FUTURE ALICE UPGRADE BEYOND 2030

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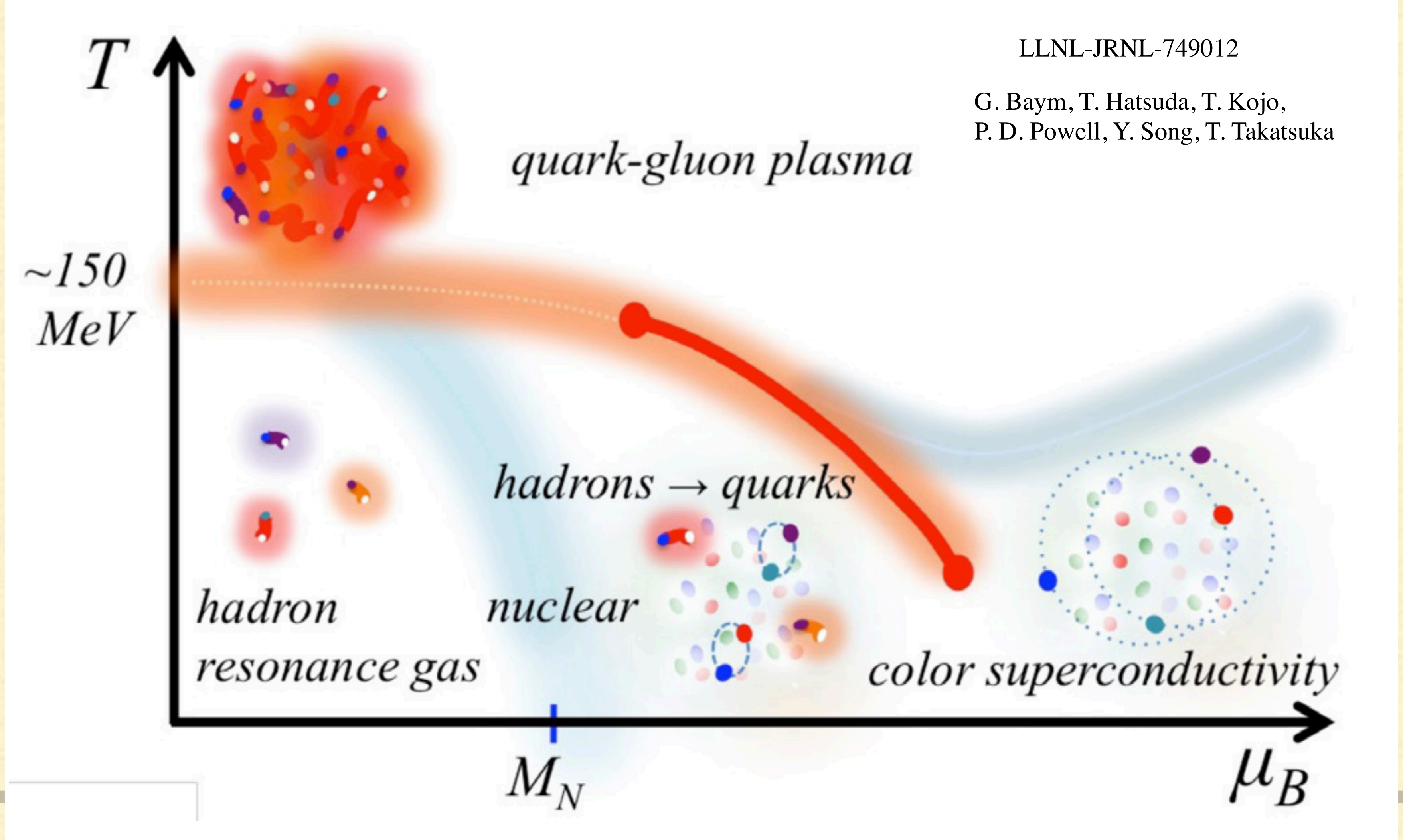
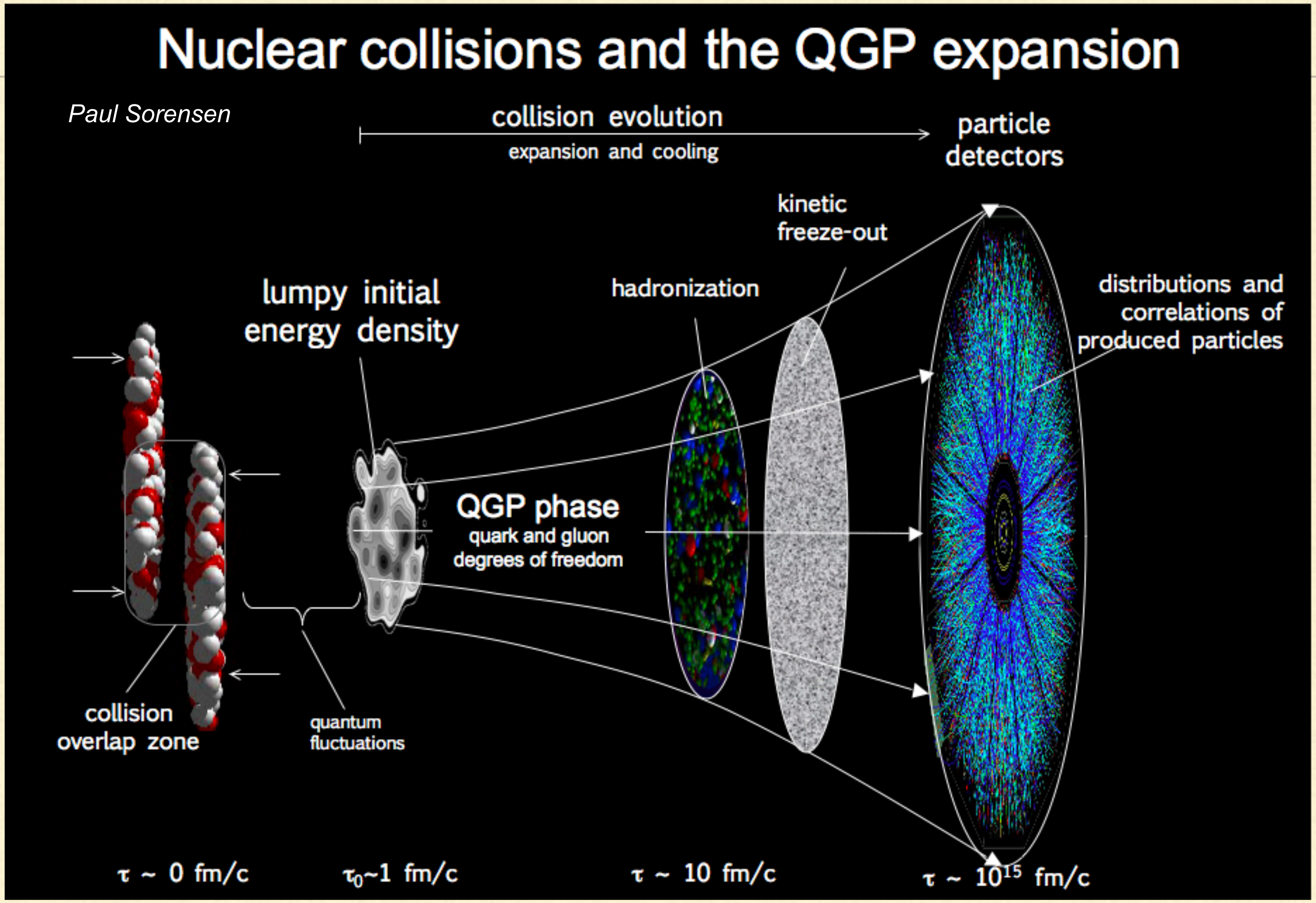
OUR (MY) GOAL…

Understanding of QCD phase diagram, phase transition, properties of QGP at various conditions (T, μ, B, etc) and emergence from fundamental interactions in QCD

→ We have many progress for many years. However, we know only a little of them…

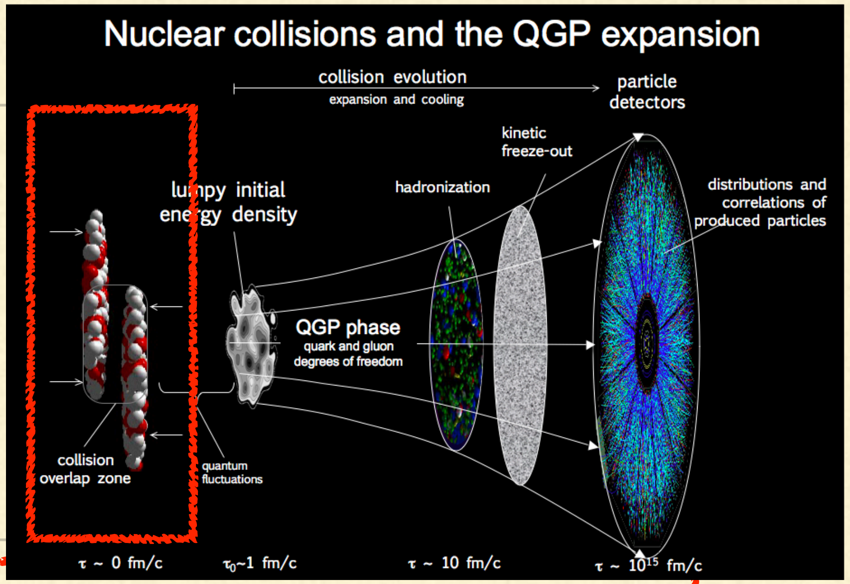


SPACE-TIME EVOLUTION

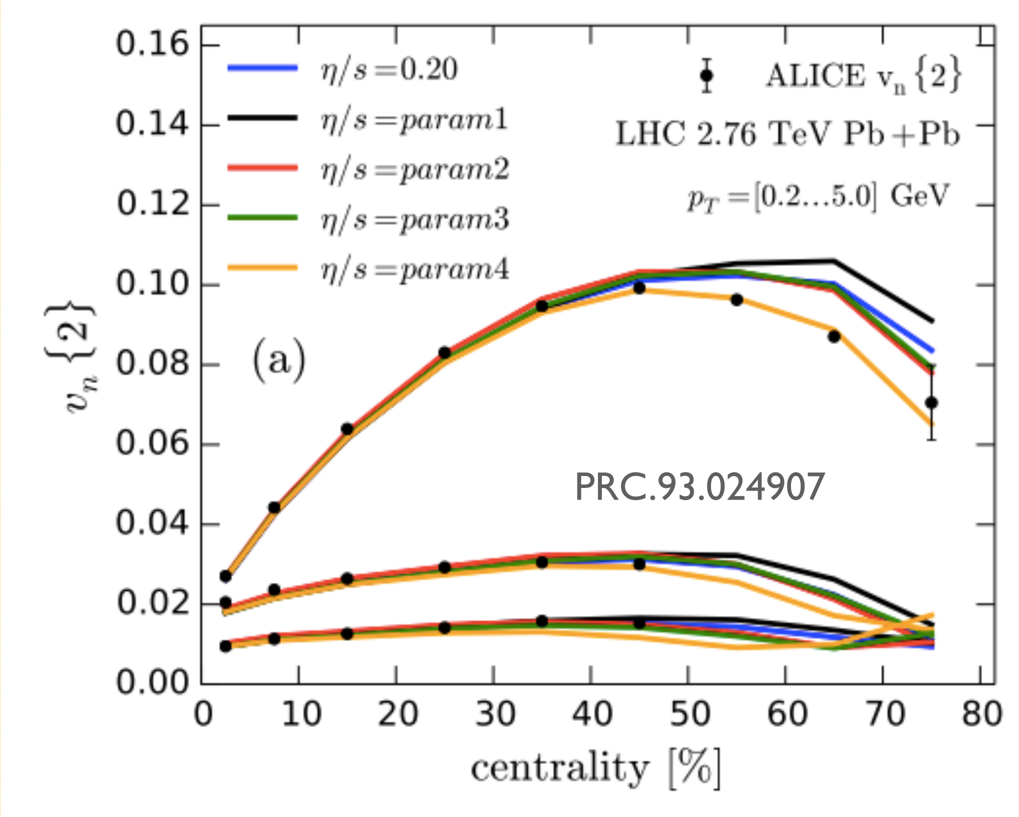


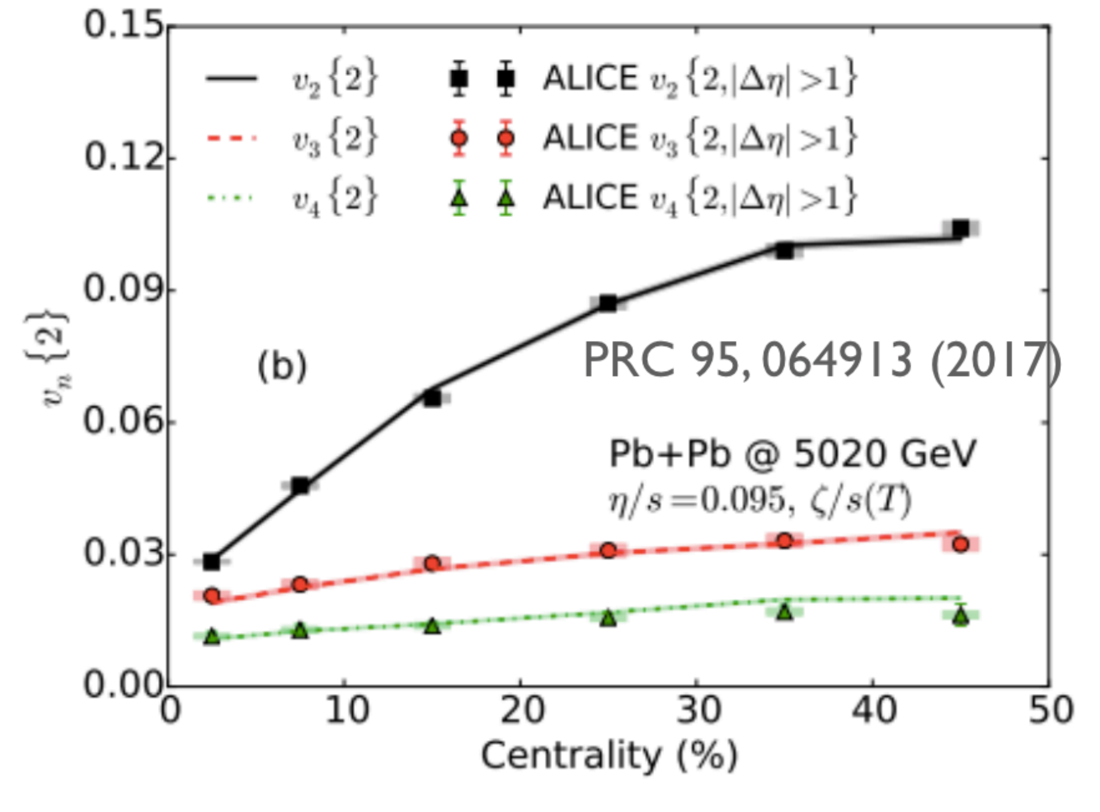
- Understanding of space-time evolution is crucial to study the properties of QGP.
- Models to describe space-time evolution (= Our Standard Model) are needed.
- Very challenging and interesting! Related to QCD non-equilibrium and non-perturbative physics.

INITIAL CONDITIONS



- **Initial conditions**
  - **Models: MC-Glauber, MC-KLN, IP-Glasma, EKRT, TRENTO,,,,,**
  - **Importance of various fluctuations ((sub-)nucleon, gluon/color, etc)**

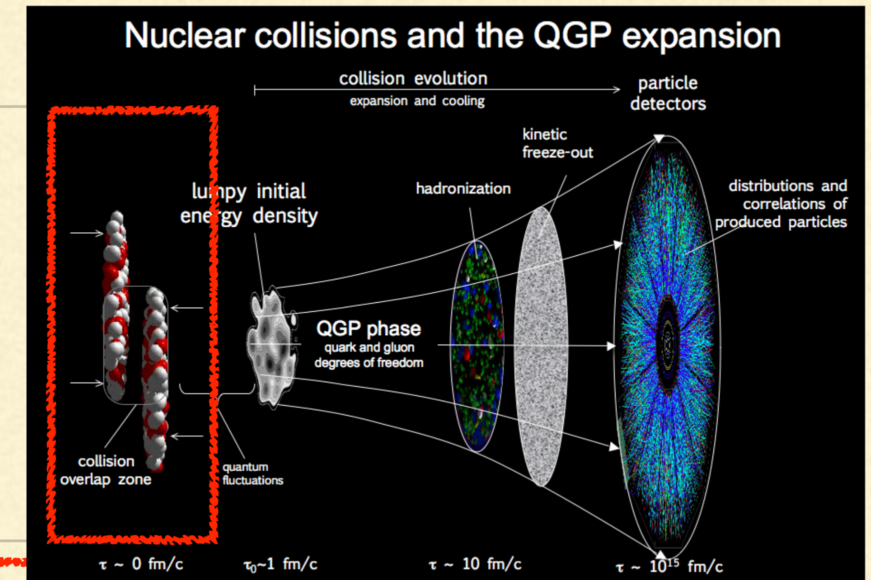




η/s = 0.1(IP-Glasma) - 0.2 (EKRT)

- It is crucial to understand I.C. to extract η/s and ζ/s.

INITIAL CONDITIONS



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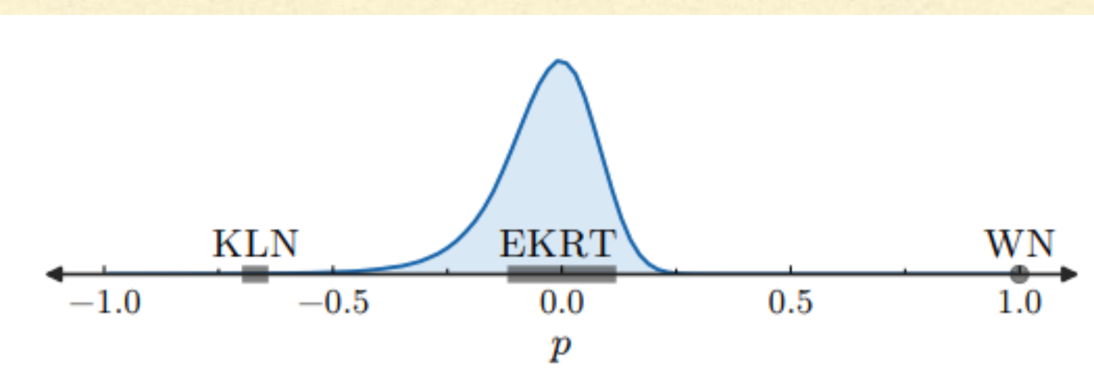
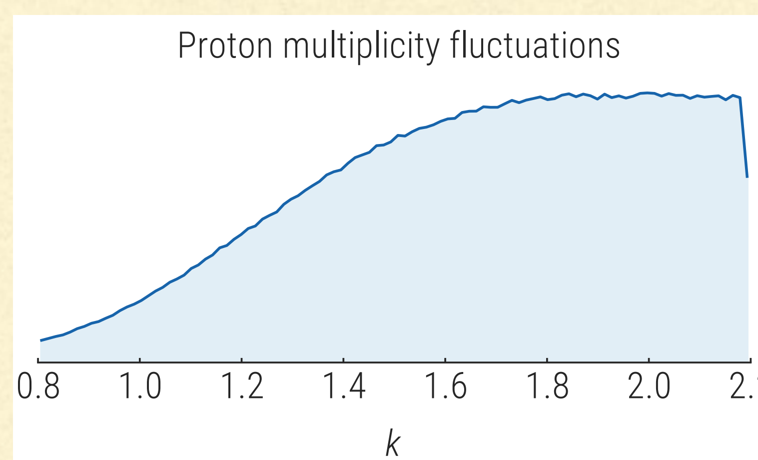
NPA 967 (2017) 67–73

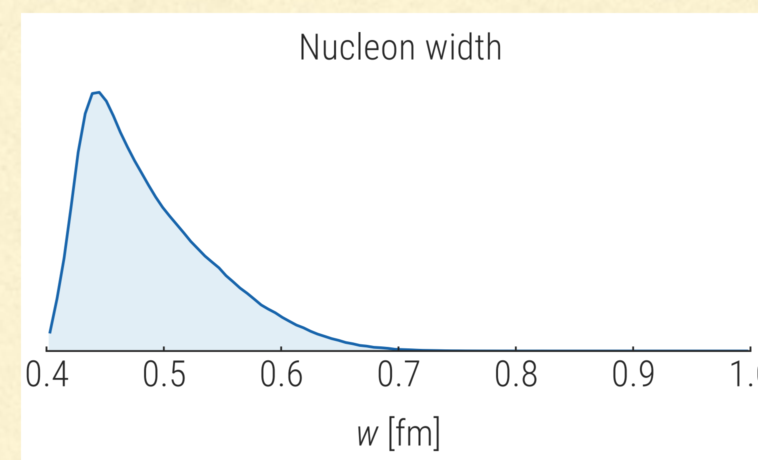
$$s \propto \begin{cases} \max(\tilde{T}_A, \tilde{T}_B) & p \to +\infty, \\ (\tilde{T}_A + \tilde{T}_B)/2 & p = +1, \ \text{(arithmetic)} \\ \sqrt{\tilde{T}_A \tilde{T}_B} & p = 0, \ \text{(geometric)} \\ 2\tilde{T}_A \tilde{T}_B/(\tilde{T}_A + \tilde{T}_B) & p = -1, \ \text{(harmonic)} \\ \min(\tilde{T}_A, \tilde{T}_B) & p \to -\infty. \end{cases}$$

$$\tilde{T}(x,y) = \sum_{i=1}^{N_{\rm part}} \gamma_i \, T_p(x - x_i, y - y_i),$$

$$T_p(x,y) = \frac{1}{2\pi w^2} \exp\left(-\frac{x^2+y^2}{2w^2}\right)$$

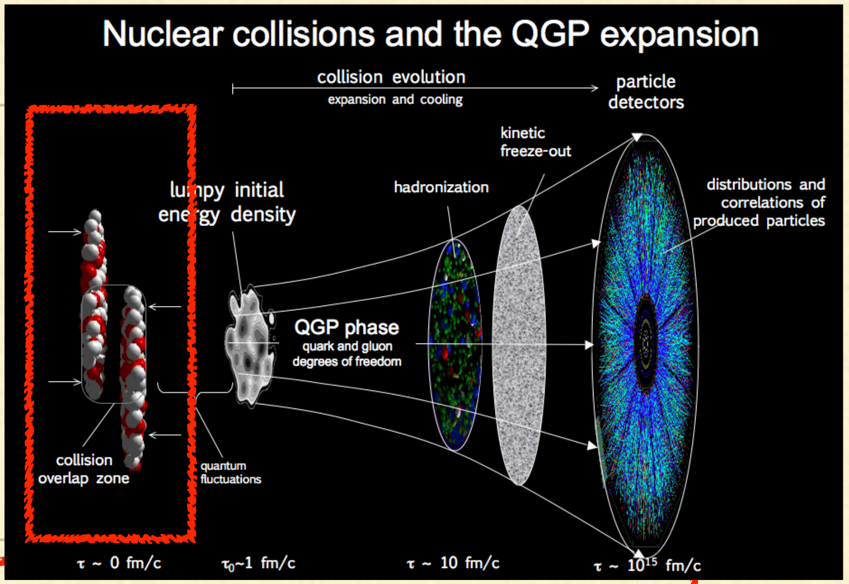






- Bayesian analysis by S. Bass et al shows EKRT/IP-Glasma like I.C. is favored.
- Glauber and KLN are really excluded?

INITIAL CONDITIONS



- **Initial conditions**
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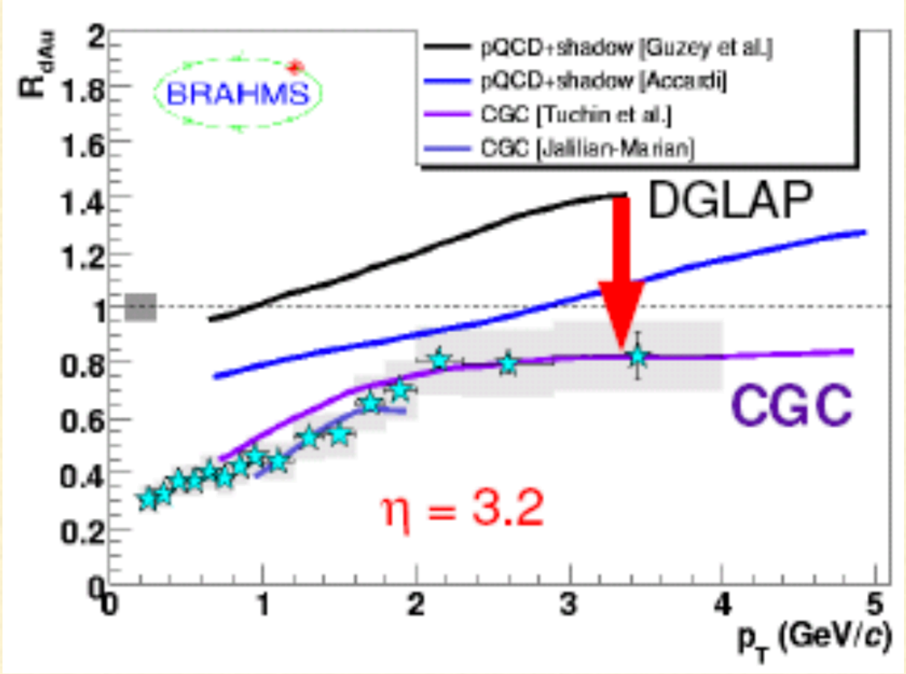
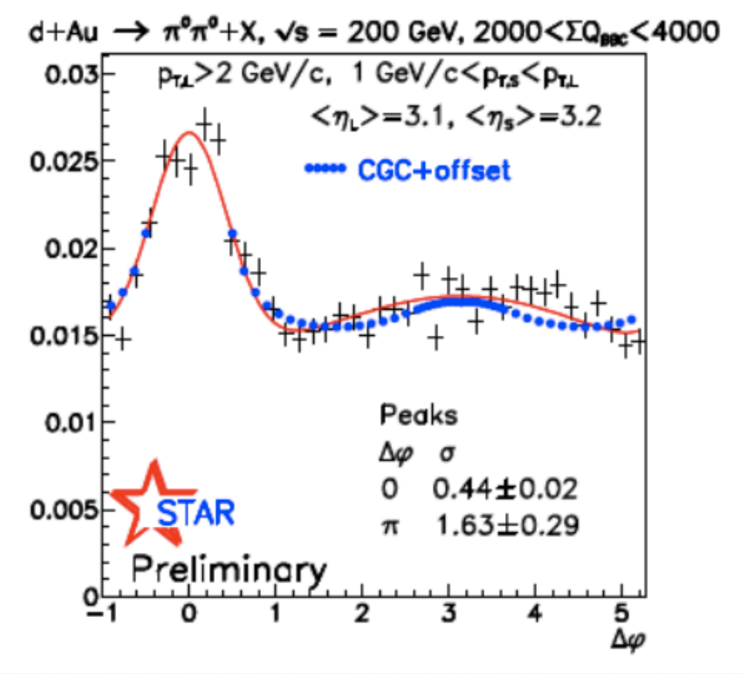
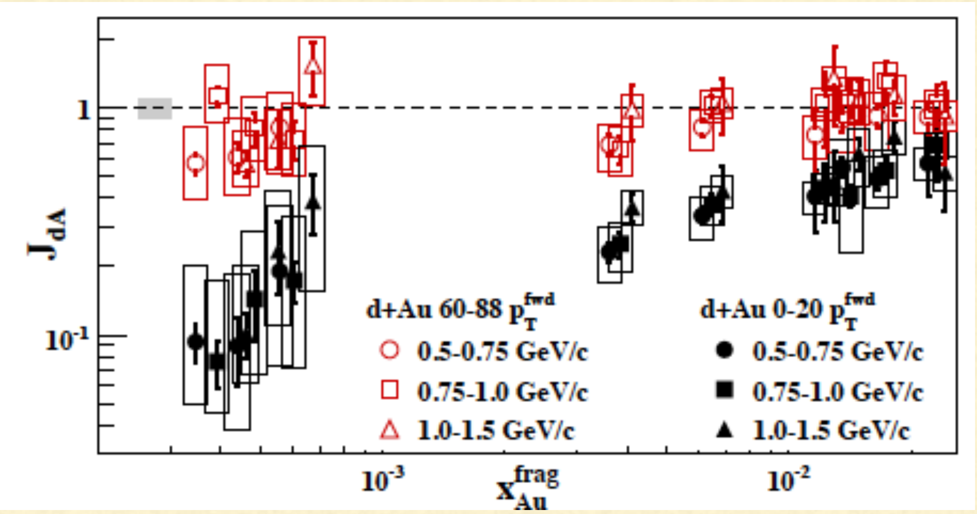
Any direct hints on I. C. from experiments?

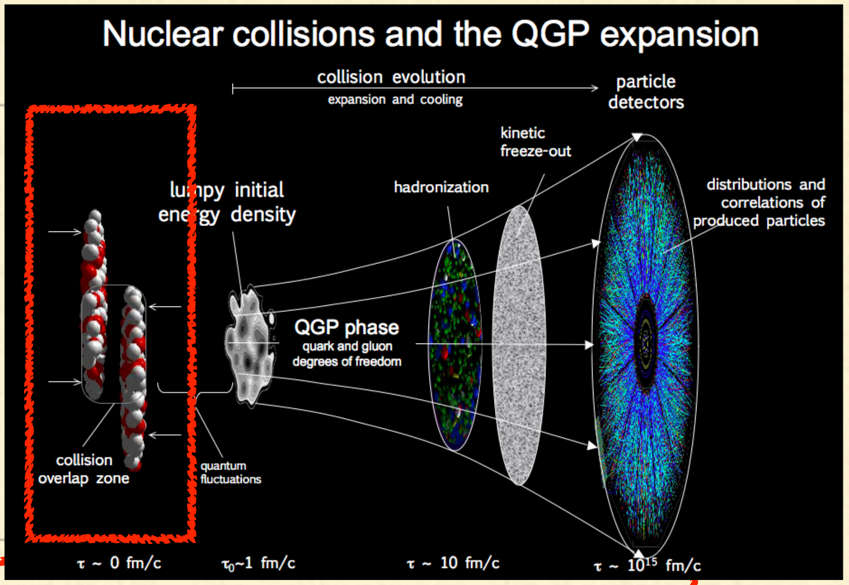




$$x_{Au}^{frag} \equiv \frac{\langle p_{T1} \rangle e^{-\langle \eta_1 \rangle} + \langle p_{T2} \rangle e^{-\langle \eta_2 \rangle}}{\sqrt{s}}$$



We saw some hints at RHIC forward rapidities (and at HERA (γ+p → J/Ψ)).



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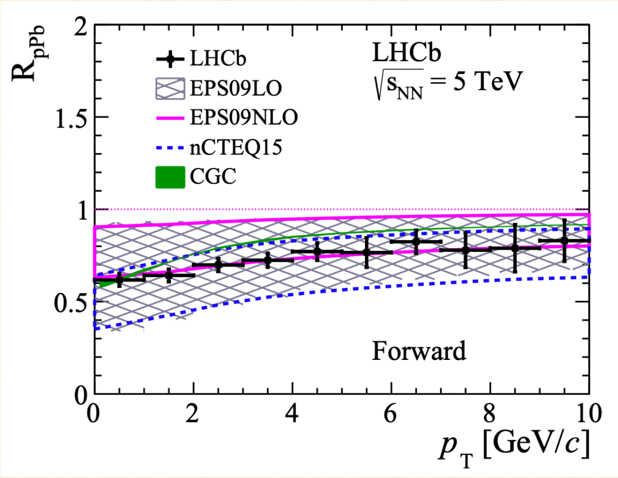
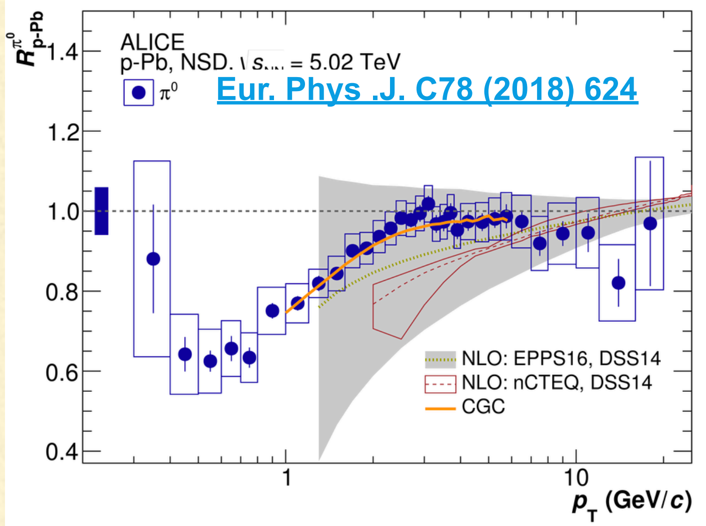
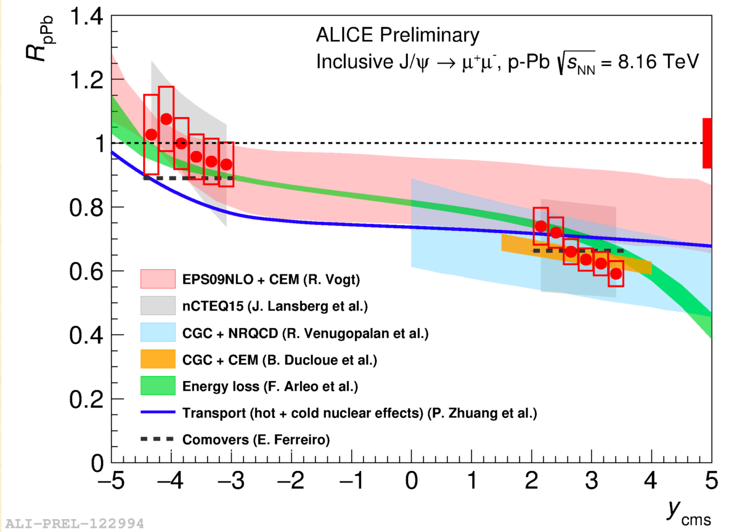
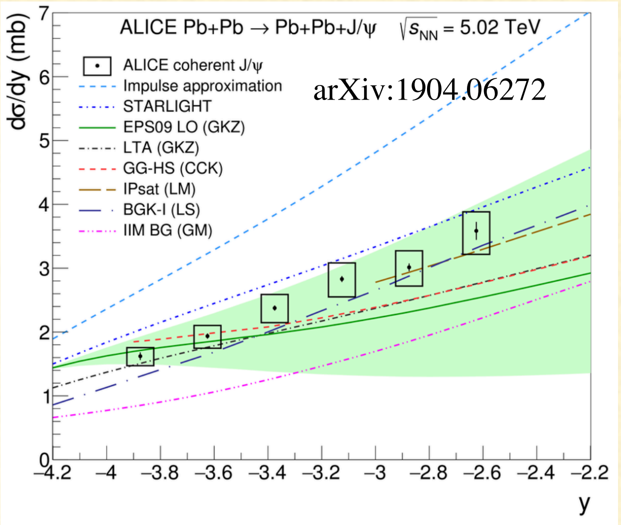
D^0 meson, LHCb
JHEP 1710 (2017) 090



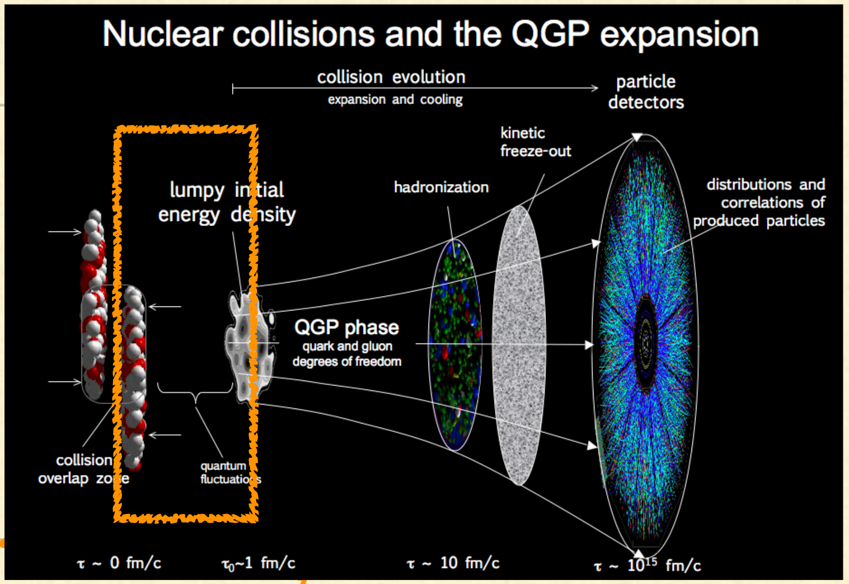






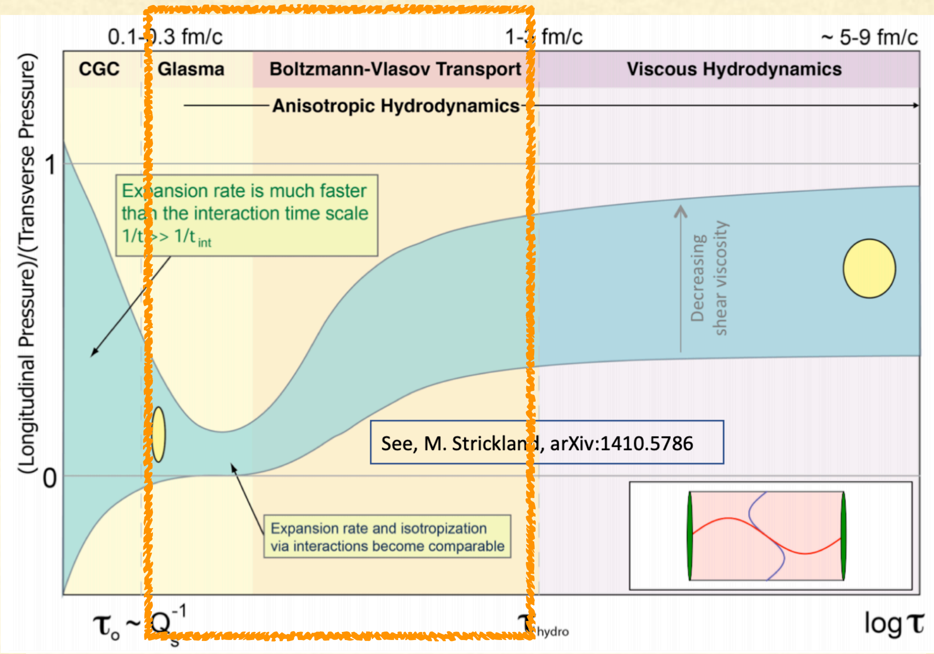
Effects of nPDF or CGC are visible but both are consistent with data within the uncertainties.
More measurements from forward rapidities, photons, γp/γA collisions

VERY EARLY STAGE



- **Thermalization mechanism**
  - **Instability (source?) and rapid thermalization?**
  - **Dynamical Models: anisotropic hydro? Core-Corona?**

A. Mazeliauskas, QM2018,
M. Alqahtani, QM2018



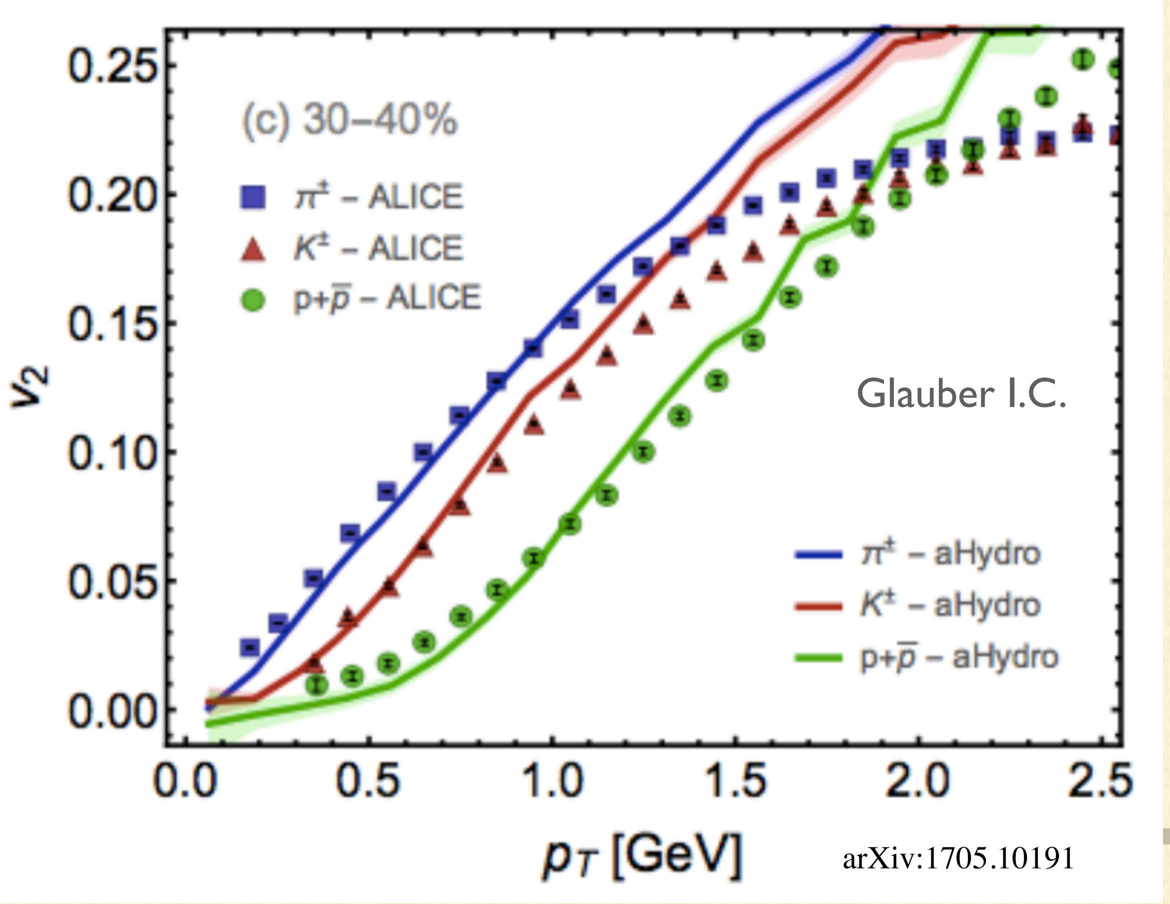
$$p^\mu \partial_\mu f + \frac{1}{2}\partial_i m^2 \partial^i_{(p)} f = -\mathcal{C}[f]$$

$\frac{\eta}{s} = 0.159$, T_0 =600 MeV at τ_0=0.25 fm/c, T_{FO}=130 MeV.

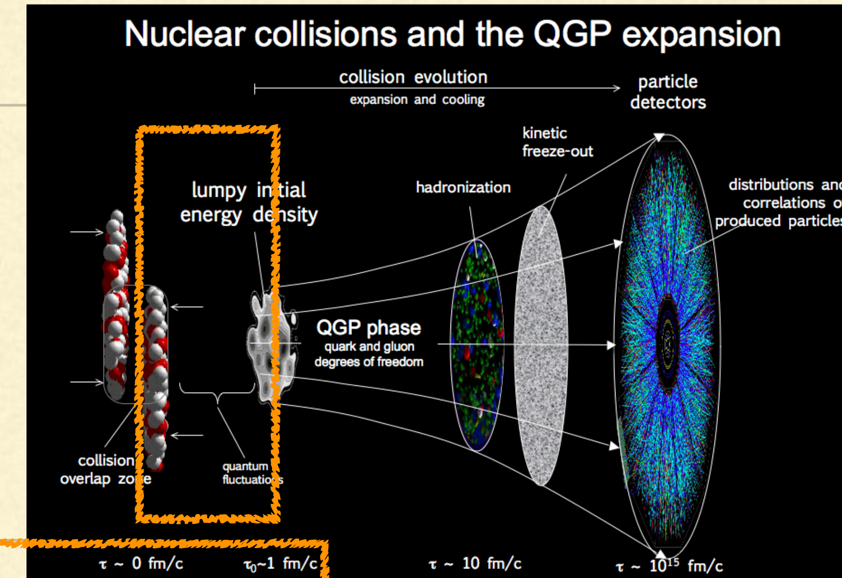
$$f(x,p) = f_{\rm eq}\left(\frac{\sqrt{p^\mu \Xi_{\mu\nu}(x) p^\nu}}{\lambda(x)}\right) + \delta f(x,p)$$

$$\Xi^{\mu\nu} = u^\mu u^\nu + \xi^{\mu\nu} - \Delta^{\mu\nu}\Phi$$

u^μ LRF four velocity
$\xi^{\mu\nu}$ the traceless anisotropy tensor
$\Delta^{\mu\nu}$ the transverse projector
Φ the degree of freedom associated with bulk



arXiv:1705.10191



VERY EARLY STAGE

- **Thermalization mechanism**
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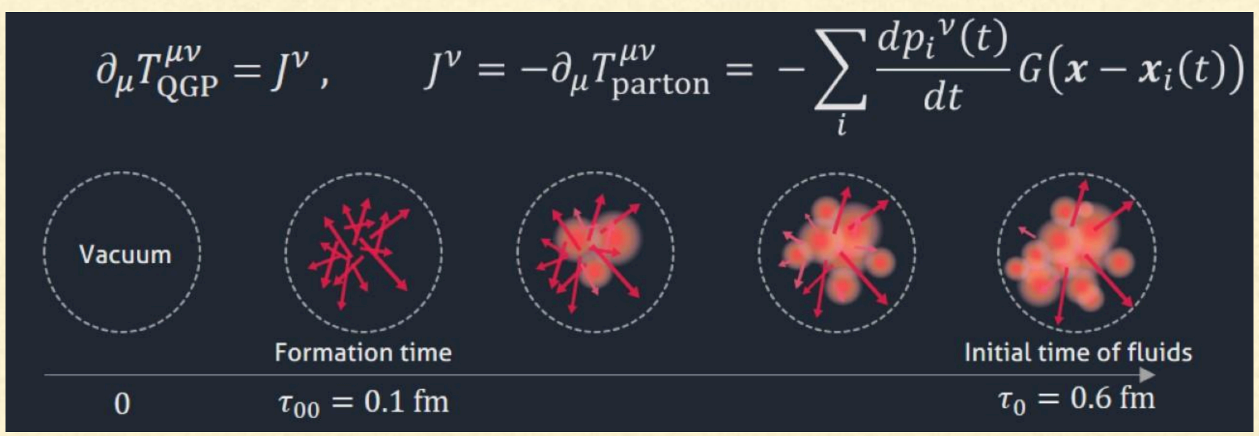
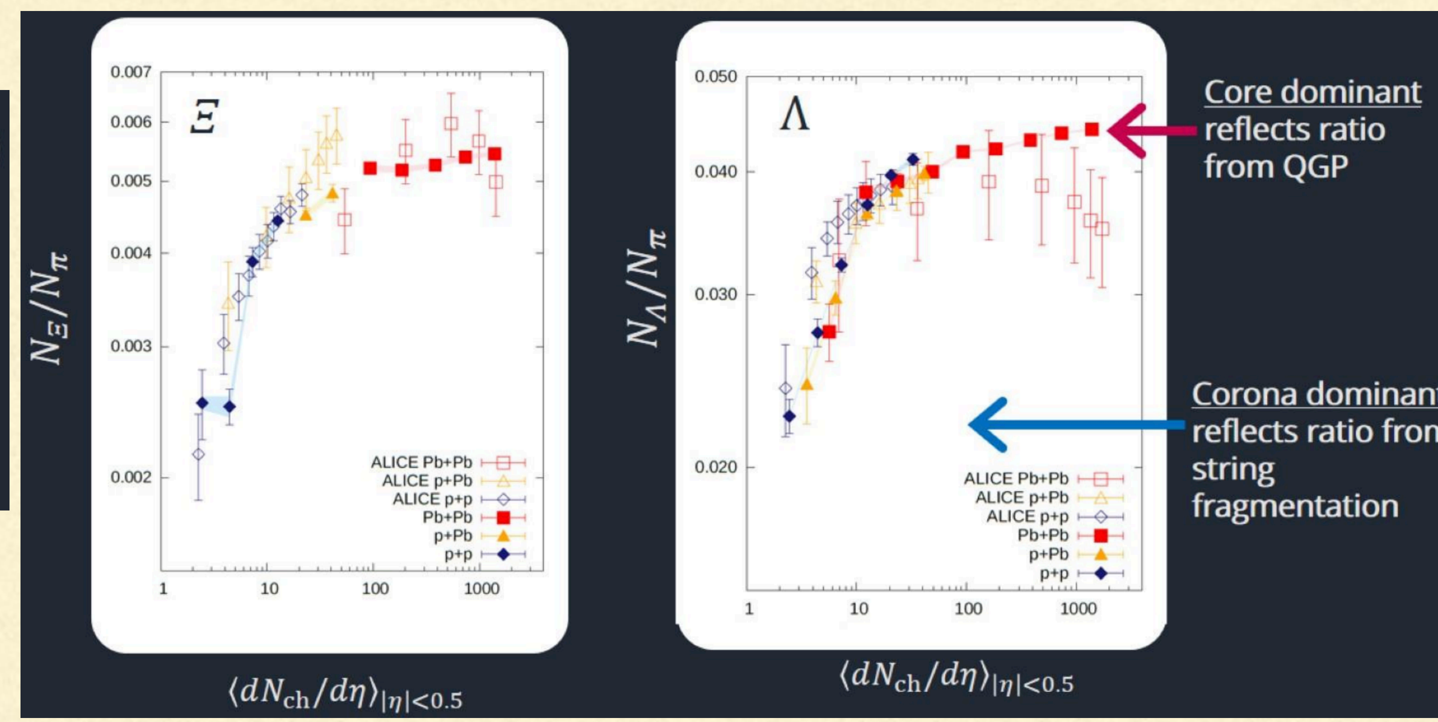
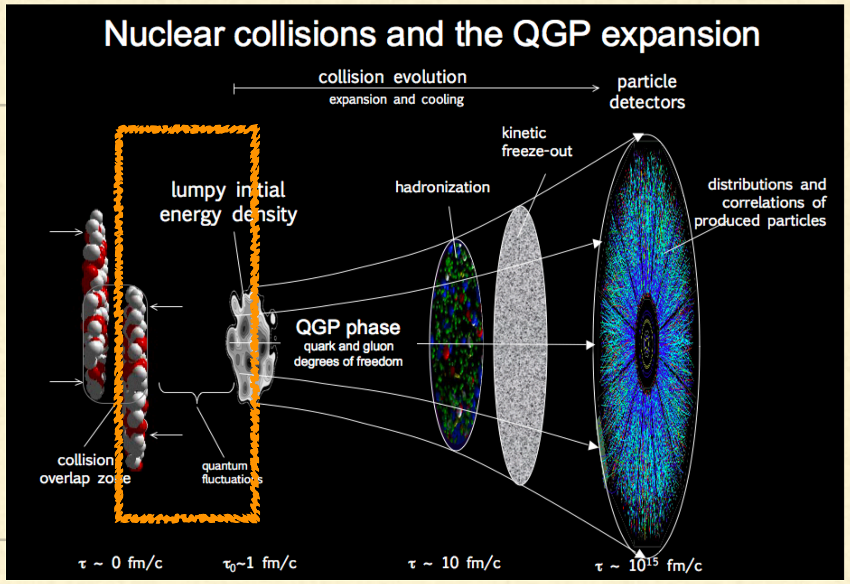
Kanakubo, SQM2019





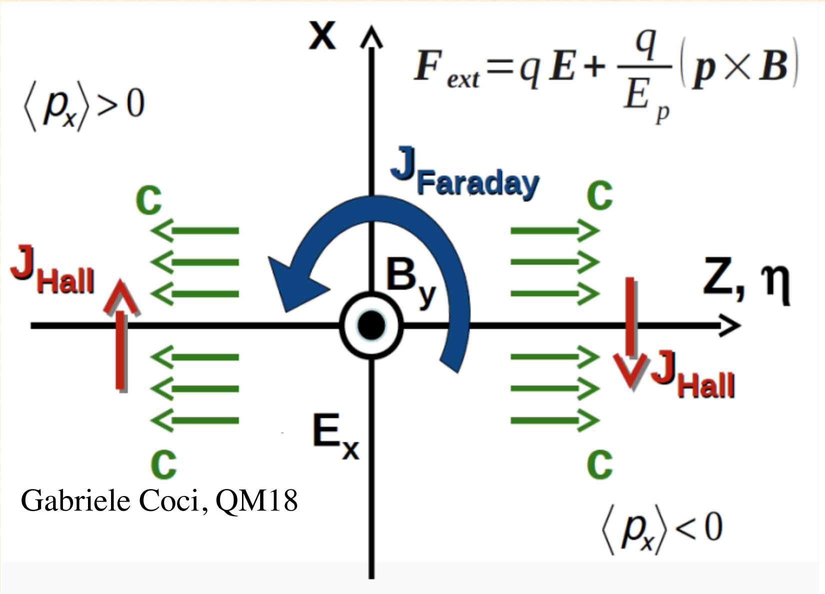
- Most difficult part of HI physics(but surely interesting!).
- How to access and probe pre-thermalization stage experimentally?

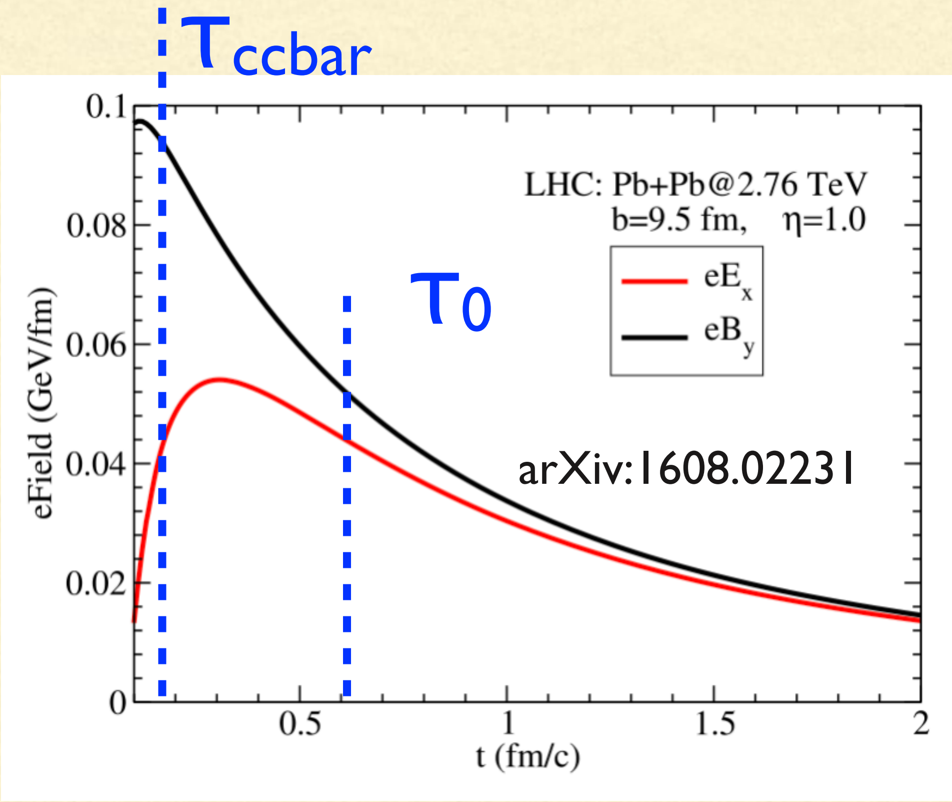
VERY EARLY STAGE

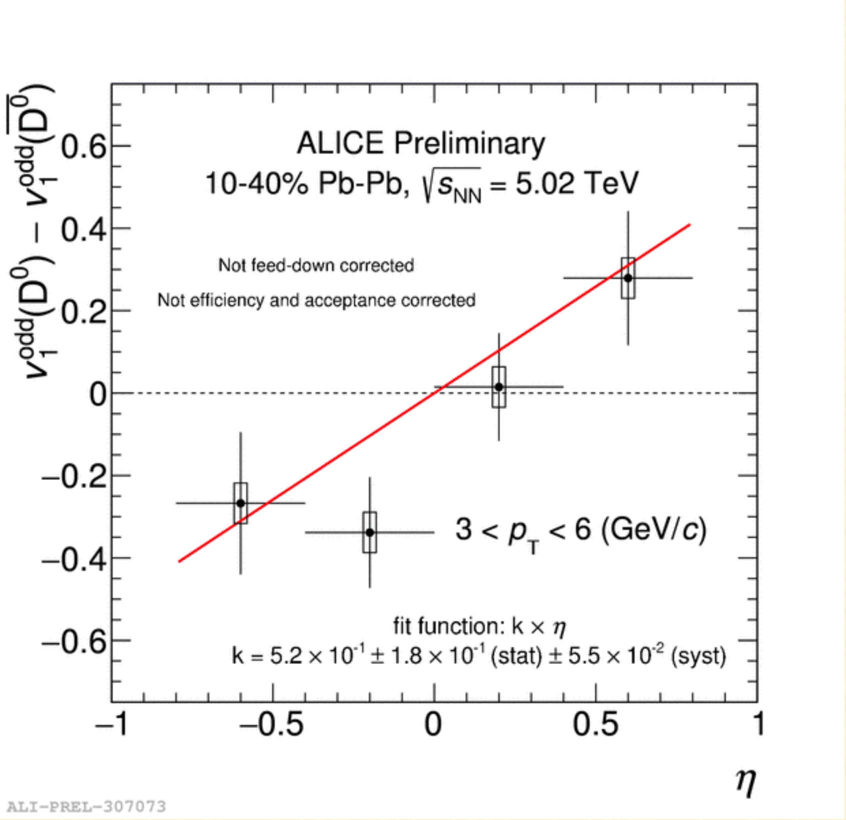


- **Strong EM field and its evolution?**

Tuchin PRC88, Adv. High En. Phys. 1 (2013)
Gürsoy, Kharzeev, Rajagopal PRC89 (2014)

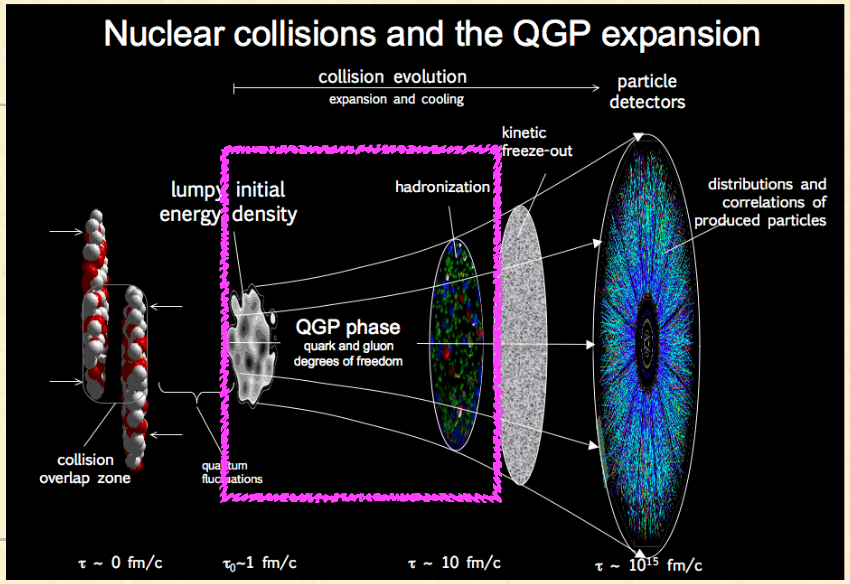






- HQ v_1 is sensitive to the EM field in very early stage of collisions (and σ_{el})
- Large v_1 (compared to hadrons, k(10^{-4})) gives some hints for relativistic magnet+fluctuating hydro and dynamics of early stage?

HYDRO EVOLUTION

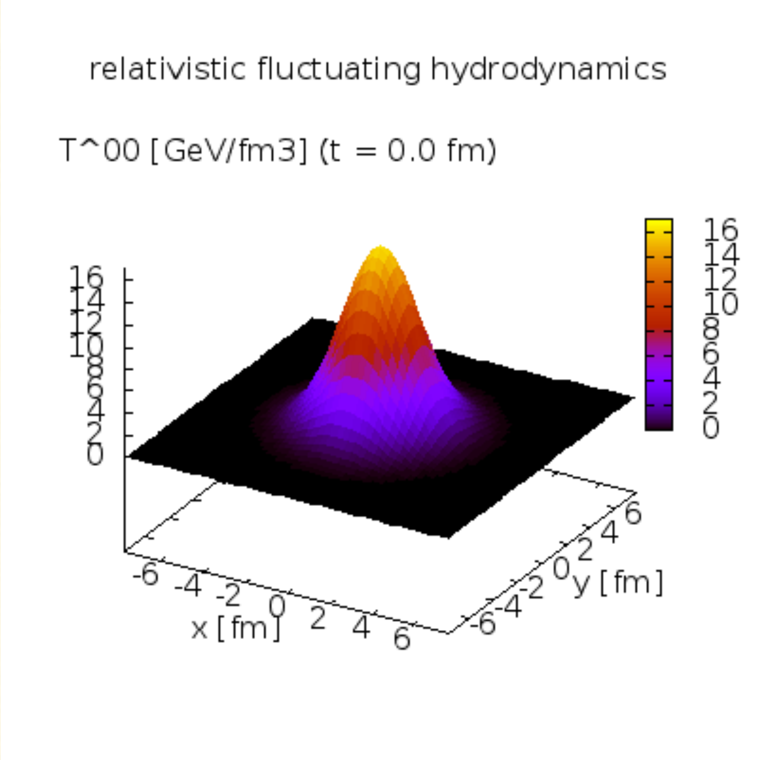


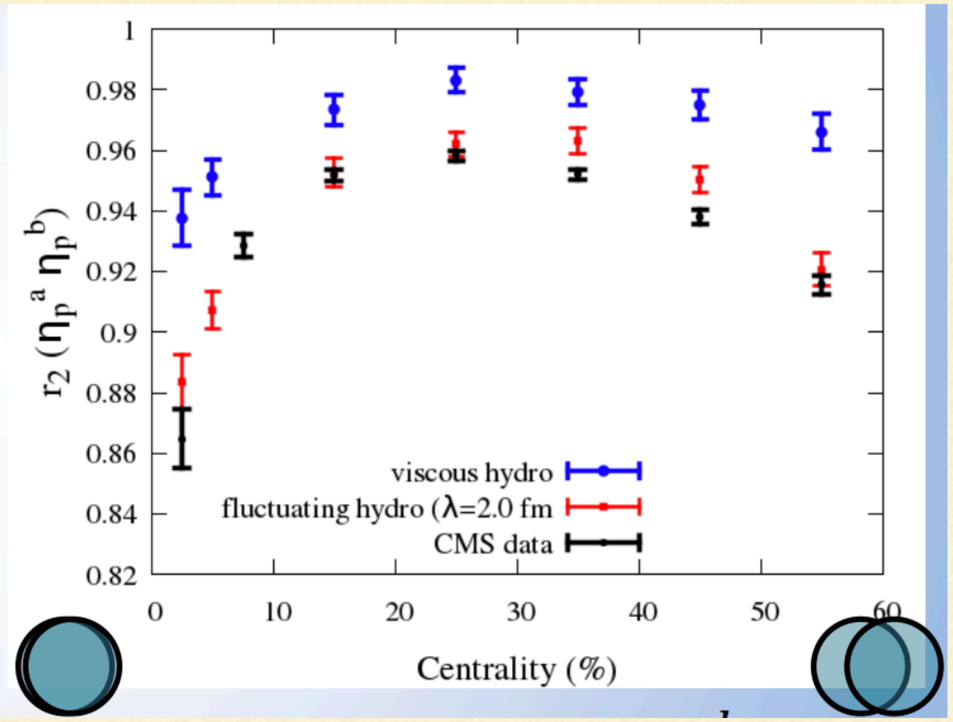
- **Hydrodynamics**
  - **Fluctuating hydrodynamics**
  - **Higher order dissipative corrections**

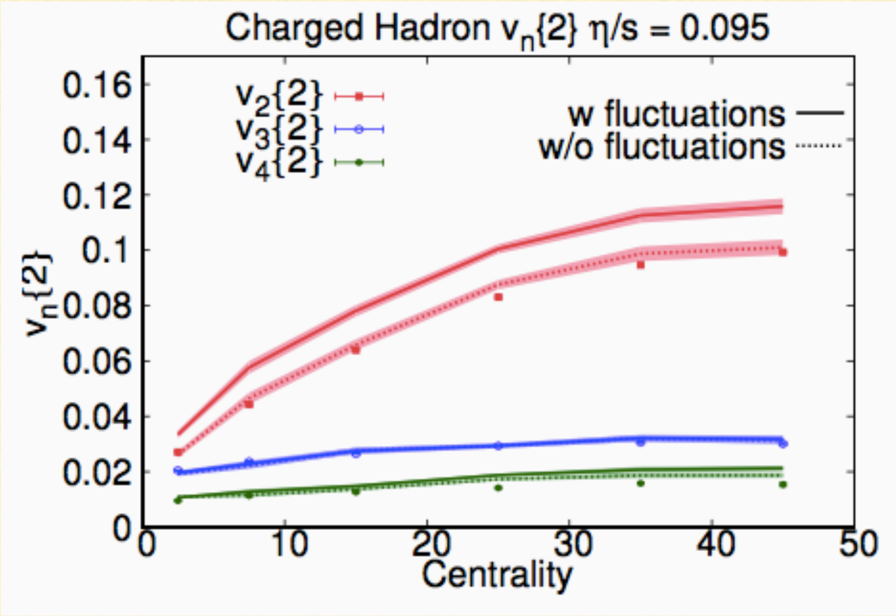
$$T^{\mu\nu} = eu^{\mu}u^{\nu} - (\mathcal{P} + \Pi)\Delta^{\mu\nu} + \pi^{\mu\nu} + S^{\mu\nu}$$

A. Sakai, NN2018

M. Singh, QM2018





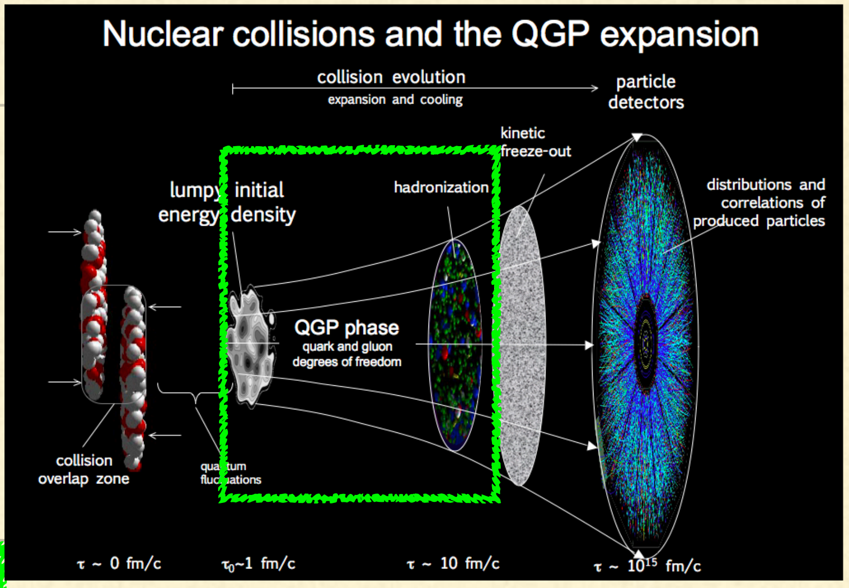


Many development over the decades (ideal → viscous → fluctuating hydrodynamics → ???)

What are next steps in the current fluctuating hydrodynamics?

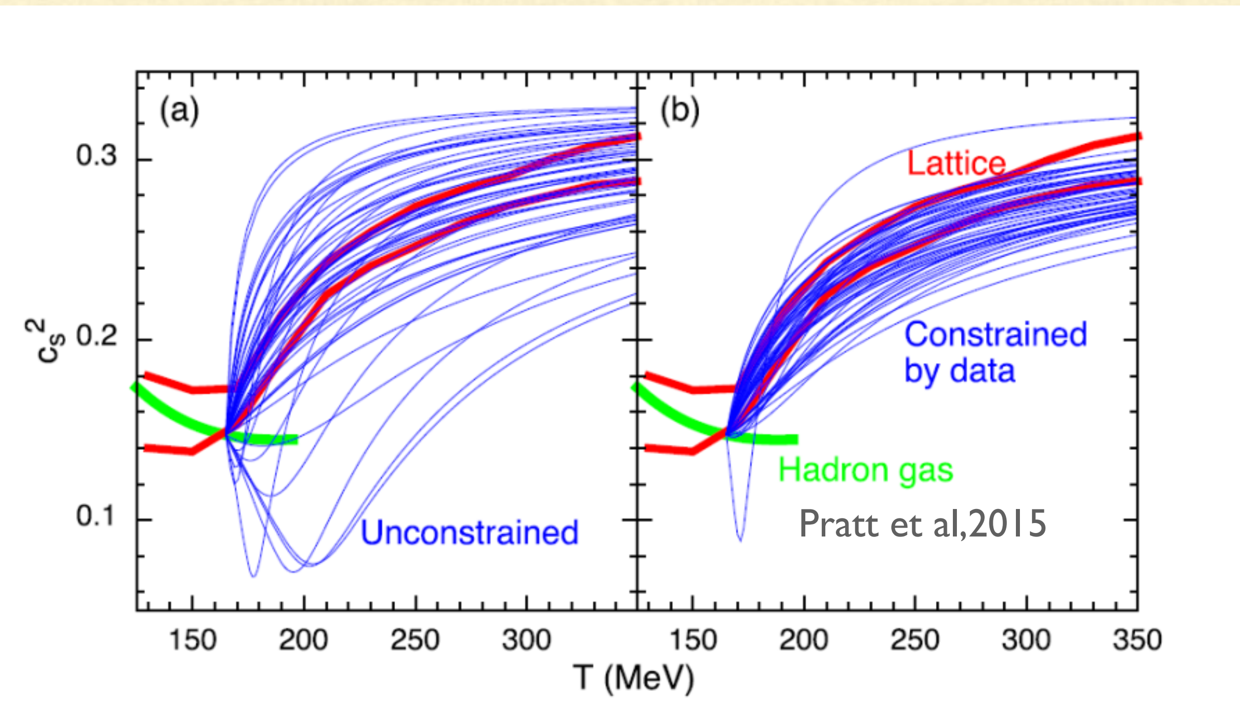
What we have to measure towards more reliable hydrodynamical models?

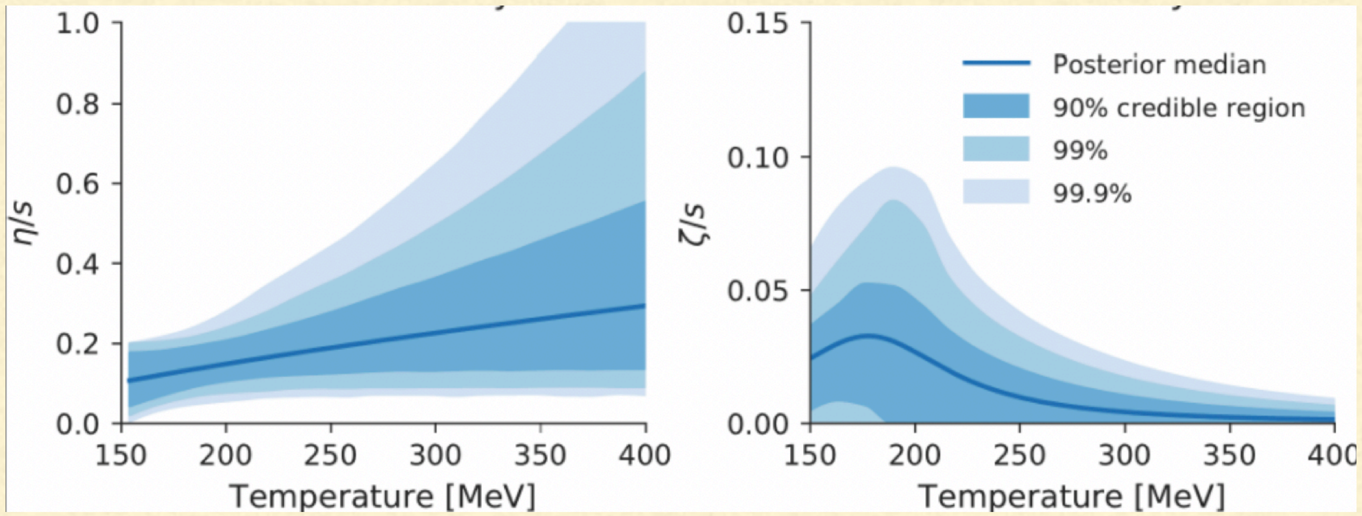
TRANSPORT PROPERTIES

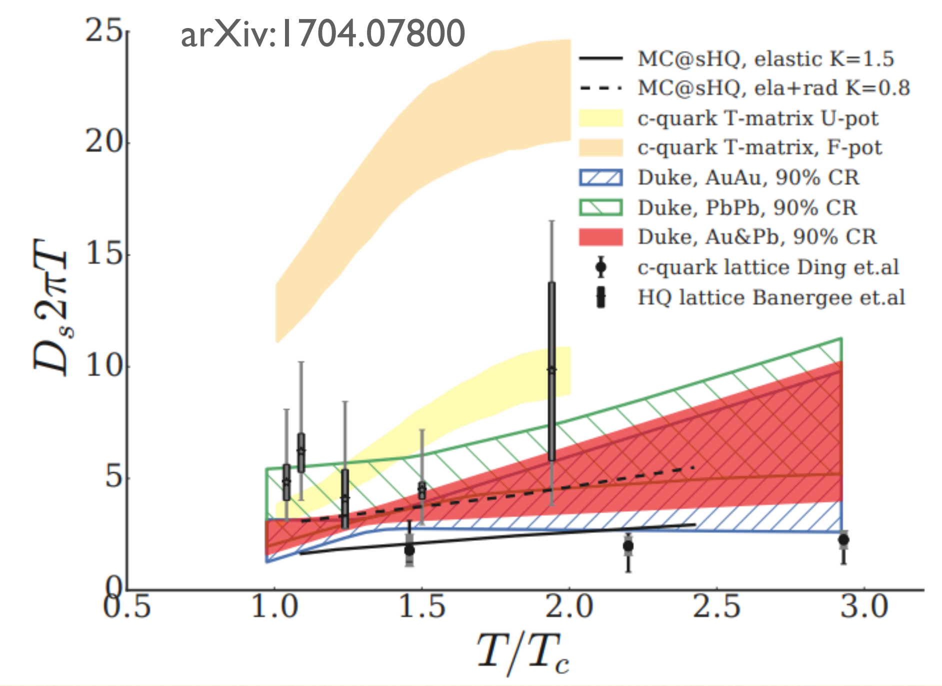


- **EoS, viscosity/entropy, diffusion constant**
  - **Recent development based on Bayesian analyses**

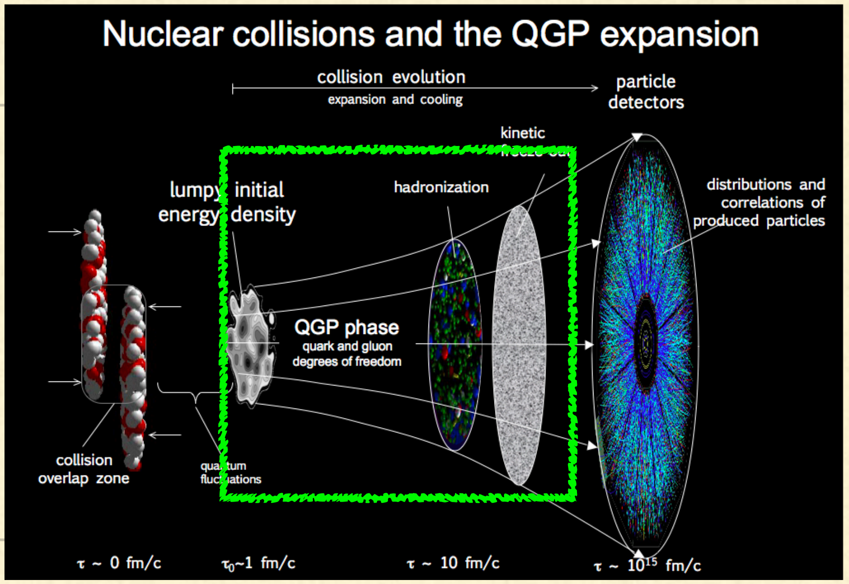
Paquet, QM2018







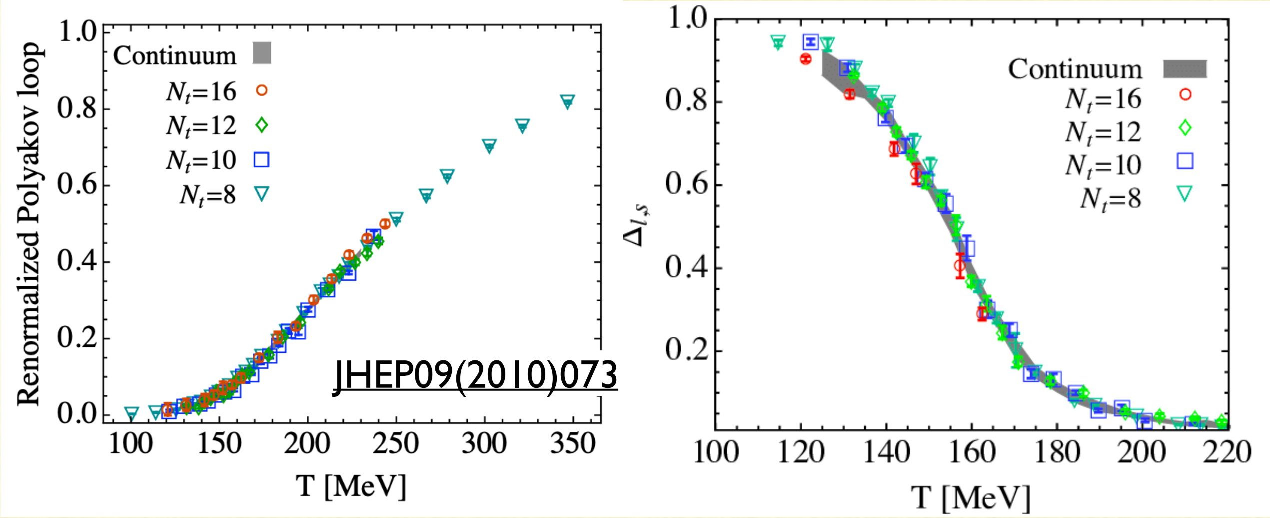
- Properties around Tc are relatively determined very well.
- What should we measure to access the properties at higher temperature?

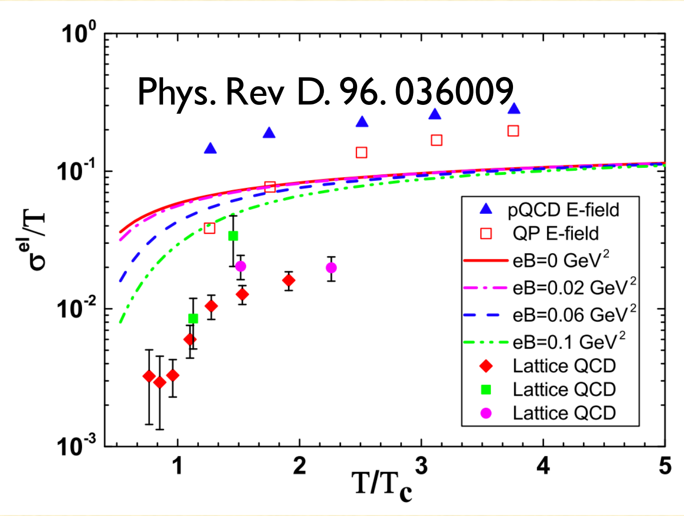


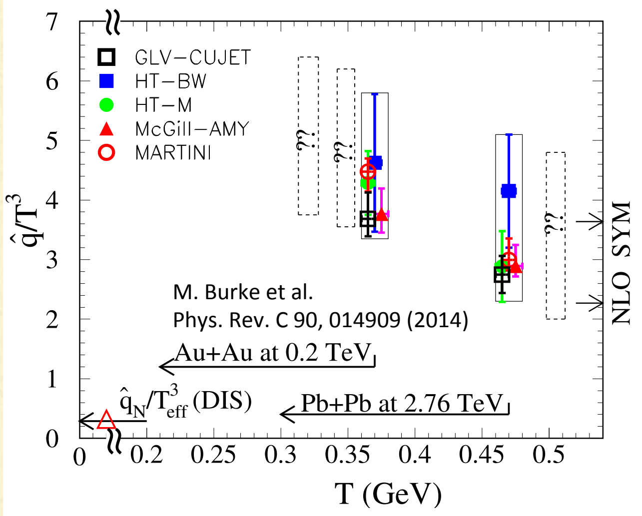
OTHER PROPERTIES

- **How about other properties?**
  - **Conductivity, correlation length, susceptibility, plasma frequency, degree of freedom**
- **Nature of QCD phase transition?**

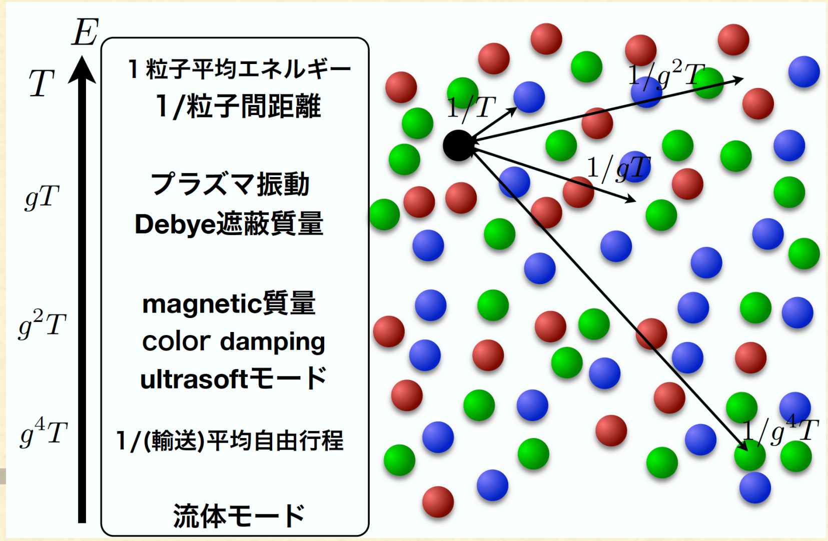
Phys. .Rev C.C90, 014909(2014)







- We only know some of the bulk properties (η/s, ζ/s, Ds…)
- How about other properties and what are the microscopic (short length) nature of the QGP?
- How to access those information experimentally?

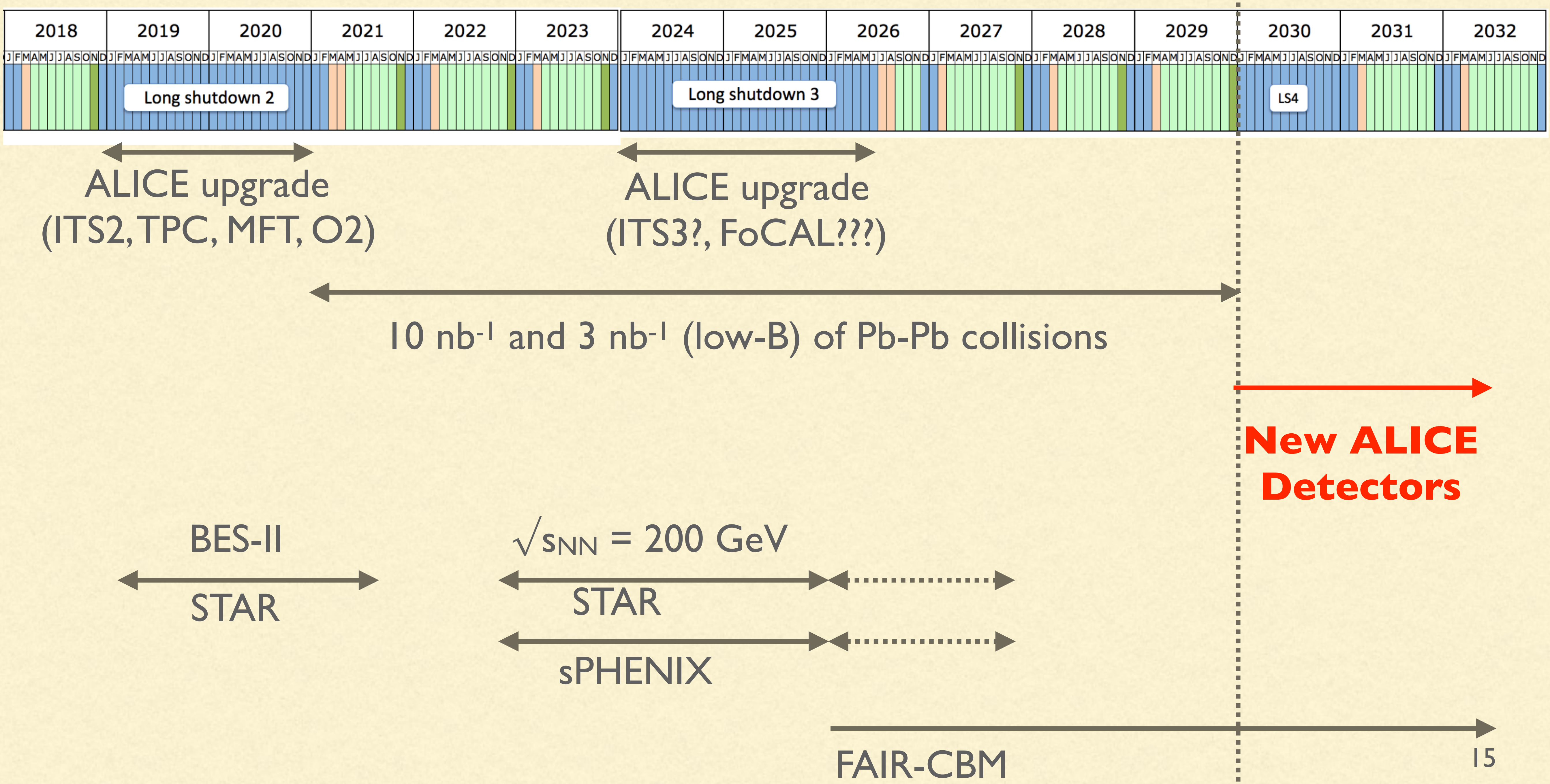


Hidaka, 2015

MY PERSONAL SHOPPING LISTS

1. Fixing Initial conditions
2. Detecting EM fields and detecting something related to the dynamics in pre-thermalization (very early stage of collisions)
3. Probing medium properties at high temperature regime
4. Studying other properties, especially microscopic properties
5. Detecting something related to the QCD phase transition
6. (Moving to the studies of high dense QCD matters - Quarkyonic and color superconductivity)

LONG TERM PLAN OF HI EXPERIMENTS



ALICE UPGRADE DURING LS2

New Inner Tracking System (ITS) *Novel MAPS technology*

- CMOS Active Pixel Sensors

→ improved resolution, less material, faster readout

New Muon Forward Tracker (MFT)

- CMOS Active Pixel Sensors

→ vertex tracker at forward rapidity

New TPC Readout Planes *Largest GEM application*

- 4-GEM detectors, new electronics

→ continuous readout

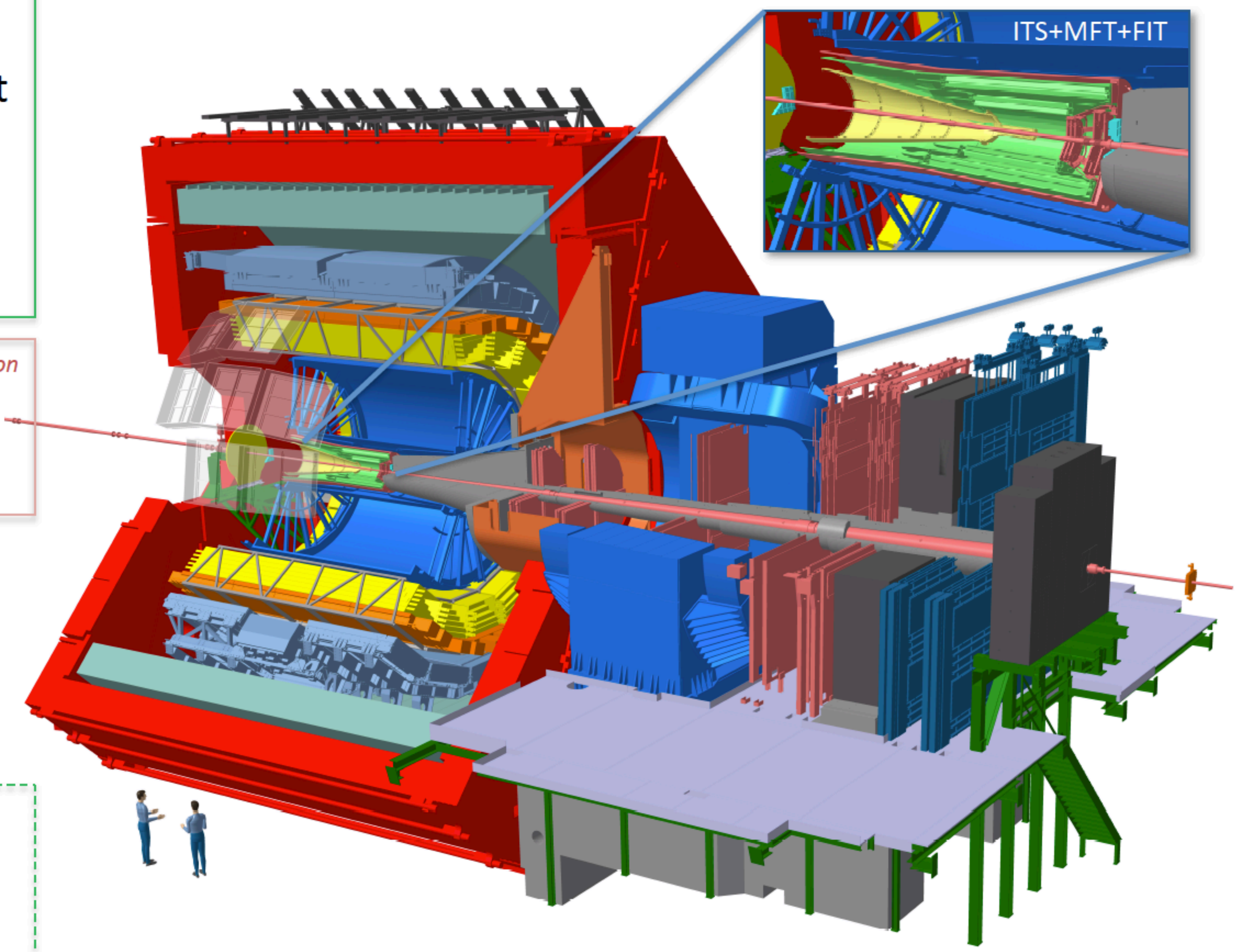
New trigger detectors (FIT, AD)

- Centrality, event plane

Upgrades readout for TOF, TRD, MUON, ZDC, Calor.

Integrated Online-Offline system (O^2)

- Record minimum-bias Pb-Pb data at > 50kHz (currently ~ 1 kHz)



x100 data taking capabilities after LS2 upgrade

ALICE UPGRADE DURING LS2

arXiv:1812.06772

CERN-LPCC-2018-07
December 18, 2018

Future physics opportunities for high-density QCD at the LHC with heavy-ion and proton beams

Report from Working Group 5 on the Physics of the HL-LHC, and Perspectives at the HE-LHC

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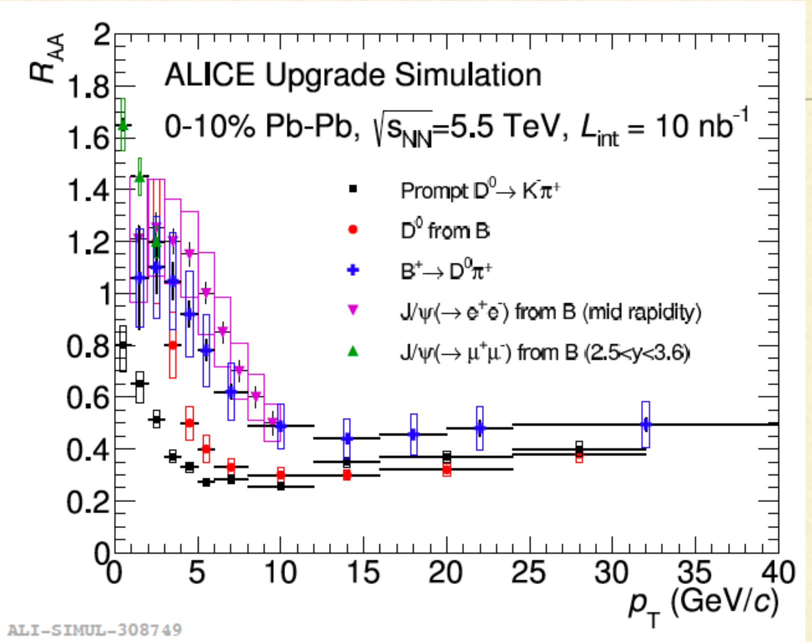
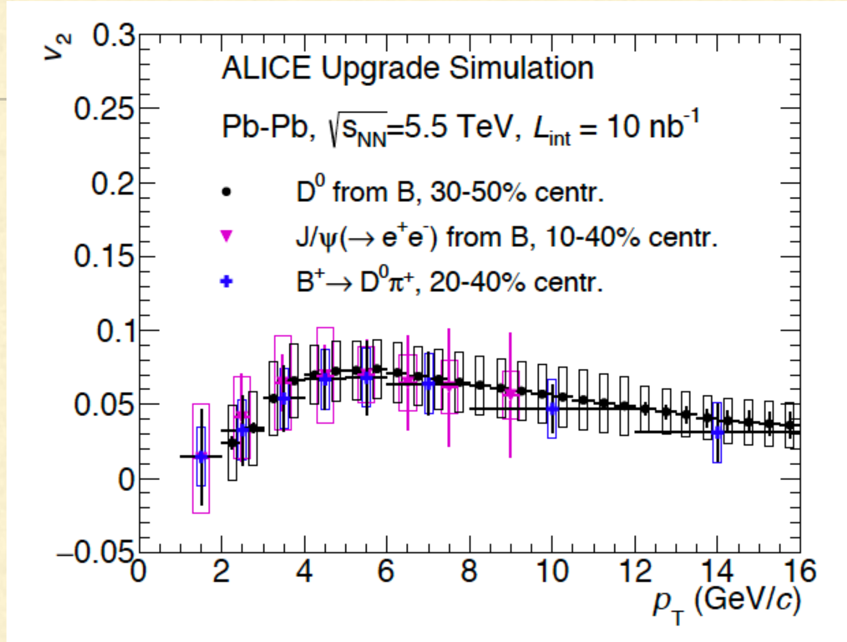
** deceased*

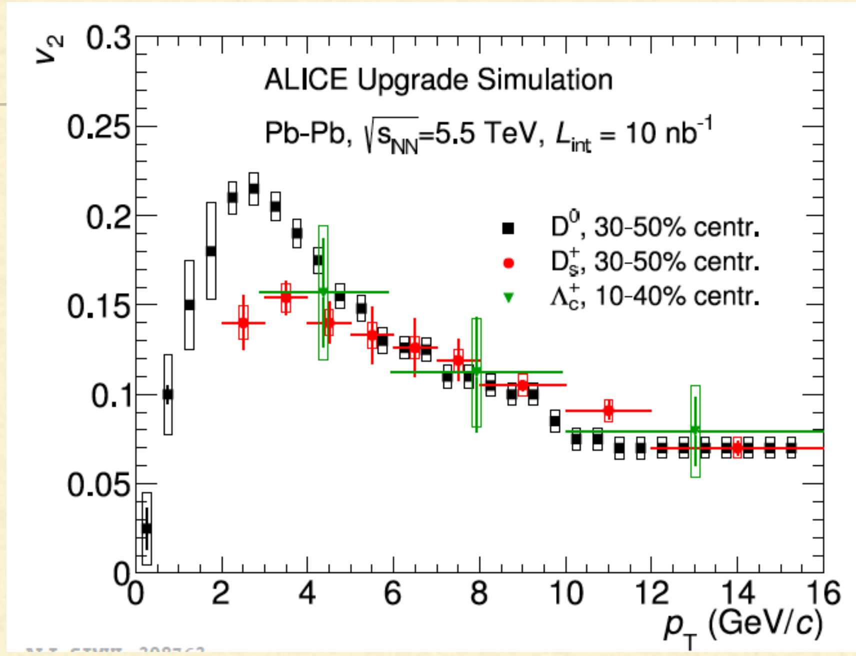
arXiv:1812.06772v1 [hep-ph] 17 Dec 2018

- Yellow Report that summarizes future prospects in Run3+4 (<2030):
  - Light flavor and Nuclei
  - Flow & correlations
  - **Open heavy flavor**
  - Jets and Parton energy loss
  - **Quarkonia**
  - **EM Radiation**
  - Small systems and UPC

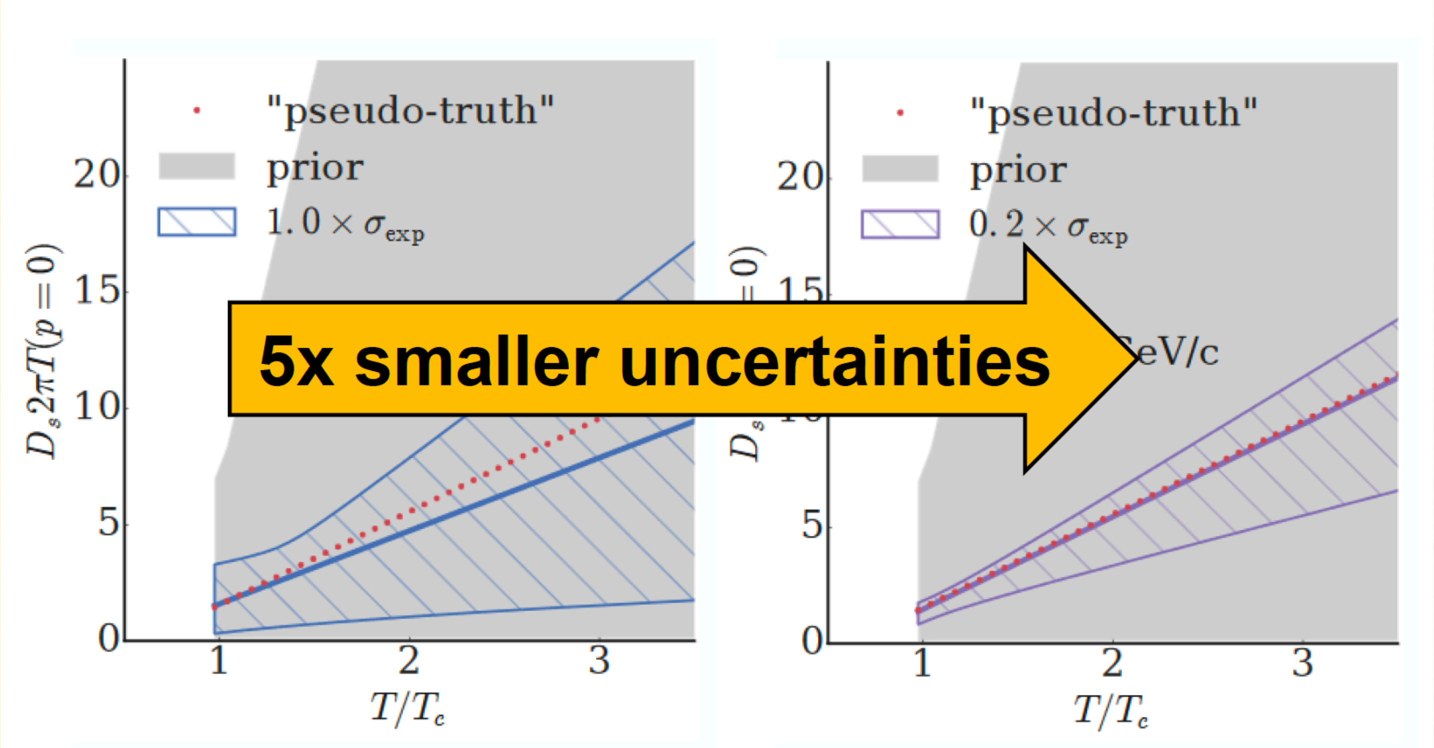
HEAVY FLAVOR







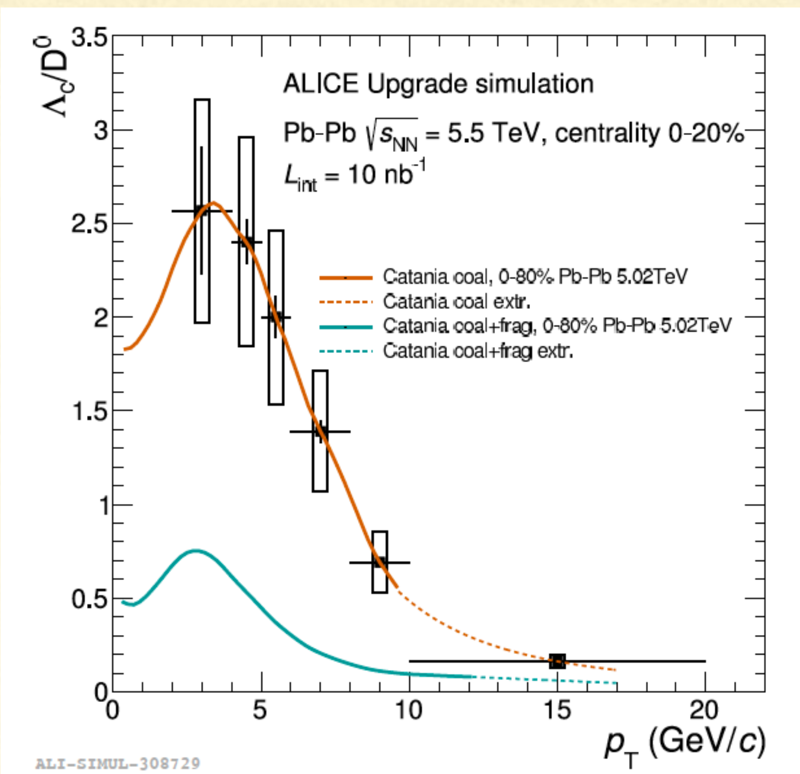
- First low p_T beauty measurements in ALICE
- Better constraint of diffusion constant at higher temperature
- Better v1 measurements

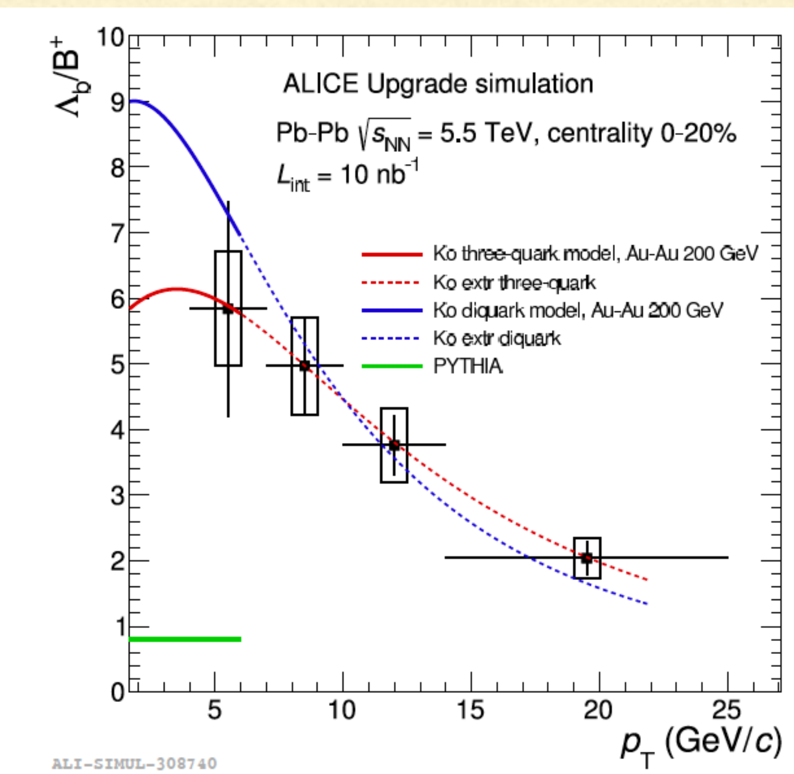


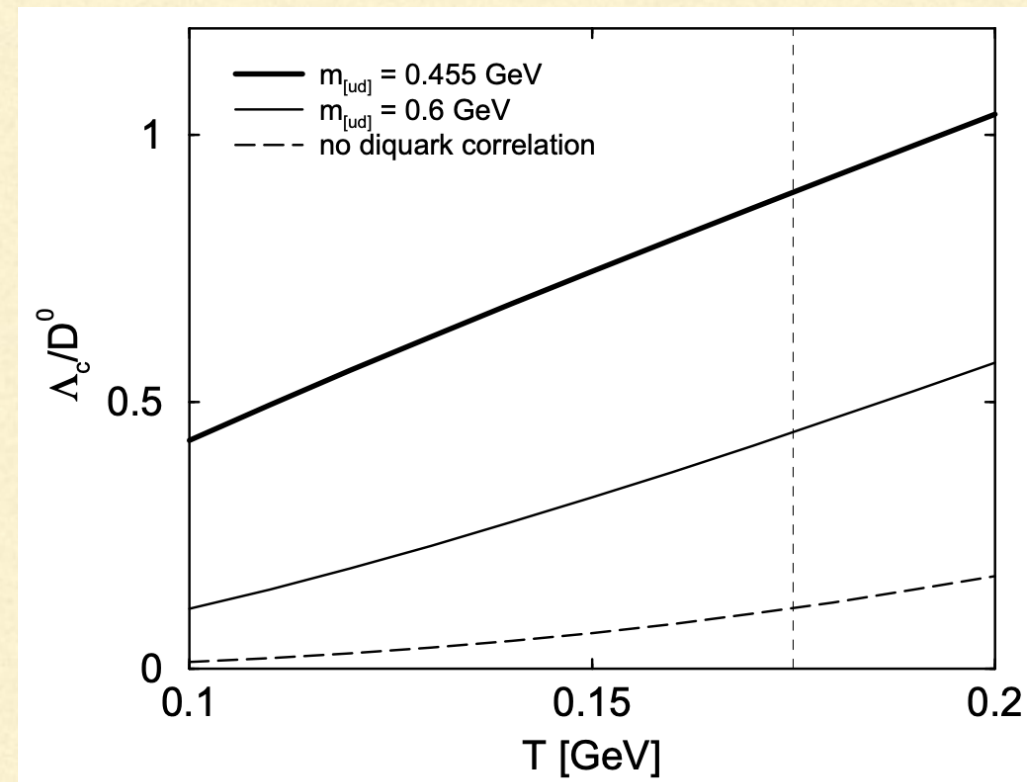
Stefan Bass, WG5 HI Meeting, 06.03.18

HEAVY FLAVOR

$$m_{[ud]} \approx m_u + m_d - C\,\vec{s}_u \cdot \vec{s}_d \frac{1}{m_u m_d} \approx 450\,\mathrm{MeV}$$

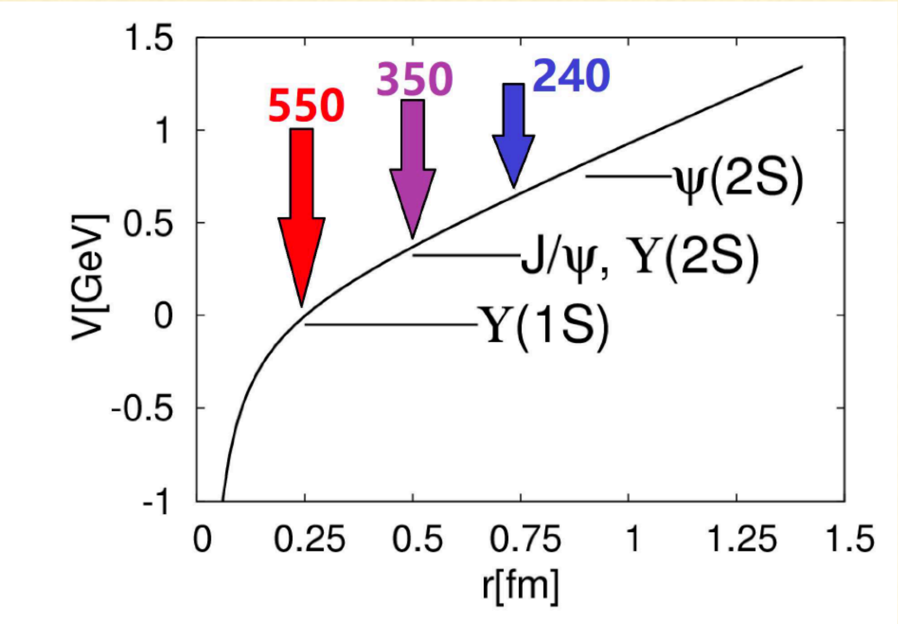




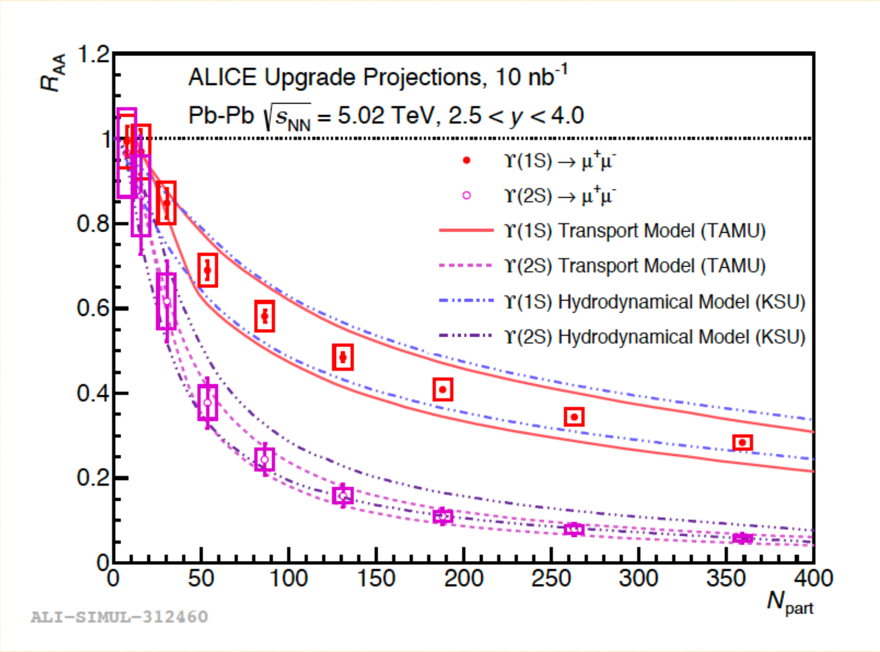


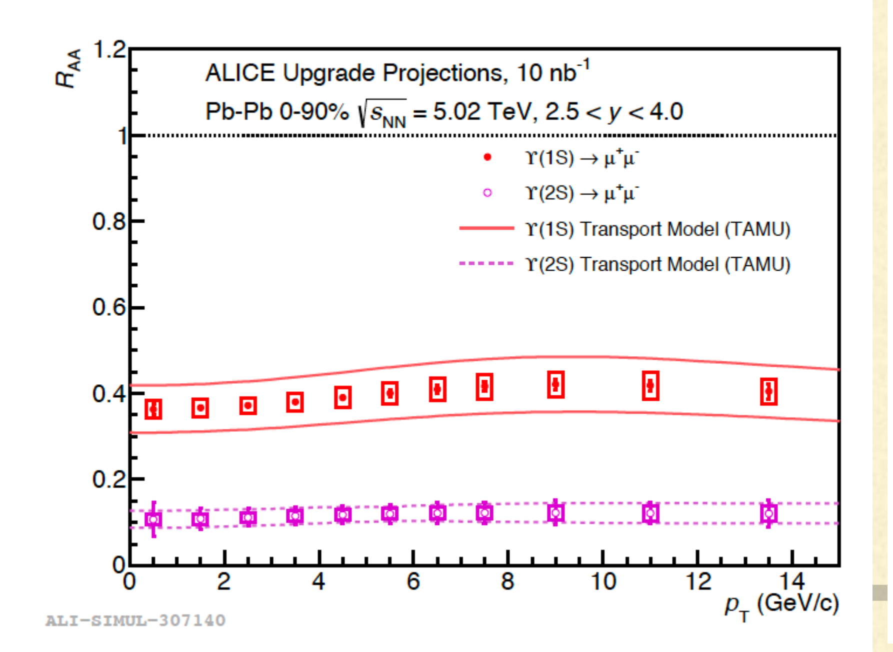
- First measurement of low p_T charm and beauty baryons (Λ_c, Λ_b, Ξ_c)
- Yield depends on di-quark correlation (→ effective degree of freedom, chiral symmetry restoration) in the QGP
  - Other baryon states(Ω_c, Ξ_b, Ω_b), double charm baryons(Ξ_{cc}, Ω_{cc}), exotic charm baryons(XYZ) will be the scope beyond 2030…

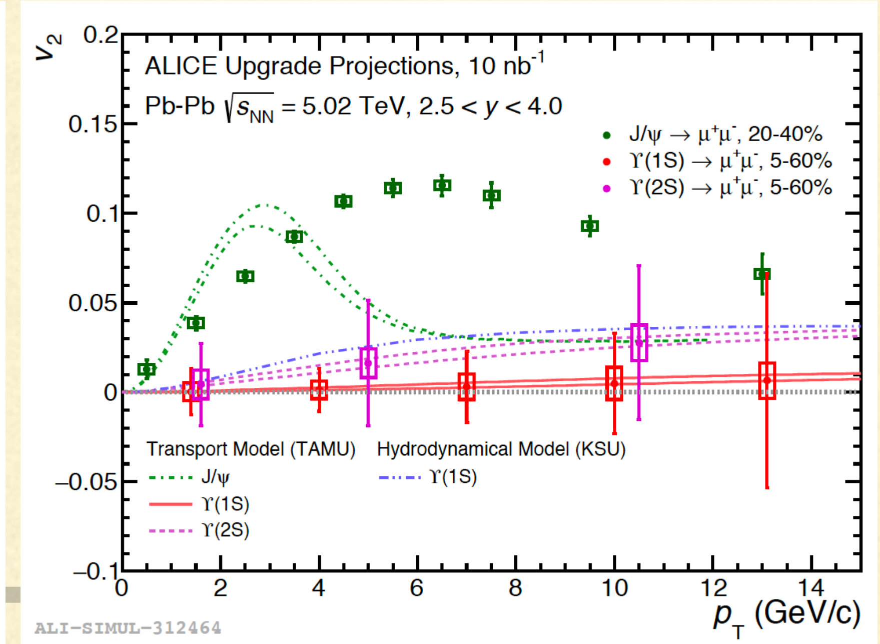
QUARKONIA



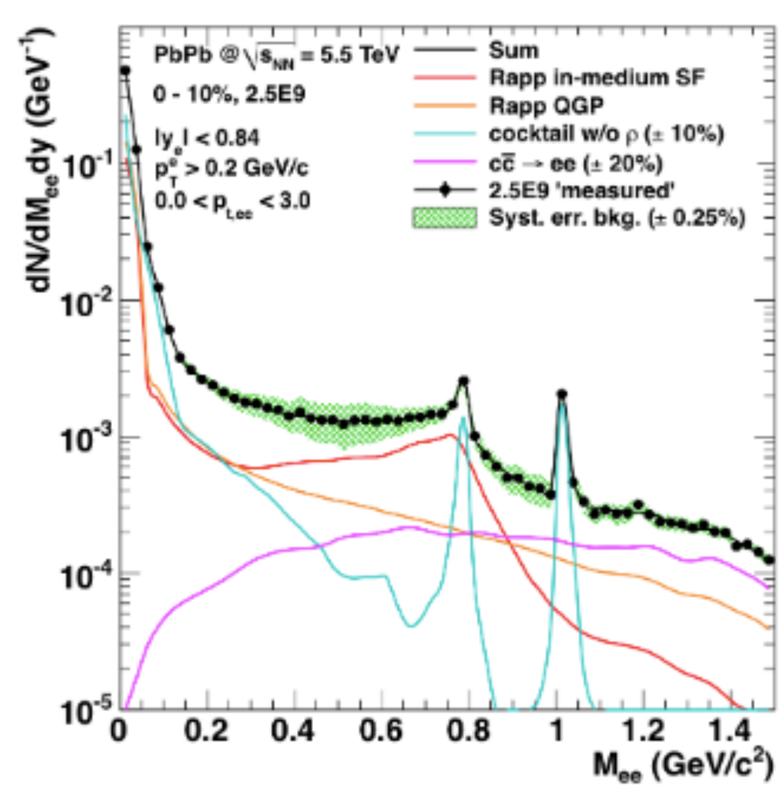
- Precise Υ measurements and J/ψ v2:
- Better understanding on correlation length of the QGP (→microscopic properties)
- Better understanding of charm dynamics in QGP

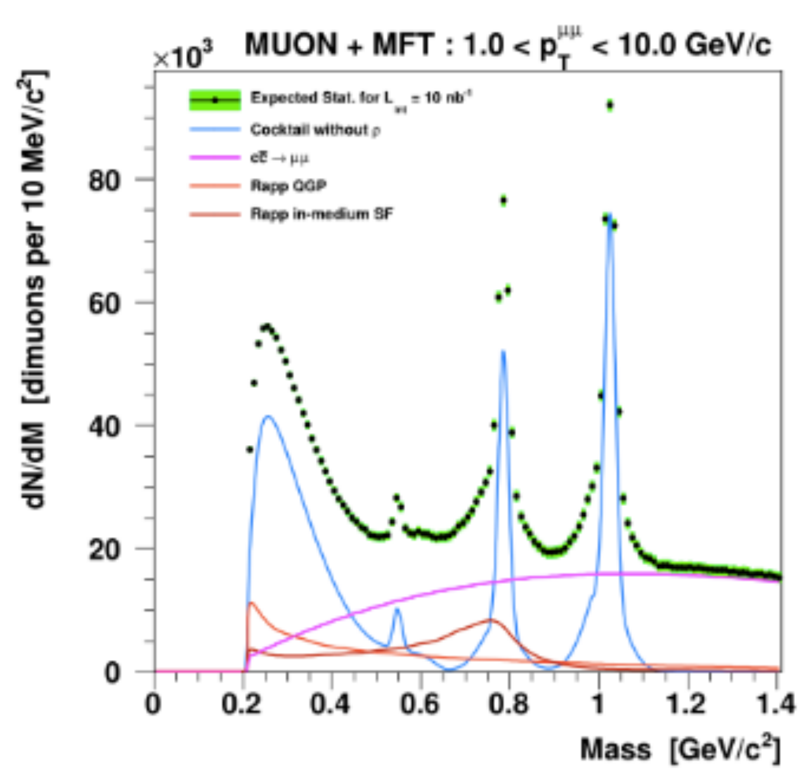


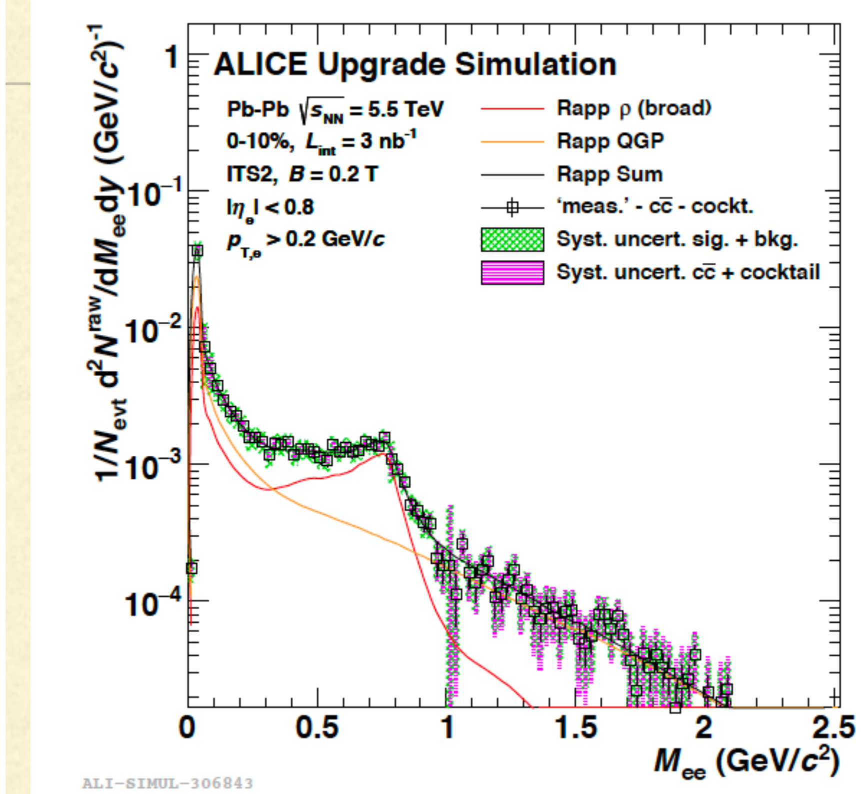




DILEPTON





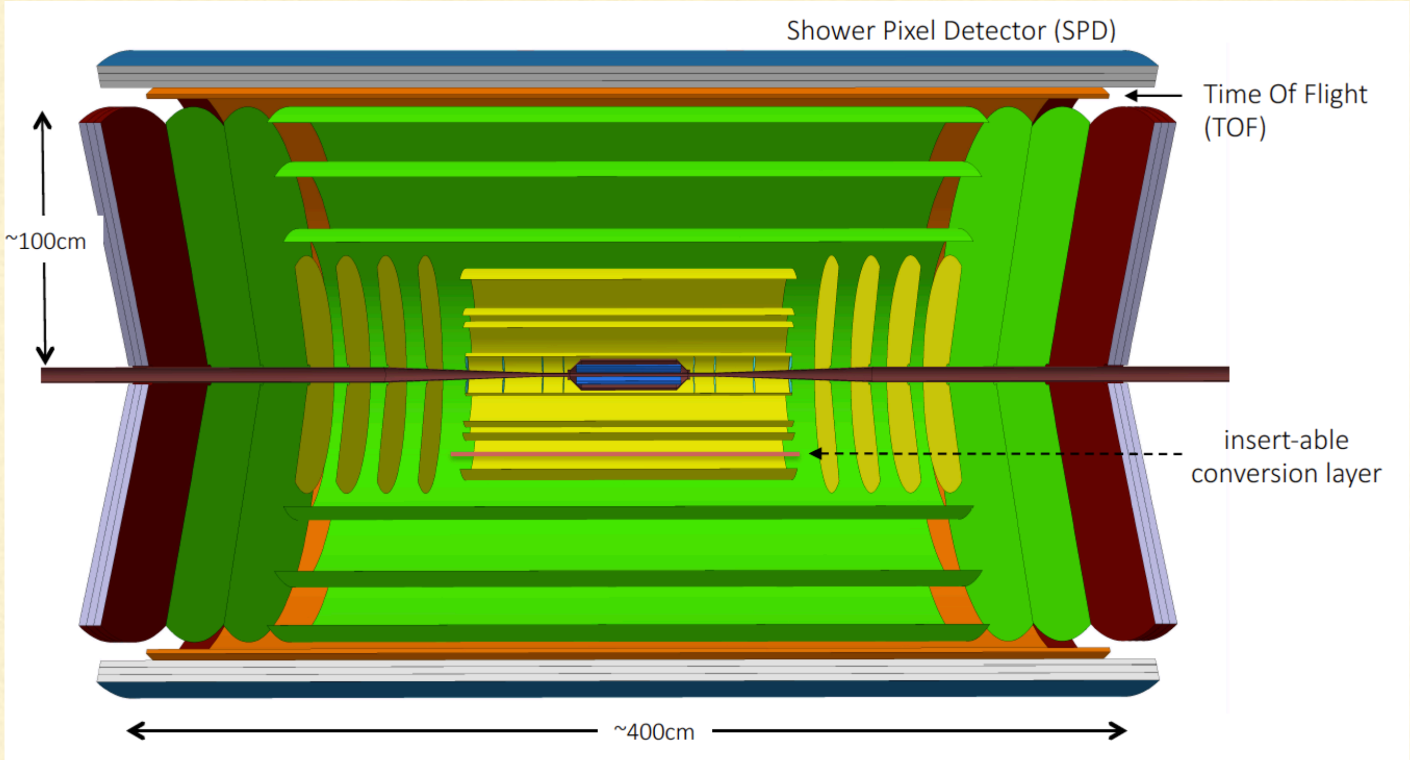


- First measurement of precise dielectron and dimuon measurements
  - Line shape of LVM → chiral symmetry restoration?
  - Thermal dielectrons → yield and v2 gives temperature dependent medium properties directly
  - Low energy (pT) dielectrons → electric conductivity
- Still qualitative level in Run3+Run4. Quantitative studies beyond 2030?

ALICE BEYOND 2030

- ALICE is now thinking further upgrade beyond 2030
- Compact detectors all made of Silicon Technologies

arXiv:1902.01211



A next-generation LHC heavy-ion experiment

Authors

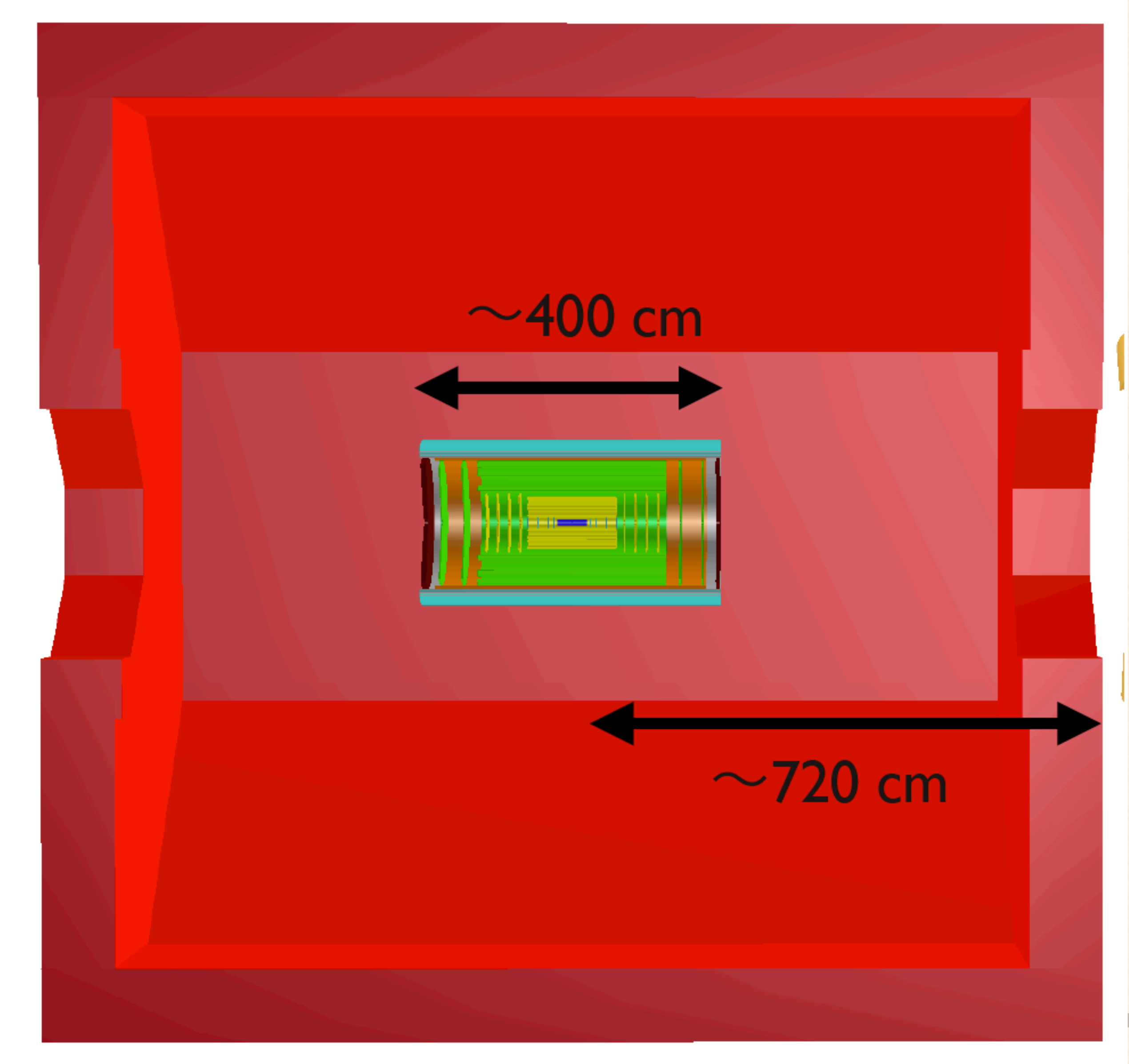
Abstract

The present document discusses plans for a compact, next-generation multi-purpose detector at the LHC as a follow-up to the present ALICE experiment. The aim is to build a nearly massless barrel detector consisting of truly cylindrical layers based on curved wafer-scale ultra-thin silicon sensors with MAPS technology, featuring an unprecedented low material budget of 0.05% X_0 per layer, with the innermost layers possibly positioned inside the beam pipe. In addition to superior tracking and vertexing capabilities over a wide momentum range down to a few tens of MeV/c, the detector will provide particle identification via time-of-flight determination with about 20 ps resolution. In addition, electron and photon identification will be performed in a separate shower detector. The proposed detector is conceived for studies of pp, pA and AA collisions at luminosities a factor of 20 to 50 times higher than possible with the upgraded ALICE detector, enabling a rich physics program ranging from measurements with electromagnetic probes at ultra-low transverse momenta to precision physics in the charm and beauty sector.

Geneva, Switzerland
December 10, 2018

ALICE BEYOND 2030

- ALICE is now thinking further upgrade beyond 2030
- Compact detectors all made of Silicon Technologies



There are many empty spaces in L3 magnet.

What we should measure beyond 2030? Which detectors we should install and where?

ALICE BEYOND 2030

Discussion: What we really should measure?

- **Precision Studies of Heavy Flavor Baryons**
  - Precision measurements of Λc, Λb, Ξc, Ξb, Ωc, Ωb,,,,
  - Multi Heavy Flavor baryons (Ξcc, Ωcc, Ωccc)
  - Exotic hadrons (X, Y, Z, Pc,)

→ di-quark correlations & di-quark mass = effective degree of freedom, chiral symmetry restoration

- **v1 of HF hadrons (c and b) over wide rapidity ranges**

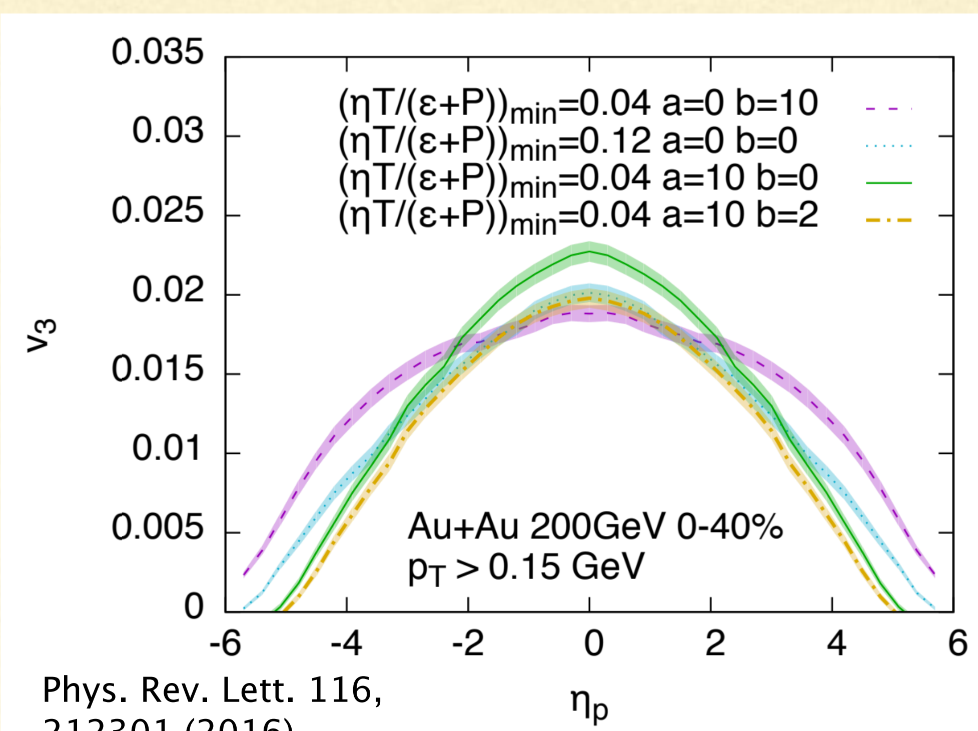
→ understanding of early stage of dynamics and evolution of EM fields and conductivity

ALICE BEYOND 2030

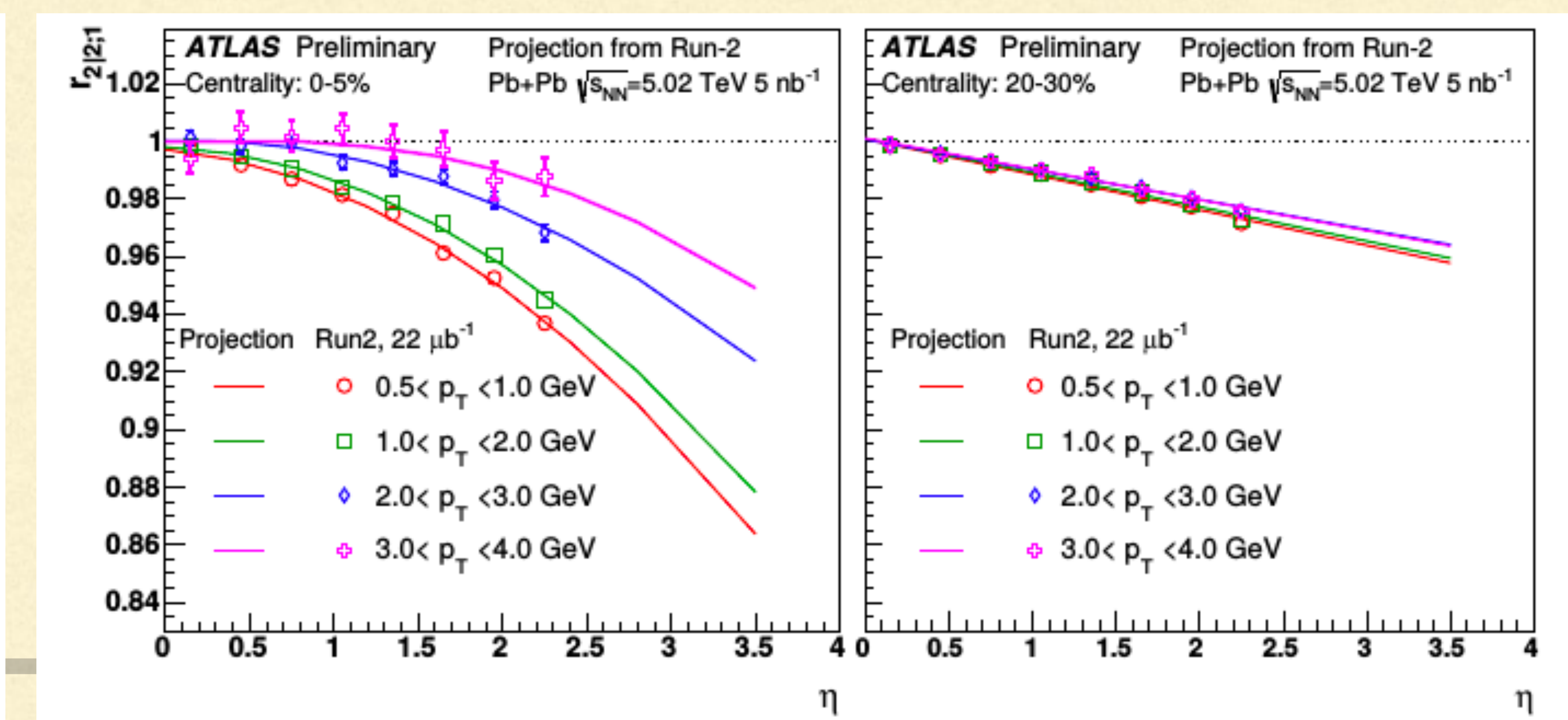
Discussion: What we really should measure?

- **Flow of PID hadrons and HFers over wide rapidity ranges (and down to zero pT for B)**
- **Flow factorization over wide rapidity ranges**
  - **PID dependence?**

→ understanding of η/s(T) and hydro fluctuations



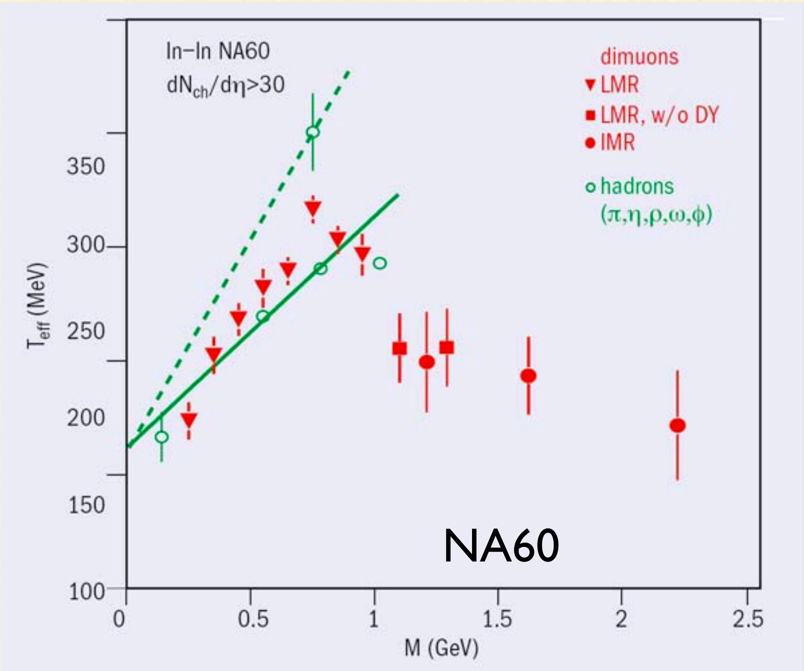
Phys. Rev. Lett. 116, 212301 (2016)

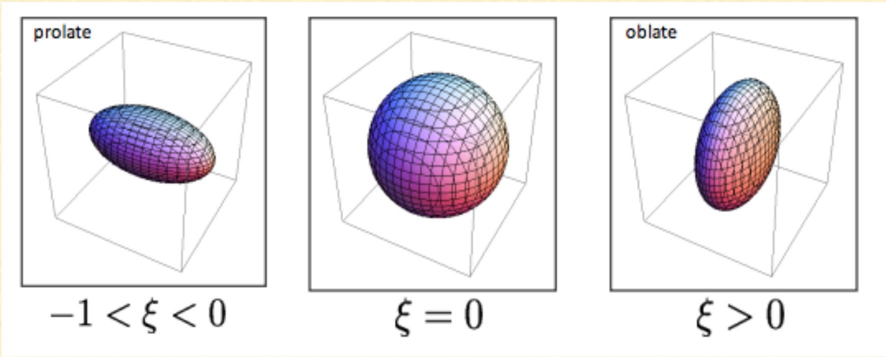


ALICE BEYOND 2030

Discussion: What we really should measure?

- **Precision measurements of Quarkonia**
  - χ_{c0}, χ_{c1}, χ_{c2}, χ_{b1}, χ_{b2}, …
- **Precision measurements of dileptons and photons over wide range**
  - Emission from partonic phases
  - Some hints of pre-thermalzation stage (quark distribution functions)





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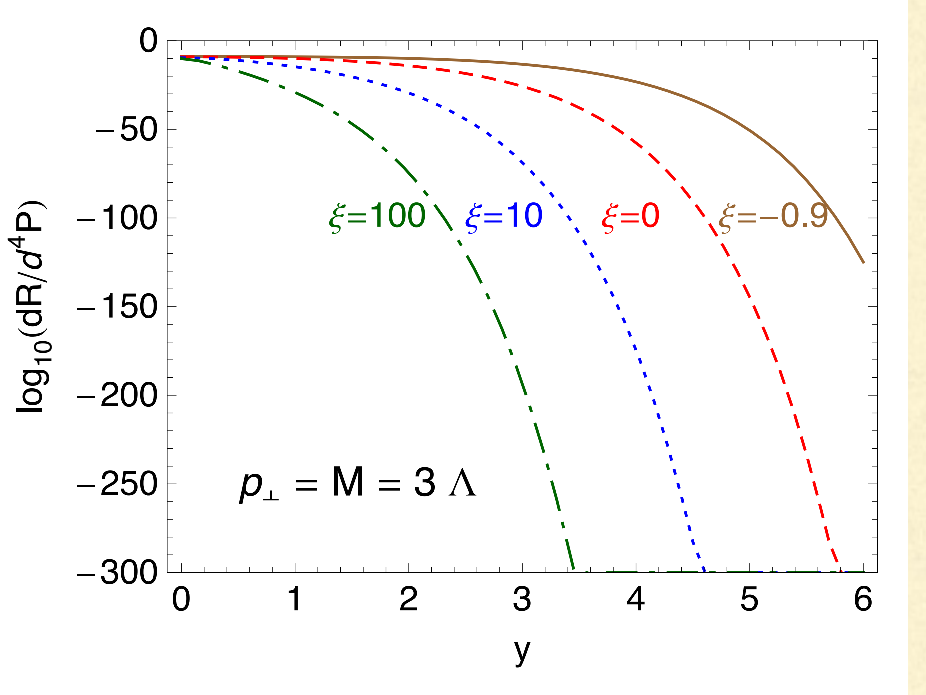
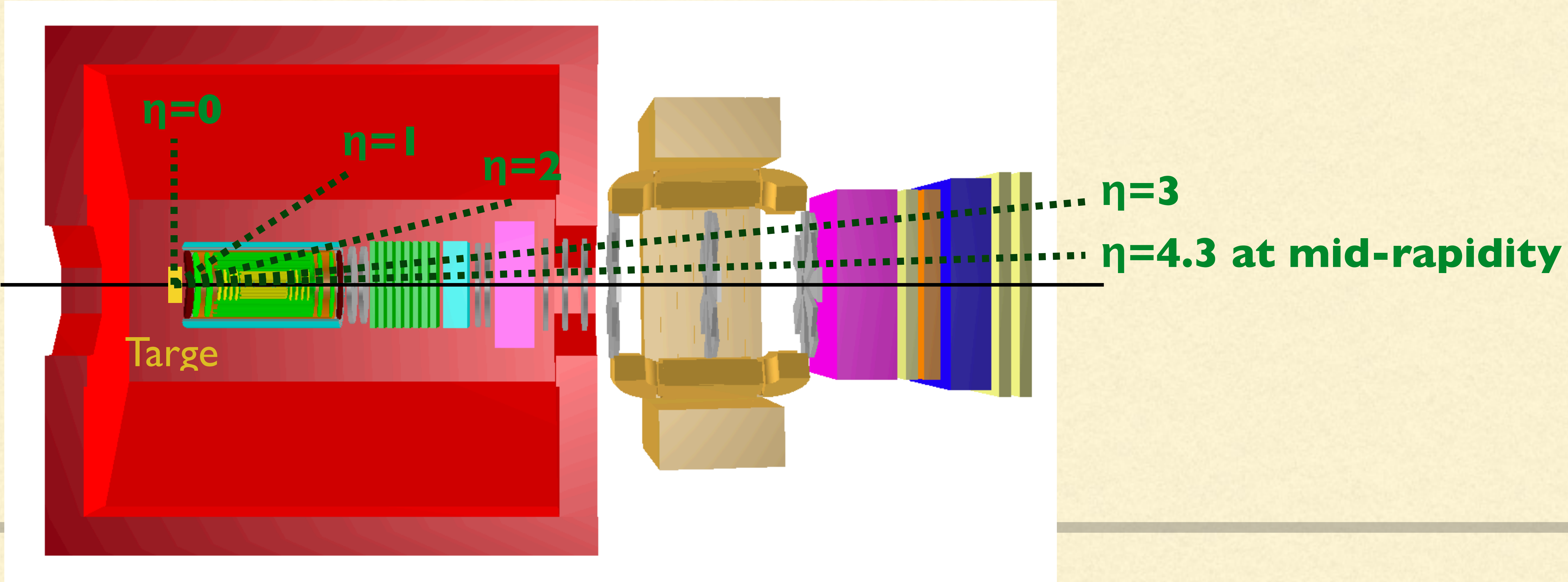
Phys. Rev. D 92, 025026 (2015)



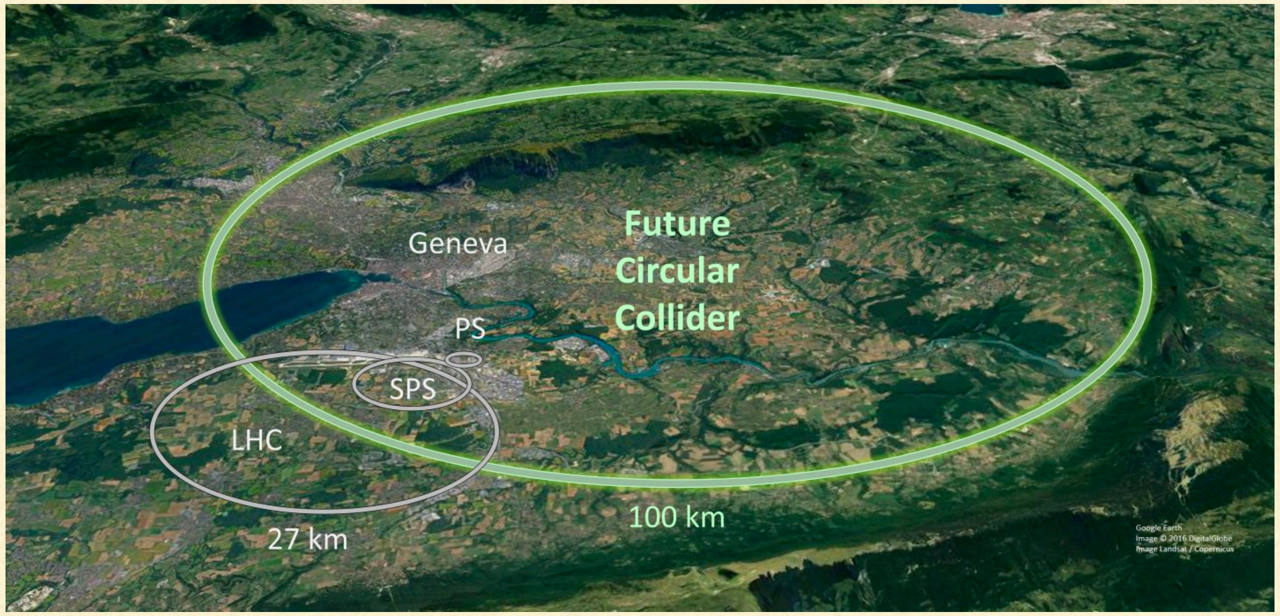
ALICE BEYOND 2030

Discussion: What we really should measure?

- Fixed target experiment:
  - This fixed target will be a unique place to cover $\sqrt{s_{NN}}$ ~ 70 GeV beyond 2030…
  - LHCb like PID detectors in forward region
  - Forward PID v_n, heavy flavors, thermal and high M/pT dileptons,



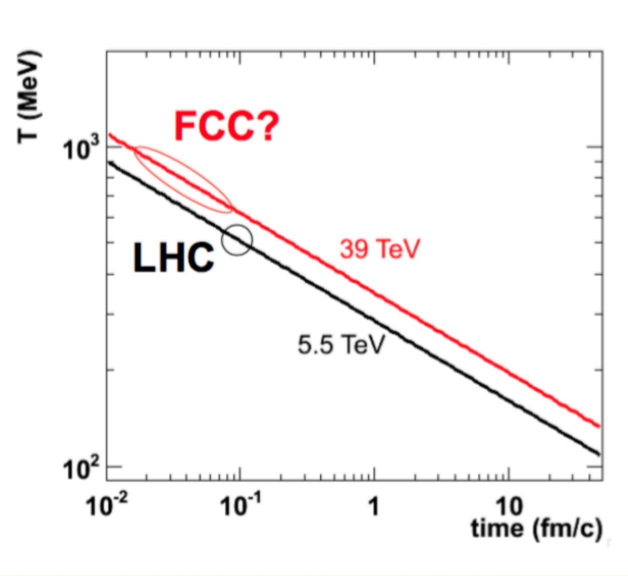
FUTURE CIRCULAR COLLIDER

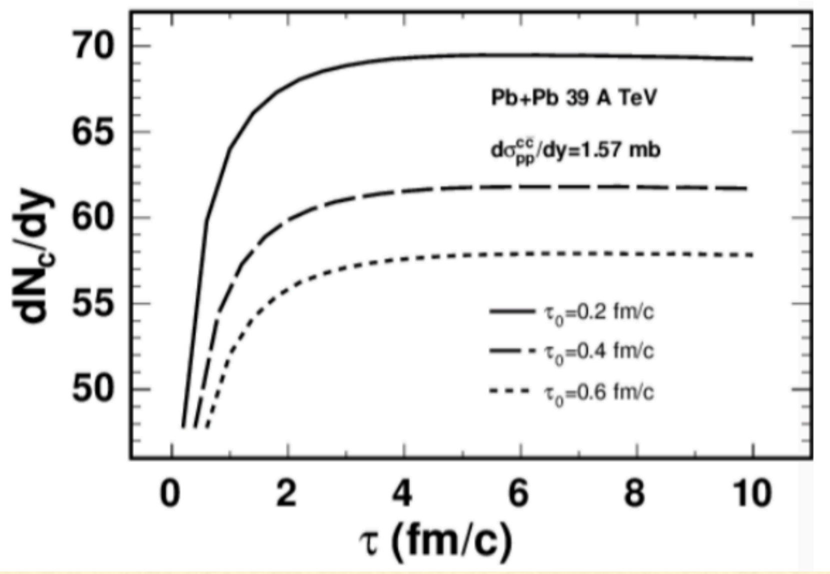


Quantity	Pb–Pb 2.76 TeV	Pb–Pb 5.5 TeV	Pb–Pb 39 TeV
$dN_{ch}/d\eta$ at $\eta = 0$	1600	2000	3600
$dE_T/d\eta$ at $\eta = 0$	1.8–2.0 TeV	2.3–2.6 TeV	5.2–5.8 TeV
Homogeneity volume	5000 fm^3	6200 fm^3	11000 fm^3
Decoupling time	10 fm/c	11 fm/c	13 fm/c
ε at $\tau = 1$ fm/c	12–13 GeV/fm^3	16–17 GeV/fm^3	35–40 GeV/fm^3

- FCC: 100km accelerator after LHC
- FCC-hh : 2045 as earliest. Lumi ~ x10 LHC

arXiv:1605.01389





- Some interesting observables:
  - Thermal photons and dileptons
  - Thermal charm production
  - Y(1S) regeneration
  - Boosted top quark energy loss
  - Gluon saturation

SUMMARY

- Many developments, improvements, and progress in heavy-ion physics
- But still there are many things to understand.
  - Initial conditions, pre-thermalization, EM fields, medium properties at high temperature, micro-scopic properties, QCD phase transition…
- ALICE upgrade in LS2, Future ALICE upgrade beyond 2030, and FCC
  - Any feedbacks from theorists are very welcome.
  - What do you want us to measure?
    - For me, dilepton, heavy flavors, and quarkonia are of special interests…