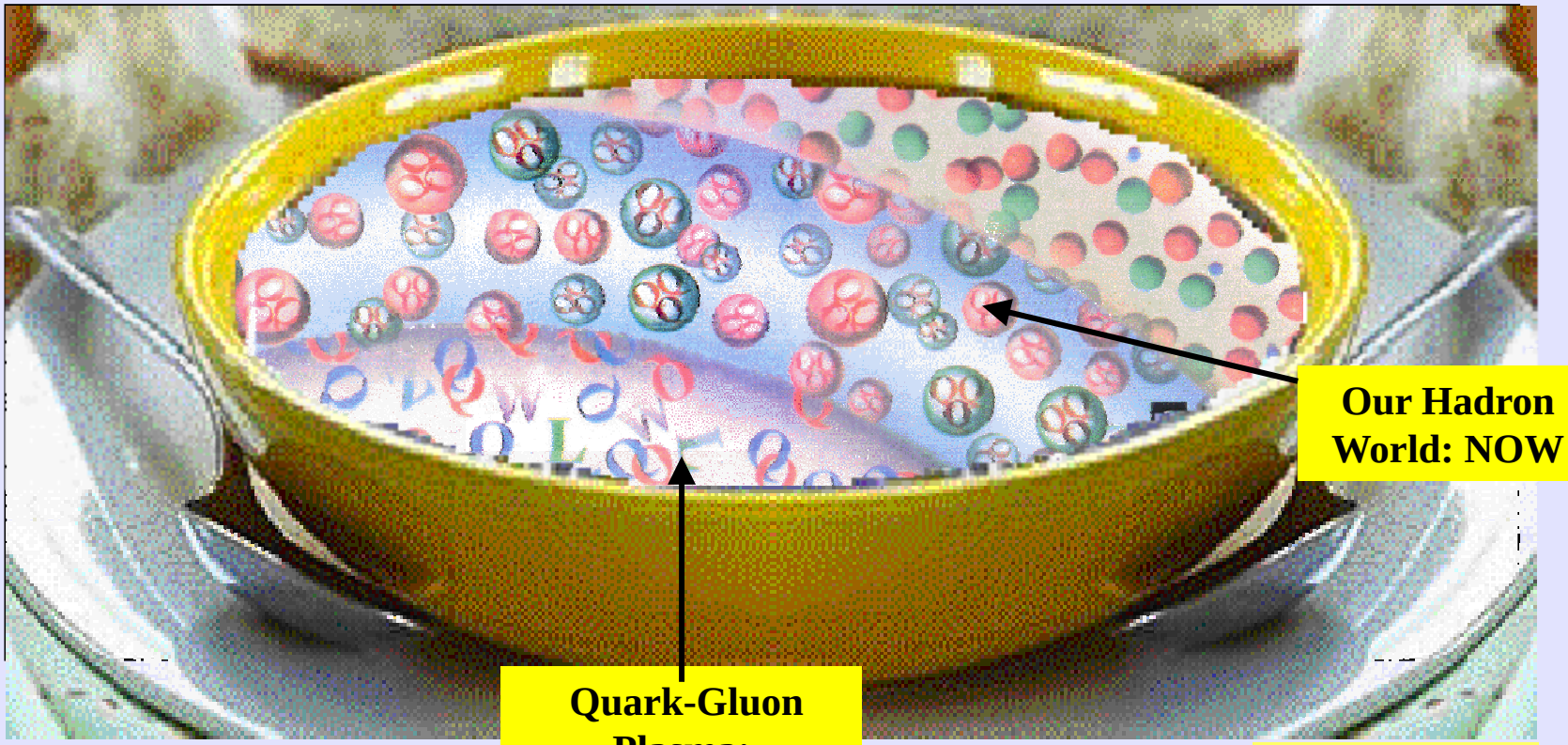
The primordial 'soup' of QUARKS and GLUONS Can we make and study it on earth?



Our Hadron World: NOW

Quark-Gluon Plasma:

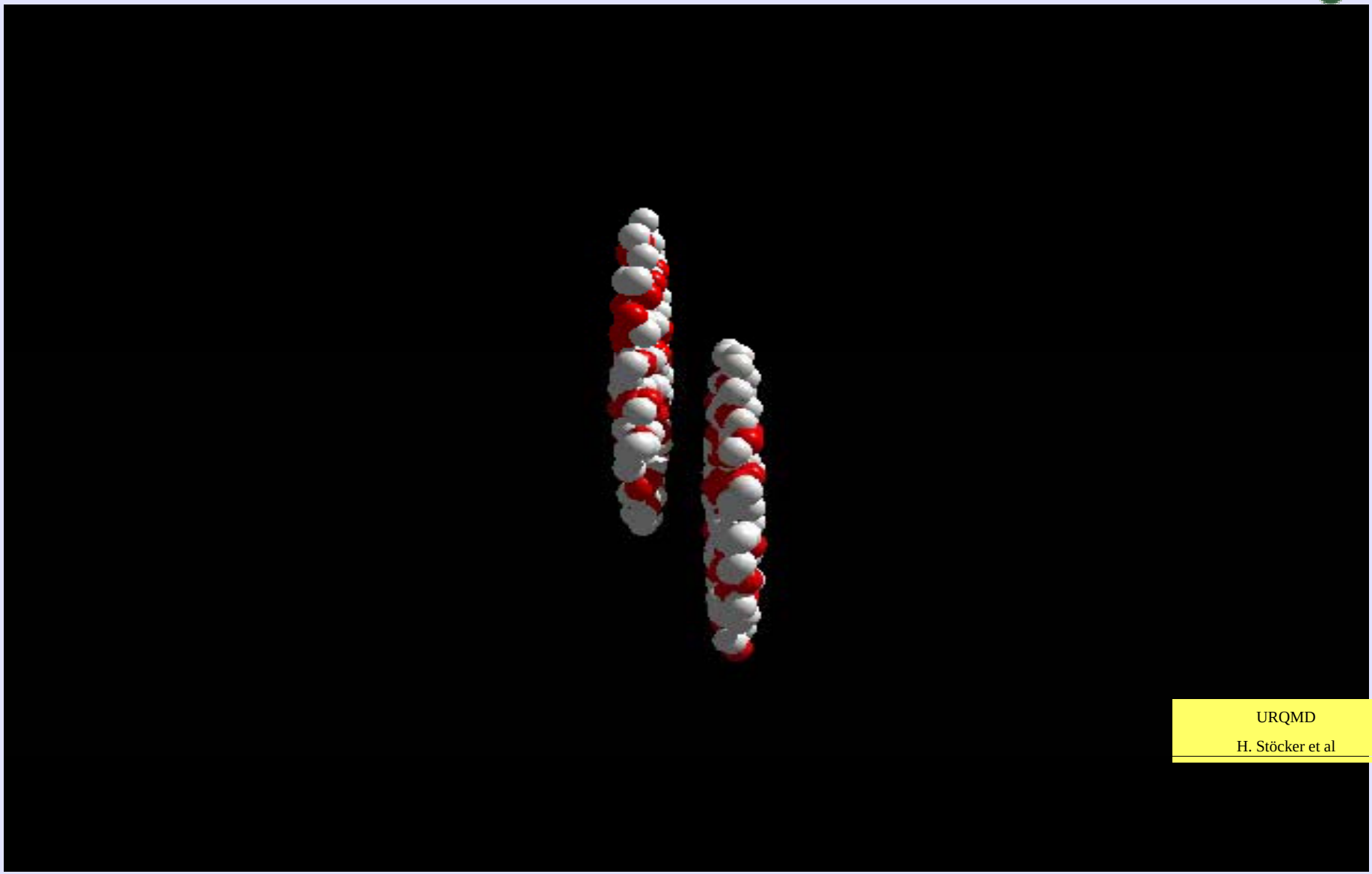
OUR PAST

M. Turner Natl. Geog. Mag.

J. Harris, Yale

Quark Gluon Plasma in Universe: $t < 10^{-6}$ sec

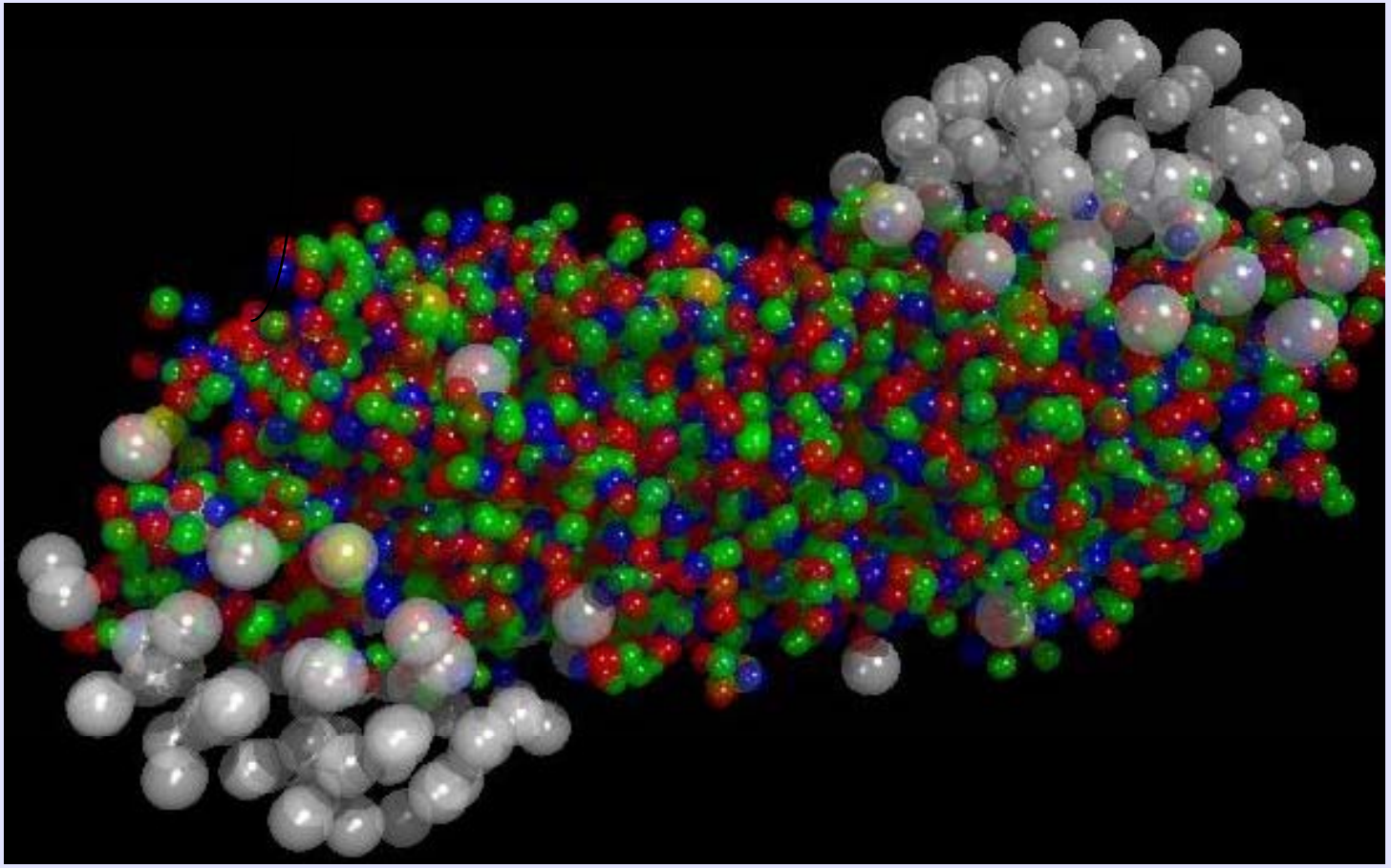
Searching for the Quark Gluon Plasma: Ultra Relativistic Collisions



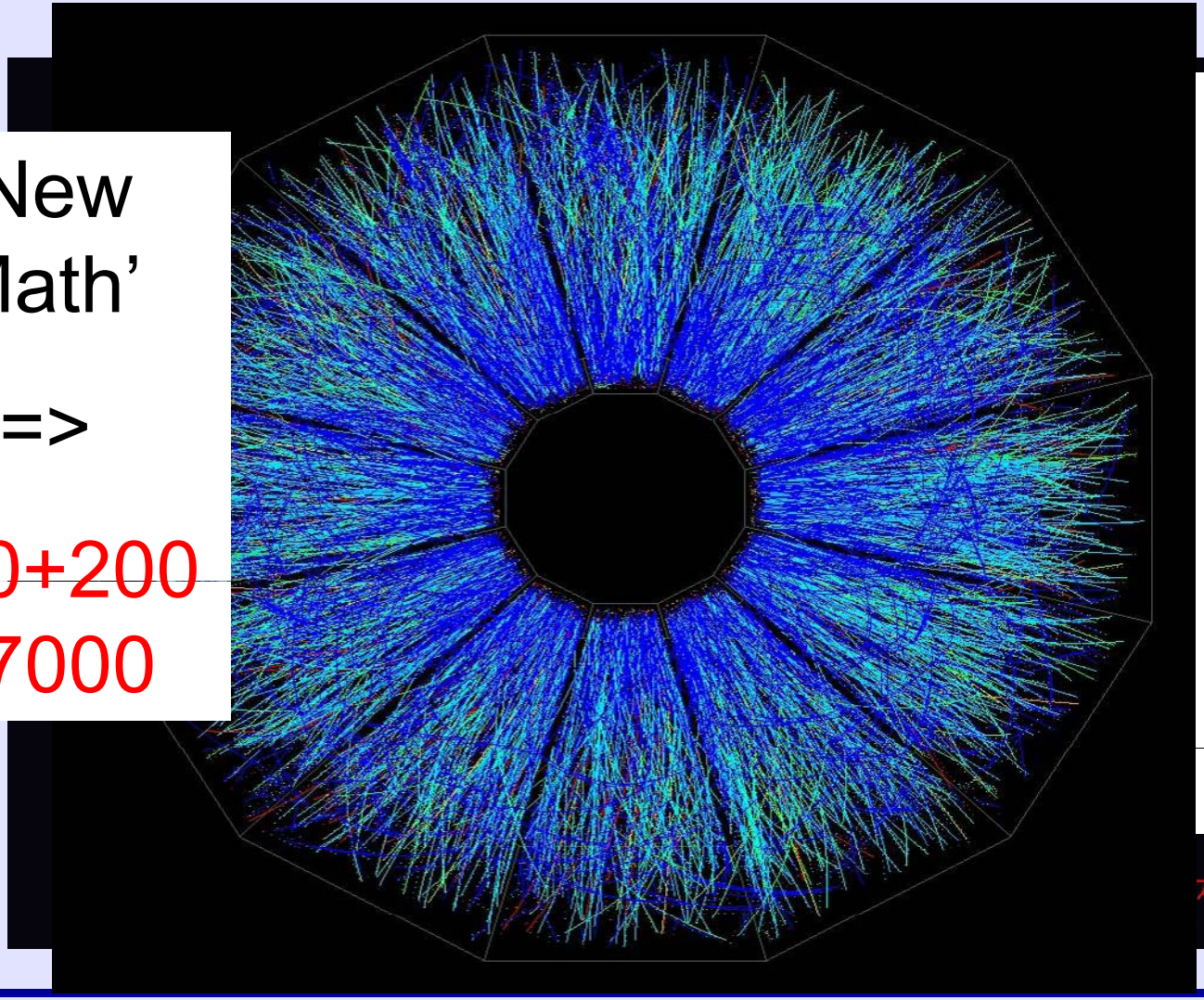
URQMD

H. Stöcker et al

Do we form a Quark Gluon Plasma?



The traces of the Little Big Bang



'New Math'

=>

200+200 =7000

$E=Mc^2$

=>

'Create' Matter & Antimatter

The basic building blocks of nature: the Standard Model

PARTICLES **FORCES**

FERMIONS matter constituents spin = 1/2, 3/2, 5/2, ...

Leptons spin = 1/2

Flavor	Mass GeV/c²	Electric charge
ν_e electron neutrino	$<1\times10^{-8}$	0
e electron	0.000511	1
ν_μ muon neutrino	<0.0002	0
μ muon	0.106	−1
ν_τ tau neutrino	<0.02	0
τ tau	1.7771	−1

Quarks spin = 1/2

Flavor	Approx. Mass GeV/c²	Electric charge
u up	0.003	2/3
d down	0.006	−1/3
c charm	1.3	2/3
s strange	0.1	−1/3
t top	175	2/3
b bottom	4.3	−1/3

BOSONS force carriers spin = 0, 1, 2, ...

Unified Electroweak spin = 1

Name	Mass GeV/c²	Electric charge
γ photon	0	0
W^-	80.4	−1
W^+	80.4	+1
Z^0	91.187	0

Strong (color) spin = 1

Name	Mass GeV/c²	Electric charge
g gluon	0	0

Quark 'Lego'.
Explains present complex particles

Baryons qqq and Antibaryons $\bar{q}\bar{q}\bar{q}$

Baryons are fermionic hadrons.
There are about 120 types of baryons.

Symbol	Name	Quark content	Electric charge	Mass GeV/c^2	Spin
p	proton	uud	1	0.938	1/2
$\bar{p}$	anti-proton	$\bar{u}\bar{u}\bar{d}$	−1	0.938	1/2
n	neutron	udd	0	0.940	1/2
Λ	lambda	uds	0	1.116	1/2
Ω^-	omega	sss	−1	1.672	3/2

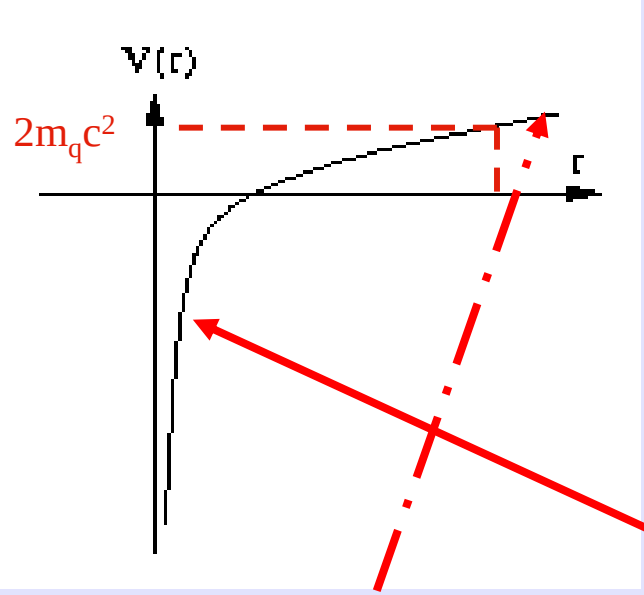
Mesons $q\bar{q}$

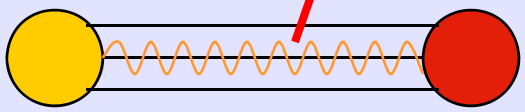
Mesons are bosonic hadrons.
There are about 140 types of mesons.

Symbol	Name	Quark content	Electric charge	Mass GeV/c^2	Spin
π^+	pion	$u\bar{d}$	+1	0.140	0
K^-	kaon	$s\bar{u}$	−1	0.494	0
ρ^+	rho	$u\bar{d}$	+1	0.770	1
B^0	B-zero	$d\bar{b}$	0	5.279	0
η_c	eta-c	$c\bar{c}$	0	2 .980	0

The STRONG force: Quarks are confined

The quark-quark potential



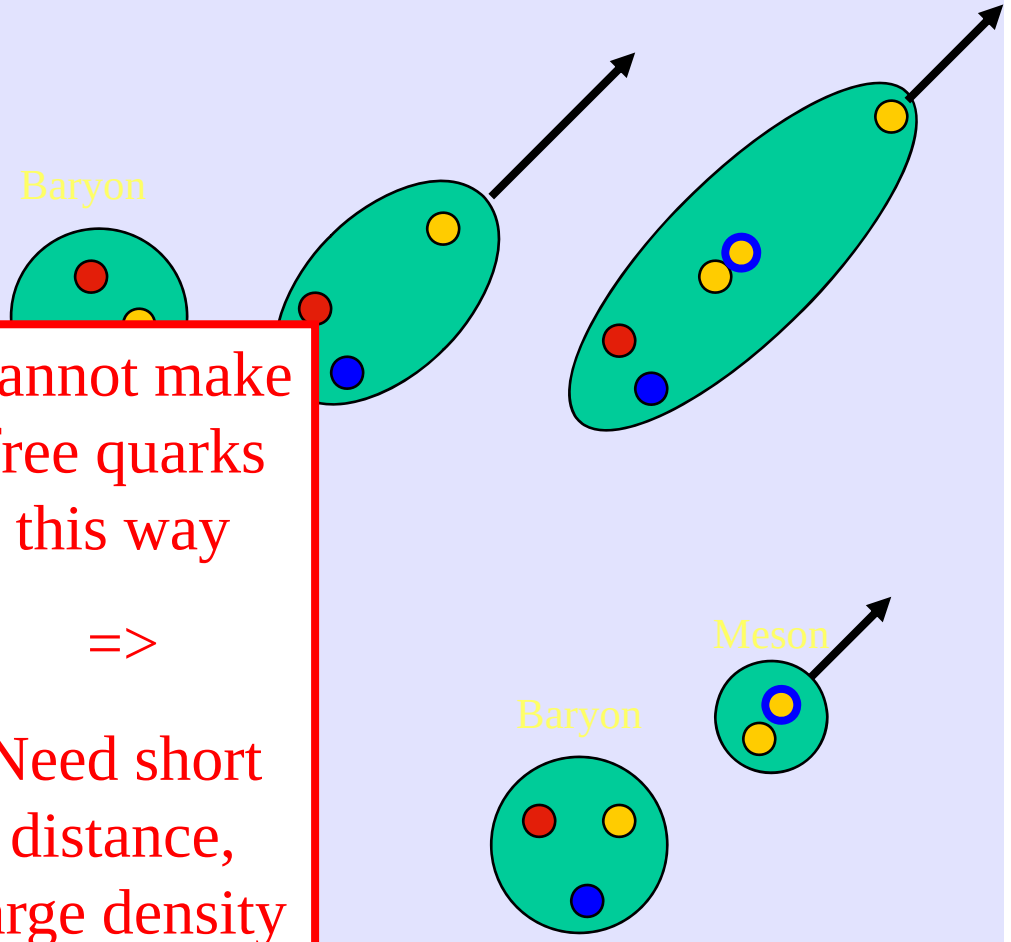


Cannot make free quarks this way

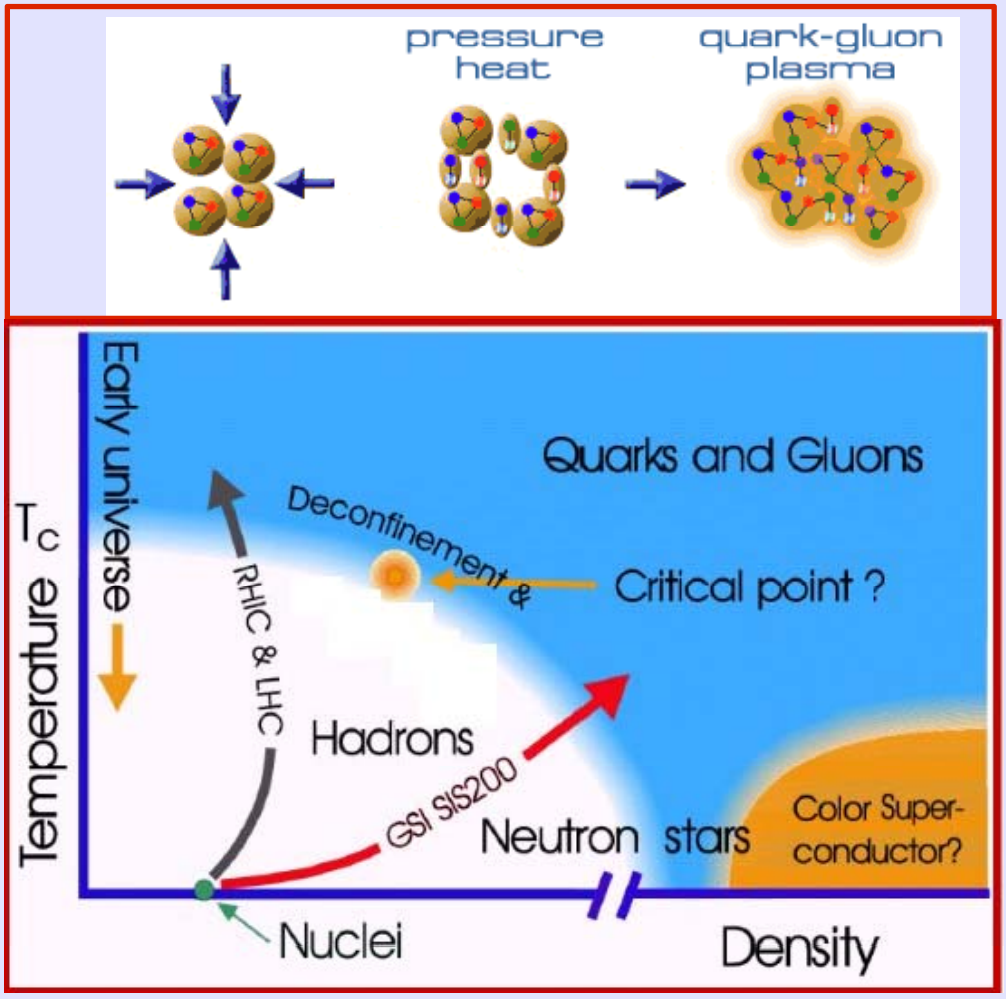
=>

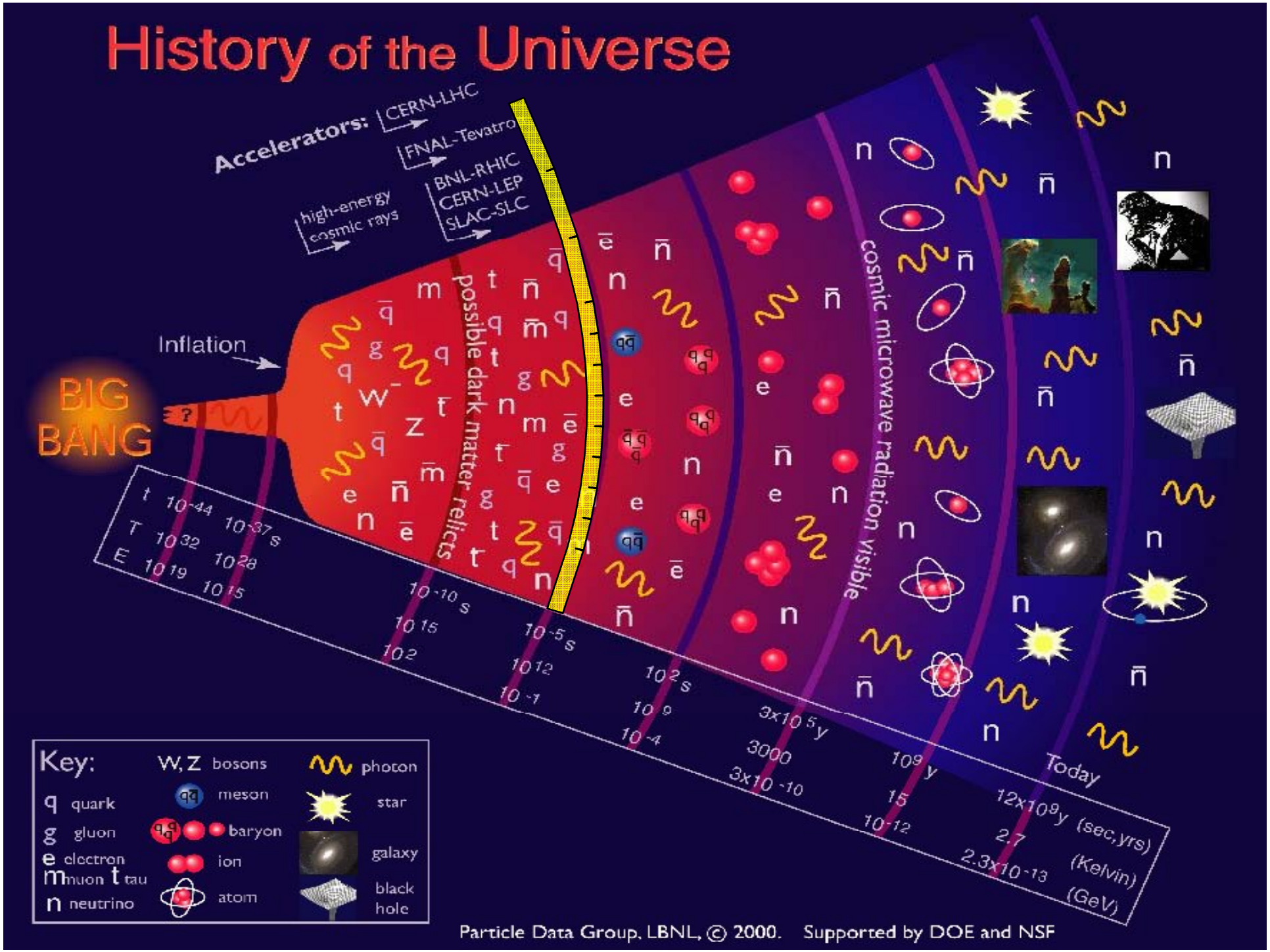
Need short distance, large density

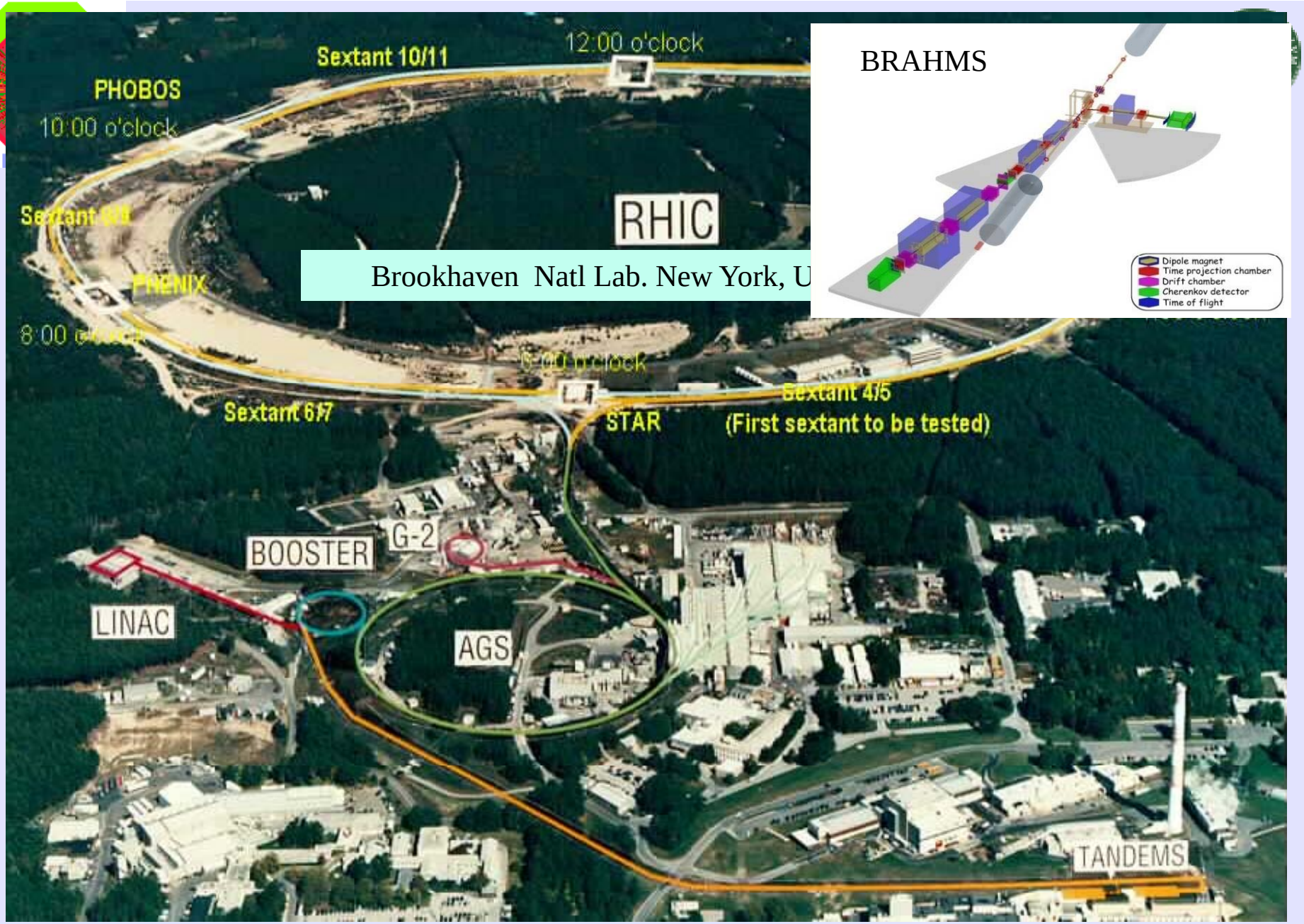
QGP



The PHASES of Nuclear Matter



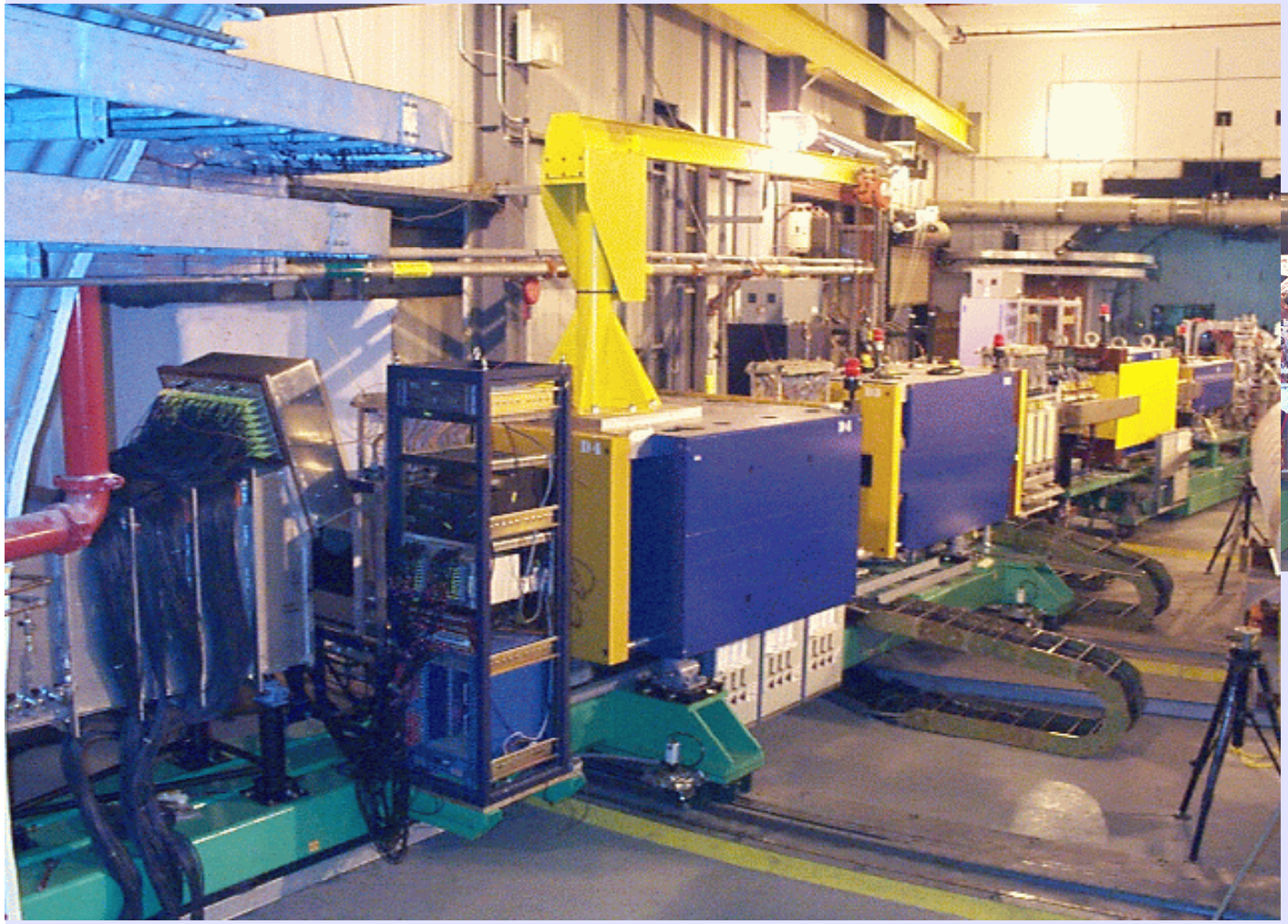

History of the Universe
Accelerators:
CERN-LHC
FNAL-Tevatron
BNL-RHIC
CERN-LEP
SLAC-SLC
high-energy cosmic rays
Inflation
BIG BANG
possible dark matter relicts
cosmic microwave radiation visible
Today
t 10-44 10-37 s
T 10 32 10 28
E 10 19 10 15
10-10 s
10 15
10 2
10-5 s
10 12
10 -1
10 2 s
10 9
10 -4
3x10 5 y
3000
3x10 -10
10 9 y
15
10-12
12x10 9 y (sec,yrs)
2.7 (Kelvin)
2.3x10 -13 (GeV)
Key:
q quark
g gluon
e electron
m muon t tau
n neutrino
W, Z bosons
meson
baryon
ion
atom
photon
star
galaxy
black hole
Particle Data Group, LBNL, © 2000. Supported by DOE and NSF

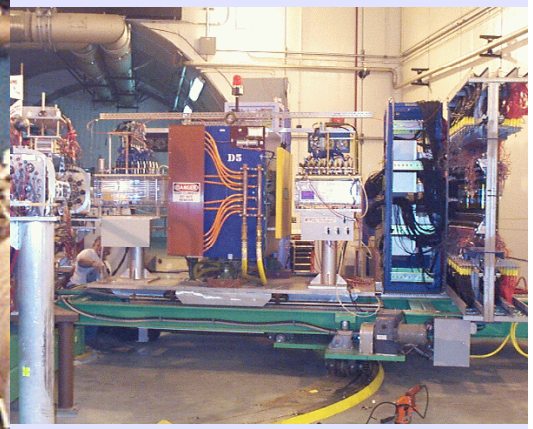


Brookhaven Natl Lab. New York, U

BRAHMS

The forward experiment





Af kvark-gluon-plasma er du kommet

Berlingske · Søndag 25. januar 2004

Oakland Tribune
Serving Oakland for 129 years

SCIENCE

Researchers find quarks like those from Big Bang

■ Lively debate on the subject likely this week at conference in Oakland

By Ian Hoffman
STAFF WRITER

In this world, there's no such thing as a free quark.

Dubbed the "quark-gluon plasma," it's billions of times hotter than the heart of the sun and as dense as the core of a neutron star.

If Wang is right, the plasma winks into existence a few million times a year, when atoms of gold smash head-on inside the Relativistic Heavy Ion Collider at Brookhaven National Laboratory in New York.

TUESDAY, January 13, 2004

Found State of Matter Could Yield Insights Into Basic Laws of Nature

MES GLANZ

Calif., Jan. 12 — A ense state of matter, some respects to a f subatomic pudding, vered deep within the ry gold atoms, scien- okhaven National Lab- at a conference here

was described by some as a breakthrough in the powerful, im- plex forces that hold uilding blocks of atom- ons and neutrons. Evi-

ter at minuscule scales.

"This is nothing short of a major discovery," said Dmitri Kharzeev, a theoretical physicist at Brookhaven who was not involved in the experiments. "I think it's going to trigger a real revolution in nuclear physics."

The nuclear pudding, as strange as it is, has a simple structure and could turn out to be a universal property of nuclei speeding at high energies, Dr. Kharzeev said. The simplicity stands in sharp contrast to the messy and sometimes incomprehensible structure of many atomic nuclei. The newly discovered state could let physicists cut through those complexities

hard, pointlike particles called quarks, as well as similarly pointlike particles called gluons, which carry the strong force that binds the quarks together.

Each proton (and each neutron) contains three quarks. Normally there is just a handful of gluons flitting among the quarks, said Dr. Larry McLerran, leader of Brookhaven's nuclear theory group.

That arrangement means that atomic nuclei, though comparatively dense, are something like little planetary systems: particles whirling through mostly empty space. But subatomic matter is nothing if not

more easily, theorists predicted. And because, according to Einstein's theory of relativity, time slows down when particles move close to the speed of light, those brief fluctuations could in effect last longer.

In that state, according to work by

> Excitement over a fleeting glimpse of subatomic pudding.

finger through chocolate pudding than through a bag of marbles.

And that is exactly what a particle detector called Brahms, for Broad Range Hadron Magnetic Spectrometer, saw at Brookhaven, said Dr. Ramiro Debbe, a physicist on the experiment. As deduced by the number of collision products shooting straight down the axis of the accelerator, deuterons did not have nearly as many collisions with gluons inside the gold as they would have if the gluons had all been flying about separately.

So, Dr. Debbe said, the Brahms data indicated that the deuterons

Tests Suggest Scientists Have Found Big Bang Goo

By JAMES GLANZ

OAKLAND, Calif., Jan. 13 — At

Physicists would like to study the quarks individually, but the force carried by the gluons is something like a rubber band that never loses its elasticity. So a given quark can never escape the embrace of another quark and roam free. The lone exception — theoretically, at least — should occur when a collection of ordinary particles becomes so hot and dense that their innards can spill out and form a kind of quark soup, the quark-gluon plasma.

What has been created is up for debate

▸ QUARK, from News 1

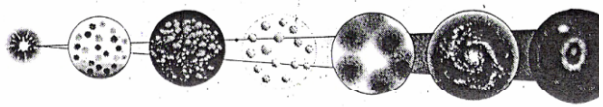
Precisely what nuclear physicists have created and what it means are ripe for debate this week in the Oakland Convention Center, at this year's Quark Matter conference.

"This entire week, people will be fighting over whether the plasma really was there," says Michigan State physicist Gary Westfall.

Early in the construction of the Long Island collider, better known as RHIC, a handful of European scientists predicted horrors. Bashing gold atoms head-to-head could give birth to a black hole. It could devour

Expansion of the Universe

A few millionths of a second after the Big Bang, the universe was a blazing hot soup of quarks and gl atomic nuclei. It took 400,000 years of cooling to settle into the structure of today's matter. Scientists re-created the quark-gluon plasma inside a Long Island lab, providing clues to the infancy of the unive



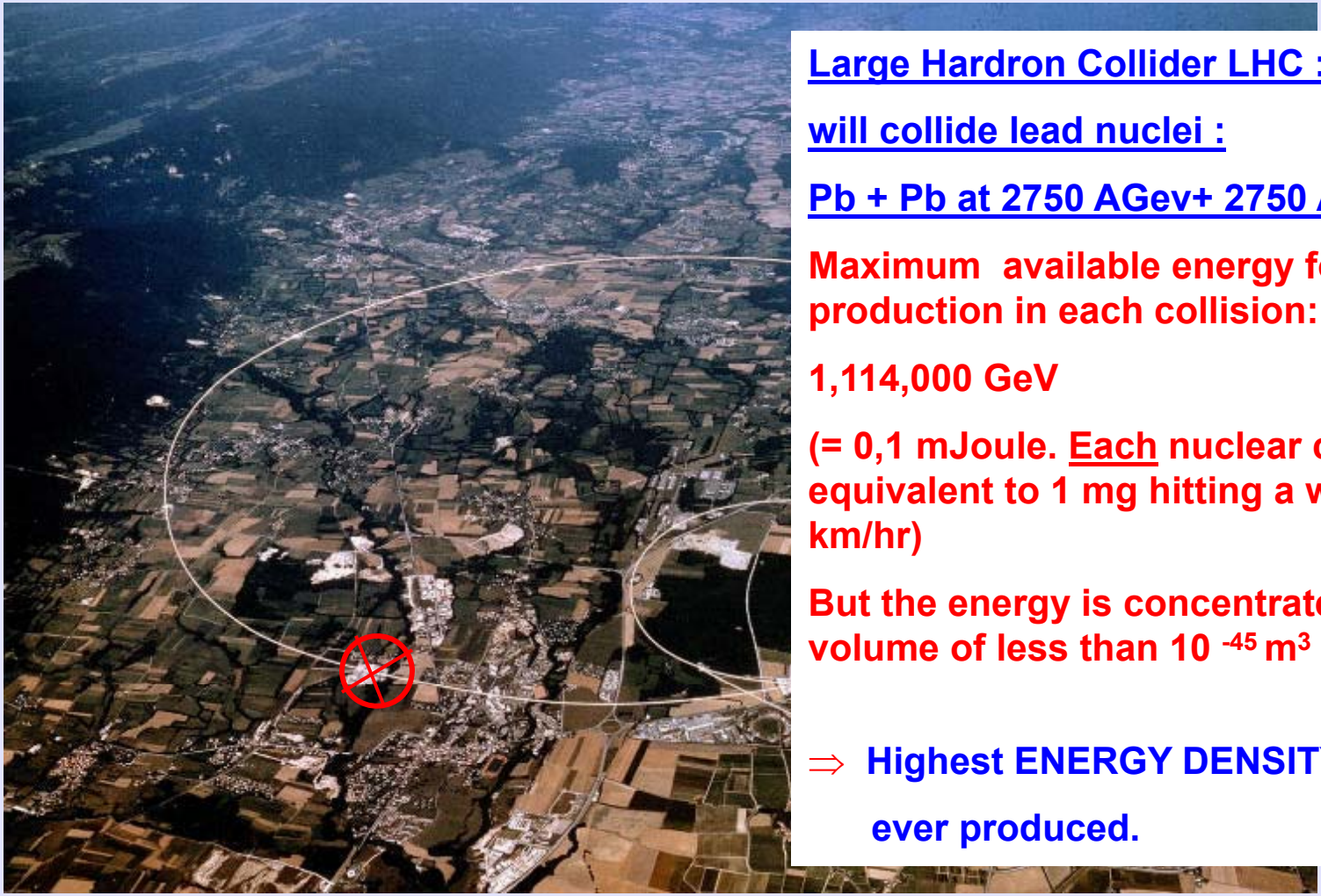
Big Bang	Quark-gluon plasma	Proton & neutron formation	Formation of low mass nuclei	Formation of neutral atoms	Star formation	Supernova dispersion massive el
Time	A few millionths of a second	A few thousandths of a second	3 minutes	400,000 years	1 billion years	Several billi years

Source: Lawrence Berkeley National Laboratory

At first, theorists conceived a hot mass of nuclear particles. Even if t

Det Lille Big Bang

Large Hadron Collider (LHC)
CERN, Genève, CH.



Large Hardron Collider LHC : 27 km

will collide lead nuclei :

Pb + Pb at 2750 AGev+ 2750 AGeV

Maximum available energy for particle production in each collision:

1,114,000 GeV

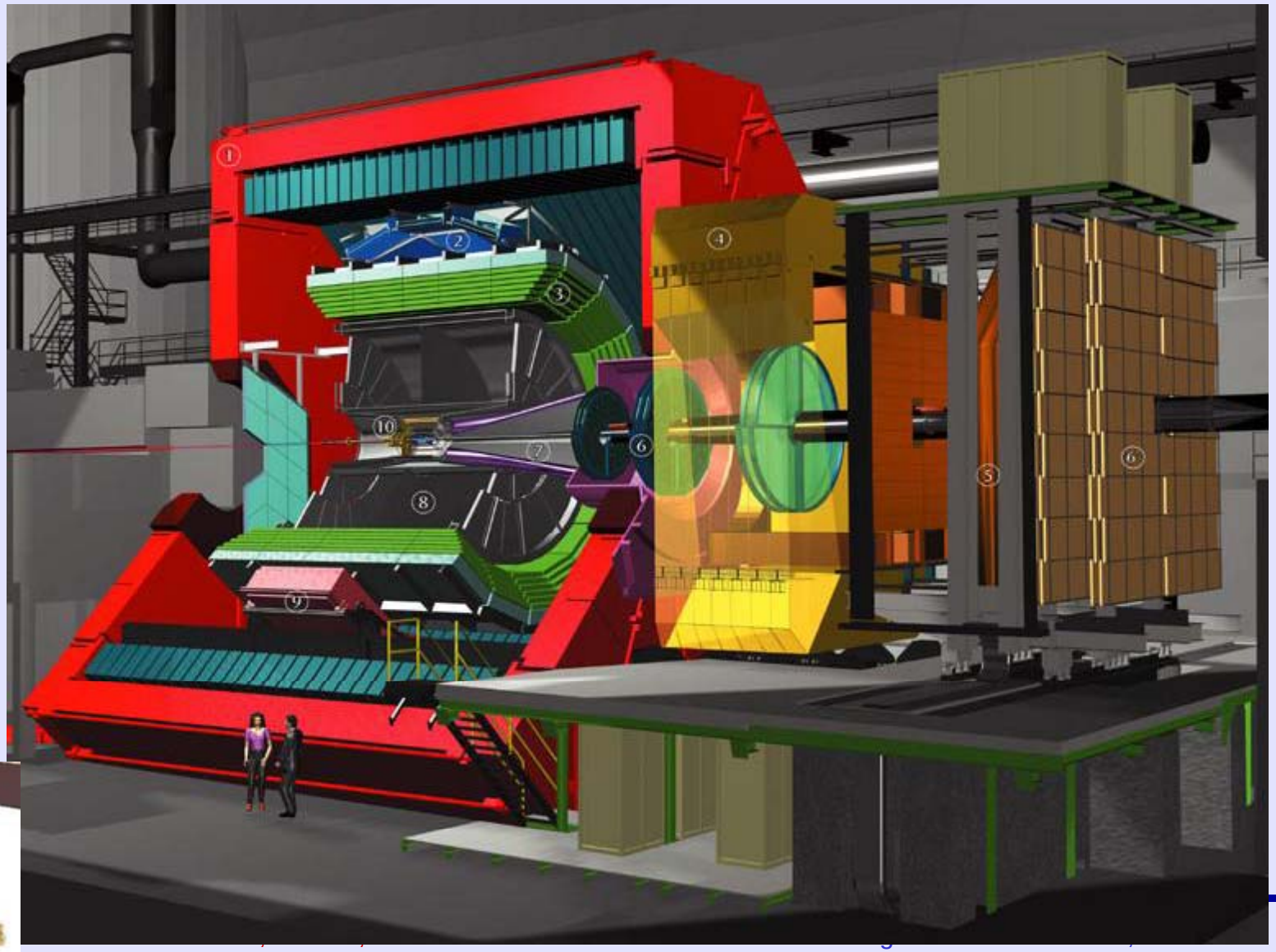
(= 0,1 mJoule. Each nuclear collision equivalent to 1 mg hitting a wall at 50 km/hr)

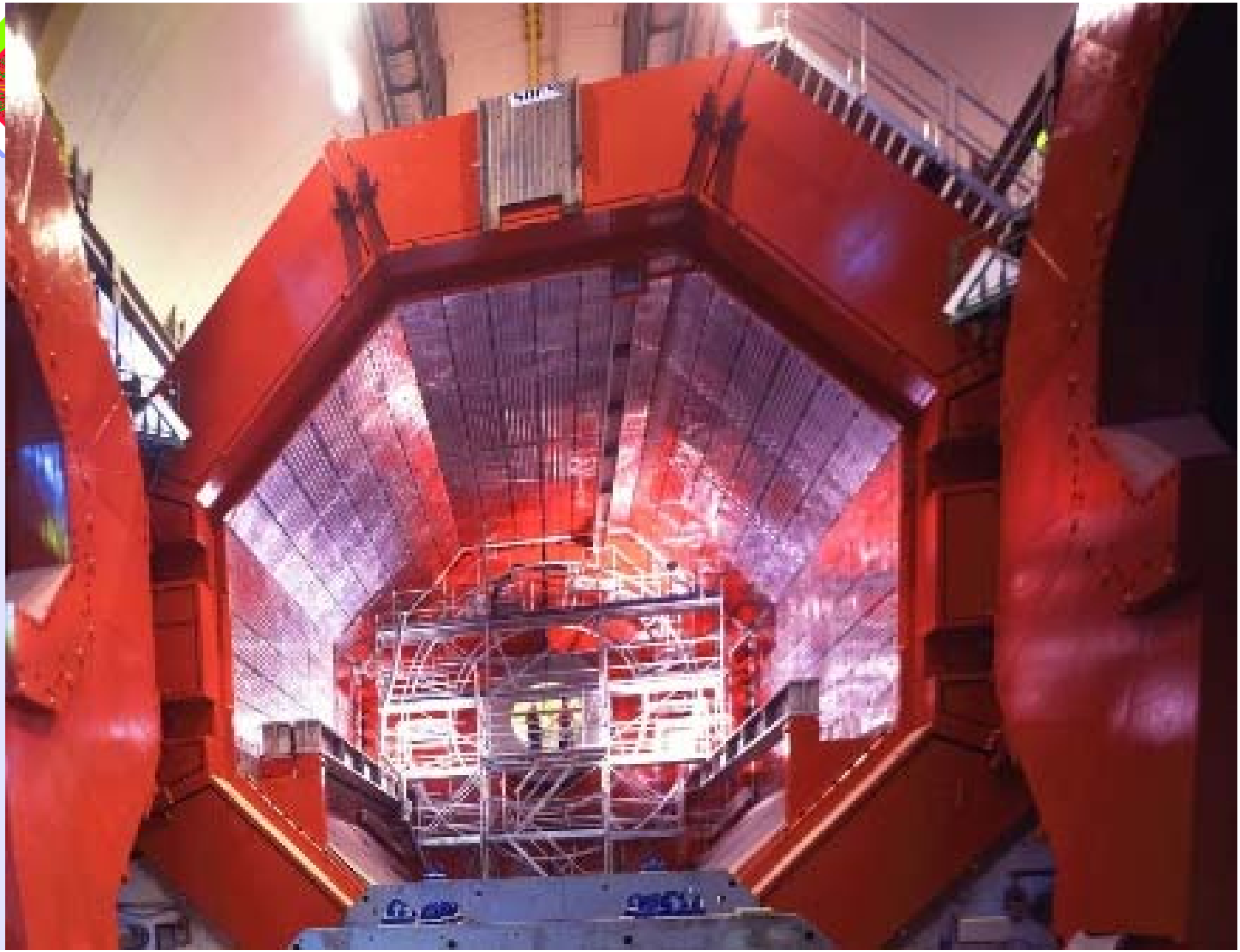
But the energy is concentrated in a volume of less than 10^{-45} m^3 !

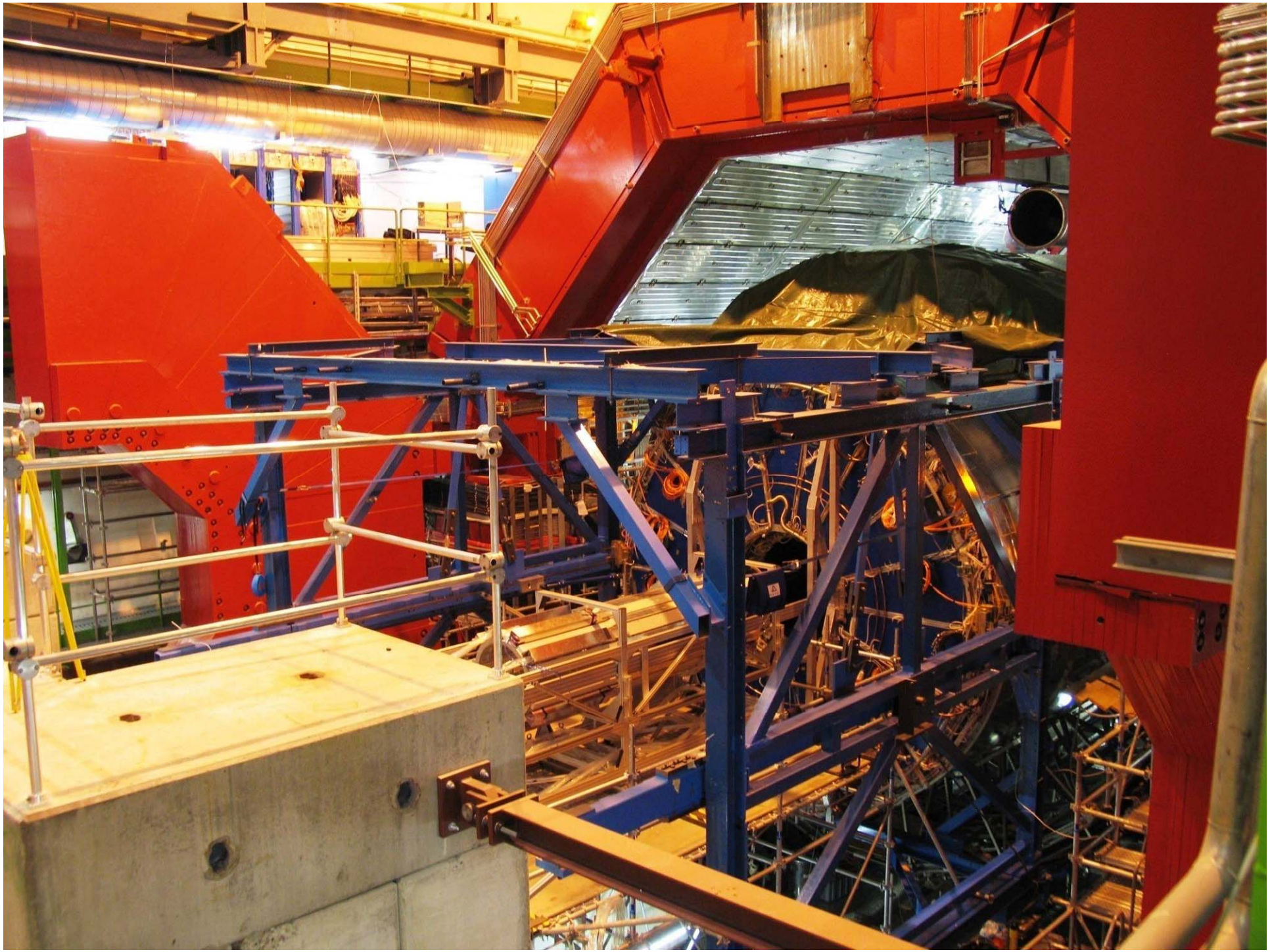
⇒ **Highest ENERGY DENSITY ever produced.**

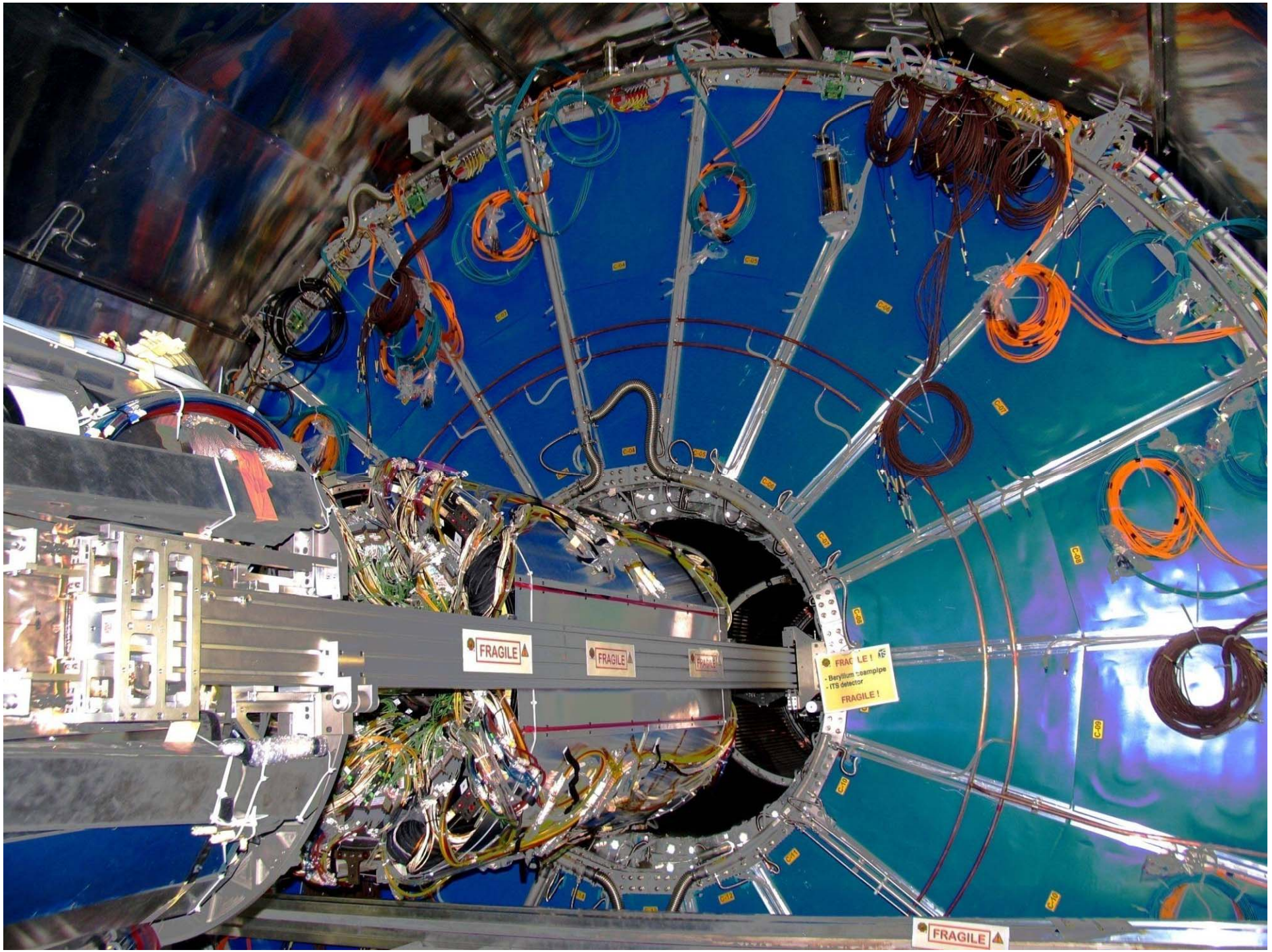

Fermilab

ALICE experiment at CERN's new LHC accelerator will record up to 80 000 particle pr. collision.

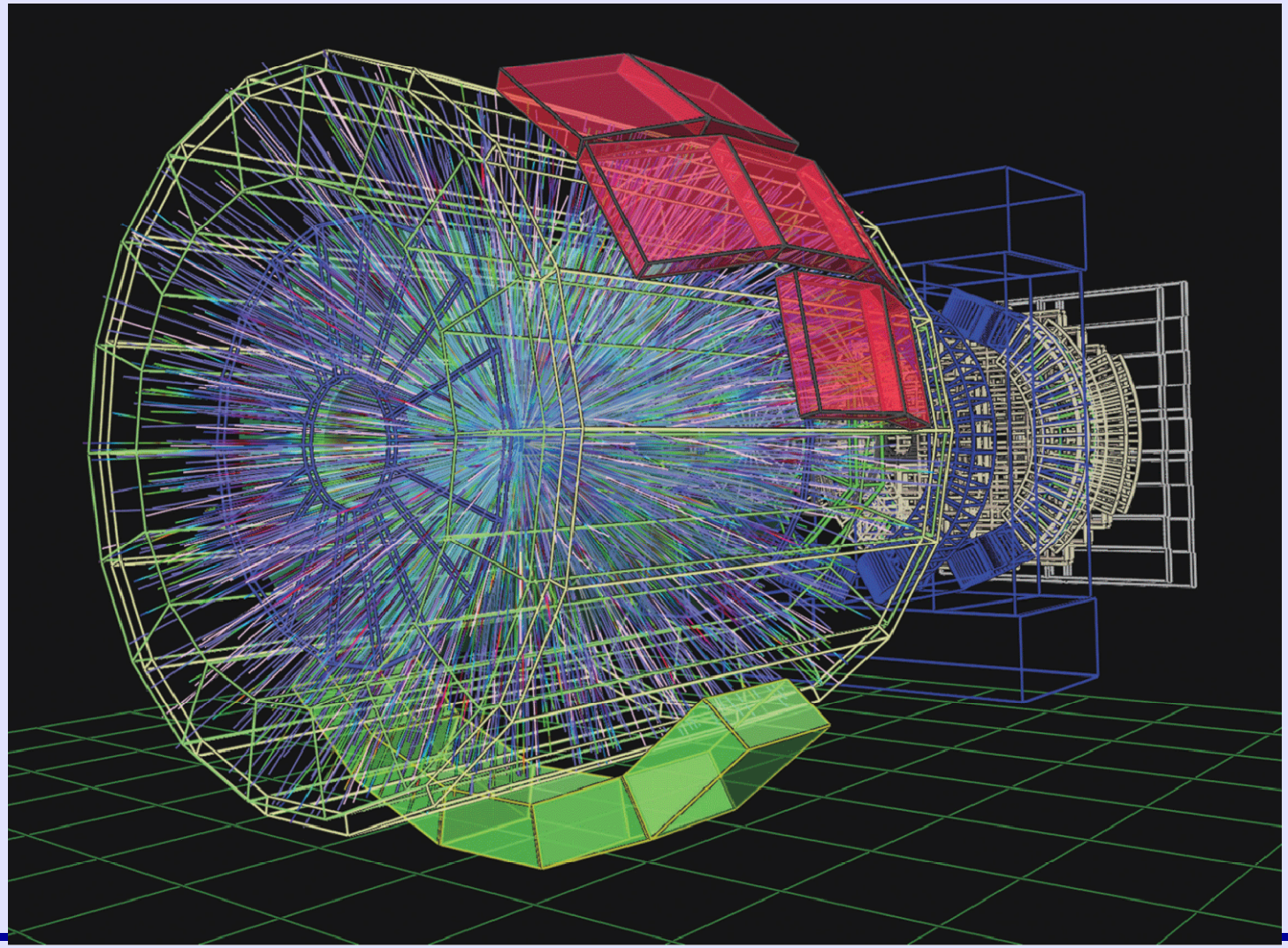






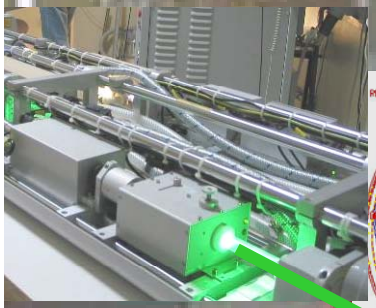

FRAGILE
FRAGILE
FRAGILE
- Beryllium beampipe
- ITS detector
FRAGILE !
FRAGILE

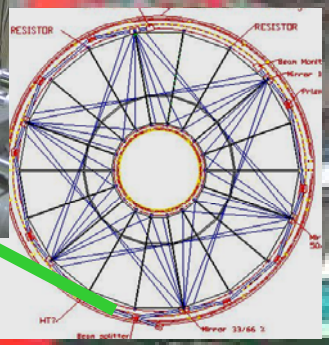
Up to 80.000 particles produced in each collision in ALICE.
10.000 collisions per second, for 15.000.000 seconds each year.
=> Millions of GigaBytes to be stored and analyzed.



… ready to take first data from the summer 2008. A bientôt…

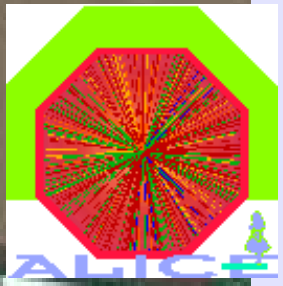
The ALICE TPC laser and FMD detector





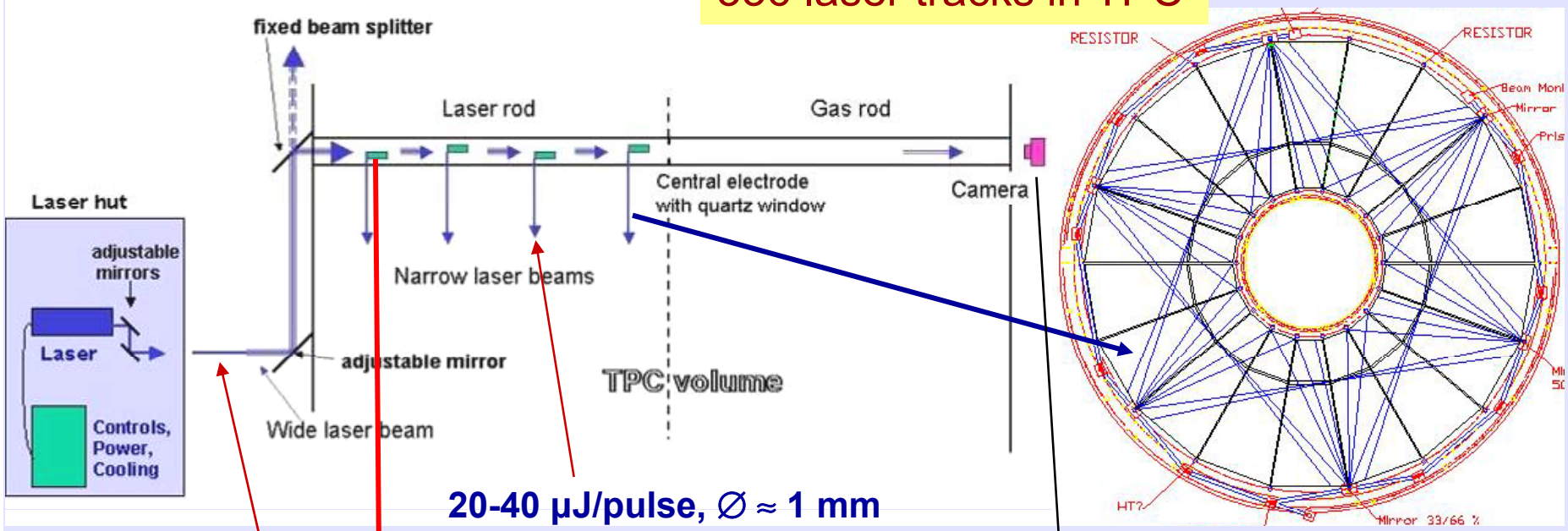
TPC laser

FMD



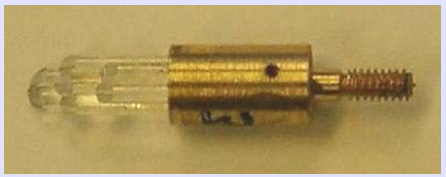
TPC laser calibration

336 laser tracks in TPC

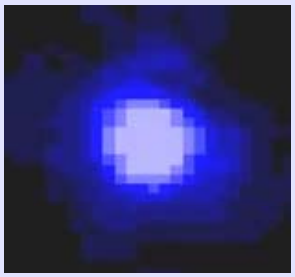


20-40 µJ/pulse, ∅ ≈ 1 mm

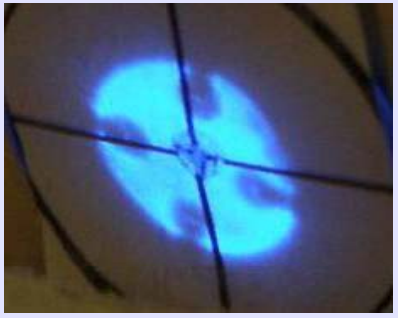
266 nm, 100 mJ/pulse, 5 ns pulse, ∅ ≈ 25 mm



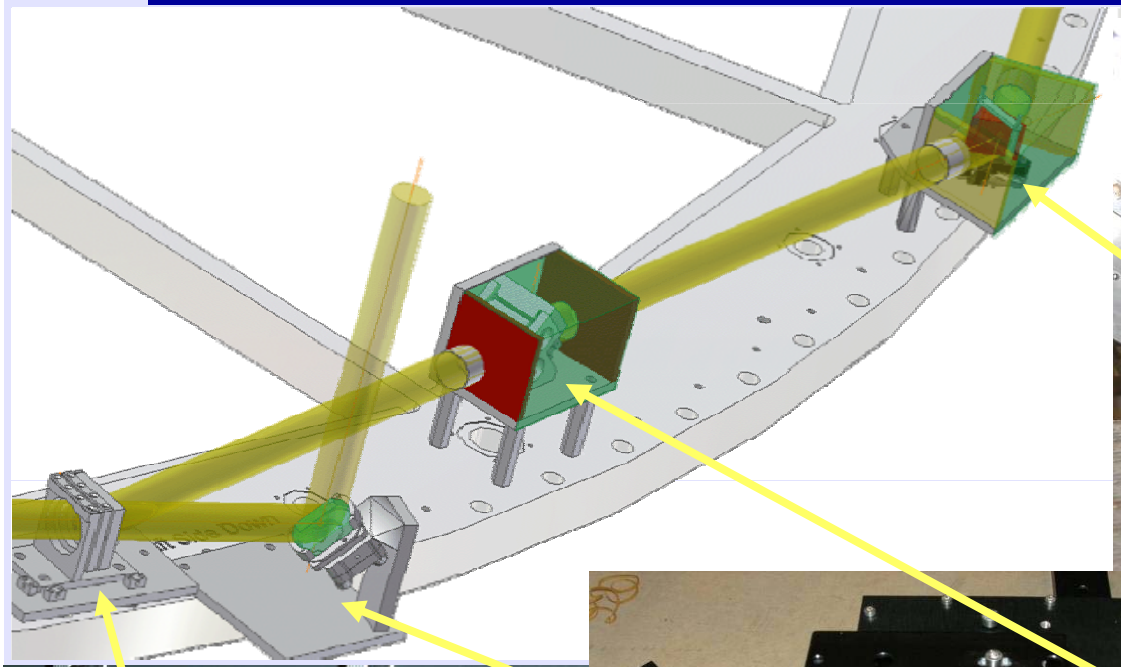
1.5 mm

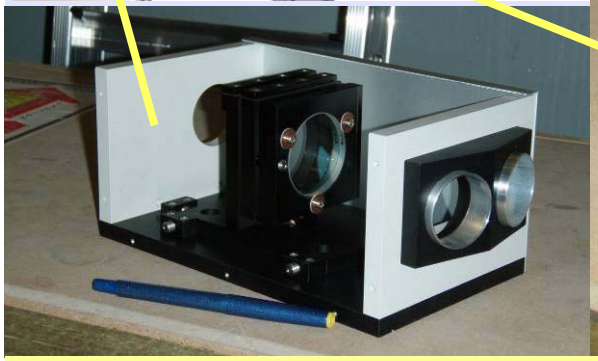


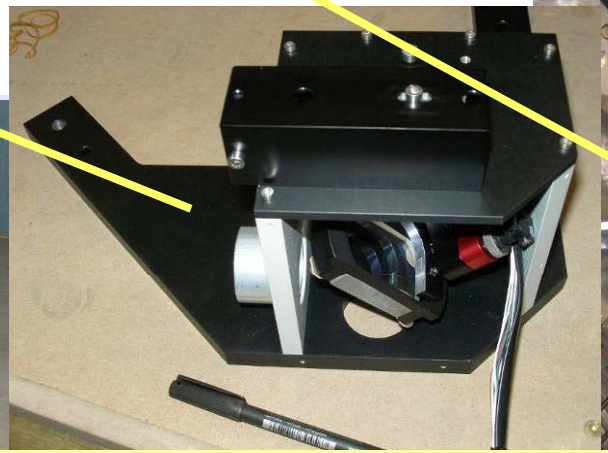
25 mm



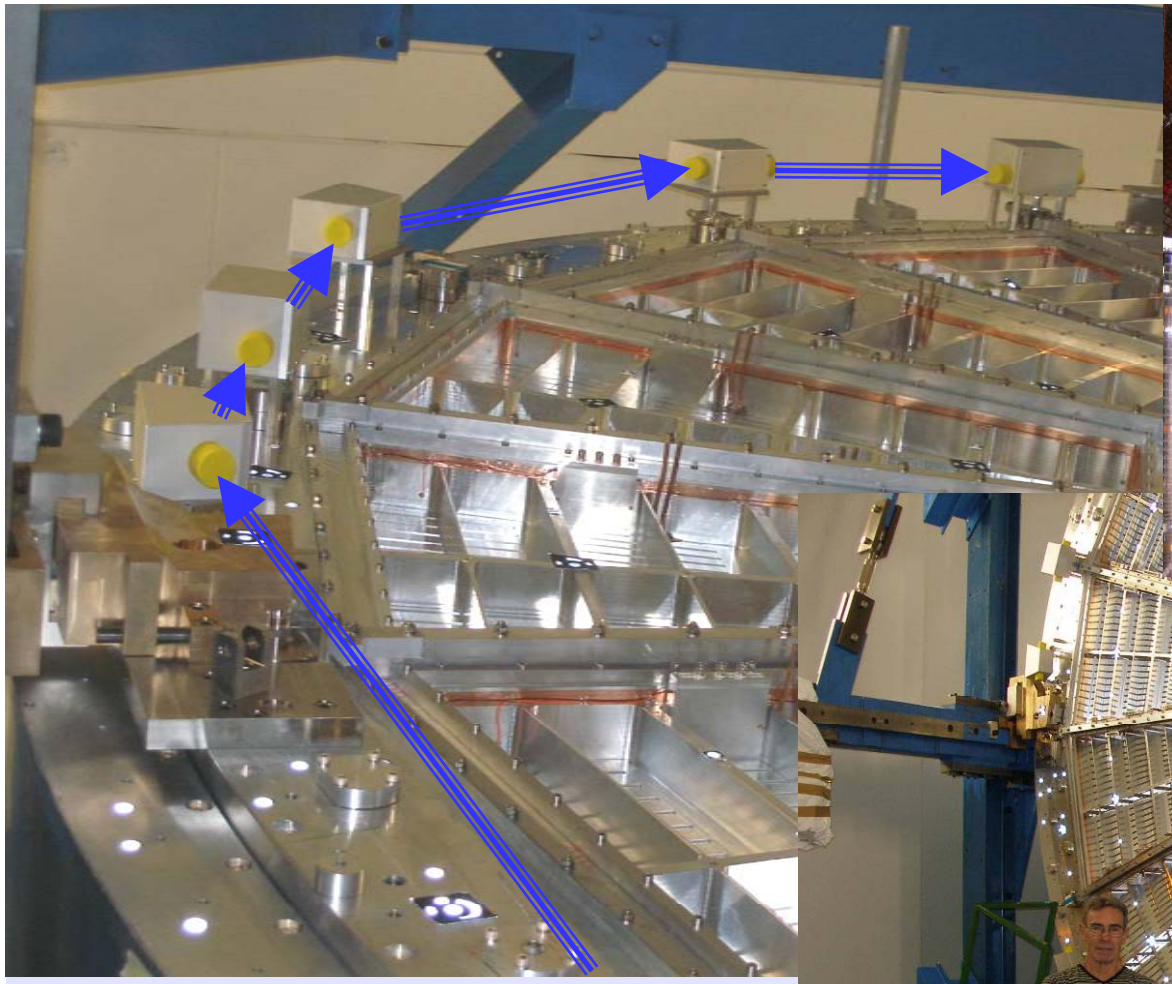
Optical components outside TPC volume

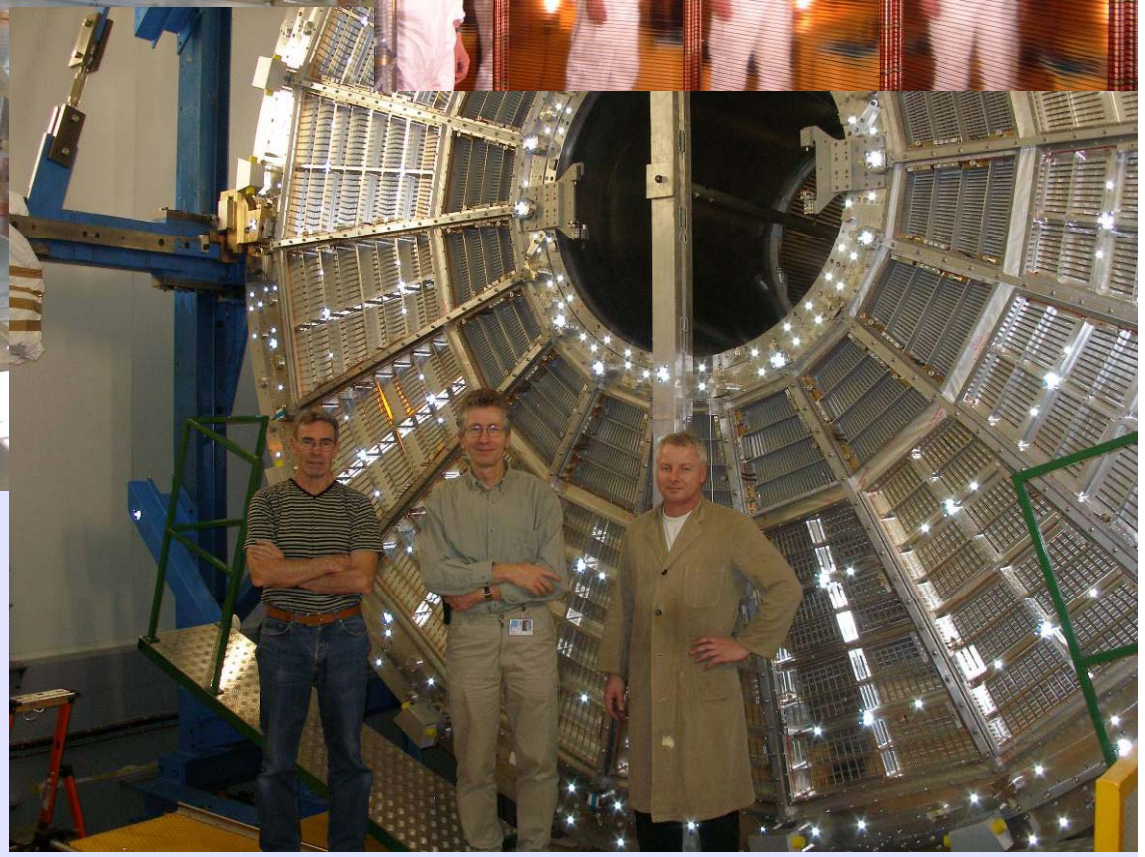






Optics holders all designed and produced at NBI workshop

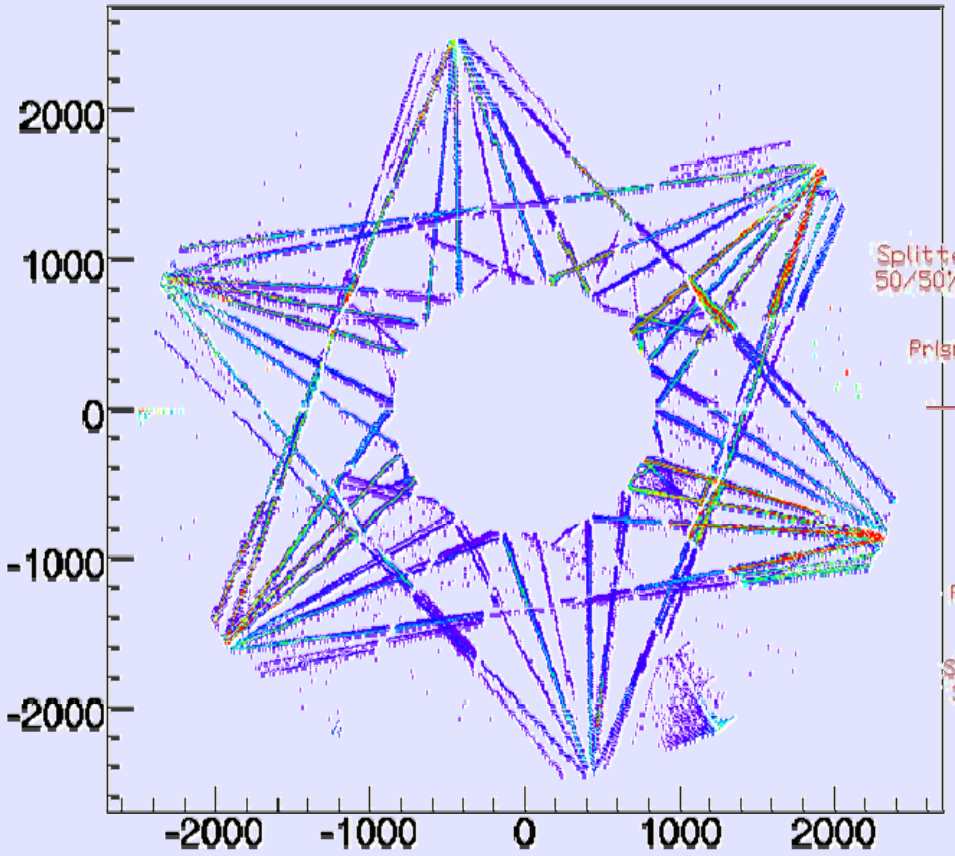




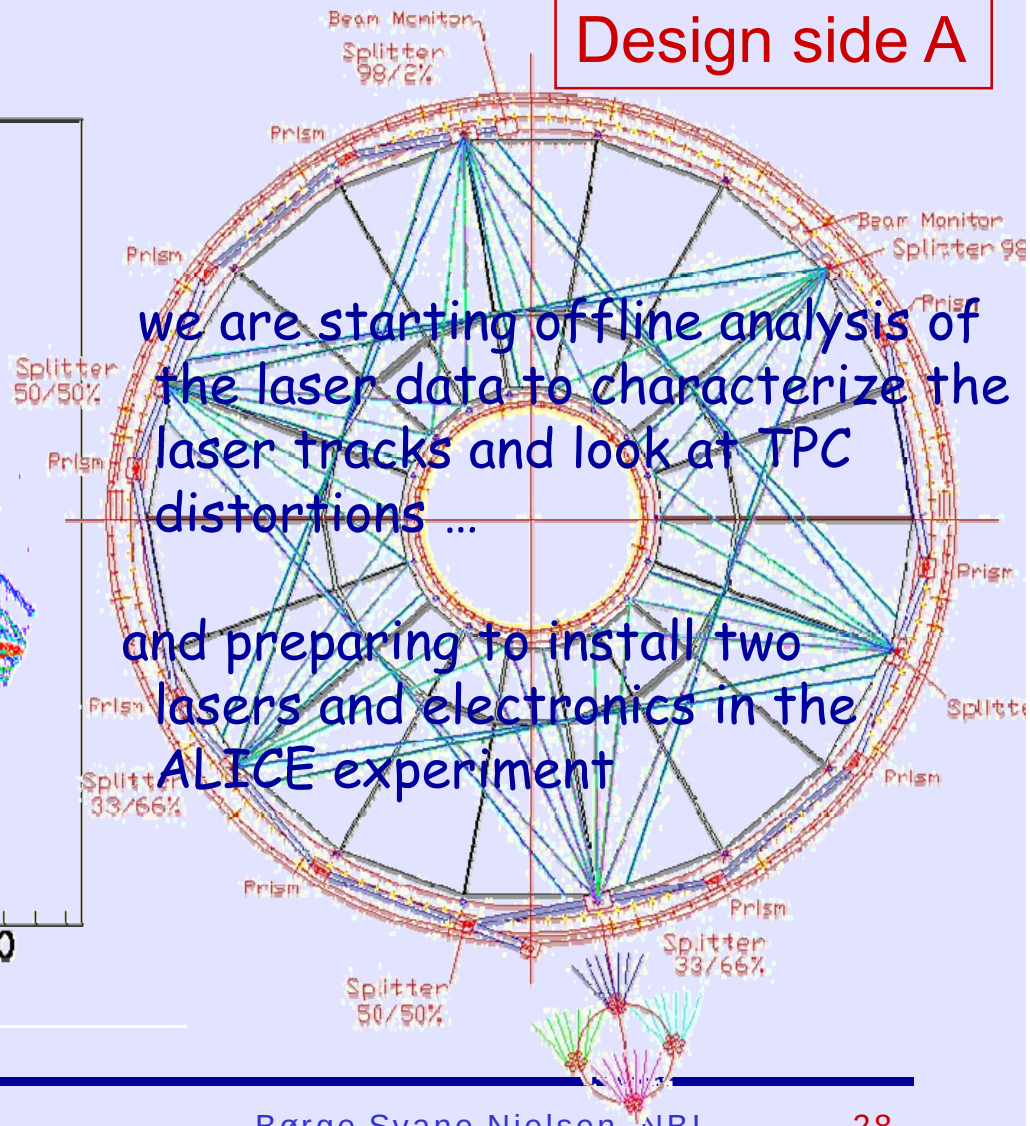
Installation at CERN

Analysis of data from TPC commissioning

Measured side A



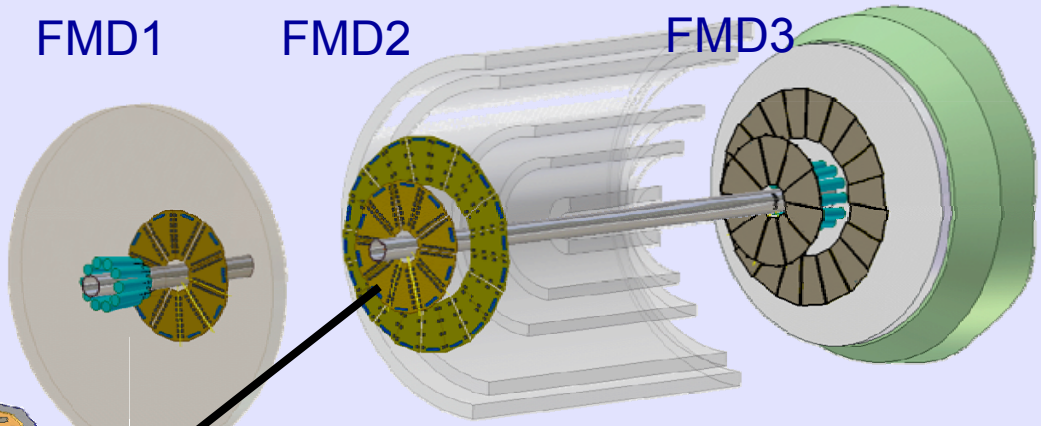
Design side A

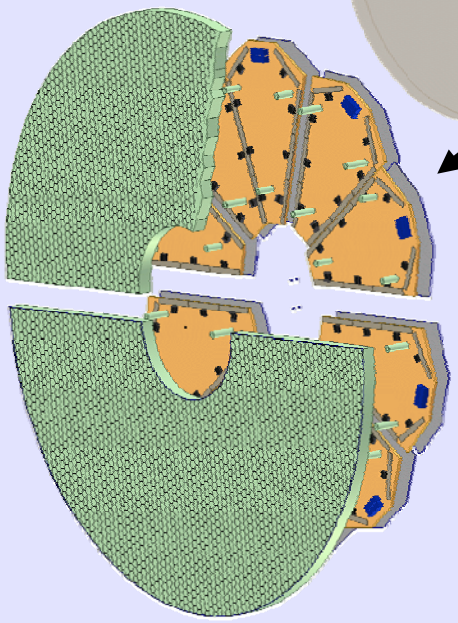


we are starting offline analysis of the laser data to characterize the laser tracks and look at TPC distortions …

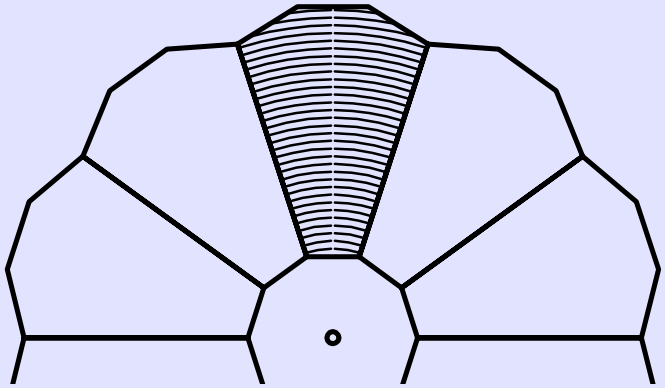
and preparing to install two lasers and electronics in the ALICE experiment

FMD: Si strip detector



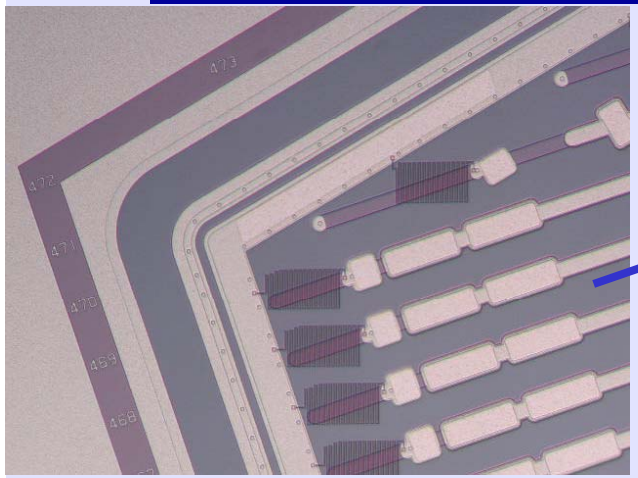


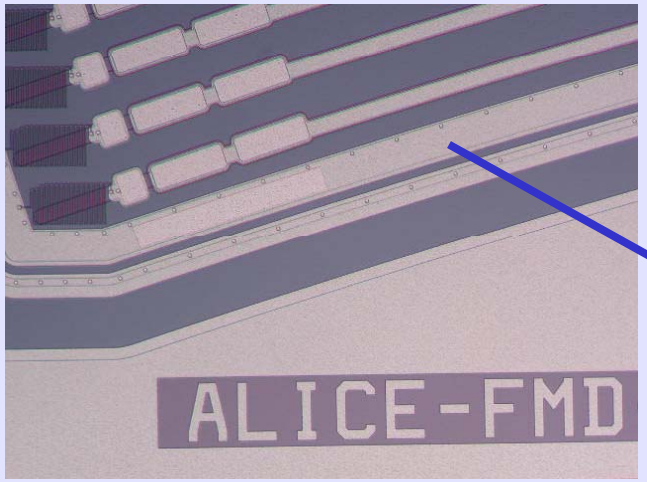
3 inner rings: 20 φ sectors, 512 strips
2 outer rings: 40 φ sectors, 256 strips
Total 51,200 strips

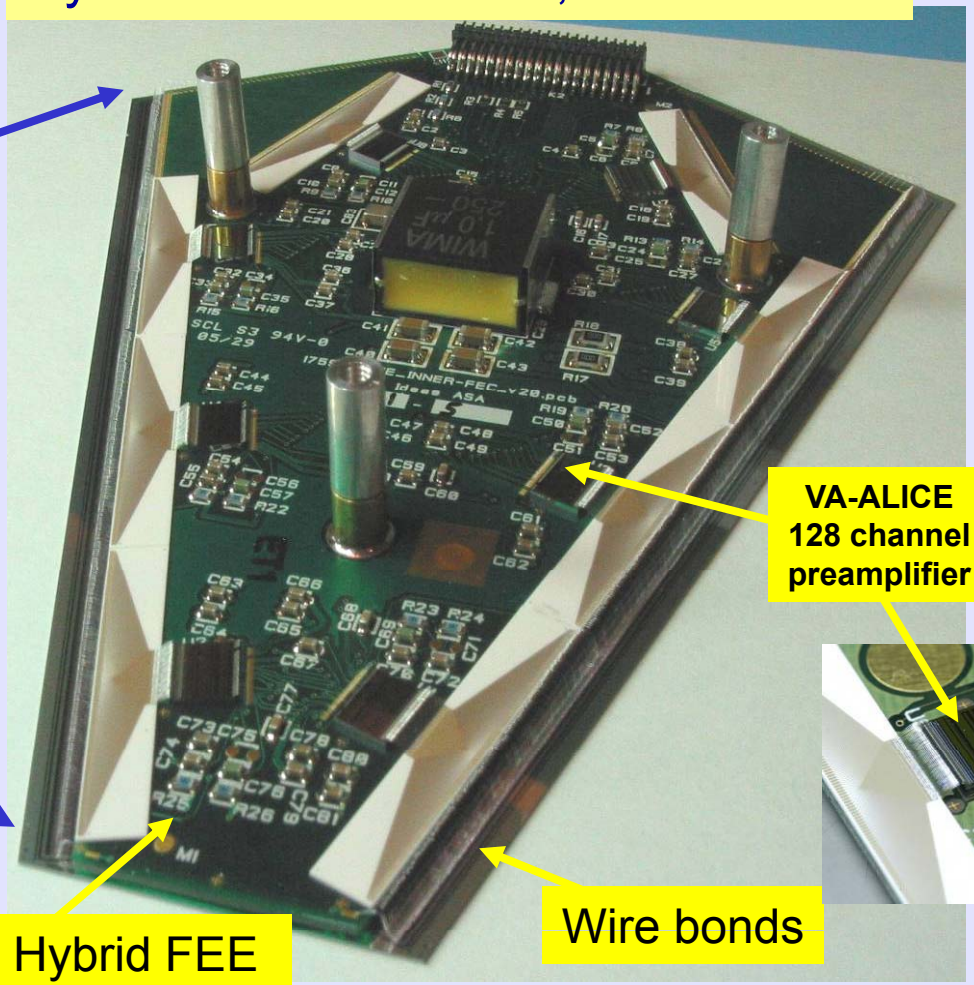


Silicon sensors and hybrids

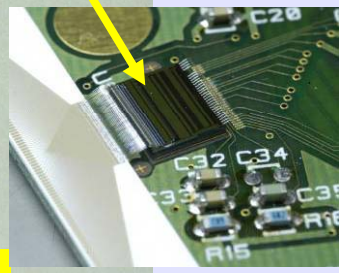
Sensors from Hamamatsu Photonics
Hybrids from Ideas AS, Oslo







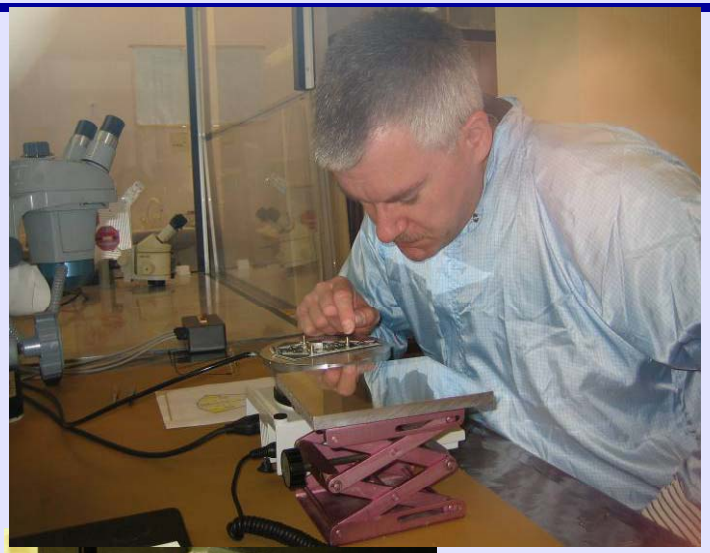
VA-ALICE
128 channel
preamplifier



Hybrid FEE

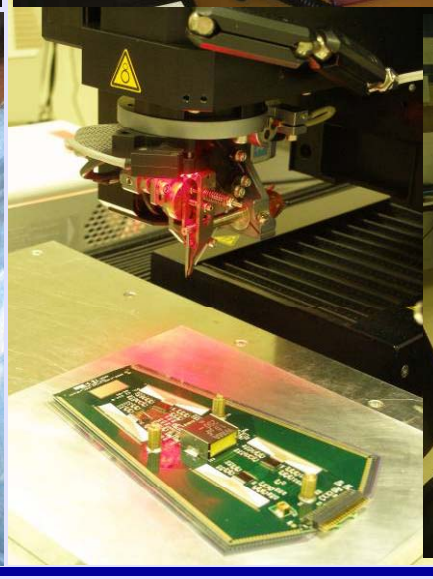
Wire bonds

Module production

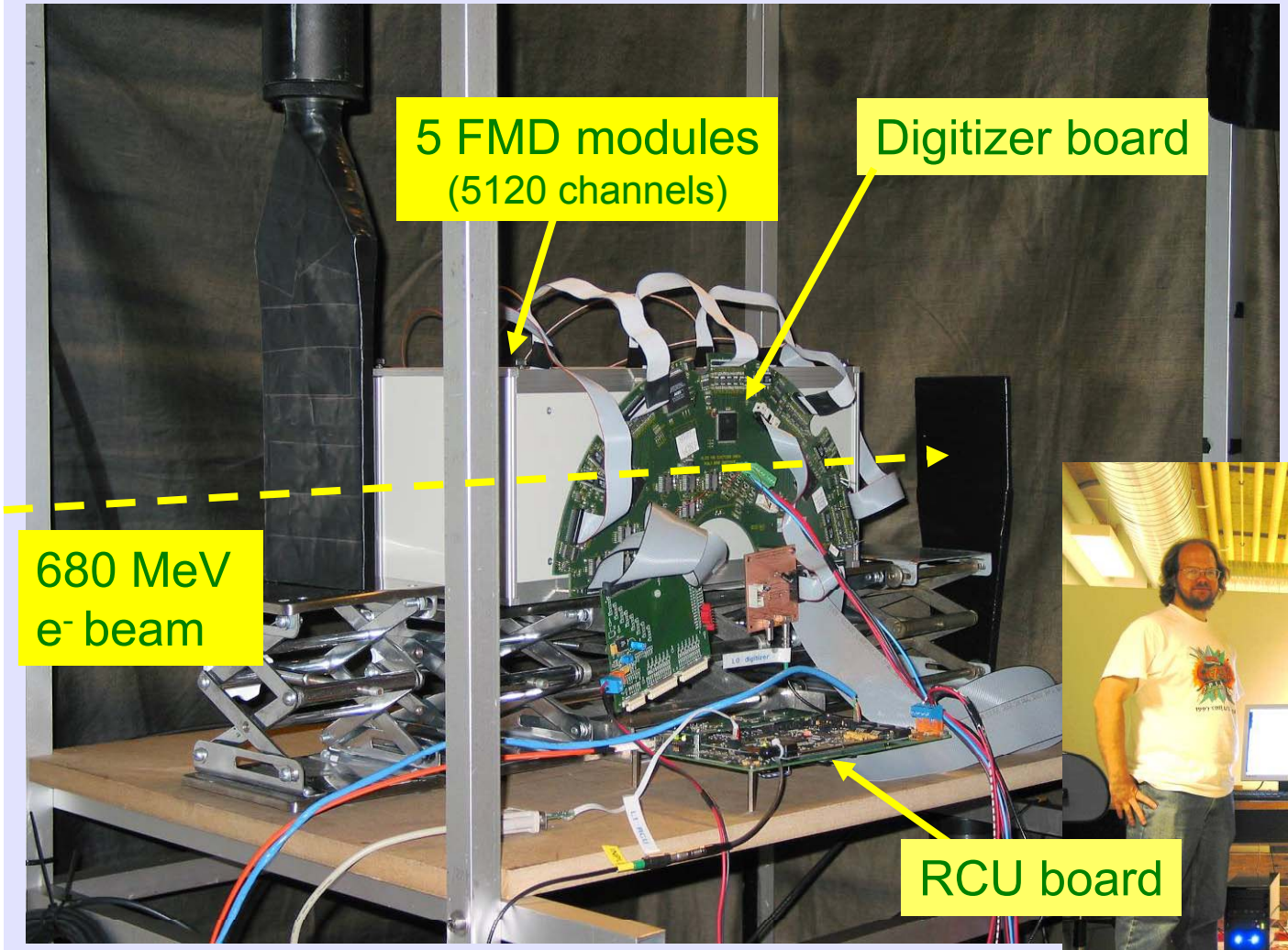


Module gluing in Copenhagen

Bonding at CERN



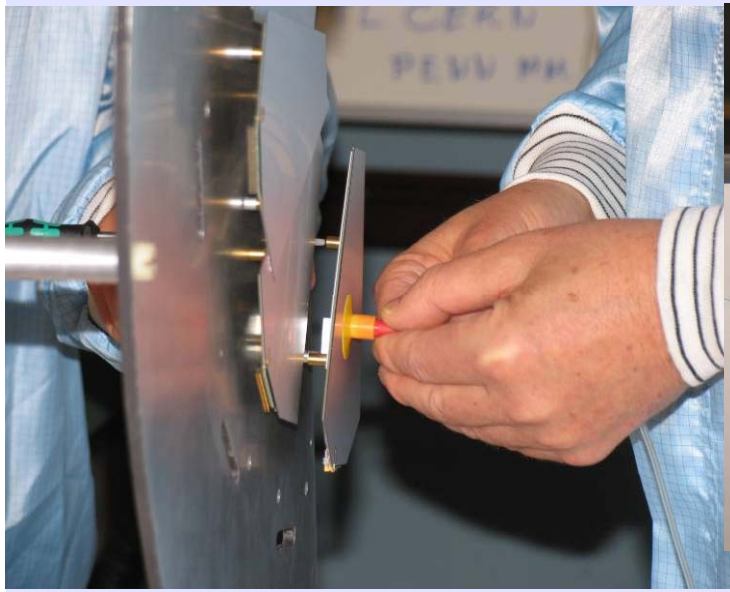
Test beam at Astrid ring

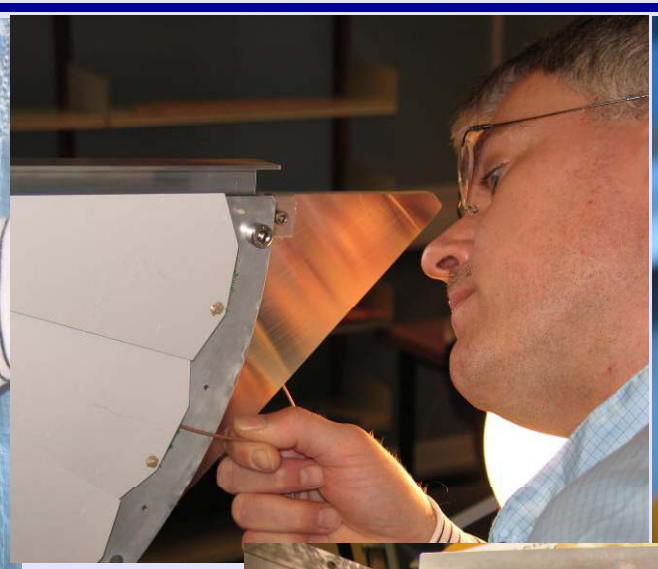


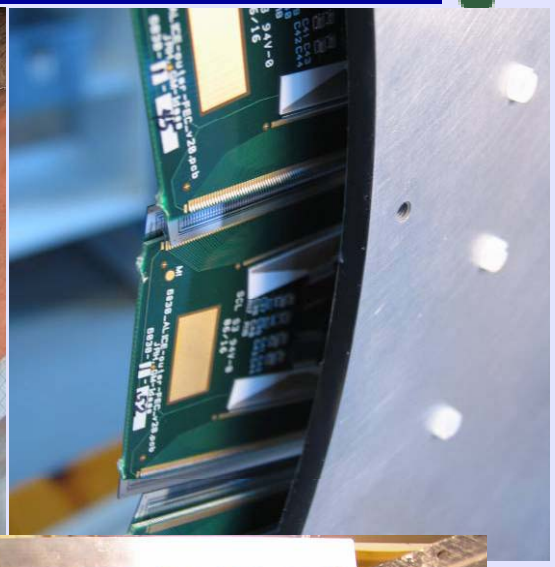
Beam test with
5 complete modules
(equivalent to a full inner half-ring)

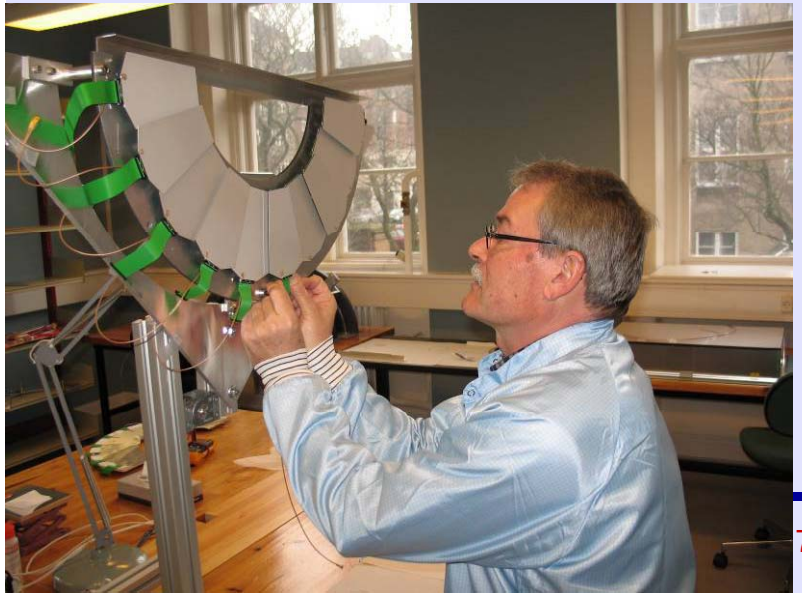
Complete read-out chain used

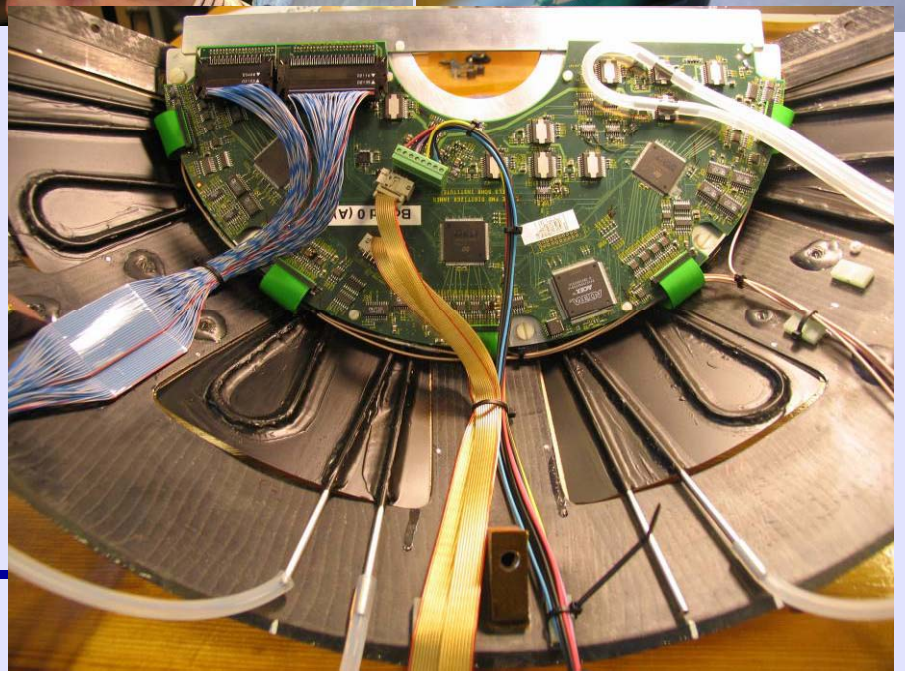
Assembly of FMD3 cone and FMD2 at NBI



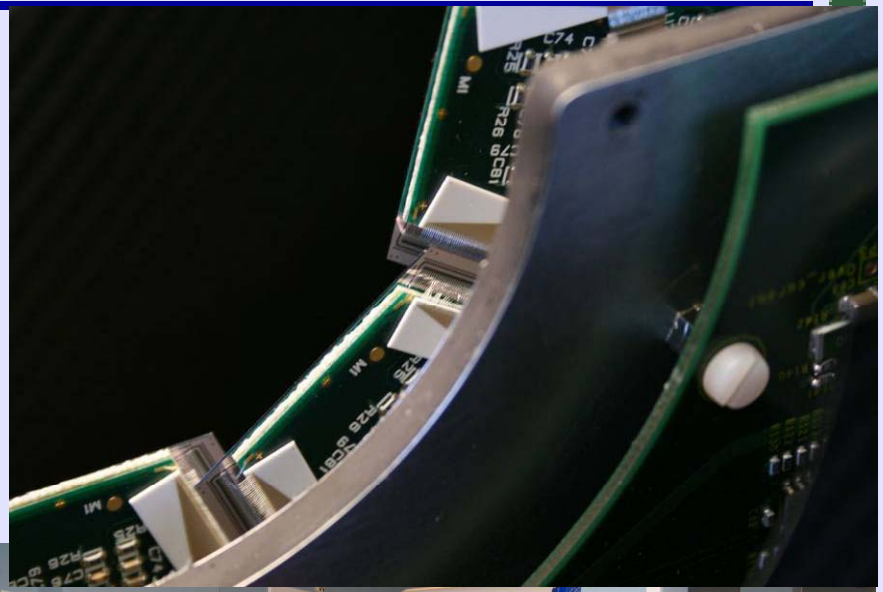




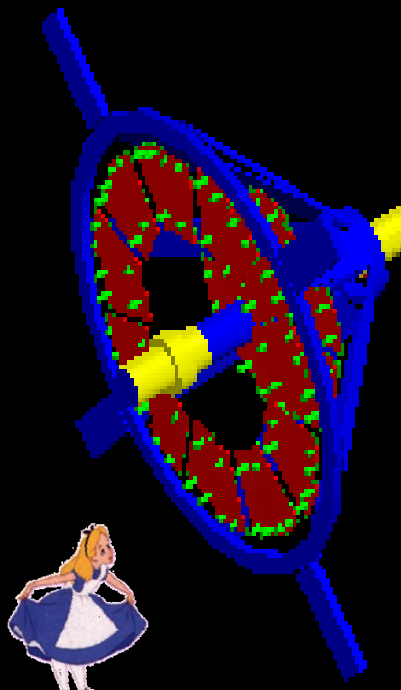




Assembly of FMD3 cone and FMD2 at NBI



ALICE FMD rejsegilde



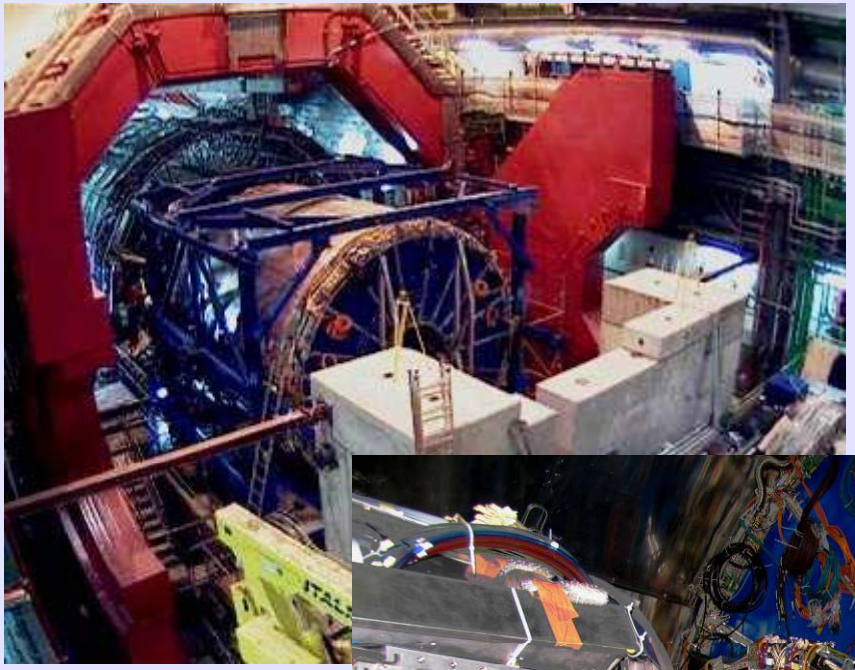
Invitation til reception
torsdag den 1. marts
kl 15:00 i Ma-14

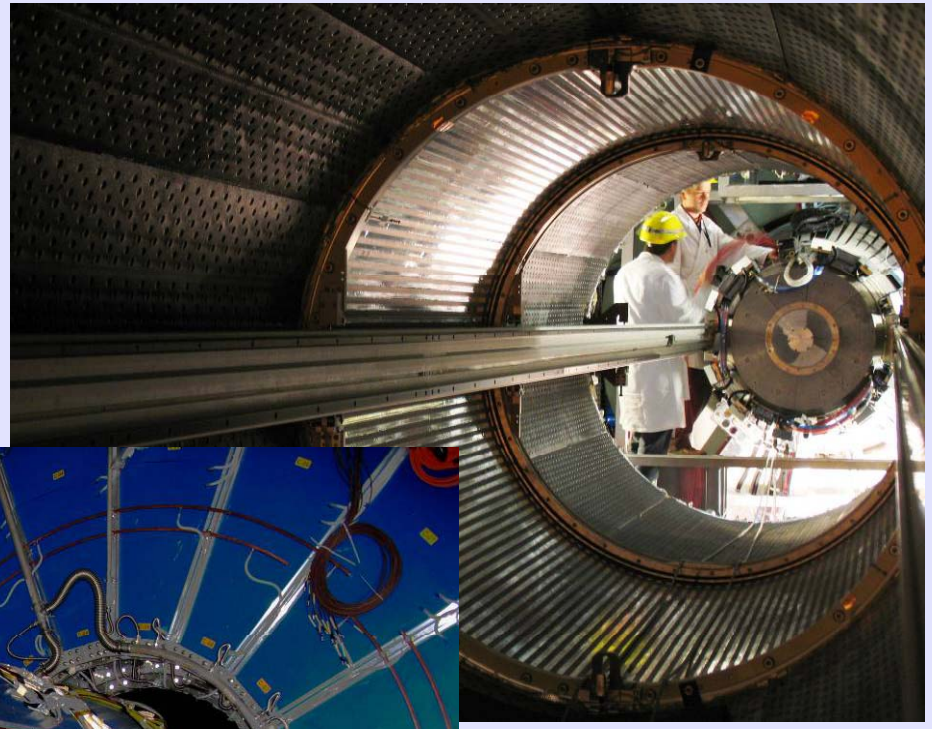
i anledning af afslutningen på konstruktionen af vores silicium detector og dens snarlige afsendelse til CERN

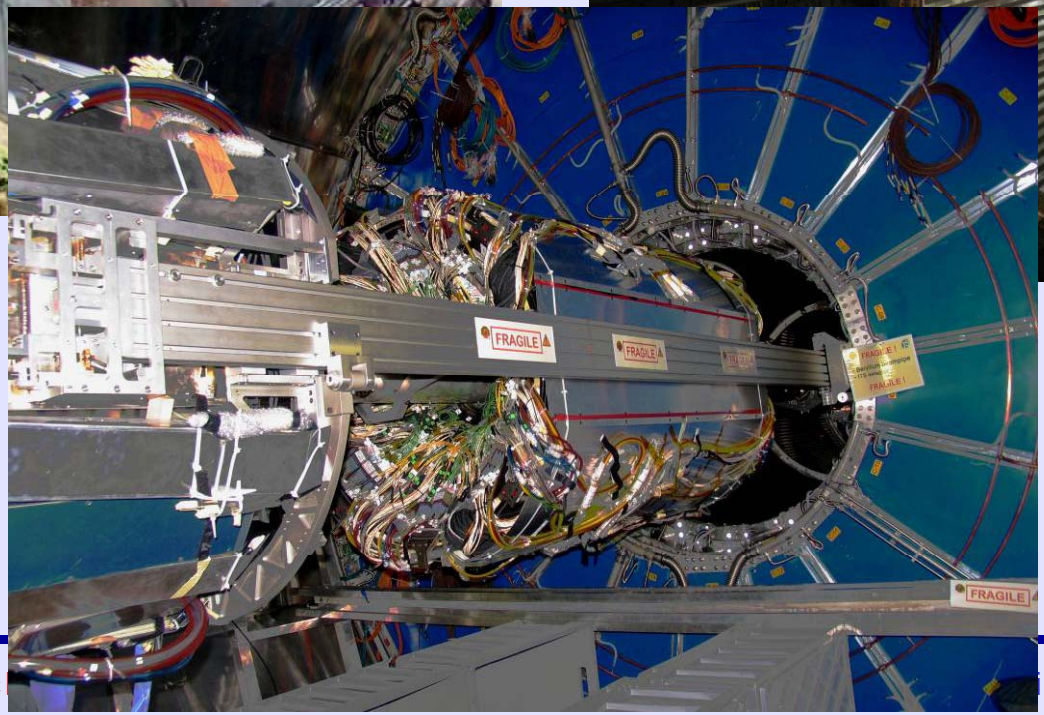
Jens Jørgen og Børge

Moving to CERN

Installation of FMD3 in ALICE







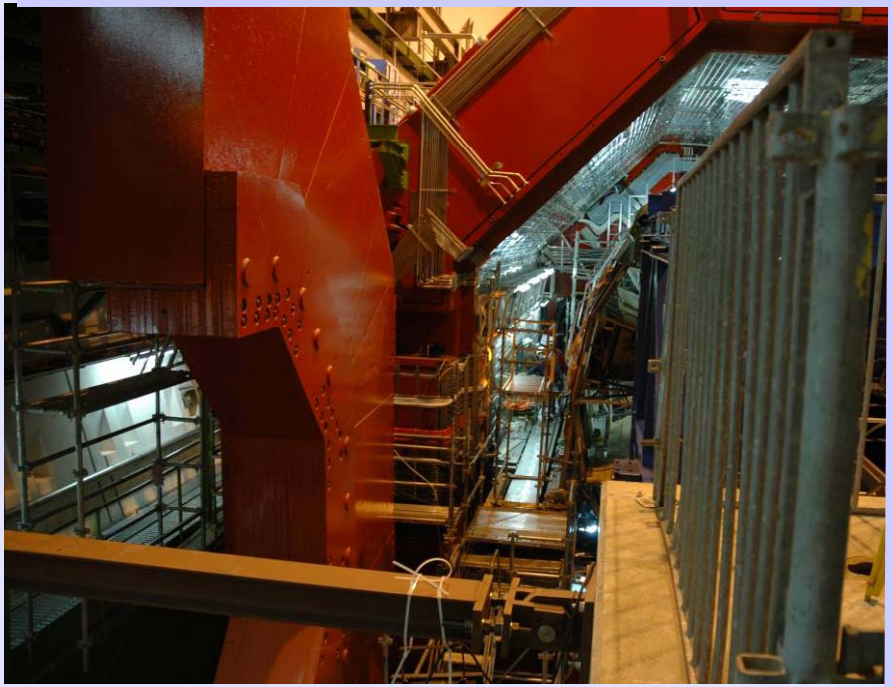
ALICE seen from outside

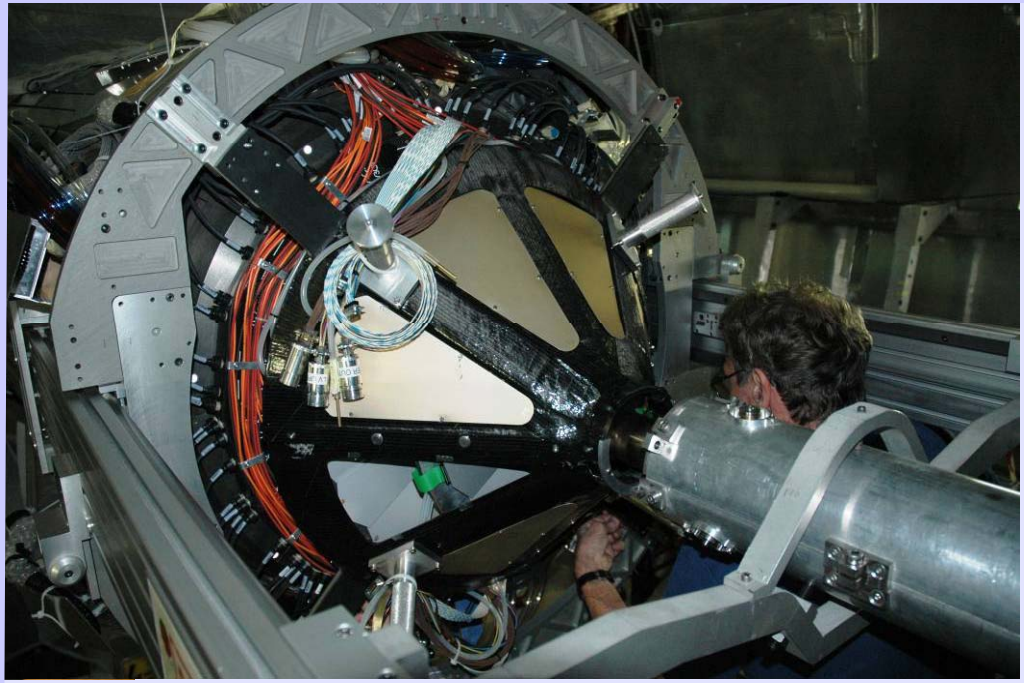
and inside

Installation of FMD3 in ALICE

FMD3 day =

Friday,
13. April 07





FMD in ALICE

FMD3 installed and ready

FMD2 to be installed 24 June,
FMD1 still to be constructed,
… and still lots of cabling and testing
before first beam next summer …


Let's go visit