Systematic Study of High-p_T Direct Photon Production with the PHENIX Experiment at RHIC

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for the PHENIX Collaboration

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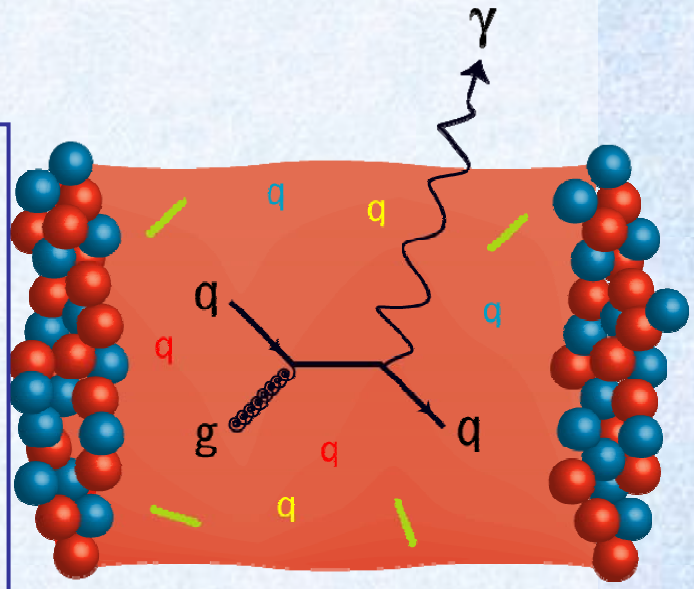
Ultra-Relativistic Nucleus-Nucleus Collisions
at Shanghai, China

Motivation for direct photon measurement

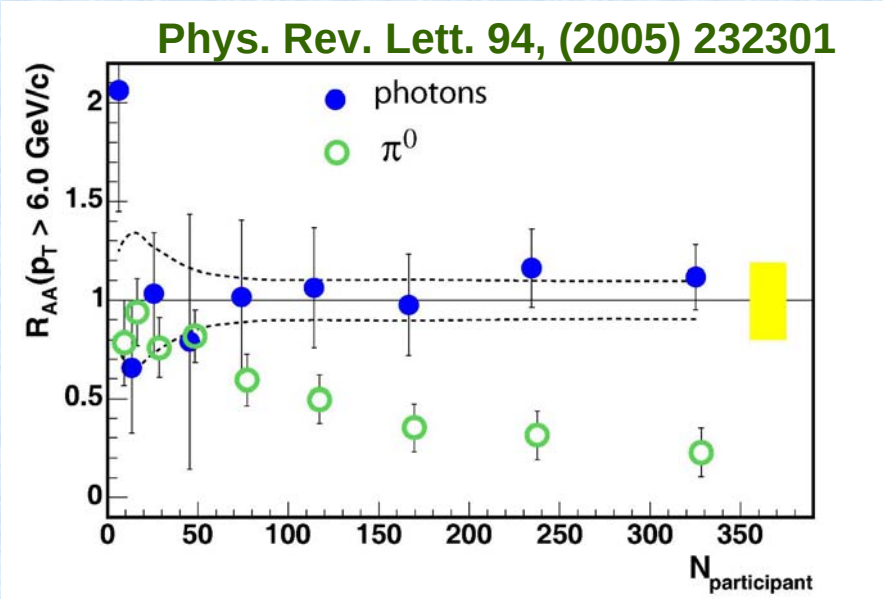
- **For study of the hot and dense matter created in relativistic heavy ion collisions.**
- Direct photon: not from hadron decay.
- Penetrating probe for the bulk matter produced by Au+Au collision.
  - Don't interact strongly, long mean free path.
- Can be described with elementary processes.
  - Compton, Annihilation, Bremsstrahlung.

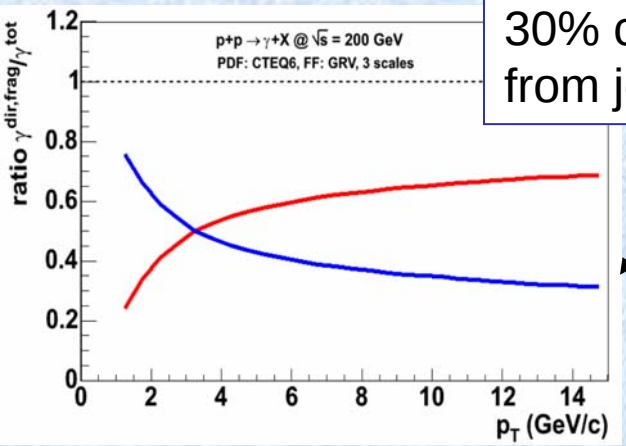
- High-p_T direct photon
  - Hard scattering
- Low-p_T direct photon
  - Thermal emission from QGP.
  - Talk by D. Peressounko (2.3 5:20pm)
- Azimuthal anisotropy of direct photon
  - Talk by V.S. Panteuev (2.2 3:20pm)



High-p_T direct photons: where are we?

- p+p: agreement with NLO pQCD.
- Run2 high-p_T direct photons in Au+Au: consistent with binary scaled NLO pQCD.
- Binary scaling is not obvious.
  - 70% prompt photon + 30% jet fragmentation at high-p_T.
  - Fragmentation photons are suppressed by jet-quenching effect at RHIC?
  - Compensated by other contribution?



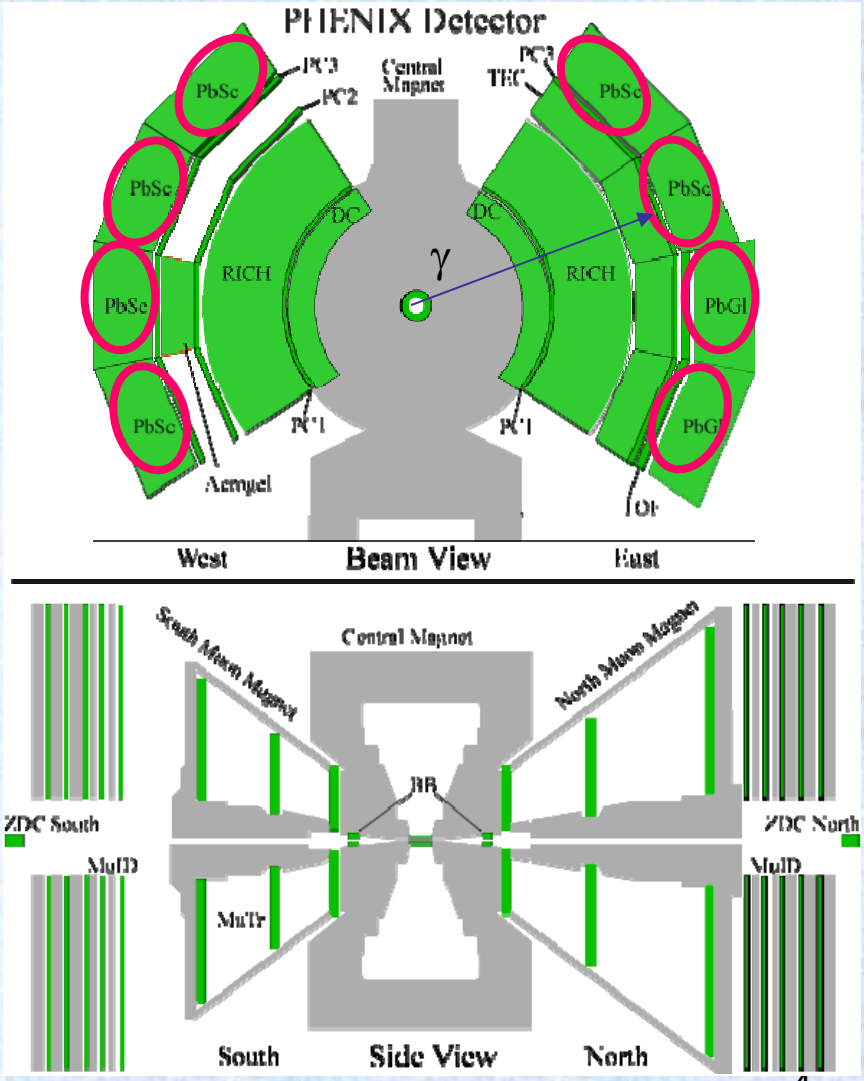


30% contribution from jet frag.

Direct photon measurement at RHIC-PHENIX

- Au+Au 200GeV Run at Year-4
  - Sampled Luminosity 241μb^{-1}
    - 1.5B events
- p+p 200GeV Run
  - @Year-3 0.35pb^{-1}
  - @Year-5 3.8pb^{-1}

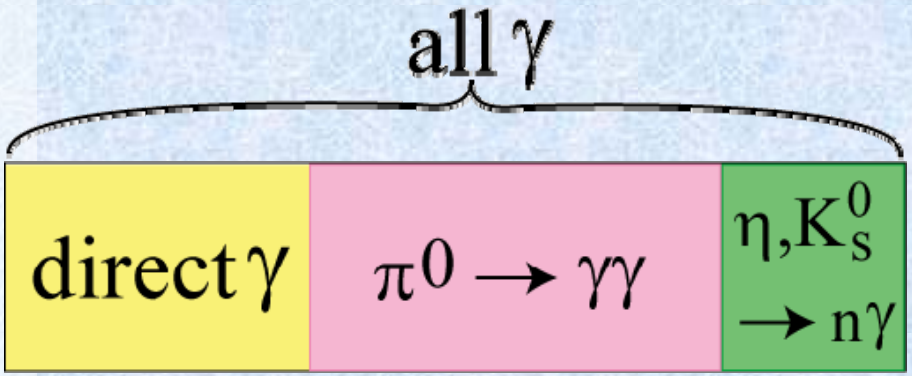
- **Photon measurement using PHENIX- Electromagnetic Calorimeter (EMCal)**
  - Lead Scintillator Type (PbSc, 18X_0)
  - Lead Glass Type (PbGl, 14.4X_0)
- Min. Bias trigger from BBC-ZDC coincidence
  - used for Centrality determination
    - 0%: central, 100%: peripheral collision



Method for direct photon measurement

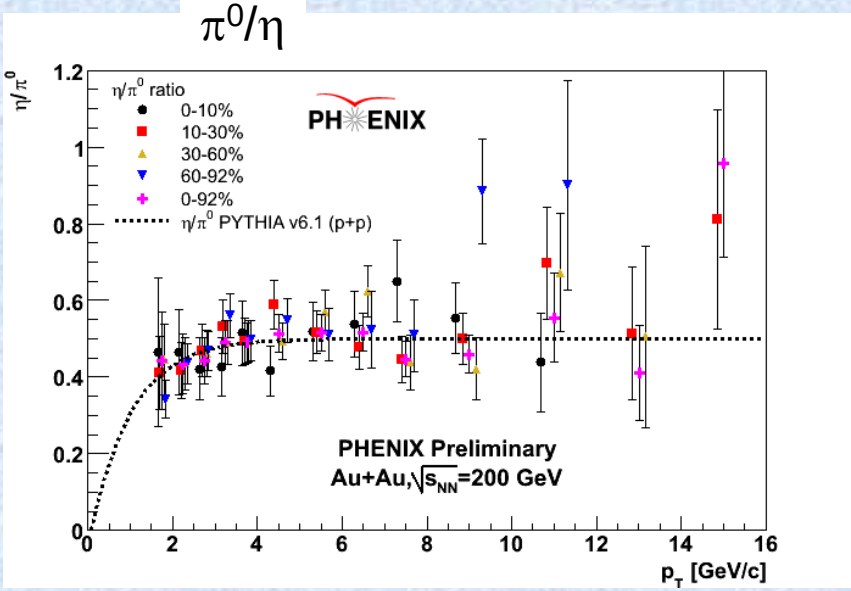
- **Subtraction method**

$$\gamma^{Direct} = \gamma^{All} - \gamma^{Hadronic}$$

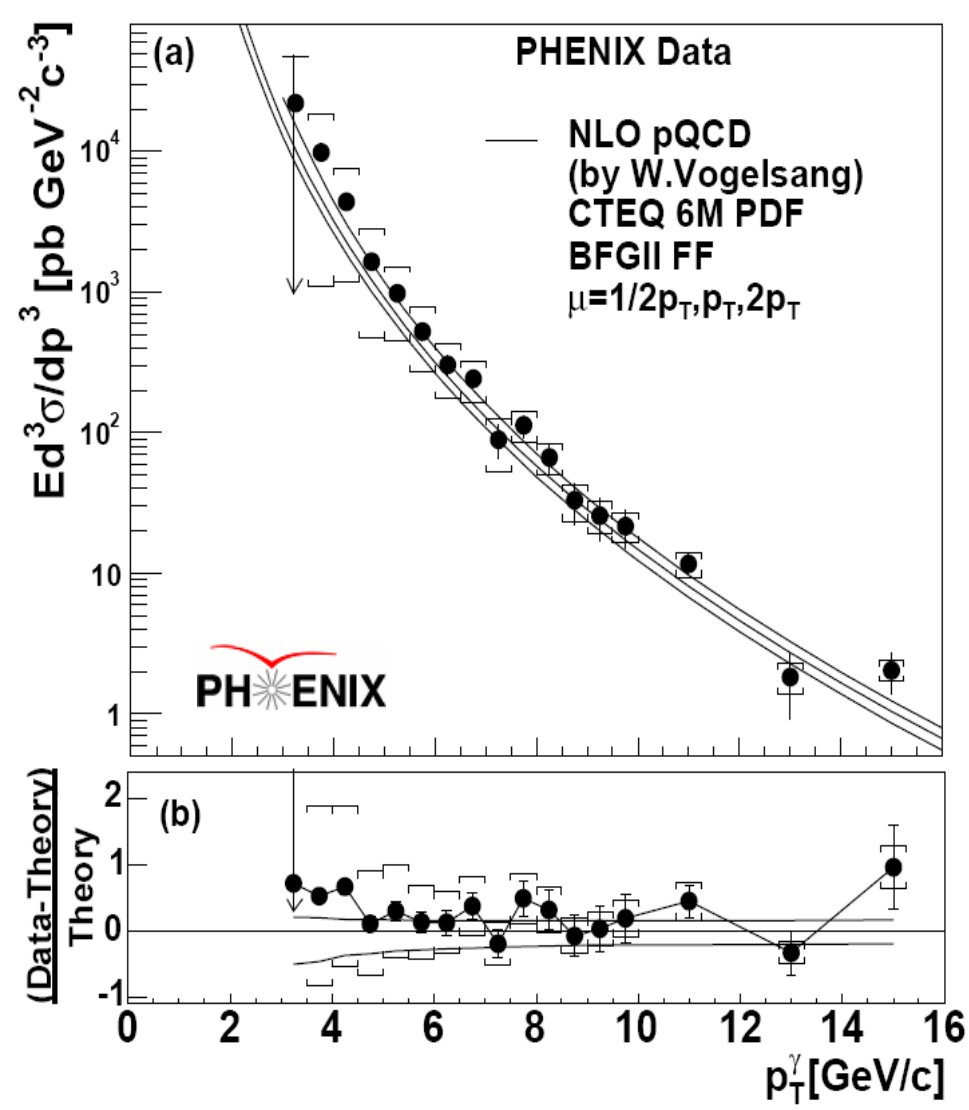


  - Measure π^0 and η with good accuracy
  - Estimate hadronic decay background with MC
    - π^0, η, K^0_s, η', ω..
      - Main contribution from π^0->2γ decay
    - Reconstruct the slope with m_T scaling.

π^0/η



Direct photon cross section in p+p $\sqrt{s}$ = 200GeV



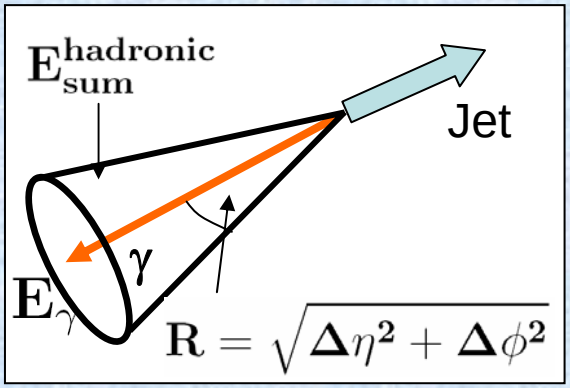
- **PHENIX Year-3 final result.**
  - Submitted to PRL
  - hep-ex/0609031
- Good agreement with theoretical calculation (NLO pQCD) within the error and theoretical uncertainty.

Fraction of fragmentation photons

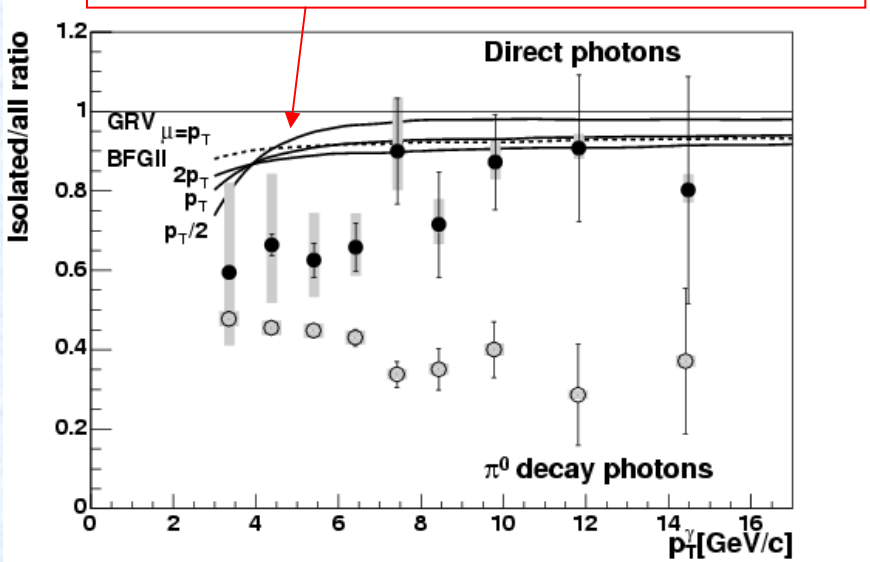
- Fraction of fragmentation photons is evaluated in terms of the fraction of isolated photons in 200GeV p+p collisions.
- If energy of cone around a target photon is much less than the energy of photon, the photon is defined as isolated photon.

$$E_{sum}^{hadronic}(R < 0.5\ rad) < 0.1 \times E_{\gamma}$$

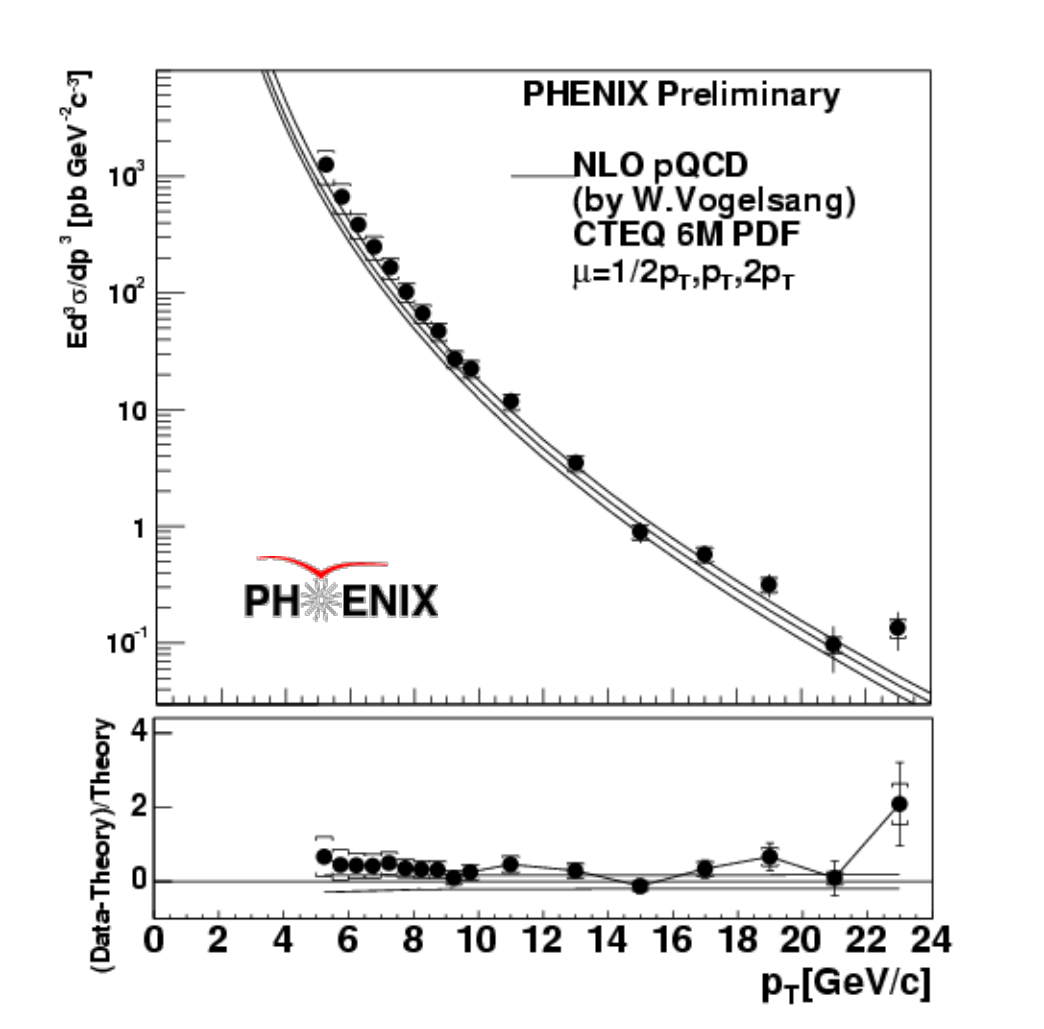
  - Isolation cut removes fragmentation (Bremsstrahlung) photons.
- Data are consistent with theoretical expectation within the error.
  - hep-ex/0609031



Theoretical predictions where PHENIX acceptance is taken into account



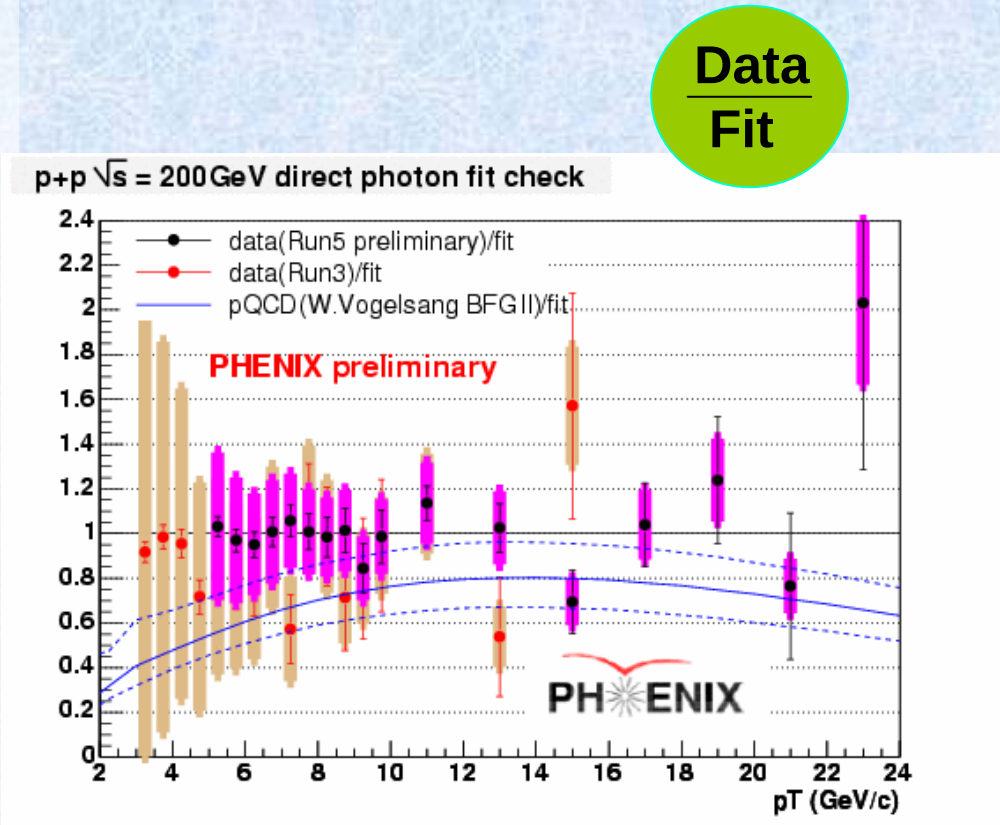
RHIC-PHENIX year-5 direct photon cross-section



- **PHENIX Year-5 preliminary result.**
- p_T region is extended up to 25GeV/*c*.
- Good reference for the evaluation of nuclear effect for high-p_T direct photon production at RHIC.

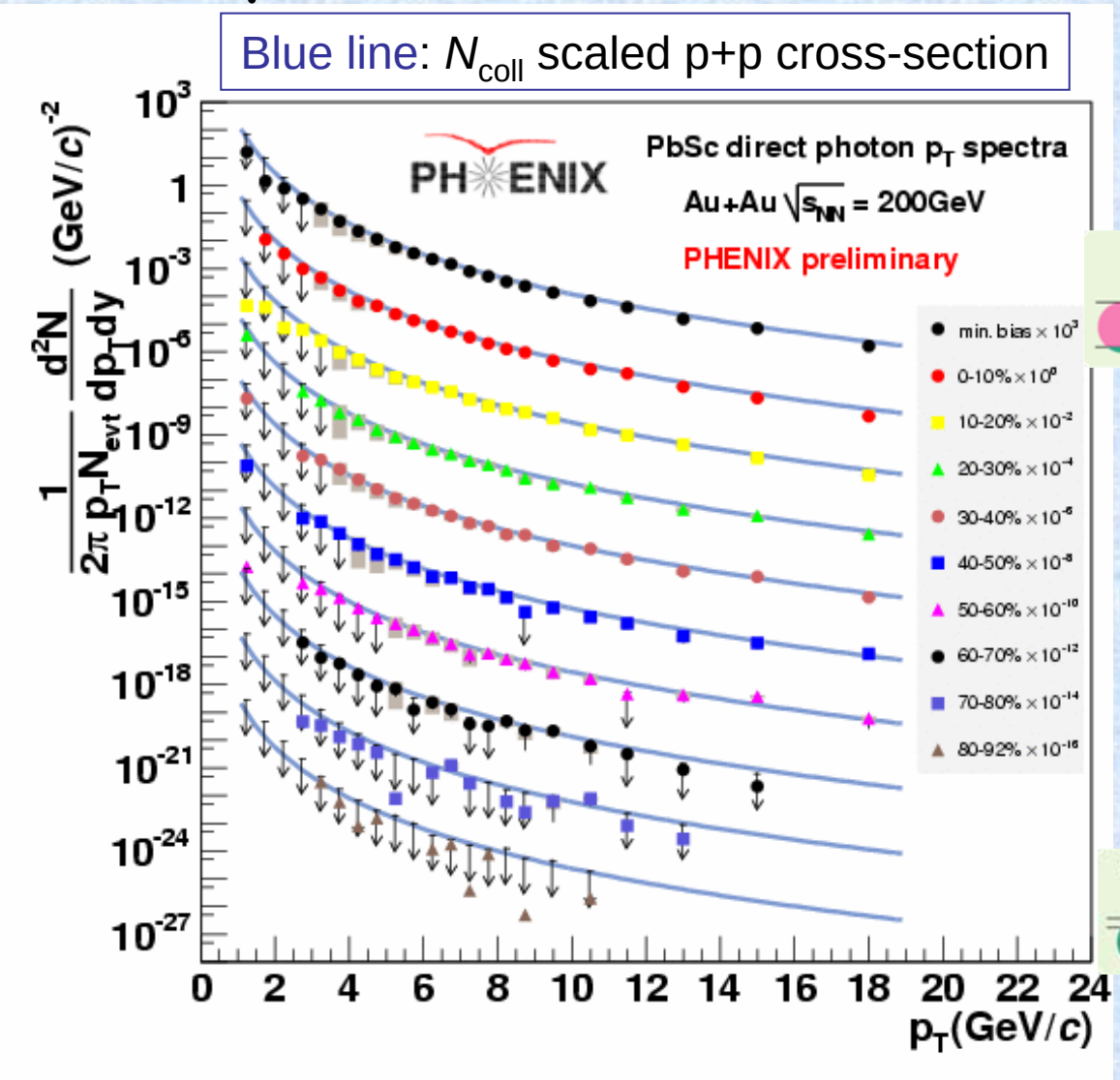
Parameterization of the p+p data

- For the calculation of nuclear modification factor, p+p reference is parameterized using a fitting function.
- The fitting works well to parameterize the p+p photon data.
- The parameterized photon data show enhancement comparing with NLO pQCD expectation by a factor of more than 20%.



Direct photon spectra in Au+Au $\sqrt{s_{NN}}$ = 200GeV

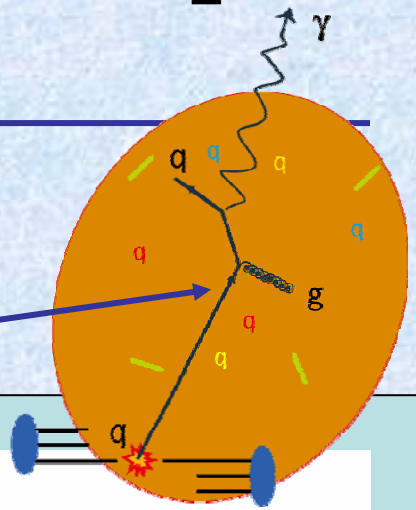
- Run4 large amount of Au+Au data make it possible to extend the p_T range up to 20GeV/*c*.

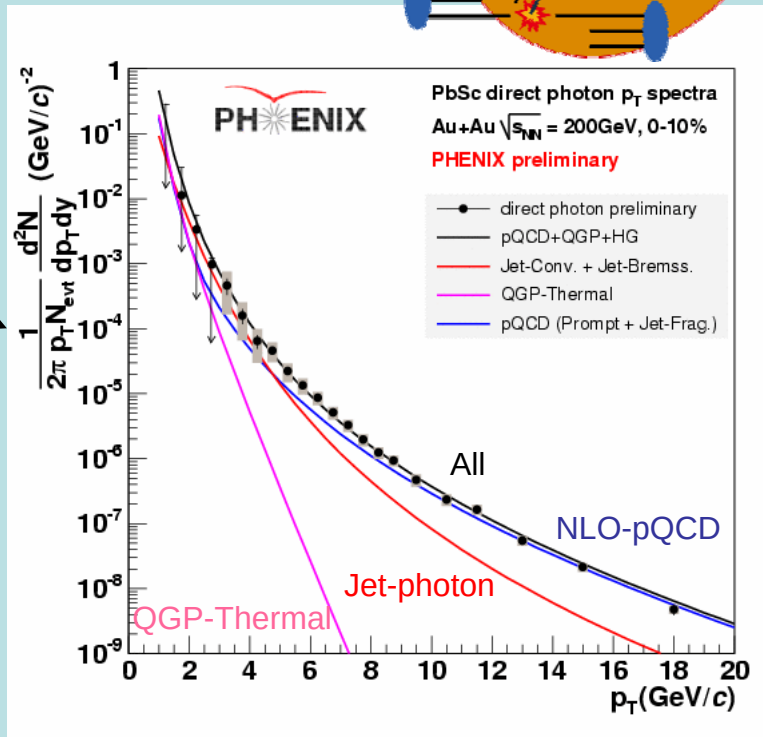


Medium induced high-p_T direct photons

- **Interaction of hard-scattered parton with dense matter.**
  - Compton scattering (jet-photon conv.)
    - R.J. Fries, Phys.Rev. C72 (2005) 041902
      - Over estimation at high-pT
    - S. Turbide, Phys.Rev. C72 (2005) 014906
      - Reproduce data well
  - Bremsstrahlung
    - B.G. Zakharov, JETP Lett. 80 (2004) 1
- If it is observed, it can be used as hard probe of bulk matter.

Hard scattered parton interacts with gluon in bulk matter





Jet-quenching effect for fragmentation photons are estimated with AMY formalism.

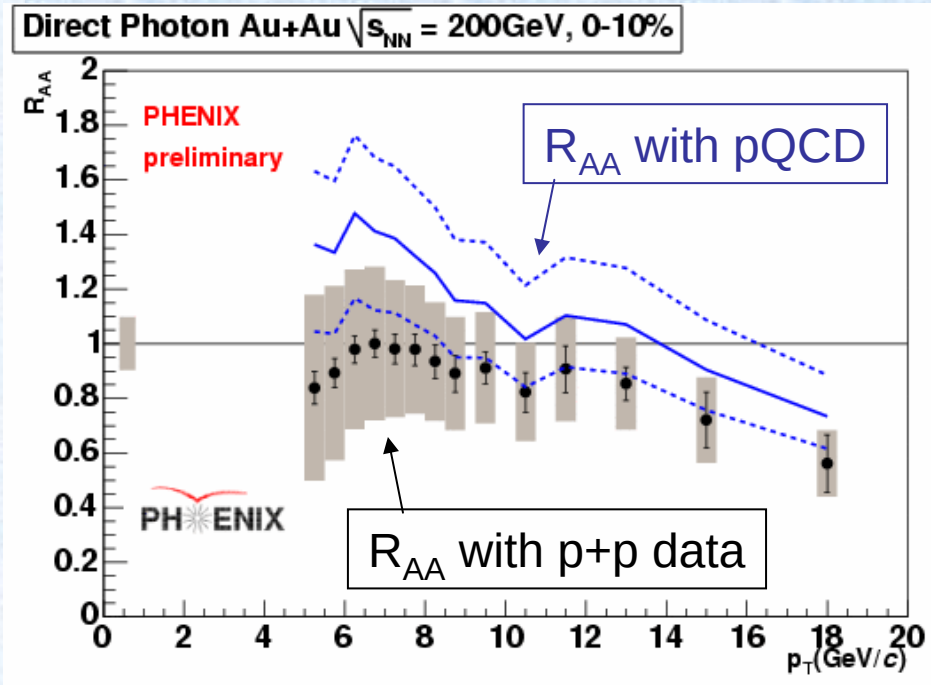
Direct photon R_{AA}

- Nuclear modification factor
  - Yield from hard processes can be scaled with N_{coll} (# of collisions).
  - divided by expected (binary scaled) yield from p+p data.

$$R_{AA}(p_T) = \frac{d^2N^{AA}/dp_T d\eta}{T_{AA} d^2N^{NN}/dp_T d\eta}$$

$$T_{AA} = N_{coll}/\sigma_{inel.}$$

- R_{AA} is consistent with N_{coll} scaled p+p reference.
- R_{AA} of very high-p_T direct photons is below one.
  - A hint of jet-quenching effect for fragmentation photons?
  - R_{AA} using pQCD shows different tendency.

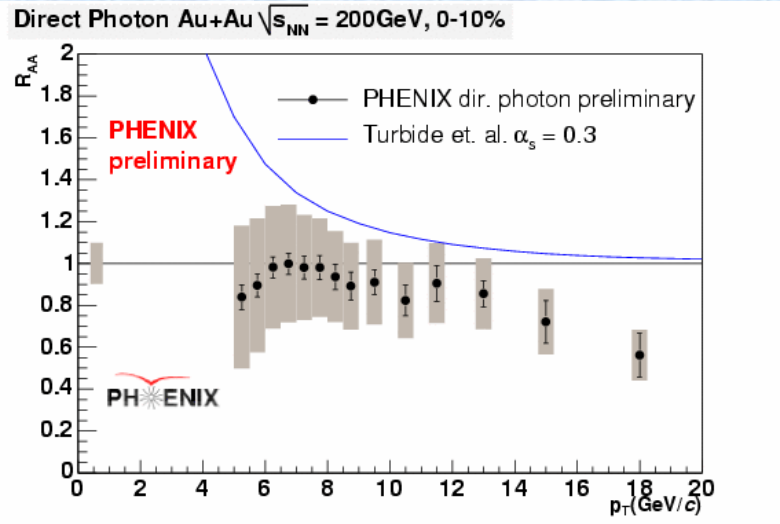


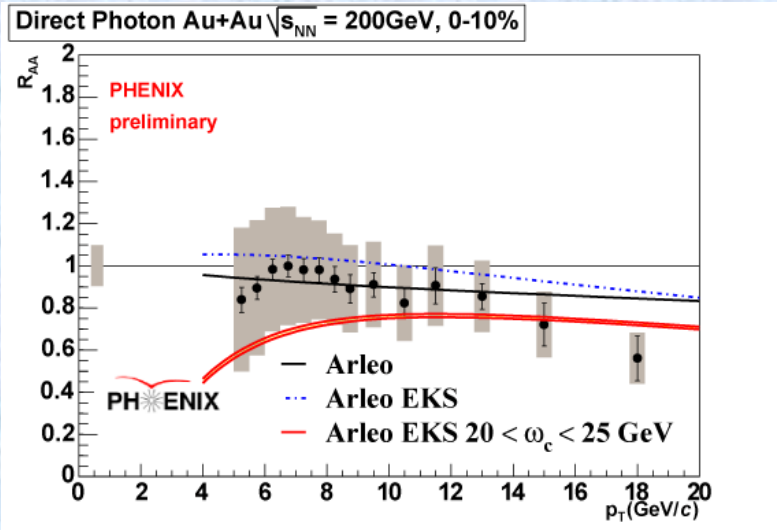
First data using p+p data as reference!

Thanks to the more accurate p+p/Au+Au data.

Comparison of R_{AA} with theoretical calculation

- Turbide et al.
  - Phys. Rev. C72 (2005) 014906 + Private communication.
    - AMY formalism for jet-quenching effect for fragmentation photons.
  - Systematically data points are below theoretical prediction.
- F. Arleo
  - JHEP 0609 (2006) 015
    - High-p_T suppression due to isospin effect, in addition to jet-quenching and shadowing.
      - BDMPS for jet-quenching.
    - Medium induced jet-photon is not taken into account.
  - The suppression of very high-p_T photon is well reproduced.





Summary

- Direct photons in 200GeV p+p collisions.
  - Published final year-3 p+p data.
  - Preliminary year-5 data.
  - Consistent with NLO pQCD within uncertainty.
- Direct photons in 200GeV Au+Au collisions.
  - Clear signal of direct photon at high-p_T thanks to the strong suppression of neutral hadrons.
  - Spectra up to 20GeV/*c*.
- First direct photons R_{AA} in 200GeV Au+Au collisions with p+p reference.
  - Almost consistent with binary scaled p+p data.
  - R_{AA} seems to be below one at very high-p_T region.

Related Poster

- 88 Takao Sakaguchi: System size and energy dependence of photon production measured at RHIC
- 91 Takuma Horaguchi: Measurement of the Direct photon cross section in proton-proton collisions at sqrt(s) = 200GeV with PHENIX
- 181 TadaAki Isobe: Measurement of direct photon with EMCal in sqrt(s_NN)=200GeV Au+Au collisions at RHIC-PHENIX

Thank you!

backup

Systematic error on direct photon spectra in AuAu 200GeV

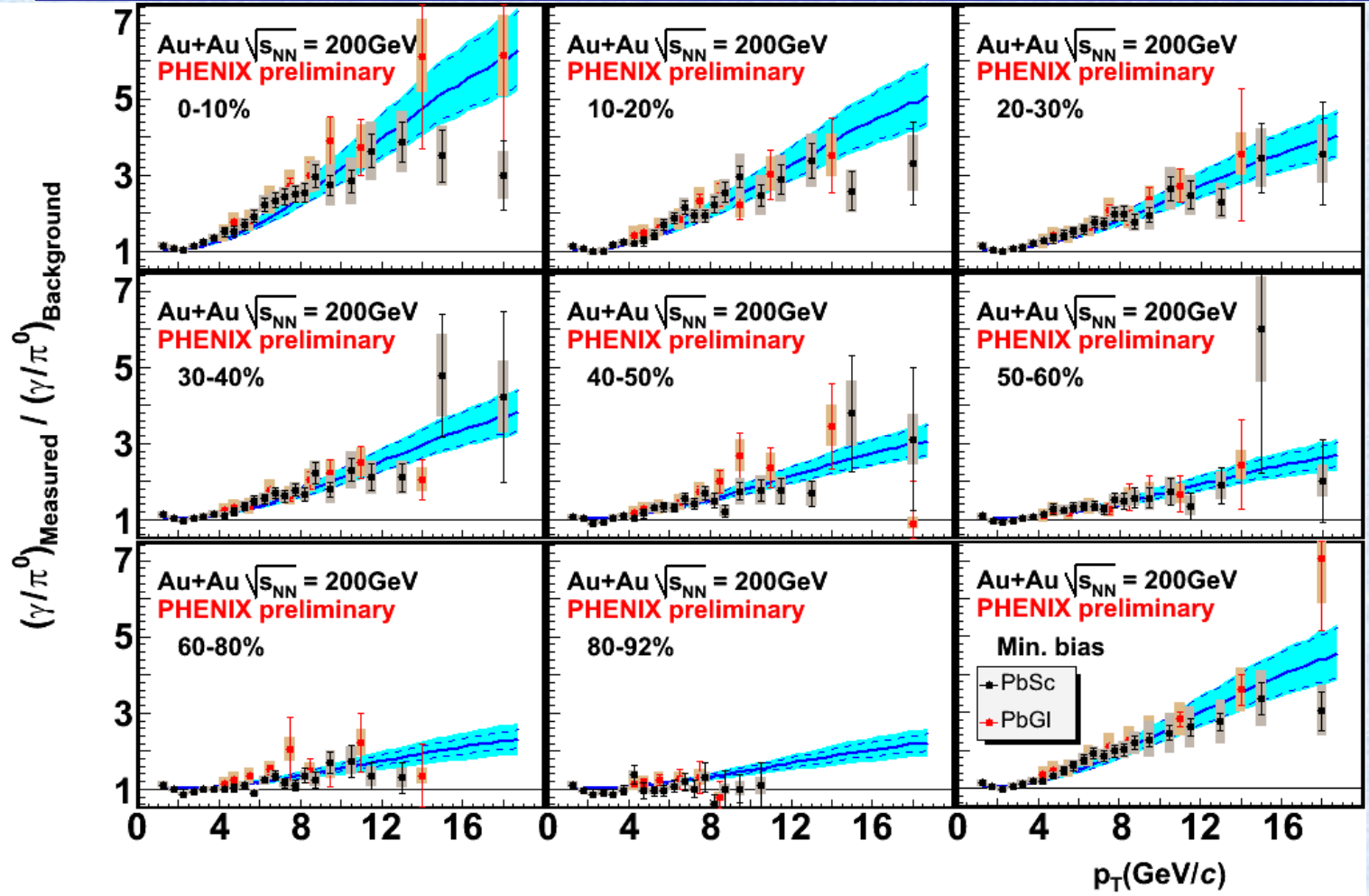
	Central Events			Peripheral Events		
	6 GeV	12 GeV	18 GeV	6 GeV	12 GeV	type
peak extraction	8.5%	2.1%	2.5%	30%	7.5%	A
energy scale	22%	12%	13%	56%	20%	B
off-vertex	4.2%	2.1%	2.1%	12%	3.8%	B
hadron contamination	17%	4.3%	4.3%	42%	16%	B
γ unfolding	14%	7.1%	7.1%	36%	11%	B
η/π^0	3%	0.7%	0.7%	10%	2.5%	C
merging corr.	1.5%	7%	8.4%	5%	25%	B
γ_{bg}/π^0 fit	4.2%	1%	1%	15%	3.7%	A
Conv. corr.	4.2%	2.1%	2.1%	12%	3.8%	C
Total	33%	17%	18%	88%	39%	

Systematic error on direct photon spectra in p+p 200GeV

TABLE I: Relative systematic uncertainties of the direct photon spectra.

p_T [GeV/c]	4.5-5	7.5-8	10-12
Signal fraction	9%	27%	49%
(a) Global	16.8%	14.9%	14.9%
(b) Inclusive photons	12.3%	4.7%	3.1%
(c) Photons from π^0	30.1%	10.7%	6.5%
(d) Other hadrons	21.4%	6.7%	3.8%
(e) Non-linearity (+ remaining)			
(e_1) π^0 tagging	42.7%	6.8%	5.4%
(e_2) cocktail	69.5%	20.4%	13.4%
Total	71.6%	25.2%	19.8%

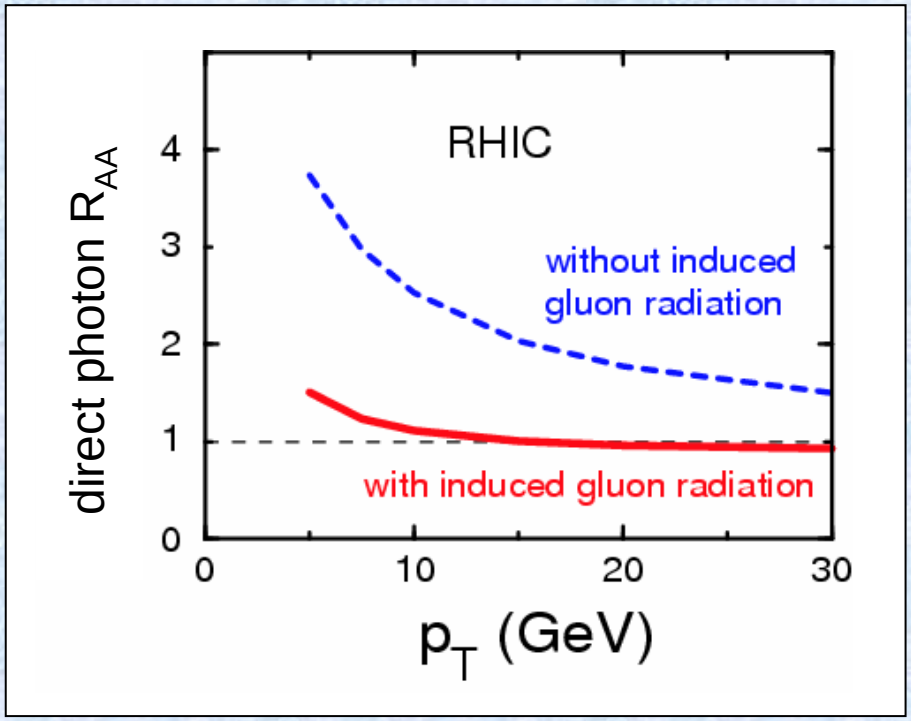
Direct photon excess ratio in $\sqrt{s_{NN}}$ = 200GeV Au+Au collisions

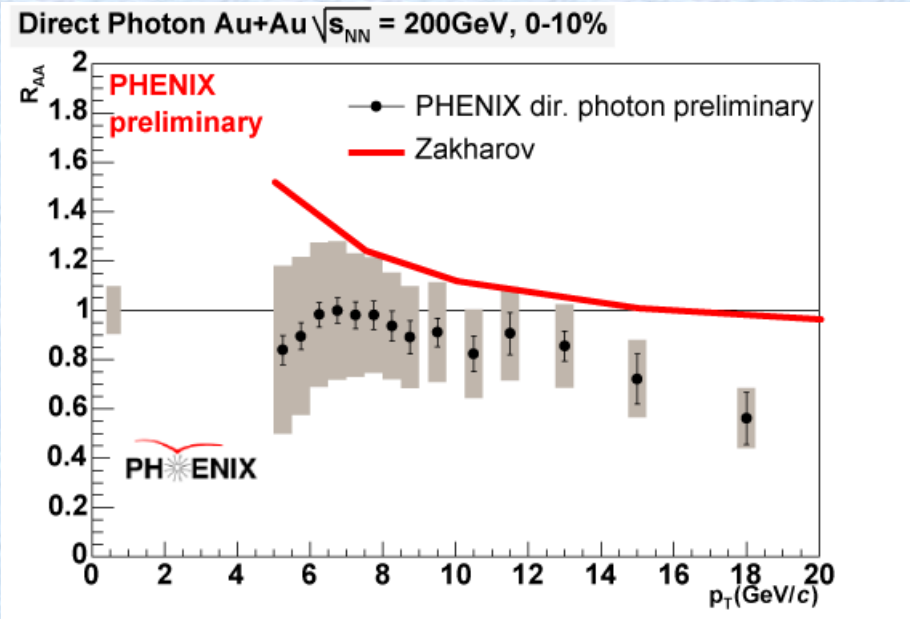


Compared with pQCD calculation. (dashed lines: theoretical uncertainty, blue bands: including also *N*coll uncertainty)

- **Clear extraction of high-p_T direct photon signal thanks to the strong suppression of hadrons.**

Direct photon source





Bremsstrahlung photons through bulk matter
B.G. Zakharov, JETP Lett. 80 (2004) 1

$$q \rightarrow q\gamma$$