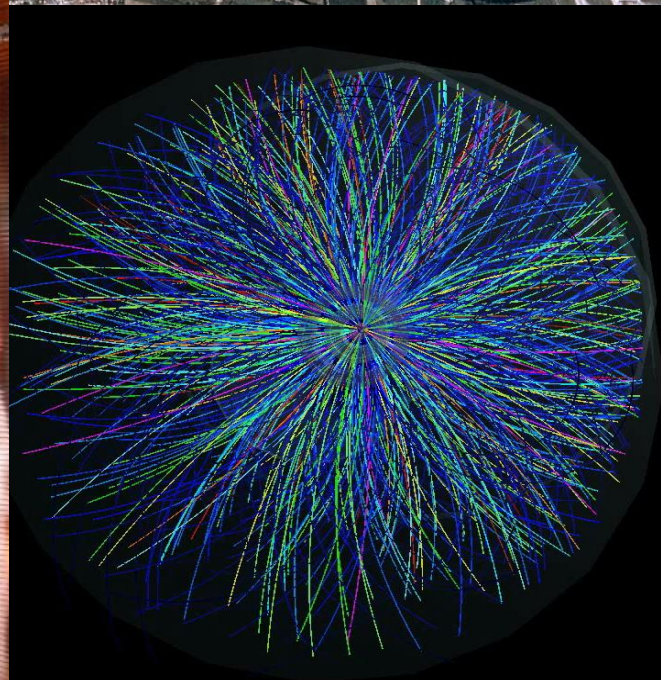
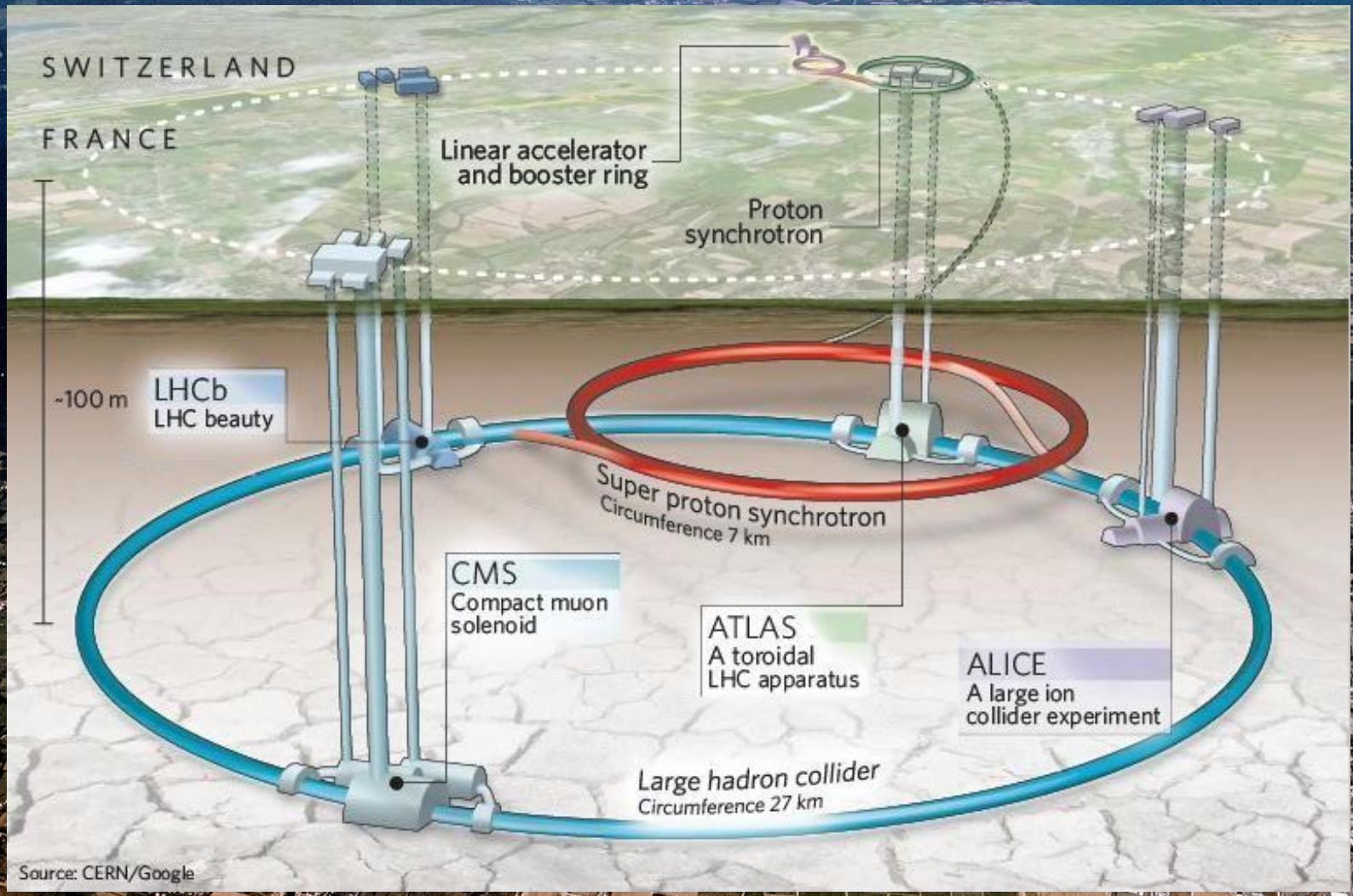
Acceleratorer og detektorer

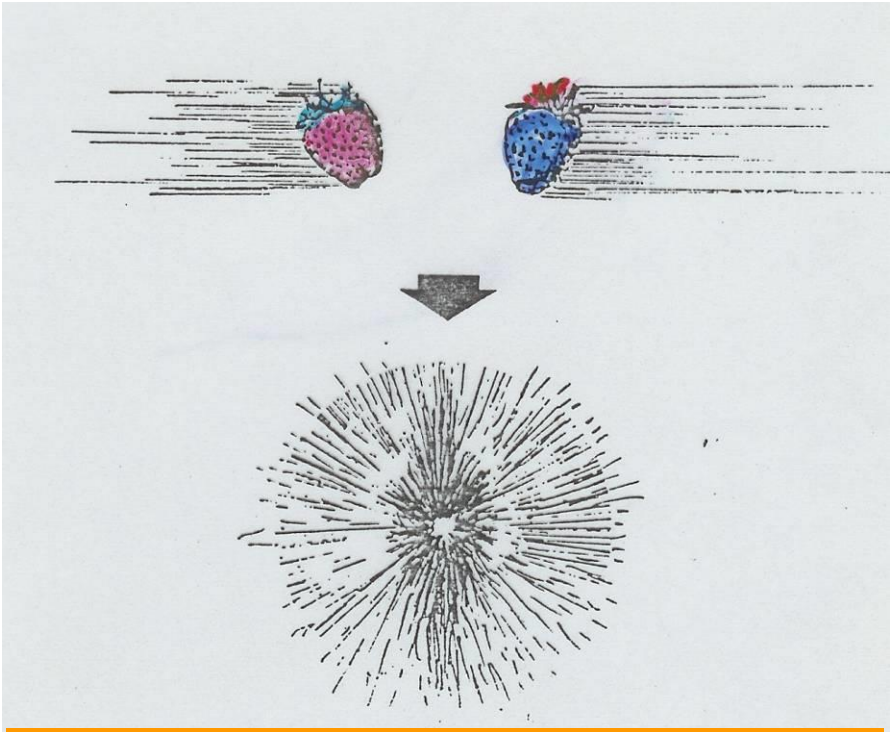
IHSSP, CERN, 27. september 2021

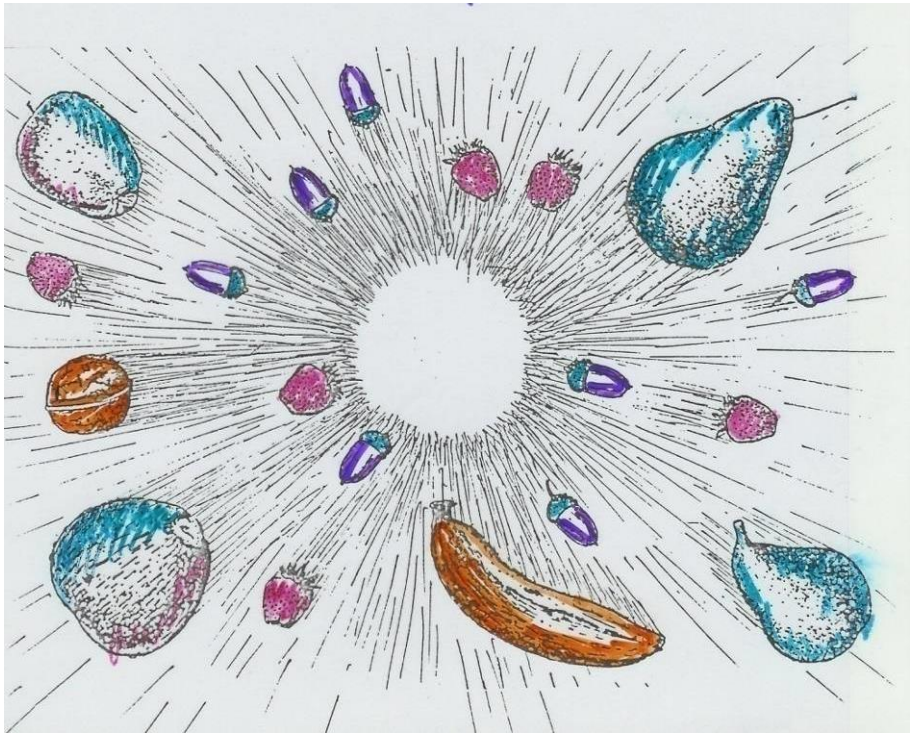
Børge Svane Nielsen, Niels Bohr Institutet, København




SWITZERLAND
FRANCE
Linear accelerator and booster ring
Proton synchrotron
~100 m
LHCb
LHC beauty
Super proton synchrotron
Circumference 7 km
CMS
Compact muon solenoid
ATLAS
A toroidal LHC apparatus
ALICE
A large ion collider experiment
Large hadron collider
Circumference 27 km
Source: CERN/Google

$E = m c^2$ eller $E \approx kT$



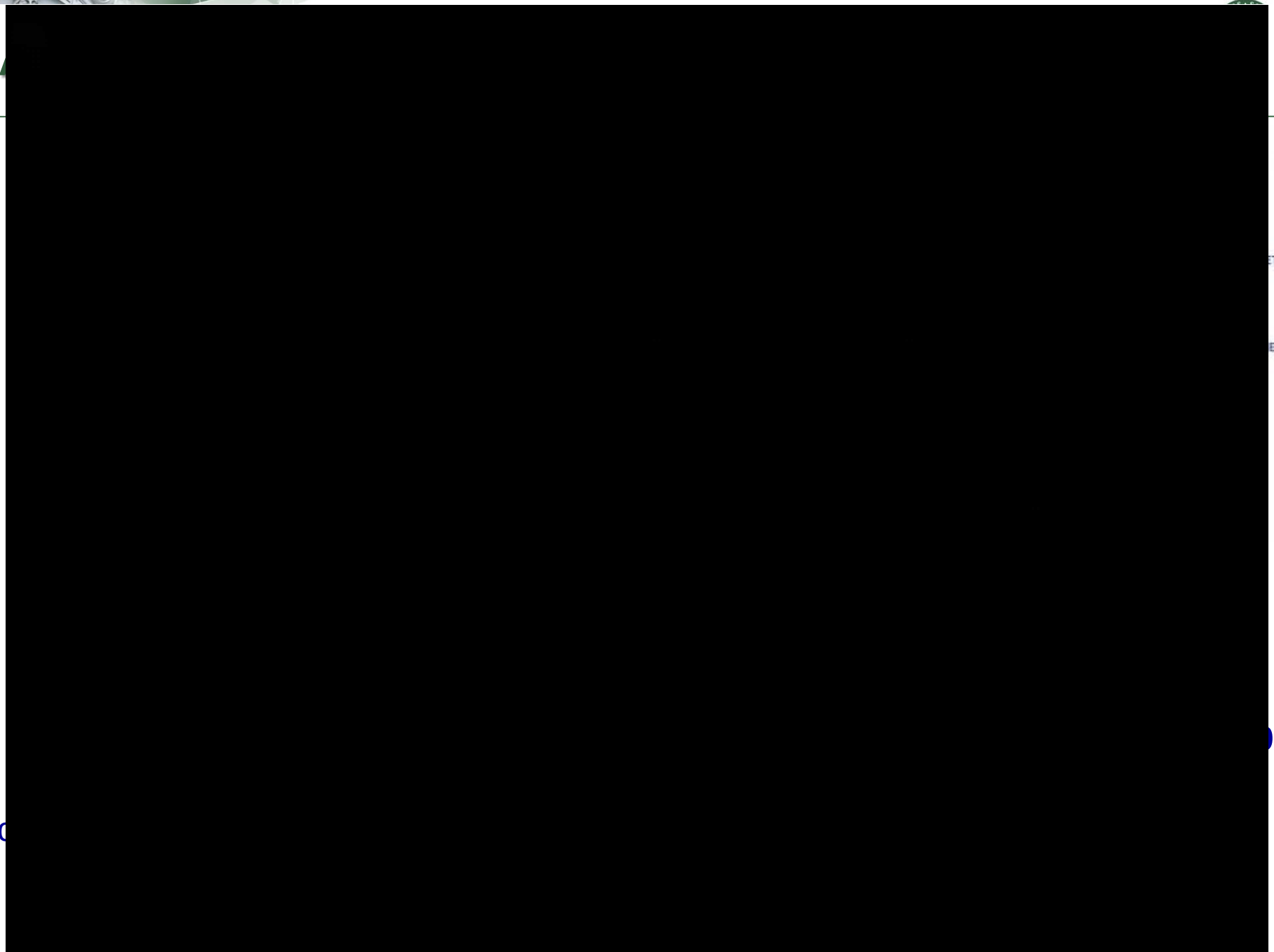


Kollisioner af protoner eller tunge atomkerner

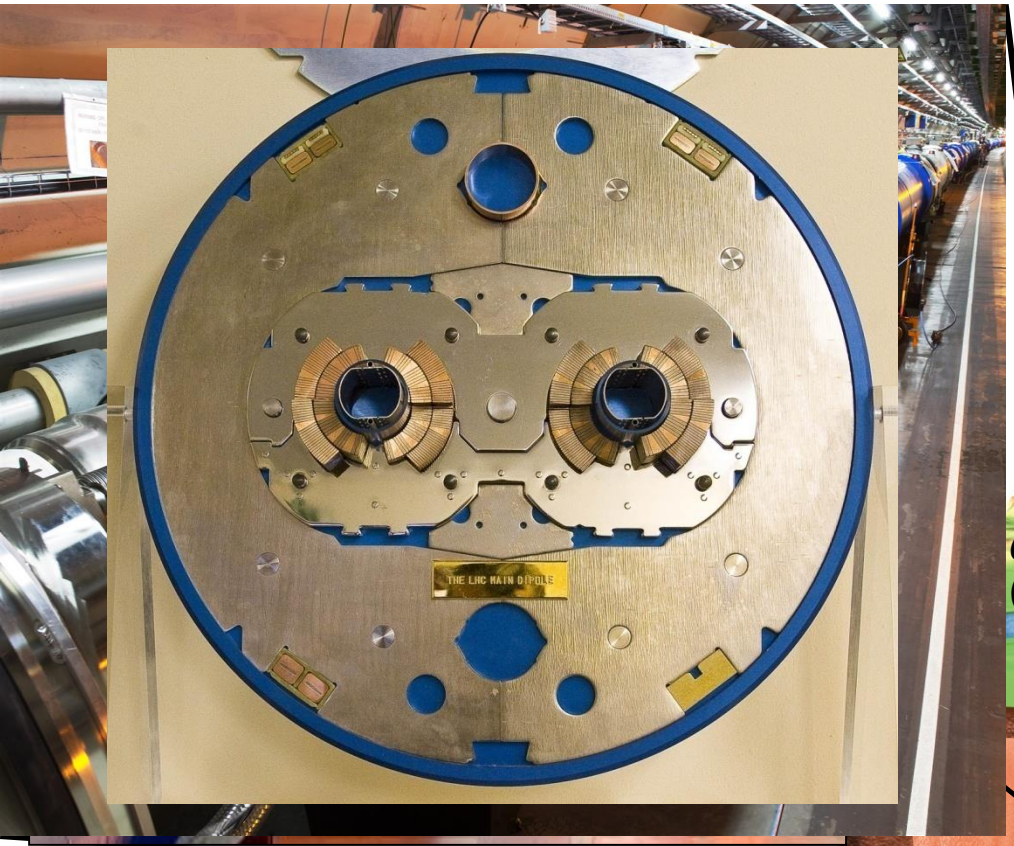
1. **Omdanner kinetisk energi til stof (masse)**
2. **Skaber høje stoftætheder ('Mini-Big Bang')**

$E=14$ TeV $\Rightarrow m=14.900\ m_p$

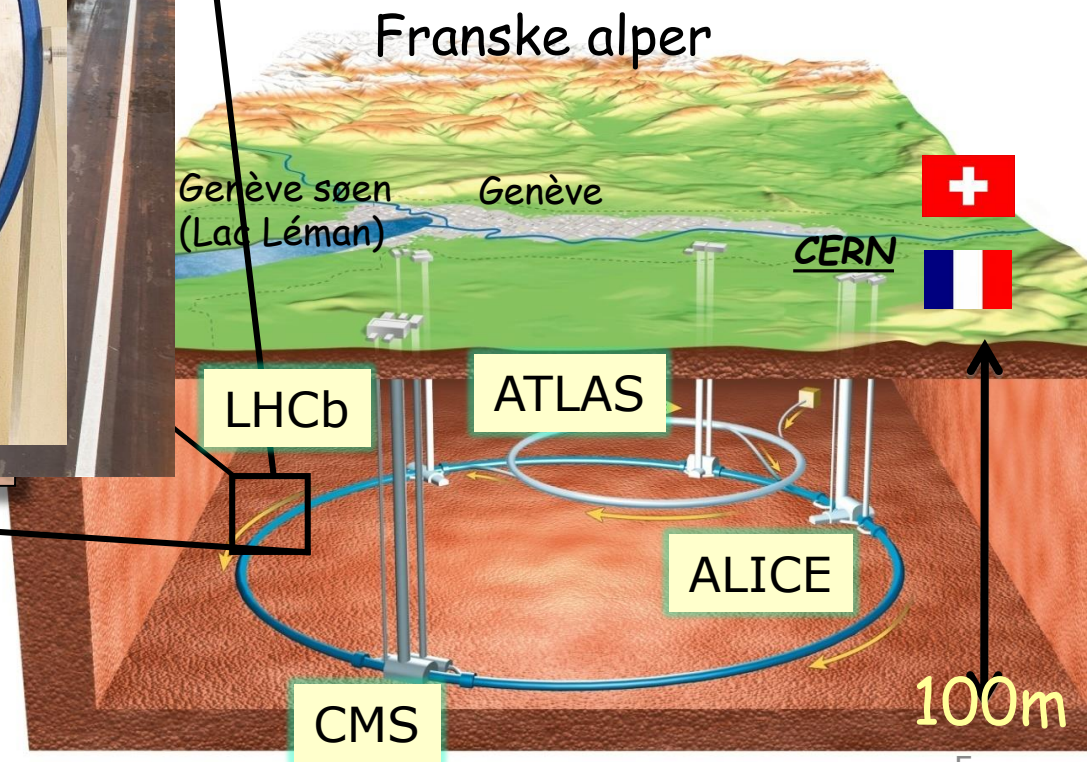
$\Rightarrow T \approx 1{,}60 \cdot 10^{17}$ K



Large Hadron Collider

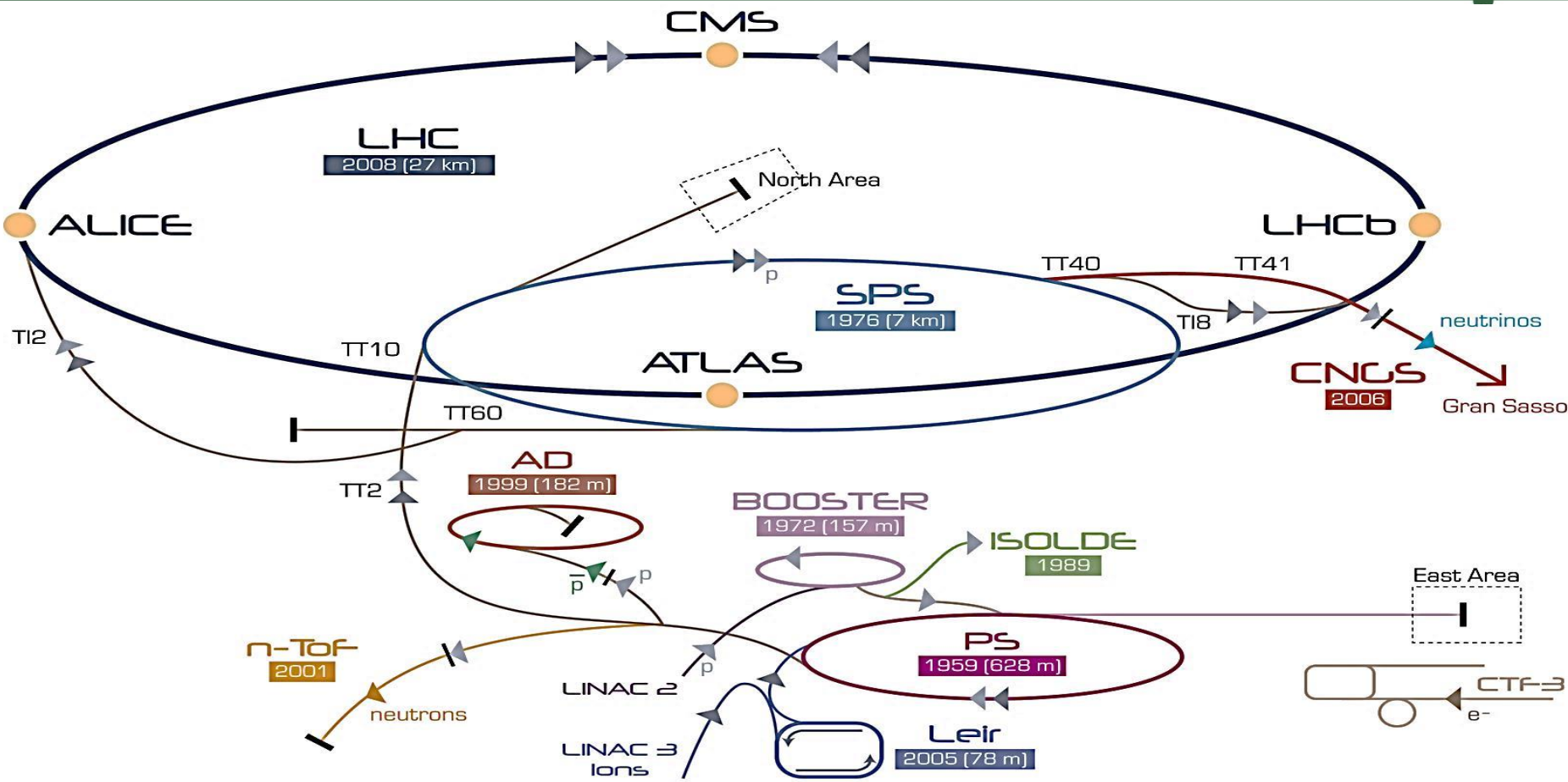


Partikerne bevæger sig med
99.9999991% af lysets hastighed.
Proton-proton kollisioner med
svimlende energi: 14.000.000.000.000 eV
Svarende til energien af en myg i bevægelse!



Pakker med 100 milliarder partikler
1.000.000.000 kollisioner i sekundet!
Energien i alle partikler tilsammen er
som et eksprestog i fart!

CERNs accelerator kompleks



LHC Large Hadron Collider SPS Super Proton Synchrotron PS Proton Synchrotron

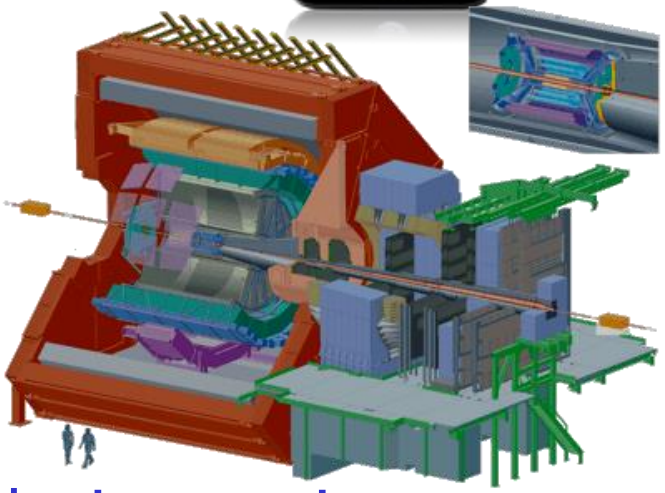
AD Antiproton Decelerator CTF-3 Clic Test Facility CNGS Cern Neutrinos to Gran Sasso ISOLDE Isotope Separator OnLine DEvice

LEIR Low Energy Ion Ring LINAC LINear ACcelerator n-ToF Neutrons Time Of Flight

Eksperimenterne

Eksperimenterne/detektorerne

Til verdens største mikroskop **LHC**
behøves
verdens største superkameraer……

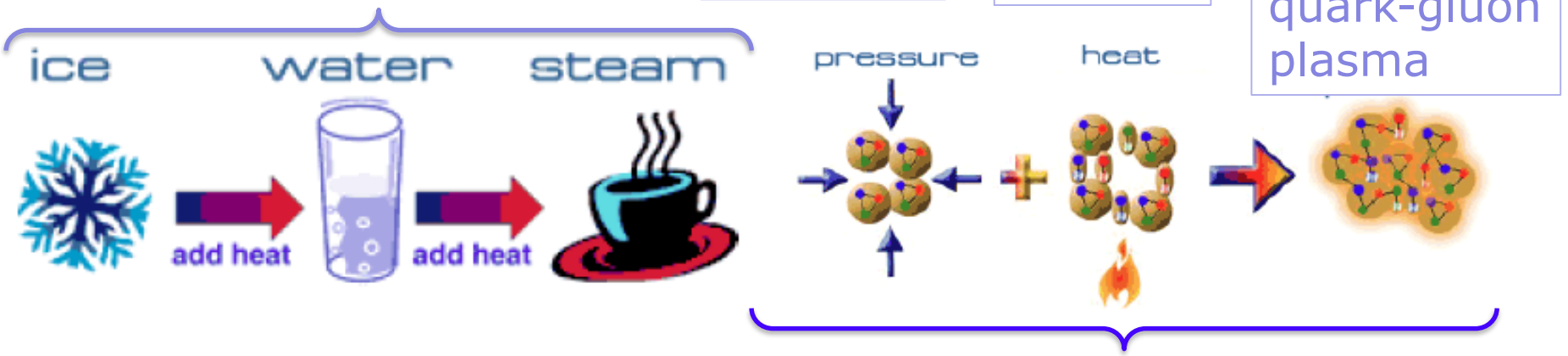


- **3-d**
- **Ultra-præcise:**
  Bedre end tykkelsen af et hår
- **Ekstremt hurtige:**
  40 millioner billeder per sekund
- **Kæmpestore:**
  Skal kunne analysere partikler med høj energi

Eksperimenterne: ATLAS, ALICE, CMS og LHCb

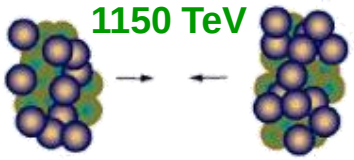
Hvordan laver man Universets "urstof"?

Stof findes i flere faser

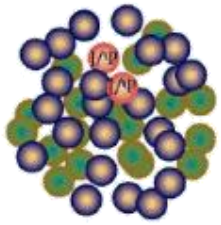


- Er det muligt at smelte atomkerner?
- Hvis vi kan gøre det, kan vi forstå det meget tidlige Univers
- Varme + tryk: Blykerner i en accelerator!

Tunge ioner i LHC

^{208}Pb 

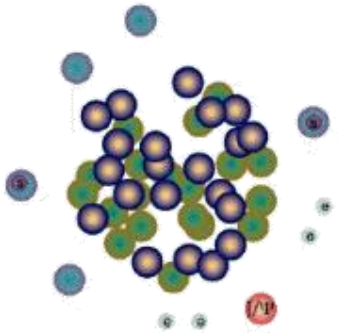
^{208}Pb kollision



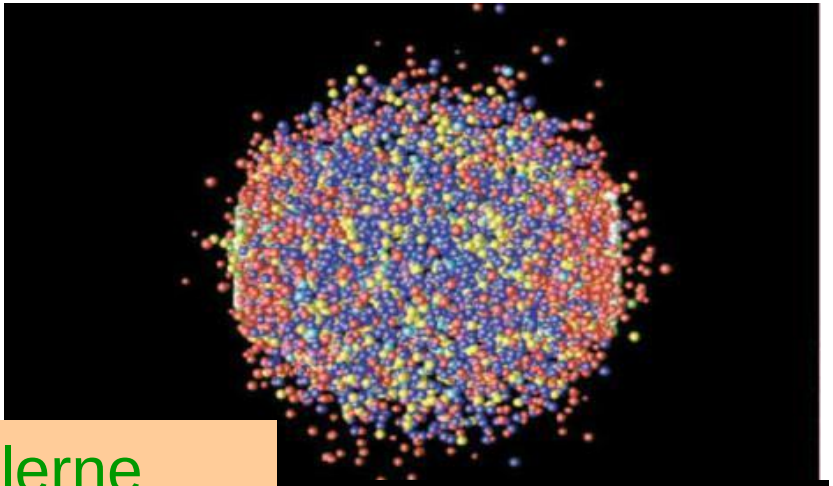
superkerne med
høj energi

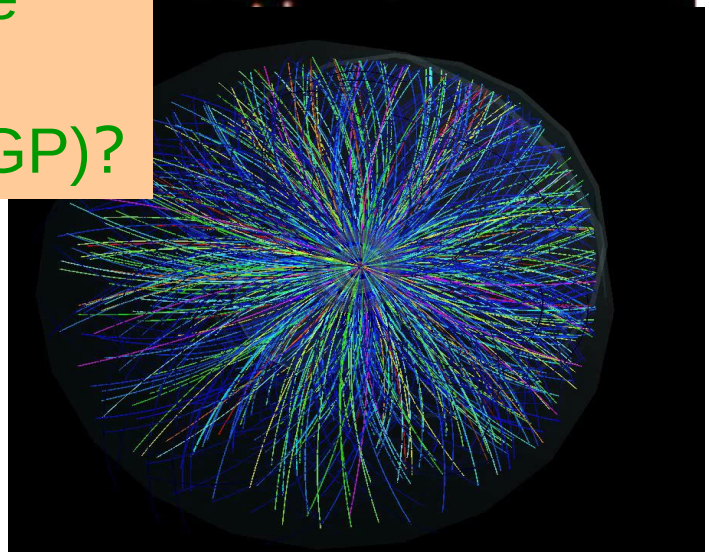
?

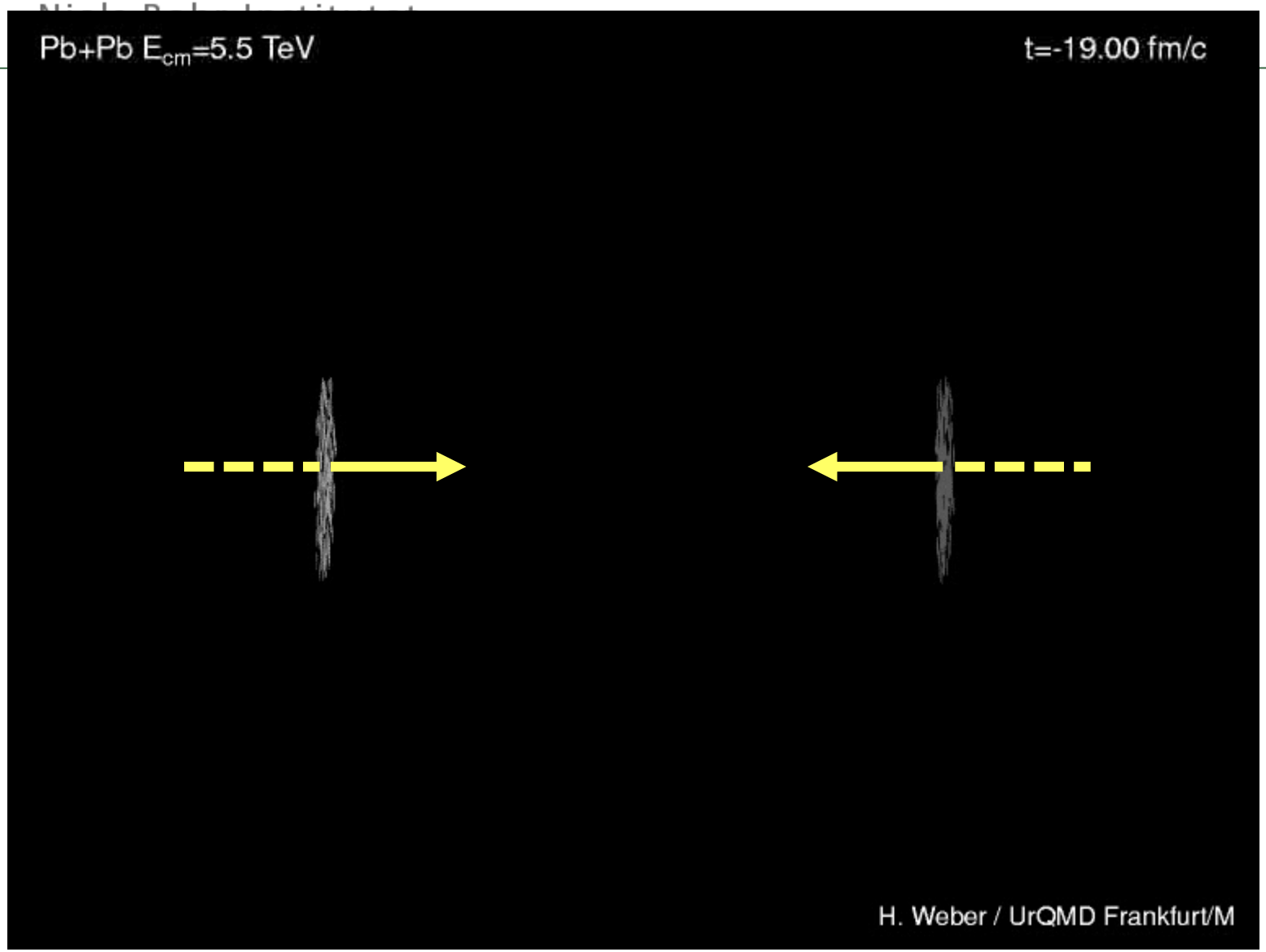
smelter kernepartiklerne
sammen til et
kvark-gluon plasma (QGP)?



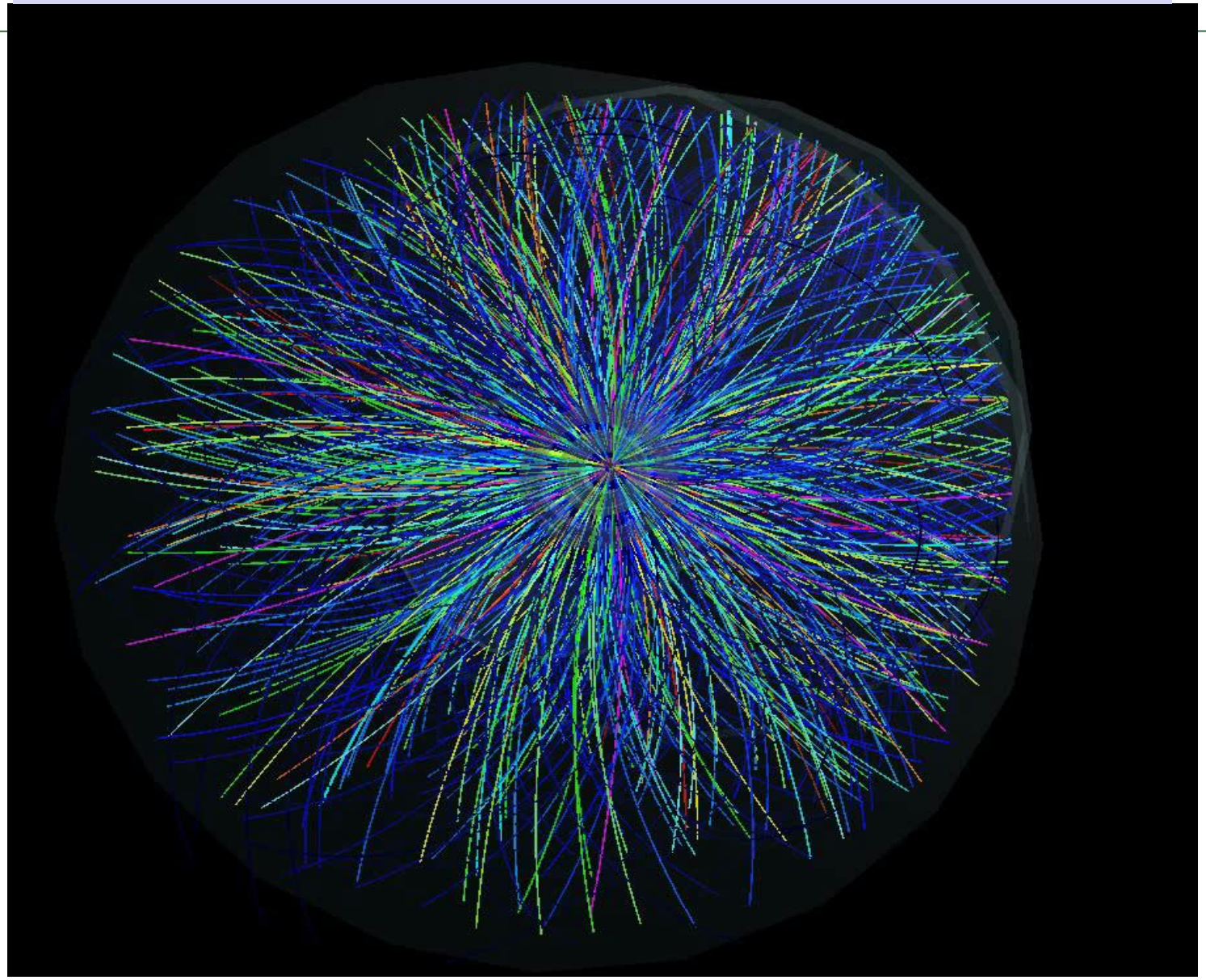
mini Big Bang



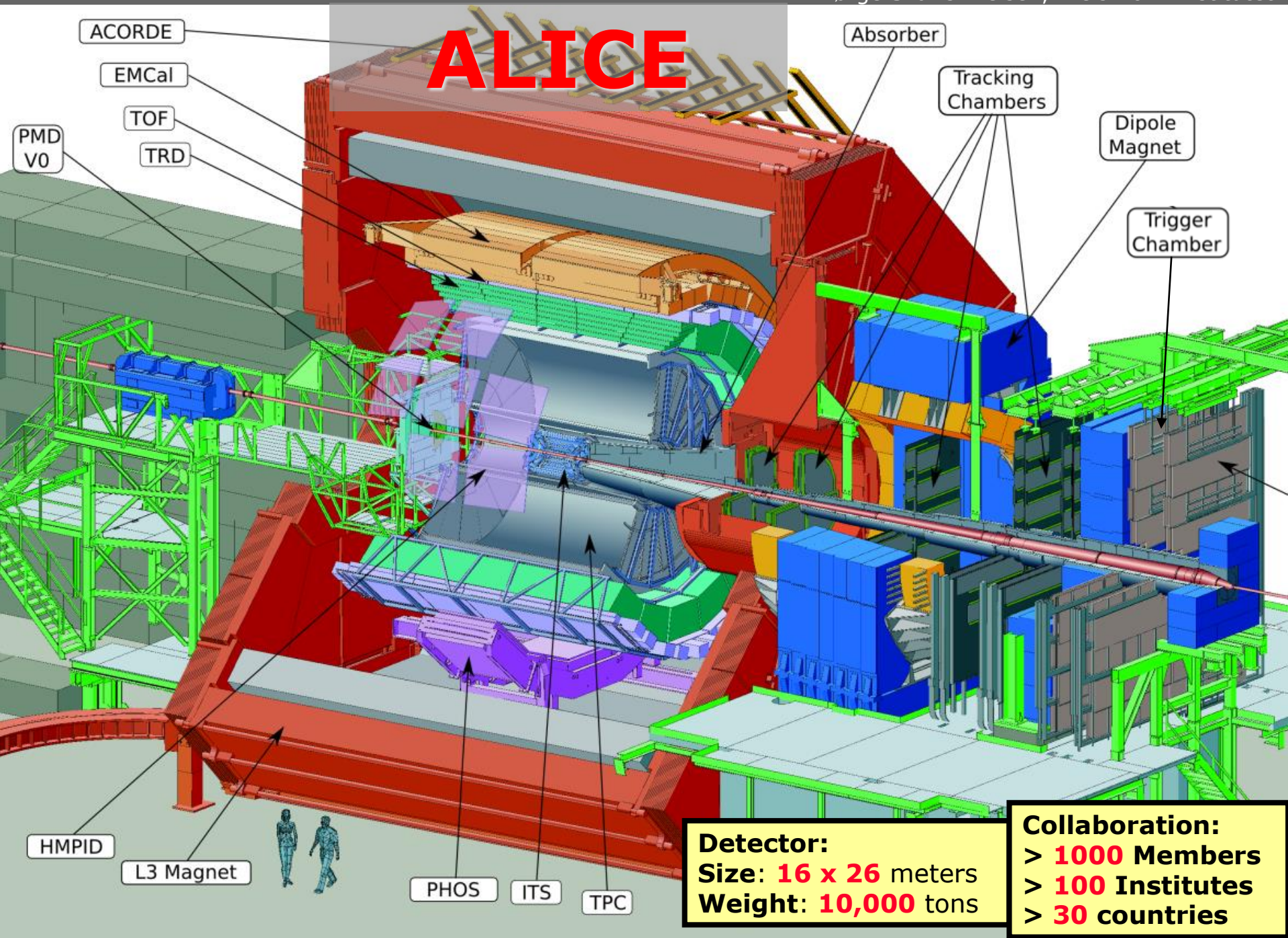



Pb+Pb E_{cm}=5.5 TeV
t=-19.00 fm/c
H. Weber / UrQMD Frankfurt/M

Pb-Pb sammenstød, 574 TeV, set i ALICE

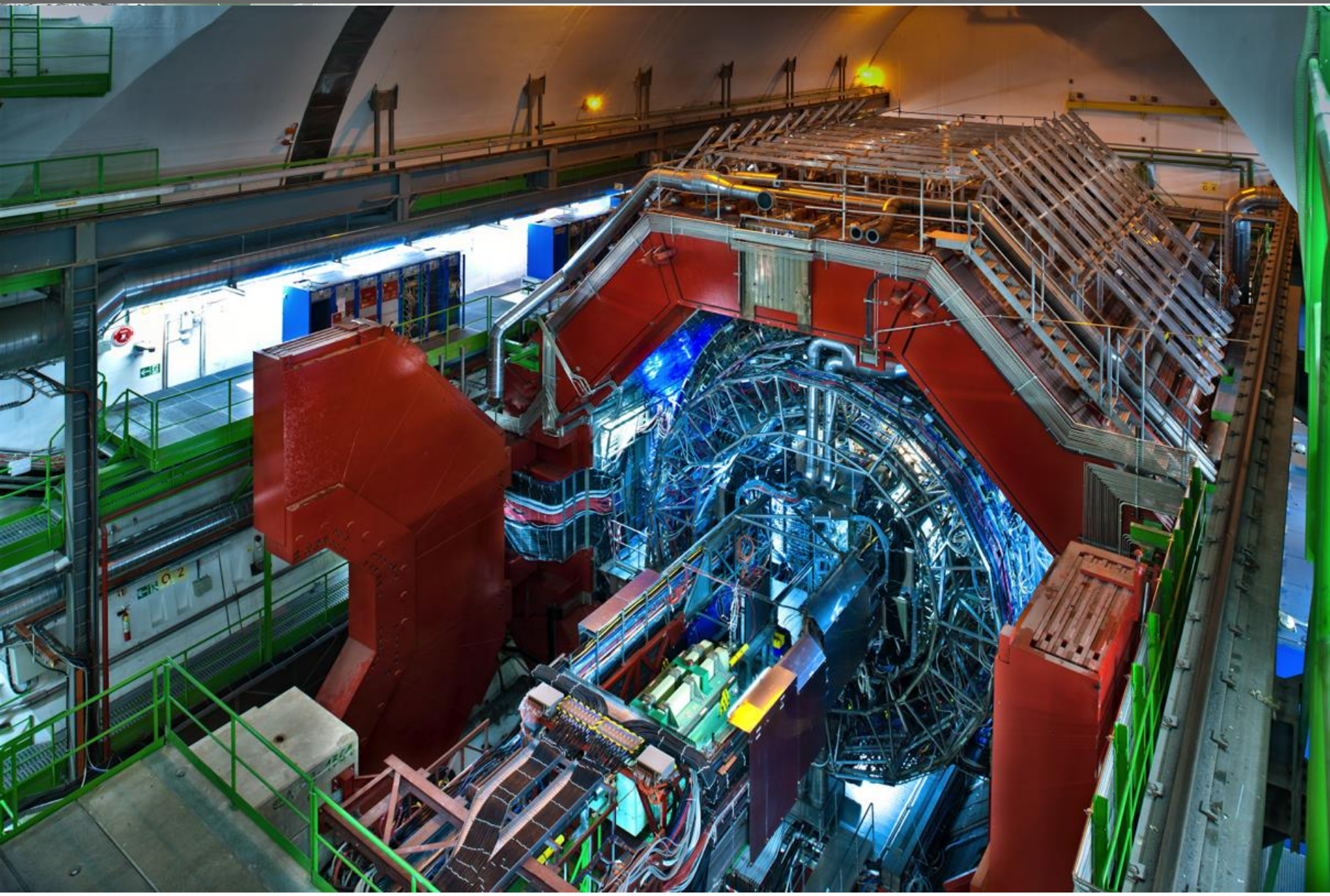


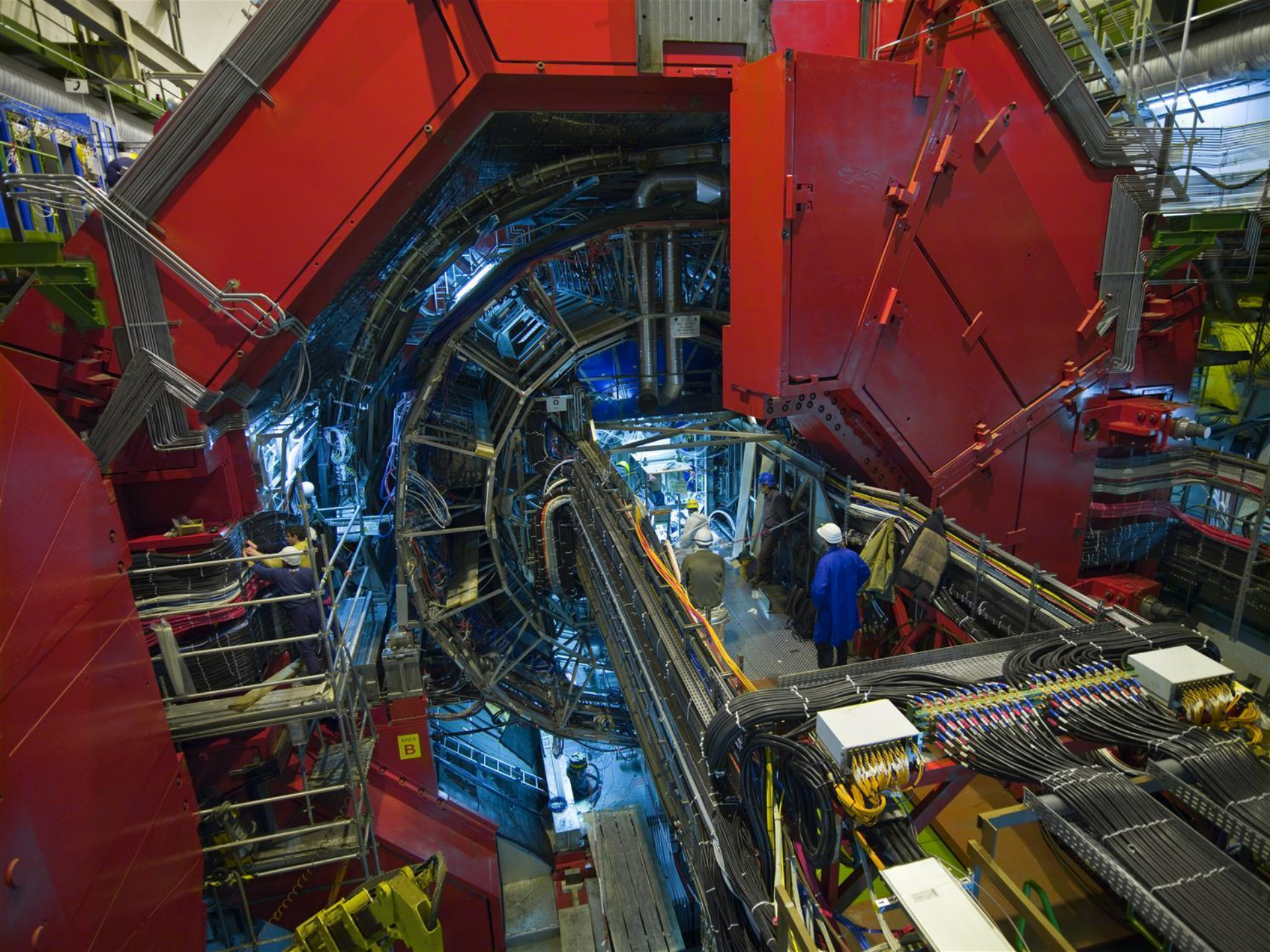
ALICE



Detector:
Size: **16 x 26** meters
Weight: **10,000** tons

Collaboration:
> 1000 Members
> 100 Institutes
> 30 countries




AREA
B

ALICE: Hovedtyper af detektorer

- og deres formål:

a. Tids- og hit-målere:

start tid / trigger	scintillationstællere
koincidens	silicium detektorer

b. Spordetektorer:

impulsmåling	gasdetektorer
henfald (V's and "kinks")	silicium detektorer

c. Partikel-identifikation:

adskil efter masse	dE/dx (ionisering)
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	Cherenkov detektorer
adskil ved vekselvirkning	kalorimetre

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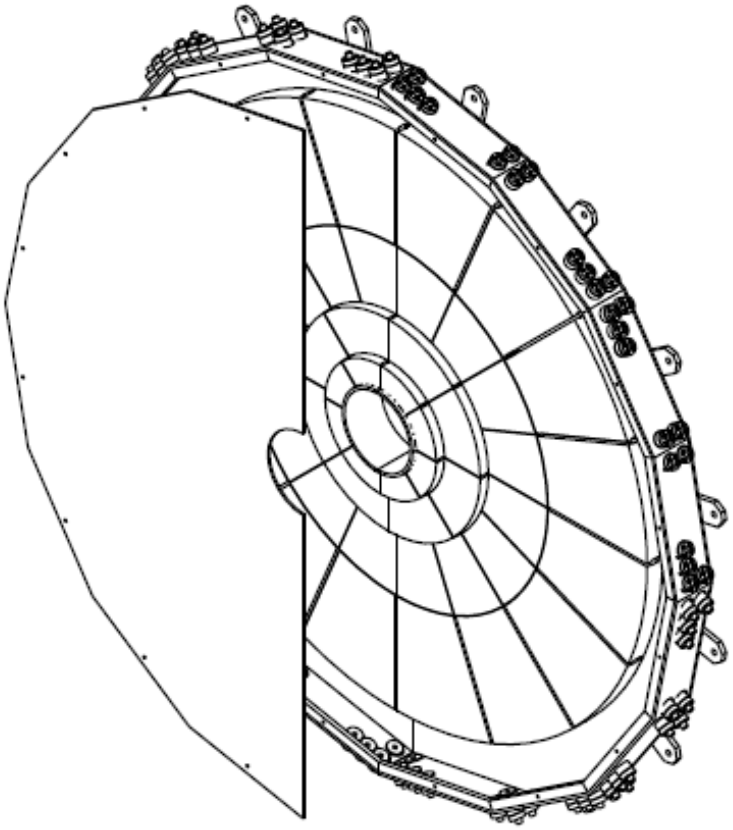
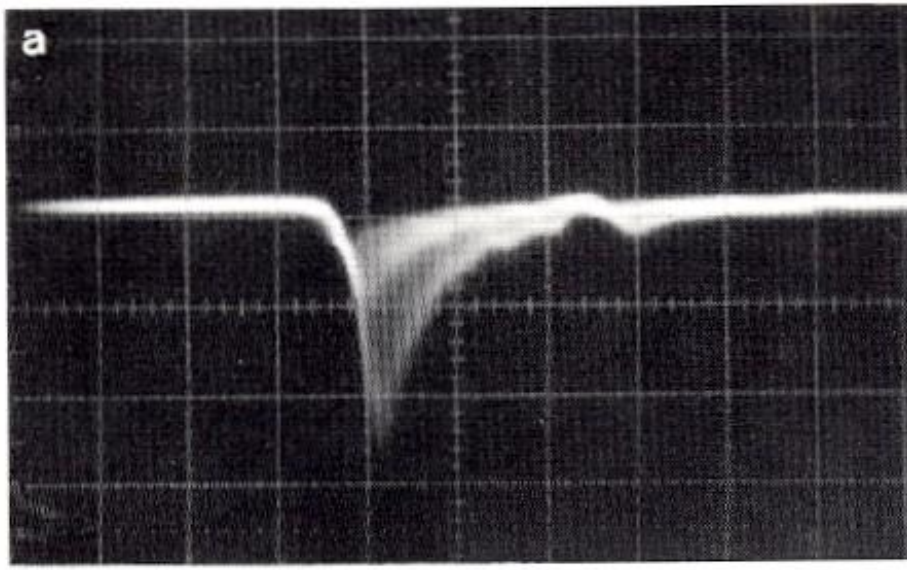
V0: Plastik scintillator





Plastic scintillator

Plastic

Vert. scale : 0.2 V/cm
Hor. scale : 10 ns/cm
Source : ^{207}Bi 10μCi

10 nsec / division

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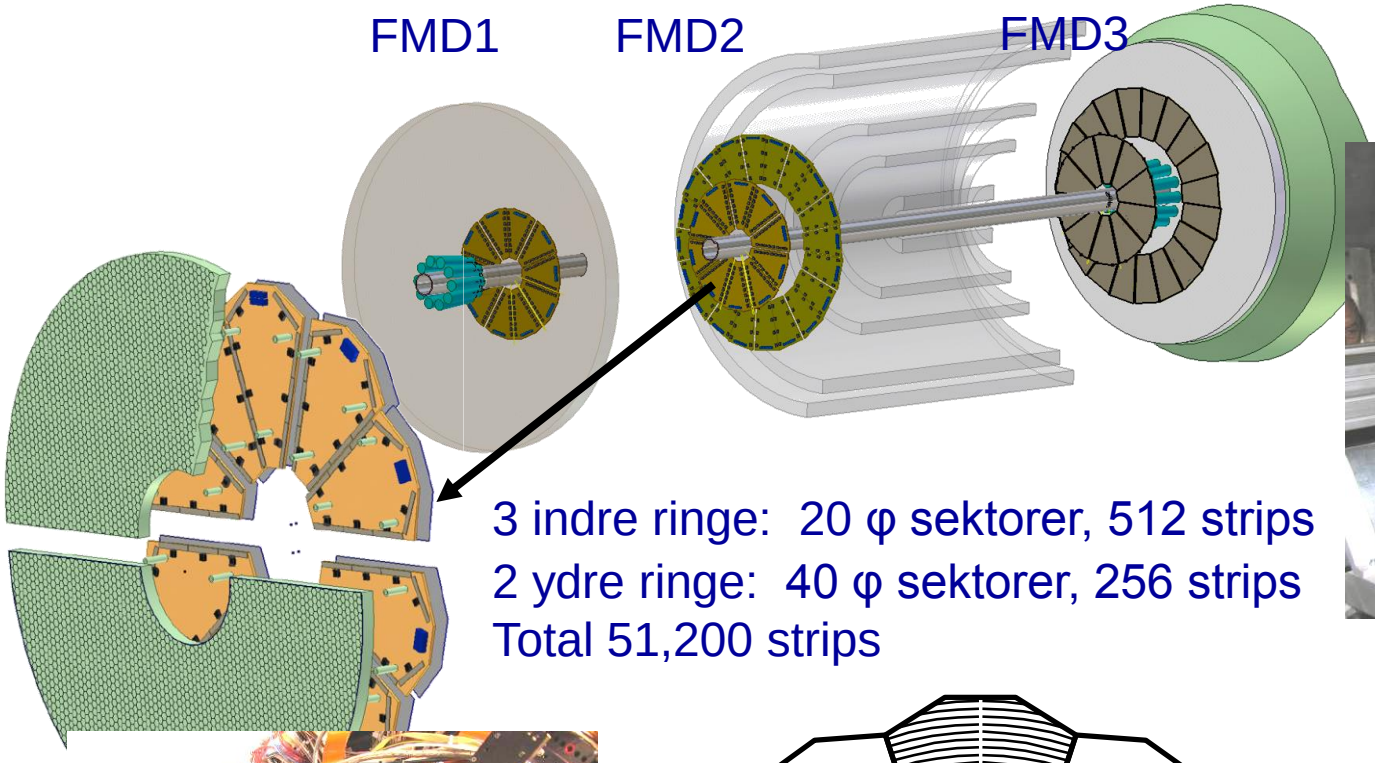
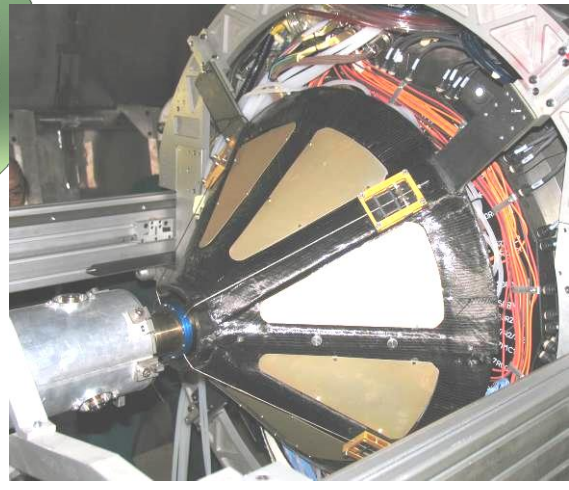
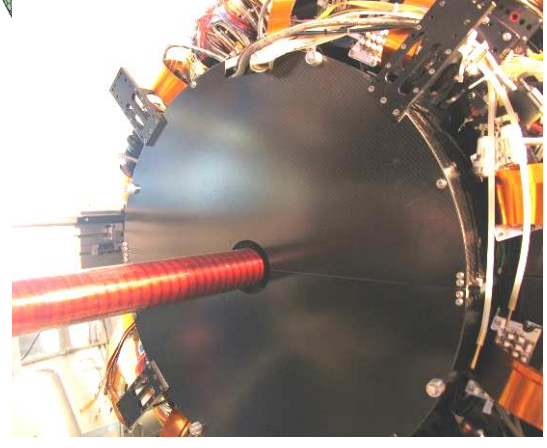
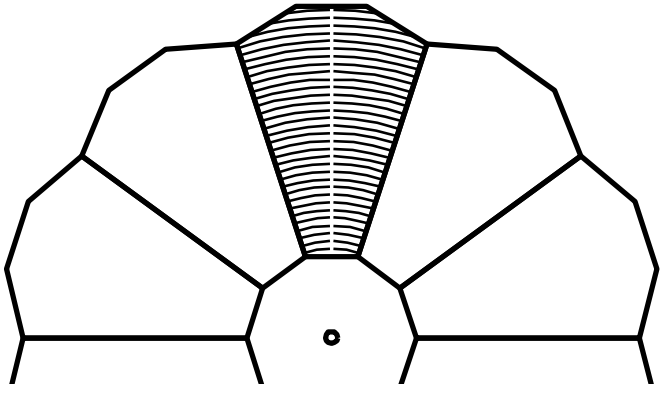
FMD: Silicium strip detektor





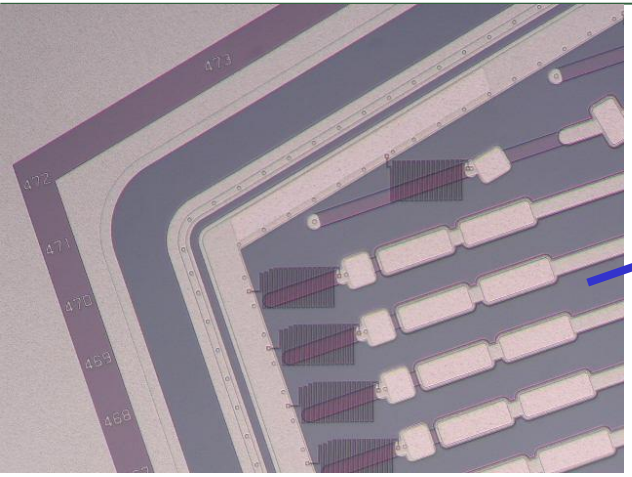
3 indre ringe: 20 φ sektorer, 512 strips
2 ydre ringe: 40 φ sektorer, 256 strips
Total 51,200 strips

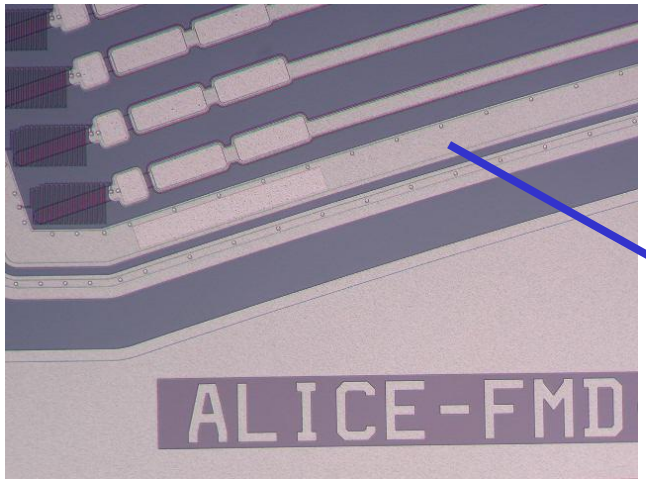


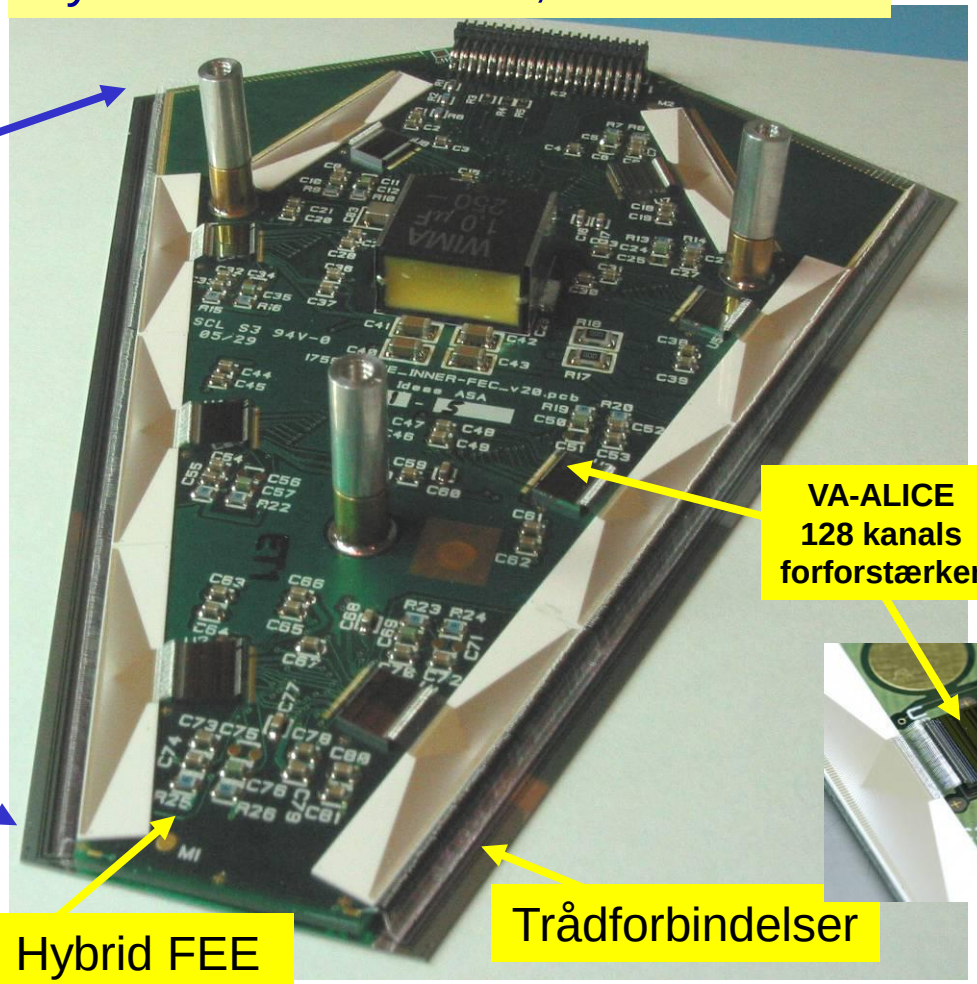


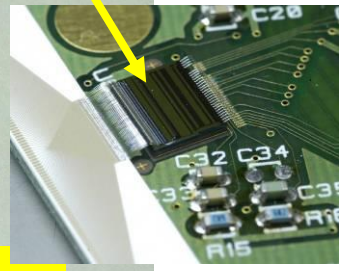
Silicium sensorer og hybrider

Sensorer fra Hamamatsu Photonics
Hybrider fra Ideas AS, Oslo





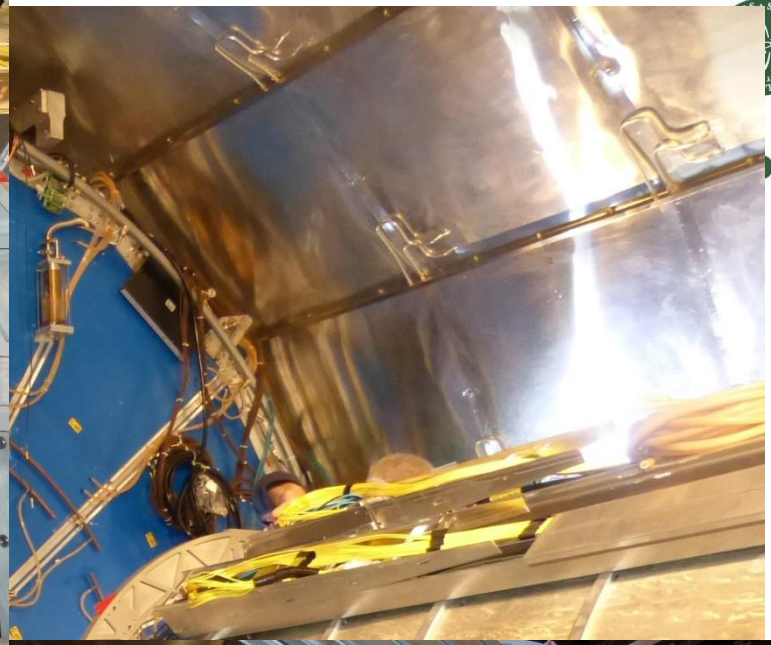


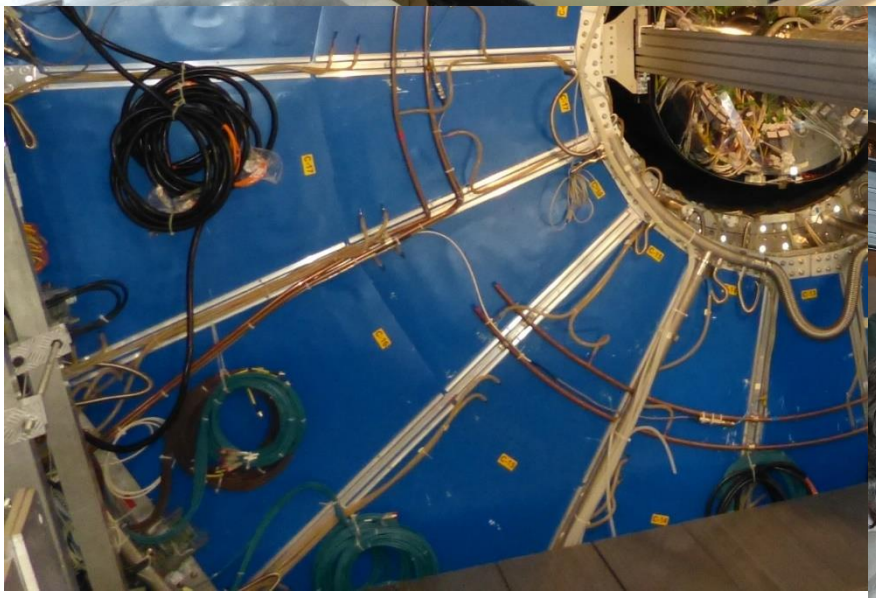


VA-ALICE
128 kanals
forforstærker

Hybrid FEE

Trådforbindelser





ALICE: Hovedtyper af detektorer

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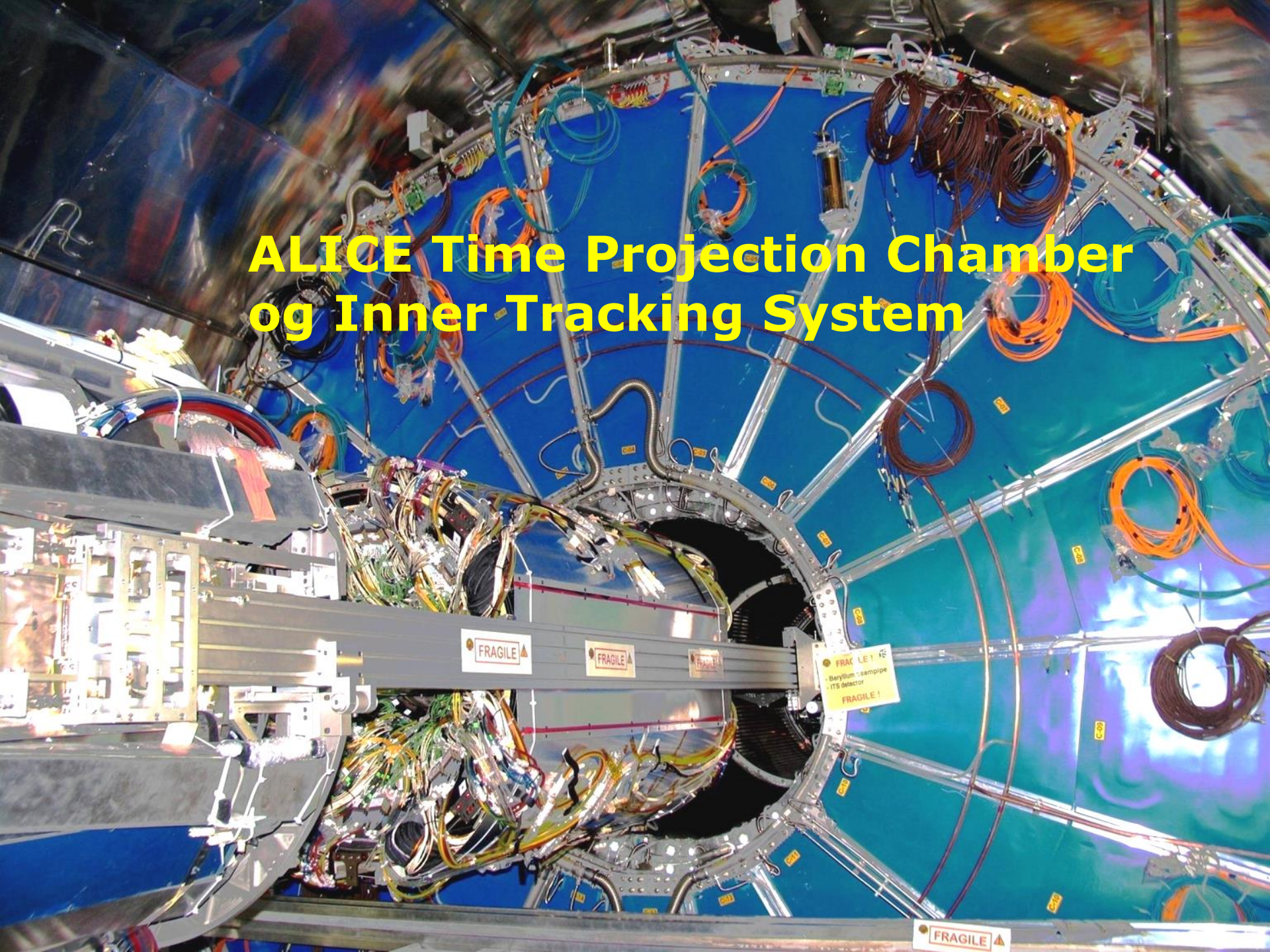
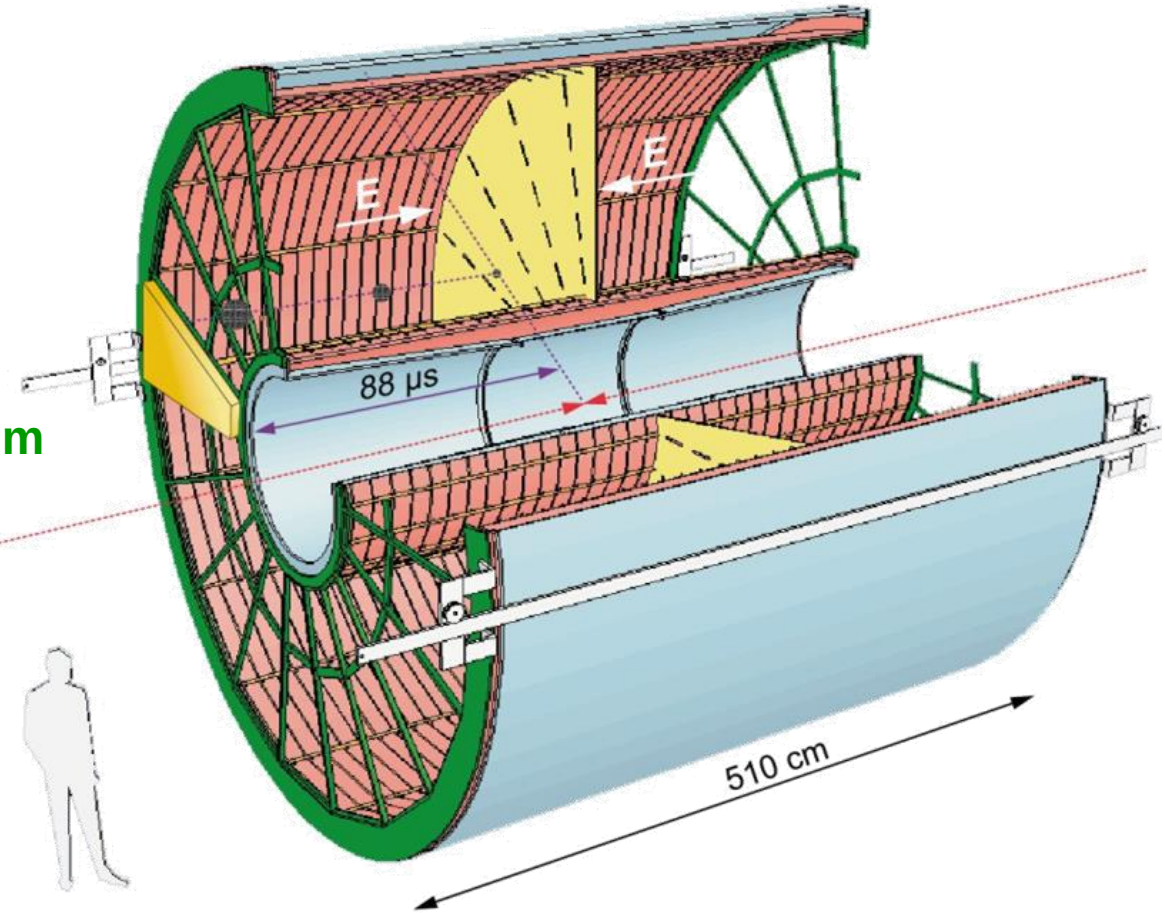
adskil ved vekselvirkning	kalorimetre

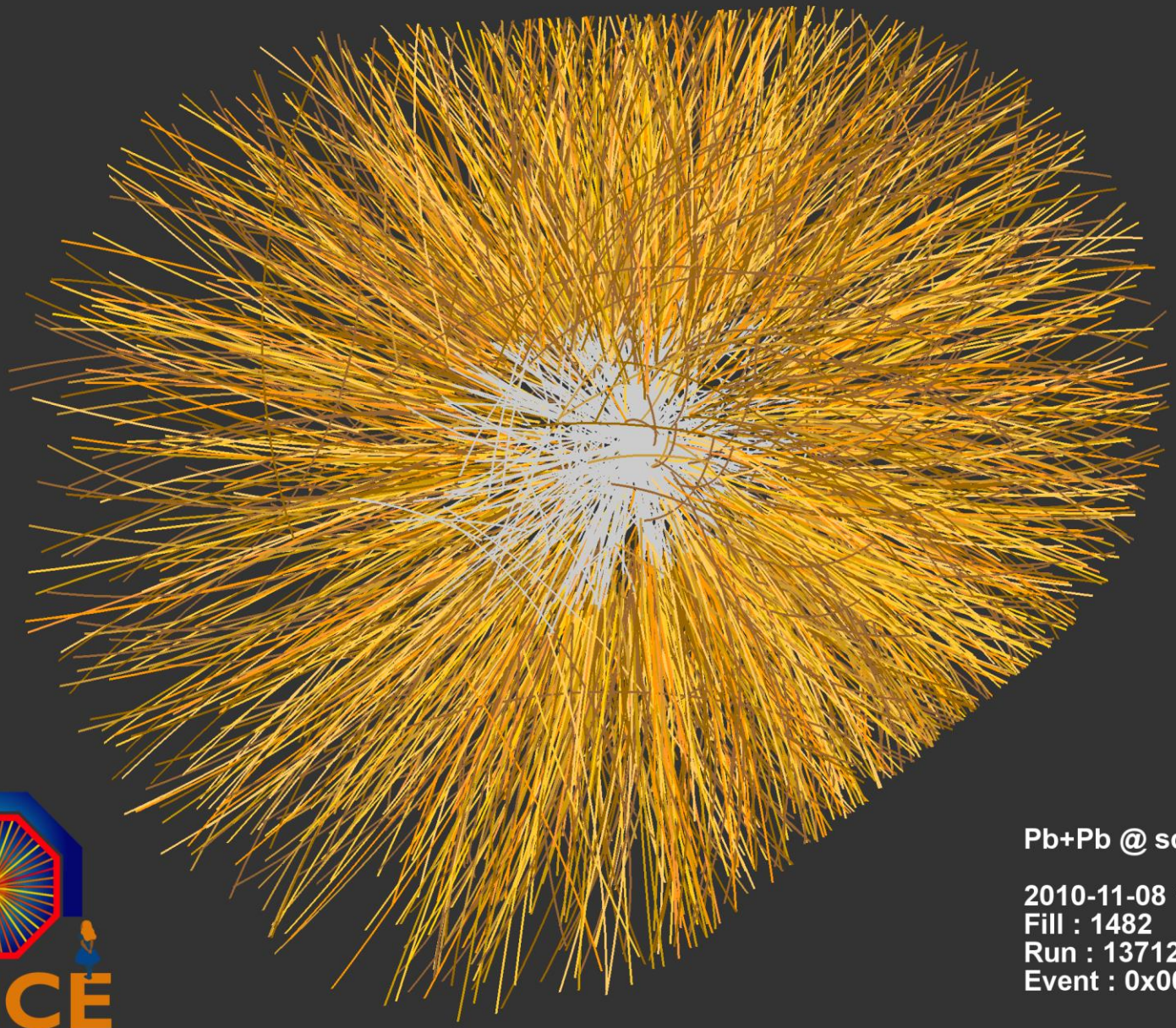

ALICE Time Projection Chamber
og Inner Tracking System
FRAGILE
FRAGILE
FRAGILE
FRAGILE

ALICE Time Projection Chamber

- Active volume 88 m^3
- Gas $Ne/CO_2/N_2$ 90/10/5
- Drift field 400V/cm
- Gas gain $>10^4$
- Position resolution σ= 0.25mm
- Diffusion: σ_t= 250μm $\sqrt{cm}$
- Pads inside: 4x7.5mm
- Pads outside: 6x15mm
- B-field: 0.5T



Et af de første Pb-Pb sammenstød set i ALICE



ALICE

Pb+Pb @ sqrt(s) = 2.76 ATeV

2010-11-08 11:29:42
Fill : 1482
Run : 137124
Event : 0x00000000271EC693

The principle of the laser system for the TPC

Support rings for
μ-mirror bundles

μ-mirror bundle

TPC volume

Central Electrode

Narrow laser beams:
20-40 μJ/pulse, ø 1 mm

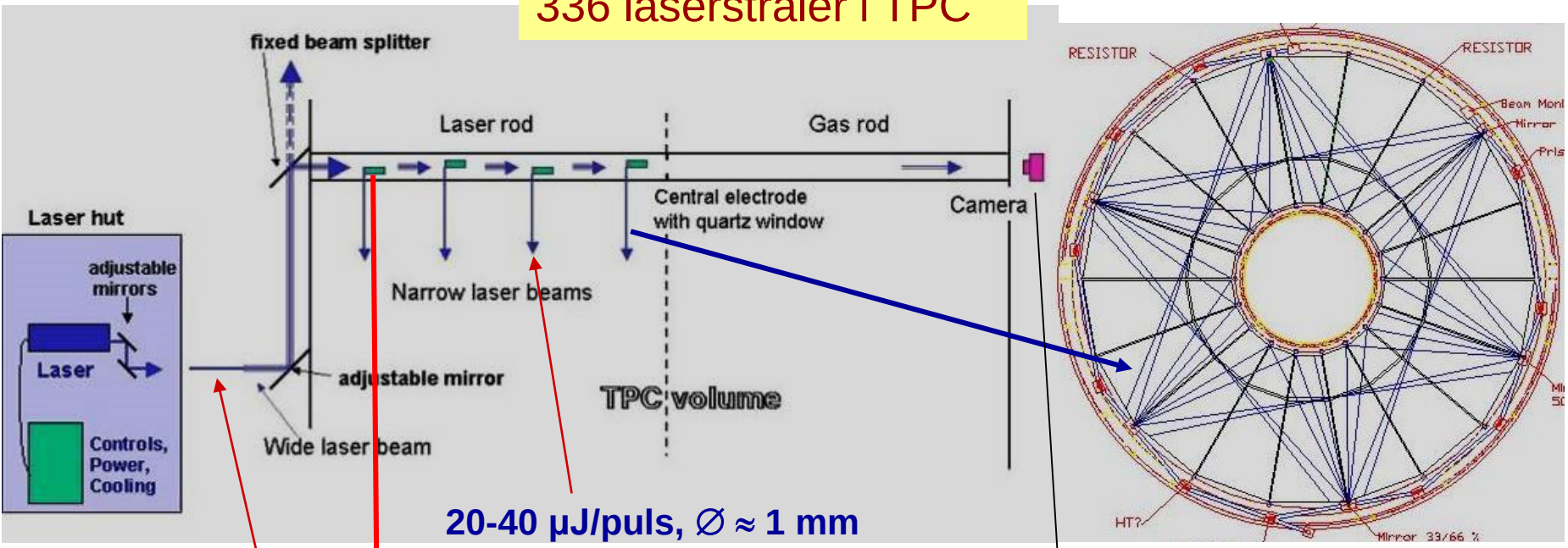
Four shadows of the
μ-mirror bundles

Wide laser beams: 266 nm,
100 mJ/pulse, 5 ns pulse, ø 25 mm

laser beam
splitter
adjustable mirror
prism
camera
rod

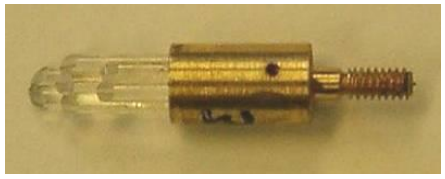
TPC laser kalibration

336 laserstråler i TPC

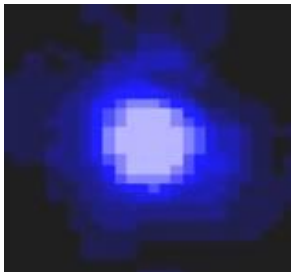


20-40 µJ/puls, ∅ ≈ 1 mm

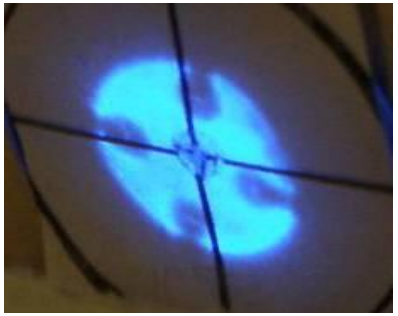
266 nm, 100 mJ/puls, 5 ns puls, ∅ ≈ 25 mm



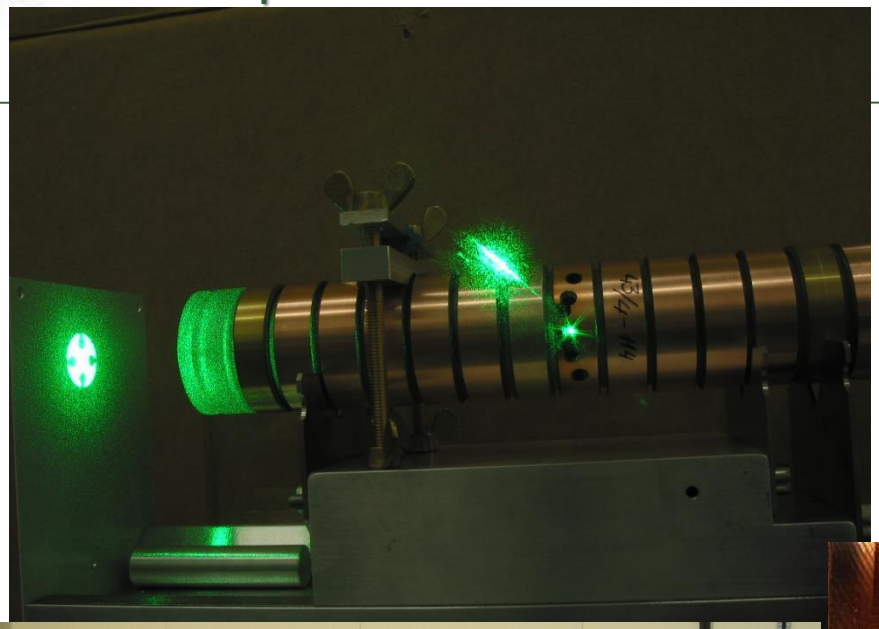
1.5 mm



25 mm



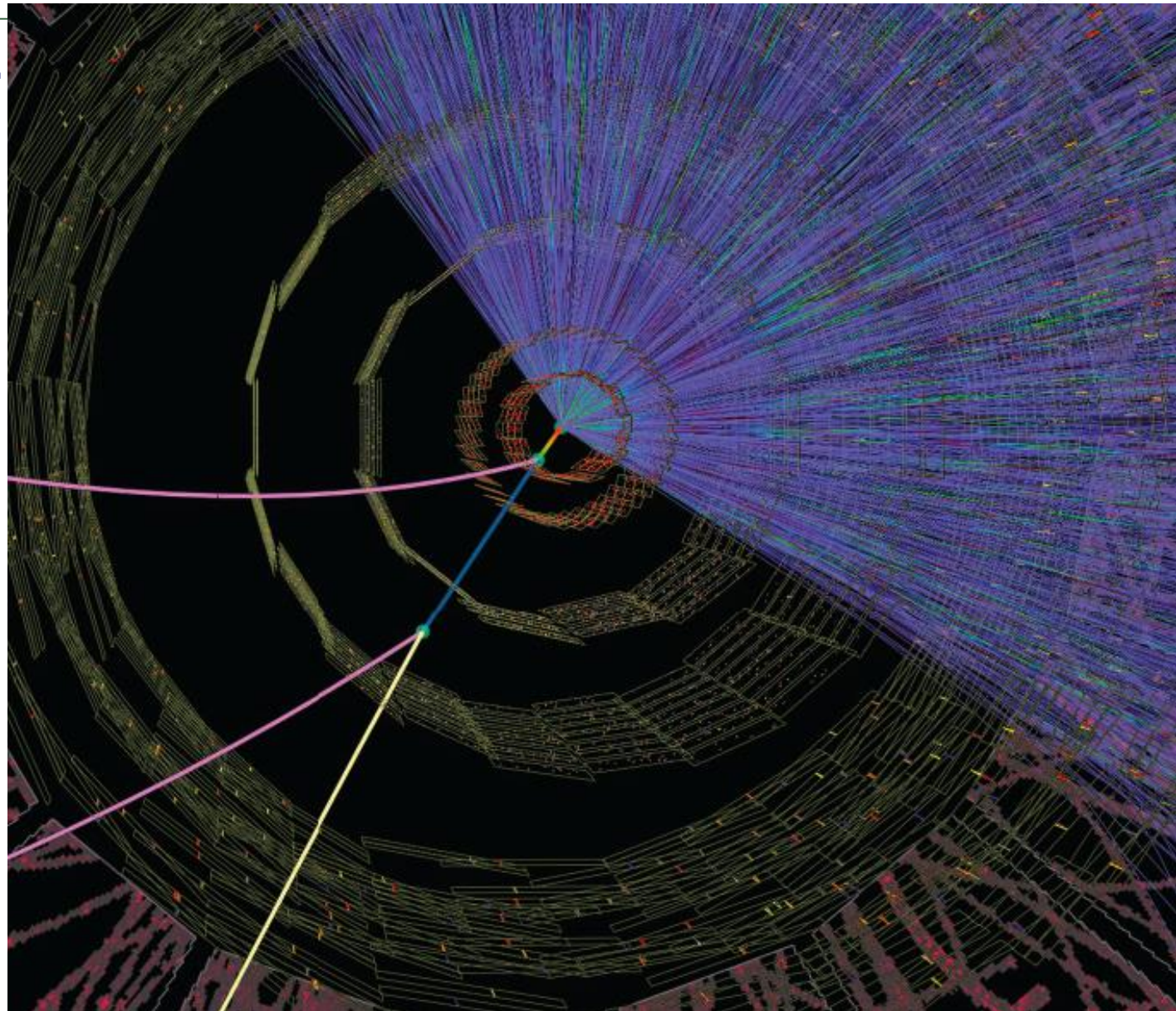
Optiske komponenter indeni TPC volumenet



Godt vi har computere …

i venstre del er en masse 'uinteressante' partikelspor fjernet for at øjet kan se, hvad computeren har fundet:

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



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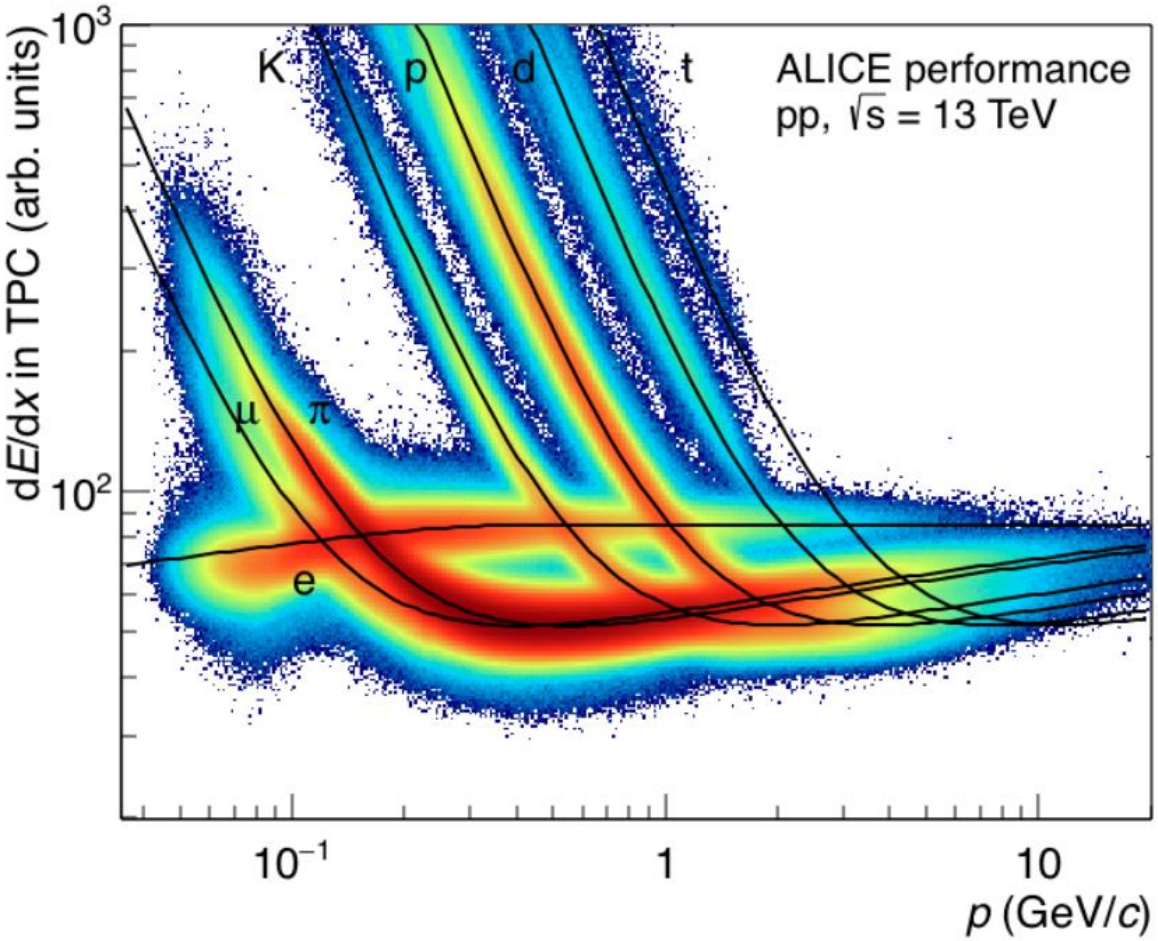
adskil ved vekselvirkning	kalorimetre

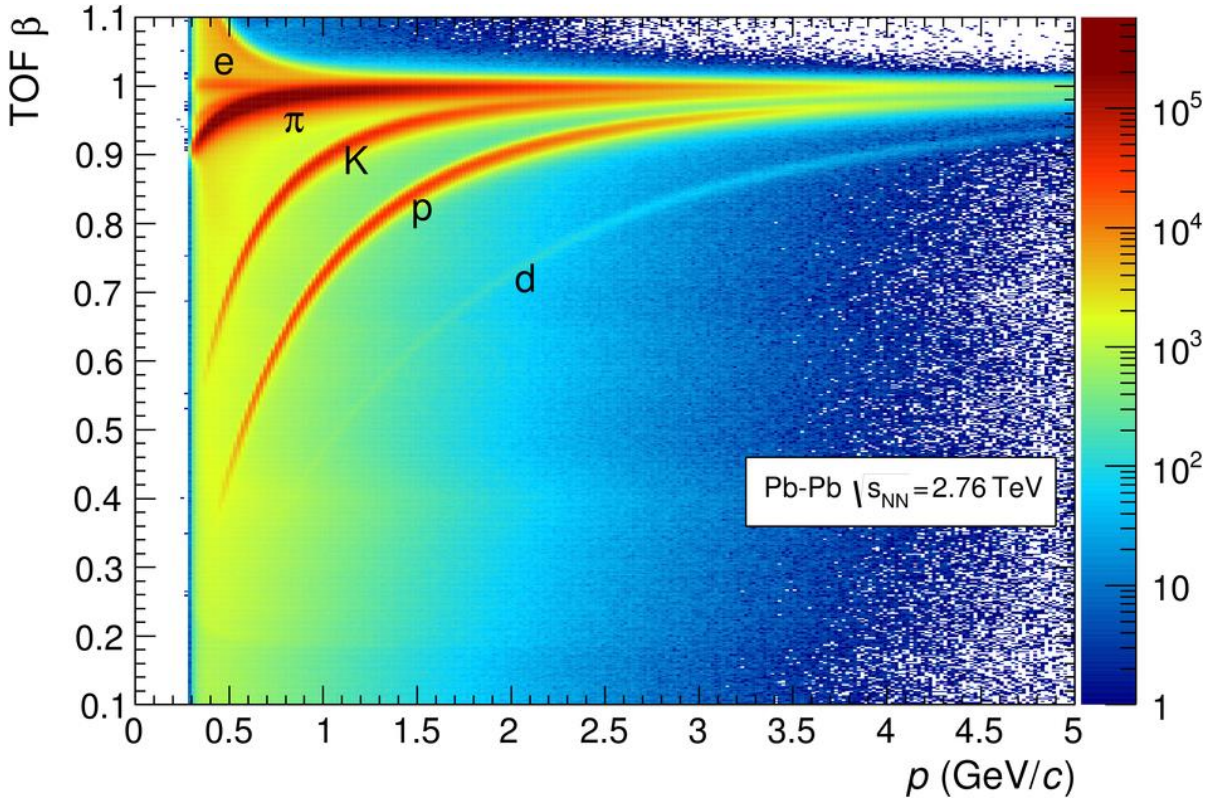
ALICE dE/dx identifikation i TPC

Bethe Bloch:

$$-\frac{dE}{dx} = \frac{D q^2 n_e}{\beta^2}\left[\ln\left(\frac{2m_e c^2\beta^2\gamma^2}{I}\right) - \beta^2 - \frac{\delta(\gamma)}{2}\right]$$



Time-of-Flight detektorer (TOF)



Bestem partiklens masse, m, ved:

$p = \gamma m \beta c$ impuls p måles med en spordetektor i magnetfelt

$\beta c = v = L/T$ måles i en spordetektor + TOF

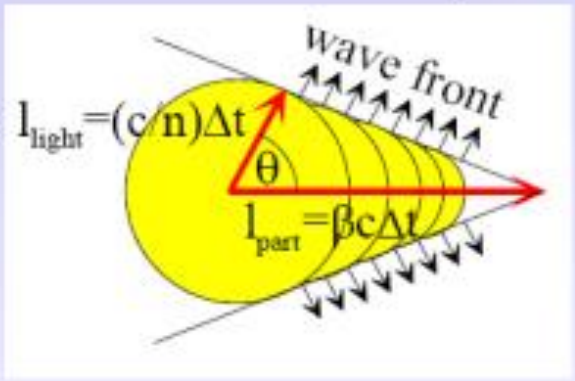
$\gamma = 1/\sqrt{1-\beta^2}$

Cherenkov detektorer

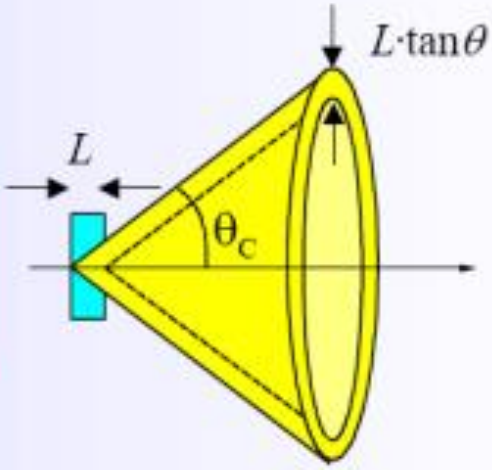
Jane Nielsen, Niels Bohr Institutet

Cherenkov stråling udsendes når en ladet partikel bevæger sig gennem et materiale hurtigere end lyshastigheden i materialet (chockbølge).

with velocity $\beta \geq \beta_{thr} = \frac{1}{n}$ n : refractive index



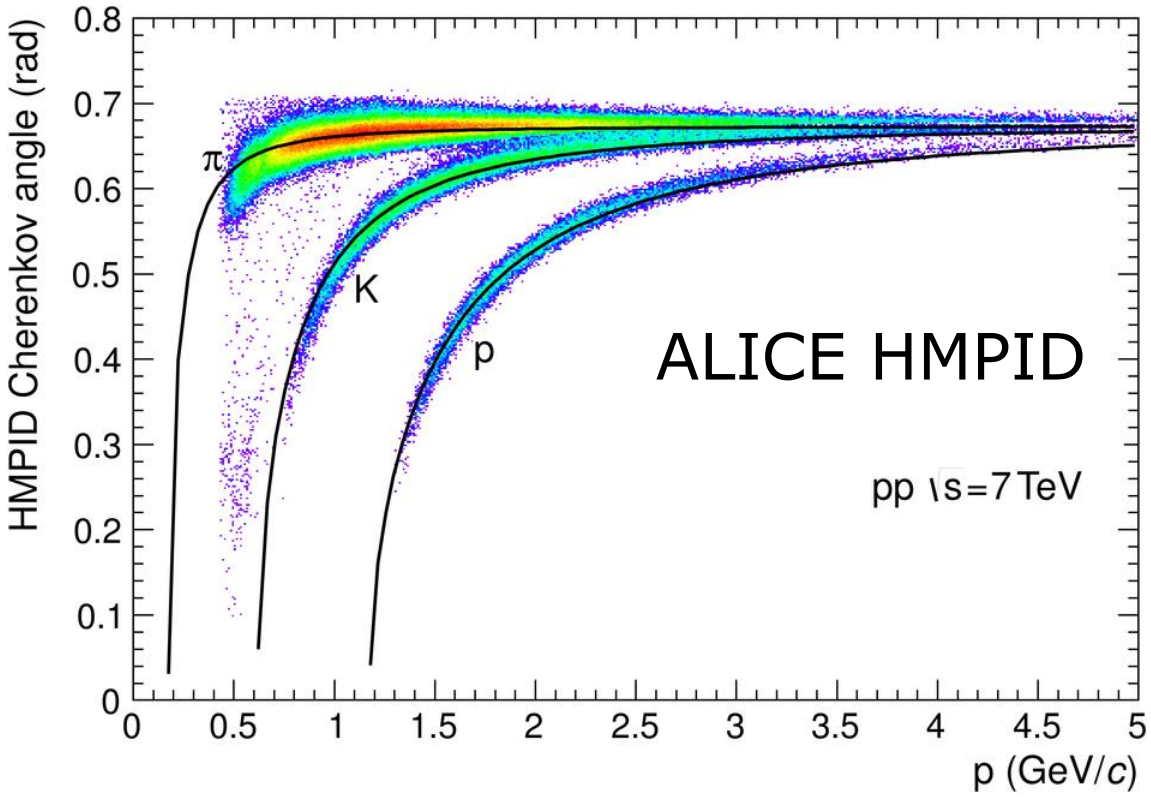
$$\cos\theta_C = \frac{1}{n\beta}$$
with $n = n(\lambda) \geq 1$

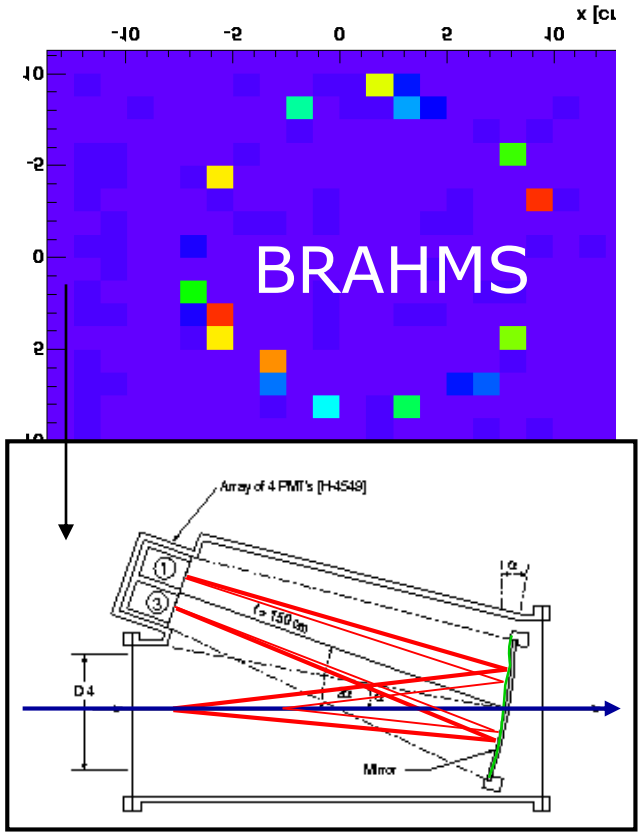


- $\beta_{thr} = \frac{1}{n} \rightarrow \theta_C \approx 0$ Cherenkov threshold
- $\theta_{max} = \arccos\frac{1}{n}$ 'saturated' angle (β=1)

Cherenkov detektorer bruges som
-- tærskel tællere
-- Ring Imaging CHerenkov (RICH) detektorer

Ring Imaging Cherenkov detektorer





Ringens radius i en RICH afhænger af hastigheden.

En RICH bruges til at identificere hadroner direkte eller som VETO-tæller.

ALICE: Hovedtyper af detektorer

- og deres formål:

a. Tids- og hit-målere:

start tid / trigger	scintillationstællere
koincidens	silicium detektorer

b. Spordetektorer:

impulsmåling	gasdetektorer
henfald (V's and "kinks")	silicium detektorer

c. Partikel-identifikation:

adskil efter masse	dE/dx (ionisering)
	time-of-flight (TOF)
	Cherenkov detektorer
adskil ved vekselvirkning	kalorimetre

Elektromagnetiske eller hadroniske kalorimetre

LHC og de to "danske" LHC eksperimenter