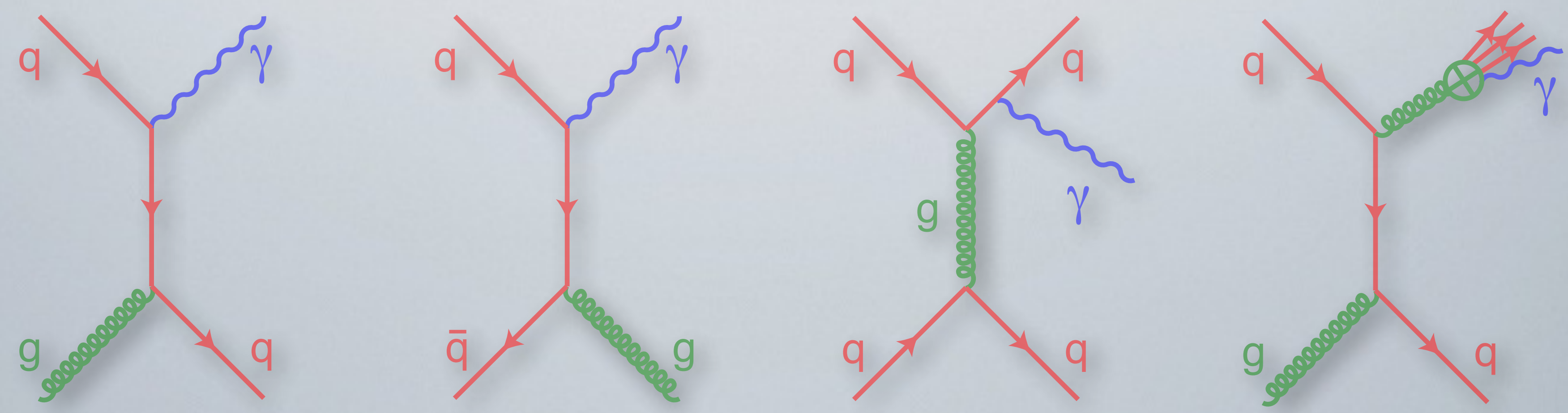


Direct Photon Production in High-Energy Nuclear Collisions

T. Peitzmann (Utrecht University/Nikhef)

XI Quark Confinement and the Hadron Spectrum, St. Petersburg, Sept. 8-12, 2014

Outline

- Introduction
- Prompt Photons
- Thermal Photons
    - Yield and Anisotropy
- Photons as Saturation Signal
- Conclusions

Direct Photons

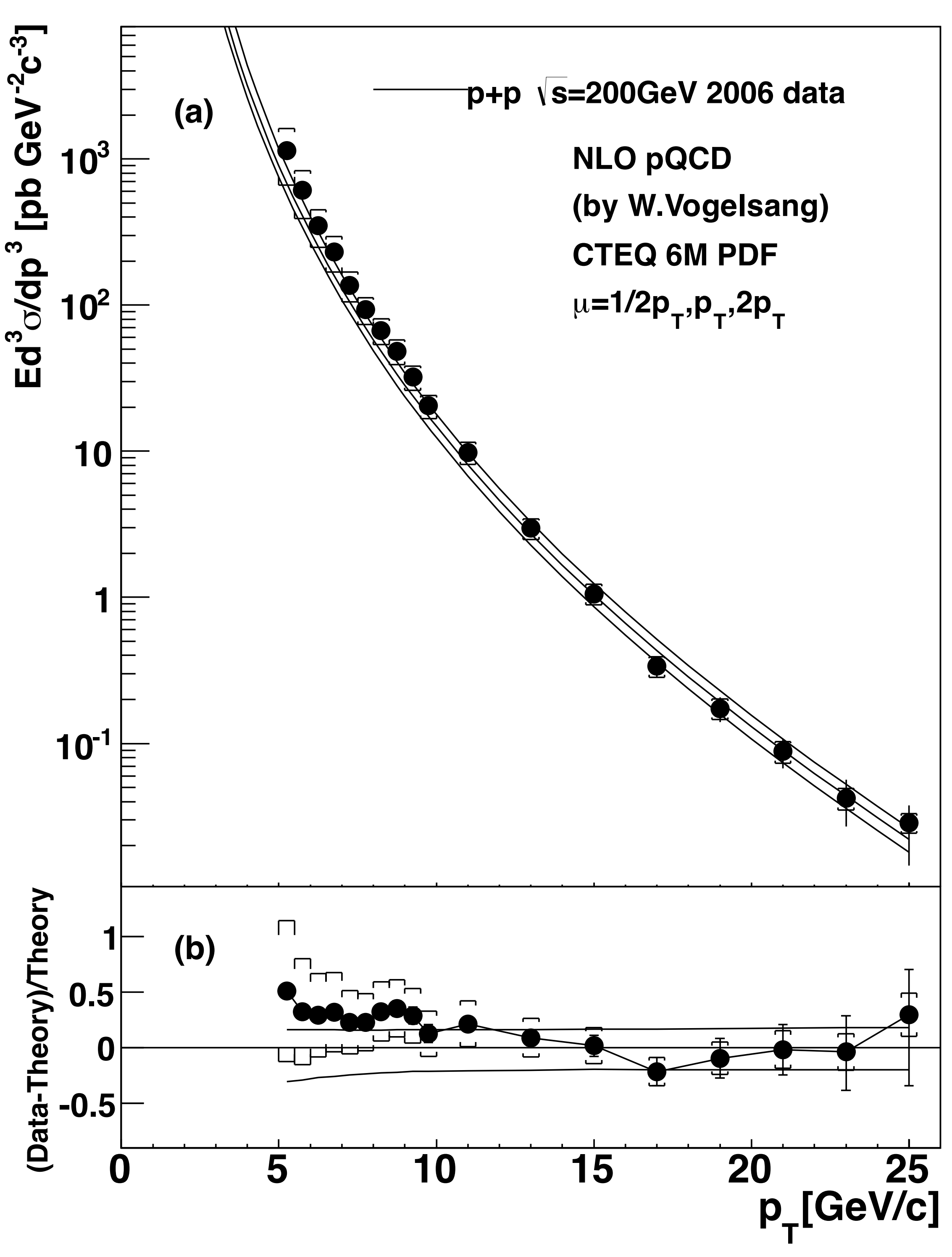
- electromagnetic probe
- advantages:
  - elementary production processes well understood
    - reduce systematic uncertainty in interpretation
  - little modification in final state
    - probing early phases
- disadvantages:
  - small signal/large background

The Two Faces of Photons

- prompt photons:
  - produced in hard scatterings
    - described by pQCD, dominate at high p_T
  - probing the initial state
    - nPDFs, saturation, …
- thermal photons:
  - thermal QCD (+hadrons)
    - good theoretical understanding, dominate at low p_T
  - em radiation from thermal system (QGP)
    - information on temperature from early phase
      … one of the holy grails of heavy-ion physics

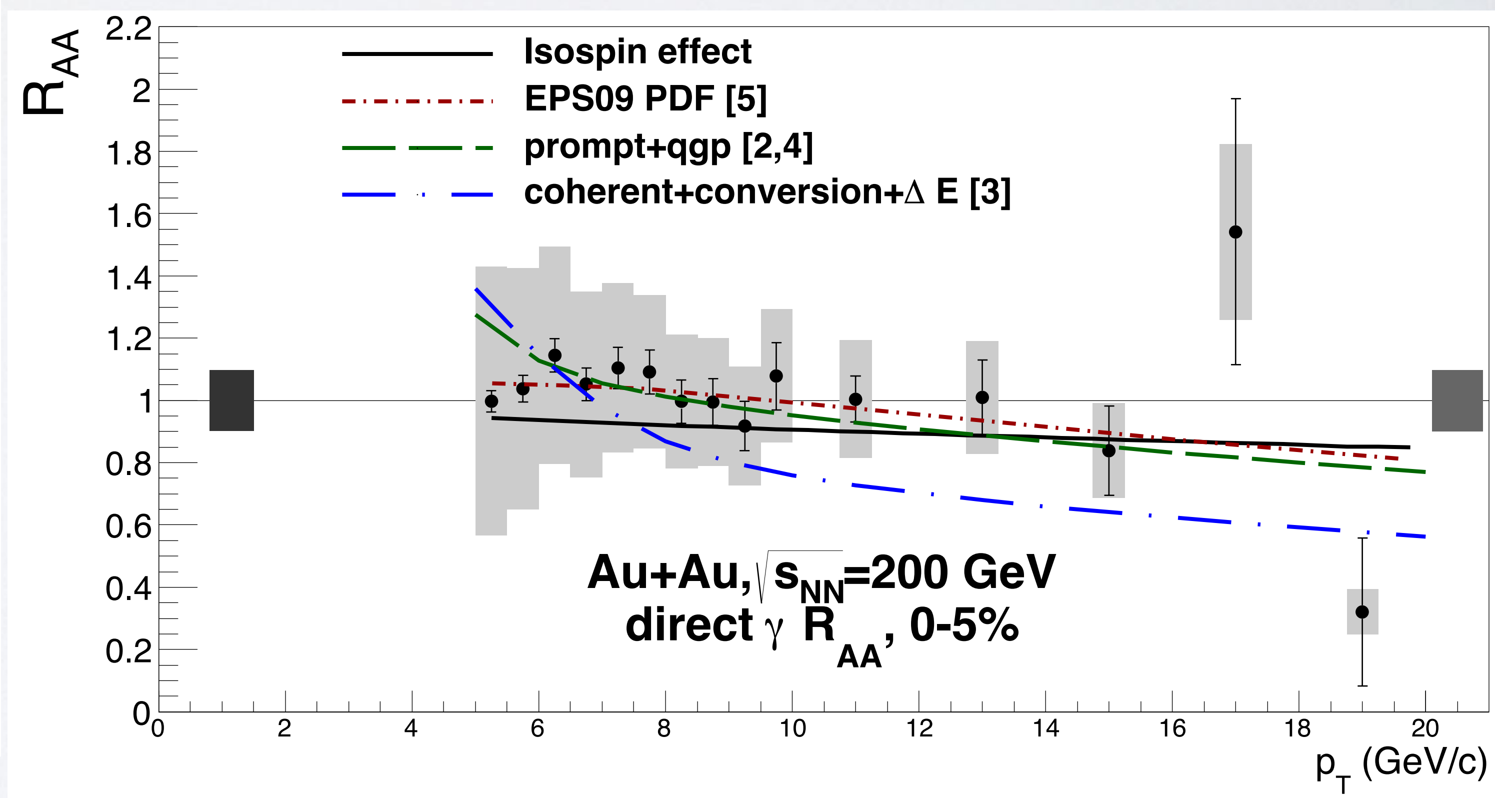
Prompt Photons at RHIC

PHENIX, Phys. Rev. Lett.104:132301,2010



- for pp collisions good description with NLO pQCD
  - some tension at low p_T
- for central Au–Au collisions compatible with N_{coll} scaling

$$R_{AA} = \frac{dN/dp_T^2(AA)}{\langle N_{coll}\rangle \cdot dN/dp_T^2(pp)}$$



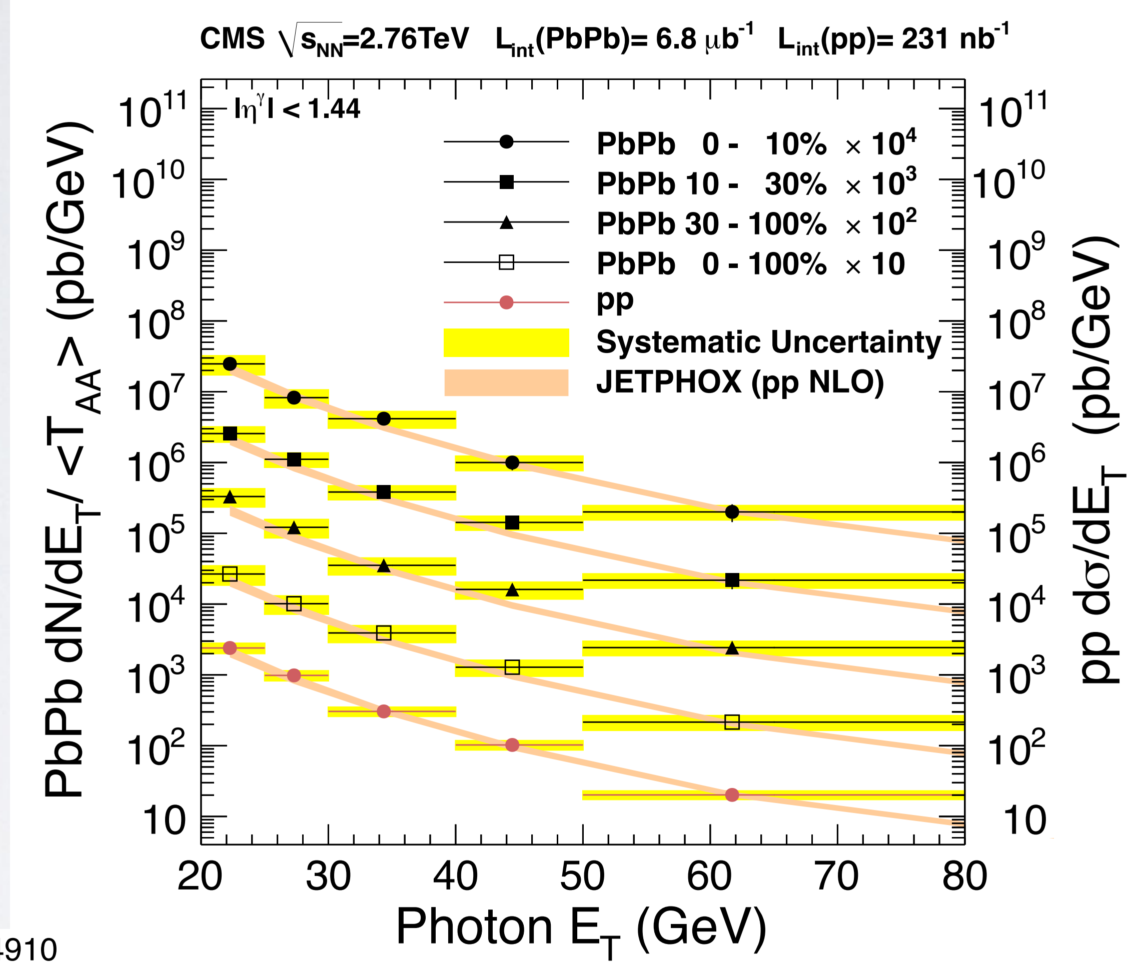
PHENIX, Phys. Rev. Lett.109:152302,2012

Prompt Photons at LHC

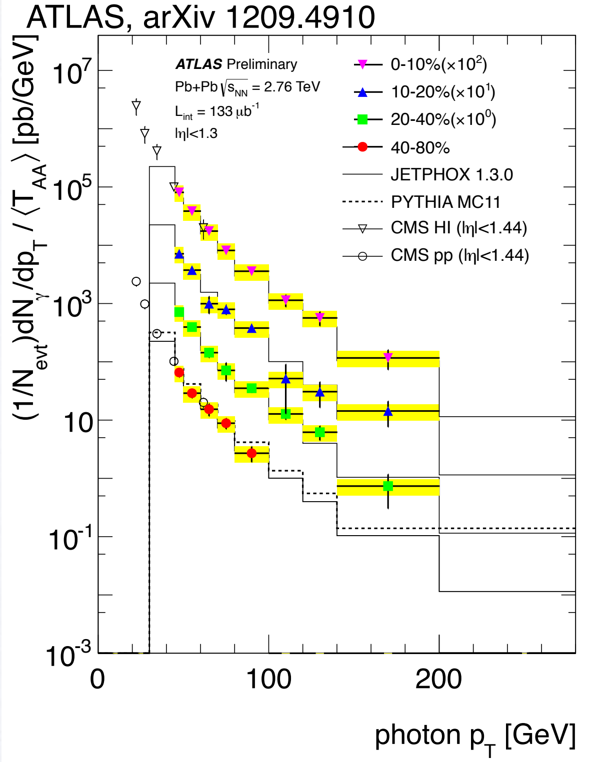
- isolated photons for $p_T > 20$ GeV in pp and Pb–Pb
  - needs significant correction for underlying event in Pb–Pb
  - agreement with NLO pQCD
  - N_{coll} scaling for Pb–Pb
- no strong nuclear effects expected
  - large p_T implies large Bjorken-x

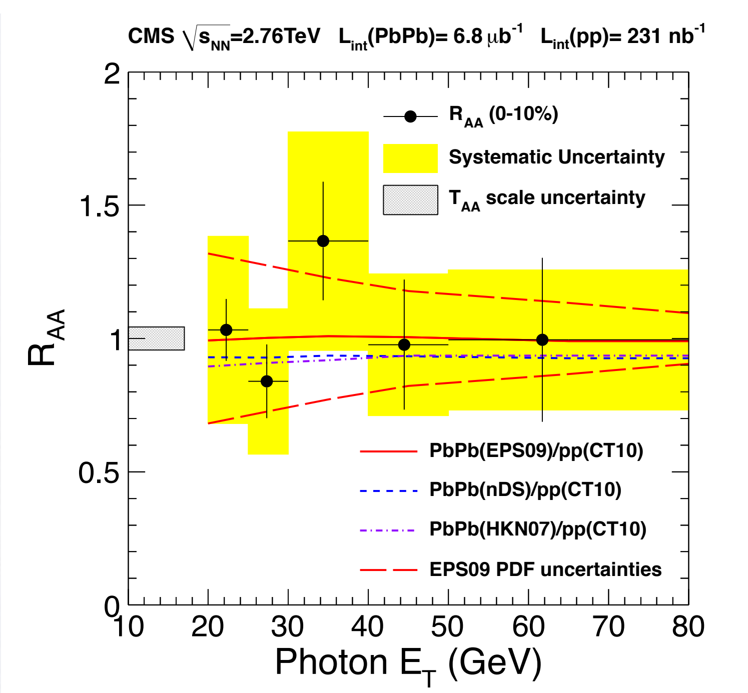
$$x \approx \frac{2p_T}{\sqrt{s}} > 0.01$$

CMS, Physics Letters B, 710 (2012) 256–277



ATLAS, arXiv 1209.4910



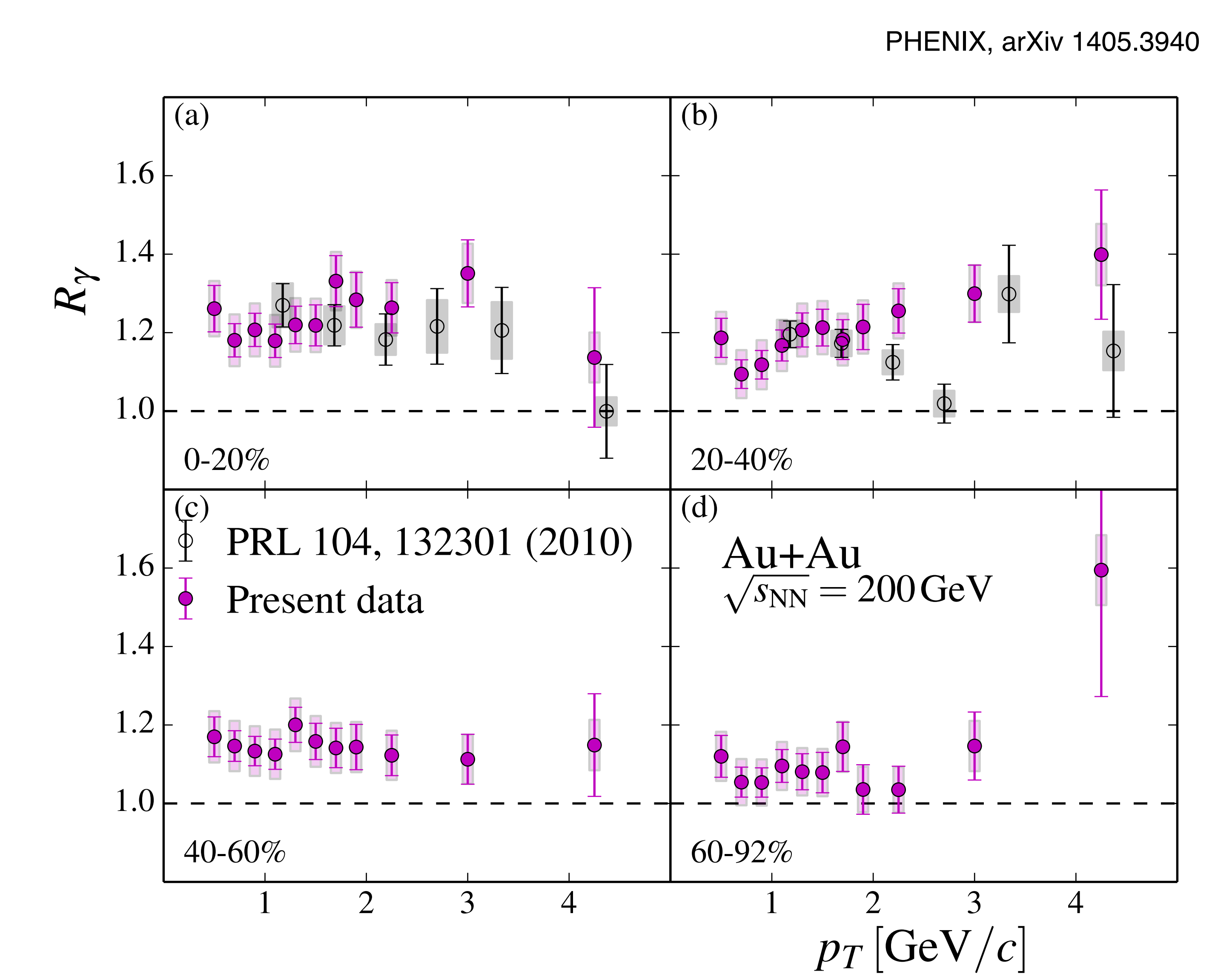


Thermal Photons at RHIC

- for thermal photons: lower p_T
- more difficult:
    - smaller S/B expected

$$R_\gamma = \frac{N_\gamma^{\mathrm{inc}}}{N_\gamma^{\mathrm{dec}}} = 1 + \frac{N_\gamma^{\mathrm{dir}}}{N_\gamma^{\mathrm{dec}}}$$

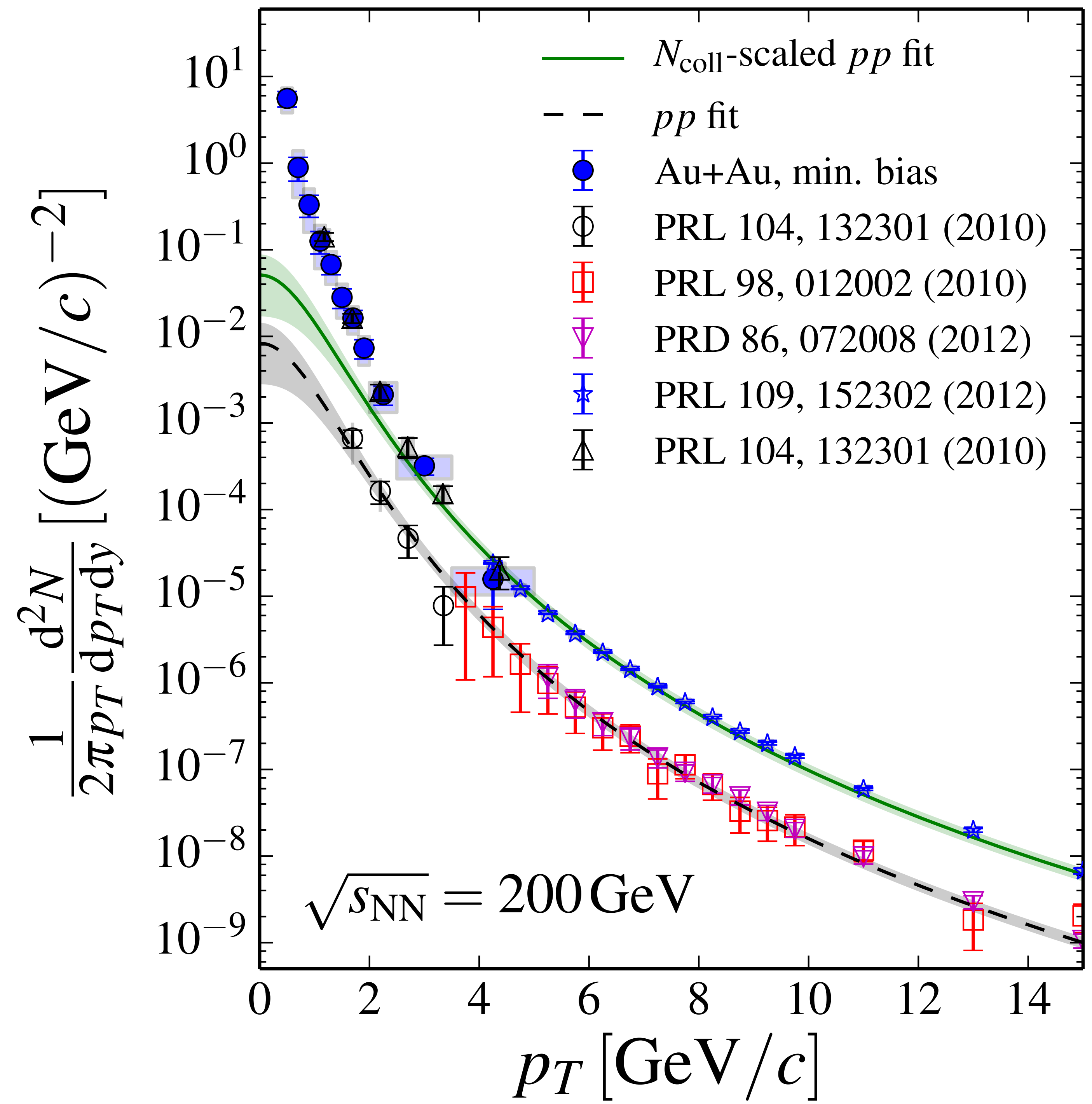
- S/B improves for central Au–Au
    - main contribution to decay photons (neutral mesons) suppressed in Au–Au



Thermal Photons at RHIC

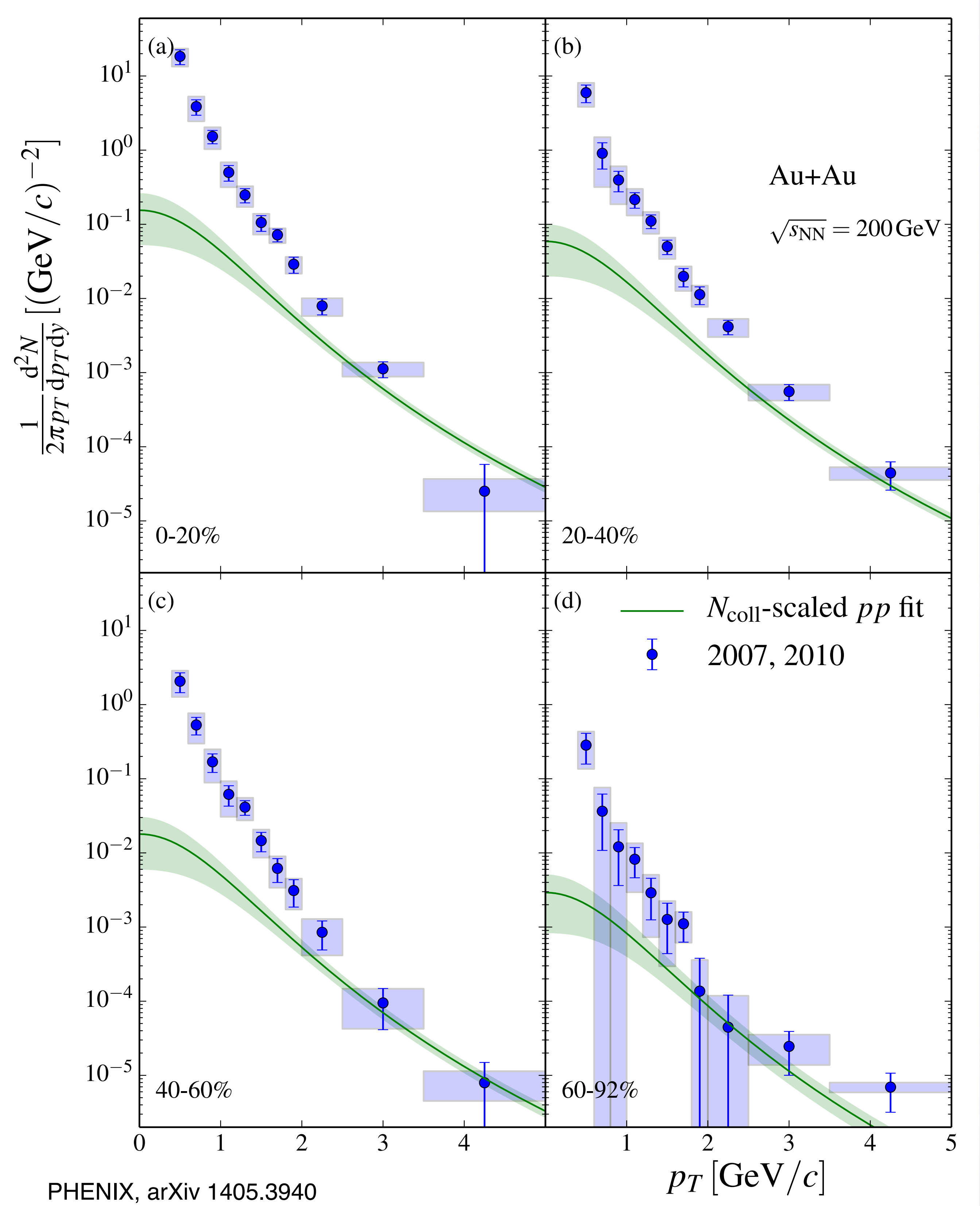
- advanced measurements from PHENIX combining:
  - calorimetry
  - low-mass virtual photons
  - photon conversions
- shape in pp and Au–Au at high p_T very similar
  - unmodified pQCD
- excess at low p_T beyond extrapolation of pp data
  - thermal photons
  - uncertainty of extrapolation?

PHENIX, arXiv 1405.3940



Thermal Photons at RHIC

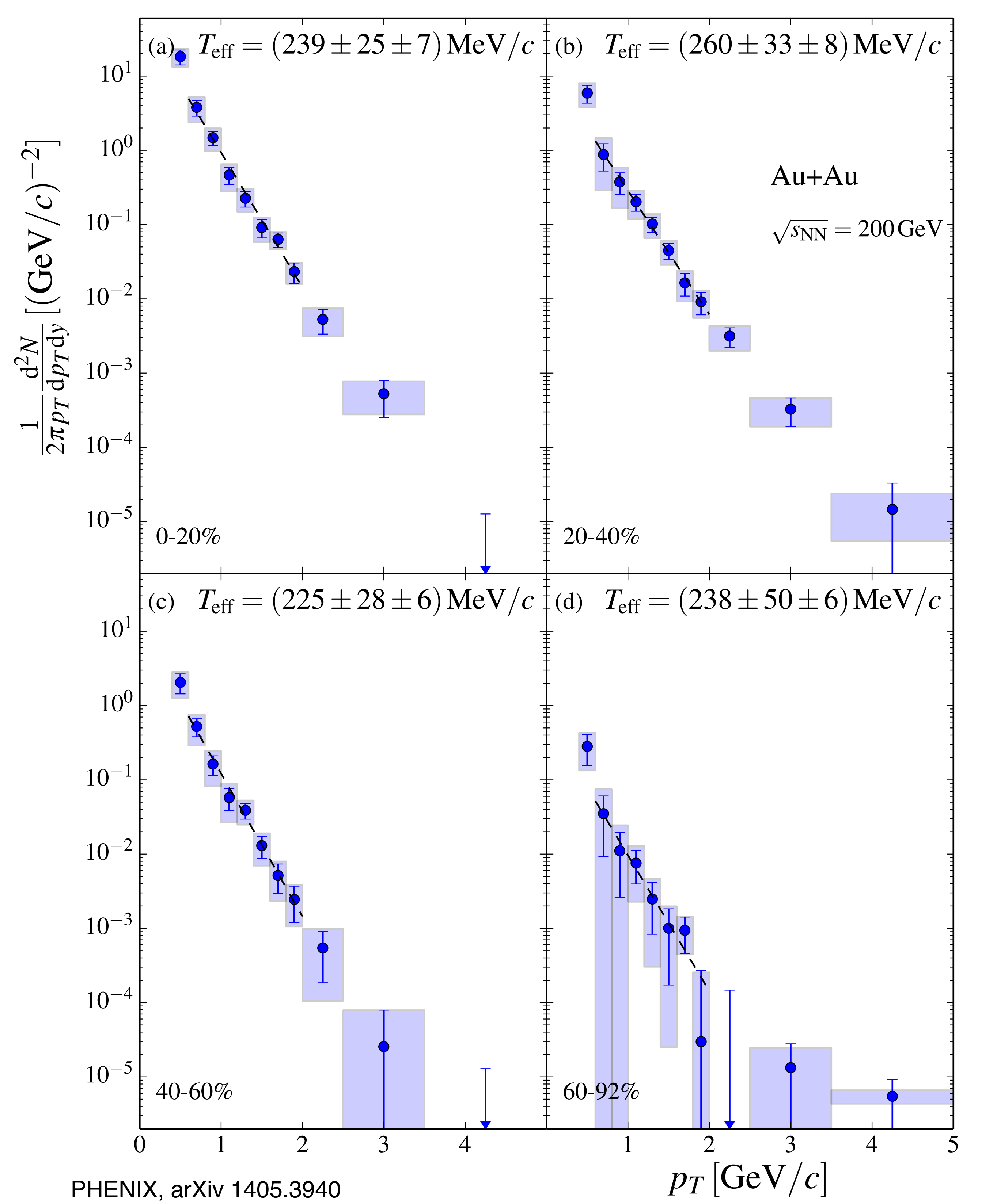
- direct photons in Au–Au for different centralities
- compared to scaled pp-fit
  - question to theory: how well understood is low-p_T non-thermal production?
- scaling assumption can be used to extract direct photon excess: thermal photons



PHENIX, arXiv 1405.3940

Thermal Photons at RHIC

- centrality dependence of photon excess
  - increases more strongly than number of participants
- fit with exponential yield similar slope parameter for all with T ≈ 240 MeV
  - expectation from theory?



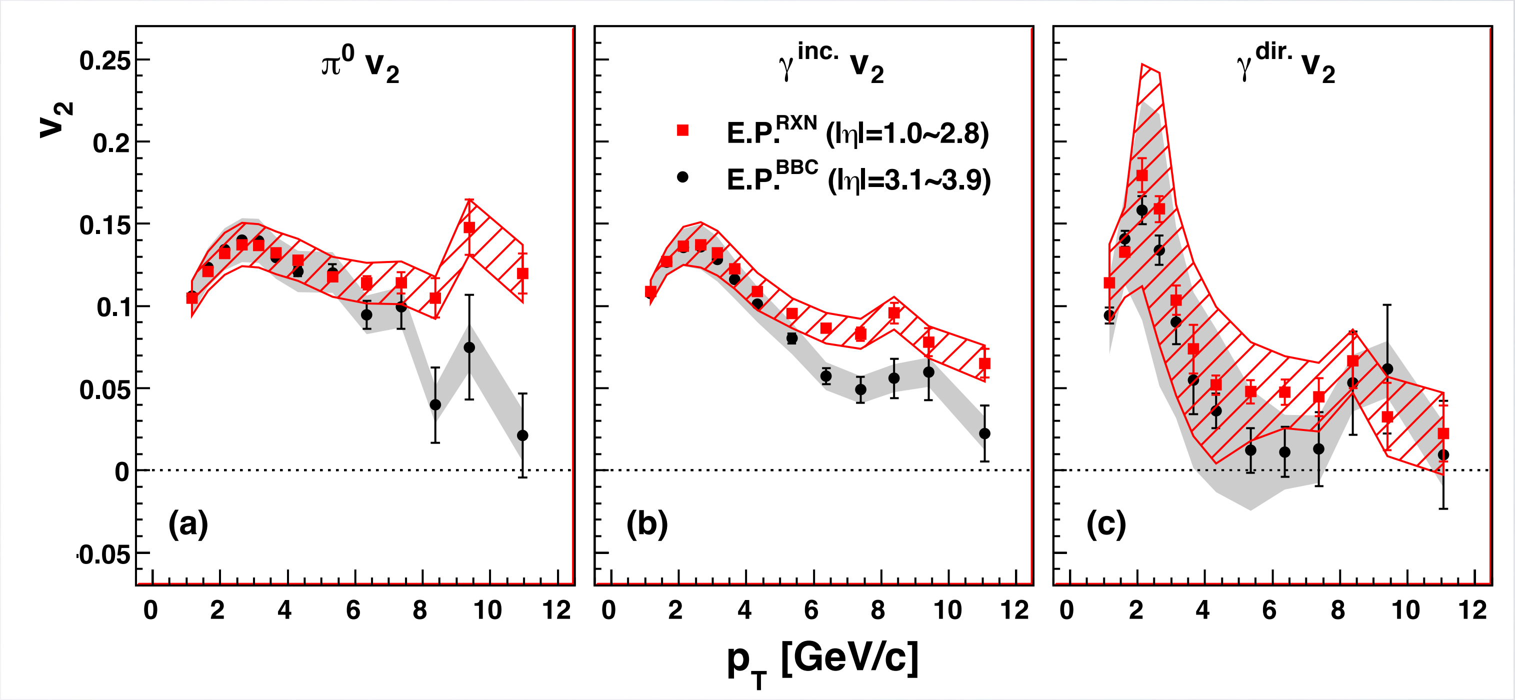
PHENIX, arXiv 1405.3940

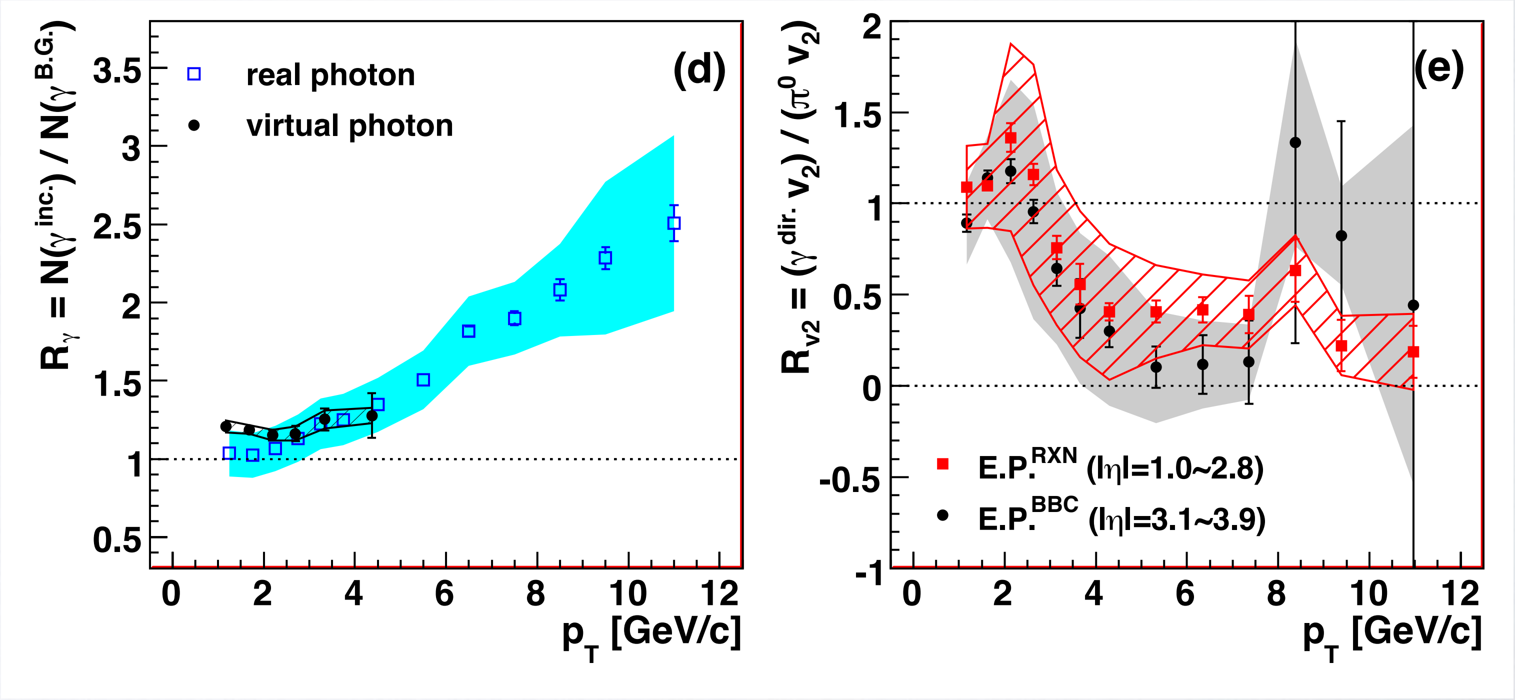
Thermal Photon Flow at RHIC

- extraction of elliptic flow very challenging
- subtraction of two similar numbers
  - flow of inclusive and decay photons

$$v_2^{\mathrm{dir}\,\gamma} = \frac{R_\gamma \cdot v_2^{\mathrm{incl}\,\gamma} - v_2^{\mathrm{dec}\,\gamma}}{R_\gamma - 1}$$

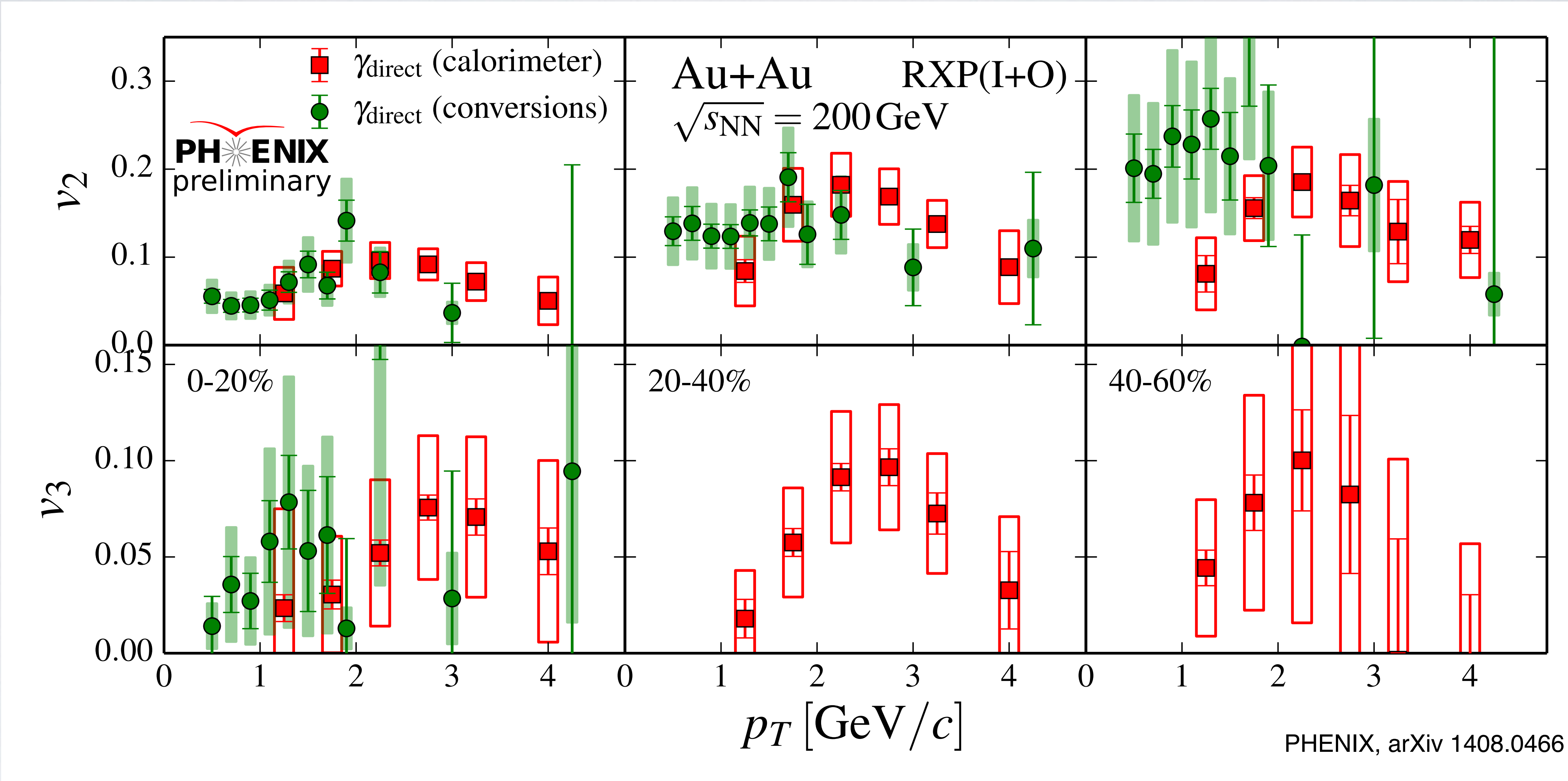
  - very sensitive to systematic errors for values of $R_\gamma \approx 1$





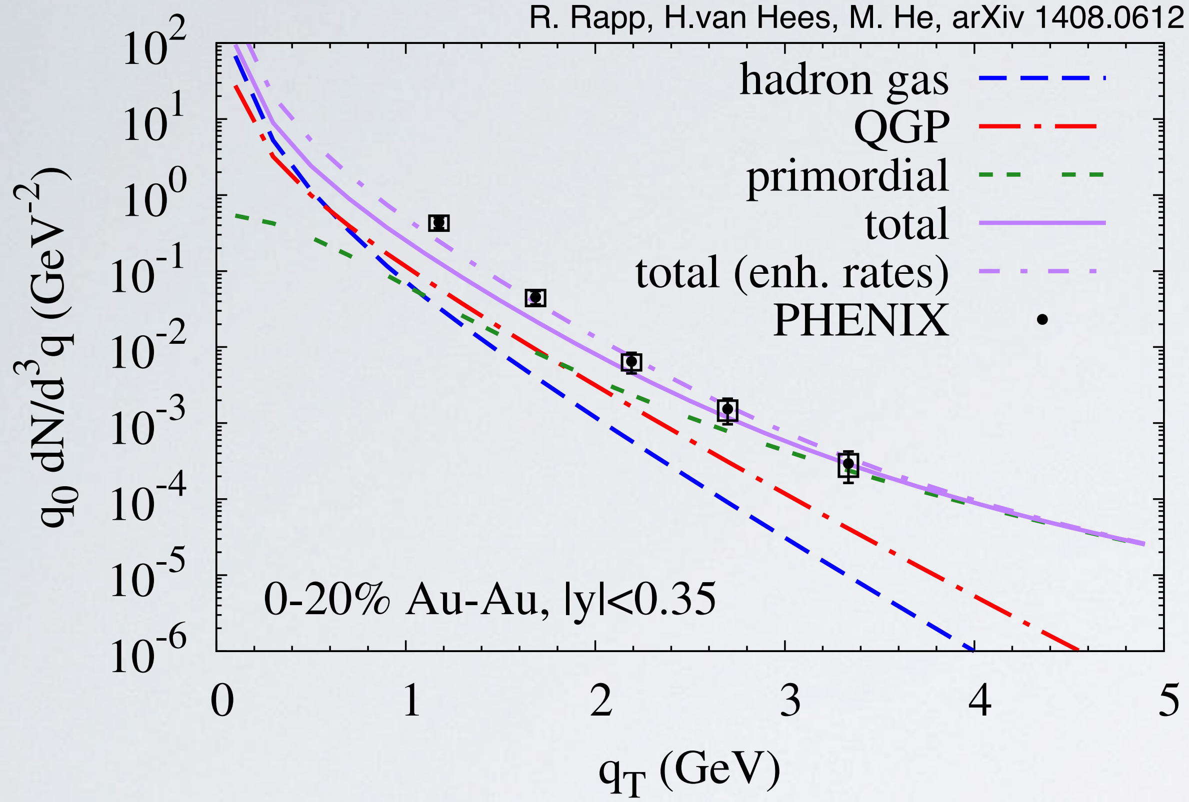
PHENIX, Phys. Rev. Lett. 109, 122302 (2012)

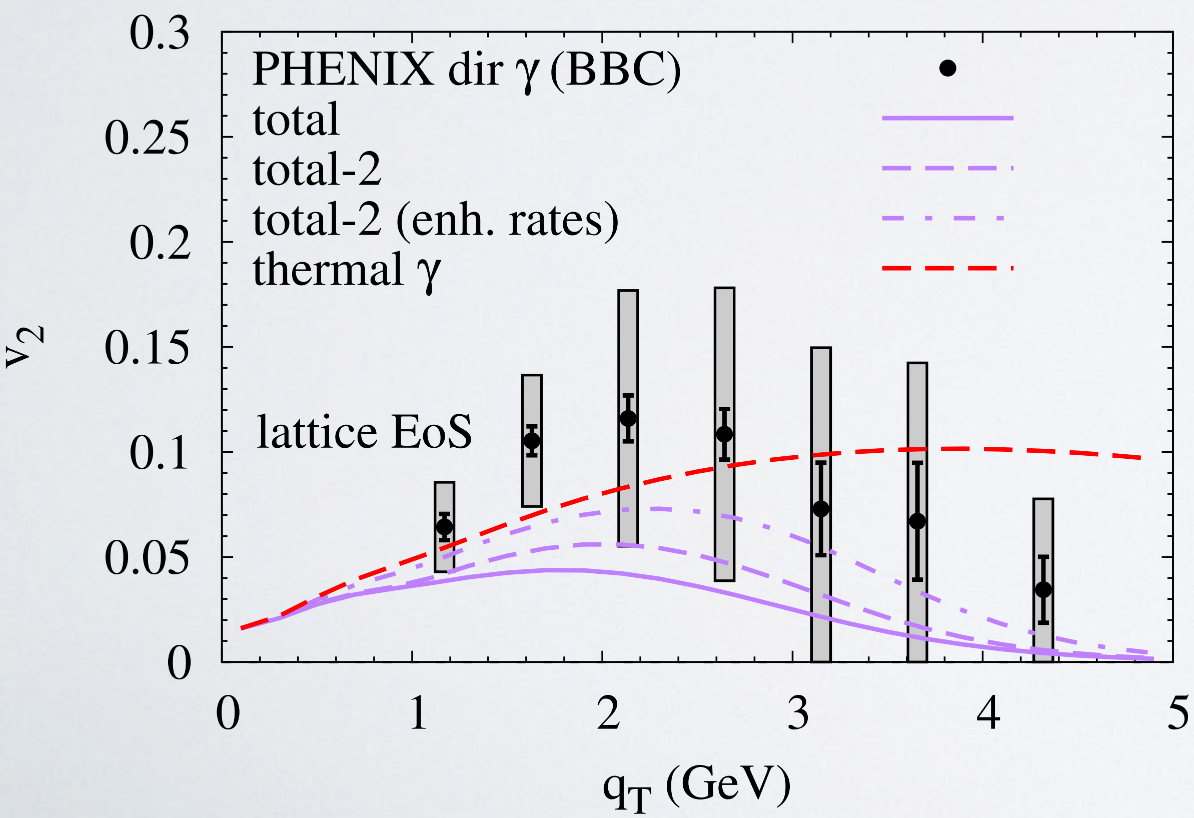
Thermal Photon Flow at RHIC



- new results: confirm significant elliptic flow v_2 for direct photons
  - also v_3 component
- difficult to describe theoretically

Thermal Photon Puzzle?

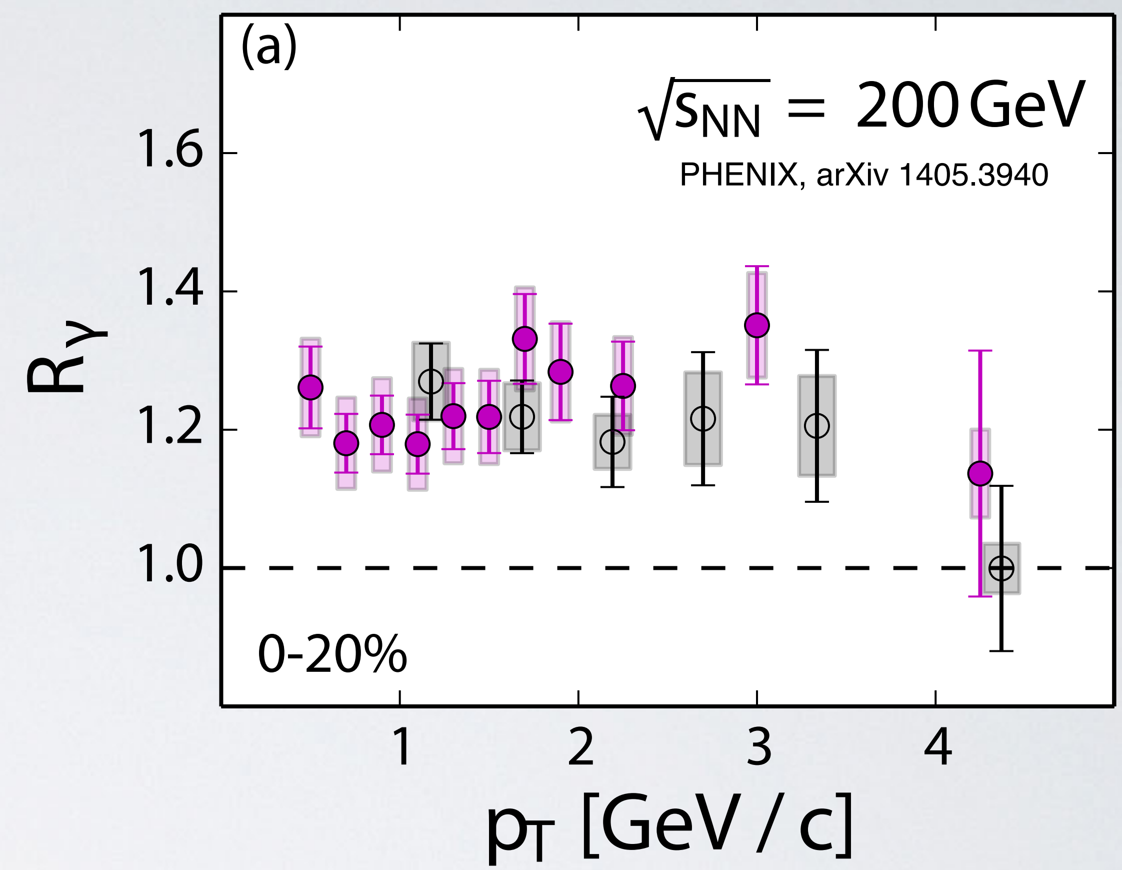


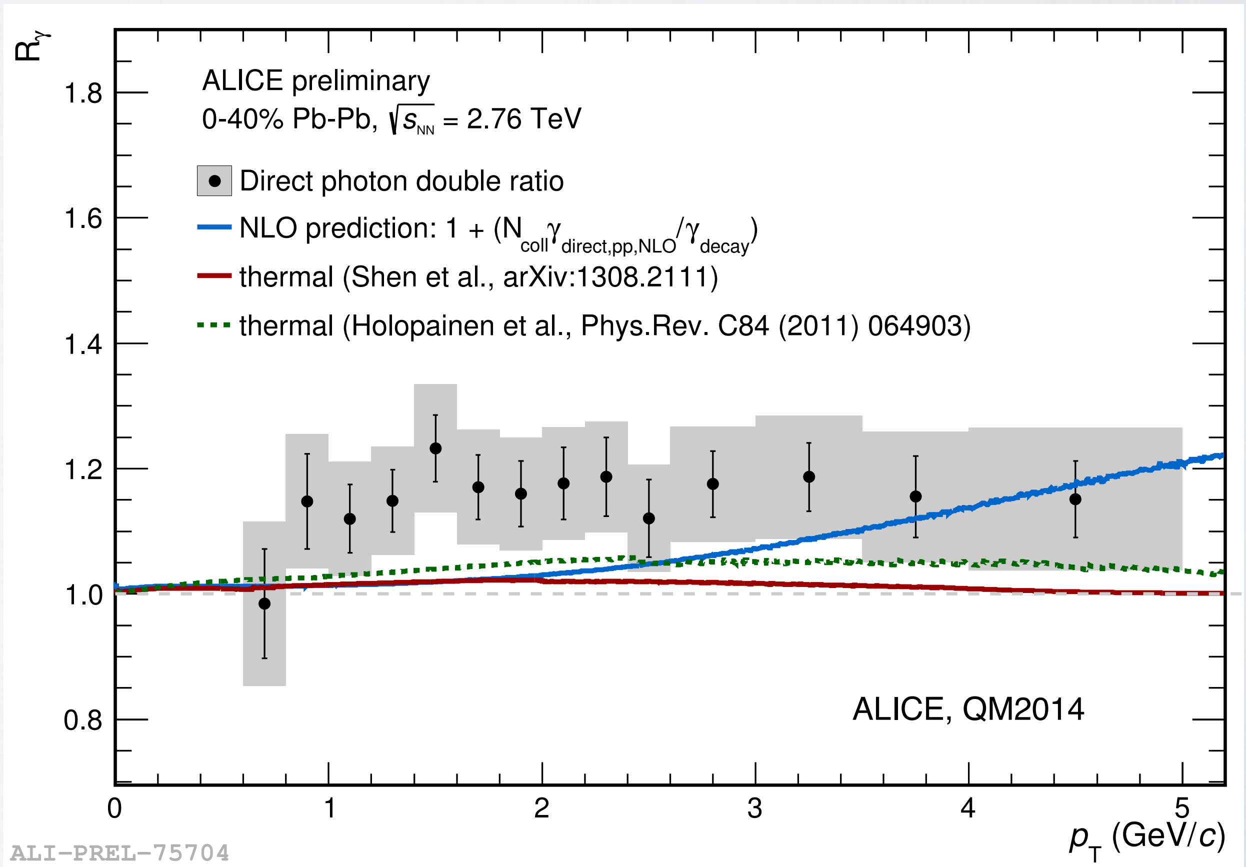


- theoretical challenges:
- high photon rates with relatively small (constant?) slope
- large anisotropy
  - favours late photon emission
- proposed:
  - “pseudocritical enhancement”?
    - maximum photon emission near transition
  - enhanced hadronic rates
    - baryonic contribution

From RHIC to LHC

- expect higher temperature at LHC: higher thermal photon yield
- but:
  - background yield increases more strongly
    - flatter hadron spectra lead to larger decay photon contribution at same p_T
- smaller S/B, larger systematic errors
  - current direct photon measurement
    less significant at LHC

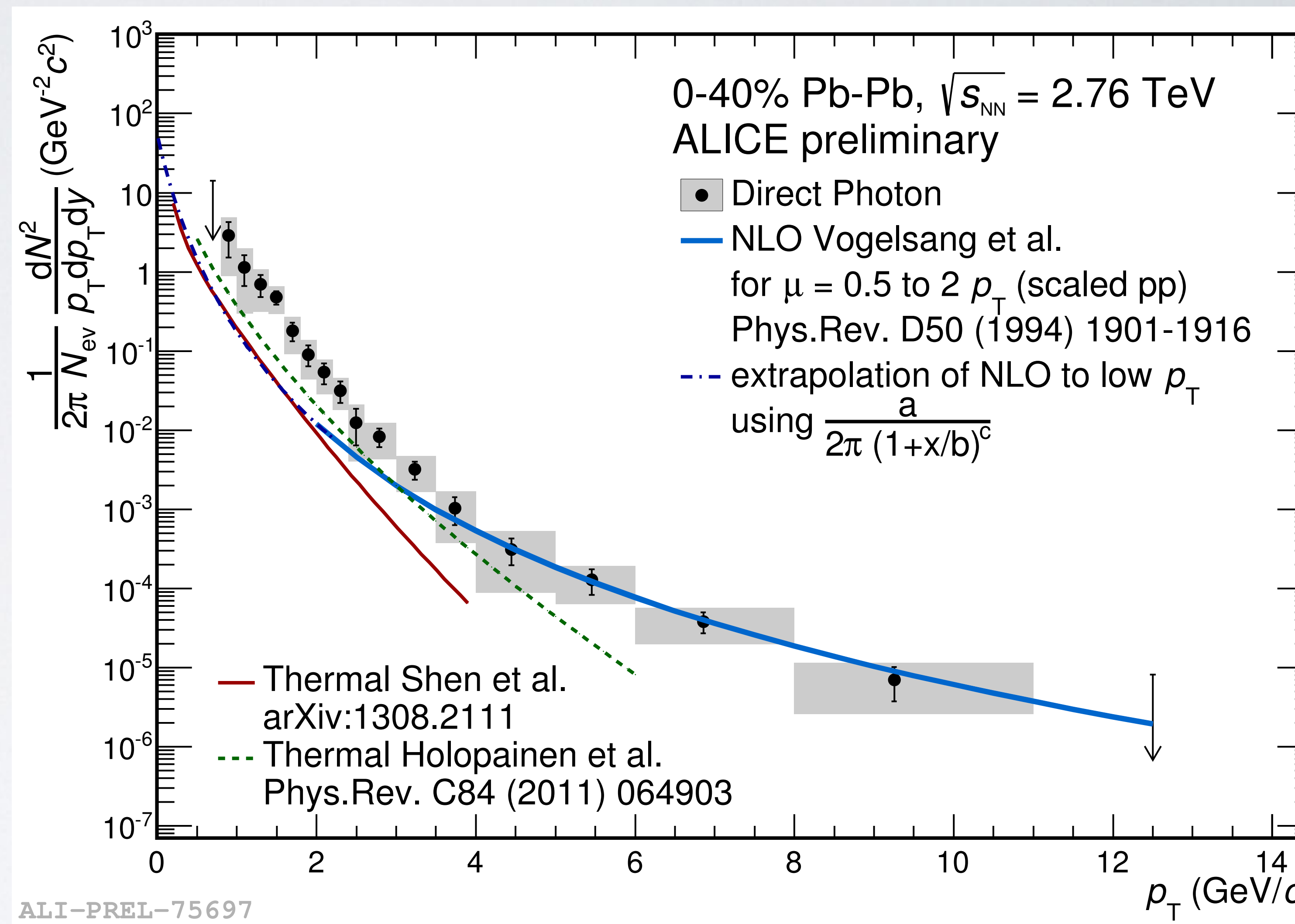




Thermal Photons at LHC

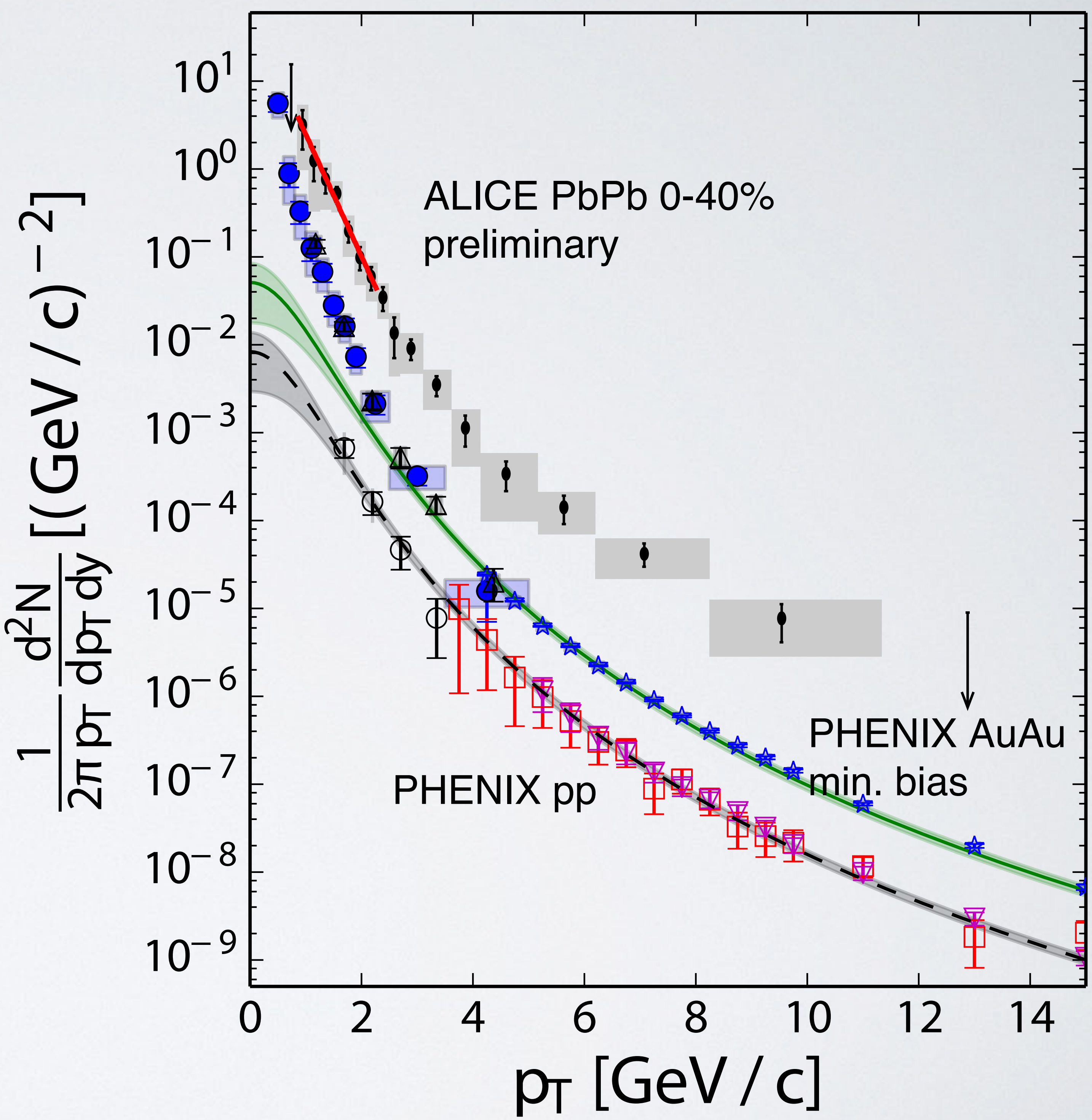
- preliminary results for direct photons in Pb–Pb at LHC
  - measured via photon conversion
- good description with pQCD at high p_T
- low p_T extrapolation can be used to extract direct photon excess
  - similar caveats apply

ALICE, QM2014



Thermal Photons: RHIC vs LHC

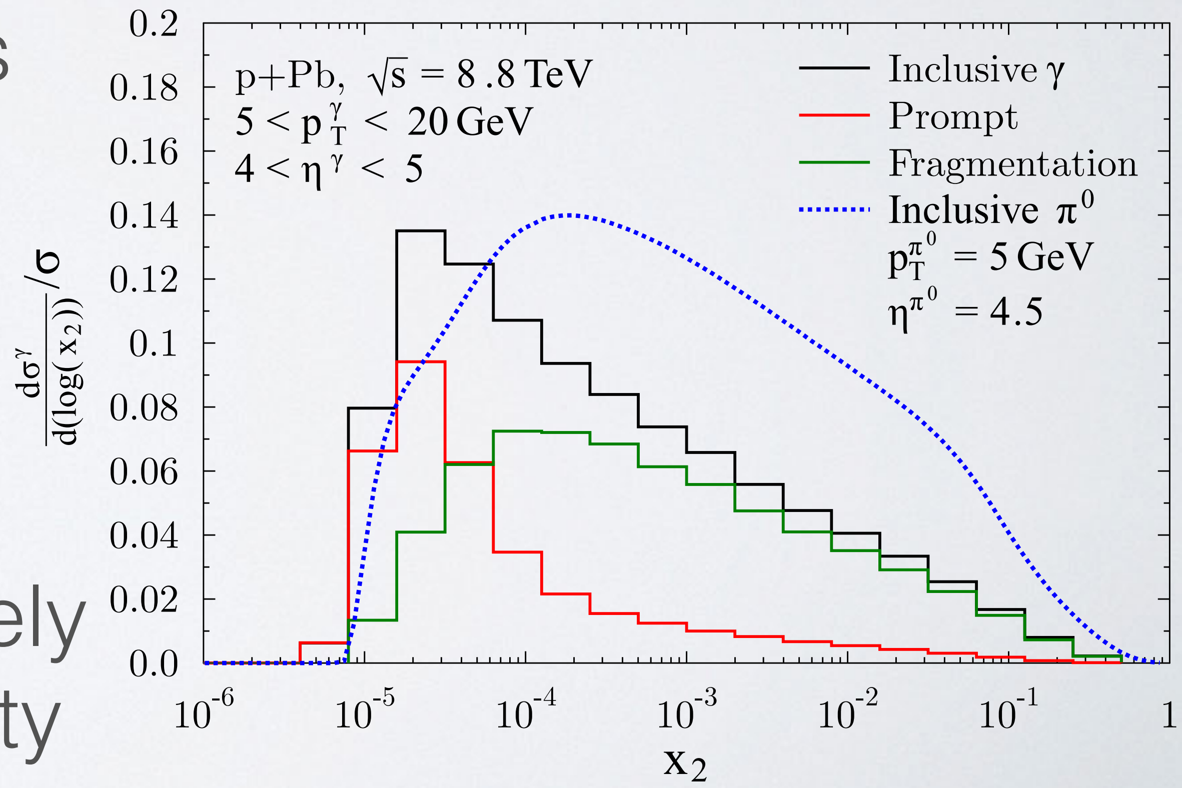
- direct yield comparison: significantly larger photon yield at LHC
  - attention: different centralities
- consistent with larger slope
- looking forward to improved systematics and higher statistics at LHC
  - hadronic contribution should be less important: more direct info from QGP?



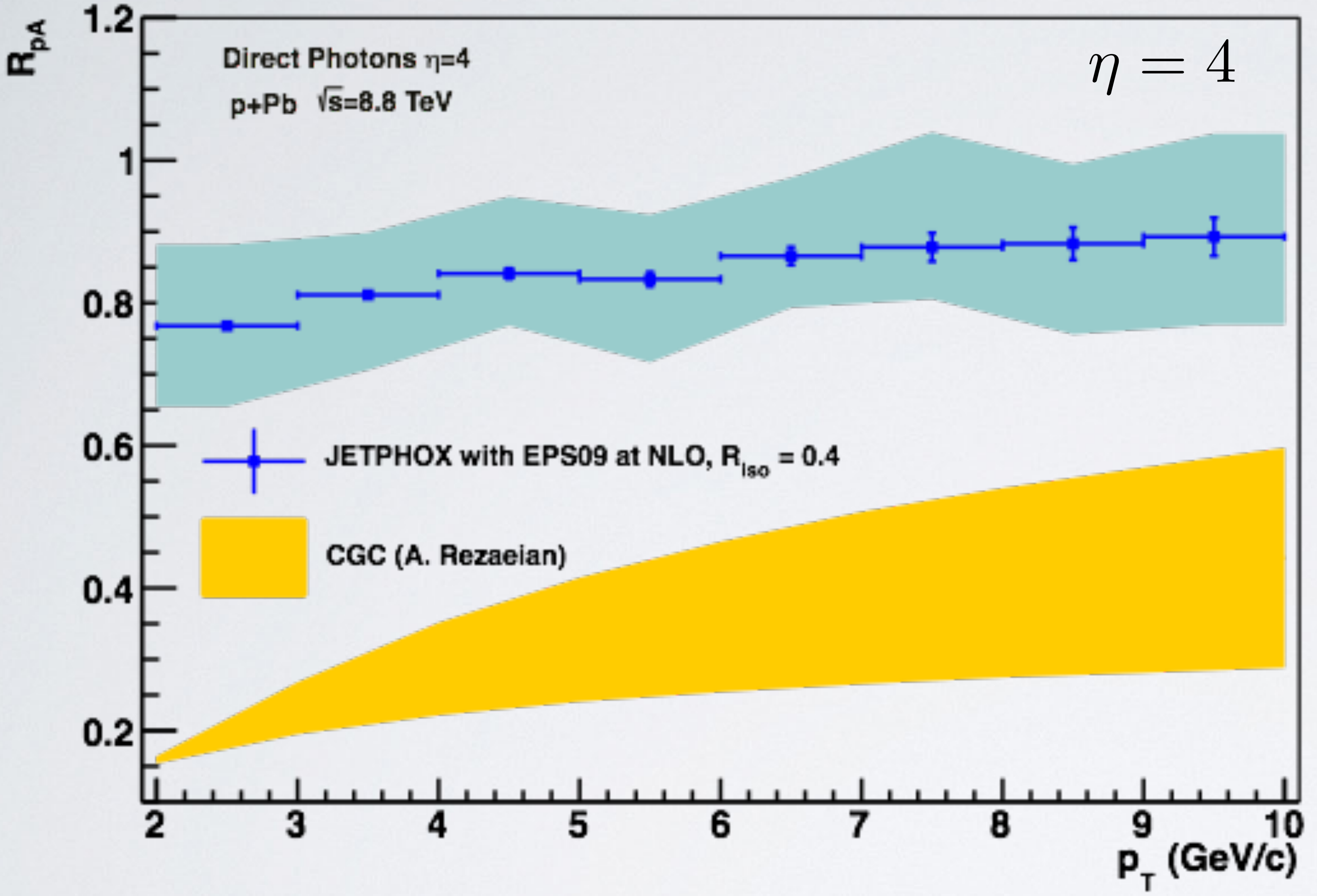
Signals of Saturation?

- interpretation of hadronic observables remains inconclusive
  - final state modifications in p–A collisions?
  - production process not fully understood for many hadrons
  - kinematic relation to Bjorken-x uncertain (e.g. fragmentation)
- cleaner observables: EM probes (direct photons, Drell-Yan)
  - no final state interaction
  - well-understood production process
  - well-defined kinematics
- advantage of direct photons:
  large cross section
  - forward p–A measurement of DY likely not possible with expected luminosity

NLO pQCD calculations with shadowing (EPS09)
Helenius, Eskola, Paukkunen, arXiv:1406.1689



Benchmark Measurement: nPDF/DGLAP vs CGC

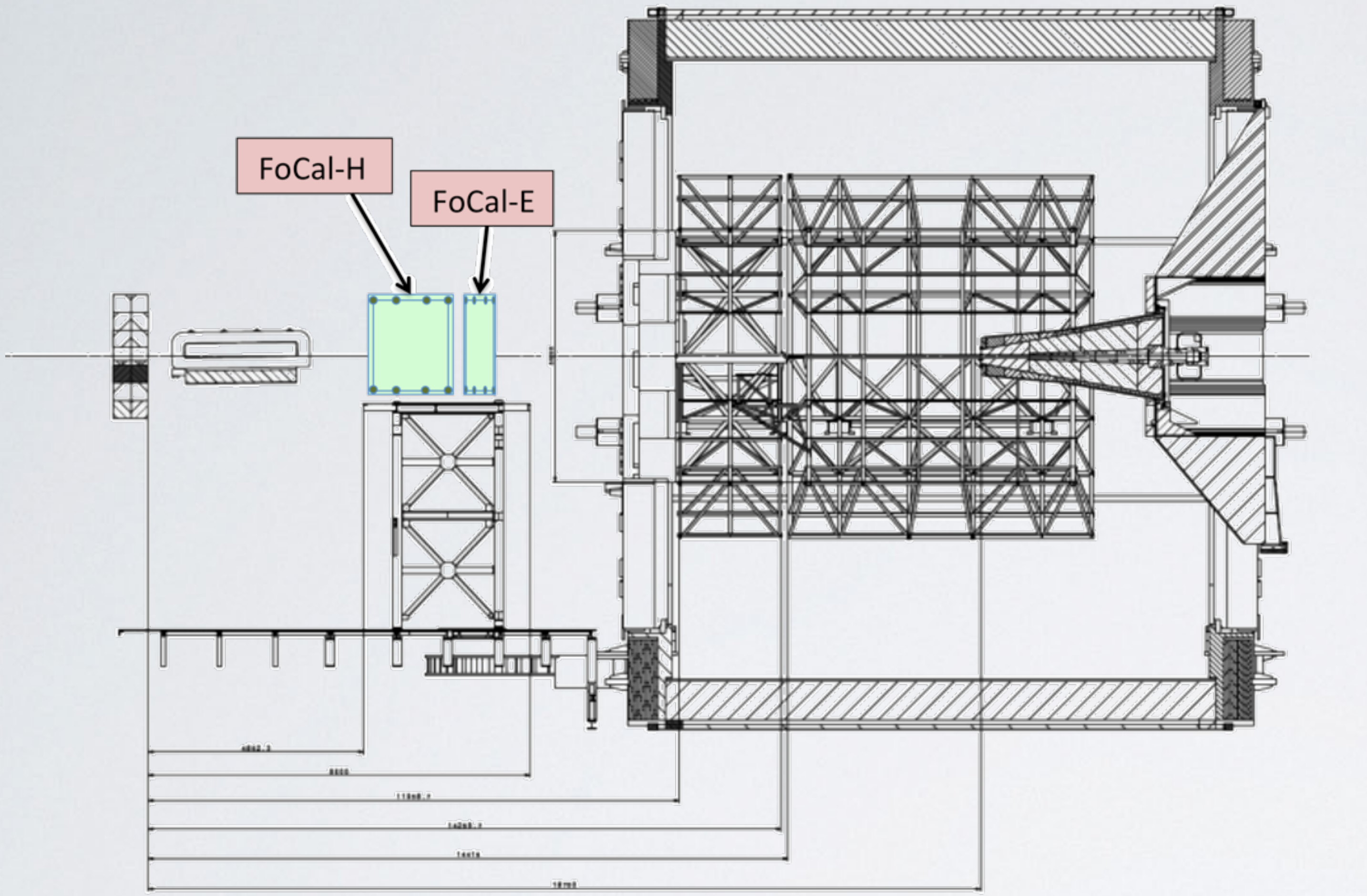


two scenarios for forward γ production in p-A at LHC:

- normal nuclear effects
  linear evolution, shadowing
- saturation/CGC
  running coupling BK evolution

- strong suppression in direct γ R_{pA}
- signals expected at forward η, low-intermediate p_T
  - transition expected - where?

FoCal Upgrade in ALICE



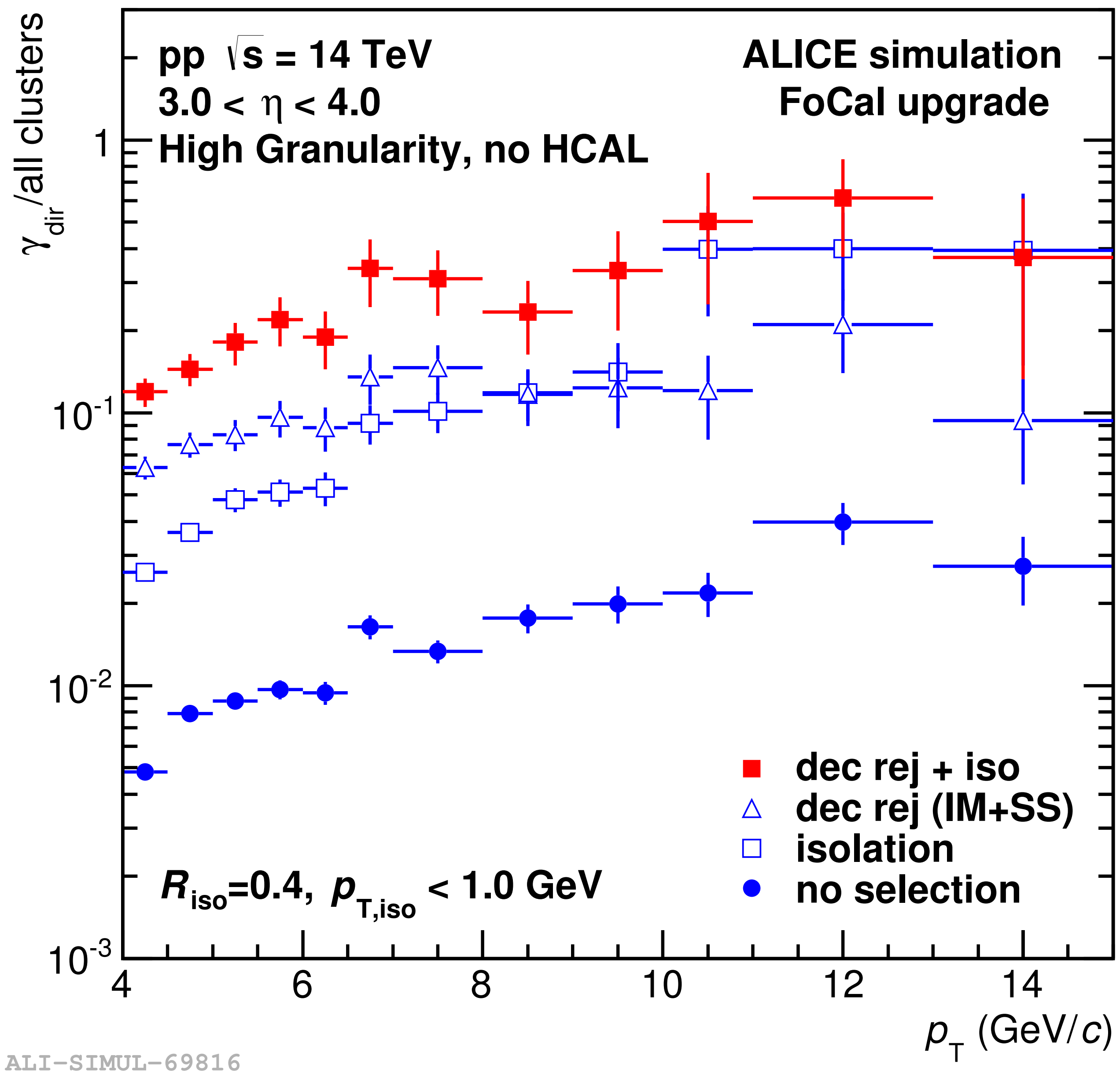
electromagnetic calorimeter for γ and π^0 measurement
+ **hadronic calorimeter** for isolation and jet measurement

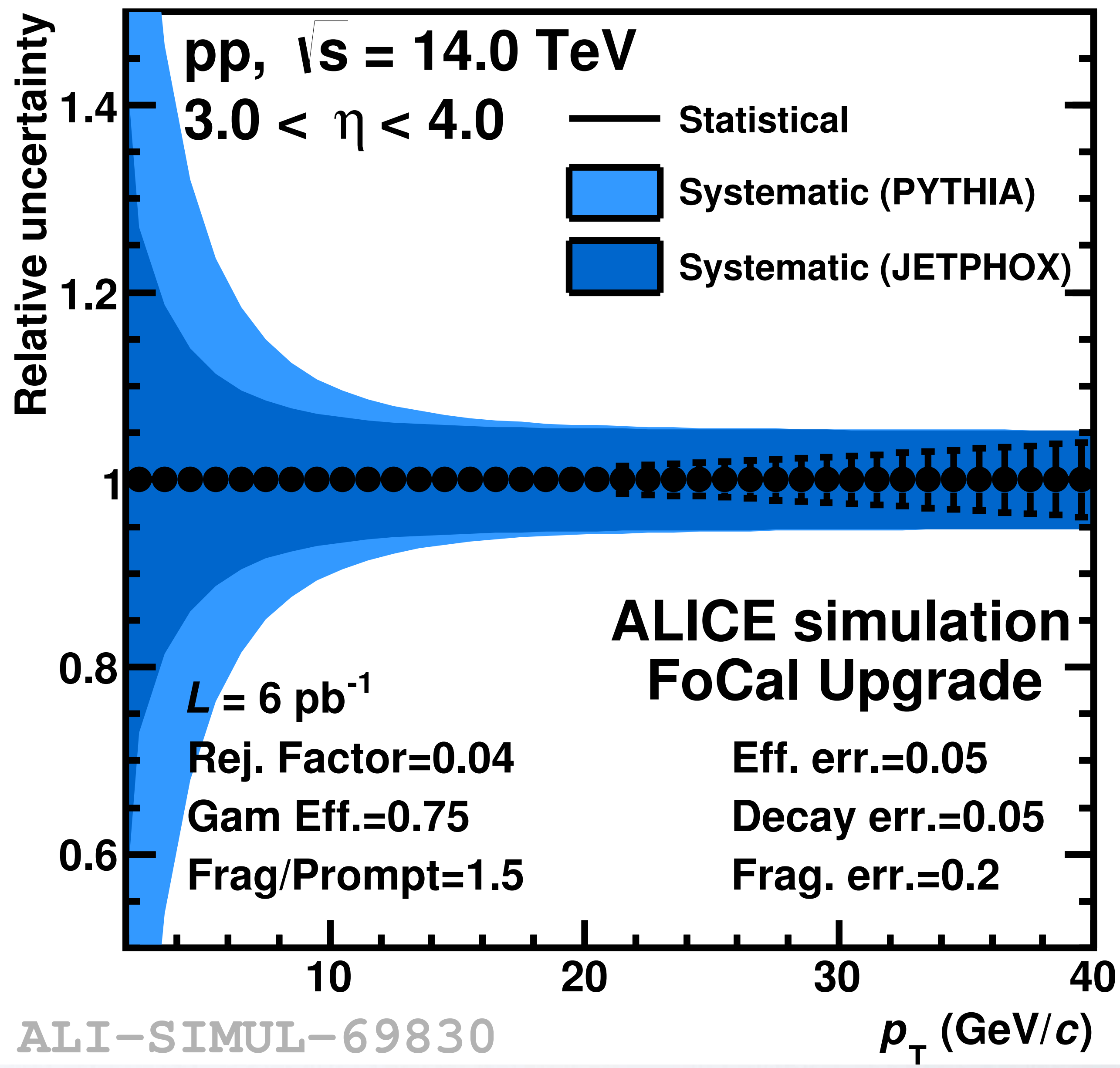
baseline scenario:
at $z \approx 7$m (outside magnet)
$3.3 < \eta < 5.3$

discussed for possible installation in LS3 (≈2024)

- main challenge: separate γ/π^0 at high energy
- need small Molière radius, high-granularity read-out
  - Si-W calorimeter, granularity ≈ 1mm²

Direct γ Performance in pp

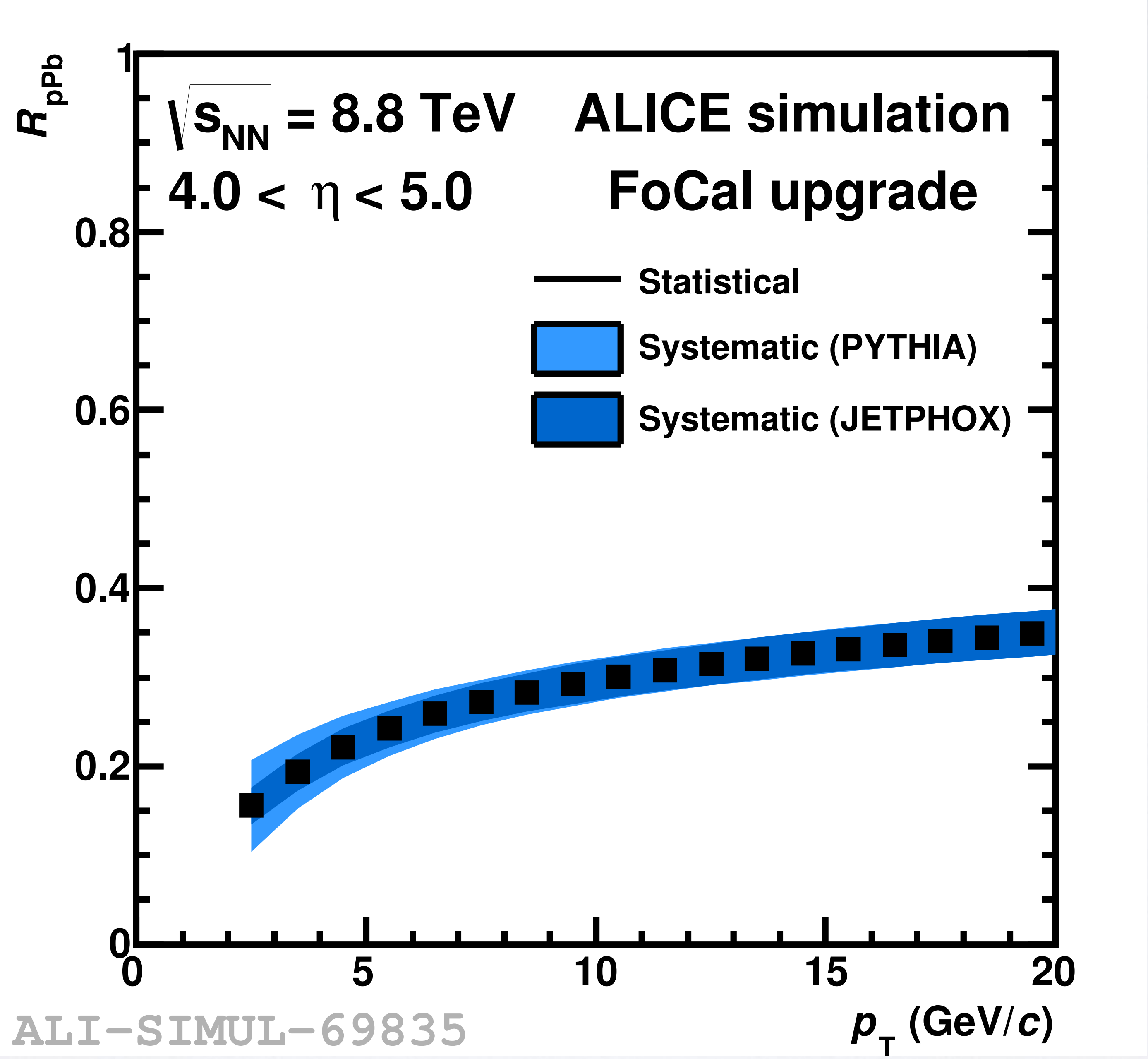




direct photon/all > 0.1
for p_T > 4 GeV/c

20-40% uncertainty
at p_T = 4 GeV/c
decreases with increasing p_T

Performance on R_{pPb}



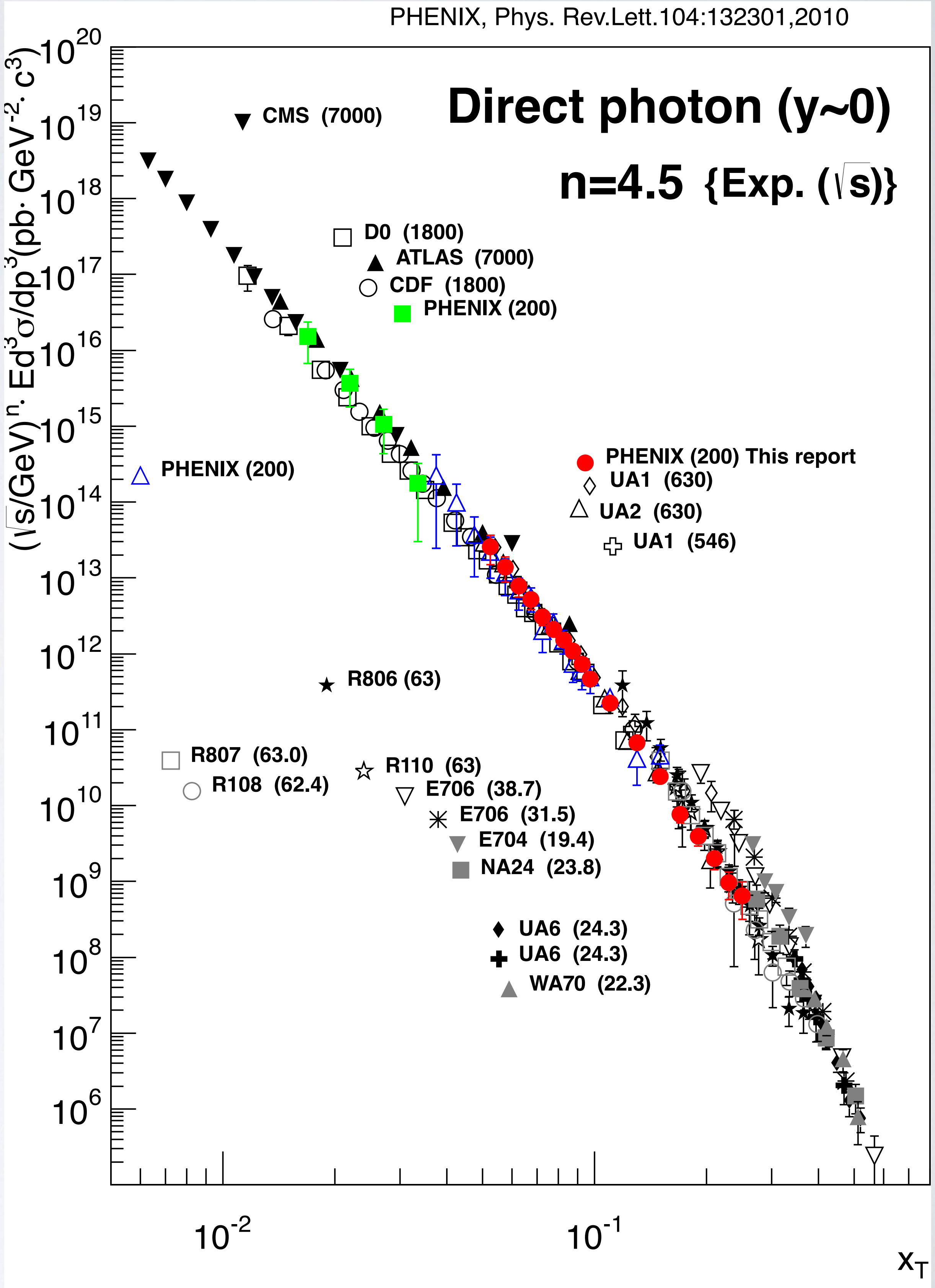
- expect significant constraint on direct photon R_{pPb}
  - confirm or refute CGC effects, constrain nPDF

Conclusions

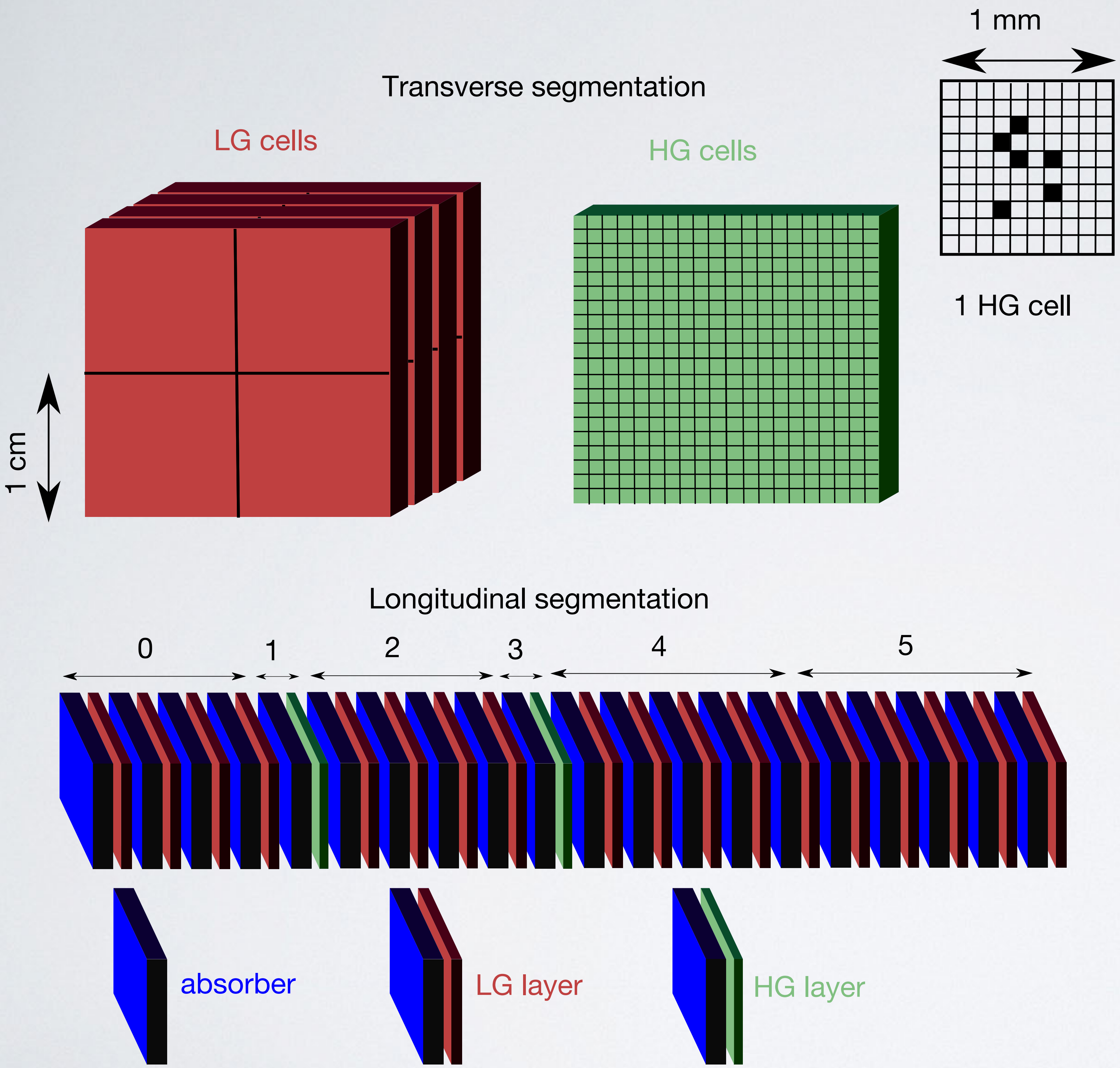
- High p_T prompt photons well described by pQCD.
  - Uncertainties at low p_T?
    - Important for thermal photons
- Low p_T photon photon excess observed.
  - Very prominent at RHIC with high yield and strong v_2.
    - Challenge for theory!
  - Preliminary results from LHC consistent.
    - Looking forward to improvements to come …
- Future challenge: Forward direct photons as a signal of saturation.
  - Crucial measurement possible through proposed ALICE upgrade.

Backup

Prompt Photons Overview



FoCal Strawman Design

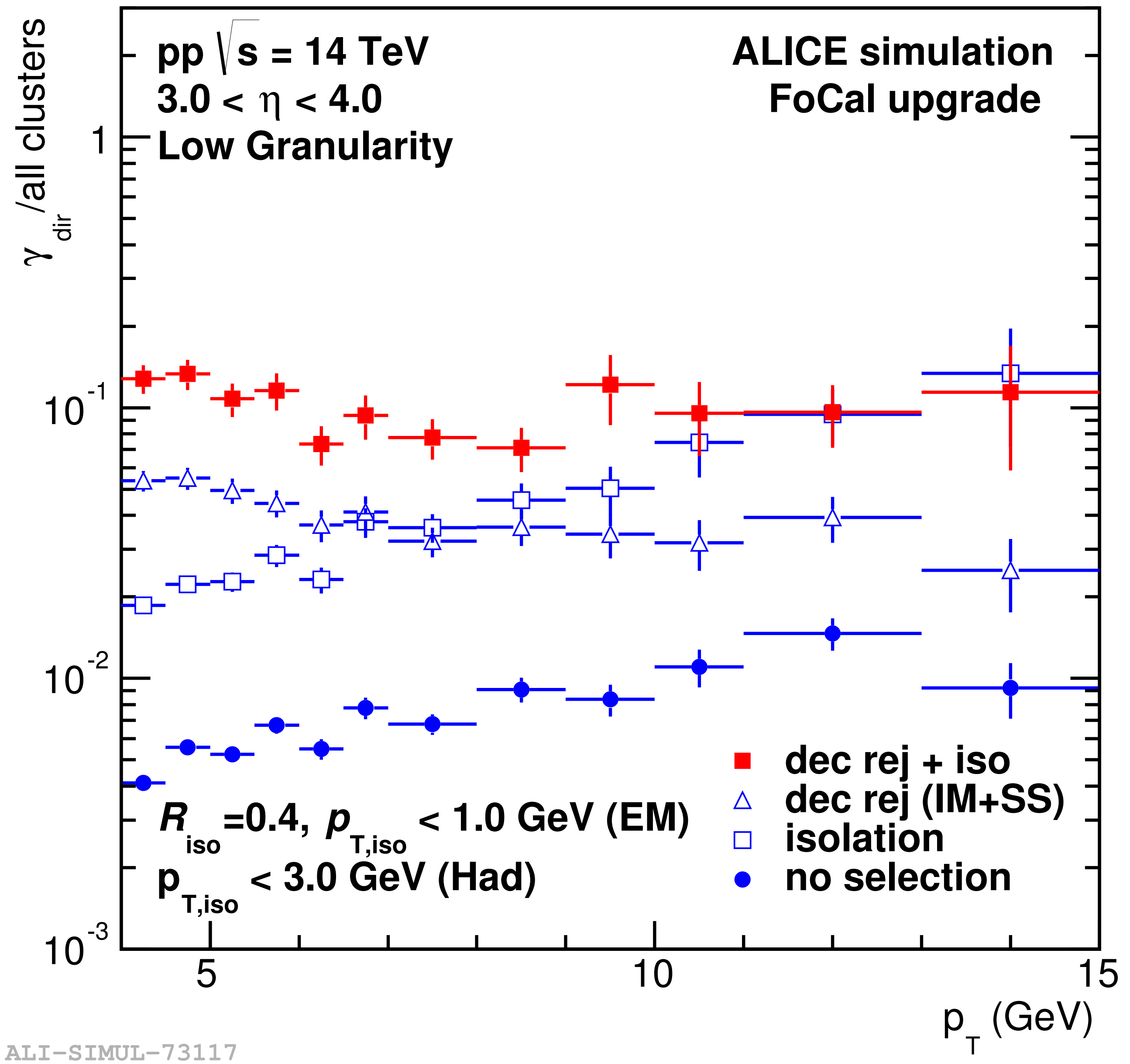


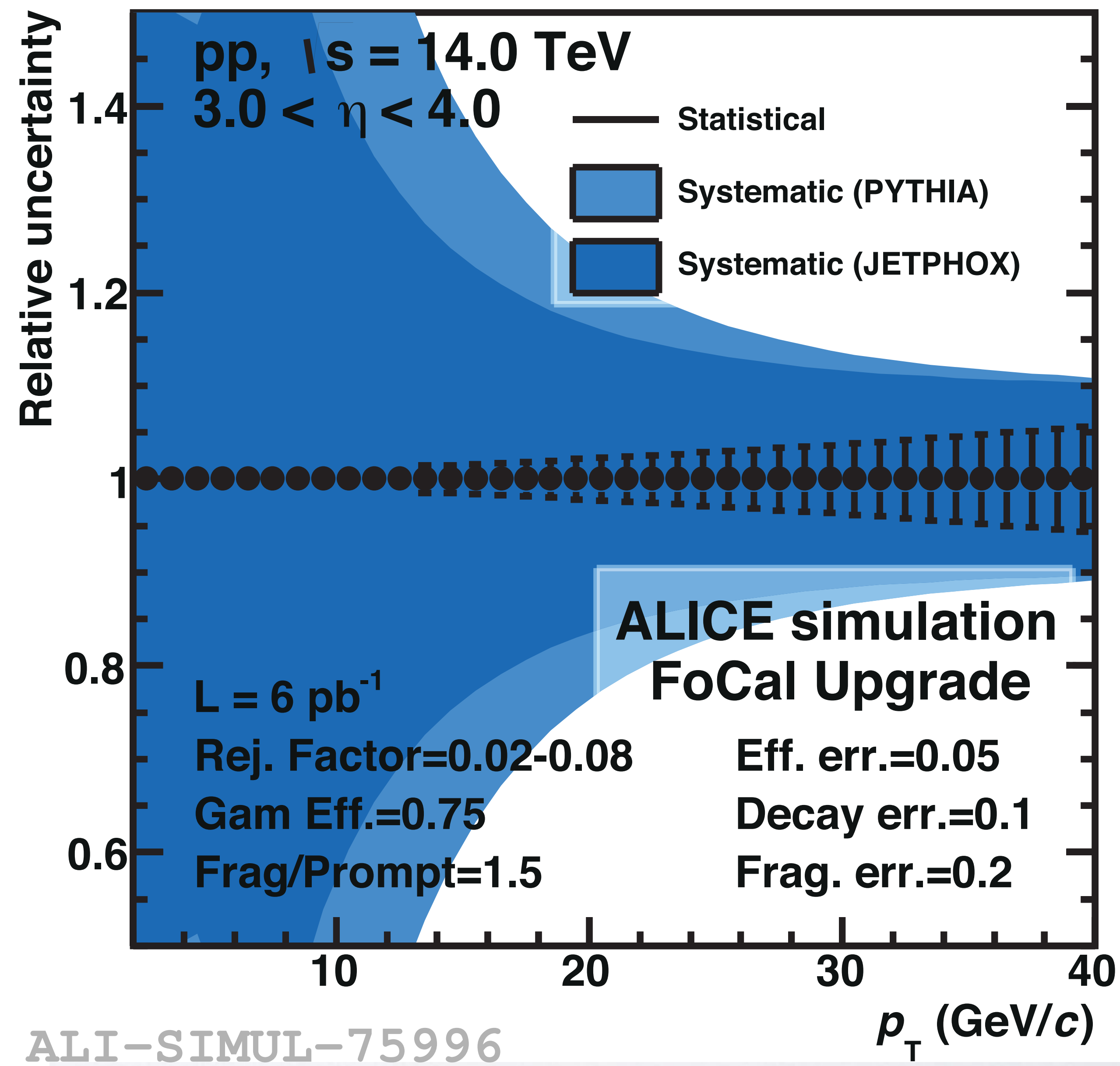
studied in performance simulations:

24 layers:
W (3.5mm ≈ 1 X_0) +
Si-sensors (2 types)

- low granularity (≈ 1 cm^2), Si-pads
- high granularity (≈ 1 mm^2), obtained with pixels (e.g. CMOS-MAPS)

Low Granularity Measurement





- low granularity (1cm²) does not allow efficient decay rejection
- direct photon/all ≈ 0.1 for all p_T

significant measurement not possible at low p_T

NB: conditions similar to LHCb