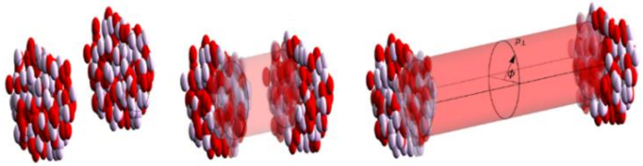
Heavy ion group



Maximilian
Attems

Urs
Wiedemann

Guilherme
Milhano

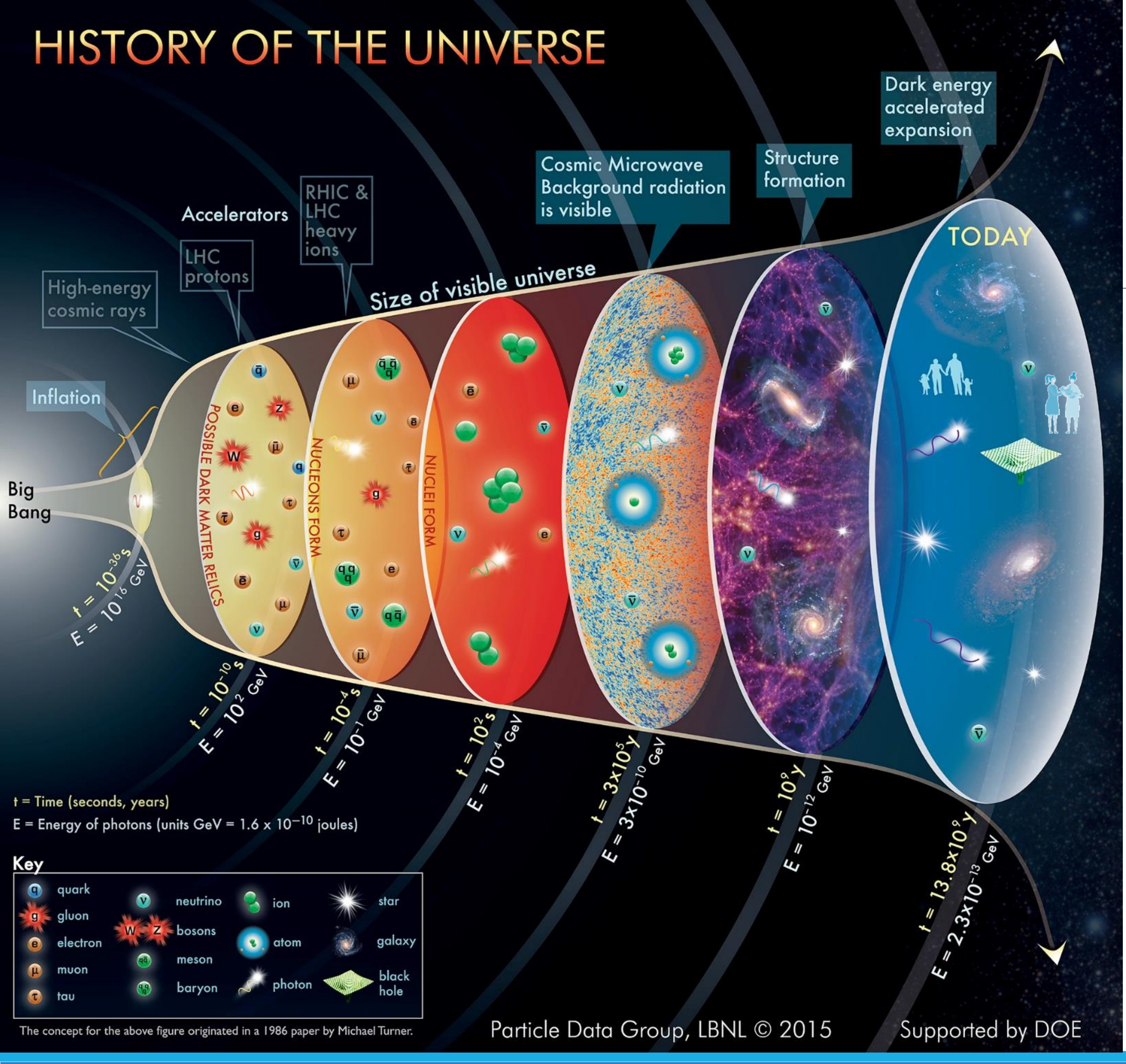
Jasmine
Brewer

Sohyun
Park

Aleksas
Mazeliauskas

Wilke
van der Schee

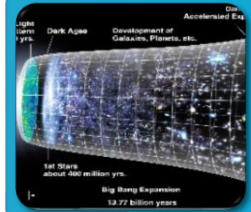
Wilke van der Schee, CERN



Quark-gluon plasma (QGP)

Quantum-Chromodynamics (QCD)

A fundamental force of nature



Recreating the big bang

At age 1 μs the entire universe was QGP!

QGP turns out interesting

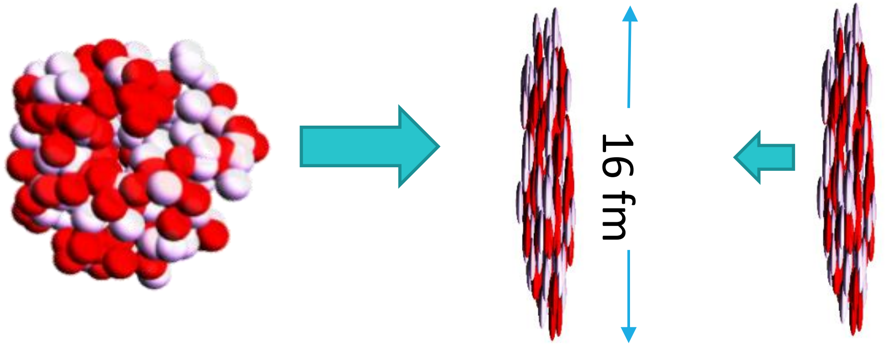
Strongly coupled quantum matter

Wilke van der Schee, CERN

How to create QGP

Colliding heavy nuclei (Pb) at high energies

Lorentz gamma factor up to 2500

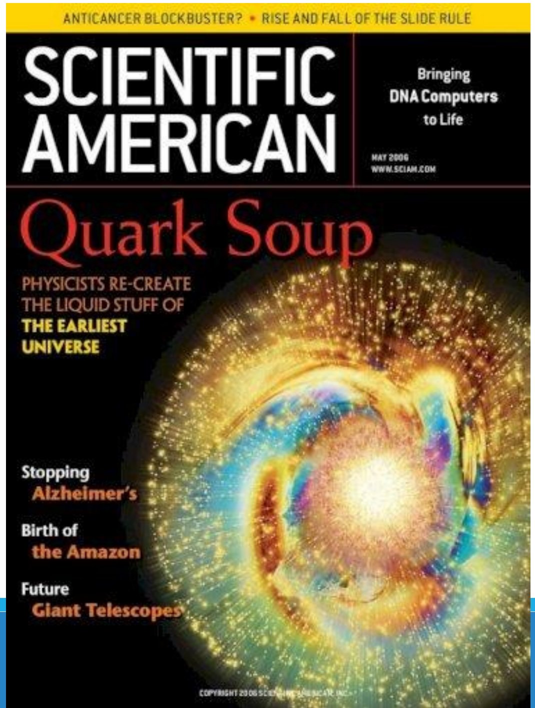


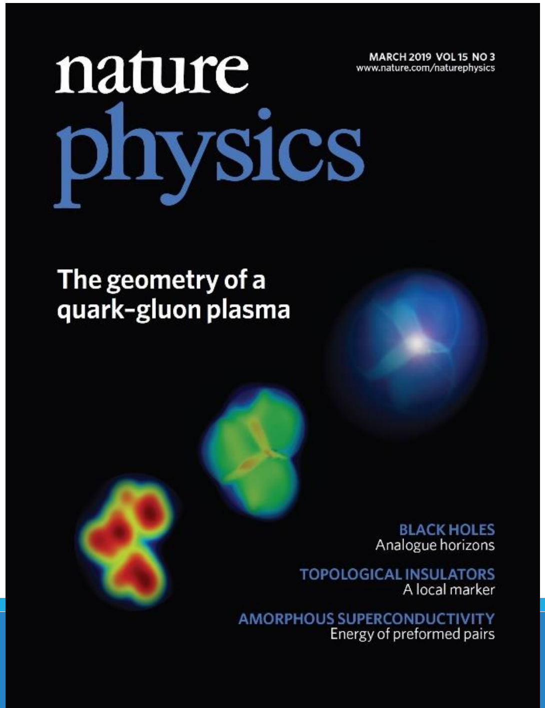
Hottest fluid:
10^{12} K

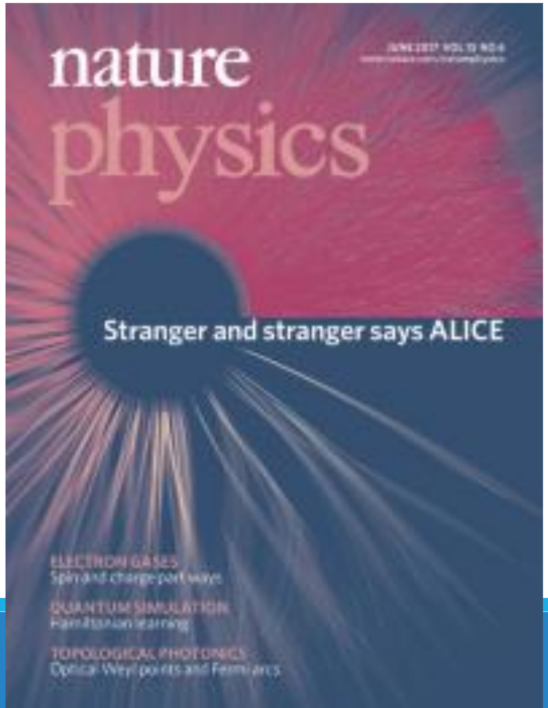
Smallest fluid:
~ 2 fm living 10^{-23} s

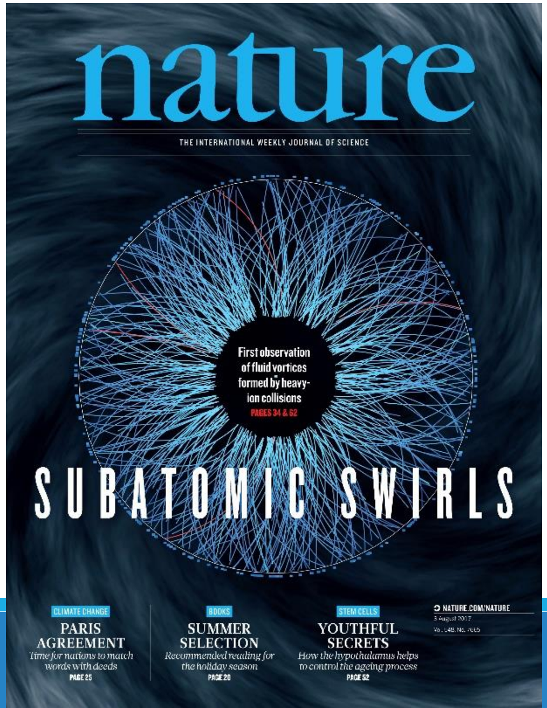
Most perfect/strange:
$\eta/s \sim 0.08$

Most vortical fluid:
$\omega \sim 10^{22}/s$





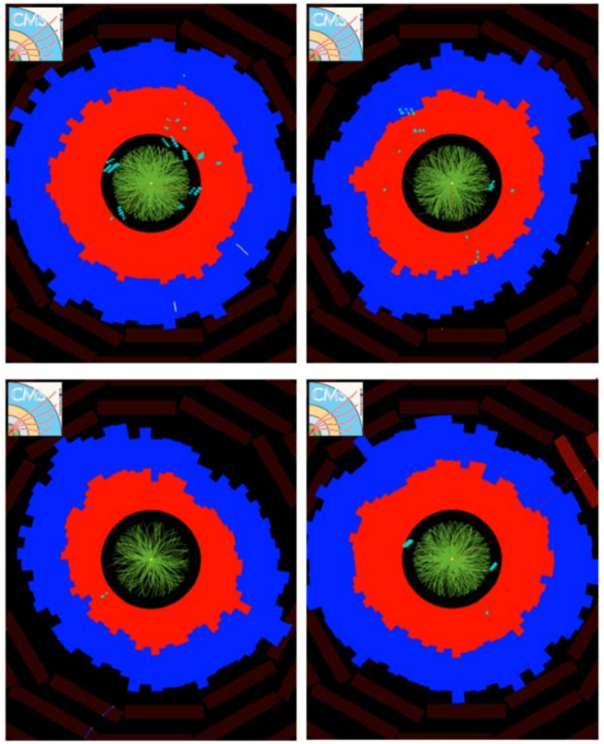


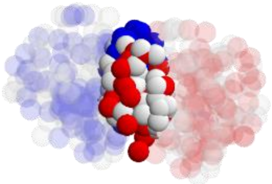


CERN accelerator complex

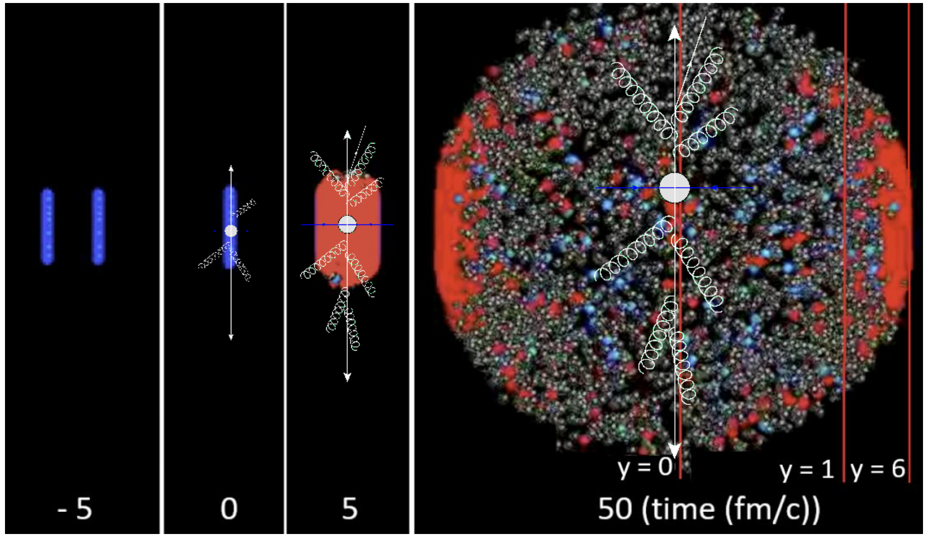
Quark-gluon plasma is strongly coupled

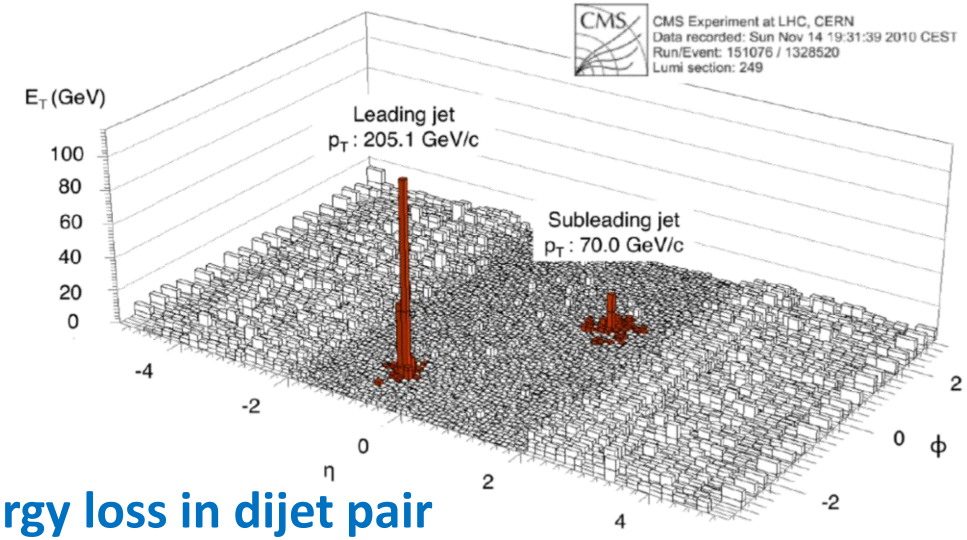
Anisotropic flow (small viscosity)



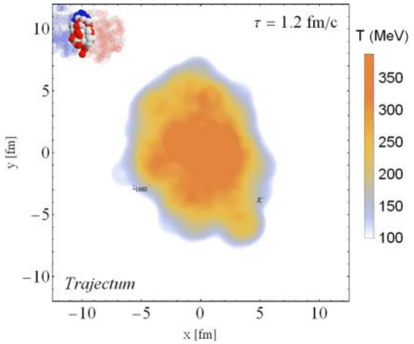


Initial stage - QGP - hadronic phase





Jet energy loss in dijet pair



A visual sketch of a PbPb collisions

1. Thermal freeze-out produces QCD resonances → decay to hadrons

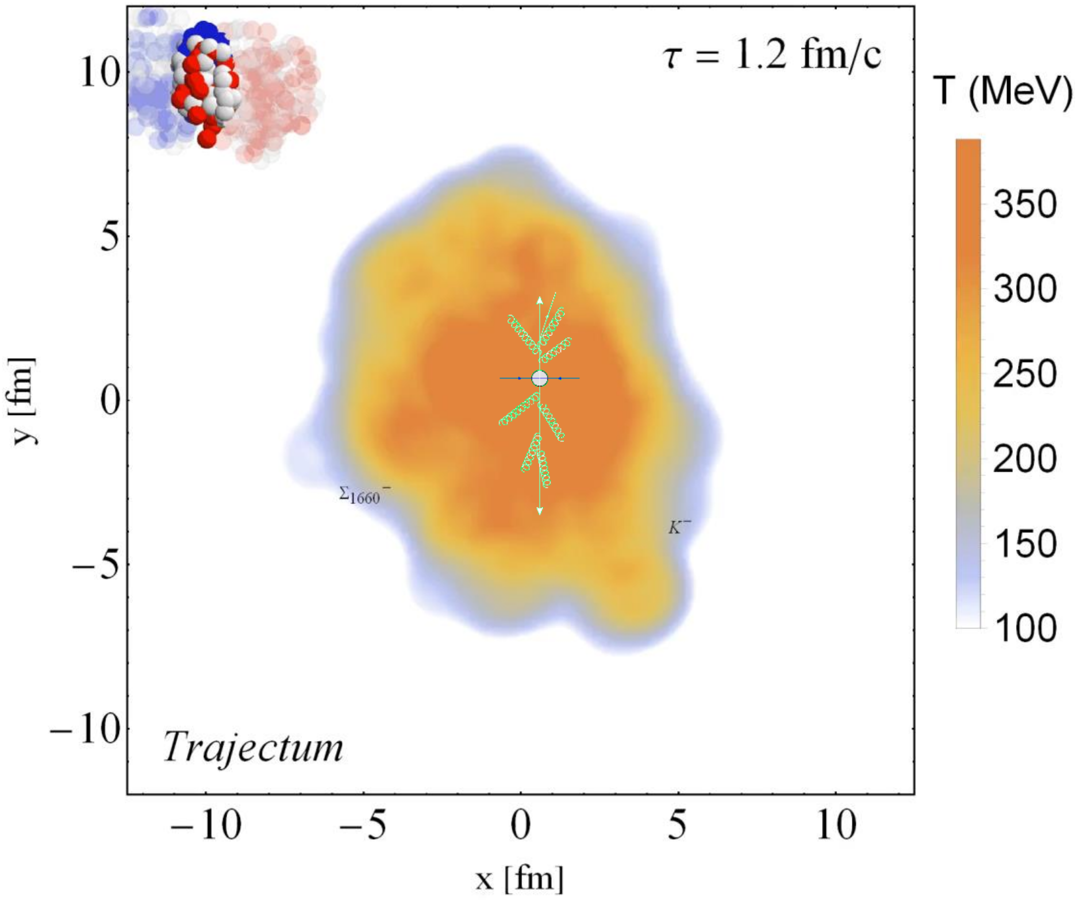
   Aleksas (1909.10485, 2104.12754)

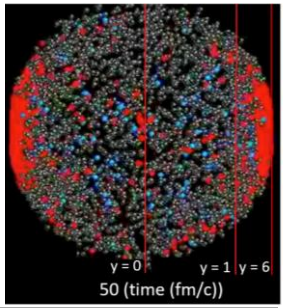
2. In rare cases: jets moving through

   Jasmine (1809.10695, 1812.05111, 2110.13159)
   Guilherme (1907.11248)

3. Lots of photons are produced (decays + bremsstrahlung)

   Sohyun and Urs (2107.05129)





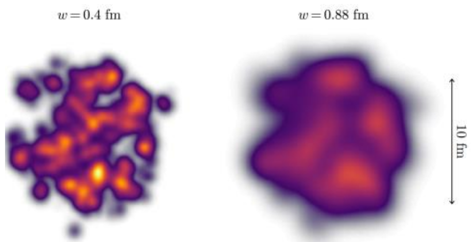
Standard model of heavy ion collisions

Jasmine (1910.00021)
Aleksas (2104.08179, 2005.12299, 1908.02866)
Maximilian (1703.09681)

Hydrodynamisation

Initial stage (9)

Subnucleonic structure?

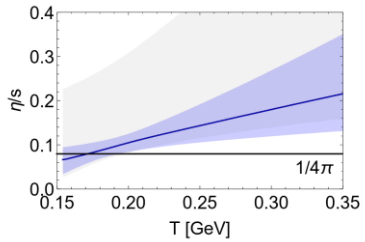


Non-thermal flow?

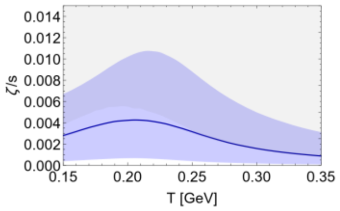
Fluctuations?

Viscous hydrodynamics (9)

Shear viscosity



Bulk viscosity



Cascade of hadrons (1)

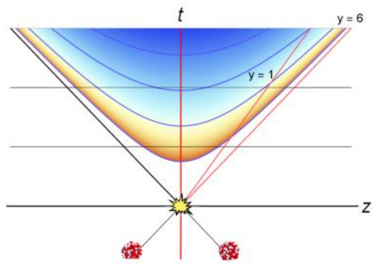
Convert quark-gluon plasma at T_{switch} to particles following Boltzmann distribution

Evolve particles with hadronic code: SMASH

Maximilian (1606.06642)

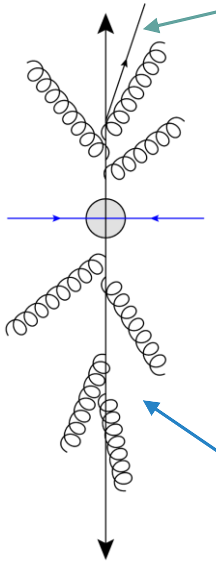
Jonah Bernhard, Scott Moreland and Steffen Bass, Bayesian estimation of the specific shear and bulk viscosity of quark–gluon plasma (2019)
Govert Nijs, WS, Umut Gursoy and Raimond Snellings, A Bayesian analysis of Heavy Ion Collisions with Trajectum (2020)

Ridges everywhere: *panta rei*

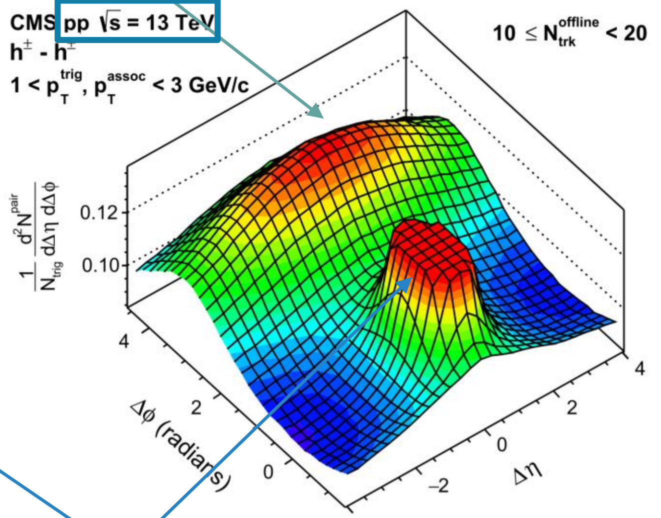


1. Ridge at $\Delta\phi$=0 and **large $\Delta\eta$**: *an initial or geometric effect*

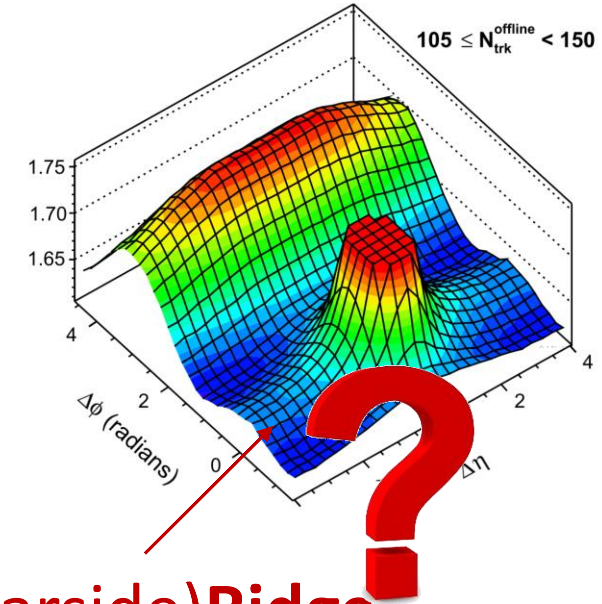
Back-to-back jet

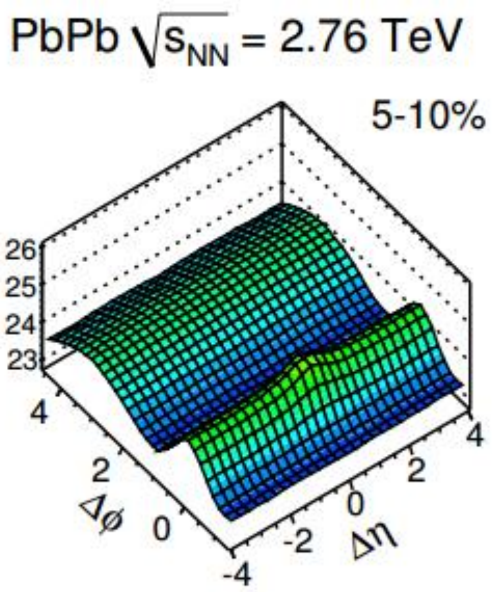


Low multiplicity



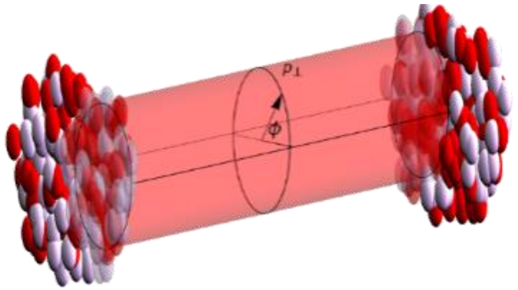
High multiplicity



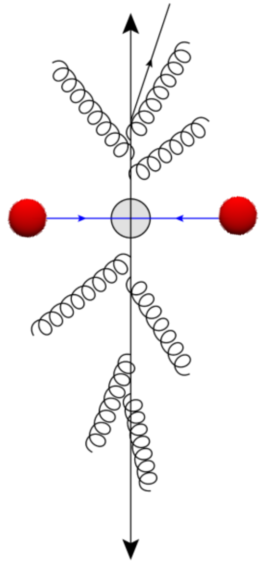


Jet fragmentation

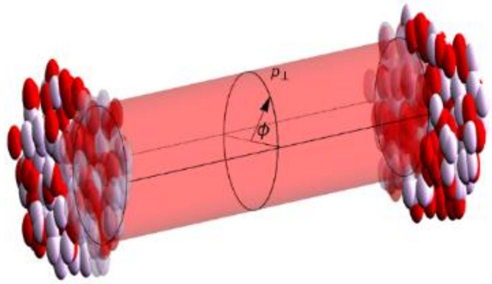
(nearside)**Ridge**



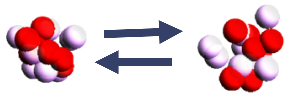
(high energy) ¿HEP versus HIP? (heavy ion)

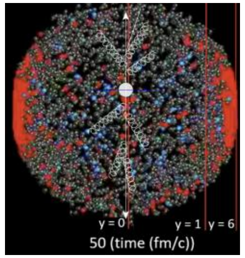


Low multiplicity	High multiplicity
Jet-like particle shower	Relatively few jets
No equilibration	Equilibration: QGP

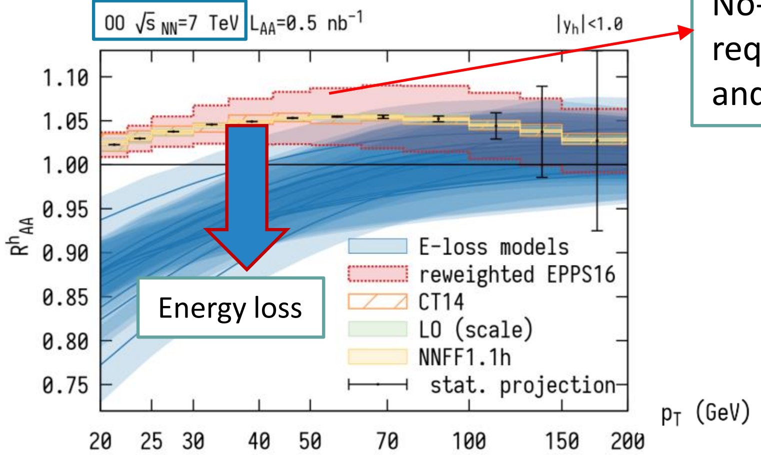


Jets important in heavy ion/small systems
Often intermediate multiplicity
QGP-type physics part of *pp* collisions





OO collisions as an example:
Nuclear modification factor: hadron R_{AA}
More energy loss → fewer hadrons
Interplay from HEP and HIP

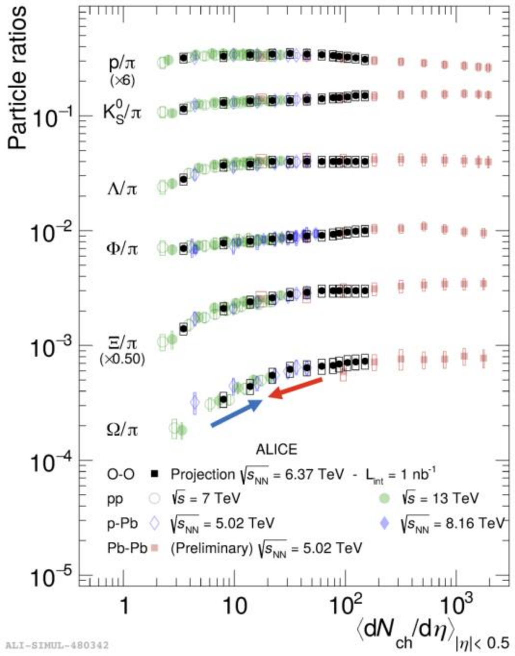


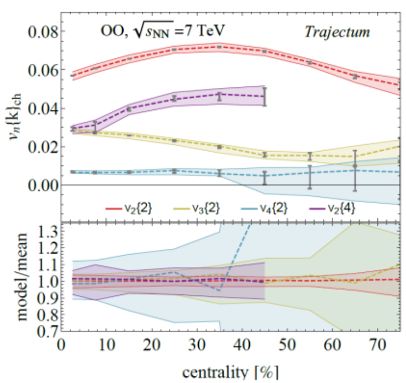
No-energy-loss baseline: requires accurate pQCD and nuclear physics

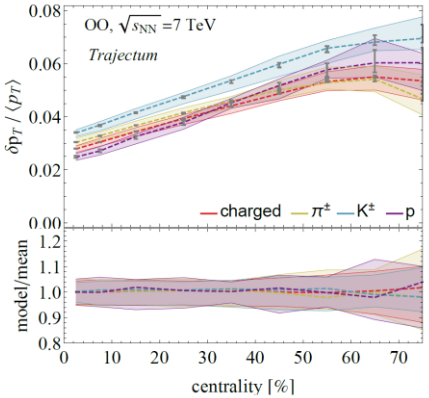
A. Huss, A. Kurkela, A. Mazeliauskas, R. Paatelainen, WS and U. Wiedemann, Discovering partonic rescattering in light nucleus collisions (2020)

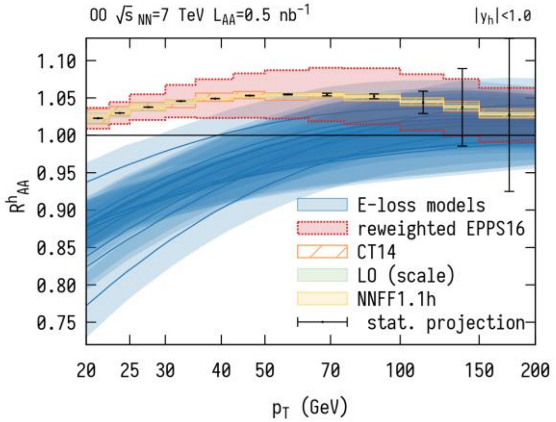
Oxygen & small systems: LHC as a light ion collider

1. Will help resolving the `flow in small systems' puzzle
2. A well-controlled environment to discover *jet quenching* in small systems
3. Bridges the gap between pPb and PbPb for strangeness enhancement
4. pO: of crucial interest in modelling cosmic ray showers (LHCf)









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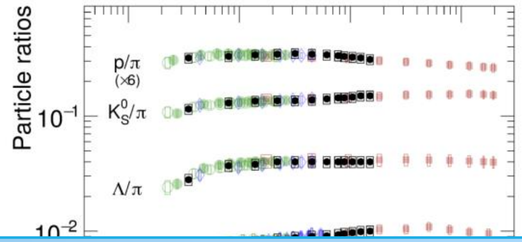
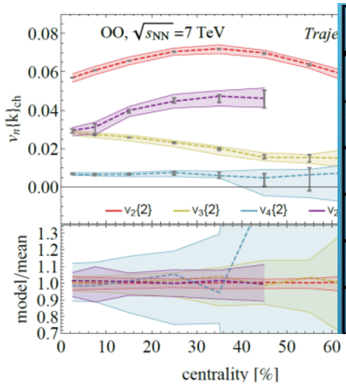


LHC as a light ion collider



Ion	Min Energy	A	Z
Pb	13	208	82
Xe	13	129	54
In	13	115	49
Ar	13	40	18
O	13	16	8
He	13	4	2

Full LHC exploitation : Oxygen run and SND

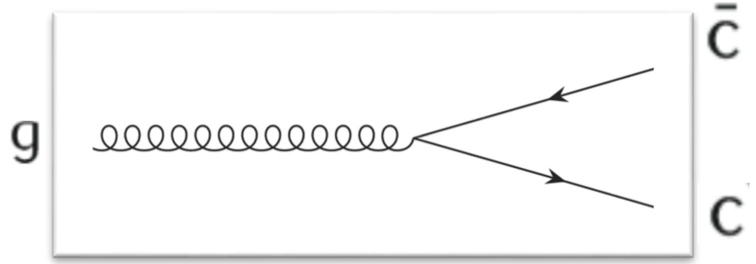
Special **O-O and p-O run**

- Physics motivations: study of emergence of collective effects in small systems; measurements relevant for cosmic rays (extensive air shower modelling), etc.
- Experiments requested ~ nb^{-1} for each of OO and pO. ~ 1 week (including commissioning), most likely in 2024
- No impediment from accelerators but radiological impact of high-intensity oxygen beam requires mitigation measures and additional beams stoppers to be able to access Booster when LEIR operates.
- Needed resources allocated in this MTP

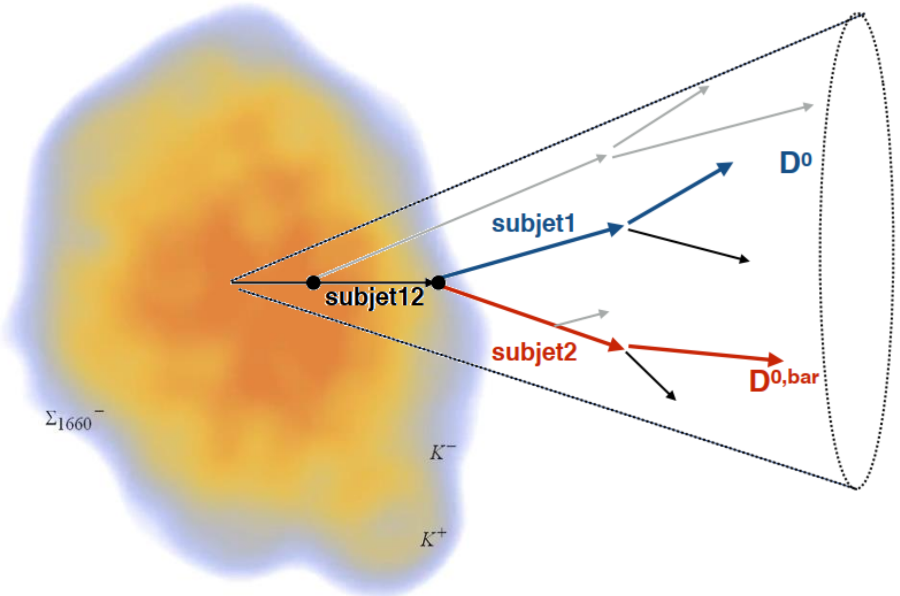
Workshop Opportunities of OO and pO collisions at the LHC, organised together with Jasmine Brewer and Aleksas Mazeliauskas, cern.ch/OppOatLHC (Feb 2021)
Alexander Huss, Aleksi Kurkela, Aleksas Mazeliauskas, Risto Paatelainen, WS and Urs Achim Wiedemann, Discovering partonic rescattering in light nucleus collisions (2020)

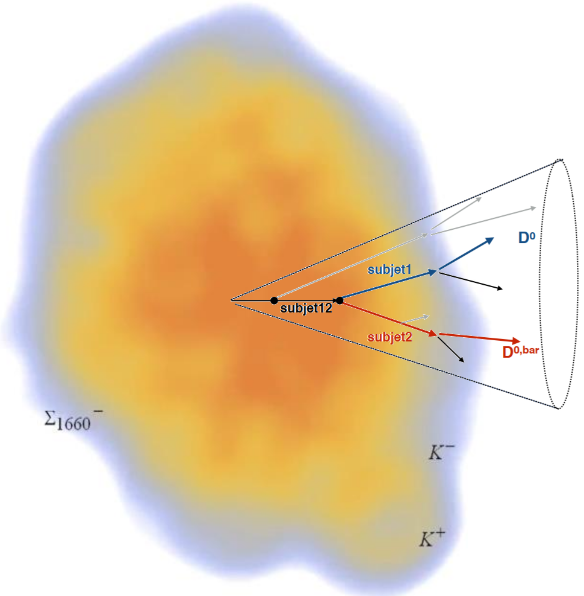
Aleksas, Jasmine, Maximilian, Sohyun, Urs, Wilke and Gian Michele (ALICE)

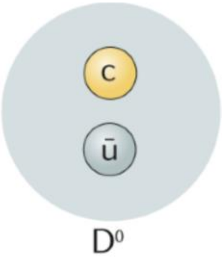
Gluon to c-cbar splitting



Illuminating the *spatio-temporal structure* of parton showers



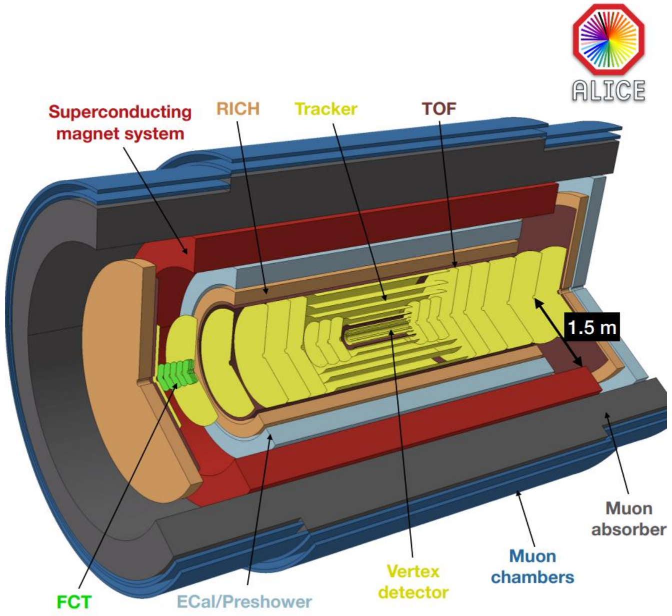


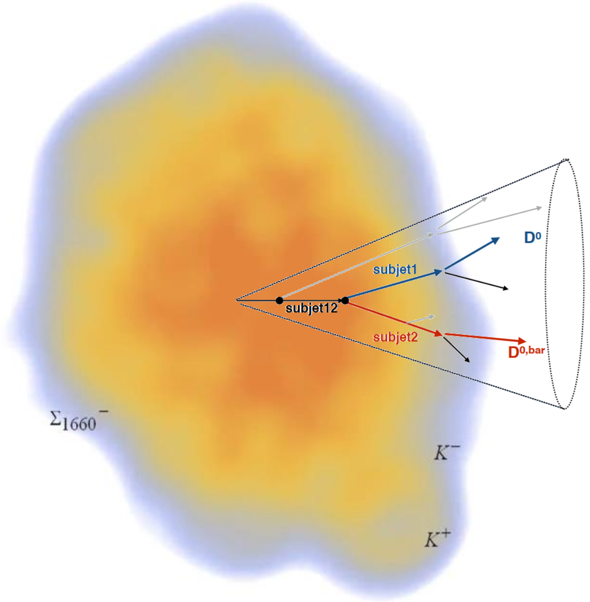


Does the gluon split within the medium?

- If yes: expect increased mass of D-Dbar system due to medium

ALICE 3 detector proposal (for 2032)

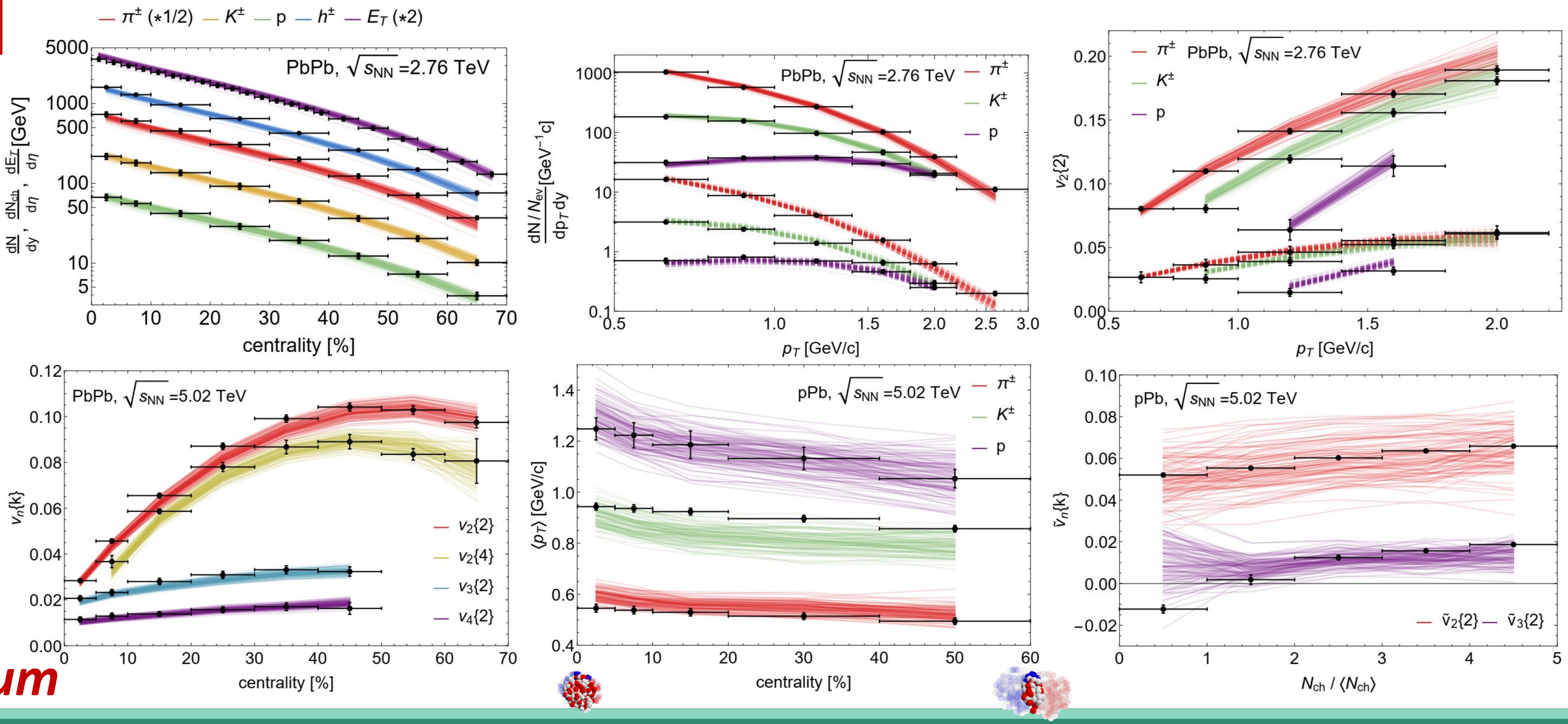




Excellent particle identification, high luminosity, 5x larger rapidity coverage

- Dealbreaker for precision analysis of small systems and (relatively) rare probes

Posterior



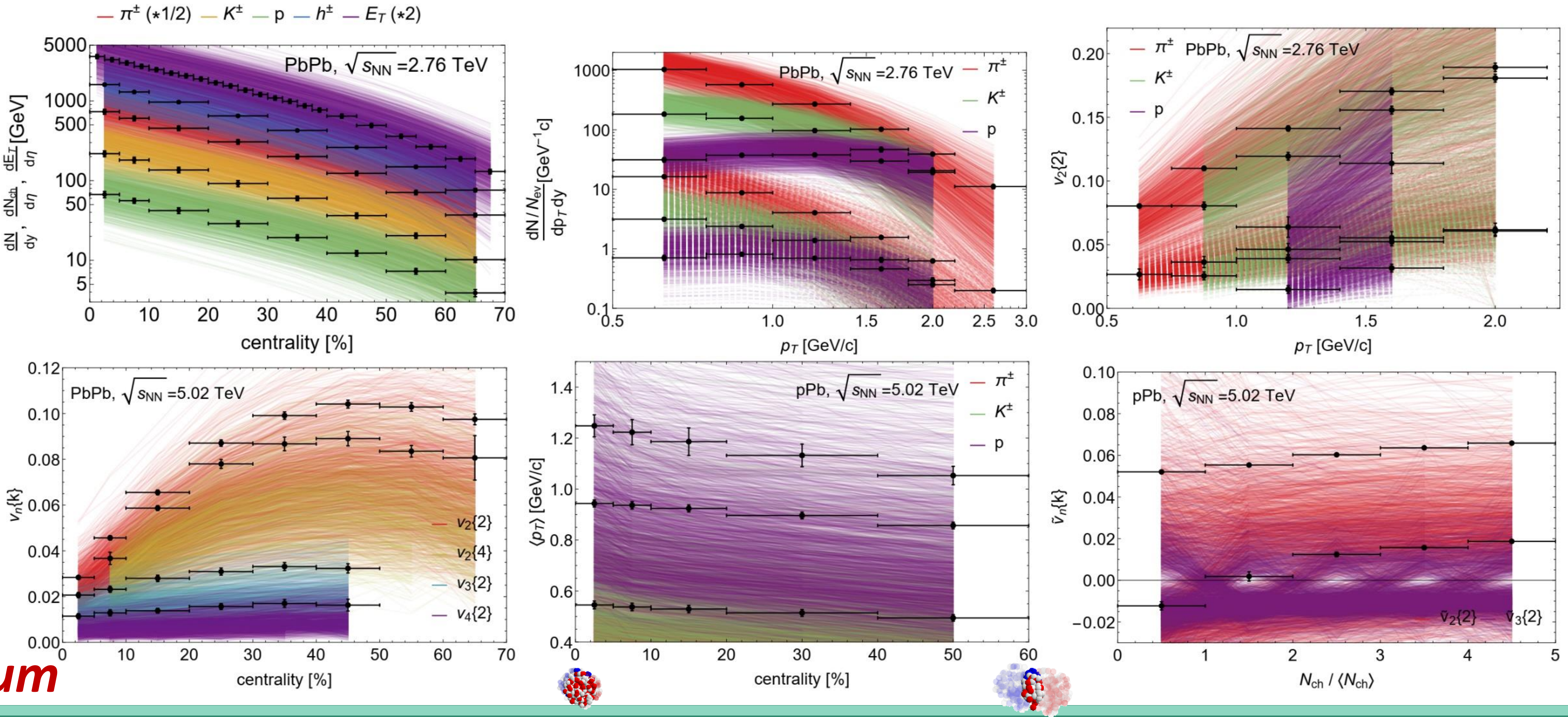
Trajectum

Experimental observables: *a wealth of data*

1. Yields, spectra, identified $v_n\{2\}$ versus p_T, *p*Pb and PbPb (514 datapoints)
2. A comprehensive analysis including **p_T-differential observables**

Govert Nijs, WS, Umut Gürsoy, Raimond Snellings, A transverse momentum differential global analysis of Heavy Ion Collisions (2020)

Design



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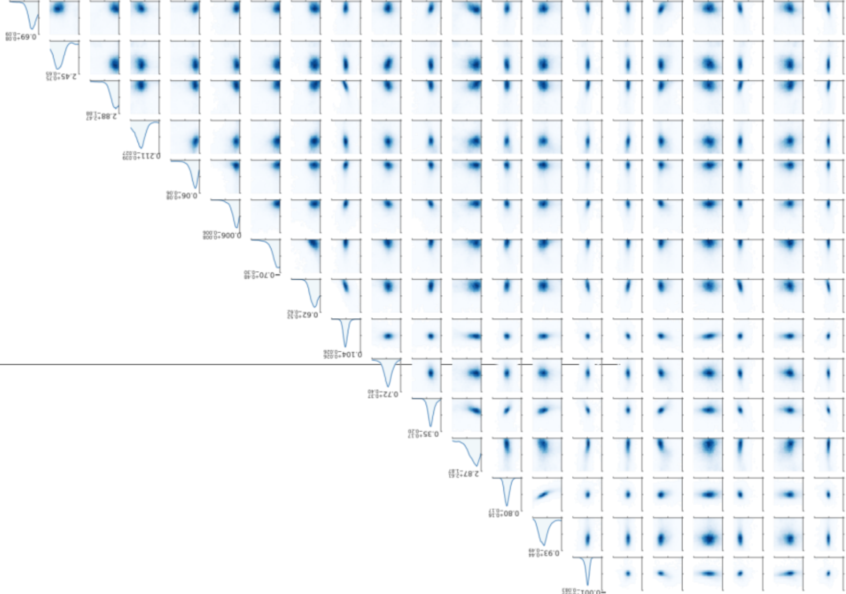
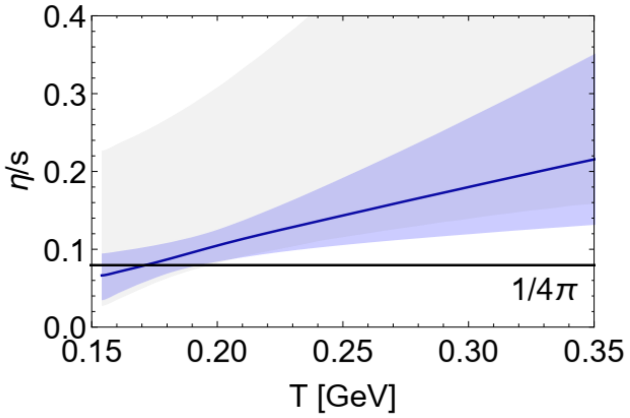
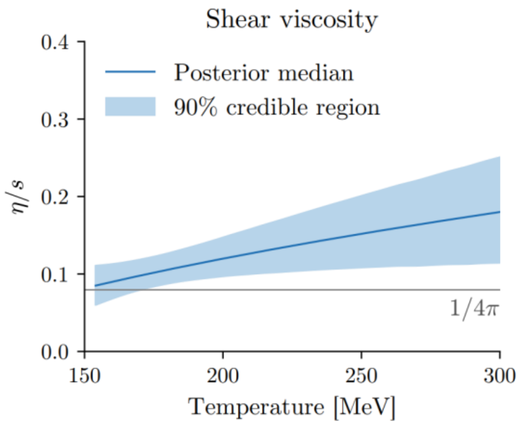


Posterior distributions – shear viscosity

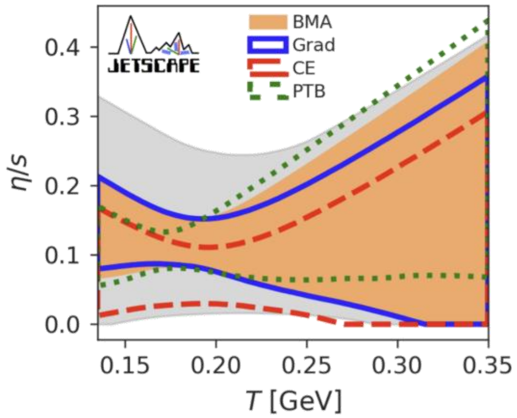
1. Shear viscosity consistent with previous work
   - More data, but also enlarged model → similar constraint on η/s



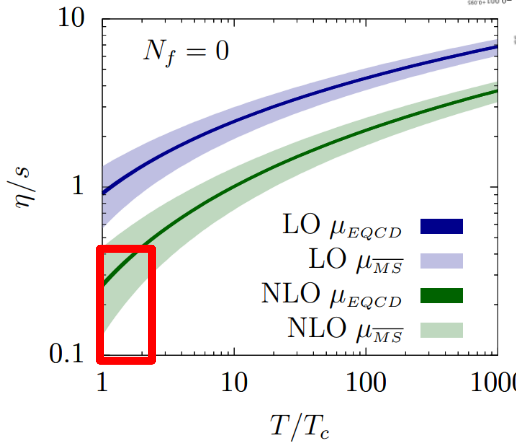
Current work (2020)



J. Bernhard, S. Moreland and S. Bass, Nature Physics (2019)



JETSCAPE (2020)



Jacopo Ghiglieri, Guy Moore and Derek Teaney
QCD Shear Viscosity at (almost) NLO (2018)

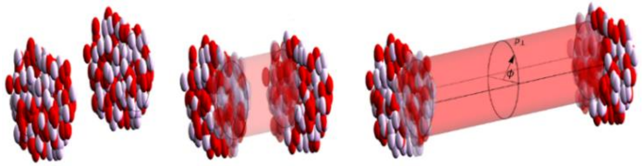
2. Work in progress on bulk viscosity and much more (hydrodynamisation, 2nd order hydro)

Heavy ion group


Maximilian Attems


Urs Wiedemann


Guilherme Milhano



PHYSICAL REVIEW C **104**, 044903 (2021)

Bremsstrahlung photons from stopping in heavy-ion collisions

Sohyun Park[*] and Urs Achim Wiedemann[†]
Theoretical Physics Department, CERN, CH-1211 Genève 23, Switzerland

PHYSICAL REVIEW LETTERS **124**, 102301 (2020)

Early- and Late-Time Behavior of Attractors in Heavy-Ion Collisions

Aleksi Kurkela,[1,2,*] Wilke van der Schee,[1,†] Urs Achim Wiedemann,[1,‡] and Bin Wu[1,§]
[1]*Theoretical Physics Department, CERN, CH-1211 Genève 23, Switzerland*

PHYSICAL REVIEW LETTERS **126**, 192301 (2021)

Discovering Partonic Rescattering in Light Nucleus Collisions

Alexander Huss,[1,*] Aleksi Kurkela,[1,2,†] Aleksas Mazeliauskas,[1,‡] Risto Paatelainen,[1,§] Wilke van der Schee,[1,‖] and Urs Achim Wiedemann[1,¶]
[1]*Theoretical Physics Department, CERN, CH-1211 Genève 23, Switzerland*

PHYSICAL REVIEW C **103**, 054903 (2021)

Predicting parton energy loss in small collision systems

Alexander Huss,[1,*] Aleksi Kurkela,[1,2,†] Aleksas Mazeliauskas,[1,‡] Risto Paatelainen,[1,§] Wilke van der Schee,[1,‖] and Urs Achim Wiedemann[1,¶]
[1]*Theoretical Physics Department, CERN, CH-1211 Genève 23, Switzerland*

Ratios of jet and hadron spectra at LHC energies: measuring high-p_T suppression without a pp reference

Jasmine Brewer,[1] Alexander Huss,[1] Aleksas Mazeliauskas,[1] and Wilke van der Schee[1]
[1]*Theoretical Physics Department, CERN, CH-1211 Geneva 23, Switzerland*

JHEP — Published for SISSA by Springer

Received: *June 22, 2021*

An analysis of Bayesian estimates for missing higher orders in perturbative calculations

Claude Duhr,[a] Alexander Huss,[a] Aleksas Mazeliauskas[a] and Robert Szafron[b]
[a]*Theoretical Physics Department, CERN, CH-1211 Geneva 23, Switzerland*
[b]*Department of Physics, Brookhaven National Laboratory,*

Opportunities of OO and pO collisions at the LHC

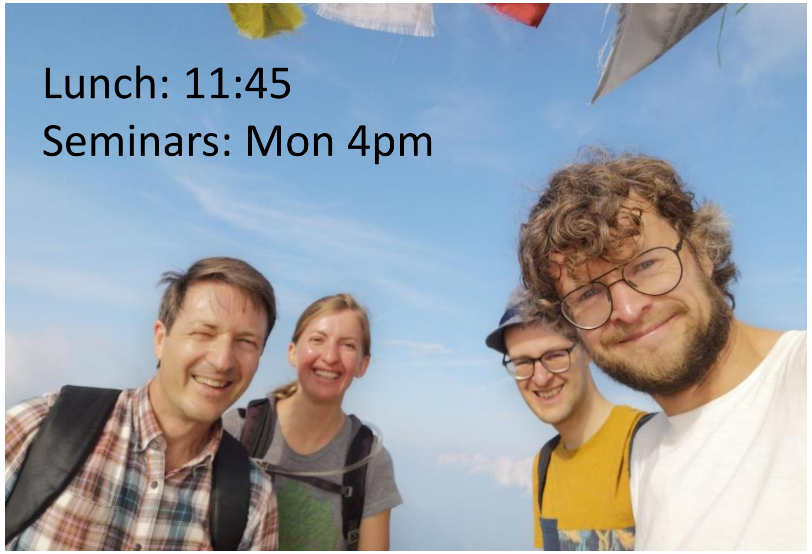
Jasmine Brewer, Aleksas Mazeliauskas and Wilke van der Schee
Theoretical Physics Department, CERN, 1211 Geneva 23, Switzerland

Jasmine Brewer


Sohyun Park


Aleksas Mazeliauskas


Wilke van der Schee

CERN