PHENIX EM probes

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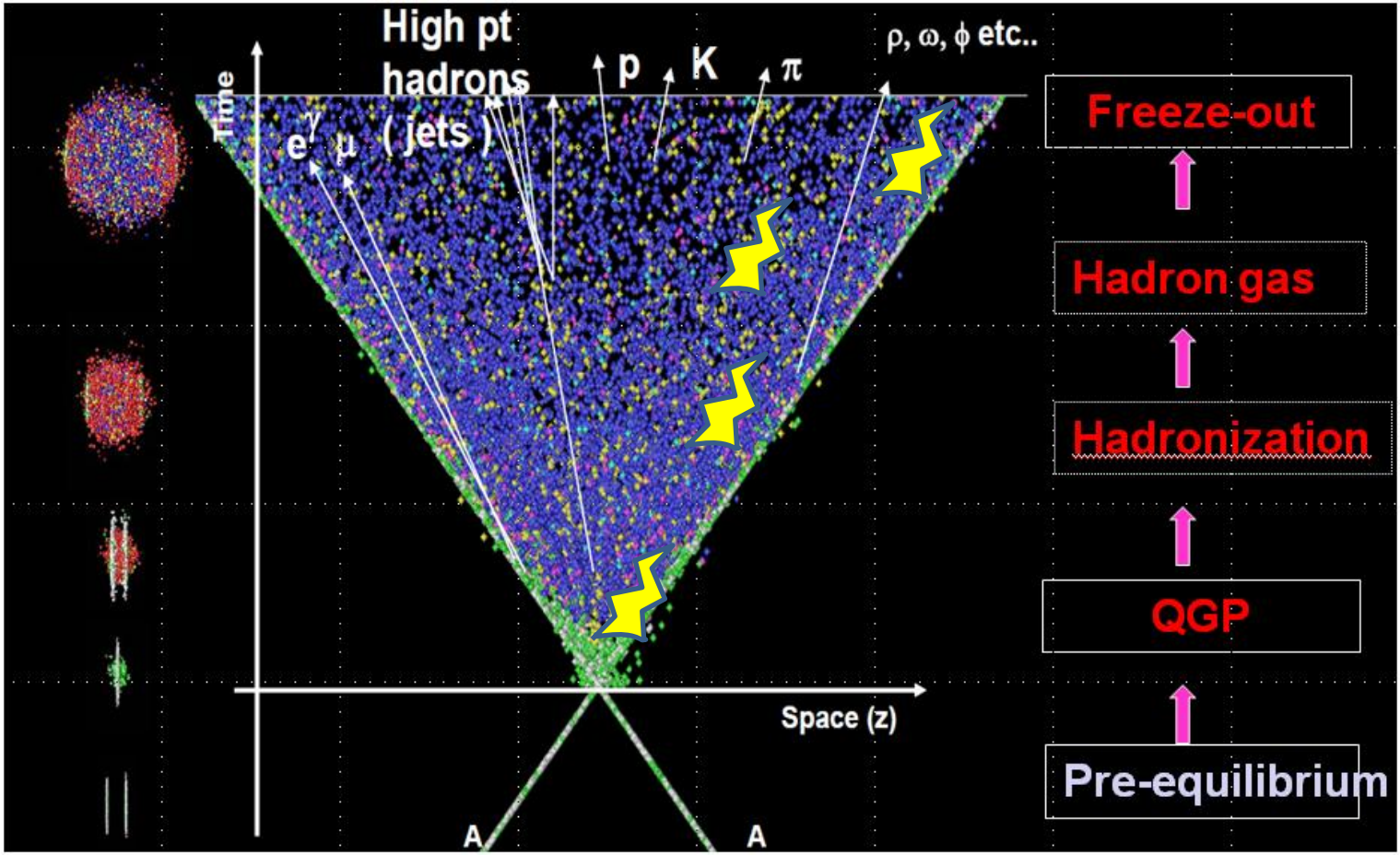
RIKEN-BNL Research Center
For the PHENIX collaboration
HP08 June 13, 2008

EM probe introduction

Penetrating probe
Emerges at every stage

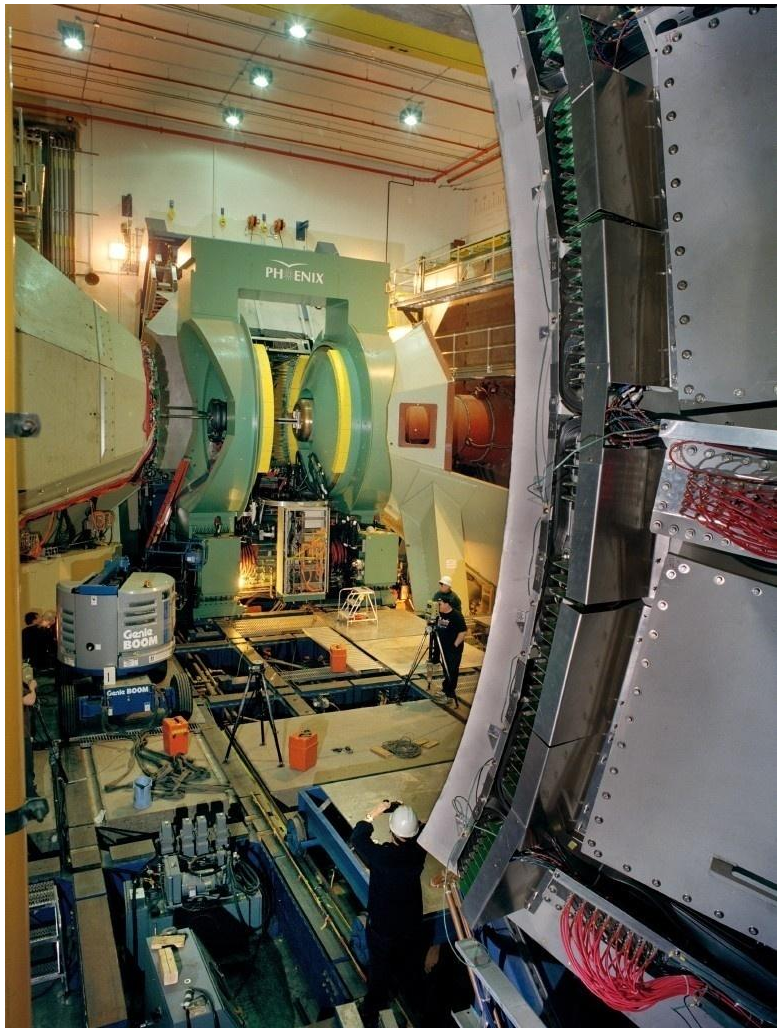


Why with PHENIX

Fine segmented EMCal
Electron identification

+

High DAQ rate
Trigger



–Outline of this talk

Direct photons at high pT
Low mass dileptons
Thermal photons via di-electrons

(Only for the mid rapidity)

Direct photon

Measurement

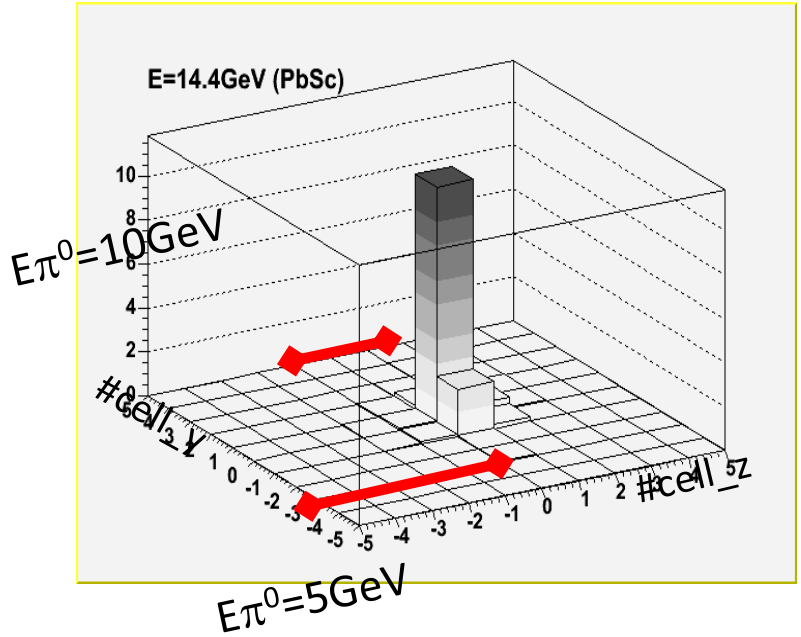
Background subtraction

π^0 to 2γ

π^0 2gamma distance

> 28 tower / $E\pi^0$ [GeV]

EMCal hit example

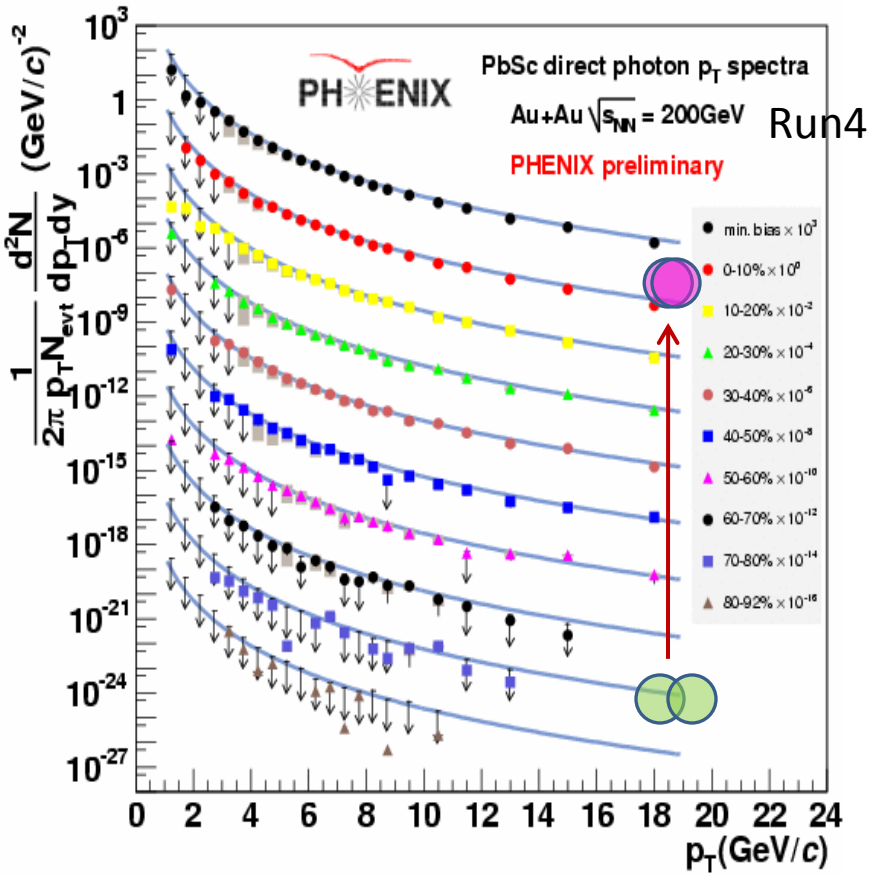


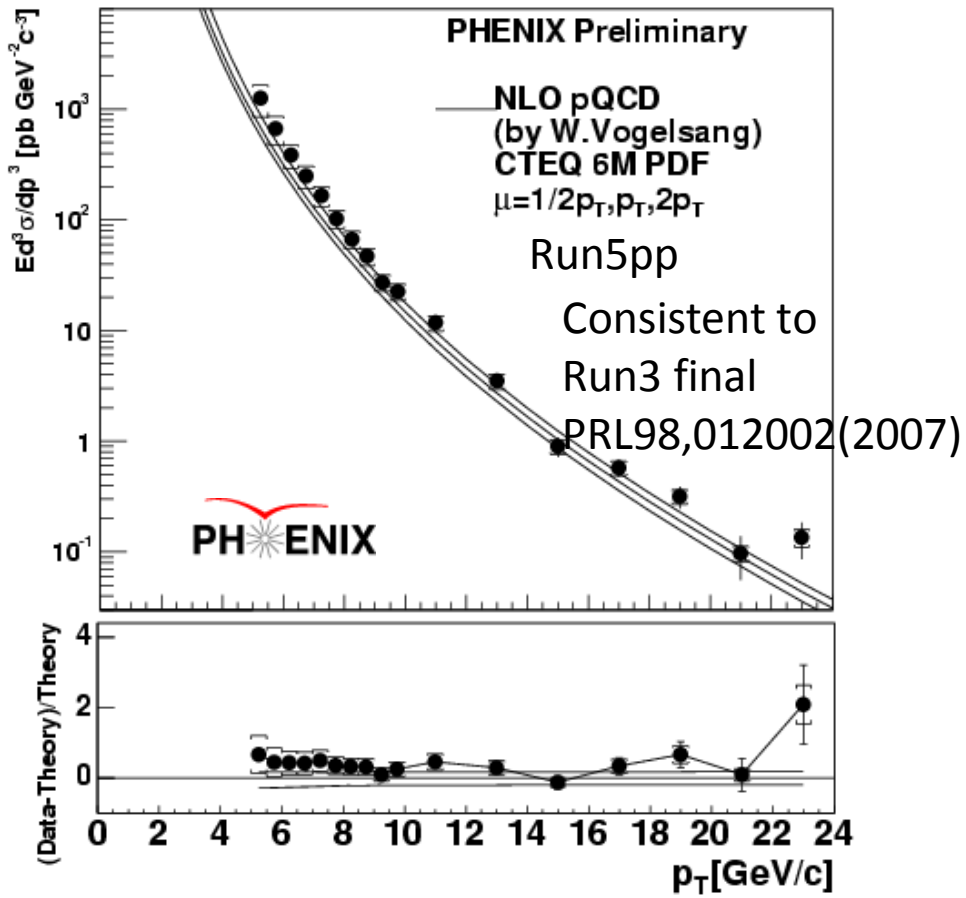
Thanks to the fine granularity!

Direct photon spectra

Au+Au 200GeV

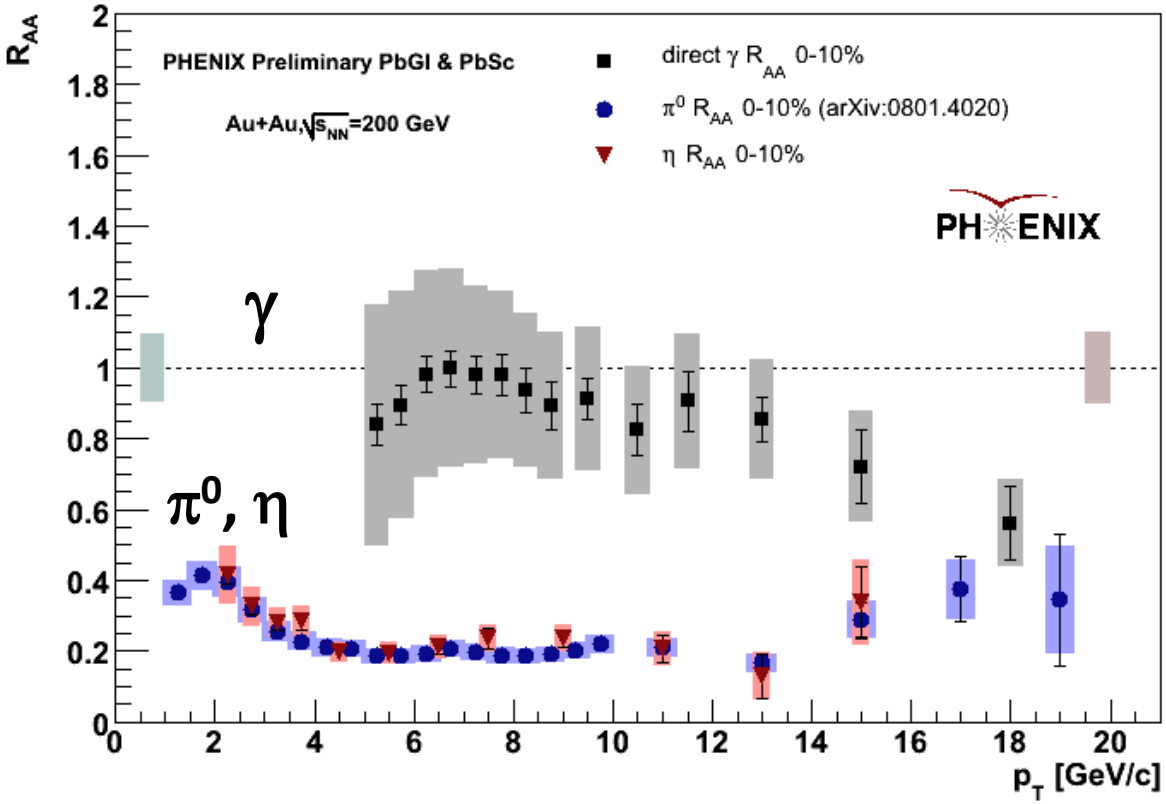
p+p 200GeV
Good agreement with pQCD





Direct photon R_{AA}

R_{AA} (since QM06)



This plot is already shown many times as a preliminary.

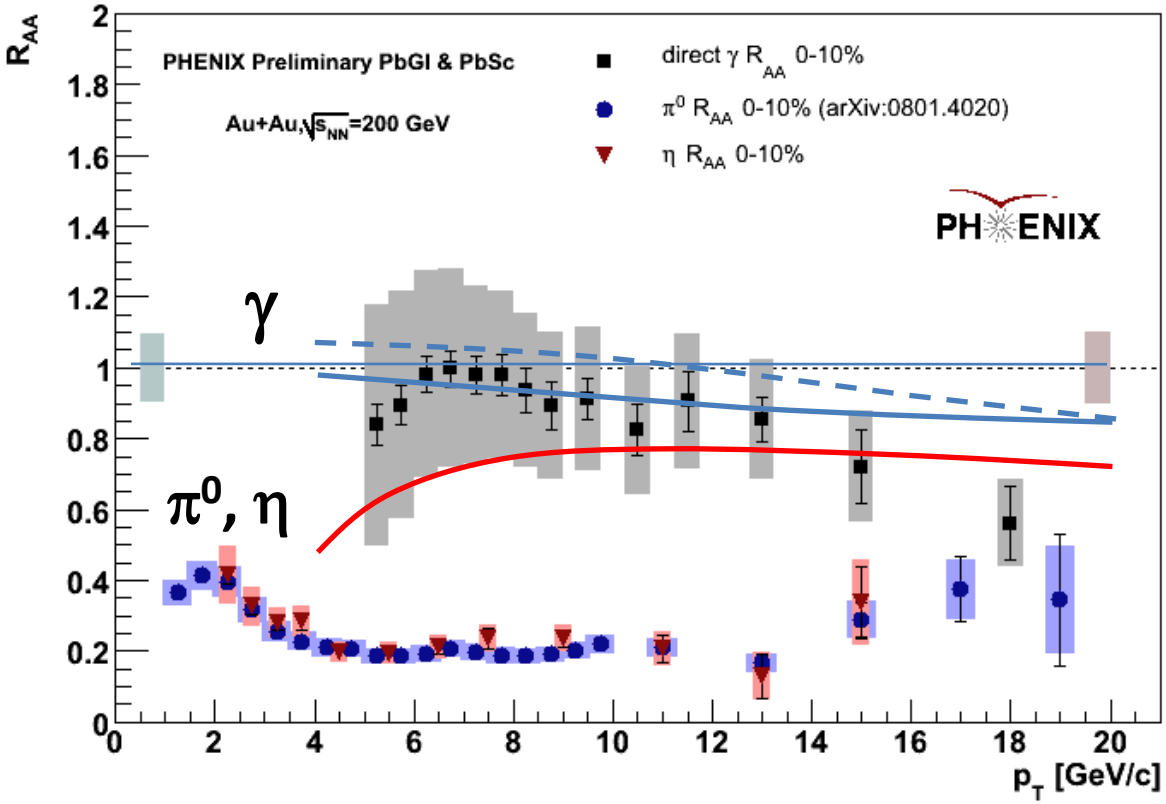
Comments
A difficulty in high pT region. (=pi0 merging, very rare.) We need to be careful.

Various checks are done. It is confirmed that the decrease of R_AA at high pT is real, but with a slight increase.

The final plot is coming soon!

Direct photon R_{AA}

R_{AA} (since QM06)



Curves : F.Arleo JHEP09(2006)015

- Isospin effect
- +cold nuclear effect (EKS)
- +energy loss $20<\omega_c<25$GeV

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Comments
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We need to be careful.

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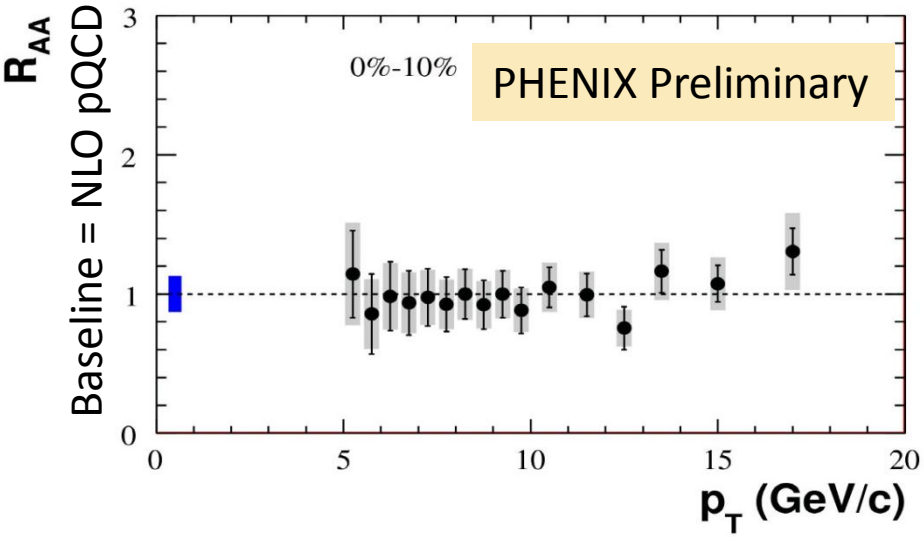
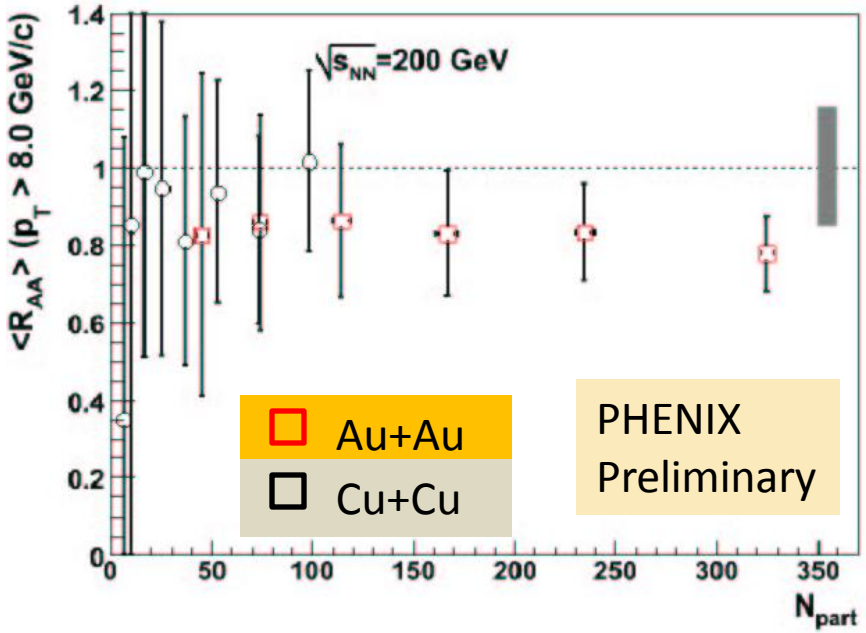
Cu+Cu $\sqrt{s}$=200GeV

(Run 5)



Direct γ R_{AA} vs N_{part}

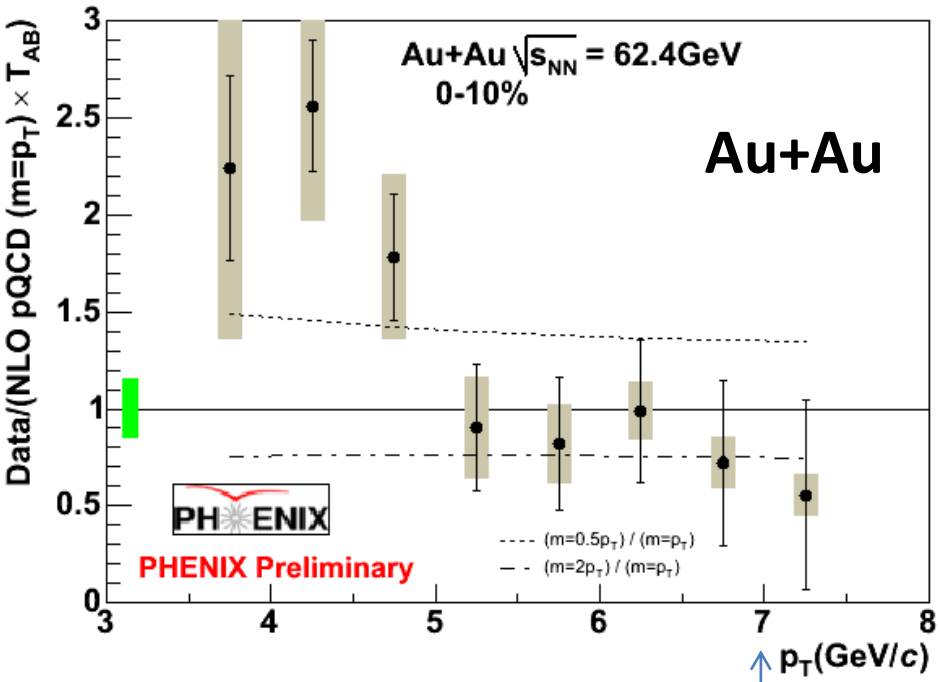


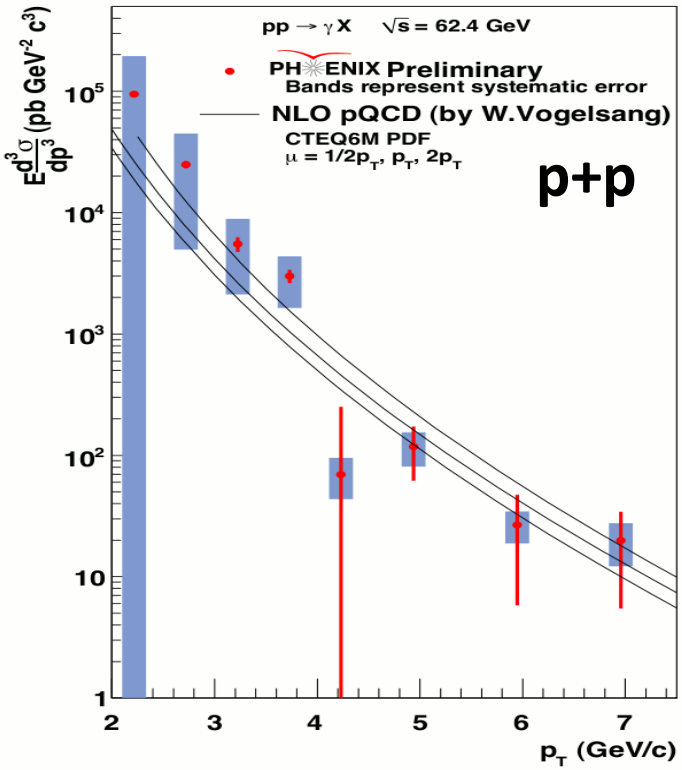
- Direct γ R_{AA} ~ 1
- Is there other evidence for nuclear effects?
  - Reduced/enhanced radiation due to jet quenching

Au+Au and p+p √s=62.4GeV

pT=21GeV at √s=200GeV corresponds to pt=7GeV at √s=62GeV in x_T

Free from the difficulty of pi0 photons merging.
The isospin effect should appear.





√s=200GeV pT=21GeV
at the same xT

Fragmentation photons

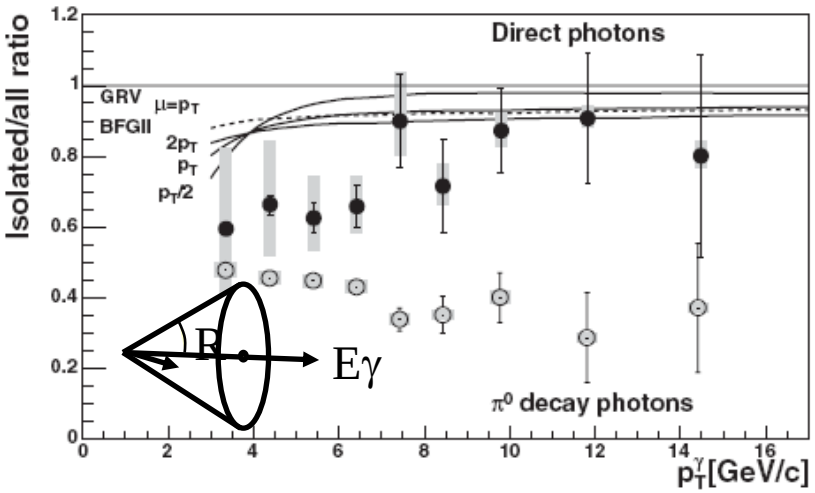
Components

Direct = prompt + fragmentation + medium effect

It is important to include the jet quenching effect to understand the direct photon yield

—Decomposition study (for p+p case to begin with.)

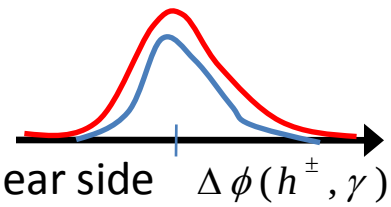
γ(Isolated)/γ(all direct)



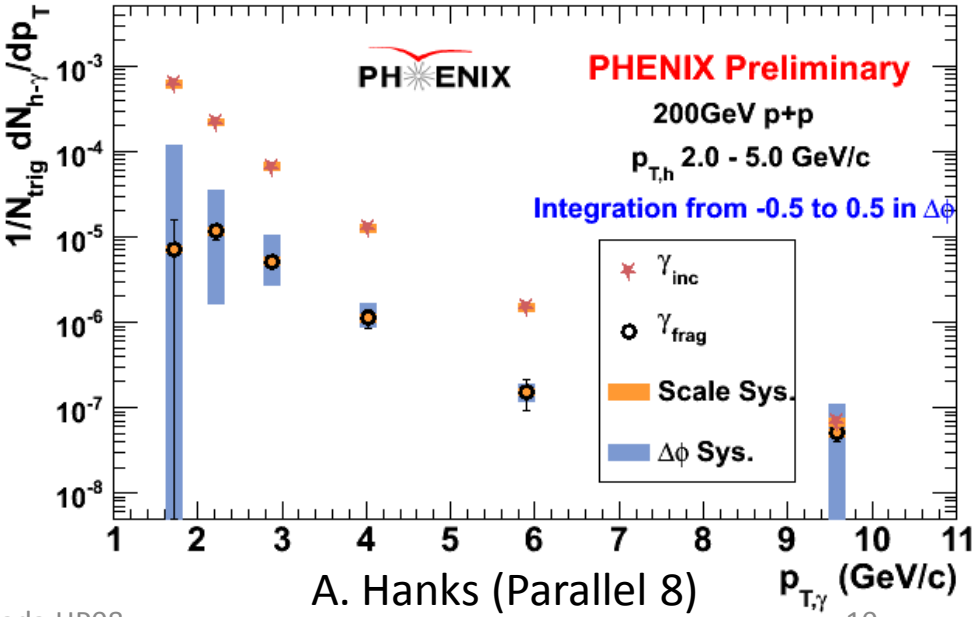
PHENIX, PRL98, 012002 (2007)

An isolation cut
(high pT region : easy to understand
Low pT region : underlying activity effect.
Difficult with a limited acceptance?)

Hadron tagged events Δϕ correlation



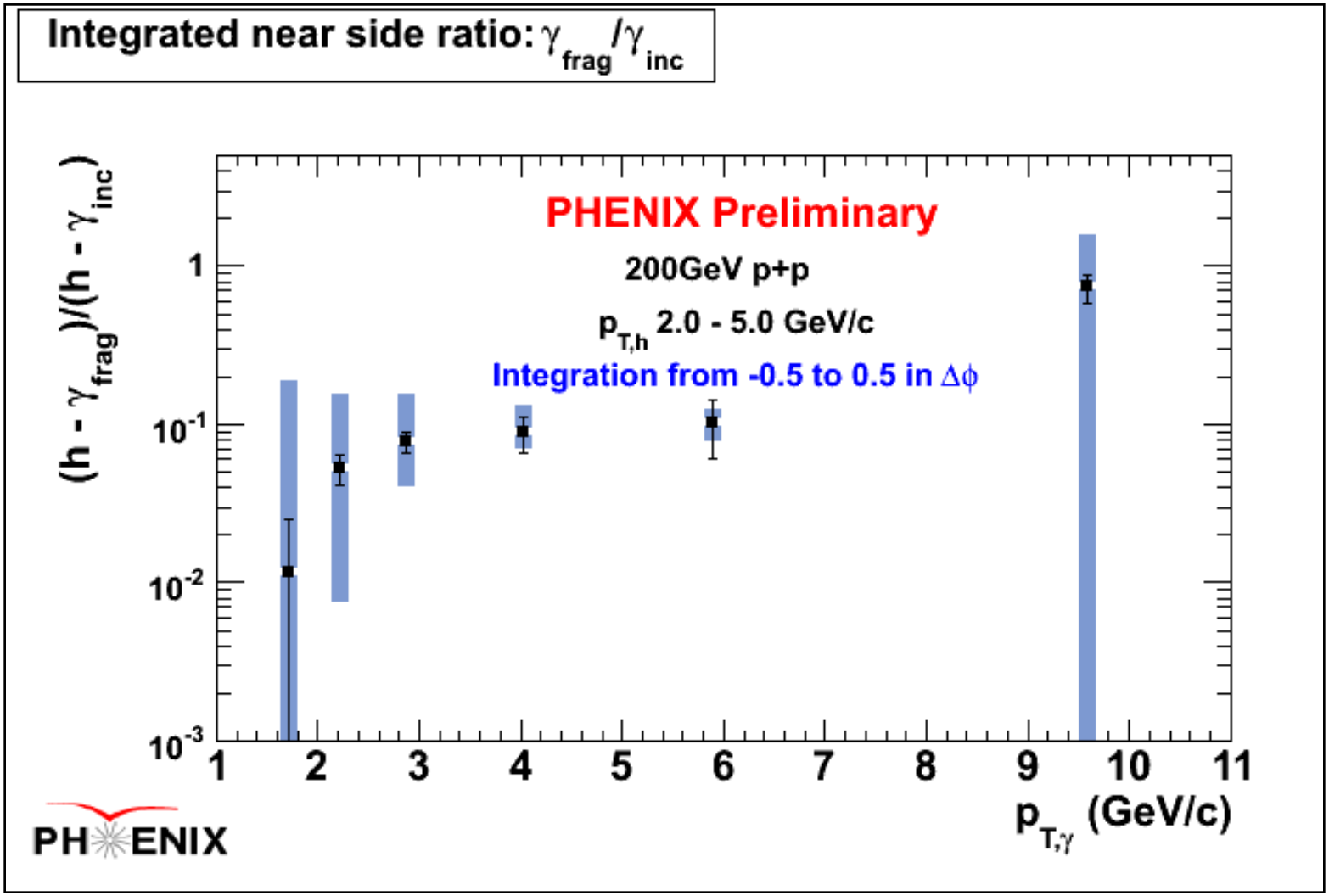
$$Y_{frag}(\Delta\phi) = Y_{inclusive} - Y_{decay}$$



A. Hanks (Parallel 8)

Fragmentation photons

Hadron tagged events Δϕ correlation



Electron(s)

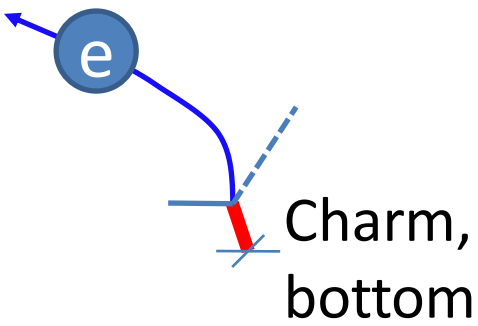
Another EM probe in PHENIX

It is the main player in low pT region.

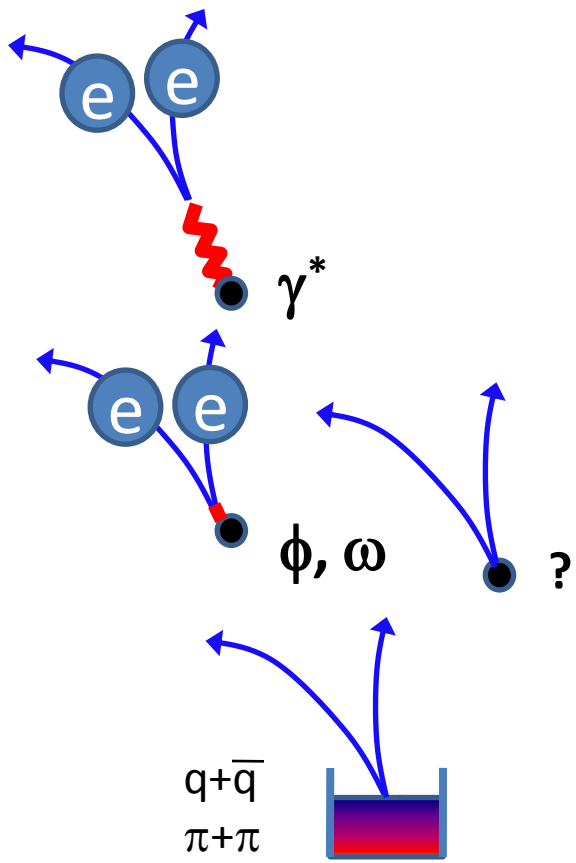
It is hard to analyze the EMCal photons

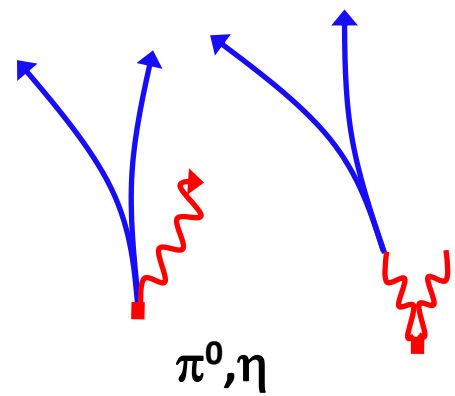
- low signal to background ratio (nature and far from the collision)

- poor resolution



→Another topic
(A.Dion Wednesday)





Dalitz decay,
External conversion

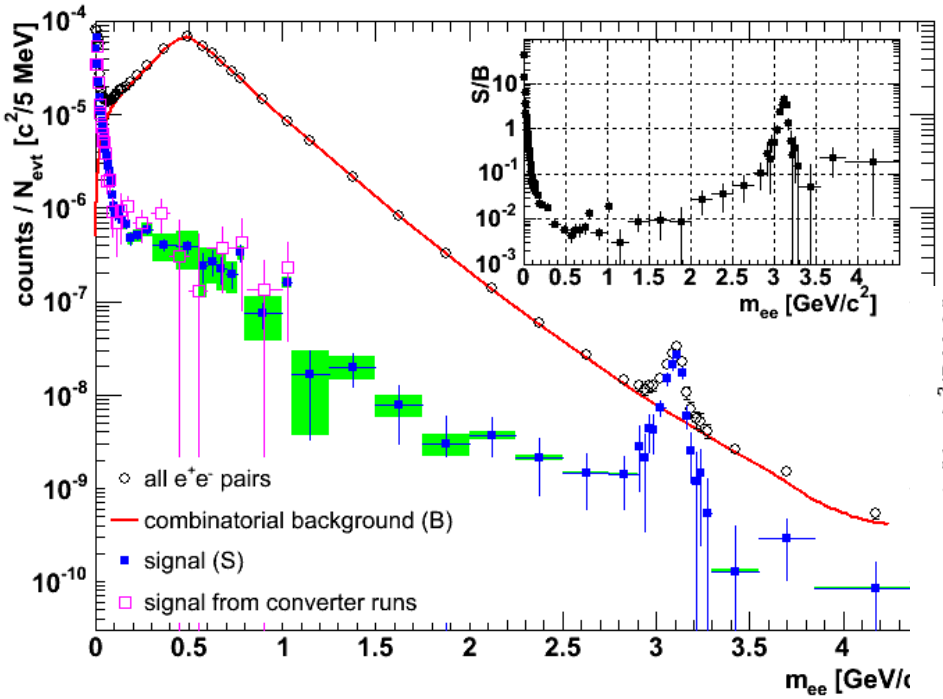
And combinations
(= background)

Dielectron analysis

Signal extraction from the ee sample

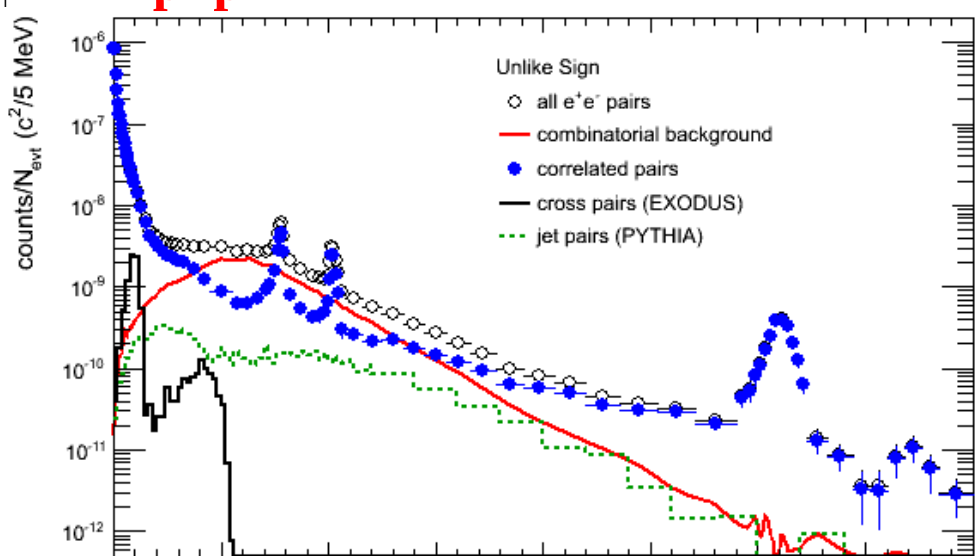
- **Signal definition : from the same origin or open charm/beauty pair origin**

Au+Au



There are huge combinatorial background.
But it is well controlled.

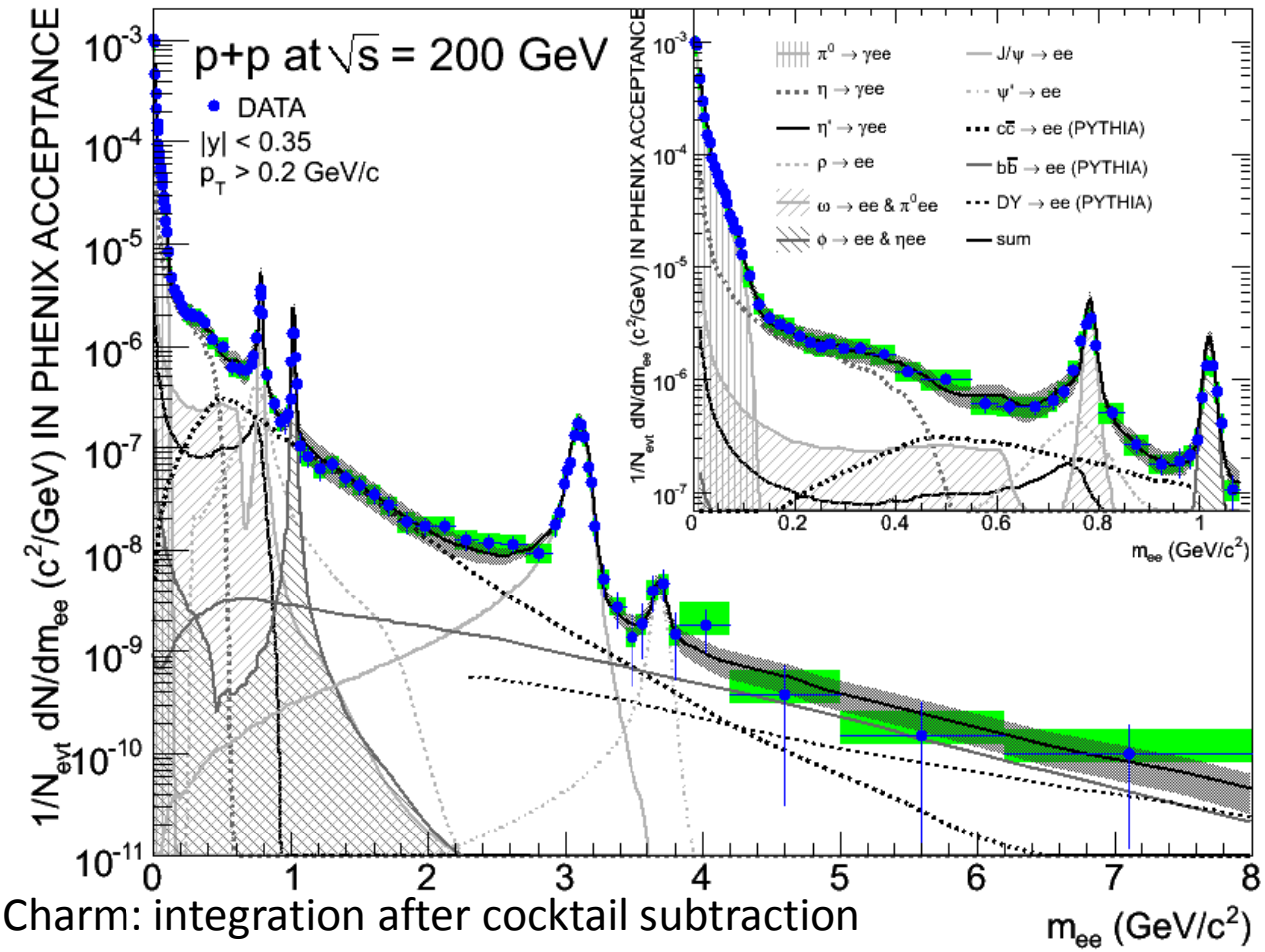
p+p



The signal contains Dalitz decays of mesons, let's see the cocktail calculation!

p+p cocktail comparison

What's in p+p?



- Data absolutely normalized
- Excellent agreement data-cocktail
- Extract charm and bottom cross section (→heavy quark A.Dion)

submitted to Phys. Lett.B
arXiv: 0802.0050

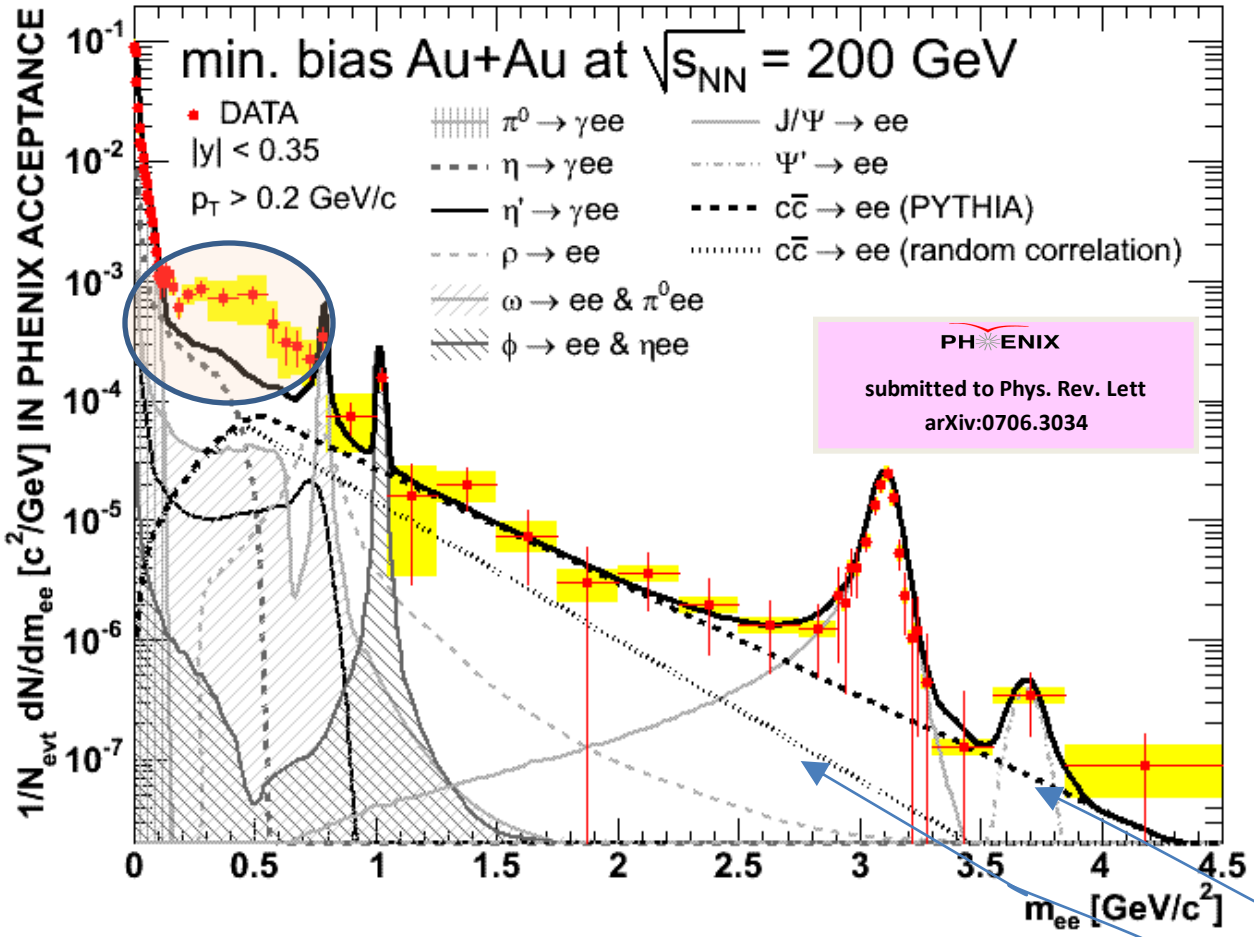
Charm: integration after cocktail subtraction

- σ_{cc}=544 ± 39 (stat) ± 142 (sys) ± 200 (model) μb

Simultaneous fit of charm and bottom:

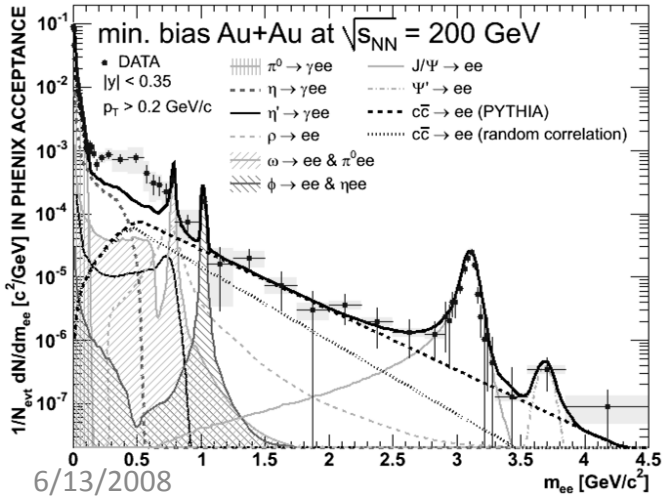
- σ_{cc}=518 ± 47 (stat) ± 135 (sys) ± 190 (model) μb
- σ_{bb}= 3.9 ± 2.4 (stat) +3/-2 (sys) μb

Au+Au Cocktail comparison



A huge excess is seen in the low mass continuum.
Charm correlation is unknown. (2 assumptions: random and PYTHIA)

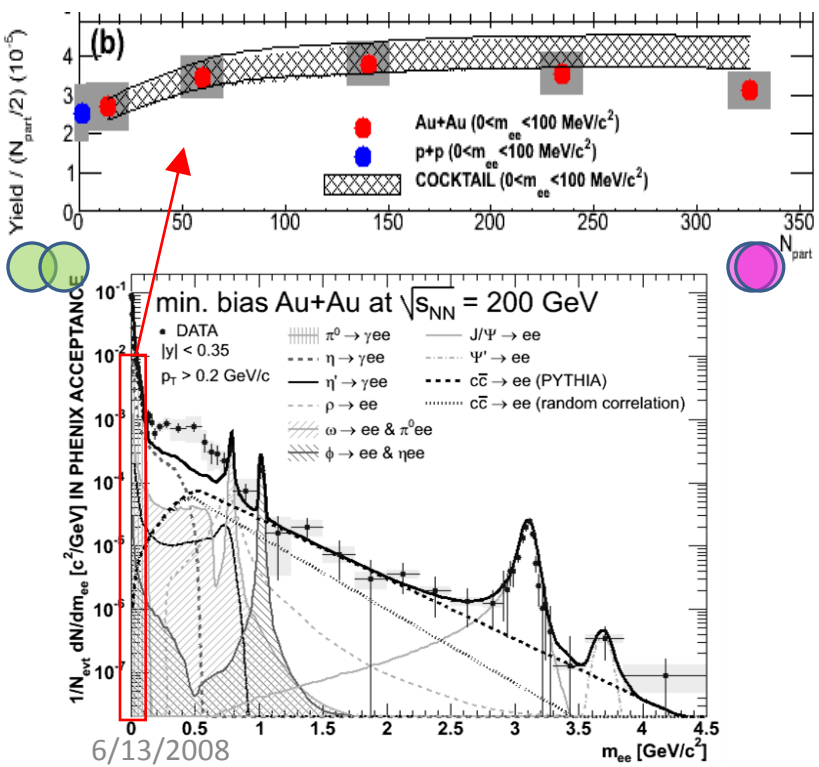
Centrality Dependence



Centrality Dependence

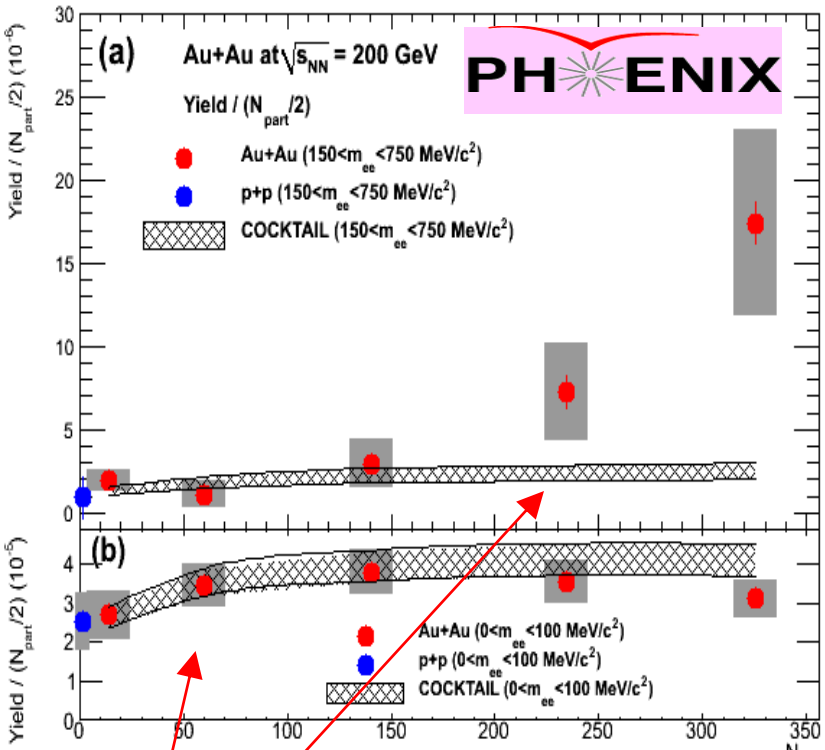
π^0 region:

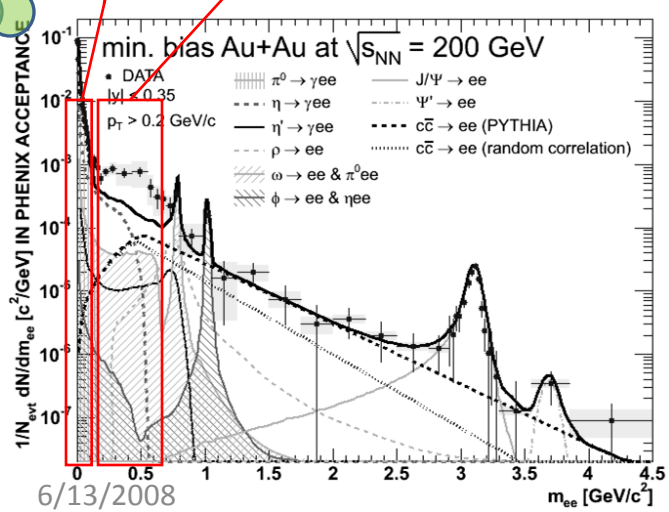
- Agreement with cocktail



Centrality Dependence

LOW MASS





π^0 region:

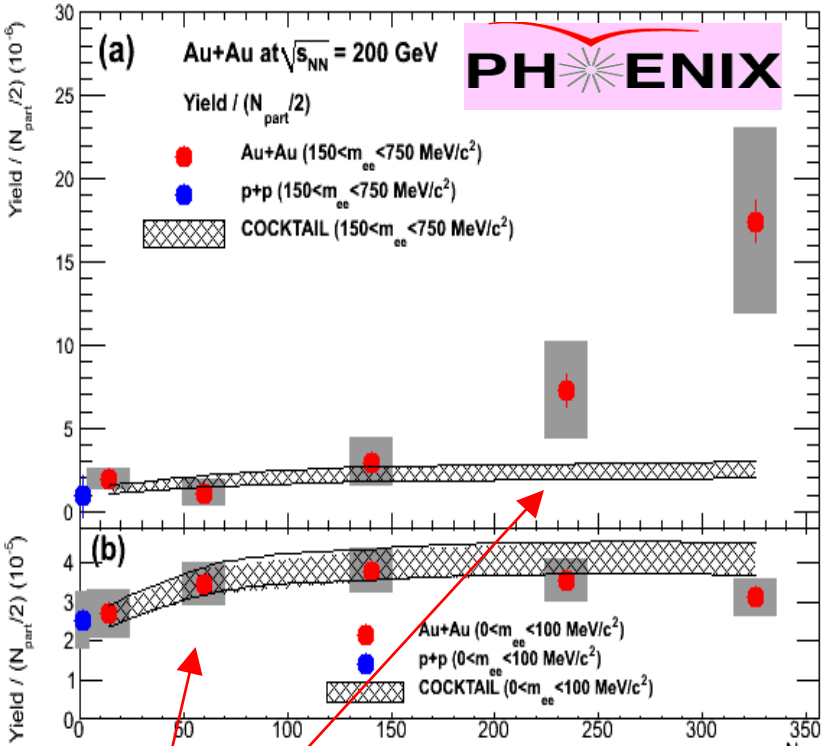
- Agreement with cocktail

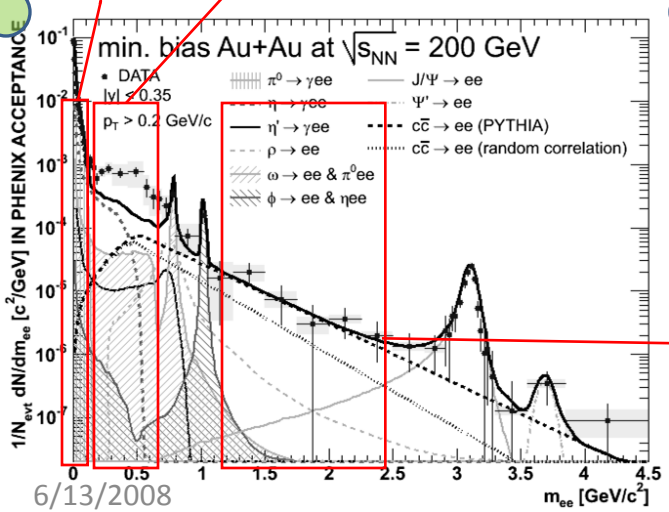
Low Mass:

- yield increases faster than proportional to N_{part}
  → enhancement from binary annihilation ($\pi\pi$ or qq) ?

Centrality Dependence

LOW MASS





π^0 region:

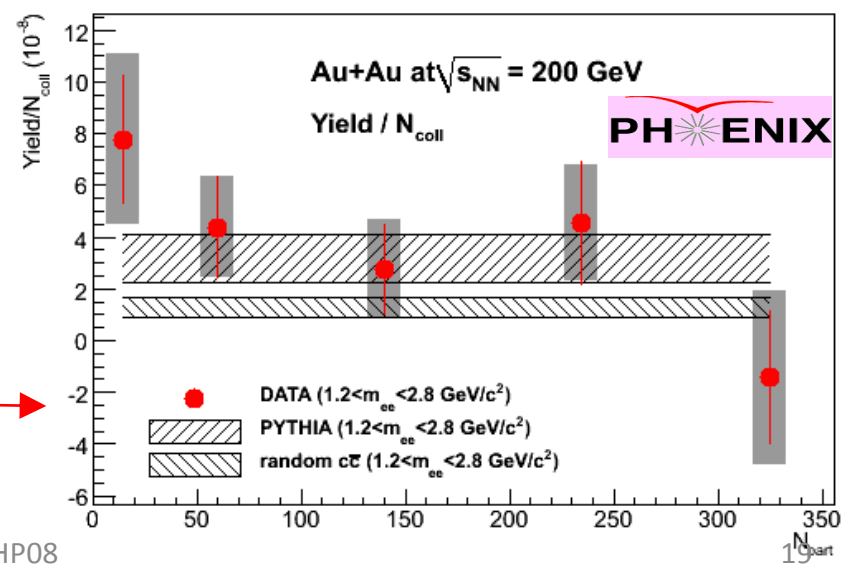
- Agreement with cocktail

Low Mass:

- yield increases faster than proportional to N_{part}
  → enhancement from binary annihilation ($\pi\pi$ or qq) ?

Intermediate Mass:

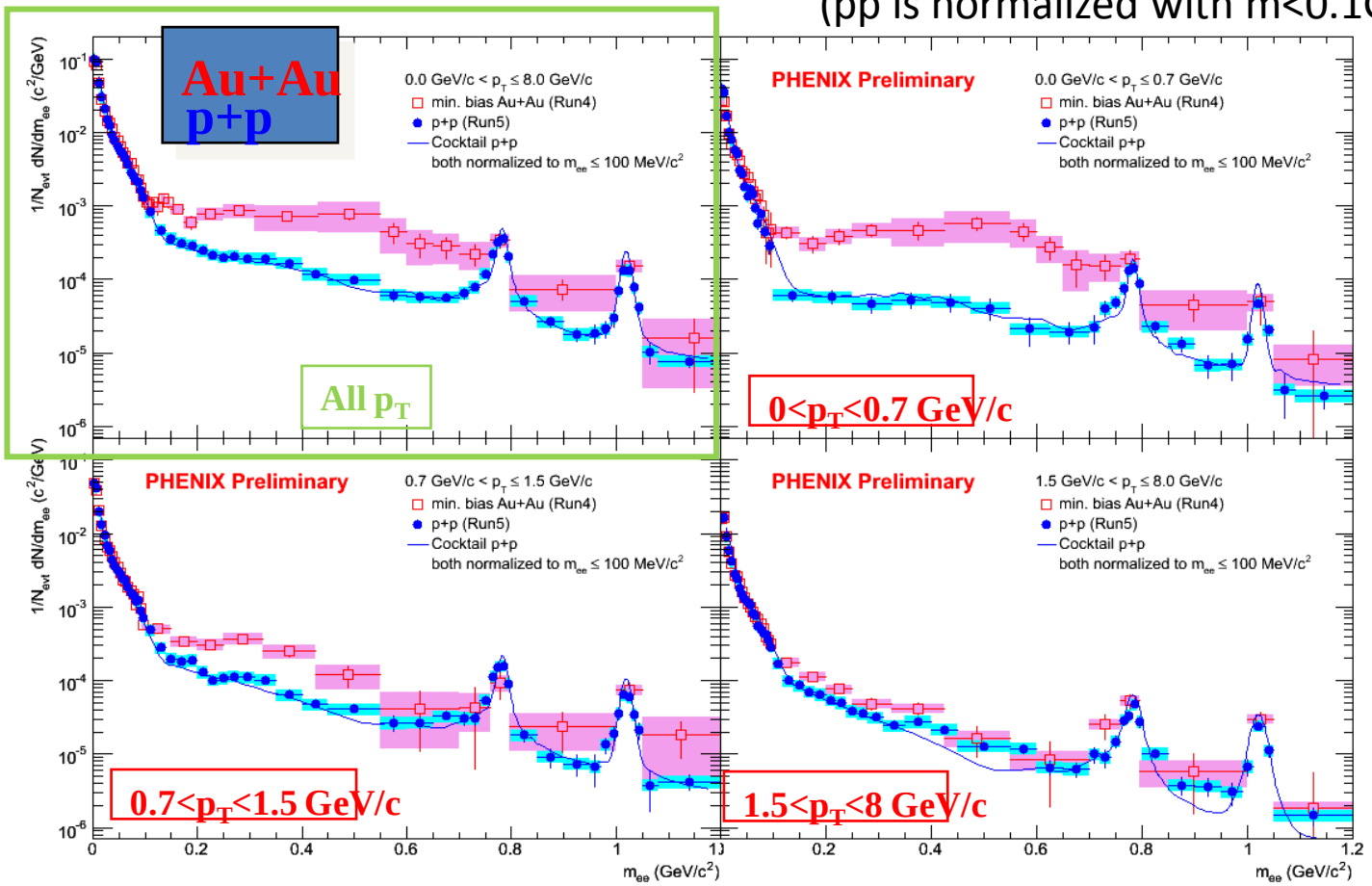
- yield increase proportional to N_{coll}
  → charm follows binary scaling



Dielectrons

The p_T dependence of the excess in AuAu.

(pp is normalized with m<0.1GeV region.)



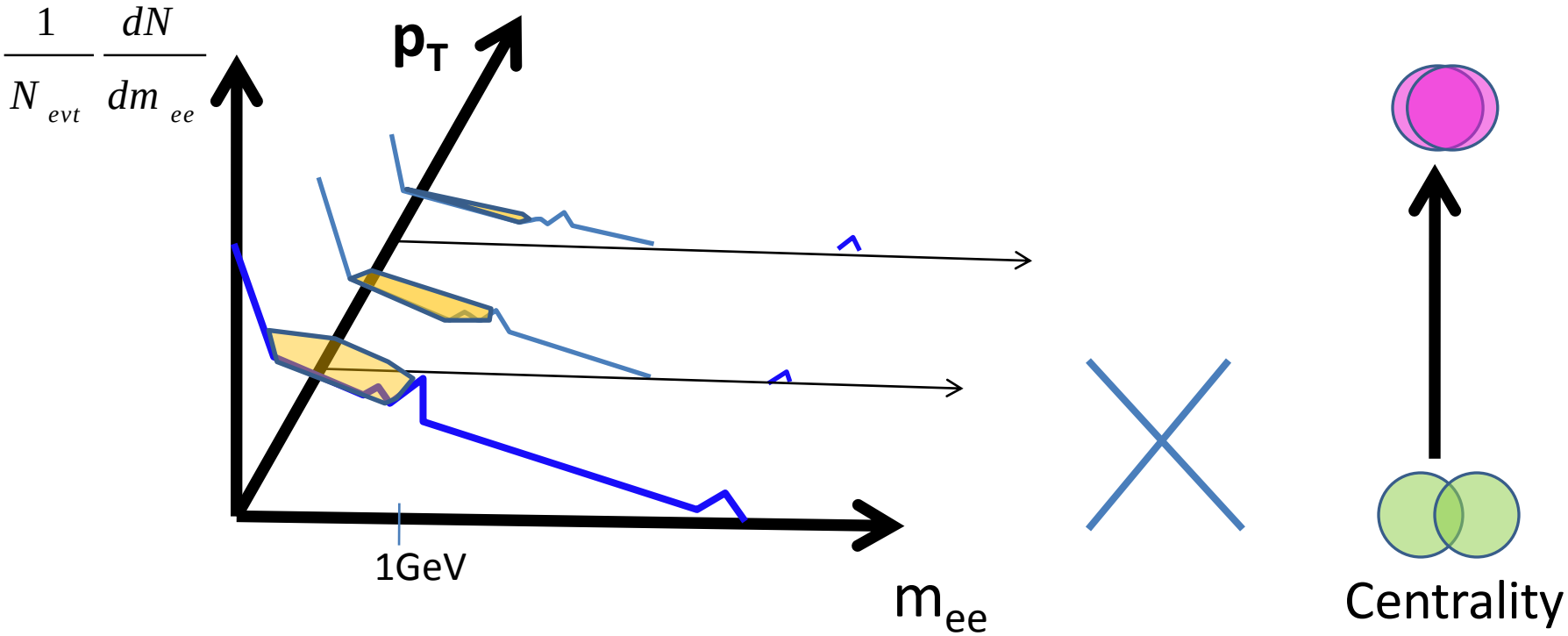
p+p: follows the cocktail

The enhancement is dominant in the low pT region.

The pT dependence is not explained by a model of vector meson modification. (the detail is in the backup slide.)

Dielectons

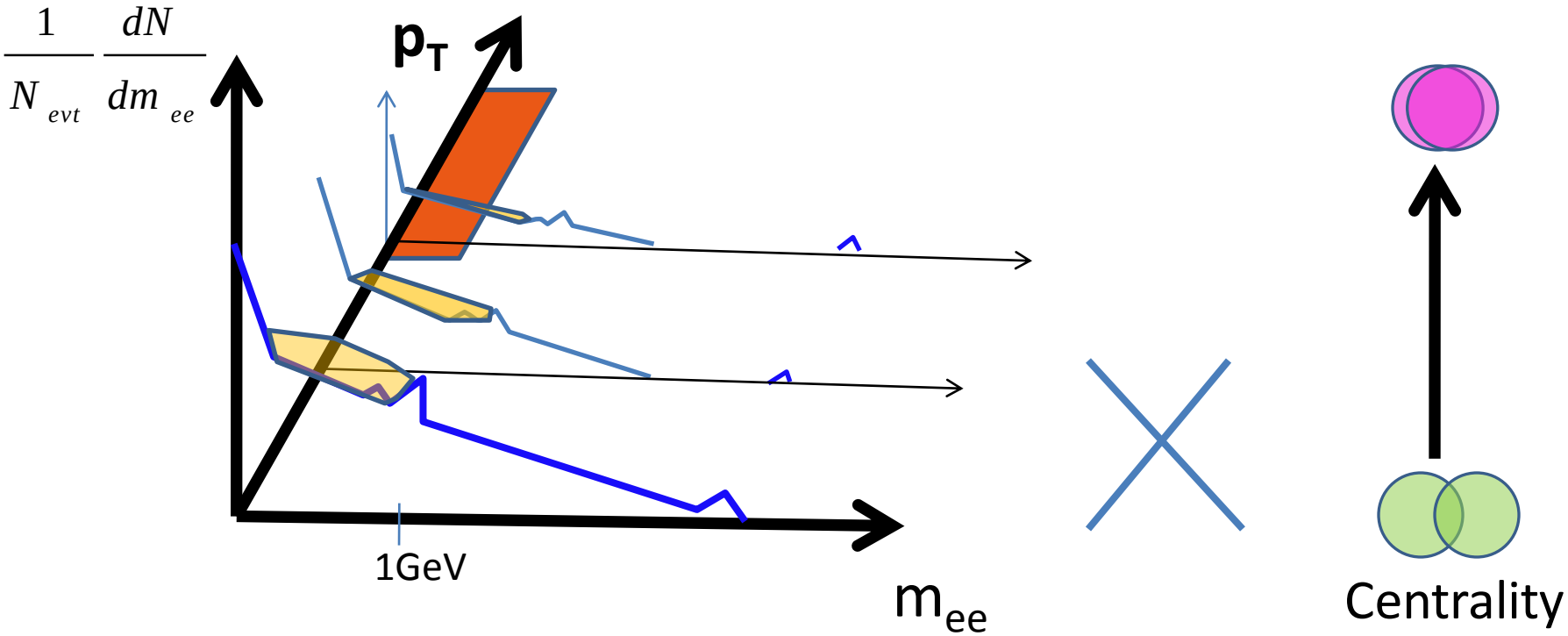
There are three dimensions ; m_{ee}, pT_{ee}, Centrality.



: The low mass enhancement.

Dielectons

There are three dimensions ; m_{ee}, pT_{ee}, Centrality.



: The low mass enhancement.

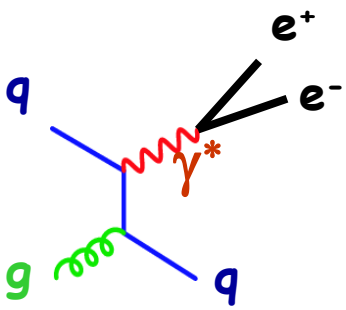
pT >1, low mass region to be attributed to direct photon production.

Dielectron = photon?

They have the same quantum number.

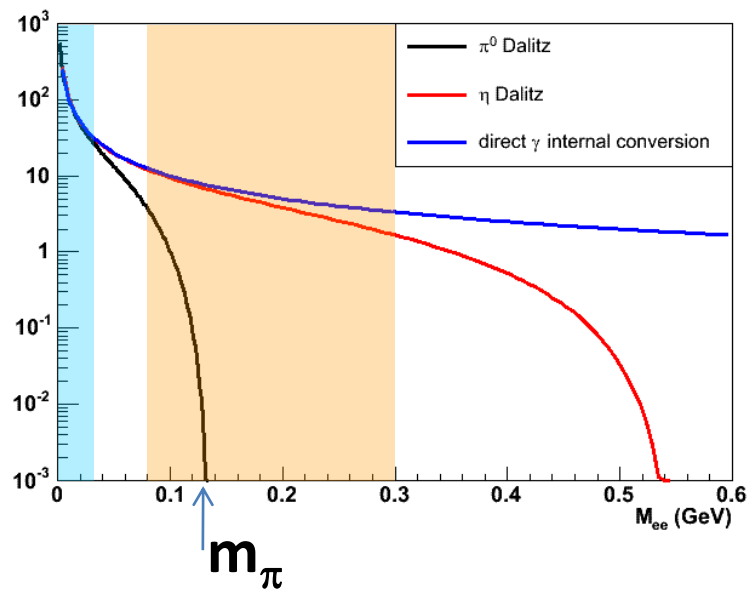
Kroll-Wada formula connects the real γ and (ee) yield.

$$\frac{d^2N}{dM_{ee}} = \frac{2\alpha}{3\pi}\sqrt{1-\frac{4m_e^2}{M_{ee}^2}}\left(1+\frac{2m_e^2}{M_{ee}^2}\right)\frac{1}{M_{ee}}SdN_\gamma$$



When $p_T^2 >> M_{ee}^2$ **, S=1 for photons.**

Independent of the origin in the very low mass region (M_{ee} < ~30MeV)
Pi0 Dalitz dies out above the pi0 mass. → The key to improve the S/N ratio.
Direct photon follows $1/M_{ee}$.

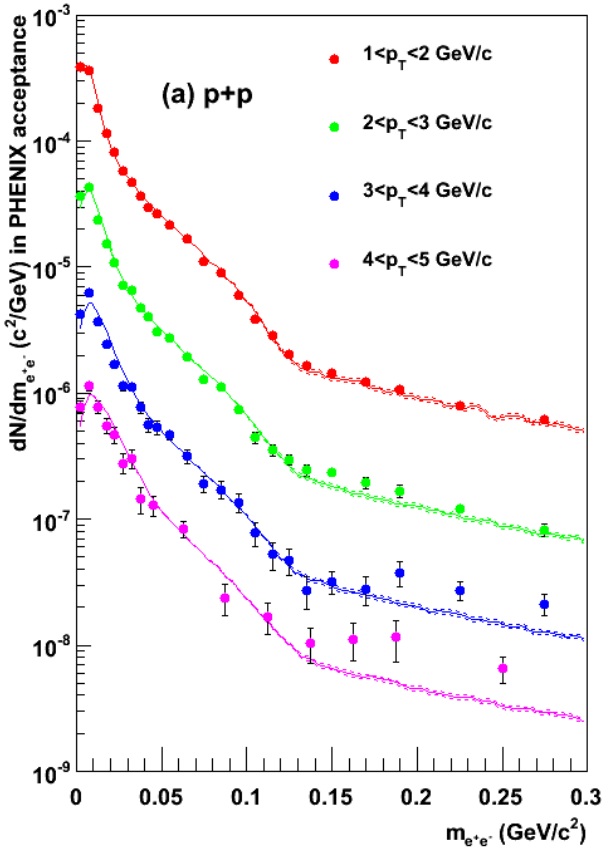


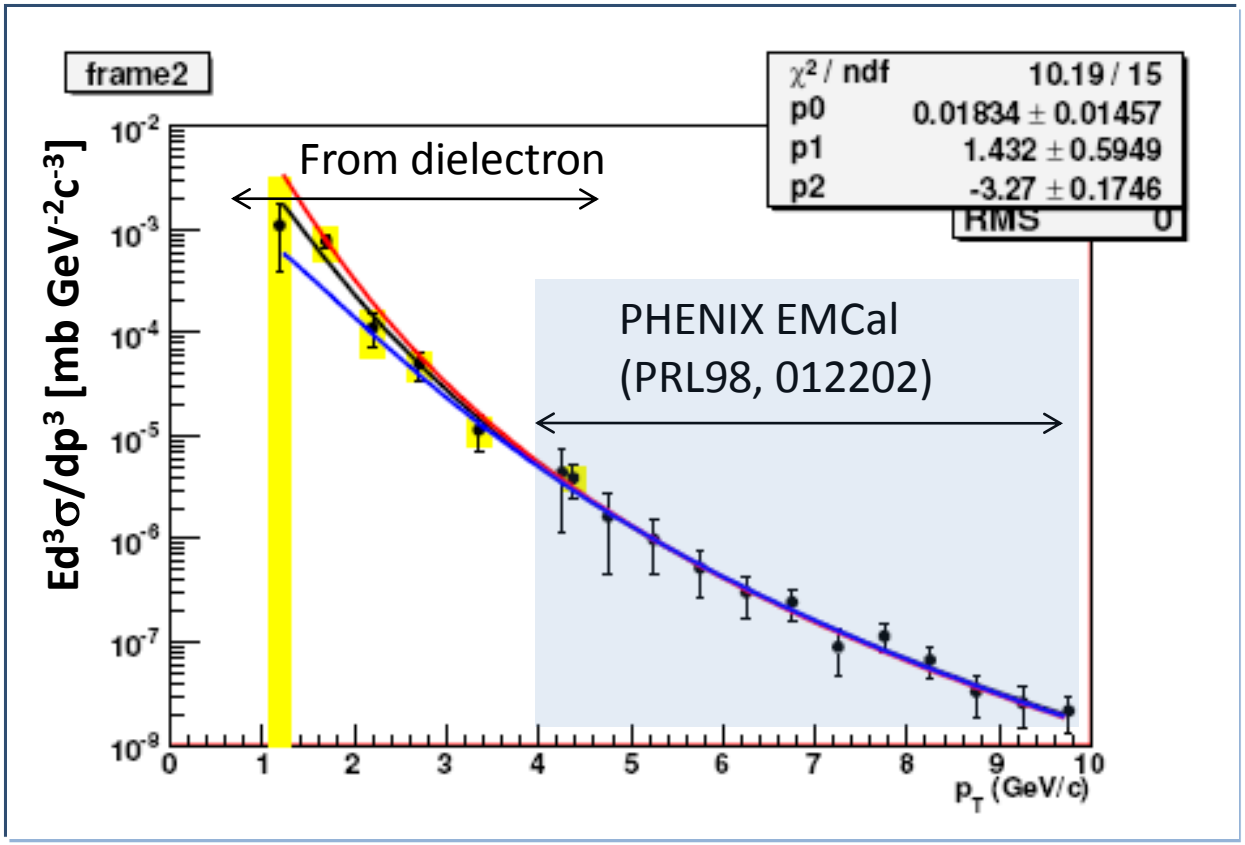
Procedure

Cocktail
Normalized in the very low mass region
Extract the direct photon component

Dielectron=photon

In p+p, the signal appears above pT=2GeV/c.
The result agrees with the EMCal result.





The first direct photon measurement below pt at 3GeV/c.
Surprisingly the pQCD calculation agrees down to 1 Gev/c.

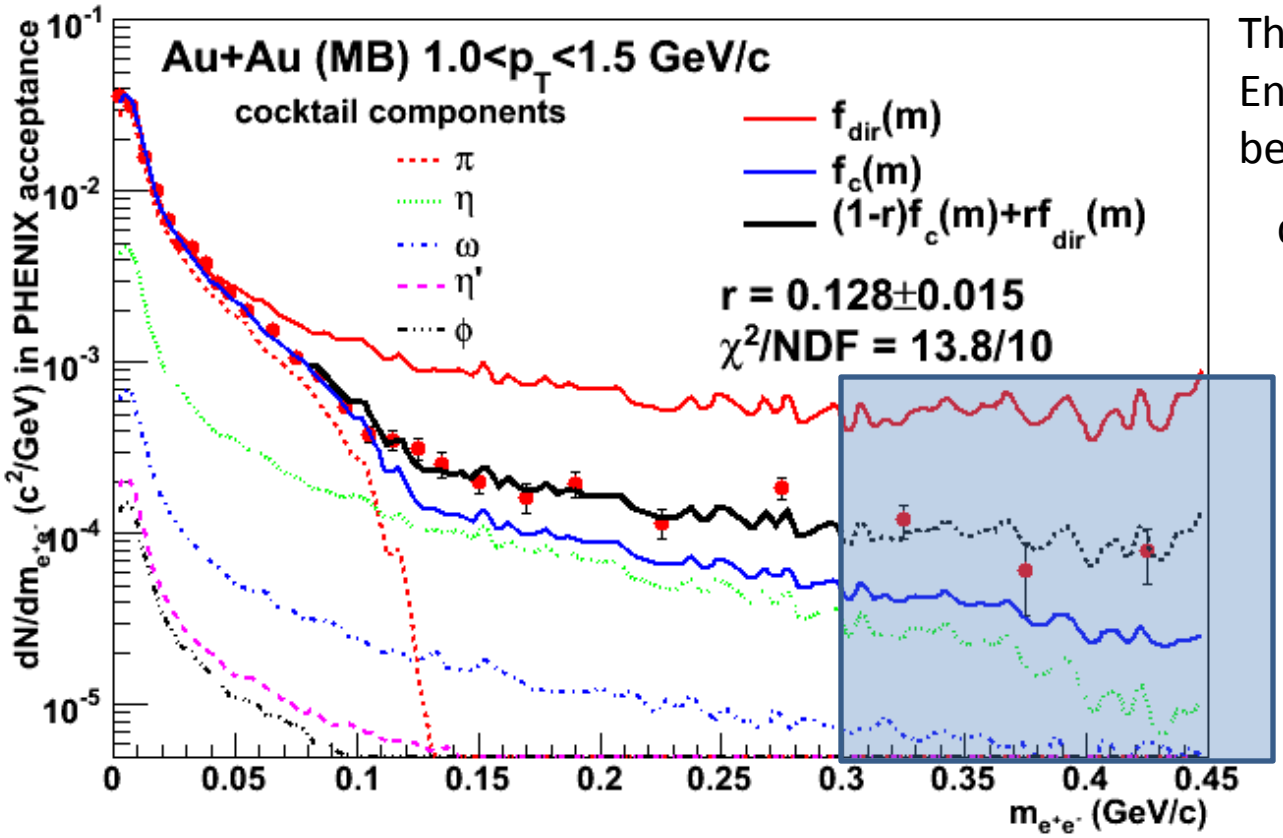
(the comparison is not on the plot.)

Dielectron=photon

In Au+Au,

$$f_{data}(m_{ee}) = (1-r)\cdot f_{cocktail}(m_{ee}) + r\cdot f_{direct}(m_{ee})$$

Independent of the origin in the very low mass region (M_{ee} < 30MeV)



The effect of the low mass Enhancement is thought to be small

qq,ππ : Mee<0.3GeV

Dielectron=photon

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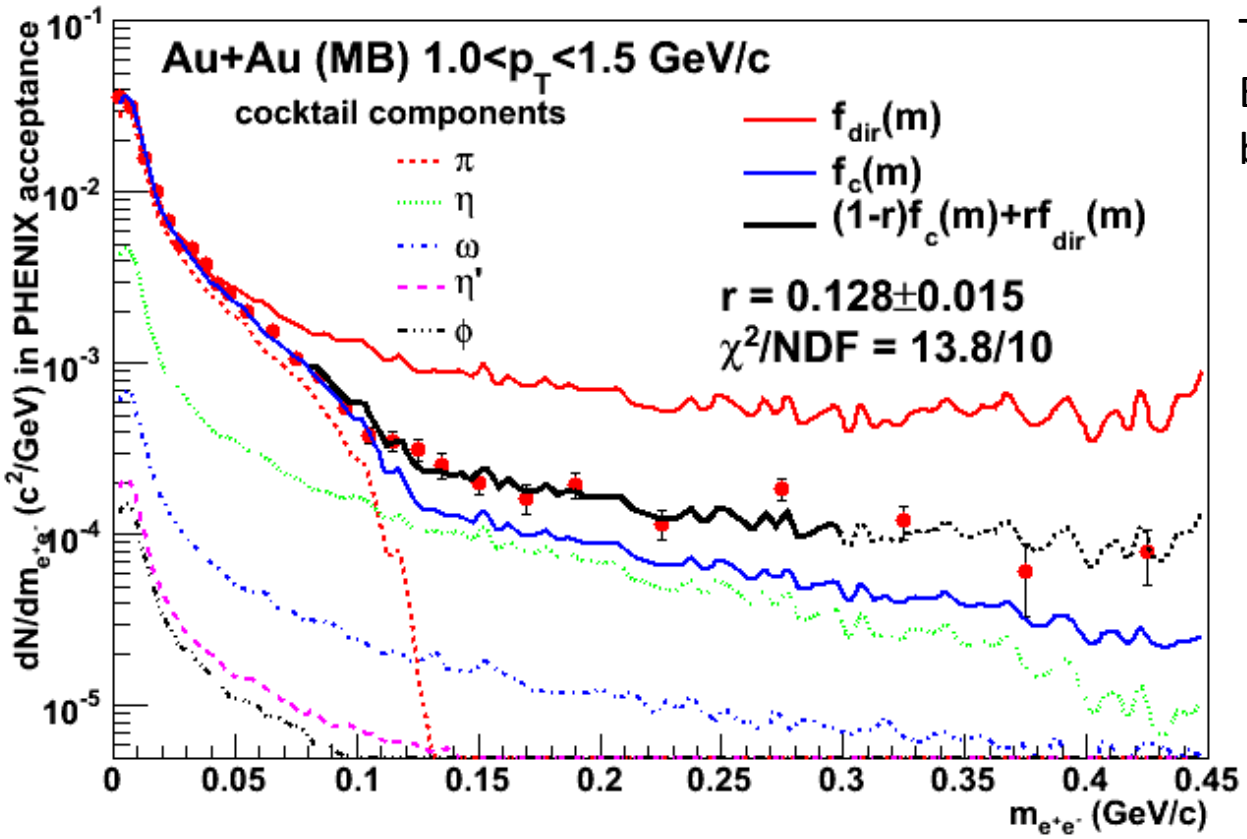


The effect of the low mass Enhancement is thought to be small

qq,ππ : Mee<0.3GeV

The fit follows the data points.

Dielectron=photon

The Au+Au result is compared to p+p.

Submitted to PRL, arXiv:0804.4168

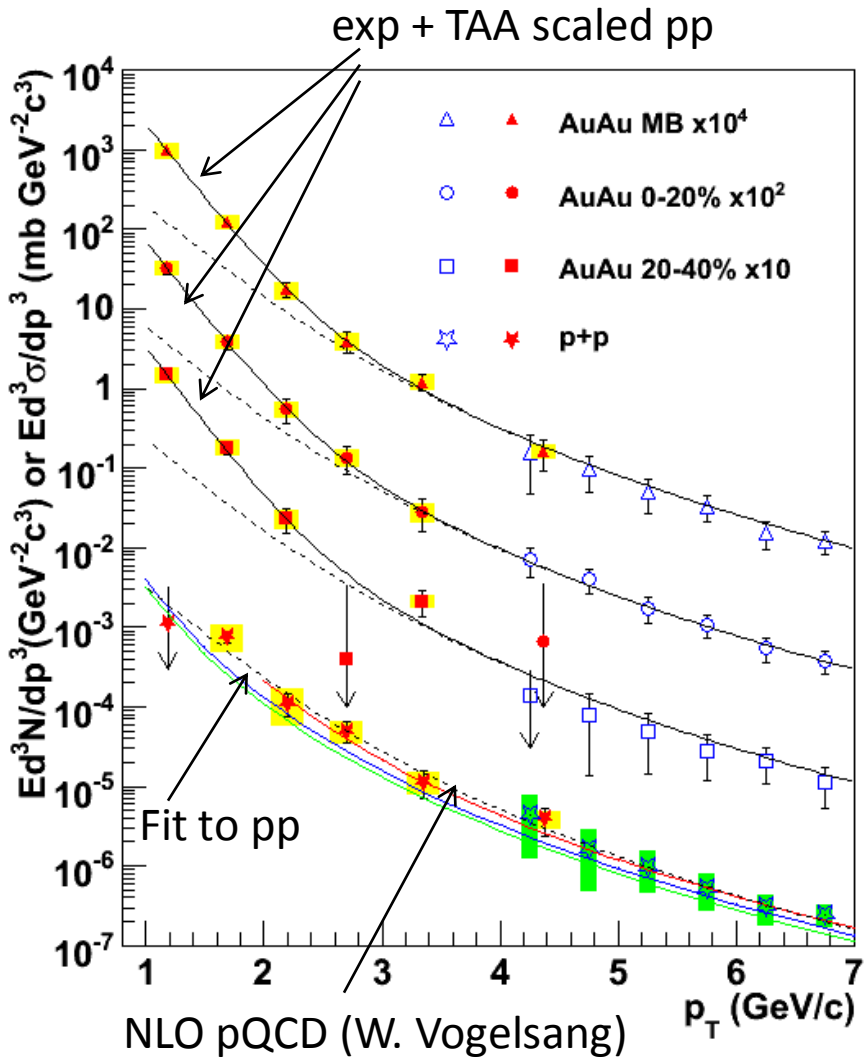


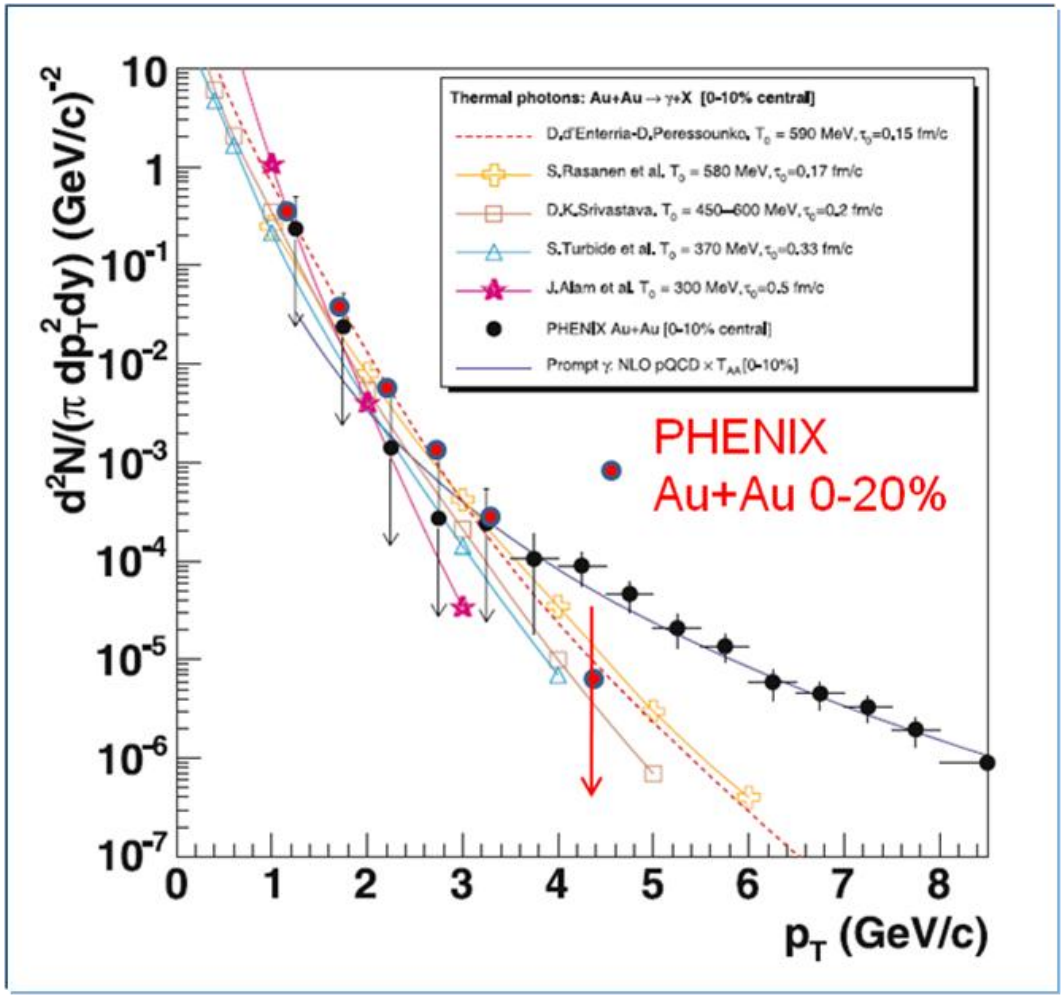
TABLE I: Summary of the fits. The first and second errors are statistical and systematical, respectively.

centrality	$dN/dy(p_T > 1\mathrm{GeV}/c)$	$T(\mathrm{MeV})$	χ^2/DOF
0-20%	$1.10 \pm 0.20 \pm 0.30$	$221 \pm 23 \pm 18$	3.6/4
20-40%	$0.52 \pm 0.08 \pm 0.14$	$214 \pm 20 \pm 15$	5.2/3
MB	$0.33 \pm 0.04 \pm 0.09$	$224 \pm 16 \pm 19$	0.9/4

- Significant yield of the exponential component (excess over the scaled p+p)
- The inverse slope is ~220MeV. (If power-law is used for the pp component, the value of T would increase by ~24MeV)
- Since it's an integration of the entire evolution, the result ~220MeV indicates the initial temperature much higher than the critical temperature.

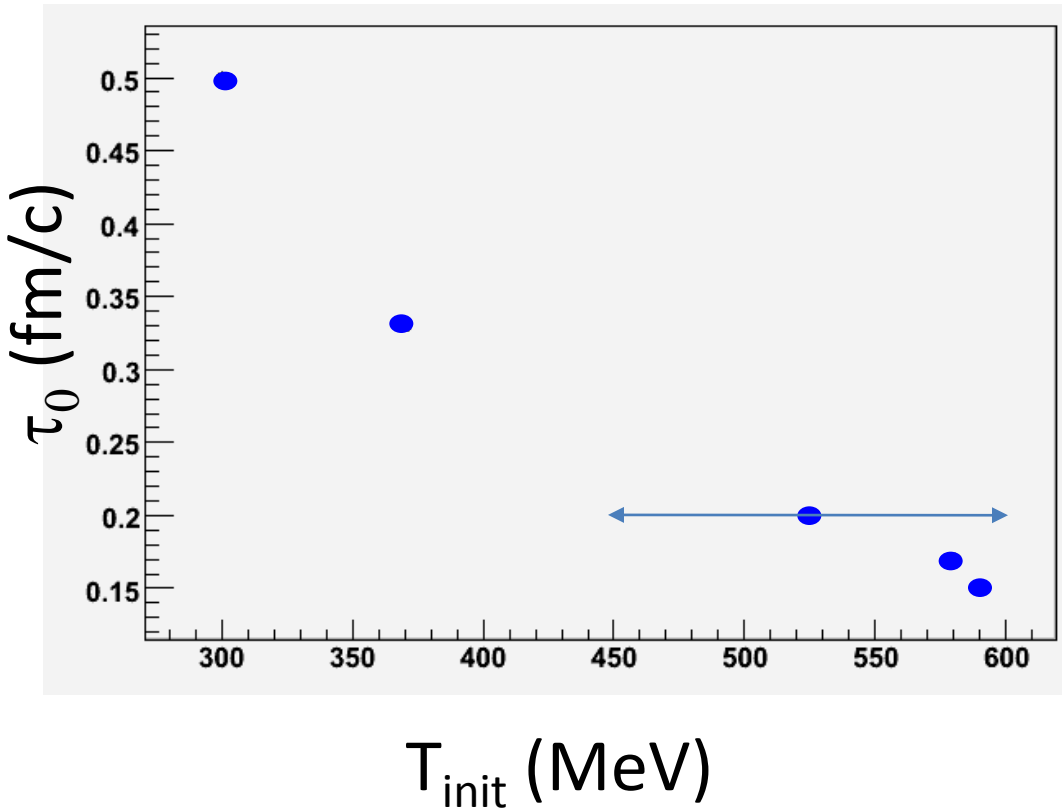
Theory comparison

Thery compilation by D. d'Enterria and D. Peressounko
EPJC46, 451 (2006)



- D.d'Enterria &D.Peressounko
  - T=590MeV, τ_0=0.15fm/c
- S. Rasanen et al.
  - T=580MeV, τ_0=0.17fm/c
- D. K. Srivastava
  - T=450-600MeV, τ_0=0.2fm/c
- S. Turbide et al.
  - T=370MeV, τ_0=0.33fm/c
- J. Alam et al.
  - T=300MeV, τ_0=0.5fm/c
- Hydrodynamical models are agreement with the data within a factor of 2 in spite of these models have wide-ranging conditions.

Initial temperature (with aid of models)*



Hydrodynamical models in qualitative agreement with the data: Eur.Phys.J. C46 (2006) 451

D.d'Enterria &D.Peressounko
T=590MeV, τ_0=0.15fm/c

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S. Turbide et al.
T=370MeV, τ_0=0.33fm/c

J. Alam et al.
T=300MeV, τ_0=0.5fm/c

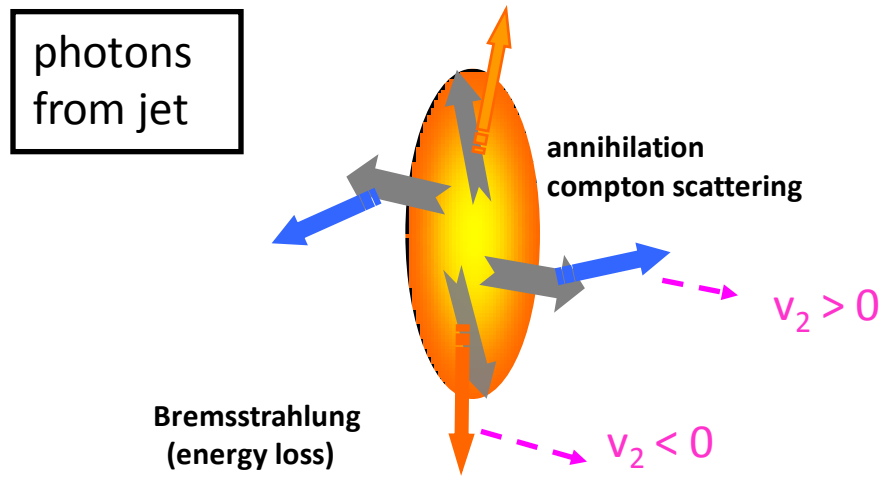
$T_{init} > T_c$ even for simple exponential!

* and 1 billion events …

RP dependence

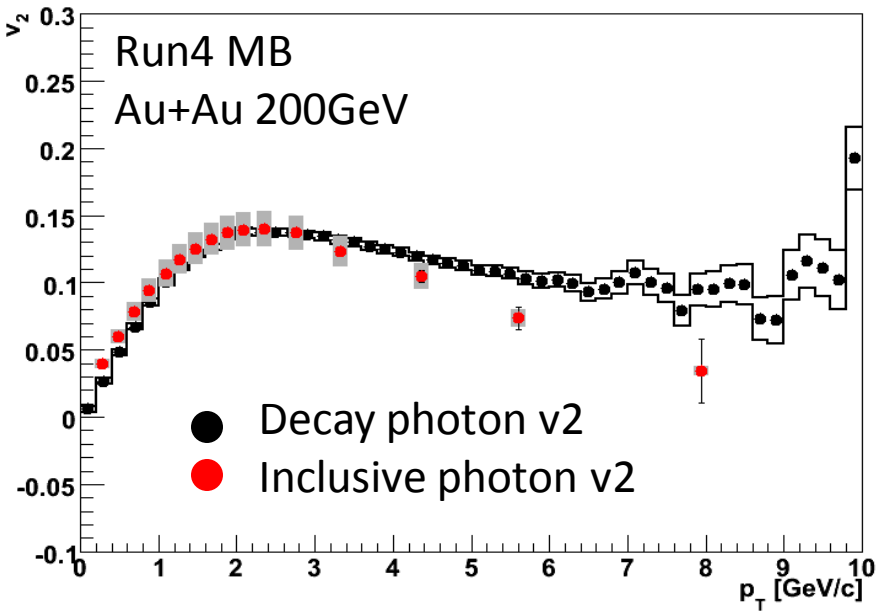
Ideas

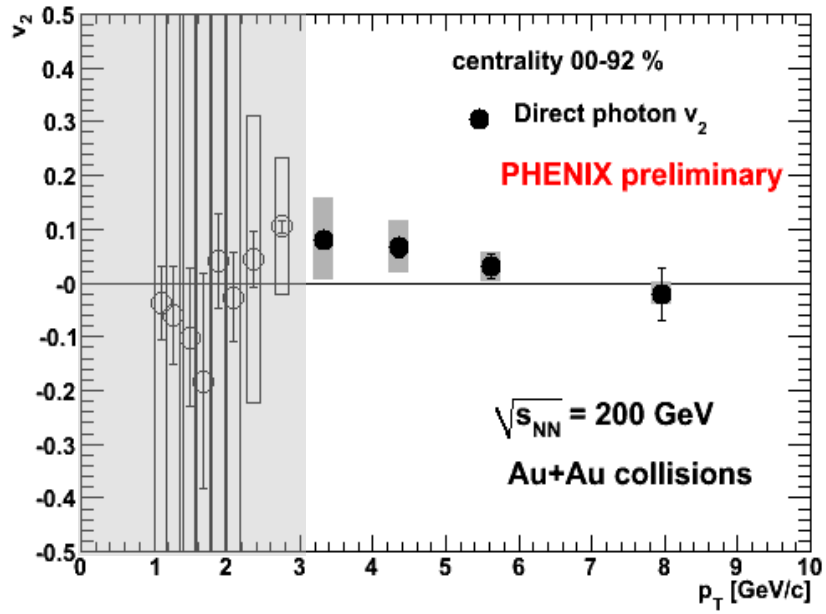
hard scatter	$v_2 = 0$
Jet Brems.	$v_2 < 0$
Jet Fragment	$v_2 > 0$
sQGP	$v_2 \geq 0$



It is an additional sight of the matter.

v_2 Measurement





$$v_2^{dir.photon} = \frac{R * v_2^{inc.photon} - v_2^{BG\_photon}}{R-1} \qquad R = \frac{N^{inc.photon}}{N^{BG\_photon}}$$

The v2 is small at high pT !

How can we improve the precision?
→Statistics Run7=3*Run4, and *4 equivalent with RXPN.
→S/N improvement with the dielectron method.

Summary

Results

- The PHENIX detector is powerful for the EM probes.
- Direct photon cross section is measured from pT = 1GeV/c to 20GeV/c.
  R_AA drops at highest pT, it can be explained by the isospin effect.
  At low pT, there is an excess in Au+Au. From the inverse slope, the temperature is estimated to be ~220MeV.
  The v2 is small at high pT.
- In the dielectron mass spectra, a large enhancement is seen in the low mass region.
  We see it is dominated in low pT region.

Next

- Run7 Au+Au statistics (3*Run4) with reaction plane detector
- Run8 dAu Check the cold nuclear effect.

- HBD for dielectron analysis.
- NCC extends the coverage to forward.

- High luminosity enables more precise correlation analysis.

BACKUPS

Something not in the slide

d+Au
photon HBT analysis
Direct photon consistency with external conversion method and pi0 tagging method.

PHENIX Data Sets

Run	Year	Species	√s (GeV)	∫Ldt	N_{tot} (samp.)	Data Size
Run1	2000	Au + Au	130	1 μb^{-1}	10 M	3 TB
Run2	2001/02	Au + Au	200	24 μb^{-1}	170 M	10 TB
		Au + Au	19		< 1 M	
		p + p	200	0.15 pb^{-1}	3.7 B	20 TB
Run3	2002/03	d + Au	200	2.74 nb^{-1}	5.5 B	46 TB
		p + p	200	0.35 pb^{-1}	6.6 B	35 TB
Run4	2003/04	Au + Au	200	241 μb^{-1}	1.5 B	270 TB
		Au + Au	62.4	9 μb^{-1}	58 M	10 TB
Run5	2005	Cu + Cu	200	3 nb^{-1}	8.6 B	173 TB
		Cu + Cu	62.4	0.19 nb^{-1}	0.4 B	48 TB
		Cu + Cu	22.4	2.7 μb^{-1}	9 M	1 TB
		p + p	200	3.8 pb^{-1}	85 B	262 TB
Run-6	2006	p + p	200	10.7 pb^{-1}	230 B	310 TB
		p + p	62.4	0.1 pb^{-1}	28 B	25 TB
Run-7	2007	Au + Au	200	813 μb^{-1}	5.1 B	650 TB
Run-8	2007/08	d + Au	200	80 nb^{-1}	160 B	437 TB
		p + p	200	5.2 pb^{-1}	115 B	118 TB
		Au + Au	9.2			

3 x AuAu

30 x dAu

Collided 4 different species in 8 years: Au+Au, d+Au, p+p, Cu+Cu
6 energies run: 9.2 GeV, 19 GeV, 22.5 GeV, 62.4 GeV, 130 GeV, 200 GeV

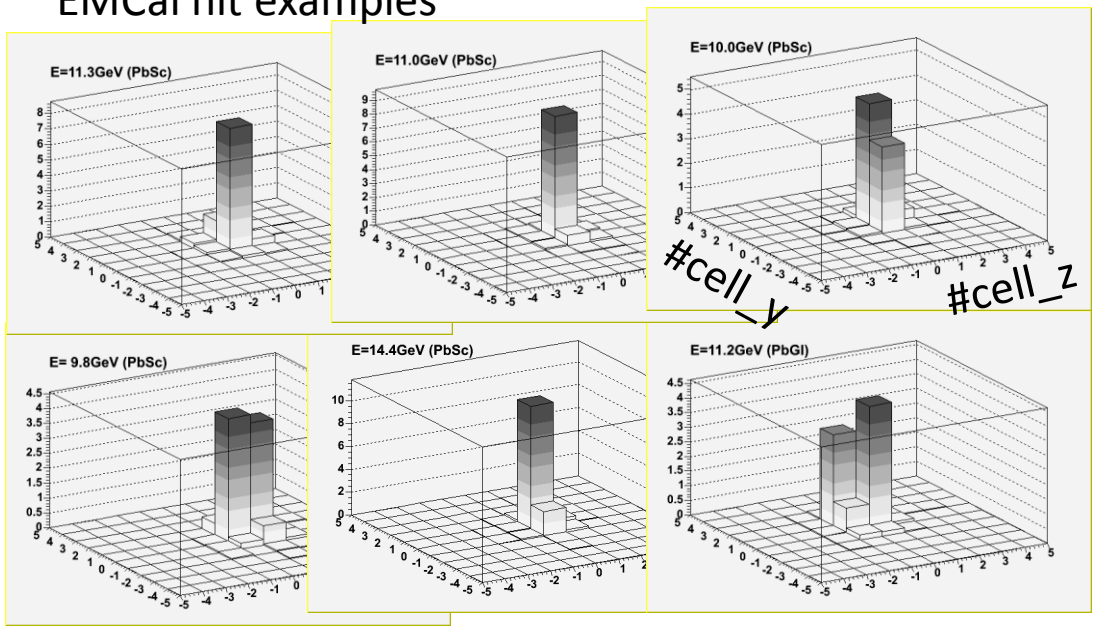
Direct photon

Measurement

Background subtraction

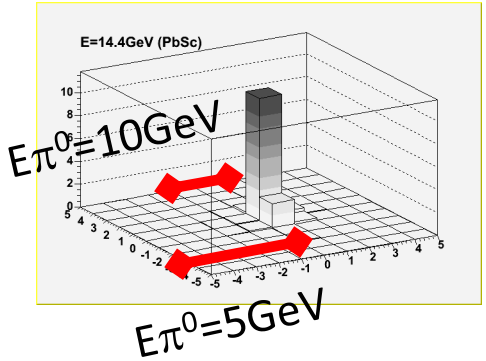
π^0 to 2γ

EMCal hit examples



π^0 2gamma distance

> 28 tower / $E\pi^0$ [GeV]

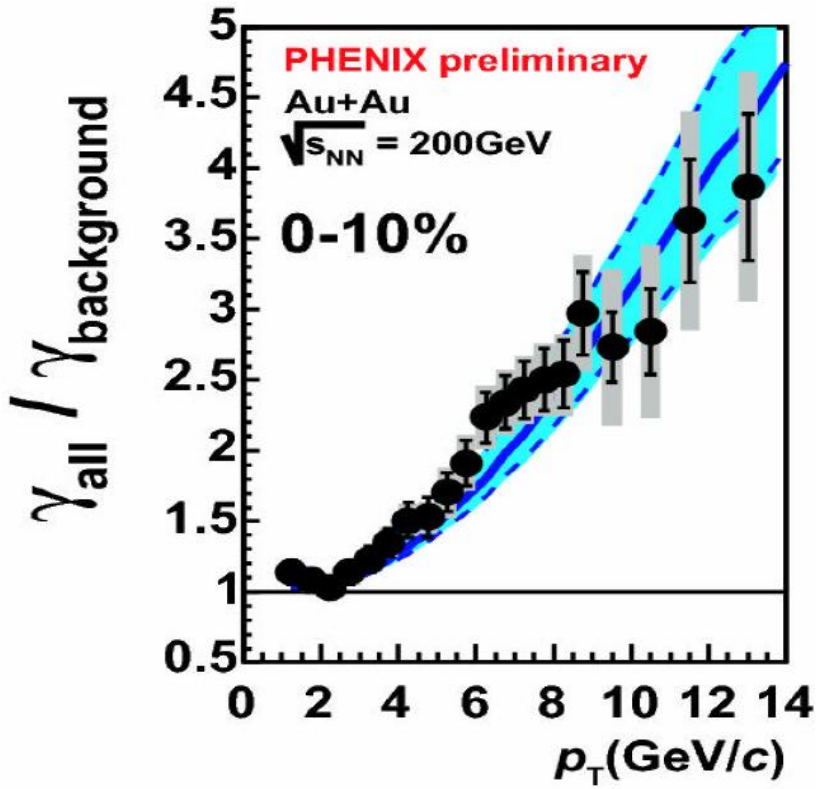


Thanks to the fine segmentation!

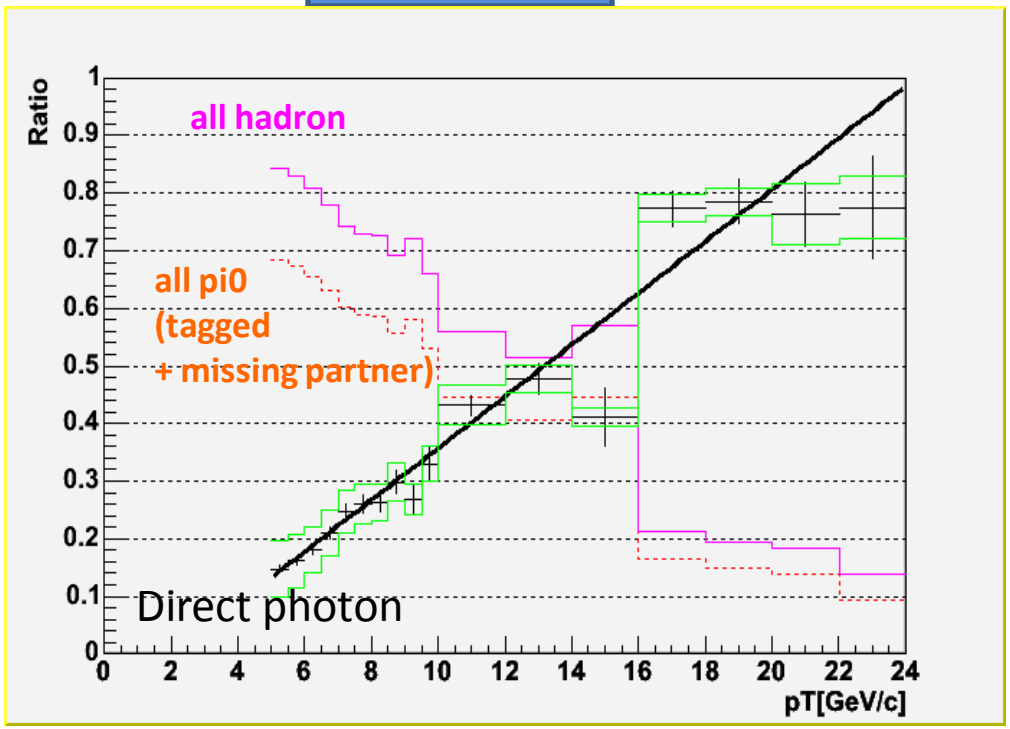
Direct photon

Signal : direct photons
Noise : hadronic decay photons (mostly from π^0)

Au+Au (S+N)/N

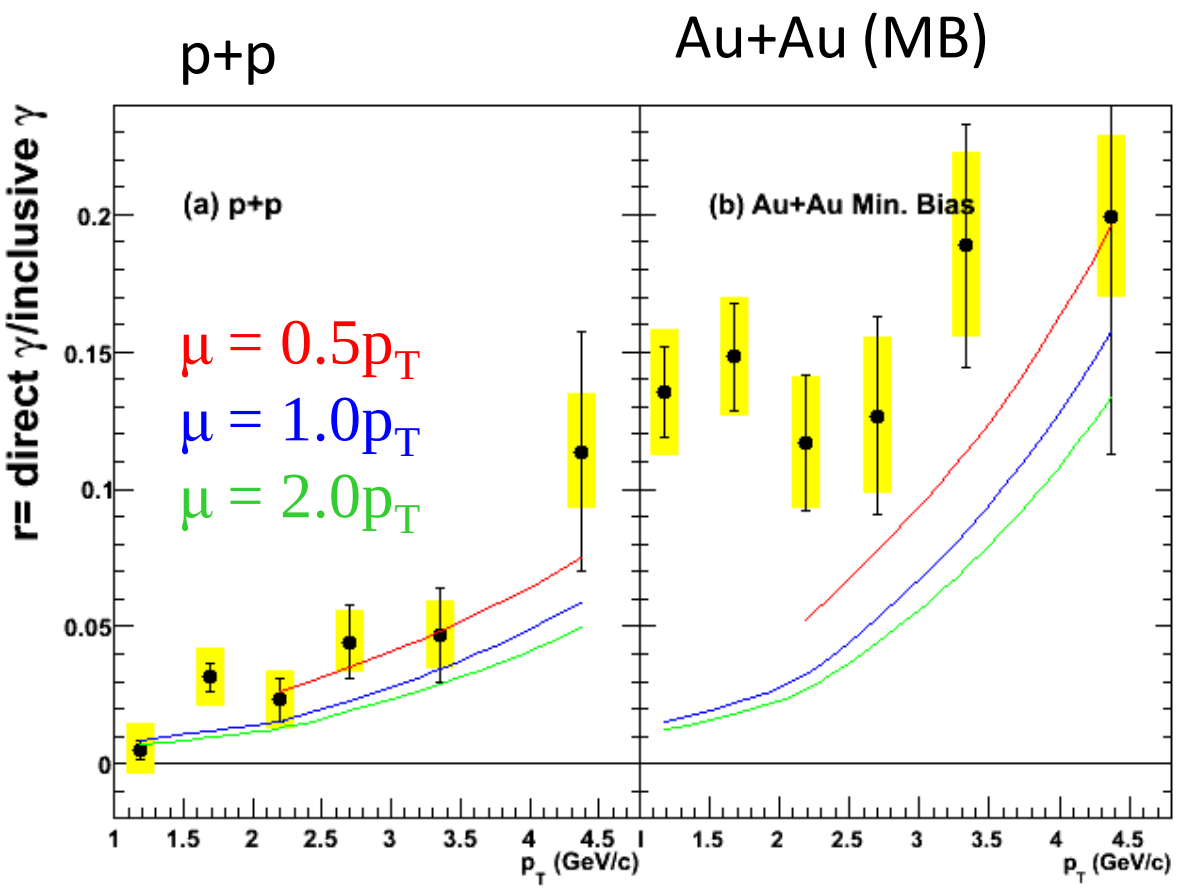


p+p S/(S+N)



The signal is significant for pT more than 3~5 GeV/c.

Fraction of direct photons



- Fraction of direct photons
- Compared to direct photons from pQCD

p+p

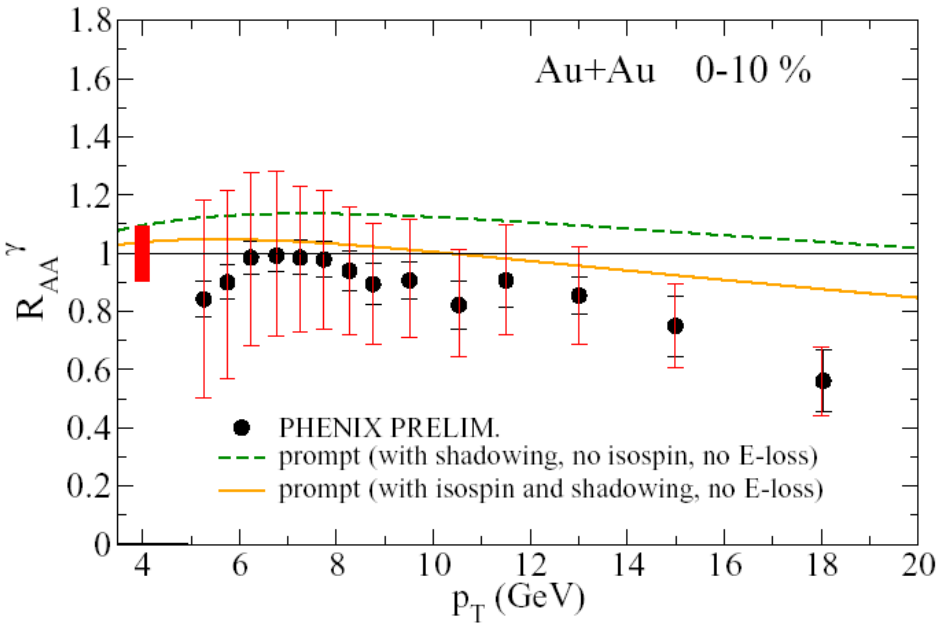
- Consistent with NLO pQCD
- favors small μ

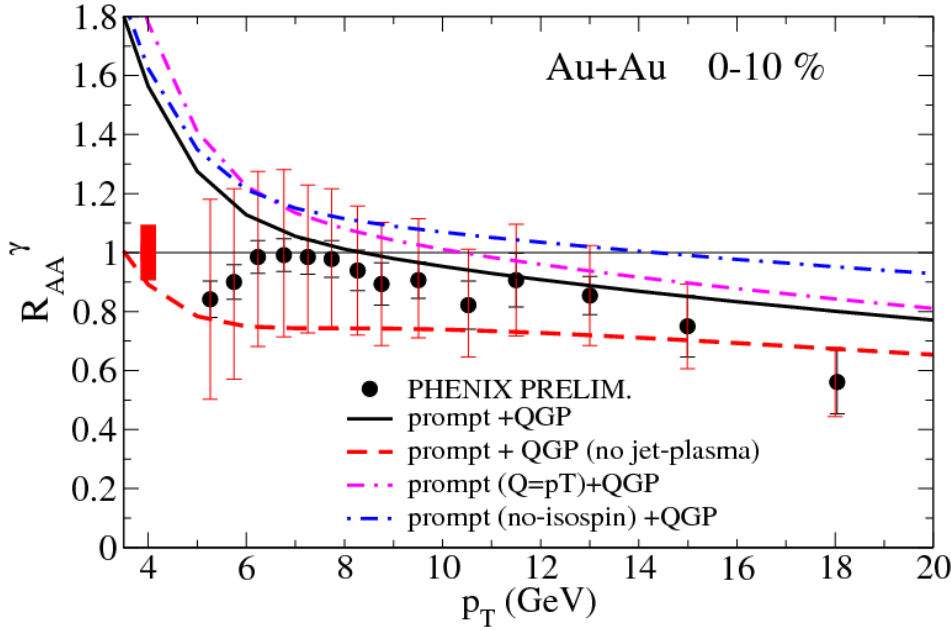
Au+Au

- Clear excess above pQCD

NLO pQCD calculation is provided by Werner Vogelsang

Results: R_{AA}



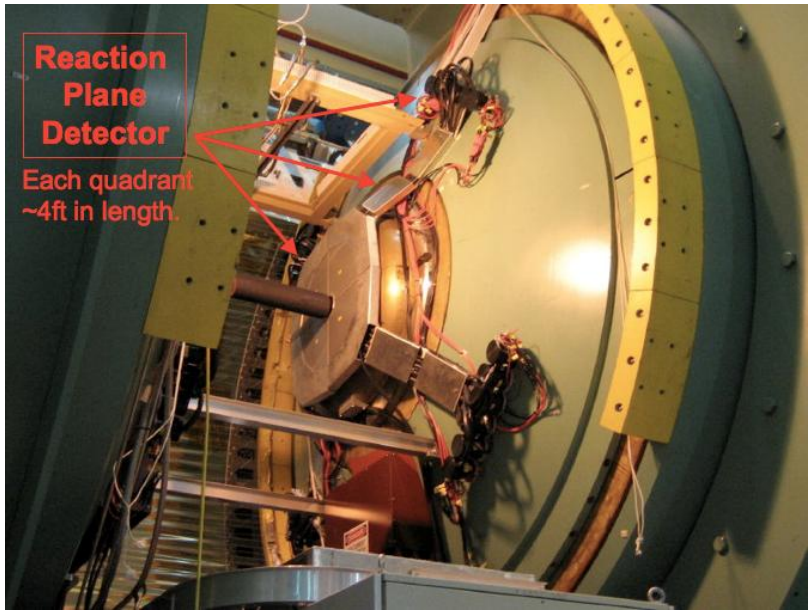


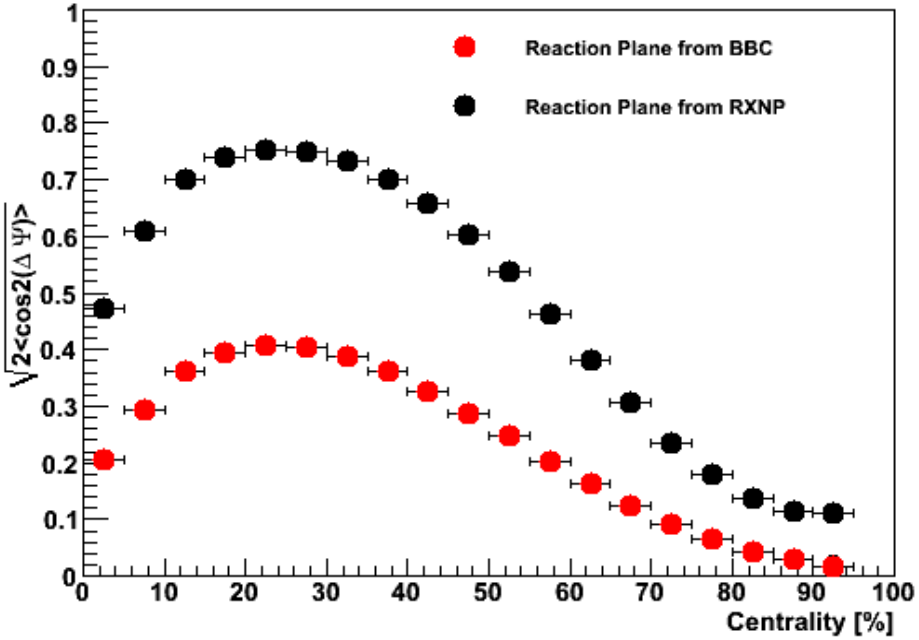
The discrimination between models is dependent on the high p_T photons

See also F. Arleo, JHEP (2007)

Reaction plane detector (RXNP)

Run7 has new detector for reaction plane definition.

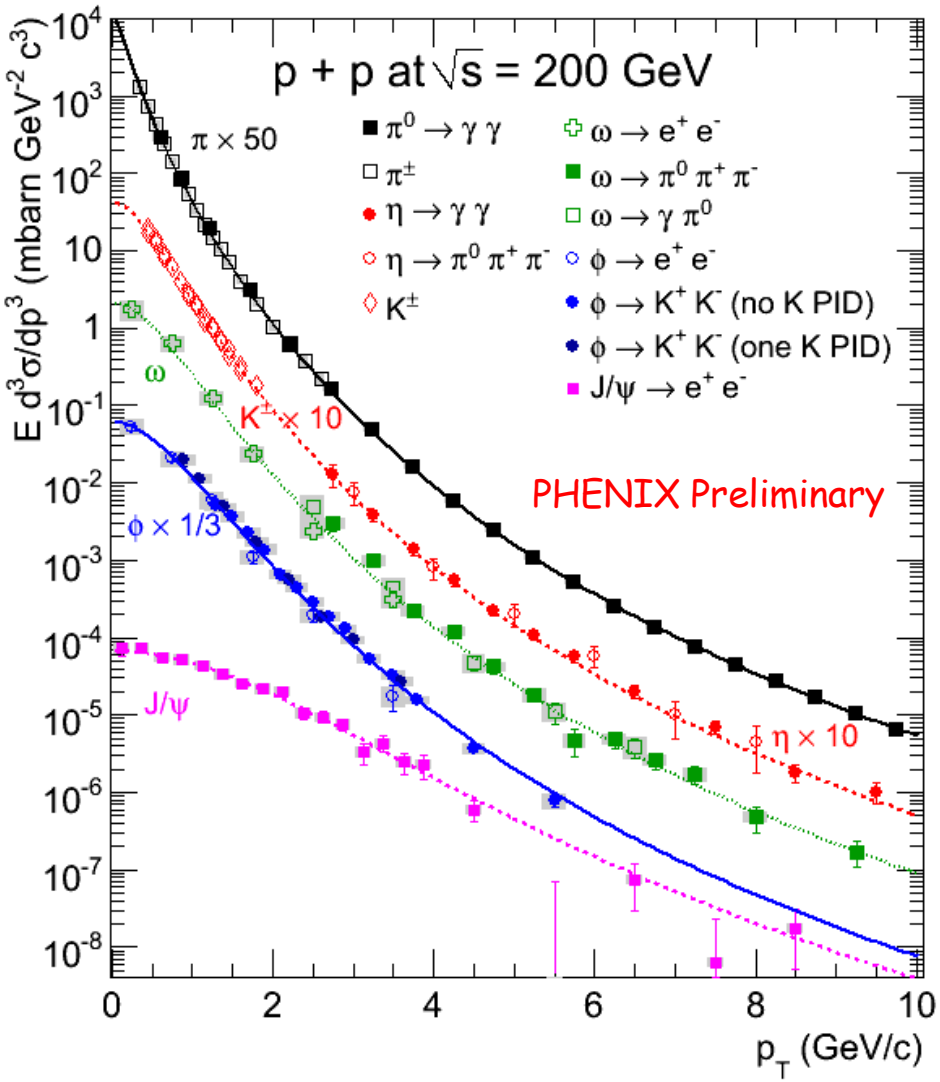




RXNP has twice better resolution than BBC.

Hadronic cocktail

Origins



Hadronic cocktail from our measurements.

An excellent data set!

$$E\frac{d^3\sigma}{d^3p} = \frac{A}{\left(\exp(-ap_T - bp_T^2) + p_T/p_0\right)^n}$$

Other mesons well measured in electronic and hadronic channel

Other mesons are fit with:

m_T scaling of π^0 parameterization

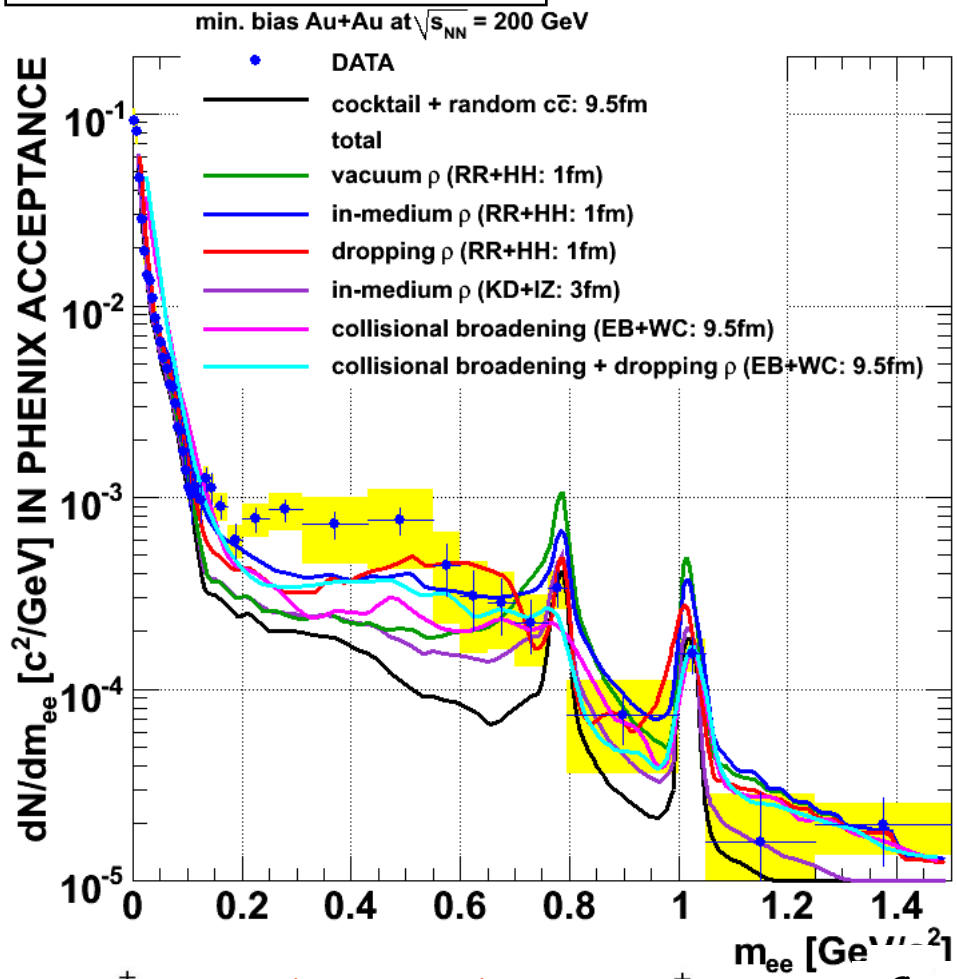
$p_T \rightarrow \sqrt{(p_T^2 + m_{meson}^2 - m_\pi^2)}$

fit the normalization constant

6/13/2008

R.Rapp + H.vanHees
K.Dusling + I.Zahed
E.Bratkovskaja + W.Cassing

Theory comparison



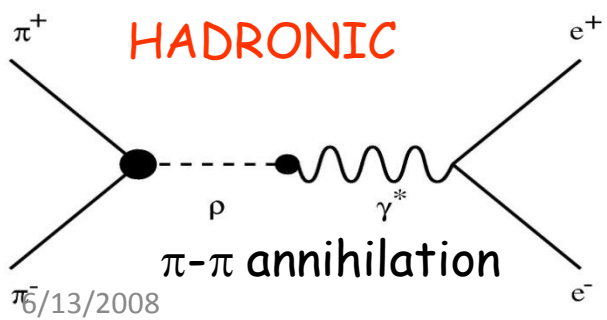
- Freeze-out Cocktail + "random" charm + ρ spectral function

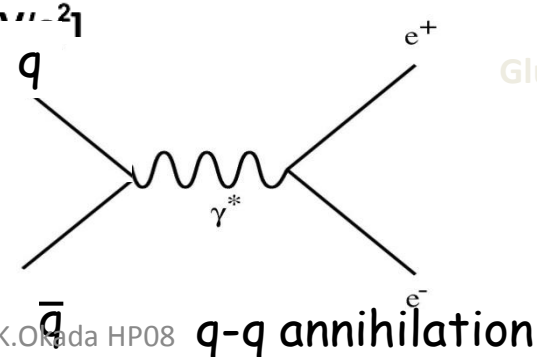
Low mass

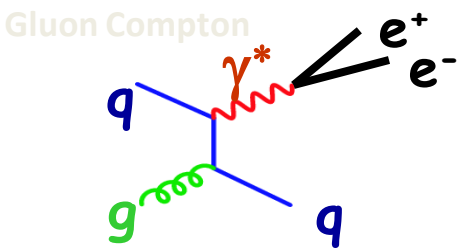
- M>0.4GeV/c^2: some calculations OK
- M<0.4GeV/c^2: not reproduced

Intermediate mass

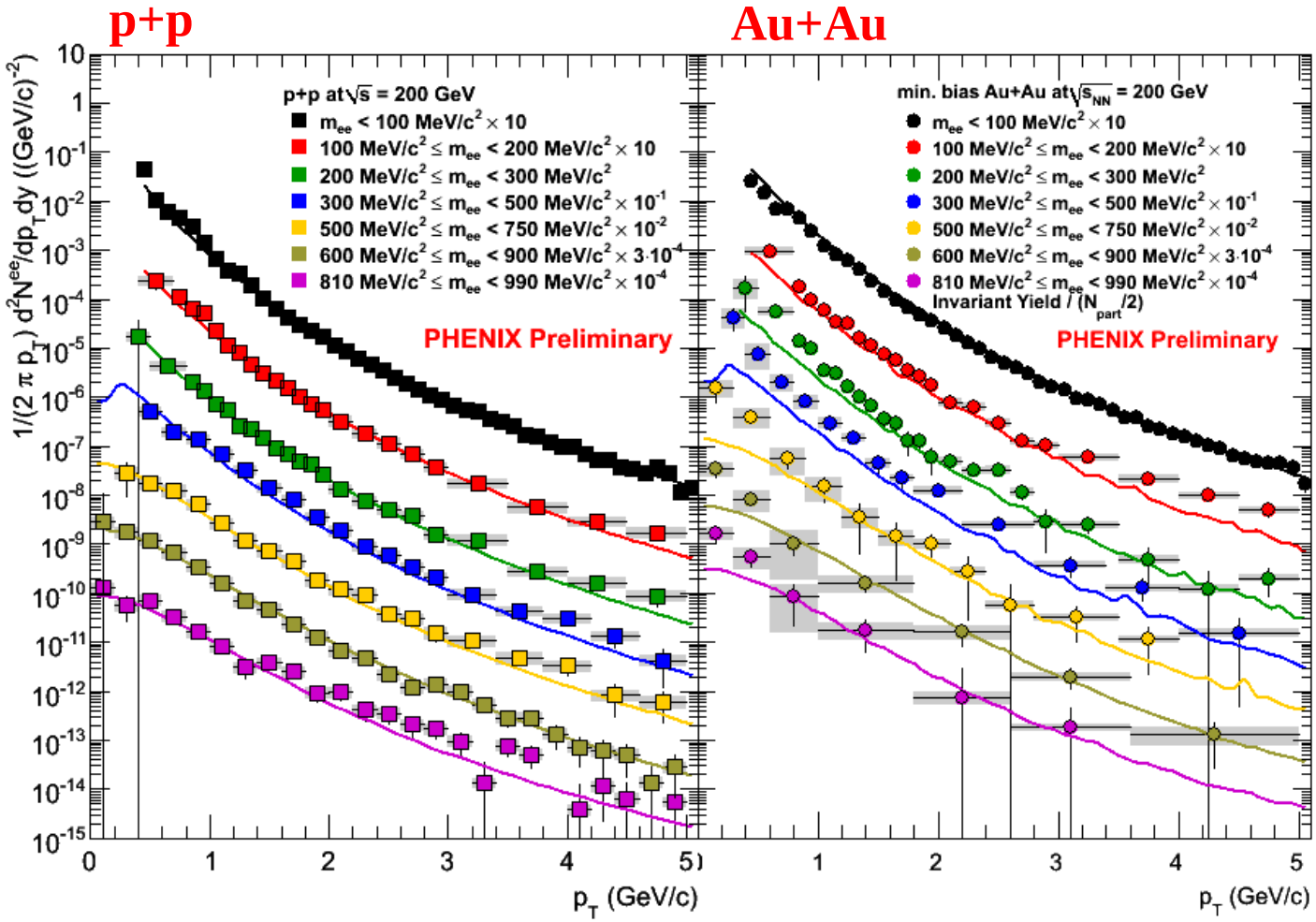
- Random charm + thermal partonic may work







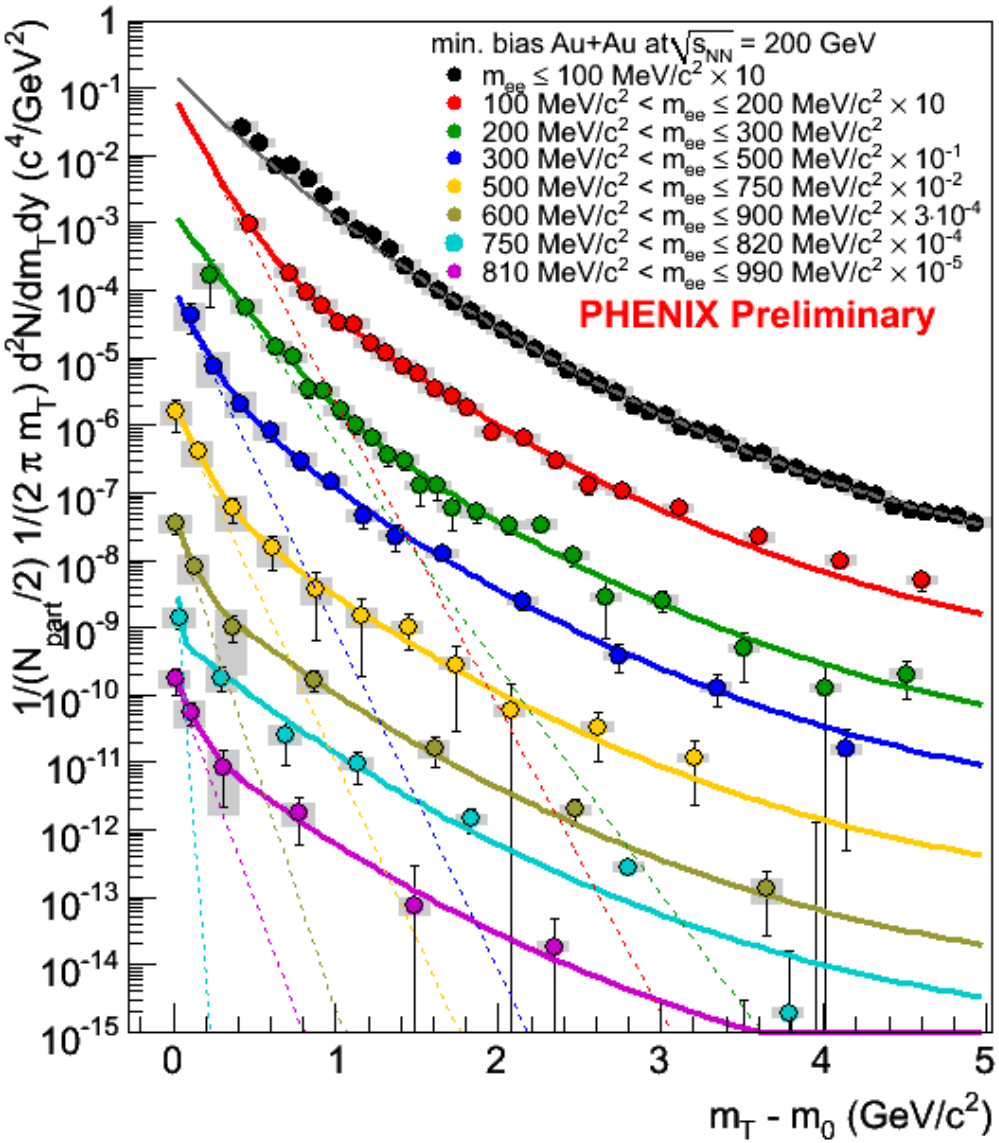
p_T dependence II



p+p: follows the cocktail for all the mass bins

Au+Au: significantly deviate at low p_T

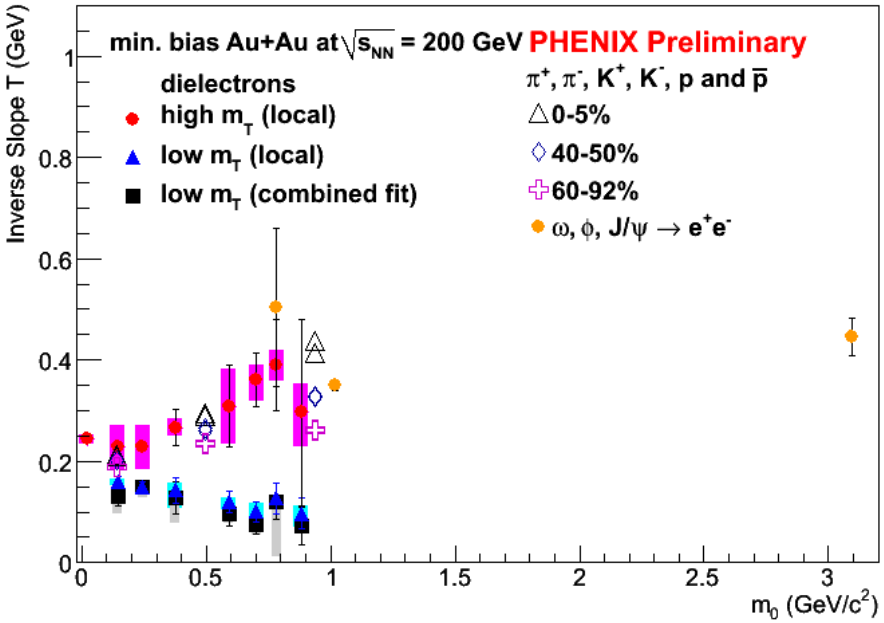
Understanding the p_T dependence



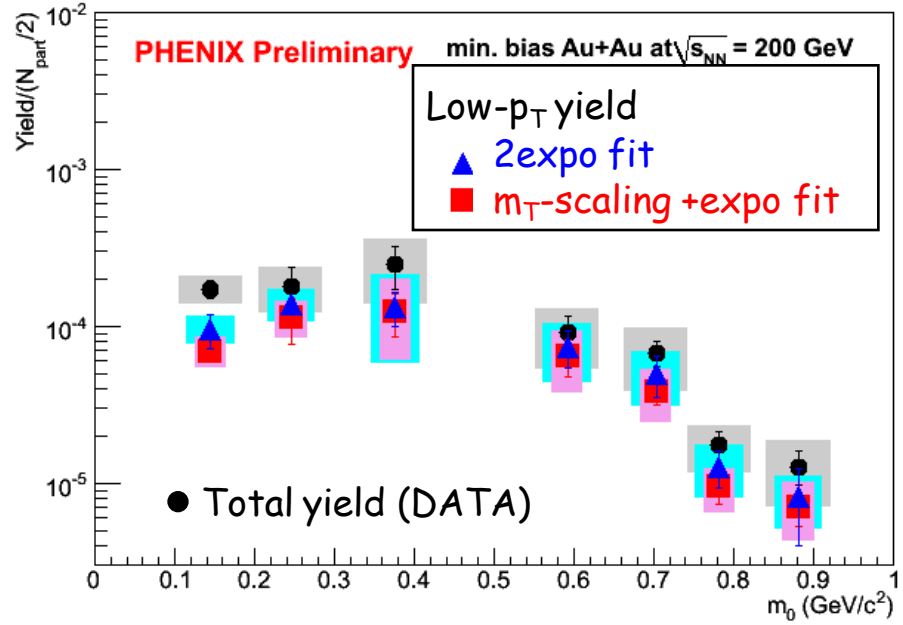
- **Comparison with cocktail**
- **Single exponential fit:**
  - **Low-p_T: $0<m_T<1$ GeV**
  - **intermediate-p_T: $1<m_T<2$ GeV**
- **2-components fits**
  - **2exponentials**
  - **m_T-scaling of π^0 + exponential**
- **Low p_T:**
  - **inverse slope of ~ 120MeV**
  - **accounts for most of the yield**

Yields and Slopes

SLOPES

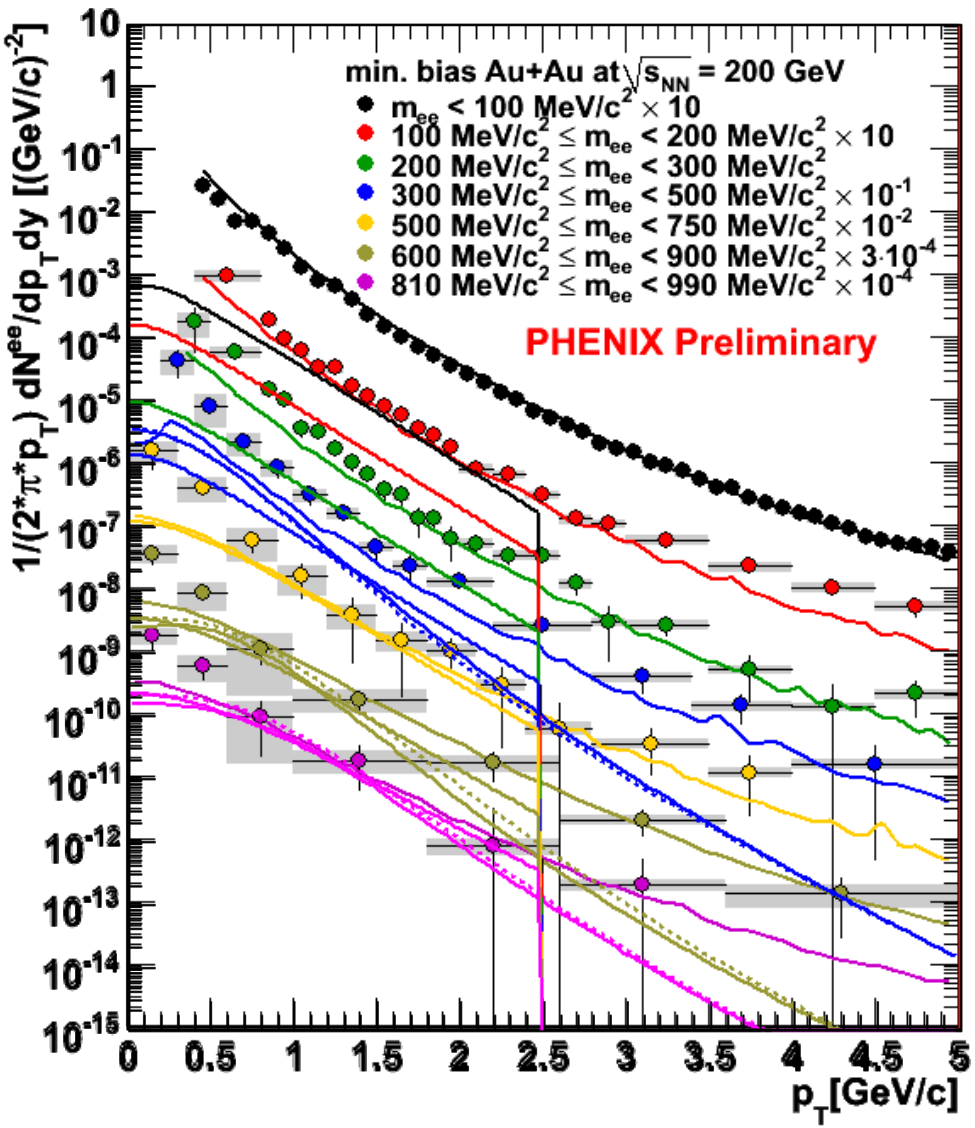


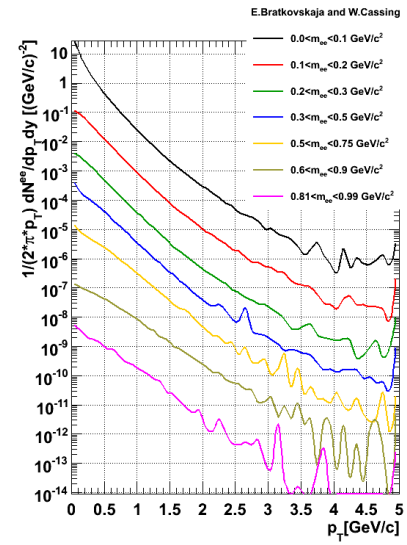
YIELDS



- **Intermediate p_T**: inverse slope increase with mass, consistent with radial flow.
- **Low p_T**:
  - inverse slope of only ~ 120MeV!!!
  - accounts for most of the yield!!!
  - Cold and Bright

Theory Comparison II



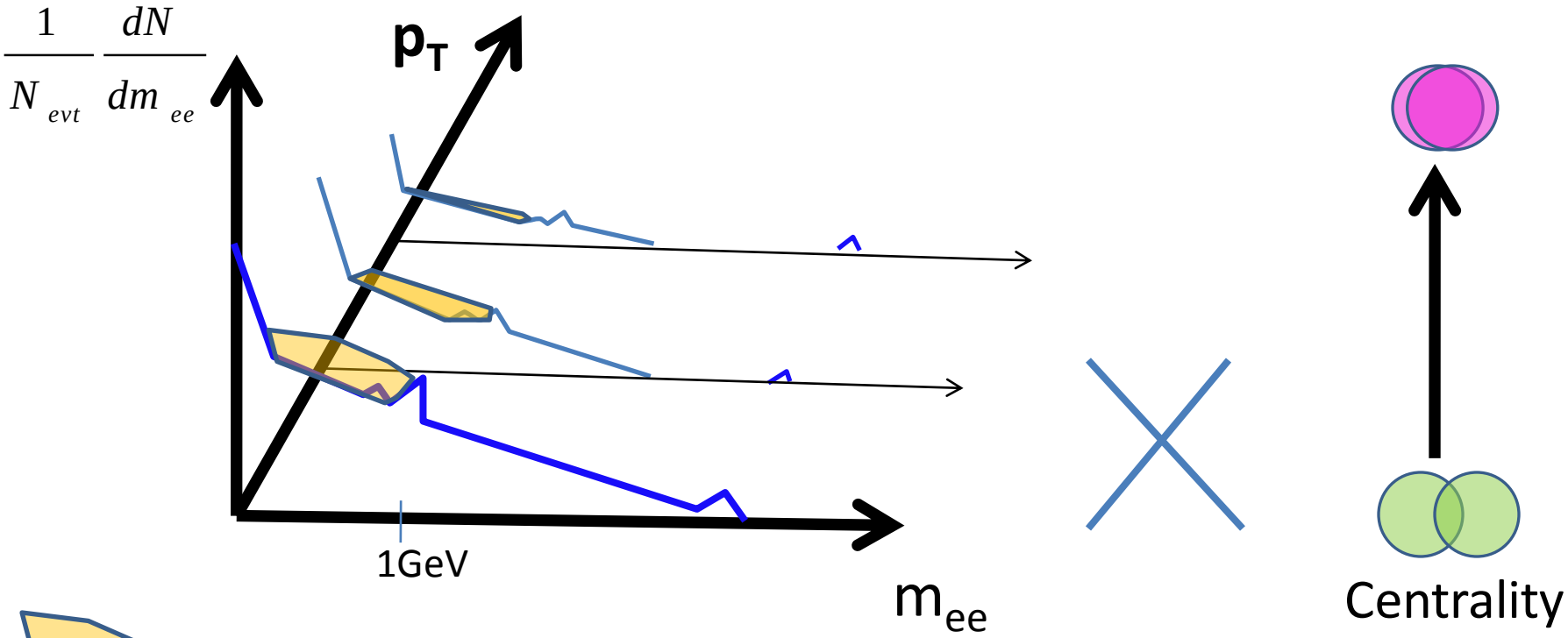


Calculations from
R.Rapp & H.vanHees
K.Dusling & I.Zahed
E.Bratovskaja & W.Cassing (in 4π)

The cold component is not yet explained

Dielectons

There are three dimensions ; m_{ee}, p_{Tee}, Centrality.



: The low mass enhancement.

The following slides show

- The centrality dependence of integrated pT
- The pT dependence of integrated centrality.