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CERN  
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Scientific Software for  
Heterogeneous Architectures

1-7 May 2022  
Cargèse, Corsica – France



Deadline for Application: 23<sup>rd</sup> January 2022  
<https://indico.cern.ch/e/tCSC-2022>



# Little Big Bang

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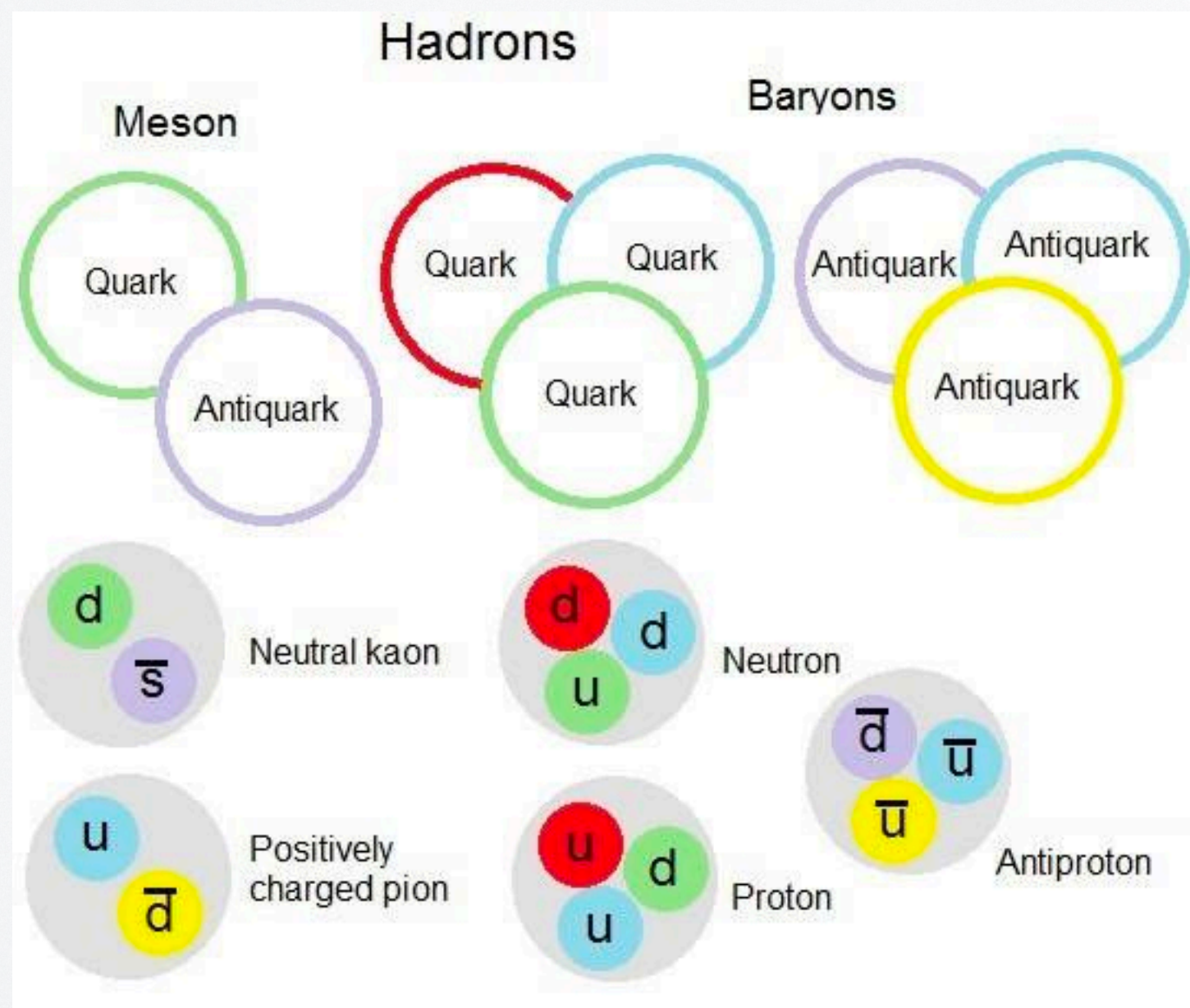
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# What we all know

- Quarks confined in hadrons
  - $q\bar{q}$  = meson
  - $qqq$  = baryon
  - + sea quarks and gluons



# Standard Model of Elementary Particles

	three generations of matter (fermions)			interactions / force carriers (bosons)		
	I	II	III			
QUARKS	mass $\approx 2.2 \text{ MeV}/c^2$ charge $\frac{2}{3}$ spin $\frac{1}{2}$ <b>u</b> up	mass $\approx 1.28 \text{ GeV}/c^2$ charge $\frac{2}{3}$ spin $\frac{1}{2}$ <b>c</b> charm	mass $\approx 173.1 \text{ GeV}/c^2$ charge $\frac{2}{3}$ spin $\frac{1}{2}$ <b>t</b> top	mass 0 charge 0 spin 1 <b>g</b> gluon	SCALAR BOSONS	mass $\approx 124.97 \text{ GeV}/c^2$ charge 0 spin 0 <b>H</b> higgs
	mass $\approx 4.7 \text{ MeV}/c^2$ charge $-\frac{1}{3}$ spin $\frac{1}{2}$ <b>d</b> down	mass $\approx 96 \text{ MeV}/c^2$ charge $-\frac{1}{3}$ spin $\frac{1}{2}$ <b>s</b> strange	mass $\approx 4.18 \text{ GeV}/c^2$ charge $-\frac{1}{3}$ spin $\frac{1}{2}$ <b>b</b> bottom	mass 0 charge 0 spin 1 <b><math>\gamma</math></b> photon		
	mass $\approx 0.511 \text{ MeV}/c^2$ charge -1 spin $\frac{1}{2}$ <b>e</b> electron	mass $\approx 105.66 \text{ MeV}/c^2$ charge -1 spin $\frac{1}{2}$ <b><math>\mu</math></b> muon	mass $\approx 1.7768 \text{ GeV}/c^2$ charge -1 spin $\frac{1}{2}$ <b><math>\tau</math></b> tau	mass $\approx 91.19 \text{ GeV}/c^2$ charge 0 spin 1 <b>Z</b> Z boson		GAUGE BOSONS VECTOR BOSONS
	mass $< 1.0 \text{ eV}/c^2$ charge 0 spin $\frac{1}{2}$ <b><math>\nu_e</math></b> electron neutrino	mass $< 0.17 \text{ MeV}/c^2$ charge 0 spin $\frac{1}{2}$ <b><math>\nu_\mu</math></b> muon neutrino	mass $< 18.2 \text{ MeV}/c^2$ charge 0 spin $\frac{1}{2}$ <b><math>\nu_\tau</math></b> tau neutrino	mass $\approx 80.39 \text{ GeV}/c^2$ charge $\pm 1$ spin 1 <b>W</b> W boson		





# Motivation for this contribution

- ALICE is one of the four big LHC experiments
- So why nobody knows what we are doing? 😞
  - Yesterday during lunch “so ALICE only ran for a few weeks during LHC Run 2?”
- Also, QGP is not only studied by ALICE!



ALICE representation  
at tCSC 2022

LHC Seminar

## Systematic studies of parton-quark gluon plasma interactions with ATLAS

by Qipeng Hu (Lawrence Livermore Nat. Laboratory (US))

📅 Tuesday 10 May 2022, 11:00 → 12:00 Europe/Zurich

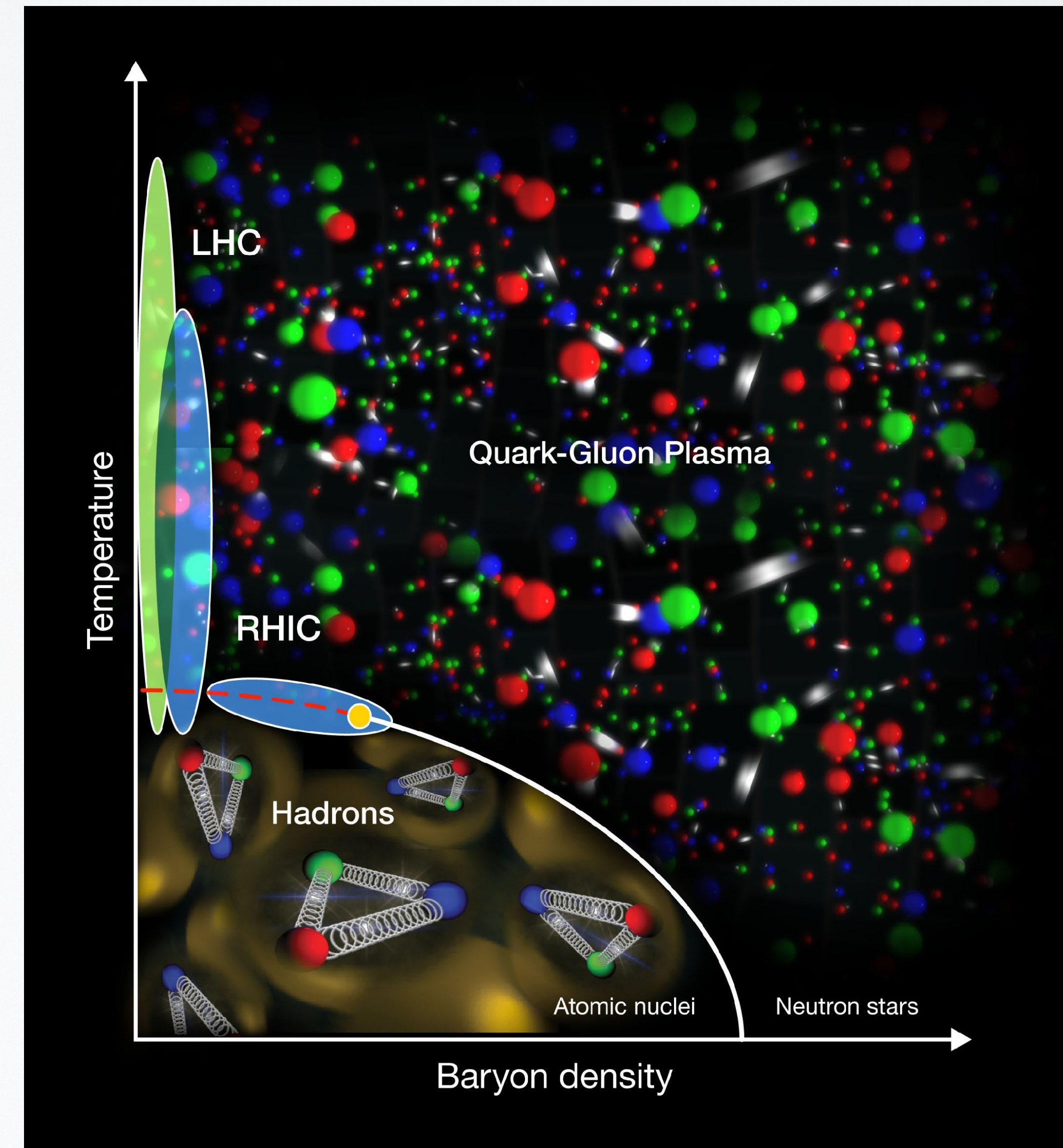
**Description** Jet quenching, in which partons lose energy through interactions with a colour-charged medium, is one of the major signatures of quark-gluon plasma (QGP) formation in relativistic heavy-ion collisions. The seminar presents recent jet quenching measurements based on Run-2 data collected with the ATLAS detector. Using the results of inclusive jet production as a baseline, these new studies systematically explore how jet quenching depends on the mass and colour charge of the initiating parton, the parton shower's path-length in the QGP medium, and the jet substructure.





# What happens when we increase the temperature?

- Cargèse today  $\sim 295$  K
- Temperature in the middle of the Sun: 15 700 000 K
- Temperature needed for the creation of QGP: 2 000 000 000 000 K
- Very extreme conditions (both temperature and density) lead to a creation of the different state of the matter where quarks and gluons are deconfined — and **quark-gluon plasma** is created!
- Existed shortly after the **Big Bang**, recreated in ultra-relativistic heavy-ion collisions (at LHC and RHIC) — our **Little Big Bangs**

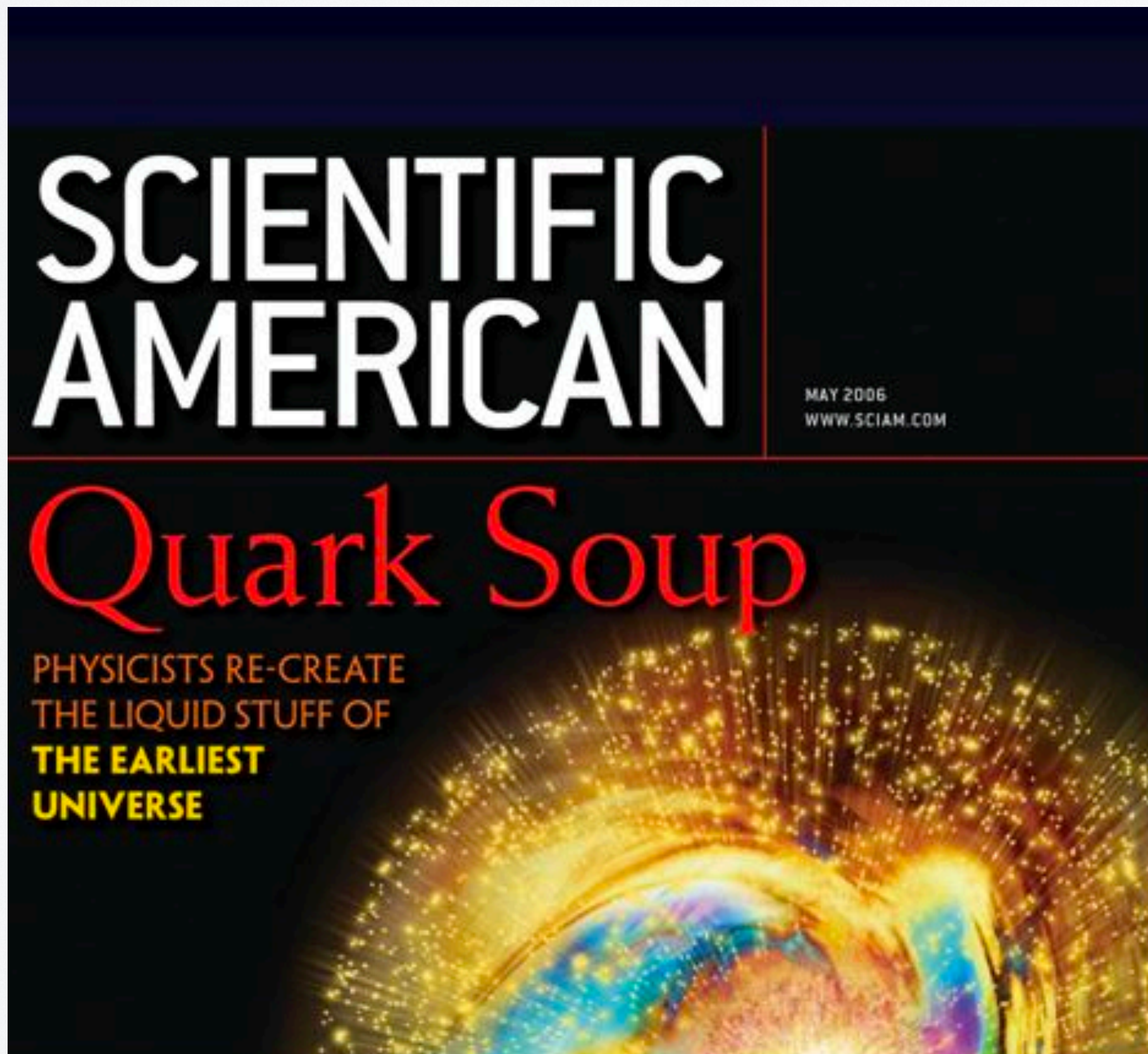






# Properties

- Most **perfect fluid** — at the theoretical limit of viscosity
- It means we can describe it by hydrodynamics!

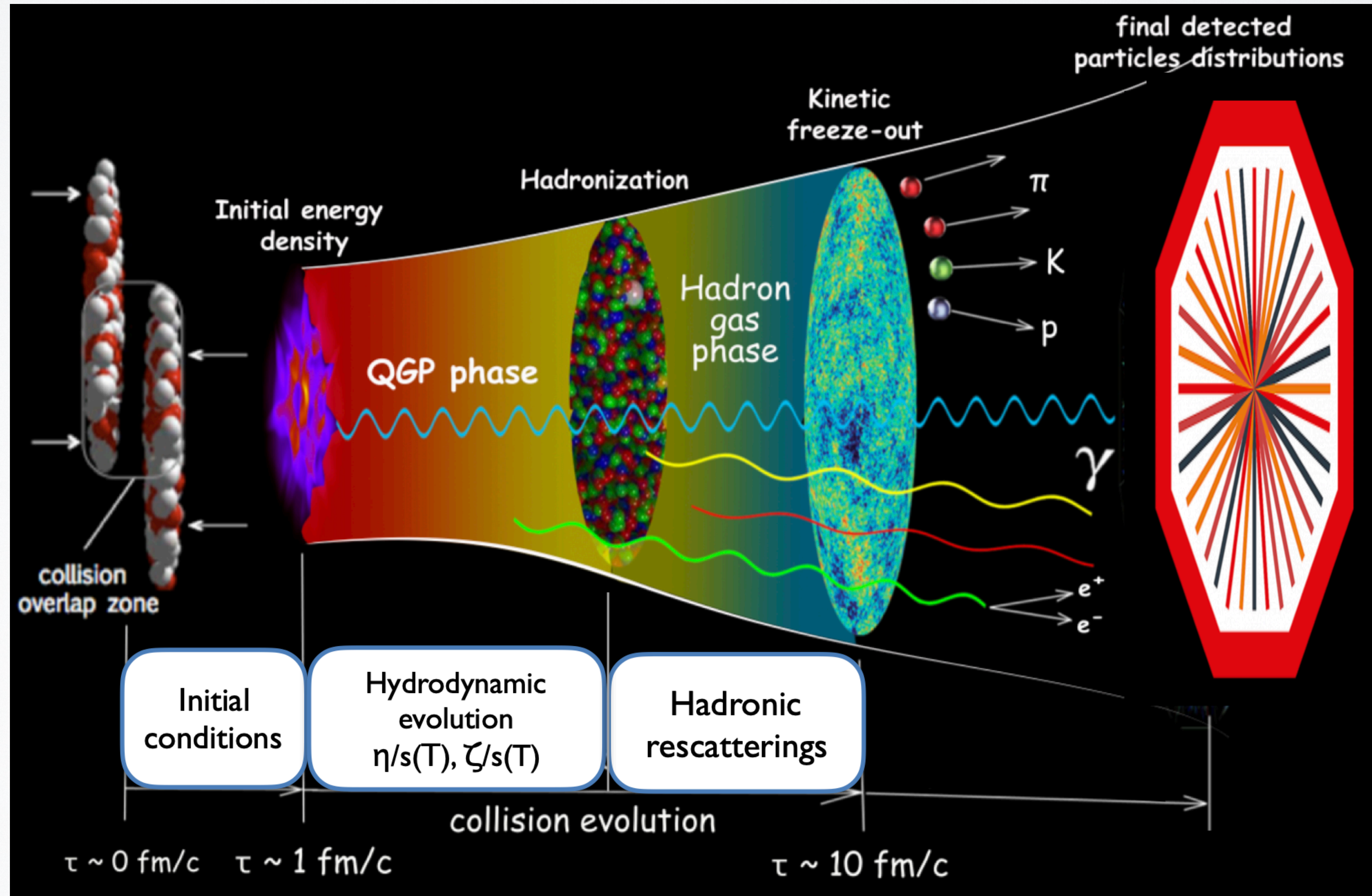






# Evolution of QGP

- Lorentz-contracted heavy-ion “pancakes” collide
- QGP is created
- QGP very quickly expands, cools down, and hadronizes
- We see “only” final-state particles, not QGP itself
- Very nice **animation**

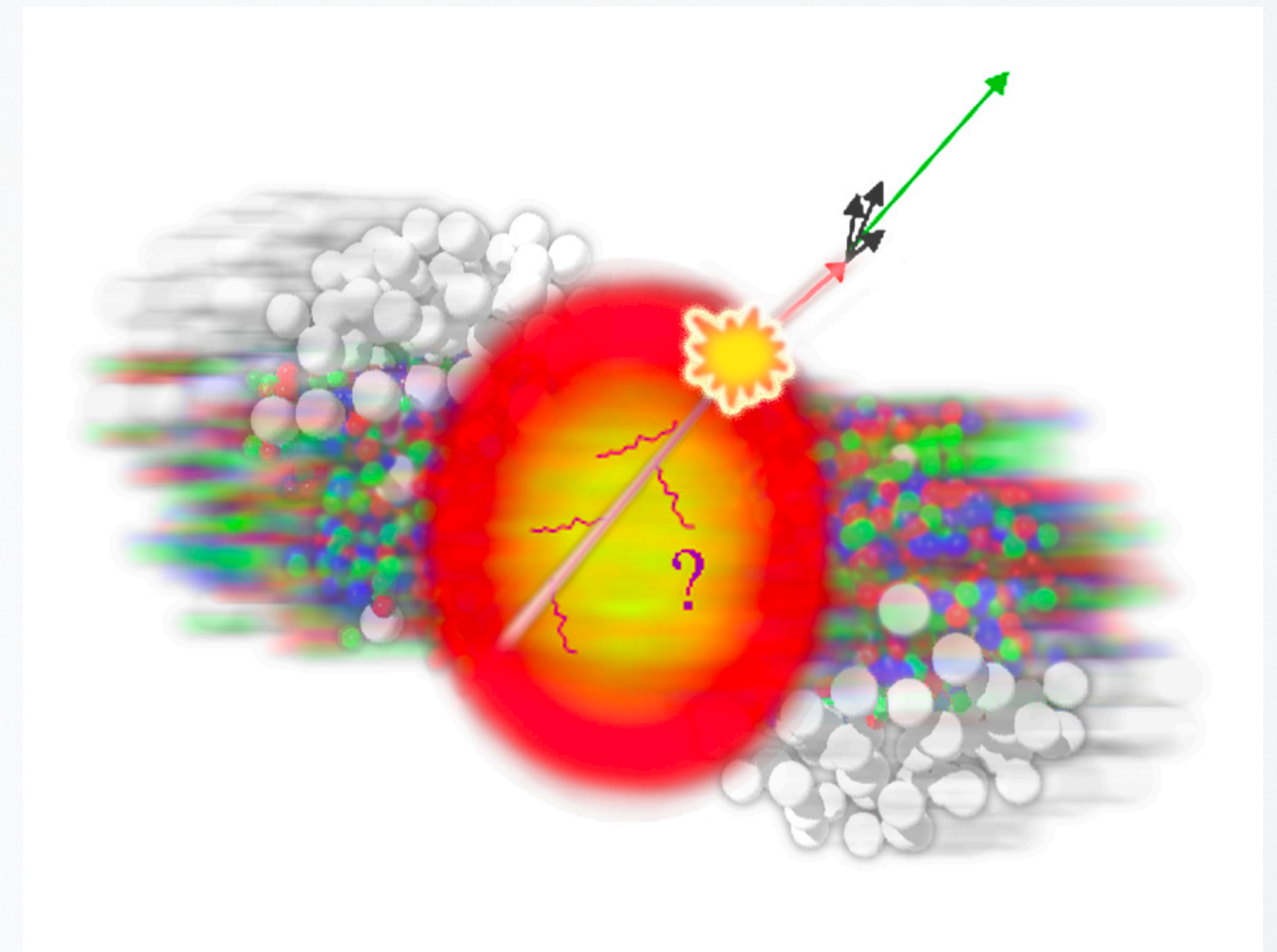
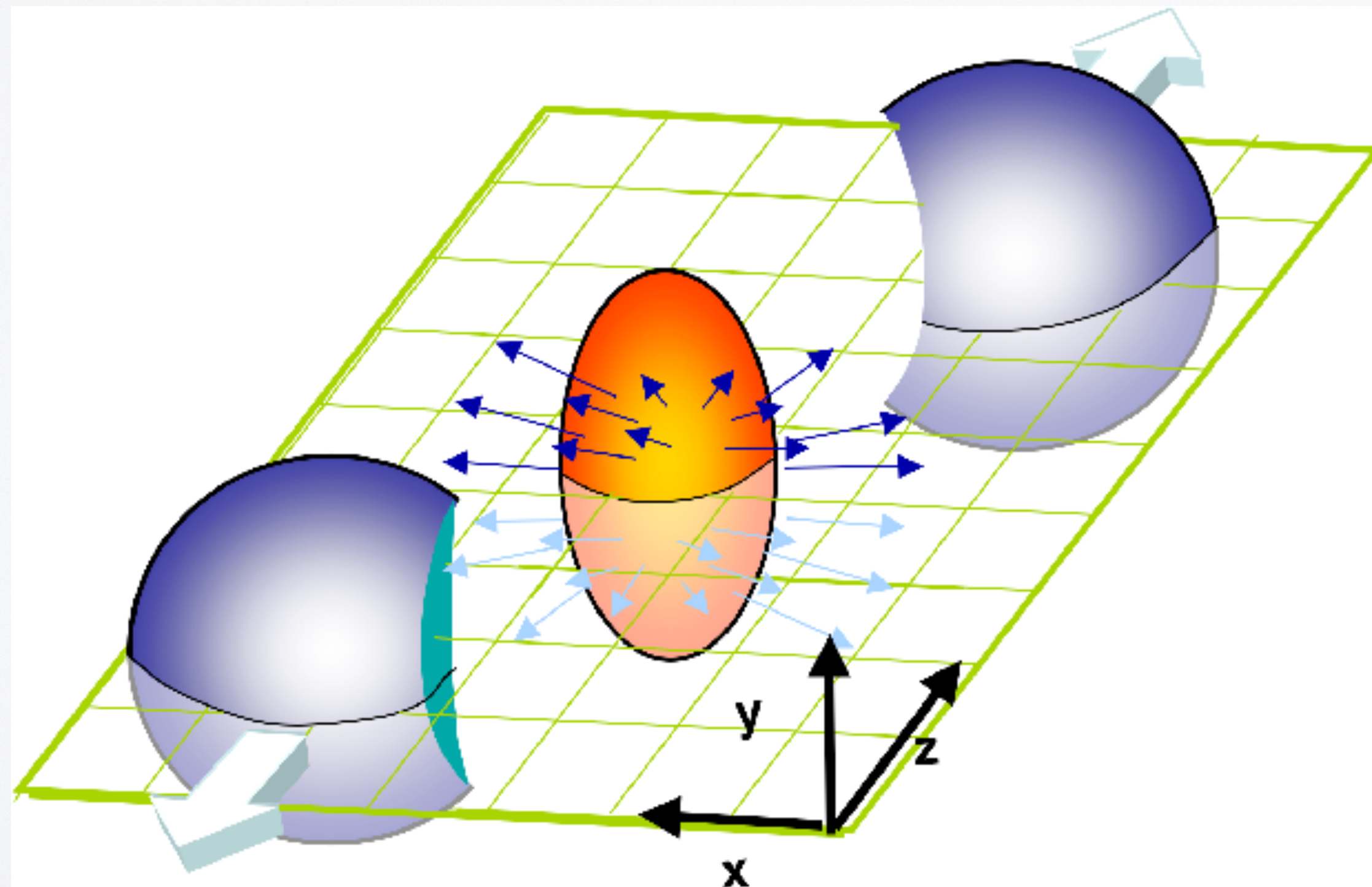






# Studies of QGP & small system puzzle

- Not possible to observe or study QGP directly, fortunately, we have:
  - **Anisotropic flow** — in both large and small collision systems
  - **Jet quenching** — only in large systems
- And other things for which I don't have time now 🙄

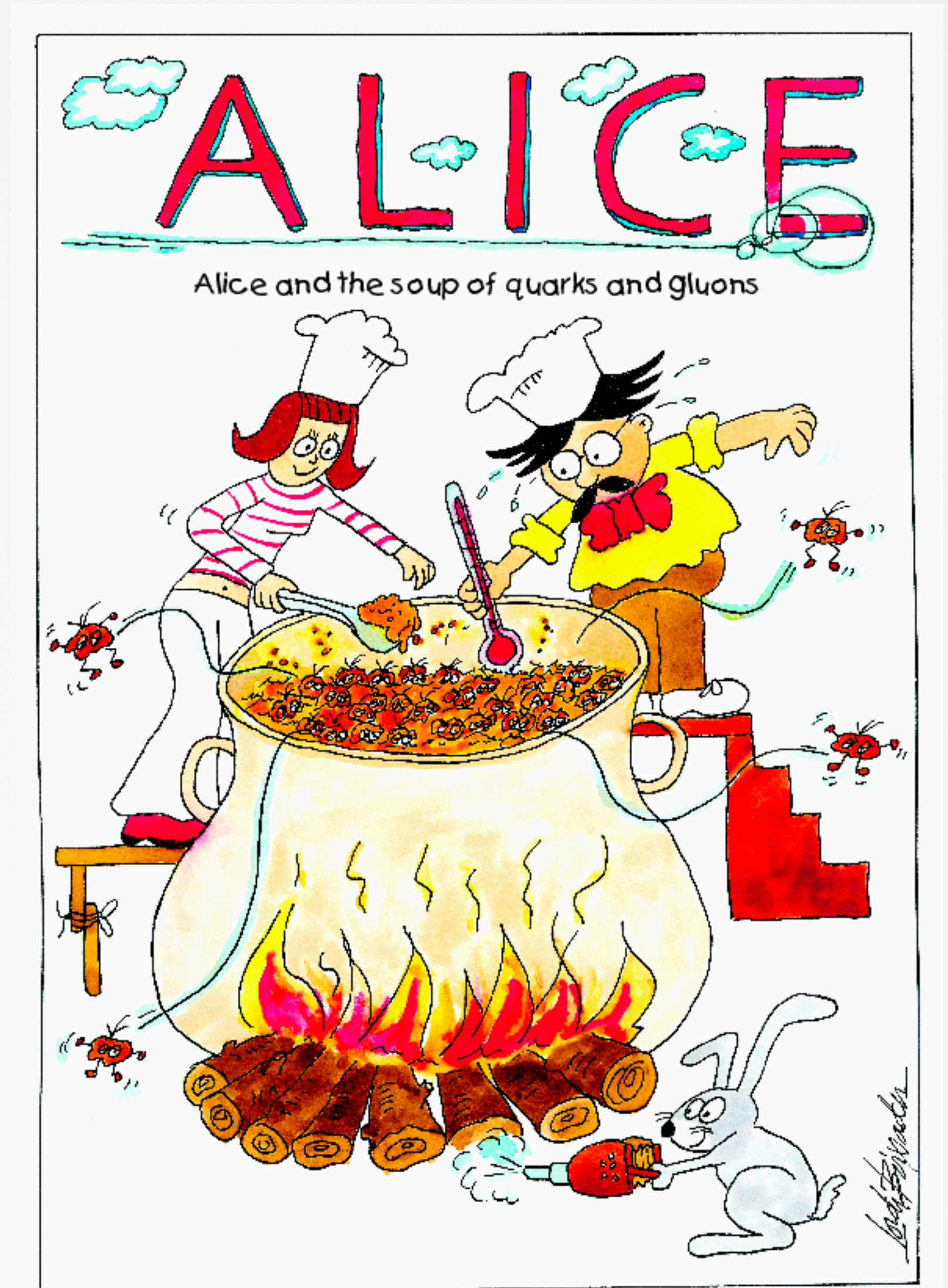






# Conclusion

- At ALICE, we are creating **Little Big Bangs** by colliding ultra-relativistic heavy-ion collisions
- With conditions just like after the **Big Big Bang**, we can melt hadrons into the soup of quarks and gluons
- Quark-gluon plasma is a different state of matter, a perfect fluid following hydrodynamics
- Studying quark-gluon plasma is tricky as we only see final-state particles affected by the it
- There are signs that **a droplet of QGP** *might* be also in small collision systems







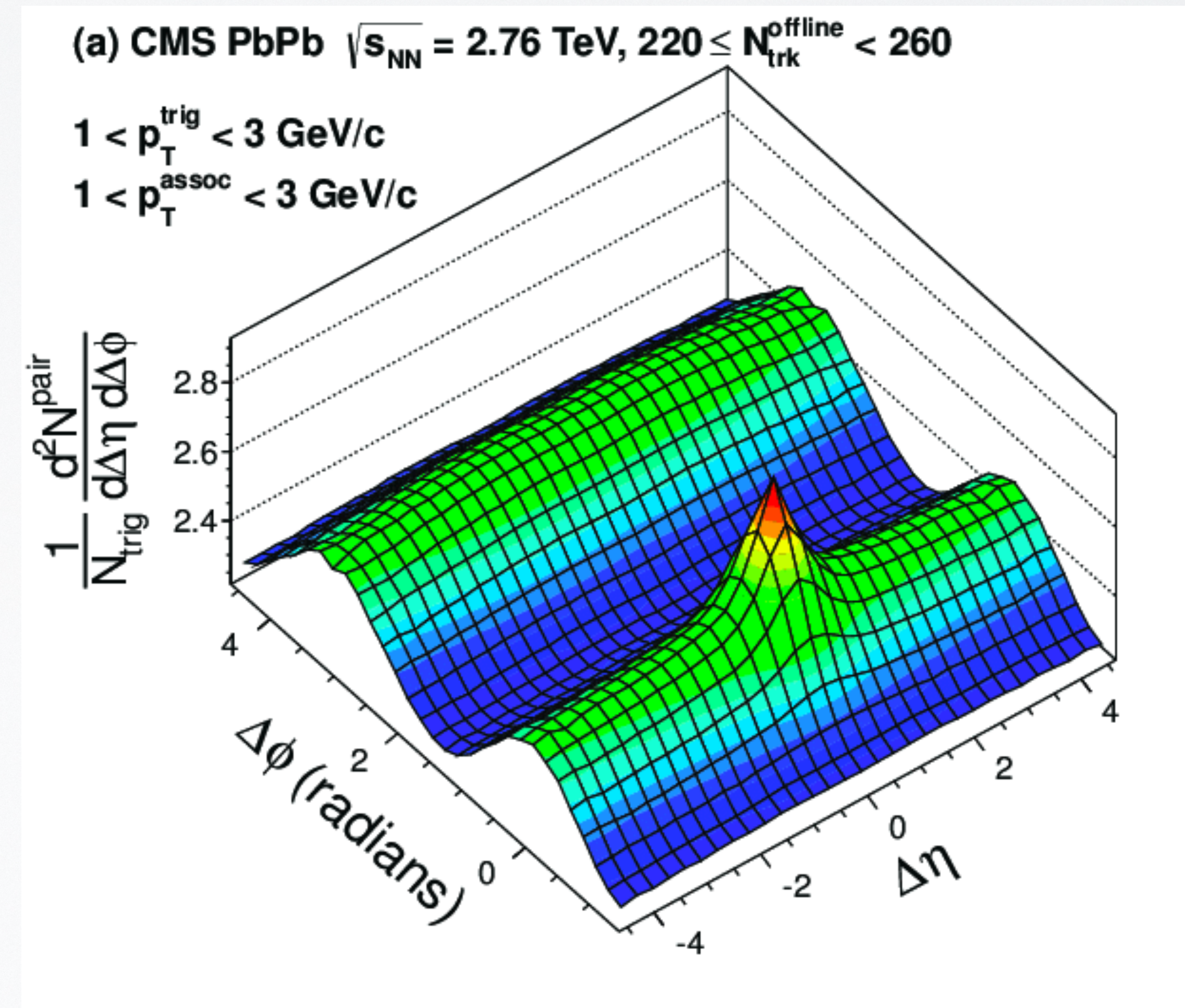
# Back up





# A droplet of QGP in small systems?

- My PhD project is about flow in small systems
- Flow needs collective effects
- Collectivity = long-range multi-particle correlations, a sign of QGP
- Double ridge, observed in Pb-Pb collision, is a clear sign of collectivity
- Measurements at next slides served as a “motivation” for my studies — telling us we should look into all systems!
- Flow now measured across all systems

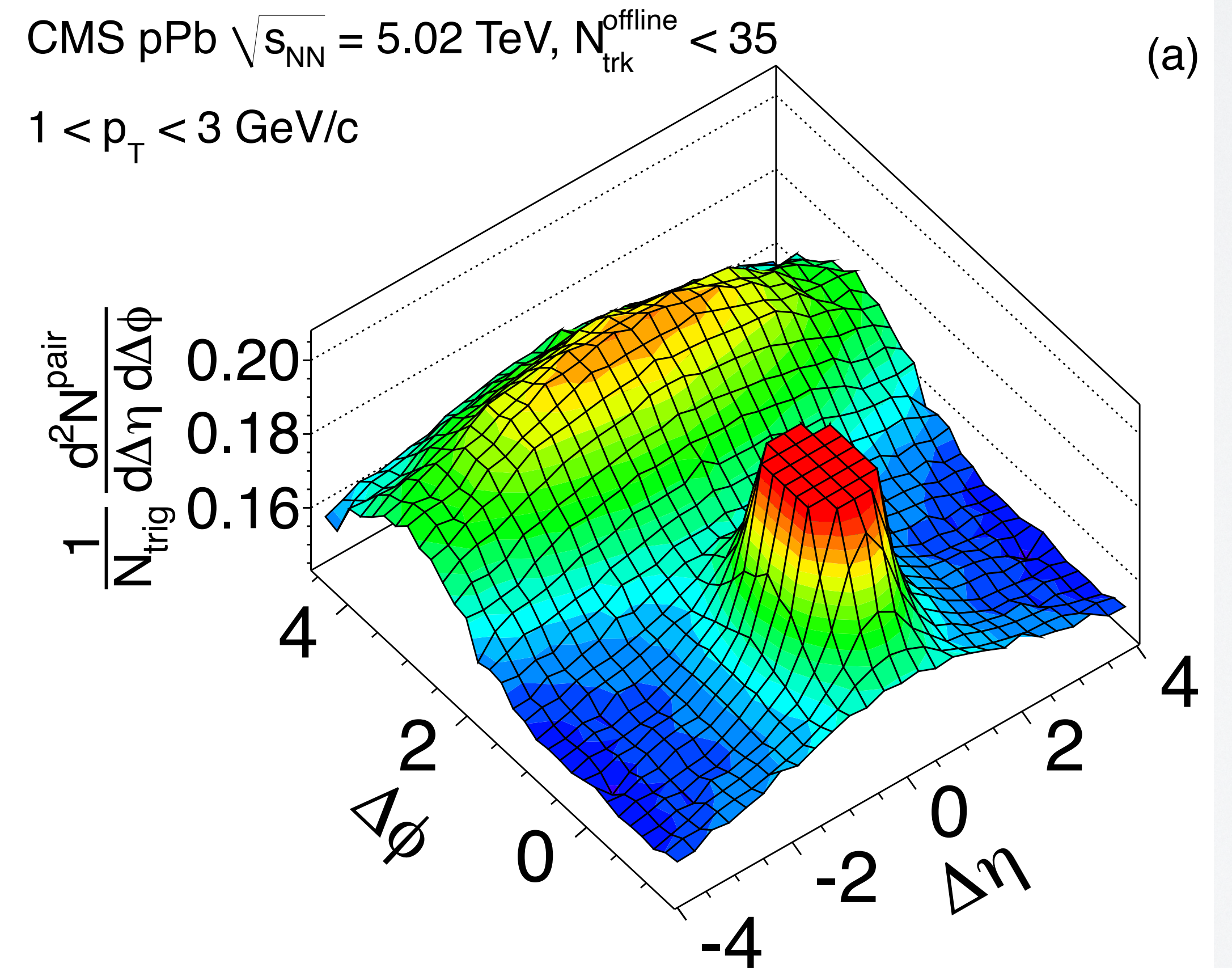
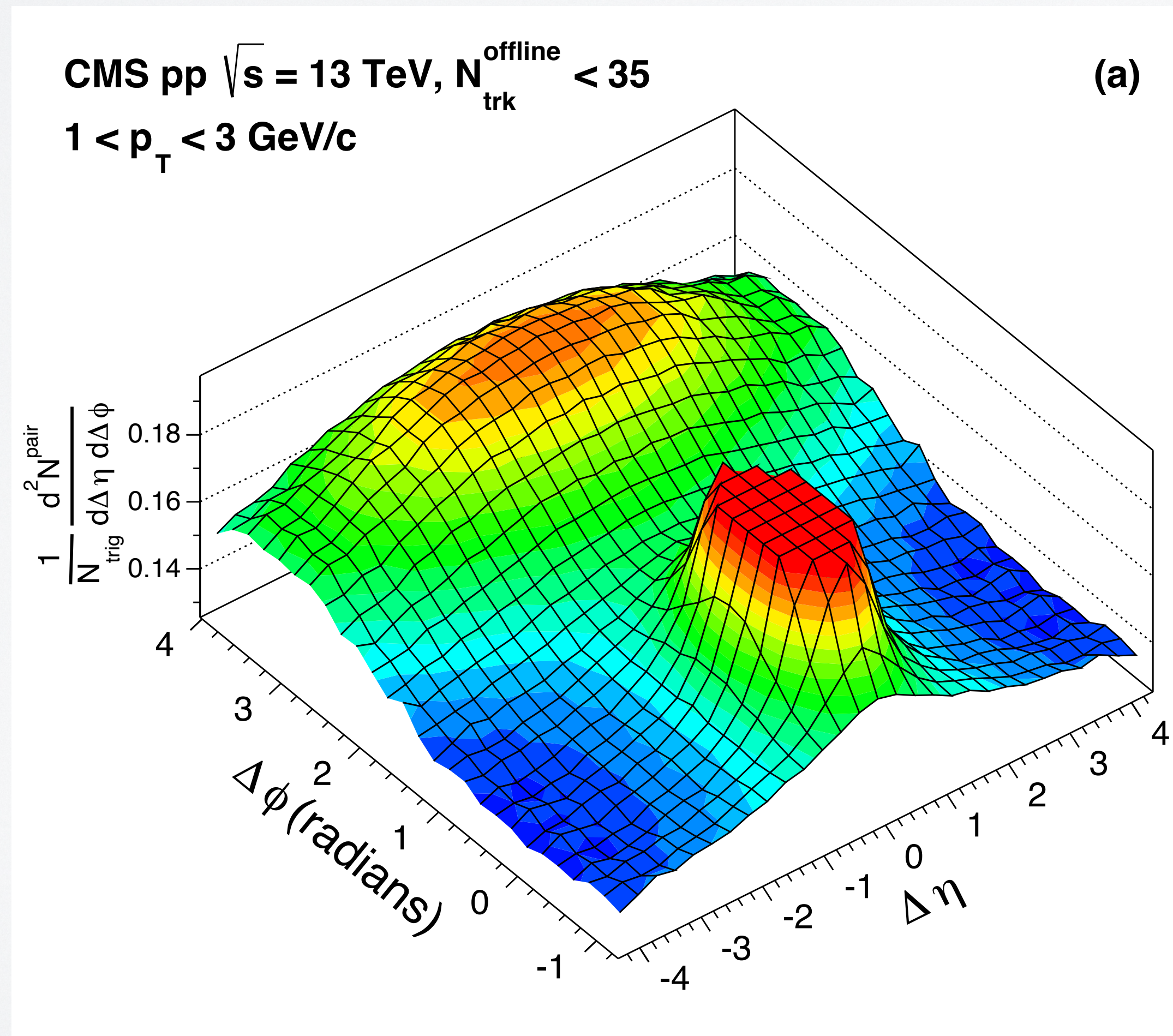






# A droplet of QGP in small systems?

- Low multiplicity collisions in p-Pb and pp collisions







# A droplet of QGP in small systems?

- High multiplicity collisions in p-Pb and pp collisions — double ridge is there!

