Experimental overview of electromagnetic and weak probes

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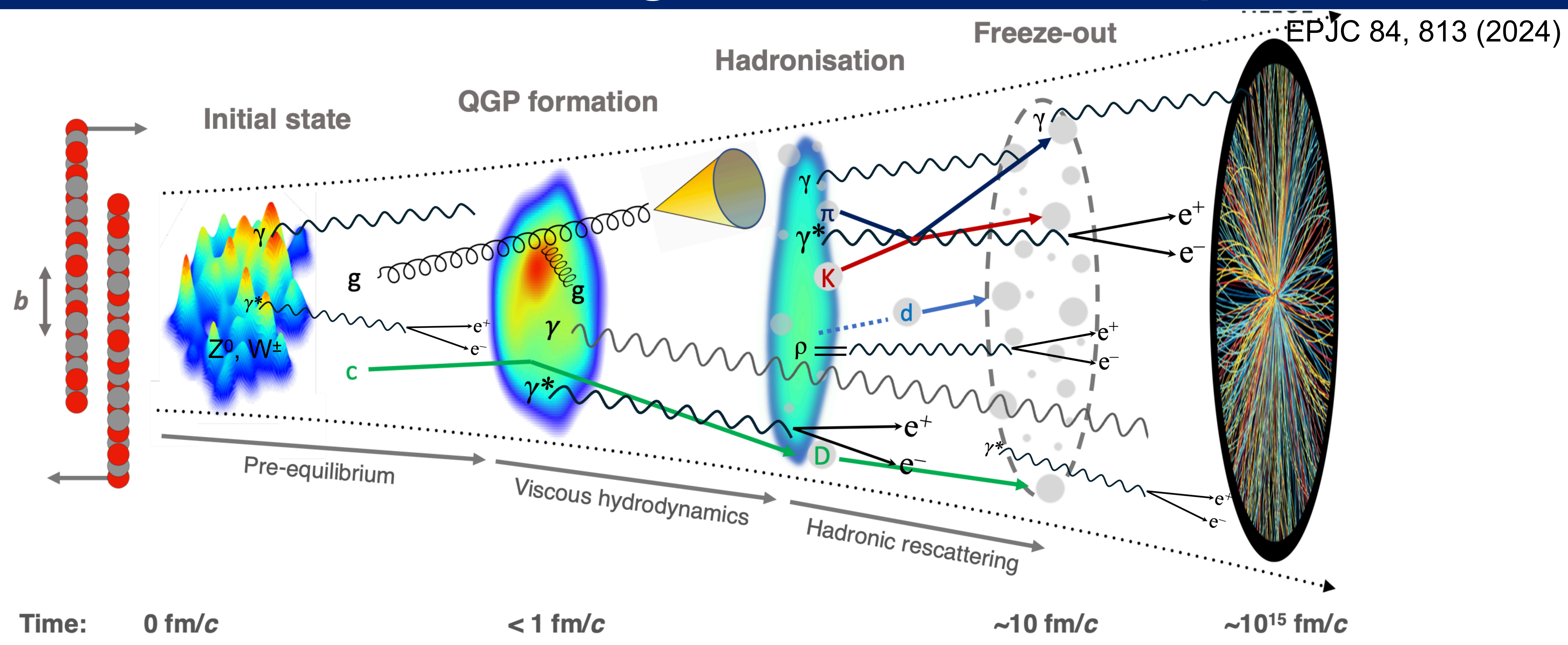
September 26th, 2024

HP2024
NAGASAKI

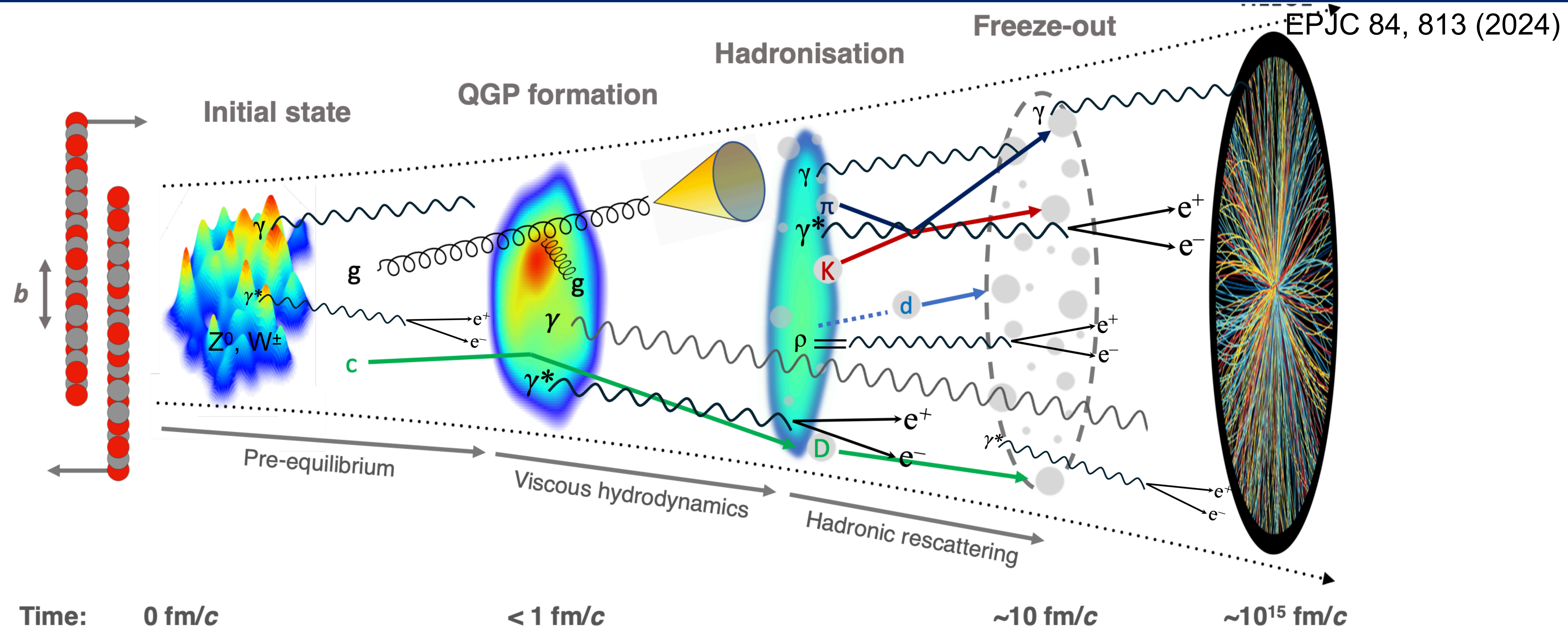
Uniqueness of electromagnetic and weak probes

EPJC 84, 813 (2024)



- Emitted from all stages of the collision
- Leave the system with negligible strong final-state interaction
- Carry undistorted information at the time of their production

Source of electromagnetic and weak probes



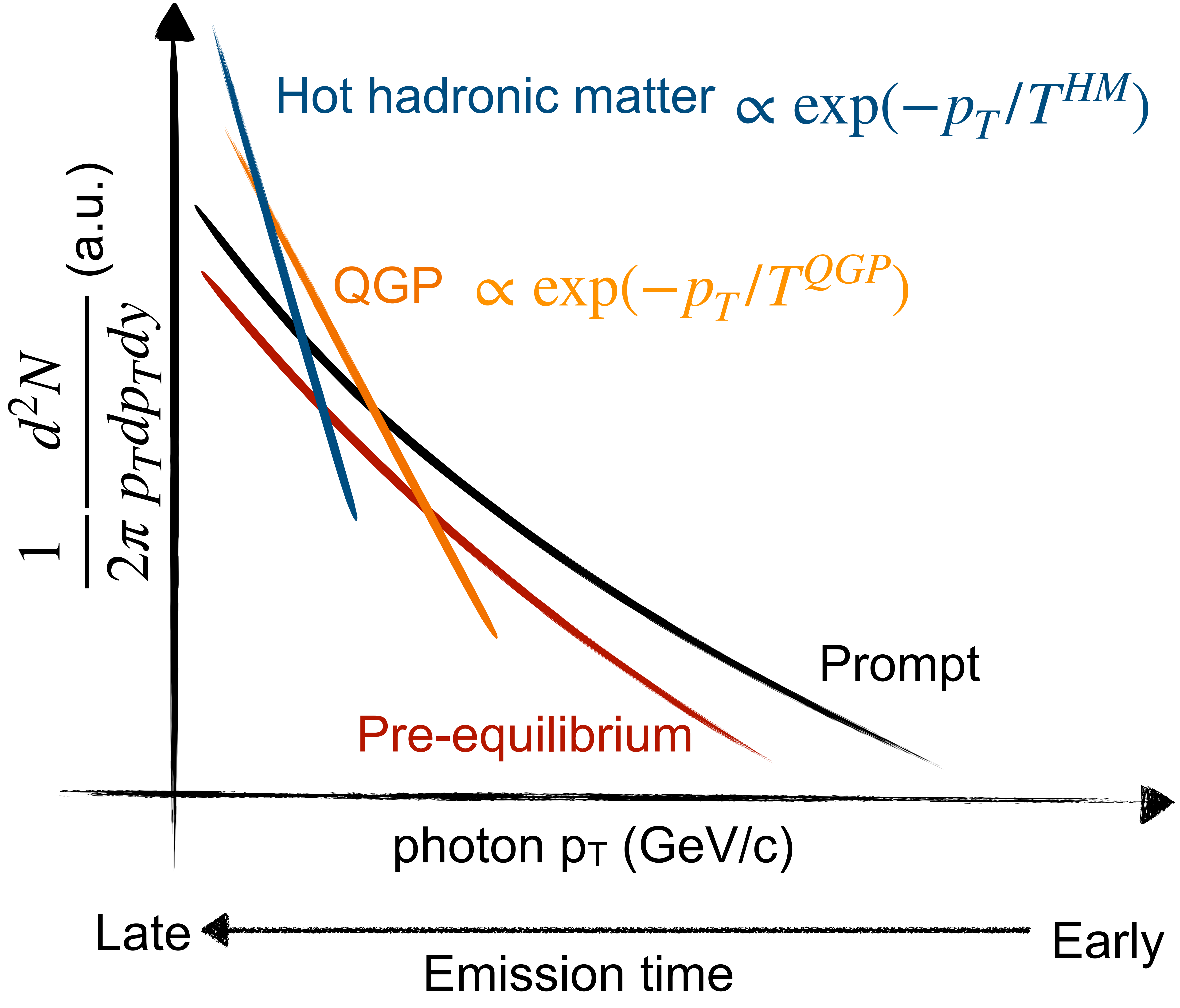
Hard scatterings
- Test pQCD
- Constrain nPDFs
- Reference for medium response (γ-jet, Z-jet)

Pre-equilibrium phase
- Mechanism of equilibrium

Thermal radiation
- Constrain space-time evolution
- Averaged temperature

Chiral symmetry restoration
- ρ broadening
- ρ-a_1 mixing

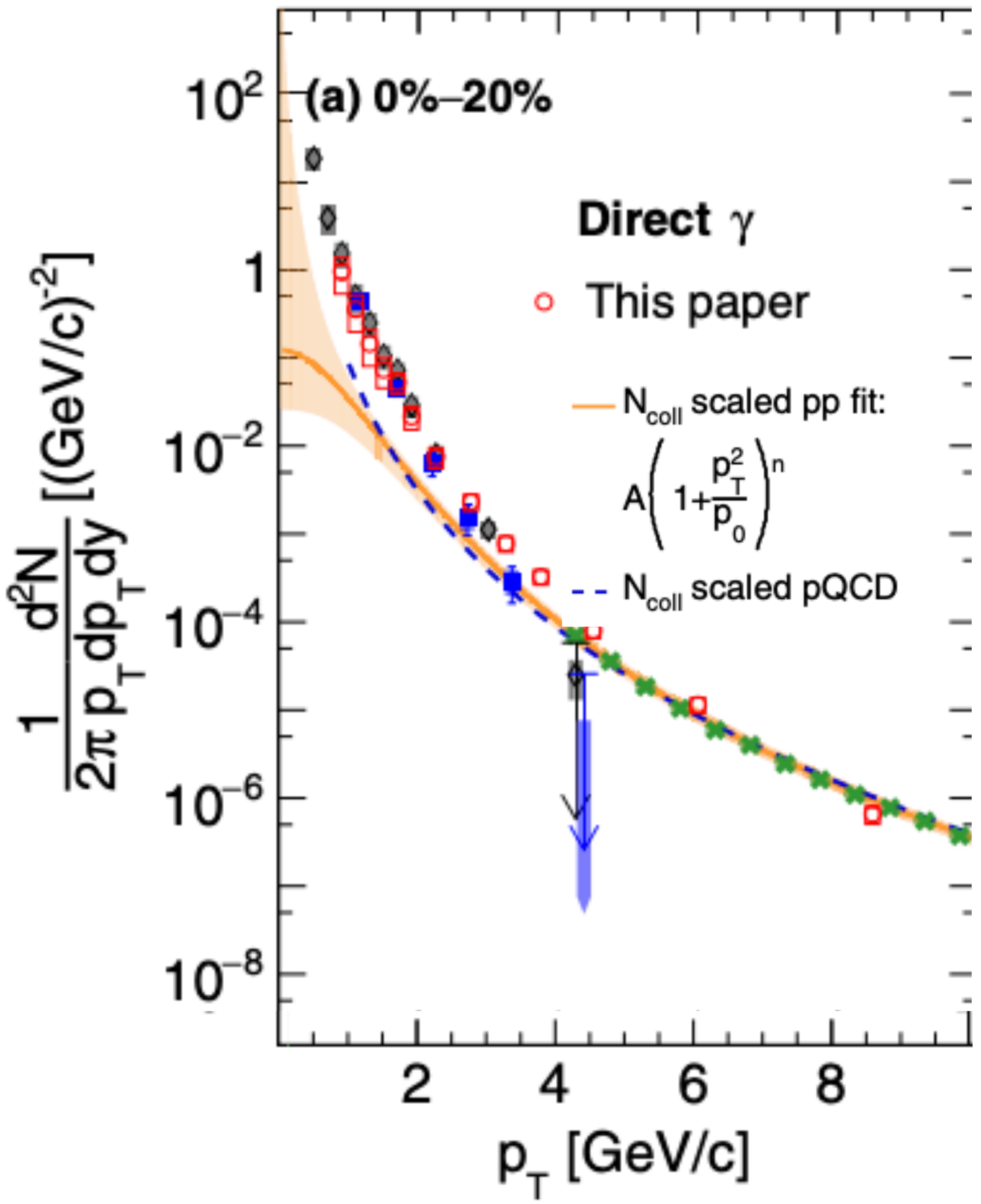
Direct photons

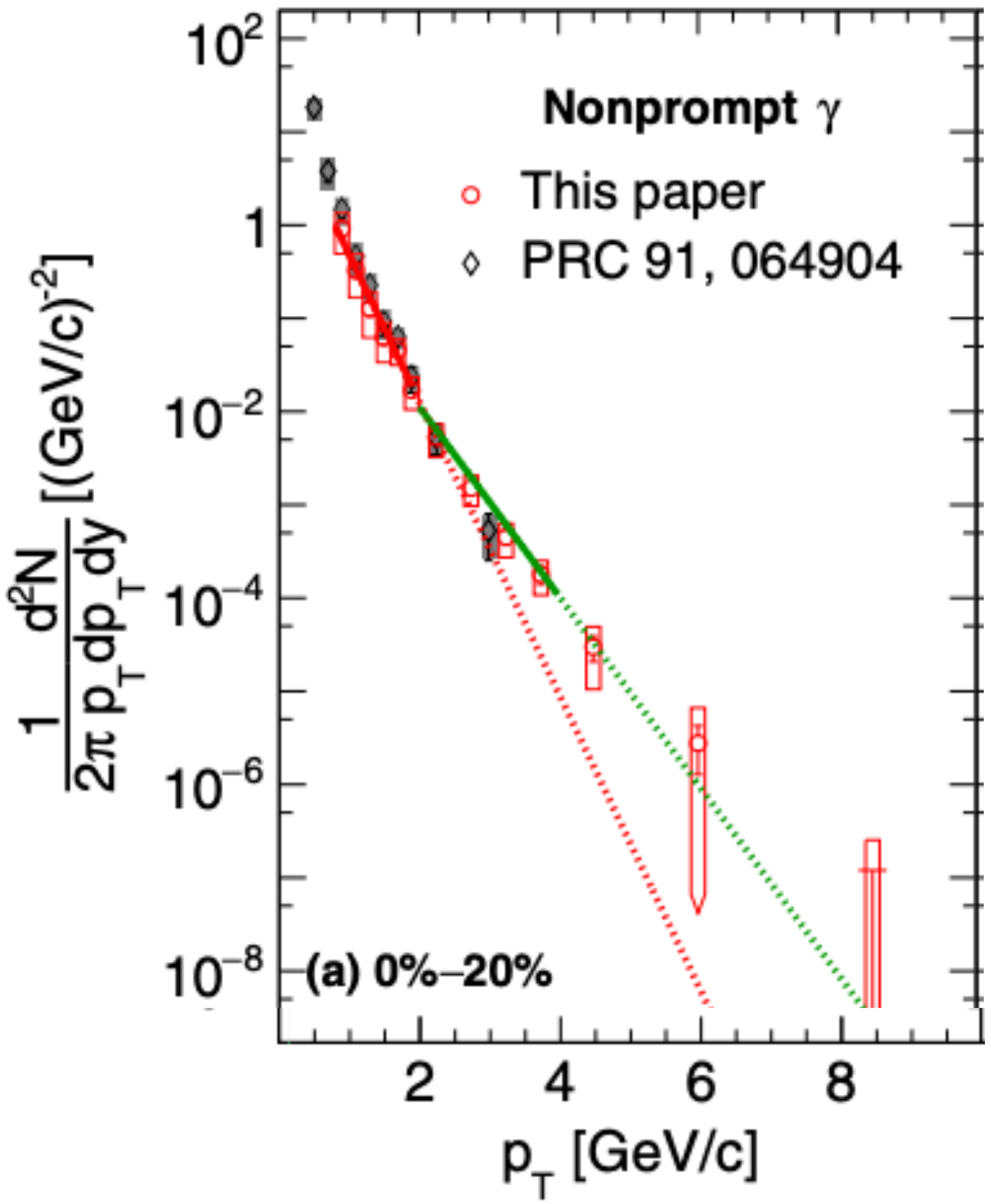


Direct photons: photons not originating from hadron decays

- Prompt photons
  - Initial hard scatterings
  - Fragmentation
- Pre-equilibrium radiation
- Thermal radiation
  - QGP
  - Hot hadronic matter
- Jet-medium photons (Not covered in this talk)

Direct photons in PHENIX



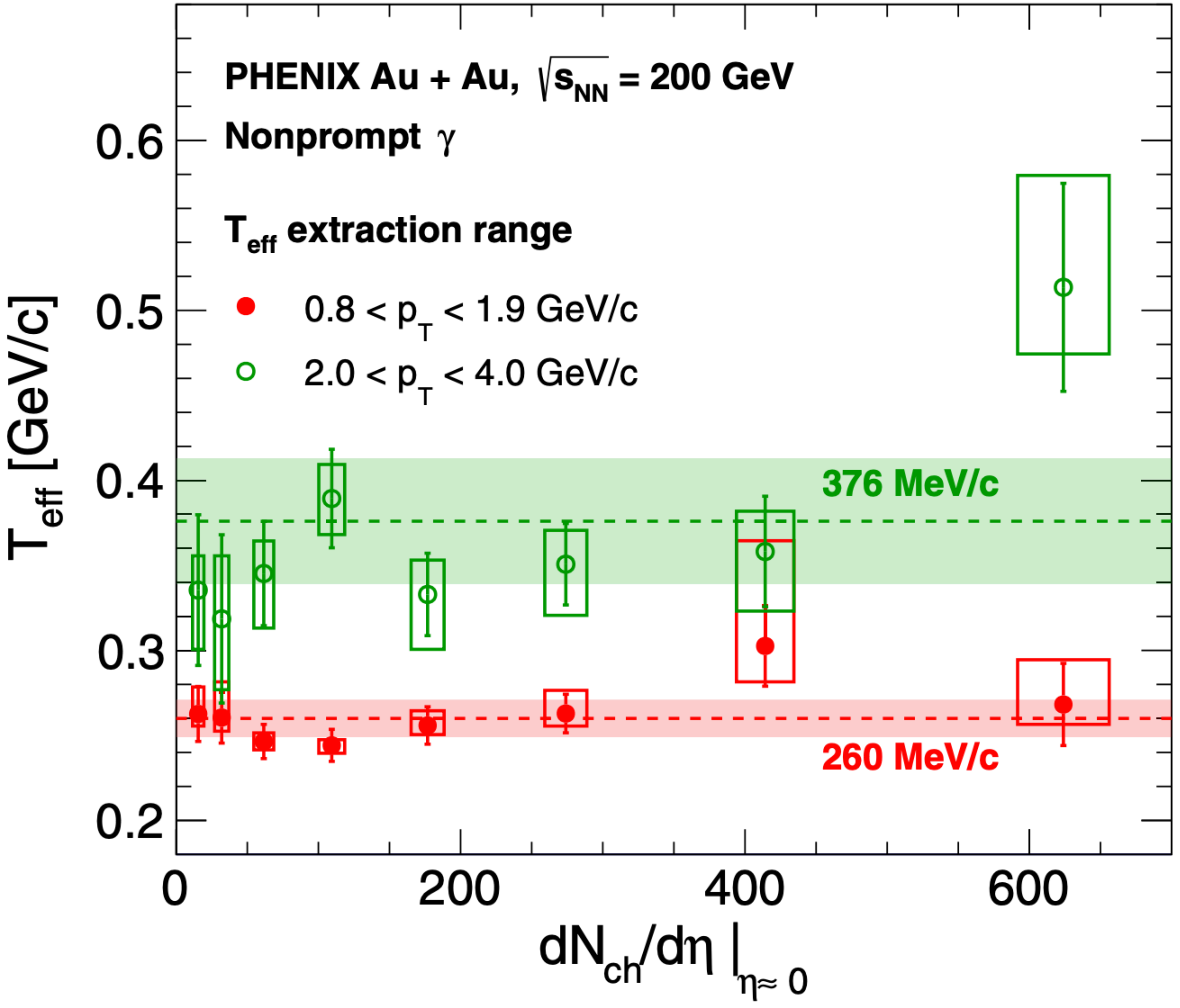


Vassu Doomra, Sep. 24th
PRC 109, 044912 (2024), PHENIX

- Nonprompt direct photons = direct photons – prompt photons = pre-eq. + thermal photons
- Experimentally, direct photons in AA – N_{coll}-scaled pp data at the same energy

Interpretation of inverse slope T_{eff}

Vassu Doomra, Sep. 24th
PRC 109, 044912 (2024), PHENIX

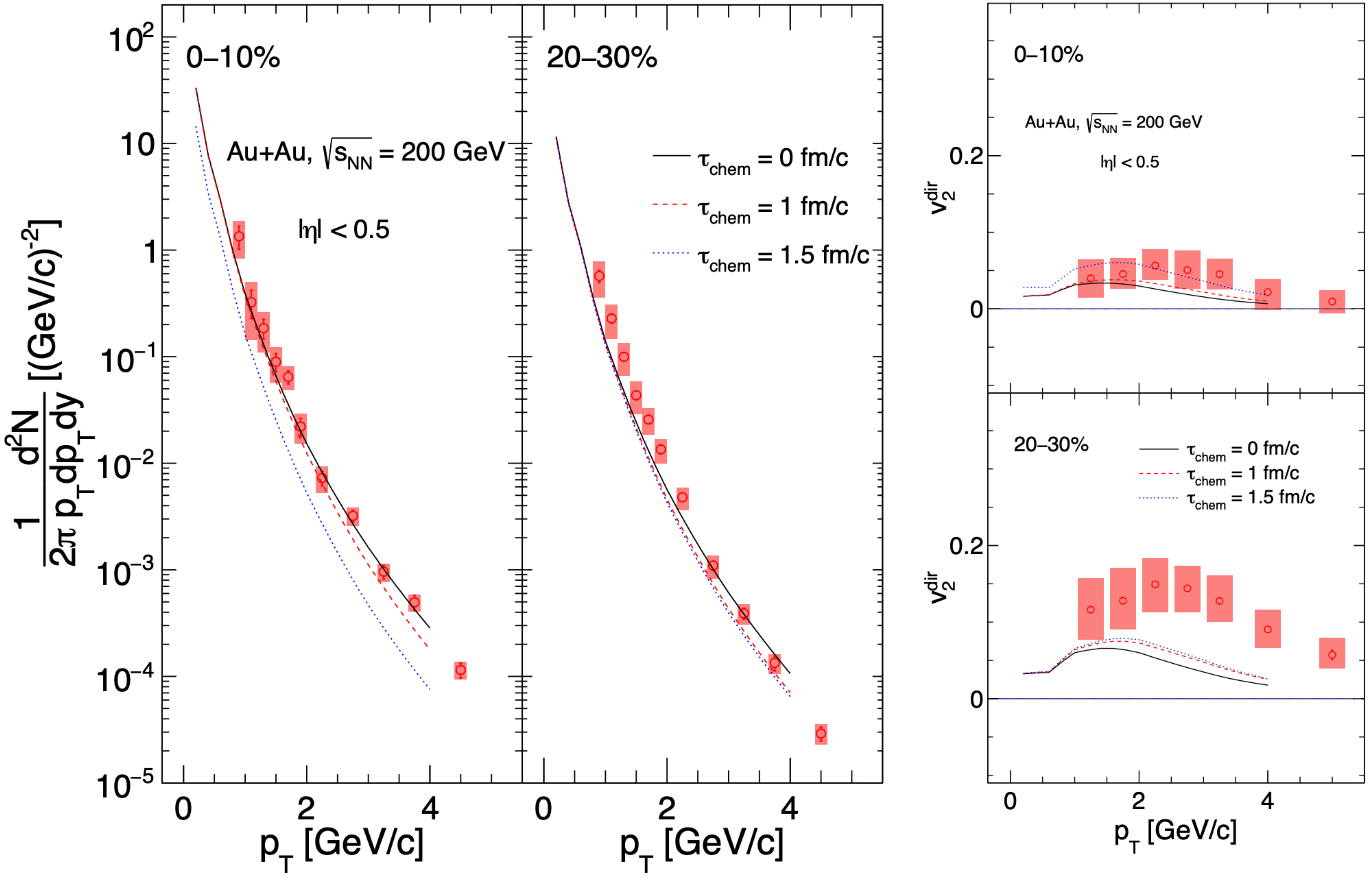


- T_{eff} from nonprompt direct photons
- No clear dependence on $dN_{ch}/d\eta$, but small increase is not excluded either

- Naive idea:
  - higher p_T; earlier emission and higher T
- In reality:
  - Blueshift due to radial flow
    - Global effect is small due to integration over space-time
    - Can be studied by simple model: $T_0 = \dfrac{T_{eff}}{1 - \dfrac{5}{2}\dfrac{T_{eff}}{p_T}}$
  - Pre-eq. contribution

arXiv:2205.12299
arXiv:2305.10669
arXiv:2308.09747

Direct-photon puzzle



Vassu Doomra, Sep. 24th
PRC 109, 044912 (2024), PHENIX
Theory curve: PRC 105, 014909 (2022)

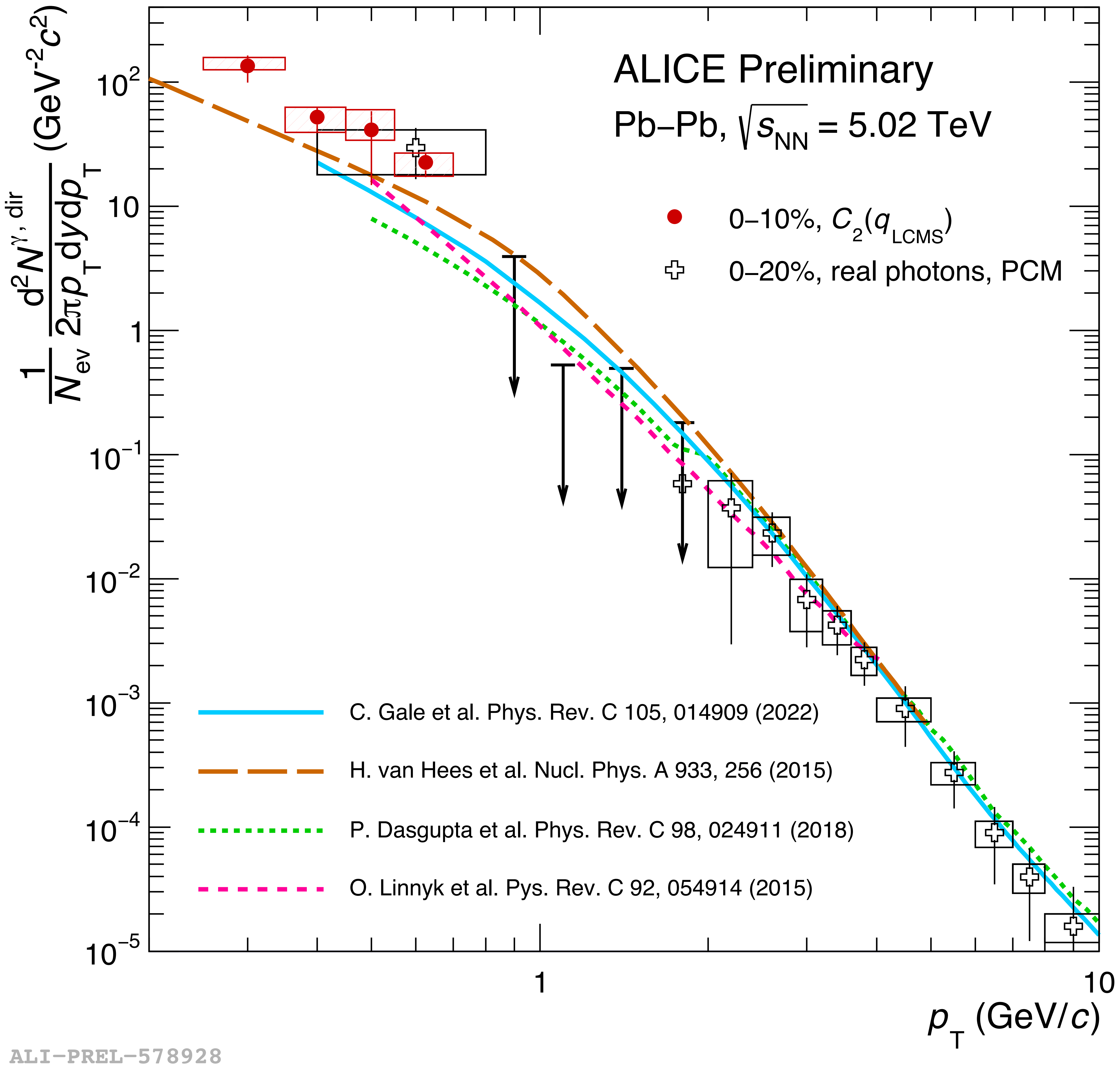
- Large yield: early emission
- Large v_2: late emission

- Difficult to describe the large yield and v_2 simultaneously

- Not observed in ALICE due to large uncertainty

PLB 789 (2019) 308, ALICE

Direct-photon HBT in ALICE

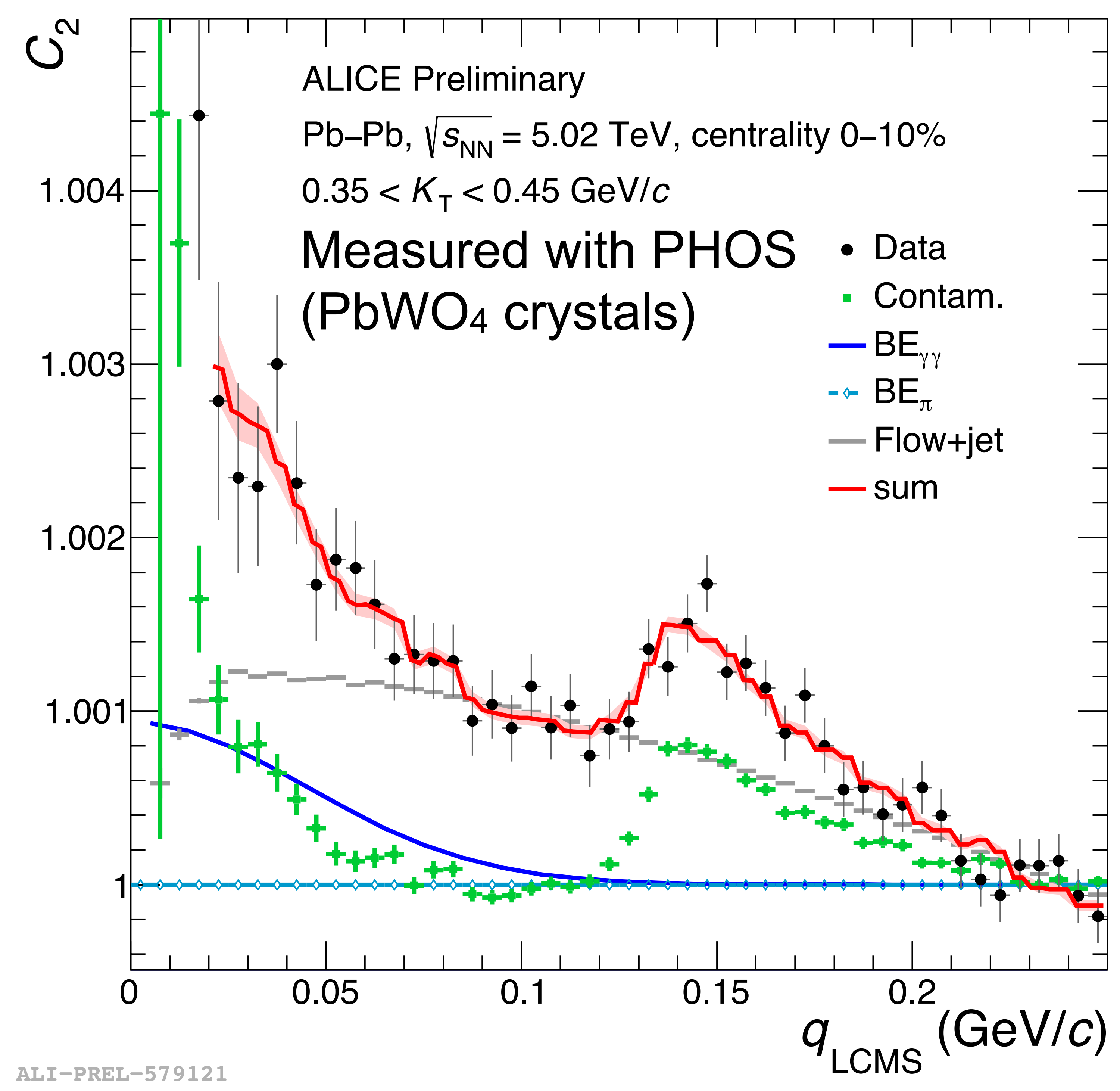


First two-photon interferometry: PRL 93 (2004) 022301, WA98
Dmitri Peresunko, Sep. 24th

- Alternative approach for direct photons at low p_T
  - λ: correlation strength
  - q: momentum difference between two photons
- Four-component template fit to data

$$A(1+\lambda \exp(-q^2R^2)+a_{contam}Cont+a_{BE\,\pi\pi}(C_2^{BE\,\pi\pi}-1)+a_{Flow}(C_2^{Flow}-1))$$

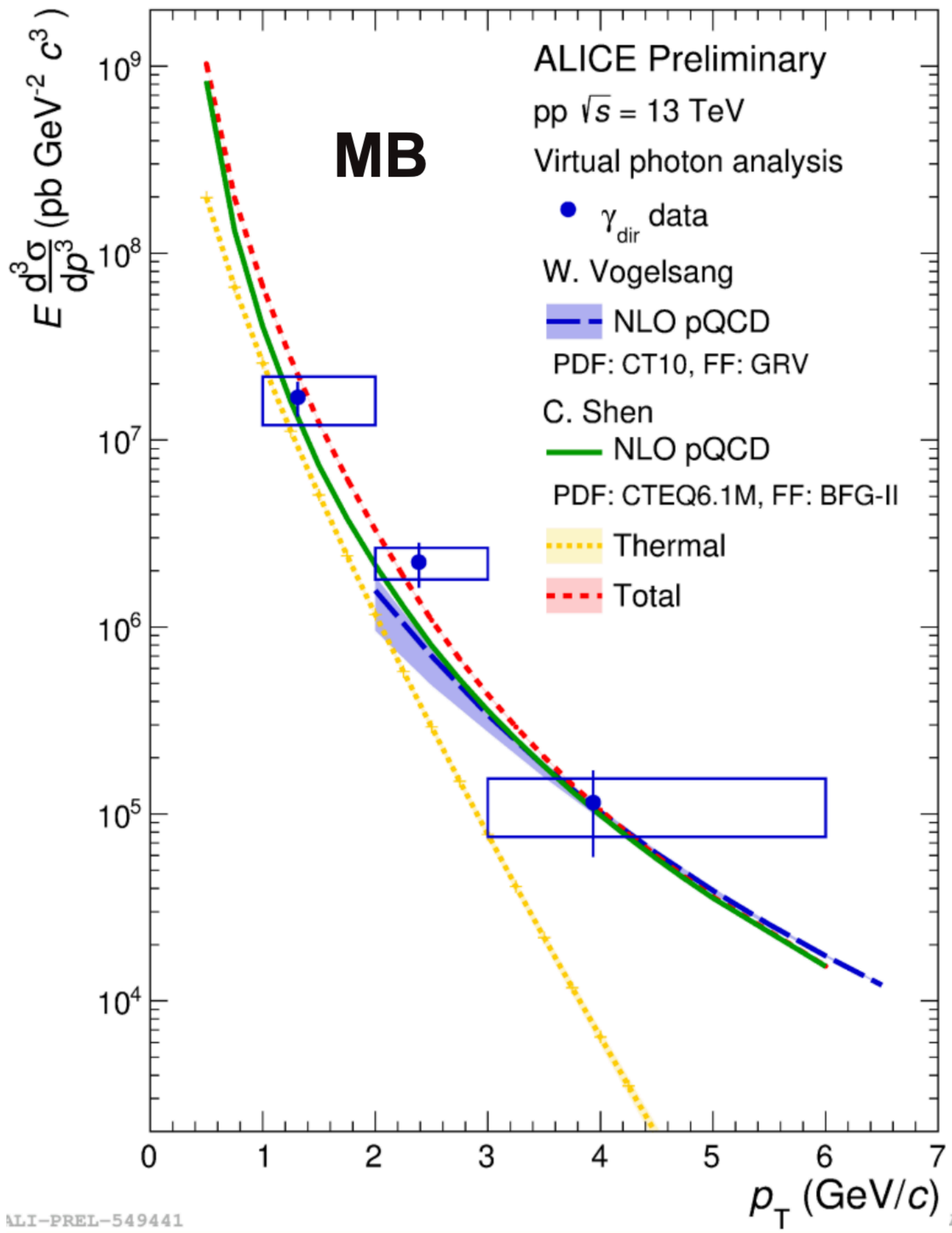
$$\lambda=\frac{1}{2}\left(\frac{N_\gamma^{dir}}{N_\gamma^{incl}}\right)^2$$

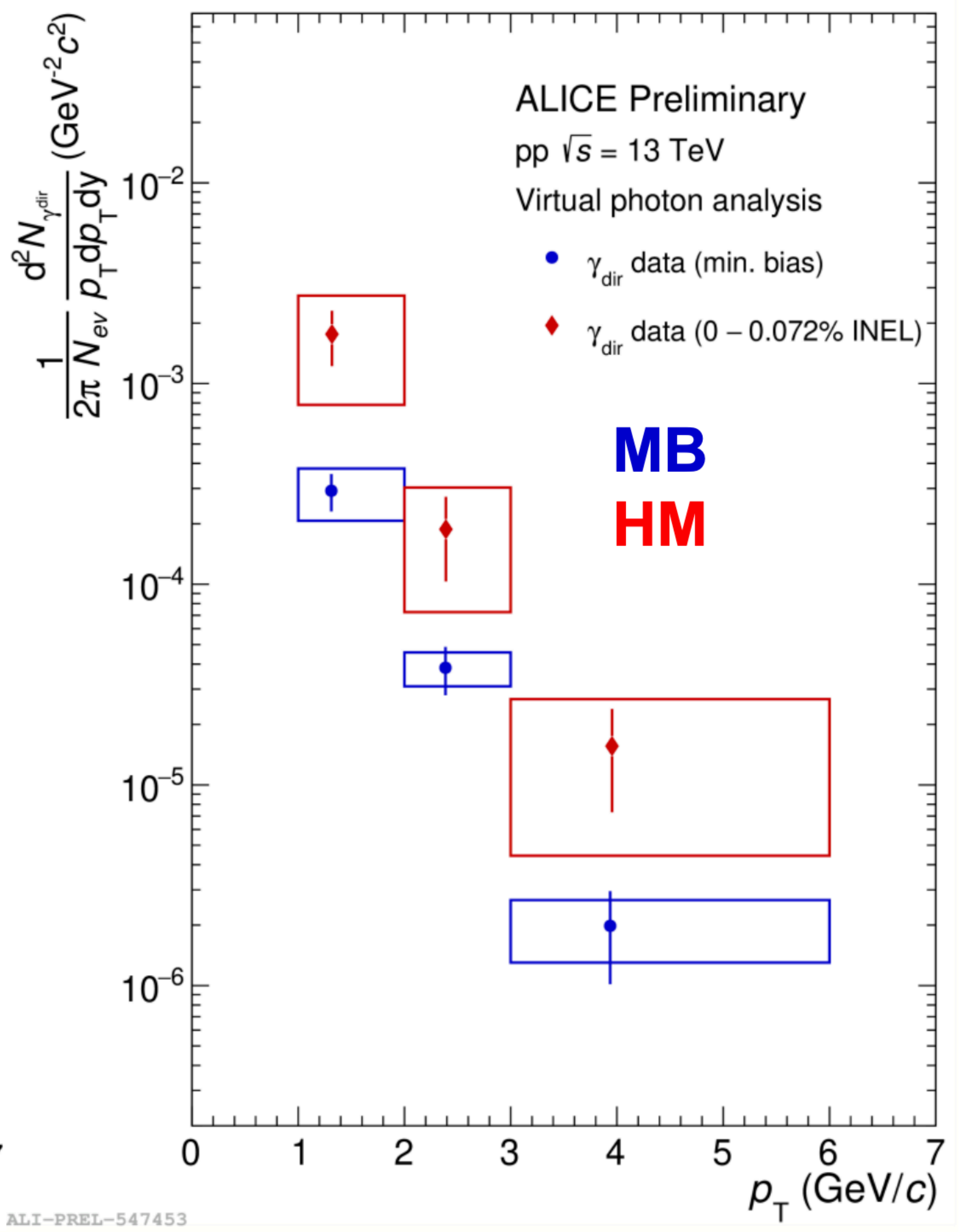


First direct-photon measurement at p_T ~ 0.3 GeV/c at the LHC

Direct photons in small system with ALICE

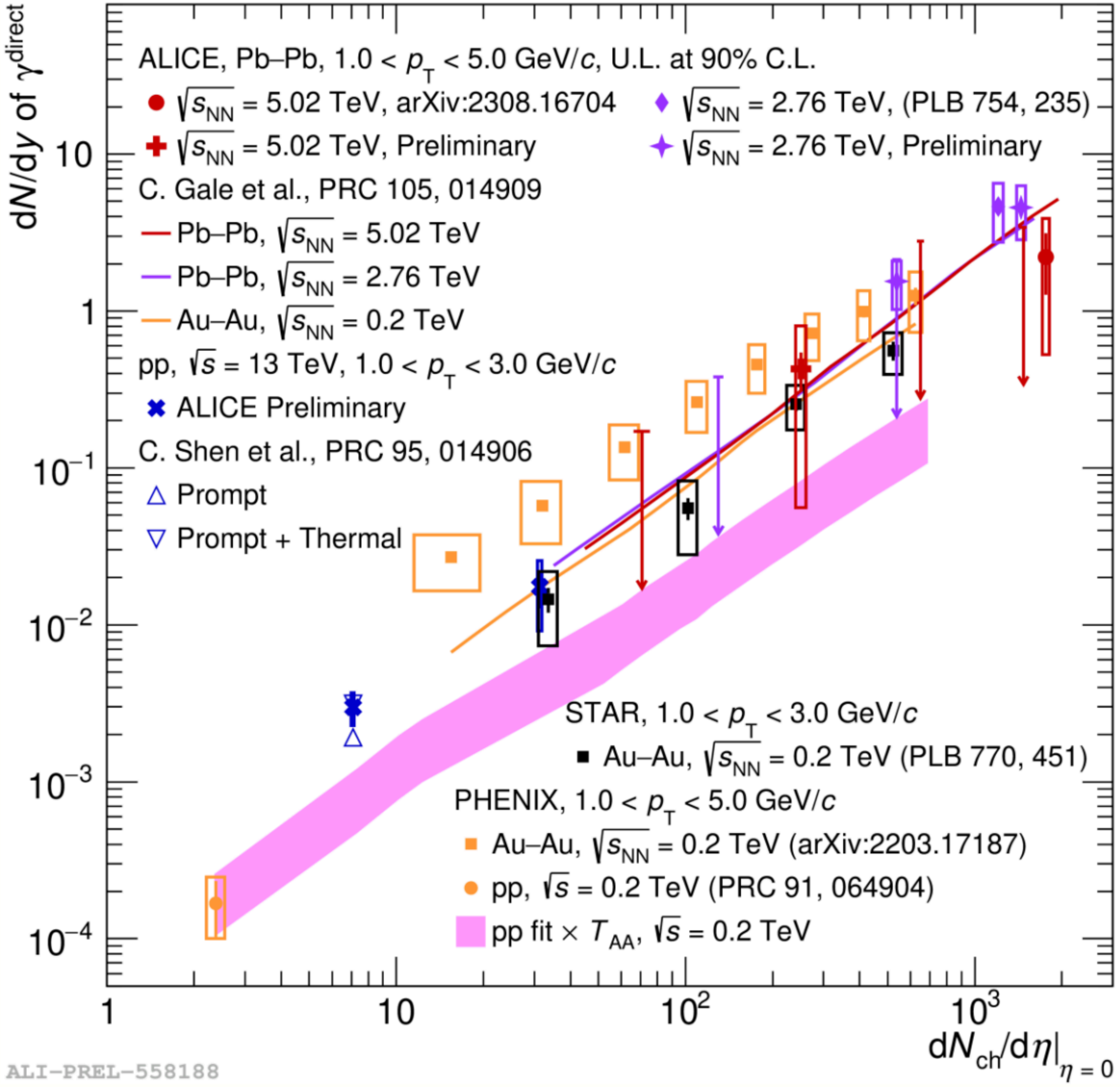
Jerome Jung, Sep. 24th





- First measurement of direct photons in pp at low p_T at the LHC
- MB: described by both prompt only and prompt + thermal radiation
- HM: significant increase of the yield from that in MB pp
- Challenging to calculate direct photon yield in HM pp collisions

Scaling of direct-photon yields vs. $dN_{ch}/d\eta$



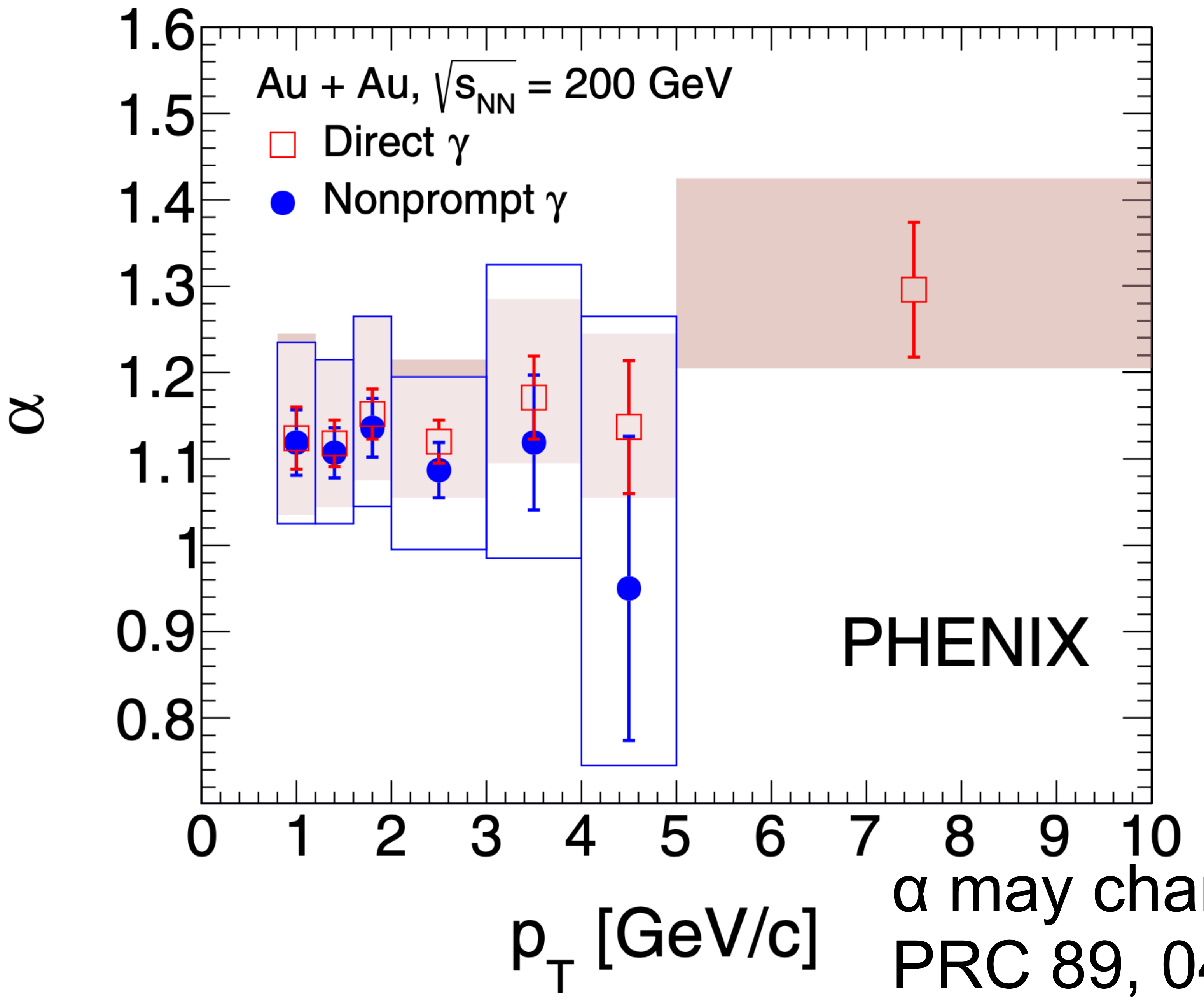
Jerome Jung, Sep. 24th
Vassu Doomra, Sep. 24th

- Power-law scaling was suggested by PHENIX
- Various measurements by PHENIX, STAR, and ALICE

$$\frac{dN_\gamma}{dy} = \int_{p_{T,\min}}^{p_{T,\max}} \frac{dN_\gamma^{\mathrm{dir}}}{dp_T dy} dp_T = A \times \left(\frac{dN_{\mathrm{ch}}}{d\eta}\right)^\alpha$$

- Scaling factor α does not depend on p_T integration range

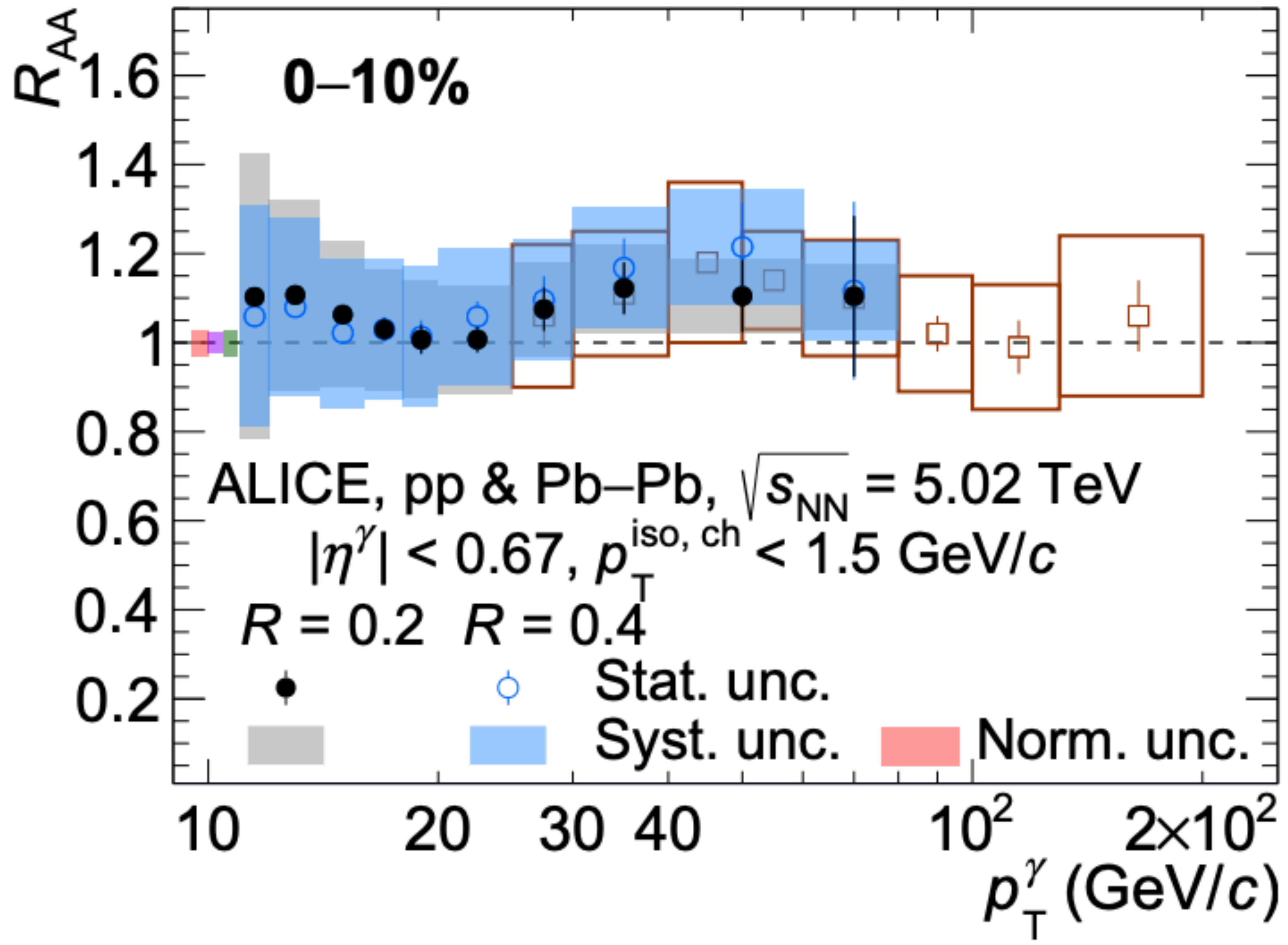
PRC 109, 044912 (2024), PHENIX



α may change in different p_T ranges.
PRC 89, 044910 (2014)

Isolated photons in ALICE

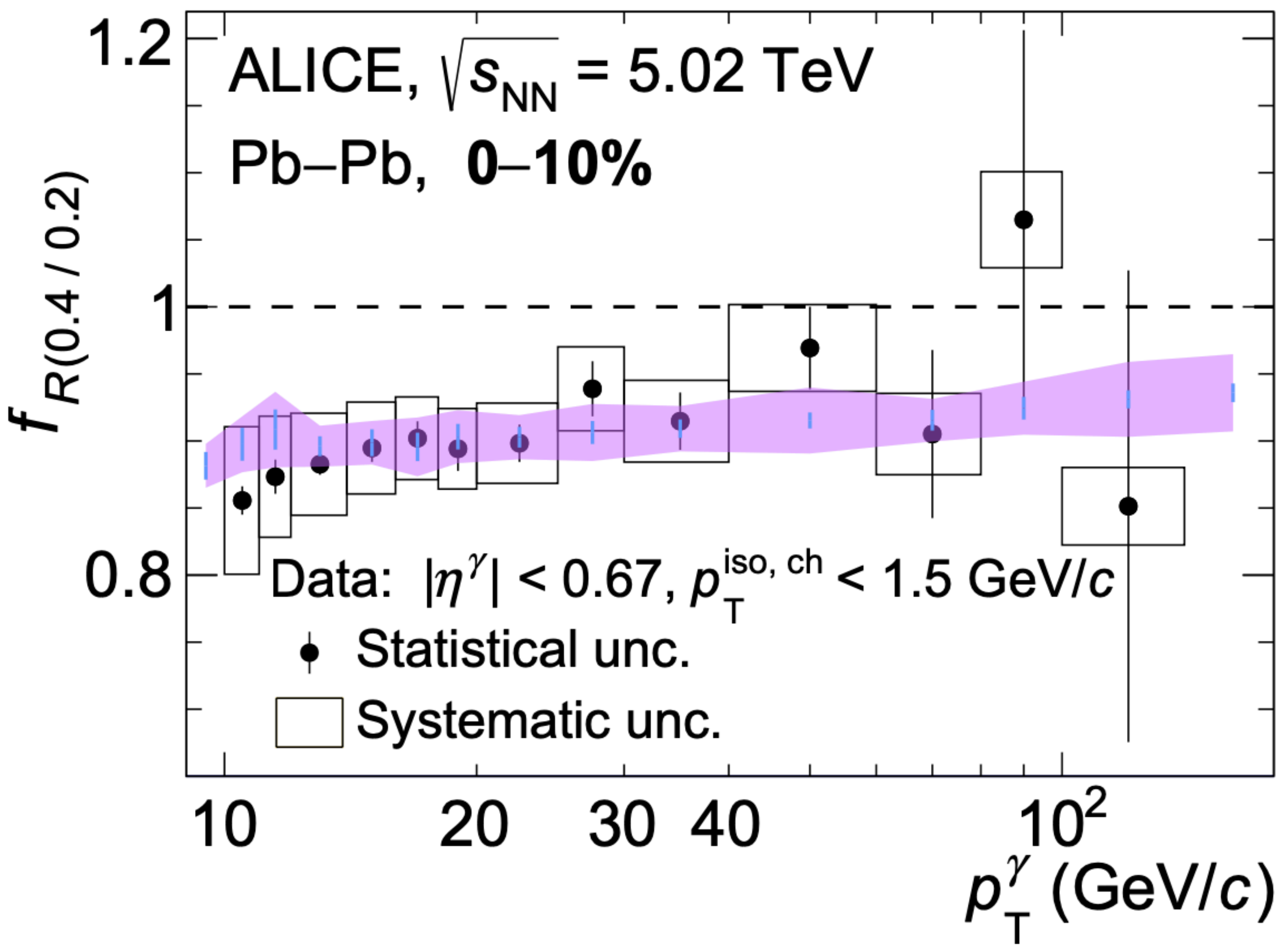
Gustavo Conesa Balbastre, Sep. 25th
arXiv:2409.12641
arXiv:2407.01165

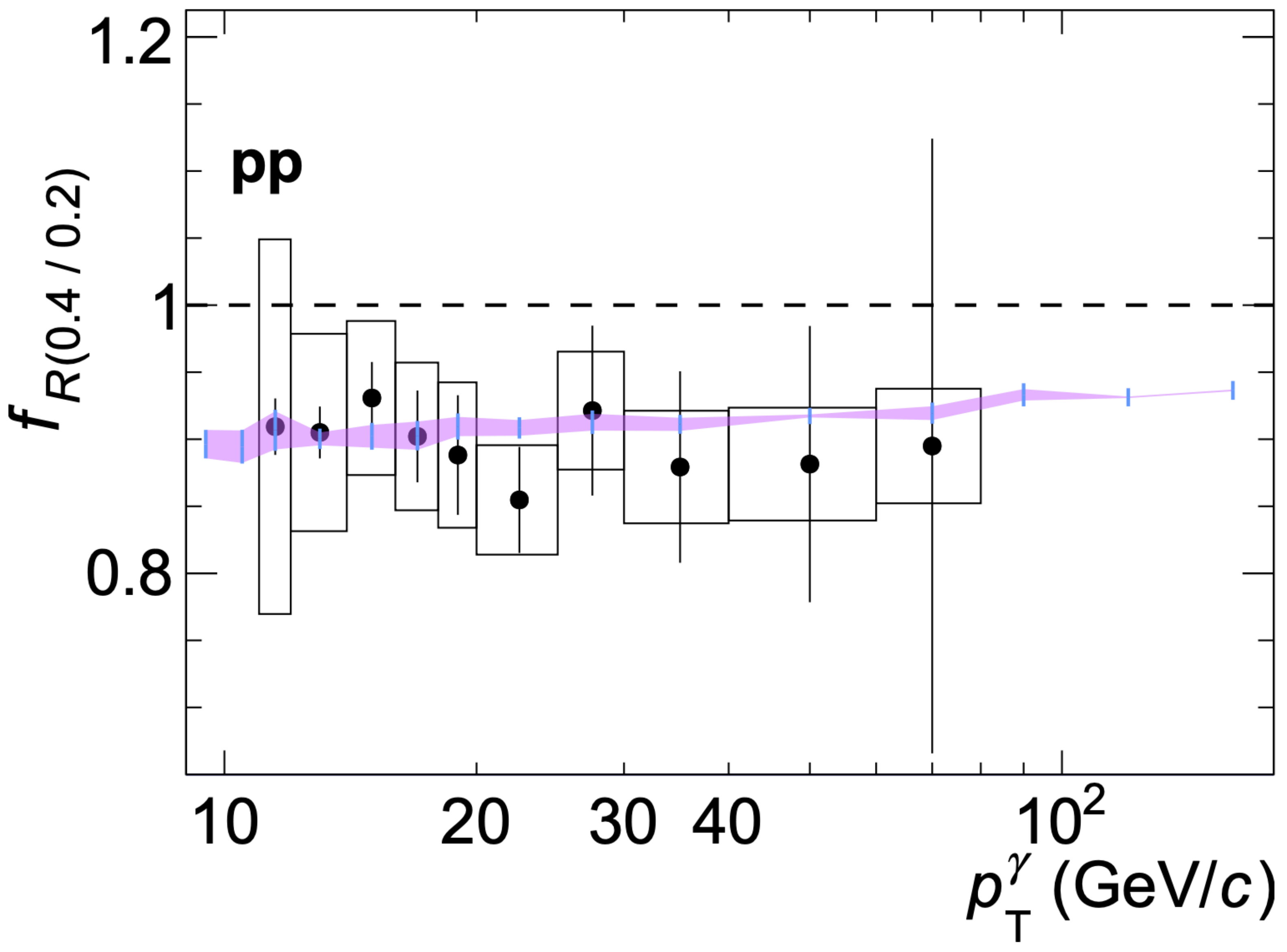


CMS, JHEP07(2020)116
$|\eta^{\gamma}| < 1.44$, $I < 1$ GeV/c, $R = 0.4$
Stat. unc. L_{int} unc.
Syst. unc. $\langle T_{AA} \rangle$ unc.

- R_{AA} is consistent with unity
  - Not modified in QGP as expected

- Sensitive to fraction of fragmentation photons passing the isolation cut
  - Interesting for theoretical models
  - Theory (NLO) controls the isolation mechanism for fragmentation γ and prompt γ in both pp and Pb–Pb



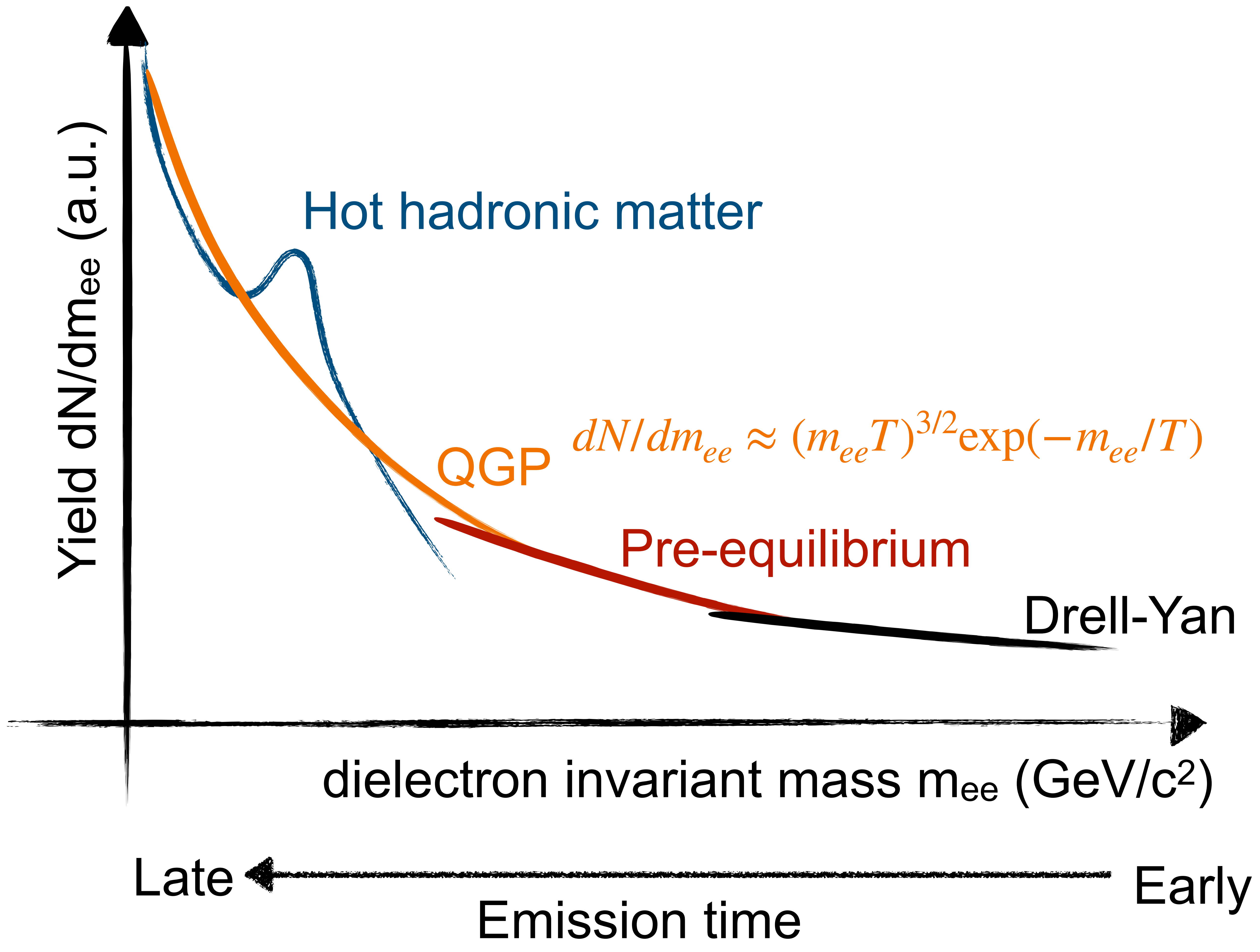


NLO (JETPHOX): $p_T^{iso} < 2$ GeV/c, BFG II FF
pp NNPDF40, Pb–Pb nNNPDF30
Statistical unc.
PDF unc.

ATLAS paper
JHEP07(2023)086

Dileptons

Schematic view of dielectron mass spectrum



Additional information: invariant mass

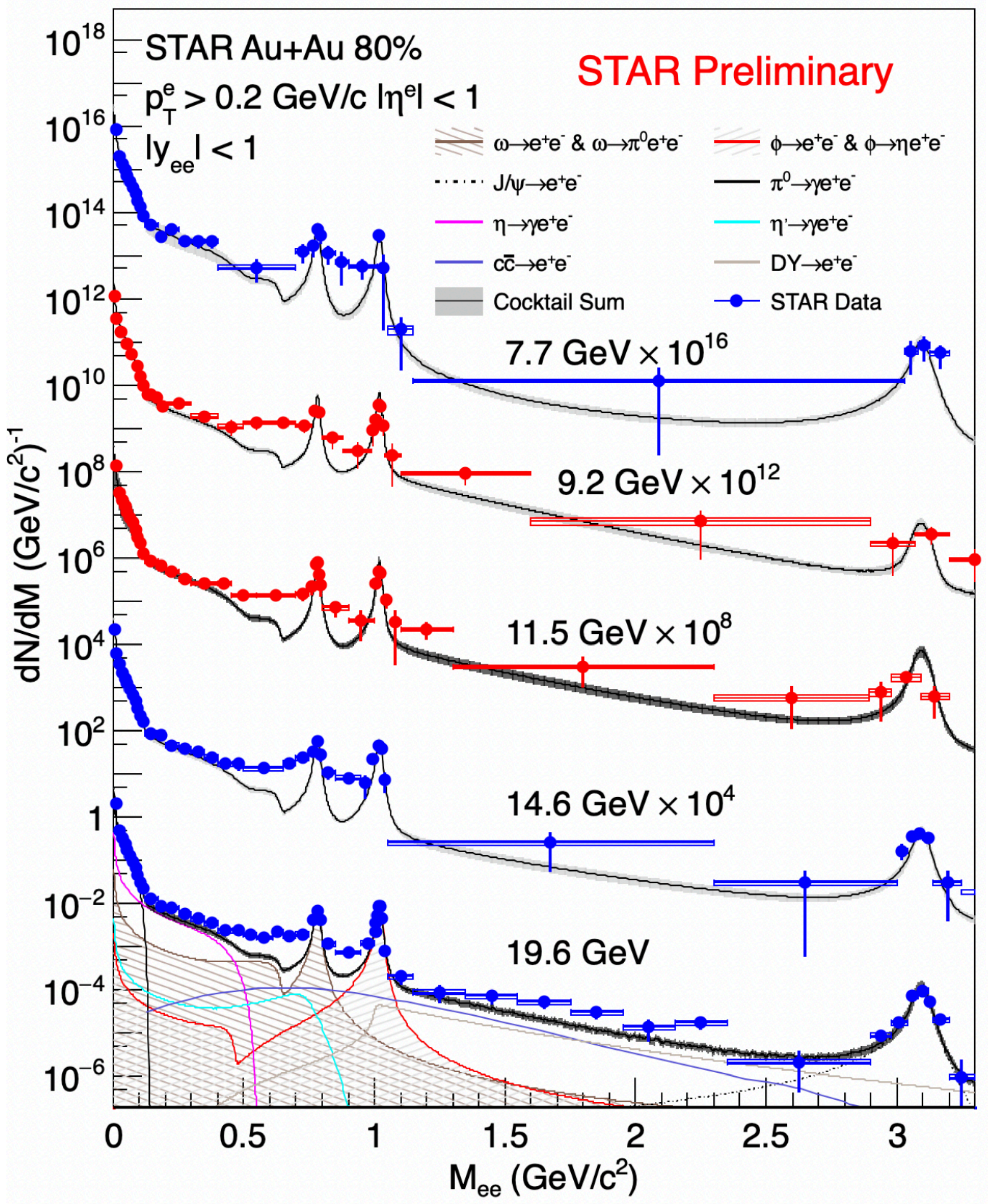
- Serves as a clock
  - Differentiate EM radiations from different stages
- No radial flow effect
  - Average temperature of QGP without blueshift
- Sensitive to in-medium spectral function of ρ meson

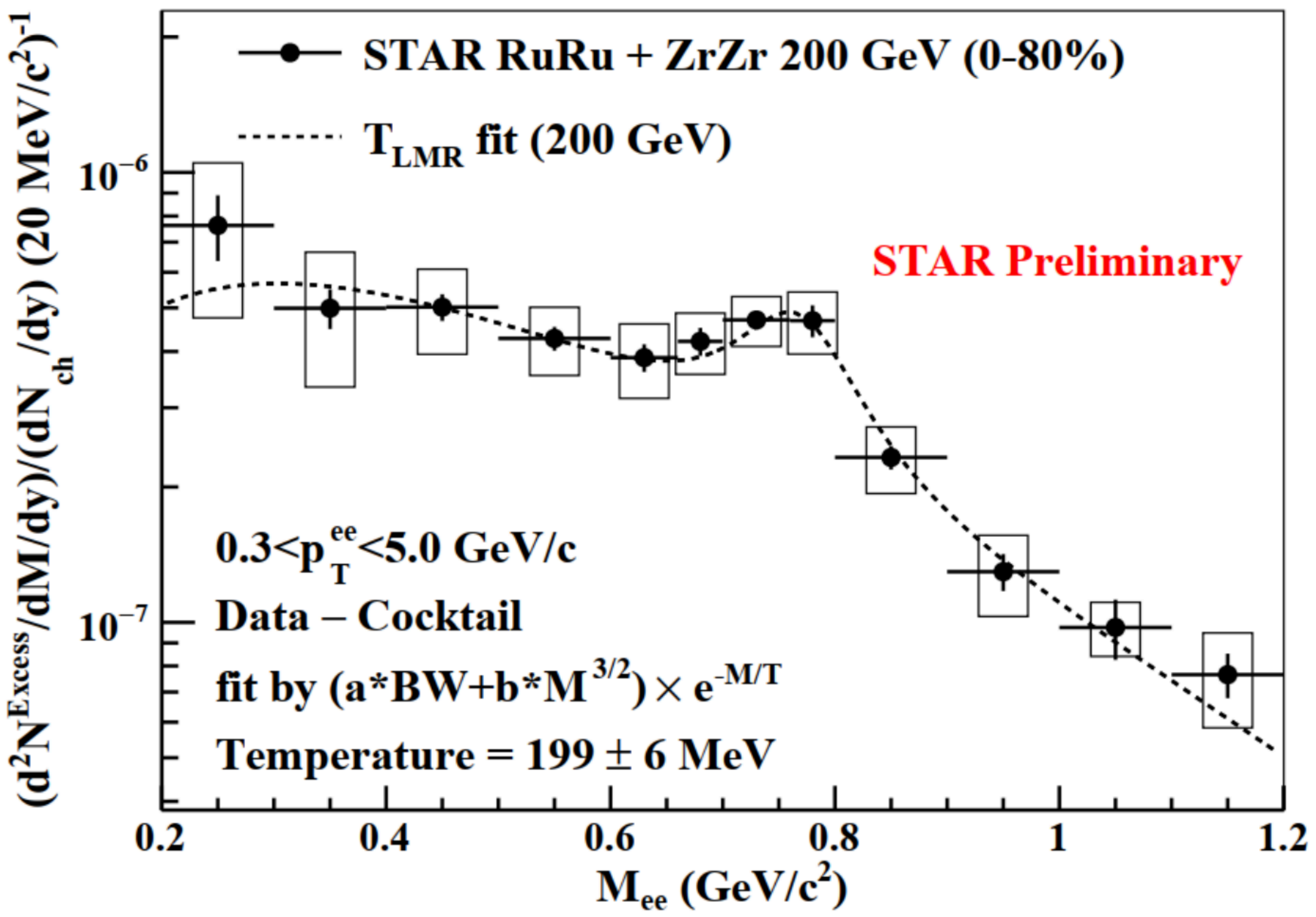
Thermal dielectrons with STAR

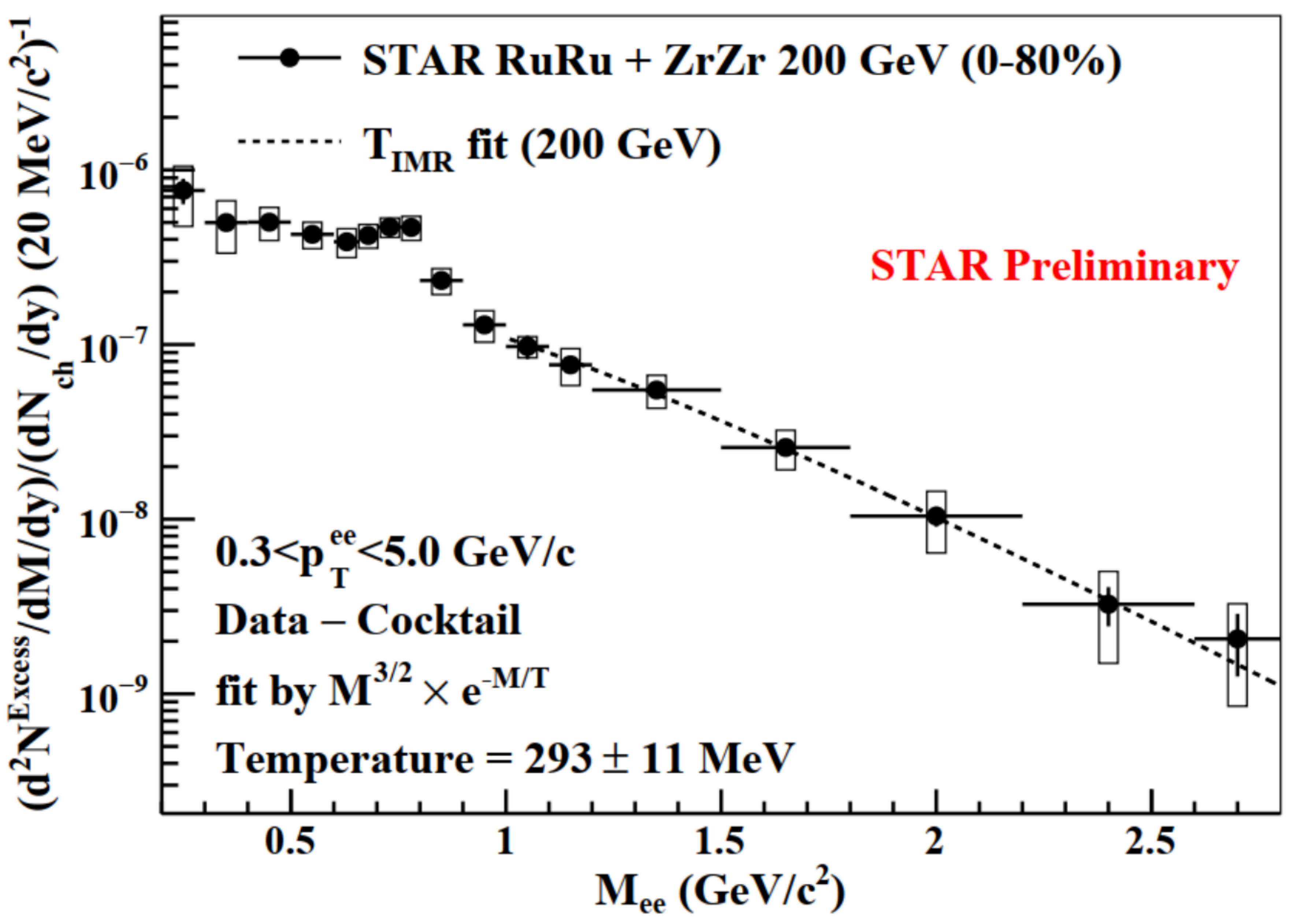
- BES-I : $\sqrt{s_{NN}}$ = 19.6, 27, 39, 62.4 GeV
- BES-II : $\sqrt{s_{NN}}$ = 7.7, 9.2, 11.5, 14.6, 19.6 GeV
- Isobar collisions (Zr+Zr, Ru+Ru)

STAR BES-I: PRC 107, L061901 (2023)
Chenliang Jin, Sep 24th
Jiaxuan Luo, Sep 24th

Exploring different total baryon density and temperature







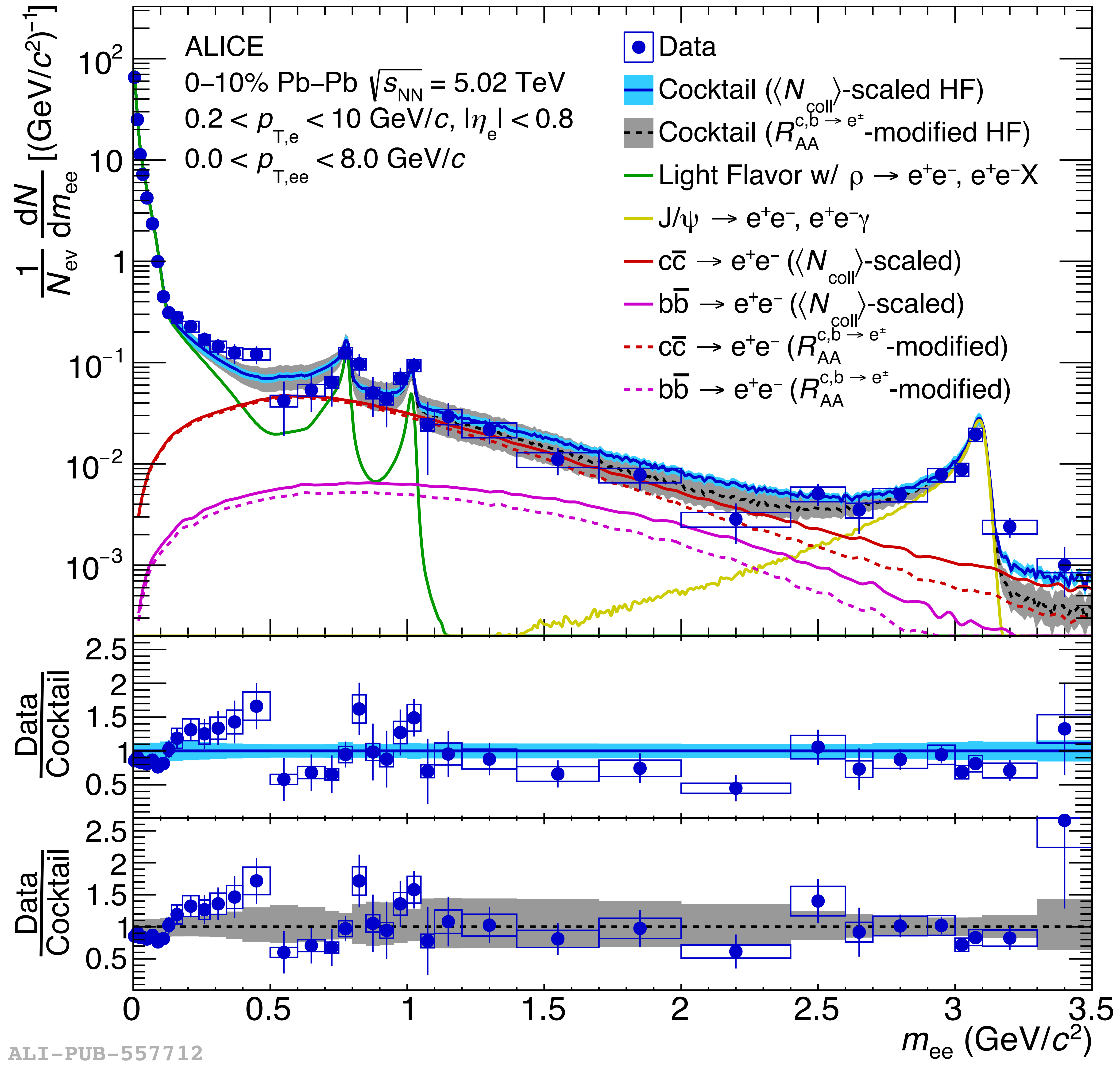
$T_{LMR}^{Isobar\ 200GeV}$ = 199 ± 6 (stat.) ± 13 (sys.) MeV

T_{IMR}^{200GeV} = 293 ± 11 (stat.) ± 27 (sys.) MeV

Difficult to extract T from LMR due to ρ broadening.
Looking forward to results in Au+Au at 200 GeV!

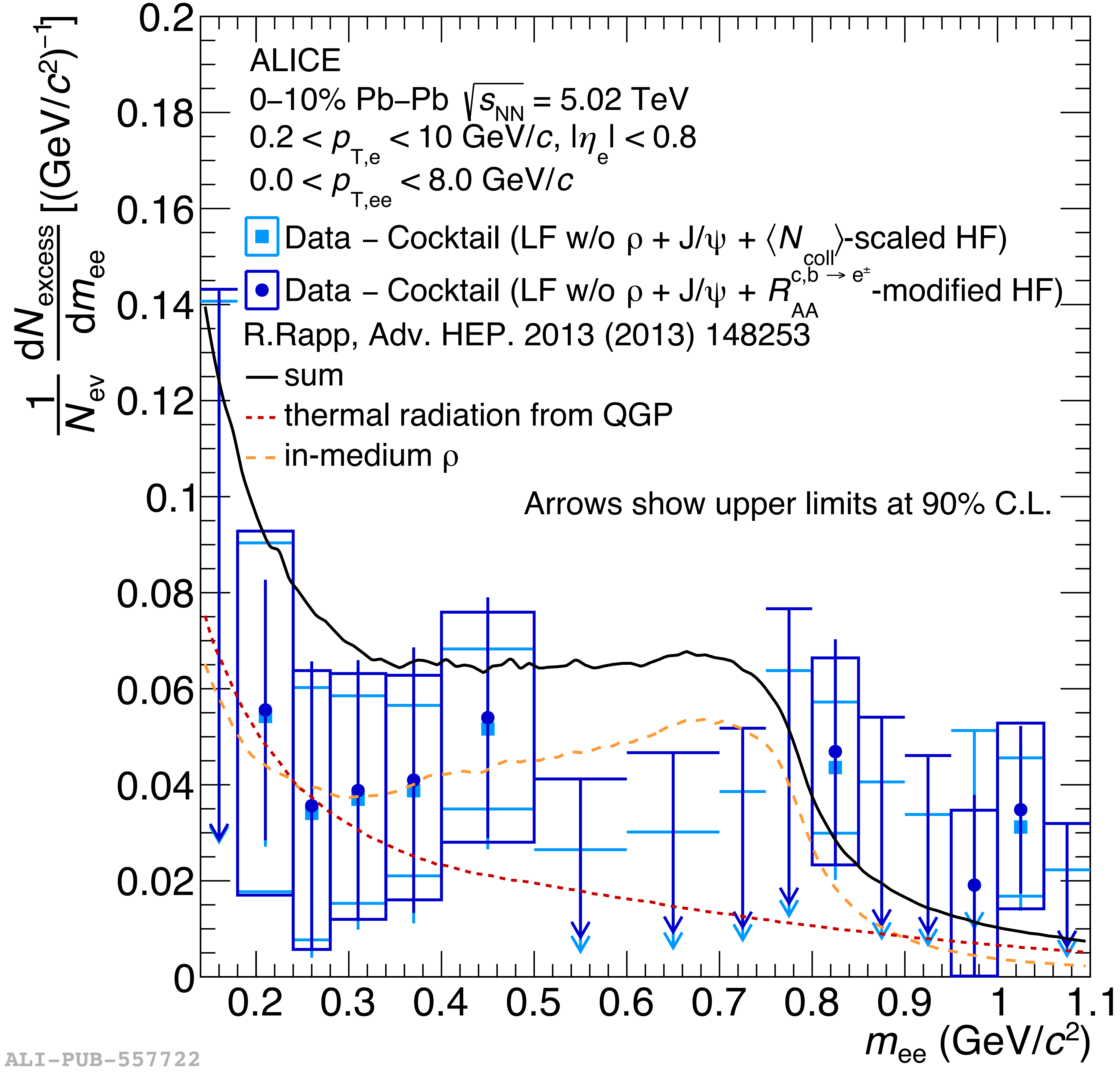
Thermal dielectrons in ALICE

Jerome Jung, Sep. 24
arXiv:2308.16704



- Comparison to two types of hadronic cocktail
  - N_{coll}-scaled pp data (vacuum expectation)
  - Modified by measured R_{AA} of c,b → $e^{\pm}$ and EPS09

Excess of dielectron at low mass in ALICE



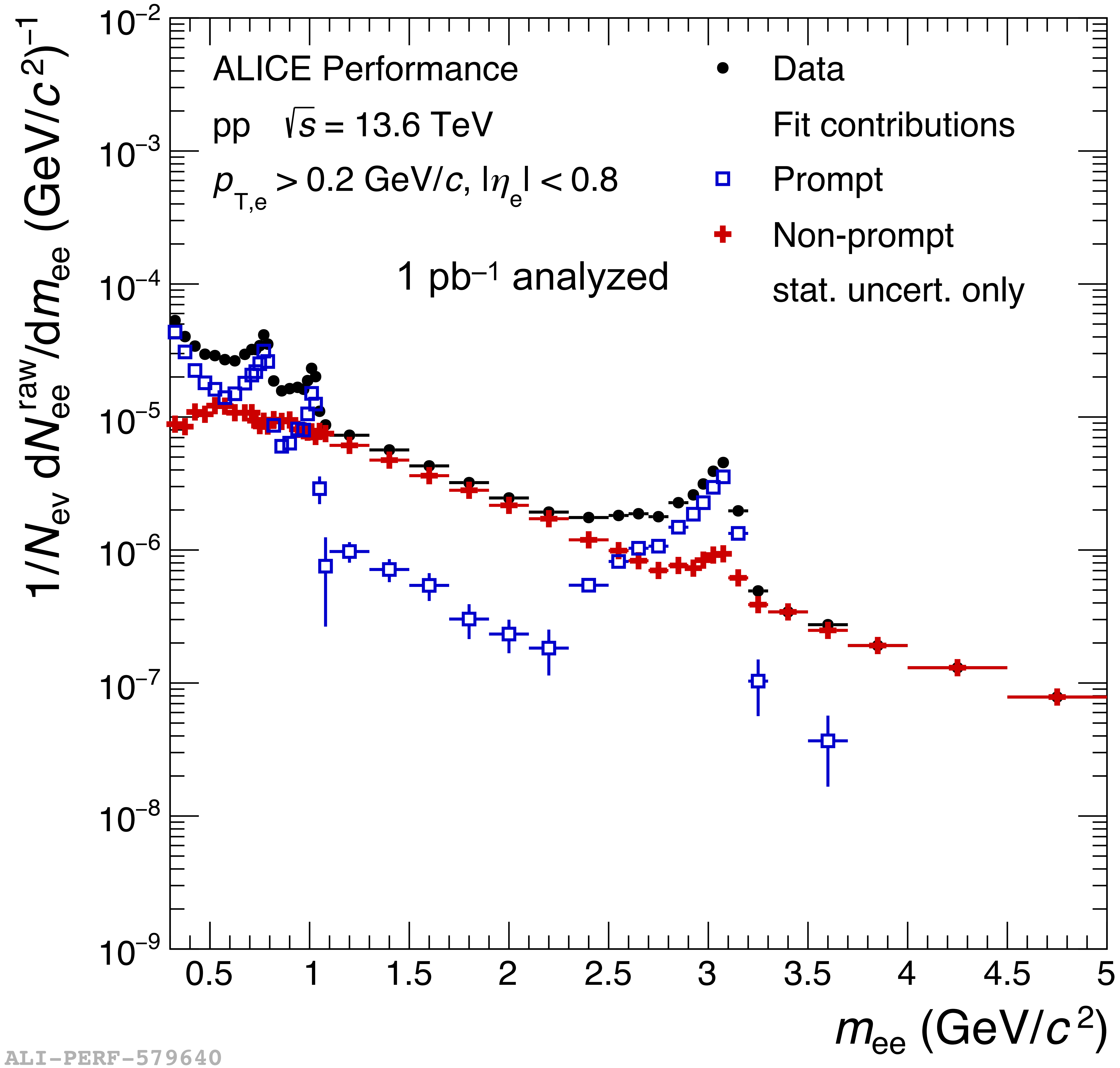
Jerome Jung, Sep. 24
arXiv:2308.16704

- Excess ≡ data – cocktail
- Comparison to theoretical models
  - Thermal radiation from hadronic matter
  - Thermal radiation from QGP
- Large cocktail uncertainty of heavy flavors

  → Need cocktail-independent method

  Topological separation with DCA (Distance-of-Closest Approach)

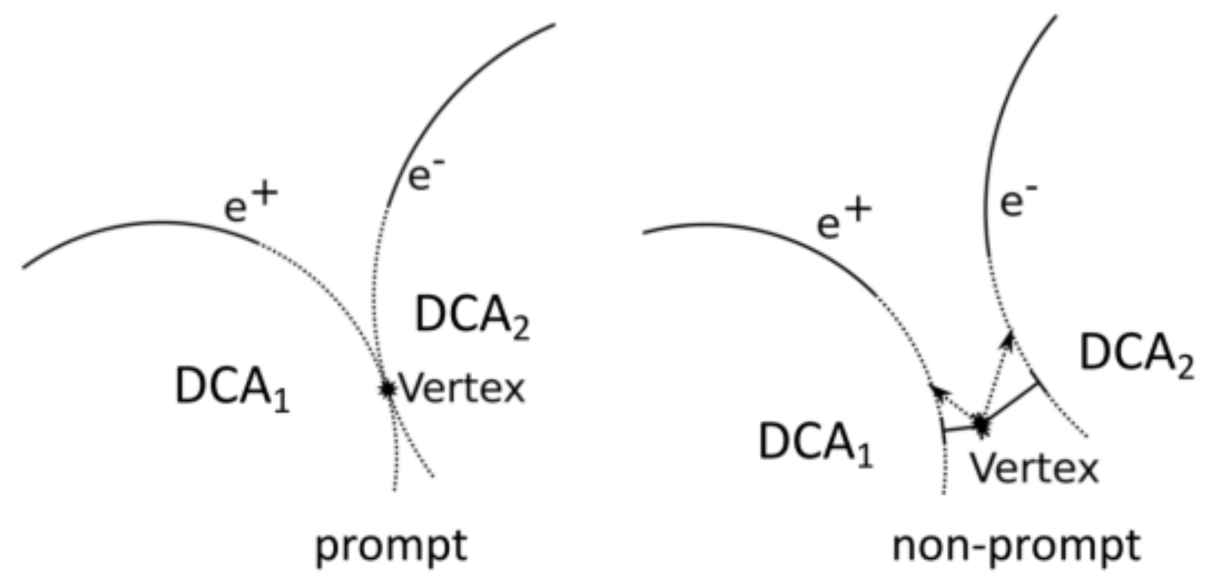
Topological separation in ALICE



Florian Eisenhut (poster)
Emma Charlotte Ege (poster)

- First attempt to decompose mass spectrum with template fit to DCA
  - Prompt (vector mesons)
  - Nonprompt ($c\bar{c} \to e^+e^-, b\bar{b} \to e^+e^-$, J/ψ from b hadrons)

Distance-of-closest approach (DCA):

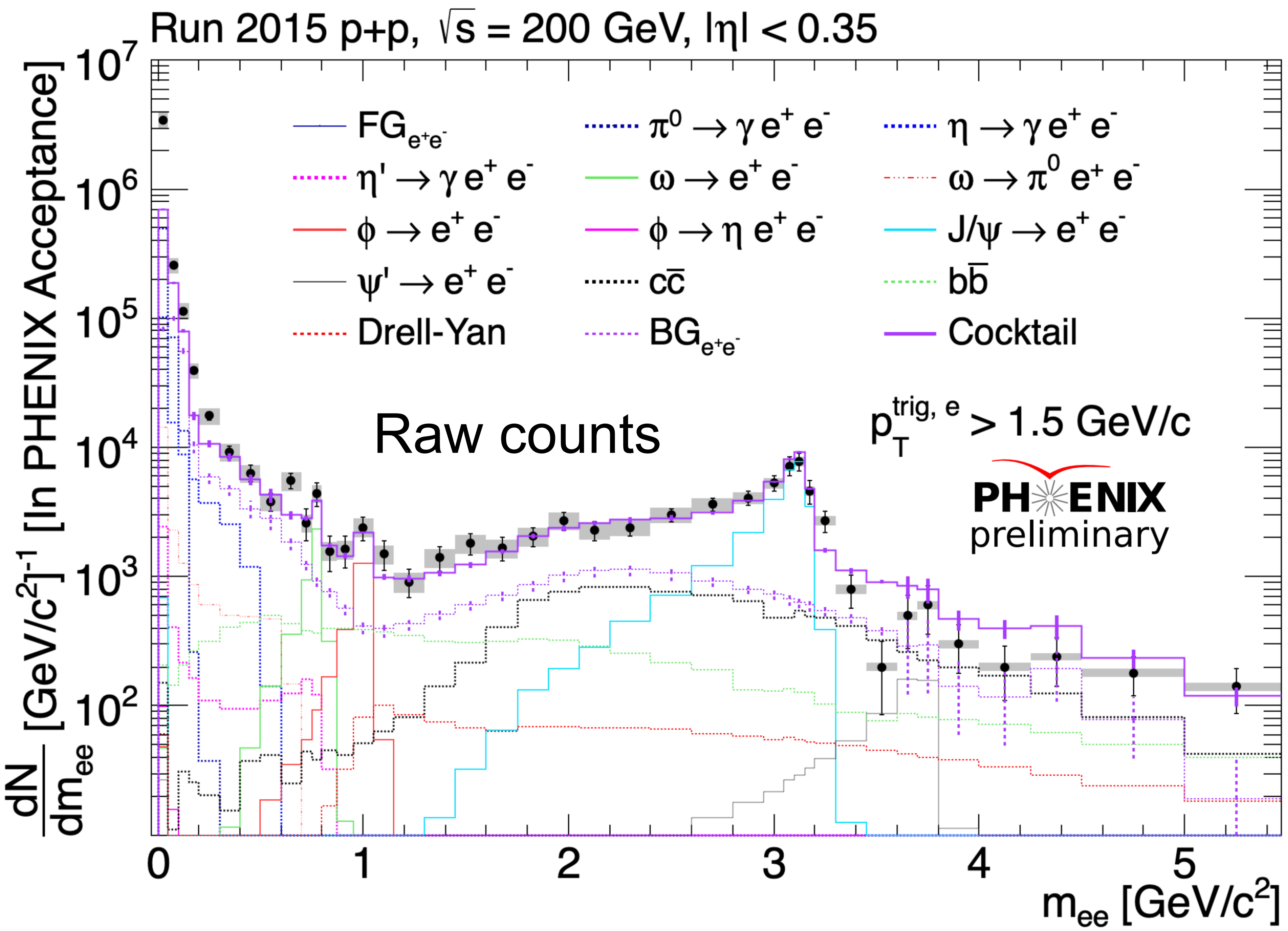


$$DCA_{ee} = \sqrt{\frac{(DCA_1/\sigma_1)^2 + (DCA_2/\sigma_2)^2}{2}}$$

- Thanks to two major upgrades
  - High statistics due to continuous readout after GEM upgrade of TPC
  - Better pointing resolution with ITS2

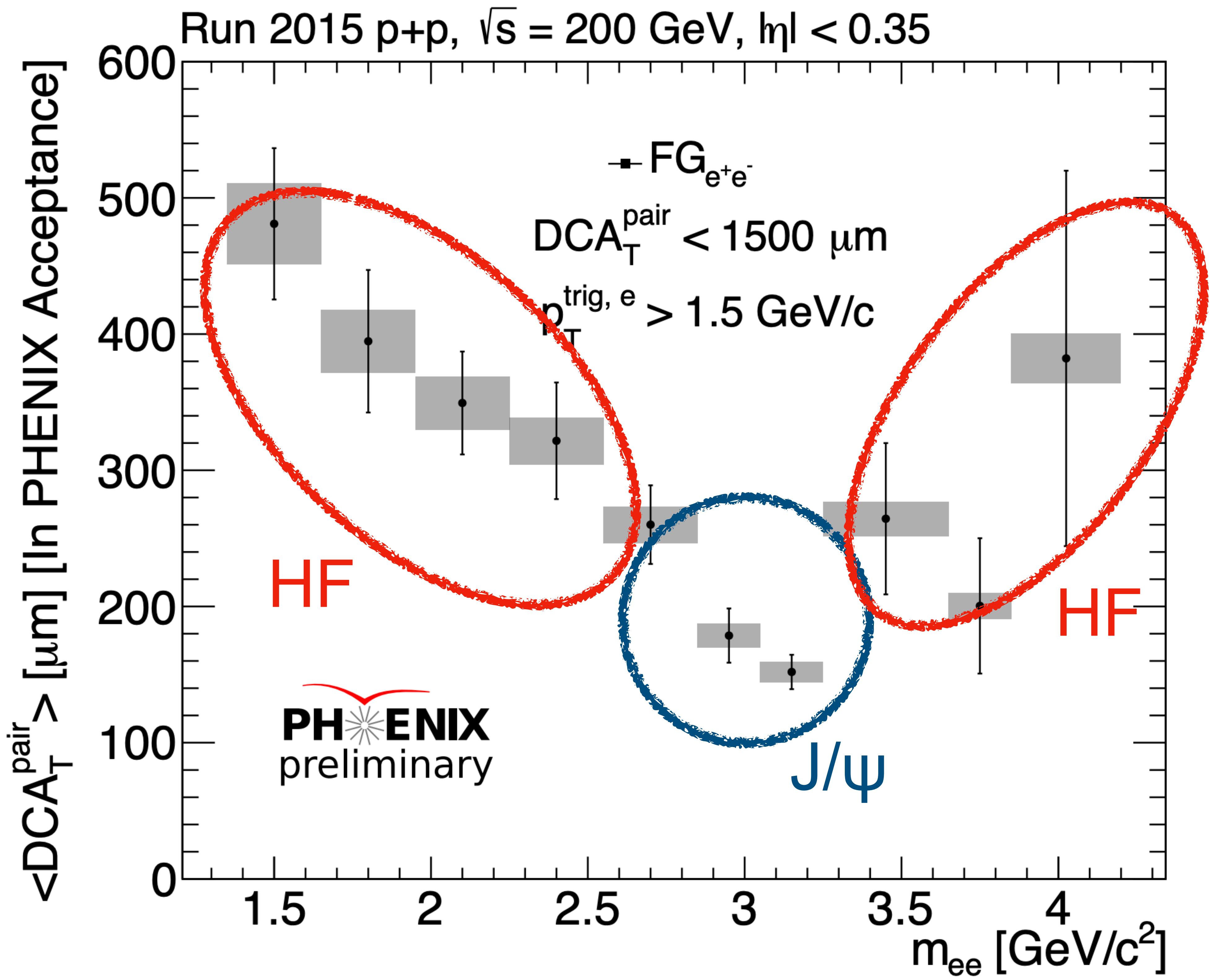
Dielectrons in PHENIX

Vassu Doomra, Sep. 24th



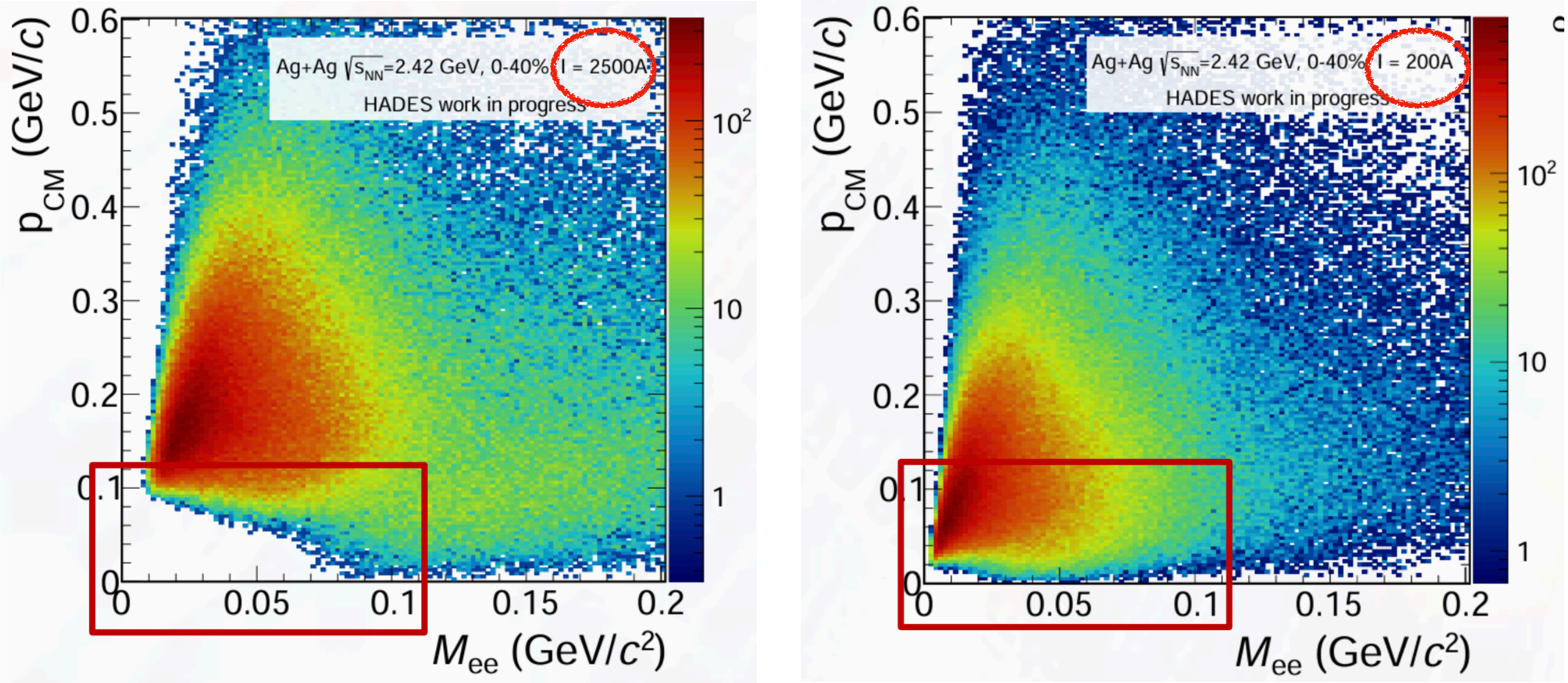
- Huge photon conversion rejection
- Good agreement between measured signal and hadronic cocktail

$$DCA_T^{pair} = \sqrt{|DCA_{e^-}^2 - DCA_{e^+}^2|}$$



Low-mass and low-p_T γ^* in HADES at SIS18

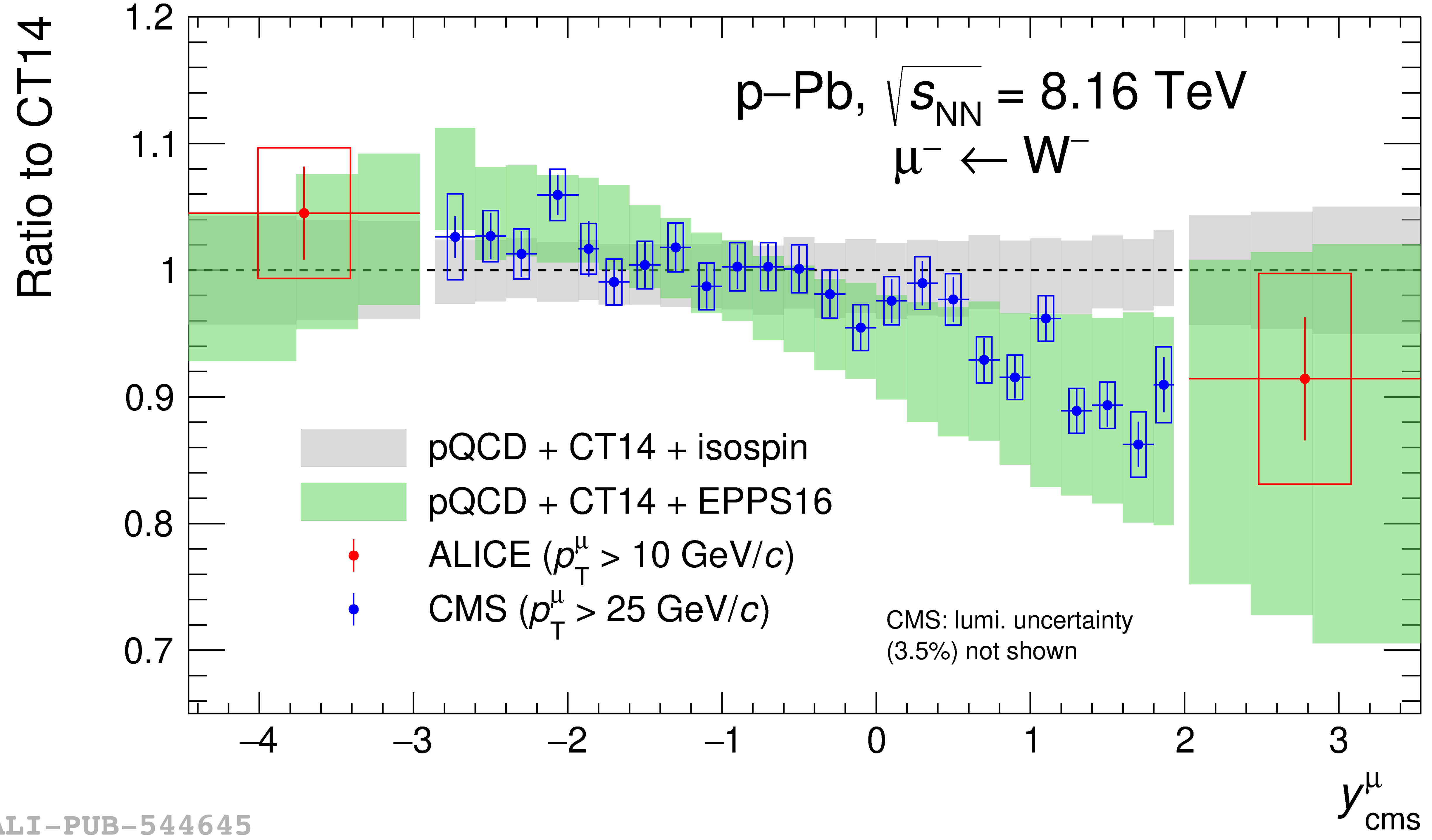
Iuliana Carina Udrea (Poster)

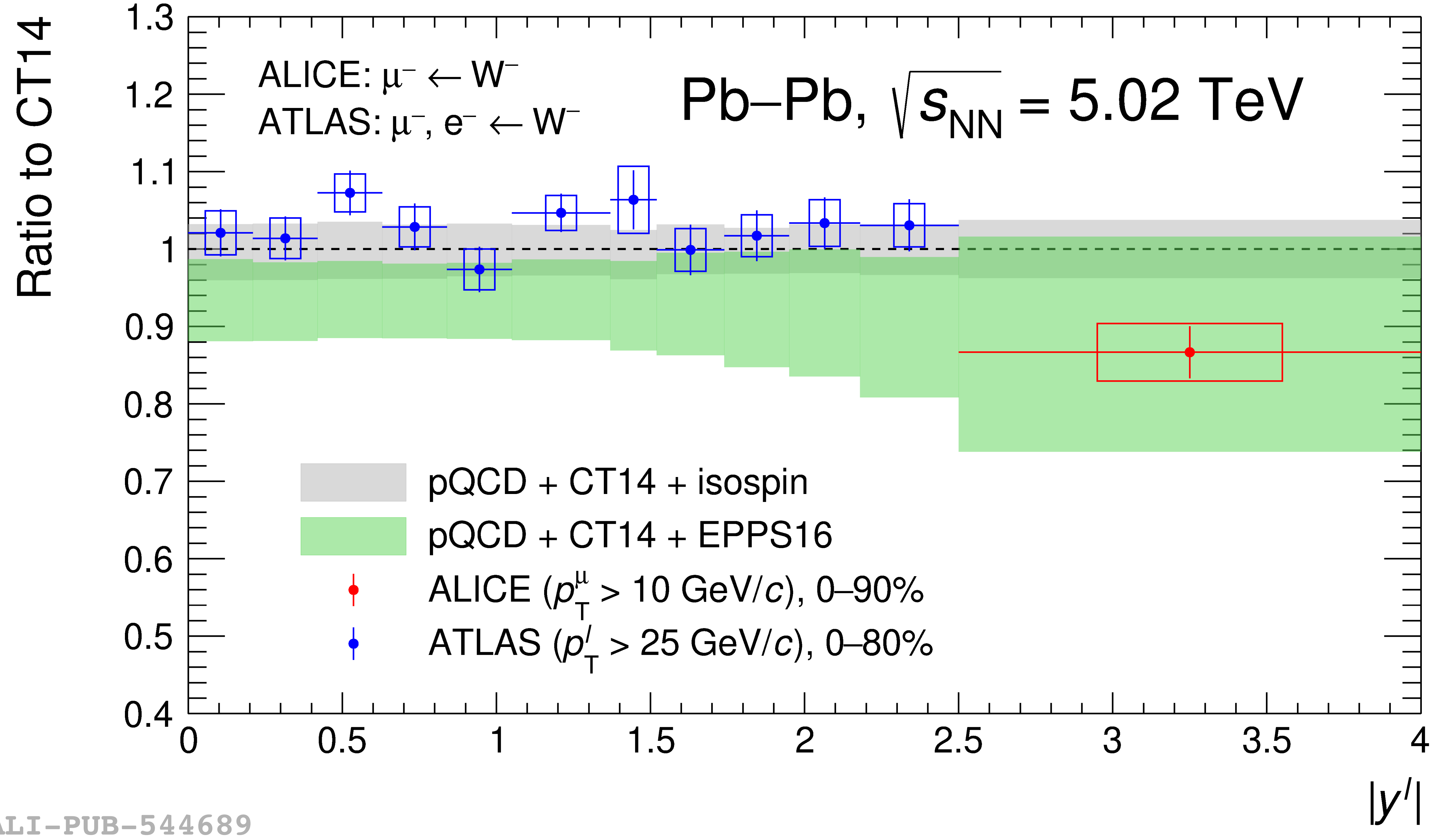


- Motivation: extract electric conductivity. Namely, dilepton yield at p = 0 GeV/c with $M_{ee} \rightarrow 0$.
  - Phase-space coverage in low mass and low momentum is critical
- Au+Au at $\sqrt{s_{NN}}$ = 2.23 GeV with low B field to be collected in 2025

EW boson productions in ALICE

Shingo Sakai, Sep. 25th





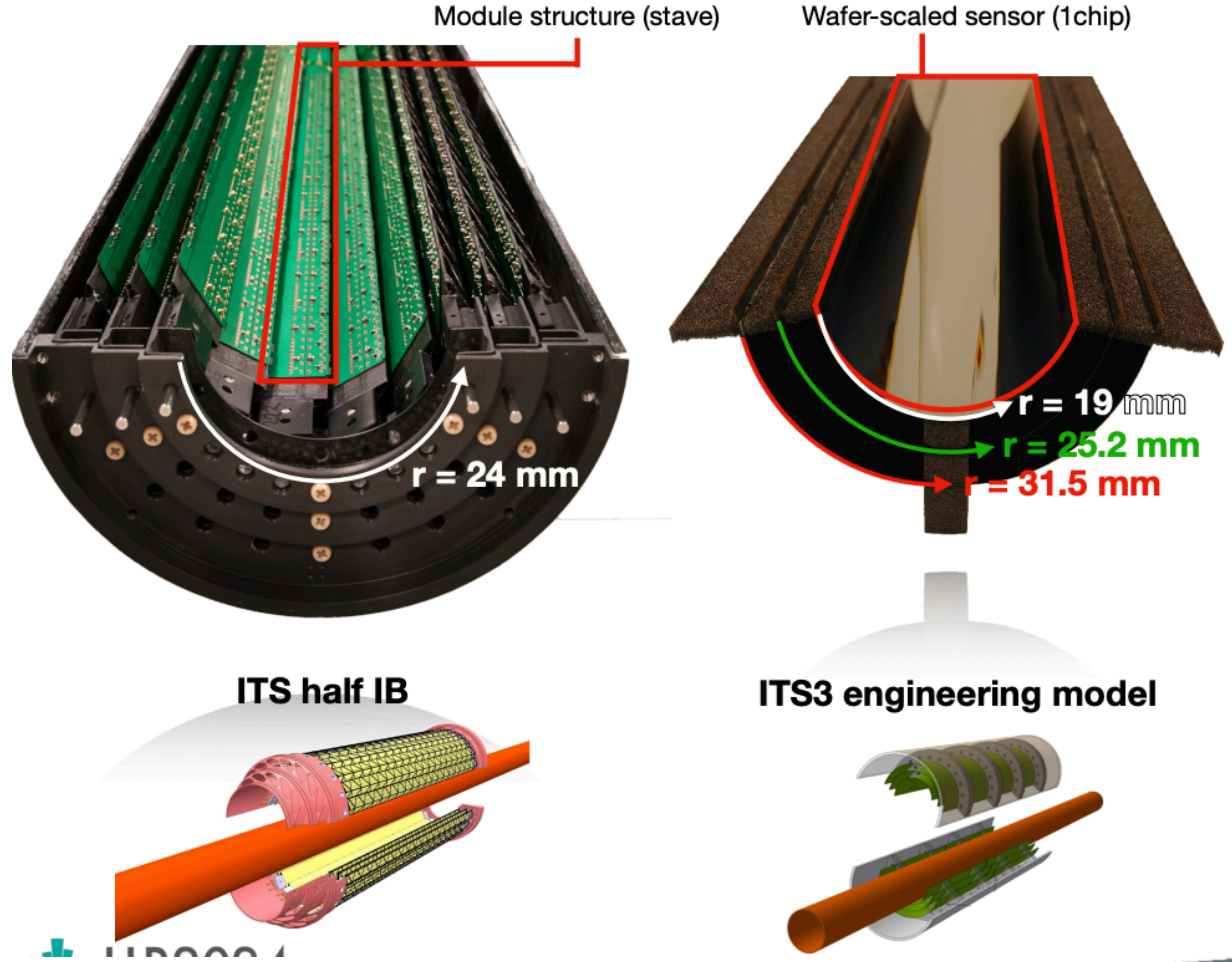
- Sensitive to initial condition of nucleus
- Ratio to CT14 is smaller than unity at large rapidity
  - Suggests modification of PDF

JHEP 05 (2022) 036, ALICE
EPJC 79 (2019) 935, ATLAS
PLB 800 (2020) 135048, CMS
JHEP 06 (2023) 022, LHCb

Future facilities

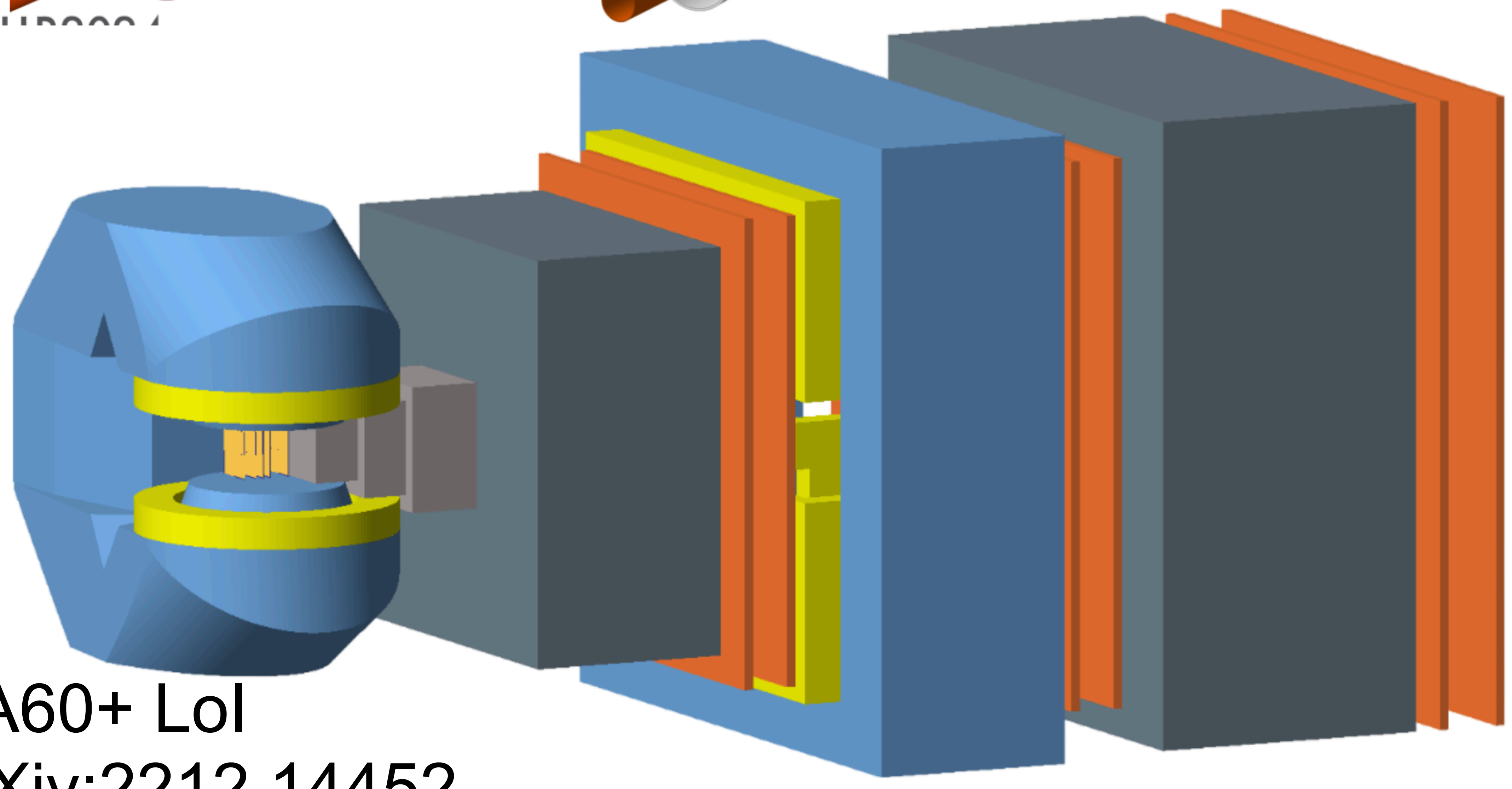
ALICE ITS3: LHC Run4 (2029 - 2032)

NA60+: Alexander Milov, Sep. 24th
ITS3: Bong-Hwi Lim, Sep. 24th
ALICE3: Cas Van Veen, Sep. 24th

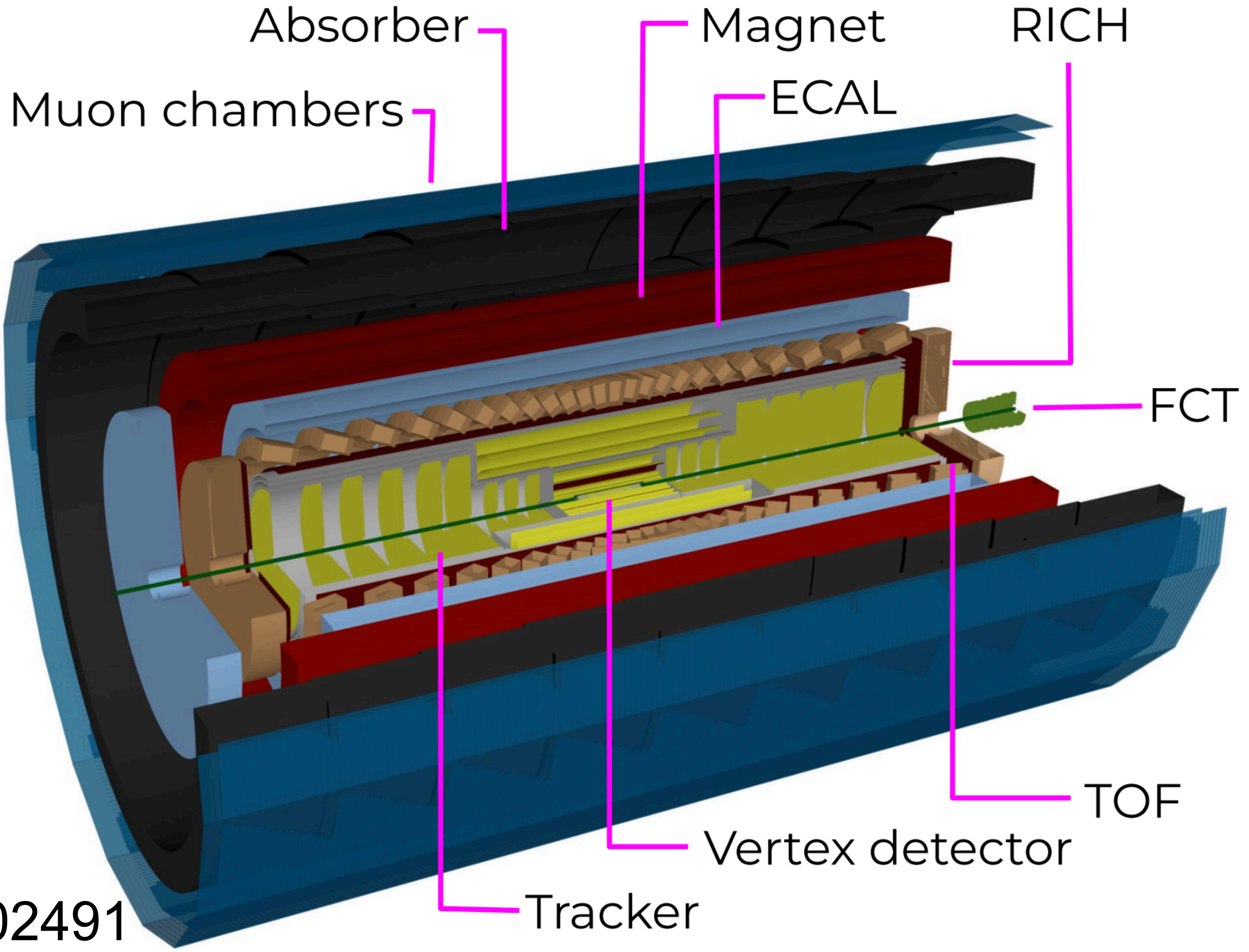


- Differential study of thermal radiation
- Chiral symmetry restoration

Precise pointing resolution is the key to reject leptons from charm hadrons.



NA60+ LoI
arXiv:2212.14452



ALICE3 LoI
arXiv:2211.02491

Summary

- Direct photons
  - Direct photon puzzle still there
    - Need common efforts from experiment and theory
  - Prompt photons serve as a reference to study medium response in QGP

- Dileptons
  - Different μ_B and temperature with different accelerators
  - Significant experimental progress has been recently achieved concerning HF rejection.
  - v_2 vs. mass will ultimately solve the direct photon puzzle. (LMR: hadronic phase, IMR: partonic phase)

We have variety of temperature results with both direct photons and dielectrons now!

- EW bosons
  - Sensitive to initial condition of heavy-ion beam
  - Suggest modification of PDFs

Many thanks to Harald Appelshäuser, Raphaelle Bailhache, Vassu Doomra, Jerome Jung, Jean-Francois Paquet, Klaus Reygers, Shingo Sakai, Florian Seck, Sebastian Scheid, and Ye Zaochen for discussions.