第一届HIAF高能终端谱仪合作组会议

Dilepton production at high baryon density

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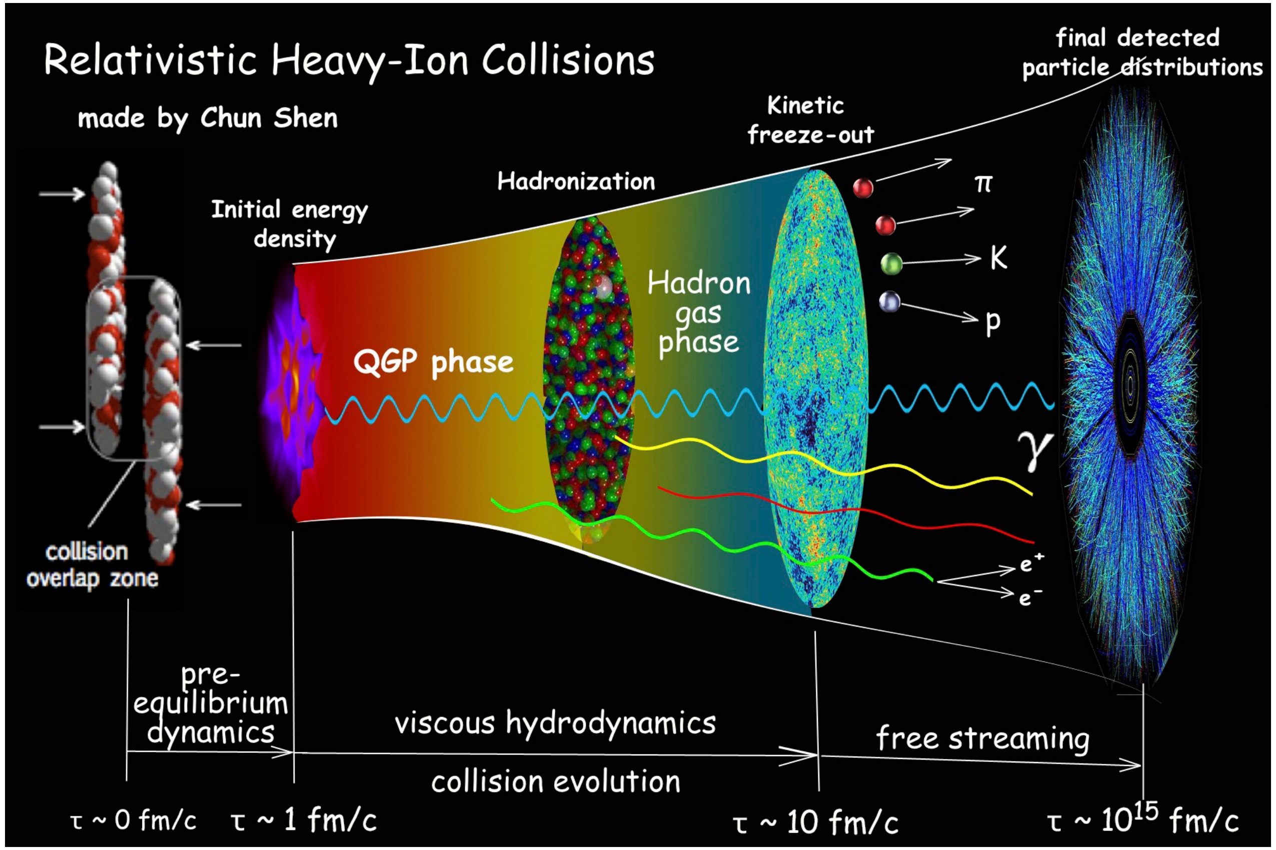
Huizhou, November 17, 2024

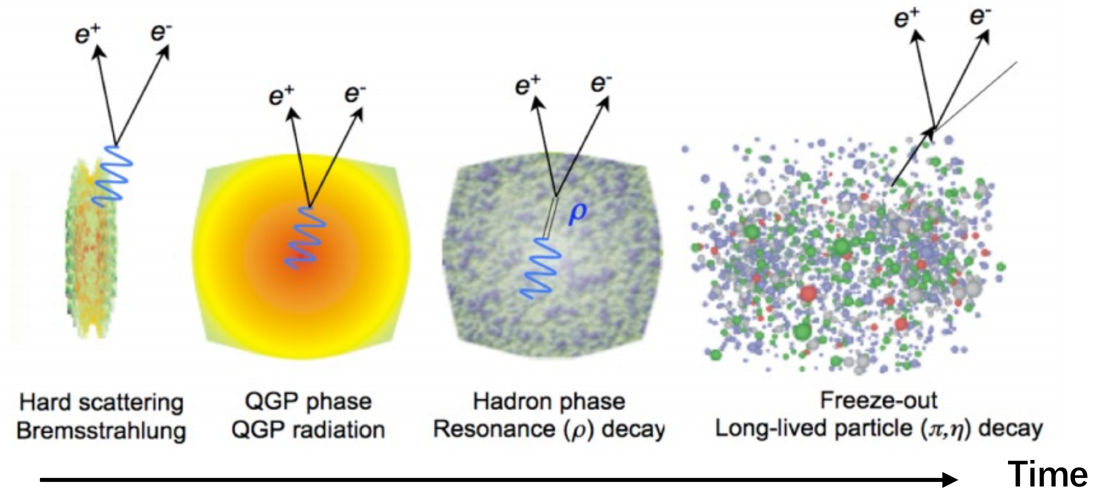
Outline

- Introduction
- Dilepton measurements at high baryon density
- Summary
- Discussion at HIAF energy

Introduction: penetrating probe in HIC



C. Shen



Electromagnetic probes =>

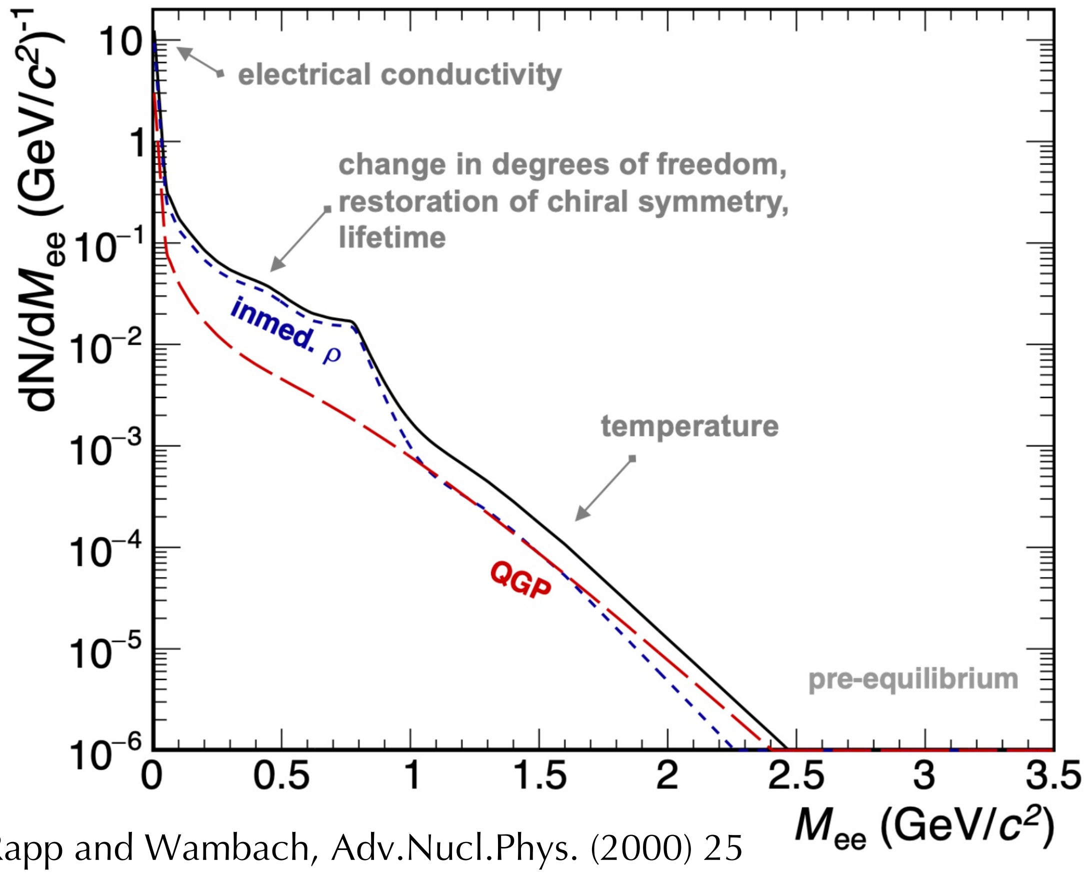
Do not participate in strong interactions.

Bring undistorted information as where produced.

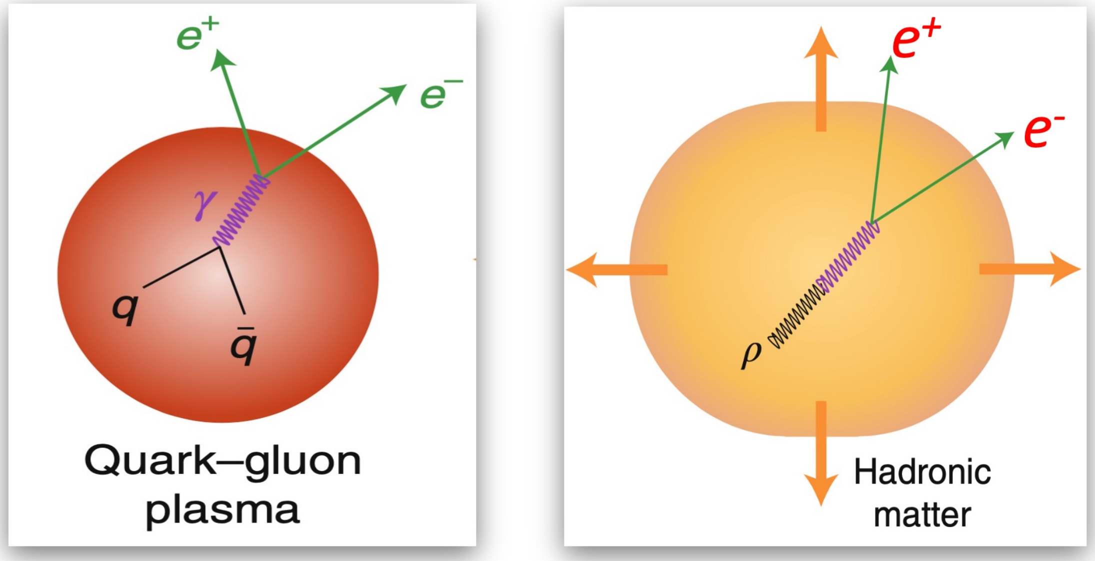
Penetrate medium properties.

Challenge: Time-space integrated from all stages. Continuum at IMR.

Introduction: in-medium dileptons



Rapp and Wambach, Adv.Nucl.Phys. (2000) 25



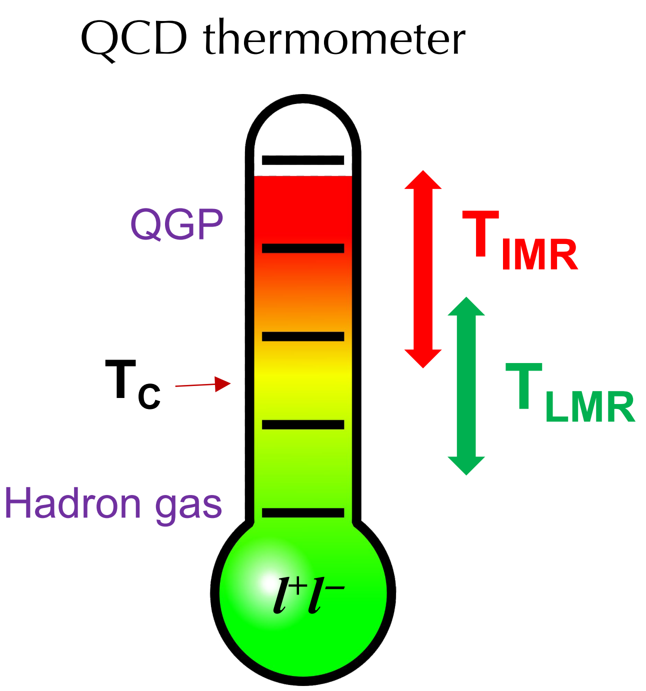
$q + \bar{q} \longrightarrow \gamma^* \longrightarrow e^+ + e^-$ $\quad \pi^+ + \pi^- \longrightarrow \rho \longrightarrow e^+ + e^-$

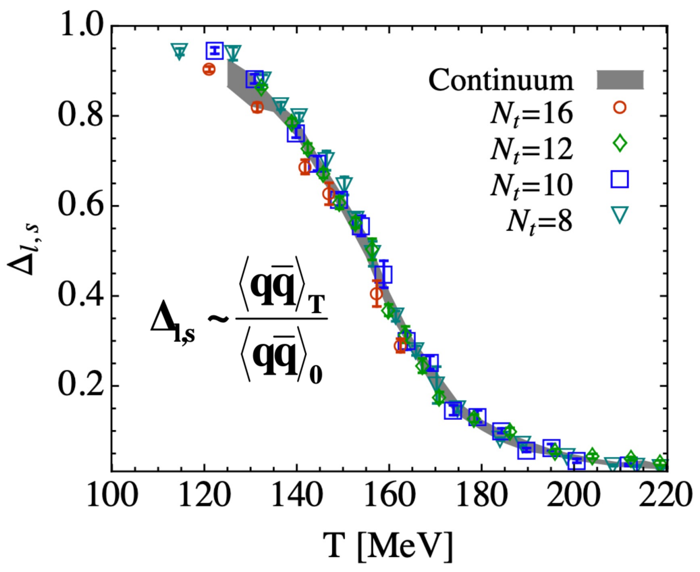
Courtesy of Ralf Rapp

Rapp and v. Hess, PLB 753 (2016) 586;
Shuryak and Brown, NPA 717, 322 (2003); STAR, PRL 92, 092301 (2004)

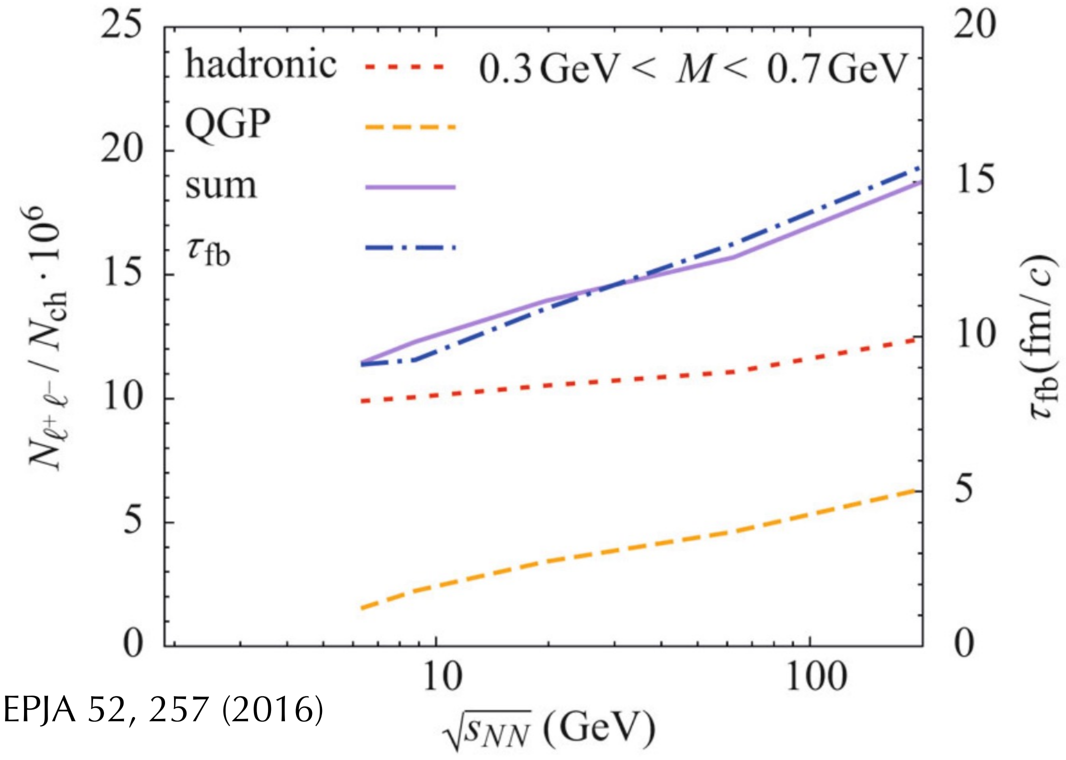
- **IMR**: Fireball properties like temperature, lifetime, pressure anisotropy.
- **LMR**: ρ modification, chiral symmetry restoration, baryon catalyst, deconfinement or chiral transition
- **VLMR**: Electrical conductivity, transport property as fundamental as η/s

Introduction: in-medium dileptons





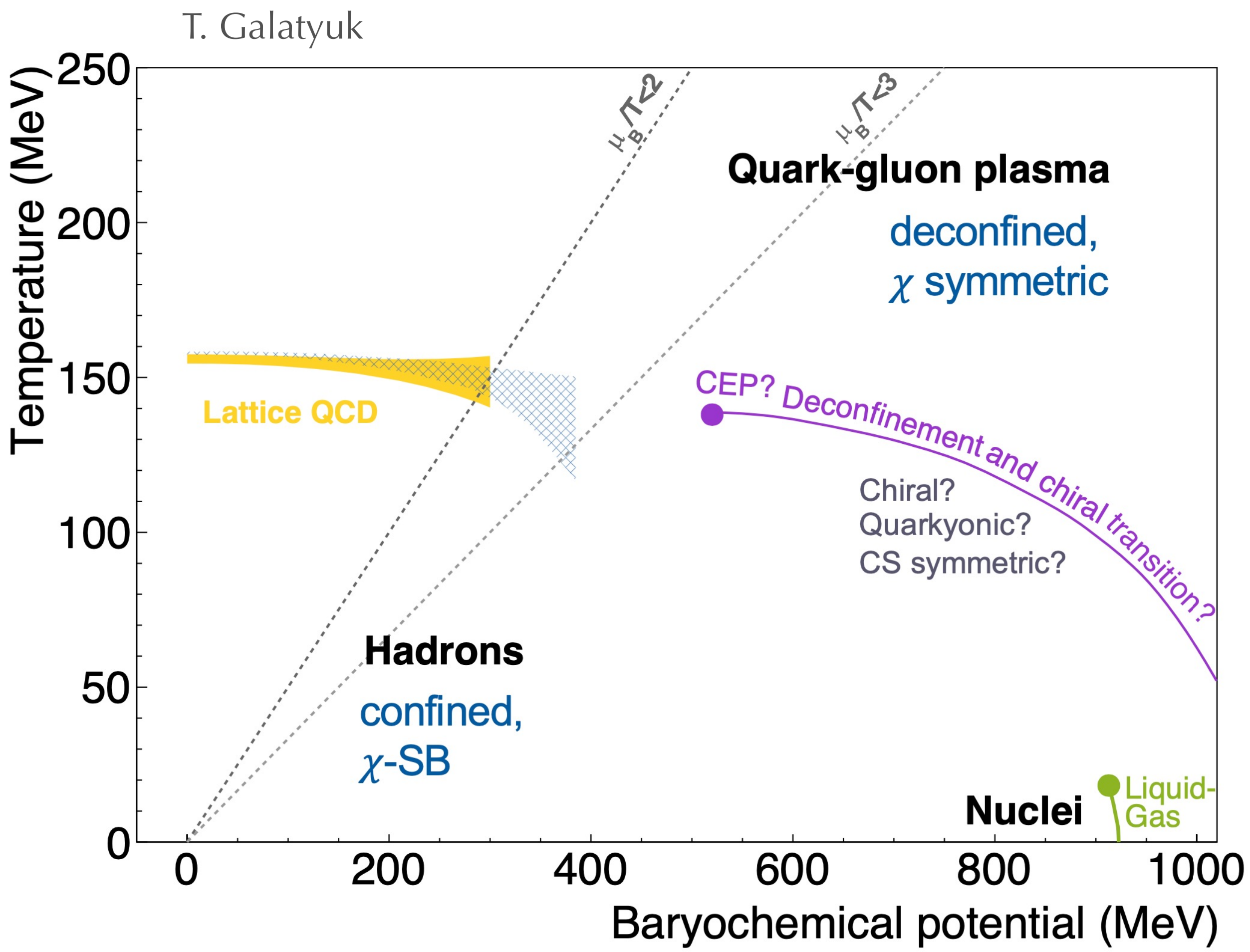
LQCD: JHEP 09 (2010) 073



R. Rapp, EPJA 52, 257 (2016)

- Thermometer: **Medium diagnostics**, extract temperature from mass spectra
- Chronometer: **Emission archaeology**, predict lifetime from integrated yield

Introduction: searching for QCD phase diagram



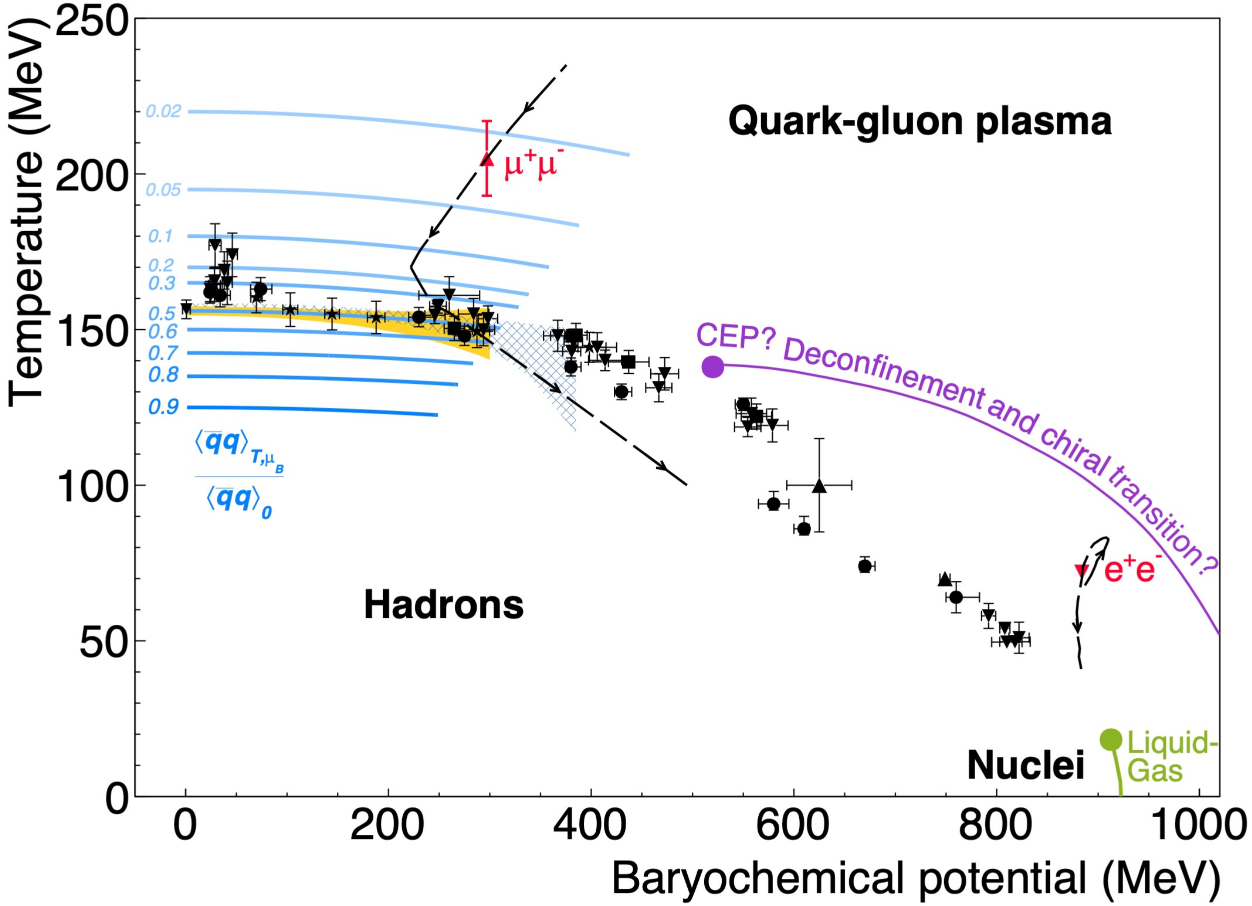
Gao, Pawlowski, PLB 820 (2021) 136584
Cuteri, Philipsen, Sciarra, JHEP 11 (2021) 141
McLerran, Pisarski, NPA 796 (2007) 83
Glozman, Philipsen, Pisarski, EPJA 58 (2022) 12, 247

Key features of phase structure:

- QGP and hadronic phase
- Crossover at small μ_B $(\frac{\mu_B}{T} < 2)$ – compatible to all experimental observations.
- Transition temperature (T_C~156 MeV) – Lattice QCD and verified by exp. chemical freeze-out.
- 1st order phase transition at large μ_B and **critical end point (CEP)** are conjectured.

Introduction: searching for QCD phase diagram

T. Galatyuk



HADES, Nature Phys. 15 (2019) 10, 1040-1045
NA60, Specht *et al.*, AIP Conf.Proc. (2010) 1322
Andronic *et al.*, Nature 561 (2018) no.7723

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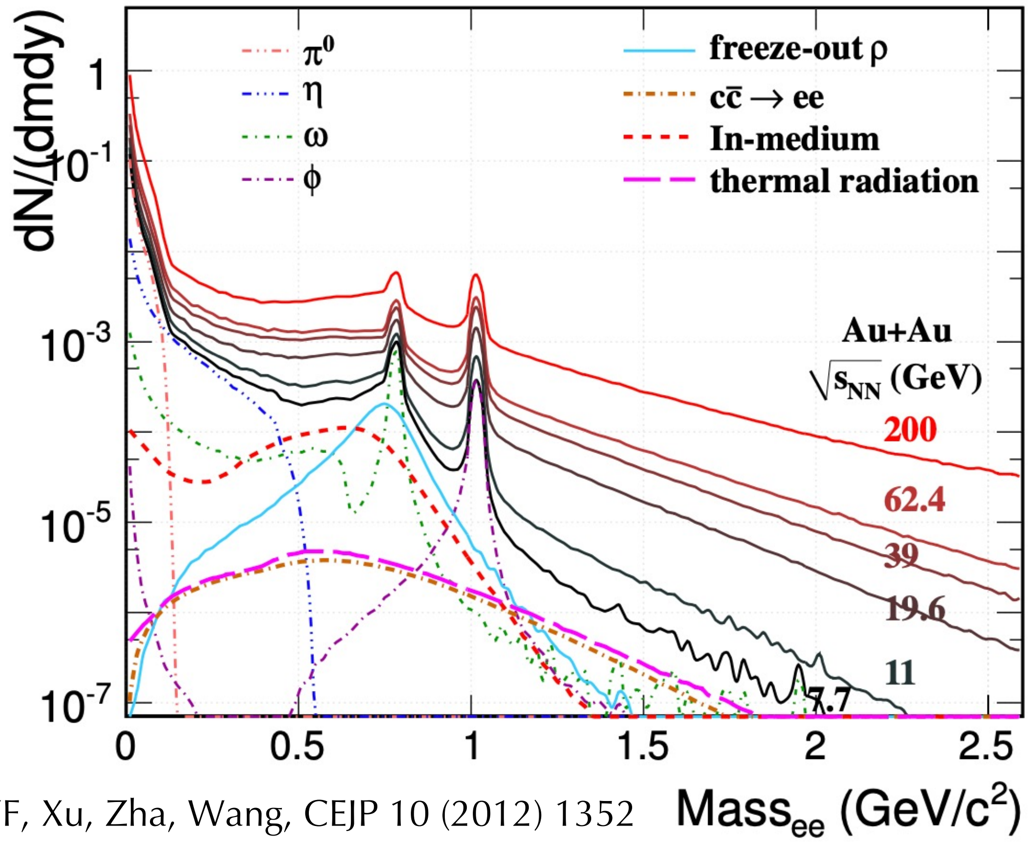
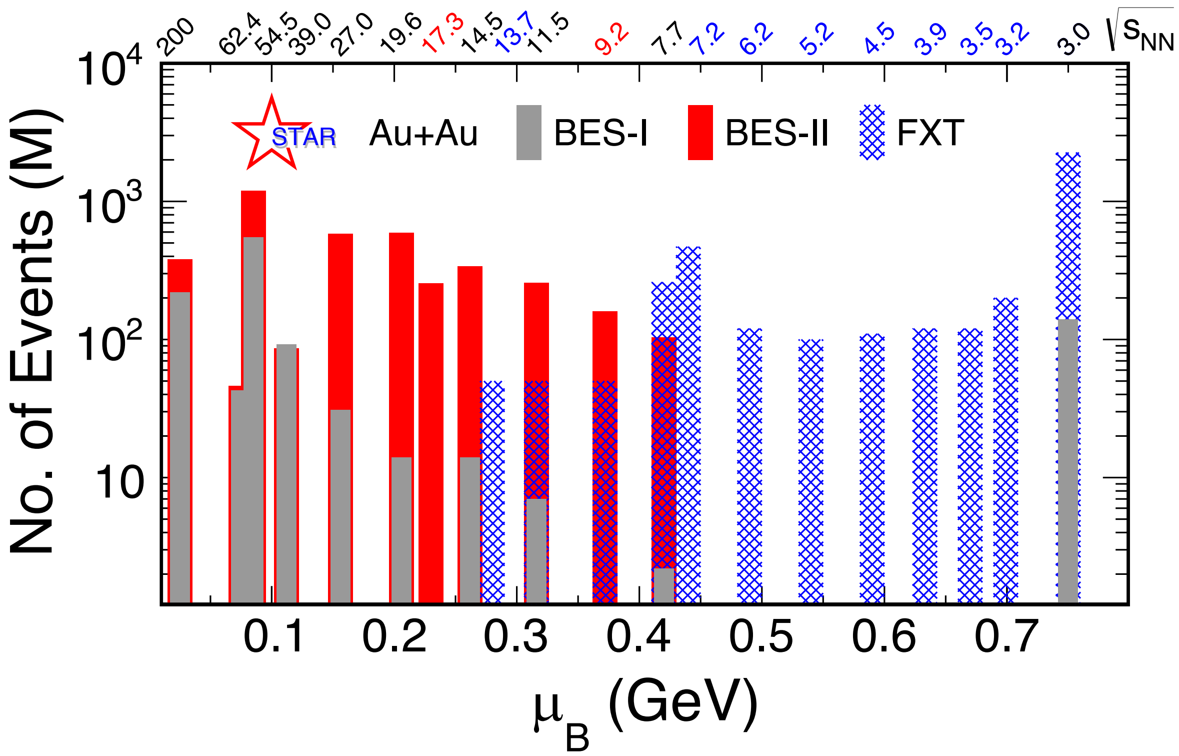
- Transition temperature (T_C~156 MeV) – Lattice QCD and verified by exp. chemical freeze-out.
- 1st order phase transition at large μ_B and **critical end point (CEP)** are conjectured.
- Dilepton sensitive to medium property, μ_B dependence, especially high baryon density region.

Nuclear matter phase tomography

RHIC BES-II program

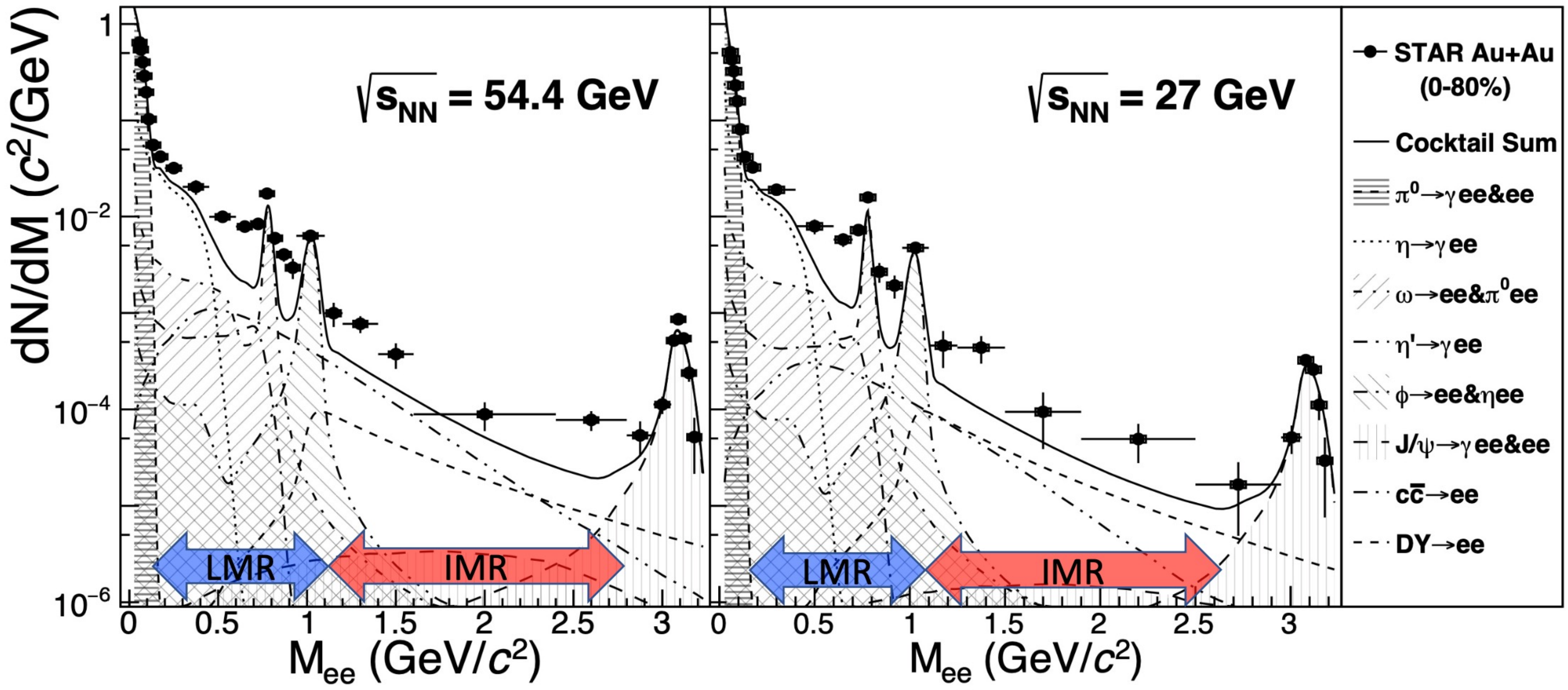


ZYF, Xu, Zha, Wang, CEJP 10 (2012) 1352



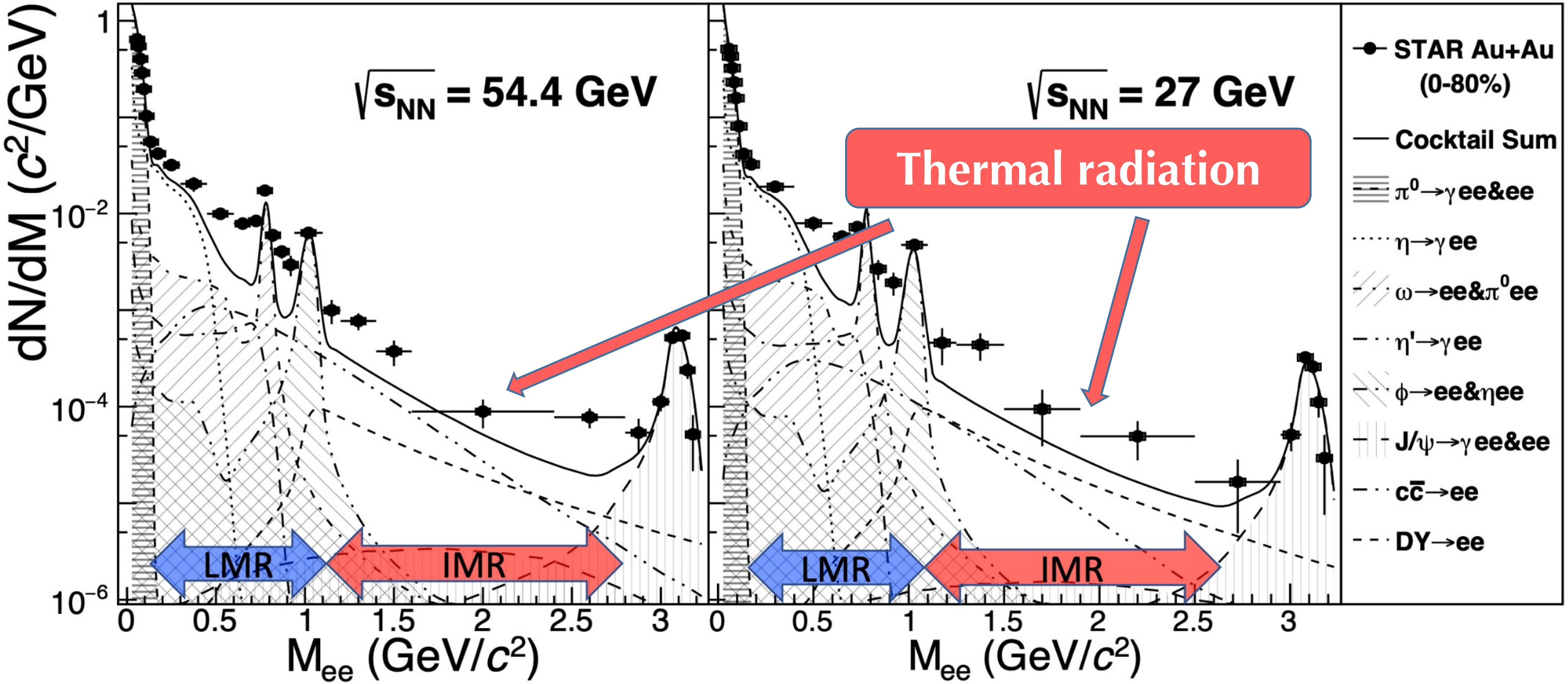
- Medium emissivity (excess yield and temperature) strongly dependents on collision energy.
- Large statistics and iTPC upgrade provide a great opportunity to study dilepton production.

Dilepton mass spectra



- **Clear enhancement** compared to cocktail contributions in both low mass region (**LMR**) and intermediate mass region (**IMR**)

Dilepton mass spectra



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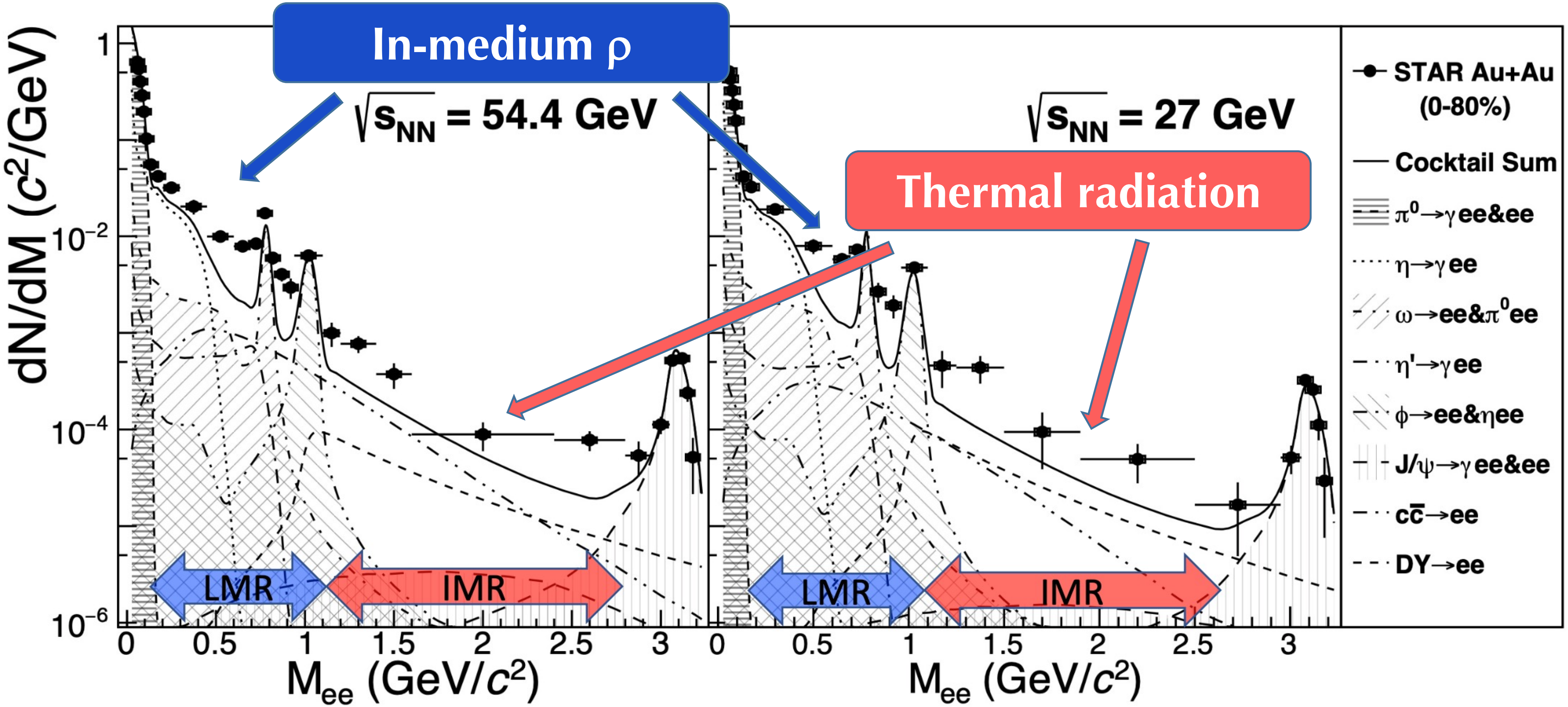

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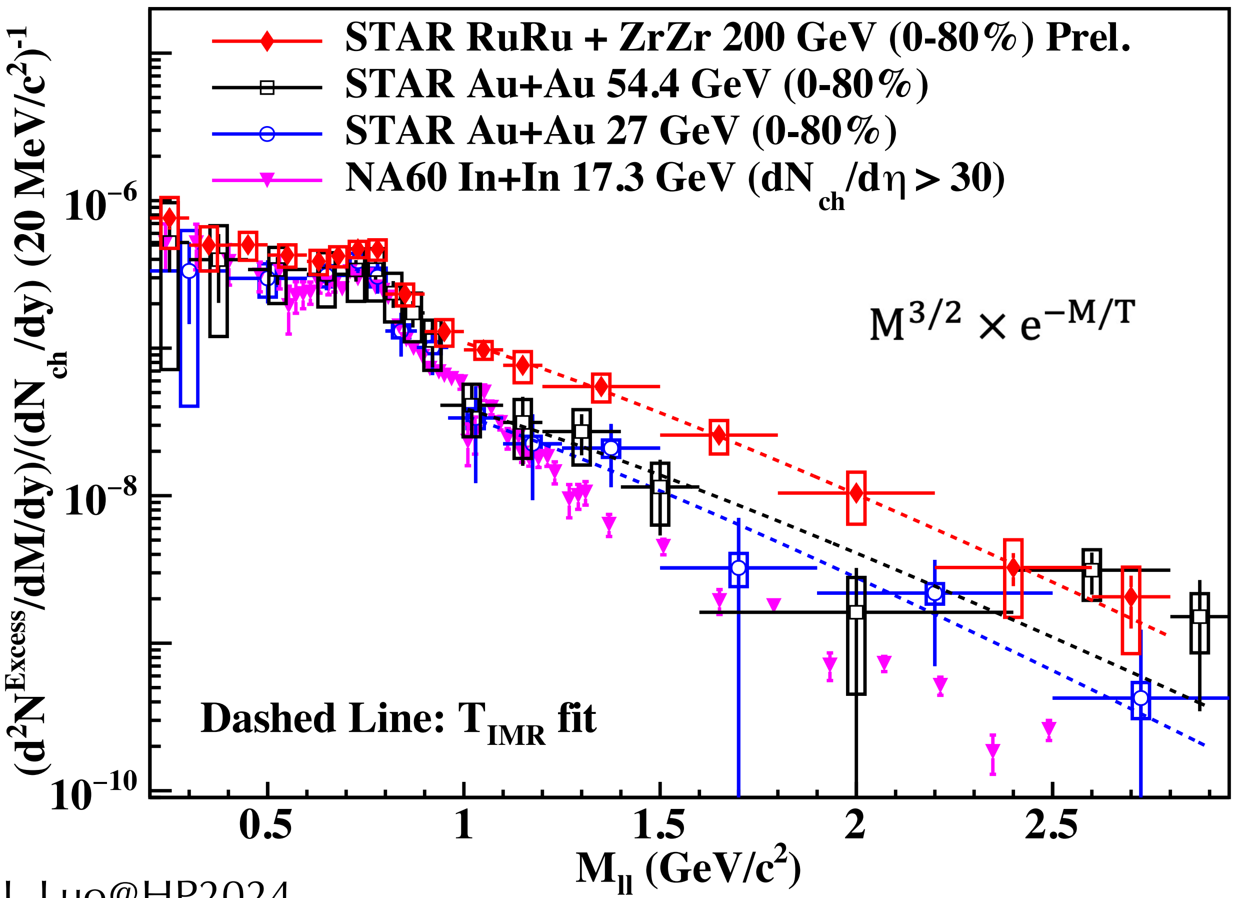
Dilepton IMR from high to low energy



J. Luo@HP2024

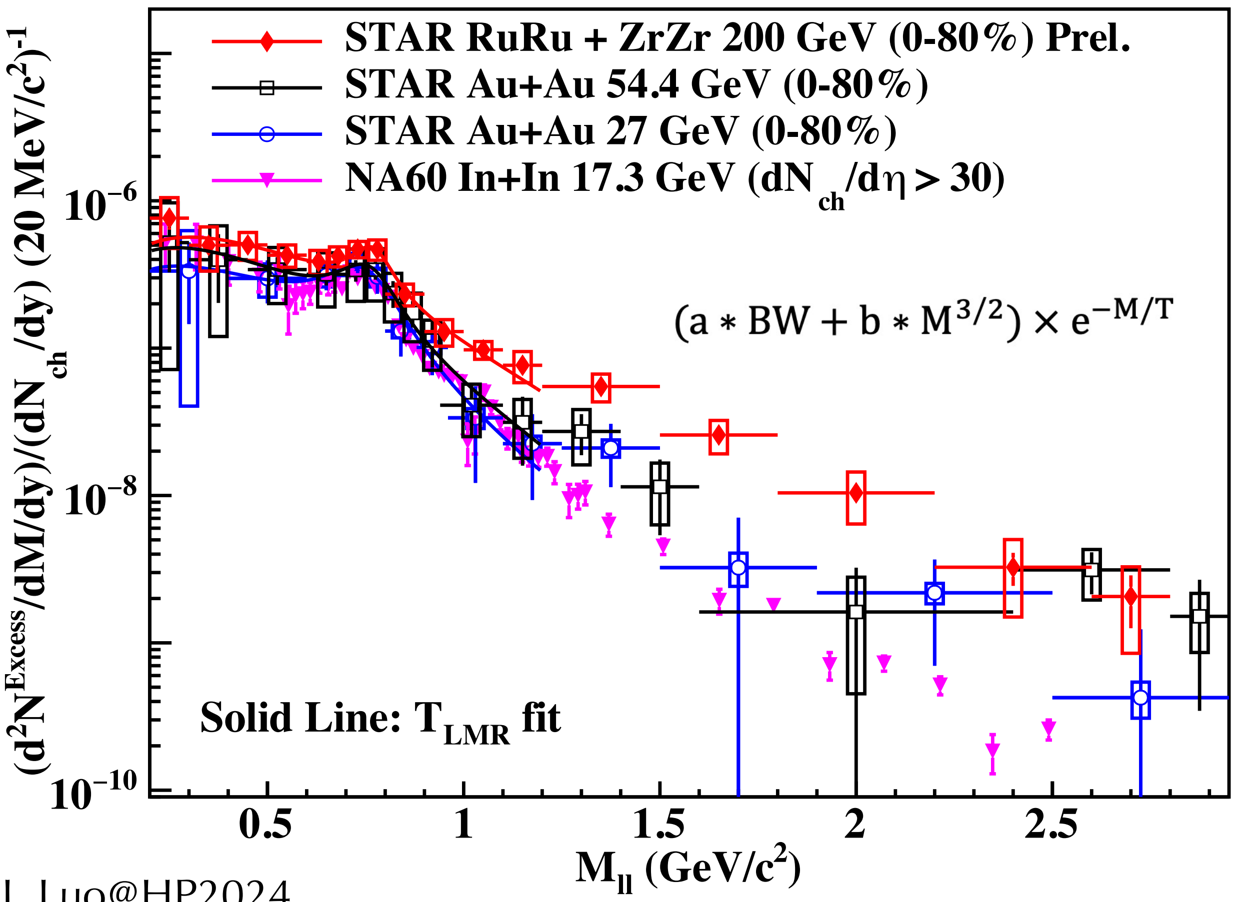
NA60: EPJC 59 (2009) 607
STAR 27 & 54.4 GeV: arXiv: 2402.01998

Intermediate Mass Region:

- Excess yield at 200 GeV **higher** than lower energy
- **T is similar** within uncertainties **despite** significant **differences** in collision **energy** and system **size**
- T_{IMR} is higher than T_{LMR}, ~ 2.9 σ at 200 GeV

T_{IMR}^{200GeV} = 293 ± 11 (stat.) ± 27 (sys.) MeV
$T_{IMR}^{54.4GeV}$ = 303 ± 59 (stat.) ± 28 (sys.) MeV
T_{IMR}^{27GeV} = 280 ± 64 (stat.) ± 10 (sys.) MeV
$T_{IMR}^{17.3GeV}$ = 245 ± 17 MeV

Dilepton LMR from high to low energy



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Low Mass Region:

- Excess yield (normalized by the charged particle multiplicity) increases with collision energy
- 27 & 54.4 GeV: **in-medium ρ dominant**
- 200 GeV: hint of **higher QGP contribution**

T_{LMR}^{200GeV} = 199 ± 6 (stat.) ± 13 (sys.) MeV
$T_{LMR}^{54.4GeV}$ = 172 ± 12 (stat.) ± 18 (sys.) MeV
T_{LMR}^{27GeV} = 167 ± 21 (stat.) ± 18 (sys.) MeV
$T_{LMR}^{17.3GeV}$ = 165 ± 4 MeV

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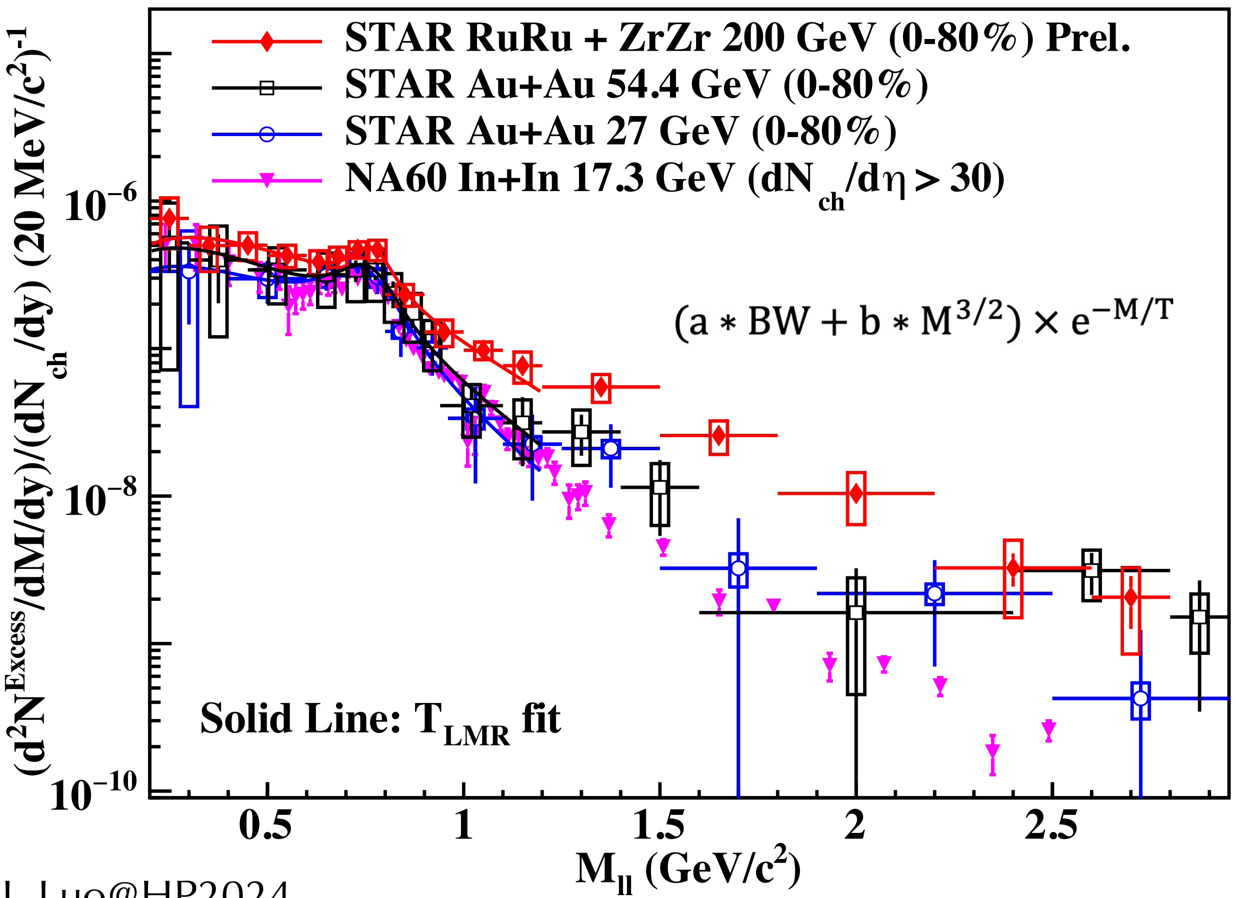
Dilepton LMR from high to low energy



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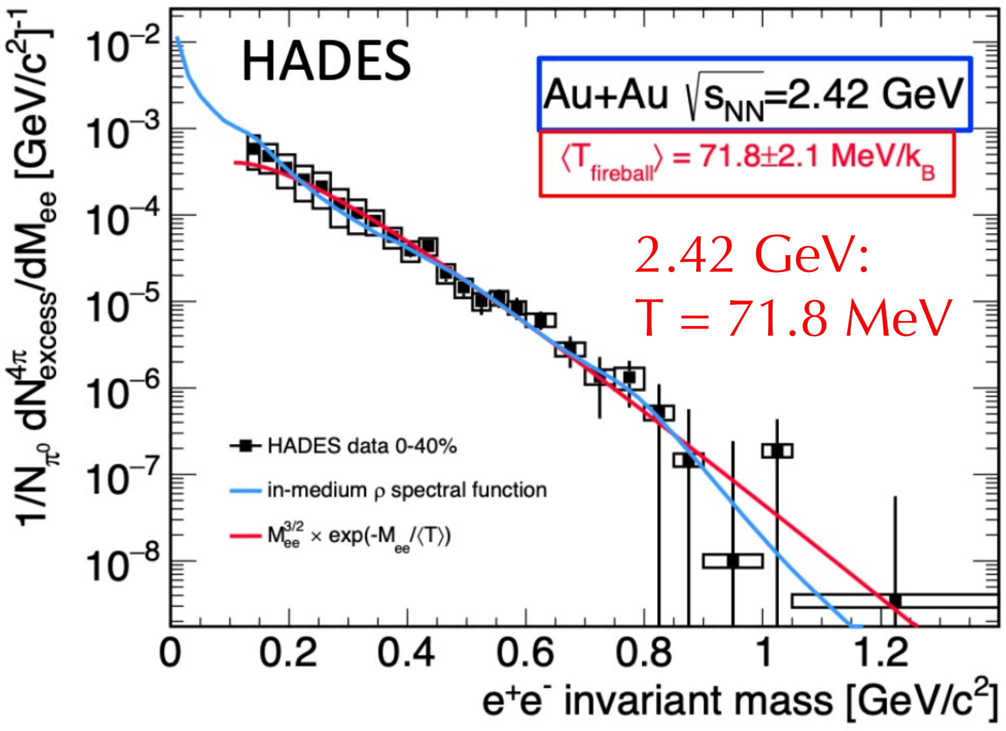
HADES: Nature Physics 15, 1040-1045 (2019)



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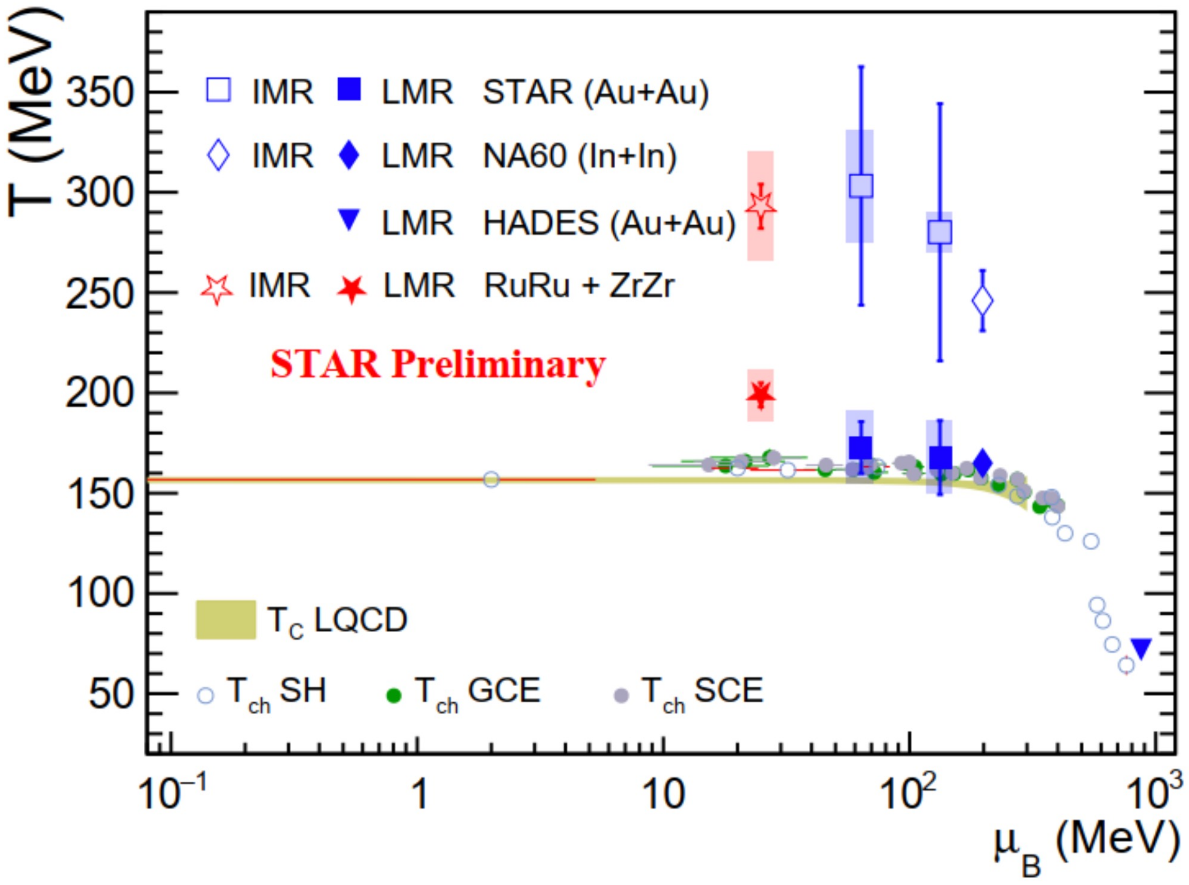
Thermometer: temperature vs. μ_B



NA60: EPJC 59, 607–623 (2009)
HADES: Nat. Phys. 15, 1040-1045 (2019)
HotQCD: Phys. Lett. B 795, 15-21 (2019)
T_{ch} SH: P. Braun-Munzinger et al. Nat. 561, 321-330 (2018)
T_{ch} GCE/SCE: STAR Phys. Rev. C 96, 044904 (2017)

Thermal dielectrons in LMR:

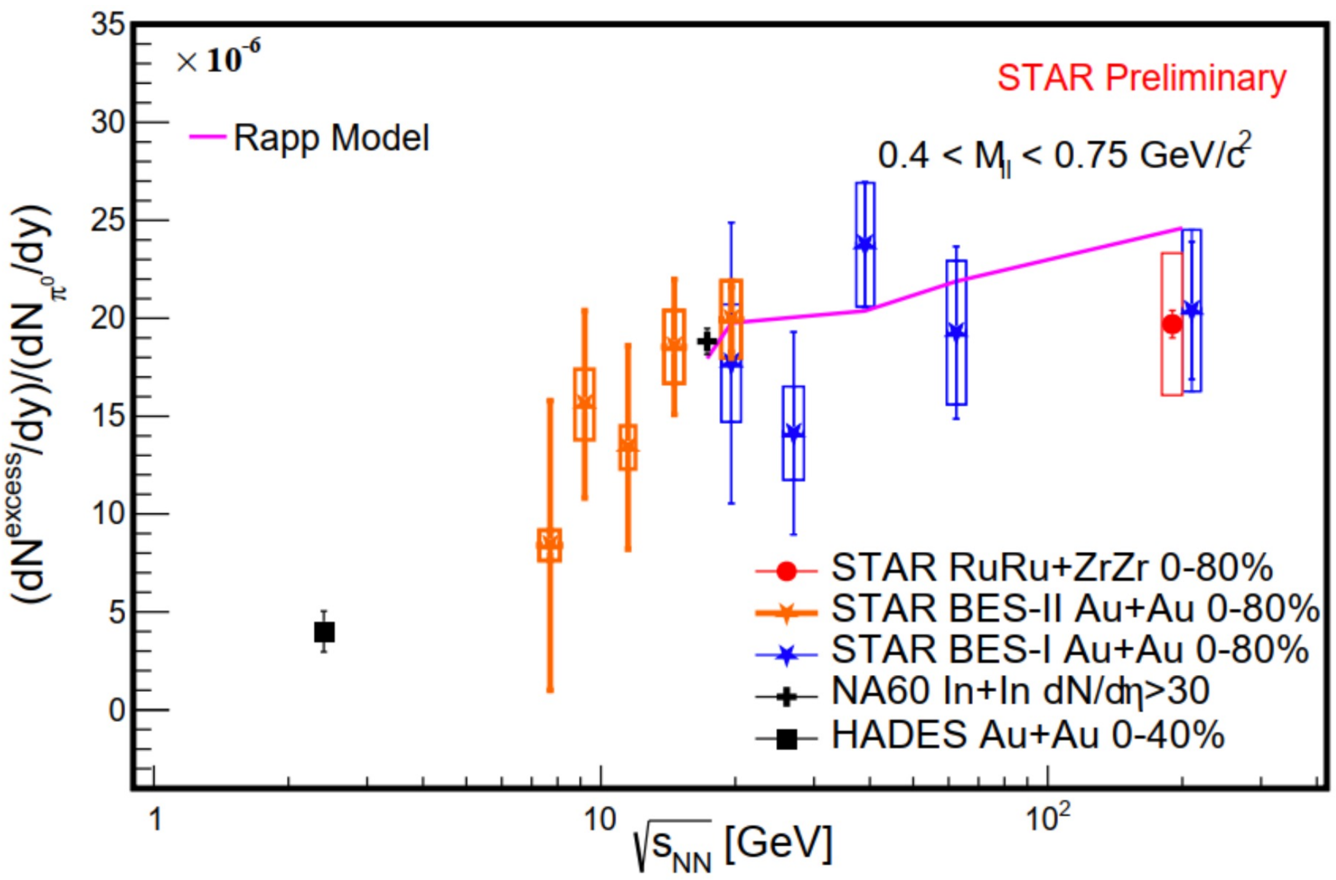
- T_{LMR} at 27 & 54.4 GeV is close to the T_{pc} and T_{ch}
  - ✓ Emitted form the hadronic phase
  - ✓ Dominantly around the **phase transition**
- T_{LMR} at 200 GeV is higher than the T_{pc} and T_{ch}
  - ✓ Hint of **higher QGP contribution**

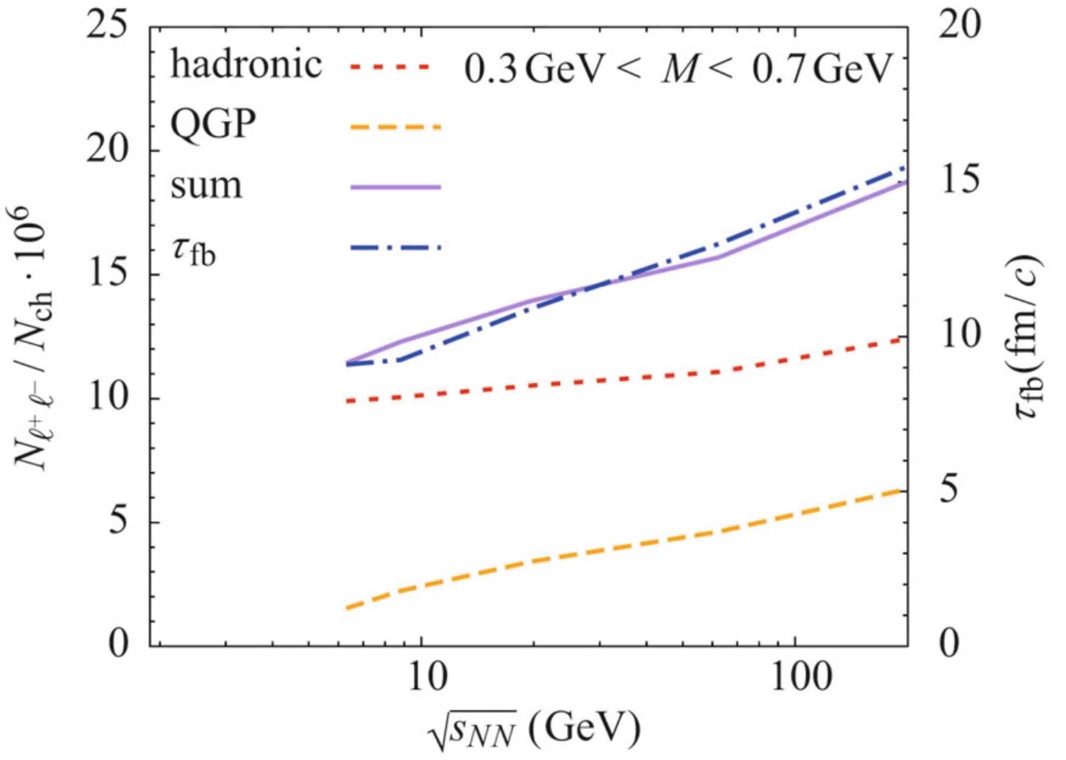
Thermal dielectrons in IMR:

- T_{IMR} is higher than T_{LMR}, T_{pc} and T_{ch}
  Emitted from the partonic phase

T_{ch}: Chemical freeze-out temperature
T_{pc}: Pseudo critical temperature

Chronometer: excess yield vs. collision energy





R. Rapp, EPJA 52, 257 (2016)

NA60: EPJC 59 (2009) 607
STAR 27 & 54.4 GeV: arXiv: 2402.01998

- Higher energy longer lifetime more excess yield
- Consistent with model calculation including QGP radiation and in-medium ρ modification

Summary

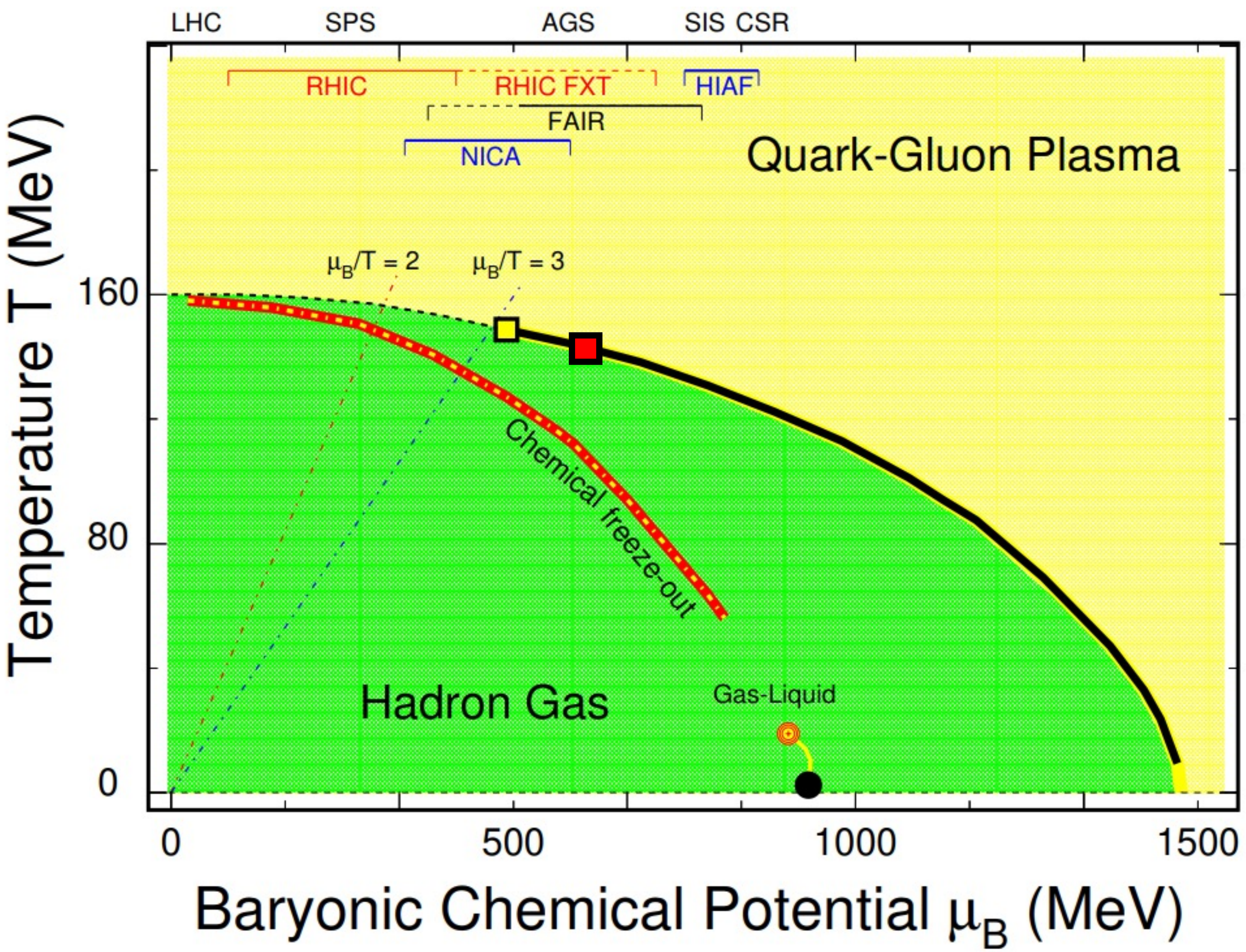
- Dilepton is ideal **penetrating probe** for QCD medium evolution and sensitive to its properties.
- In-medium ρ is significantly broaden. Excess yields play **chronometer** role for medium lifetime.
- Medium diagnostics with dilepton as **thermometer**:
  - T_{LMR} ~70-80 MeV at SIS18
  - $T_{LMR} \sim T_{ch} \sim T_{pc}$ at RHIC and SPS, hadronic phase dominant
  - $T_{IMR} \sim$ 250-300 MeV $> T_{pc}$ at RHIC and SPS: QGP phase dominant
- Current experiment with large uncertainties, data are still missing at lower energy region

  => **The matter is far from over!**

Discussion

What can we do at HIAF energy?

Experiments at high baryon density



RHIC BES-II program:

C.M.S energy: 3.0 – 27 GeV

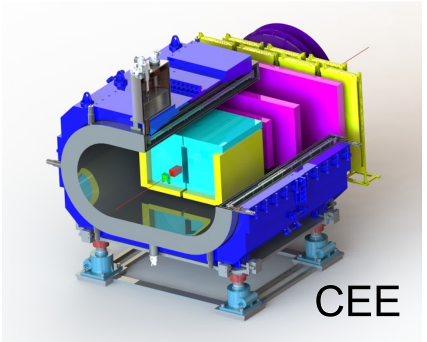
μ_B coverage up to 750 MeV

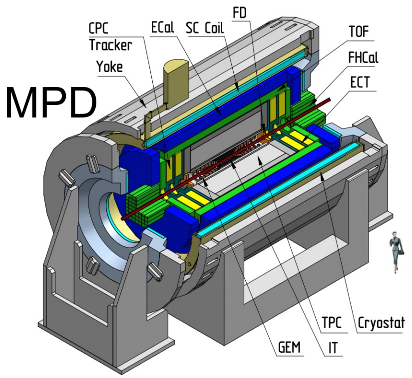
SPS/NA60+ 6-17 GeV

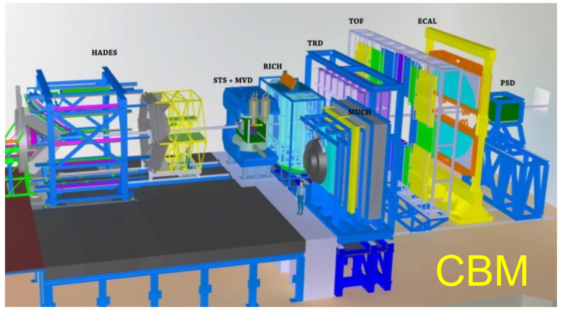
NICA/MPD 4-11 GeV

FAIR/CBM 2-5 GeV

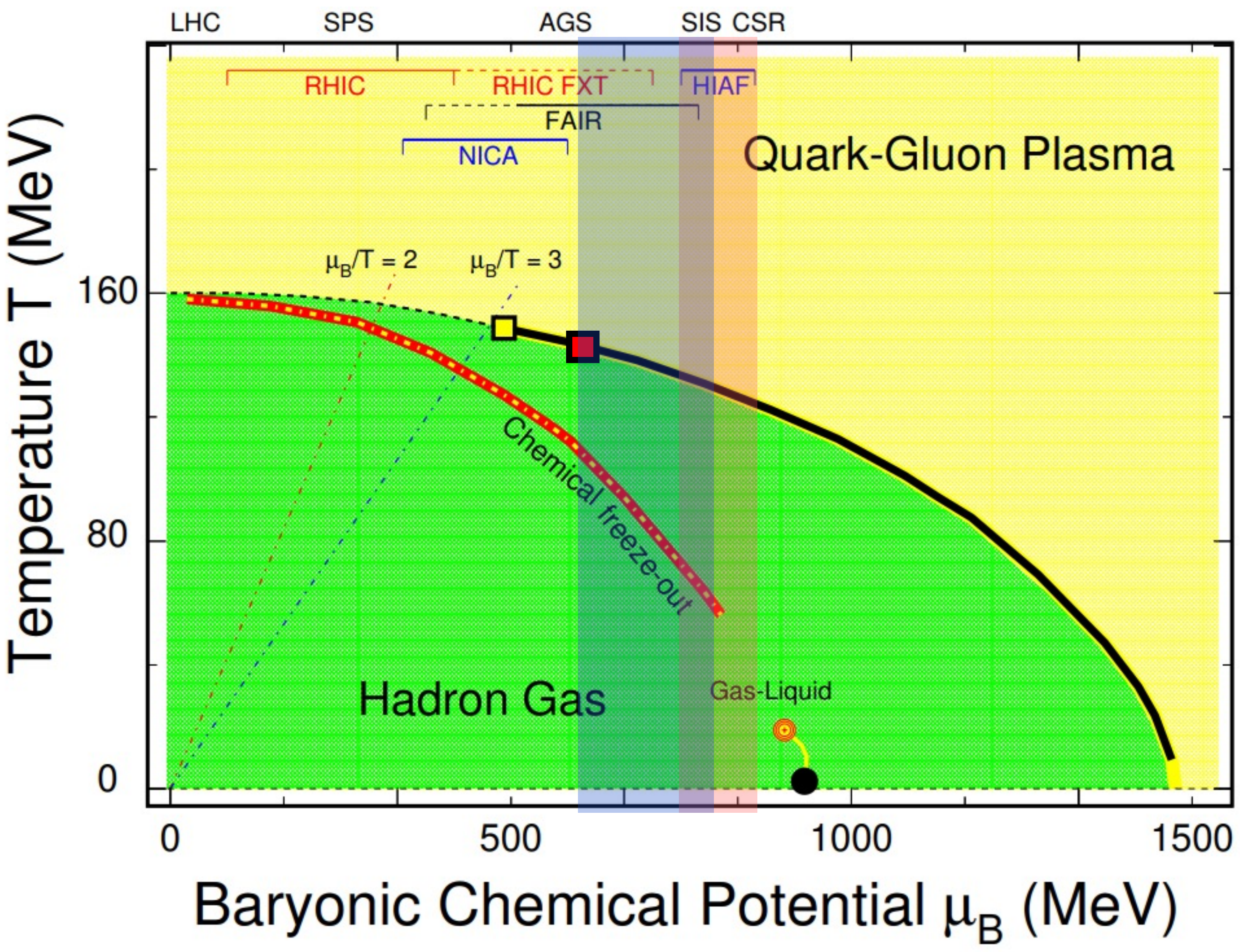
HIAF/CEE/CEE+ 2-4 GeV







Experiments at high baryon density

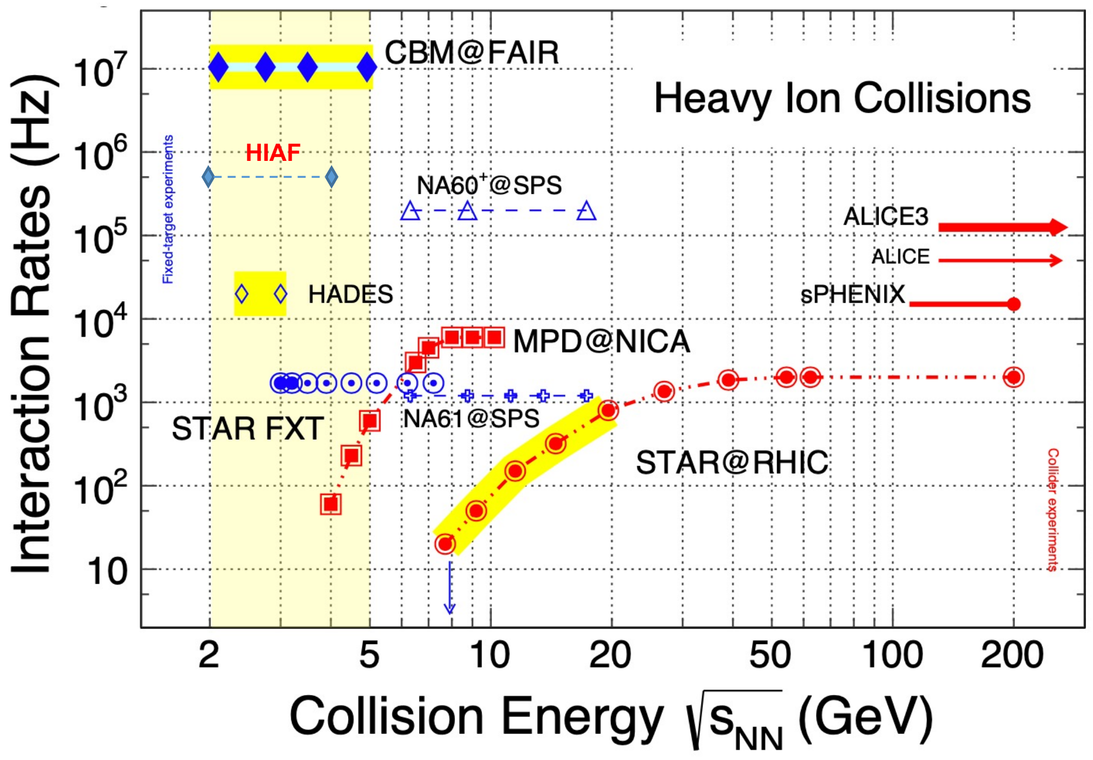


HIAF μ_B ~ 800 MeV, HIAF-U μ_B ~ 590 MeV

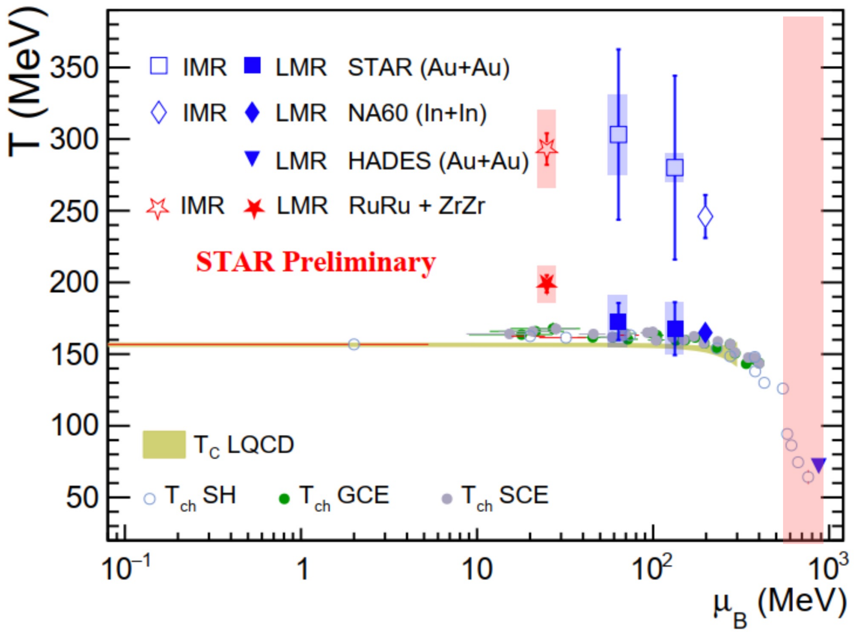
Q. Hao@Nov.16

	E_k (GeV/u)	$\sqrt{s_{NN}}$ (GeV)
HIAF p束	<9.3	<4.58
HIAF U束	<2.45	<2.85
HIAF-U U束	<9.1	<4.54

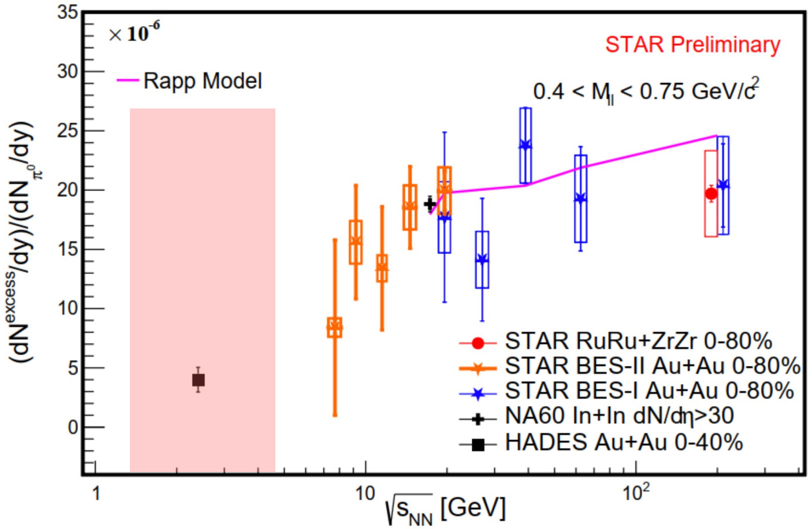
What we can do at HIAF energy?



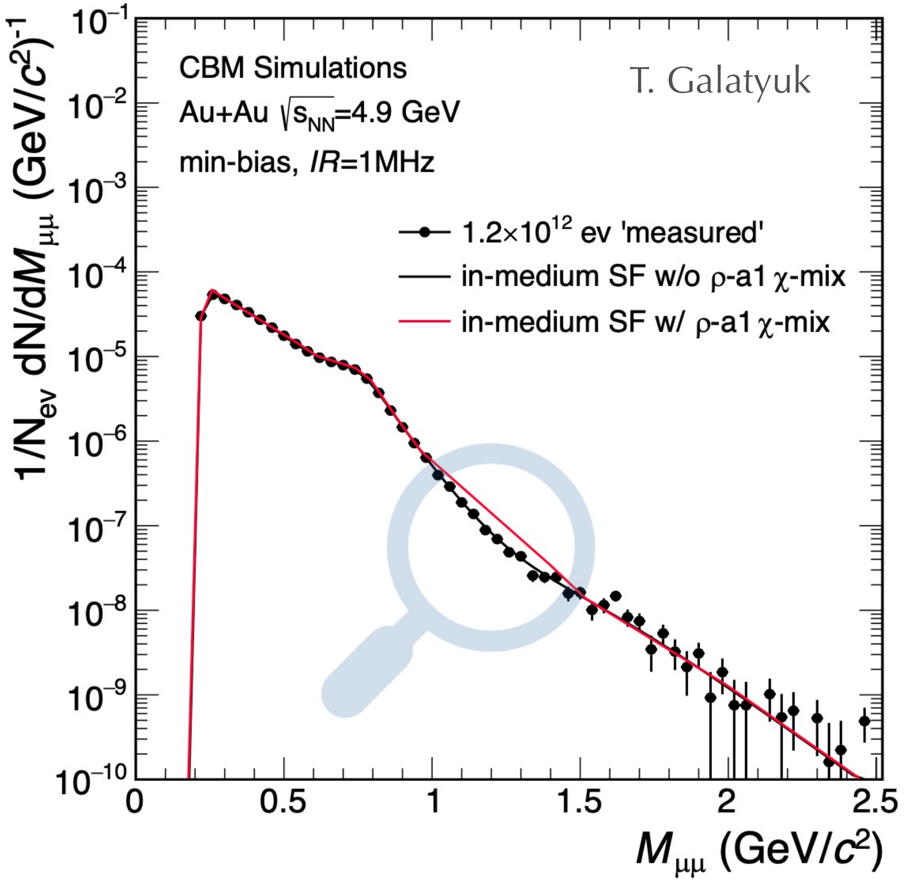
Thermometer:
Baryon catalyst
Phase transition
Critical point
Freeze-out



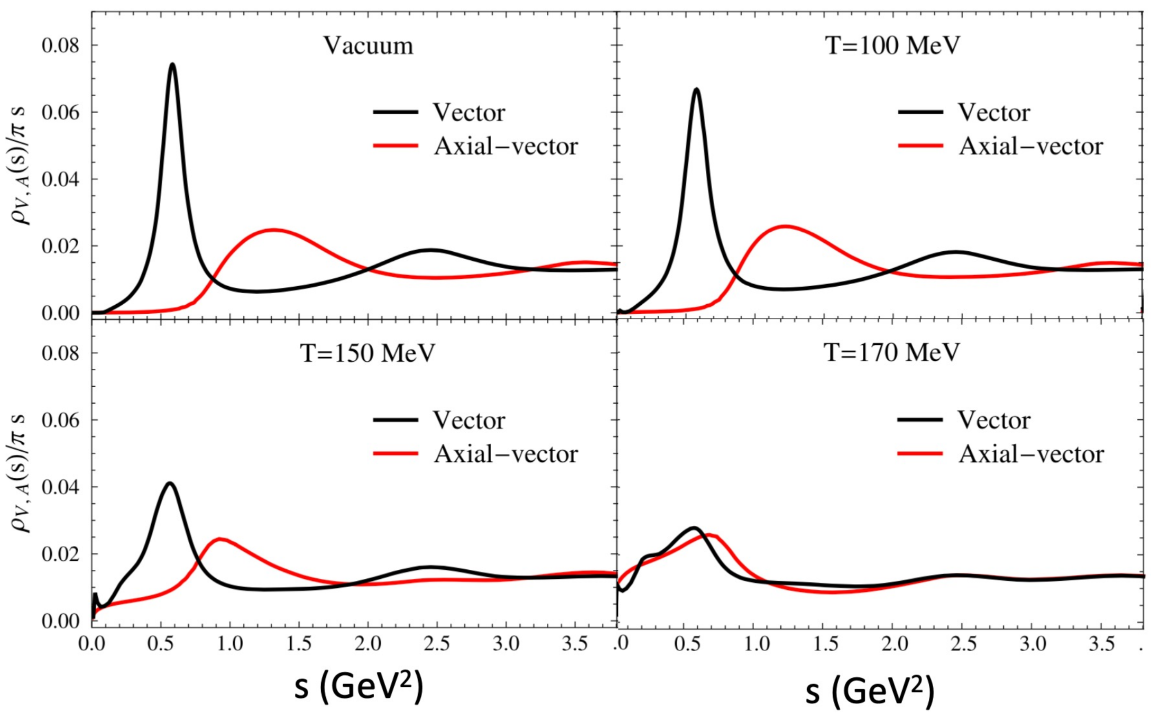
Chronometer:
How long dense matter live?
Mechanisms?



Possible evidence of chiral symmetry restoration



Rapp and Hohler: PLB 731 (2014) 103-109



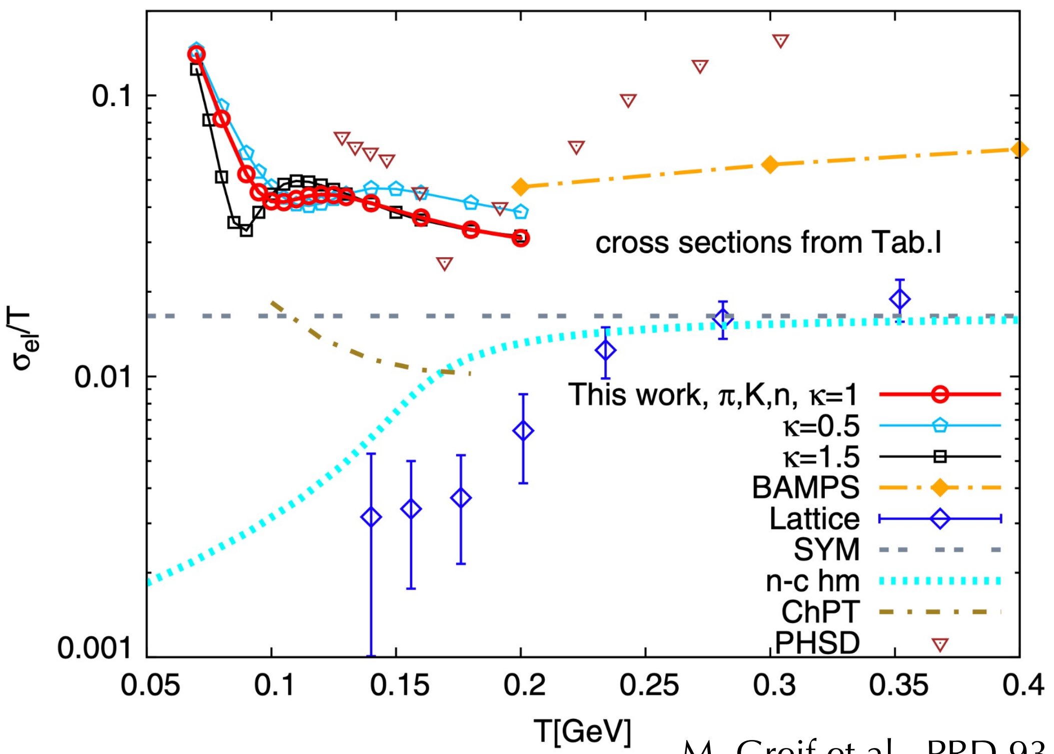
- a1 is theoretically merged with ρ in hot medium
  `=> **chiral symmetry is restored**
- **20-30% enhancement** w.r.t. no χ–mixing is predicted

Experimental challenge: physics background ($M_{\ell\ell}$ > 1 GeV/c^2)

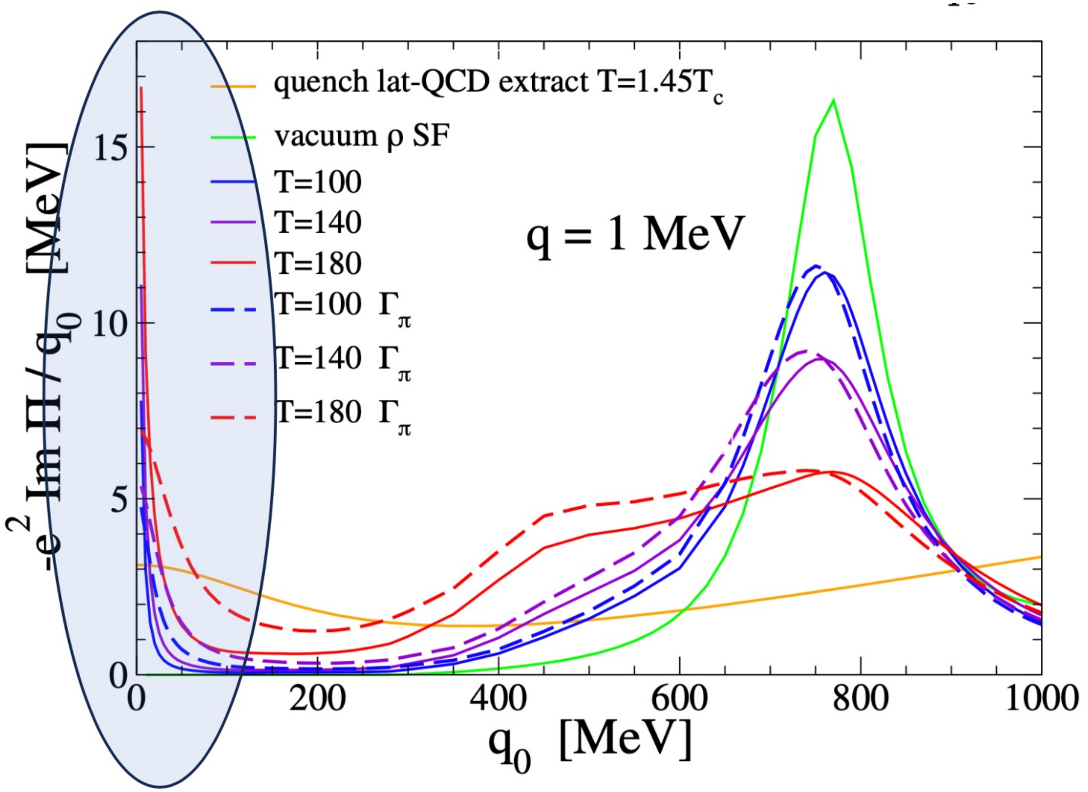
- correlated charm: excellent vertex resolution → topological separation of prompt and non-prompt source employing DCA cut
- QGP: decrease towards lower energy
- Drell-Yan: pp, pA measurements

Electric conductivity of QCD matter

No measurement, poorly known in theory



M. Greif et al., PRD 93 (2016) 096012



R. Rapp, et al, NPA 673 (2000) 357

- Enhancement at **very low pT** and **very low mass** region
- **Challenges**: detector acceptance, resolution, Dalitz decays, photoproduction …

Extract by the EM spectral function at low-energy limit:

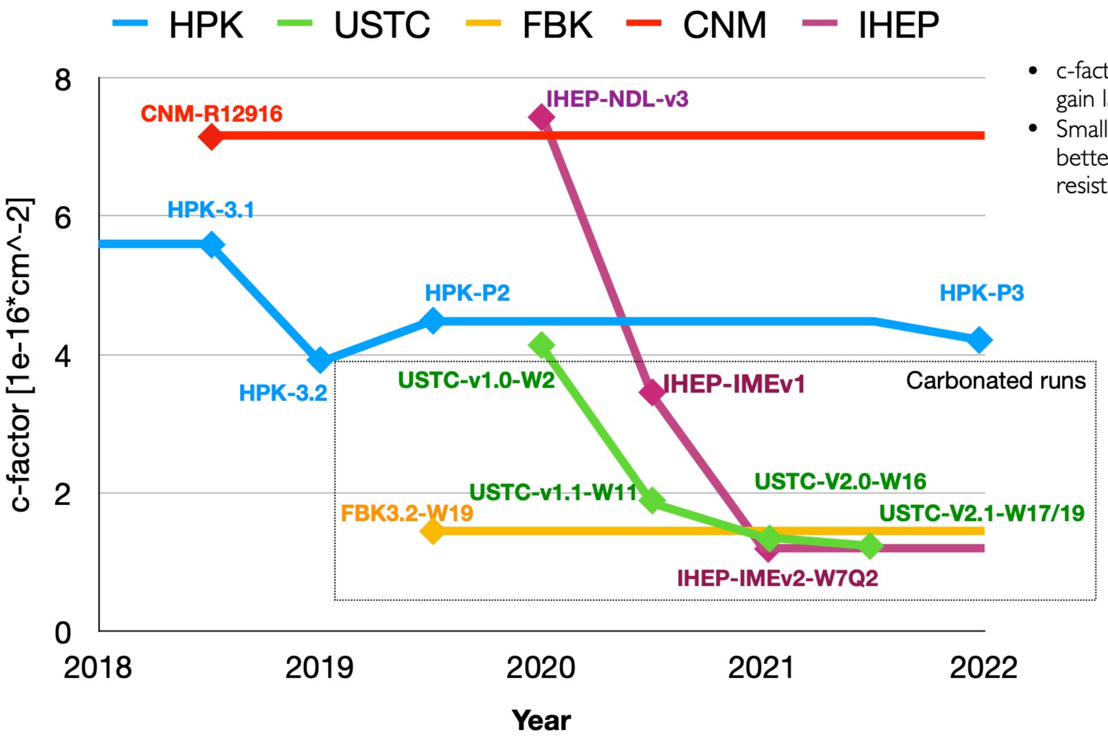
$$\sigma_{el}(T) = -e^2 \lim_{q_0 \to 0} \frac{\delta}{\delta q_0} Im\Pi_{em}(q_0, q = 0; T)$$

LGAD R&D at USTC for ATLAS HGTD

K. Ma, Y. Liu@CLHCP2024

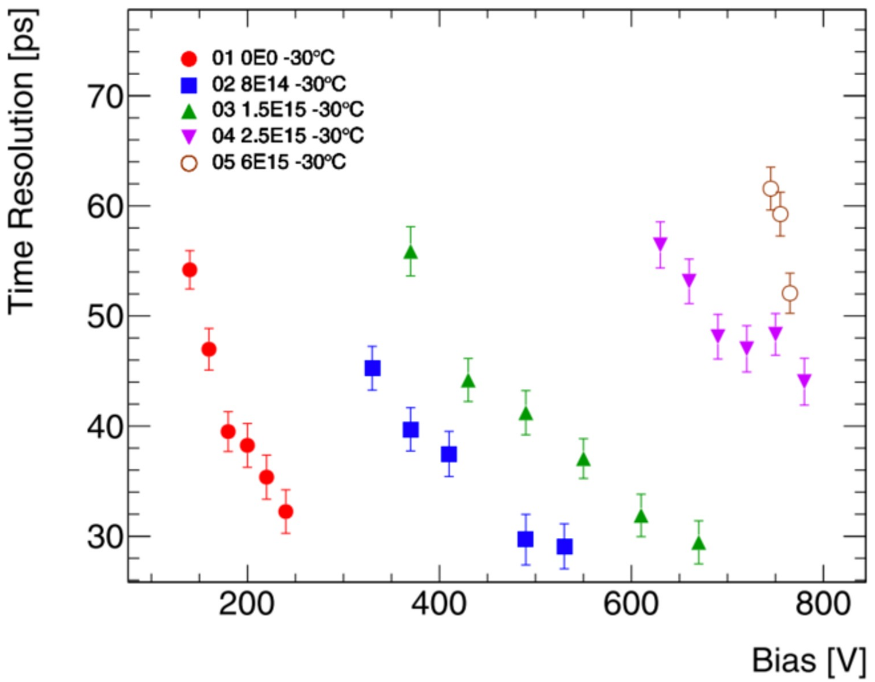
2019: Finished design of V1
2020: Fabrication of V1 at IME and tests at USTC/JSI
2021: V2 and V2.1 design and fabrication
2022: Test at USTC/JSI/DESY/CERN
2023: Pass ATLAS design Review finish pre-production
2024: Test of pre-production sensors pass production readiness review

USTC provide 10% of the LGAD sensors for ATLAS HGTD (~2000 sensors)



- c-factor: rate of the gain layer degradation.
- Smaller c-factor → better radiation resistant

Evolution of radiation tolerance of LGAD



AC-LGAD status at USTC

- Design and characterization tools fully developed during the R&D for HGTD
- Fabricated AC-LGAD prototypes at USTC

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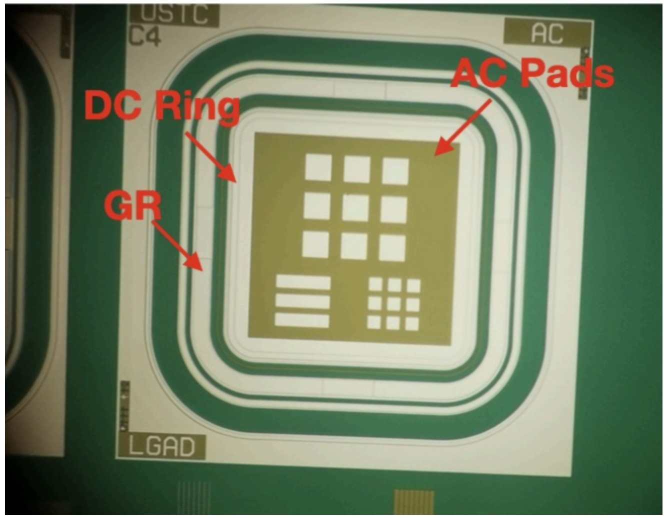
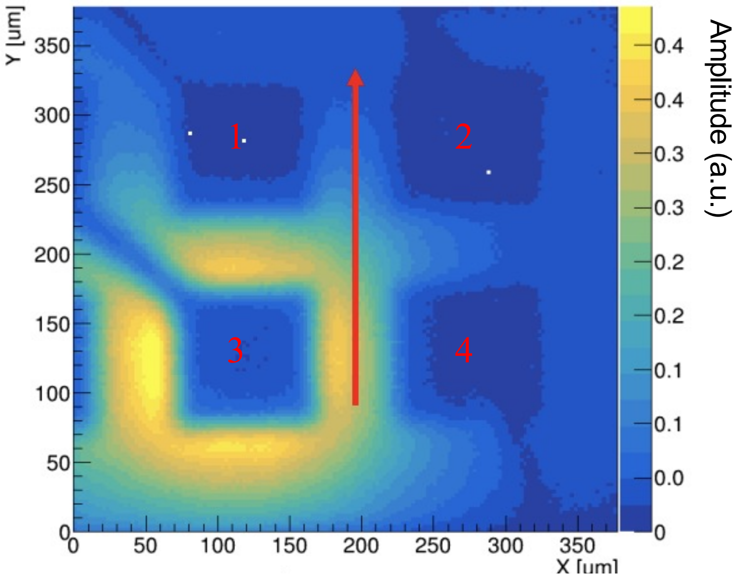
- Optimizing the AC-LGAD design to achieve:
  - time resolution of 20 ps
  - spatial resolution of order of 10 μm
- Will launch fabrication soon

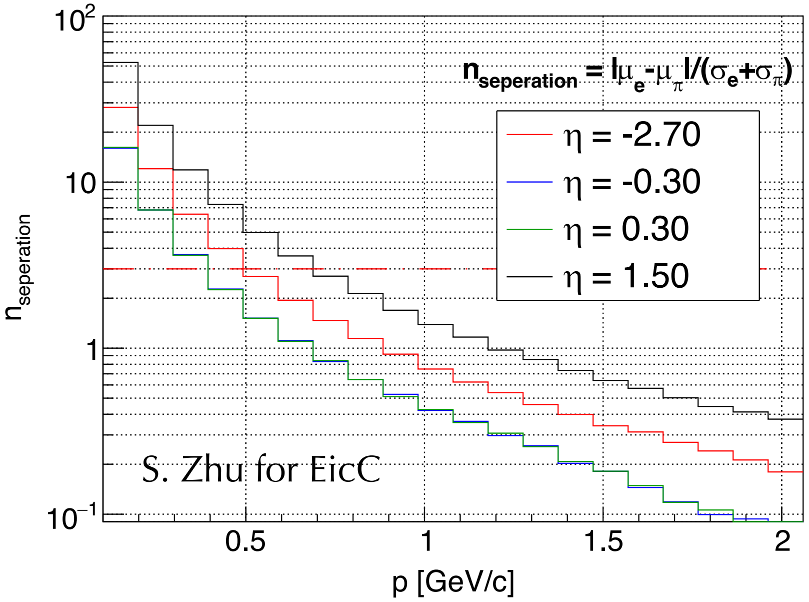


V0 AC-LGAD prototype



Response to infrared laser

e/π separation power



AC-LGAD TOF with σ = 30 ps

Thanks for your attention !