UFBA

LISHEP 2018

International School on High Energy Physics

ALICE Status and Highlights

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for the ALICE Collaboration

UNICAMP

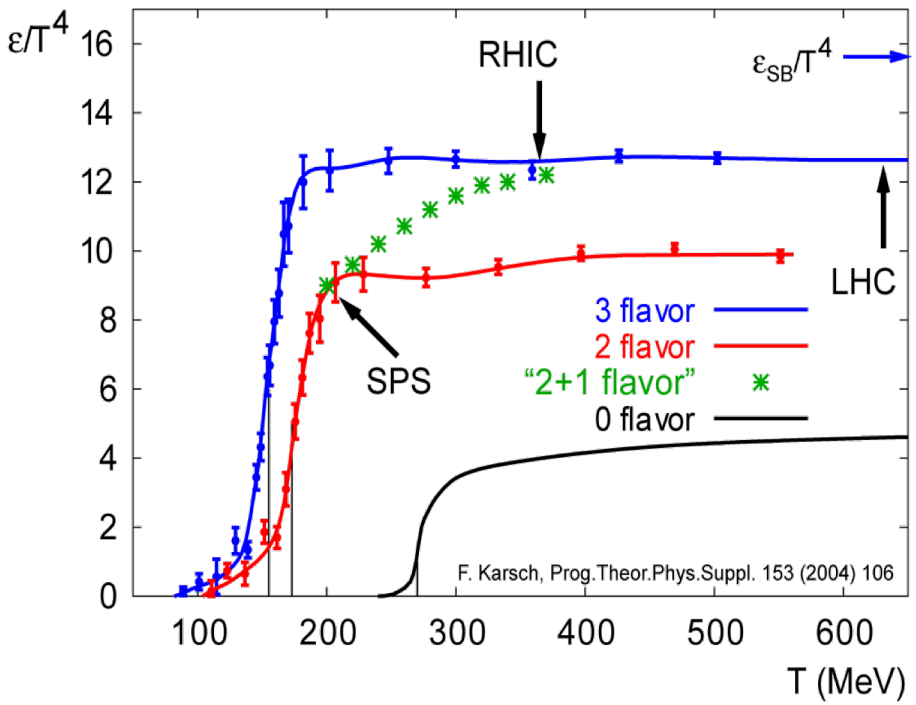
ALICE

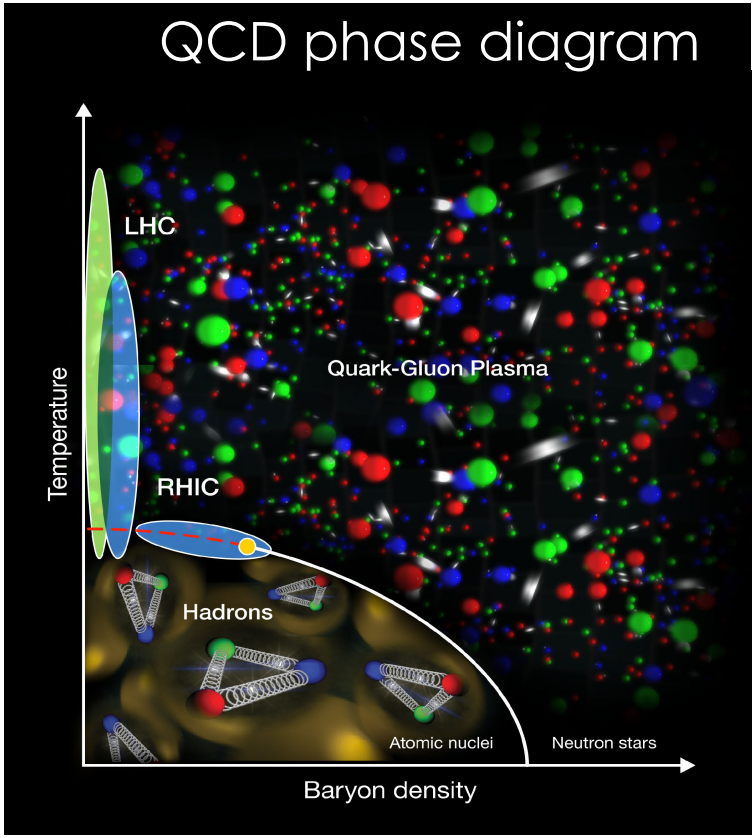
CNPq

Conselho Nacional de Desenvolvimento Científico e Tecnológico

FAPESP

Fundamental Interaction
&
Collective behavior



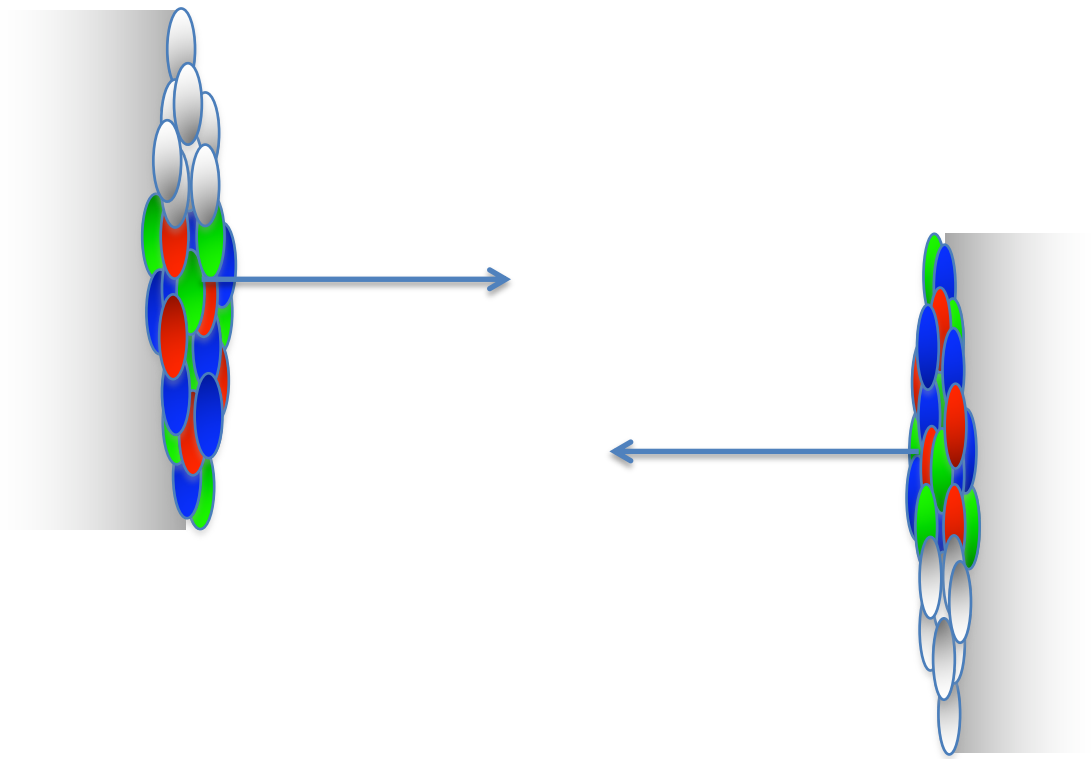


Exploring the QCD phase diagram with Heavy Ion Collisions

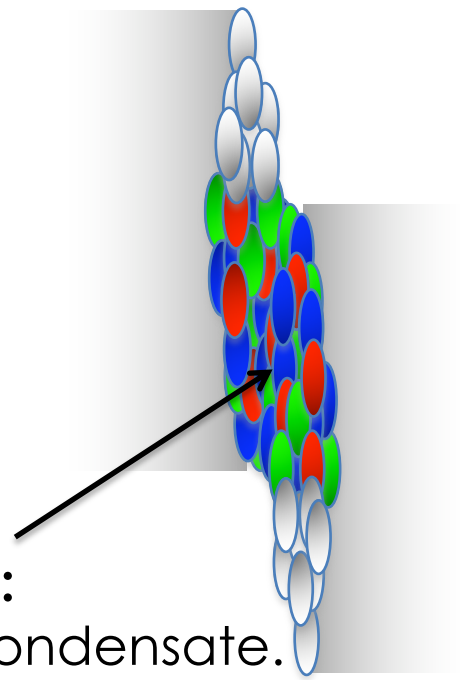
"In order to study the question of "vacuum"; …; we should investigate some bulk phenomena by distributing high energy over a relatively large volume."

T.D.Lee, Rev. Mod. Phys. 47 (1975) 267

Heavy-Ion Collisions

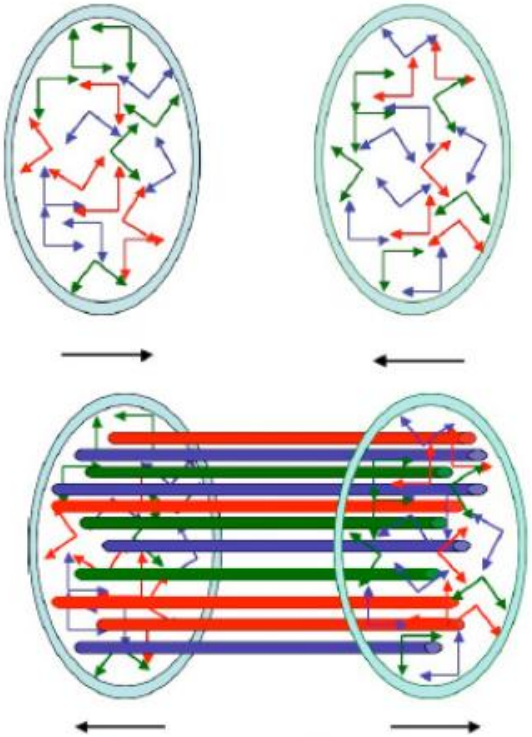


Initial Condition



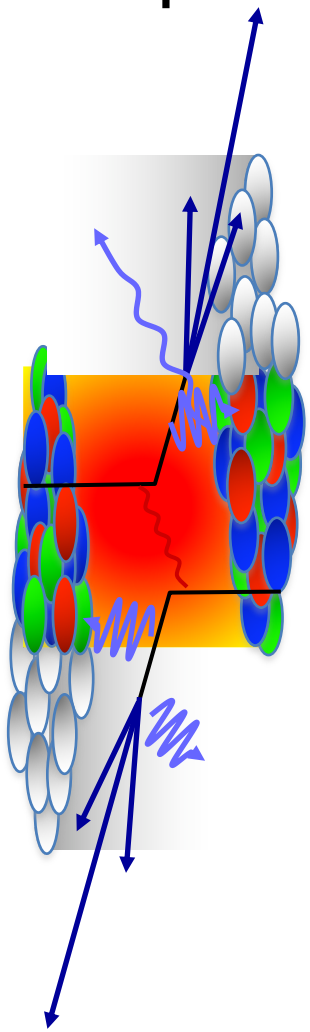
Initial Conditions:

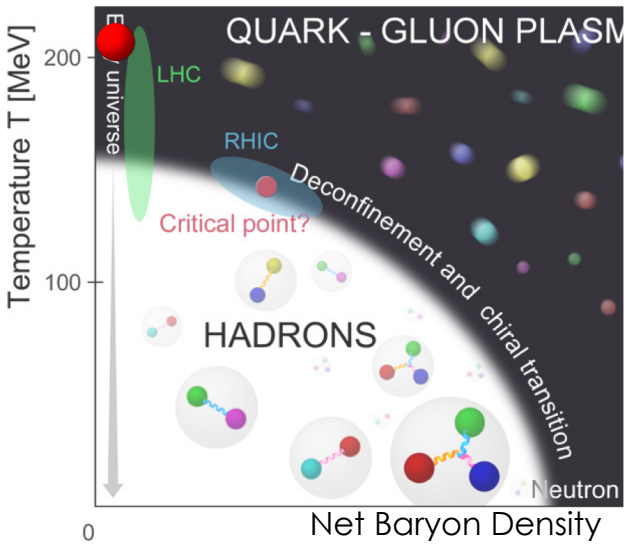
- Color Glass Condensate.
- Gluon Saturation Models. (Glasma)
- Density Fluctuations.



"Instantaneously" develop longitudinal color E and B fields

Pre-equilibrium phase

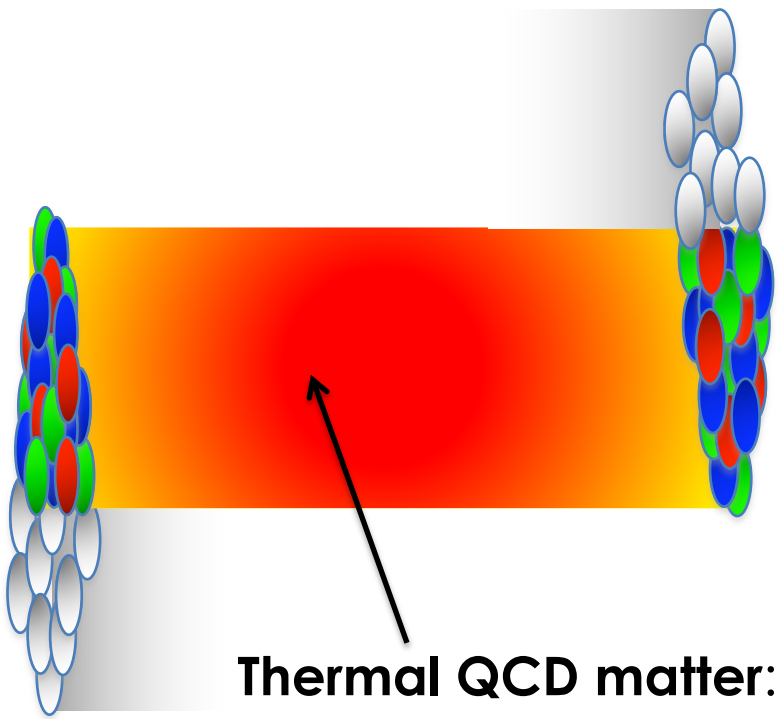


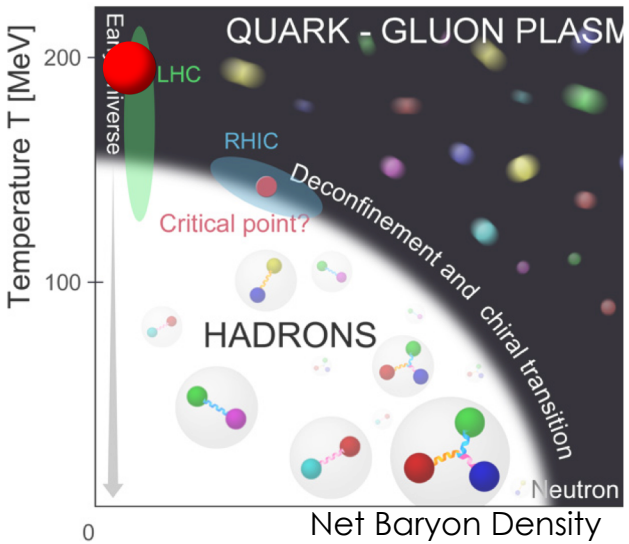


Hard Scatterings:

- Pre-equilibrium.
- Parton Distribution Functions.
- High p_T particles.
- Particle Jets.
- Heavy flavored particles.

Hot QCD Matter

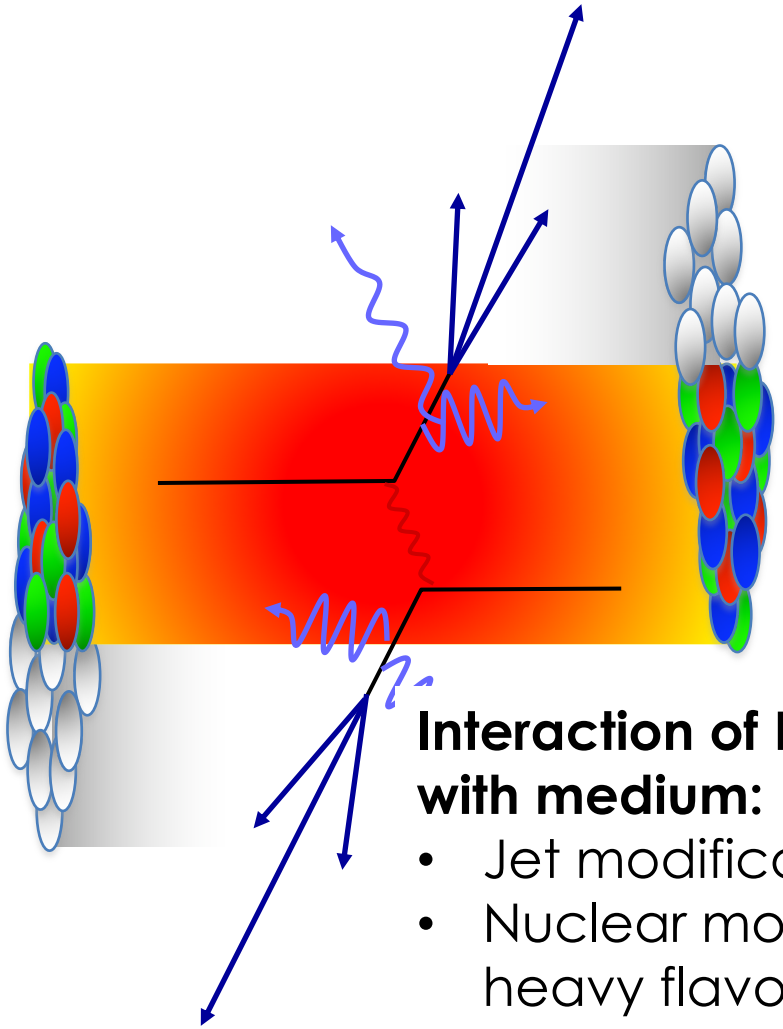


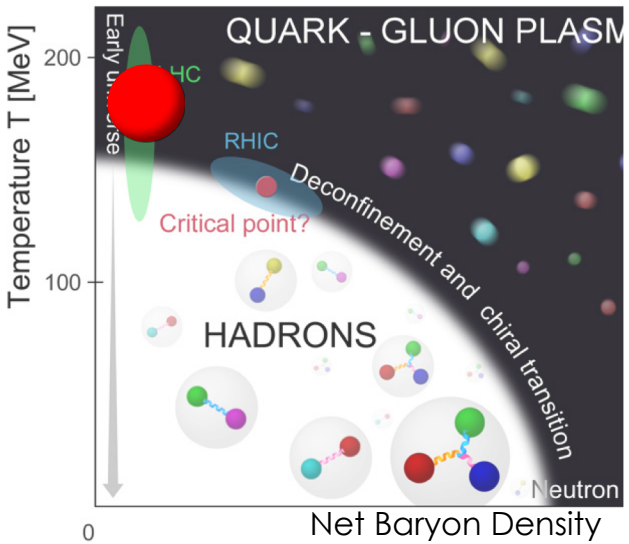


Thermal QCD matter:

- Extremely Dense & Strongly interacting.
- Collective behavior.
- Hydrodynamic Expansion with low viscosity.
- Partonic degrees of freedom.

Hot QCD Matter

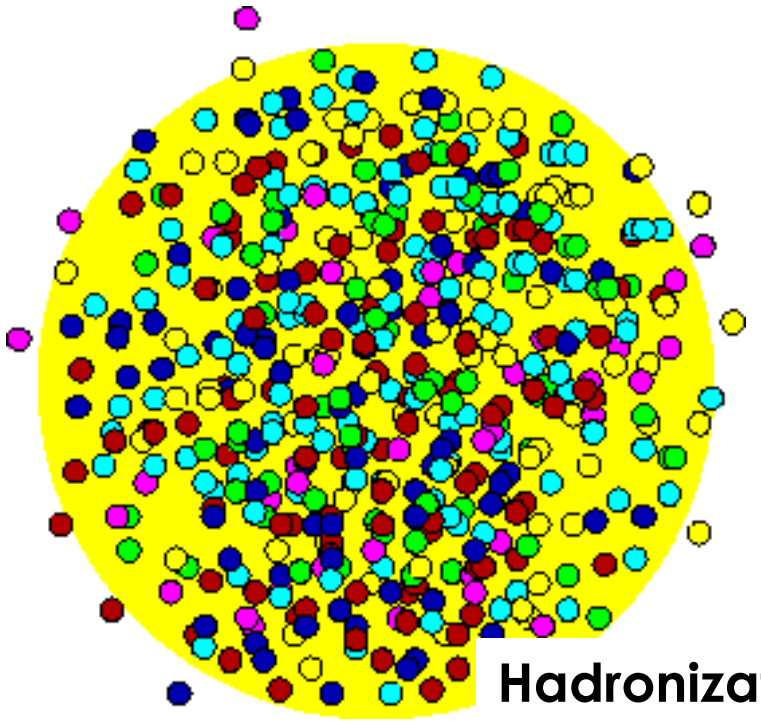


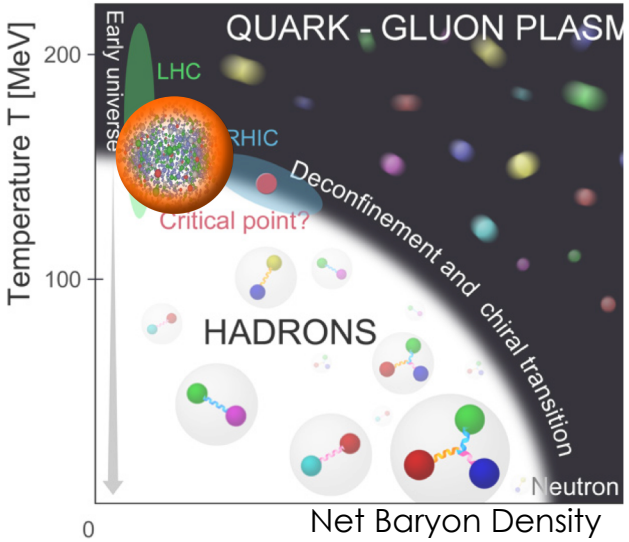


Interaction of High p_T (>~4 GeV/c) particles with medium:

- Jet modification and suppression.
- Nuclear modification factors of light and heavy flavored particles.
- Affects signatures of collectivity.

Hadronization

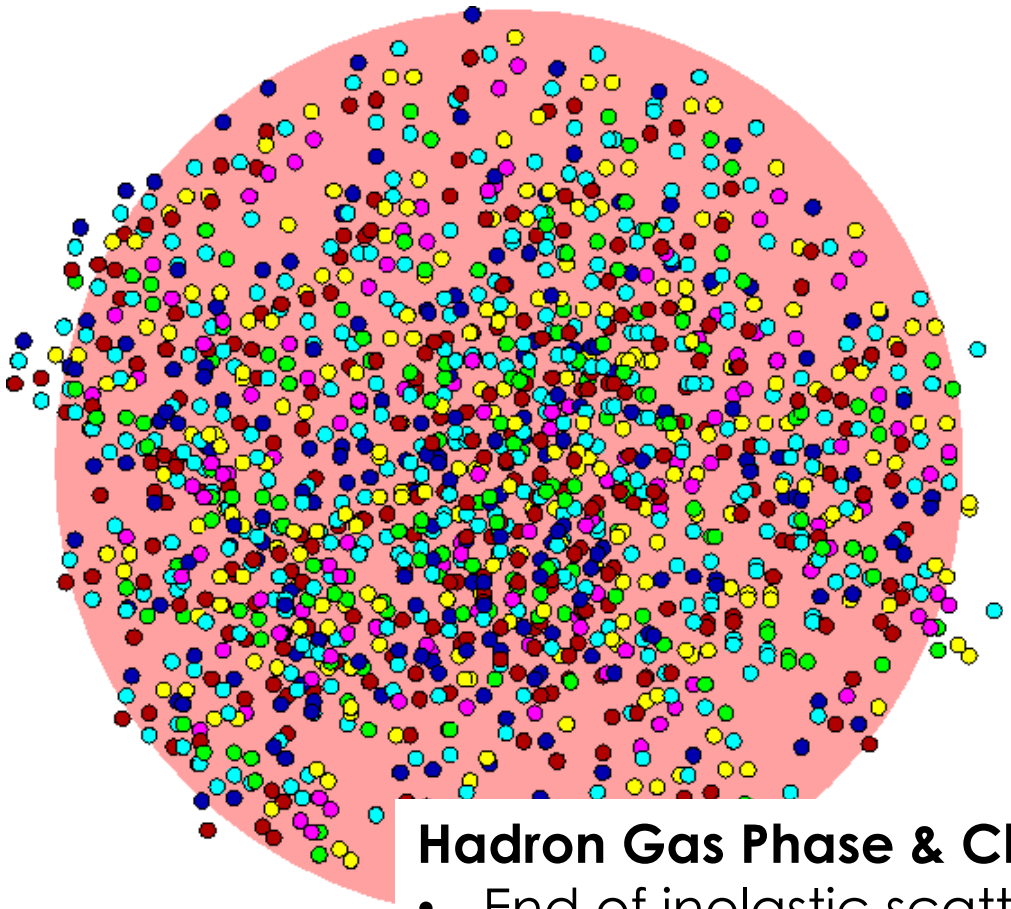


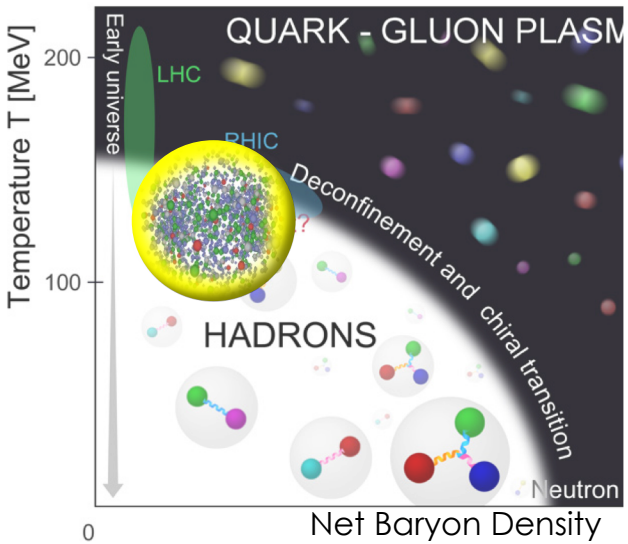


Hadronization:

- Soft probes (p_T<~4 GeV/c).
- Particle production mechanisms.
- Chiral symmetry breaking …

Chemical Freeze-out

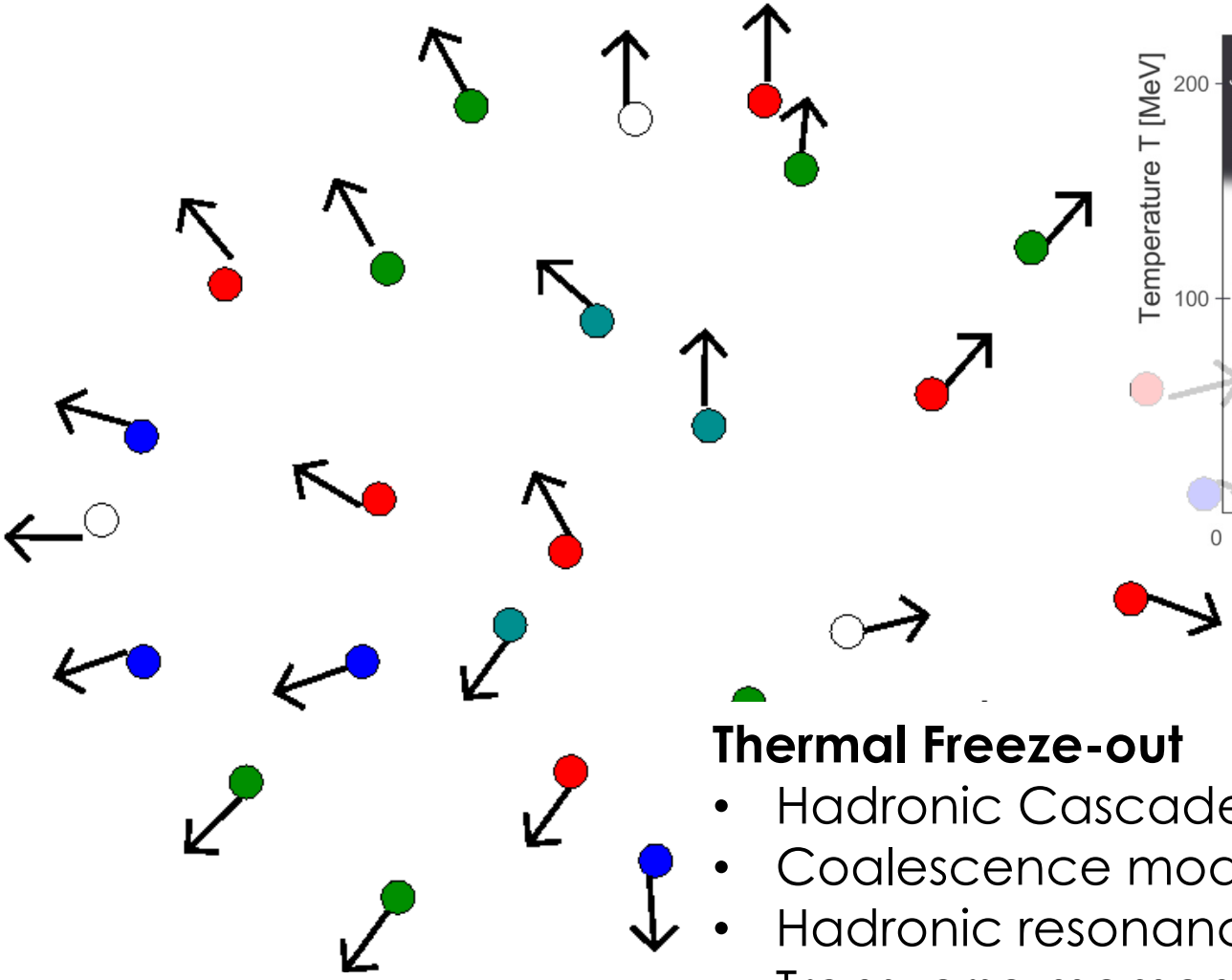


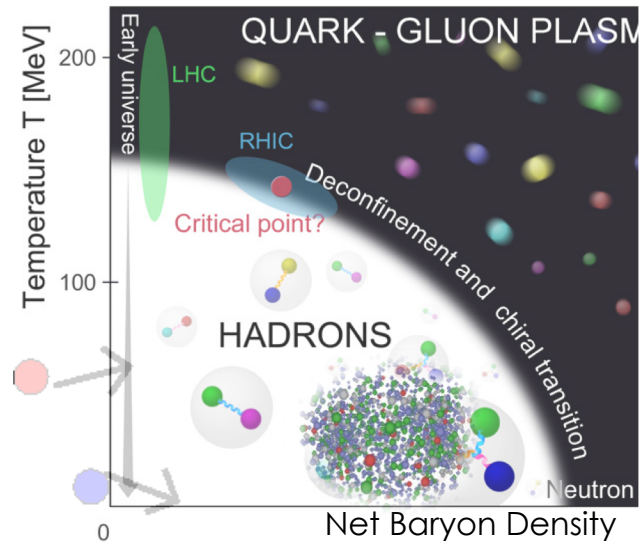


Hadron Gas Phase & Chemical Freeze-out:

- End of inelastic scattering.
- Relative particle abundance fixed.
- Application of Statistical Thermal models.

Thermal Freeze-out

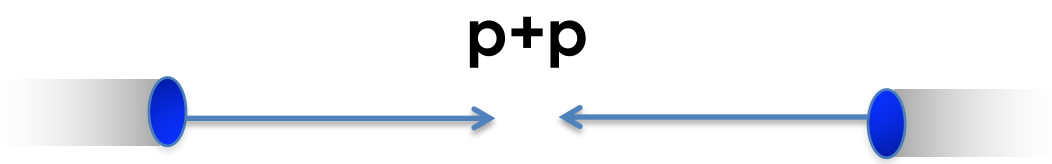




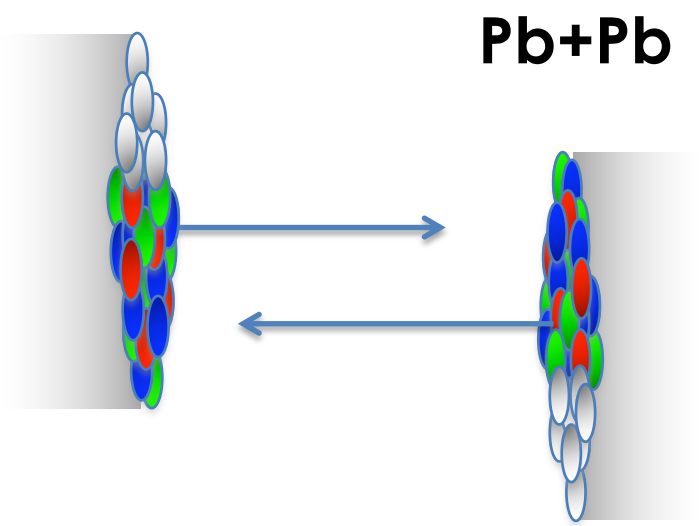
Thermal Freeze-out

- Hadronic Cascade models.
- Coalescence models.
- Hadronic resonances.
- Transverse momentum spectra.

How to study the different physics processes of HIC ?



Compare Pb+Pb results with reference data, to disentangle genuine heavy-ion collision effects.



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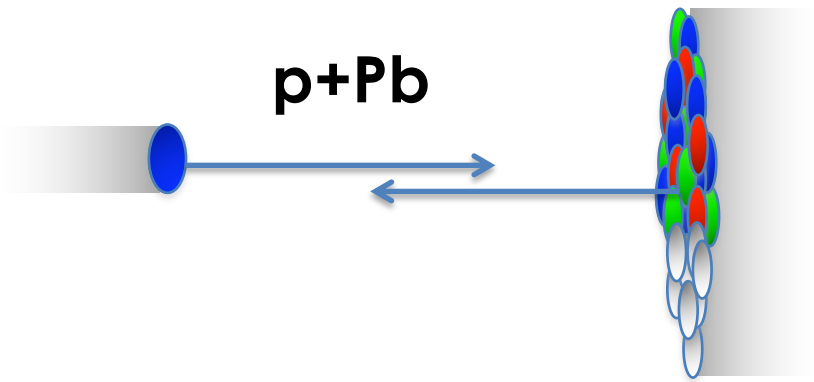
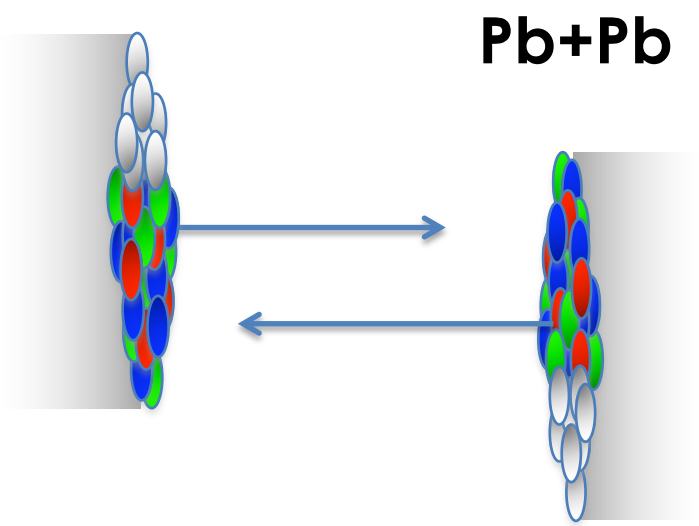


p+Pb also important as reference data:

- Initial vs. final state effects.
- Probe small x.
- Cold nuclear matter, gluon saturation and shadowing



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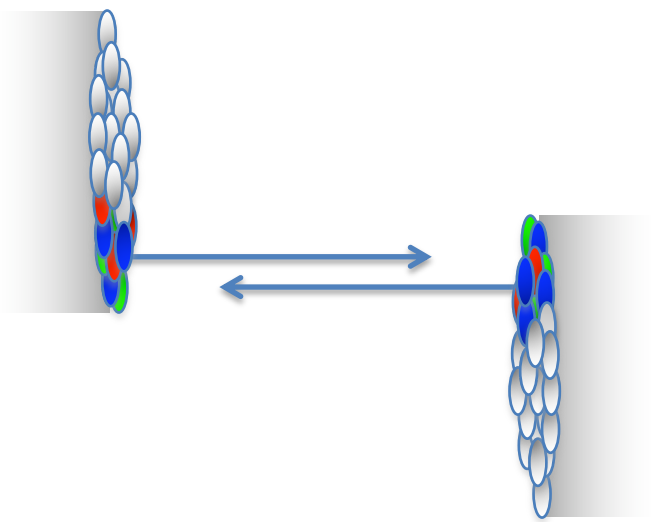
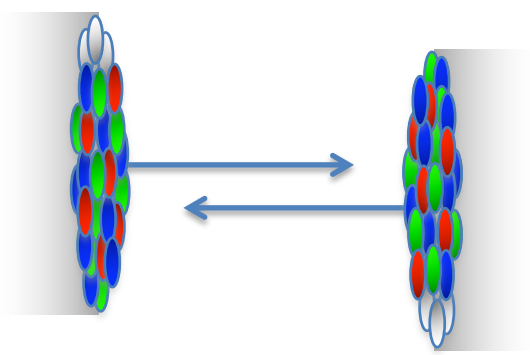


Peripheral Pb+Pb

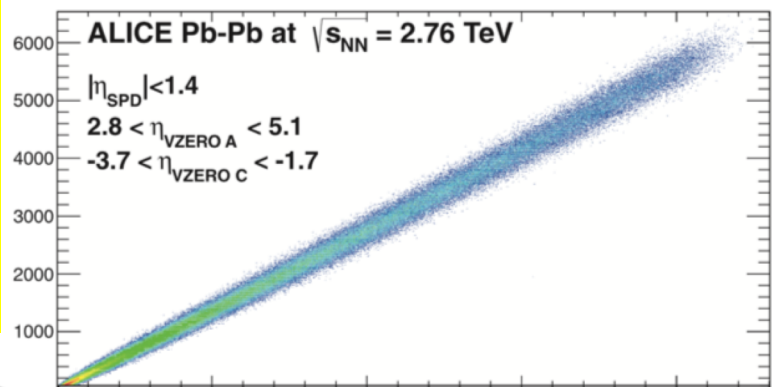
We can also change the observed system size by selecting on the collisions centrality.
Charged particle multiplicity used for this selection.

Central Pb+Pb



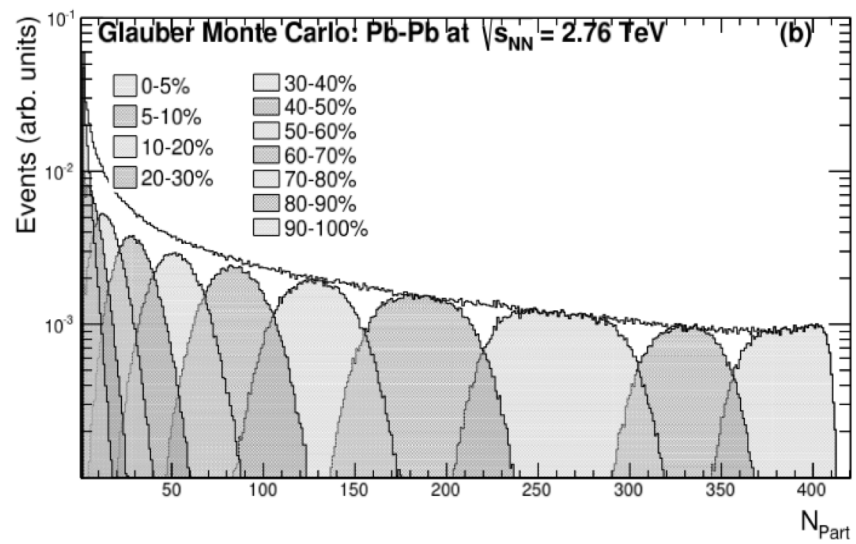
Selection of collisions geometry

Mid-rapidity multiplicity

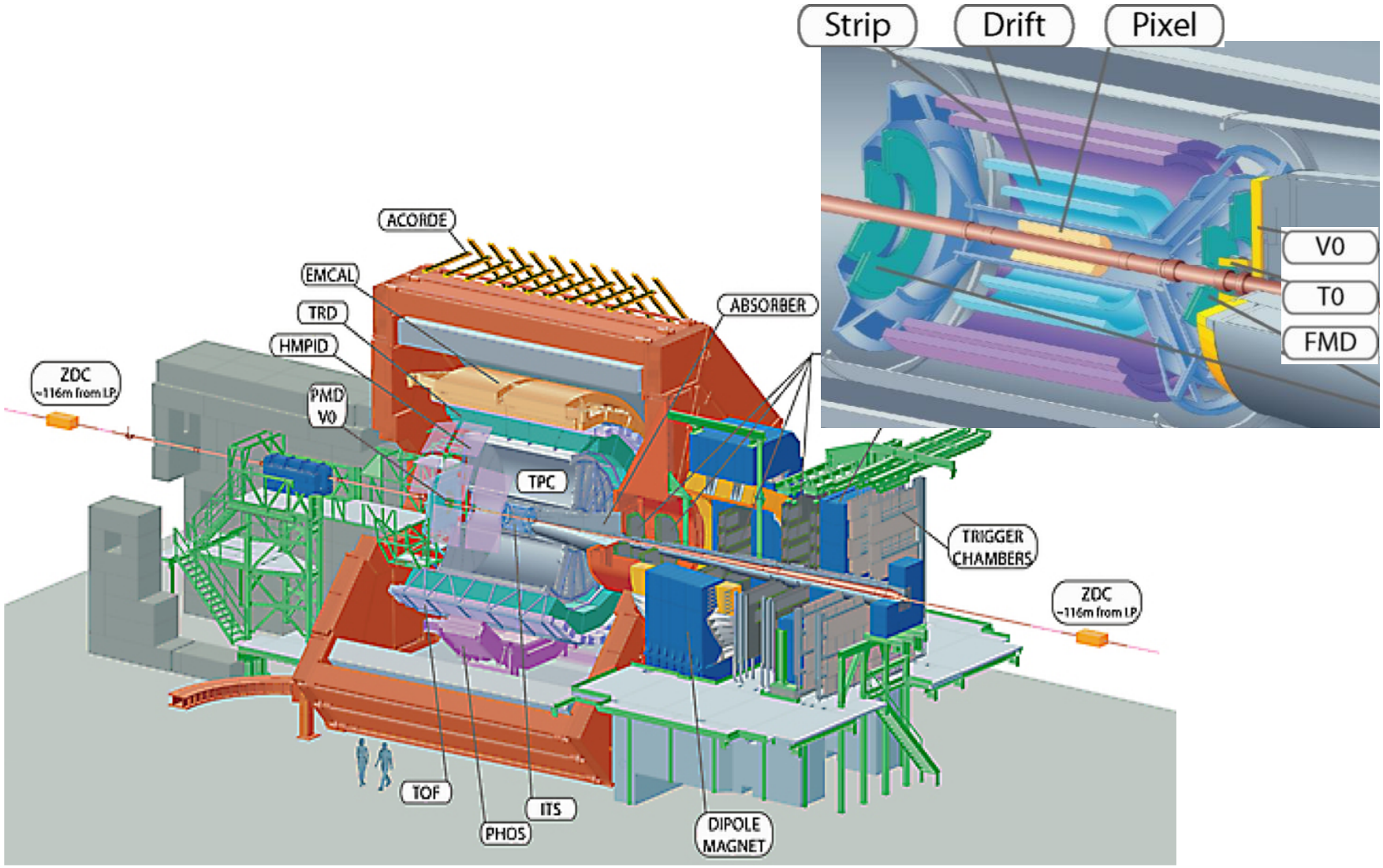


Forward Multiplicity

ALICE, PRC 88 (2013) 044909



The ALICE experiment



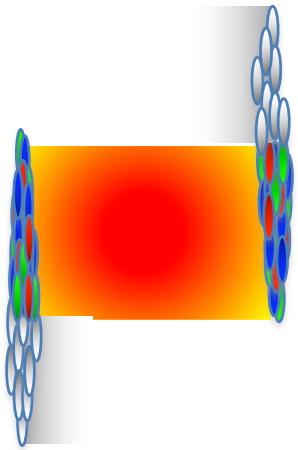
Lots of data !

Run 1 (2009-2013)		
pp	0.9 TeV	~ 200 μb^{-1}
	2.76 TeV	~ 100 nb^{-1}
	7.0 TeV	~ 1.5 pb^{-1}
	8.0 TeV	~ 2.5 pb^{-1}
p-Pb	5.02 TeV	~ 15 nb^{-1}
Pb-Pb	2.76 TeV	~ 75 μb^{-1}

Run 2 (2015-2018)		
pp	5.02 TeV	~ 1.3 pb^{-1}
	13 TeV	~ 25 pb^{-1}
p-Pb	5.02 TeV	~ 3 nb^{-1}
	8.16 TeV	~ 25 nb^{-1}
Xe-Xe	5.44 TeV	~ 0.3 μb^{-1}
Pb-Pb	5.02 TeV	~ 1 nb^{-1}

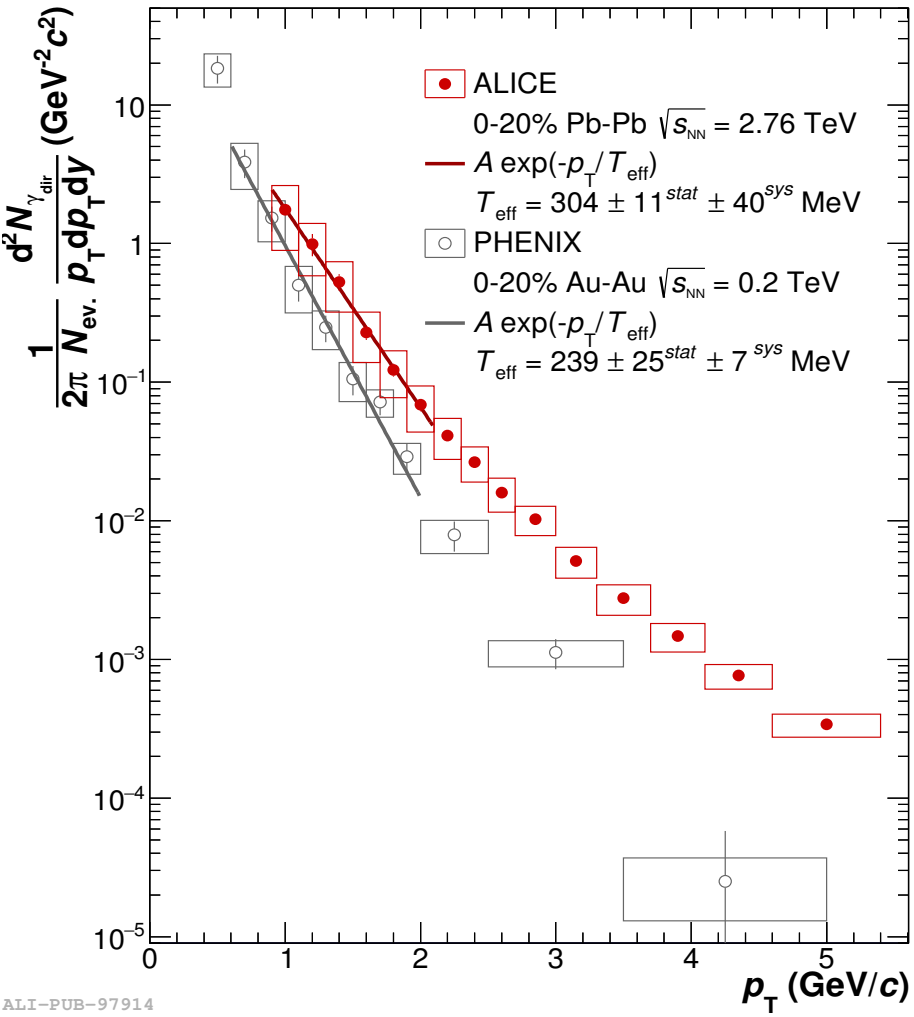
Some of the observables

1. Thermal QCD Matter.
2. Bulk particle production.
3. Jet-medium interactions.
4. Heavy flavor.



Direct photons in Pb-Pb

ALICE, Phys. Lett. B 754 (2016) 235.



Measured through Photon Conversion Method (PCM), PHOS calorimeter and EMCal.

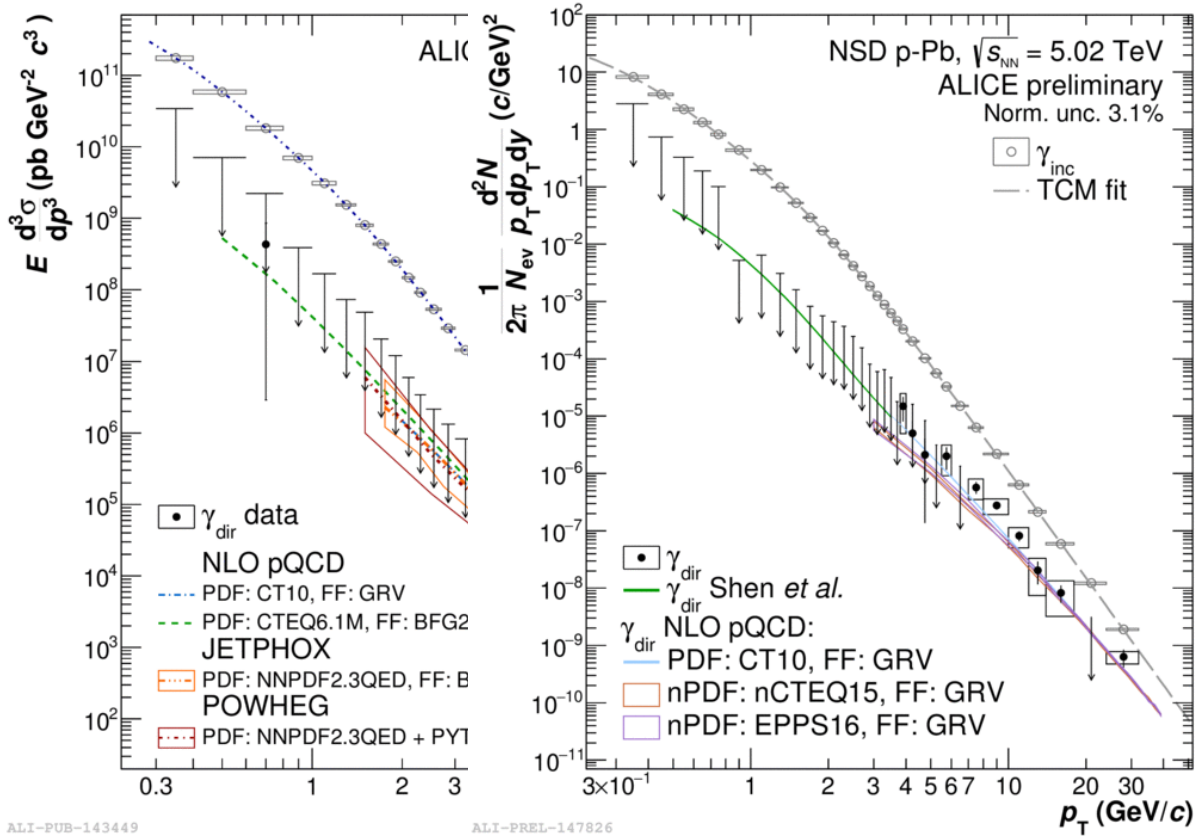
Hot QCD matter radiate photons free of final state interactions.

Hotter radiates more, so direct photon spectra probe early QGP stage.

But, needs understanding of background.

Direct photons in pp and p-Pb

ALICE, arXiv:1803.09857.



pp: NLO pQCD calculations consistent with data.

p-Pb: No excess of thermal photons seen, consistent with NSD p-Pb low-p_T data.

Some of the observables

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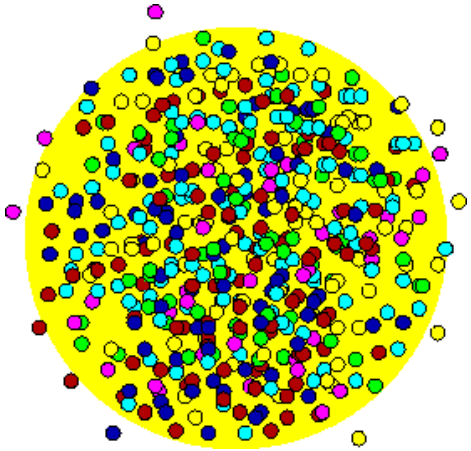
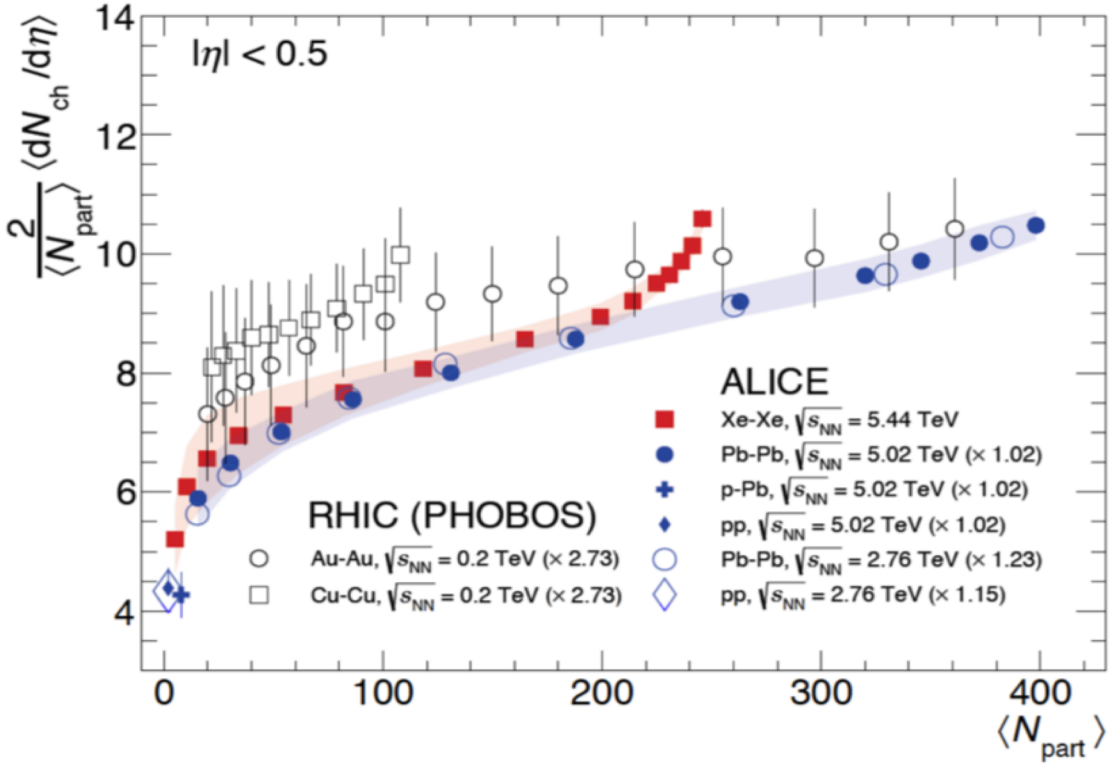


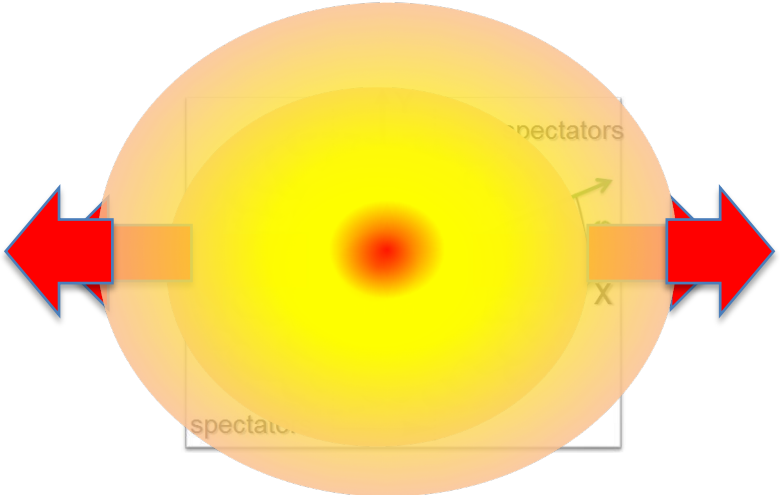
Particle Production



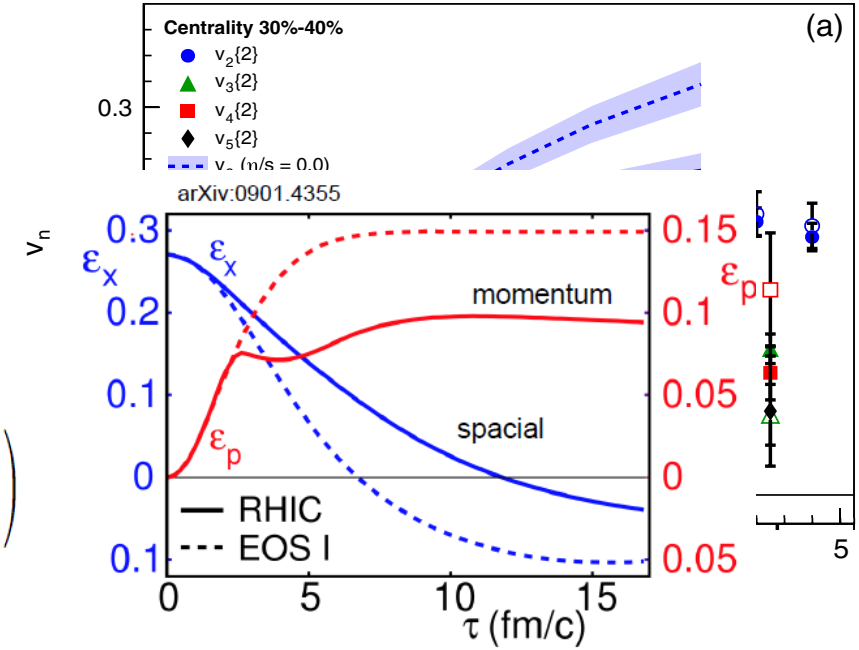
ALICE overview talk in QM2018.

- N_{part} is not a good scaling parameter. Participant quark scaling $N_{q\text{-}part}$ seems to describe better the data trend.
- Central Xe-Xe data deviates from observed N_{part} dependency.

Liquid-like evolution



ALICE, PRL 107(2011) 252301

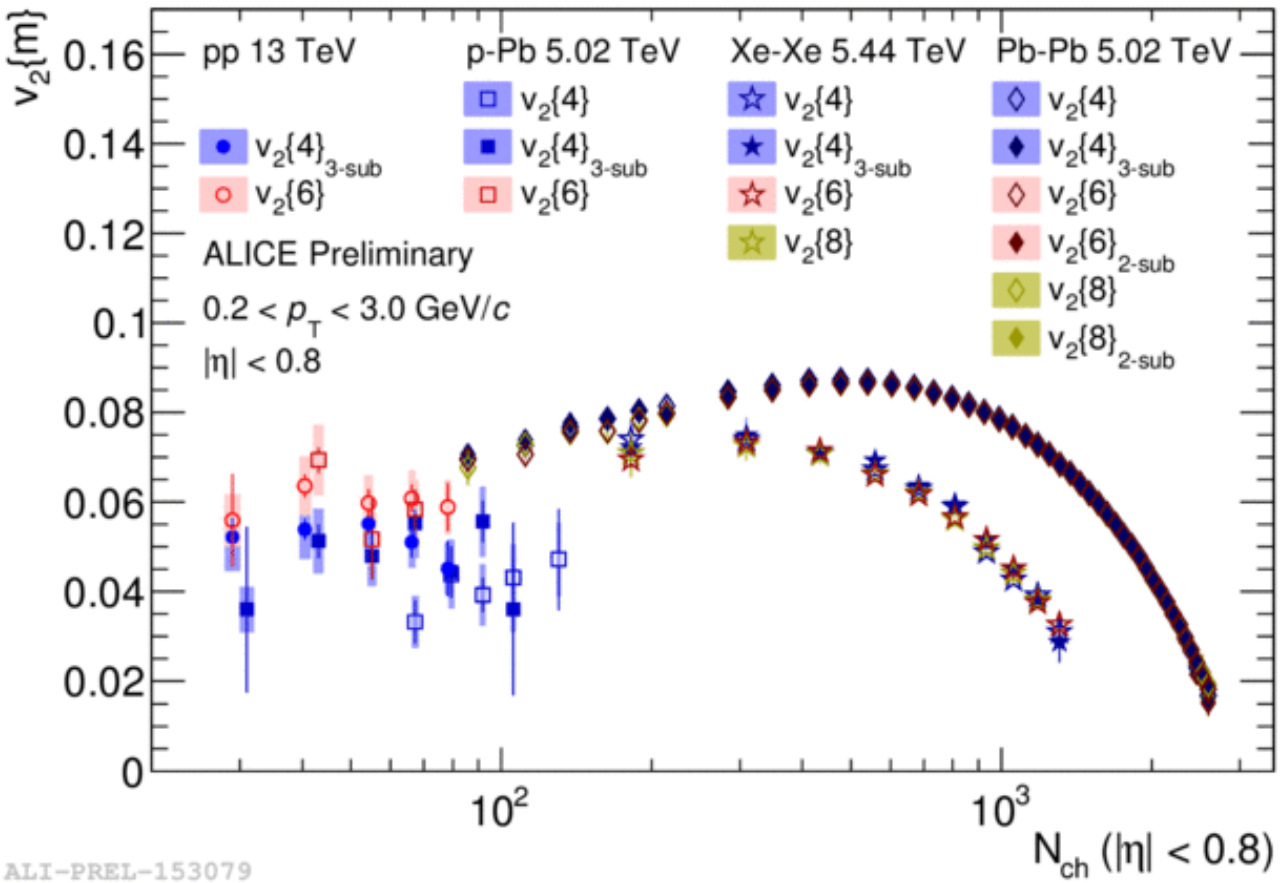


$$E\frac{d^3N}{d^3p} = \frac{1}{2\pi}\frac{d^2N}{p_t dp_t dy}\left(1+\sum_{n=1}^{\infty} 2v_n \cos[n(\phi-\Psi_r)]\right)$$

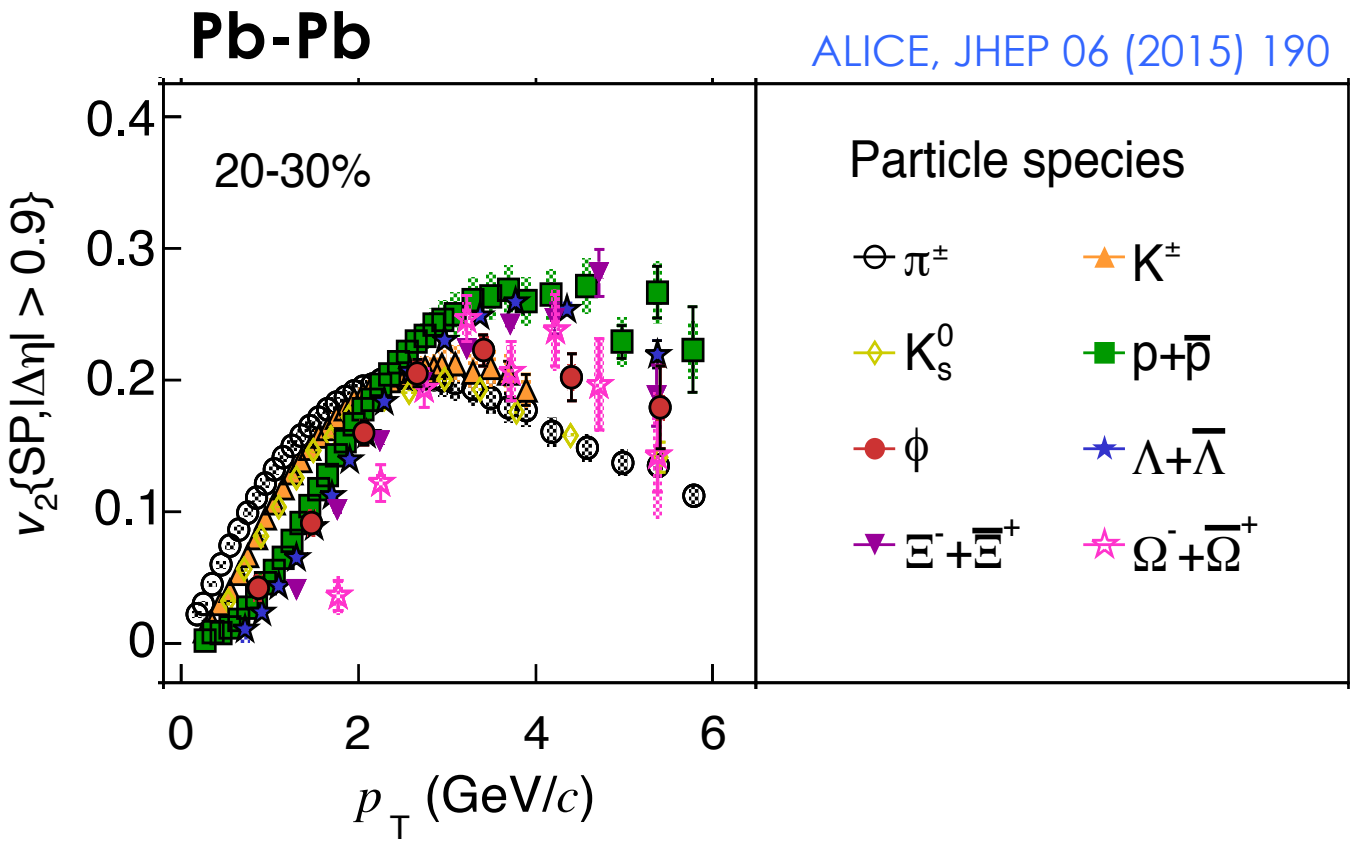
$$v_n(p_T,\eta) = \left\langle \cos\left[n(\phi-\Psi_n)\right]\right\rangle$$

Elliptic flow measurements show success of low viscosity relativistic hydrodynamics to describe the QGP evolution.

Elliptic Flow v_2



Identified particle elliptic flow

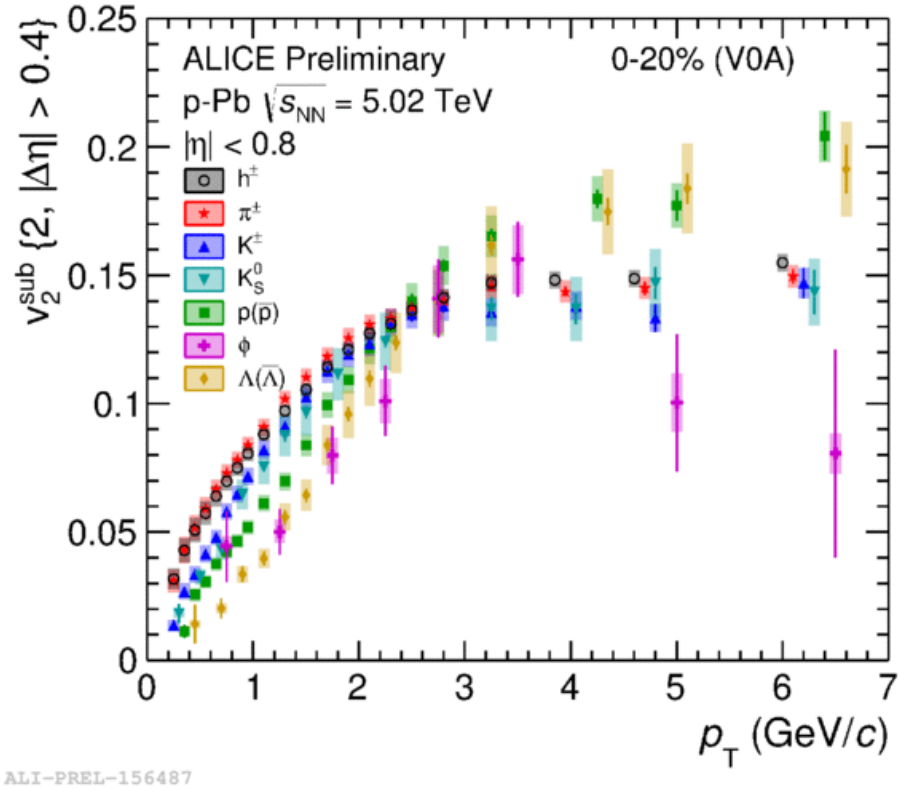


ALICE, JHEP 06 (2015) 190

Consistent with hydrodynamic expansion:

- Low p_T shows mass ordering.
- Intermediate p_T shows some grouping of baryons and mesons.

Identified particle elliptic flow

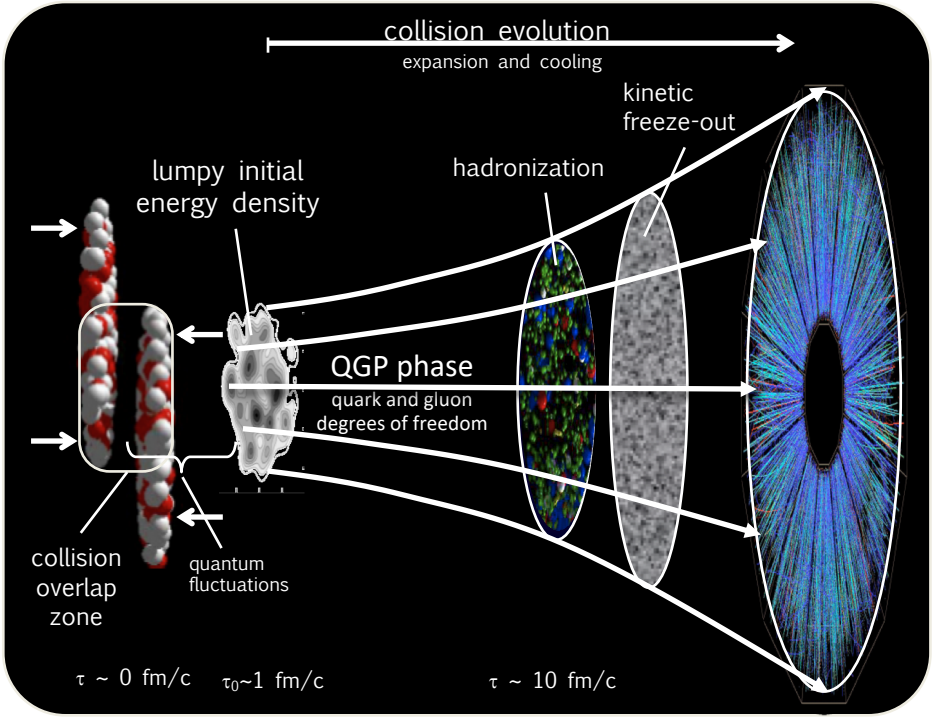


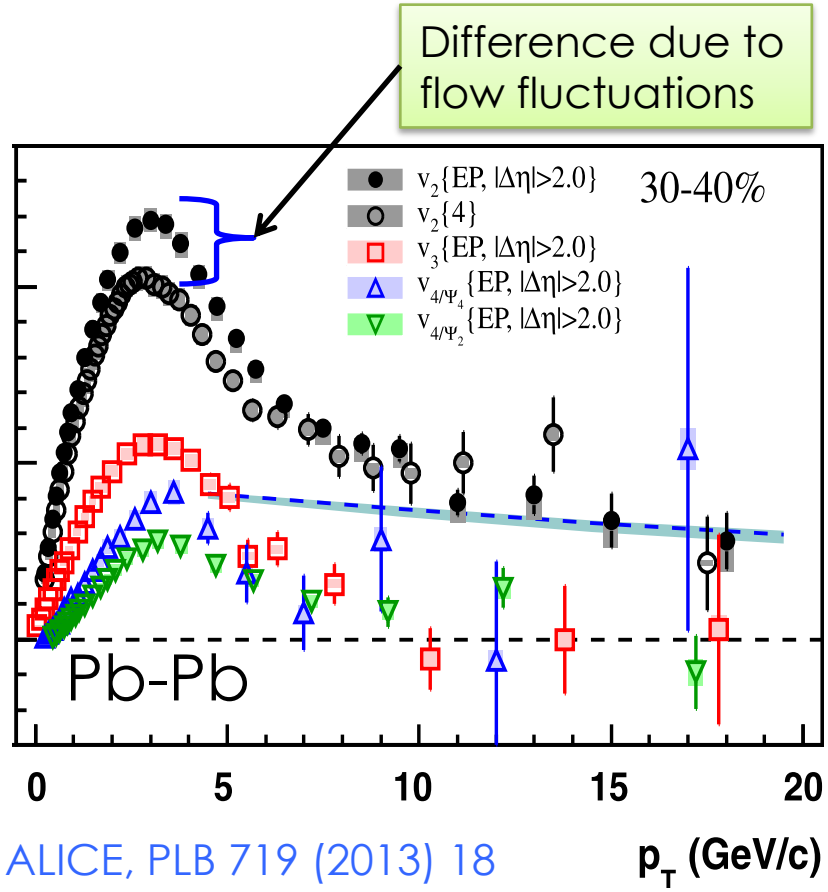
v_2 in **p-Pb** (small) system also shows signs consistent with hydrodynamic expansion.

Need to evaluate effects by other processes such as String Color Reconnection, Color Ropes (PYTHIA), parton escape (AMPT) and hadronic re-scattering (UrQMD).

V_2 as a probe to fluctuations

Initial State Fluctuations play central role in v_n data !!!!
Only possible due to low viscosity plasma.

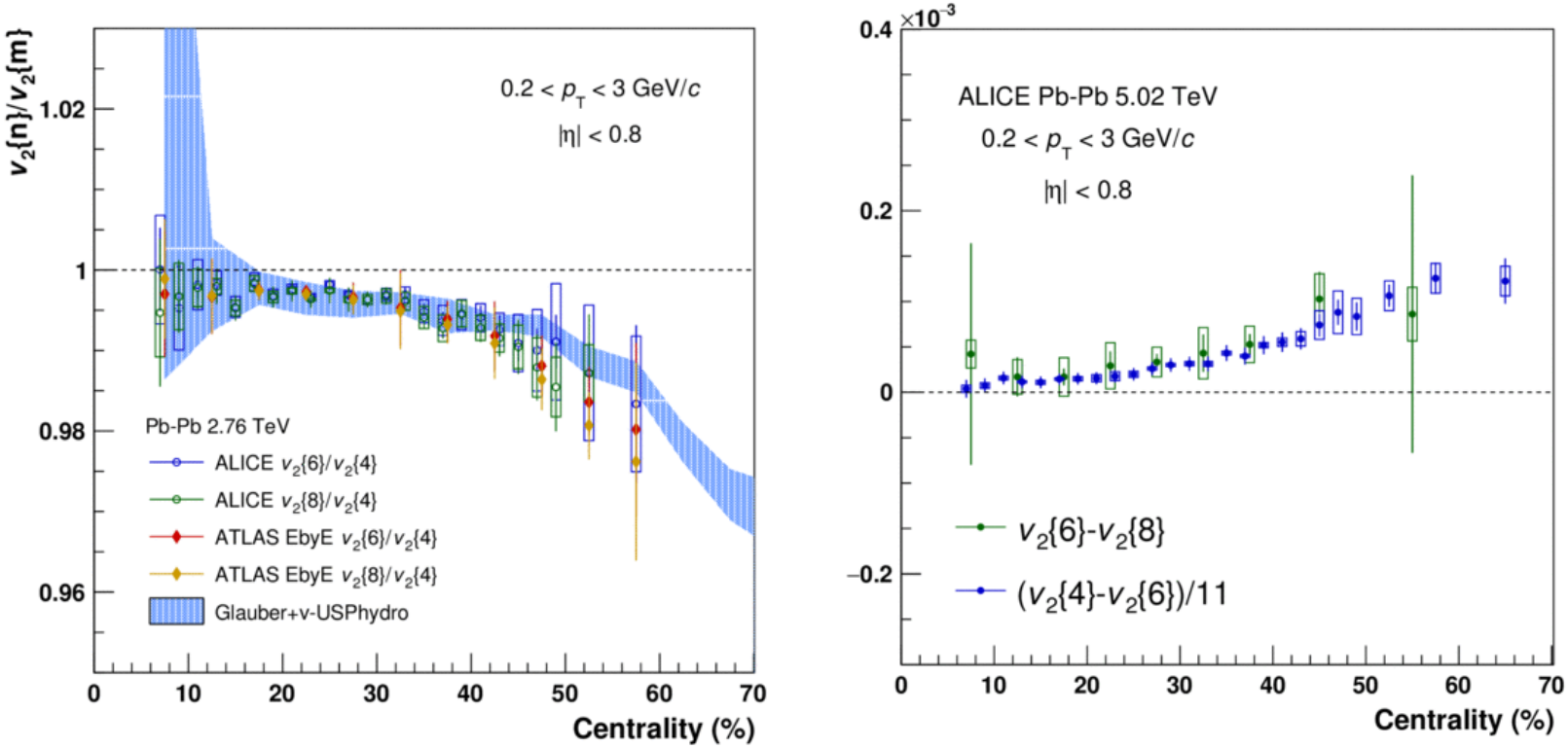




ALICE, PLB 719 (2013) 18

V_2 as a probe to fluctuations

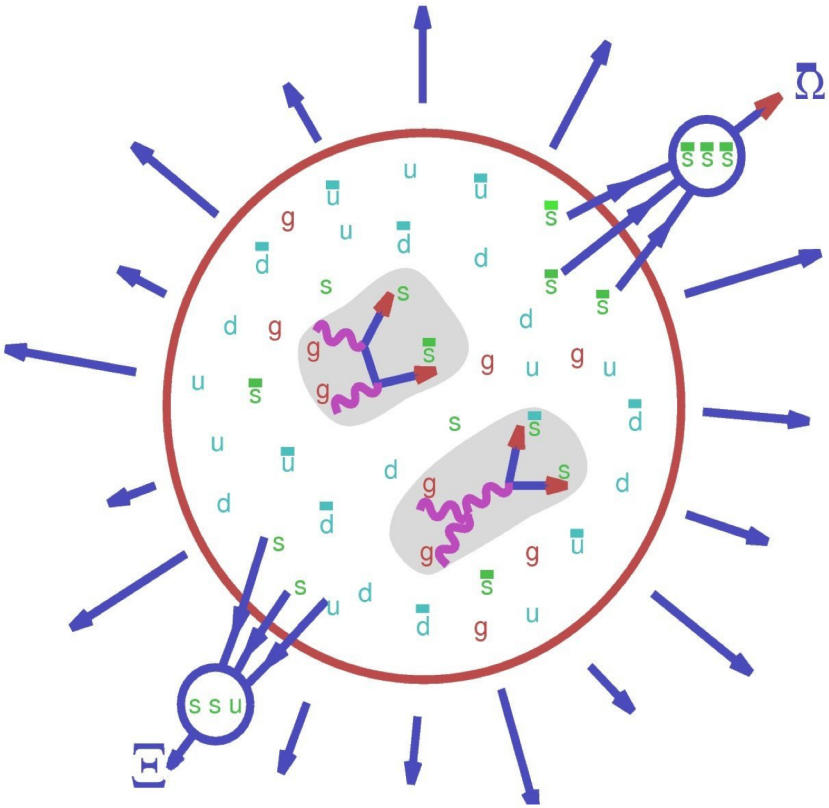
ALICE, arXiv:1804.02944



Consistent with Non-Bessel-Gaussian fluctuations.

Allows determination of Elliptic Power distribution, for comparison to initial-state models.

Strangeness Enhancement



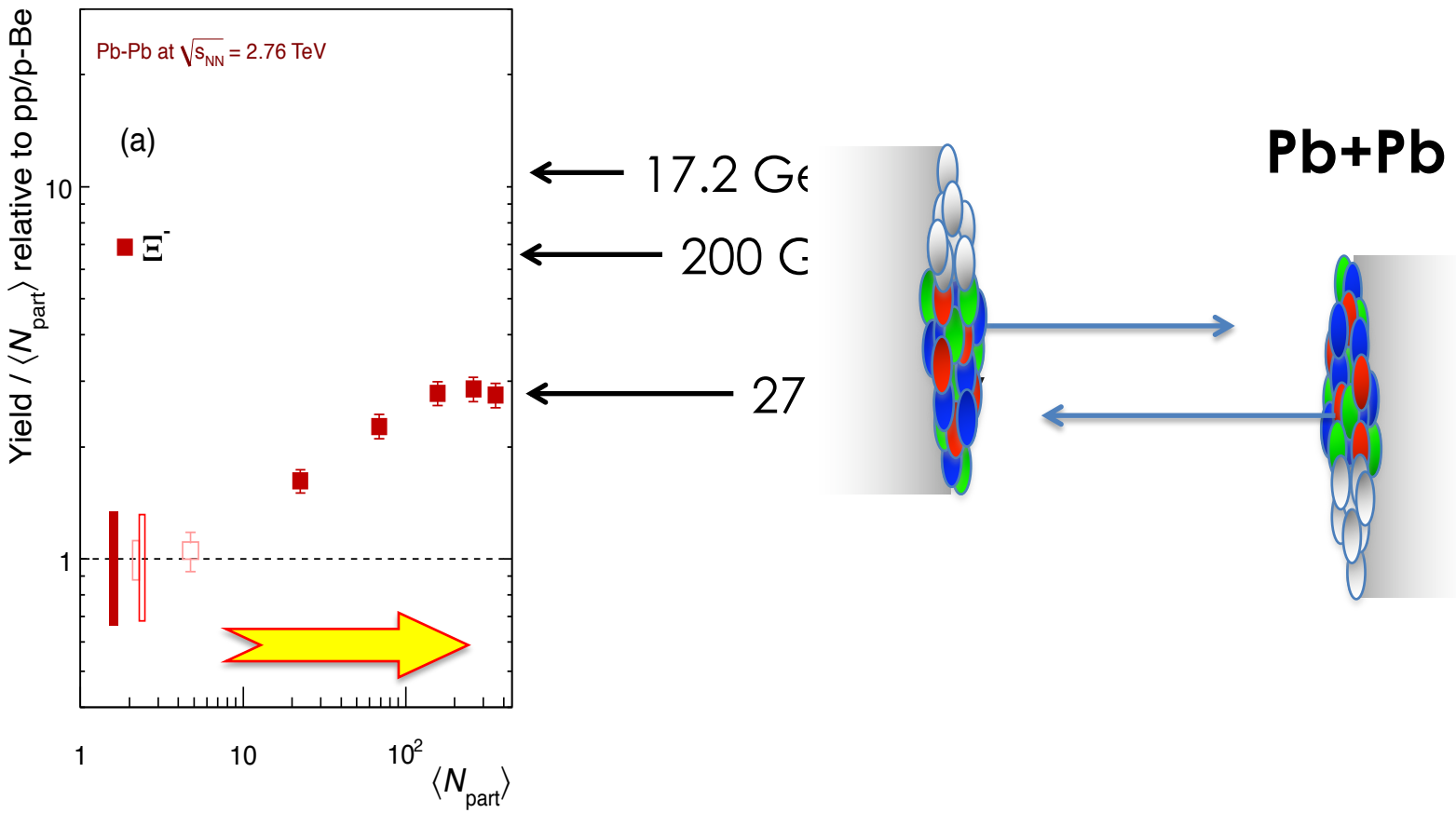
Gluon fusion dominates production of strangeness.

When $T \geq m_s$, thermal production dominates and in a chemically equilibrated QGP, strangeness abundance similar to other light quarks.

Strangeness enhancement is signature of the formation of a thermal gluon medium.

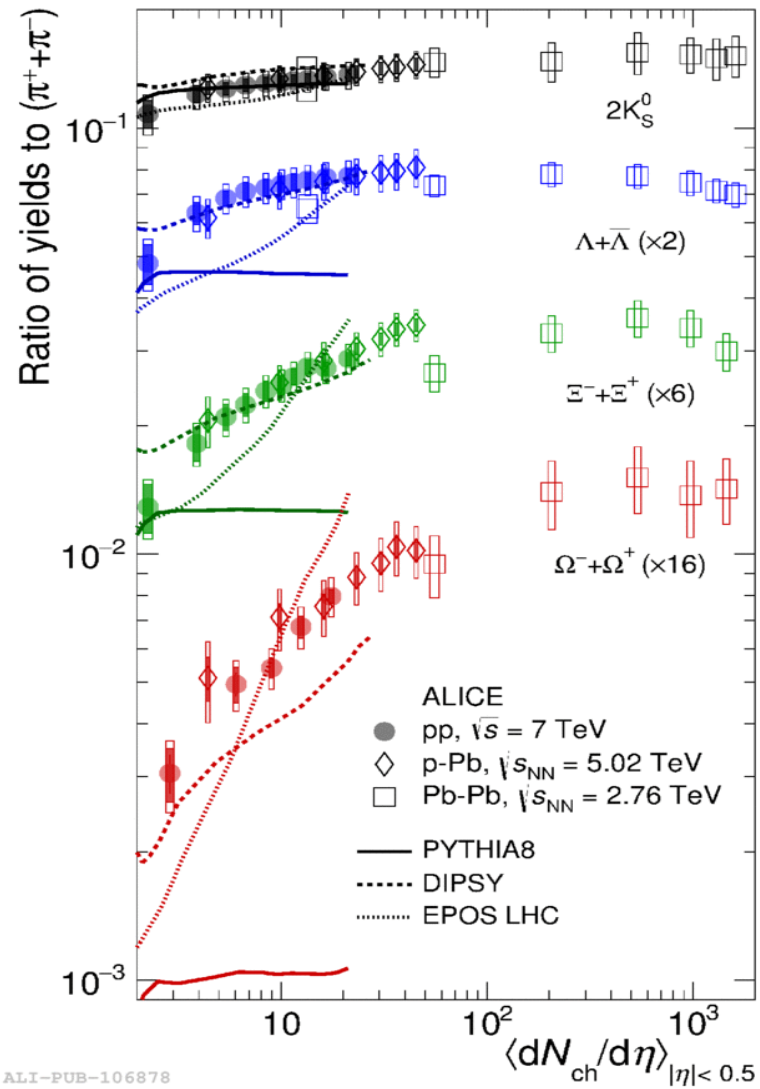
Strangeness Enhancement

ALICE, PLB 728 (2014) 216



Clear observation of Strangeness Enhancement in HIC !!!

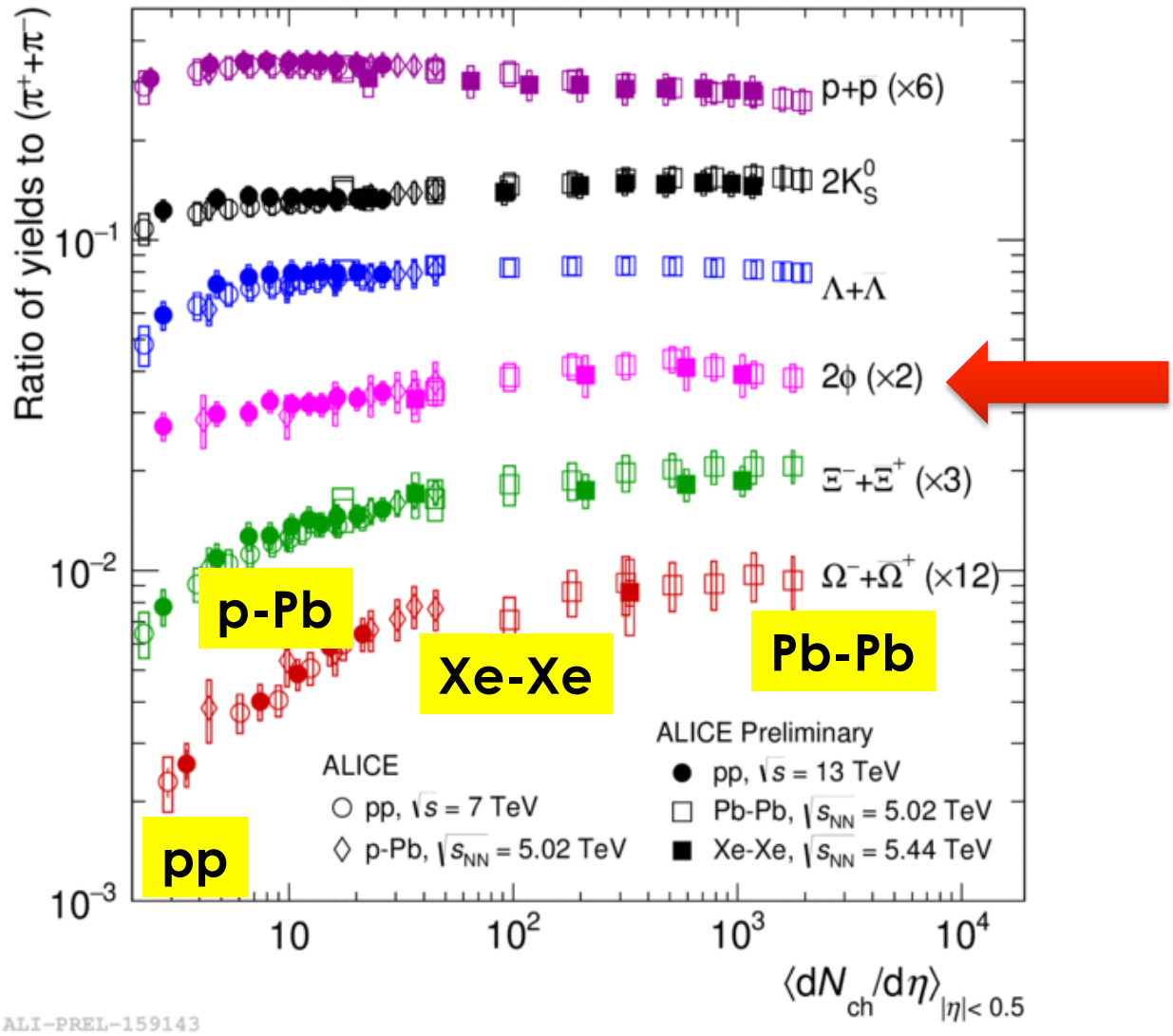
New Paradigm



ALICE, Nature Phys. 13, (2017) 535

- Strangeness Enhancement in pp data, where no QGP expected.
- Models fail to describe observed enhancement.
- Charged particle density scales strangeness enhancement measured in different systems and different energies.

Particle chemistry for all systems



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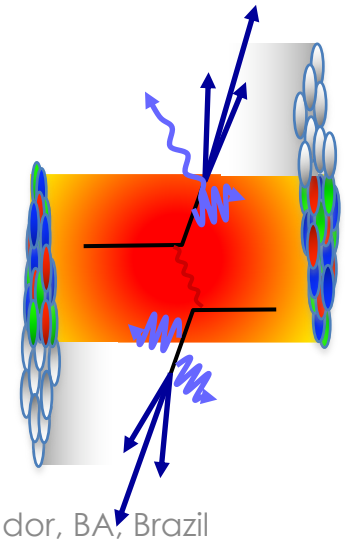
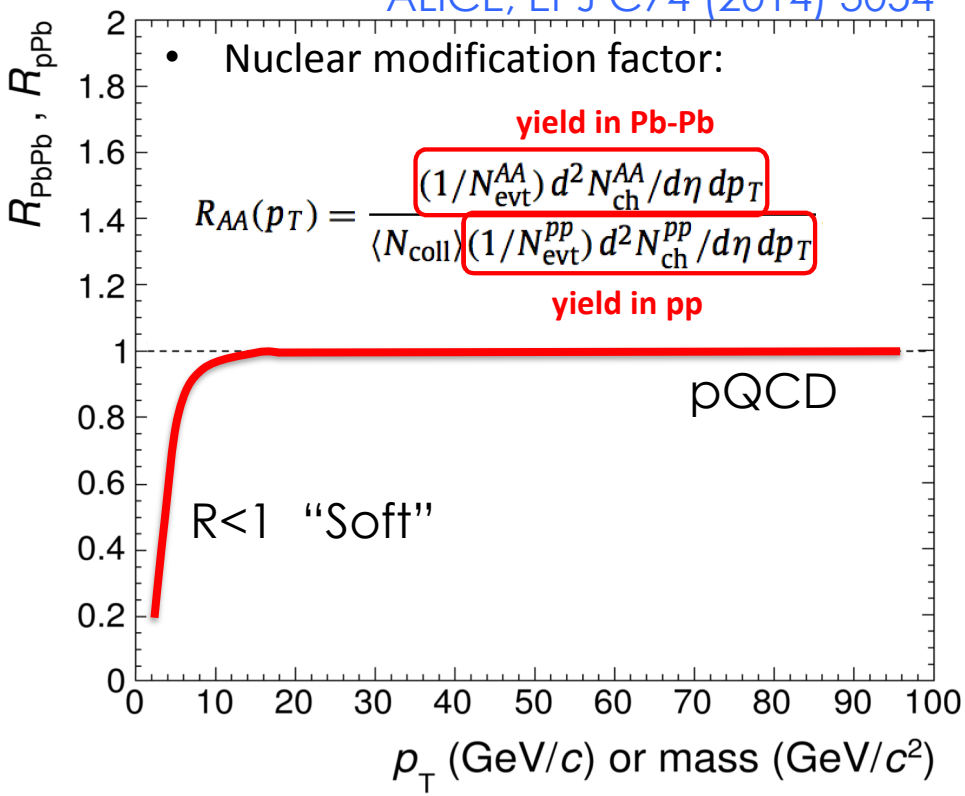
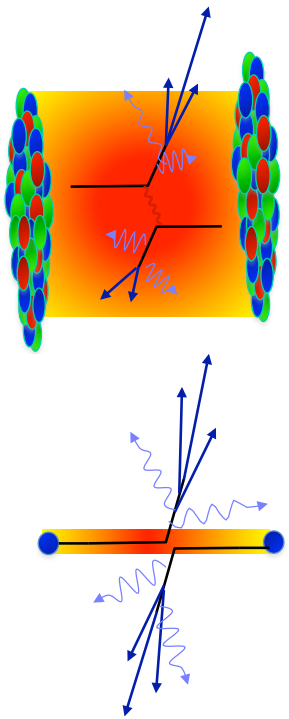


Parton Energy Loss

ALICE, EPJ C74 (2014) 3054



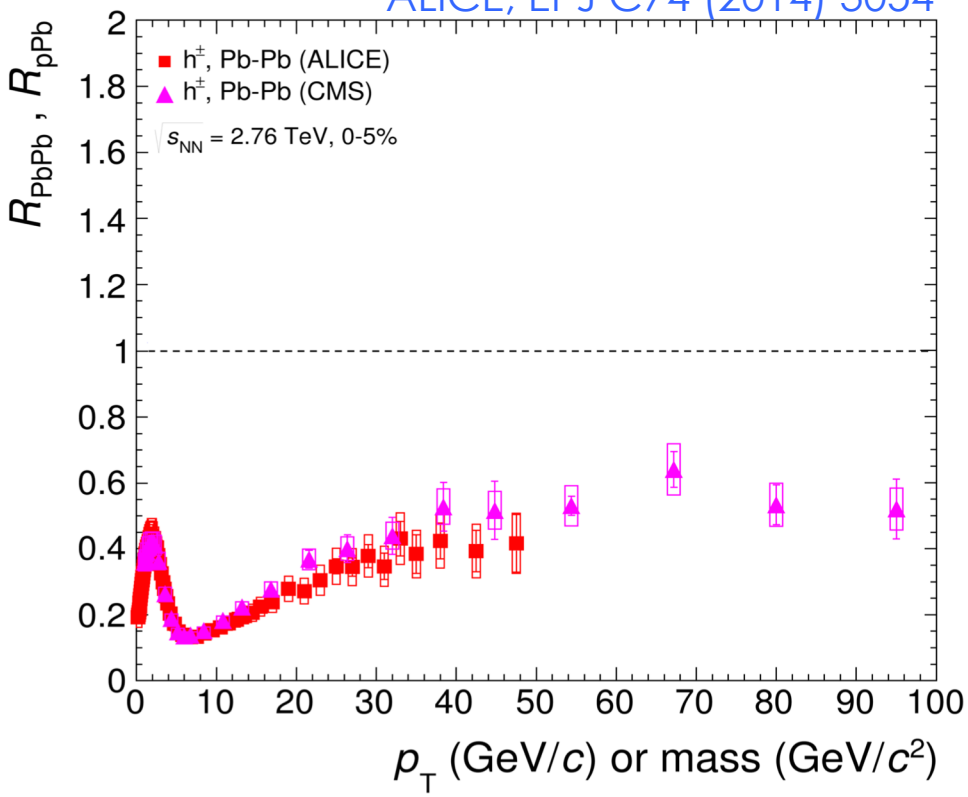


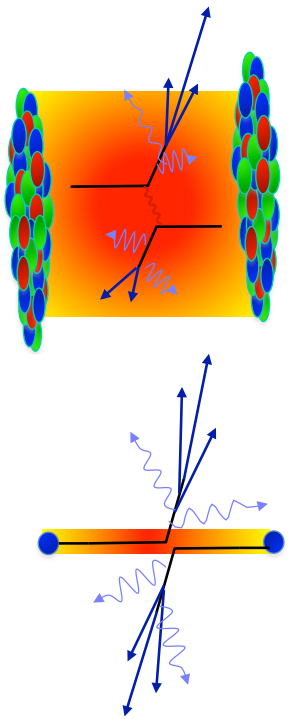
Parton energy loss to medium results in depletion of high-p_T hadrons.

Medium is highly opaque to colored probes.

Parton Energy Loss

ALICE, EPJ C74 (2014) 3054





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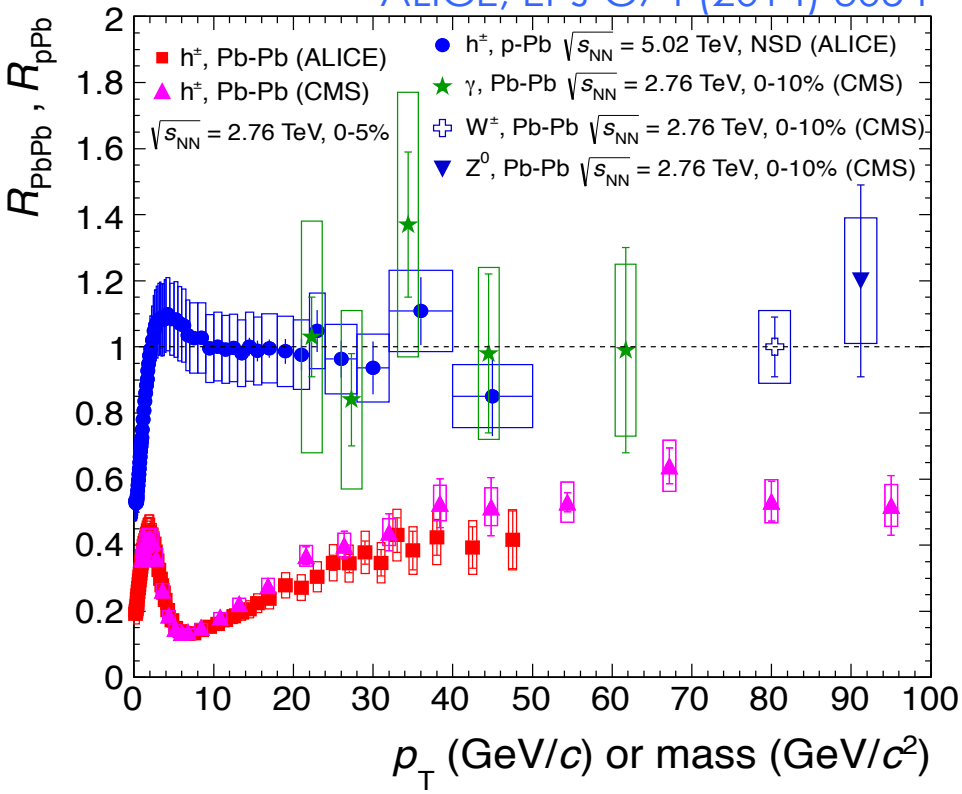
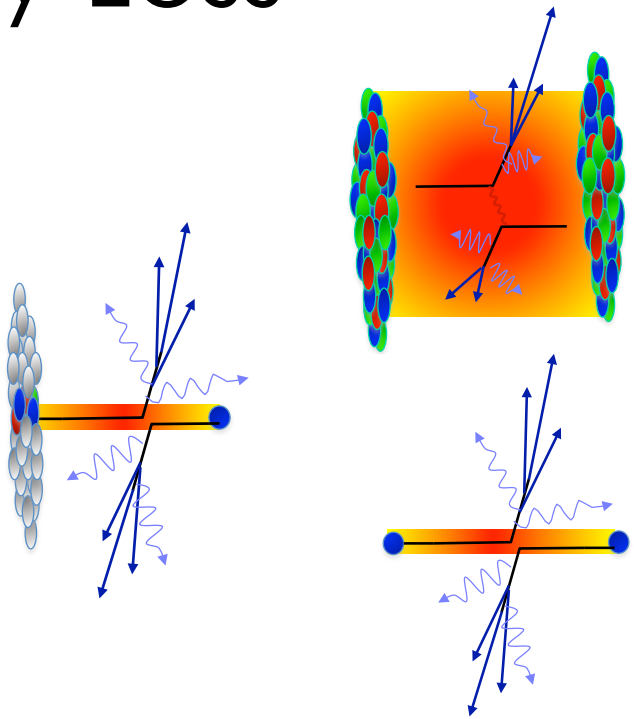
Parton Energy Loss

ALICE, EPJ C74 (2014) 3054

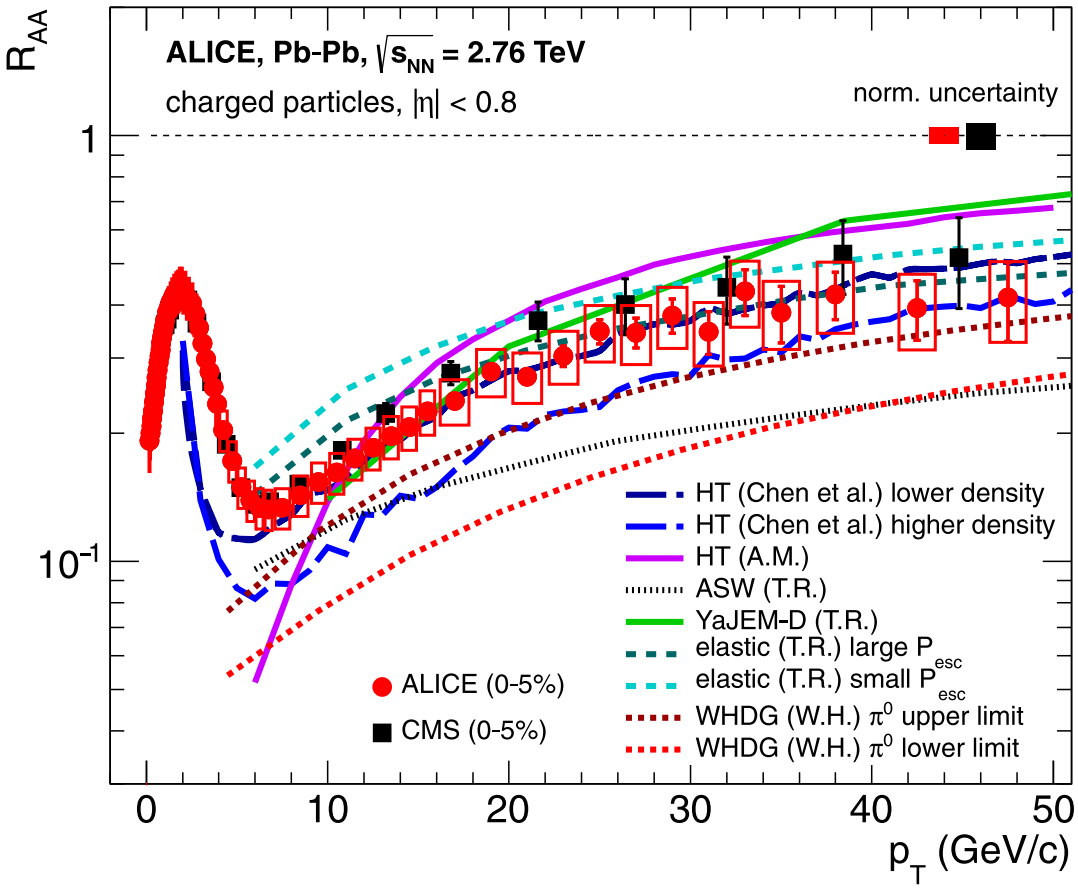


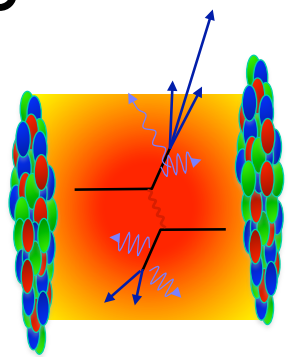


Parton energy loss to medium results in depletion of high-p_T hadrons.

Medium is highly opaque to colored probes.

Constraints to models

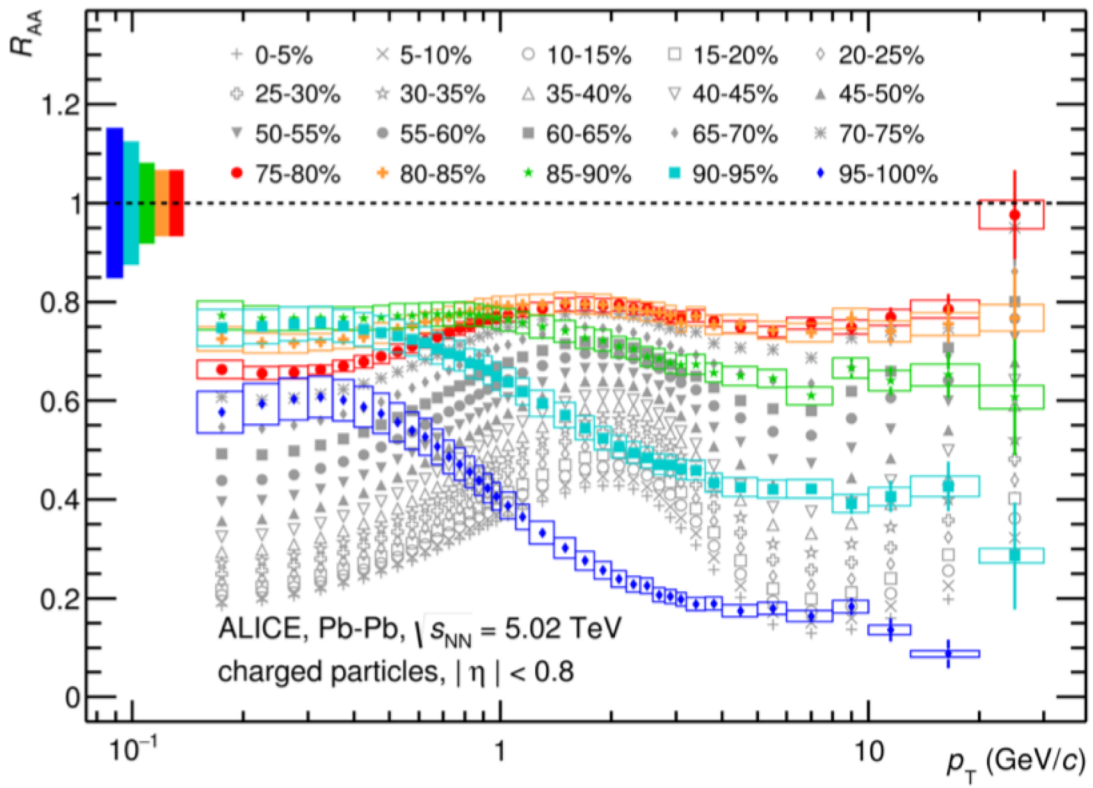




ALICE, PLB 720 (2013) 52

Comparison to parton energy loss models provides insight into QGP gluon density.

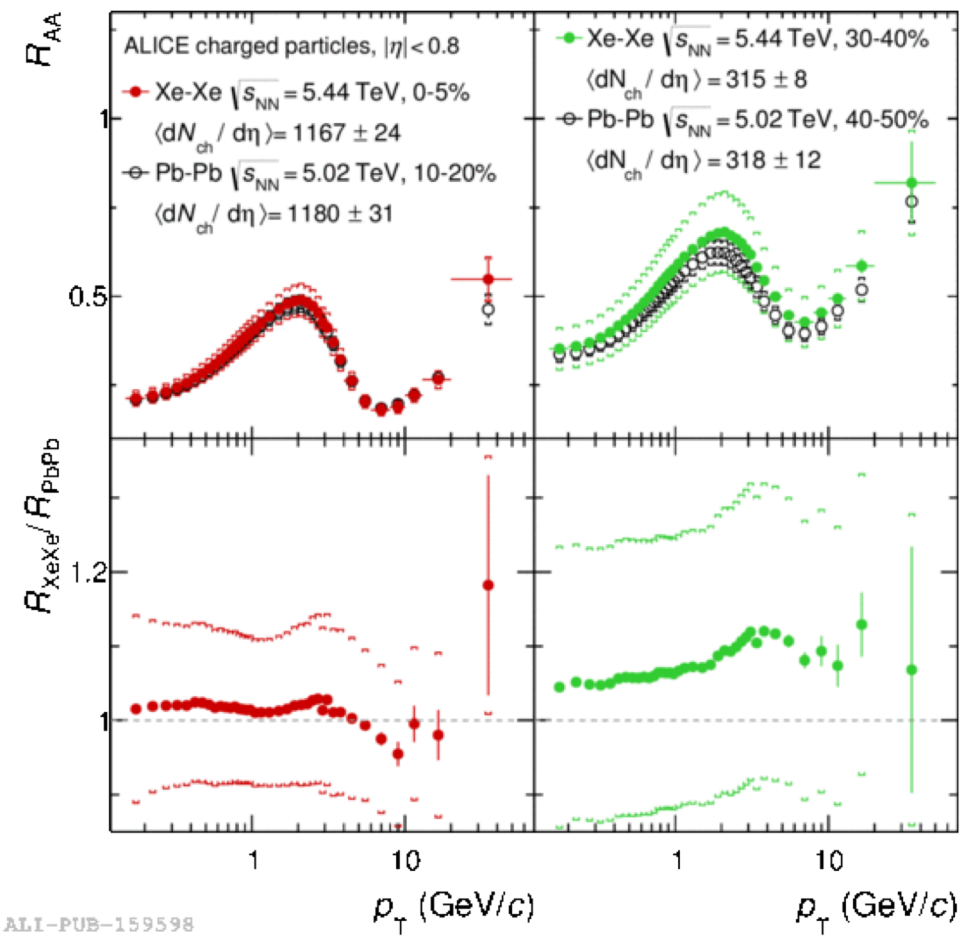
R_{AA} in very peripheral collisions



ALICE overview talk in QM2018.

- Change of behavior in trend beyond 80% centrality.
- Can be explained by event selection and collisions geometry, without nuclear modification.

R_{AA} in Xe-Xe collisions



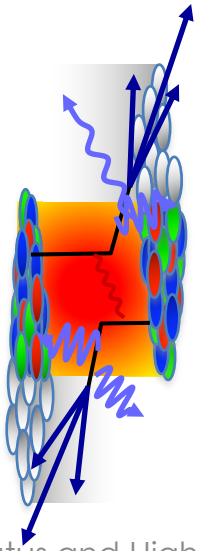
ALICE, arXiv:1805.04399

Xe-Xe and Pb-Pb compared using similar multiplicity bins.

Suppression differences could probe the interplay between geometry and path length dependence.

Some of the observables

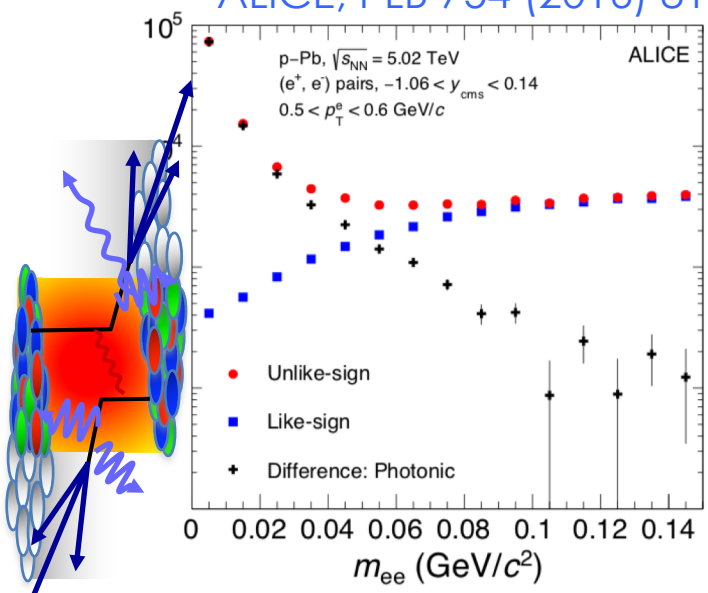
1. Thermal QCD Matter.
2. Bulk particle production.
3. Jet-medium interactions.
4. Heavy flavor.



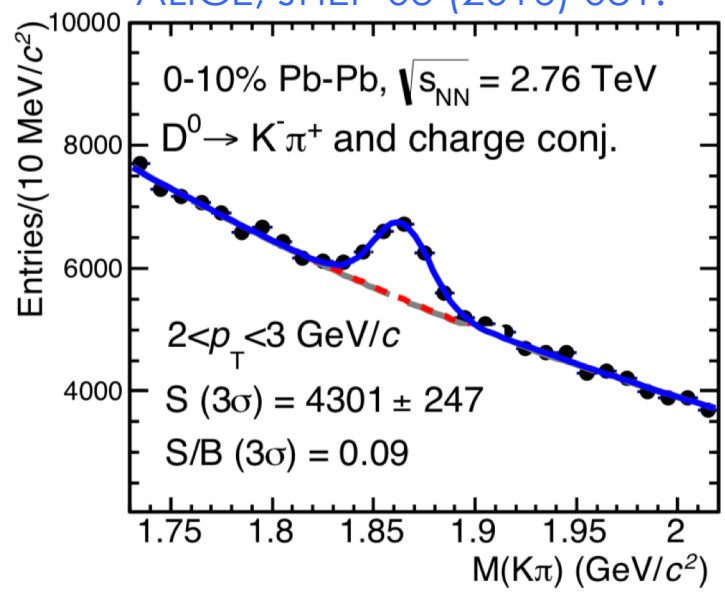
Heavy-flavor measurements

- Produced in initial hard parton scattering, so sensitive to full evolution of the QGP.
- Allows better comparison to pQCD calculations.
- Measured through the semileptonic and hadronic decay channels.

ALICE, PLB 754 (2016) 81.

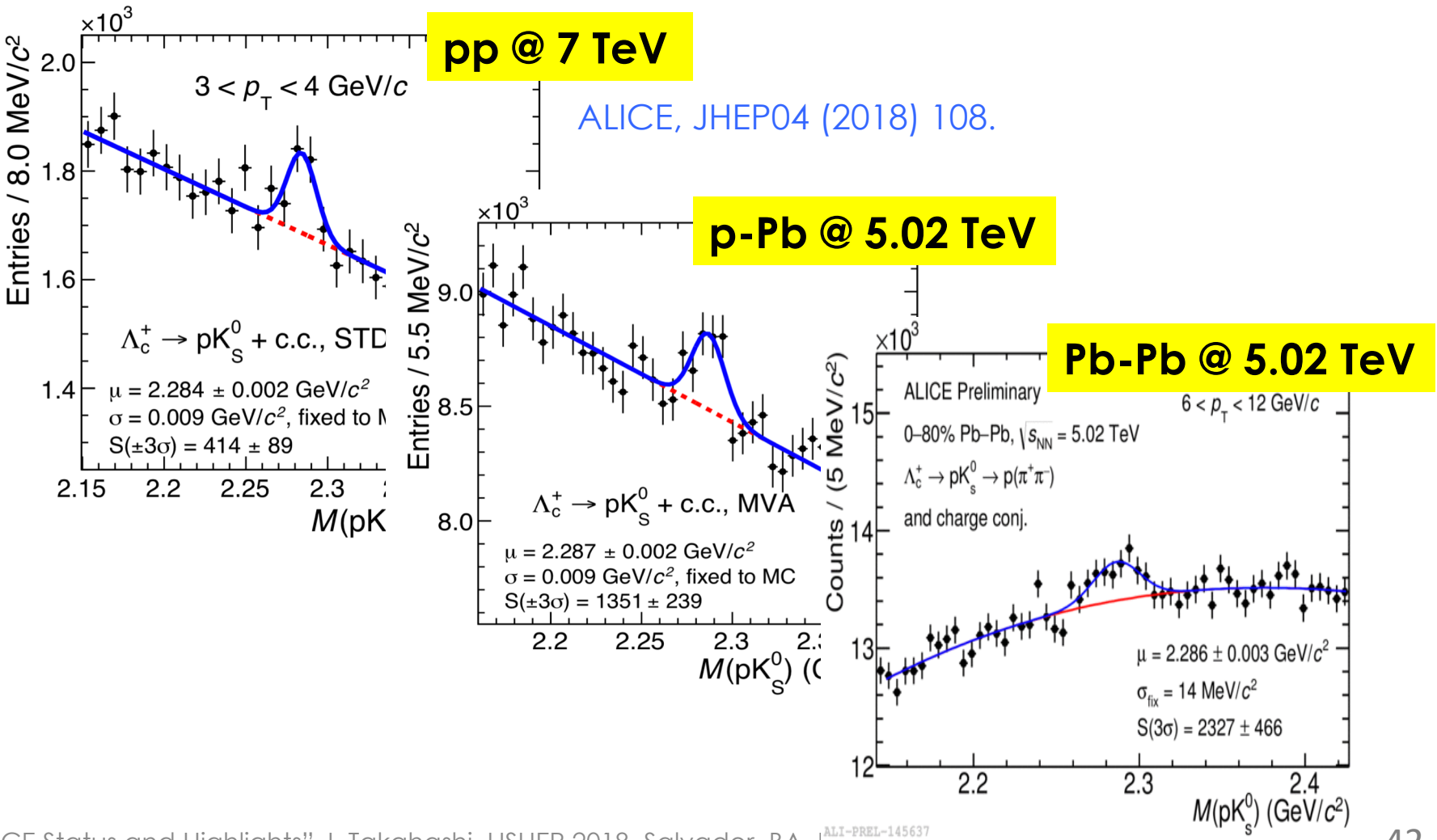


ALICE, JHEP 03 (2016) 081.



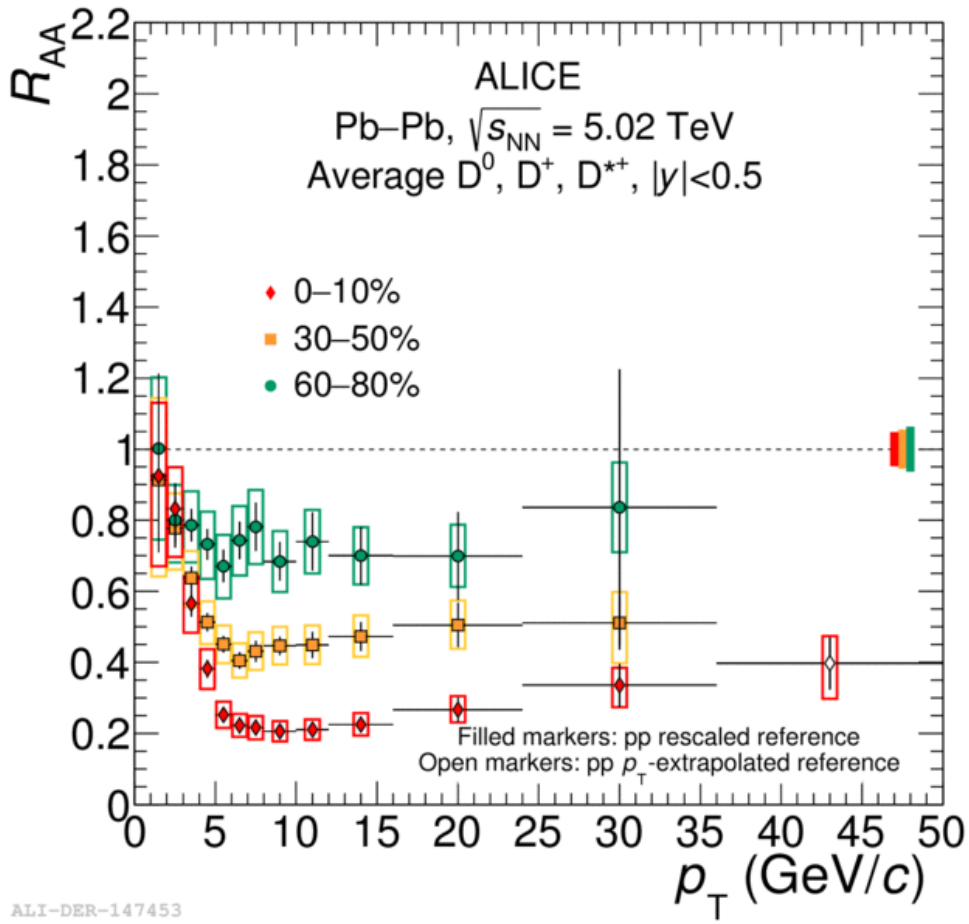
Heavy-flavor measurements

Very challenging, but feasible in **all** colliding systems!!!



Open heavy-flavor

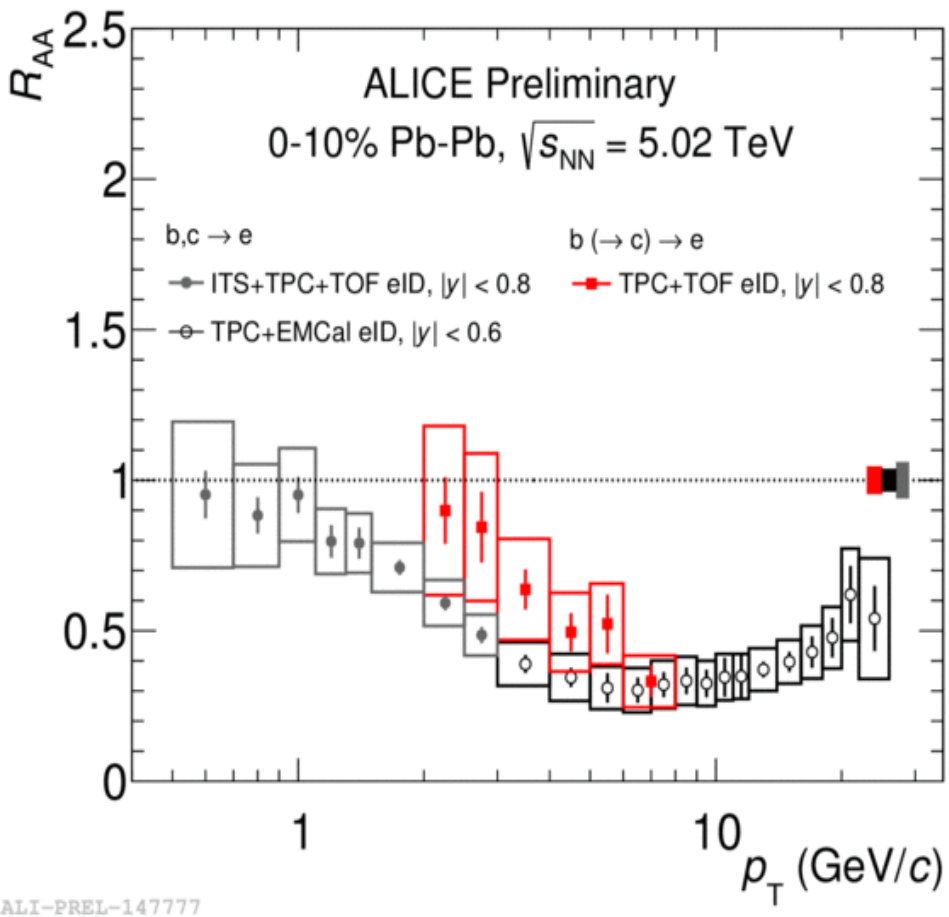
See Camila de Conti's talk on Thursday.



Heavy-flavor also shows strong suppression.

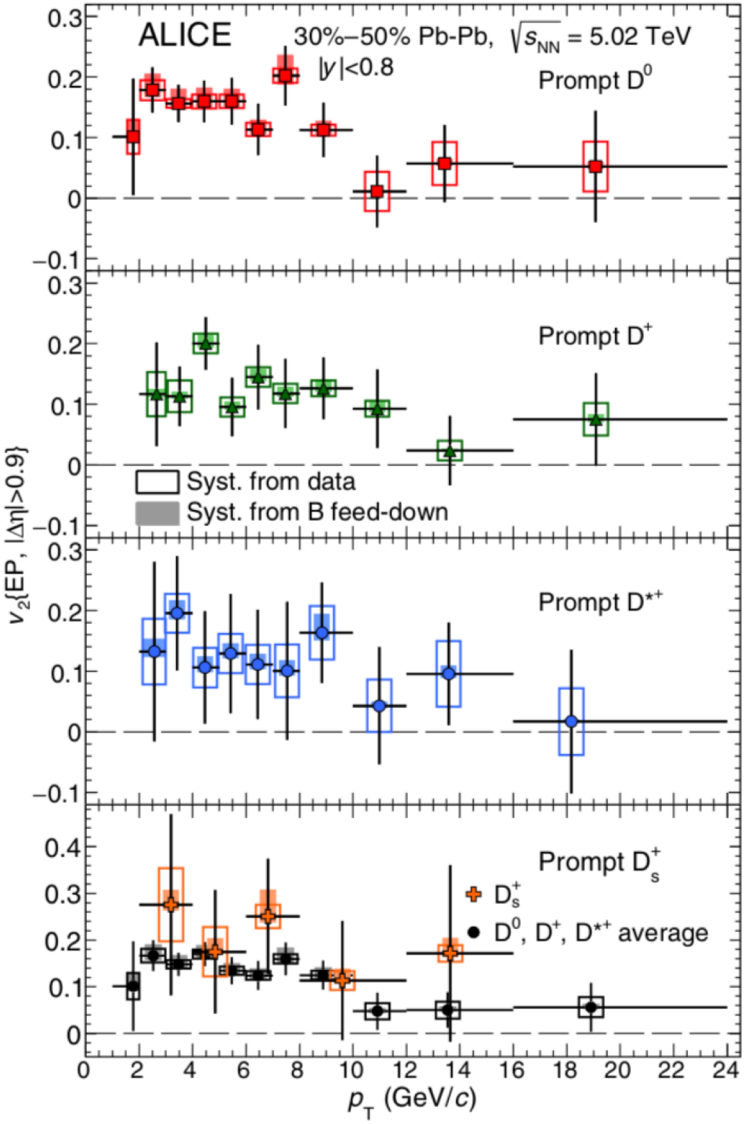
Heavy-flavor electrons

See Camila de Conti's talk on Thursday.



Smaller suppression of beauty than beauty+charm.

Correlations with heavy-flavor

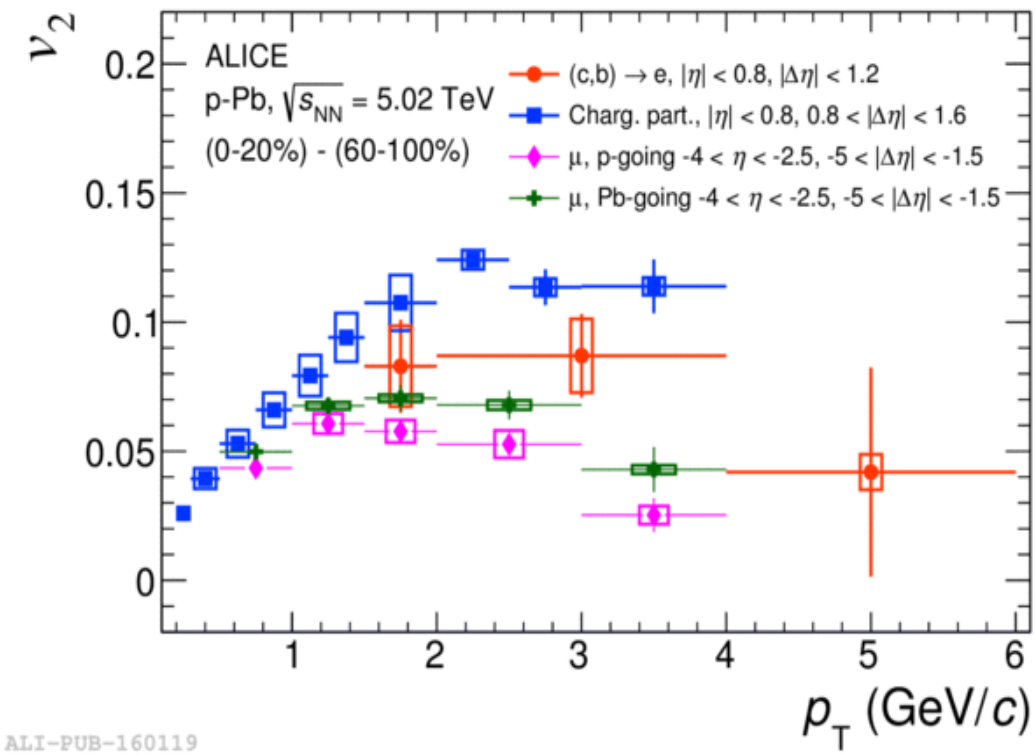


ALICE, PRL 120 (2018) 102301.

- Non-zero v_2 measured for D-mesons in Pb-Pb collisions.
- Similar v_2 for D's and π's.
- Suggests charm-quark transport in a hydro-expanding medium.

See Henrique Zanoli's talk on Friday.

Heavy-flavor electrons v_2 in p-Pb



ALICE, arXiv:1805.04367

Non-zero v_2 also observed in small system.

Important to disentangle initial and final state effects.

See Henrique Zanoli's talk on Friday.

The bright ALICE future

- Un-triggered data sample, with capability to save all Pb-Pb interactions at 50 kHz.

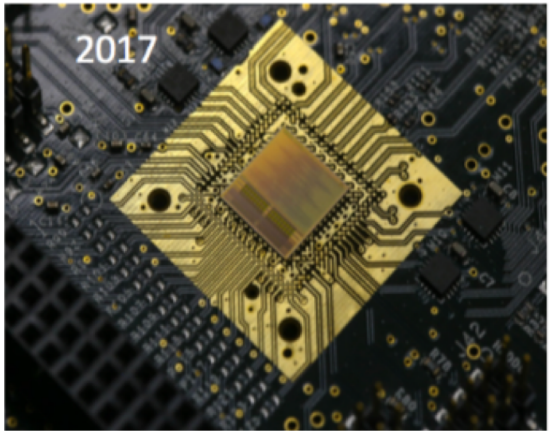
  New TPC readout, GEM + SAMPA chip.

  New Inner Tracking System (ITS).

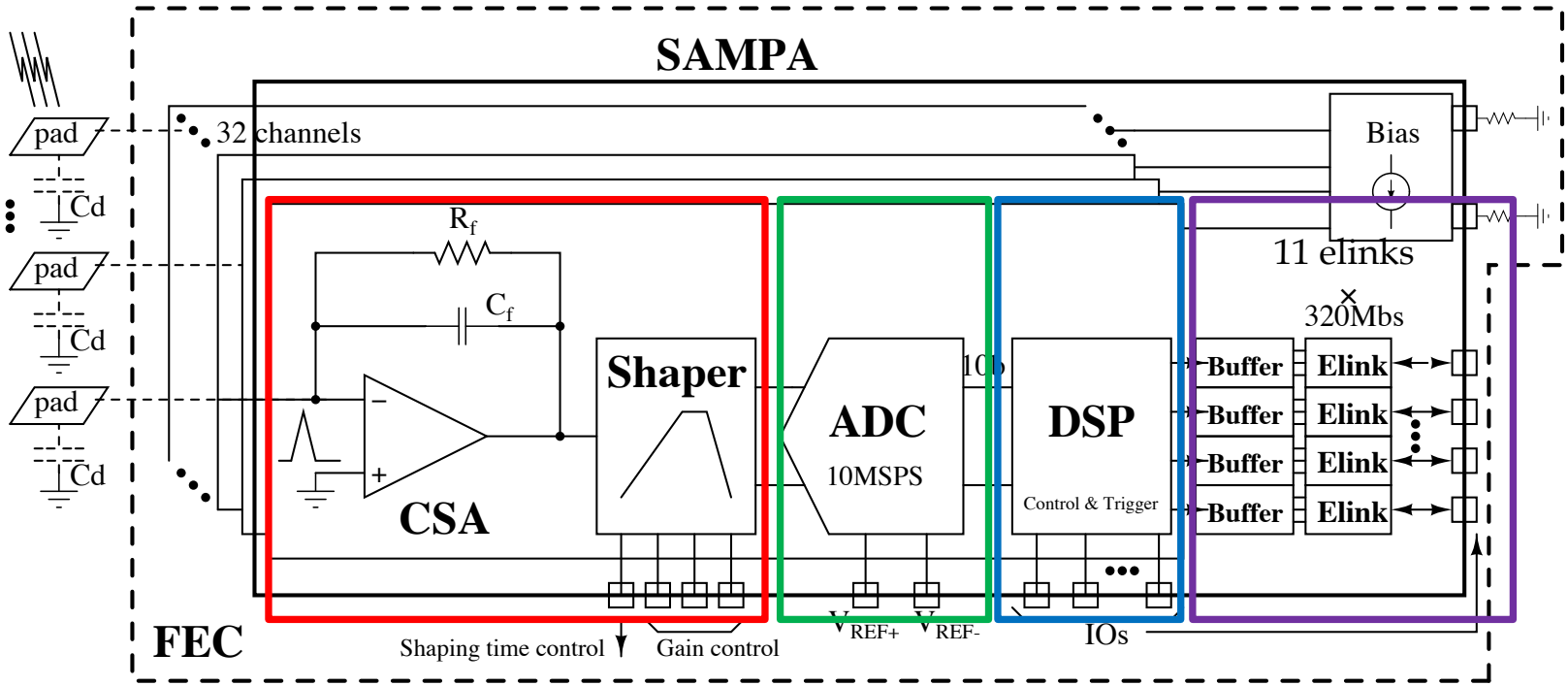
  Integrated Online-Offline system (O^2).
- Improve tracking efficiency and resolution at low-p_T.

  TPC upgrade.

  New Inner Tracking System (ITS).
- New PID detectors.



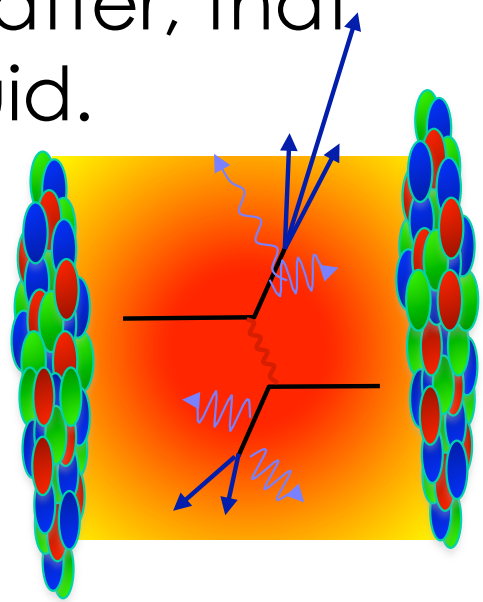
The SAMPA chip



Charge pulse amplification, shaping, digitalization, digital filters and communication with the data acquisition via a large bandwidth connection.

Final Remarks

- Large amount of data allows for detailed studies of QGP properties, including quantum fluctuations.
- Clear picture of HIC can only be done with combination of different observables.
- QGP is a strongly interacting matter, that behaves like a low viscosity liquid.



Final Remarks

- There are still many, many, many other observables measured by ALICE.
- Rich set of heavy-flavor measurements opens new probes to the QGP.
- What is going on in small systems?
- New upgrades will further improve ALICE capabilities.

Thank you !!!