PHENIX measurements of low momentum direct photons from large ion collisions as a function of beam energy and system size

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February 7th, 2017

Direct Photon Sources in Heavy Ion Collisions

Direct photons are a unique probe

- Color blind
- Probe the full time evolution

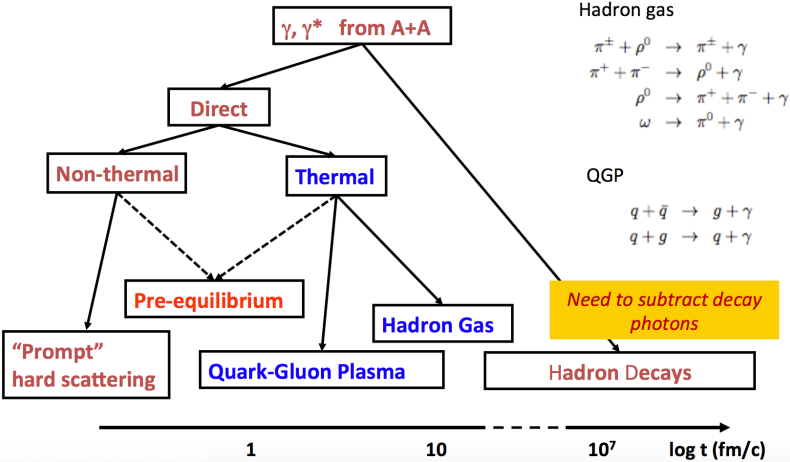
Production of photons:

Hadron gas

$$\pi^{\pm} + \rho^0 \rightarrow \pi^{\pm} + \gamma$$
$$\pi^{+} + \pi^{-} \rightarrow \rho^0 + \gamma$$
$$\rho^0 \rightarrow \pi^{+} + \pi^{-} + \gamma$$
$$\omega \rightarrow \pi^0 + \gamma$$

QGP

$$q + \bar{q} \rightarrow g + \gamma$$
$$q + g \rightarrow q + \gamma$$



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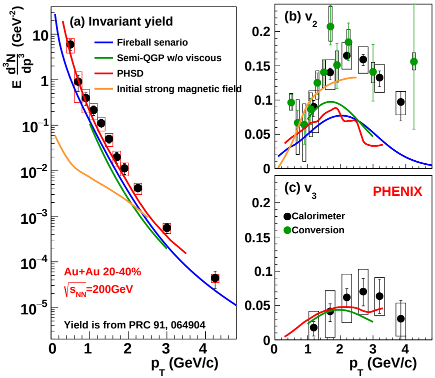
Direct Photon Puzzle

large yield and large v_2 in Au+Au



- Large yield $\rightarrow$ early emission
- Large v_2 $\rightarrow$ late emission

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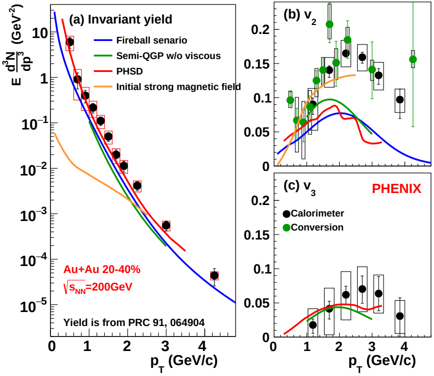

- Large yield → early emission
- Large v_2 → late emission

Challenging to describe large yield and large anisotropy simultaneously

Experimentalist can provide

- measurement of different observables:
  - Yields
  - v_2, v_3, ...
- Collision energy dependence: 200 GeV, 62 GeV, 39 GeV
- Large systems (hot medium): Au+Au, Cu+Cu, Cu+Au
- Small systems (cold ??): p+p, p+Au, d+ Au, ^{3}He+Au

New results shown in this talk

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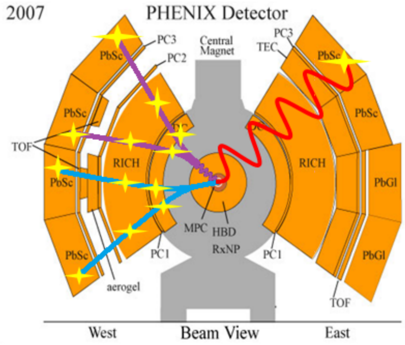
Photon Measurement Techniques in PHENIX

Three independent methods at PHENIX

- Measuring energy deposited by photons in Calorimeter
  - Good resolution at high p_T
  - Low pt contaminated by hadrons
- Internal photon conversions
  - Measure virtual photons
  - Reduction in background from π^0 Dalitz decays by a factor of 5
  - Low p_T reach is limited ($\sim$ 1 GeV) as well as high p_T
- External photon conversions
  - Measure real photons
  - Extends to $p_T << 1$ GeV, little hadron contamination
  - High p_T reach is limited



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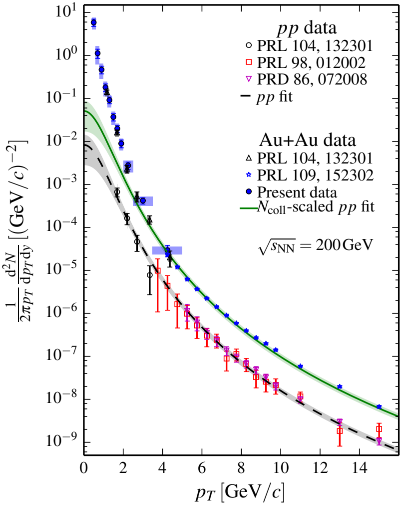
PRC91 064904 (2015)



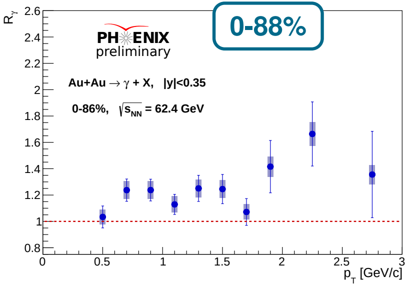
3 independent measurements in good agreement with each other

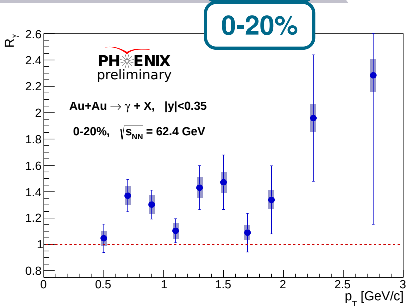
Direct Photon in Au+Au at $\sqrt{s_{NN}}$ = 62.4 GeV

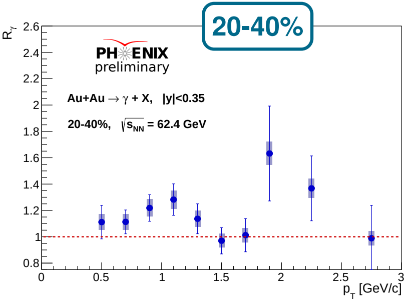
NEW

External Conversion Technique

- Conversions reconstructed at detector material (HBD back plane)
- $R_\gamma = N_\gamma^{incl} / N_\gamma^{hadron}$







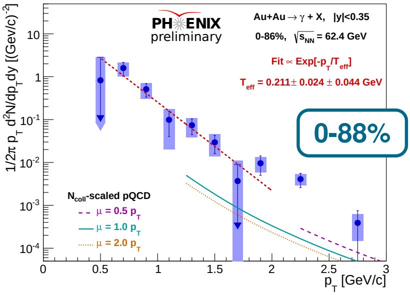
Clear direct photon signal in Au+Au at 62.4 GeV

Direct Photon in Au+Au at $\sqrt{s_{NN}} = 62.4$ GeV

NEW

Direct photon yield:

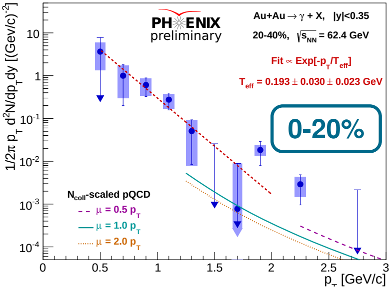
$$\gamma^{direct} = (R_\gamma - 1) \times \gamma^{hadron}$$

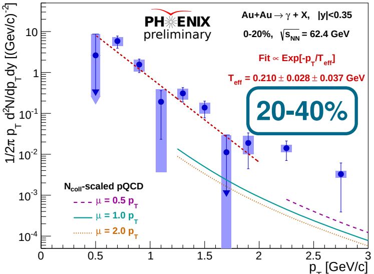


Minimum bias unsubtracted γ_{prompt}

$T_{eff} = 0.211 \pm 0.024 \pm 0.044$ GeV

pQCD calculations by W. Vogelsang





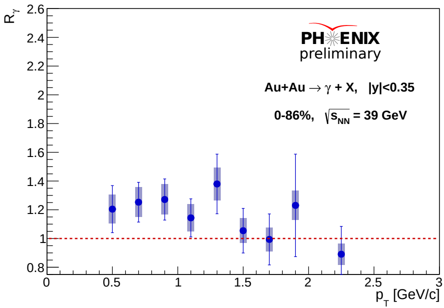
Direct Photon in Au+Au at $\sqrt{s_{NN}}$ = 39 GeV

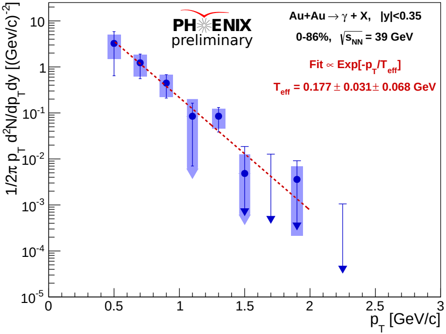
NEW

R_γ

0-86%(MB)

Yield





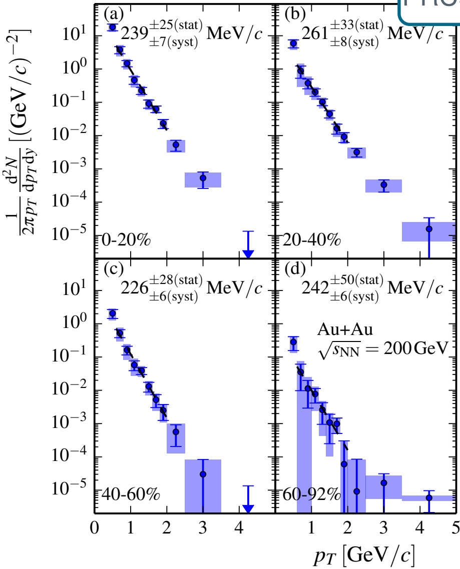
- Direct photon signal also seen in Au+Au at $\sqrt{s_{NN}}$ = 39 GeV
- Minimum bias

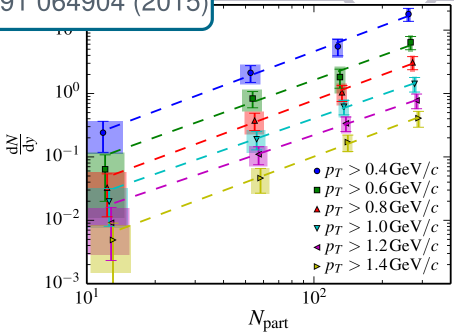
  unsubtracted γ_{prompt} $T_{eff} = 0.177 \pm 0.031 \pm 0.068$ GeV

See poster by V. Khachatryan (EM Probes: Board L18)

Centrality Dependence of Thermal Photon Yield in Au+Au at $\sqrt{s_{NN}}$ =200 GeV

PRC91 064904 (2015)





- Yield $\propto N_{part}^{\alpha}$; where $\alpha = 1.38 \pm 0.03(stat) \pm 0.07(sys)$
- Yield grows faster than N_{part}
- $T_{eff} = 0.244 \pm 0.028 \pm 0.007$ GeV

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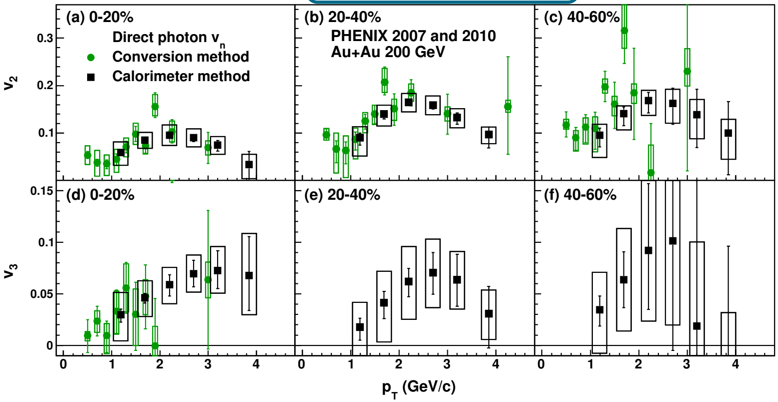
Direct Photon v_n in Au+Au at $\sqrt{s_{NN}} = 200$ GeV

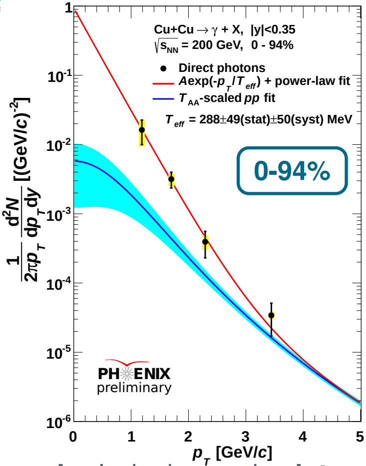
PRC94 064901 (2016)

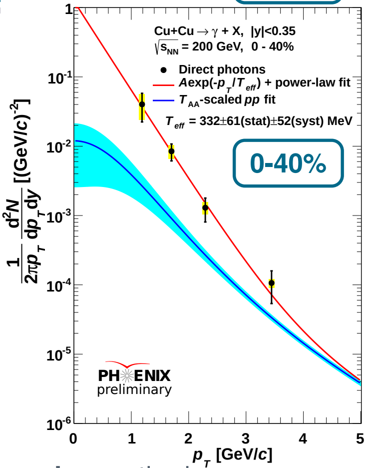


- Sizeable v_2 and $v_3(\sim v_2/2)$observed at low p_T, comparable to hadron v_2
- Strong centrality dependence for v_2, not so clear for v_3
- Unclear if $v_2 \rightarrow 0$ for $p_T \rightarrow 0$

Direct Photon in Cu+Cu at $\sqrt{s_{NN}}$ =200 GeV

NEW





- Analysis done using **internal conversion** method
- Clear direct photon signal in Cu+Cu at $\sqrt{s_{NN}}$ = 200 GeV
- T_{eff} consistent within the large uncertainty with Au+Au

See poster by T. Hoshino (EM Probes: Board J08)

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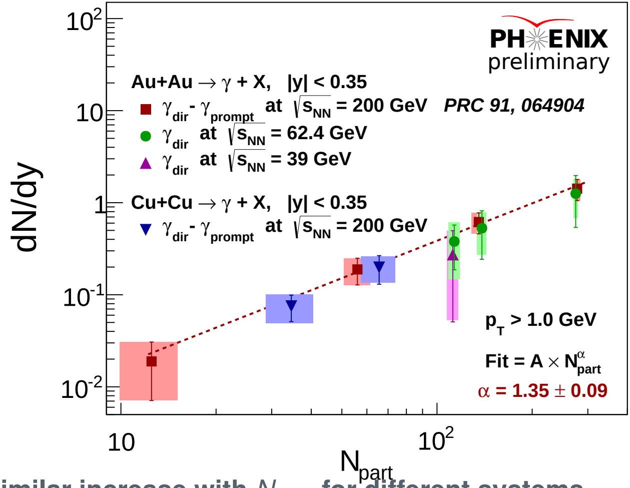
Direct Photon Yield vs N_{part}

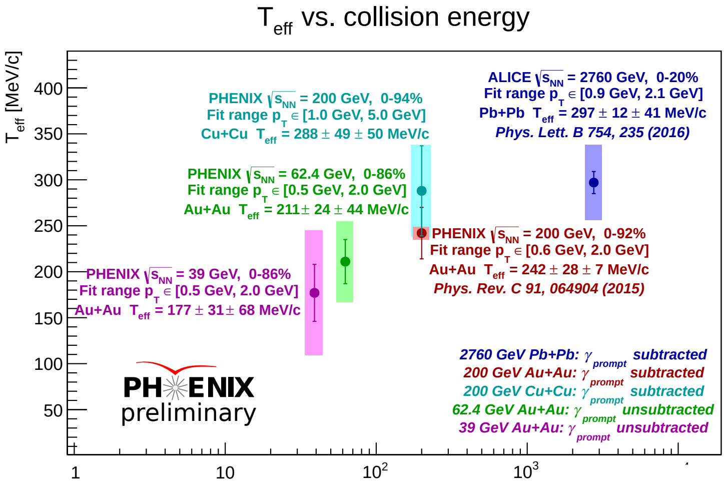
NEW



- **Similar increase with N_{part} for different systems**
- **Yield increases faster than N_{part}**

T_{eff} versus $\sqrt{s_{NN}}$

NEW



Hint of increase of T_{eff} with $\sqrt{s_{NN}}$, but also consistent with a constant fit

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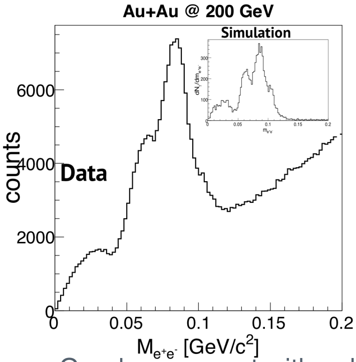
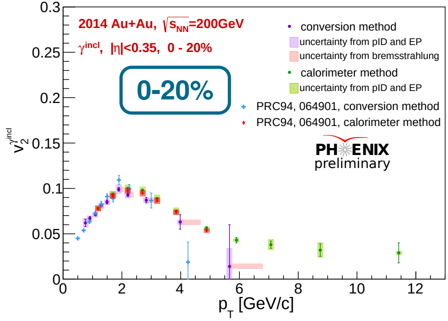
Inclusive Photon v_2 from new 2014 Au+Au Data

NEW





- Good agreement with published v_2 results
- 22% of total 2014 data
- Horizontal errors are uncertainty in the p_T reconstruction of e^+e^- resulting from bremsstrahlung due to increased material budget
- Will provide high p_T coverage for both EMCal and Conversion photon methods

See poster by W.Fan (EM probes: Board F03)

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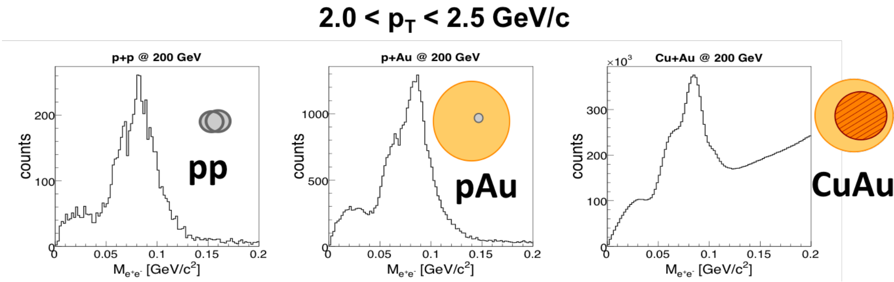
Future Measurements: Different Systems



Clear signal visible in all systems
These different systems will provide interesting information

- Direct photon spectrum shape at low p_T in p+p
- Are there thermal photons in p+Au, d+ Au, ^{3}He+Au systems?
- Cu+Au collisons to shed light on magnetic field effects if any

Summary and Outlook

Summary

- Well established measurements of low p_T direct photons in Au+Au at 200 GeV
  - Large yield above expected contribution from pQCD
  - Centrality dependence of yield $\sim N_{part}^{1.4}$
  - Large v_2 with respect to reaction plane
- Direct photon spectra measured in Cu+Cu collisions at $\sqrt{s_{NN}}$ =200 GeV and Au+Au collisions at 62.4 and 39 GeV
  - Consistent with the observed $\sim N_{part}^{1.4}$ dependence
  - Slight increase of T_{eff} with collision energy

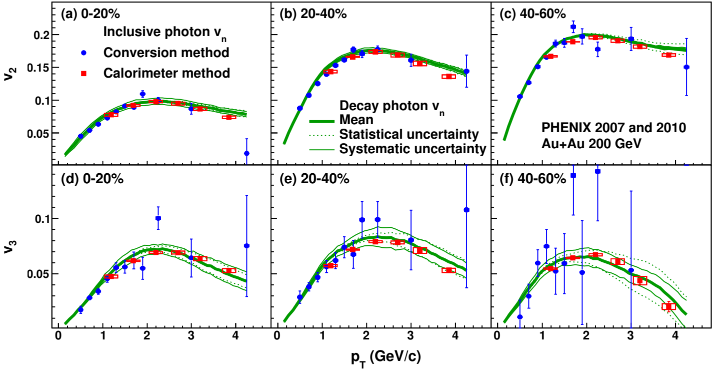
Outlook

- Significantly improved v_n results expected from 2014 Au+Au data
- Data from different collision geometry Cu+Au (2012)
- Low momentum data from p+p (2015)
- Search for direct photons in small systems: ^{3}He+Au (2014), p+Au (2015), d+ Au (2016)

Back-Ups

Inclusive and Decay Photon v_n in Au+Au at $\sqrt{s_{NN}}$ = 200 GeV

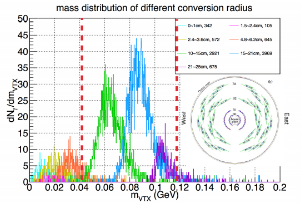
- Measure azimuthal distribution of photons relative to the reaction plane
- Results using two photon identification techniques EMCal and External conversions
- Model decay photon v_n based on the measured π^0 v_n
  - Other hadrons (η, $\eta^{/}$, ω) v_n estimated from KE_T scaling



New Conversion Photon Reconstruction Technique (2014 Au+Au data)

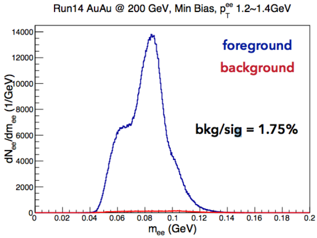
Identify and reconstruct photons via external conversion to e^+e^- pairs

- Previous method used single e^+/e^- tracks (2010)
  - Conversions at fixed radius (Hadron Blind Detector readout plane at 60cm, ~3%)
- New method used e^+e^- pairs (>2011)
  - Conversions at any material (VTX 3rd and 4th layer, ~10%)

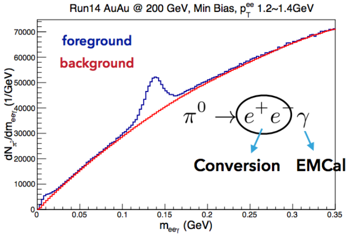


MC simulation

inclusive photon (e^+e^-) mass



π^0 ($e^+e^-\gamma$) mass



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