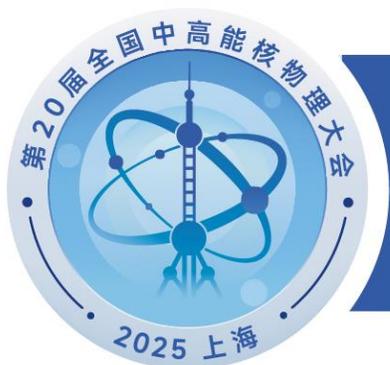


RHIC上的电磁探针实验研究

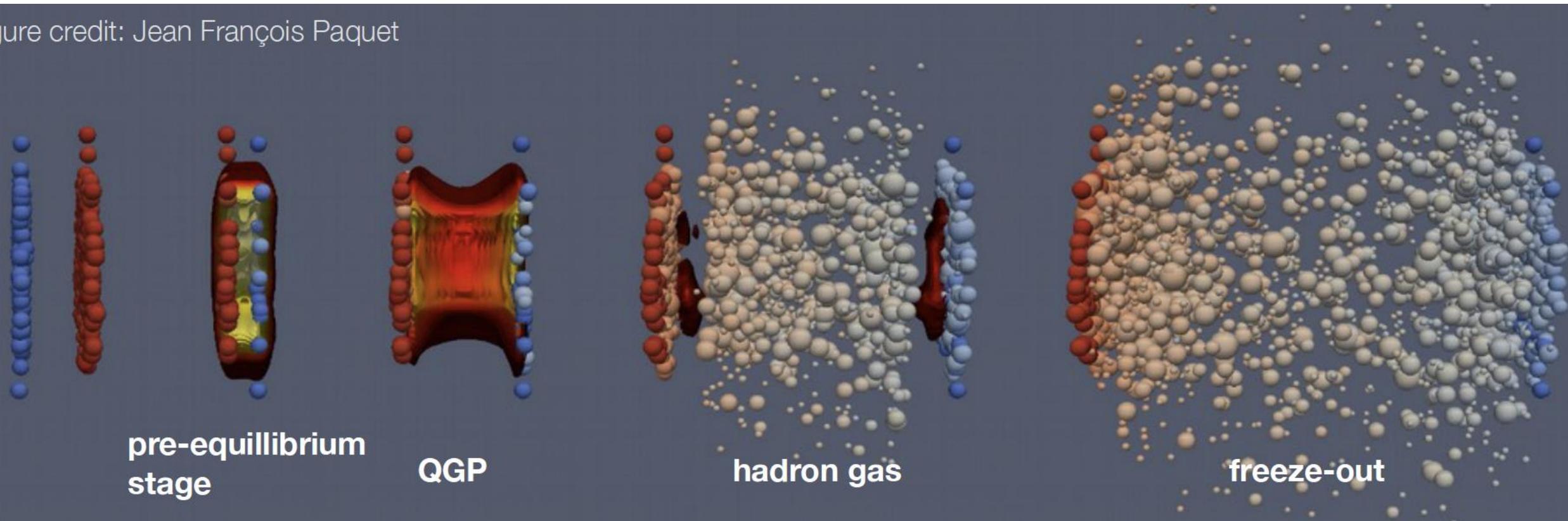
杨 驰
山东大学



第二十届全国中高能核物理大会，2025年4月25至28日，上海

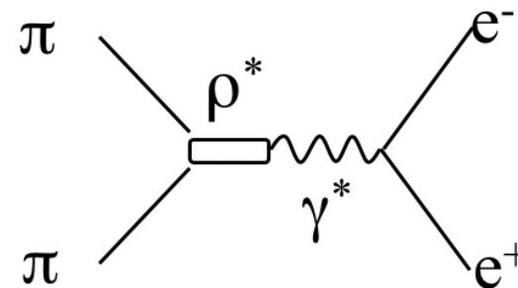
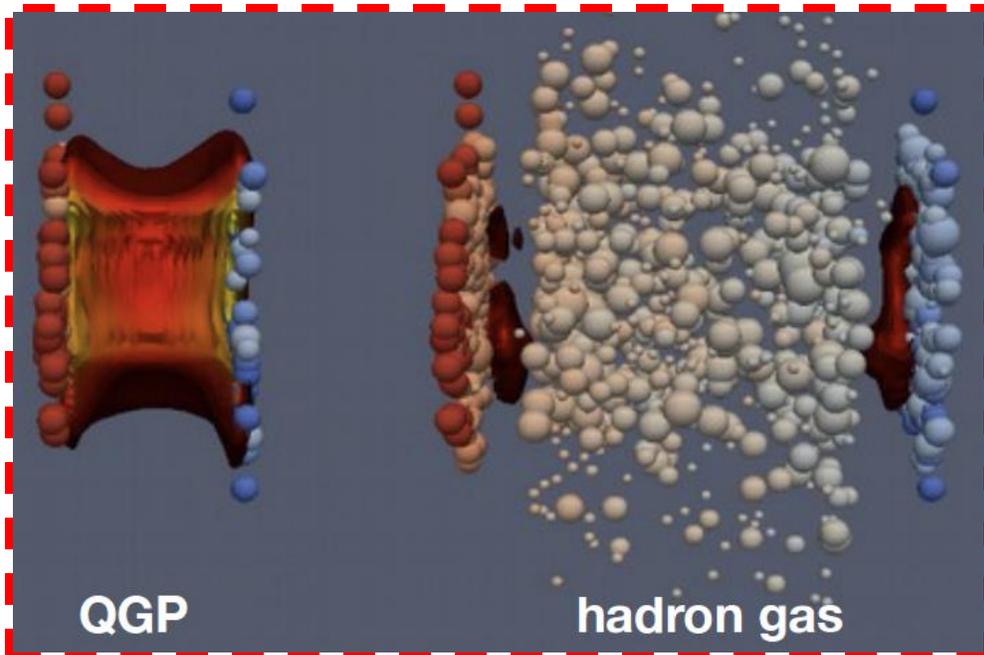
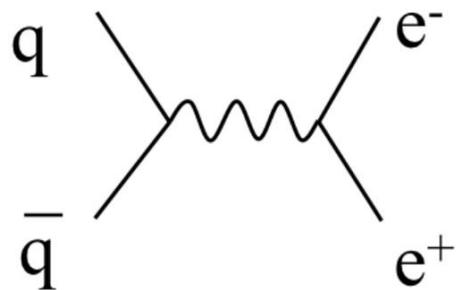
Evolution of relativistic heavy-ion collision system

figure credit: Jean François Paquet

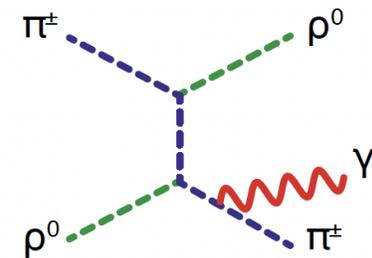
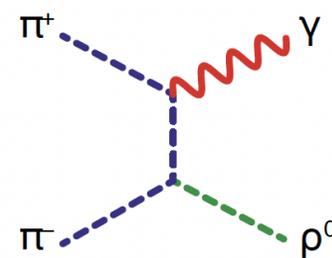
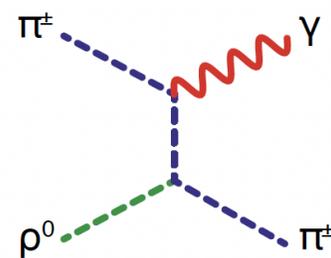
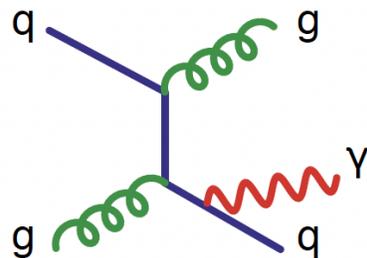
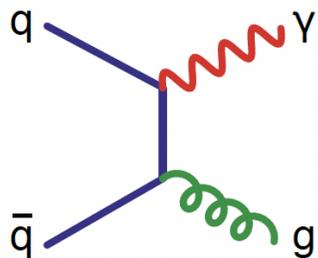
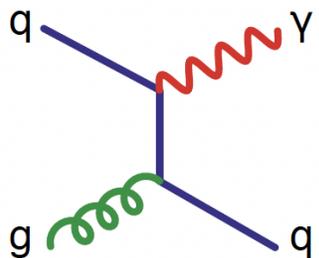


Photon and dilepton productions in hot medium

“Thermal sources”



Direct photon:
photons not from hadron decay



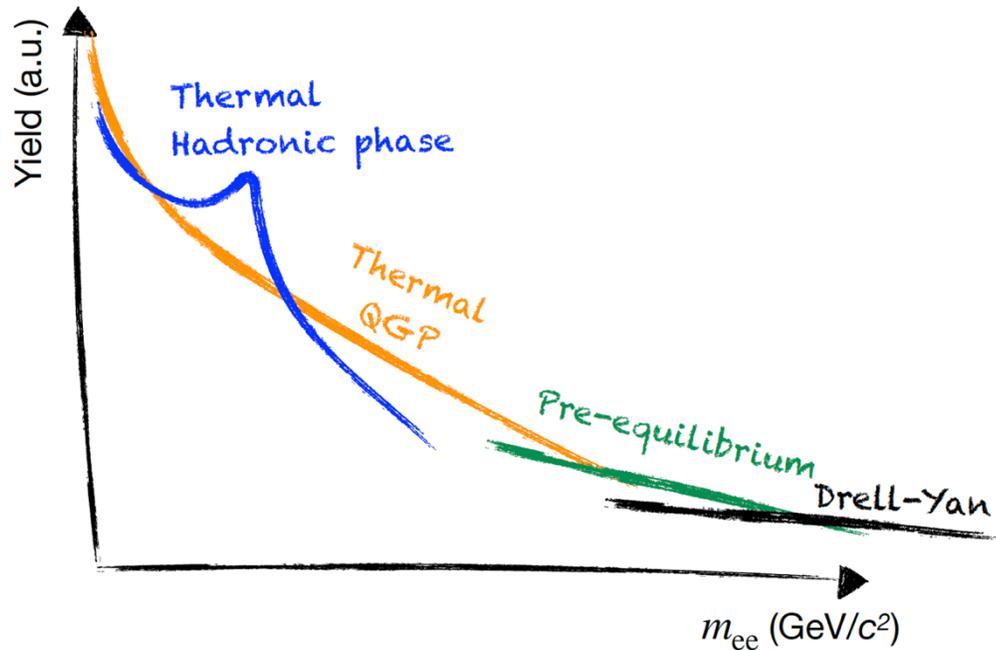
.....

γ : could be either photon or virtual photon (important to direct virtual photon measurement)

Chronometer and thermometer

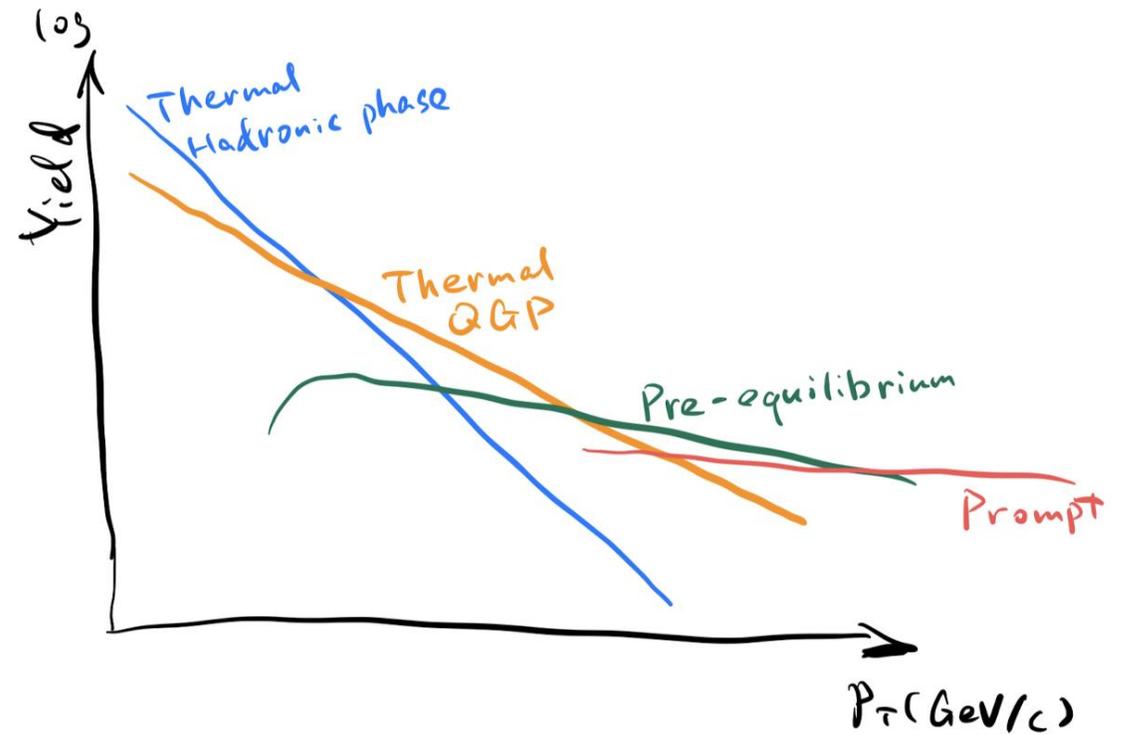
Yield and **Slope** of EM probes: sensitive to **system evolution** and **temperature**

Schematic view of dielectron invariant mass spectrum



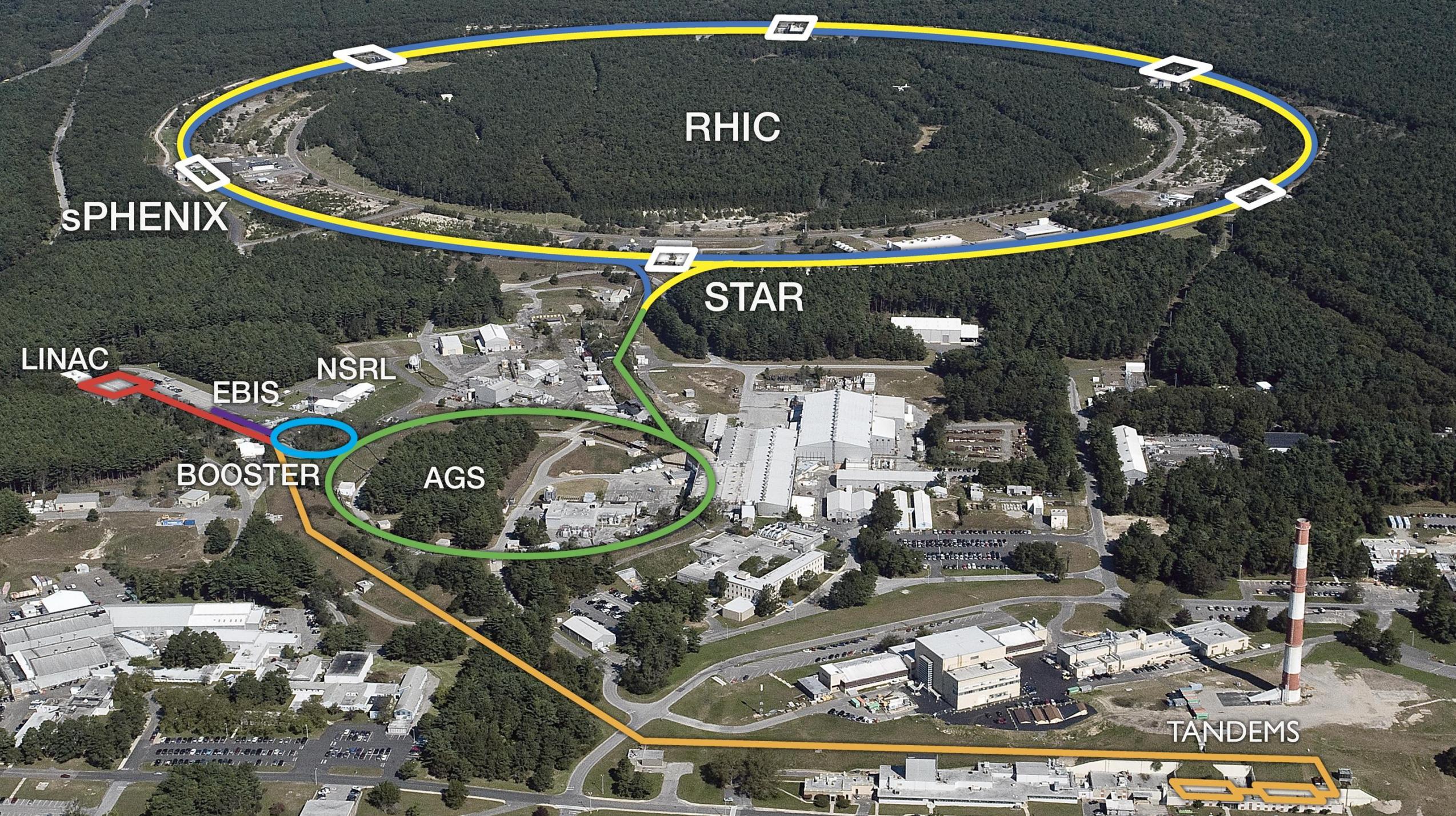
Late emission ← Early emission

Schematic view of direct photon P_T spectrum



Late emission ← Early emission

Temperature: one of the most important properties of the **HOT** and dense medium



RHIC

sPHENIX

STAR

LINAC

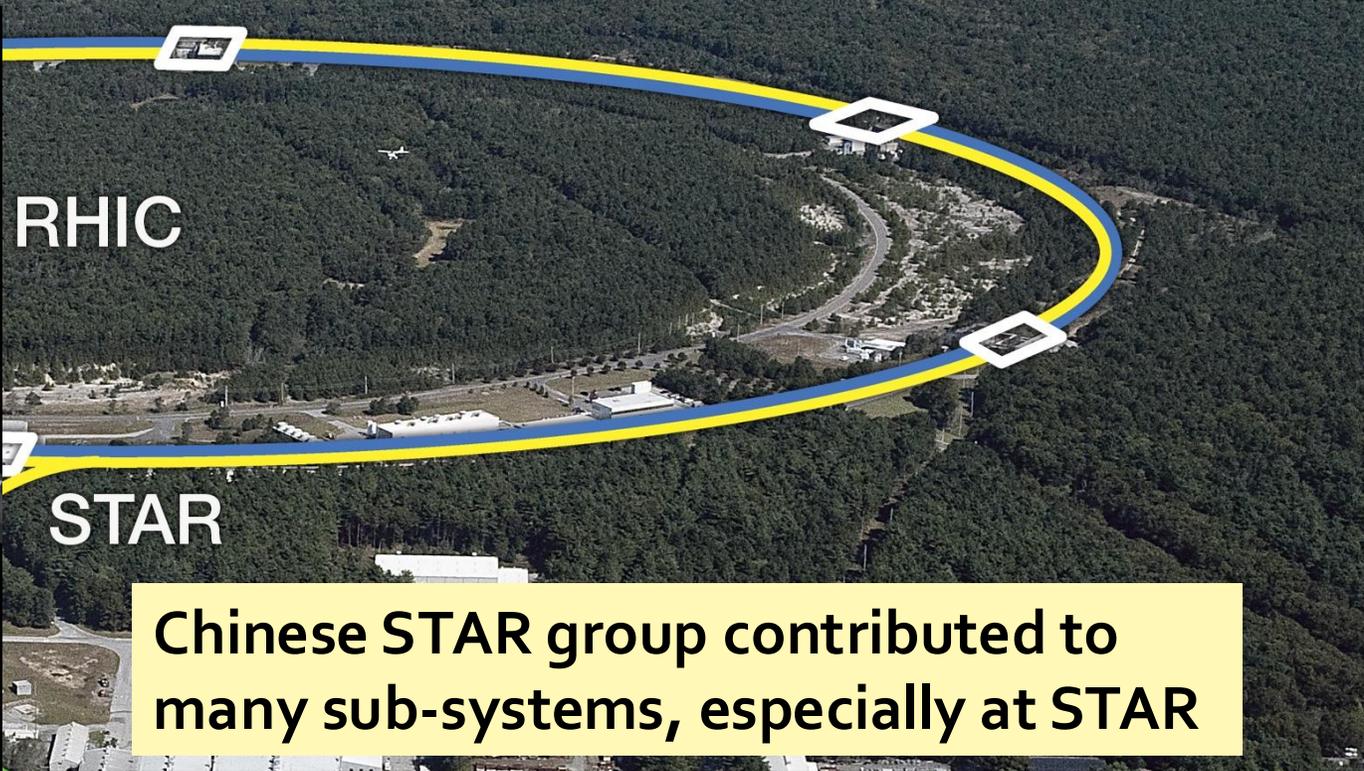
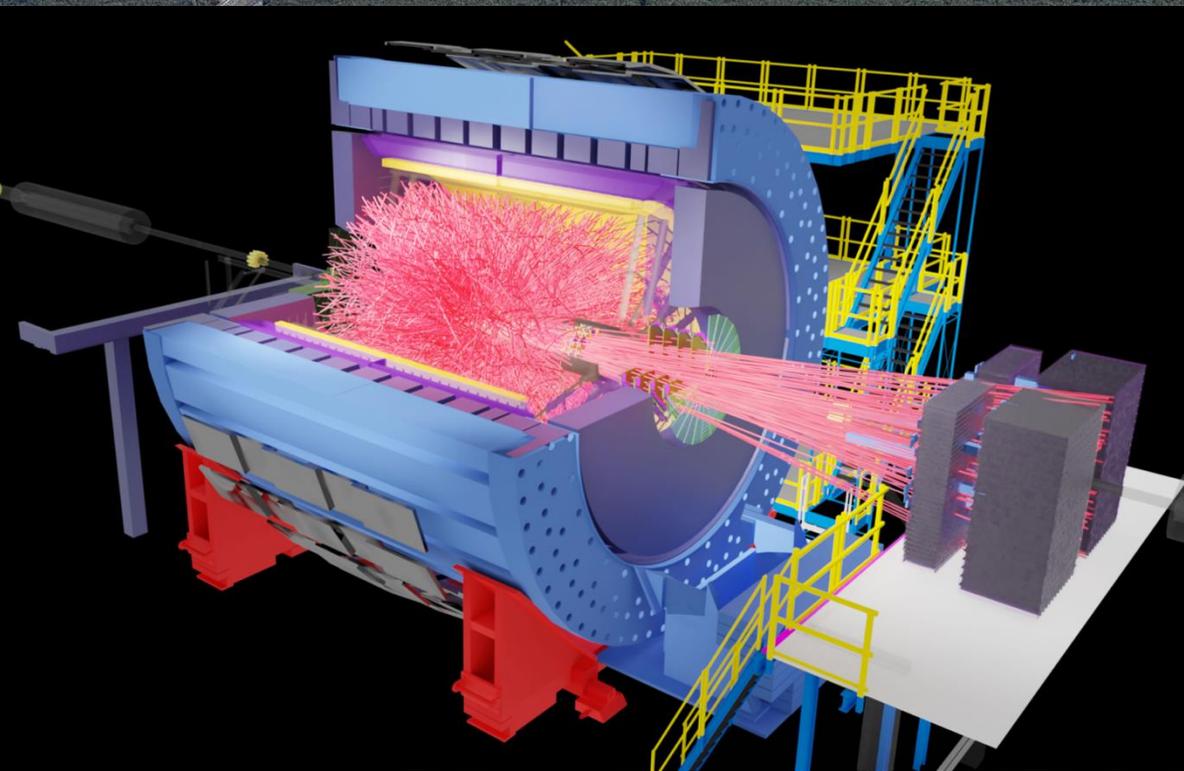
NSRL

EBIS

BOOSTER

AGS

TANDEM



	STAR	TOF	MTD	HFT	iTPC	eTOF	EPD	FST	FTT	FCS
CCNU				✓		✓	✓			
FDU		✓		✓	✓		✓			✓
IMP				✓			✓	✓		
SDU					✓			✓	✓	✓
THU		✓	✓			✓				
USTC		✓	✓		✓	✓	✓		✓	



Facing challenges: Direct Photon Puzzle as an example



Large yield: produced in early stage, high T

Large v_n : produced in late stage, low T

Theoretical calculation can not explain the spectra and v_n simultaneously

Helmholtz Alliance
Extremes of Density and Temperature: Cosmic Matter in the Laboratory

ExtreMe Matter Institute EMMI

EMMI Rapid Reaction Task Force

Direct-Photon Flow Puzzle

February 24-28, 2014

GSI, Darmstadt, Germany

Became even more complicated

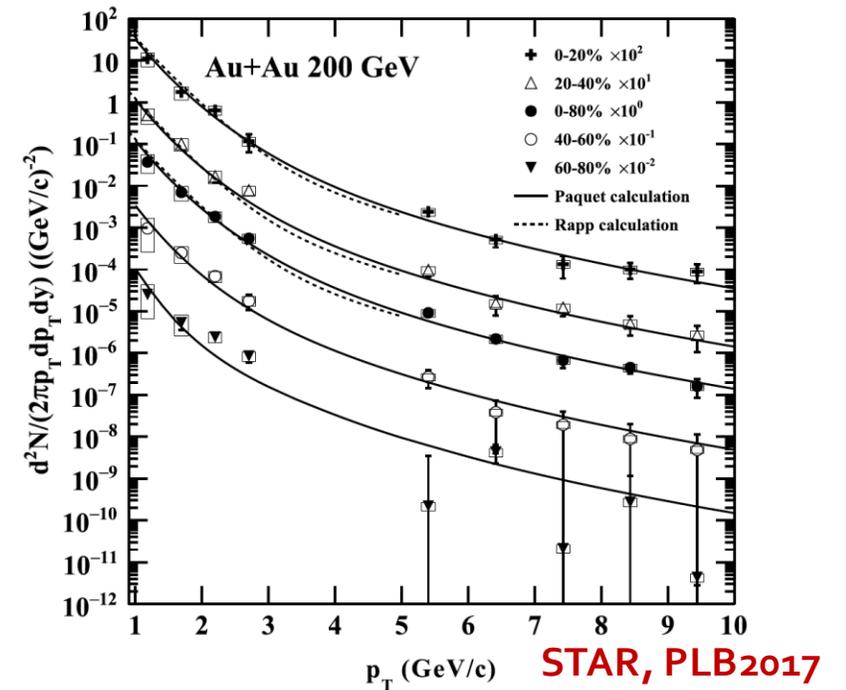
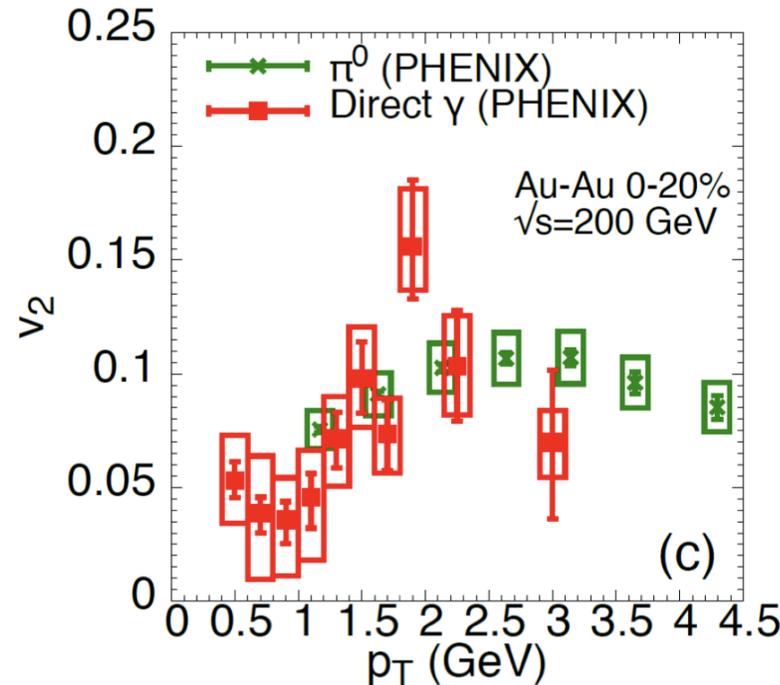
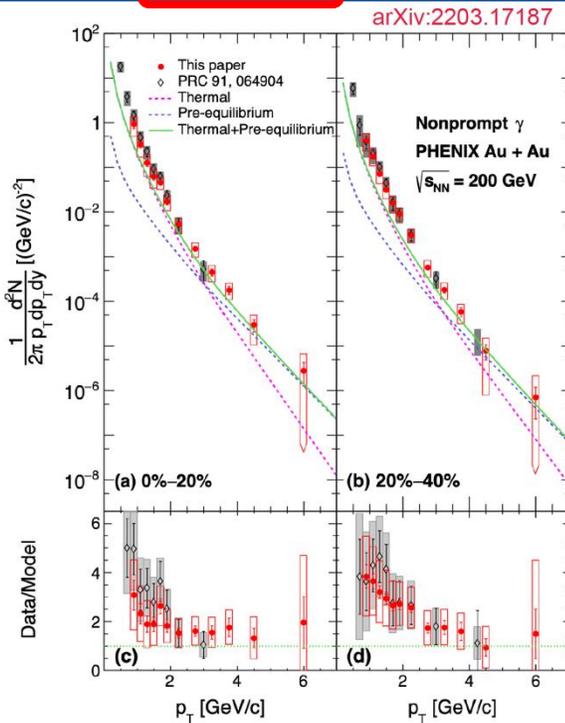


ExtreMe Matter Institute EMMI

EMMI Rapid Reaction Task Force

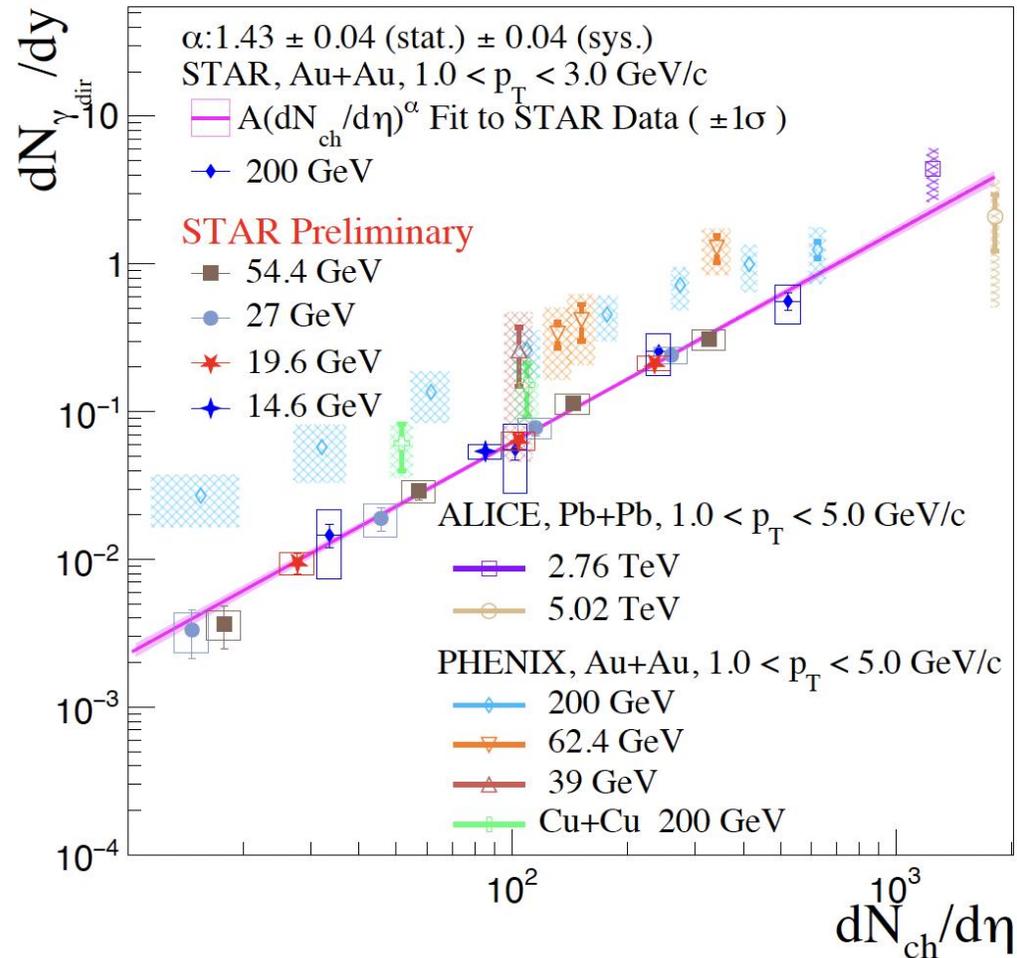
Direct-Photon Puzzle

Heidelberg University, Germany July 24 – 27, 2023



Direct photon yields at RHIC

包贤文 (山大)



- $dN_{ch}/d\eta$ scaling over centralities and energies (200 GeV to 14.6 GeV)
- Indicating **similar emission source and properties**
- Can be linked to the search of CEP?

Scaling power

STAR: ~ 1.4

PHENIX: ~ 1.1

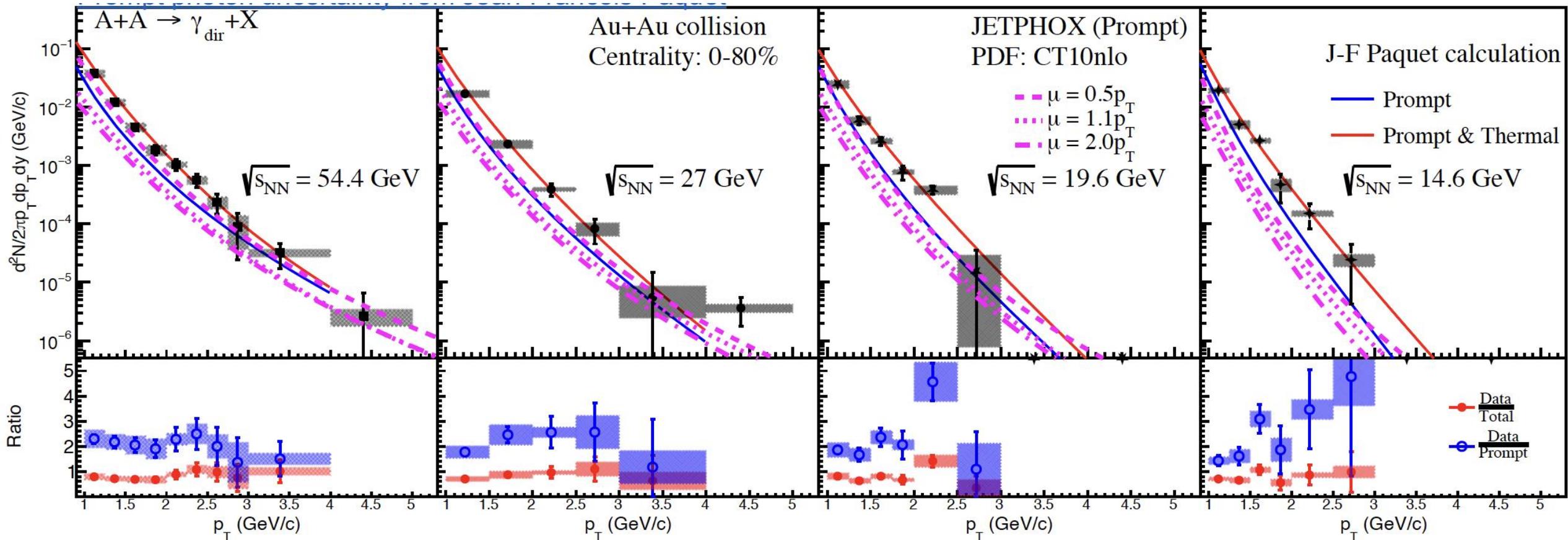
(QGP: ~ 1.8 Hadronic medium: ~ 1.2)

“A puzzle in a puzzle”

- Tension observed between STAR and PHENIX from QM14
- Need to solve/confirm this tension firstly
- Can we measure direct photon v_2 at STAR?

Direct photons in Beam Energy Scan Phase II

Yield: well described by theoretical calculation, similar to that at A+A 200GeV at STAR



About Direct Photon Puzzle

Yield

- Seems more and more clear with new measured STAR and ALICE results (arXiv: 2411.14366)

v_n

- Still need more measurements especially for π^0 and v_2 from STAR (isobar, Run 23 and 25)

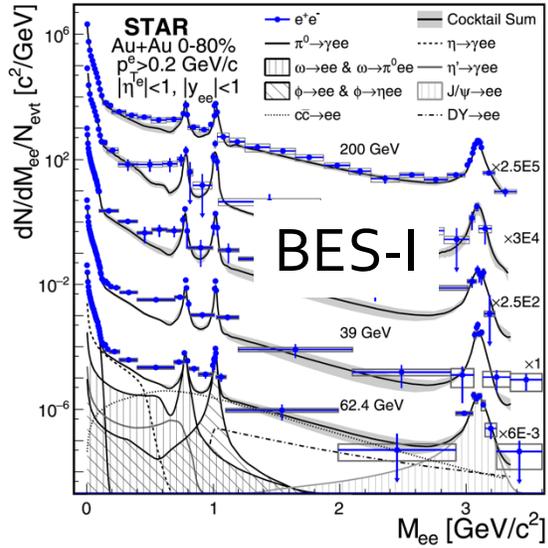
Theoretical calculations should simultaneously describe direct photons and dileptons.

“Magnetic field effect on photons in Heavy Ion Collisions”

王昕杨 周六16:10 分会场二

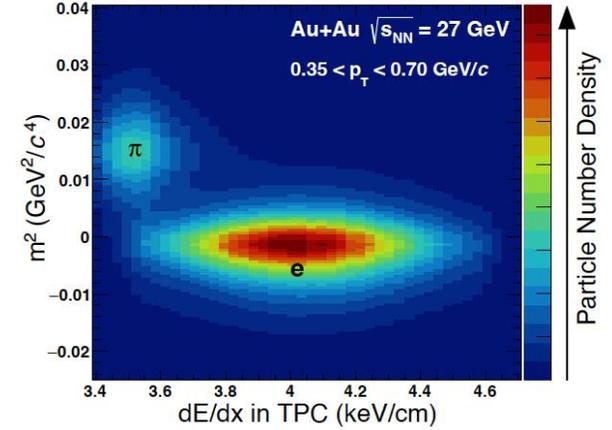
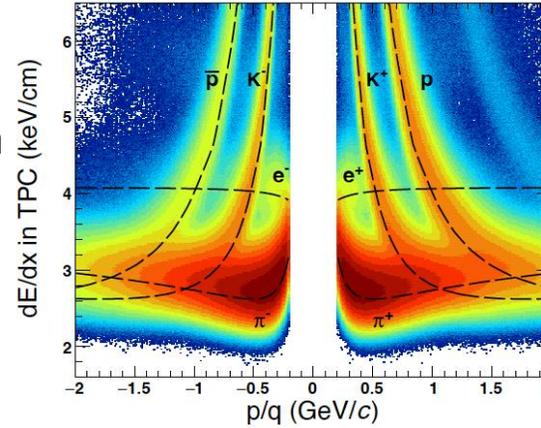
Dileptons in Beam Energy Scan and Isobar

STAR, PRC 2023



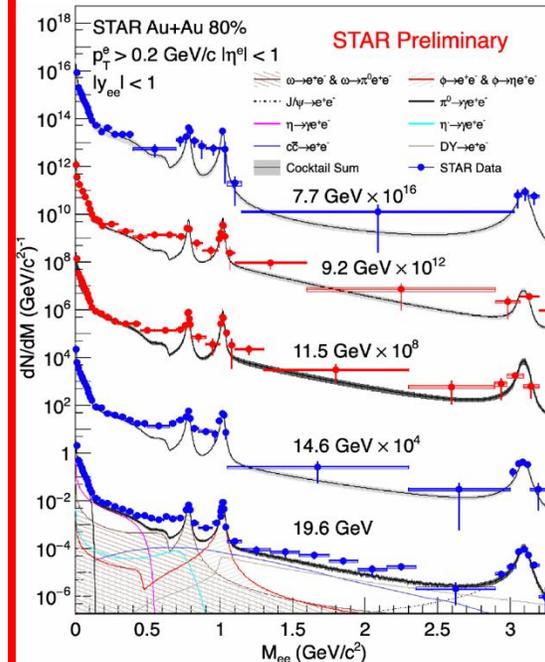
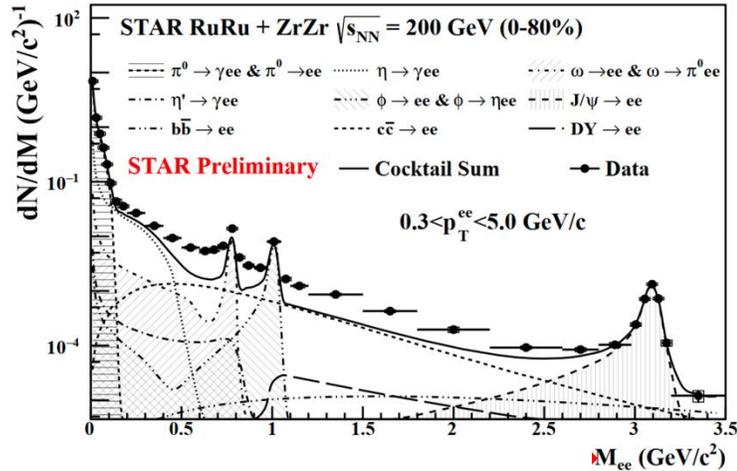
Technique challenges:

- Lepton and photon identification
- Low S/B ratio
- Pollution from hadron
- Need large statistics



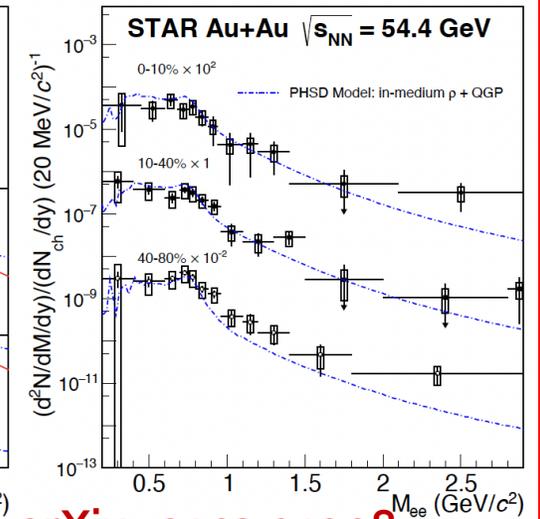
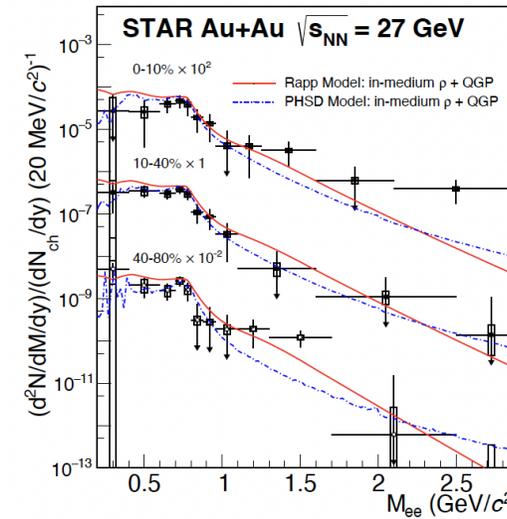
Isobar

罗加宣 (科大)



BES-II

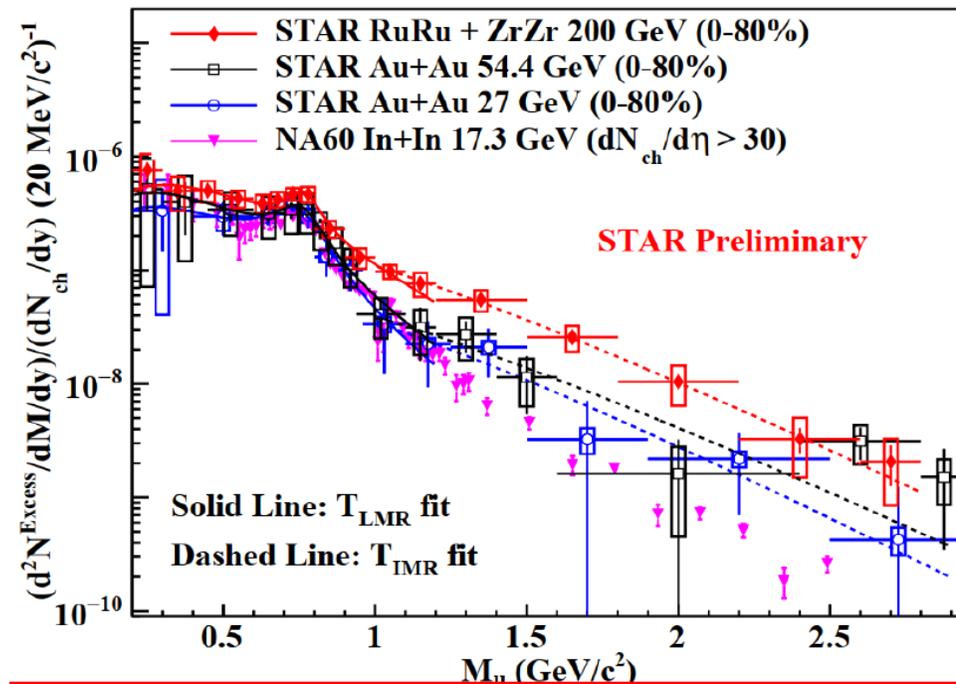
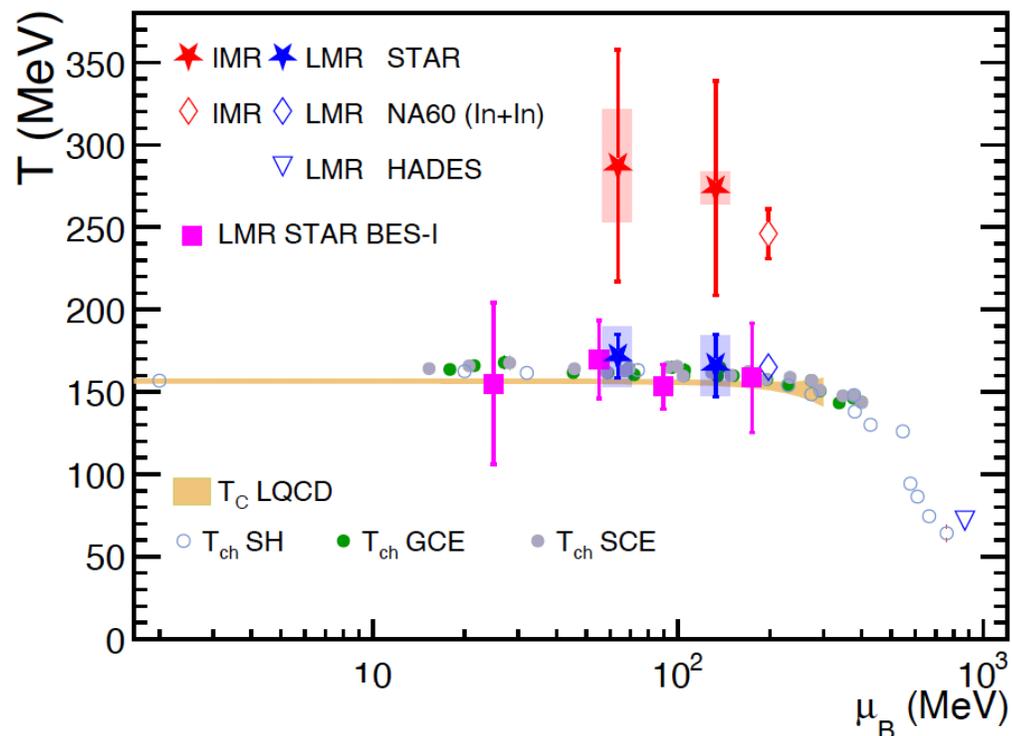
王桢 (山大)、叶早晨 (华南师大)



arXiv: 2403.01998

Temperature in different stages

arXiv: 2403.01998

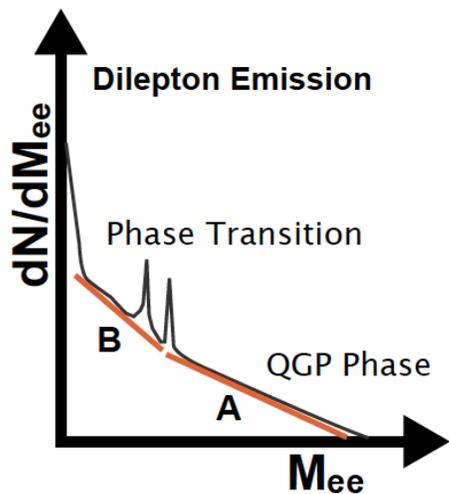


$$T_{\text{LMR}}^{\text{Isobar 200 GeV}} = 199 \pm 6 \text{ (stat.)} \pm 13 \text{ (sys.) MeV}$$

$$T_{\text{IMR}}^{\text{Isobar 200 GeV}} = 293 \pm 11 \text{ (stat.)} \pm 27 \text{ (sys.) MeV}$$

Improved precision in isobar

- **A (IMR):** above T_{pc} , emitted from partonic phase
- **B (LMR):** close or above T_{pc} ?



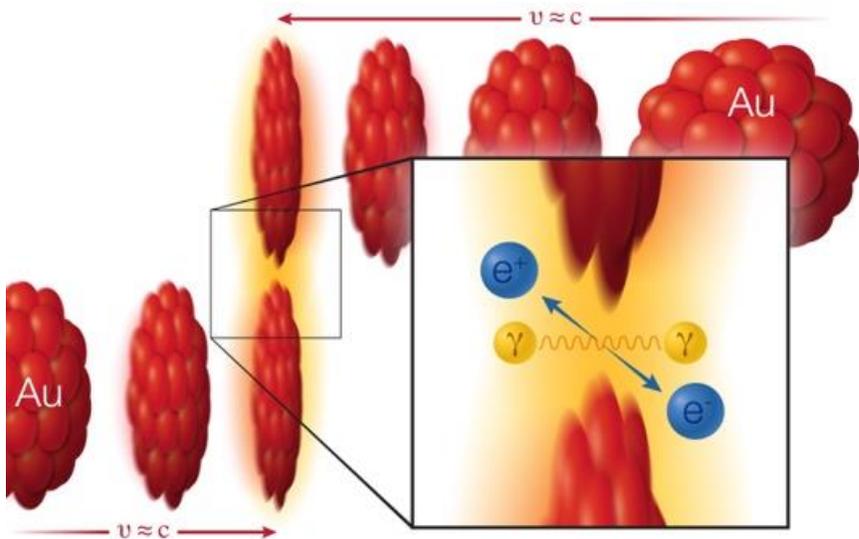
Non-equilibrium contribution needs to be considered

Link to this parallel session

分会场三
(原主会场后部)
核子结构

Global polarization study guide us to study our previous observables in spin and polarization dimensions

梁作堂、王新年 PRL2005, PLB2005



Linearly polarized photon in UPC

- Photon-photon collision
- Photon-gluon collision



Will only discuss the part related to nuclear/nucleon structure

Wangmei's UPC overview talk at Sunday
Xin's talk on 11:55 in this session
Kaifeng's poster 152

Linearly polarized photon-photon collision

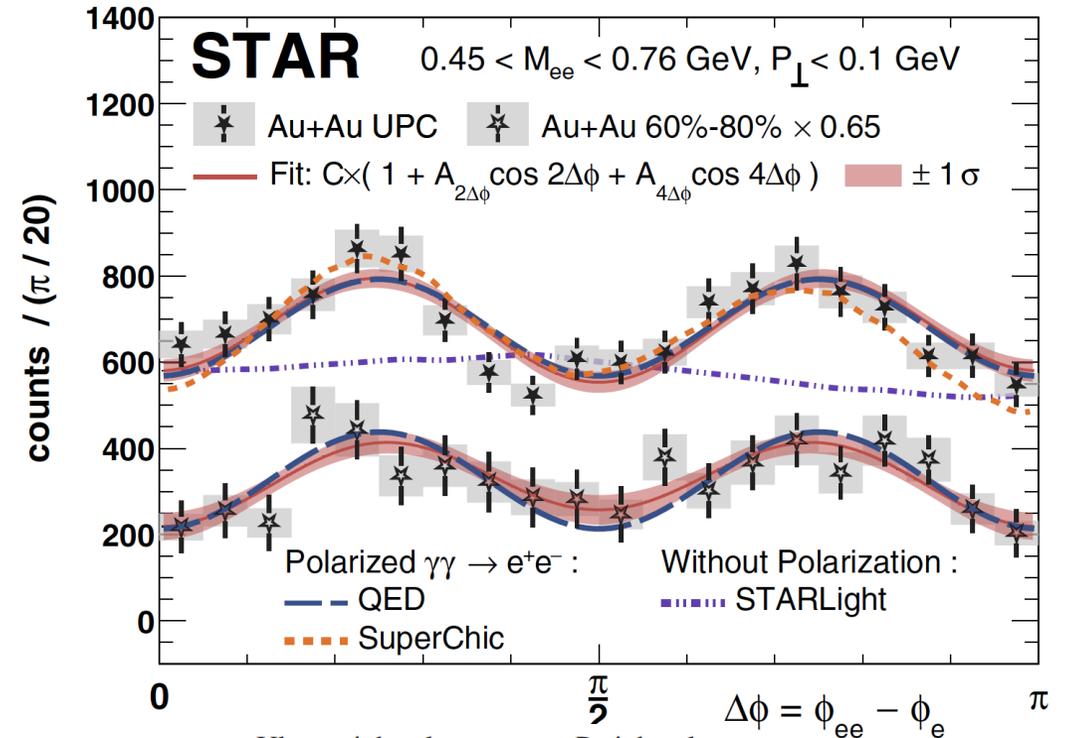
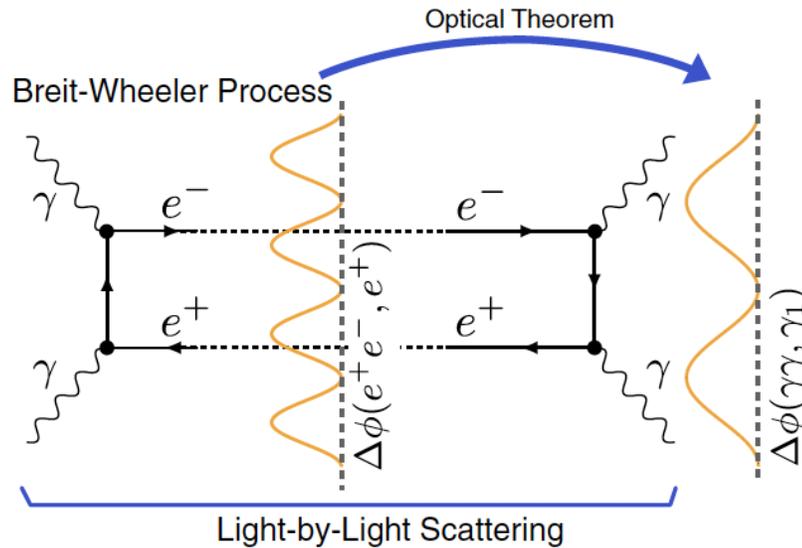
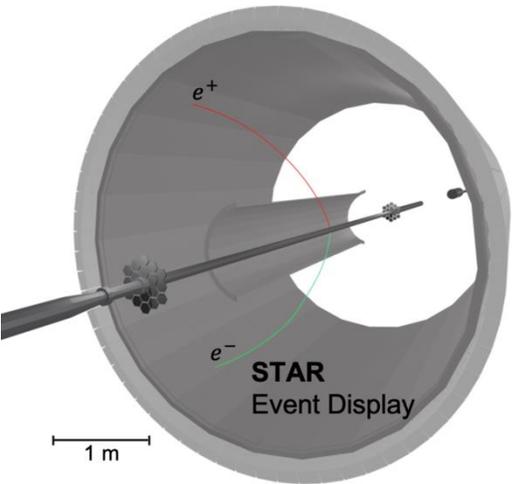
<https://www.bnl.gov/newsroom/news.php?a=119023>

Breit-Wheeler Process at RHIC-STAR

- Observe 6085 exclusive e^+e^- pairs from data collected in 2010 at STAR
- No vector meson contribution visible
- Energy spectrum
- Photon transverse polarization & spatial distribution

杨驰 (山大)、杨帅 (华南师大)、查王妹 (科大)

STAR, PRL2021



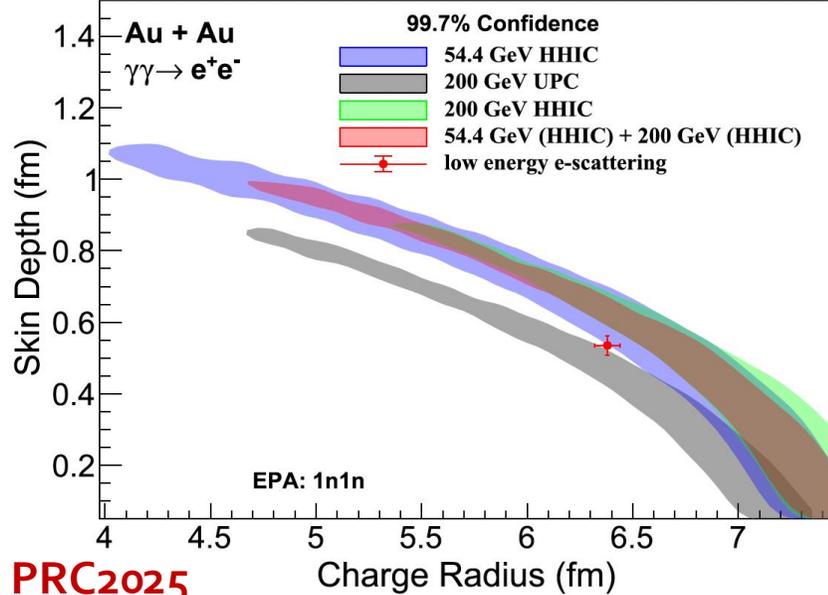
$\cos(4\Delta\phi)$ angular modulation in final state: confirmed by STAR

李聪, 周剑, 周雅瑾等 PLB2019

	Ultraperipheral				Peripheral	
	Measured	QED	SC	SL	Measured	QED
$ A_{4\Delta\phi} $ (%)	16.8 ± 2.5	16.5	19	0	27 ± 6	34.5
$ A_{2\Delta\phi} $ (%)	2.0 ± 2.4	0	5	5	6 ± 6	0
$\sqrt{\langle P_{\perp}^2 \rangle}$ (MeV)	38.1 ± 0.9	37.6	35.4	35.9	50.9 ± 2.5	48.5

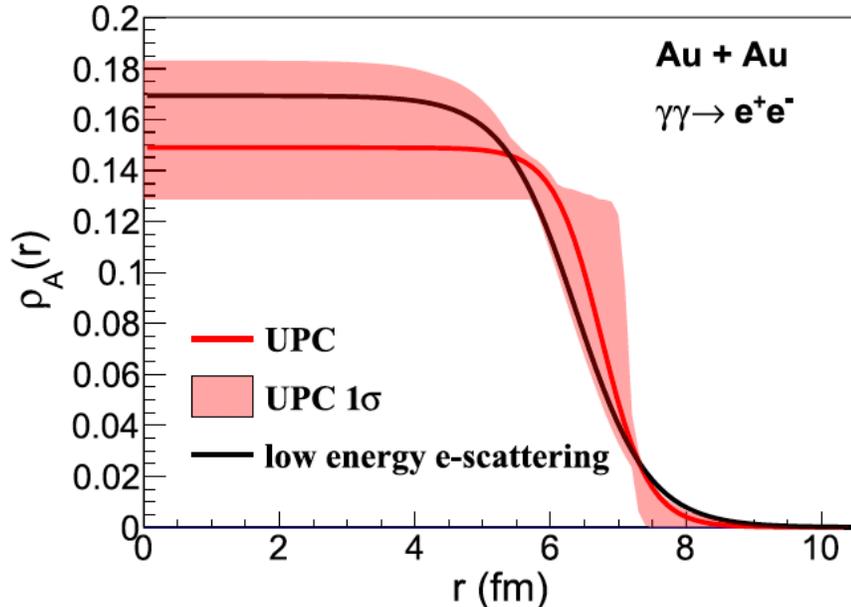
Constrain charge radius

王晓凤 (山大)



- Compare QED with precise experimental measurement (assume Wood-Saxon form)
- Difference between UPC and HHIC

$$\rho_A(r) = \frac{\rho_0}{1 + \exp[(r - R)/d]}$$

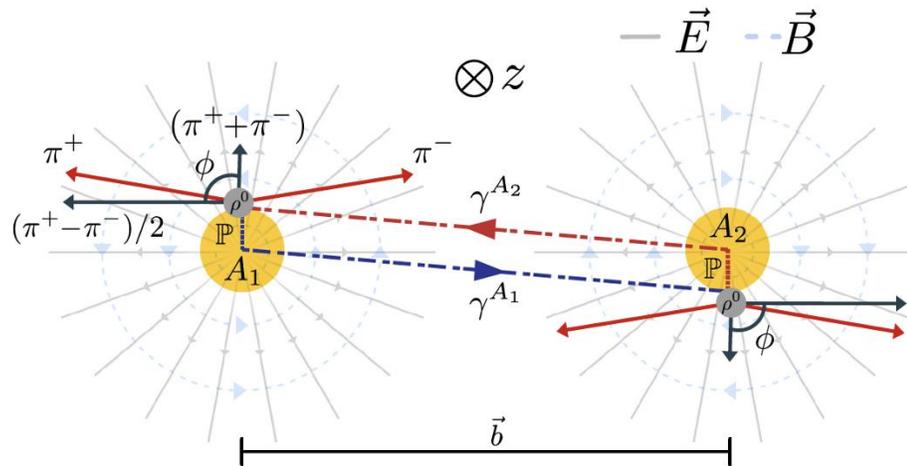


- Potential final-state effect in HHICs can modify the results of the charge radius extraction and favors an apparent large radius
- Constrain in UPC: consistent with low energy e-scattering results within 1 sigma

RHIC Run23-25 for future

Linearly polarized photon-gluon collision

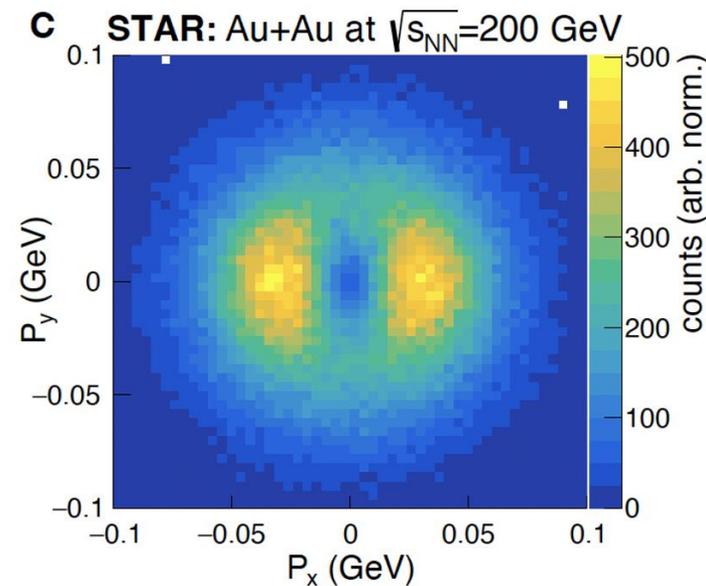
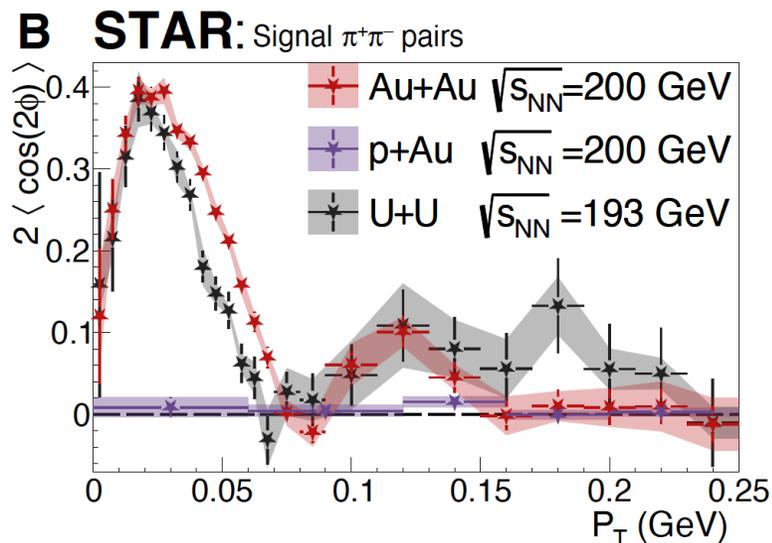
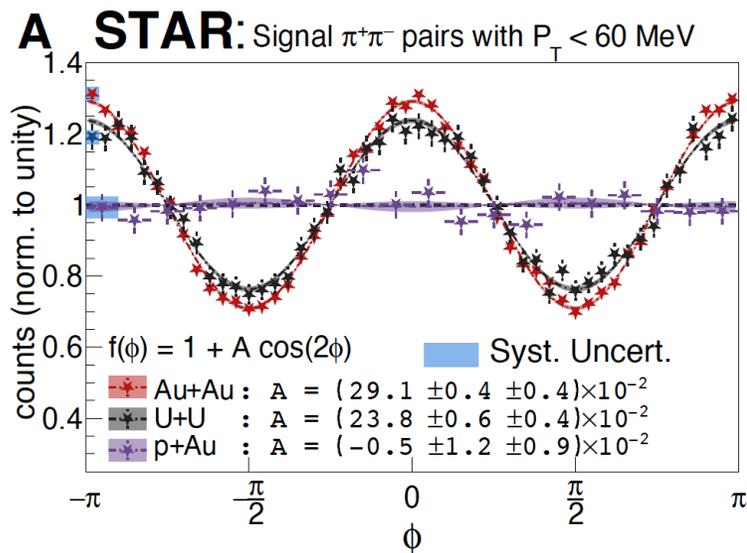
杨驰 (山大)、查王妹 (科大)



$\cos(2\Delta\phi)$ angular modulation in final state

邢宏喜, 周剑, 周雅瑾等 JHEP 2020

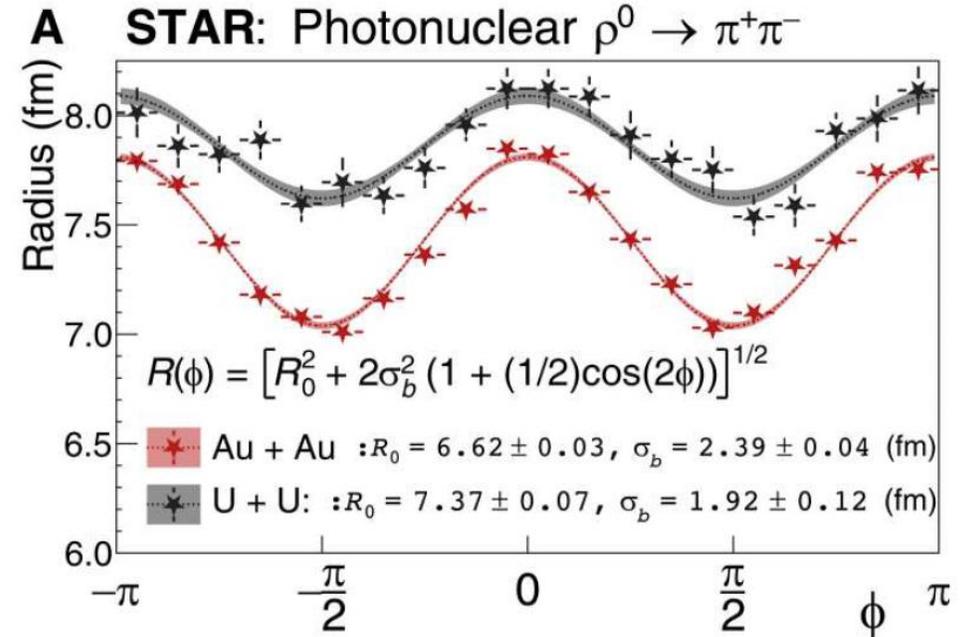
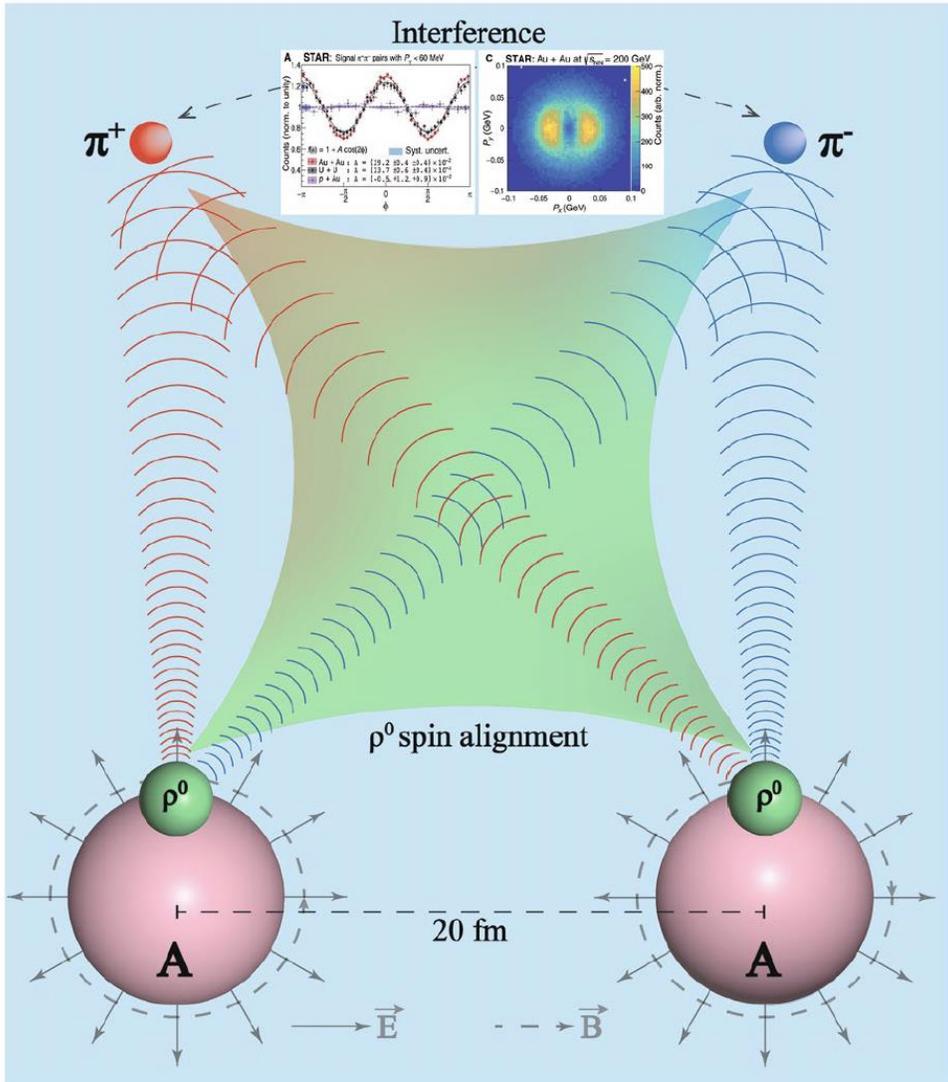
STAR, Science Advances 2023



- The pattern changes according to the nuclear radius
- Precious enough to study the nuclear structure

Double slit experiment at Fermi scale

STAR, Science Advances 2023



- Cancel the impact from interference in radius extraction
- **Solve a mystery last over 20 years**
- Can be used to study neutron skin

	^{197}Au	^{238}U
STAR R (fm)	$6.53 \pm 0.03 \pm 0.05$	$7.29 \pm 0.06 \pm 0.05$
STAR $\langle \cos 2\phi \rangle$ (%)	29.2 ± 0.4 (statistical) ± 0.4 (systematic)	23.7 ± 0.6 (statistical) ± 0.4 (systematic)

马余刚 NST2023 News&Views

查王妹等 PRC2019

Summary

Over the last decade, there are plenty of physics measurements on EM probes at RHIC

Hot QCD in HHIC

Temperature, VM in-medium modification, potential magnetic effect

Cold QCD and QED in UPC

Fundamental QED process, QED vacuum, EM field, nuclear/nucleon structure

Current and future opportunities at RHIC

- STAR detector is now at the peak of performances in resolution, acceptance, DAQ rate...
- RHIC top energy run at Run23 to Run25, large data samples for statistics hunger analysis such as EM probes
- Current BES-II, isobar and FXT data provide various chances to study EM probes
- Polarization of EM probes