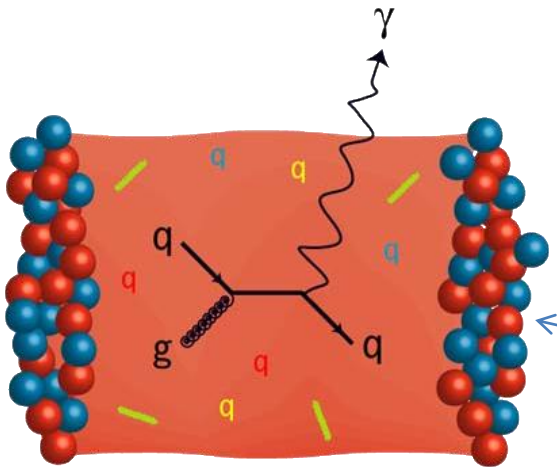
Direct photons and their Flow measured by PHENIX

Kensuke Okada
for the PHENIX collaboration
RHIC-AGS Users meeting
June 12, 2012

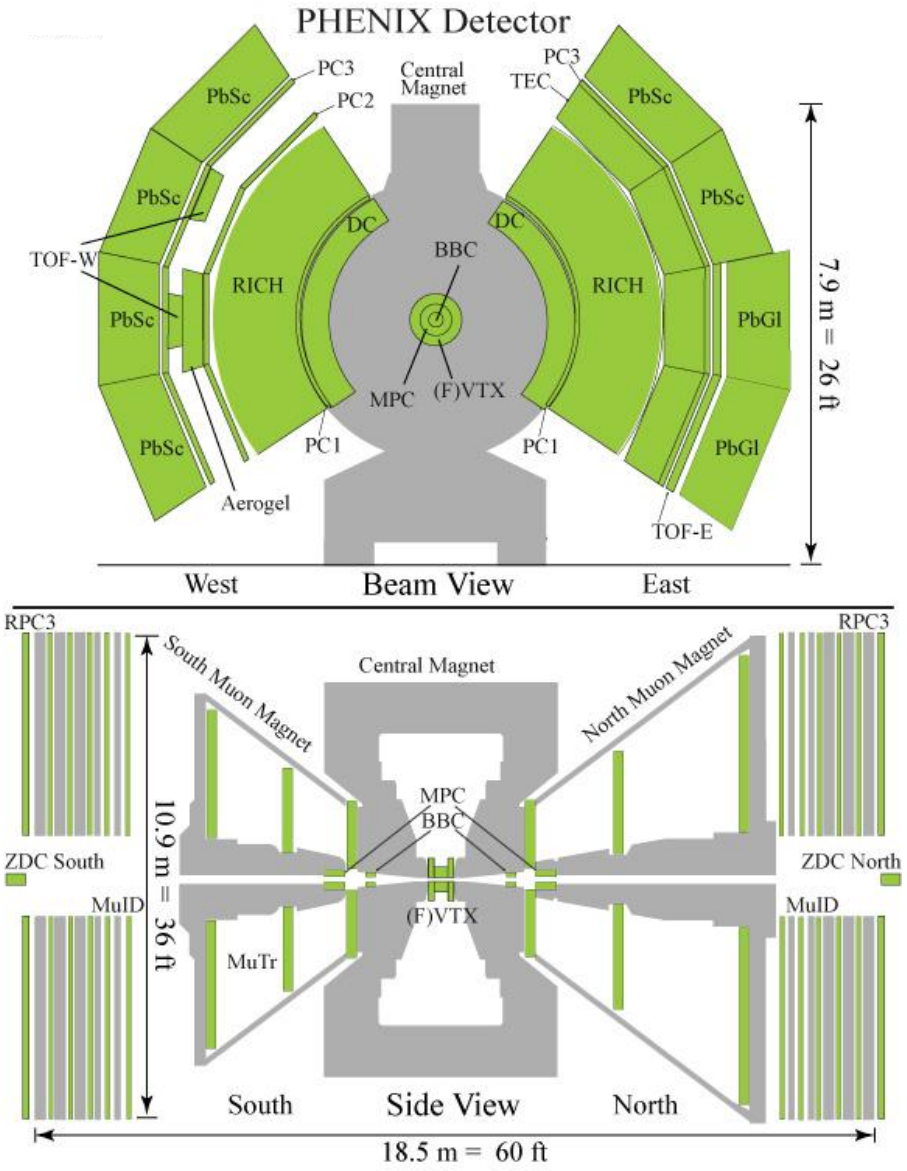
Direct photon: a unique probe



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

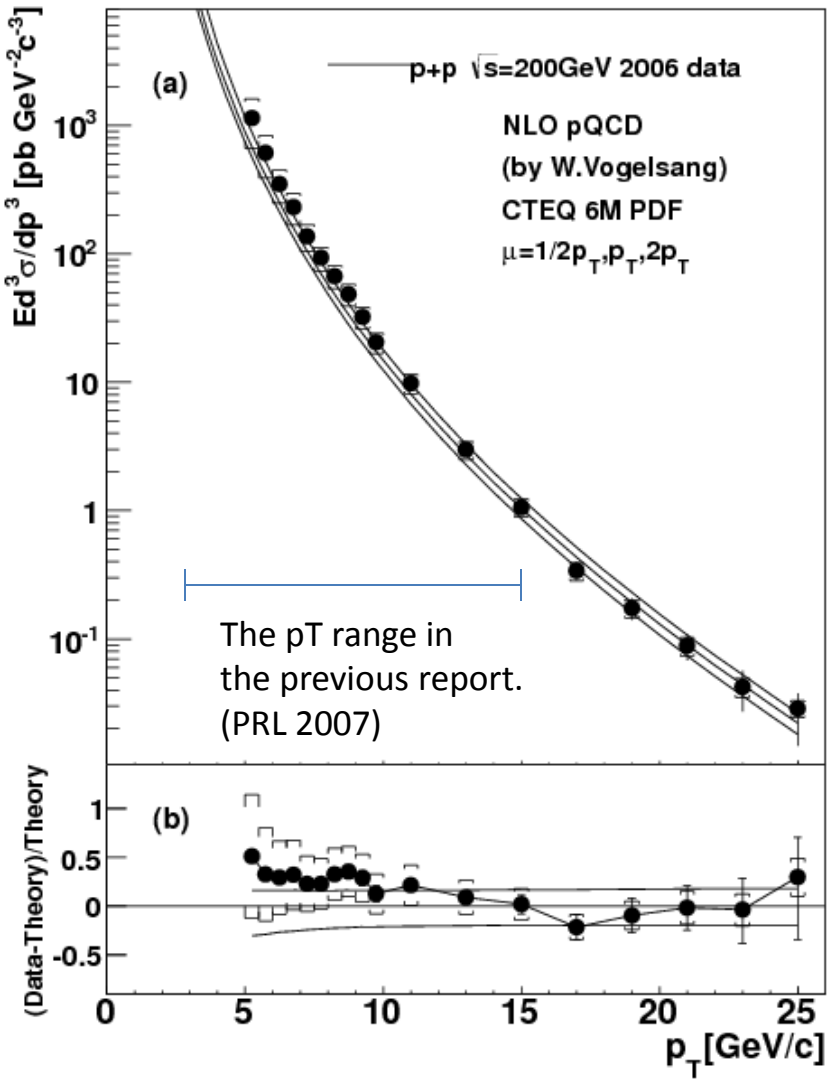
+

High DAQ rate

Trigger

Reference data (*p+p*)

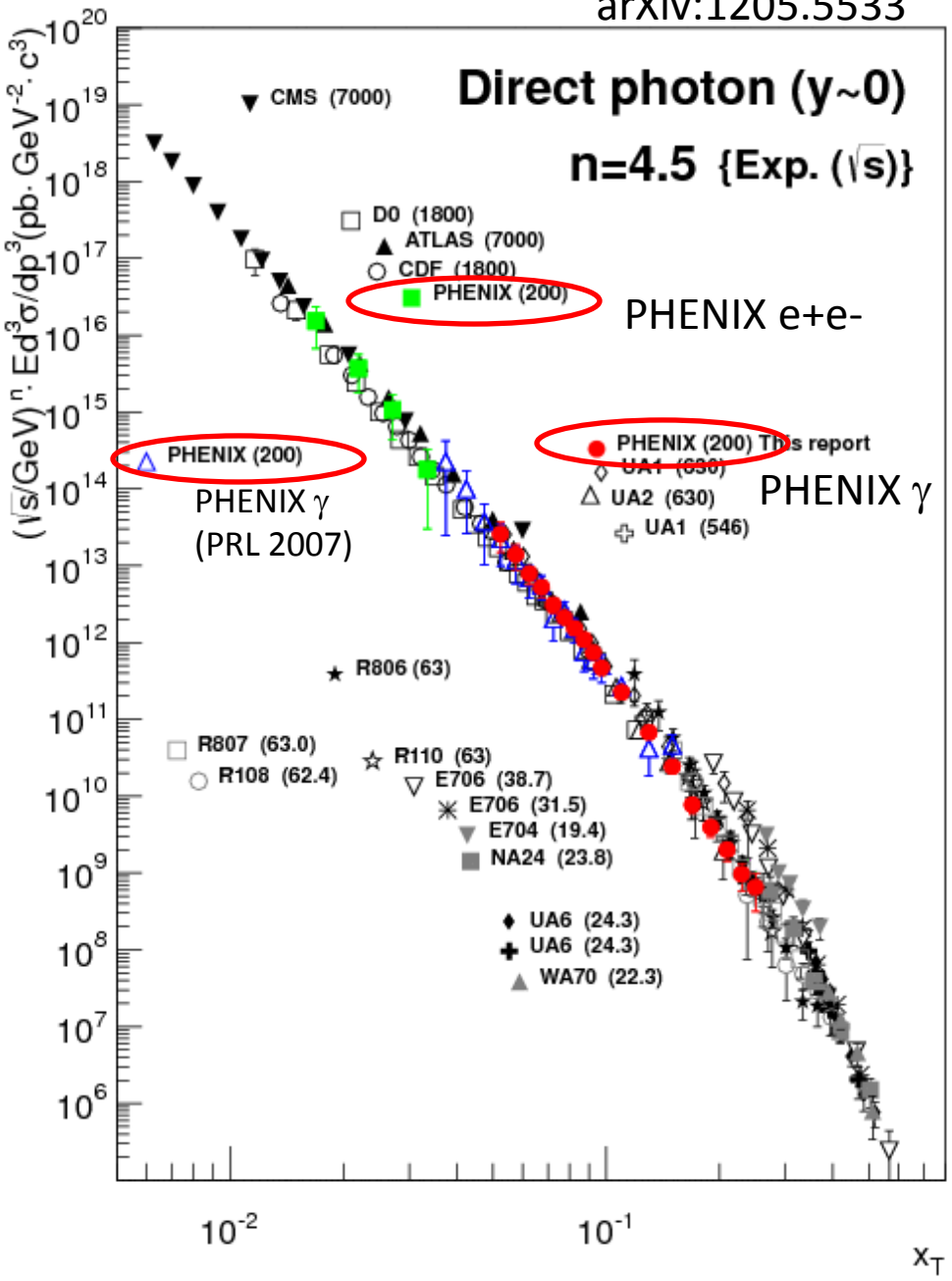
arXiv:1205.5533



Measured up to p_T=25 GeV/c.

The pQCD NLO calculation is in good agreement with data.

arXiv:1205.5533



PHENIX e+e-

PHENIX γ (PRL 2007)

PHENIX γ

x_T scaling

pp/p+pbar, inclusive/isolated

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

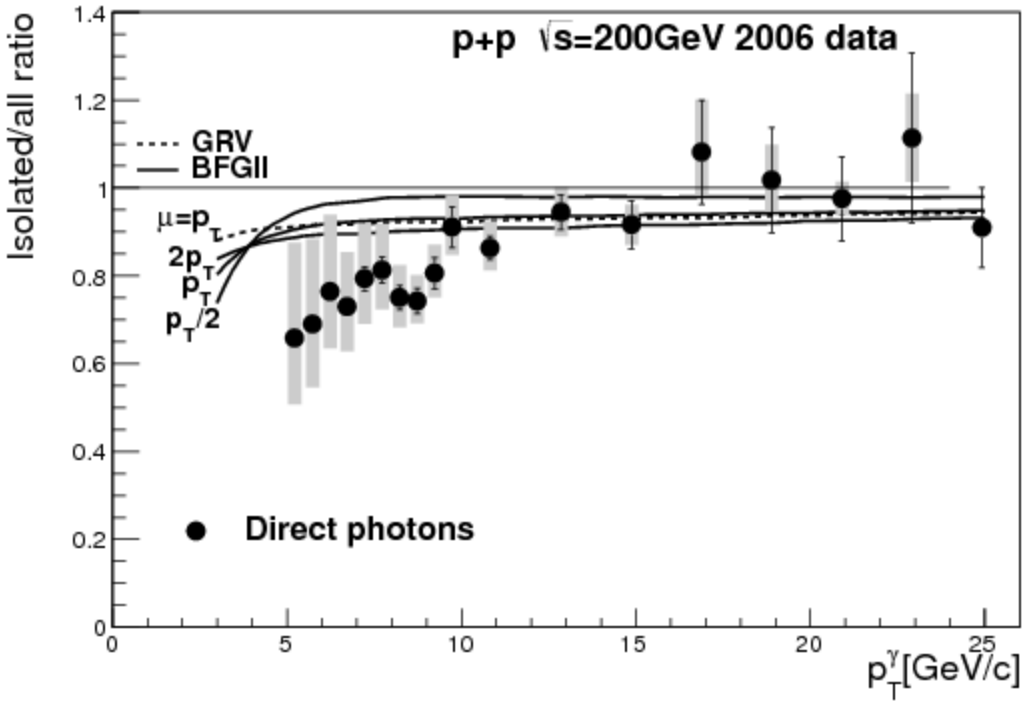
cross section scaled by $\sqrt{s}^{4.5}$

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

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

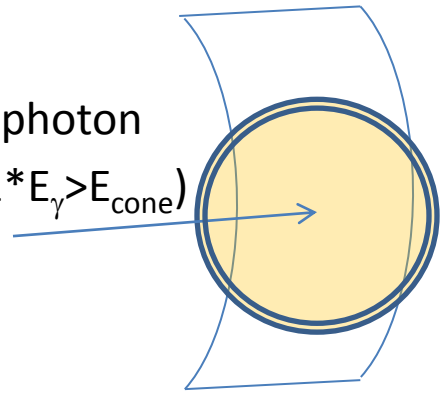
Study of the event shape

arXiv:1205.5533



Direct photon

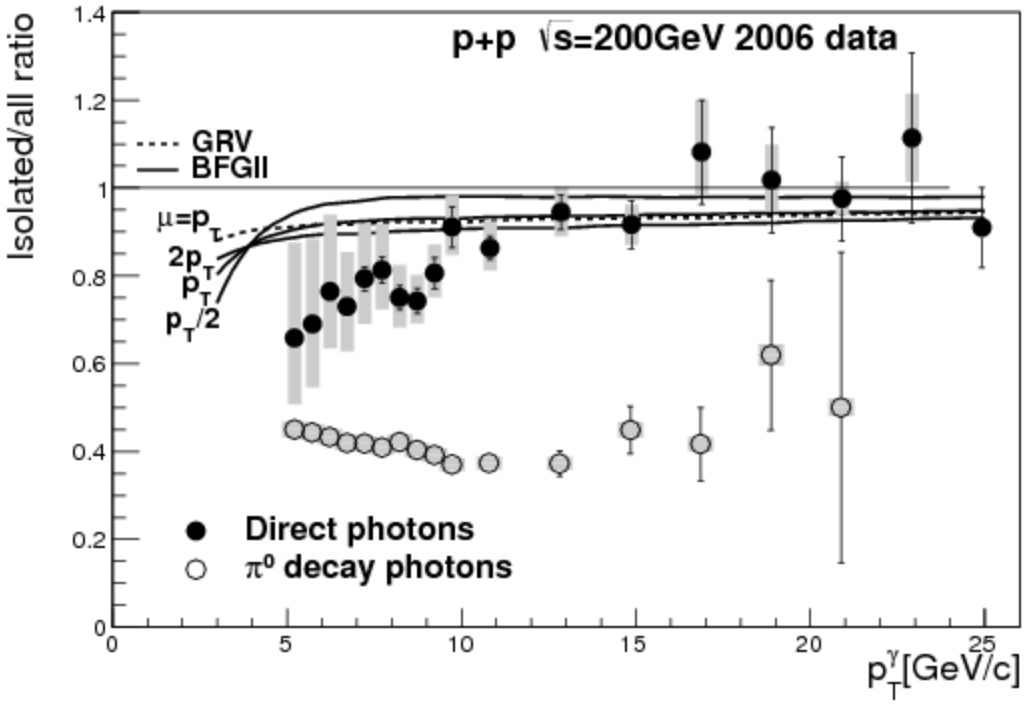
$(0.1*E_\gamma > E_{cone})$

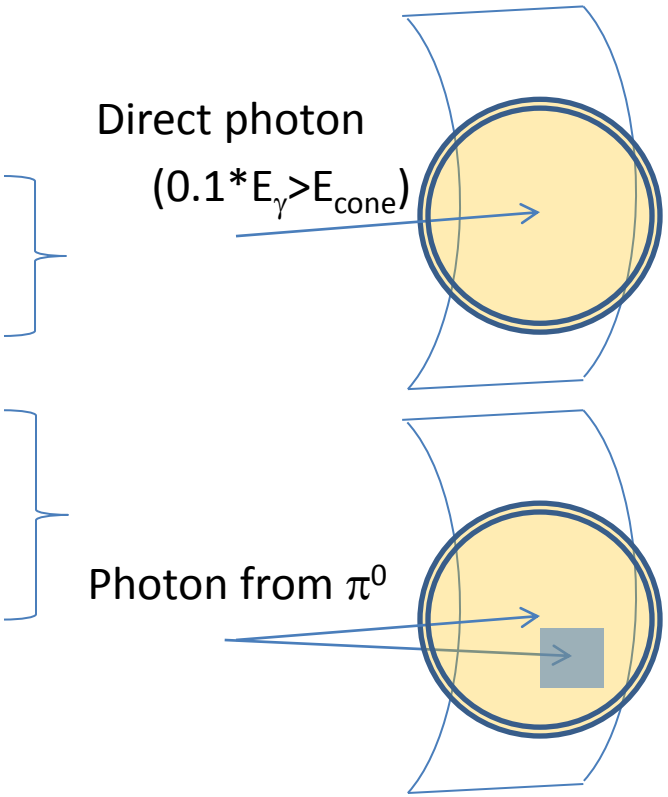


Checked the event shape with an isolation cut.
Generally the theory calculation agrees with data.
At high pT most direct photons are isolated.

Study of the event shape

arXiv:1205.5533



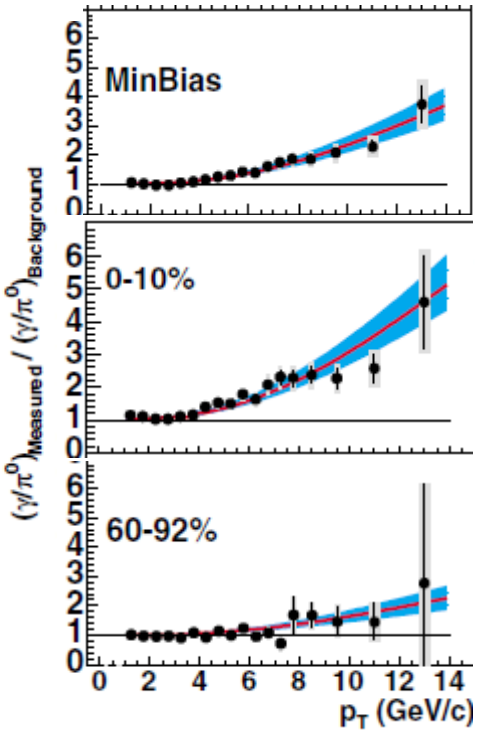


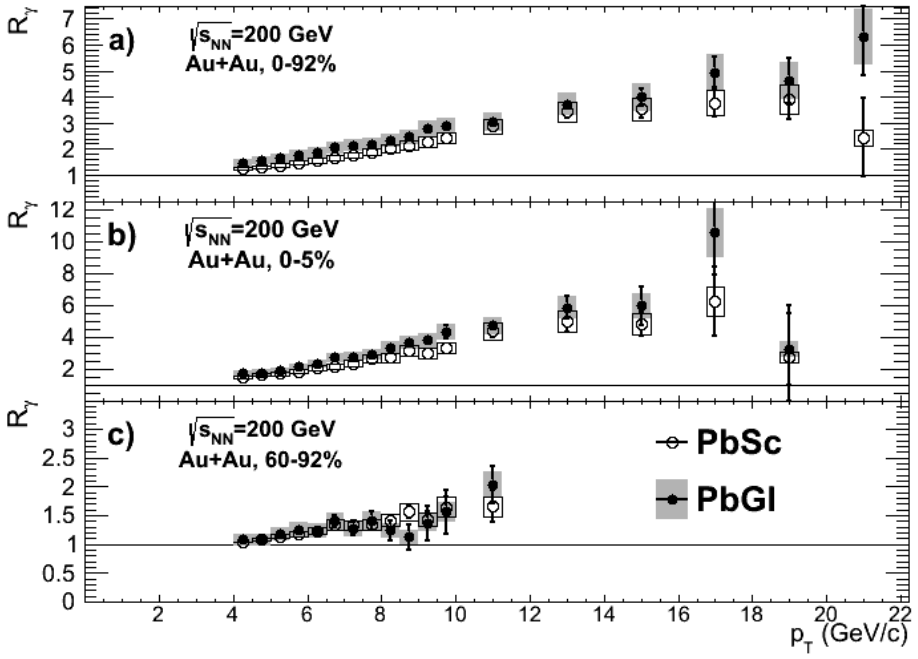
Checked the event shape with an isolation cut.
Generally the theory calculation agrees with data.
At high pT most direct photons are isolated.

Direct photon in AuAu 200GeV

high p_T

PRL94,232301 (2005) (Run2) → (Run4) arXiv:1205.5759



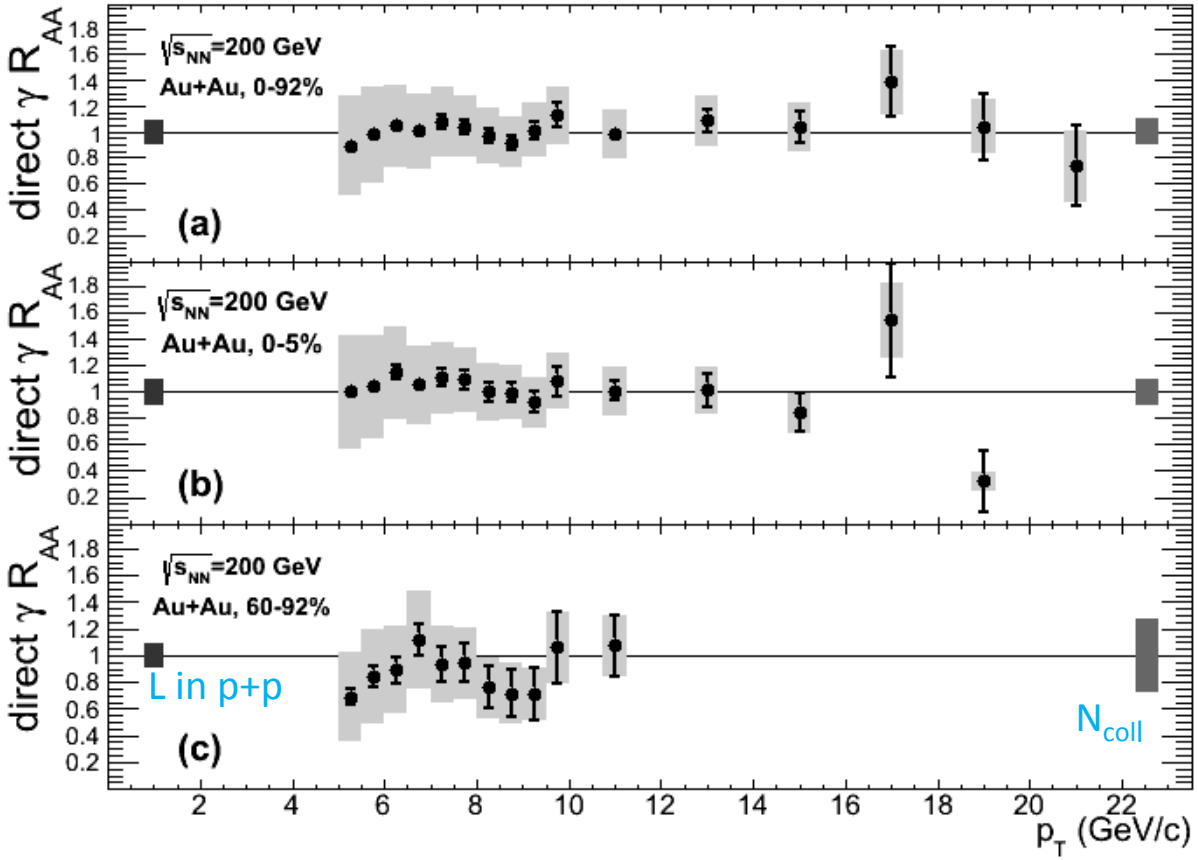


There is more than X10 statistical improvement.

→ It allows to study the R_{AA} as a function of pT.

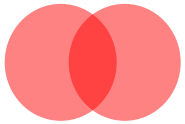
Direct photon R_{AA}

arXiv:1205.5759



Minimum bias

0-5%



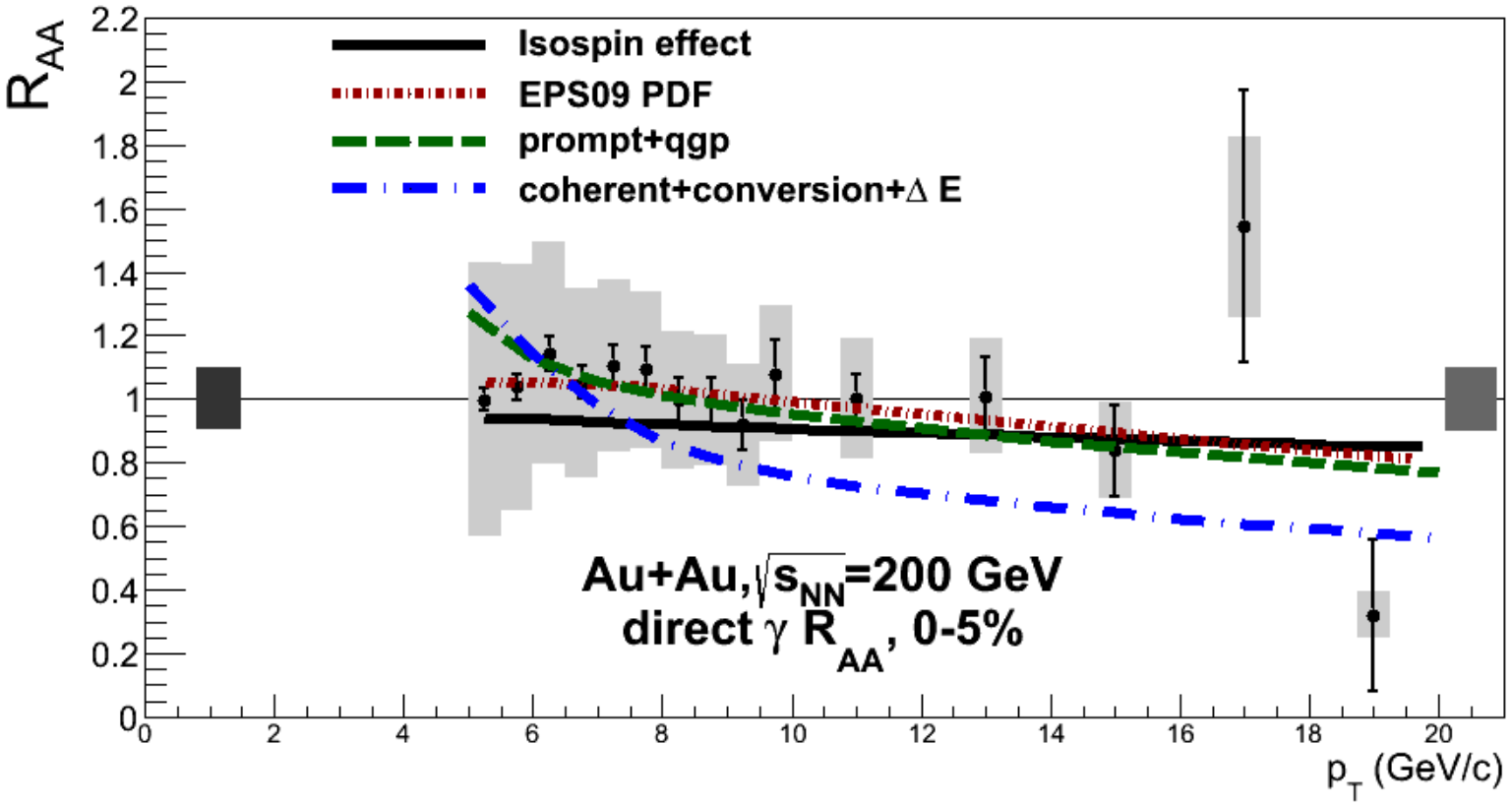
60-92%

R_{AA}~1 : Consistent with binary scaling of p+p.

However there are
Isospin difference, nPDF,
suppression of fragment photon, etc.

Comparisons with models

arXiv:1205.5759

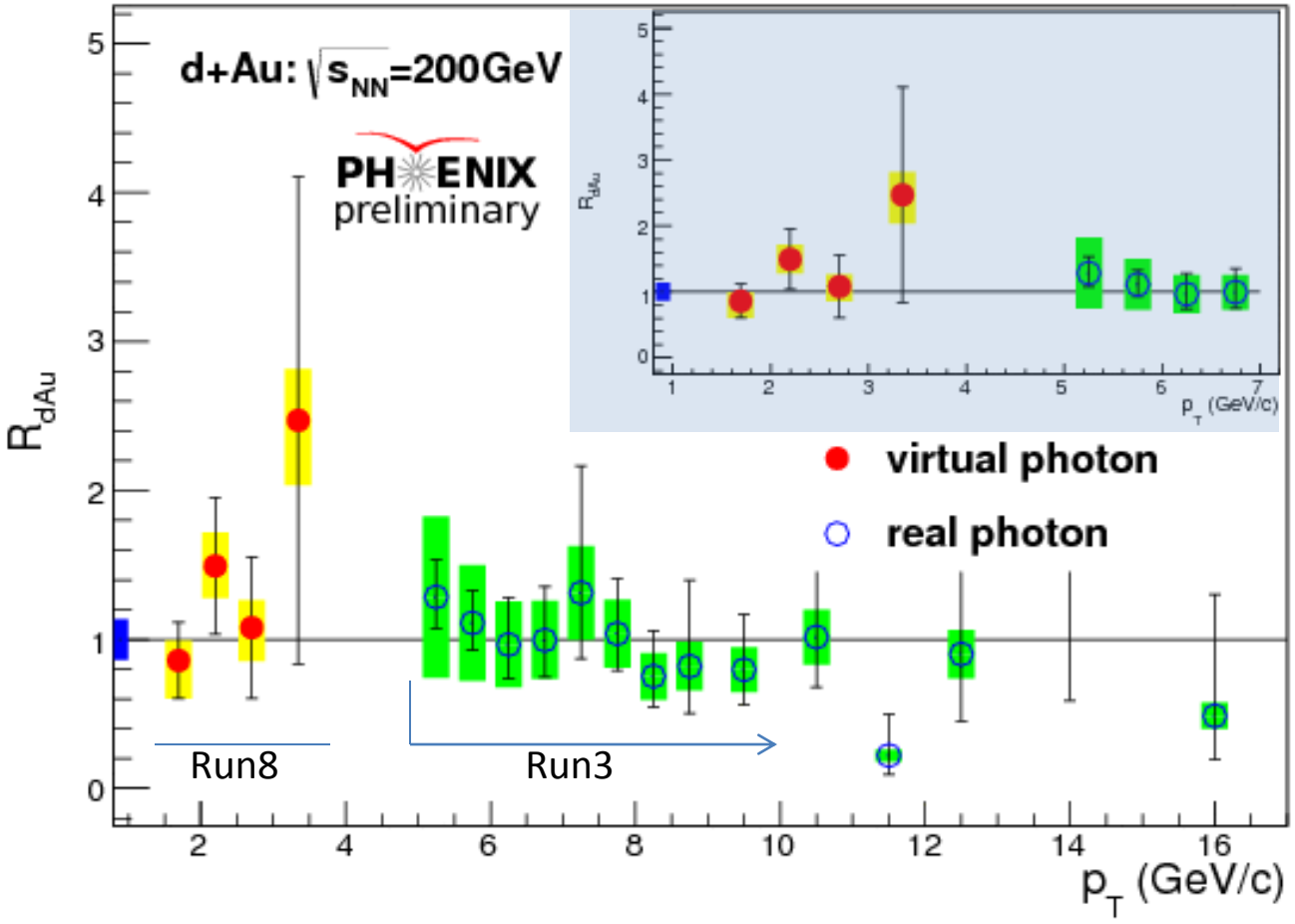


0-5%

- Initial state effects (IS) include isospin and nuclear PDF, consistent with data — JHEP1104, 055
- Final state effects (FS) include suppression of jet fragmentation photons and photons from jet-plasma interaction, consistent with data — PRC77, 024909 arXiv:0904.2184
- Another model with both IS and FS disagrees with data — PLB669, 337

Direct photon in d+Au

for CNM



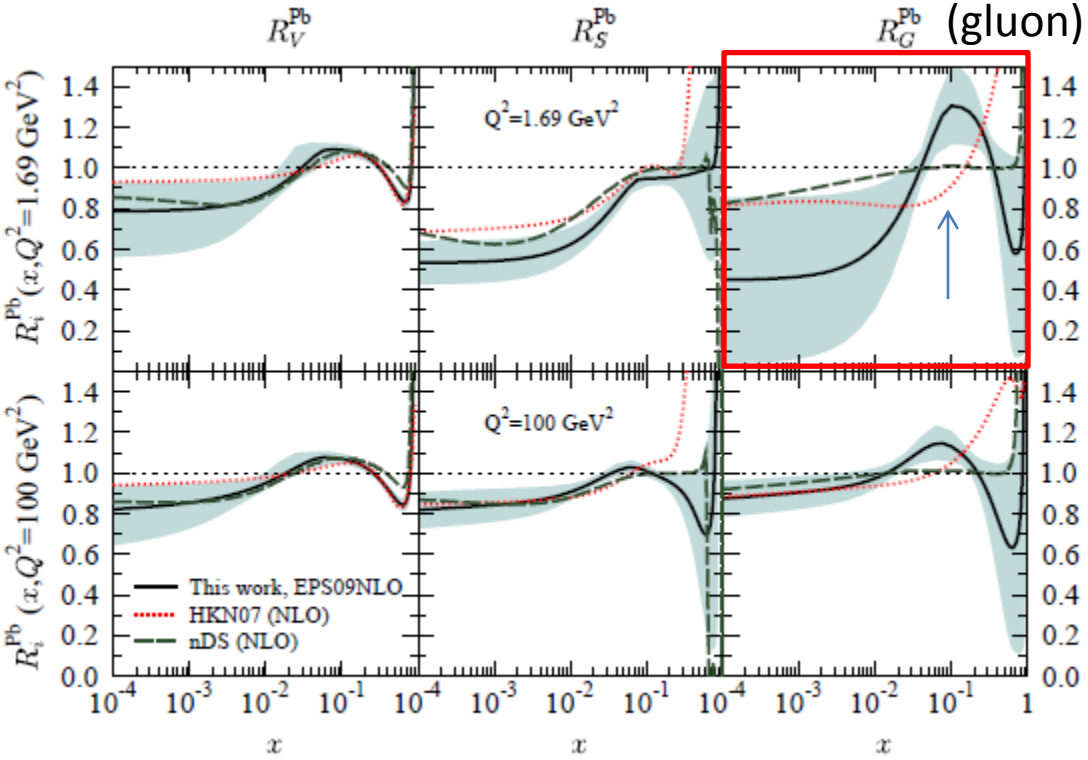
R_{d+Au} is consistent with 1.

It suggests little or no nuclear effect within our uncertainty.

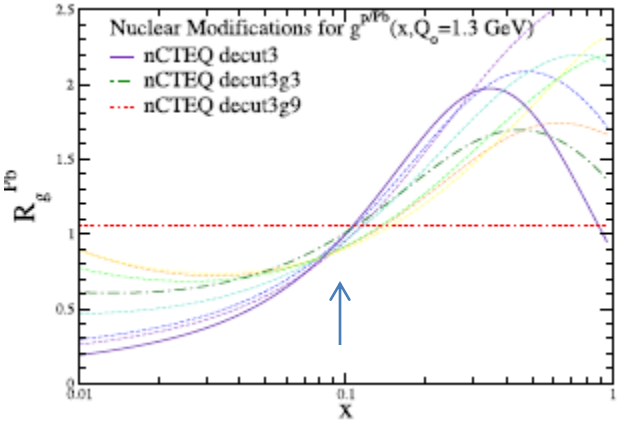
d+A Sensitive to gluon PDF

We have x30 statistics in Run8 compared to Run3.
It help constrain the gluon PDF further.

arXiv:0902.4154



arXiv:1012.1178



x=0.1

10GeV photon
in $\sqrt{s}$=200GeV

HardProbes
(Helenius,Eskola)

What if $f_i^A(x,Q,center) \neq f_i^A(x,Q,edge)$?

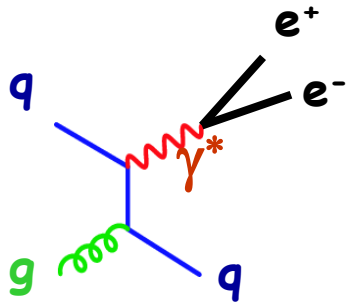
low pT

Photon = e^++e^-

They have the same quantum number.

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

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

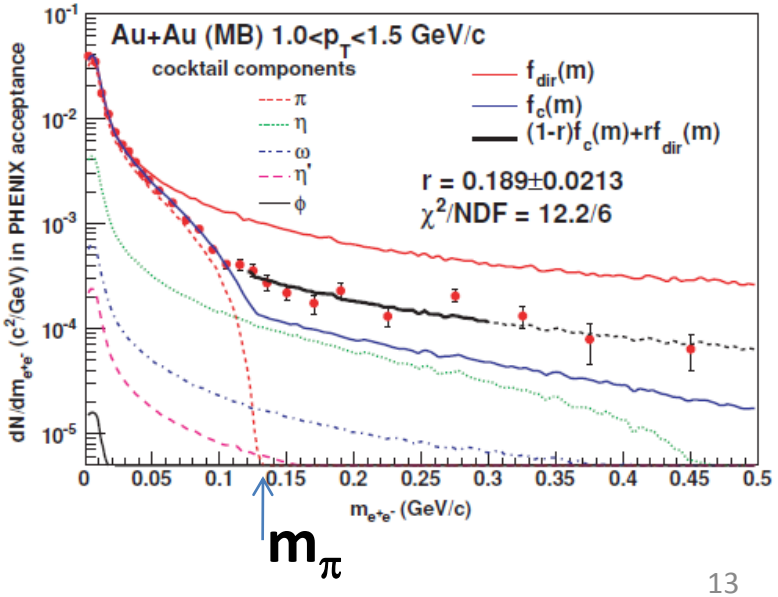


When $p_T^2 >> M_{ee}^2$ **, S=1 for photons.**

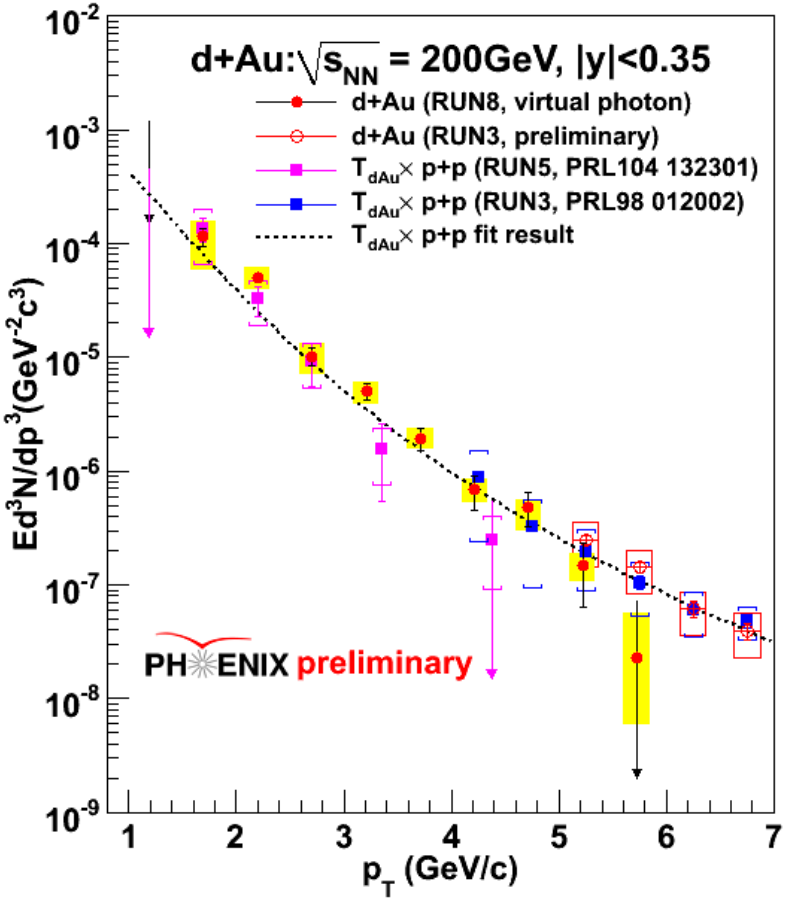
Independent of the origin in the very low mass region (M_{ee} < ~30MeV)
No π^0 Dalitz above the π^0 mass. → The key to improve the S/N ratio.
Direct photon follows 1/M_{ee}.

Procedure

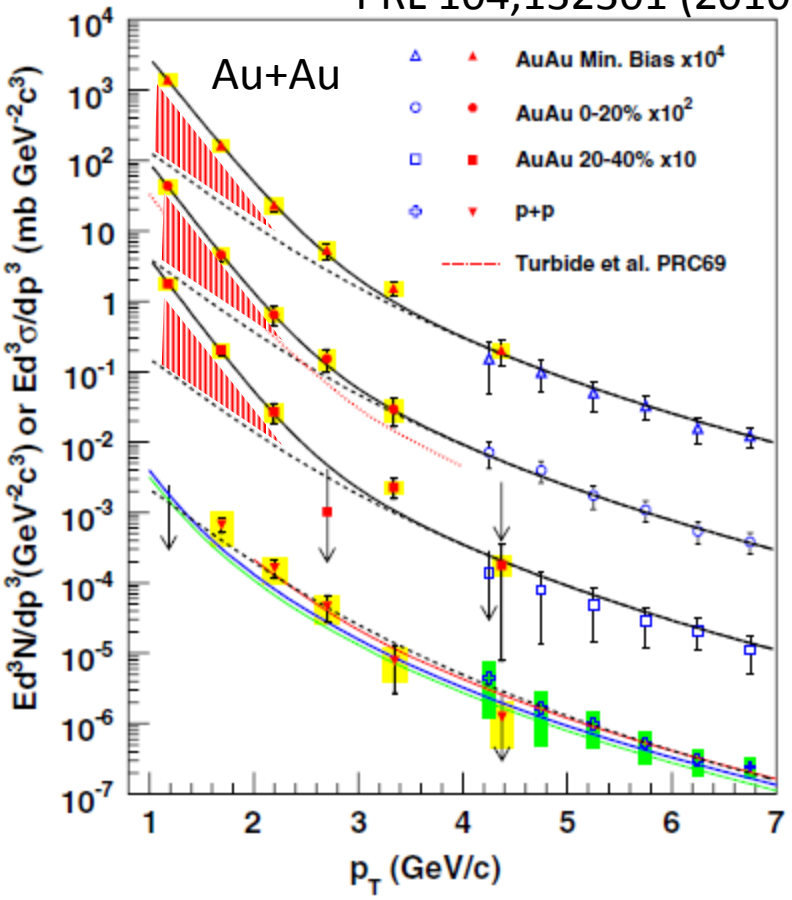
Combinatorial and correlated pair subtraction
Cocktail and direct photon shapes
Normalized in the very low mass region
Fit and Extract the direct photon component



Virtual photon spectra



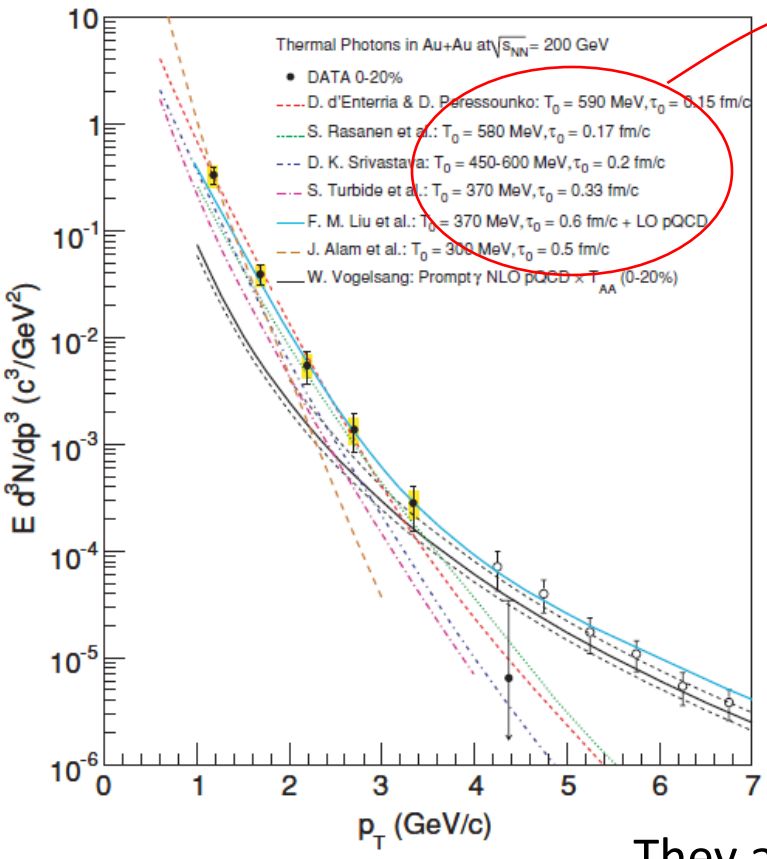
PRL 104,132301 (2010)



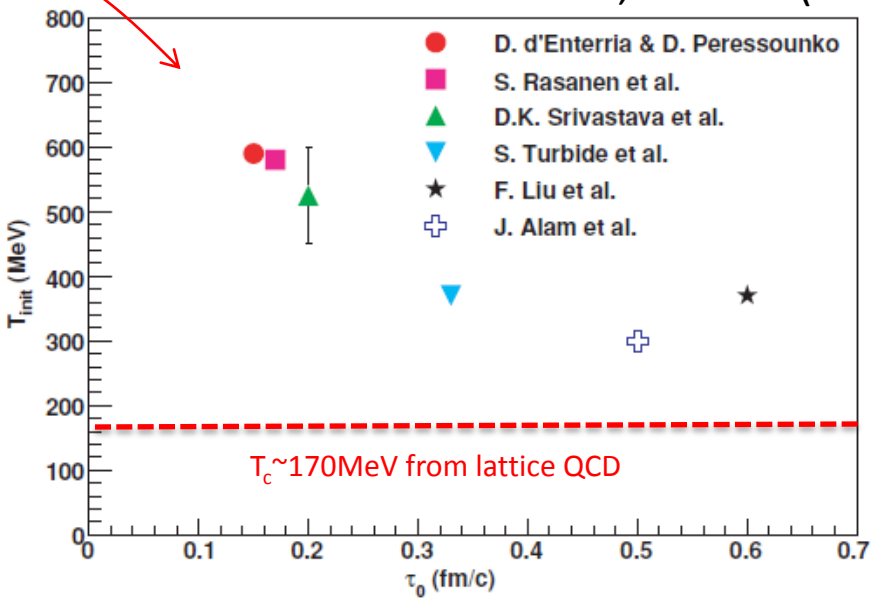
p+p: Already shown in the previous xT plot.
d+Au: Consistent with scaled p+p. Little or no nuclear effects.

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

Initial temperature & formation time



PRC 81, 034911 (2010)

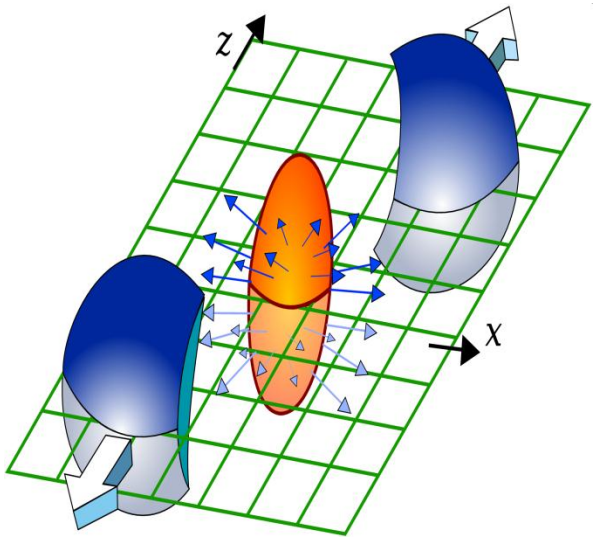


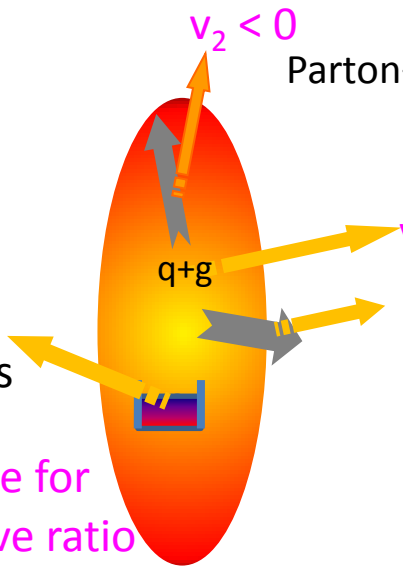
They are all above the critical temperature.
However T_{init} depends on τ_0 in the theory calculations.

→ Need additional experimental constraints

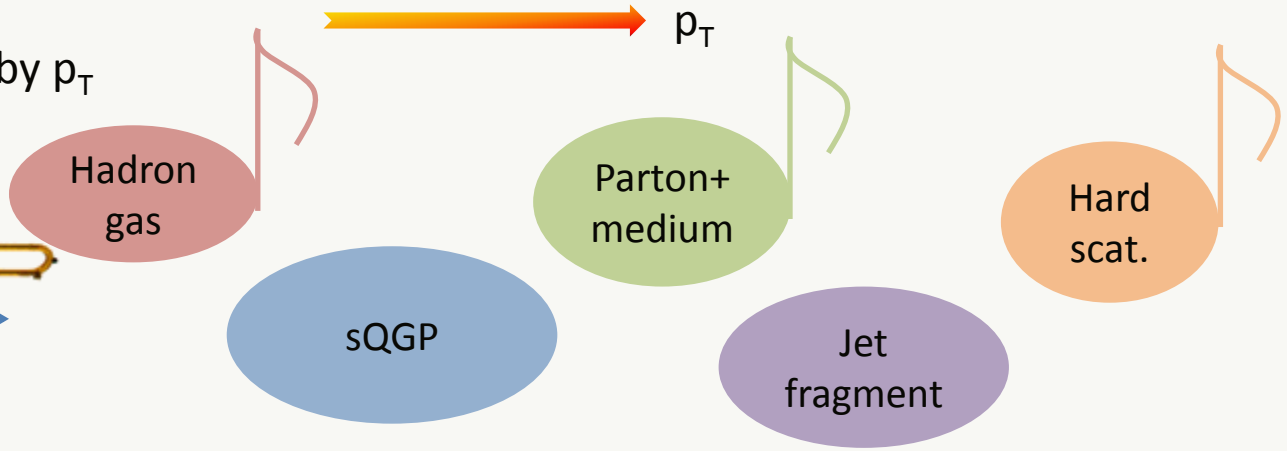
Direct photon v_2 (another knob)

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





The ingredients are tuned by p_T



Direct photon v_2

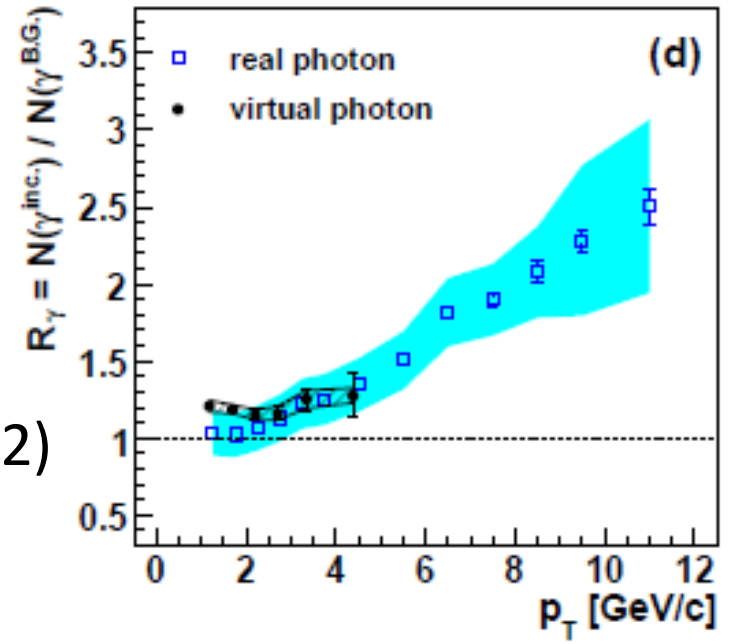
From real photon in the EMCal with virtual photon measurement

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

v_2^{inc} Inclusive photon v2

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

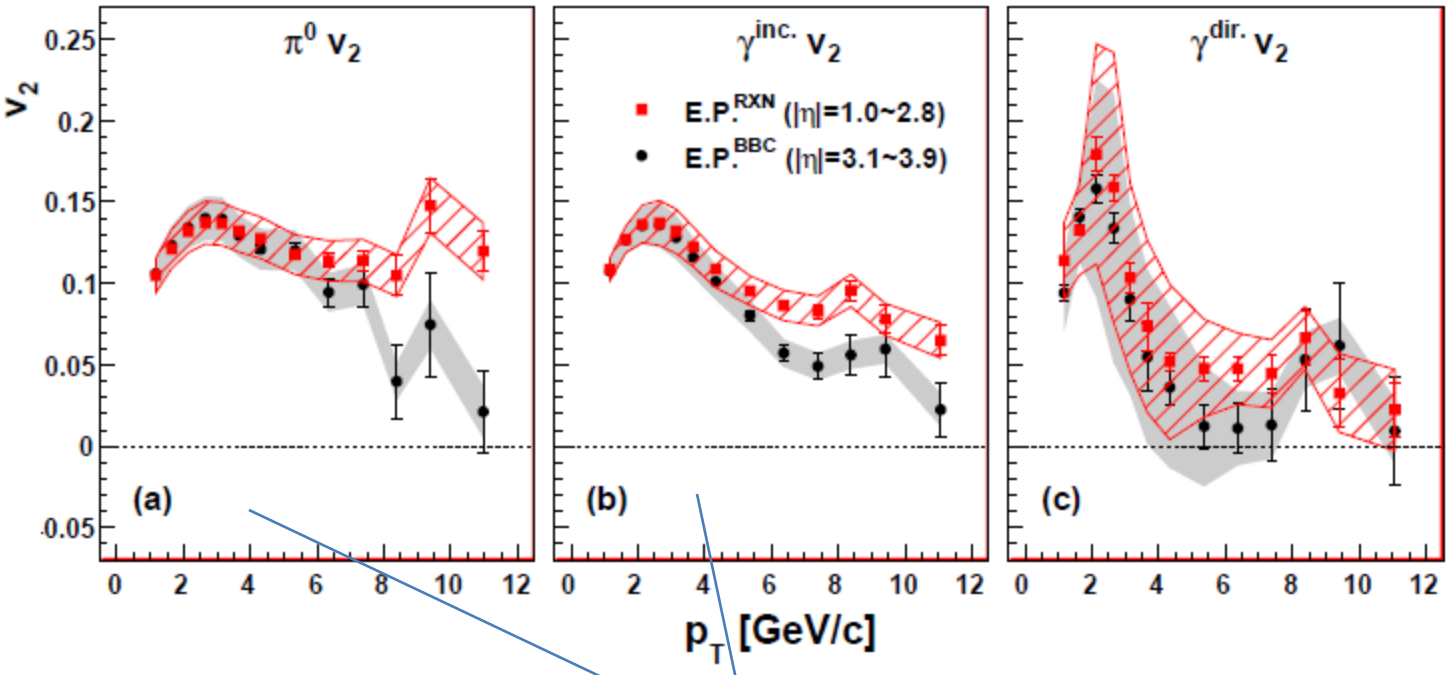
$R_\gamma = \frac{S+B}{B}$ From virtual photon measurement



Step 1,2,3

PHENIX arXiv:1105.4126

Min bias events

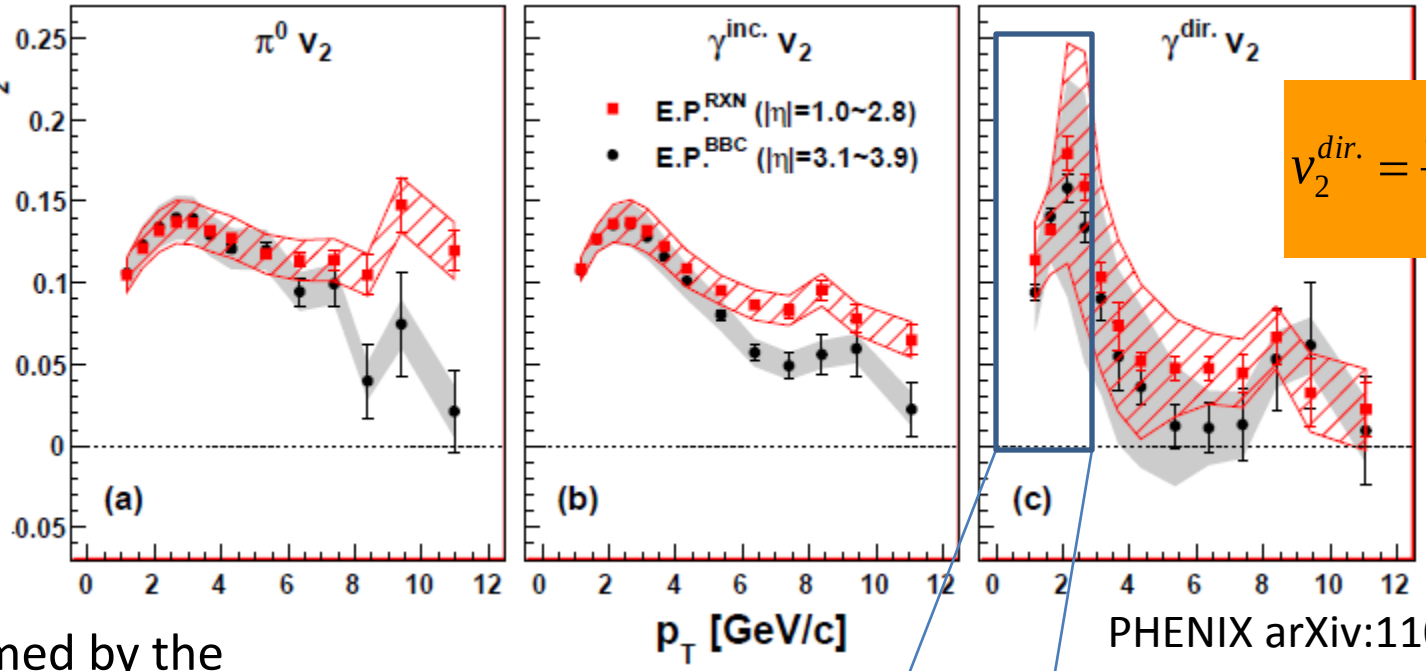


Decay, other hadrons

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

Step 1,2,3 and confirmation

Min bias events

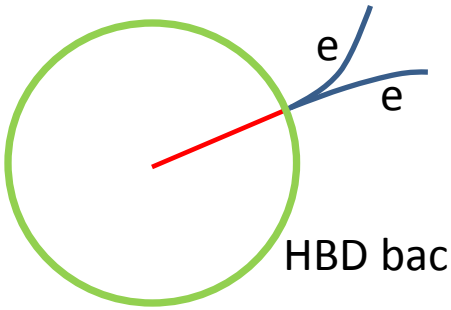


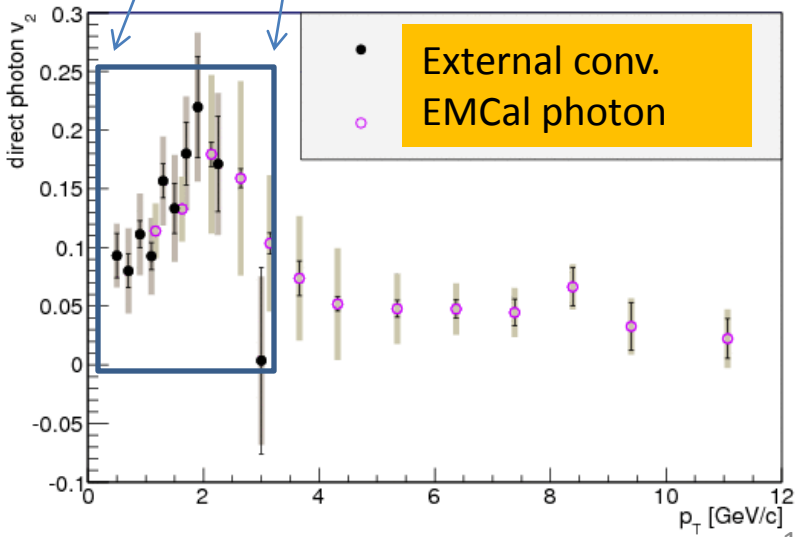
$$v_2^{dir.} = \frac{R_\gamma v_2^{inc.} - v_2^{BG}}{R_\gamma - 1}$$

PHENIX arXiv:1105.4126

Confirmed by the external conversion method

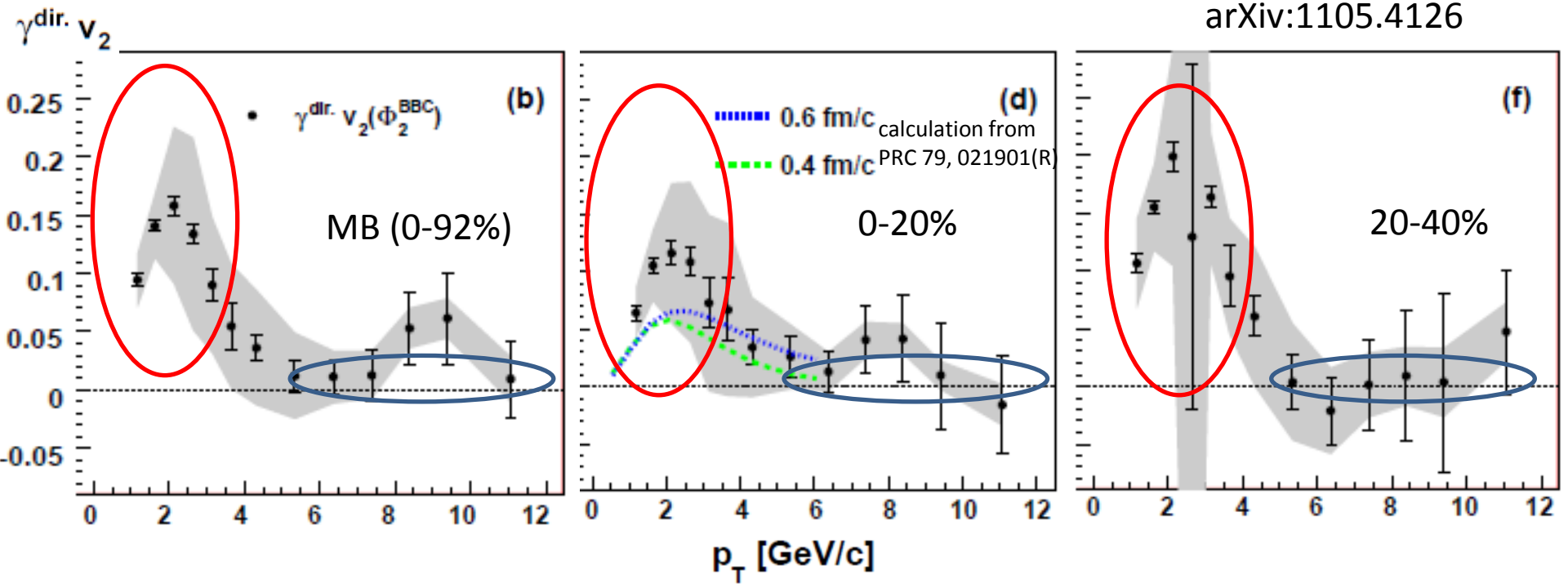
(No charged hadrons, no secondary interactions)





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

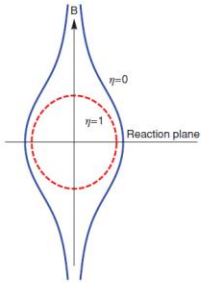
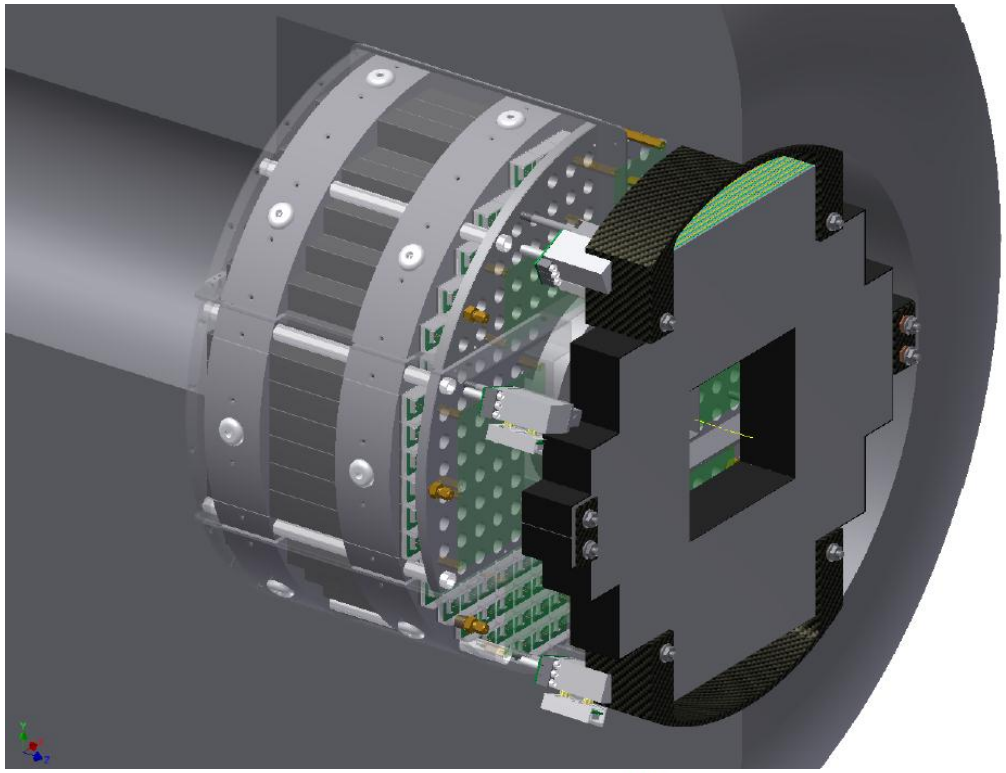


FIG. 2. (Color online) Azimuthal distribution of the decay rate of photons at different rapidities at LHC. Only the contribution of the $\gamma \rightarrow e^+e^-$ channel is shown.

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

PHENIX upgrade for photons

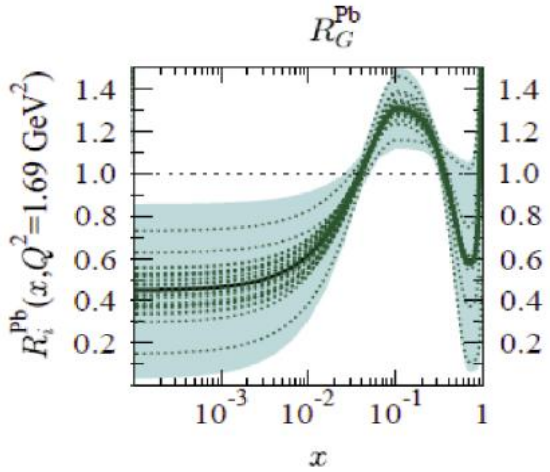


MPCEX $3.1<\eta<3.8$

To be ready for Run-14

A combined charged particle tracker and EM preshower detector – dual gain readout allows sensitivity to MIPS and full energy EM showers.

- Charged track identification
- π^0 reconstruction out to >80GeV



Measure
the Gluon Distribution in CNM at Low-x

Direct photons
($h^{\pm}$, π^0 suppression + isolation cut)

Future sPHENIX project

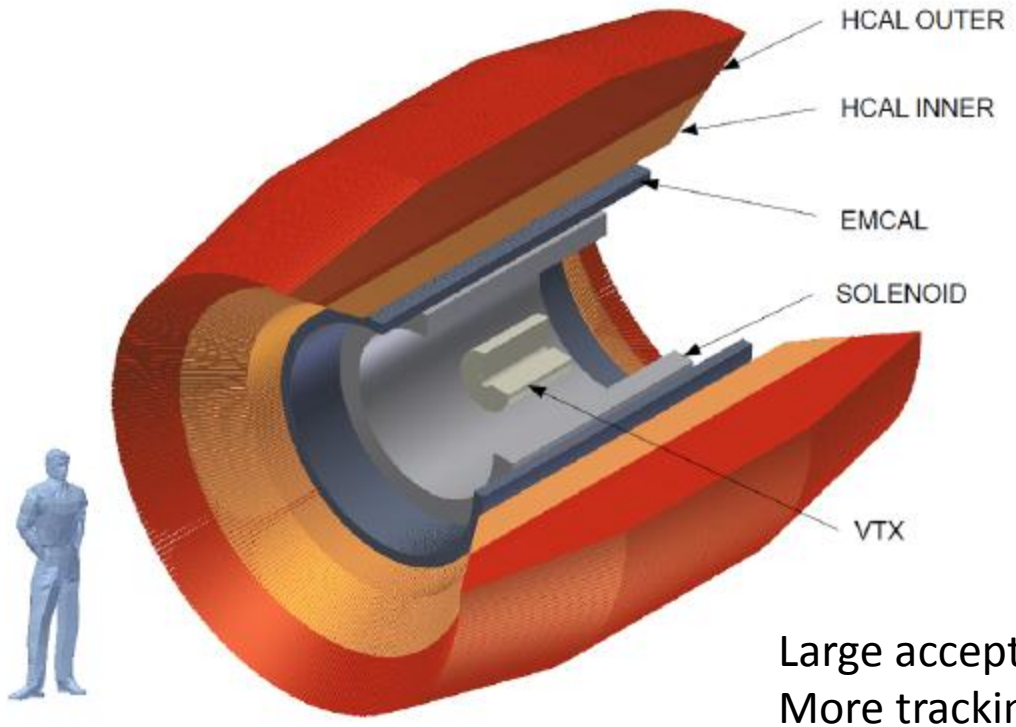


Figure 2.1: Cutway view of the detector.

A plan to upgrade the detector.

Large acceptance with high γ/π^0 separation.
More tracking layers, hope eID is still powerful.
Hadron calorimeter for γ+Jet analysis.

$\rightarrow$RHIC Upgrade Workshop (June 13, morning)

Summary

- *p+p* reference measurements are on the universal curve of world's measurements.
- No nuclear modification (R_{AA}~1) is seen in high p_T photon.
- An unexpectedly large ν_2 was measured in the low p_T region. No theoretical explanation exists so far.
- PHENIX upgrade plan is on the table.