Low Mass Dilepton and Photon Production at the CERN SPS

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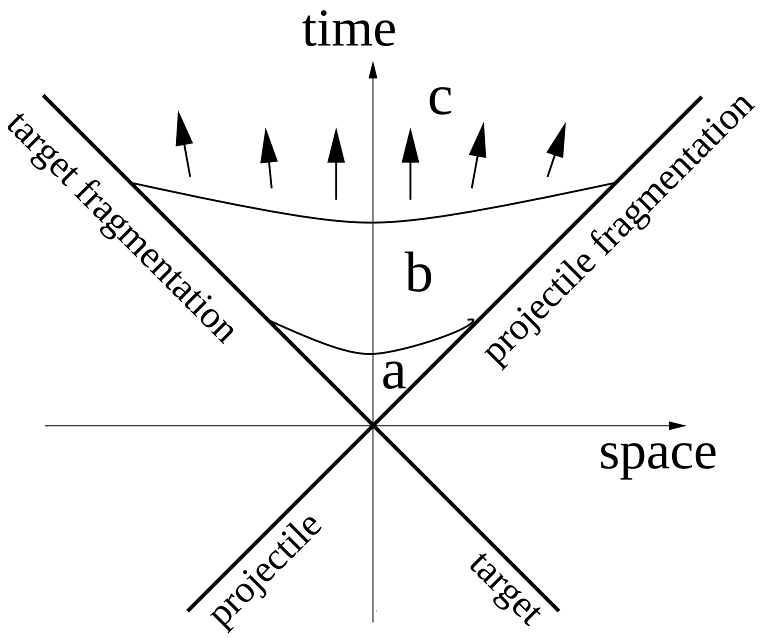
Les Houches, April 7, 1998

- **Introduction**
  - electromagnetic radiation
  - experimental program
- **p-Nucleus Collisions**
  - historical dilepton measurements
  - recent dilepton data from CERN
  - high $p_\perp$ direct photons
- **Dilepton Data from S- and Pb-beam**
  - dilepton enhancement
  - strong centrality dependence
  - largest at low $p_\perp$
- **Search for Direct Photons**
  - upper limit from O- and S-beams
  - comments on preliminary Pb-beam data
- **Interpretation of the Results**
  - hot and dense nuclear matter
  - medium effects
- **Outlook**

Electromagnetic Radiation
ideal probe for nuclear matter

- γ and e^+e^-, $\mu^+\mu^-$ emitted at any time during collision



a) formation phase
   Drell-Yan mechanism ..

b) hot and dense phase
   thermal radiation ..

c) freeze-out
   hadron decays ..

- no strong final state interaction
  carry information from time of creation to detectors

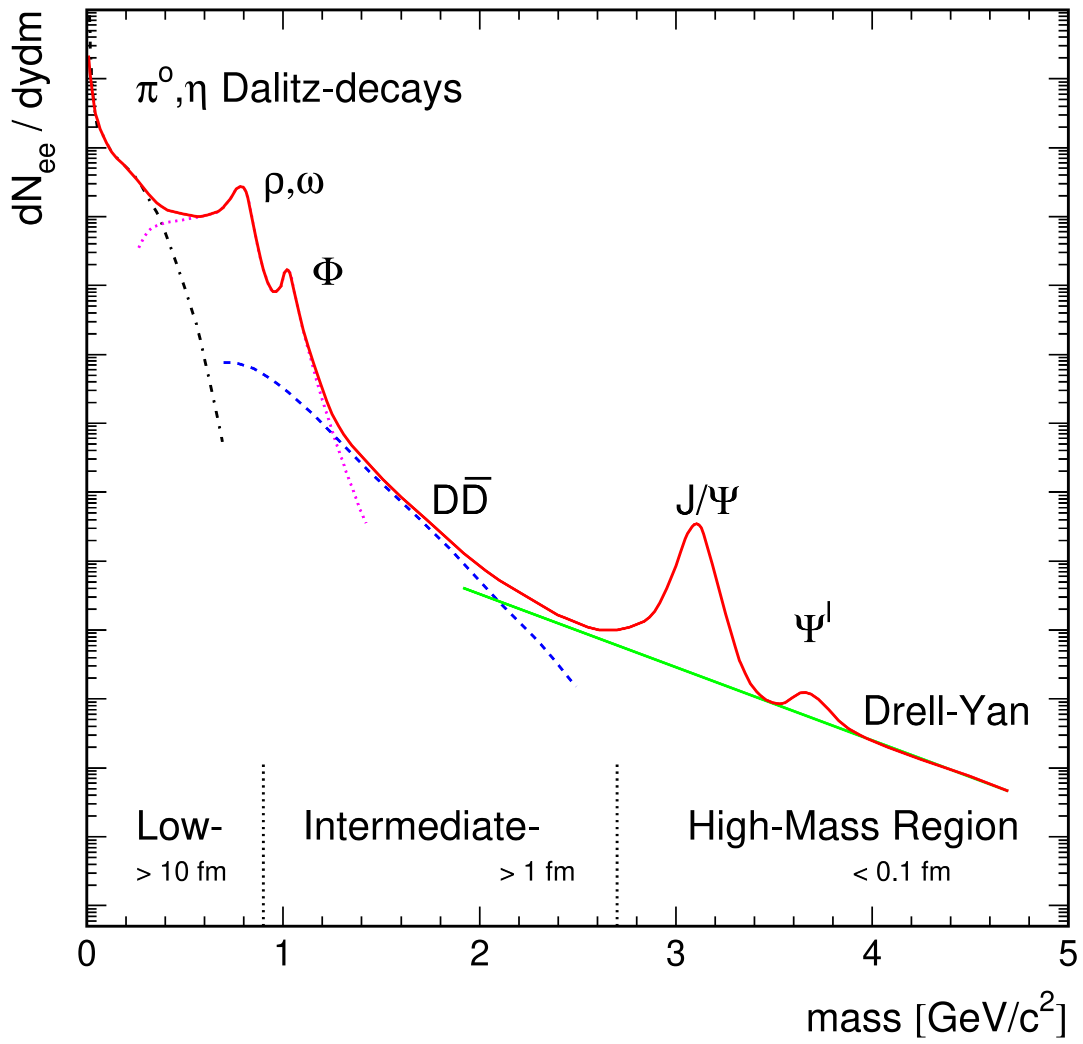
- measured spectra reflect full-space time evolution
  need careful subtraction of "conventional sources"

➡ **signal from hot and dense part of collision**

Electromagnetic Radiation e^+e^-, $\mu^+\mu^-$ and γ

- photons and lepton pairs have similar physics
  but lepton pairs carry mass $\longrightarrow$ more sensitive to new physics

Schematic View of Dilepton Production



➡ new physics expected in heavy ion collisions:

- direct radiation: $\pi\pi \rightarrow l^+l^-$ $\quad m < 1GeV$
  $q\bar{q} \rightarrow l^+l^-$ $\quad m_\phi < m < m_{J/\psi}$

- change of meson properties:
  ρ decays inside medium ($\tau_\rho = 1.3$fm)

Experimental program at the CERN SPS

4 fixed target experiments with 60 to 450 GeV beams

Dilepton Experiments:

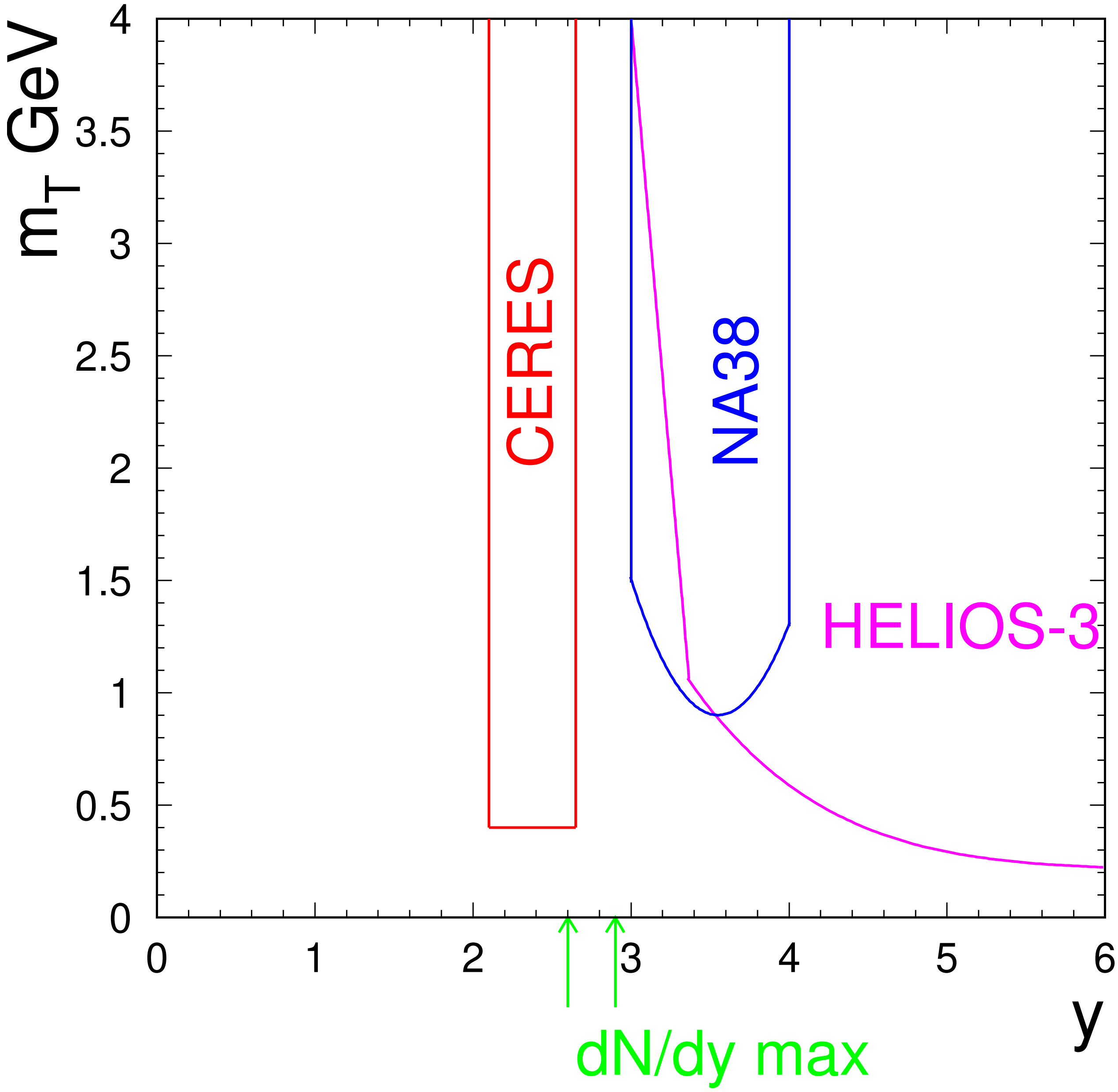
HELIOS-1	e^+e^-	$3.15 < y < 4.65$	low masses
	$\mu^+\mu^-$	$3.65 < y < 4.9$	low masses
	p-Be data (completed)		
HELIOS-3	$\mu^+\mu^-$	$3.5 < y$	up to J/Ψ
	p-W and S-W data (completed)		
CERES	e^+e^-	$2.1 < y < 2.65$	low masses
	p-Be, p-Au, S-Au and Pb-Au data		
NA38,NA50,NA51	$\mu^+\mu^-$	$3 < y < 4$	high masses
	p-A, S-U and Pb-Pb data		

Photon Experiments:

HELIOS-2		$1.0 < y < 1.5$	$0.1 < p_\perp < 1.5$ GeV
	p-W, O-W, S-W data (completed)		
WA80,WA98	O-Au	$1.5 < y < 2.1$	$0.4 < p_\perp < 2.8$ GeV
		$2.1 < y < 2.9$	$0.4 < p_\perp < 3.0$ GeV
	O-Au, S-Au and Pb-Pb data		
CERES		$2.1 < y < 2.65$	$0.4 < p_\perp < 2.0$ GeV
	S-Au and Pb-Au data		

Dilepton Experiments at CERN

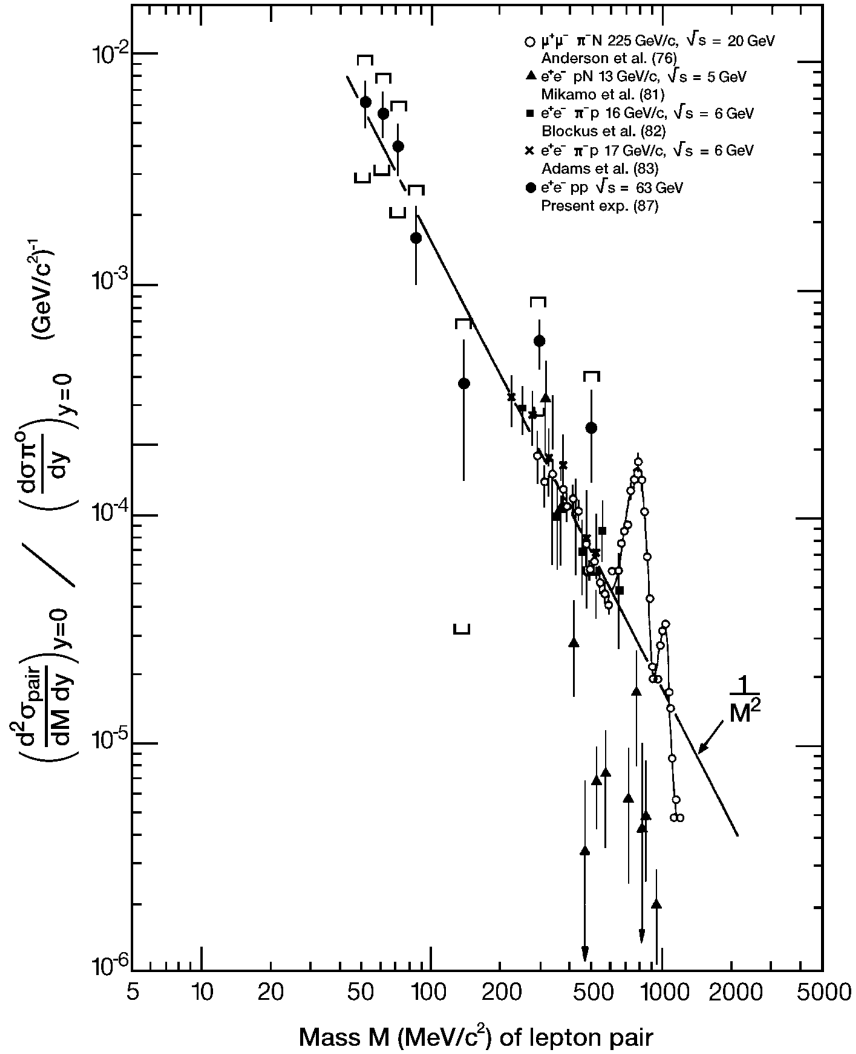
acceptance region for ion beam results



- $\mu^+\mu^-$ restricted to forward rapidity or high $m_\perp$
- e^+e^- small acceptance at mid rapidity down to low $m_\perp$

Historic Lepton Pair Measurements

H.J. Specht, Conf.Ultrarel.Nucl.-Nucl.Coll. Helsinki (1984)



- dilepton yield form different experiments normalized to π° yield
- not explained by hadron decays at the time
  anomalous low mass enhancement
  - ➡ bremsstrahlung
    (R.Rückel, Phys.Lett. B 64 (76) 39)
  - ➡ soft annihilation model $(q\bar{q} \to l^+l^-)$
    (J.D.Bjørken and H.Weisberg, Phys.Rev. D 13 (76) 1405)
    (V.Černý et al., Phys.Rev. D 24 (81) 652)
  - ➡ QGP
    (E.V.Shuryak, Phys.Lett. B 78 (78) 150)
- **BUT** at that time
  contribution from hadron decay was underestimated

The Hadronic Cocktail

neutral meson decay contribution:

photons: $\pi^\circ, \eta, \eta' \to \gamma\gamma \quad \omega \to \gamma\pi^\circ$

dileptons: $\eta, \eta' \to l^+l^-\gamma \quad \omega \to l^+l^-\pi^\circ \quad \rho, \omega, \phi \to l^+l^-$

- measure differential cross section $d\sigma/dp_\perp$ and $d\sigma/dy$ for as many neutral mesons as possible
- use empirical scaling laws (e.g. $m_\perp$-scaling) to extrapolate to non measured regions or particle species
- generate decays according to known kinematics, branching ratios and form-factors
- normalize yield to π° or n_{ch} production

contribution from formation phase:

photons: $qg \to \gamma q$ (Compton Scattering)

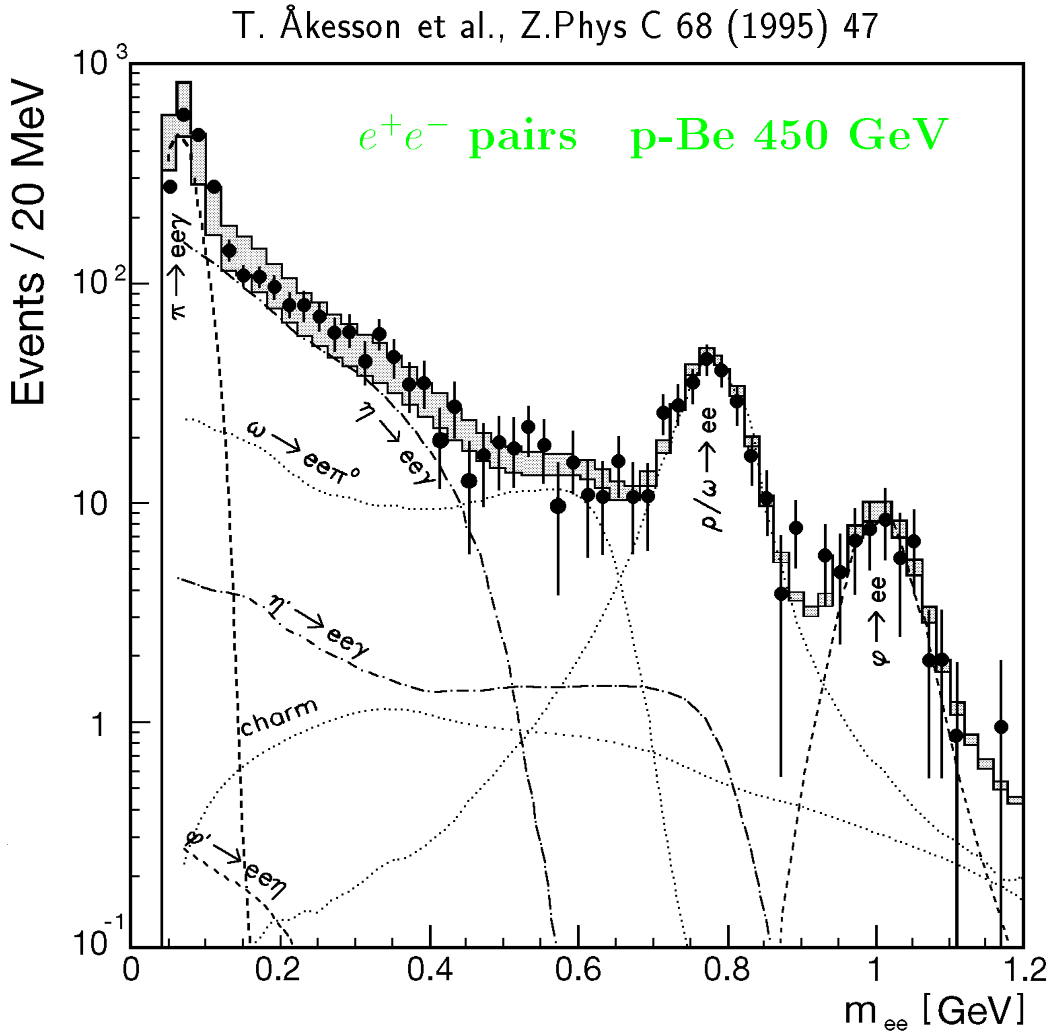
dileptons: $q\bar{q} \to l^+l^-$ (Drell Yan) and $c\bar{c}$ production

- perturbative QCD calculation of fundamental processes based on measured structure functions e.g. Pythia Event Generator which includes hadronization ($c\bar{c} \to D\bar{D}$)
- scale results to measured cross sections by k-factor
- scale with target mass A^1

fold with experimental acceptance and resolution

Pioneering Work of HELIOS 1
e^+e^- and $\mu^+\mu^-$-Pairs from p-Be

- simultaneous detection of e^+e^-, $\mu^+\mu^-$ and γ
- measure neutral mesons in final state
  exclusively reconstruct $\eta \rightarrow \gamma\gamma, \omega \rightarrow \gamma\pi^\circ$ and $\eta \rightarrow e^+e^-\gamma$



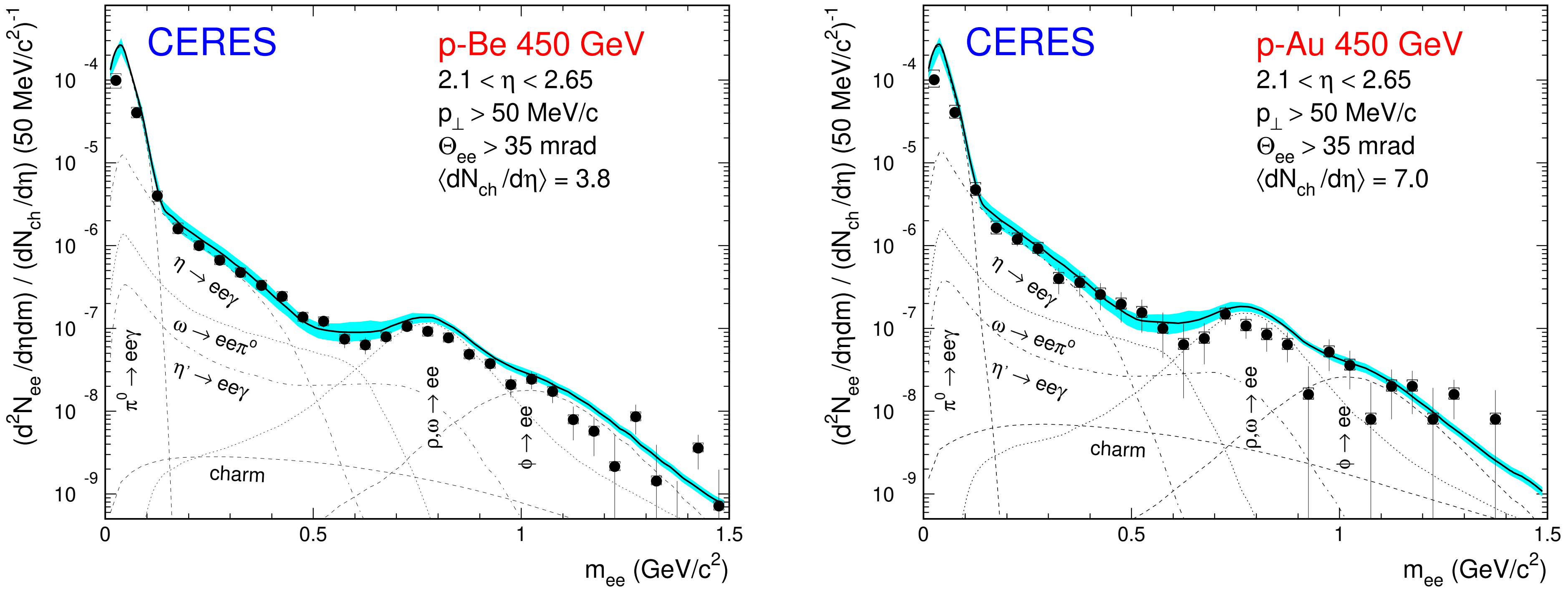
➡ decays of neutral mesons observed in final state
sufficient to account for dilepton production

➡ charm production and Drell-Yan not important for low masses

e^+e^--Pairs from p-Nucleus Collisions

joint effort of CERES and TAPS collaborations

G. Agakichiev et al. (CERES/NA45), Z.Phys C (1998) in print

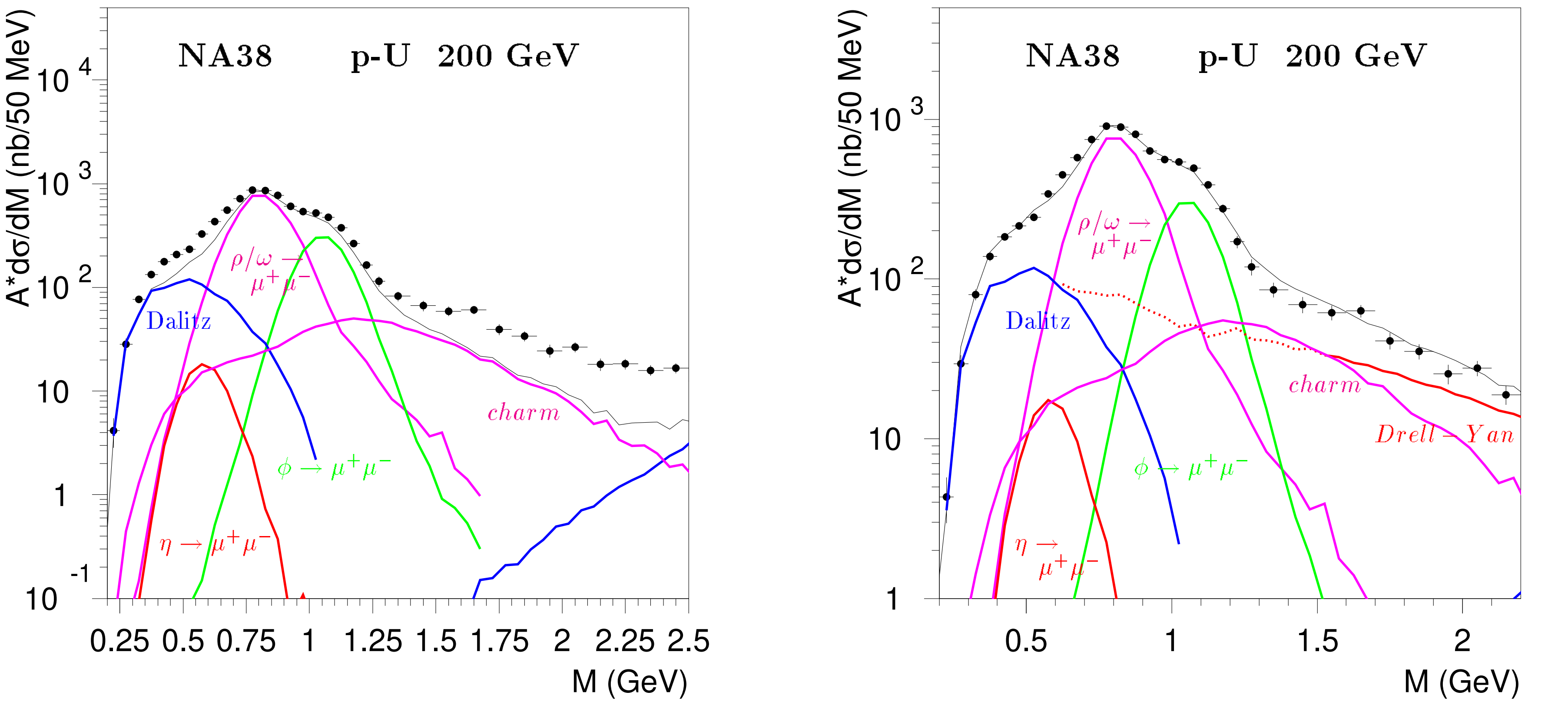


➡ within 15-40% syst. errors all electron pair result from hadron decays in p-p and p-Nucleus collisions

$\mu^+\mu^-$-Pairs from p-Nucleus Collisions

NA38 μ pairs with $m_\perp$ cutoff at ~ 1 GeV

A. De Falco et al.(NA50), Nucl.Phys. A (1998) proceedings of QM97



- neutral meson and associated $D\bar{D}$ decays + Drell Yan explain mass spectrum
- 50% enhancement at low mass (for high $m_\perp$ cut)

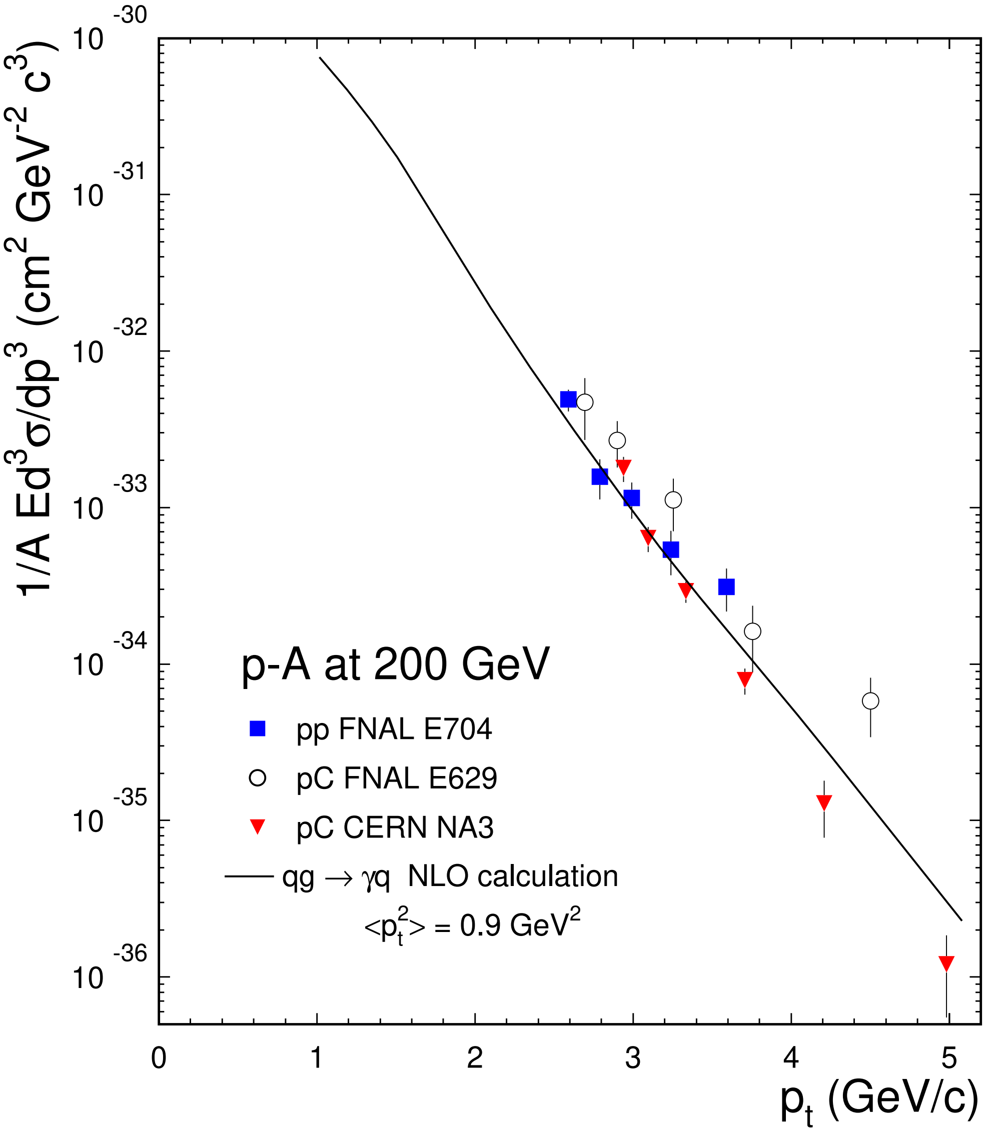
  ➡ can be explained by $q\bar{q}$ annihilation (Drell-Yan extrapolated to low mass)

- $q\bar{q}$ annihilation of produced quarks at low $m_\perp$ (soft annihilation model of Bjørken, Weisberg)??

High $p_\perp$ Direct Photons in p-Nucleus

subtract hadron decay contribution from inclusive γ $p_\perp$-spectra

C. Wong and H. Wang, hep-ph/9802378 (1998)



➡ direct photons in p-A collisions for $p_\perp > 2$ GeV

- scale like A^1 ➡ expected for hard process
- consistent with $qg \to \gamma q$ Compton scattering

"conventional" source from formation phase

Scaling to Nucleus-Nucleus

neutral meson decay contribution:

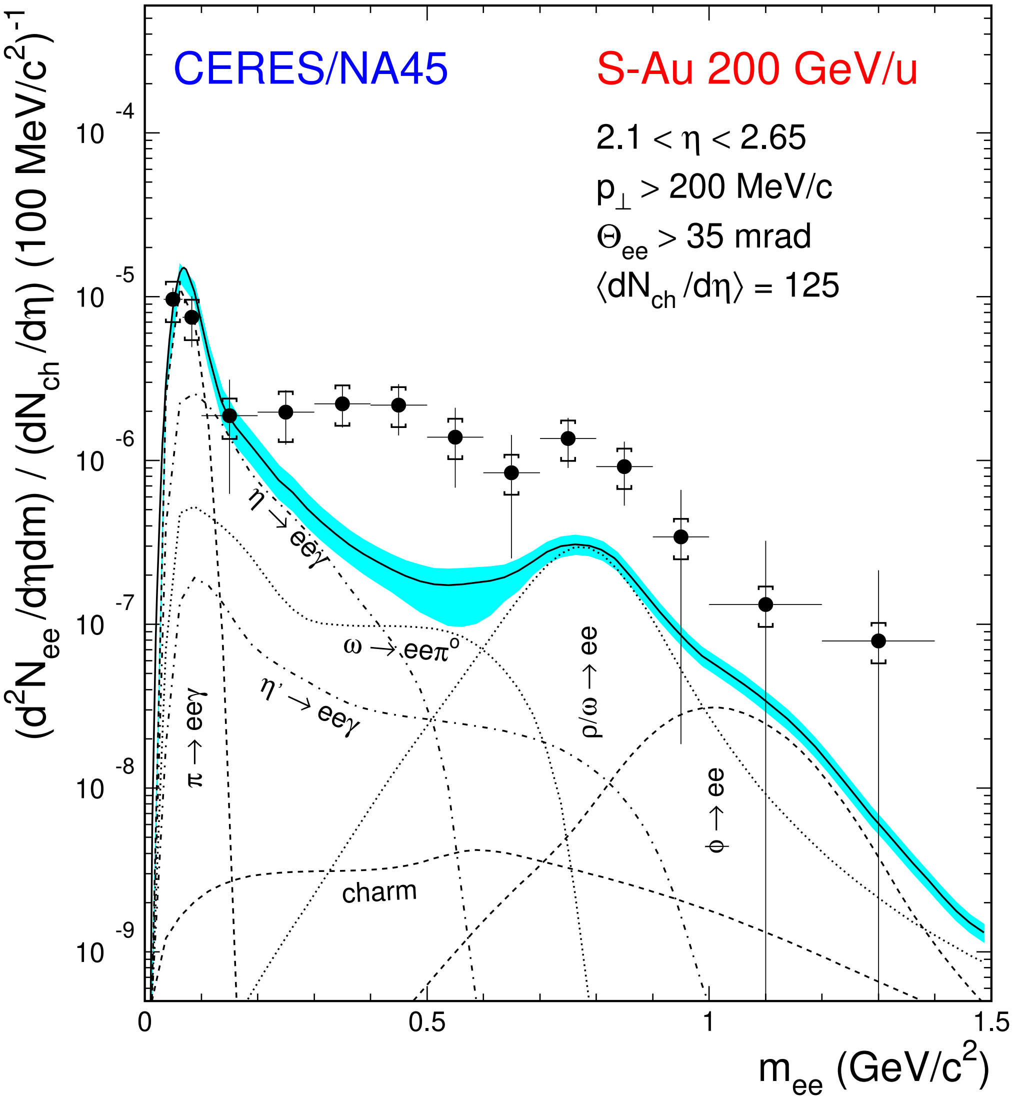
- assume universal relative particle abundances
  $\pi^\circ/\eta/\rho/\omega/\phi$ ratios independent of collision system
- rapidity distributions Gaussian shaped
  fitted to measured h^- or n_{ch} data
  scaled for other mesons by $y_{max}(m)/y_{max}(\pi)$
- $p_\perp$-distribution fitted for π and K
  assume scaling with mass based on K-distribution

contribution from formation phase:

- scale with target and projectile participants

CERES e^+e^--pairs from central S-Au

G. Agakichiev et al. (CERES), Phys.Rev.Lett. 75 (1995) 1272



enhancement of e^+e^--pairs from S-Au above conventional sources

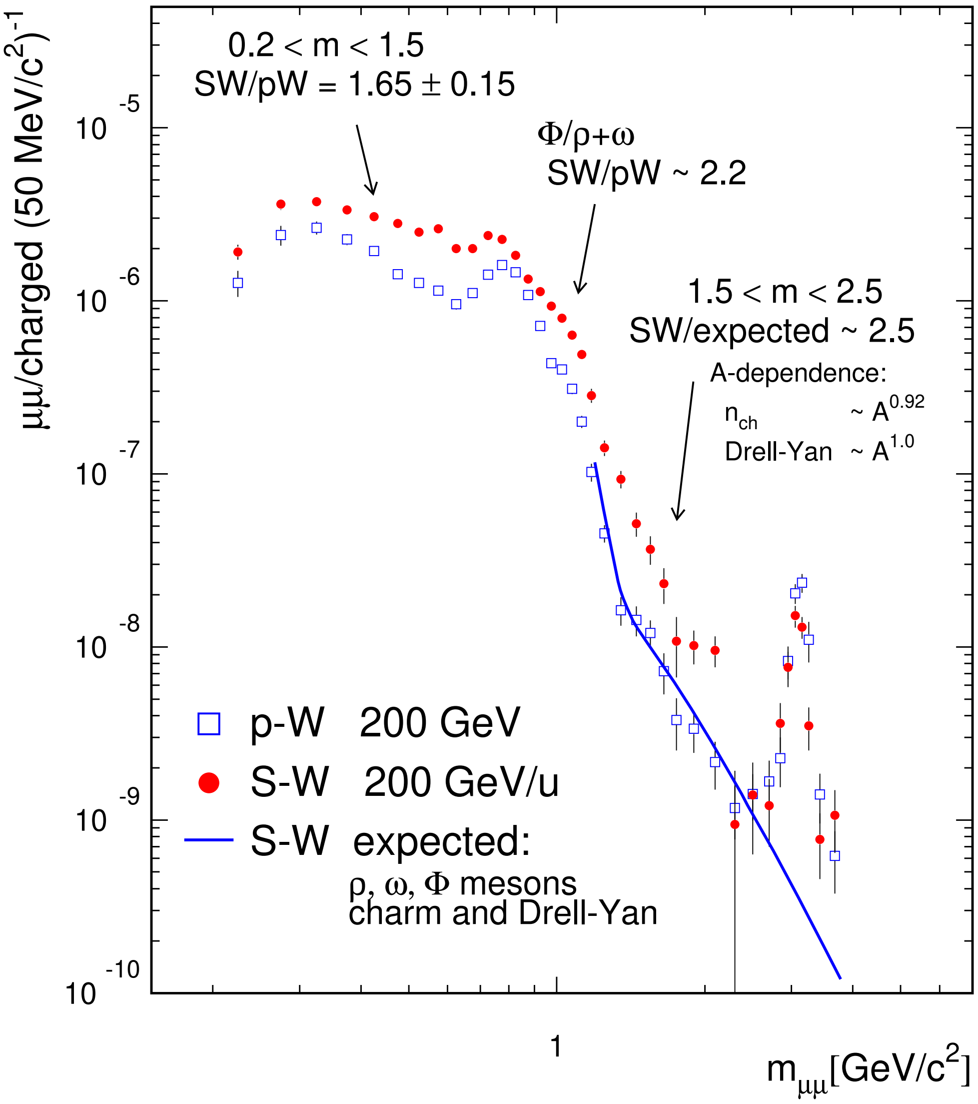
- threshold near $2m_\pi$
- spectral shape different from hadron decay contribution

enhancement factor: $$\frac{Data}{Sources} = \frac{N_{e^+e^-}^{measured}}{N_{e^+e^-}^{expected}}$$

for $0.2 < m < 1.5$ GeV/c^2 $\quad D/S = 5.0 \pm 0.7(stat) \pm 2.0(syst)$

HELIOS-3 $\mu^+\mu^-$-pairs from S-W

M. Masera et al. (HELIOS-3), Nucl.Phys. A590 (1995) 93c



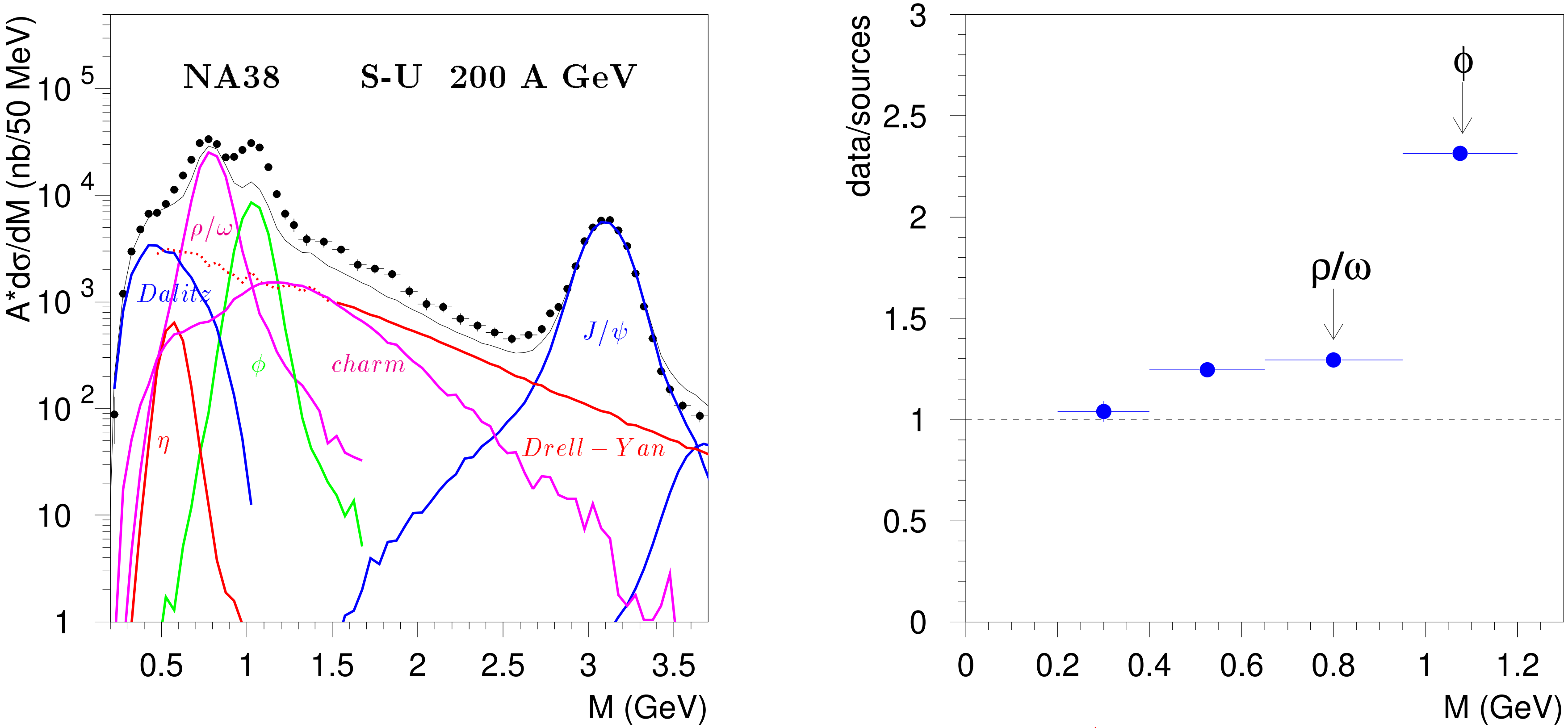
enhancement S-W/p-W from 200 MeV up to J/ψ

large impact parameter range biased towards central collisions

NA38 $\mu^+\mu^-$-Pairs from min. bias S-U Collisions

μ pairs with $m_\perp$ cutoff at $\sim$ 1 GeV

A. De Falco et al.(NA50), Nucl.Phys. A (1998) proceedings of QM97

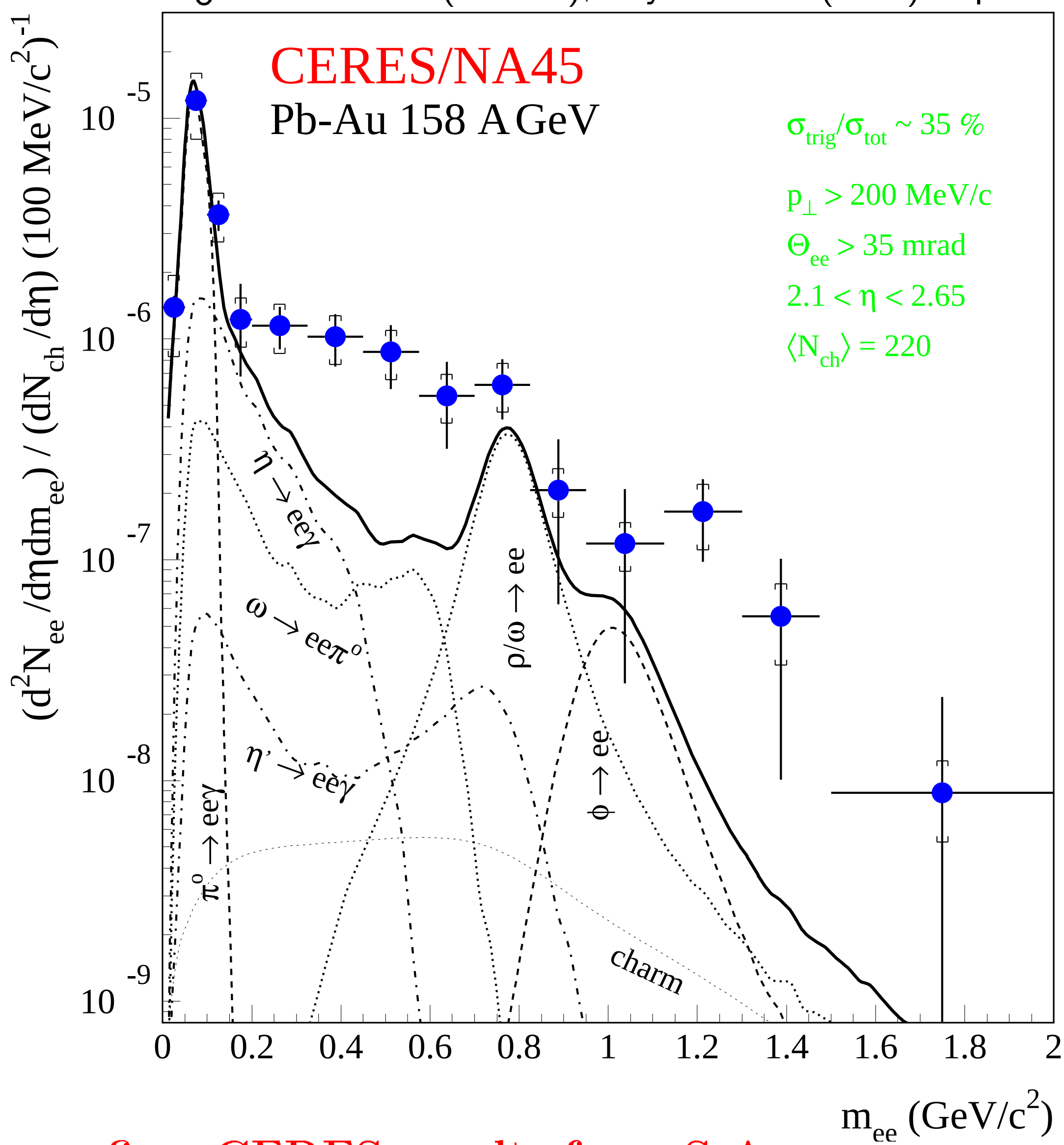


➡ **enhancement from 400 MeV up to J/ψ**

- 40% enhancement from 400 to 900 MeV
- ϕ enhancement by factor 2.5
- 50% from ϕ to J/ψ

CERES e^+e^--pairs from Pb-Au

G. Agakichiev et al. (CERES), Phys.Lett.B. (1998) in print



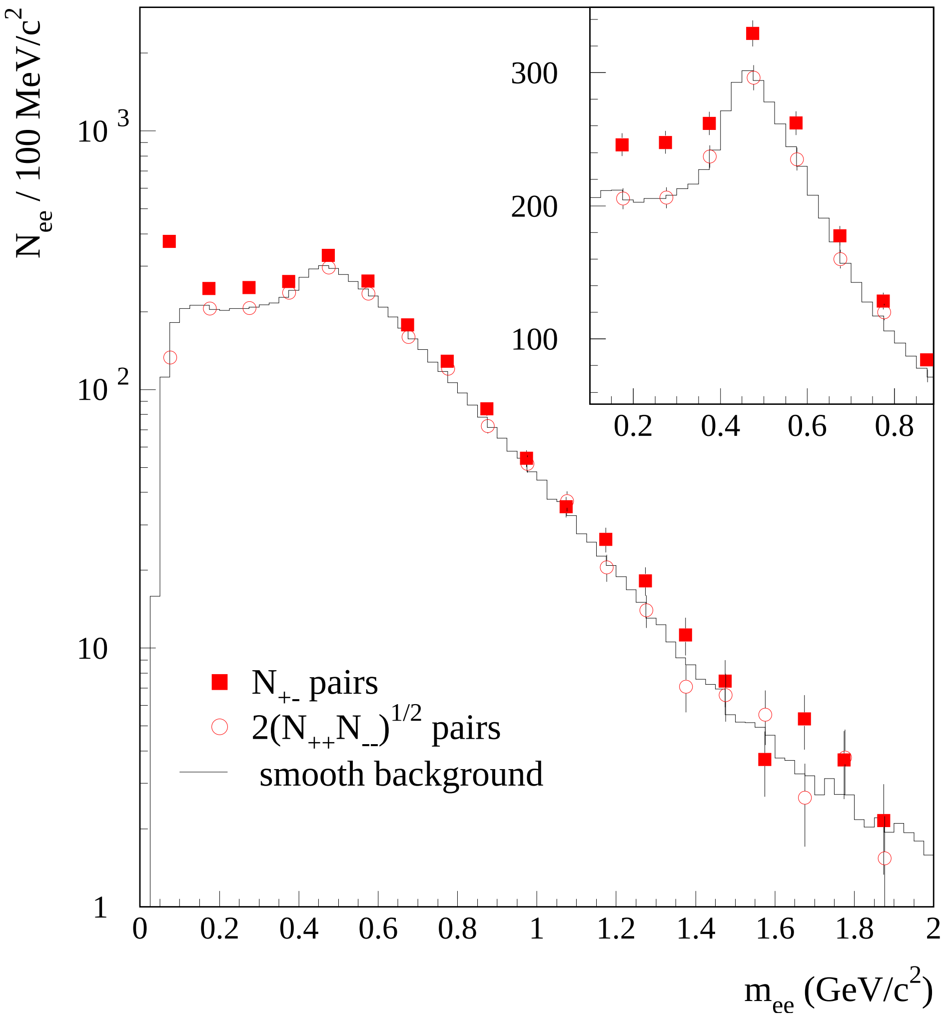
confirm CERES results from S-Au

- enhancement $(0.2 < m < 2.0)$ $3.5 \pm 0.4(stat) \pm 0.9(syst)$
  for 35% of geometrical cross section
- threshold near $2m_\pi$
- no prominent structure of ρ/ω
- corroborate enhancement at higher masses

CERES Pb-Au Subtraction of Combinatorial Background

combinatorial pairs from incompletely reconstructed $\gamma \to e^+(e^-)$ and $\pi^\circ \to (\gamma e^+)e^-$

$\sim$80% of tracks from background pairs removed by rejection cuts



- measure like-sign pairs
  dN_{--}/dm and dN_{++}/dm
- $(dN_{++}/dm)/(dN_{--}/dm)$ is constant
  within statistical errors
- small charge asymmetry
  $N_{++}/N_{--} \sim 0.92$
- dN_{--}/dm and dN_{++}/dm
  consistent with event mixing (m>200 MeV)

➡ **unlike-sign background**
$$B_{+-} = 2\sqrt{N_{++} * N_{--}}$$

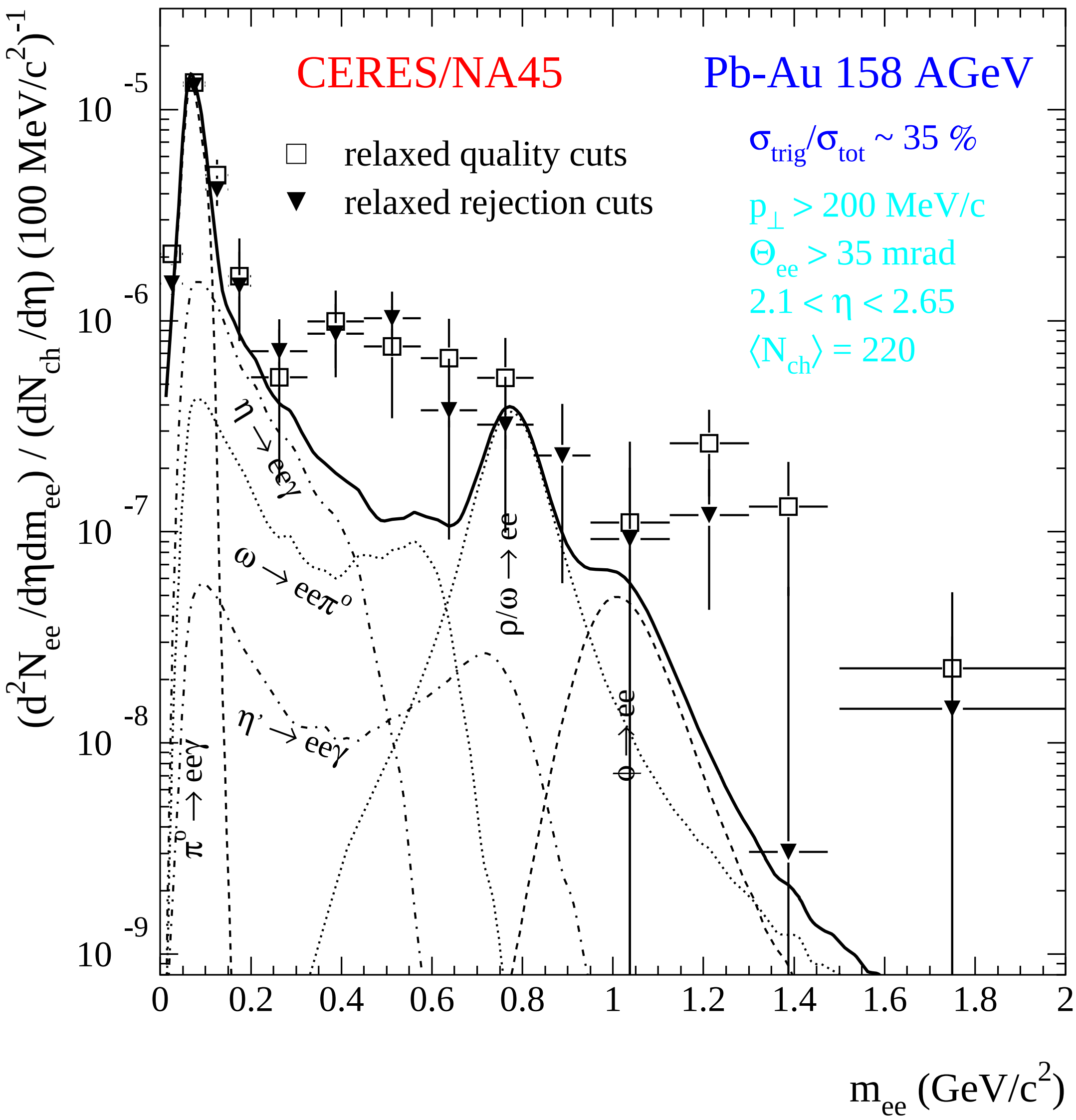
➡ **electron pair signal**
$$S = N_{+-} - 2\sqrt{N_{++} * N_{--}}$$

➡ **signal-to-background ratio** $S/B \sim 1/8$

CERES Pb-Au Cross Check of Background

repeat full analysis with different S/B ratio

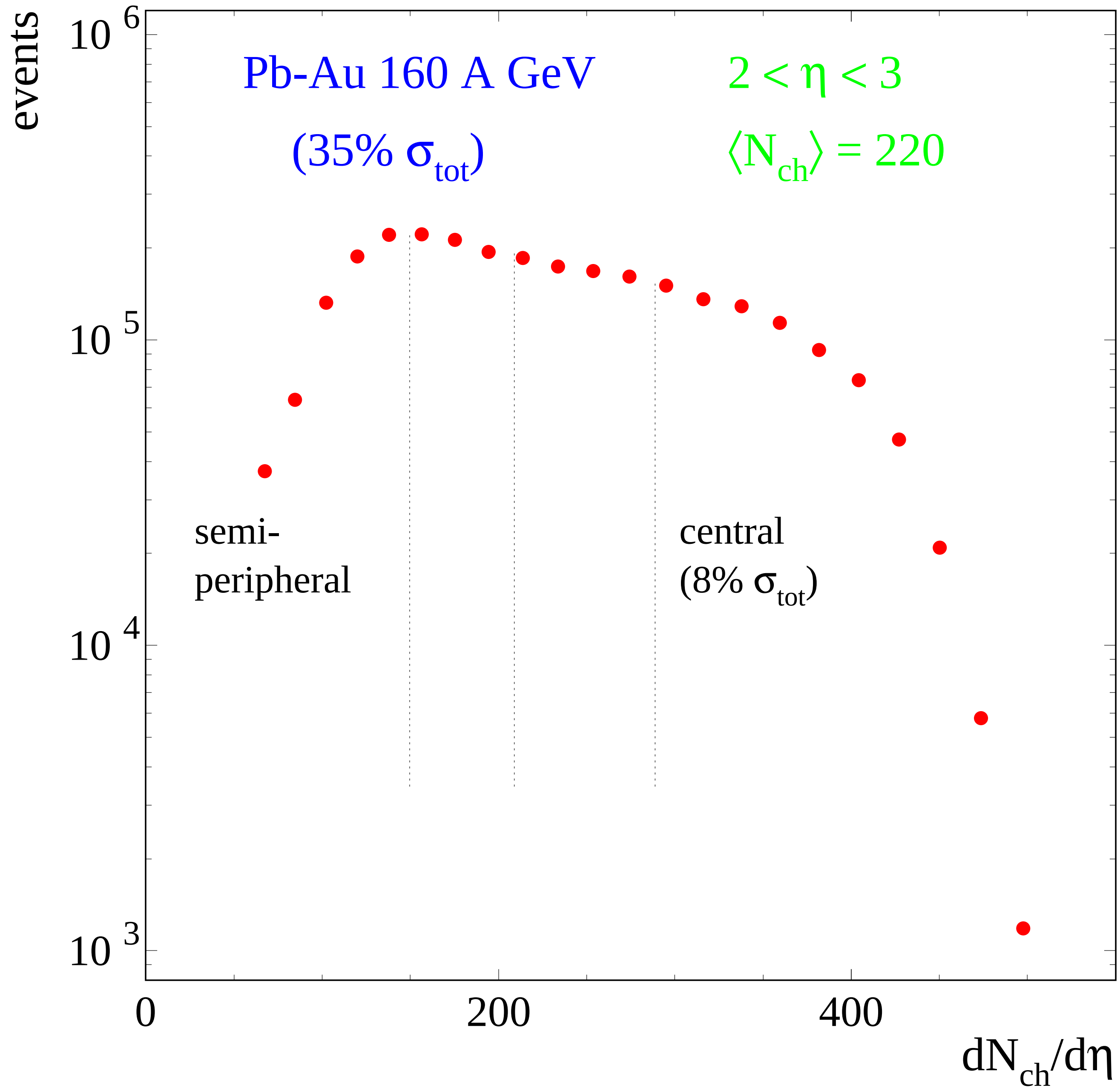
C. Voigt (CERES), Doctoral Thesis Uni. Heidelberg (1998)



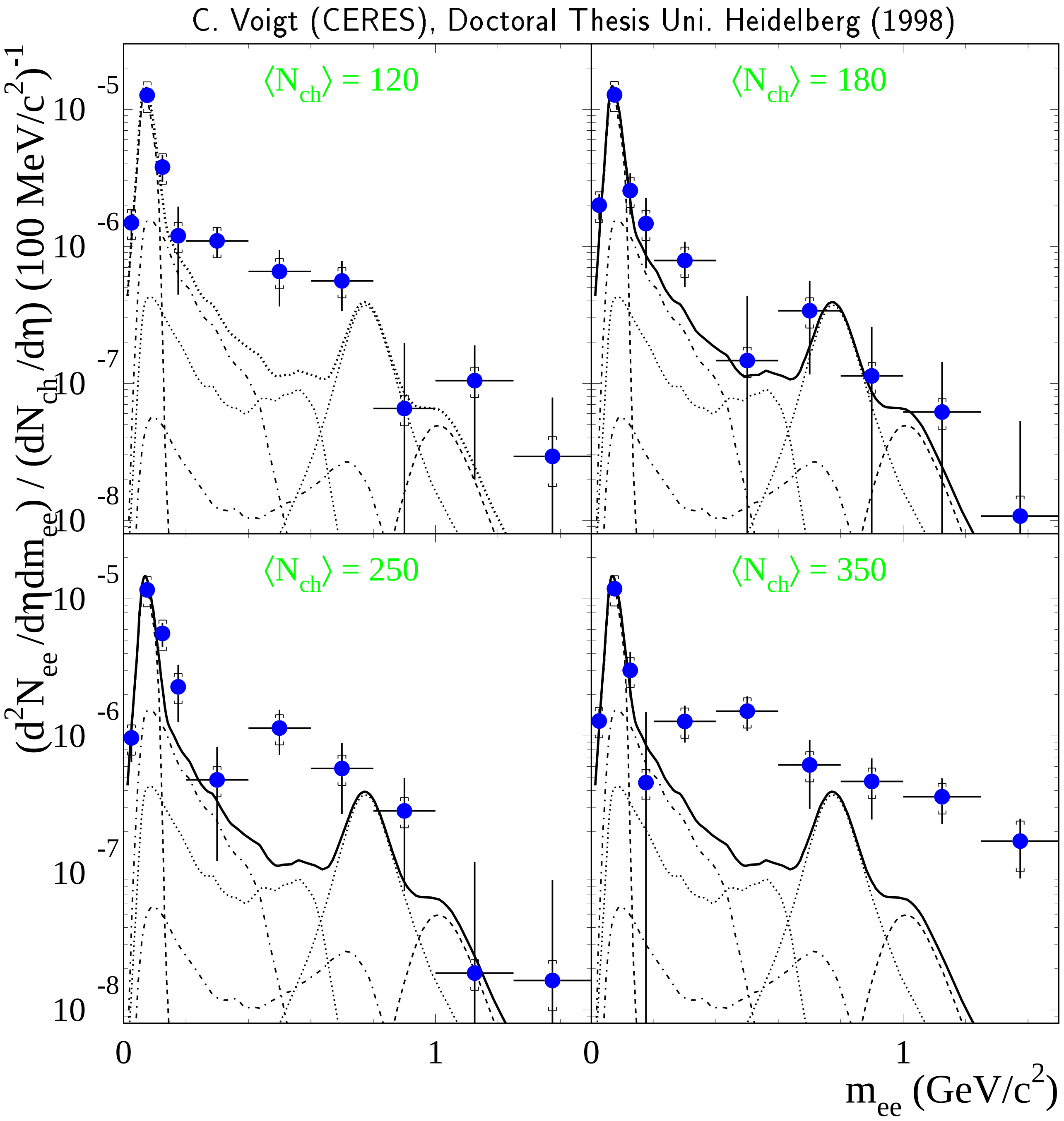
- two disjunct subsets of background rejection cuts
  S/B decreased from 1/8 to 1/22 and 1/30 (→ plot)
- full rejection but change $p_\perp$-cut from 200 to 100 MeV

➡ **result stable within systematic errors**

CERES Pb-Au impact parameter coverage



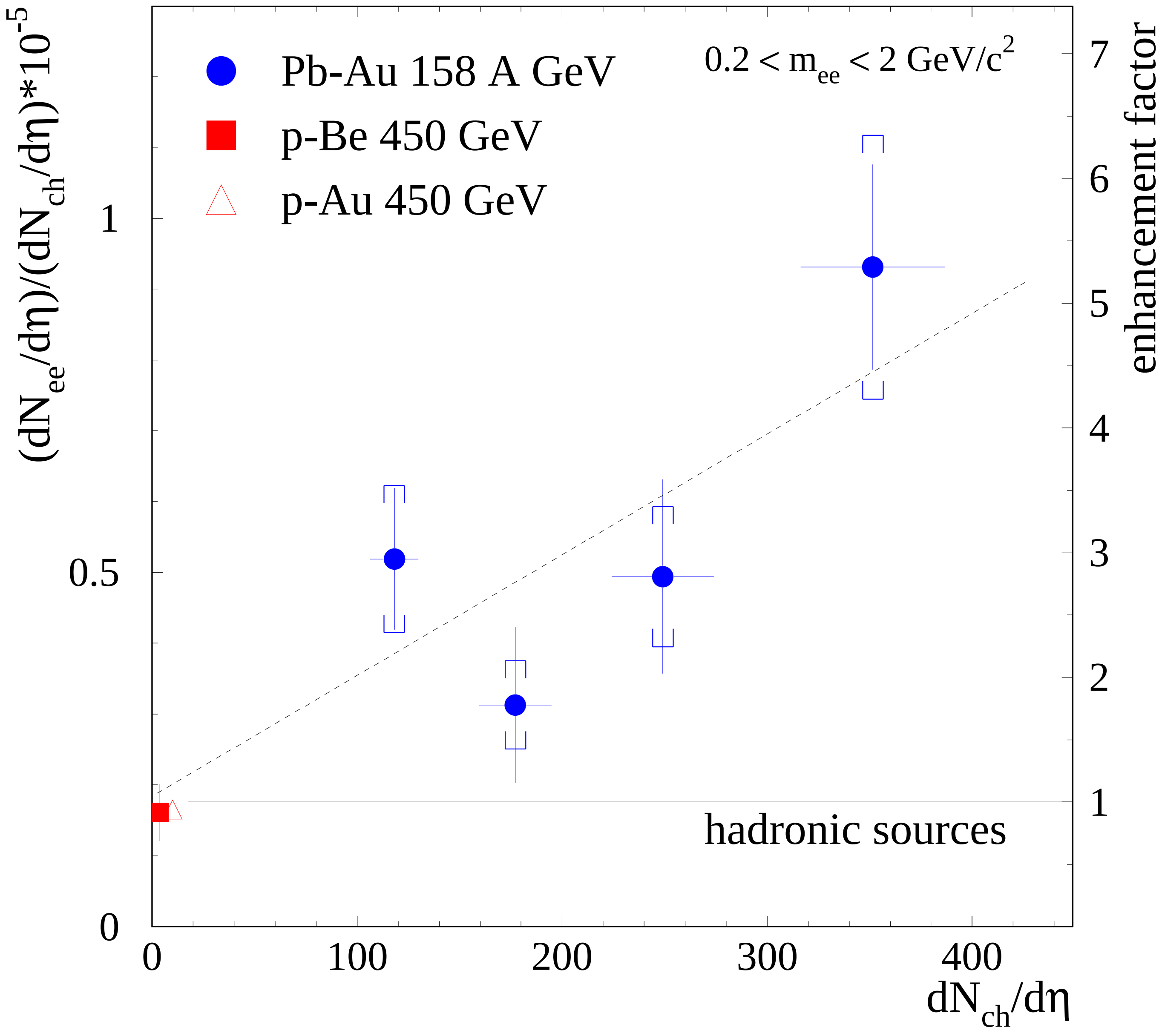
CERES e^+e^--pairs from Pb-Au



- no change in shape within errors
- increase of yield stronger than linear with multiplicity
- integrate spectra $0.2 < m < 1.5$

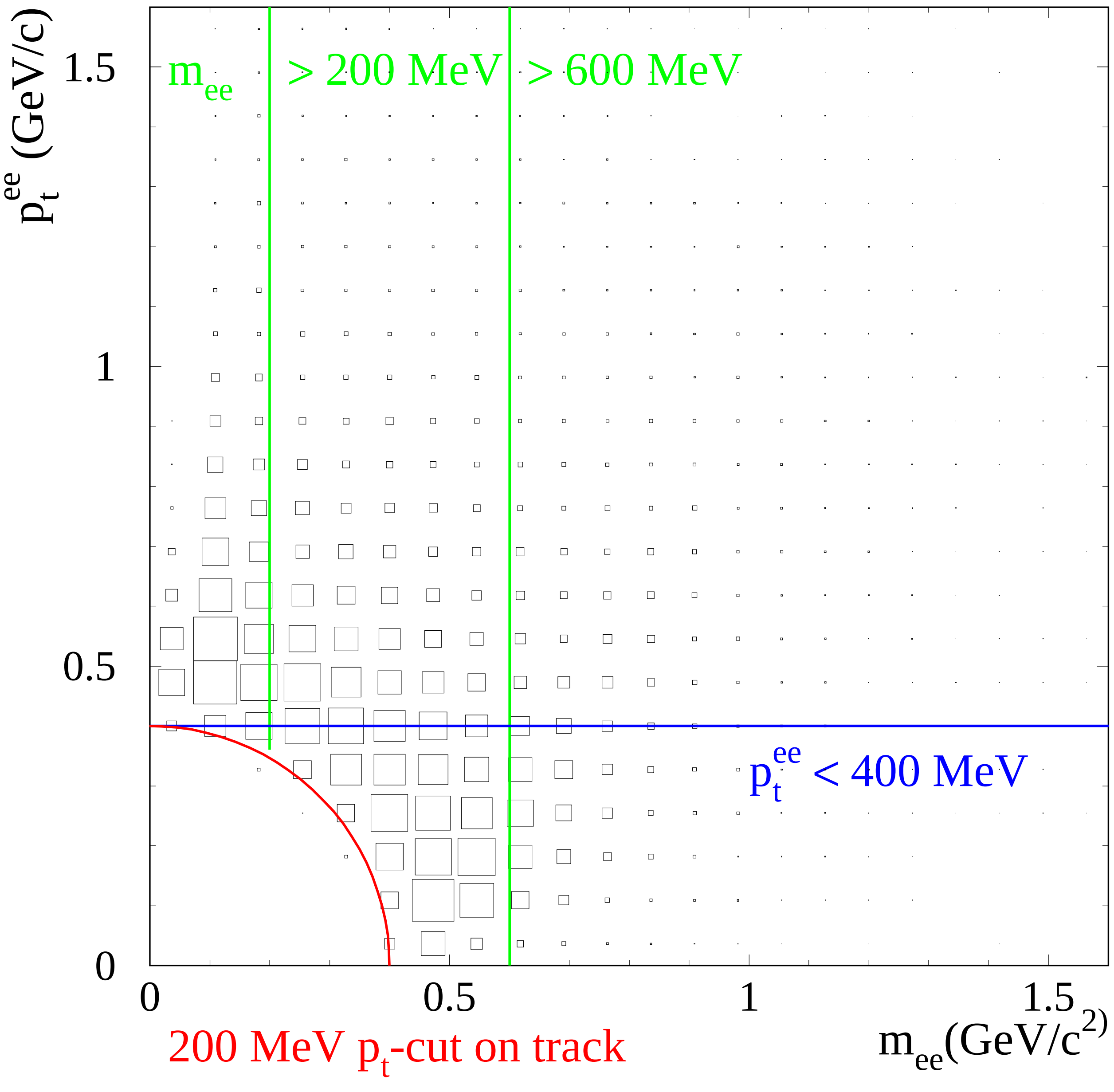
Multiplicity Dependence of e^+e^--Yield

G. Agakichiev et al. (CERES), Phys.Lett.B. (1998) in print



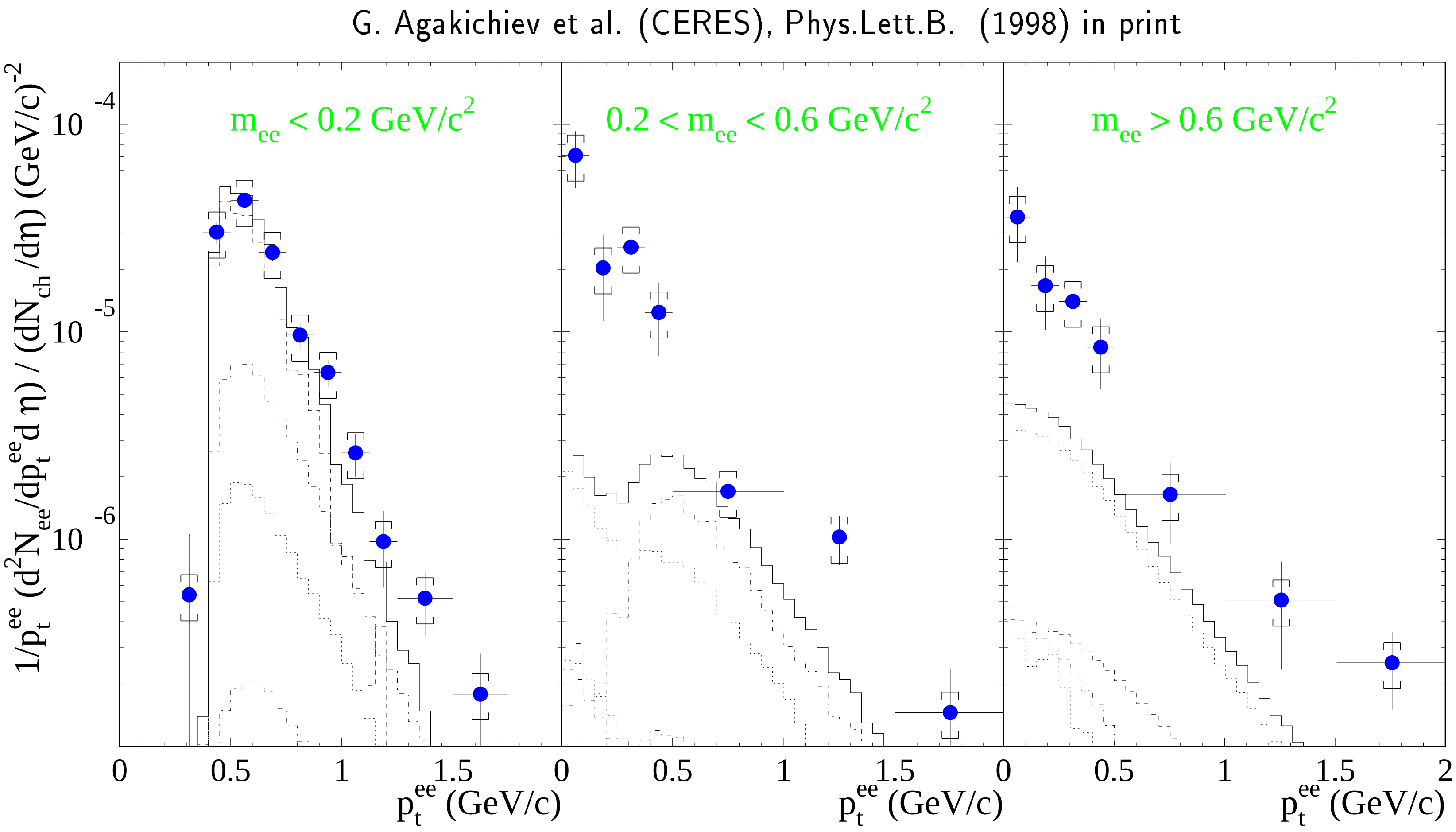
increase of e^+e^--pair yield stronger than linear with multiplicity

CERES Pb-Au Acceptance



- single track $p_\perp$-cut obscures spectra
- split data in 3 mass and 2 $p_\perp$ bins

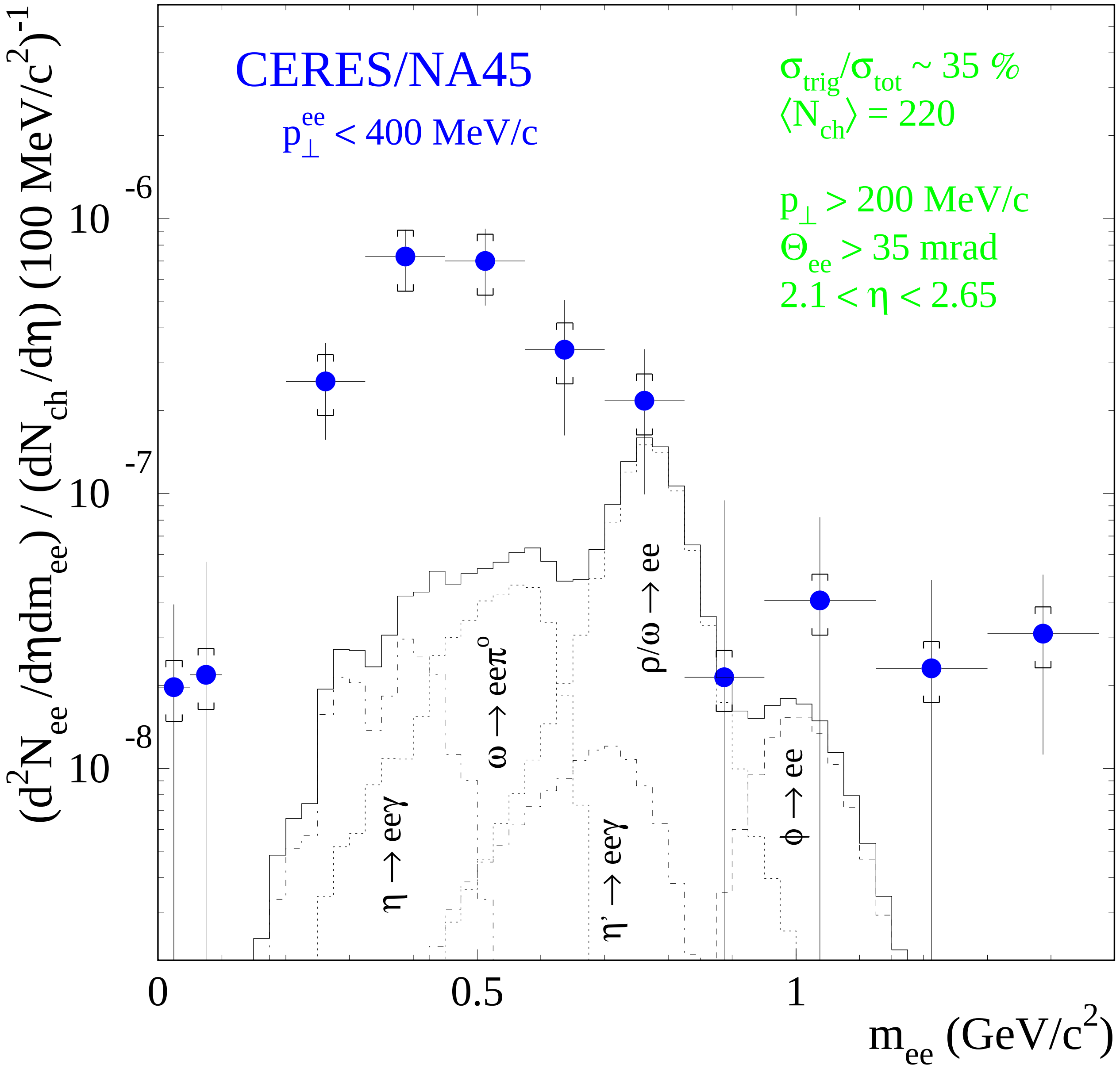
CERES Pb-Au e^+e^--pair $p_\perp$ dependence



- consistent with hadron decays only for small masses
- for m > 200 MeV enhancement over entire $p_\perp$-range
- most pronounced at low pair $p_\perp$
- largest for low pair $p_\perp$ and 200 < m < 600 MeV

CERES e^+e^--pairs from Pb-Au

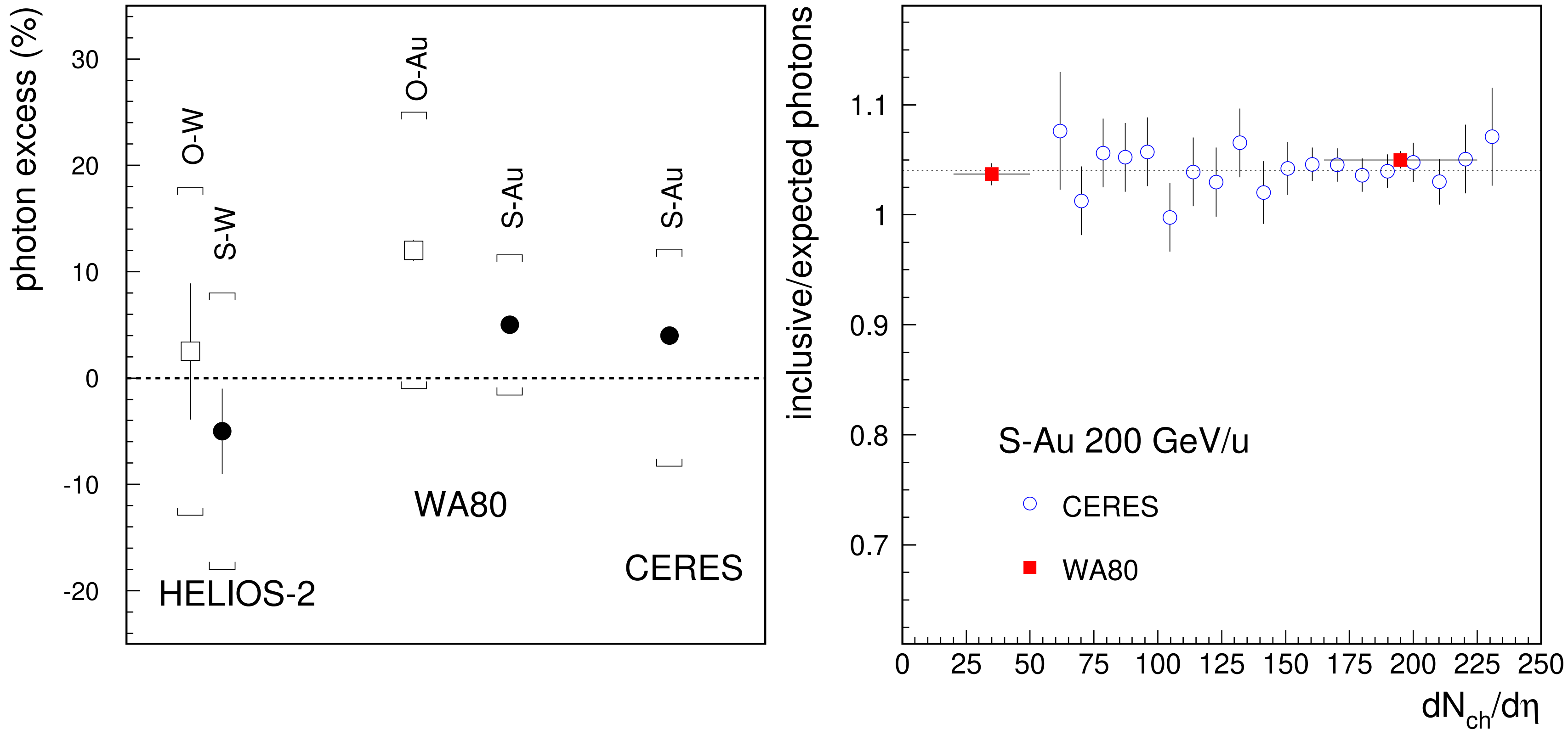
C. Voigt (CERES), Doctoral Thesis Uni. Heidelberg (1998)



- significant enhancement at low $p_\perp$
- for $200 < m < 700$ MeV yield enhancement by factor 12
- factor of 3 larger than without $p_\perp$ selection

Search for Direct Photons

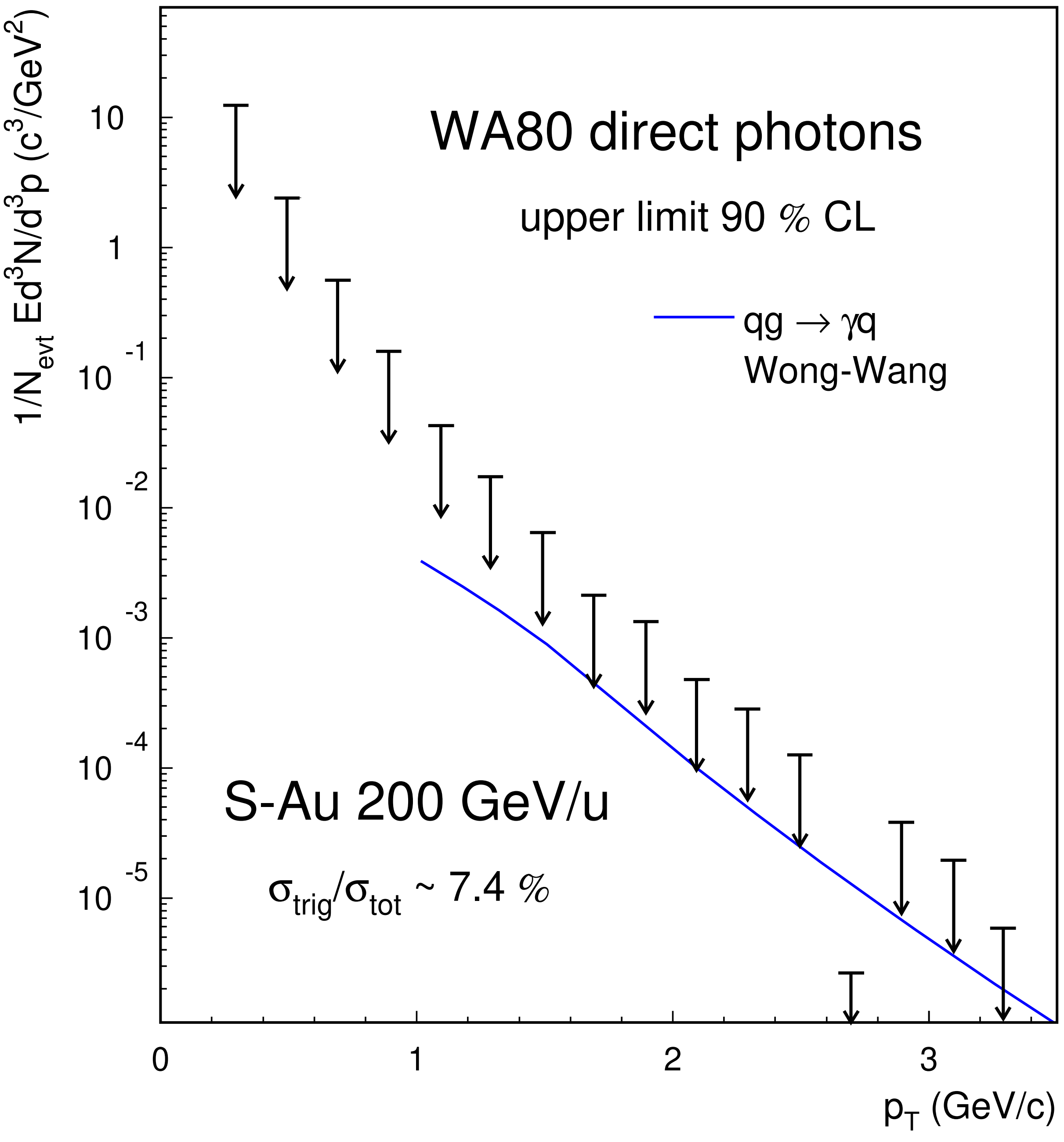
A. Drees, Nucl.Phys. A610 (1996) 536c



- for central S-Au collisions direct photon yield limited to < 13% of inclusive yield (90% CL)
- no centrality dependence yield changes from peripheral to central collisions by less than 5%

WA80 Differential Upper Limits

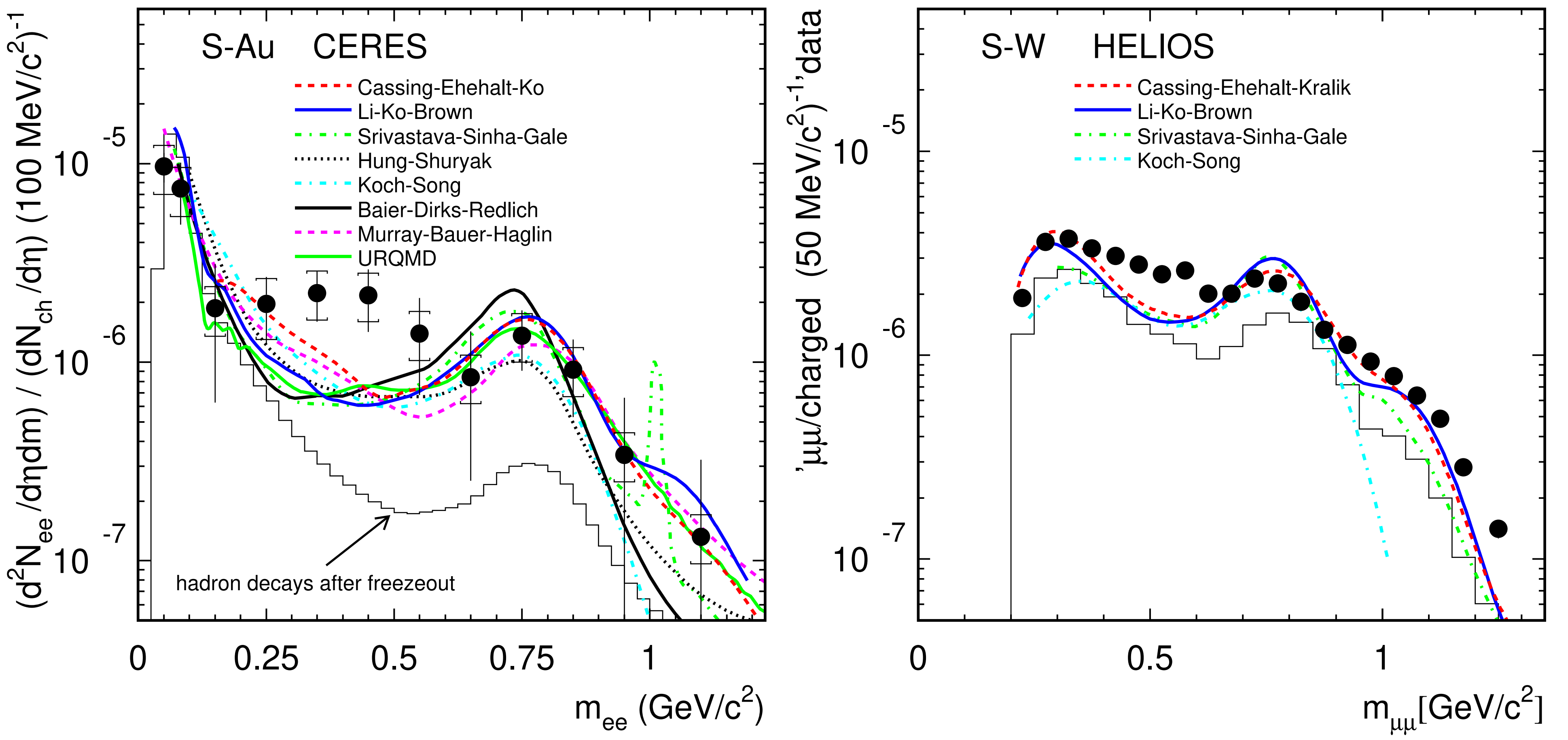
R. Albrecht et al. (WA80), Phys.Rev.Lett. 76 (1996) 3506



experiments not sensitive to QCD expectation

Radiation from Dilepton Collision System (free masses)

A. Drees, Nucl.Phys. A630 (1998) 449c



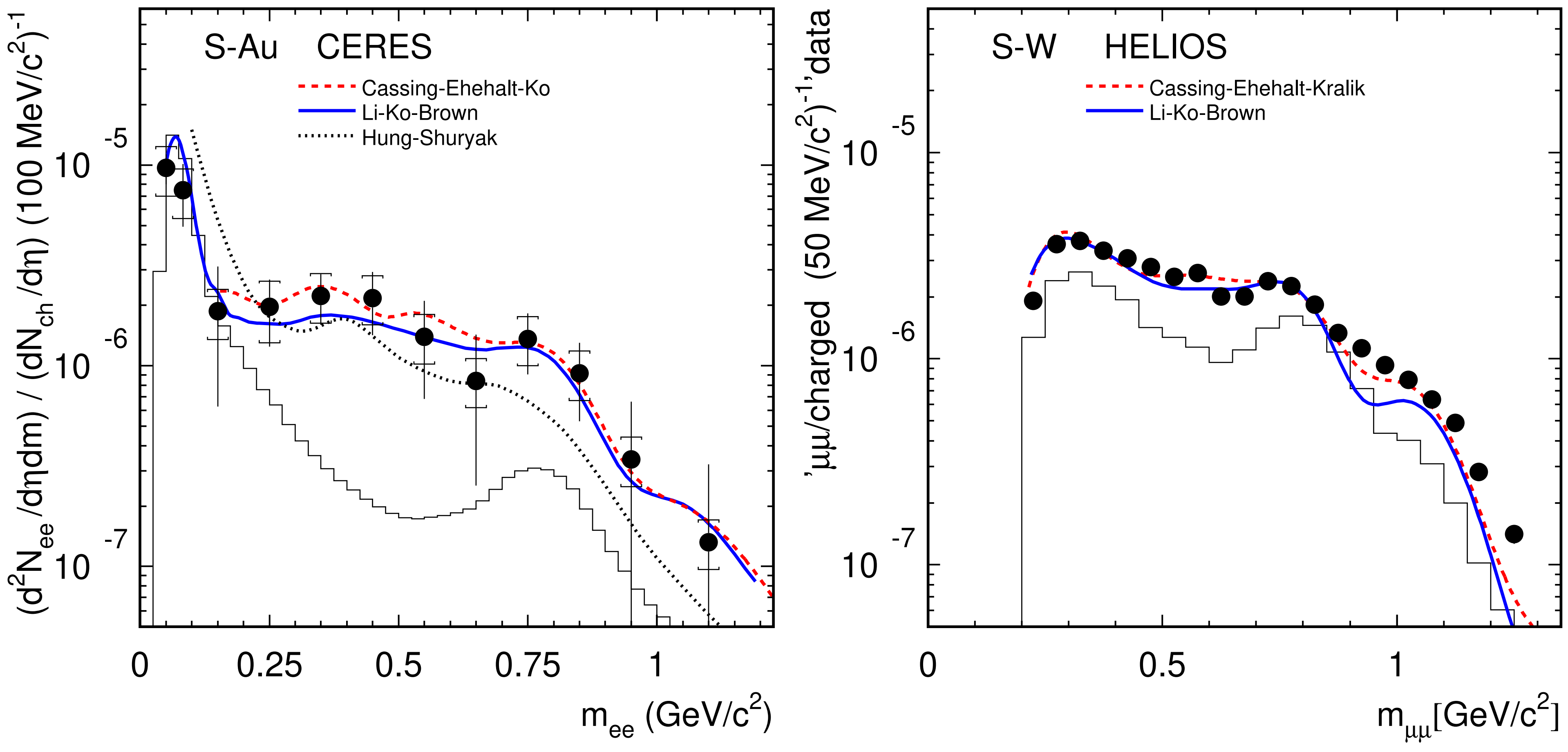
- large contribution to dilepton spectra
- $\pi\pi$-annihilation most important channel
- result insensitive to details collision dynamics and choice of processes (like $\pi\rho \rightarrow \pi e^+e^-$ ...)
- data deviates from predicted shape due to free π-form-factor

Dropping Masses in Hot and Dense Nuclear Matter

inspired by Brown-Rho scaling

meson masses drop while chiral symmetry is restored ($< \bar{q}q > \rightarrow 0$)

A. Drees, Nucl.Phys. A630 (1998) 449c

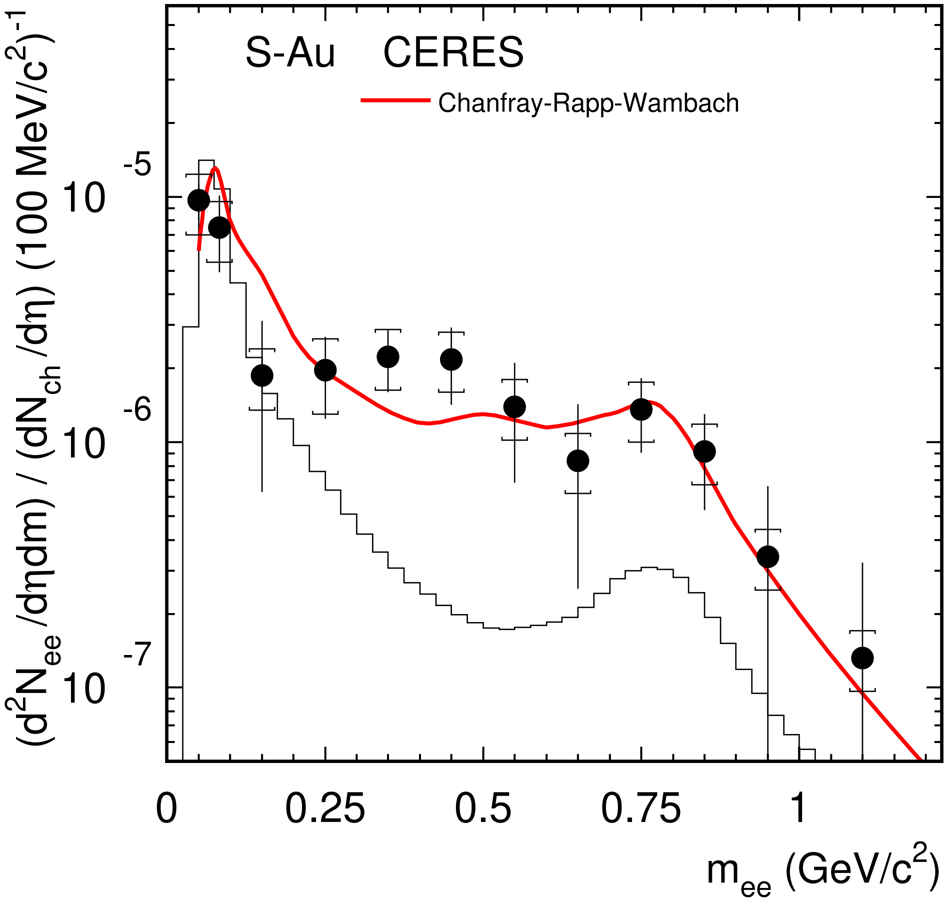


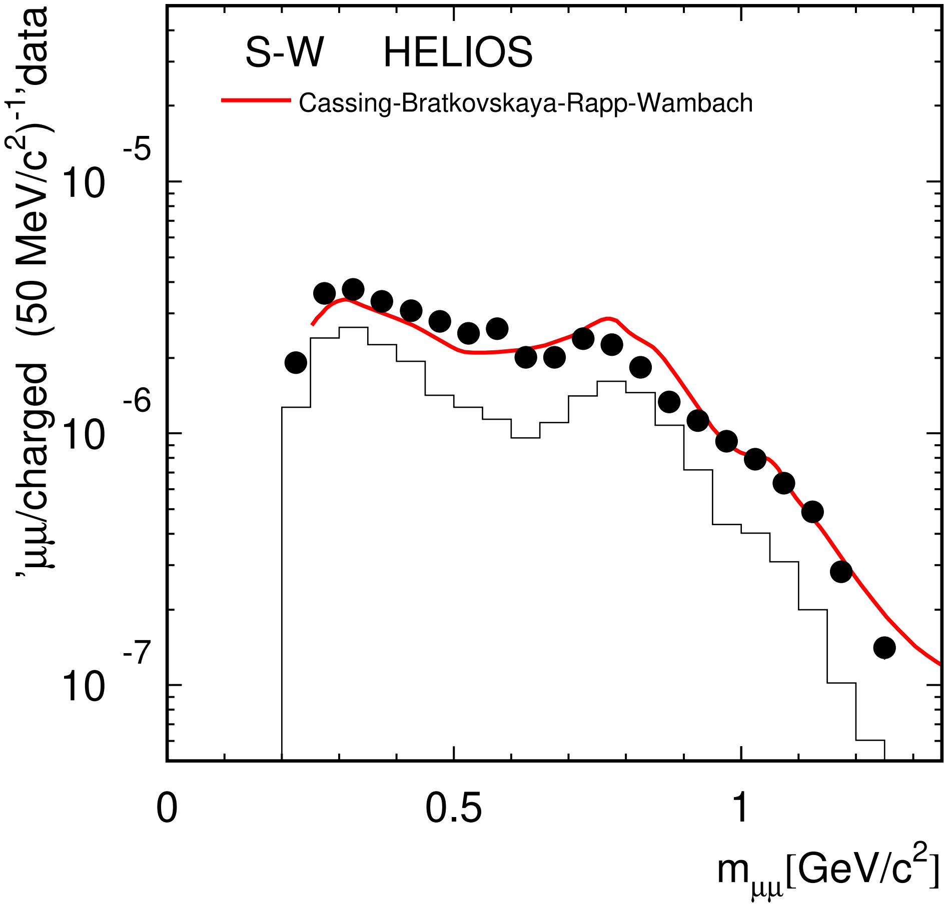
- excellent simultaneous description of CERES and HELIOS data

Increasing Meson Widths in Dense Reaction Volume

collisions in dense medium change the spectral functions
ρ-meson widths increase and strength is shifted to low and high masses

A. Drees, Nucl.Phys. A630 (1998) 449c

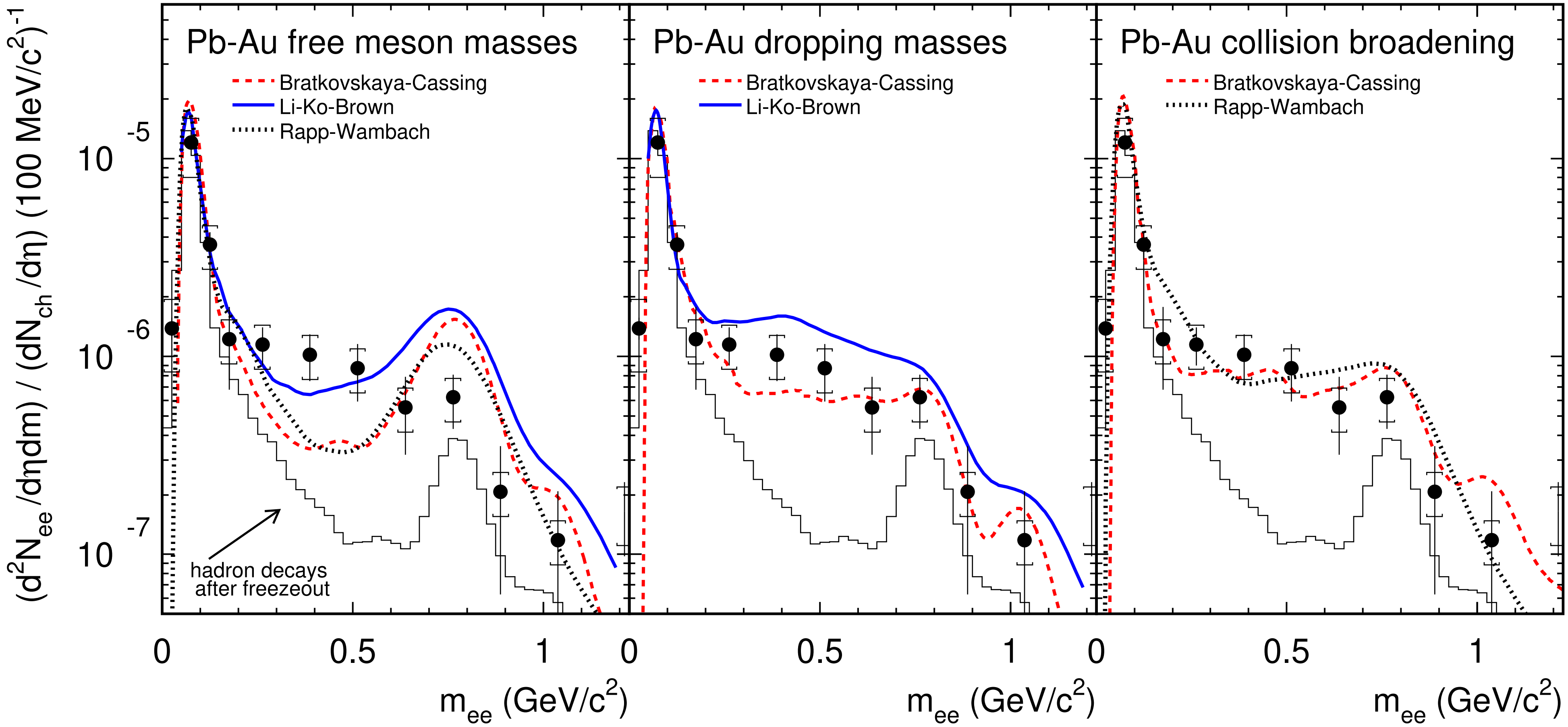




- CERES and HELIOS data is described equally well

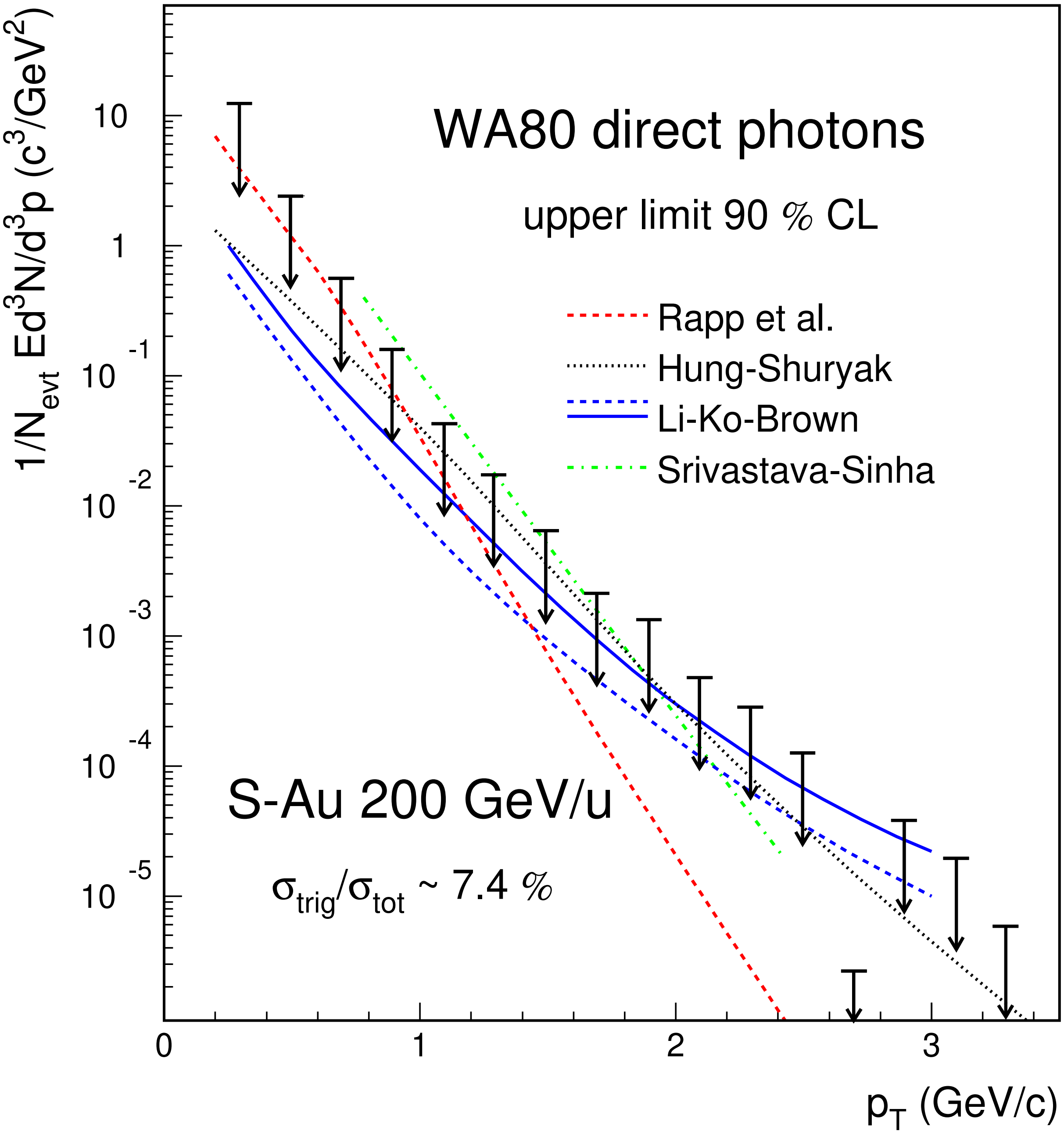
Predictions for Pb-Pb Collisions

rescaled calculation to fit experimentally observed dN_{ch}/dy



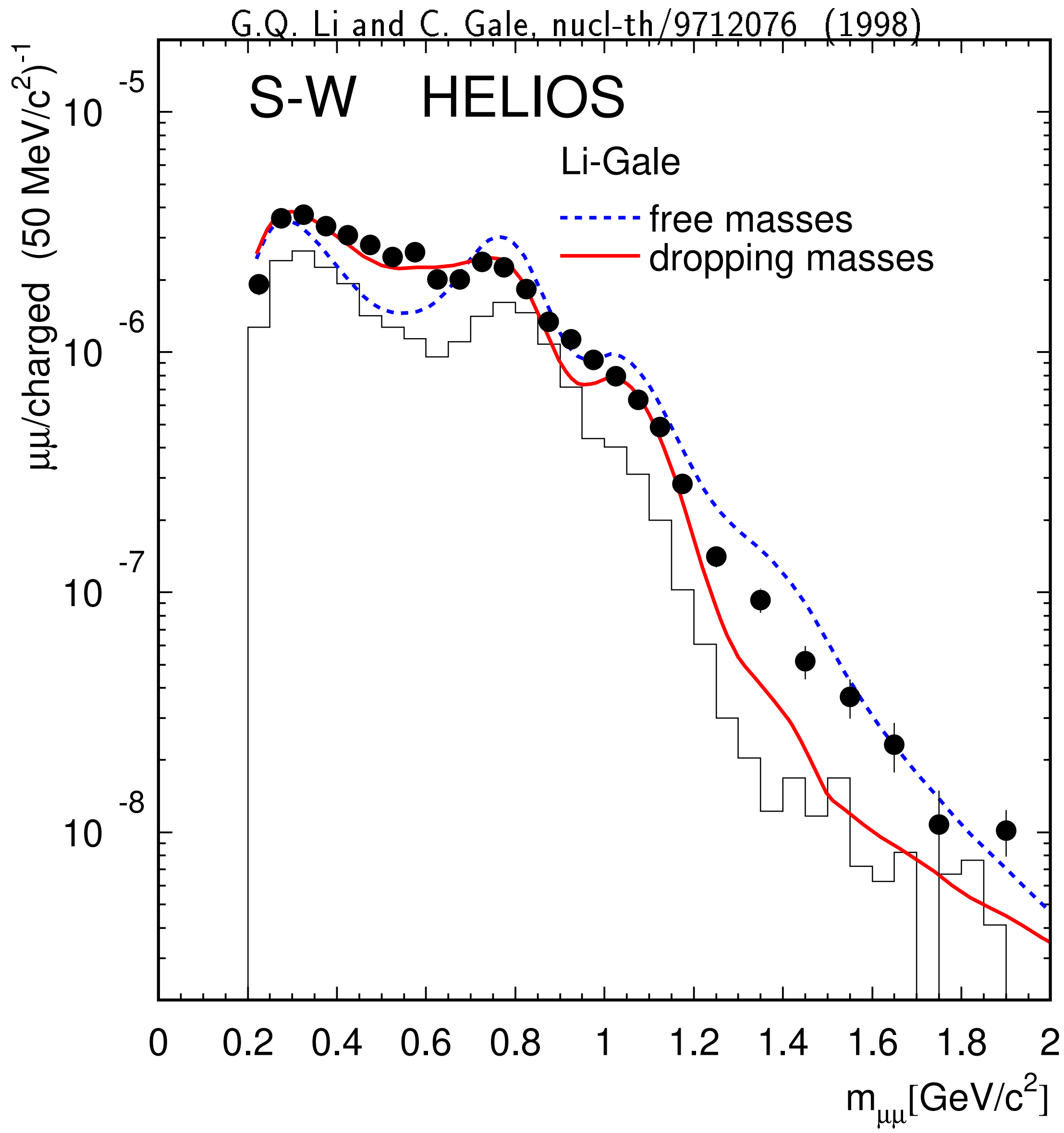
- same situation as for S-beam data
- dropping masses and collision broadening is not distinguished

Photon Radiation from Collision



- all calculations consistent with upper limits
- Note some calculations only exclude $\pi \rightarrow \gamma\gamma$ and $\eta \rightarrow \gamma\gamma$

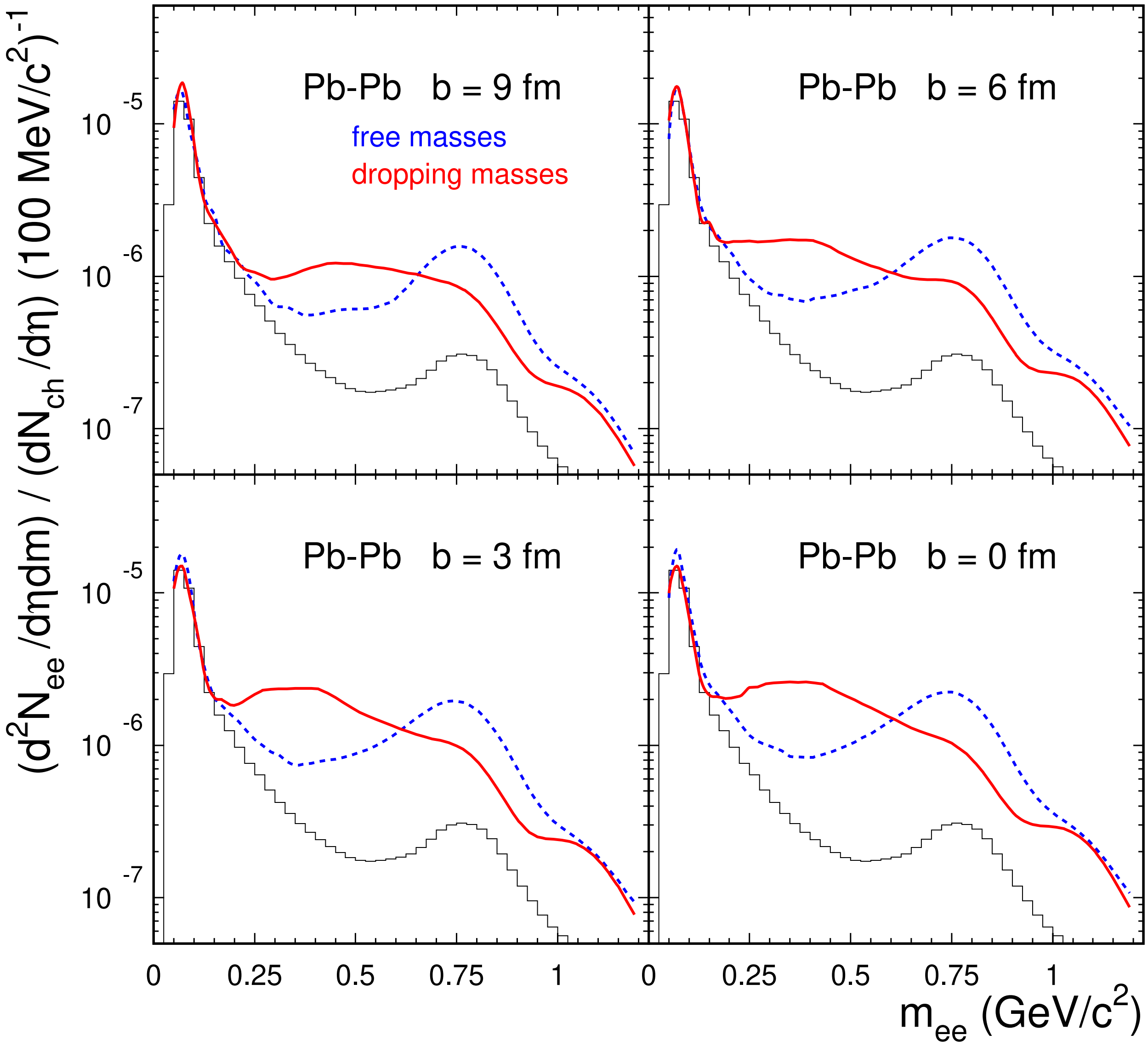
Dilepton Production at Higher Masses



- most important channel $a_1\pi \rightarrow \mu^+\mu^-\pi$
- dropping mass calculation underestimates yield
- free mass calculation overestimates yield
- collision broadening will increase the yield further

Centrality Dependence

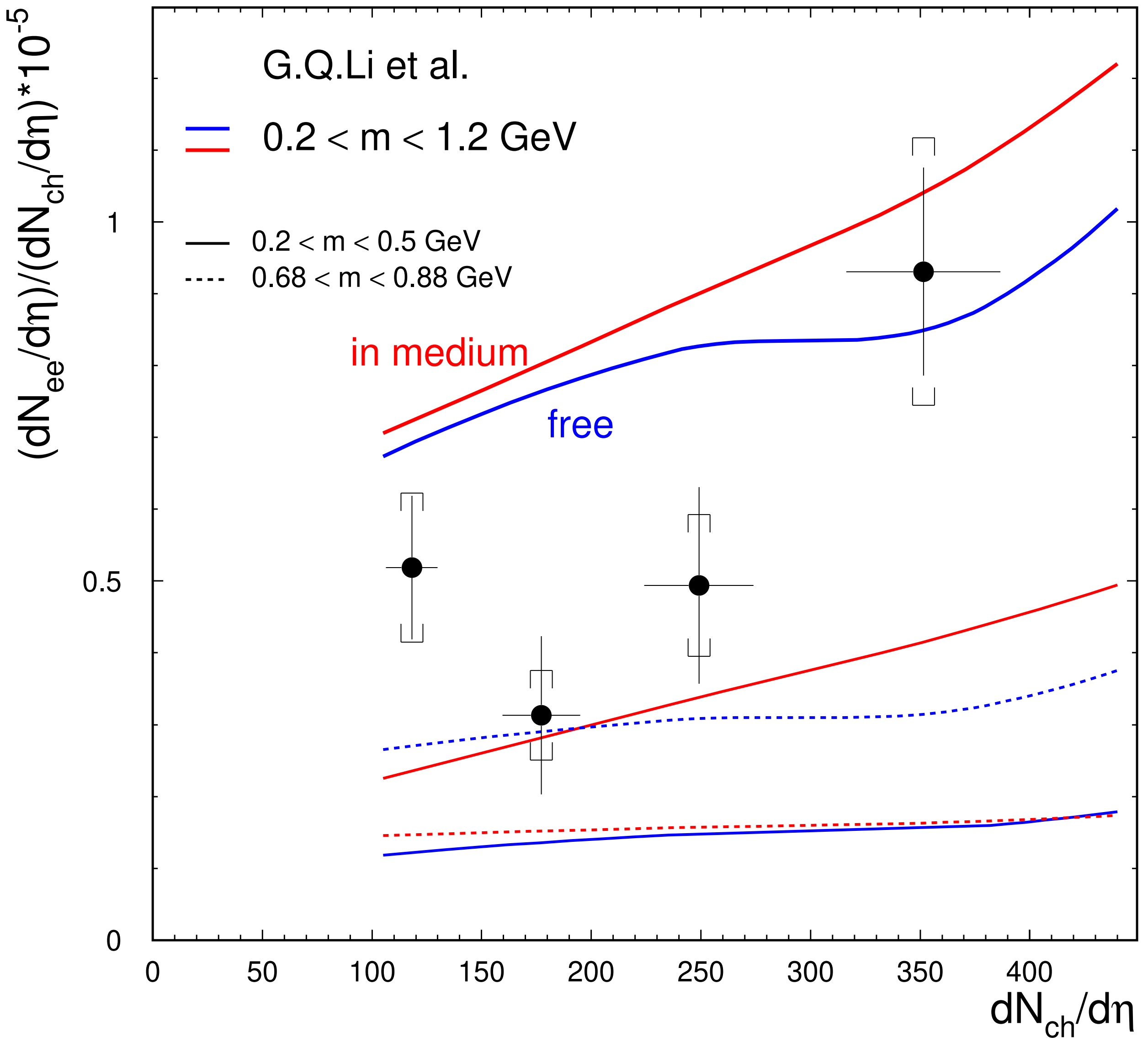
G.Q. Li et al., Nucl.Phys. A611 (1996) 539



- free mass calculation: little impact parameter dependence
- dropping mass calculation: change in shape with centrality
- strongest increase of yield 200 < m < 600 MeV

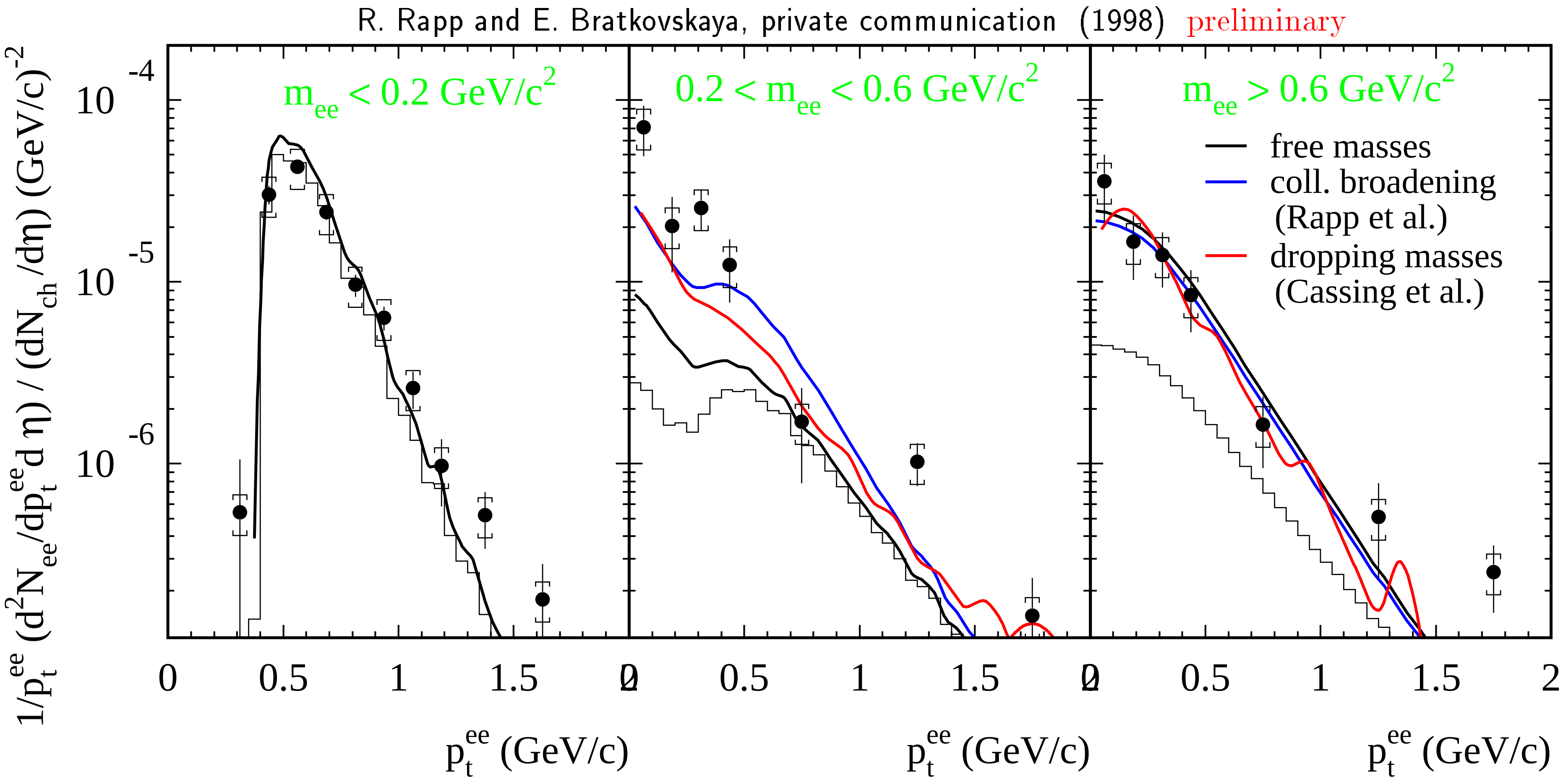
Centrality Dependence

integrated dilepton yields



- small difference if integrated from 0.2 to 1.5 GeV
- $d\sigma_{ee}/dmdN_{ch}$ reviels significant differences
- note Cassing et al. predict different centrality dependence

$p_\perp$ Dependence of Dilepton Yield

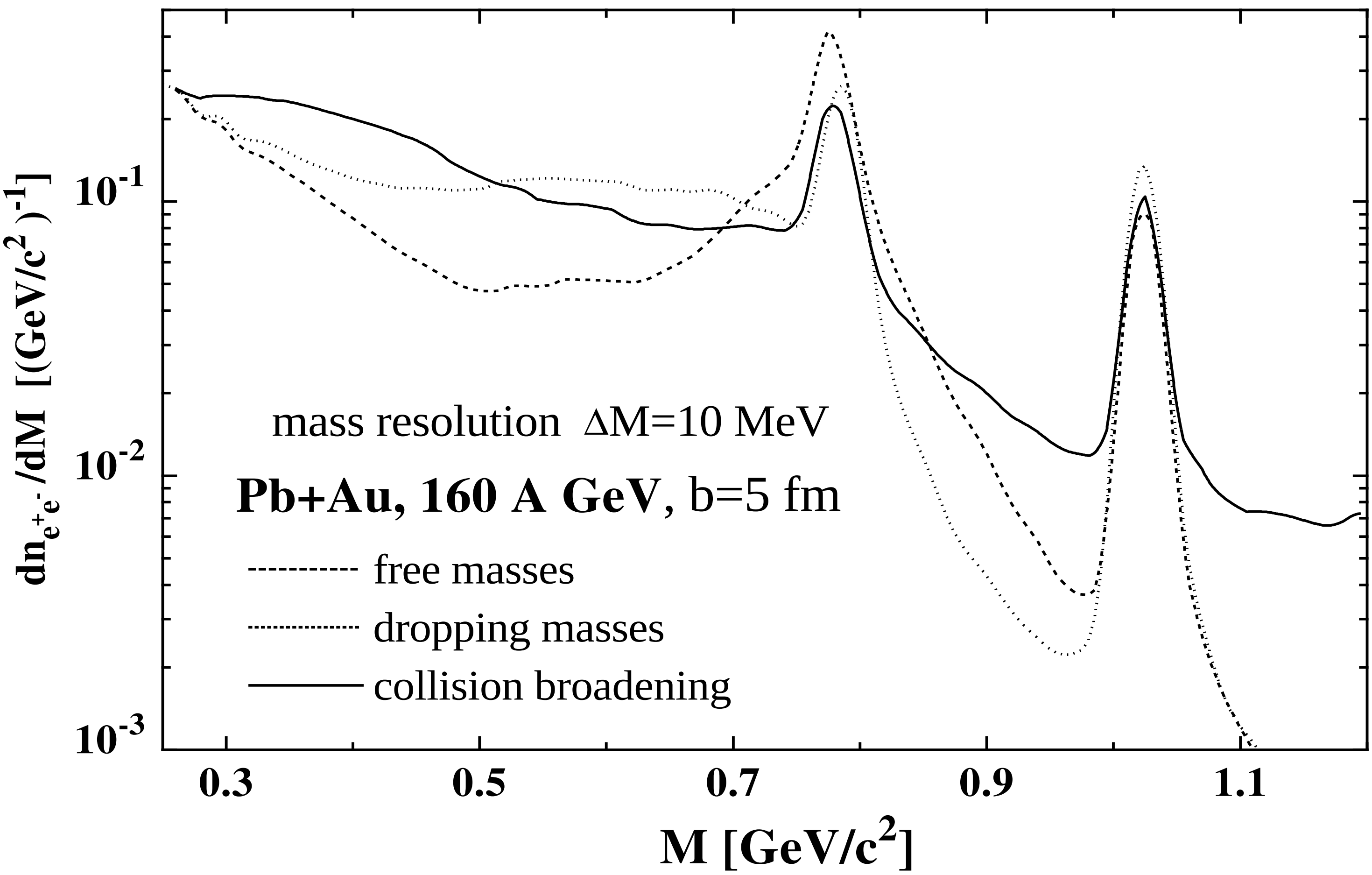


- dense collsion system radiates soft lepton pairs
- calculations reproduce data in ρ mass region
- from $2m_\pi$ to m_ρ in medium effects further soften spectrum

Improved Mass Resolution

study in detail region arround vector mesons ρ, ω and ϕ

W. Cassing et al., Phys.Rev. C57 (1998) 916



- ρ disappears if in medium effects are present ($\sim$ 700 MeV)
- predicted in medium effect between ω and ϕ differ by factor 10
- significant differences also above 1.1 GeV large differences