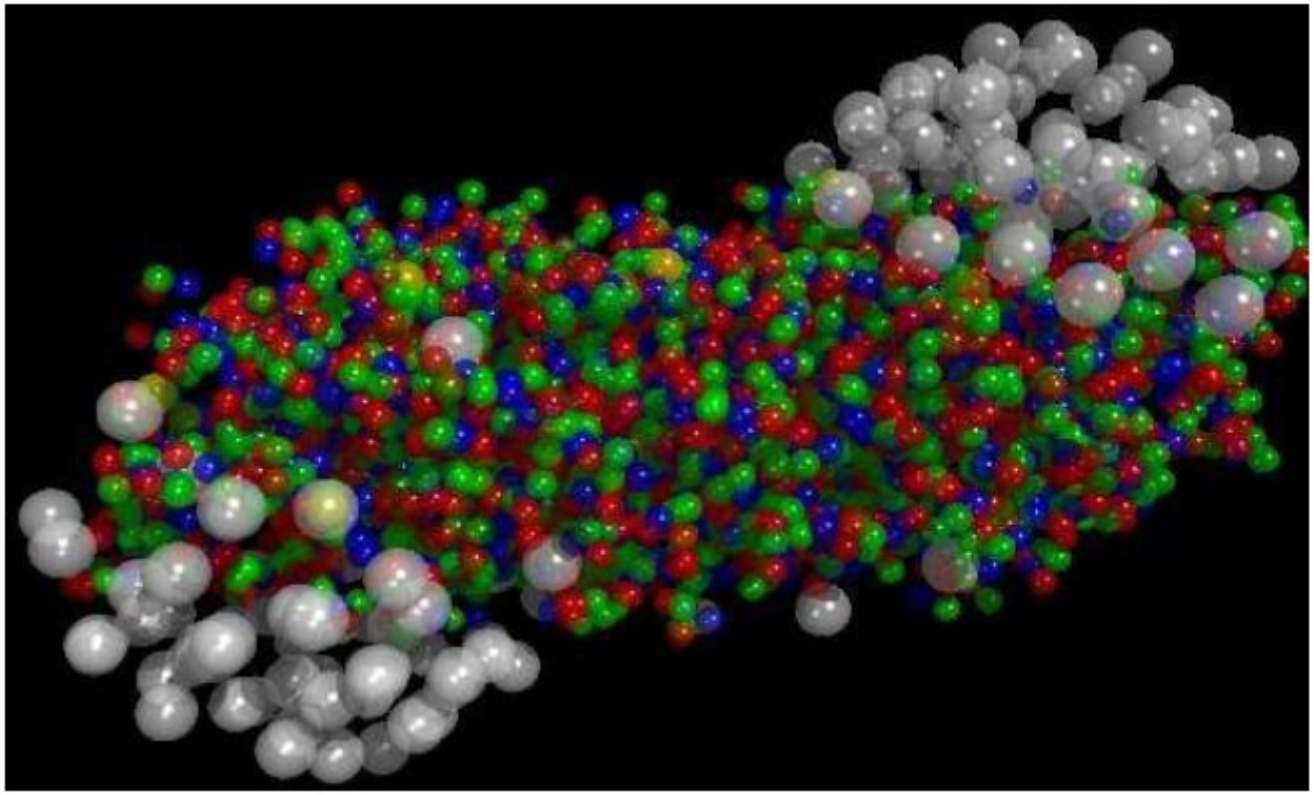
Quark-gluon plasma – a few introductory remarks



in relativistic nucleus-nucleus collisions, a new state of matter is produced, in which colored quarks and gluons roam freely

Simulation: UrQMD, Frankfurt

Liverpool
Jan. 30, 2013

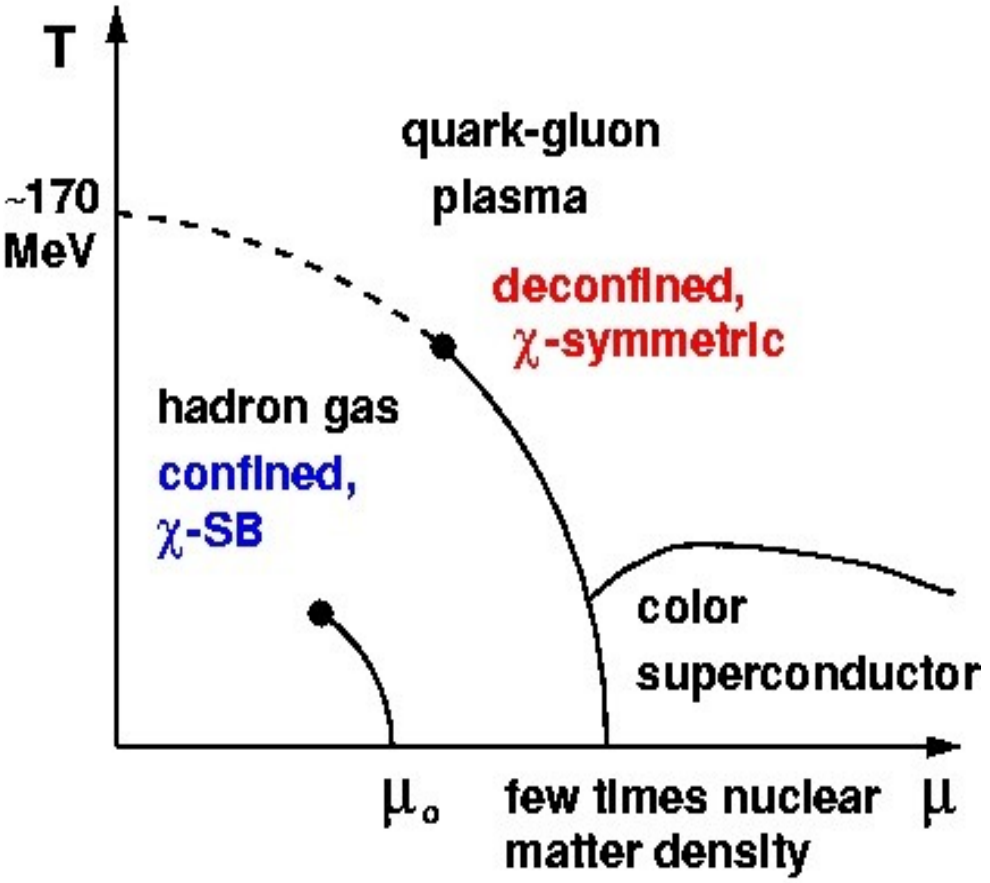
EMMI
FIAS-Frankfurt

The phase diagram of strongly interacting matter

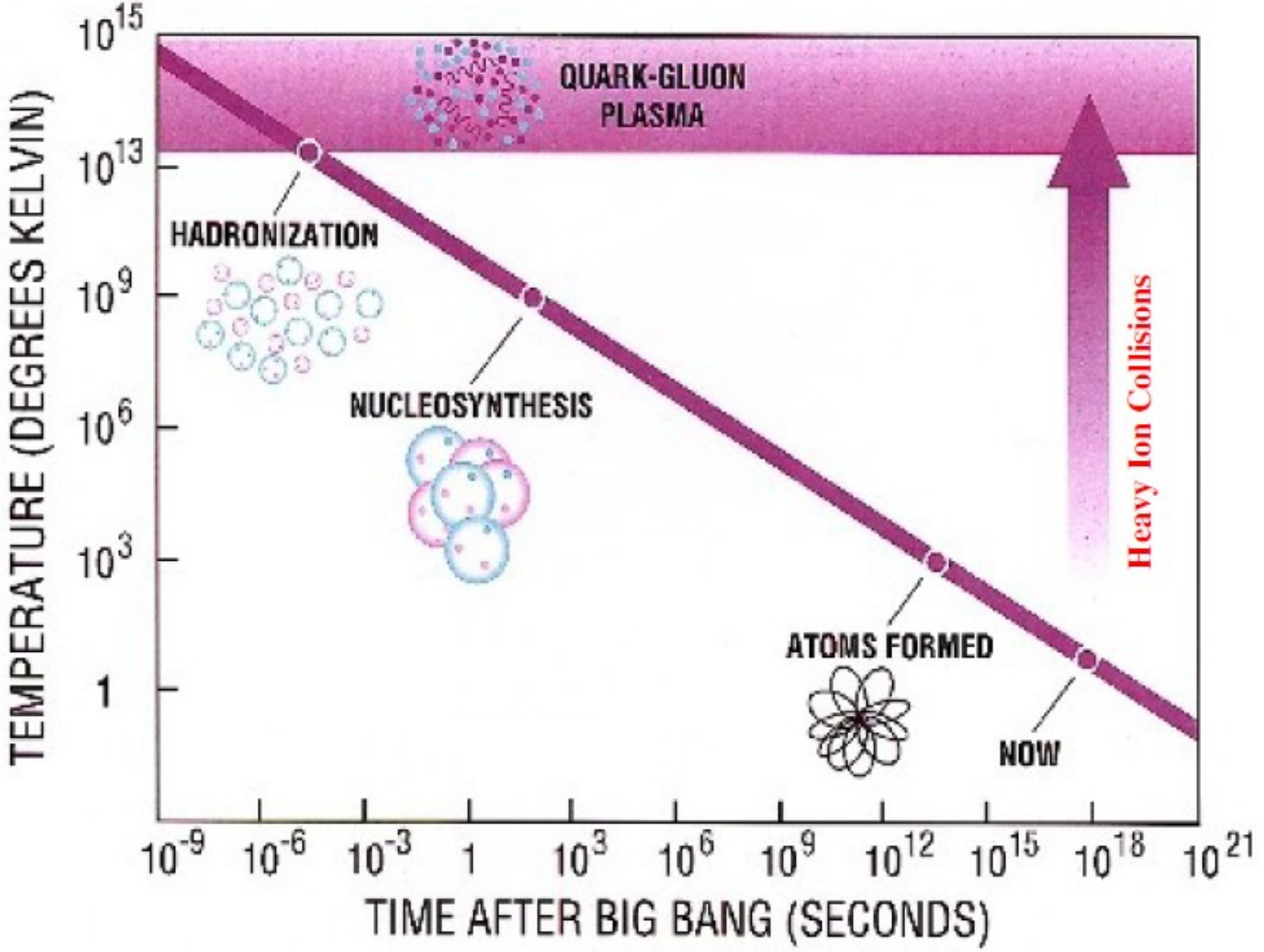
at low temperature and normal density
colored quarks and gluons are bound in colorless hadrons - confinement
chiral symmetry is spontaneously broken (generating 99% of proton mass e.g.)
1972 QCD (Gross, Politzer, Wilczek)
asymptotic freedom at small distances

at high temperature and/or high density
quarks and gluons freed from confinement -> new state of strongly interacting matter
1975 (Collins/Perry and Cabibbo/Parisi)

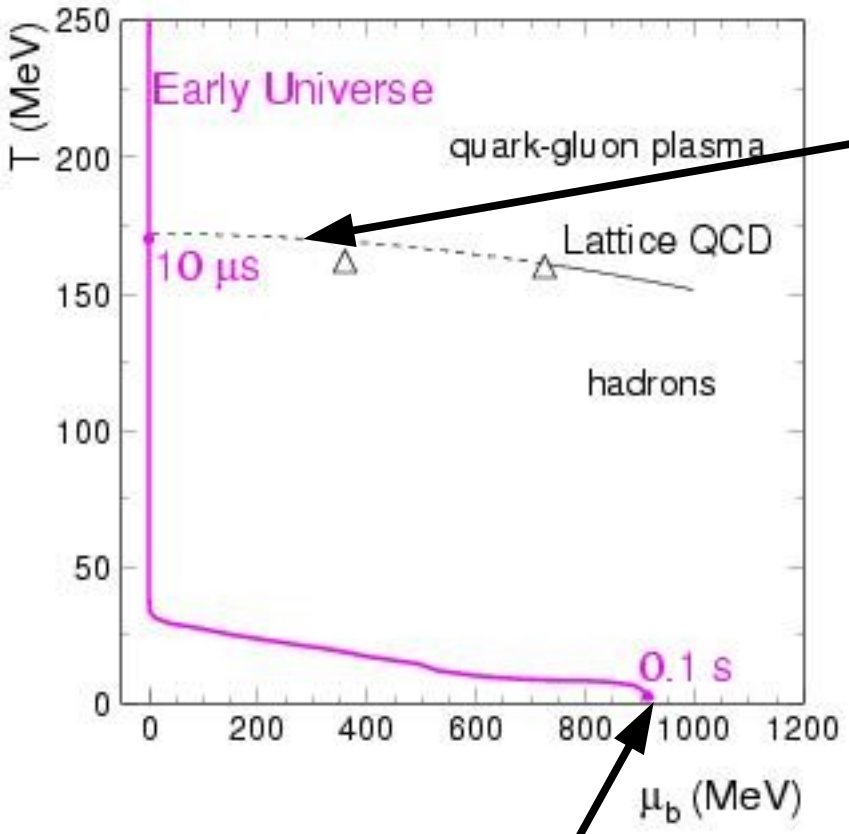
now called **Quark-Gluon Plasma (QGP)**



Quark-gluon plasma and the early universe



Evolution of the Early Universe



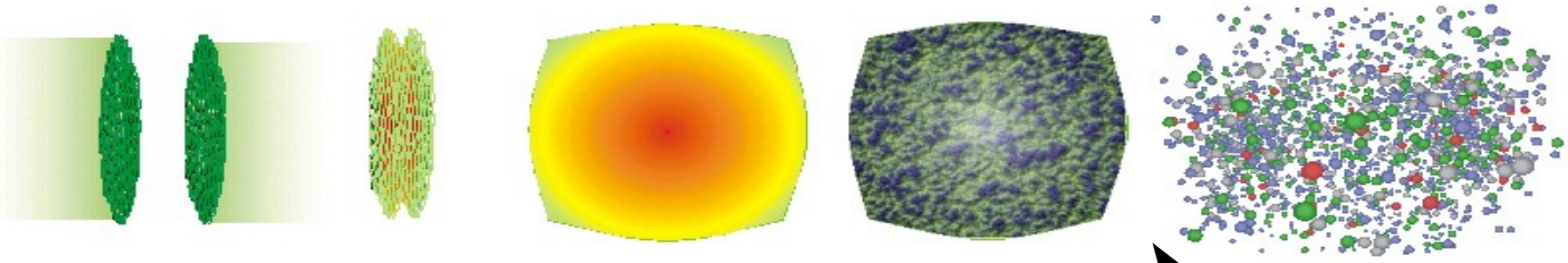
QCD Phase Boundary

Homogeneous Universe in Equilibrium, this matter can only be investigated in nuclear collisions

- Charge neutrality
- Net lepton number = net baryon number
- Constant entropy/baryon

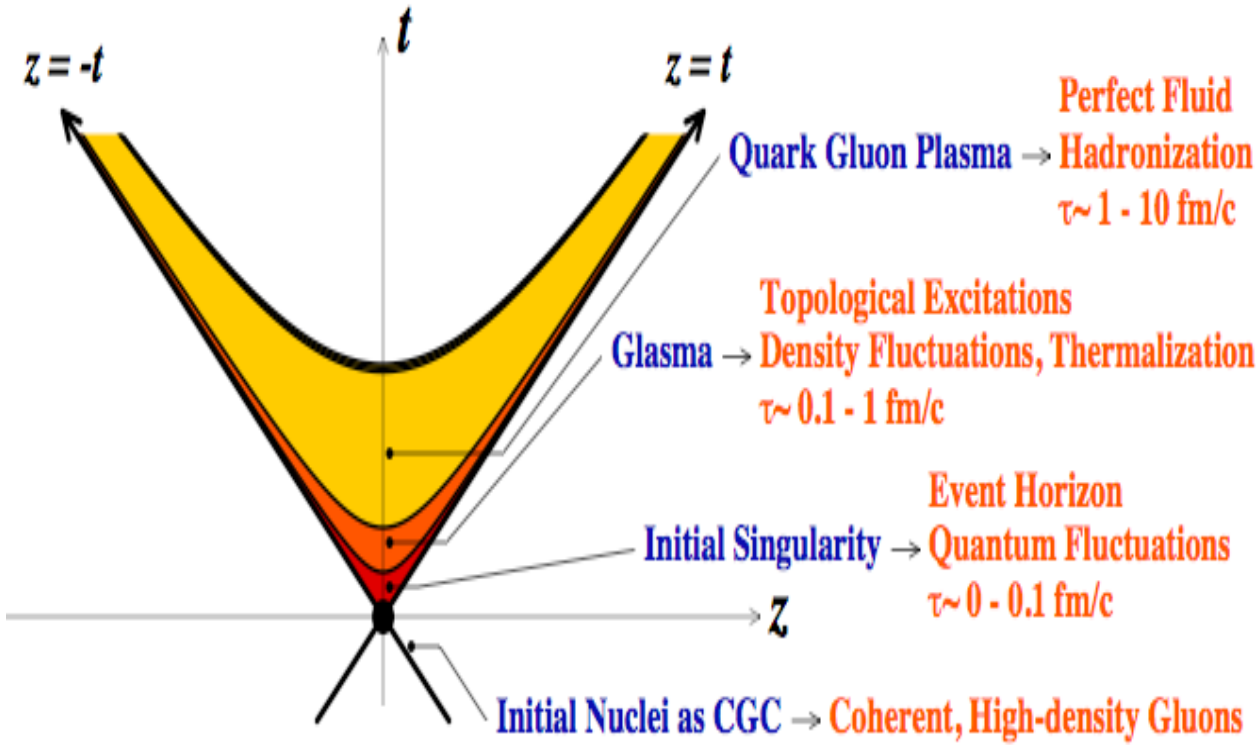
neutrinos decouple and light nuclei begin to be formed

The Space-Time Evolution of a Relativistic Nuclear Collision

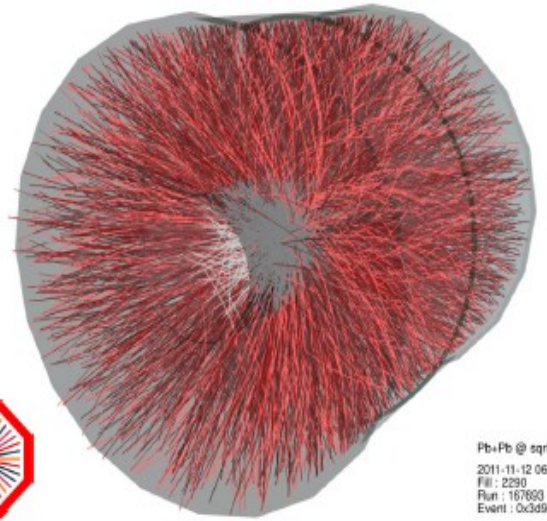


CGC | Initial Singularity | Glasma | sQGP | Hadron Gas

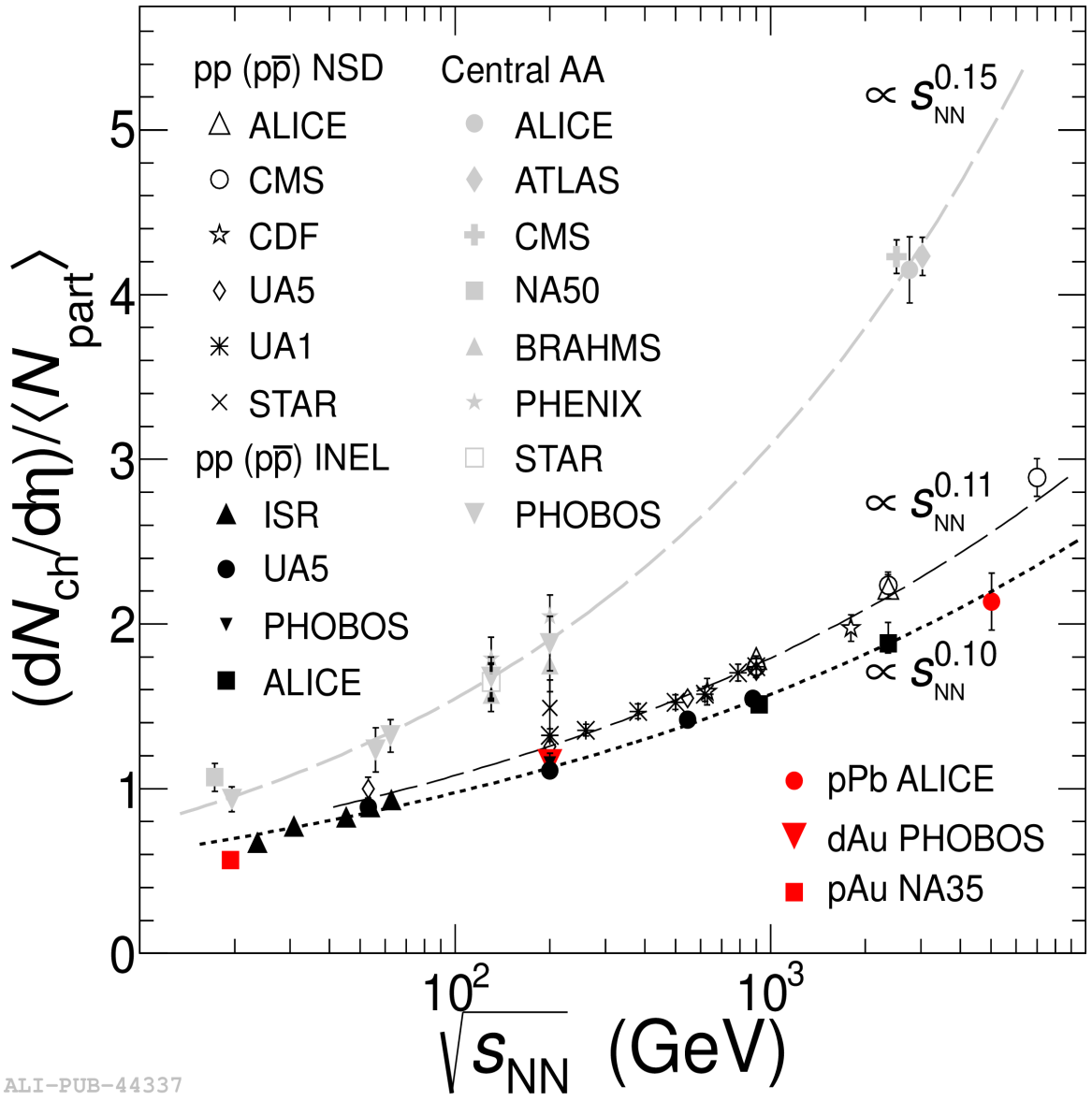
Hot fireball, equilibrized matter



one possible view (courtesy Larry McLerran)



Charged particle multiplicity in pp, pPb and central PbPb collisions

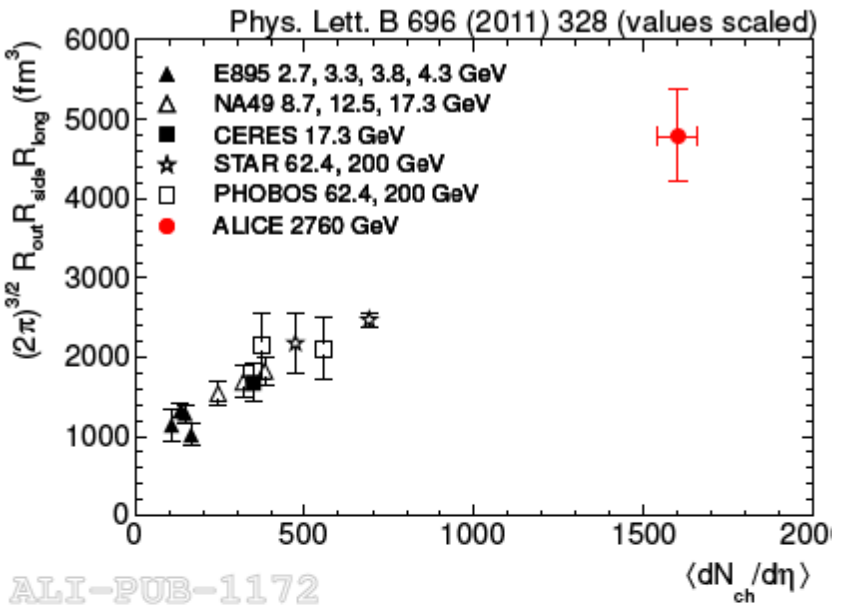


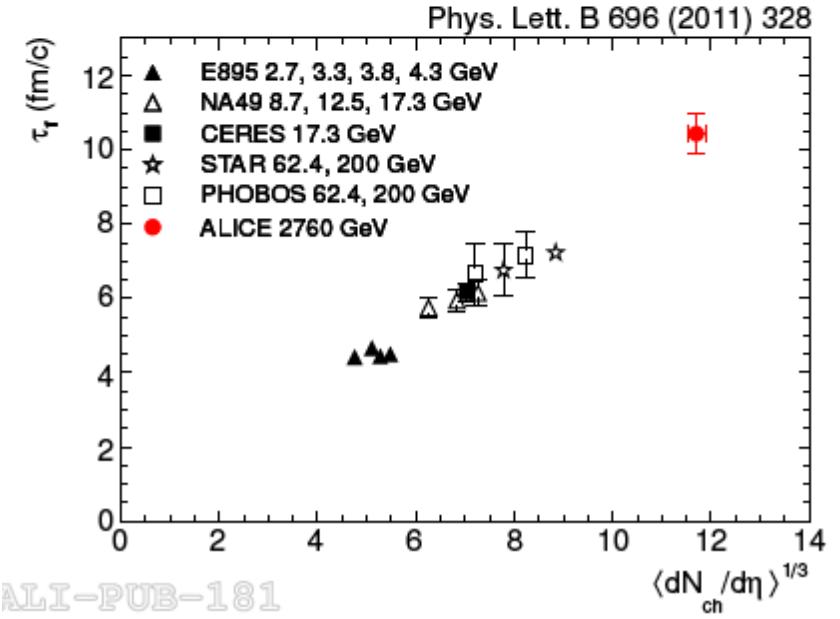
increase with beam energy significantly steeper than in pp

Fireball at LHC energy has much larger size and lives

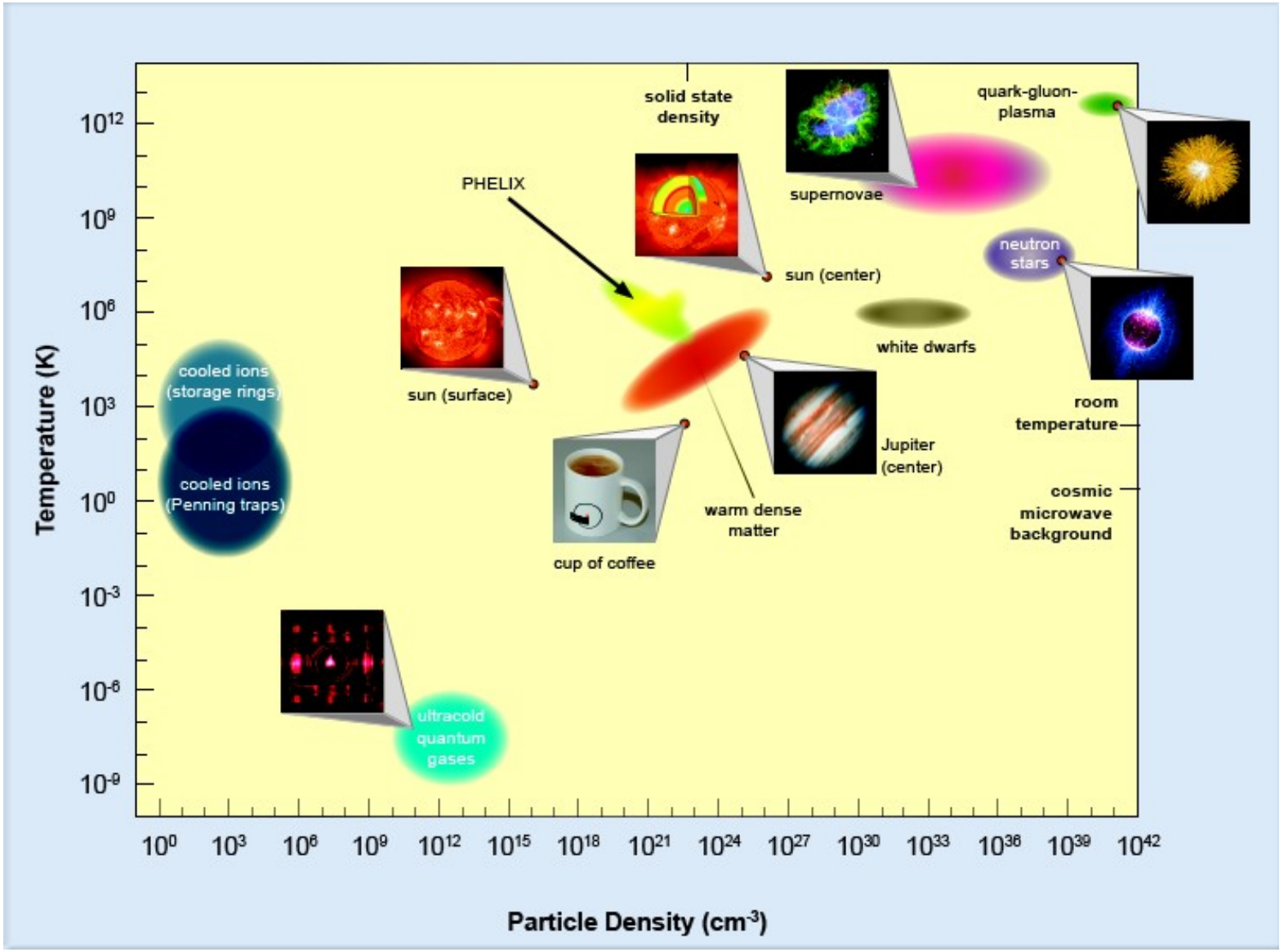
volume and lifetime
from HBT analysis

fireball volume at freeze-
out is about 5 x large than
volume of a Pb nucleus





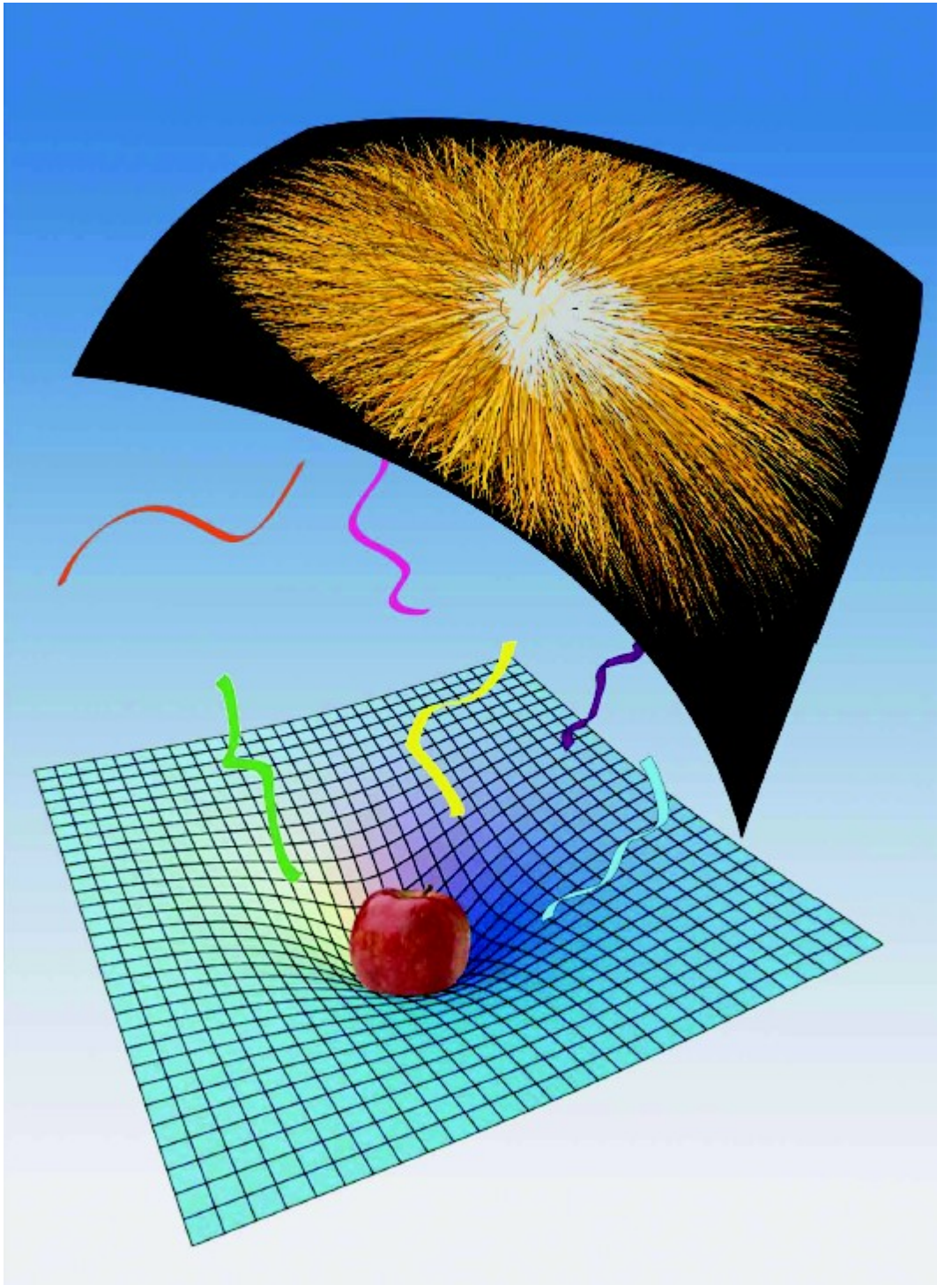
from ultra-cold to ultra-hot



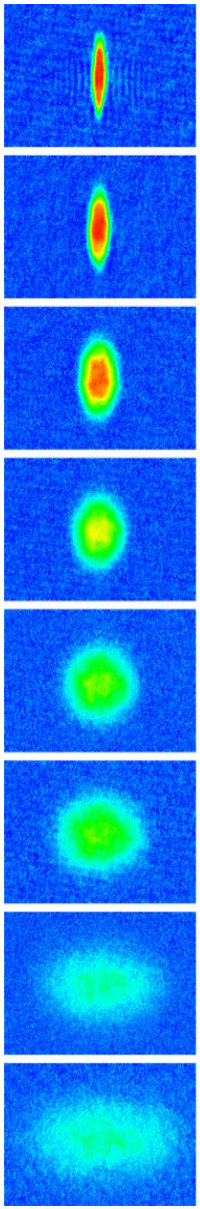
QGP and the 'gauge-gravity' dual

See, e.g. E. Witten, 'Quantum Mechanics of Black Holes, Science 337 (3 August 2012)

The strongly coupled QCD-like gauge theory is dual to weakly coupled gravitation with a large, negative cosmological constant, Kovtun,Son, Starinets, PRL 94 (2005) 111601



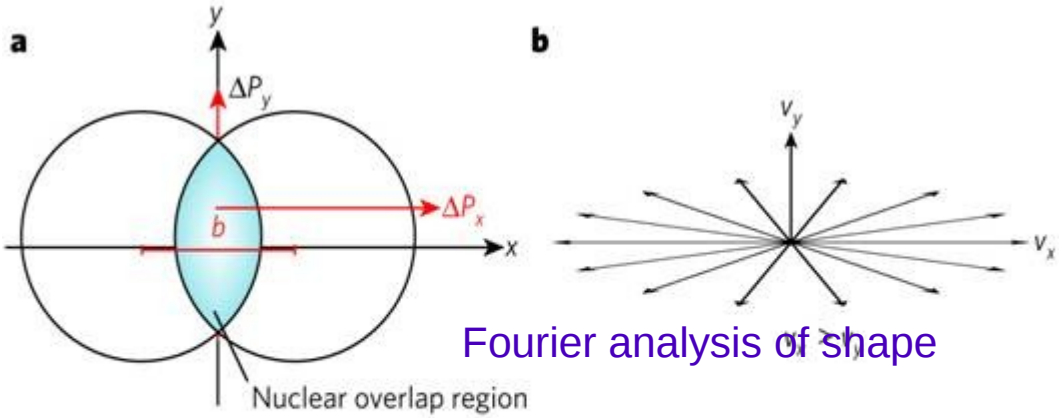
QGP and Ultra-cold Quantum Gases



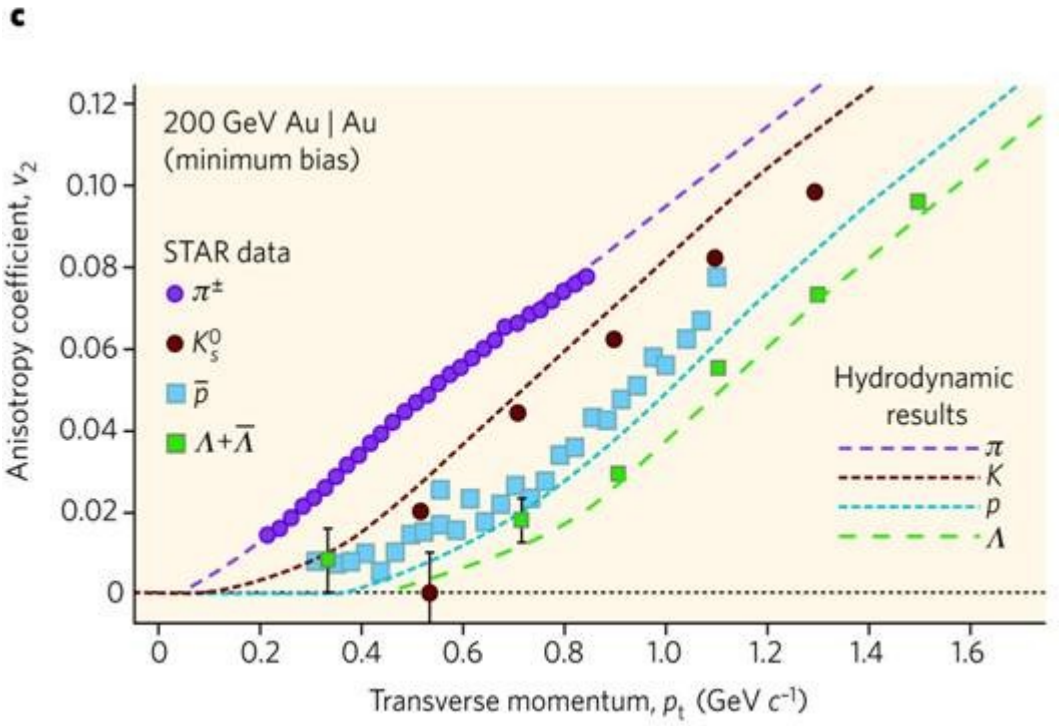
ultra-cold ^{6}Li
10 nK
~10^{-12} eV

QGP
2.1 TK
~10^{8} eV

collective expansion at strong coupling



Fourier analysis of shape



The Large Hadron Collider (LHC)

27 km long, 8 sectors

1232 **dipole** magnets (15m, 30 tonnes each) to bend the beams

Cooled with **120 tonnes of He at 1.9 K**

pp: 2808 bunches/ring, each 1.15×10^{11} protons (8 min filling time)

Design luminosity: $\mathbf{10^{34}\ cm^{-2}s^{-1}}$

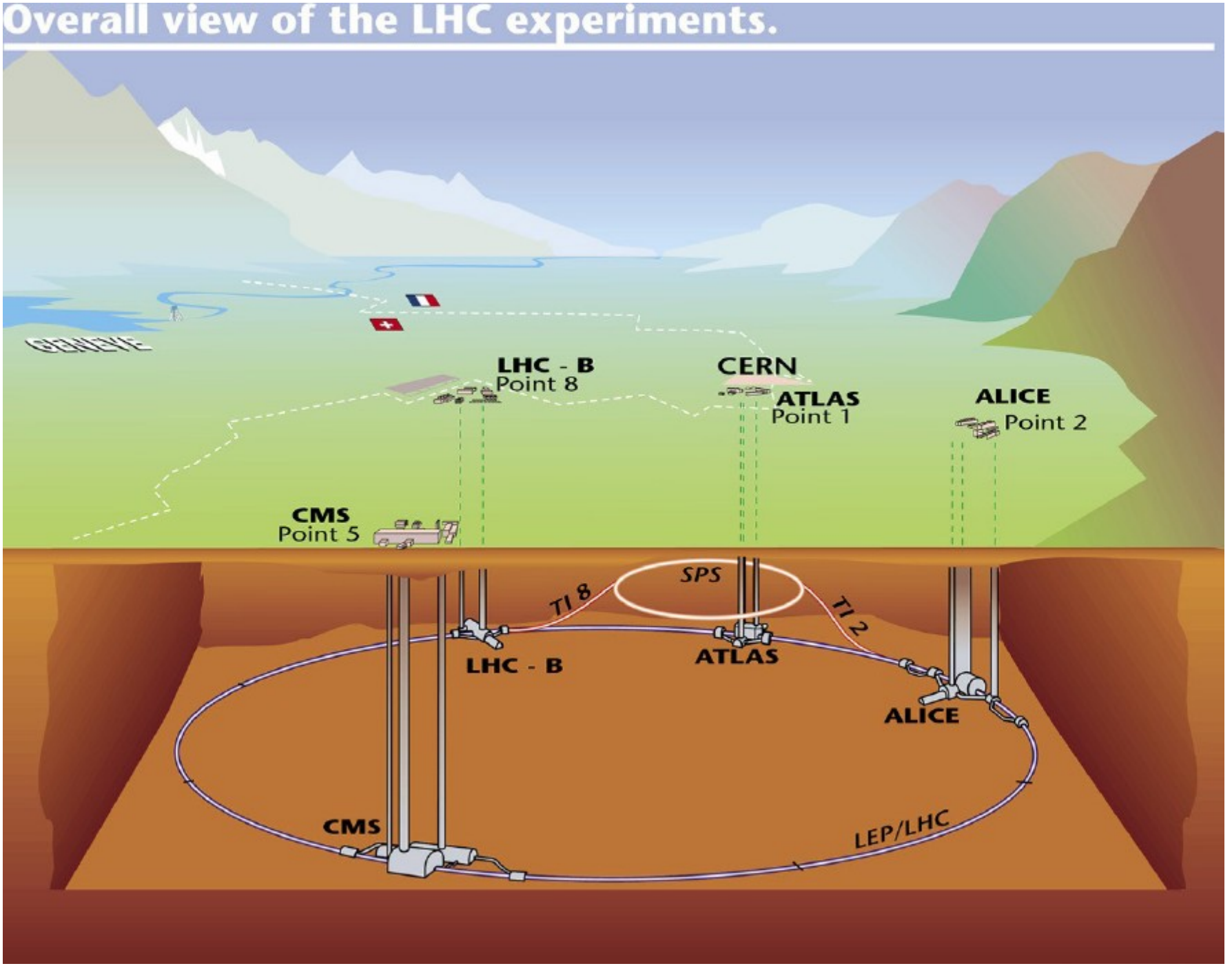
PbPb: 592 bunches/ring, each 7×10^{7} Pb ions

Design luminosity: $10^{27}\ cm^{-2}s^{-1}$

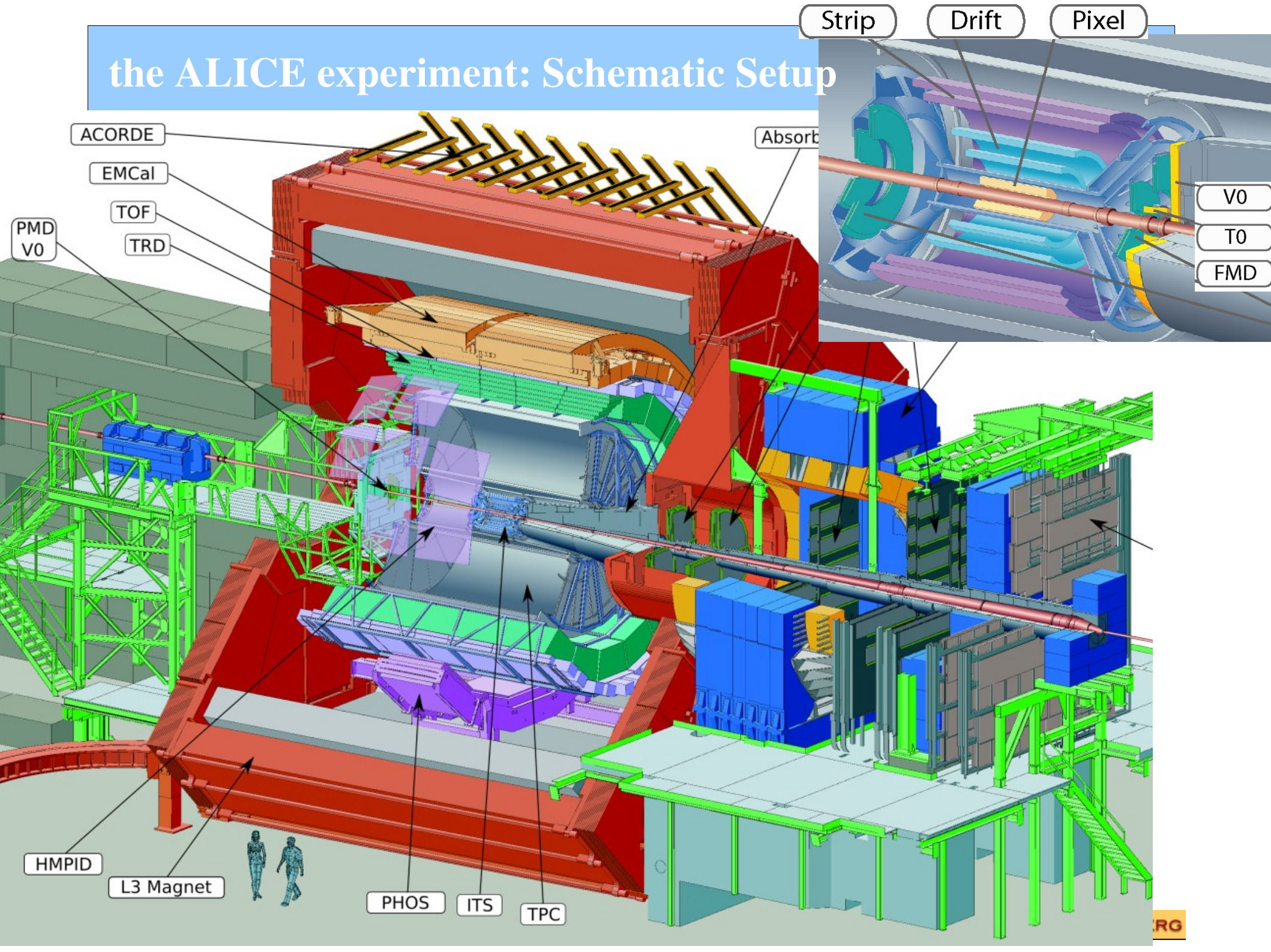
Transverse r.m.s beam size: **16 µm**, r.m.s. bunch length: 7.5 cm

Beam kinetic energy: 362 MJ per beam (1 MJ melts 2 kg copper)

Total stored electromagnetic energy: **8.5 GJ** (dipole magnets only)

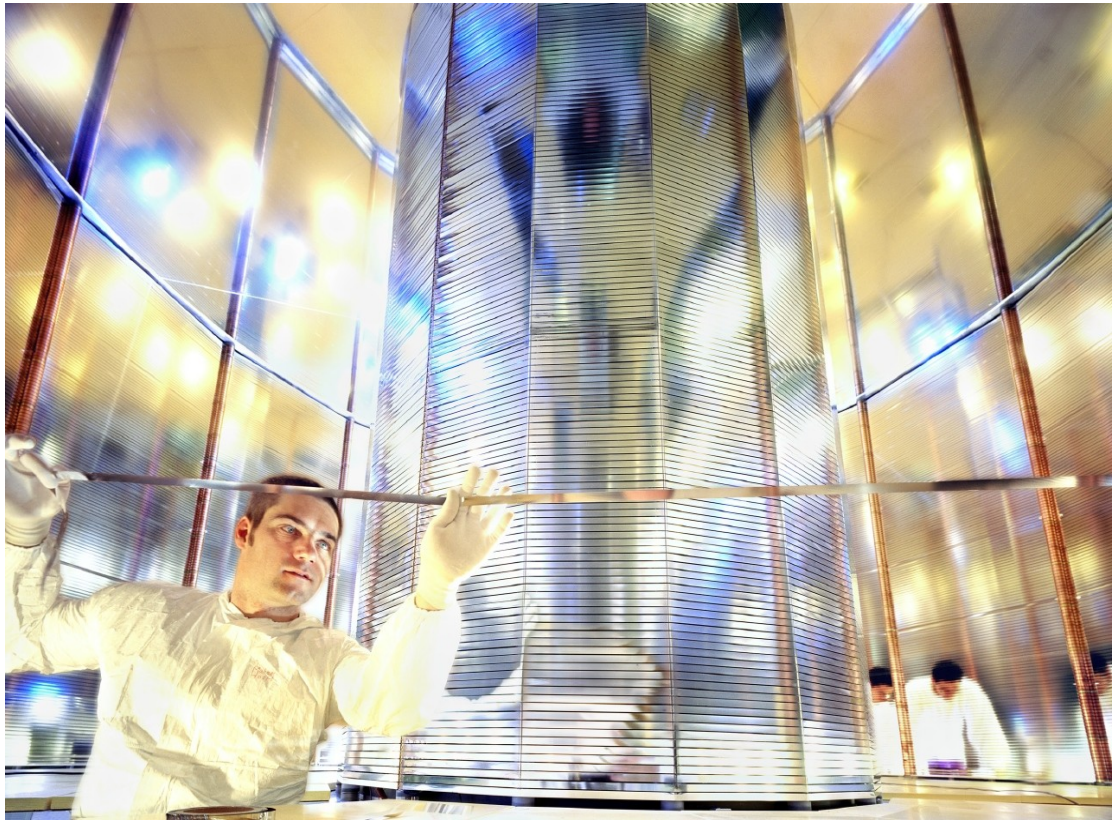

Overall view of the LHC experiments.
GENEVE
LHC - B
Point 8
CERN
ATLAS
Point 1
ALICE
Point 2
CMS
Point 5
SPS
TI 8
TI 2
LHC - B
ATLAS
ALICE
CMS
LEP/LHC

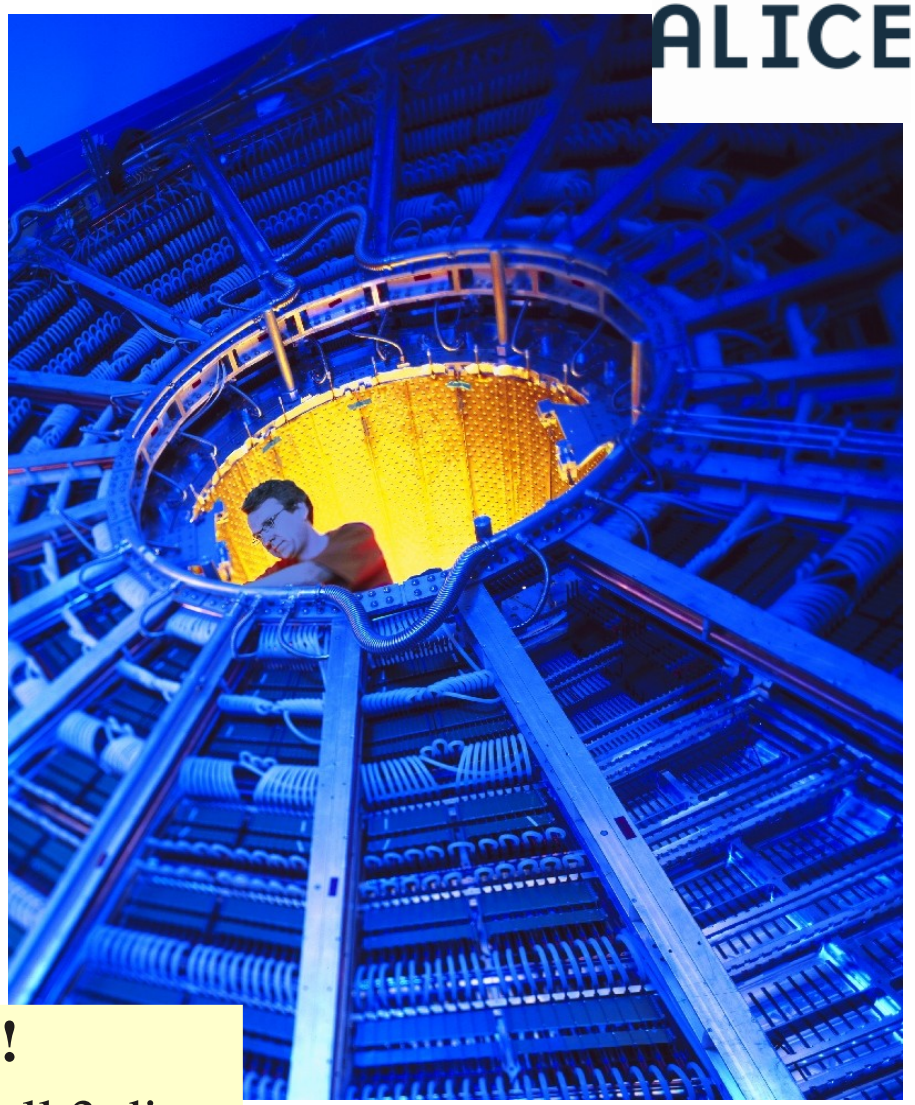
the ALICE experiment: Schematic Setup



the TPC (Time Projection Chamber) - 3D reconstruction of up to 15 000 tracks of charged particles per event

with 95 m^3 the largest TPC ever





560 million read-out pixels!

precision better than 500 µm in all 3 dim.

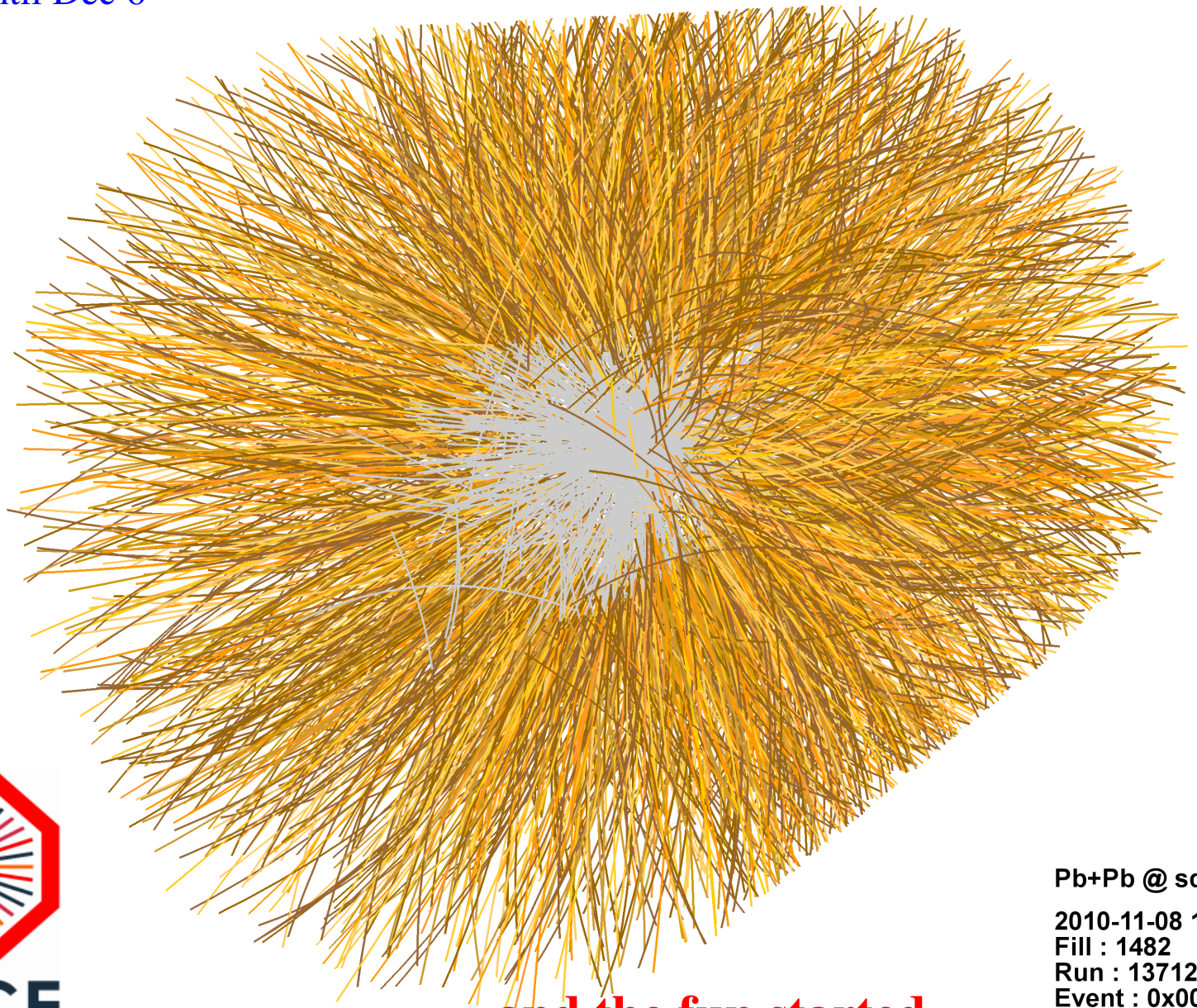
180 space and charge points per track


The interior of the TPC, 2004

first PbPb collisions at LHC at √s = 2.76 A TeV

setup for ion collisions: November 4
first collisions with stable beams:
November 8 until Dec 6

already in Dec 2010
5 publications in PRL and PLB



Pb+Pb @ sqrt(s) = 2.76 ATeV

2010-11-08 11:30:46
Fill : 1482
Run : 137124
Event : 0x00000000D3BBE693

ALICE

and the fun started