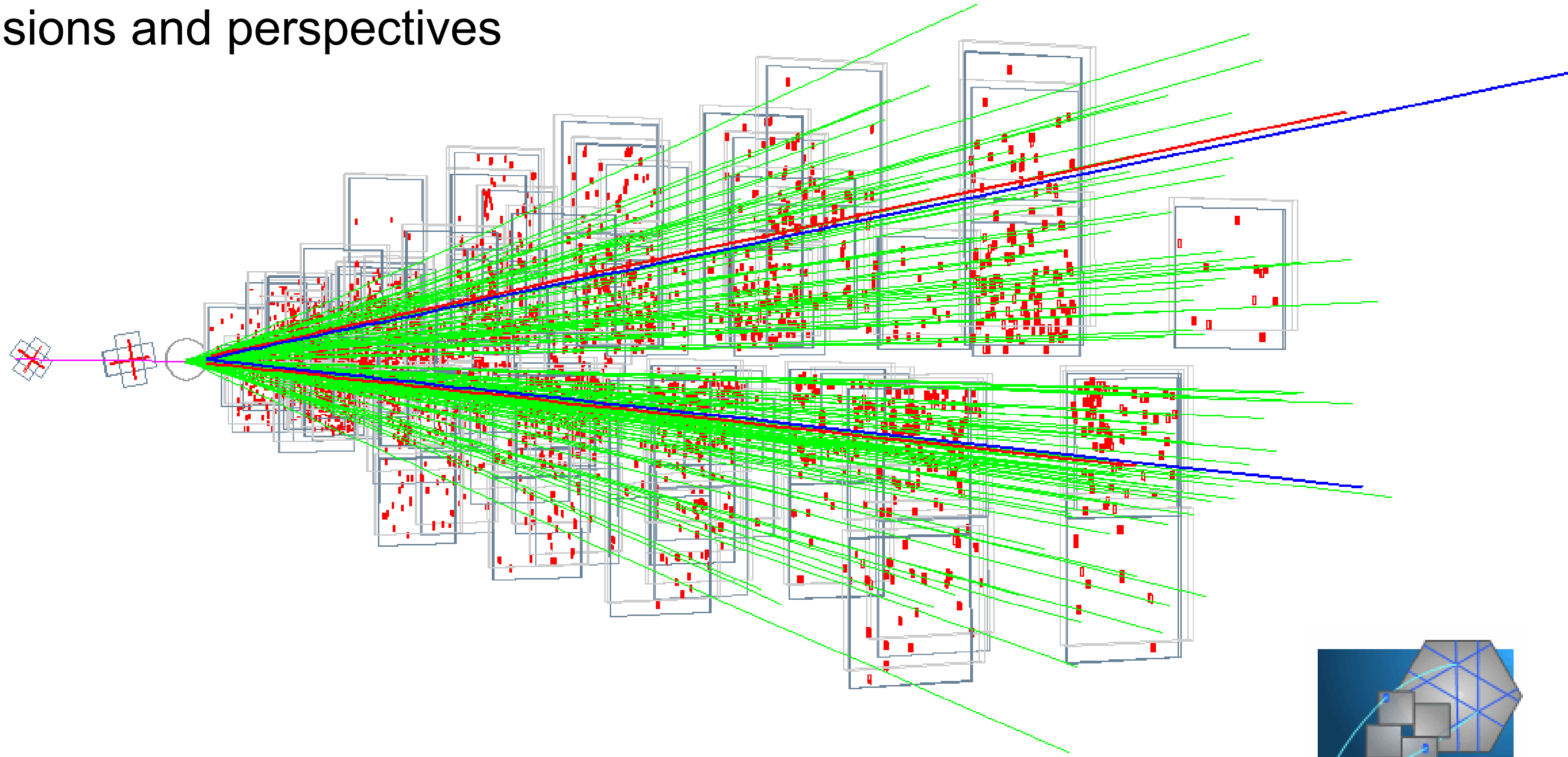
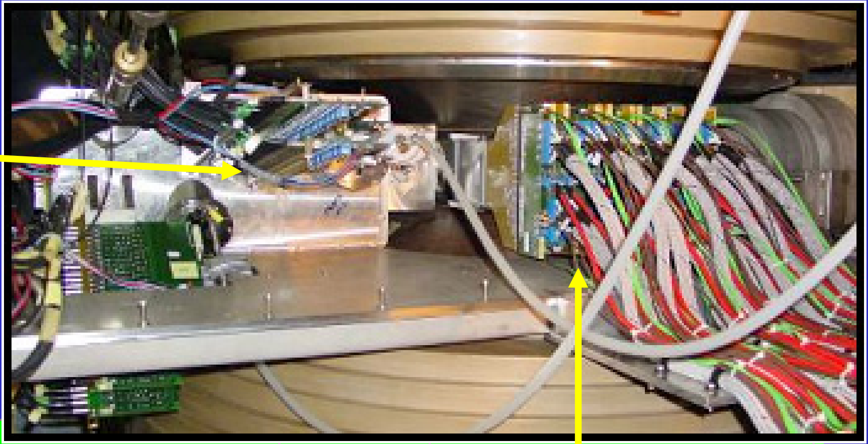
Results from NA60 experiment at the CERN SPS

- The NA60 experiment: detector concept and performance
- Physics results from the In-In run
- Conclusions and perspectives

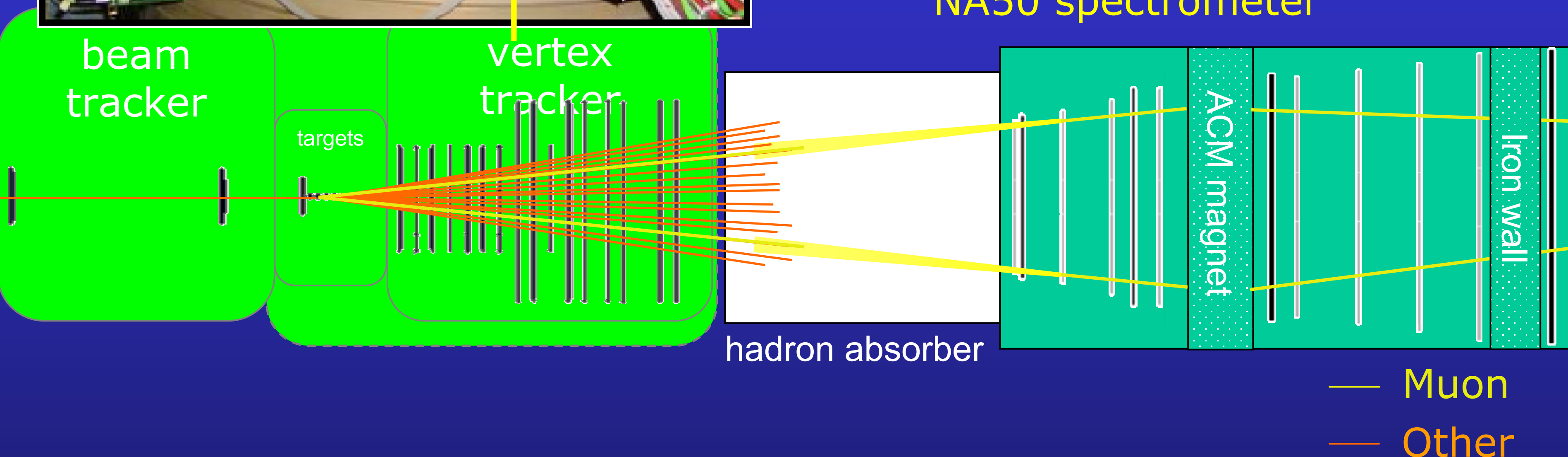


G. Usai – INFN and University of Cagliari (Italy)
on behalf of the NA60 Collaboration

NA60: detector concept

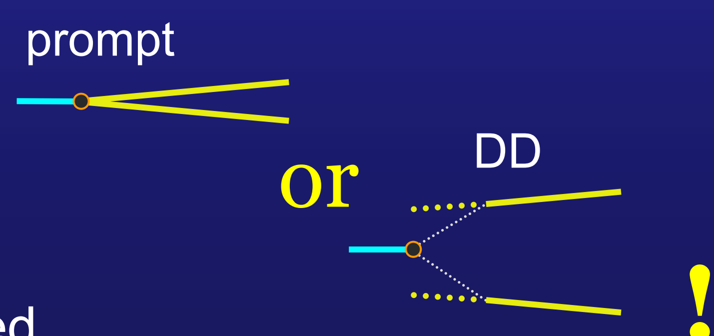


Muon trigger and tracking
NA50 spectrometer

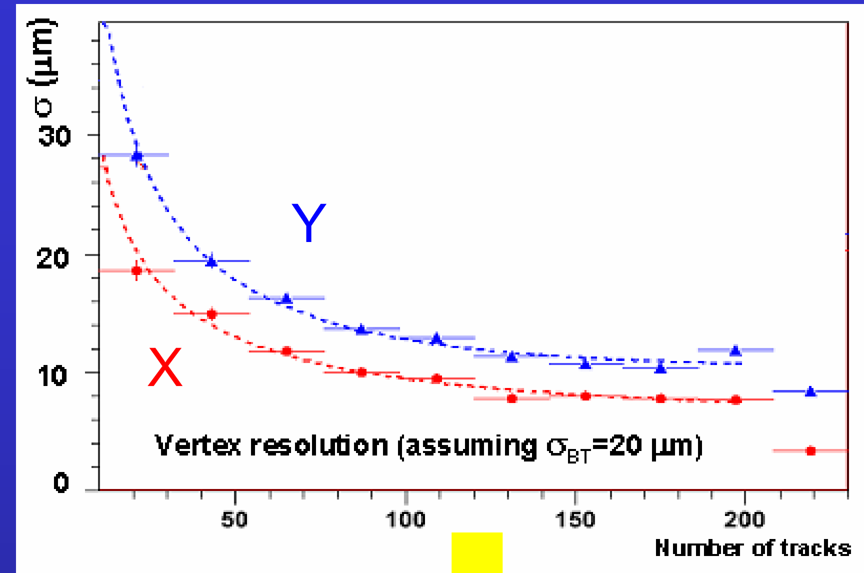


Matching in coordinate and momentum space

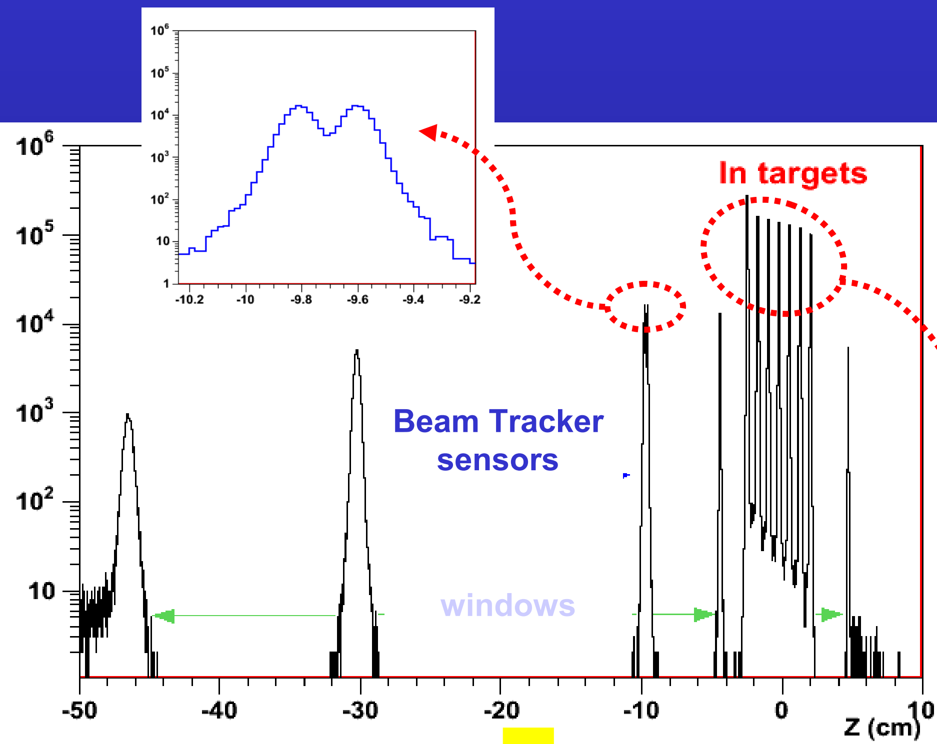
- Improved dimuon mass resolution
- Origin of muons can be accurately determined



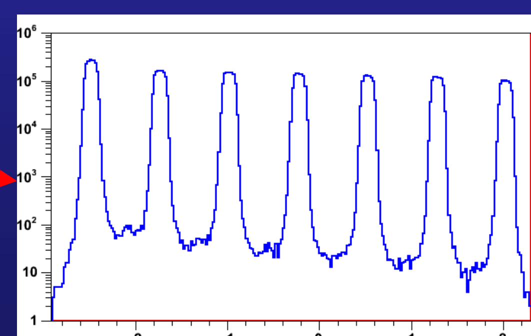
Using the vertex spectrometer



Resolution ~ 10 - 20 μm in the transverse plane



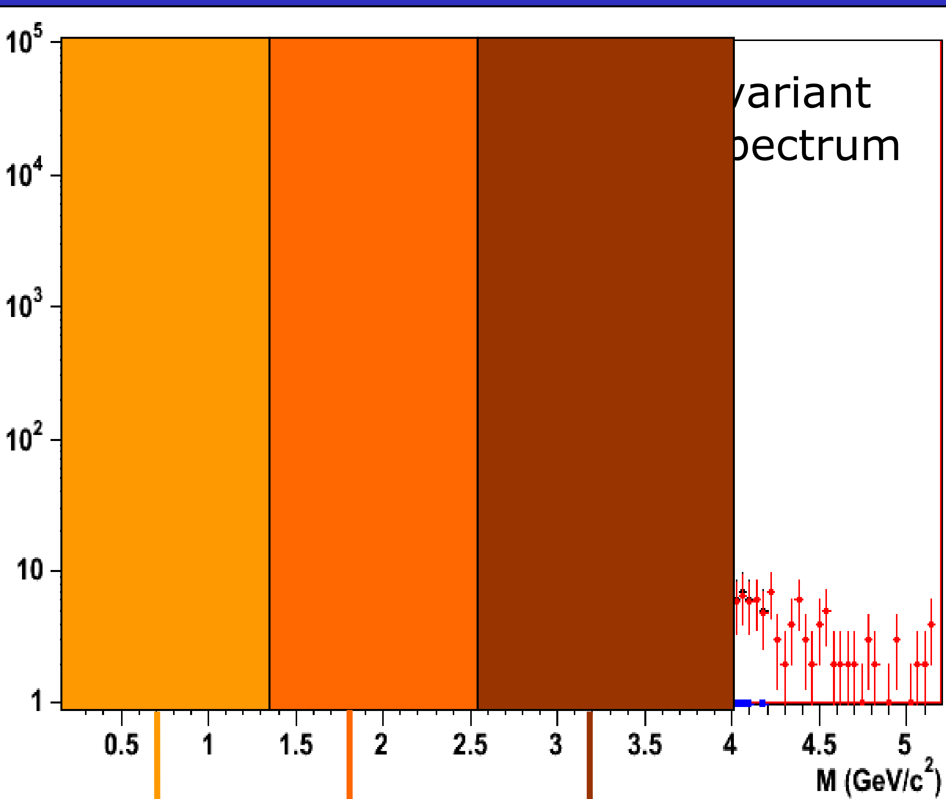
σ_z ~ 200 μm along the beam direction
Good vertex identification with $\geq$ 4 tracks



Extremely clean target identification (Log scale!)

Data taking: In-In collisions

- 5-week long run in 2003 – In-In @ 158 GeV/nucleon
- ~ 4×10^{12} ions on target
- ~ 2×10^{8} dimuon triggers collected



→ J/ψ region

IMR (Drell Yan, DD)

Low mass continuum and resonances

Two muon spectrometer settings:

Set A (low ACM current)
- Good acceptance at low mass
- Used for LMR and IMR analysis

Set B (high ACM current)
- Good resolution at high mass
- Used for J/ψ suppression

Centrality selection
- Spectator energy in the ZDC
- charged multiplicity in the vertex spectrometer

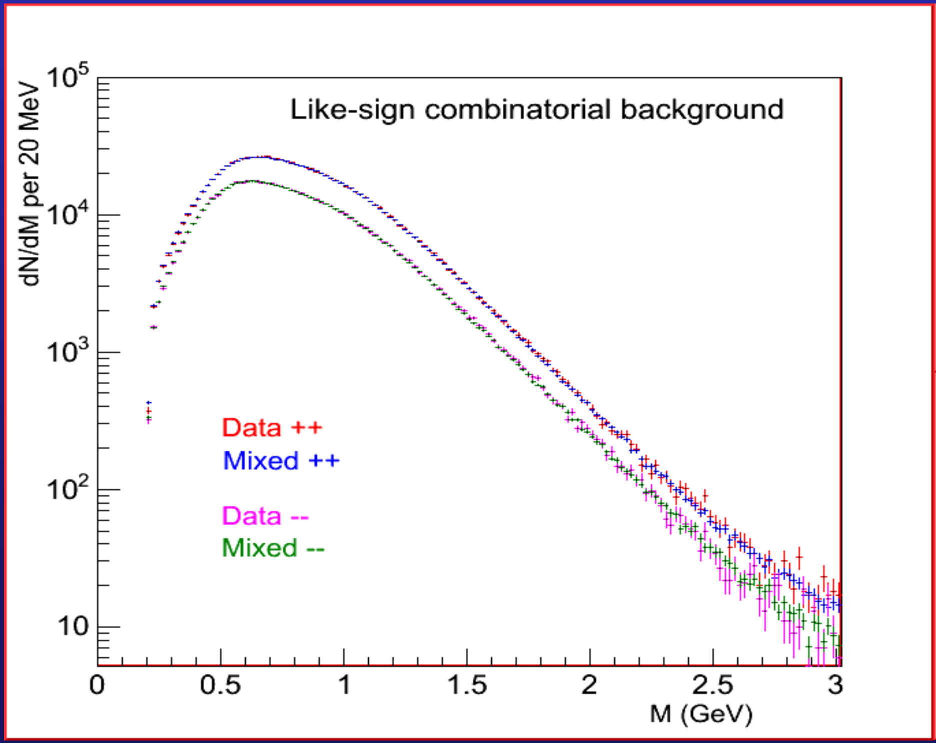
3 distinct physics topics

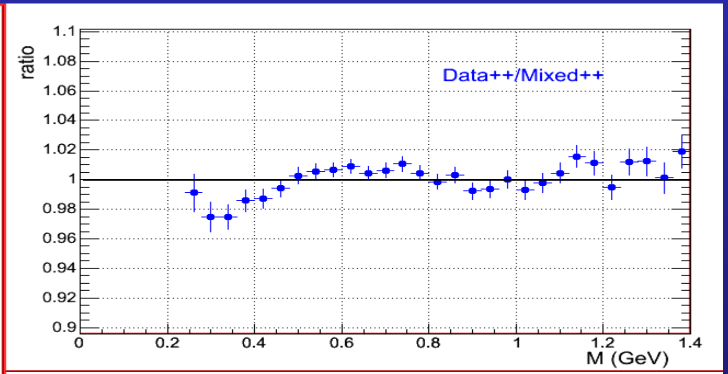
Combinatorial background subtraction

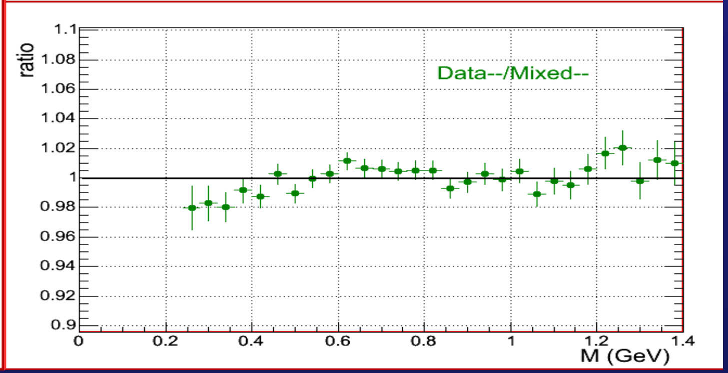
- Significantly reduced by the track matching procedure
- Nevertheless, still the dominant dimuon source for $m_{\mu\mu}<2$ GeV/c^2

	0.5 GeV	1 GeV (ϕ)	2 GeV	3 GeV (J/ψ)
signal/comb.	0.1	0.3	0.5	>100

- NA60 acceptance quite asymmetric $\Rightarrow$ cannot use $N^{\pm}_{bck} = 2\sqrt{N^{++}N^{--}}$
- Mixed event technique developed $\Rightarrow$ accurate to ~1%





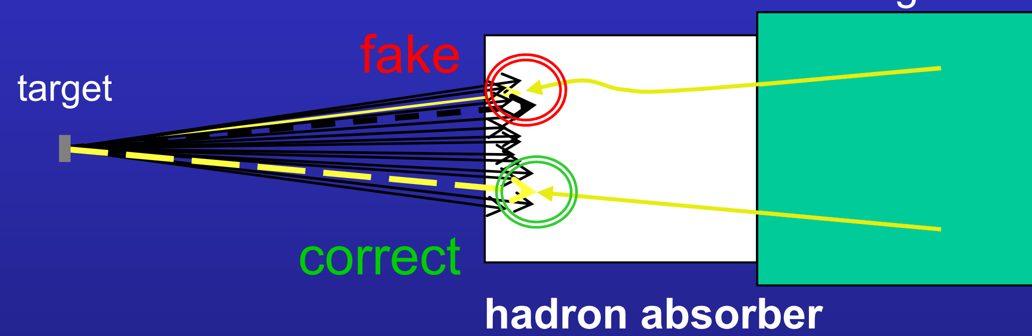


Fake match background subtraction

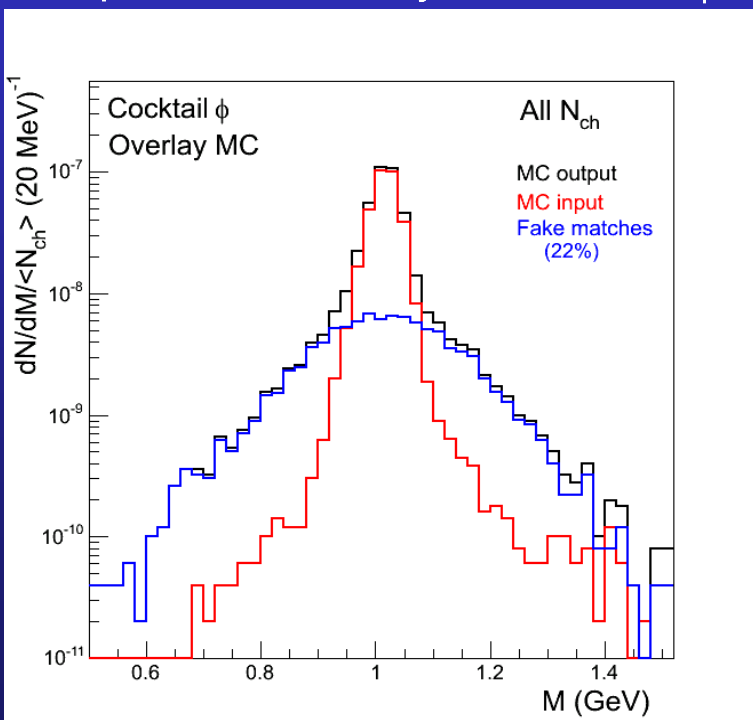
Fake match: muon matched to a wrong vertex telescope track

Two methods for rejection (in agreement within 5%)

- Overlay MC ⇒ simpler approach
- Mixed events ⇒ more complicated, rigorous approach



Example from overlay MC for the ϕ



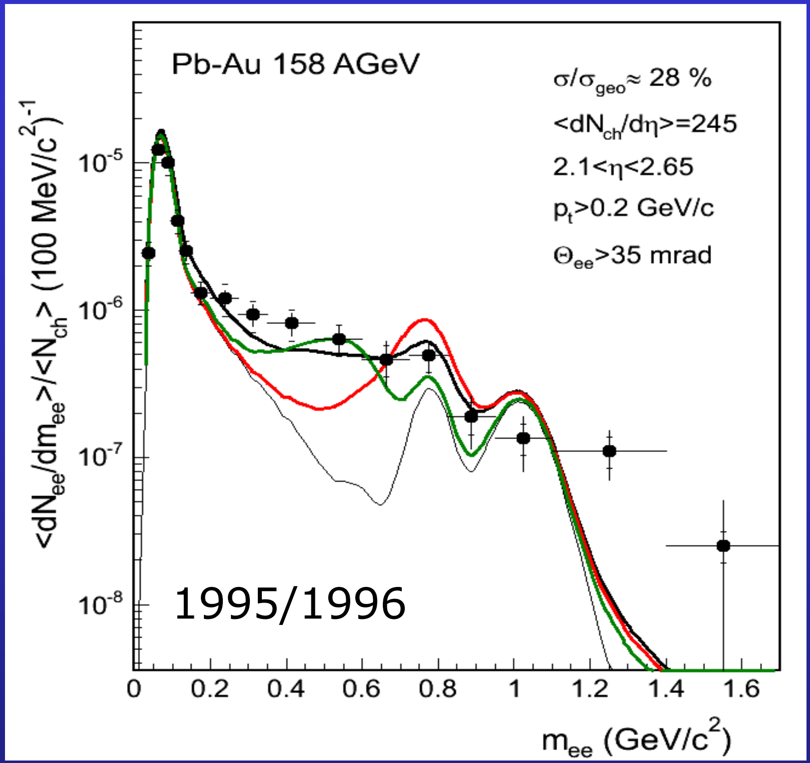
Fake-match contribution localized in mass (and p_T) space

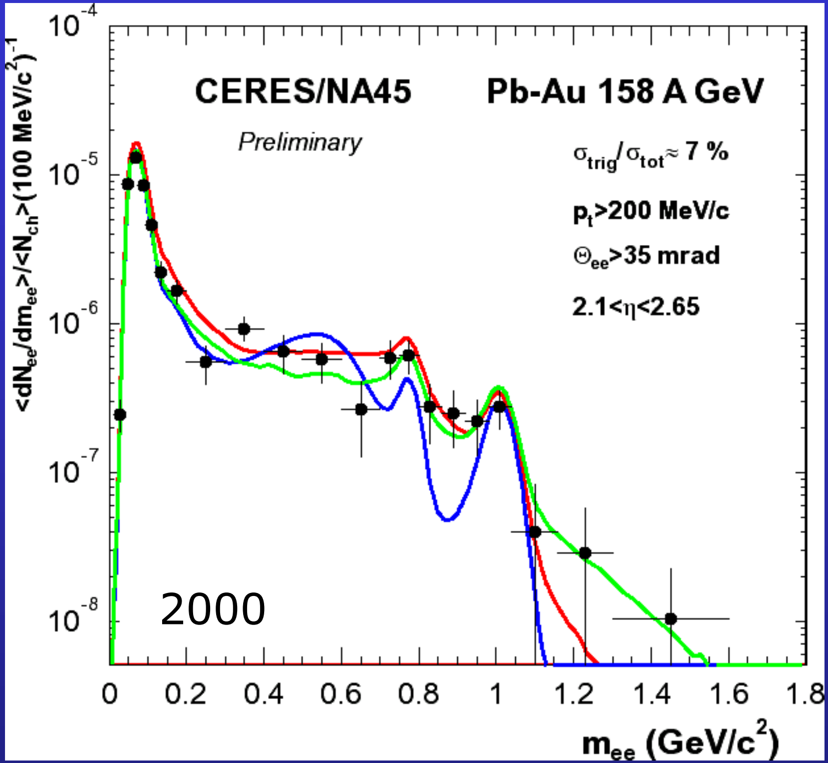
σ_ϕ = 23 MeV

σ_{fake} = 110 MeV

	0.5 GeV	1 GeV (ϕ)	2 GeV	3 GeV (J/ψ)
signal/fake	1.4	2.8	14	>100

Physics topics 1: low mass continuum

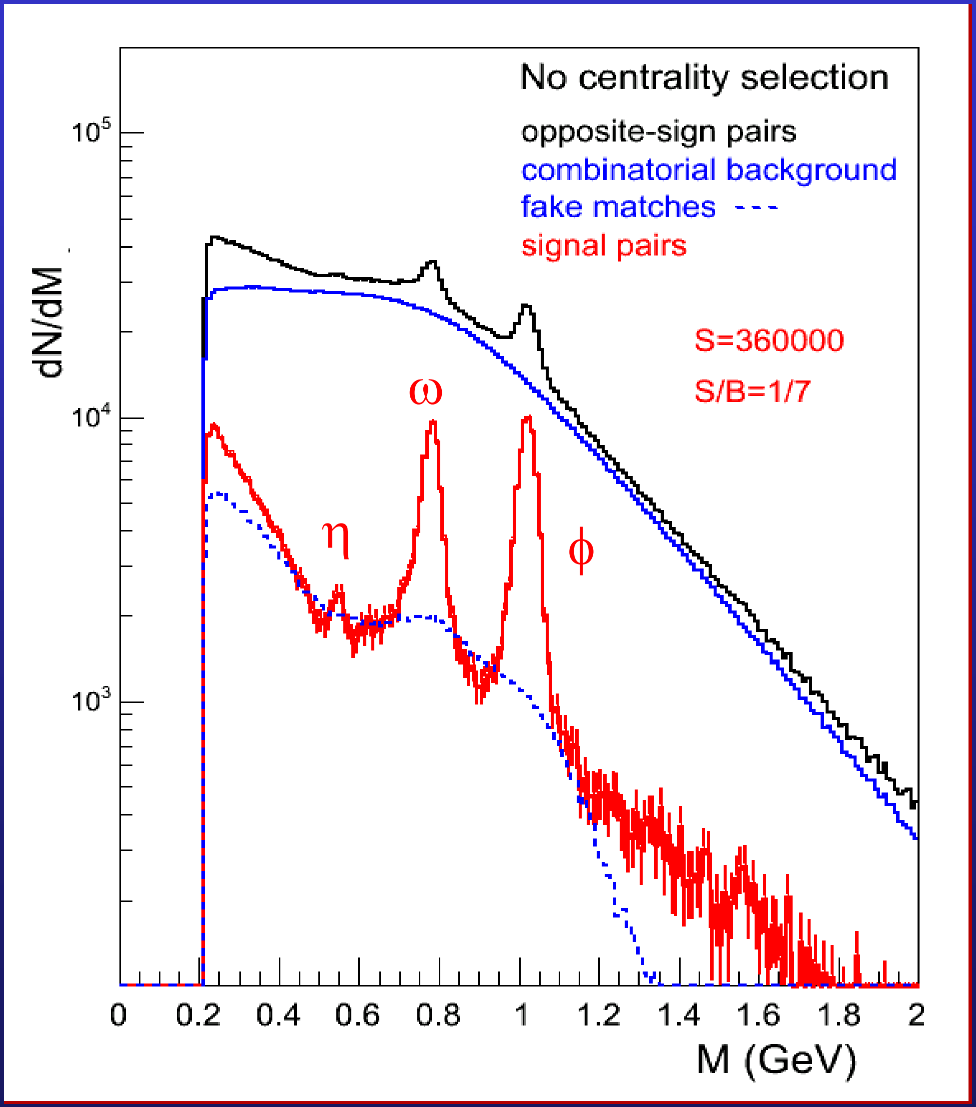




- Low mass excess well established by CERES (dielectrons)
- Next step: clear discrimination between the various theoretical explanations

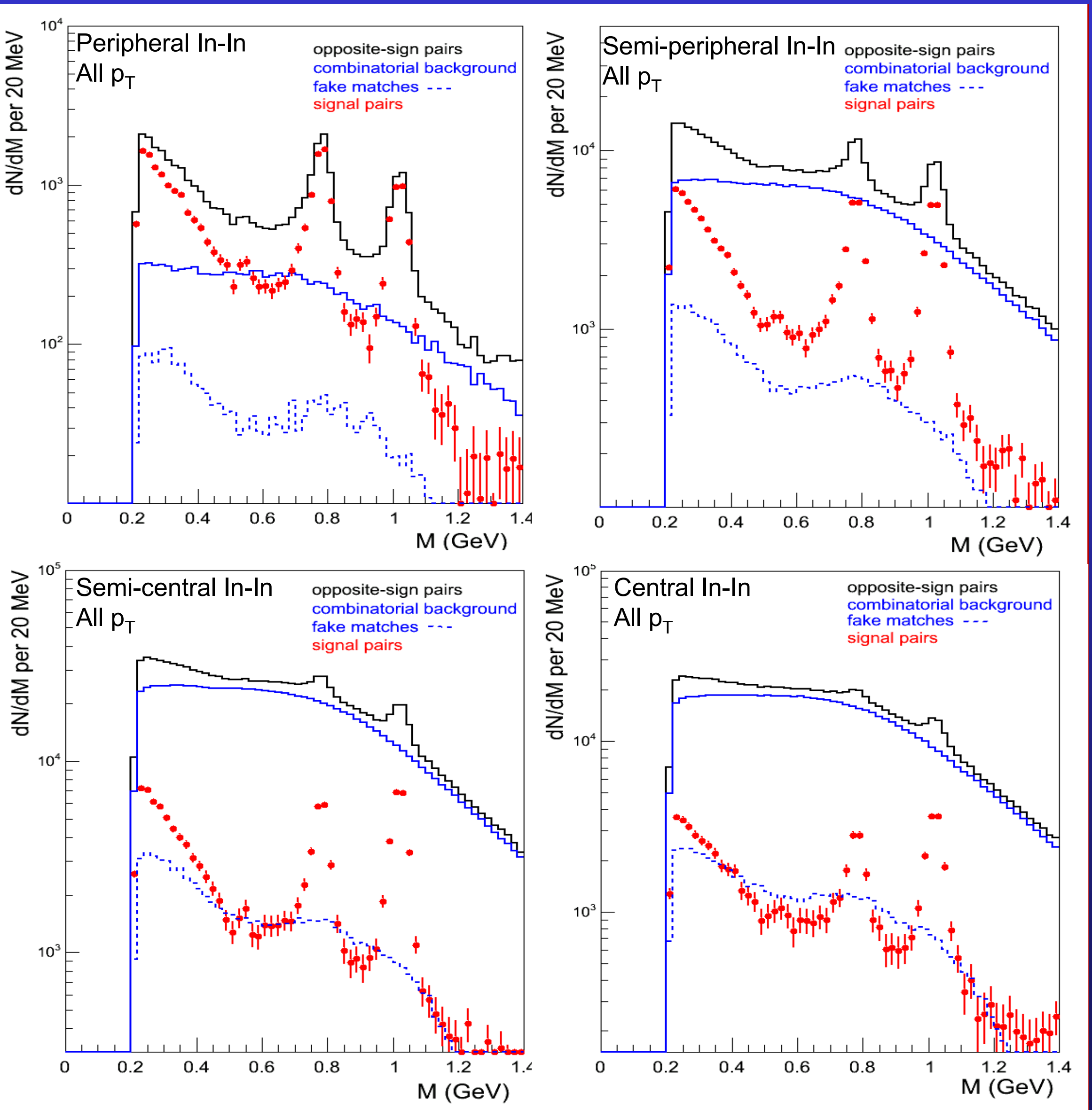
➡ Good statistics AND mass resolution are needed

Low mass – NA60 In-In data



- Net data sample: 360000 events, ~ 50% of total statistics
- For the first time ω and φ peaks clearly visible in dilepton channel (23 MeV mass resolution at the φ)
- $\eta \rightarrow \mu\mu$ also visible
- Fakes/CB < 10 %

Low mass: centrality selection



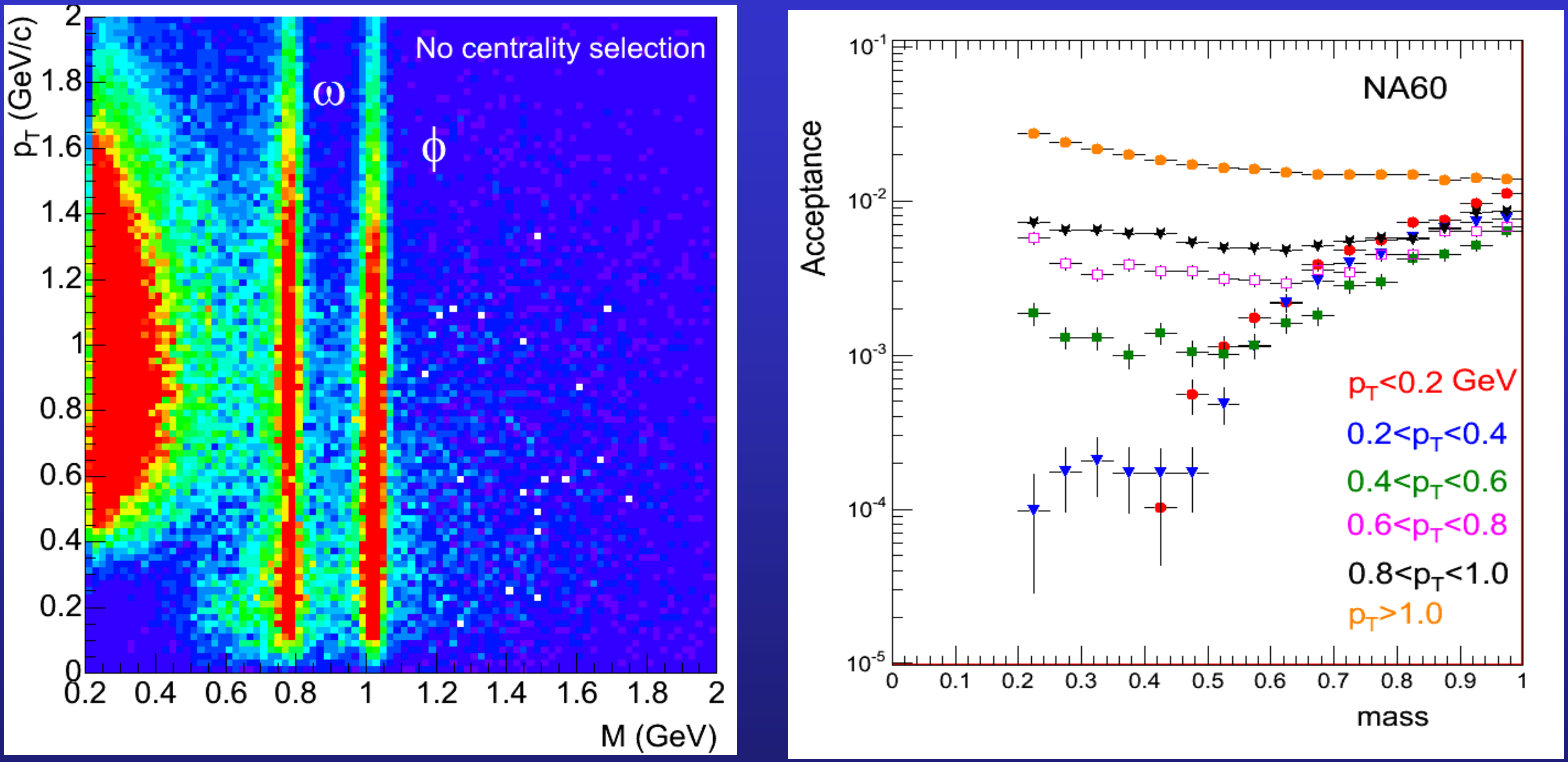
4 multiplicity bins used in analysis

bins	multiplicity	$<dN_{ch}/d\eta>$
peripheral	4-28	17
semi-periph.	28-92	63
semi-central	82-160	133
central	>160	193

Decrease of S/B with centrality, as expected

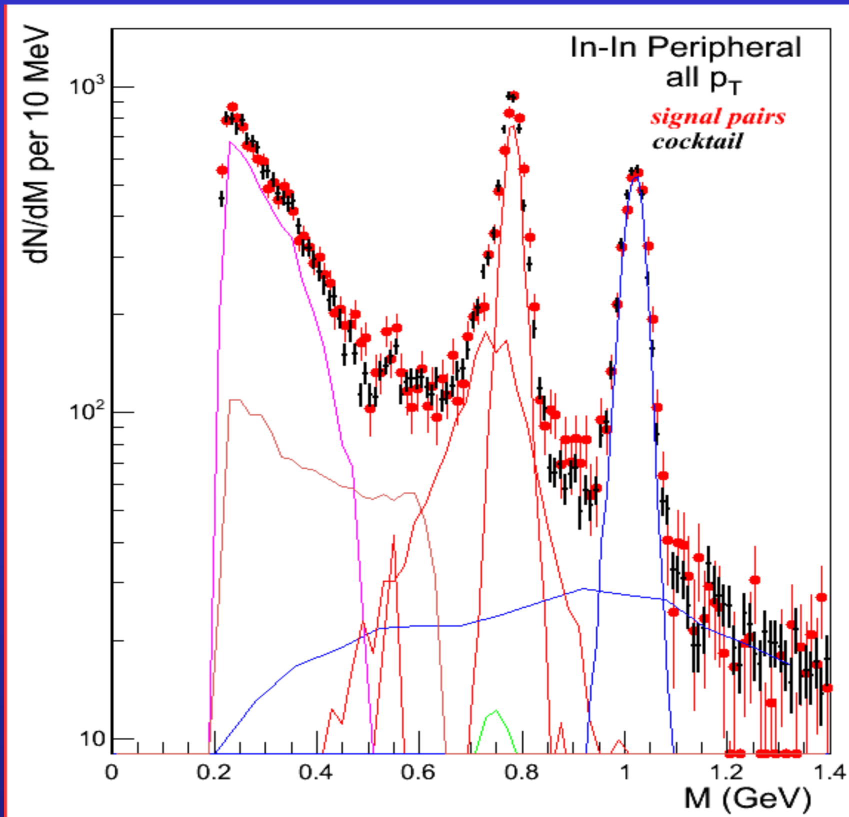
bins	S/B
peripheral	2
semi-periph.	1/3
semi-central	1/8
central	1/11

Low mass: phase space coverage

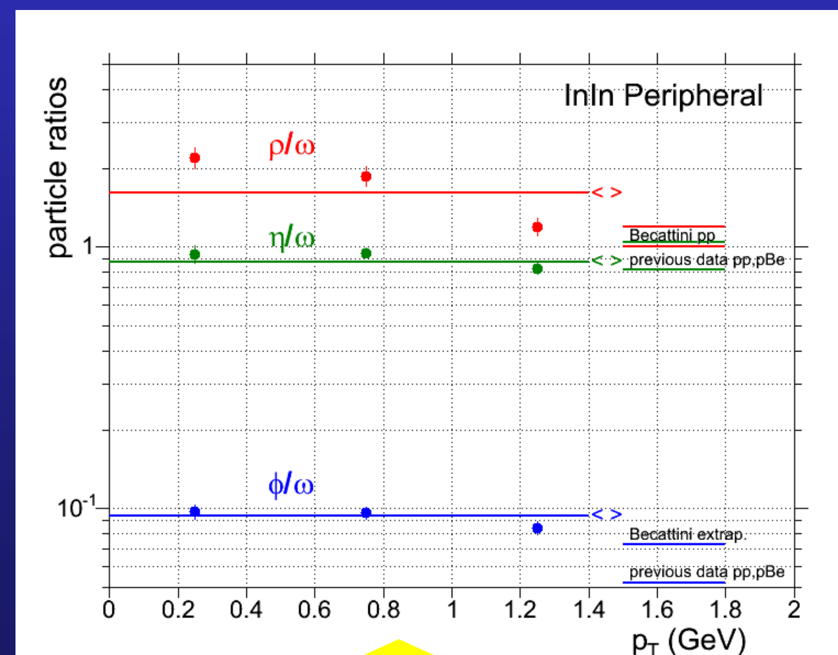


- The NA60 acceptance extends down to low m_T
- Rapidity coverage: $0<y_{cm}<1$ (slightly p_T dependent)

Low mass: peripheral collisions



- Fit independently in 3 p_T bins hadron decay cocktail and $D\bar{D}$ to the data ($m_{\mu\mu}$<1.4 GeV/c²)
- Free parameters:
  - η/ω, ρ/ω, ϕ/ω, $D\bar{D}$, ($\eta'/\eta = 0.12$, fixed)
  - overall normalization



- Peripheral data well reproduced by the hadronic cocktail (for all p_T bins)
- Good fit quality down to low mass and p_T (low acceptance region well under control)

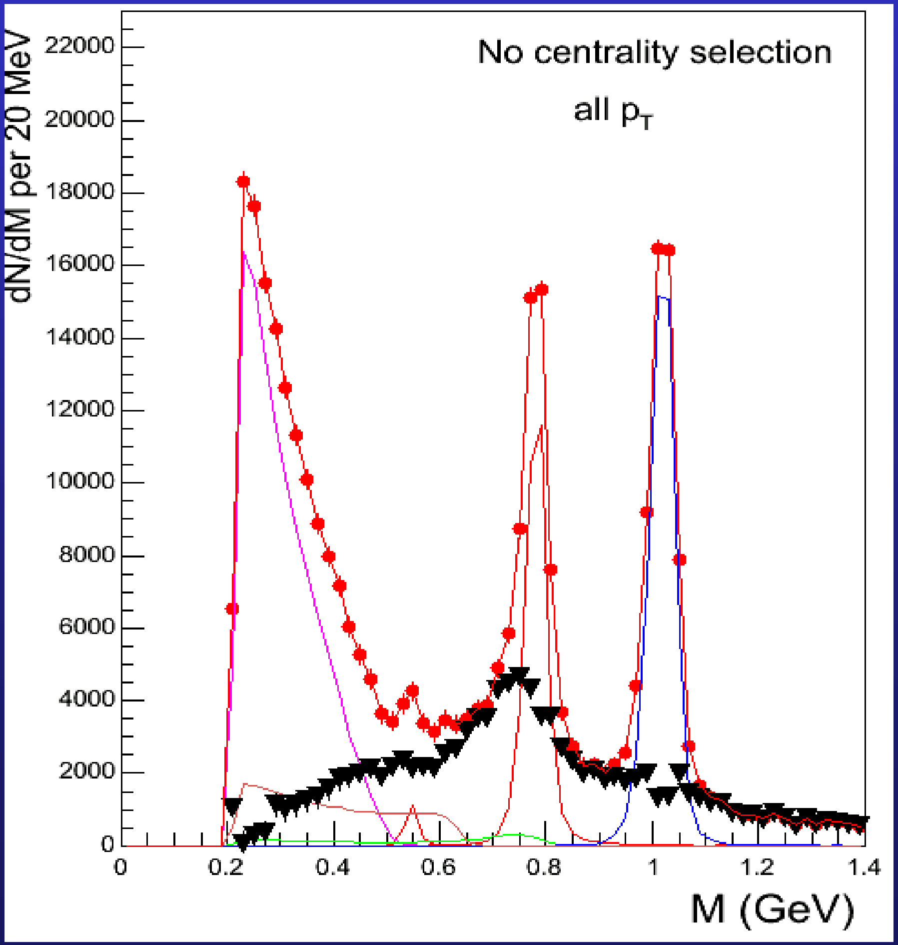
Reasonable values for the yields

Understanding the more central data

Cocktail parameters from peripheral data?

How to fit in the presence of an unknown source?

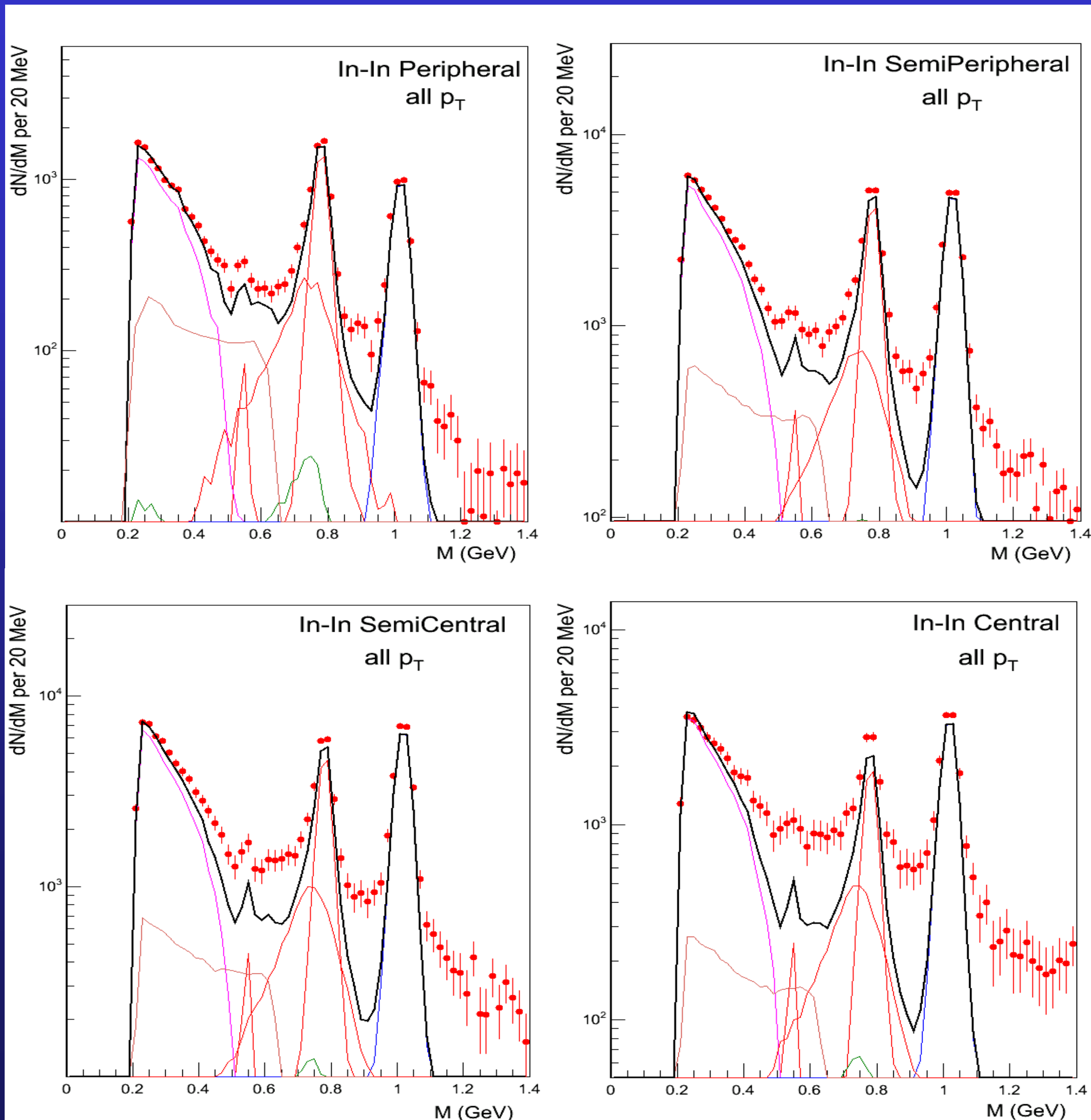
→ Try to find excess above cocktail (if it exists) without fit constraints



A simple approach is used to subtract known sources (except the ρ):

- ω and φ: yields fixed to get, after subtraction, a smooth underlying continuum
- η: set upper limit by "saturating" the yield in the mass region 0.2–0.3 GeV
  ⇒ leads to a lower limit for the excess at low mass
- ρ/ω =1.2, fixed from high p_T data

Low mass: excess in central In-In collisions

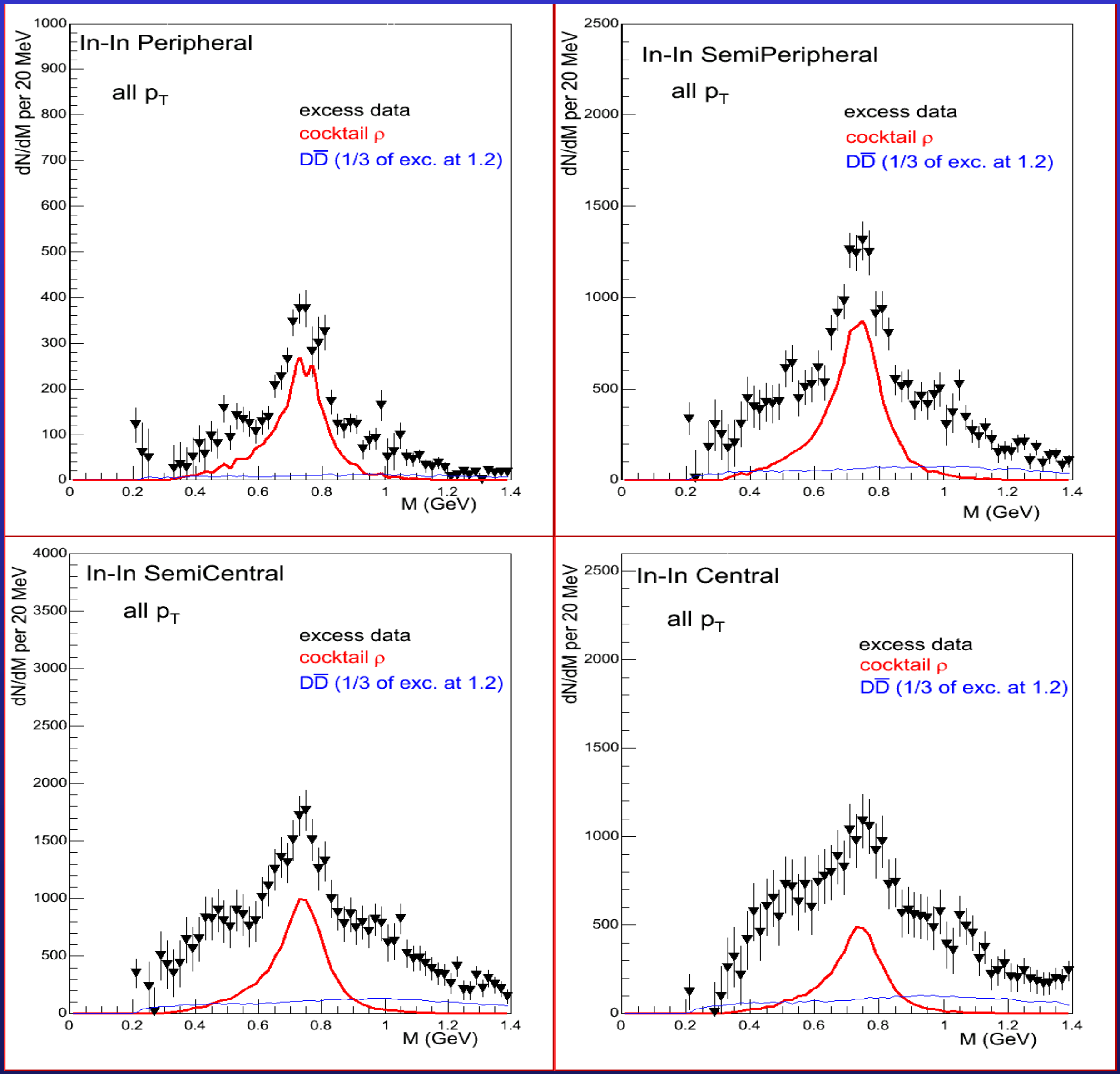


- data
- sum of cocktail sources including the ρ

- Clear excess of data above cocktail

  $\Rightarrow$ rising with centrality
  $\Rightarrow$ more important at low p_T

Excess spectra from difference data-cocktail



- No cocktail ρ and no D$\overline{D}$ 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

Systematics

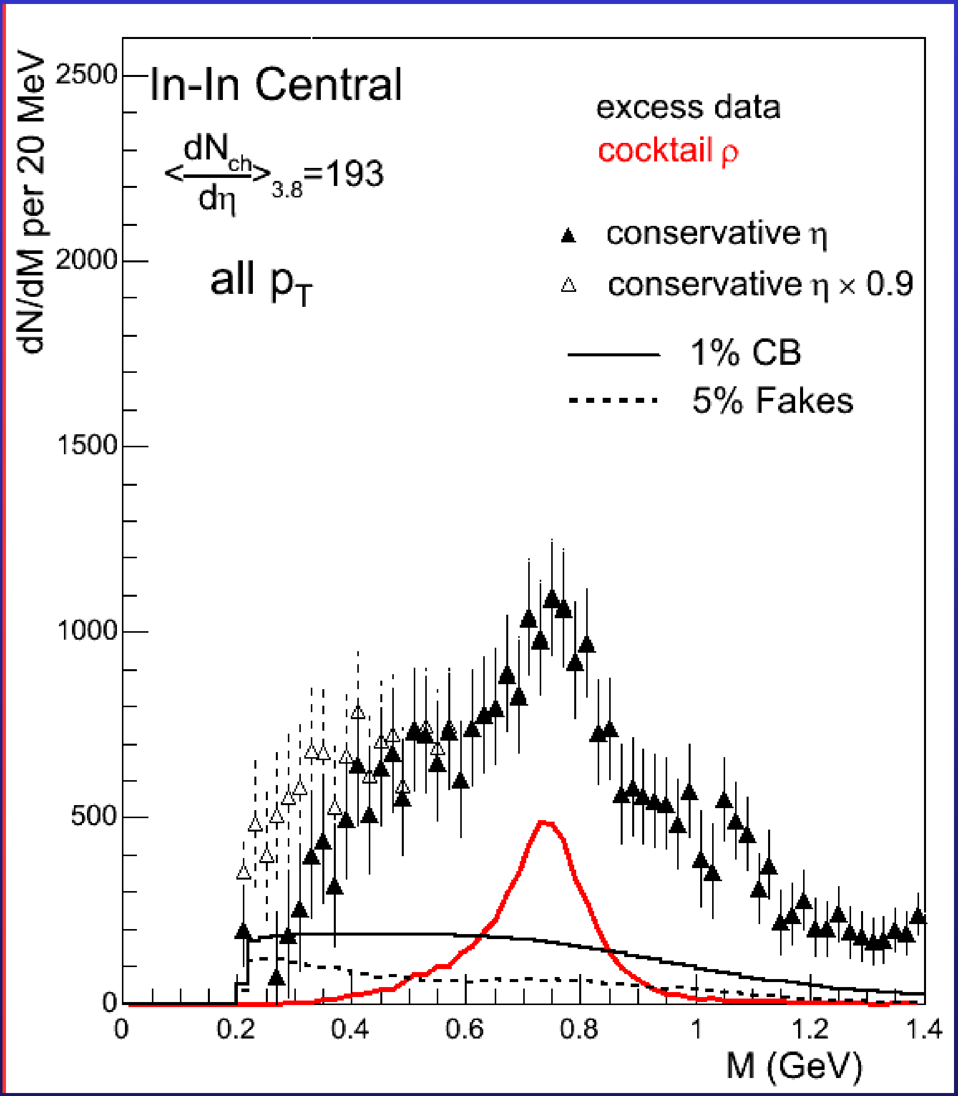


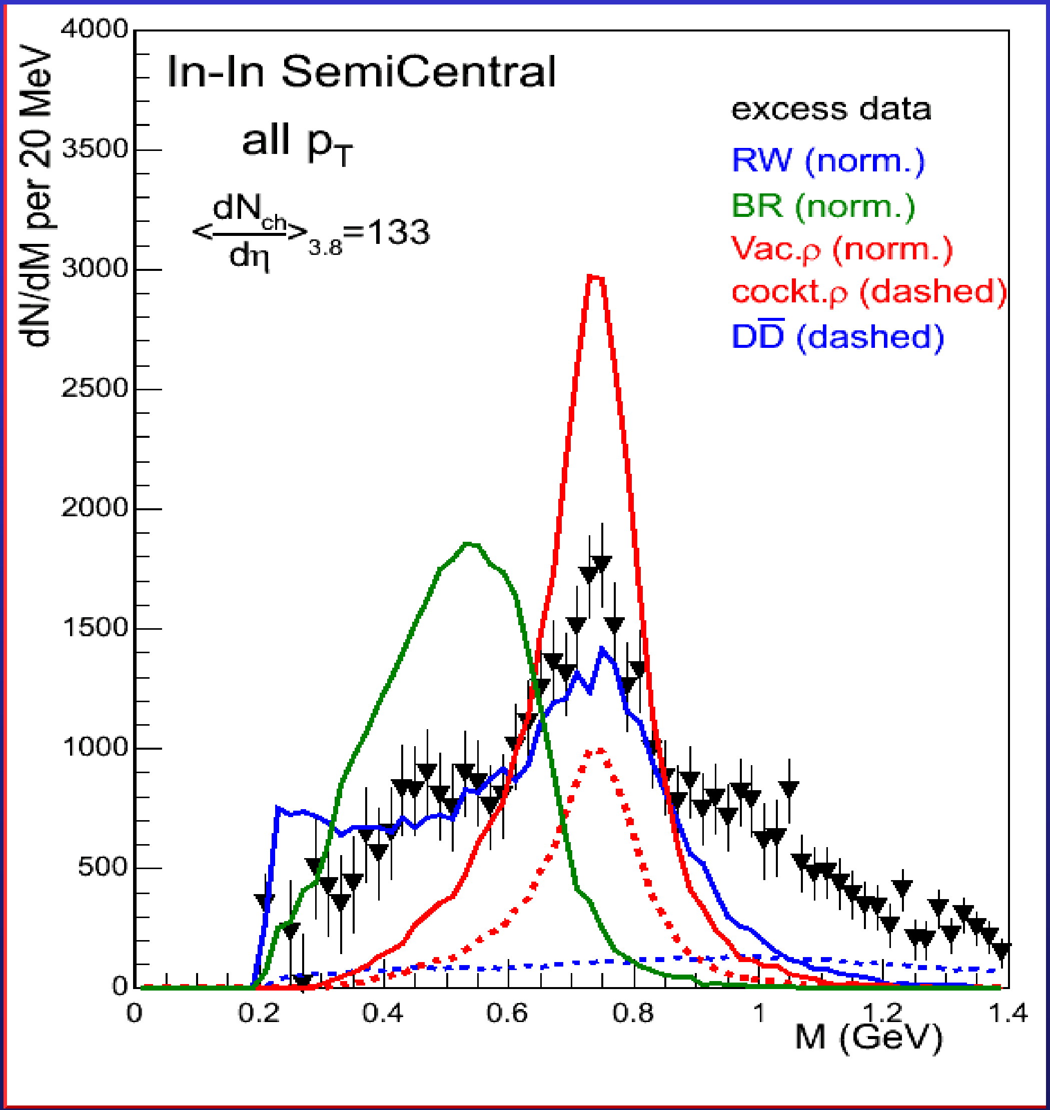
Illustration of sensitivity

- to correct subtraction of combinatorial background and fake matches
- to variation of the η yield

Systematic errors of continuum 0.4<M<0.6 and 0.8<M<1GeV   25%

Structure in ρ region completely robust

Comparison to RW, BR and vacuum ρ



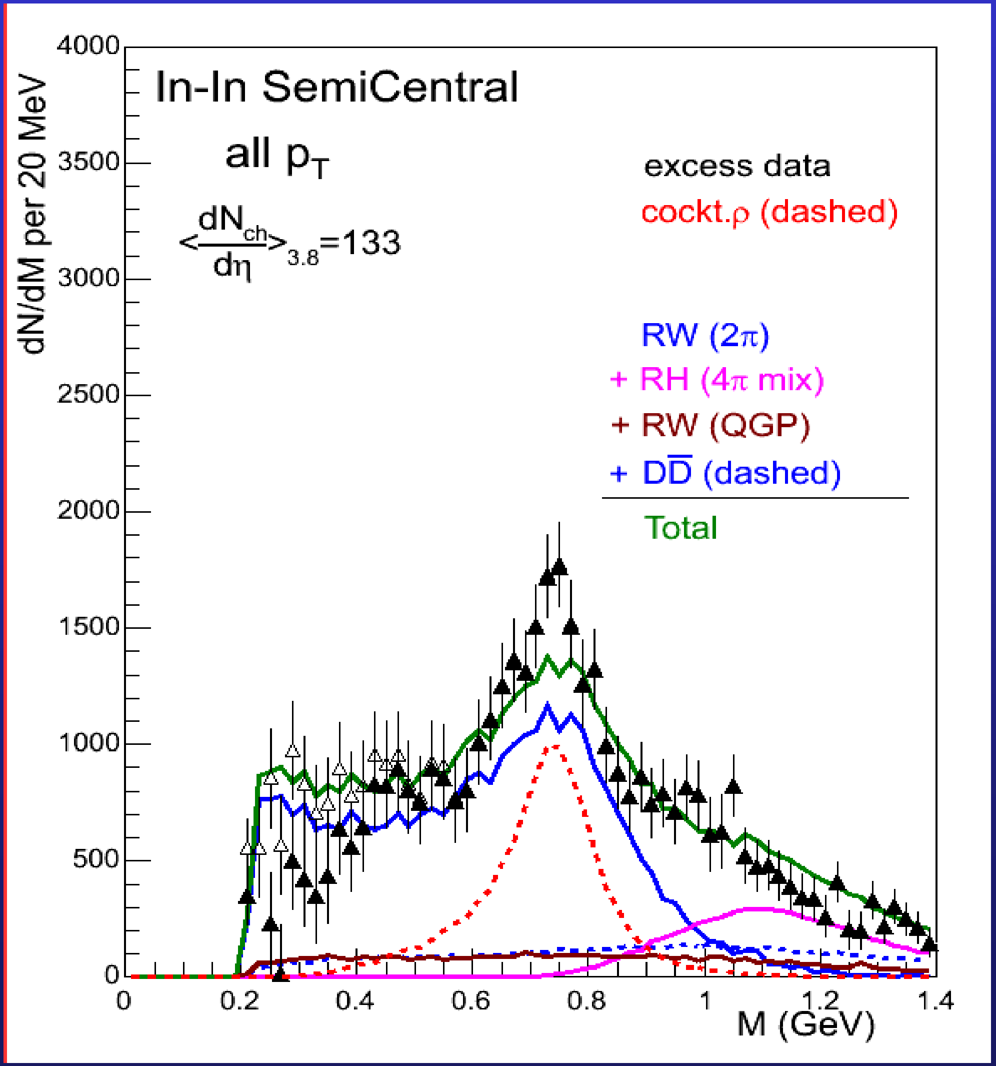
Predictions for In-In by Rapp et al (2003) for $dN_{ch}/d\eta$ = 140, covering all scenarios

Theoretical yields, folded with acceptance of NA60 and normalized to data in mass interval < 0.9 GeV

Only broadening of ρ (RW) observed, no mass shift (BR)

Comparison to RW(2π+4π+QGP)

Predictions for In-In by Rapp et al. (11/2005) for $dN_{ch}/d\eta = 140$

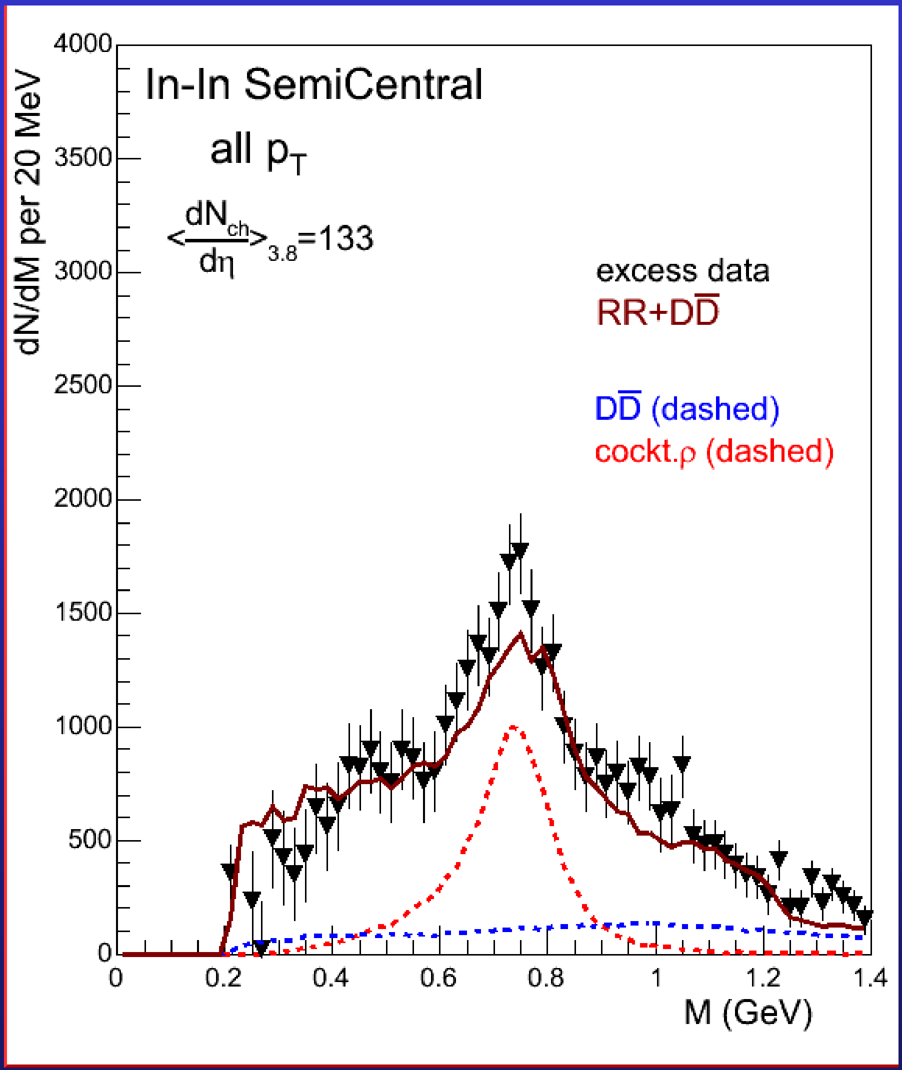


Now the whole spectrum is reasonably well described, even in absolute terms (resulting from improved fireball dynamics)

direct connection to IMR results >1 GeV from NA60

The yield above 0.9 GeV can be sensitive to the degree of vector-axialvector mixing and therefore to chiral symmetry restoration!

Comparison to RR



broadening described

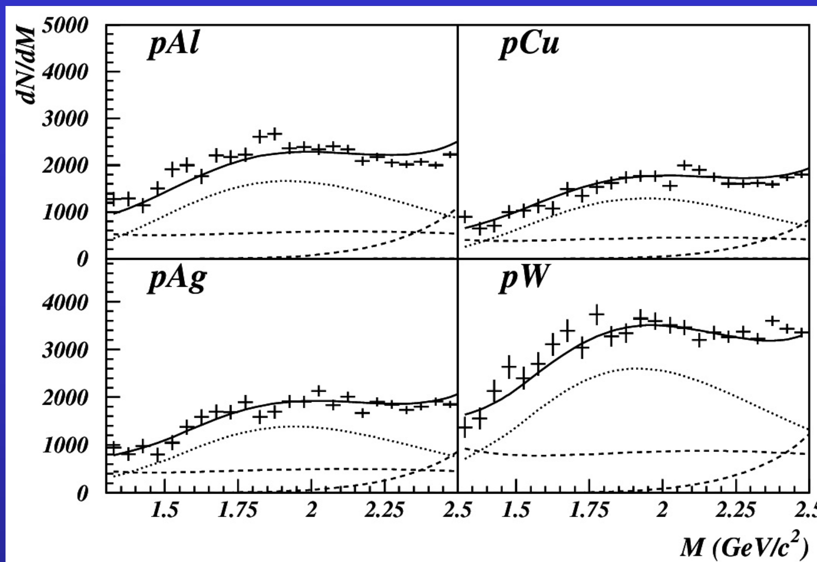
Ruppert / Renk, Phys.Rev.C (2005)

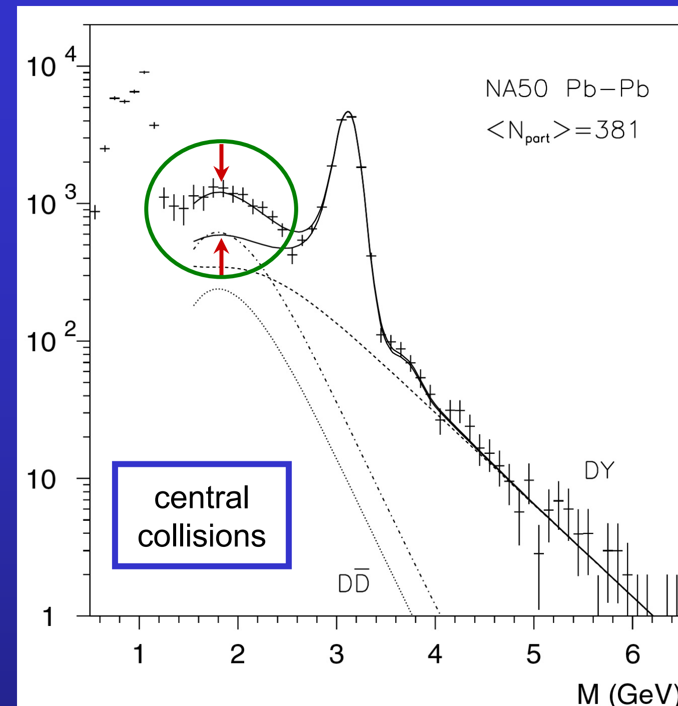
Spectral function only based on hot pions, no baryon interactions included (shape similar RW)

$$D_\rho(M,q;T)=[M^2-m_\rho^2-\Sigma_{\rho\,\pi\pi}]^{-1}$$

continuum contributions, in the spirit of quark-hadron duality, also added (fills high mass region analogous to NA50 IMR description)

Physics topics 2: intermediate mass region



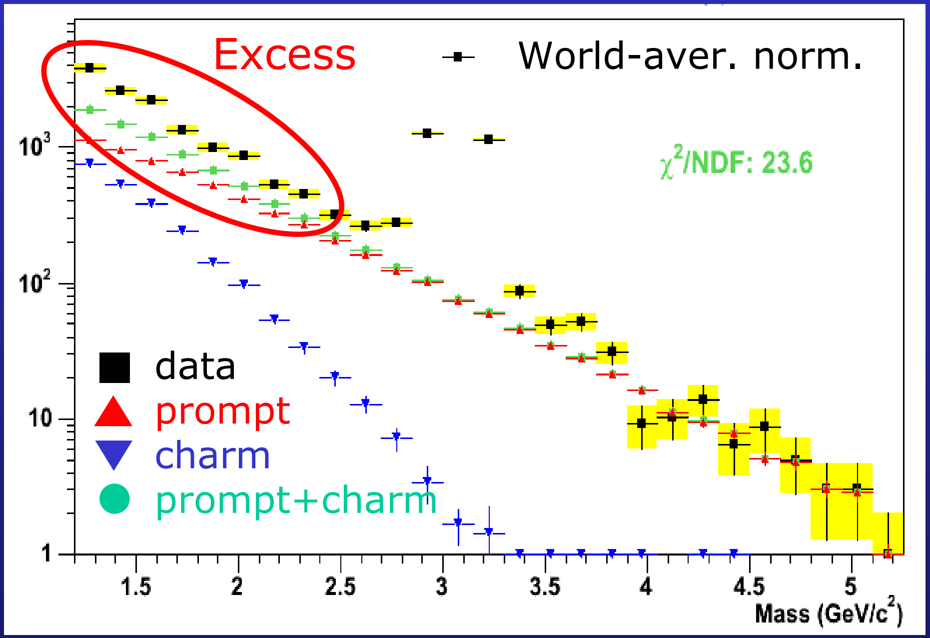


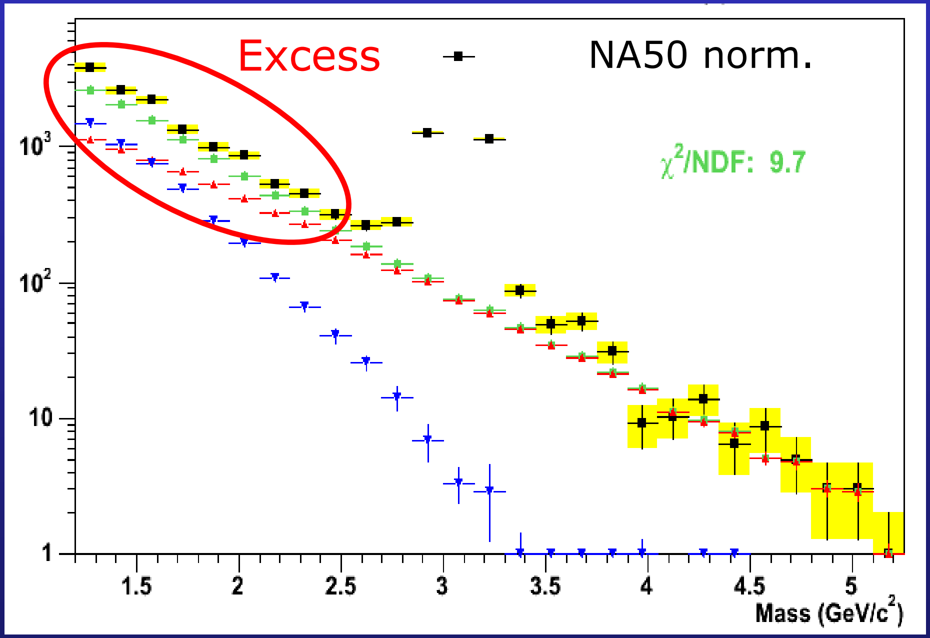
- IMR excess in S-U/S-W and Pb-Pb, with respect to p-A, established by NA38/NA50 and Helios-3
- Can be ascribed to both:
  - Anomalous open charm enhancement
  - Thermal dimuon production

NA60 proposal: discriminate between the two explanations, by tagging, through the muon offsets, the semi-leptonic decays of DD pairs

IMR – NA60 In-In data: is an excess present ?

- Open charm and Drell-Yan generated with PYTHIA
- Drell-Yan normalization fixed using the high mass region
- Open charm normalization: use
  - ⇒ NA50 p-A result (better control of systematics related to μμ channel)
  - ⇒ World-average $c\bar{c}$ cross section (based on direct charm measurements)
    (differ by a factor ~ 2)





- Answer: Yes, an excess in the IMR is clearly present
  (same order of magnitude of the NA50 result)

IMR: measuring the muon offset

As in NA50, the mass shape of the In-In excess is compatible with open charm $\Rightarrow$ not conclusive, muon offset information needed

Muons from D $\rightarrow \mu$ + X do not converge to the interaction vertex

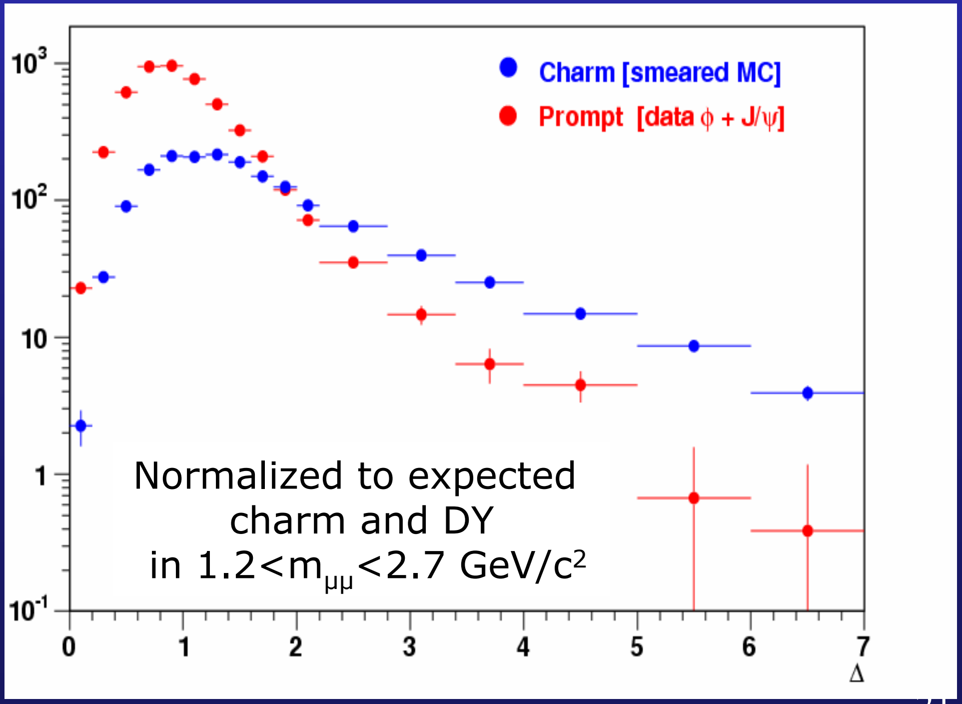
- Typical offset of muons $\begin{cases} D^+ : c\tau = 312\ \mu m \\ D^o : c\tau = 123\ \mu m \end{cases}$

Offset resolution 40-50 μm (measured on J/ψ data)

- Muon offsets: Δx, Δy between the vertex and the track impact point in the transverse plane at Z_{vertex}
- $\Delta_\mu \Rightarrow$ offset weighted by the covariance matrices of the vertex and of the muon track

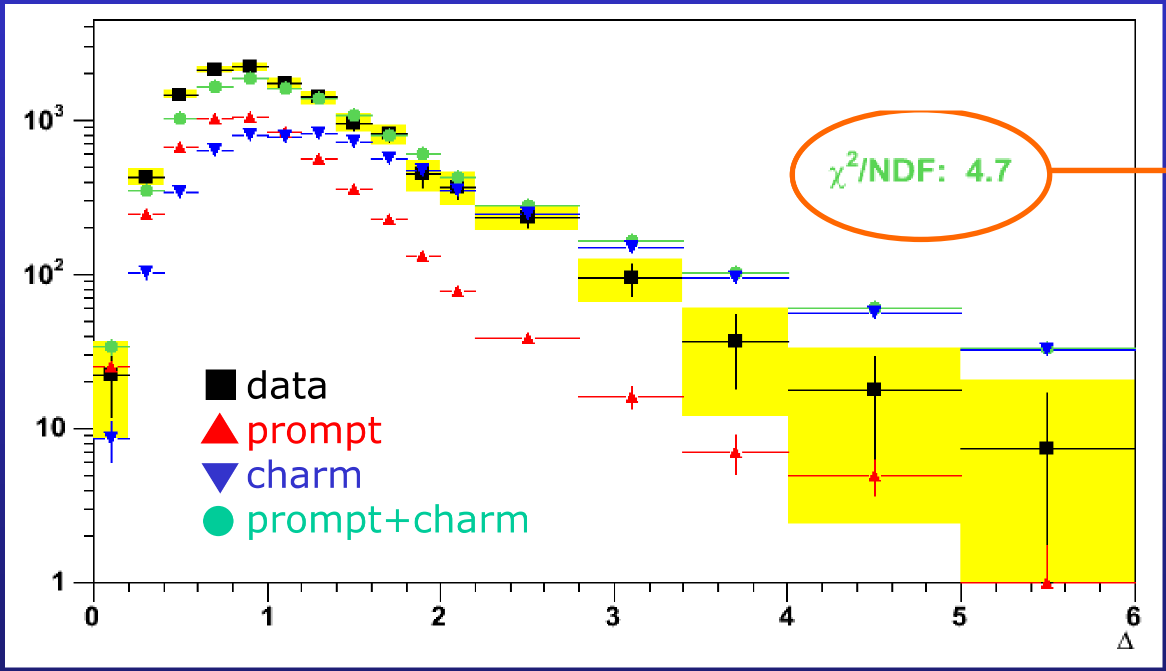
$$\Delta_\mu = \sqrt{(\Delta x^2 V_{xx}^{-1} + \Delta y^2 V_{yy}^{-1} + 2\Delta x \Delta y V_{xy}^{-1})/2}$$

$$\Delta = \sqrt{(\Delta_{\mu 1}^2 + \Delta_{\mu 2}^2)/2}$$



IMR: is the excess due to open charm ?

⇒ Fit IMR Δ distribution fixing prompt contribution
to the expected Drell-Yan yield

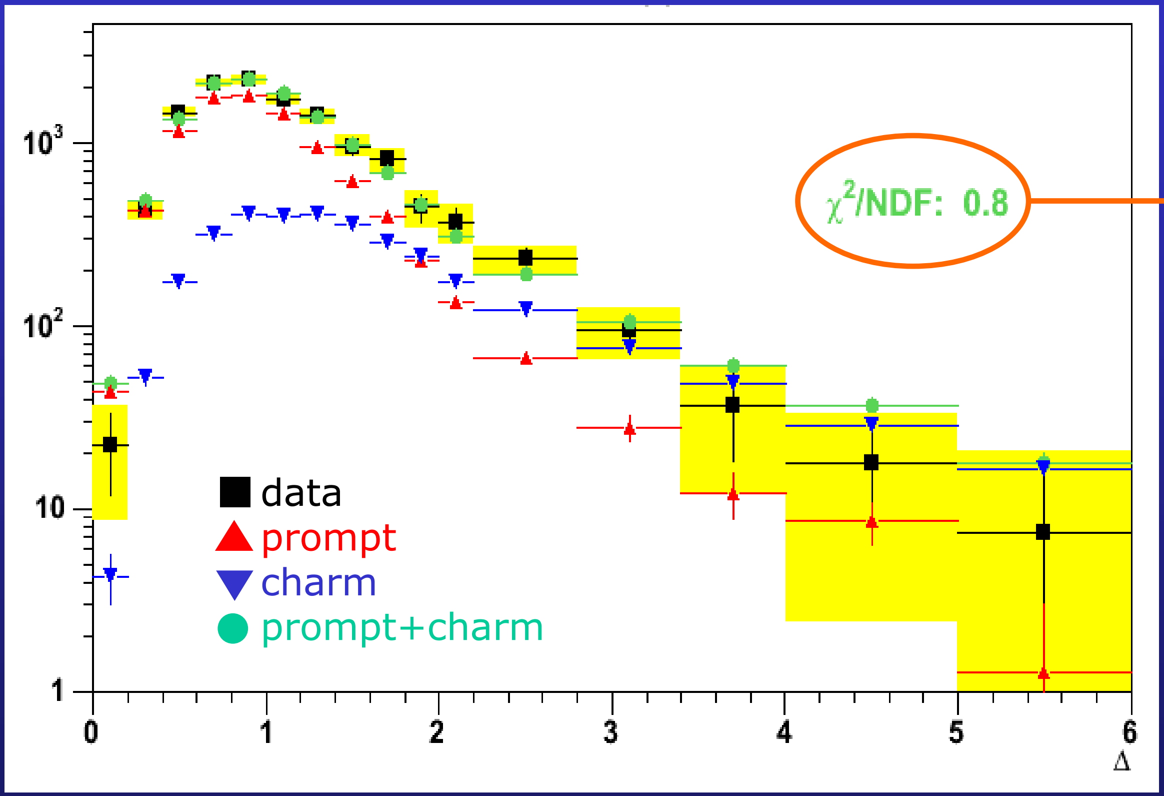


Fit fails

- Answer: No, the excess seen in In-In is not due to open charm enhancement

IMR: is the excess due to prompt dimuons?

⇒ Fit IMR Δ_μ distribution fixing open charm contribution to the expected value (from NA50 p-A)



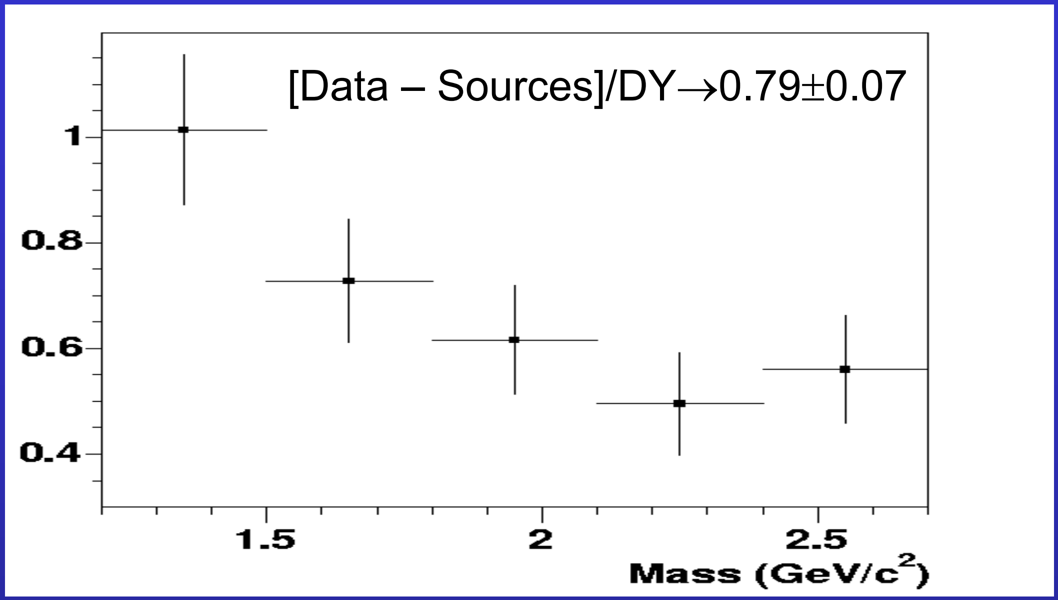
Fit converges, good χ^2

$$\frac{\text{Meas. prompt}}{\text{Exp. prompt}} = 1.91 \pm 0.11$$

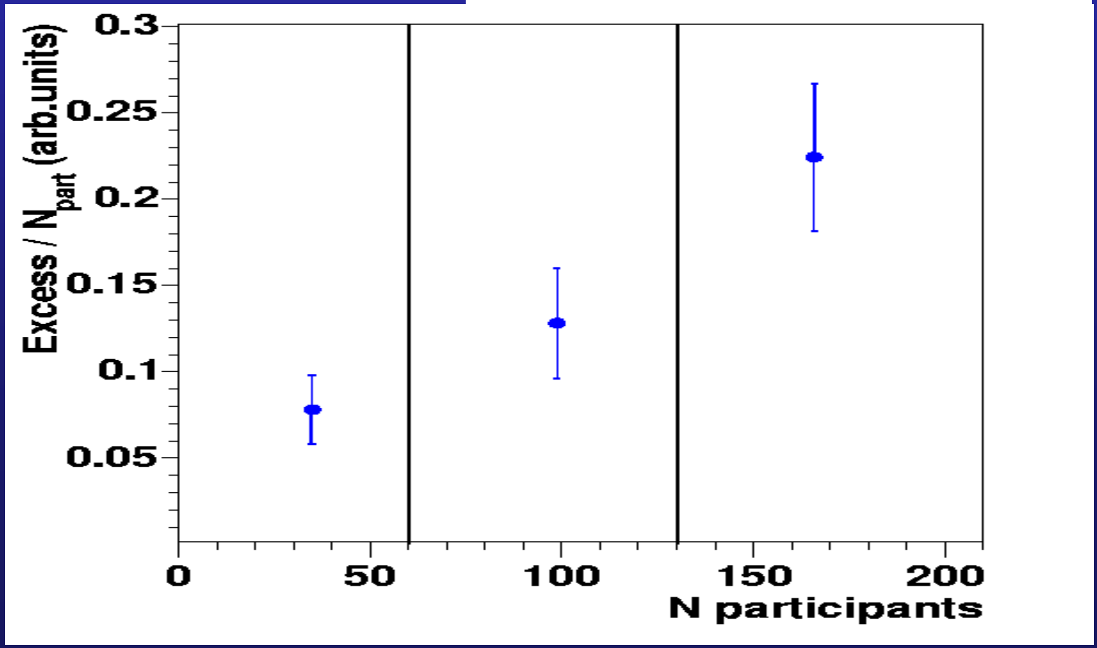
(2.10 ± 0.07 when world-average norm. is used)

- Answer: Yes, the excess seen in In-In is prompt

Mass shape and centrality dependence of the excess



The mass distribution of the excess is steeper than Drell-Yan

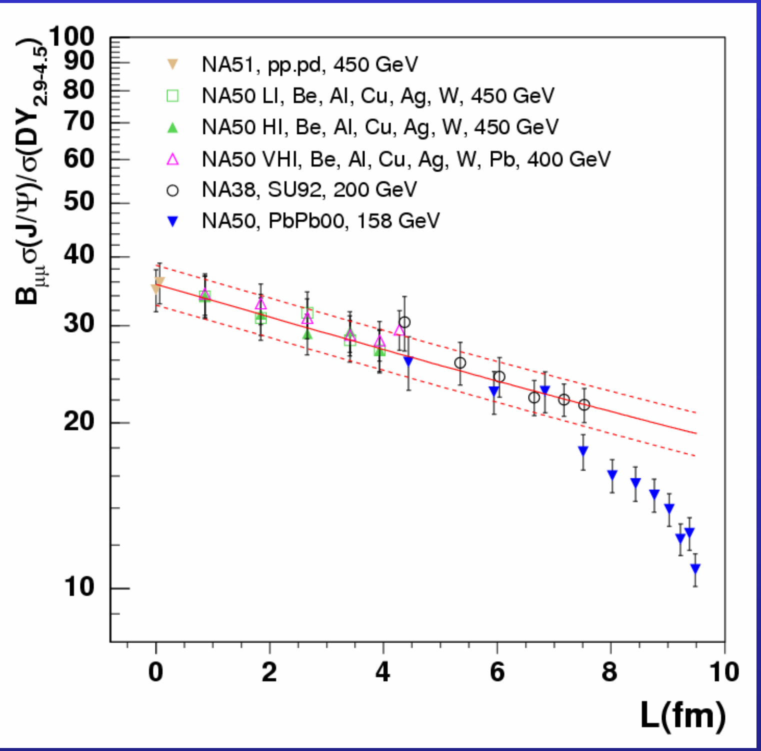


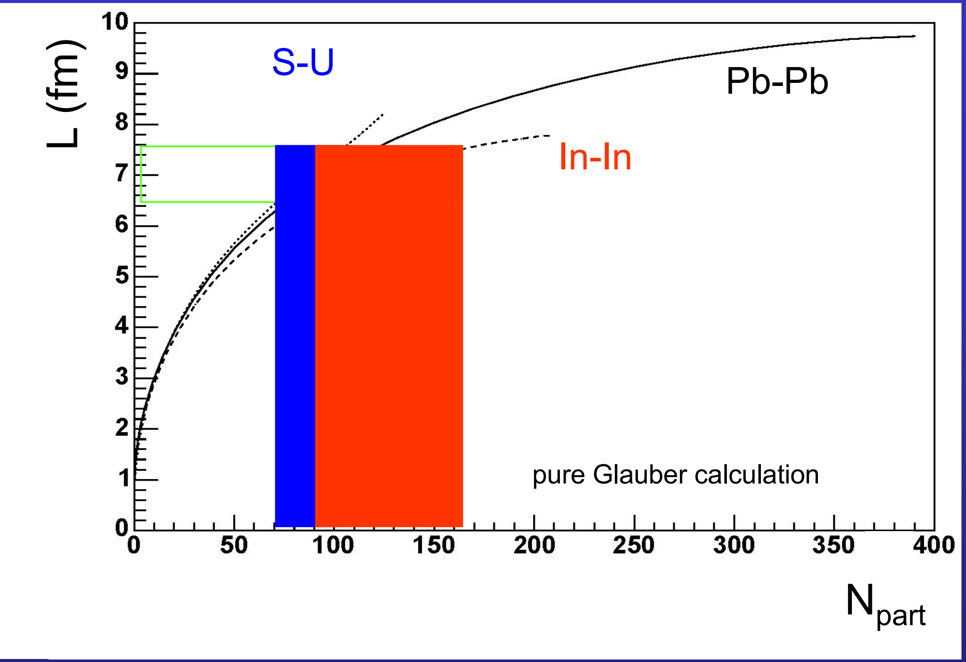
[Data – Sources]/ω
(Arbitrary normalization)

ω scales with $N_{participants}$

$\Rightarrow$The excess grows faster than $N_{participants}$

Physics topics 3: J/ψ suppression





Anomalous J/ψ suppression, discovered by NA50 in Pb-Pb collisions

NA60 proposal: is anomalous suppression present also in lighter nuclear systems?

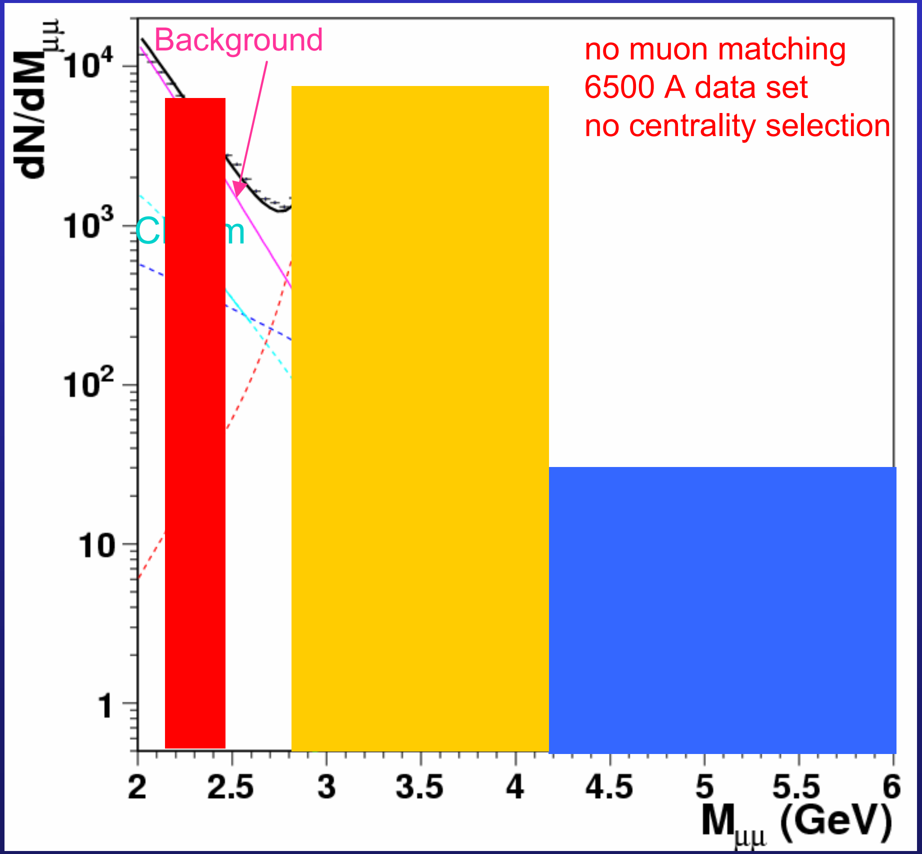
Can we identify a scaling variable for the suppression?
L, N_{part}, density of participants, energy density?

J/ψ suppression – NA60 In-In data

At SPS energies, the reference process commonly used to quantify J/ψ suppression versus centrality is Drell-Yan

→ Drell-Yan production scales with the number of binary N-N collisions

→ No sizeable final state effects (shadowing or absorption)



Multi-step fit (max likelihood):

a) **M > 4.2 GeV** : normalize the DY

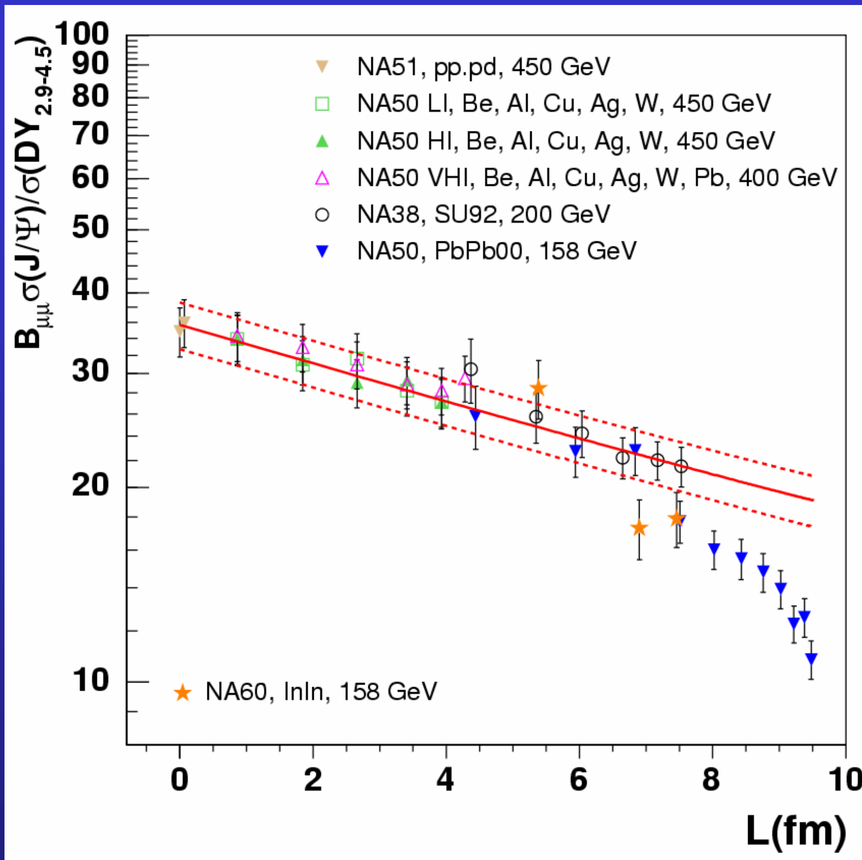
b) **2.2 < M < 2.5 GeV**: normalize the charm (DY fixed)

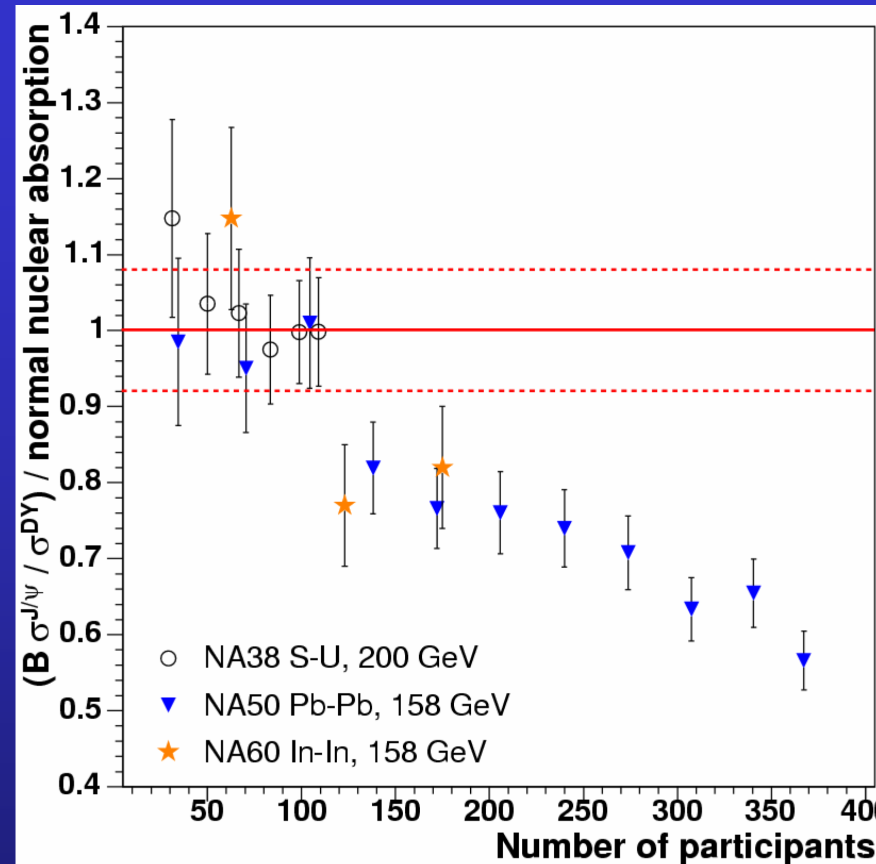
c) **2.9 < M < 4.2 GeV**: get the J/ψ yield (with DY & charm fixed)

Considerable J/ψ statistics: > 4×10^4

But Drell-Yan statistics ($m_{\mu\mu}$ > 4 GeV/c^2) marginal in NA60 (~300 events)

J/ψ suppression - “standard” analysis





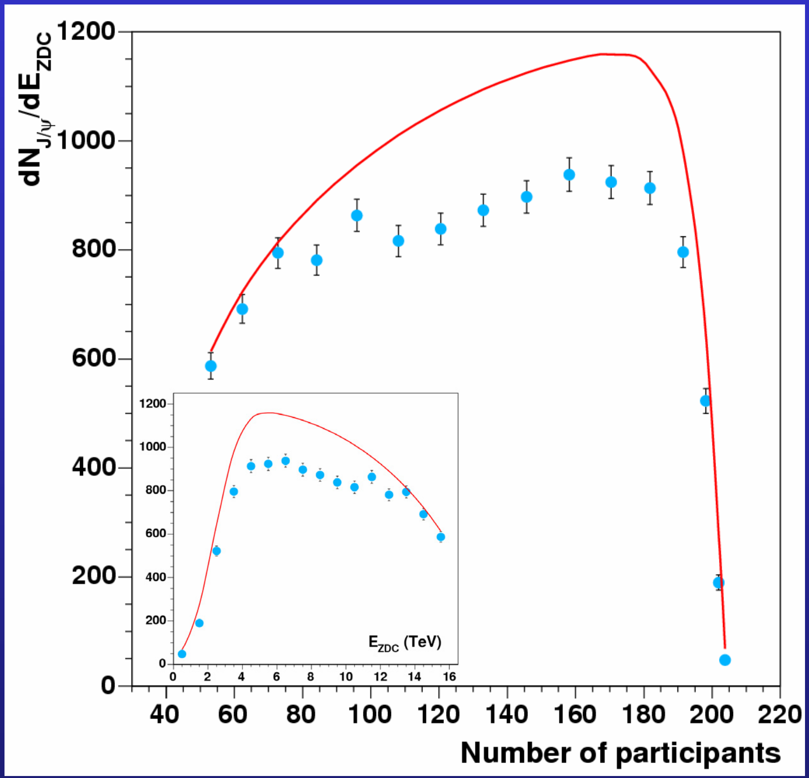
- 3 centrality bins, defined through E_{ZDC}
- J/ψ nuclear absorption → $\sigma^{J/\psi}_{abs}$ = 4.18 ± 0.35 mb (from NA50 @ 450 GeV)
- ~ 8% uncertainty on the rescaling to 158 GeV

Anomalous J/ψ suppression is present in In-In collisions

A finer centrality binning is needed to sharpen the picture

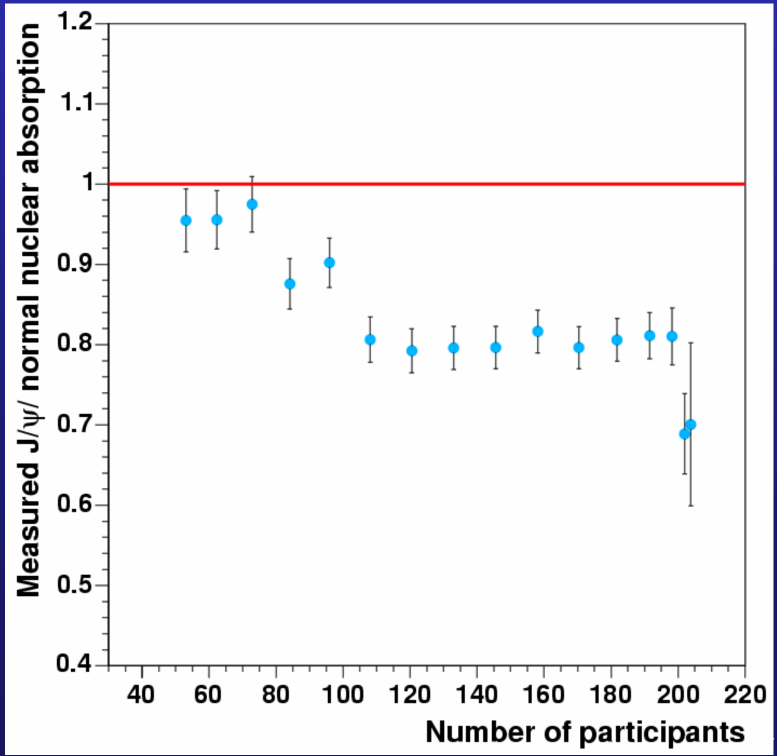
Direct J/ψ sample

To overcome the problem of DY statistics, directly compare the measured J/ψ centrality distribution with the distribution expected in case of pure nuclear absorption



$$\left.\frac{\left(dN_{J/\psi}/dE_{ZDC}\right)_{Meas}}{nuclear\ abs.}\right|_{0-11TeV} = \left.\frac{\left(\sigma_{J/\psi}/\sigma_{DY}\right)_{Meas}}{nuclear\ abs.}\right|_{0-11TeV}$$

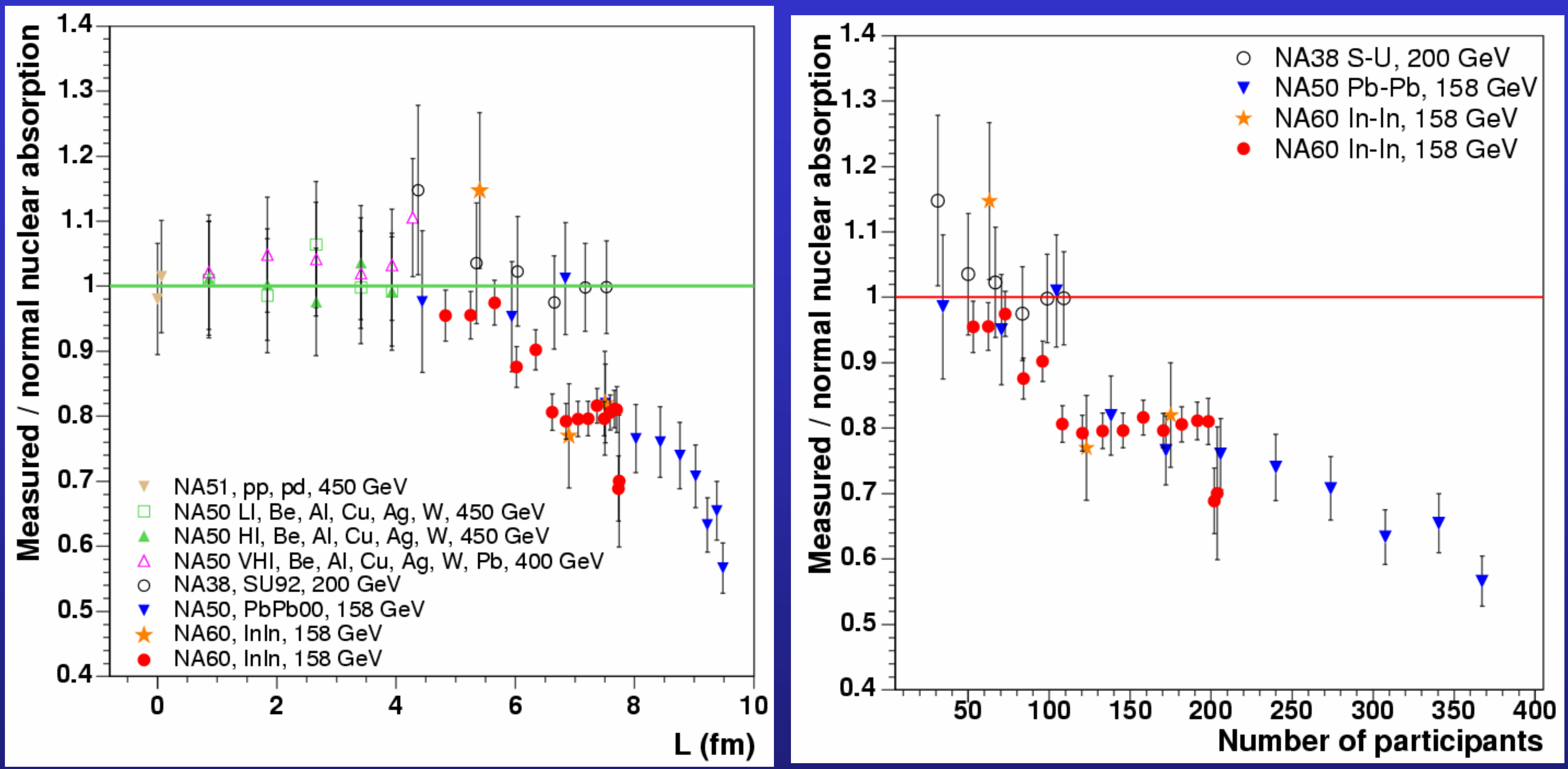
→ good agreement is found in the peripheral zone between data and theoretical curve



The following pattern is observed:

- Onset of anomalous suppression between $80 < N_{Part} < 100$
- Saturation at large N_{Part}

Comparison with previous results



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

⇒new set of Pb-Pb results needed, with reduced error bars

Systematics no significant effect present on the measured shape except for the very central points where systematic error can be larger than statistical one

Comparison with theoretical models (I)

Good accuracy of NA60 data allows a quantitative comparison with the predictions of the various theoretical models

Suppression by hadron comovers

(Capella-Ferreiro)

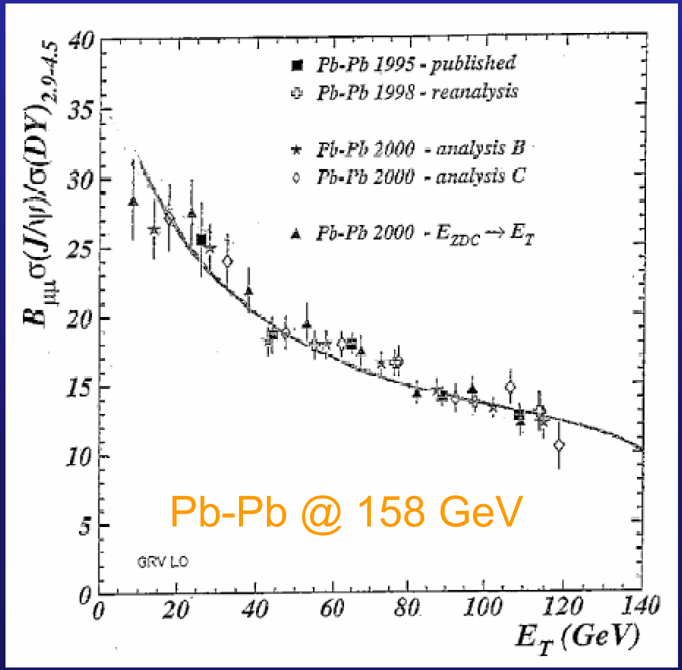
nuclear absorption and comovers interaction

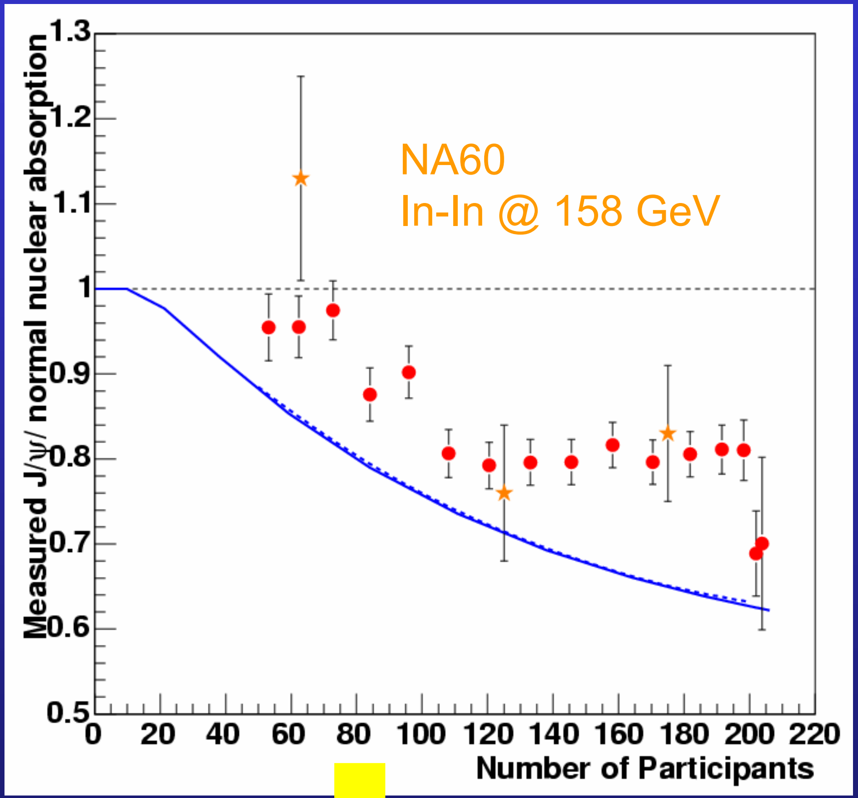
σ_{abs} = 4.5 mb

σ_{co} = 0.65 mb

(Capella-Ferreiro)

Tuned on NA50 data:





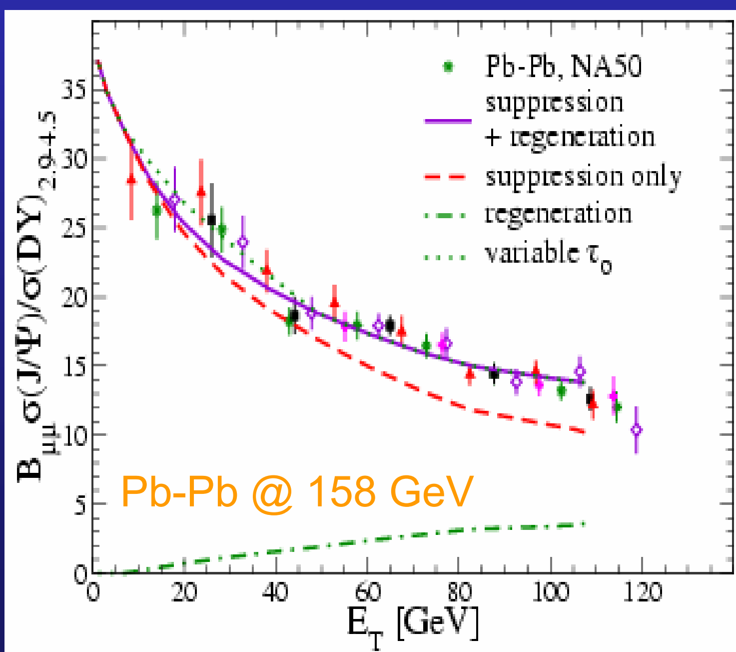
The prediction of Capella and Ferreiro fails to describe the In-In data

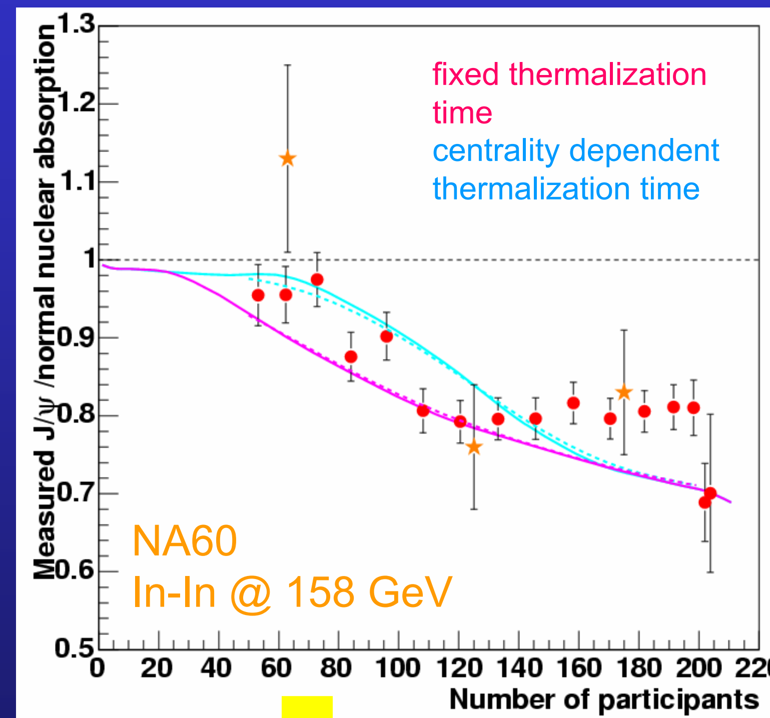
Comparison with theoretical models (II)

The smeared form (dashed line) is obtained taking into account the resolution on N_{Part}, due to our experimental resolution

Small difference in the $\sigma^{J/\psi}_{abs}$ used (4.4 mb)

QGP+hadrons+regeneration+in-medium effects (Grandchamp, Rapp, Brown)

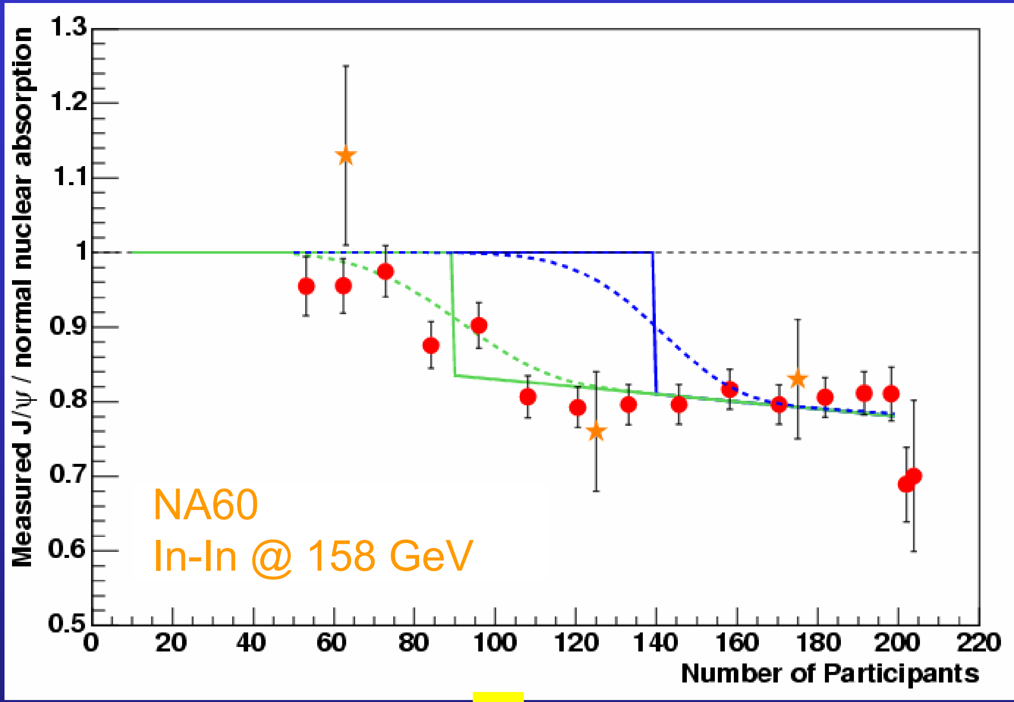




The model does not follow the measured J/ψ suppression pattern in the central In-In collisions (though better than comovers …)

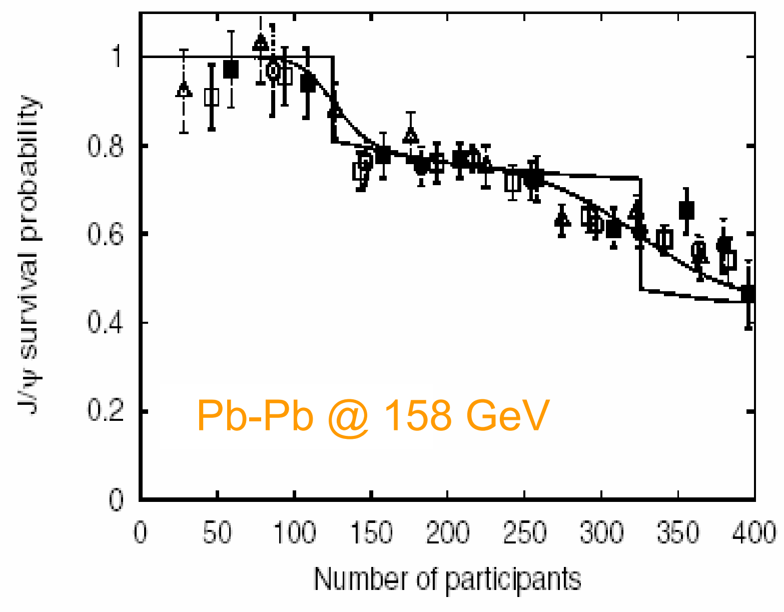
Comparison with theoretical models (III)

The dashed line includes the smearing due to the ZDC resolution



Percolation model (Digal, Fortunato, Satz)

Sharp onset (due to the disappearance of the χ_c meson) at N_{part} ~ 125 for Pb-Pb and ~ 140 for In-In



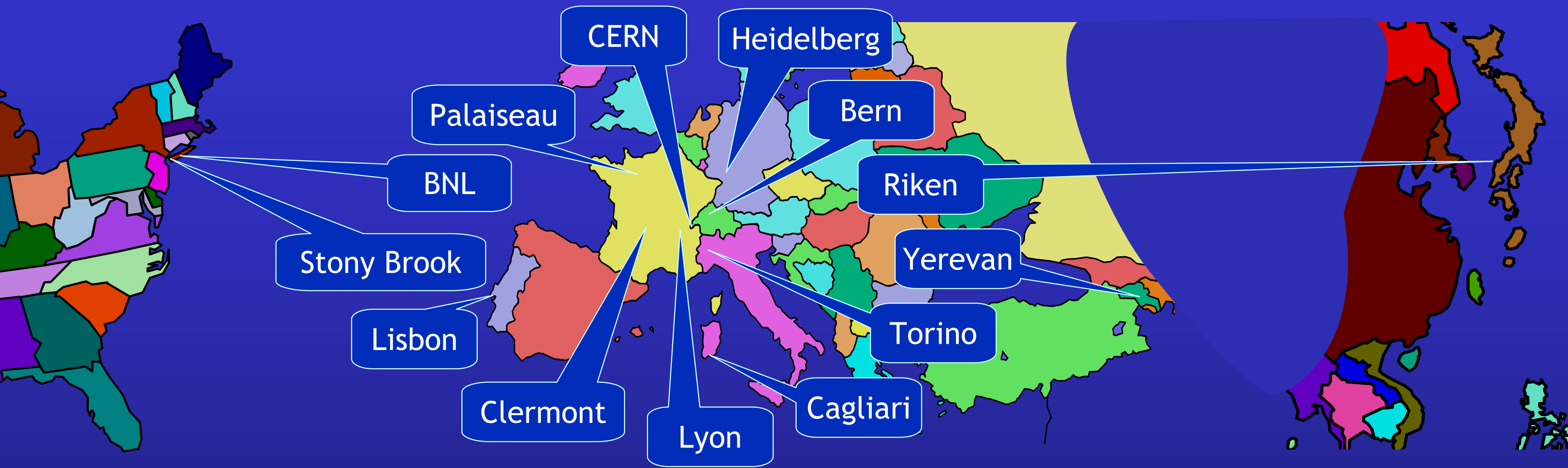
The measured data show a similar pattern but the anomalous suppression sets in at N_{part} ~ 90

Conclusions

- Low-mass region
  - Lepton pair excess at SPS energies confirmed
  - Models predicting strong mass shift of the intermediate ρ not confirmed
  - Models predicting strong broadening can describe data
  - ϕ puzzle under study
- Intermediate-mass region
  - Enhancement of dimuon yield confirmed
  - Not consistent with an enhancement of open charm
  - Consistent with an enhanced prompt source
- J/ψ suppression
  - Anomalous J/ψ suppression present also in In-In
  - Centrality dependent, with an onset around N_{part}=90
  - Theoretical predictions (tuned on Pb-Pb) do not properly describe our data

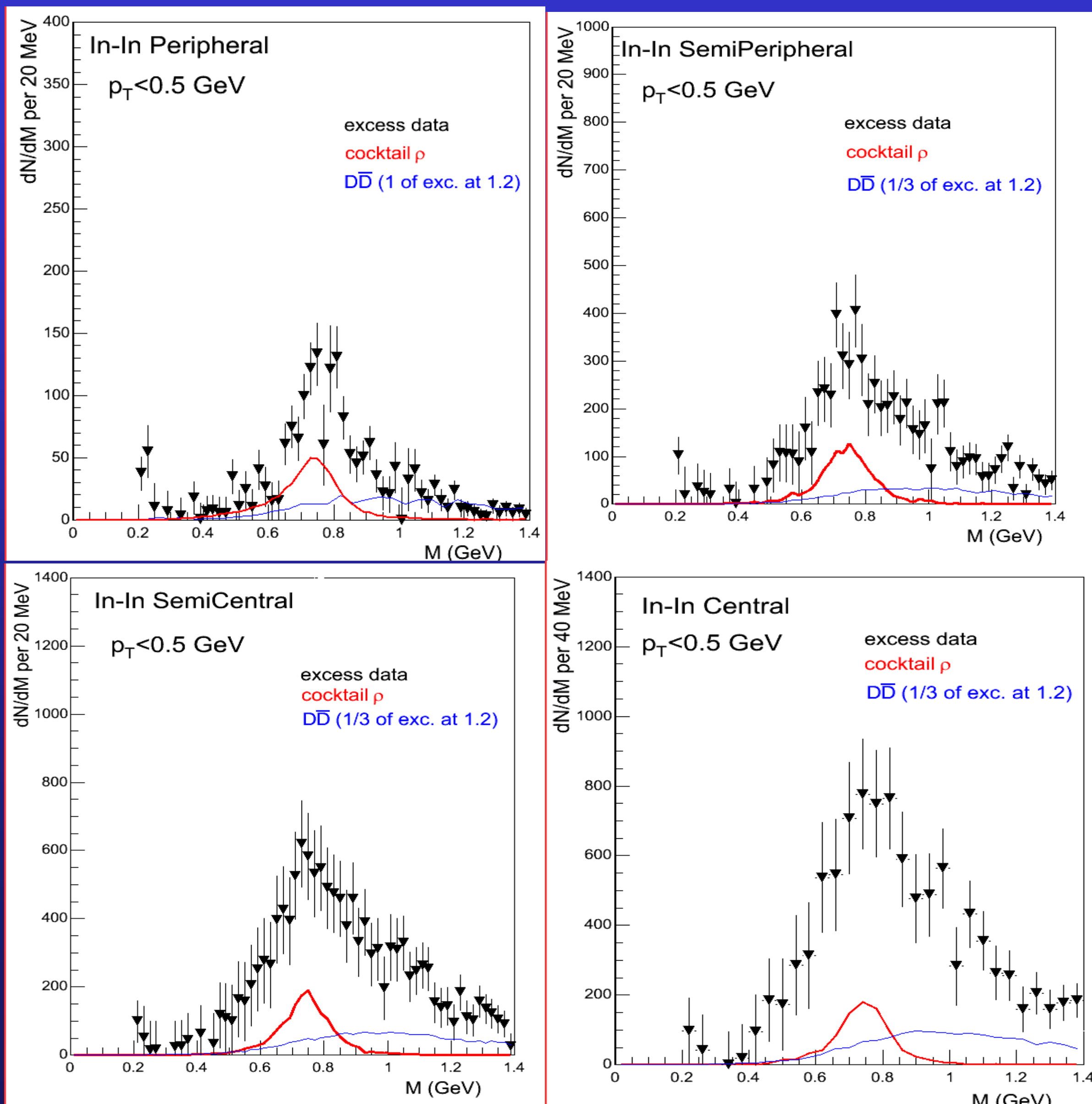
http://cern.ch/na60

The NA60 experiment



R. Arnaldi, 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

Excess spectra from difference data-cocktail



$p_T < 0.5$ GeV

No cocktail ρ and no D$\bar{D}$ subtracted

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

Similar behaviour in the other p_T bins

Perspectives

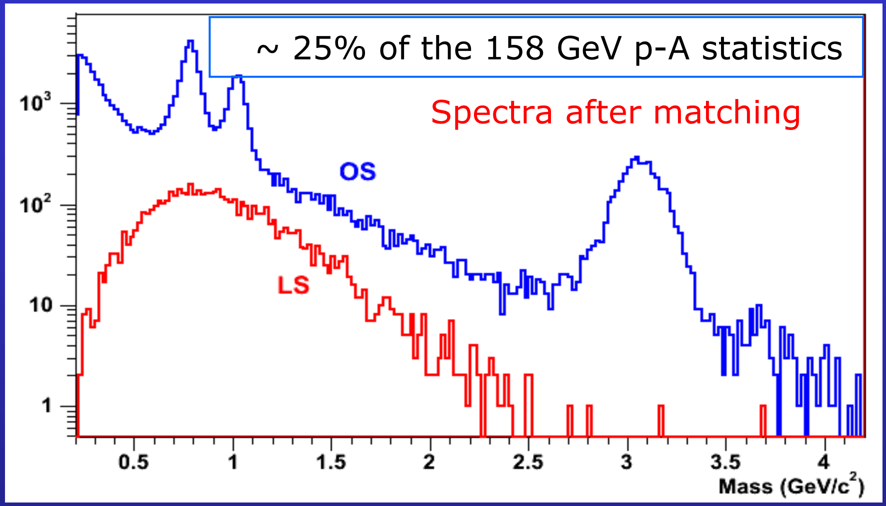
(now) writing papers

Analysis of In-In data still ongoing

- Acceptance corrected LMR spectra
- Complete $\phi \rightarrow$ KK analysis
- Radial flow for ω and ϕ
- Improve alignment (IMR)
- Detailed study of the J/ψ suppression pattern

- Use full statistics (now 50%)

p-A: data being analyzed

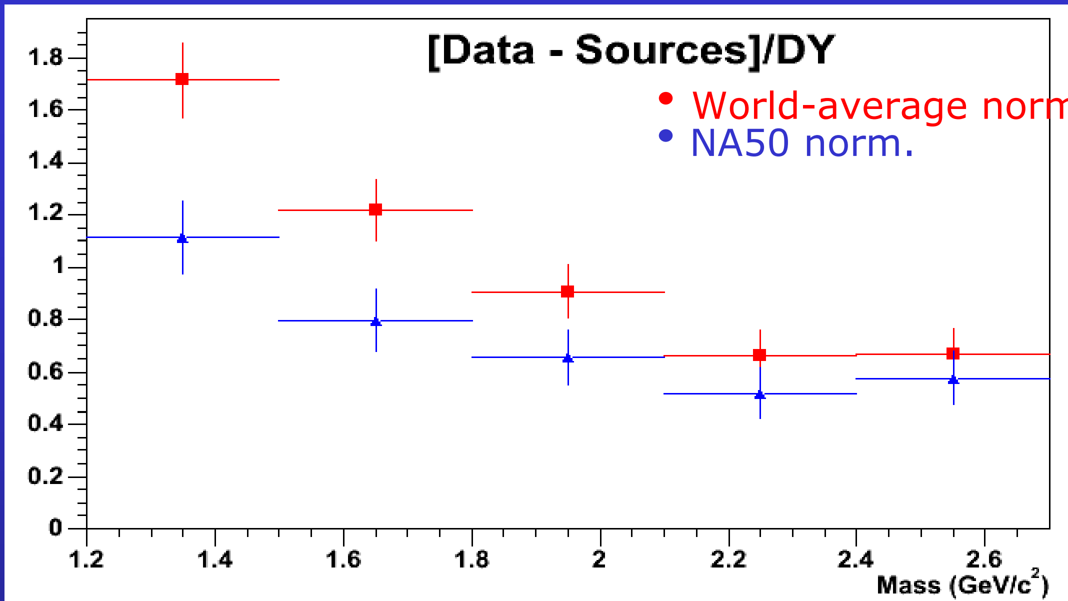


Crucial reference for:

- IMR studies (400 GeV)
- Estimate of J/ψ nuclear absorption (158 GeV)
- χ_C nuclear dependence

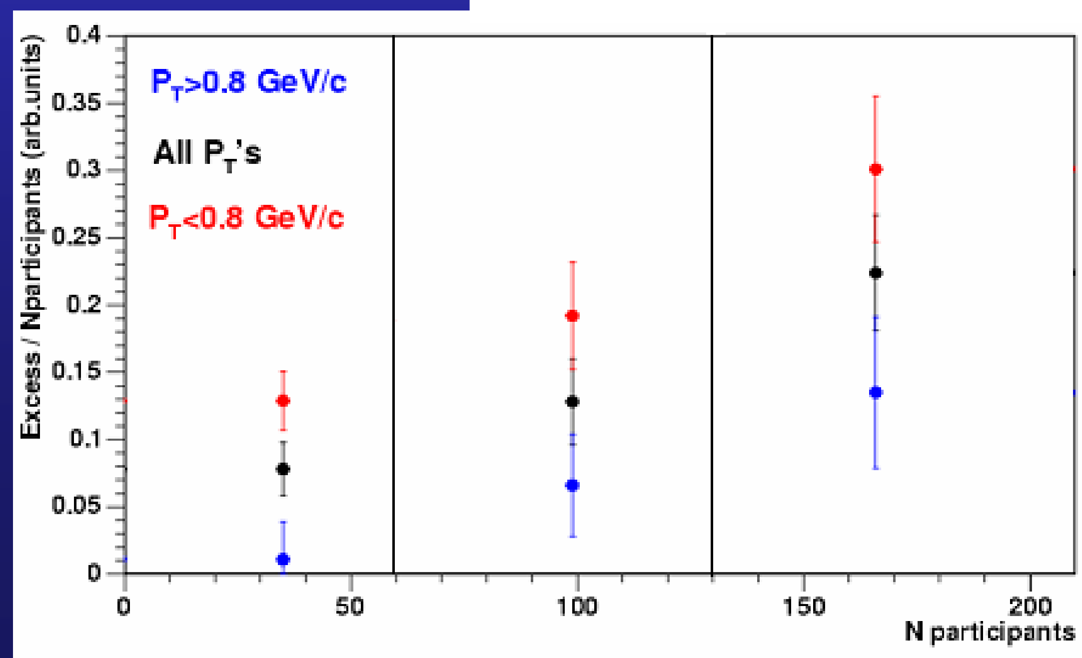
It would be interesting to have such good quality data with other collision systems

Mass shape and centrality dependence of the excess



The mass distribution of the excess is steeper than Drell-Yan

[Data – Sources]/ω
(Arbitrary normalization)



ω scales with $N_{participants}$

⇒The excess grows aprox. as the square of $N_{participants}$

Introduction

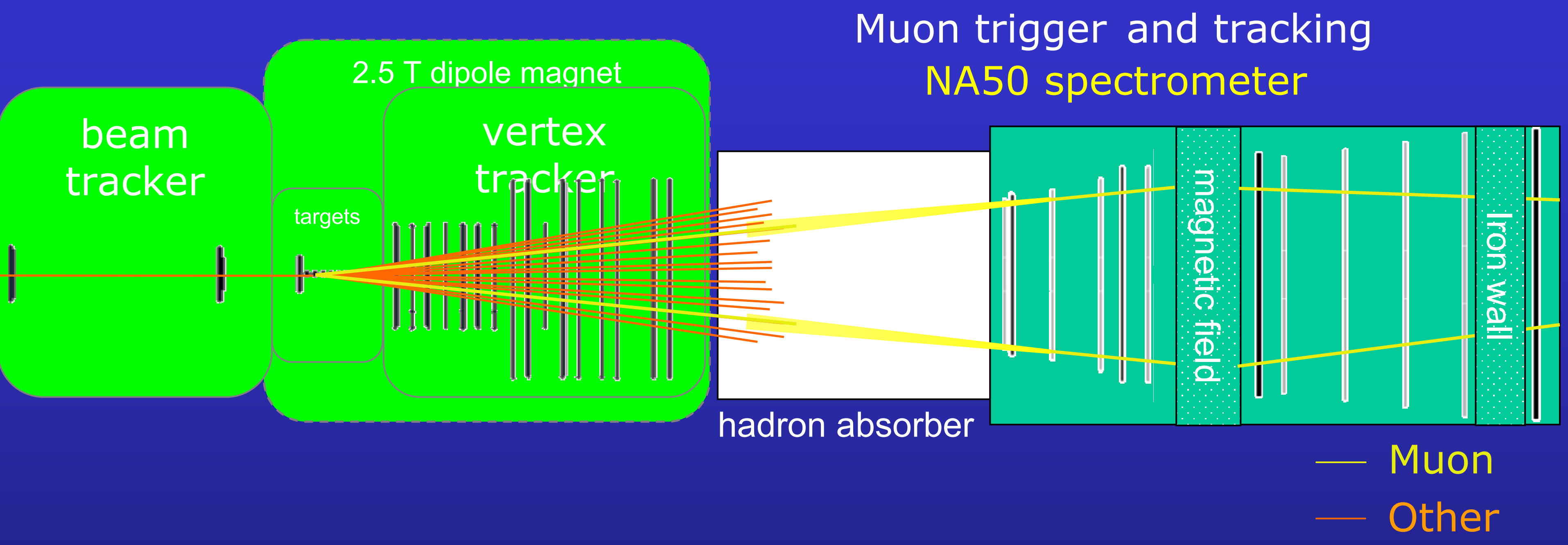
• NA60 is a second generation experiment, designed to answer specific questions left open, in the leptonic sector, by the previous round of SPS experiments, finished in 2000 (and that can hardly be addressed at RHIC and LHC)

• It has been designed in order to reach unprecedented accuracy in the measurement of muon pair production in HI collisions

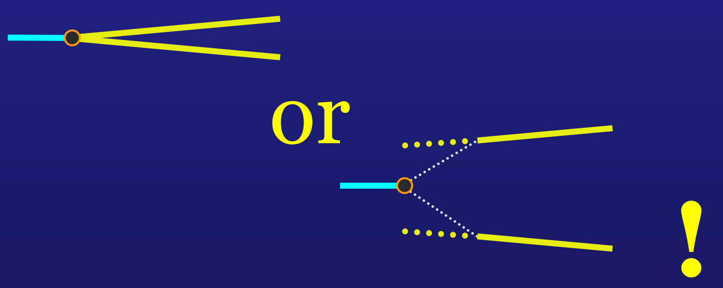
• After its approval in 2000, NA60 has taken data in 2002 (p-A), 2003 (In-In) and 2004 (p-A), now being analyzed

• First answers to the physics questions at the basis of the NA60 program are now available

NA60: detector concept



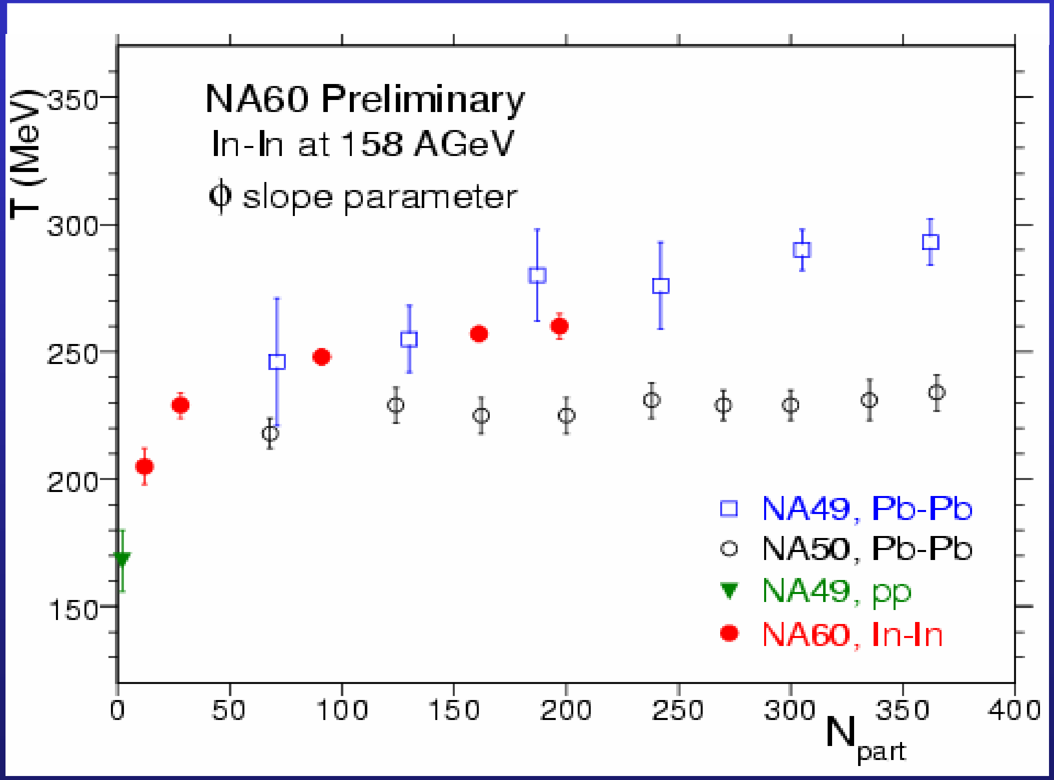
Matching in coordinate
and momentum space



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

Interlude: investigating the ϕ puzzle

- In-In data should help solving the long debated ϕ puzzle
- NA50 ($\phi \rightarrow \mu\mu$) measures lower T values than NA49 ($\phi \rightarrow KK$)
- NA49 sees an increase of T with centrality



The difference between NA49 and NA50 is not due to the different decay channel under study

- NA60 can measure both $\phi \rightarrow \mu\mu$ and $\phi \rightarrow KK$ decay modes
- Work in progress for $\phi \rightarrow KK$ (no PID available!)