Dimuon Measurements by NA60

Axel Drees, Stony Brook University
RHIC AGS Users Meeting, June 2007, BNL

- NA60 overview
- Charmonium production: J/ψ
- Intermediate mass dimuons and open charm
- m_T distribution from dimuons
- Summary

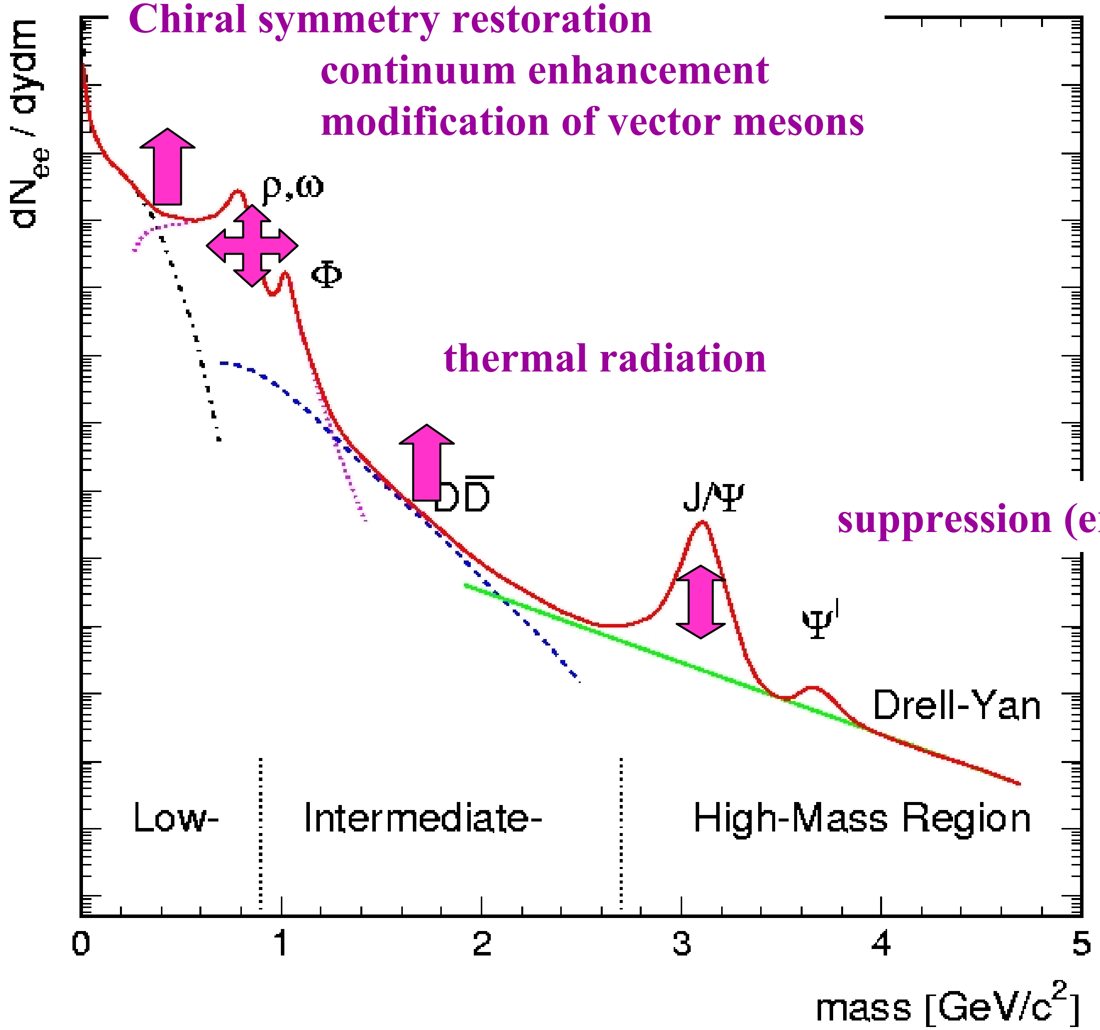
Lepton-Pair (NA60) Physics Topics

Modifications due to QCD phase transition

Chiral symmetry restoration
continuum enhancement
modification of vector mesons

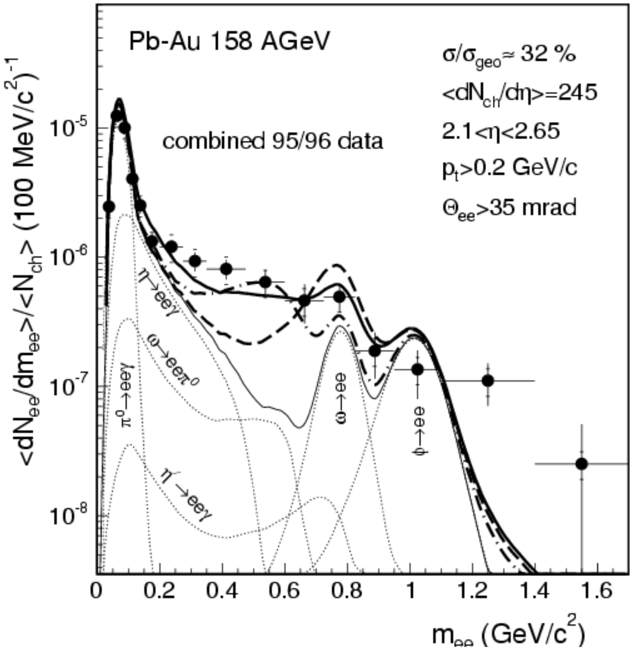
thermal radiation

suppression (enhancement)



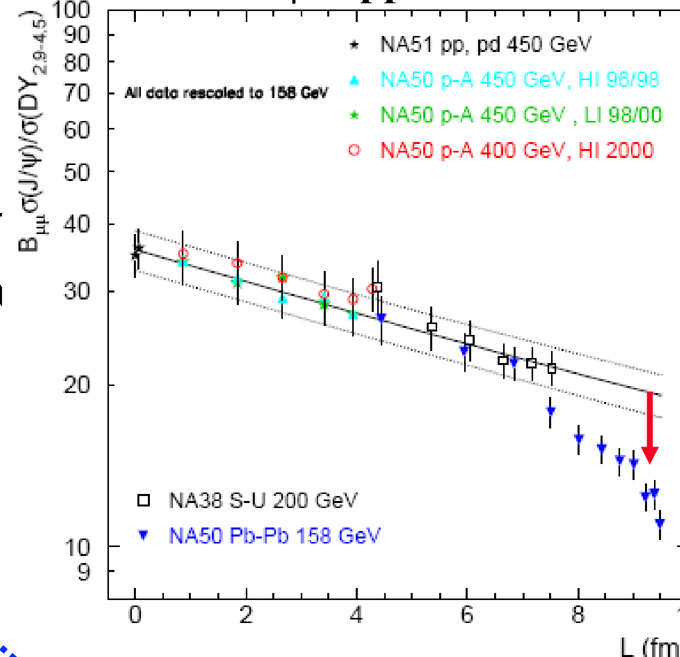
Many medium effects expected in dilepton spectra

Discoveries at the SPS

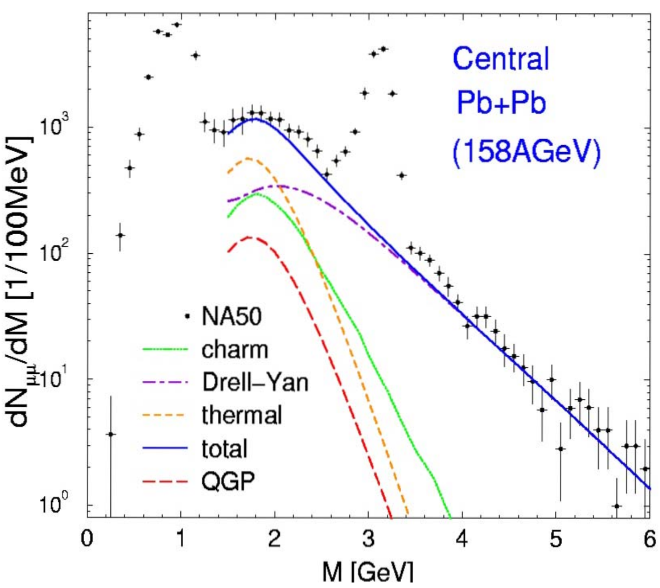


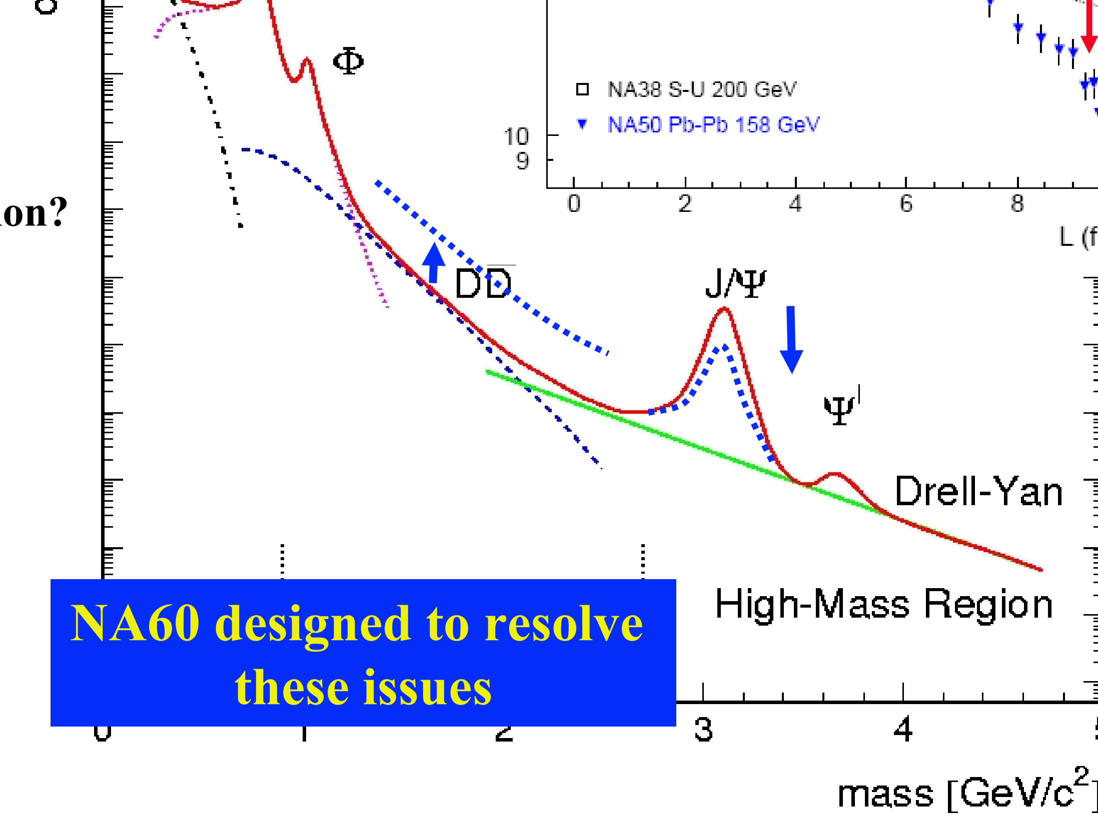
medium modified spectral functions?

J/ψ suppression



Charm enhancement or thermal radiation?



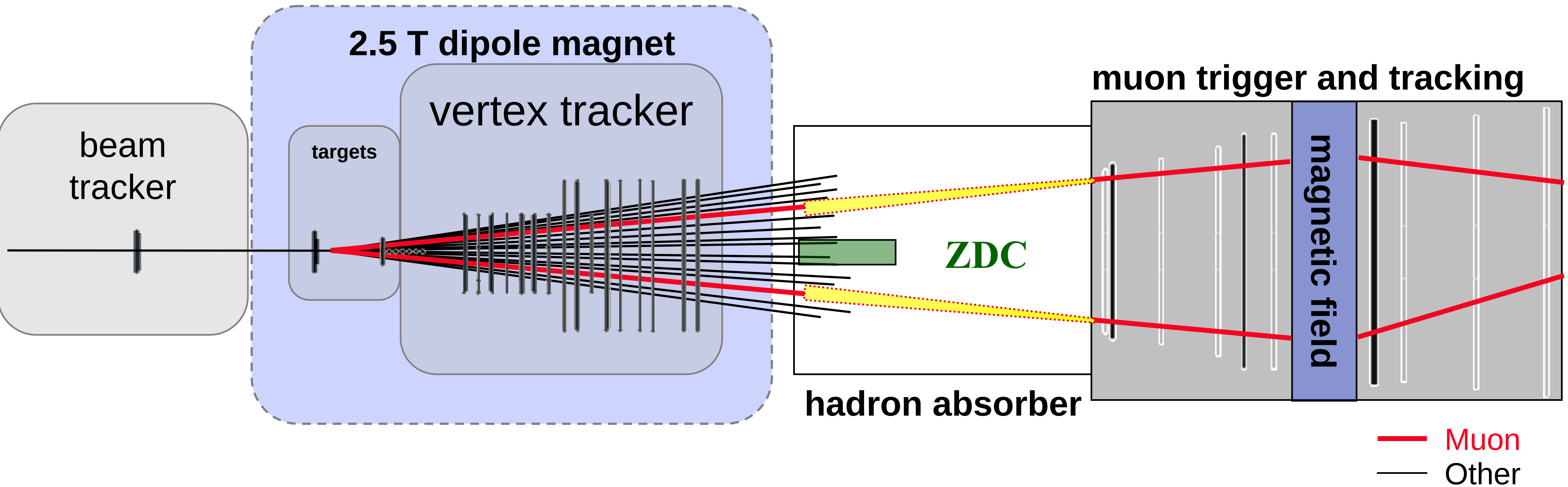


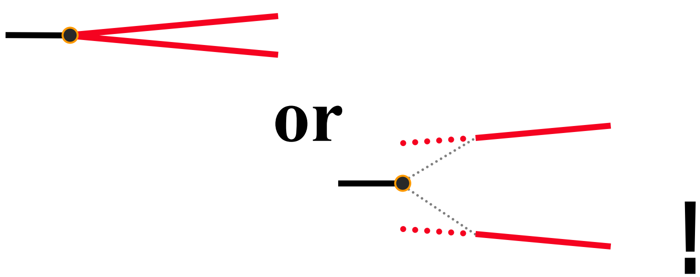
NA60 designed to resolve these issues

NA60 Detector Setup

Silicon Pixel Vertex Telescope

Muon Spectrometer (NA50)





Matching of muon tracks in position and momentum space

Improved dimuon mass resolution, reduced background, and open heavy flavor identifiction

STONY BROOK

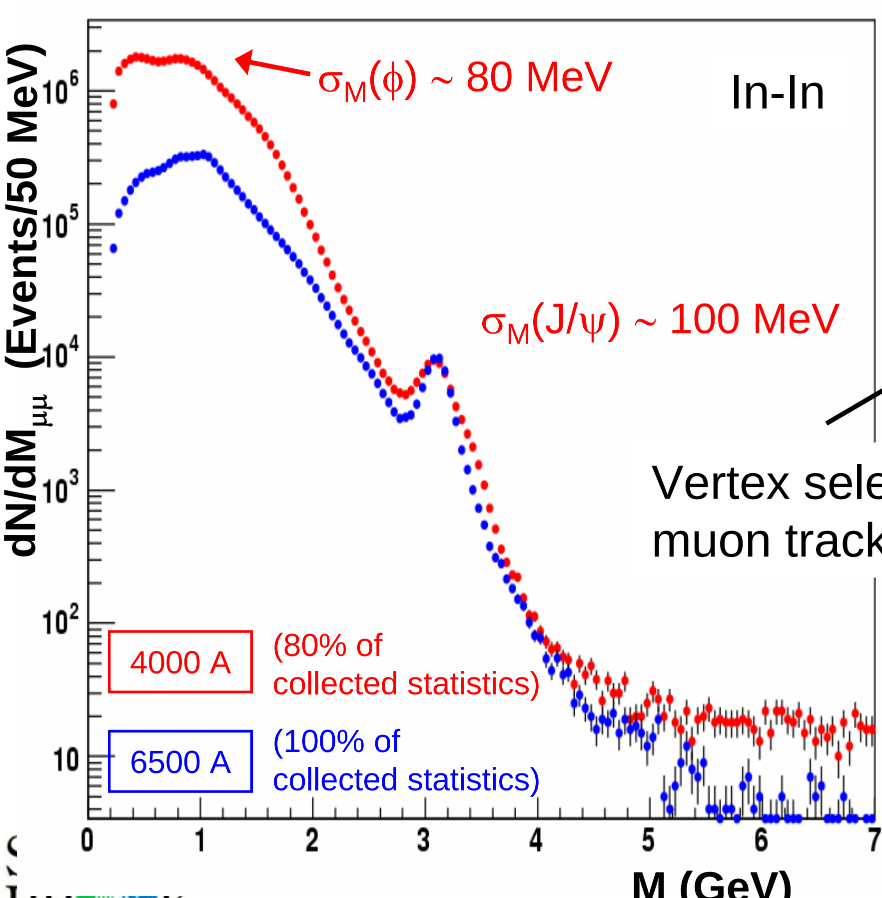
A New Era: NA60 Data from In-In Collisions

2003 In-In run at 158 AGeV

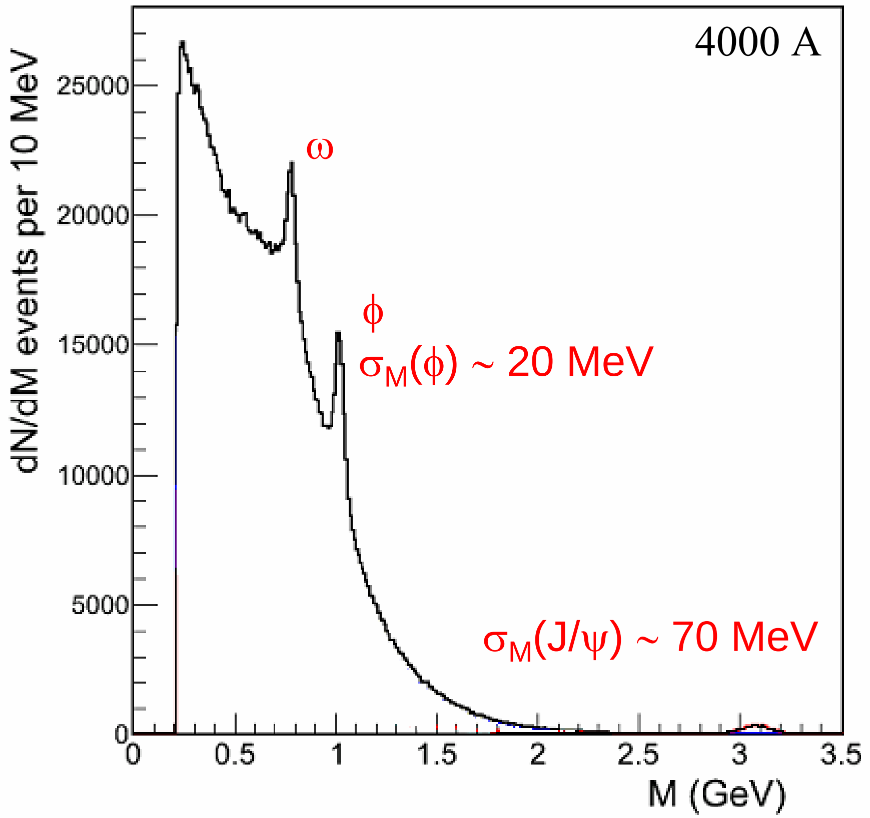
5×10^{12} ions on target

2.3×10^{8} dimuons recorded

Raw unlike-sign dimuon mass distributions



Vertex selection
muon track matching



Narrow vector mesons clearly resolved

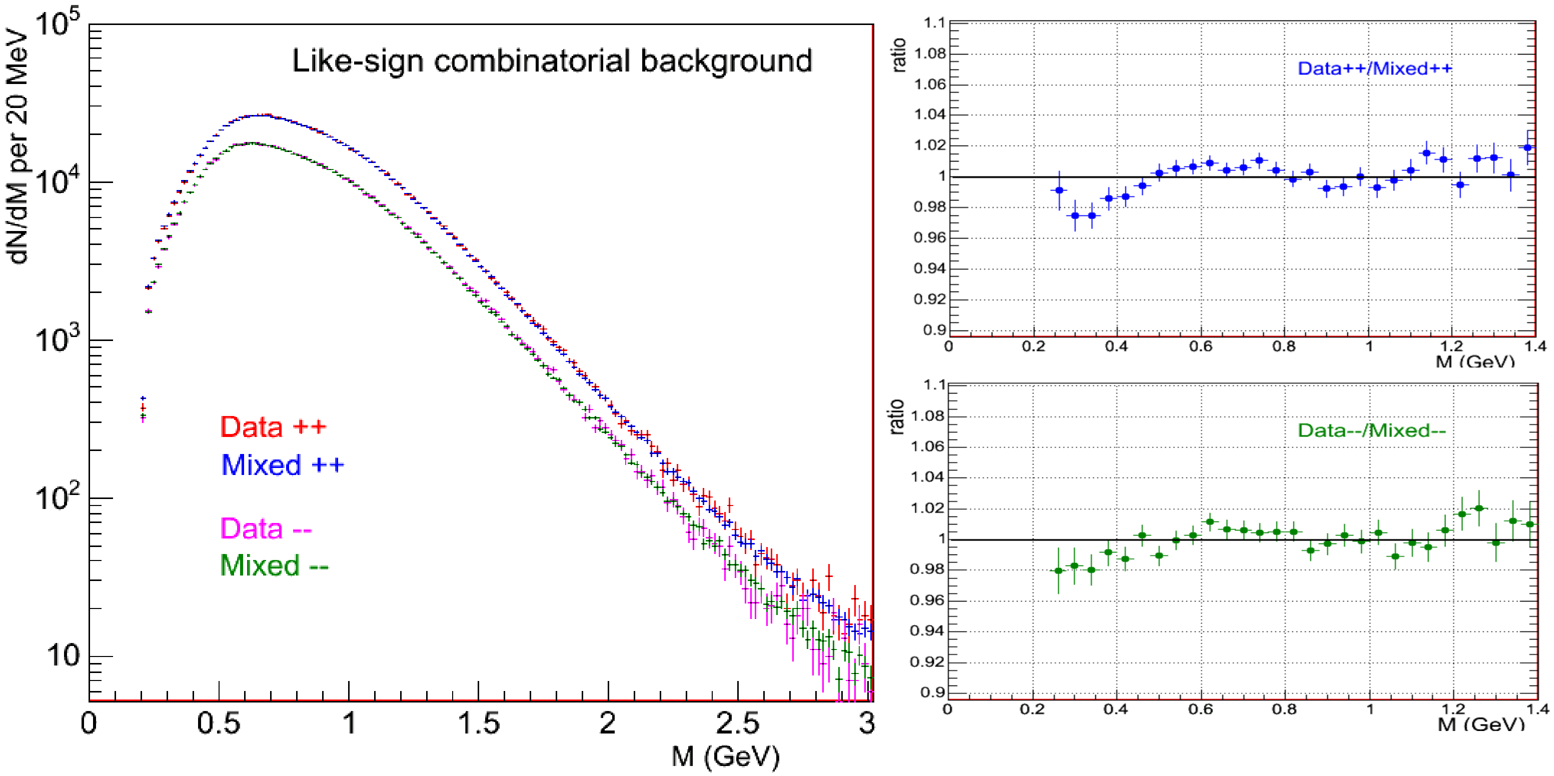
Significant background rejection

But still remaining unphysical background

Axel Drees

Combinatorial Background from Event Mixing

- **Combinatorial background from decays of π and K mesons**
- **Use event mixing method**
- **Accuracy estimated by comparing to measured like-sign spectra N_{++} and N_{--}**

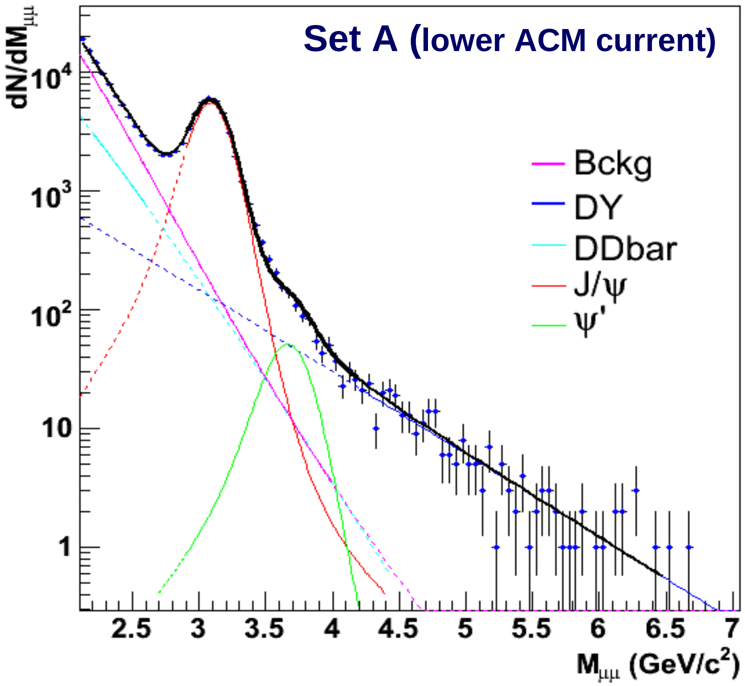


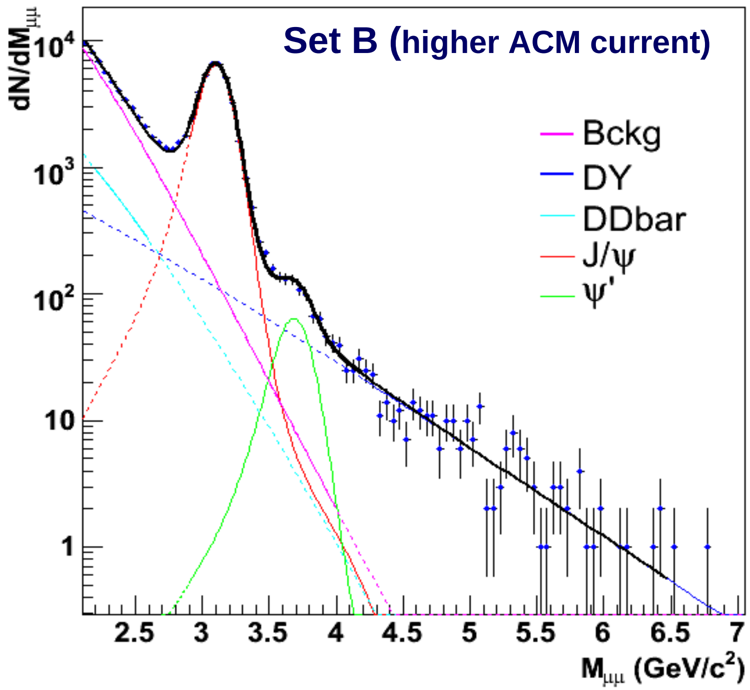
Accuracy ~1% independent of mass

STONY BROOK

Axel Drees

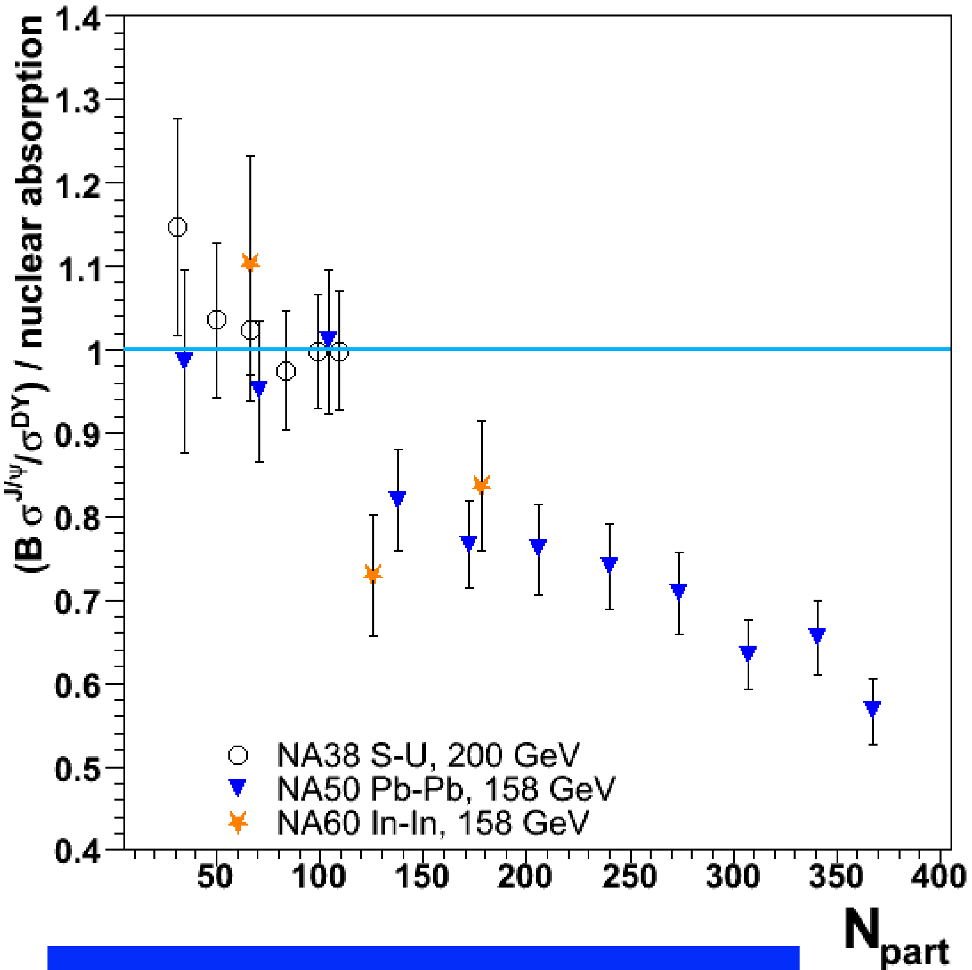
J/ψ / DY Analysis





- **Deconvolve spectrum by sequentially fitting different contribution**
  - **Mass shape of signal processes from MC (PYTHIA+GRV94LO PDF)**
  - **First fit Drell-Yan for mass > 2 GeV**
  - **Fix combinatorial background and charm in intermediate mass region 2.2<M<2.5 GeV**
  - **Last extract charmonia yields**
- **Results from both data sets consistent → use average in the following**
- **Systematic checks of the J/ψ / DY ratio:**
  - **Change of input distributions in MC calculation → 0.3% (cosϑ), 1% (rapidity)**
  - **Tuning of quality cut for muon spectrometer tracks → < 3%**

J/ψ / DY vs Centrality



Anomalous suppression present in Indium-Indium

- **3 centrality bins defined by E_{ZDC}**
  - **bin1 → ⟨Npart⟩ = 63**
  - **bin2 → ⟨Npart⟩ = 123**
  - **bin3 → ⟨Npart⟩ = 175**

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

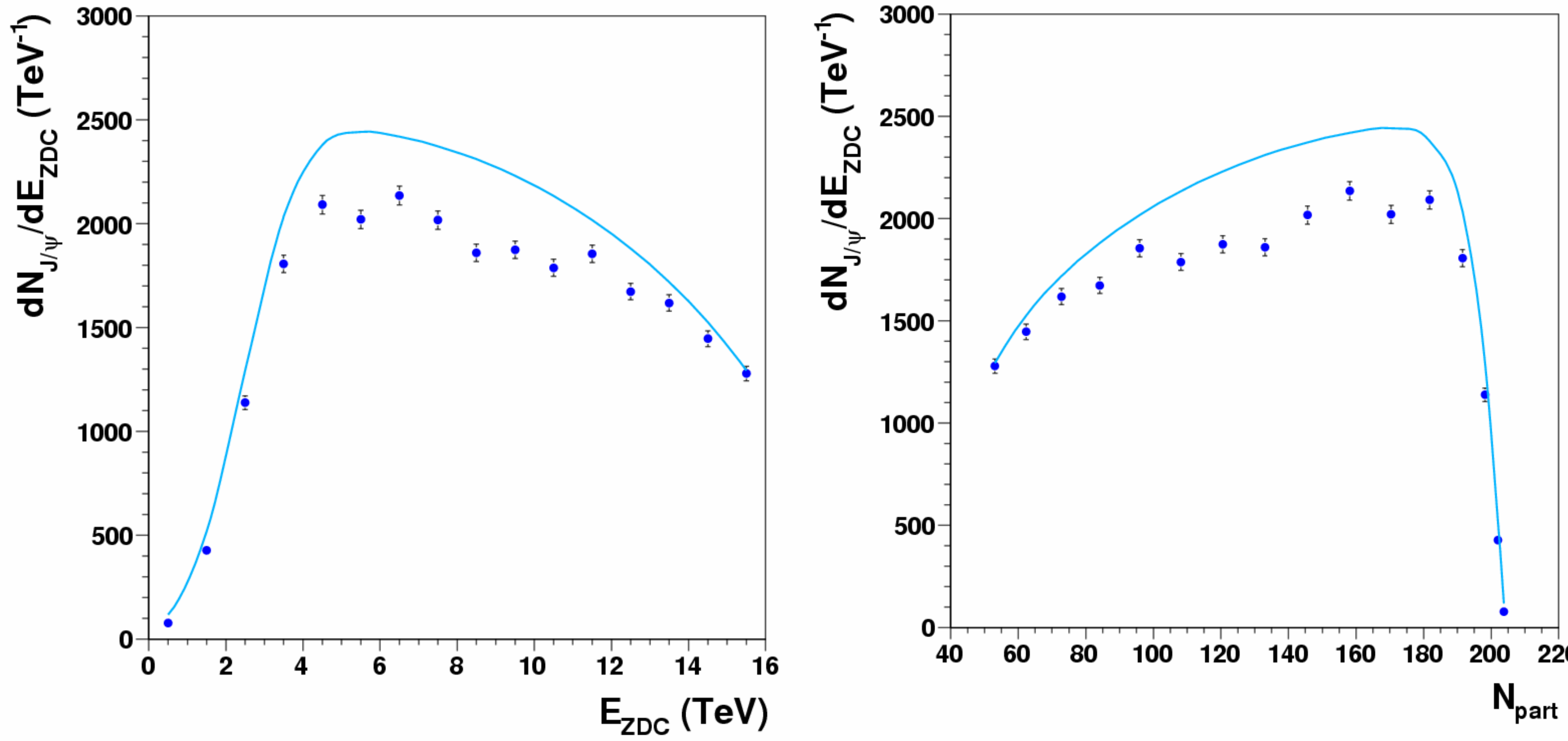
$$\sigma^{J/\psi}_{abs} = 4.18 \pm 0.35 \text{ mb}$$

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

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

- **Quantitative agreement with NA50 results as a function of N_{part}**

J/ψ Yield vs Nuclear Absorption (NA)



- **J/ψ yield extracted from fit to data**
- **J/ψ expectation (NuclearAbsorption) calculated as:**
  - **pp yield scaled by number of binary collisions**
  - **Suppressed by nuclear absorption (σ_{abs} =4.18 mb)**
  - **Both taken from measurements by NA50**
- **Relative normalization adjusted to min. bias value of (J/ψ)/DY = 0.87 ± 0.05**

Discussion of Uncertainties (in terms of NA)

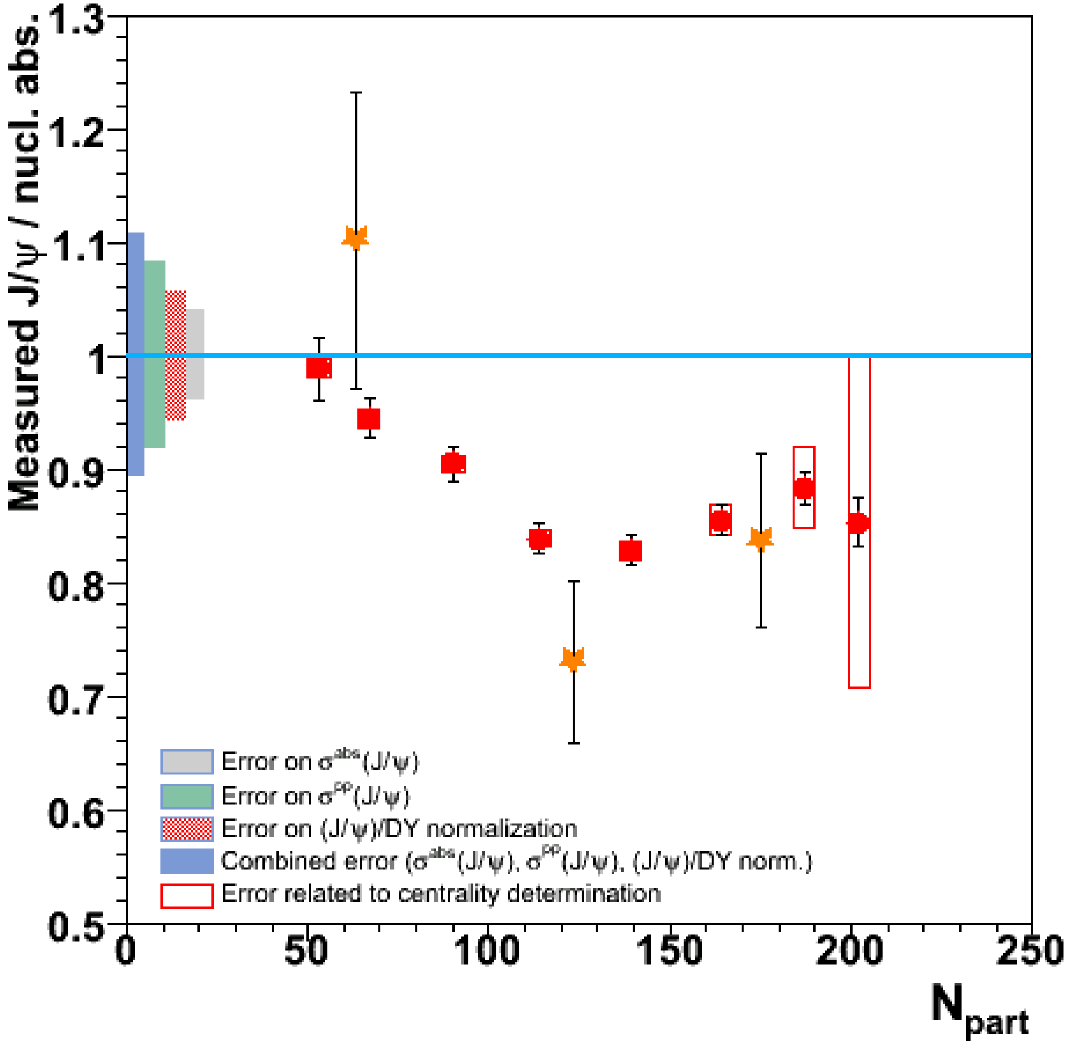
- **Statistical errors substantially reduced by avoiding Drell-Yan normalization**
- **At the price of slightly increased systematic errors:**
  - **statistical error on normalization** ~ 6%
  - **Glauber model parameters** ~ 12% (only central collisions)
  - **E_{ZDC} to N_{part}** ~ 9% (mostly for central coll.)
- **Sytematic error common to both analysis:**
  - **nuclear absorption parameters**

    $\sigma_{abs}(J/\psi)$ ~ 4%

    $\sigma_{pp}(J/\psi)$ ~ 8%

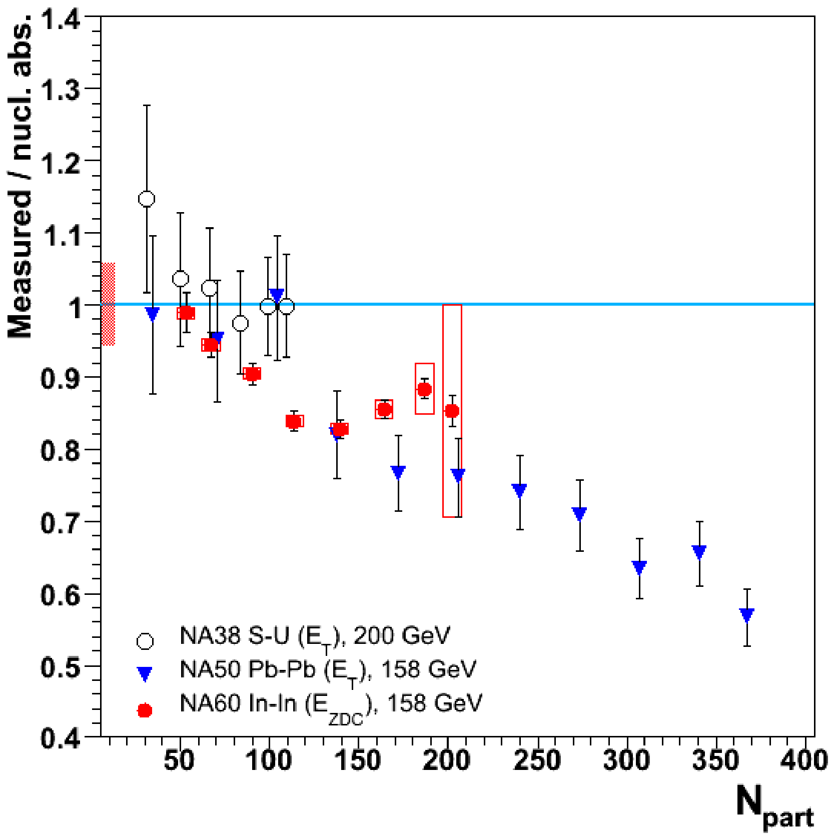
Systematic error on scale (analysis 2)	11%
Systematic error comparing analysis 1&2	6%
Centrality dependent sys. Errors	<15%

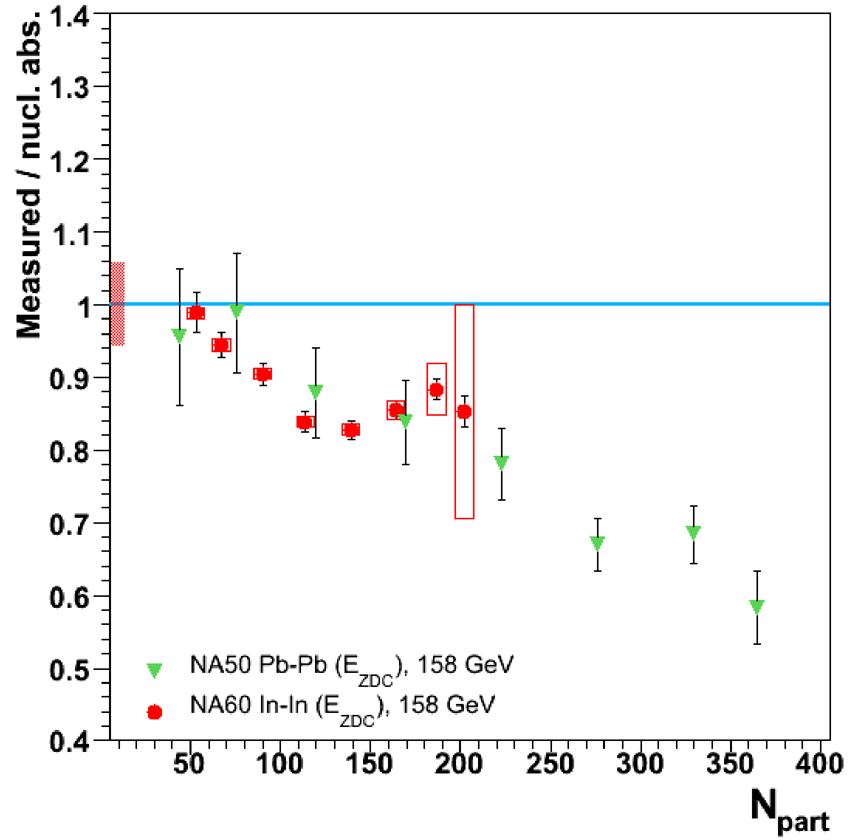
Annomalous J/ψ Suppression in In-In



Axel Drees

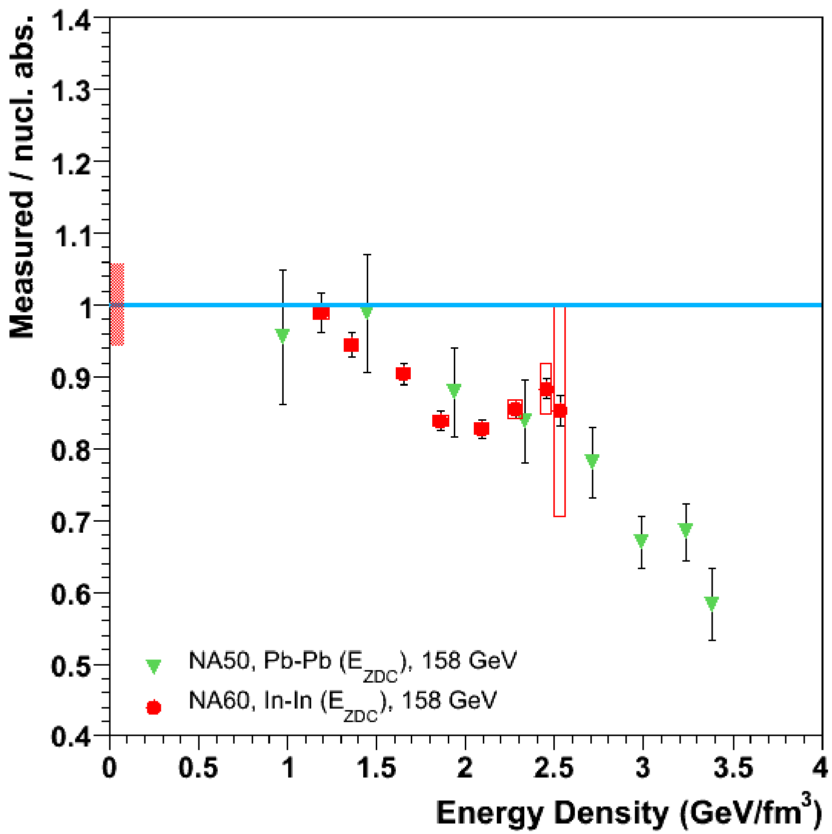
Comparison with Previous Results (vs Npart)

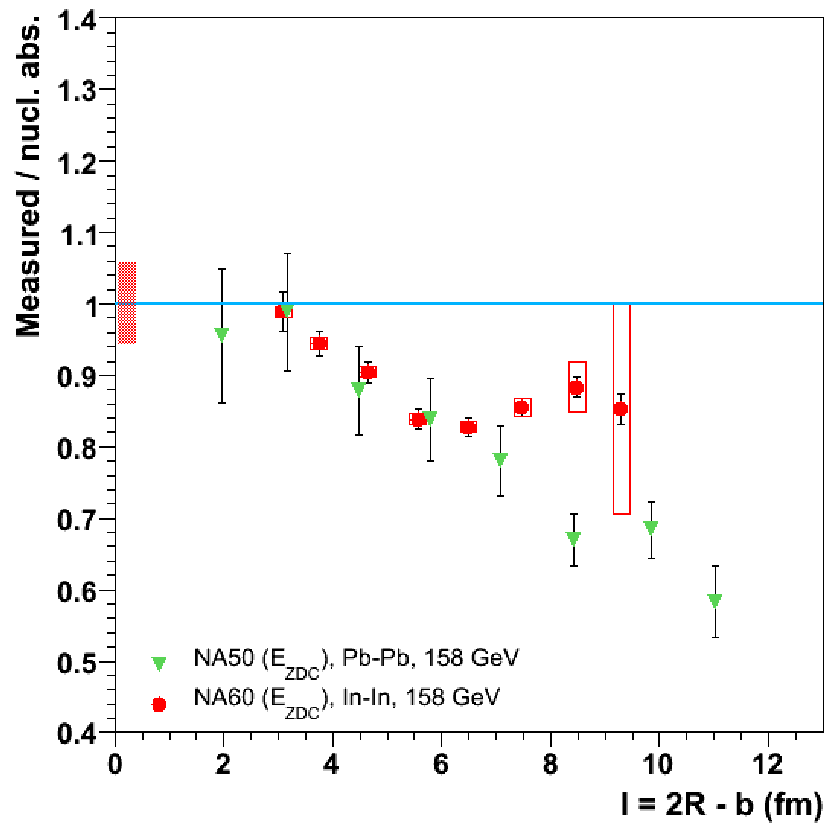




- **Na50: N_{part} estimated through E_T (left), or E_{ZDC} (right, as in NA60)**
  - **Good agreement with PbPb**
  - **S-U data may show a different behavior?**

Various Centrality Estimators (ε,l)



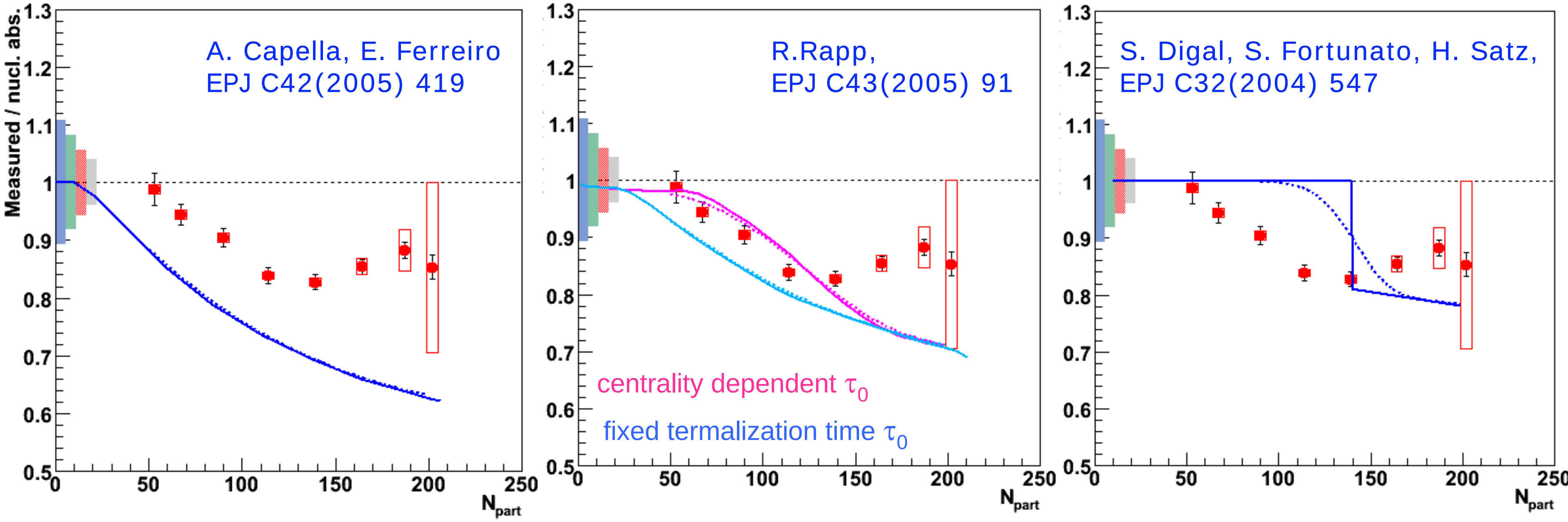


- **Suppression vs energy density and fireball's transverse size**
  - **Anomalous suppression sets in at ε ~ 1.5 GeV/fm3 (τ0=1 fm/c)**
  - **What is the best scaling variable for the onset ?**

    → Clear answer requires more accurate Pb-Pb suppression pattern

Axel Drees

Comparison with Theoretical Predictions



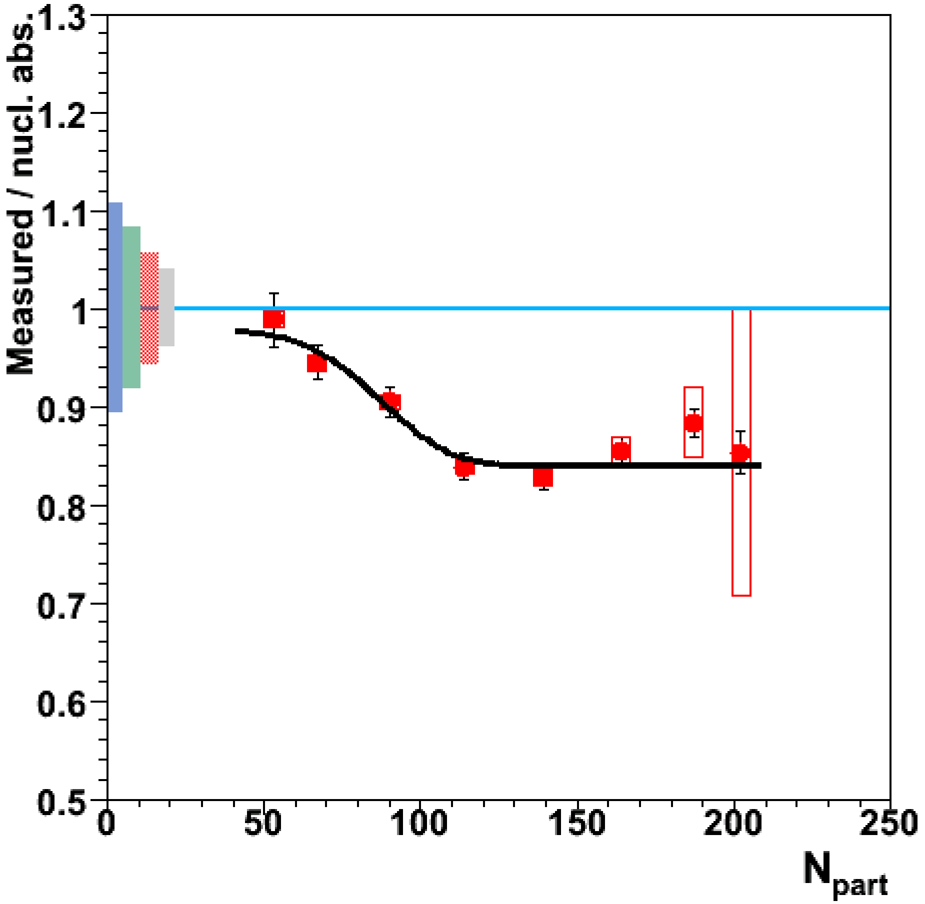
Suppression by hadronic comovers (σ_{co} = 0.65 mb, tuned for Pb-Pb collisions)

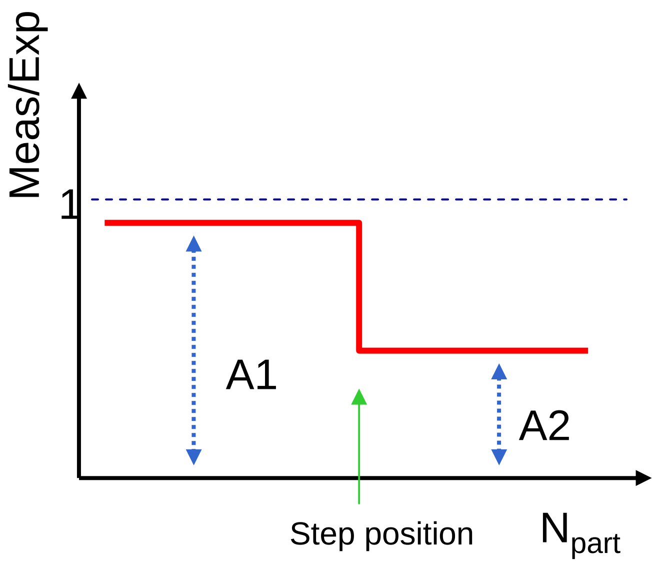
Dissociation and regeneration in QGP and hadron gas

Percolation, with onset of suppression at N_{part}~140

Size of the anomalous suppression reasonably reproduced
Quantitative description not satisfactory

Smooth effect or Sharp Drop ?





Step folded with E_{ZDC} resolution (~10%)

Step position: N_{part} = 86 ± 8

(ε_{Bj} ~ 1.6 GeV/fm^3)

A1 = 0.98 ± 0.02

A2 = 0.84 ± 0.01

χ^2/dof = 0.7

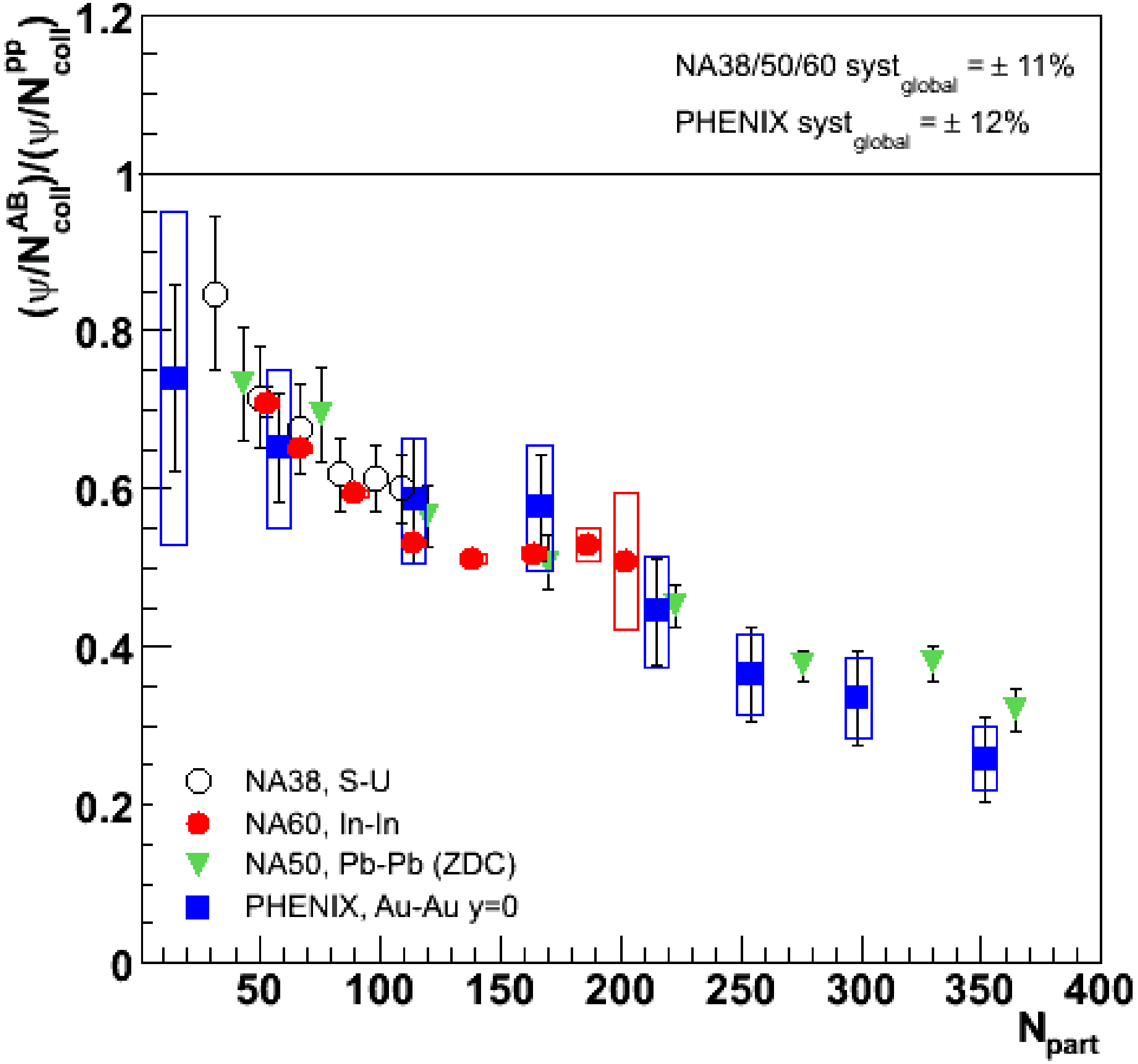
data are compatible with a sharp drop
onset smoother than our resolution on N_{part} (~20) is disfavored

STONY BROOK

Axel Drees

Comparison between SPS and RHIC

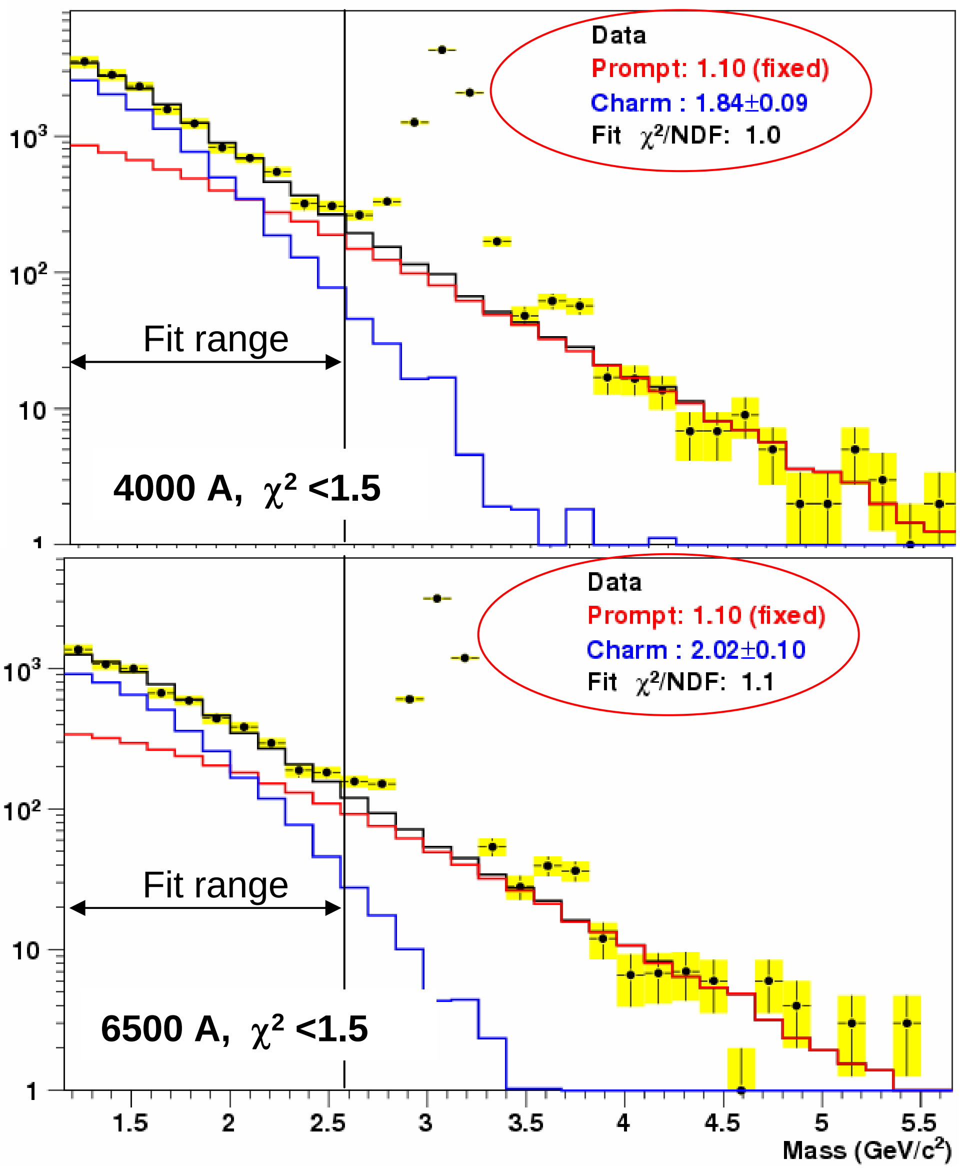
Plot J/ψ yield vs N_{part}, normalized to collision scaling expectations



Surprising scaling of suppression from SPS to RHIC!

Challenge for theorists: Consistent interpretation of SPS and RHIC data

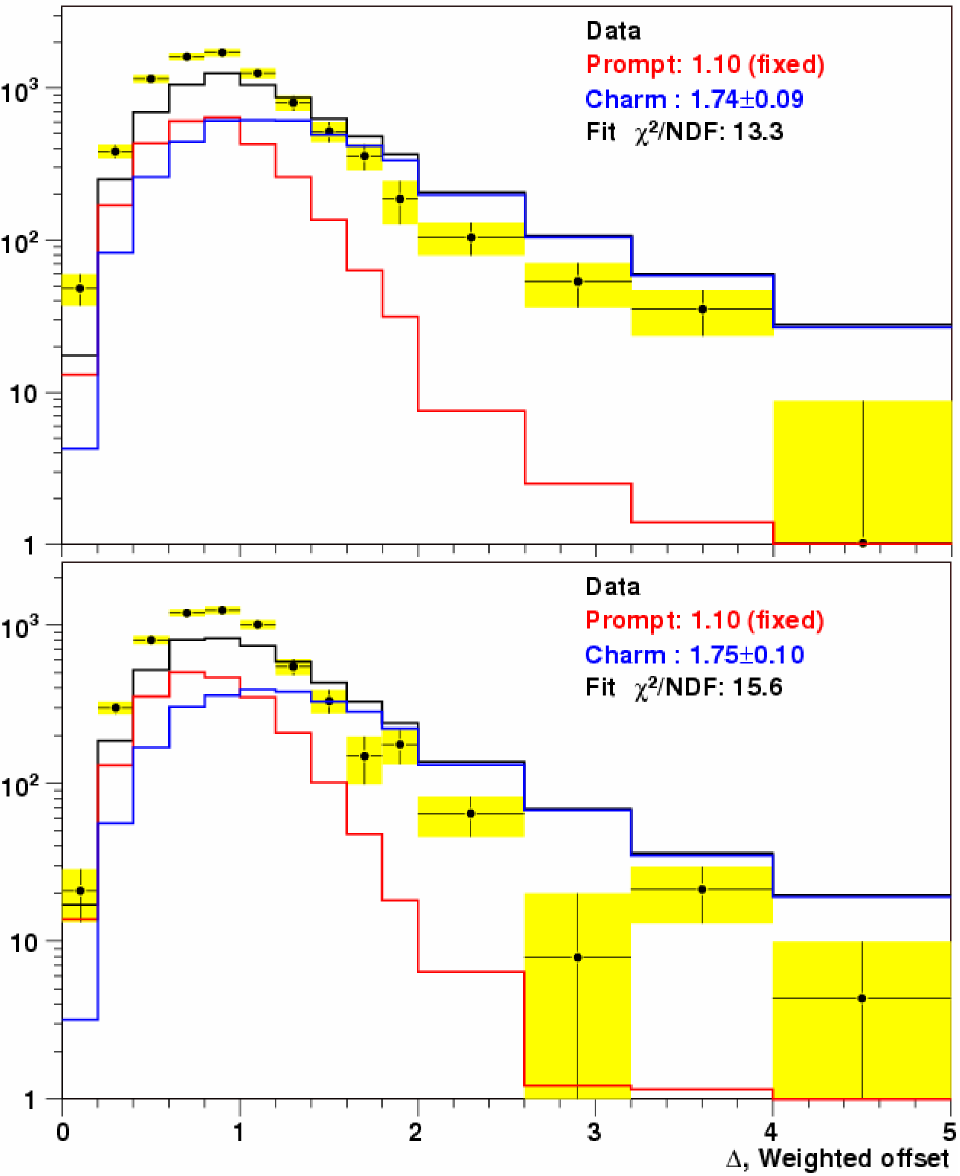
Dimuons in the Intermediate Mass Region (IMR)



- **Method used by NA50:**
  - Describe mass distribution by two components: DY and charm
  - Shape from PYTHIA
  - Fit Drell-Yan above J/ψ
  - Fit Charm in range 1.2 to 2.6 GeV, keeping DY fixed

Apparent increase of charm by factor ~2

Disentangling the Signal Sources in the IMR

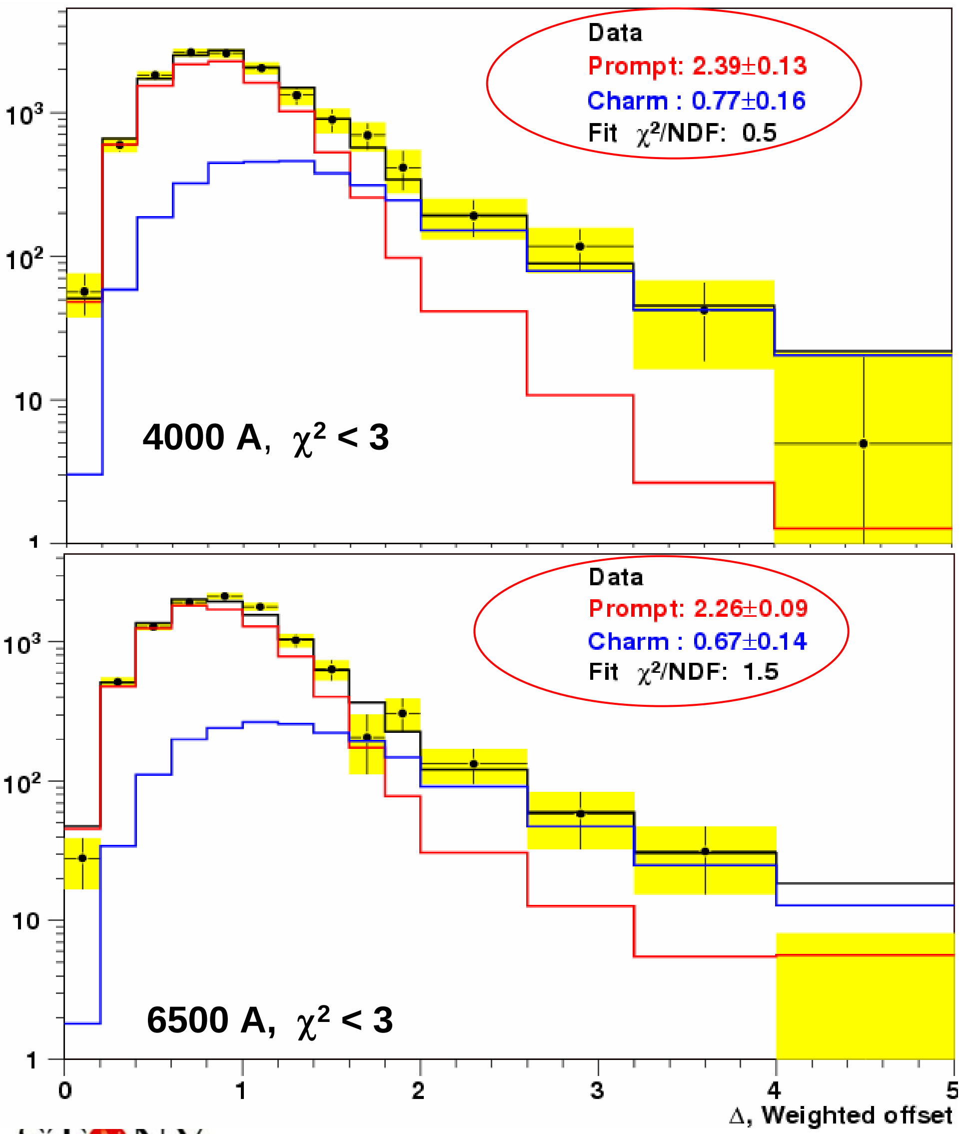


The dileptons from charm decay can be identified by tagging their production point with respect to the primary interaction vertex

- **NA60 vertex telescope**
  - **Excellent resolution (~20-30 μm, in the transverse plane)**
  - **Sufficient to identify the typical offset of D-meson decay (~100 μm)**

Signal requires enhanced prompt component and not enhanced charm!

Charm and Prompt Contributions

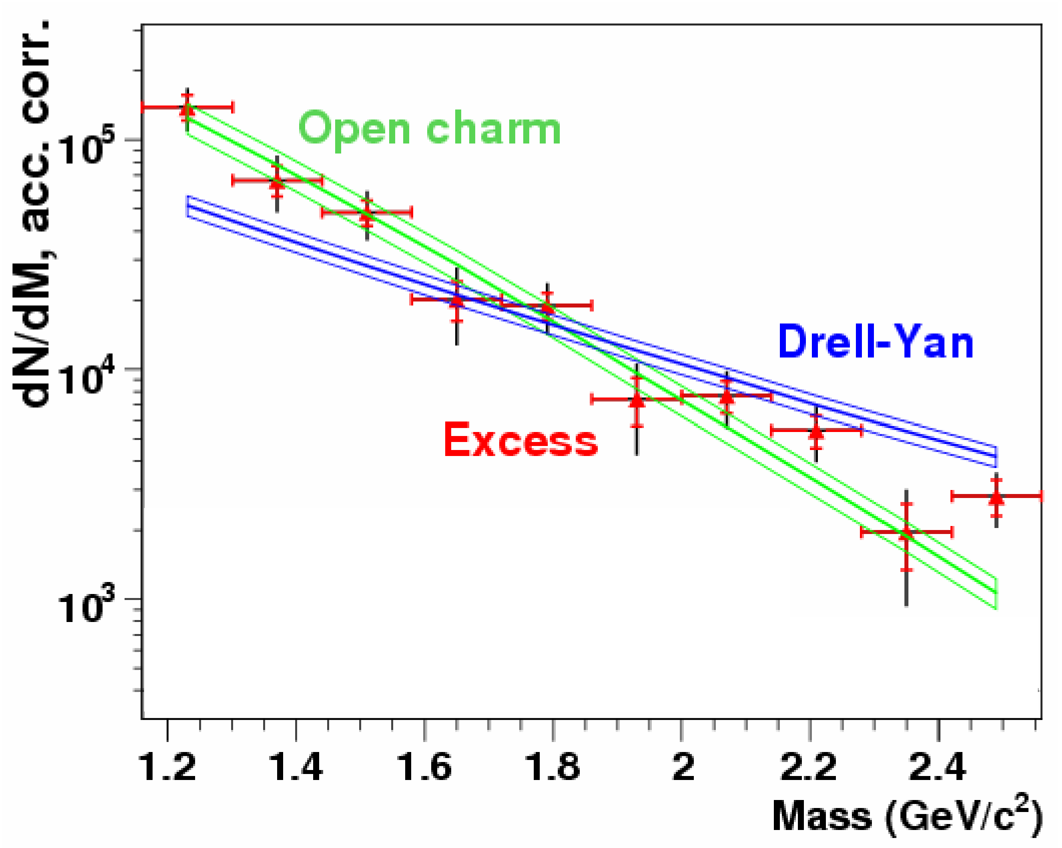


- **Fit offset data with both components: prompt and charm**
  - **Prompt component factor ~2.4 larger than DY**
  - **Charm contribution ~70% of yield extrapolated from NA50 p-A**

Large prompt component
Possibly reduced charm yield

Decomposition of Mass Spectrum (1.16<M<2.56 GeV/c²)

Define the Excess as Signal – [Drell-Yan (1 ± 0.1) + Open Charm (0.7±0.15)]

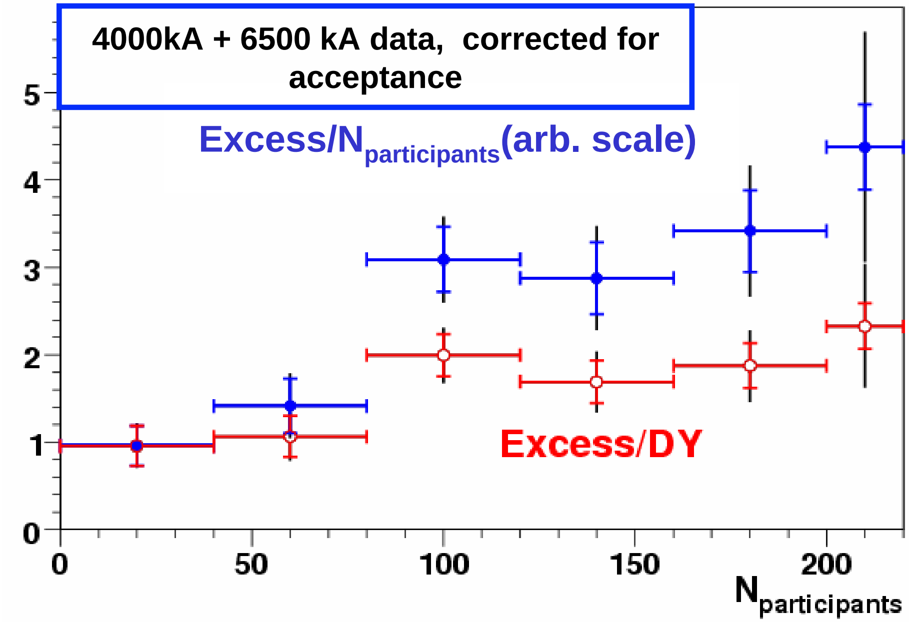


Yield corrected for the acceptance in -0.5 < cos θ < 0.5 and 2.92 < y_{lab} < 3.92

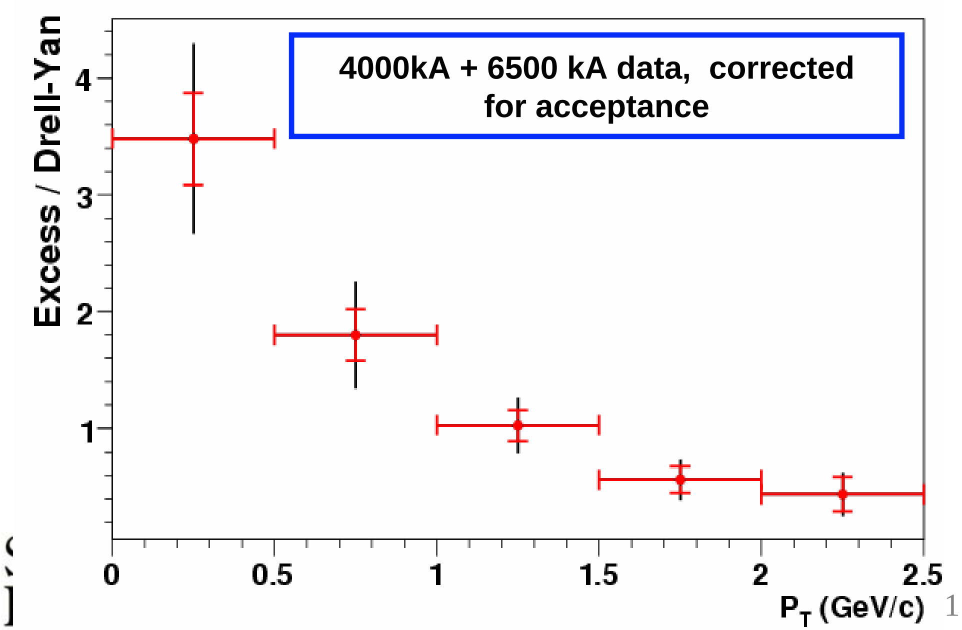
Sum 4000 and 6500 A data samples

STONY BROOK

Centrality & p_T Dependence of IMR Excess



Excess increases faster than proportional to N_{part} but also faster than hard processes (N_{coll})

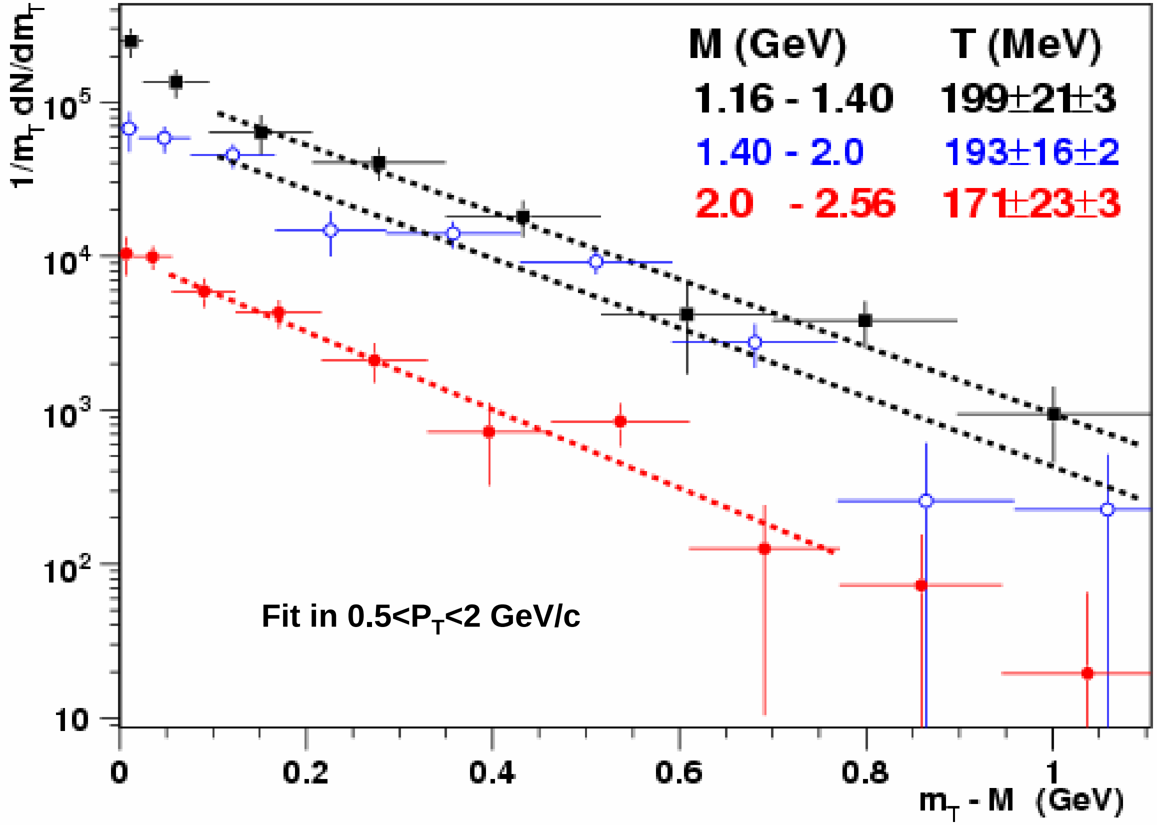


Excess has significantly softer p_T distribution than Drell-Yan

More Detailed Look at p_T Dependence

- **Present Excess in different mass regions as function of m_T**
  - **Fit exponential function**
  - **Extract T_{eff} slope parameter**

$$\frac{dN}{m_T dm_T} \propto e^{-m_T / T_{eff}}$$



$\langle T_{eff} \rangle \sim 190$ MeV/c^2
Is this related to temperature?

Interpretation of T_{eff}

- **Interpretation of T_{eff} from fitting to $\exp(-m_T/T_{eff})$**
  - **Static source: T_{eff} interpreted as the source temperature**
  - **Radially expanding source:**

    T_{eff} reflects temperature and flow velosity

    T_{eff} dependens on the m_T range

    Large p_T limit: $$T_{eff} = T_f \sqrt{\frac{1+v_T}{1-v_T}} \quad p_T >> m$$

    Low p_T limit: $$T_{eff} \approx T_f + \frac{1}{2} m \left\langle v_T \right\rangle^2 \quad p_T << m$$

- **Final p_T spectra from space-time history $T_i \rightarrow T_{fo}$ and emmision time**
  - **hadrons: interact strongly**

    freeze out at different times depending on cross section with pions

    T_{eff} → temperature and flow velocity at thermal freeze out
  - **dileptons: do not interact strongly**

    decouple from medium after emission

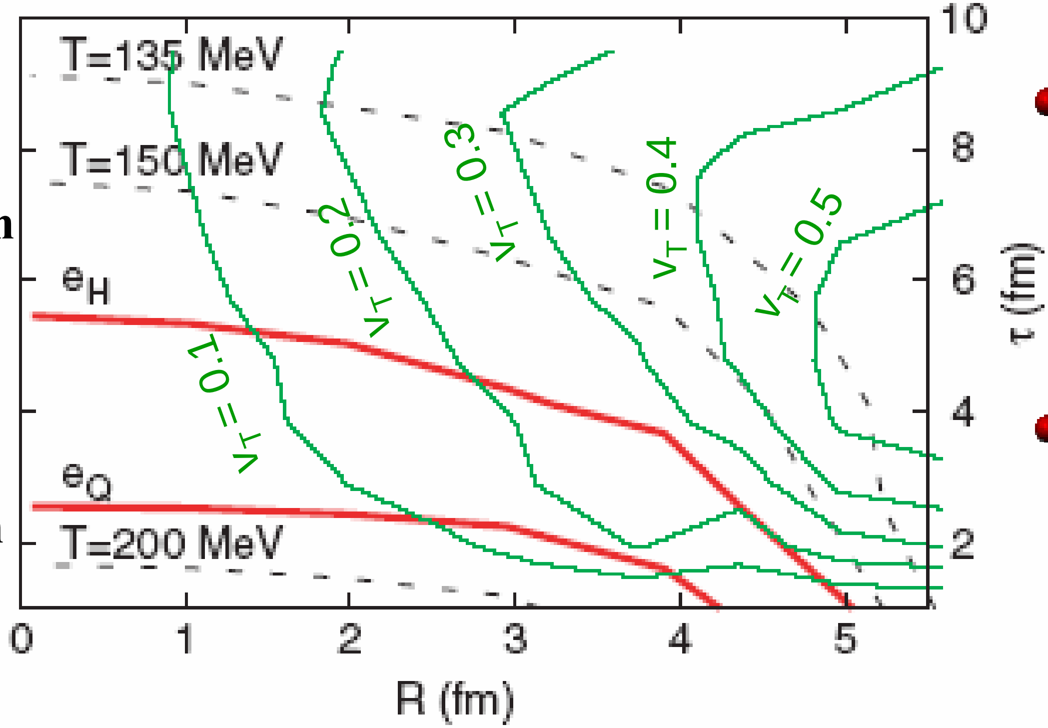
    T_{eff} → temperature and velocity evolution averaged over emission time

Example of Hydrodynamic Evolution

(specific for In-In – Dusling et al.)

hadron phase

parton phase

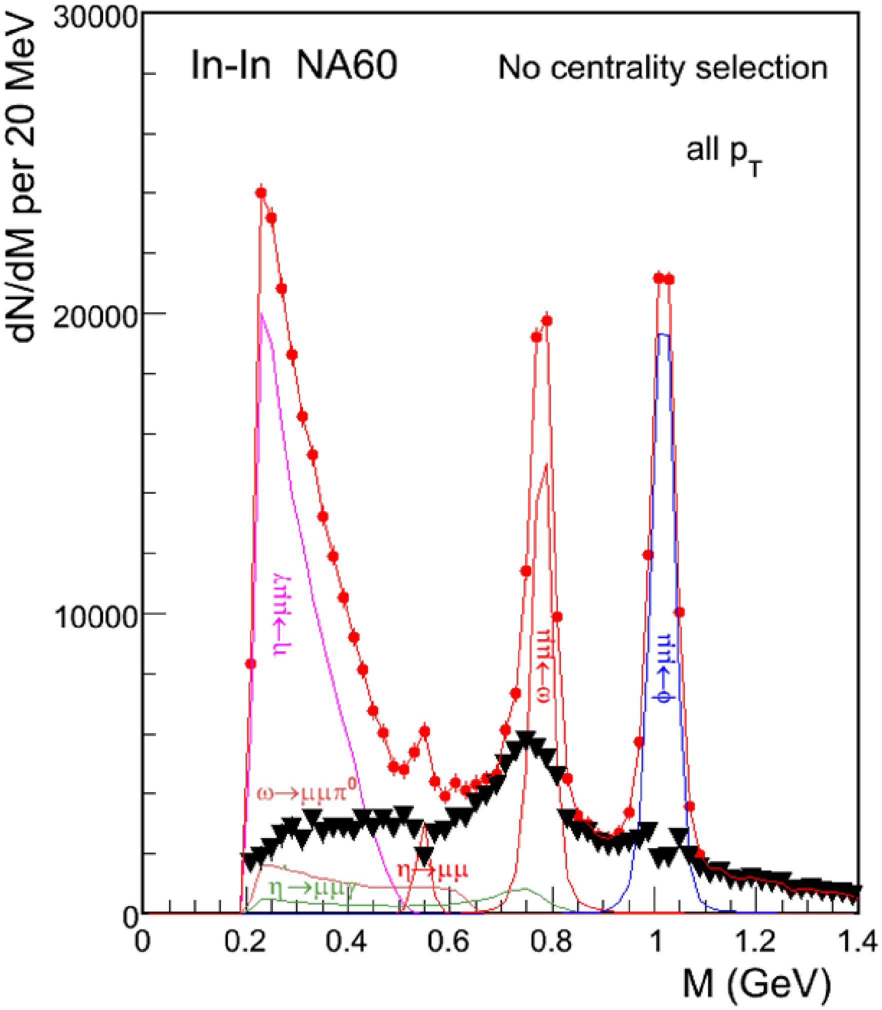


- **Monotonic decrease of T from:**
  - **early times to late times**
  - **medium center to edge**
- **Monotonic increase of v_T from:**
  - **early times to late times**
  - **medium center to edge**

- **Dileptons may allow decoupling or deconvolving of emission times:**
  - **Early emmision times (from parton phase): high T, small v_T**
  - **Late emission times (from hadronic phase): low T, high v_T**

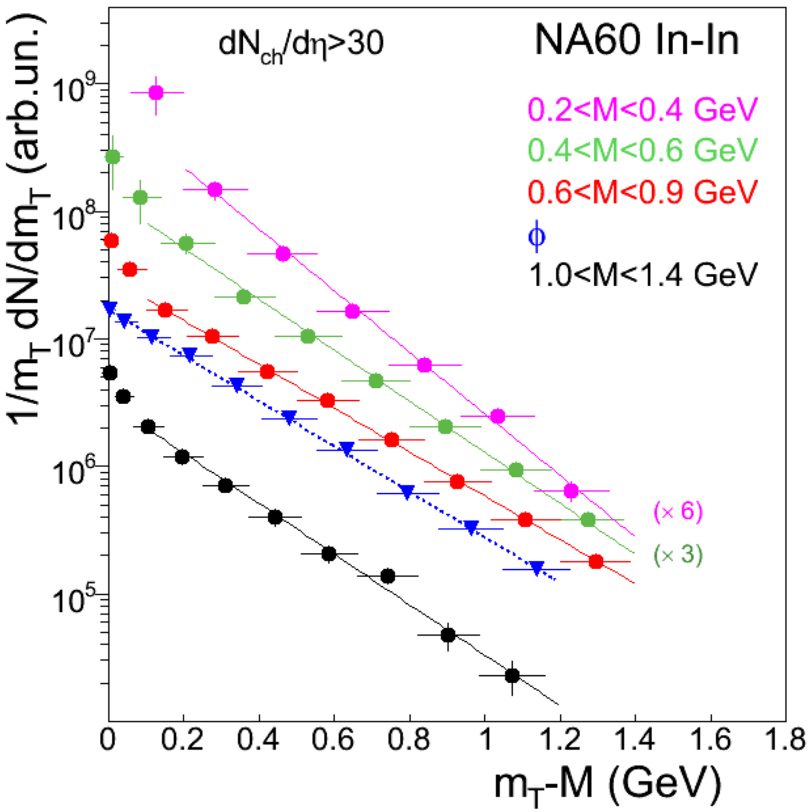
NA60 analysis of m_T spectra in In-In

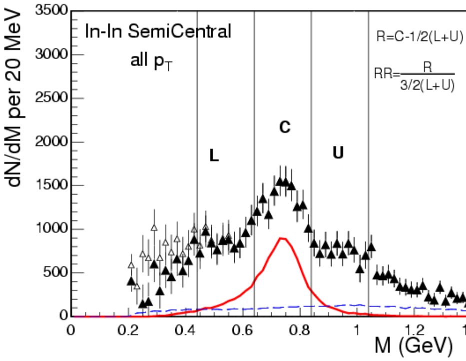
Phys. Rev. Lett. 96 (2006) 162302

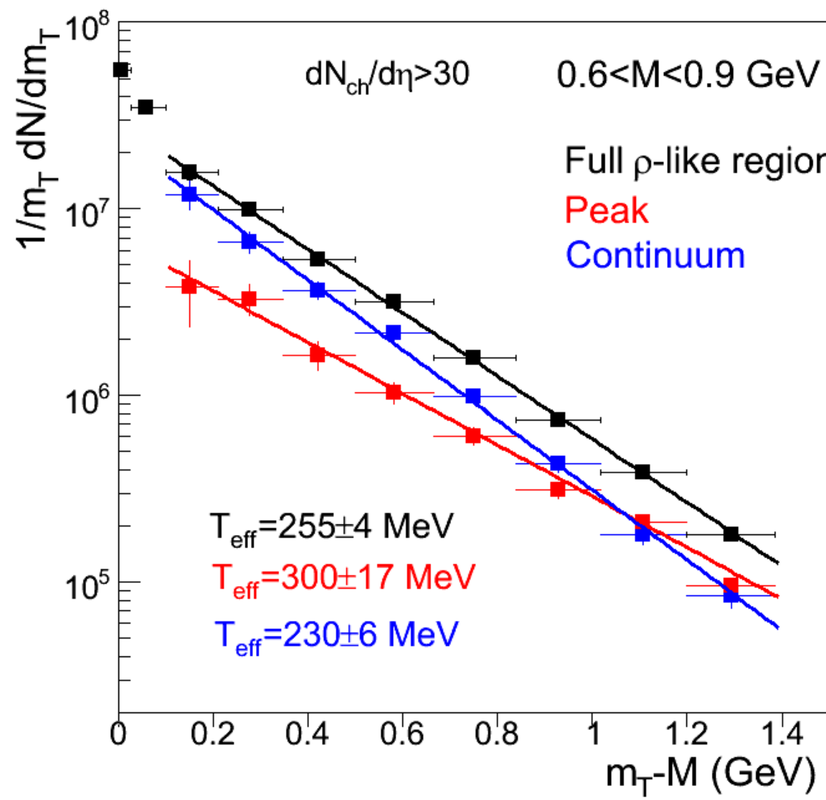


- **Decompose low mass region**
  - **Contributions of mesons (η,ω,ϕ)**
  - **Continuum plus ρ meson**
  - **Extract vacuum ρ**
- **Hadron m_T spectra for**
  - **η,ω,ϕ**
  - **Vacuum ρ**
- **Dilepton mT spectra for**
  - **Low mass excess**
  - **Intermediate mass excess**

Examples of m_T Distributions

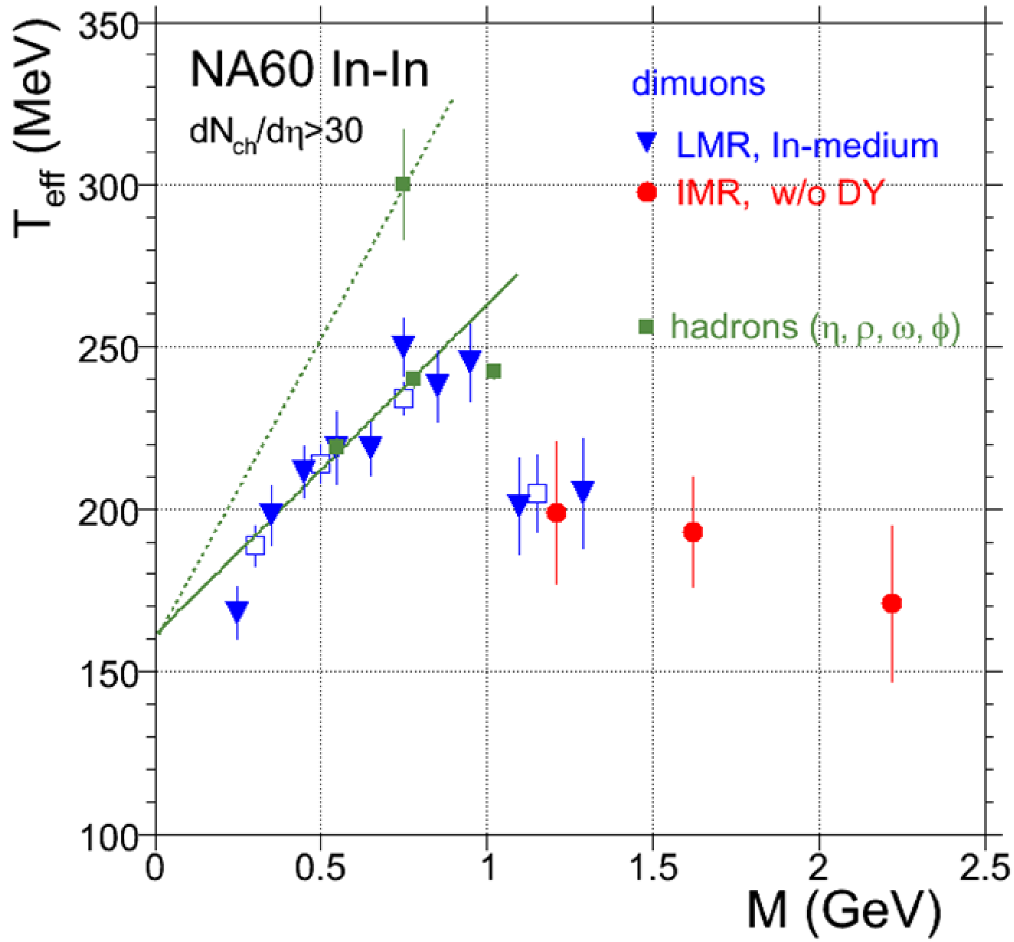






STONY BROOK

Comparison with T_{eff}



- **Hadrons (η, ω, ρ, ϕ)**
  - **T_{eff} depends on mass**
  - **T_{eff} smaller for ϕ, decouples early**
  - **T_{eff} large for ρ, decouples late**
- **Low mass excess**
  - **Clear flow effect visible**
  - **Follows trend set by hadrons**
  - **Possible late emission**
- **Intermediate mass excess**
  - **No mass dependence of T_{eff}**
  - **Indication for early emission**

Summary

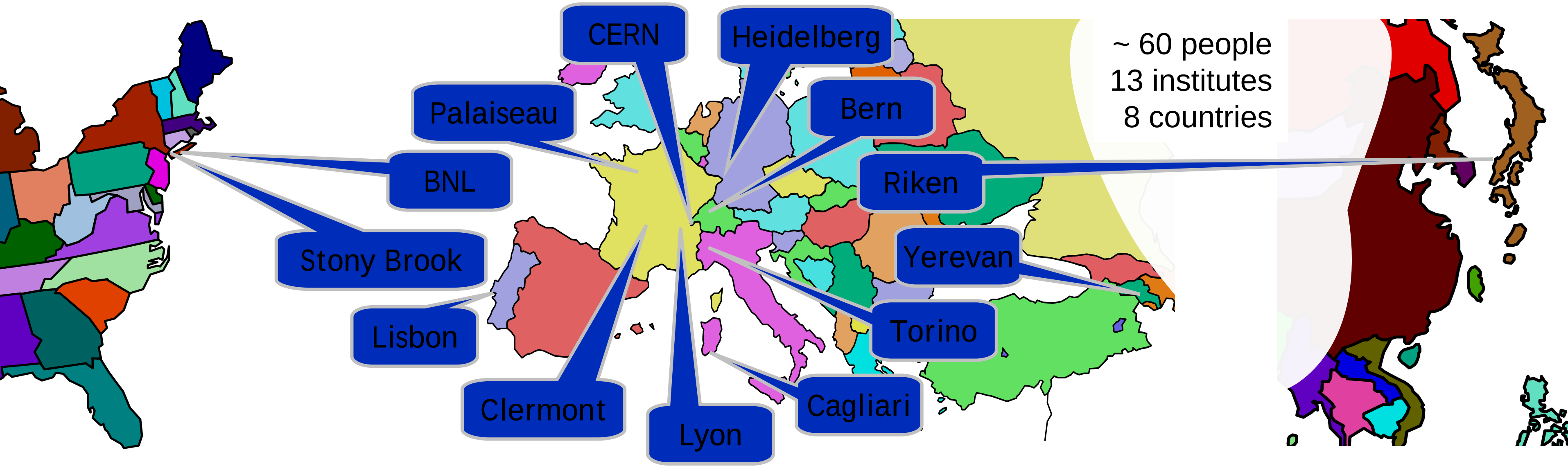
- **Anomalous J/ψ suppression in In-In collisions**
  - Consistent with NA50 data
  - Scaling with N_{part}, ε, L can not be distinguished
  - Theoretical predictions only qualitatively describe data
  - Unexpected similarity of suppression pattern at SPS and RHIC

- **Large prompt component in IMR**
  - Excess in mass range between ϕ and J/ψ
  - Not from open heavy flavor, it is a prompt component
  - Excess increases faster than Drell-Yan (N_{coll}) with centrality
  - Excess exponential in m_T independent of mass with $T_{eff} \sim 190$ MeV/c^2

- **Dilepton m_T spectra promise to separate time scales**
  - Low mass dileptons shows clear flow contribution indicating late emission
  - Intermediate mass show no flow contribution hinting toward early emission

The NA60 experiment

http://cern.ch/na60

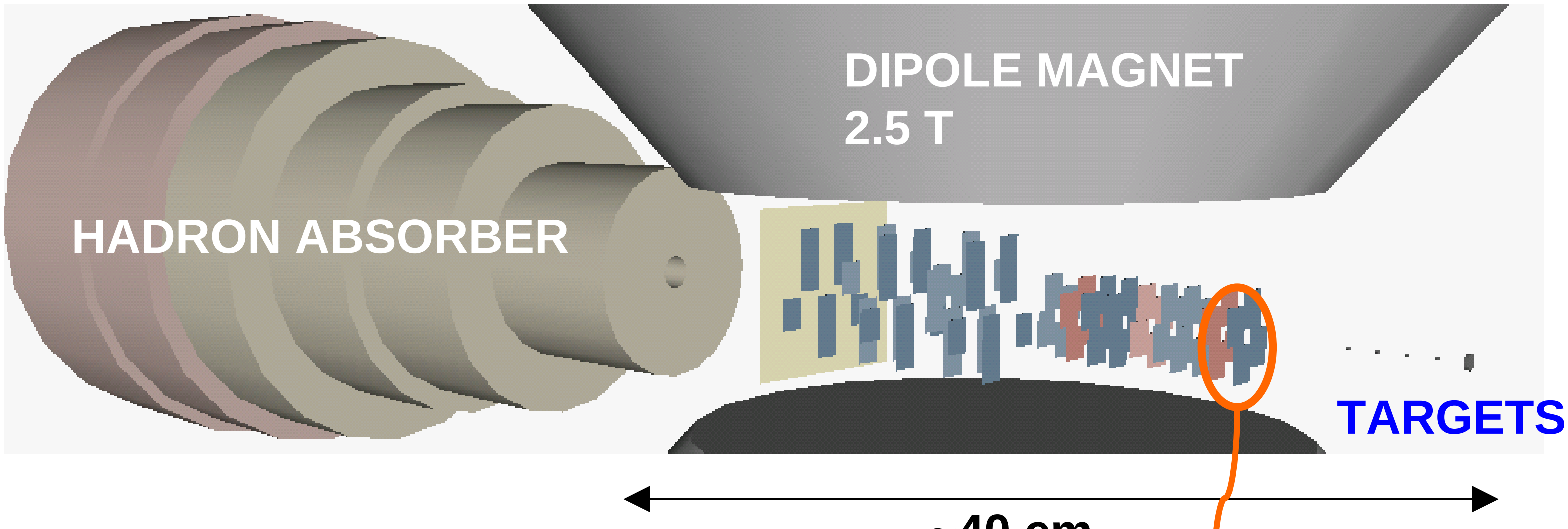


~ 60 people
13 institutes
8 countries

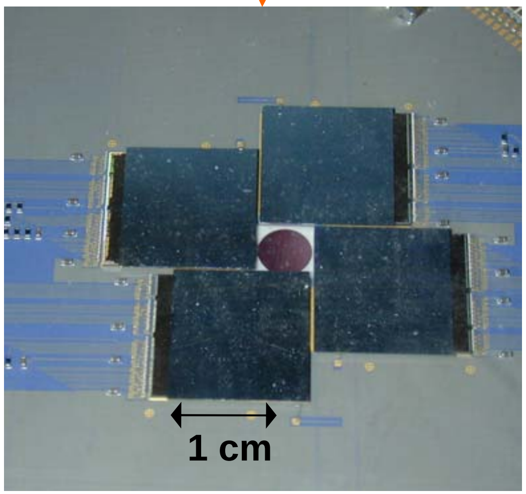
R. Arnaldi, R. Averbeck, K. Banicz, K. Borer, J. Buytaert, J. Castor, B. Chaurand, W. Chen, B. Cheynis, C. Cicalò, A. Colla, P. Cortese, S. Damjanović, A. David, A. de Falco, N. de Marco, A. Devaux, A. Drees, L. Ducroux, H. En'yo, A. Ferretti, M. Floris, P. Force, A. Grigorian, J.Y. Grossiord, N. Guettet, A. Guichard, H. Gulkanian, 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, 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

NA60 Pixel Vertex Detector



- **12 tracking points with good acceptance**
  - **8 “small” 4-chip planes, plus**
  - **8 “big” 8-chip planes (4 tracking stations)**
- **~ 3% X0 per plane**
  - **750 µm Si read-out chip**
  - **300 µm Si sensor**
  - **ceramic hybrid**
- **800’000 R/O channels - 96 pixel assemblies**

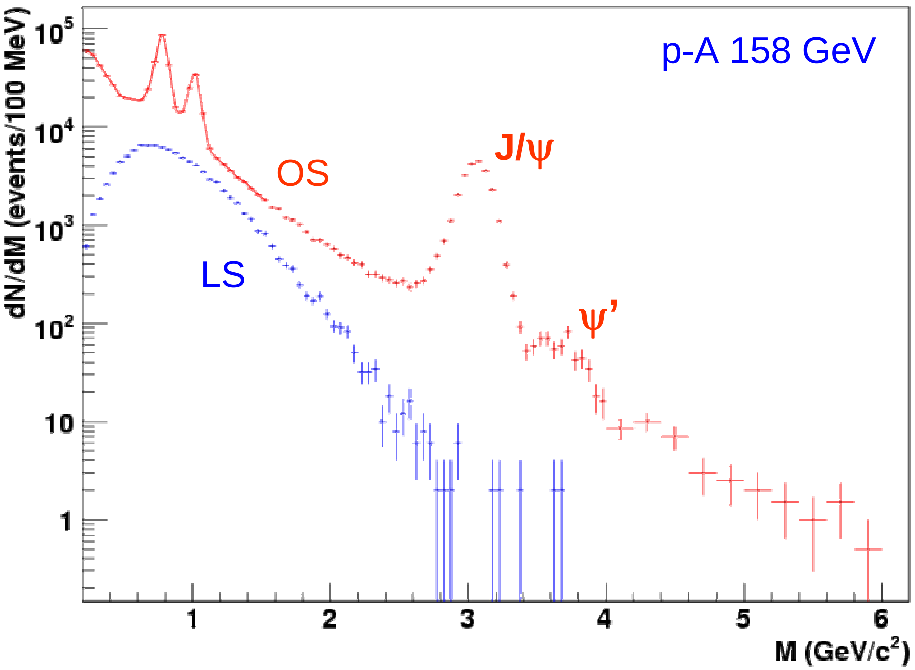


Outlook: the NA60 2004 proton-nucleus data

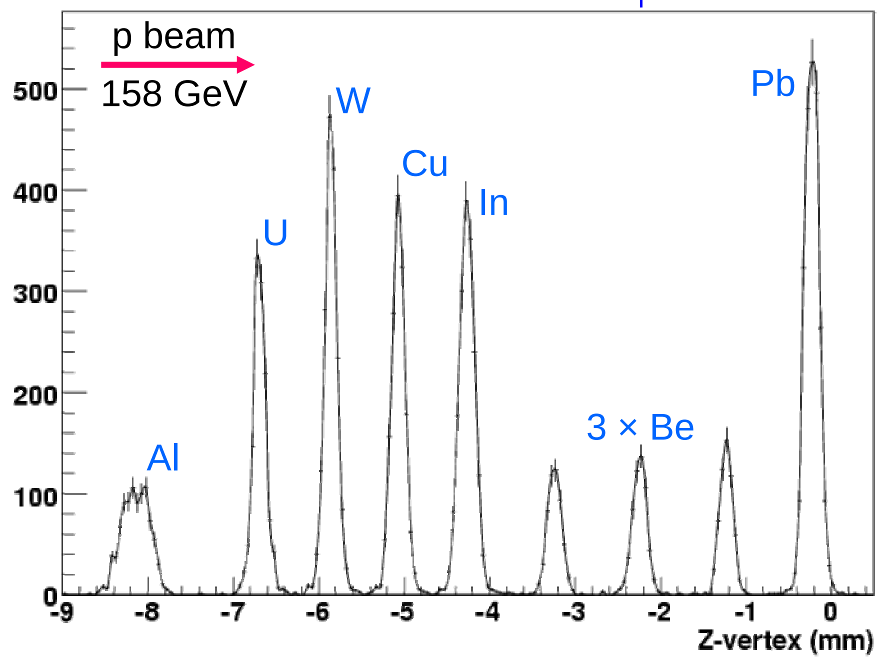
NA60 collected p-nucleus data with 7 nuclear targets and two beam energies:

400 GeV: ~ 300 000 J/ψ events, before matching
→ study χ_c, open charm, low and intermediate mass dimuons

158 GeV: ~ 11 000 J/ψ events, after matching
→ determine the normal nuclear absorption curve at the energy of the heavy-ion data by measuring $\sigma_0(J/\psi)$ and $\sigma_{abs}(J/\psi)$

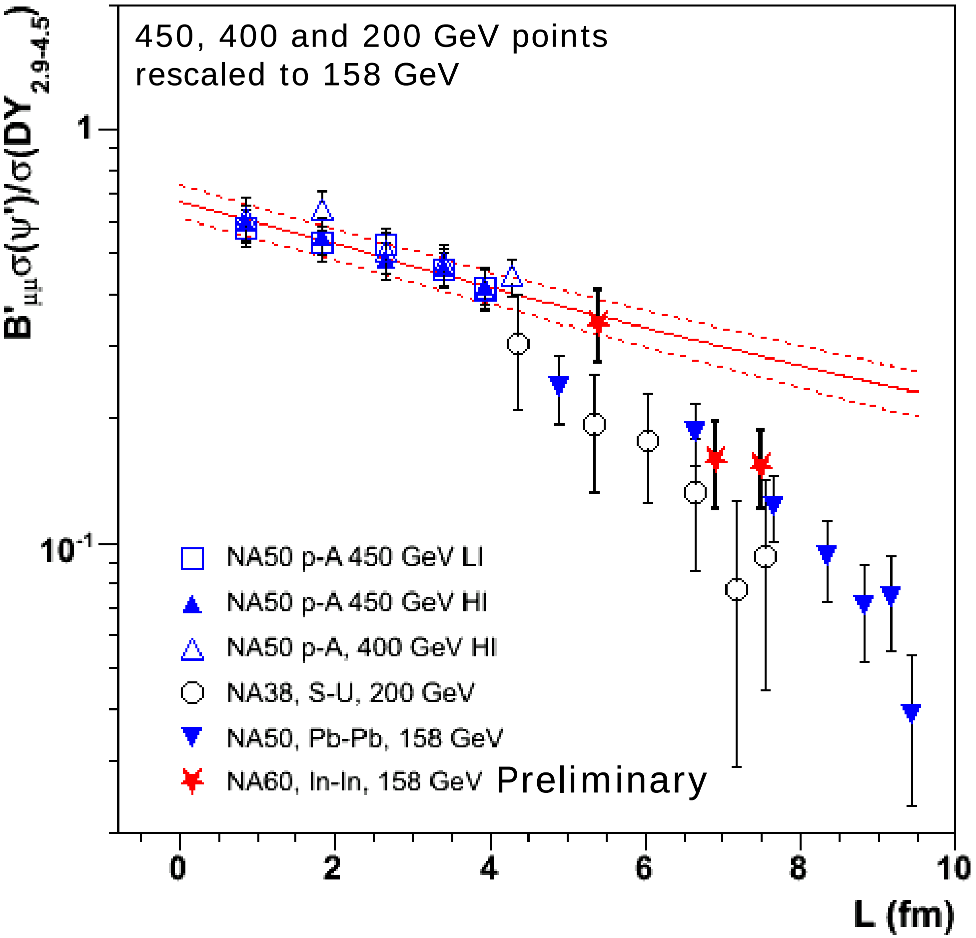


Matched J/ψ z-vertex



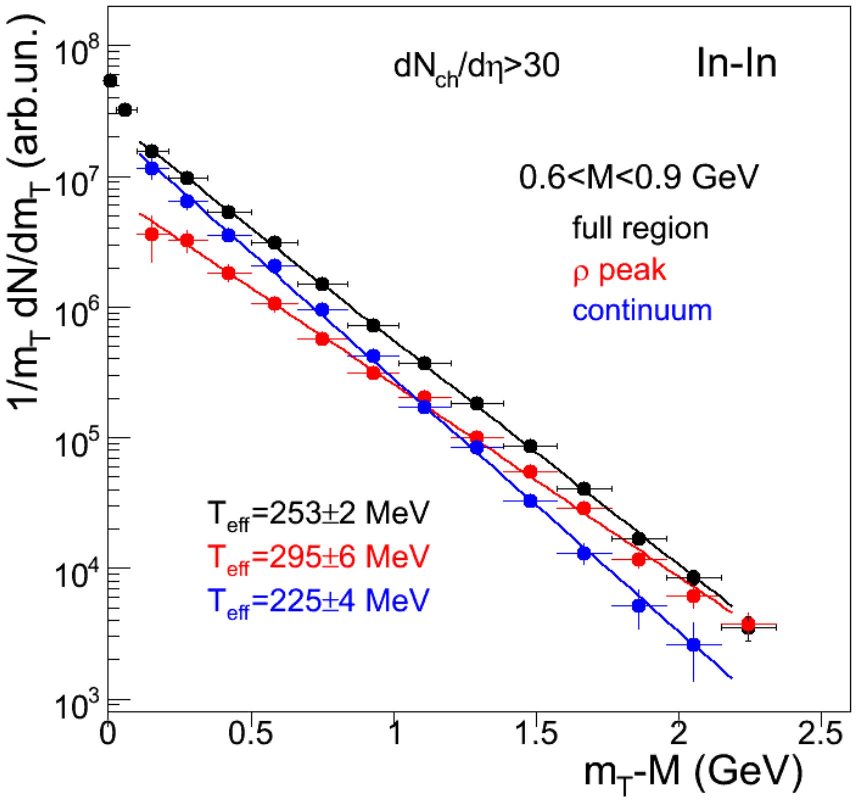
ψ' suppression in In-In collisions

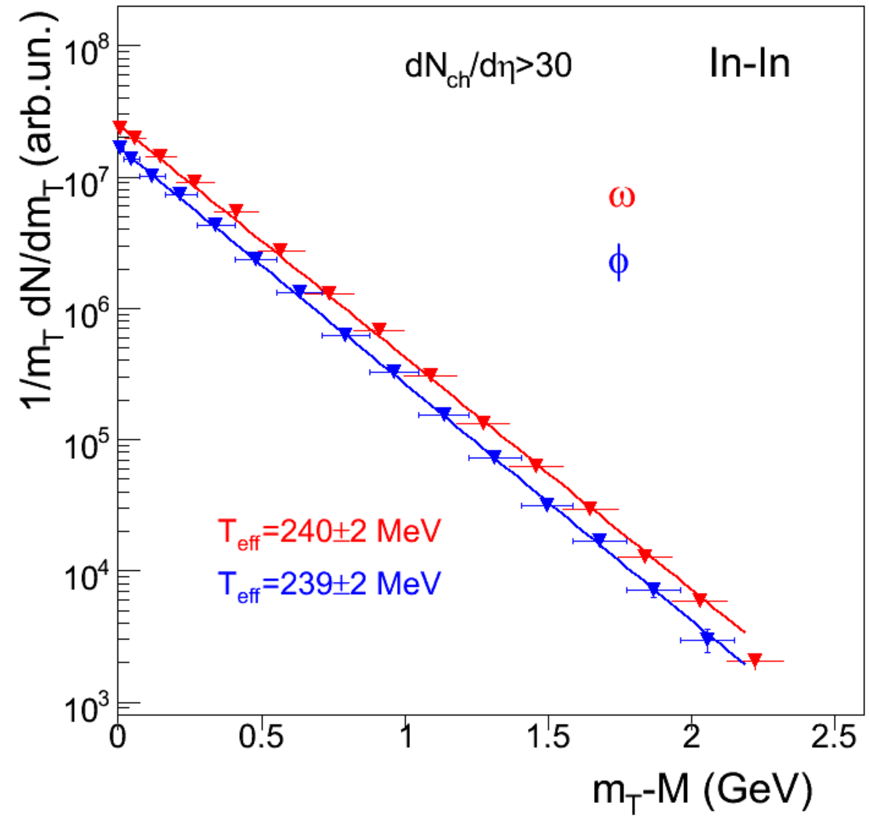
- Use selection 2 (matching of muon spectrometer tracks)
- Study limited by statistics ($N_{\psi'}$ ~ 300)
- Normalized to Drell-Yan yields



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

Extension of p_T Spectra to 3 GeV





nearly exponential shape, no hardening towards high p_T

large difference between ρ and ω (same mass) to within 9σ

STONY BROOK

Axel Drees