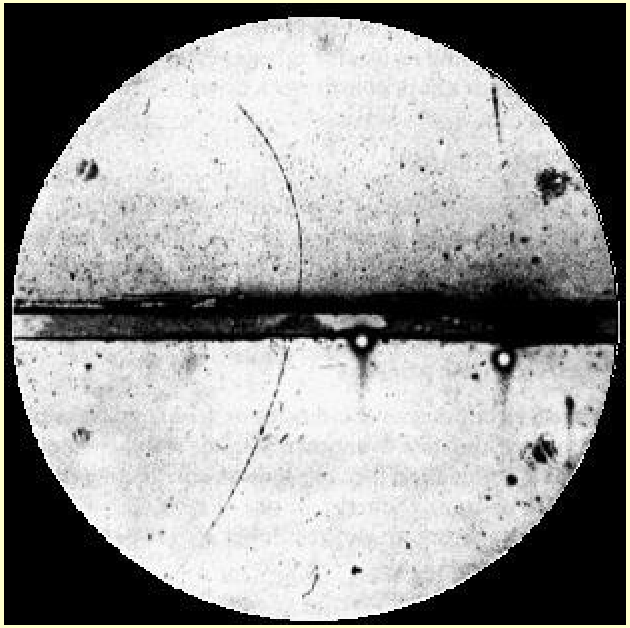
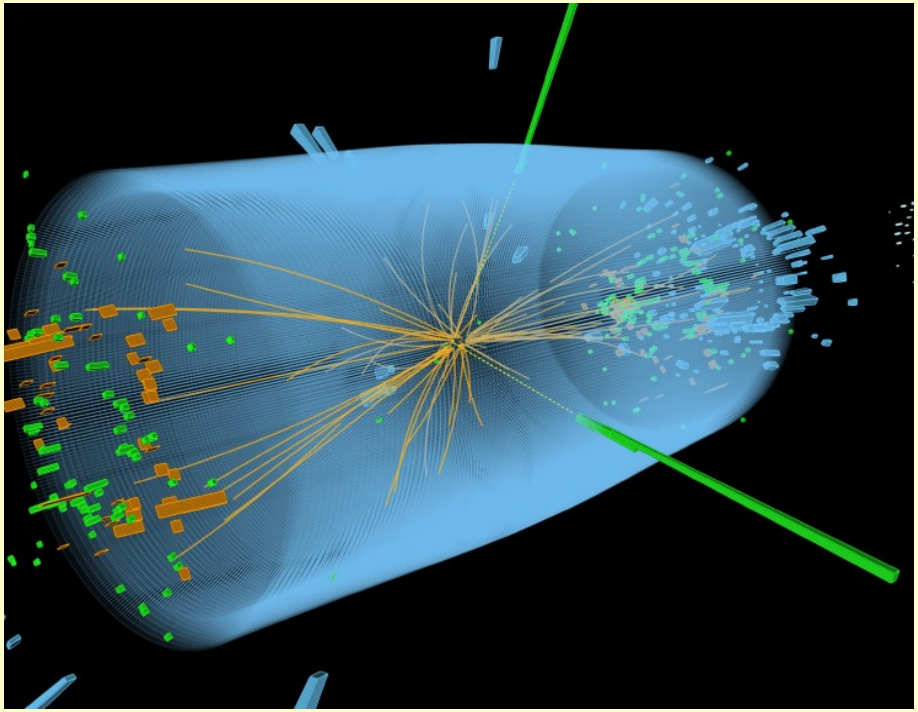
Моделирование в физике высоких энергий

Рогачевский О.В.
ОИЯИ & ПИЯФ

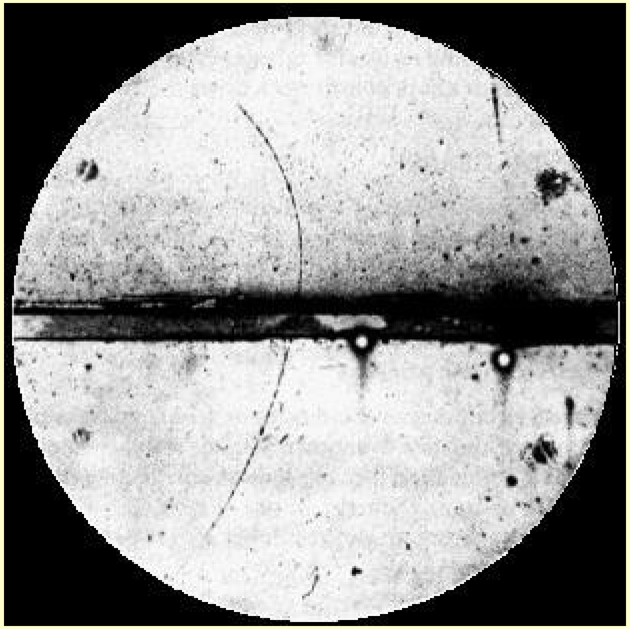
III школа-конференция
ОМУС





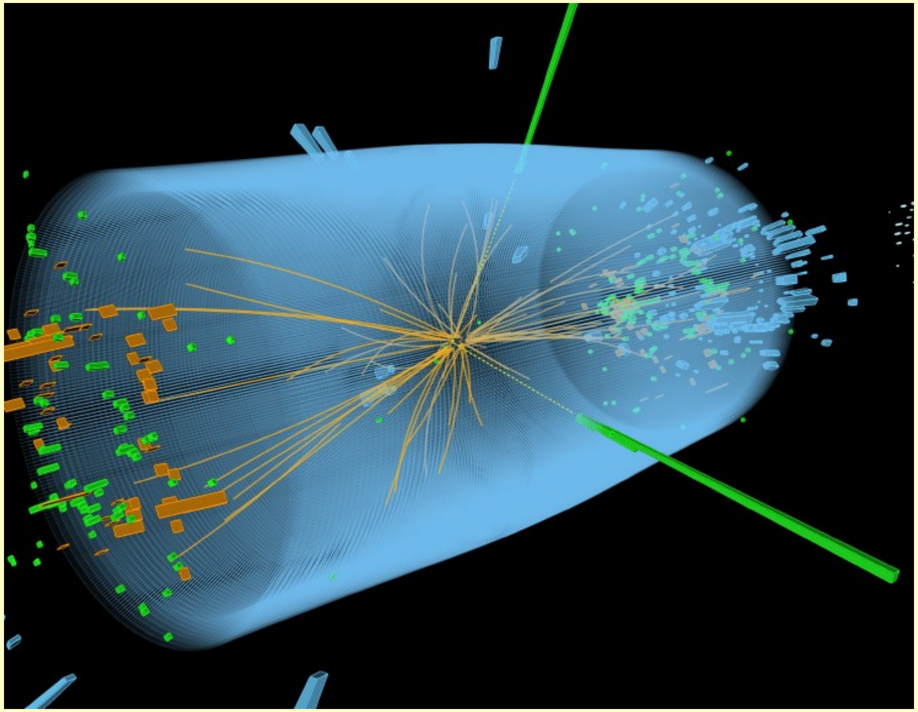
From reality to simulation

Positron discovery,
Carl Andersen 1933

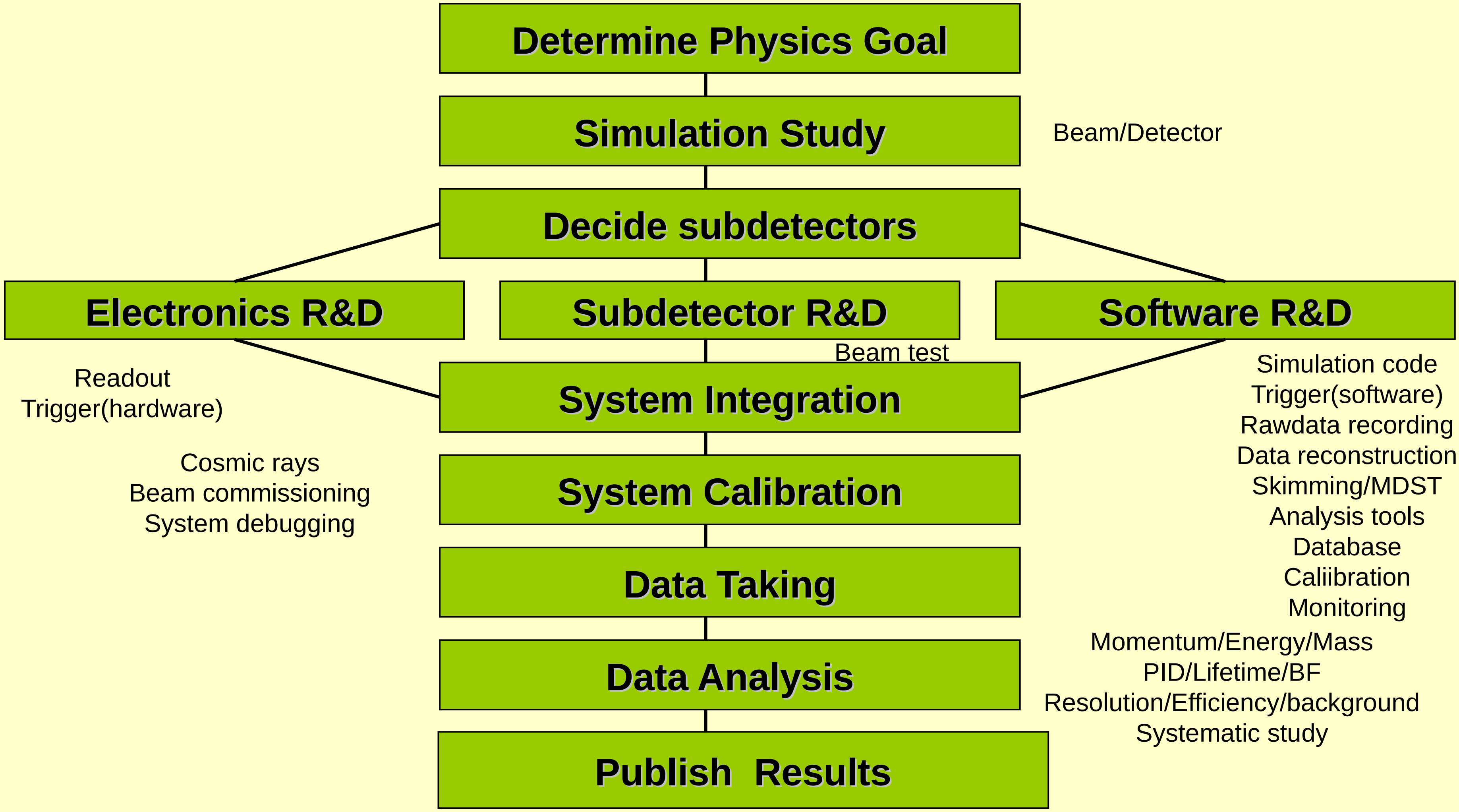


Magnetic field 15000 Gauss,
chamber diameter 15cm. A 63 MeV
positron passes through a 6mm lead plate,
leaving the plate with energy 23MeV.

Higgs boson discovery,
CMS 2012



Global Sketch of HEP Experiment



Outline

I. History of detectors
II. Physics of detectors
III. Tools
IV. Event generators
V. GEANT
VI. Event display
VII. ROOT
VIII.
IX. ...

History of

Instrumentation

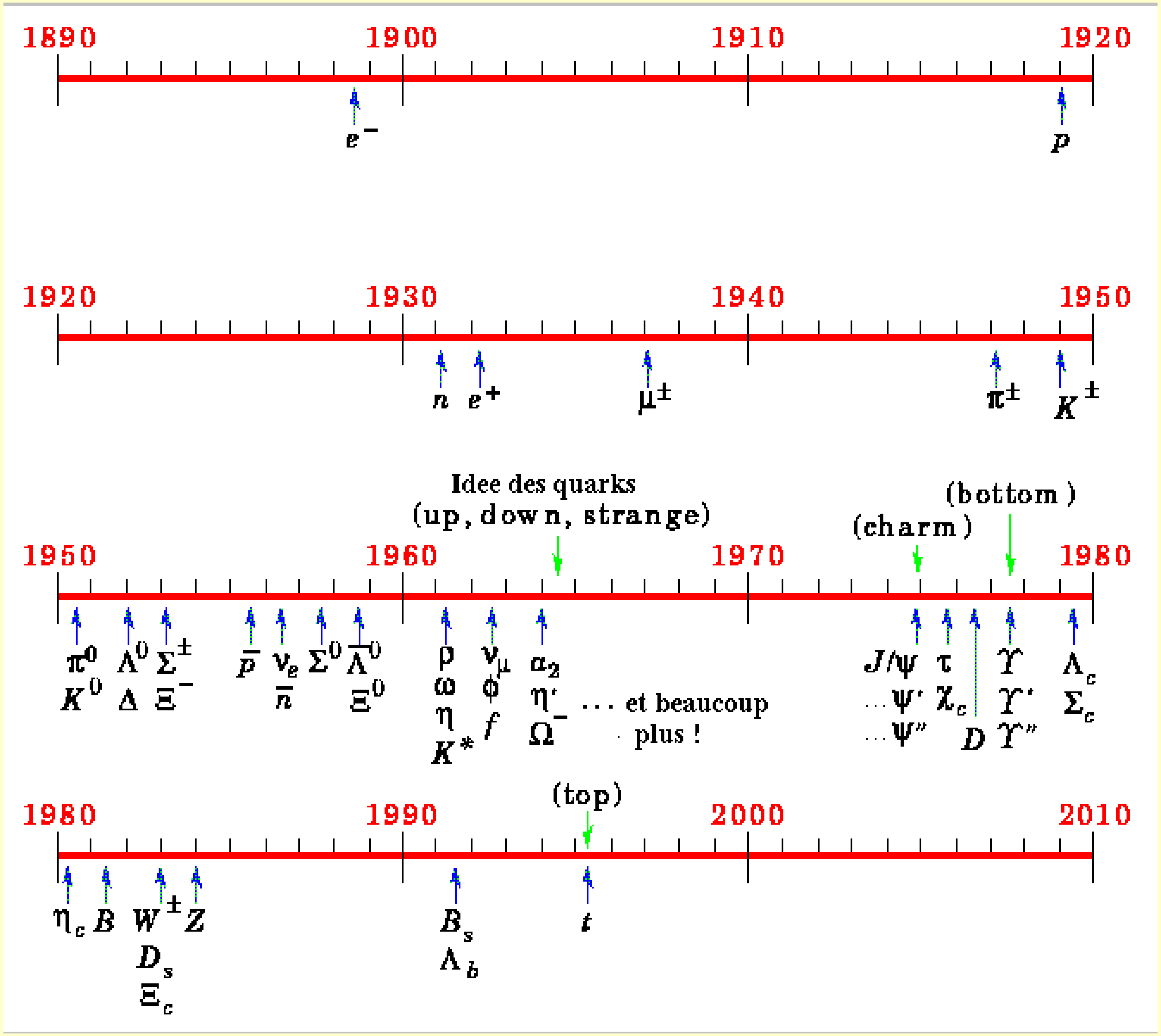
1906: Geiger Counter, H. Geiger, E. Rutherford
1910: Cloud Chamber, C.T.R. Wilson
1912: Tip Counter, H. Geiger
1927: C.T.R. Wilson, Cloud Chamber
1928: Geiger-Müller Counter, W. Müller
1929: Coincidence Method, W. Bothe
1930: Emulsion, M. Blau
1939: E. O. Lawrence, Cyclotron
1940-1950: Scintillator, Photomultiplier
1948: P.M.S. Blacket, Cloud Chamber
1952: Bubble Chamber, D. Glaser
1948: P.M.S. Blacket, Cloud Chamber
1960: Donald Glaser, Bubble Chamber
1962: Spark Chamber
1968: Luis Alvarez, Bubble Chamber
1968: Multi Wire Proportional Chamber, C. Charpak
1992: Georges Charpak, Multi Wire Proportional Chamber

Particle Physics

1895: X-rays, W.C. Röntgen
1896: Radioactivity, H. Becquerel
1899: Electron, J.J. Thomson
1911: Atomic Nucleus, E. Rutherford
1919: Atomic Transmutation, E. Rutherford
1920: Isotopes, E.W. Aston
1920-1930: Quantum Mechanics, Heisenberg, Schrödinger, Dirac
1932: Neutron, J. Chadwick
1932: Positron, C.D. Anderson
1937: Mesons, C.D. Anderson
1947: Muon, Pion, C. Powell
1947: Kaon, Rochester
1950: QED, Feynman, Schwinger, Tomonaga
1955: Antiproton, E. Segre
1956: Neutrino, Rheines


NOBEL PRIZES FOR INSTRUMENTATION
http://www.lhc-closer.es/php/index.php?i=1&s=9&p=2&e=0
1927: C.T.R. Wilson, Cloud Chamber
1939: E. O. Lawrence, Cyclotron
1948: P.M.S. Blacket, Cloud Chamber
1950: C. Powell, Photographic Method
1954: Walter Bothe, Coincidence method
1960: Donald Glaser, Bubble Chamber
1968: L. Alvarez, Hydrogen Bubble Chamber
1992: Georges Charpak, Multi Wire Proportional Chamber
7

Timeline


1890
1900
1910
1920
e⁻
p
1920
1930
1940
1950
n
e⁺
μ±
π±
K±
Idee des quarks
(up, down, strange)
(charm)
(bottom)
1950
1960
1970
1980
π⁰ K⁰
Λ⁰ Δ
Σ± Ξ⁻
p̄
νe n̄
Σ⁰
Λ̄⁰ Ξ⁰
ρ ω η K*
νμ φ f
a2 η' Ω⁻
... et beaucoup
plus !
J/ψ ...ψ' ...ψ''
τ χc
D
ϒ ϒ' ϒ''
Λc Σc
(top)
1980
1990
2000
2010
ηc
B
W± Ds Ξc
Z
Bs Λb
t

Particles in the mid 50ies

By 1959: 20 particles

e- : fluorescent screen
n : ionization chamber

7 Cloud Chamber:
e+
μ +, μ-
K0
Λ0
Ξ-
Σ-

6 Nuclear Emulsion:
π+,π -
anti-Λ0
Σ+
K+ ,K-

3 with Electronic techniques:
anti-n
anti-p
π0

2 Bubble Chamber :
Ξ0
Σ0

ОИЯИ ЛВЭ

АНТИСИГМА-МИНУС ГИПЕРОН

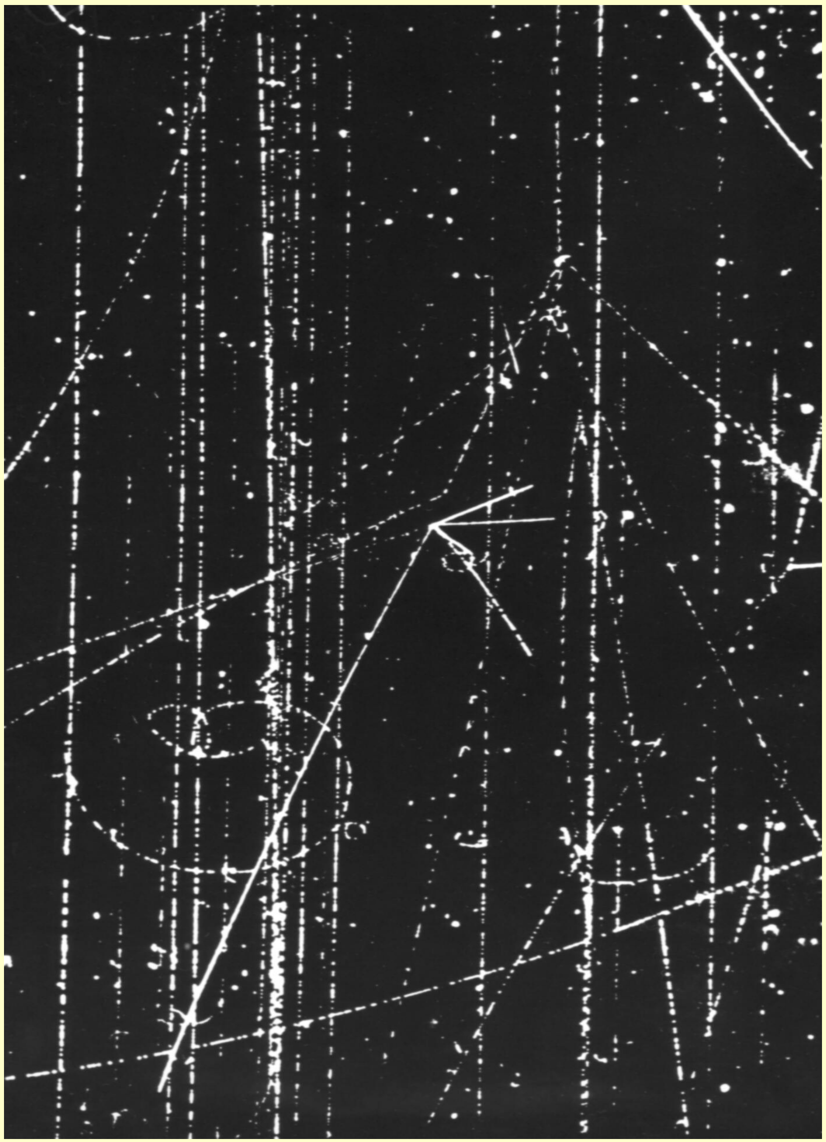
Коллектив ученых Объединенного института ядерных исследований (г. Дубна), в том числе ученые СССР: акад. В. И. Векслер, докт. физ.-мат. наук М. И. Соловьев, канд. физ.-мат. наук Н. М. Вирясов, канд. физ.-мат. наук Е. Н. Кладницкая, канд. физ.-мат. наук А. А. Кузнецов, А. В. Никитин; гр. ЧССР канд. физ.-мат. наук И. Врана, гр. СРР канд. физ.-мат. наук А. Михул, гр. КНДР канд физ.-мат. наук Ким Хи Ин, гр. ДРВ канд. физ.-мат. наук Нгуен Дин Ты и граждане КНР докт. физ.-мат. наук Ван Ган-чан, Ван Цу-цзен и Дин Да-цао обнаружили неизвестное ранее явление в мире элементарных частиц — образование и распад антисигма-минус гиперон.

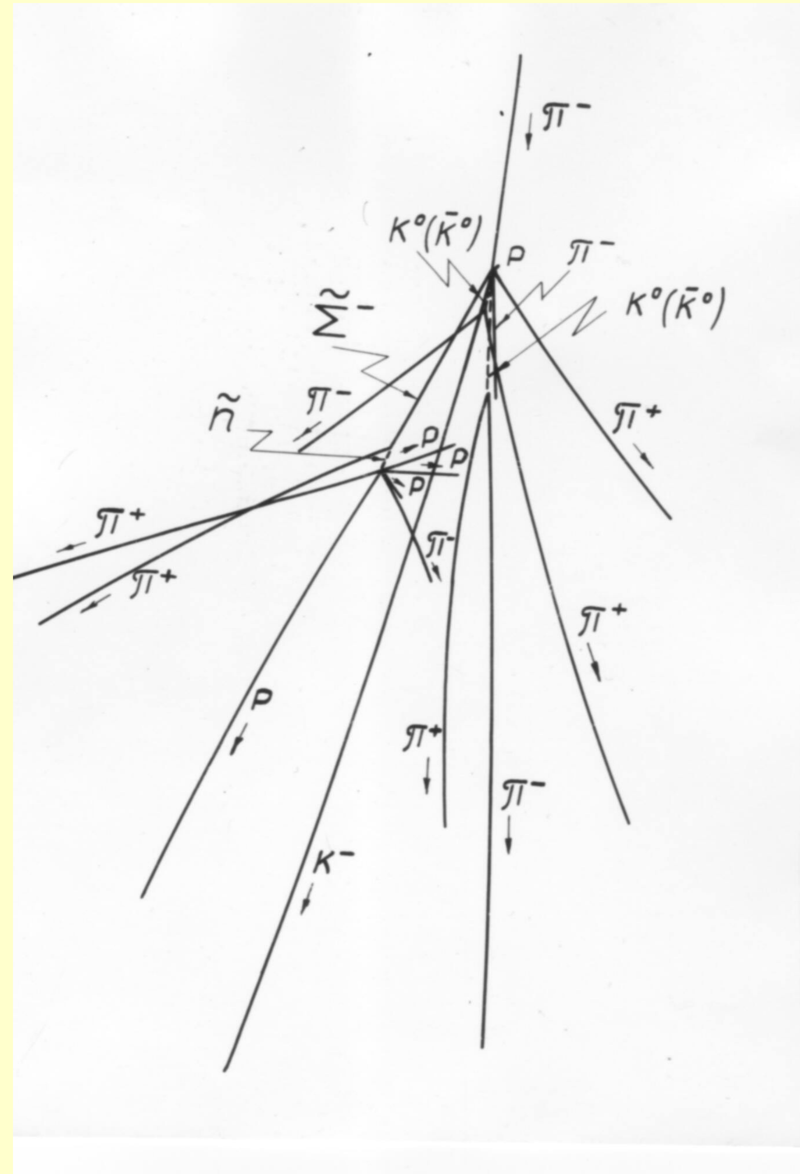
По заявке № ОТ-5036 от 6 марта 1966 г. на основании заключения Академии наук СССР Комитет по делам изобретений и открытий при Совете Министров СССР 26 марта 1968 г. принял решение о регистрации открытия за № 59 с приоритетом 24 марта 1960 г. (по дате поступления статьи о сущности открытия в редакцию «Журнала экспериментальной и теоретической физики», 1960, т. 38, стр. 1356).

$$\pi^- + C \rightarrow \bar{\Sigma}^- + K^0 + \bar{K}^0 + K^- + p^+ + \pi^+ + \pi^- + \text{nucleus recoil}$$

$$\bar{\Sigma}^- \rightarrow \bar{n}^0 + \pi^-$$

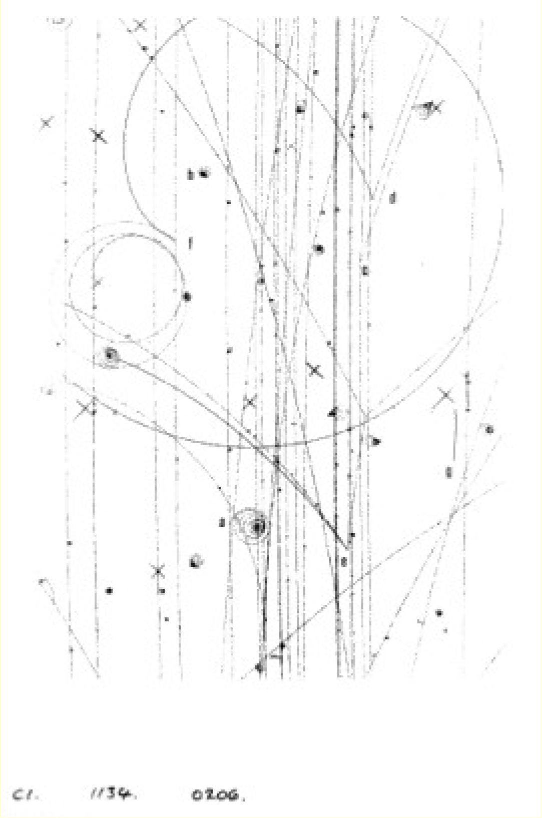
anti-Σ^-

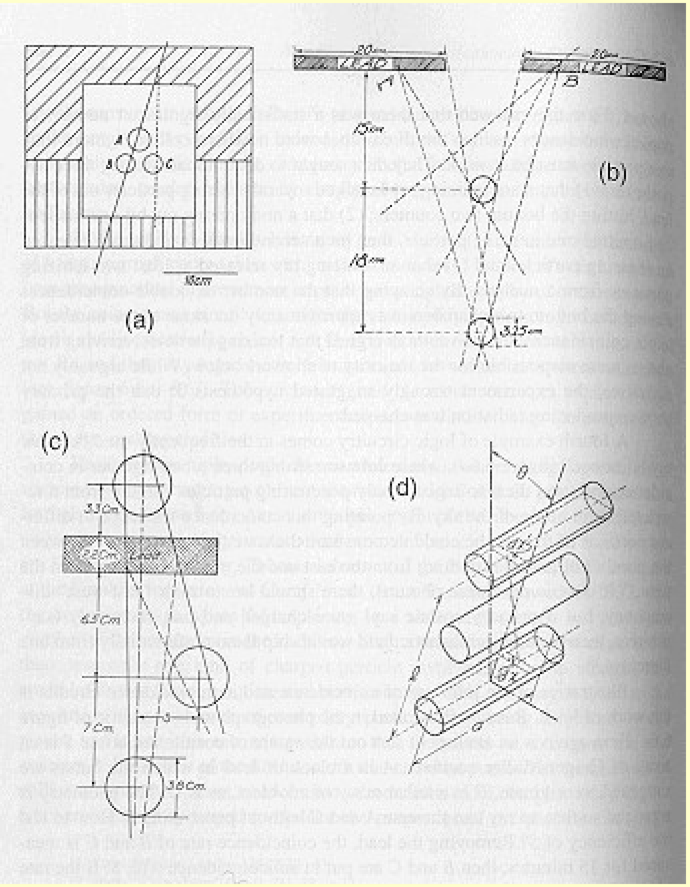




π^-
$K^0(\bar{K}^0)$
p
π^-
$K^0(\bar{K}^0)$
$\tilde{\Sigma}^-$
$\tilde{n}$
π^-
π^+
p
p
p
π^+
π^+
π^-
π^+
p
π^+
π^-
K^-

Image and Logic





Drawbacks

- ✔ The drawback of the bubble chamber is the low rate capability (a few tens/ second). e.g. LHC 10^9 collisions/s.
- ✔ The fact that it cannot be triggered selectively means that every interaction must be photographed.
- ✔ Analyzing the millions of images by ‘operators’ was a quite laborious task.

“ ... Robert Oppenheimer used to tell of the pioneer mysteries of building reliable Geiger counters that had low background noise.
Among his friends, he said, there were two schools of thought.
One school held firmly that the final step before one sealed off the Geiger tube was to peel a banana and wave the skin three times
sharply to the left.
The other school was equally confident that success would follow if one waved the banana peel twice to the left and then once smartly to the right ... “
(Alvarez, Adventures of a Physicist)

History of ‘Particle Detection’

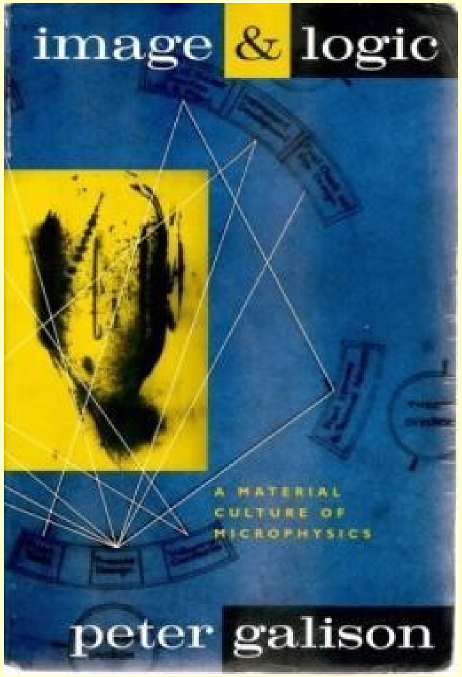
Peter Galison,
Image and Logic: A Material
Culture of Microphysics

Image Tradition:

Cloud Chamber

Emulsion

Bubble Chamber



Logic Tradition:

Scintillator

Geiger Counter

Tip Counter

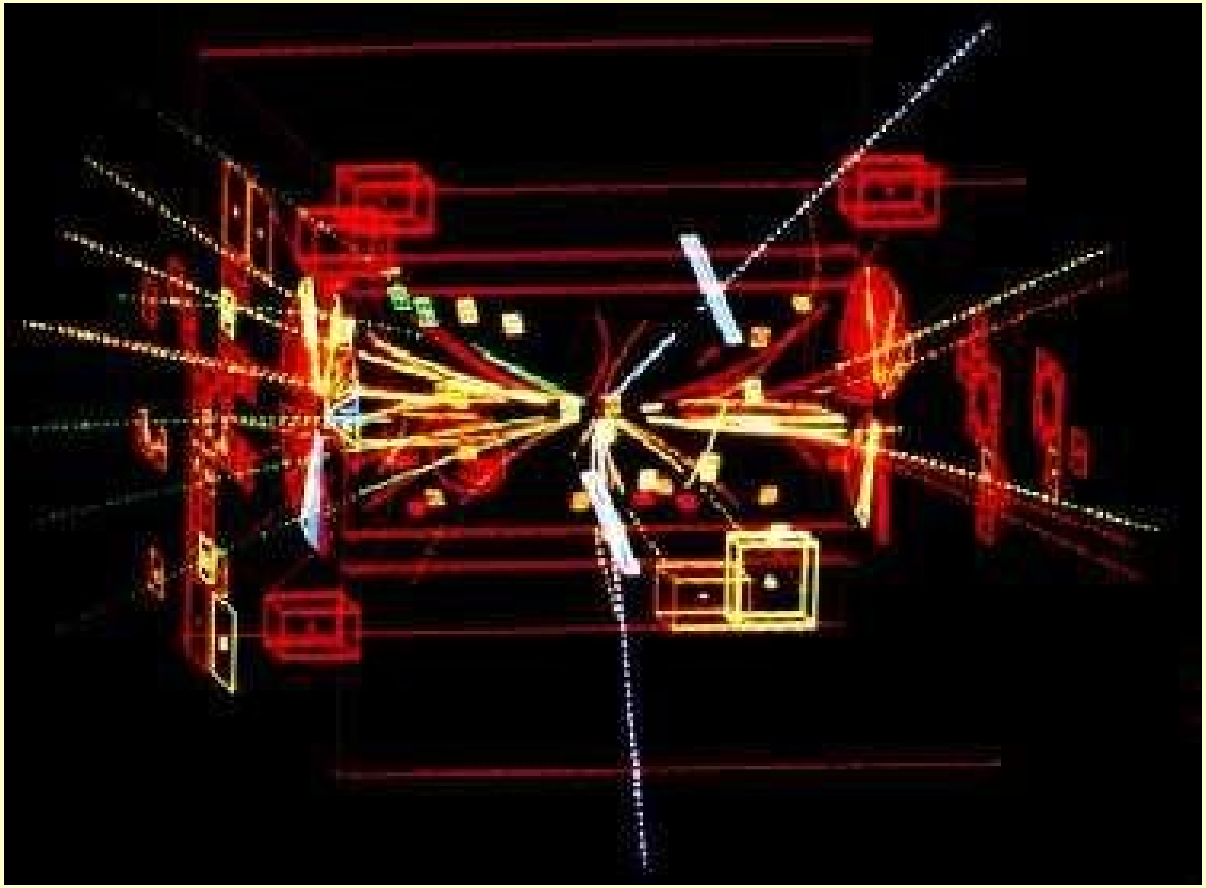
Spark Counter

Electronics Image:
wire Chamber,
TPC chamber,
silicon detector, ...

Electronics Image

Both traditions combine during the 1970ies

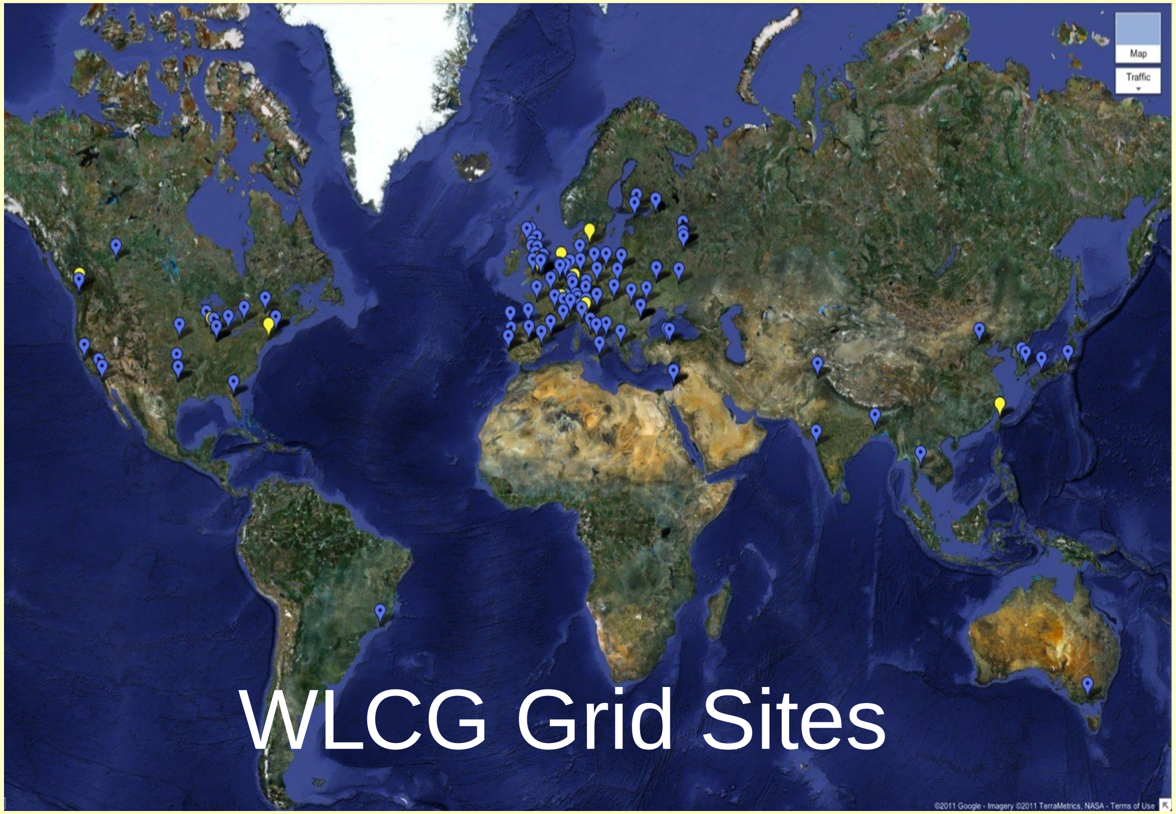
Z-Discovery
at UA1 CERN
in 1983



This computer reconstruction shows the tracks of charged particles from the proton-antiproton collision. The two white tracks reveal the Z's decay. They are the tracks of a high-energy electron and positron.

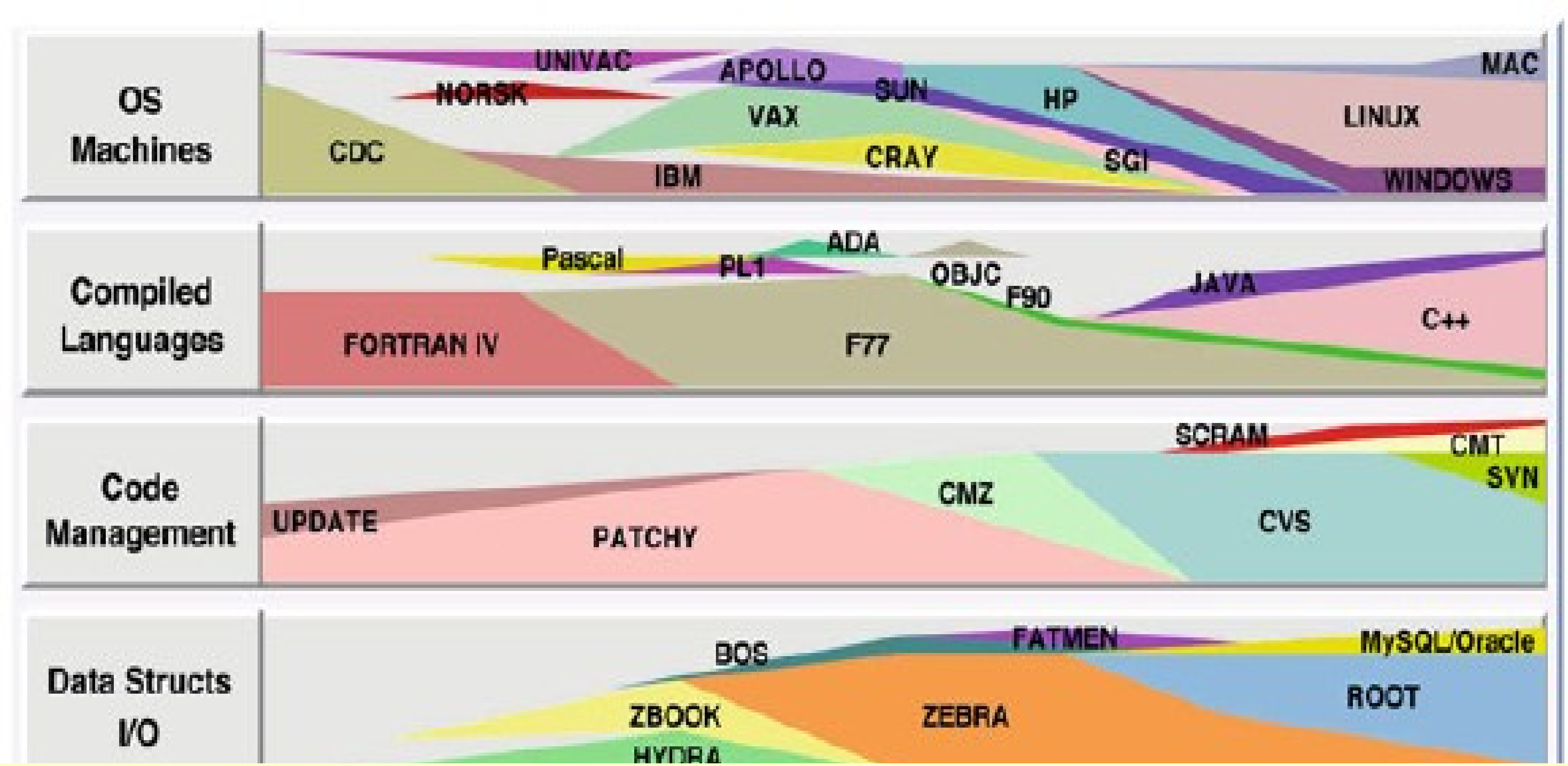
Computing power

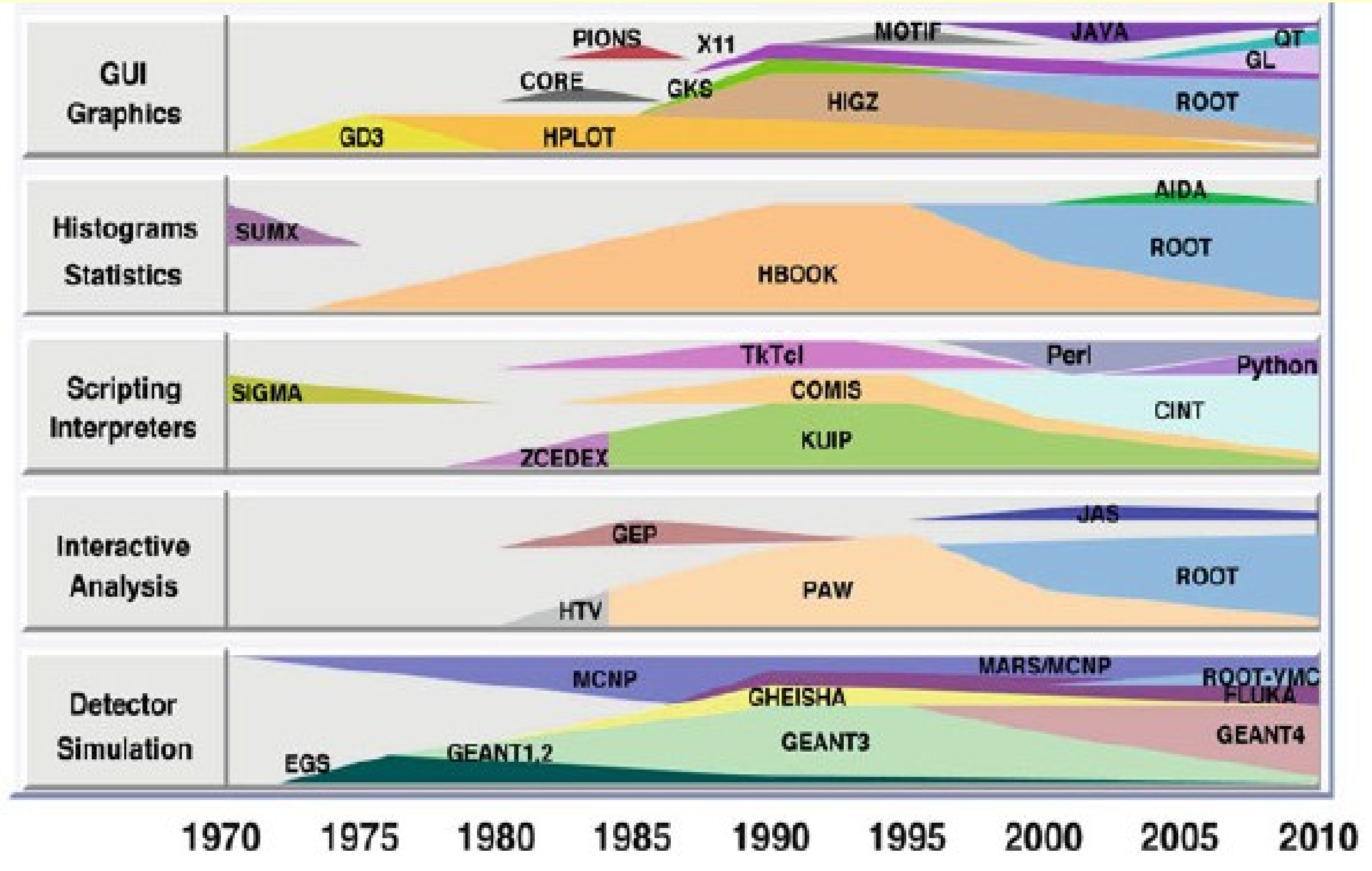
At the end of the fifties, the first computer at CERN was a man, Wim Klein. He was able to compete with the first CERN computer, a Ferranti Mercury in 1958, or even more elaborate machines in the early sixties.



- Tier 0
- Tier 1
- Tier 2

- Today >140 sites
- >250k CPU cores
- >150 PB disk


OS
Machines
UNIVAC
NORSK
APOLLO
SUN
HP
MAC
LINUX
VAX
CDC
IBM
CRAY
SGI
WINDOWS
Compiled
Languages
Pascal
PL1
ADA
OBJC
F90
JAVA
C++
FORTRAN IV
F77
Code
Management
SCRAM
CMT
SVN
UPDATE
PATCHY
CMZ
CVS
Data Structs
I/O
BOS
FATMEN
MySQL/Oracle
ZBOOK
ZEBRA
ROOT



GUI Graphics
PIONS
X11
MOTIF
JAVA
QT
GL
CORE
GKS
HIGZ
ROOT
GD3
HPLOT
Histograms Statistics
AIDA
SUMX
ROOT
HBOOK
Scripting Interpreters
TkTcl
Perl
Python
SIGMA
COMIS
CINT
KUIP
ZCEDEX
Interactive Analysis
JAS
GEP
ROOT
PAW
HTV
Detector Simulation
MCNP
MARS/MCNP
ROOT-VMC
FLUKA
GHEISHA
GEANT4
GEANT3
EGS
GEANT1,2
1970
1975
1980
1985
1990
1995
2000
2005
2010

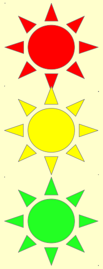
MONTE CARLO GENERATORS

Monte Carlo simulation

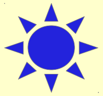
- What is Monte Carlo
  - throwing random numbers
    - to calculate integrals
    - to pick among possible choices
- Why Monte Carlo
  - because Einstein was wrong: God does throw dice! Quantum mechanics: amplitudes => probabilities
    - Anything that possibly can happen, will! (but more or less often)
  - Want to generate events in as much detail as Mother Nature
    - get average and fluctuations right
    - make random choices,∼as in nature

MC generators

- PYTHIA   pp   LUND
- FRITIOF
- HIJING



- UrQMD
- PHSD
- LAQGSM
- FastMC
- SHIELD



- ...

Other codes

General

Fluka (FLUktuierende KAskade)
Geant3,4
MARS
MCNP / MCNPX

Dedicated to electromagnetic physics

ETRAN
EGS4 (Electron Gamma Shower)
EGS5
EGSnrc
Penelope

Detector simulation

- Geometry of the system
- Materials used
- Particles of interest
- Generation of test events of particles
- Interactions of particles with matter and EM fields
- Response to detectors
- Records of energies and tracks
- Visualization of the detector system and tracks
- Analysis of the full simulation at whatever detail you like

GEANT
GEometry ANd Tracking
(Generation of Events ANd Tracks)

History

the first versions of the GEANT simulation package, GEANT 1 and
GEANT 2, were developed for NA4 1976.

SPS

First versions of the GEANT 3 detector simulation programme were developed for OPAL detector 1980

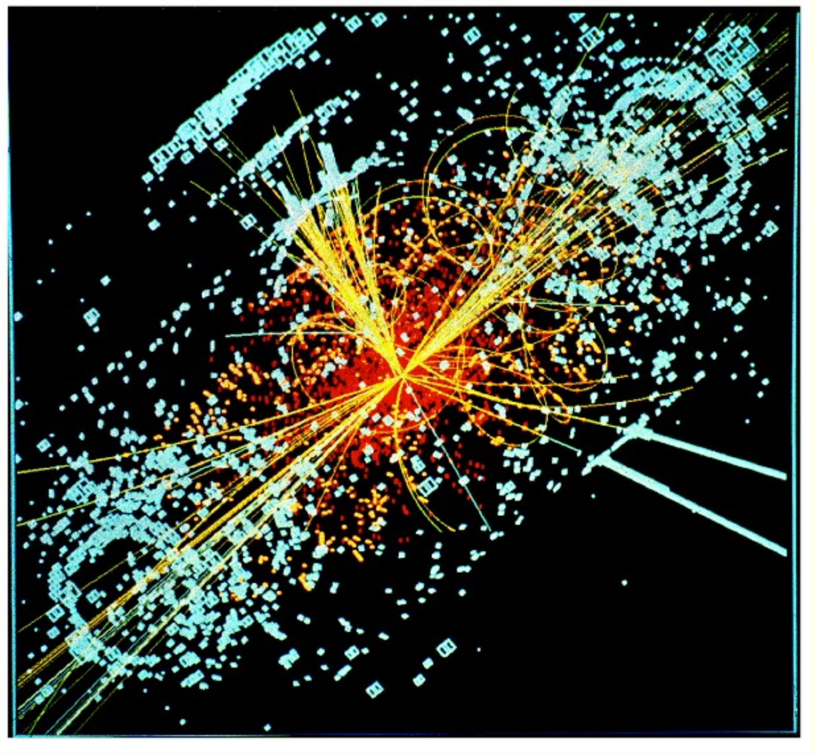
LEP

In 1994 several Research and Development (RD) projects were launched at CERN, in particular the RD44 project to implement in C++ a new version of GEANT known since as GEANT 4

LHC

What is Geant4?

- A software (C++) toolkit for the Monte Carlo simulation of the passage of particles through matter
  - ‘propagates’ particles through geometrical structures of materials, including magnetic field
  - simulates processes the particles undergo
    - creates secondary particles
    - decays particles
  - calculates the deposited energy along the trajectories and allows to store the information for further processing (‘hits’)

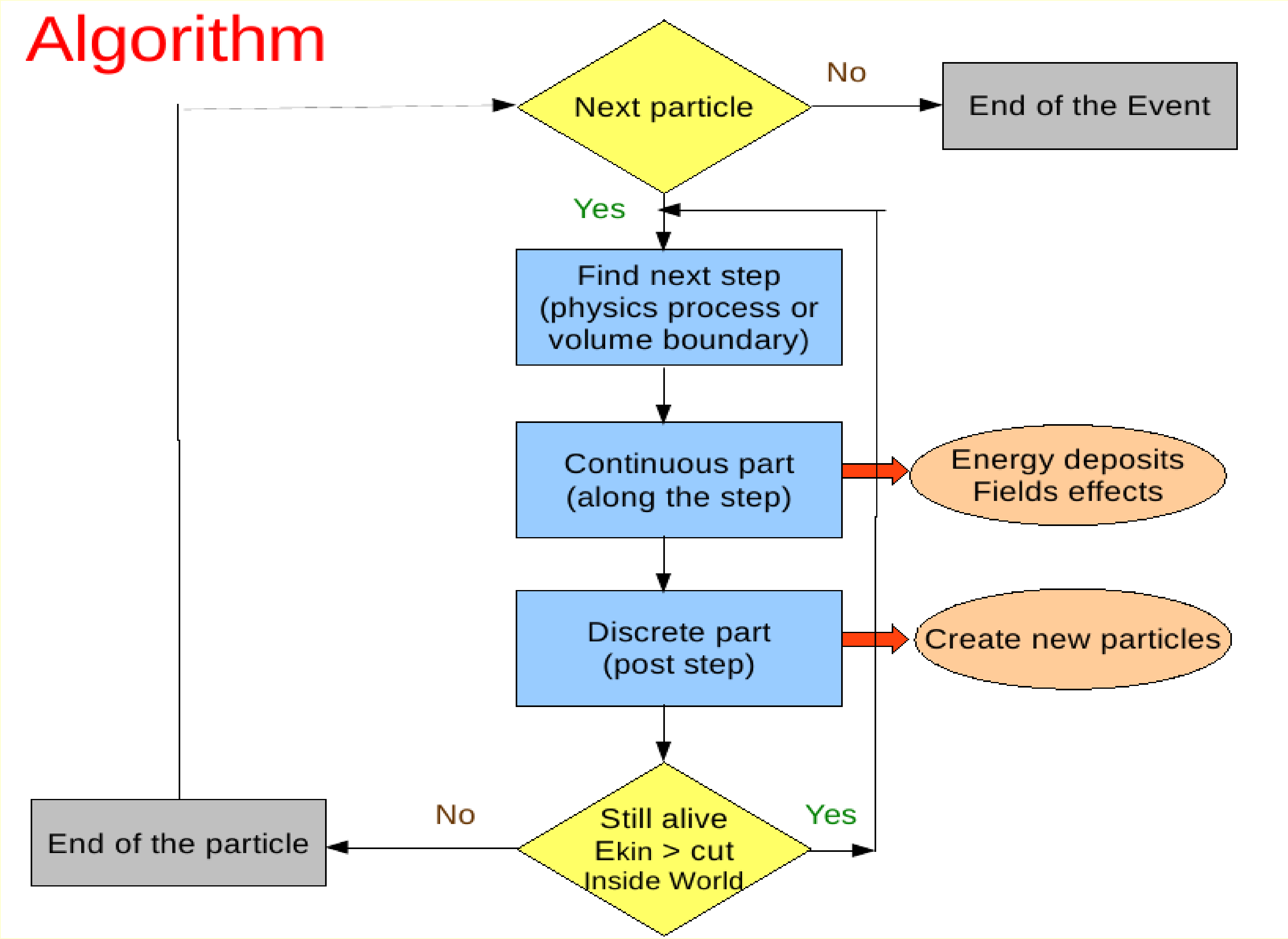


Simulated Higgs event in CMS

Why do we need it?

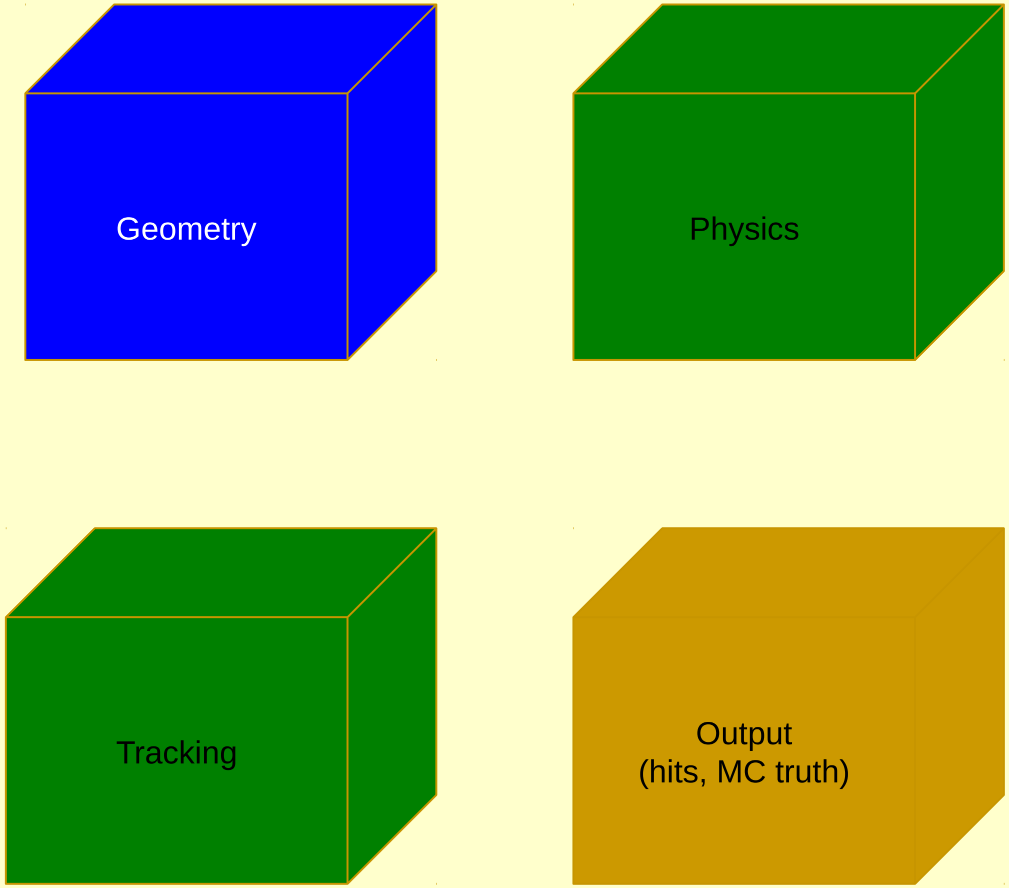
- to design and to construct the devices
  - to get what we are looking for
    - to be able to see the relevant ‘events’
  - not to get what we do not want
    - radiation damage, etc
- to operate the devices
  - to adjust and to tune the aparatus
    - medical physics: dose calculation, etc
- to understand the experimental results
  - to compare to the existing theories and models
  - to make discoveries

How it works



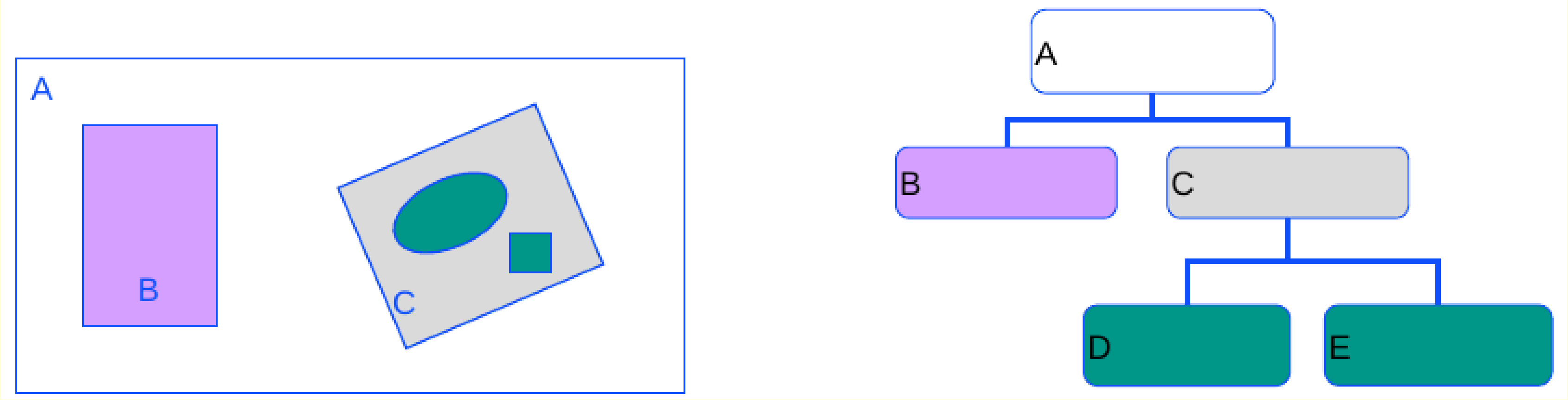
Algorithm
Next particle
No
End of the Event
Yes
Find next step
(physics process or
volume boundary)
Continuous part
(along the step)
Energy deposits
Fields effects
Discrete part
(post step)
Create new particles
End of the particle
No
Still alive
Ekin > cut
Inside World
Yes

Geant components

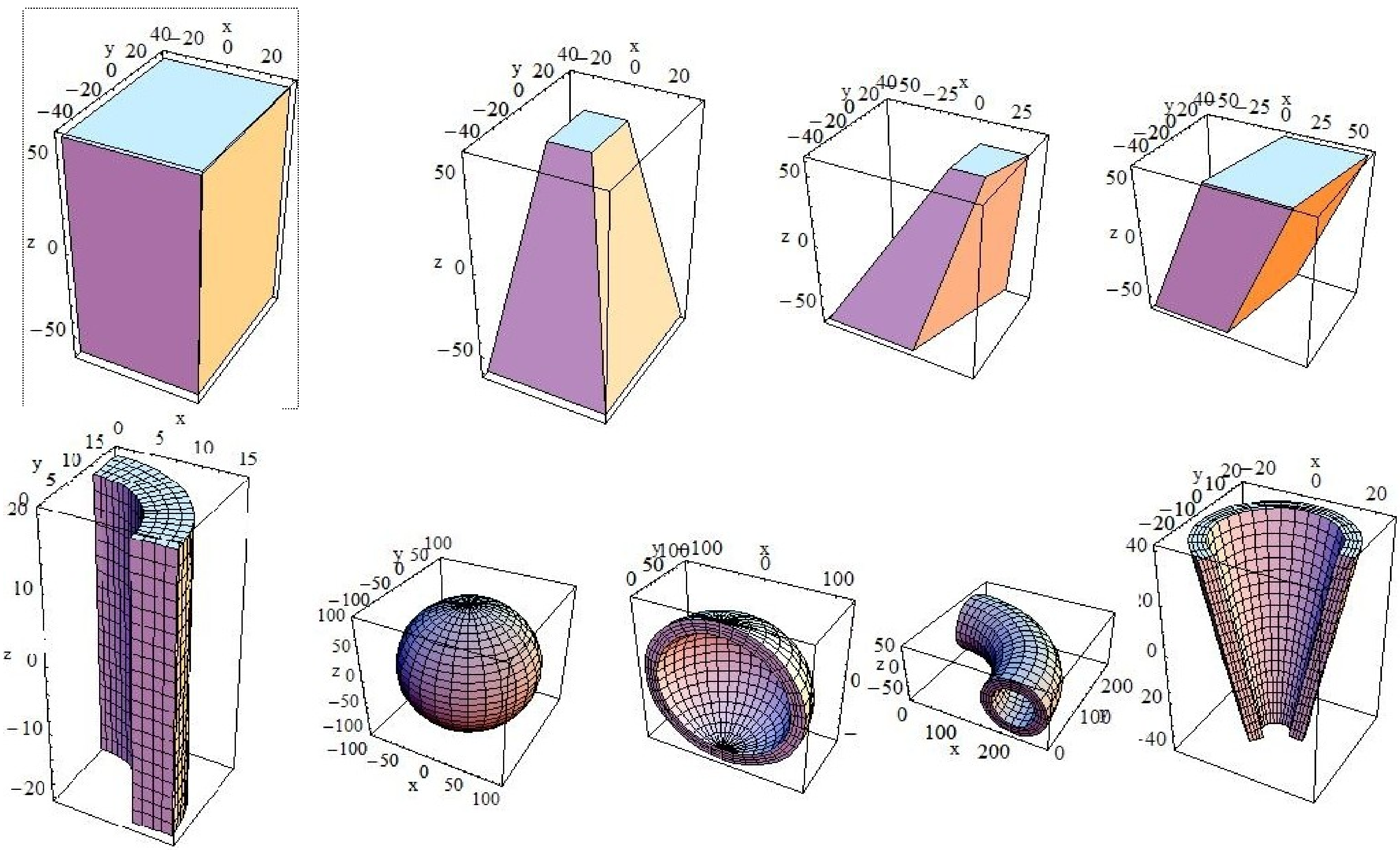


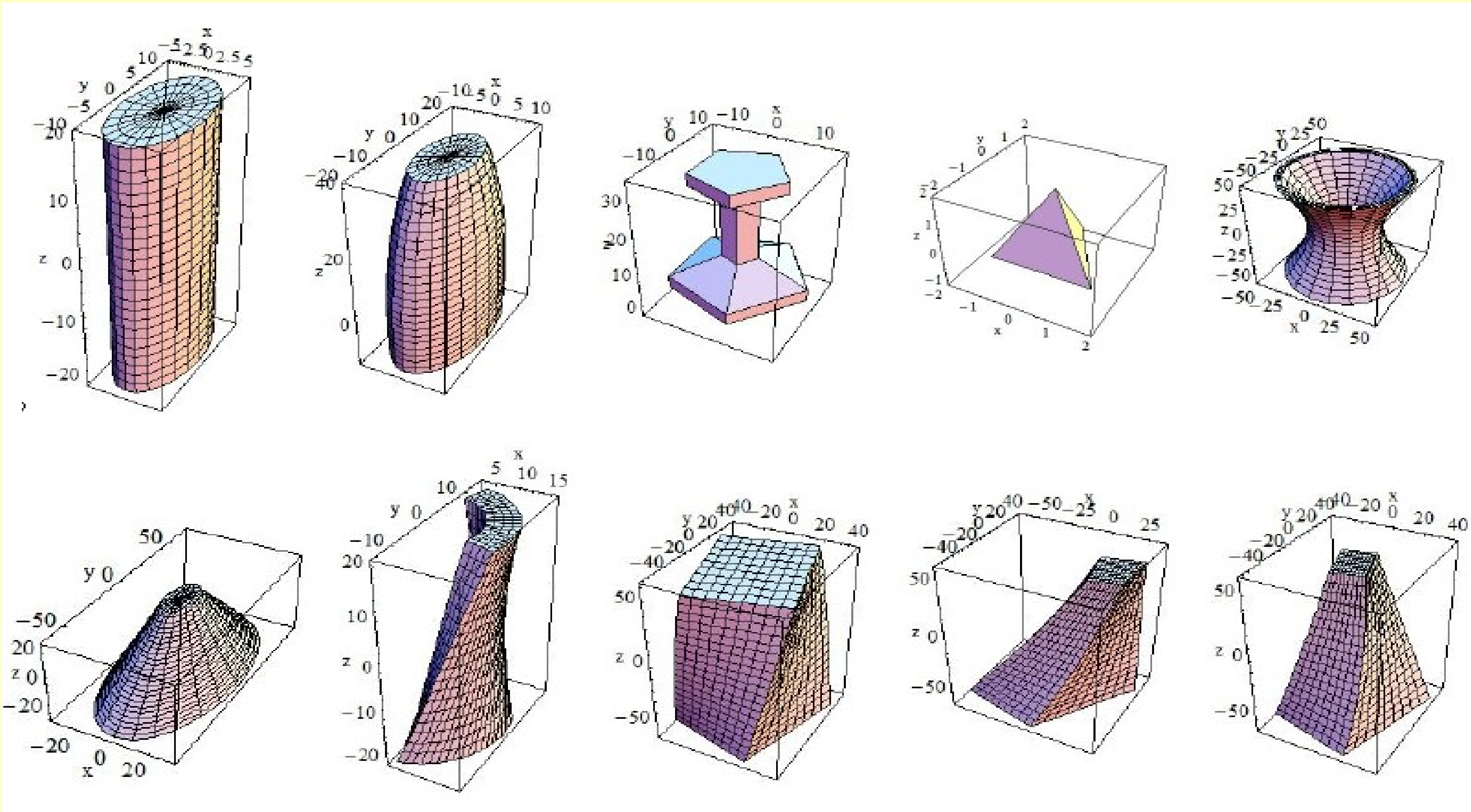
Geometry

- The way to describe the geometry varies widely between
- the different simulation engines
- ● In Geant4, you need to write some C++ code
- – Geometry objects are instances of classes
- – Geometry parameters (e.g. dimensions) are arguments of the constructors
- The geometry can be "flat" or "hierarchical"
- ● In Geant4, it is hierarchical: a volume is placed in its
- mother volume; there are mother-daughter relationships
- A material should be assigned to each volume

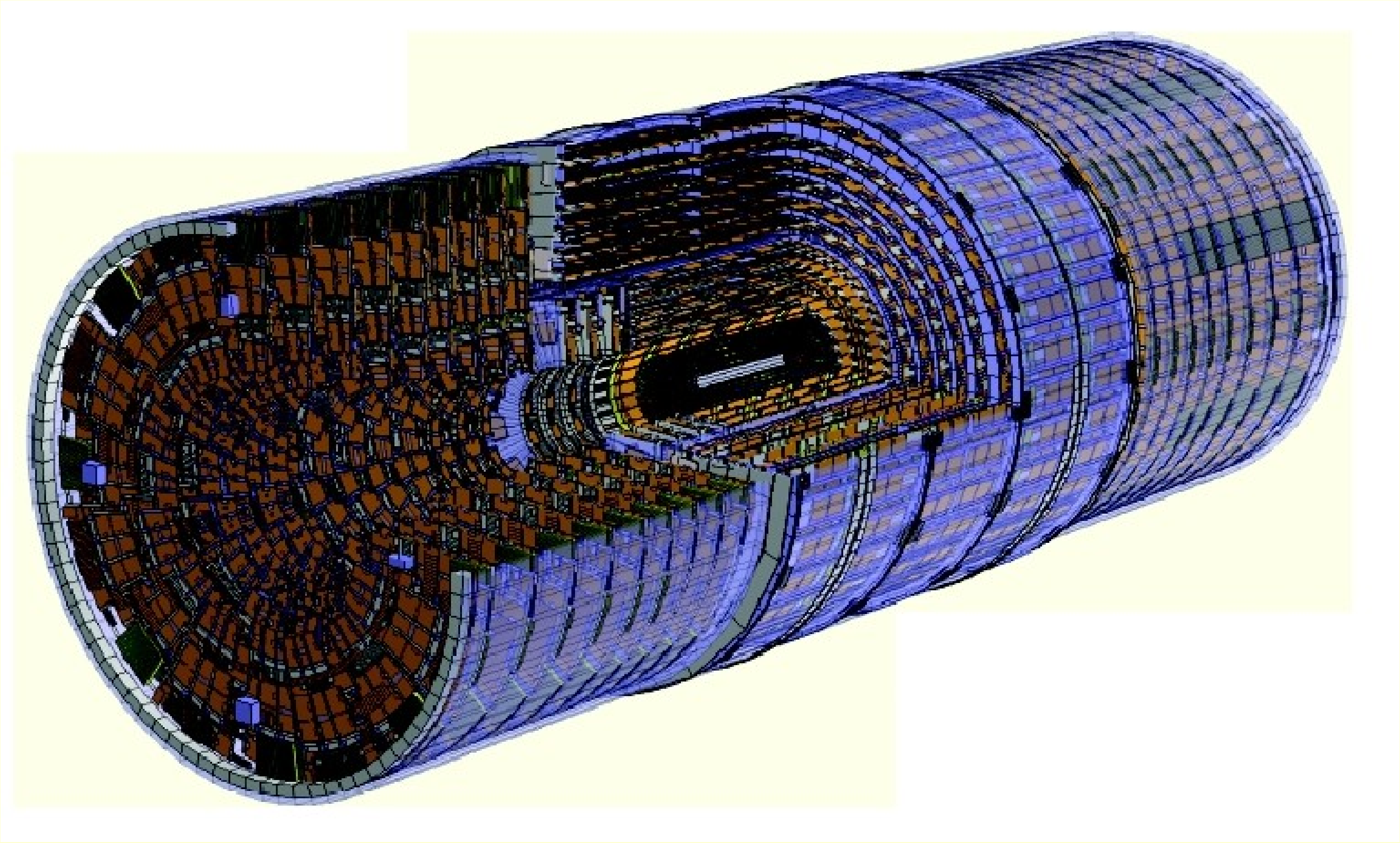


CGS(constracted geometry)SOLIDS

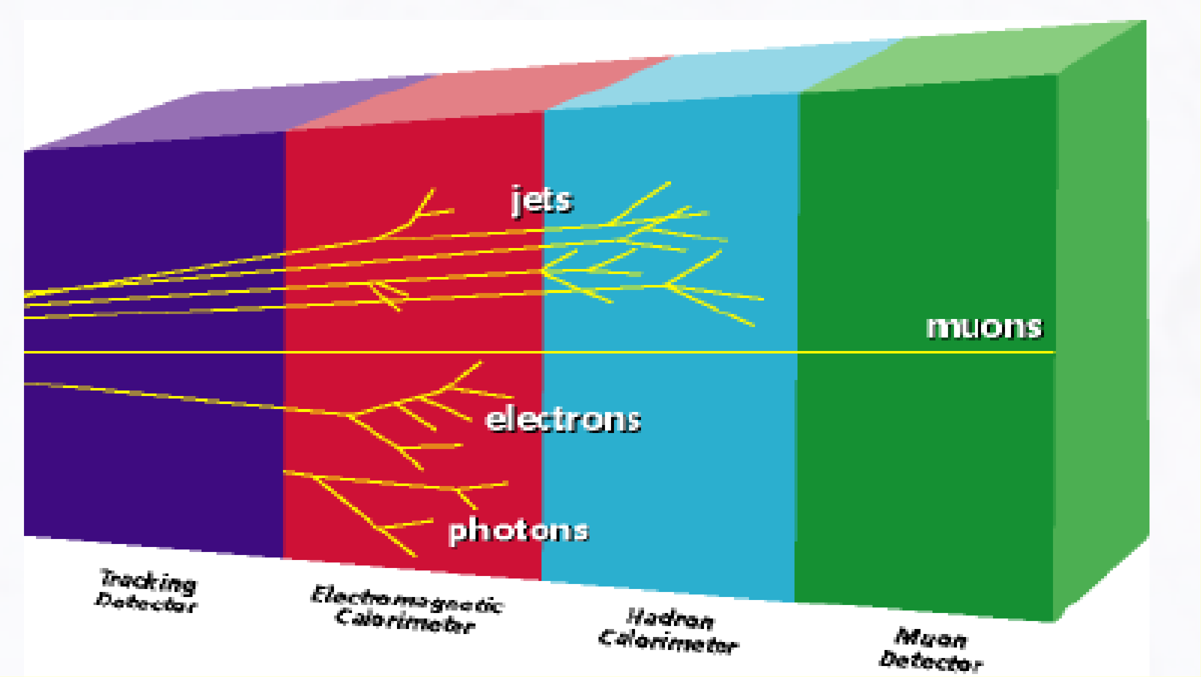




CMS tracker

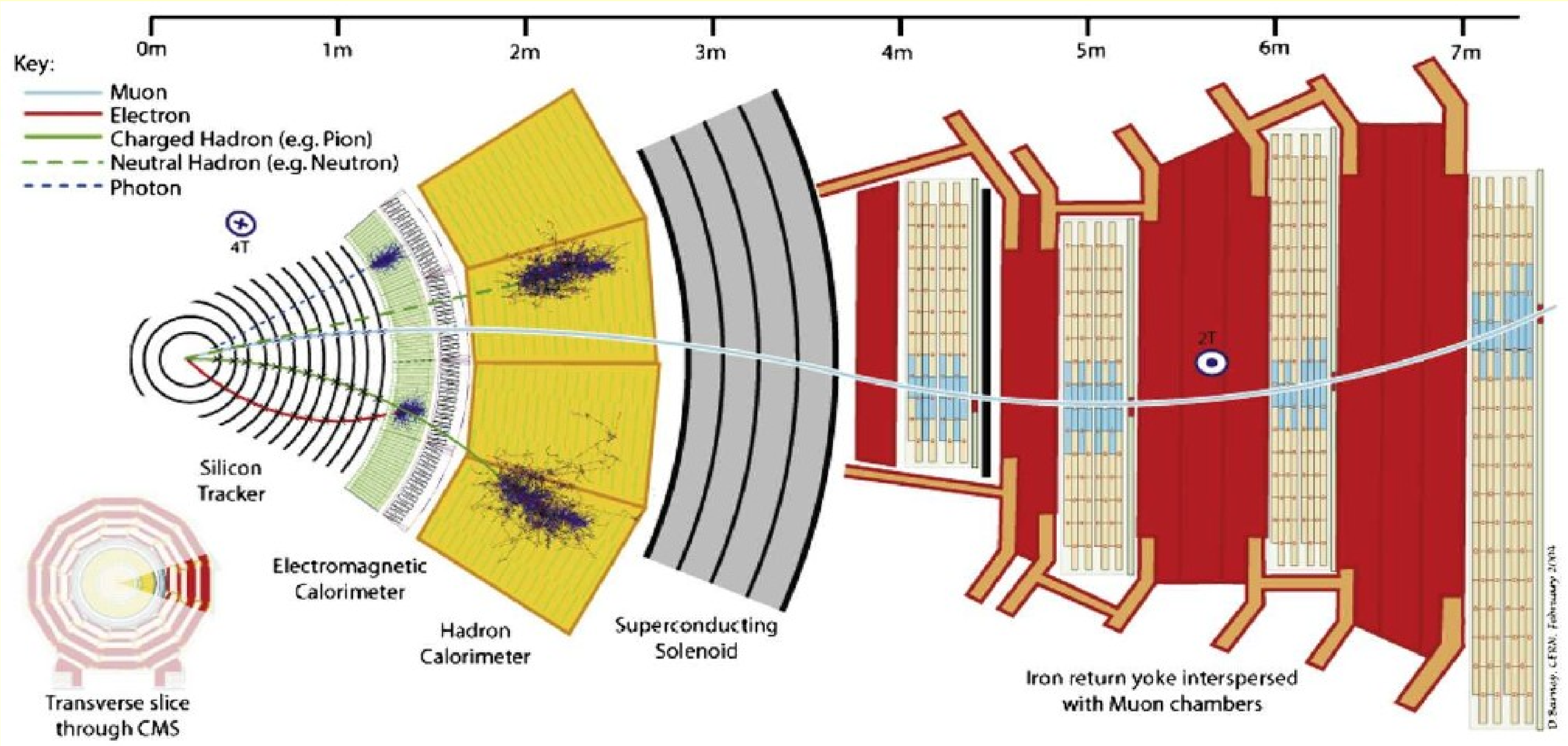


Particle id



- Electrons ionize and show bremsstrahlung due to the small mass
- Photons do no ionize but undergo pair production in high Z material
- Charge hadrons ionize and produce hadron shower in dense material
- Neutral hadron do not ionize but produce hadron shower in dense material

Physics



0m
1m
2m
3m
4m
5m
6m
7m
Key:
Muon
Electron
Charged Hadron (e.g. Pion)
Neutral Hadron (e.g. Neutron)
Photon
4T
2T
Silicon Tracker
Electromagnetic Calorimeter
Hadron Calorimeter
Superconducting Solenoid
Iron return yoke interspersed with Muon chambers
Transverse slice through CMS

Electromagnetic processes

- Gammas:
  - Gamma-conversion, Compton scattering, Photo-electric effect
- Leptons(e, μ), charged hadrons, ions
  - Energy loss (Ionisation, Bremstrahlung), Multiple scattering, Transition radiation, Synchrotron radiation, e+ annihilation.
- Photons:
  - Cerenkov, Rayleigh, Reflection, Refraction, Absorption, Scintillation
- High energy muons

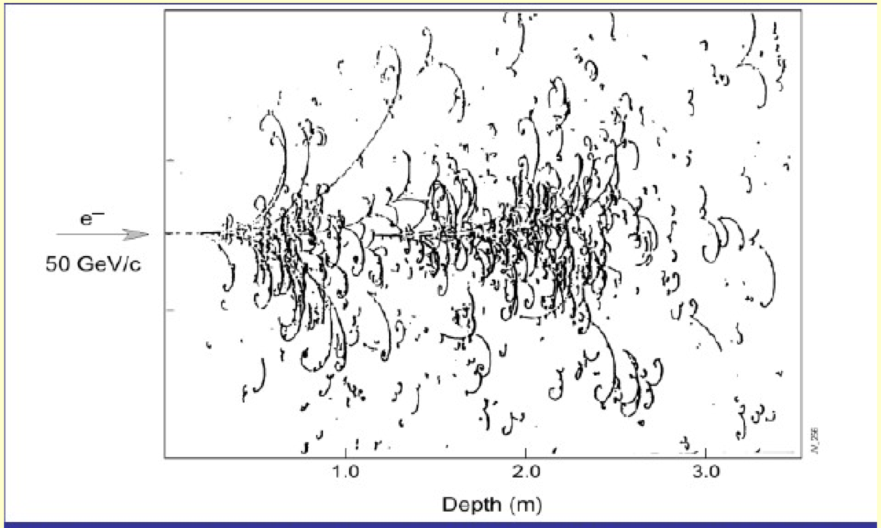
  Bremstrahlung, Multiple scattering,

  Pair production, ionization

Charged hadrons, ions

  Bremstrahlung, Multiple scattering,

  ionization



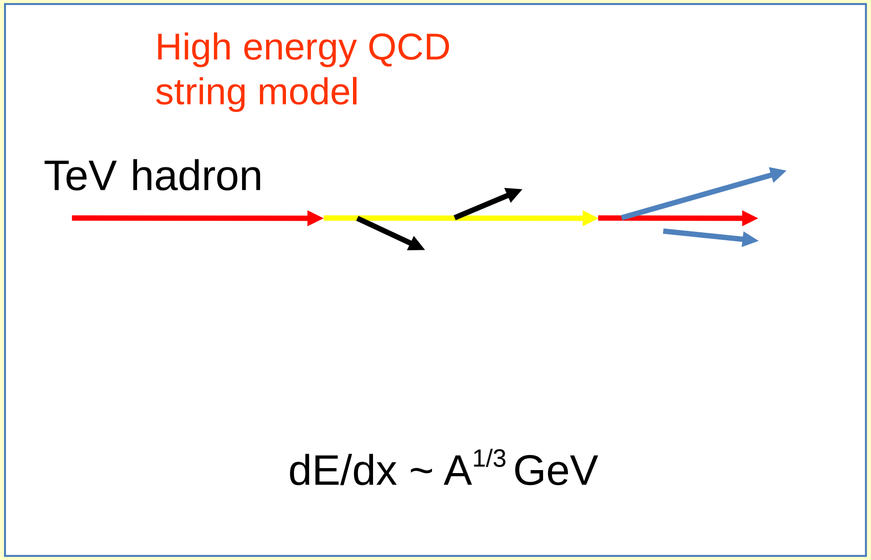
Big European Bubble Chamber filled with Ne:H_2 = 70%:30%, 3T Field, L=3.5 m, X_0≈34 cm, 50 GeV incident electron

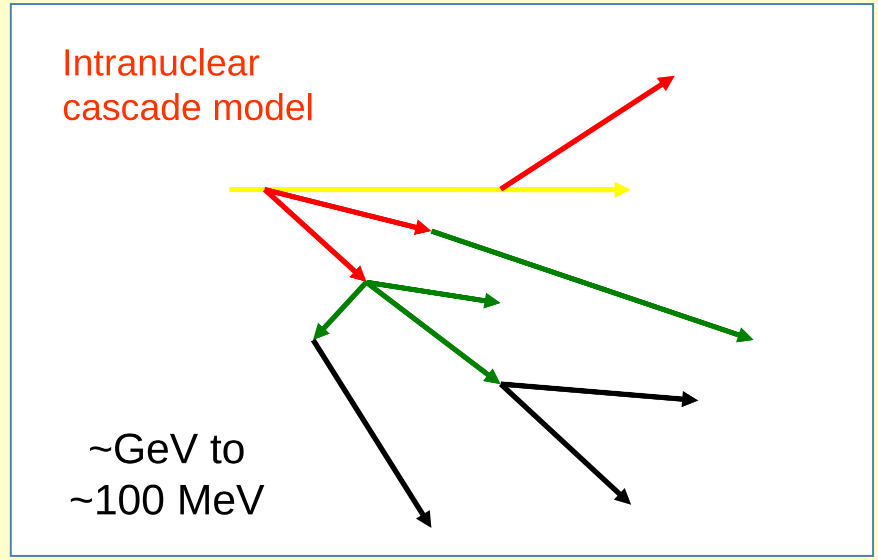
A choice of implementations for most processes

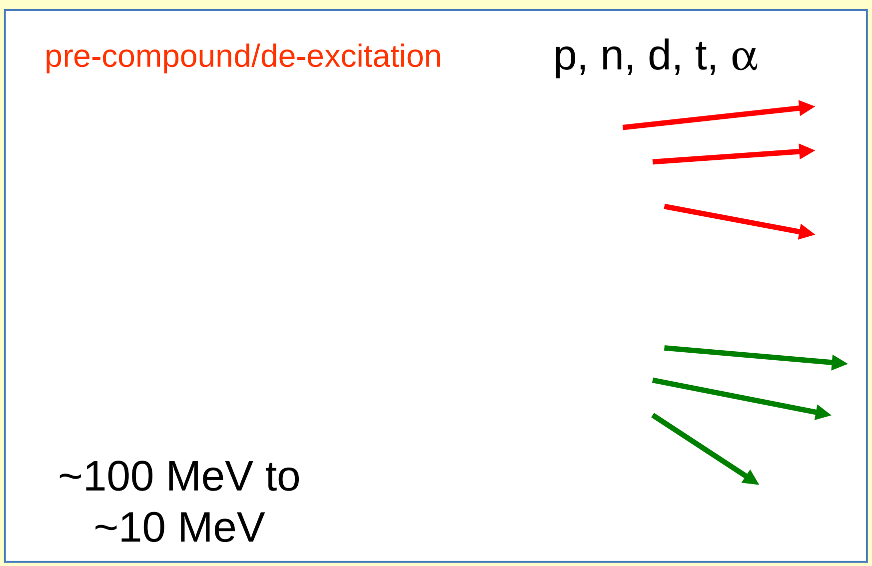
"Standard": performant, where relevant physics above 1 KeV

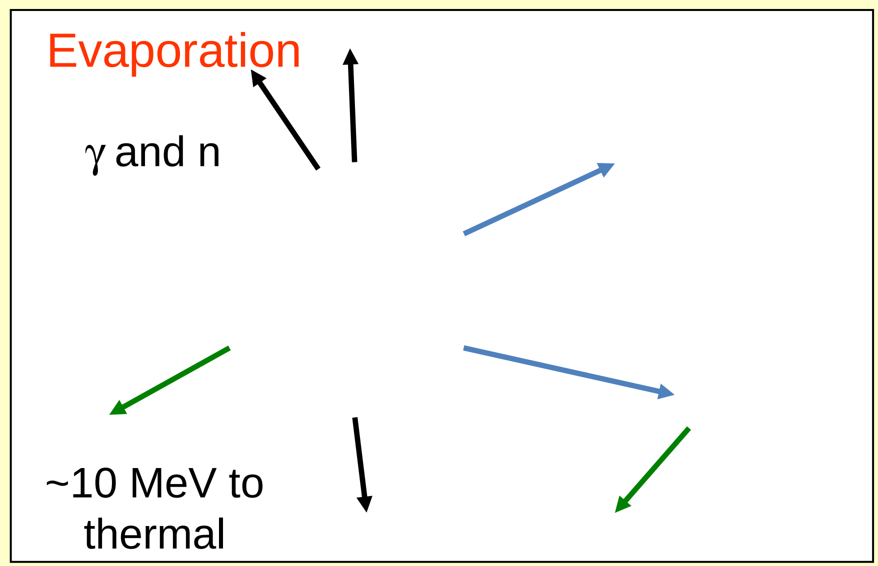
"Low Energy": Extra accuracy, for application delving below 1 KeV

Hadronic interactions





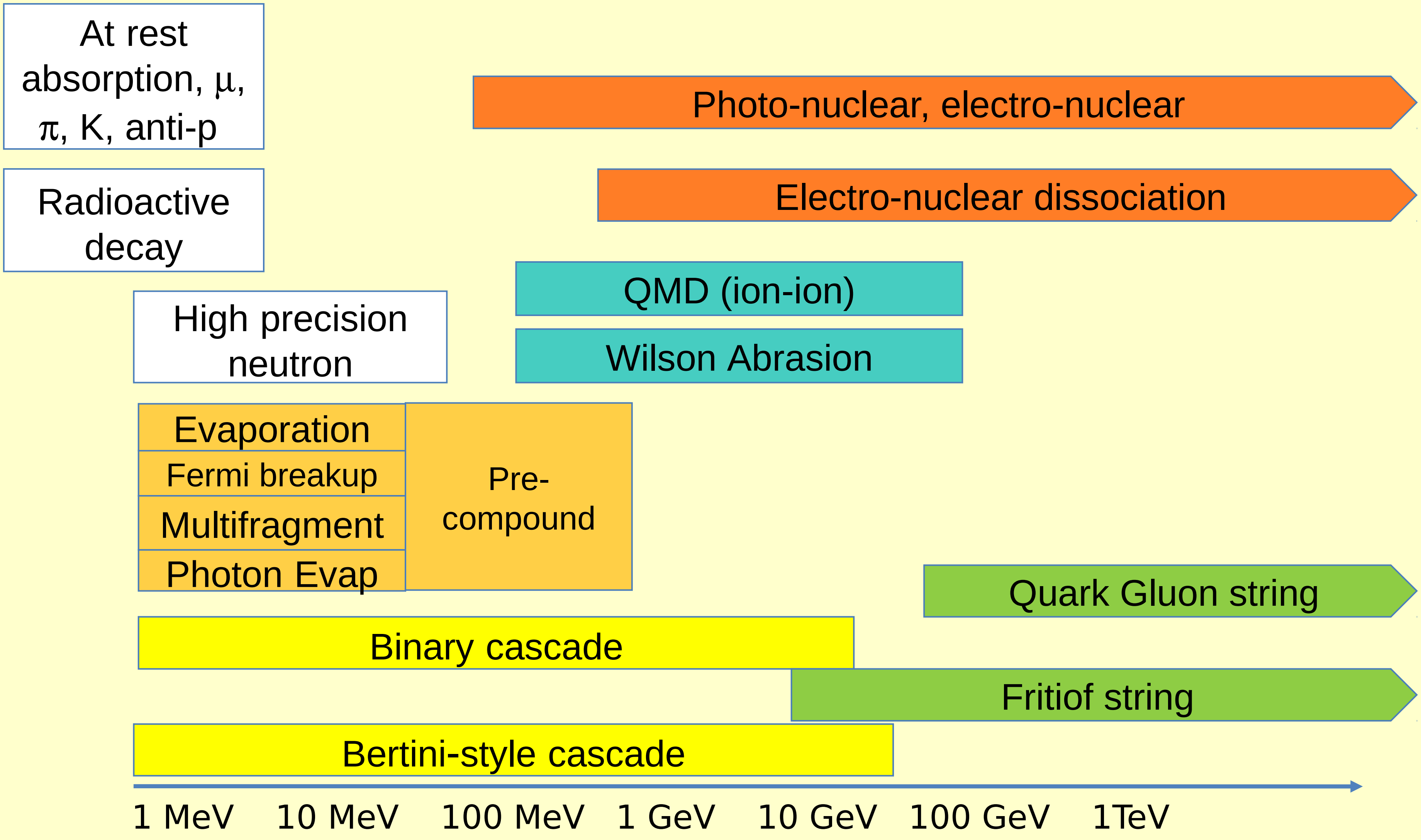




Hadronic processes

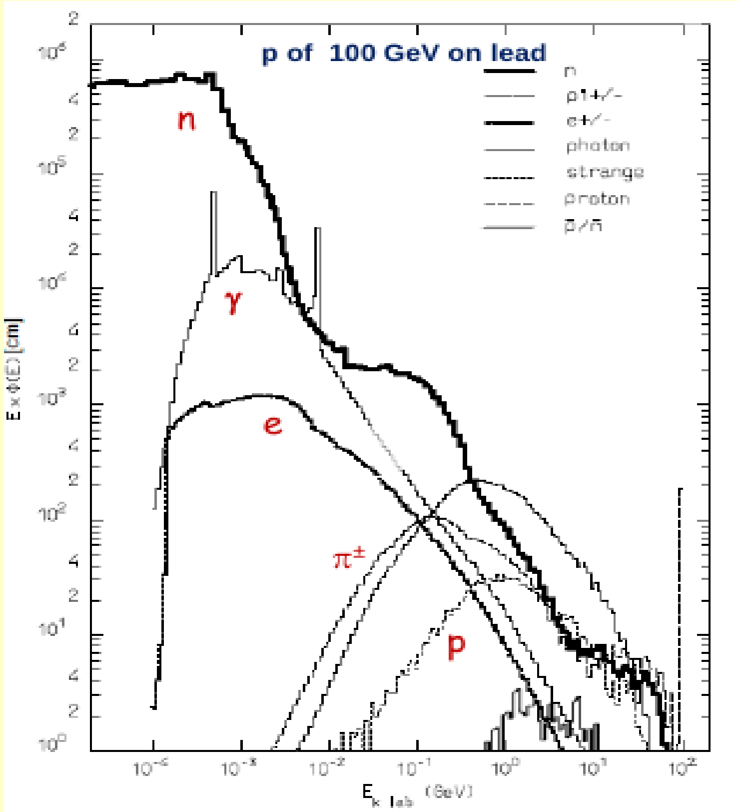
- hadrons at rest
  - π, K absorption
  - neutron capture
  - anti-proton, anti-neutron annihilation
  - μ- capture
- hadrons in flight
  - inelastic scattering
  - elastic scattering
  - fission
  - neutron, anti-neutron capture

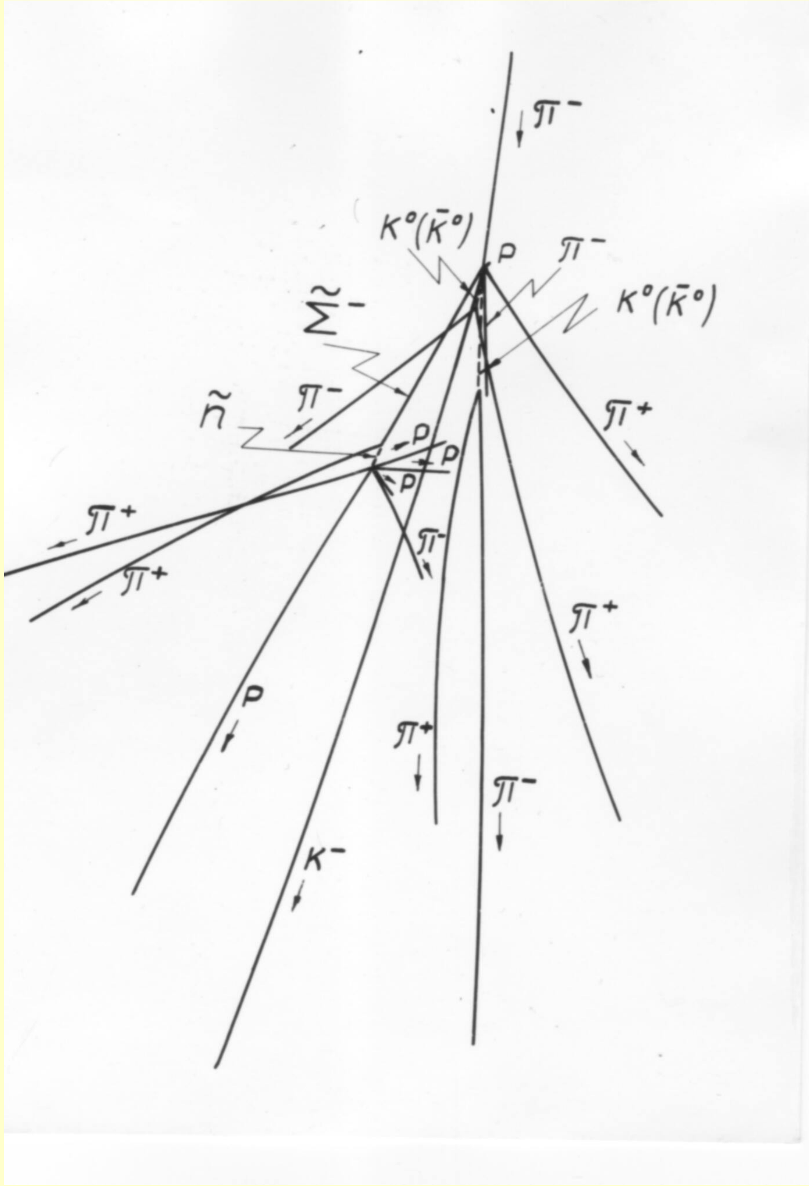
Partial hadronic model inventory



Hadronic shower

- Number of physical processes is large
- Particle energies span over many orders of magnitude
- Makes also the simulations very difficult





Digitization

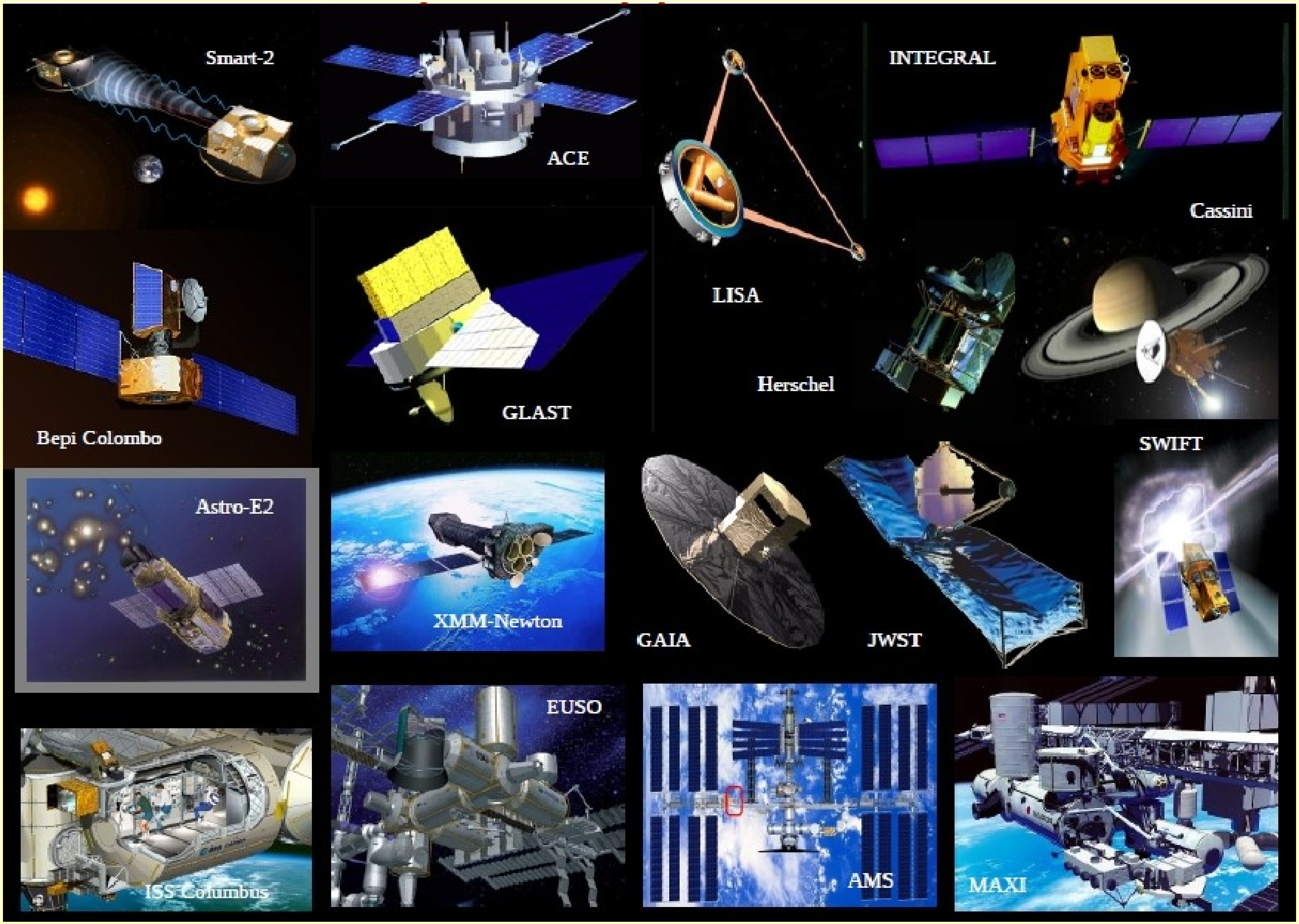
- Besides the geometry, another experiment-specific aspect of the detector simulation is the "digitization"
- It is not part of the general radiation transportation codes
- It consists of producing the detector response in terms of electric current & voltage signals, as it would happen in the real experiment
- The same reconstruction chain can be applied for both real and simulated data
- The general radiation transportation codes provide energy deposits in the whole detector;
  from these, the "digitization" simulates the electrical signals induced in the sensitive parts of the detector

Application

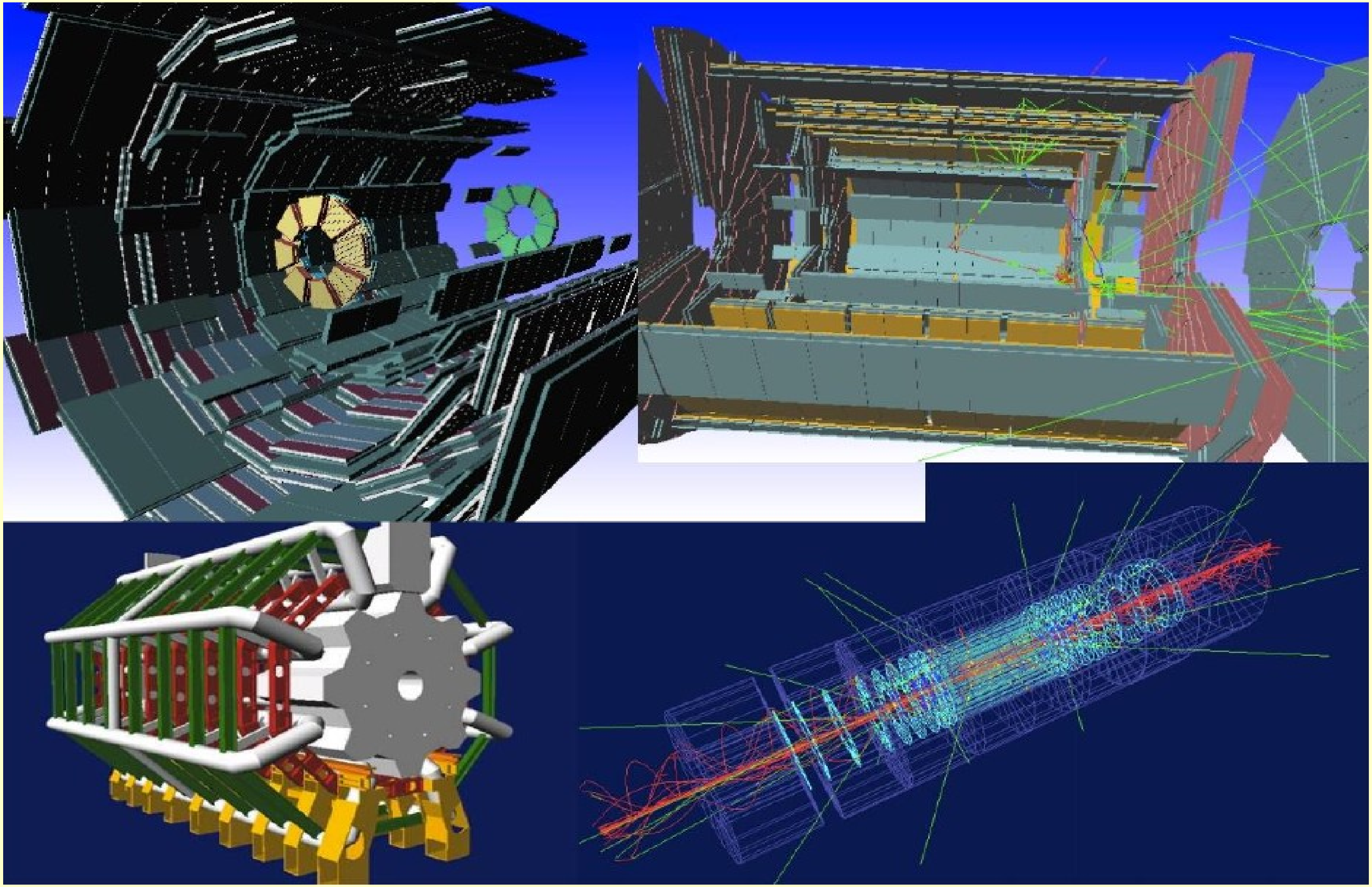
There are other domains where the same radiation transportation codes are successfully used:

- Nuclear physics
- Accelerator science
- Astrophysics
- Space engineering
- Radiation damage
- Medical physics
- Industrial applications
- So, detector simulation is a multi-disciplinary field!

Space applications



HEP applications



Frameworks

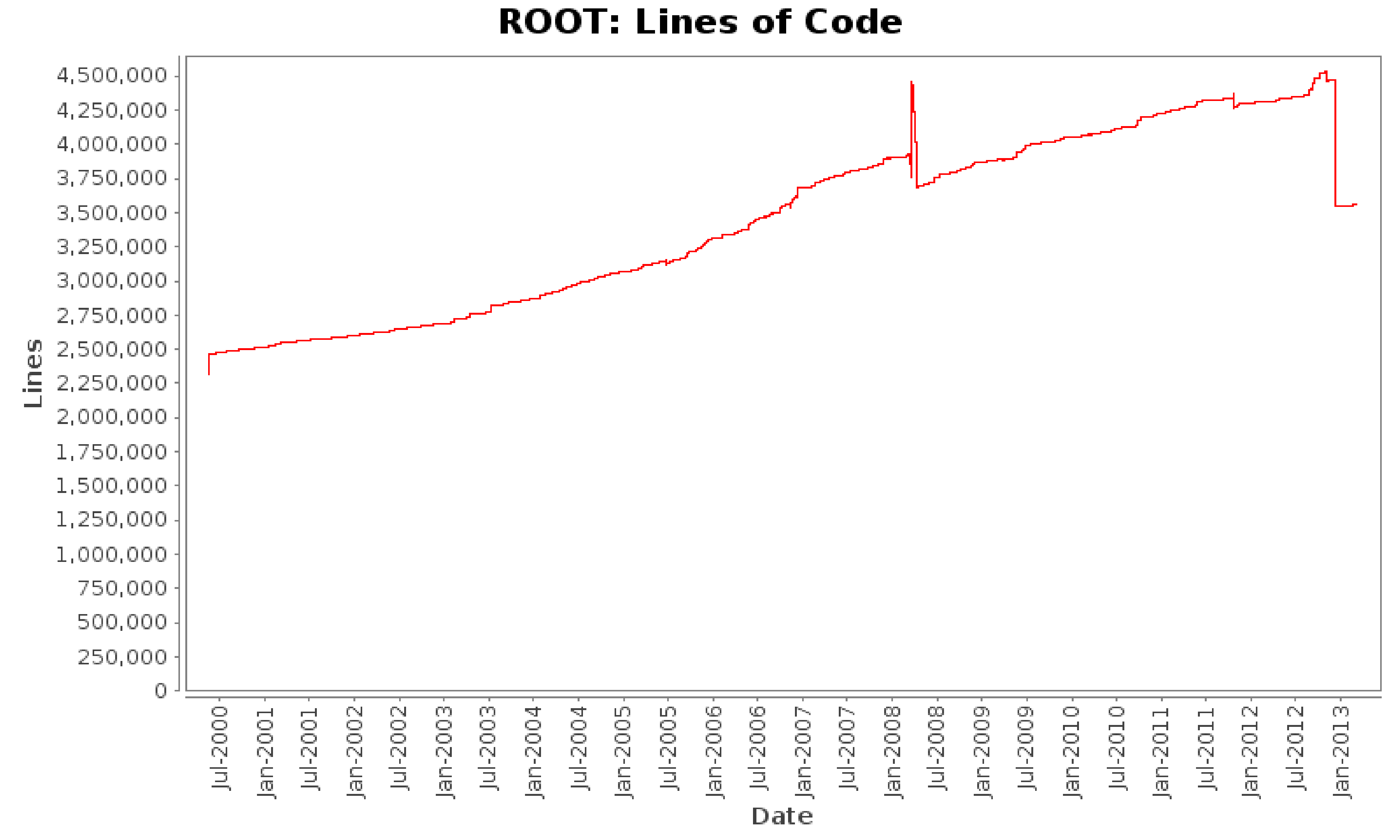
ROOT

Rene object-oriented Technology

ROOT - The Beginning

- Jan 95: Thinking/writing/rewriting/more thinking
- Nov 95: Public seminar, presentation of ROOT 0.5
- Spring 96: decision to use CINT
- Jan 97: ROOT version 1.0
- Jan 98: ROOT version 2.0
- Mar 99: ROOT version 2.21/08 (1st ROOT workshop FNAL)
- Feb 00: ROOT version 2.23/12 (2nd ROOT workshop CERN)
- Sep 00: ROOT version 2.25/03
- Dec 00: ROOT version 3.00/01
- Jun 01: 3rd ROOT Users Workshop at FNAL
- ...
- 2005: ROOT finally becoming mainstream at CERN
- ...
- Mar 13: 8th ROOT Users Workshop Saas-Fee

ROOT is officially forbidden at CERN for LHC since 1996 --2002


ROOT: Lines of Code
Lines
4,500,000
4,250,000
4,000,000
3,750,000
3,500,000
3,250,000
3,000,000
2,750,000
2,500,000
2,250,000
2,000,000
1,750,000
1,500,000
1,250,000
1,000,000
750,000
500,000
250,000
0
Jul-2000
Jan-2001
Jul-2001
Jan-2002
Jul-2002
Jan-2003
Jul-2003
Jan-2004
Jul-2004
Jan-2005
Jul-2005
Jan-2006
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Jan-2007
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Jul-2008
Jan-2009
Jul-2009
Jan-2010
Jul-2010
Jan-2011
Jul-2011
Jan-2012
Jul-2012
Jan-2013
Date

As of today
177 PB
of LHC data
stored in ROOT format

ALICE: 30PB, ATLAS: 55PB, CMS: 85PB, LHCb: 7PB

ROOT 5 started May 6, 2005: 8 years ago

- Future-proof everywhere - but interpreter:
  - CINT parser limitation wrt modern C++
  - Inconsistency from gccxml / Reflex / Cintex / CINT
- Need to answer:
  - Dictionary performance
  - C++11
  - Maintenance load

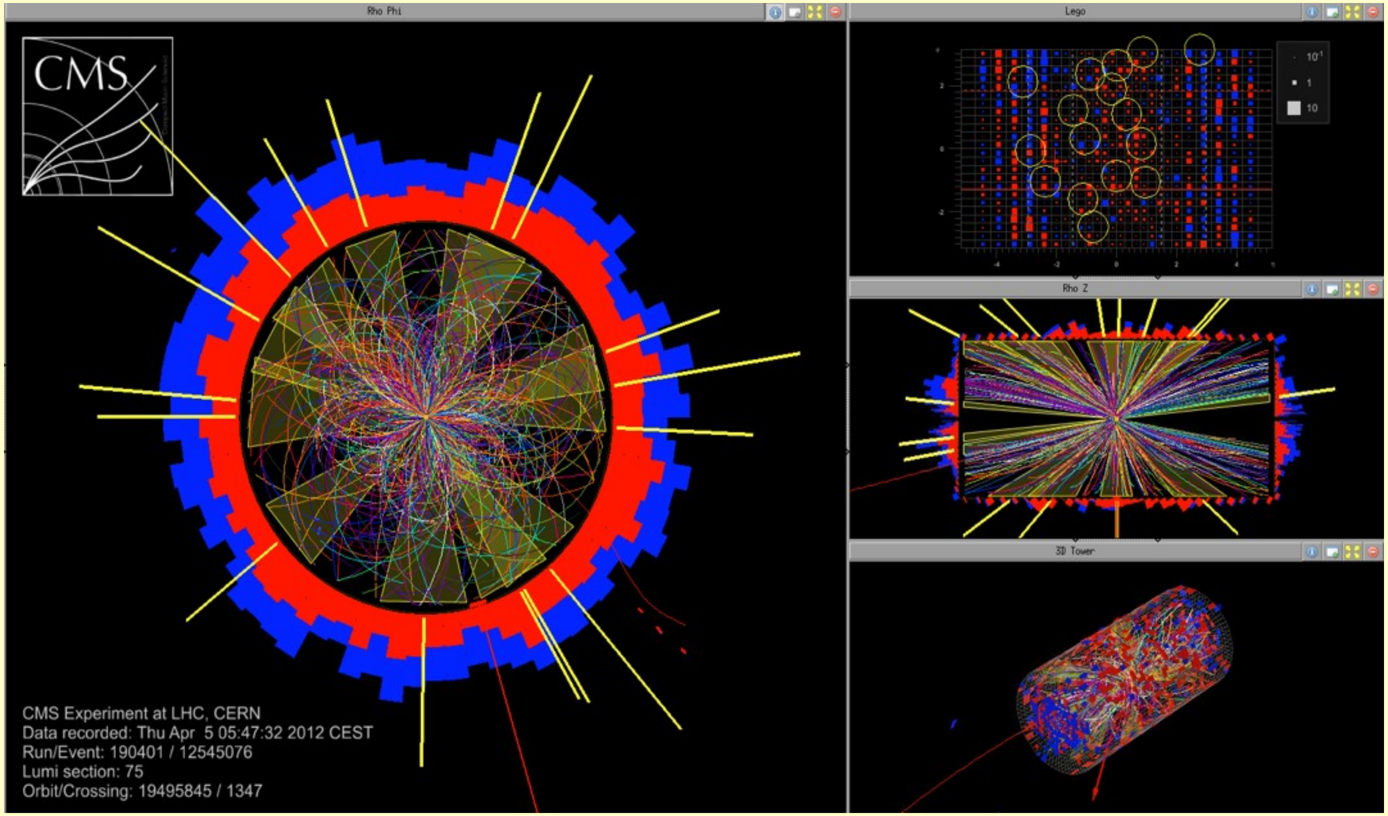
Visualisation

visualize

- geometry
- tracks
- hits

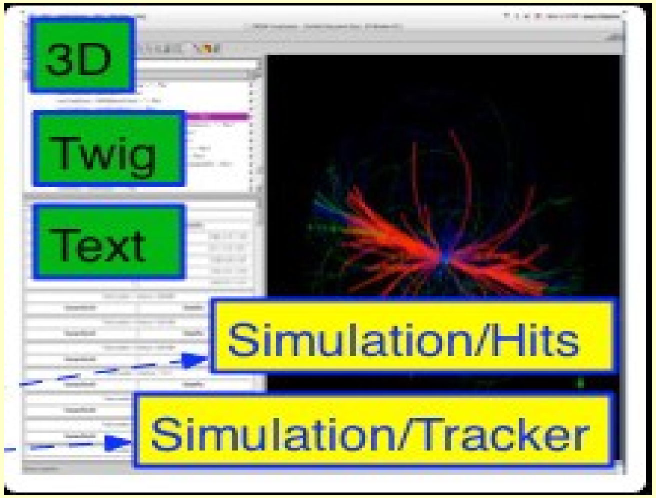
available visualization
 drivers

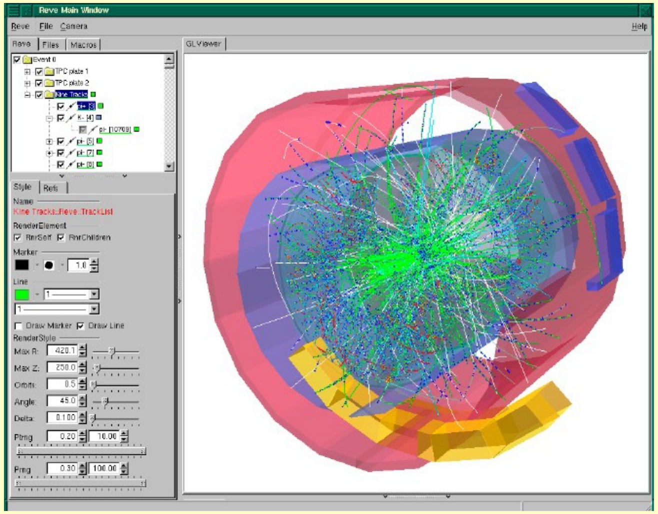
- OpenGL
- OpenInventor
- HepRep
- DAWN
- VRML
- RayTracer
- gMocren
- ASCIITree



Experiments

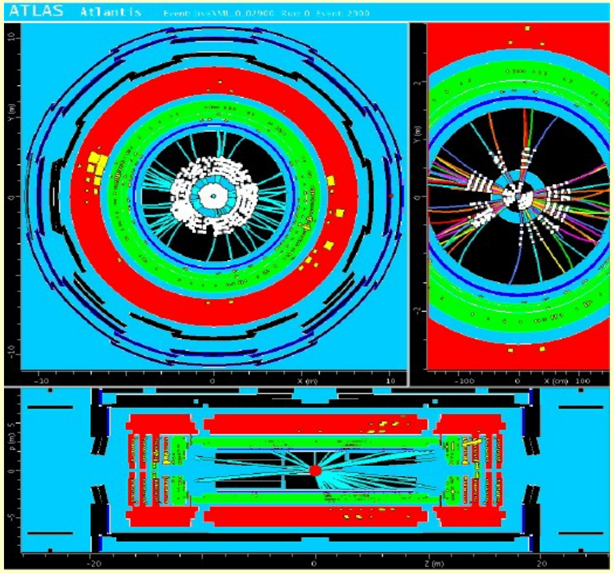
CMS (IGUANA)

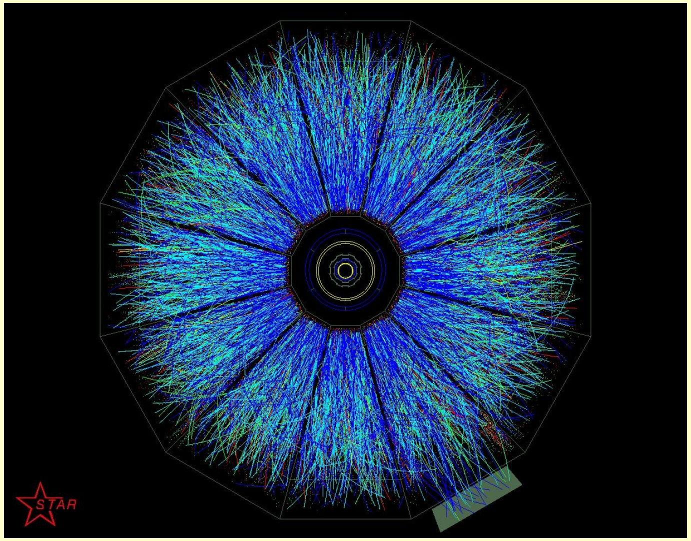




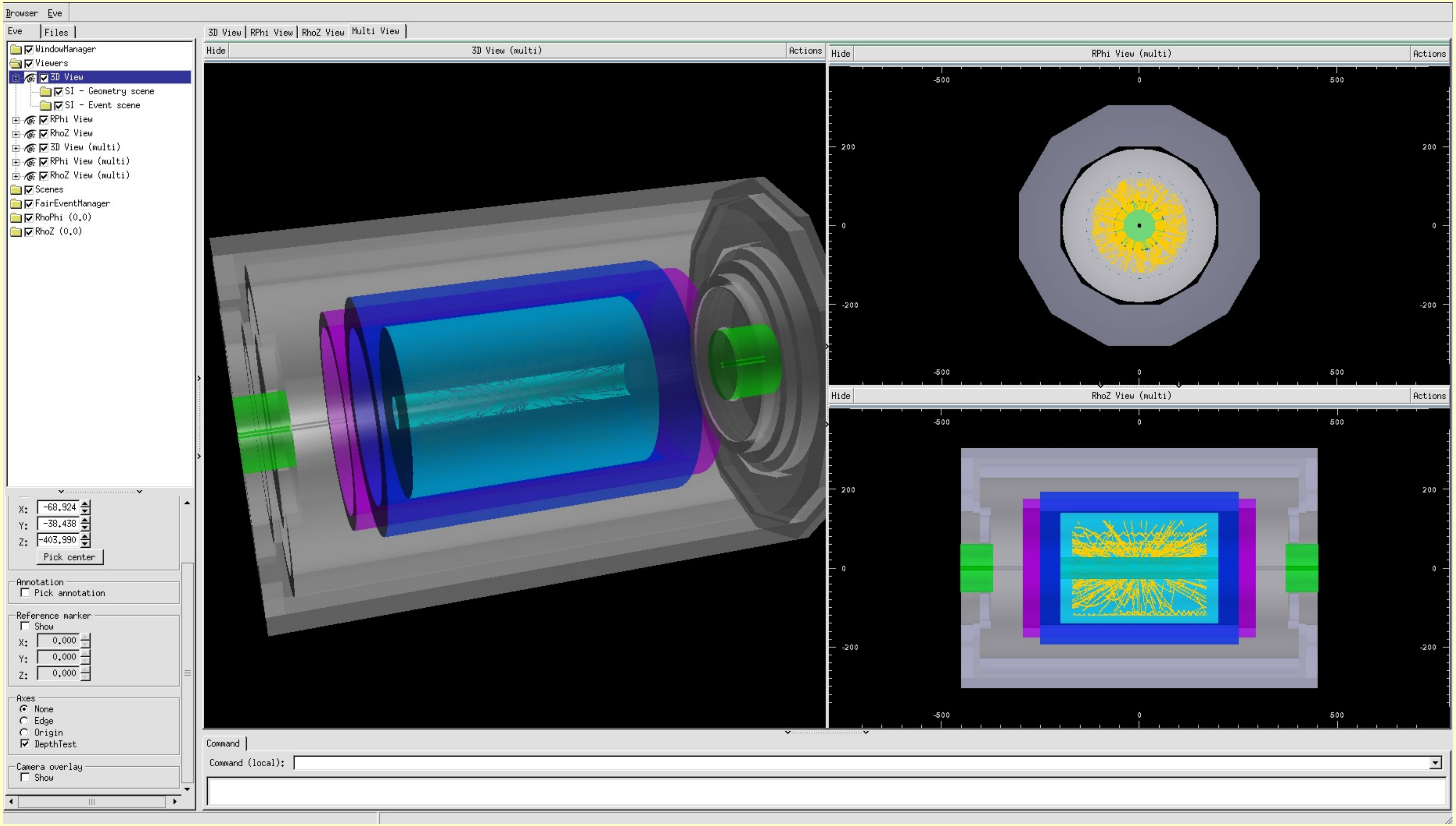
ALICE (AliEVE)

ATLAS (ATLANTIS)



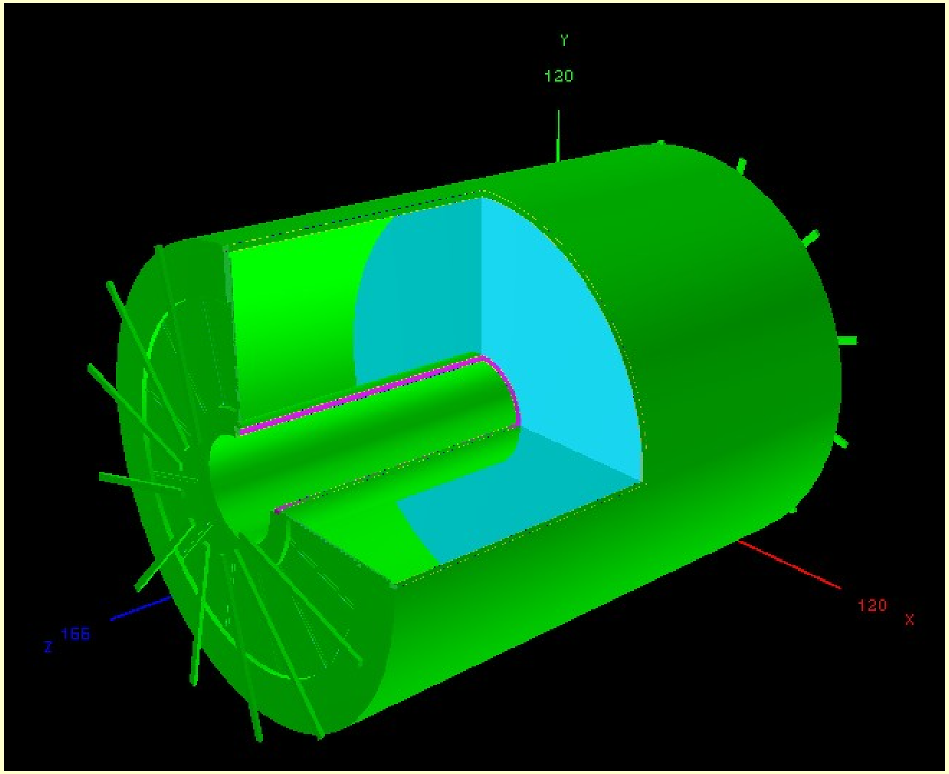


MPD Event Display

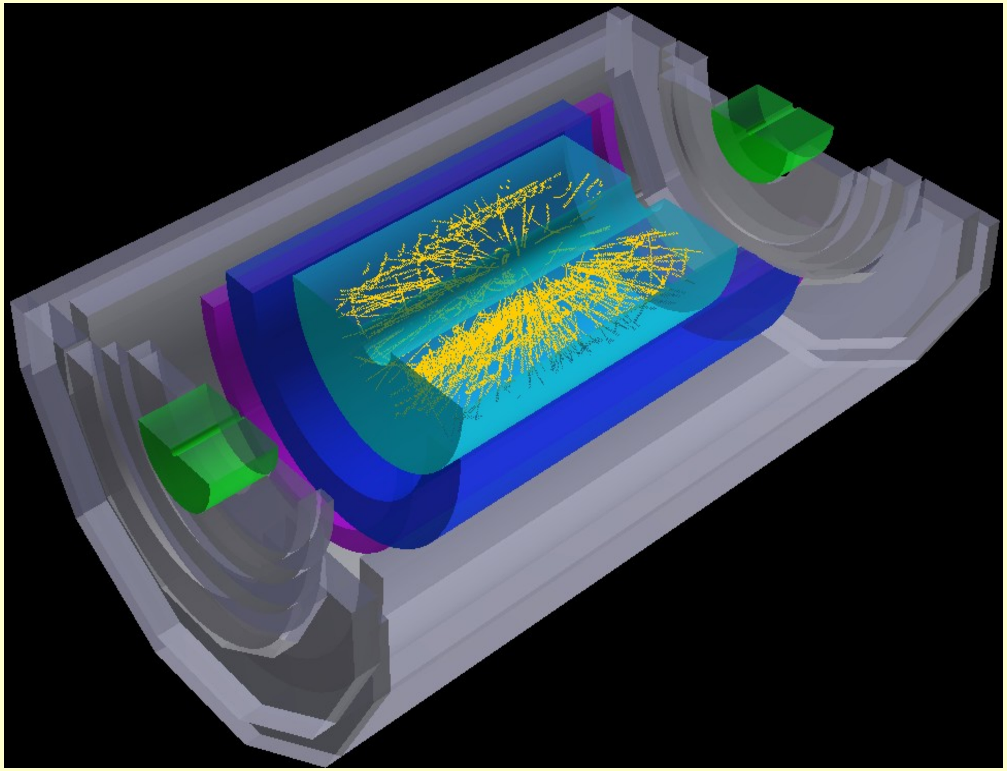


MPD Event Display

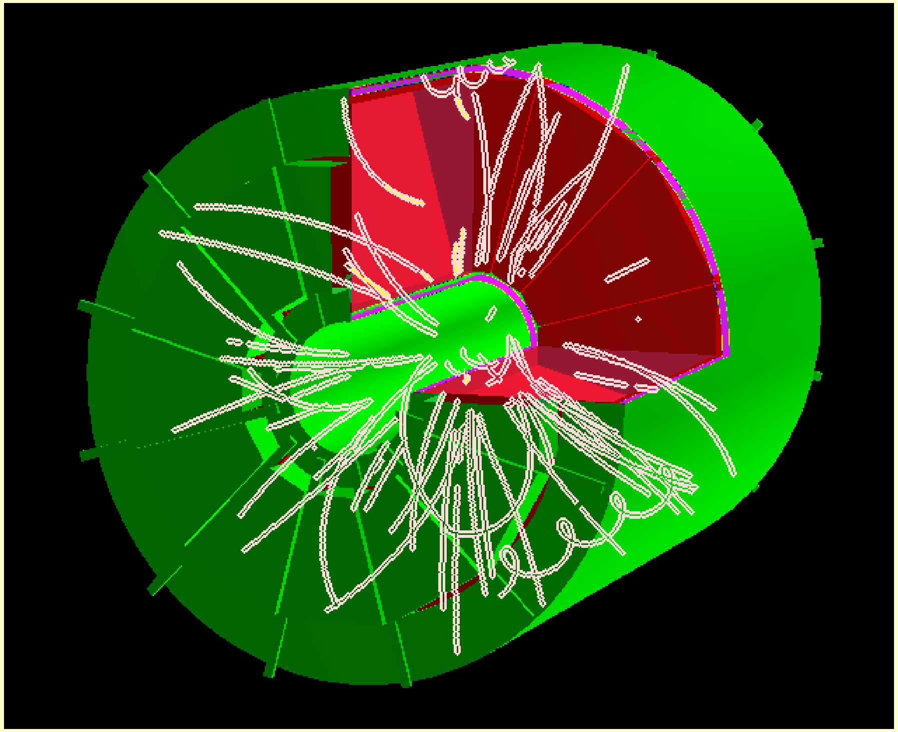
Mpd Tpc

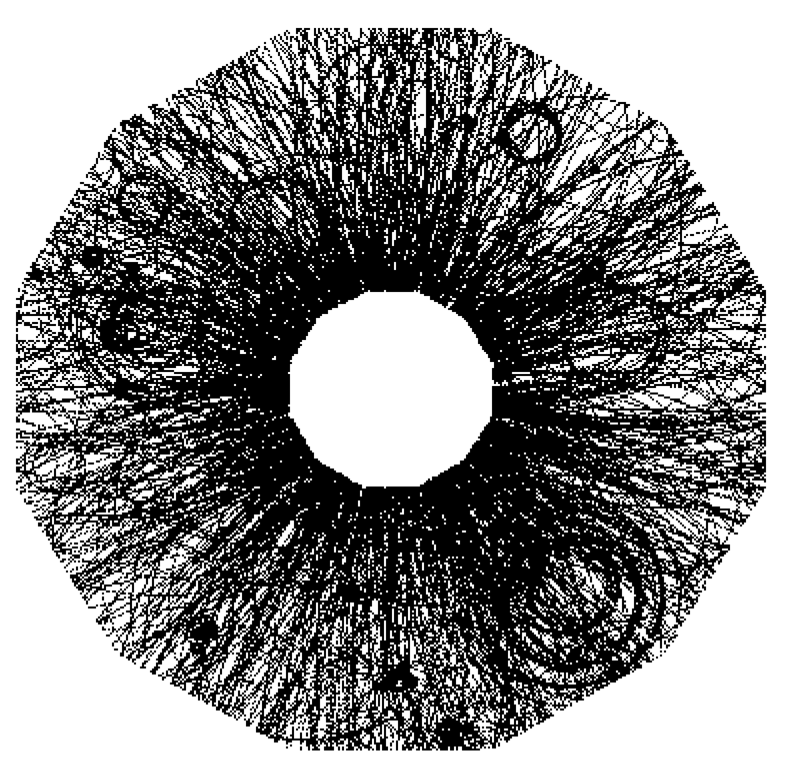


MpdTpcHits (clusters)



MPD AuAu at 9 GeV

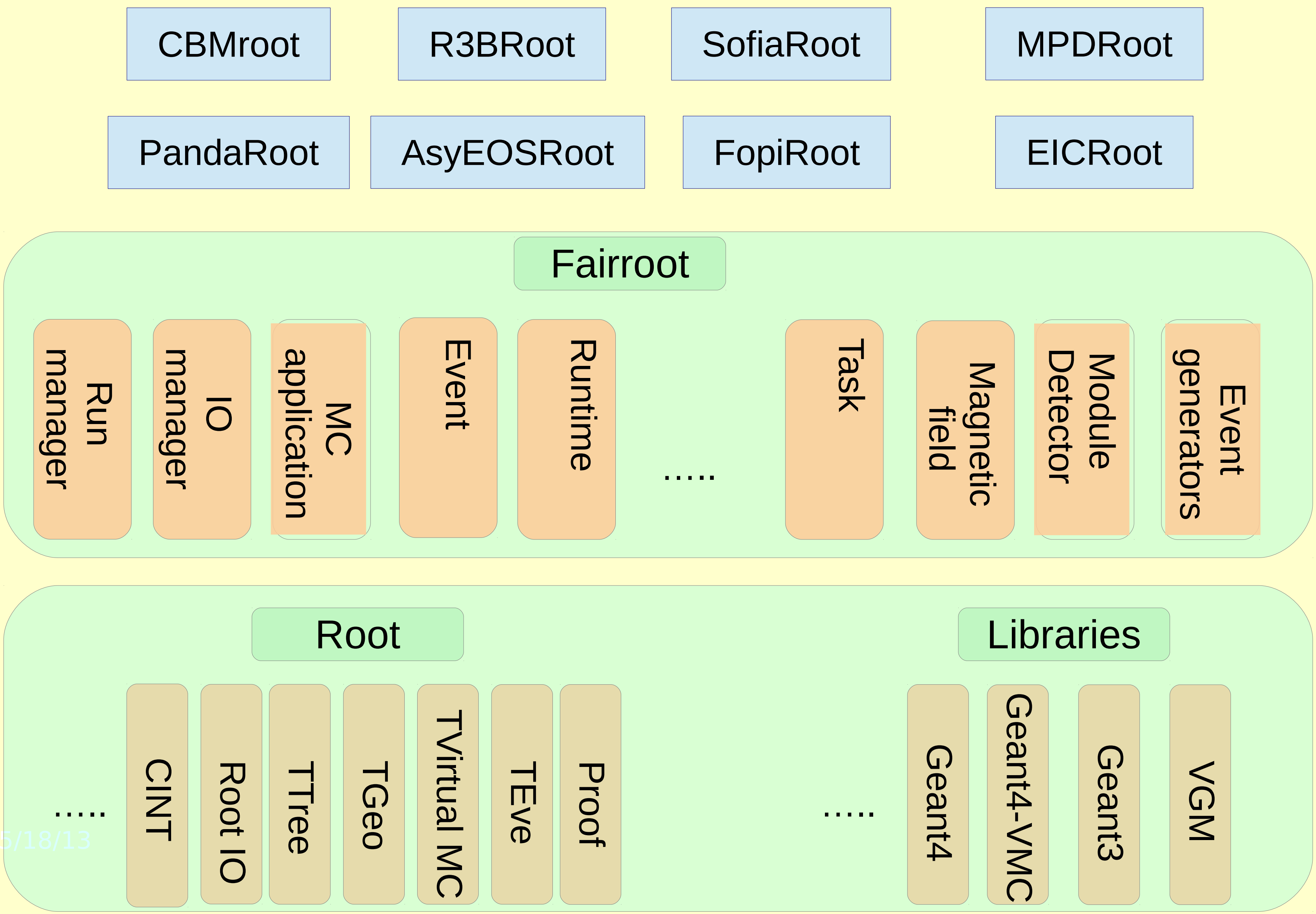




FAIRroot

- Simulation-, Reconstruction-, and Analysis-Framework (not only) for the FAIR experiments
- Based on ROOT
- 2003 started as 2 person project for the CBM experiment
- 2013 ≈ 10 experiments use FairRoot as base for their developments
- Core team of 5 Developers (3.5 FTE)
- Many people contribute to make the project a success

FAIRroot



CBMroot
R3BRoot
SofiaRoot
MPDRoot
PandaRoot
AsyEOSRoot
FopiRoot
EICRoot
Fairroot
Run manager
IO manager
MC application
Event
Runtime
.....
Task
Magnetic field
Module Detector
Event generators
Root
Libraries
.....
CINT
Root IO
TTree
TGeo
TVirtual MC
TEve
Proof
.....
Geant4
Geant4-VMC
Geant3
VGM

ALFA - a common concurrency framework for ALICE and FAIR experiments

ALICE

ALIroot

FAIRroot

ROOT Roadmap

- Current version is v5-34-05
  - It is an LTS (Long Term Support) version
  - New features will be back ported from the trunk
- Version v6-00-00 is scheduled for when it is ready
  - It will be Cling based
  - It will not contain anymore CINT/Reflex/Cintex
  - GenReflex will come in 6-02
  - It might not have Windows support (if not, likely in 6-02)
  - Several “Technology Previews” will be made availble
    - Can be used to start porting v5-34 to v6-00

Спасибо за внимание