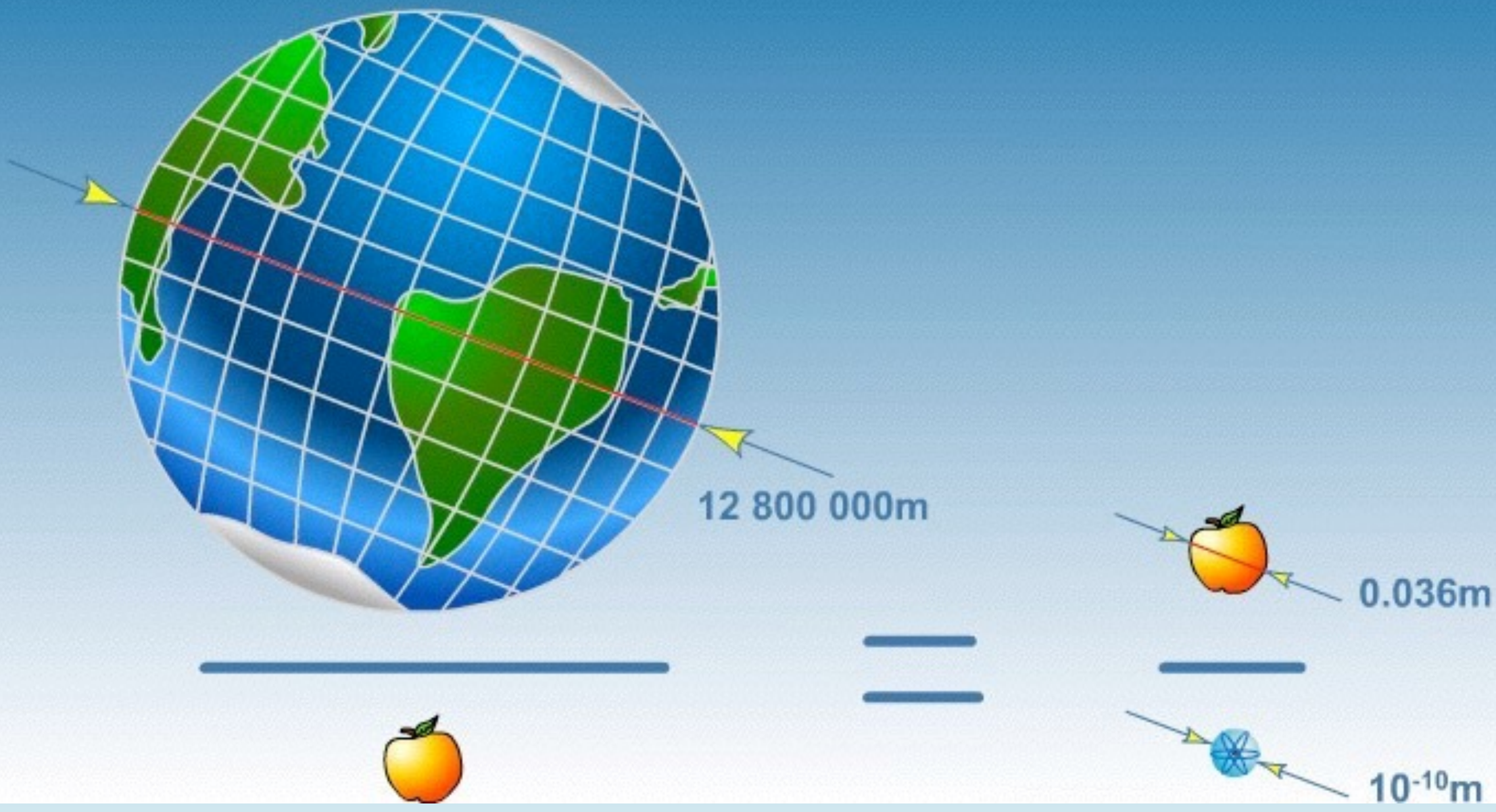
In-Kwon Yoo / Pusan Nat'l Univ.

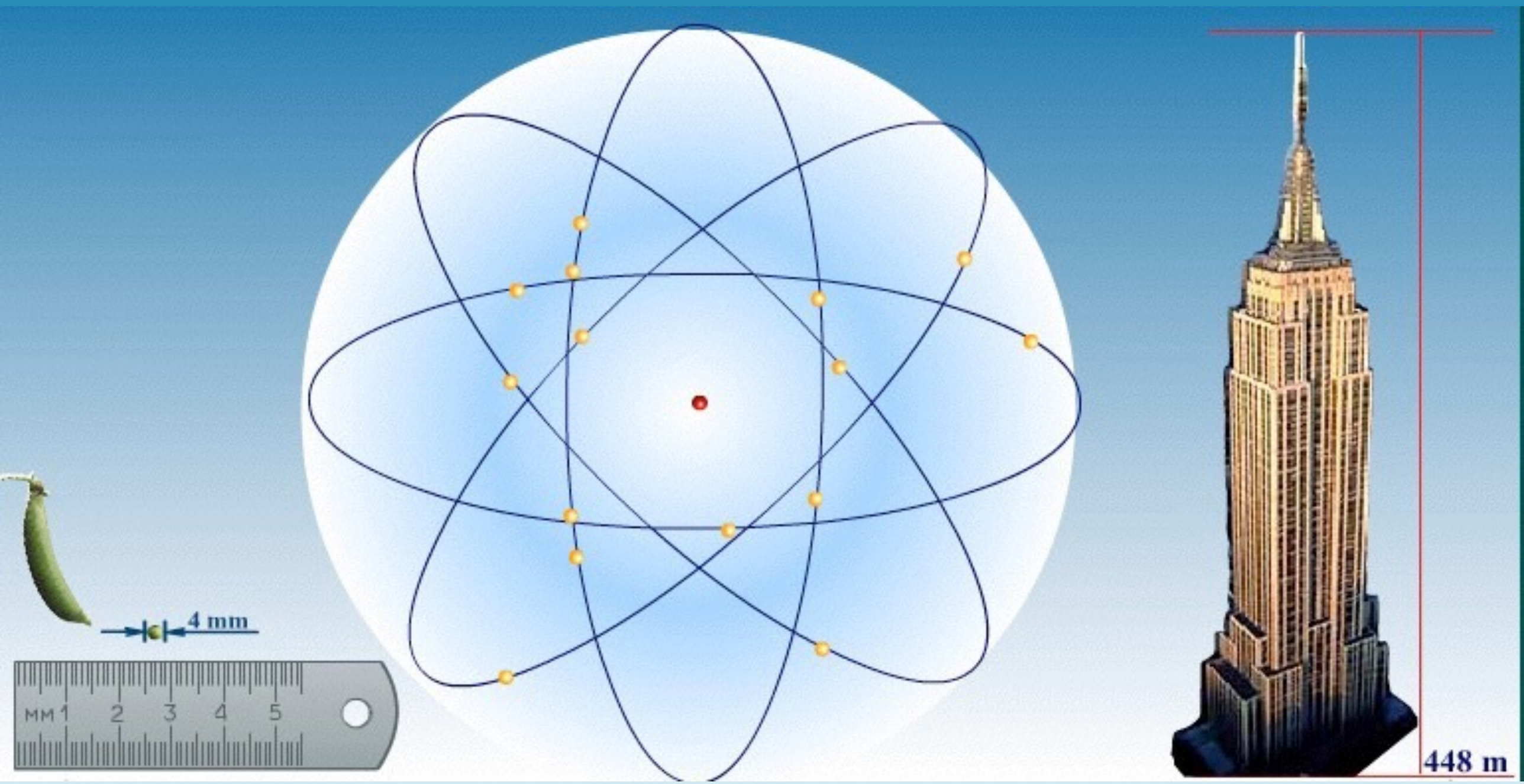
Outline

- High Energy Physics
  - Fundamental Questions
  - Strategy
- CERN & LHC & Experiments
  - ALICE (A Large Ion Collider Experiment)
  - CMS (Compact Muon Solenoid)
- High Energy Physics Experiment
  - Signal Processing
  - Data Acquisition
  - Data Analysis
- Computing Infrastructure
    - Tier Structure
    - GRID computing

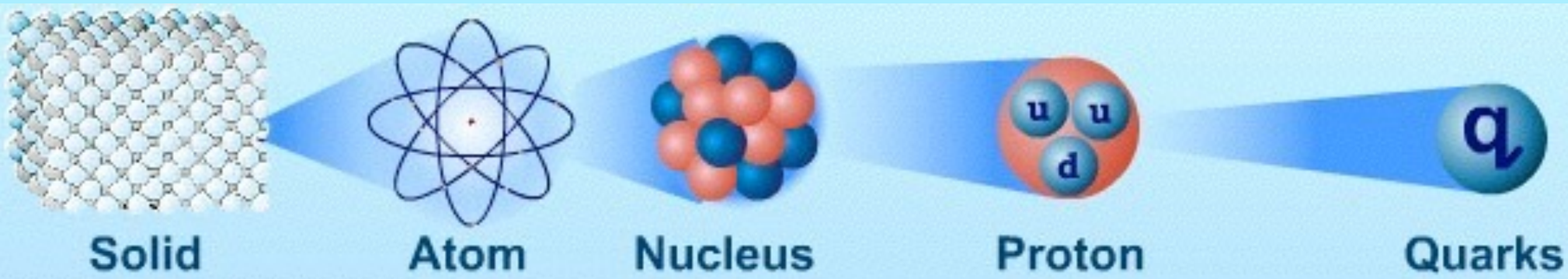
Size of an atom

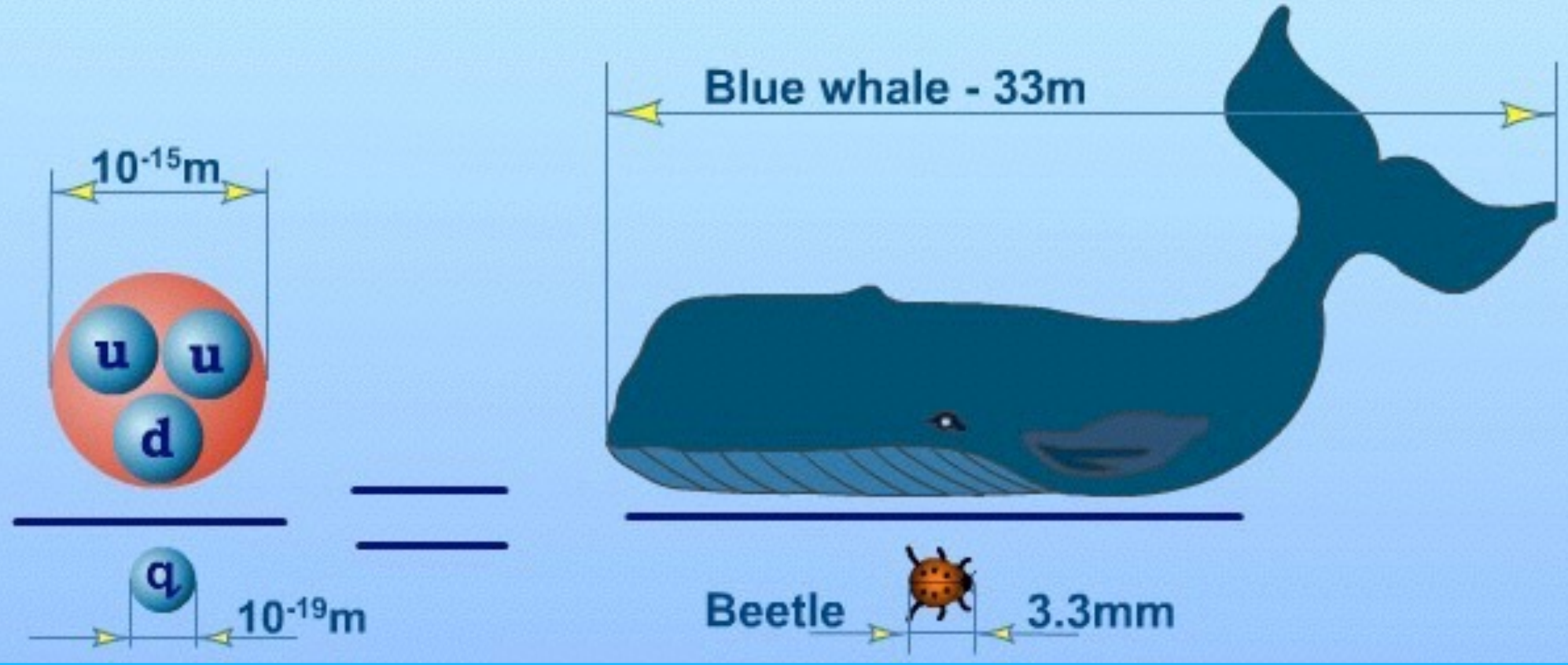


Atom to Nucleus



Proton to Quark





Big Bang

Quark-gluon plasma

0.000001 sec
> 1 trillion °C

Proton & neutron formation

0.00001 sec
one trillion °C

Low mass nuclei formation

3 minutes
one billion °C

Neutral atoms formation

400000 years
4000 °C

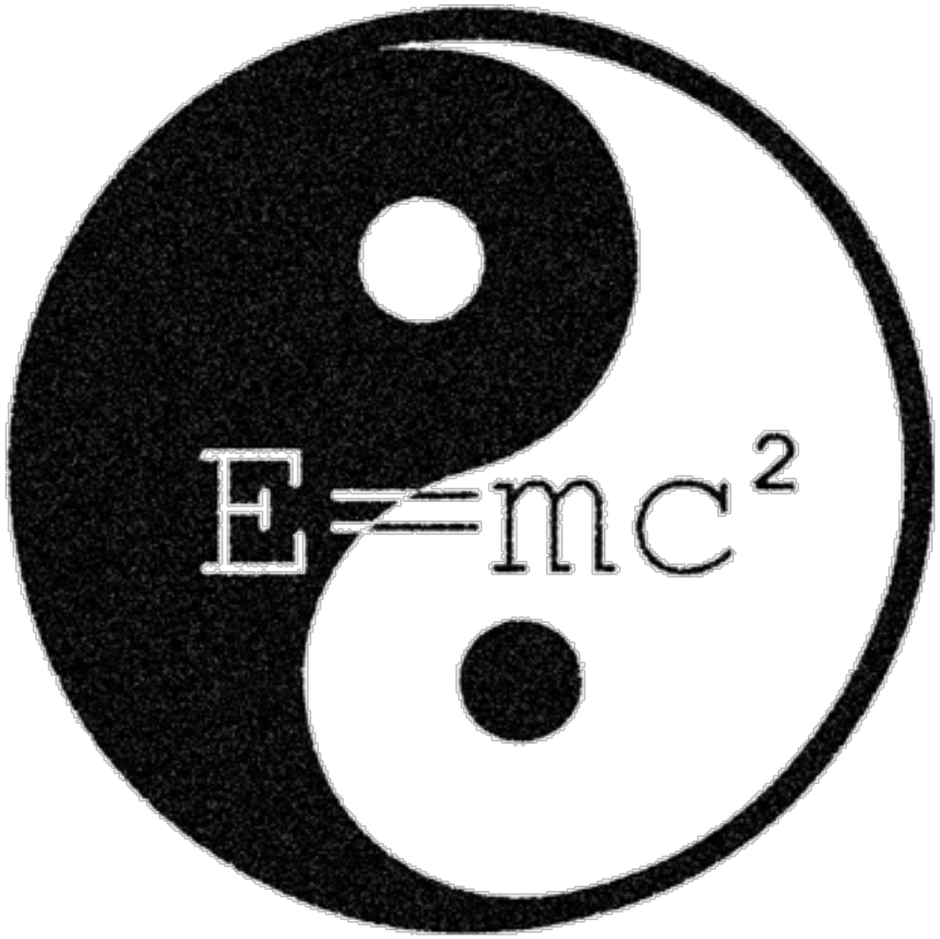
Star formation

>1 billion years
≈ -240 °C

today

13 billion years
≈ -270 °C

SPACE, TIME and What ?



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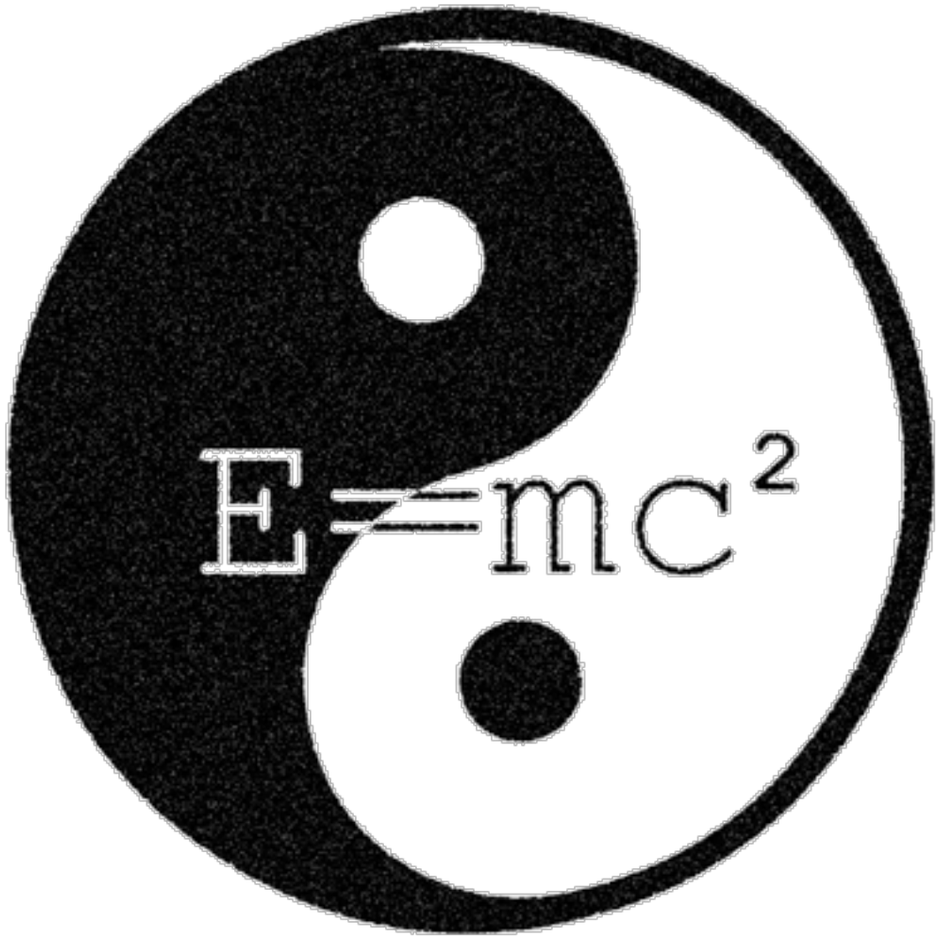
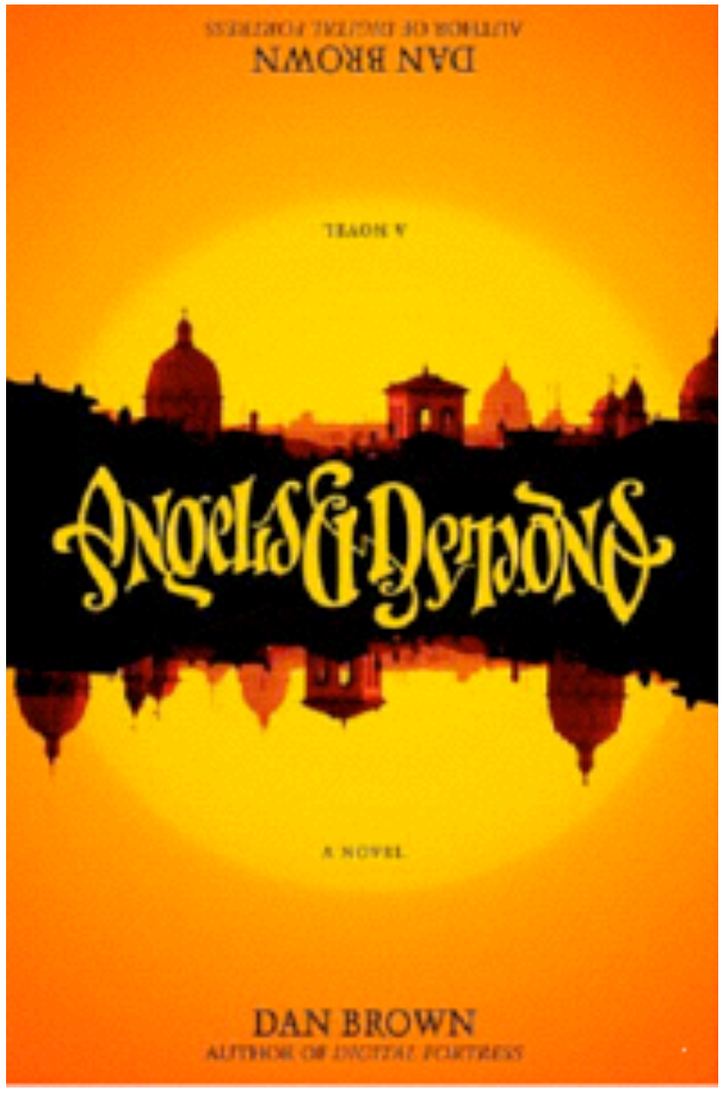
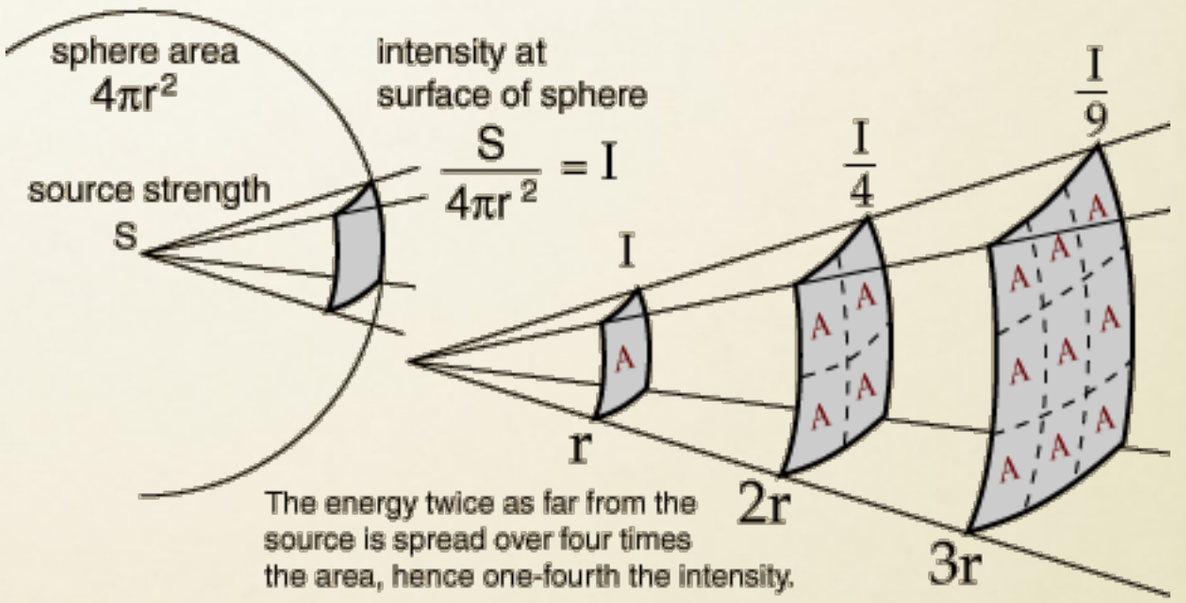


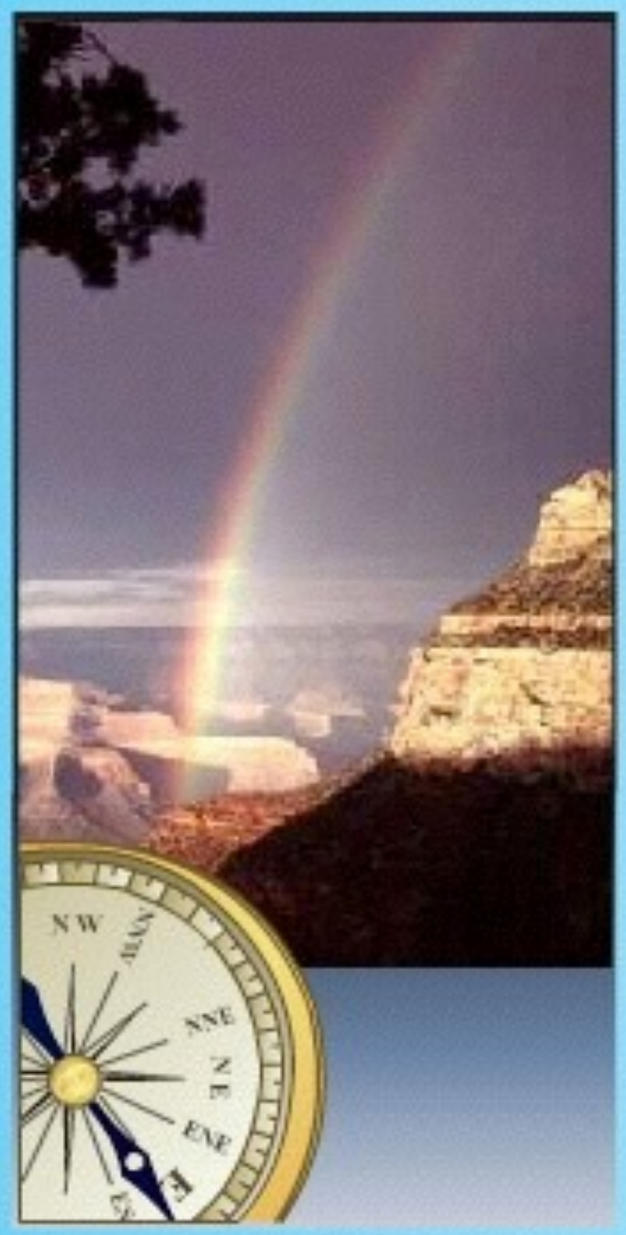
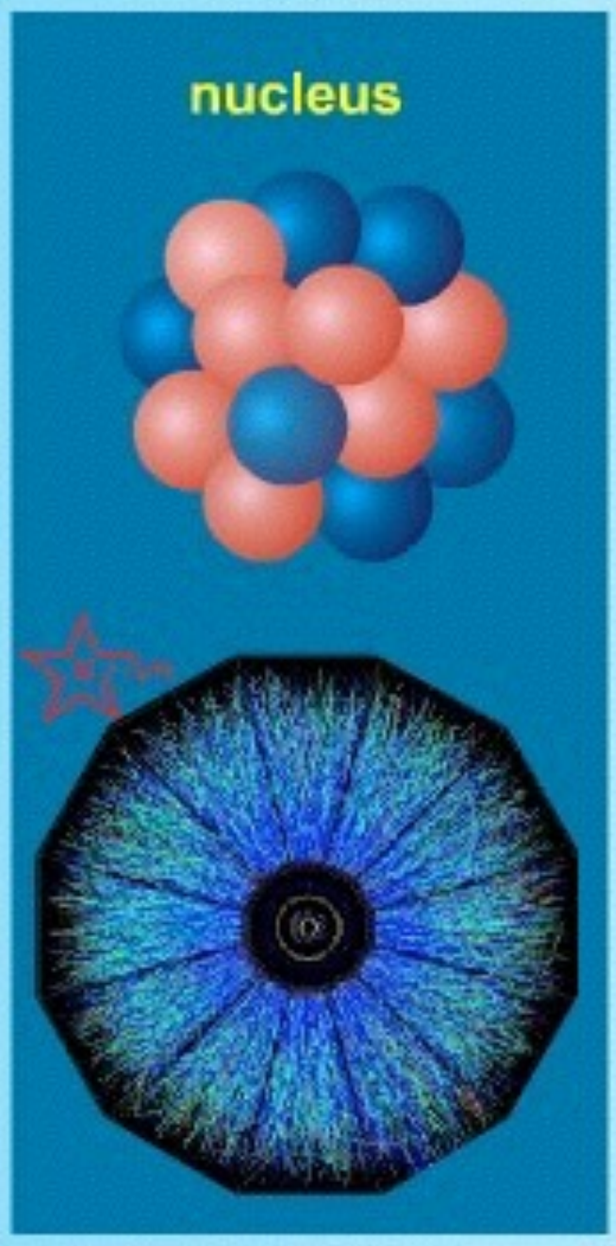
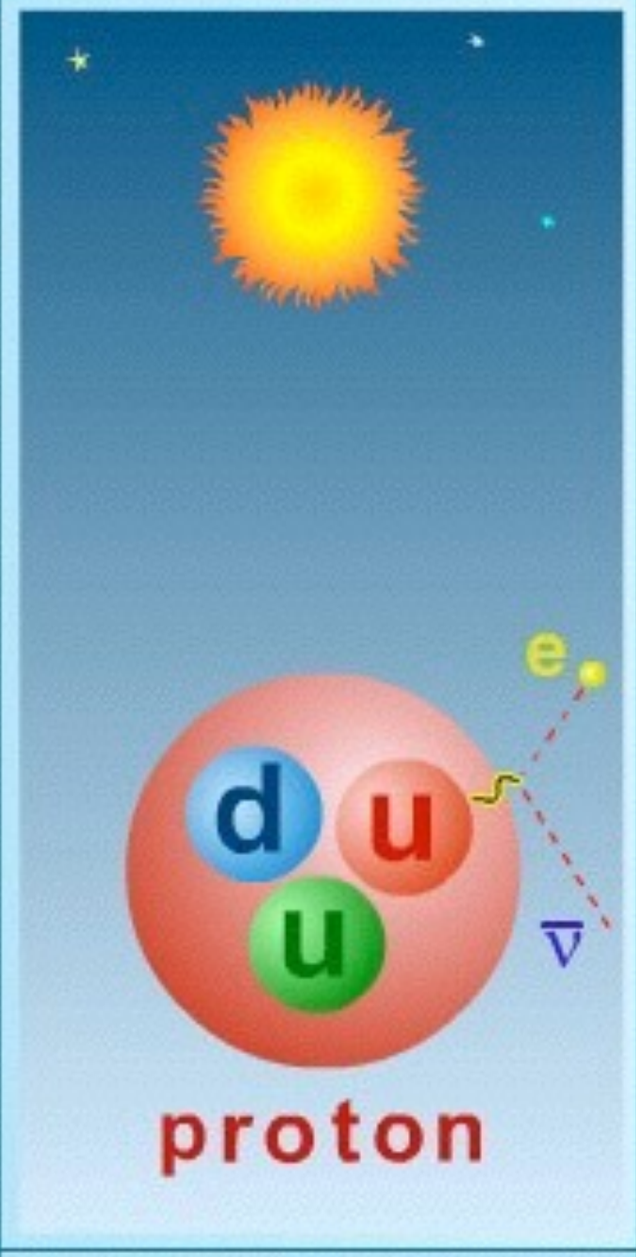


Paradigm

- Force
  - Newtonian
  - Field
  - Gauge Boson
- Relativity : c < infinity
- Quantum : h > 0
- Standard Model

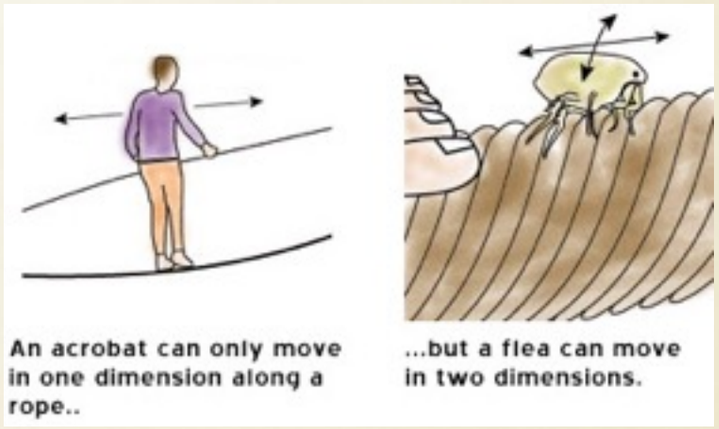


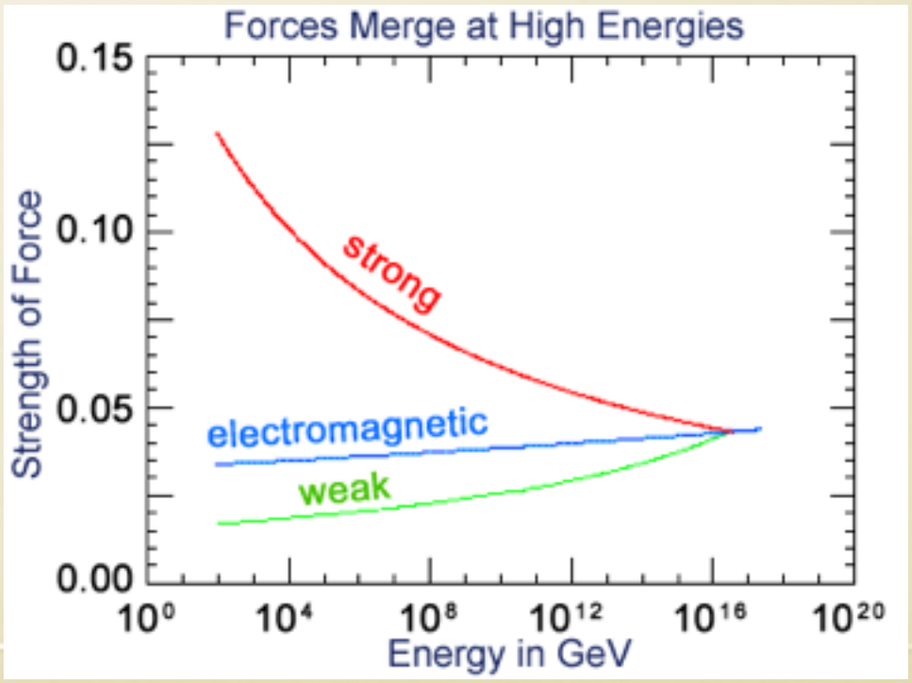
4가지 힘들

1	2	3	4
			
gravity	electromagnetic	strong	weak

Mysteries, Yet!

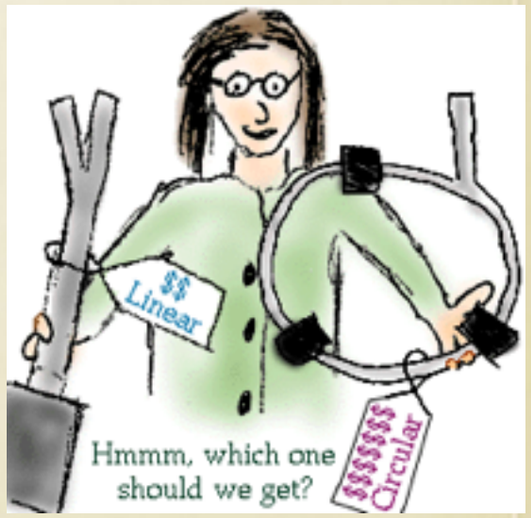
- Origin of Mass (질량)
- God Particle : Higgs
- Extra Dimension
- Grand Unification Theory
- Quark-Gluon Plasma
- etc.





Accelerator

- Telescope / Microscope / Accelerator
- Electron / Light Source / Proton / Heavy Ion
- Linear / Cyclotron / Synchrotron / Collider
- Major Accelerators
- Large Hadron Collider
- Korea Rare Isotope Accelerator / ILC



CERN : World Largest Accelerator Center

- 65 countries : 20 mem. + 6 obs. + EU + Unesco + 39 non.
- Council : 2 x 20 / Director General (Dr. R. Heuer)
- Budget : 1B CHF ('08) / 2500 Employee ('08)
- 8000 scientists from > 500 Institutions
- World-Wide Web / 7 Nobel prizes
- Extension Plan : Assoc. membership / CERN Schools

CERN (유럽 핵 및 입자물리 연구소)

Birth Place of the **'WWW (World Wide Web)'**

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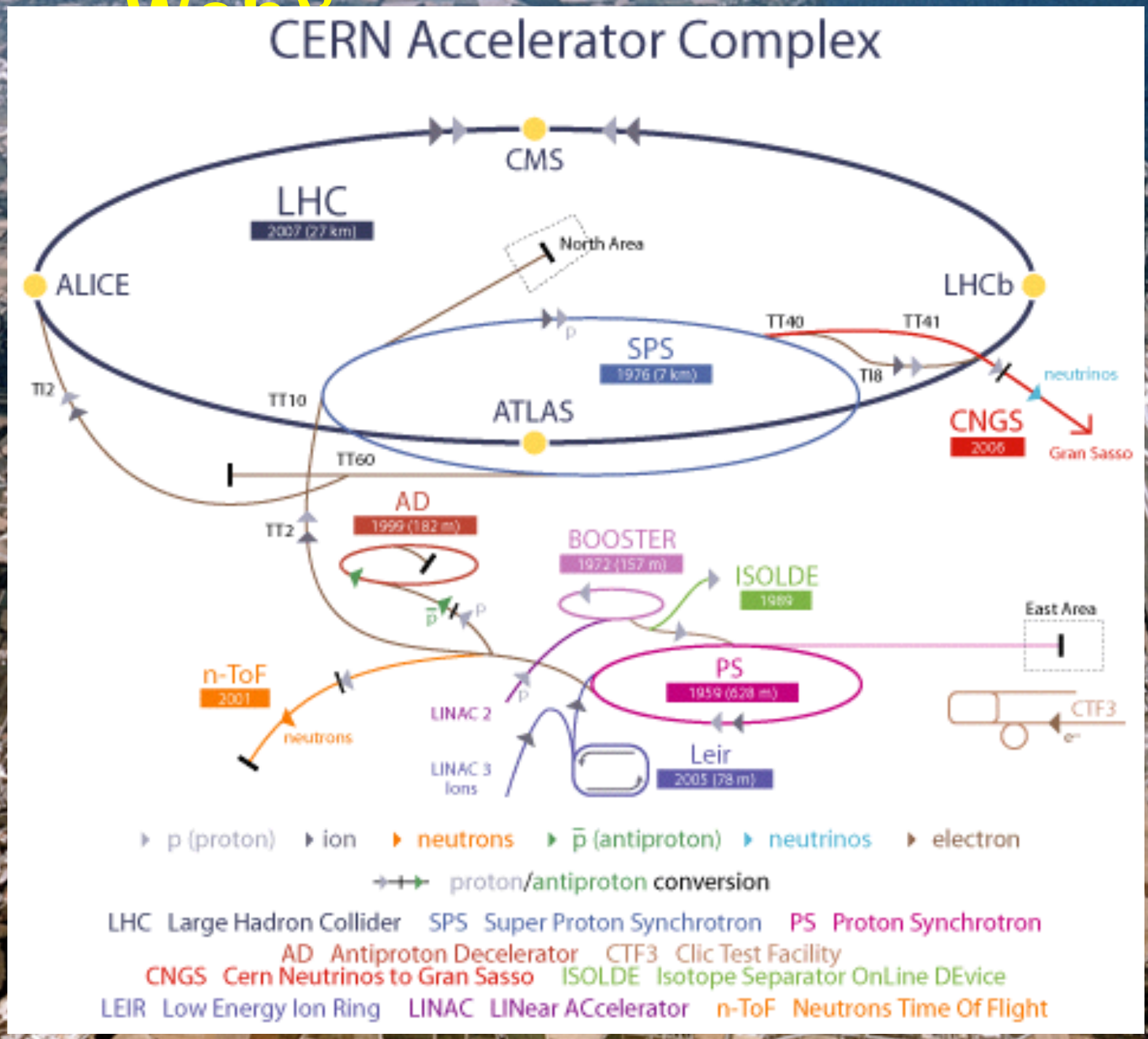

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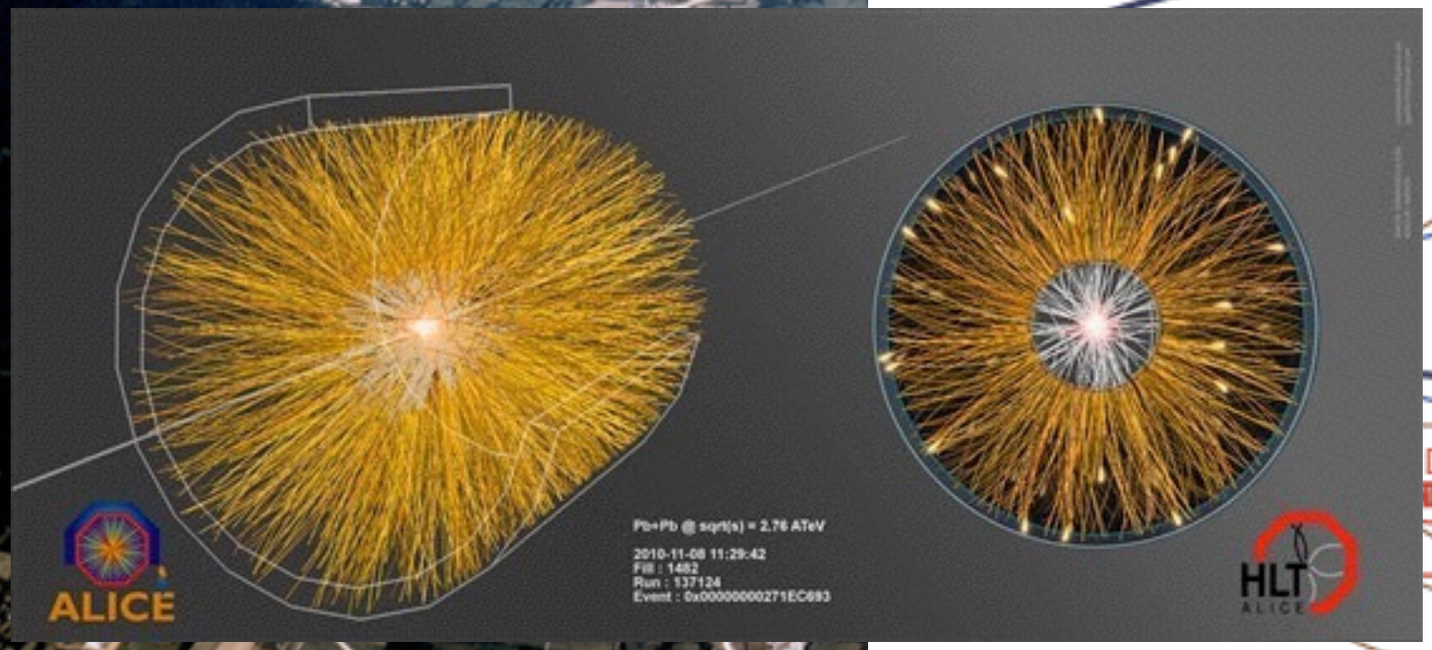
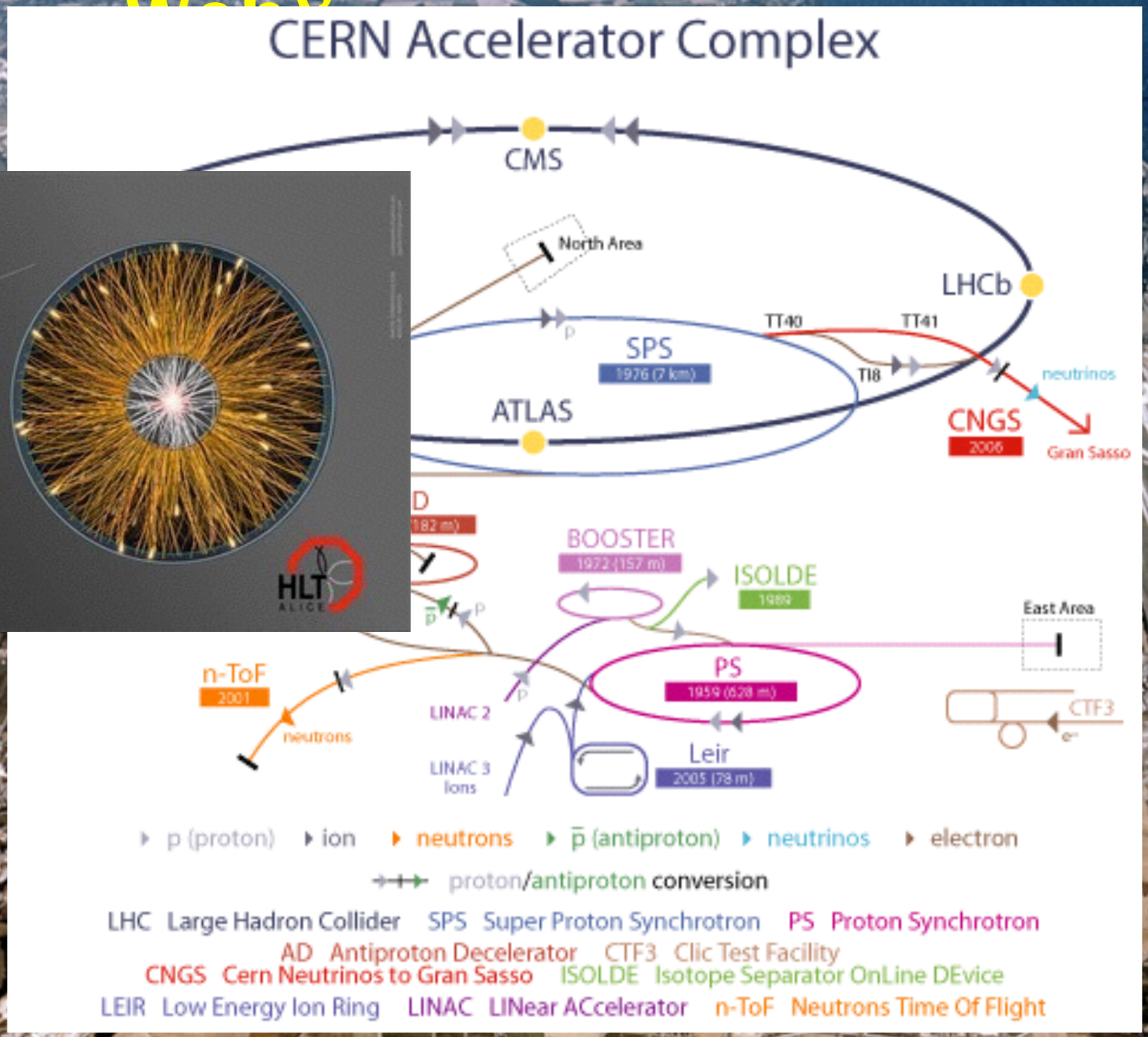
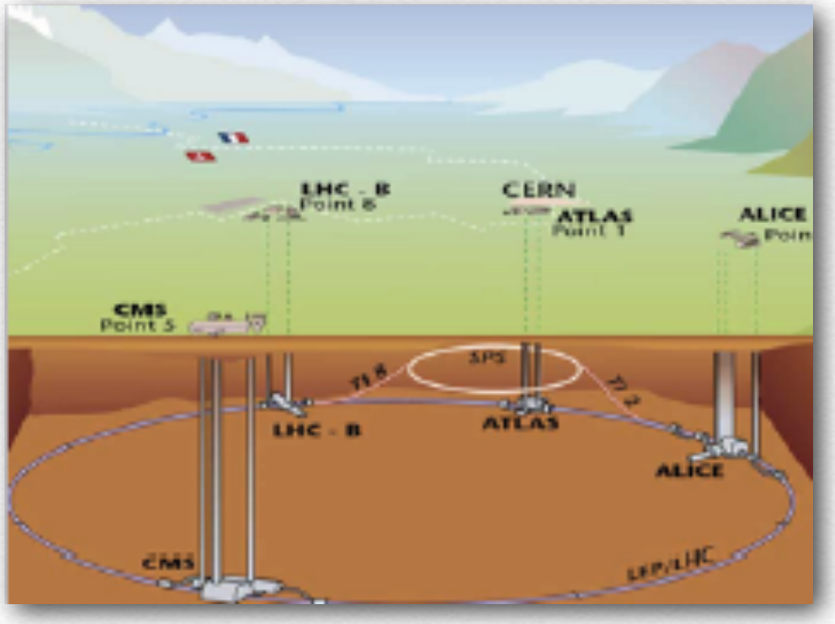
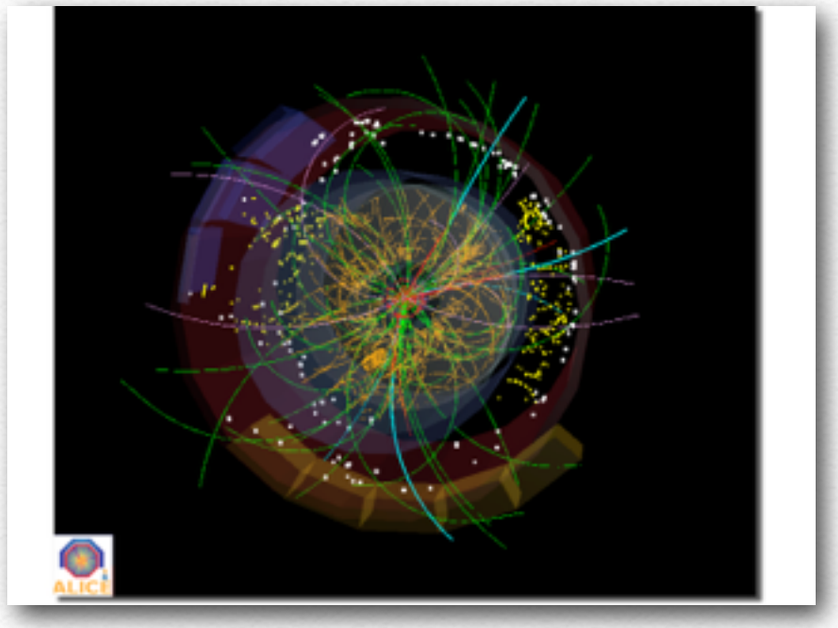




Large Hadron Collider





Large Hadron Collider

Large Hadron Collider

- The Largest Machine in the world : 26,659m, 9300 Magnets, -193.2C (80K), 10,080 tonnes of liq.N_2,120 tonnes of liq.He (-271.3C = 1.9K)

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- The Most Powerful Supercomputing in the world : 100,000 DL DVDs/yr, 10,000 super-computers over the world via GRID

PbPb@5.5TeV at Large Hadron Collider

27 km circumference
~ 100 m underground
Energy 14,000 GeV (pp)
1144,000 GeV (PbPb)

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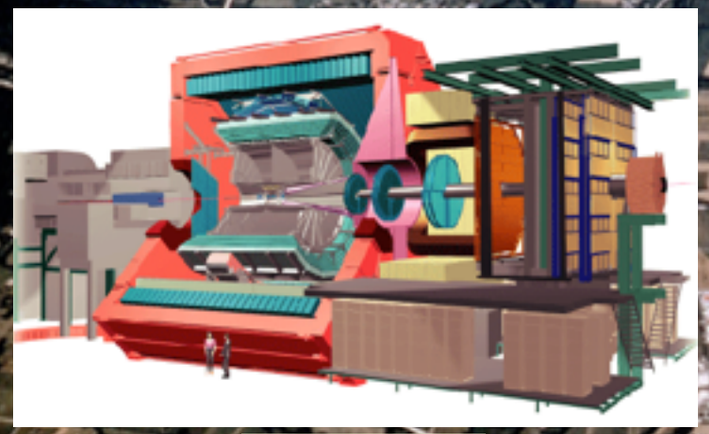

ALICE

ATLAS

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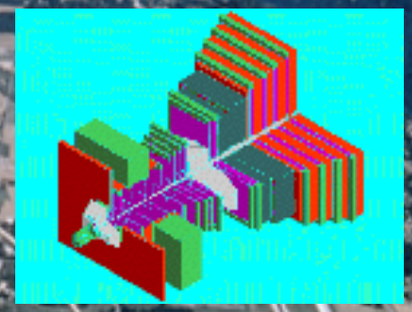
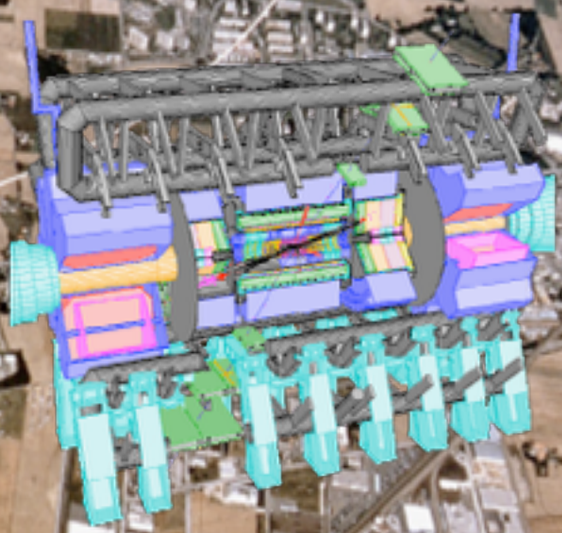
CMS



LHCb

ALICE

ATLAS



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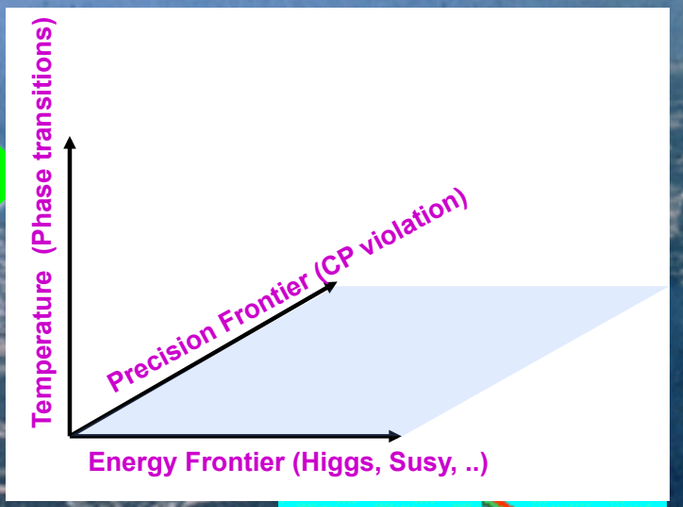
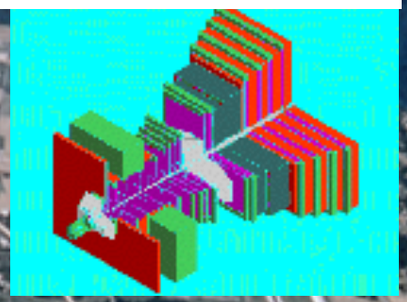


CMS



LHCb

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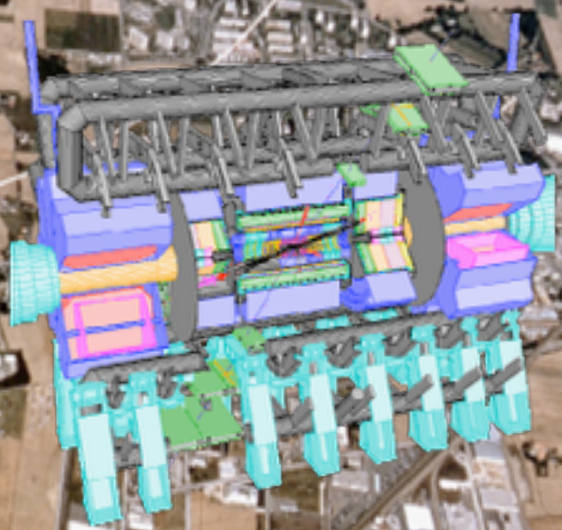

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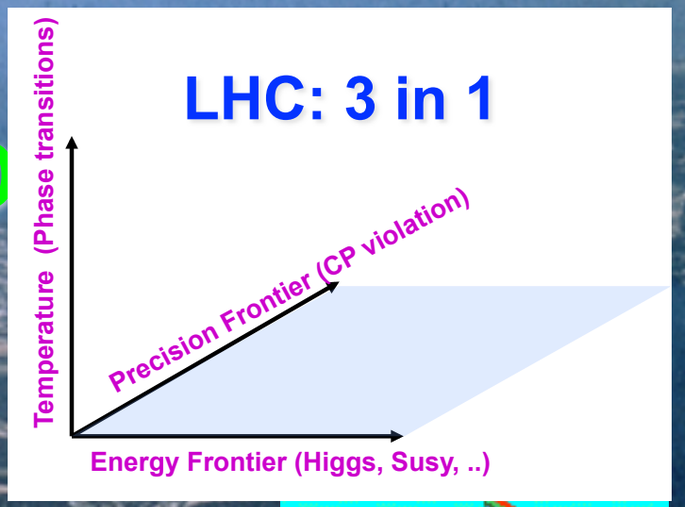
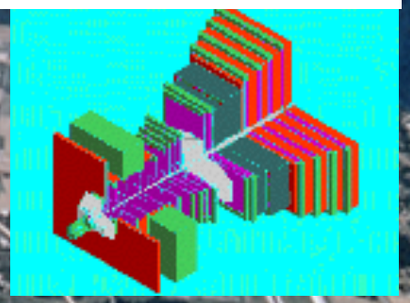
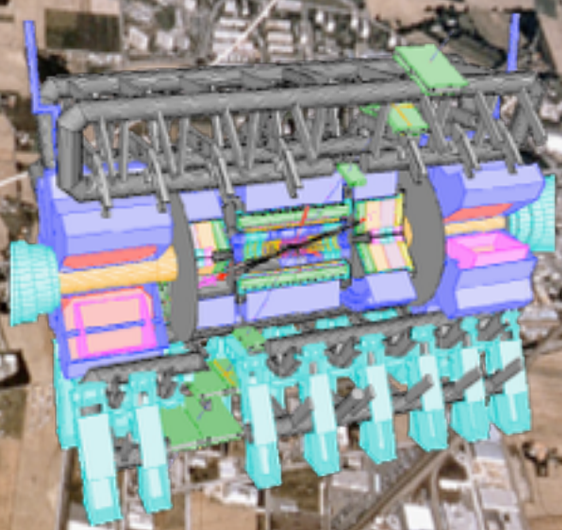


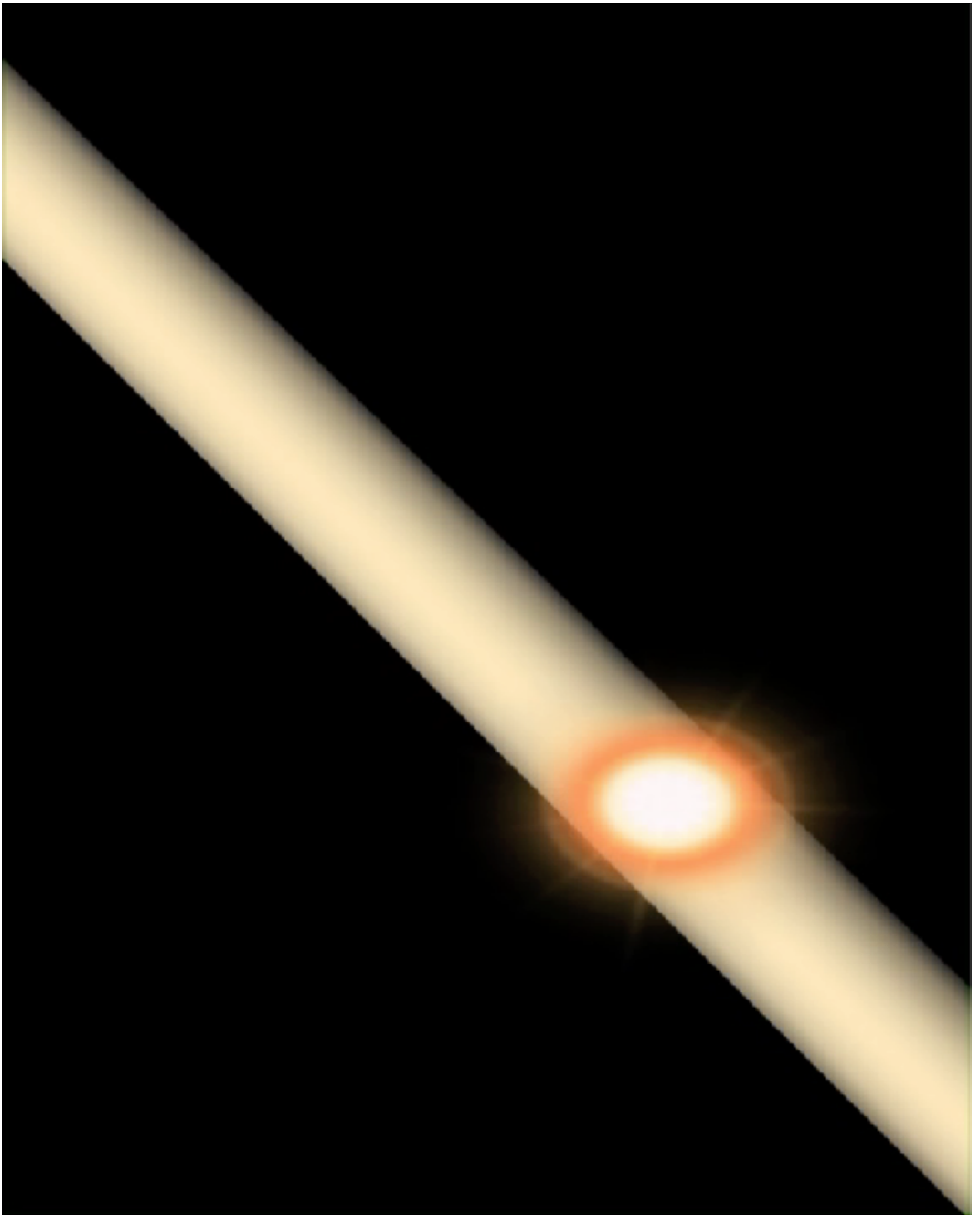


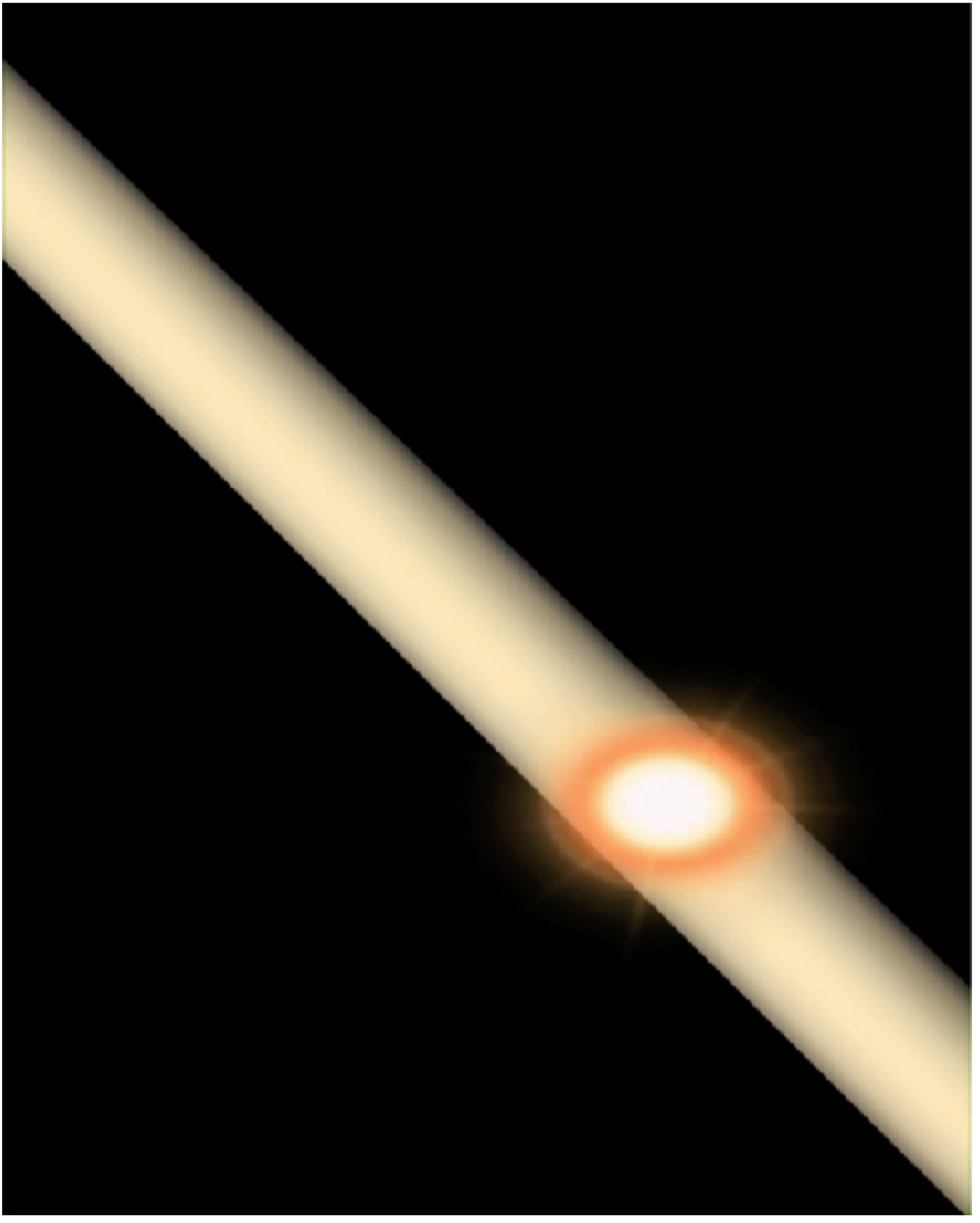
LHCb

ALICE

ATLAS

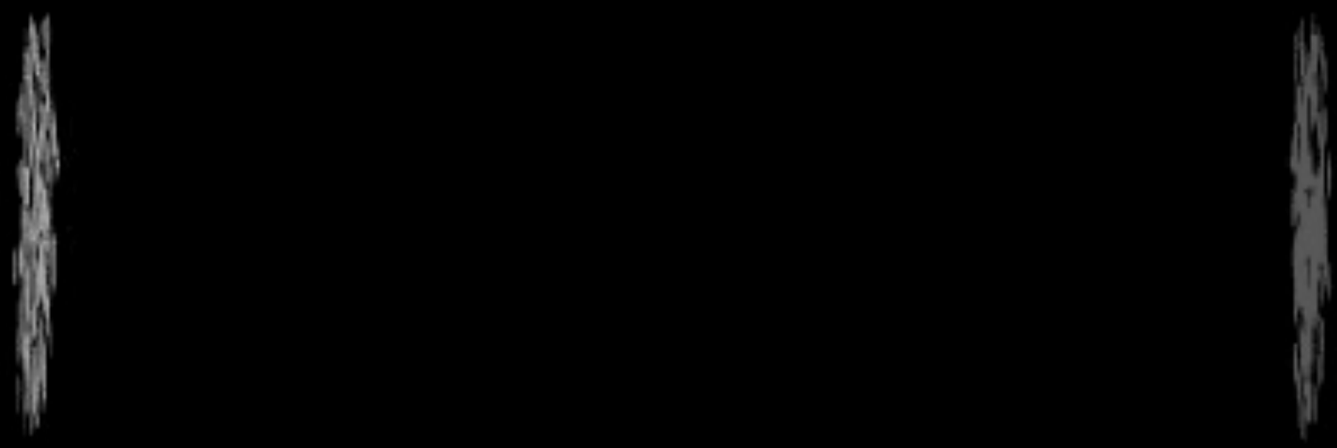






Pb+Pb E_{cm}=5.5 TeV

t=-19.00 fm/c



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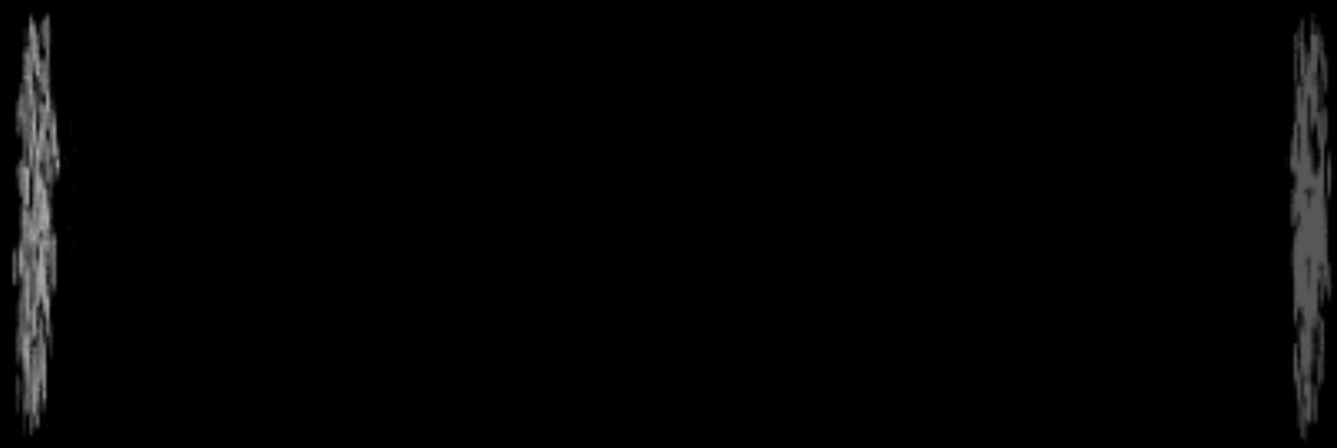

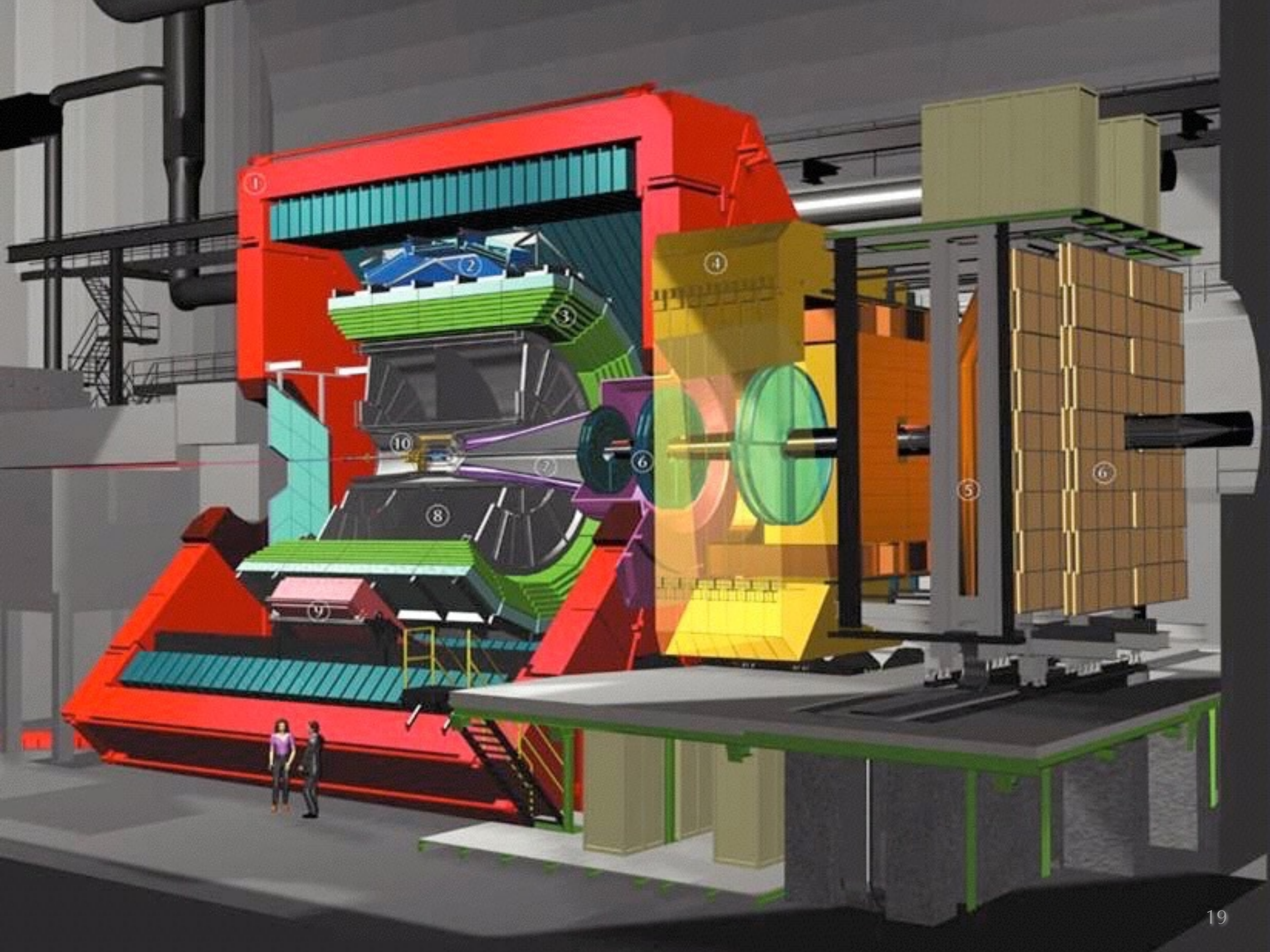
1
2
3
4
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6
7
8
9
10

Solenoid magnet 0.5 T

Central tracking system:


Solenoid magnet 0.5 T
Central tracking system:

Solenoid magnet 0.5 T

Central tracking system:

- ITS

Solenoid magnet 0.5 T

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- ITS

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Central tracking system:

- ITS
- TPC

Solenoid magnet 0.5 T

Central tracking system:

- ITS
- TPC
- TRD
- TOF

MUON Spectrometer:

Solenoid magnet 0.5 T

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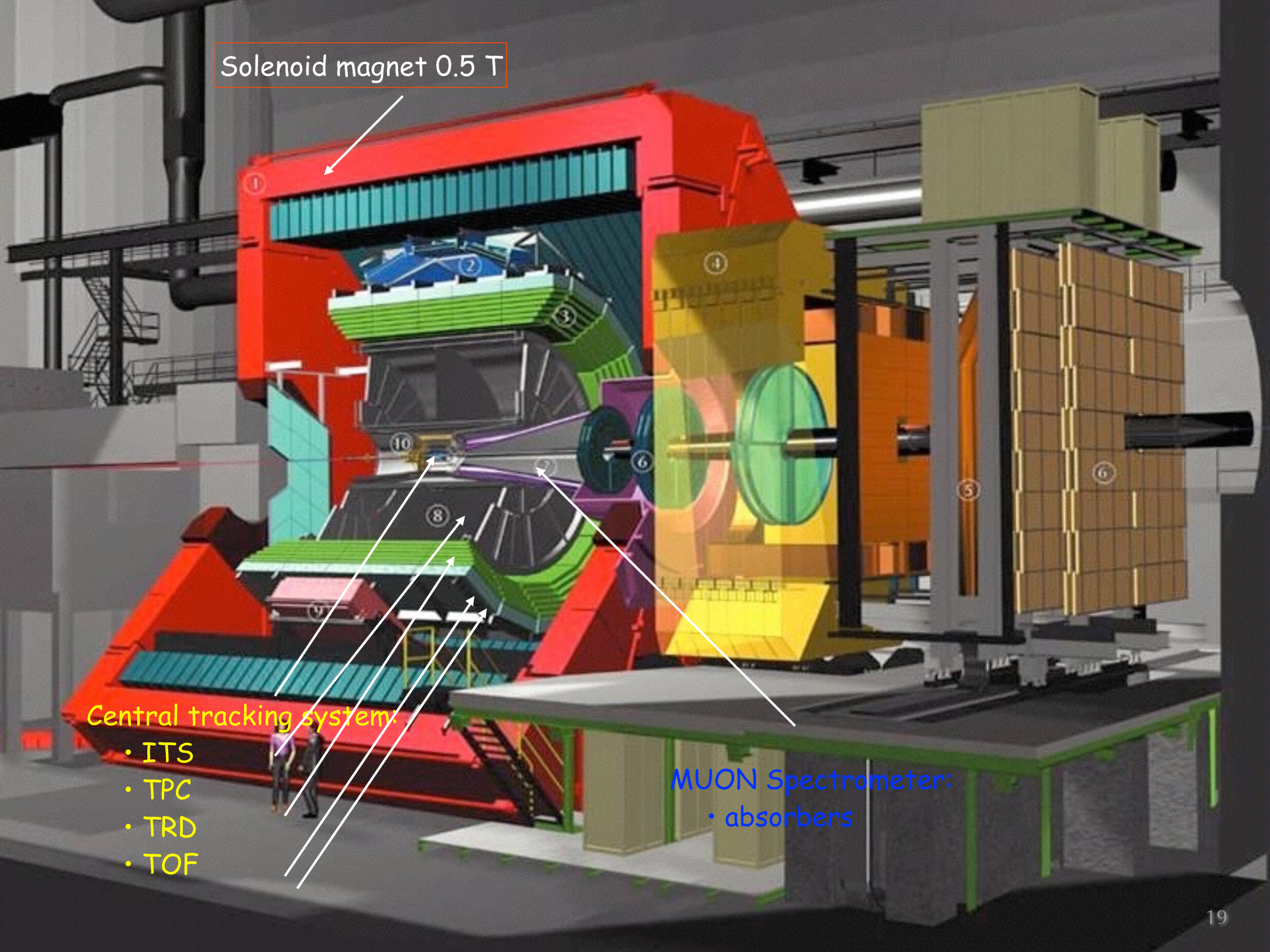
Solenoid magnet 0.5 T
Central tracking system:
• ITS
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• TOF
MUON Spectrometer:
• absorbers

Solenoid magnet 0.5 T

Central tracking system:
- ITS
- TPC
- TRD
- TOF

MUON Spectrometer:
- absorbers
- tracking stations
- trigger chambers
- dipole

Solenoid magnet 0.5 T

Forward detectors:

Specialized detectors:
- HMPID
- PHOS

Central tracking system:
- ITS
- TPC
- TRD
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MUON Spectrometer:
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Solenoid magnet 0.5 T

Forward detectors:
- PMD

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MUON Spectrometer:
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Solenoid magnet 0.5 T

Cosmic rays trigger

Forward detectors:
- PMD
- FMD, T0, V0, ZDC

Specialized detectors:
- HMPID
- PHOS

Central tracking system:
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- TRD
- TOF

MUON Spectrometer:
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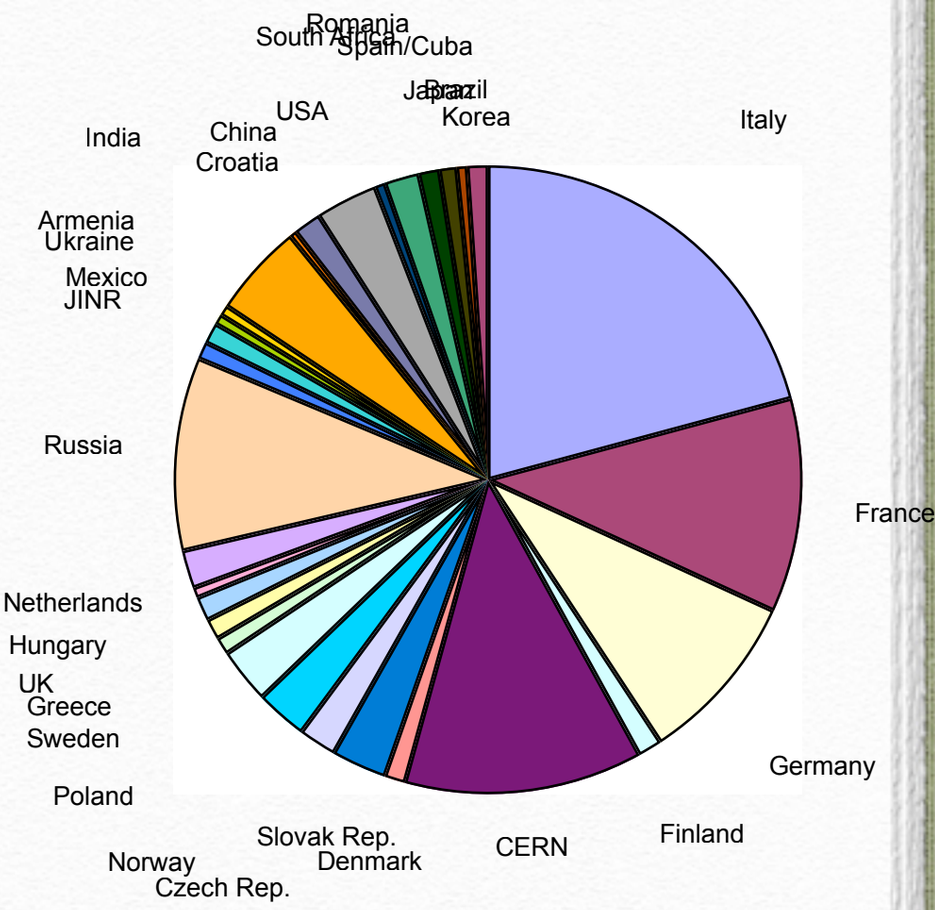
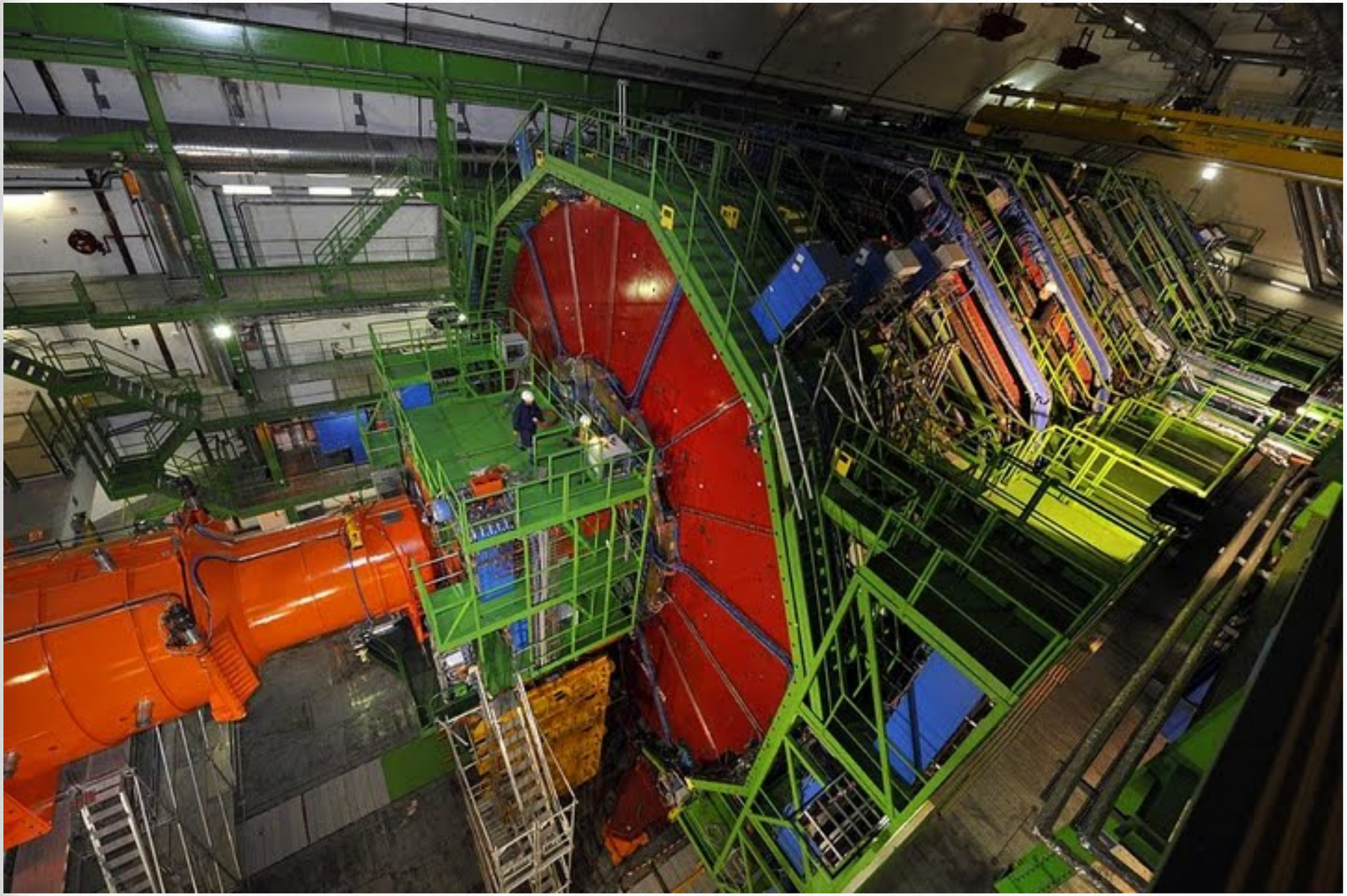
A Large Ion Collider Experiment

- Recreation of mini Big-Bang : Quark Matter (QGP) Evolution Research
- 'Early Universe was a liquid' (Nature '05)
- 31 Countries, 109 Institutions, > 1000 Researchers
- Heavy Ion RUN (PbPb) @ 2.75 TeV in Nov. 2010



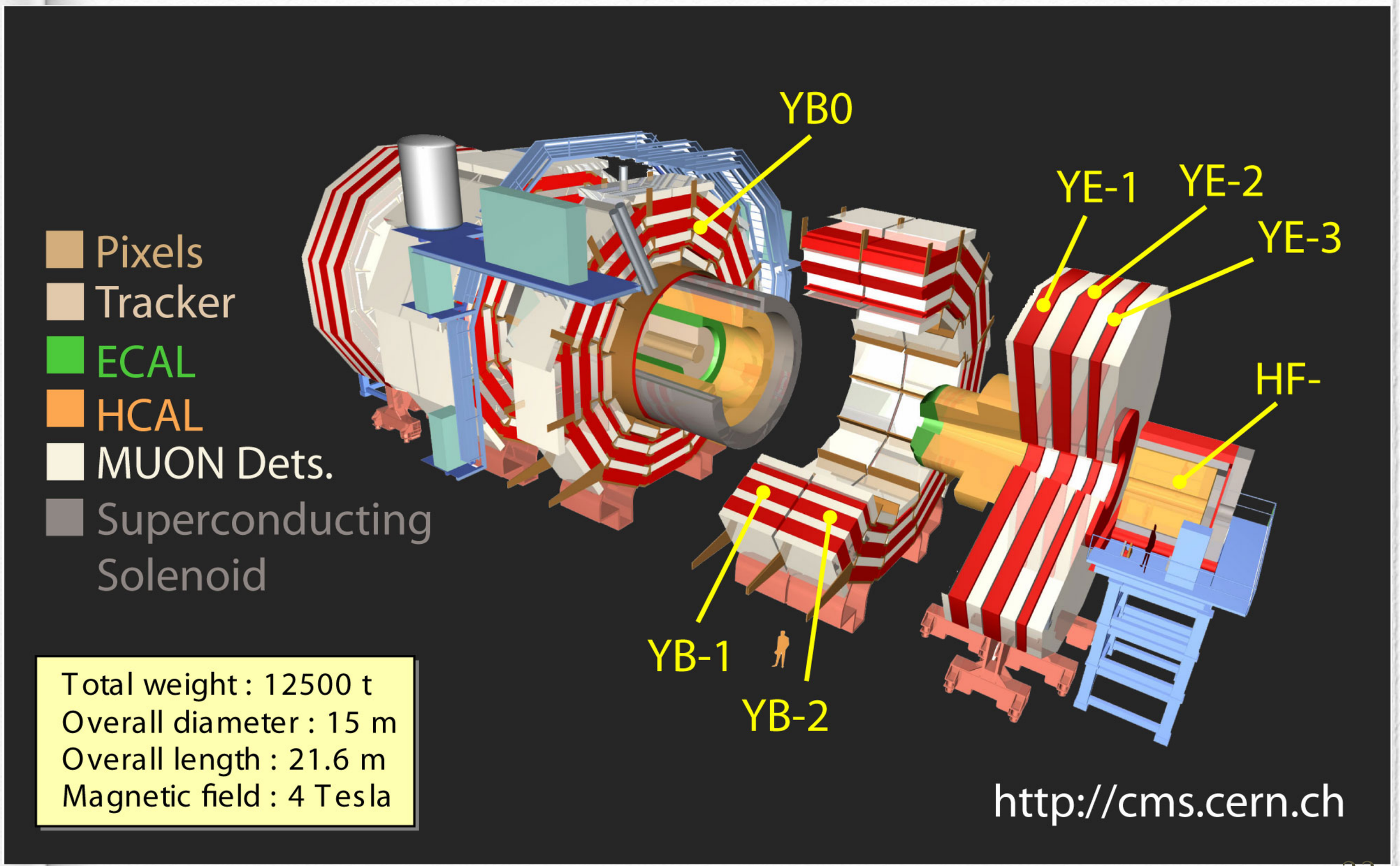
Compact Muon Solenoid



Beyond Standard Model

- God Particle : Higgs - Generator of Mass
- Super Symmetry Particles
- Extra Dimension, Dark Matter etc.
- Quark-Gluon Plasma in HI program

CMS Detectors



Physics: System Evolution

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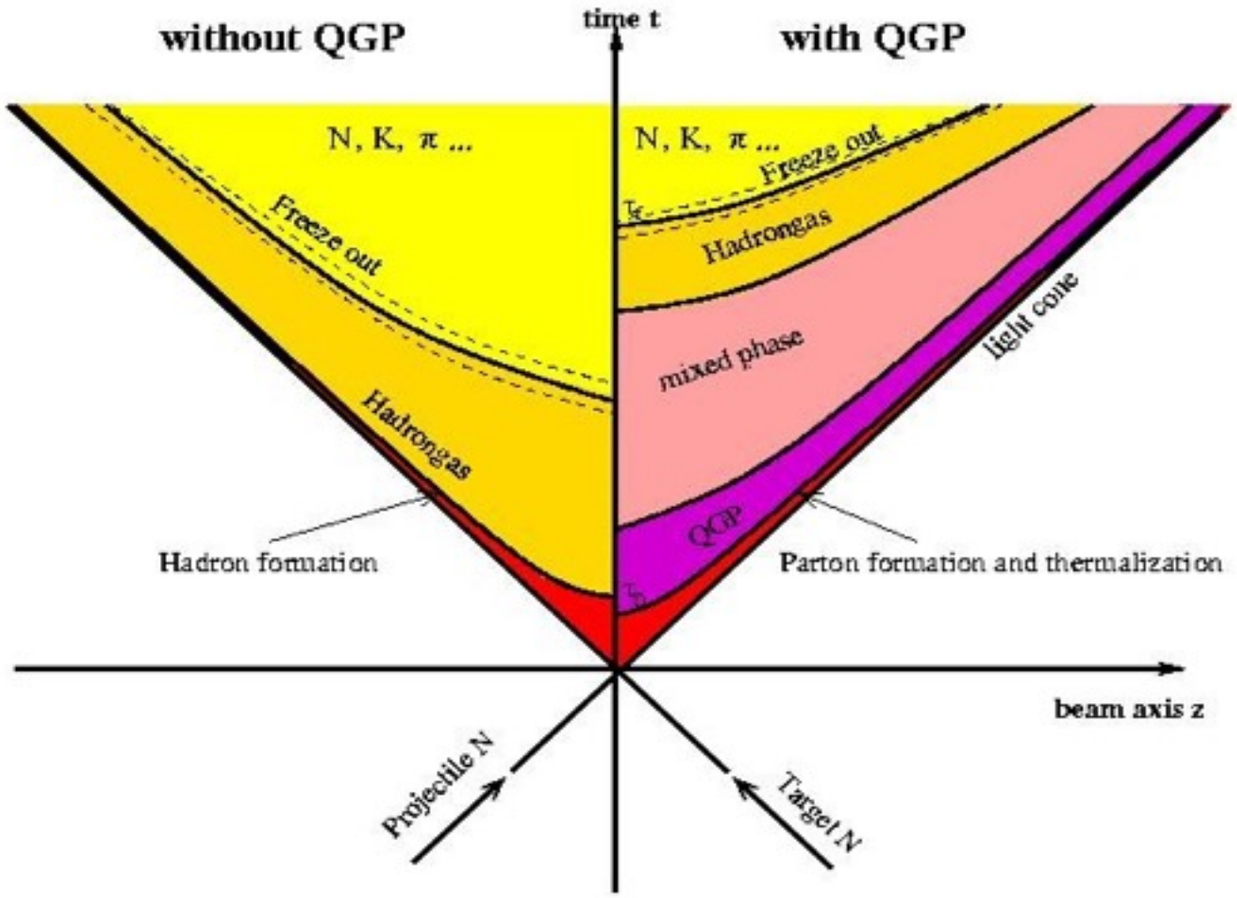

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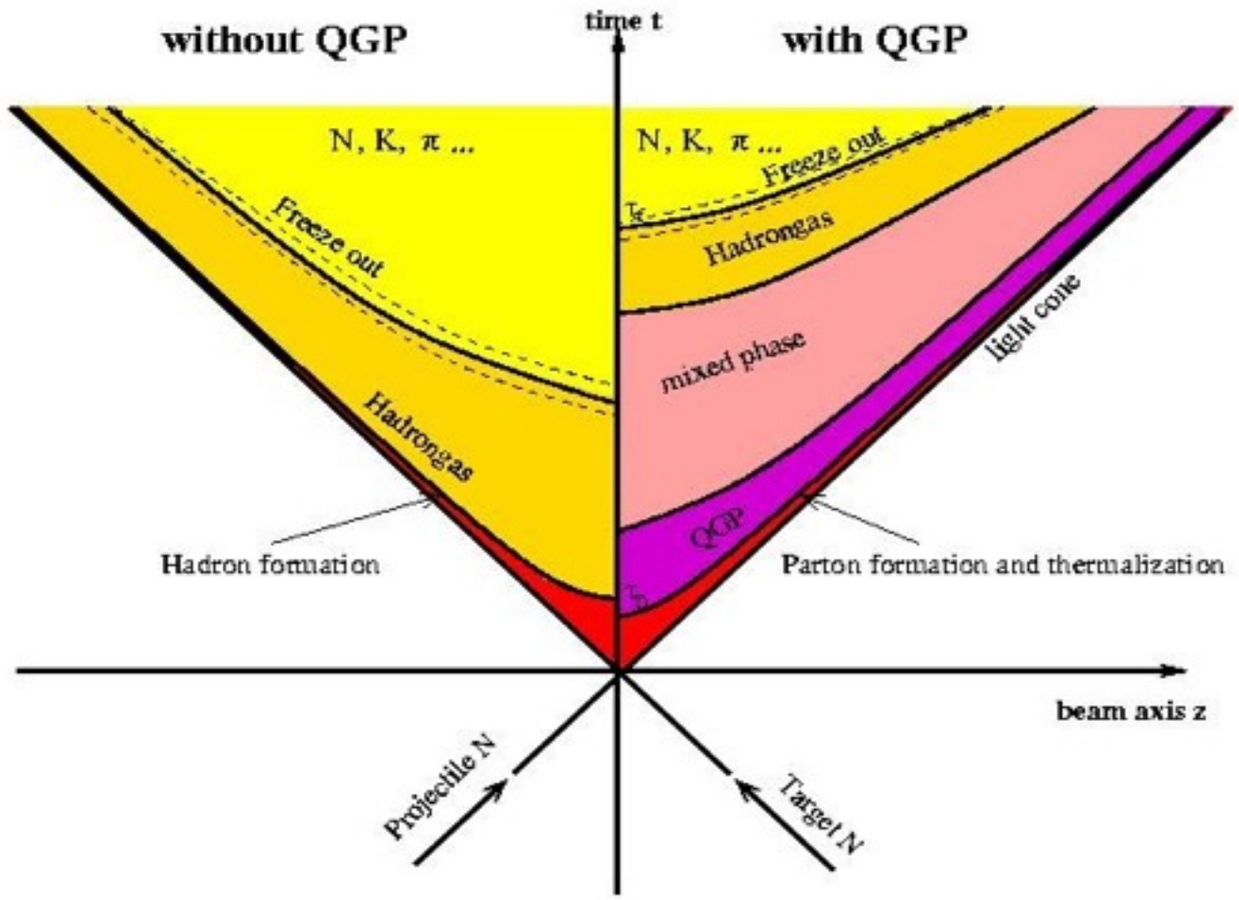


Nuclear Collisions

Expansion

Temperature Falling

Hadronization

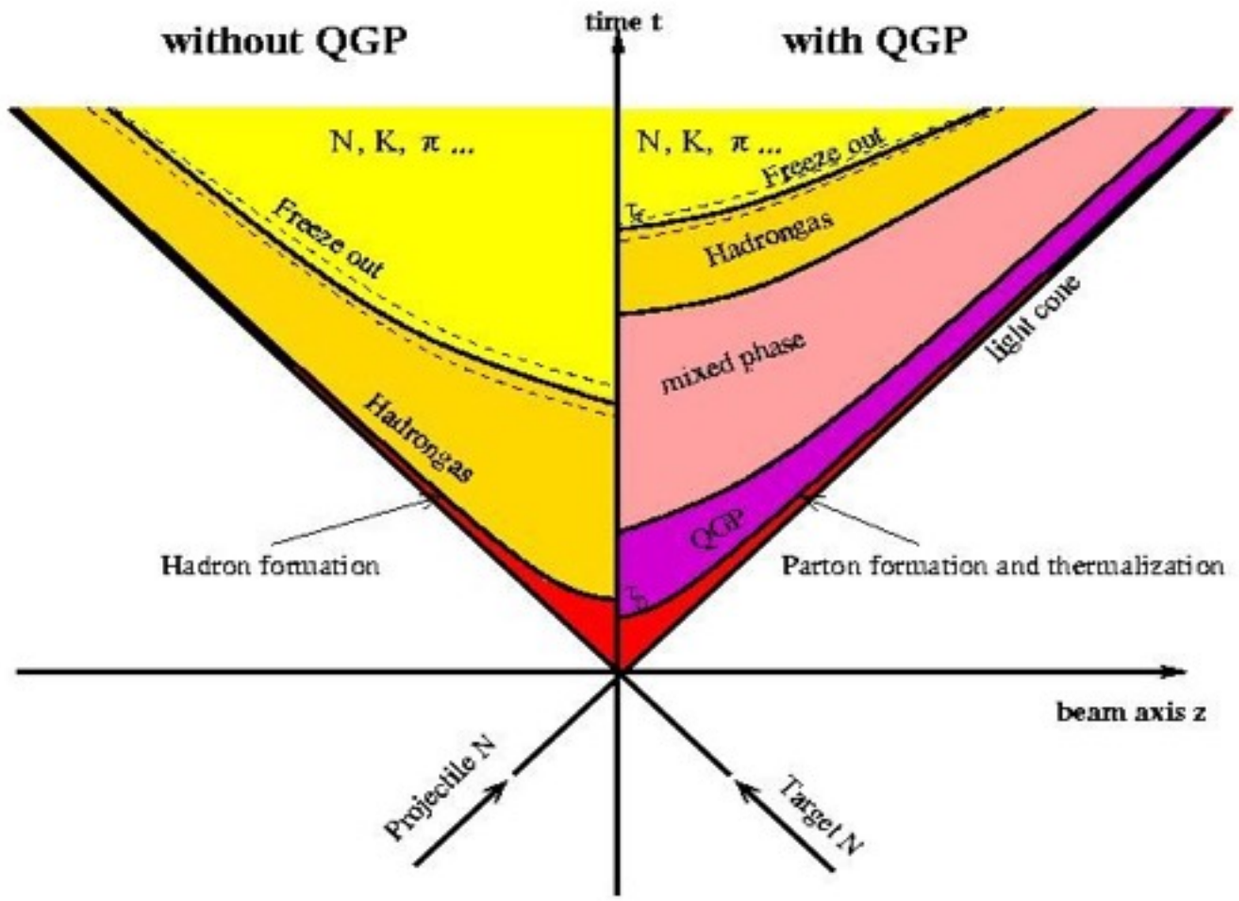
End of the hadronic Interactions

Freeze out

Stream out

Physics: System Evolution

N, K, π, γ, e, μ, …



Nuclear Collisions

Expansion

Temperature Falling

Hadronization

End of the hadronic Interactions

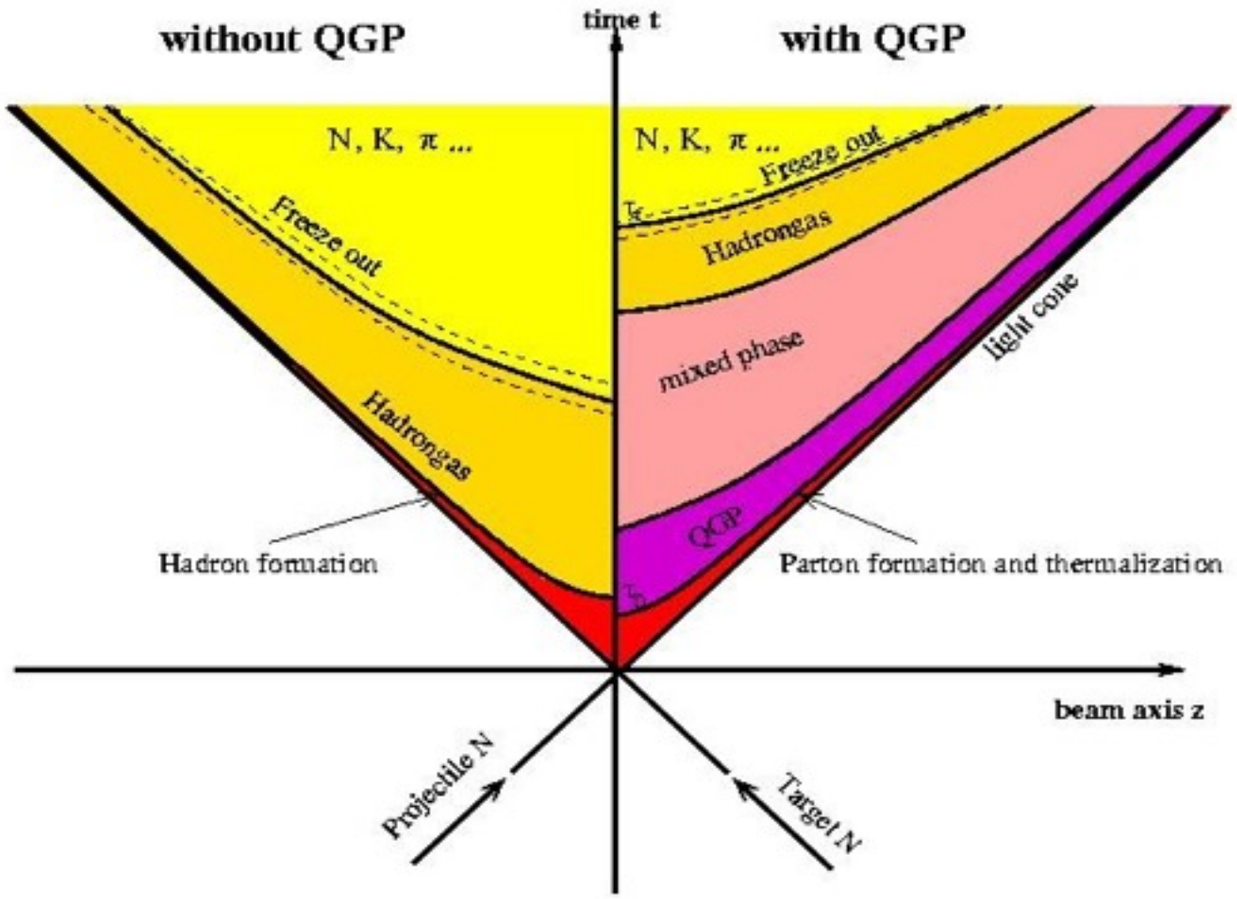
Freeze out

Stream out

Physics: System Evolution

N, K, π, γ, e, μ, …

Λ, Ξ, Σ, ϕ, …



Nuclear Collisions

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Experiment & Processing

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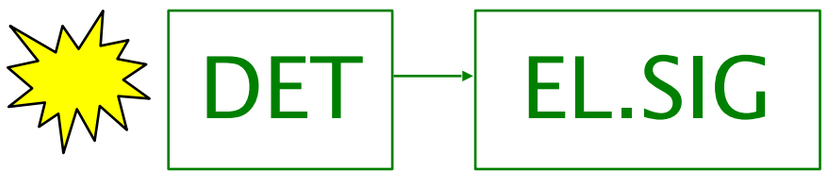

Experiment & Processing

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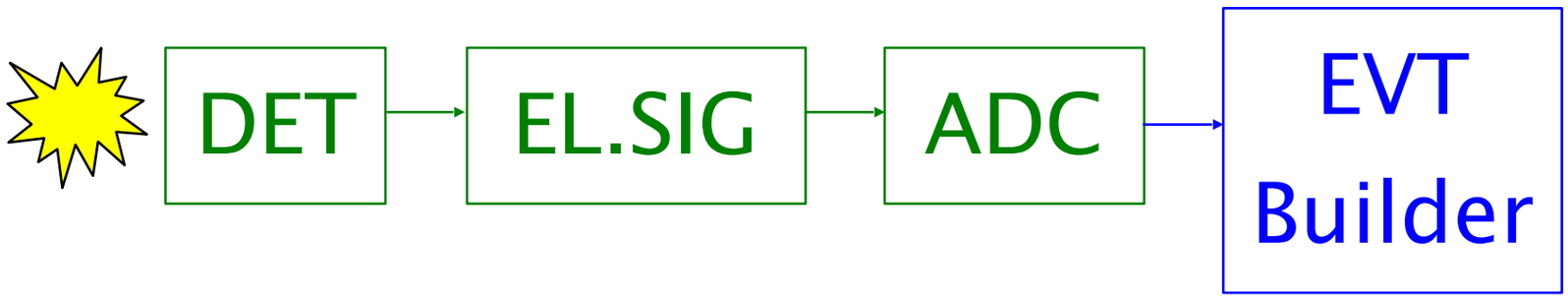

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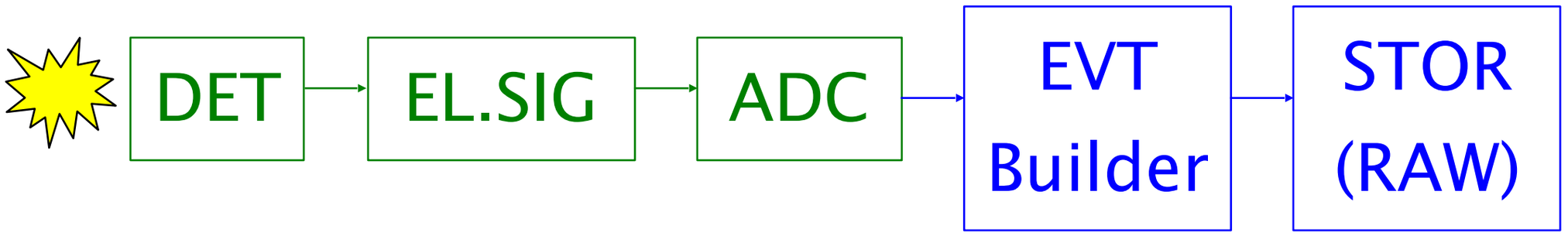

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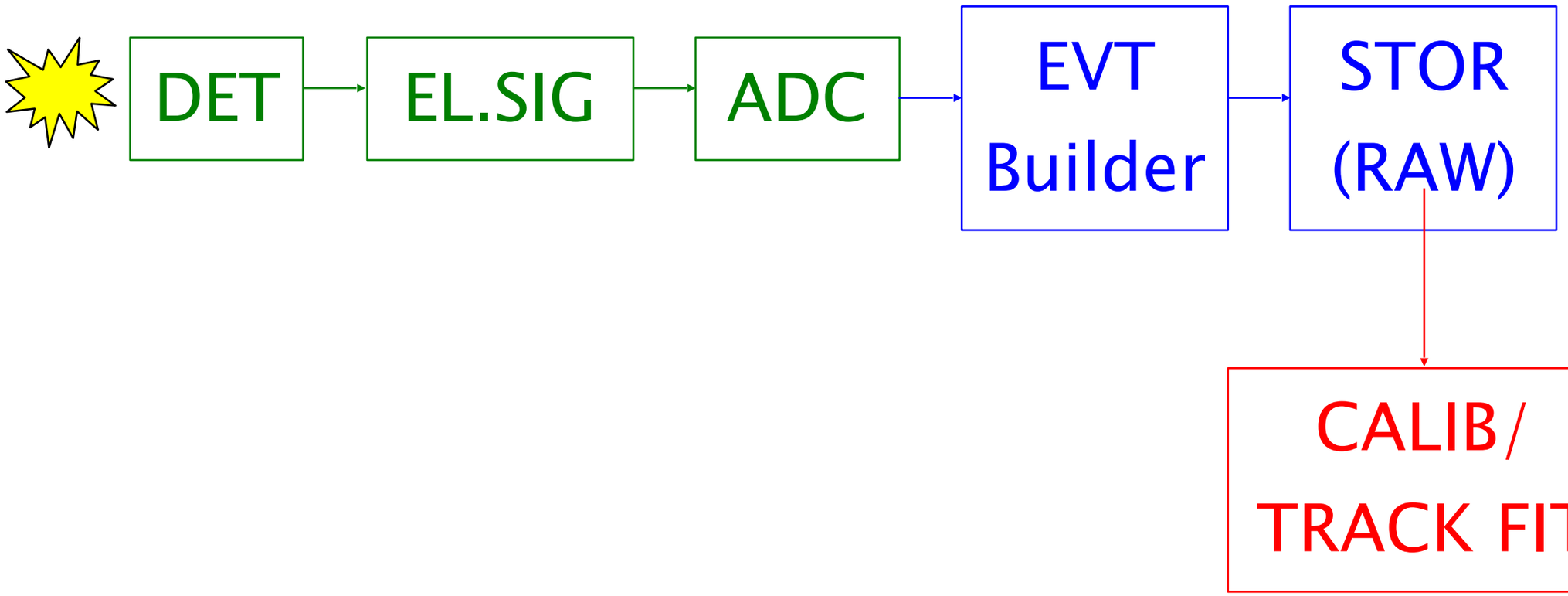

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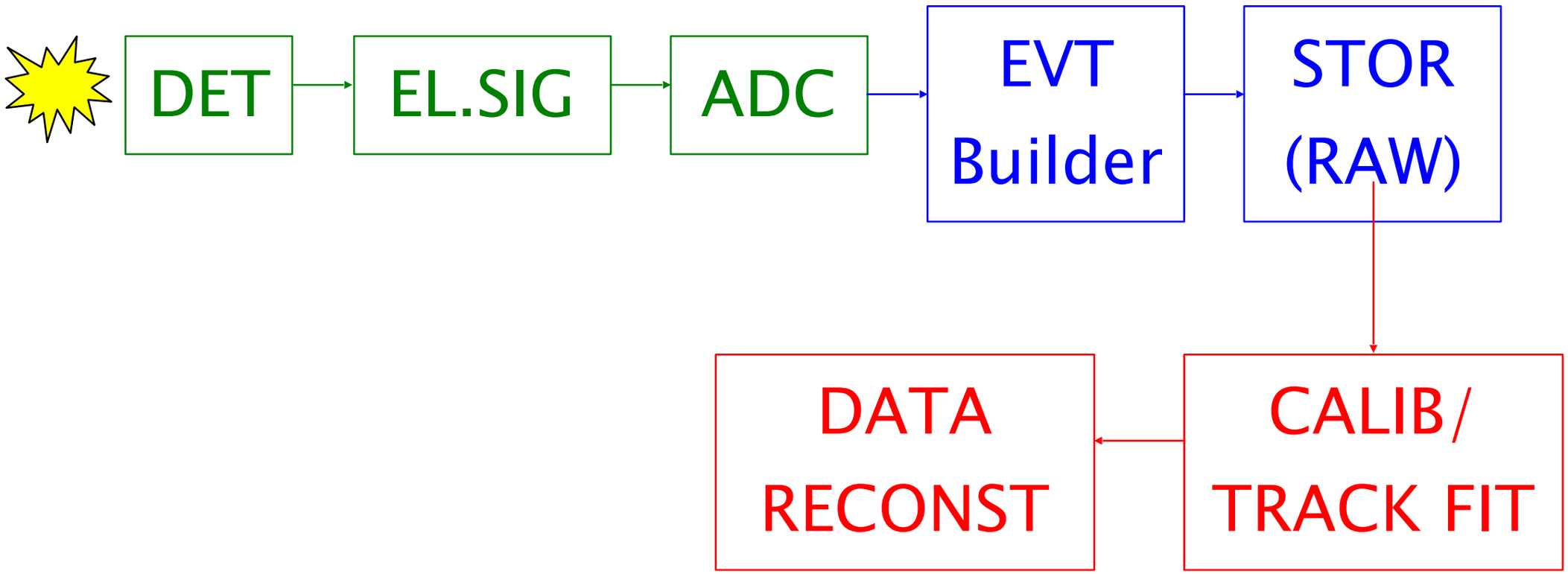

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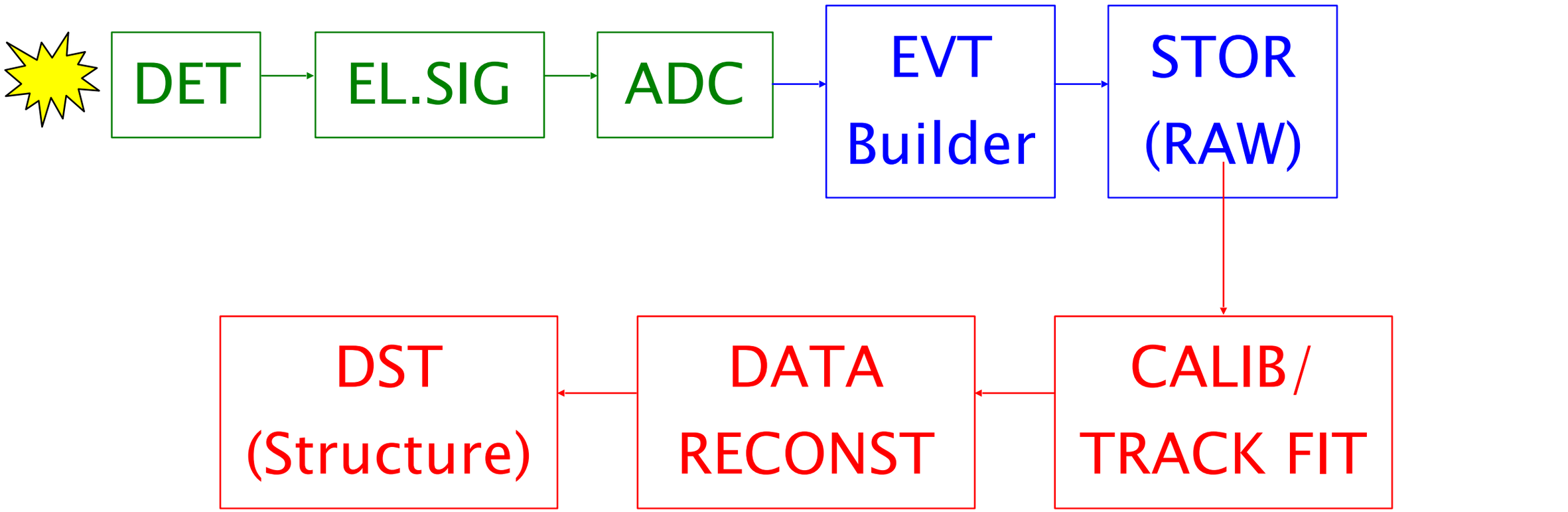

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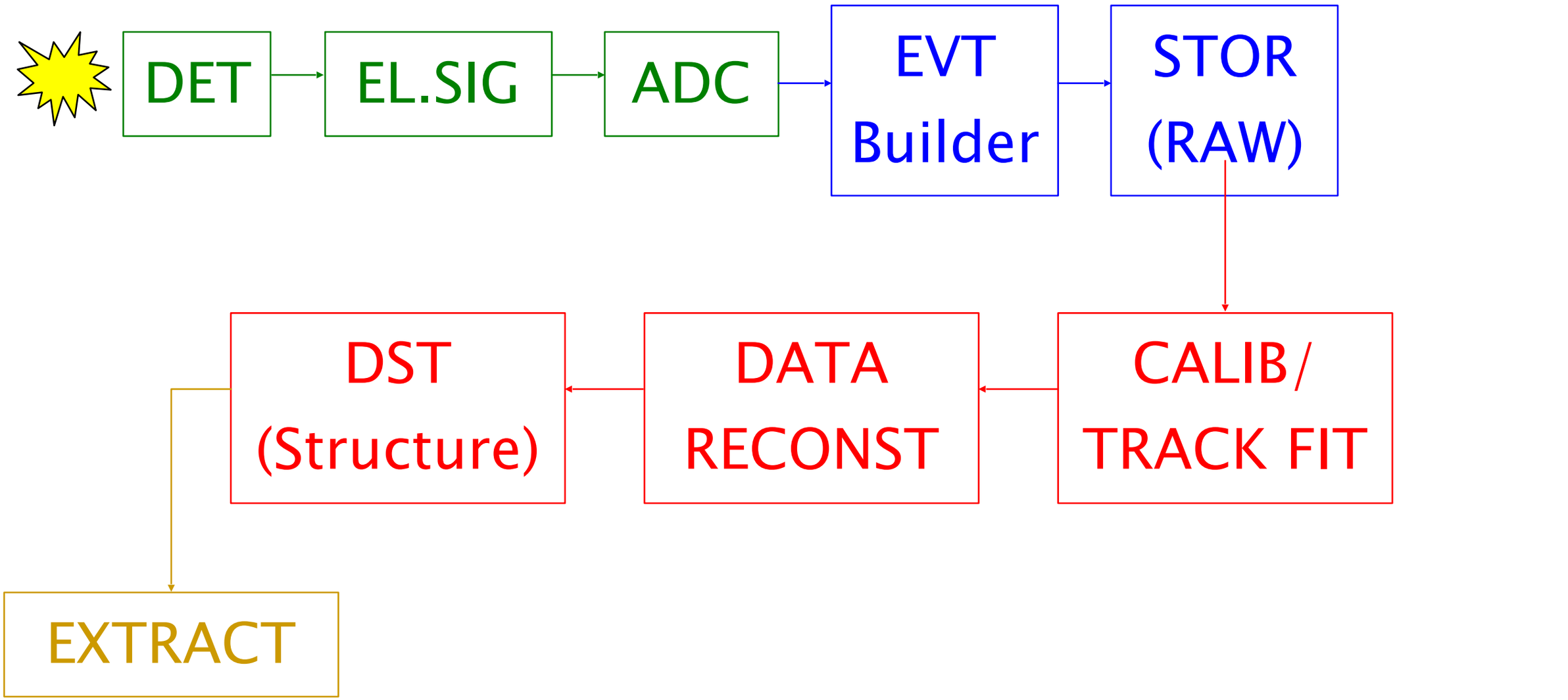

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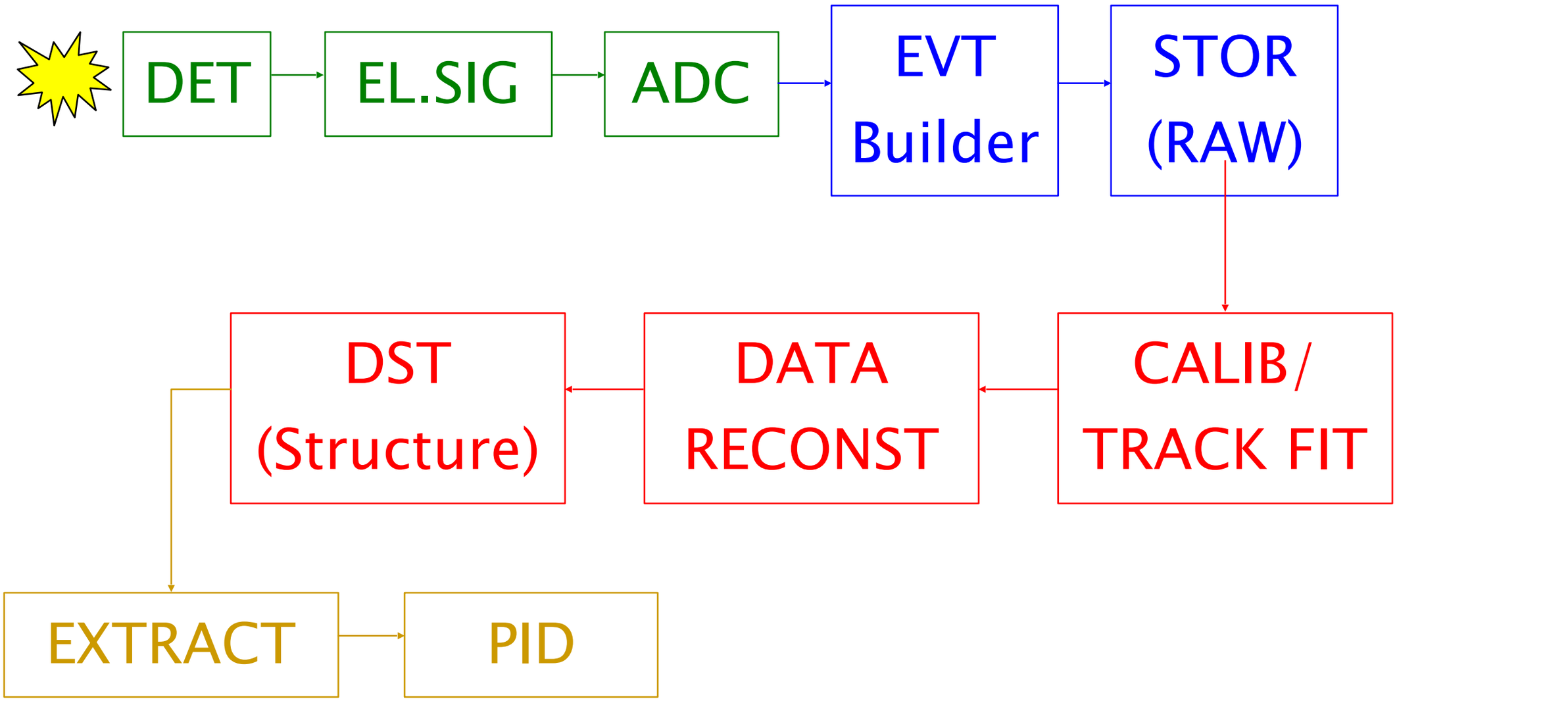

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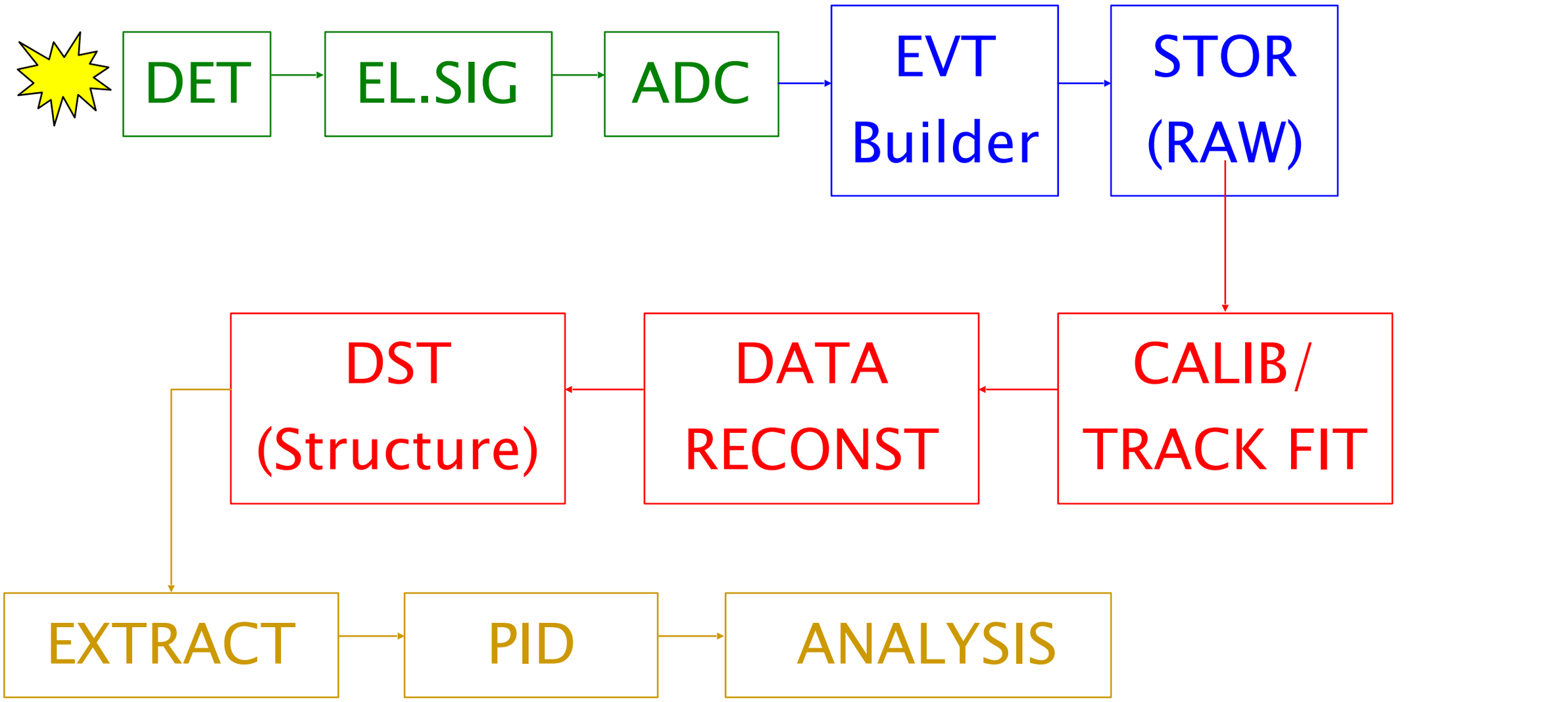

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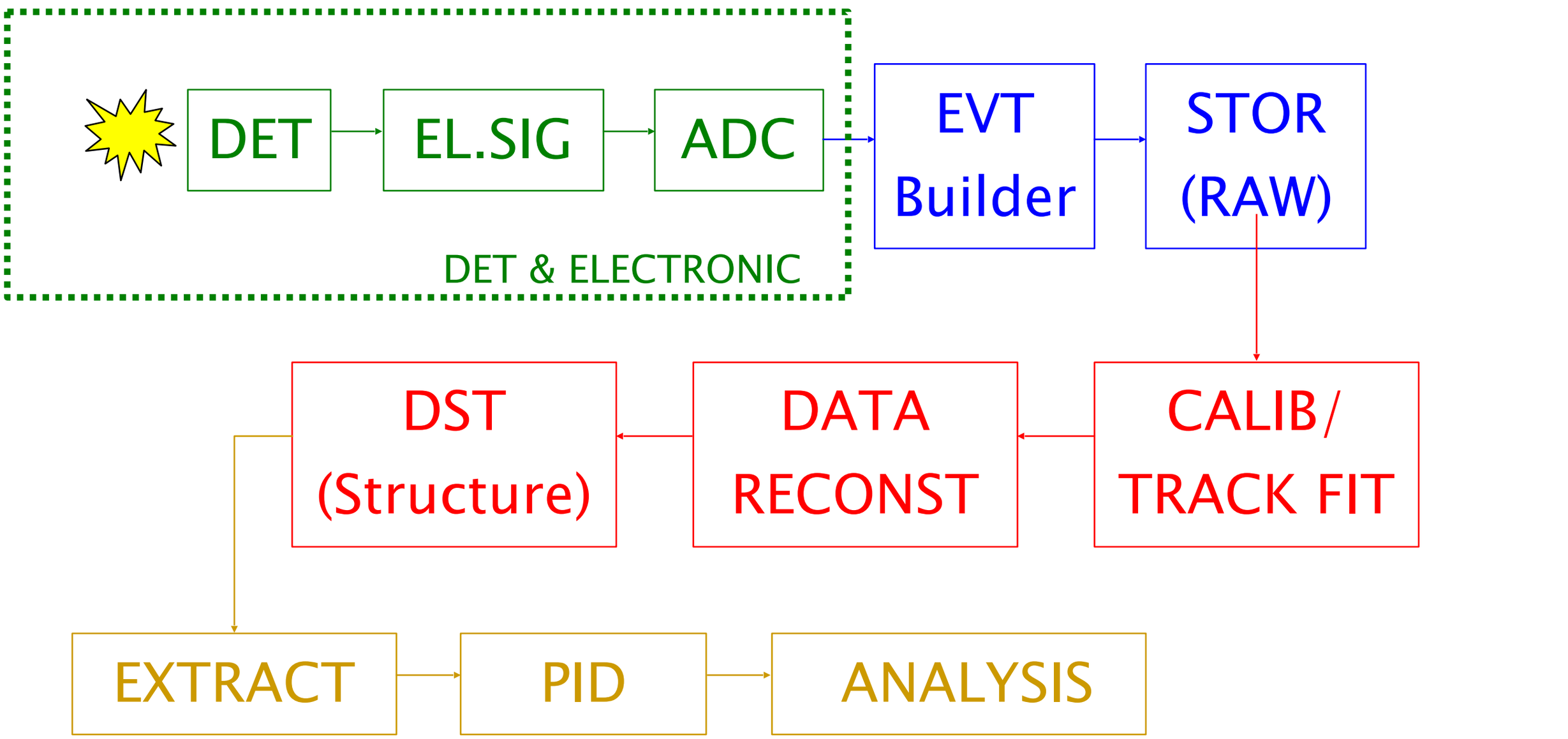

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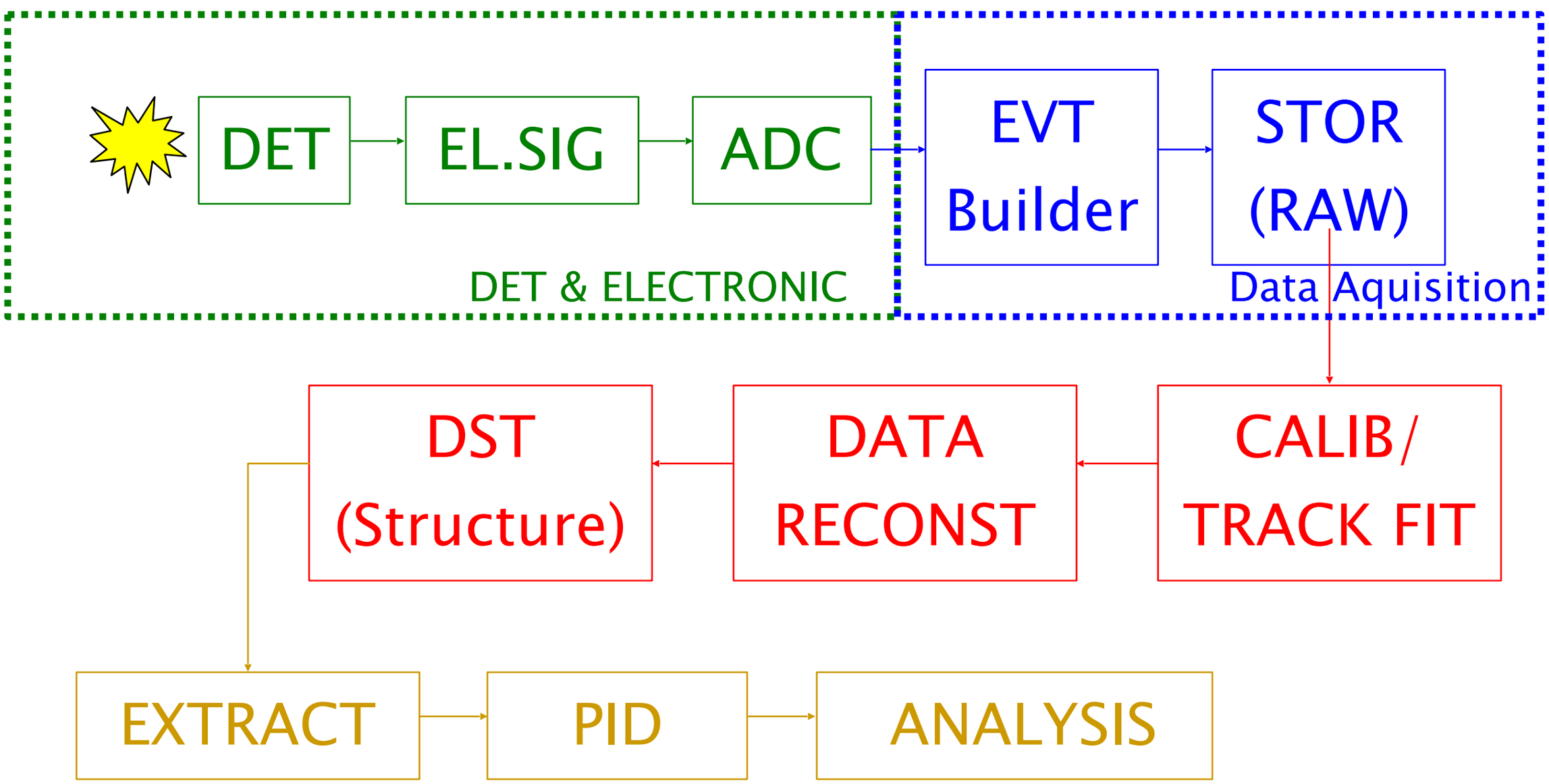

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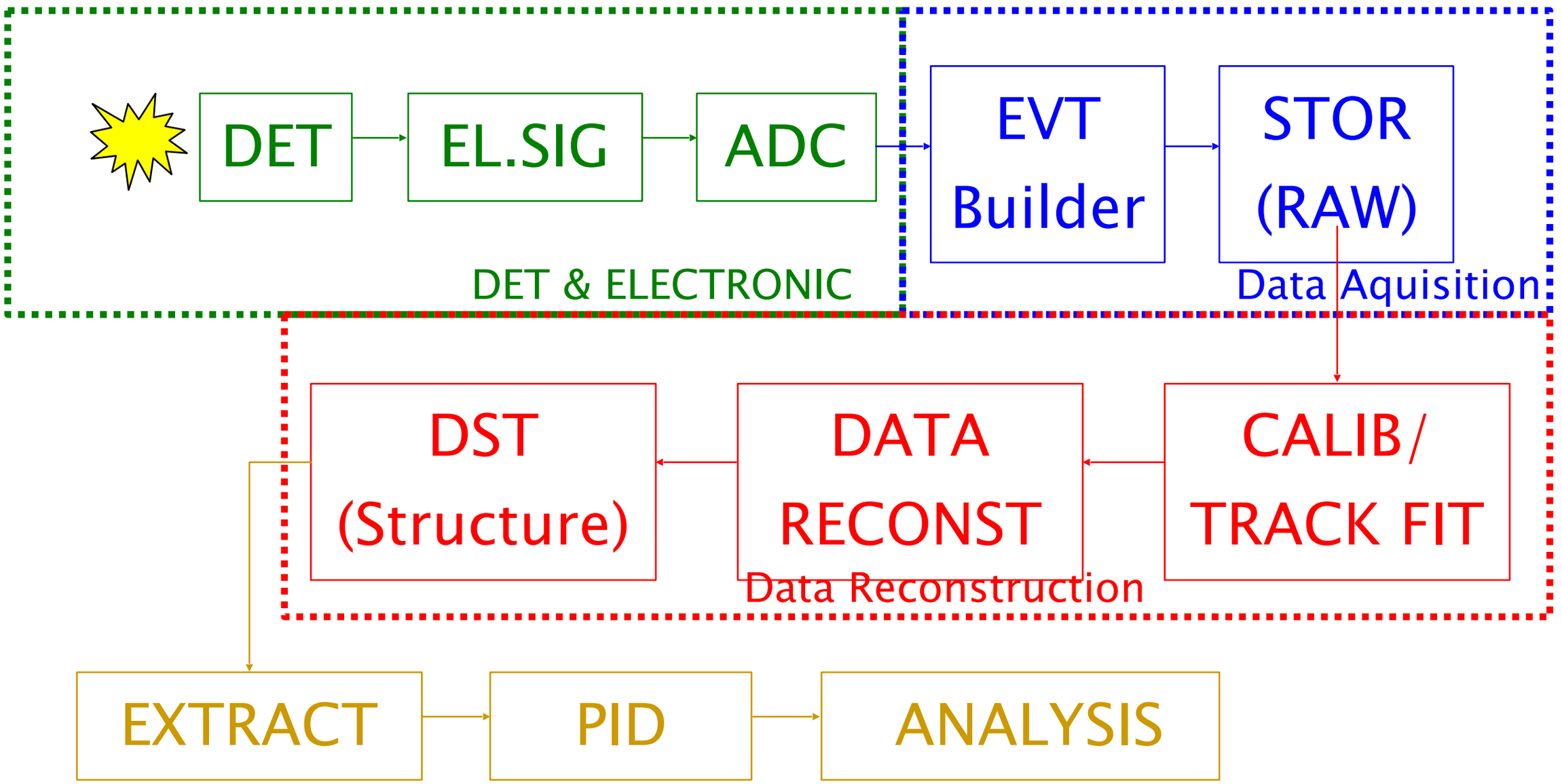

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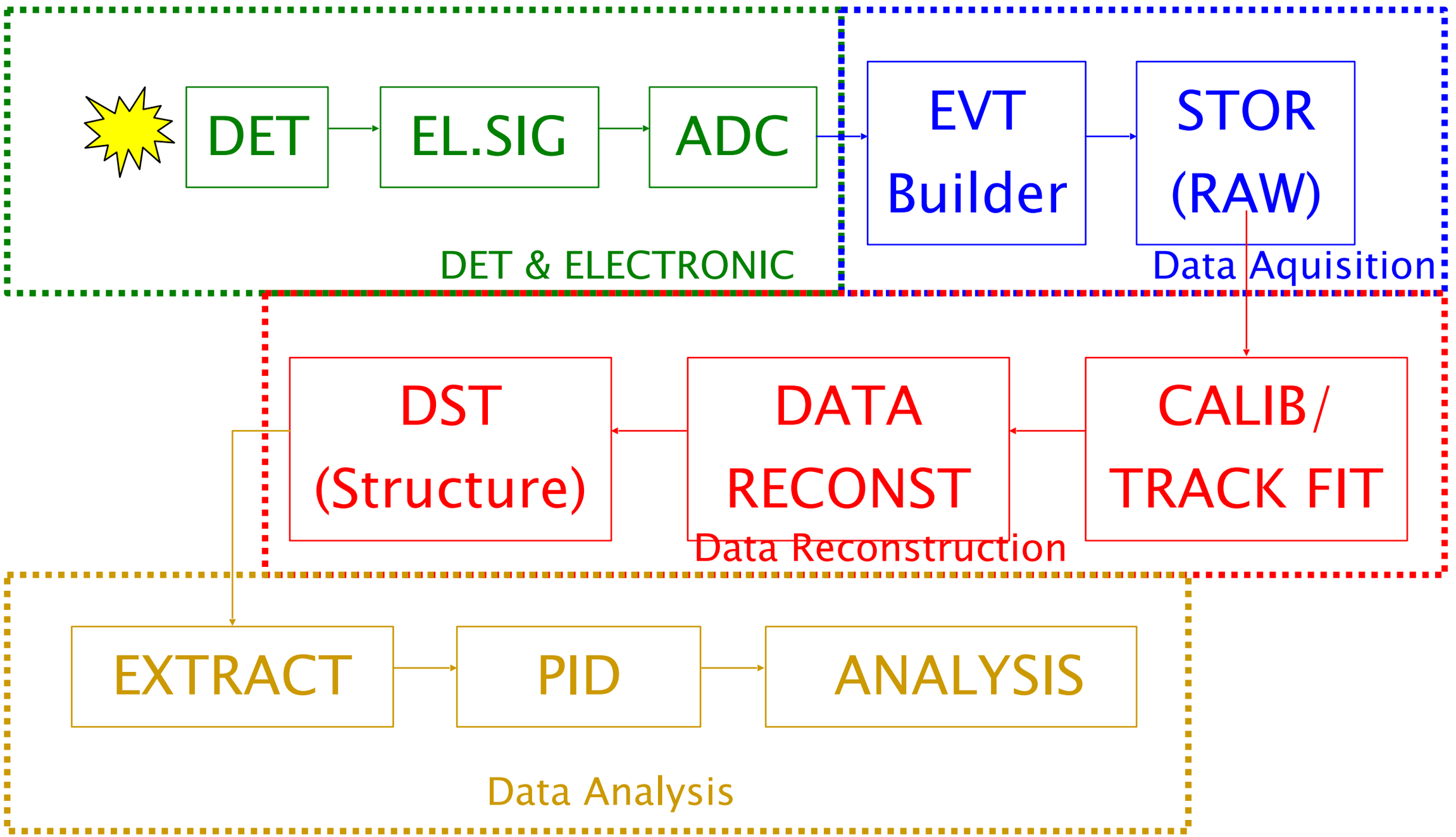

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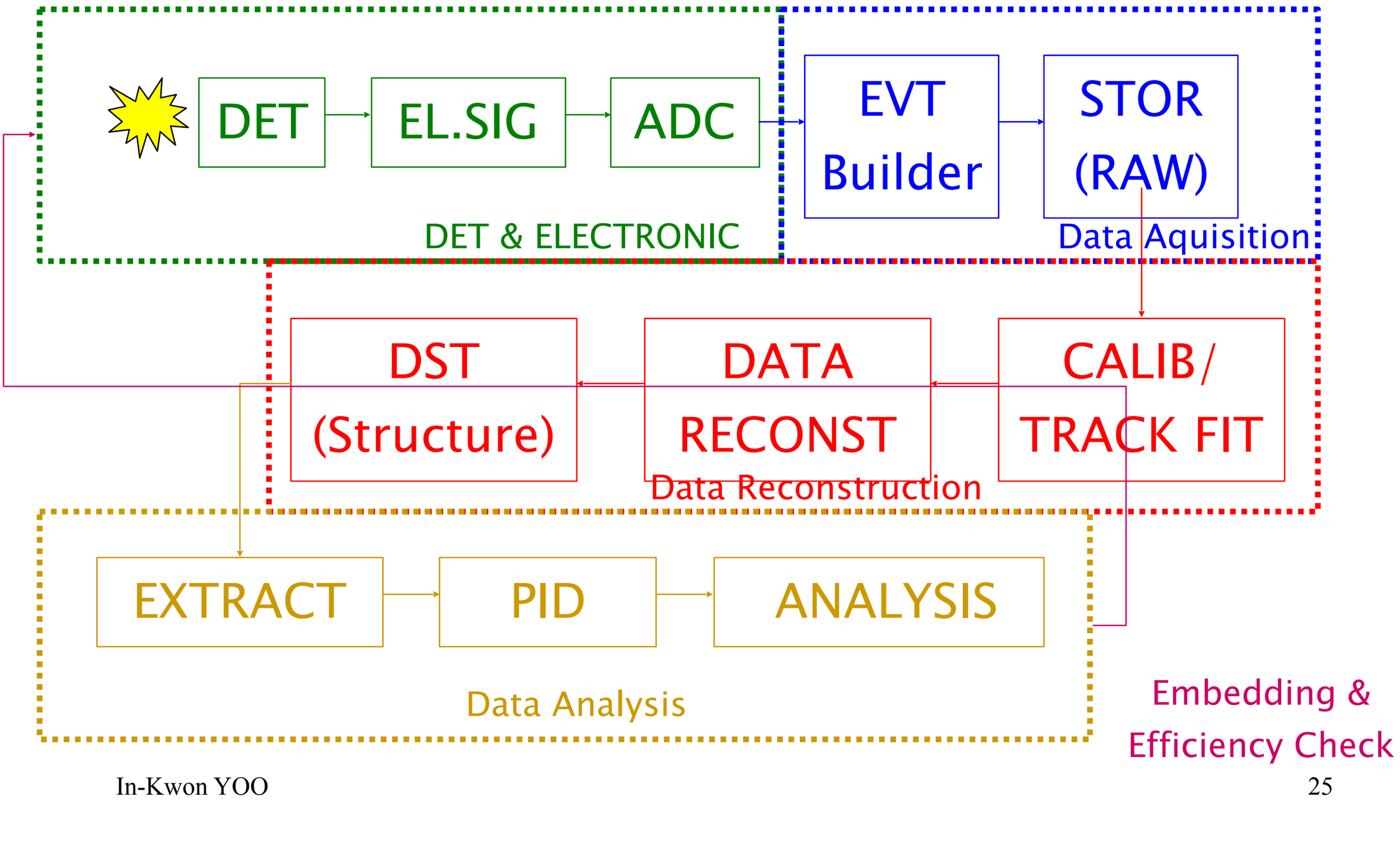


Database: Event —> Track —> etc.

Candidates selections

Event selection

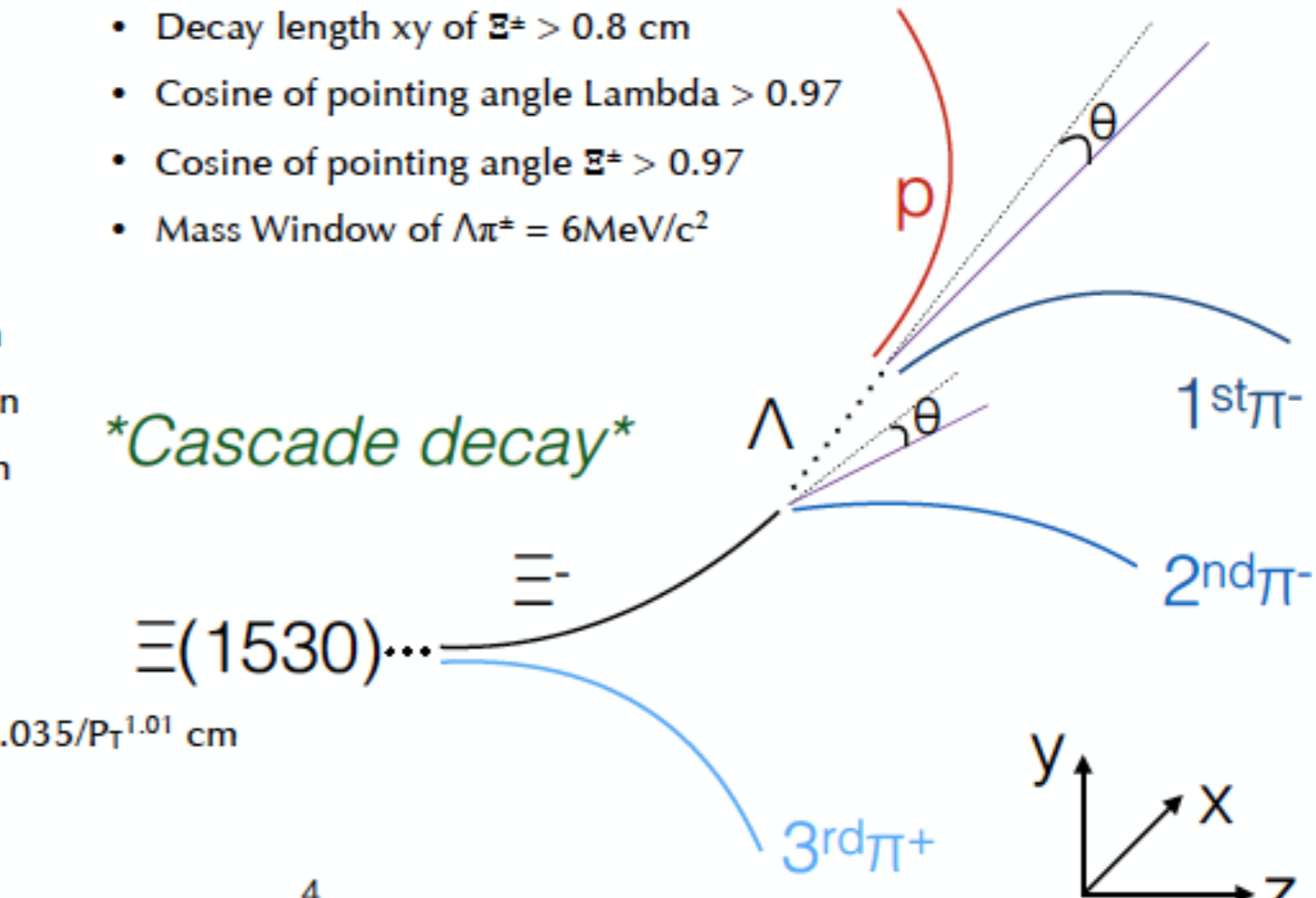
- Minimum bias events is selected
- Pile-up events are rejected
  - via SPD detector
- -10 < Vz < 10 cm

Track Cuts

- Pt > 0.15 GeV/c
- -0.8 < η < 0.8 for 3rd pion
- SetTPCminNClusters(70) proton
- SetTPCminNClusters(70) 1st pion
- SetTPCminNClusters(70) 2nd pion
- SetTPCminNClusters(70) 3rd pion
- PV DCA of proton > 0.04 cm
- PV DCA of 1st pion > 0.04 cm
- PV DCA of 2nd pion > 0.05 cm
- PV DCA xy 3rd pion < $0.0182+0.035/P_T^{1.01}$ cm
- PV DCA z of 3rd pion < 2cm

Topological Cuts

- PV DCA Lambda > 0.07 cm
- DCA Proton and 1st pion < 1.6 cm
- DCA Lambda and 2nd pion < 1.6 cm
- Decay length xy of Lambda > 1.4 cm
- Decay length xy of Ξ± > 0.8 cm
- Cosine of pointing angle Lambda > 0.97
- Cosine of pointing angle Ξ± > 0.97
- Mass Window of $\Lambda\pi^{\pm} = 6 MeV/c^2$



Particle Identification

Particle Identification

- Track Curvature $\rightarrow$

Particle Identification

- Track Curvature $\rightarrow$ Momentum

Particle Identification

- Track Curvature → Momentum
- Specific dE/dx →

Particle Identification

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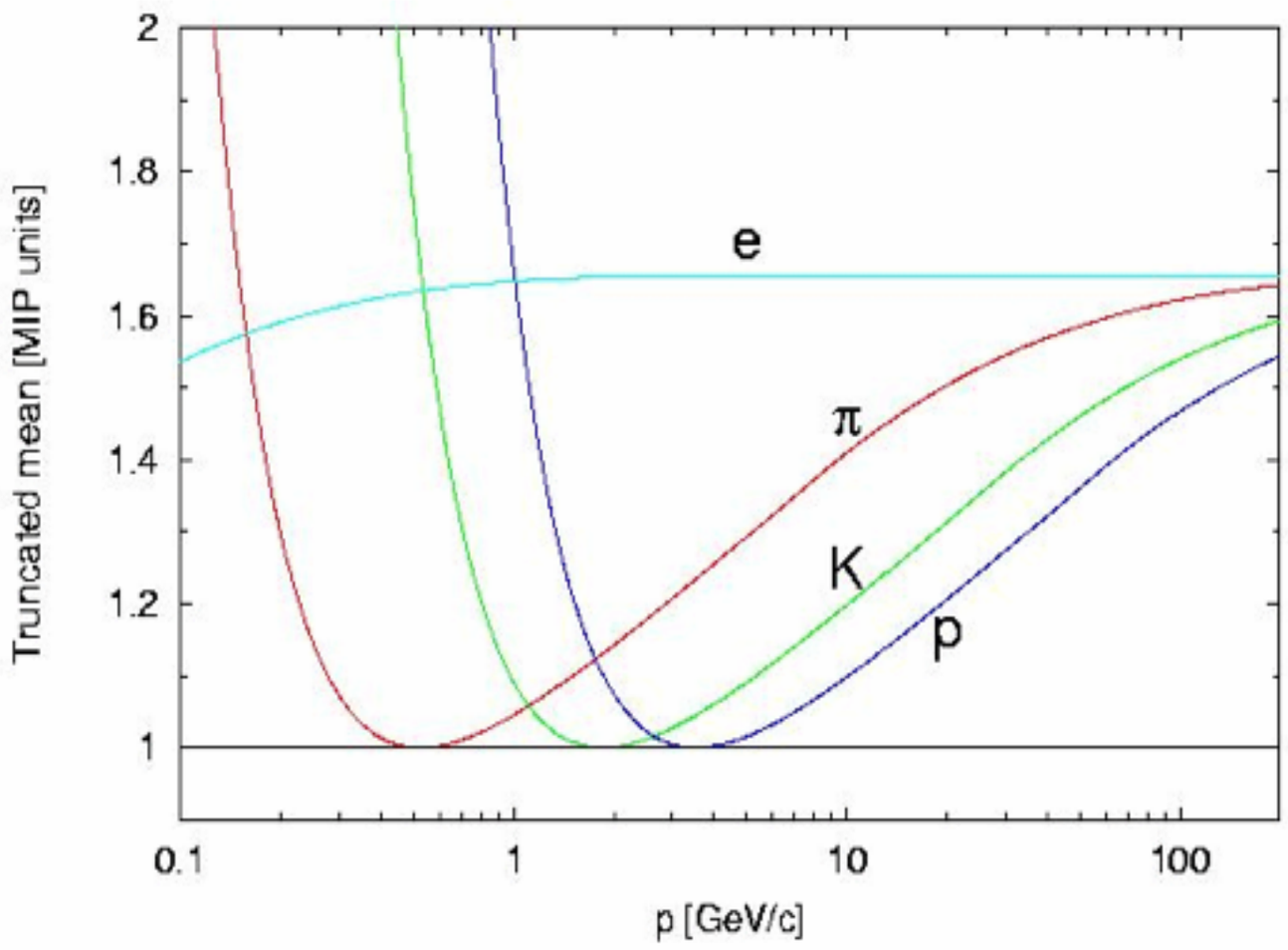
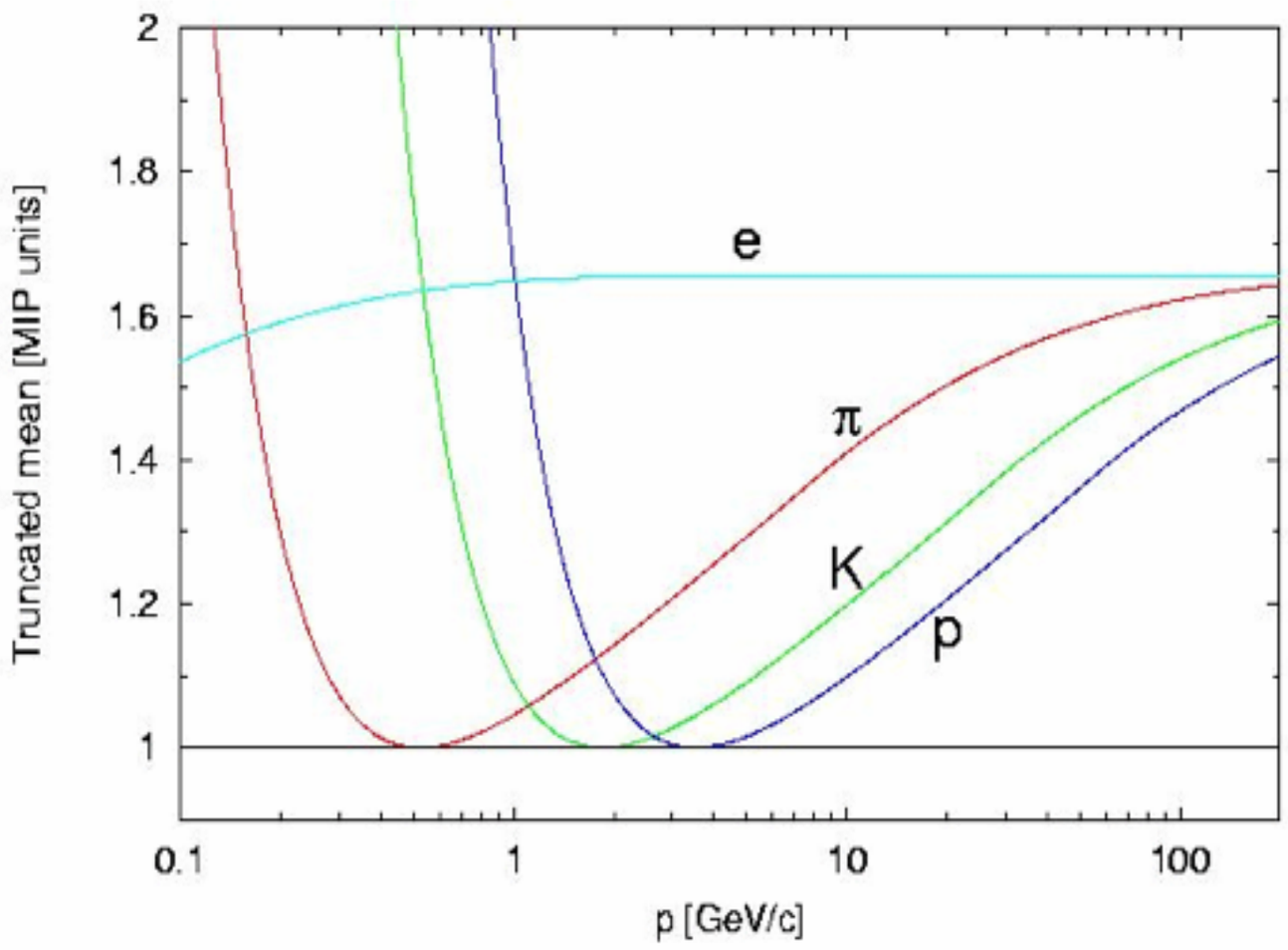


Particle Identification

- Track Curvature → Momentum
- Specific dE/dx → Bethe-Bloch
- dE/dx PID



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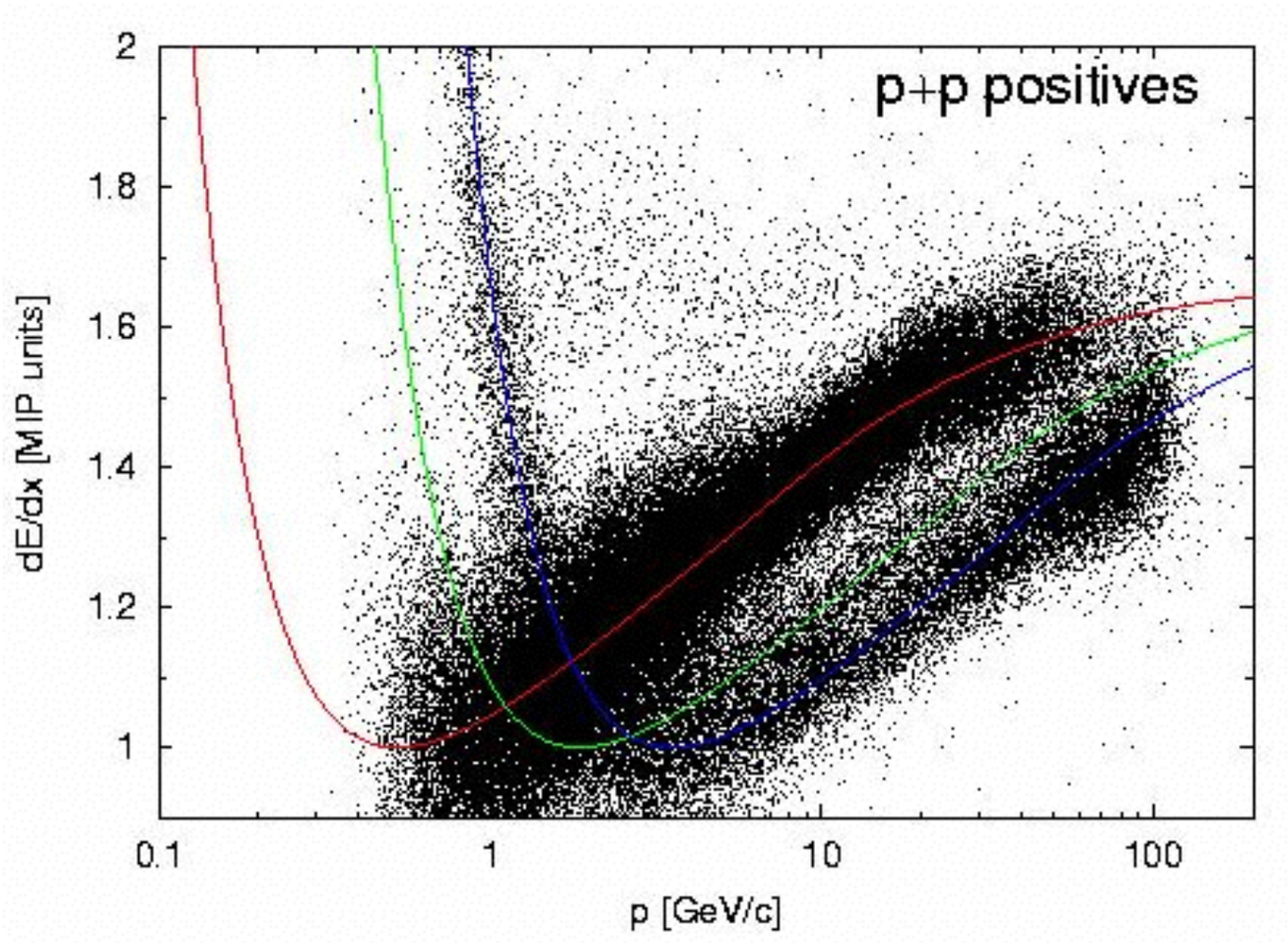

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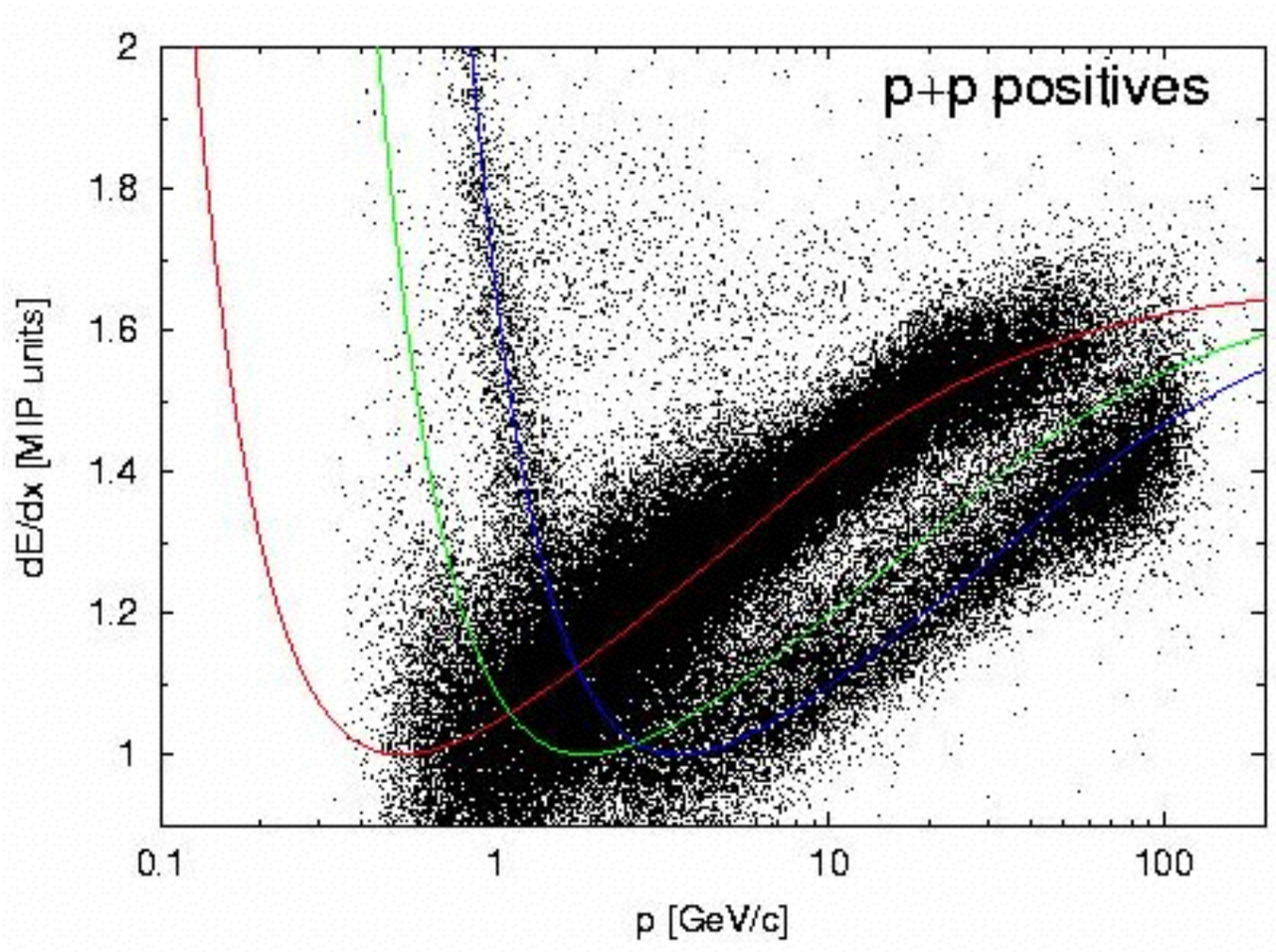
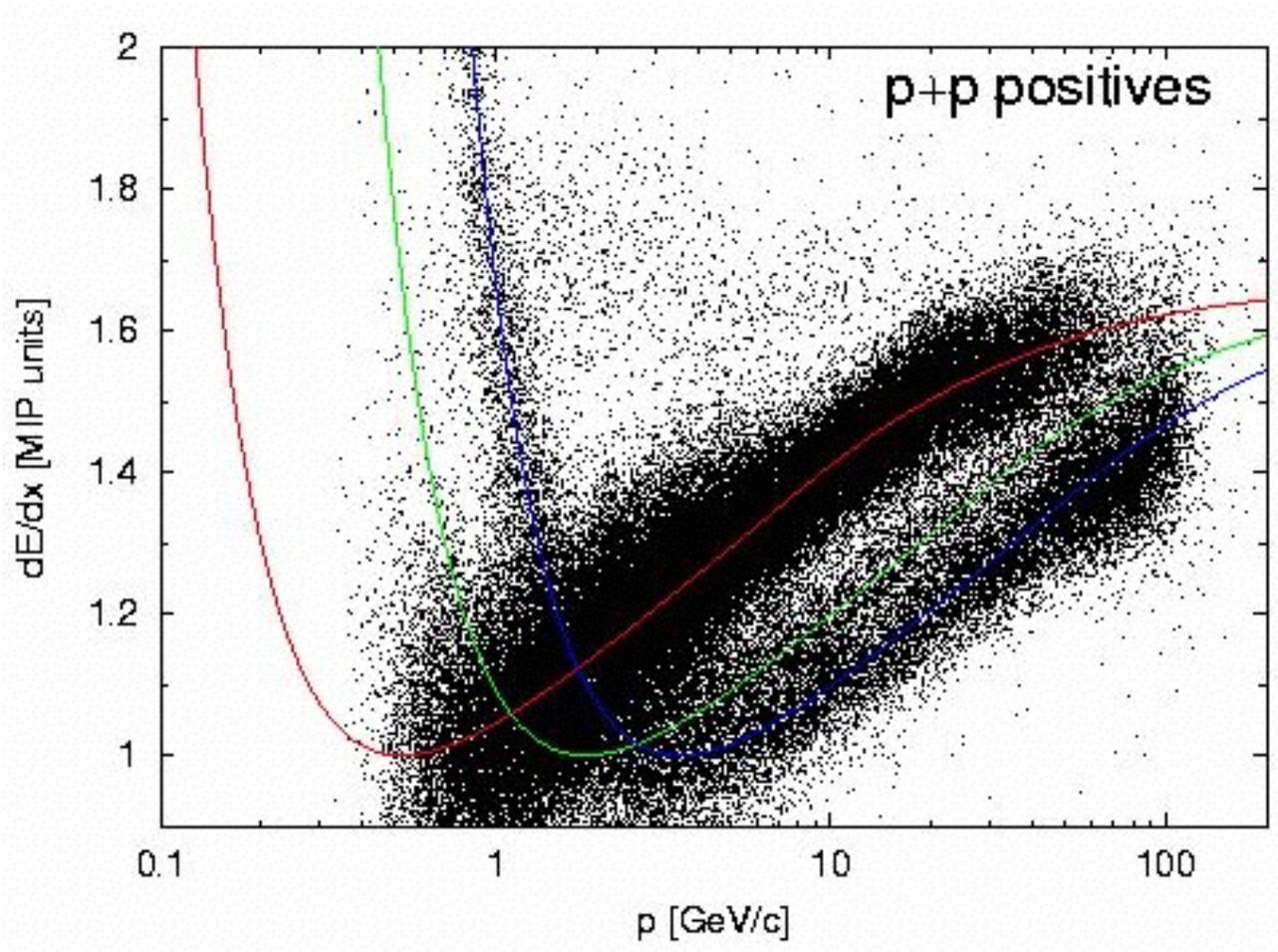


- Time-Of-Flight & Tracklength

→

Particle Identification

- Track Curvature → Momentum
- Specific dE/dx → Bethe-Bloch
- dE/dx PID



- Time-Of-Flight & Tracklength
  → Velocity
  →

Particle Identification

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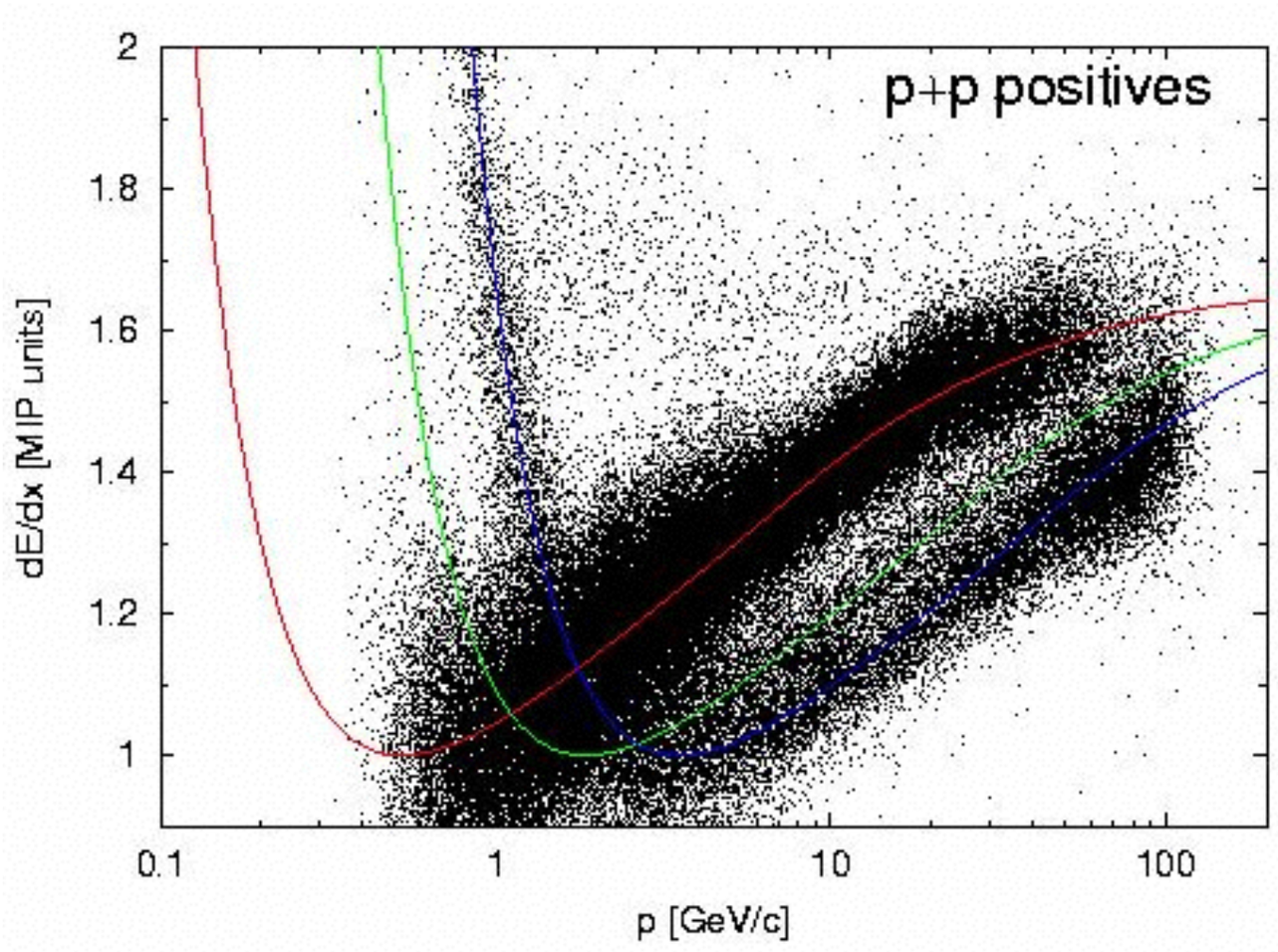

- Time-Of-Flight & Tracklength
  - → Velocity
  - → Mass
  - →

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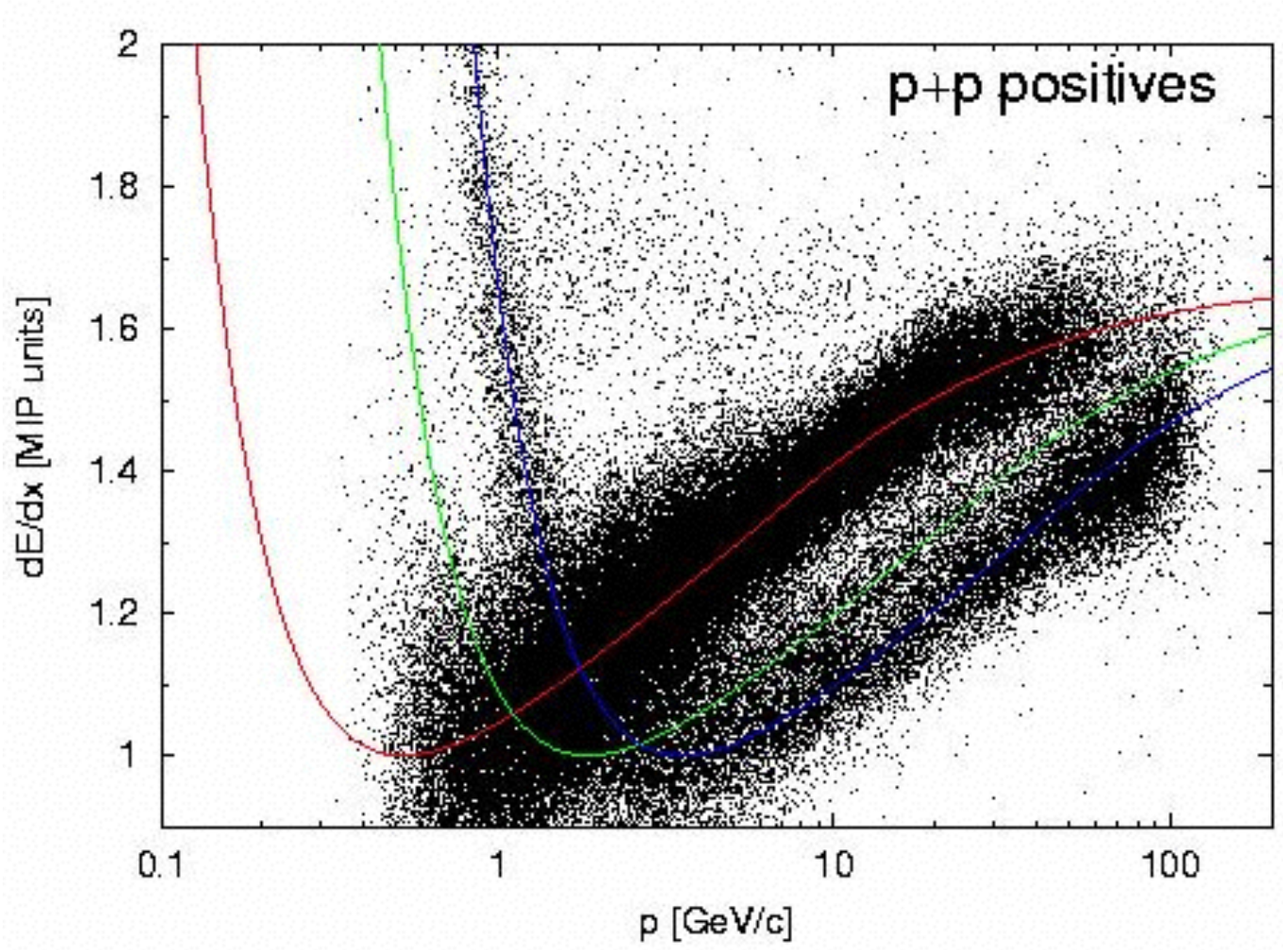

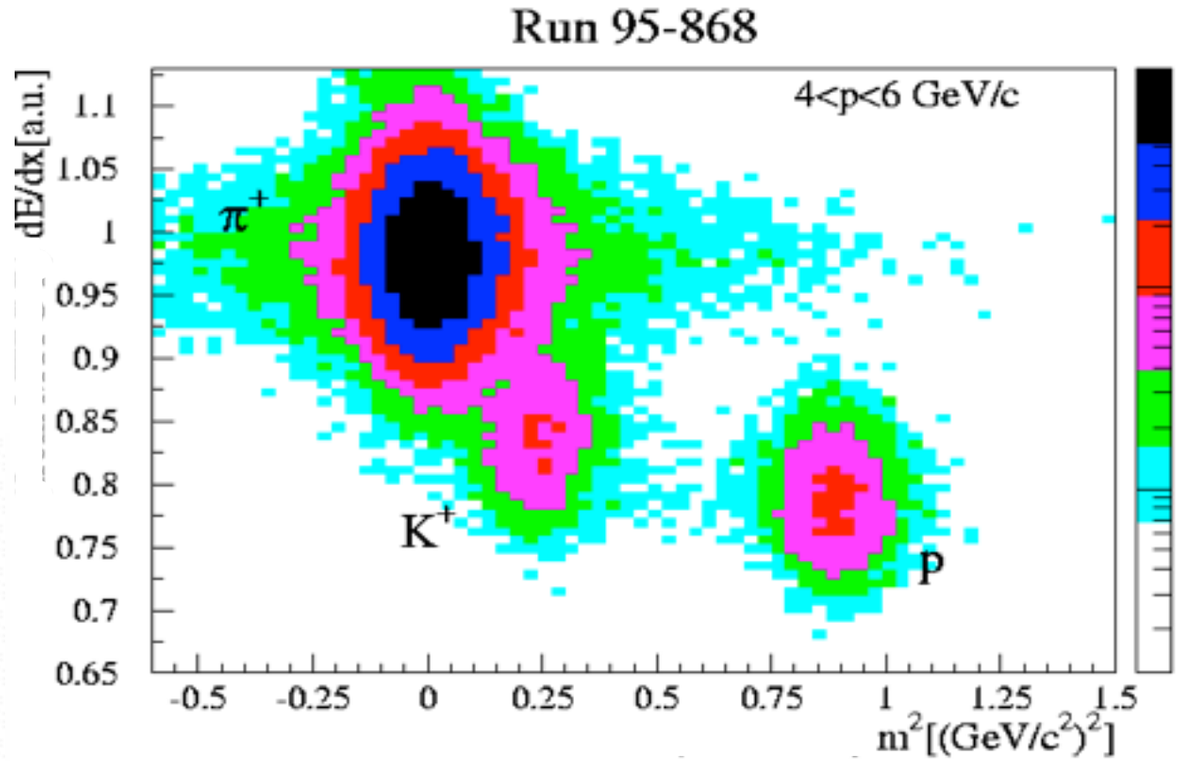

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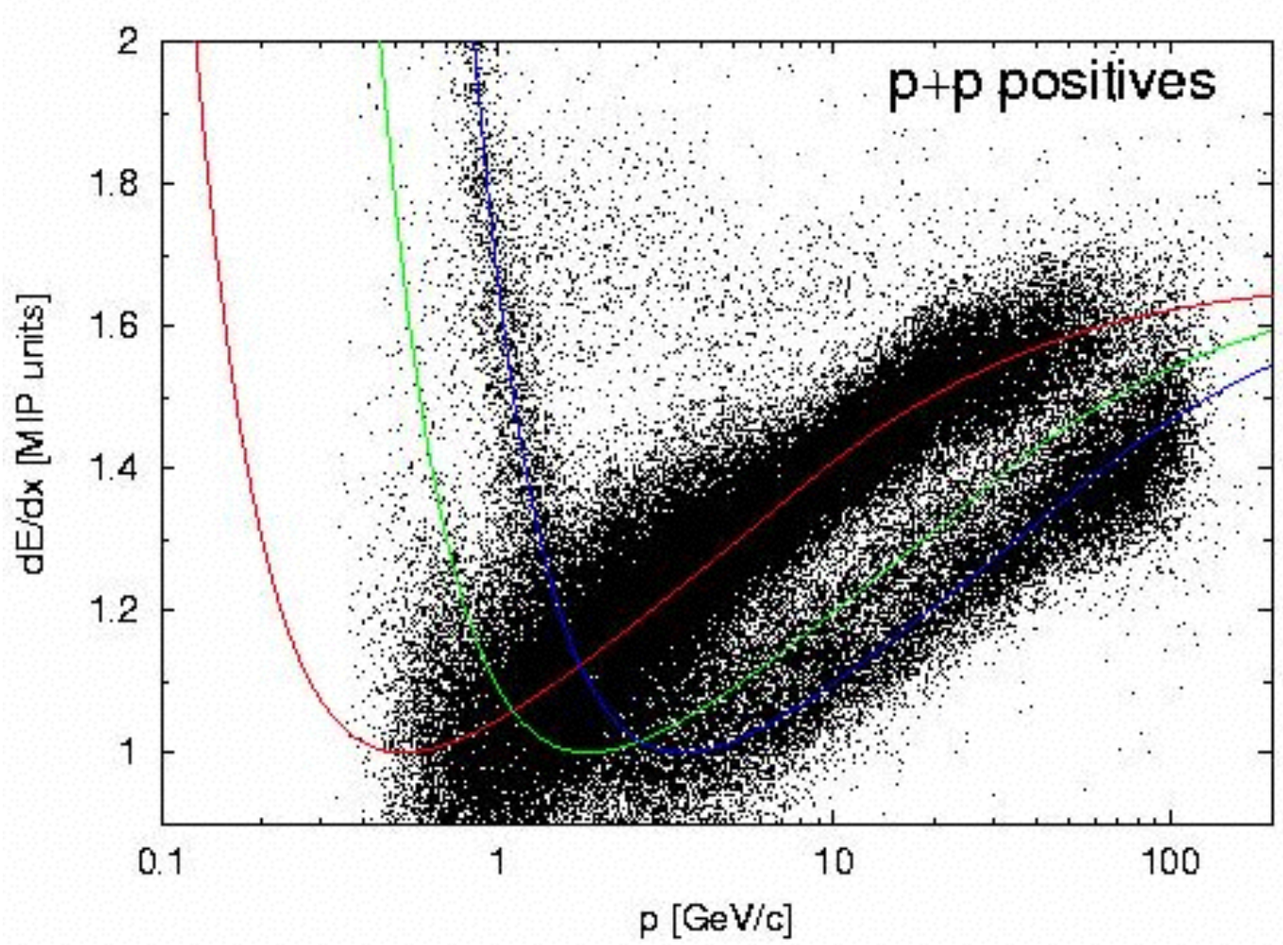

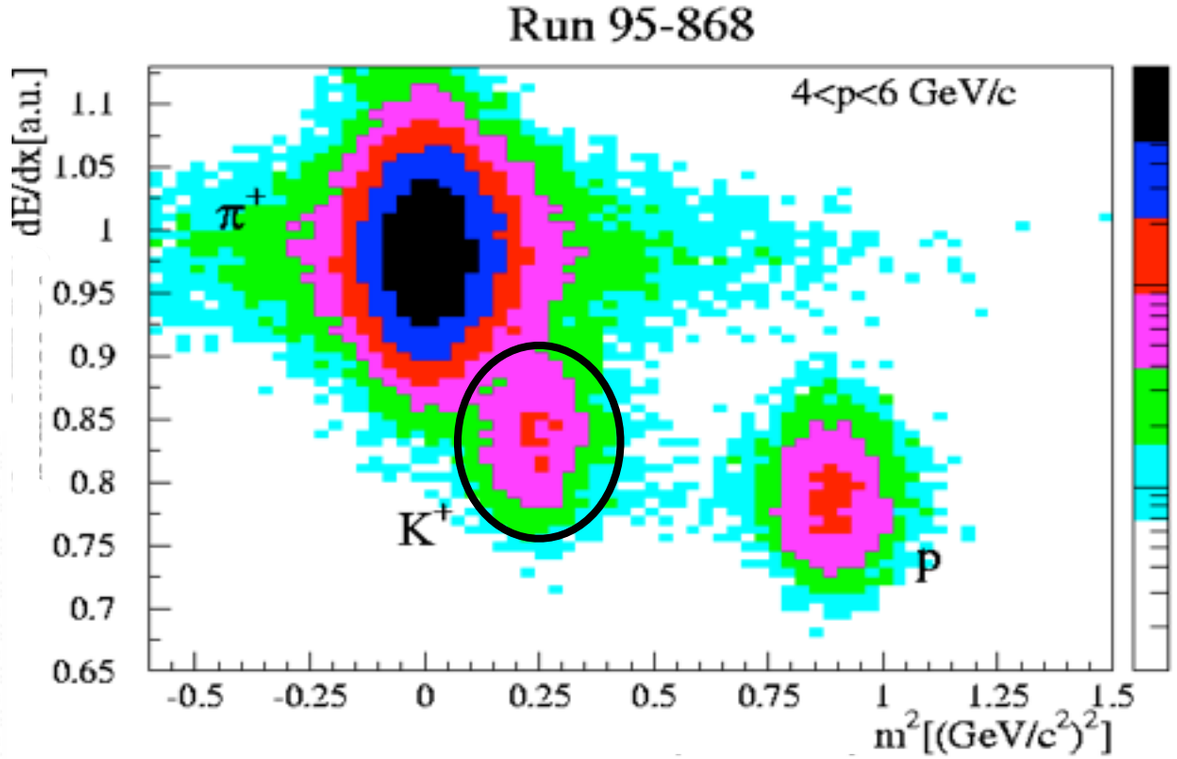

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  - → Velocity
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  - →

Particle Identification

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- Specific dE/dx → Bethe-Bloch
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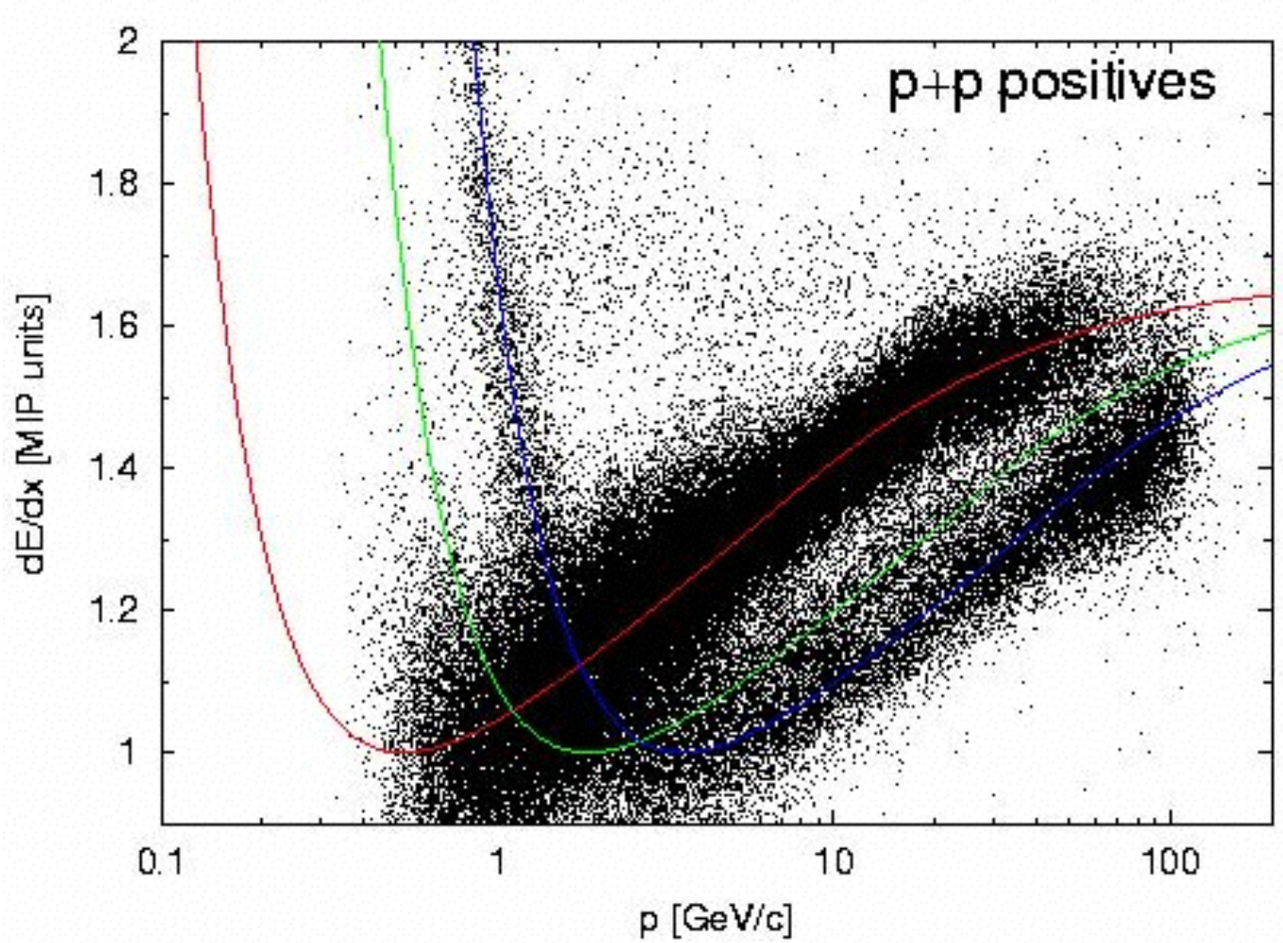
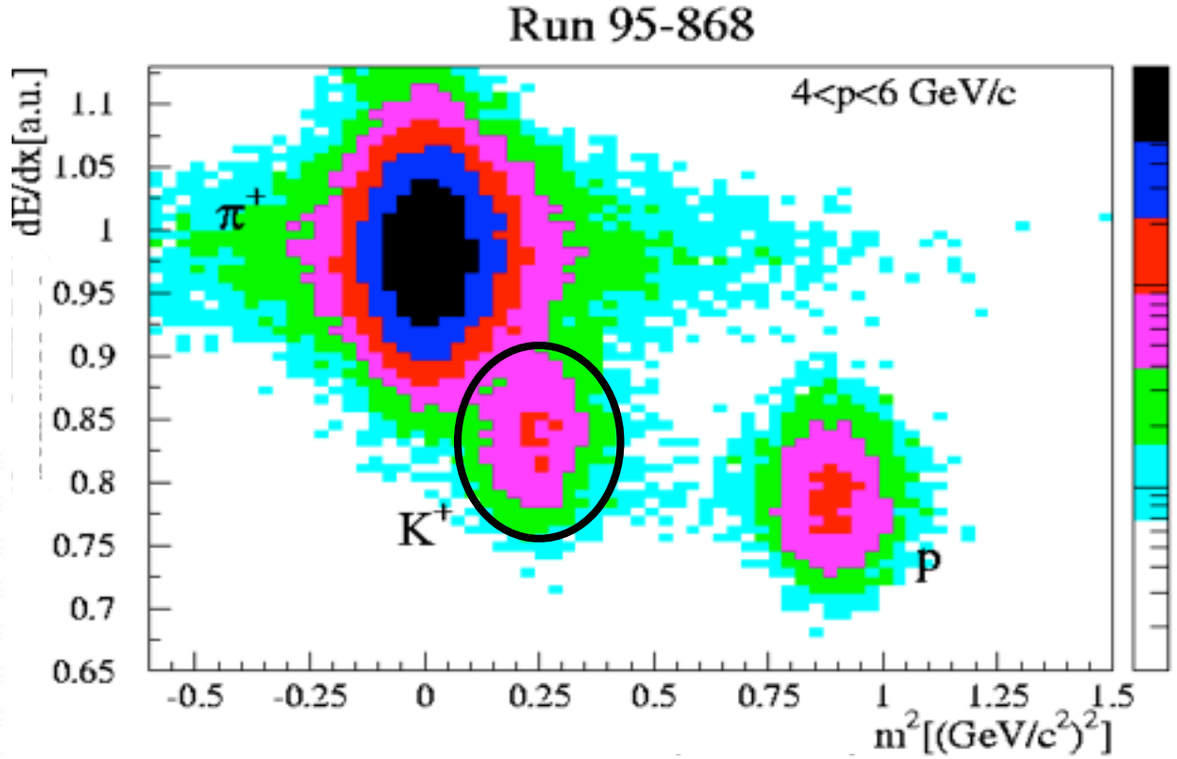
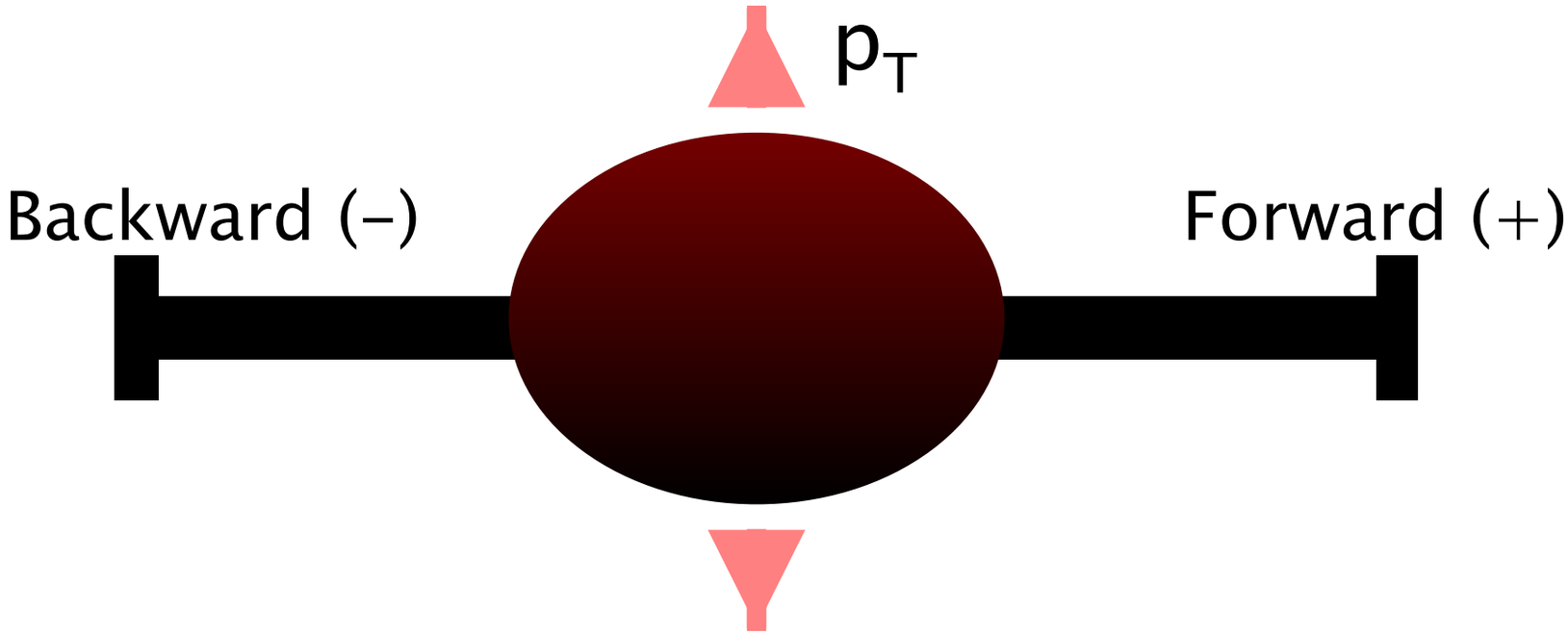




- Time-Of-Flight & Tracklength
  - → Velocity
  - → Mass
  - → TOF PID

(Pseudo) Rapidity vs. transv. Momentum



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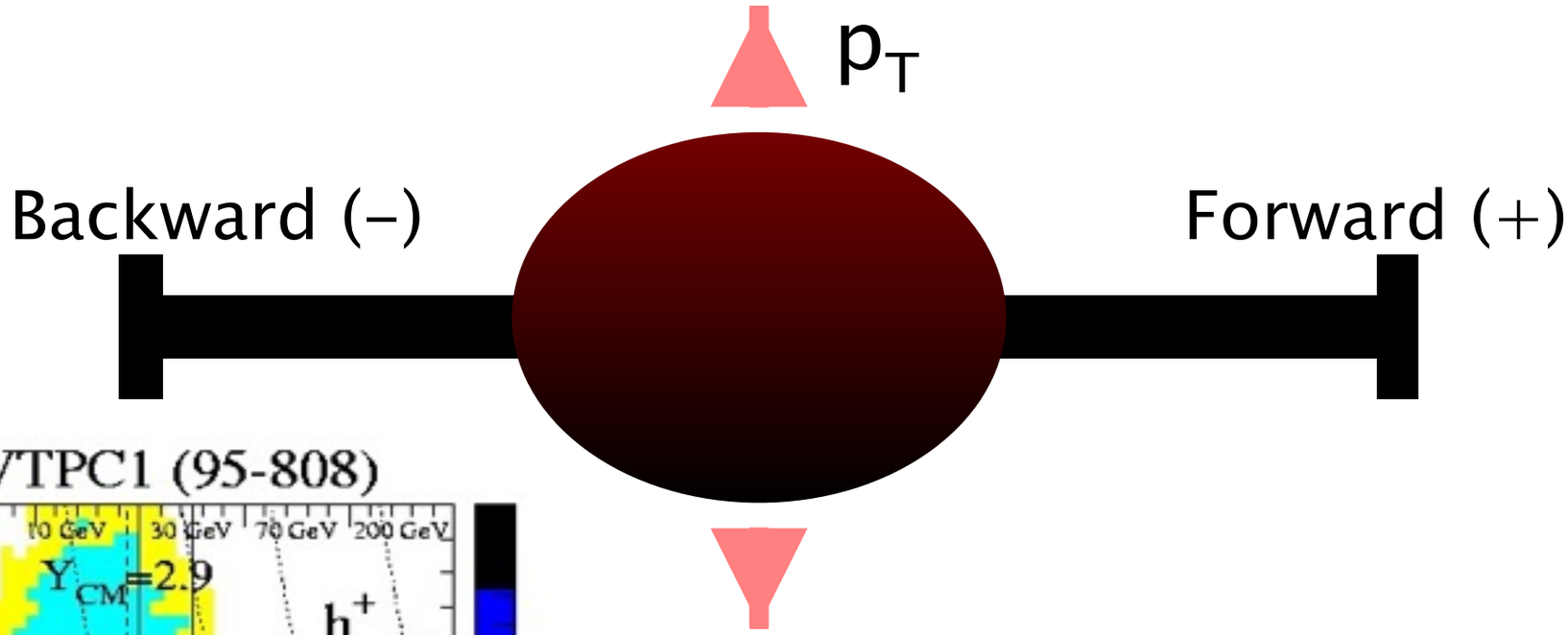

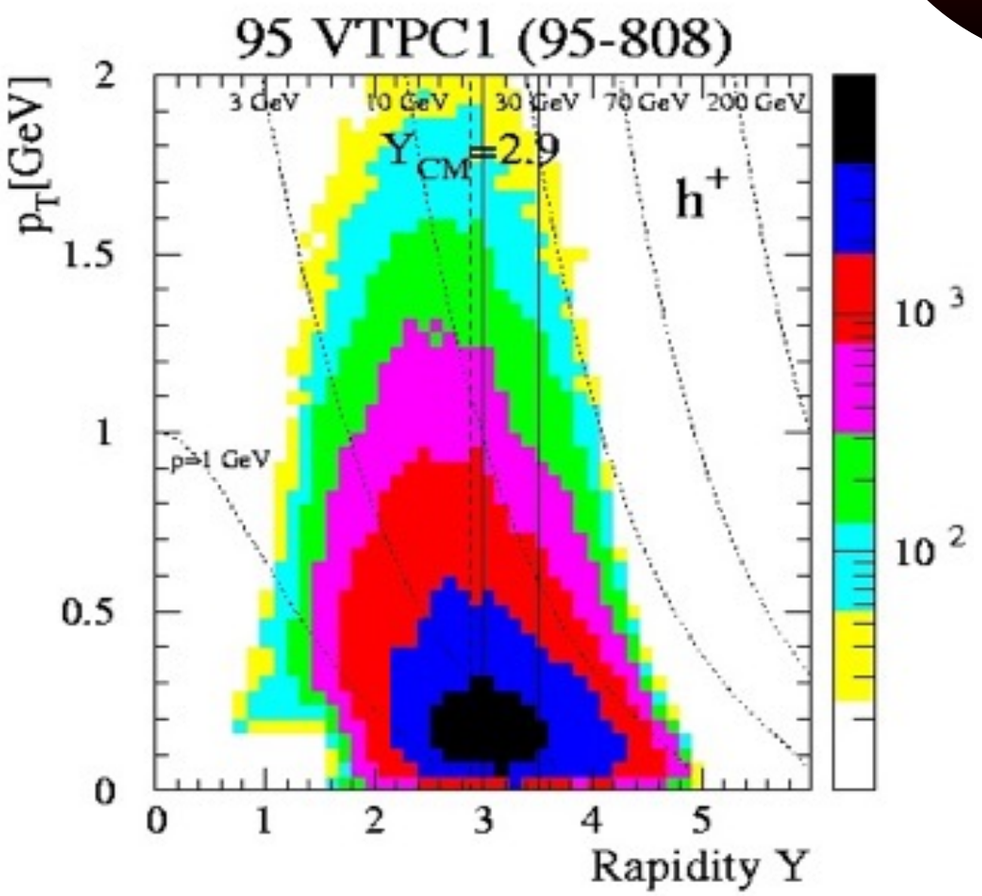

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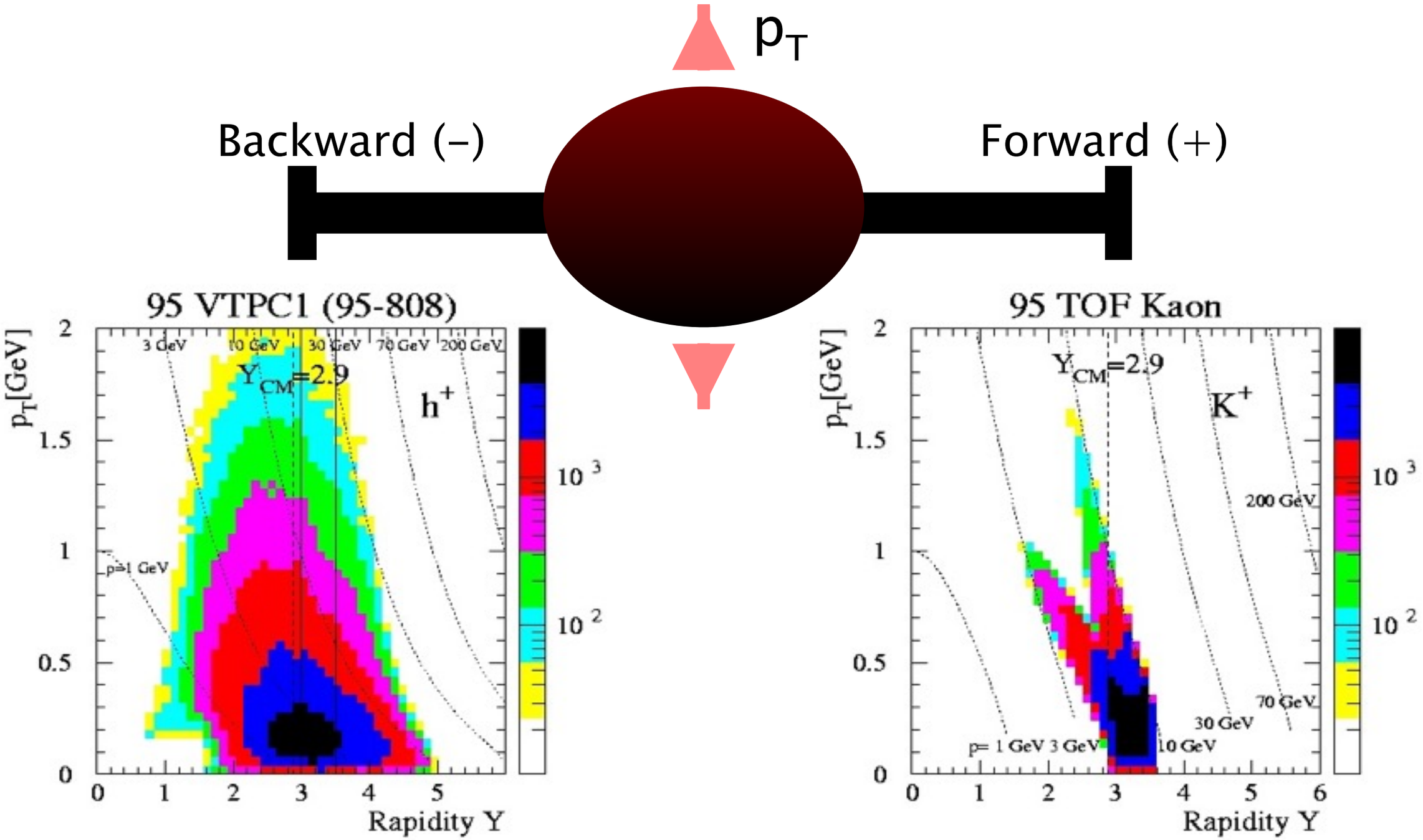

Resonance Reconstruction

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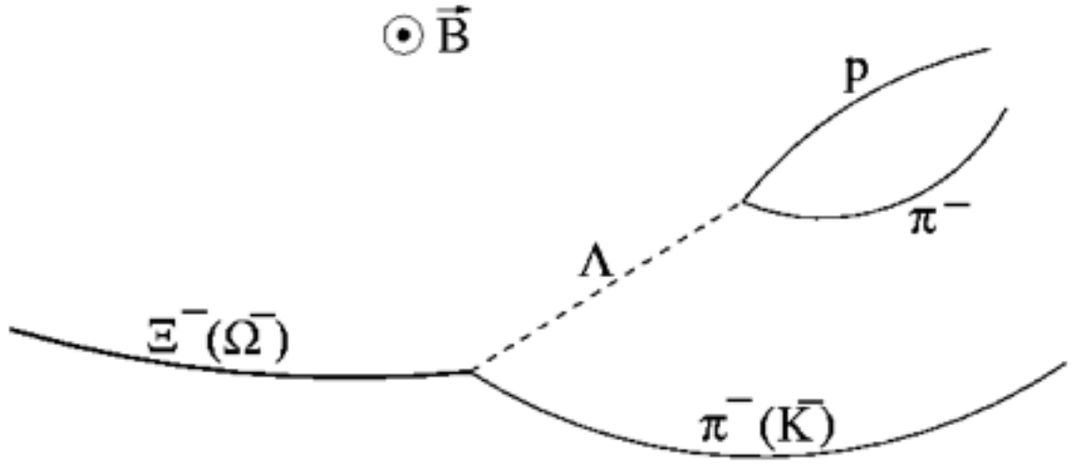
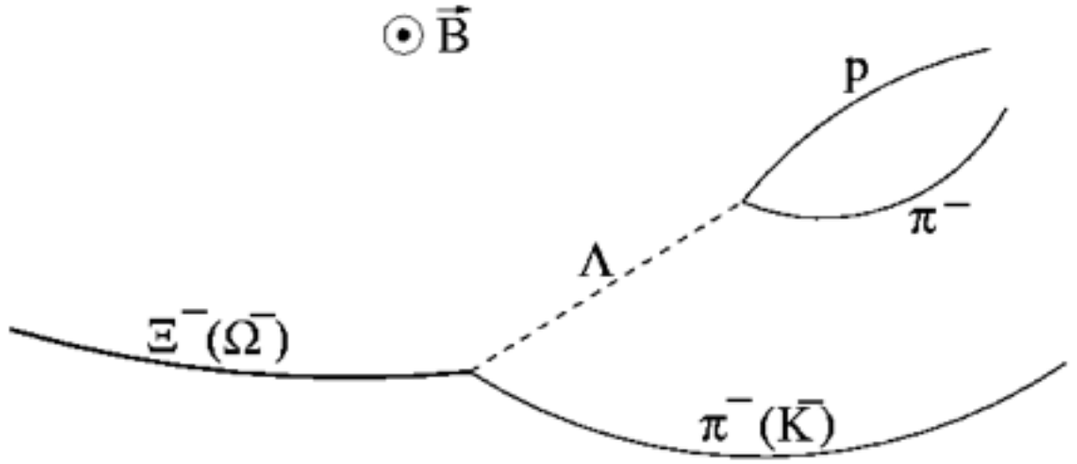


Resonance Reconstruction

$$m_{inv} = [(E_1+E_2)^2-(\overrightarrow{p_1}+\overrightarrow{p_2})^2]^{1/2}$$

- Identify secondary vertices
- Examples in Pb+Pb@158AGeV



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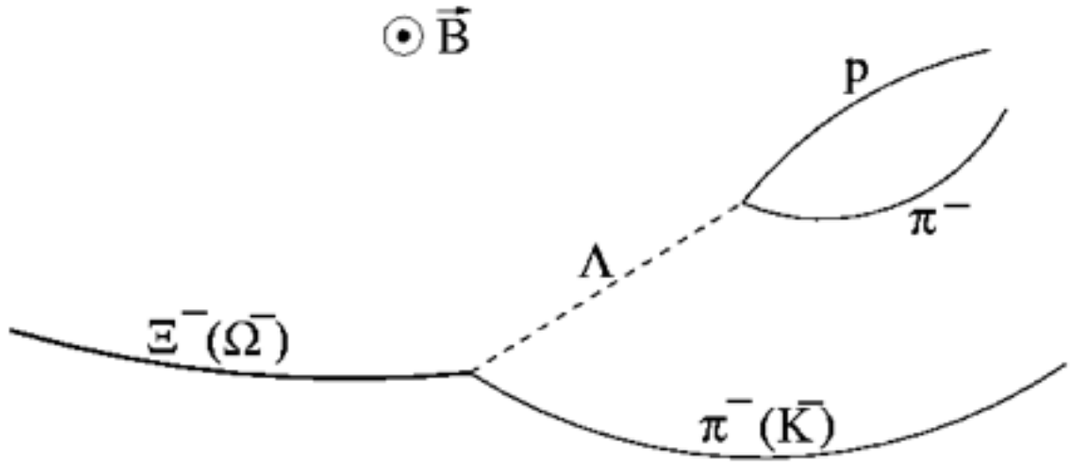

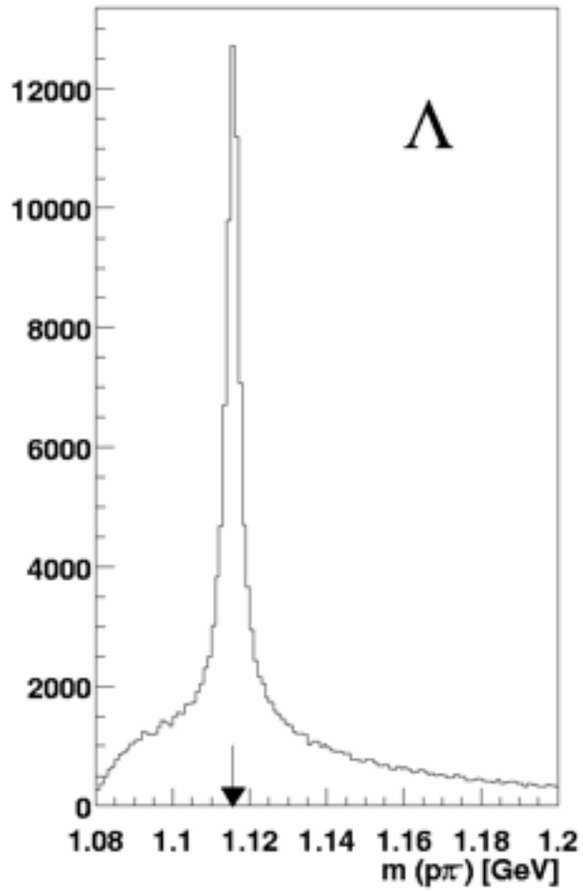

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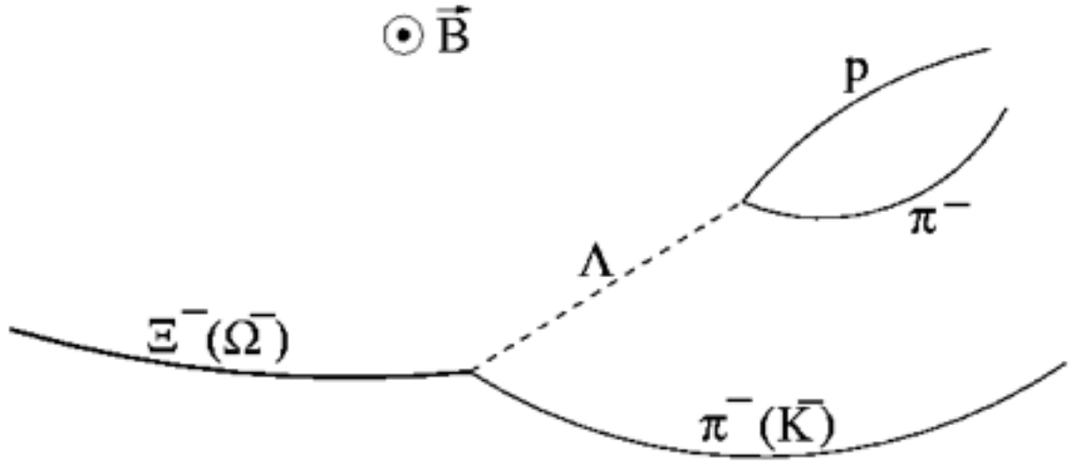

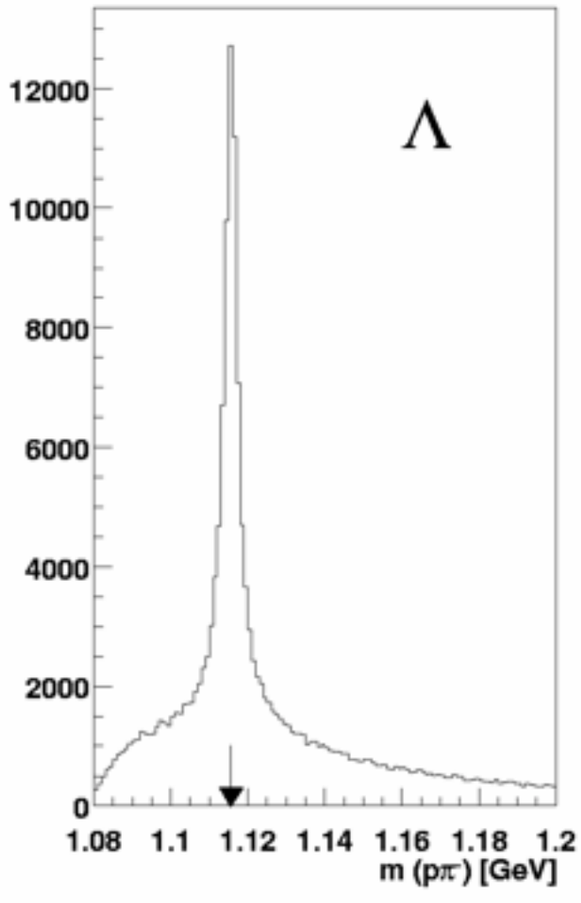

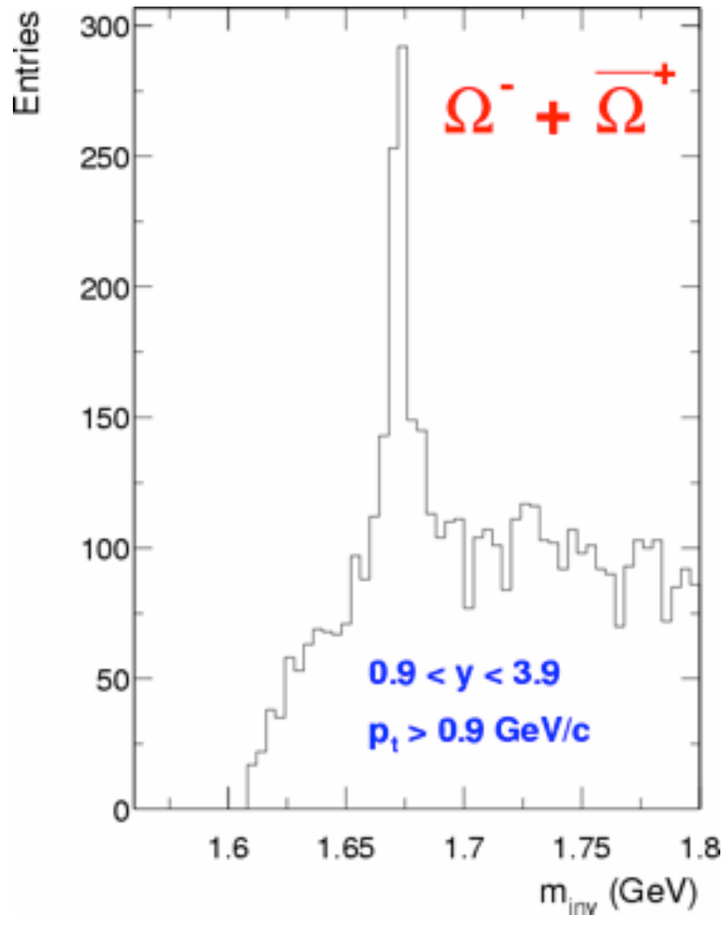

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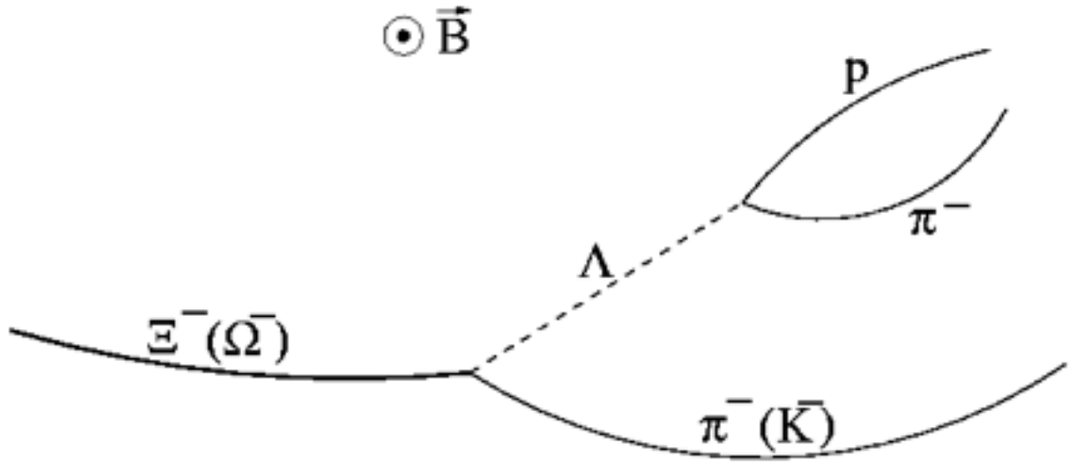
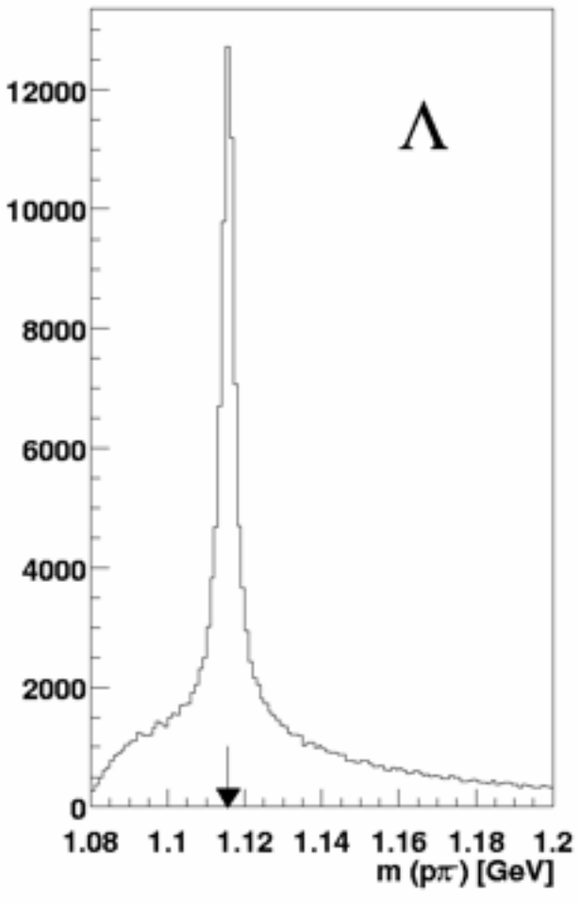
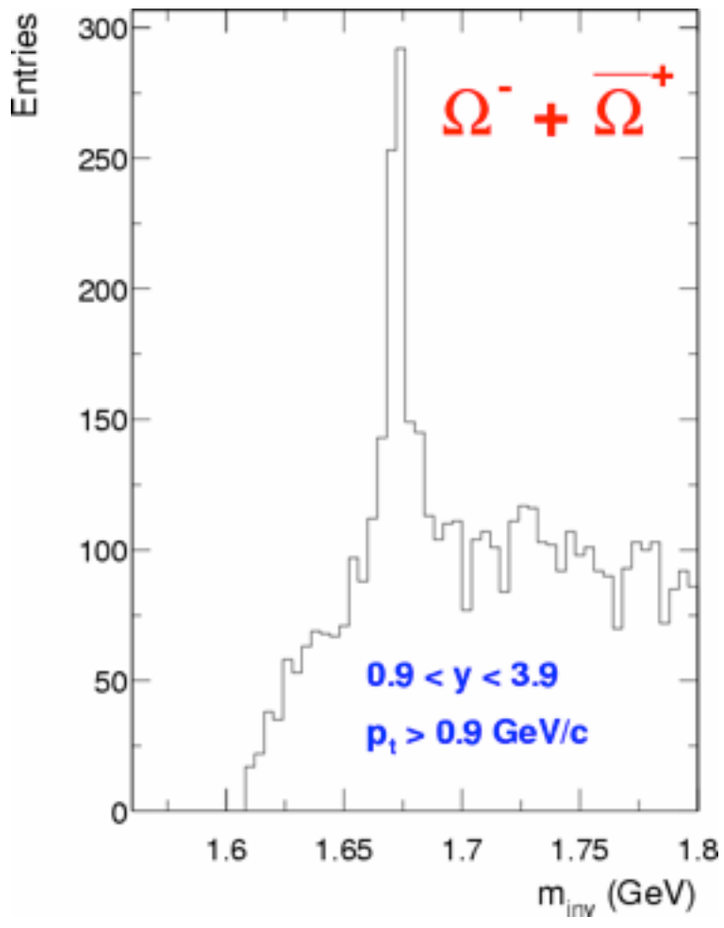
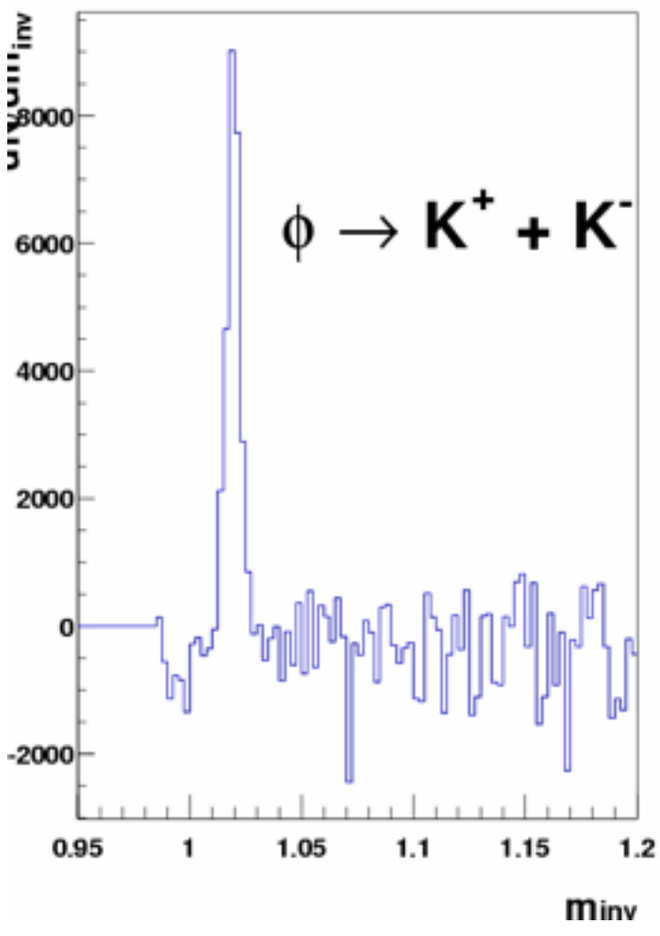
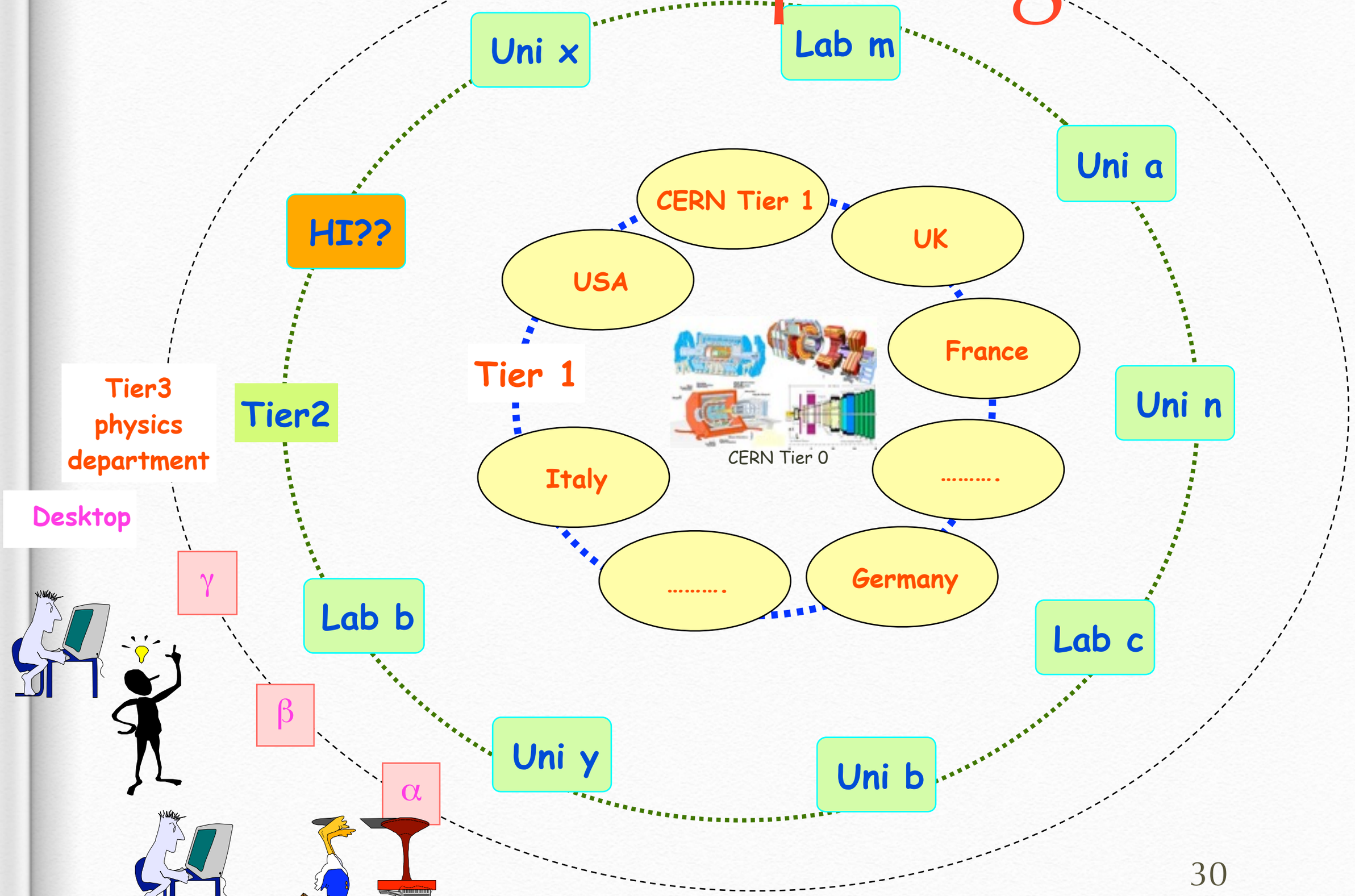




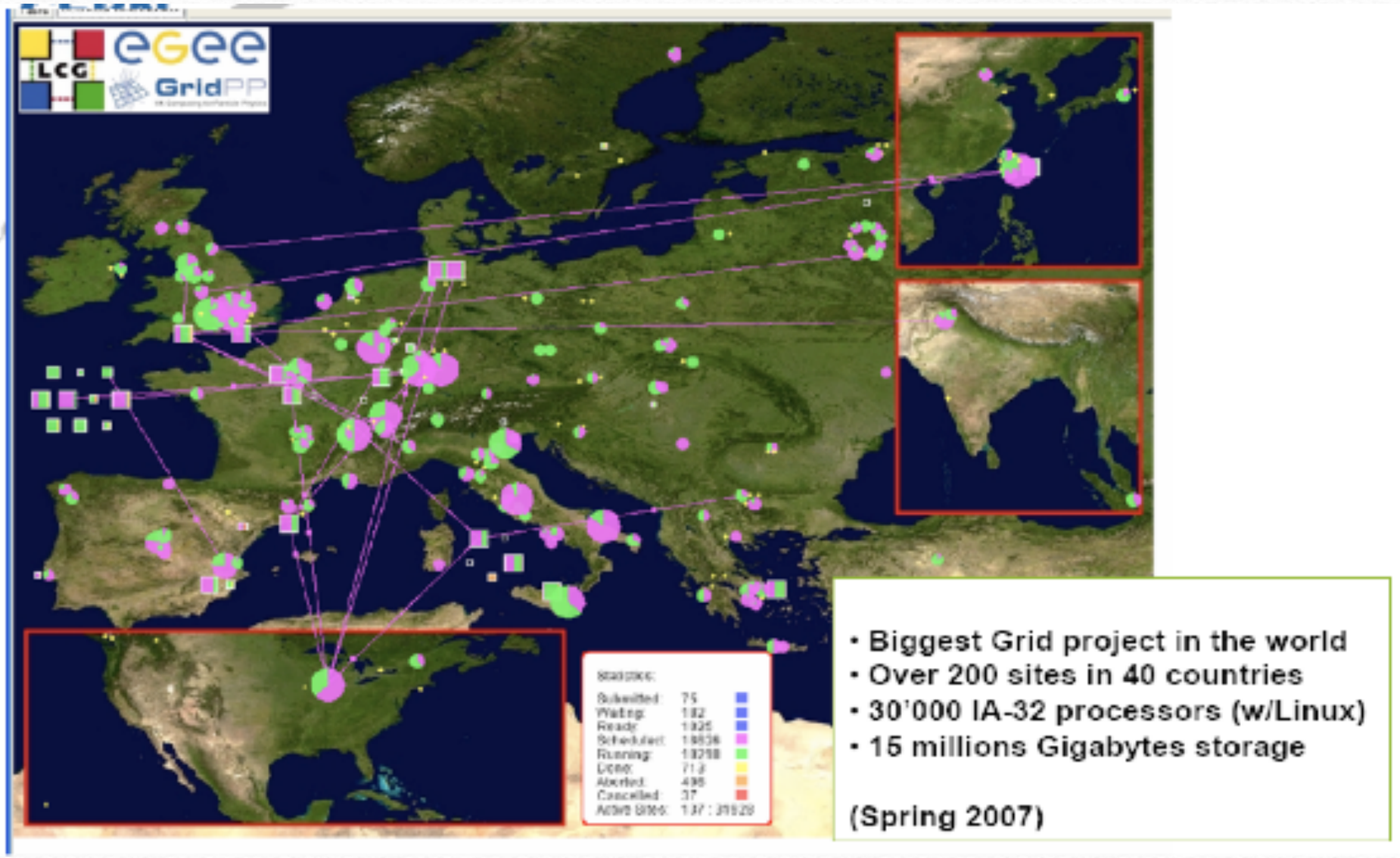




LHC Computing



LHC Computing Grid



- Introducing A really New Concept : GRID >> Cloud Computing
- Potential of Fundamental Science! >> Opening New Era!