Probing Dense and Hot Matter with Dileptons and Photons

Hard Probes 2004

Lisbon, November 4-10 , 2004

Itzhak Tserruya

Outline

- Low-mass pairs and chiral symmetry restoration (DLS, CERES, HADES, KEK P235)
- The Φ meson (CERES,NA49, NA50, NA60, PHENIX)
- Thermal photons
- Summary

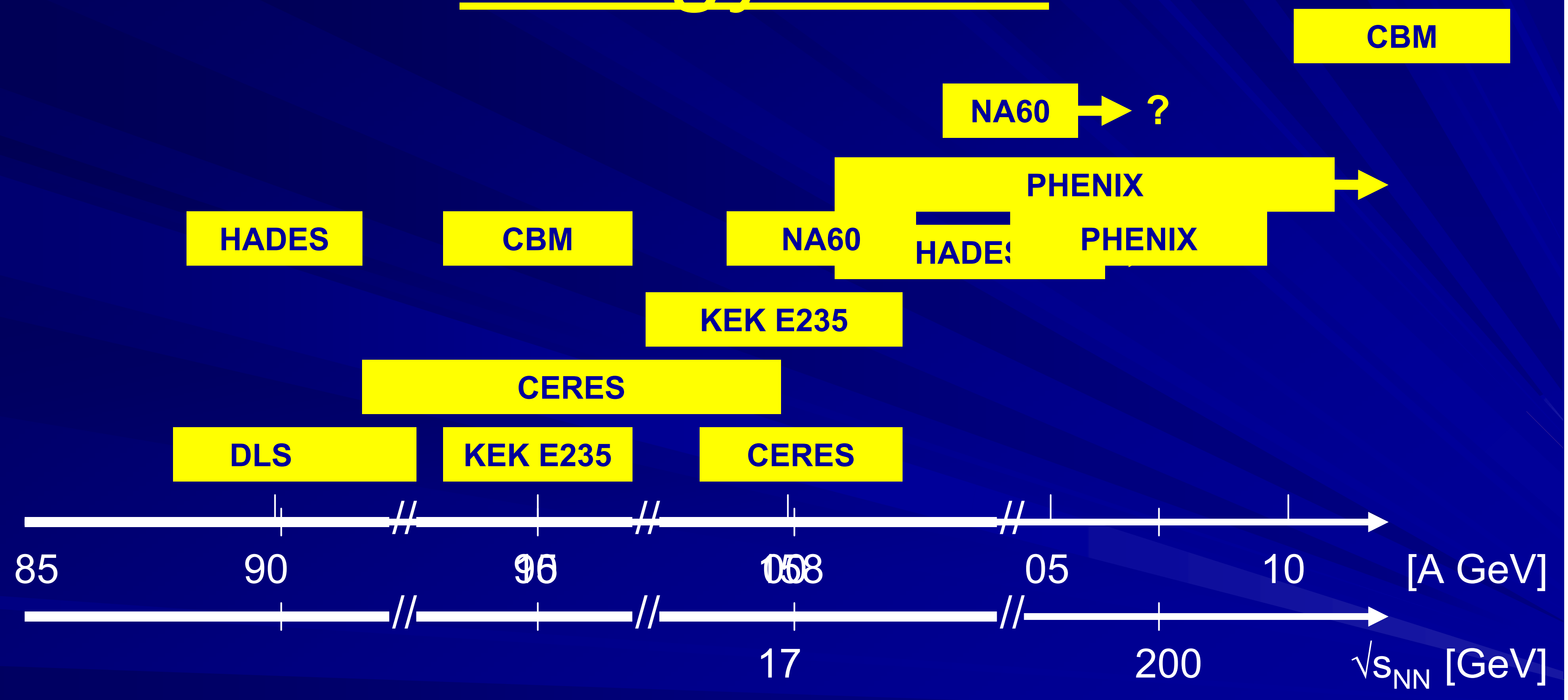
- Low-mass dileptons and chiral symmetry restoration

Low-mass dilepton experiments

- CBM
- CERES
- DLS
- HADES
- HELIOS
- KEK P235
- NA38/50
- NA60
- PHENIX

Low-Mass Dileptons at a Glance:

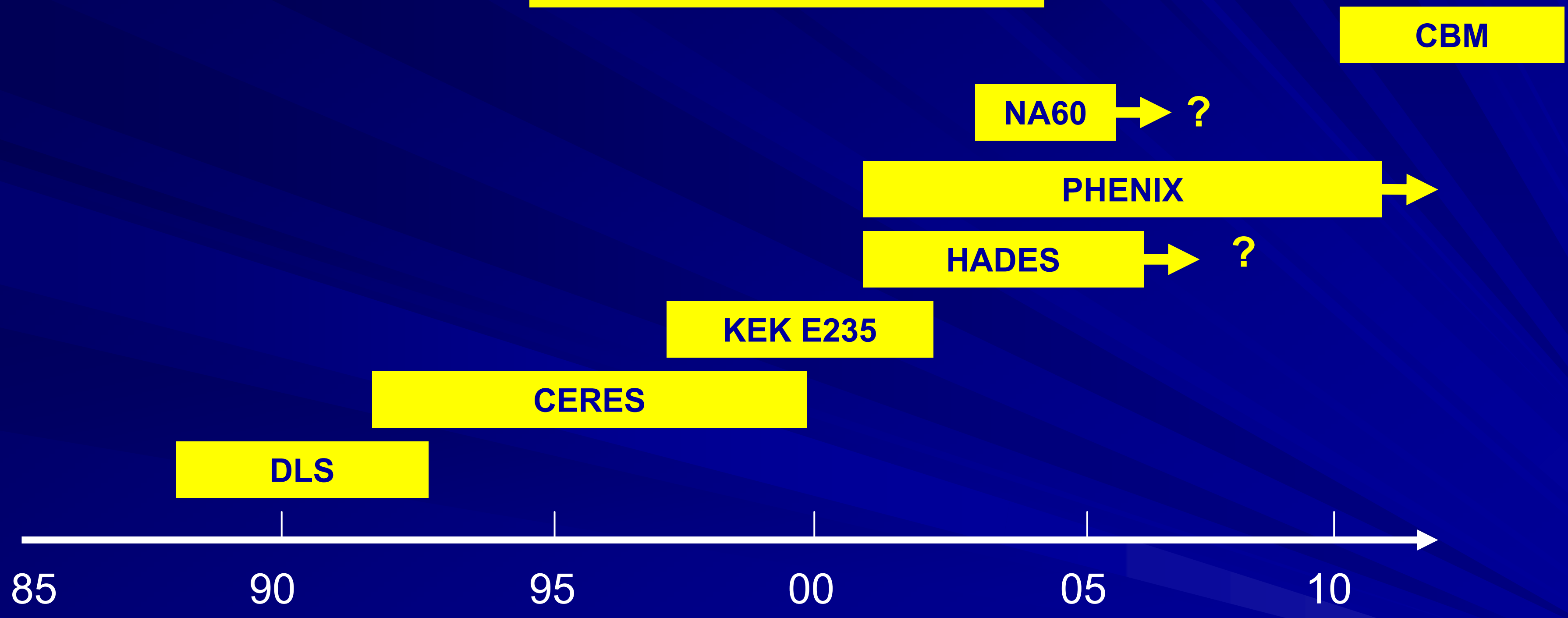
Time Scale
Energy Scale



= Period of data taking

Low-Mass Dileptons at a Glance:

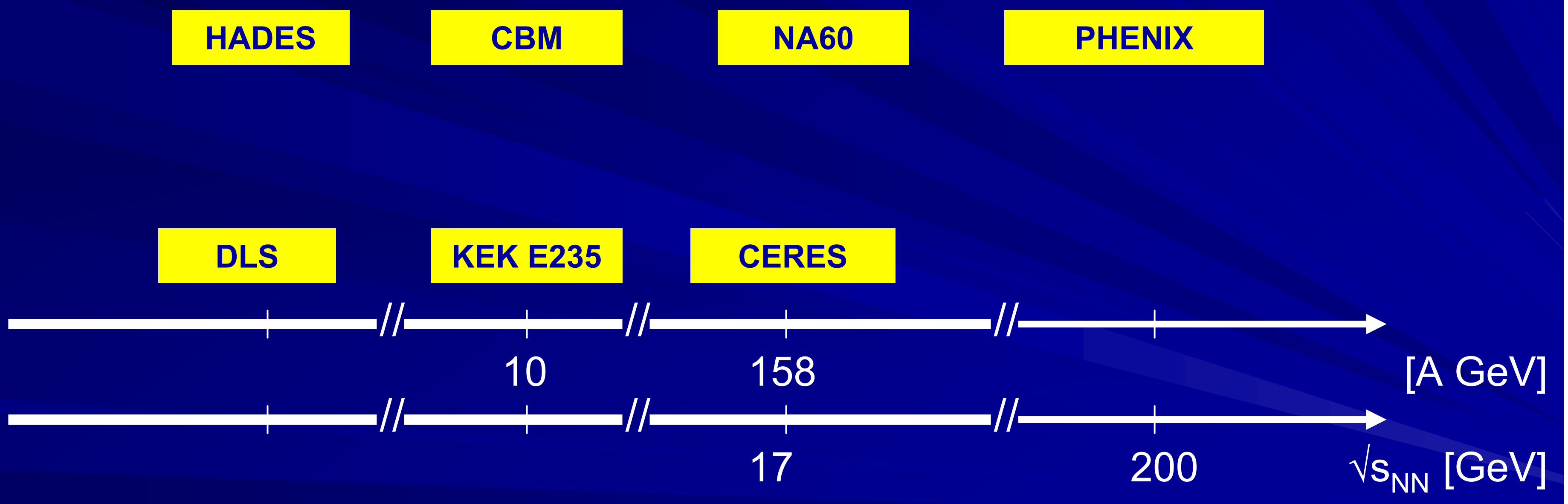
Time Scale



= Period of data taking

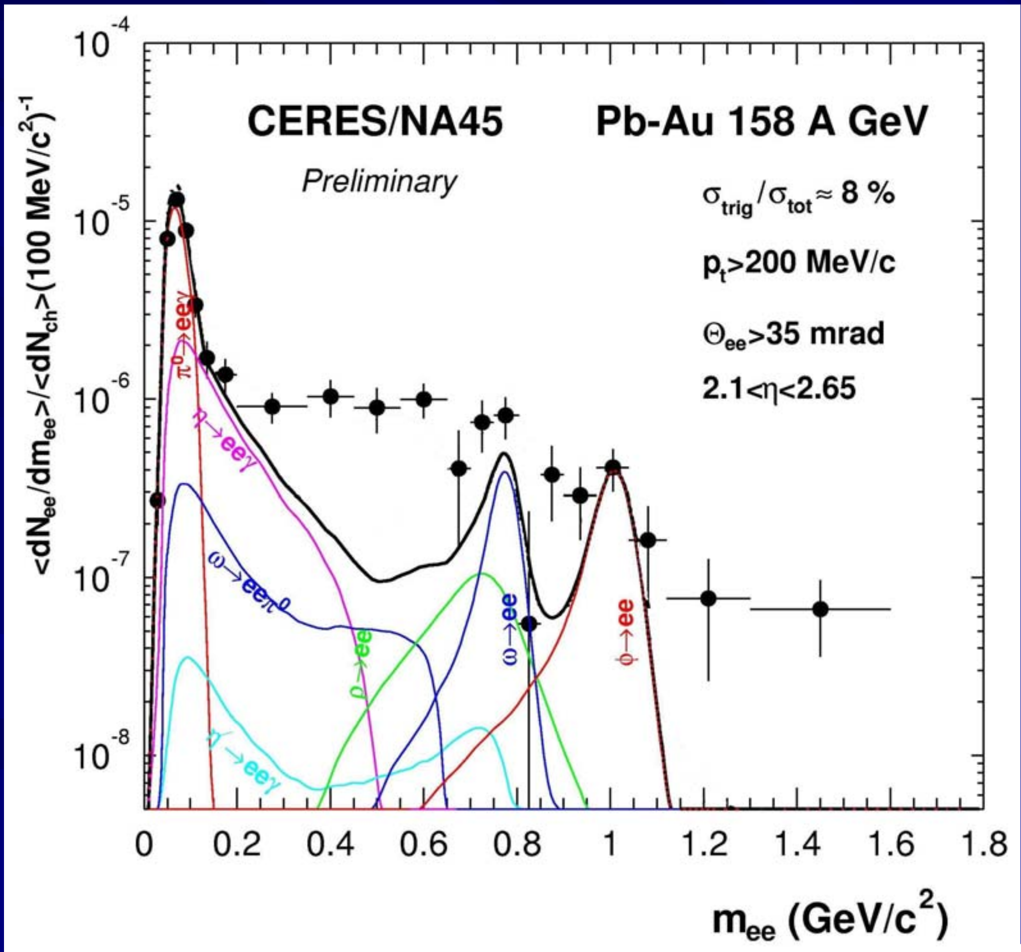
Low-Mass Dileptons at a Glance:

Energy Scale



Low-mass Dileptons: Main Result

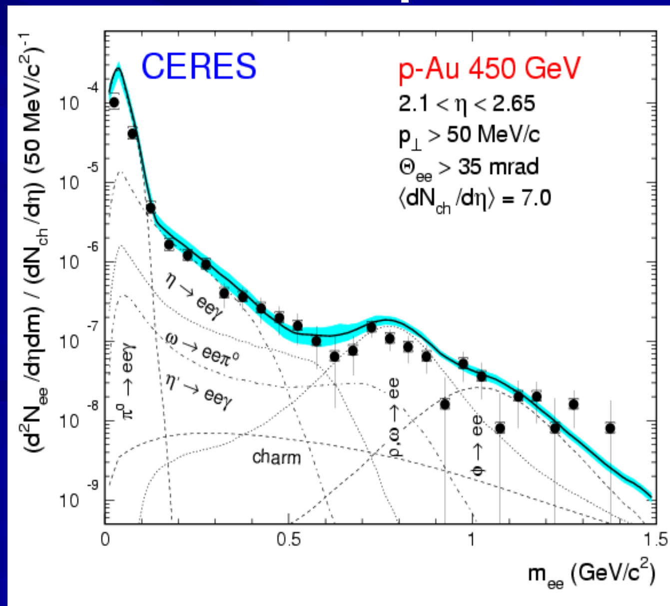
Strong enhancement of low-mass e^+e^- pairs in A-A collisions (wrt to expected yield from known sources)



Most updated CERES result (from 2000 Pb run):

Enhancement factor (0.2 <m < 1.1 GeV/c^2) 3.1 ± 0.3 (stat)

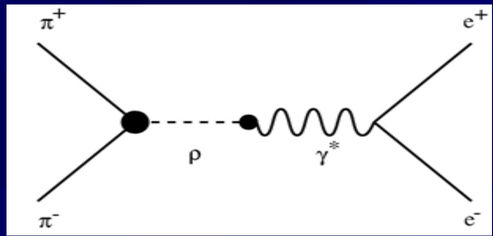
No enhancement in pp nor in pA



Dropping Mass or Broadening (I) ?

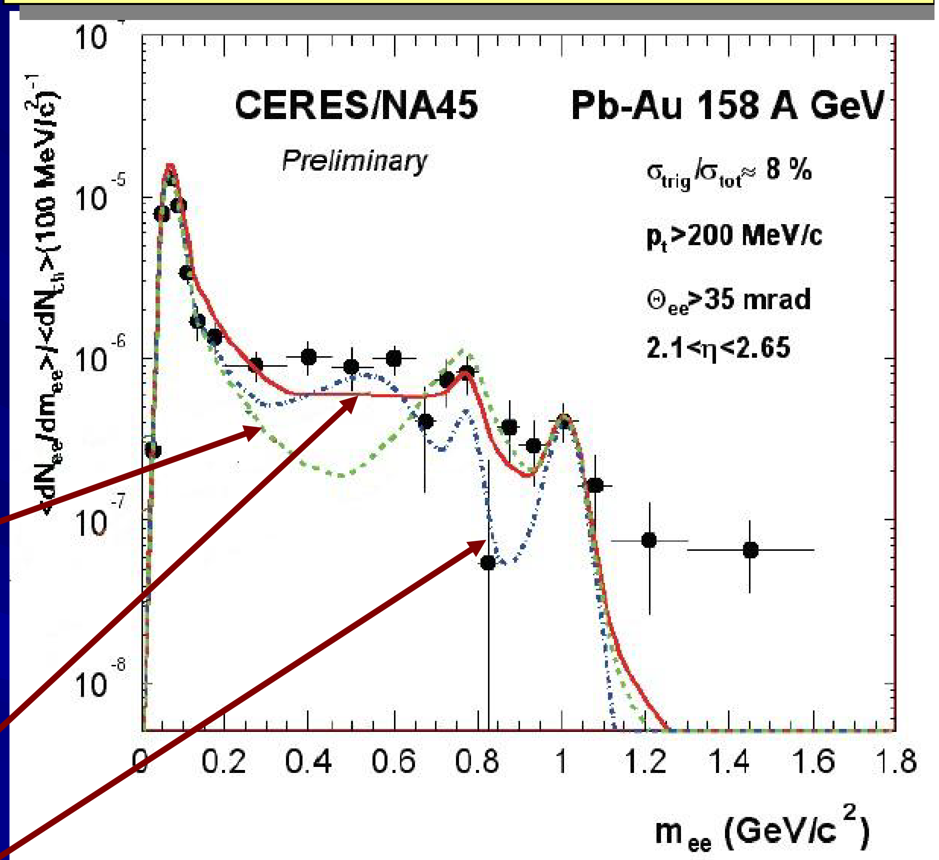
Interpretations invoke:

* $\pi^+\pi^- \rightarrow \rho \rightarrow \gamma^* \rightarrow e^+e^-$



thermal radiation from HG

CERES Pb-Au 158 A GeV 2000 data



* **vacuum ρ not enough to reproduce data**

* **in-medium modifications of ρ:**

❖ **broadening ρ spectral shape**

(Rapp and Wambach)

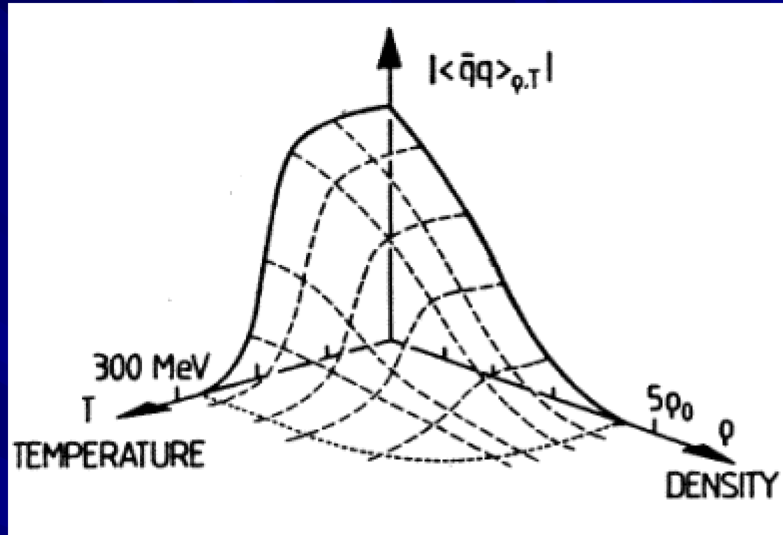
❖ **dropping ρ meson mass**

(Brown et al)

Dropping Mass or Broadening (II)?

Conceptually different:

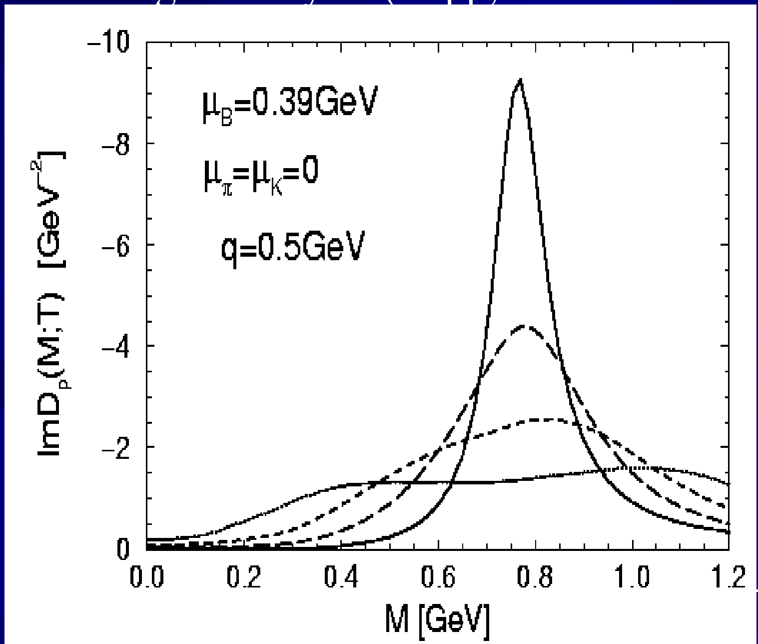
ρ-meson broadening: d.o.f hadrons
Dropping ρ-meson mass: d.o.f. quarks



Common feature:

At SPS both models rely on the high baryon density at mid-rapidity.

ρ scattering off baryons(Rapp, Wambach et al)



Brown-Rho scaling (PRL 66, (1991) 2720)

$$\frac{m_\rho^*}{m_\rho} \approx \frac{m_\omega^*}{m_\omega} \approx \left(\frac{<\bar{q}q>_{\rho^*}}{<\bar{q}q>_0}\right)^{1/3} = 1 - 0.26\,\frac{\rho^*}{\rho_0}$$

$$= 1 - 0.16\,\frac{\rho^*}{\rho_0}$$

Hatsuda & Lee (PR C42, (1992) R34)

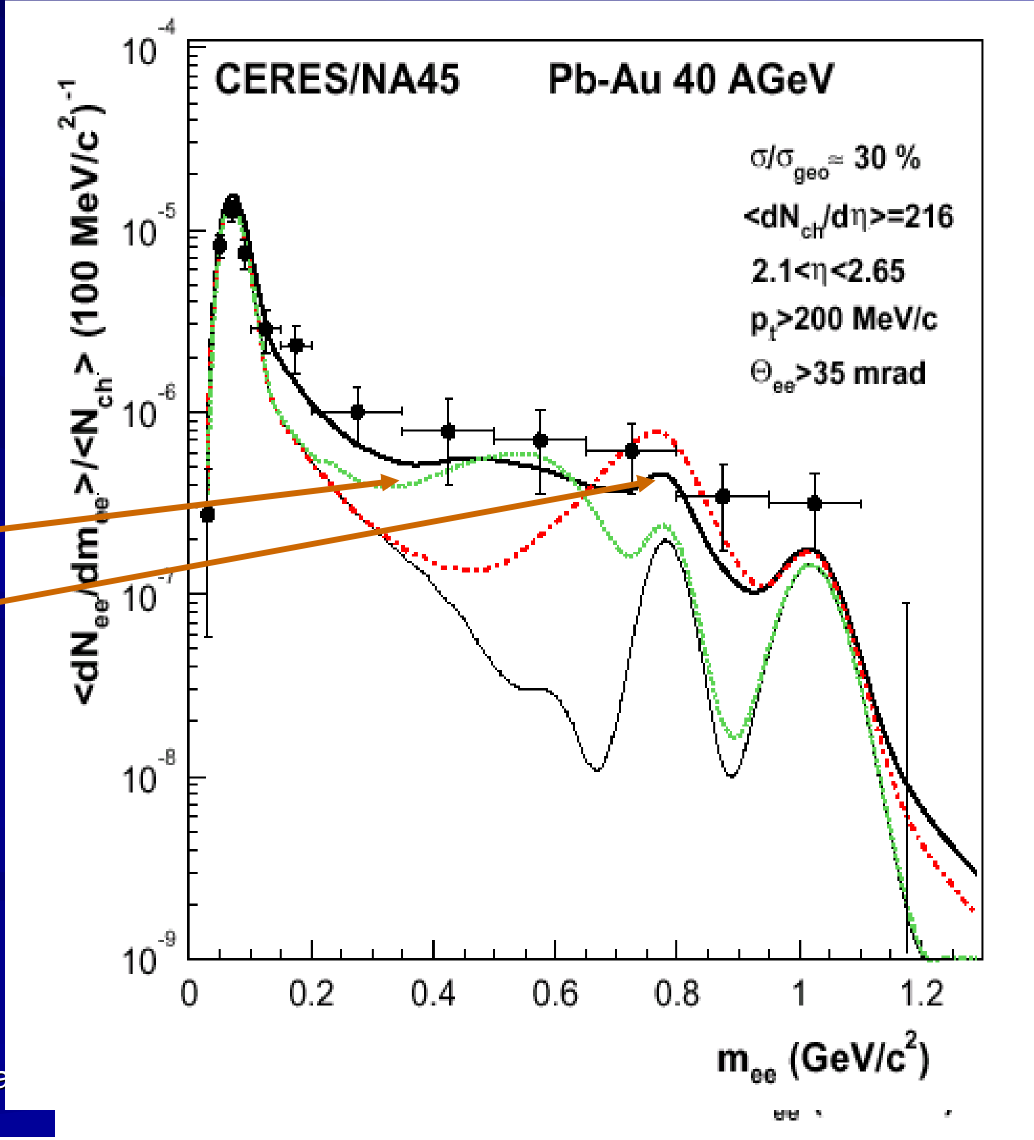
Dropping Mass or Broadening (III)?

CERES-99 low-energy run Pb-Au 40 A GeV

- Very strong enhancement
- Consistent with interpretation that the in-medium modifications are due to the baryons.

- **Dropping mass and collision broadening give very similar predictions**

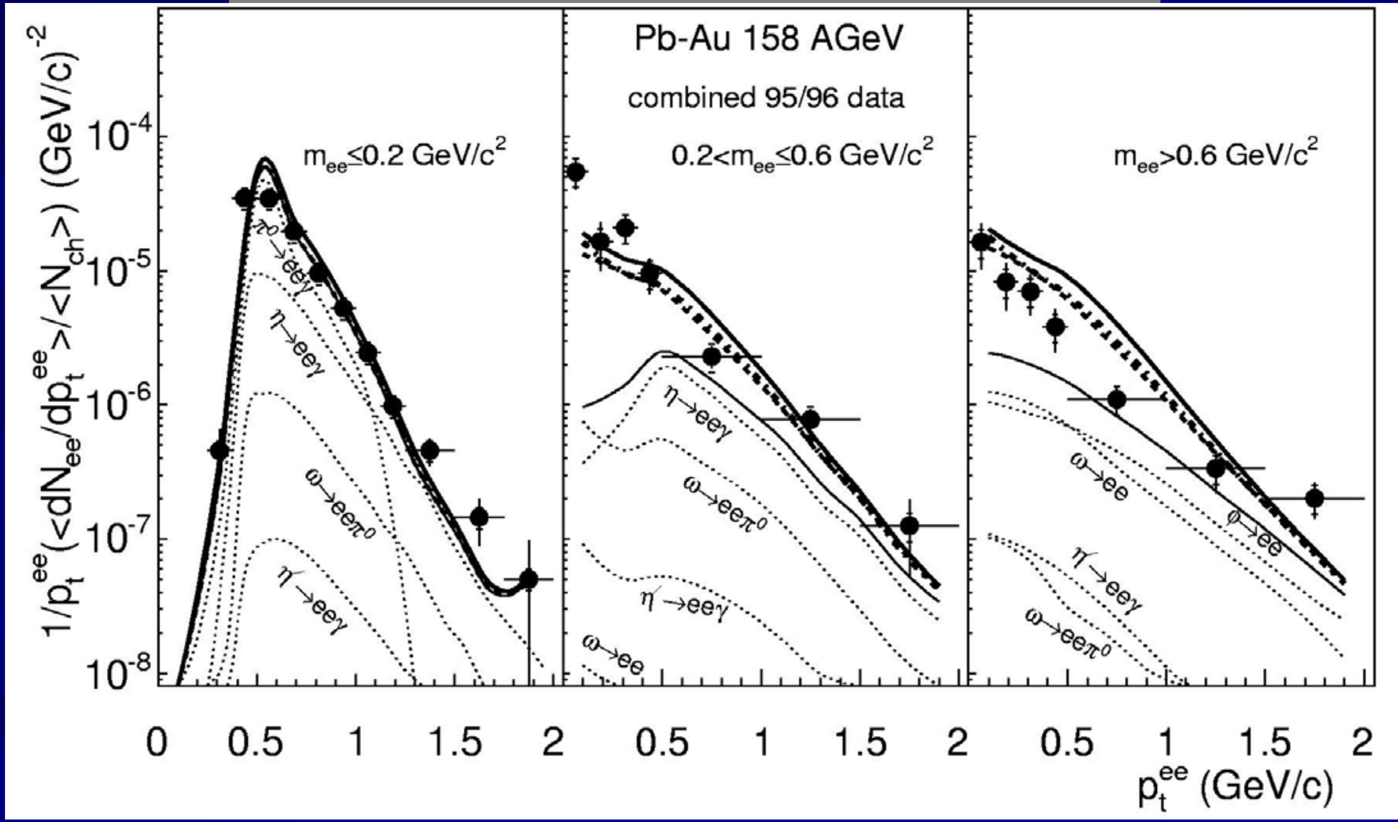
- Data not precise enough for a clear discrimination among the two models



Dropping Mass or Broadening (IV)?

p_T Distribution

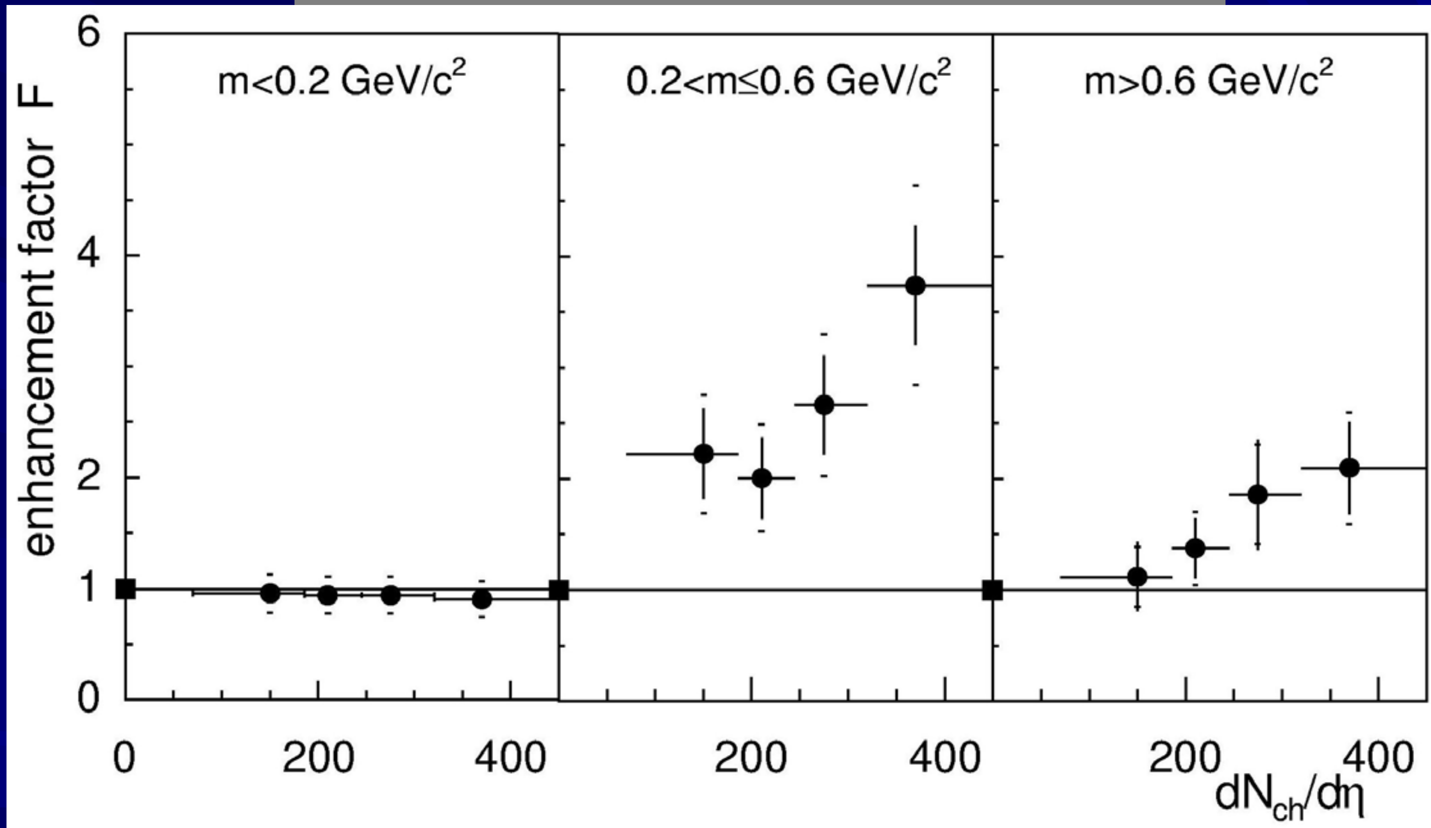
CERES 95+96 data Pb-Au 158 A GeV



• p_T distribution is not of much help

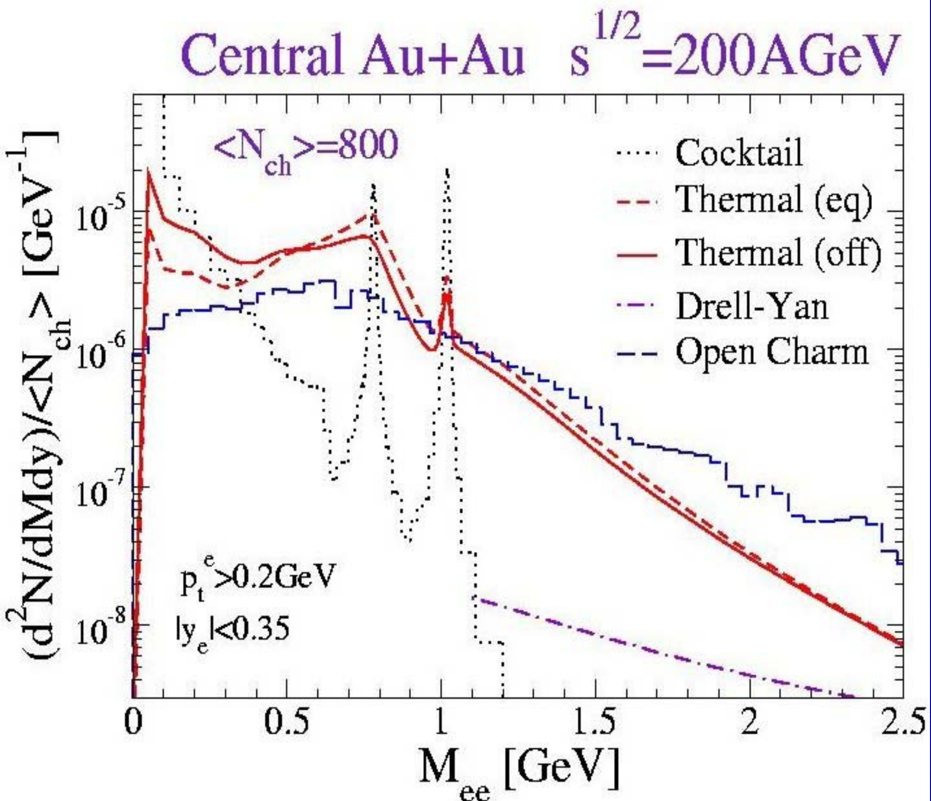
Dropping Mass or Broadening (IV)? Multiplicity Dependence

CERES 95+96 data   Pb-Au   158 A GeV

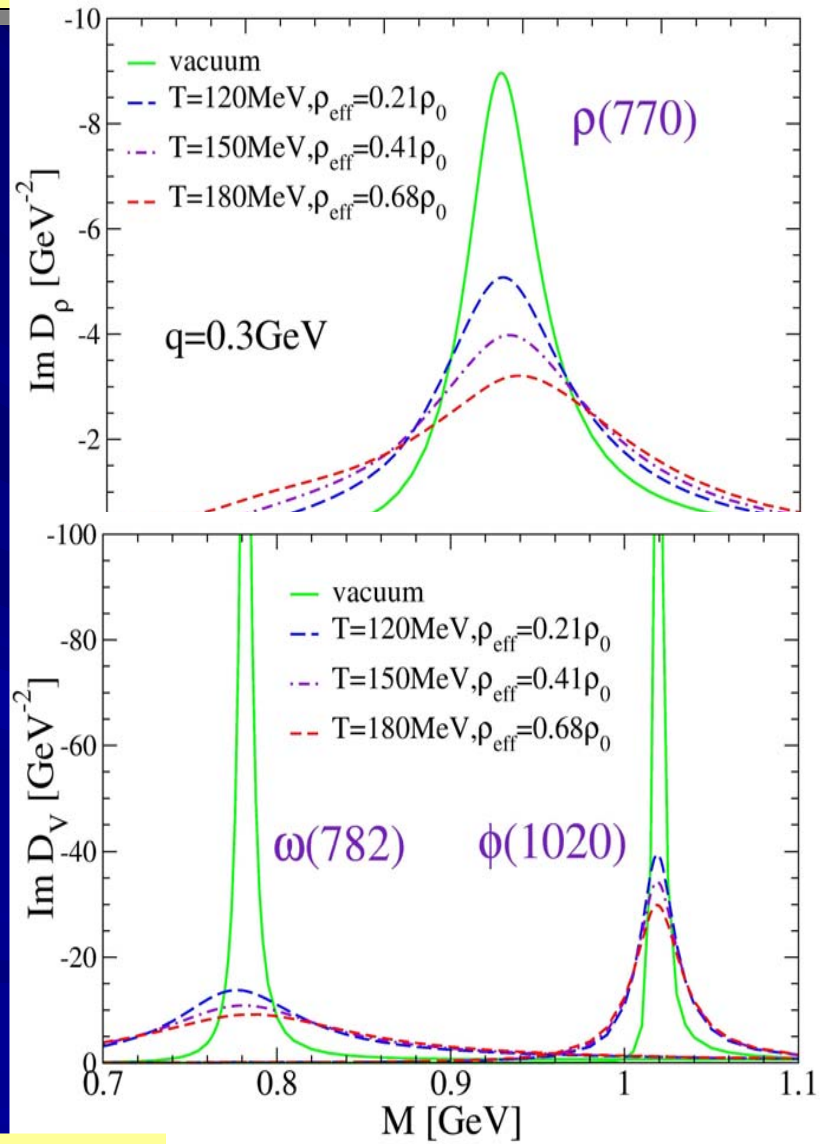


- **Enhancement factor rises linearly with $dN_{ch}/d\eta$**
  → pair yield $\propto (dN_{ch}/d\eta)^2$

Low-mass e^+e^- Pairs: Prospects at RHIC



R. Rapp nucl-th/0204003



- interpretation of SPS data rely on a high baryon density at mid rapidity.

♣Baryon density is almost the same at RHIC and SPS

♣ **Strong enhancement of low-mass pairs persists at RHIC**

♣ **HBD upgrade for PHENIX under construction**

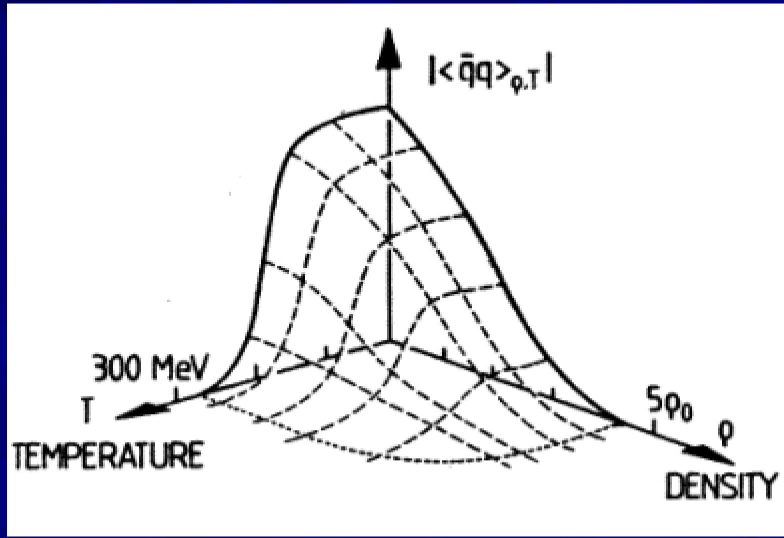
Dropping Mass or Broadening (II)?

Conceptually different:

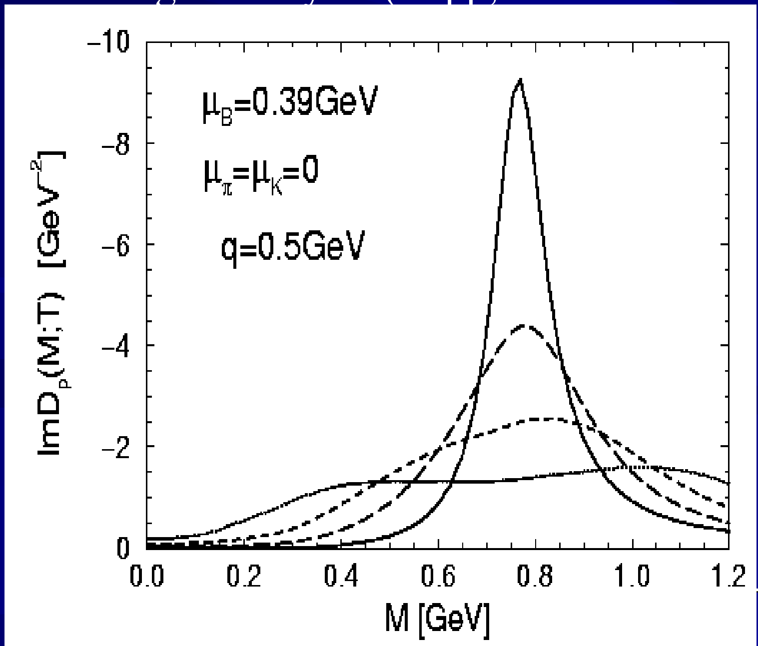
ρ-meson broadening: d.o.f hadrons
Dropping ρ-meson mass: d.o.f. quarks

Common feature:

At SPS both models rely on the high baryon density at mid-rapidity.



ρ scattering off baryons(Rapp, Wambach et al)



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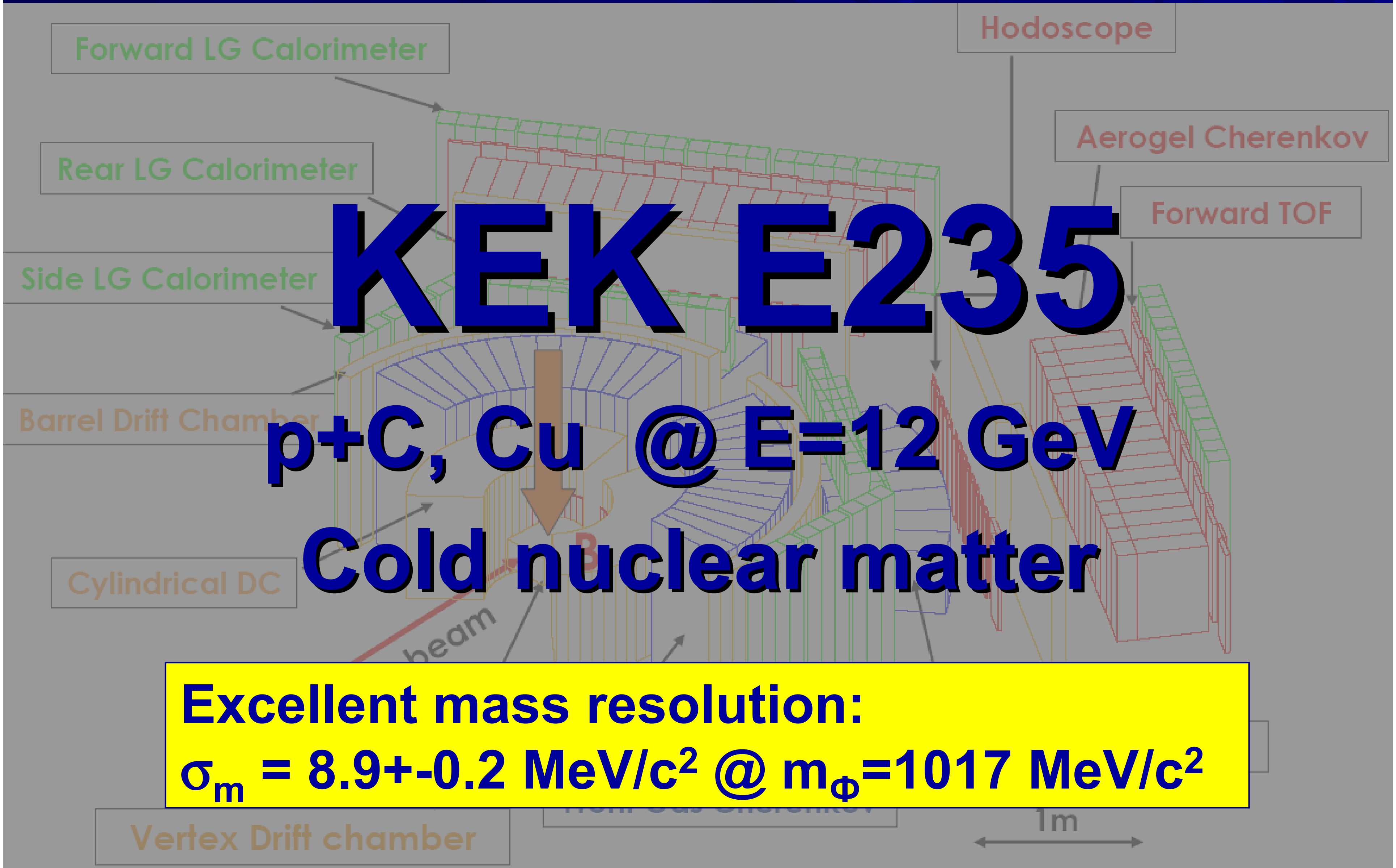


KEK E235

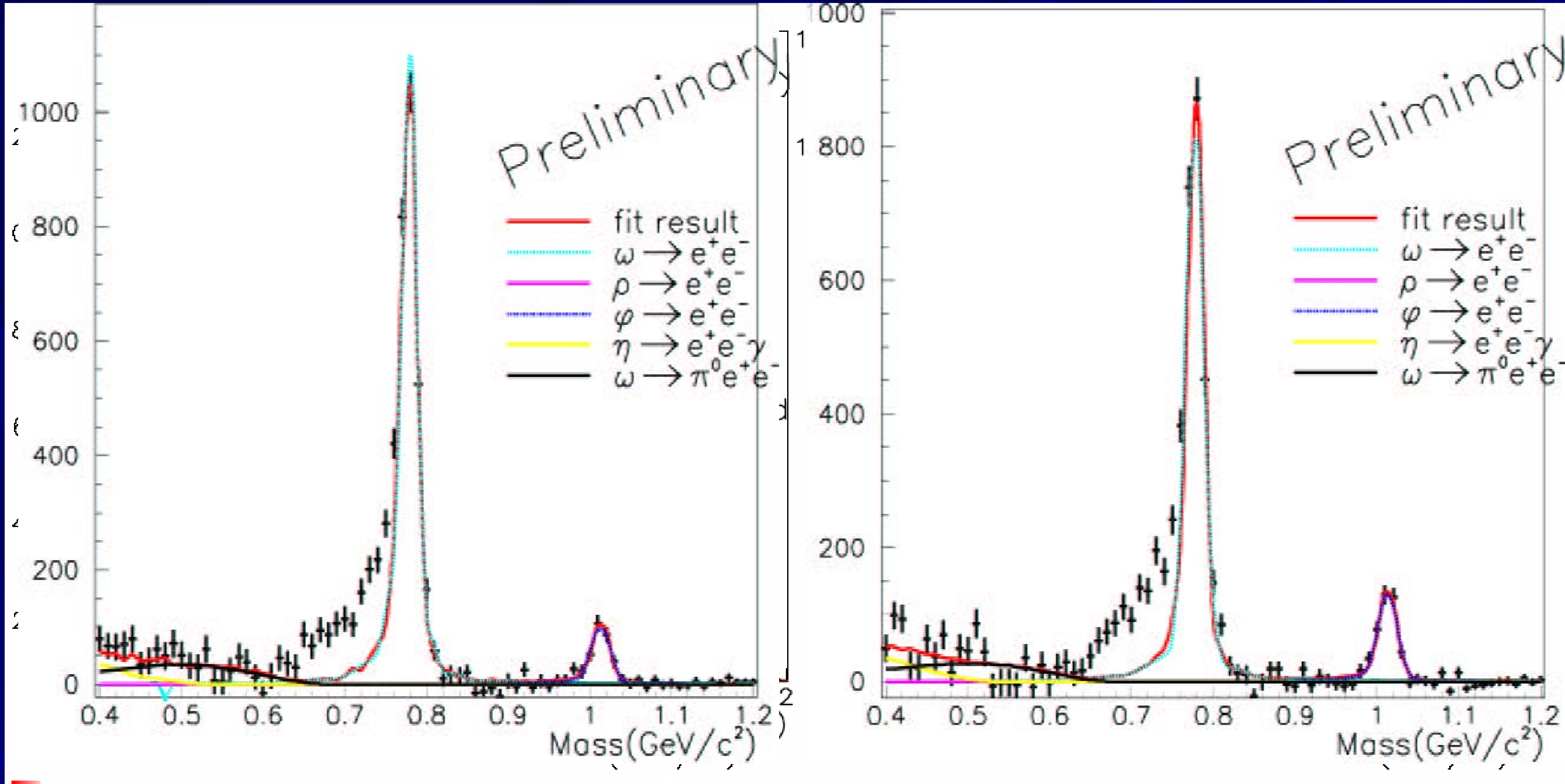
p+C, Cu @ E=12 GeV

Cold nuclear matter

Excellent mass resolution:
σ_m = 8.9+-0.2 MeV/c^2 @ m_Φ=1017 MeV/c^2

Raw spectra Fitted with known sources.

Di-electron spectrum (bkg subtracted).



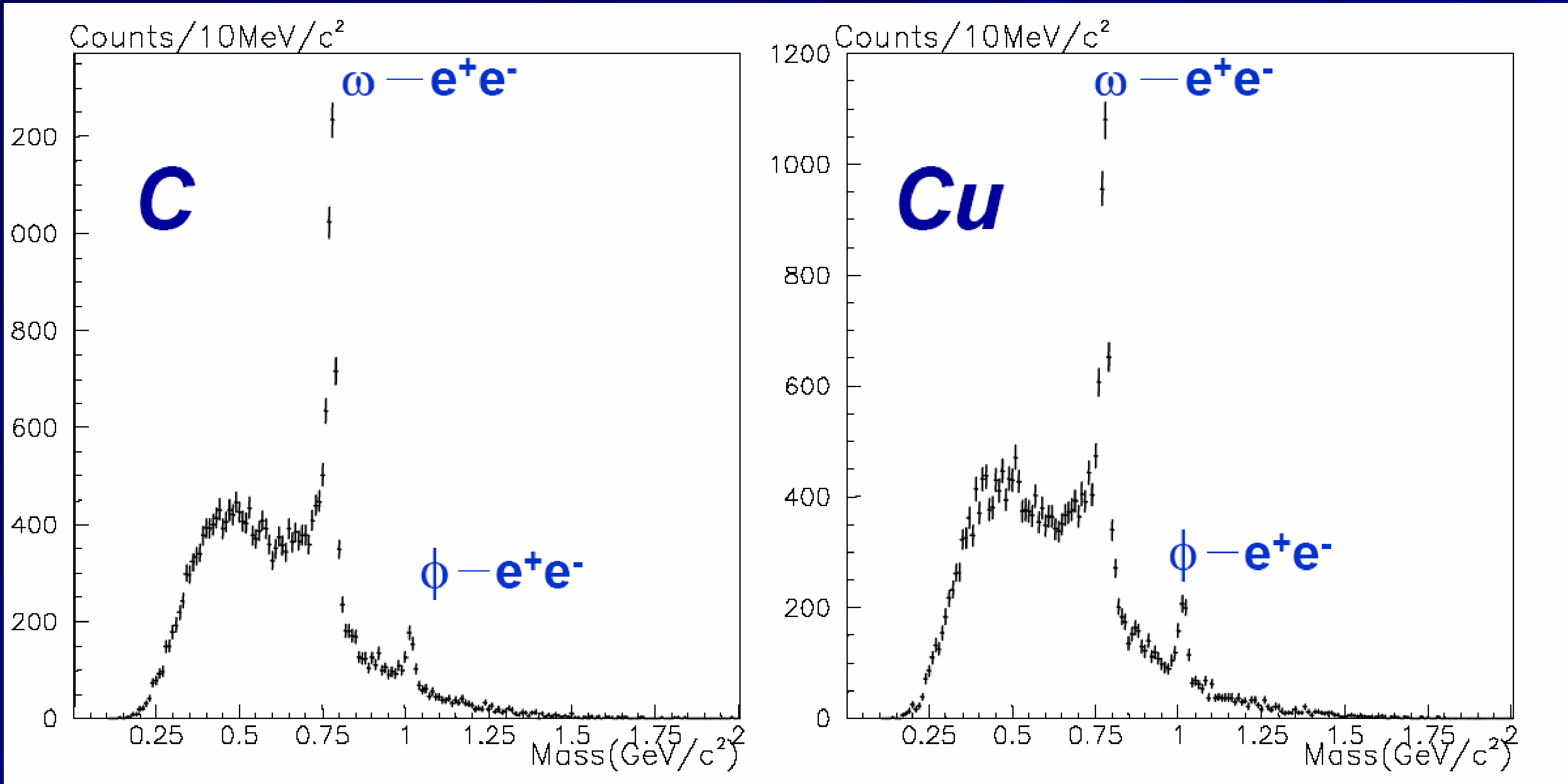
- Hadronic sources: ρ, ω, Φ -> e^+e^-, ω ->π e^+e^- , η -> γ e^+e^-

Cannot fit the ρ with m and Γ from PDG

ρ yield consistent with zero

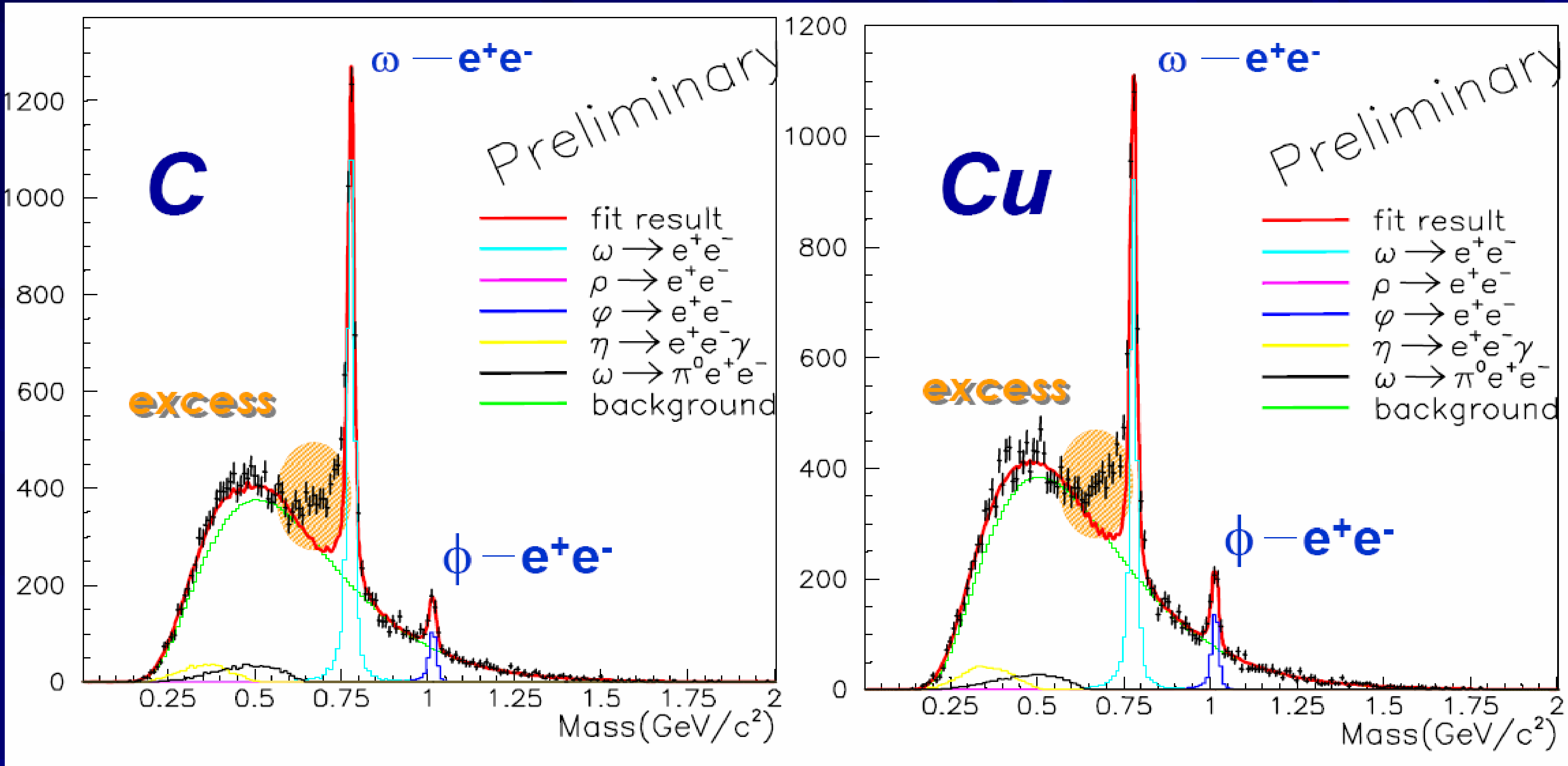
- Combinatorial background : event mixing method

Raw spectra



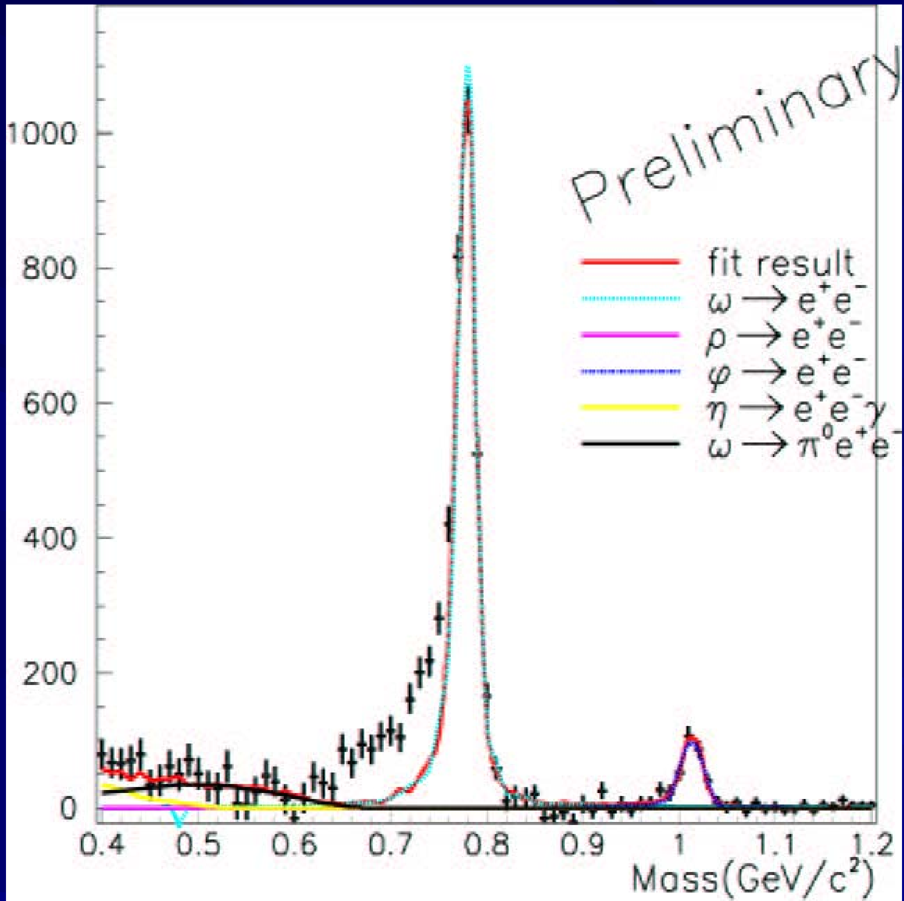
Counts/10MeV/c²
ω — e⁺e⁻
C
φ — e⁺e⁻
200
000
800
600
400
200
0
0.25
0.5
0.75
1
1.25
1.5
1.75
2
Mass(GeV/c²)
Counts/10MeV/c²
ω — e⁺e⁻
Cu
φ — e⁺e⁻
1200
1000
800
600
400
200
0
0.25
0.5
0.75
1
1.25
1.5
1.75
2
Mass(GeV/c²)

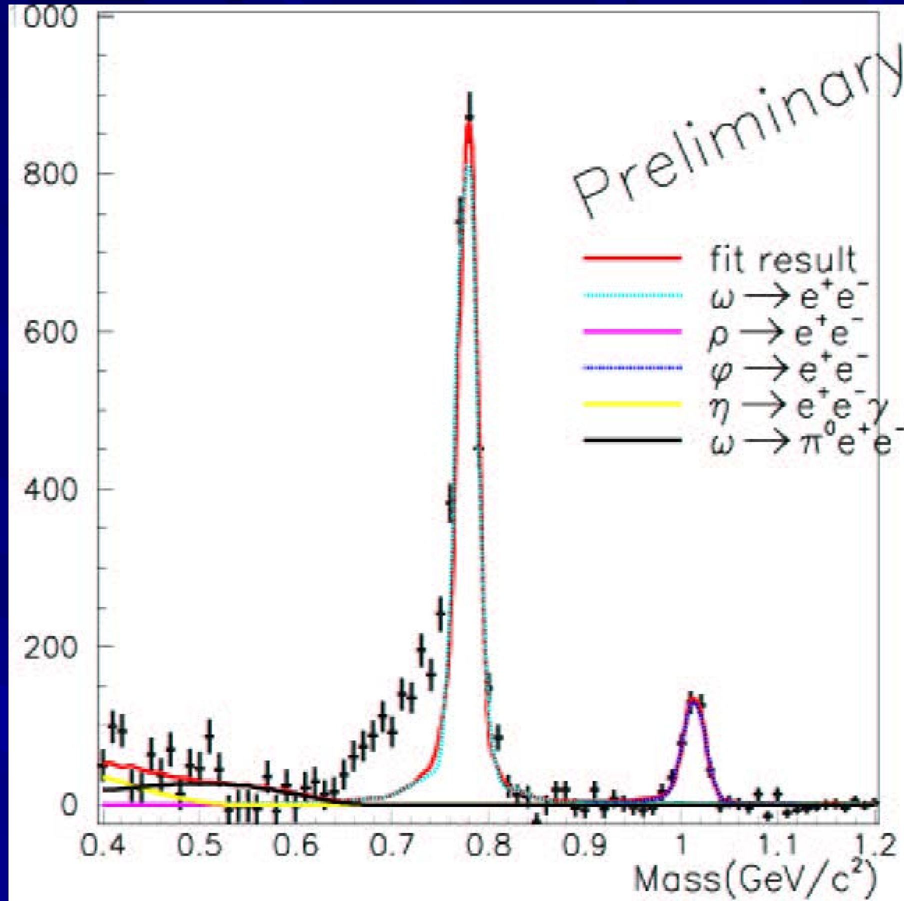
Raw spectra fitted with known sources.



- Hadronic sources: ρ, ω, Φ -> e^+e^-, ω ->π e^+e^- , η -> γ e^+e^-
  - Width: Breit-Wigner shape convoluted with experimental resolution.
  - Position: PDG values
  - Relative abundances determined by fit
- Combinatorial background : event mixing method

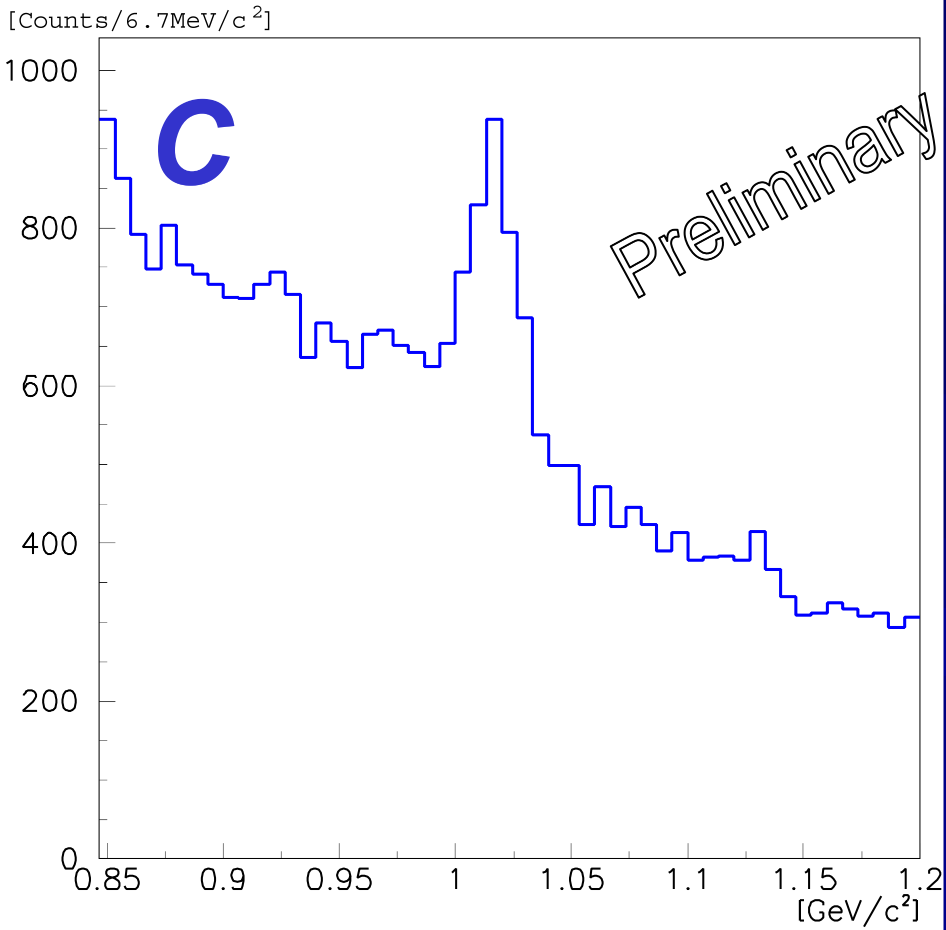
Dilepton spectrum (bkgd subtracted)

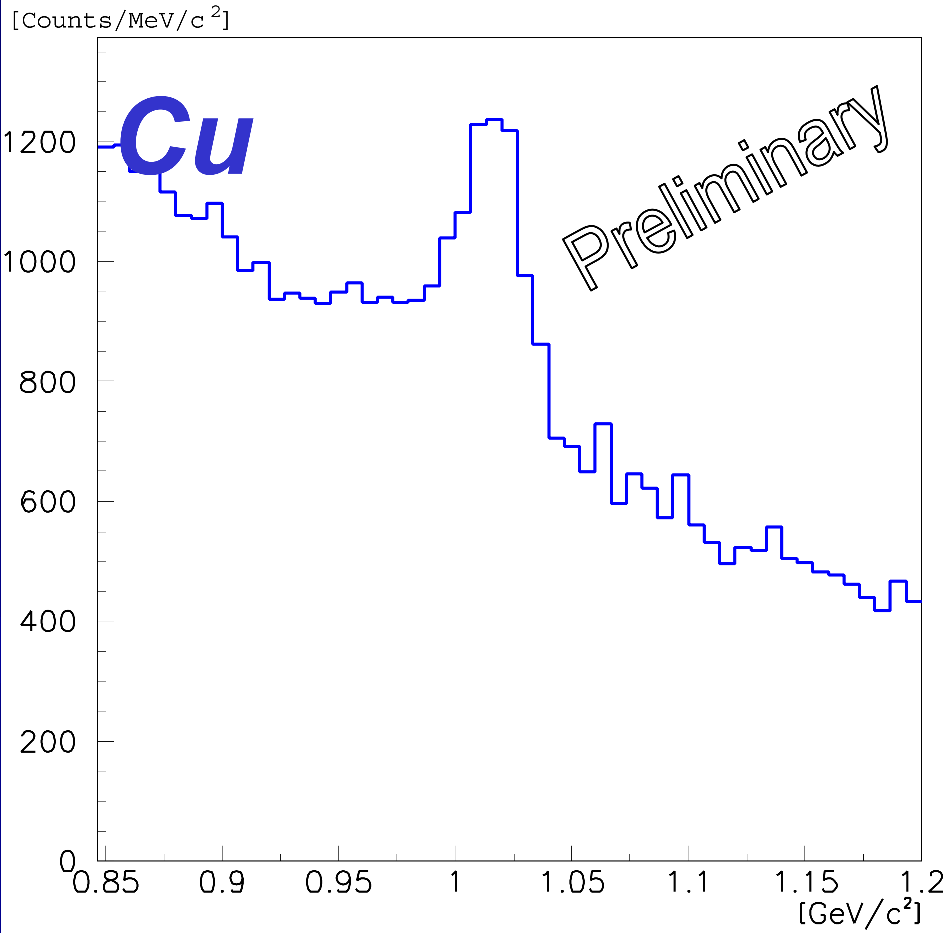




Cannot fit the ρ with m and Γ from PDG
ρ yield consistent with zero

φ Mass region

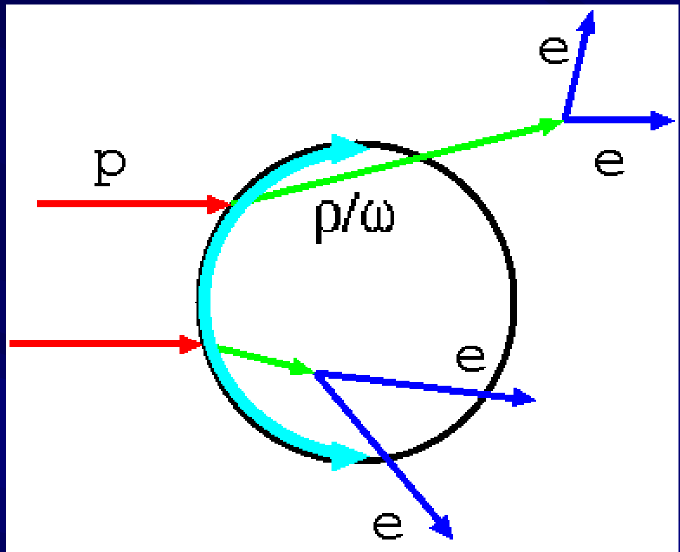




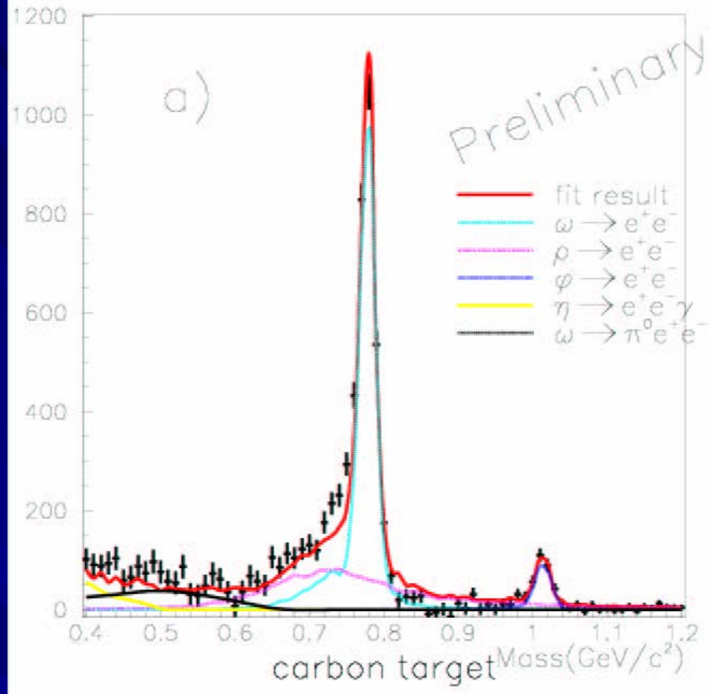
Nφ ~ 1400 ***Nφ ~ 2200***

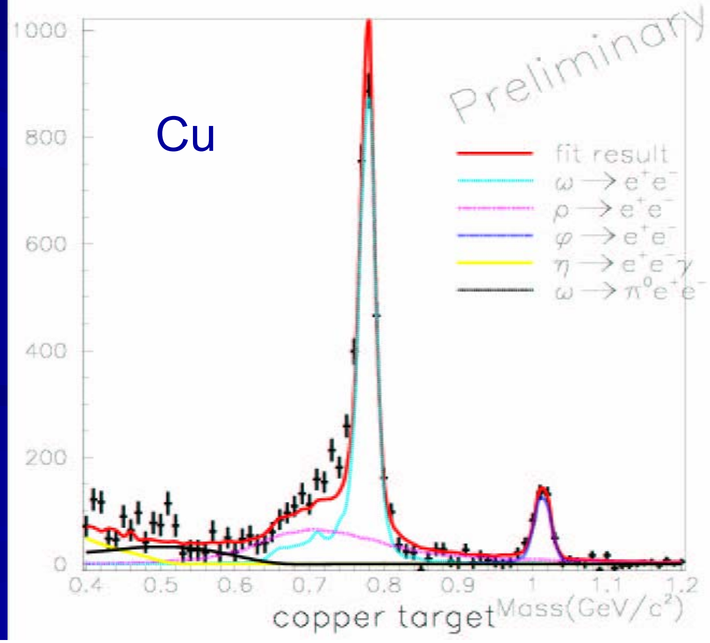
Clear difference between the C and Cu targets

Toy model

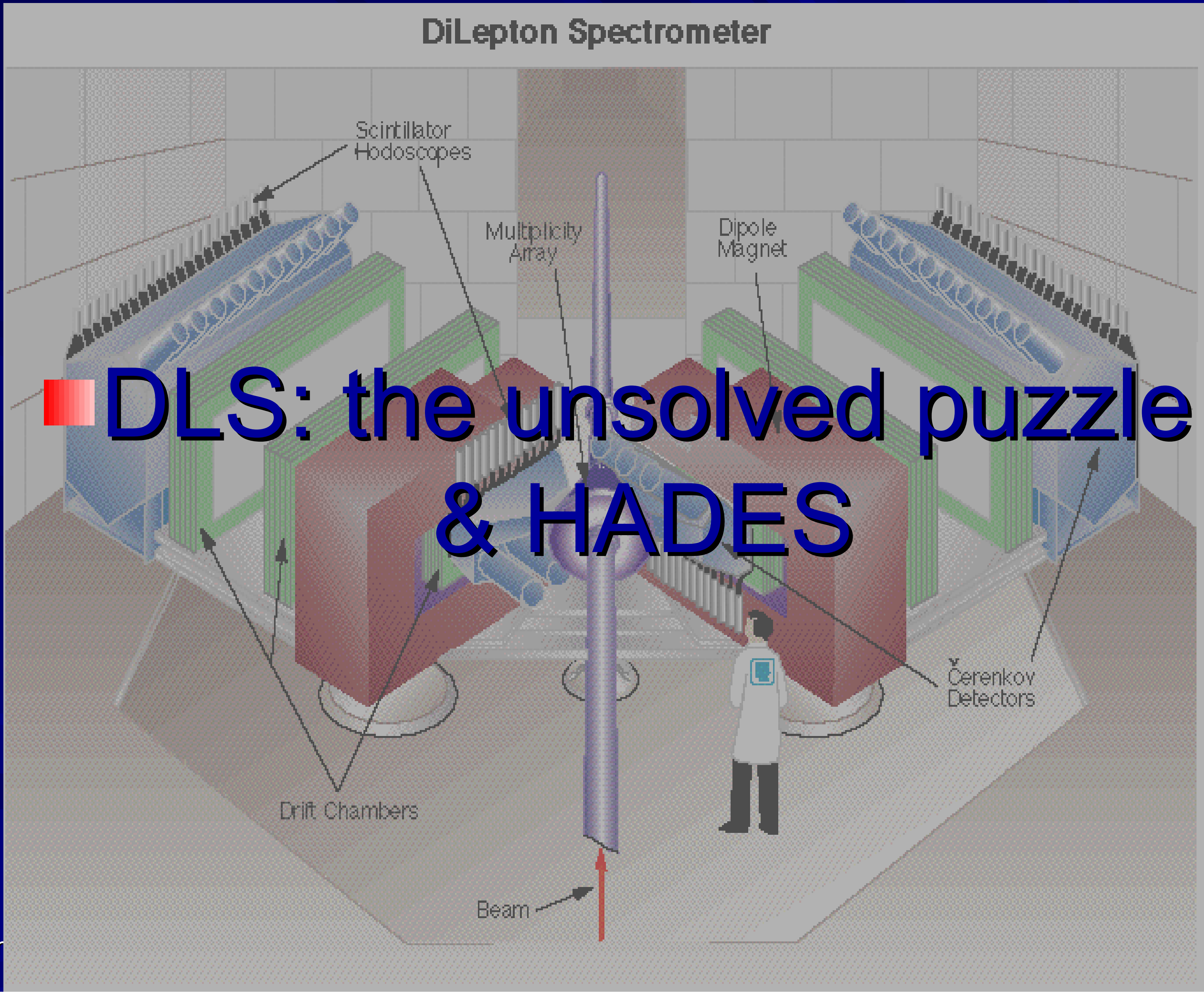


- ρ / ω produced at nuclear surface, decay with modified mass if decay point is inside the nucleus
- ρ / ω ratio equal 1
- Mass shift : $m^*/m0 = 1 - 0.16\ \rho^*/\rho_0$ (Hatsuda & Lee, '92,'95)

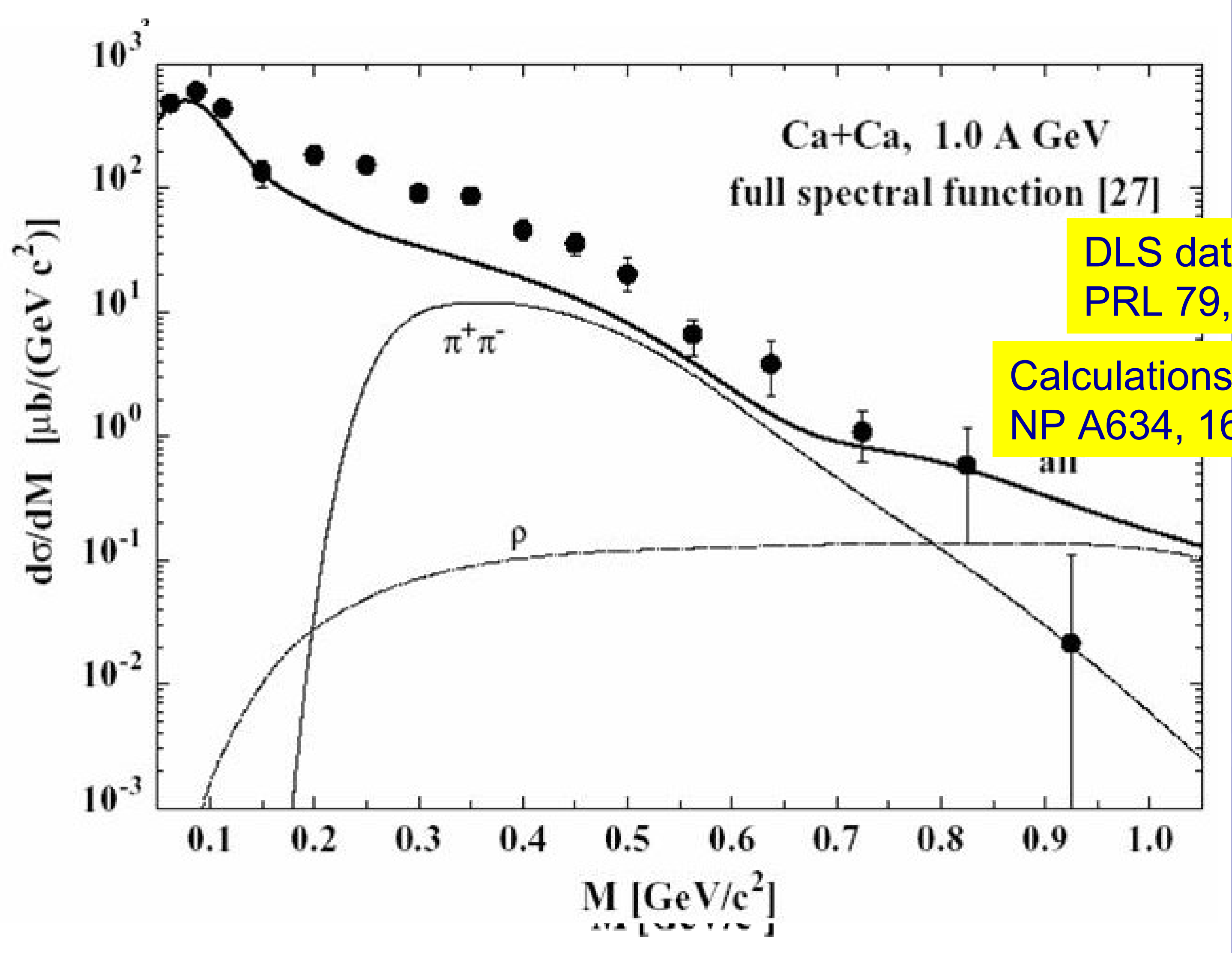




DLS: the unsolved puzzle & HADES



DLS



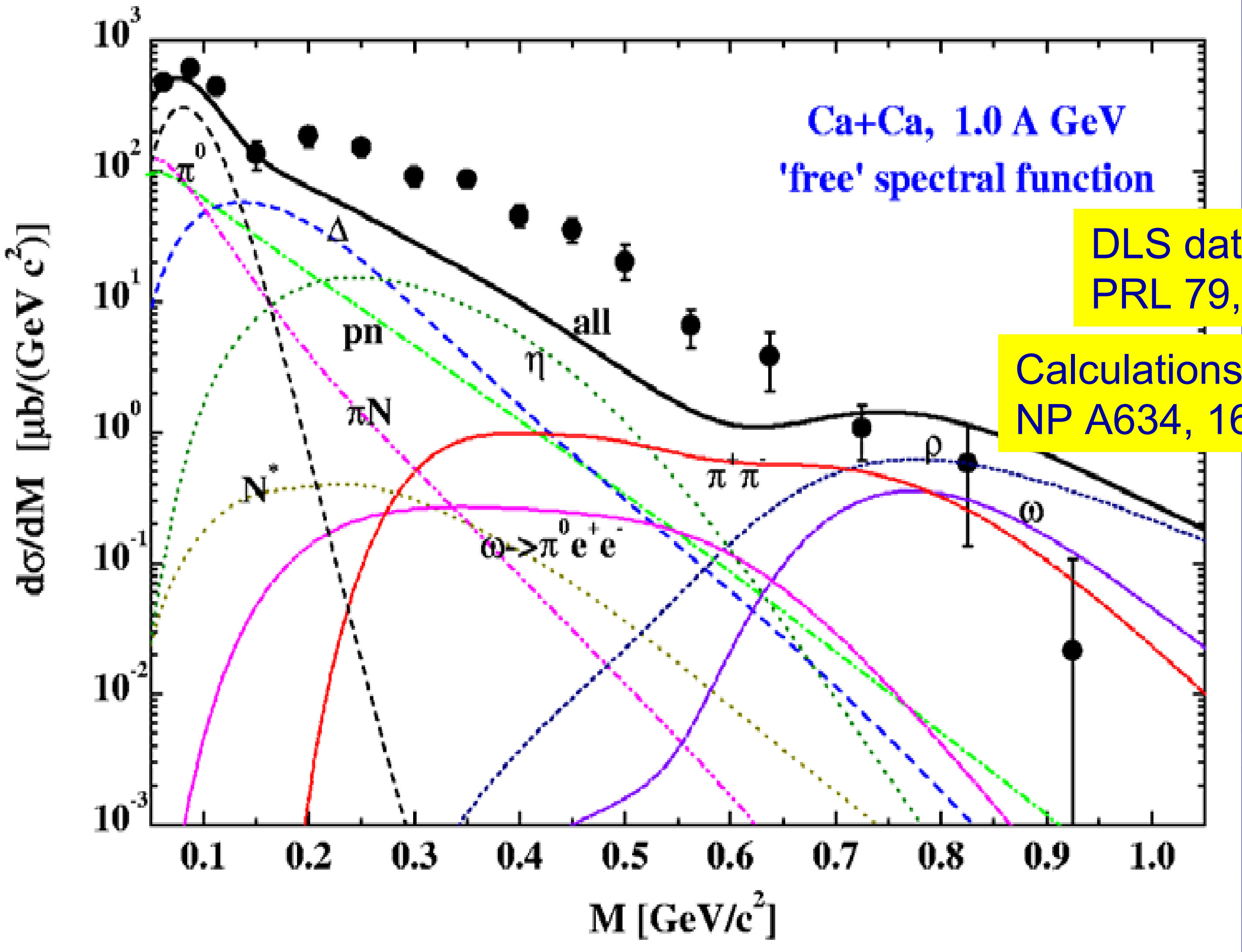
DLS data: Porter et al., PRL 79, 1229 (1997)

Calculations: Bratkovskaya et al., NP A634, 168 (1998)

Strong enhancement not described by cocktail with 'free' ρ spectral function

Enhancement described by in-medium ρ spectral function

DLS



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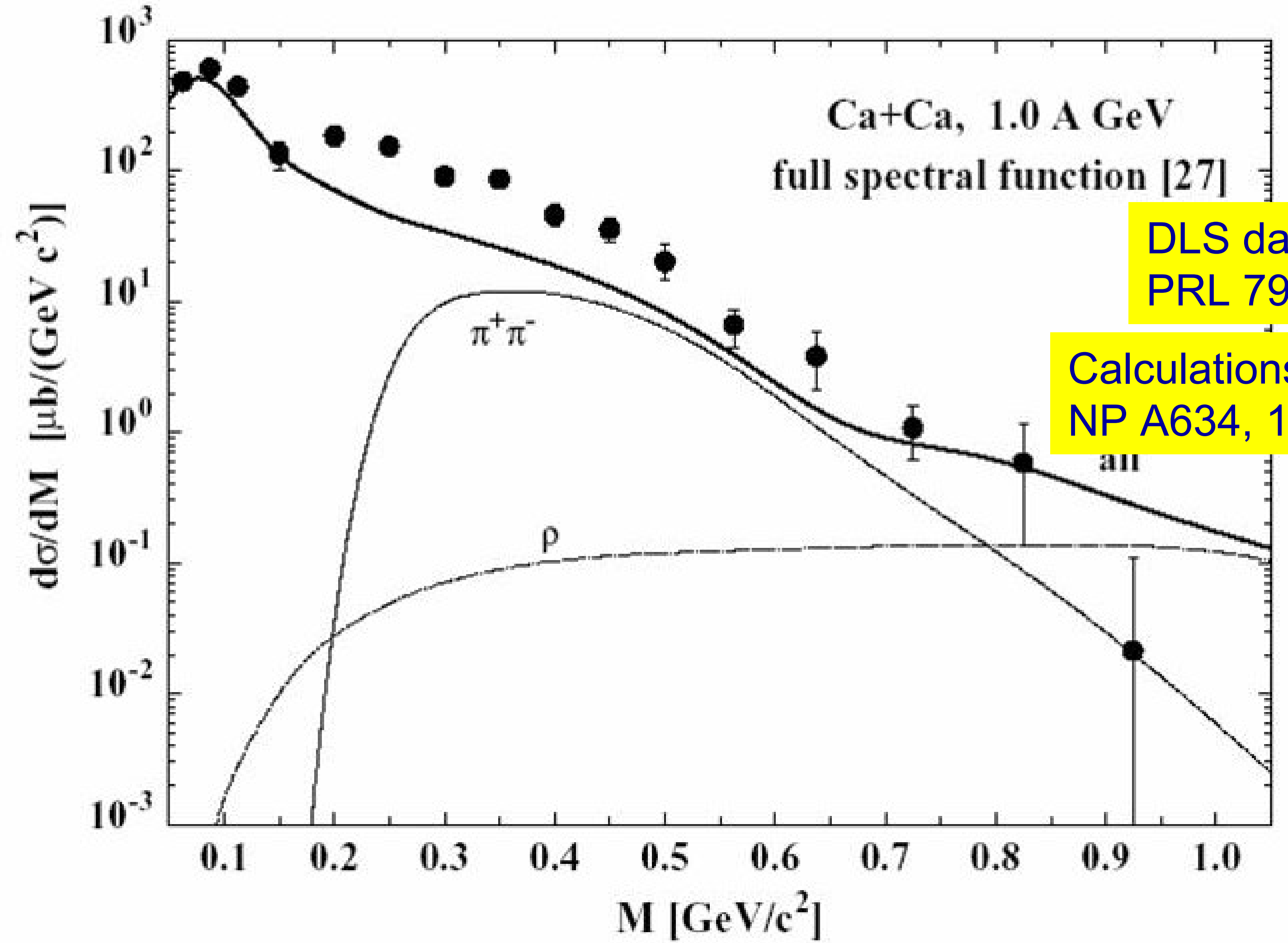
Strong enhancement over hadronic cocktail with "free" ρ spectral function

DLS



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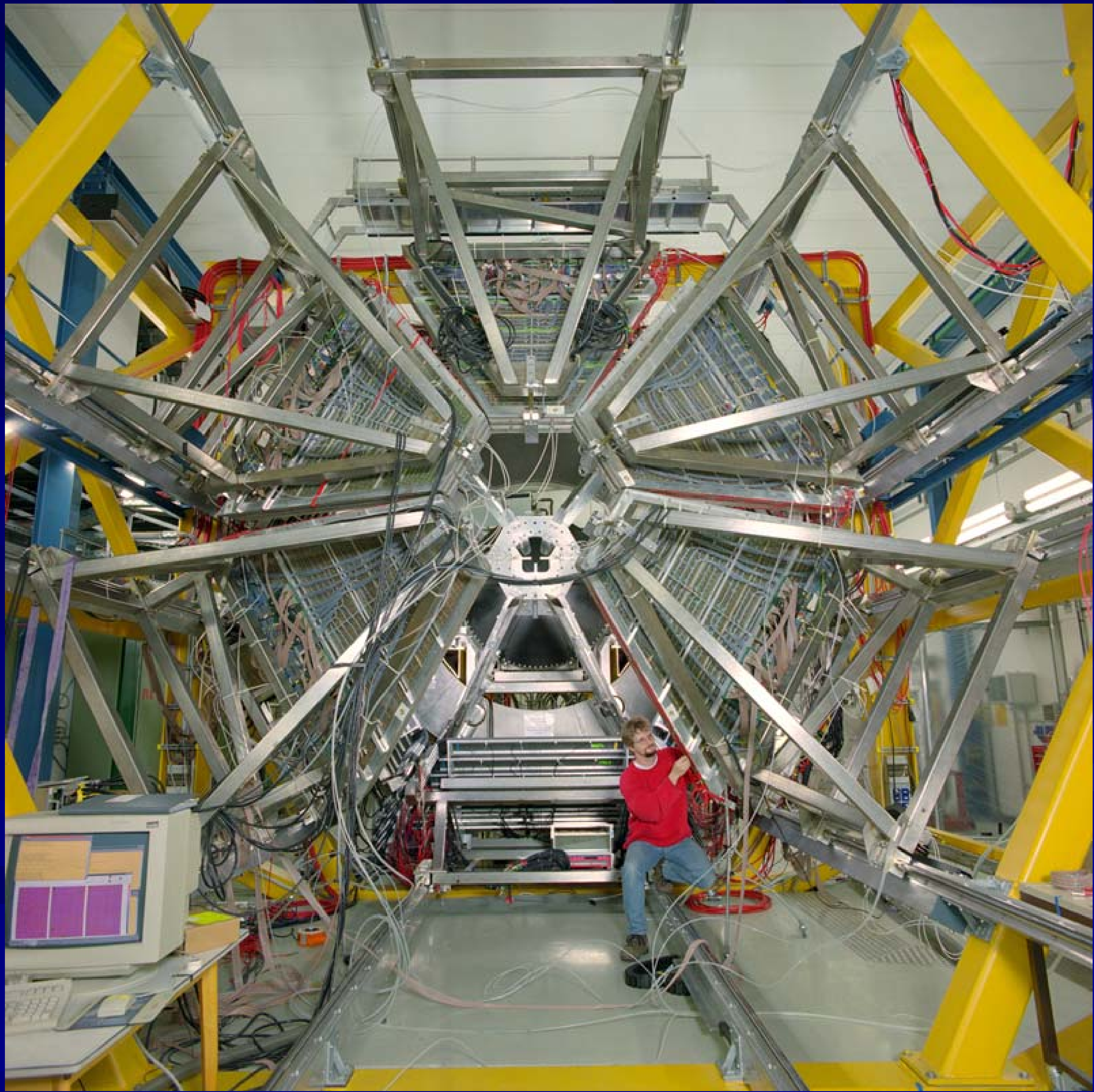
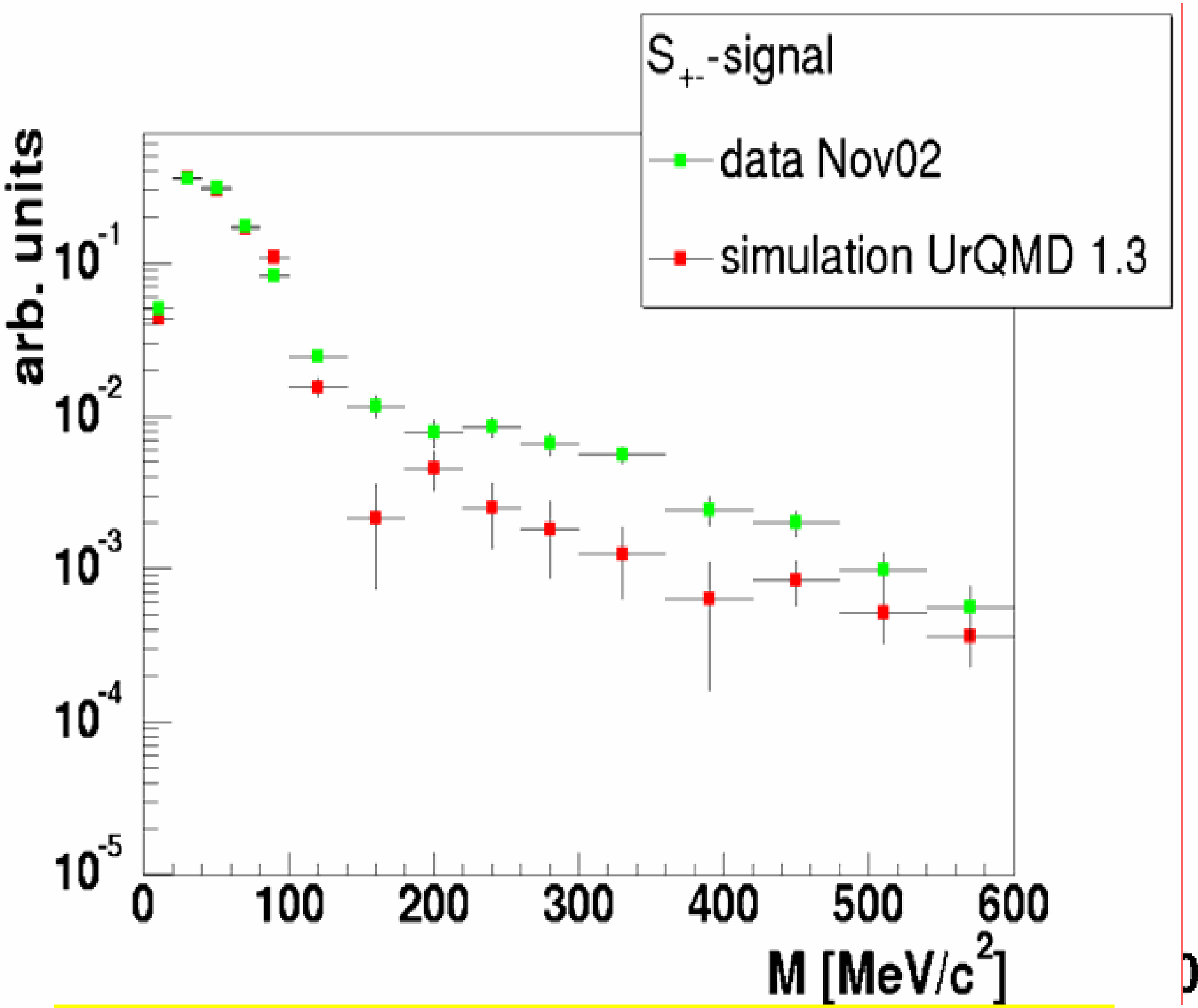
HADES



HADES: dielectrons from C+C @ 2 AGeV



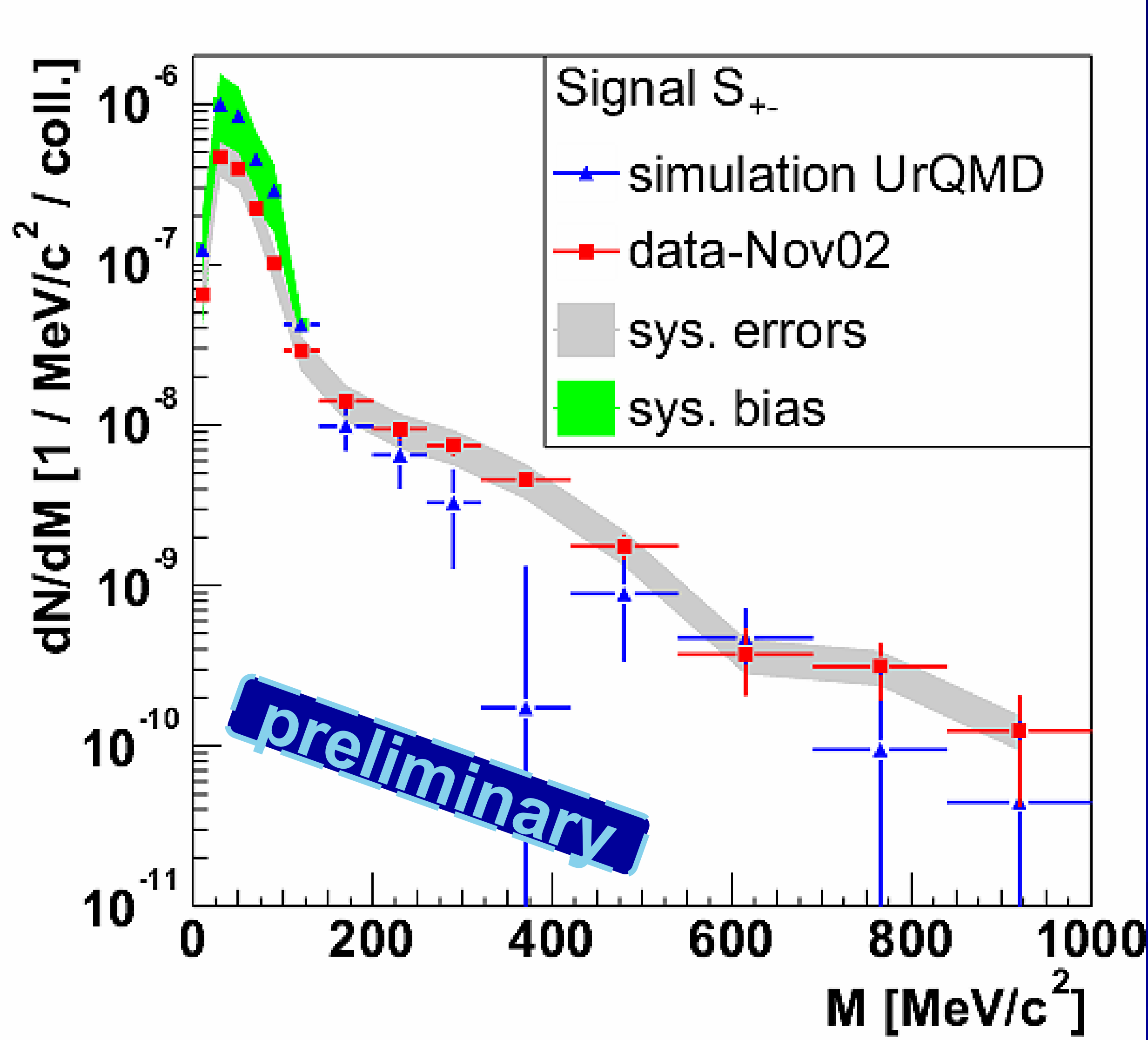
Normalization to the yield in m<140 MeV/c²

- 2 10^8 events
- 1400 pairs at m>150 MeV

❖ Not corrected for acceptance and reconstruction efficiency

- Comparable statistics for C+C @ 1 A GeV

HADES: dielectrons from C+C @ 2 AGeV



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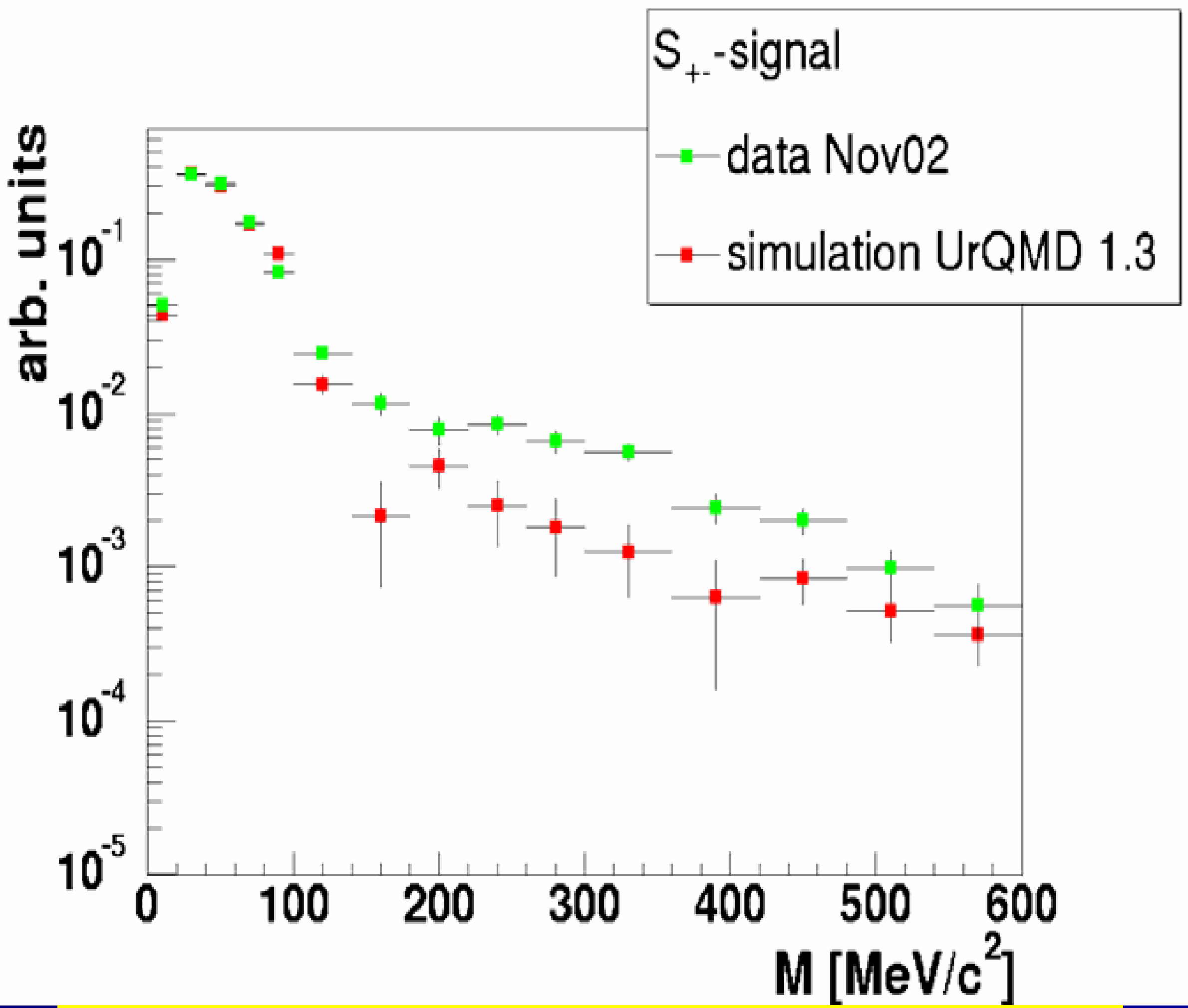

- 2 10^8 events
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Normalization to the yield in m<140 MeV/c²

Φ meson

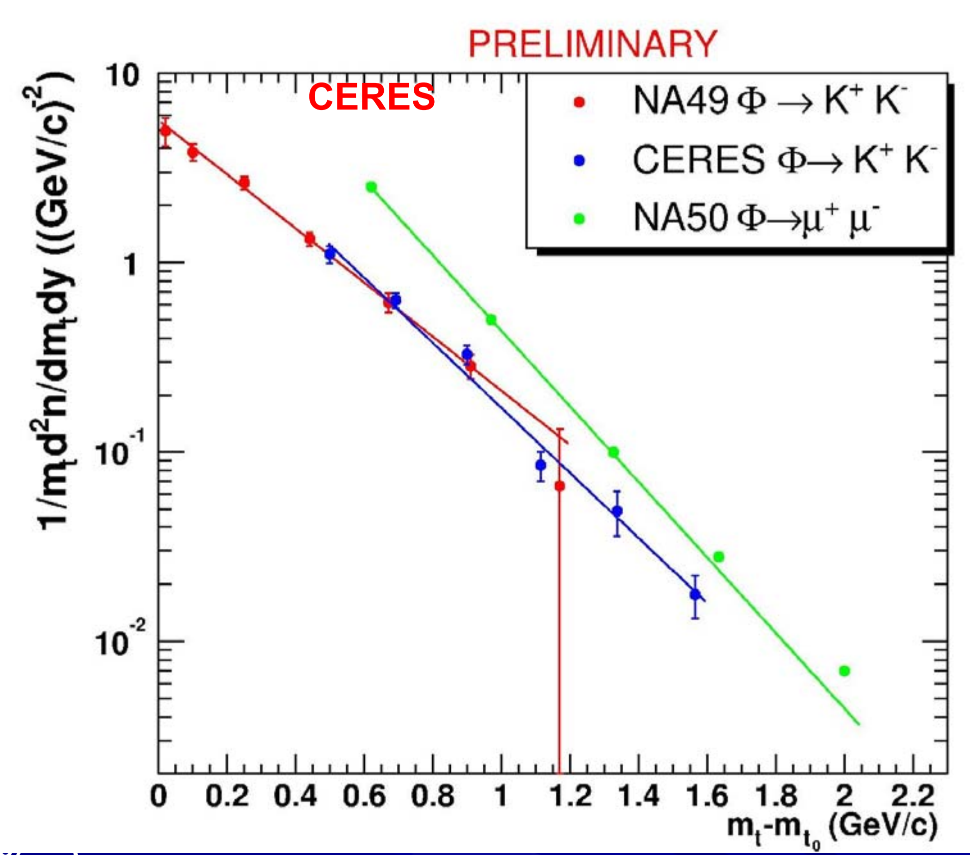
A special probe for CSR

τ=44 fm but m(Φ) ≈ 2 m(K)

Φ meson: SPS Results

Central Pb-Pb 158 A GeV

	T (MeV)
NA49 Φ → $K^+ K^-$	**305 +- 15**
CERES (prel.)	**253 +- 11**
NA50 Φ → $\mu^+ \mu^-$	**228 +- 10**



	dN/dy	
NA49 Φ → $K^+ K^-$	**2.35**	(y=2.9, top 4%)
CERES (prel.)	**2.39**	(y=2-2.4 top 8%)
NA50 Φ → $\mu^+ \mu^-$	No specific quote.	

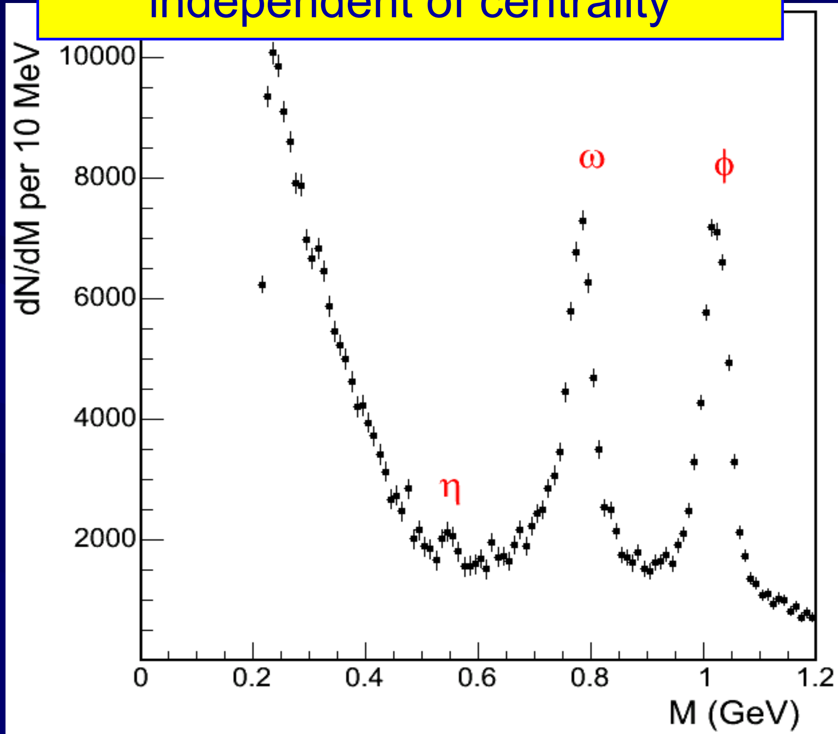
exceeds NA49 by factors of 2 – 4 in common m_T region

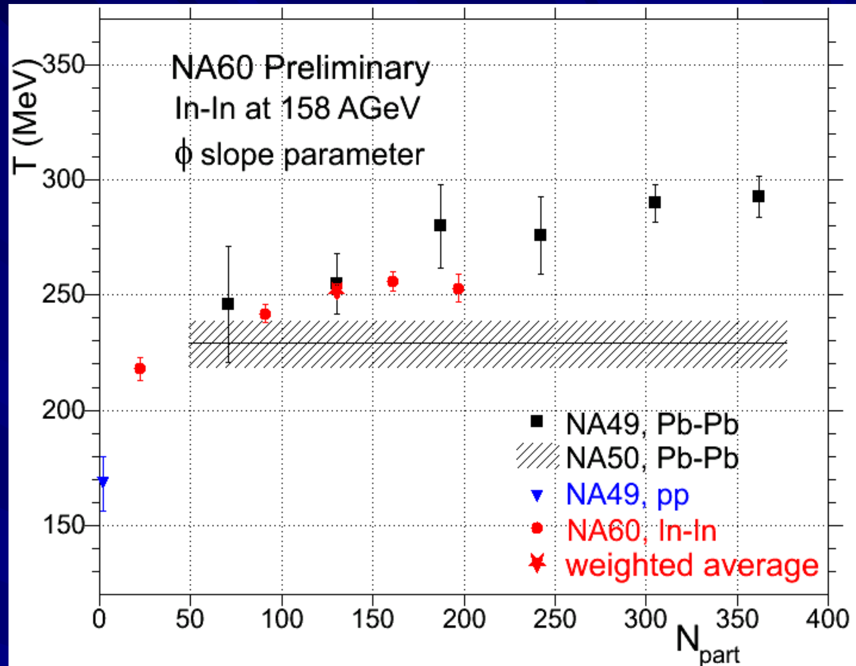
Φ/ω seems to be in agreement with thermal model

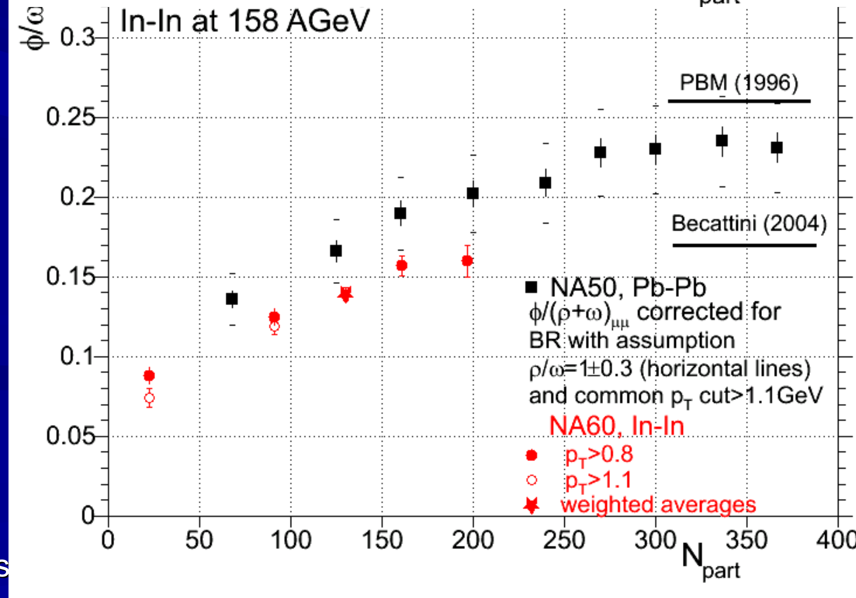
CERES Φ → $e^+ e^-$ seems to be in agreement with thermal model

Φ meson: NA60 In-In 158 AGeV

23 MeV mass resolution at the ϕ independent of centrality







- NA50 and NA60 are compatible with each other.
- Φ / ω yields are close to the thermal model

Φ meson: SPS Results

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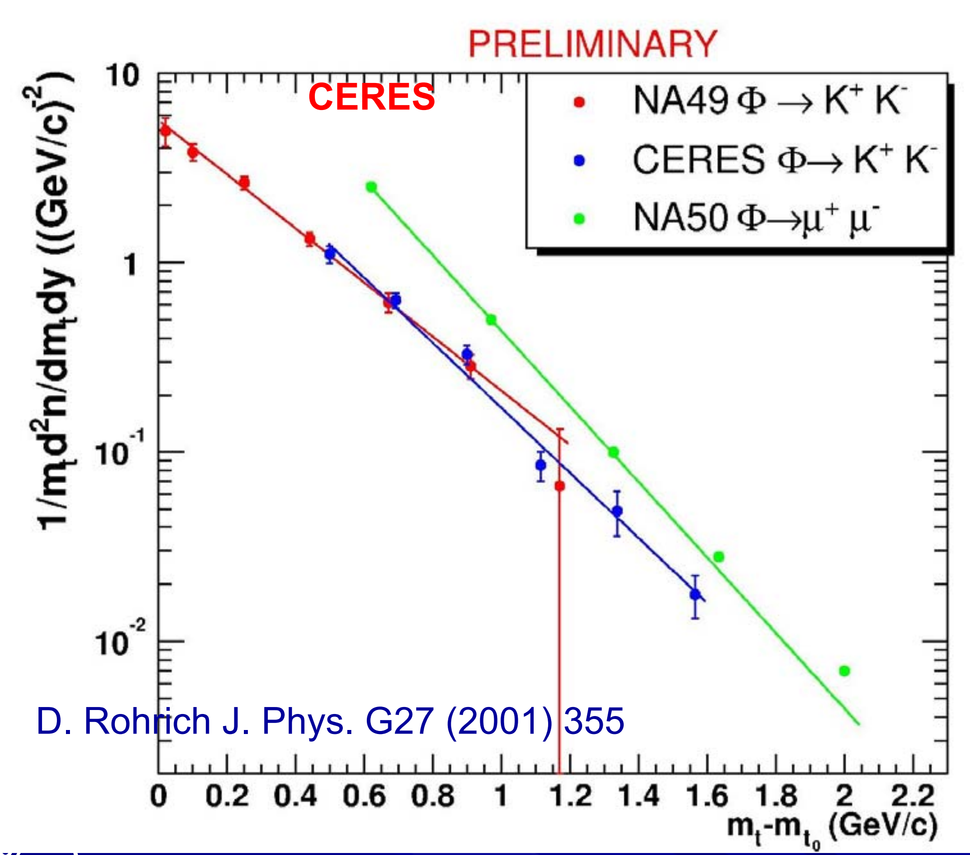

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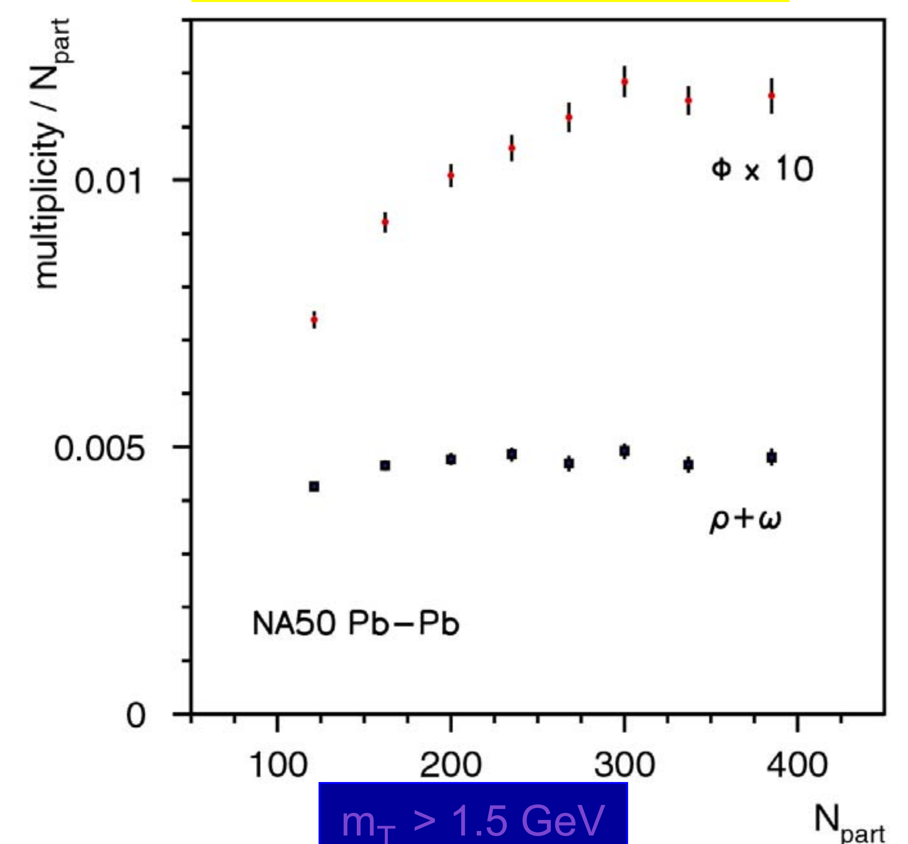
CERES	2.39	(y=2-2.4 top 8%)

NA50 Φ → $\mu^+ \mu^-$ No specific quote.
exceeds NA49 by factors of 2 – 4 in common m_T region
Integrating the m_T spectrum gives dN/dy ~ 11 !!!
Φ/ω seems to be in agreement with thermal model

CERES Φ → $e^+ e^-$ seems to be in agreement with thermal model

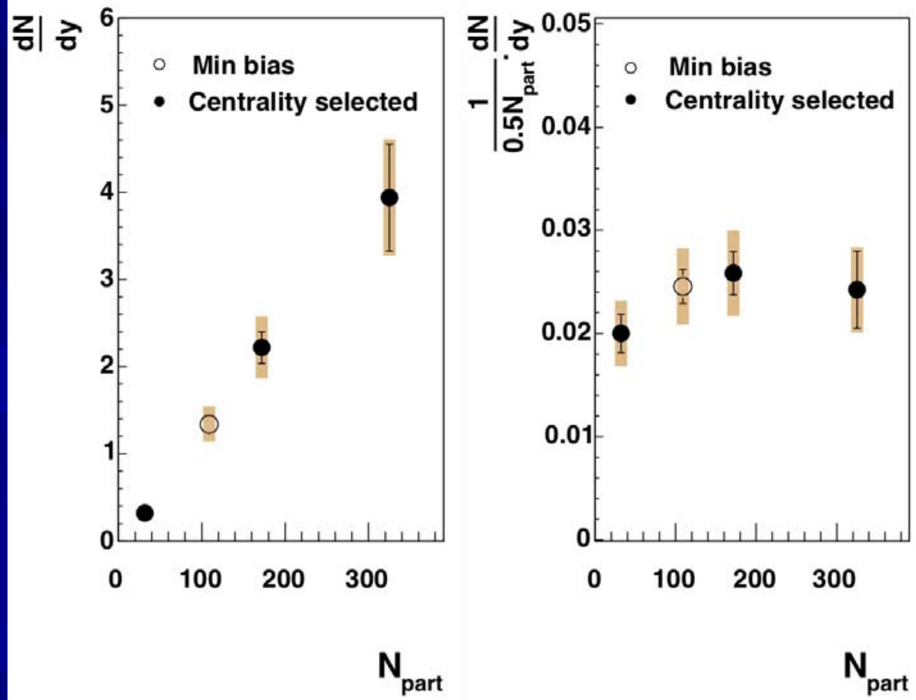
Φ Multiplicity dependence

NA50 Φ → μ⁺ μ⁻ Pb-Pb



m_T > 1.5 GeV

PHENIX Φ → K⁺ K⁻ Au-Au

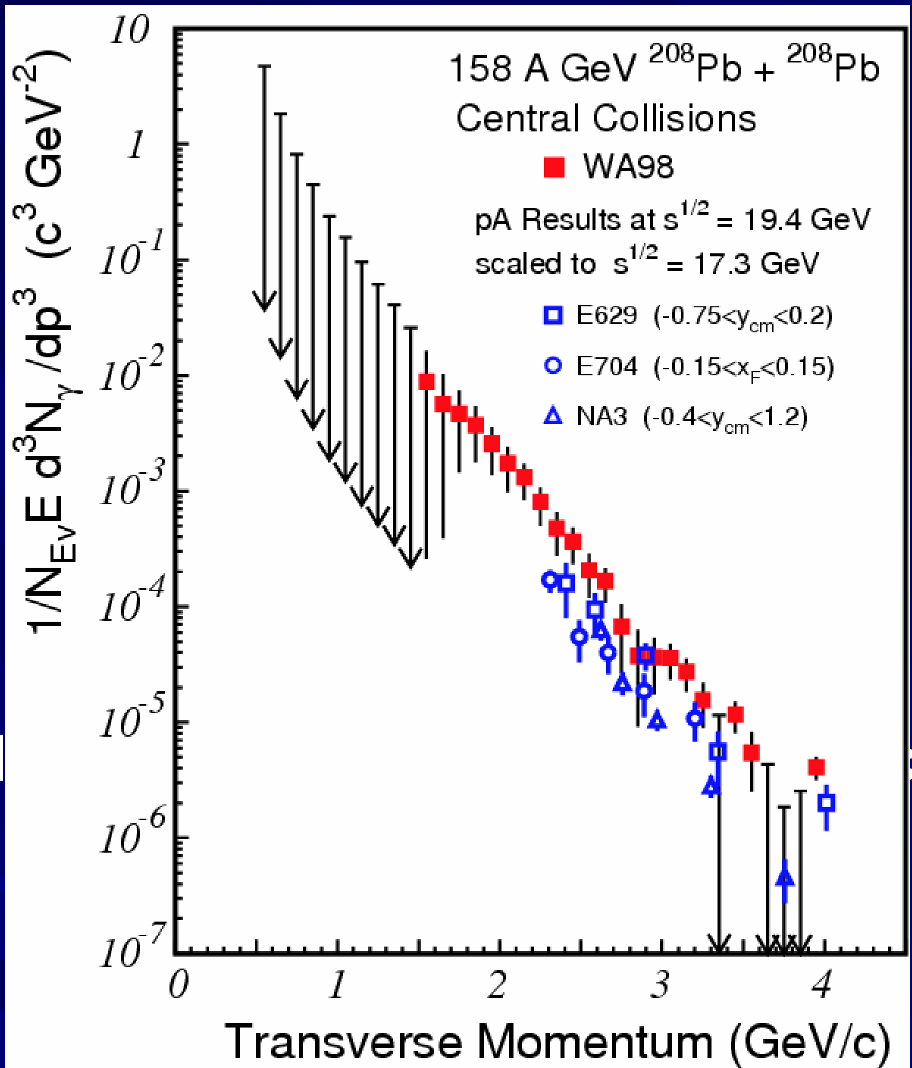


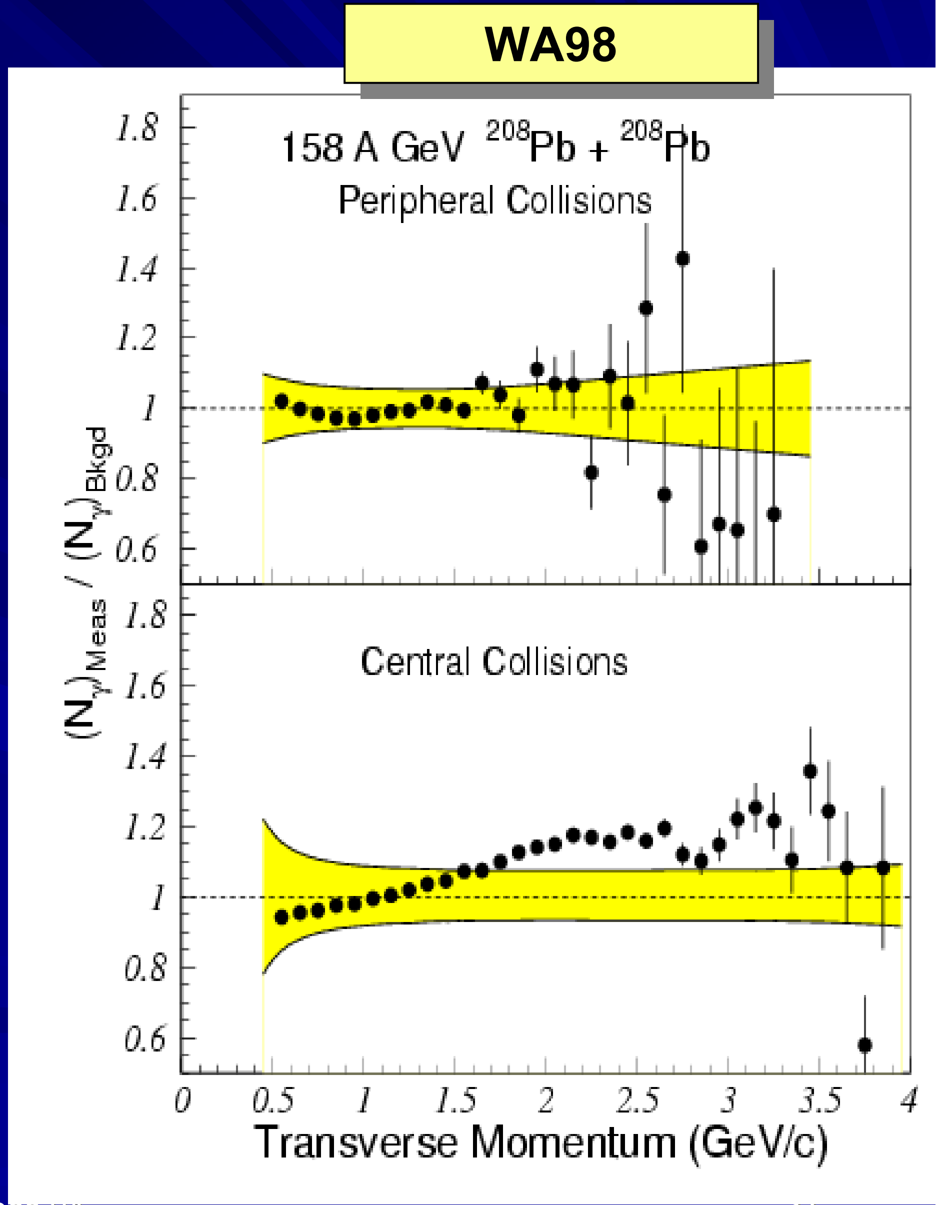
➤ **PHENIX will have soon results on both channels Φ → e^+e^- and K^+K^-**

Thermal Photons

- A direct signature of QGP
- Direct measurement of plasma T
- But where are they?

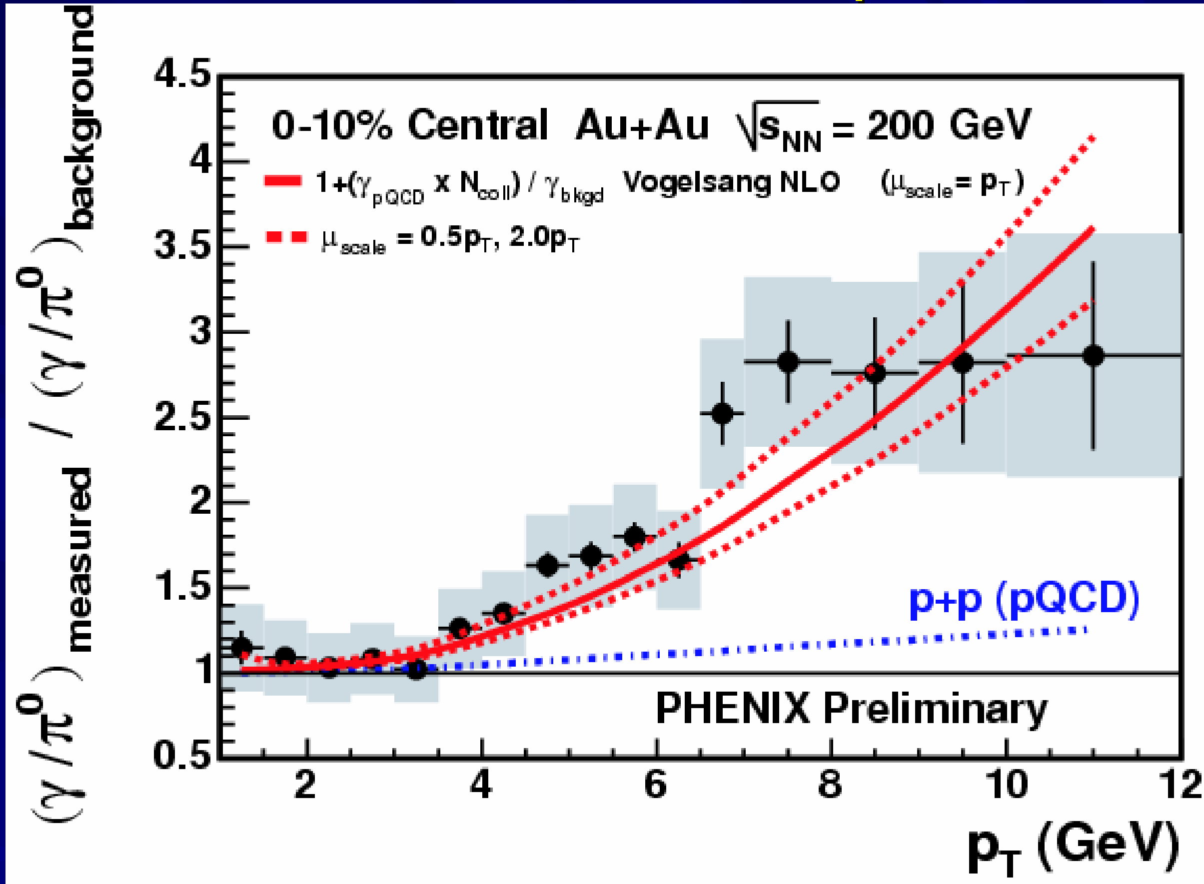
Direct Photons at CERN





Excess beyond pQCD photons?
Need precise reference pp data

Photon excess at high p_T compatible with pQCD



Strong direct photon signal at RHIC

Thermal photon signal limited by present error bars
Significant improvement expected from run-4 data

Summary

- Low-mass pairs: precise data (pp reference data and high mass resolution) → NA60 and PHENIX
- Intriguing results from KEK. No further input before CBM?
- The Φ meson: are dN/dy results correct ?
- Thermal photons: very tough measurement. First good opportunity → RHIC run 4