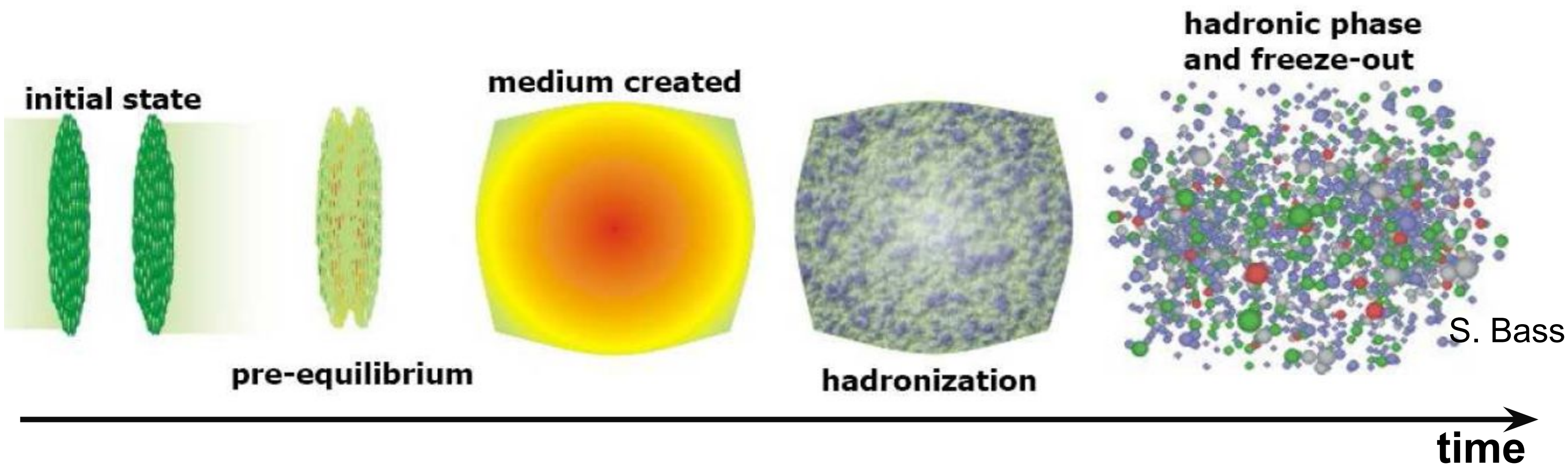
Electroweak Physics (summary)

Rupa Chatterjee
Variable Energy Cyclotron Centre, Kolkata

HP2020

Different stages of heavy ion collisions

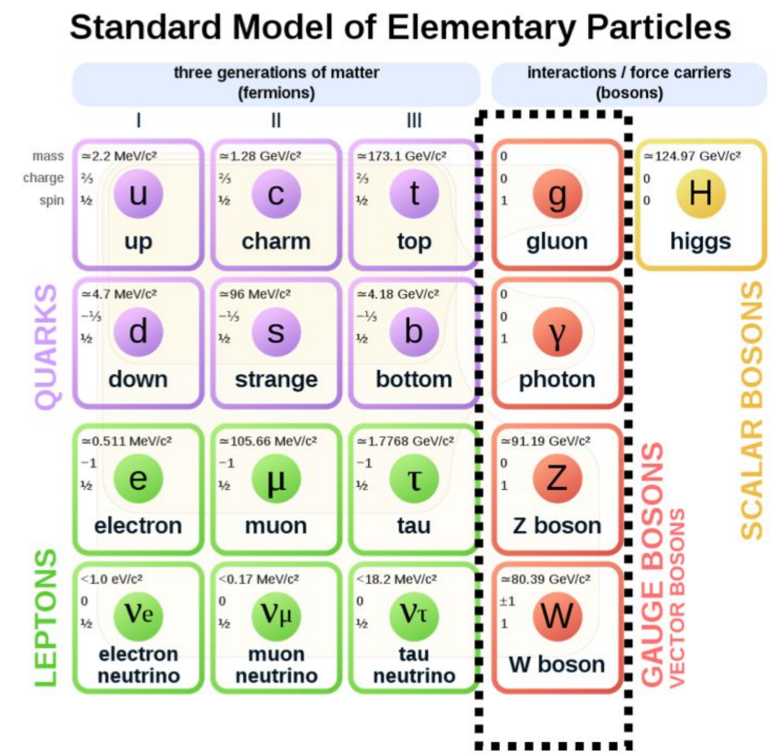


ELECTROWEAK PROBES:

- photons: γ
- leptons: e^+, e^-, μ^+,μ^-, (τ^+, τ^-)
- gauge bosons: W^+, W^-, Z^0

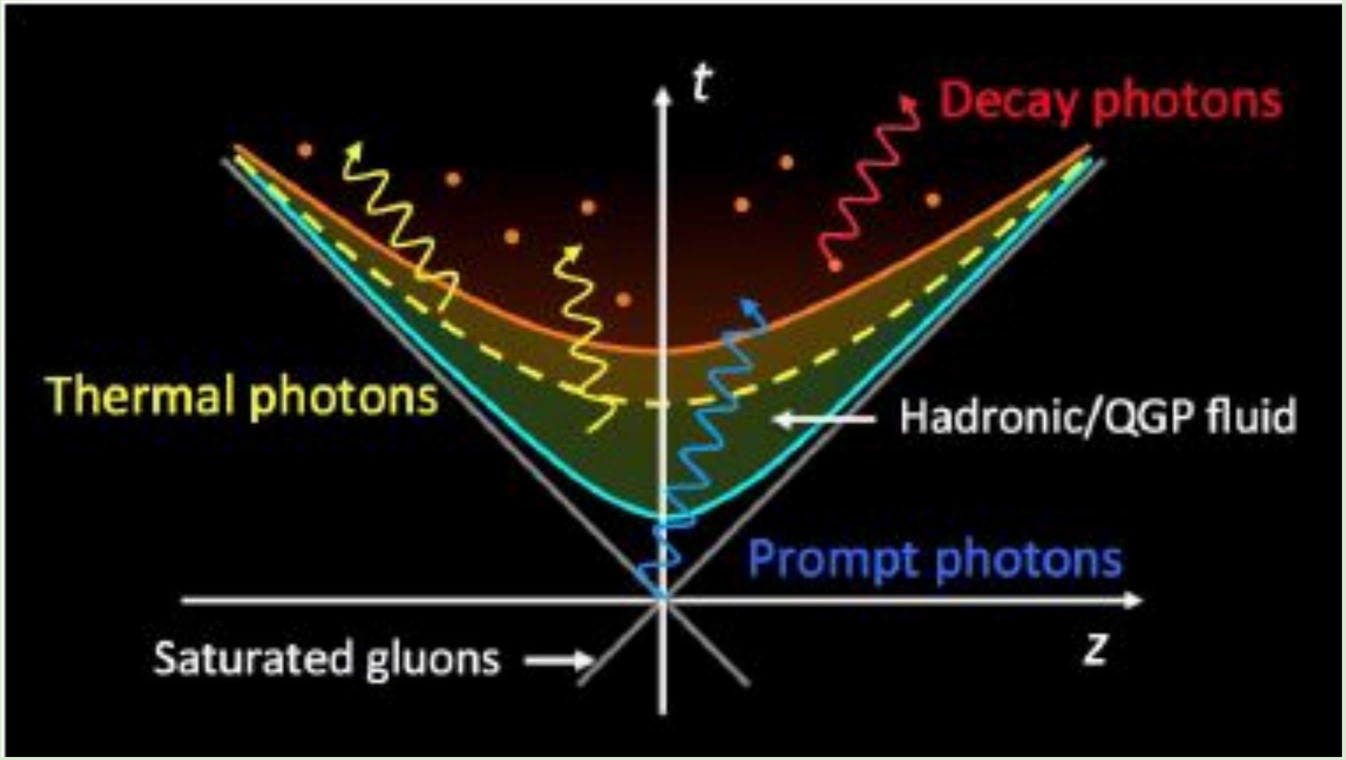
Electroweak (EW) probes

- Bosons produced by electroweak symmetry breaking
- Nambu-Goldstone theorem tells when a symmetry is broken, mass of gauge boson is split into zero and heavy ones
  - Zero-mass: γ
  - Heavy-mass: Higgs (H)
  - c.f, π^0 (135) and σ(500) in QCD
- γ, γ^*: Interact only electromagnetically
- W^-, W^+, Z^0 : mass created by coupling with Higgs
  - Mediator of Weak interaction
  - W~80GeV/ c^2, Z~90GeV/c^2
  - Mass determines the interaction strength



Takao Sakaguchi, HP2020

Photons from relativistic heavy ion collisions



Graphics by Akihiko Monnai

Electromagnetic radiation is known as the thermometer of the medium from early days of heavy ion collision and initially direct photons were studied in order to get the temperature of the system.

Experimental challenges

- Inclusive photon spectrum contains a huge background.

The main sources of production of decay photons are π^0 and η mesons. ω, η′ etc. also contribute to the decay photon spectrum marginally. Subtraction of the decay background from inclusive photon spectrum is a very challenging task.

Direct photon measurement by the subtraction method: WA98 PRL 85 (2000) 3595, PHENIX PRL 94 (2005) 232301

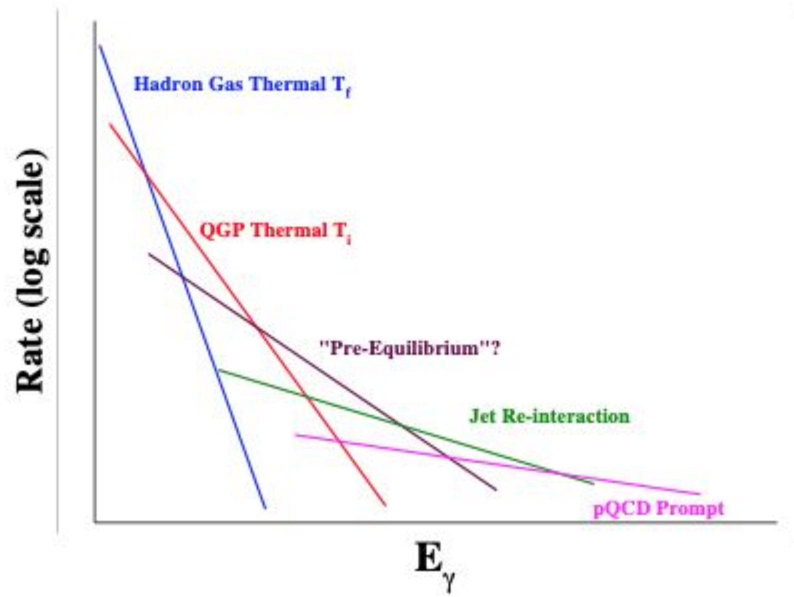
Direct Photons:

Prompt

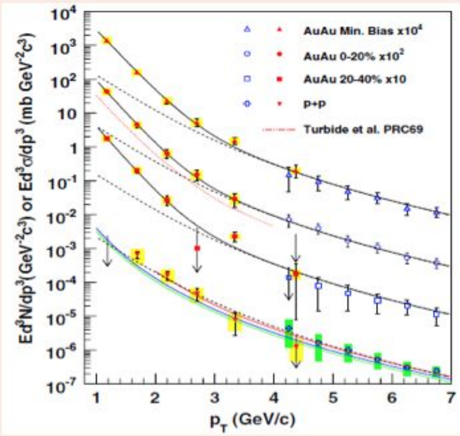
Pre-equilibrium

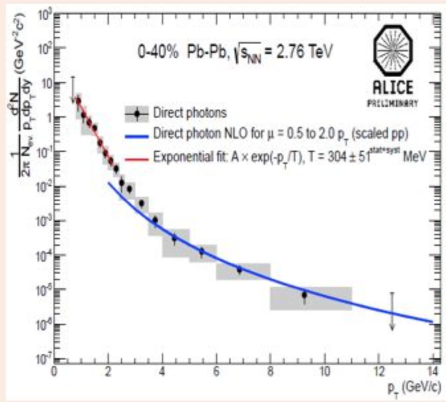
Jet-conversion

Thermal (QGP & hadronic)



Direct photon spectra at RHIC and LHC





Excess of direct photon yield over p+p at p_T<4 GeV at RHIC and LHC.

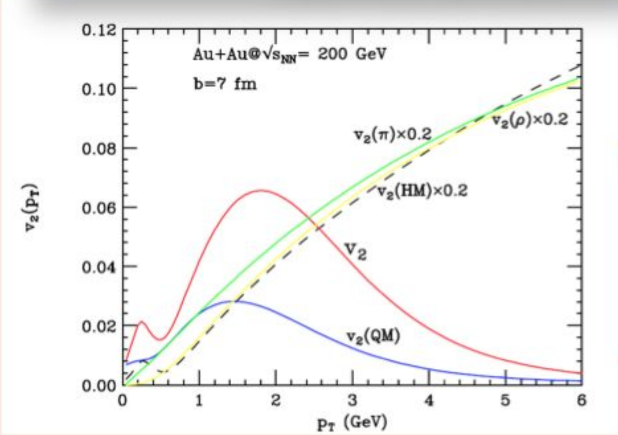
$T_{eff} \approx$ 221 MeV in 0-20% Au+Au@RHIC.

$T_{eff} \approx$ 304 MeV in 0-40% Pb+Pb@LHC.

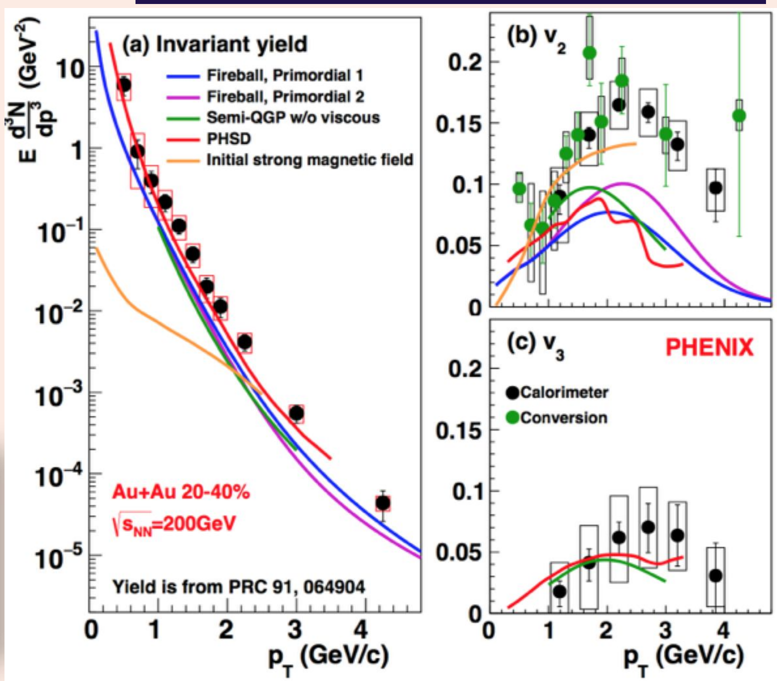
Low p_T direct photon elliptic flow measurement could provide direct constraints on QGP dynamics.

Direct photon puzzle

Elliptic flow of thermal photons



RC, E. Frodermann, U. W. Heinz, and D. K. Srivastava, Phys. Rev. Lett. 96 (2006) 202302.

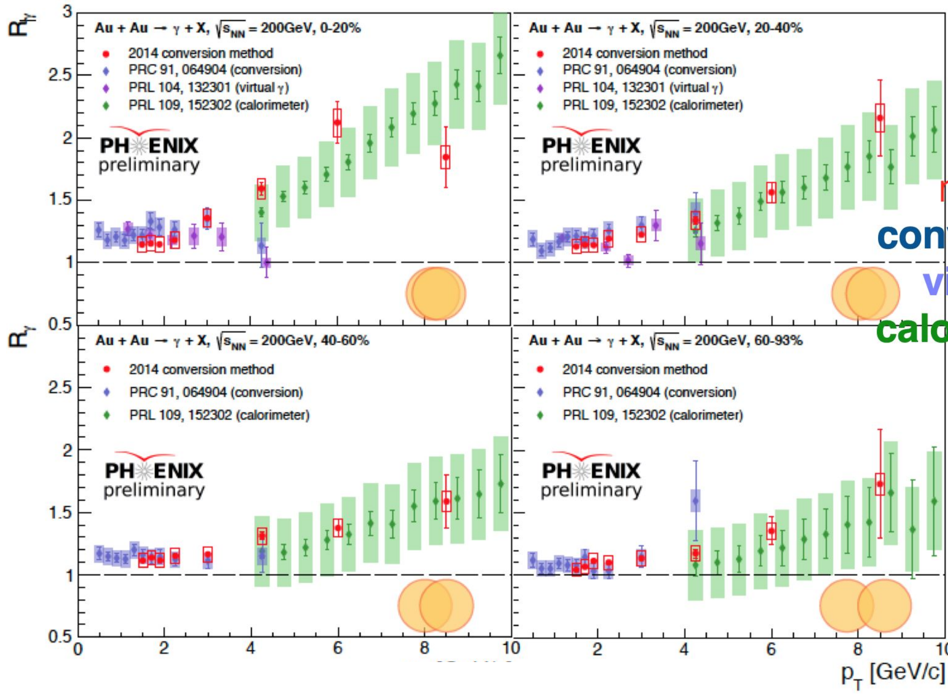


PRC94, 064901 (2016)

Direct photons (PHENIX)

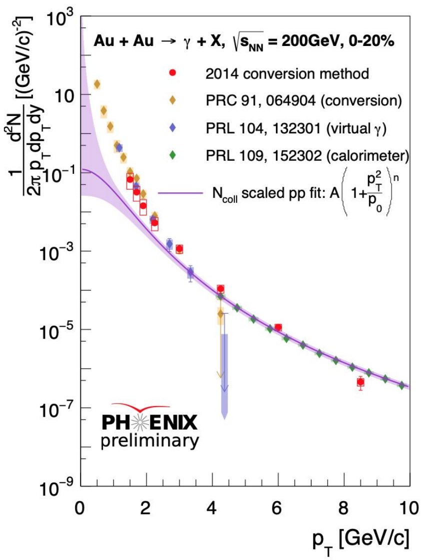
Large systems: Au+Au 200, 62, 39 GeV and Cu+Cu at 200 GeV

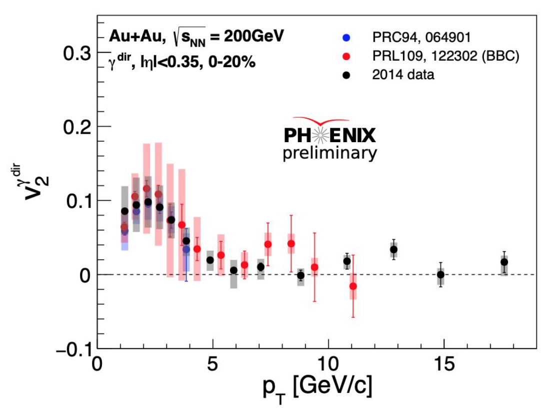
Small systems: p+p, p+Au, d+Au (MB) at 200 GeV



new result vs:
conversion method
virtual method
calorimeter method

Talk by Veronica Canoa Roman





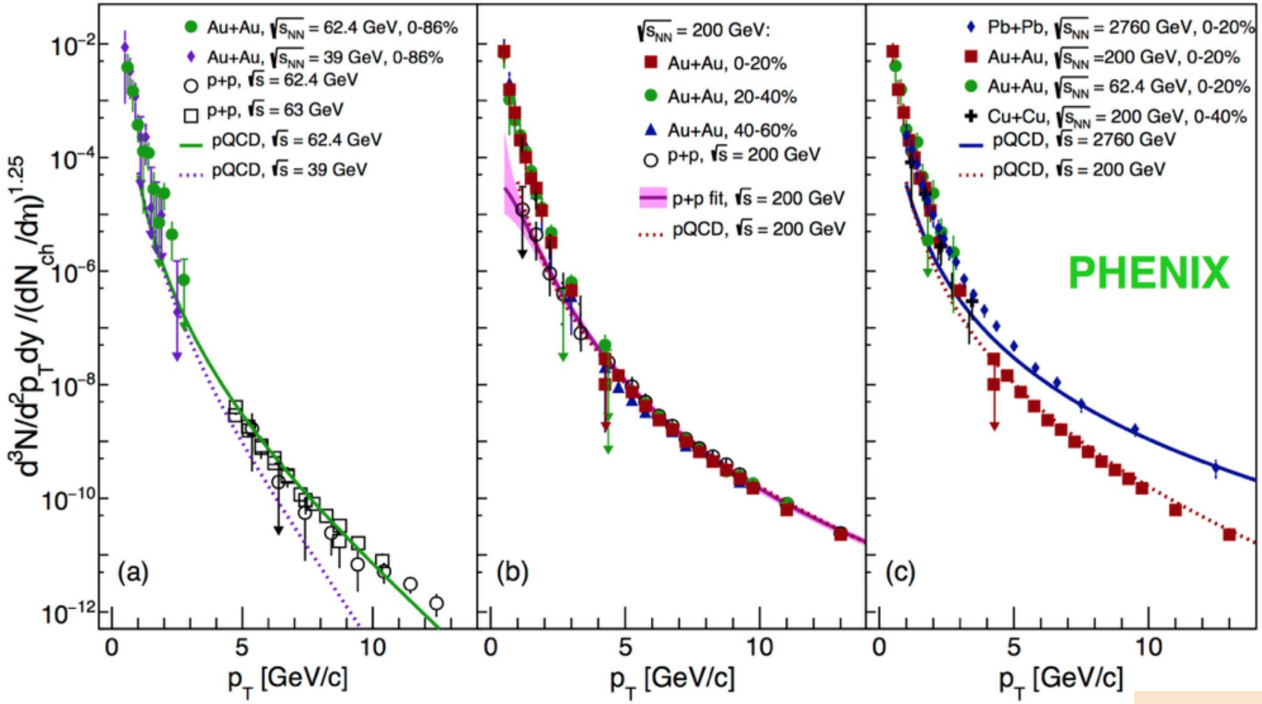
$$R_\gamma = \frac{\gamma^{incl}}{\gamma^{hadron}} = \frac{\left\langle \varepsilon_\gamma f \right\rangle \left(\frac{N_\gamma^{incl}}{N_\gamma^{\pi^0 tag}} \right)_{Data}}{\left(\frac{\gamma^{hadron}}{\gamma^{\pi^0}} \right)_{Sim}}$$

- **Measured raw yields**
- **Conditional tagging efficiency**
- **Simulated based on hadron data**

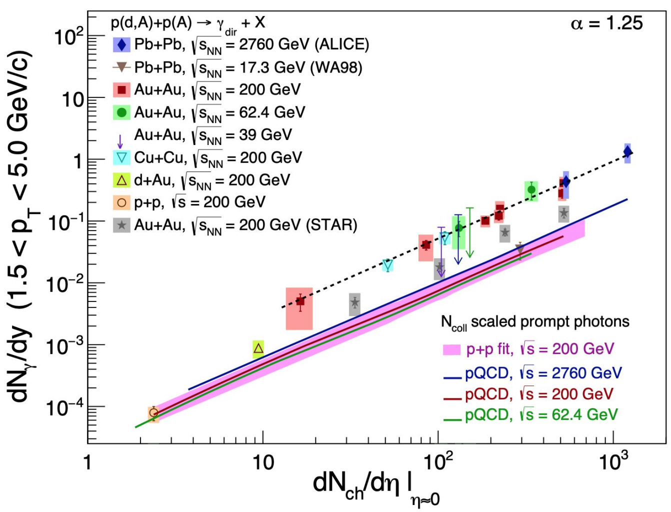
$$\gamma^{direct} = (R_\gamma - 1)\,\gamma^{hadron}$$

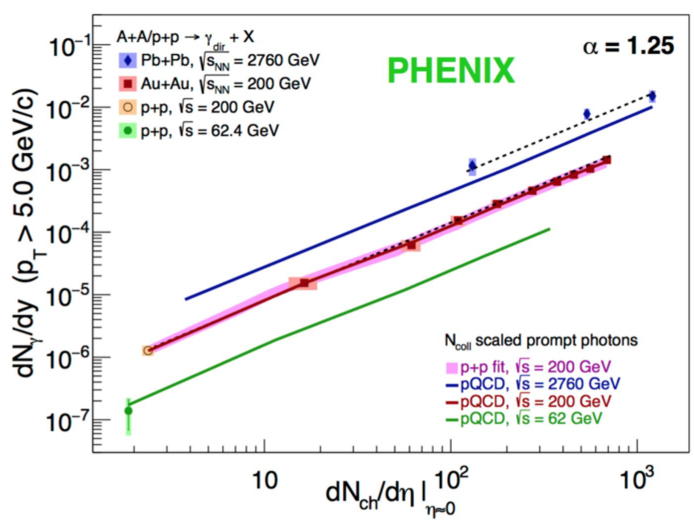
New independent analysis of direct photon emission from data set with x10 statistics
-> Consistent with previous results

Direct photon scaling



Talk by Veronica Canoa Roman





Photon yield dominated by

thermal radiation for p_T > 1 GeV

prompt radiation for p_T > 5 GeV

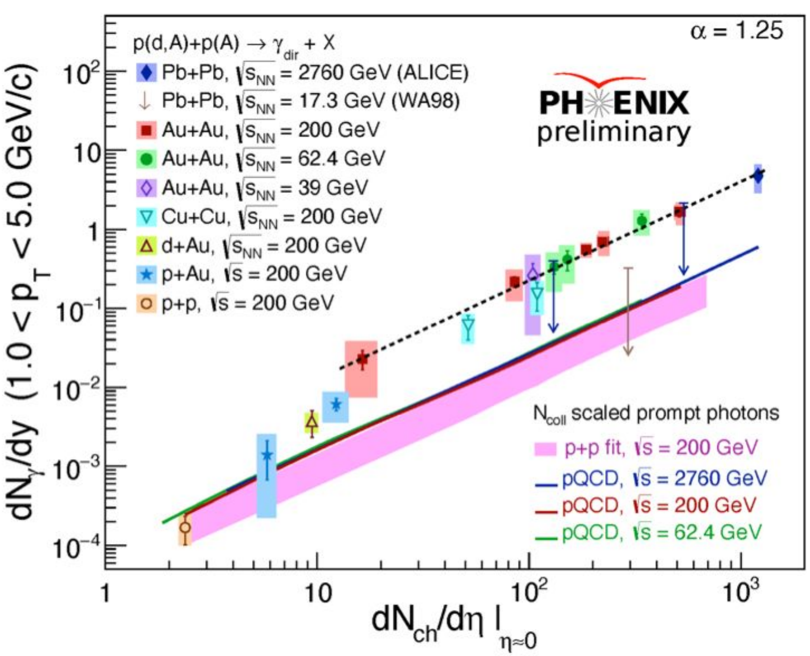
STAR results show scaling the behavior also, but magnitude is lower

EQUATION OF STATE OF HADRONIC MATTER AND ELECTROMAGNETIC RADIATION FROM RELATIVISTIC HEAVY ION COLLISIONS

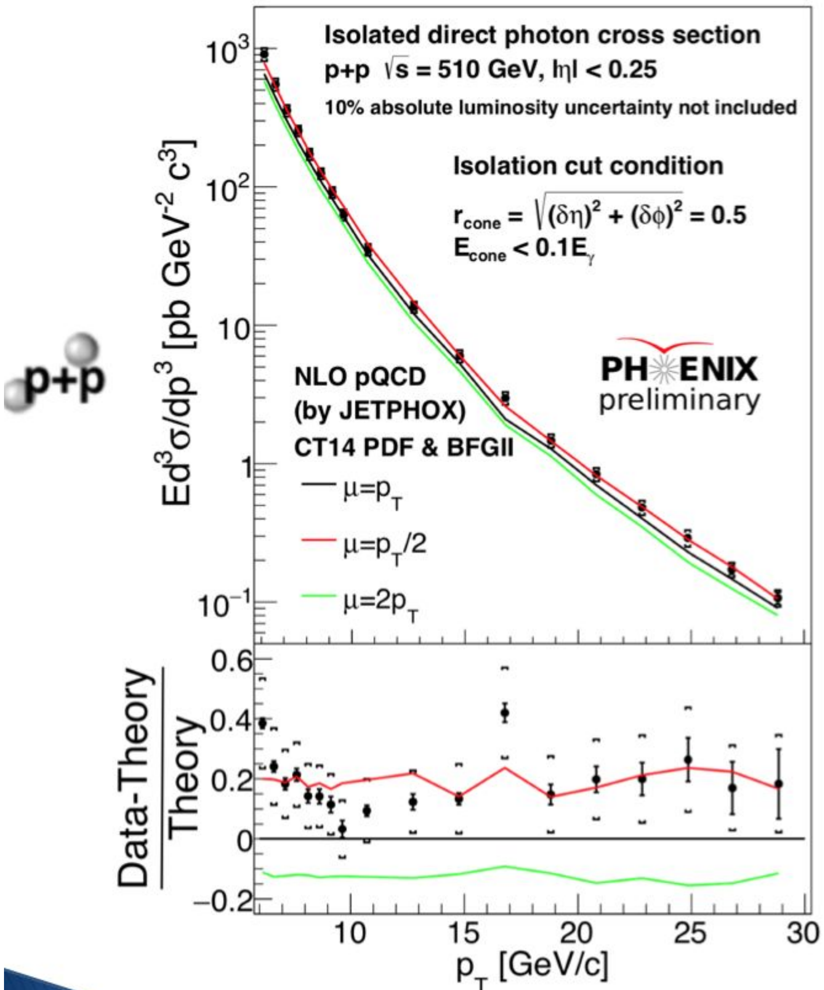
Jean Cleymans, Krzysztof Redlich, & Dinesh Kumar Srivastava
Phys.Lett. B420 (1998) 261-266

$$\frac{dN_\gamma}{dy} \simeq K \left(\frac{dN_{\rm ch}}{dy}\right)^\alpha, \qquad (6)$$

where $\alpha \simeq 1.2$ and K depends on the equation of state.



Direct Photon Cross Section at $\sqrt{s}$ =510 GeV

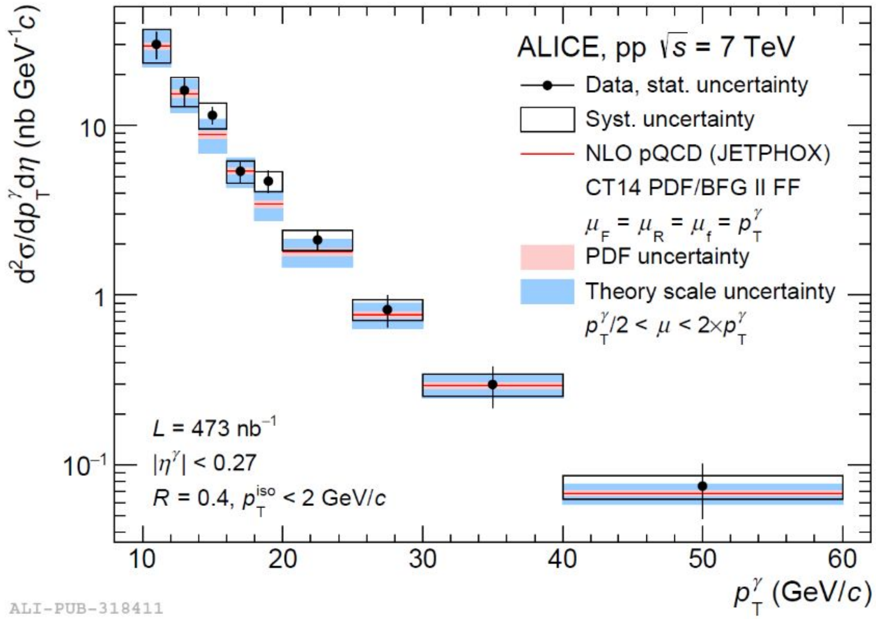


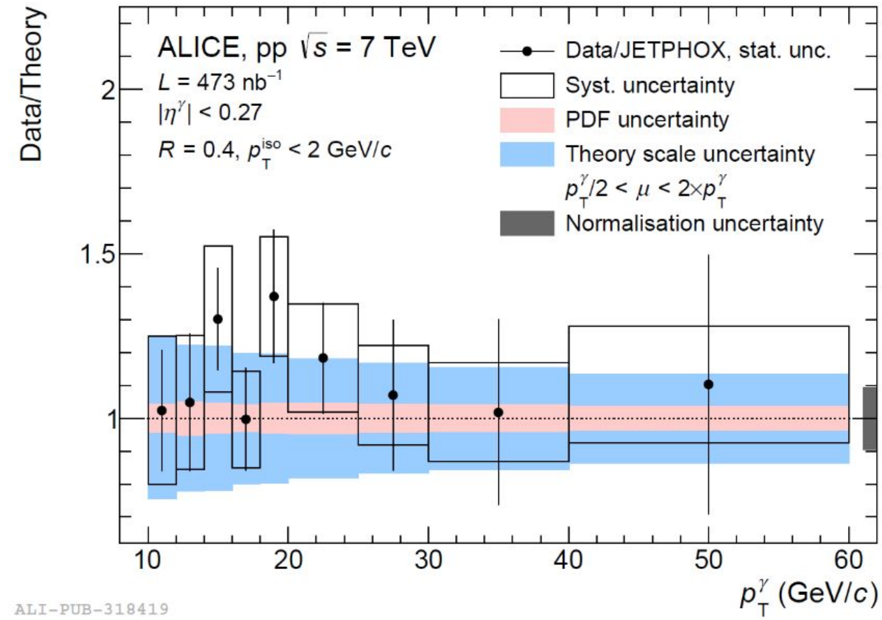
- First measurement of direct photon cross section in pp $\sqrt{s}$ =510 GeV
- A NLO pQCD calculation agrees well with the measurement

Talk by M. Rosati

Poster by Zhongling Ji

Isolated Photon Cross Section in pp at $\sqrt{s_{NN}} = 7$ TeV





Eur. Phys. J. C (2019) 79: 896

- Isolated photon cross section in pp at $\sqrt{s_{NN}} = 7$ TeV measured by ALICE
- Compared with JETPHOX NLO pQCD calculations – good agreement with JETPHOX

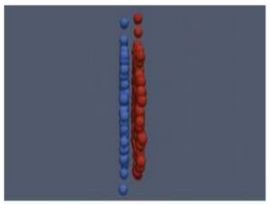
Dhruv Utpal kumar Dixit

- Underlying event subtraction: $p_T^{iso} = \sum_{\text{track} \in \Delta R < 0.4} p_T^{\text{track}} - \rho \times \pi \times 0.4^2$
- Select photon clusters with $p_T^{iso} < 1.5$ GeV/c

Illuminating the early stages of relativistic heavy-ion collisions: the pre-hydro phase as seen through photons and hadrons

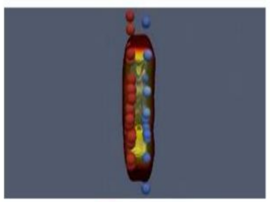
Talk by Jean-François Paquet

Multistage model of the heavy ion collision



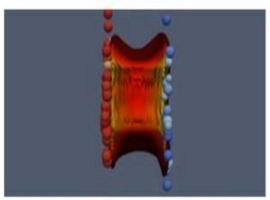
$\tau = \text{"}0^{+}\text{"}$: IP-Glasma

- Incoming nuclei described using Color-Glass-Condensate effective theory
- Glasma evolution described by solving the Yang-Mills equations



$\tau = 0.1$ fm: KøMPøST

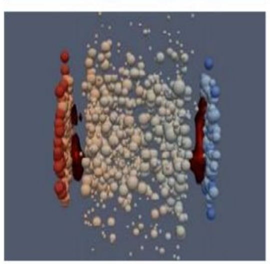
- Energy-momentum tensor divided in background and perturbations
- Background evolved w/ locally boost-invariant QCD ("AMY") effective kinetic theory
- Perturbations evolved w/ nonequilibrium **linear** response, also in "AMY" kinetic theory



$\tau = 0.8$ fm: Beginning of "hydrodynamic phase"

- 2+1D relativistic viscous hydrodynamics [MUSIC]
- Equation of state: hadron resonance gas + lattice QCD
- Shear and bulk viscosity [Constant η/s=0.12; temperature-dependent ζ/s (shown later)]

[MUSIC ref.: Schenke et al, PRC (2010), PRL (2011); Paquet et al, PRC (2016); EOS ref.: HotQCD Coll., PRD (2014); Bernhard (2018)]



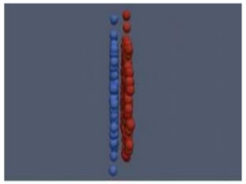
$\tau \sim 10$ fm: End of "hydrodynamic phase"

- Fluid converted to hadrons
- Hadronic interactions with UrQMD hadronic transport
- Photon emission NOT calculated from UrQMD; instead, estimated from hydrodynamics

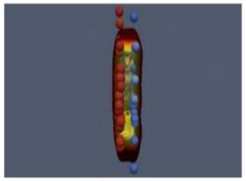
[UrQMD ref.: Bass et al PPNP (1998), Bleicher et al, JPG (1999), Petersen et al, PRC (2008)]

Photons: contribution of different sources

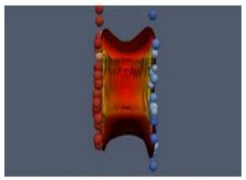
AuAu @ 200 GeV, 20-40%



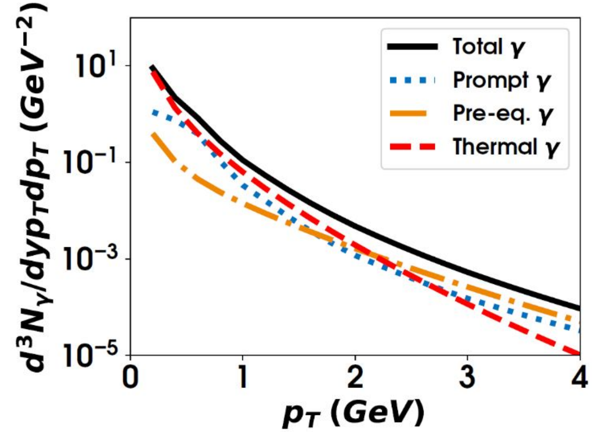
$\tau = "0^+"$:
- Prompt photons

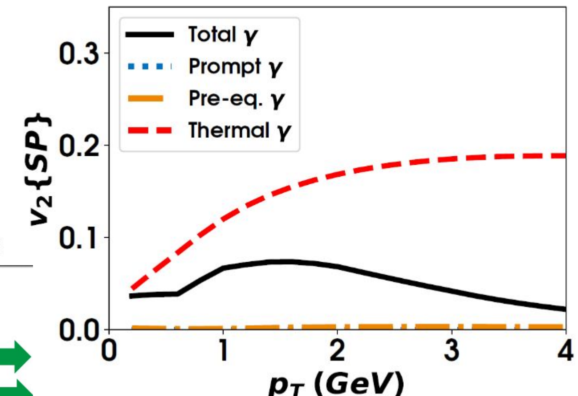


$\tau = 0.1$ fm: KøMPøST
- Pre-equilibrium photons



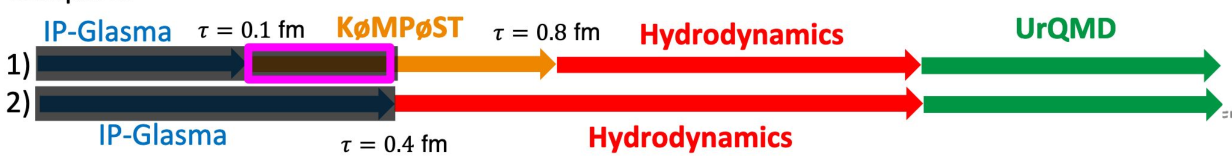
$\tau = 0.8$ fm: Hydrodynamics
- "Thermal" photons



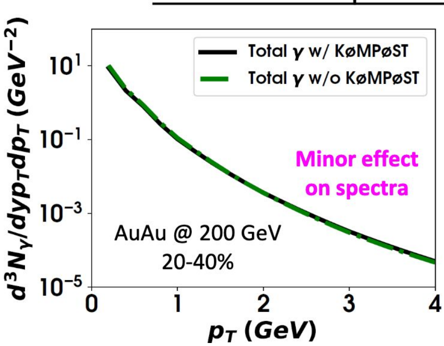


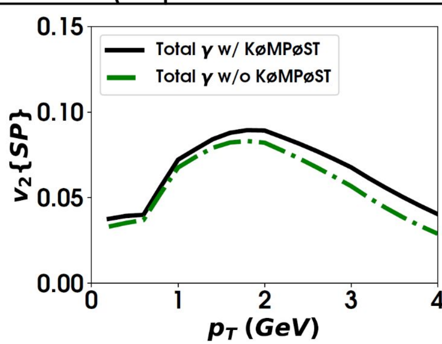
- Thermal photons dominate v_2, and low p_T dN/dp_T
- Pre-eq. photons: large dN/dp_T at high p_T but negligible v_2

Compare:



Remove extra spacetime volume (no photon emission before $\tau = 0.4$ fm)





- Higher v_2 w/ KøMPøST

Take home:

Effect of pre-eq. phase depends on question being asked

Jean-François Paquet

Radiative Recombination in QGP

One of Photon Production Processes

- Photon emission at hadronization process
  - Photon's flow is as strong as hadrons' flow.
- A photon is produced from pairing of hadrons
  - Radiative recombination brings enhancement of photon yield.

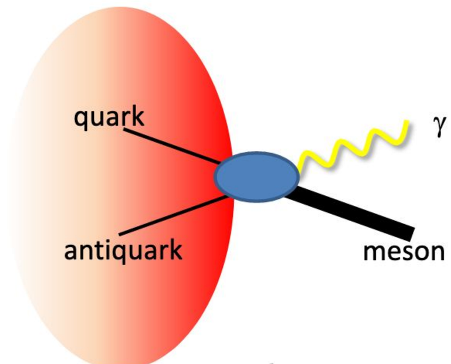
Photon emission at hadronization from quark-gluon plasma

Chiho Nonaka

Radiative Recombination in QGP

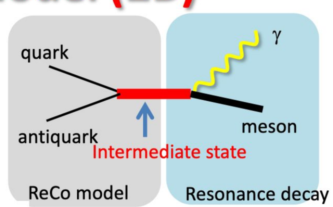
- Non perturbative process
- Not possible to use the inverse process
- Not equilibrium process

⇨ **Recombination Model**



Features of the Model (2D)

$$M^* \to M + \gamma$$

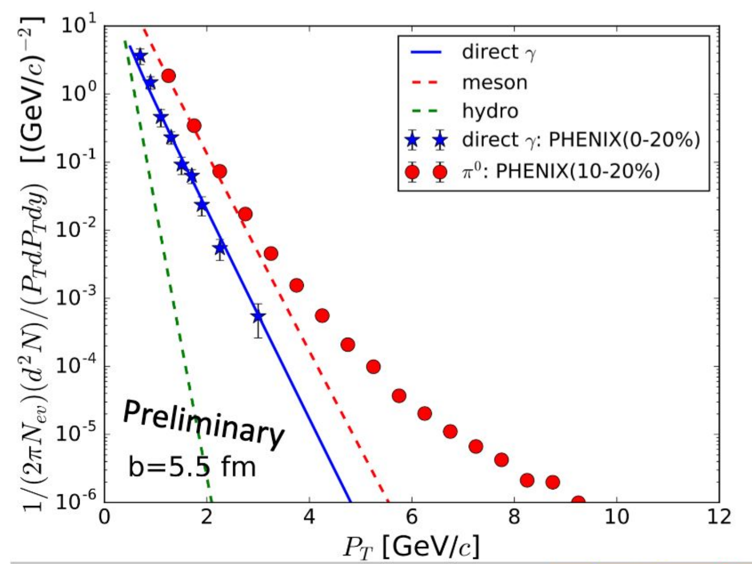


- P_T distribution
  - M and γ : shift to low P_T
  - Kinematics: threshold value
  - T_{eff} : $T_{\rm eff}(M) \sim T_*$ $\quad T_{\rm eff}(\gamma) = (1 - \frac{M^2}{M_*^2})T_*$
- Elliptic flow

$v_2^M(K_T) \sim v_2^{M_*}(P_T)$ $\quad v_2^\gamma(k_T) \sim v_2^{M_*}(\frac{k_T}{1-\frac{M^2}{M_*^2}})$

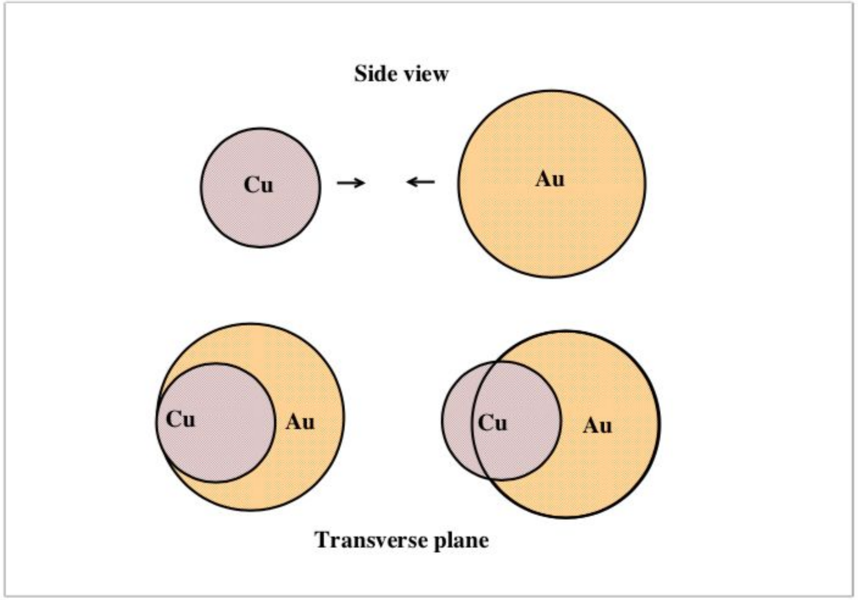
momentum shift

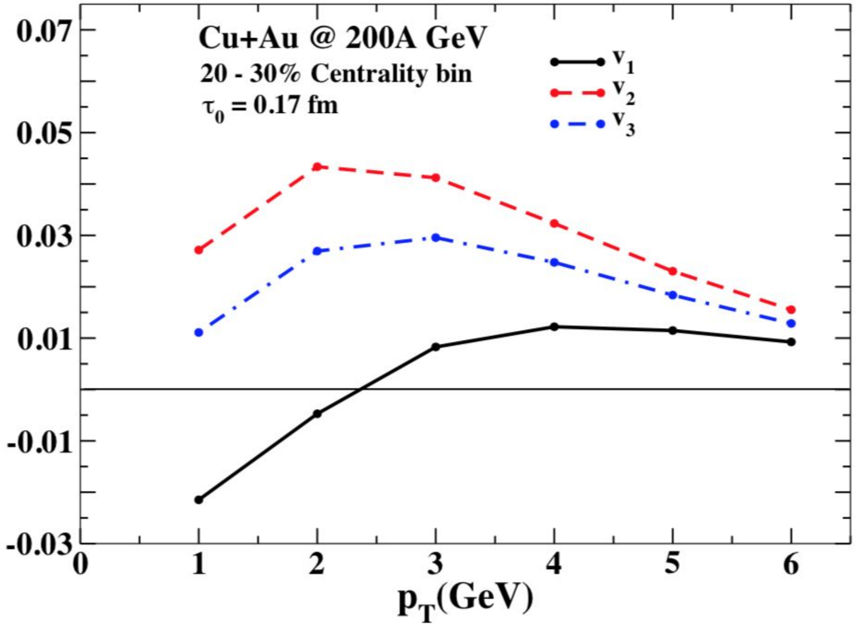
- Quark Number Scaling



Directed flow of photons in Cu+Au collisions at RHIC

P. Dasgupta, RC, D.K. Srivastava
J Phys G (2020)





The directed flow (v_1) of photons is found to be non-zero and significantly large.

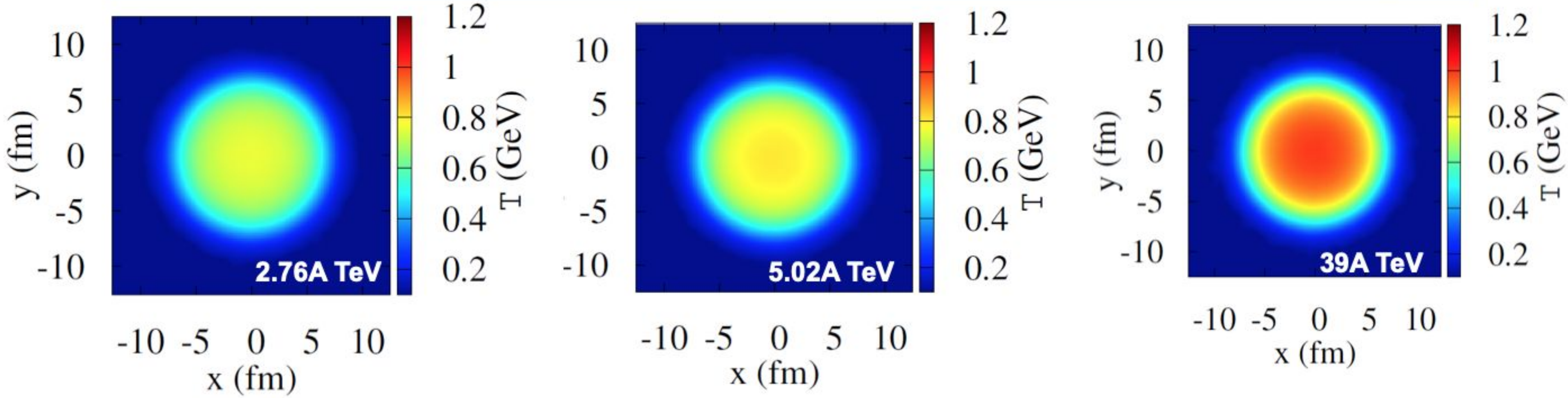
v_1 shows a different nature compared to the elliptic and triangular flow parameters.

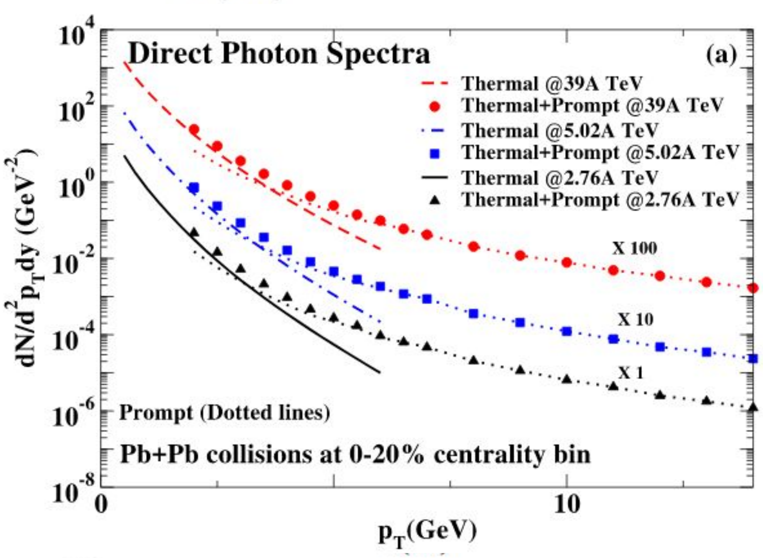
Photon v_1 is completely dominated by QGP radiation.

The v_1 is more sensitive to the initial formation time compared to v_2 and v_3.

Photon production from Pb+Pb collisions at 2.76A TeV and 5.02 A TeV at LHC and at 39 A TeV at the upcoming Future Circular Collider (FCC)

Temperature distribution on the transverse plane at formation time for the three energies





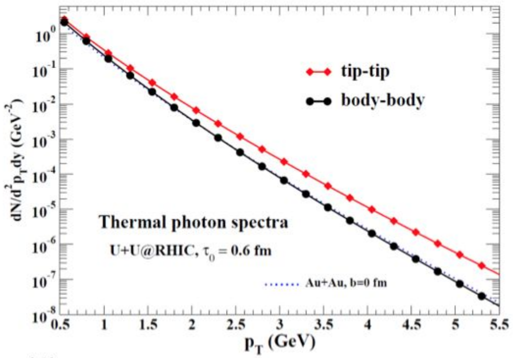
P. Dasgupta et al PRC98, 024911 (2018)

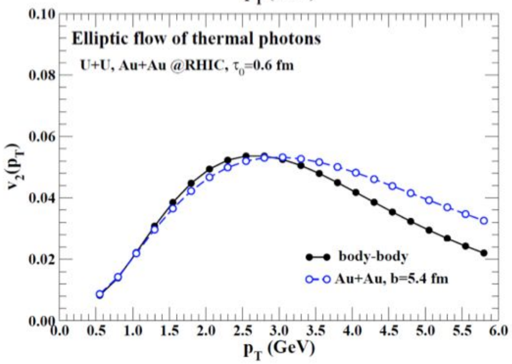
At FCC the central temperature (more than 1 GeV) is significantly larger than the maximum central temperatures at the LHC energies.

The prompt photons production increases by a factor of 5 to 15 at 39A TeV in the p_T region 2 to 15 GeV compared to 2.76A TeV .

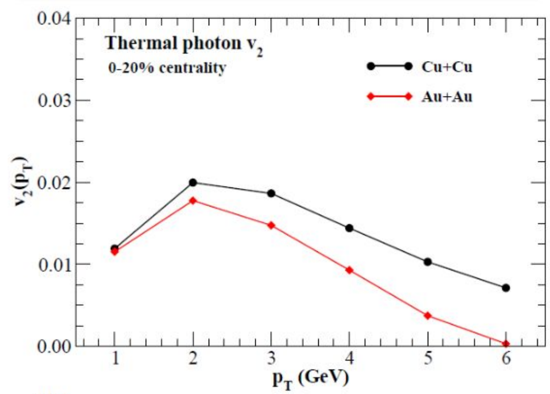
The relative enhancement in the production of thermal photons is found to be more compared to prompt photons at FCC than at the LHC energies.

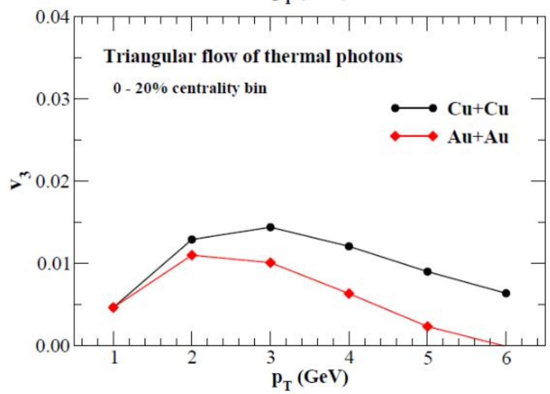
Thermal photons from fully overlapping U+U collisions at RHIC



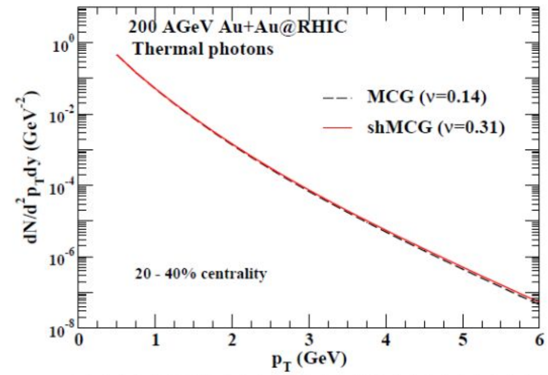


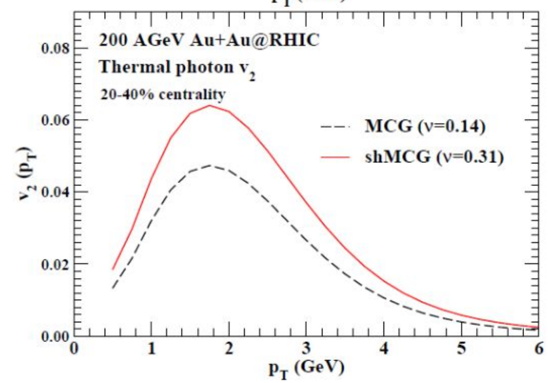
Anisotropic flow of thermal photons from Au+Au and Cu+Cu collisions at RHIC





Effect of initial state nucleon shadowing on elliptic flow of thermal photons

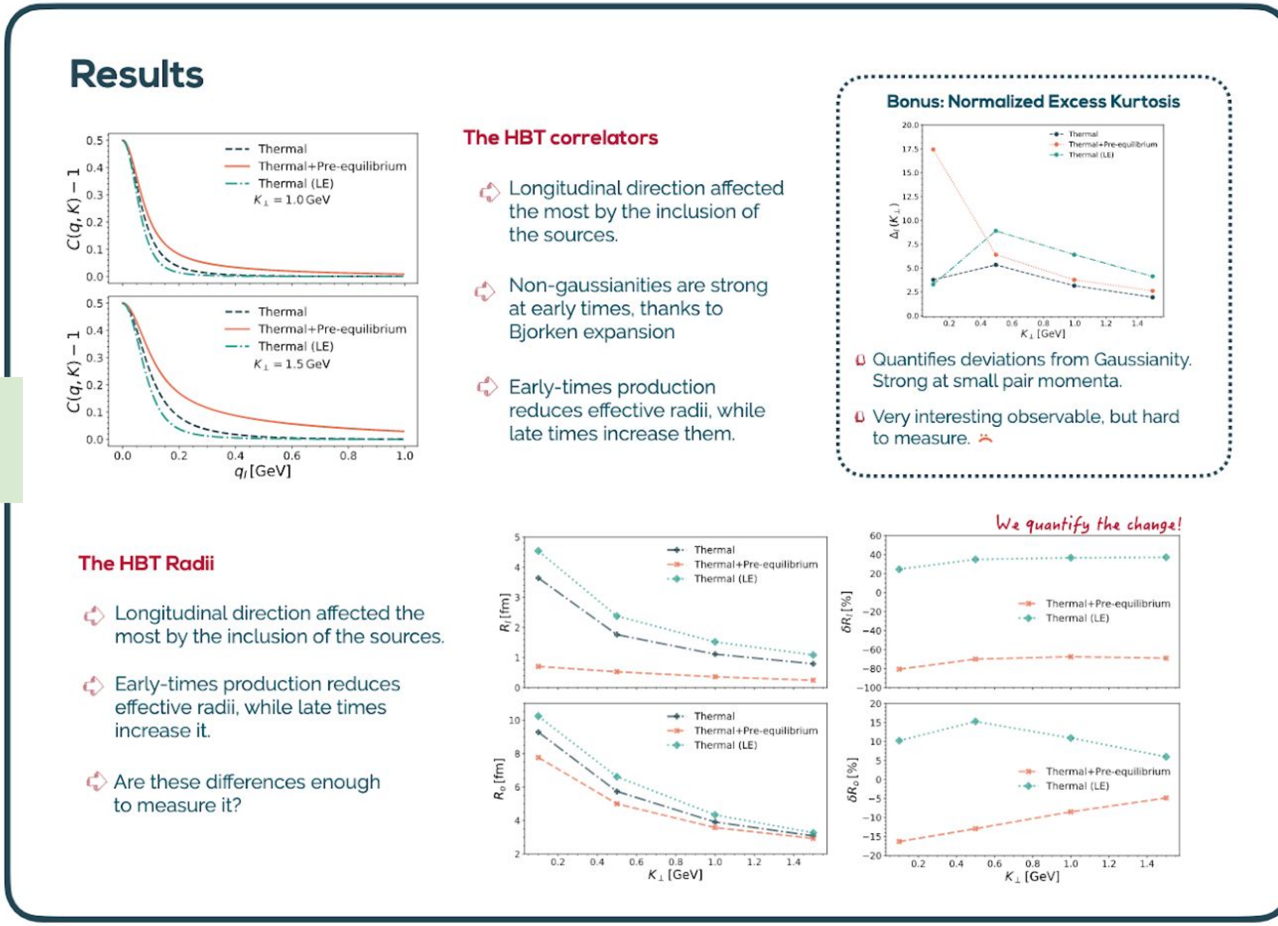




- ★ Photon production from U+U collisions can be complementary to the results from Au+AU collisions at RHIC. Phys. Rev. C 95, 064907 (2017)
- ★ Fluctuations in the initial density distribution results in larger anisotropic flow in Cu+Cu collisions than in Au+Au collisions. Phys. Rev. C 96, 014911 (2017)
- ★ The inclusion of initial state nucleon shadowing enhances the anisotropic flow of thermal photons significantly. Phys. Rev. C 97, 034902 (2018)

Photon Interferometry

Poster by Oscar Garcia-Montero



$$C(p_1,p_2) = 1 + \frac{1}{d}\frac{|S(q,K)|^2}{S(0,p_1)S(0,p_2)}$$

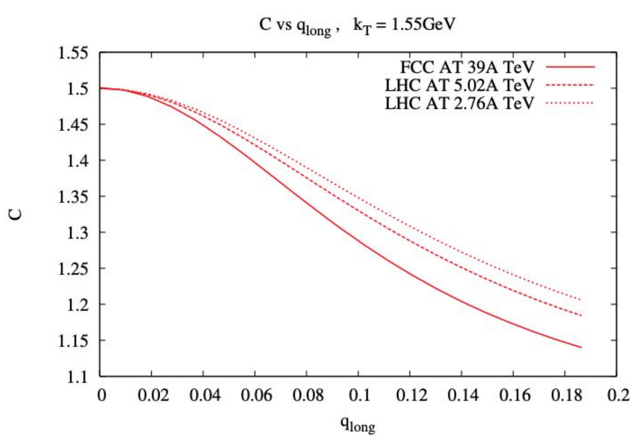
$$\sim 1 + \frac{1}{2}\exp\left[-q_i R^{ij} q_j\right],$$

$S(x,K)$ → Emission Function (rate)

$R_{ij}(K)$ → HBT Radii

Radii are computed using

$$\langle\langle q_i q_j\rangle\rangle = \int d^3q\, q_i\, q_j\, g(q;K) \equiv \frac{1}{2}(R^{-1})_{ij} \quad \text{with} \quad g(q;K) \equiv \frac{C(q,K)-1}{\int d^3q\,[C(q,K)-1]}$$



Photon interferometry
P. Dasgupta & RC

Photon-Jet correlations in p-p and A-A collisions using the JETSCAPE framework

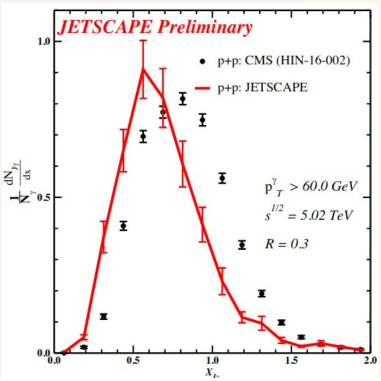
Chathuranga Sirimanna

Photons: p-p 5.02 TeV

Gamma-Jet transverse momentum imbalance (Gamma-Jet Asymmetry)

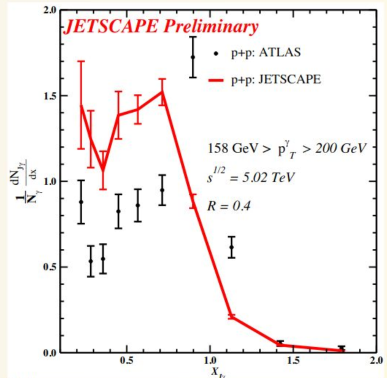
$p_T^{jet} > 30\ GeV,\ |\eta_\gamma| < 1.44,\ |\eta_{jet}| < 1.6, |\Delta\phi| > \frac{7\pi}{8}$

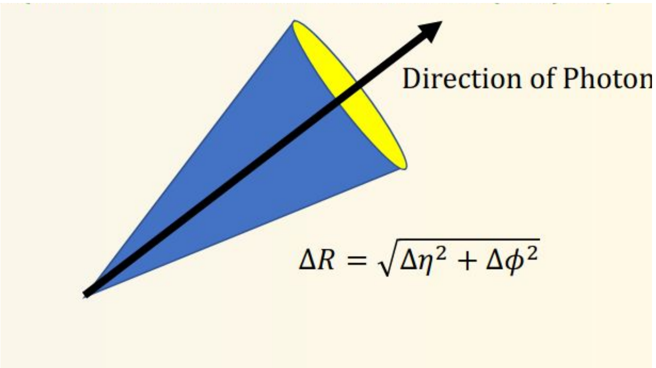
Isolation cut (E < 5 GeV) $\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2} = 0.4$



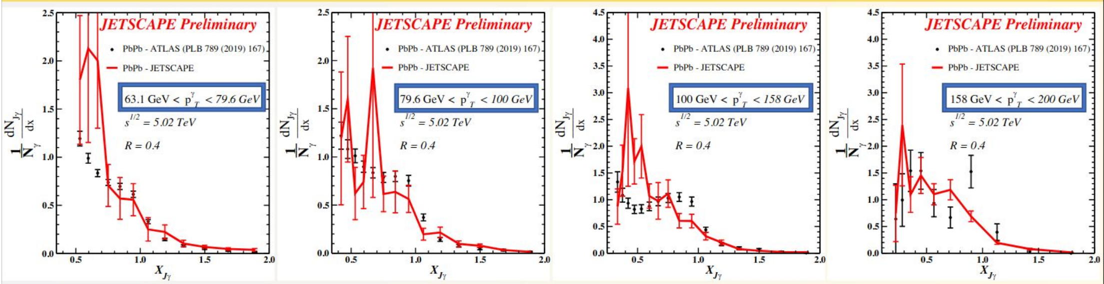
$p_T^{jet} > 31.6\ GeV;\ \ |\eta_\gamma| < 2.37$ (excluding the region $1.37 < |\eta_\gamma| < 1.52$); $|\eta_{Jet}| < 2.8, |\Delta\phi| > \frac{7\pi}{8}$

Isolation cut (E < 3 GeV) $\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2} = 0.3$





Photons: Pb-Pb 5.02 TeV

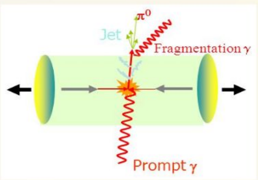


Gamma-Jet transverse momentum imbalance (Gamma-Jet Asymmetry)

$p_T^{jet} > 31.6\ GeV;\ \ |\eta_\gamma| < 2.37$ (excluding the region $1.37 < |\eta_\gamma| < 1.52$); $|\eta_{Jet}| < 2.8, |\Delta\phi| > \frac{7\pi}{8}$

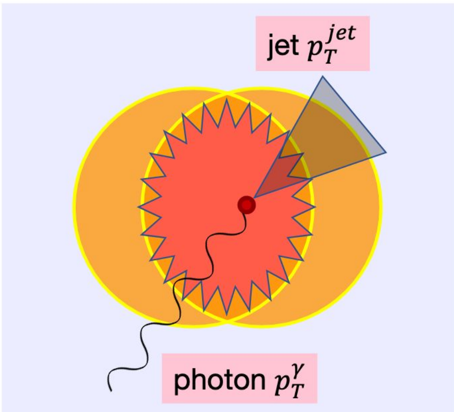
Isolation cut (E < 8 GeV) $\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2} = 0.3$

- Photons included in the analysis
  - Photons from initial hard scattering (prompt photons)
  - Photons radiated from intermediate shower
  - Photons radiated by hadrons in the process of hadronization



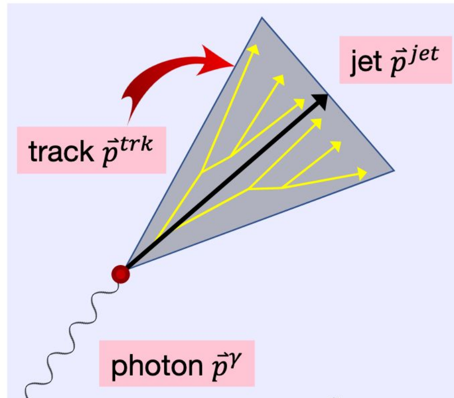
Observables

Momentum Imbalance



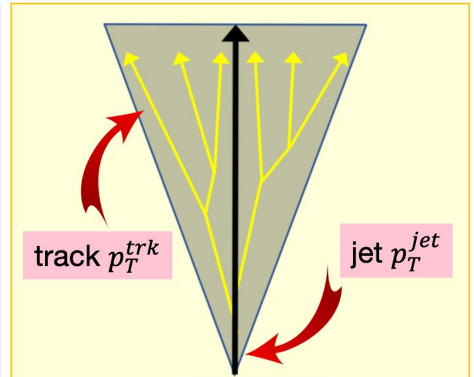
$$x_{jet,\gamma} = p_T^{jet}/p_T^{\gamma}$$

Fragmentation Function



$$\xi_T^{\gamma} = \ln \frac{-\left|\vec{p}_T^{\,\gamma}\right|^2}{\vec{p}_T^{\,trk} \cdot \vec{p}_T^{\,\gamma}}$$

Jet Shape



$$r = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$$

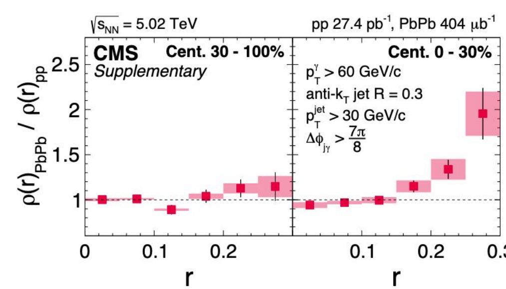
$$\rho(r) = \frac{1}{\delta r} \frac{\sum_{jets} \sum_{r_a<r<r_b} p_T^{trk}/p_T^{jet}}{\sum_{jets} \sum_{0<r<r_f} p_T^{trk}/p_T^{jet}}$$

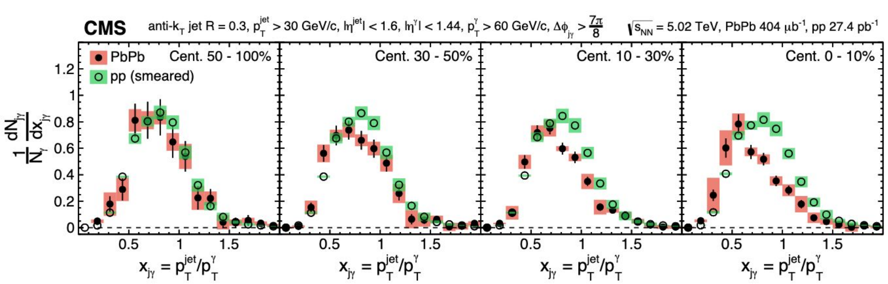
track transverse distribution

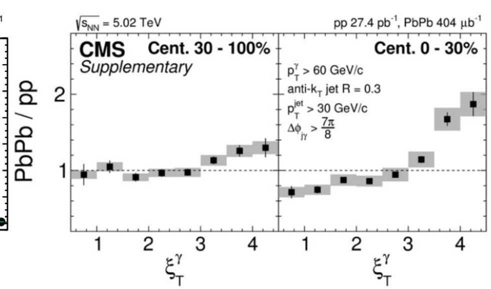
Study of in-medium momentum broadening with photon-jet momentum correlations in PbPb collisions at 5.02 TeV with the CMS experiment

M. Taylor

- PbPb data has larger γ-jet asymmetry
  => jet energy loss
- Enhancement of low p_T particles
- Depletion of high p_T particles
- Small relative modification of jet core
- Enhancement of particles away from jet axis







Dileptons

'Primordial' $q\bar{q}$ annihilation (Drell-Yan):

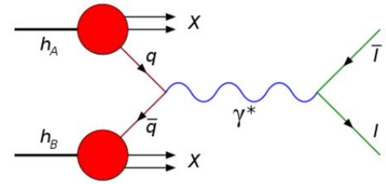
- $NN \rightarrow e^+e^-X$

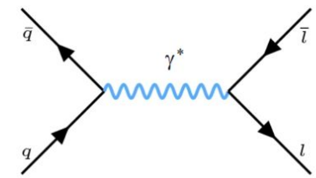
Thermal radiation from QGP and hadrons:

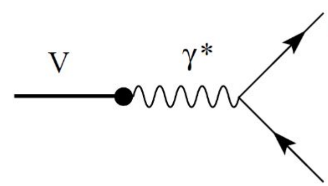
- $q\bar{q} \rightarrow e^+e^-$, ...
- $\pi^+\pi^- \rightarrow e^+e^-$, ...
- short-lived states: ρ, a_1, Δ, N^*, ...
- multi-meson reactions ('4π'): $\pi\pi$, $\pi\rho$, $\pi\omega$, $\rho\rho$, πa_1, ...

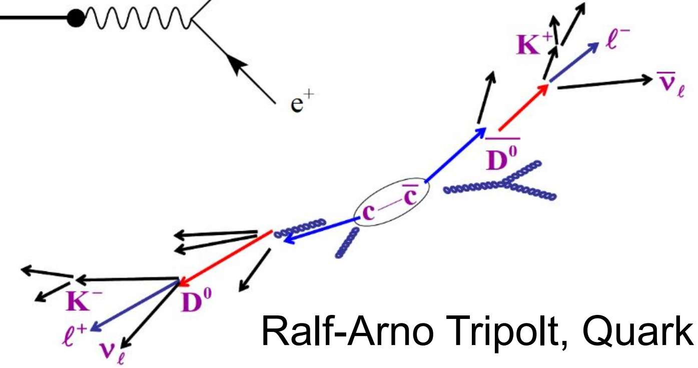
Decays of long-lived mesons and baryons:

- π^0, η, ϕ, J/Ψ, Ψ', correlated $D\bar{D}$ pairs, ...

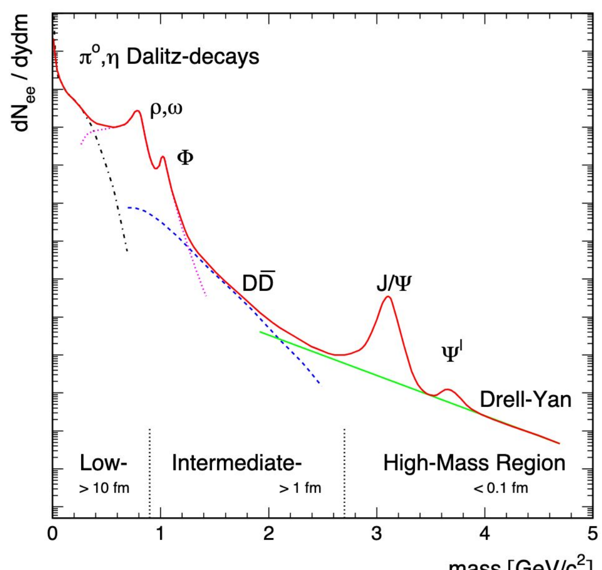








Ralf-Arno Tripolt, Quark Matter 2019

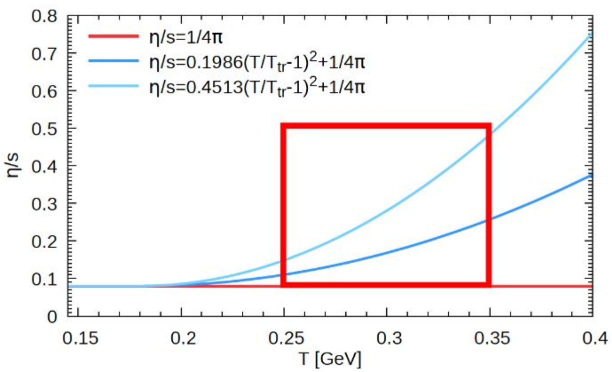


R. Rapp, J. Wambach 1999

Dileptons have an advantage over real photons: an additional variable, the invariant pair mass M_{ll}

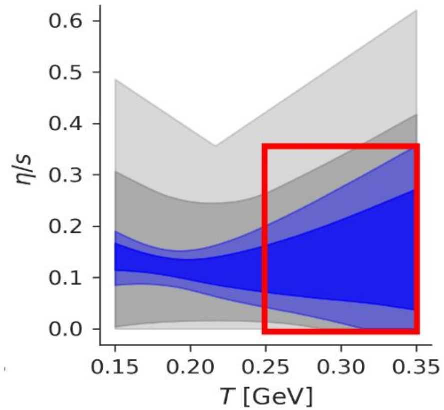
Dileptons as chronometer, thermometer & viscometer ✓

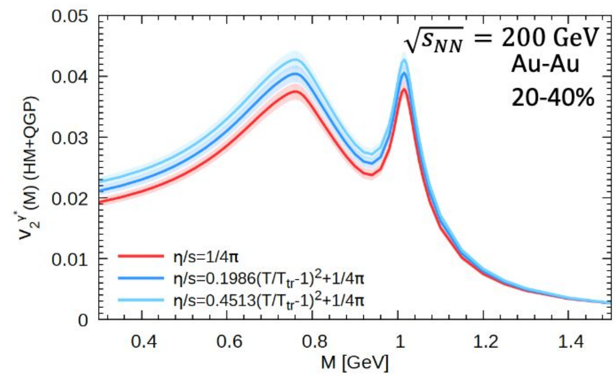
- Size of $\int \frac{dN}{dM} \in 0.3 < M < 0.7$ GeV [R. Rapp, H. van Hees, Phys. Lett. B 753, 586-590 (2016)]
- Slope of $\frac{dN}{dM} \in 1.5 < M < 2.5$ GeV [NA60, Phys. Rev. Lett. 100, 022302 (2008)]
- Size of $v_2(M)$ [$or\ v_n(M)$]



[G.V. et al., Phys. Rev. C 98, 014902 (2018)]

Preliminary results by
JETSCAPE SIMULATIONS GROUP





[G.V. et al., Phys. Rev. C 98, 014902 (2018)]

- A joint Bayesian analysis (dileptons & hadrons) may help constrain on $(\eta/s)(T)$.
- An accurate measurement of dilepton v_2 is needed ⇒ possible following ALICE Upgrade

[CERN Yellow Rep. Monogr. 7, 1159 (2019)]

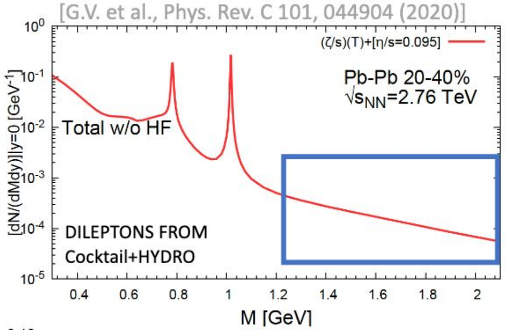
Talk by Gojko Vujanovic

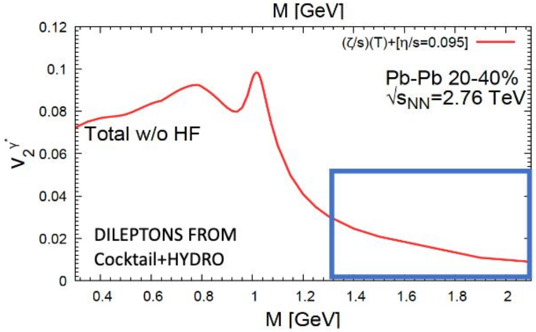
Dilepton flow at $M \gtrsim 1$ GeV as probe of QGP

- A heavy flavor tracker can reduce/remove HF signal exposing direct QGP radiation ($M \gtrsim 1$ GeV)
  - Need to measure $\frac{dN}{dM}$ and v_2!
  - Increased sensitivity to transport coefficients
- EM are sensitivity to $\tau_\pi = b_\pi \eta/(\varepsilon + P)$

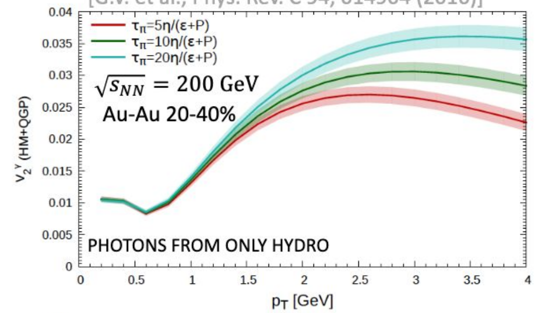
Gojko Vujanovic

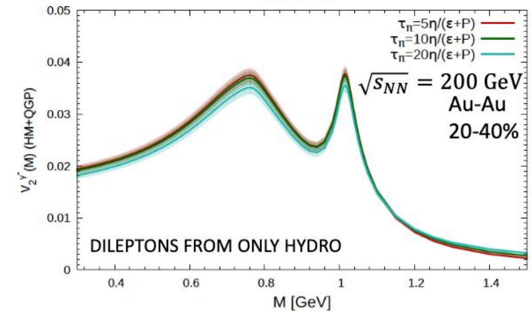
[G.V. et al., Phys. Rev. C 101, 044904 (2020)]

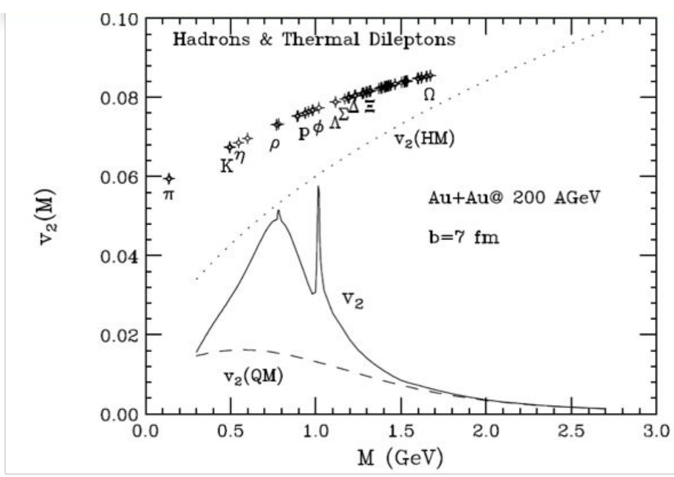




[G.V. et al., Phys. Rev. C 94, 014904 (2016)]



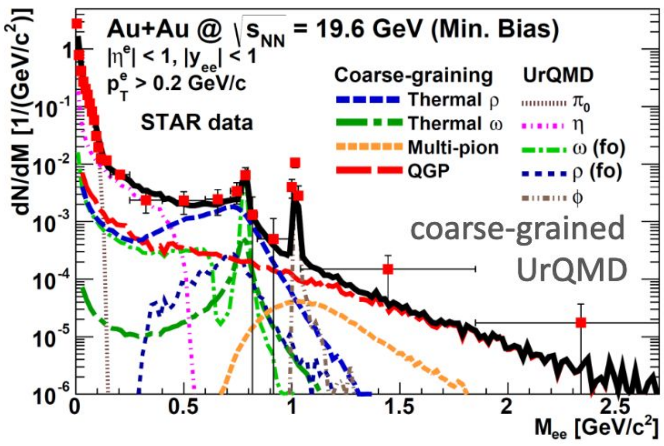




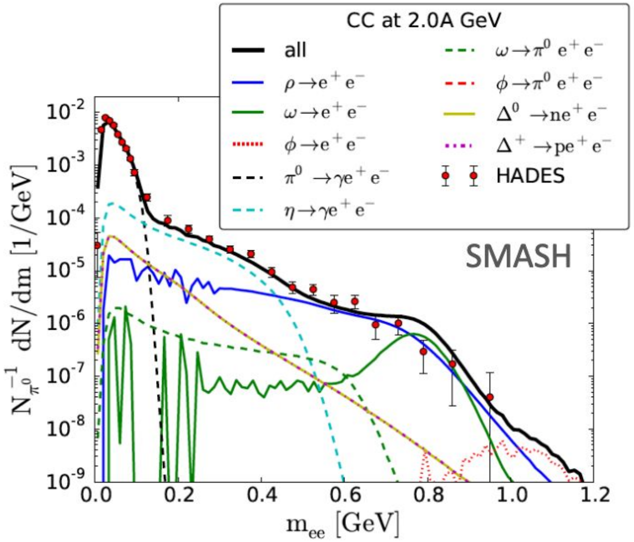
R. Chatterjee, D. K. Srivastava, U. Heinz, C. Gale, PRC75(2007)054909.

Dileptons from transport ✓

- At lower $\sqrt{s_{NN}}$, more dileptons from transport



[S. Endres al., Phys. Rev. C 94, 024912 (2016)]



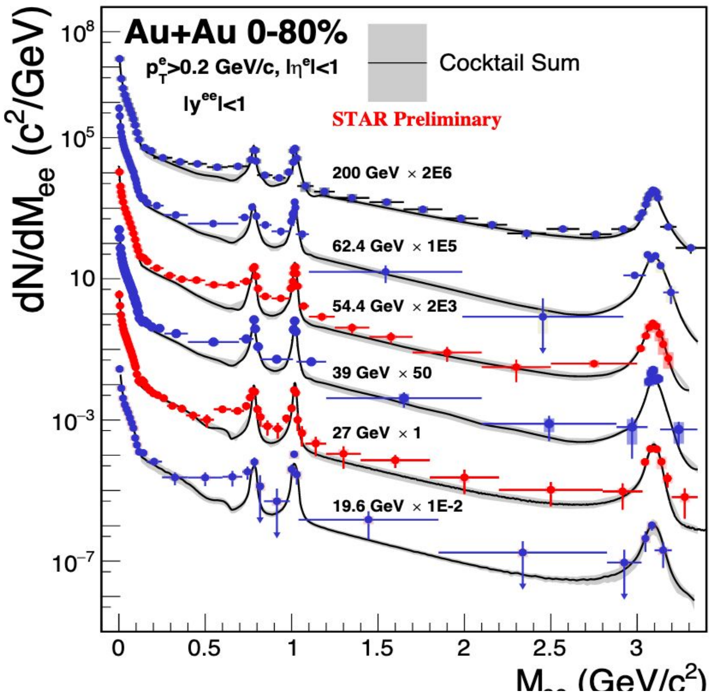
[J. Staudenmaier et al., Phys. Rev. C 98, 054908 (2018)]

- Consistent description at all beam energies ⇒ combining transport & hydrodynamical calculations.

- Bayesian comparisons of dileptons at various $\sqrt{s_{NN}}$ ⇒ learn more dilepton production mechanisms
  - Exclude rates w/o chiral symmetry restoration by comparison with data?
  - Determine uncertainties of calculations & accurate measurements

Talk by Gojko Vujanovic

Measurements of dielectron production in Au+Au collisions at $\sqrt{s_{NN}}$ = 27 and 54.4 GeV with the STAR experiment



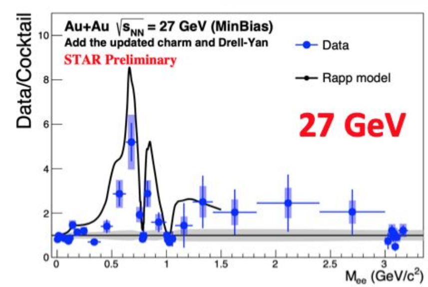
- LMR ($M_{ee} < M_{\phi}$): in-medium modifications linked to the chiral symmetry restoration
- IMR ($M_{\phi} < M_{ee} < M_{J/\psi}$): excess from thermal radiation → medium temperature

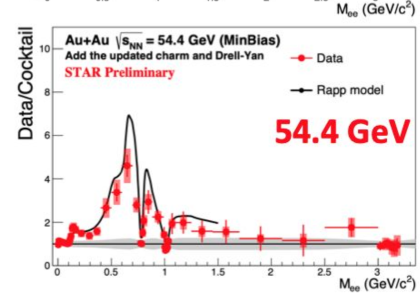
New measurements at $\sqrt{s_{NN}}$ = 27 and 54.4 GeV :

- Enough statistics for differential measurements vs p_T, centrality, etc.
- Rapp theory calculation overestimates in low mass region
- A hint of excess in the intermediate mass region can be observed in both $\sqrt{s_{NN}}$ = 27 and 54.4 GeV measurements

BES-II Program:

- Systematically study energy dependence of low mass region excess $\sqrt{s_{NN}}$ = 7.7 and 19.6 GeV
- Reduced charm cross section enhances sensitivity to thermal radiation in the intermediate mass region

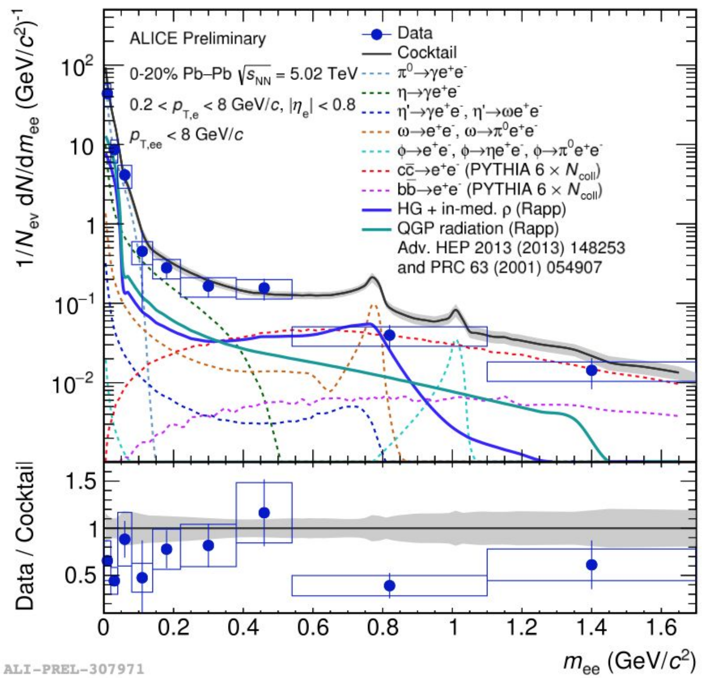




Talk by:
Z Wang
Zaochen Ye

Low-mass dielectron measurements in Pb-Pb collisions with ALICE at the LHC

Talk by Daiki Sekihata



- Hint of enhancement in $m_{ee} < 0.5$ GeV/c^2
- Suppression at IMR
  - energy-loss of charm quarks?
  - nPDF?
- Consistent with QGP radiation by R.Rapp
- Analyzing high statistics data is ongoing
  - 10 times more in 0-10 %
  - 9 times more in 30-50 %

- The first measurement of dielectron production in pp collisions at $\sqrt{s}$ = 5.02 TeV
- The first measurement of dielectron production in p-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV

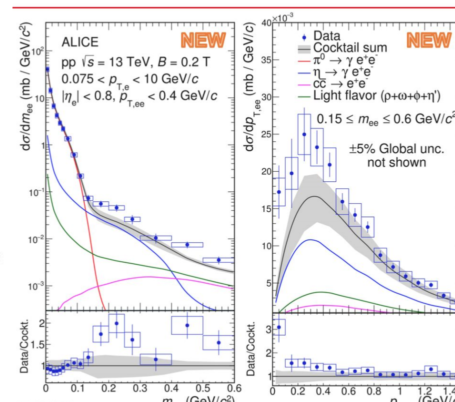
HF cross section and CNM effects in pp/p-Pb at $\sqrt{s_{NN}}$ = 5.02 TeV (arXiv:2005.11995),

Soft dielectron in pp at $\sqrt{s}$ = 13 TeV with B = 0.2 T (arXiv:2005.14522)

· Analyzing 2018 Pb-Pb data is ongoing

Soft dielectron in pp at $\sqrt{s}$ = 13 TeV with B = 0.2 T

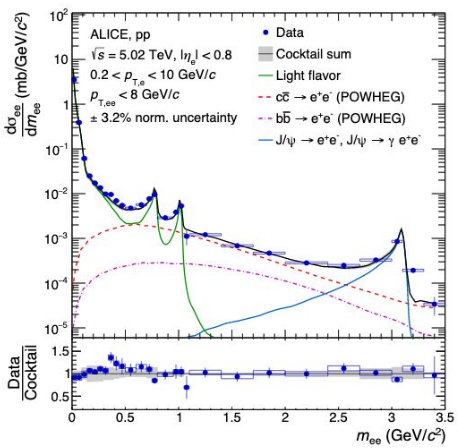
arXiv:2005.14522

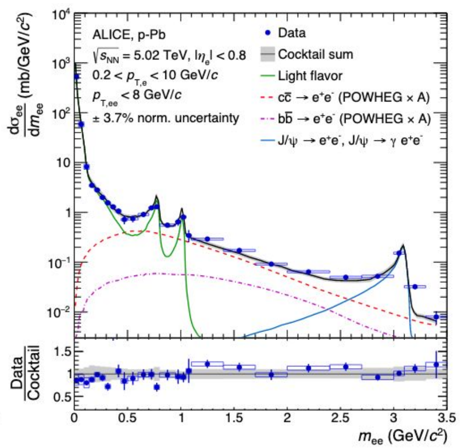


- Dedicated low B field campaign with 0.2 T
  - $p_{T,e}$ > 75 MeV/c
  - better TOF acceptance
- Further constrained η mesons at low p_T from SPS experiments
- Enhancement observed in the η mass region at $p_{T,ee} < 0.4$ GeV/c
  1.69 ± 0.14 (stat.) ± 0.18 (syst) ± 0.36 (cocktail)

Di-Electrons in pp & pPb @5 TeV

New!





- Cocktail describes ALICE pp data well, fits well with 7&13 TeV
- pPb data also well described by cocktail

DCA studies for separating prompt and non-prompt dielectrons in p–Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV with ALICE

Sebastian Scheid for the ALICE Collaboration

$\mu^+\mu^-$ pairs Enhancement in Peripheral Au+Au

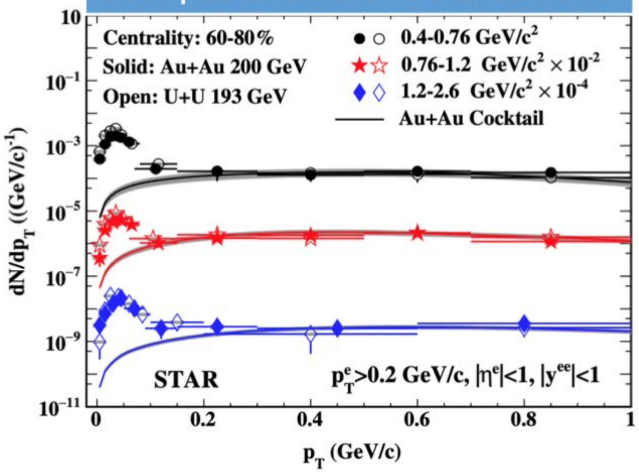
STAR

Z. Liu, 2 June, 11:00, C2

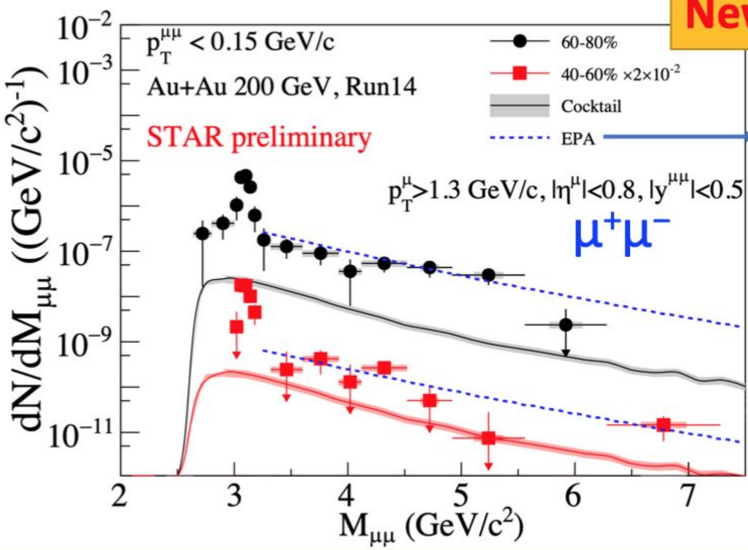
Significant enhancement of the very low-p_T J/ψ and low mass e^+e^- pairs observed in peripheral A+A collisions at STAR

STAR, Phys. Rev. Lett. 123 (2019)132302, STAR, Phys. Rev. Lett. 121 (2018) 132301

STAR published e^+e^- enhancement



New



Equivalent **P**hoton **A**pproximation
- Photon as real
- Weizsacker–Williams method to estimate photon flux

W.M. Zha et al., Phys. Lett. B 800 (2020) 135089

First dimuon enhancement from STAR:
- Similar as in previous dielectron measurements at M_{ee}<3.2 GeV/c², extend to the higher mass region
- Consistent with EPA model calculations

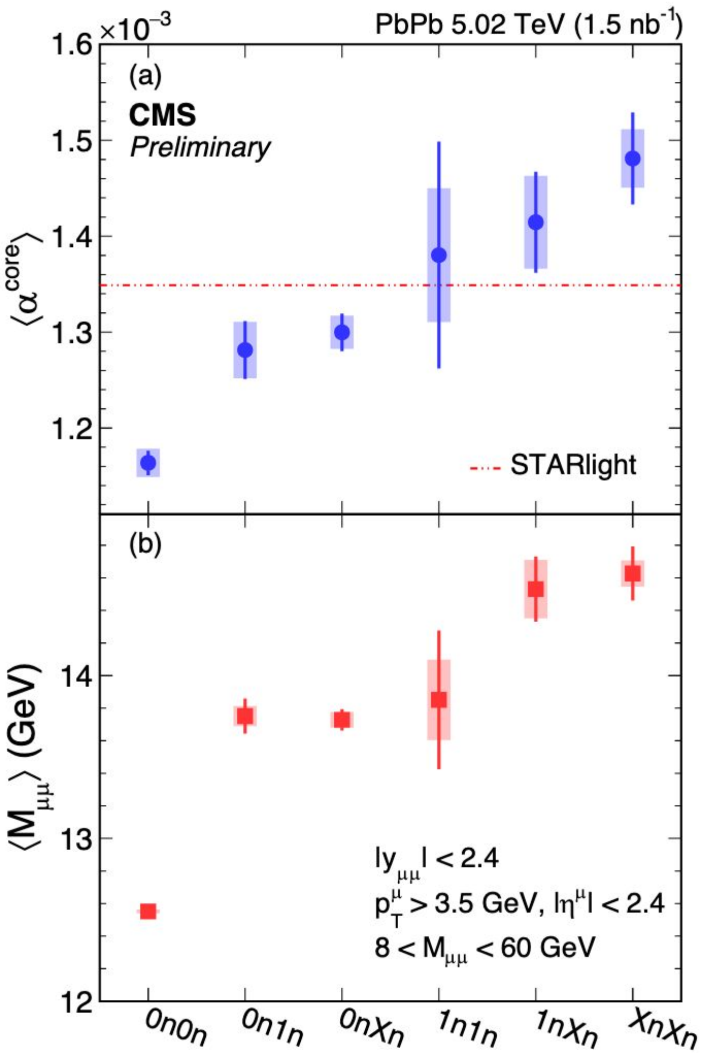
A significant $\mu^+\mu^-$ enhancement w.r.t. cocktail is observed at very low p_T in peripheral Au+Au collisions at 200 GeV

Zaochen Ye

Measured in high mass region 3.2 < $M_{\mu\mu}$< 10 GeV/c²

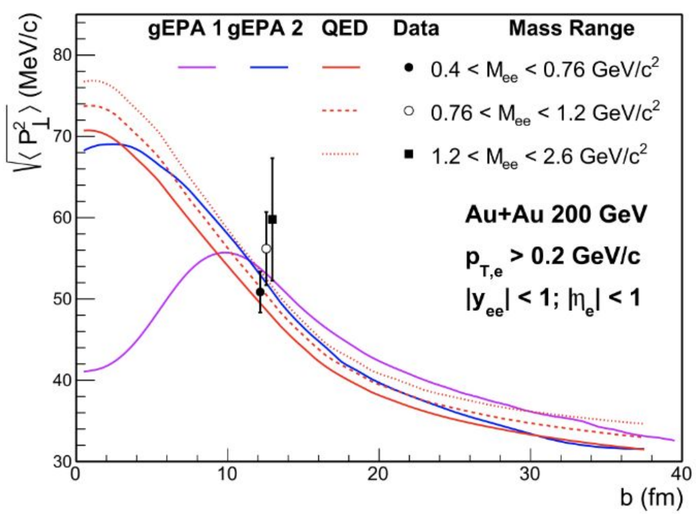
Excess entirely happens below p_T≈ 0.15 GeV/c
Compatible with the theoretical calculation.

Observation of **b** dependence of $\mu^+\mu^-$ acoplanarity in ultra-peripheral PbPb collisions



$$\alpha = 1 - \frac{|\phi^+ - \phi^-|}{\pi}, \alpha \propto p_T^{l^+l^-}$$

- Observed strong neutron multiplicity dependence of $\langle \alpha^{core} \rangle$ and $\langle M_{\mu\mu} \rangle$ in UPC for the first time
  - ***b*** **dependence of photon p_T and energy**
  - Constrain initial photon induced models
  - Controllable reference for searching possible final-state EM effects



Shuai Yang (for the CMS Collaboration)

Production of muon-pairs from photon photon scattering in Non-Ultra Peripheral Pb+Pb collisions

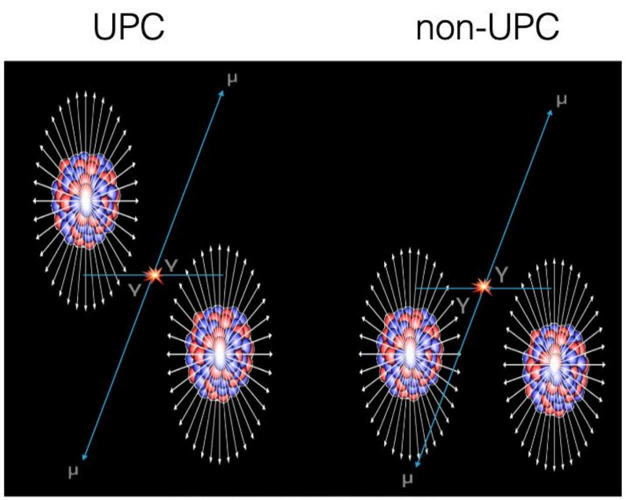
Non UPC di-muons

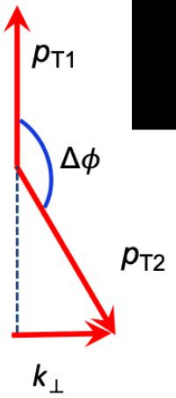
Soumya Mohapatra
Wednesday 10:30
(E2 - Electroweak Probes III)

Poster by Benjamin Gilbert

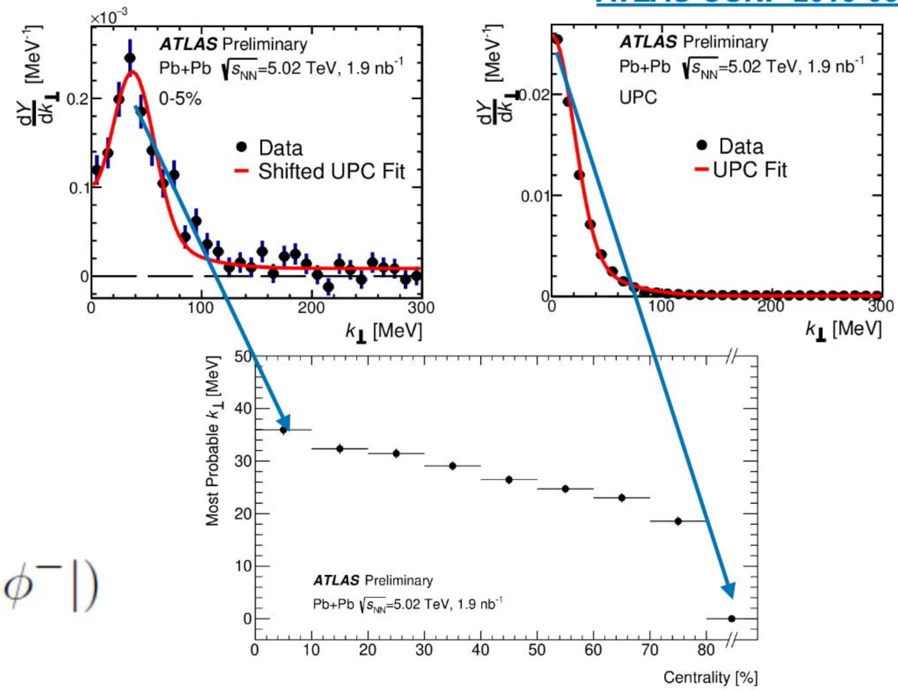
ATLAS-CONF-2019-051

UPC di-muons may probe EM degrees of freedom of QGP if they are produced on top of the heavy ion collisions





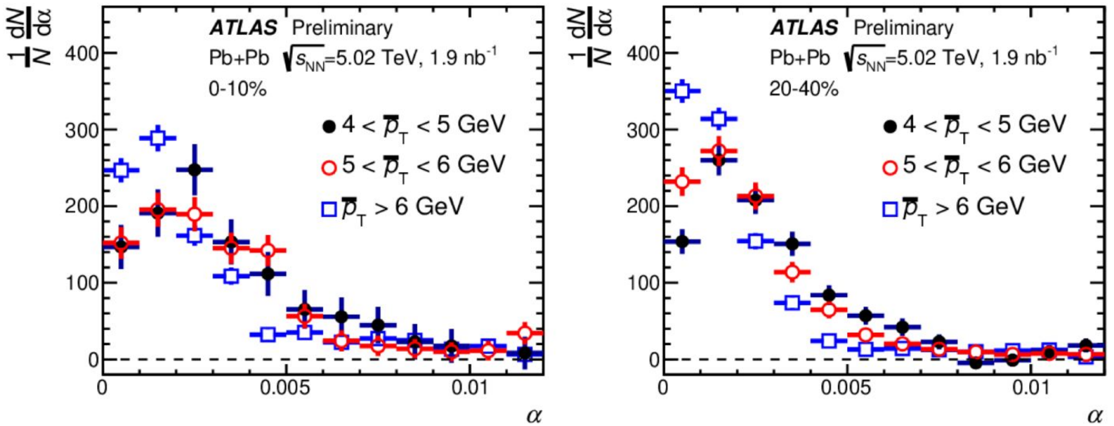
$$k_\perp = \frac{p_T^+ + p_T^-}{2}(\pi - |\phi^+ - \phi^-|)$$



Centrality dependent, shift of the distribution going from UPC to peripheral to central events

Dominik Derendarz

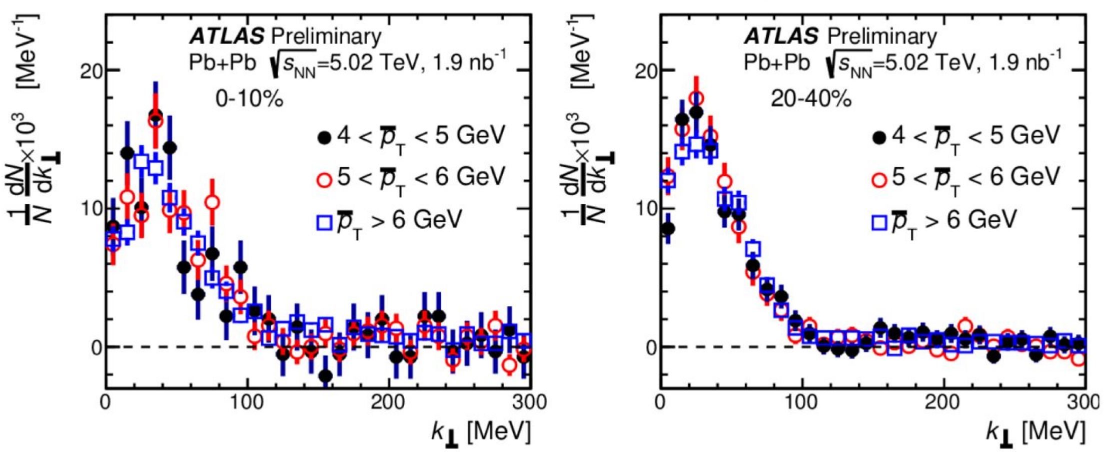
Acoplanarity distributions : p_T Dependence



Soumya Mohapatra

- Strong p_T dependence observed in the shape of the acoplanarity distribution
- Distribution becomes sharper and depletion becomes weaker at higher p_T
- Are higher p_T particles affected less?

$k_\perp$ distributions : p_T Dependence



- Much weaker p_T dependence observed for $k_\perp$ distributions.
- Indicates similar momentum kick at different p_T
  - Thus higher p_T particles deflected less.

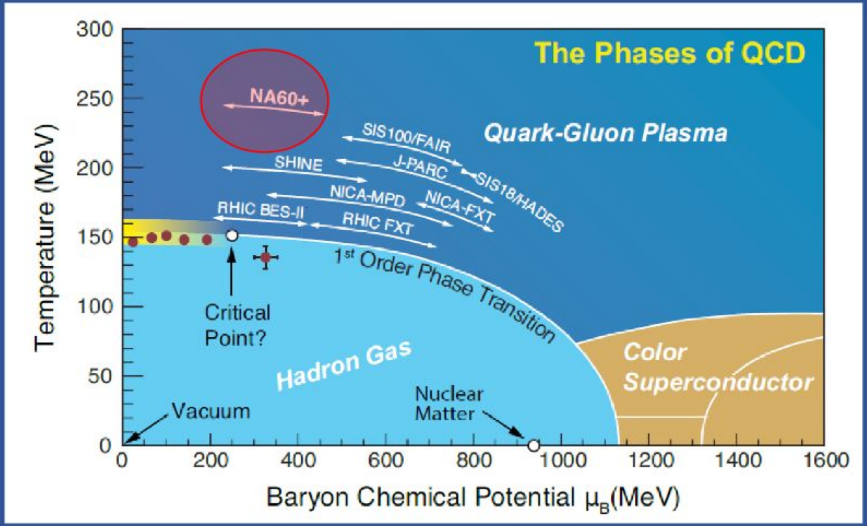
The NA60+ experiment at the CERN SPS: physics goals and prospects

Talk by Enrico Scomparin

NA60+

Study of hard and electromagnetic processes at the CERN-SPS: an investigation of the high-μ_B region of the QCD phase diagram via an energy scan ($\sqrt{s_{NN}}$=6 to 17 GeV)

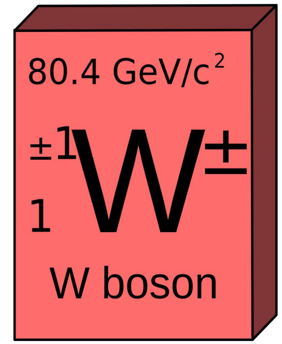
Facility/ Experiment	$\sqrt{s_{NN}}$ (GeV)	μ_B (MeV)	Interaction rate	Dileptons	Charm
SPS NA60+	∼6–17.3	440–220	>MHz	yes	yes
SPS NA61/SHINE	∼5–17.3	540–220	5 kHz	no	yes
SIS100 CBM, HADES	2.7–5.5	740–510	>MHz	yes	yes
RHIC STAR	3–19.6	710–200	∼1 kHz	yes	yes
NICA MPD	4–11	620–320	∼7 kHz	yes	yes
Nuclotron BM@N	2.3–3.5	800–660	20–50 kHz	(yes)	no
J-PARC-HI DHS, D2S	2–6.2	840–480	>MHz	yes	(yes)

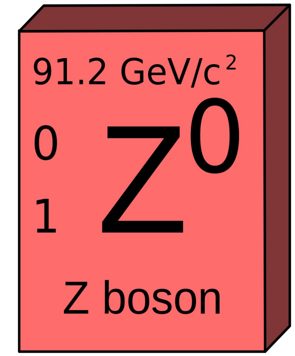


- Main features
  - Coverage of a very wide μ_B region
  - Precision physics: possibility of reaching very high interaction rates (>MHz)
  - Complete physics reach for dileptons and charm
  - Energy range complementary to FAIR/GSI (and J-PARC)

Produced by initial hard processes:

- $u\bar{d} \rightarrow W^+ \rightarrow e^+\nu_e, \mu^+\nu_\mu$
- $\bar{u}d \rightarrow W^- \rightarrow e^-\bar{\nu}_e, \mu^-\bar{\nu}_\mu$
- $\bar{u}u, \bar{d}d \rightarrow Z^0 \rightarrow e^+e^-, \mu^+\mu^-$





Excellent tool to constrain the initial state effects,

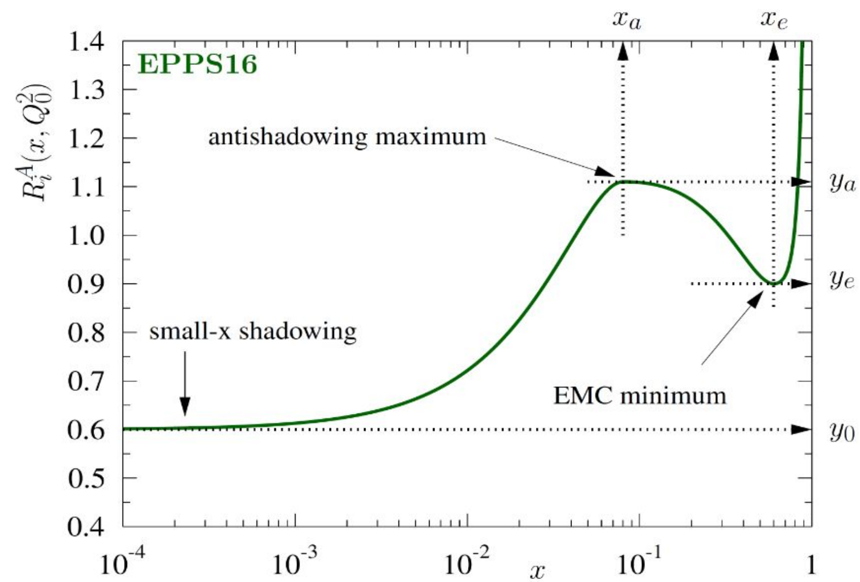
sensitive probes of the nuclear modifications of the Partonic Distribution Functions (PDF)

nPDFs are obtained by multiplying free PDFs with a nuclear modification factor R_i^A (x, Q^2):

$$f_i^{\mathrm{p}/A}(x, Q^2) \equiv R_i^A(x, Q^2)\, f_i^{\mathrm{p}}(x, Q^2)$$

Nuclear modifications

Free proton baseline



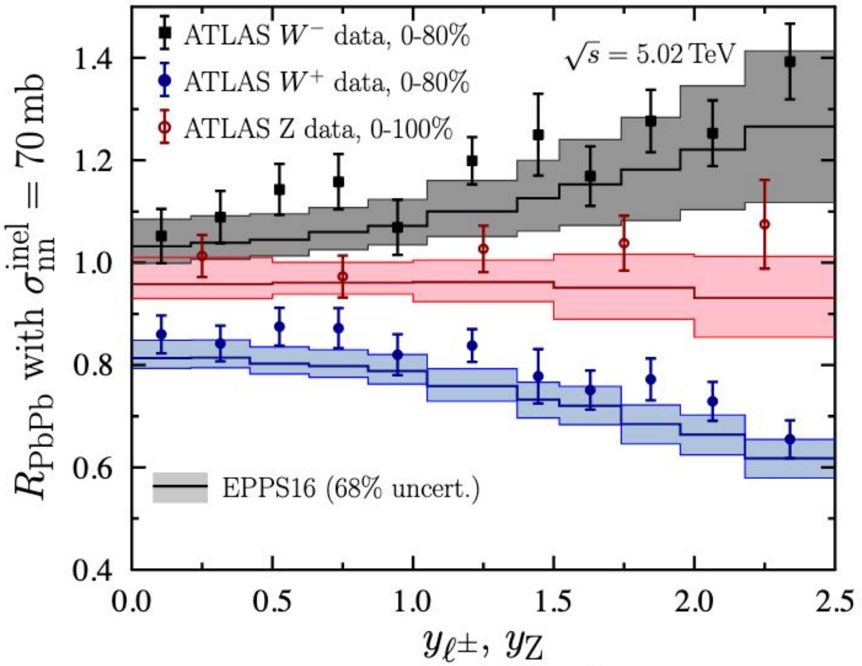
Evidence of shadowing in inelastic nucleon-nucleon cross section

Talk by Mikko Kuha

arXiv:2003.11856

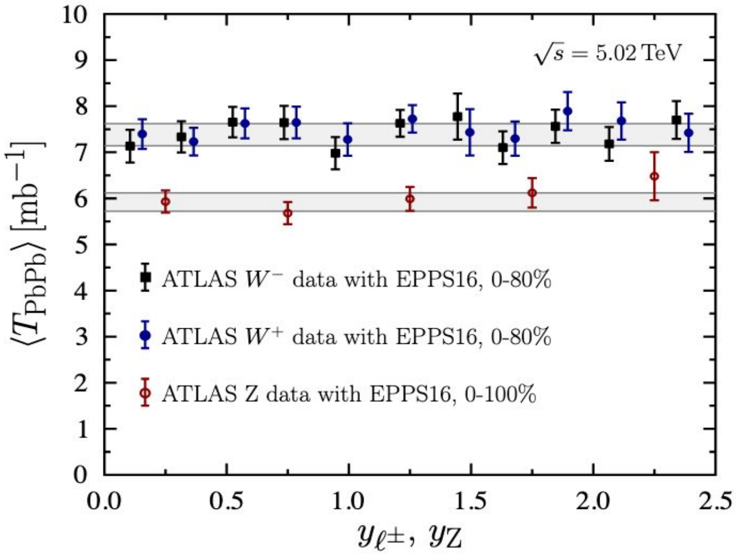
Motivation

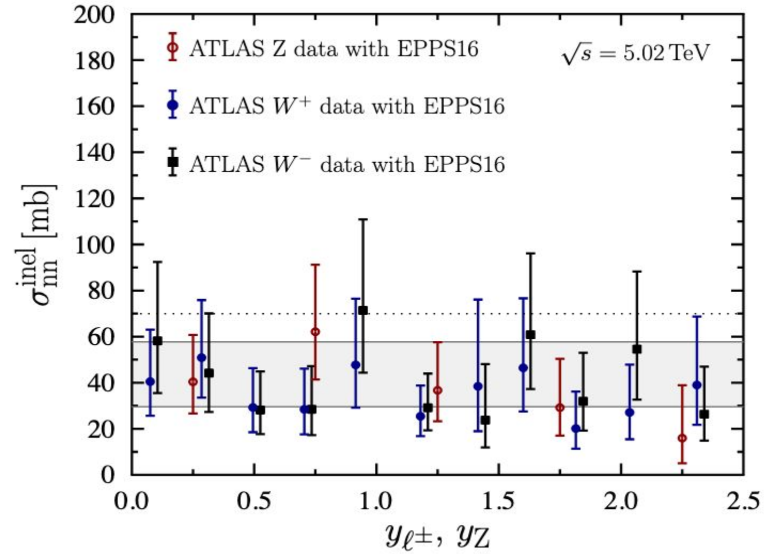
R_{PbPb} from ATLAS



$$R_{\mathrm{PbPb}}^{\mathrm{theor}}(y) = \frac{1}{(208)^2} \frac{d\sigma_{\mathrm{PbPb}}^{W^\pm,Z}/dy}{d\sigma_{\mathrm{pp}}^{W^\pm,Z}/dy}$$

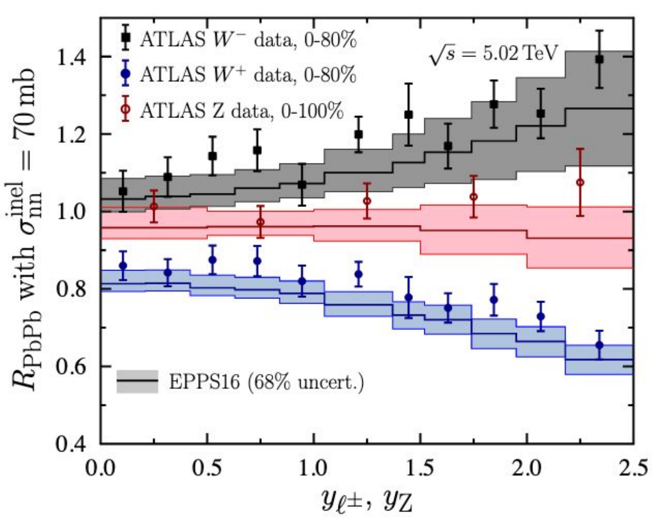
- The calculations in NNLO pQCD with NNPDF3.1 proton PDFs and EPPS16 nuclear modifications, a theory standard candle
- NNPDF3.1 PDFs match ATLAS data for $W^\pm$ and Z in p+p at $\sqrt{s} = 5.02$ TeV very well. On the other hand, EPPS16 matches p+Pb results very well.
- $R_{\mathrm{PbPb}}^{\mathrm{exp}}$ lies slightly, but clearly, above the calculated result
- Our suggestion: Use these data to calibrate the Glauber model!



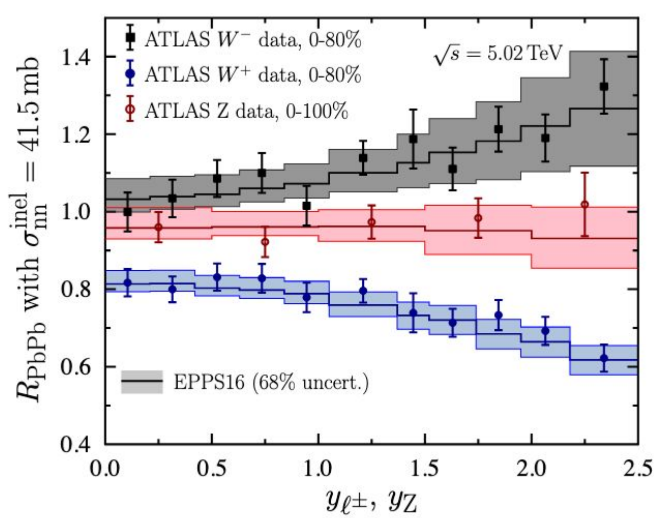


- Data points here obtained by equating $R_{\rm PbPb}^{\rm exp}$ and $R_{\rm PbPb}^{\rm theor}$, and solving for $\langle T_{AA} \rangle$
- $\sigma_{\rm nn}^{\rm inel} = 70 \pm 5$ mb $\rightarrow 41.5^{+16.2}_{-12.0}$ mb

Mikko Kuha



The original ATLAS data with $\sigma_{\rm nn}^{\rm inel} = 70$ mb



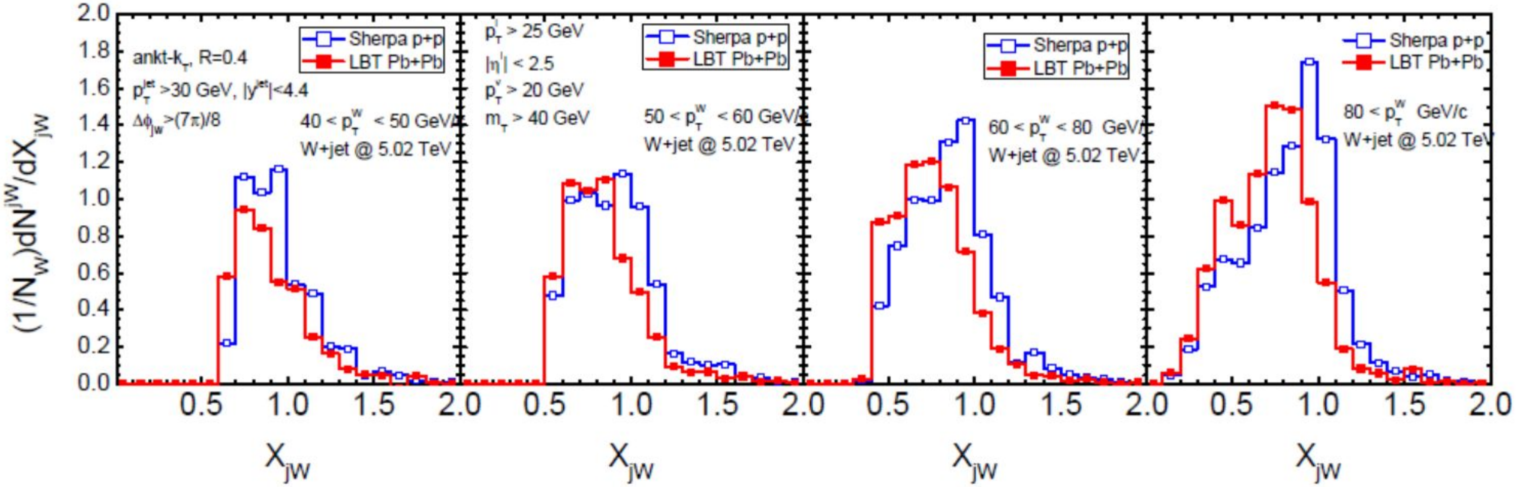
Data re-normalized using the central fit value of $\sigma_{\rm nn}^{\rm inel} = 41.5$ mb

Modification of W+jet in Heavy ion collisions

Shan-Liang Zhang

W+jet asymmetry

- Shift of momentum imbalance $x_{jW} = p_T^{jet}/p_T^W$



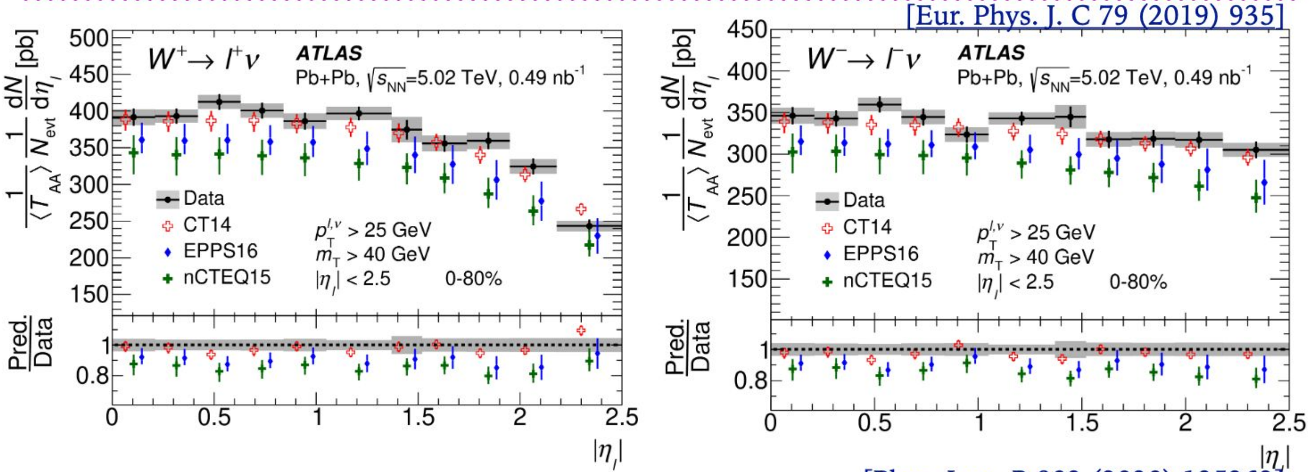
x_{jw} is shifted to smaller value.

- Transverse momentum of W boson is unattenuated.
- Jet transverse momentum is modified by medium.

Electroweak probes in heavy-ion collisions with ATLAS

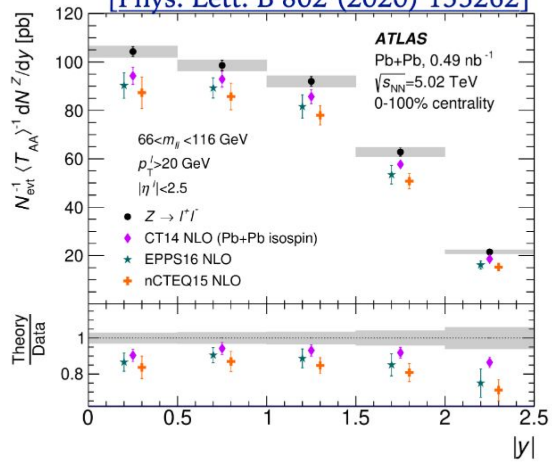
Talk by Iwona Grabowska-Bold

[Eur. Phys. J. C 79 (2019) 935]



- **Normalised W± and Z boson production yields** measured in $|\eta_\ell|$ or $|y|$ in 5.02 TeV Pb+Pb
  - Combined muon and electron channels
- Data compared to NLO pQCD predictions **(MCFM)** using free PDF CT14 or nPDFs: EPPS16 and nCTEQ15
  - All predictions account for the **isospin effect**
  - **All predictions describe shape well,** while **normalisation is underestimated** by 2-3% (CT14) and 10-20% (nPDFs)

[Phys. Lett. B 802 (2020) 135262]



Measurements of long-range correlations in small systems with ATLAS

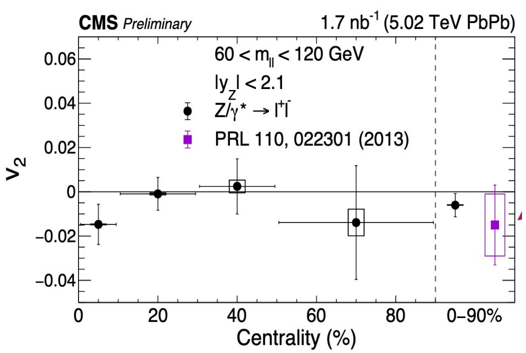
Talk by Blair Daniel Seidlitz

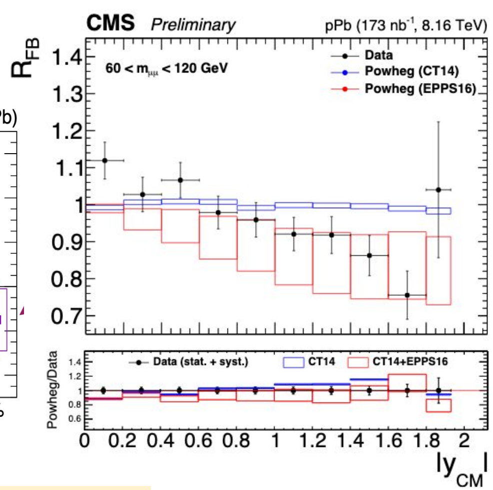
- azimuthal anisotropy in Z-tagged *pp* collisions at 8 and 13 TeV.
- Collectivity in pp collisions tagged by Z-boson production. Z-tagged and inclusive pp v_2 are consistent.

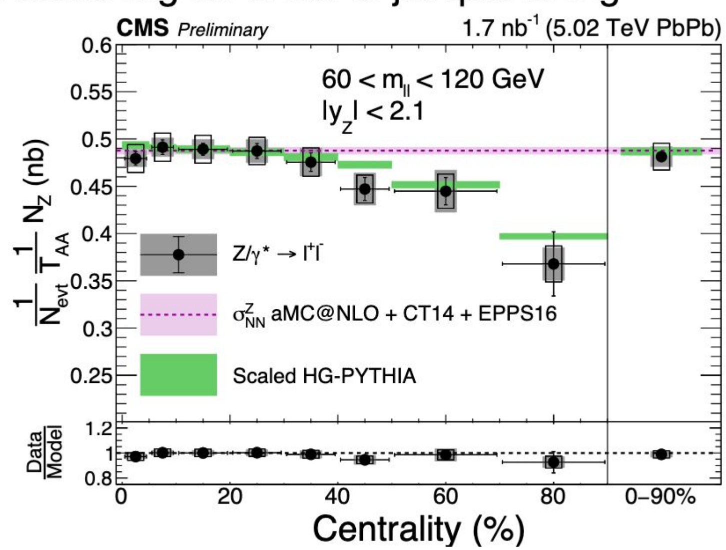
Z bosons in PbPb and Drell-Yan in pPb (CMS)

Austin Alan Baty

- New pPb Drell-Yan measurement extended to lower mass region to offer new nPDF constraints
- Shadowing in EPPS16 favored over free nucleon pdf
- PbPb Z boson v_2 consistent with zero and yields support N_{col} scaling in central events
- Downward trend seen in peripheral Z boson yields - seems to be described by HG-PYTHIA
- Z provides data-driven method to study bias effects when searching for onset of jet quenching







Poster by Émilien Chapon

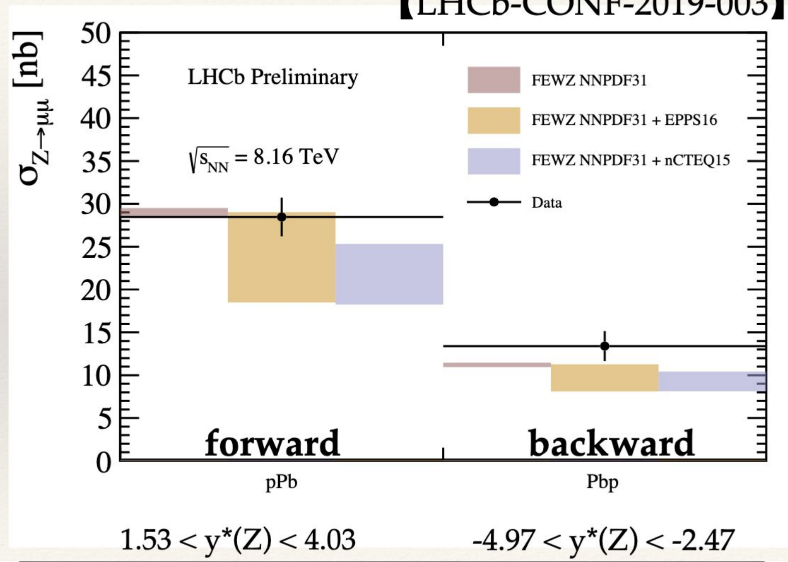
Z production in pPb collisions at LHCb

Talks by Hengne Li Cesar L. da Silva

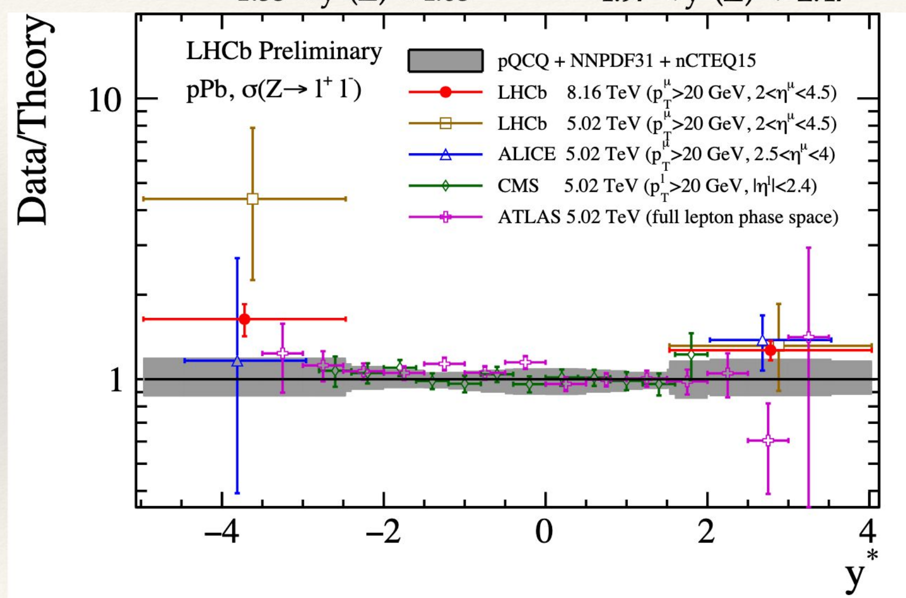
- Fiducial cross-section results:
  $\sigma_{Z\to\mu^+\mu^-,\, pPb}$ (forward)
  $= 28.5 \pm 1.7(\text{stat.}) \pm 1.2(\text{syst.}) \pm 0.7(\text{lumi.})$ nb
  $\sigma_{Z\to\mu^+\mu^-,\, Pbp}$ (backward)
  $= 13.4 \pm 1.0(\text{stat.}) \pm 1.4(\text{syst.}) \pm 0.3(\text{lumi.})$ nb
- Much higher precision
- Compatible with theoretical predictions using FEWZ(NNLO pQCD+NLO pEW) with NNPDF3.1(PDF) for p and
  - NNPDF3.1(PDF)
  - EPPS16 (nPDF)
  - nCTEQ15 (nPDF)

  } for Pb

【LHCb-CONF-2019-003】



- **Results are compatible with previous 5 TeV results from various experiments**
- **The 20 times higher statistics bring higher precision in the measurements**



* only exp. uncert. shown on data/theory ratio, theo. PDF uncert. shown separately on the line at one.

Talk by Guillaume Taillepied

W and Z with ALICE

Collision system	Energy	Luminosity	Year	Analyses
Pb–Pb	5.02 TeV	$\sim 225\ \mu b^{-1}$	2015	W NEW!
Pb–Pb	5.02 TeV	$\sim 750\ \mu b^{-1}$	2015 + 2018	Z NEW!
p–Pb Pb–p	5.02 TeV	$5.03 \pm 0.18\ nb^{-1}$ $5.81 \pm 0.20\ nb^{-1}$	2013	Z, W
p–Pb Pb–p	8.16 TeV	$8.47 \pm 0.18\ nb^{-1}$ $12.77 \pm 0.25\ nb^{-1}$	2016	Z, W NEW !

New results:

- Z in Pb–Pb at $\sqrt{s_{NN}} = 5.02$ TeV: new pre-print of measurement combining the data from the 2015 and 2018 periods
- Z in p–Pb at $\sqrt{s_{NN}} = 8.16$ TeV: submitted along the Pb–Pb results
- W in p–Pb at $\sqrt{s_{NN}} = 8.16$ TeV and Pb–Pb at $\sqrt{s_{NN}} = 5.02$ TeV: preliminary results, first measurements at large rapidities

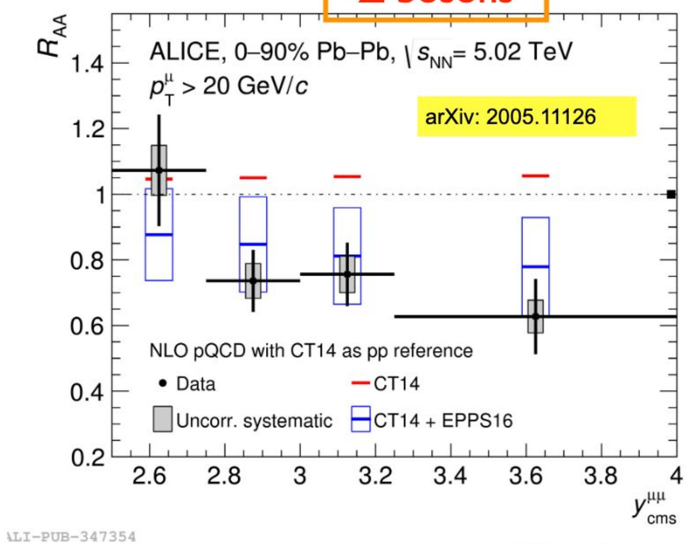
New paper on ArXiv: `arXiv:2005.11126[nucl-ex]`.

Measurement of electroweak-boson production in p-Pb and Pb-Pb collisions at the LHC with ALICE

Talk by Y. Mao

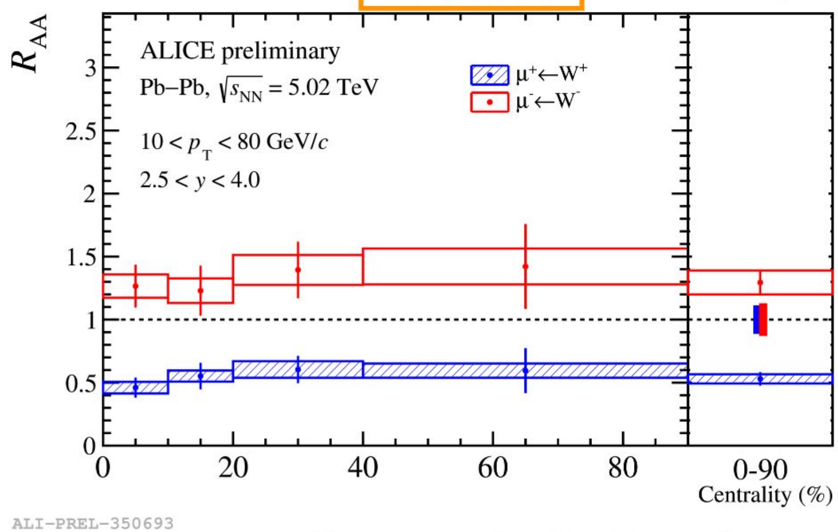
Probing nPDFs with forward W and Z bosons

Z bosons



W bosons

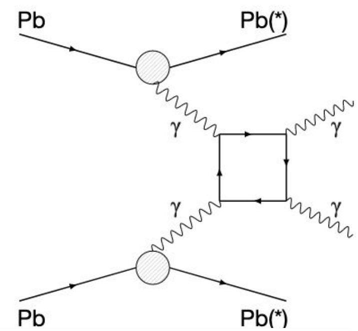
→ G. Taillepied, Tue, 12:20



- Color neutral probes (Z, W) used to study initial state effects with Pb-Pb (shown) and p-Pb
  - Z boson R_{AA} consistent with theoretical calculation including nPDFs (EPPS16)
  - Strong deviation of Z boson R_{AA} at large rapidity with respect to free-nucleon PDF calculation
  - No centrality dependence of W boson R_{AA}

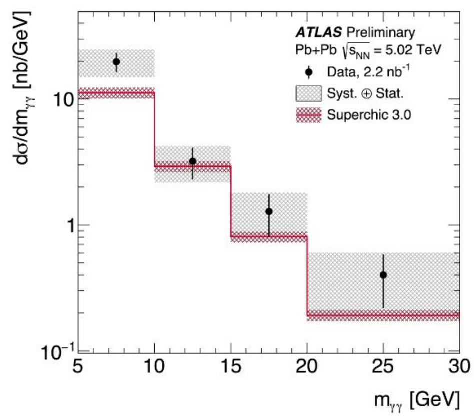
LIGHT-BY-LIGHT SCATTERING AND AXIONS

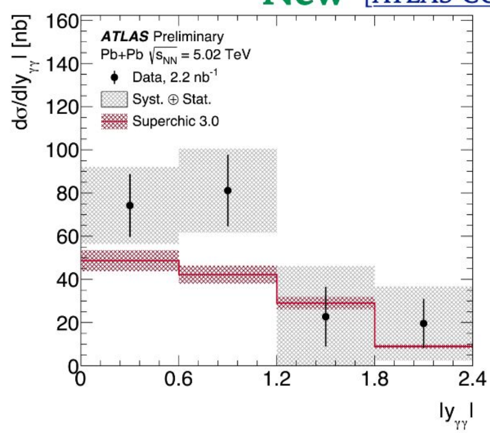
- **NEW** result on **LbyL scattering** ($\gamma\gamma \rightarrow \gamma\gamma$) from ATLAS
  - **Fundamental QED** process with a **tiny cross section**
    - Prior to the LHC, tested indirectly (anomalous magnet moment of the electron and muon)
  - **Sensitive to new physics**
    - Possible contributions from new particles beyond SM
    - Anomalous gauge couplings

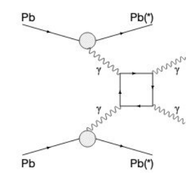


LIGHT-BY-LIGHT CROSS SECTIONS

New [ATLAS-CONF-2020-010]







- Cross section in the fiducial region $E_T^\gamma > 2.5$ GeV, $m_{\gamma\gamma} > 5$ GeV, $|\eta^\gamma| < 2.4$, $p_T^{\gamma\gamma} < 1$ GeV

$$\sigma_{\text{fid}}^{\text{meas}} = 120 \pm 17\ (\text{stat.}) \pm 13\ (\text{syst.}) \pm 4\ (\text{lumi.})\ \text{nb}$$

- Comparison to theory predictions

$\sigma_{\text{fid}}^{\text{theory1}} = 80 \pm 8$ nb by M.Klusek-Gawenda et al. [Phys. Rev. C 93 (2016) 044907]

$\sigma_{\text{fid}}^{\text{theory2}} = 78 \pm 8$ nb from SuperChic 3.0 [Eur. Phys. J. C 79 (2019) 39]

  - **Theory about 50% below data**
- Differential cross sections measured in four variables: $m_{\gamma\gamma}, |y_{\gamma\gamma}|, |\cos\theta^*|, (p_T^{\gamma 1} + p_T^{\gamma 2})/2$
  - **Good agreement in shape**, differences in the normalisation

Talk by
Iwona Grabowska-Bold

Photon-jet angular correlations in high energy proton-nucleus collisions: from low to high transverse momenta

Jamal Jalilian-Marian

Photon radiation in hot nuclear matter by means of chiral anomalies **Kirill Tuchin**

Open charm and dileptons from relativistic heavy-ion collisions **Elena Bratkovskaya**

. . .

Thank You