Conference Highlight: Electroweak Probes

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VANDERBILT UNIVERSITY

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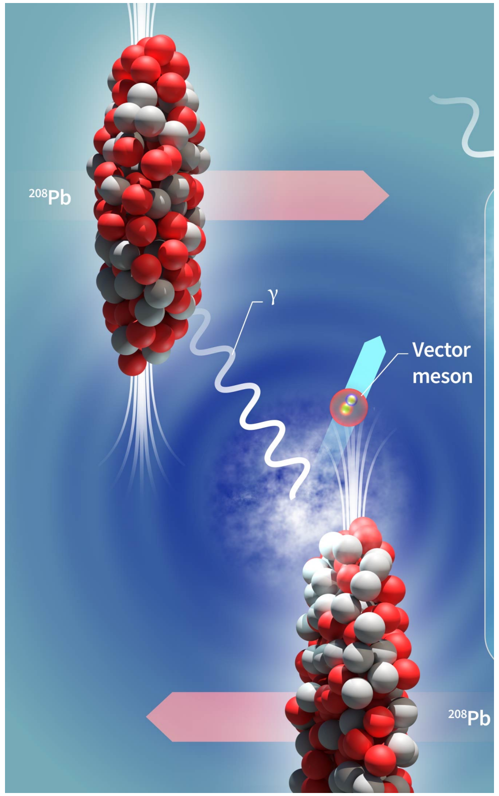
NAGASAKI

Thank you to all the electroweak probe speakers and poster presenters for their help. Special thanks to Charles Gale, Gabor David, Oscar Garcia Montero, Frank Geurts, Dennis Perepelitsa, Dmitri Peresunko and Lijuan Ruan for last-minute clarifications.

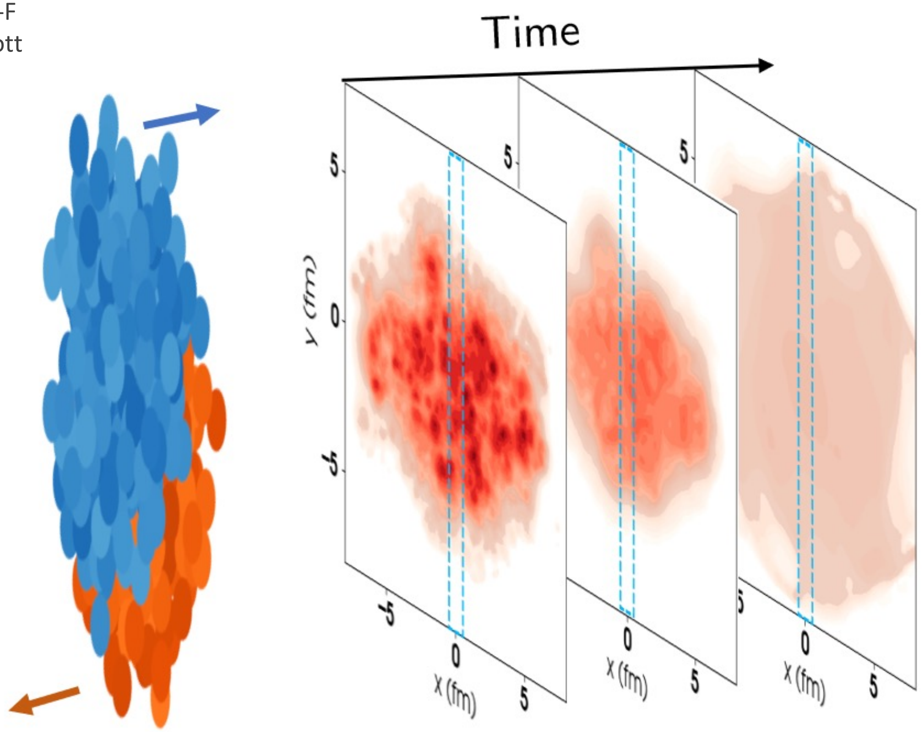
Electroweak probes in heavy-ion collisions

Figure credit: CERN



Reactions induced by initial state photons
[Minjung Kim]

Figure credit: J-F Paquet and Scott Moreland



High-energy prompt photons, W/Z bosons

Photons and dileptons radiation from plasma

High-energy electroweak probes in heavy-ion collisions

Isospin effect+"nuclear p.d.f.'s"/shadowing

$$\frac{dN^{AA}}{dp_T} = N_{coll}[(\text{parton dist. fct}) \otimes (\text{parton dist. fct}) \otimes (\text{partonic cross section})]$$

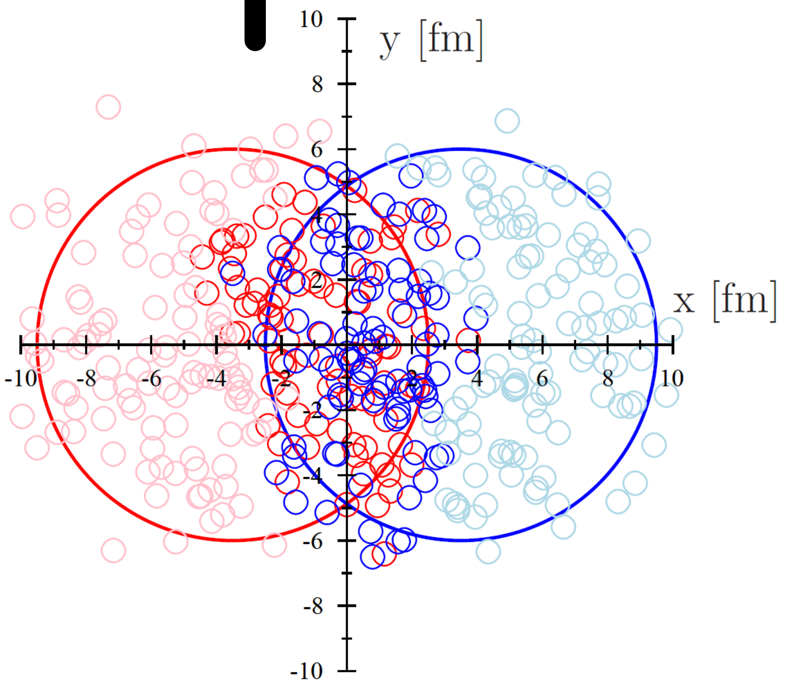
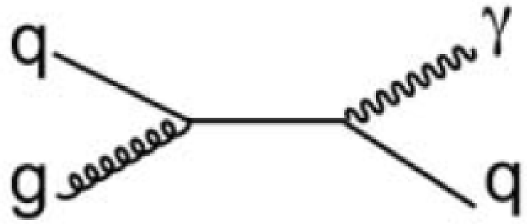


Figure by H. Holopainen



High-energy electroweak probes in heavy-ion collisions

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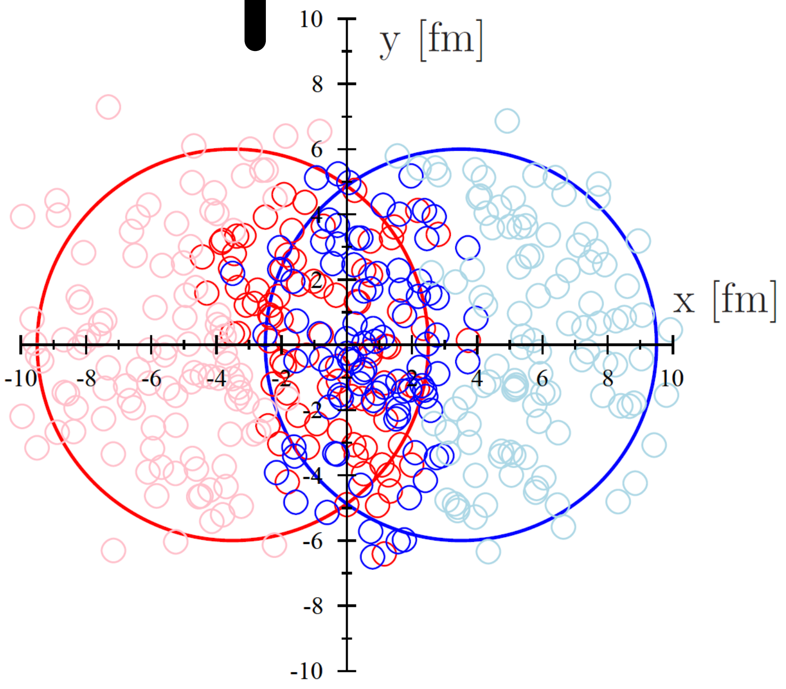
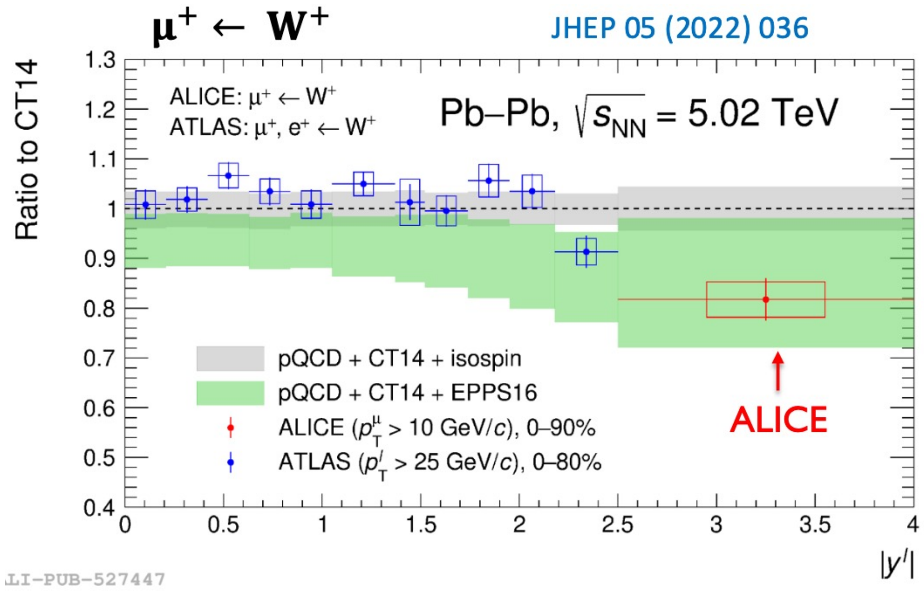


Figure by H. Holopainen

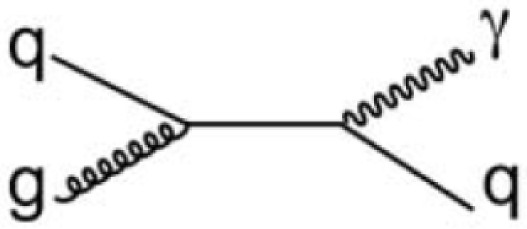
- Probe of initial conditions



- Correlation with jets to study parton energy loss

[Shingo Sakai (ALICE)]

$W^{\pm}$ in Pb–Pb at 5.02 TeV from ALICE

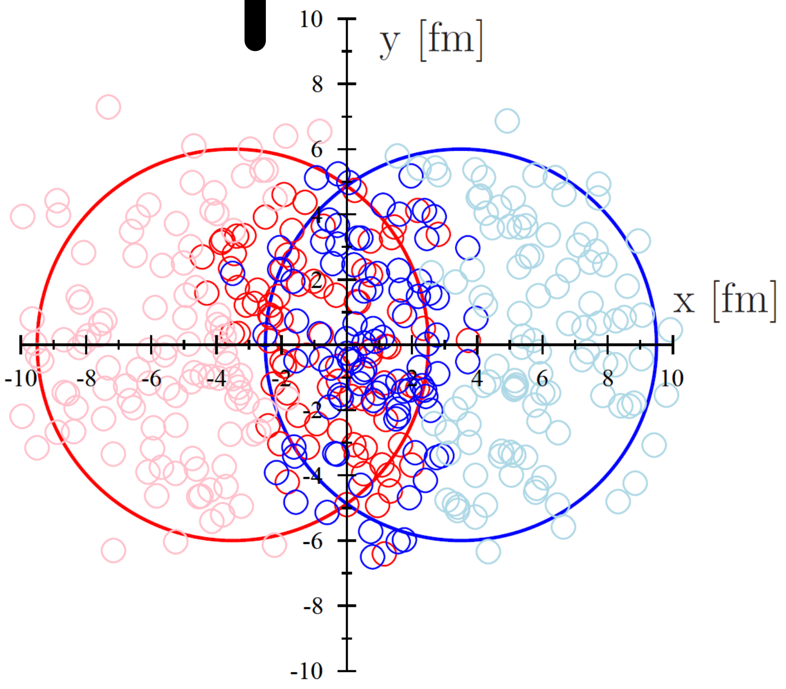


High-energy photons in heavy-ion collisions

Isospin effect+"nuclear p.d.f.'s"/shadowing

Parton energy loss effect

$$\frac{dN^{AA}}{dp_T} = N_{coll}[[(\text{parton dist. fct}) \otimes (\text{parton dist. fct}) \otimes (\text{partonic cross section})] + (\text{fragmentation } \gamma)]$$



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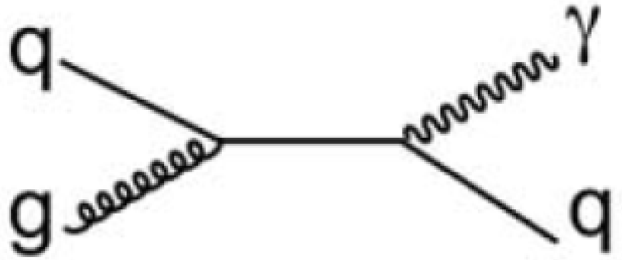
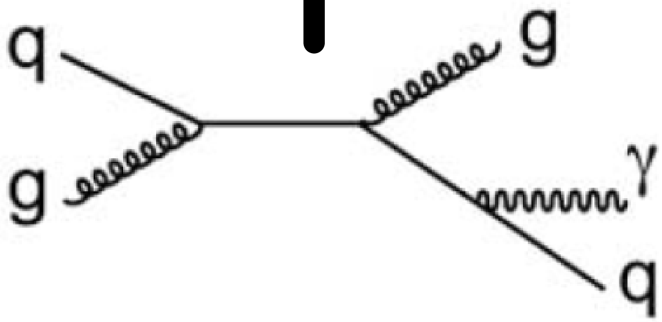
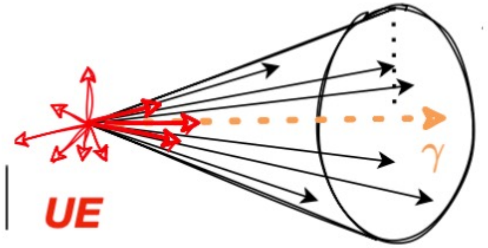


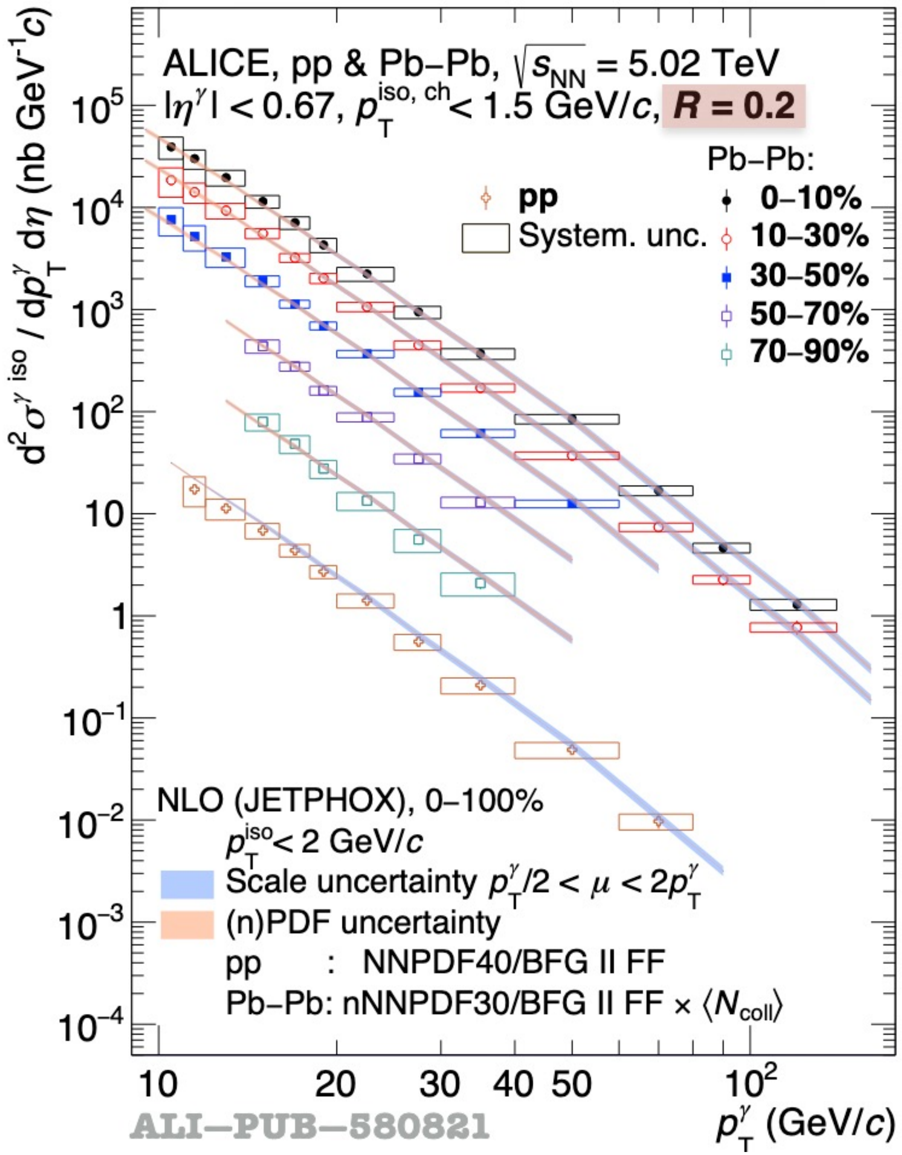


Isolated photon measurements reduce fragmentation component

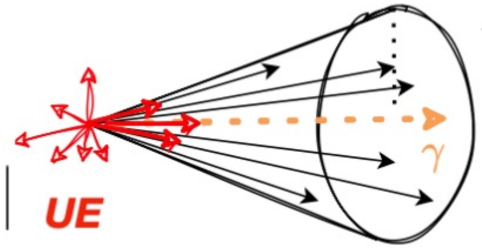


Isolated photons from ALICE

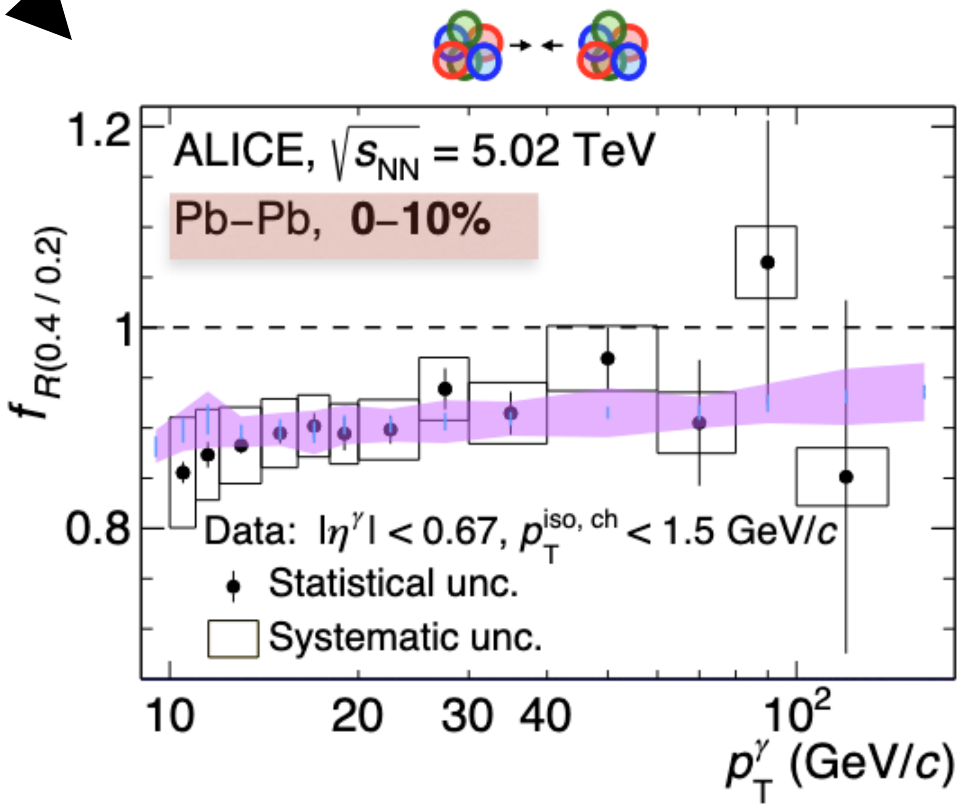
[Gustavo Conesa Balbastre (ALICE)]



$$f_{R(0.4/0.2)} = \left.\frac{d^2\sigma}{dp_T\, d\eta}\right|_{(R=0.4)} \Big/ \left.\frac{d^2\sigma}{dp_T\, d\eta}\right|_{(R=0.2)}$$



⇒ Sensitivity to suppression of fragmentation photon?

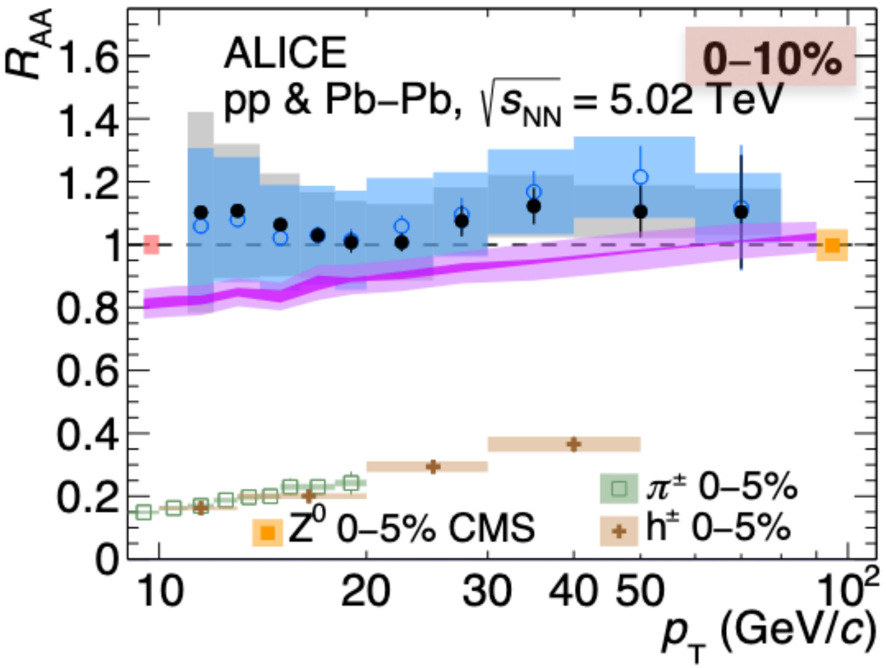


R_{AA}^{γ} and binary scaling in Pb-Pb and p-Pb collisions

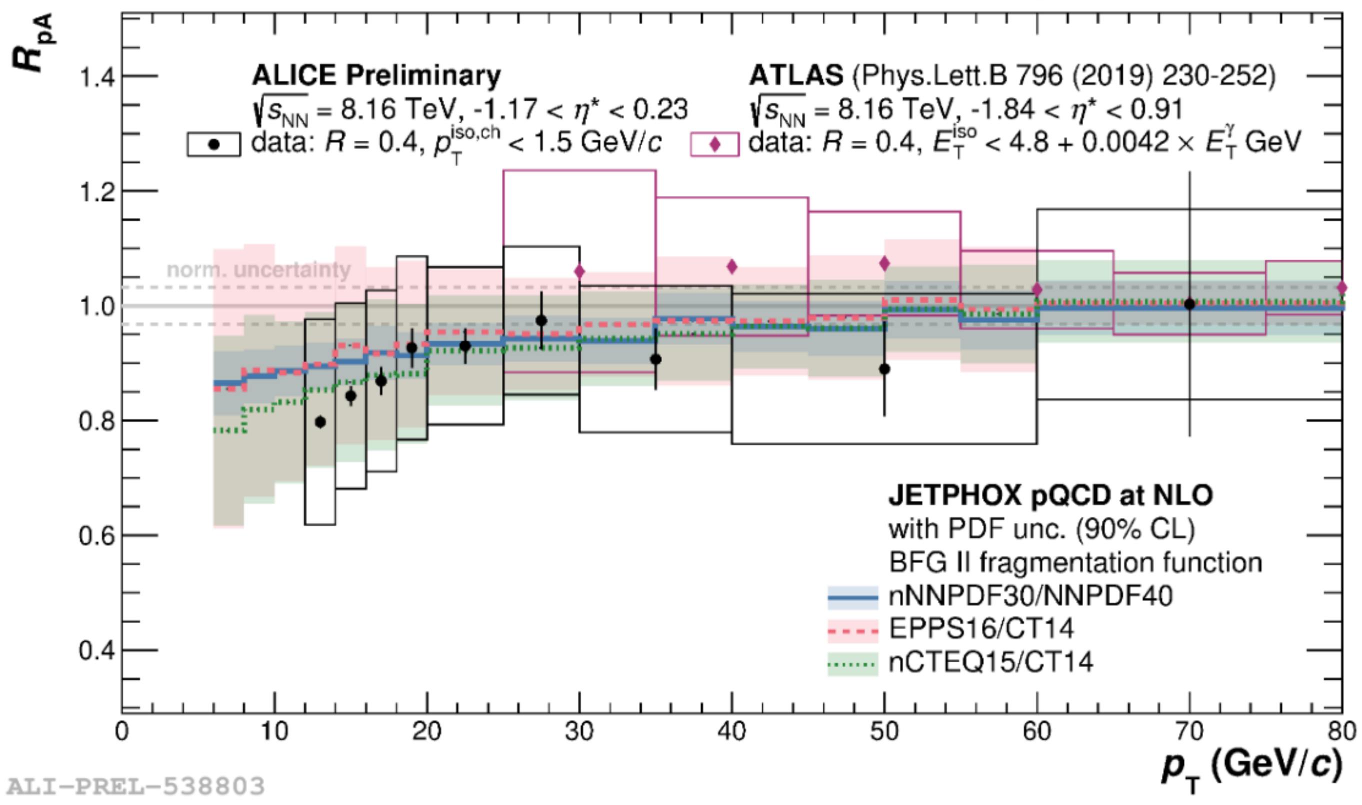
[Gustavo Conesa Balbastre (ALICE)]

$$R_{AA}^{\gamma} = \frac{\frac{dN_{\gamma}^{AA}}{dp_T}}{N_{coll}\frac{dN_{\gamma}^{pp}}{dp_T}} \overset{?}{\triangleq} 1 + $$(correction from isospin, nuclear p.d.f., ~~frag. photon energy loss~~)

p-p & Pb-Pb @ 5.02 TeV



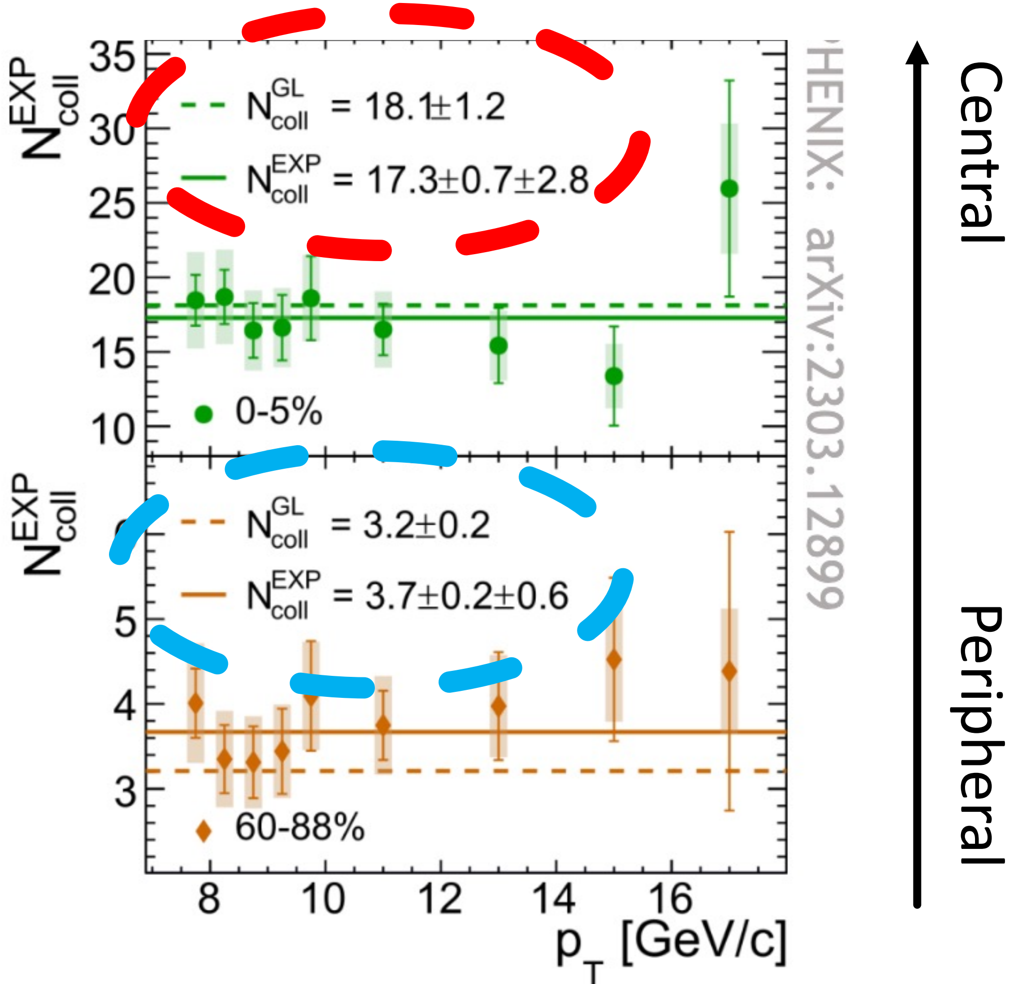
p-Pb @ 8.16 TeV

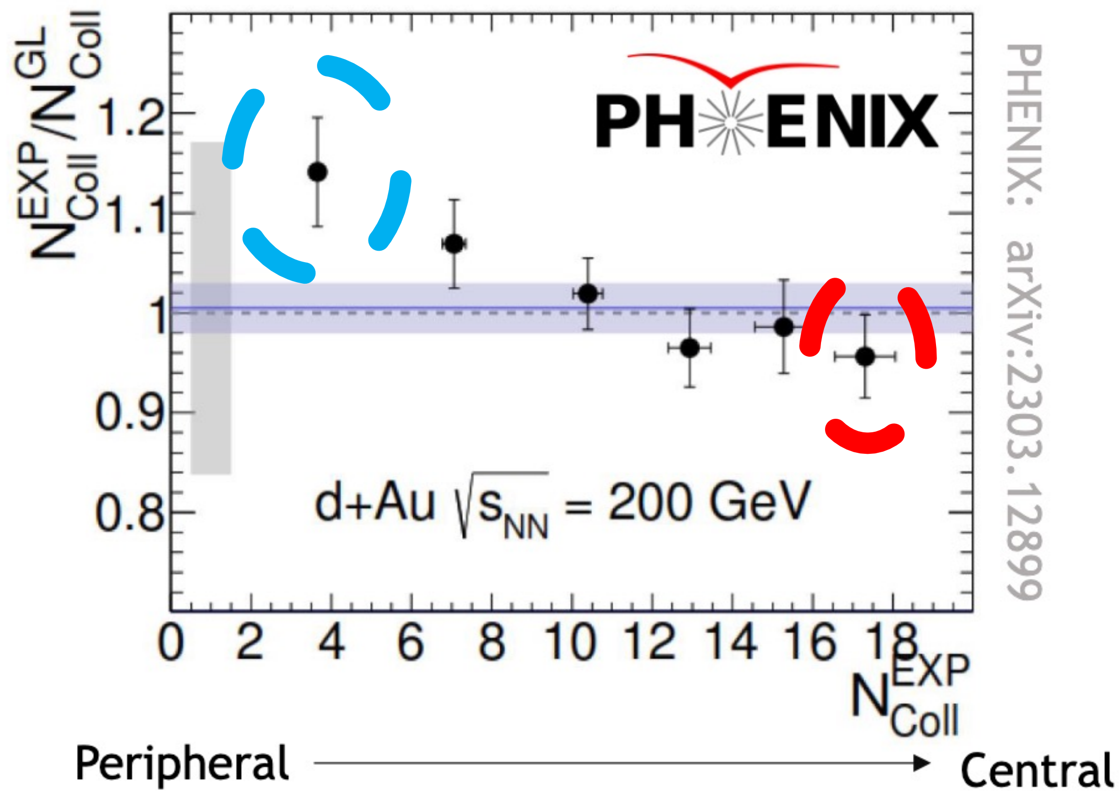


Binary scaling in d-Au @ 200 GeV

[Vassu Doomra (PHENIX)]

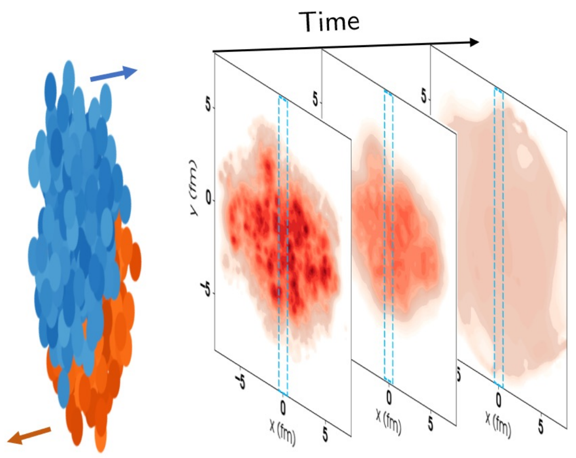
$$\frac{dN_\gamma^{AA}}{dp_T} / \frac{dN_\gamma^{pp}}{dp_T} \overset{?}{\triangleq} N_{coll} + $$(correction from isospin, nuclear p.d.f., ~~frag. photon energy loss~~)

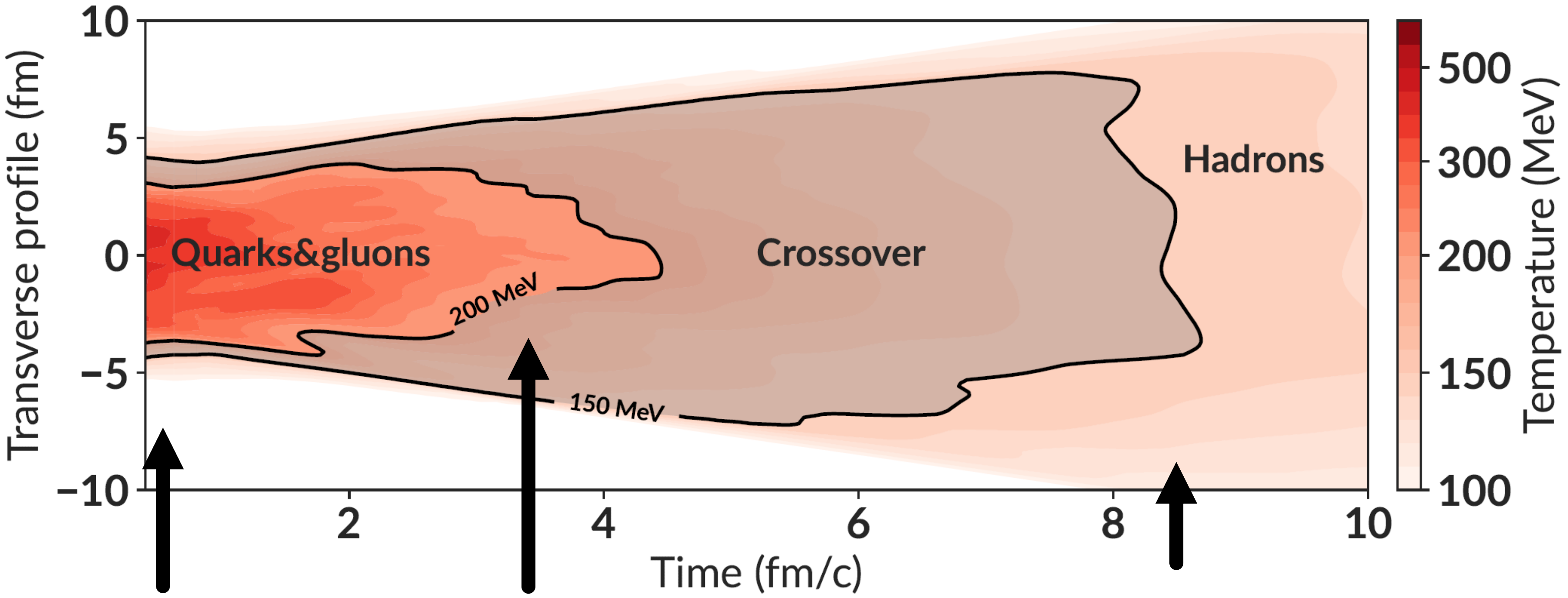




[See Dennis Perepelitsa's talk]

~Low-energy photons/dileptons in heavy-ion collisions





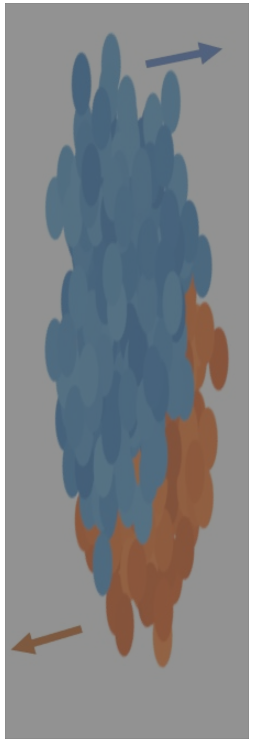
Pre-equilibrium photons/dileptons

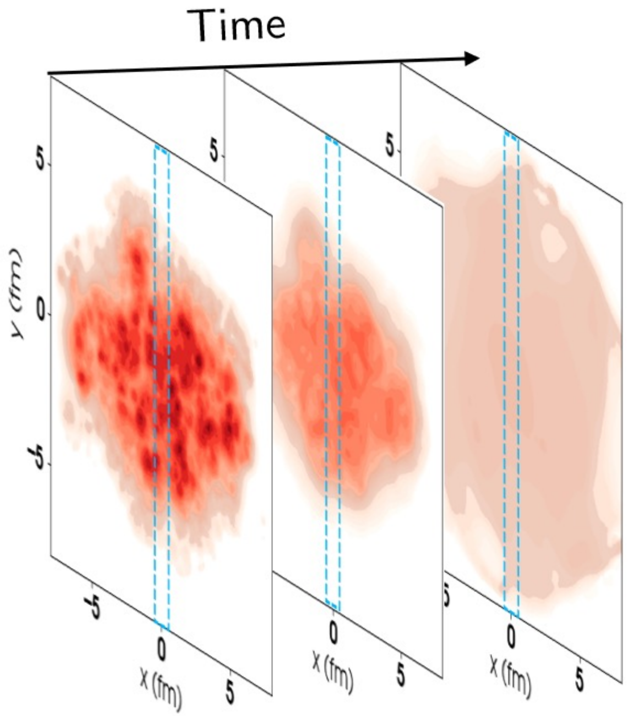
Thermal photons and dileptons

Late-stage photons and dileptons (including hadronic and heavy quark decays)

Electromagnetic radiation from deconfined medium

Figure credit: J-F Paquet and Scott Moreland

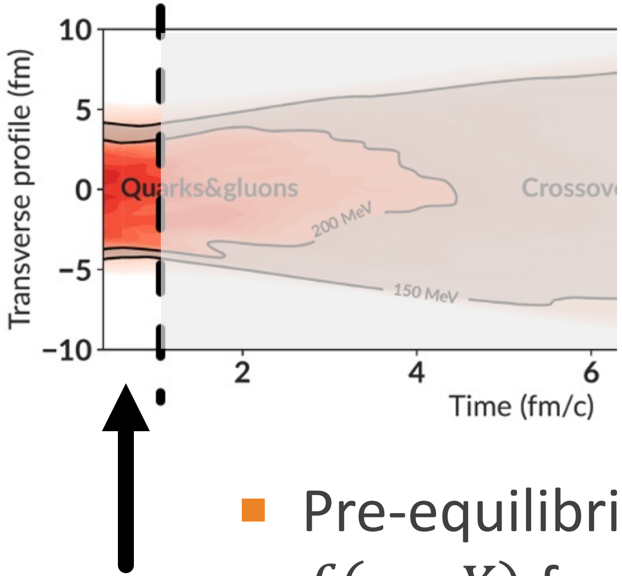




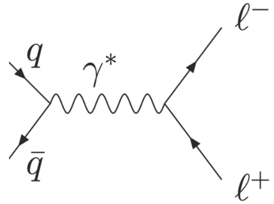
Photons and dileptons radiation from plasma

- Electromagnetic radiation from medium can probe:
  - Chemical equilibration & general early-stage dynamics of heavy-ion collisions
  - Electromagnetic fields at early time
  - Electric conductivity of plasma
  - Thermal photons&dileptons, and in-medium properties of hadrons

Pre-equilibrium emission: a quasiparticle picture



- Photons/dileptons rate per spacetime volume

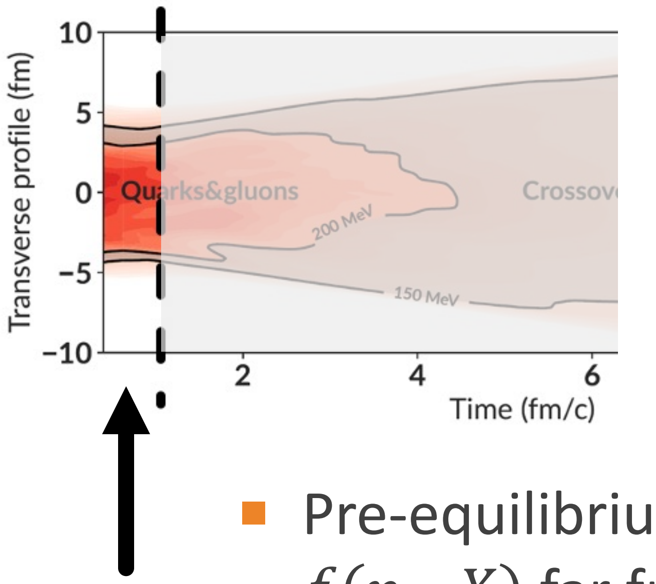


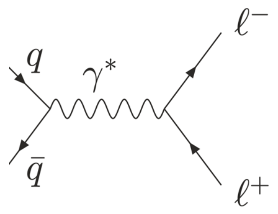
$$\frac{d\Gamma_{\gamma/l^+l^-}}{dk_T} \sim \int_{p_a,p_b,p_c} f(p_a,X) f(p_b,X)(1 \pm f(p_c,X)) \left|\mathcal{M}_{ab\to c(\gamma/l^+l^-)}\right|^2$$

with $f(p,X)$ is the quark/gluon momentum distribution

- Pre-equilibrium photons/dileptons:
  $f(p_a,X)$ far from Fermi-Dirac/Bose-Einstein at temperature T(X)

Pre-equilibrium emission: a quasiparticle picture





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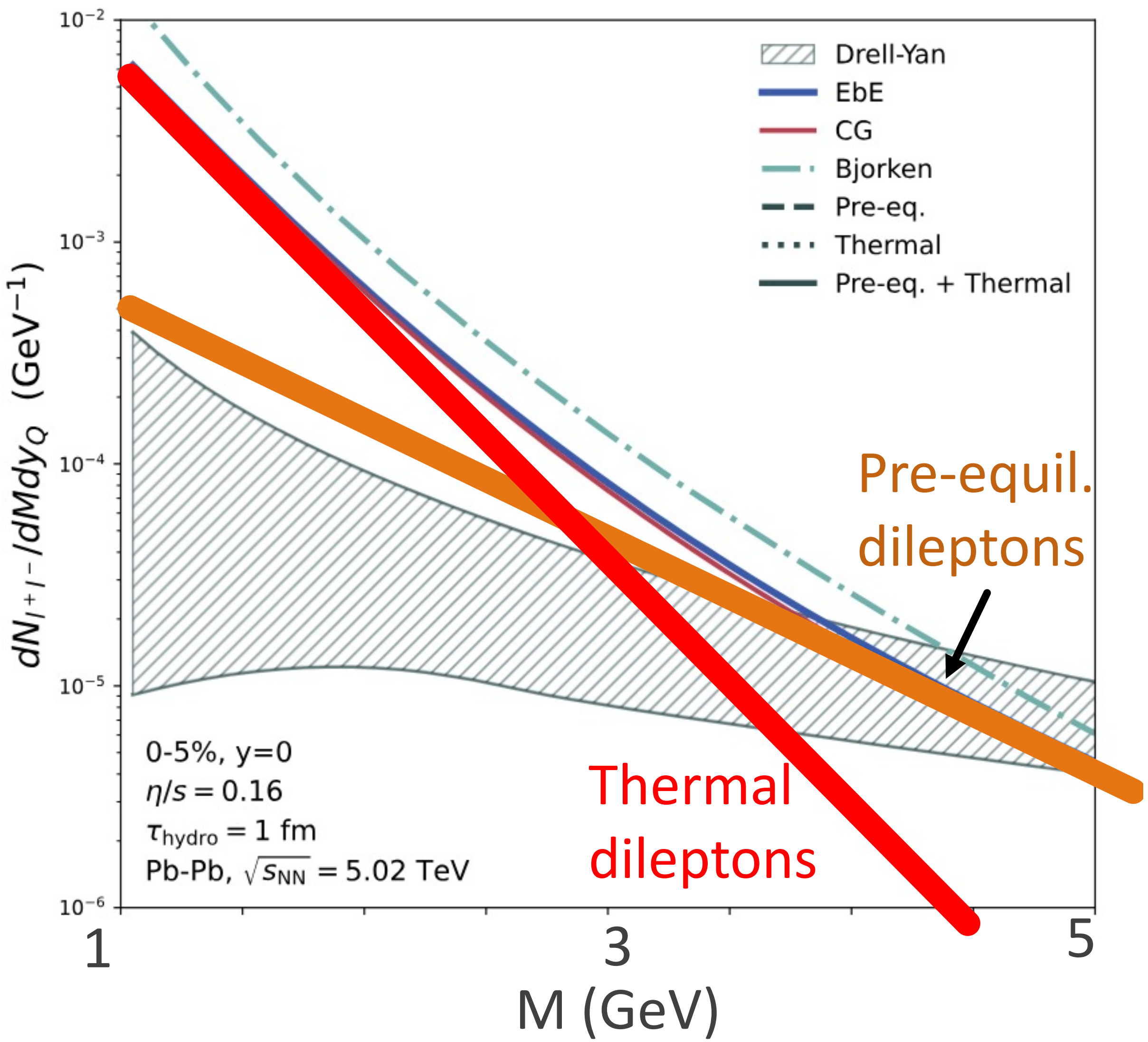
with $f(p,X)$ is the quark/gluon momentum distribution

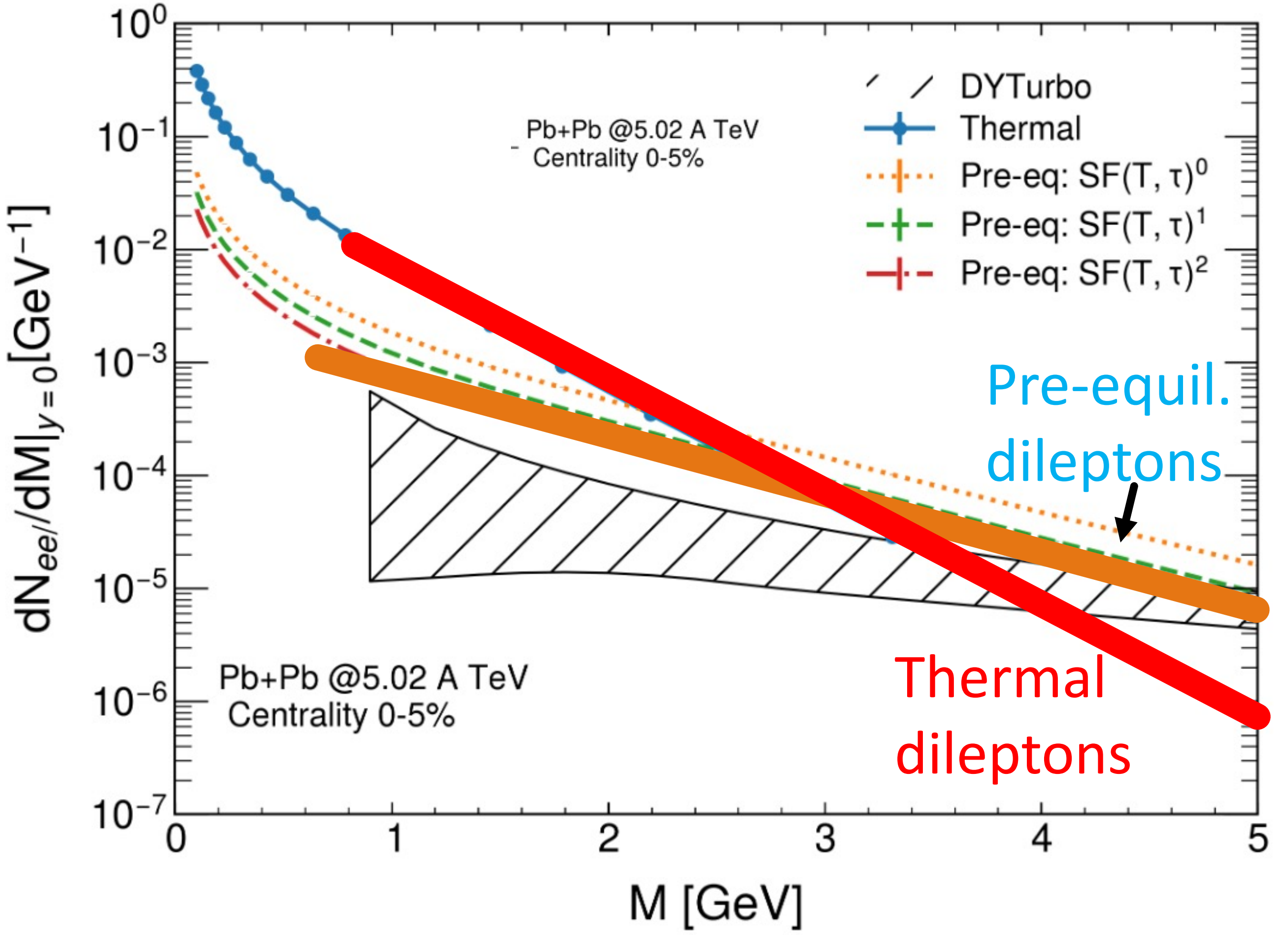
- Pre-equilibrium photons/dileptons:
  $f(p_a,X)$ far from Fermi-Dirac/Bose-Einstein at temperature T(X)
- Two different approaches, based on early-time attractors:
  - Track thermalization of $f(p,X)$ with QCD kinetic theory [Oscar Garcia Montero]
  - Track thermalization of energy-momentum tensor to estimate
    $f(p_a,X) = f_{eq}(p_a,X) + \delta f(p_a,X)$ [Xiang-Yu Wu]

Pre-equilibrium v. thermal dileptons

[Oscar Garcia Montero]

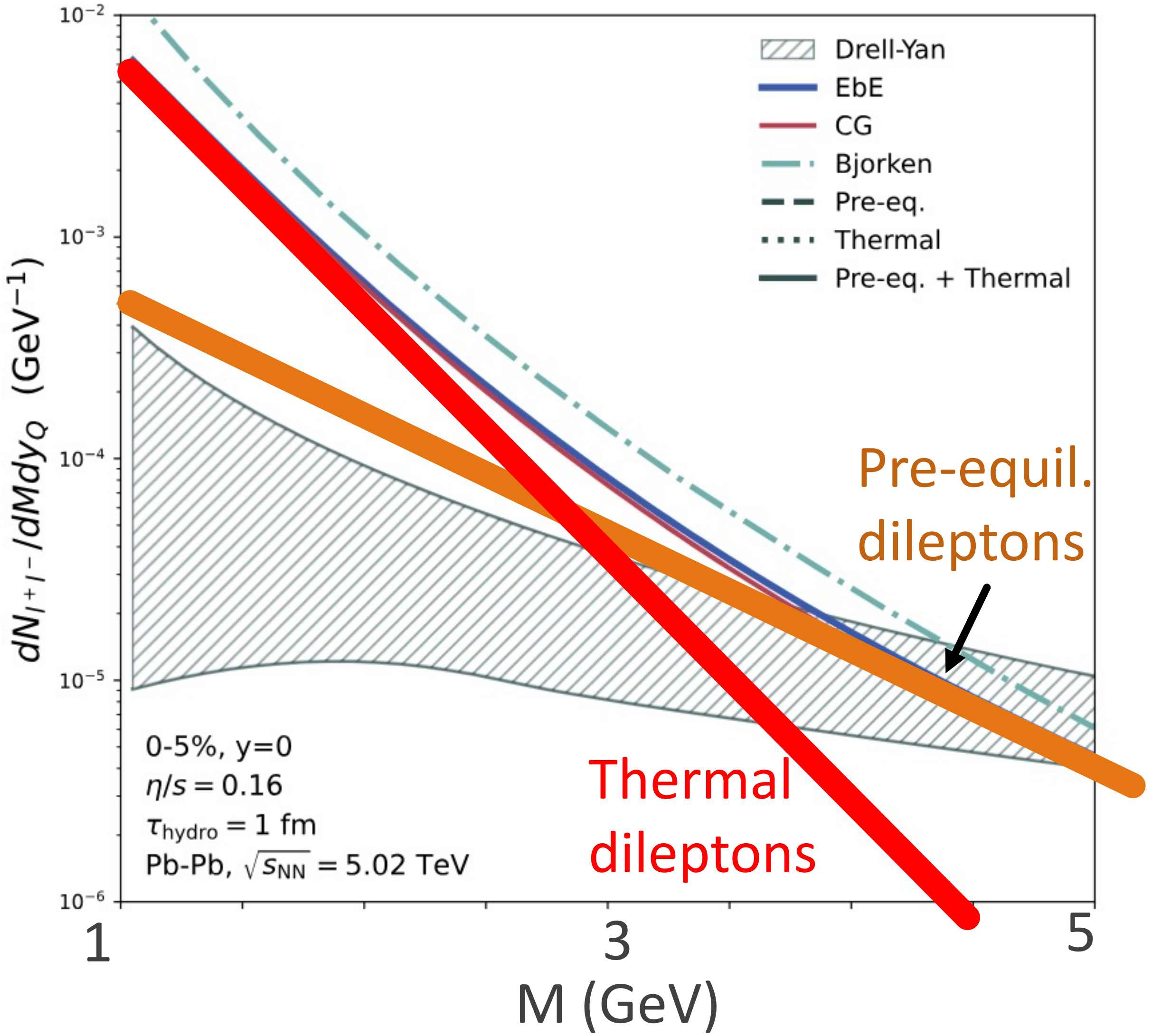


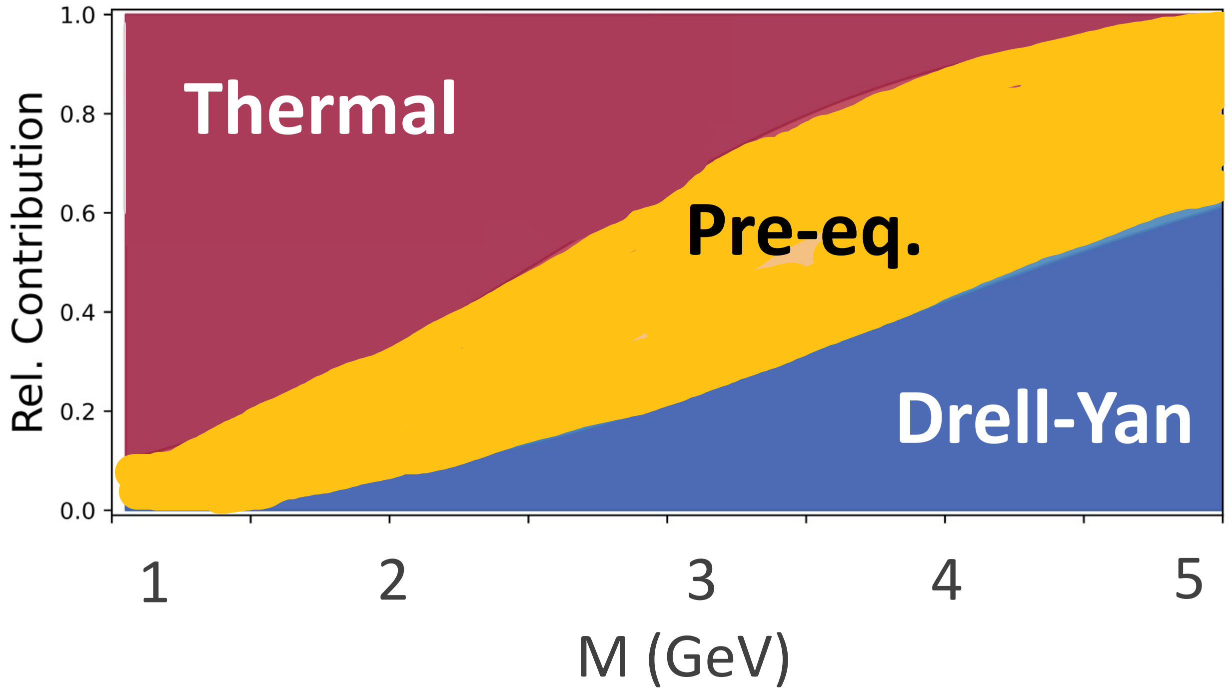
[Xiang-Yu Wu]



Pre-equilibrium v. thermal dileptons

[Oscar Garcia Montero]

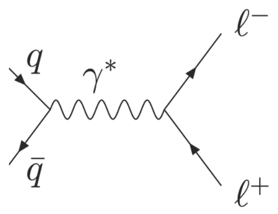


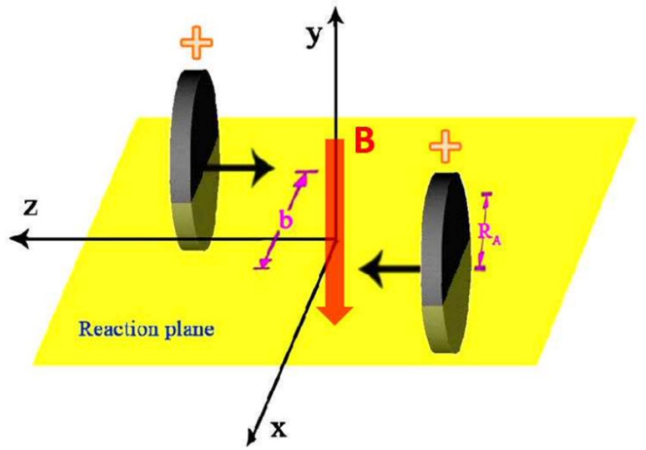


Note that boundary between pre-eq. and thermal is ambiguous

Magnetic field & pre.-eq dileptons

[Han Gao]





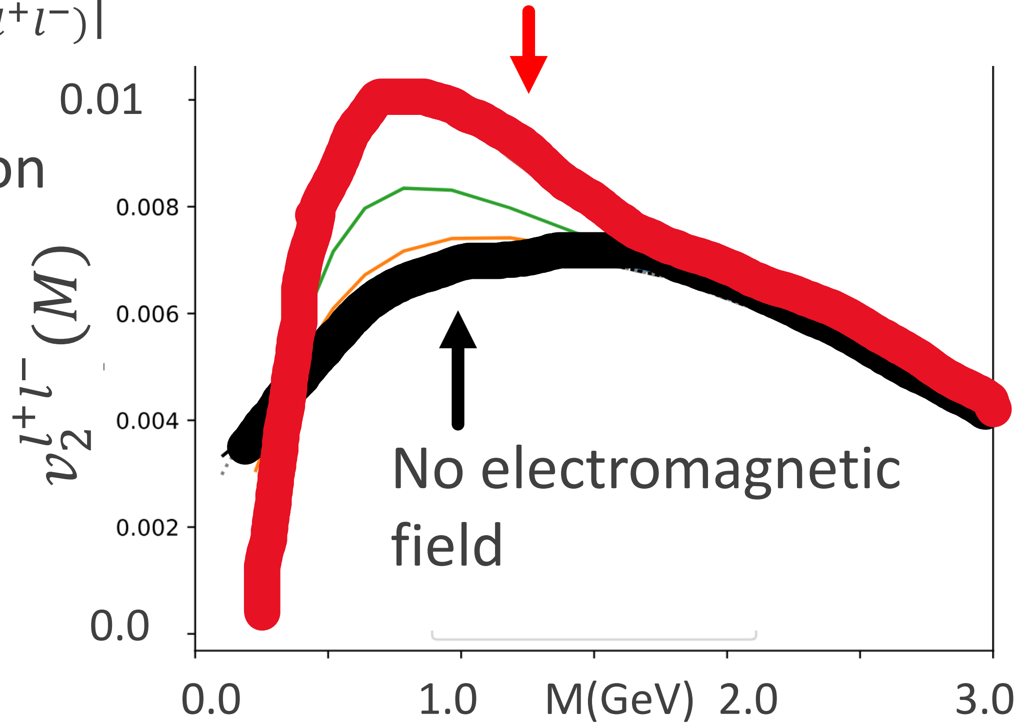
- Photons/dileptons rate per spacetime volume

$$\frac{d\Gamma_{\gamma/l^+l^-}}{dk_T} \sim \int_{p_a,p_b,p_c} f(p_a,X) f(p_b,X)(1 \pm f(p_c,X)) \left|\mathcal{M}_{ab\to c(\gamma/l^+l^-)}\right|^2$$

with $f(p,X)$ is the quark/gluon momentum distribution

- $f(p,X)$ can be modified by magnetic field

$eB(\tau = \tau_{\text{hydro}}) = 1.0 m_\pi^2$

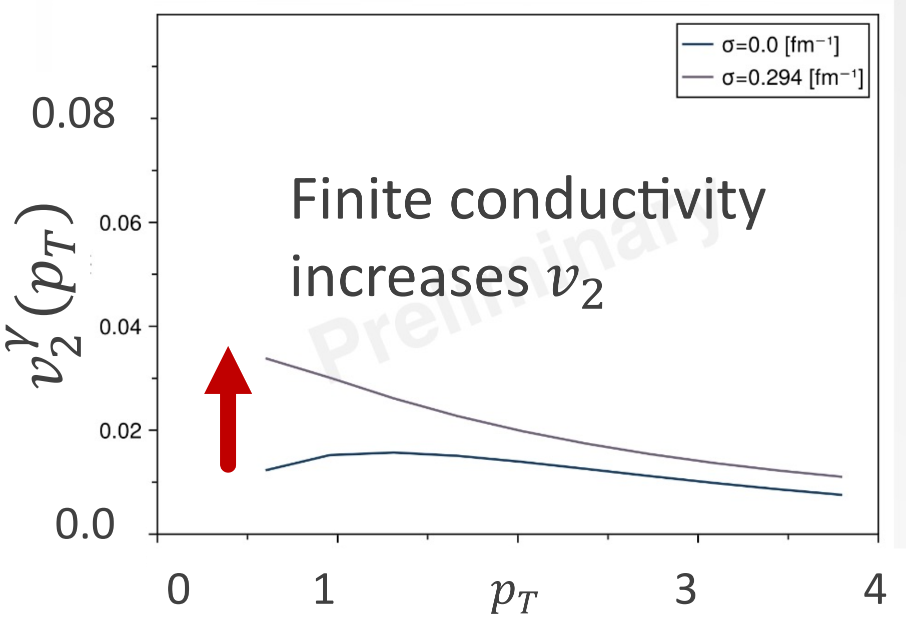


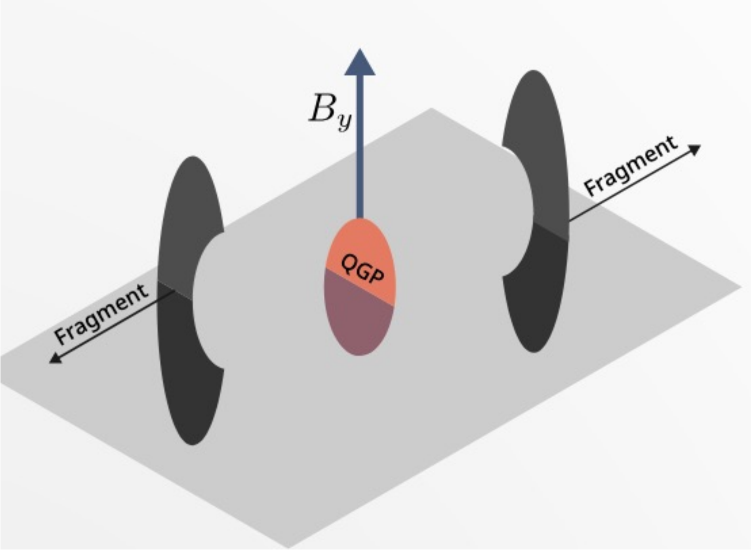
- Result for dilepton v_2 in AuAu@19.6 GeV (dileptons from quark-gluon plasma only, not from hadron gas)

Magnetohydrodynamics and electric conductivity

[Nicholas J. Benoit]

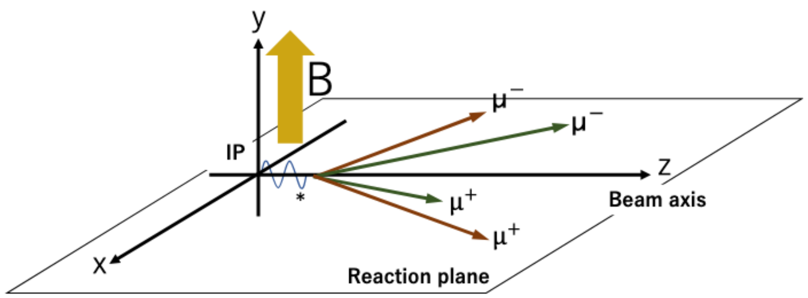
Photon v_2^γ sensitive to plasma's electric conductivity



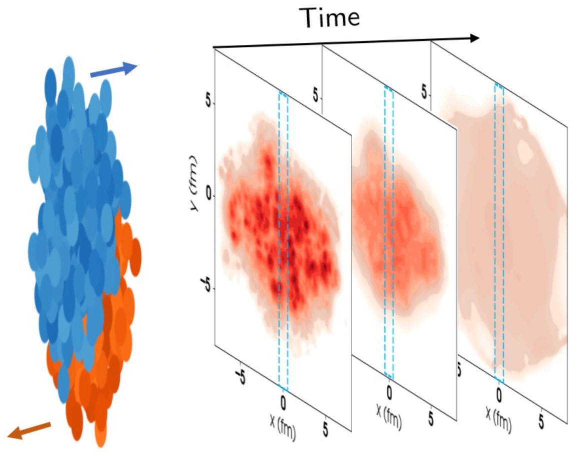


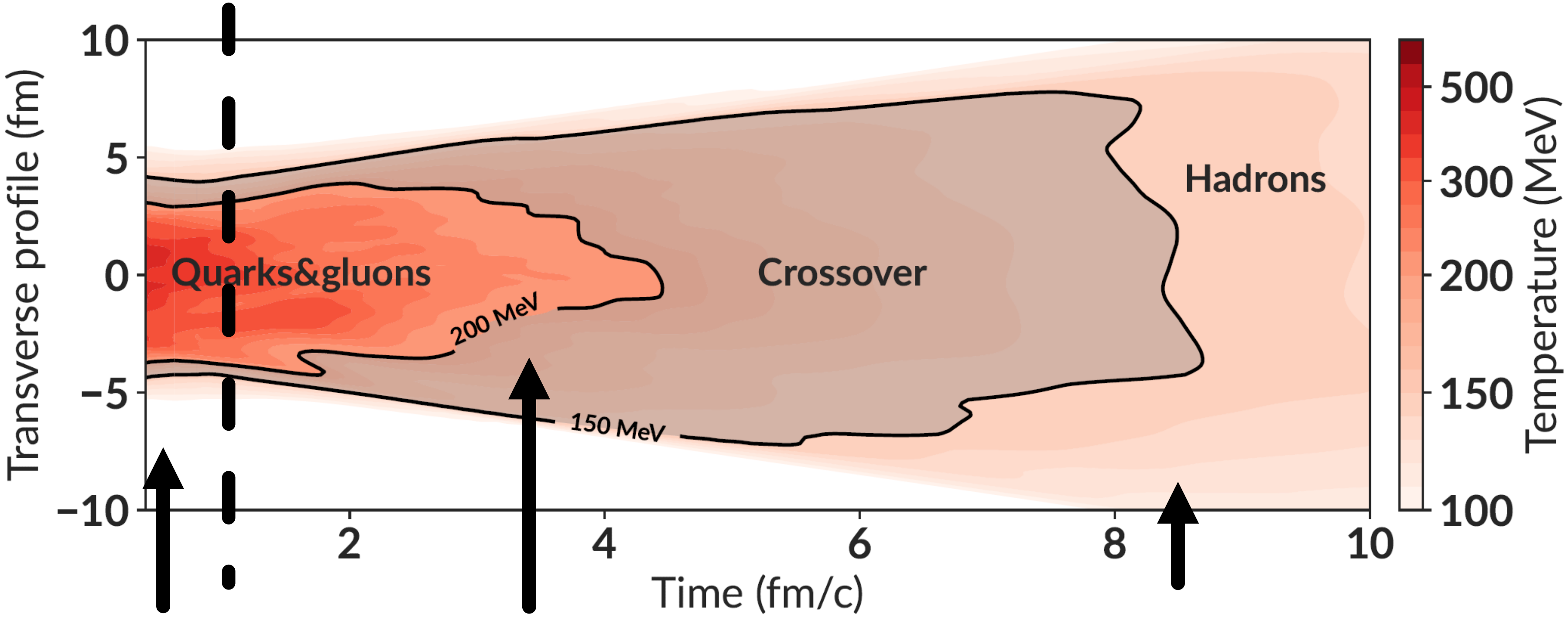
[Kento Kimura]

Dimuons photon polarization as probe of the magnetic field



Thermal **dileptons**: probing QGP and in-medium properties of hadrons





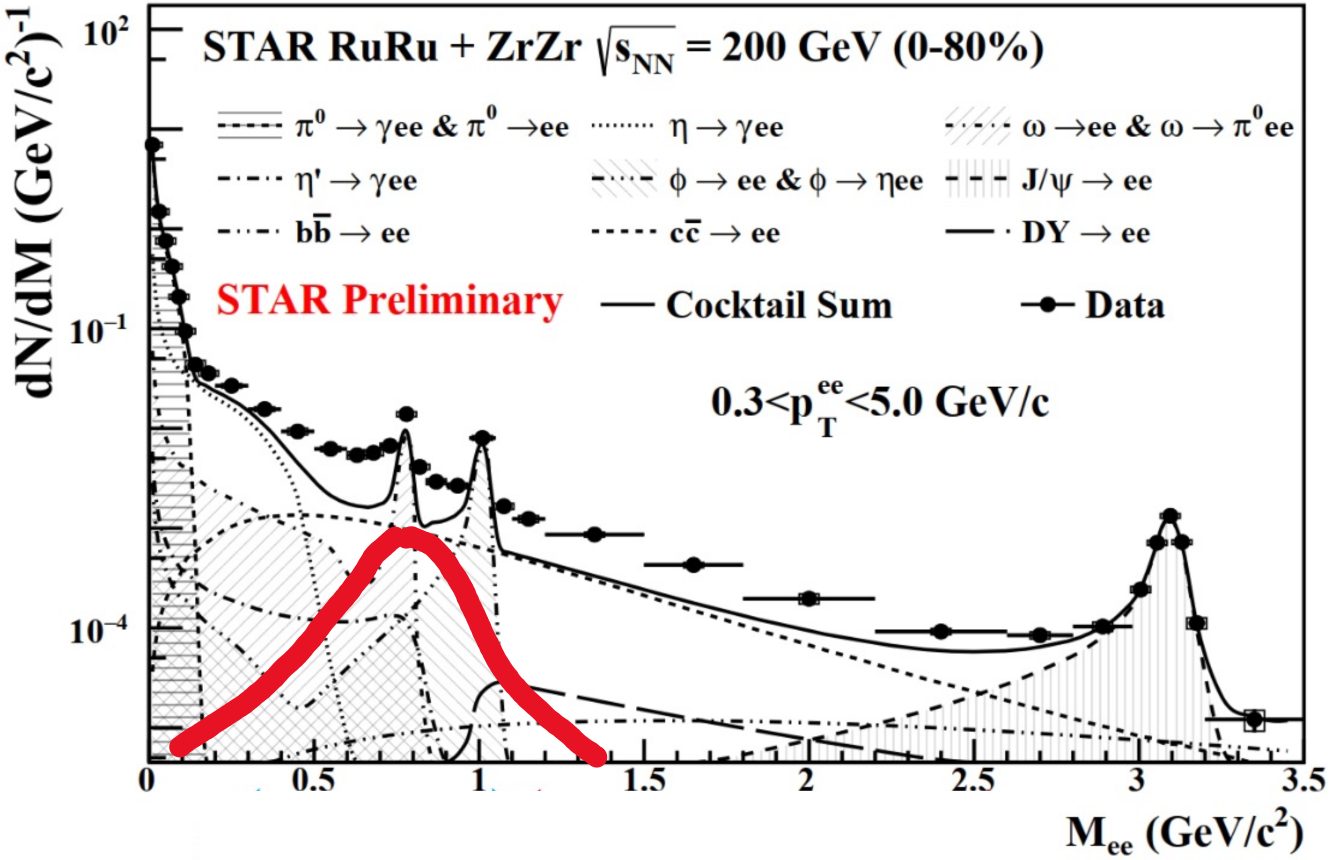
Pre-equilibrium photons/dileptons

Thermal photons and dileptons

Late-stage photons and dileptons **(including hadronic decays and heavy quark decays)**

Dilepton invariant mass spectrum: signal vs background

[Jiaxuan Luo (STAR)] STAR dilepton results for the isobar run



Physical background (Cocktails):

- $\omega, \phi, J/\psi \to e^+e^-$
- $\pi^0, \eta, \eta' \to \gamma e^+e^-$
- $\omega \to \pi^0 e^+e^-$
- $\phi \to \eta e^+e^-$
- $c\bar{c} \to e^+e^-X$
- $bb \to e^+e^-X$
- Drell-Yan

} Modified for effect of energy loss

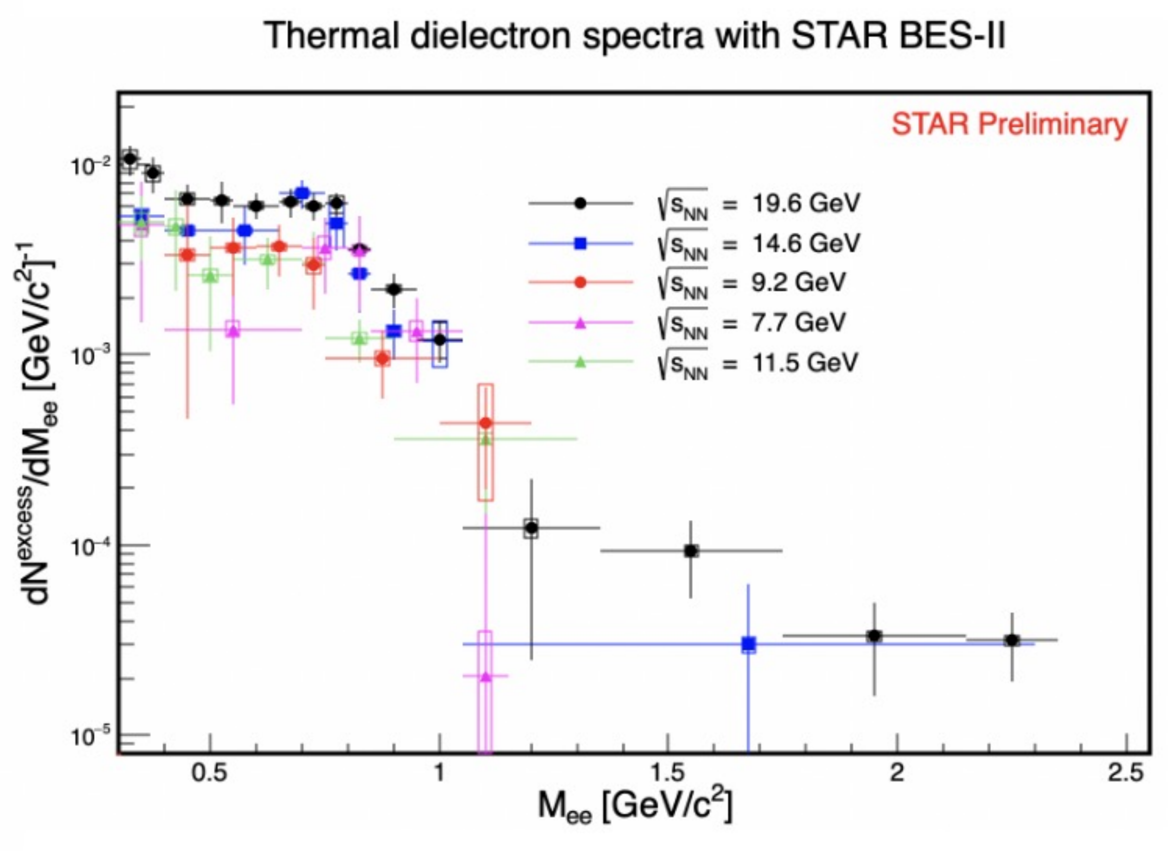
Signal: - **ρ meson decay with finite-temperature effects ("broadening")**

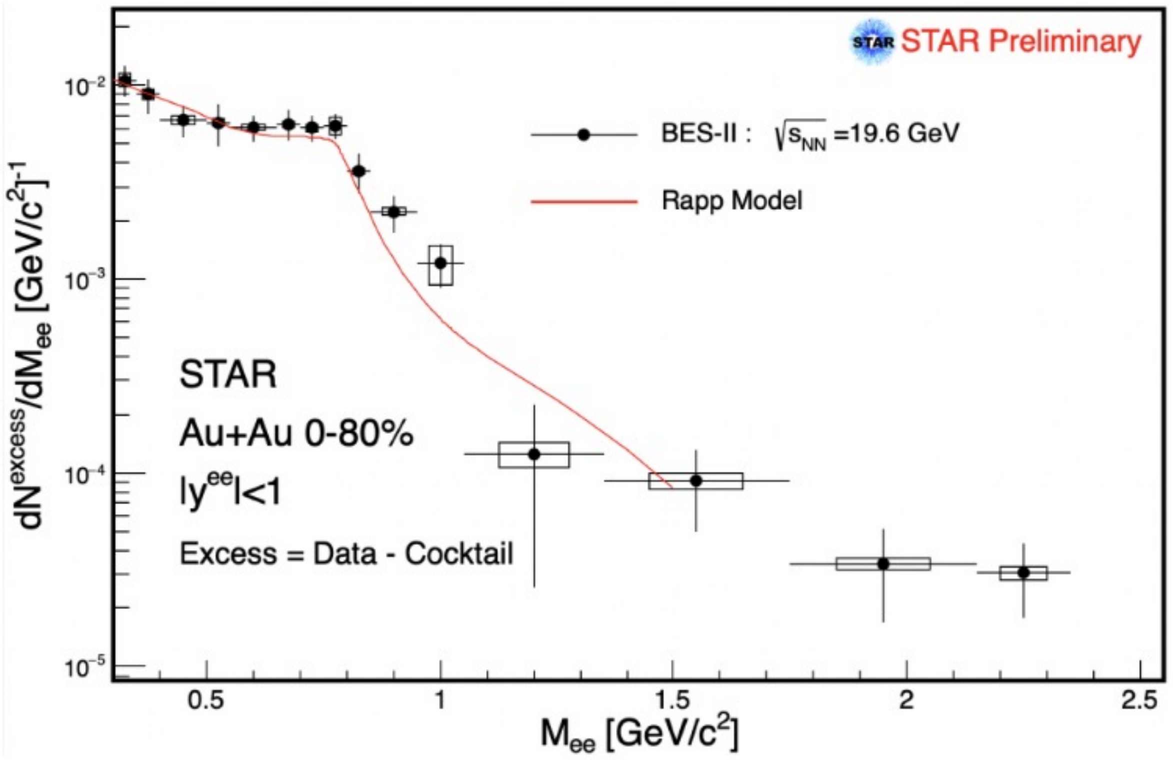
- **Dilepton emission from quark-gluon plasma and hadronic interactions**

Dilepton excess in beam energy scan [Chenliang Jin (STAR)]

Excess = Measurement - Background

Dilepton excess in good agreement with theoretical expectation

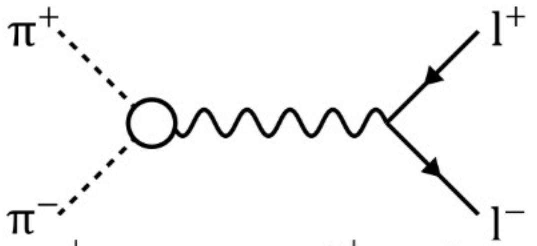




Probes of low temperature, high density medium

[Kentaro Hayashi]

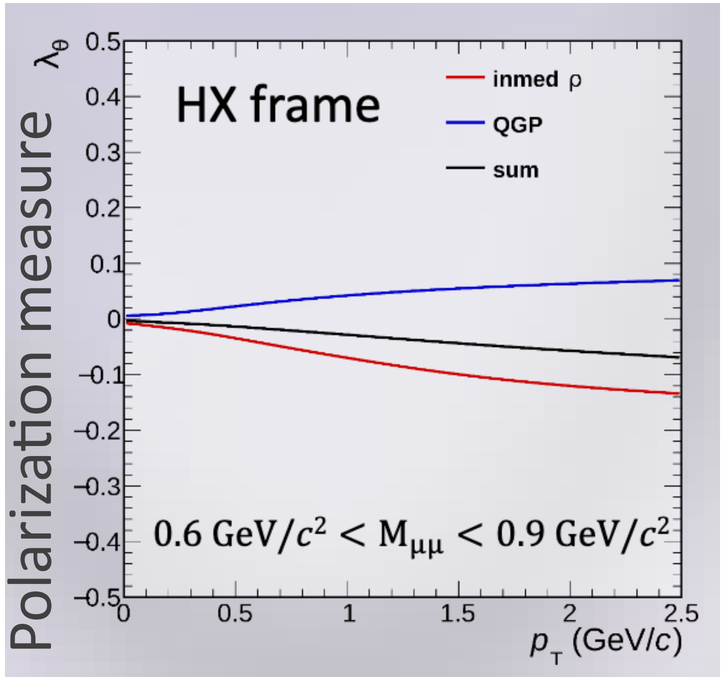
Dilepton to study inhomogeneous chiral condensed phase



$$\pi^+ + \pi^- \to l^+ + l^-$$

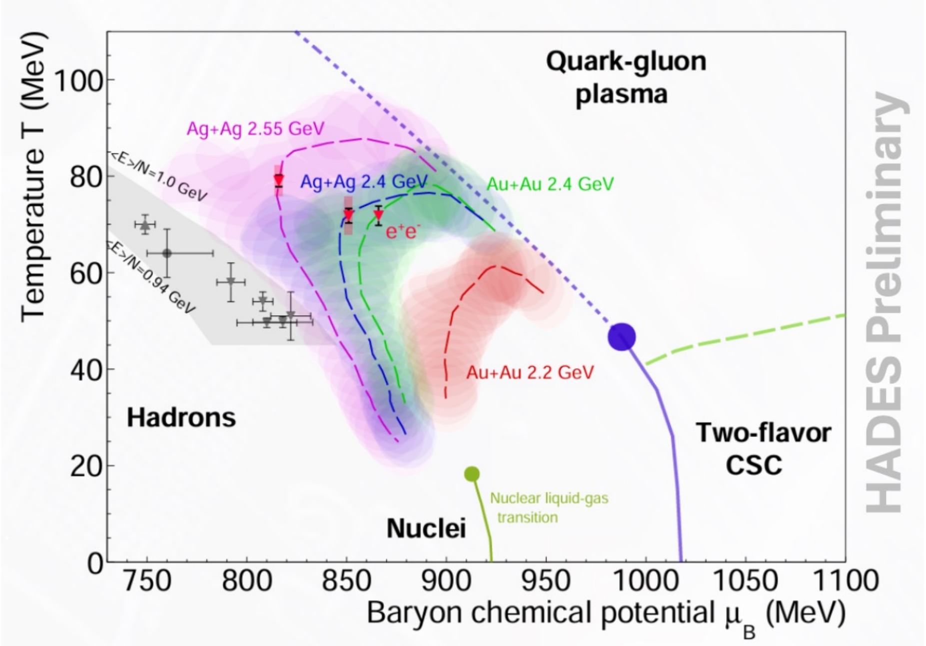
[Florian Seck]

Dilepton polarization to distinguish different sources



[Iuliana-Carina Udrea]

Low-mass, low-momentum virtual photon from HADES



Isolating the dilepton background

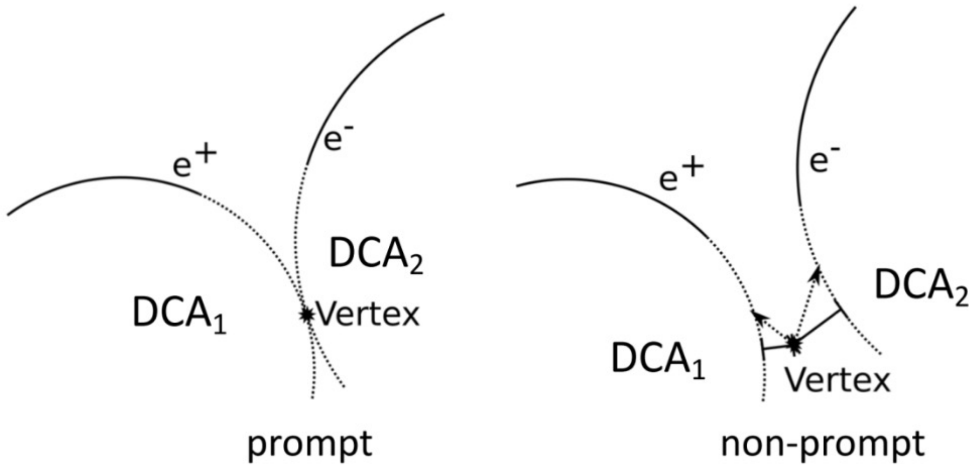
[Jerome Jung; Florian Eisenhut; Emma Charlotte Ege (ALICE)]

[See also Vassu Doomra (PHENIX) for p+p results]

Topological separation

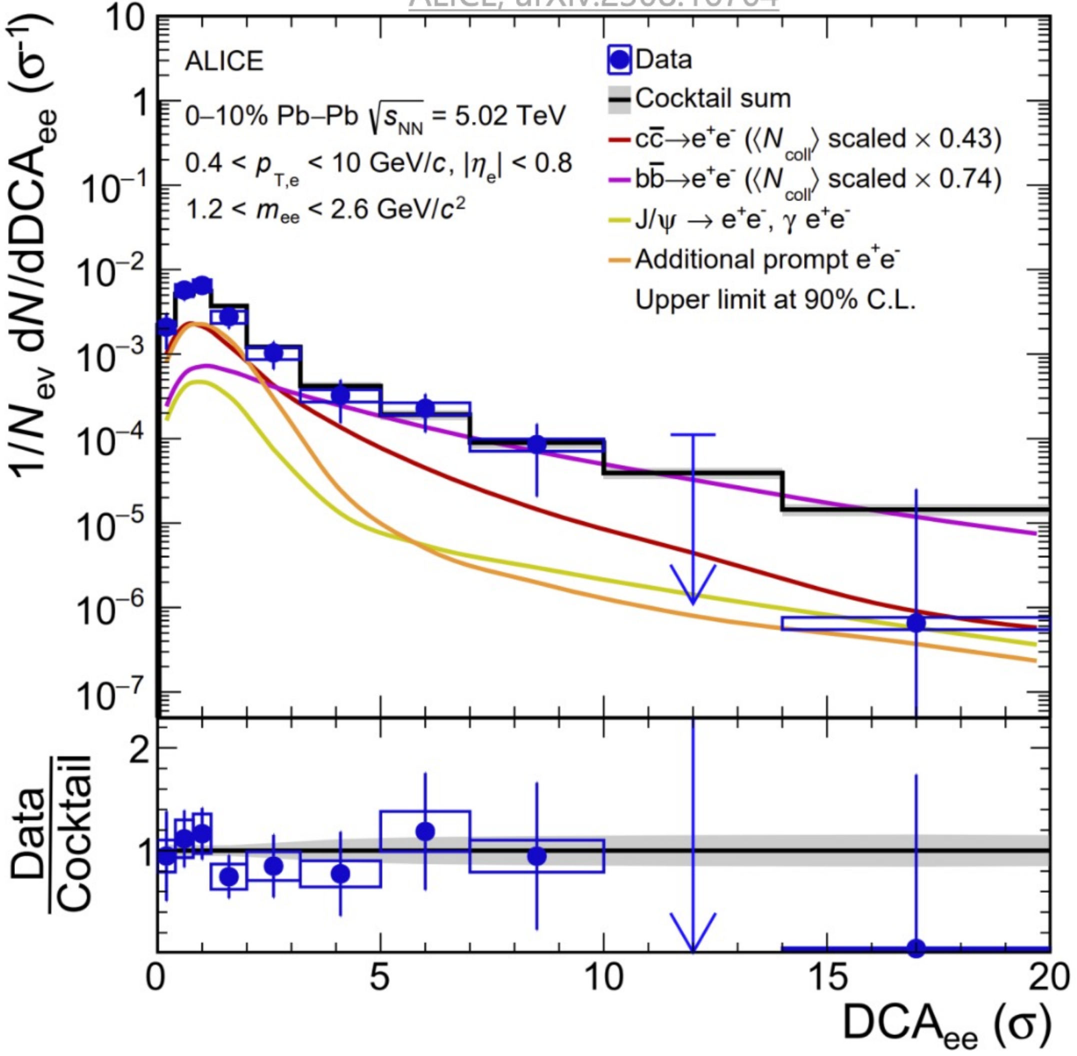
Approach

Distance-of-closest approach (DCA):

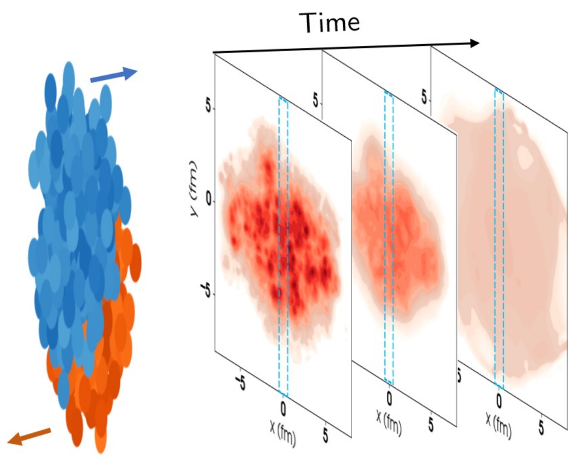


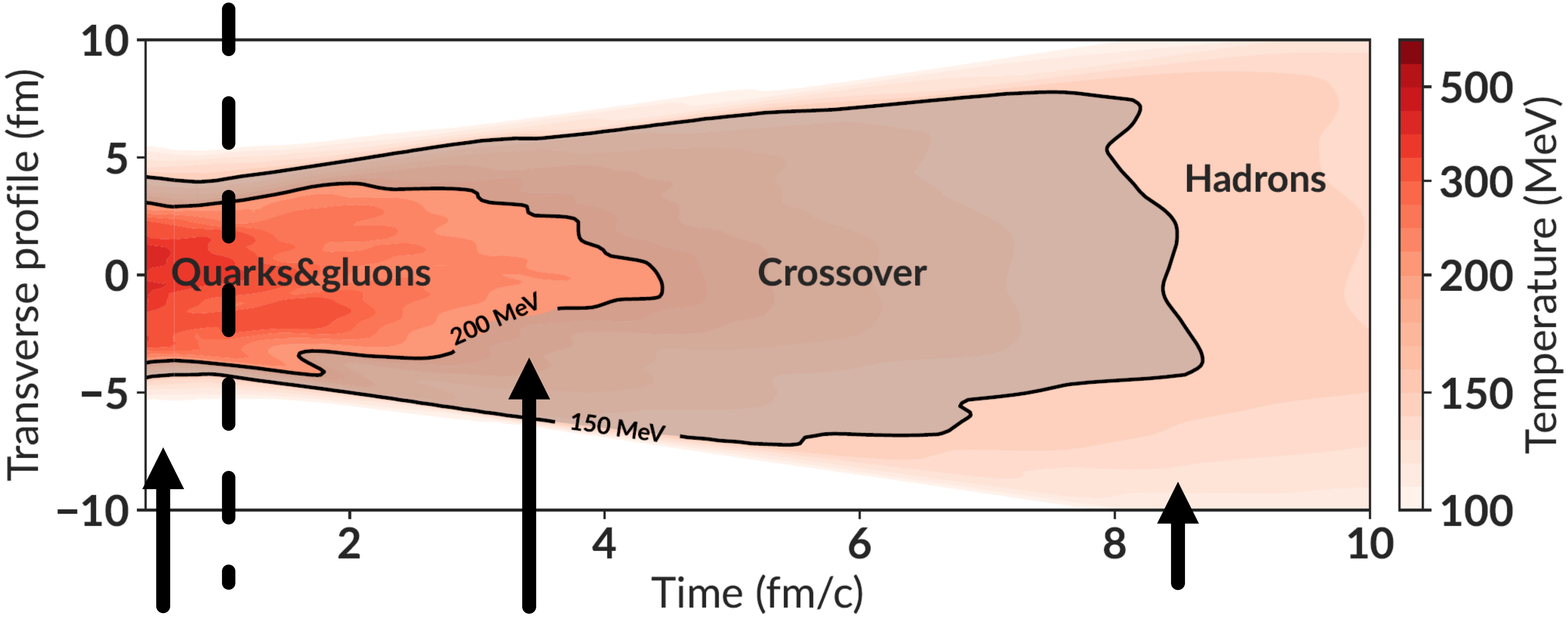
→ $DCA_{ee}(\text{thermal}) < DCA_{ee}(\text{HF})$

ALICE, arXiv:2308.16704



Thermal (direct) **photons**: probing QGP and in-medium properties of hadrons





Pre-equilibrium photons/dileptons

Thermal photons and dileptons

Late-stage photons and dileptons ~~(including hadronic decays and heavy quark decays)~~

Direct photon Bose–Einstein correlations from ALICE

[Dmitri Peresunko]

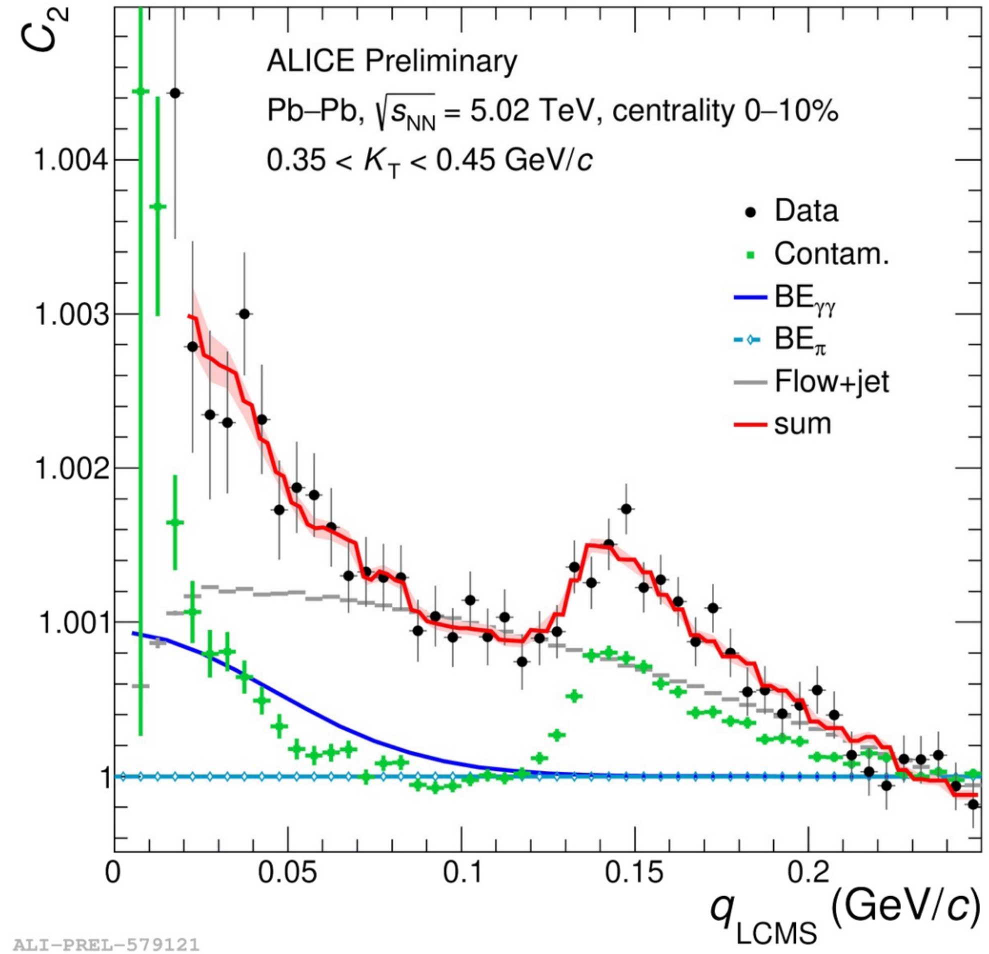
$$A(1+\lambda \exp(-q^2 R^2)+a_{contam} Cont + a_{BE\,\pi\pi}(C_2^{BE\,\pi\pi}-1)+a_{Flow}(C_2^{Flow}-1))$$

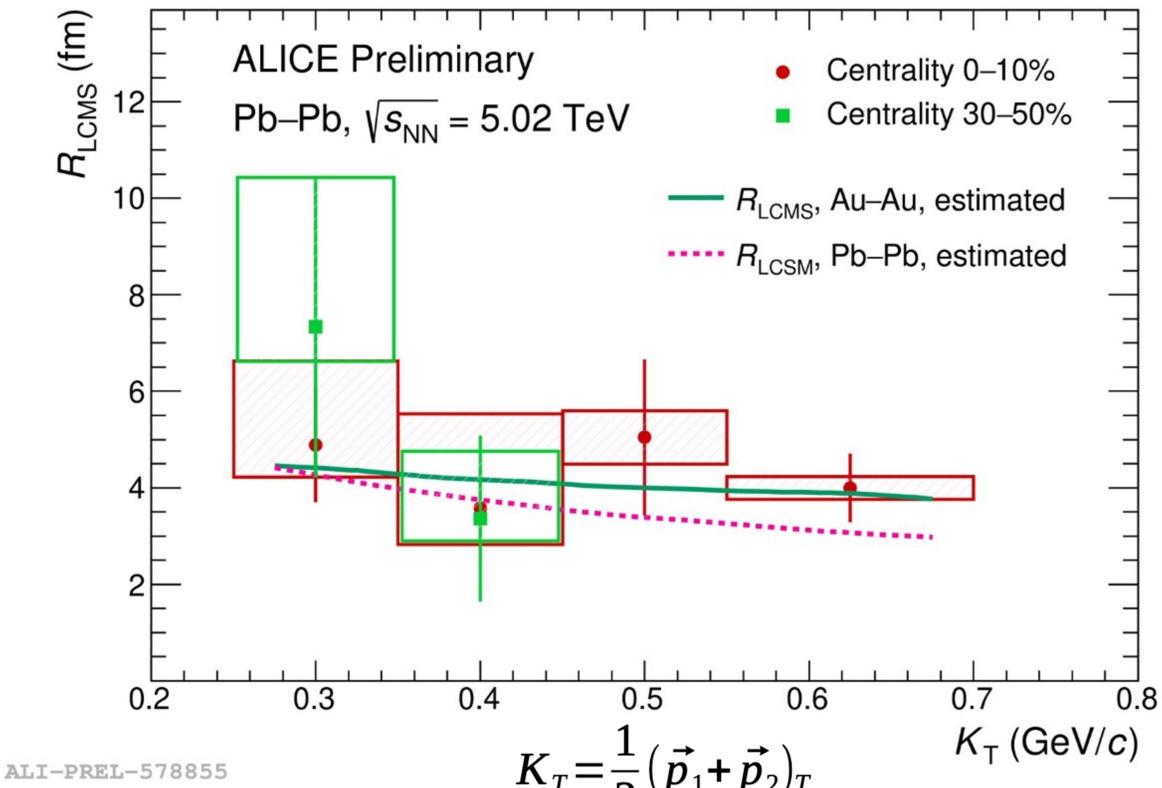
$$q_{LCMS}=|\vec{p}_1-\vec{p}_2|$$

Photon HBT radius

$$K_T=\frac{1}{2}(\vec{p}_1+\vec{p}_2)_T$$

Photon correlation





$$K_T=\frac{1}{2}(\vec{p}_1+\vec{p}_2)_T$$

Direct photon Bose–Einstein correlations from ALICE

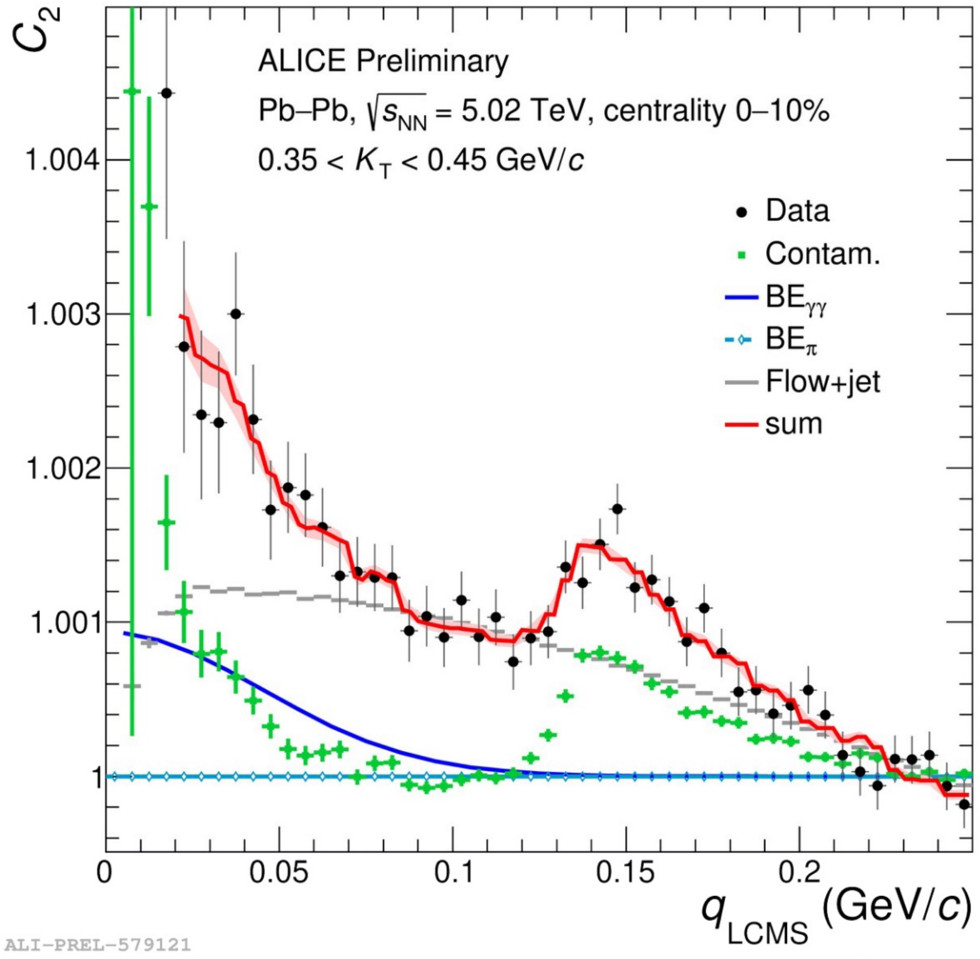
[Dmitri Peresunko]

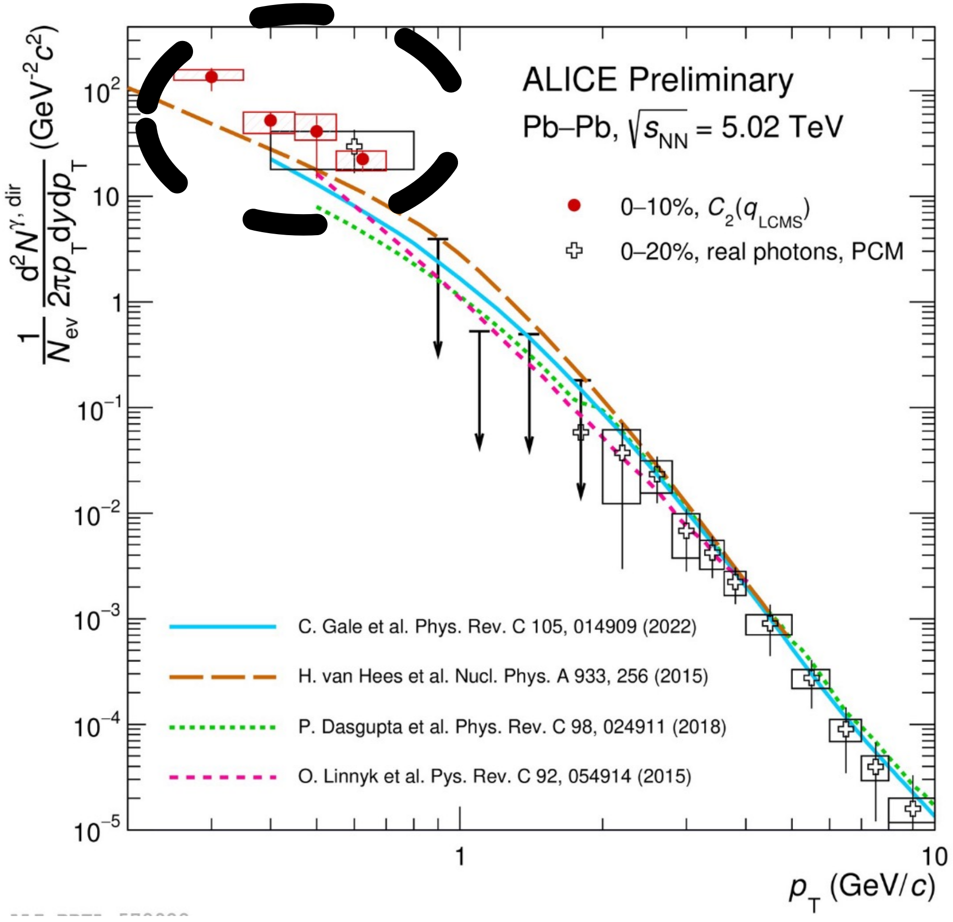
$$K_T = \frac{1}{2}(\vec{p}_1 + \vec{p}_2)_T \qquad q_{LCMS} = |\vec{p}_1 - \vec{p}_2|$$

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

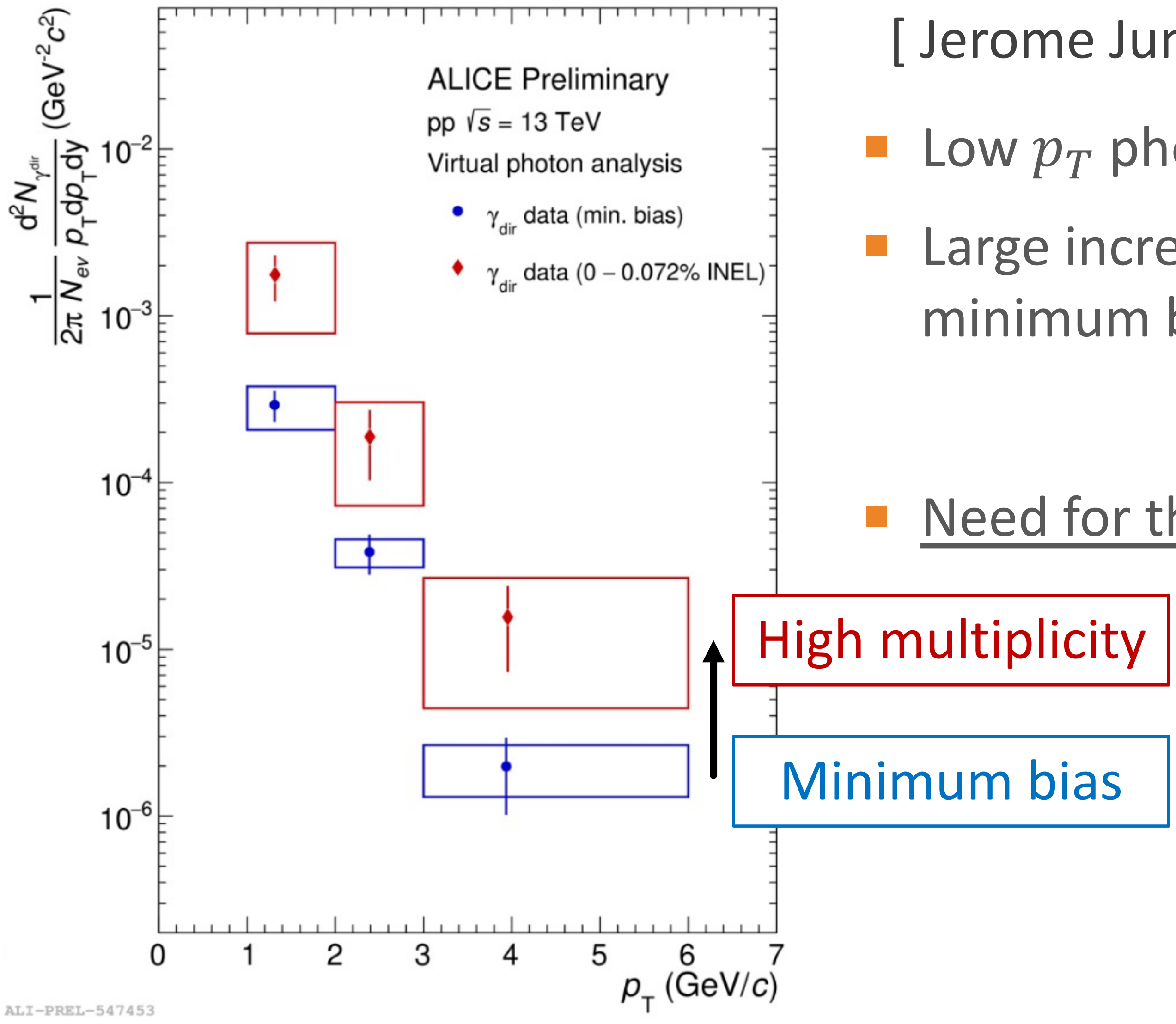
$$\lambda = \frac{1}{2}\left(\frac{N_\gamma^{dir}}{N_\gamma^{incl}}\right)^2$$

Photon correlation





Photons in high-multiplicity proton-proton collisions

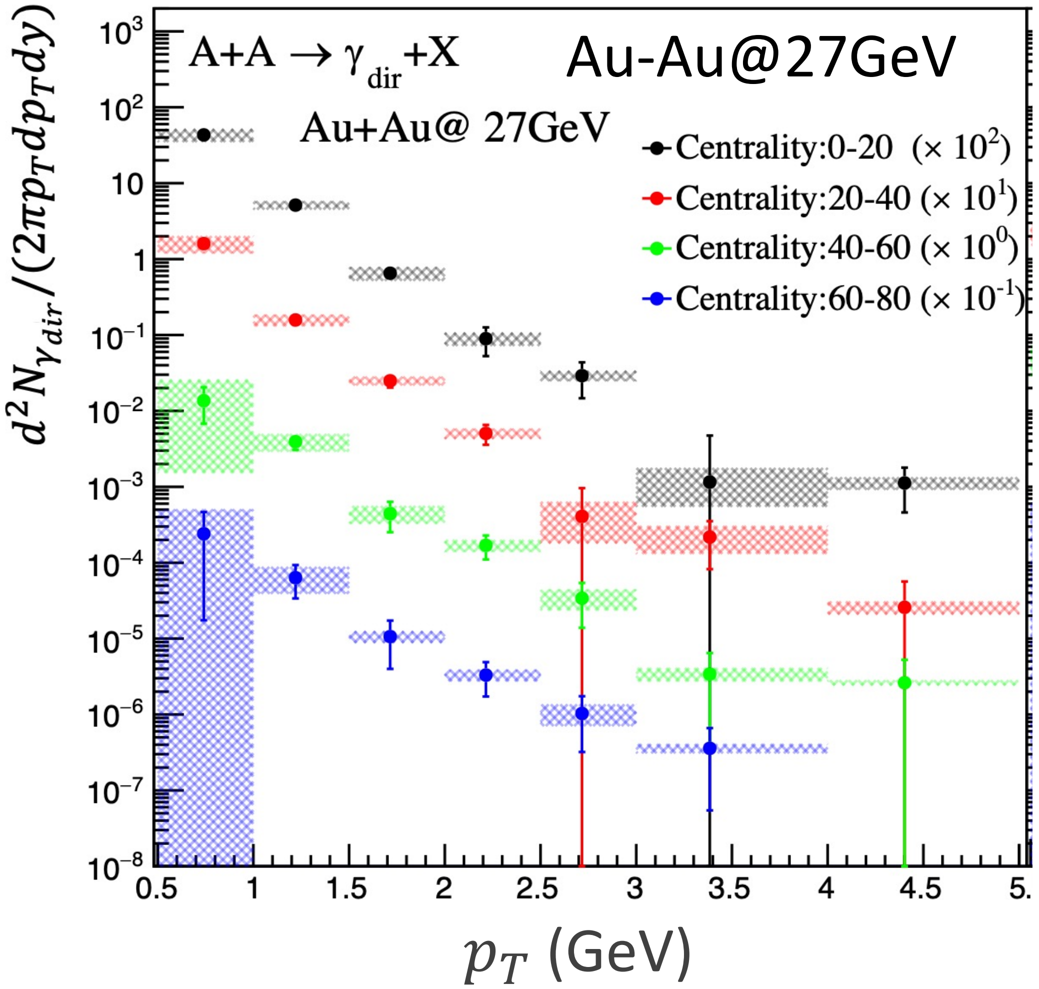


[Jerome Jung (ALICE)]

- Low p_T photon spectrum in high-multiplicity p-p@13 TeV
- Large increase in photon spectrum compared to minimum bias
- Need for theory calculations

Low p_T direct photons in beam energy scan

[Xianwen Bao (poster+flash talk)]

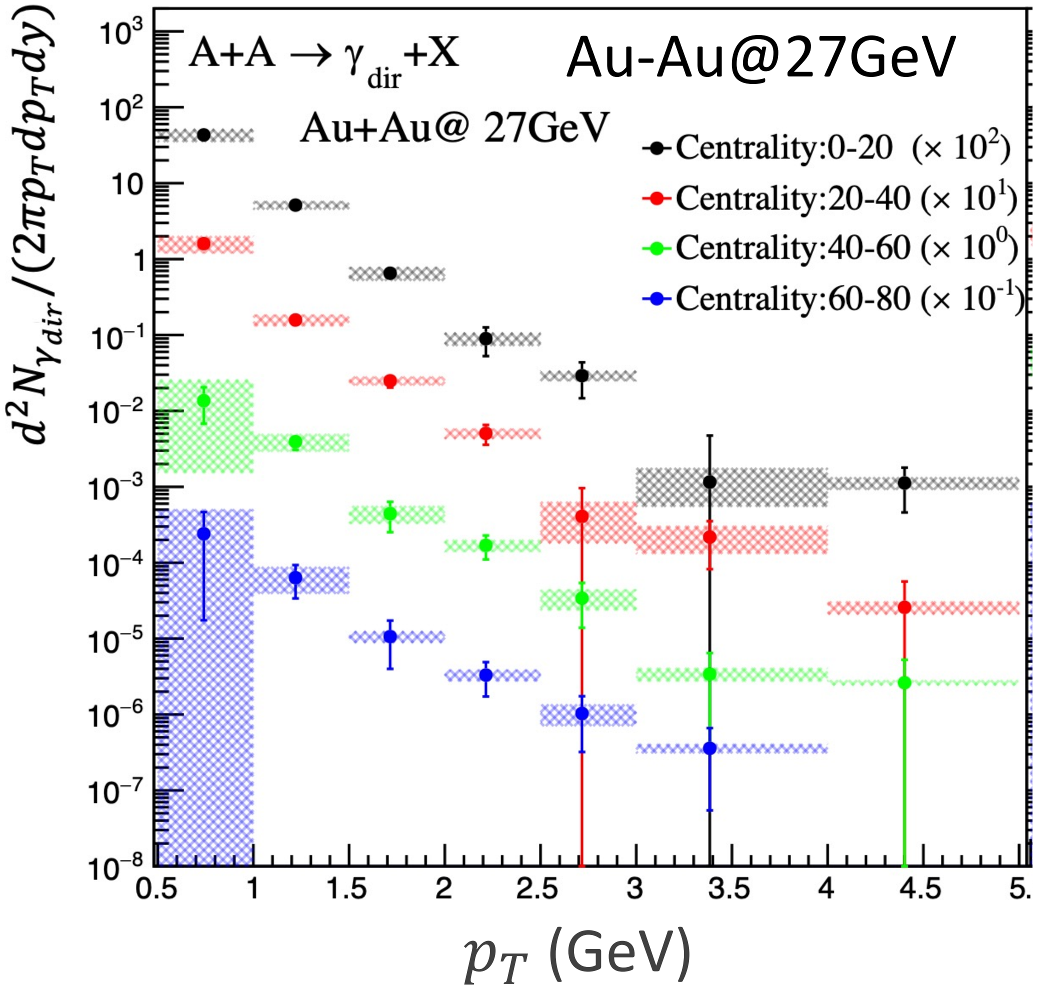


Also measured at 54.4 GeV

Strong incentive to improve low p_T photon calculation in proton-proton collisions (<u>or measure it</u>)

Low p_T direct photons in beam energy scan

[Xianwen Bao (poster+flash talk)]



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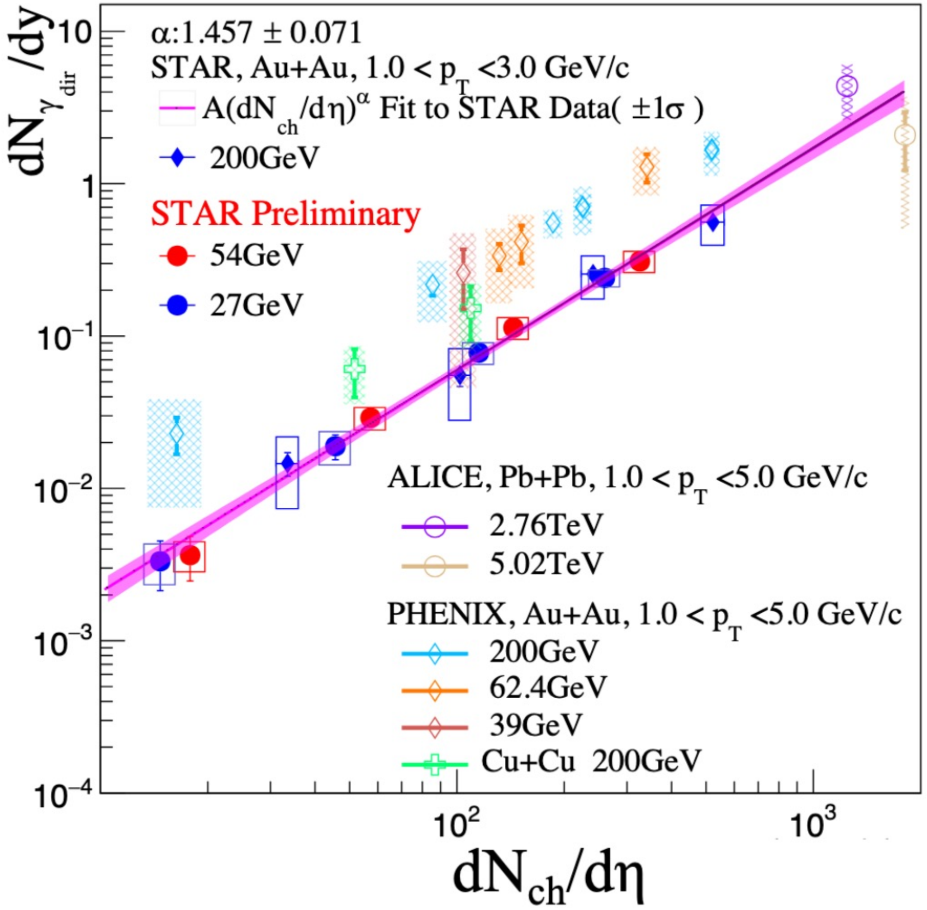

Strong incentive to improve low p_T photon calculation in proton-proton collisions (or measure it)

Low p_T direct photons in beam energy scan

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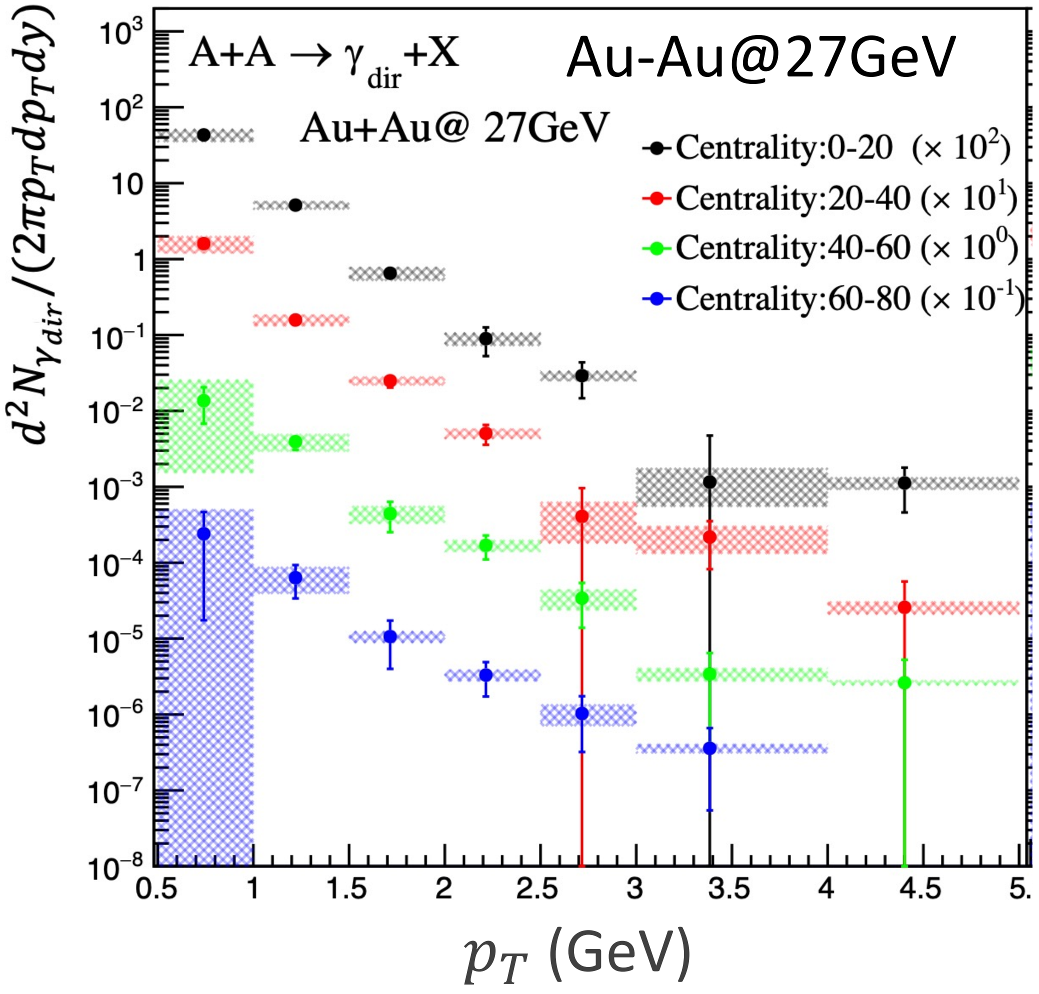
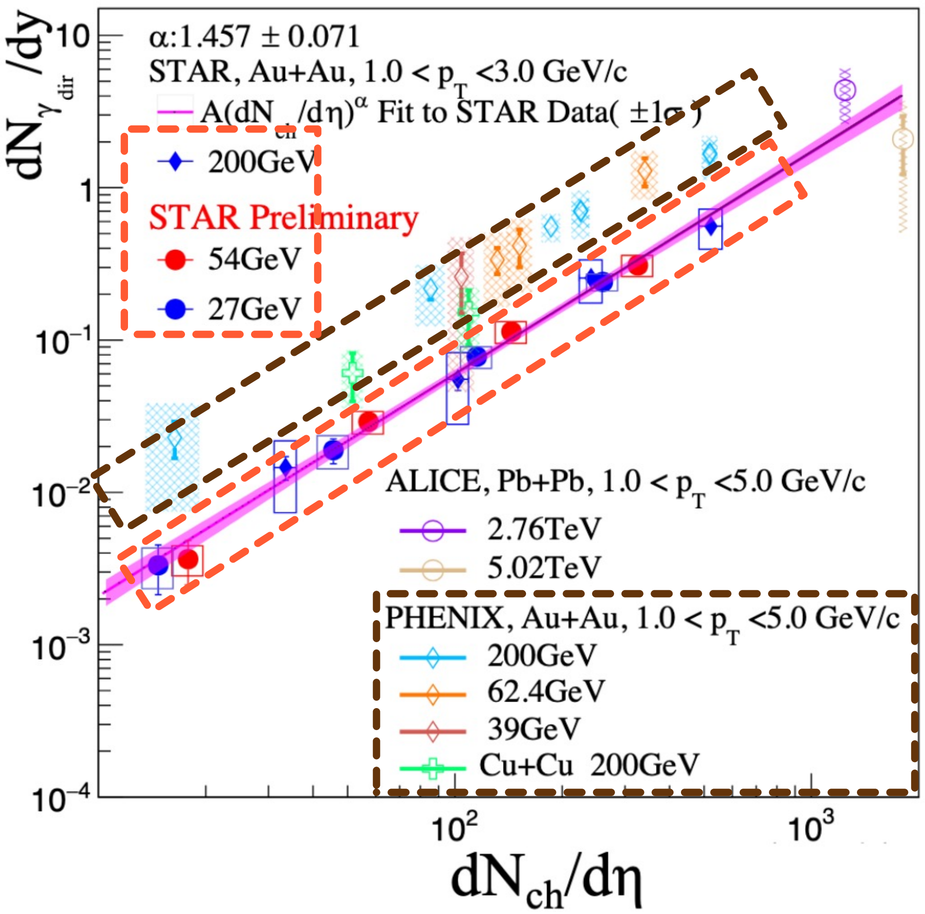


Also measured at 54.4 GeV



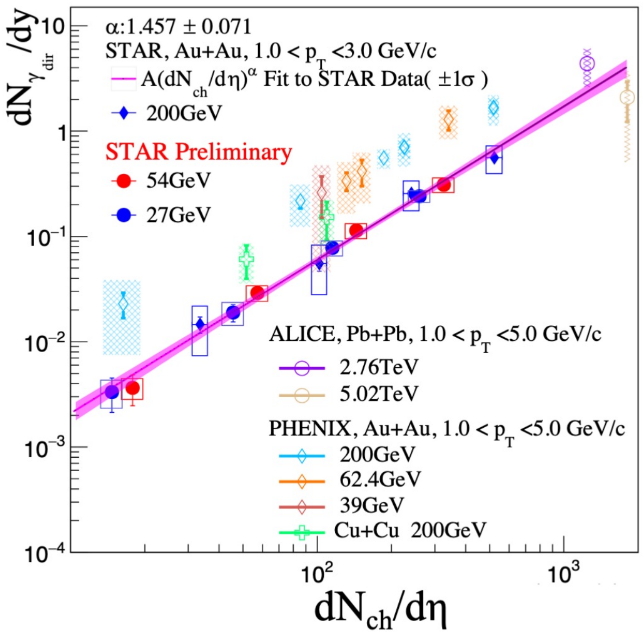
Results are preliminary, but…

continuing tension between STAR and PHENIX?

SUMMARY

Summary

- Exciting new data for low p_T photons and low/intermediate invariant mass dileptons:
  - STAR photon spectrum in Au-Au @27&54.4 GeV
  - STAR dilepton spectrum for isobars and beam energy scan
  - ALICE low p_T photon spectrum and HBT radii Pb-Pb @ 5.02 TeV
  - ALICE photon spectrum in high-multiplicity p-p @ 13 TeV
  - PHENIX dilepton spectrum in p-p @ 200 GeV



- <u>Great opportunity for the theory community to constrain:</u>
  - Early stage of heavy-ion collisions (equilibration, magnetic field, …)
  - Intermediate energy collisions and QCD at finite baryon chemical potential
  - Finite temperature properties of QGP and hadrons

Multimessenger astrophysics

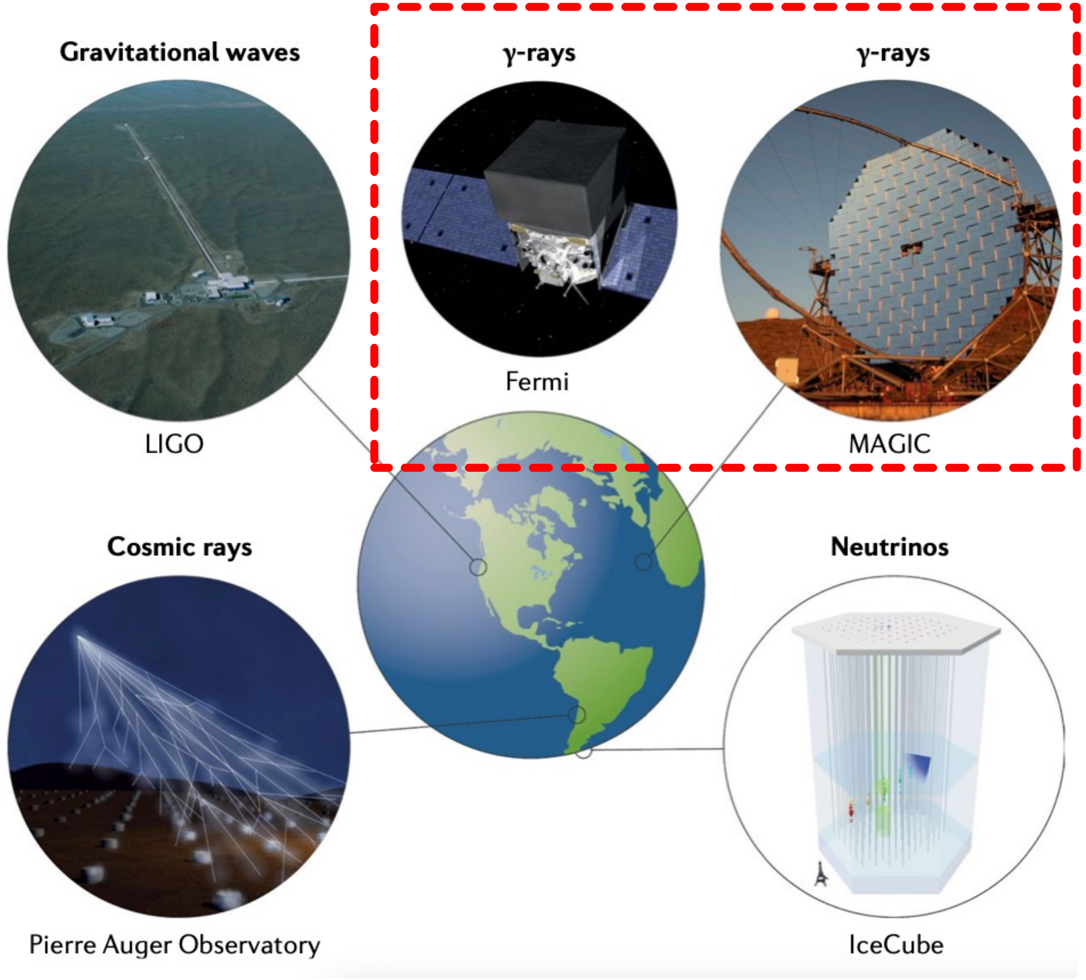
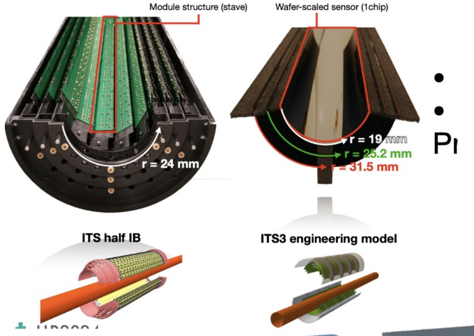


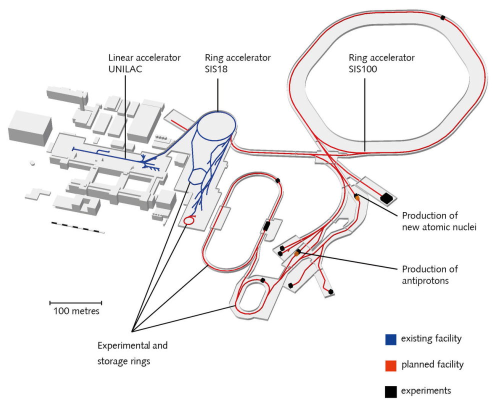
Figure ref.: Mészáros, Fox, Hanna and Murase (2019) Nature Reviews Physics

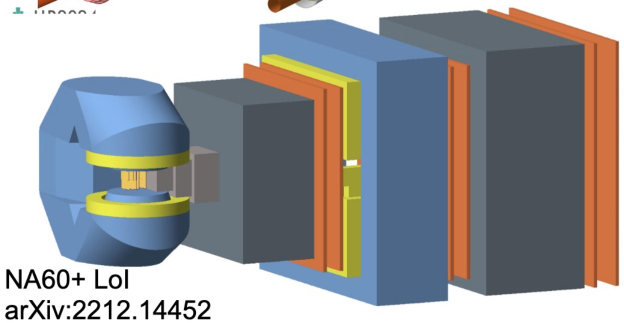
Multimessenger heavy-ion physics

ALICE ITS3: LHC Run4 (2029 - 2032)

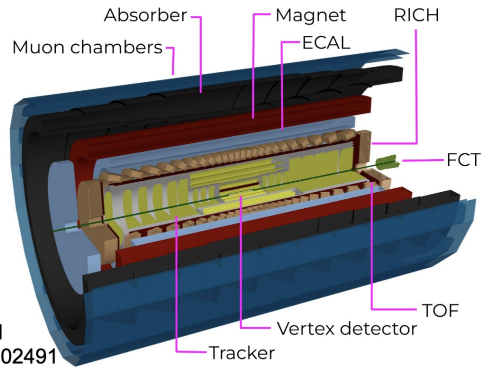


FAIR





NA60+ LoI
arXiv:2212.14452



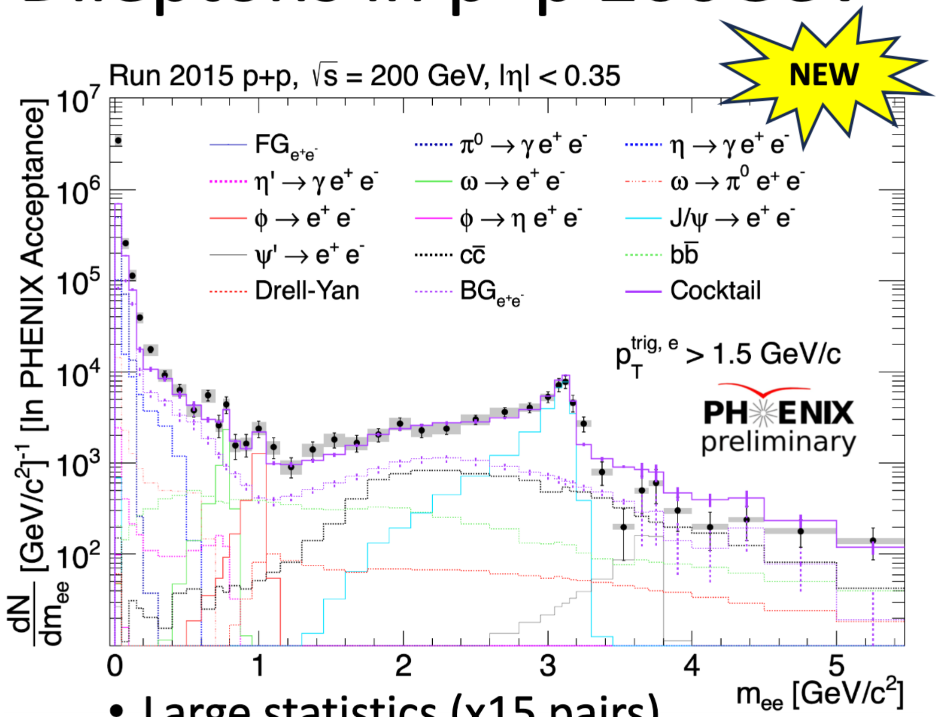
ALICE3 LoI
arXiv:2211.02491

(Slide partly borrowed from Daiki Sekihata)

BACKUP

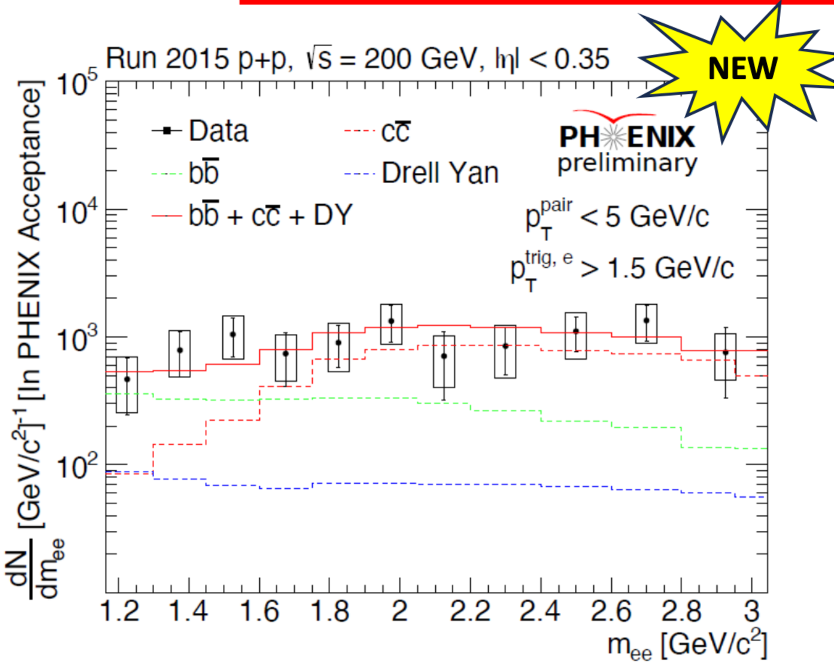
PHENIX

Dileptons in p+p 200GeV



PHENIX

Vassu Doomra (Tue. 11:10 Thermal)

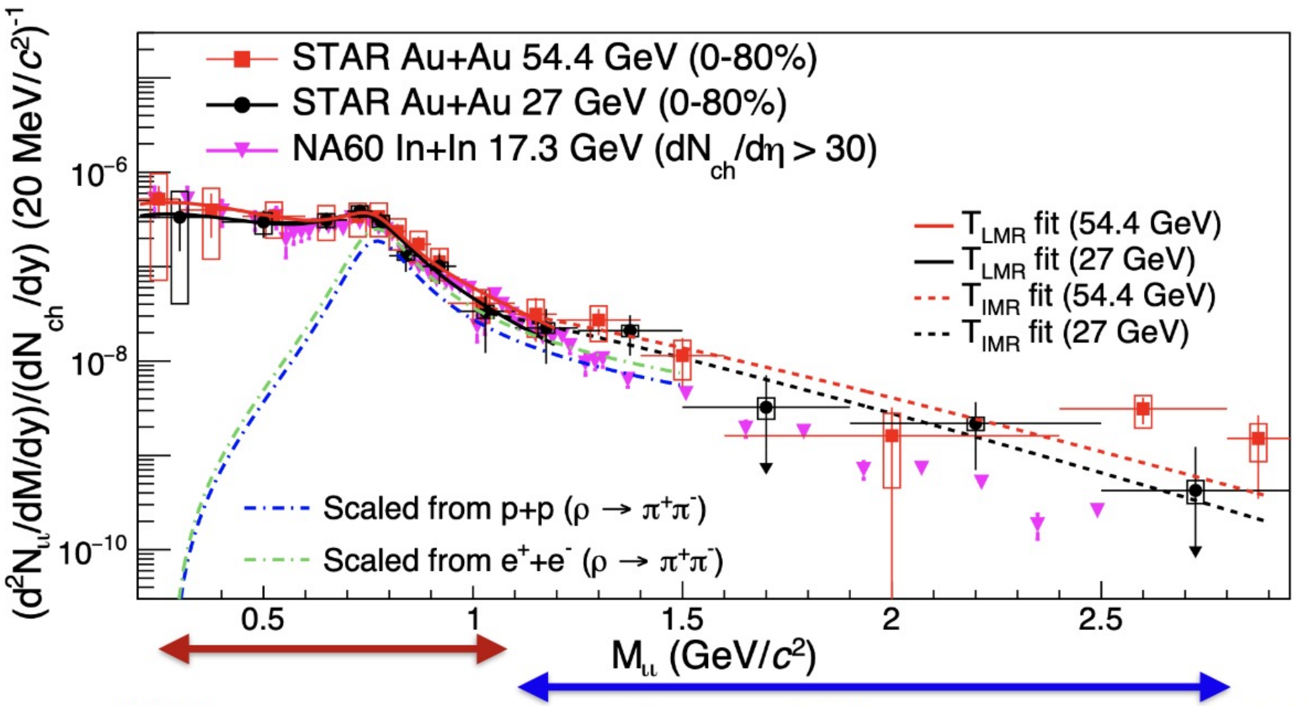


- Large statistics (x15 pairs)
- Good agreement with the cocktail calculation
- Baseline for thermal photons at IMR in Au+Au

Screenshot ACHIYA PHENIX OVERVIEW at Hard Probes 2024, Sep. 23

Effective temperatures

[Chenliang Jin (STAR)]



$T_{LMR}^{54.4\,GeV} = 172 \pm 12(stat.) \pm 18(sys.)$ MeV

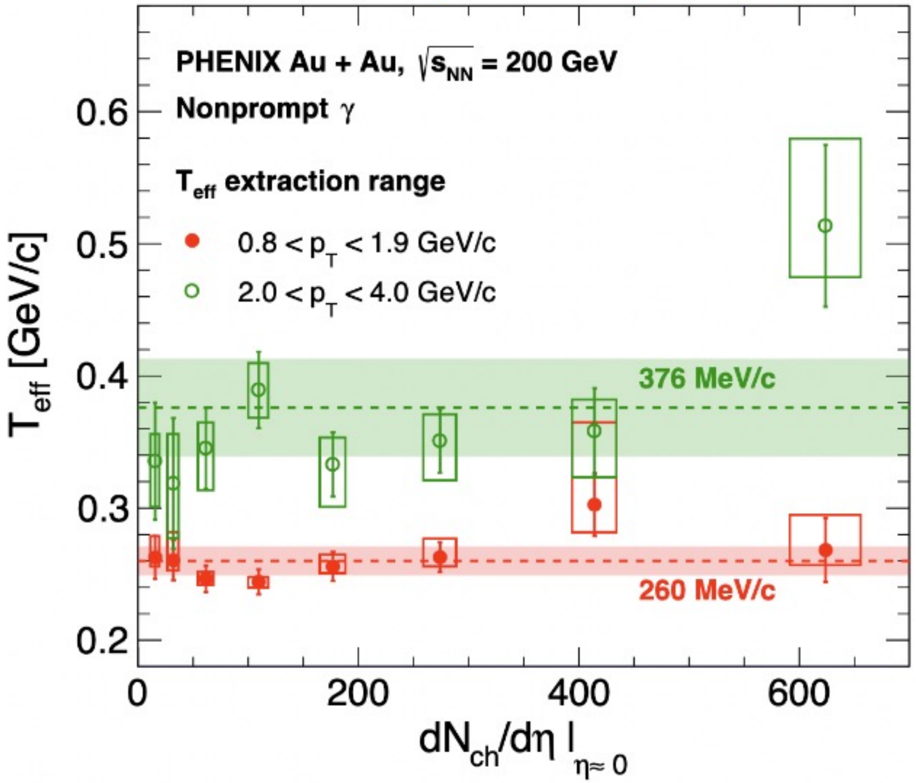
$T_{LMR}^{27\,GeV} = 167 \pm 21(stat.) \pm 18(sys.)$ MeV

$T_{IMR}^{54.4\,GeV} = 303 \pm 59(stat.) \pm 28(sys.)$ MeV

$T_{IMR}^{27\,GeV} = 280 \pm 64(stat.) \pm 10(sys.)$ MeV

[Vassu Doomra (PHENIX)]

Phys.Rev.C 109 (2024) 4, 044912

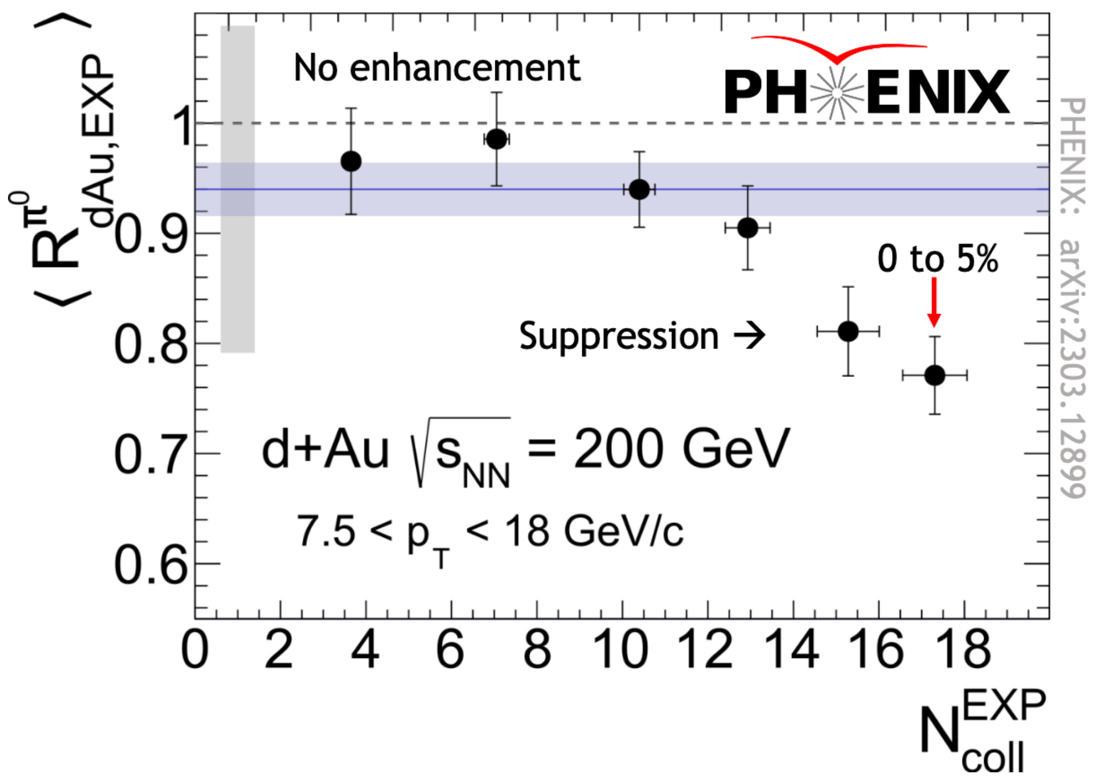


Binary scaling in Pb-Pb and p-Pb collisions

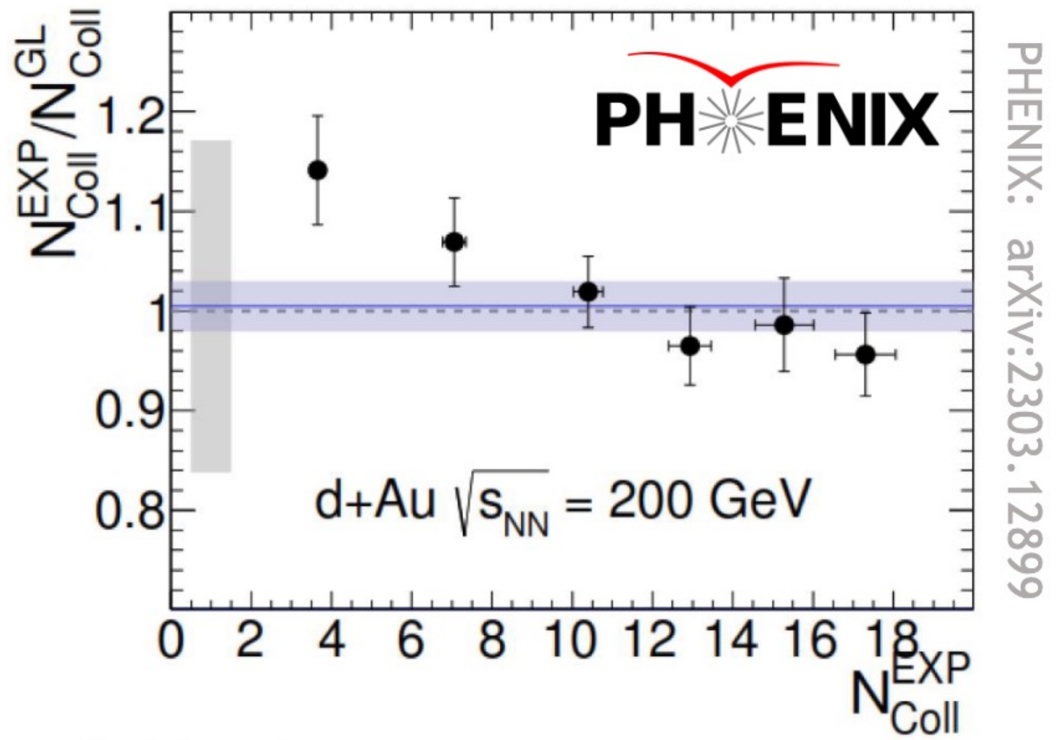
$$\frac{dN_\gamma^{AA}}{dp_T} / \frac{dN_\gamma^{pp}}{dp_T} = N_{binary} + \text{(correction from isospin, nuclear p.d.f., frag. photon energy loss)}$$

p_T averaged R_{AA}

Peripheral → Central



15% deviation is seen in peripheral collisions



Peripheral → Central