A Bright Future

Status and Perspectives of Electromagnetic Probes

Axel Drees, Stony Brook University
Hard Probes 2004 Ericeria, Portugal, Nov. 10 2004

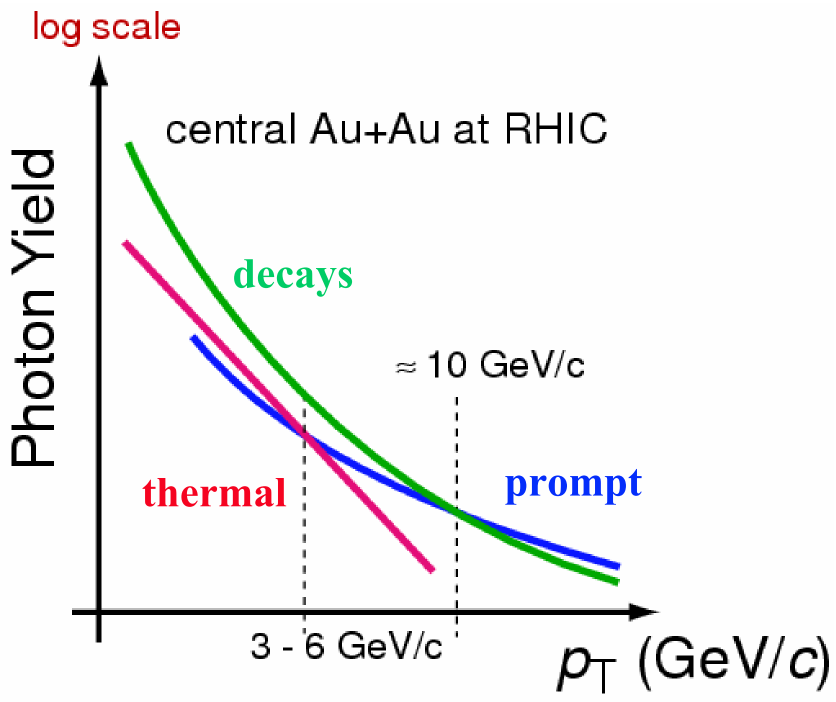
- **Hunt for direct photons**
  - Upper limits on thermal photons at SPS
  - Prompted photons at RHIC
- **Dilepton measurements at CERN**
  - 1st and 2nd generation experiments
  - First results from CERES-2
  - New era: NA60 sneak preview
- **Other dilepton experiments**
  - At 1 to 10 GeV beam energies
  - Future dilepton measurements at RHIC
- **Outlook**

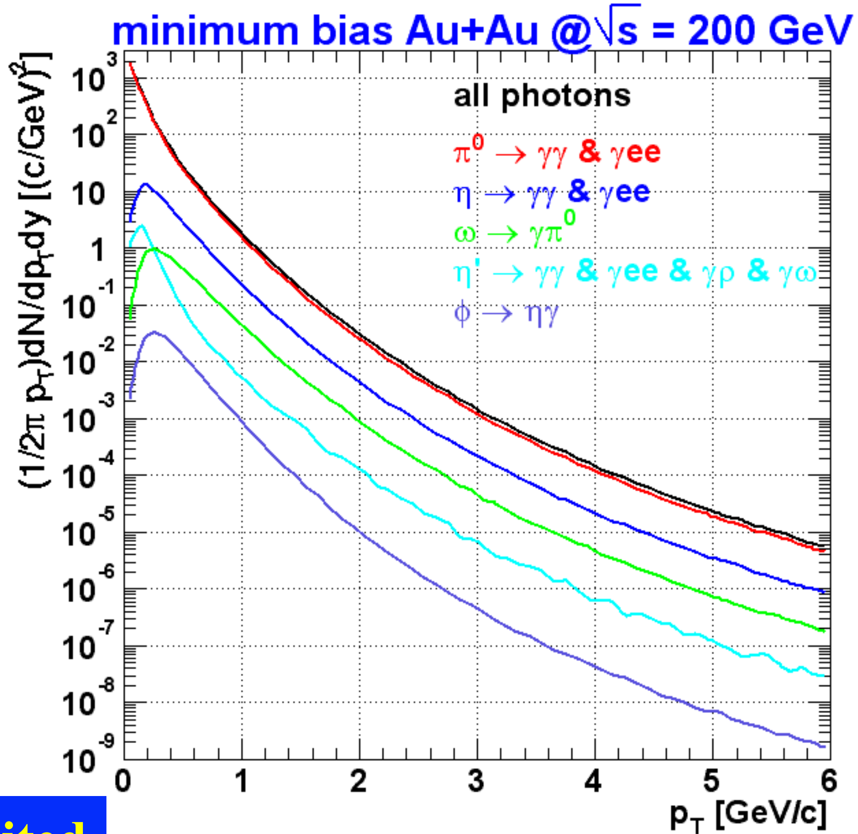
Experimental overview
Many transparencies from:

	C.Gale
	I.Tserruya
CERES	H.Appelshäuser
NA60	R.Shahoyan
	G.Usia
	H.Wöhri
PHENIX	K.Reygers
	K.Ozawa:

Direct Photon Search

- **Direct photons**
  - **From initial hard scattering “prompt”**
  - **From medium: “thermal”, “pre-equilibrium”, other effects**
- **Competes with large hadron decay background**
  - **Thermal component ≤ 10% and limited to low p_T**
  - **Requires careful modeling of decay contribution**





Measurement systematic error limited

Search for Direct "Thermal" Photons at the SPS

- 1st and 2nd generation experiments gave upper limits
  - With oxygen and sulfur beams
  - Measurement limited by systematic errors on data analysis & η production

Experiment	published	y	p_T (GeV/c)	system	Upper limit
HELIOS 2	Z.Phys. C46 (90)	1.0-1.9	0.1 – 1.5	p-W, O-W, S-W	13%
WA80	Z.Phys. C51 (91)	1.5-2.1	0.4 – 2.8	O-Au	15%
WA98	PRL (96)	2.1-2.9	0.5 – 2.5	S-Au	12.5%
CERES	Z.Phys. C71 (96)	2.1–2.65	0.4 – 2.0	S-Au	14%

~13% upper limits on direct photon production from central O and S beams

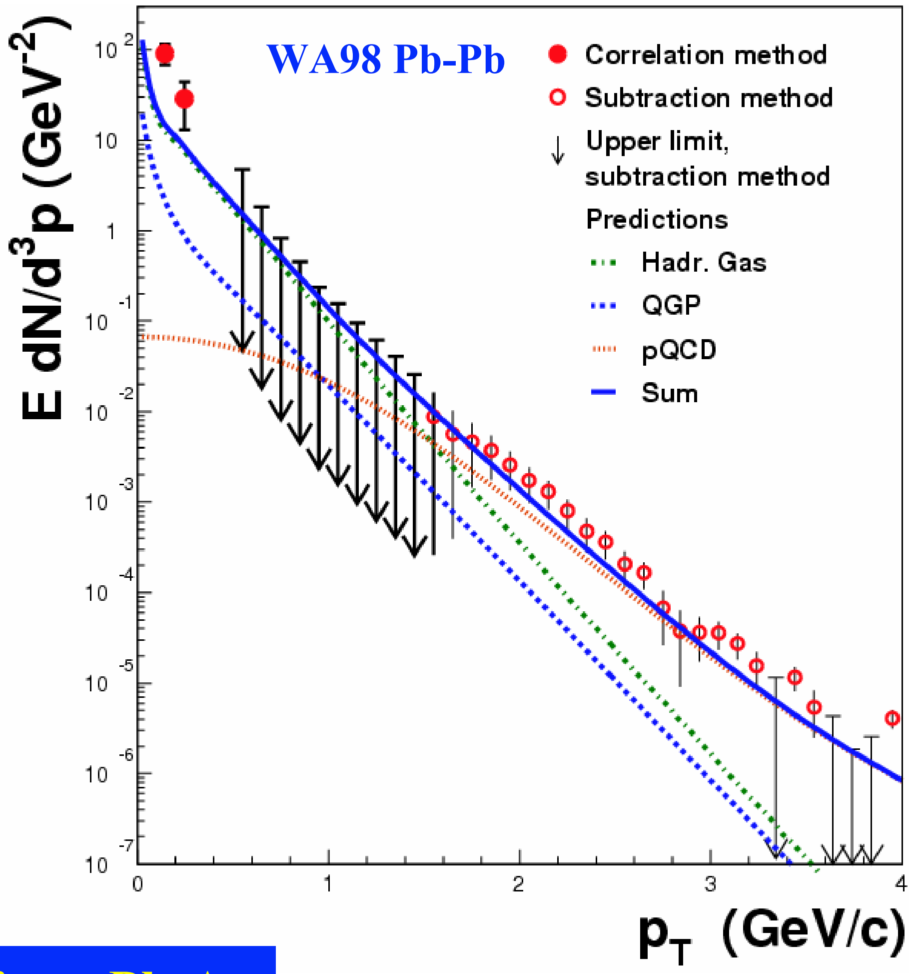
First Direct Photon Measurement in Heavy Ion Collisions

- **WA98 data from Pb-Pb collisions**
  - **Published 2000**
  - **14 years after start of SPS program**

- **Clear signal above 2 GeV/c**
  - **Access beyond prompt component**
  - **Consistent T_{init}~200-270 MeV**
  - **Remains ambiguous**

- **Upper limits below 1.5 GeV/c**
  - **Systematic errors at low p_T remain prohibitive**

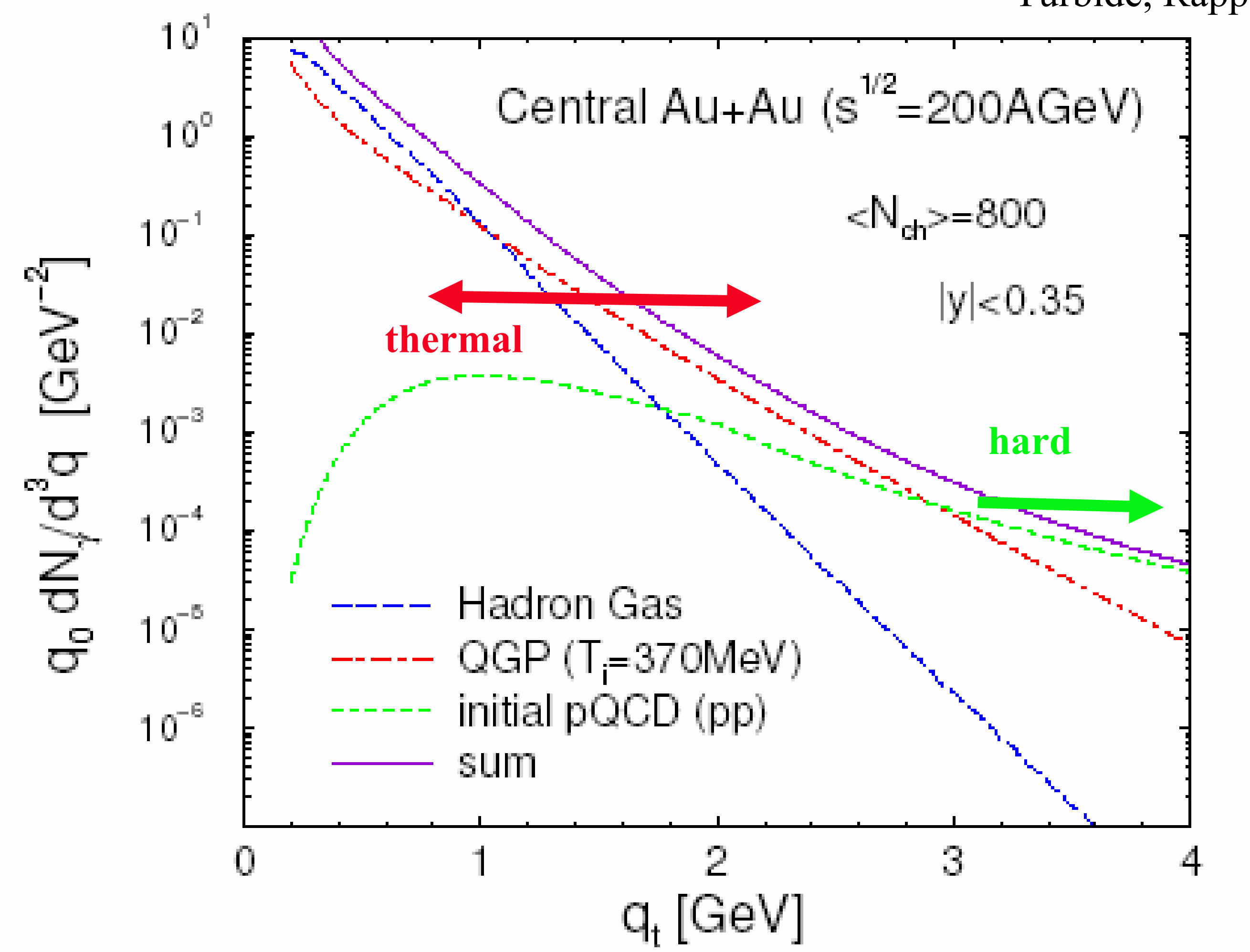
Data: WA98, PRL 85 (2000) 3595
Theory: Turbide, Rapp & Gale PRC (2004)



First hint of direct photons from Pb-Au

Theoretical Expectation for RHIC

Turbide, Rapp & Gale PRC (2004)

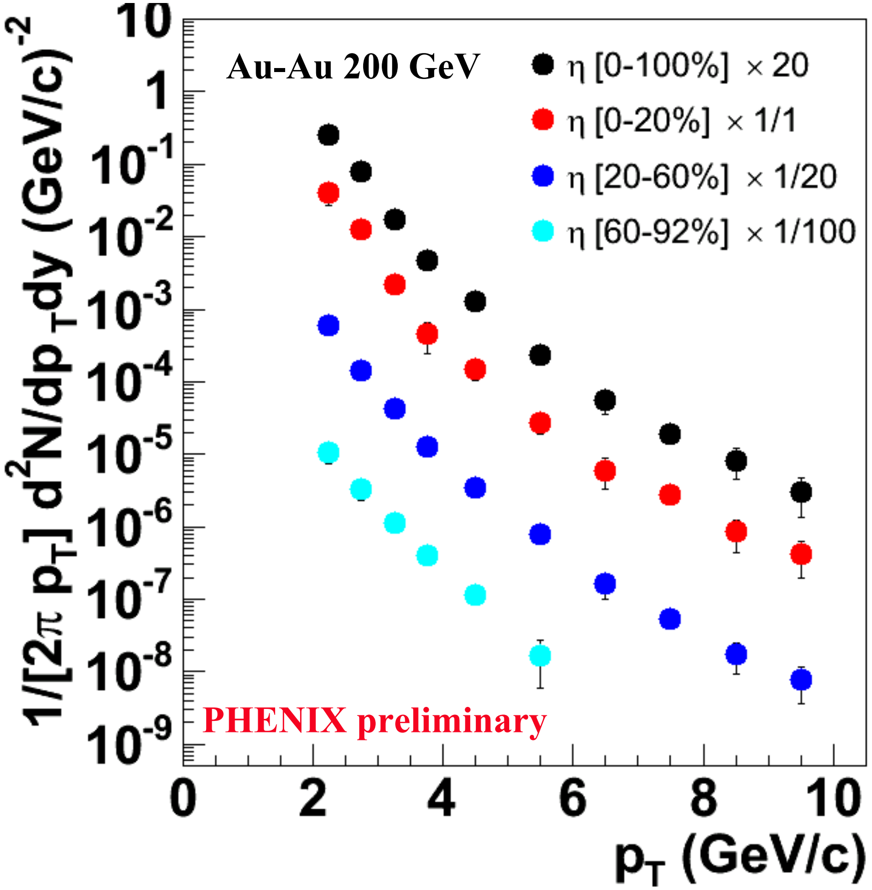


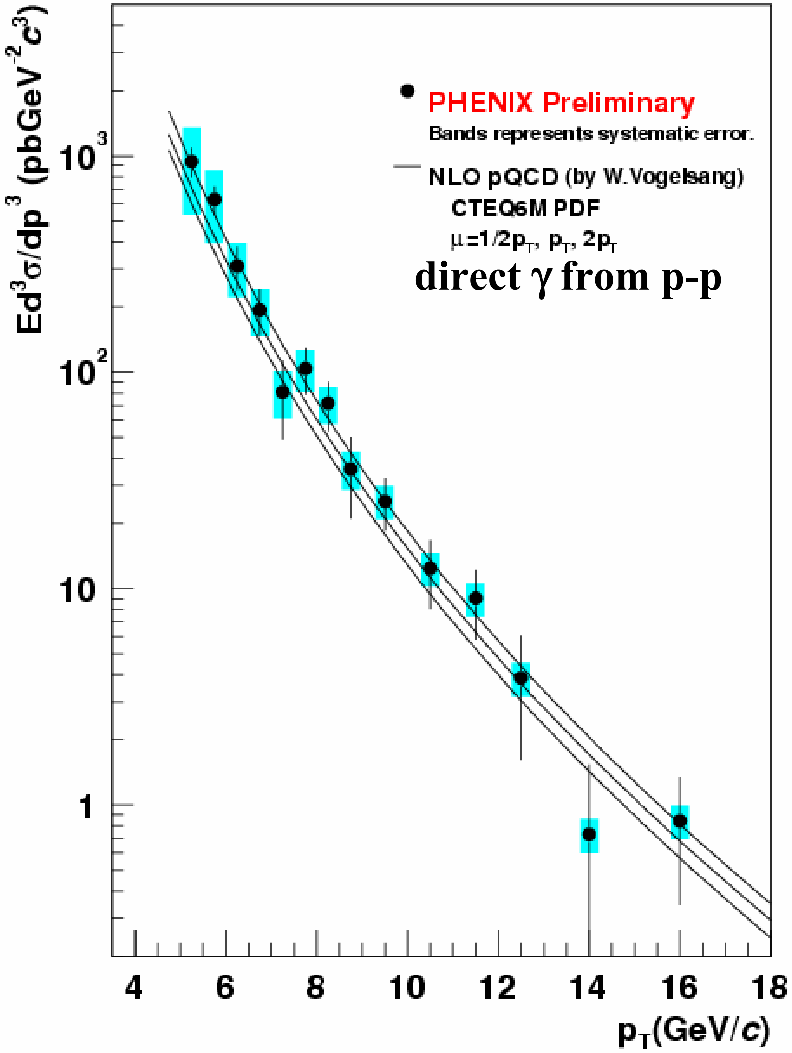
Window for thermal radiation: 0.5 to 2.5 GeV

Direct Photon Search in the RHIC Era

- **Expect significant progress:**
  - **Jet quenching reduces background**
  - **Better input to decay cocktail**
    π^0 and η measured more accurately
  - **Well measured reference from p-p**

Shown by K.Reygers





RHIC: promising at higher p_T

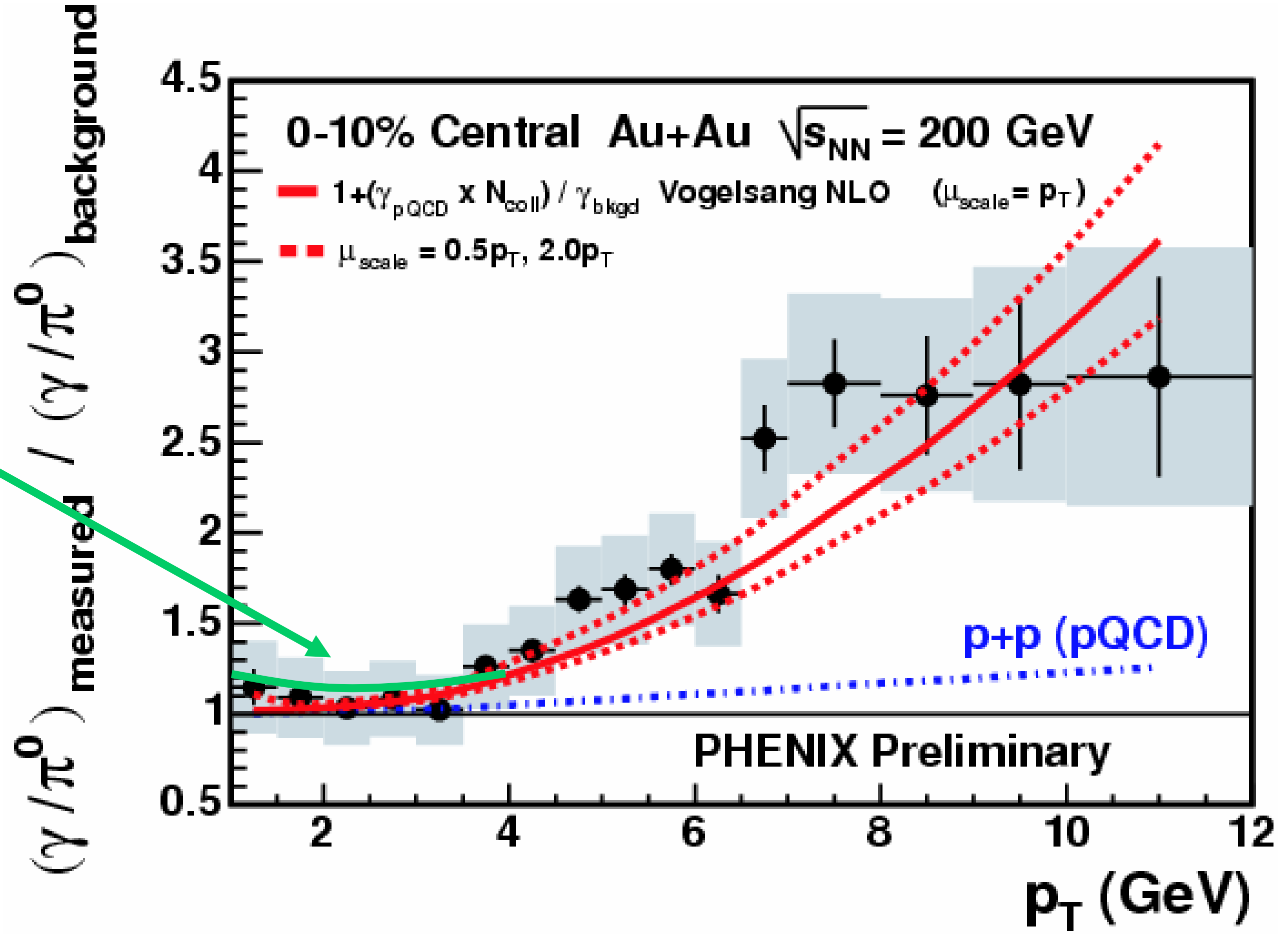
PHENIX Direct Photons at RHIC

Shown by K.Reygers

- Strong direct photon signal in central Au+Au
  - Within systematic errors consistent with hard scattering expectation + jet quenching
  - Present systematic error prohibit detection of thermal component

Search for Thermal Photons ongoing:

(i) reduce systematic
(ii) use $\gamma \rightarrow e^+e^-$ down to 500 MeV/c



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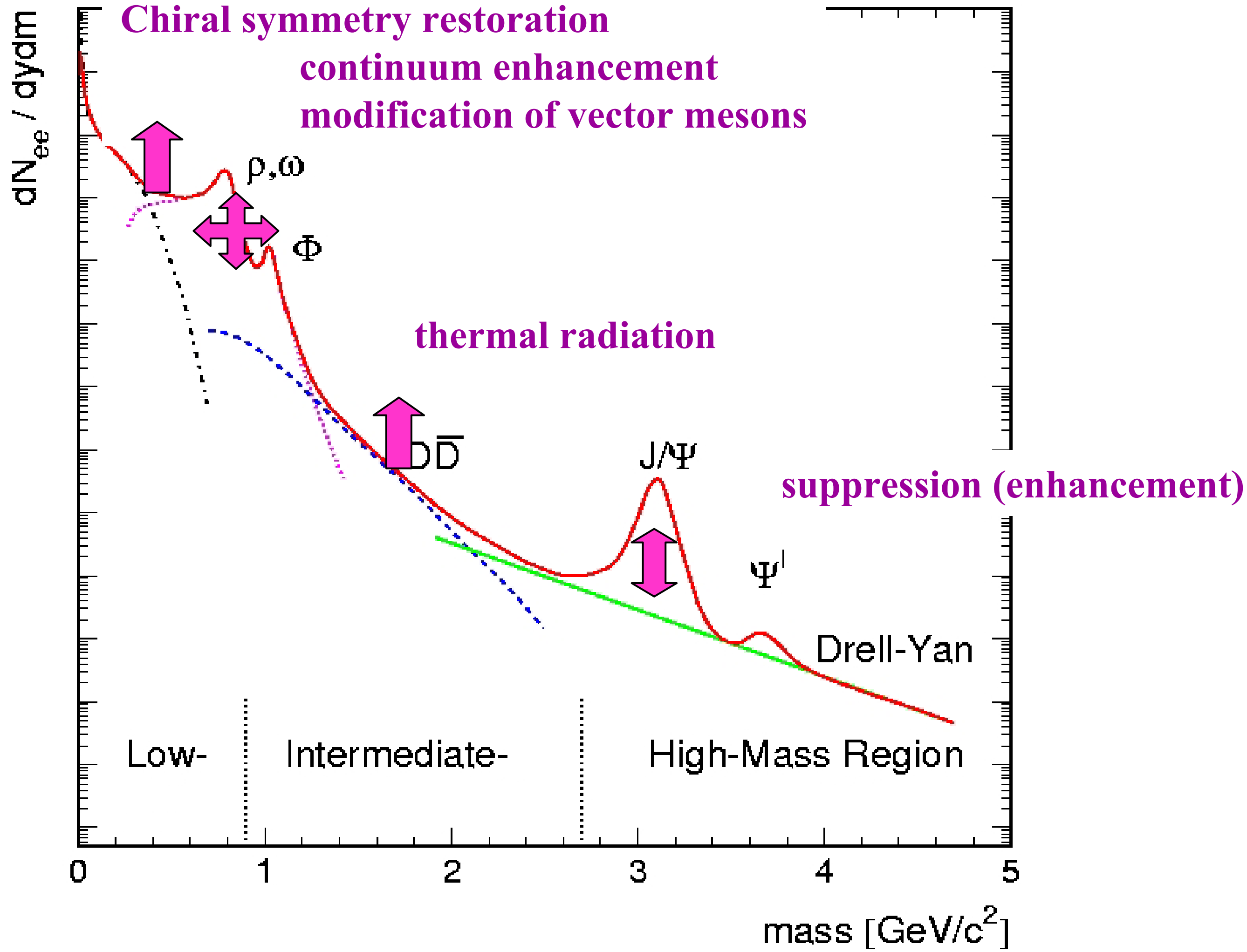
Continuum Lepton-Pair Physics

Modifications due to QCD phase transition



Continuum sensitive to chiral symmetry restoration and thermal radiation

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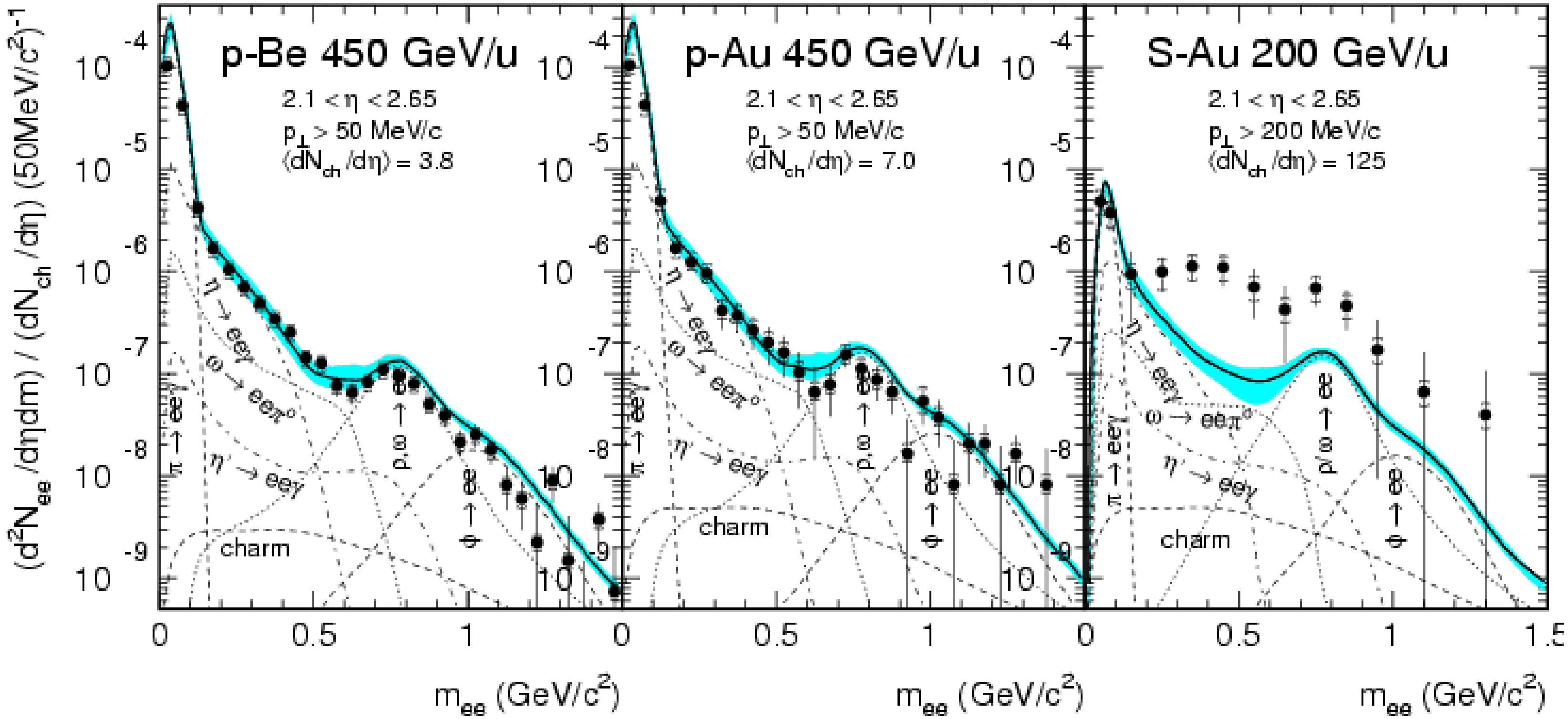
Dedicated Dilepton Experiments at CERN SPS

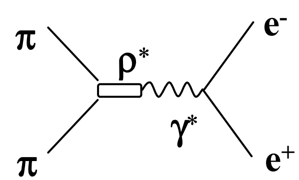
Experiment		System	Mass range	Publications
HELIOS-1	μμ ee	p-Be (86)	low mass	Z.Phys. C68 (1995) 64
HELIOS-3	μμ	p-W,S-W (92)	low & Intermediate	E.Phys.J. C13(2000)433
CERES	ee	pBe, pAu, SAu (92/93) Pb-Au (95) Pb-Au (96)	low mass	PRL (1995) 1272 Phys.Lett. B (1998) 405 Nucl.Phys. A661 (1999) 23
CERES-2	ee	Pb-Au 40 GeV (99) Pb-Au 158 GeV (2000)	low mass	PRL 91 (2002) 42301 preliminary data 2004
NA38/ NA50	μμ	p-A, S-Cu, S-U, Pb-Pb	low (high m_T) intermediate	E.Phys.J. C13 (2000) 69 E.Phys.J. C14 (2000) 443
NA60	μμ	p-A, In-In (2002,2003) p-A (2004)	$>2m_\mu$	preliminary data 2004 data taking

Pioneering Dilepton Results form CERN

CERES PRL 92 (95) 1272 with 321 citations



- **Discovery of low mass dilepton enhancement in 1995**
  - **p-Be and p-Au well described by decay cocktail**
  - **Significant excess in S-Au (factor ~5 for m>200 MeV)**
  - **Onset at ~ 2 m_π suggested π–π annihilation**
  - **Maximum below ρ meson near 400 MeV**



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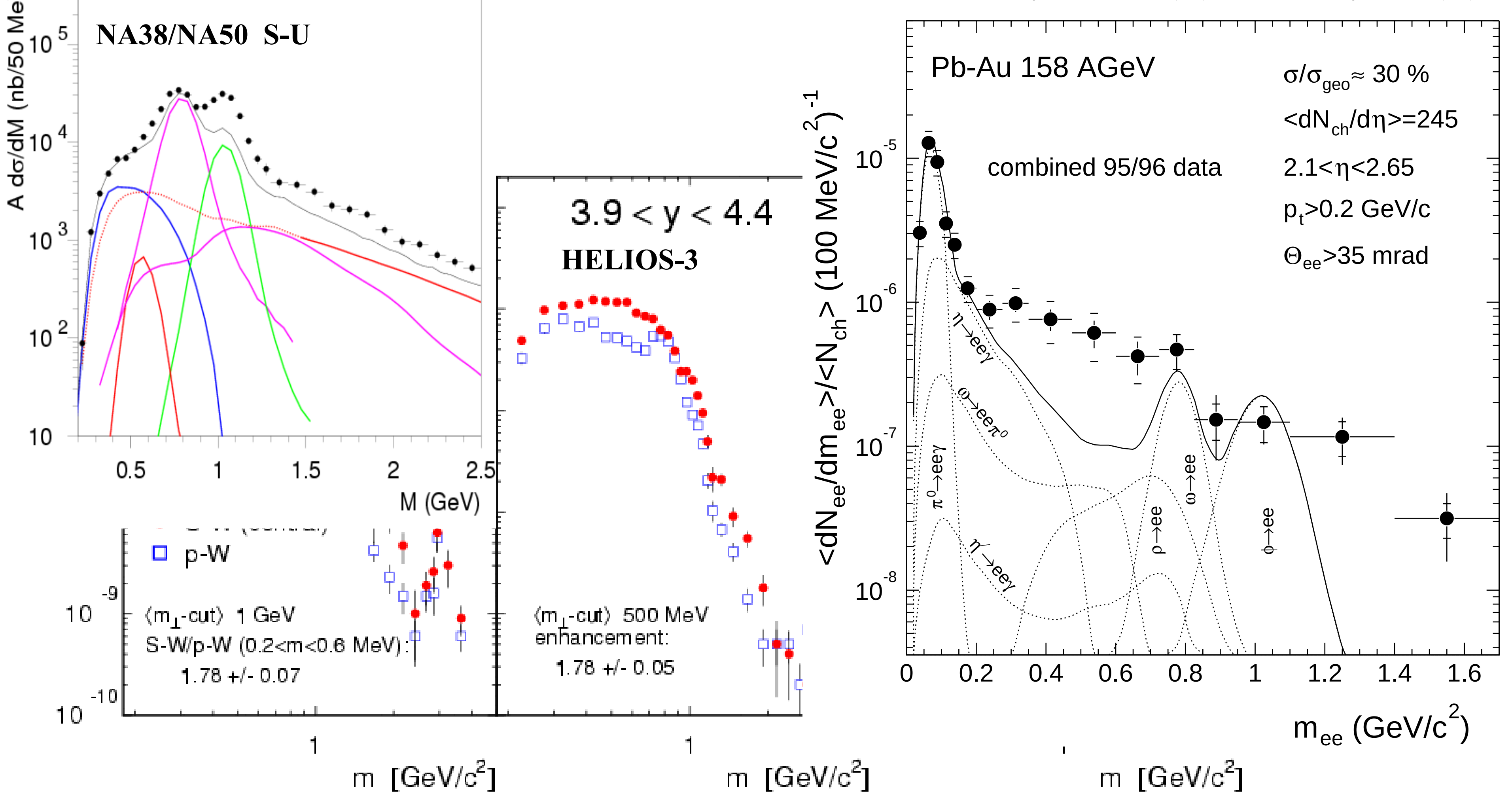
Hints towards modified ρ meson in dense medium

Discovery of Low Mass Dilepton Enhancement

NA38/NA50 E.Phys.J. C13 (2000) 69

CERES Phys.Lett.B422 (98) 405; Nucl.Phys.A661(99) 23



HELIOS-3 E.Phys.J. C13 (2000) 433

Dilepton excess at low and intermediate masses well established

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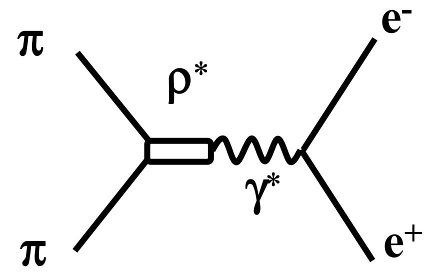
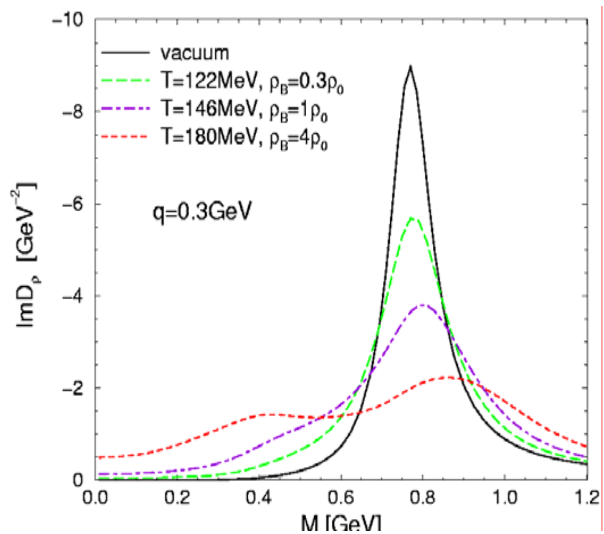
Theoretical Calculation of π-π Annihilation

- **Low mass enhancement due to ππ annihilation**
  - **Spectral shape dominated ρ meson**
- **Vacuum ρ propagator**
  - **Vacuum values of width and mass**
- **In medium ρ propagator**
  - **Brown-Rho scaling**
    Dropping masses as chiral symmetry is restored
  - **Rapp-Wambach melting resonances**
    Collision broadening of spectral function
    Only indirectly related to chiral symmetry restoration
  - **Medium modifications driven by baryon density**
- **Model space-time evolution of collision**
  - **Different approaches**
  - **Consistent with hadron production data**
  - **Largest contribution from hadronic phase**

>> 100 publications since 1995



$$\frac{m_\rho^*}{m_\rho} \approx \left(\frac{<\bar{q}q>_{\rho^*}}{<\bar{q}q>_0} \right)^{1/3} = 1 - 0.16\frac{\rho^*}{\rho_0}$$



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Comparison of Theory and CERES Data

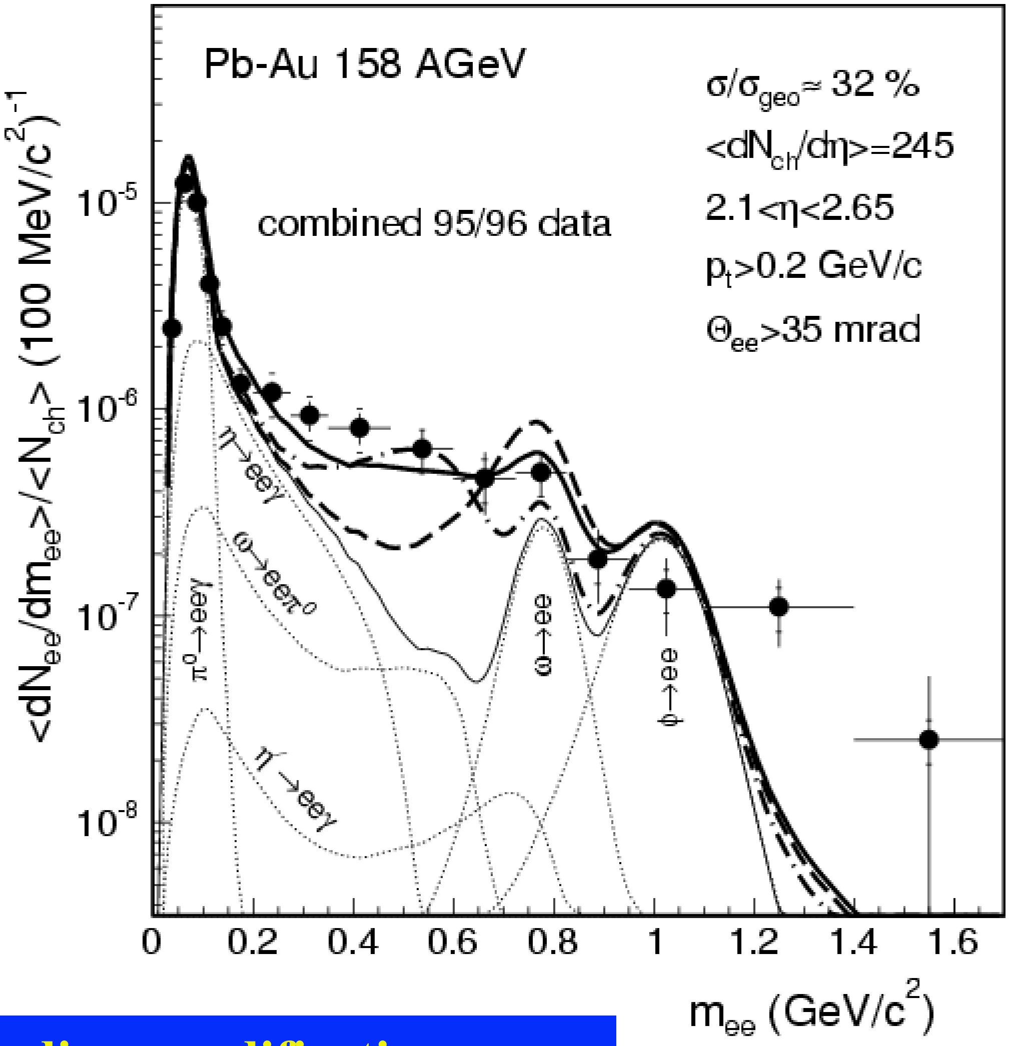
- **Vacuum ρ meson (– – – -)**
  - **Inconsistent with data**
  - **Overshoots in ρ meson region**
  - **Undershoots at low masses**

- **Modification ρ meson**
  - **Necessary to describe data**
  - **Data do not distinguish between**

——— **broadening or melting of ρ-meson (Rapp-Wambach)**

– · – · **Dropping masses (Brown-Rho)**

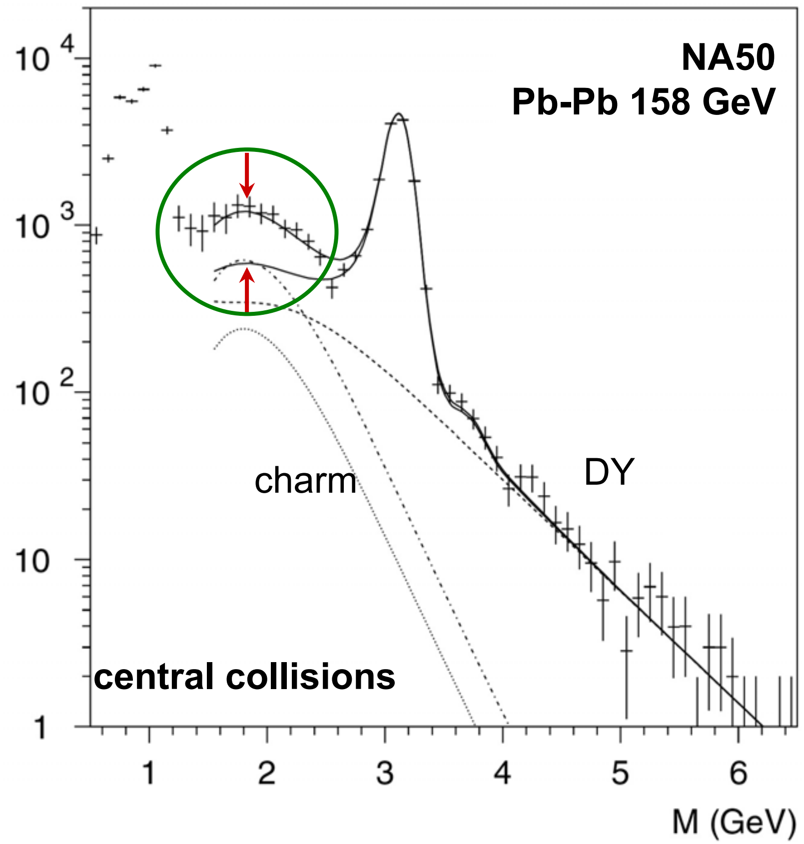
- **ρ/ω to φ mass region most sensitive to constrain models**

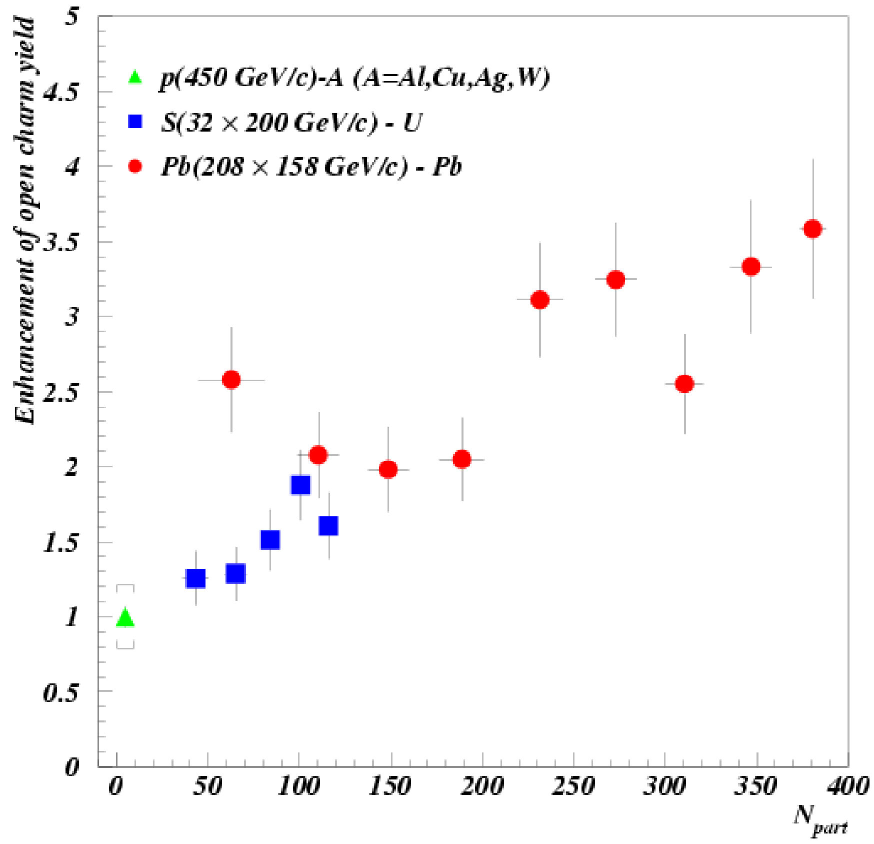


Clear evidence for medium modifications, data not accurate enough to distinguish models

Intermediate Mass Region

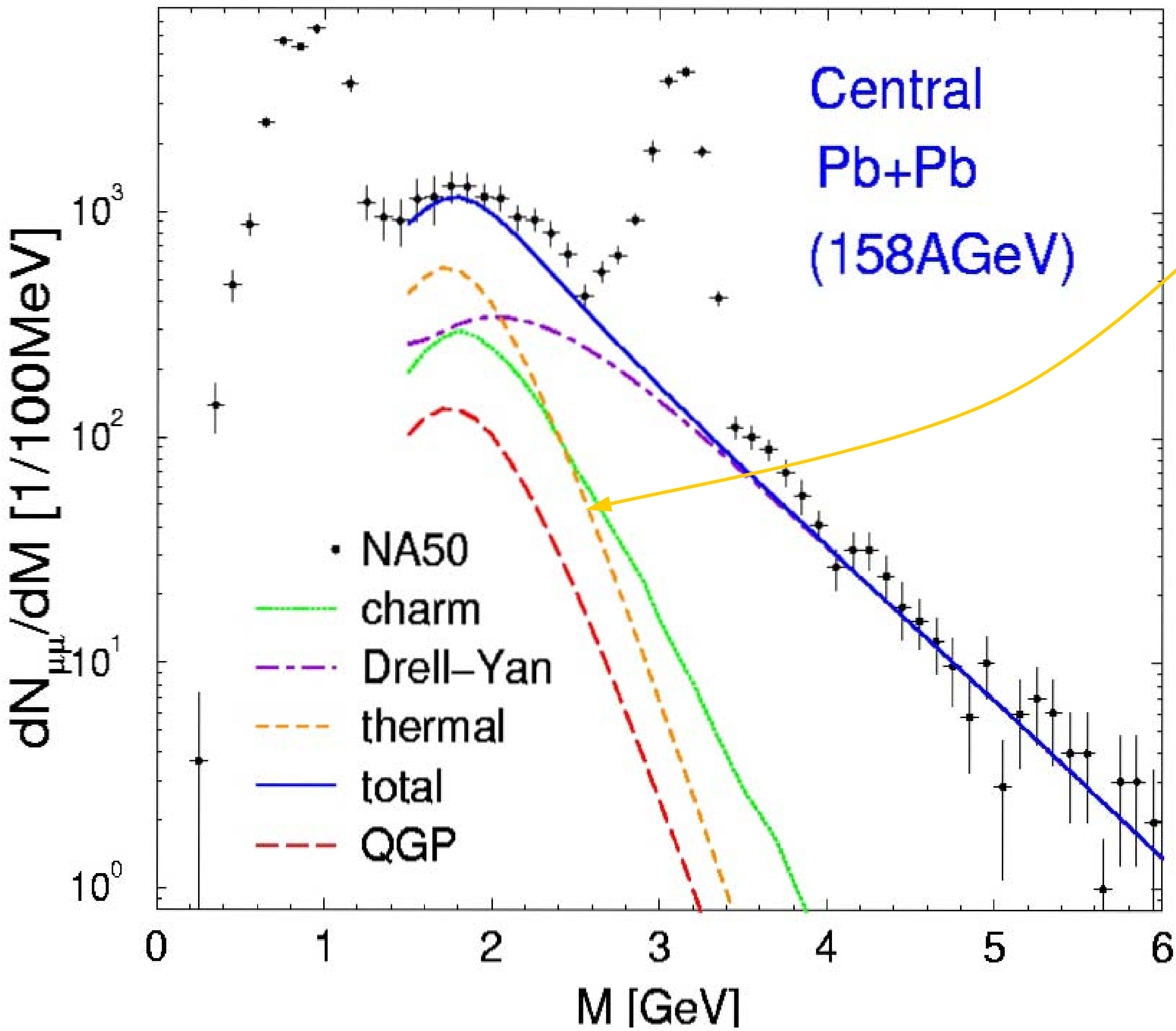
NA38/NA50 E.Phys.J. C14 (2000) 443



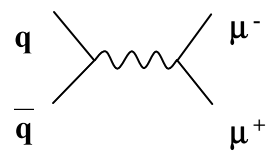


Large enhancement
Consitent with charm enhancement by factor 3
Strong centrality dependence

Comparison to Calculation of Thermal Radiation



R.Rapp & E.Shuryak, Phys.Lett B473 (2000) 13



Data also consistent with thermal radiation

Need direct measurement of open charm contribution

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Data from CERES-2 with TPC Upgrade

- **Data taking in 1999 and 2000**
  - **Improved mass resolution**
  - **Improved background rejection**
  - **Results remain statistic limited**

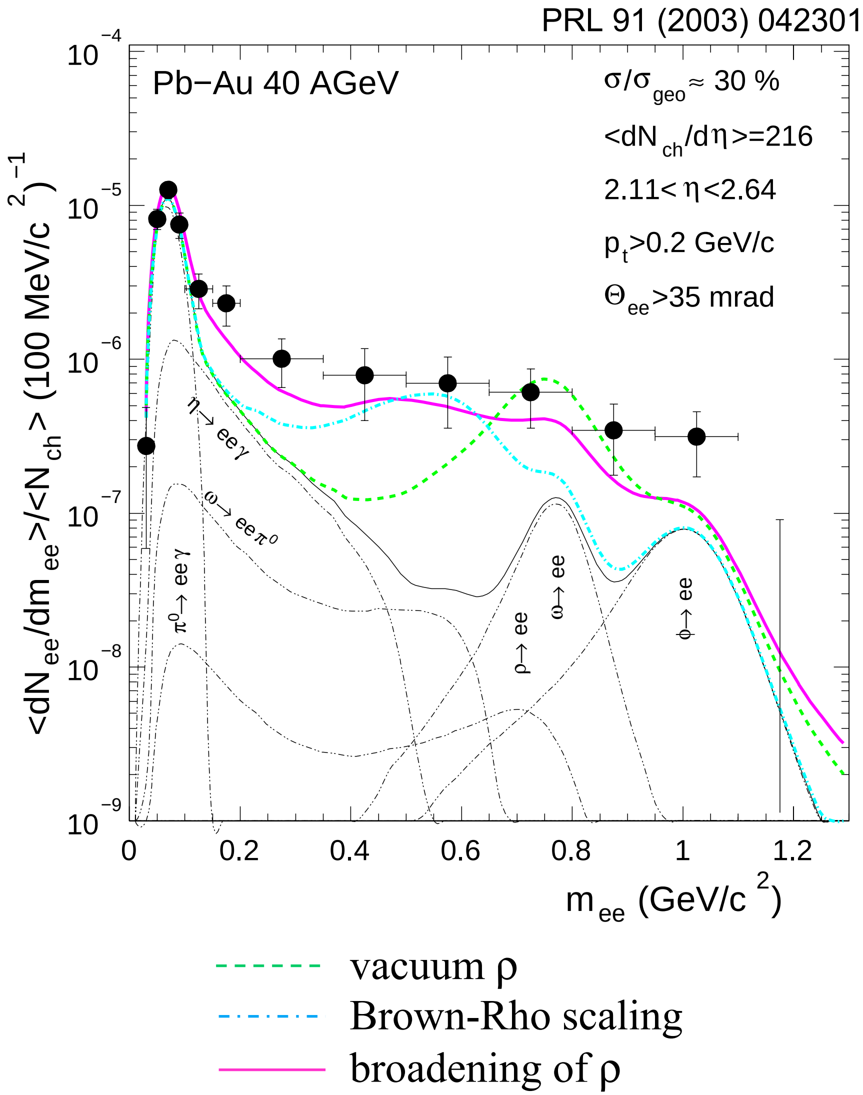
- **Pb-Au data from 40 AGeV**

  Enhancement for m_{ee}> 0.2 GeV/c^2

  5.9±1.5(*stat*)±1.2(*syst*)±1.8(*decays*)

Strong enhancement at lower $\sqrt{s}$ or larger baryon density

- **Preliminary 158 AGeV Pb-Au data**
  - **Consistent with 95/96 CERES data**
  - **Increase centrality 30% → 8%**
  - **Analysis in progress**



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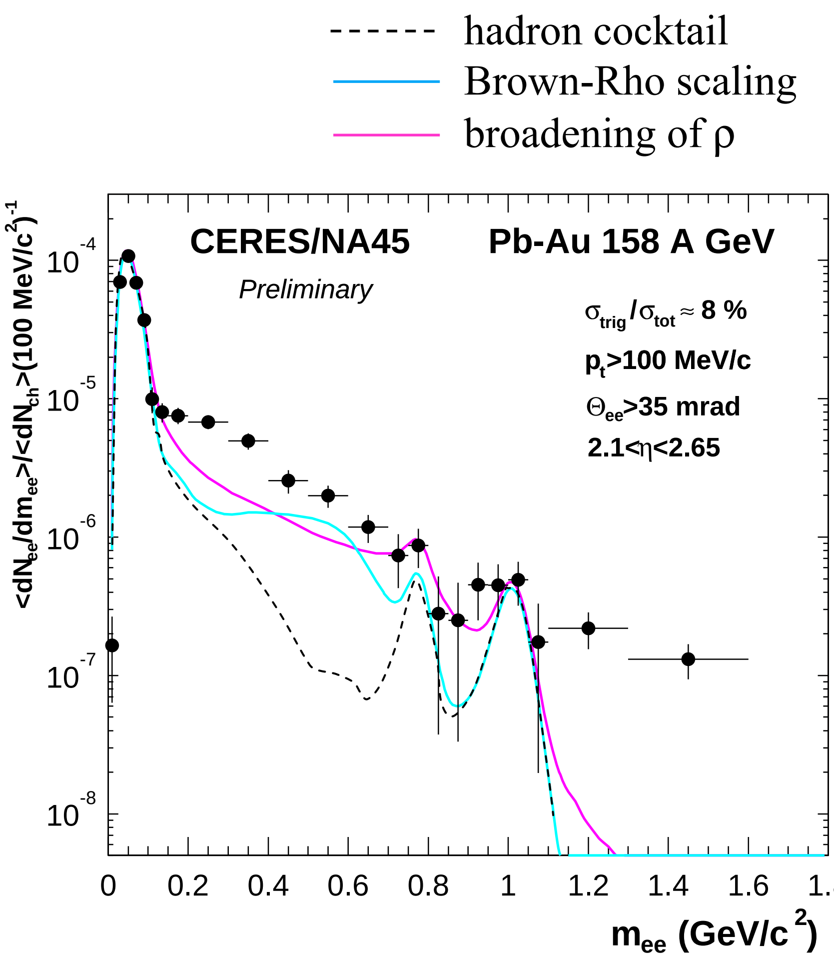
First Results from CERES-2

shown by H.Appelshäuser

- **Preliminary data Pb-Au at 158 AGeV**
  - Cocktail normalized to π^0
  - Statistical errors only
- **Increased resolution**
  - May constrain models once systematic errors evaluated
- **Lower pT cut**
  - Enhancement (m_{ee}> 0.2 GeV/c^2) increases

3.3±0.3(*stat*) p_T>200 MeV/c

5.6±0.4(*stat*) p_T>100 MeV/c



Enhancement increases at low p_T

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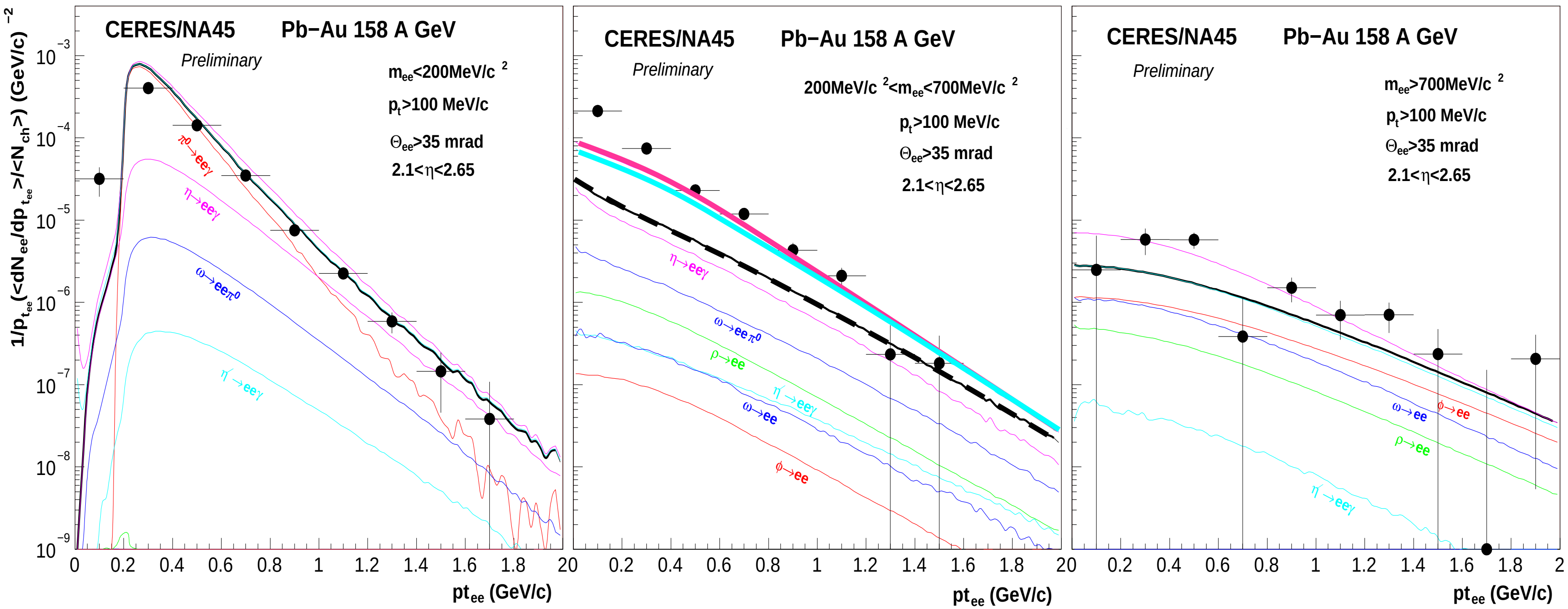
Large Enhancement at Low p_T

$m_{ee}<0.2$ GeV/c² | $0.2<m_{ee}<0.7$ GeV/c² | $m_{ee}>0.7$ GeV/c²



- Low mass dilepton enhancement at low p_T
  - Qualitative in a agreement with ππ annihilation
  - p_T distribution has little discriminative power

- - - - - - hadron cocktail
——— Brown-Rho scaling
——— broadening of ρ

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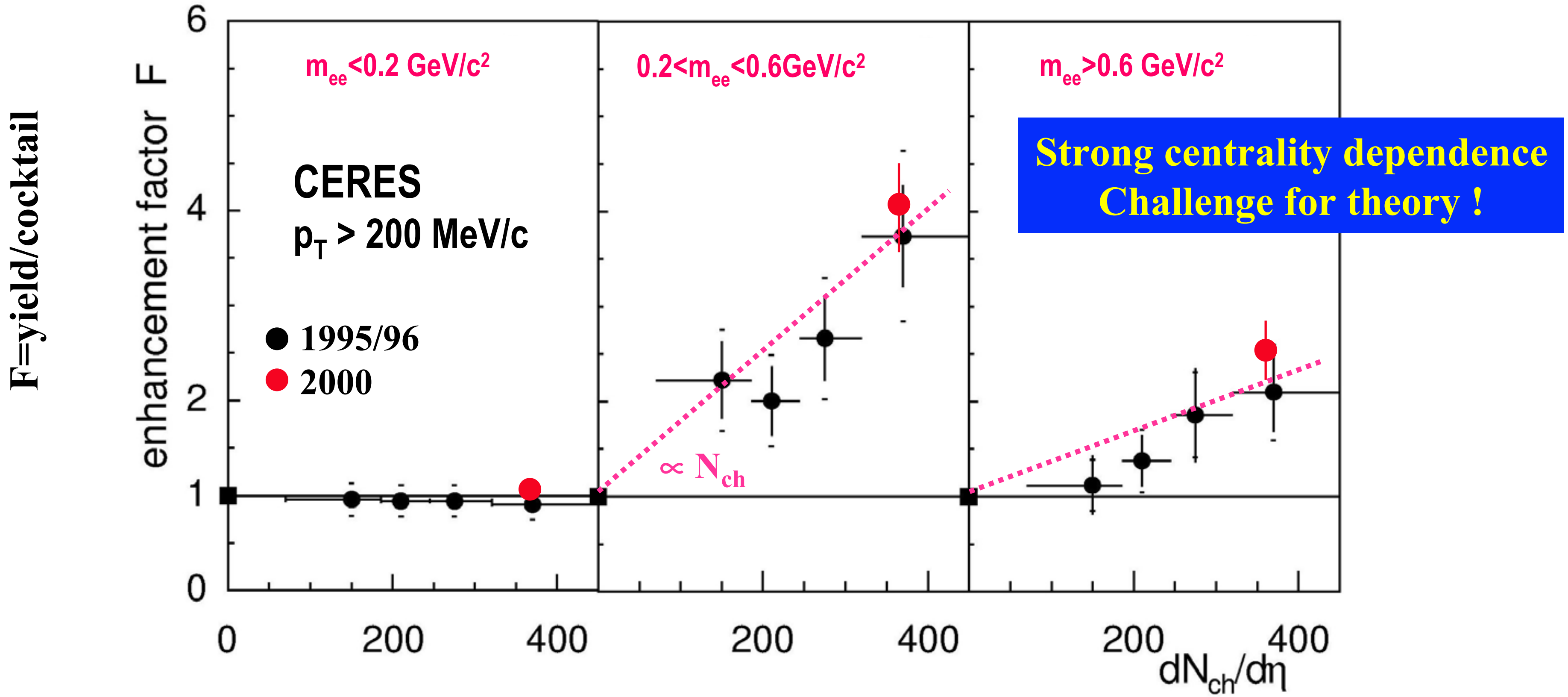
CERES: Centrality Dependence of Enhancement



- Naïve expectation: Quadratic multiplicity dependence
  - medium radiation ∝ particle density squared
- More realistic: smaller than quadratic increase
  - Volume change
  - Density profile (e.g. participant density) in transverse plane
  - Life time of reaction volume

Comparison of Data from Different Experiments

- **Different phase space regions**
  - **Map out new source in m_T-y plane**
  - **Qualitative analysis only; data obtained from:**

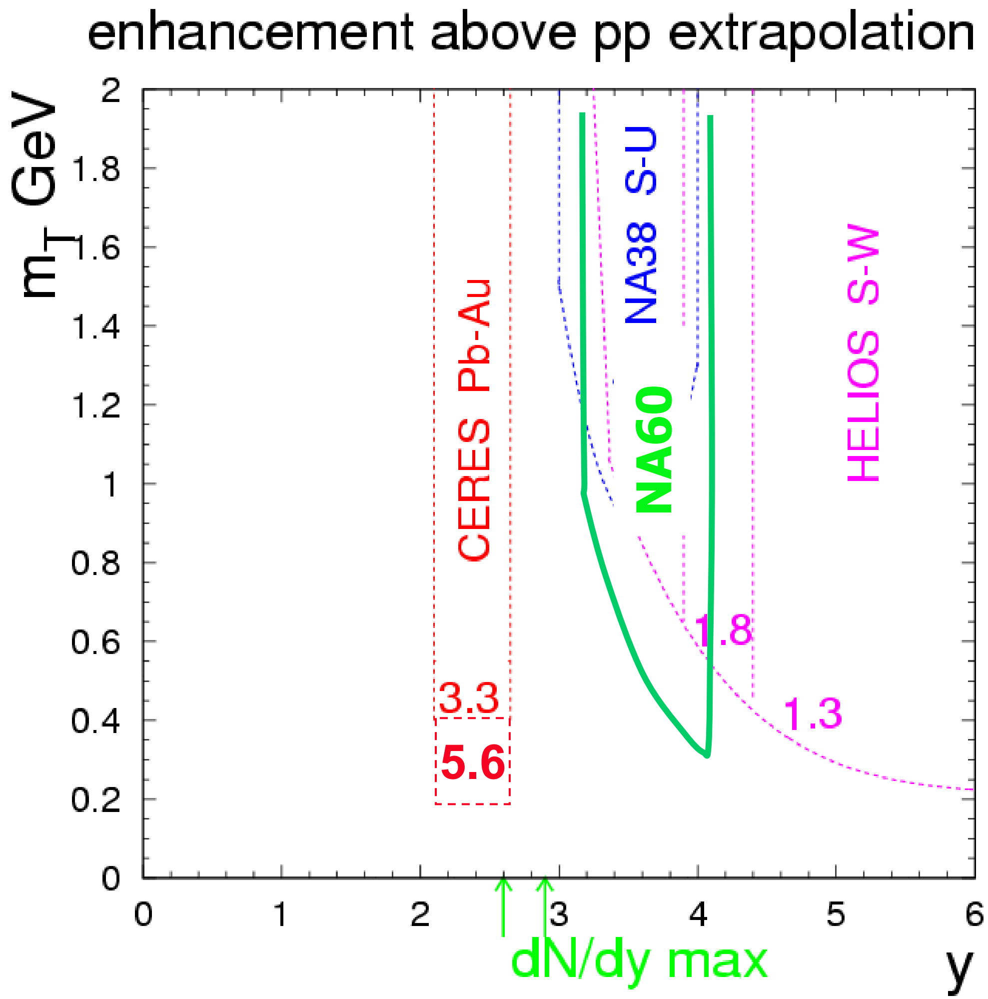
    Different mass ranges

    Different centralities

    Different expected sources

- **Dilepton Excess**
  - **Concentrated at midrapidity**
  - **And at low p_T**
  - **Consistent with $\pi-\pi$ annihilation and medium modifications**

- **Insufficient accuracy, limited power to constrain models**



Need higher statistics, better resolution

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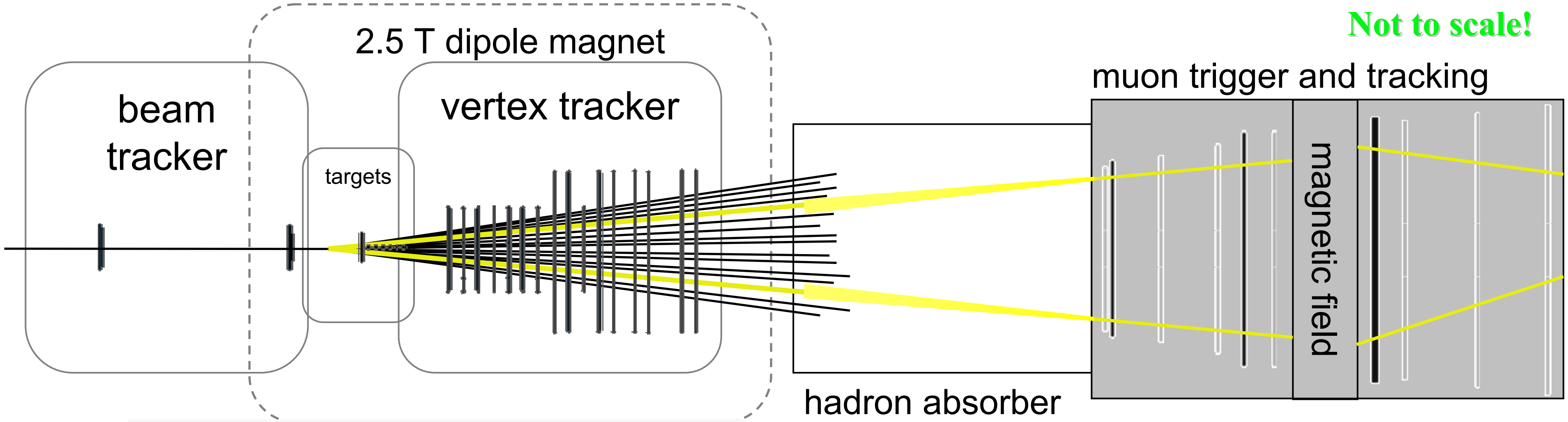
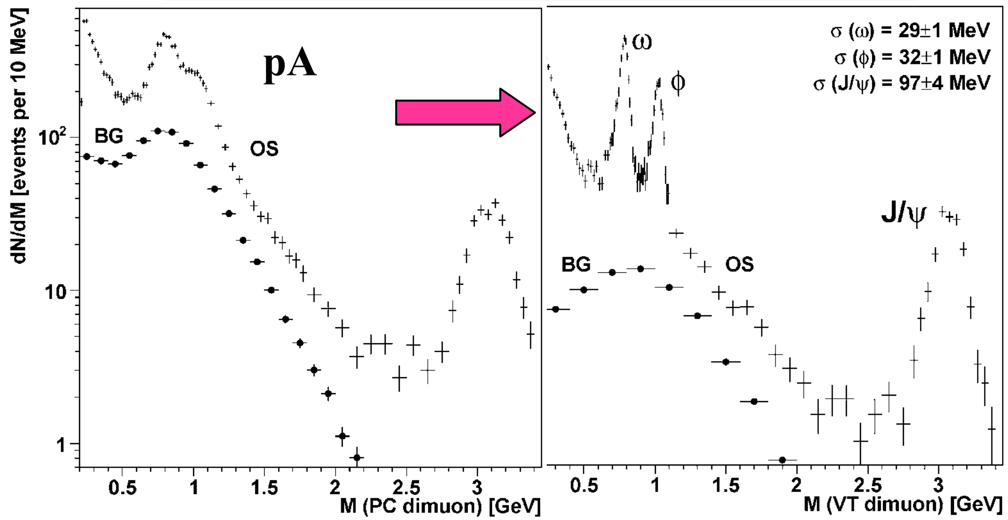
A New Era: The NA60 Experiment

- **Combine Silicon pixel telescope with NA50 muon spectrometer**



Match vertex tracks with muon tracks in coordinate and momentum space



- **Improved detector performance**
  - **Much better mass resolution**
  - **Reduce remaining π, K decay background**
  - **Larger low mass acceptance**
  - **Capability to reconstruct secondary vertex**

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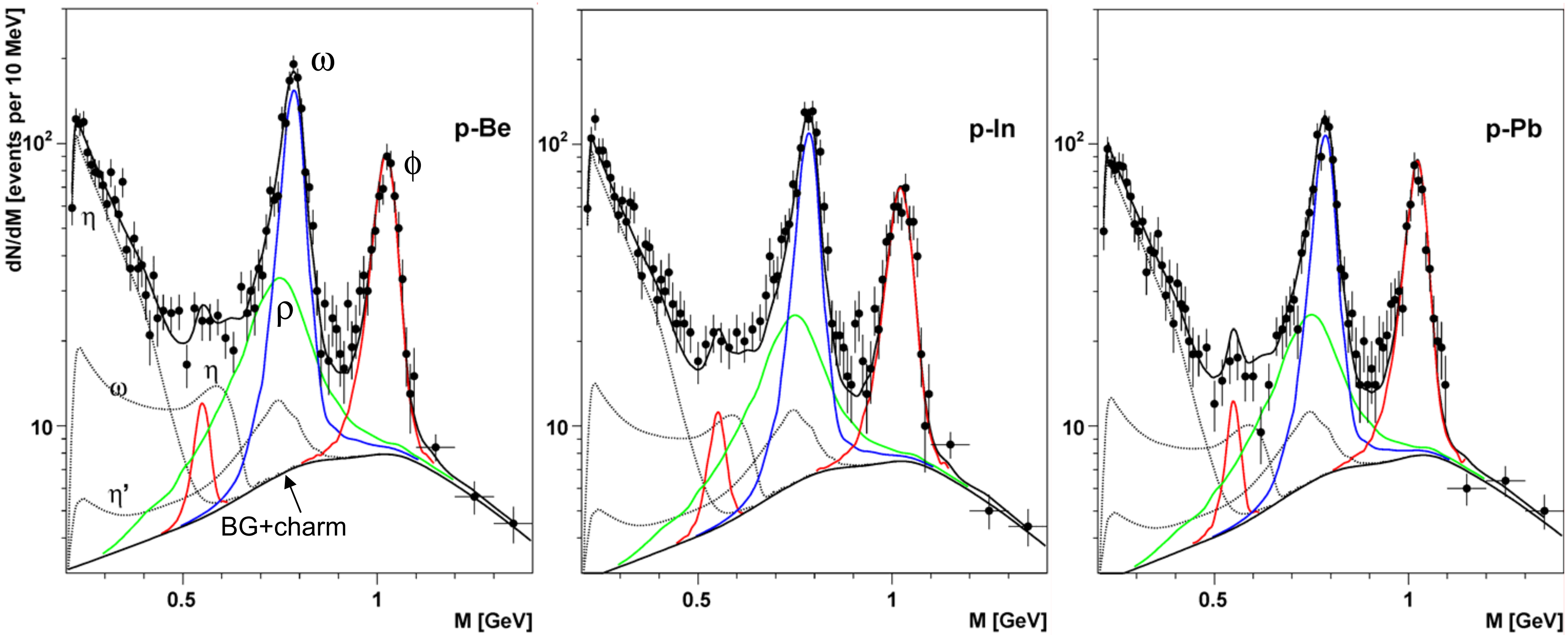
Detailed p-A Reference Data from NA60

Shown by Hermine Wöhri



Elementary 4π meson production cross-sections
Nuclear dependence of production cross-sections

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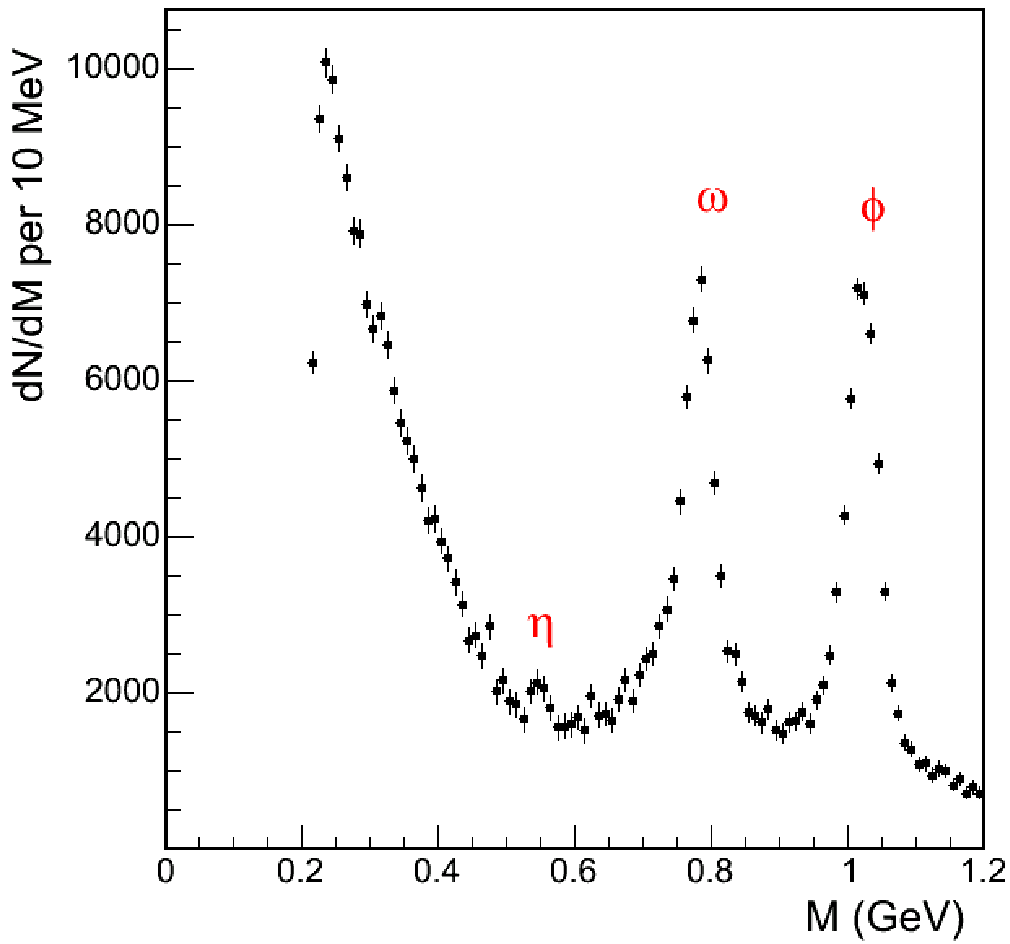
First Look at Low Mass Region in In-In

Shown by Gianluca Usia



- **Low mass continuum**
  - **High statistics from $2m_\mu$ upward**
  - **Low pair acceptance for low mass low p_T**
  - **Pair acceptance different from CERES**
- **Clearly visible hadron decays**
  - $\phi \rightarrow \mu\mu$
  - $\omega \rightarrow \mu\mu$
  - $\eta \rightarrow \mu\mu$ **BR: (5.8 +/- 0.8) 10^{-6})**
  - **Eventually well calibrated cocktail**
  - **For heavy ion collisions**
- **First quantitative analysis of ϕ**

First quantitative analysis of ϕ in In-In

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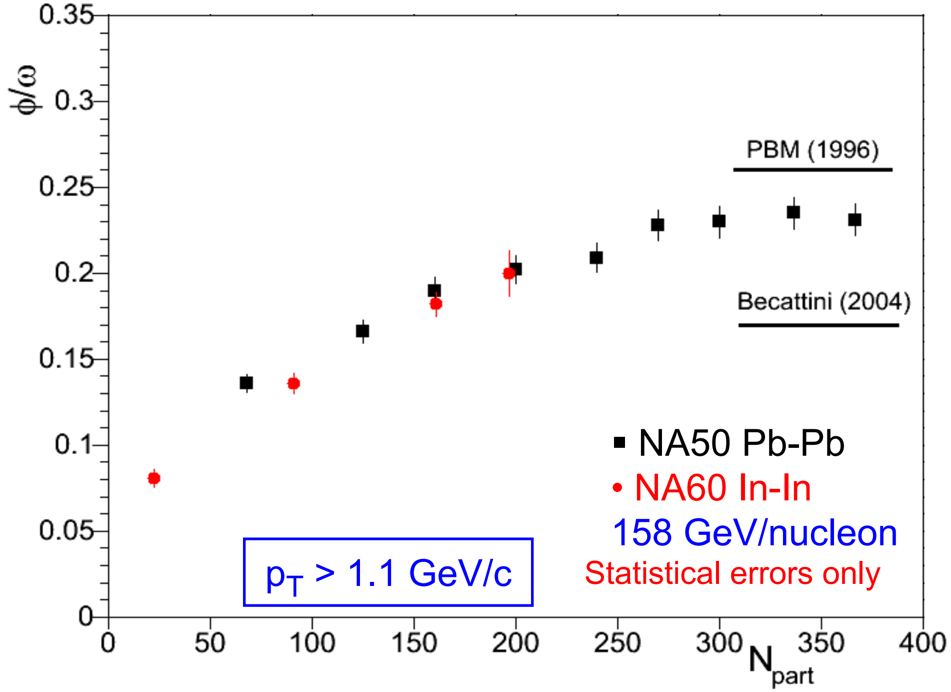
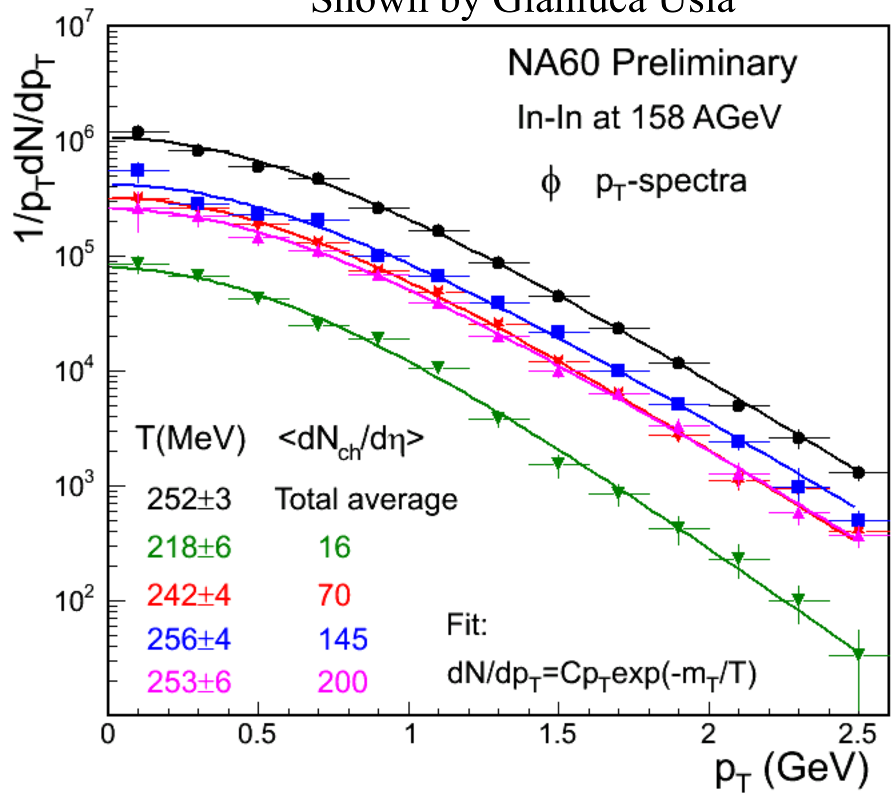
First Look at ϕ Meson from In-In

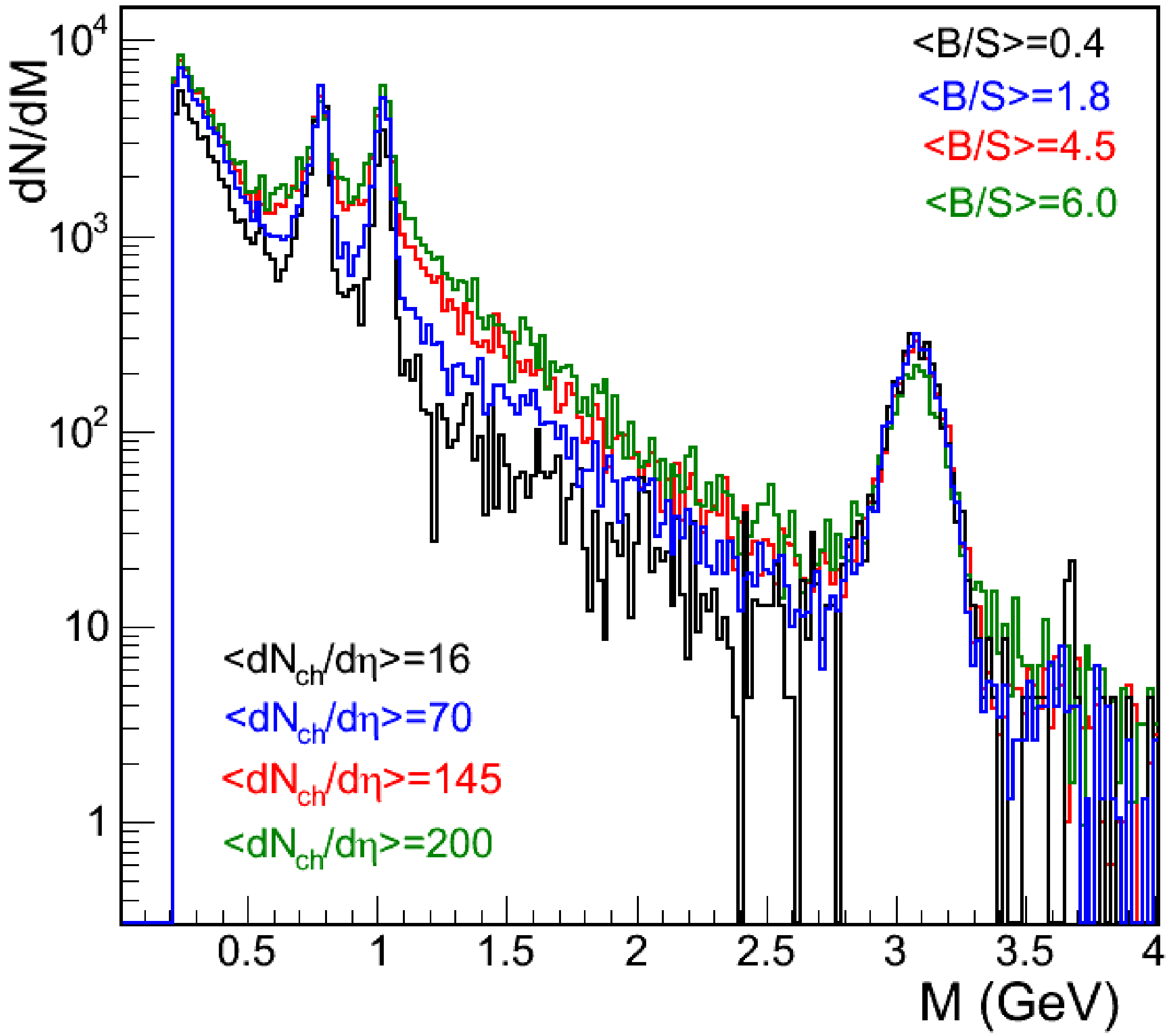
Shown by Gianluca Usia





- **Step towards clarifying the SPS ϕ puzzle**
  - **Accurately measured yields, slopes, and centrality dependence**
- **No indication for medium modifications of ϕ**
  - **m_ϕ independent of N_{part} within few MeV**

First Look at Centrality Dependence of Continuum



Shown by Gianluca Usia

- **Full systematic vs N_{part}**
  - **Dimuon spectra normalized to ω**
    ~ normalized to $1/N_{ch}$
    similar to CERES
- **Centrality dependence stronger than linear in N_{part}**
  - **In the IM region**
  - **Between ρ/ω and ϕ**
  - **Below ρ/ω**
- **Also visible**
  - **ϕ enhancement**
  - **J/ψ suppression**

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Preview on Open Charm Measurement

Shown by Ruben Shahoyan

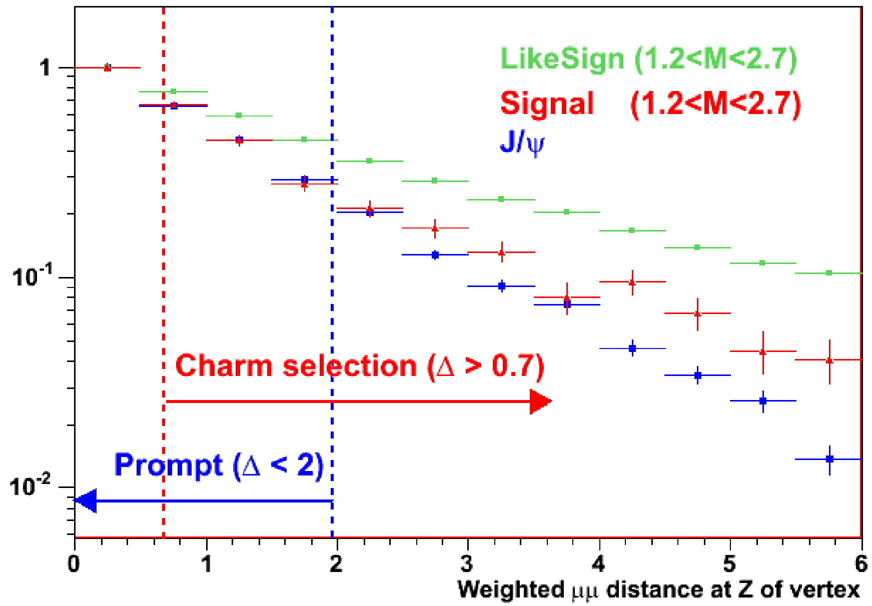
- Use decay length of D mesons

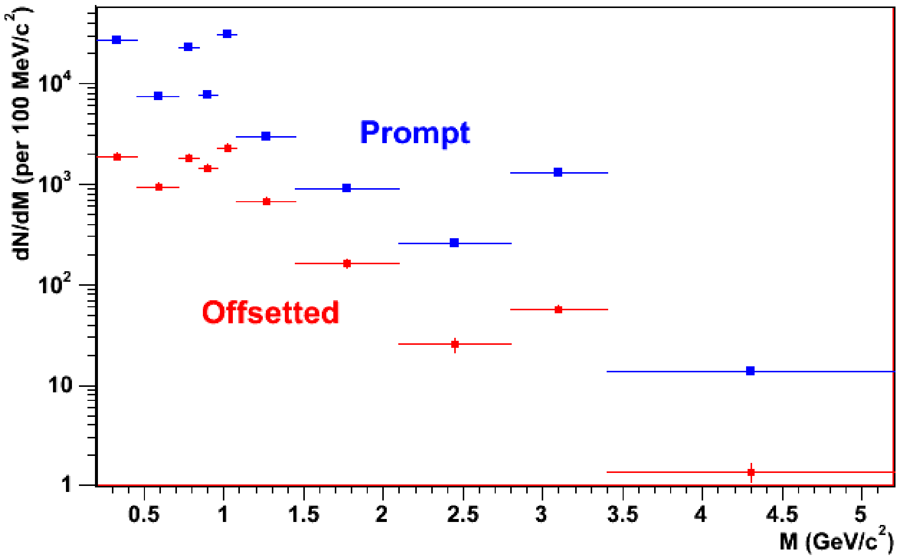
  $D^+ : c\tau = 312\ \mu m$
  $D^o : c\tau = 123\ \mu m$

- Analysis:
  - Charm Measure vertex x,y,z with beam tracker & vertex tracker
  - Measure the muon track offset at the vertex
  - Cut on weighted distance

    prompt and offset μμ sample

- Sneak preview:
  - Charm continuum clearly enriched in charm selection





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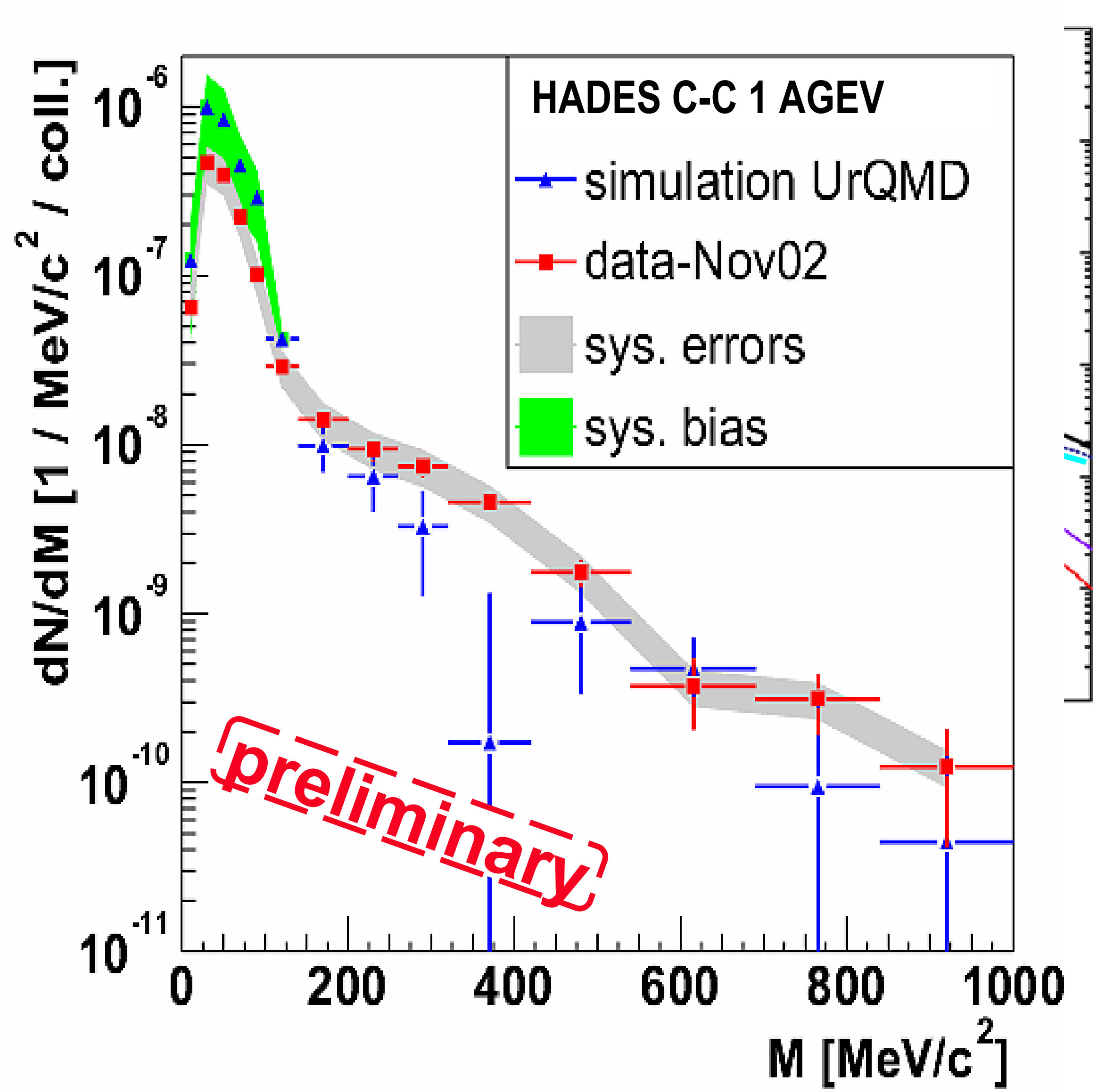
Dileptons Measured at Low Energies

- **DLS puzzle**
  - **Strong enhancement over hadronic cocktail with "free" ρ spectral function**
  - **Enhancement not described by in-medium ρ spectral function**
- **Verification expected to come soon from HADES**
- **Connection of enhancement to SPS results not clear**



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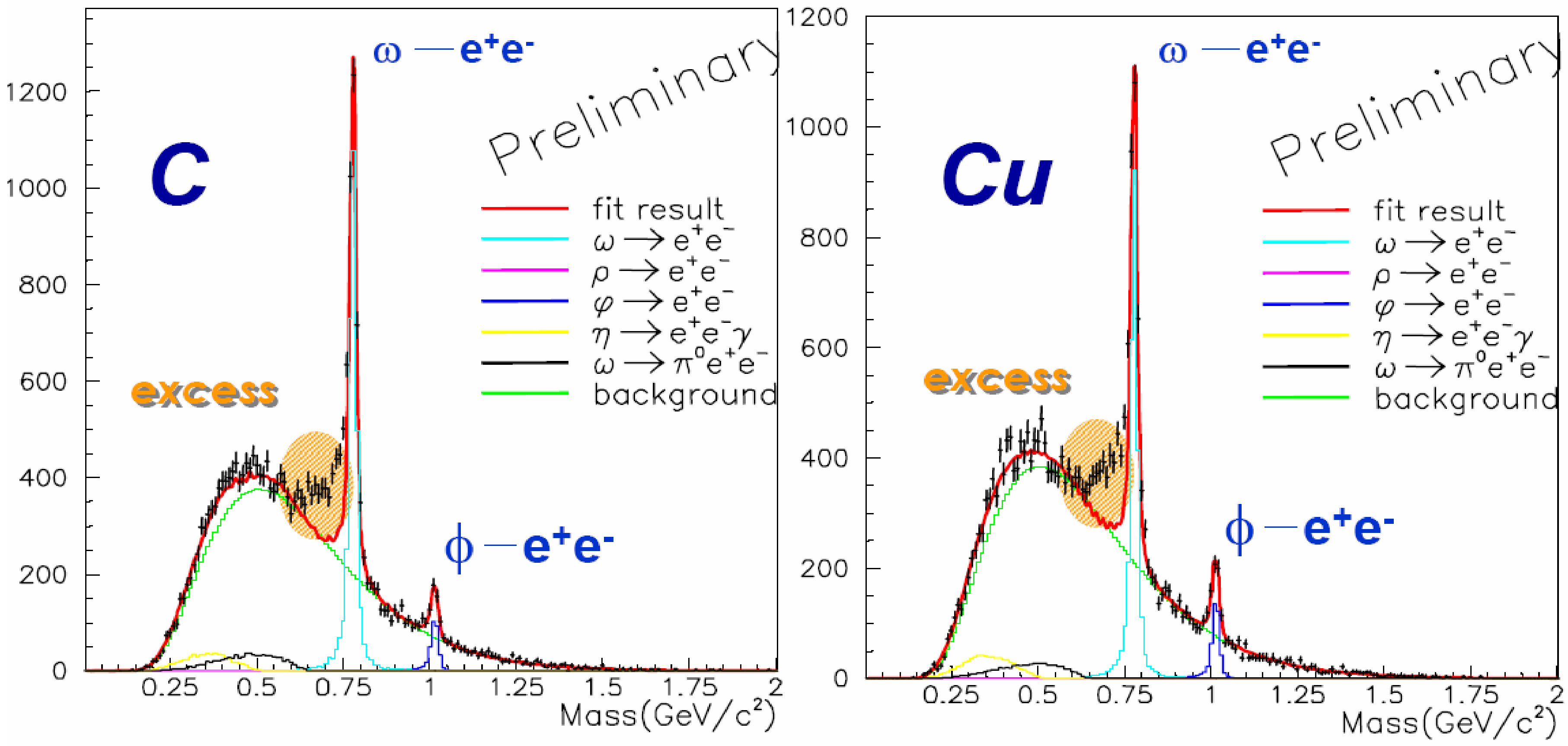
KEK E235 p-A Collisions at 12 GeV Beam Energy

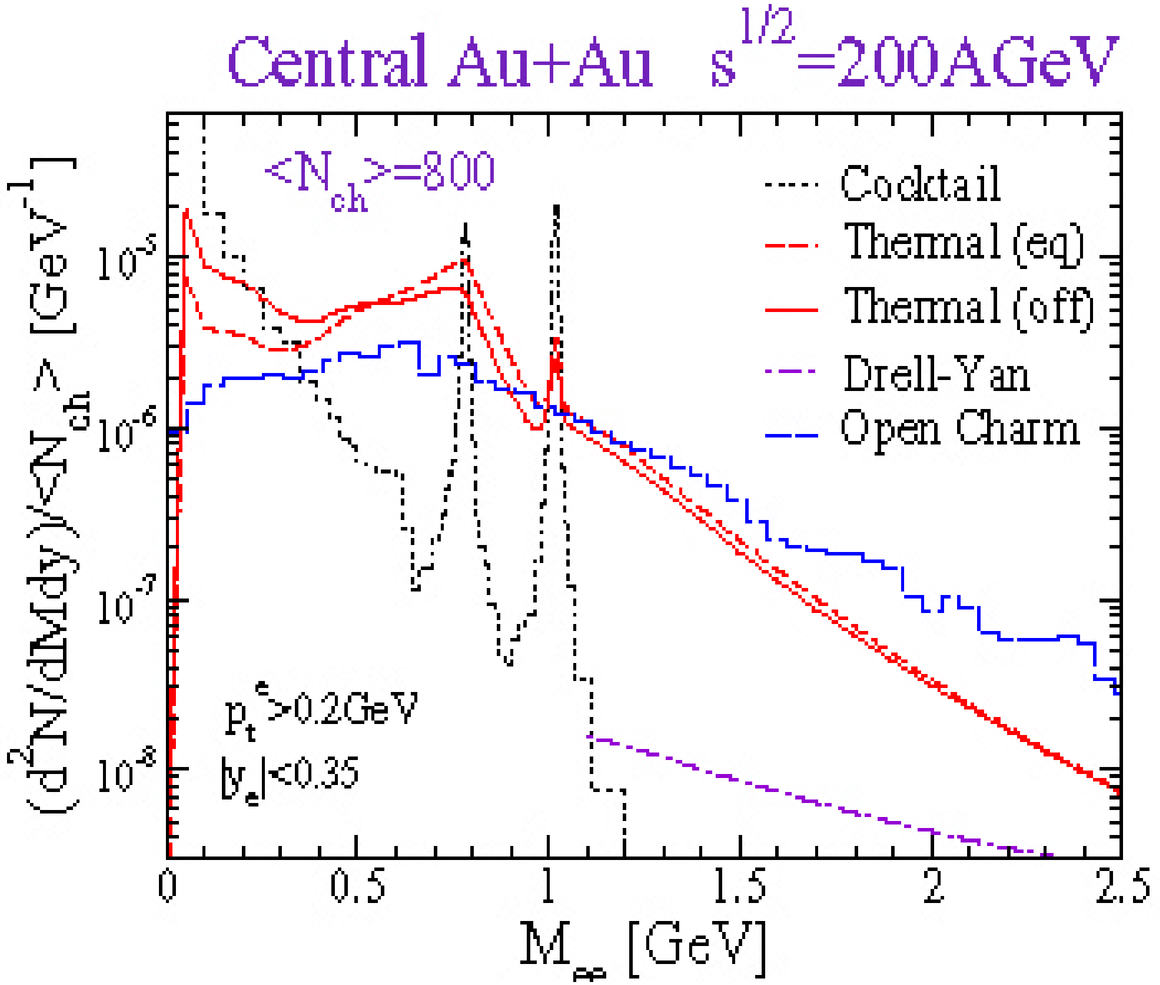


- Access over hadronic sources: ρ, ω, Φ -> e^+e^-, ω ->π e^+e^- , η -> γ e^+e^-
  - Shoulder below ρ,ω
  - Changed ϕ width C → Cu target

Hints for medium modification in cold nuclear matter?

Predictions for RHIC

- Same framework as for SPS calculations
  - Experimental observation: large baryon+antibaryon yield
  - Consequence: Large enhancement at low and IM masses
  - Competes with large charm background



R. Rapp, nucl-ex 0204003

Dilepton measurement at RHIC very promising

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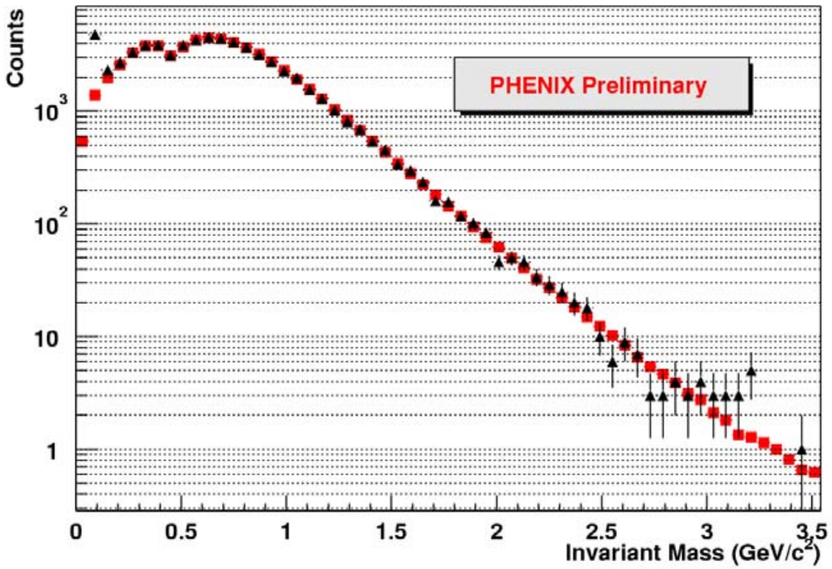
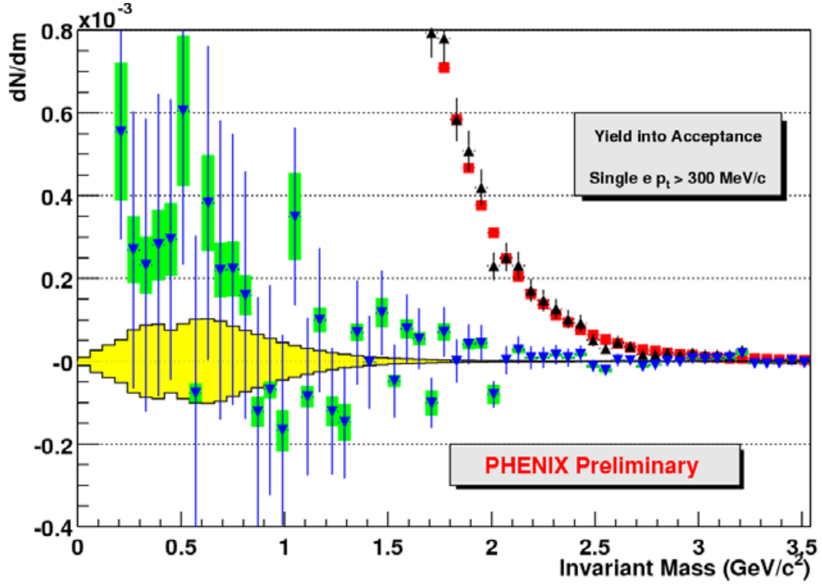
PHENIX Measures Electron Pairs

- **First attempt from 2002 run with Au-Au**
  - **S/B ~ 1/500 for min. bias events**
  - **Two small statistics**

Real and **Mixed** e^+e^- Distribution



Real - **Mixed** with systematic errors



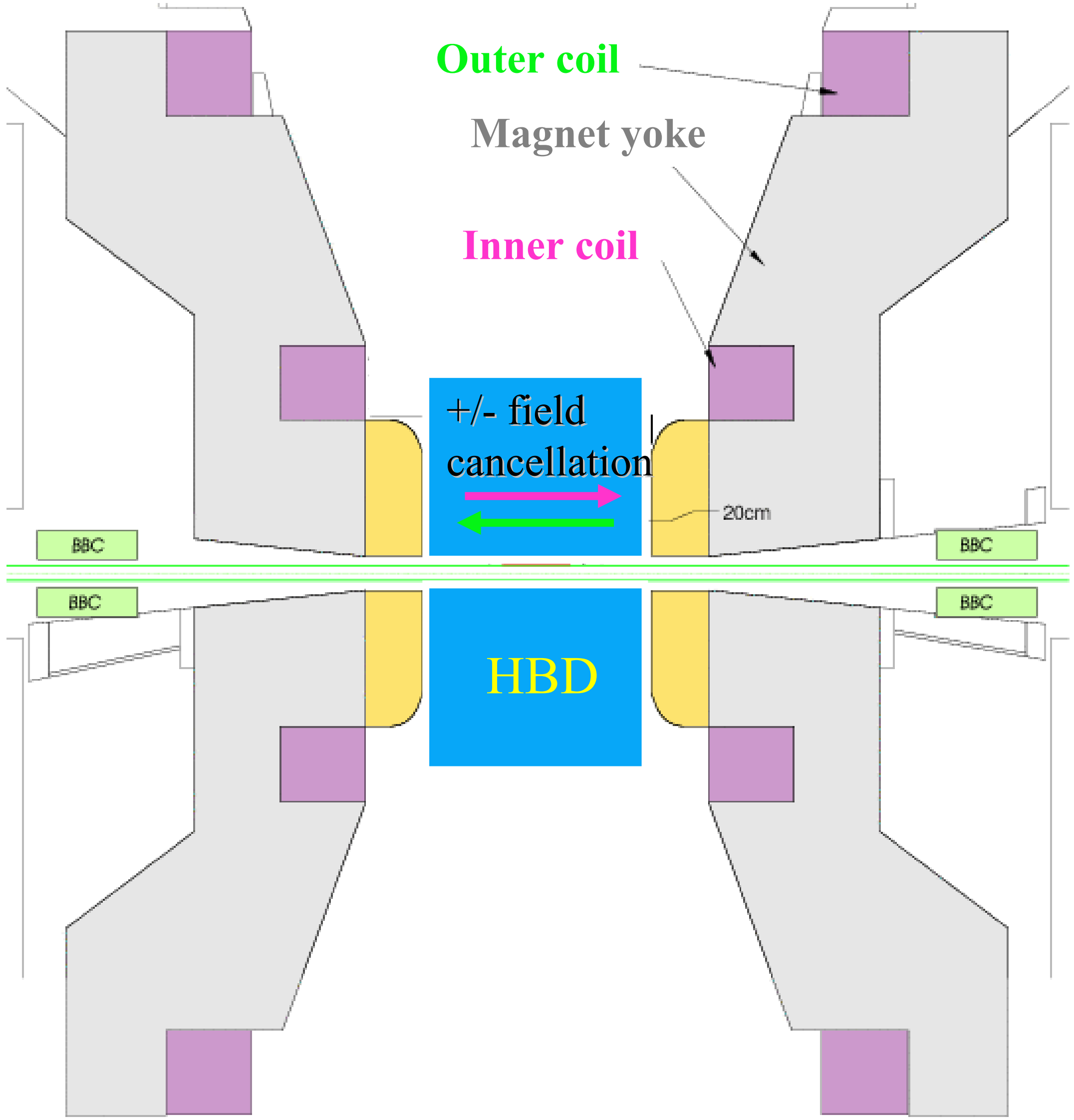
- **Au-Au data taken in 2004**
  - **~ 100x statistics**
  - **Photon conversions reduced by factor 2-3**
  - **Expect background reduction by ~ 2**

Maybe first measurement ala CERES possible?

Precision Dilepton Measurement with PHENIX

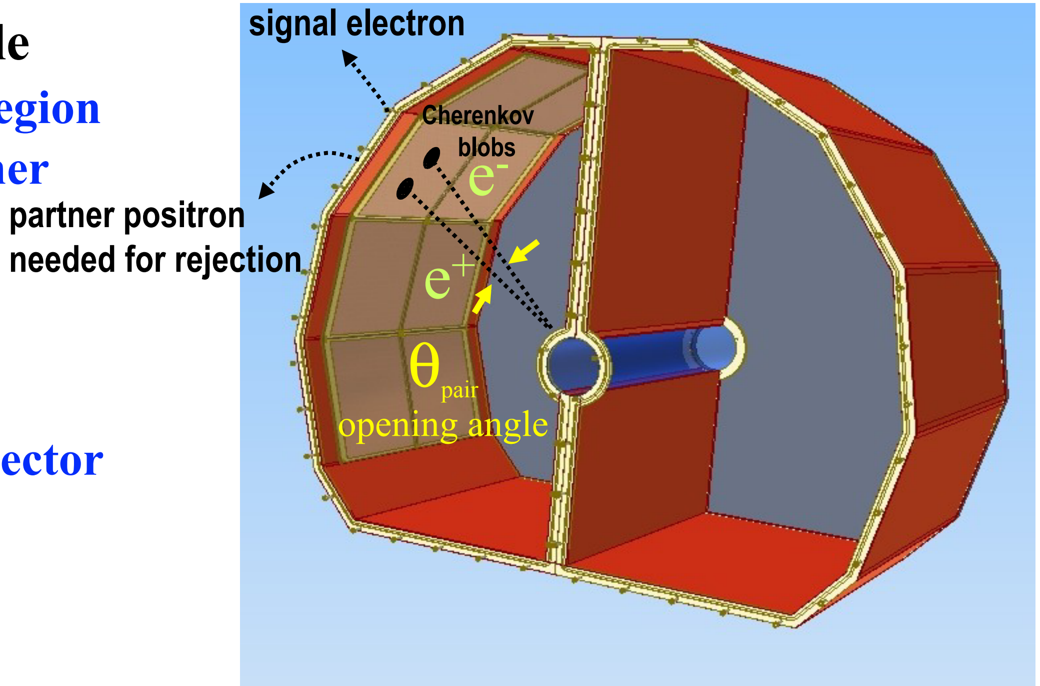
Requires:
Dalitz rejection (HBD)
& charm measurement
(vertex tracker)

Top view of PHENIX magnet region



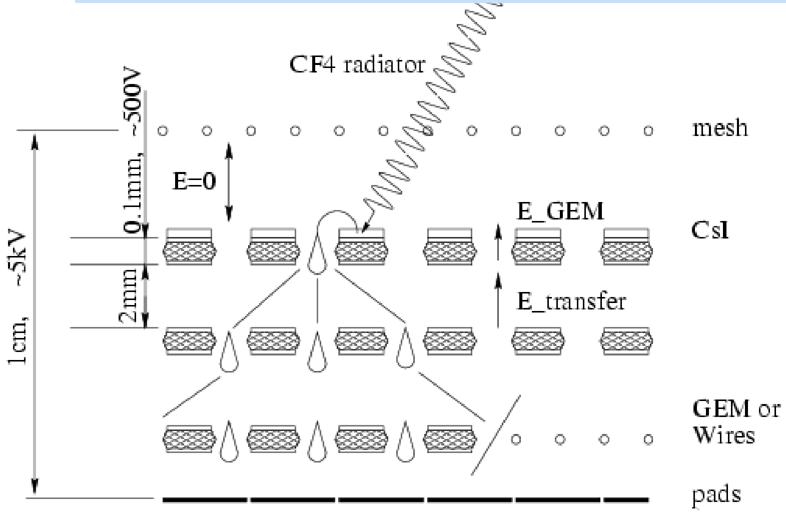
Hadron Blind Detector (HBD)

- **Dalitz rejection via opening angle**
  - **Identify electrons in field free region**
  - **Veto signal electrons with partner**



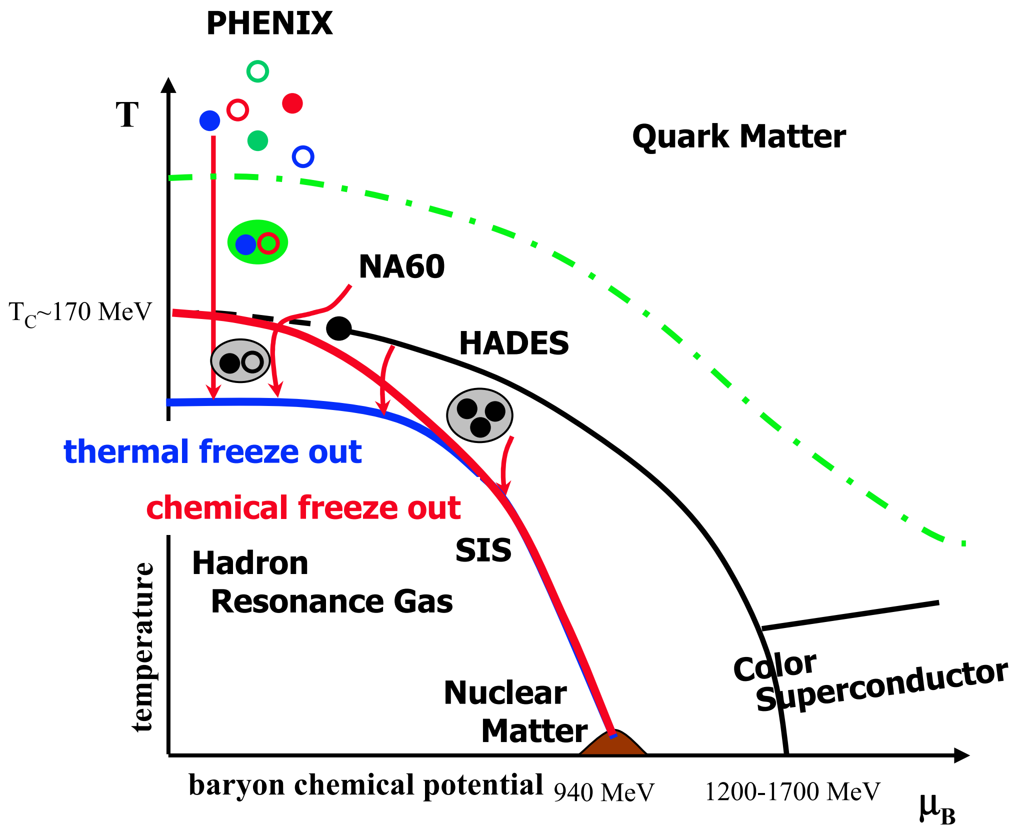
- **HBD concept:**
  - **windowless CF4 Cherenkov detector**
  - **50 cm radiator length**
  - **CsI reflective photocathode**
  - **Triple GEM with pad readout**

- **Construction/installation 2005/2006**



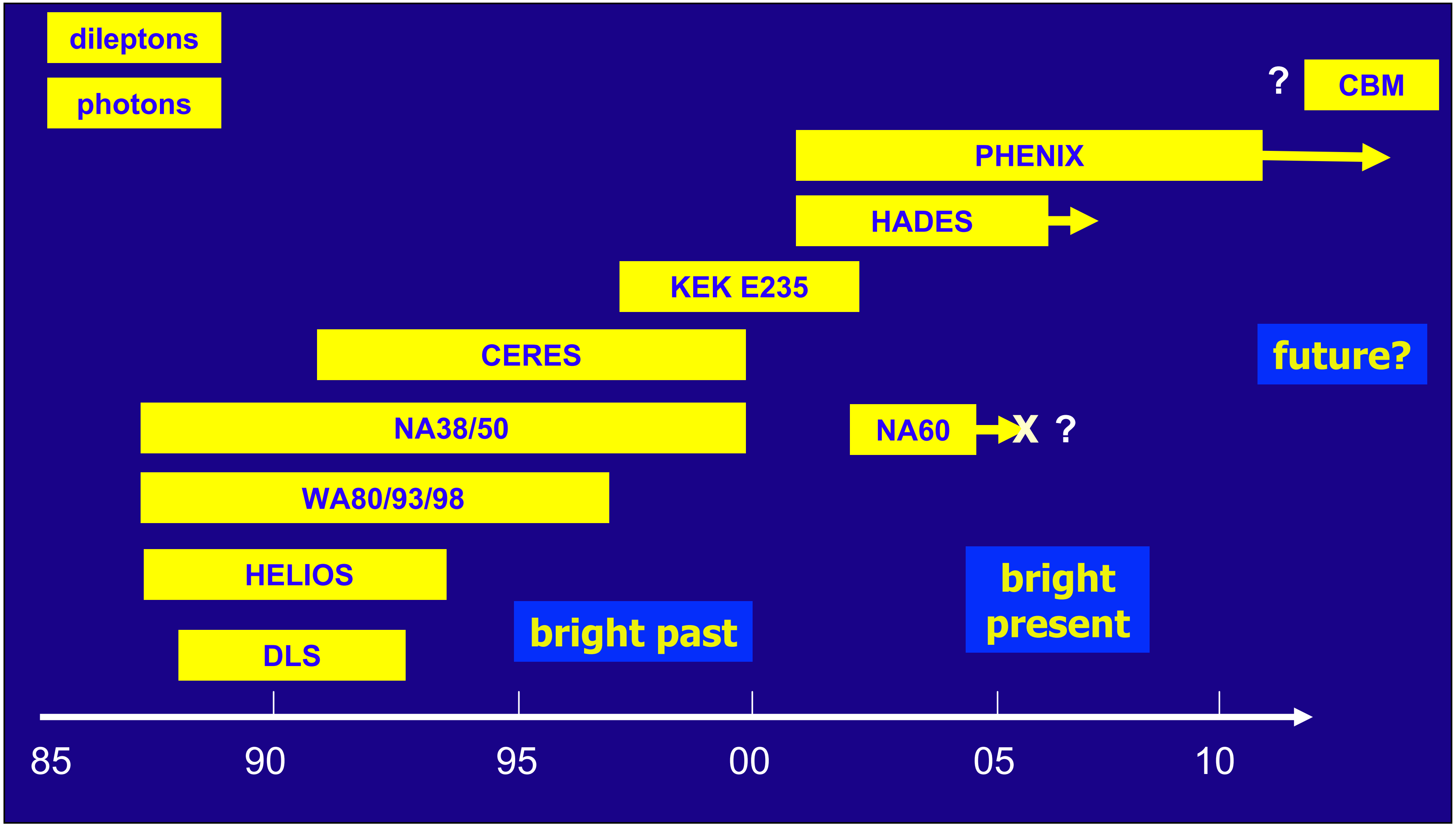
STONY BROOK

Future for Electromagnetic Probes



- **Experiments at different √s probe different regions of phase diagram**
  - **NA60 μμ pairs at the SPS**
    transition region
  - **HADES ee pairs at SIS**
    dense hadronic matter
  - **PHENIX ee pairs and γ at RHIC**
    strongly coupled plasma

Dilepton and Photons



Cocktail of Known Sources

- **Hadron decays**
  - **Dalitz decays π^0, η**
  - **Direct decays ρ/ω and ϕ**
- **Hard processes**
  - **Charm (beauty) production**
  - **Important at high mass & high p_T**
  - **Much larger at RHIC than at the SPS**
- **Cocktail of known sources**
  - **Measure spectra & yields**
  - **Use known decay kinematics**
  - **Apply detector acceptance**