Direct photon at RHIC-PHENIX

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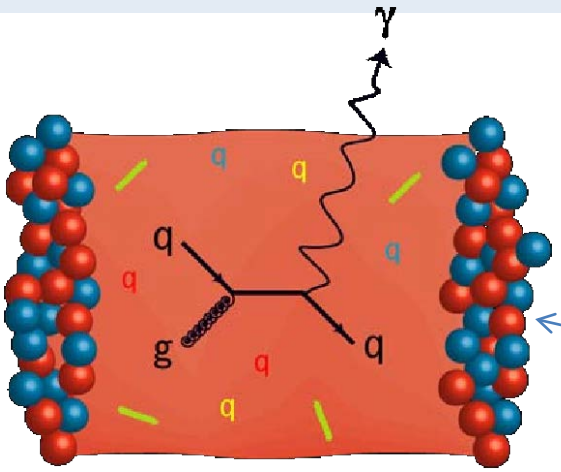
For the PHENIX collaboration
Rencontres de Moriond
March 13, 2012

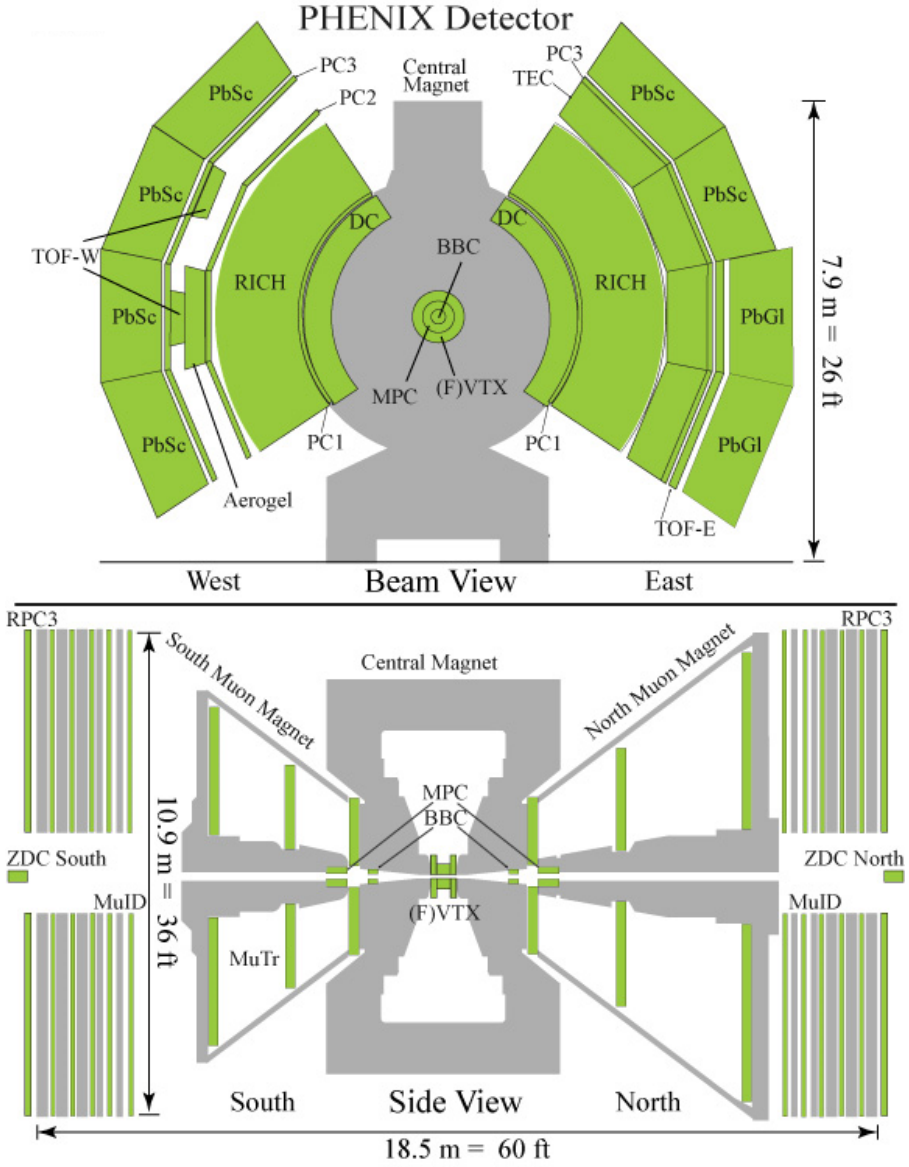
Direct photon: a unique probe



A new state of the matter (sQGP)
Produced by HI collision.

- high pT: Known source, Penetrating probe
  - A good reference to jet quenching
- low pT : QGP production mechanism
  - Spectra : A thermometer
  - Azimuthal dependence to the reaction plane : Probe for the formation mechanism

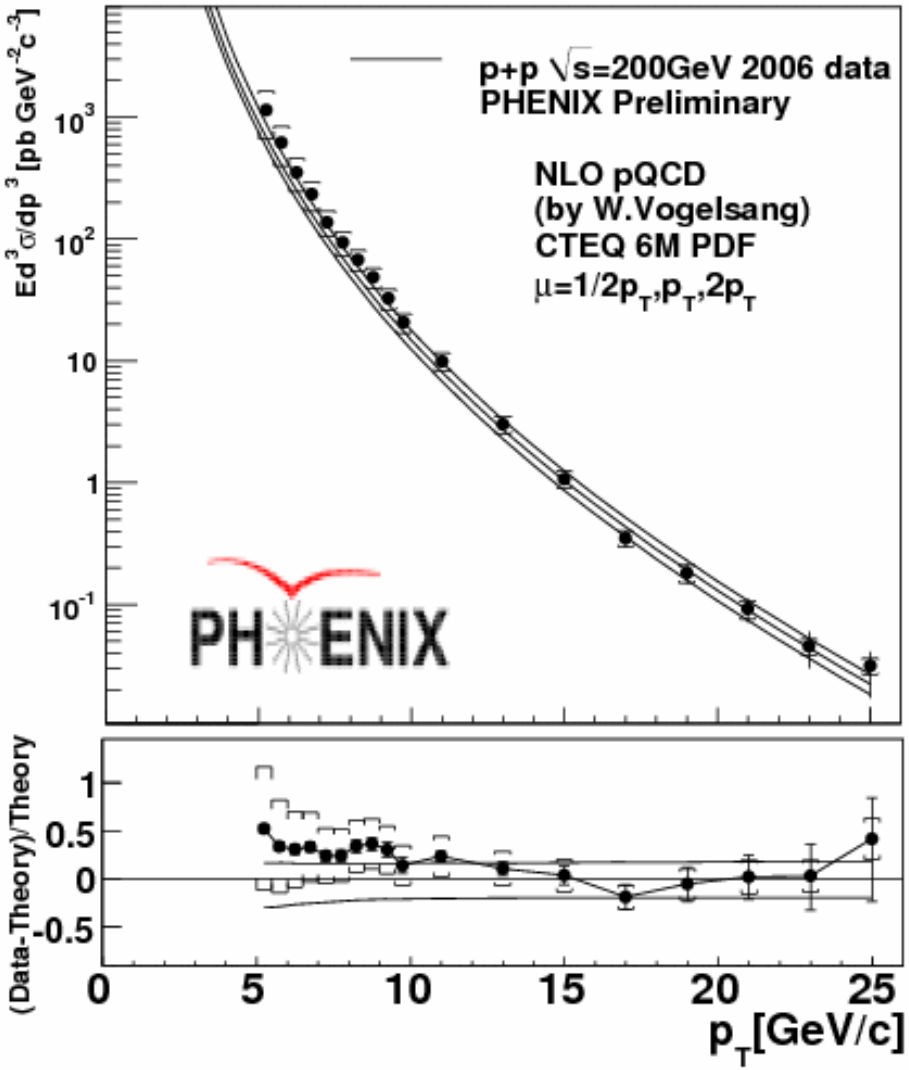
PHENIX detector



The central arm spectrometer

Fine segmented EMCal
Electron identification, tracking
+
High DAQ rate
Trigger

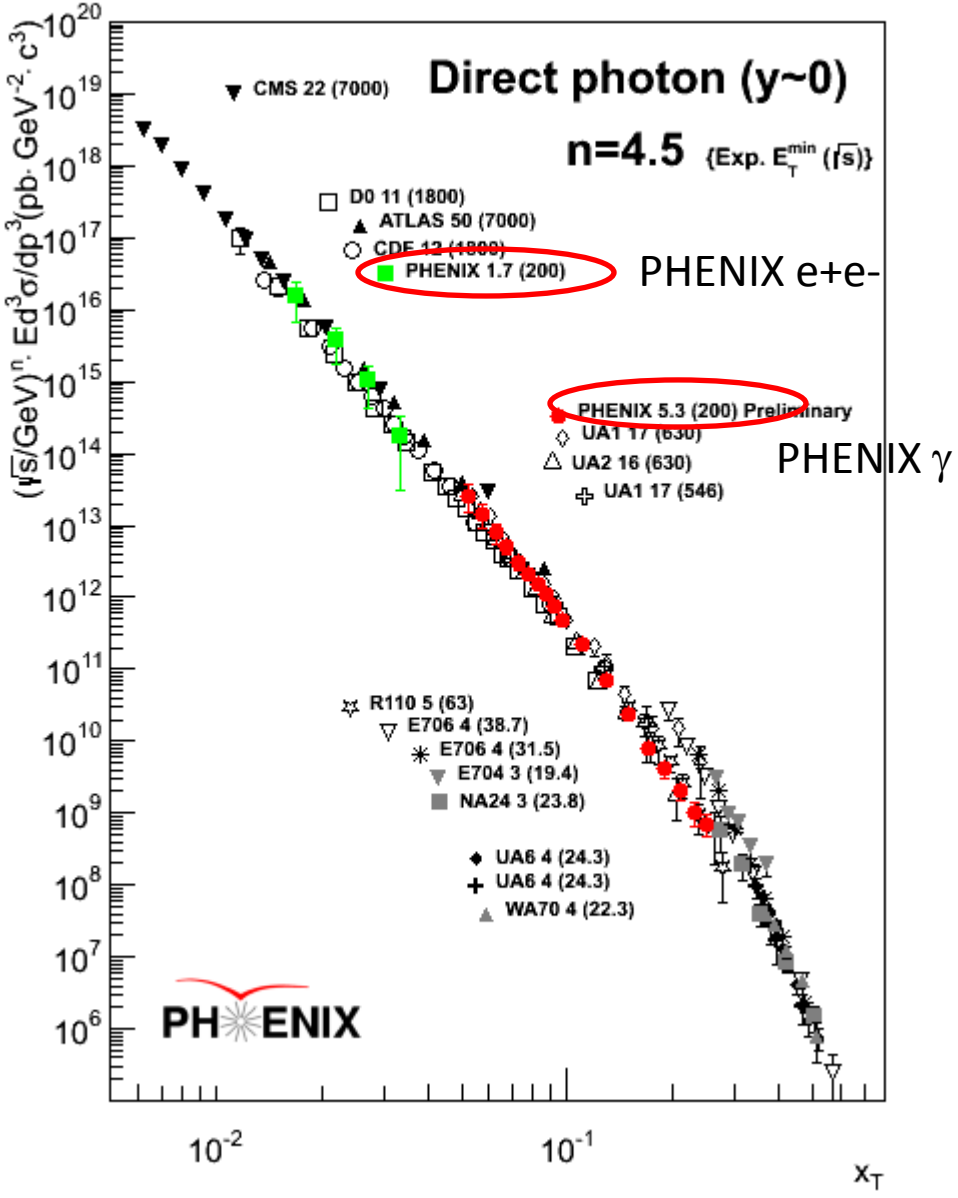
Reference data (*p+p*)



Measured up to p_T=25 GeV/c.

The pQCD NLO calculation is in good agreement with data.

x_T scaling



PHENIX e+e-

PHENIX γ

pp/p+pbar, inclusive/isolated

$x_T \equiv 2p_T/\sqrt{s}$

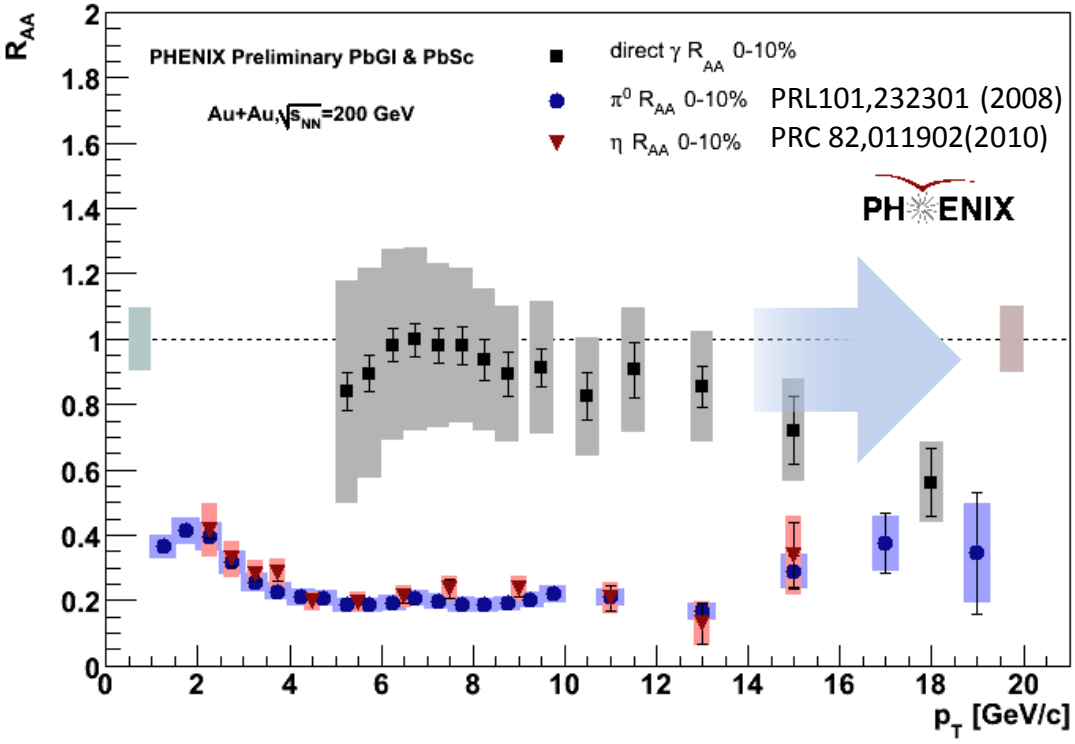
cross section scaled by $\sqrt{s}^{4.5}$

They are on a universal curve except one experiment, from LHC to fixed target experiments.

n=4.5 is in a range consistent with expectations from NLO pQCD.

high p_T

Direct photon R_{AA}



Nuclear modification factor (R_AA)
Photon vs. hadron

There is a difficulty in high pT region in the measurement. (=π^0 merging BG, cosmic BG in *p+p*.)

Various checks are done.
Final results will come out soon.

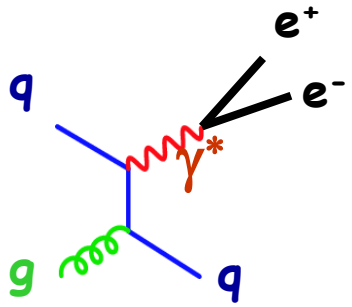
low pT

Photon = e^++e^-?

They have the same quantum number.

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

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

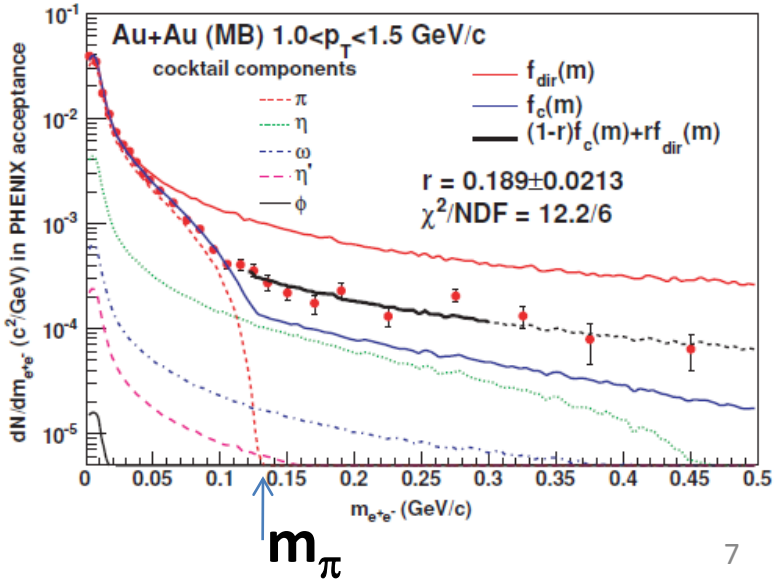


When $p_T^2 >> M_{ee}^2$ **, S=1 for photons.**

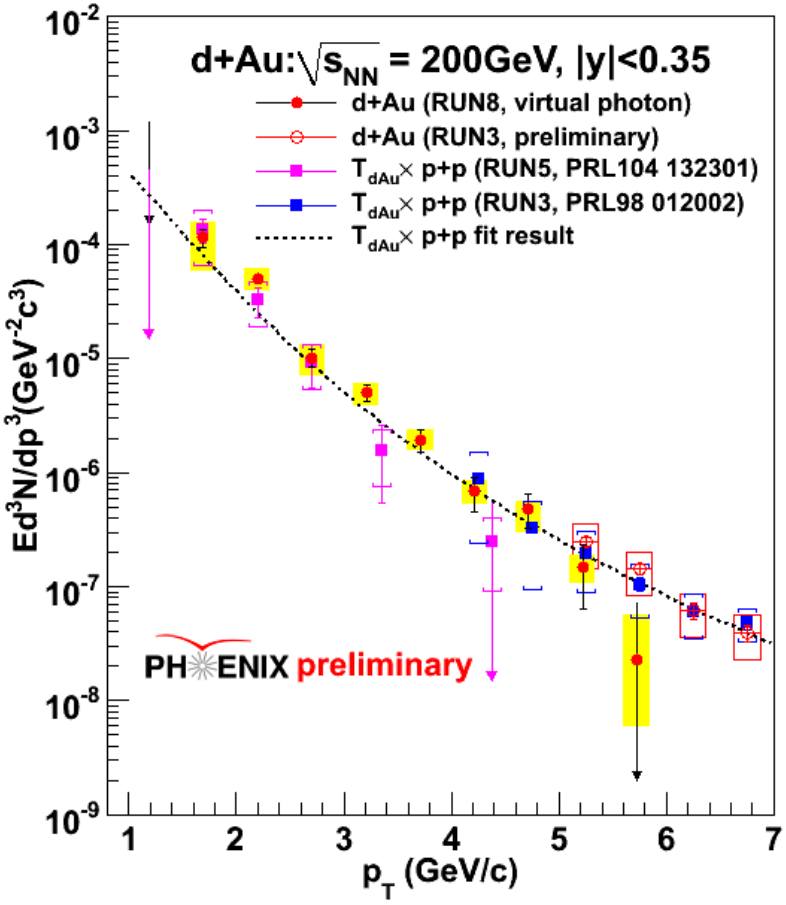
Independent of the origin in the very low mass region (M_{ee} < ~30MeV)
No π^0 Dalitz above the π^0 mass. → The key to improve the S/N ratio.
Direct photon follows 1/M_{ee}.

Procedure

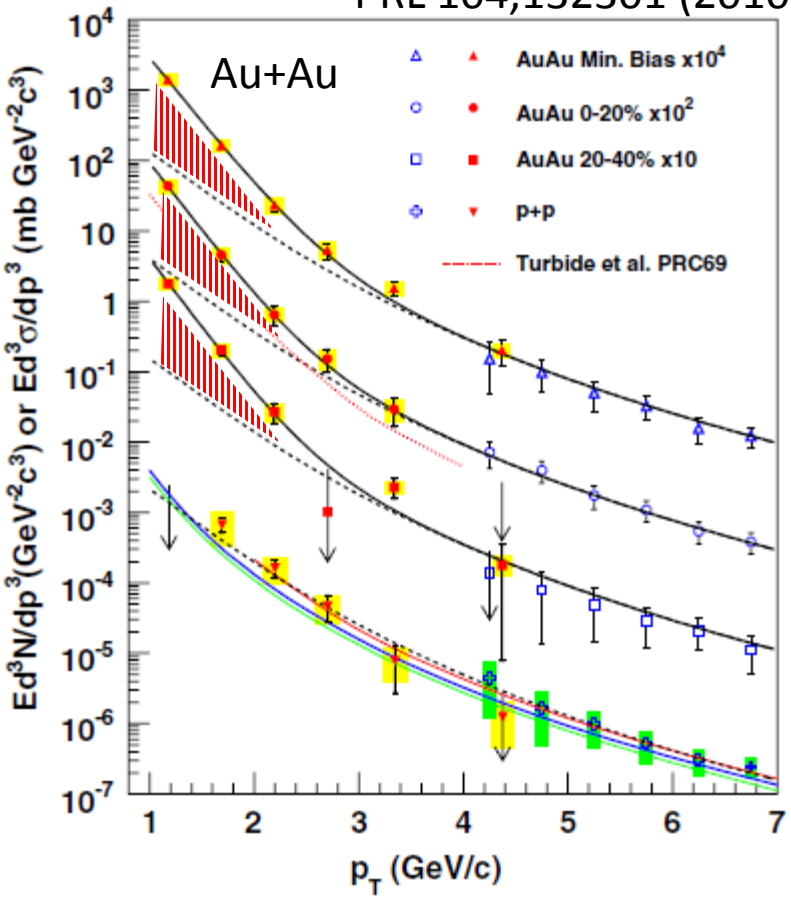
Combinatorial and correlated pair subtraction
Cocktail and direct photon shapes
Normalized in the very low mass region
Fit and Extract the direct photon component



Virtual photon spectra



PRL 104,132301 (2010)

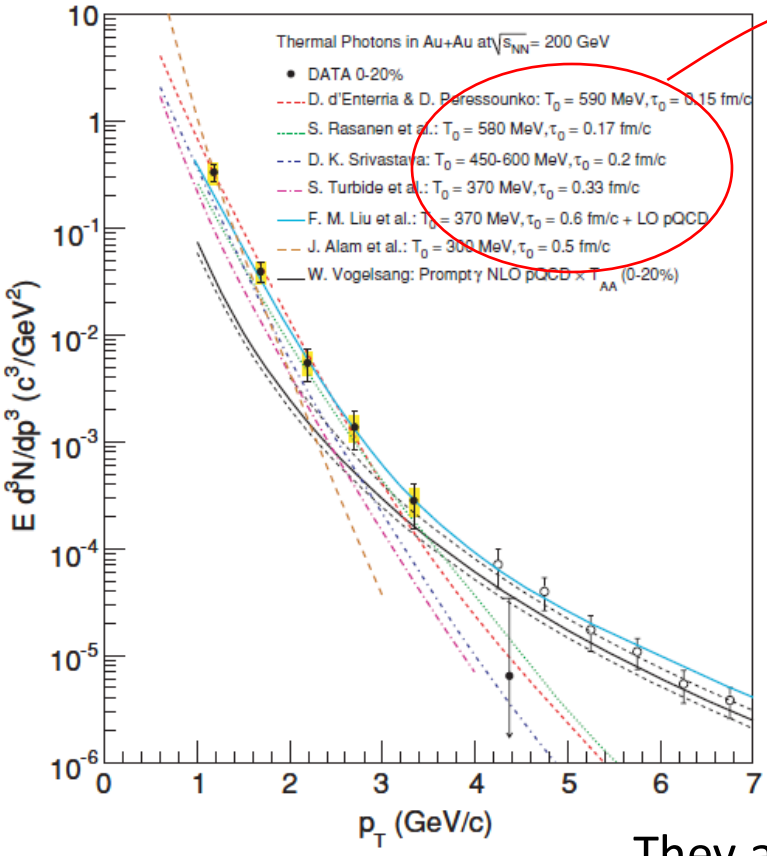


p+p: Already shown in the previous xT plot.

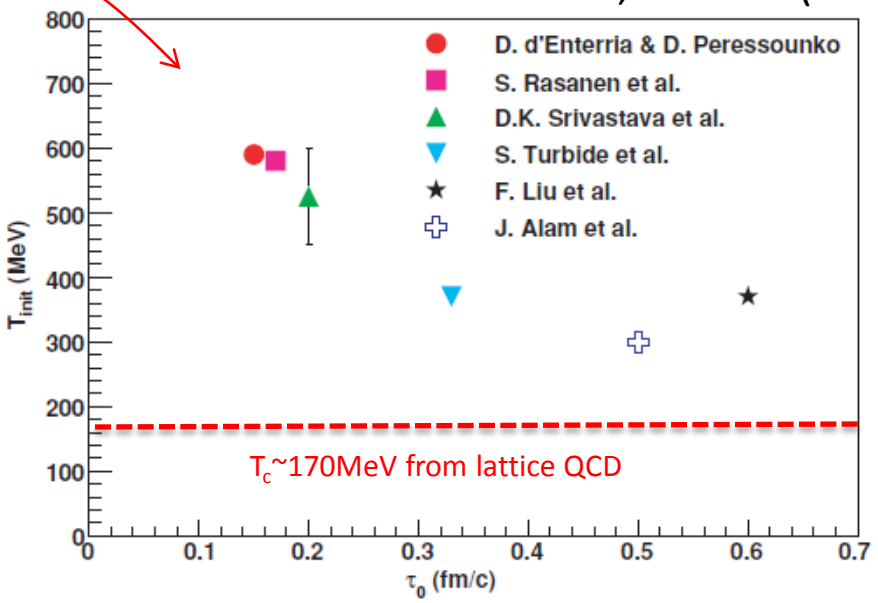
d+Au: Consistent with scaled p+p. Little or no nuclear effects.

Au+Au: Large excess in low pT region.
<T> is extracted from the inverse slope.

Initial temperature & formation time



PRC 81, 034911 (2010)

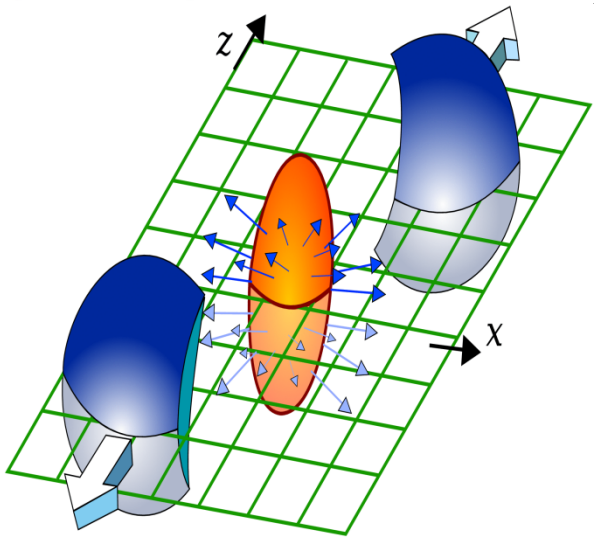


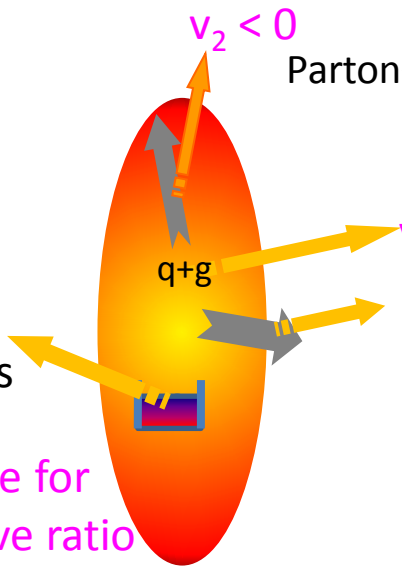
They are all above the critical temperature.
However T_{init} depends on τ_0 in the theory calculations.

→ Need additional experimental constraints

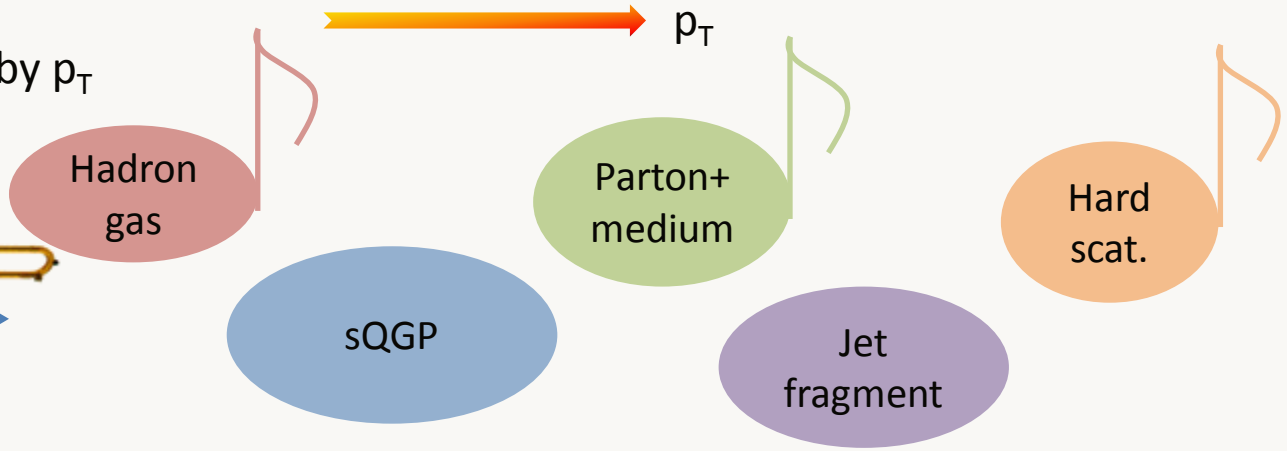
Direct photon v_2 (another knob)

$$\frac{dN}{d(\phi - \Psi_{\mathrm{RP}})} \propto N_0[1 + 2v_2 \cos\{2(\phi - \Psi_{\mathrm{RP}})\}],$$





The ingredients are tuned by p_T



Direct photon v_2

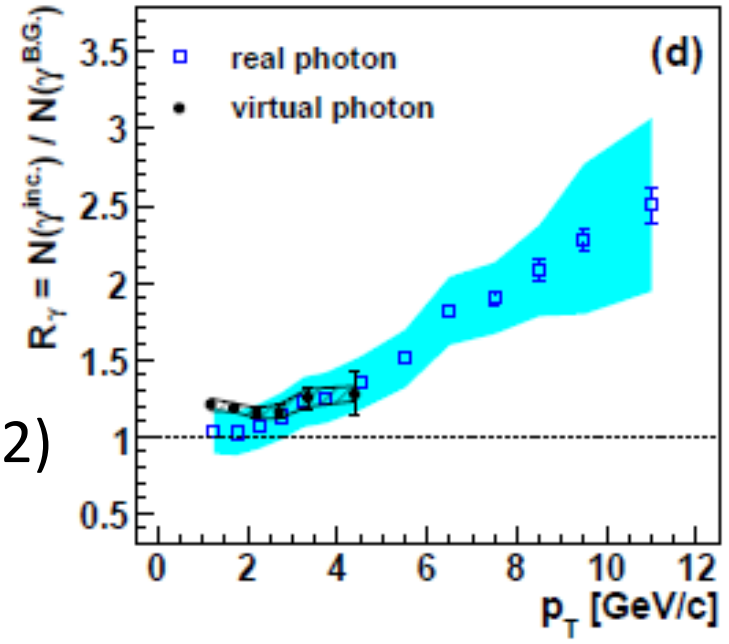
From real photon in the EMCal with virtual photon measurement

$$v_2^{dir.} = \frac{R_\gamma v_2^{inc.} - v_2^{BG}}{R_\gamma - 1}$$

v_2^{inc} Inclusive photon v2

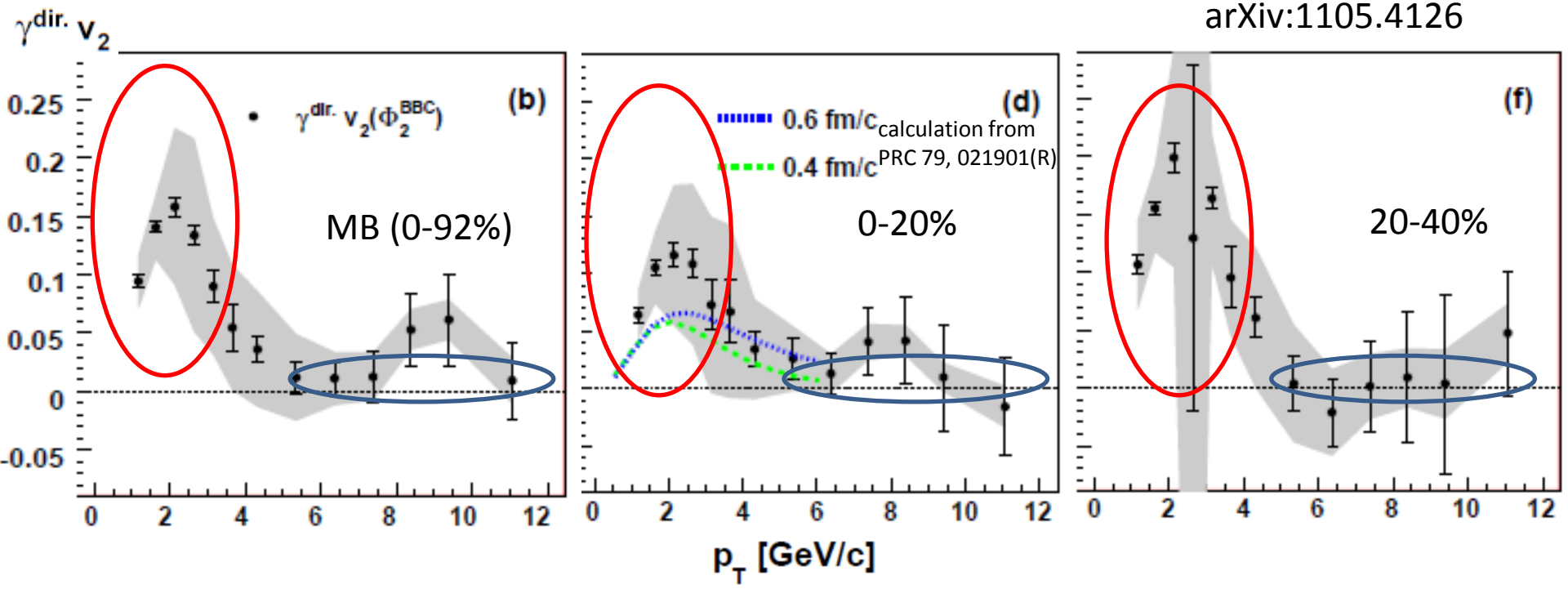
v_2^{BG} BG photon v2
(From π^0 and other mesons v2)

$R_\gamma = \frac{S+B}{B}$ From virtual photon measurement



Direct photon v_2

arXiv:1105.4126



At high pT, v2~0. It is consistent with the hard scattering source.
At low pT (thermal region), an unexpectedly large v2 is observed!

It depends on the formation time.
But theory predictions are too small.

early $\rightarrow$ late $\Rightarrow$ small $\rightarrow$ large

Next step: v_2 of virtual photon

Advantage (systematic)

v2 from combinatorial BG and remaining Dalitz decay can be well controlled.

Disadvantage (statistics)

Total statistics goes down by a factor of ~200.
Even in 1-3 GeV/c bin, it's statistically challenging.

sys. uncertainty table
arXiv:1105.4126

real photon

Source	1–3ĠeV/c	10–16ĠeV/c
inclusive γ v_2		
remaining hadrons	2.2%	N/A
v_2 extraction method	0.4%	0.6%
π^0 v_2		
particle ID	3.7%	6.0%
normalization	0.4%	7.2%
shower merging direct γ	N/A	4.0%
R_γ	3.1%	22%
common reaction plane	6.3%	6.3%

virtual photon

❖ $\gamma \rightarrow ee$ are induced in a strong magnetic field in HI collisions?
PRC 83, 017901 (2011) Tuchin

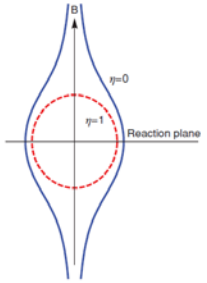
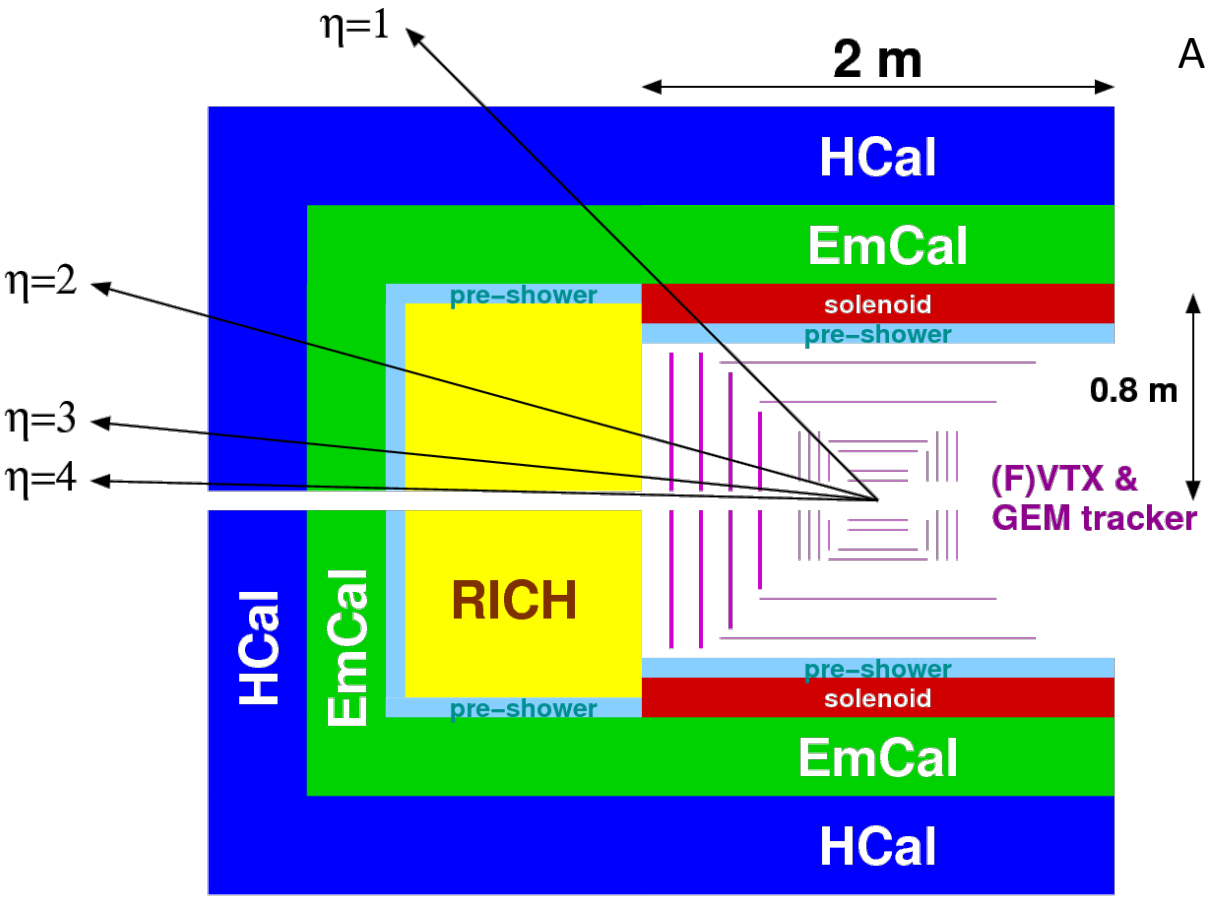


FIG. 2. (Color online) Azimuthal distribution of the decay rate of photons at different rapidities at LHC. Only the contribution of the $\gamma \rightarrow e^+e^-$ channel is shown.

If it is true, it affects the assumptions in all virtual photon results.
Anyway it is interesting.

Future sPHENIX project

A plan to upgrade the detector.



What can we add to the current RHIC detectors?

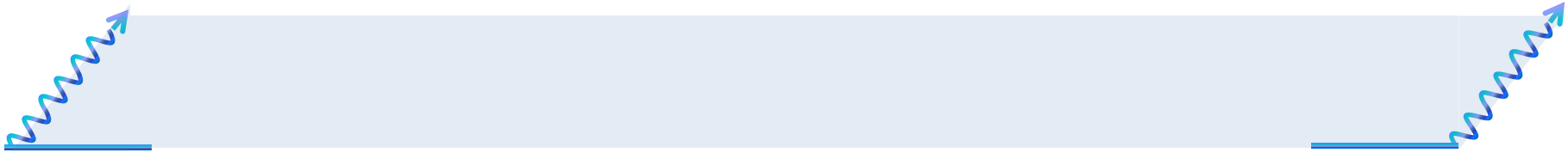
Large acceptance with high γ/π^0 separation.

More tracking layers, hope eID is still powerful.

Hadron calorimeter for γ+Jet analysis.

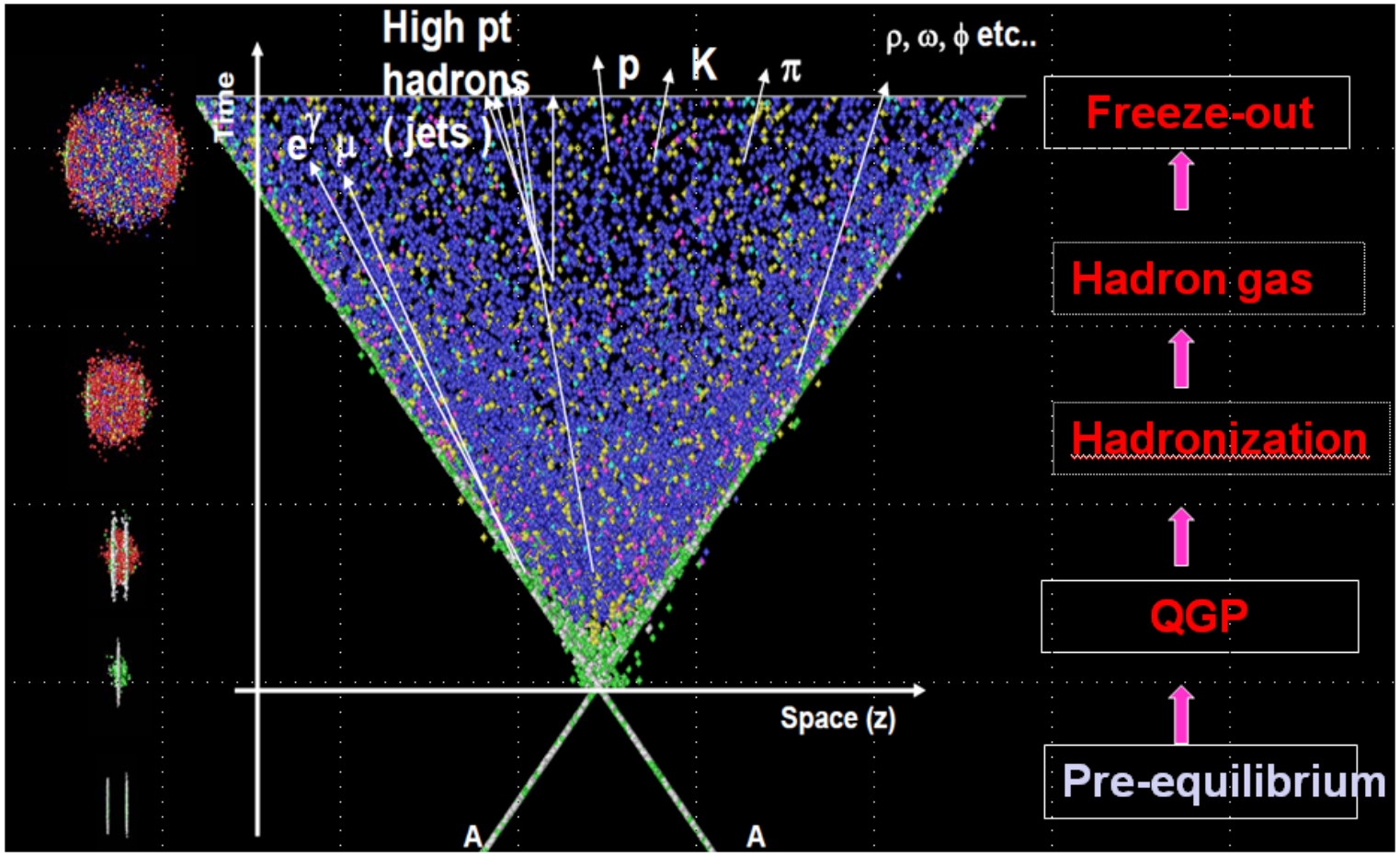
Summary

- Showed PHENIX (selected) photon results
- *p+p* reference measurements are on the universal curve of world's measurements.
- An unexpectedly large v_2 was measured in the low p_T region. No theory explanation so far.
- PHENIX upgrade discussion is on going.

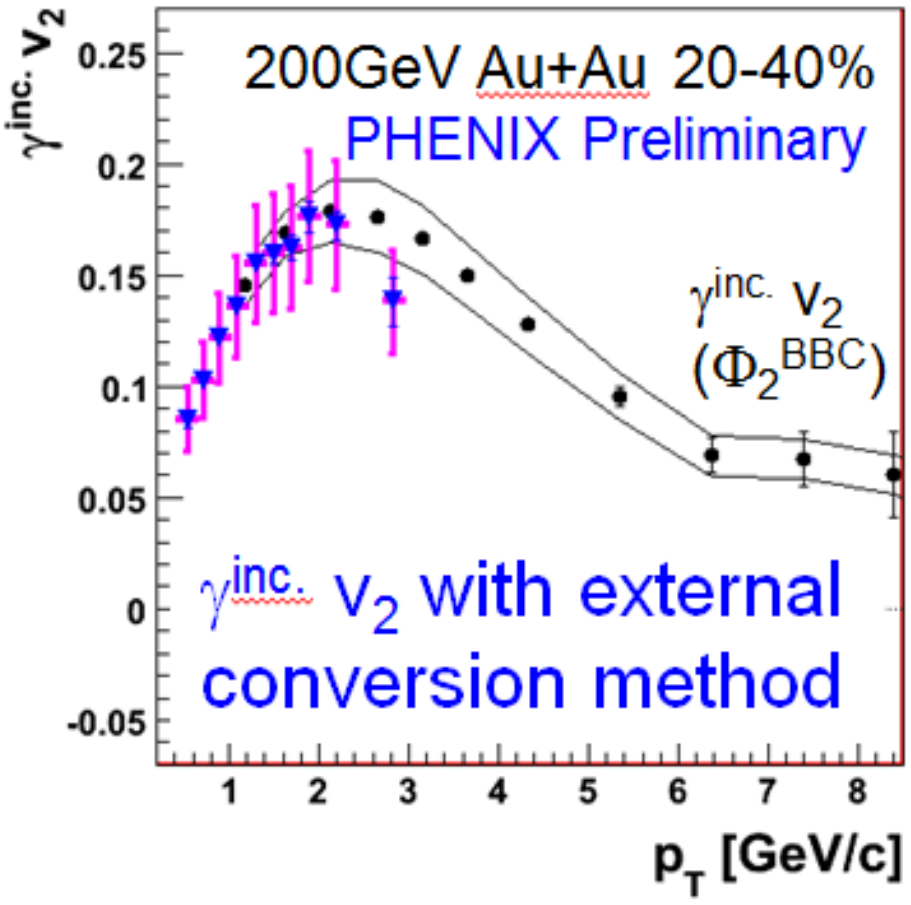


Backup

Space time evolution



Hadron contamination check

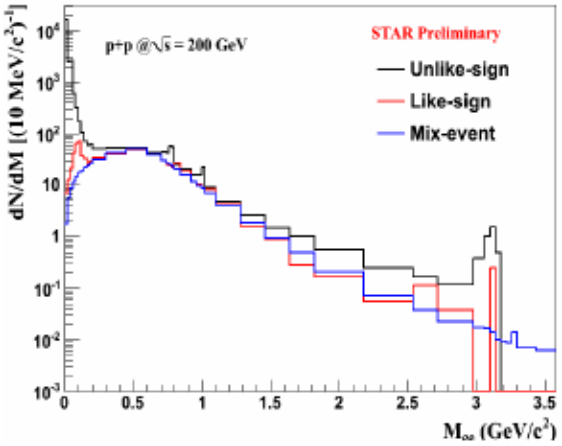


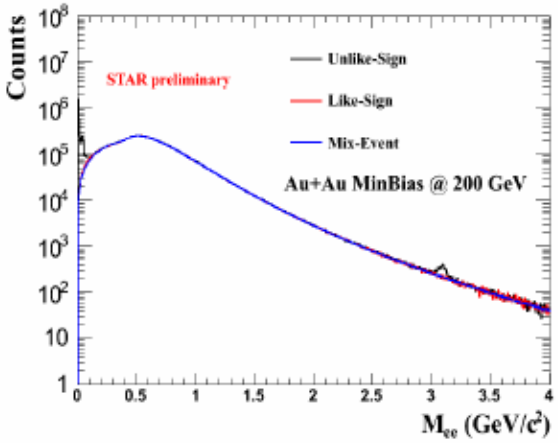
- Hadron contamination can be significant
- Check with an external conversion analysis
  - Identify photons via conversion in material to dileptons
  - No hadron contamination
- Two measurements are consistent
- Hadron contamination in the real photon (EMCal) measurement well understood

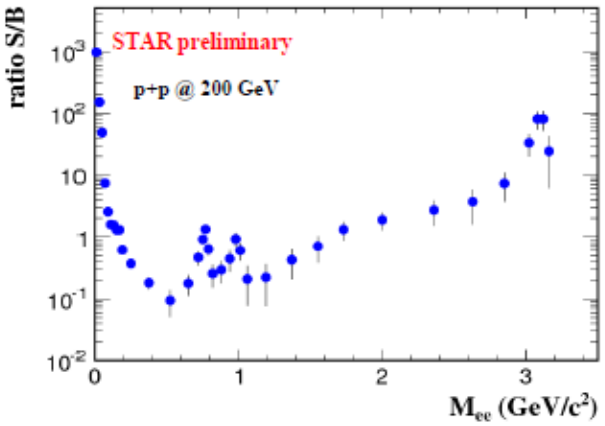
STAR

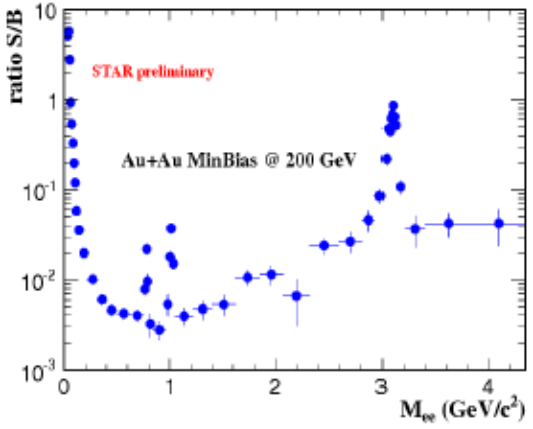
BROOKHAVEN NATIONAL LABORATORY

Di-electron signals in p+p and Au+Au





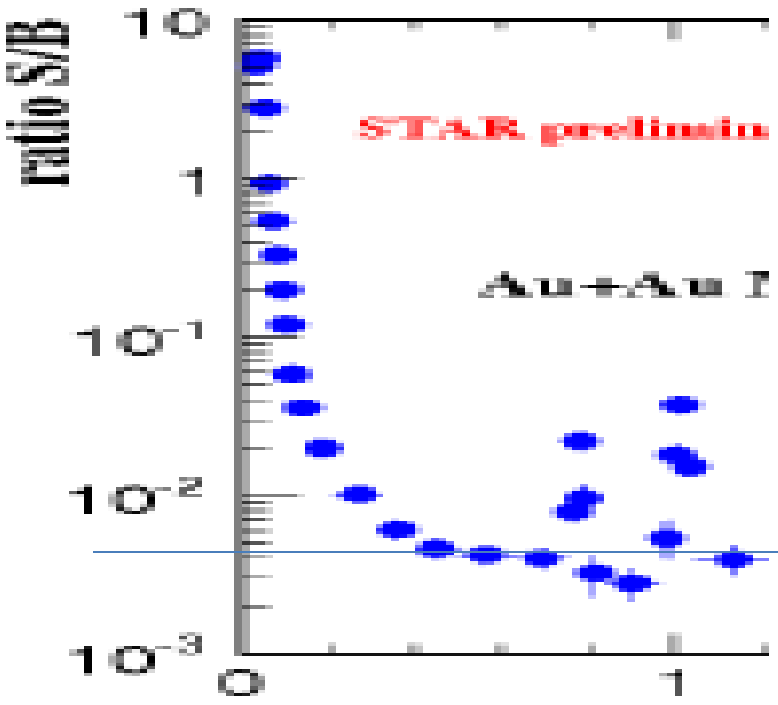


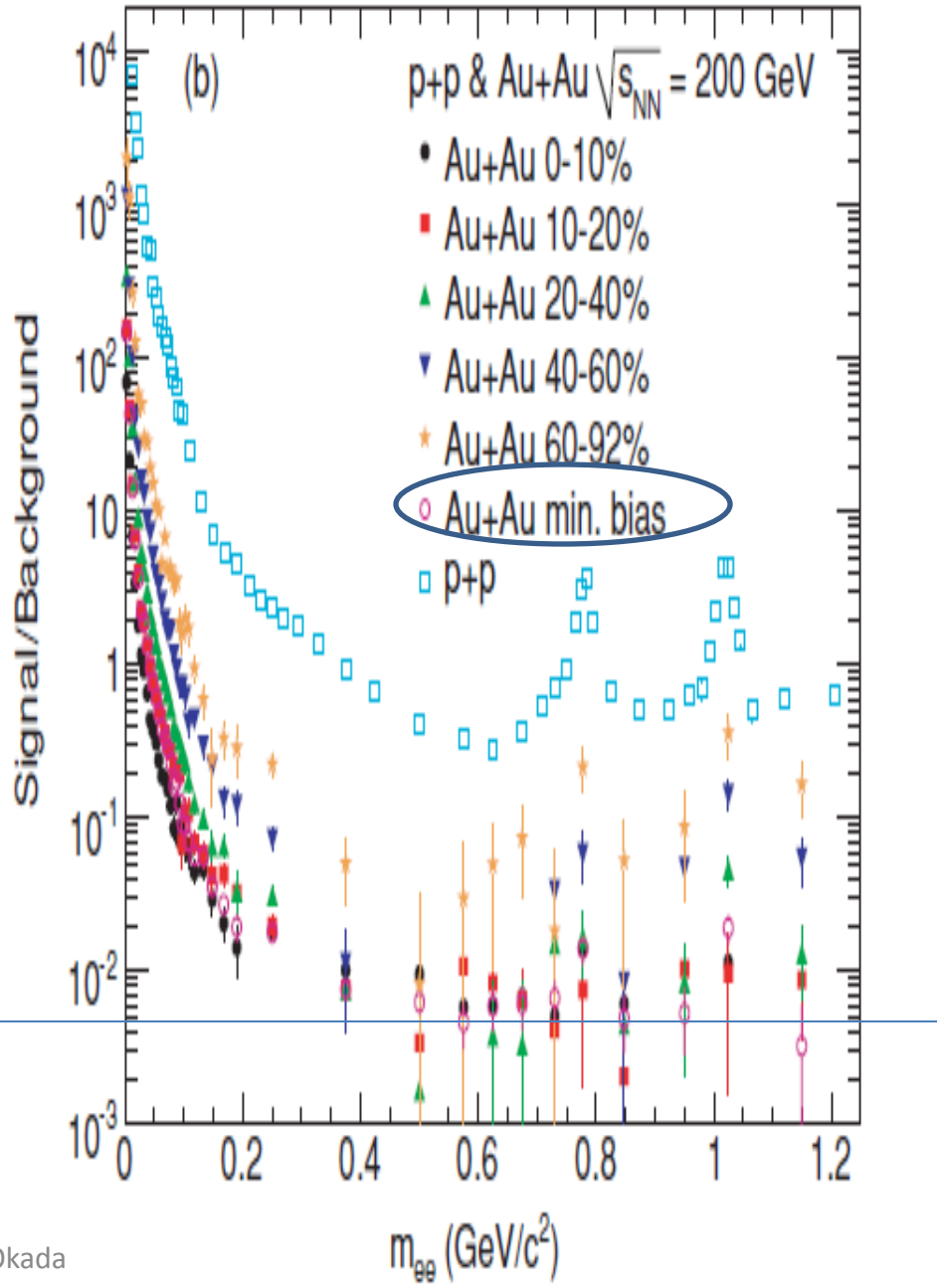


12/05/2011 Thermal photons and dileptons, BNL, Dec 5-7 11

STAR vs PHENIX

PHENIX has a little better S/B ratio.
Acceptance STAR = 6*PHENIX
DAQ STAR(~1kHz) vs PHENIX(~6kHz)





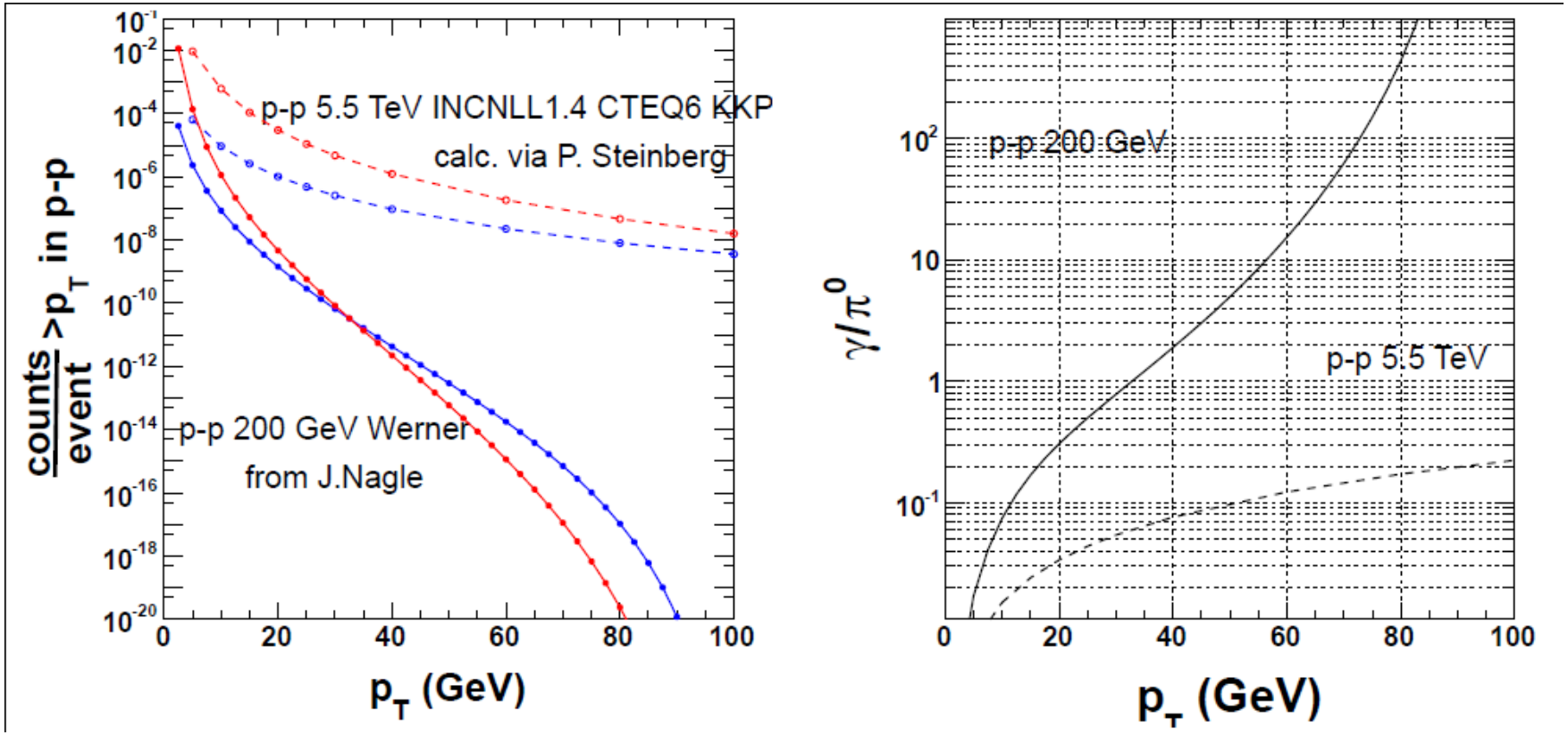
PHENIX Au+Au Statistics

Run	species	AuAu200 intL	comment
4	AuAu200, 64.4	1.5G (0.241/nb)	
7	AuAu200,	5.1G(0.813/nb)	RXN, HBD prototype
8	dAu, p+p		
9	p+p500, 200		
10	AuAu200, lowE	(1.25/1.07/nb) for 30/20cm	RXN, HBD
11	pp500,AuAu19.6, 200	(0.913/0.788/nb) for 30/12cm	VTX

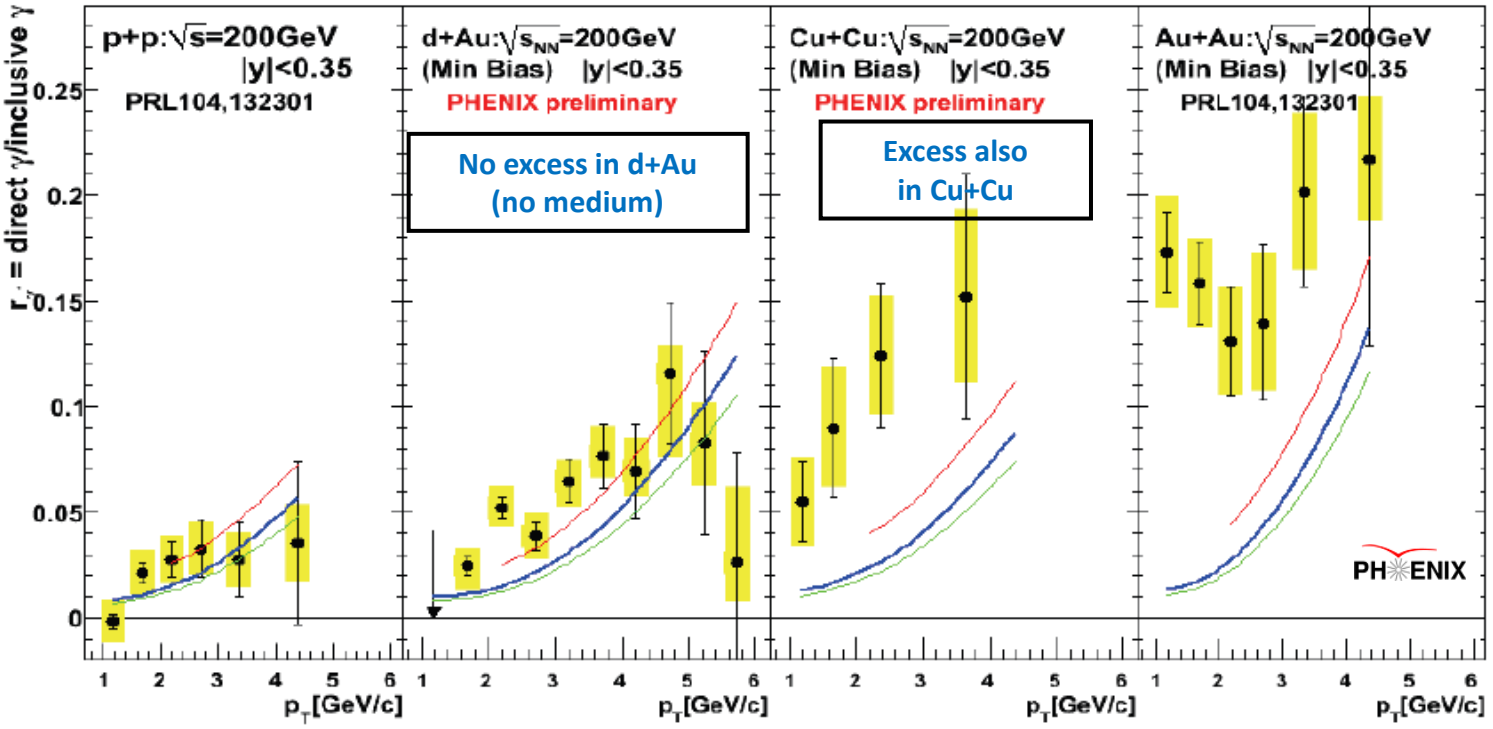
In Run10, 11, the integrated luminosity is comparable to Run7.
Can we remove Dalitz decay to reduce the combinatorial?
Then small Mee will be cut out. It needs some trick for the mass shape fit.

STAR has an advantage if their claim for the combinatorial BG is true.

RHIC advantage to LHC



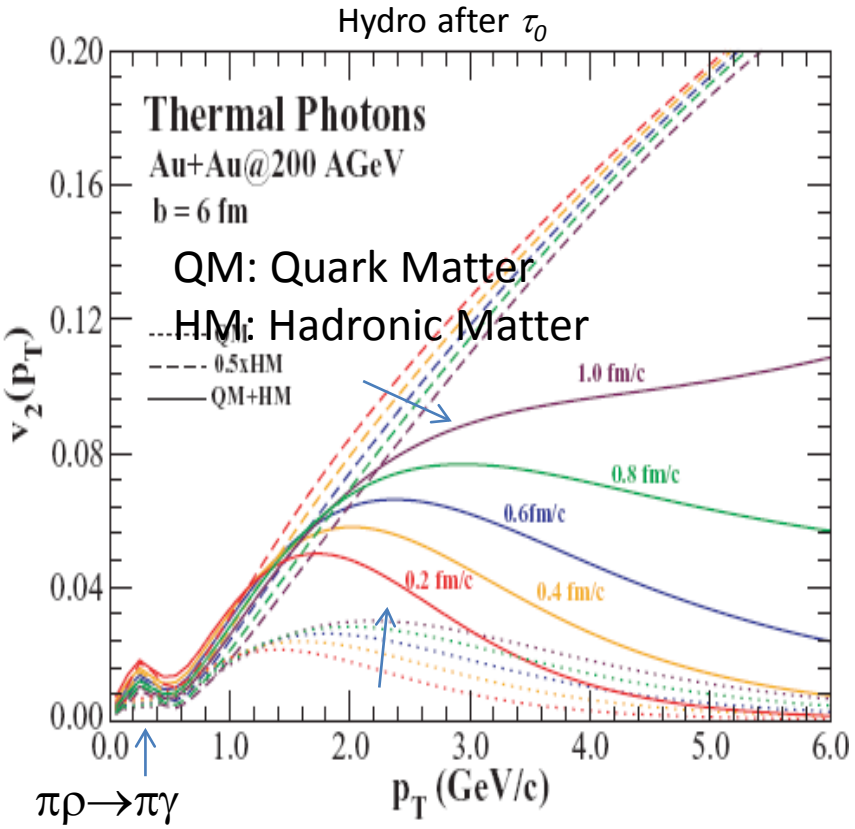
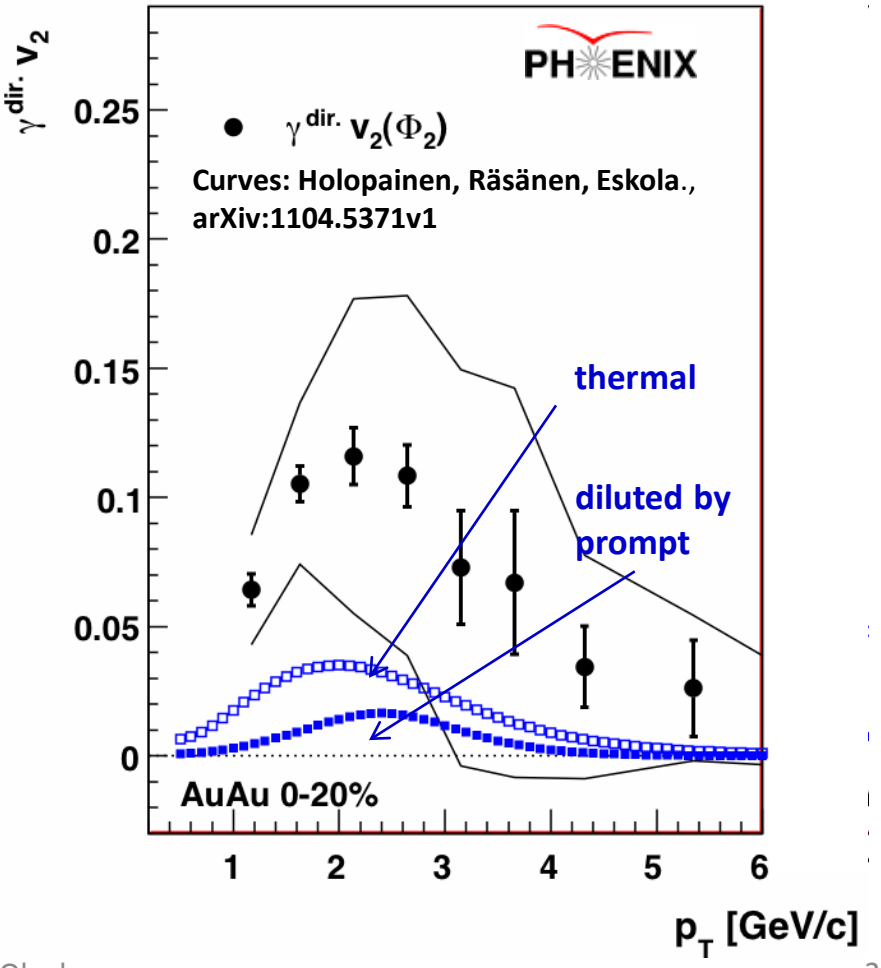
System size dependence of γ fraction



- γ fraction = $\text{Yield}_{\text{direct}}$ / $\text{Yield}_{\text{inclusive}}$
- Largest excess above pQCD is seen at Au+Au.
  - Moderately in Cu+Cu also.

Comparison with models. No success..

- Later thermalization gives larger v_2 (QGP photons)
- Large photon flow is not explained by models for QGP



Chatterjee, Srivastava PRC79, 021901 (2009)