Heavy-Ion Meeting
Yong Pyong, Korea, February 25-27, 2010

Particle Detectors for Relativistic Heavy-Ion Collisions

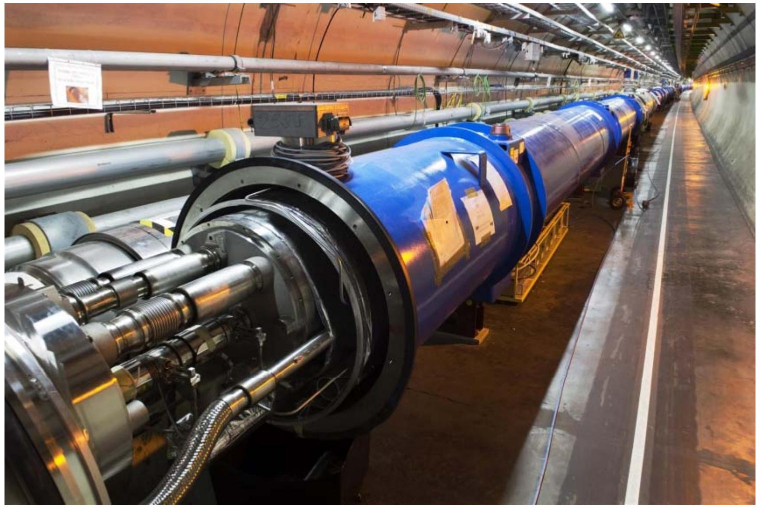
Byungsik Hong
Korea University

Outline

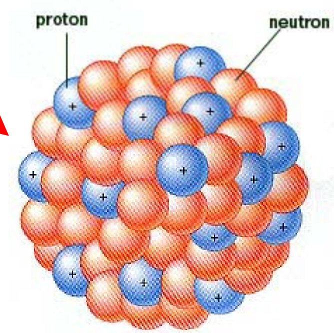
- Introduction
  - I will skip the physics motivation!
  - What are the basic ingredients of relativistic heavy-ion collision experiments?
  - How have they been developed?
- Principles of Particle Detection
  - What needs to be measured?
  - How to measure them?
- Some Examples
  - Mostly, RHIC & LHC experiments

Basic Ingredients

Relativistic **Heavy Ion** **Collision** **Experiment**



High-energy accelerators



Heavy Ions or, essentially, heavy nuclei

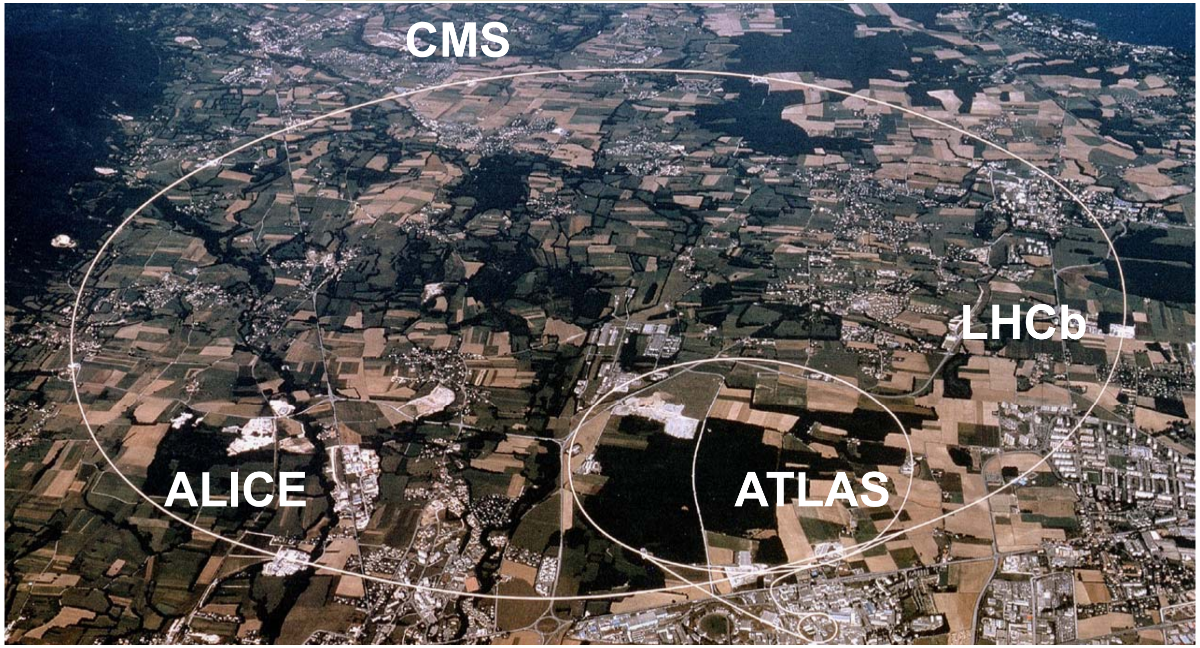
Detectors and most importantly people

Accelerators

Many generations of accelerators provided higher and higher energy beam particles for experiments

Ernest Lawrence
(1901 - 1958)

¾ of century later



LHC at CERN
(27 km circumference)

HI Accelerators in the meantime

BEVALAC(=Bevatron+SuperHILAC) at LBNL

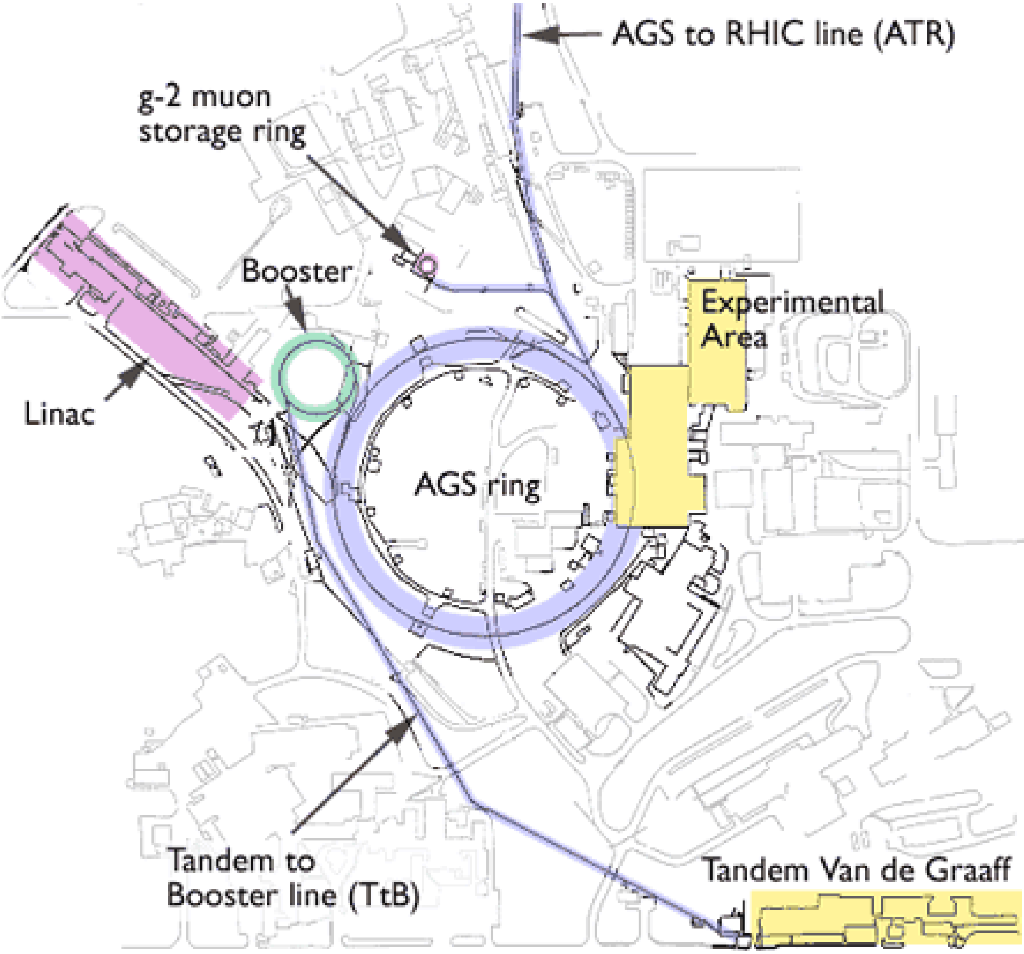
Billions of eV Synchrotron

(1971-1993)

Discovery of antiproton in 1955
by E. Segrè & O. Chamberlain
(Nobel Prize in Physics 1959)

HI Accelerators in the meantime

AGS (Alternating Gradient Synchrotron) at BNL (1986-1996)



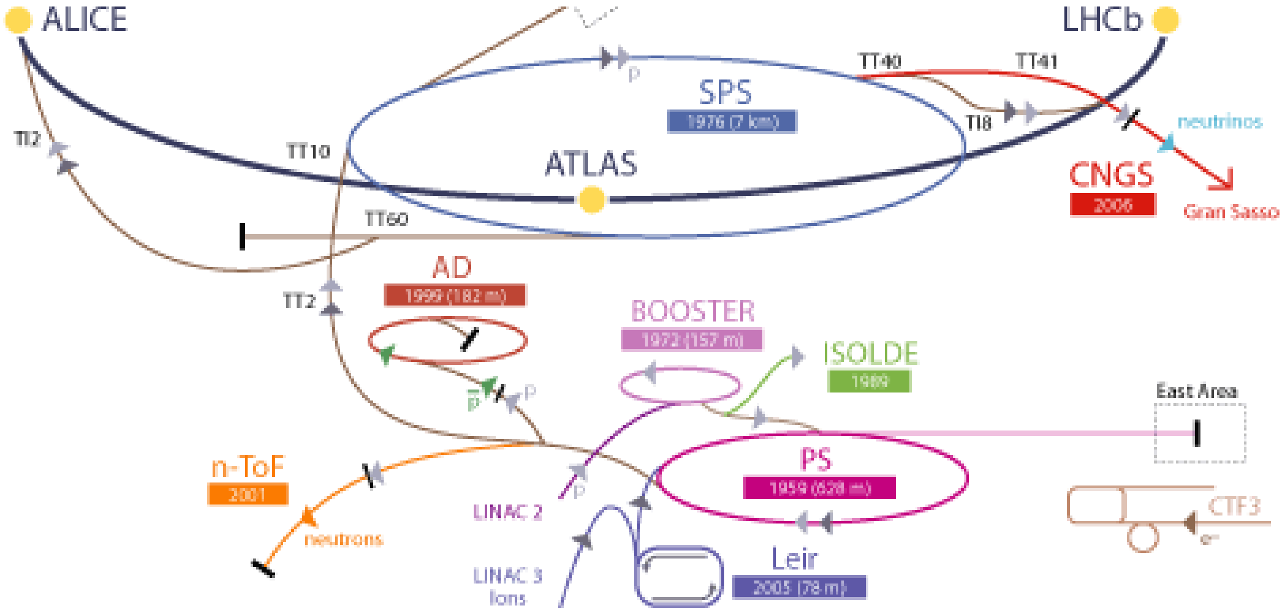
Discovery of ν_μ in 1962 by L. Lederman, M. Schwartz & J. Steinberger (Nobel Prize in Physics 1988)

Discovery of CP violation in 1963 by J. W. Cronin & V. L. Fitch (Nobel Prize in Physics 1980)

Discovery of J(/ψ) particle and charm quark in 1974 by S. Ting (Nobel Prize in Physics 1976)

HI Accelerators in the meantime

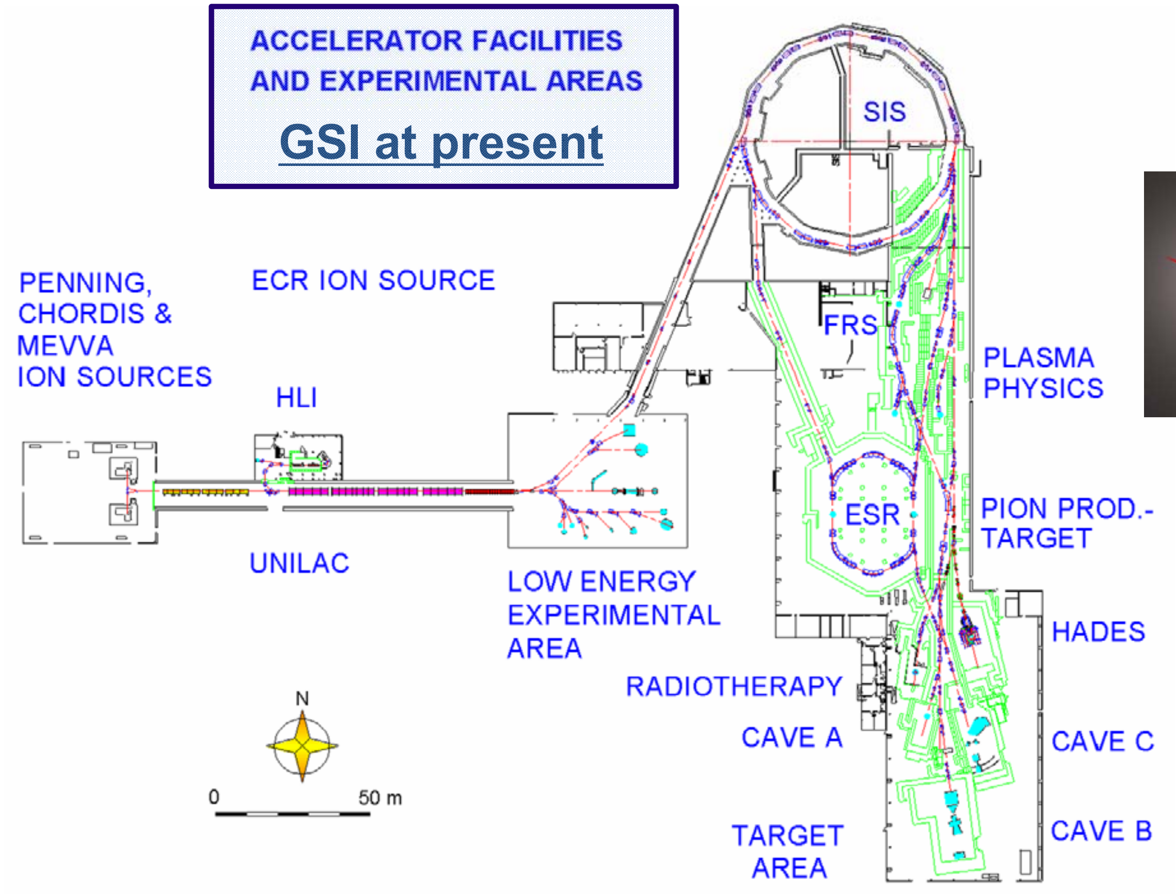
SPS (Super Proton Synchrotron) at CERN (1986-Present)



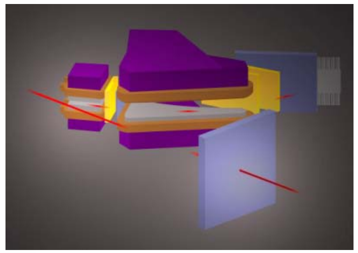
Discovery of W & Z in 1983 by UA1 & UA2 experiments
(C. Rubbia & S. Van de Meer: Nobel Prize in Physics in 1984)

HI Accelerators in the meantime

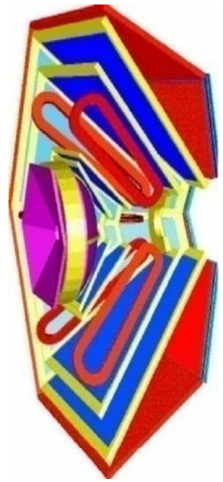
SIS18 (Heavy Ion Synchrotron in German) at GSI
(1990-Present)



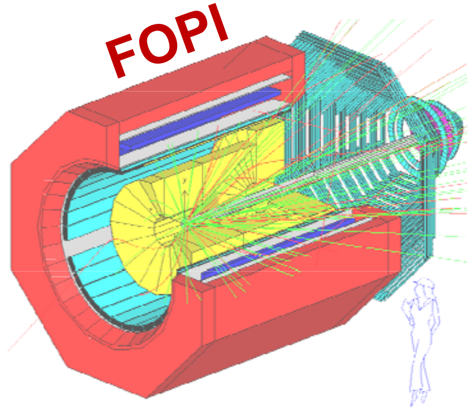
KaoS



HADES

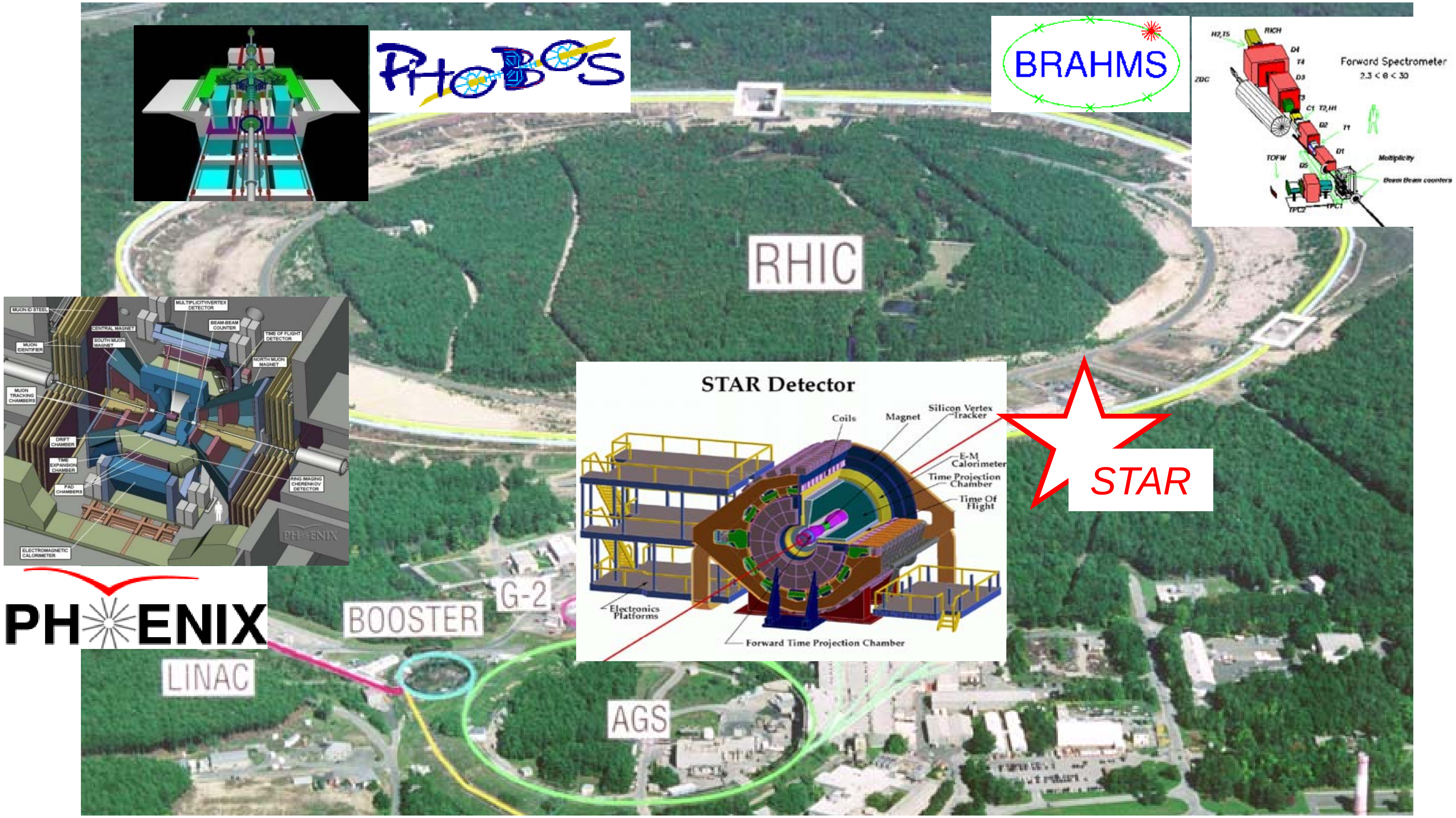


FOPI



HI Accelerators in the meantime

RHIC (Relativistic Heavy Ion Collider) at BNL (2000-Present)

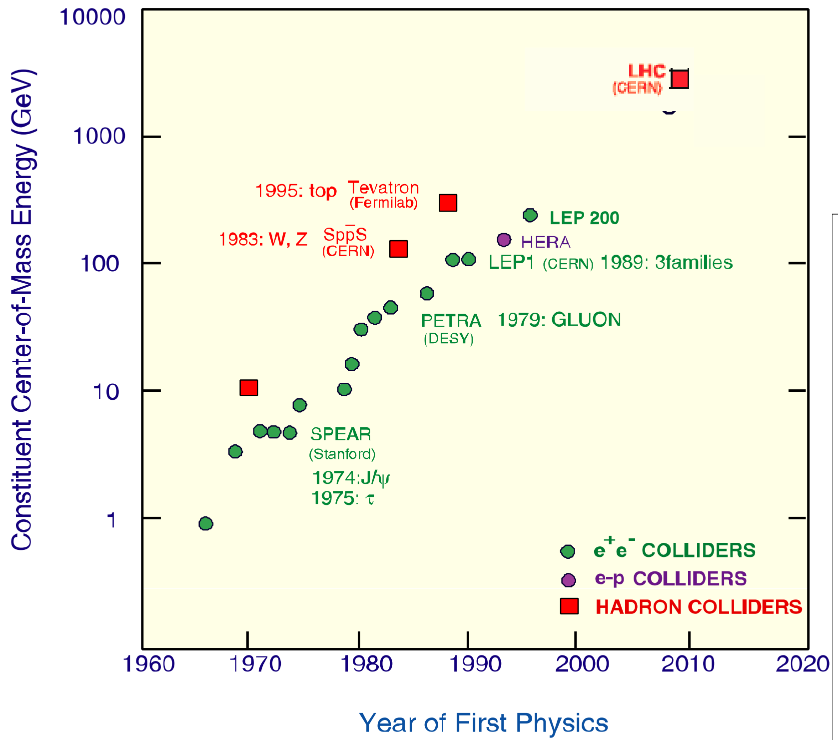


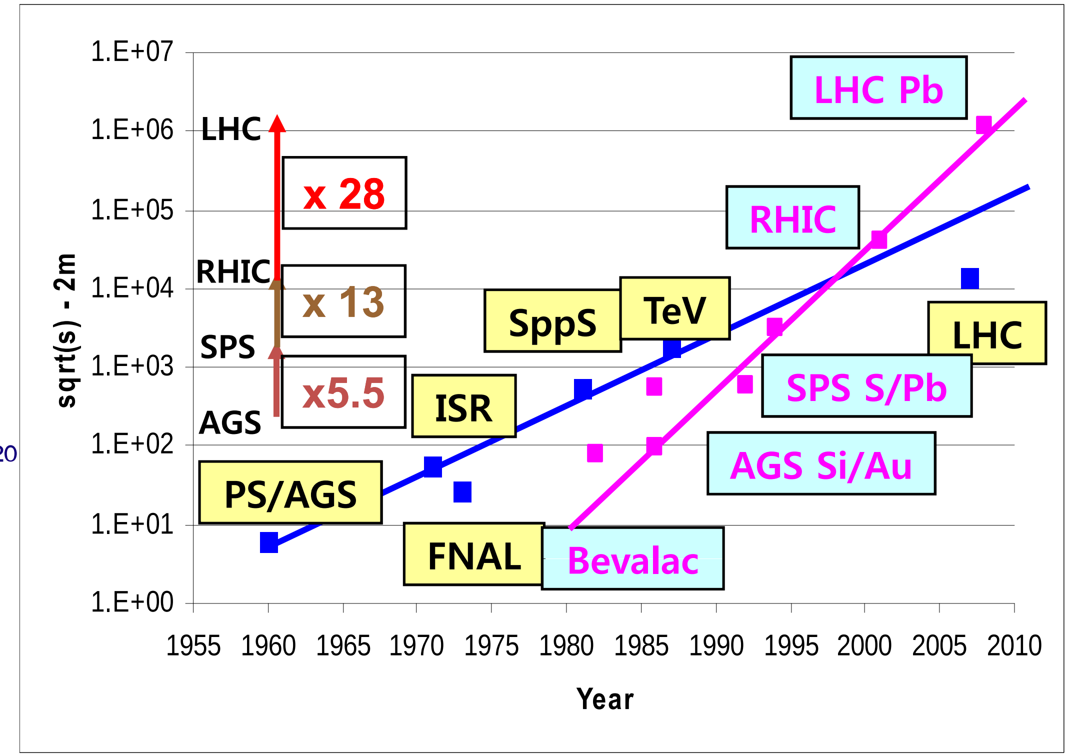
Comparison of Beam Energy

Accelerator	$\sqrt{s_{NN}}$ (GeV)	Status
SIS18 (GSI, Germany)	2A (A = mass number)	Running
AGS (BNL, USA)	5A	Finished
SIS300 (GSI, Germany)	8A	Plan to run from ~2016
SPS (CERN, Switzerland)	18A	Finish soon
RHIC (BNL, USA)	200A	Running from 2000
LHC (CERN, Switzerland)	5500A	Plan to start in 2010

Development of Energy

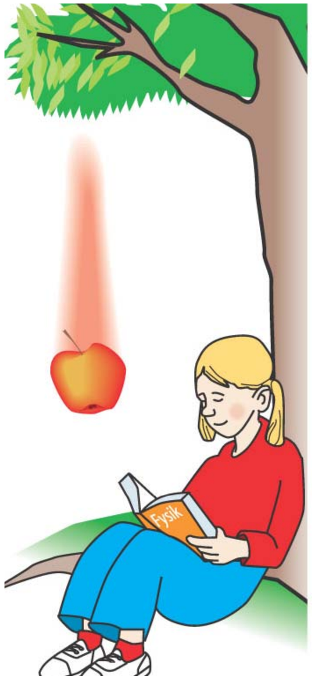
Total center-of-mass energy versus time



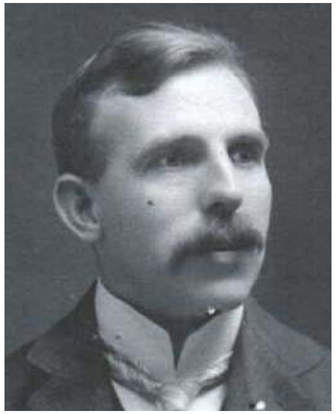


Old-Fashioned Detector

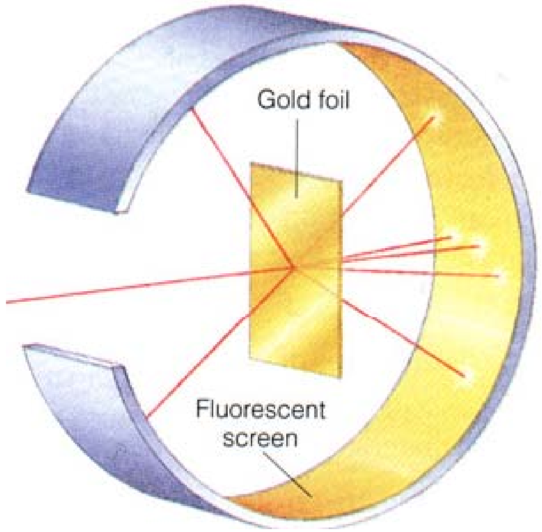
Tool to measure something



Issac Newton
(1642 - 1727)



Ernest Rutherford
(1871 - 1937)

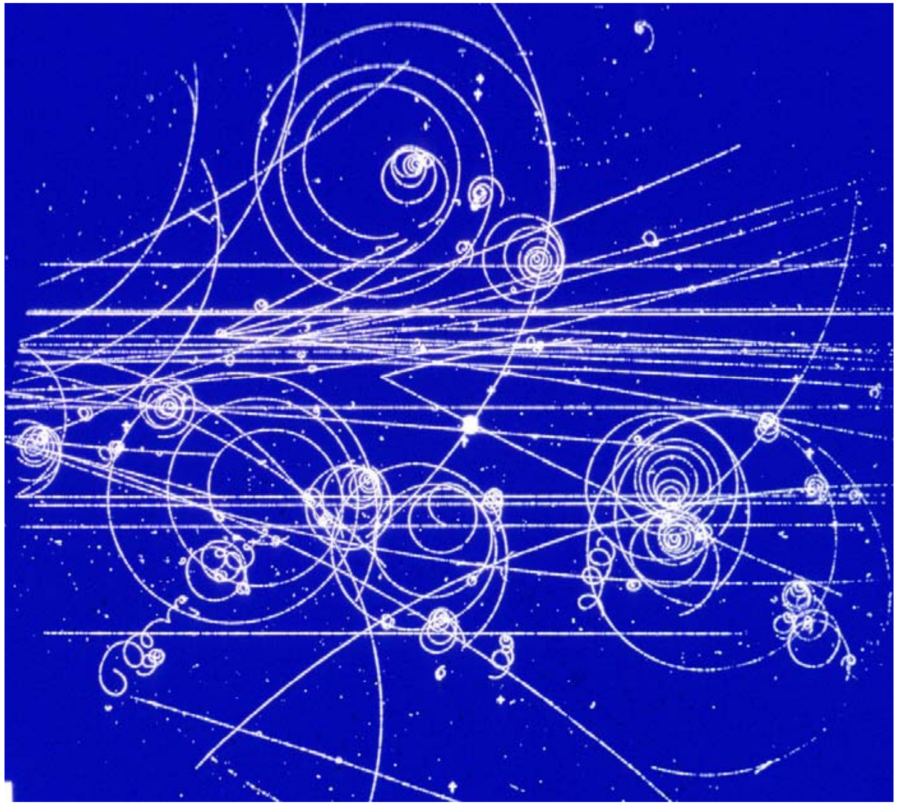


Eyes

Fluorescent (ZnS) Screen

Old-Fashioned Detector

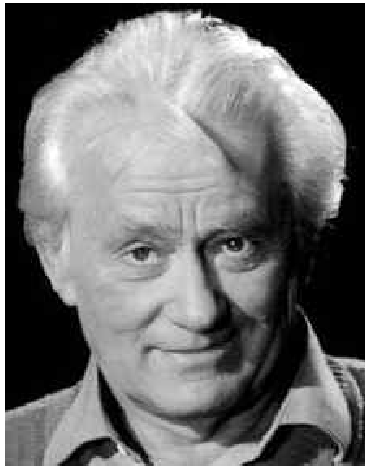
Bubble Chamber



BEBC: Big European Bubble Chamber

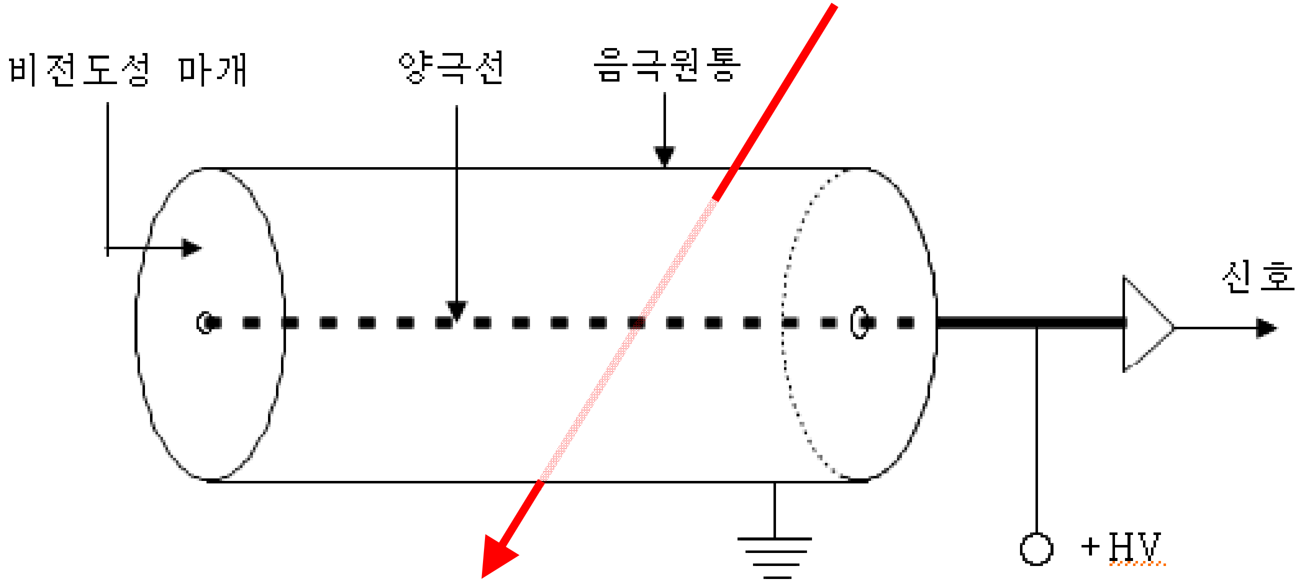
Modern Detector

- There is a clear limitation in accumulating statistics with old-fashioned detectors.
- In these days, we want to measure one particle in several hundred millions or billion collision events.
- We usually use electronics devices to record huge amount of data for a given time.
  - For example, several hundred MB data per second for each LHC experiment
- First multi-channel electronics detector
  - Multi-wire proportional chamber (MWPC)
  - Invented by G. Charpak in 1968
  - Nobel Prize in Physics in 1992



Ionization Detector

Principle



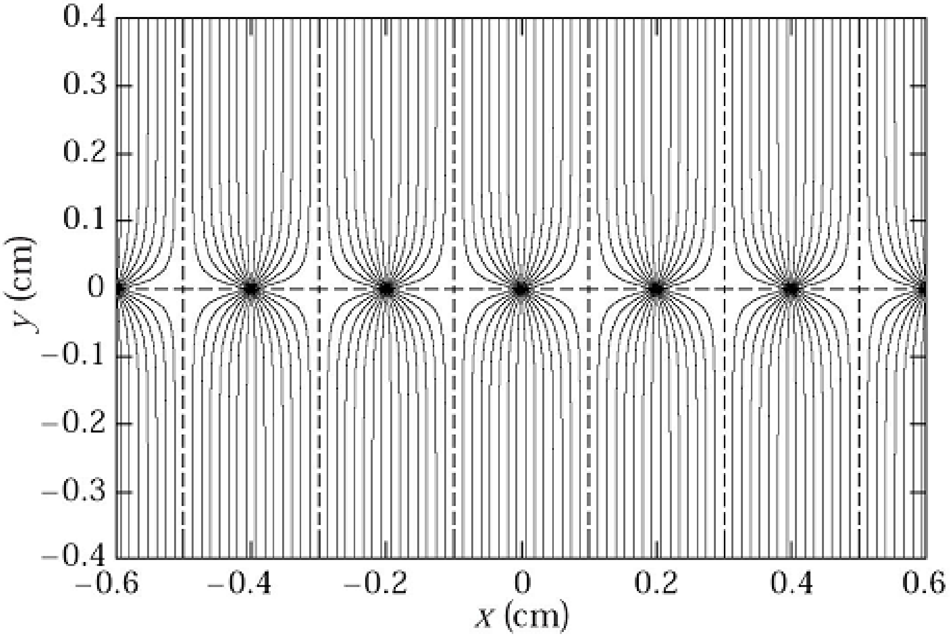
Number of free electrons at $x : n = n_0 \exp(\alpha \cdot x)$

$(\alpha :$ Townsend coefficient$)$

Multiplication factor : $M = \dfrac{n}{n_0} = \exp(\alpha \cdot x)$

Condition for ionization process : $\alpha \cdot x < 20$ (Raether limit)

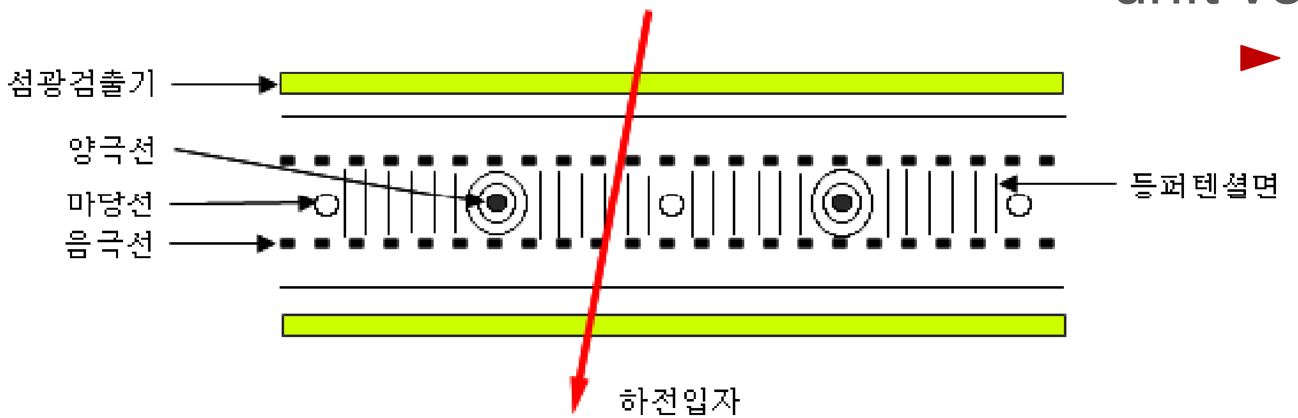
Multi-Wire Proportional Chamber



Electric Field Lines in MWPC

We can get more accurate position information by using the arrival time and drift velocity of electrons

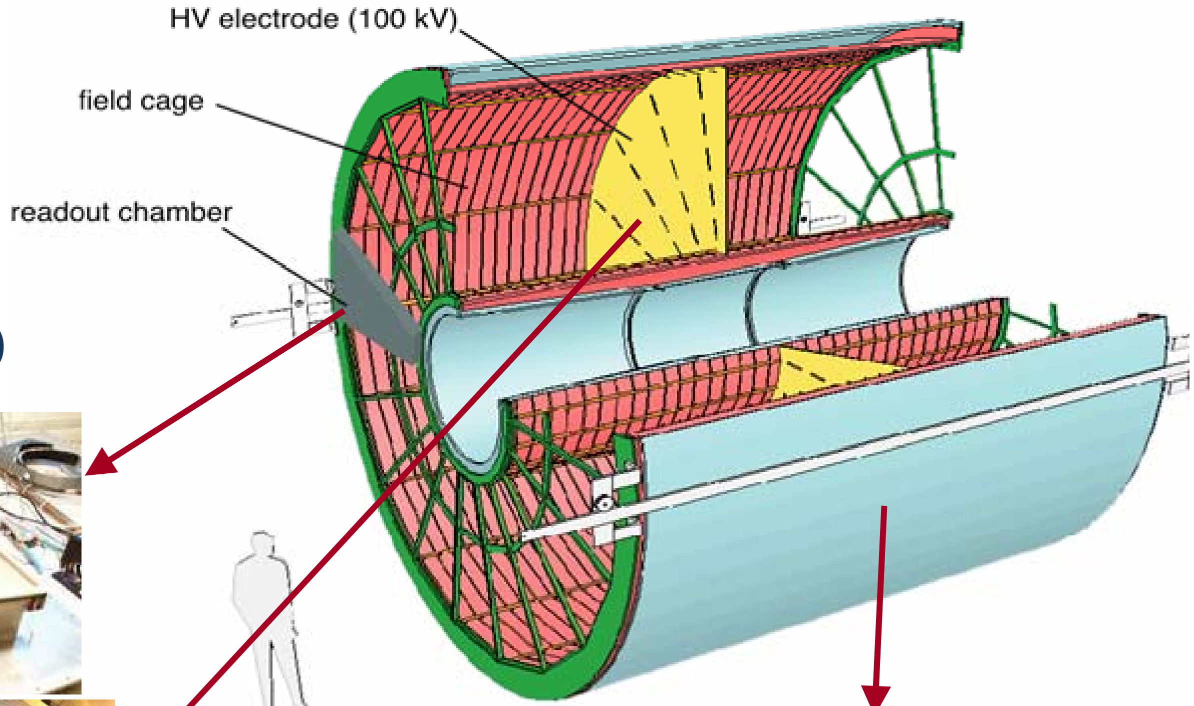
► Drift Chamber ◄

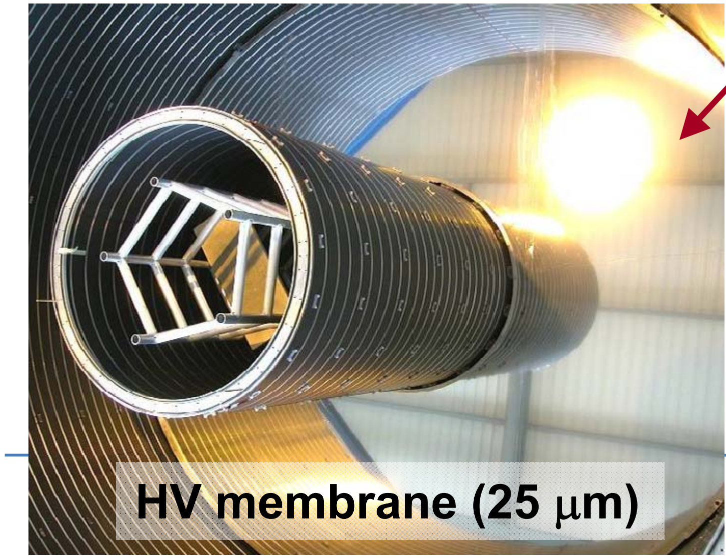


Time Projection Chamber

ALICE TPC

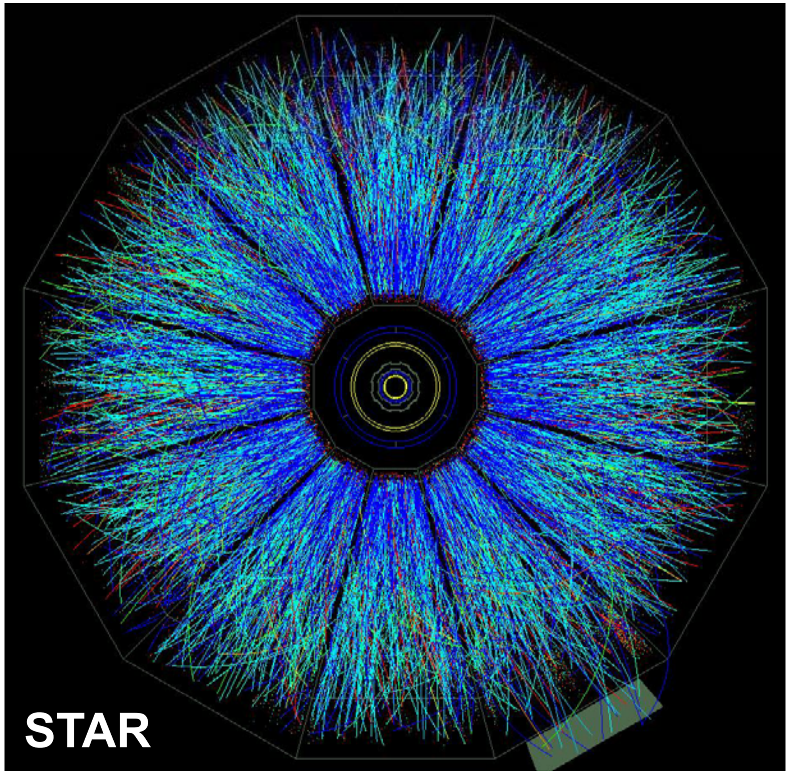
- Total volume = 88 m^3
- Length = 5 m
- Diameter = 5.6 m
- # of channels = 570k
- Drift gas ($Ne:CO_2:N_2$=86:9:5)

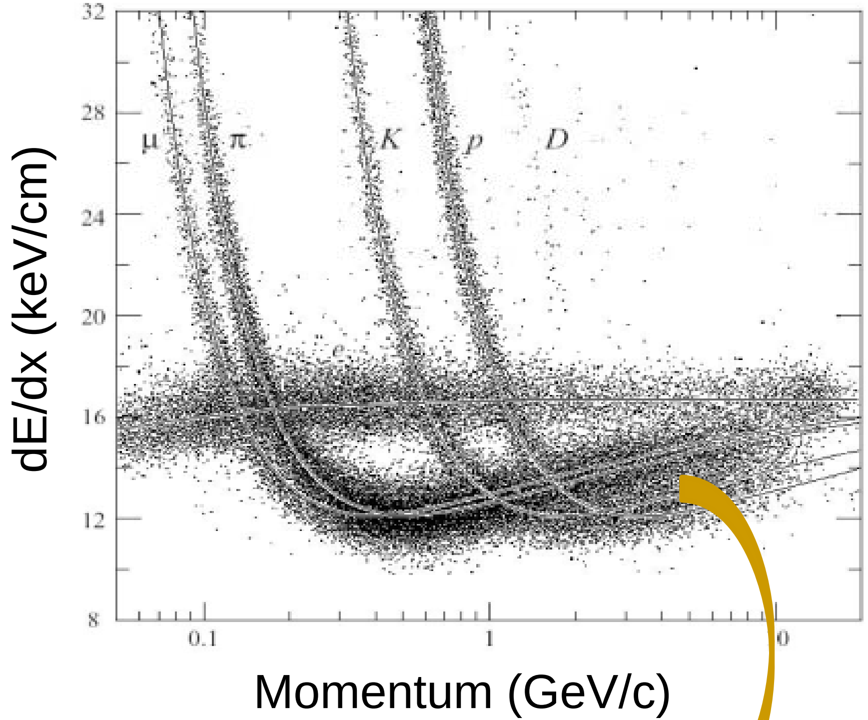



HV membrane (25 μm)


Field Cage

Time Projection Chamber

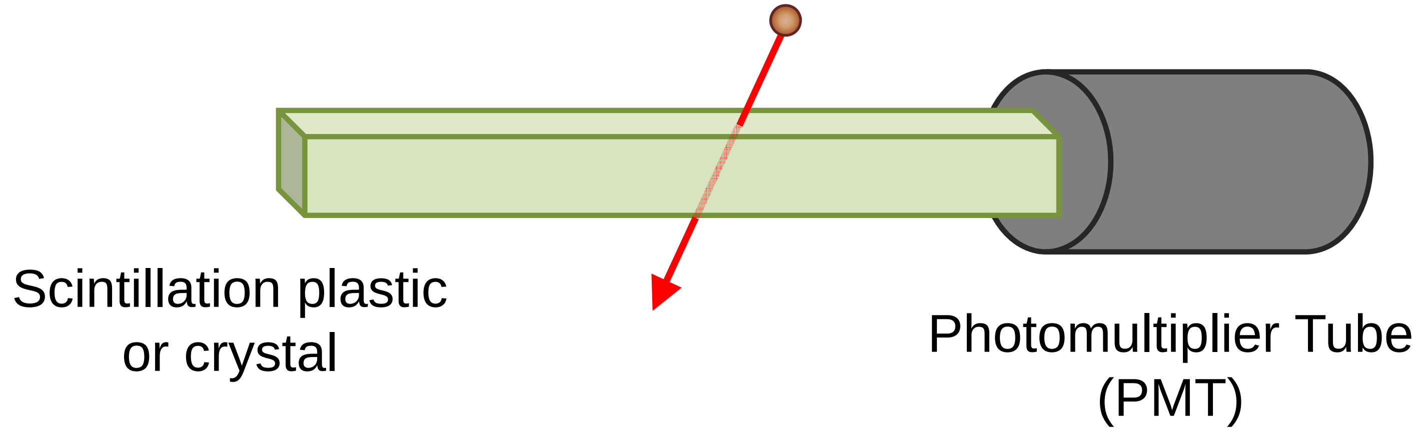


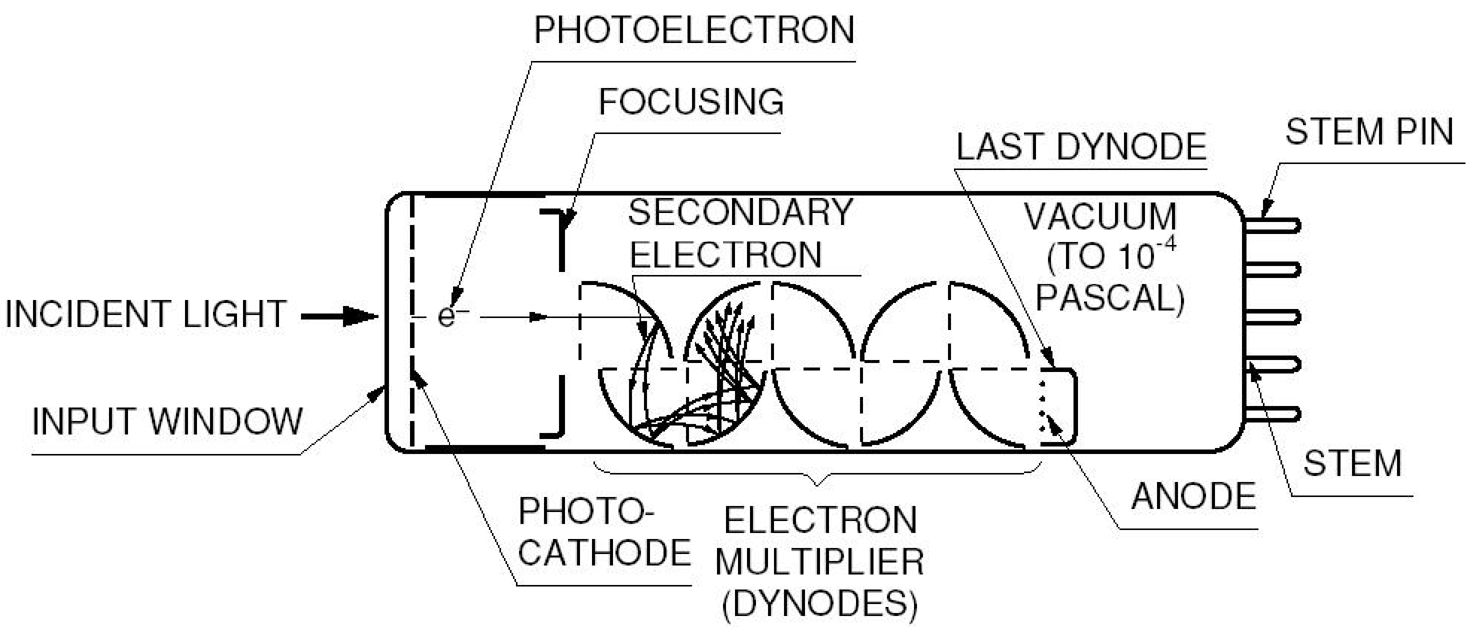


Lines: Bethe-Bloch Equation

$$-\frac{dE}{dx} = Kz^2\frac{Z}{A}\frac{1}{\beta^2}\left[\frac{1}{2}\ln\frac{2m_ec^2\beta^2\gamma^2T_{\max}}{I^2} - \beta^2 - \frac{\delta}{2}\right]$$

Scintillation Detector & PMT



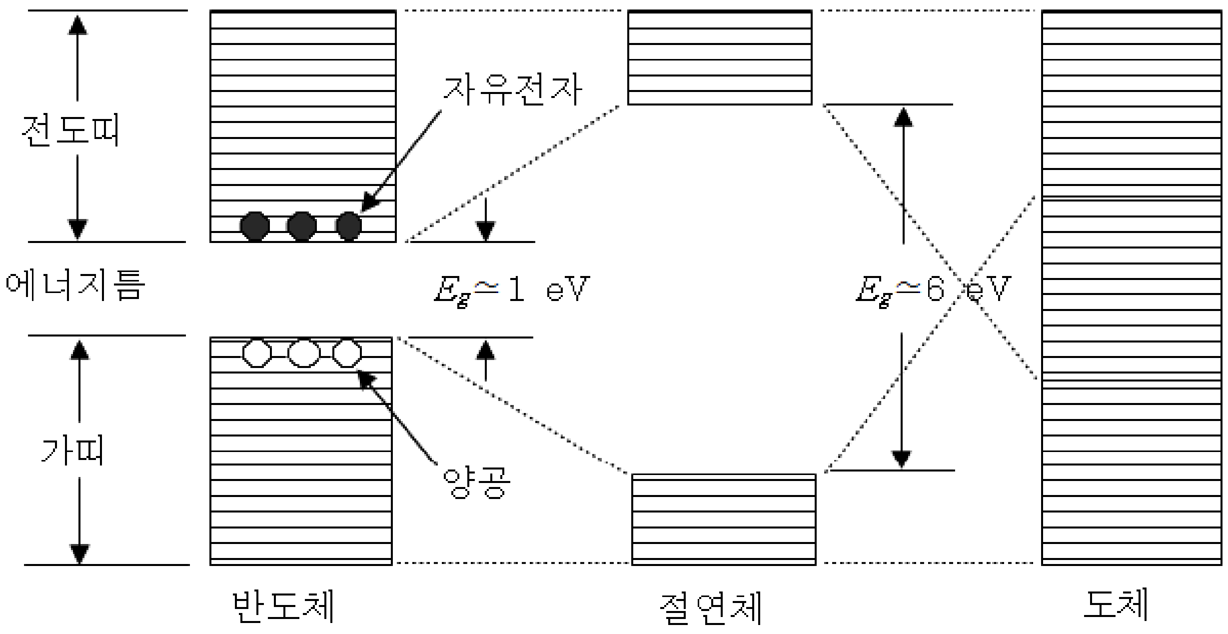


Scintillation Material

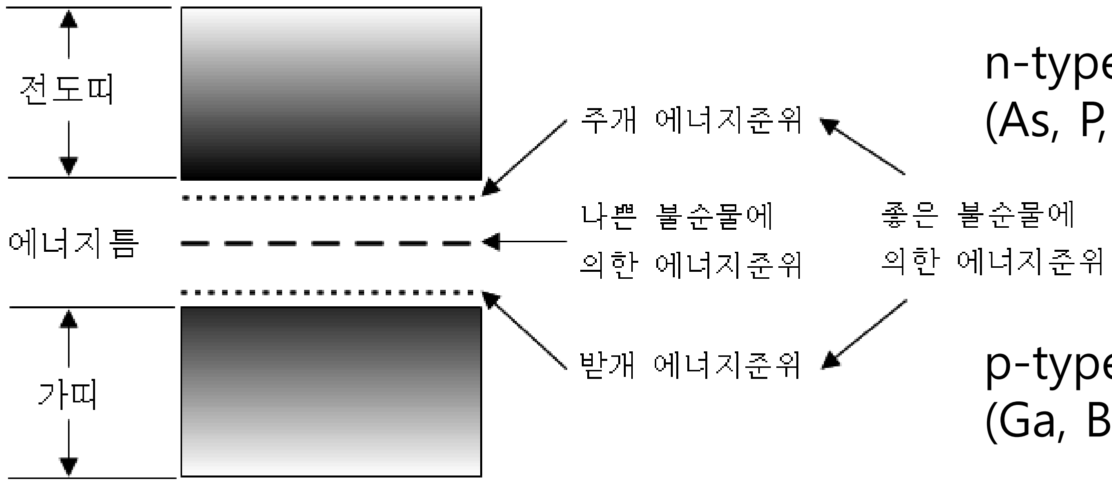
	섬광물질	최대광자방출파장 (nm)	용 도
플라스틱	NE102A	423	γ, α, β, fast n
	NE111A	370	ultra-fast timing
	Pilot U	391	ultra-fast timing
액체	NE216	425	α, β(internal counting)
	NE224	425	γ, fast n
	NE226	430	γ, insensitive n
	NE228	385	n
결정	NaI(Tl)	413	γ, *X-rays*
	BaF_2	220(fast)/310(slow)	γ, heavy particles ultra-fast timing
	CsI(Tl)	580	γ, heavy particles ultra-fast timing
	BGO($Bi_4Ge_3O_{12}$)	480	γ

Semiconductor Detector

Band Structure



For doped semiconductor

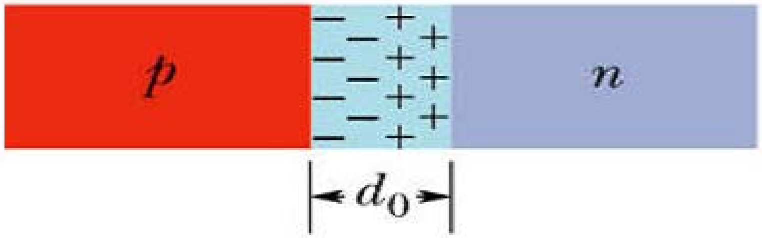


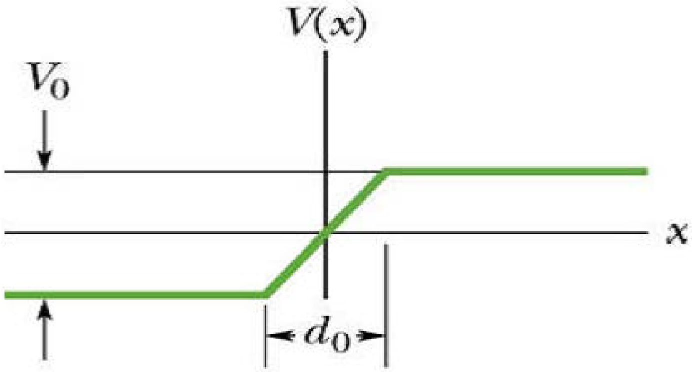
n-type
(As, P, Sb, etc.)

p-type
(Ga, B, In, etc.)

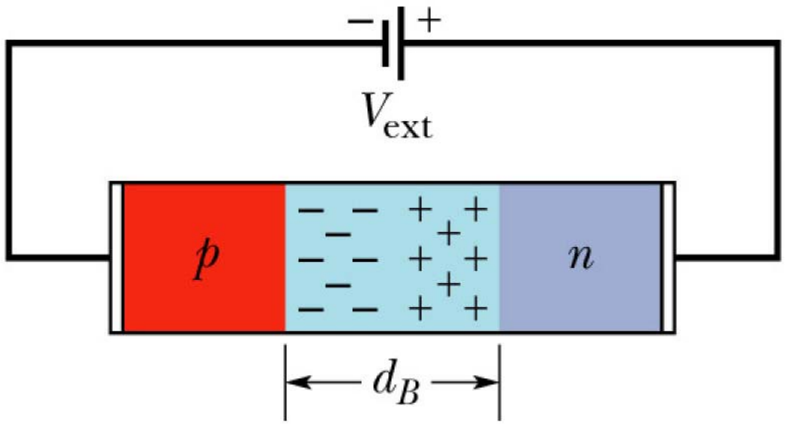
Semiconductor Detector

pn-junction





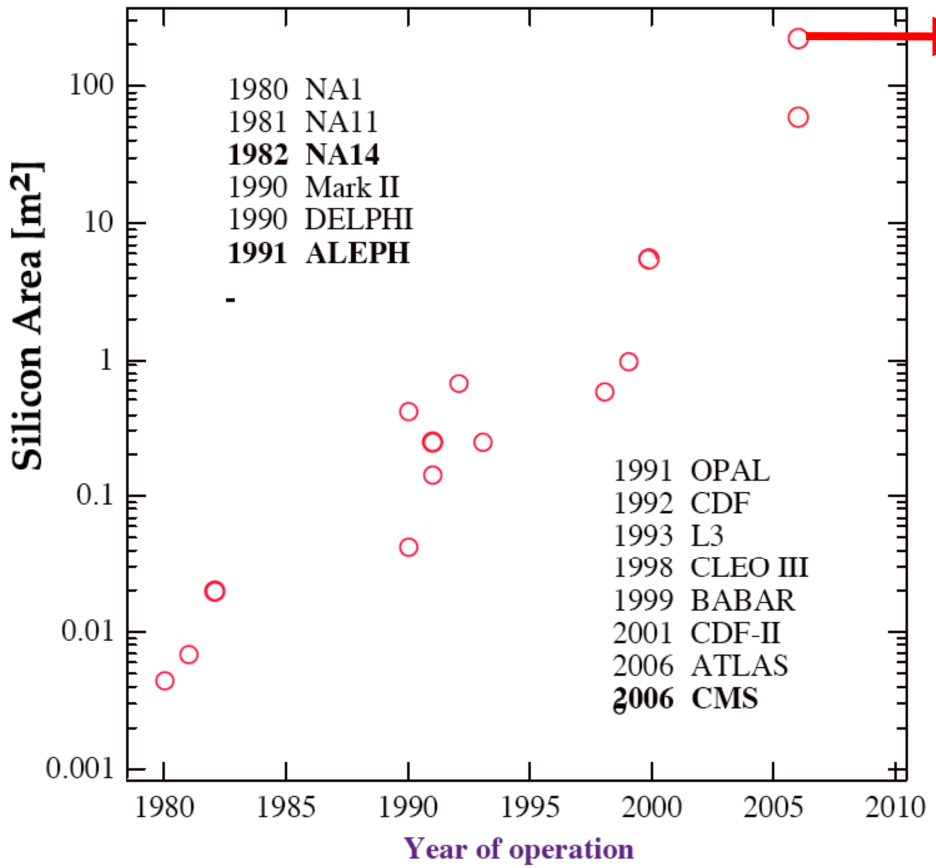
Inversed bias increases the depleted volume



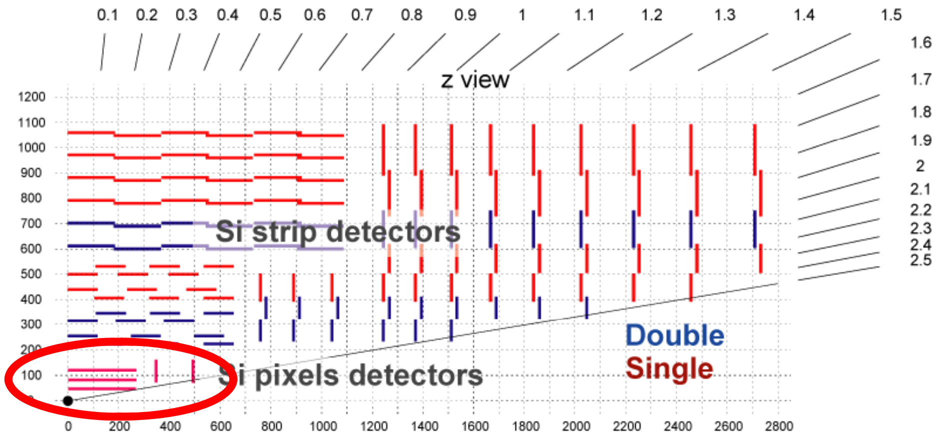
Depletion region = Effective volume for the particle detection

Maximum inversed voltage, V_{max}, determined by ρ of semiconductor

CMS Silicon Tracker

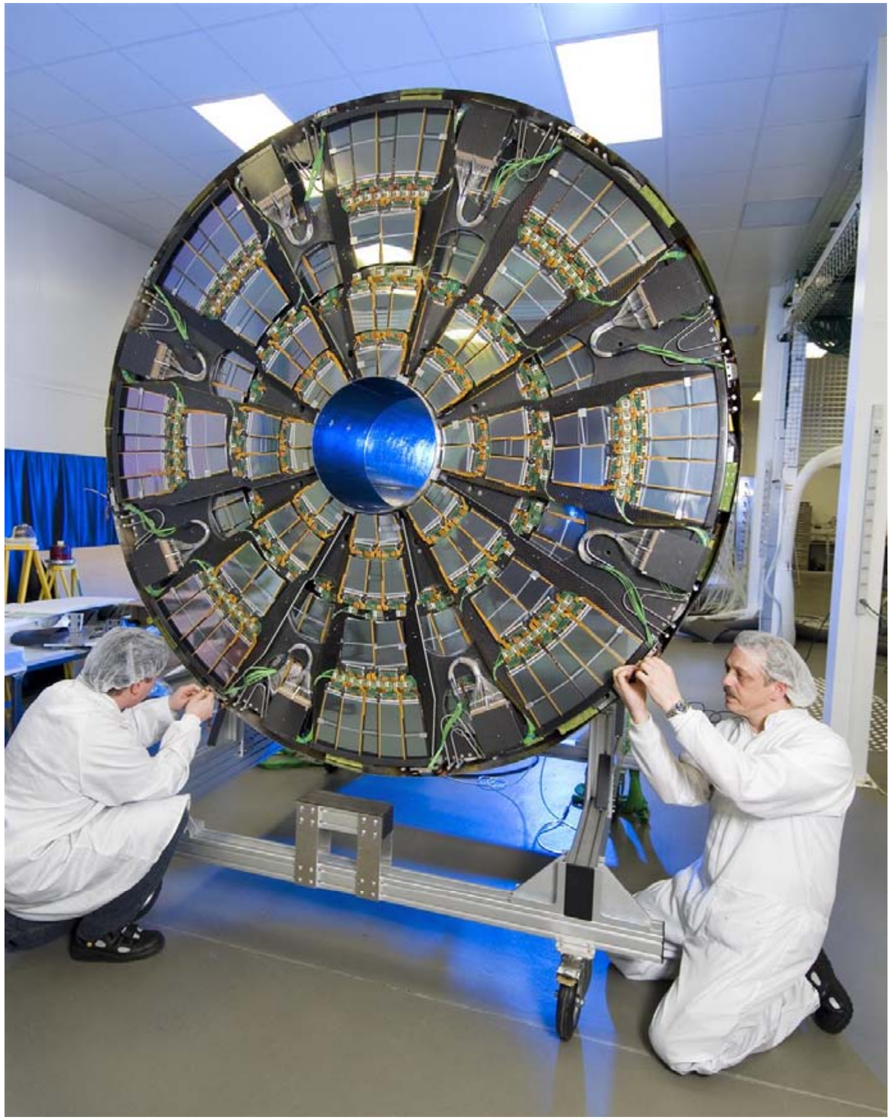


Largest Si detector ever built
(66M Si Pixels+11M Si Strips)

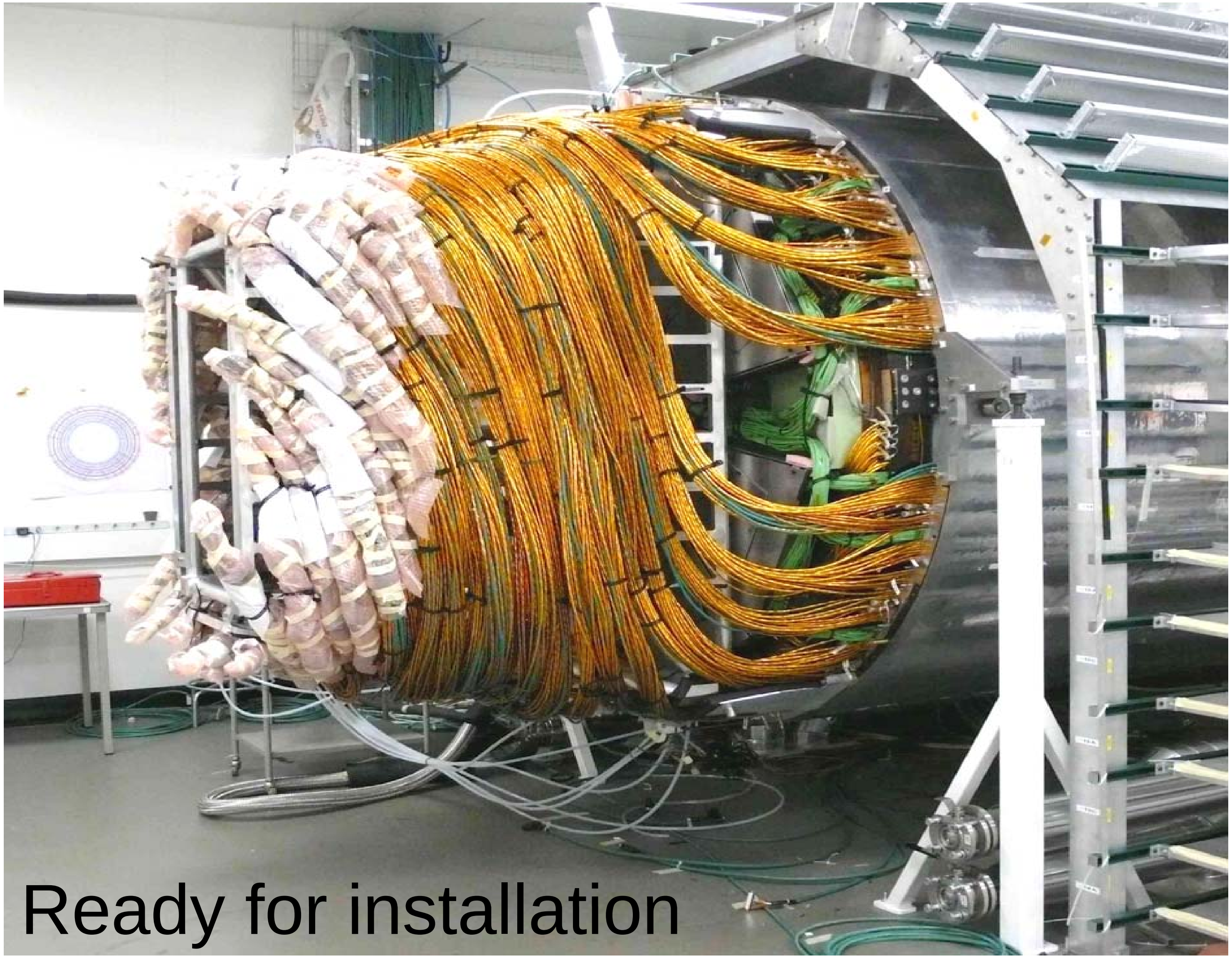


The layout of the CMS inner tracker

CMS Silicon Tracker



CMS Silicon Tracker

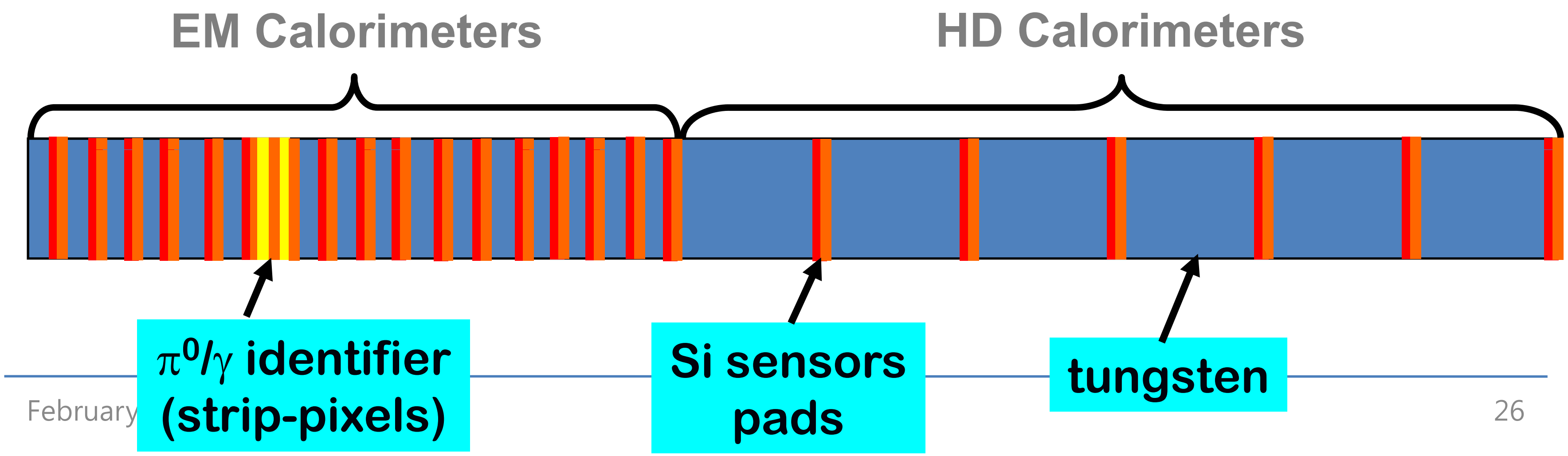


Ready for installation

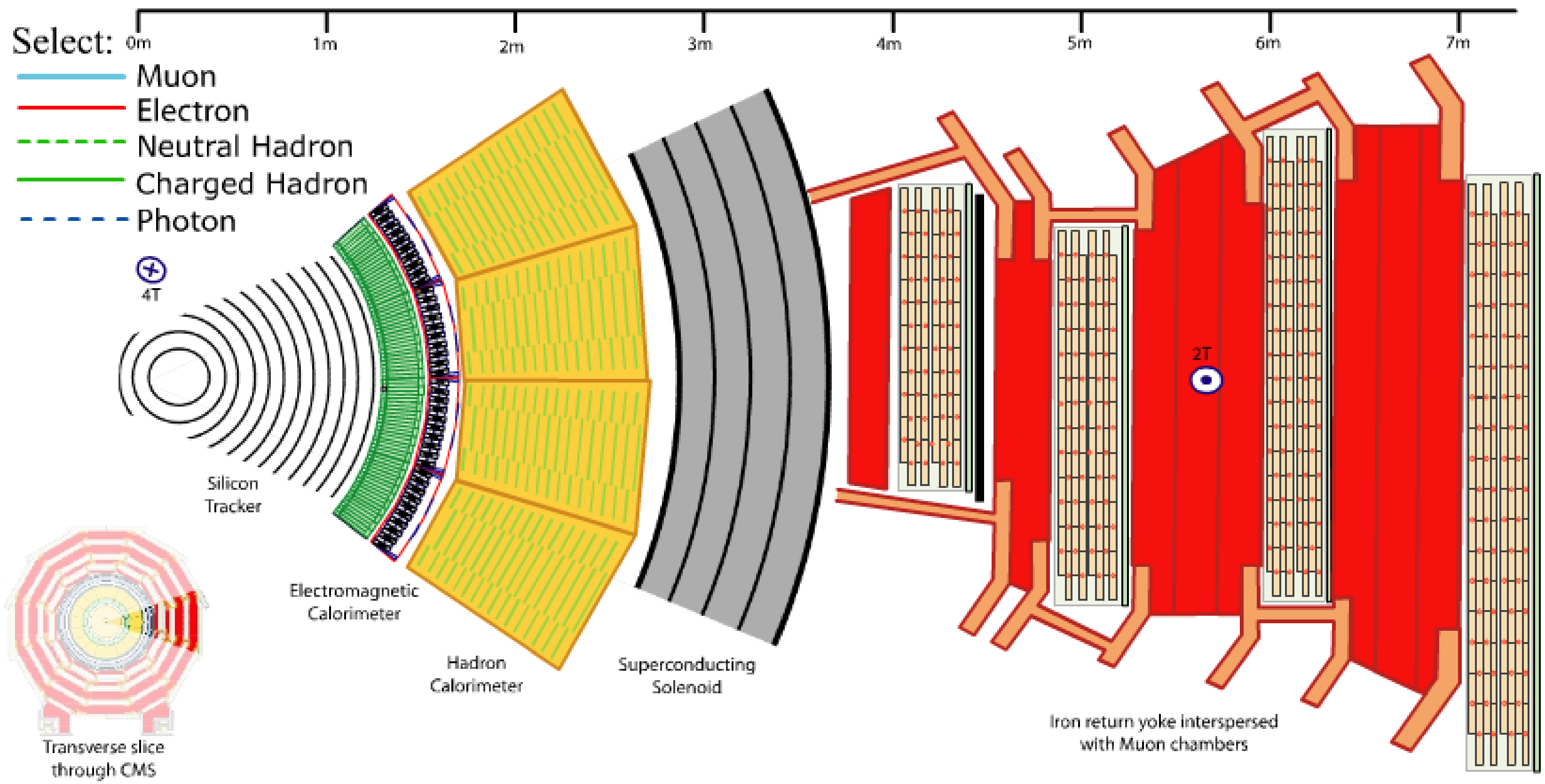
Calorimeter

- Apparatus to measure the energy of particles
- Classification by Function
  - Electromagnetic(EM) Calorimeter
  - Hadronic(HD) Calorimeter
- Classification by Structure
  - Homogeneous Calorimeter
  - Sampling Calorimeter

PHENIX FOCAL
(Forward Calorimeter)

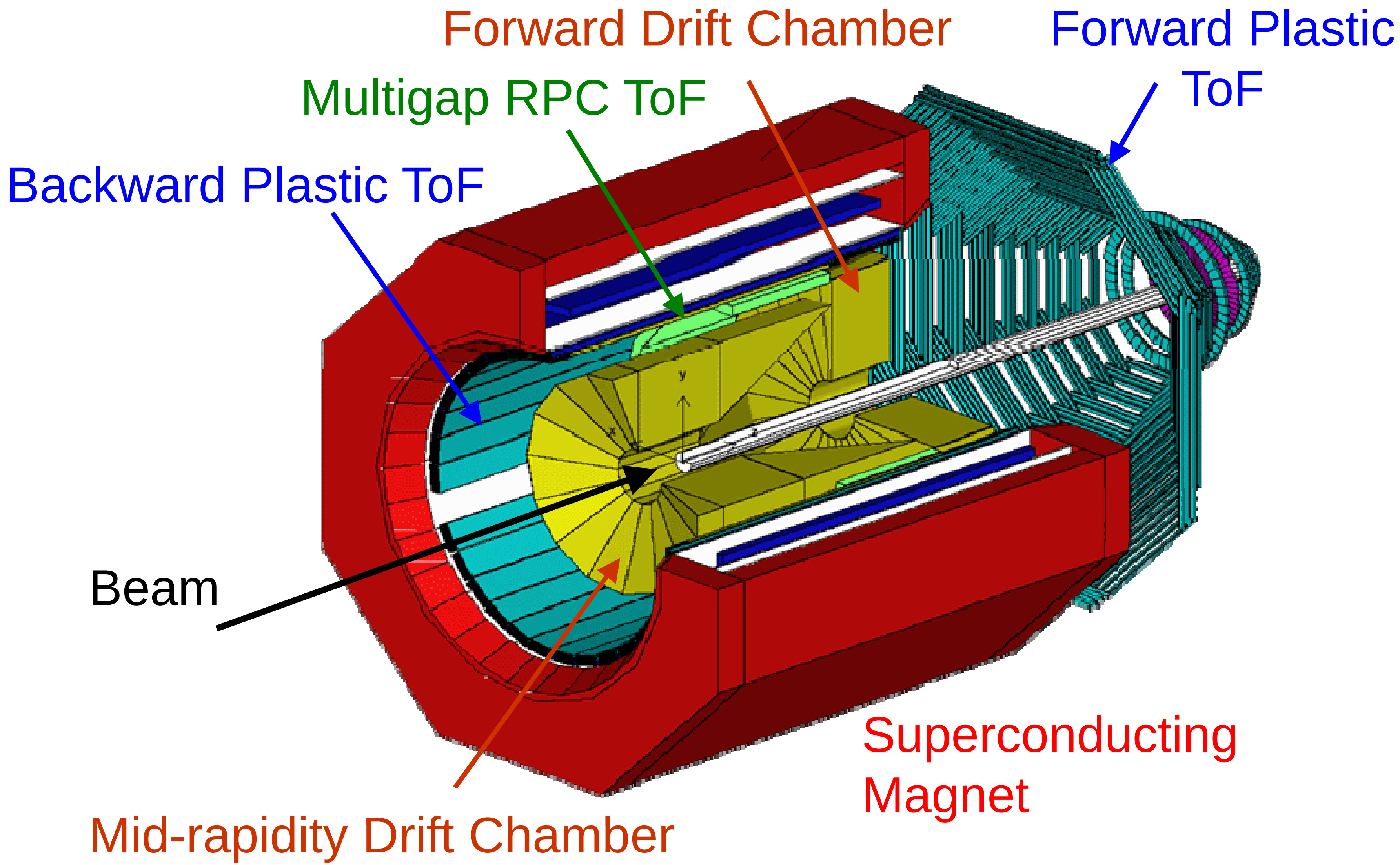


Principles of Particle Detection

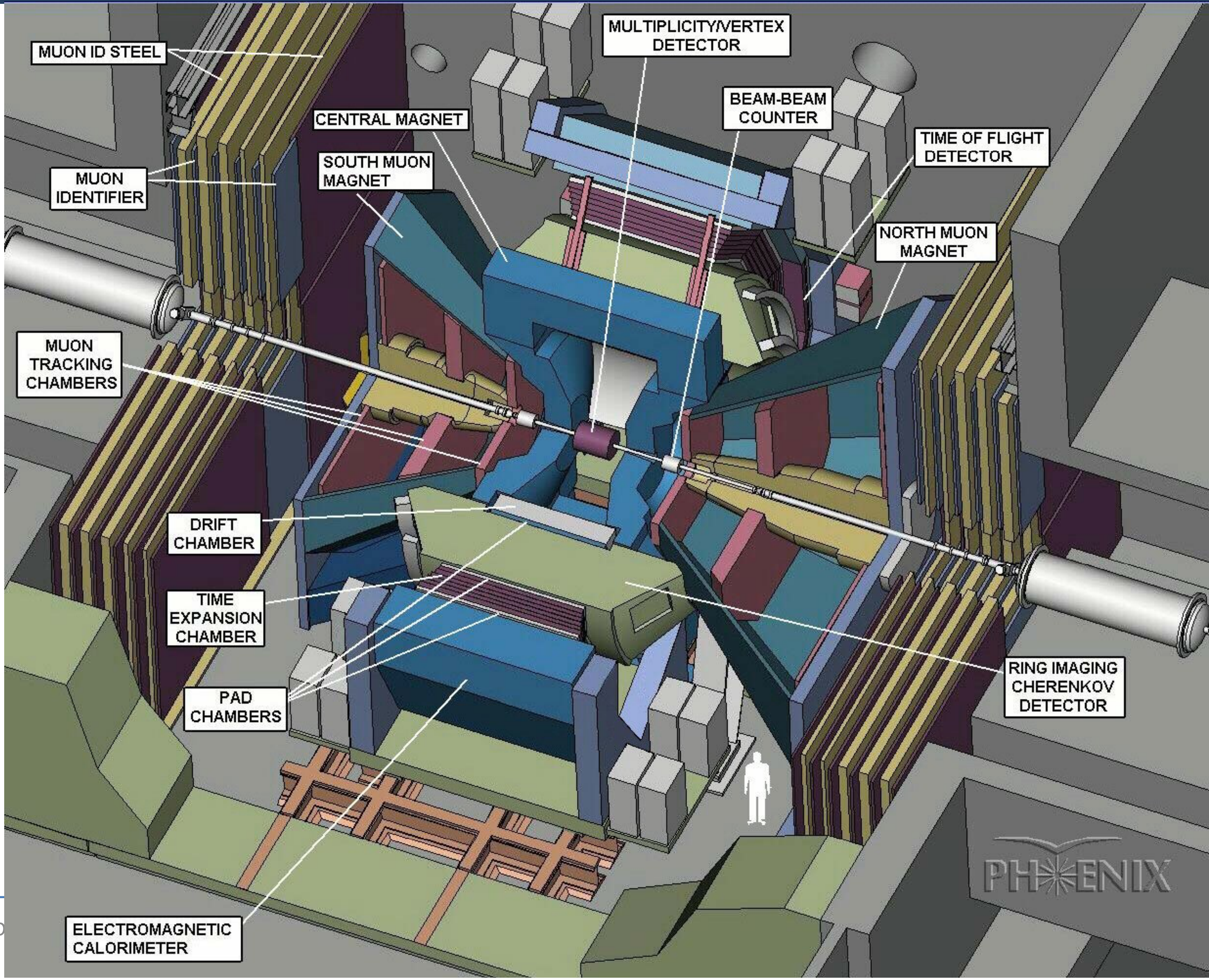


Click the above figure

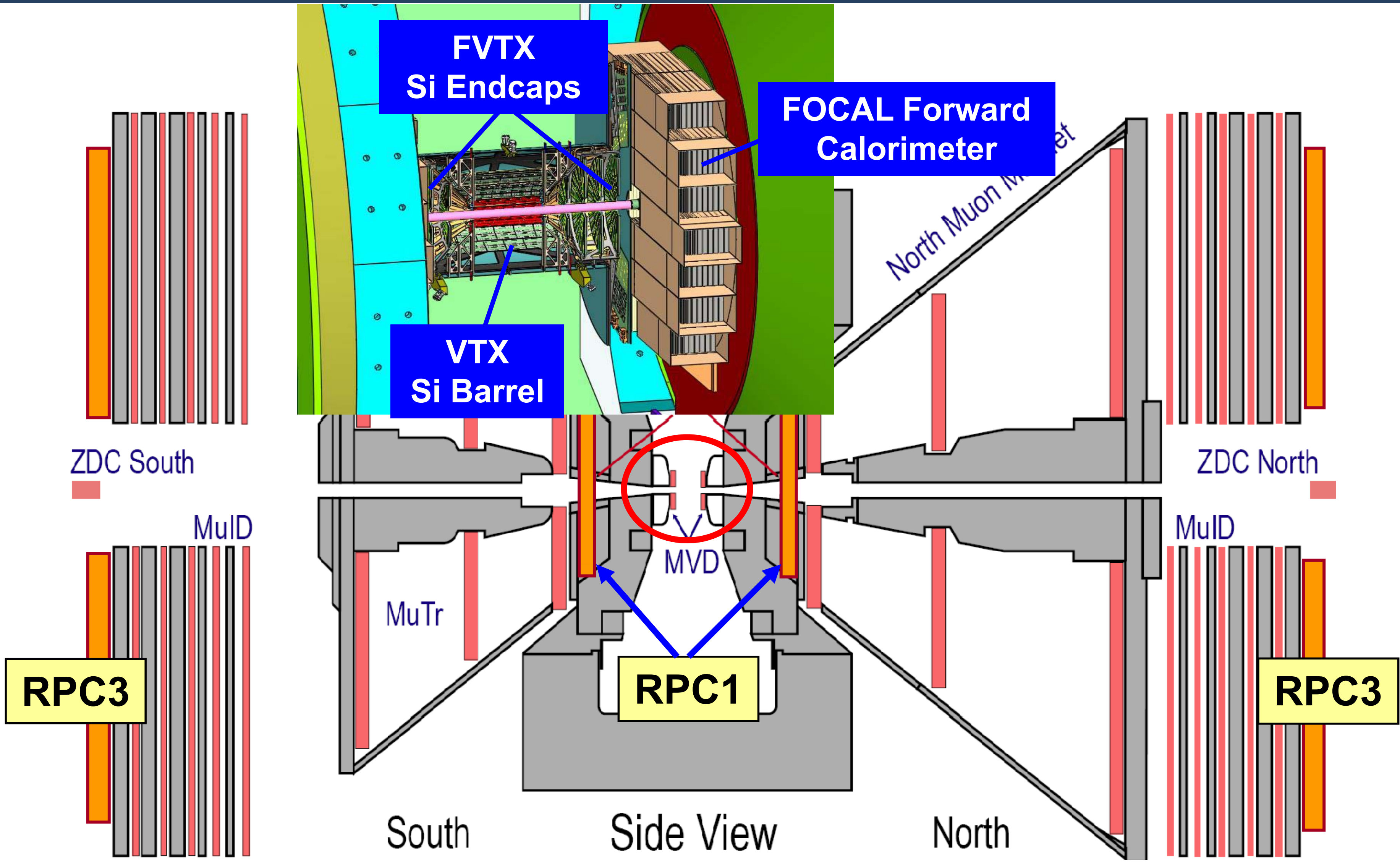
FOPI Detector @ SIS18



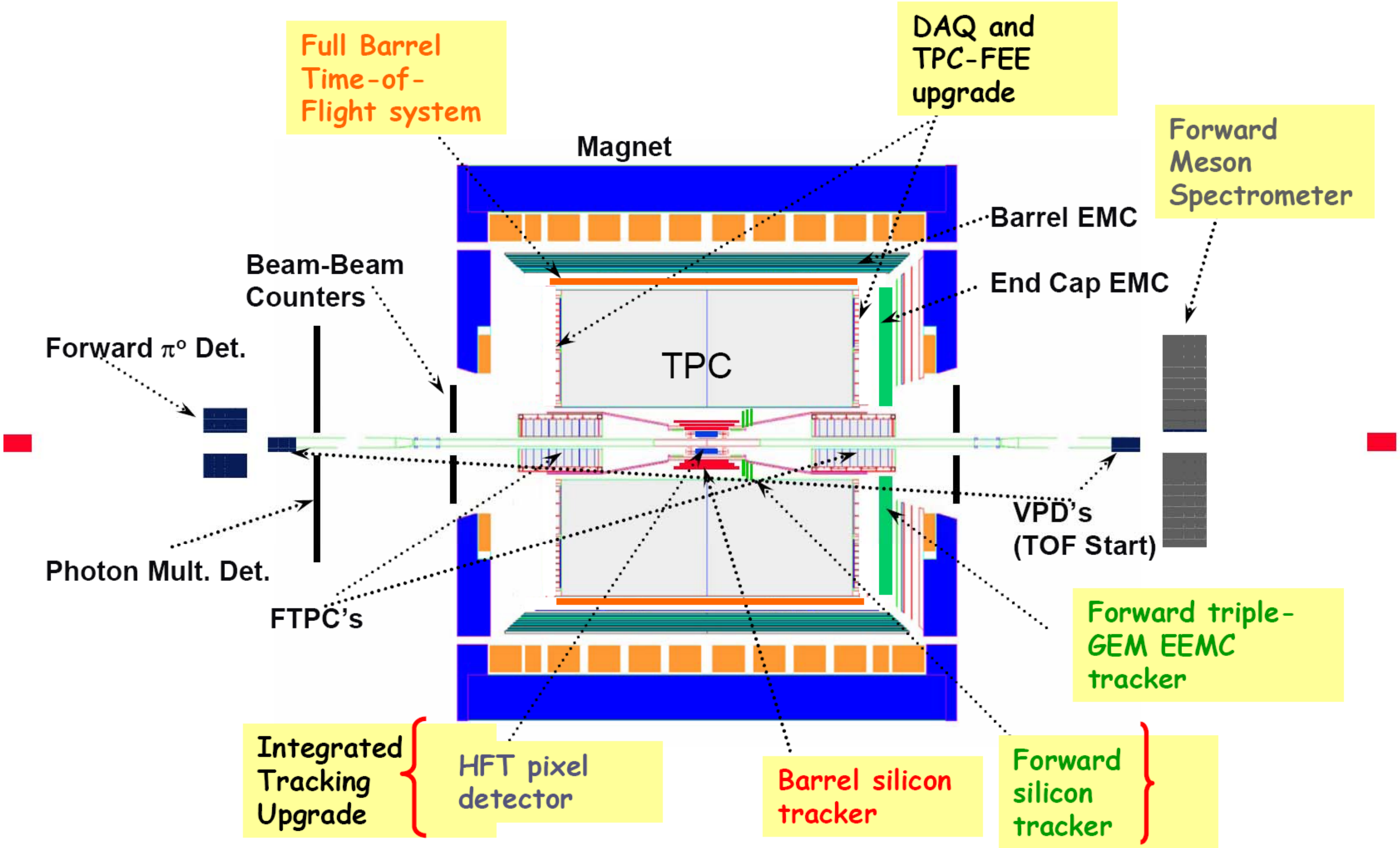
PHENIX Detector @ RHIC



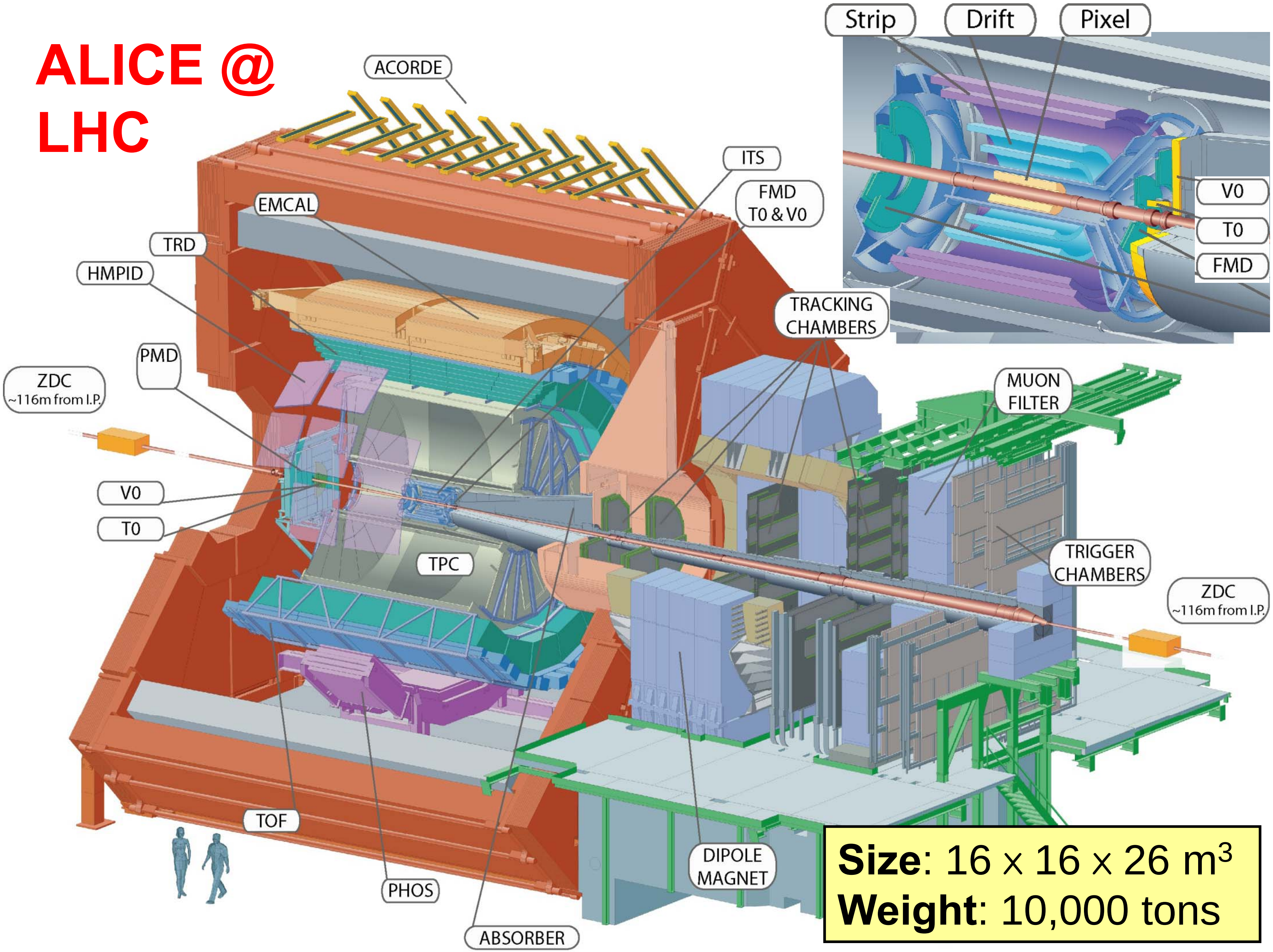
PHENIX Upgrade



STAR Detector @ RHIC



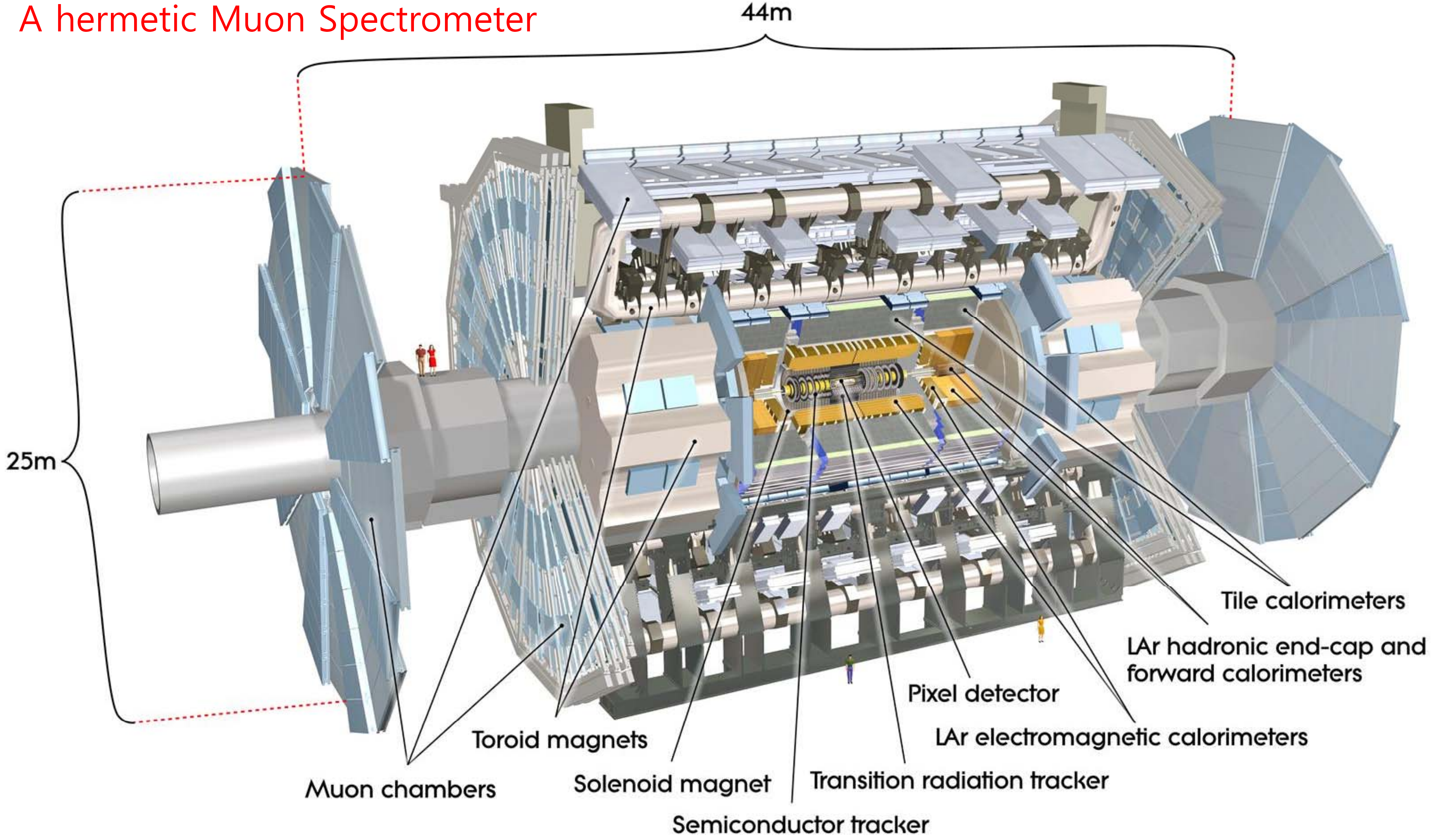
ALICE @ LHC



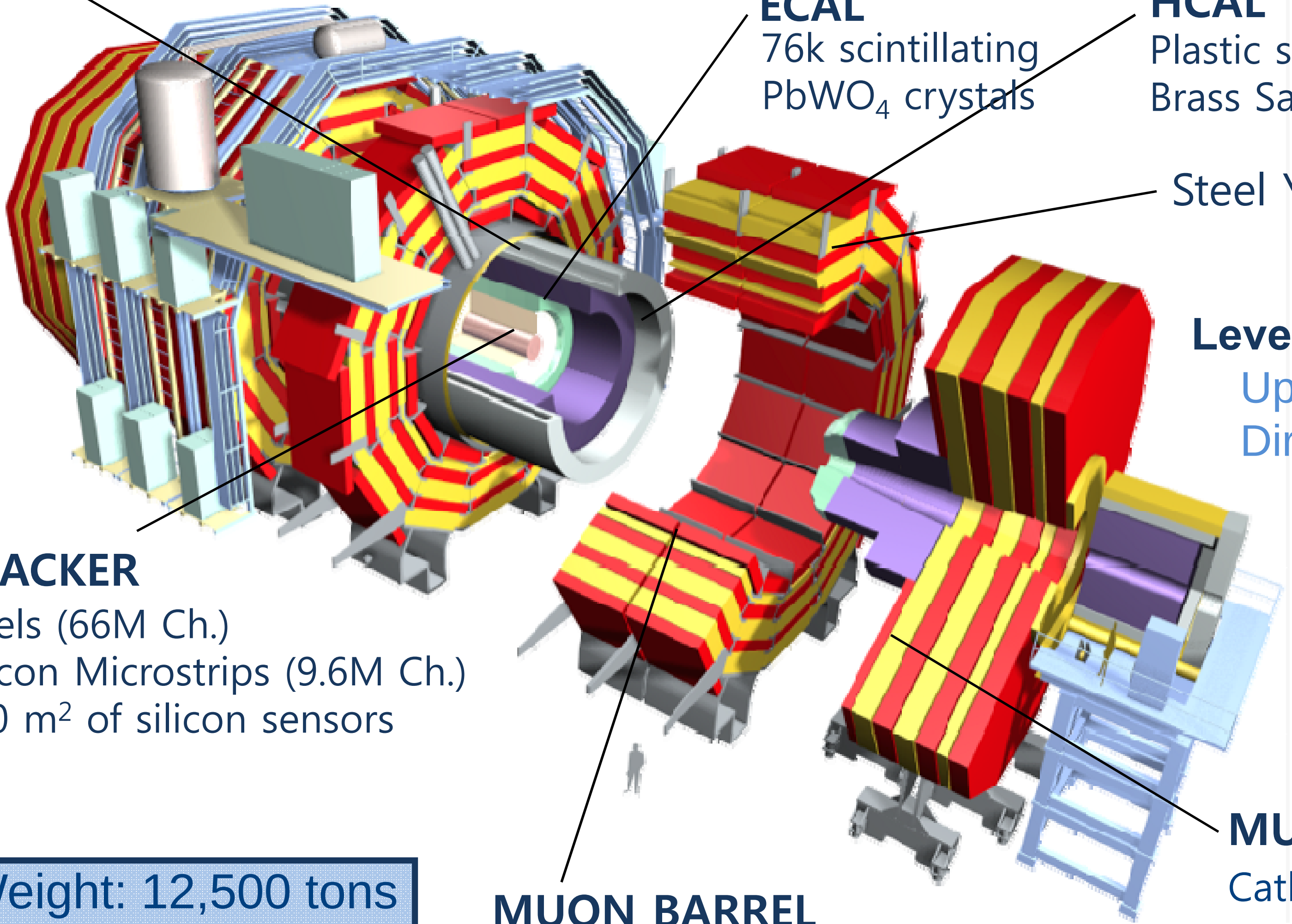
Size: 16 x 16 x 26 m^3
Weight: 10,000 tons

ATLAS Detector @ LHC

An Excellent Calorimetry
A large acceptance Inner Tracker
A hermetic Muon Spectrometer



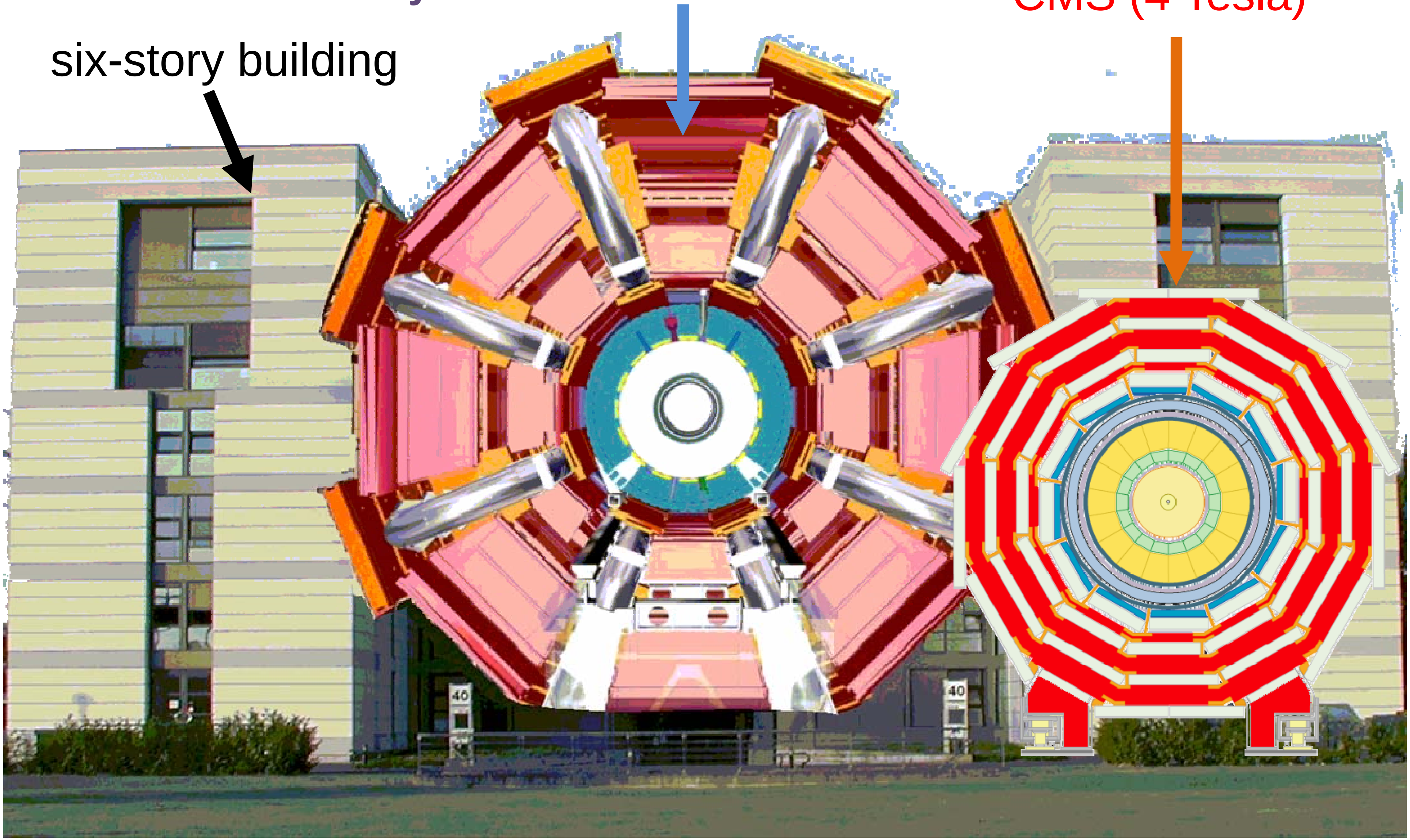
CMS Detector @ LHC



Weight: 12,500 tons
Diameter: 15 m
Length: 22 m

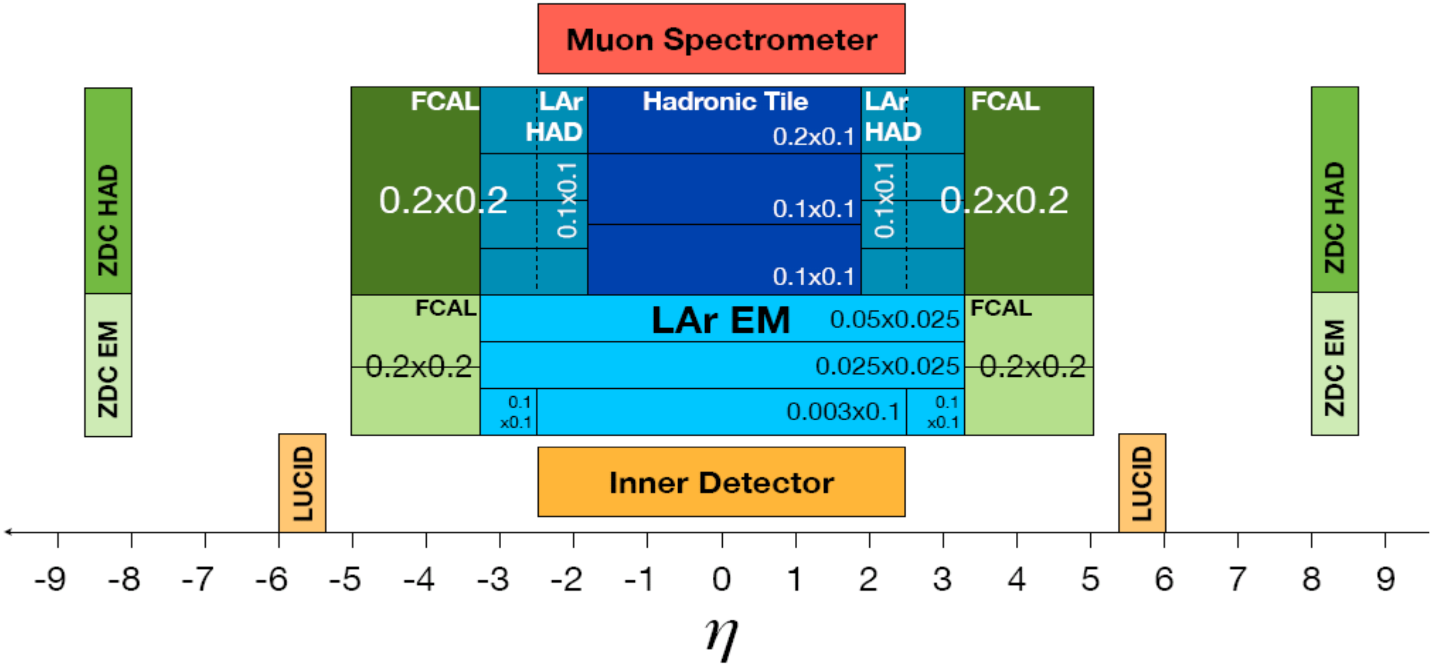
ATLAS vs. CMS

ATLAS is twice as big, but CMS is twice as heavy



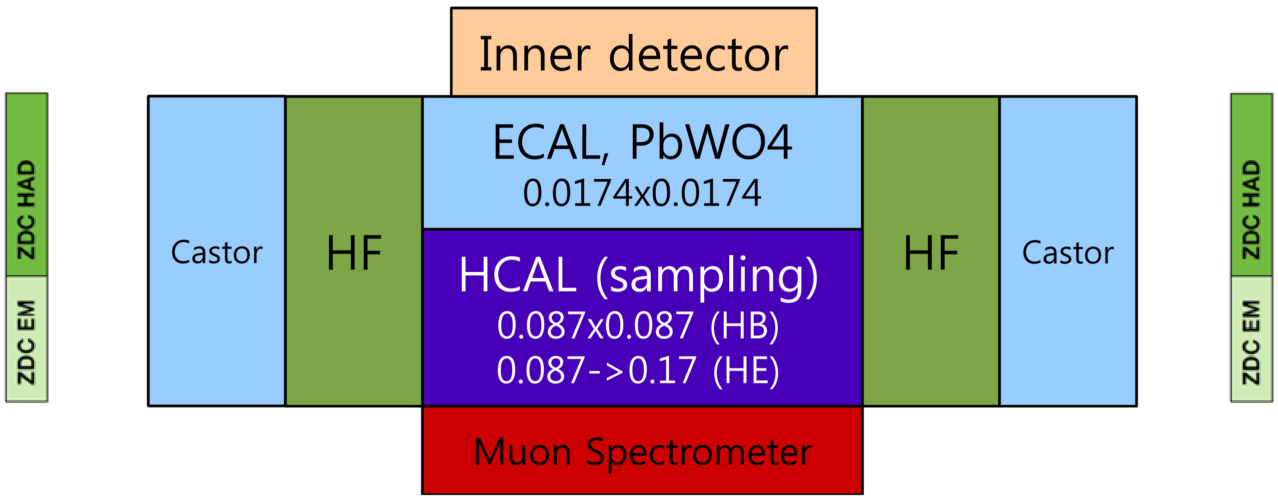
ATLAS vs. CMS

Different technologies but close acceptances – possibility to cross-check



ATLAS

Inner Det. (|η|<2.5)
ECAL (|η|<3.2)
HCAL (|η|<3.2)
HF (3.2<|η|<5)
Muon (|η|<2.7)
Lucid (5.5<|η|<6)
ZDC (|η|>8)

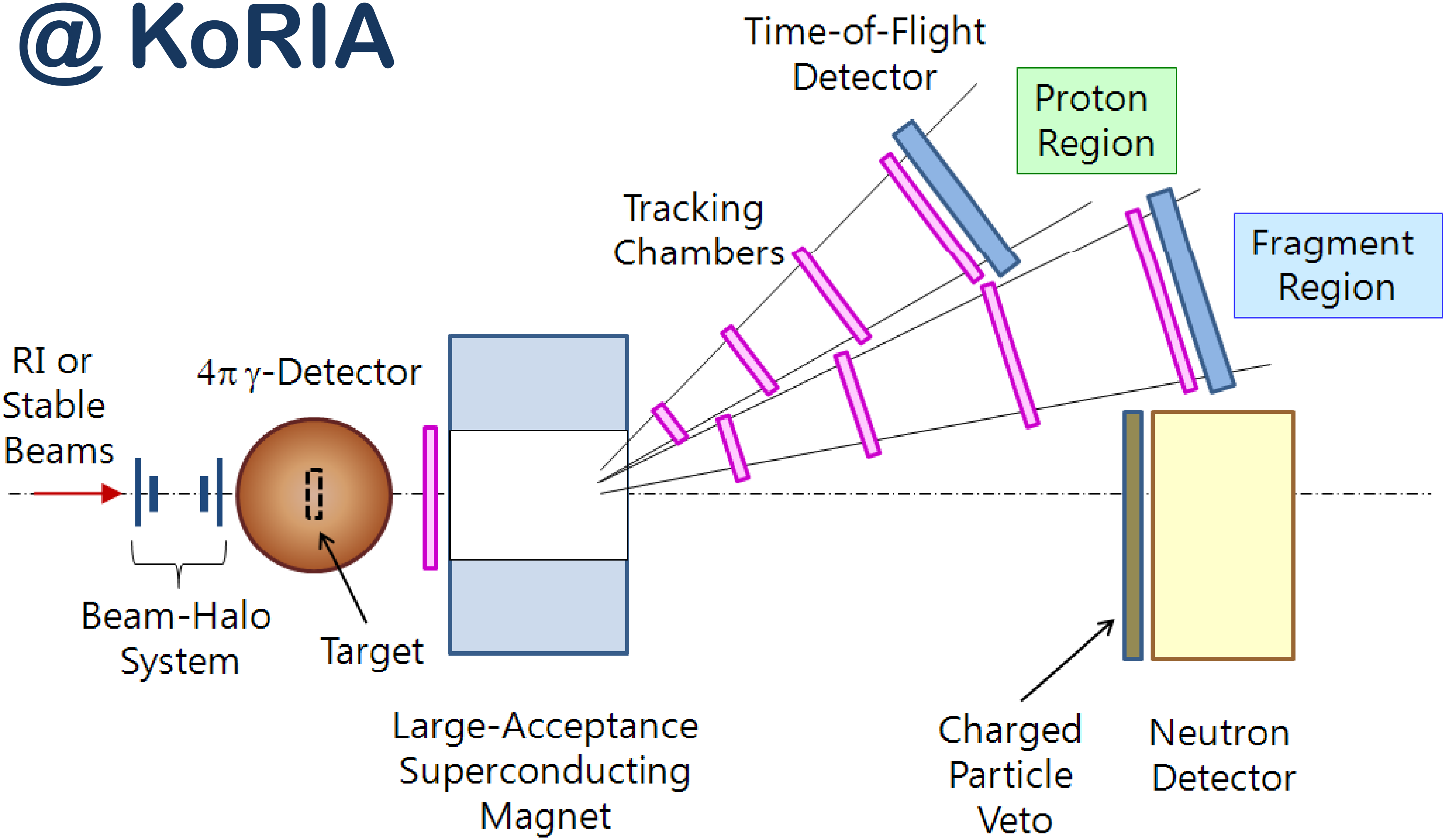


CMS

Inner Det. (|η|<2.5)
ECAL (|η|<3)
HCAL (|η|<3)
HF (3<|η|<5)
Muon (|η|<2.4)
Castor (5<|η|<6.7)
ZDC (|η|>8)

KRIB Multipurpose Spectrometer

@ KoRIA



Summary

- Incredible technological advances for the last ~100 years or so
  - Accelerators
  - Detectors
- A lot of applications of the particle detectors
- Many dedicated experts are (and will be) needed.
- Future is extremely bright !