L'Universo primordiale: la produzione del Quark Gluon Plasma in ALICE-LHC

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Laboratori Nazionali di Frascati

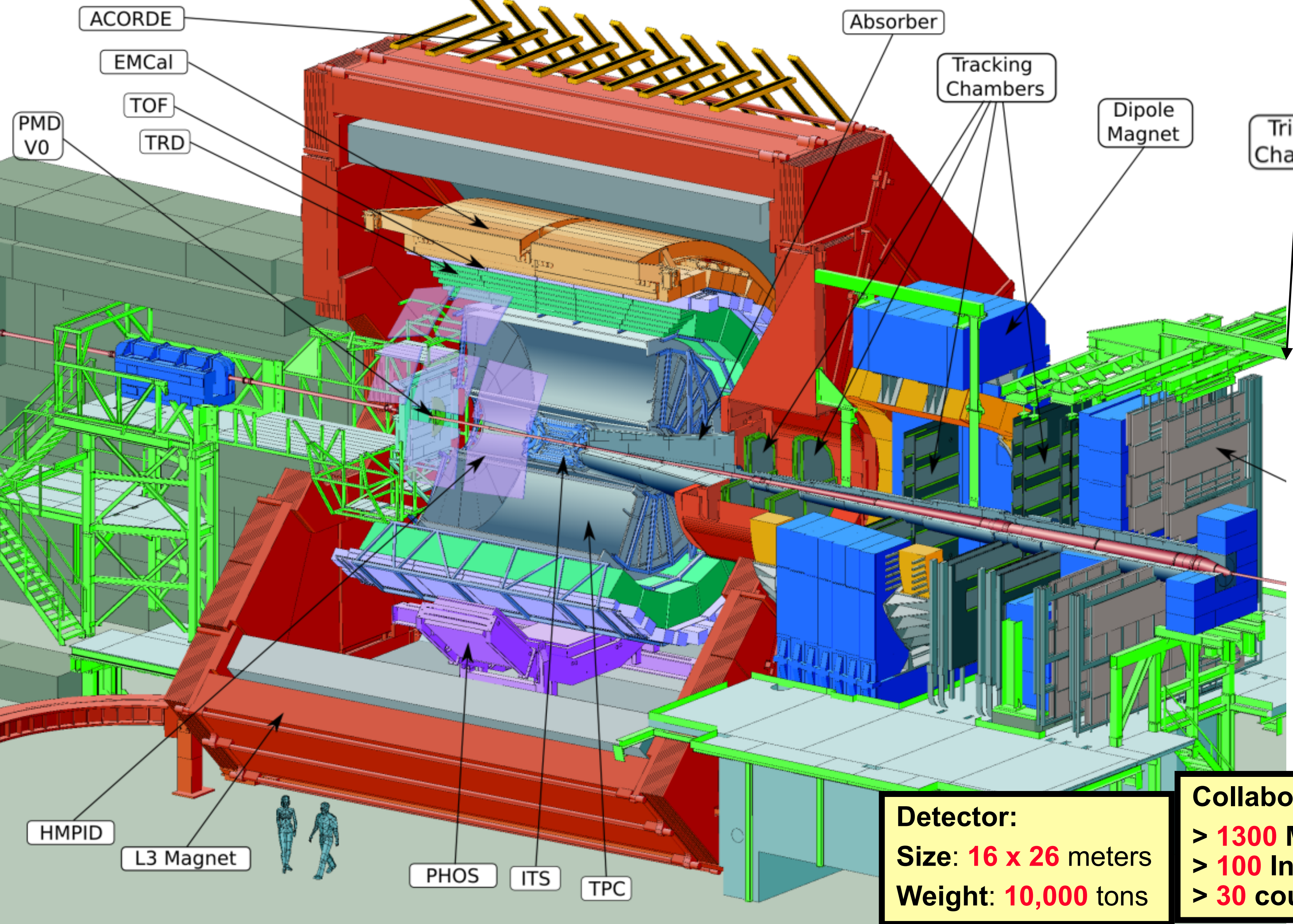
International Particle
Physics Outreach Group

11th International Masterclasses
hands on Particle Physics

INTERNATIONAL MASTERCLASSES
hands on particle physics

A Large Ion Collider Experiment

European Organisation for Nuclear Research


ACORDE
EMCal
TOF
PMD
V0
TRD
Absorber
Tracking Chambers
Dipole Magnet
Trigger Chamber
HMPID
L3 Magnet
PHOS
ITS
TPC

Detector:

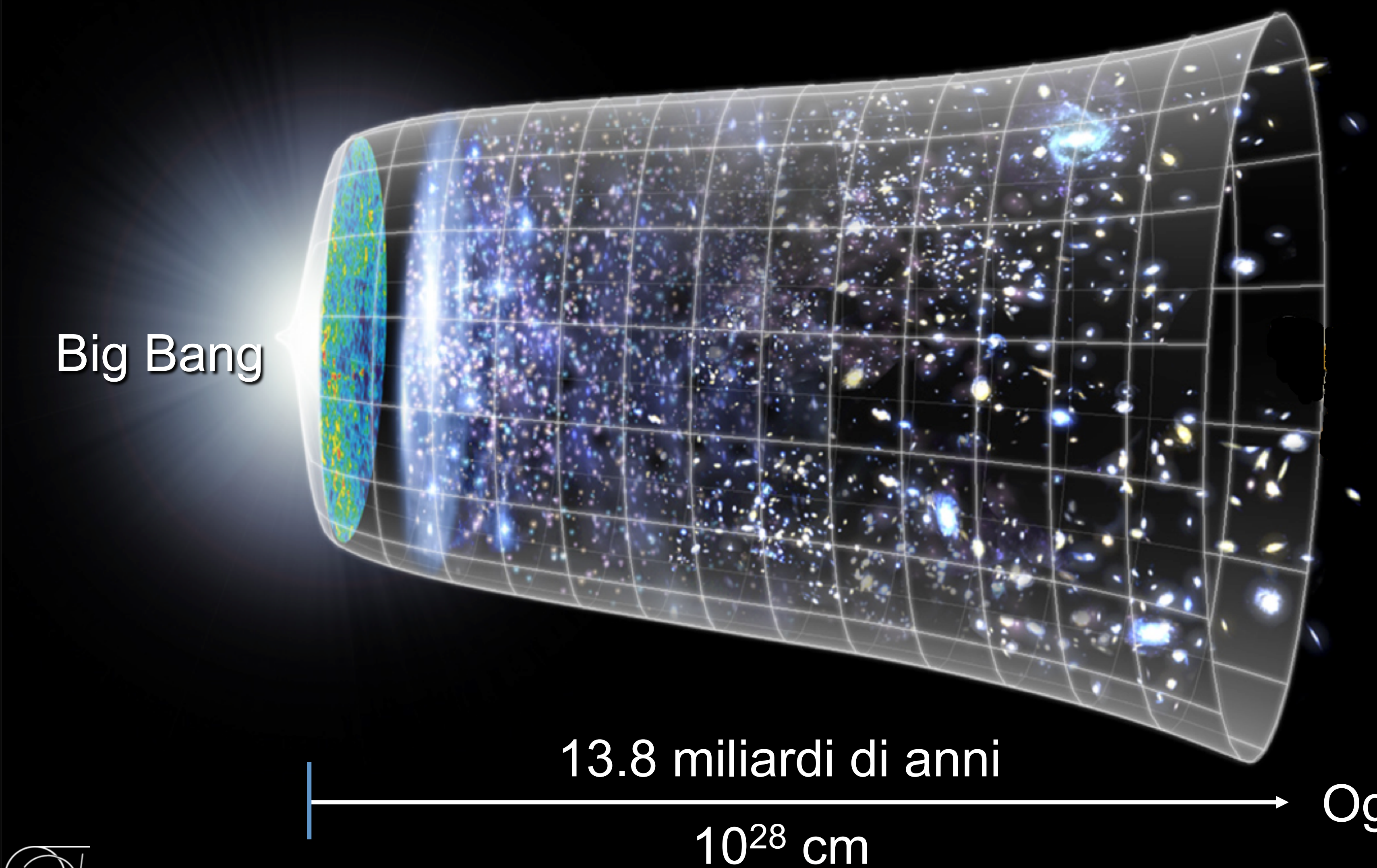
Size: 16 x 26 meters

Weight: 10,000 tons

Collaboration:

- **> 1300 Members**
- **> 100 Institutes**
- **> 30 countries**

Comprendere i primissimi istanti di vita del nostro Universo dopo il Big Bang



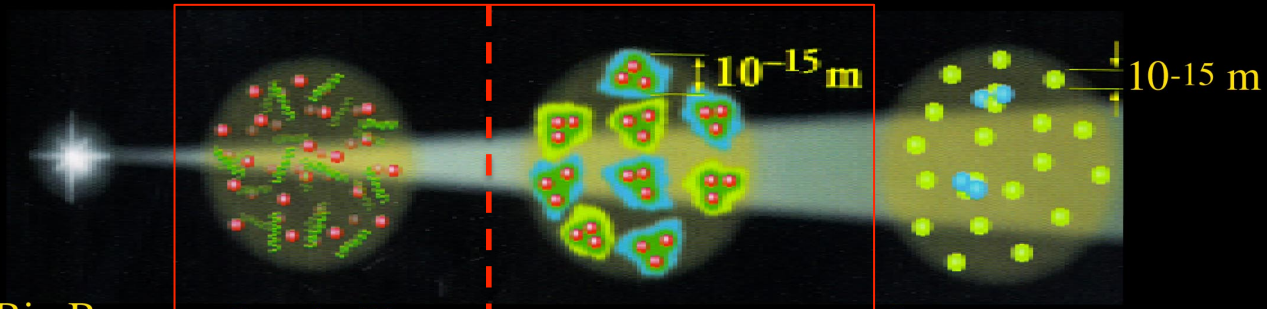
Big Bang

13.8 miliardi di anni

Oggi

10^{28} cm

History of the Universe

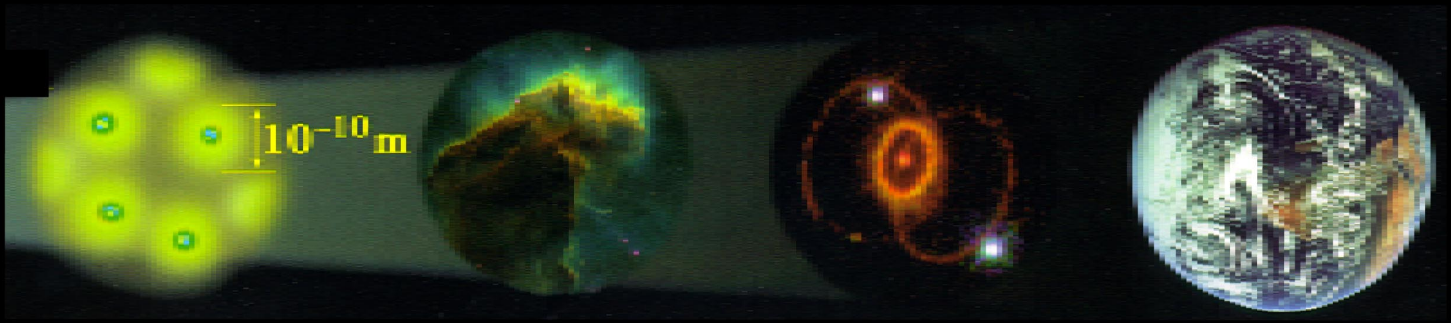


Big Bang

Quark-Gluon
Plasma
10^{13}K, 10^{-6}s

Protons&
Neutrons
10^{12}K, 10^{-4}s

Low-mass
Nuclei
10^{9}K, 3 min



Neutral
Atoms
4000K, 10^{5}y

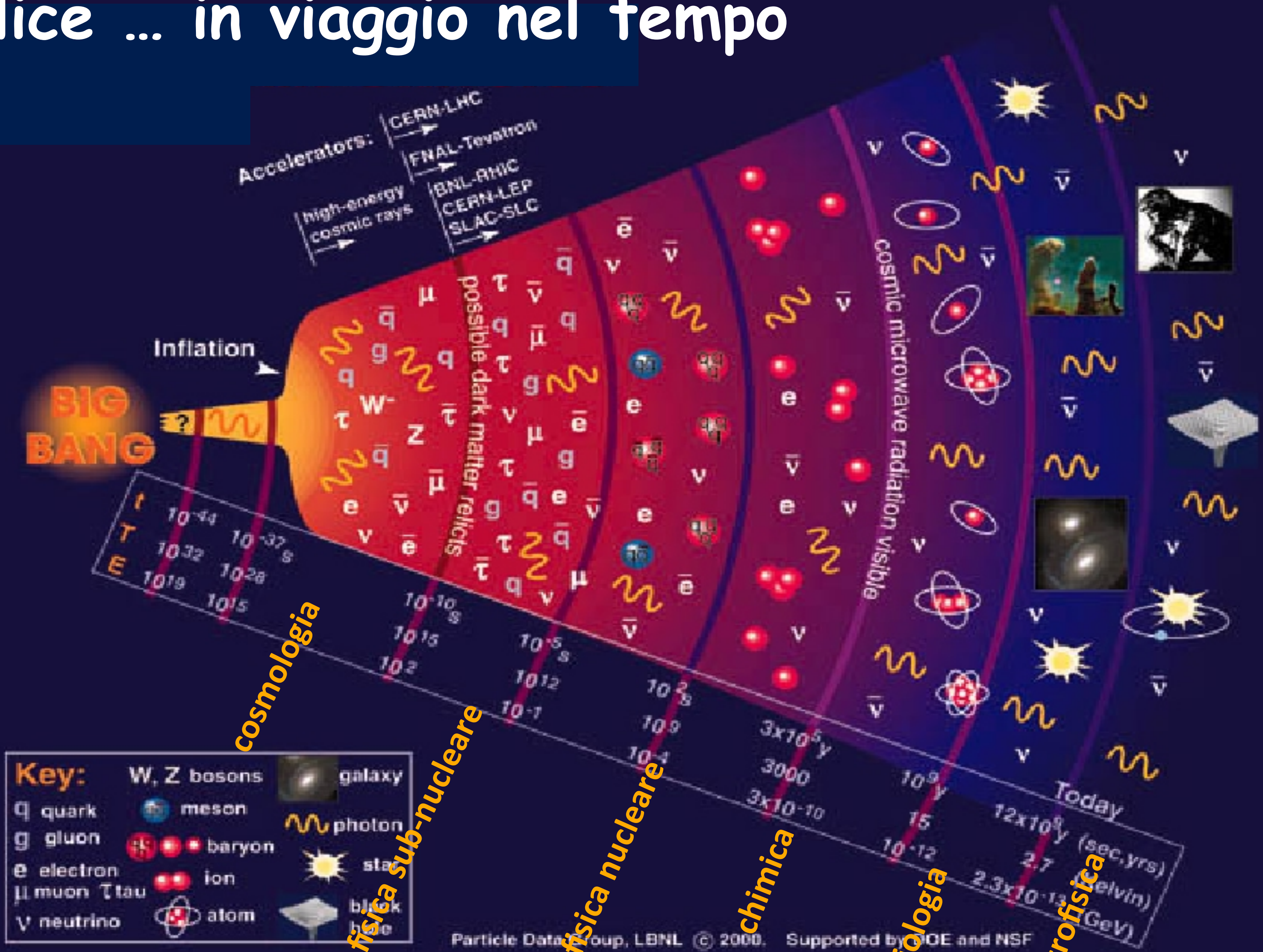
Star
Formation
10^{9}y

Heavy
Elements
>10^{9}y

Today

Source: Nuclear Science Wall Chart

Alice … in viaggio nel tempo


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
t
T
E
10^{-44}
10^{32}
10^{19}
10^{-37} s
10^{28}
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}
Today
$12x10^{9}$ y (sec,yrs)
2.7 (Kelvin)
$2.3x10^{-13}$ (GeV)
Key:
q quark
g gluon
e electron
μ muon τ tau
ν neutrino
W, Z bosons
meson
baryon
ion
atom
galaxy
photon
star
black hole

Particle Data Group, LBNL © 2000. Supported by DOE and NSF

cosmologia

fisica sub-nucleare

fisica nucleare

chimica

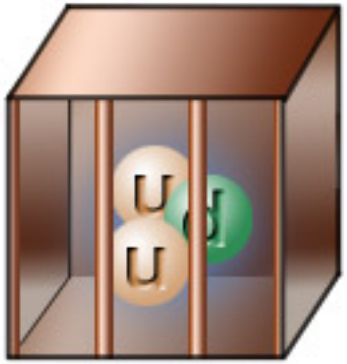
biologia

astrofisica

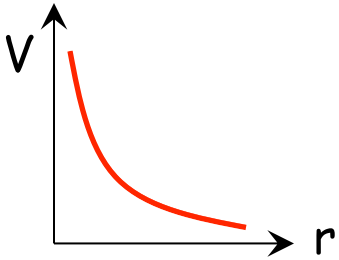
Fino a circa un centomillesimo di secondo dal Big Bang (10^{-37} - 10^{-5} s) l'Universo era formato da una "zuppa" di quark e gluoni … il Quark Gluon Plasma (QGP)

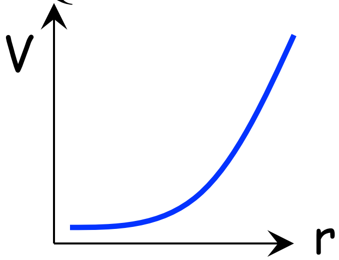
- Perchè studiare il QGP?
- Quali sono le caratteristiche del QGP?
- E' possibile riprodurlo in laboratorio?

Libertà Asintotica → Confinamento



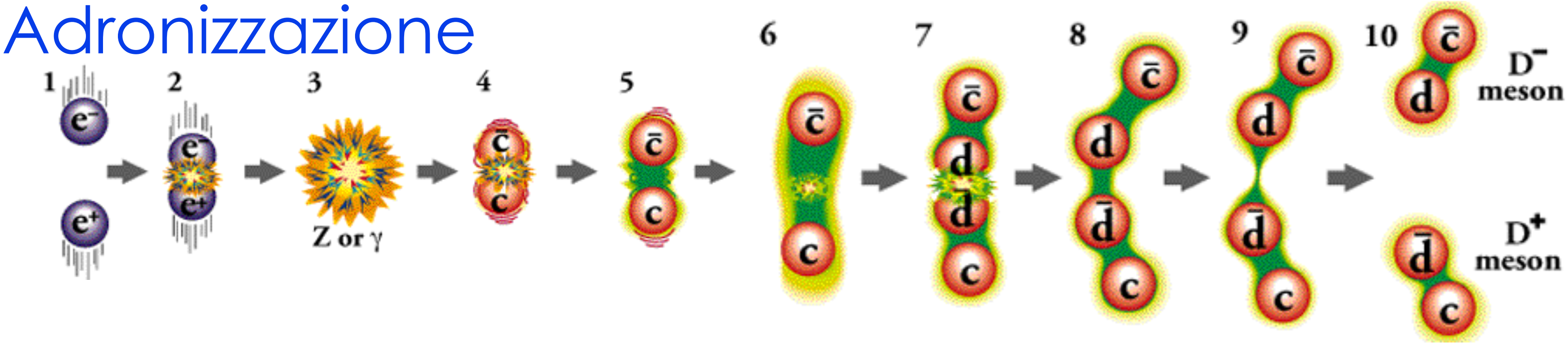
$$V_{Coulomb} \propto \frac{q_1 q_2}{r} \Rightarrow V_{QCD} \propto e^{k\cdot r}$$



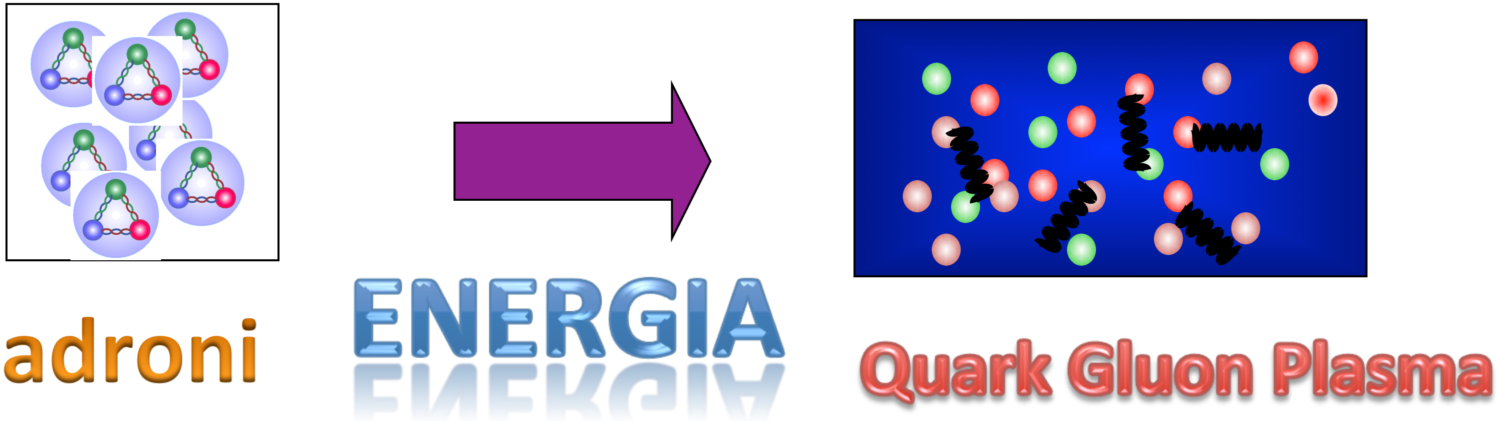


Allontanando i quark, si crea una tensione con energia sufficiente a creare altre particelle (1000 MeV / fm)

Adronizzazione


1
2
3
4
5
6
7
8
9
10
e⁻
e⁺
Z or γ
c̄
c
d
d̄
D⁻ meson
D⁺ meson

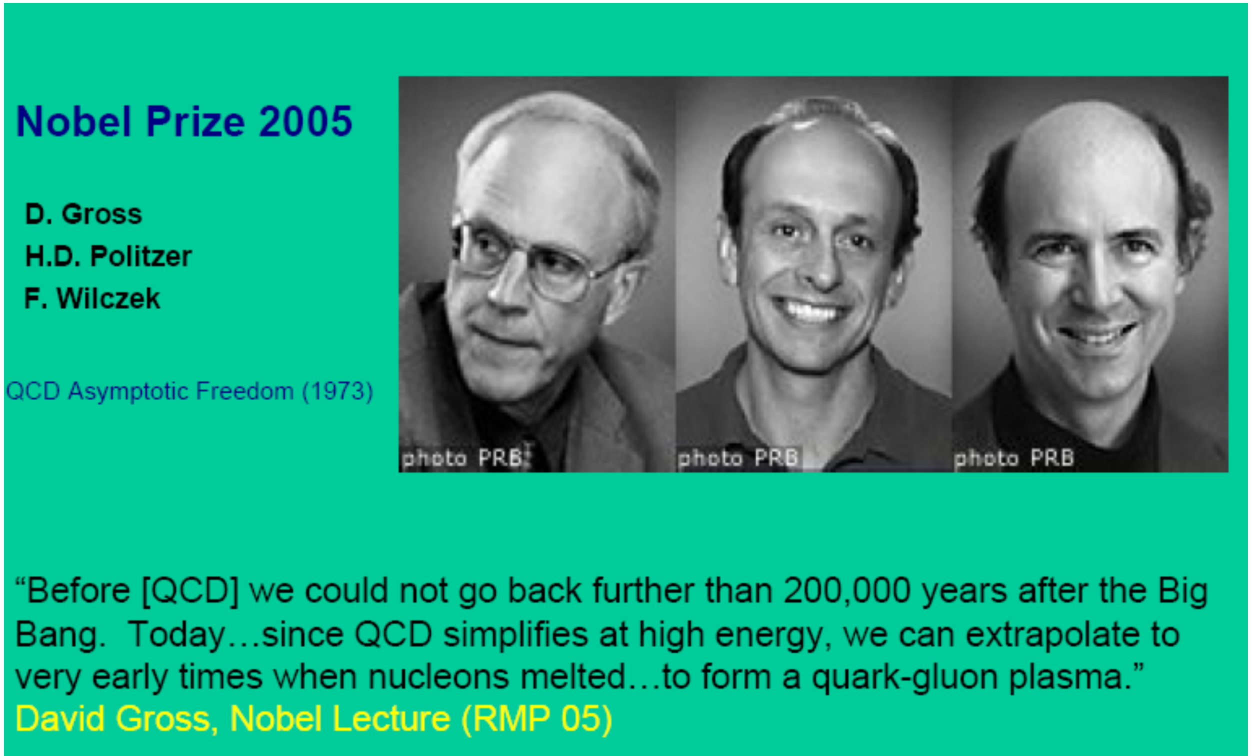
Bisogna creare un sistema che abbia una densità enorme (ptc a distanza infinitesima) tale da rendere trascurabile l’interazione forte



adroni

ENERGIA

Quark Gluon Plasma



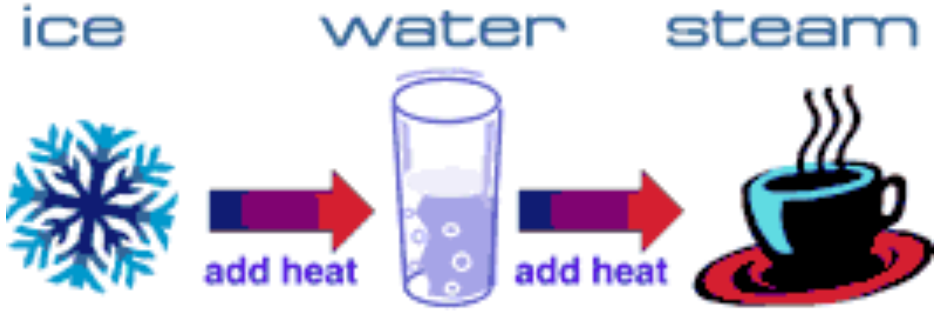
Nobel Prize 2005

D. Gross
H.D. Politzer
F. Wilczek

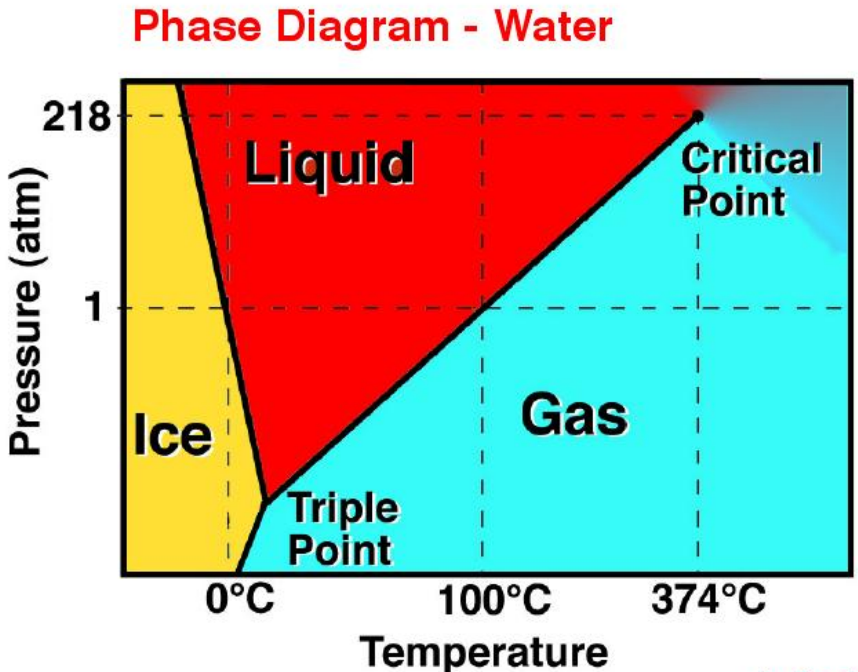
QCD Asymptotic Freedom (1973)

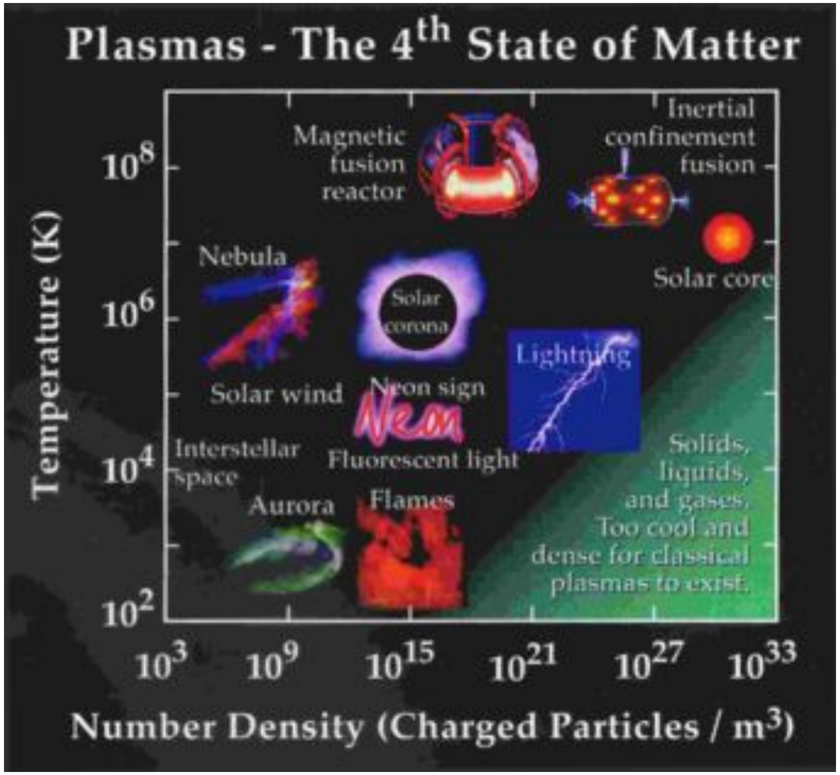
“Before [QCD] we could not go back further than 200,000 years after the Big Bang. Today…since QCD simplifies at high energy, we can extrapolate to very early times when nucleons melted…to form a quark-gluon plasma.”
David Gross, Nobel Lecture (RMP 05)

Fasi della materia "normale"


ice
water
steam
add heat
add heat

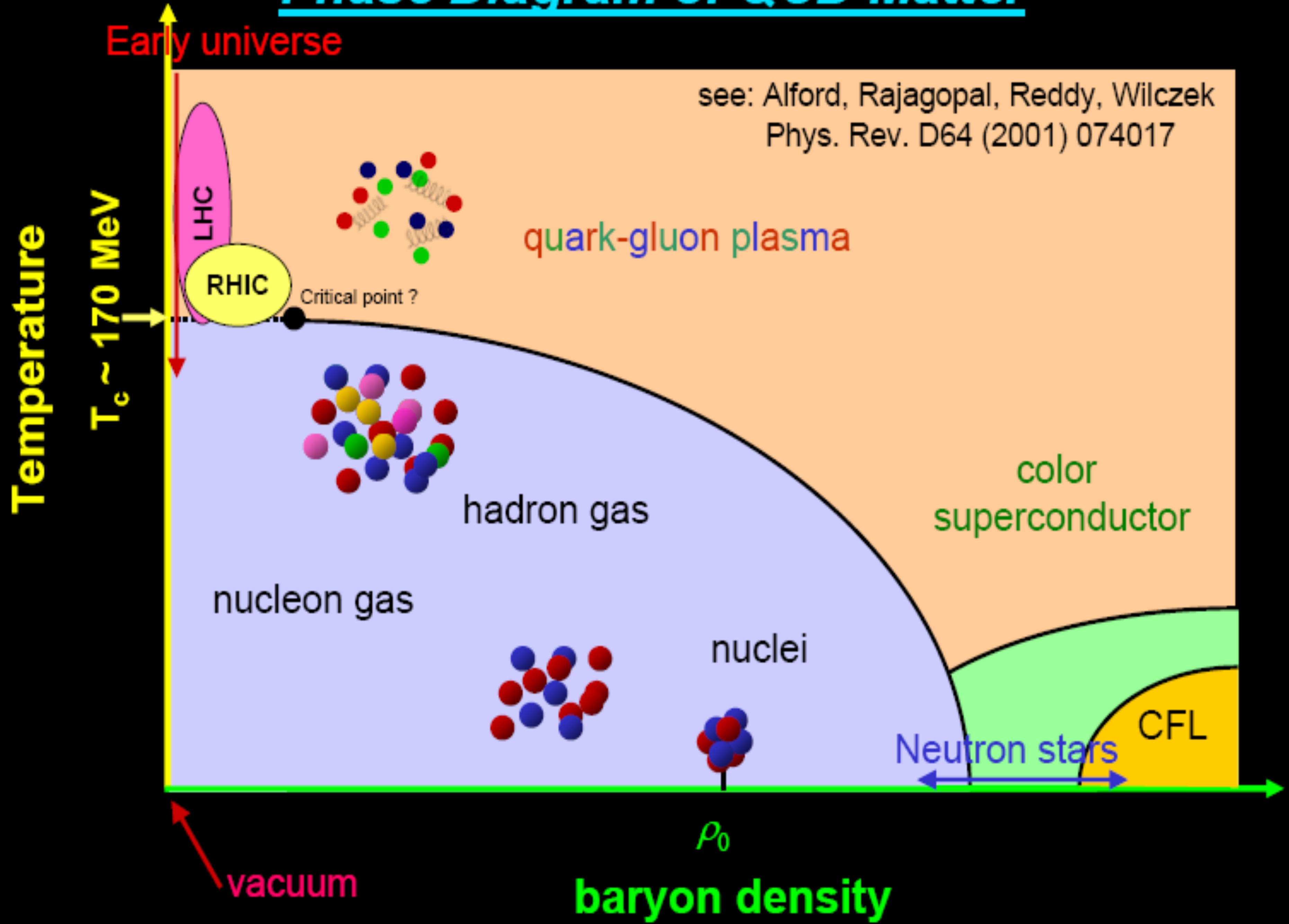
solido liquido gassoso





Plasma Classico

Phase Diagram of QCD Matter


Early universe
see: Alford, Rajagopal, Reddy, Wilczek
Phys. Rev. D64 (2001) 074017
LHC
RHIC
Critical point ?
quark-gluon plasma
Temperature
$T_c \sim 170$ MeV
hadron gas
color
superconductor
nucleon gas
nuclei
CFL
Neutron stars
ρ_0
vacuum
baryon density

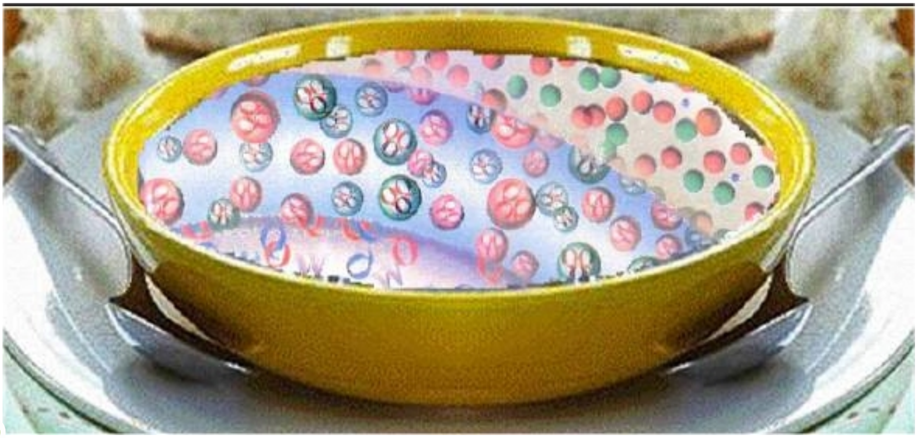
Una "zuppa" ricca di informazioni

Evoluzione spazio-temporale della nascita di un adrone

Proprietà della QCD ad alte temperature: gradi di libertà, viscosità, conduttività, …

Flusso ellittico

Restaurazione della simmetria chirale



Freezout

Puzzle barionico

Instabilità di plasma, caos di colore

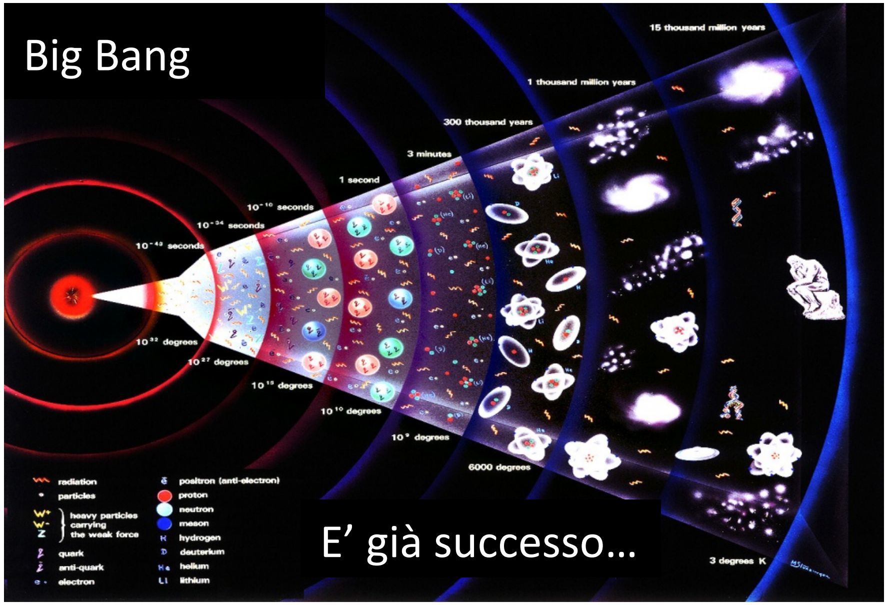
Transizione di fase q-g nelle teorie cosmologiche dell'Universo primordiale

Equazione di stato della QCD

Perdita di energia partonica

Composizione chimica

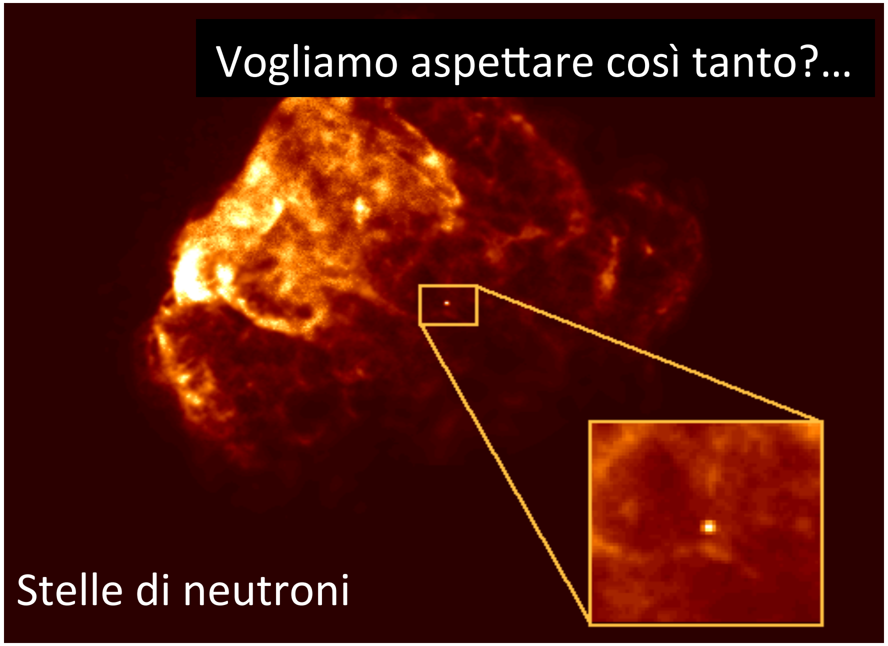
Dove si produce il QGP ?


15 thousand million years
1 thousand million years
300 thousand years
3 minutes
1 second
10^{-10} seconds
10^{-34} seconds
10^{-43} seconds
10^{32} degrees
10^{27} degrees
10^{15} degrees
10^{10} degrees
10^{9} degrees
6000 degrees
3 degrees K
radiation
particles
W+ W- Z heavy particles carrying the weak force
quark
anti-quark
e- electron
ē positron (anti-electron)
proton
neutron
meson
H hydrogen
D deuterium
He helium
Li lithium

Big Bang

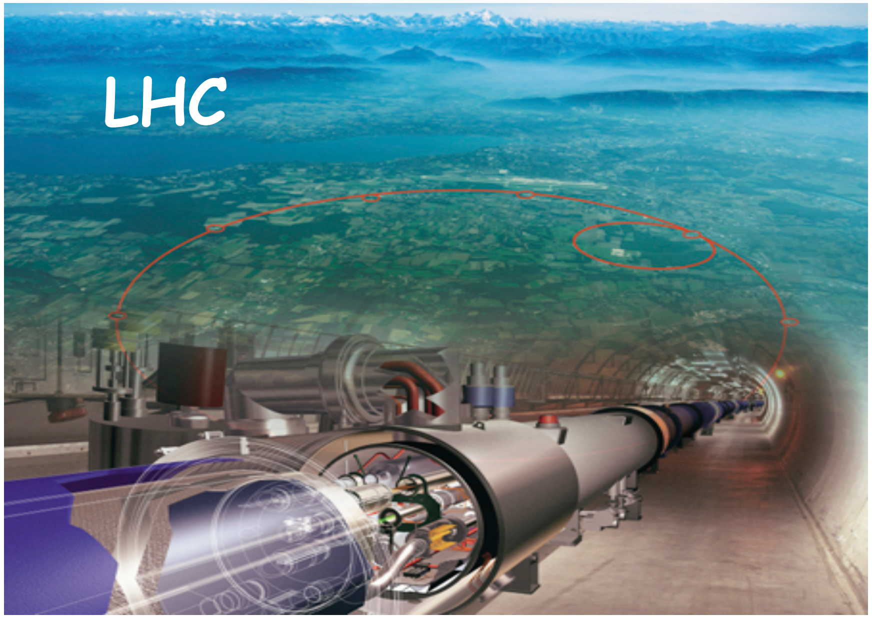
E' già successo…

Lattice QCD



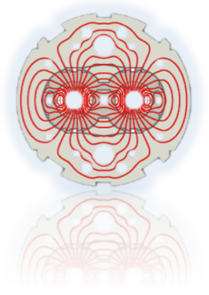
Vogliamo aspettare così tanto?…

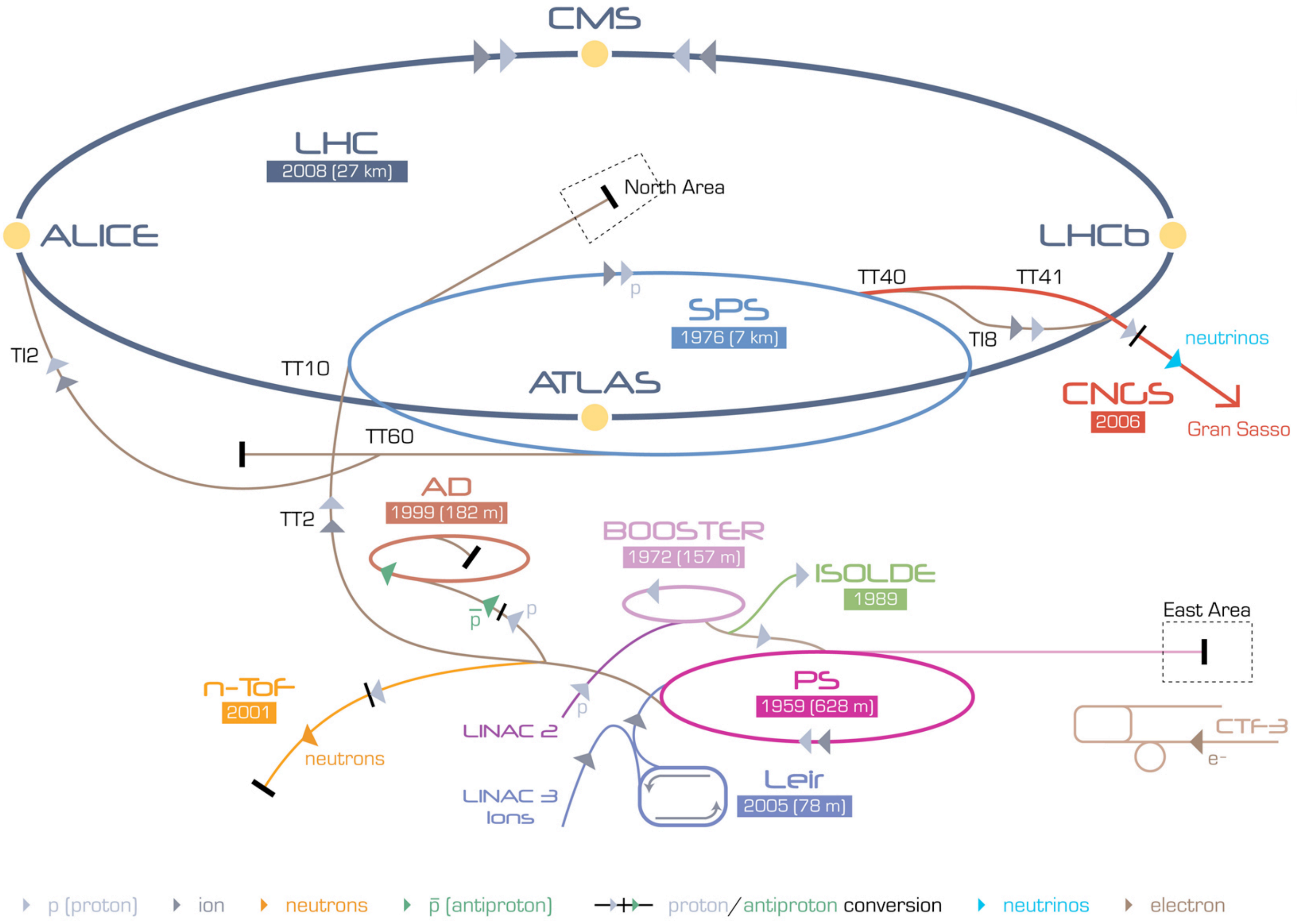
Stelle di neutroni



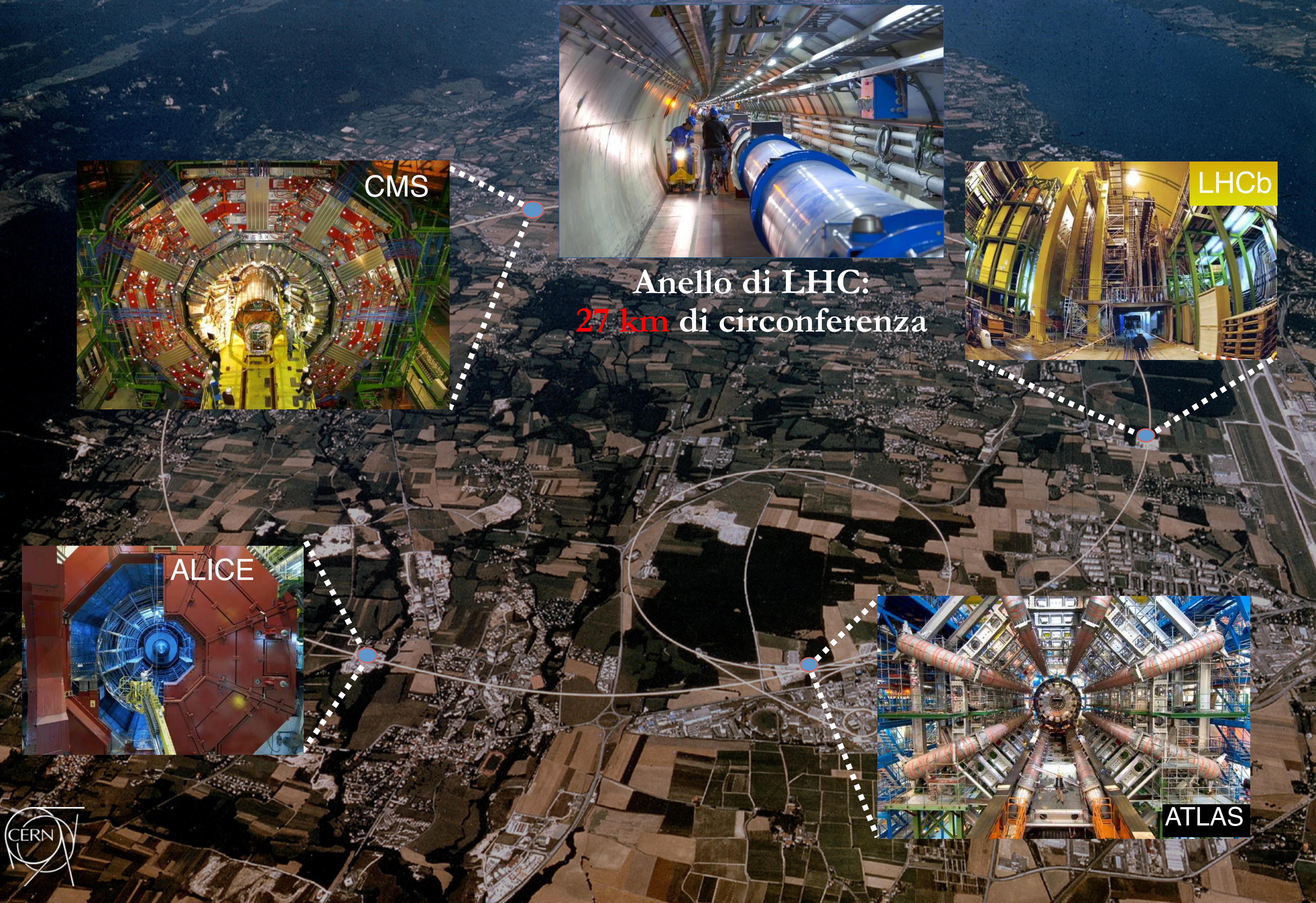
LHC

Complesso degli acceleratori del CERN




CMS
LHC
2008 (27 km)
North Area
ALICE
LHCb
TT40
TT41
p
SPS
1976 (7 km)
TI8
neutrinos
TI2
TT10
ATLAS
CNGS
2006
Gran Sasso
TT60
AD
1999 (182 m)
TT2
BOOSTER
1972 (157 m)
ISOLDE
1989
p̄
p
East Area
n-ToF
2001
PS
1959 (628 m)
p
LINAC 2
CTF3
e–
neutrons
LINAC 3
Ions
LEIR
2005 (78 m)
p (proton)
ion
neutrons
p̄ (antiproton)
proton/antiproton conversion
neutrinos
electron

LHC, il più potente acceleratore del mondo


CMS
LHCb
ALICE
ATLAS

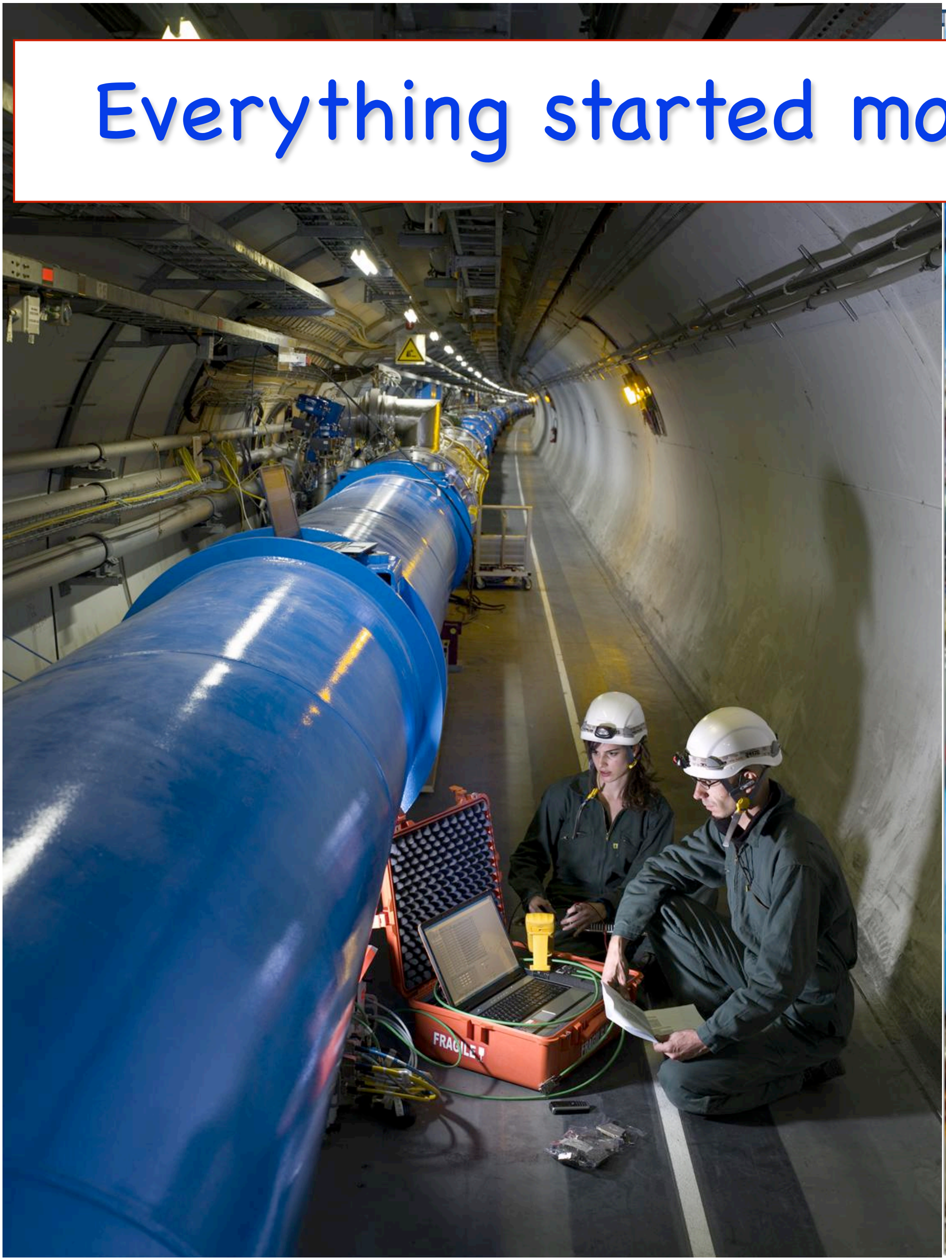
Anello di LHC:
27 km di circonferenza

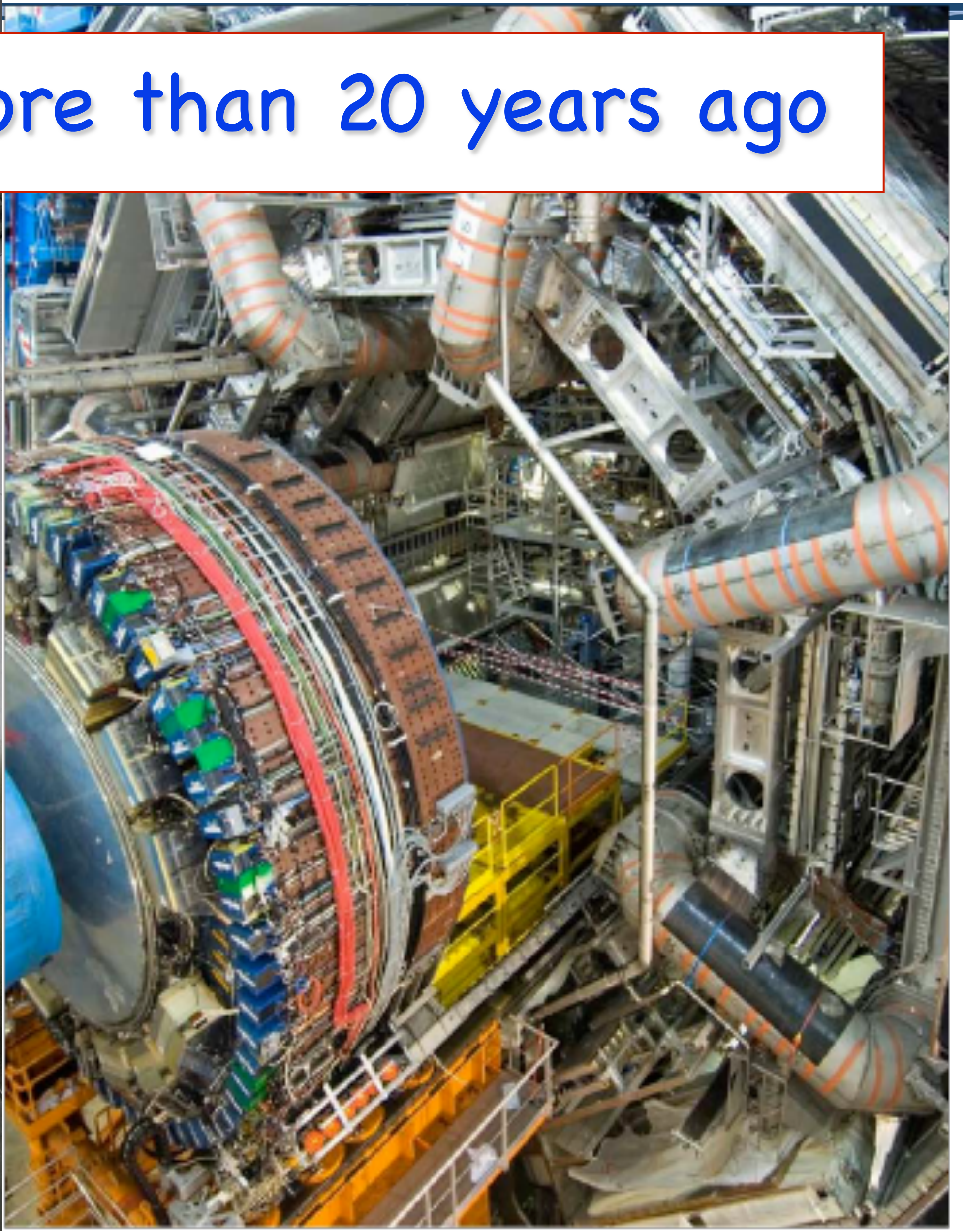
Colliders

LHC at CERN, Geneve 2009

The global adventure

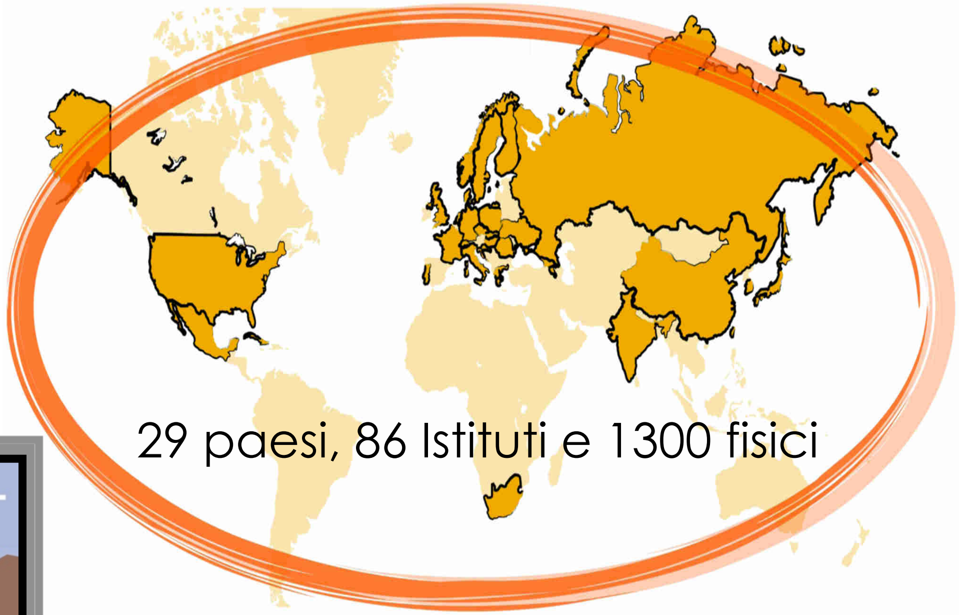
Everything started more than 20 years ago



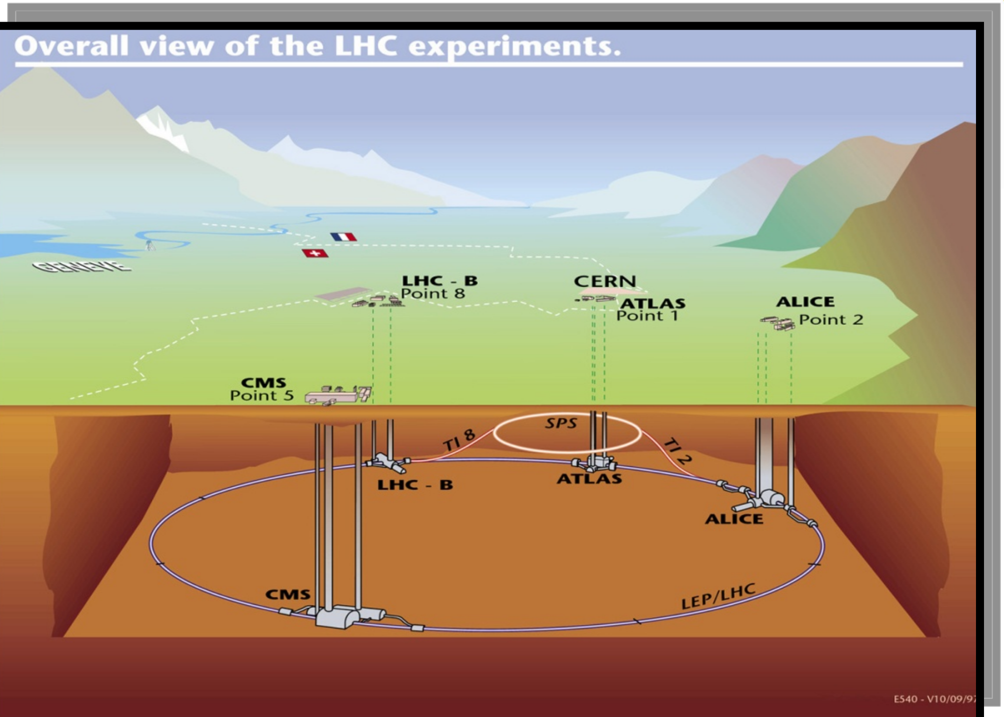


ALICE: A Large Ion Collider Experiment

Alice è l’unico esperimento a LHC dedicato alla fisica con fasci di ioni (5.5 TeV PbPb)



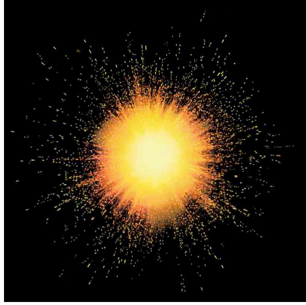
29 paesi, 86 Istituti e 1300 fisici


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
E540 - V10/09/97

INFN
Istituto Nazionale di Fisica Nucleare

200 fisici Italiani: BA, BO, CA, CT, LNF, LNL, PD, RM1, SA, TO, TS

Un Mini-Bang in laboratorio



- Abbiamo bisogno di un “sistema piccolo” tale da poterlo accelerare a velocità ultrarelativistiche (99.9% c)

- Tale sistema (p.es. una quantità microscopica di materia e non una sola particella) deve poter seguire semplici regole termodinamiche e poter formare nuovi stati di materia sotto particolari condizioni

- Possiamo usare “ioni pesanti” (p.es. Pb); sono piccoli abbastanza ($\sim 10^{-14}$ m) ma hanno un volume finito tali da poterli sottoporre a misure/variazione di pressione e temperatura

Proveremo a forzare la materia, attraverso una transizione di fase, a passare in un nuovo stato: il “Quark Gluon Plasma”

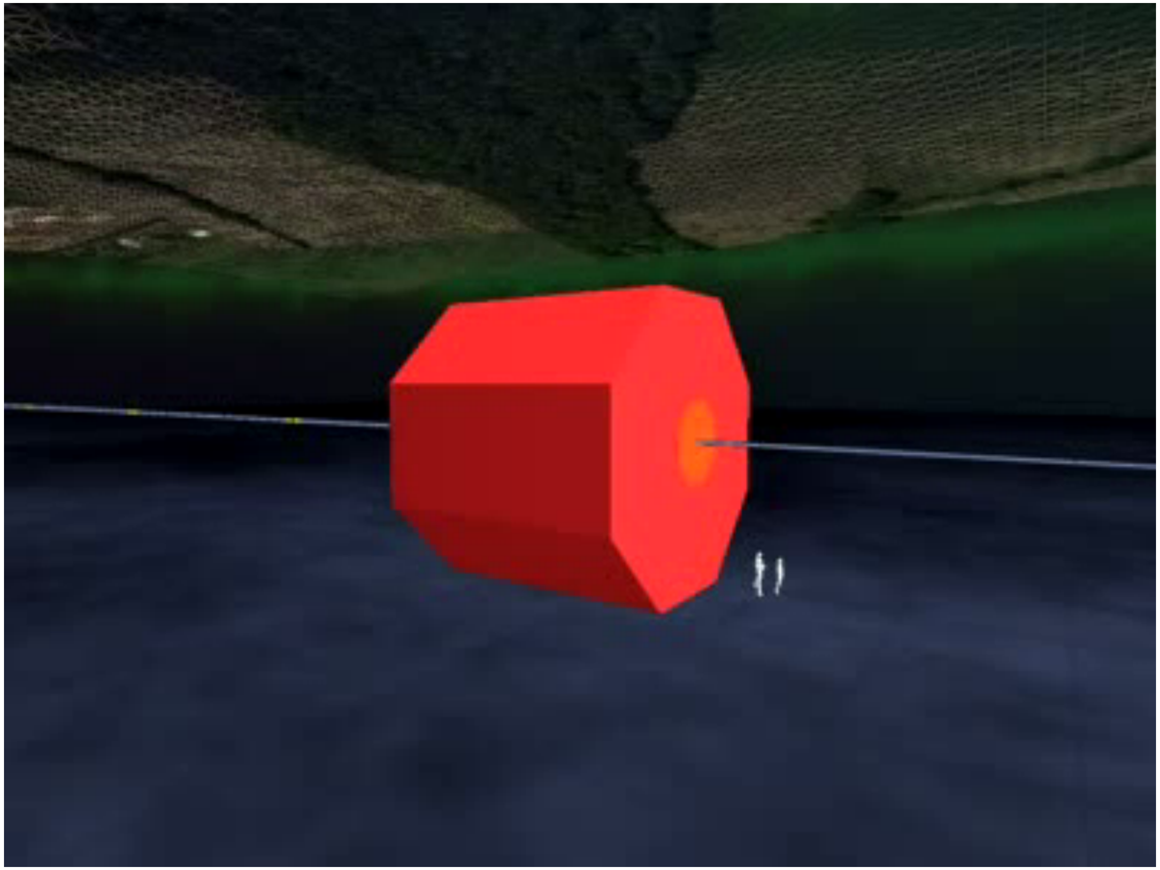
QGP attraverso gli Heavy Ions

2 nuclei di Piombo collidono ad altissima energia creando un sistema ad altissima densità

Pb+Pb E_{cm}=5.5 TeV
t=-19.00 fm/c

H. Weber / UrQMD Frankfurt/M

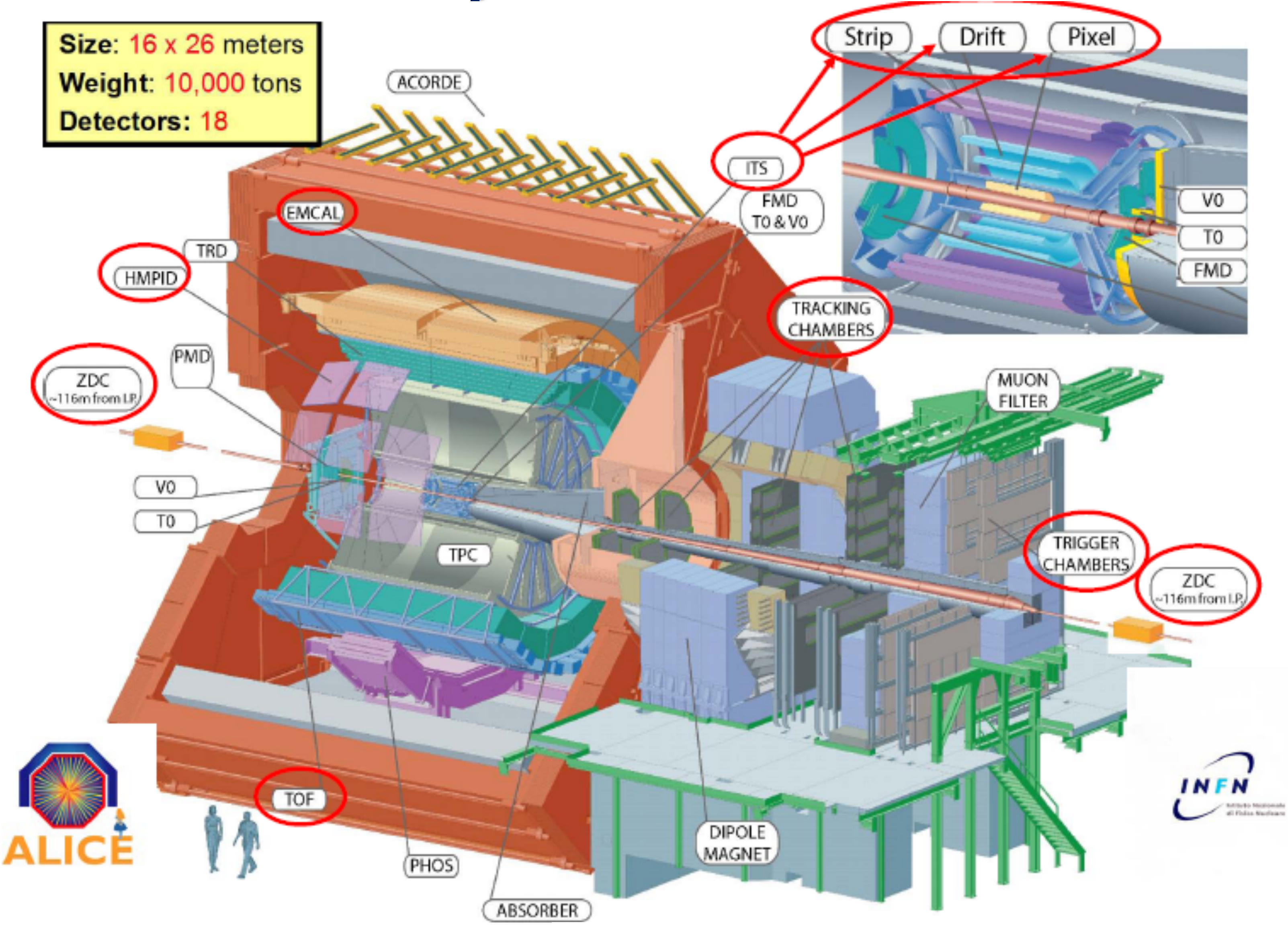
La collisione in Alice



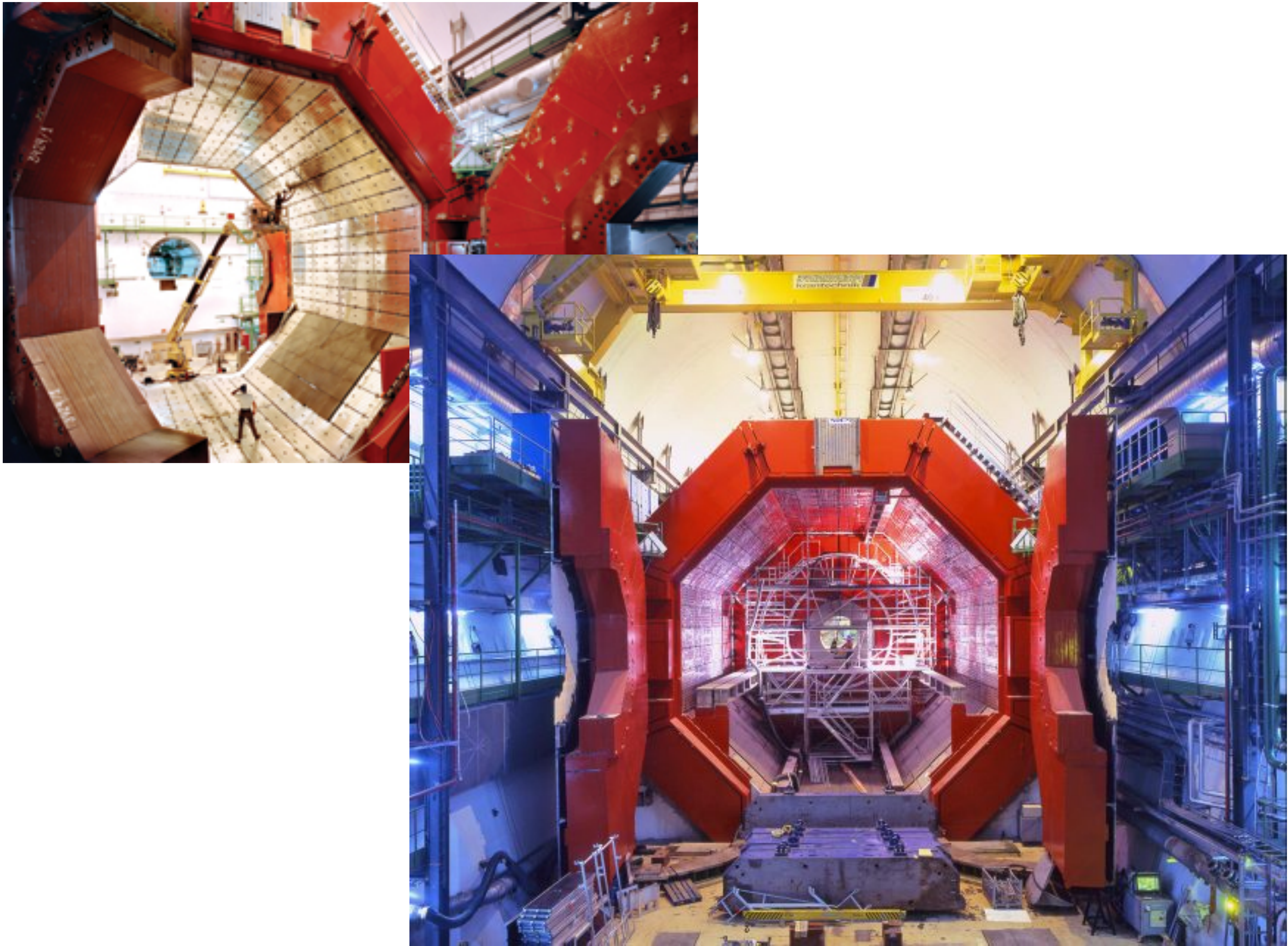
E=mc²
cess of the
PR

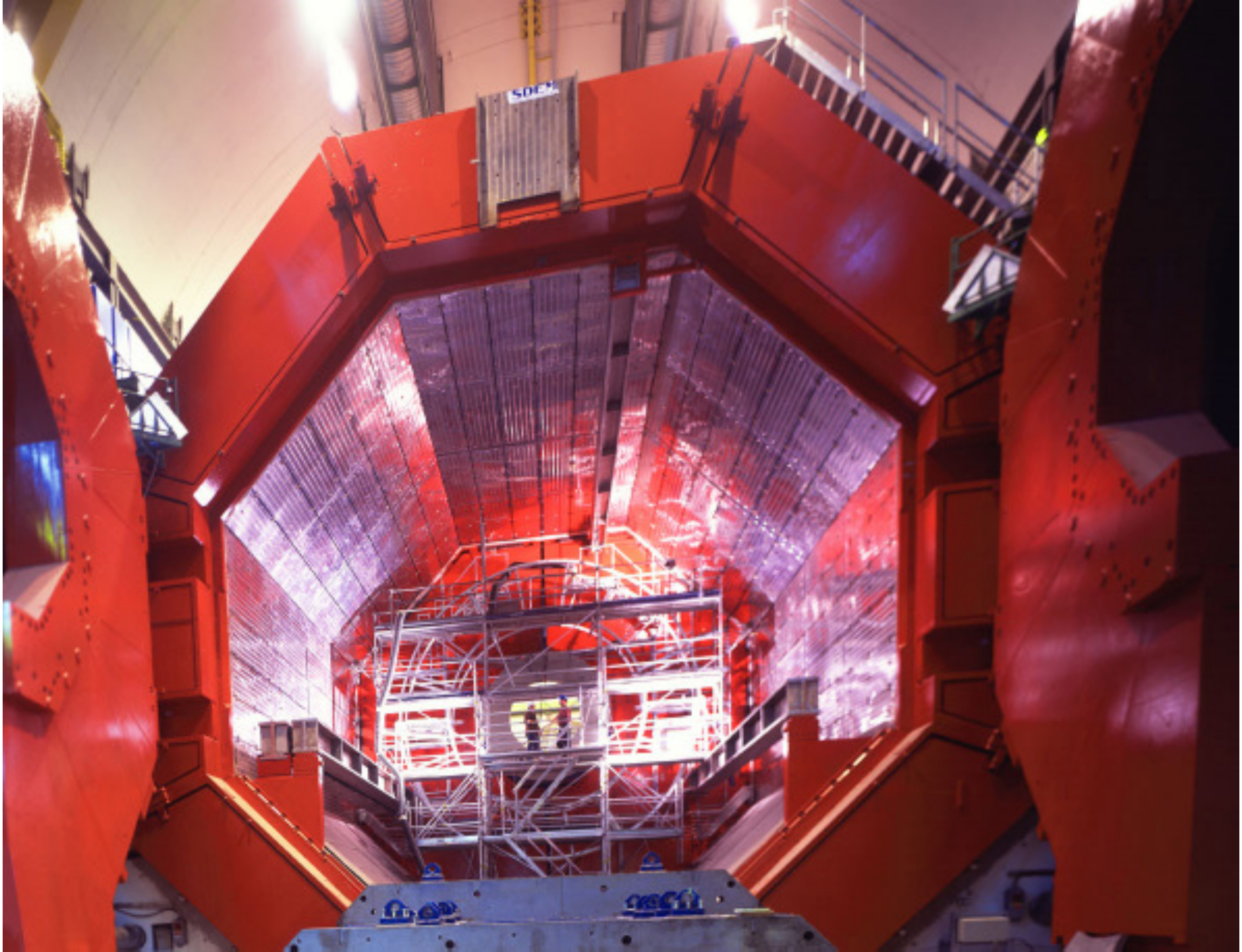
Lo spettrometro

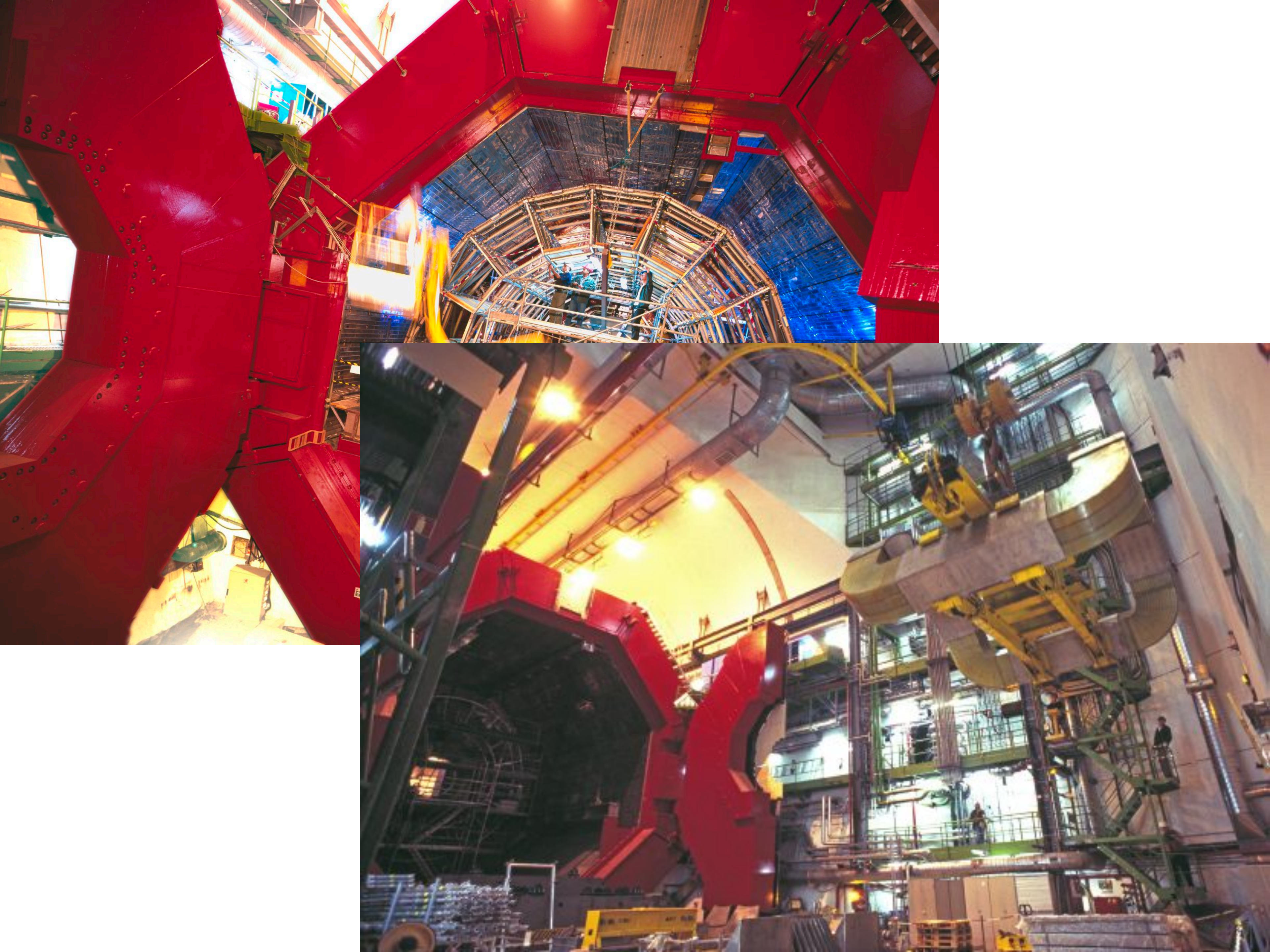
Size: 16 x 26 meters
Weight: 10,000 tons
Detectors: 18

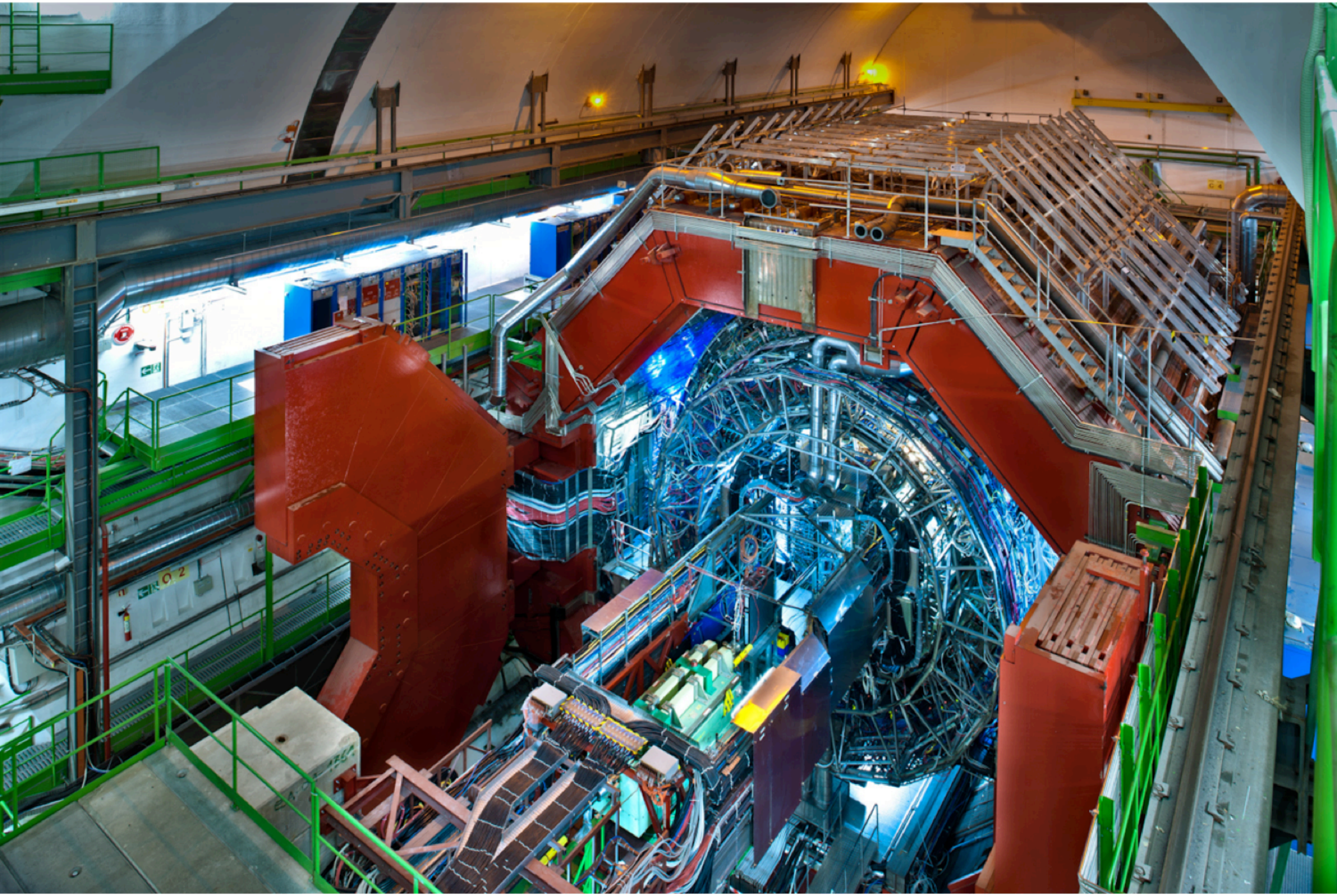

Strip
Drift
Pixel
ACORDE
ITS
FMD
T0 & V0
V0
T0
FMD
EMCAL
TRD
HMPID
TRACKING CHAMBERS
PMD
ZDC
~116m from I.P.
MUON FILTER
V0
T0
TPC
TRIGGER CHAMBERS
ZDC
~116m from I.P.
TOF
DIPOLE MAGNET
PHOS
ABSORBER

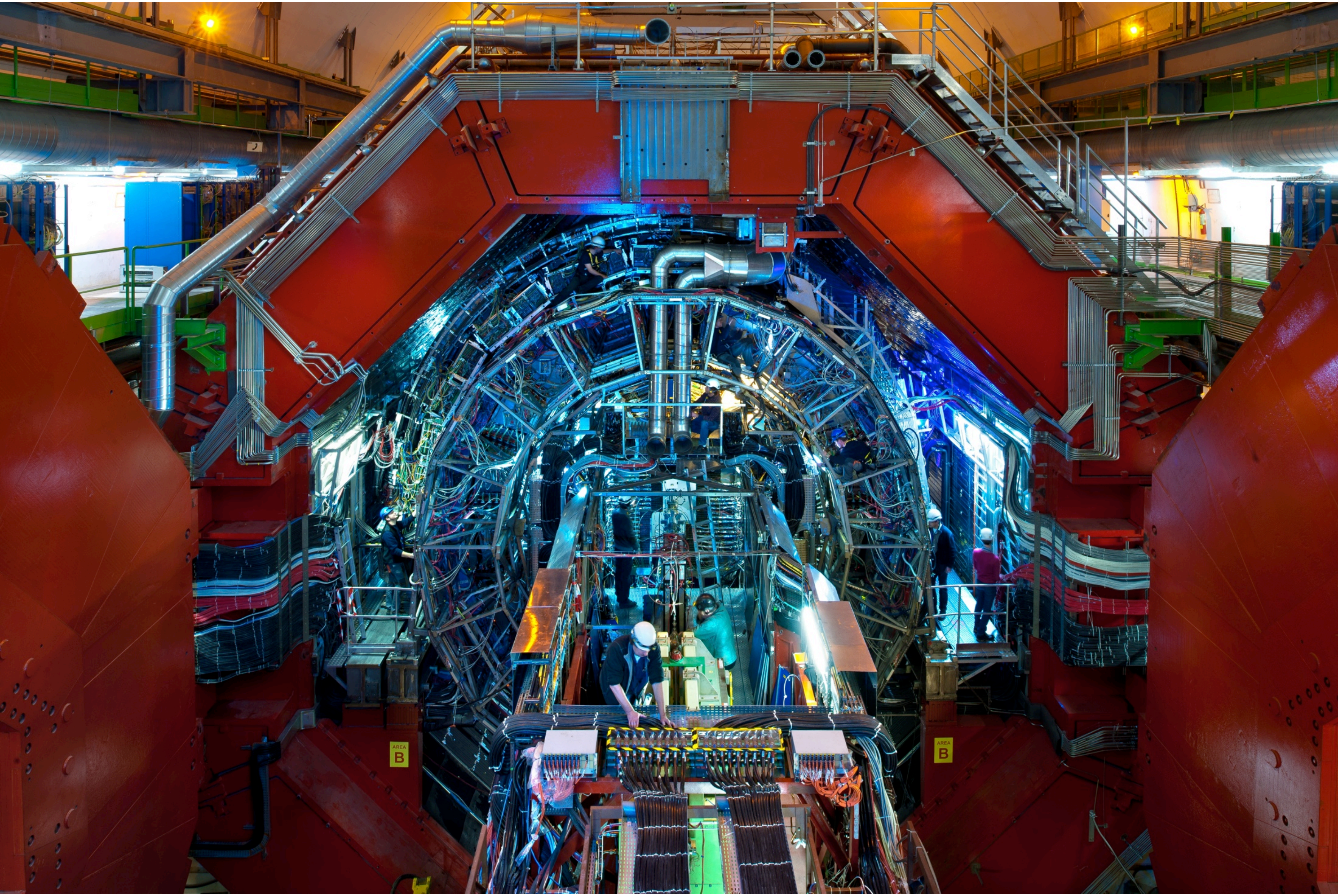
◯ : Rivelatori sotto la completa o parziale responsabilità INFN



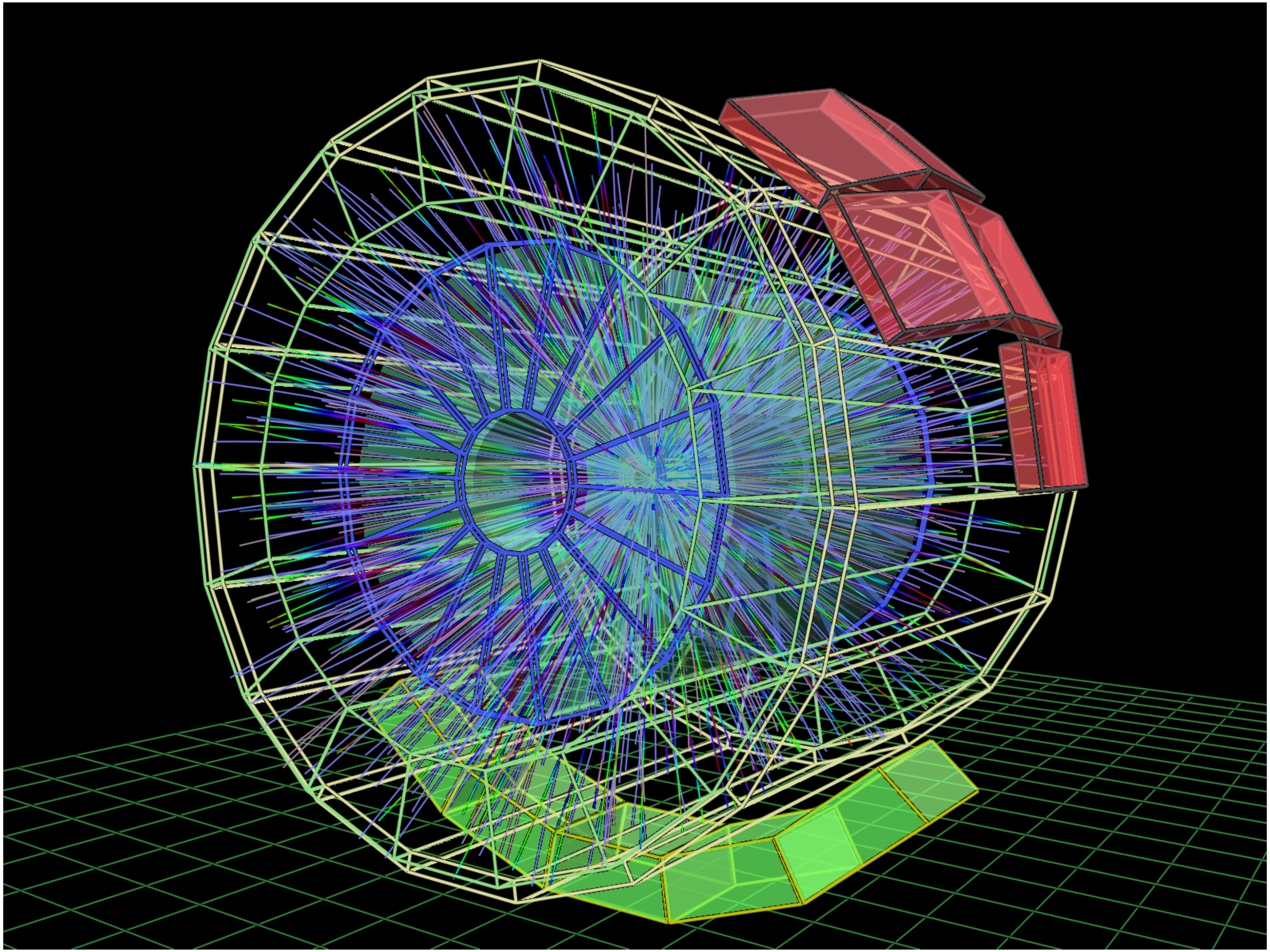




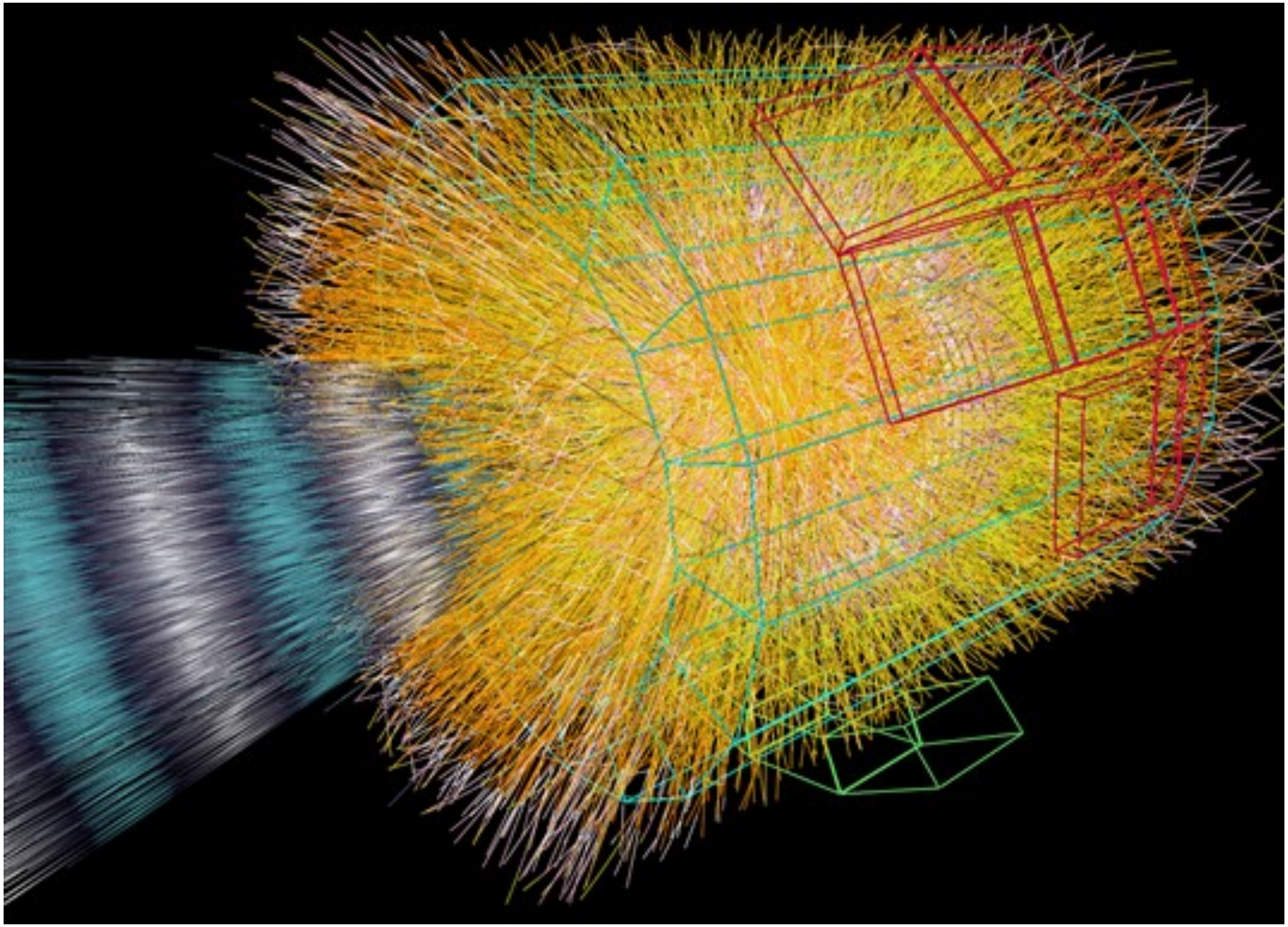



AREA B
AREA B

Eventi pp in Alice



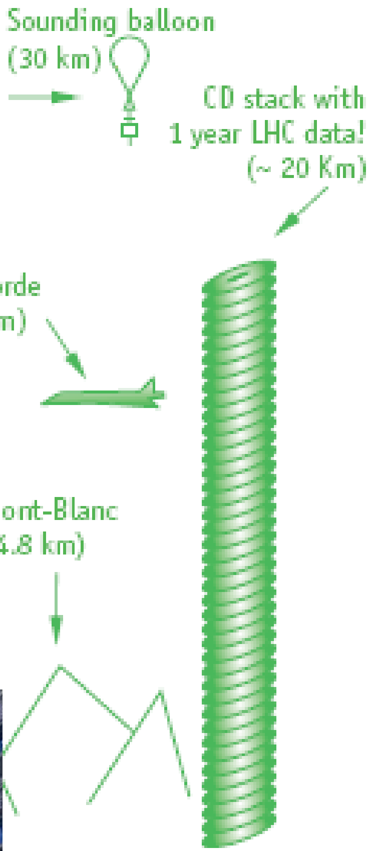
Eventi PbPb in Alice



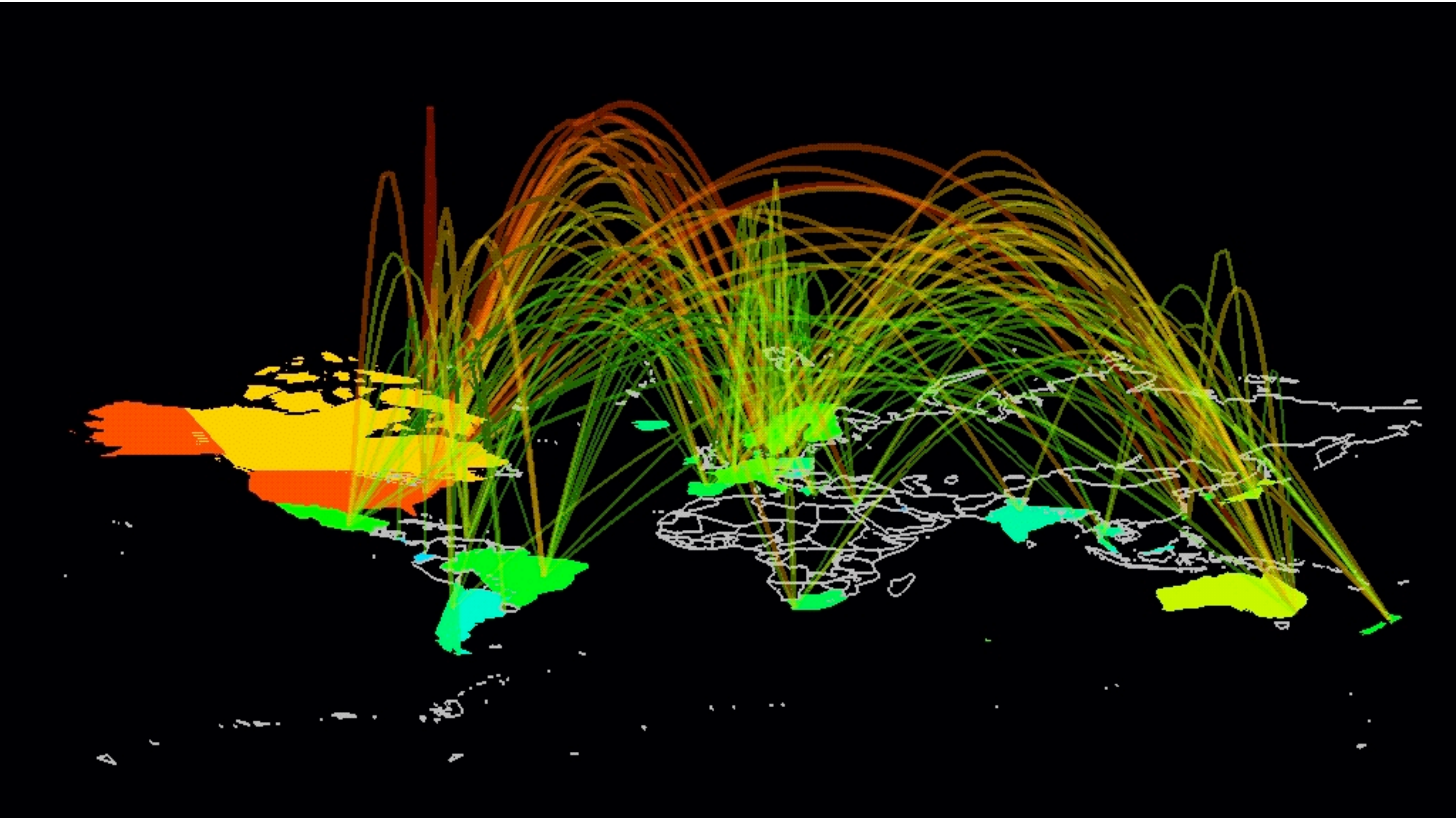
Migliaia di tracce prodotte ad ogni interazione (25 ns)

Dati sperimentali all’LHC

- La quantità dei dati prodotta è enorme! ~1.3 GB/s
- Se dovessimo salvare i dati su CD produrremmo una colonna di 20 km di dischi ogni l’anno
- Nuova soluzione sviluppata: GRID


Sounding balloon
(30 km)
CD stack with
1 year LHC data!
(~ 20 Km)
Concorde
(15 km)
Mont-Blanc
(4.8 km)

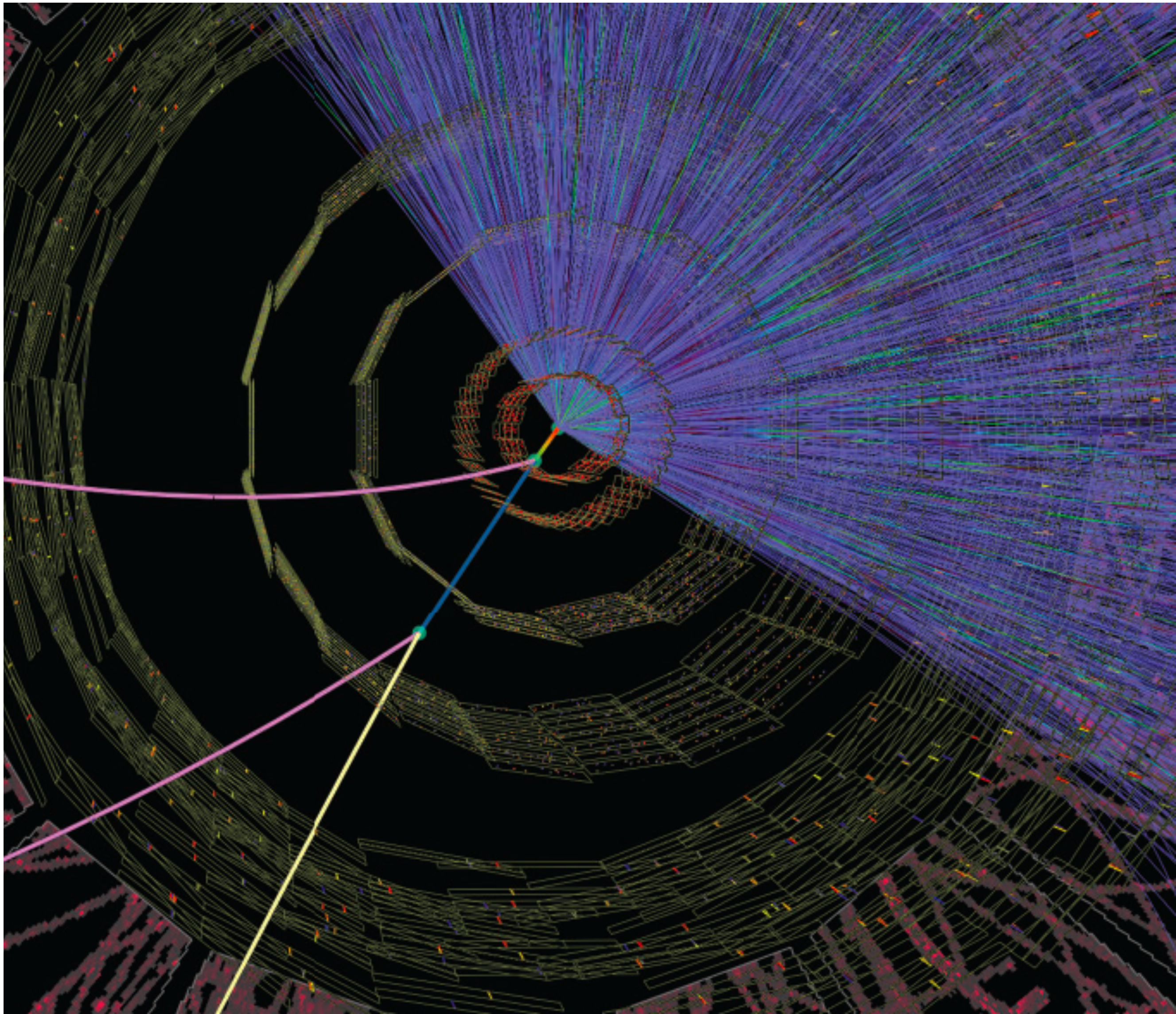
GRID architecture



Selezione di tracce “buone”

Eccellente tracking + vertice + Identificazione di particelle (PID)

$$\Xi^- \rightarrow \Lambda\pi^-$$



$\pi(u\overline{u})$

$Ks(d\overline{s})$

$p(uud)$

$n(udd)$

$\Lambda(uds)$

$K^0_s \rightarrow \pi^+\pi^-$

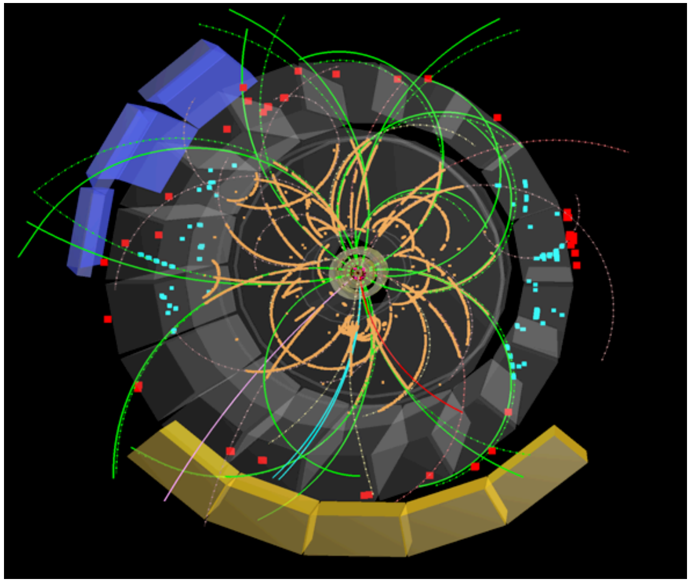
τ = 0.89 x 10^{-10} s

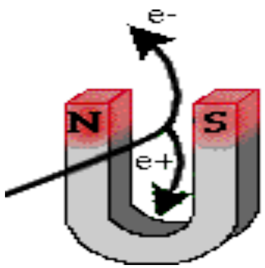
cτ = 3x10^{10} cm s^{-1} x 0.89 x10^{-10} s = 2.67 cm dal punto d'interazione

$\Lambda \rightarrow \pi^- p$

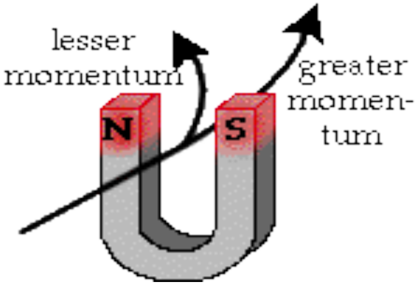
τ = 2.6 x 10^{-10} s

cτ = 3x10^{10} cm s^{-1} x 10^{-9} s = 7.2 cm dal punto d'interazione



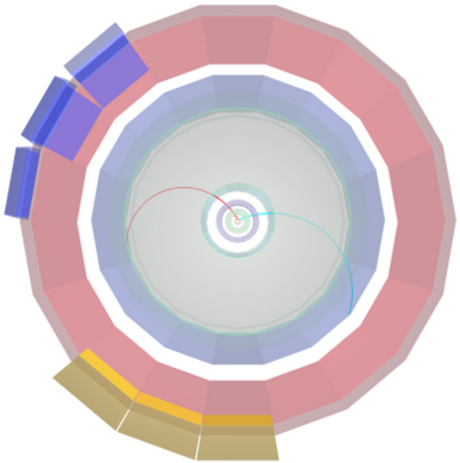


Identifica la carica


lesser momentum
greater momen- tum
N
S

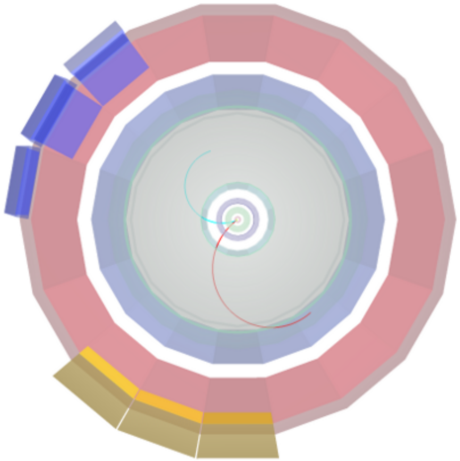
Misura l'impulso

Simmetrico



$\boxed{K^0_s \rightarrow \pi^+\pi^-}$

Asimmetrico



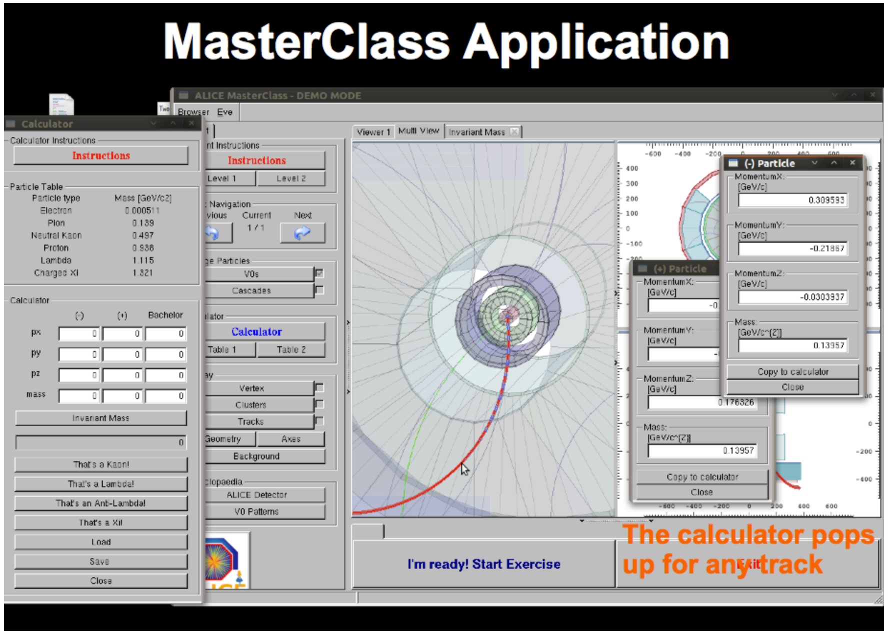
$\Lambda \rightarrow \pi^- p^+$

Prima parte

- Identificare i V0 (K^0_s, Λ , anti-Λ) dai decadimenti

  (V0 : due tracce con carica opposta provenienti da uno stesso vertice secondario)

- Calcolo della massa invariante
- Classificare le particelle secondo la loro massa invariante ed il tipo di particelle di decadimento



MasterClass Application

Particle Table

Particle type	Mass [GeV/c2]
Electron	0.000511
Pion	0.139
Neutral Kaon	0.497
Proton	0.938
Lambda	1.115
Charged Xi	1.321

Calculator

	(-)	(+)	Bachelor
px	0	0	0
py	0	0	0
pz	0	0	0
mass	0	0	0

Invariant Mass: 0

(-) Particle

MomentumX: [GeV/c] 0.309593

MomentumY: [GeV/c] -0.21867

MomentumZ: [GeV/c] -0.0303937

Mass: [GeV/c^{2}] 0.13957

(+) Particle

MomentumZ: [GeV/c] 0.176326

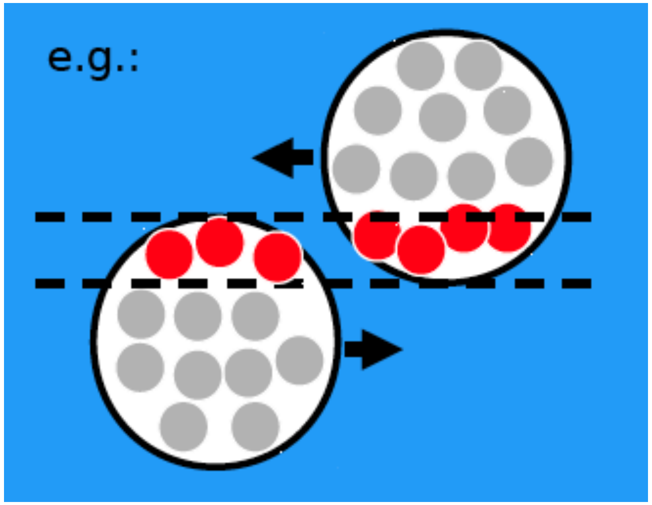
Mass: [GeV/c^{2}] 0.13957

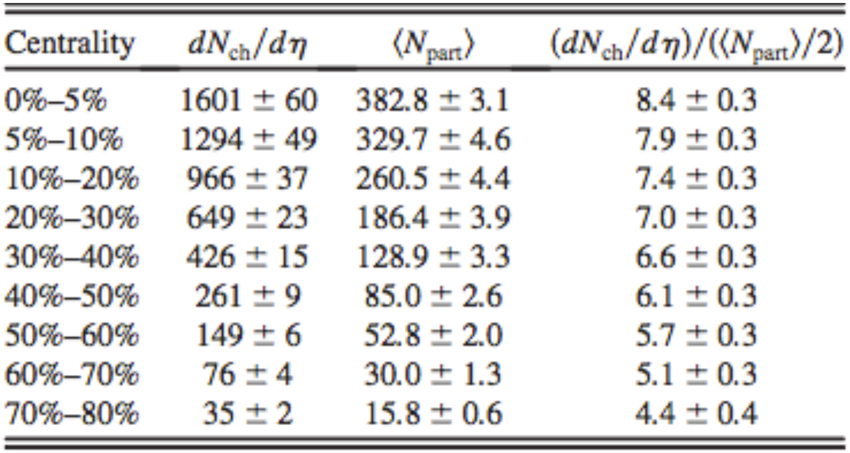
The calculator pops up for any track

Calculator
Calculator Instructions
Instructions
That's a Kaon!
That's a Lambda!
That's an Anti-Lambda!
That's a Xi!
Load
Save
Close
ALICE MasterClass - DEMO MODE
Browser
Eve
Level 1
Level 2
Navigation
Current
Next
1 / 1
V0s
Cascades
Calculator
Table 1
Table 2
Vertex
Clusters
Tracks
Geometry
Axes
Background
ALICE Detector
V0 Patterns
Viewer 1
Multi View
Invariant Mass
Copy to calculator
Close
I'm ready! Start Exercise
Exit

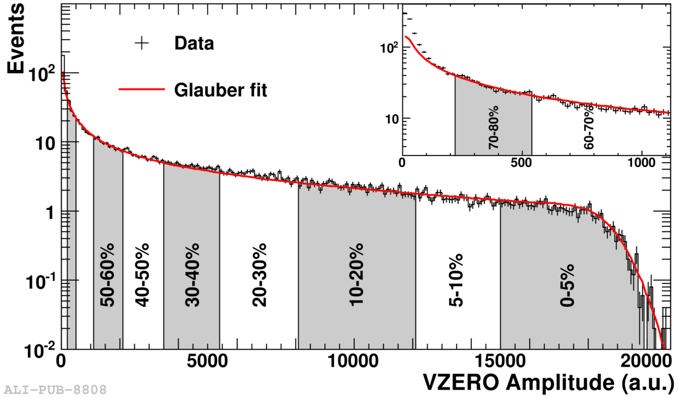
Seconda parte

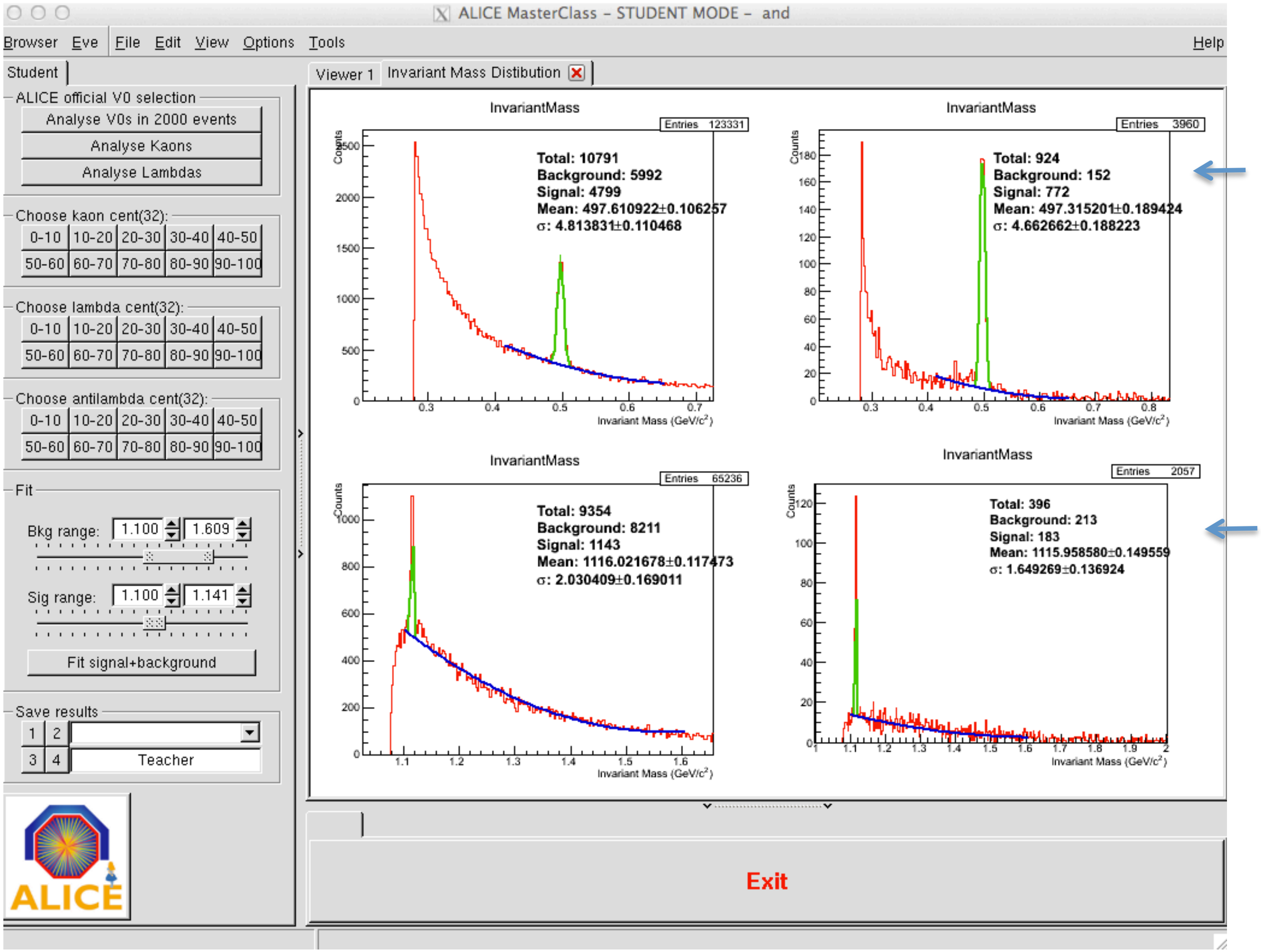
- Analisi di un campione di migliaia di eventi
- Riempire gli istogrammi di massa invariante per K_s, Λ anti-Λ
- Fit del fondo (background) con polinomio di secondo e segnale (gaussiana)
- Trovare il numero di K_s, Λ, anti-Λ dopo la sottrazione del fondo in differenti bin di centralità nelle collisioni Pb-Pb





Centrality	$dN_{ch}/d\eta$	$\langle N_{part} \rangle$	$(dN_{ch}/d\eta)/(\langle N_{part} \rangle/2)$
0%–5%	1601 ± 60	382.8 ± 3.1	8.4 ± 0.3
5%–10%	1294 ± 49	329.7 ± 4.6	7.9 ± 0.3
10%–20%	966 ± 37	260.5 ± 4.4	7.4 ± 0.3
20%–30%	649 ± 23	186.4 ± 3.9	7.0 ± 0.3
30%–40%	426 ± 15	128.9 ± 3.3	6.6 ± 0.3
40%–50%	261 ± 9	85.0 ± 2.6	6.1 ± 0.3
50%–60%	149 ± 6	52.8 ± 2.0	5.7 ± 0.3
60%–70%	76 ± 4	30.0 ± 1.3	5.1 ± 0.3
70%–80%	35 ± 2	15.8 ± 0.6	4.4 ± 0.4




ALICE MasterClass – STUDENT MODE – and
Browser Eve File Edit View Options Tools Help
Student
Viewer 1
Invariant Mass Distibution
ALICE official V0 selection
Analyse V0s in 2000 events
Analyse Kaons
Analyse Lambdas
Choose kaon cent(32):
Choose lambda cent(32):
Choose antilambda cent(32):
0-10 10-20 20-30 30-40 40-50
50-60 60-70 70-80 80-90 90-100
Fit
Fit signal+background
Save results
1 2 3 4
Teacher
ALICE
Exit
InvariantMass
Counts
Invariant Mass (GeV/c²)

Bkg range: 1.100 1.609

Sig range: 1.100 1.141

```
InvariantMass                          Entries   123331
Total: 10791
Background: 5992
Signal: 4799
Mean: 497.610922±0.106257
σ: 4.813831±0.110468
```

```
InvariantMass                          Entries   3960
Total: 924
Background: 152
Signal: 772
Mean: 497.315201±0.189424
σ: 4.662662±0.188223
```

```
InvariantMass                          Entries   65236
Total: 9354
Background: 8211
Signal: 1143
Mean: 1116.021678±0.117473
σ: 2.030409±0.169011
```

```
InvariantMass                          Entries   2057
Total: 396
Background: 213
Signal: 183
Mean: 1115.958580±0.149559
σ: 1.649269±0.136924
```

K_s

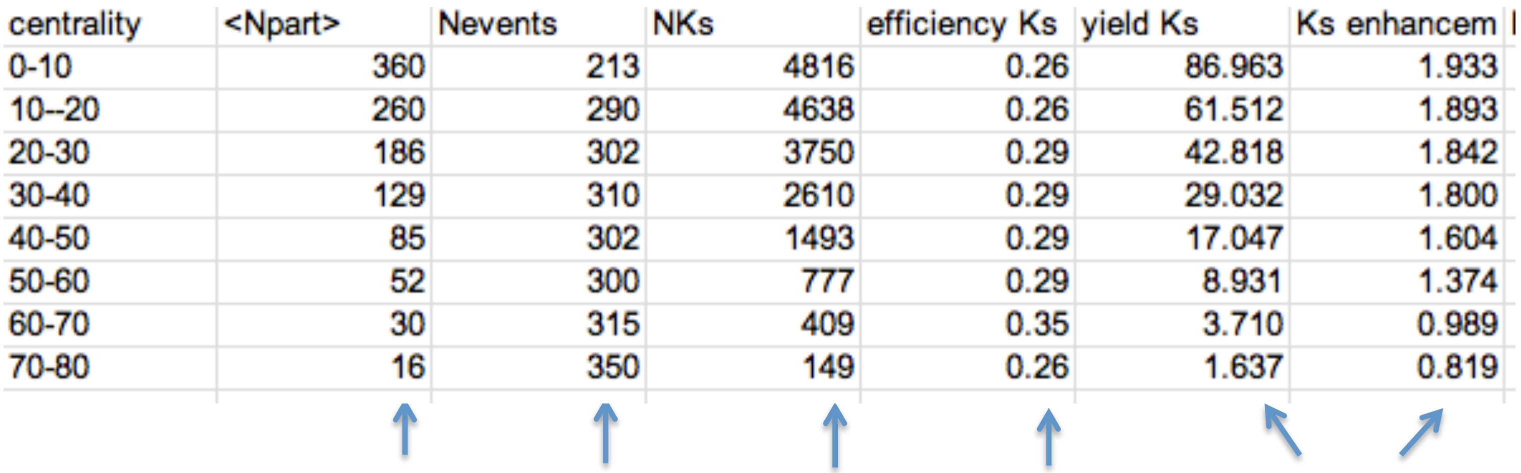
Sinistra: 0-10% centralità

Destra : 50-60% centralità

Λ

Sinistra: 0-10% centralità

Destra: 50-60% centralità



centrality	<Npart>	Nevents	NKs	efficiency Ks	yield Ks	Ks enhancem
0-10	360	213	4816	0.26	86.963	1.933
10--20	260	290	4638	0.26	61.512	1.893
20-30	186	302	3750	0.29	42.818	1.842
30-40	129	310	2610	0.29	29.032	1.800
40-50	85	302	1493	0.29	17.047	1.604
50-60	52	300	777	0.29	8.931	1.374
60-70	30	315	409	0.35	3.710	0.989
70-80	16	350	149	0.26	1.637	0.819

conosciuto dato misurato dato calcolato

Efficienza = Nparticelle(misurate)/Nparticelle(prodotte)

Yield : numero di particelle prodotte per interazione
Yield = Nparticelle(prodotte)/Neventi = Nparticelle(misurate)/(efficienza x Neventi)

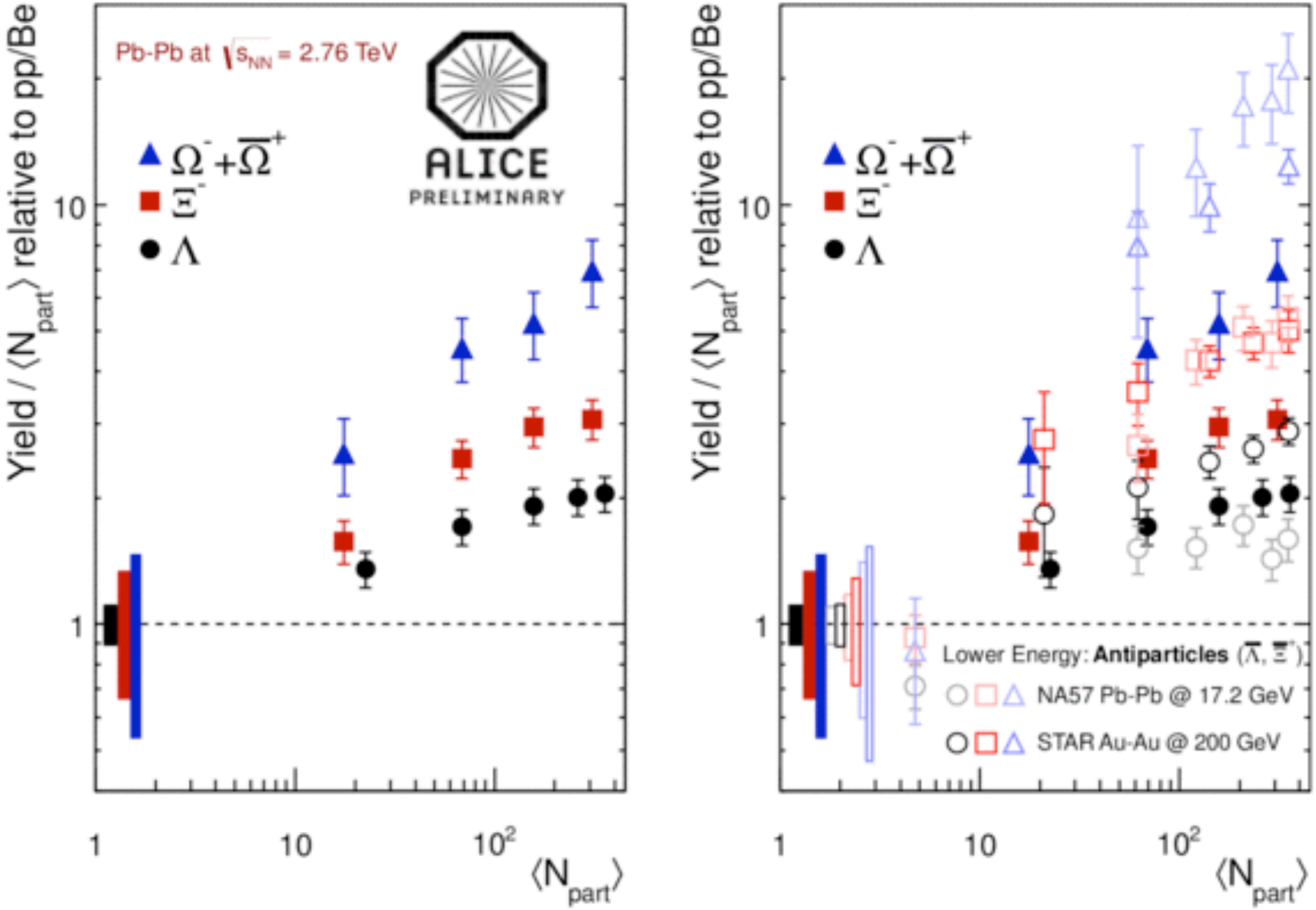
Strangeness enhancement: yield per particella normalizzato al numero di nucleoni partecipanti nella collisione e diviso per lo yield delle collisioni protone-protone

K_s-Yield (pp) = 0.25 /interazione ; Λ-Yield(pp) = 0.0617 /interazione ; $\langle N_{part} \rangle = 2$ per pp

Dove scaricare il materiale

http://alice.physicsmasterclasses.org/MasterClassWebpage.html

Video: Inside the ALICE experiment
https://www.youtube.com/watch?v=NFRSX00qelU



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