends on the correctness of Drell-Yan description by Pythia

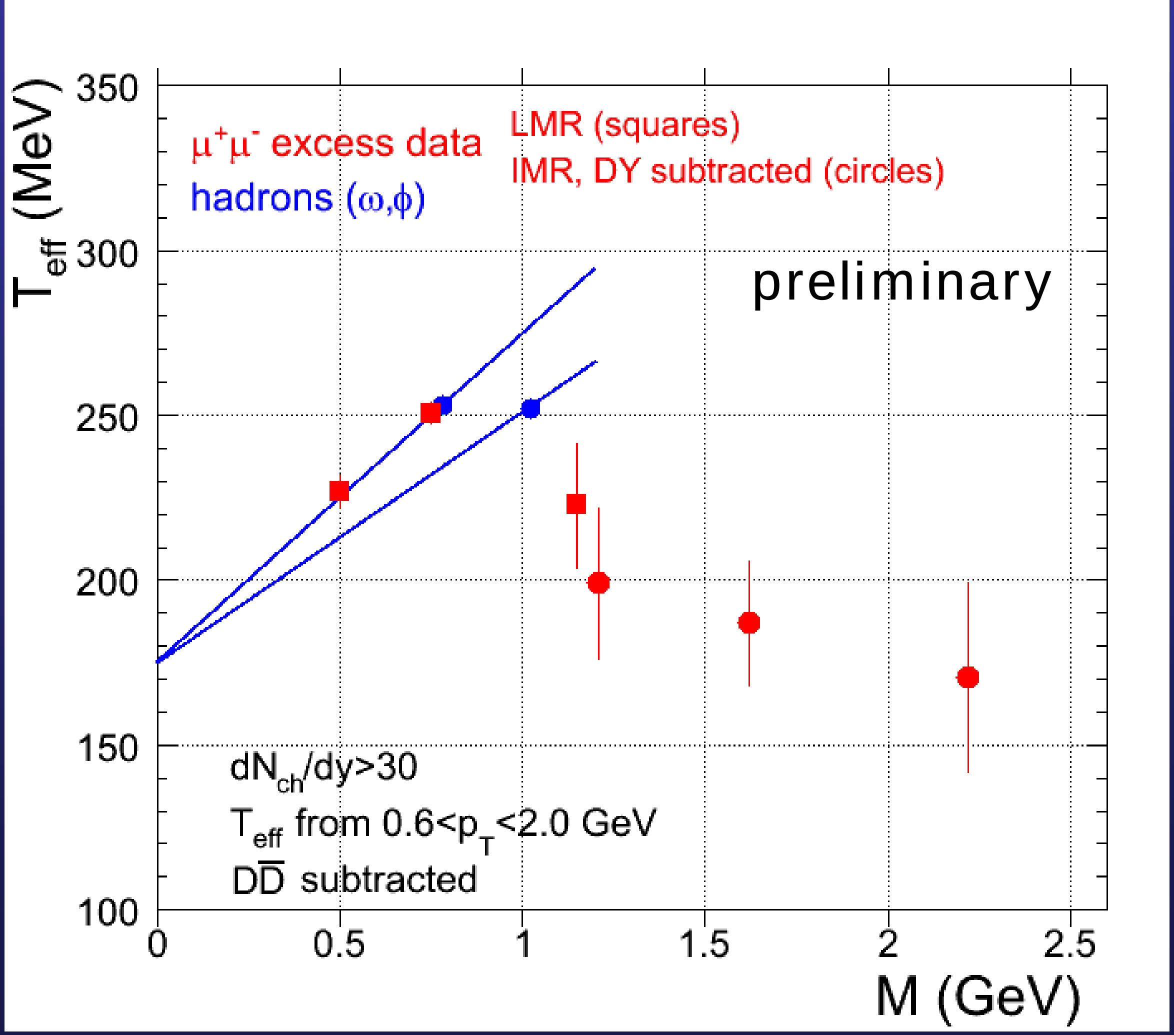


T_{eff} fits are performed in the region $0 < P_T < 2.5$ GeV/c

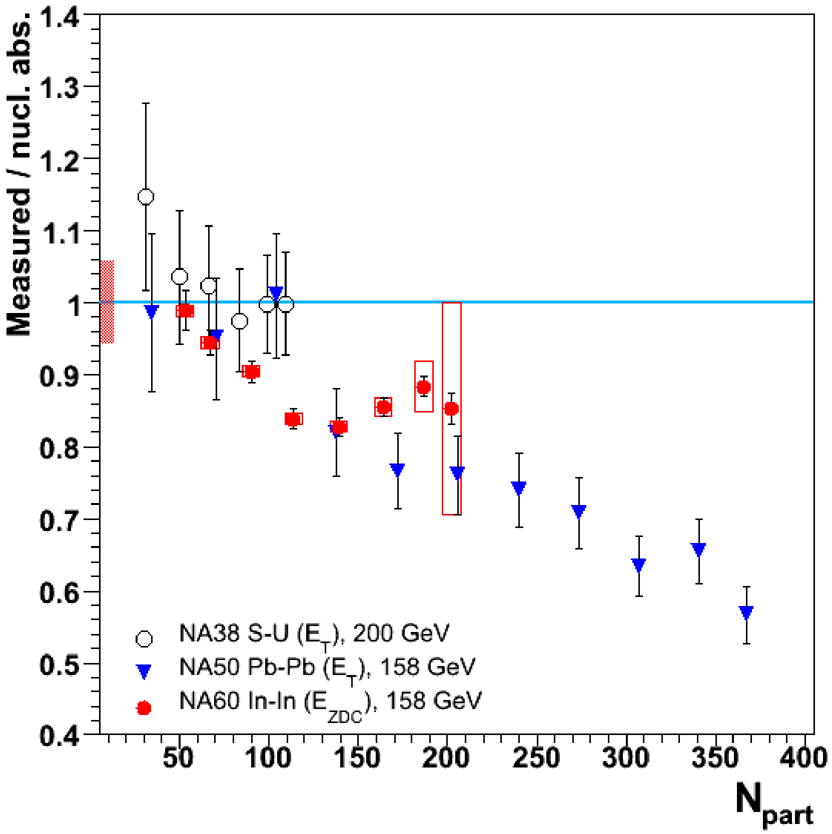


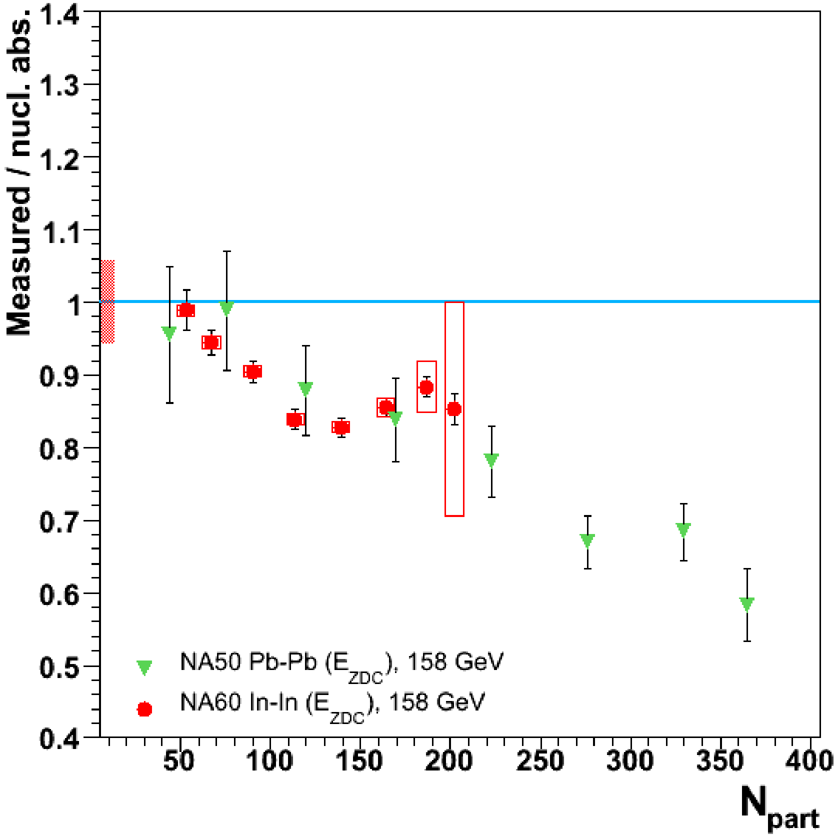


Towards a “unification” of low and intermediate dimuon mass regions: evolution of excess T_{eff} vs $M_{\mu\mu}$



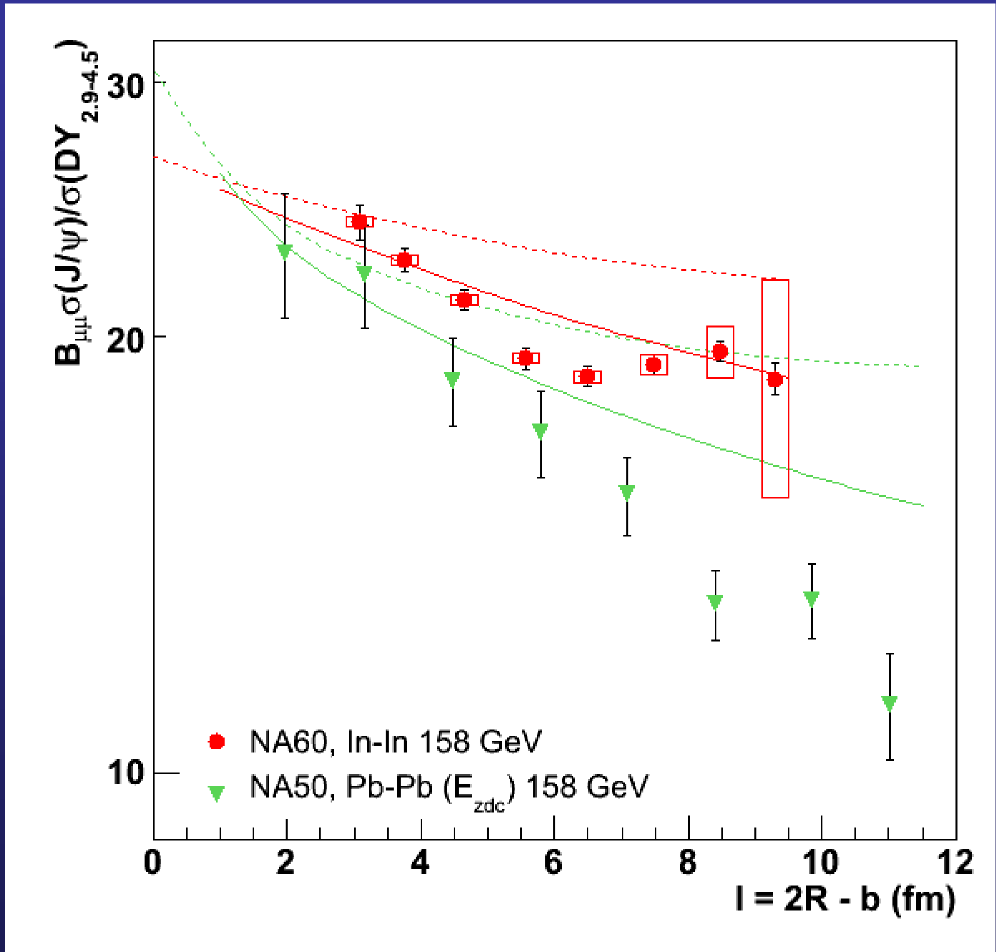
Comparison with previous results vs N_{Part}





- NA50: N_{part} estimated through E_T (left), or E_{ZDC} (right, as in NA60)
  - Good agreement with PbPb
  - S-U data seem to show a different behavior

Maximum hadronic absorption

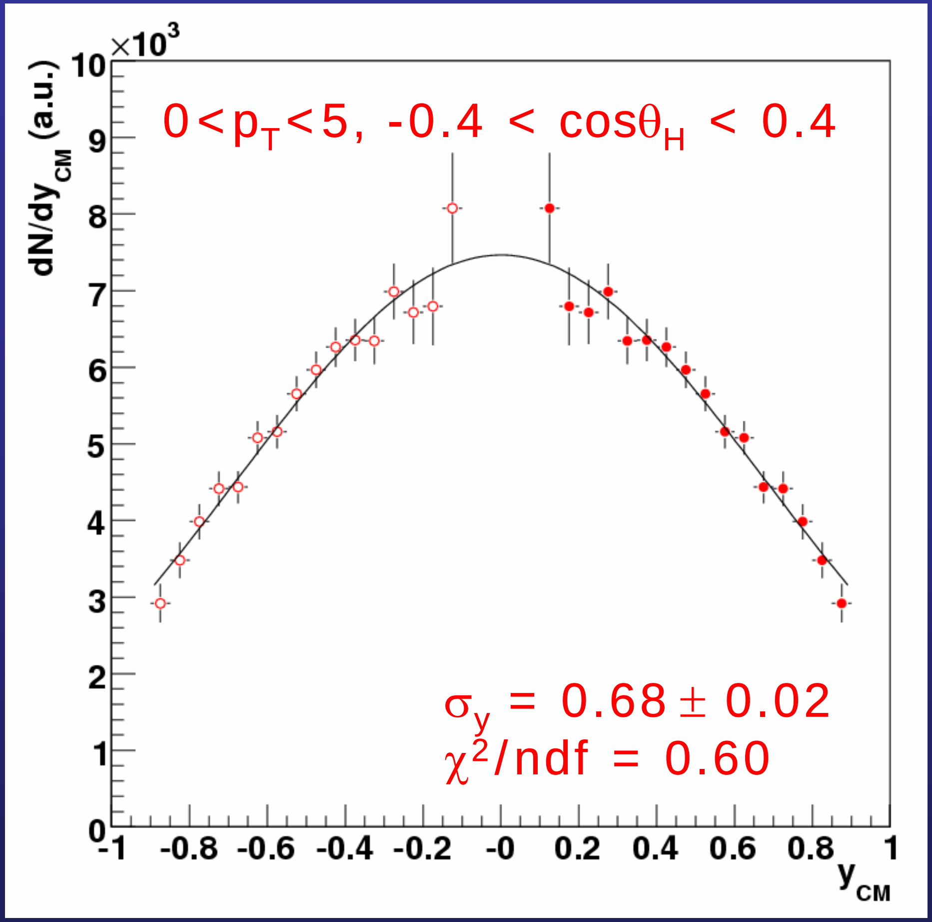


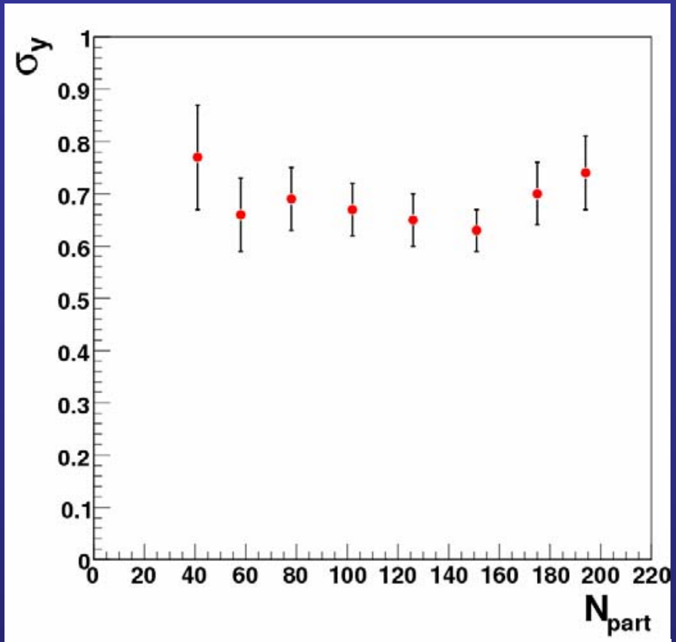
- Compare J/ψ yield to calculations assuming
  - Nuclear absorption
  - Maximum possible absorption in a hadron gas (T = 180 MeV)

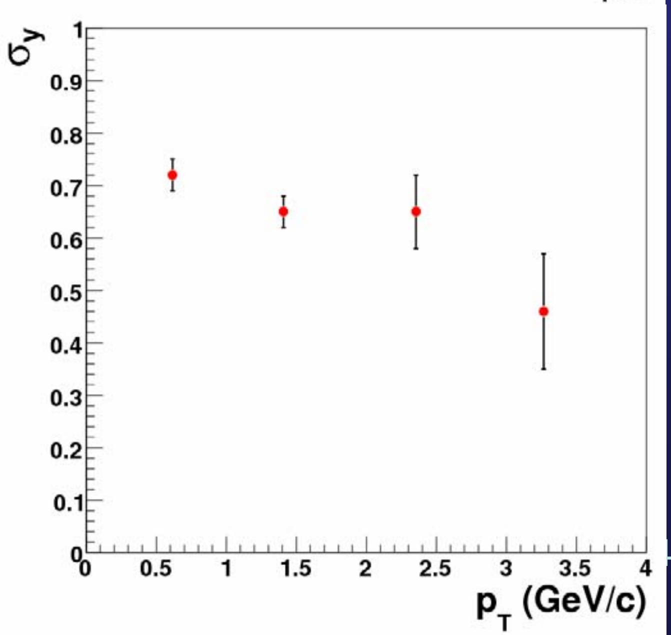
L. Maiani et al., Nucl.Phys. A748(2005) 209
F. Becattini et al., Phys. Lett. B632(2006) 233

- Both Pb-Pb and (to a lesser extent) In-In show extra-suppression

J/ψ rapidity distributions



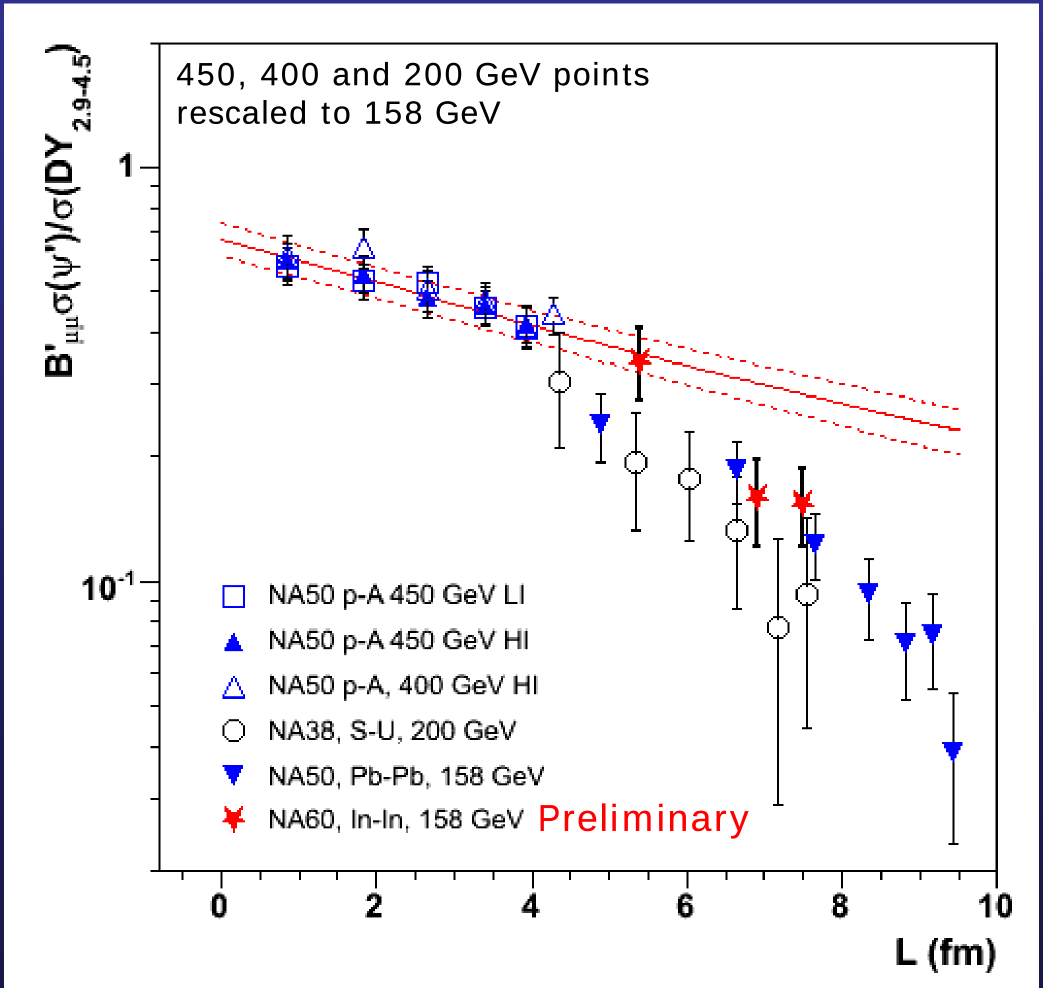




- Data are consistent with a gaussian rapidity distribution
  - Centrality independent
  - Slightly narrower at high p_T ?

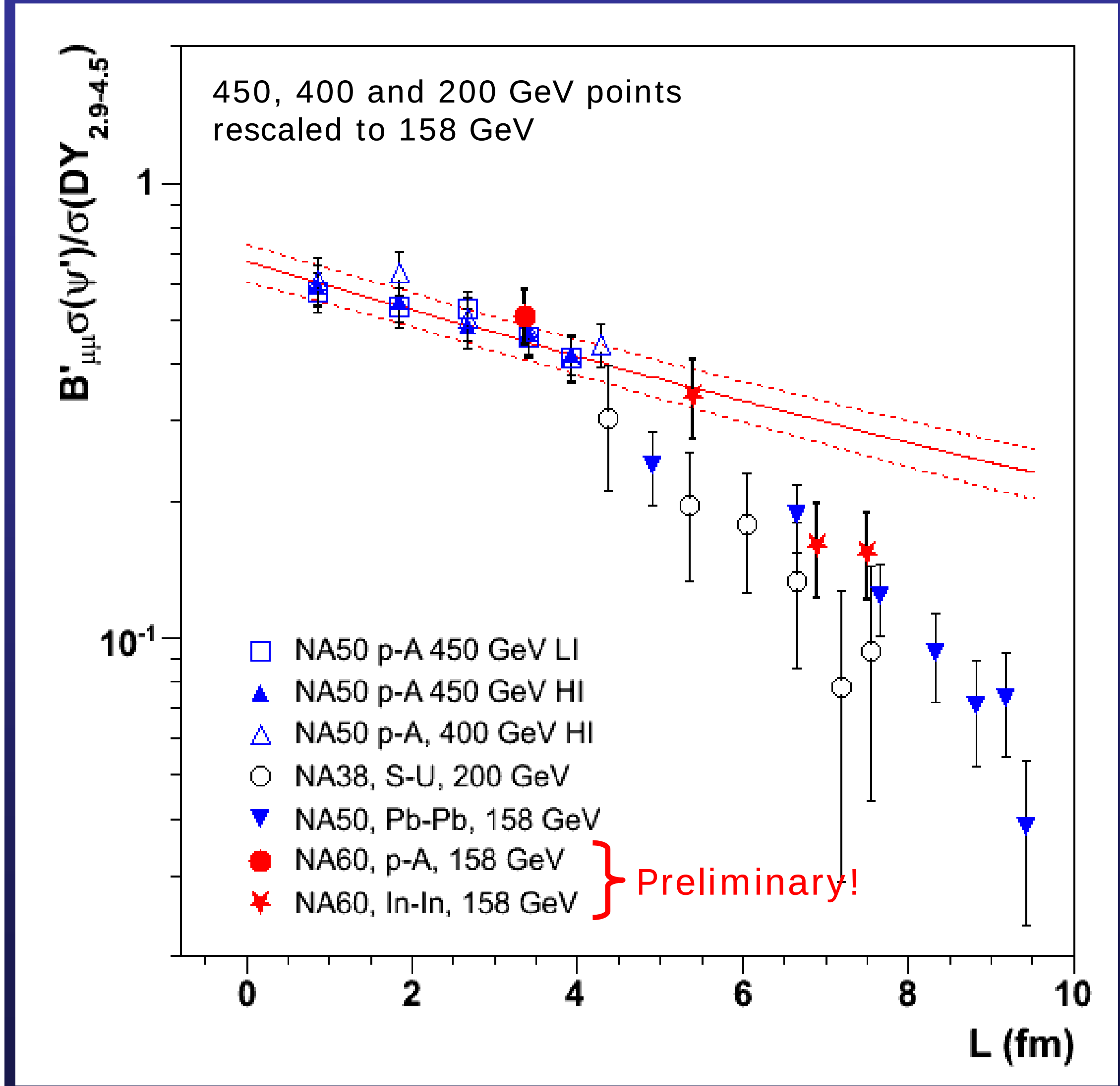
ψ' suppression in In-In collisions

- Use selection 2 (matching of muon spectrometer tracks)
- Study limited by statistics ($N_{\psi'}$ ~ 300)
- Normalized to Drell-Yan yields



- Most peripheral point (⟨N_{part}⟩ ~ 60) does not show an anomalous suppression
- Good agreement with Pb-Pb results

ψ' / DY



$\langle\psi'/DY\rangle = 0.51 \pm 0.07$
$\langle L\rangle = 3.4$ fm

Also the ψ' value measured by NA60 at 158 GeV is in good agreement with the normal absorption pattern, calculated from 450 (400) GeV data