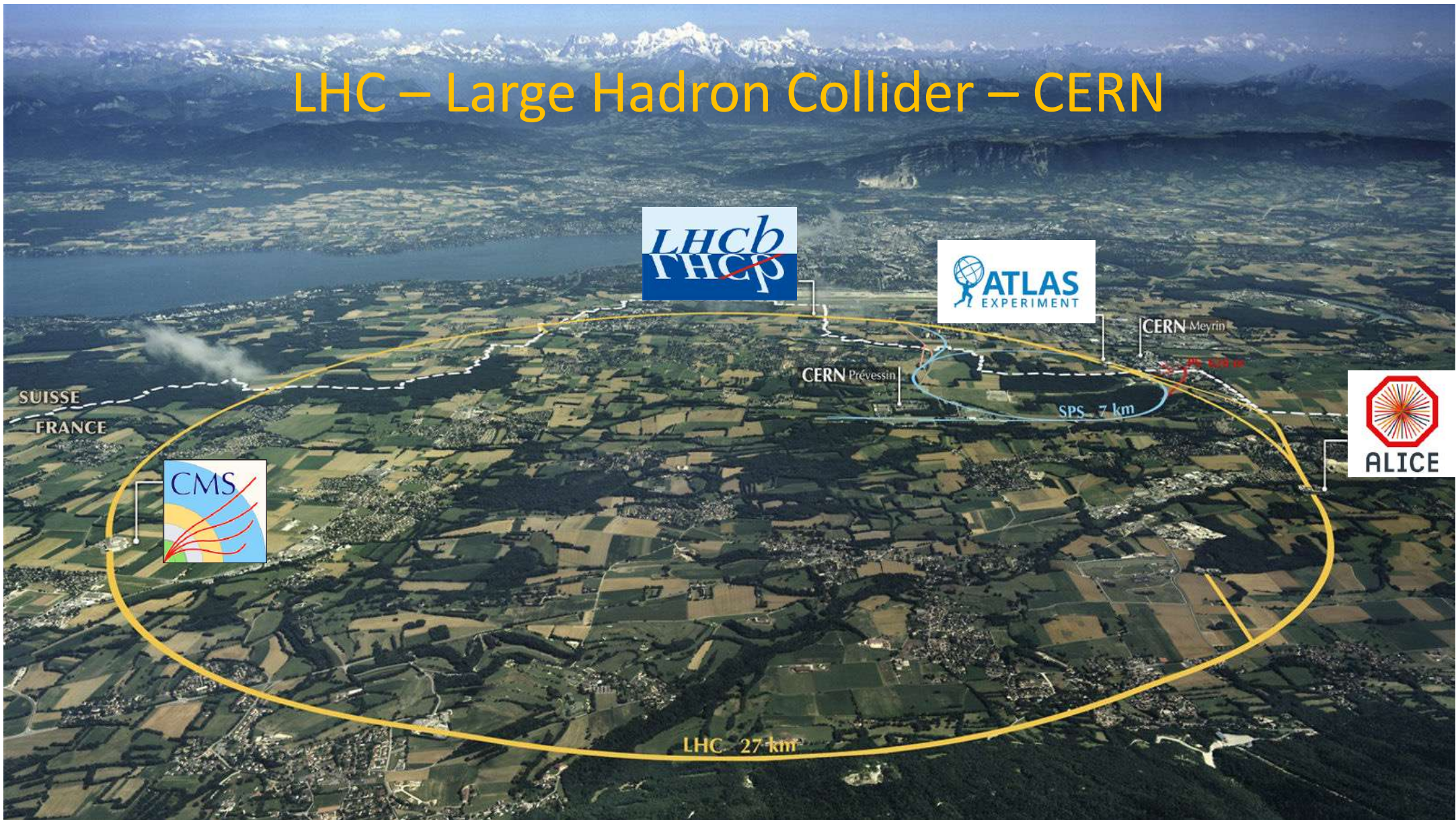


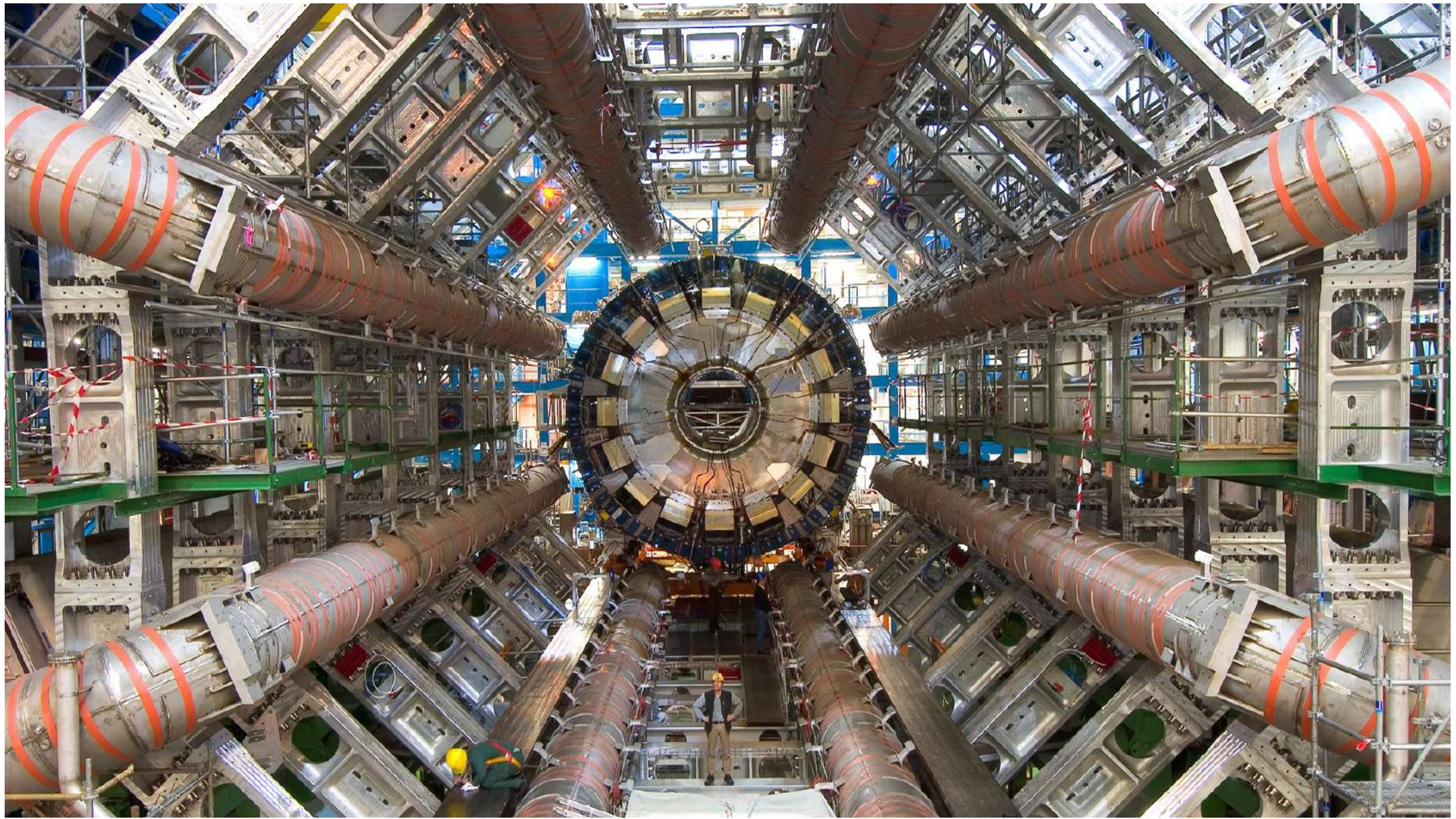
Rivelatori di Particelle

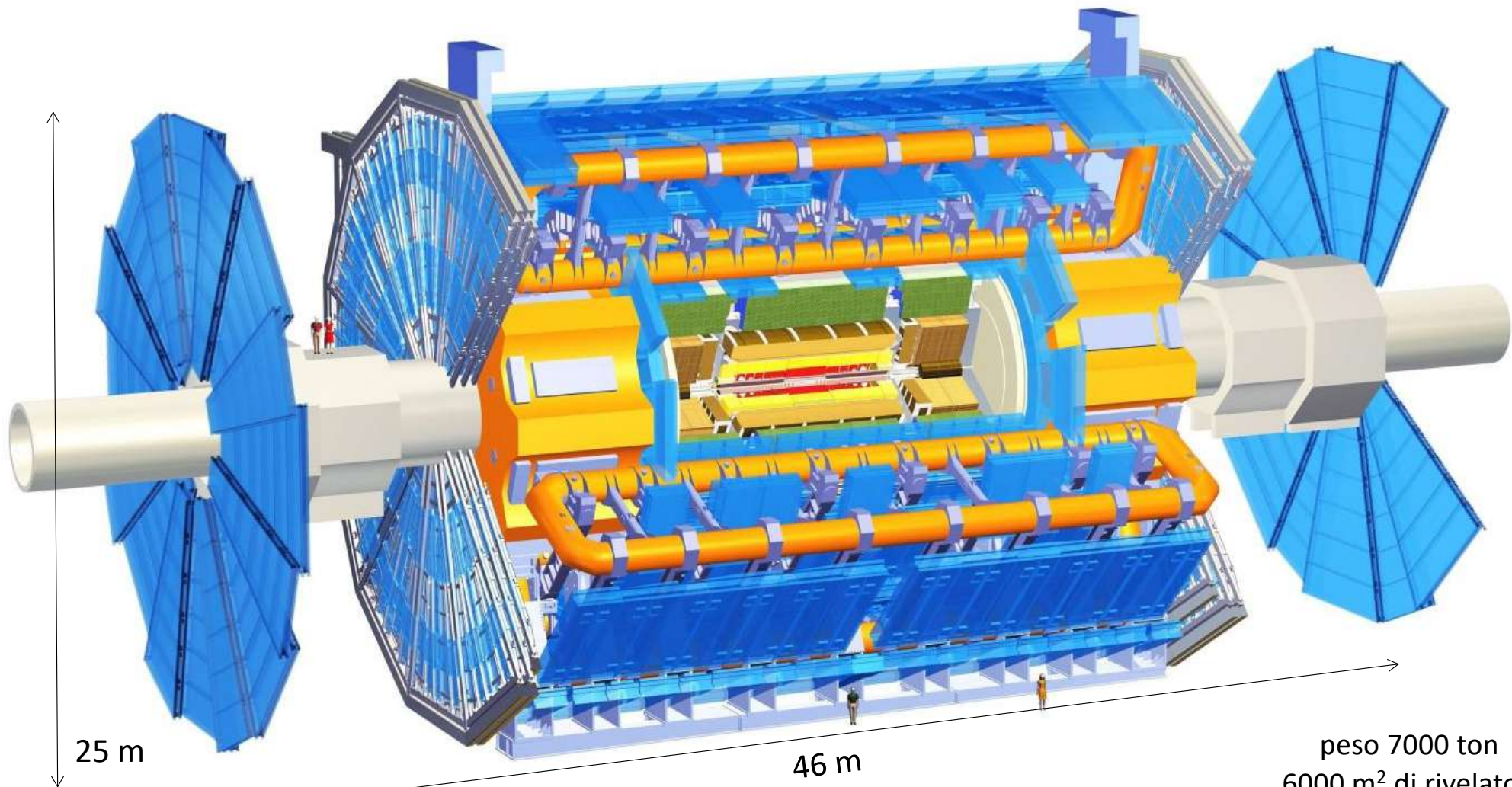
Danilo Domenici



LHC – Large Hadron Collider – CERN





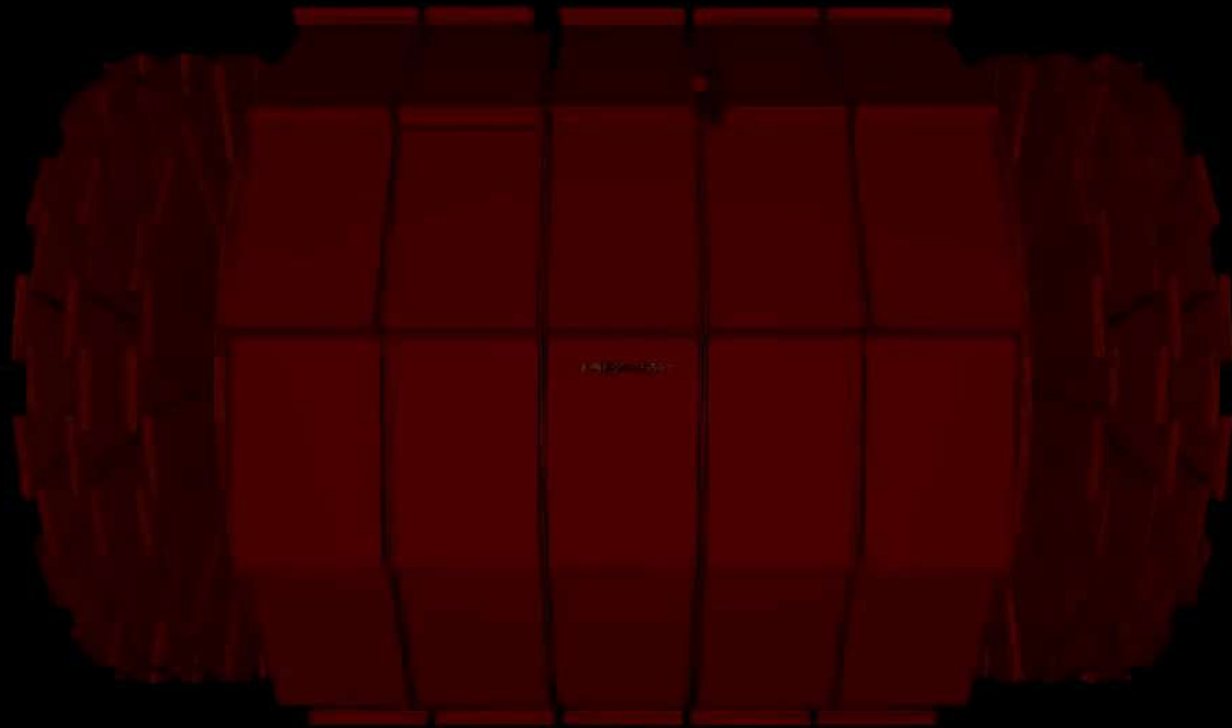


25 m

46 m

peso 7000 ton
6000 m² di rivelatori
3000 ricercatori
38 paesi del mondo

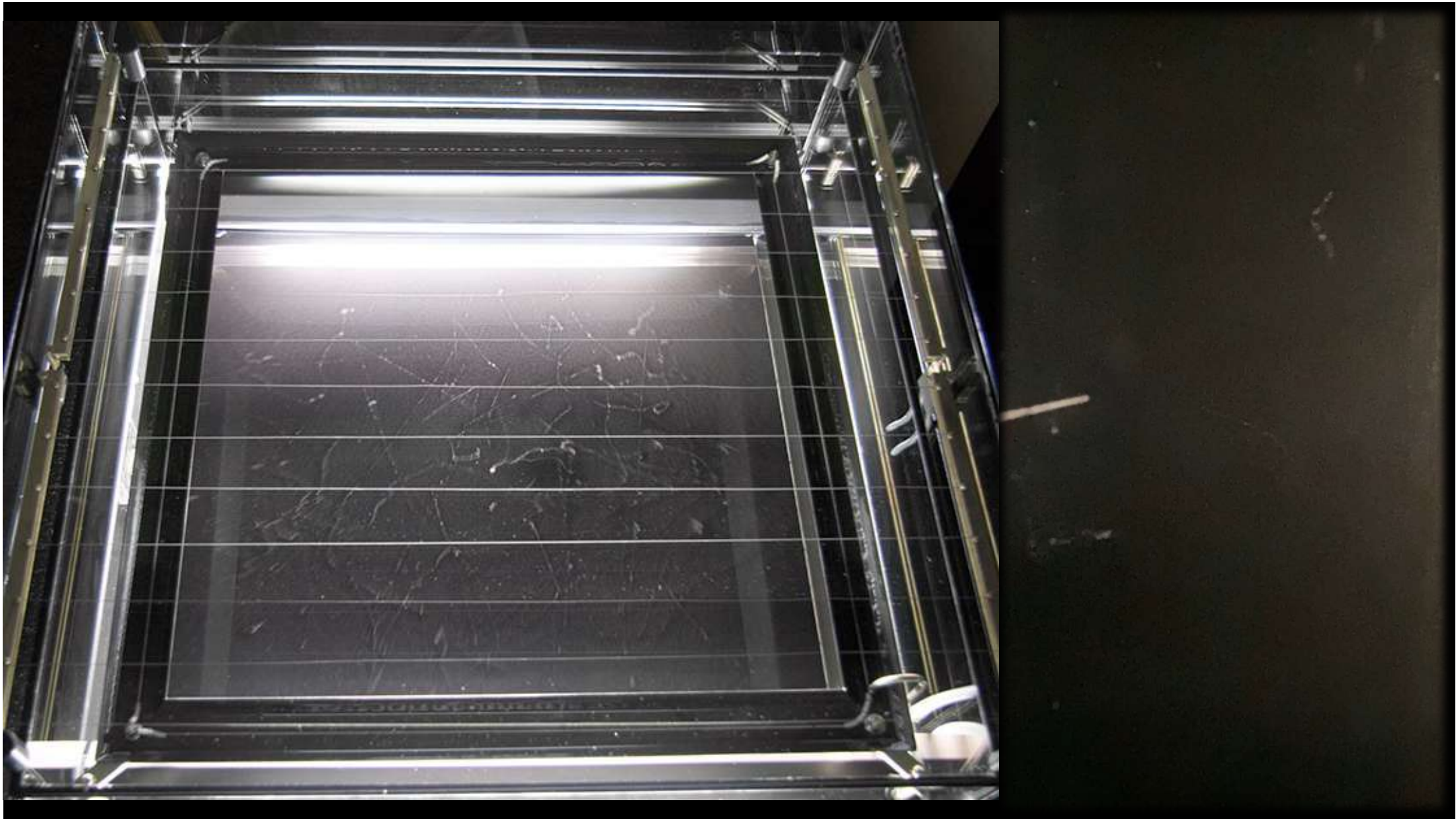
CMS Experiment at the LHC, CERN
Tue 2010-Mar-30 13:23:00 CET
Run 132440 Event 4285681
C O M Energy 7 00TeV



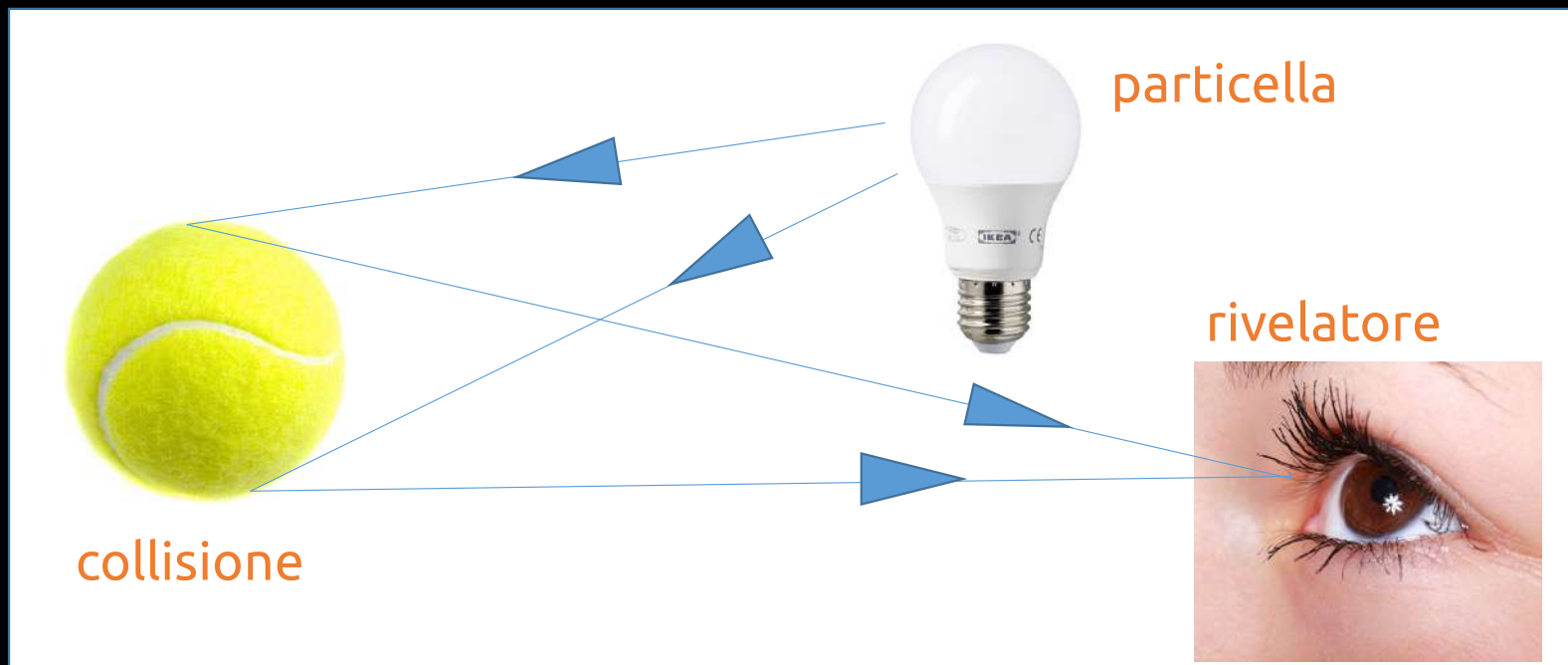
mappa concettuale





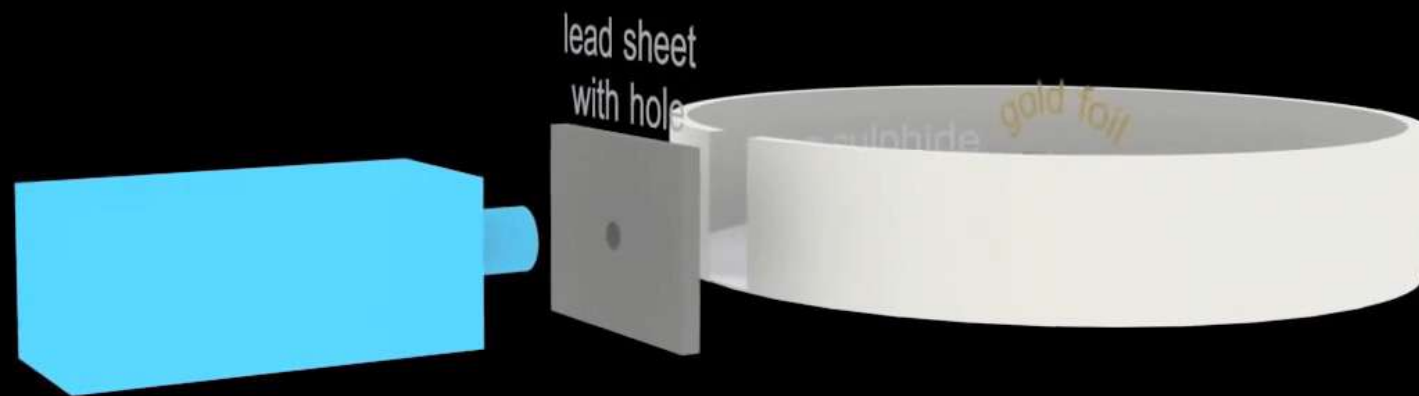


perché facciamo collidere le particelle?

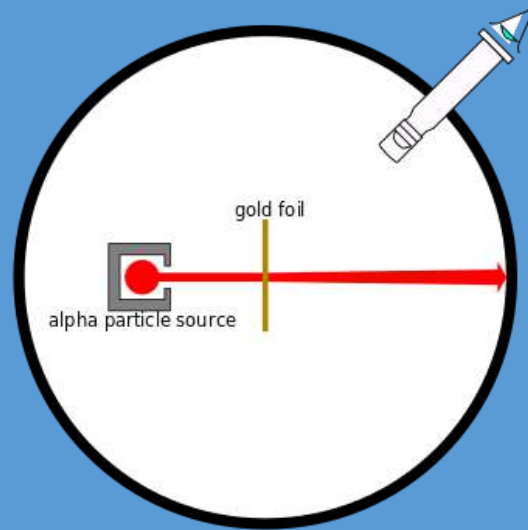
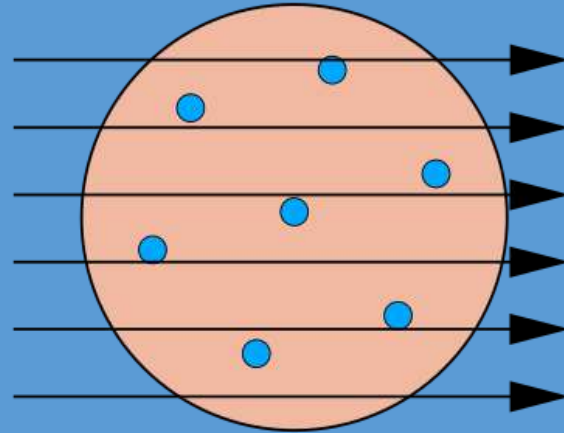


per capire come è fatta la materia

esperimento di rutherford



THOMSON MODEL



perché le facciamo collidere
a energia sempre più alta?

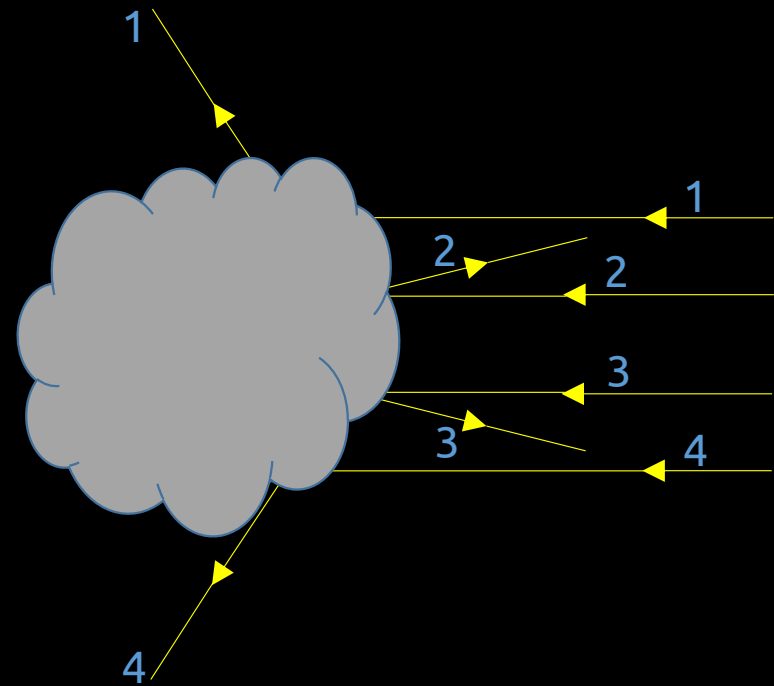
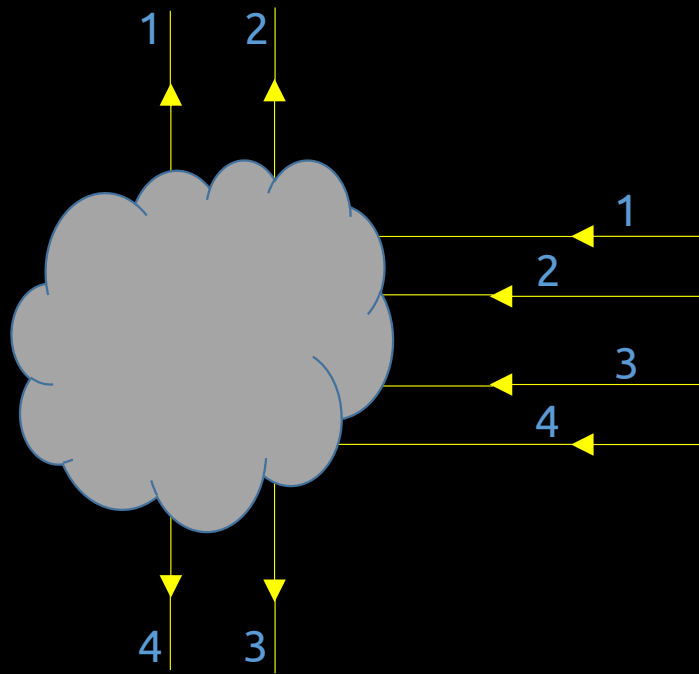
$$\lambda = \frac{h}{p}$$

diminuisce la lunghezza
che posso studiare

$$E = mc^2$$

aumenta la nuova materia
che posso creare

come vediamo l'invisibile



u

quark up

c

quark charm

\bar{u}

quark
anti-up

\bar{c}

quark
anti-charm

\bar{t}

quark
anti-top

d

quark down

s

quark strange

\bar{d}

quark
anti-down

\bar{s}

quark
anti-strange

\bar{b}

quark
anti-bottom

e^-

elettrone

μ^-

muone

e^+

anti-elettrone
(positrone)

μ^+

anti-muone

τ^+

anti-tau

ν_e

neutrino
elettronico

ν_μ

neutrino
muonico

$\bar{\nu}_e$

anti-neutrino
elettronico

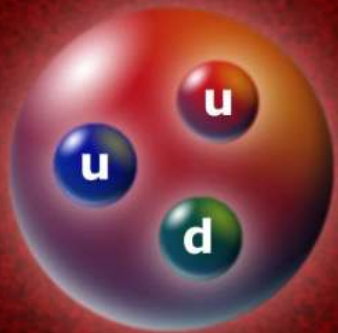
$\bar{\nu}_\mu$

anti-neutrino
muonico

$\bar{\nu}_\tau$

anti-neutrino
tau

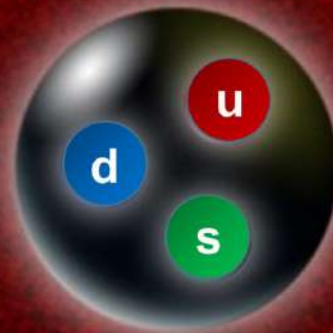
Barioni - 3 quark



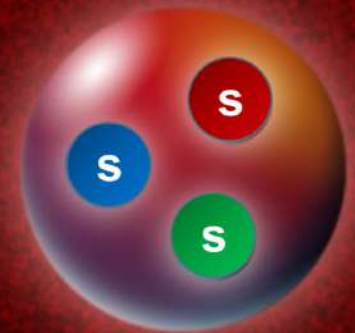
proton



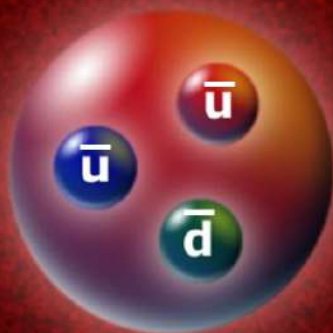
neutron



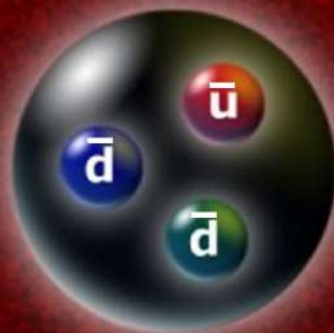
lambda



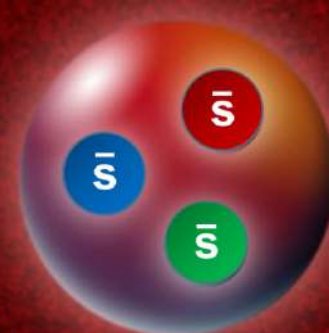
sigma



antiproton



antineutron

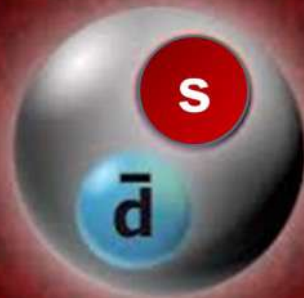


antistigma

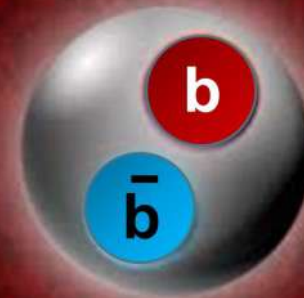
Mesoni - 1 quark 1 antiquark



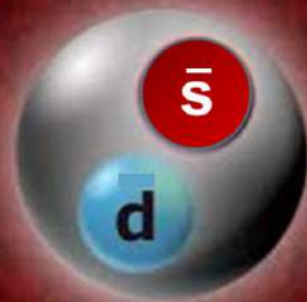
pion



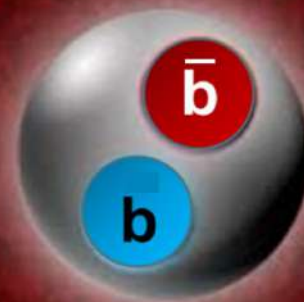
kaon



upsilon



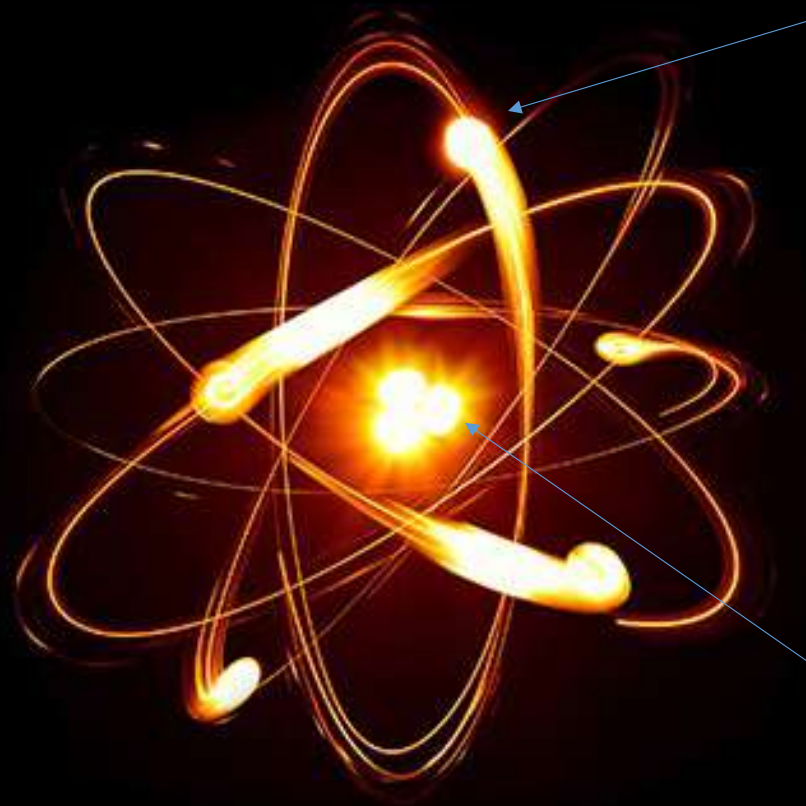
antikaon



upsilon

interazione radiazione-materia

tipi diversi
di particelle
possono interagire
con gli elettroni
o con il nucleo



elettroni
carica elettrica negativa

nucleo
carica elettrica positiva
carica forte

interazione radiazione-materia

particelle direttamente rivelabili

e

elettrone

p

protone

n

neutrone

γ

fotone

particelle stabili

μ

muone

π

pione

K

kaone

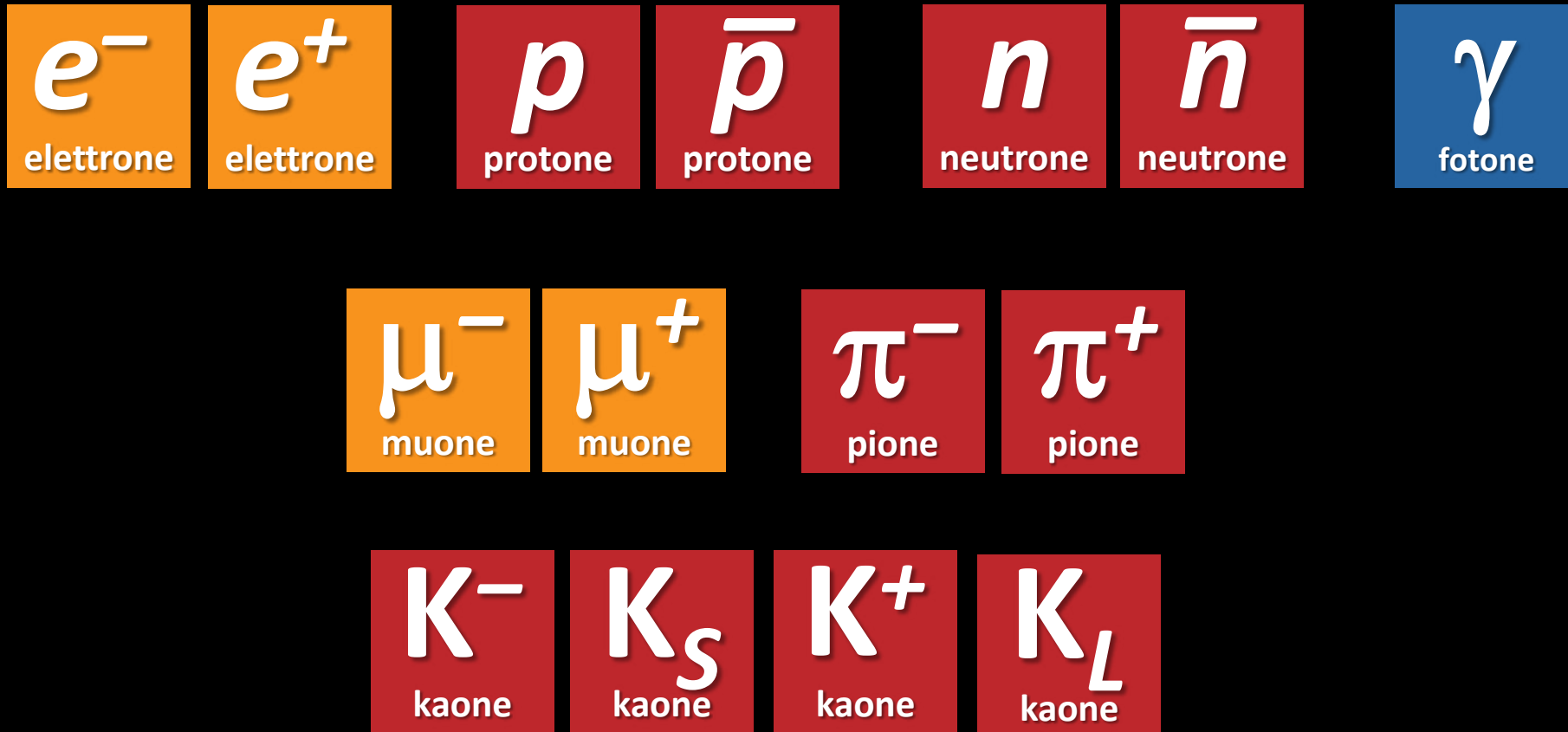
particelle con vita media $> 10^{-10}$ s

tutte le particelle con vita media $< 10^{-10}$ s
si identificano attraverso i loro prodotti di decadimento



interazione radiazione-materia

particelle e antiparticelle direttamente rivelabili



interazione radiazione-materia

urti con gli elettroni – forza elettromagnetica



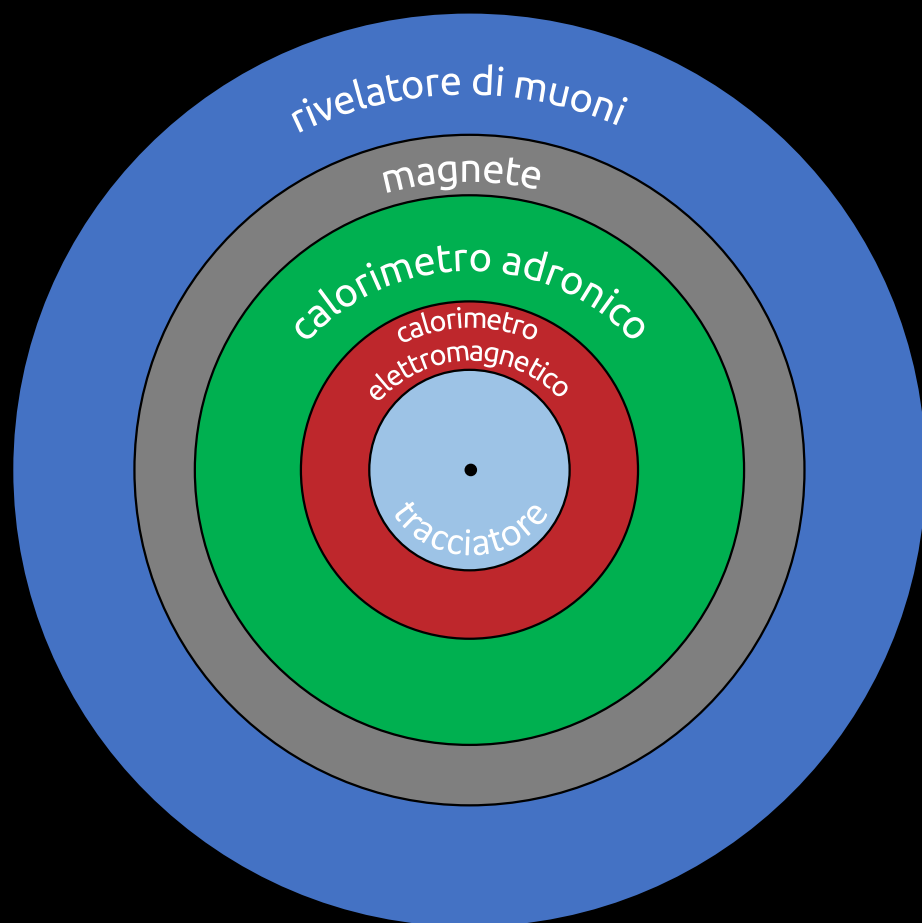
urti con il nucleo – forza forte



produzione di coppie e^+e^-



apparato di rivelazione ermetico



Rivelatore di Vertice o Tracciatore Interno
rivela le particelle cariche
e ne misura la quantità di moto

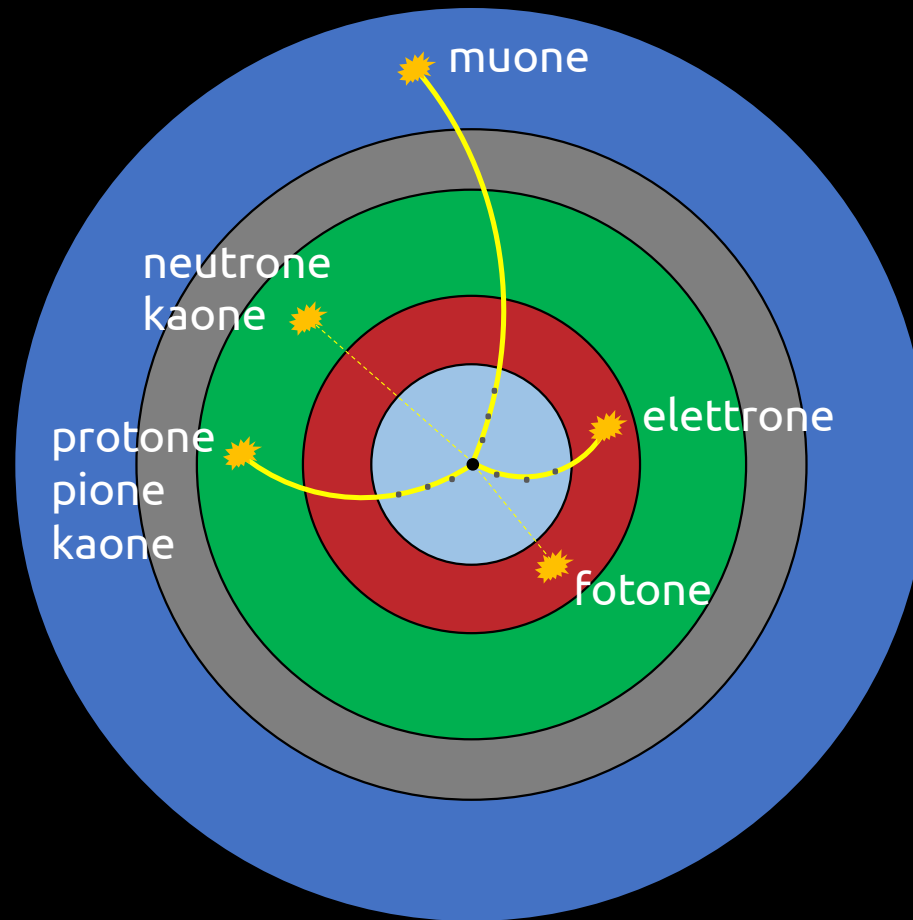
Calorimetro Elettromagnetico
rivela elettroni e fotoni
e ne misura l'energia

Calorimetro Adronico
rivela protoni, neutroni, pioni, kaoni
e ne misura l'energia

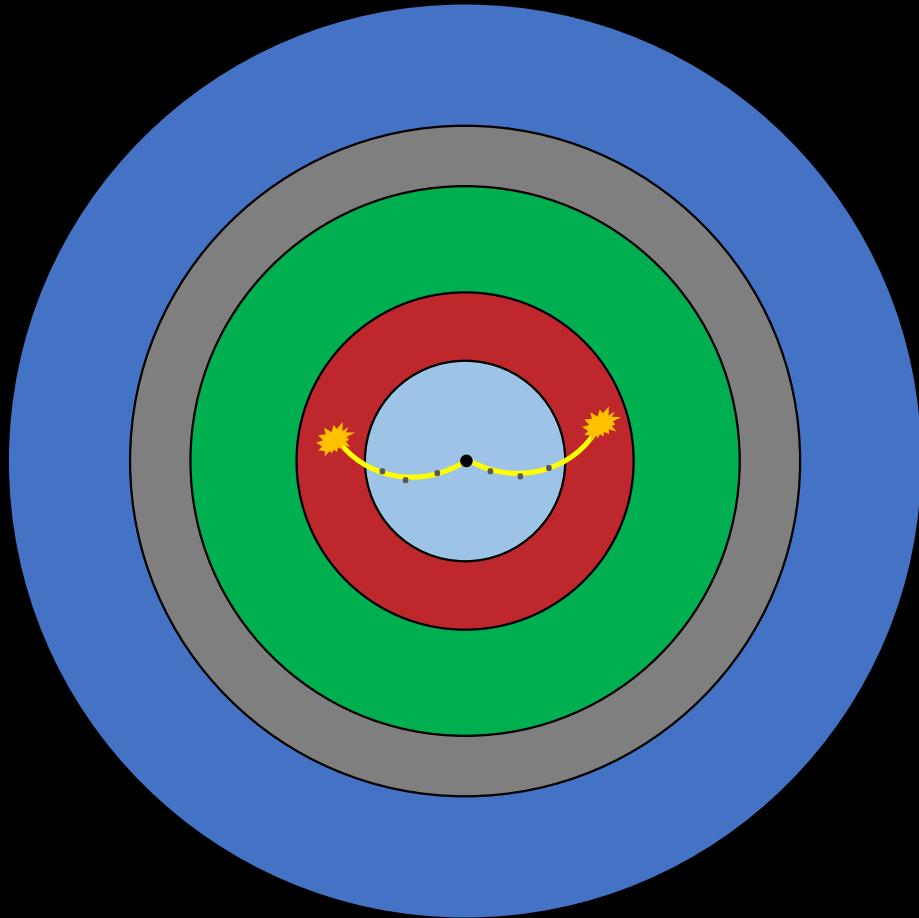
Magnete
curva le particelle cariche
e ne permette la misura della quantità di moto

Rivelatore di Muoni
rivela i muoni

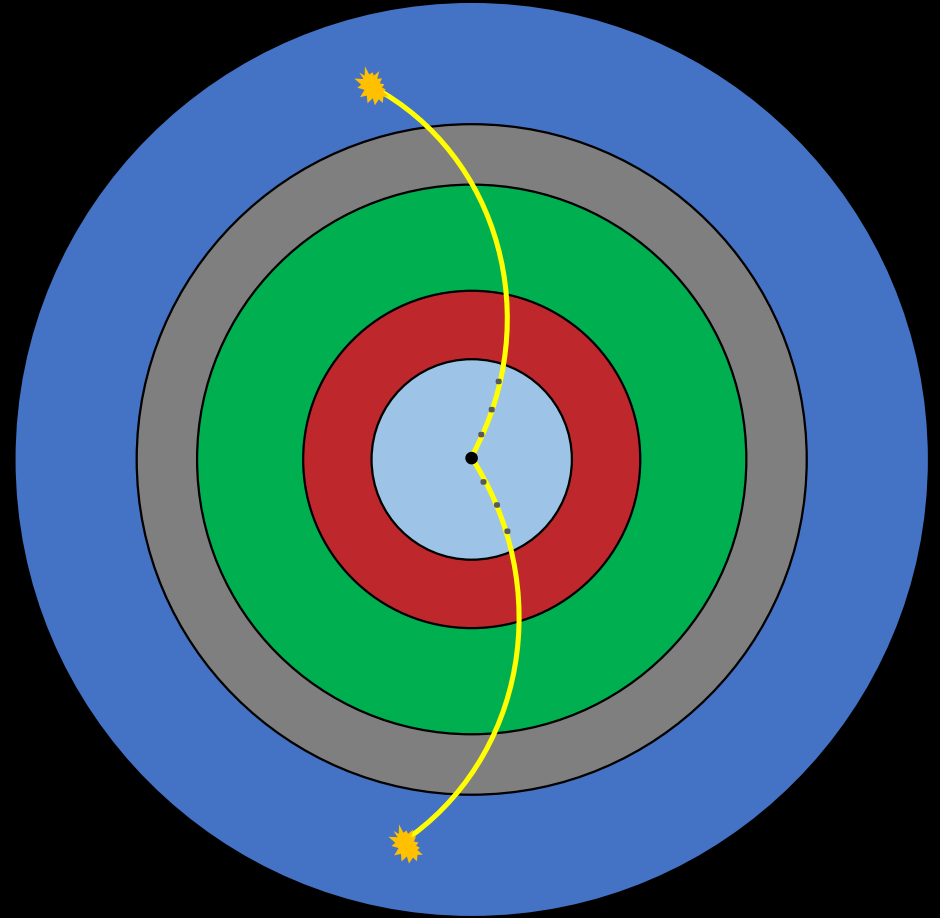
identificazione delle particelle



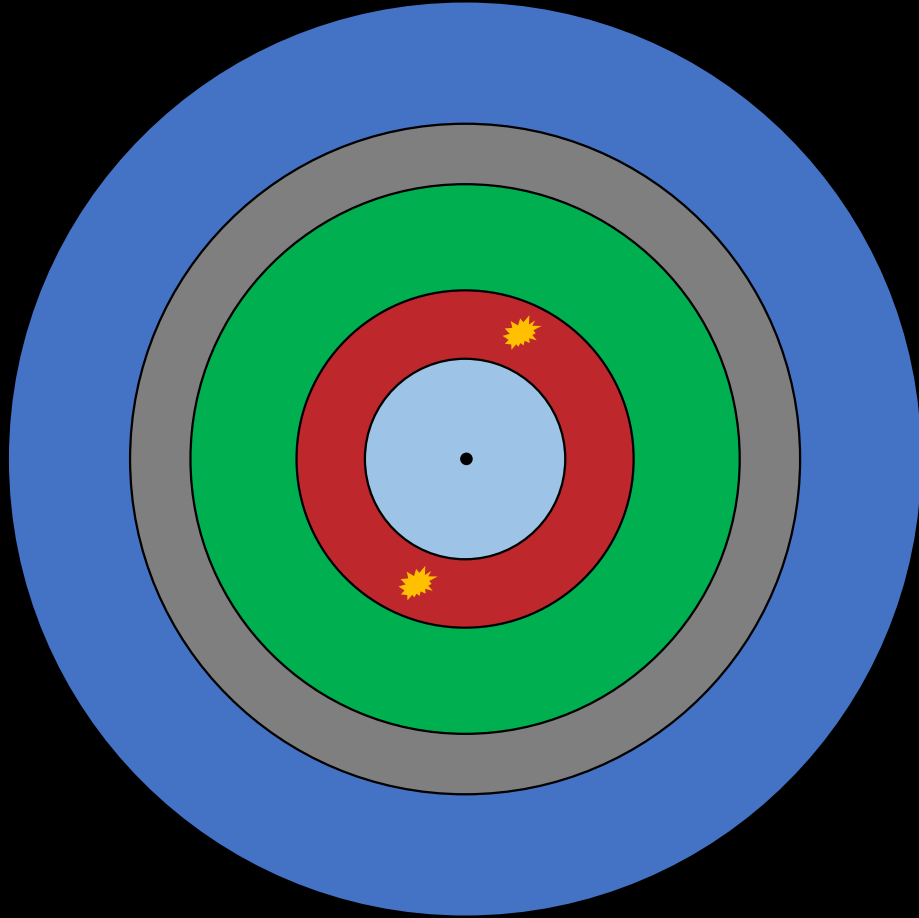
$$e^+ e^- \rightarrow e^+ e^-$$



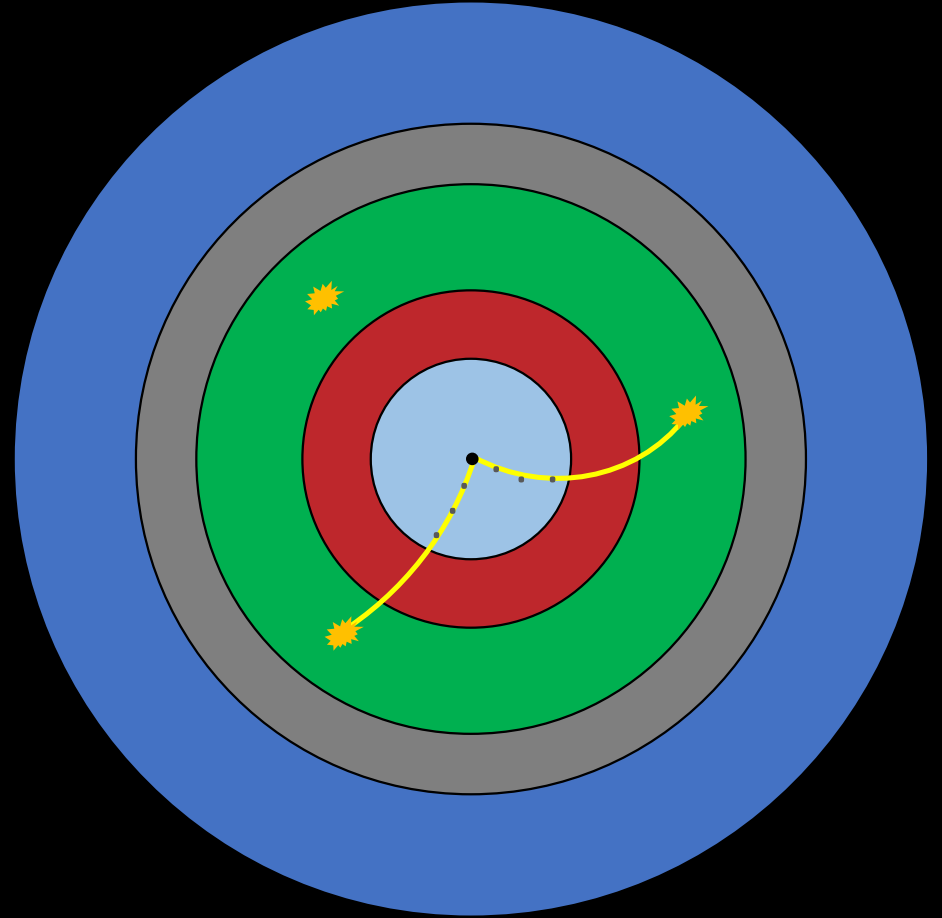
$$e^+ e^- \rightarrow \mu^+ \mu^-$$

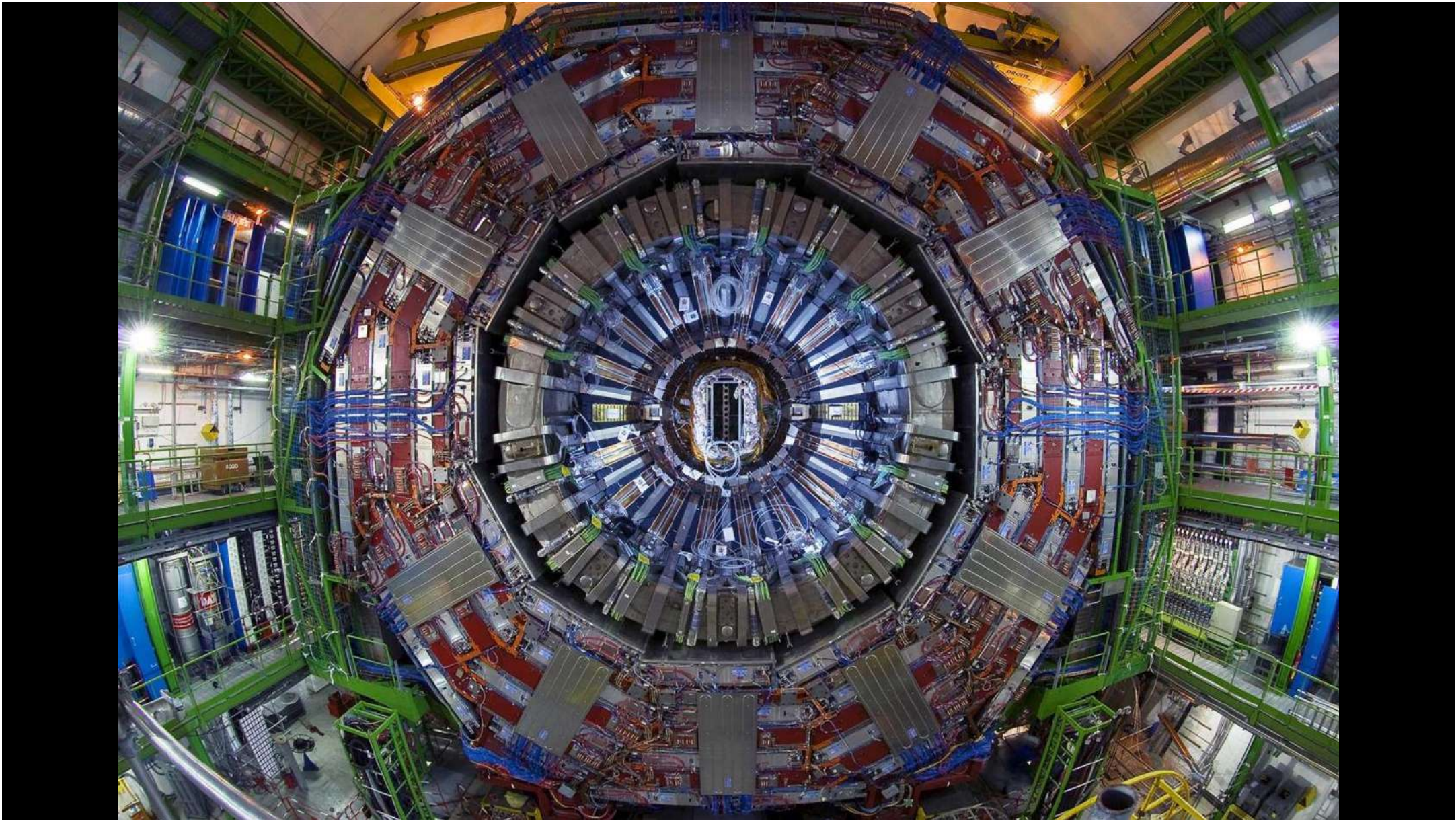


$$e^+ e^- \rightarrow \gamma \gamma$$

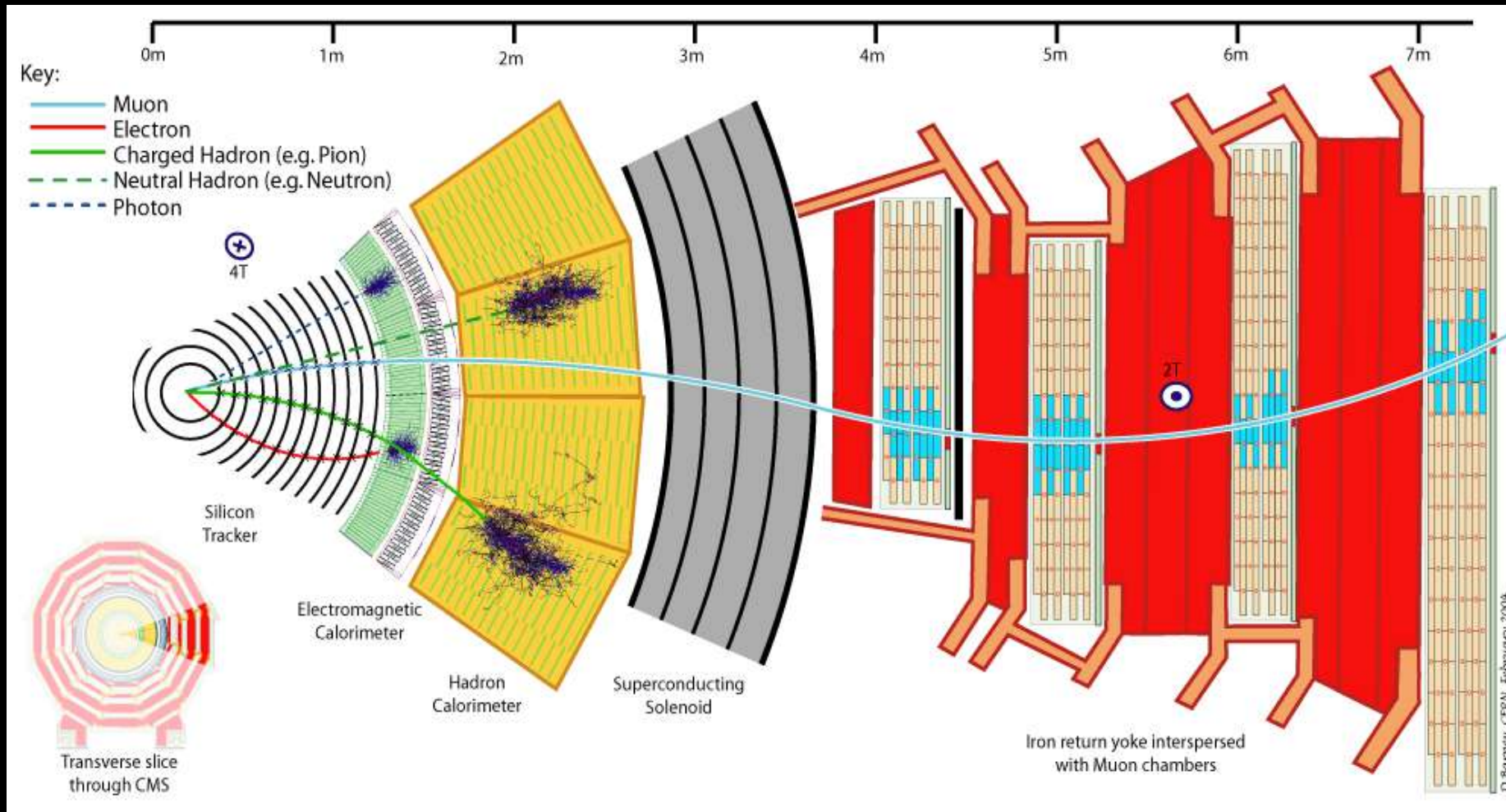


$$e^+ e^- \rightarrow \pi^+ \bar{p} n$$

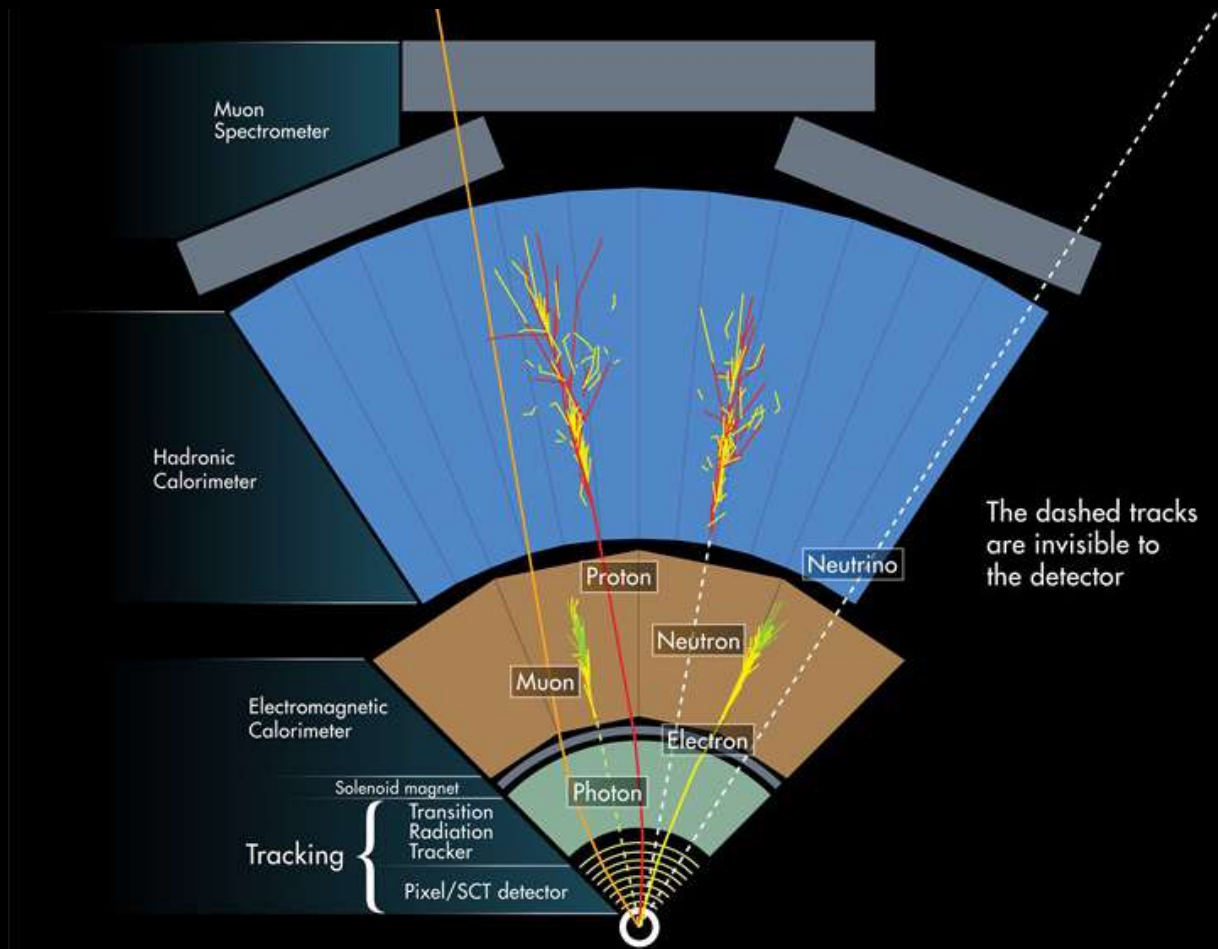


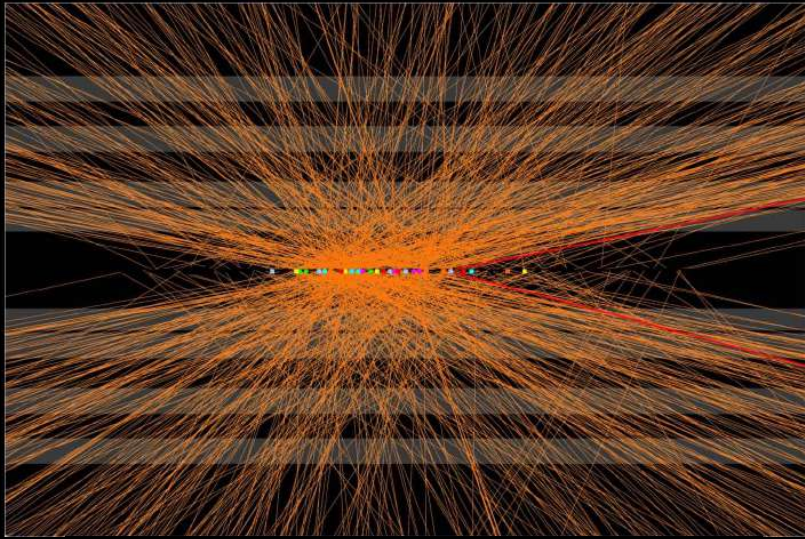


il rivelatore cms a lhc



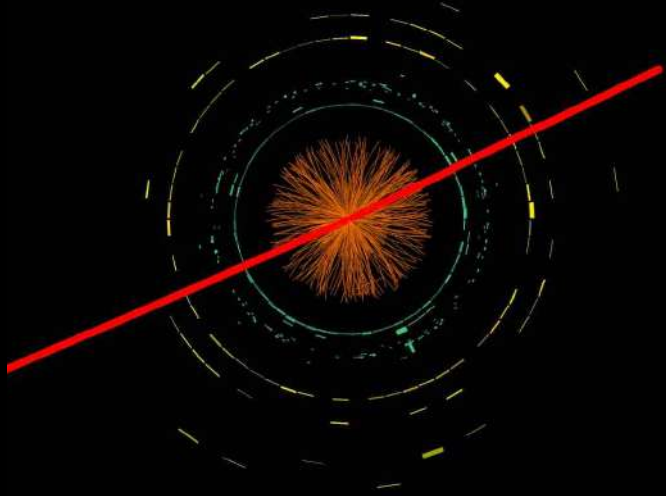
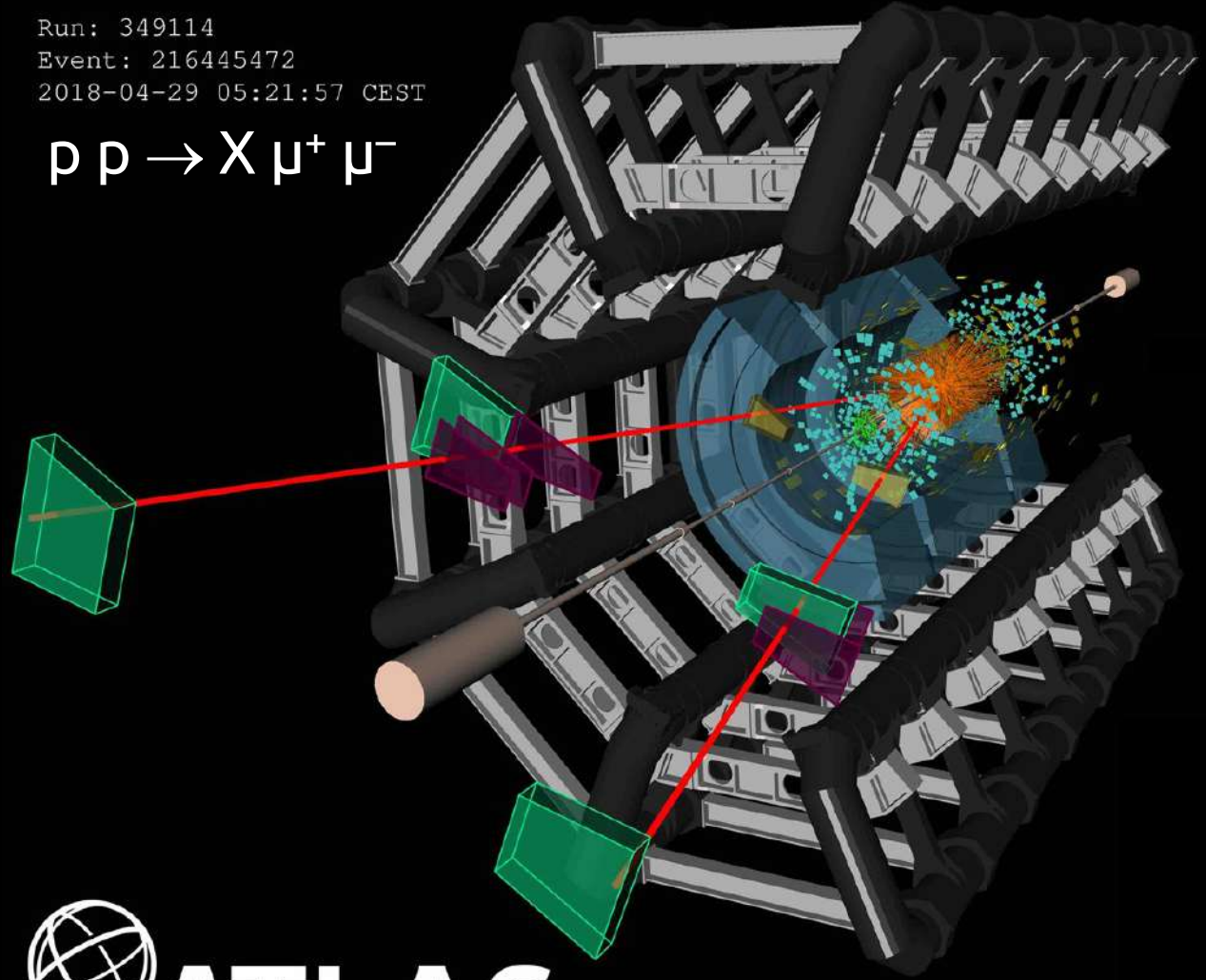
il rivelatore atlas a lhc





Run: 349114
Event: 216445472
2018-04-29 05:21:57 CEST

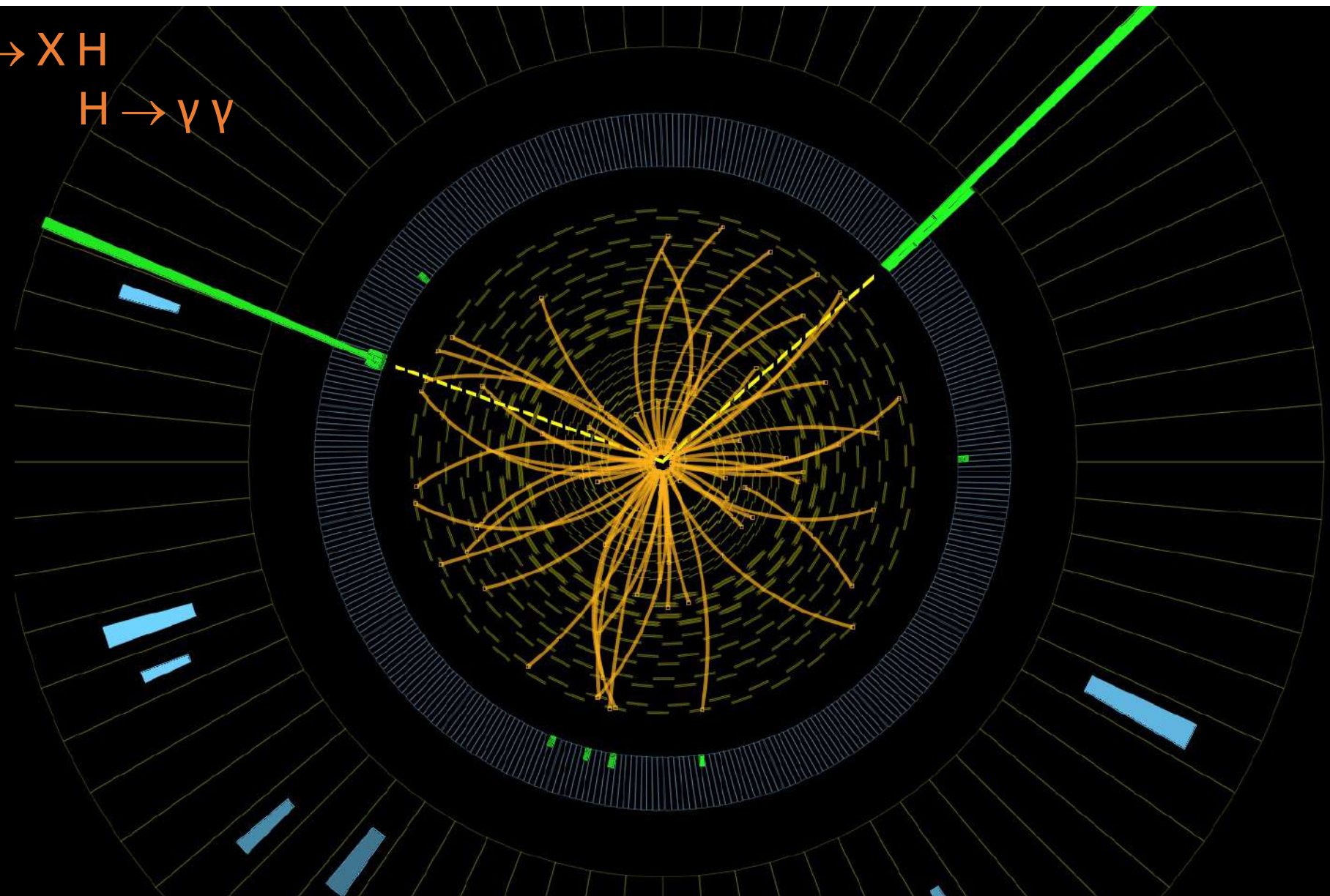
$$p p \rightarrow X \mu^+ \mu^-$$



 **ATLAS**
EXPERIMENT

$pp \rightarrow XH$

$H \rightarrow \gamma\gamma$

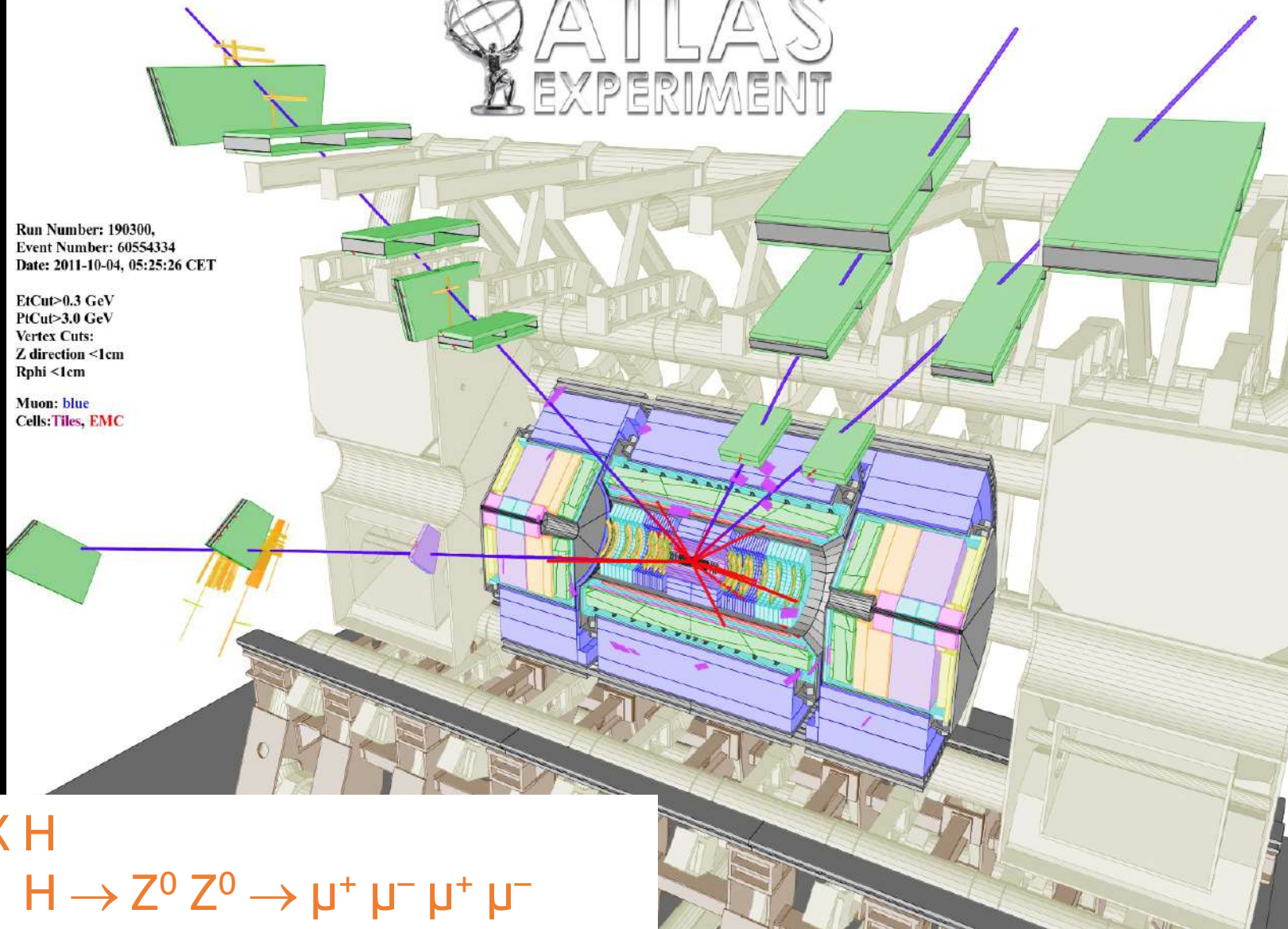


ATLAS EXPERIMENT

Run Number: 190300,
Event Number: 60554334
Date: 2011-10-04, 05:25:26 CET

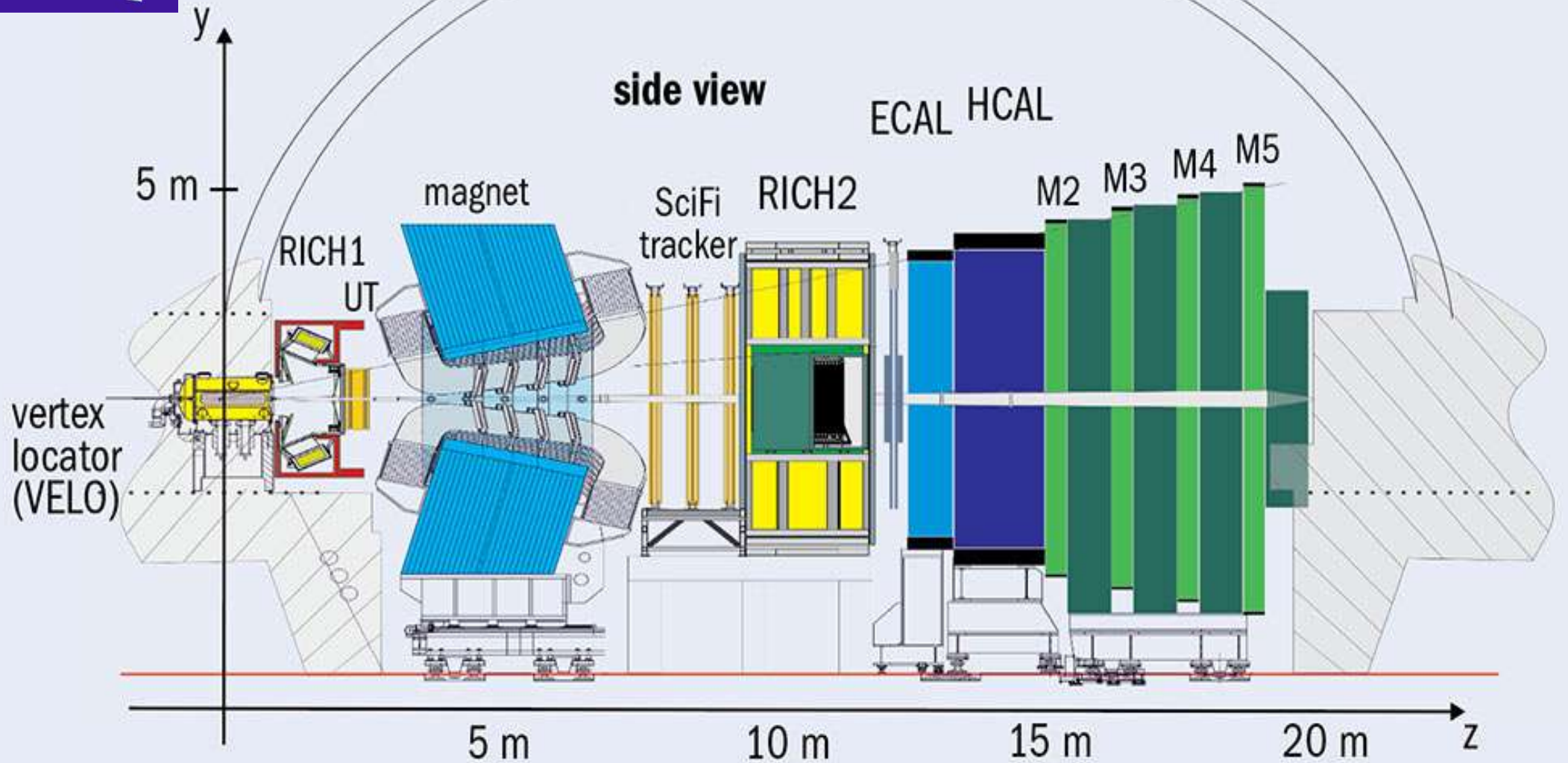
EtCut > 0.3 GeV
PtCut > 3.0 GeV
Vertex Cuts:
Z direction < 1cm
Rphi < 1cm

Muon: blue
Cells: Tiles, EMC



$pp \rightarrow X H$

$H \rightarrow Z^0 Z^0 \rightarrow \mu^+ \mu^- \mu^+ \mu^-$

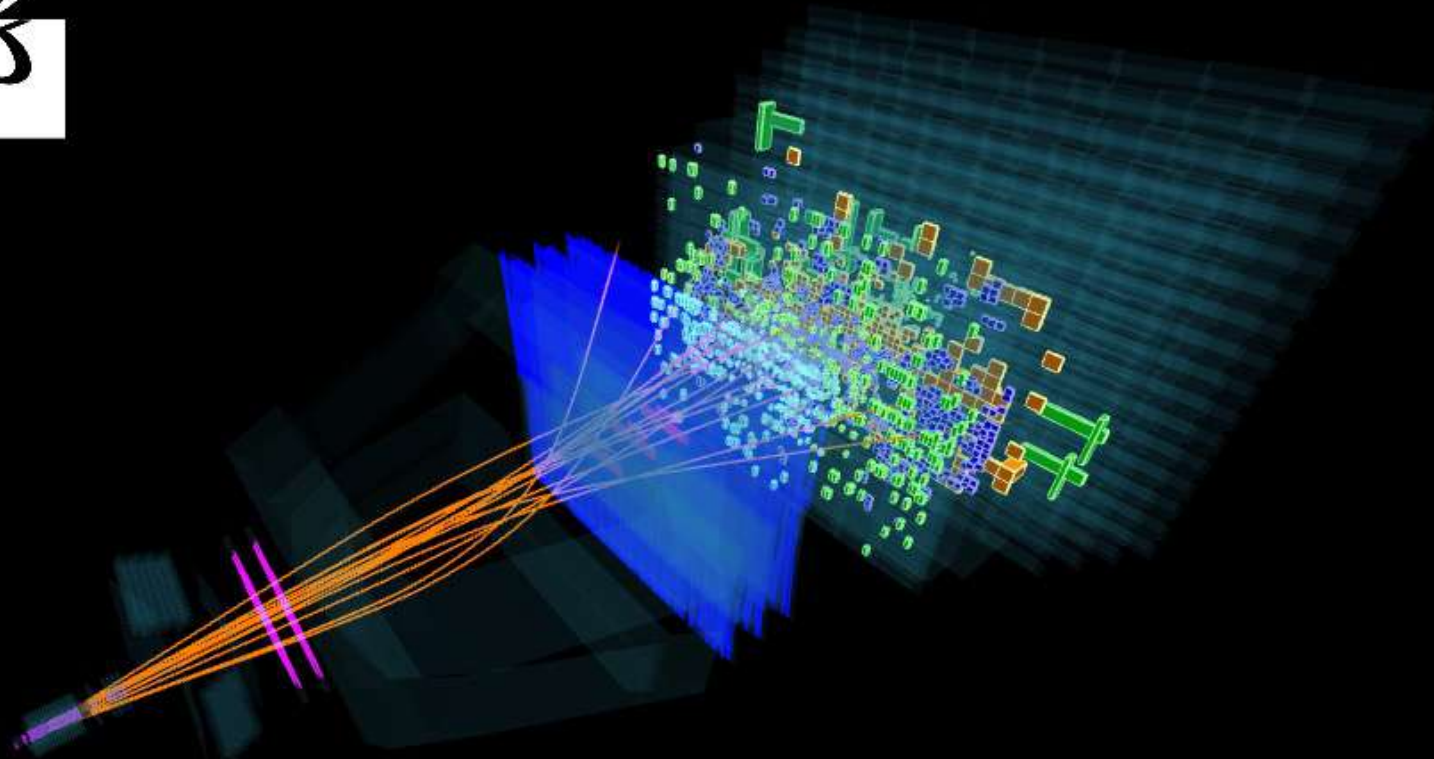


LHCb
LHCb

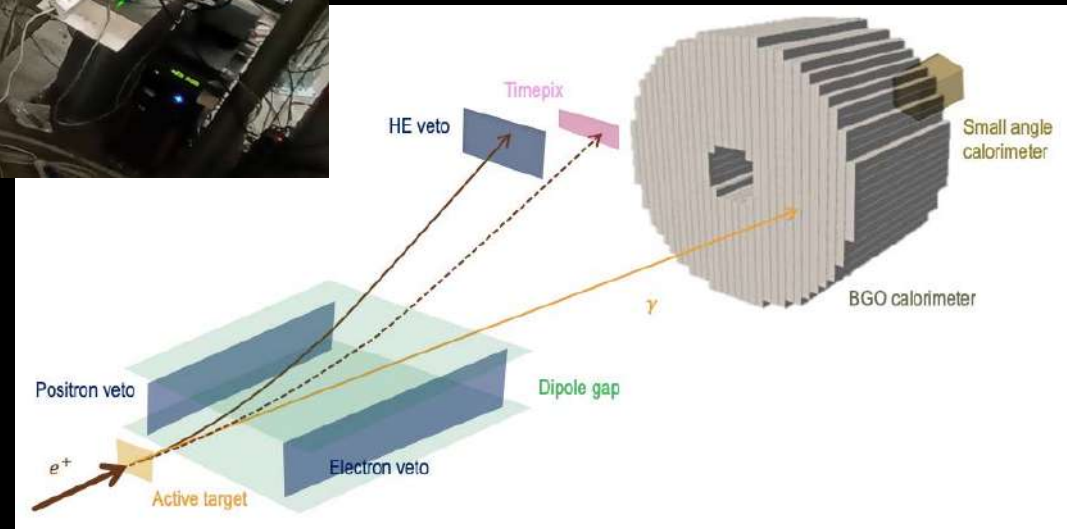
Event 2598326

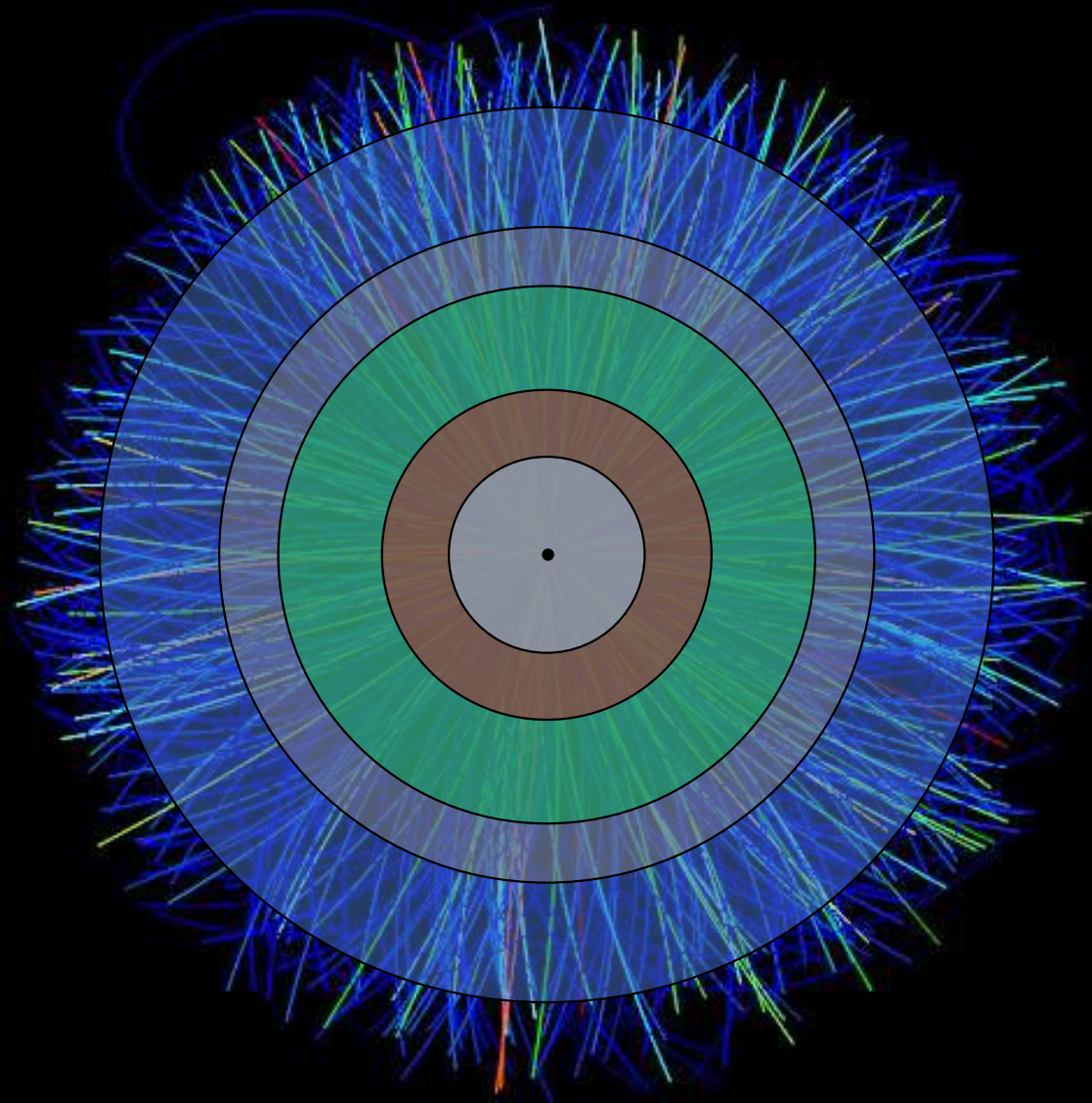
Run 168486

Wed, 25 Nov 2015 12:51:53



il rivelatore padme a Inf

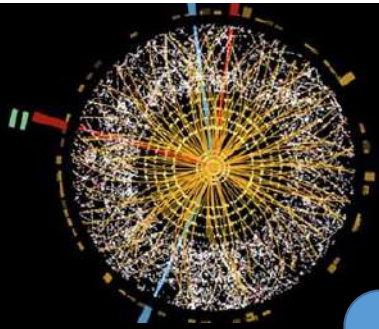




LHC computing



LHC big data



10⁹/s collisioni
x 1 MB
1000 TB/s

Trigger
Livello1

100 kHz x 1 MB
100 GB/s

Trigger
Livello2

100 MB/s
3 PB/y

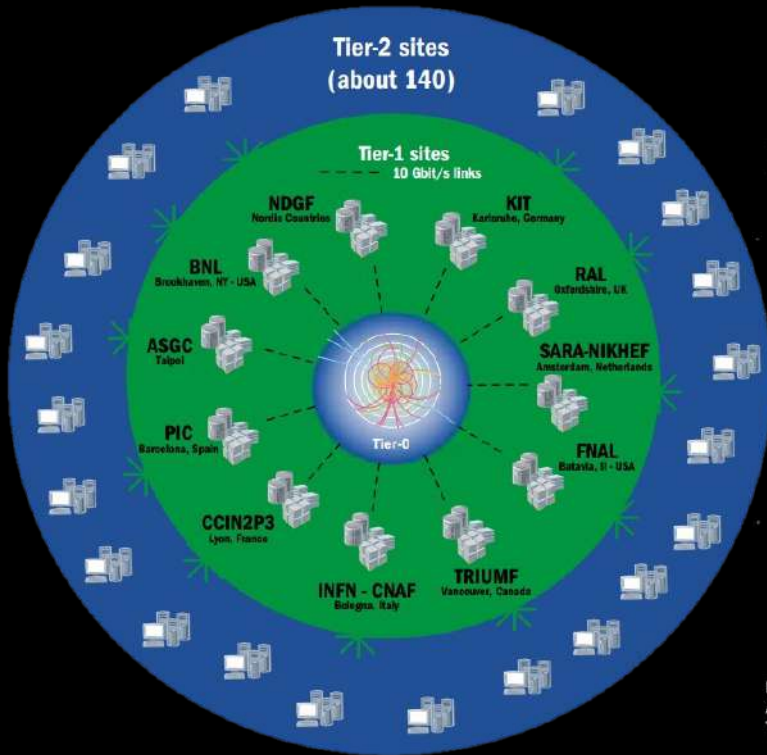
Trigger Dilemma

registrare tanti eventi interessanti
non registrare troppi eventi

Lhc computing grid



170 centri di calcolo
in 42 paesi del mondo
collegati a 10Gb/s



Running jobs: 365644
Active CPU cores: 807139
Transfer rate: 21.54 GiB/sec

caratteristiche dei rivelatori

Sensibilità

capacità di produrre un segnale per un certo tipo di radiazione e di energia

Risoluzione

capacità di distinguere tra due misure vicine di una grandezza fisica misurata (es. posizione o tempo)

Efficienza

frazione di particelle rivelate rispetto a quelle incidenti

Tempo morto

tempo necessario per essere di nuovo attivo dopo la rivelazione di una particella

tipi di rivelatori

Funzione

Tracciatori

Calorimetri

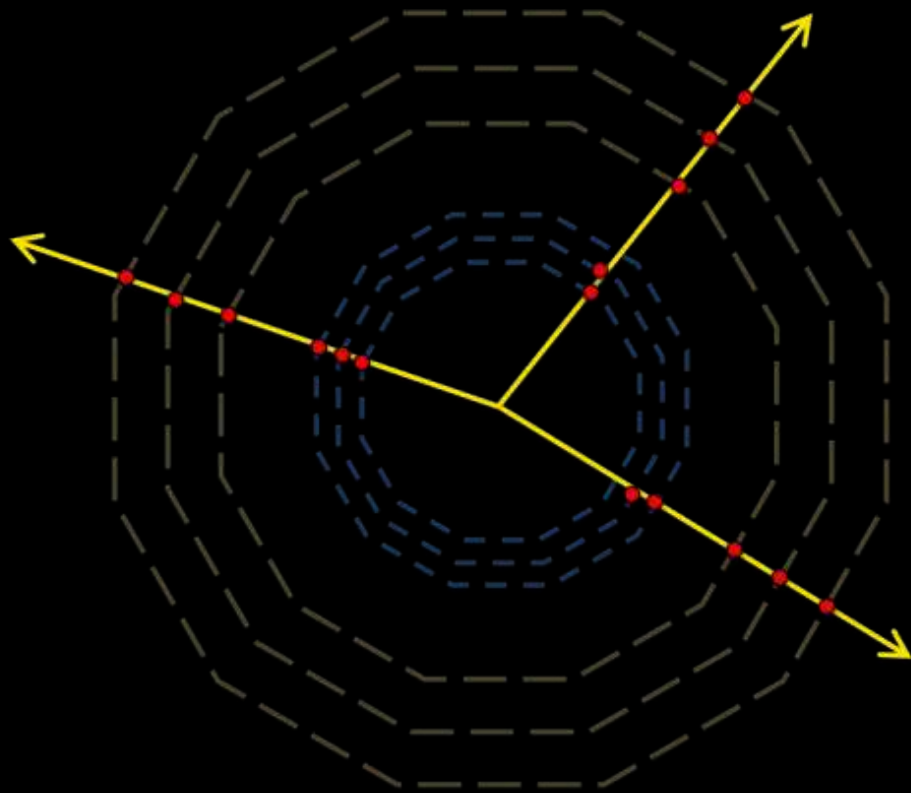
Rivelatori
Cherenkov

Materiale

Rivelatori
a gas

Rivelatori
a stato solido

tracciatori

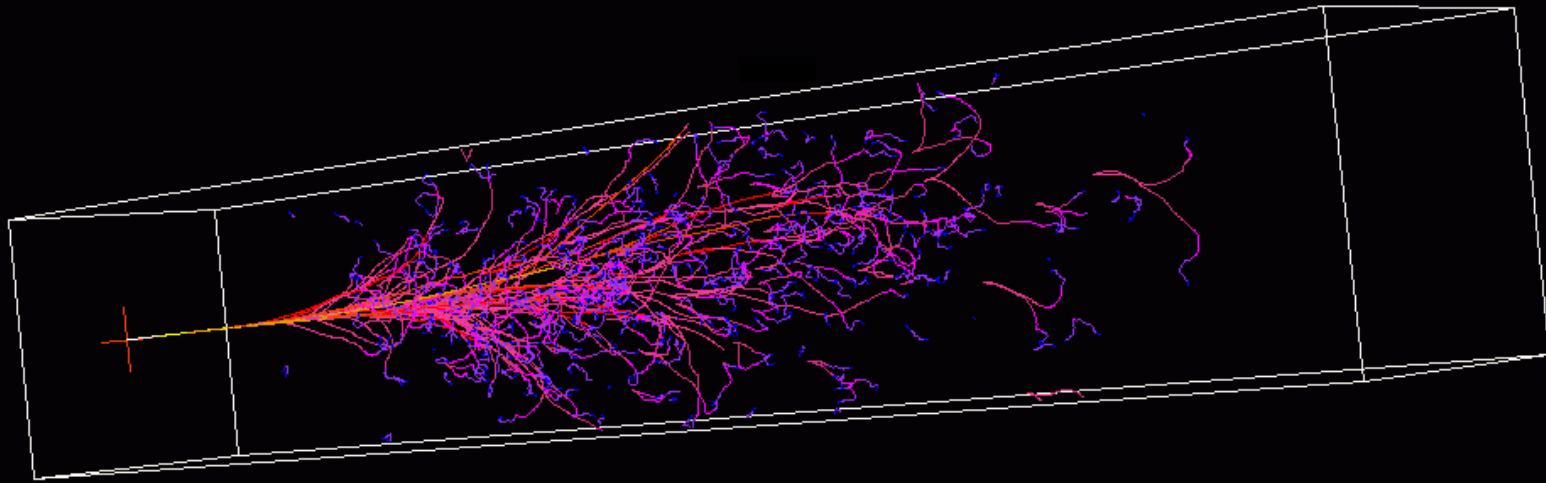


Sensibilità
tutte le particelle cariche

$p = eBr$
immersi in campo magnetico
misurano la quantità di moto

Materiali leggeri
la particella deve perdere
poca energia

calorimetri



Sensibilità

Ecal: elettroni e fotoni
Hcal: protoni, neutroni, pioni, kaoni

Energia

misurano l'energia
(senza campo magnetico)

Materiali pesanti

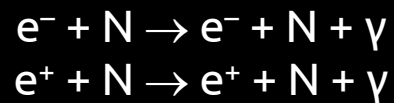
la particella deve perdere
tutta la sua energia

calorimetri

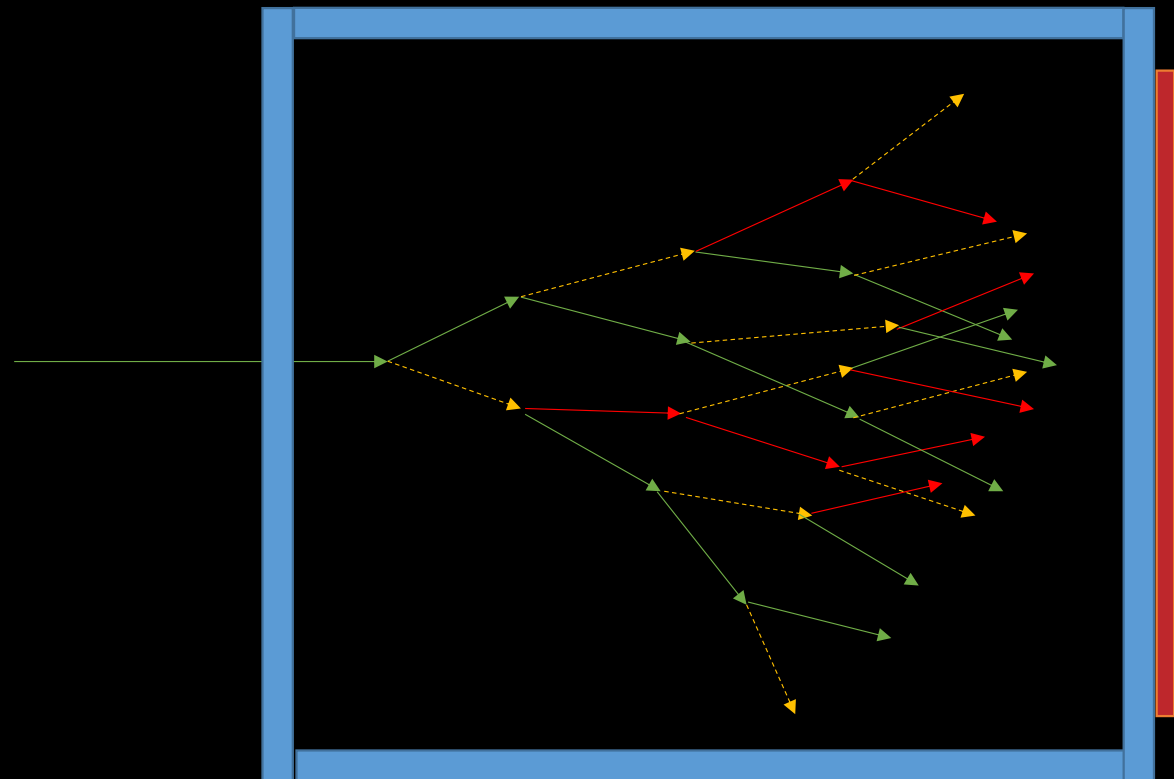
Sciame Elettromagnetico



Radiazione da Frenamento
(elettroni e positroni)



Produzione di Coppie
(fotoni)

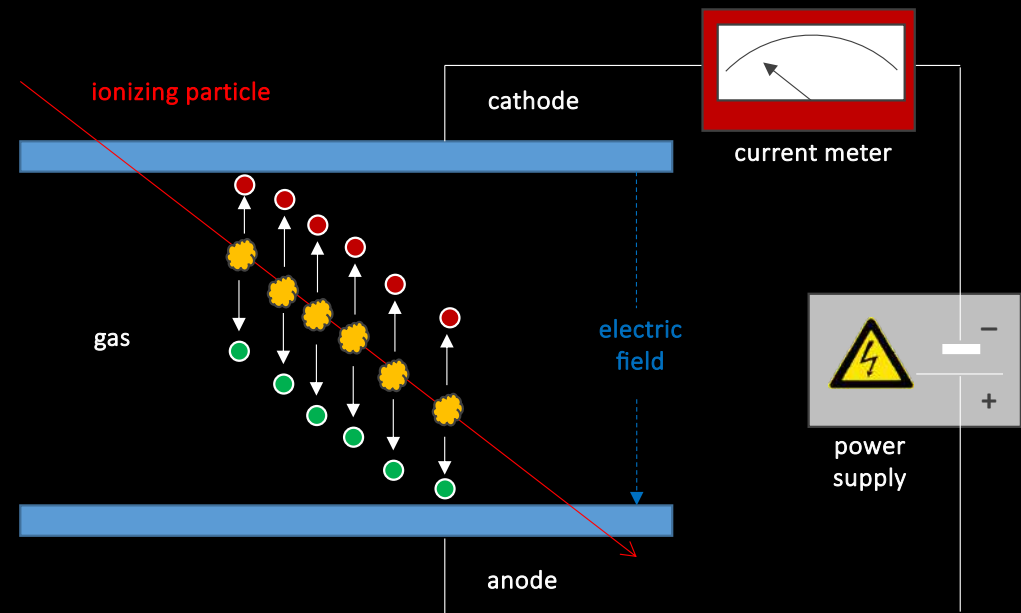


- ▶ elettrone
- ▶ positrone
- ▶ fotone

rivelatori a gas

Ionizzazione Atomica

particelle cariche
 $p + Ar \rightarrow p + Ar^+ + e^-$



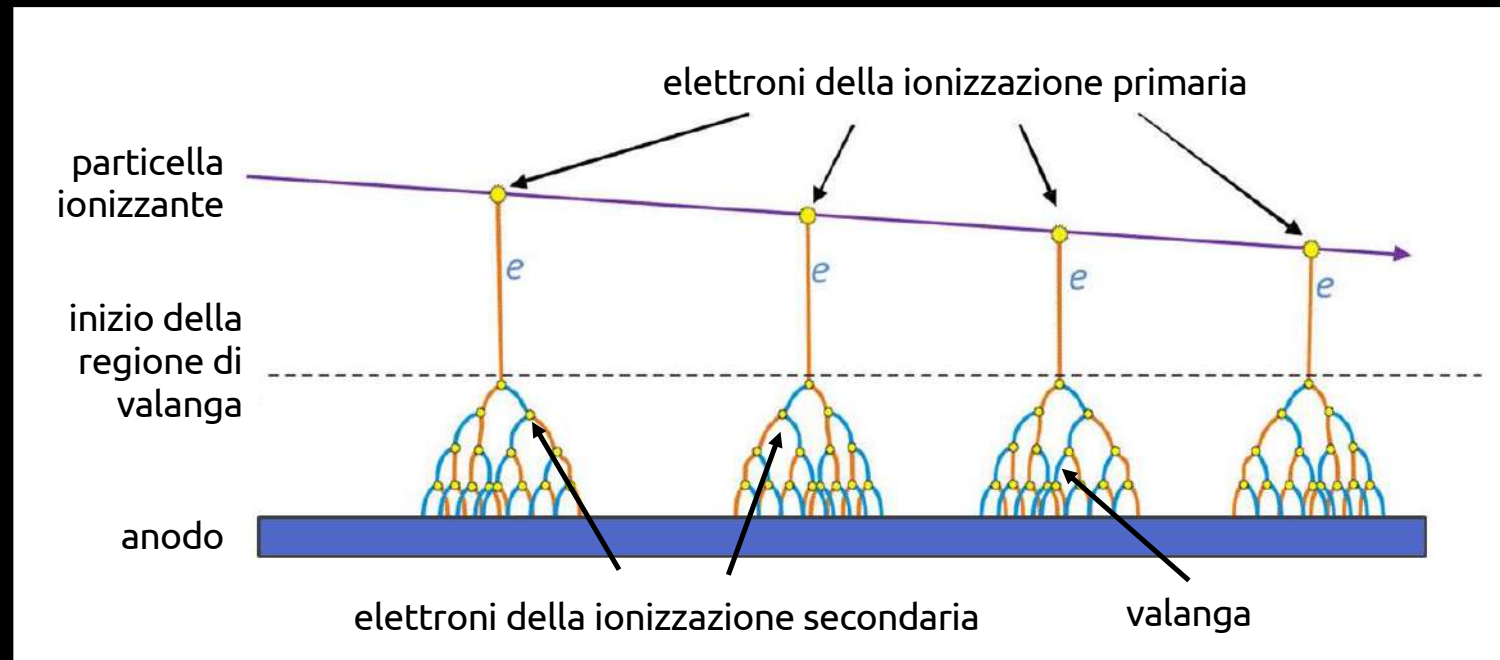
Punti di Forza
grandi volumi con poca spesa
segnale grande

Moltiplicazione a valanga

Ionizzazione Primaria
(particelle cariche)
 $p + Ar \rightarrow p + Ar^+ + e^-$



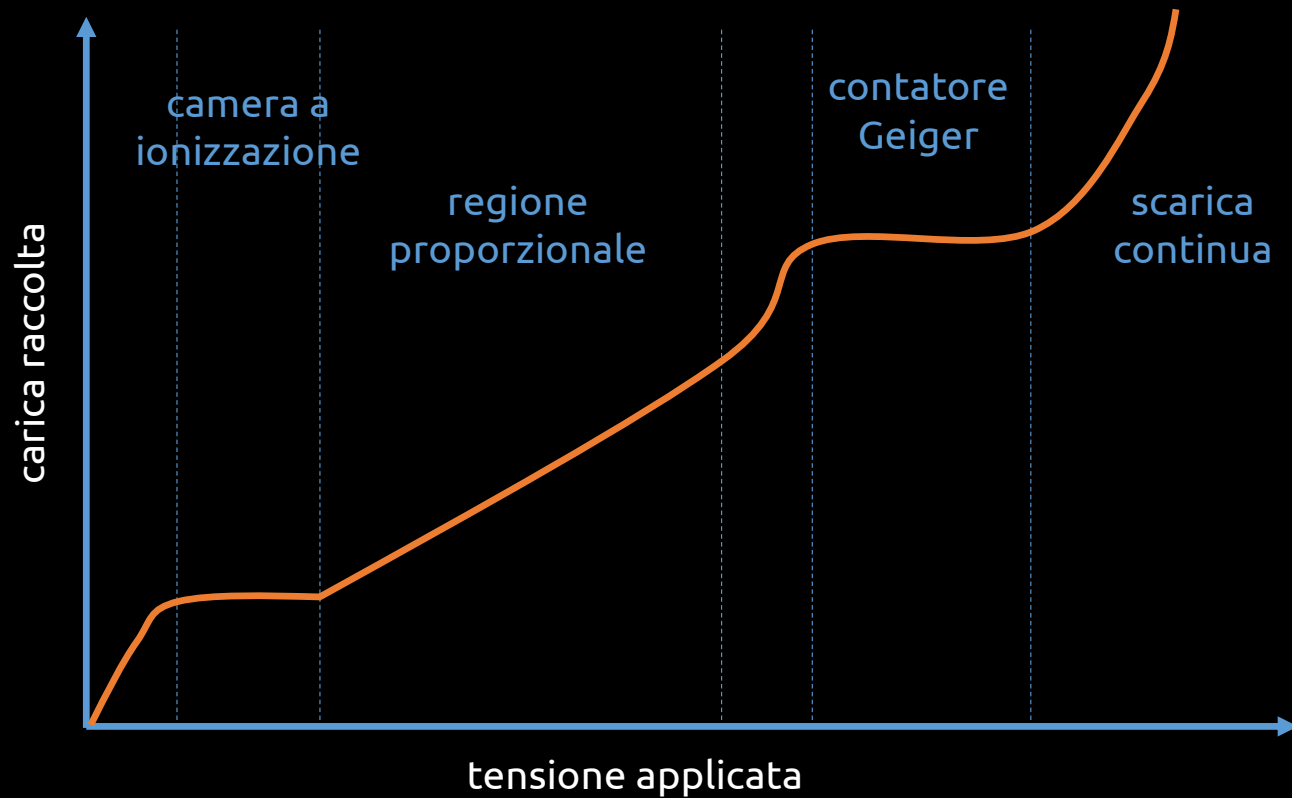
Ionizzazione Secondaria
(elettroni)
 $e^- + Ar \rightarrow e^- + Ar^+ + e^-$



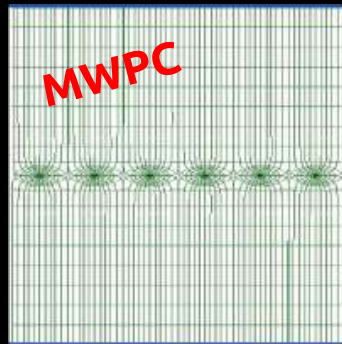
gli elettroni primari vengono **moltiplicati** dal gas
con un **guadagno G**

$$G = \frac{n_{tot}}{n_i} \approx \frac{500000}{20} = 25k$$

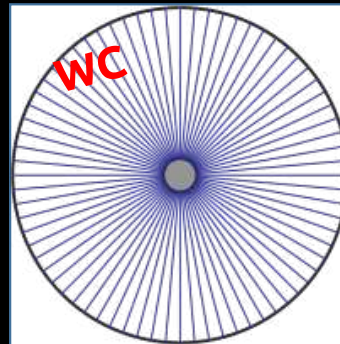
regioni operative dei rivelatori a gas



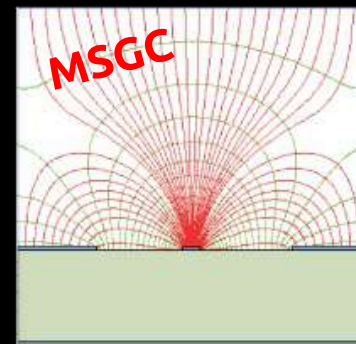
configurazioni di elettrodi



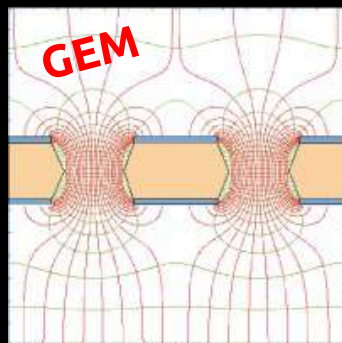
multi-filo



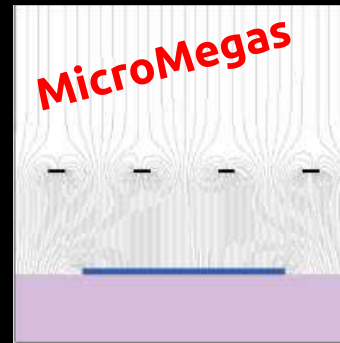
filo singolo



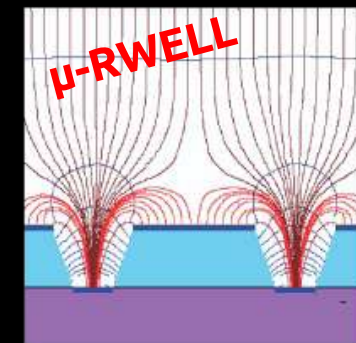
strisce



fori

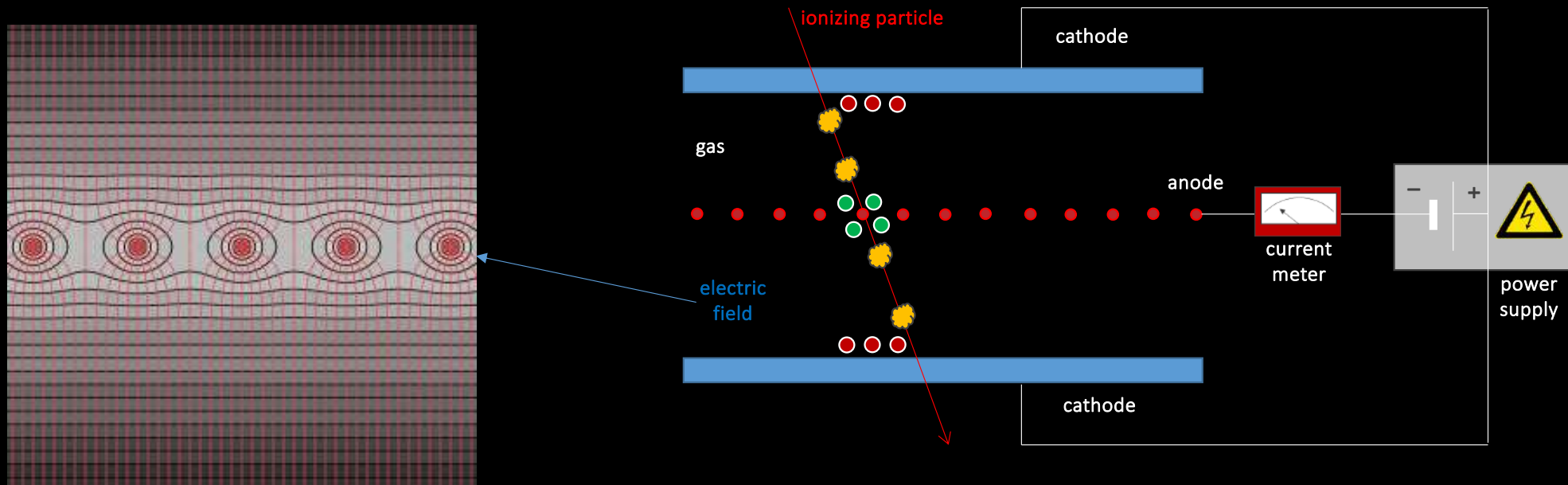


griglia

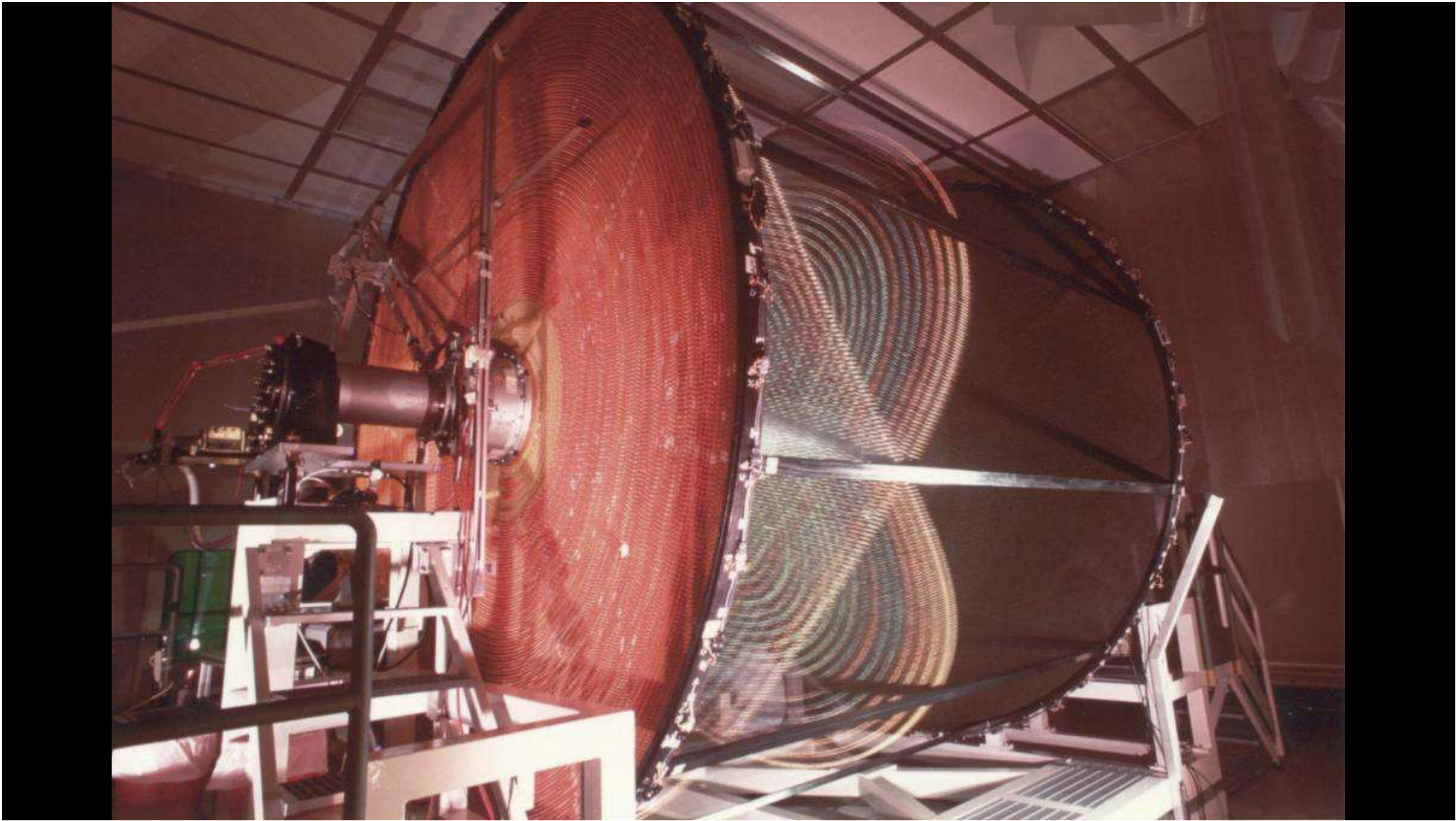


pozzi

Multiwire proportional chamber



il segnale del filo fornisce la **posizione** della particella
il campo elettrico vicino al filo ($1/r$) **moltiplica** gli elettroni



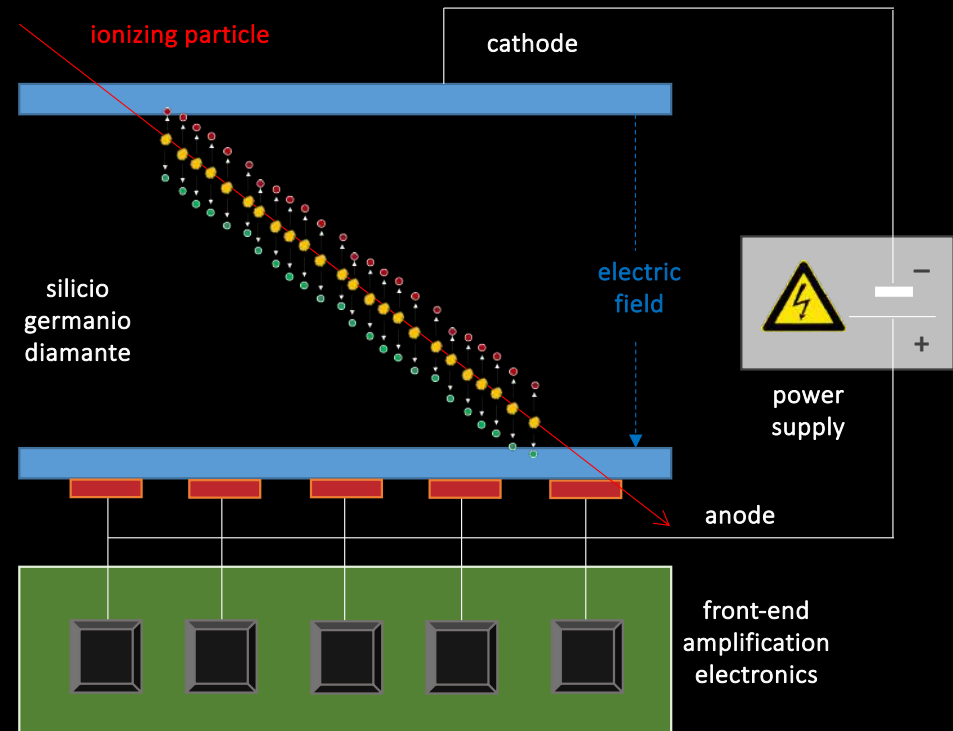
GEM cilindrica



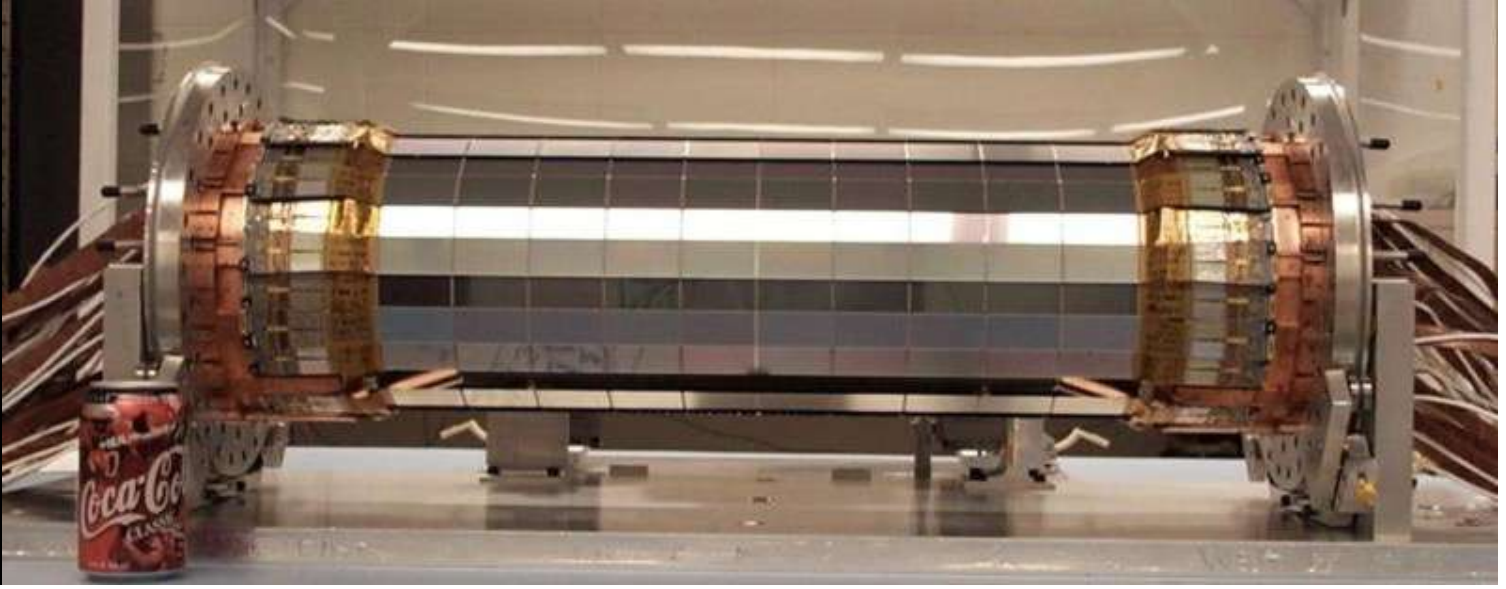
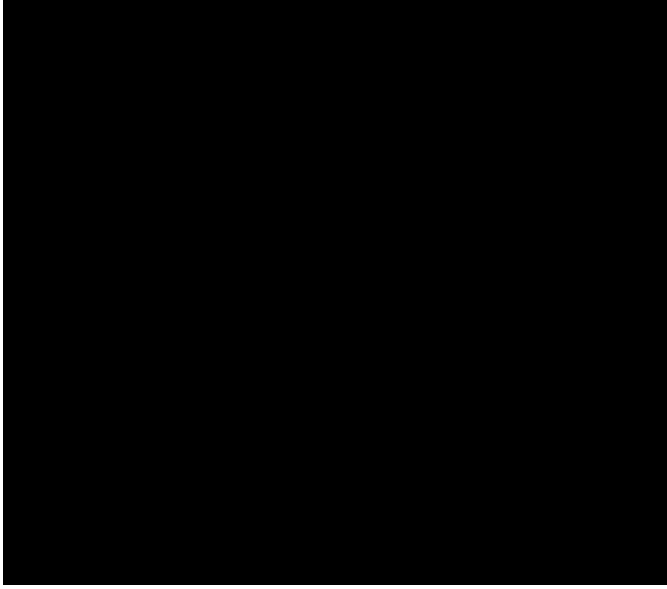
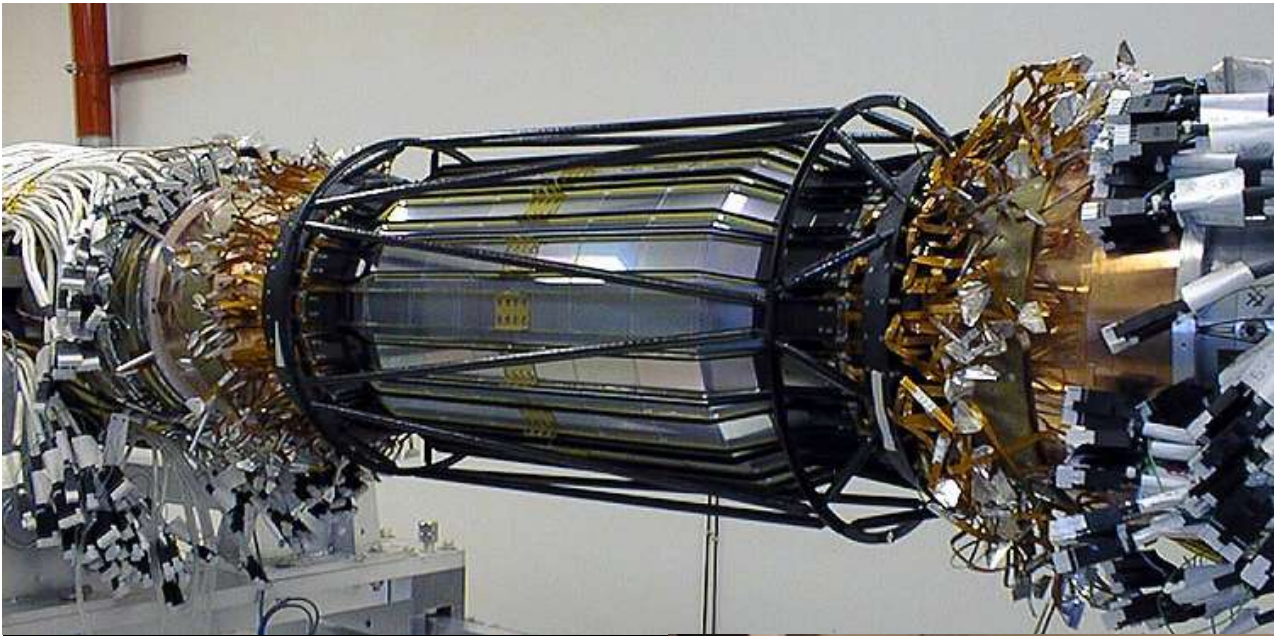
rivelatori a stato solido

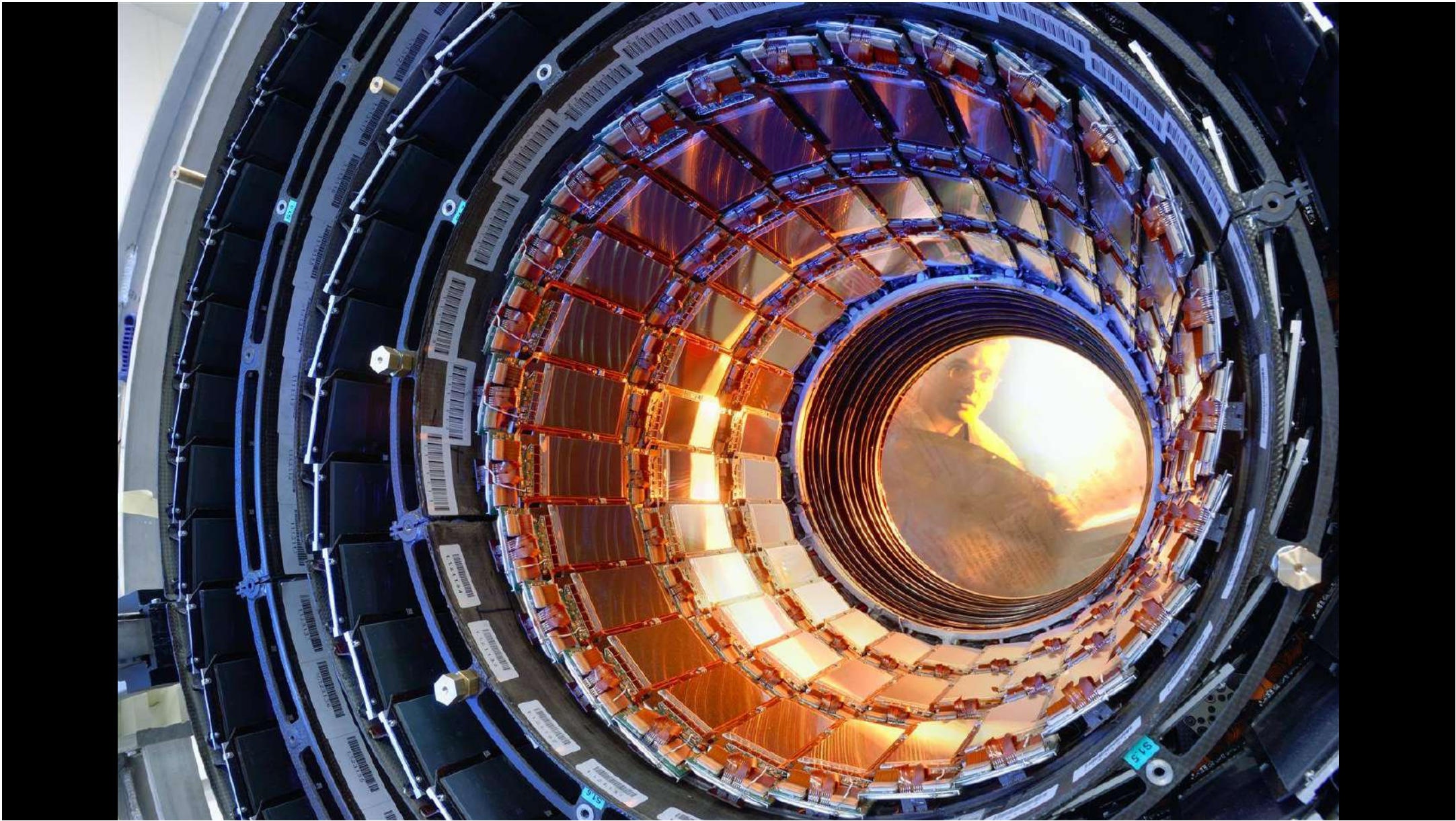
Produzione di Coppie
Elettrone - Lacuna

particelle cariche
 $p + Si \rightarrow p + e^- + h$



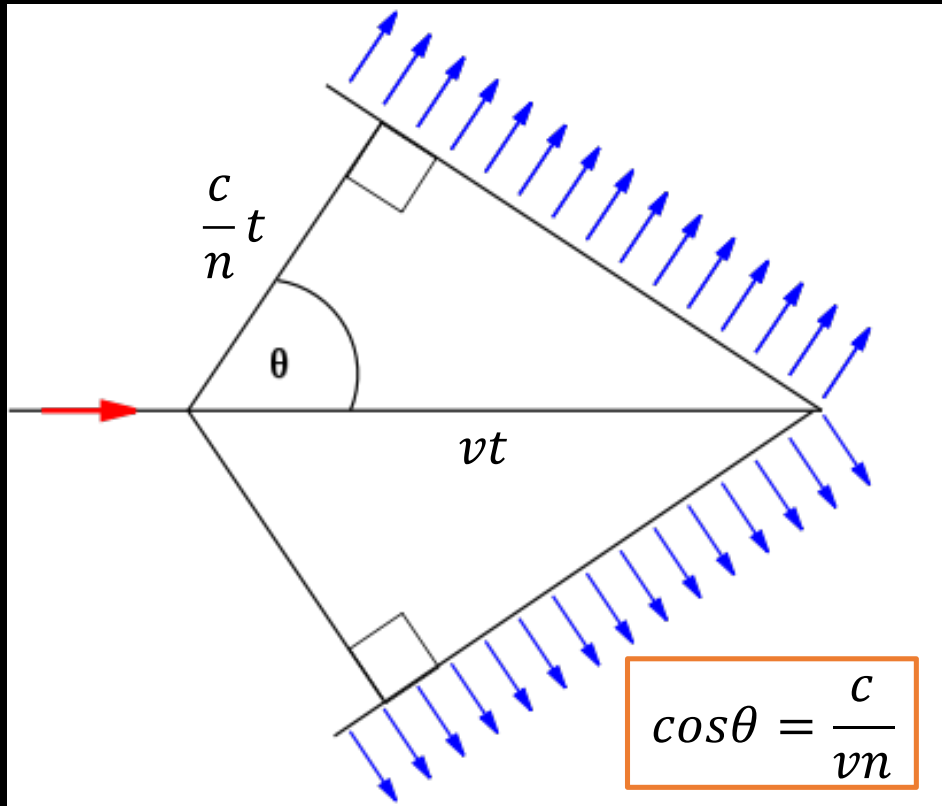
Punti di Forza
risoluzione spaziale e temporale



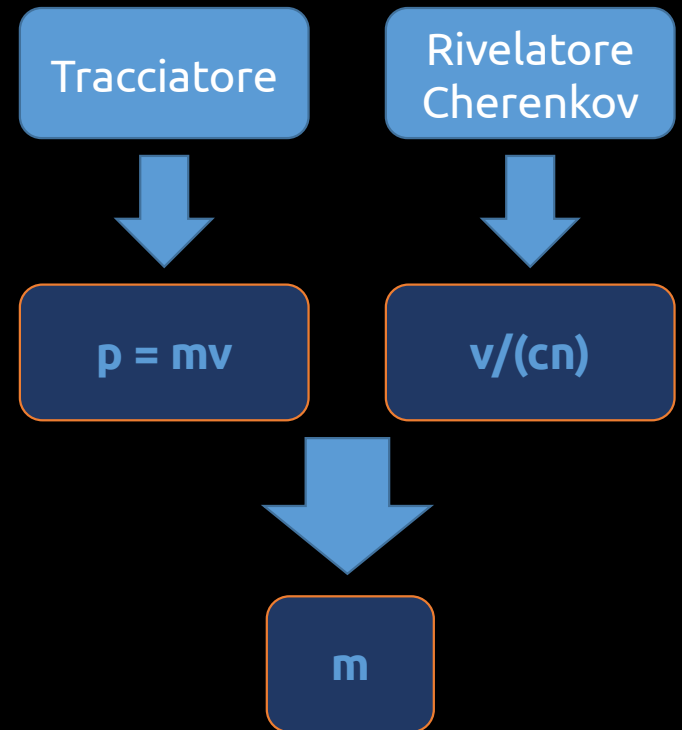
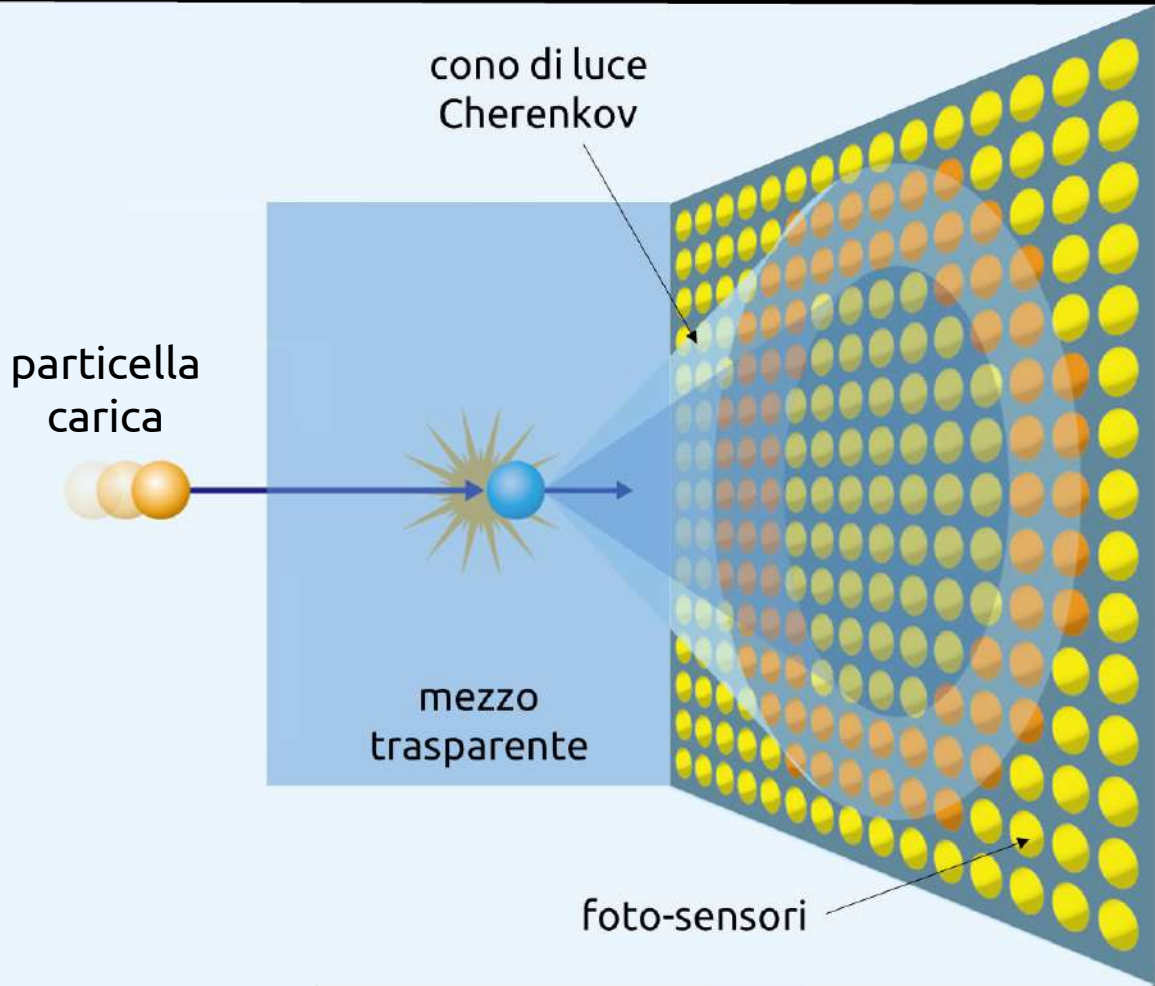




effetto cherenkov



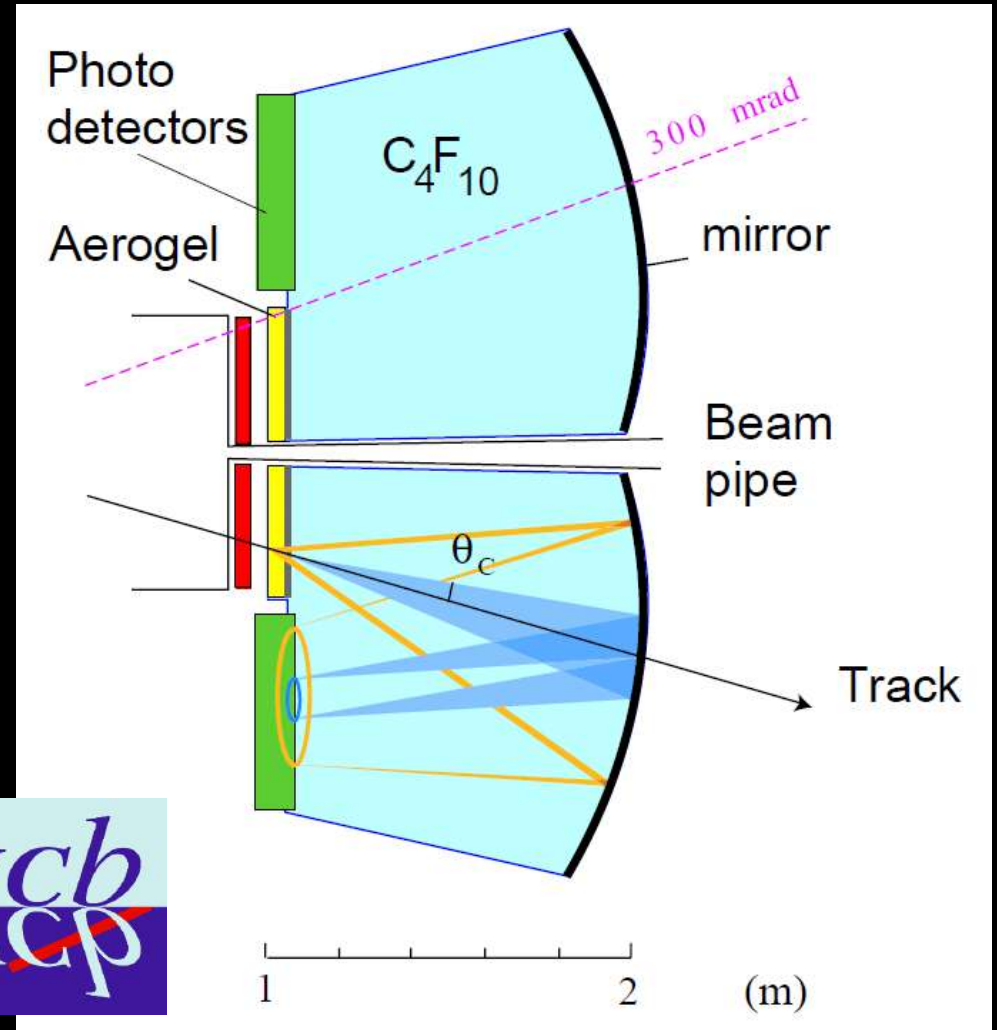
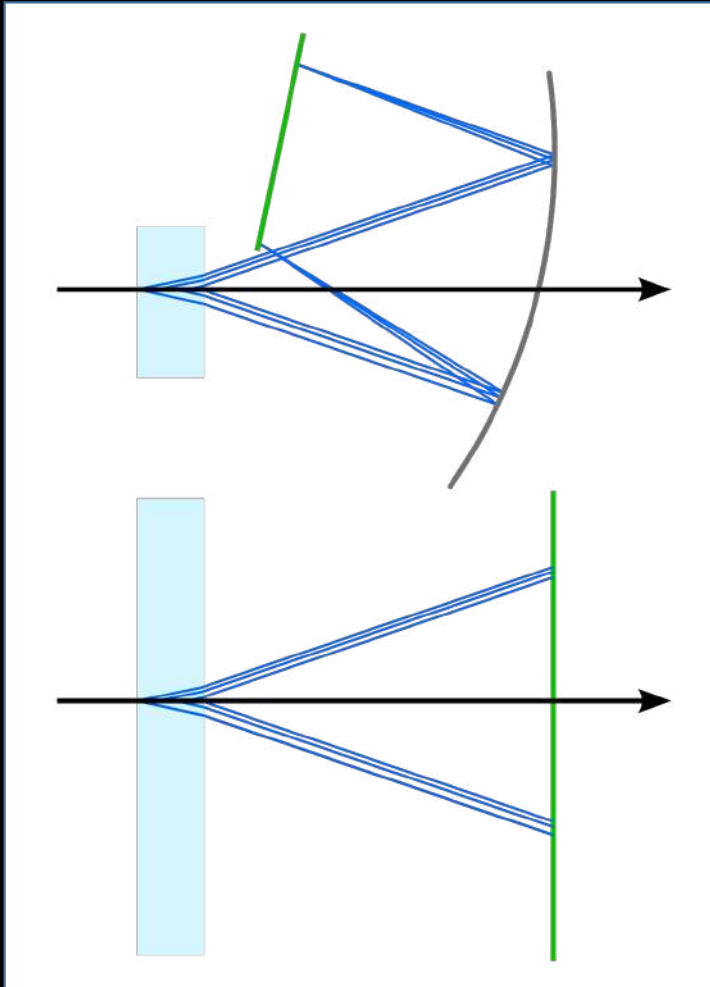
rivelatori cherenkov



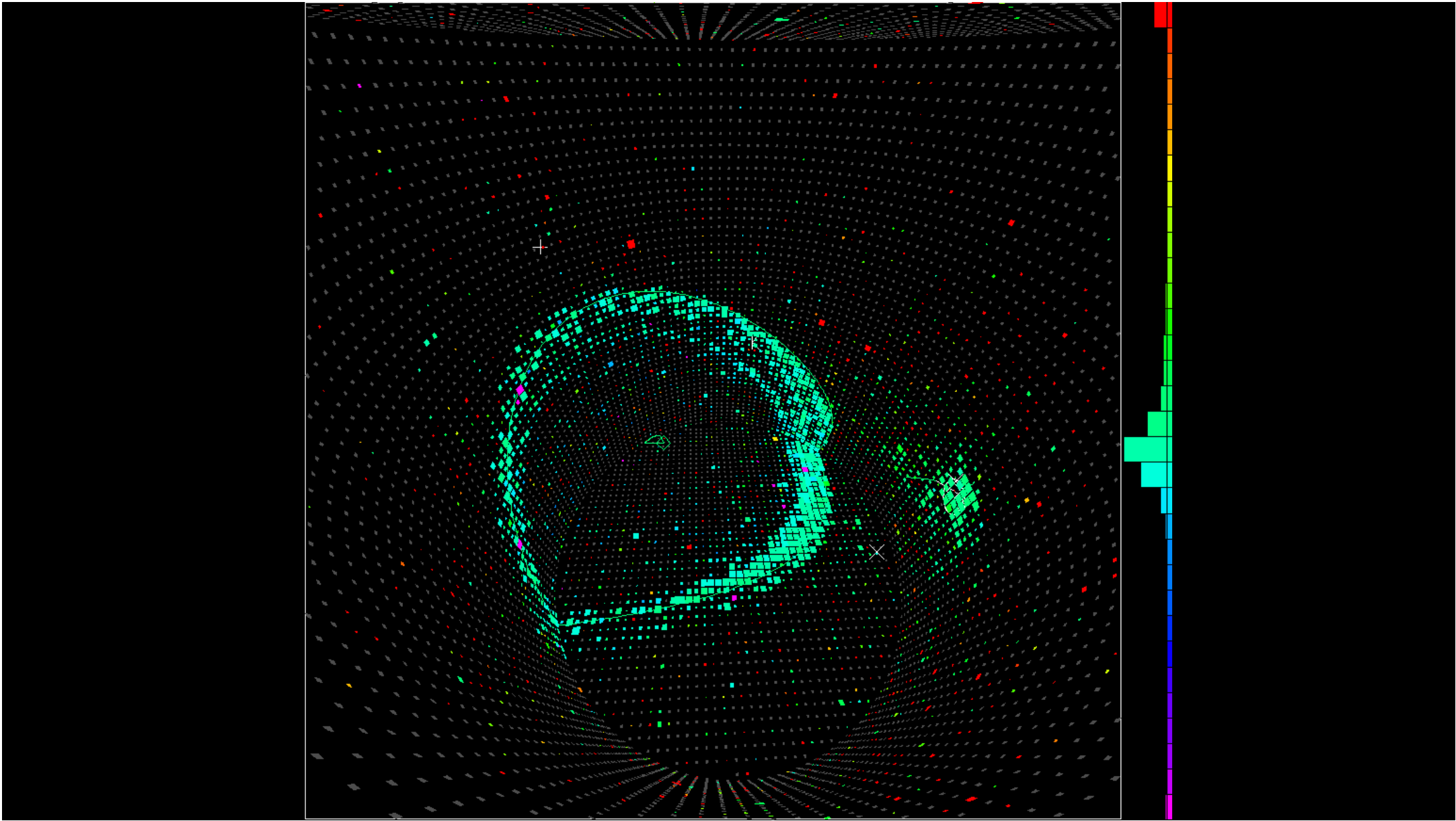
identificazione della particella

pione	140 MeV
kaone	500 MeV
protone	940 MeV

rich – ring imaging cherenkov



LHCb
ГHCР



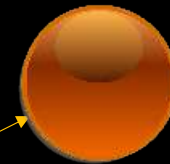
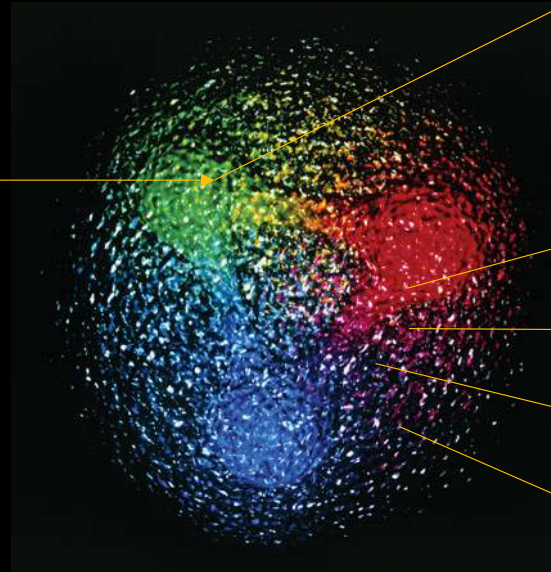
modello standard delle particelle e delle interazioni

u quark up	c quark charm	t quark top	g gluone	\bar{u} quark anti-up	\bar{c} quark anti-charm	\bar{t} quark anti-top
d quark down	s quark strange	b quark bottom	γ fotone	\bar{d} quark anti-down	\bar{s} quark anti-strange	\bar{b} quark anti-bottom
e^- elettrone	μ^- muone	τ^- tau	W, Z bosoni deboli	e^+ anti-elettrone (positrone)	μ^+ anti-muone	τ^+ anti-tau
ν_e neutrino elettronico	ν_μ neutrino muonico	ν_τ neutrino tau	H bosone di Higgs	$\bar{\nu}_e$ anti-neutrino elettronico	$\bar{\nu}_\mu$ anti-neutrino muonico	$\bar{\nu}_\tau$ anti-neutrino tau

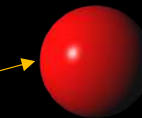
interazione dei neutrini

CC – corrente carica

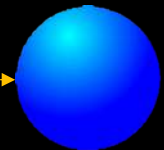
$\bar{\nu}_\mu$
anti-neutrino
muonico



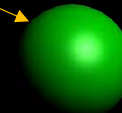
μ^+
anti-muone



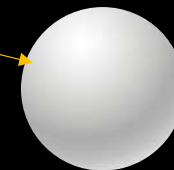
p
protone



π
pione



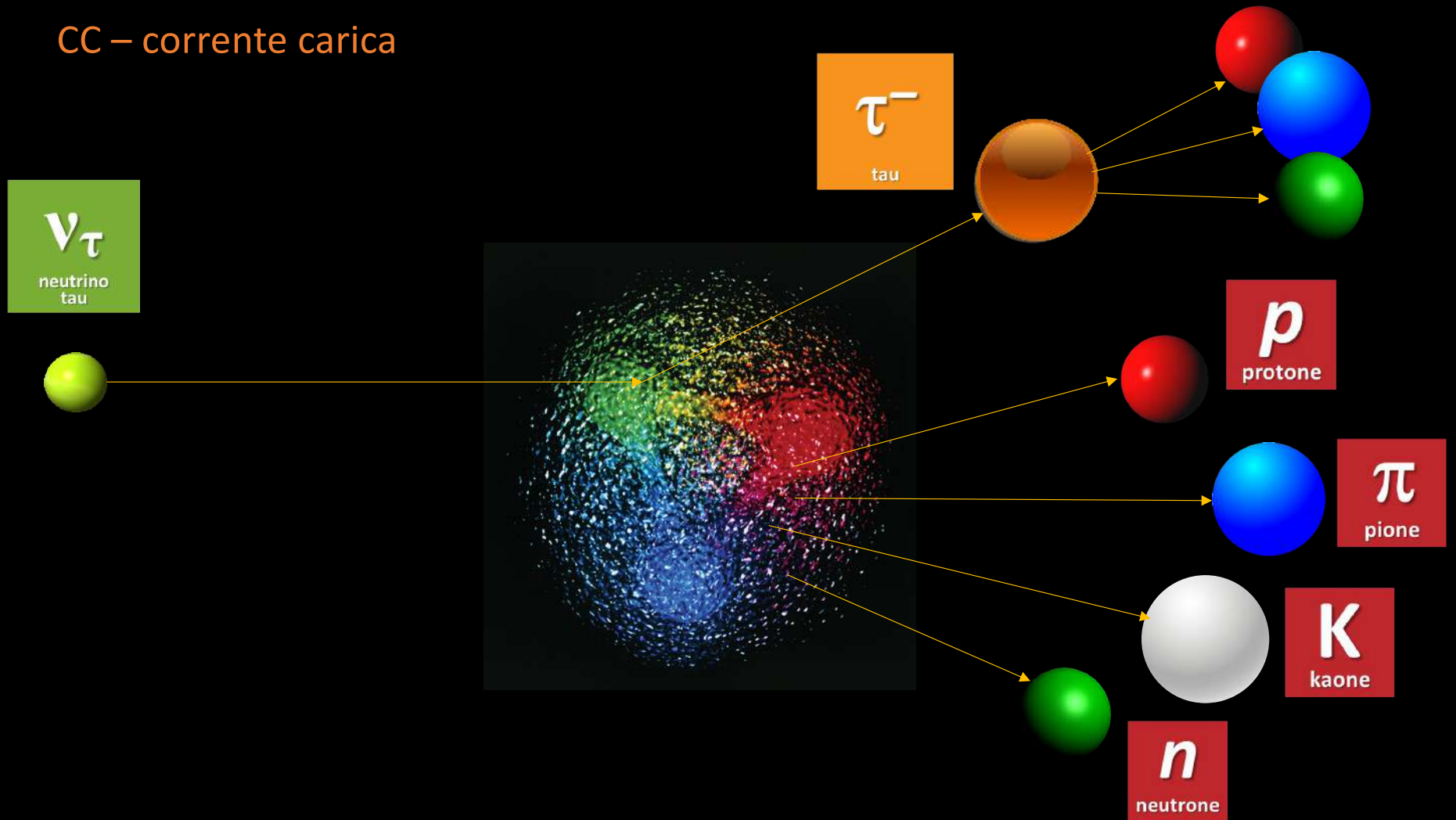
n
neutrone



K
kaone

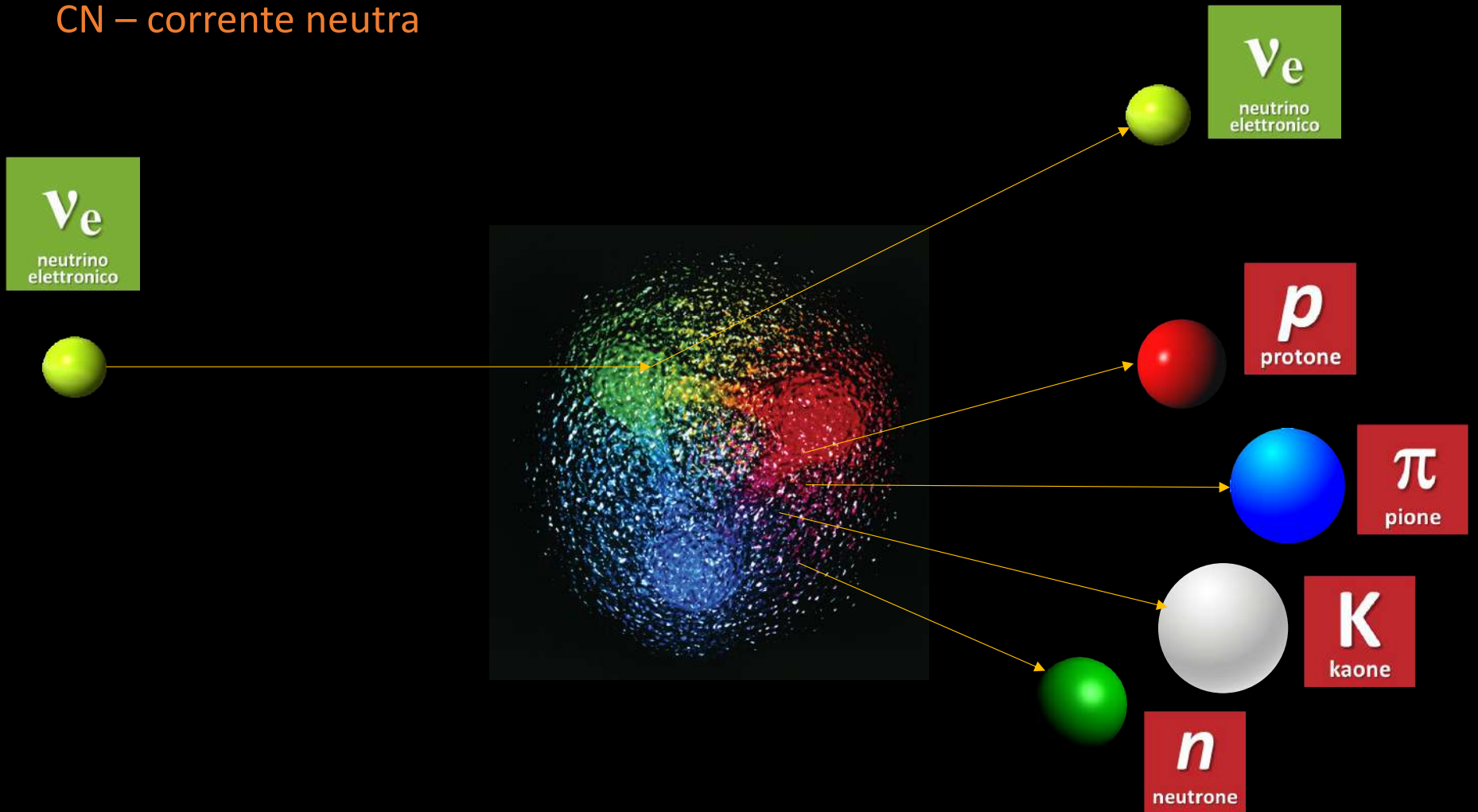
interazione dei neutrini

CC – corrente carica

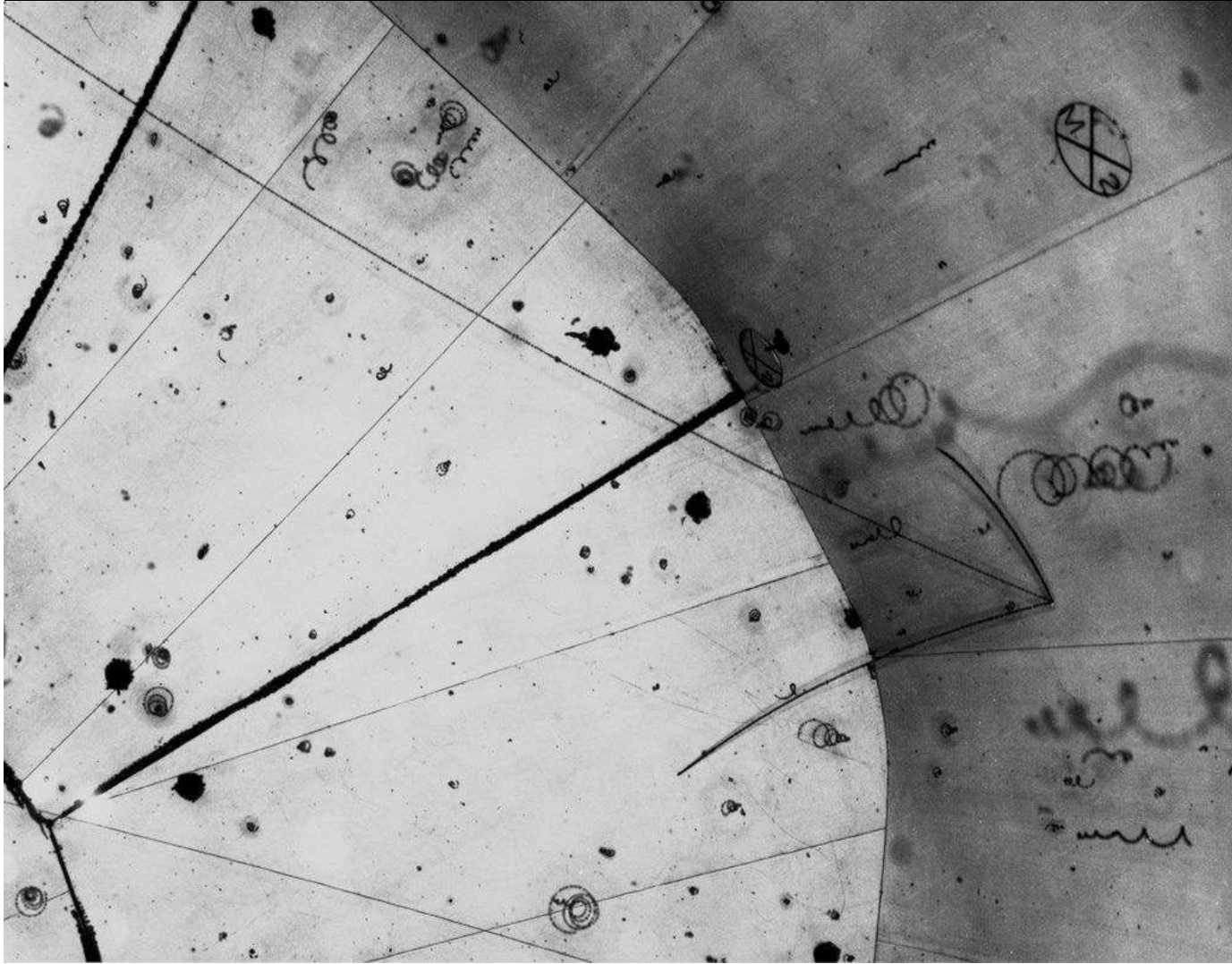


interazione dei neutrini

CN – corrente neutra

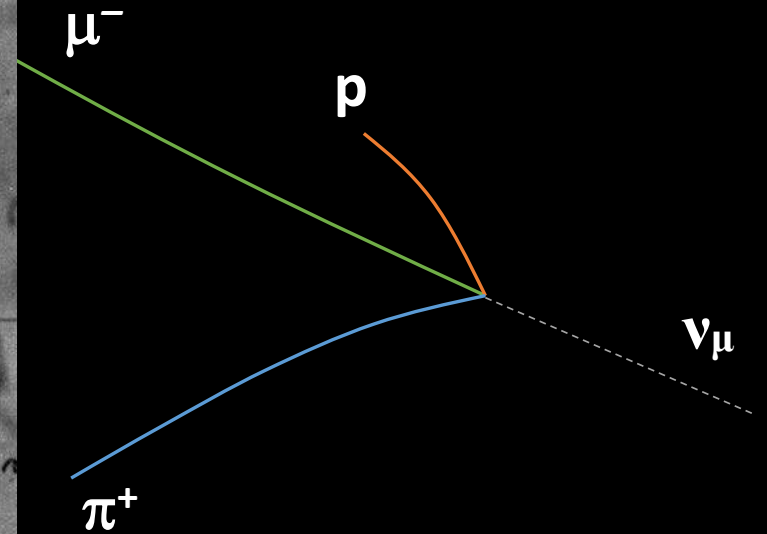


rivelare i neutrini

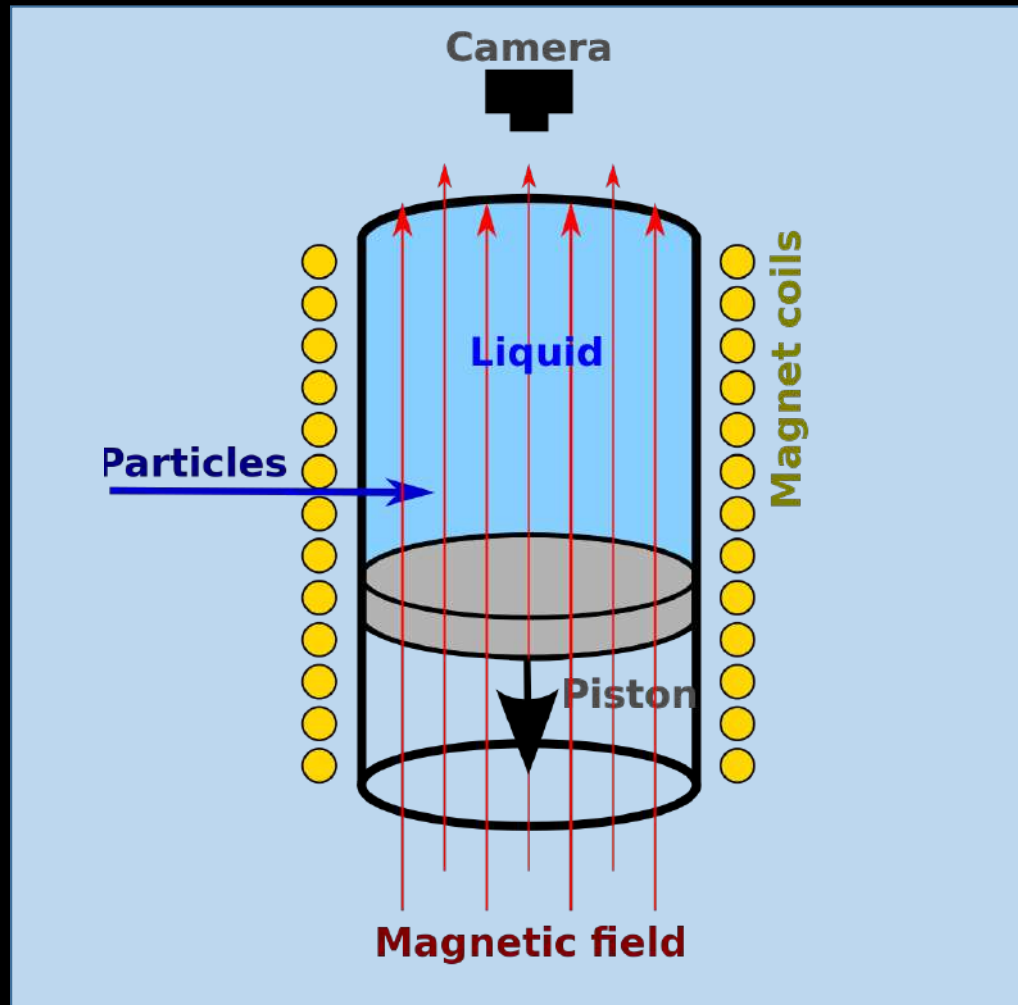


1970

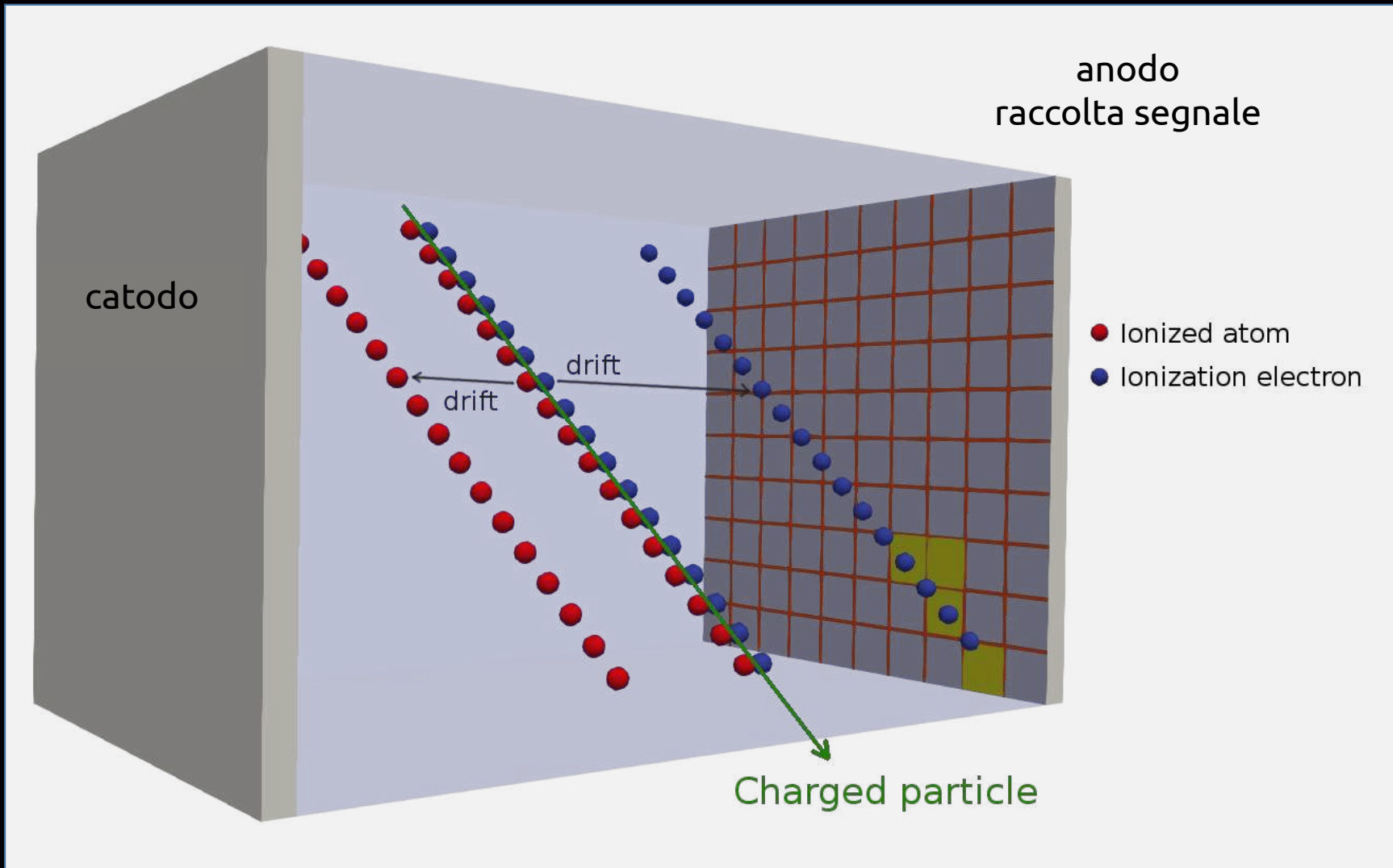
prima rivelazione di un neutrino
in una camera a bolle a idrogeno



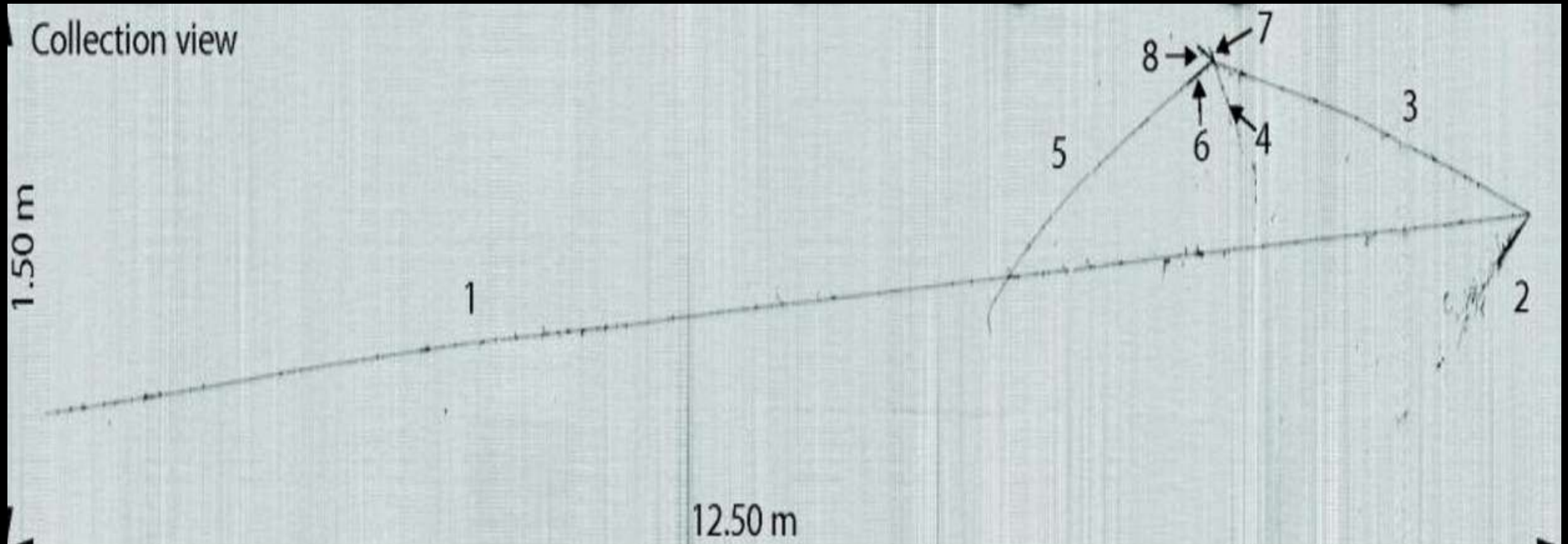
camera a bolle



time projection chamber



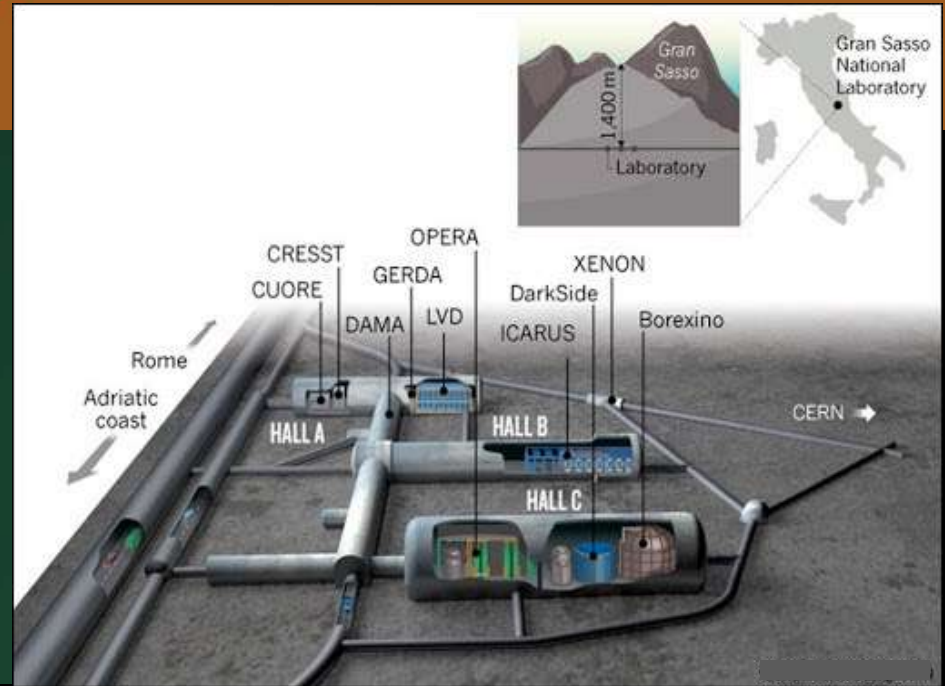
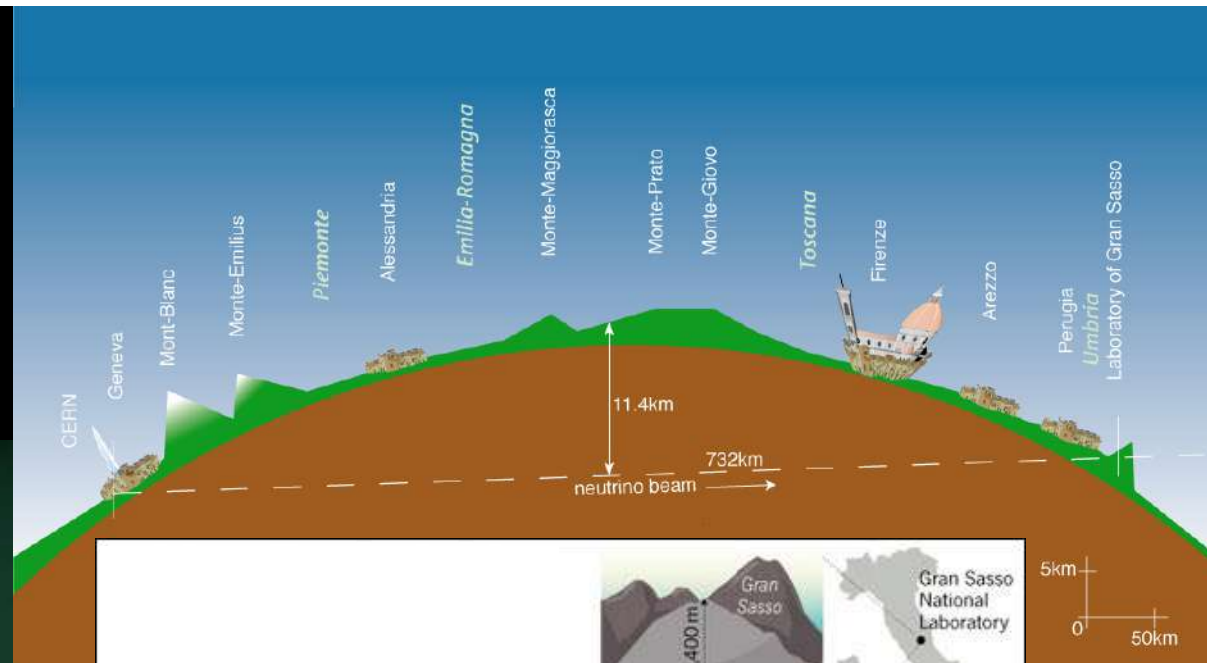
ICARUS a CNGS



Cern neutrinos to gran sasso

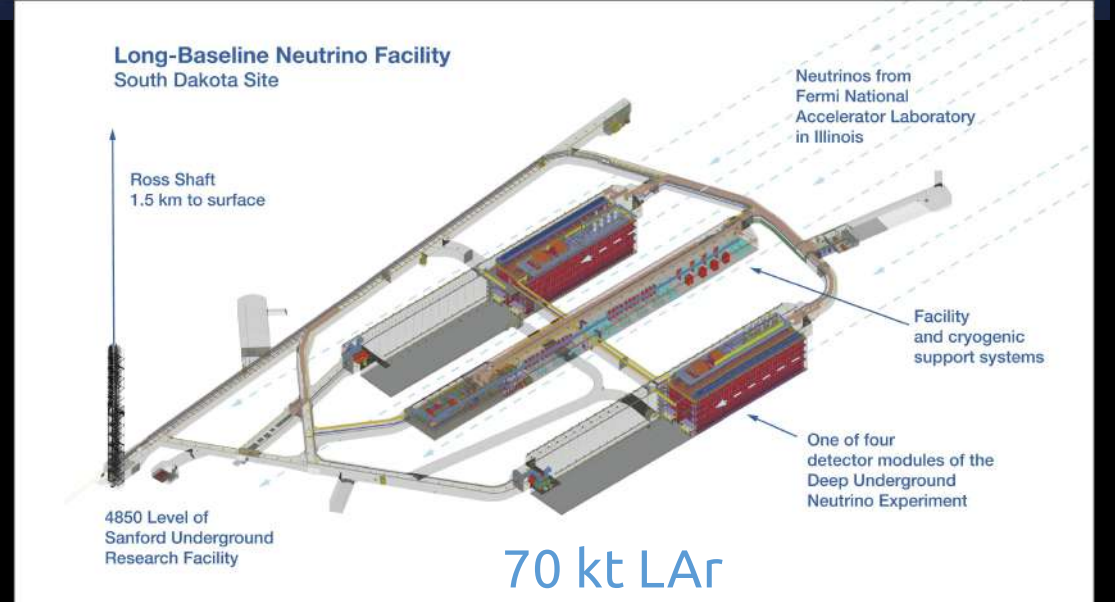
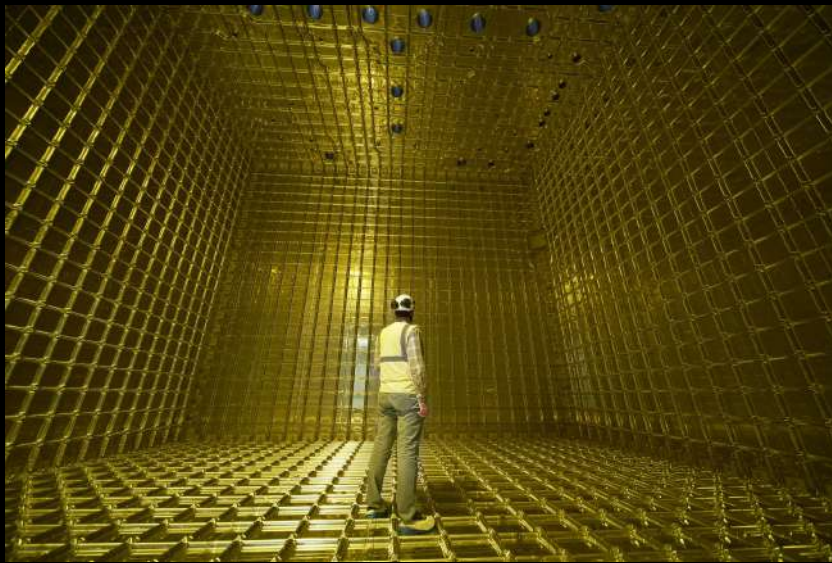
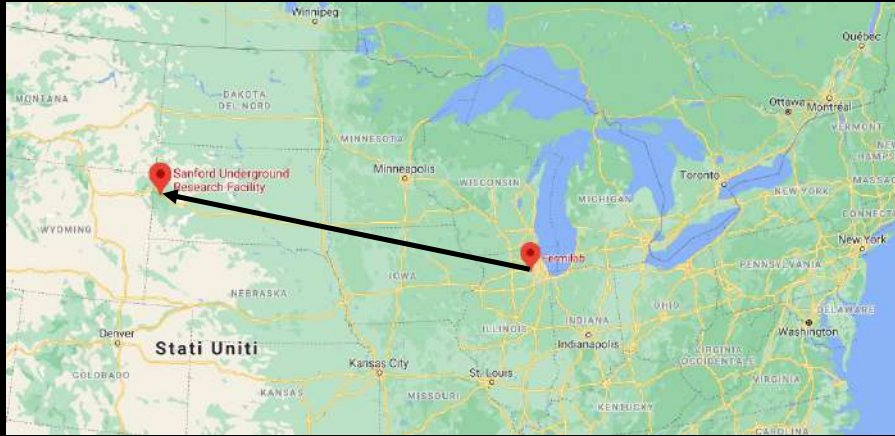
2008 – 2012
OPERA - ICARUS

CERN NEUTRINOS TO GRAN SASSO
Underground structures at CERN



DUNE

deep underground neutrino experiment





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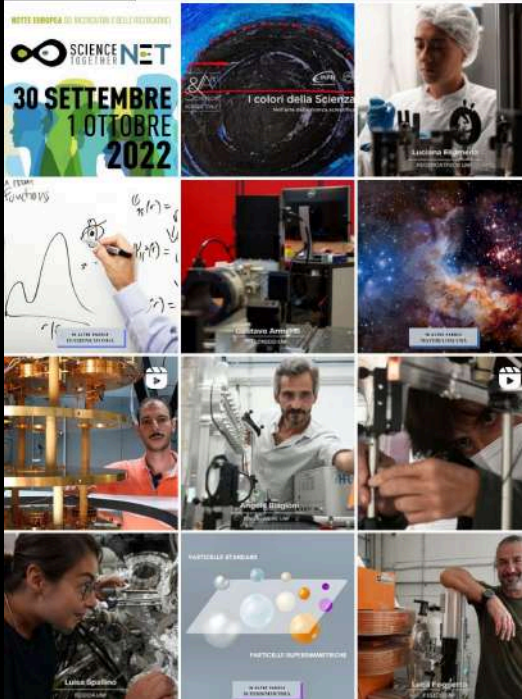
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