NA60: dimuon and charm production in p-A and In-In collisions at the CERN SPS

- Introduction and physics motivation
- The NA60 experiment: apparatus and performance
- First physics results
- Conclusions and perspectives

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on behalf of the NA60 Collaboration

Introduction

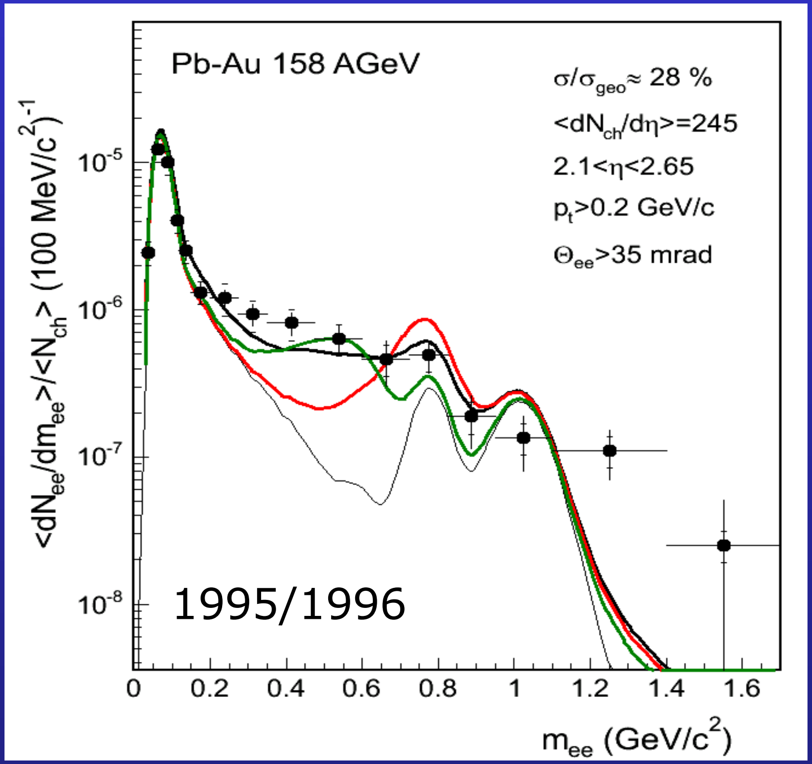
- NA60 is a second generation experiment, designed to answer specific questions left open, in the leptonic sector, by the previous round of SPS experiments, finished in 2000 (and that can hardly be addressed at RHIC and LHC)

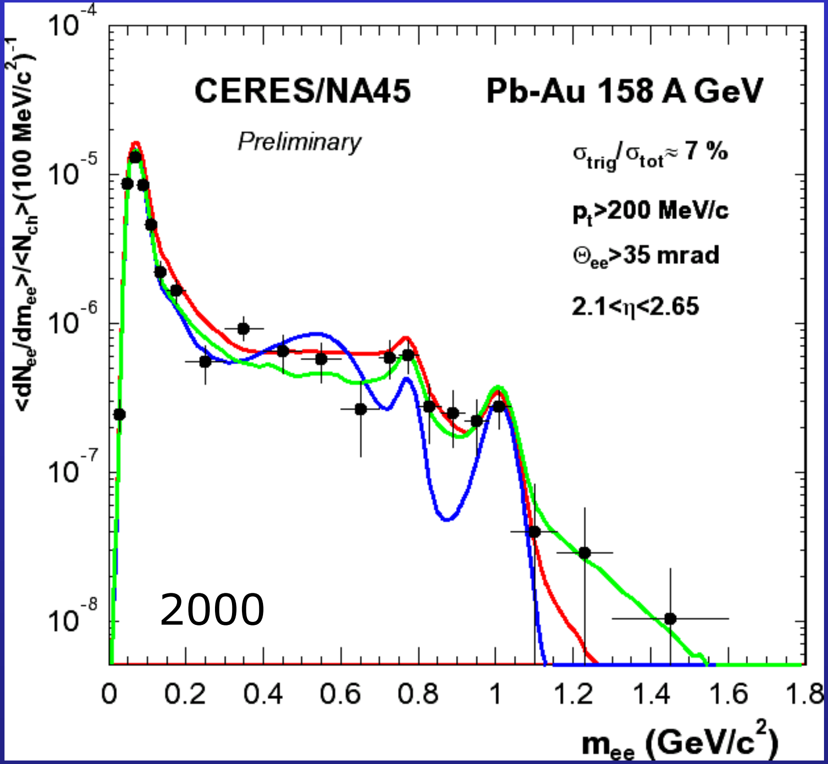
- It has been designed in order to reach unprecedented accuracy in the measurement of muon pair production in HI collisions

- 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

Physics topics: low mass continuum

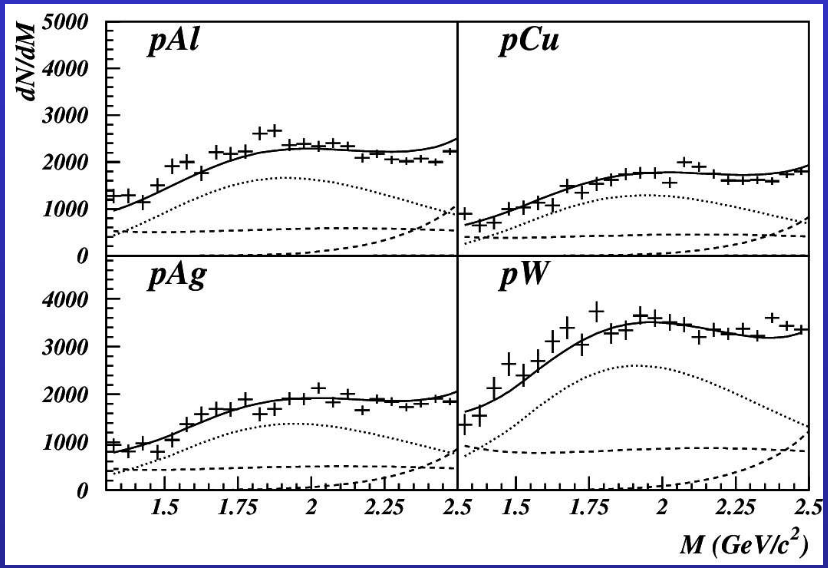


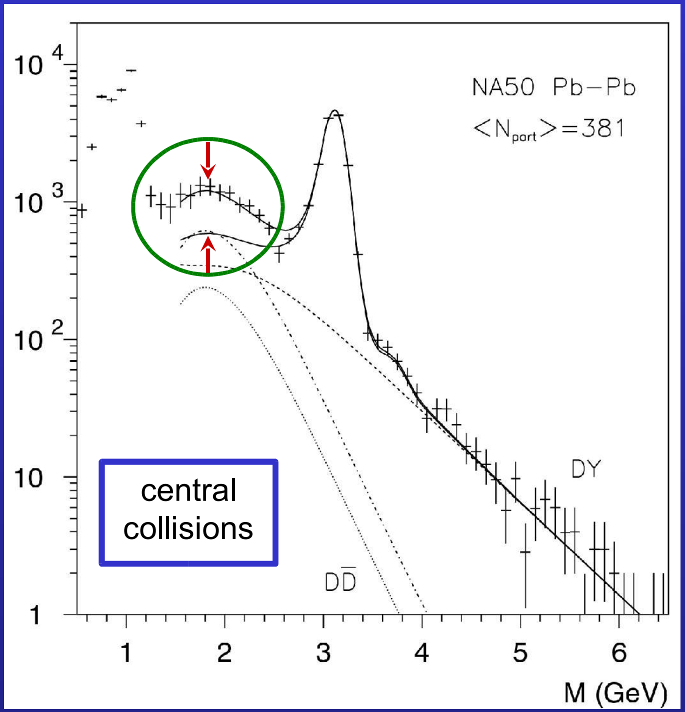


- Low mass excess well established by CERES (dielectrons)
- Still missing: clear discrimination between the various theoretical explanations

Good statistics AND mass resolution are needed

Physics topics: intermediate mass region

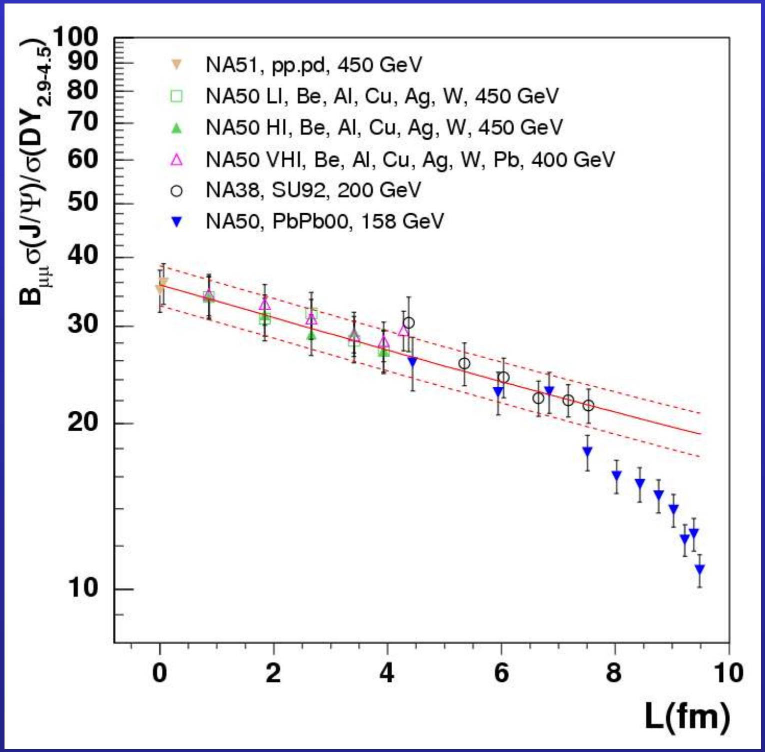


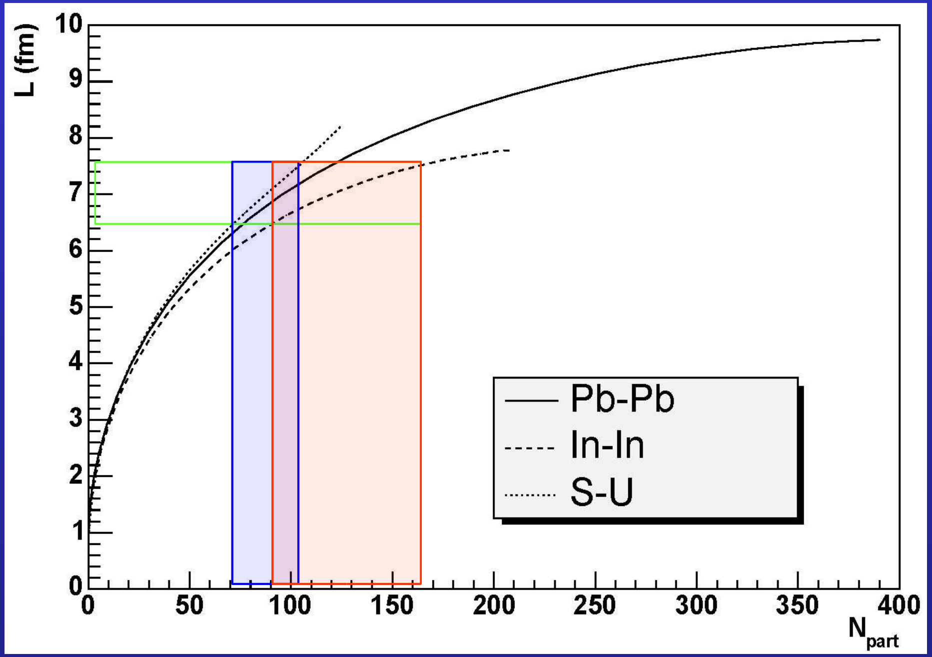


- IMR excess in S-U/S-W and Pb-Pb, with respect to p-A, established by NA38/NA50 and Helios-3
- Can be ascribed to both:
  - Anomalous open charm enhancement
  - Thermal dimuon production

NA60 proposal: discriminate between the two explanations, by tagging, using the muon offsets, the semi-leptonic decays of $D\bar{D}$ pairs

Physics topics: J/ψ suppression



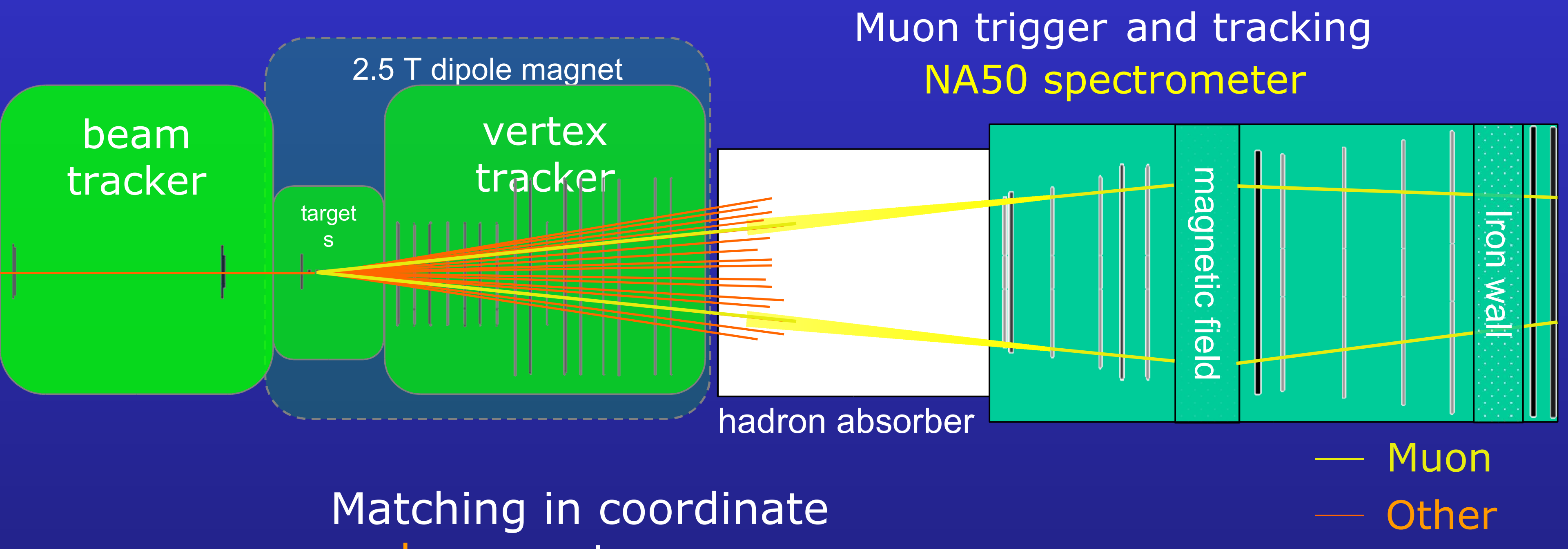


- Anomalous J/ψ suppression, discovered by NA50 in Pb-Pb collisions

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

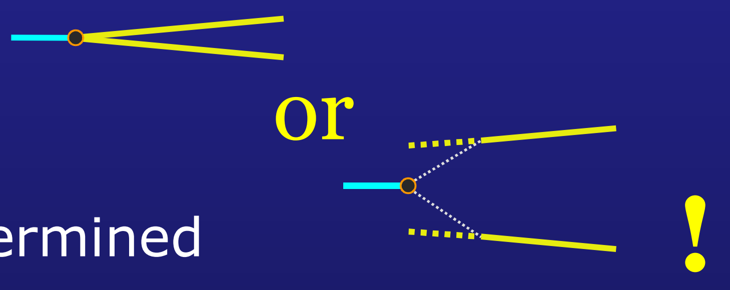
Can we identify a scaling variable for the suppression ?
L, N_{part}, density of participants, energy density ?

NA60: detector concept



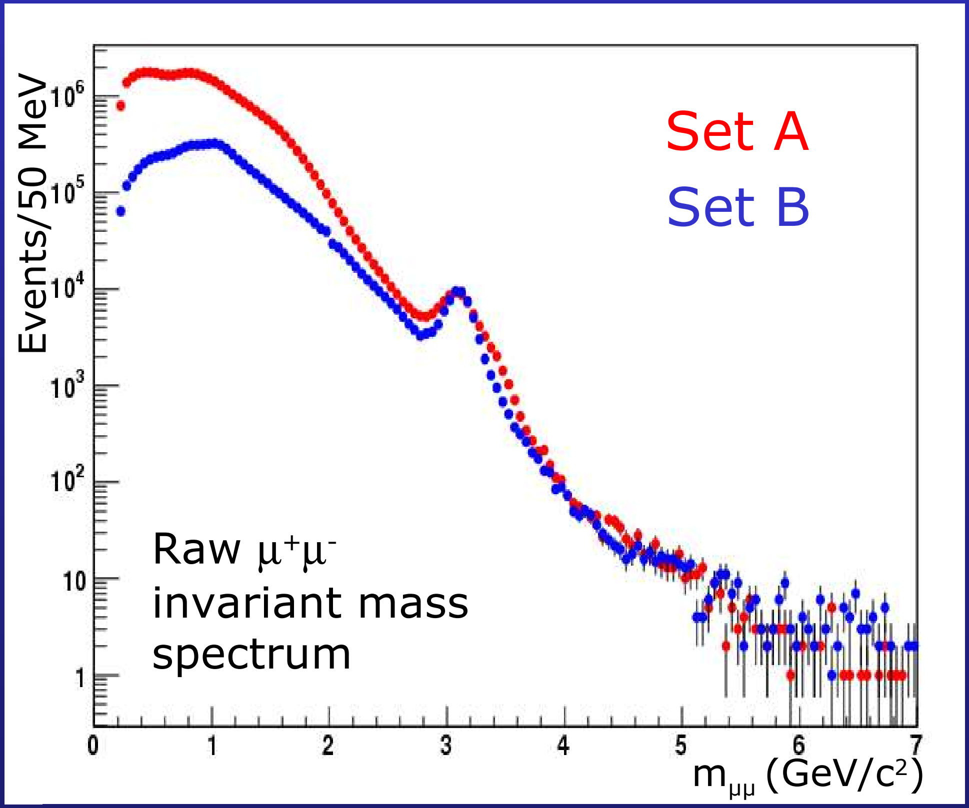
Matching in coordinate and momentum space

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



Data taking: In-In collisions

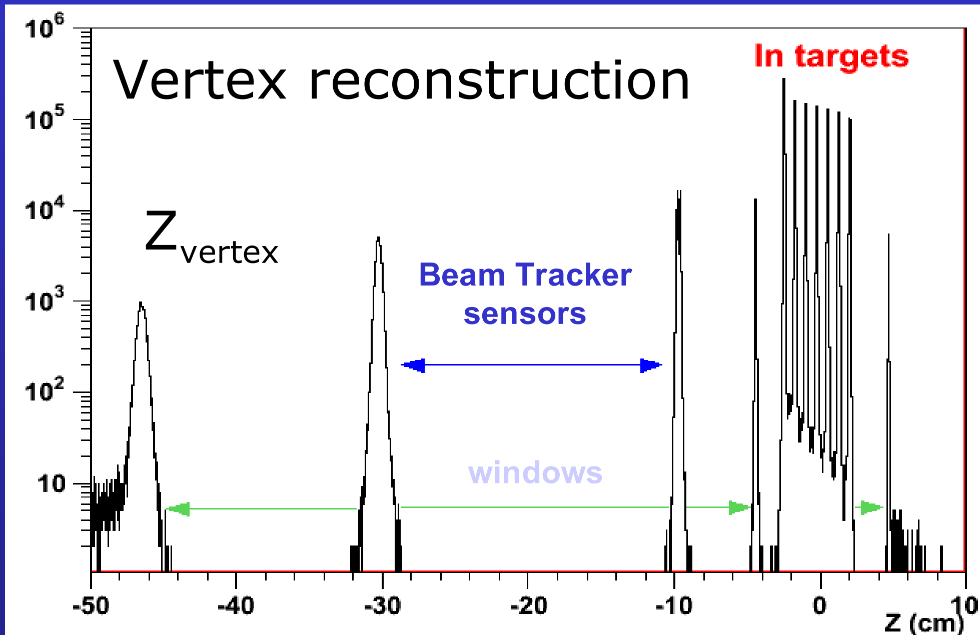
- 5-week long run in 2003 – In-In @ 158 GeV/nucleon
- ~ 4×10^{12} ions on target
- ~ 2×10^{8} dimuon triggers collected

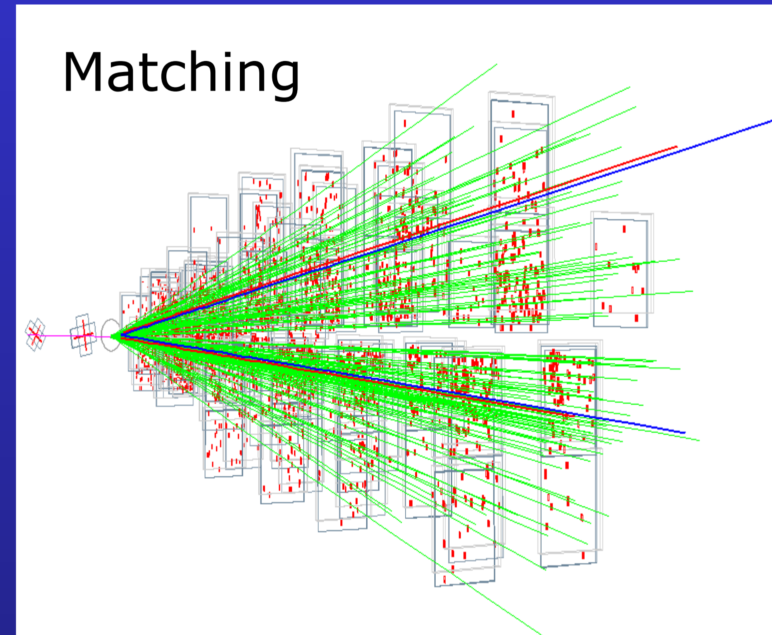


- Two muon spectrometer settings
  - Set A (low ACM current)
    - Good acceptance at low mass
    - Used for LMR and IMR analysis
  - Set B (high ACM current)
    - Good resolution at high mass
    - Used for J/ψ suppression

- Centrality selection: use
  - spectator energy in the ZDC
  - charged multiplicity in the vertex spectrometer

Using the vertex spectrometer





σ_z ~ 200 μm along the beam direction

(~ 10 - 20 μm in the transverse direction)

μ (muon spectrometer)

Matching

Tracks (vertex spectrometer)

~ 20 MeV mass resolution at φ

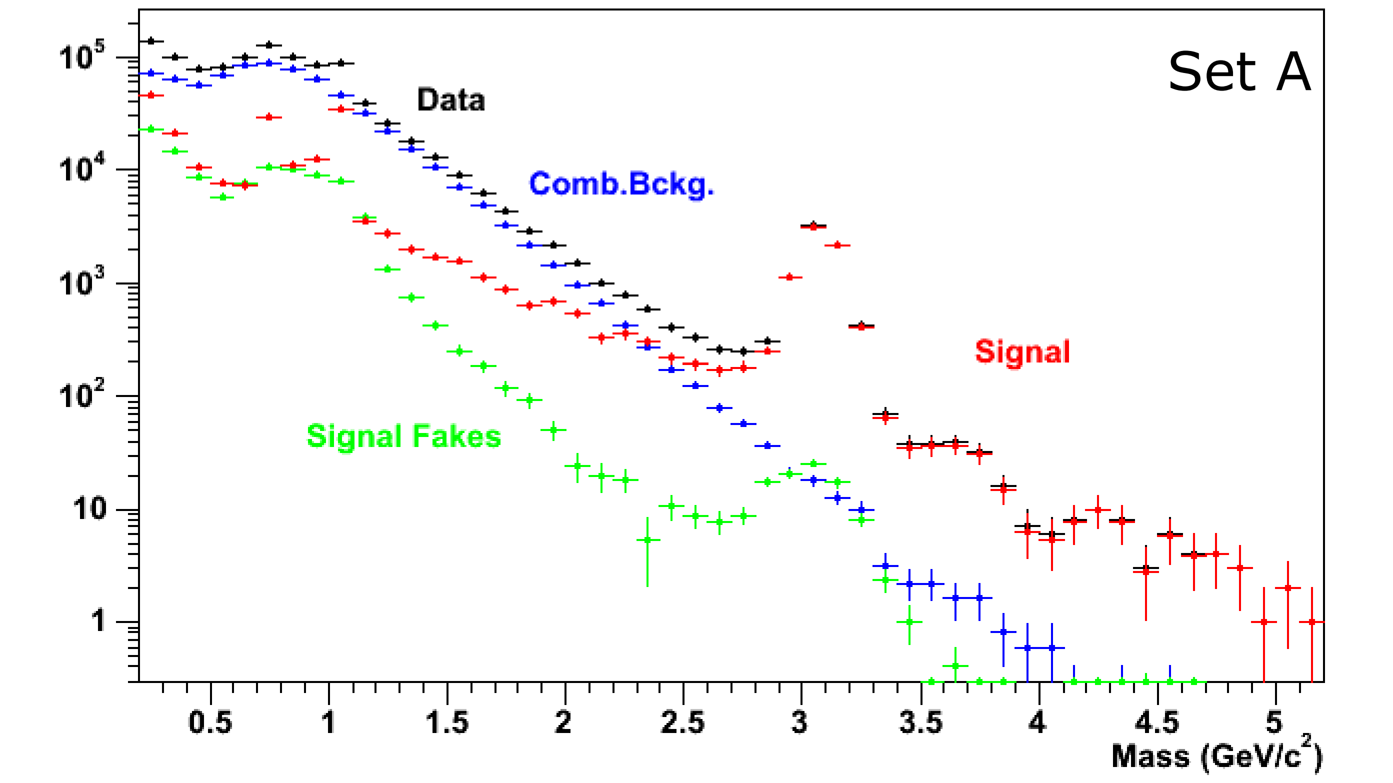
Background subtraction

- Combinatorial background
  - Significantly reduced by the track matching procedure
  - Nevertheless, still the dominant dimuon source for $m_{\mu\mu}<2$ GeV/c^2
  - NA60 acceptance quite asymmetric $\Rightarrow$ Cannot use $N^{\pm}_{bck} = 2\sqrt{N^{++}N^{--}}$
  - Mixed event technique developed $\Rightarrow$ accurate to 1-2%

- Fake matches background
  - Muon matched to a wrong vertex telescope track
  - Two methods for rejection
    - Overlay MC $\Rightarrow$ simpler approach
    - Mixed events $\Rightarrow$ more complicated, rigorous approach

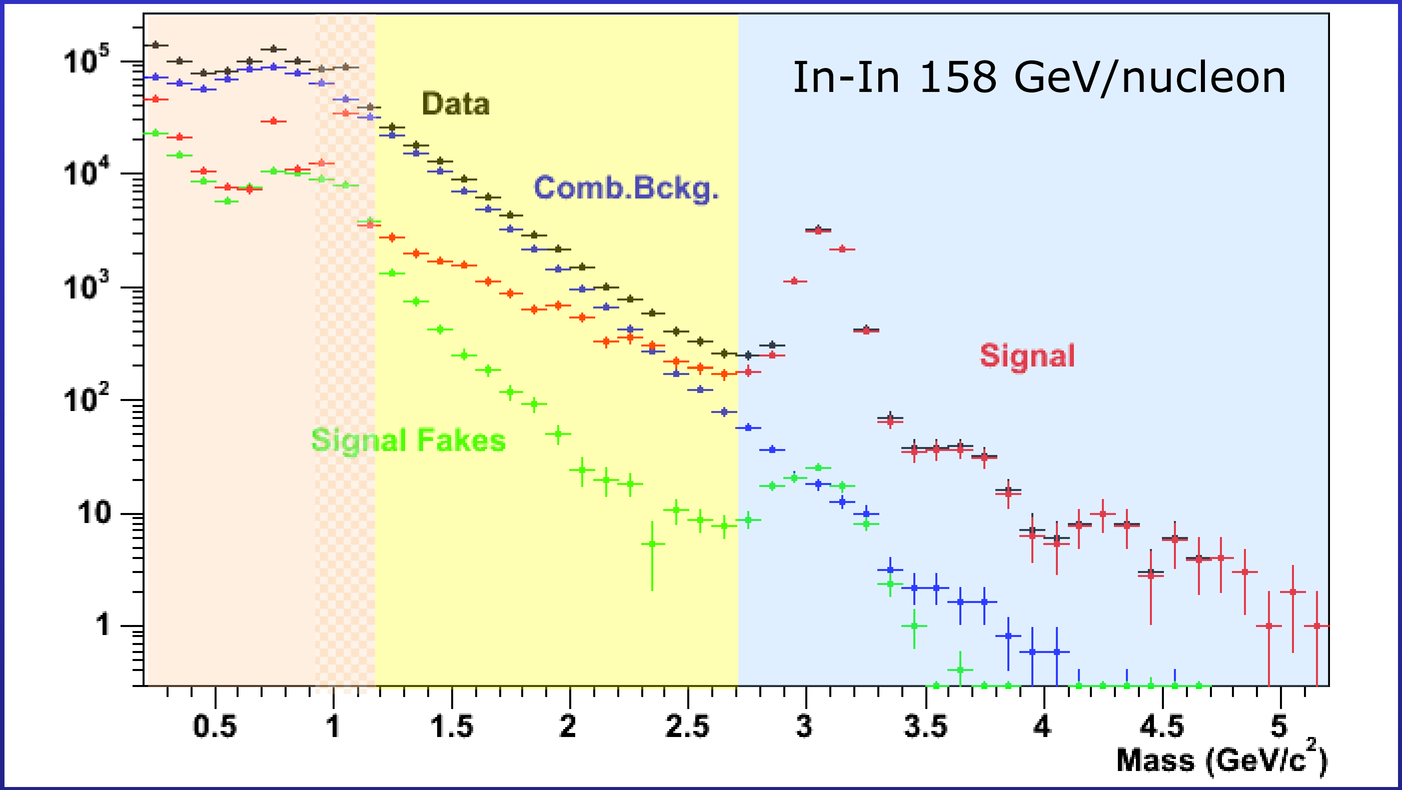
- All the details on background subtraction in the presentation by R. Shahoyan *(sect. 5b Aug. 6)*

The invariant mass spectrum



	0.5 GeV	1 GeV (ϕ)	2 GeV	3 GeV (J/ψ)
Signal/comb.	0.1	0.3	0.5	>100
Signal/fake	1.4	2.8	14	>100

..and now the results



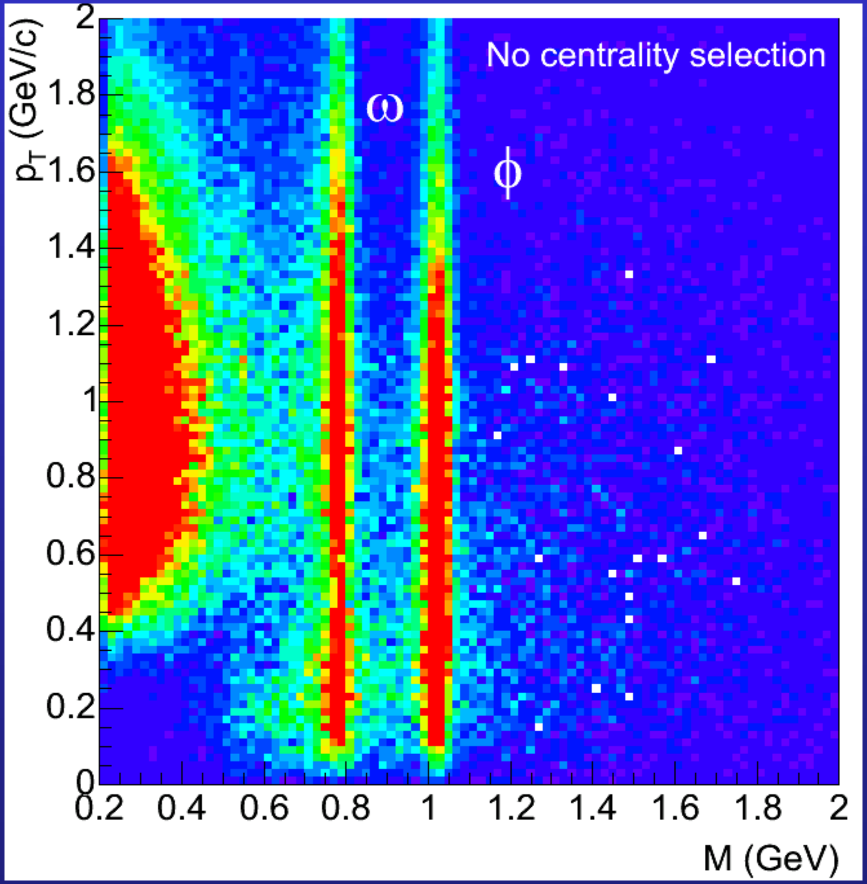
Low mass continuum
(S. Damjanovic, *sect. 6a*)

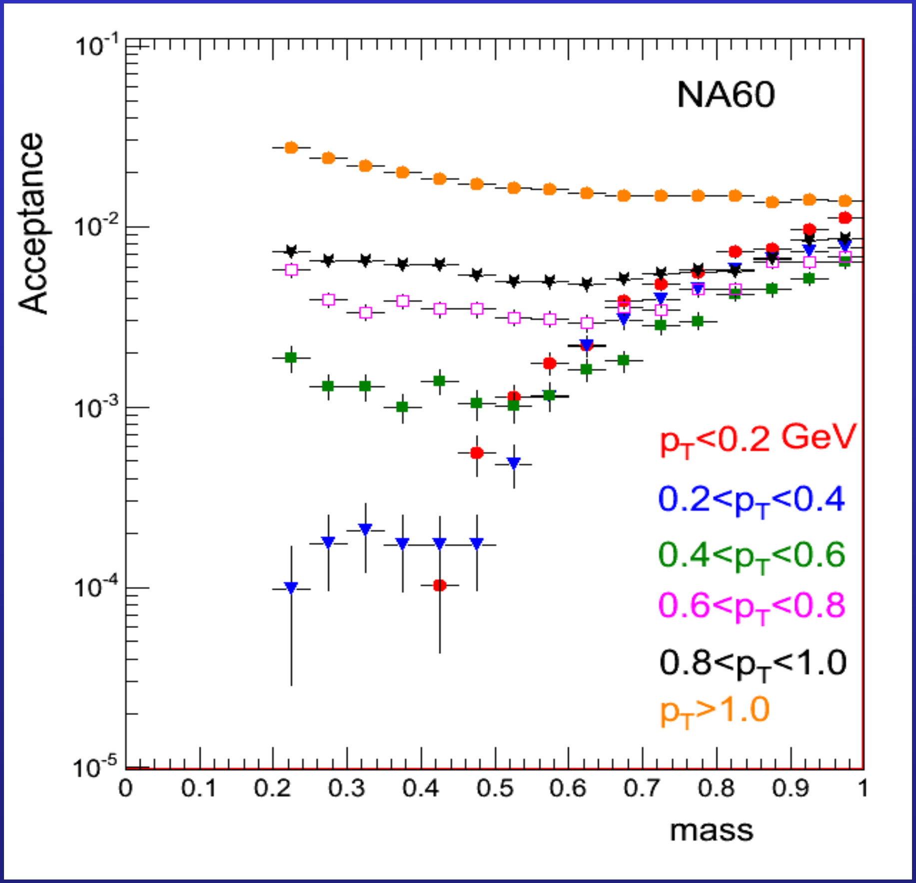
Open charm/thermal dimuons
(R. Shahoyan, *sect. 5b*)

ϕ meson
(A. De Falco, *sect. 6a*)

J/ψ suppression
(R. Arnaldi, *sect. 6a*)

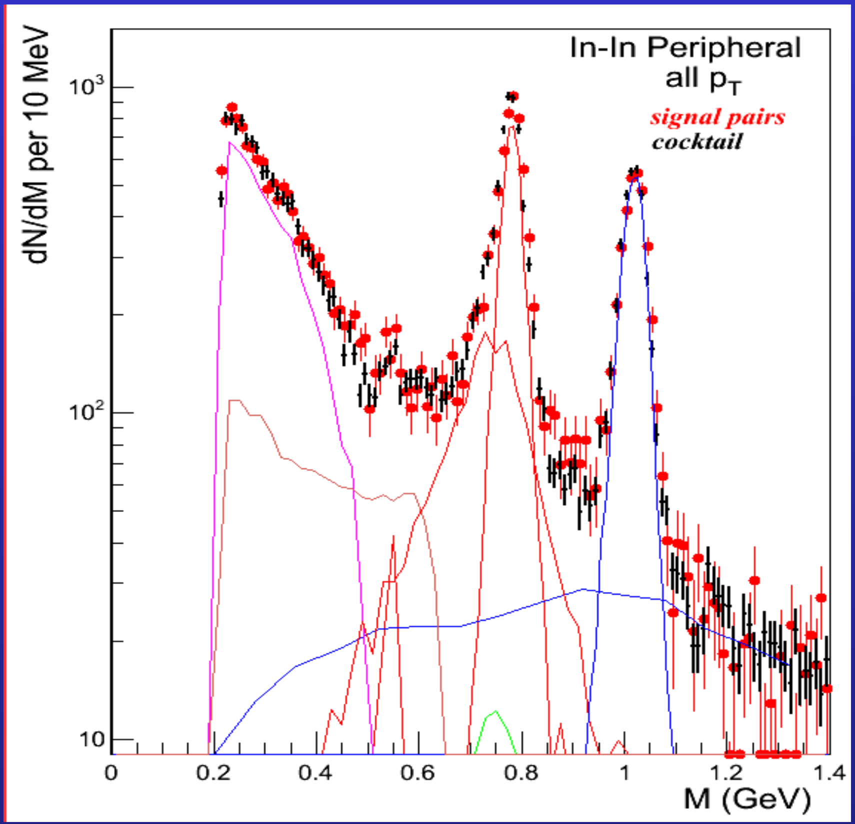
Low mass: phase space coverage



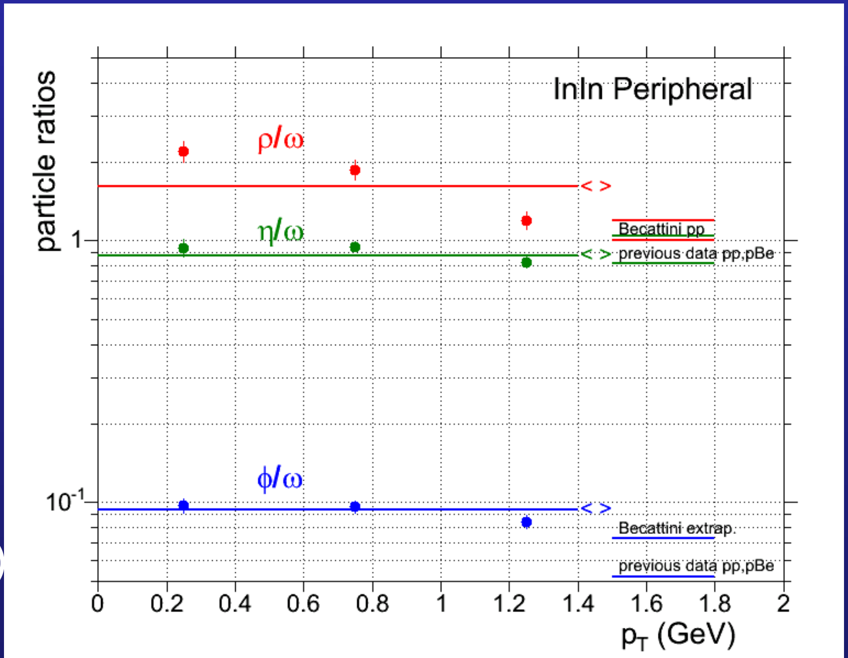


- The NA60 acceptance extends down to low m_T
- Rapidity coverage: $0<y_{cm}<1$ (slightly p_T dependent)

Low mass: peripheral collisions



- 4 centrality bins, defined through N_{ch}
- Fit independently in 3 p_T bins hadron decay cocktail and DD to the data ($m_{\mu\mu}$<1.4 GeV/c^2)
- Free parameters: η/ω, ρ/ω, ϕ/ω, DD, overall normalization



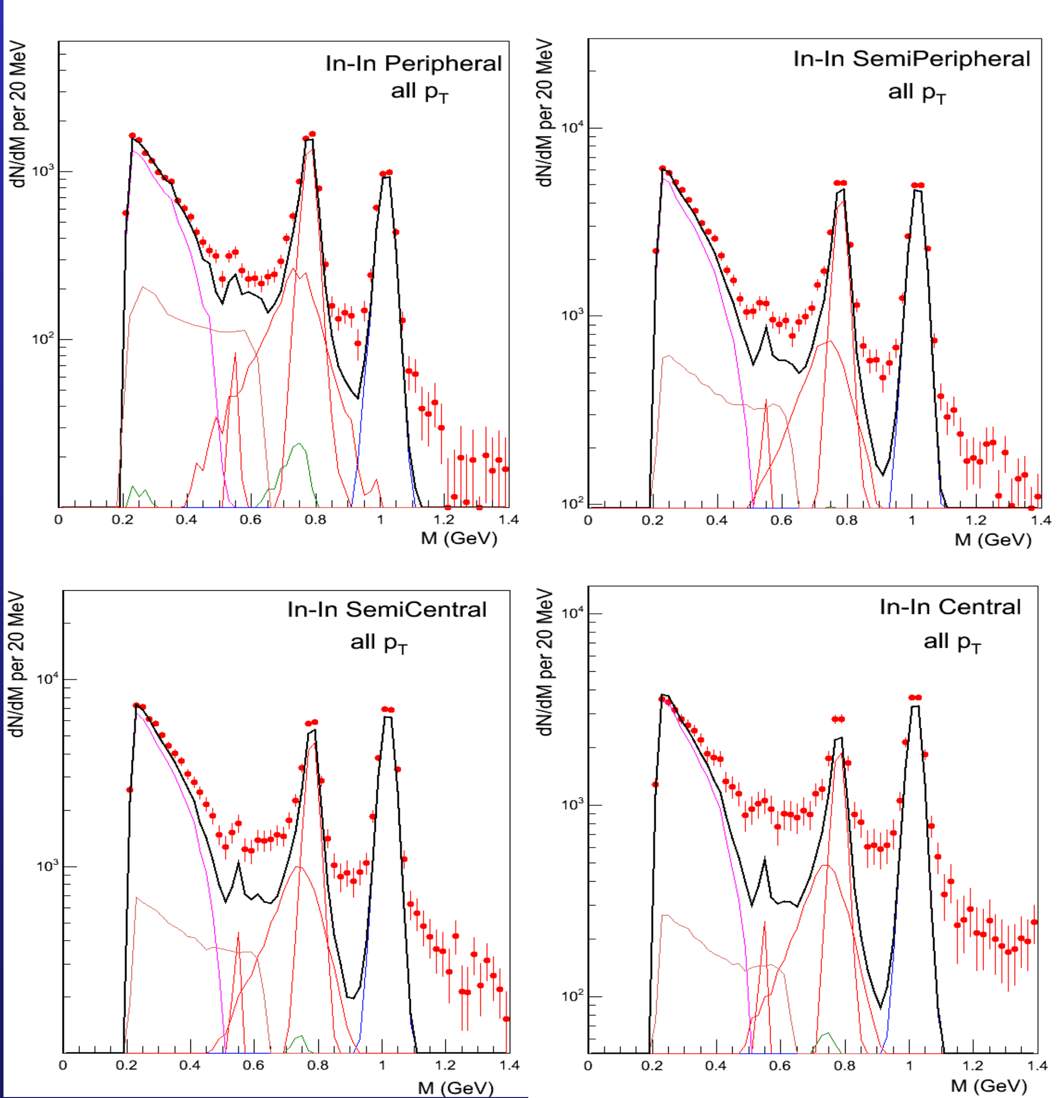
- Peripheral data well reproduced by the hadronic cocktail (for all p_T bins)
- Good fit quality down to low mass and p_T (low acceptance region well under control)

Reasonable values for the yields

Low mass: excess in central In-In collisions

• data
—— sum of cocktail sources including the ρ

See next slide for cocktail definition

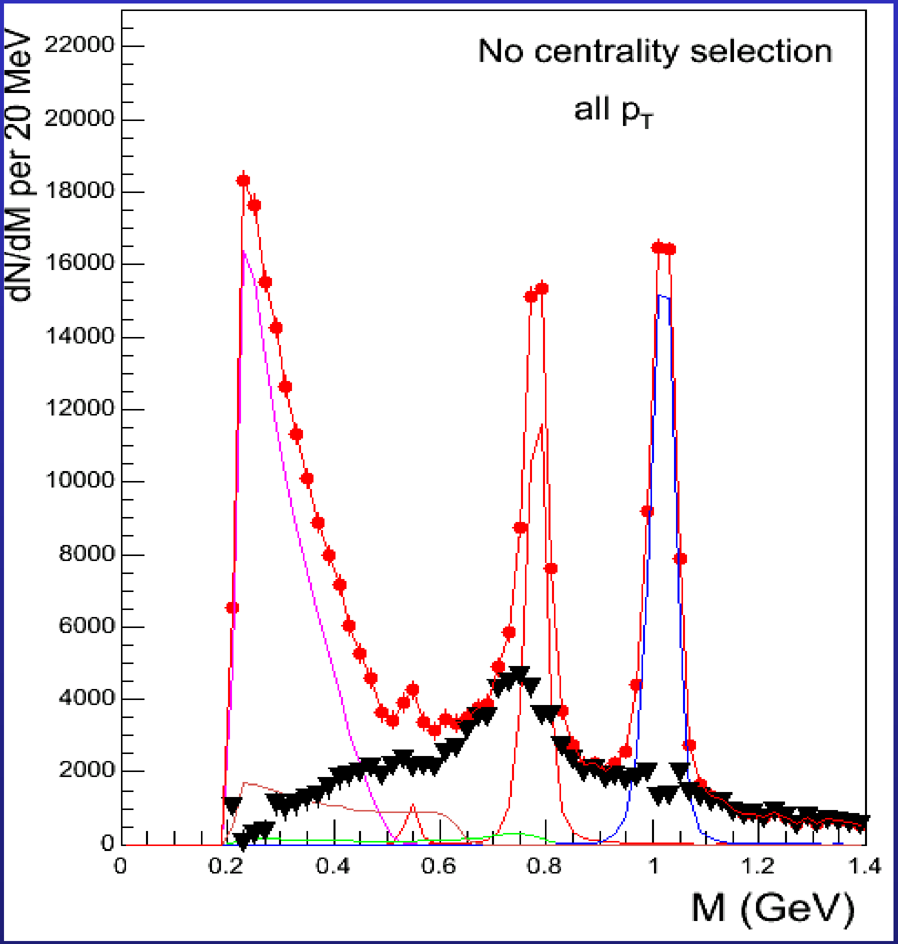


- ρ/ω =1.2, fixed from high p_T data

- Clear excess of data above cocktail

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

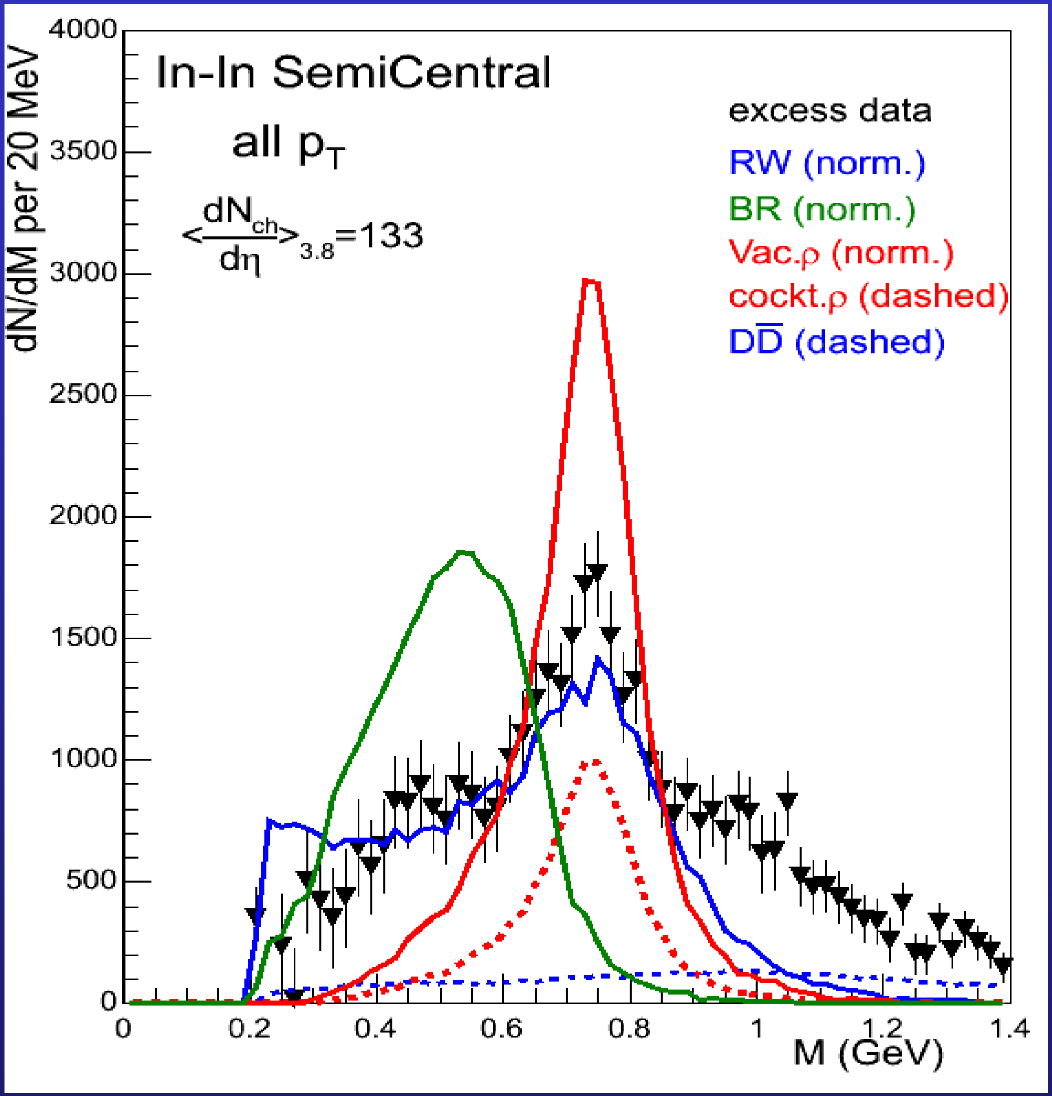
Getting the mass shape of the excess



- 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

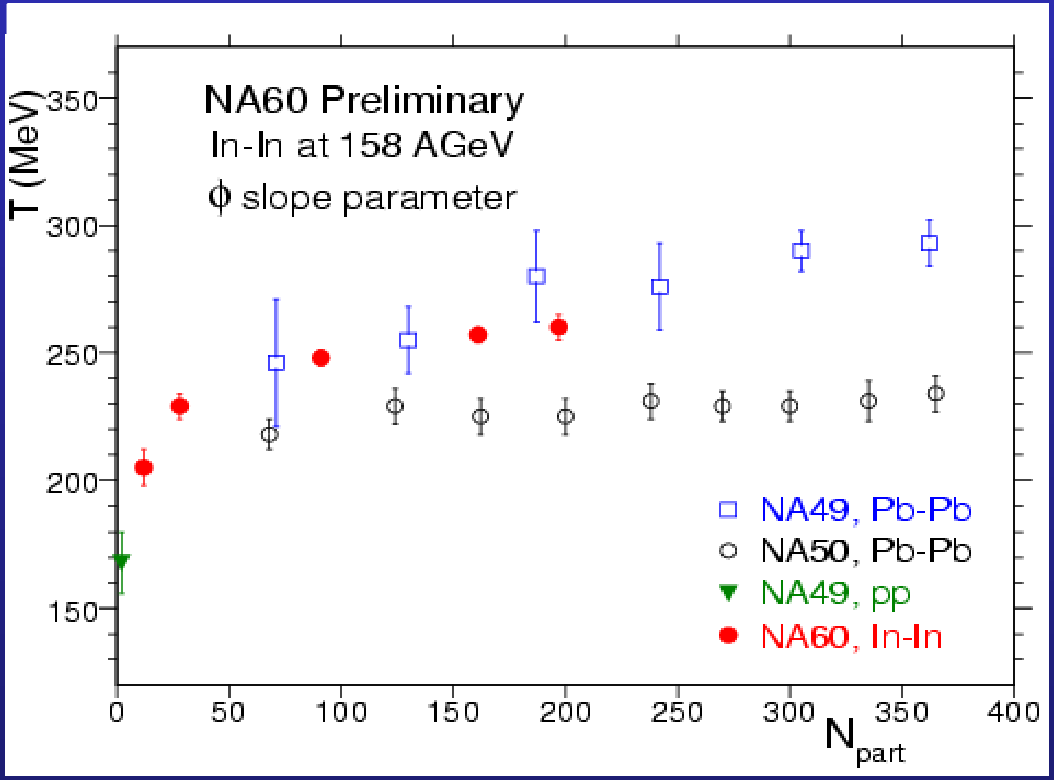
Low mass: comparison with models



- Predictions for In-In by Rapp et al. (2003) for $<dN_{ch}/d\eta> = 140$
- Theoretical yields folded with NA60 acceptance and normalized to data in the mass window $m_{\mu\mu} < 0.9$ GeV
- Excess shape consistent with broadening of the ρ (Rapp-Wambach)
- Models predicting a mass shift (Brown-Rho) ruled out
- These conclusions are also valid as a function of p_T (see parallel talk)

Investigating the ϕ puzzle

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

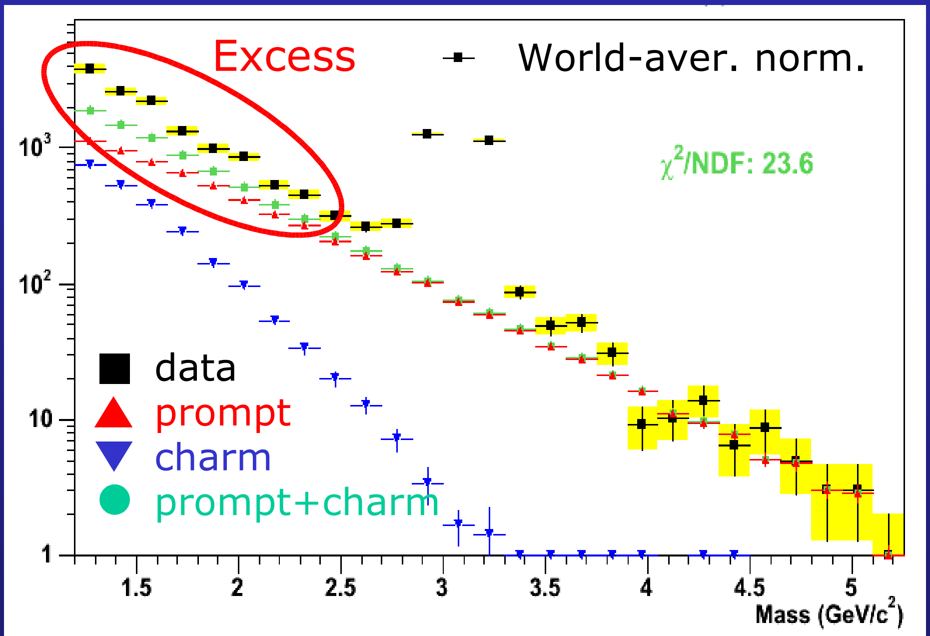


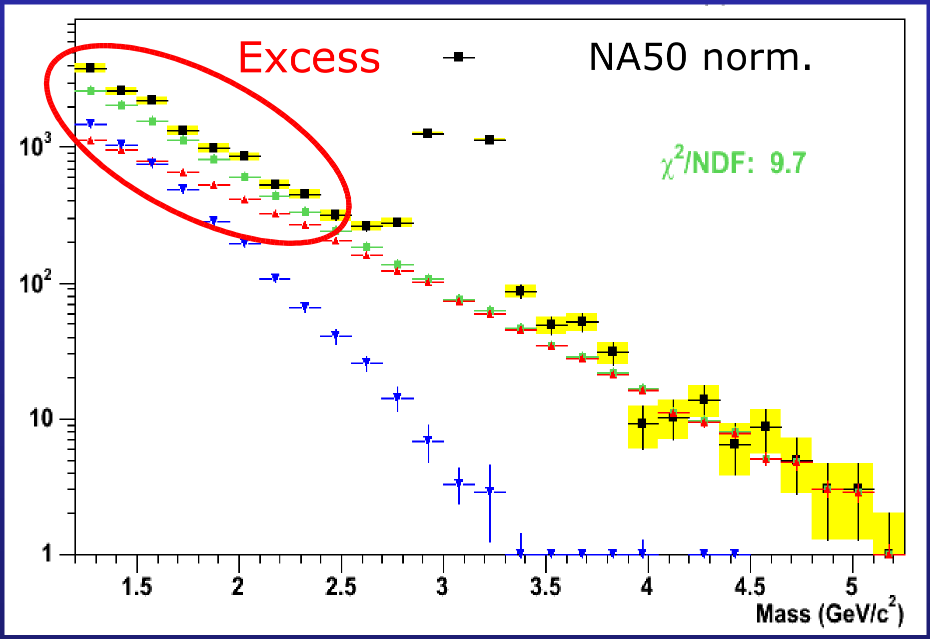
- The difference between NA49 and NA50 is not due to the different decay channel under study

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

IMR: 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 $\mu\mu$ 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

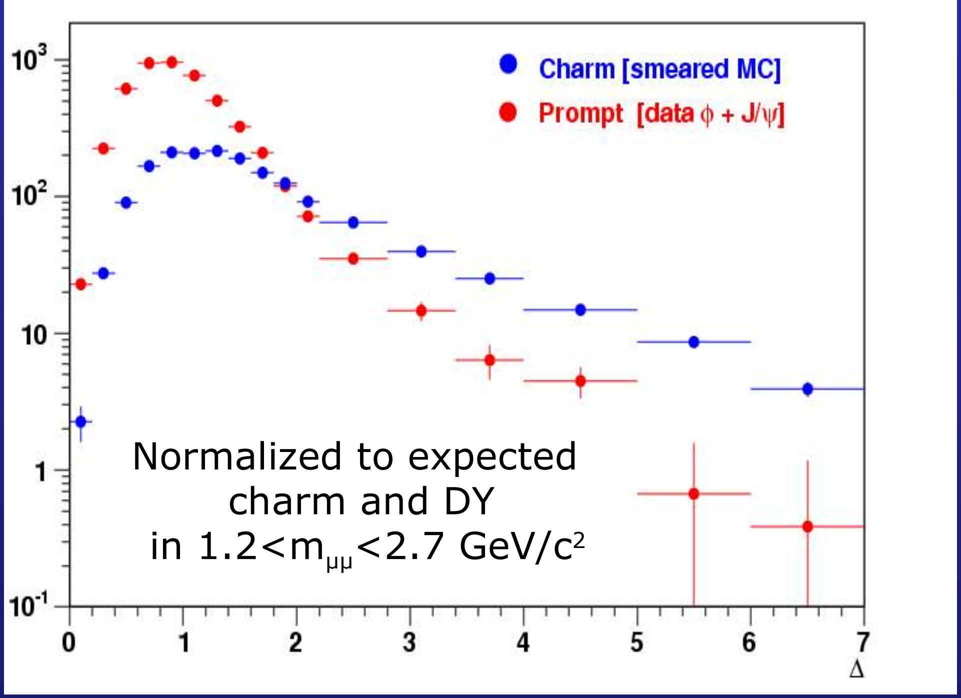
- As in NA50, the mass shape of the In-In excess is compatible with open charm ⇒ not conclusive, muon offset information needed

- Muons from D → μ + X do not converge to the interaction vertex
- Typical offset of muons $\begin{cases} D^+ : c\tau = 312\ \mu m \\ D^o : c\tau = 123\ \mu m \end{cases}$

- Muon offsets: ΔX, ΔY between the vertex and the track impact point in the transverse plane at Z_{vertex}
- Δ_μ ⇒ offset weighted by the covariance matrices of the vertex and of the muon track

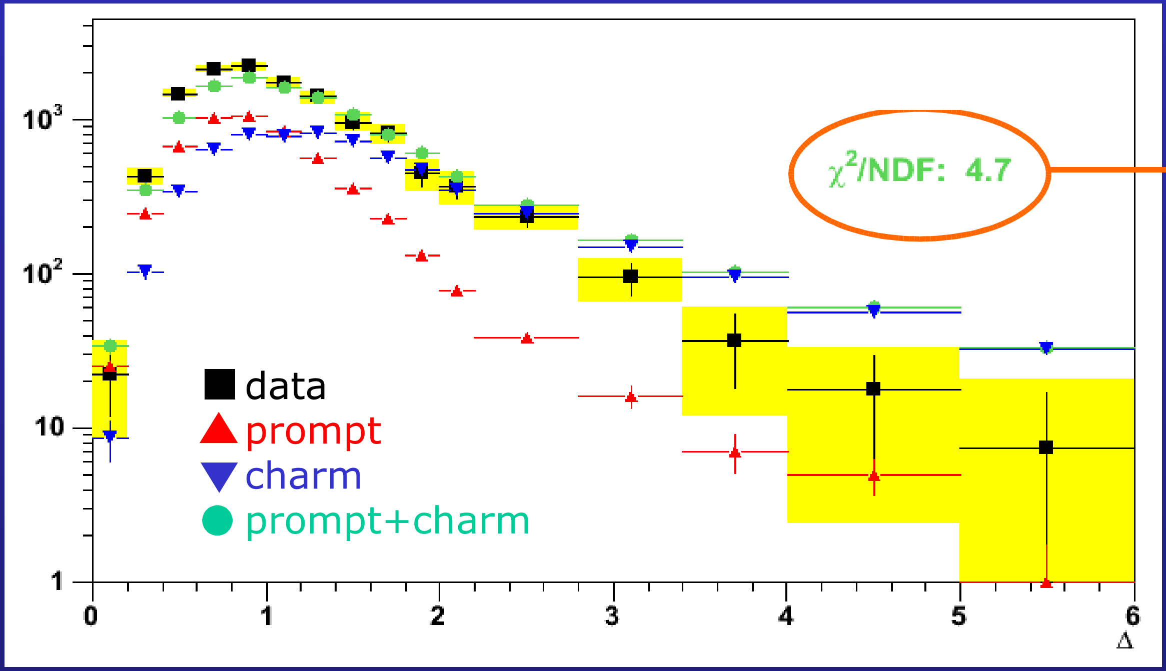
Offset resolution
(measured on J/ψ data)

40-50 μm



IMR: is the excess due to open charm ?

$\Rightarrow$ Fit IMR Δ_μ distribution fixing prompt contribution to the expected Drell-Yan yield

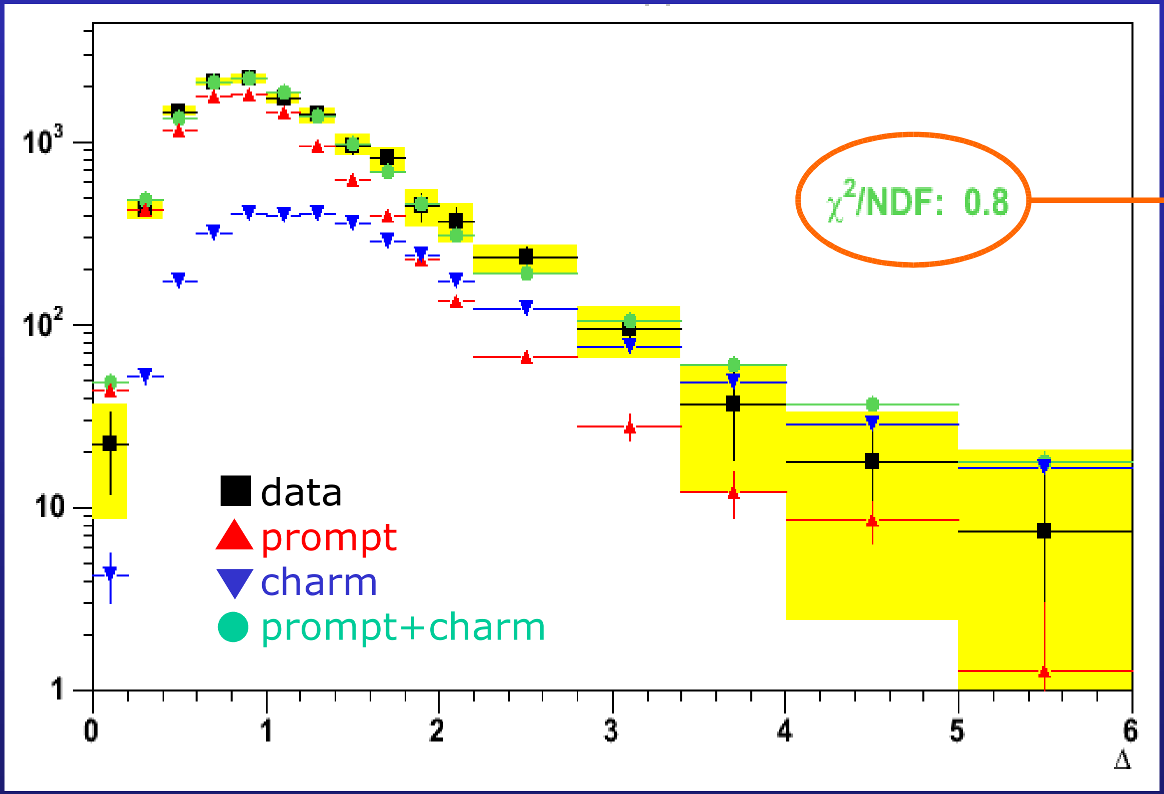


Fit fails

- 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)



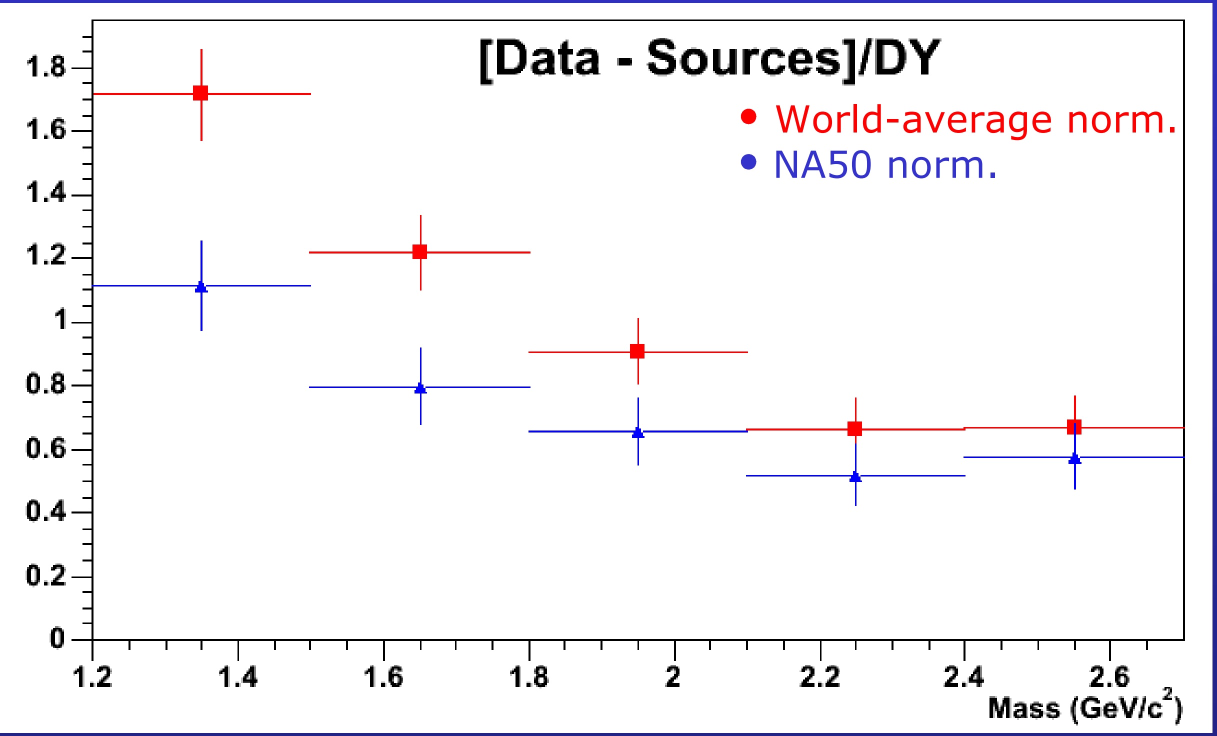
Fit converges, good χ^2

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

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

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

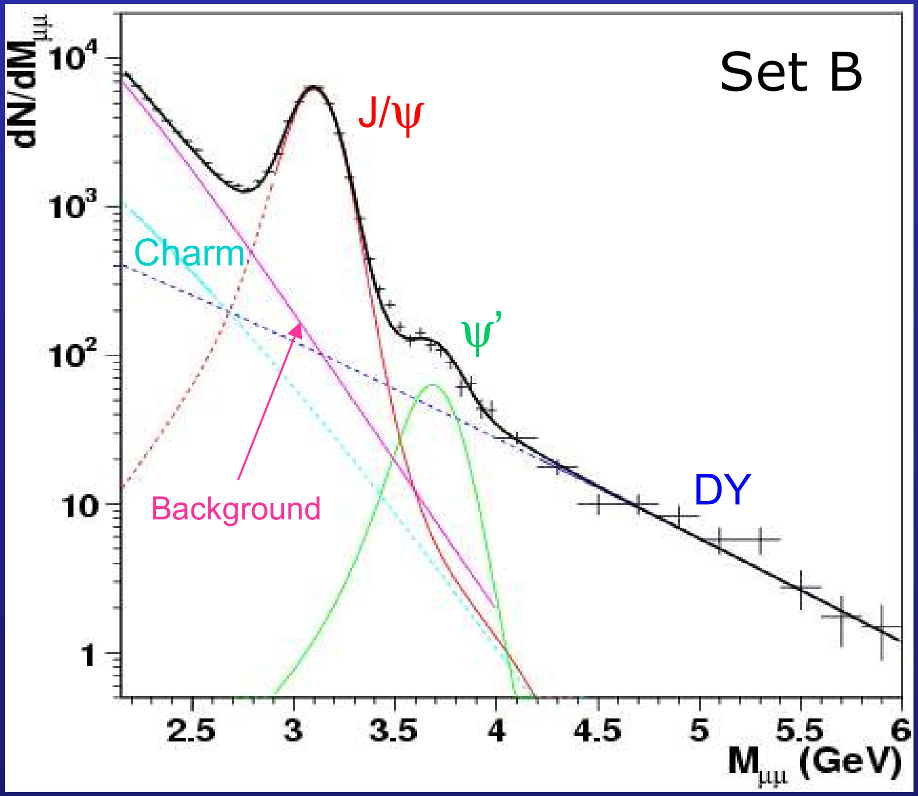
Mass shape of the IMR excess



- The mass distribution of the excess is steeper than Drell-Yan (and flatter than open charm)

J/ψ suppression in In-In

- 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)

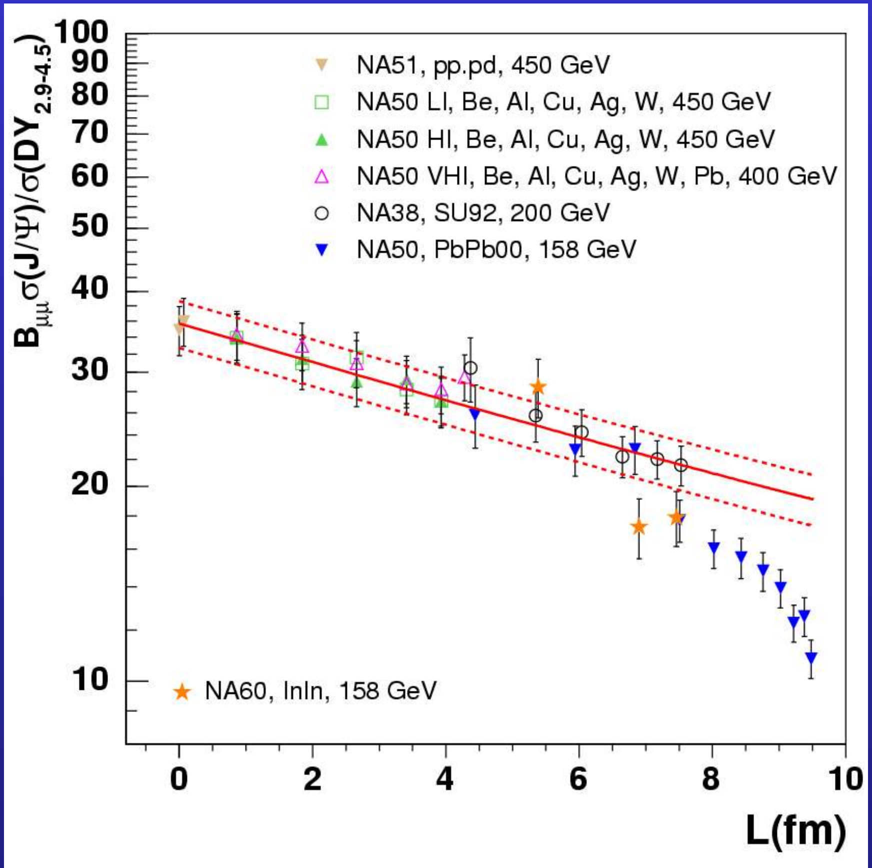


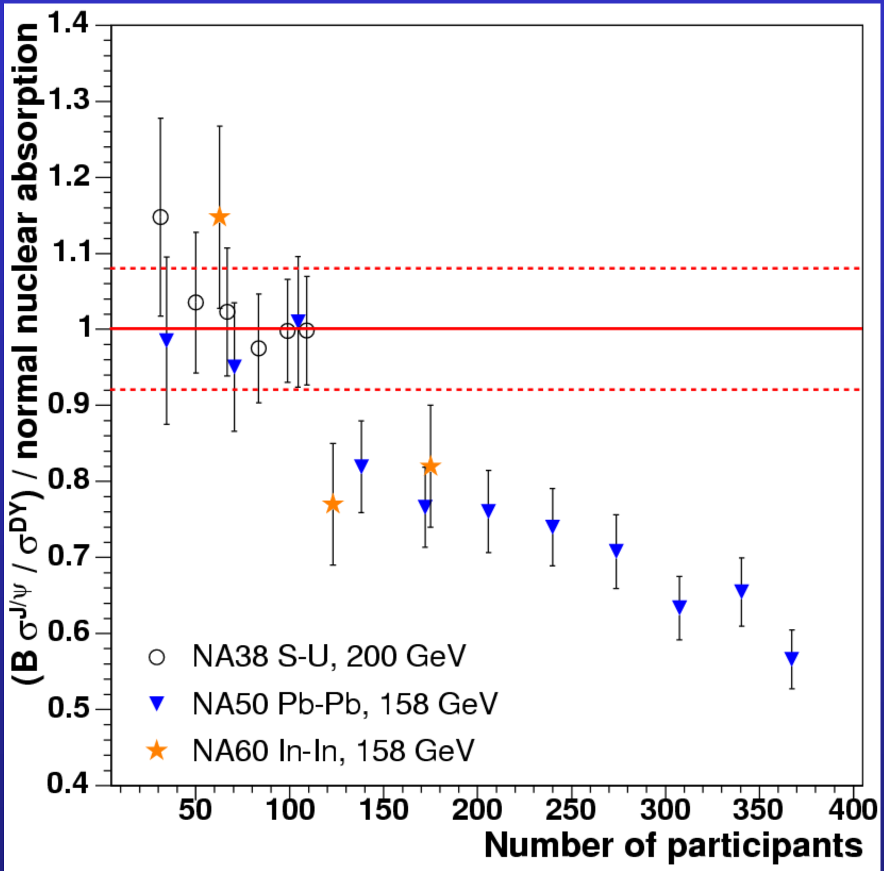
- Drawback

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

Investigate other possible normalizations in order to exploit the considerable J/ψ statistics ($>4\times10^4$)

J/ψ suppression, “standard” analysis





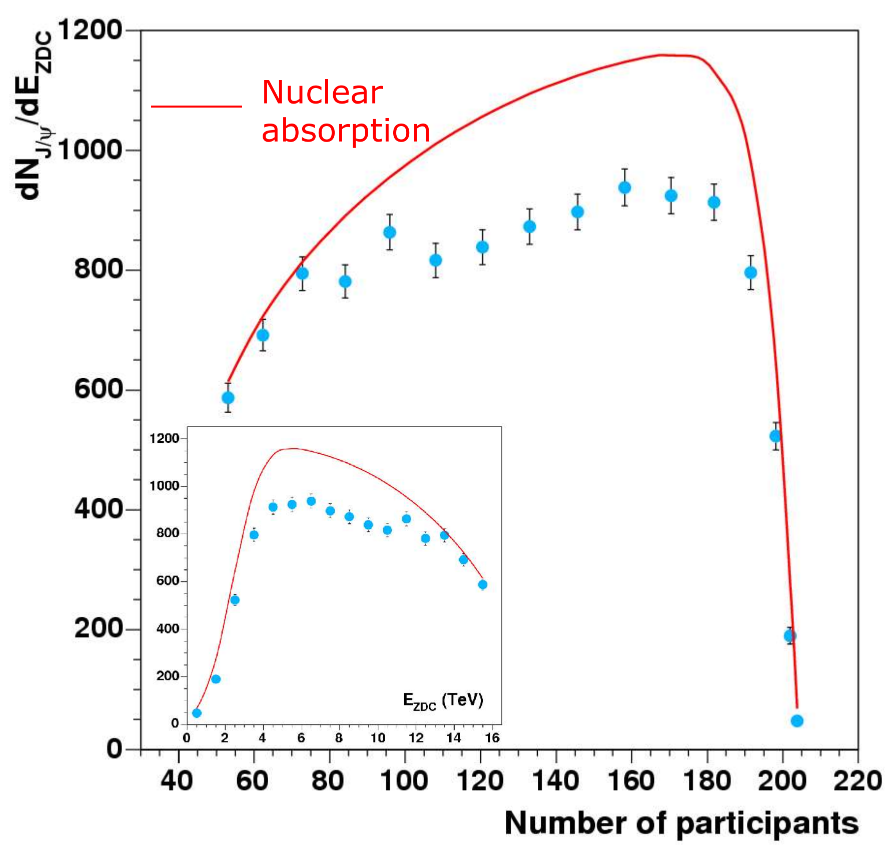
- 3 centrality bins, defined through E_{ZDC}
- J/ψ nuclear absorption → $\sigma^{J/\psi}_{abs} = 4.18 \pm 0.35$ mb (from NA50 @ 450 GeV)
- ~ 8% uncertainty on the rescaling to 158 GeV

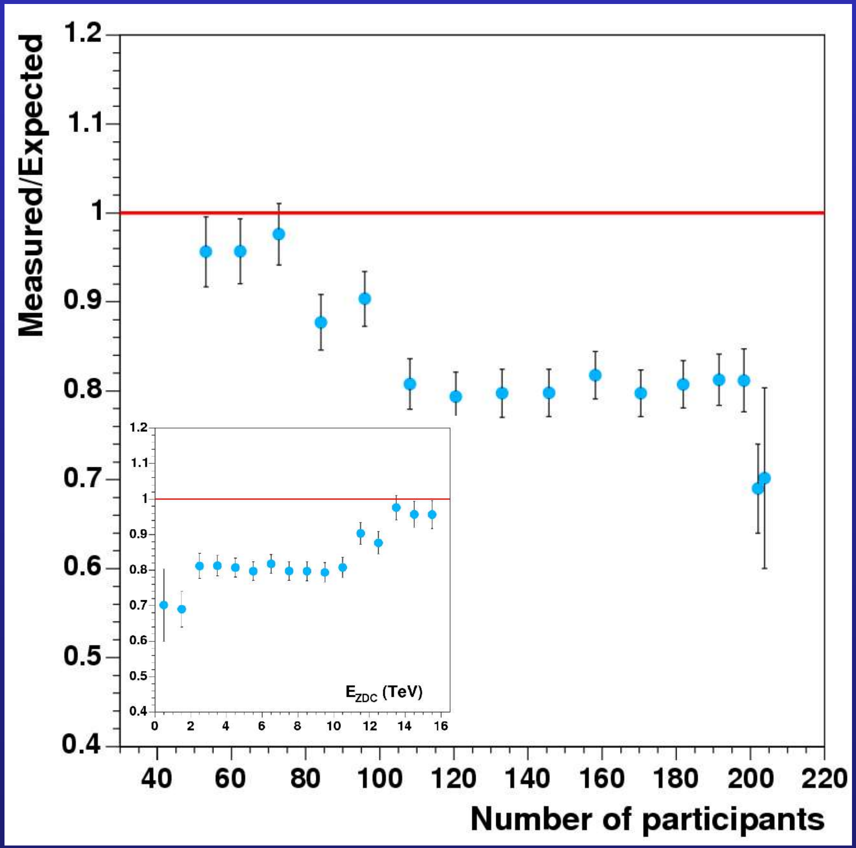
Anomalous J/ψ suppression is present in In-In collisions

A finer centrality binning is needed to sharpen the picture

Direct J/ψ sample

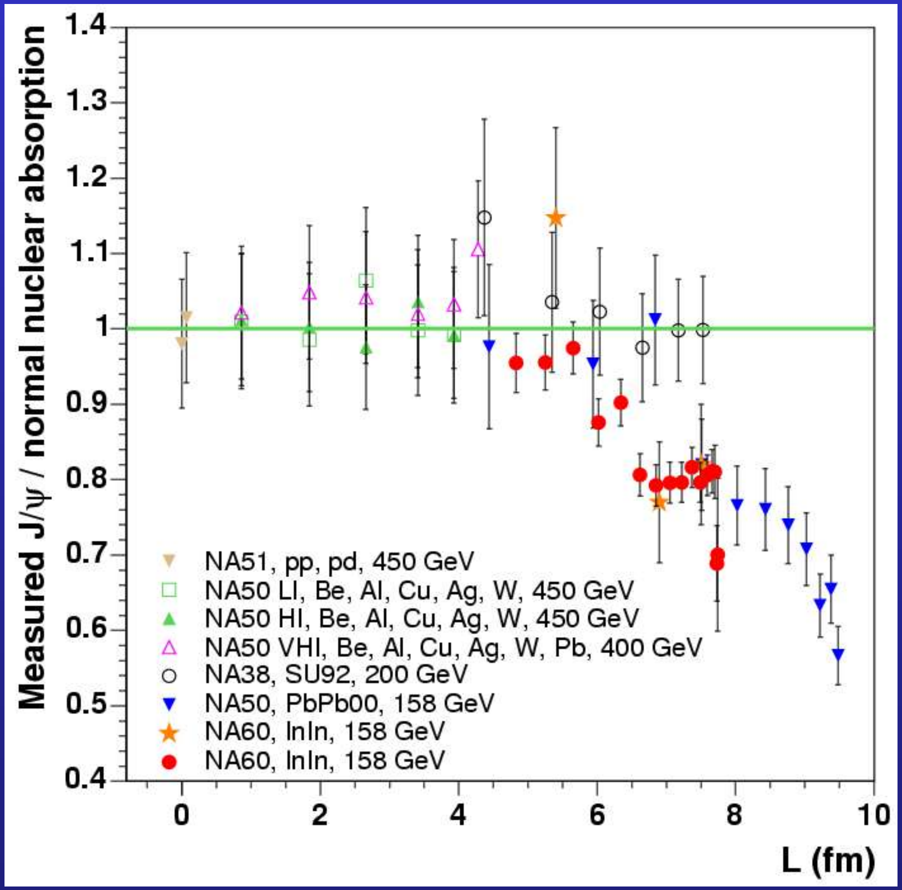
- To overcome the problem of DY statistics, directly compare the measured J/ψ centrality distribution with the distribution expected in case of pure nuclear absorption

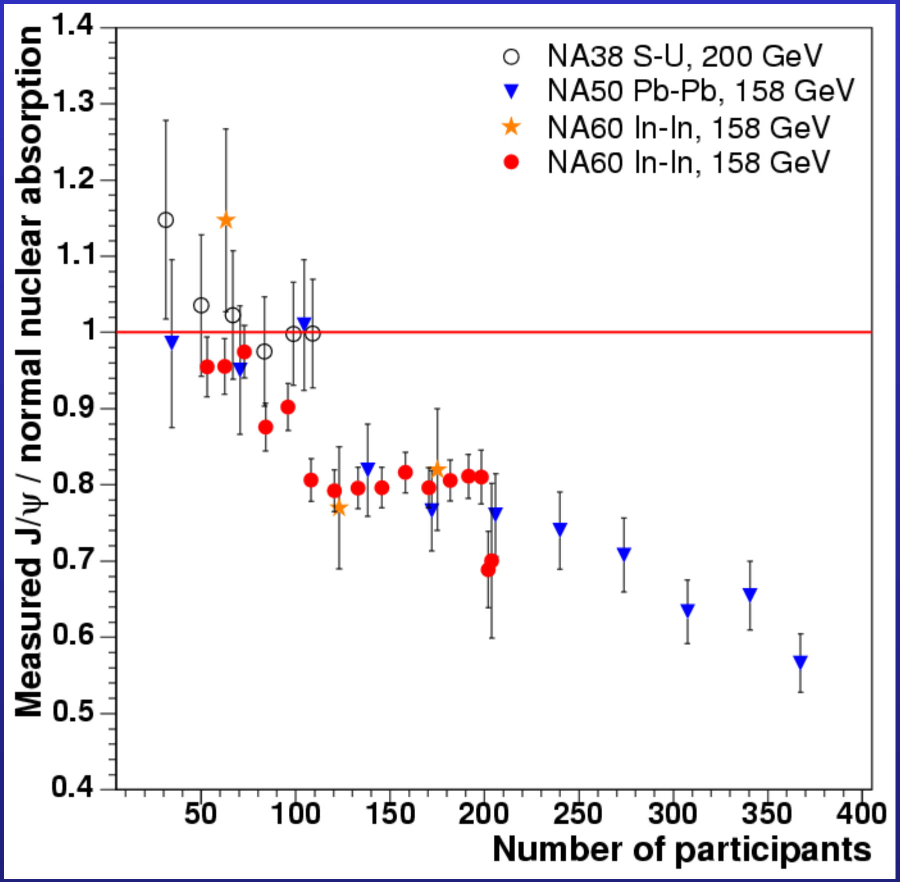




- Onset of anomalous suppression around N_{part}= 90
- Saturation at large N_{part}

Comparison with previous results





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

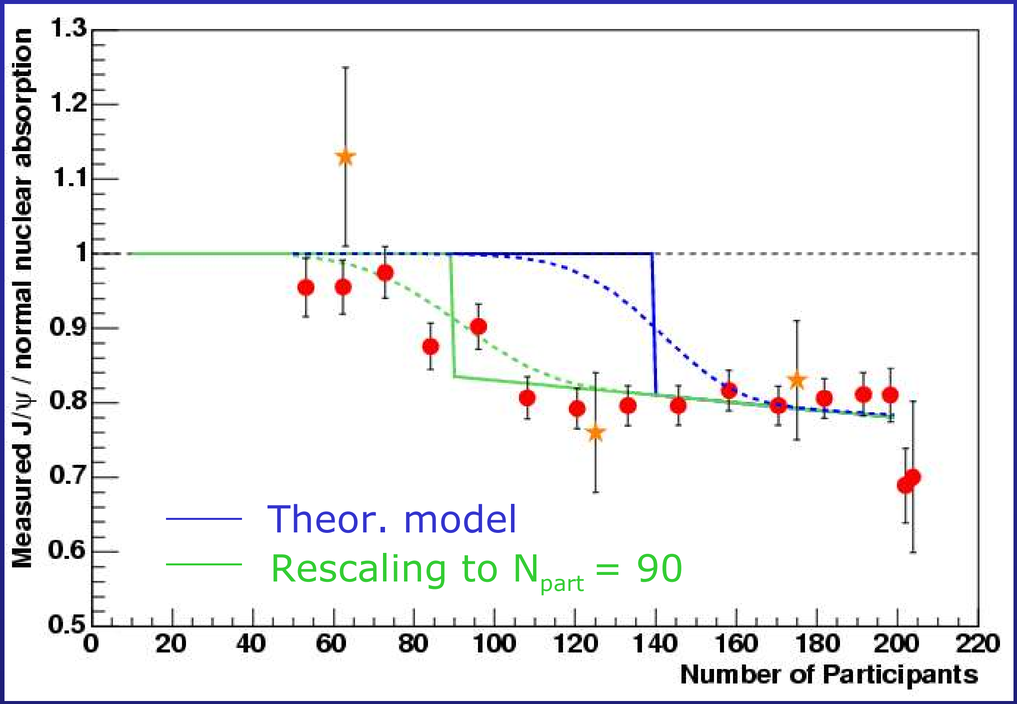
⇒ new set of Pb-Pb results needed, with reduced error bars

Comparison with theoretical models

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

- As an example, compare with predictions of a model based on percolation
  (Digal, Fortunato and Satz, Eur.Phys. J. C32(2004) 547)
- Sharp onset at N_{part}~140 predicted, smeared by experimental resolution

- NA60 observes a pattern very similar to the predicted one, but with an onset at a lower N_{part} value



For more model comparisons, see parallel session (R. Arnaldi)

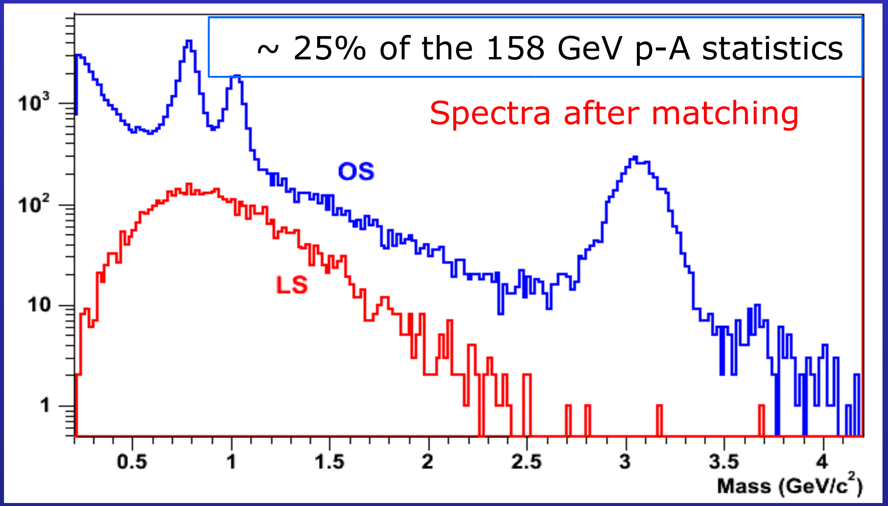
Perspectives

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

Conclusions

- Physics results from NA60 are now available (In-In collisions)

- Low-mass region
  - Lepton pair excess at SPS energies confirmed
  - Mass shift of the intermediate ρ ruled out
  - Broadening of the intermediate ρ describes data
  - ϕ puzzle under study

S. Damjanovic, Sect. 6a

A. DeFalco, Sect. 6a

- Intermediate-mass region
  - Enhancement of dimuon yield confirmed
  - Not consistent with an enhancement of open charm
  - Consistent with an enhanced prompt source

R. Shahoyan, Sect. 5b

- 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

R. Arnaldi, Sect. 6a

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