NA60 low mass muon pairs

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Outline

- Objective: put NA60 low mass data in context
- Reminder: What is NA60 good at ?
- Question: What can we contribute for
  - muon pairs near threshold (pA)
  - non-resonant pairs below 1 GeV (AA)
  - the ρ and ω peaks
  - the ϕ peak
  - masses above 1 GeV: talk of André David

NA60 features

- NA60 differs from earlier $\mu\mu$ experiments by its combination of:
  - low π/K background thanks to the short distance between target and absorber
  - both in pA and in AA collisions, an excellent mass resolution thanks to the 2-spectrometer approach: silicon vertex telescope + muon spectrometer
  - high statistics
  - improved low mass, low pT acceptance, compared with NA50
- Experience from pA data shows that these factors help understanding surprising features

NA60 statistics

- Current data sample

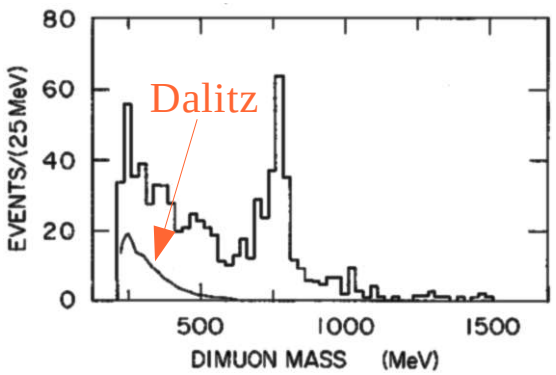
Year	Beam	Target materials	Period	Signal
2002	p: 400 GeV	Be, In, Pb	4-5 days	20,000 matched pairs 290 + 200 + 250 J/ψ
2003	In: 158 GeV/n	In	5 weeks	1,000,000 matched m < m(ϕ) 100,000 ϕ 100,000 J/ψ
2004	p: 400 GeV	Be, Al, Cu, In, W, Pb, U	30 days	320,000 J/ψ
	p: 158 GeV	idem	4 days	30,000 J/ψ

- Hope for the future:
  - 2007-2008: proton runs
  - 2009: Pb-Pb at 158 GeV + possibly a lower energy, e.g. 40 GeV

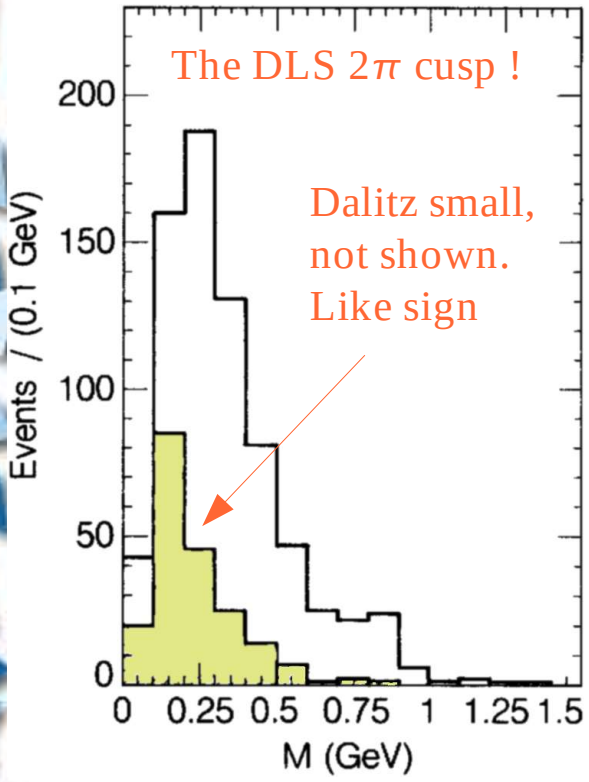
Near the mass threshold ...

- After a long history where an excess was consistently found, it now appears that:
  - in pA, most if not all of the signal is explained by Dalitz decays of the π^{o} and η;
  - other components, such as soft photons, are probably present in ee data but they are not a point of study in $\mu\mu$ experiments.

Historical examples

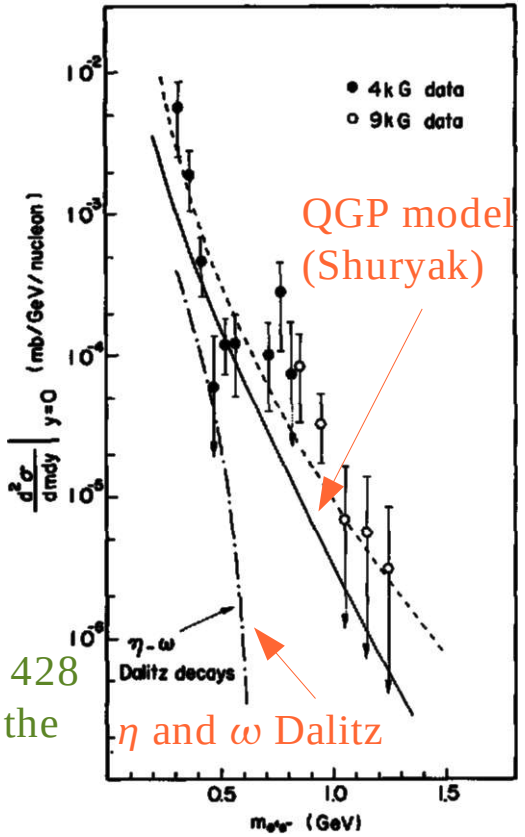


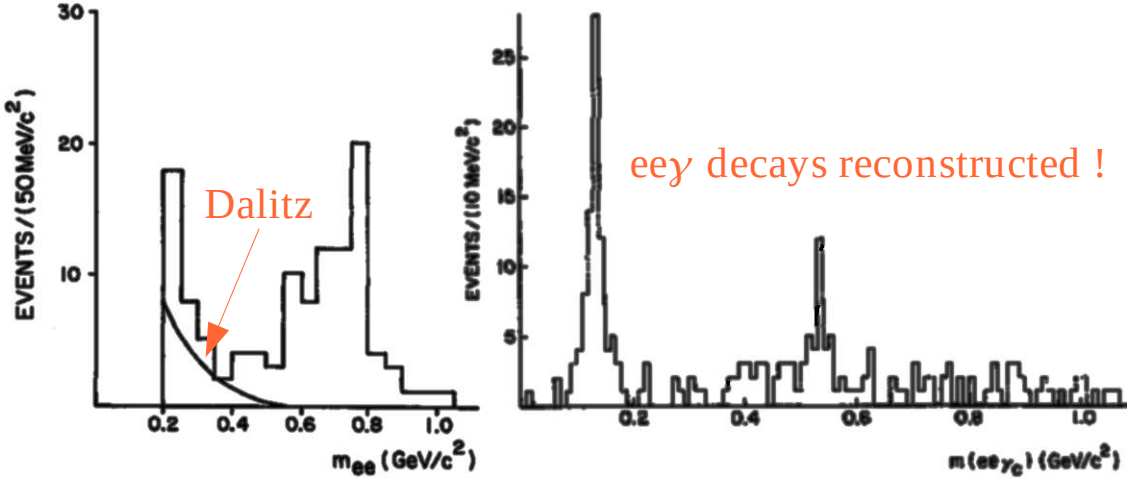
Haber *et al.*, Phys. Rev. D 22 (1980) 2107
$\mu\mu$ in πp at 15.5 GeV



DLS, Phys. Rev. Lett. 61 (1988) 1069
ee in pA below 10 GeV

Mikamo *et al.*, Phys. Lett. B 106 (1981) 428
ee in pA at 13 GeV, also compared with the soft annihilation model of Černy

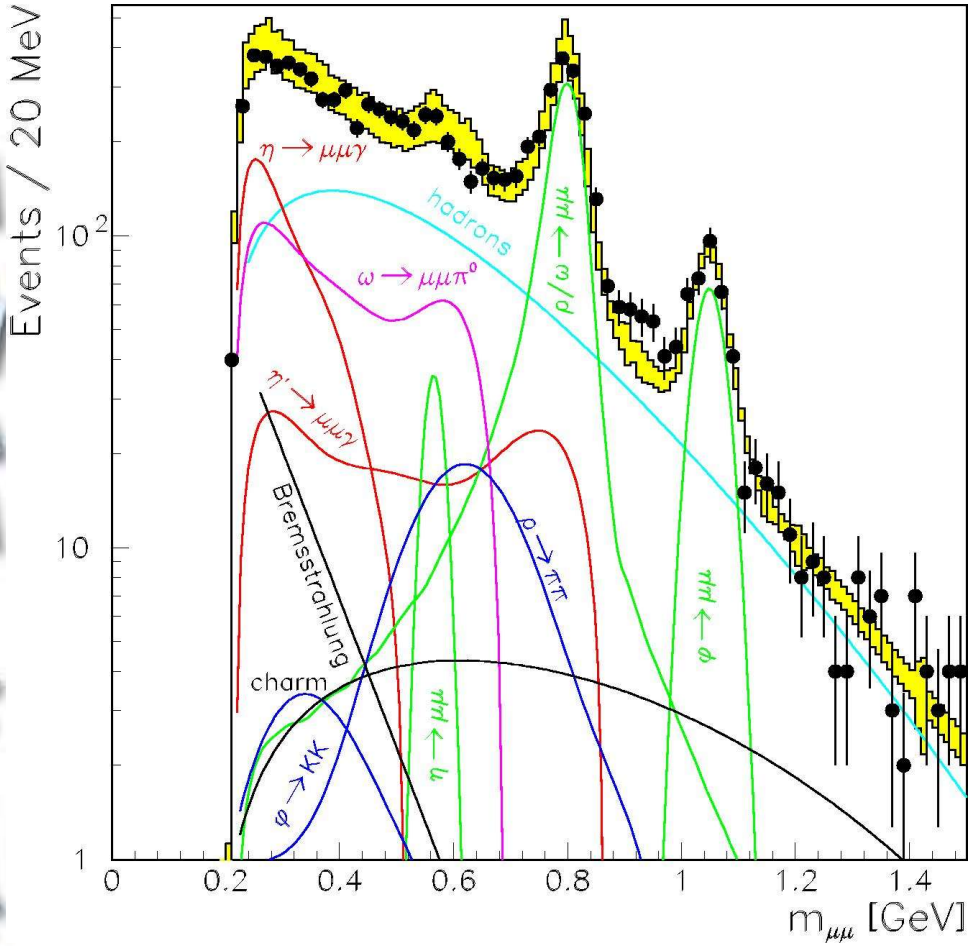


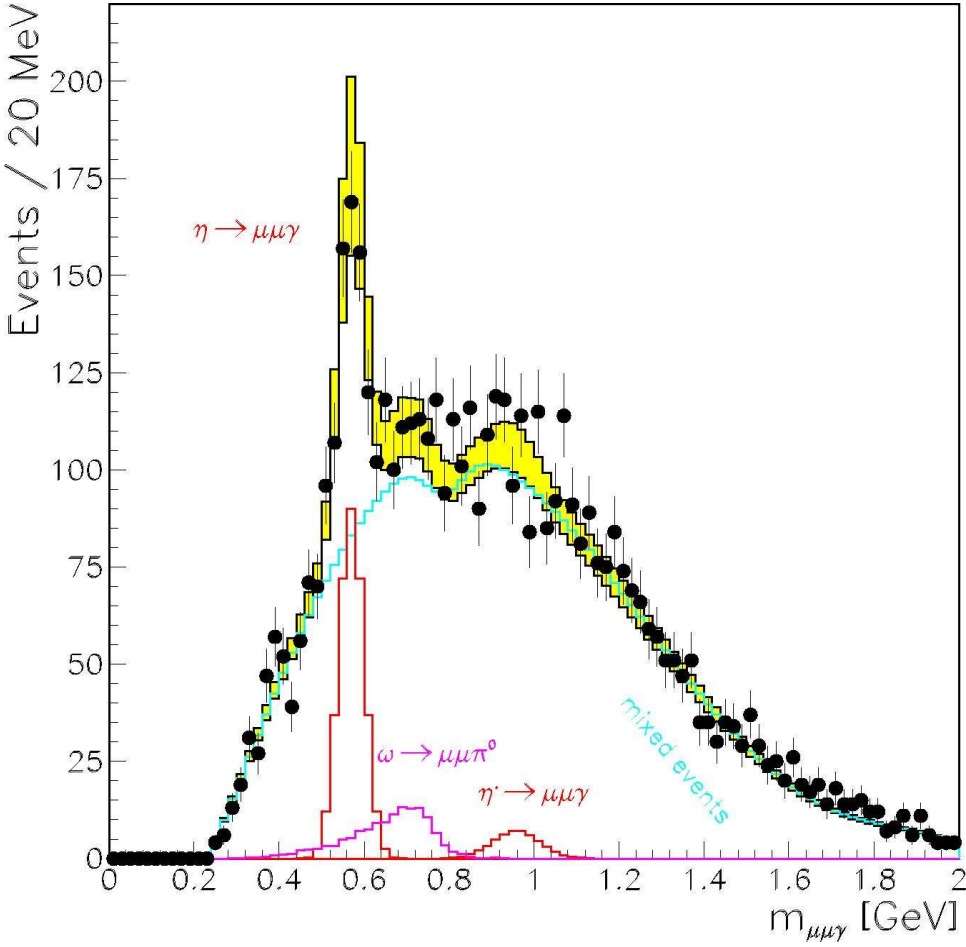


Adams *et al.*, Phys. Rev. D 27 (1983) 1977
ee in πp at 17 GeV

No excess in pA ...

- RISK first showed a clear negative result (πp)
- Soon after followed by Helios/I (pBe)



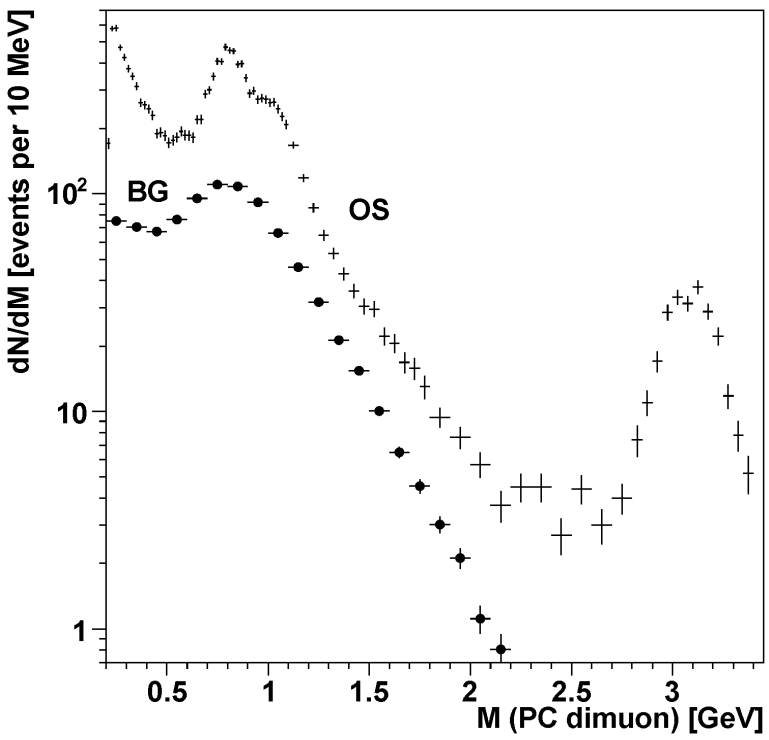


[Plots from Hermine Wöhri]

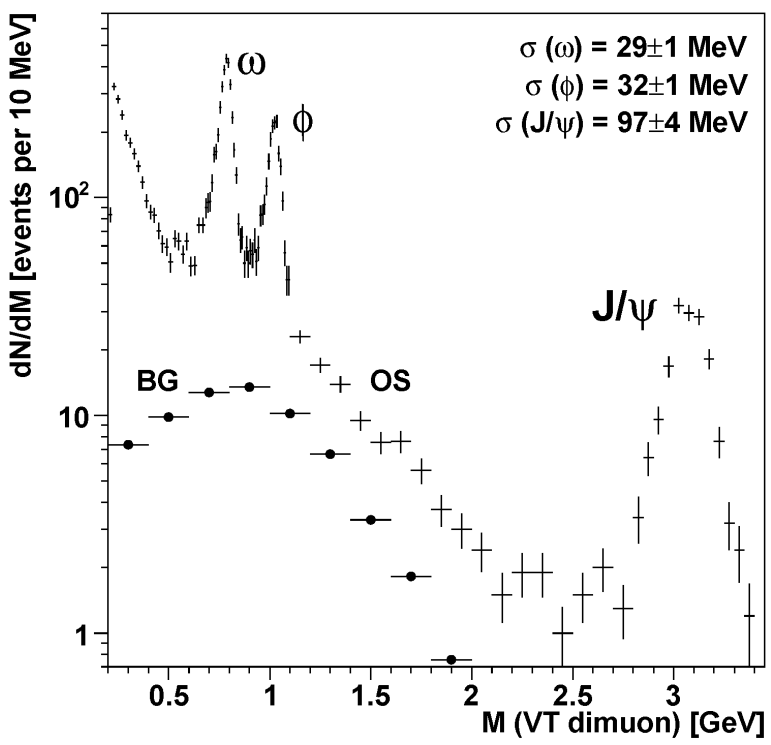
NA60 proton data 2002

- Matching improves S/B by a factor of 4
- Well resolved resonances, σ = 30 MeV

Before matching

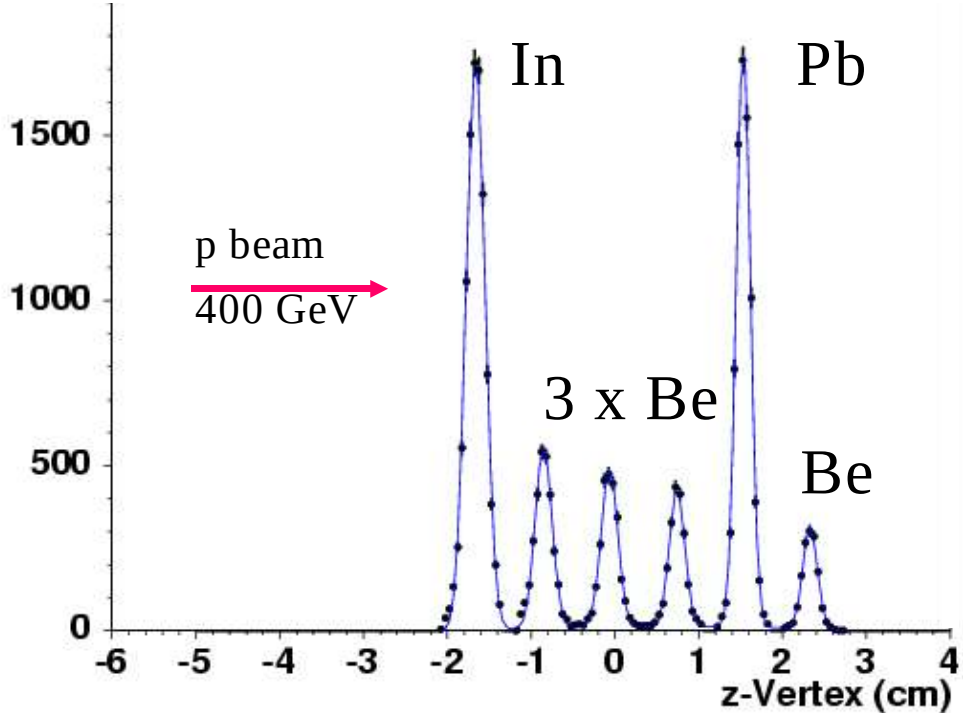


After matching



NA60 target identification in pA

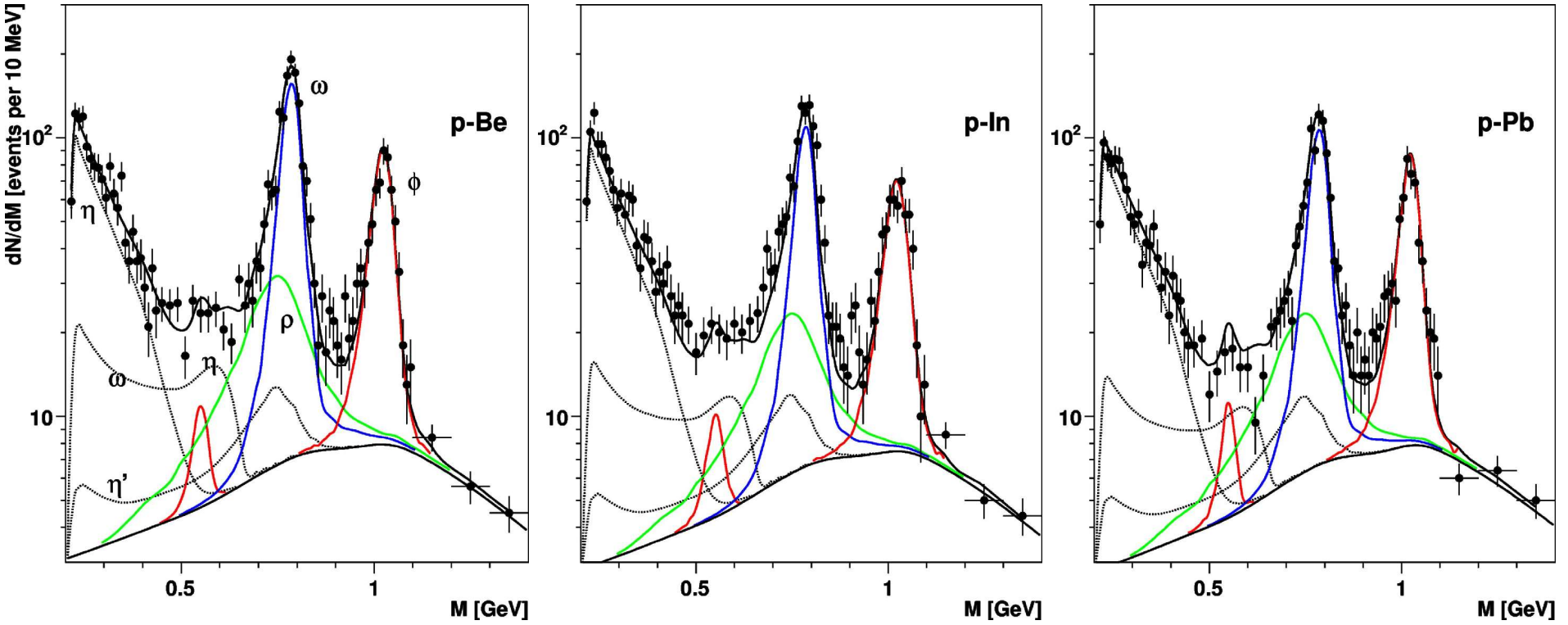
- The sub-target is identified through the silicon vertex telescope (2 % errors !)



- Target pointing is even better in the 2003 data.

NA60 proton data

- All production rates are compatible with earlier data from NA27, Helios/I and Ceres-Taps.
- No noticeable excess seen.

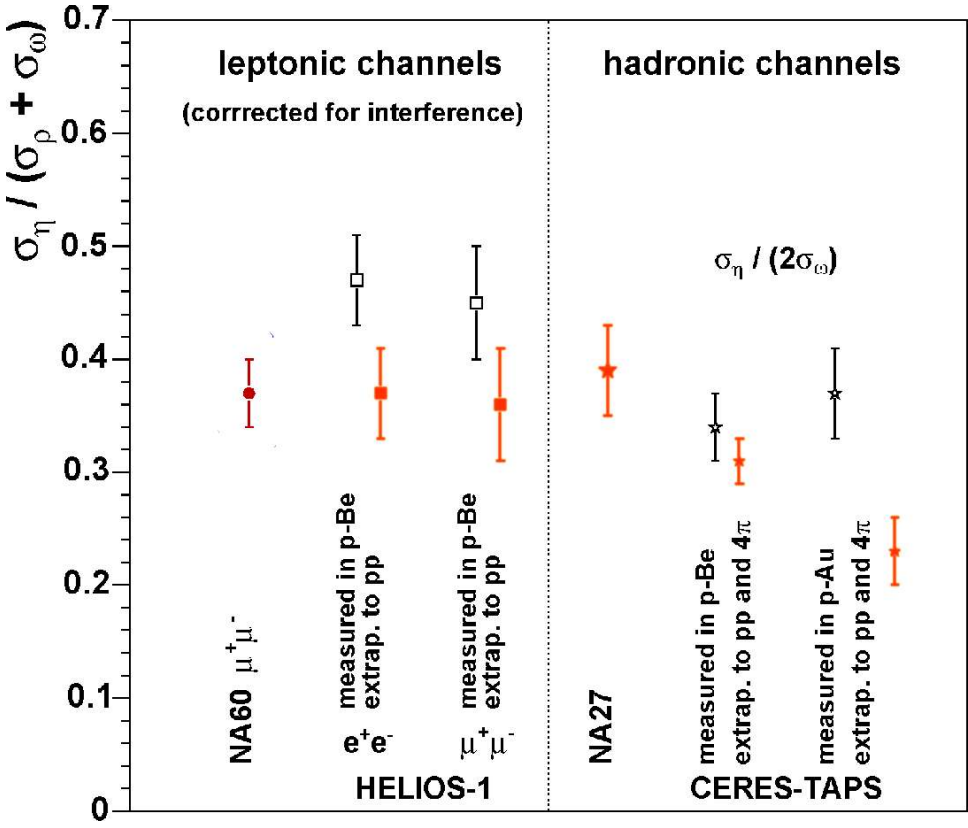


NA60 – pA fitting strategy

- Joint fit for the 3 target materials
- Branching ratios: according to PDG
- Fitting parameters
  - σ: Cross sections "for A=1"
    - free fitting parameter for $\eta,\ \rho,\ \omega,\ \phi$
    - assuming η' is 15 % of η
  - α: Scaling with A according to $\sigma = \sigma_{A=1} A^{\alpha}$
    - free fitting parameter for $\eta,\ \omega,\ \phi$
    - assuming ρ is like ω
    - assuming η' is like η
- DY + charm: fixed after fit in the IM region.
- J/ψ: not included in the fit.

NA60 – pA cross sections

- η:
  - NA60: 9.5 ± 0.6 mb
  - NA27: 9.8 ± 0.6 mb
- $\rho+\omega$:
  - NA60: 22.1 ± 1.2 mb (no interference)
  - NA60: 25.4 ± 1.3 mb (interference 15 %)
  - NA27: 25.4 ± 1.0 mb
- ϕ:
  - NA60: 0.53 ± 0.05 mb
  - NA27: 0.62 ± 0.06 mb
- Assumes a $1+\cos^2\theta$ decay angle distribution for $\rho\omega\phi$



Also Helios/I needed a smaller ϕ cross section than NA27 to explain its data

NA60 - α of the mesons in pA

- Using Be, In and Pb targets and
- assuming the cross section scaling $\sigma = \sigma_{A=1} A^{\alpha}$,
- the following scaling parameters are found:

η: 0.93 ± 0.02
ω: 0.82 ± 0.01
ϕ: 0.91 ± 0.02

Note: the average pT for the η is 1000 MeV and 700 MeV for $\rho\omega\phi$. The error bars are statistical only.

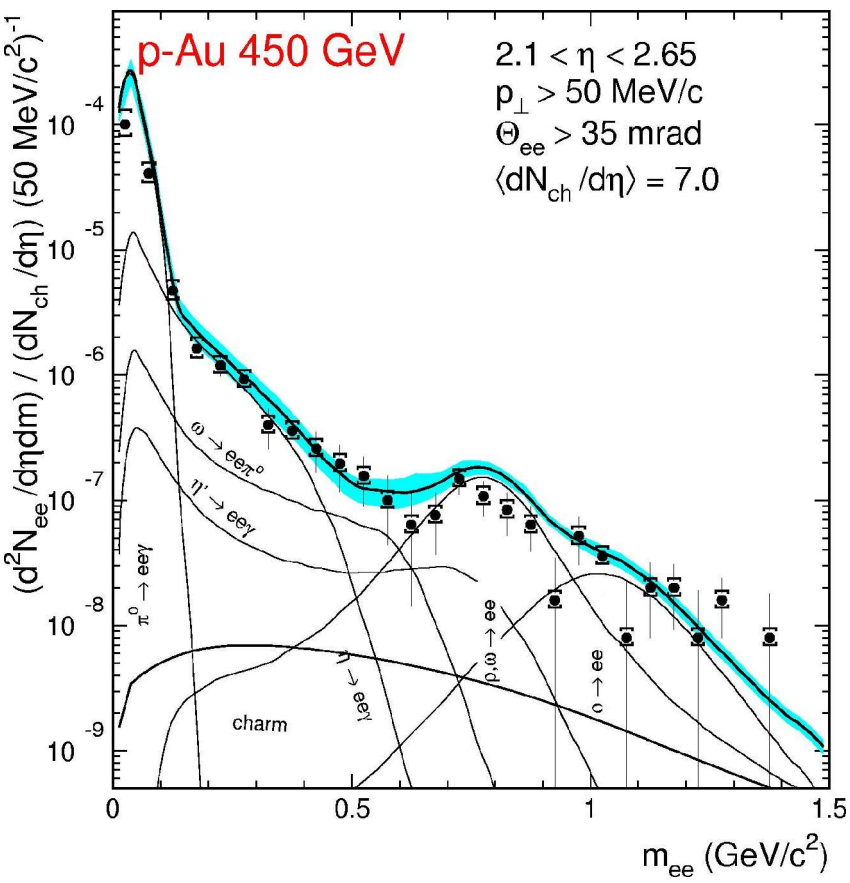
- The 2004 proton data can extend these measurements to other target materials and to measure the pT dependence of α.

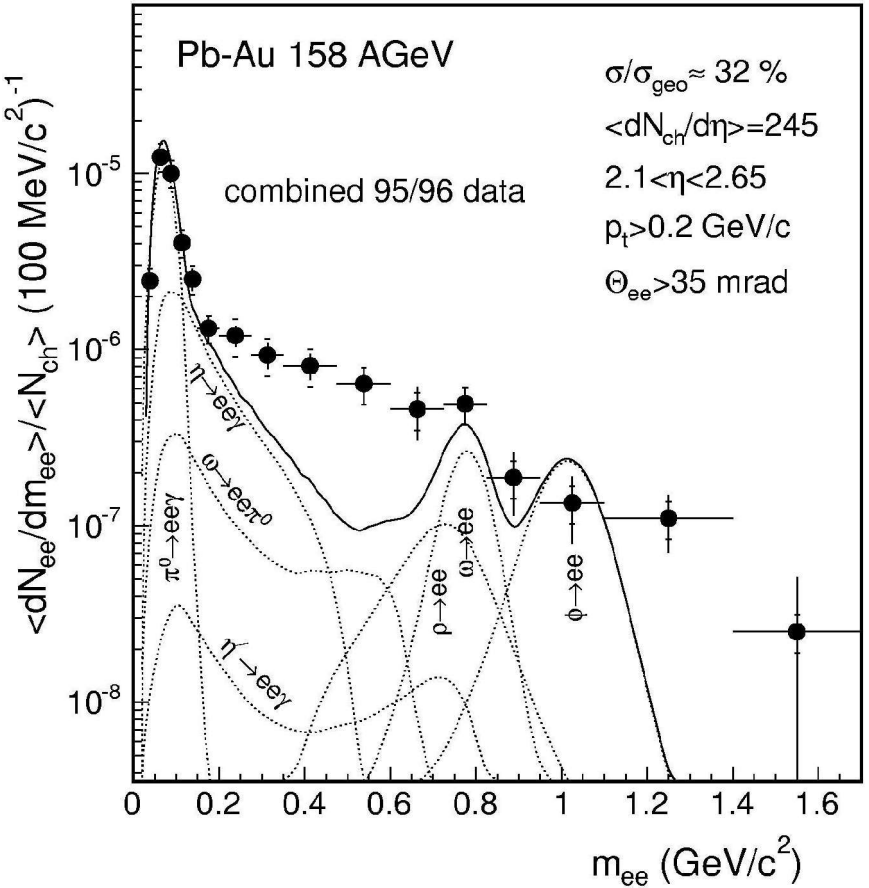
AA: non-resonant < 1 GeV

- Experiments see an excess in AA over pA
  - Ceres:
    - broad excess in AA, located mostly below the ω mass,
    - excess is concentrated at low pT,
    - excess rises faster than linear with multiplicity.
  - Helios/3:
    - broad excess in AA compared to pA.

CERES mass spectra

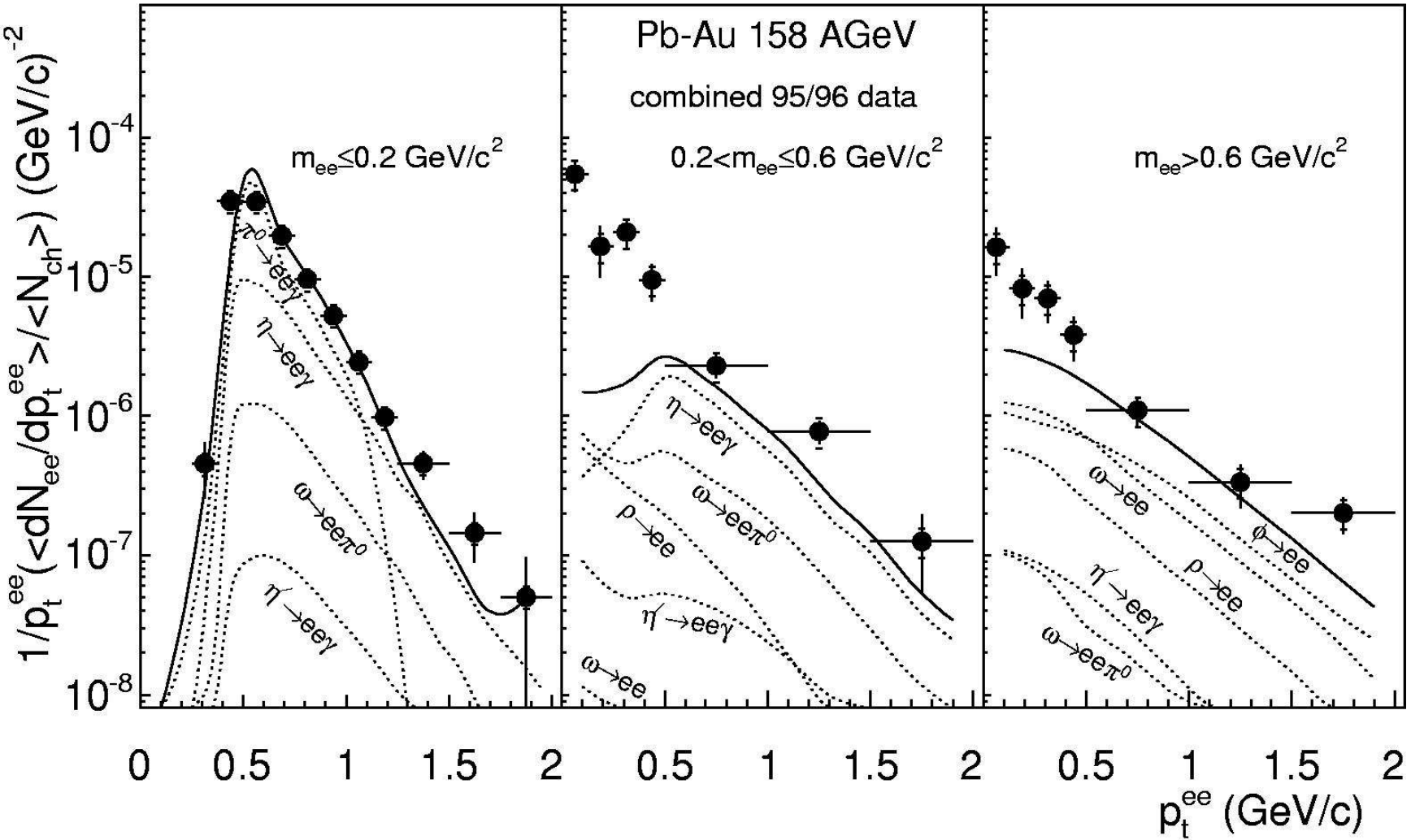
- Pb-Au in marked contrast with p-Au
  - excess from 200 MeV to 600 MeV,
  - the ρ/ω seems to have diminished.





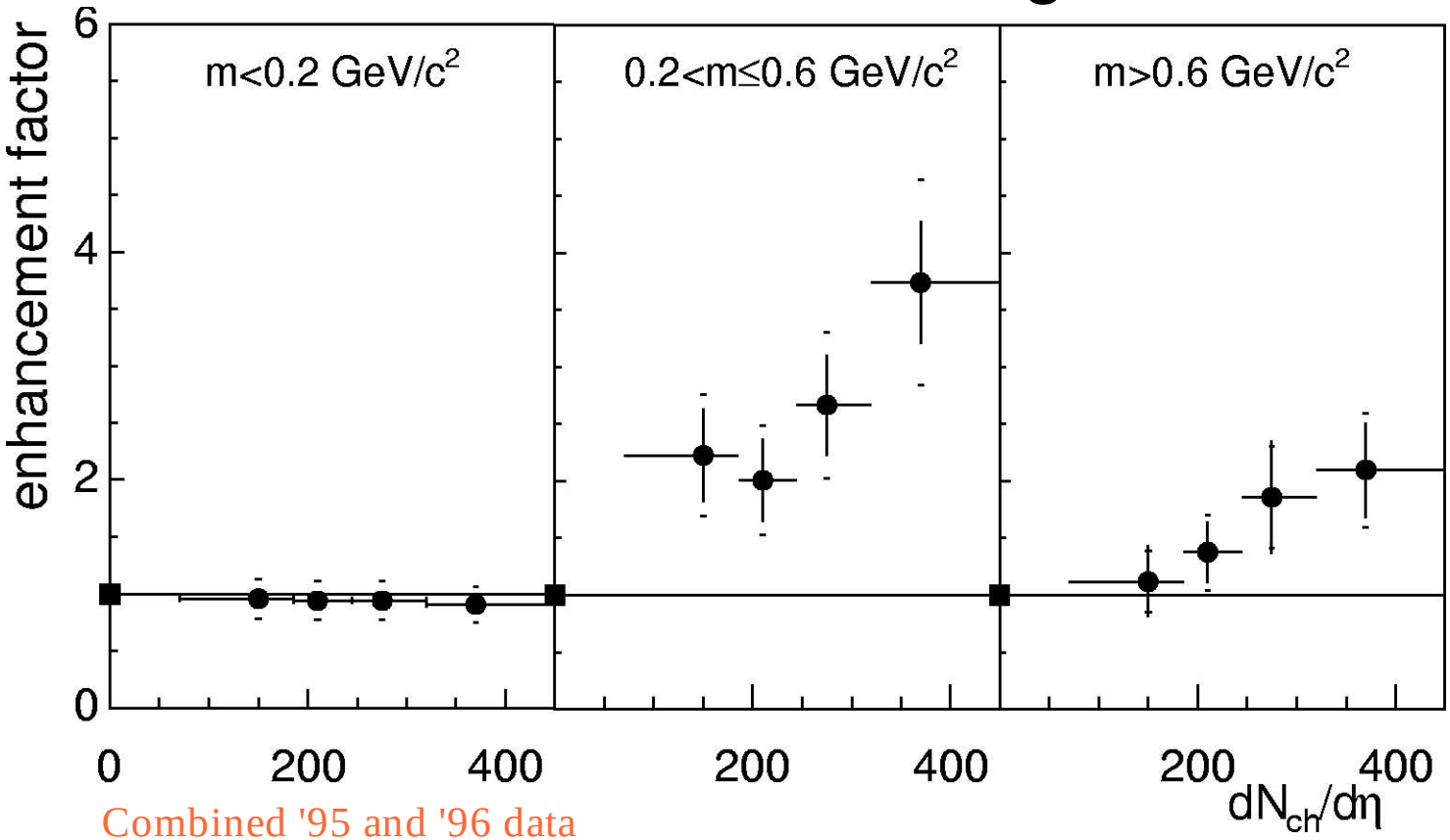
CERES transverse momentum

- The excess sits at low pT.



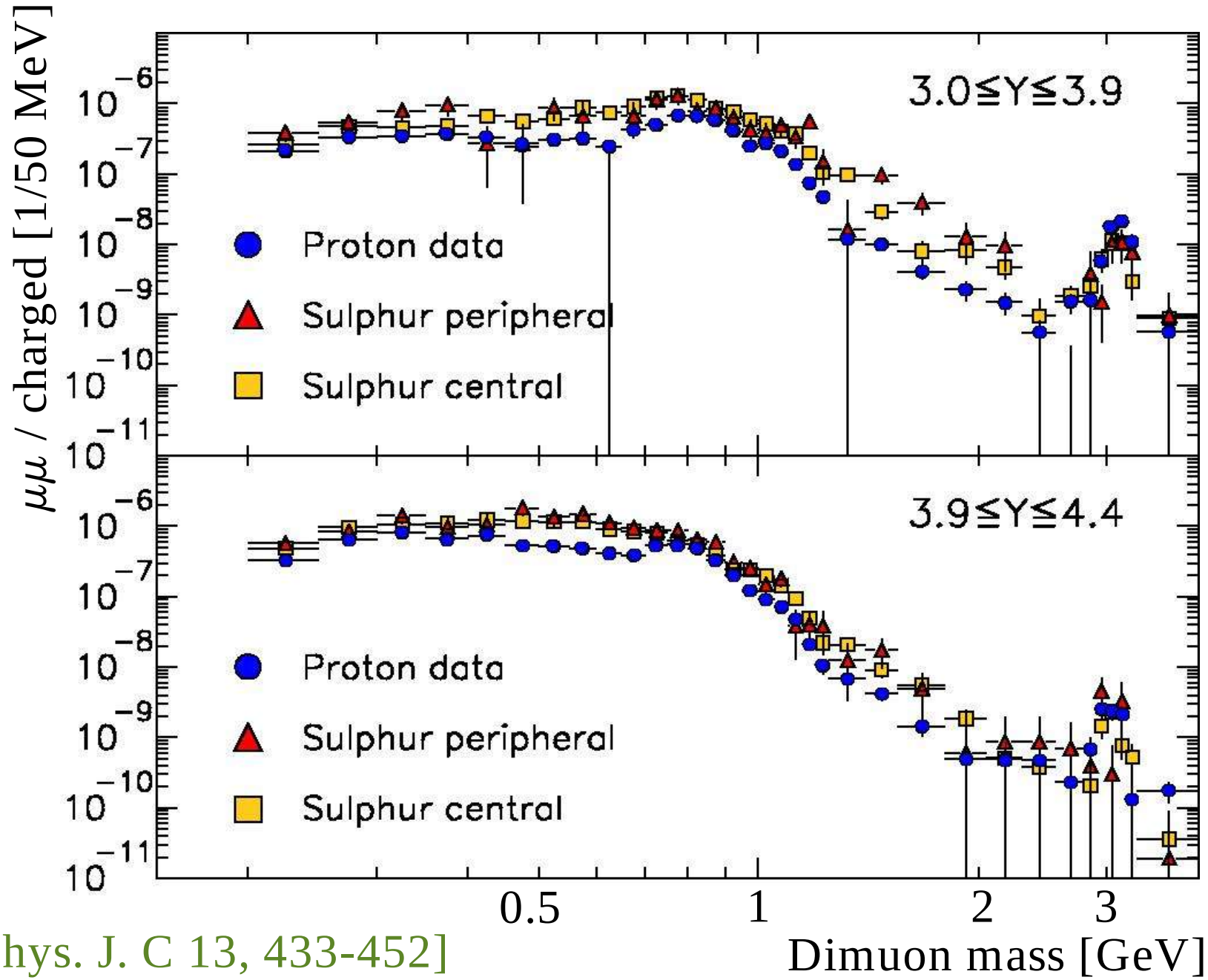
CERES multiplicity

- The excess rises faster than linearly with the charged multiplicity.
- Normalisation: meson background cocktail.



Combined '95 and '96 data

Helios/3: 200 GeV/n pW vs SW

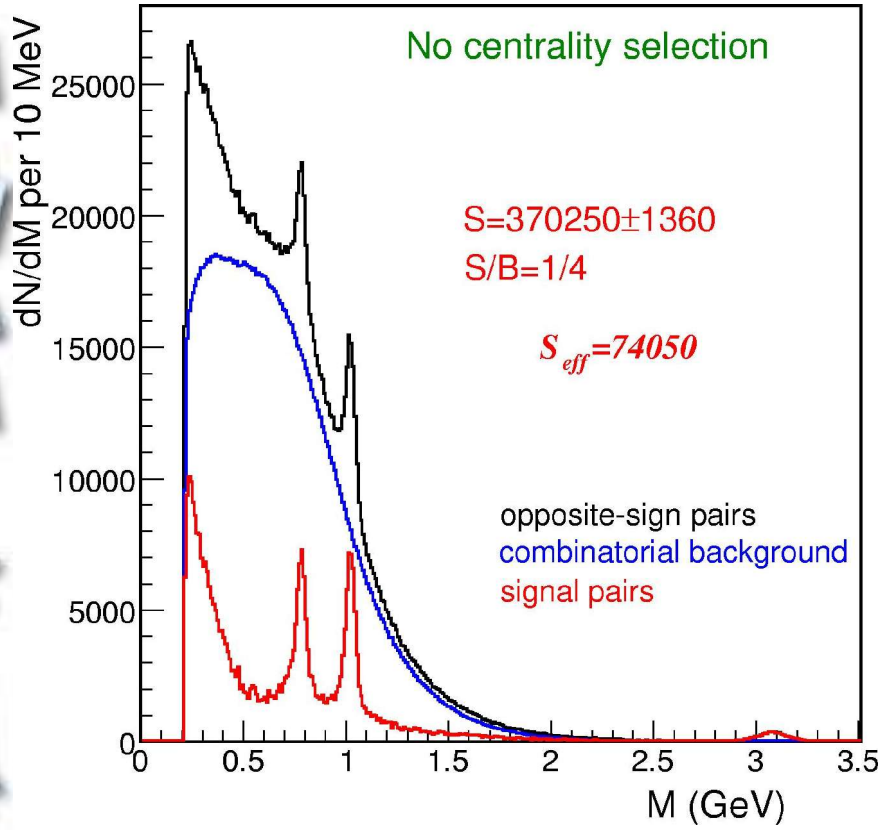


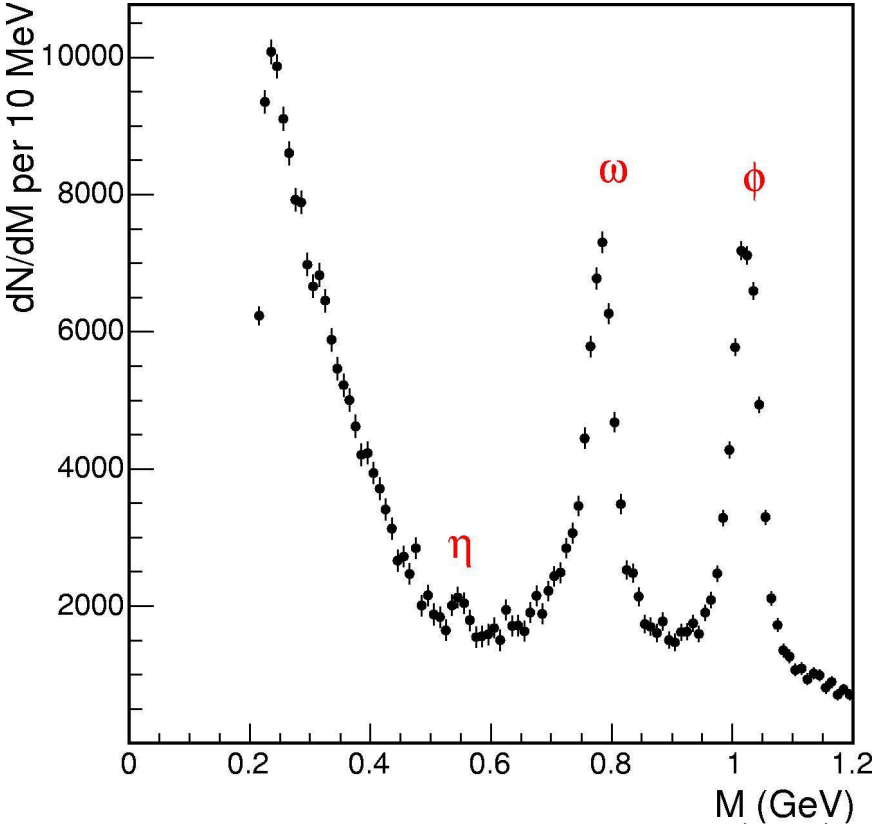
[Eur. Phys. J. C 13, 433-452]

[Plots from Sanja Damjanovic]

NA60 In-In raw data at 158 GeV/n

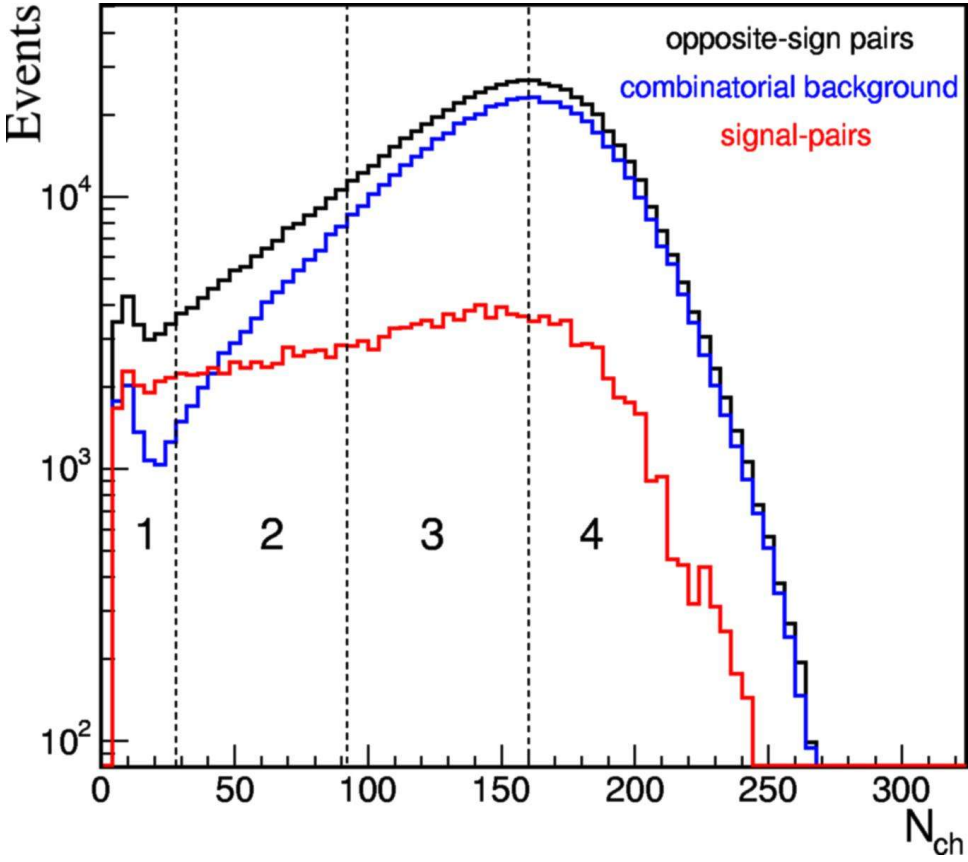
- Sofar, 35 % of total sample reconstructed.
- Better mass resolution than in proton runs !
- π/K understanding is critical m > 500 MeV.
- Current problem: understanding fake matches.





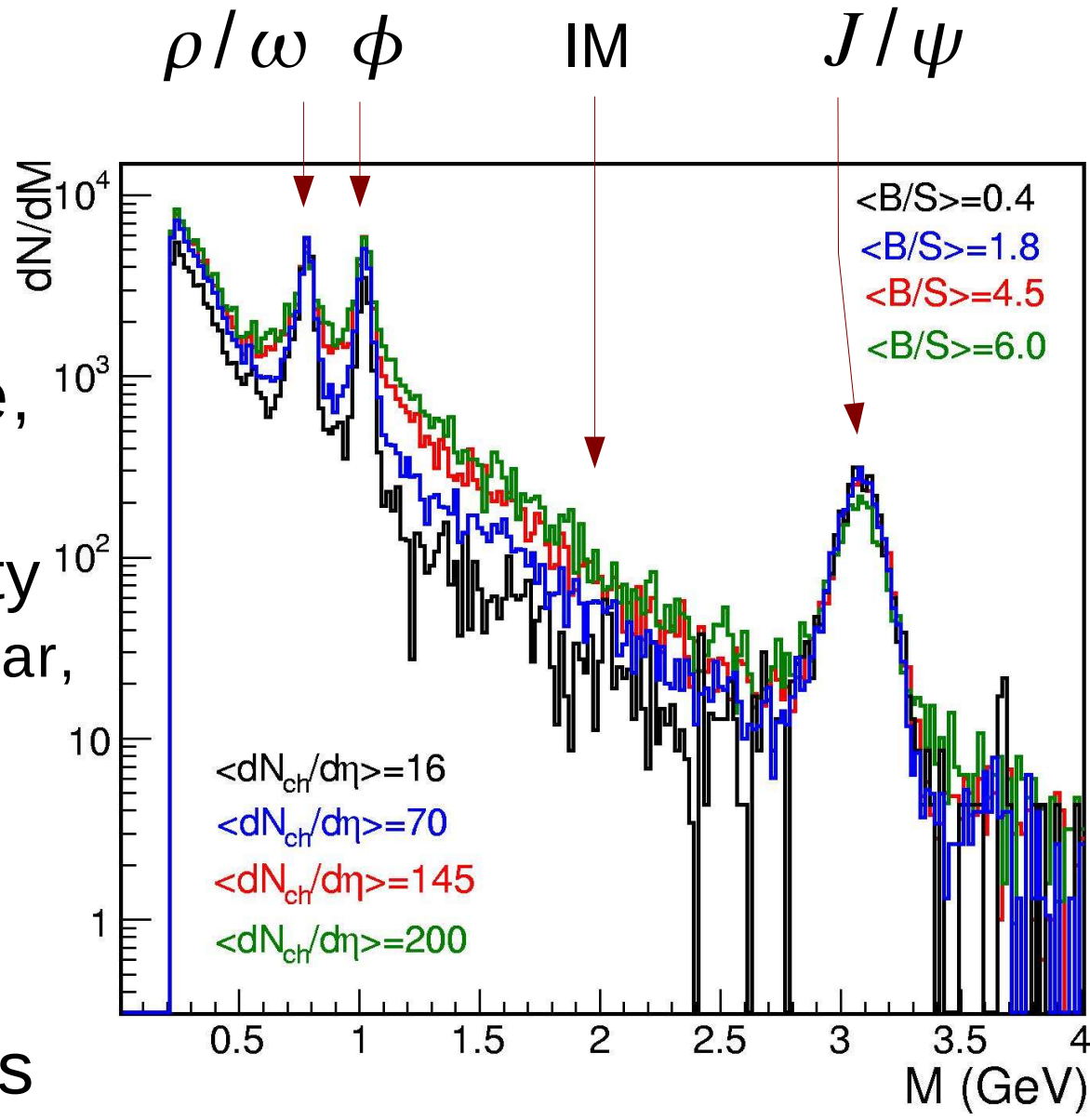
NA60 multiplicity (centrality) bins

- The InIn data is subdivided in 4 bins:
  - bin 0: Nch = 0-30
  - bin 1: Nch = 30-100
  - bin 2: Nch = 100-180
  - bin 3: Nch = 180-300
- Number of participants:
  - fit forward ZDC energy distribution in each bin with Glauber model
  - yields mean number of participants for each multiplicity bin



NA60 – by multiplicity

- Observations:
  - low mass cocktail to be clarified at low multiplicities,
  - ρ/ω clearly visible,
  - if ρ/ω is linear in charged multiplicity
    - ϕ steeper than linear,
    - IM *and* lower mass extension steeper than linear.
- Background from accidental matches is under study.

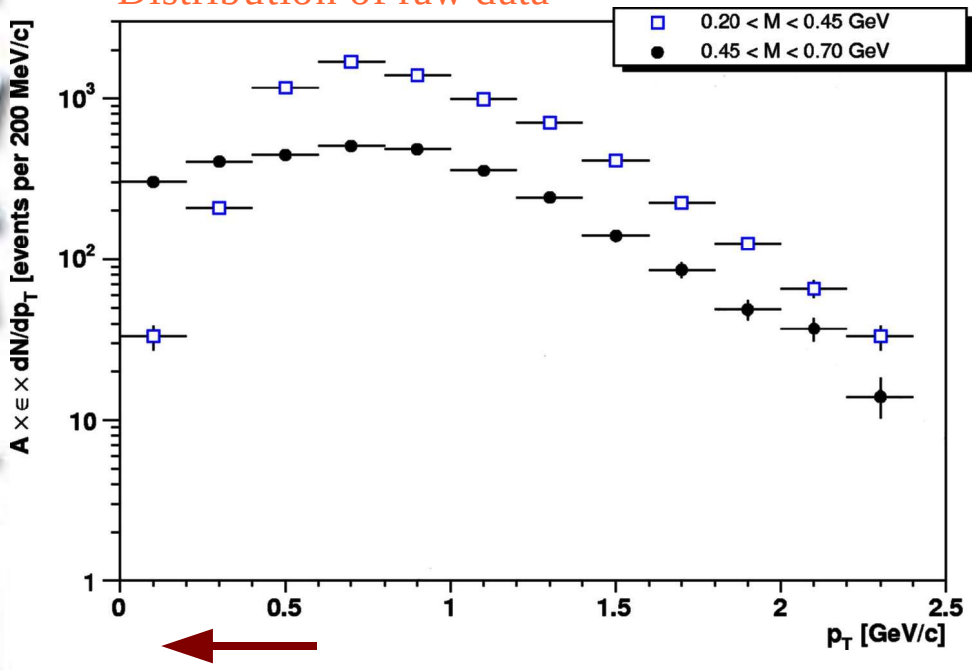


Normalised for equal area ρ/ω peaks

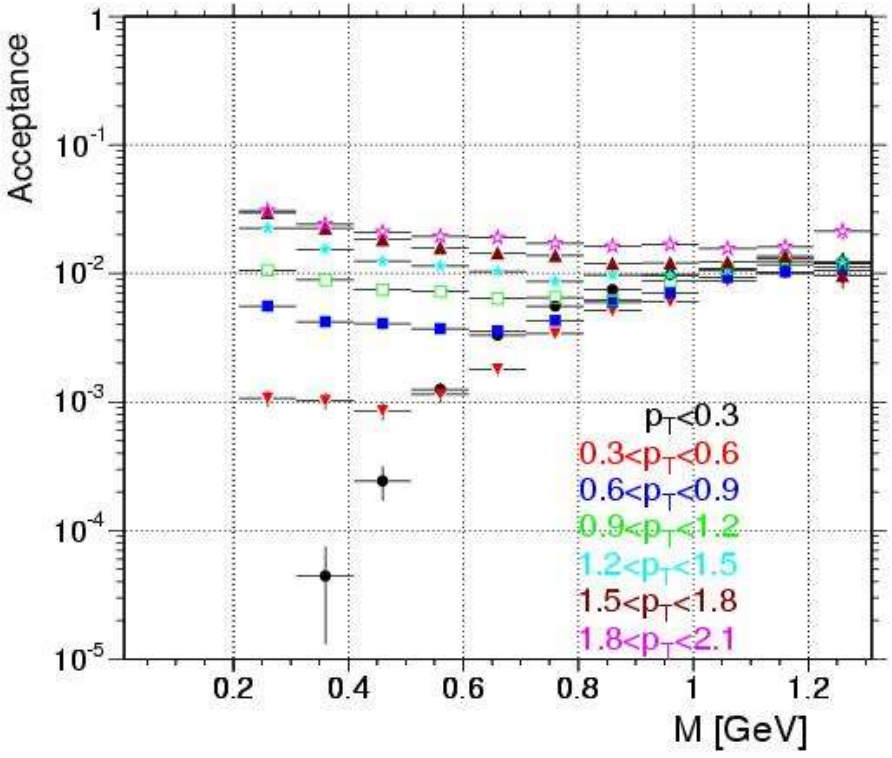
NA60 – acceptance

- NA60 has reduced and inhomogeneous acceptance where Ceres sees its excess.
- This is amply compensated by statistics.
- Improving acceptance at low pT is to be studied with a view to future data taking.

Distribution of raw data



Ceres excess

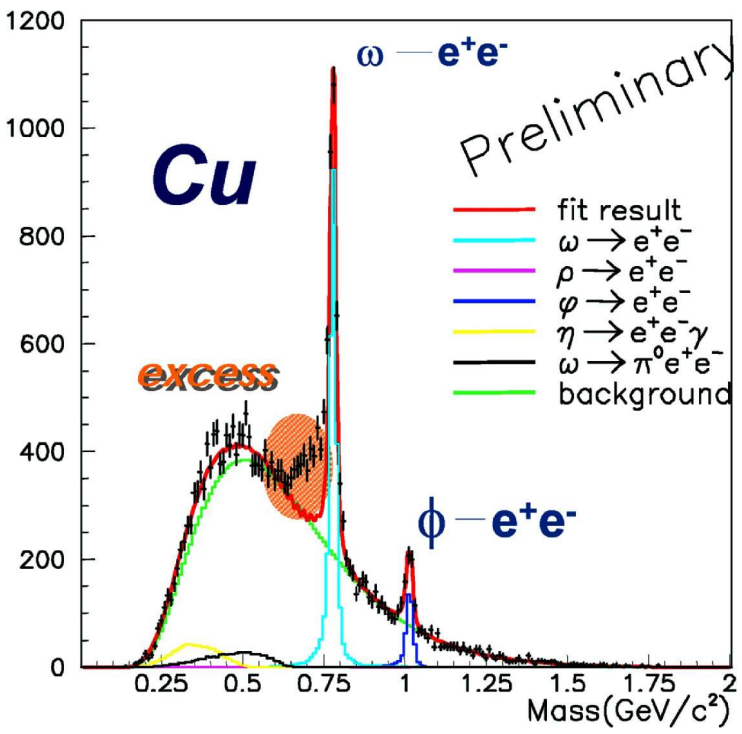


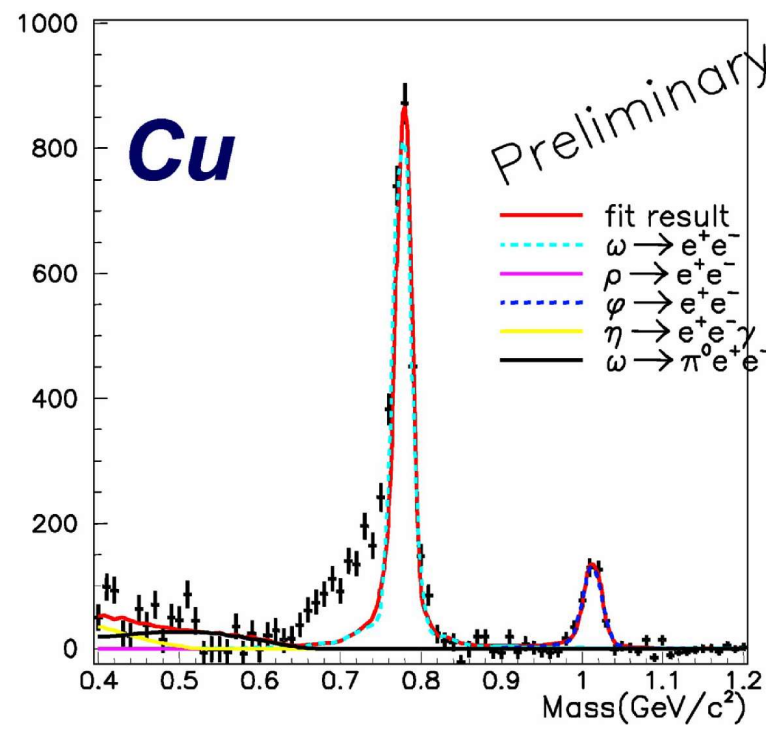
Behaviour of the ρ and ω mesons

- Compared with theoretical expectations on modifications of the ρ and ω line shapes (melting, mass shifts, medium effects ...):
  - Ceres:
    - ρ and ω peak present in pA but hardly visible in AA.
  - NA60:
    - sees a clear ρ/ω peak in In-In,
    - this peak mass does not change substantially with multiplicity,
  - KEK-E325:
    - ρ seems to be absent in 12 GeV pA collisions,
    - shape of the ω modified.

KEK-E325

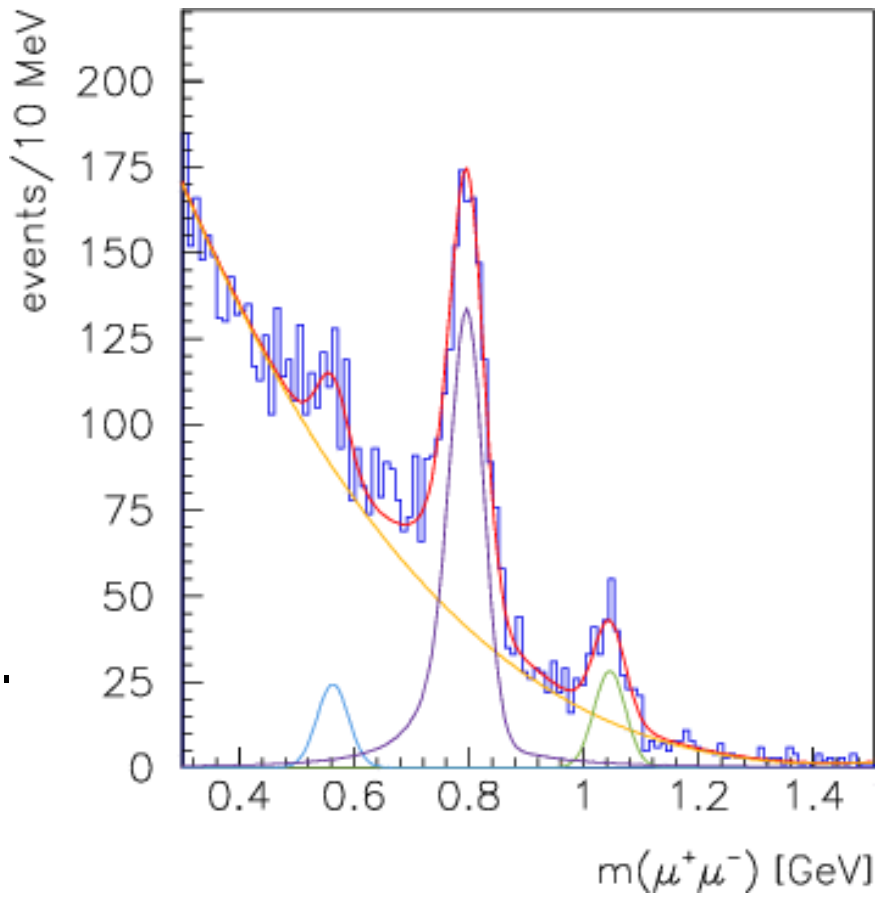
- Studies ee production in 12 GeV pA collisions.
- Superb 10 MeV mass resolution !
- Observes a non-Gaussian ω shape and finds no trace of the ρ.



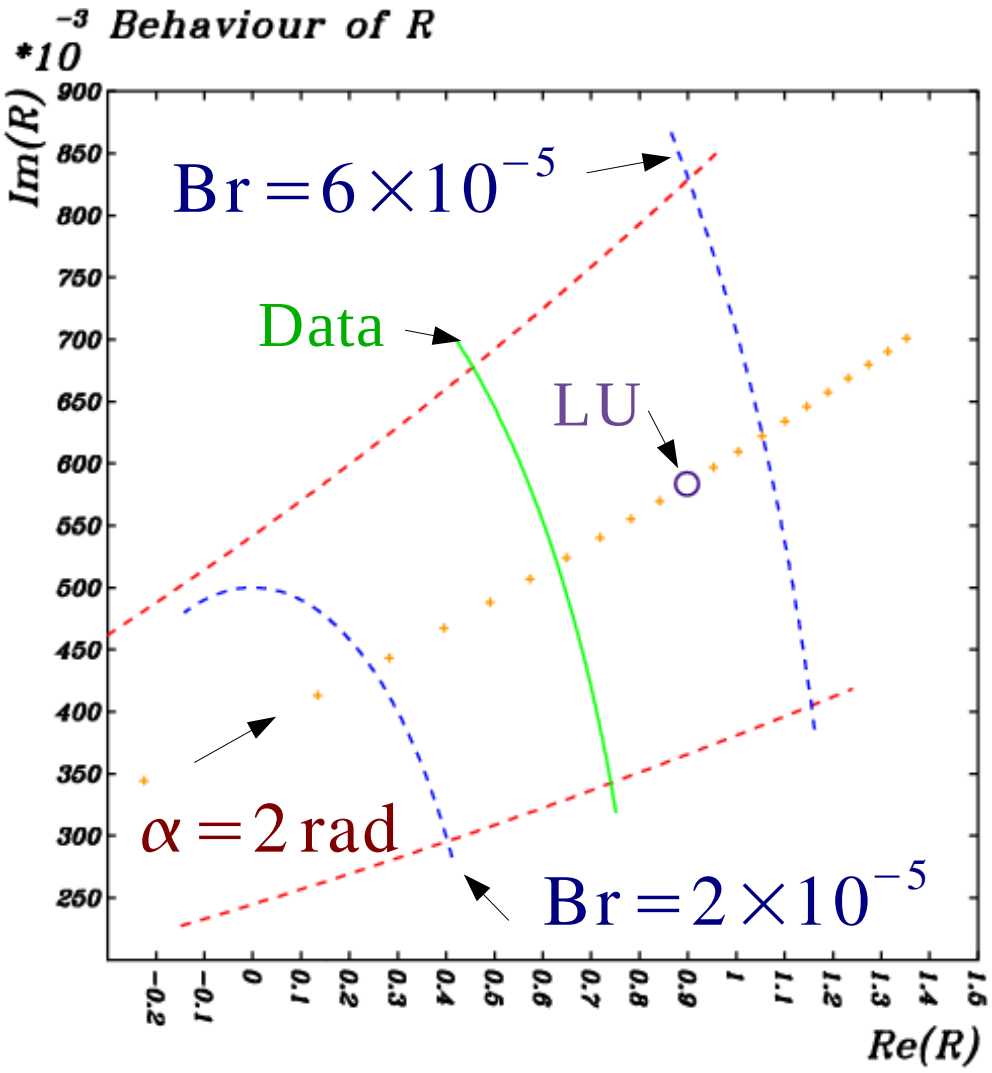


Helios/I - ρ/ω peak

- Comparison with E325:
  - Worse mass resolution: $\sigma = 23.8 \pm 2.7$ MeV
  - Mass scale uncertainty $\Delta_m < 0.3\,\%$
  - Studied with a view to the ω branching ratio.
- Observations:
  - peak looks skewed,
  - peak is shifted in mass.
- Not published !



Helios/I – interference fit



- Fitting with:
  $F(m) = \left| F_\rho(m) + R\, F_\omega(m) \right|$
- F_ω Breit-Wigner
- F_ρ Gounaris-Sakurai
- Favoured values:

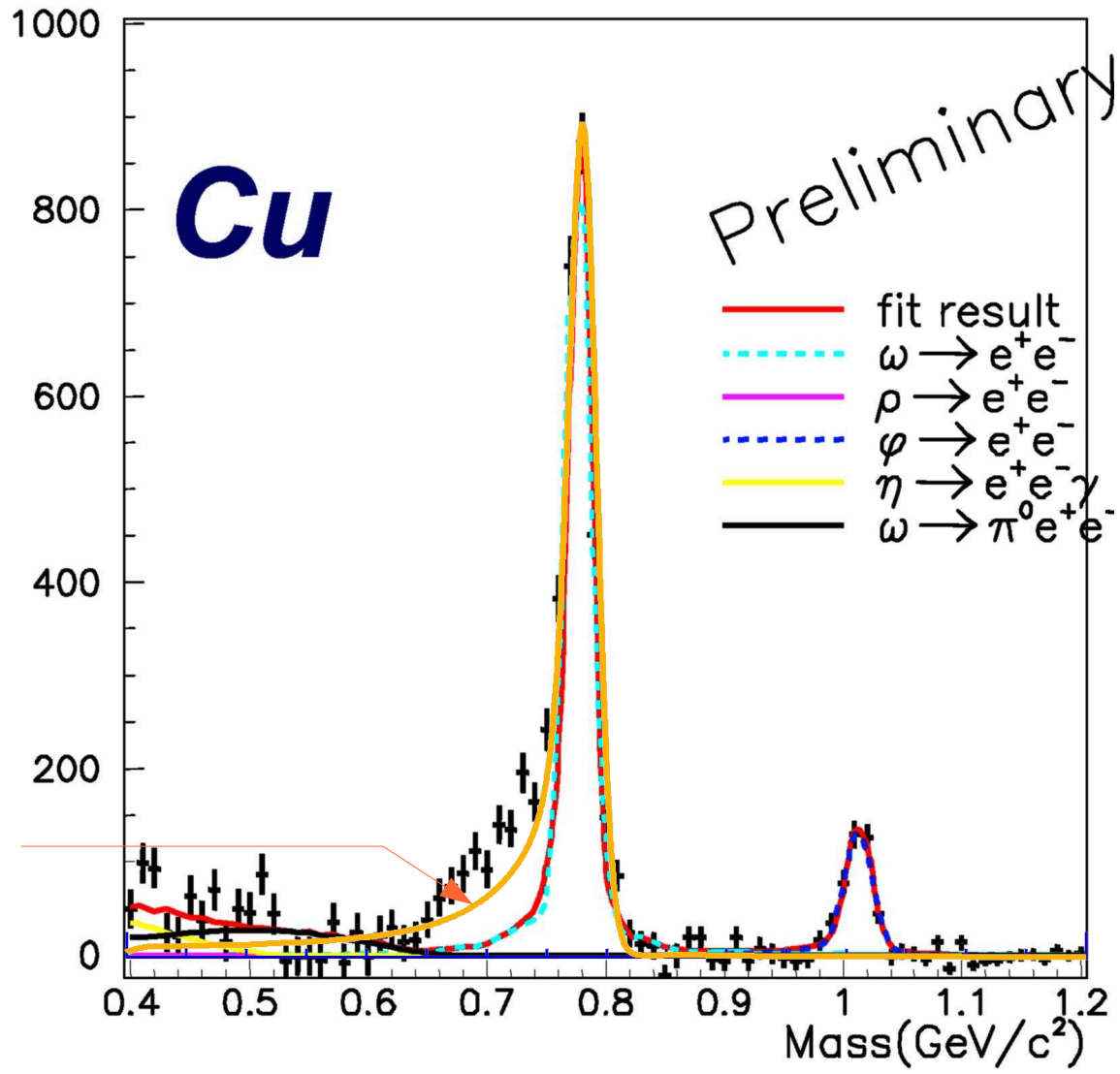
$$\alpha = 1.8 \pm 0.5 \text{ rad}$$

$$\mathrm{Br}_{\omega \to \mu^+ \mu^-} = (3\ {}^{+3}_{-1}) \times 10^{-5}$$

- Leads to a 15 % loss of visible $\rho + \omega$ signal

KEK-E325 and interference ?

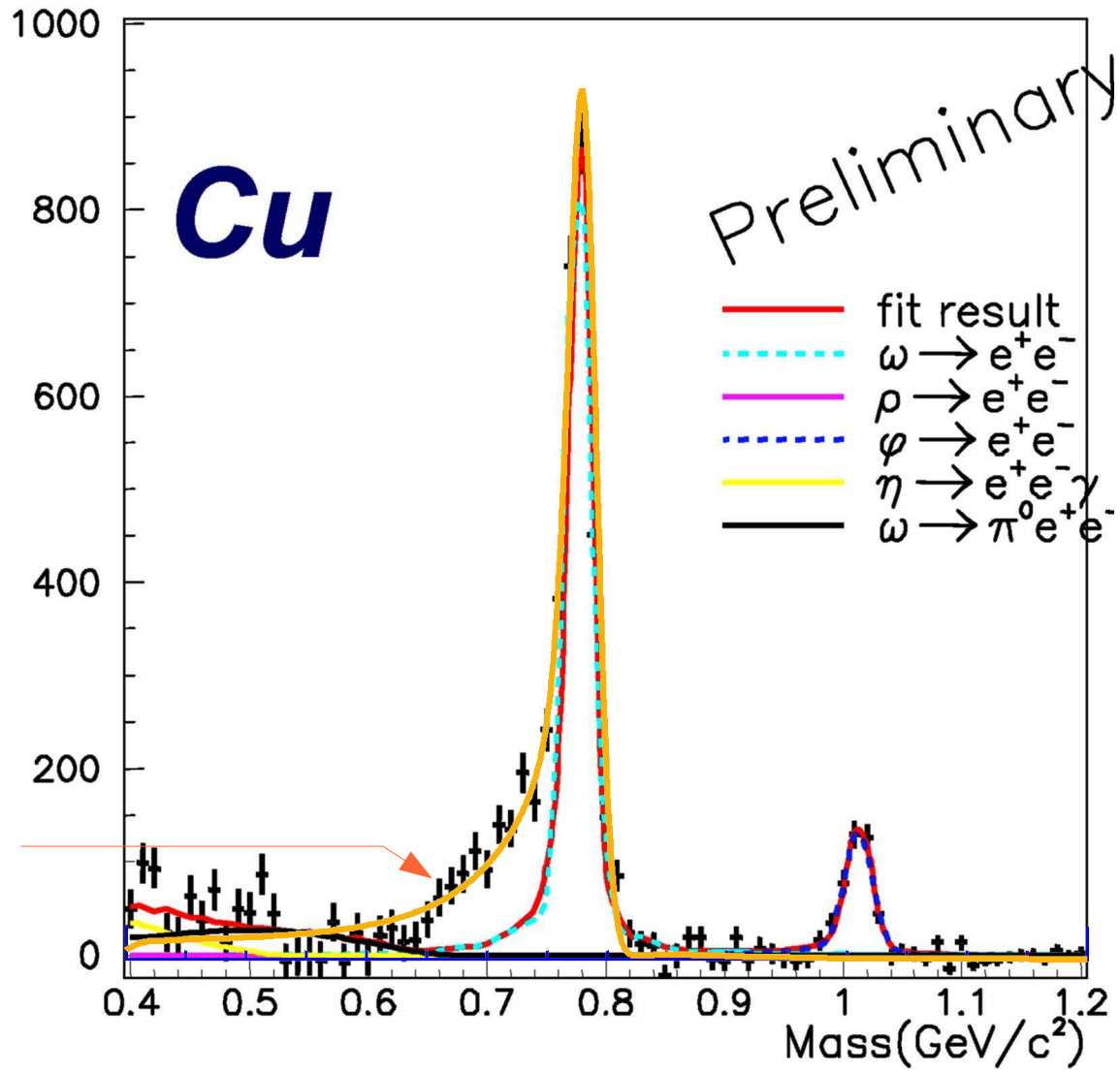
- Assuming the Helios/I fit value of R
- Interference causes a shift in peak mass: this fits !



Interfering Breit-Wigner ω and Gounaris Sakurai ρ with phase space correction, 10 MeV mass resolution

KEK-E325 and interference ?

- With a larger ρ branching ratio (as PDG)
- Conceivably interference ?



Interfering Breit-Wigner ω and Gounaris Sakurai ρ with phase space correction, 10 MeV mass resolution

NA60 – meson production studies

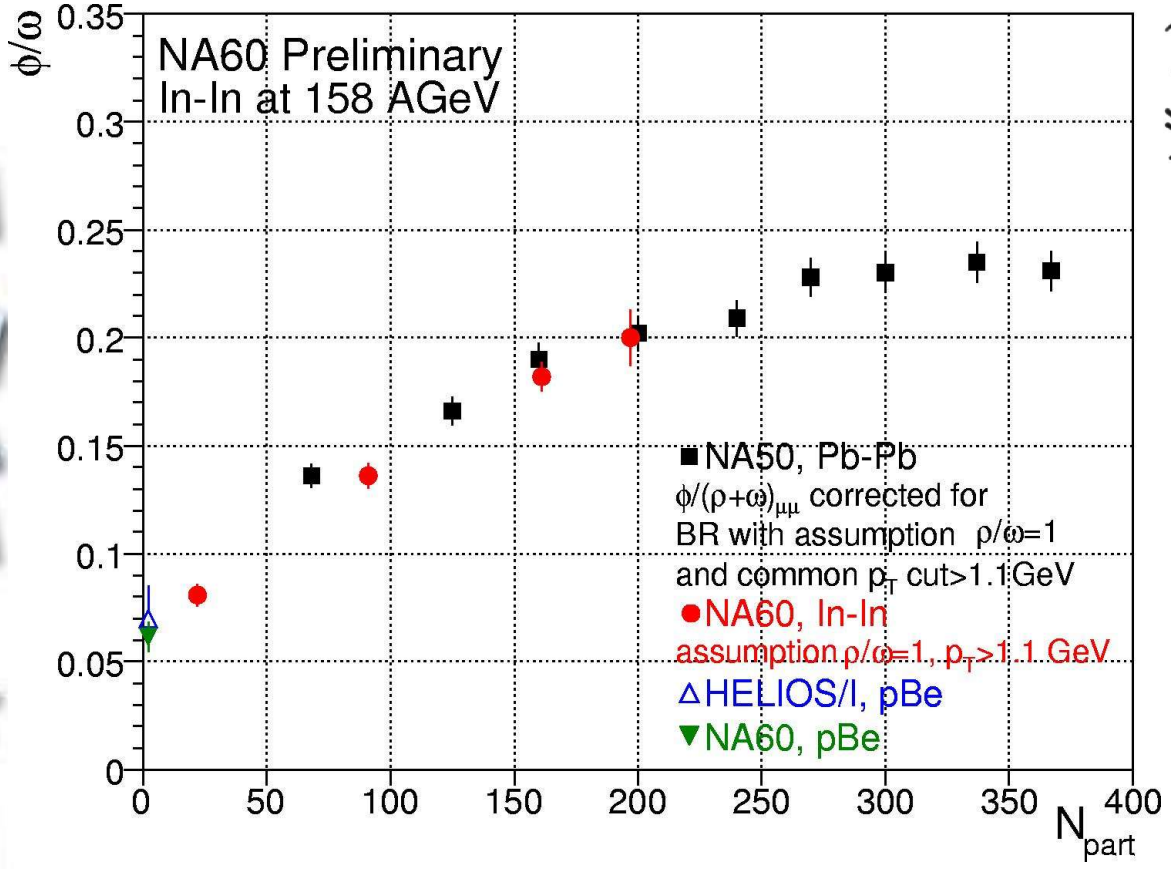
- To interpret correctly our spectra, we have to
  - calibrate contributions from η, η' and ω Dalitz decays and $\mu\mu$ decays of mesons, and
  - maximise meson production understanding.
- Studying dependence of meson production on
  - mass number A,
  - multiplicity / number of participants / ...,
  - transverse momentum, and
  - rapidity.
- The shape and location of the ρ/ω, will have to be understood relying on excellent background control and vast statistics.

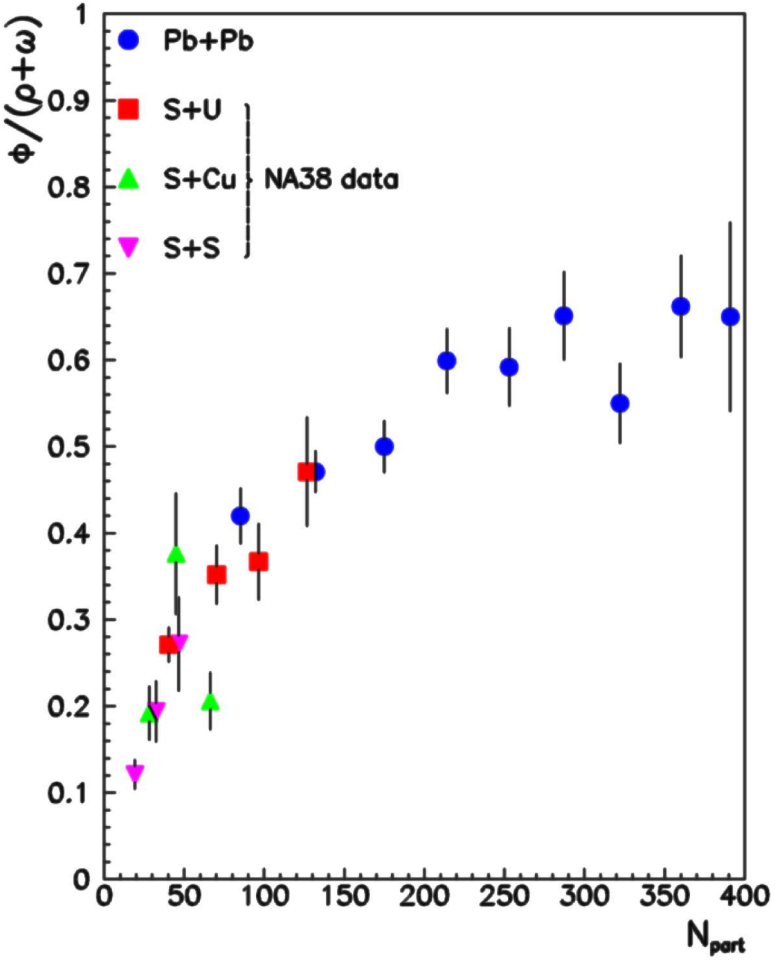
Production of the ϕ

- Production of the ϕ:
  - NA38/NA50: enhanced with energy density in AA collisions;
  - Helios/I: enhanced with multiplicity in pBe.
- NA60 finds
  - ϕ/ω ratio agrees with NA38 and NA50 and rises with the number of participants;
  - no evidence as yet of large mass shifts.

NA50 & NA60 ϕ/ω vs participants

- Confirms earlier observation from NA38 and NA50 that the ϕ rises faster than the ω.

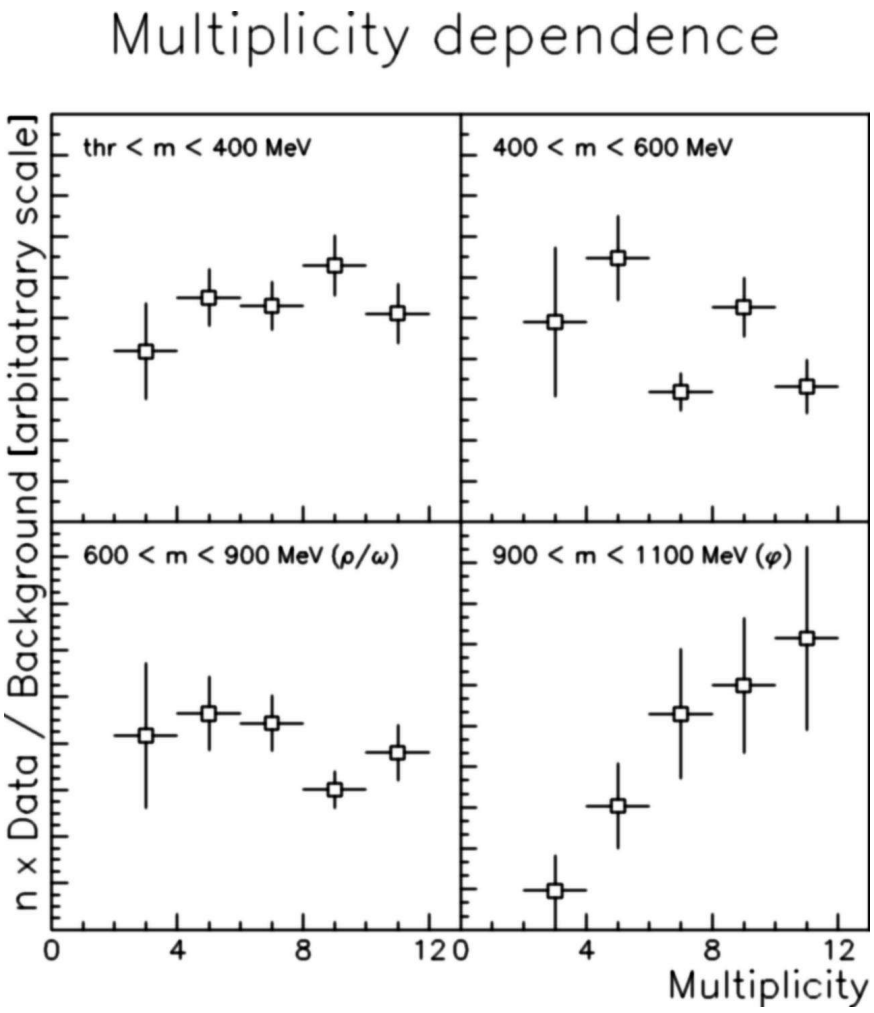


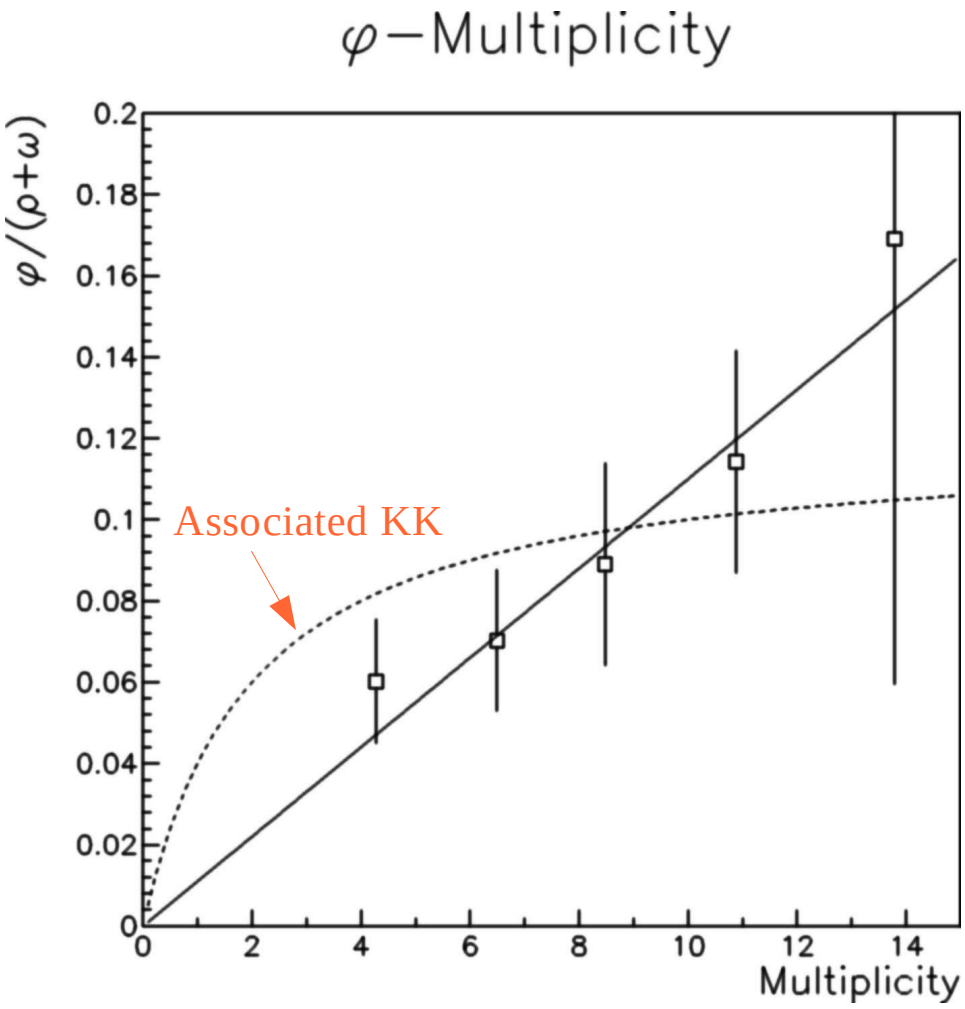


Note the difference in vertical scale !

Helios/I - di-muon multiplicity

- Linear in multiplicity, except for the φ.

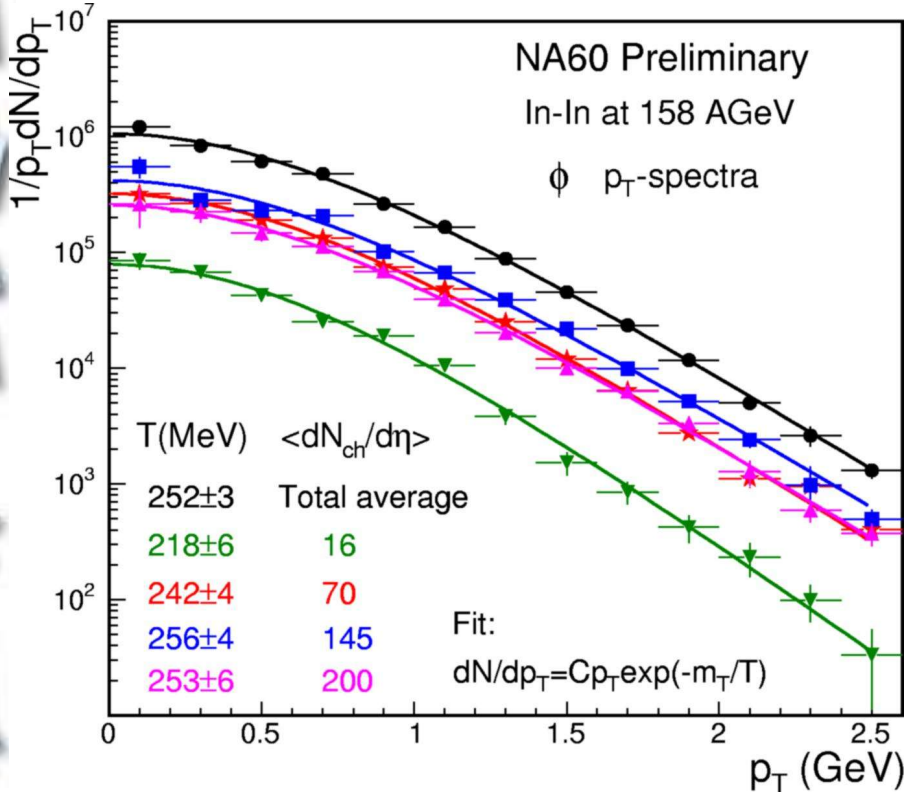


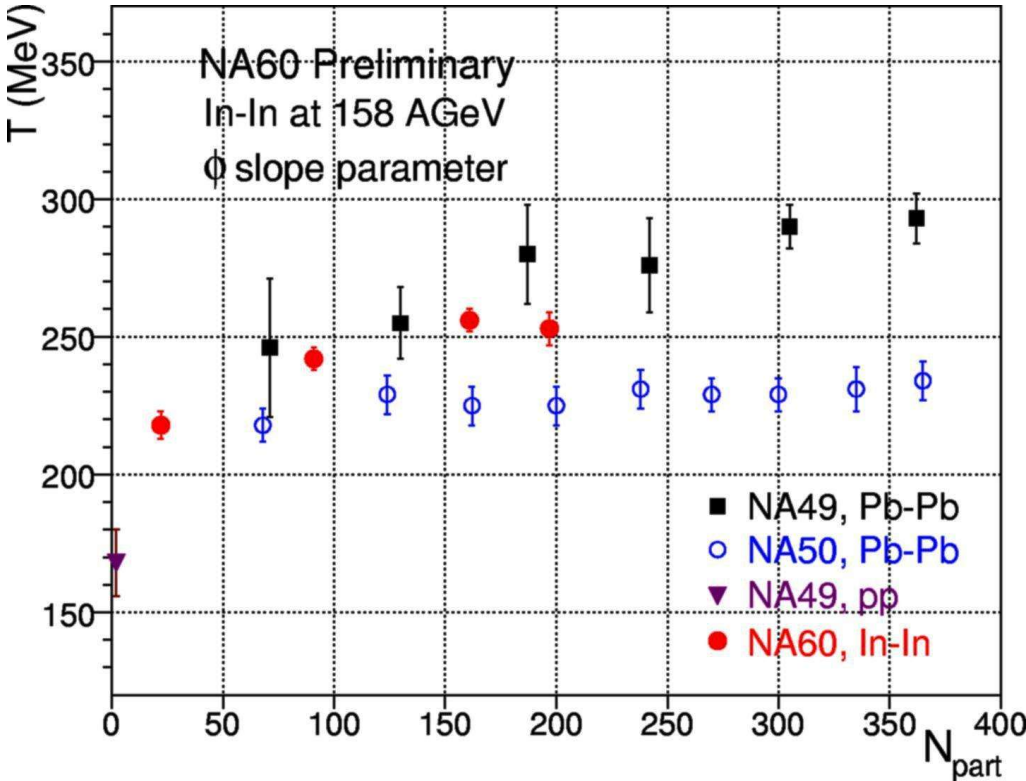


Normalised to the combinatorial background

NA60 - pT spectrum of the ϕ

- The pT inverse slope, the temperature T, increases with multiplicity !
- Compatible with NA49 p-p and Pb-Pb (hadronic decay), but not with NA50 Pb-Pb.





Conclusion on low mass studies

- NA60 has
  - reduced acceptance at the Ceres excess,
  - barely enough mass resolution to study the line shape of the ρ/ω (KEK-E235).
- But, NA60 has
  - vast statistics,
  - capability to measure multiplicity (centrality),
  - much improved mass resolution compared with Helios/3, NA50 and Ceres and
  - small pion decay background.
- This gives the experiment the ability to
  - carefully measure an excess, if any, at masses above threshold and pT > 400 MeV
  - study η, ω, ϕ and J/ψ production in detail.

NA60 observations

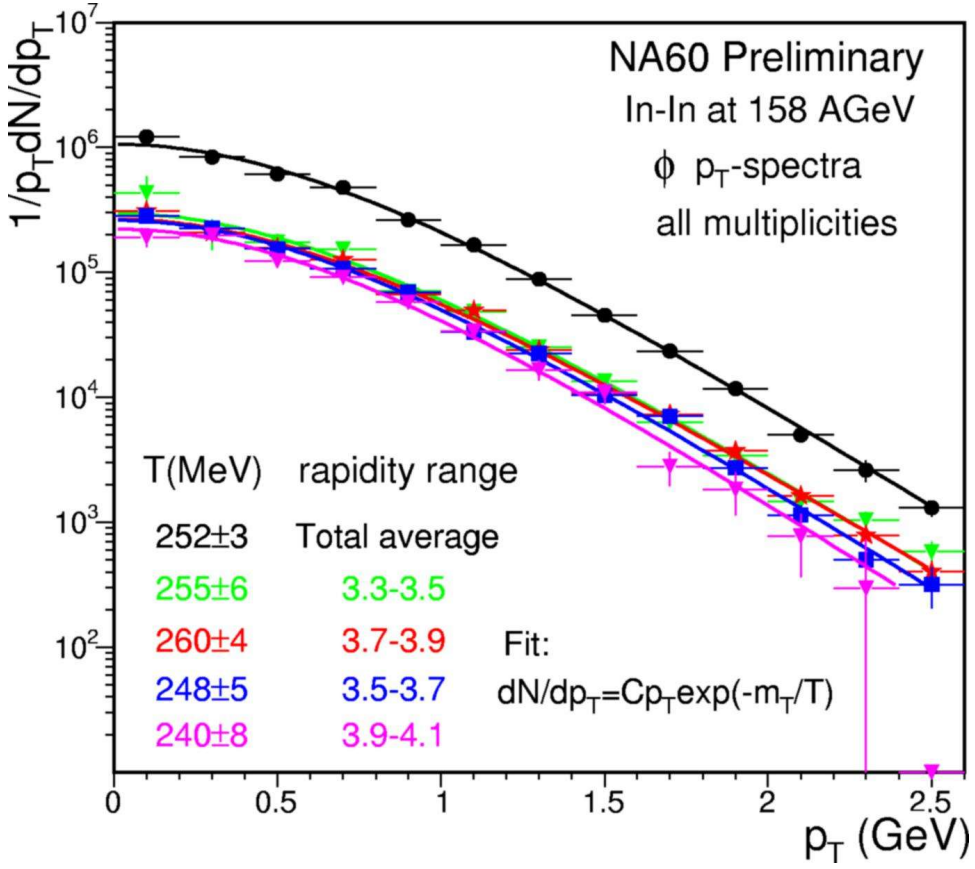
- pA:
  - di-muon production in line with known sources
  - α measured for η, ω, ϕ over Be-In-Pb
- In-In:
  - clearly visible ρ/ω and ϕ peaks
  - these peaks are not massively shifted
  - ϕ/ω rises faster than linearly with the number of participants
  - pT of ϕ measured vs number of participants
  - statement on an excess awaits further study of the accidental match background component

Backup

- Backup slides

NA60 phi T vs rapidity

- No variation of the temperature with the rapidity interval is observed



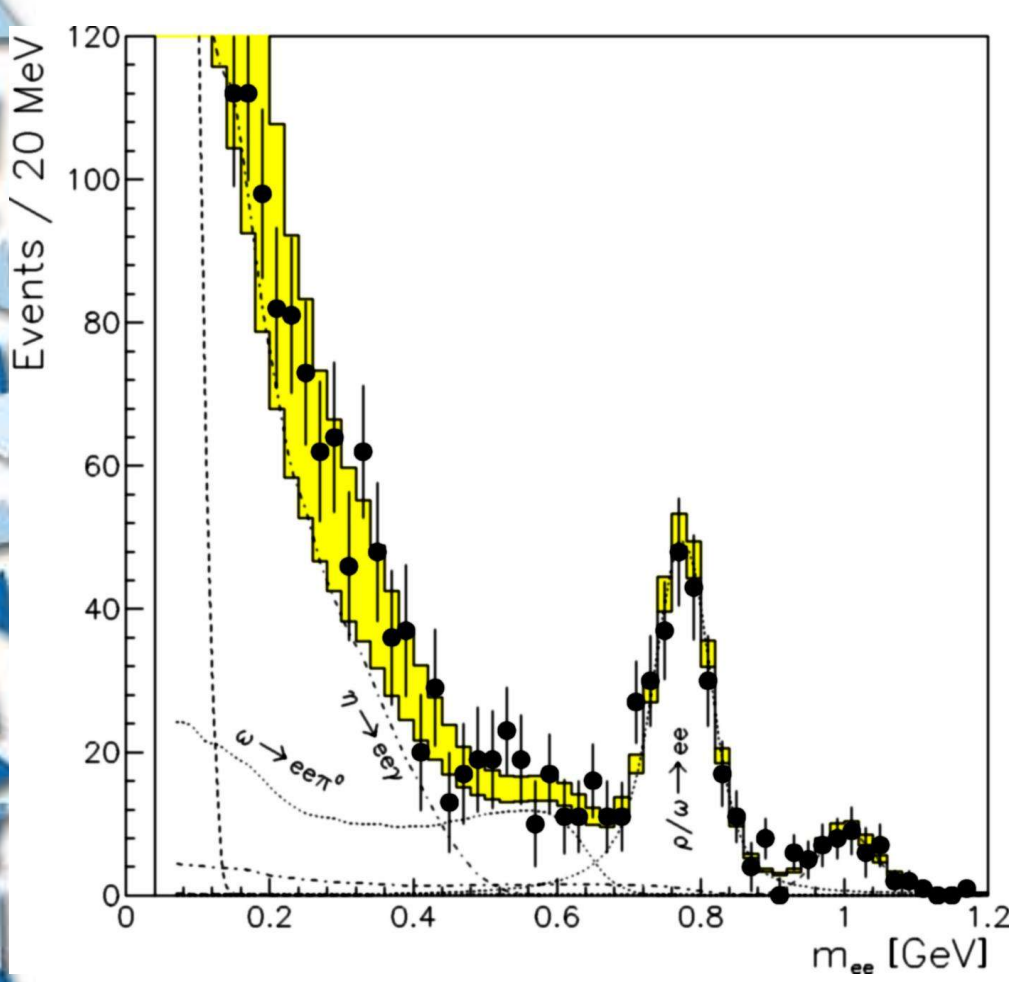
CERES statistics

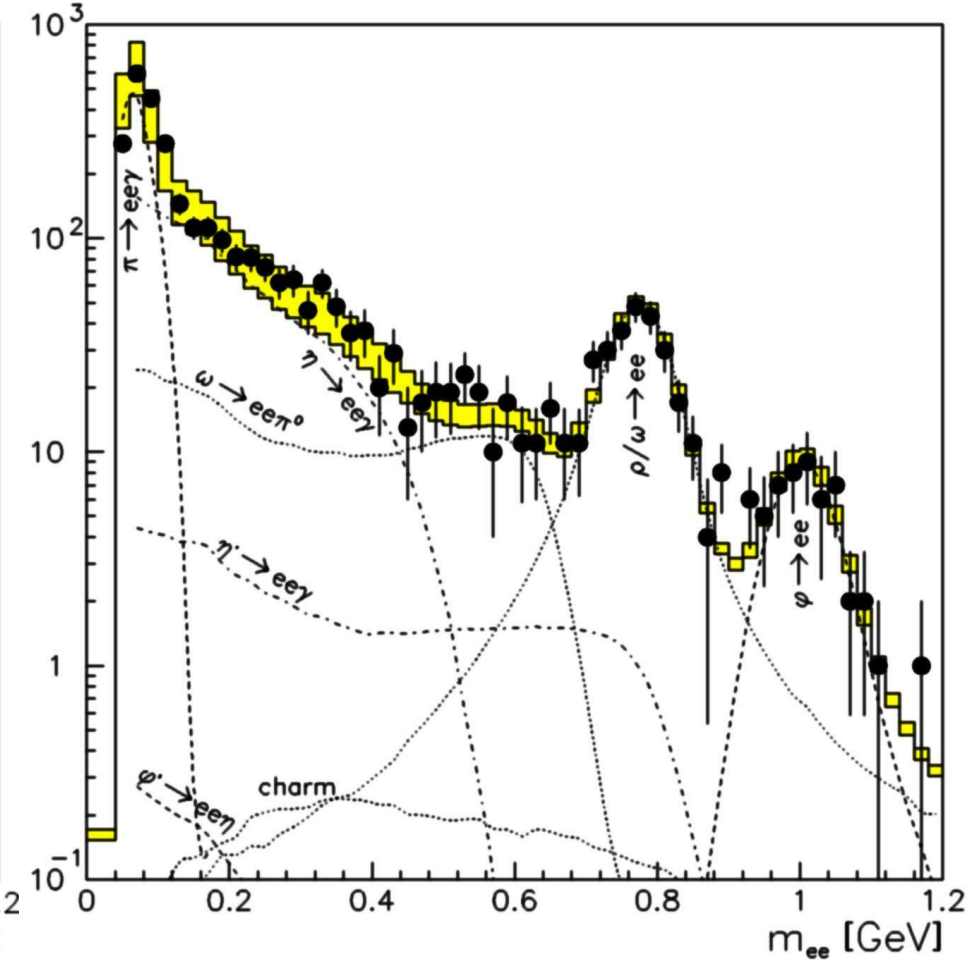
- ω and ϕ hardly resolved, partially result of intrinsic resolution (6 % at ρ/ω, 7 % at ϕ), and partially due to statistics
- J/ψ not observed, although in acceptance
- No trigger in ion runs, hence limited statistics

Year	Beam	Target	Signal	S/N
1995+1996	158 GeV Pb	Au	2600 (m>200 MeV)	1:11
	p	Be	5068 (m>200 MeV)	1:2
	p	Au	1068 (m>200 MeV)	1:3.6
2000	158 GeV Pb	Au	2200 (m>200 MeV)	1:14

Helios/I di-electron mass

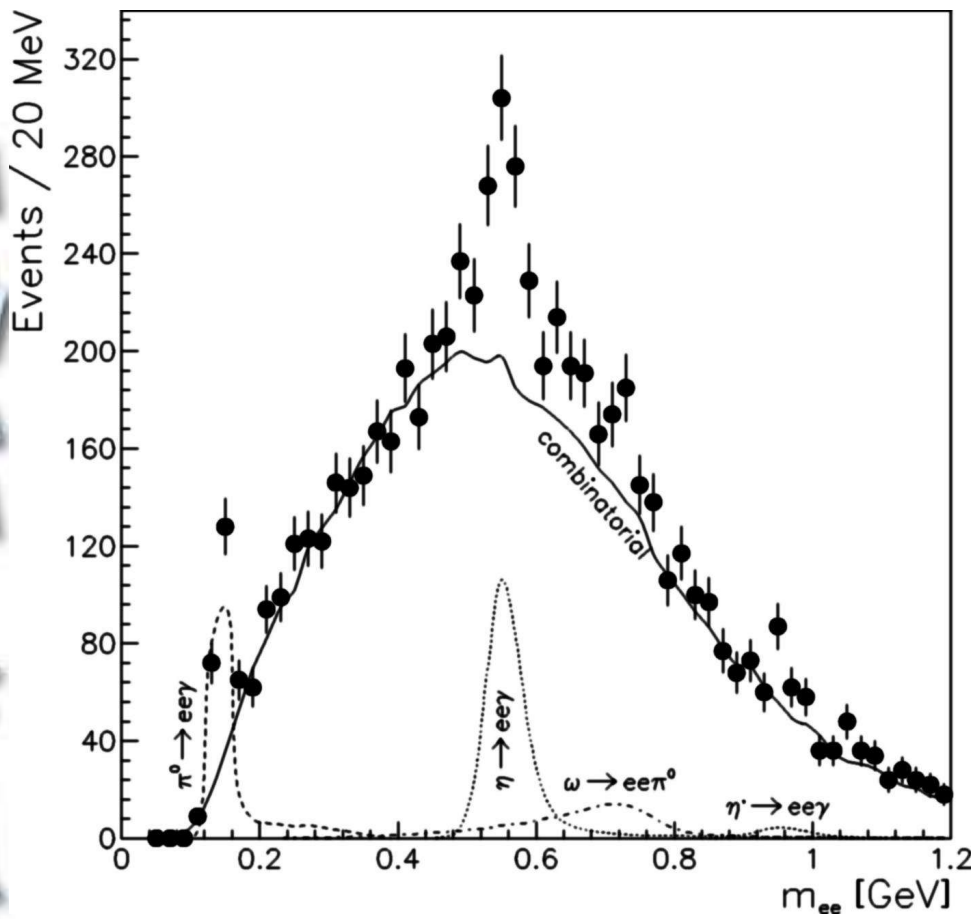
- pBe at 450 GeV: no surprises either

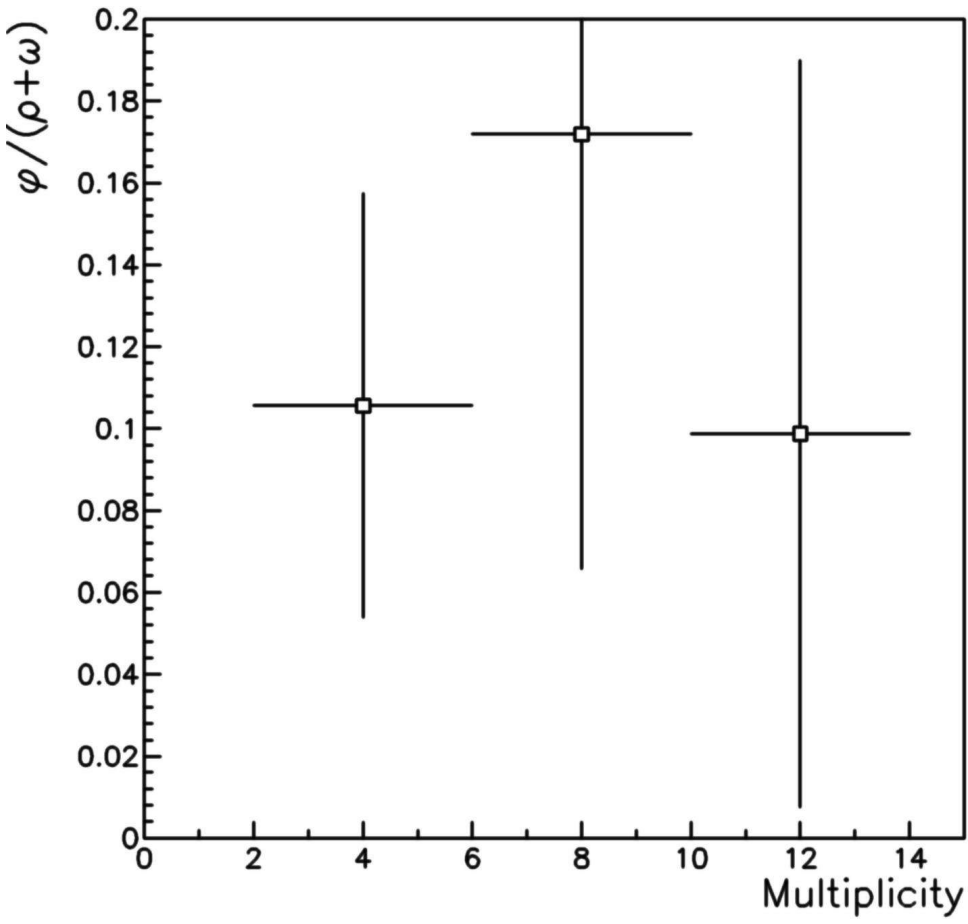


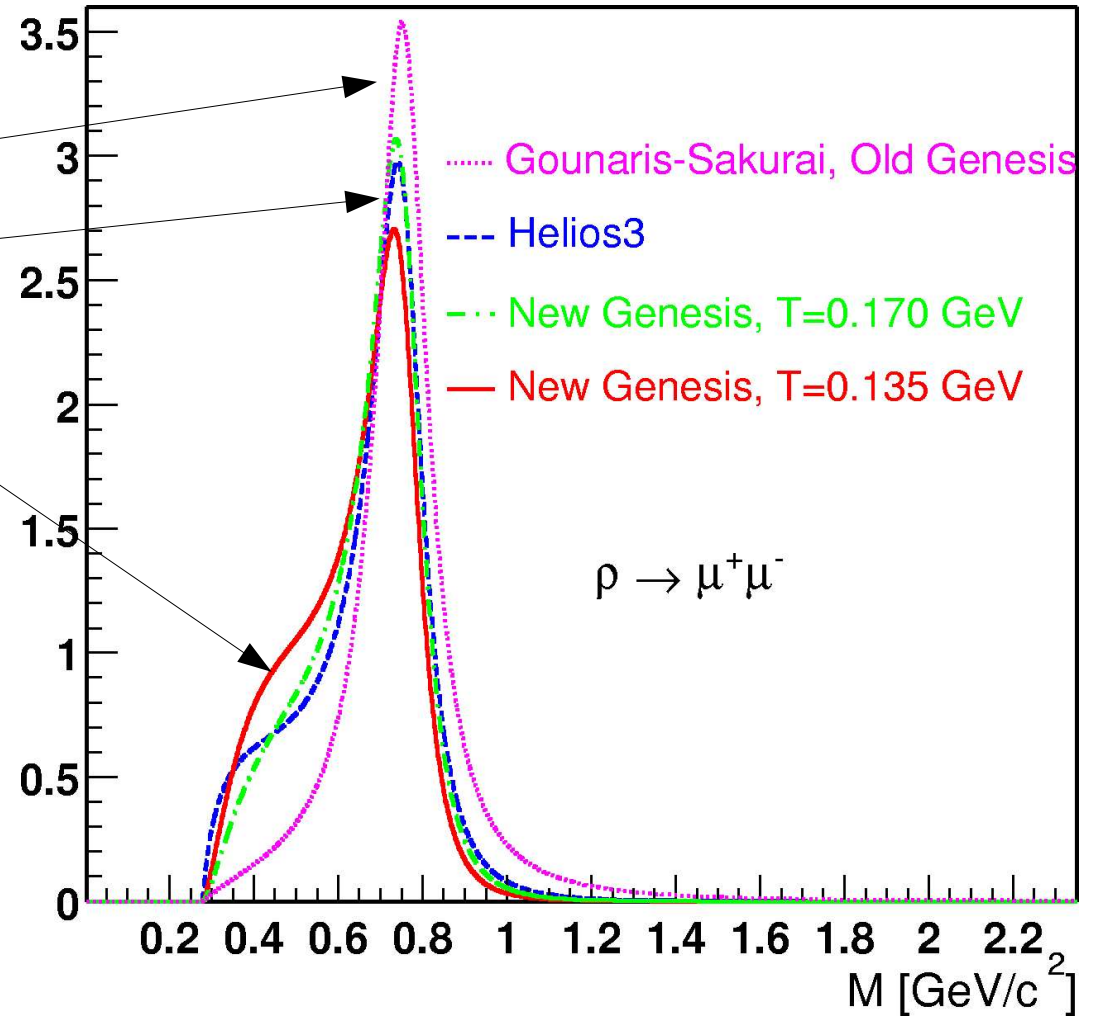


Helios/I eeg mass and multiplicity

- Eta clearly identified
- No evidence for quadratic phi





Line shape of the ρ

- Shapes in use:
  - Helios/1
  - Helios/3
  - NA60
- Differ from the Breit Wigner by phase space