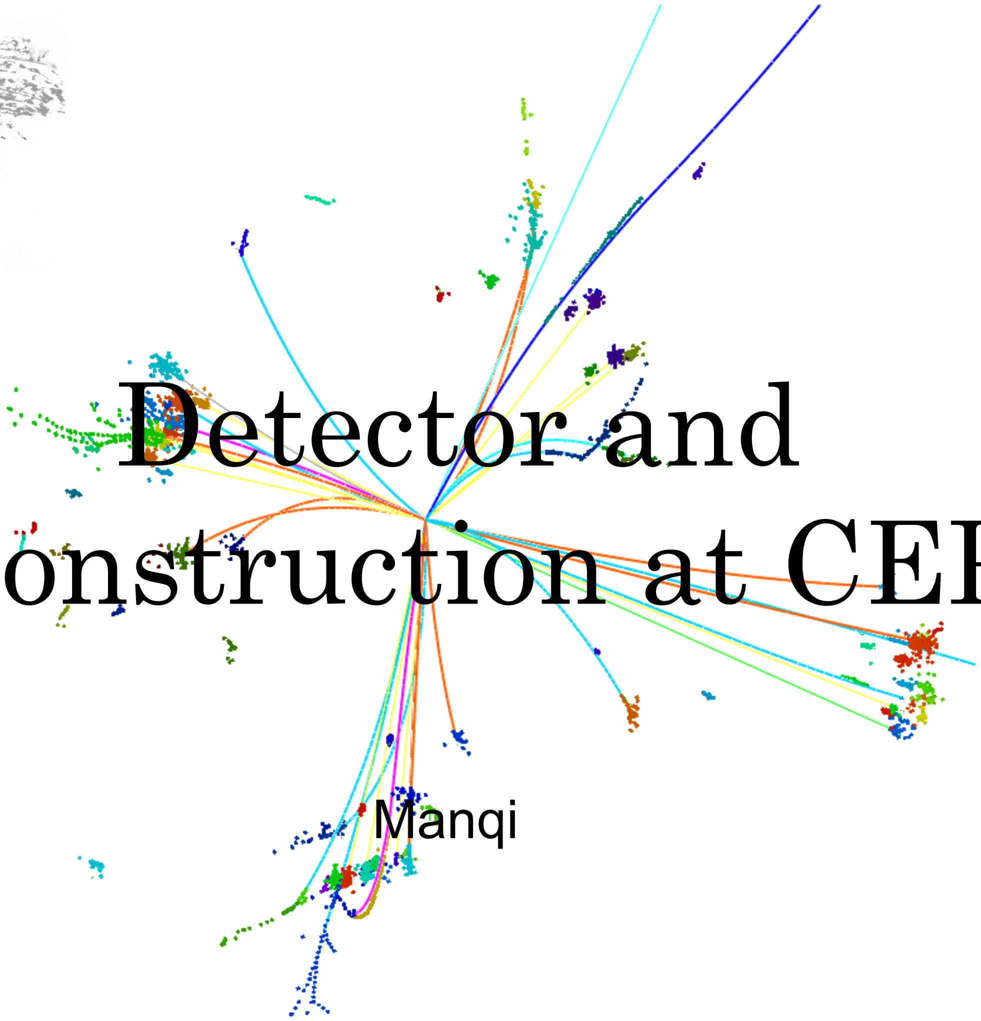


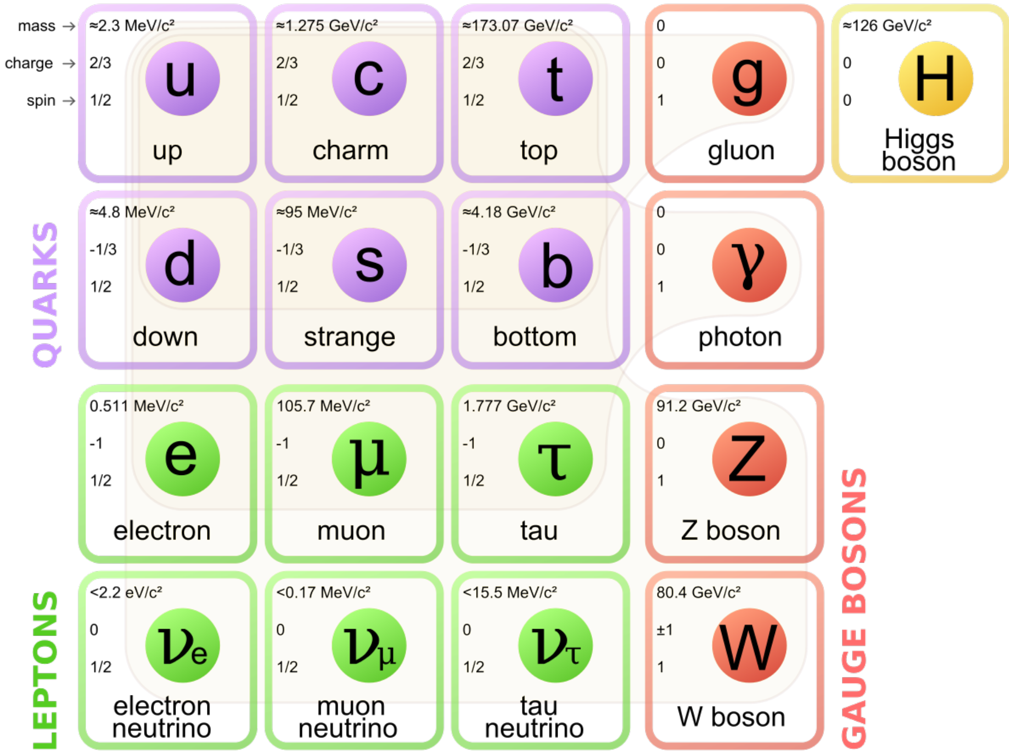
Detector and Reconstruction at CEPC

Manqi

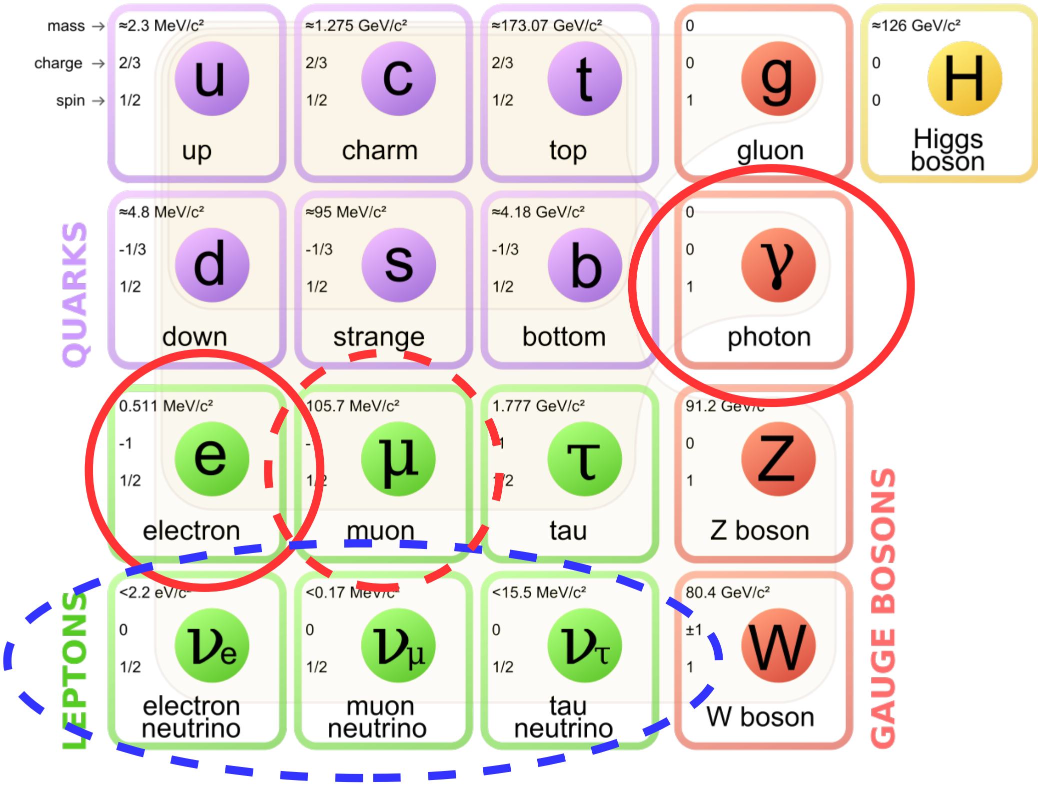
Content

- SM particles, stable or not
- Detector, geometry and how it make hits
- Tracking and Particle Flow
- Event reconstruction at CEPC detector

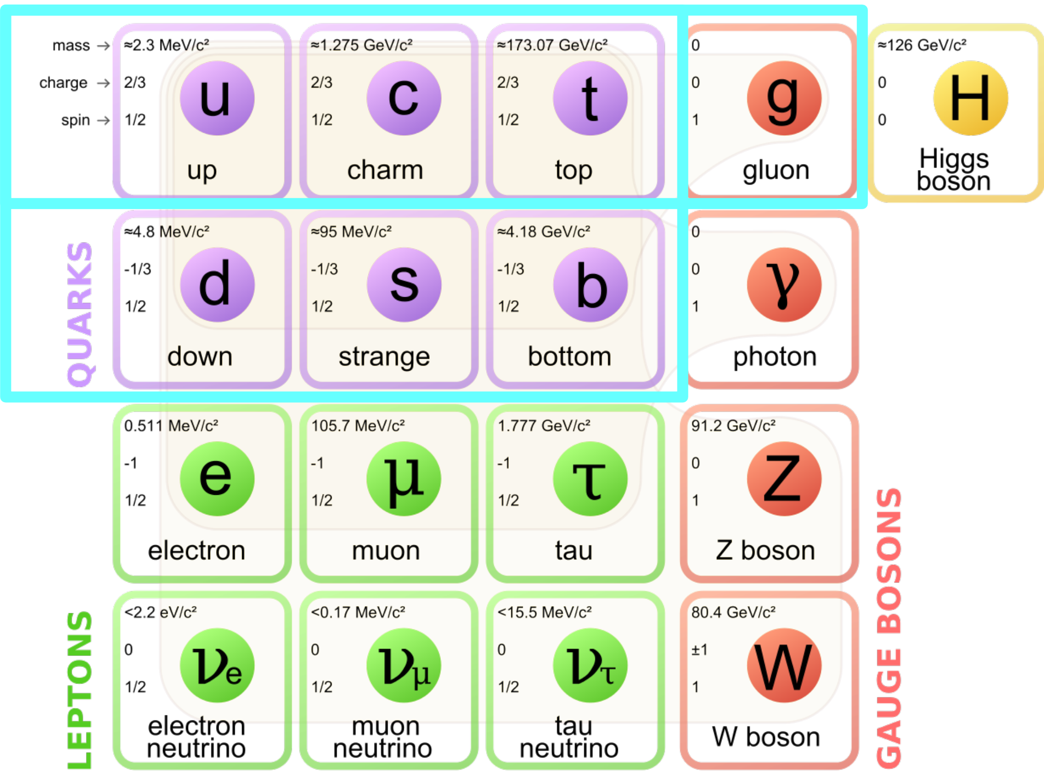
Known Building Block: SM Particles



Leptons & Photon, Stable



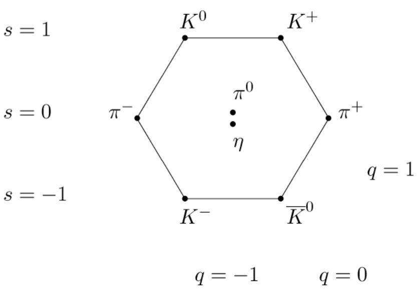
Quarks and gluons

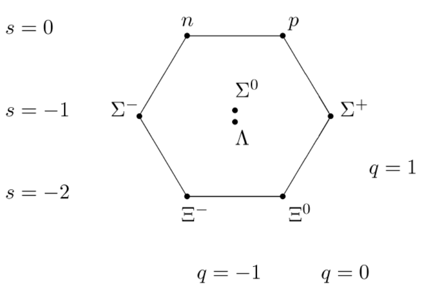


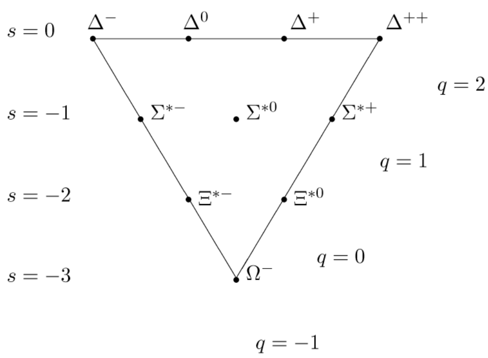
Color confinement: Cannot be directly detected
Top quark: instantly decay into W + b

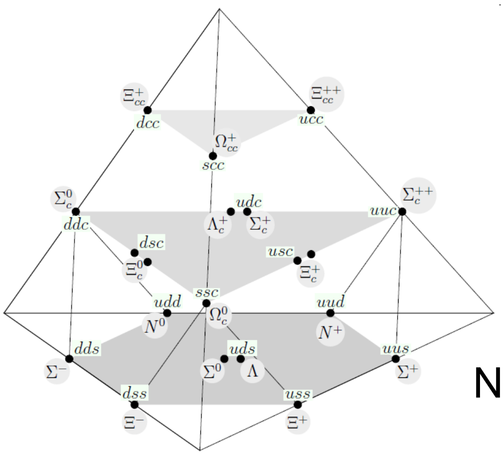
"Stable" particles: light hadrons

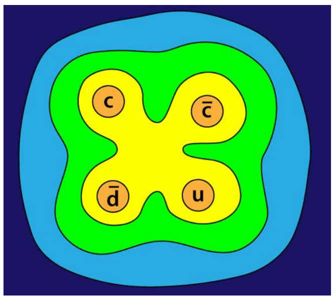
Multiple quarks (or even quarks + gluons), can form color singlet

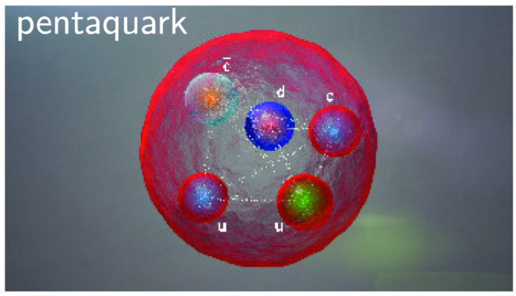




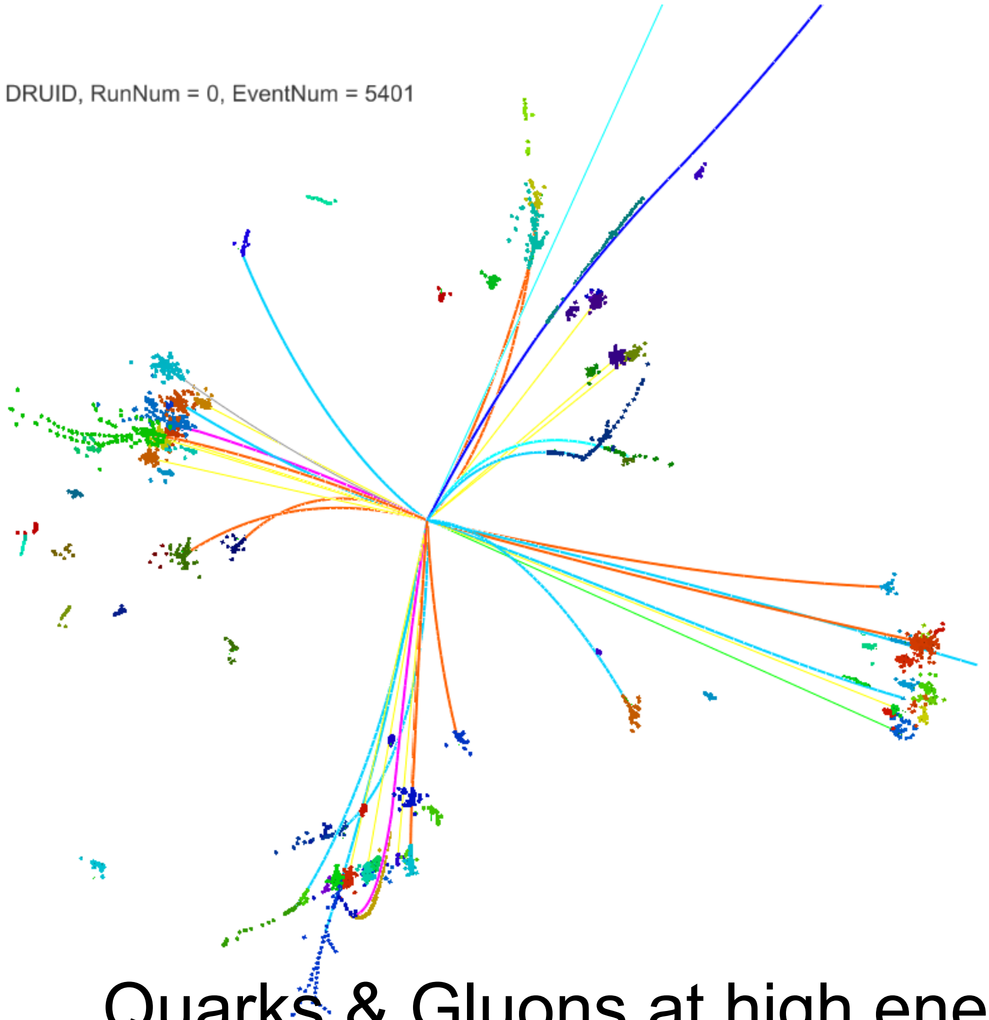






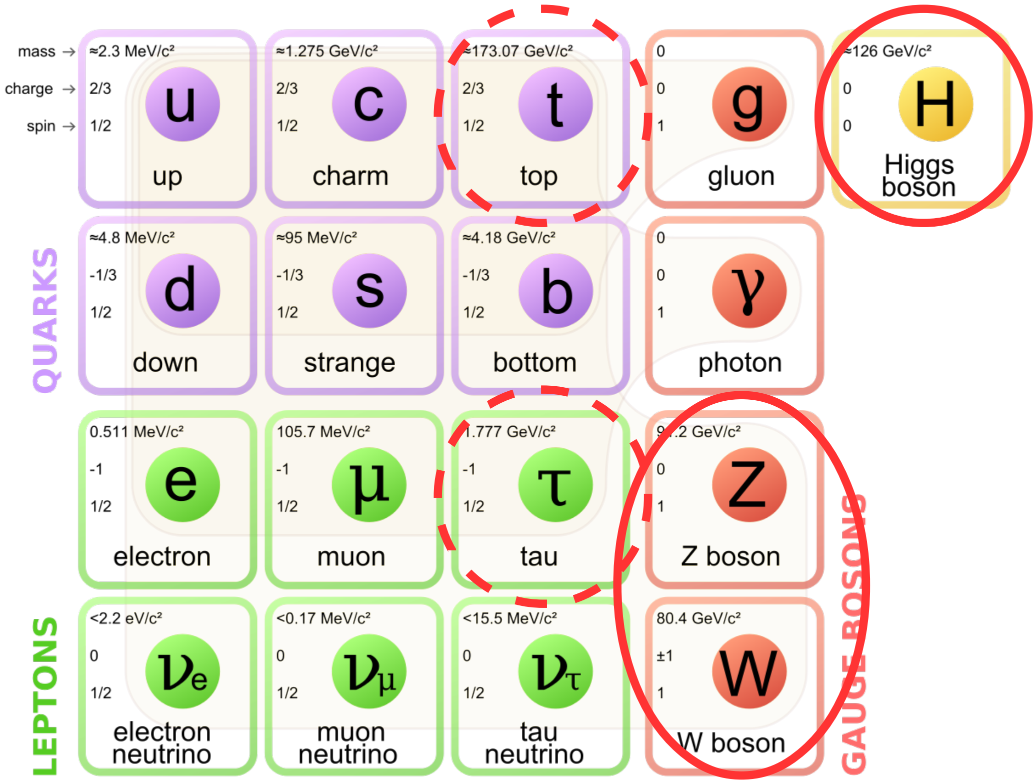


Note: flavor eigenstate != mass eigenstate...



Quarks & Gluons at high energy

Non stable particles



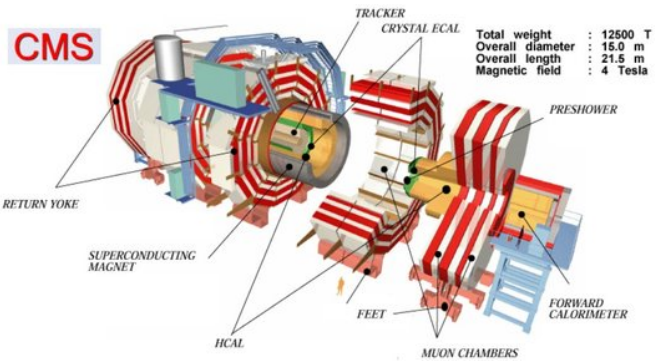
Non stable particles

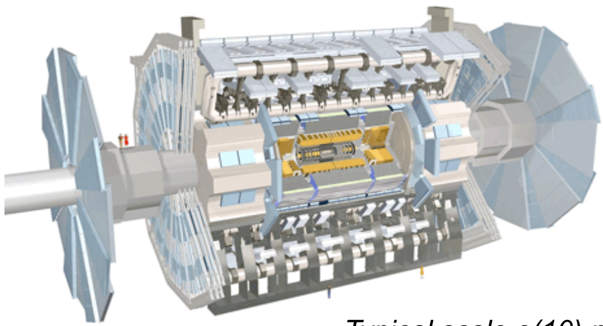
- W
  - 30% into lepton + neutrino pair
  - 70% into up-down quark pair
- Z
  - 10% into lepton-anti lepton pair
  - 20% into neutrino pair
  - 70% into quark pair
- Top quark: instantly decays into W and b quark
- Tau: decays into lepton or hadron(s) + neutrinos
- Higgs: coupled to massive particles, and to gluon & photons through loops

Mode	$b\bar{b}$	$c\bar{c}$	gg	WW^*	$\mu^+\mu^-$	$\tau^+\tau^-$	ZZ^*	$\gamma\gamma$	$Z\gamma$
BR (%)	57.8	2.7	8.6	21.6	0.02	6.4	2.7	0.23	0.16

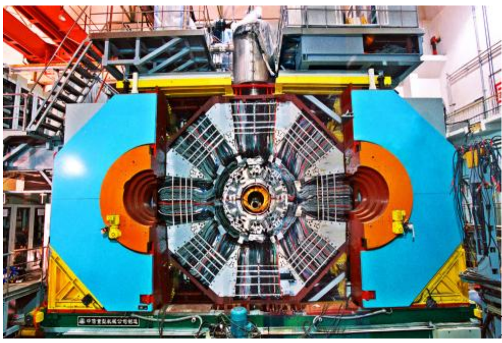
Detector at Colliders

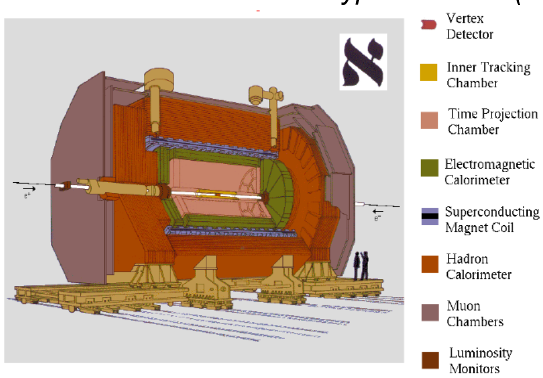
- Take snapshot of physics event: through Detector hits
- Understand the physics event: through Reconstruction





Typical scale o(10) m





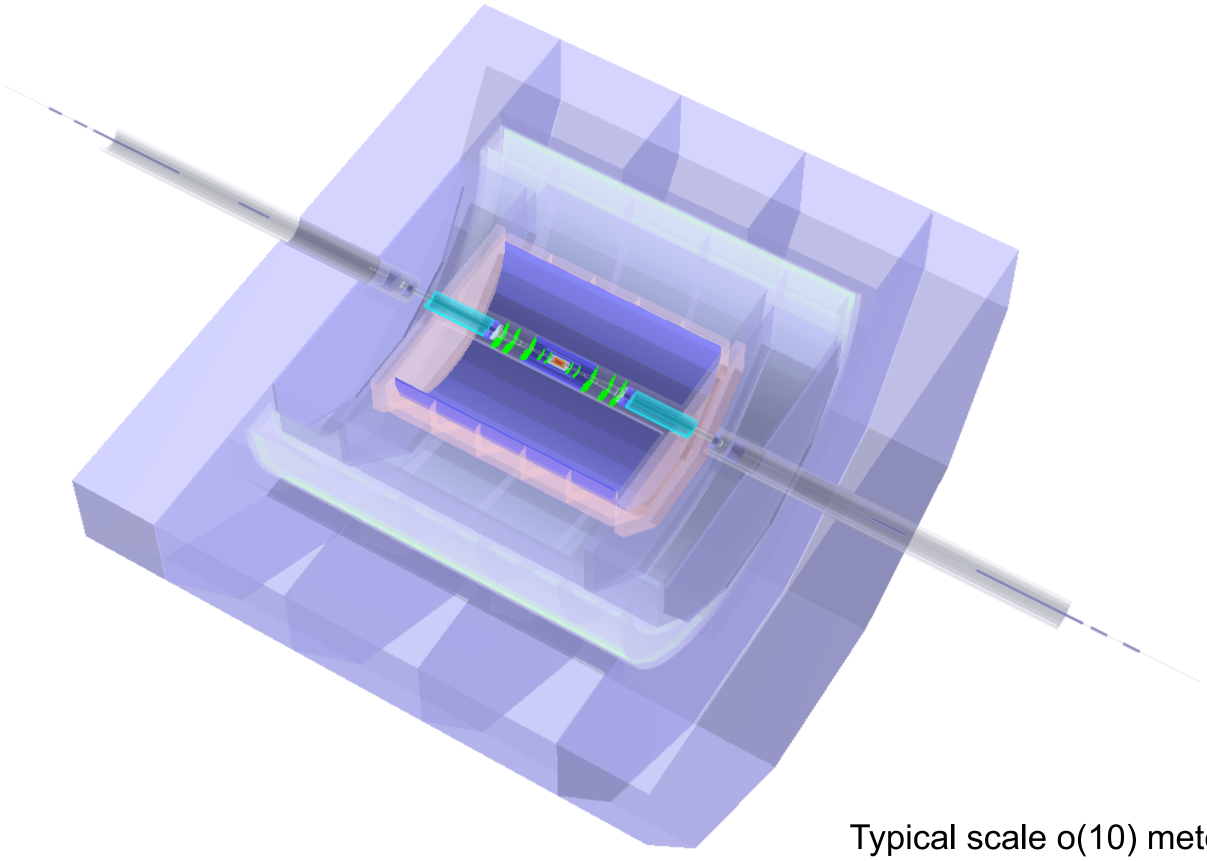
The ALEPH Detector

SM particles

		Stable	Quasi-Stable	Non-Stable
Charged	Elementary	Electron, positron	Muon, anti-muon,	Top, Tau, W+, W-
	Composited	Proton	Pion, Kaon, etc	
Neutral	Elementary	Photon, Neutrinos		Z, Higgs
	Composited		Neutron (τ ~ 500 s) Klong, Kshort, etc	

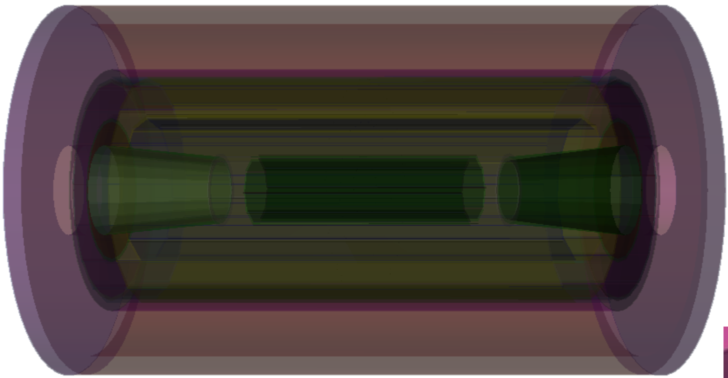
- New Physics Particles, can also decay into SM final states
- Quasi-Stable: $c^*\tau$ > 10 m
- Quarks and Gluon: color confinement (as into hadrons)
  - Form hadrons
  - Giving enough energy (w.r.t confined system): Form hadronic jets

CEPC Conceptual detector

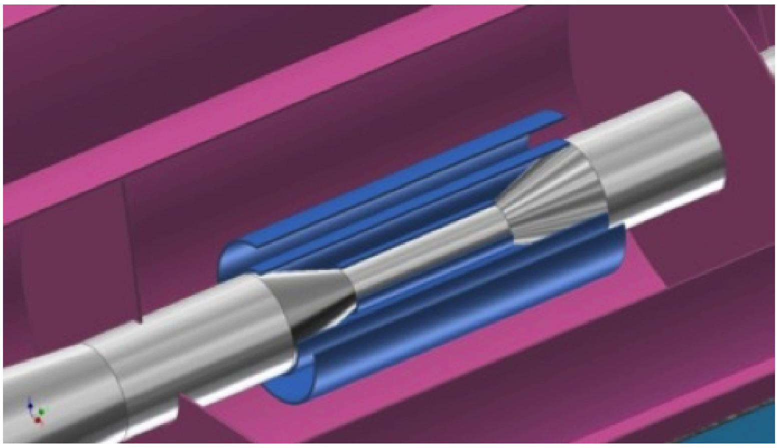


Typical scale o(10) meter

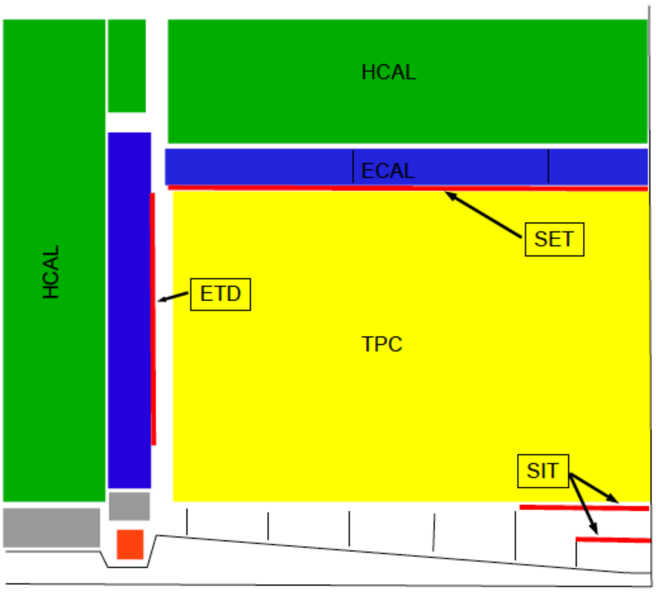
Vertex detector

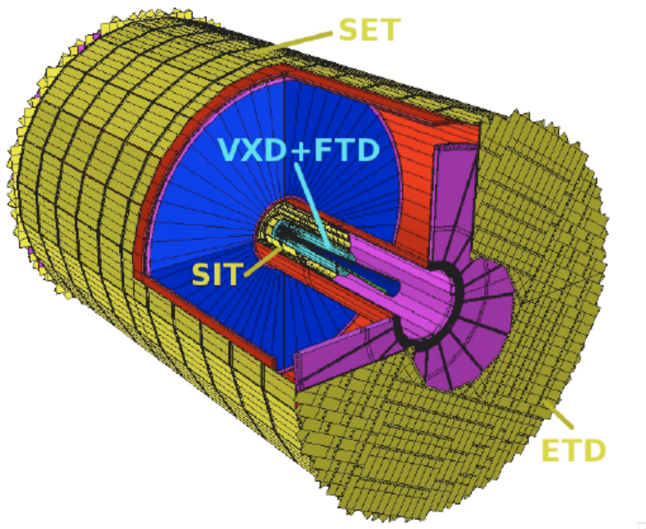


Inner most layer Radius: ~15 mm
Spatial resolution: ~ 5 μm



Silicon Tracking at ILD





- Massive usage of silicon pixel/strips in the tracking system & VTX: ensures good accuracy in Impact parameter & momentum measurement

ILD Main Tracker: TPC

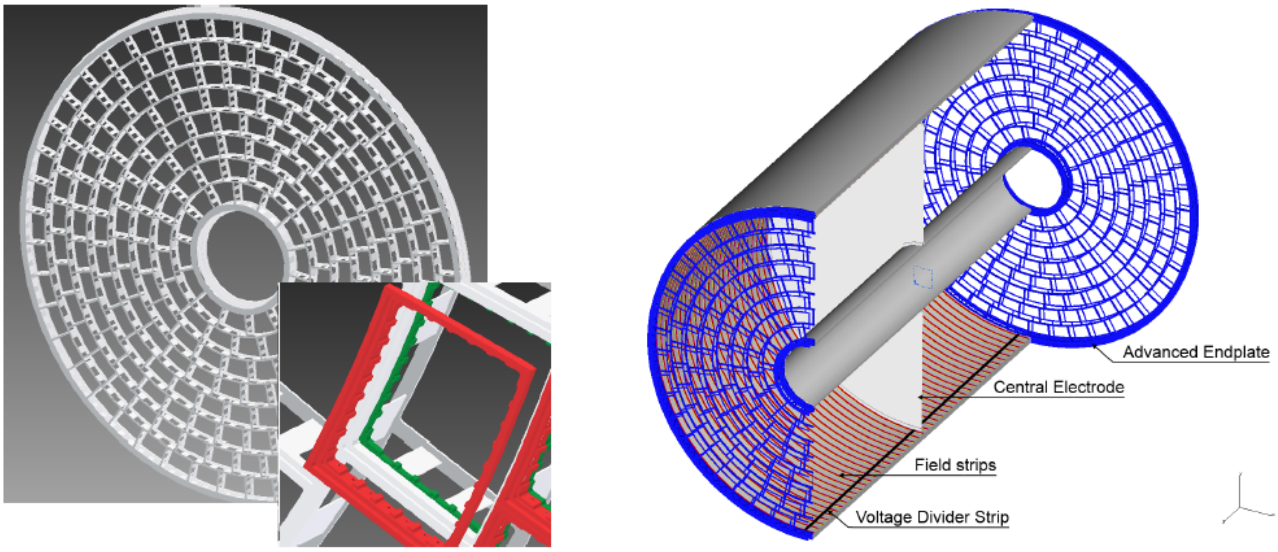
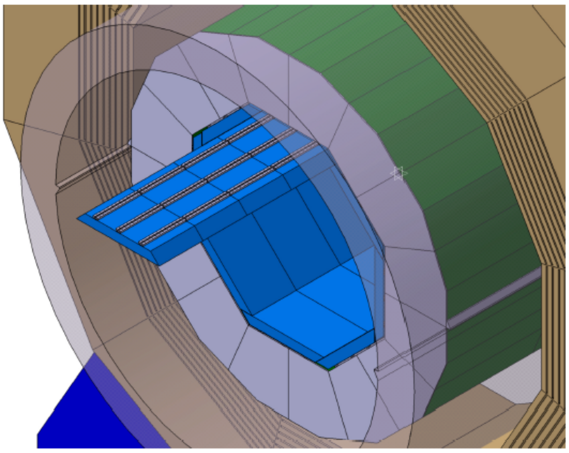
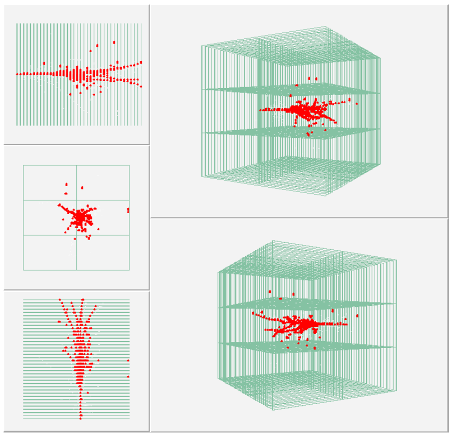
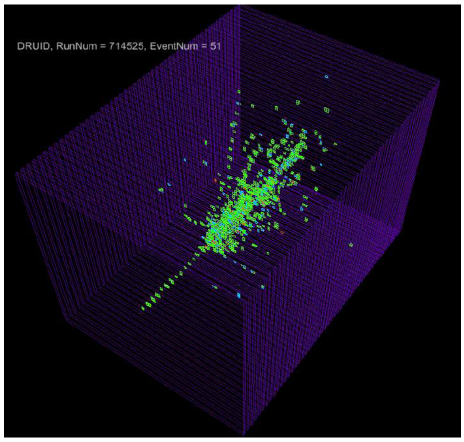


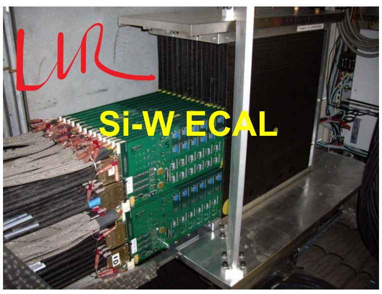
Figure III-2.11. Left: Drawing of the proposed end-plate for the TPC. In the insert a backframe which is supporting the actual readout module, is shown. Right: Conceptual sketch of the TPC system showing the main parts of the TPC (not to scale).

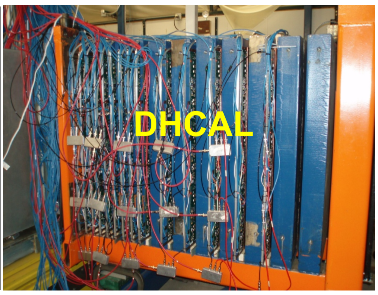
Calorimeter R&D for ILD











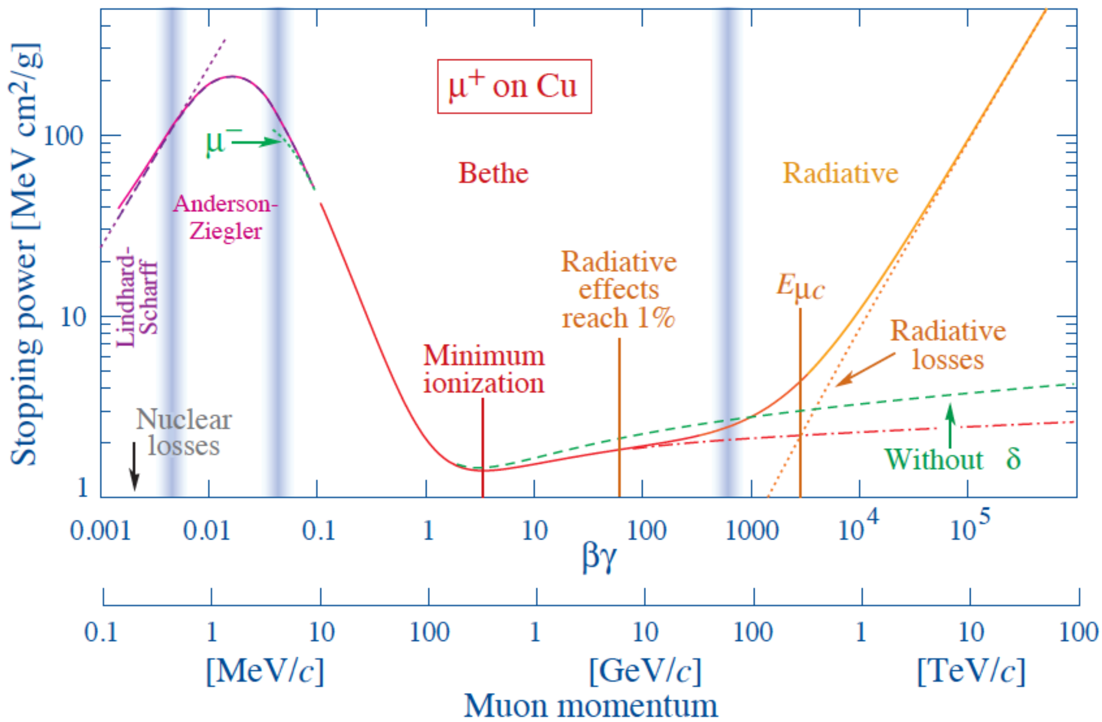
Ultra high granularity ~ 1 channel cm^{-3}. 3d, 4d or 5d image...

CEPC Detector structure

- Tracking system
  - Made of light materials (Air as for the TPC, Si for VTX)
  - Used to measure trajectories of charged particle
- Calorimeter system,
  - Made of heavy, dense and thick material (W, Fe as for absorber)
  - Used to measure energy deposition of everything except neutrinos
- Both systems have very high granularity: to record as much information as we can
  - # channels ~ $o(10^8)$

Hit: particle – matter interaction

http://pdg.lbl.gov/2014/reviews/rpp2014-rev-passage-particles-matter.pdf



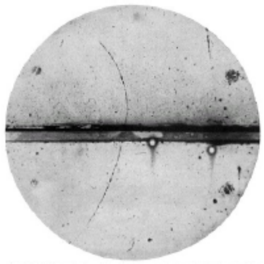
1GeV MIP Particle, penetrating 1 Meter of Iron.

Tracking: a bit history

- Cloud chamber

(a) Wilson

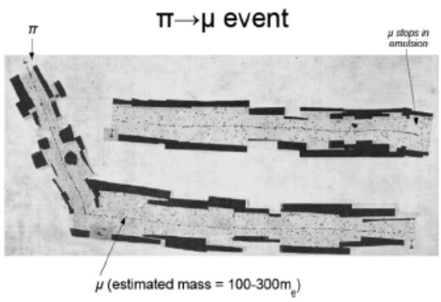
(b) Anderson



(c) Positron

- Nuclear emulsion: very high spatial resolution $\sim 1\ \mu\mathrm{m}$

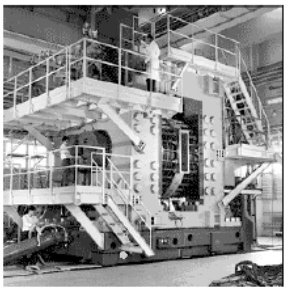
(a) Powell



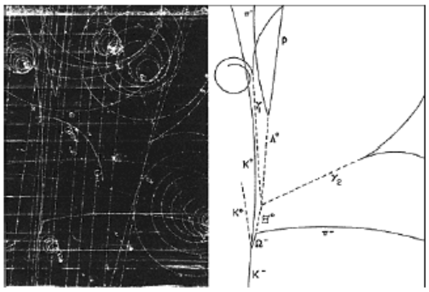
(b) π decay

- Bubble chamber

(a) Glaser

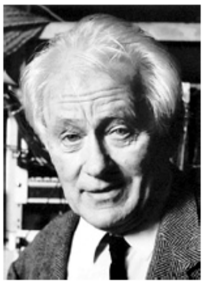


(b) B.C.

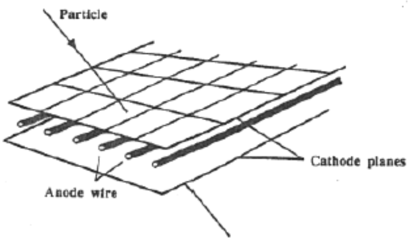


(c) Ω^-

- Multi Wire Proportional Chamber: electronic readout $\Longrightarrow$ fast



(a) Charpak



(b) MWPC

- TPC is a modern tracking detector invented by D. Nygren in 1970s[Kle98]

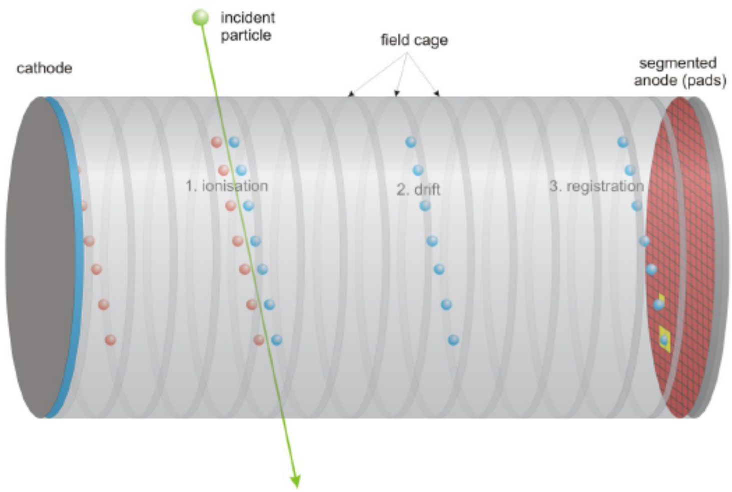


Figure 1 : The principle of TPC

Kalman Filter

For each site, Kalman filter algorithm has two steps:

- Prediction:

$$\boldsymbol{a}_k^{k-1} = \boldsymbol{f}_{k-1}(\boldsymbol{a}_{k-1}), \tag{4}$$

in which, $\boldsymbol{f}_k$ is propagation function[1]. And the corresponding **propagation matrix** is defined by

$$\boldsymbol{F}_{k-1} = \frac{\partial \boldsymbol{f}_{k-1}}{\partial \boldsymbol{a}_{k-1}}. \tag{5}$$

- Filtering:

$$\boldsymbol{a}_k = \boldsymbol{a}_k^{k-1} + \boldsymbol{K}_k \left(\boldsymbol{m}_k - \boldsymbol{h}_k(\boldsymbol{a}_k^{k-1}) \right), \tag{6}$$

where $\boldsymbol{K}_k$ is the gain matrix, $\boldsymbol{h}_k$ is the measurement function. It means the state vector is adjusted according to the predicted and real measurement.

http://indico.ihep.ac.cn/event/3825/contribution/10/material/slides/0.pdf

Tracking

- Input: spatial positions recorded by tracker sensors
- Output: tracks, parametrized as an helix:
  - Described by its curvature, direction, starting point and endpoints
  - Represent the momentum, charge of incident charged particle
  - Particle type information (Electronic signal ~ particle charge & mass)

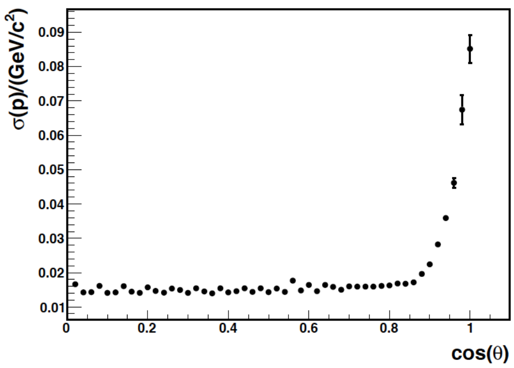


Fig. 4. Tracker Performance at different Polar angle

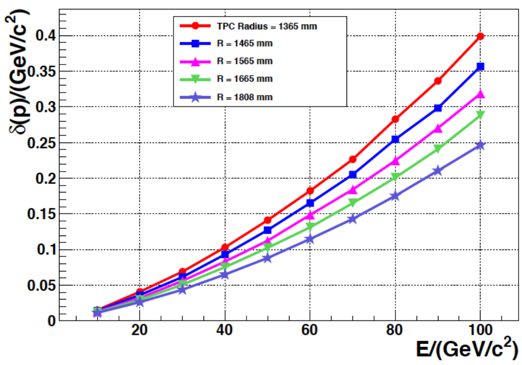
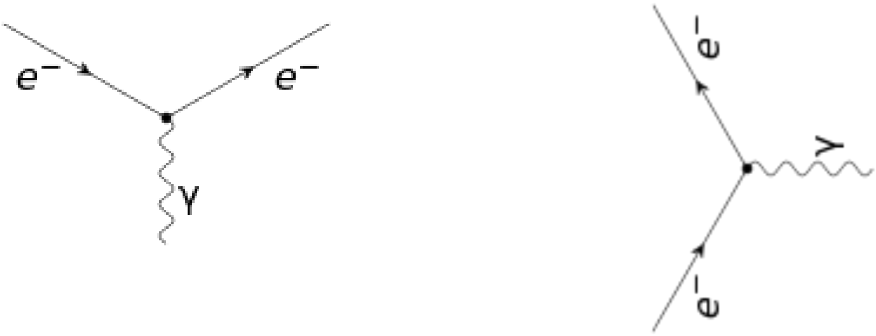


Fig. 6. Tracker Performance at different TPC Radius

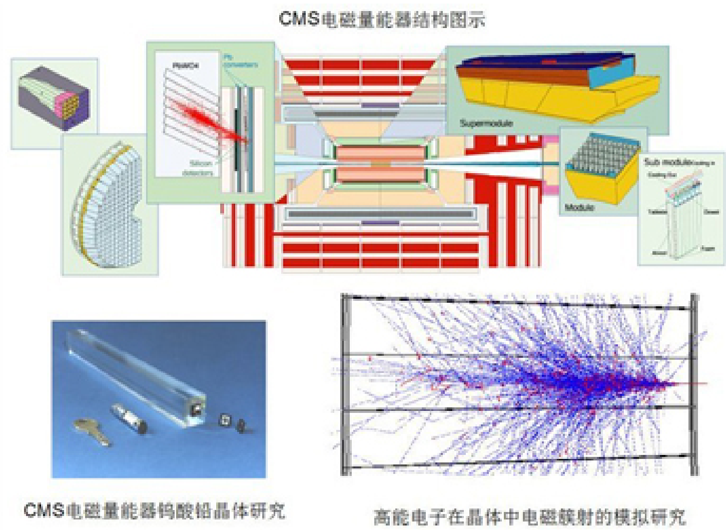
Calorimeter Shower

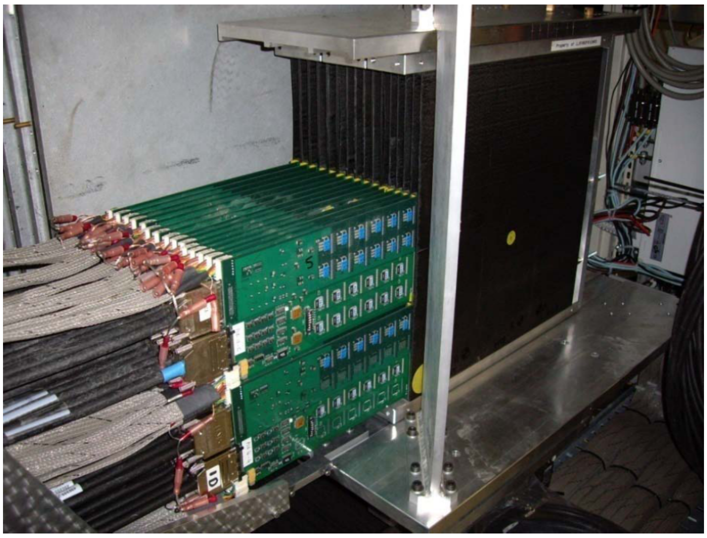
- Showers, clusters of hits, produced by various interactions
  - Minimal ionization
  - EM interactions: pair production and bremsstrahlung



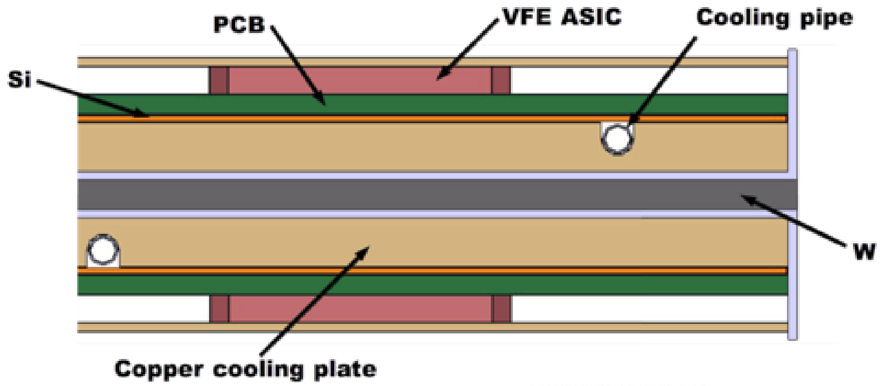
  - Hadronic interaction: many interactions
    - Pi+ + N - pi0 + P - Proton + di photon
    - ...

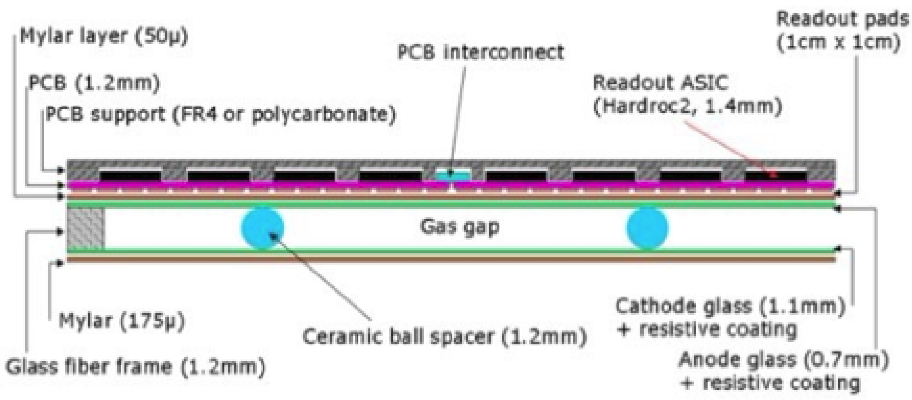
Energy Vs Spatial information



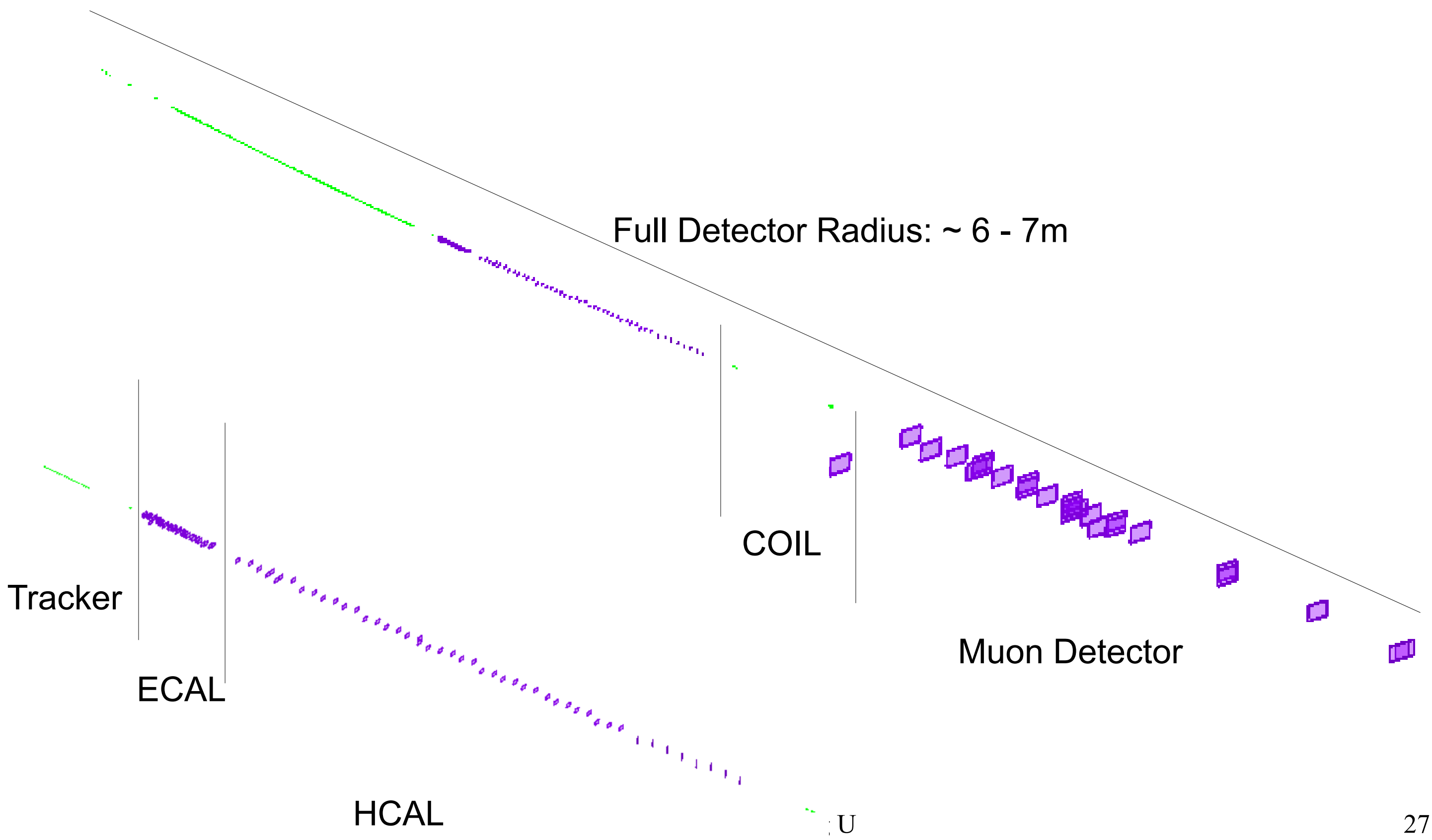


Sampling Calorimeter Structure

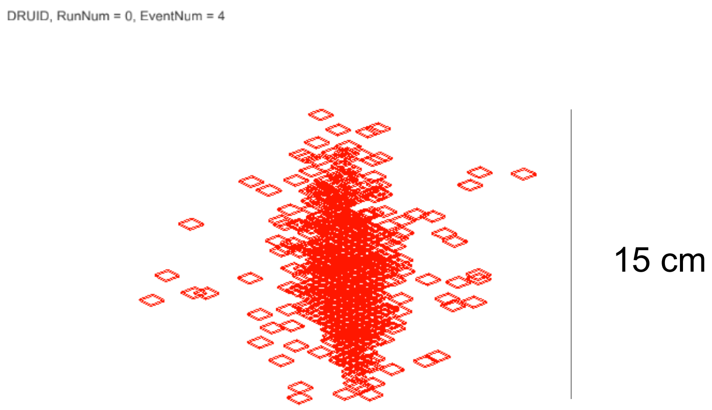




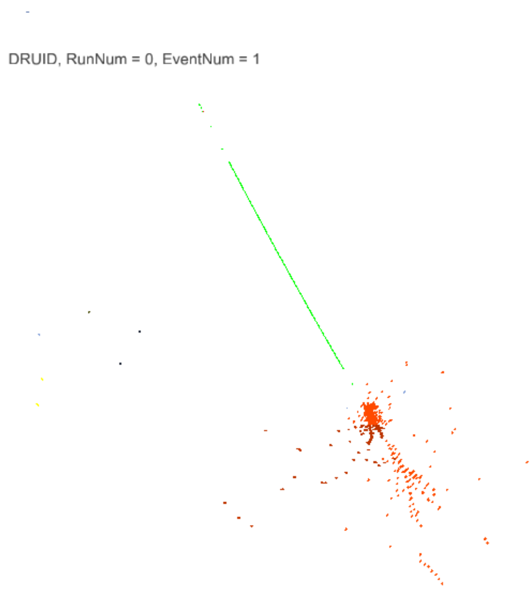
Calorimeter: MIP signal

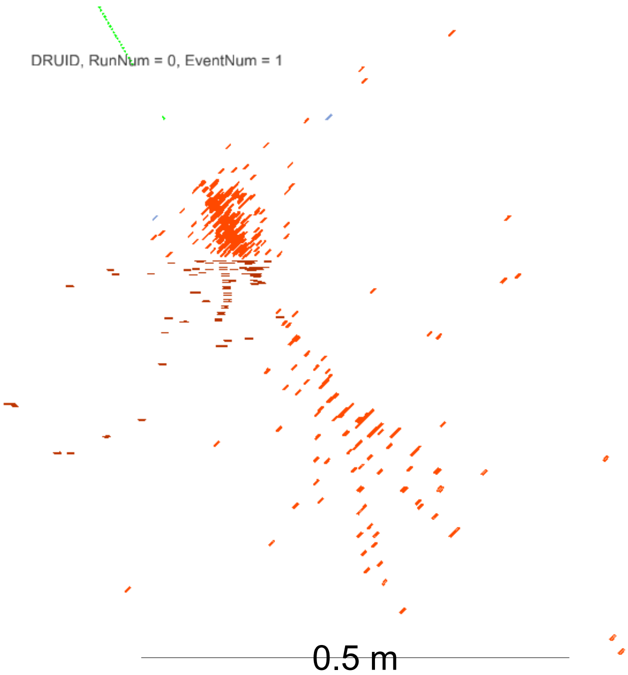


Calorimeter: EM Signal



Calorimeter: Hadronic Signal

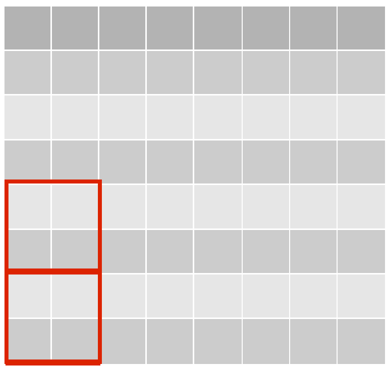




Fractal dimension of particle shower

$$FD_\beta = \left\langle \frac{\log(R_{\alpha,\beta})}{\log(\alpha)} \right\rangle + 1.$$

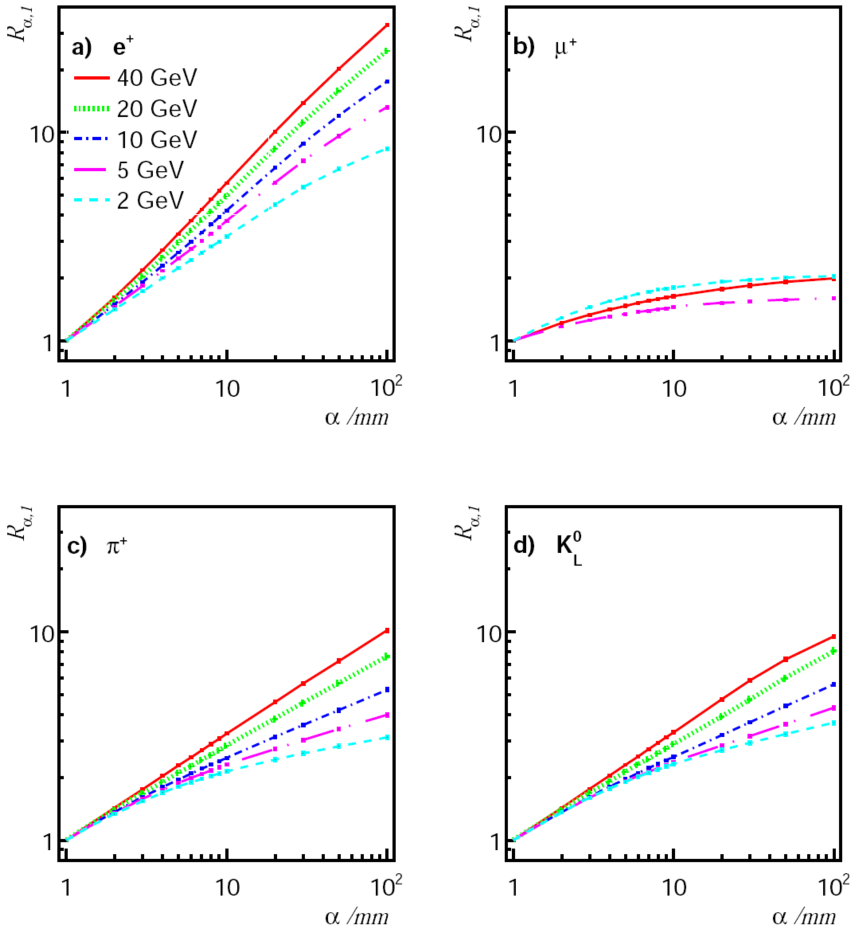
$$R_{\alpha,\beta} = N_\beta / N_\alpha.$$



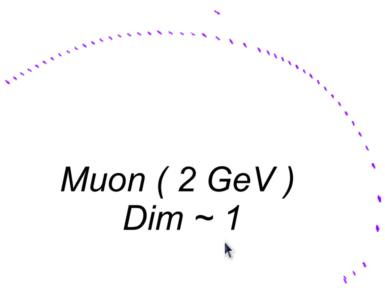
Ultimate cell size: 1mm

Resize cell: 2 – 10, 20, 30, 50, 60, 90, 120, 150 mm.

Sample: particle gun events at ILD SDHCAL

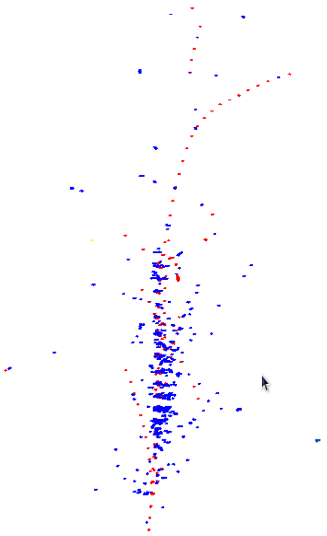


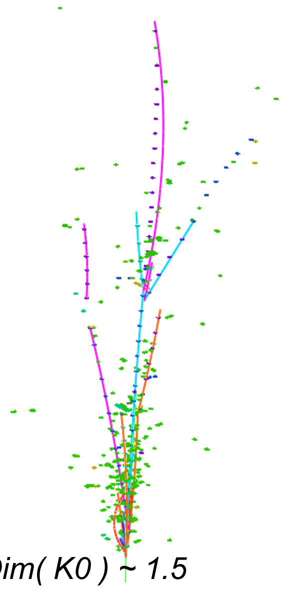
Fractals in Nature



Muon (2 GeV)
Dim ~ 1

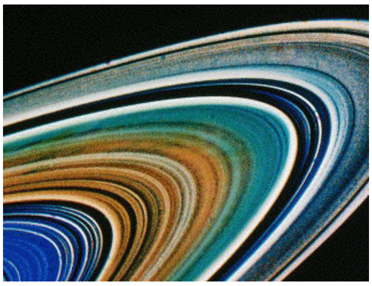
Straight line:
Dim = 1

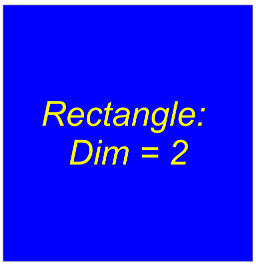




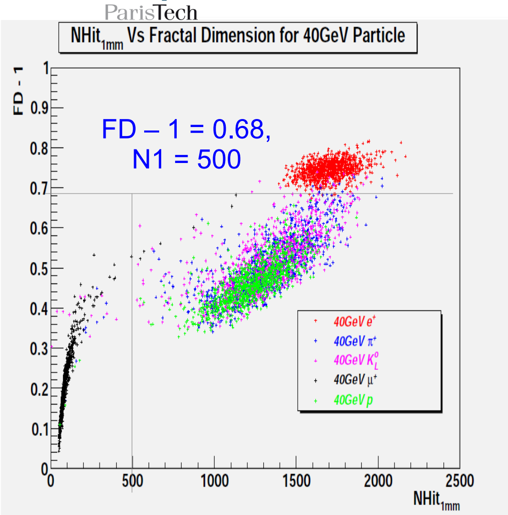
Hadrons: Dim(pi) < Dim(K0) ~ 1.5

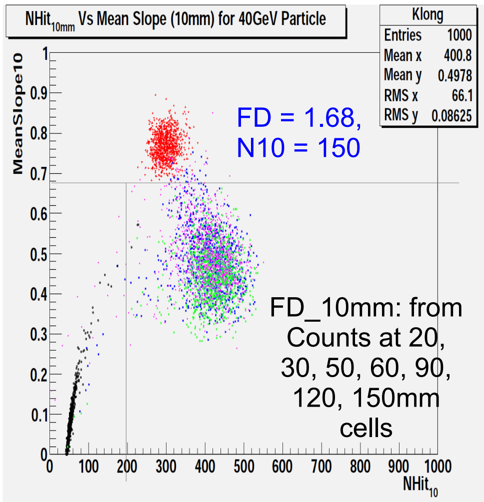
Positron (40GeV)
Dim ~ 1.75

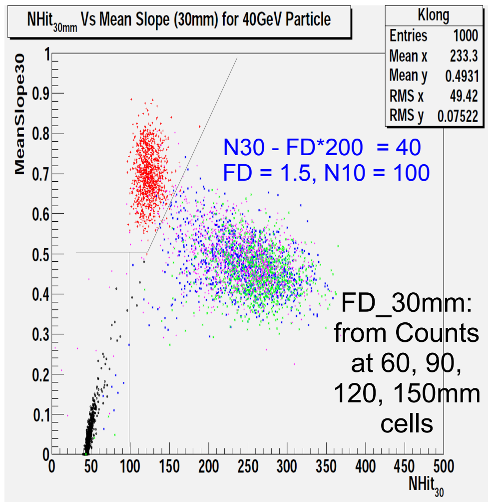




Potential tool for PID







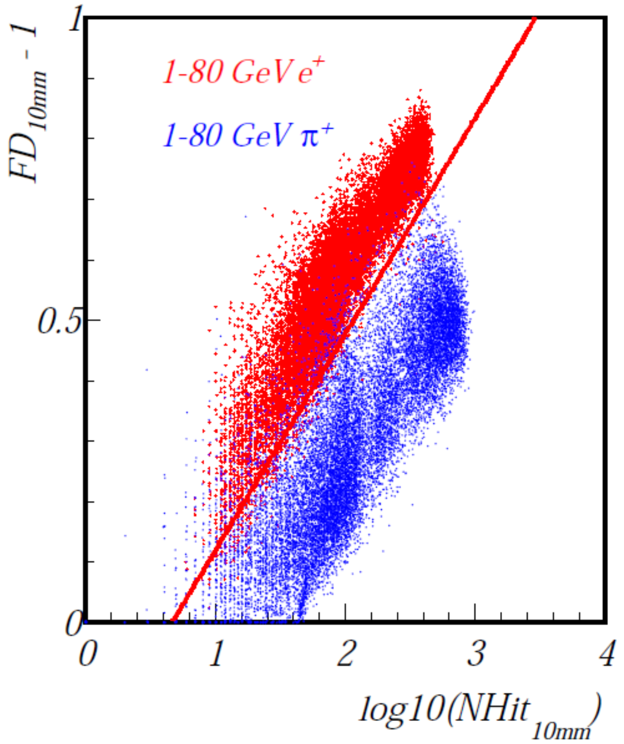
FD together with hit counts: Clear separation at different scales

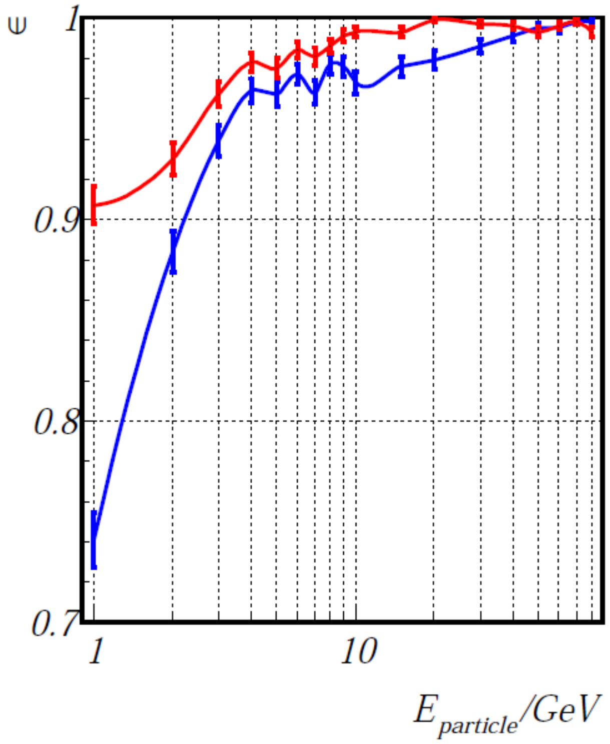
1mm	e+	u	h
e+	998	0	2
u	1	994	5
h	15	14	971

10mm	e+	u	h
e+	1000	0	0
u	0	995	5
h	17	14	969

30mm	e+	u	h
e+	1000	0	0
u	0	996	4
h	18	11	971

Without knowing energy information





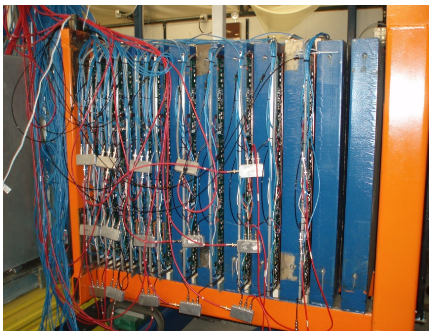
Remark: FD is only the transverse shower information...

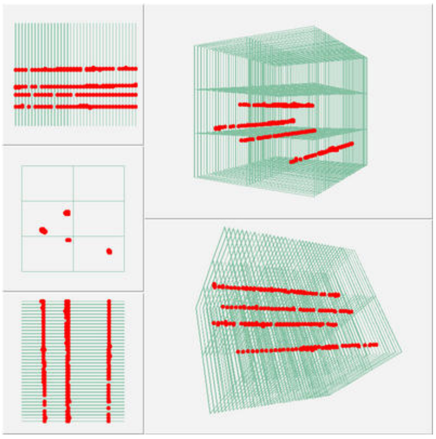
Promising PID over full energy range

Logarithmic dependence on particle energy

$$FD_{1\mathrm{mm}}^{em}(E) = 1.41 + 0.21 \times \log_{10}(E/\mathrm{GeV})$$
$$FD_{1\mathrm{mm}}^{had}(E) = 1.24 + 0.15 \times \log_{10}(E/\mathrm{GeV})$$
$$FD_{1\mathrm{mm}}^{mip}(E) = 1.2$$

In Real data

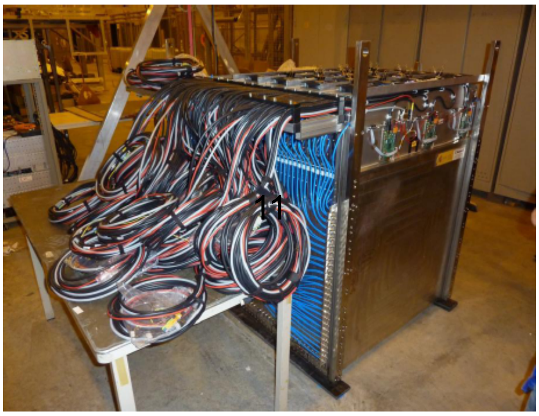




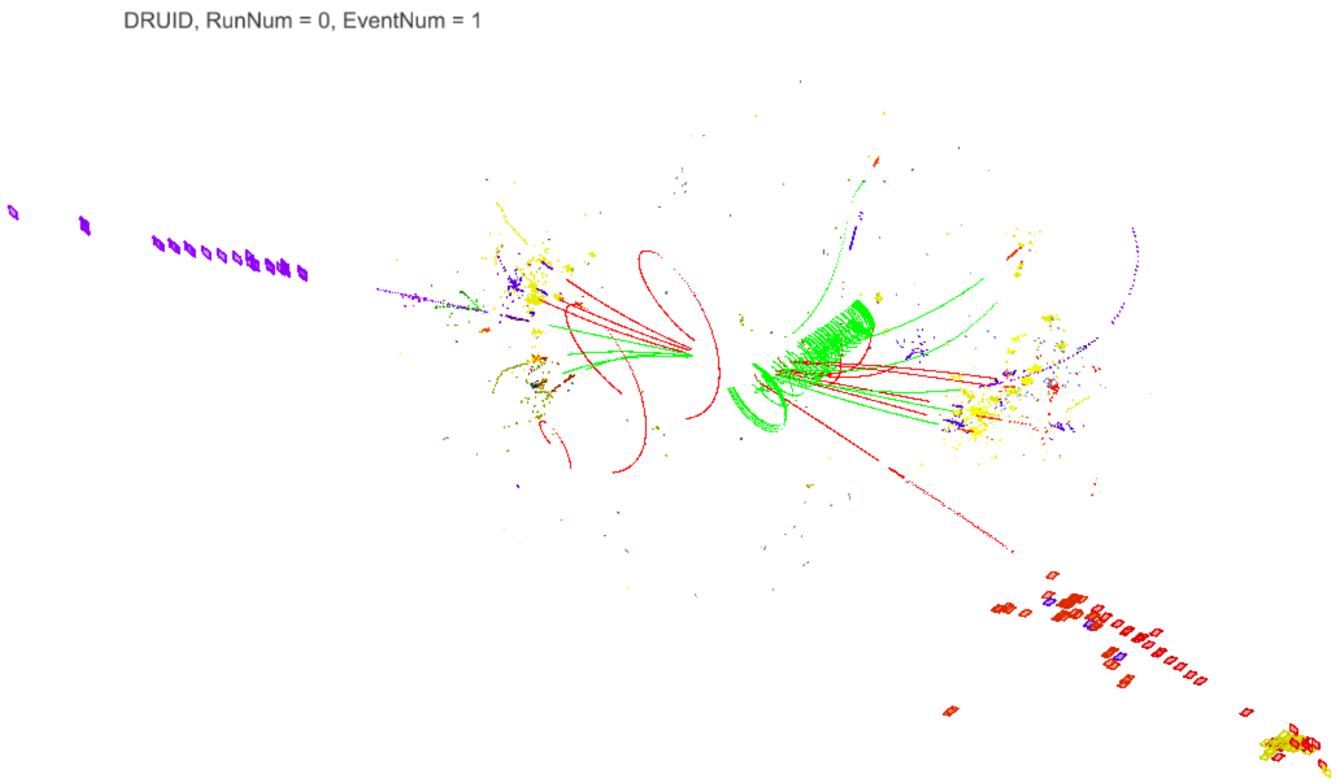
Fermi lab test beam, multiple muon events
Signal triggered by pairs of scintillator tile located
in the front/end of the prototype.

ÉCOLE
POLYTECHNIQUE
ParisTech

In Real data



CERN SPS Test beam experimental data
Extremely low noise rate - triggleless mode: Significant cosmic ray component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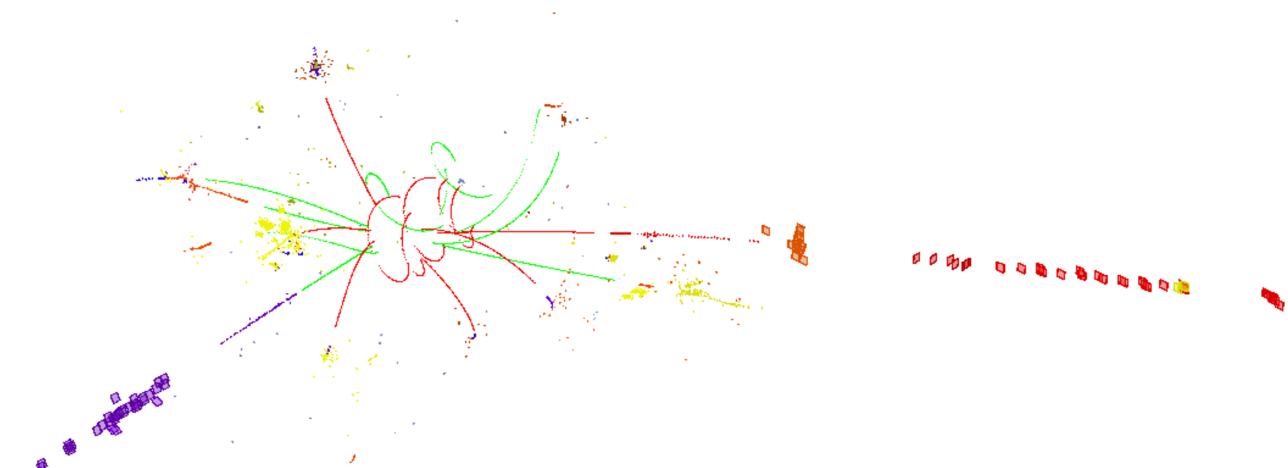
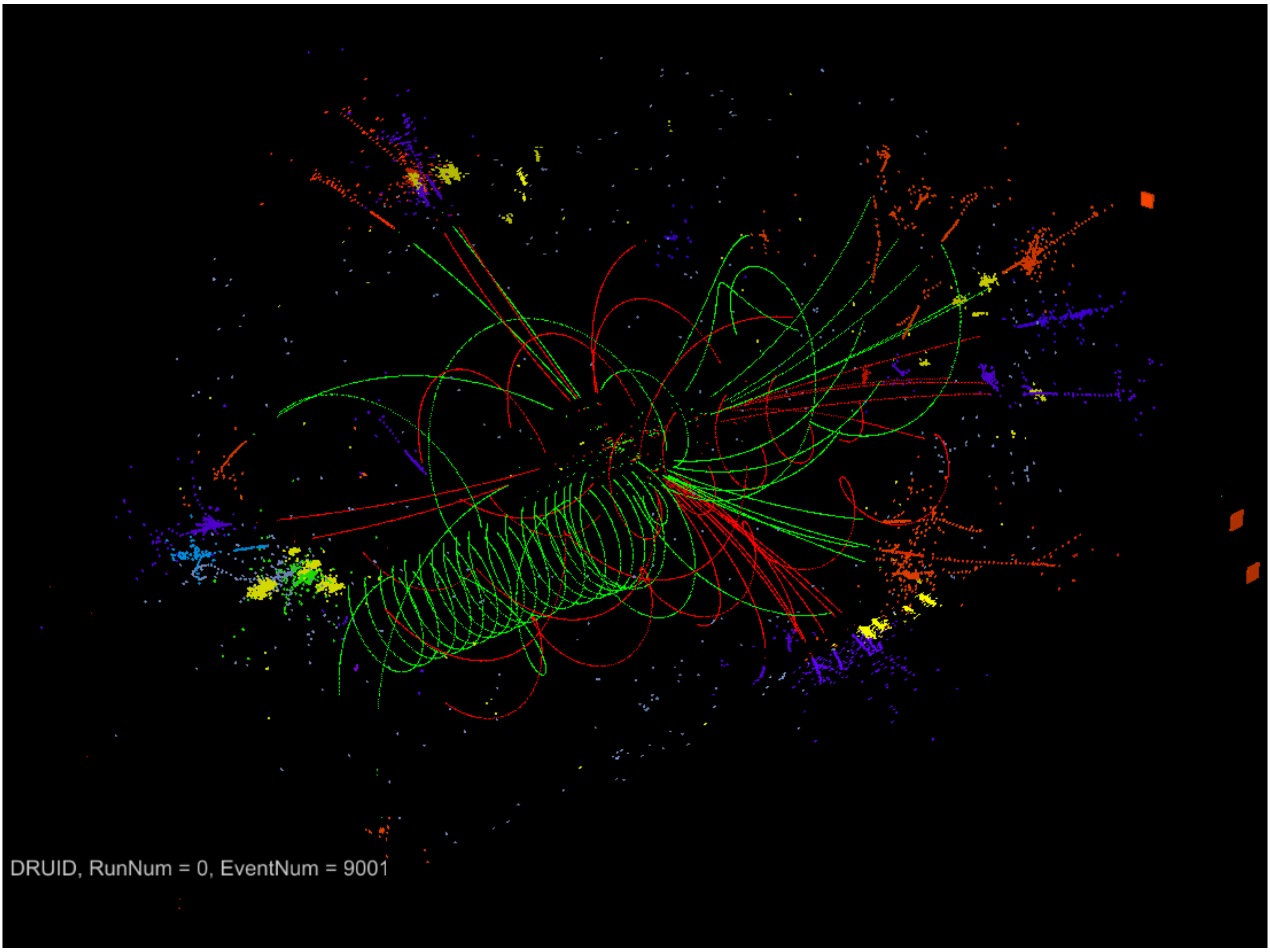
DRUID, RunNum = 0, EventNum = 2

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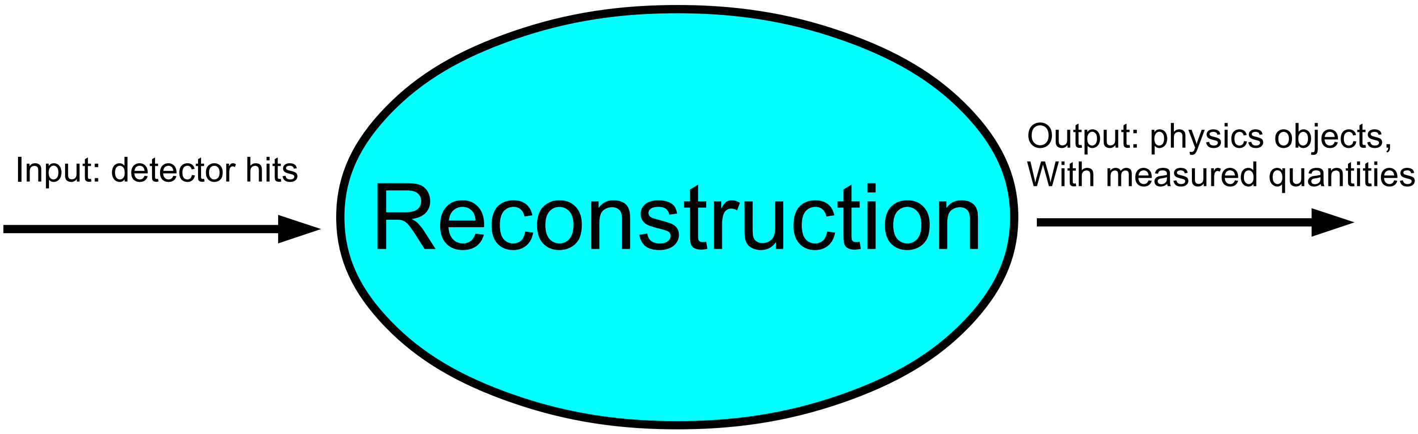


Detector hits, from every sub detector:
- Tracking System: VTX, tracker,
- Calorimeter, Muon, Forward...

Physics object: Lepton, Photon, Jets, Taus, MET, ...

Reconstruction

- At sub-detector level
  - Tracker: build tracks with tracker hits & tracking algorithm
  - Calorimeter: build calorimeter clusters with calorimeter hits
- Build final state particles (stable/quasi-stable)
- Build object composed with final state particles
  - Jets
  - Tau
  - MET

Some experiments builds jets directly from hits

Reconstruction

- At sub-detector level
  - Tracker: build tracks with tracker hits & tracking algorithm
  - Calorimeter: build calorimeter clusters with calorimeter hits
- Build final state particles (stable/quasi-stable)
- Build object composed with final state particles
  - Jets
  - Tau
  - MET

PFA

Some experiments builds jets directly from hits

Particle Flow Algorithm

Particle Follow Reconstruction

following, identify each individual final state particle

and reconstruct them in the most suited sub-detectors

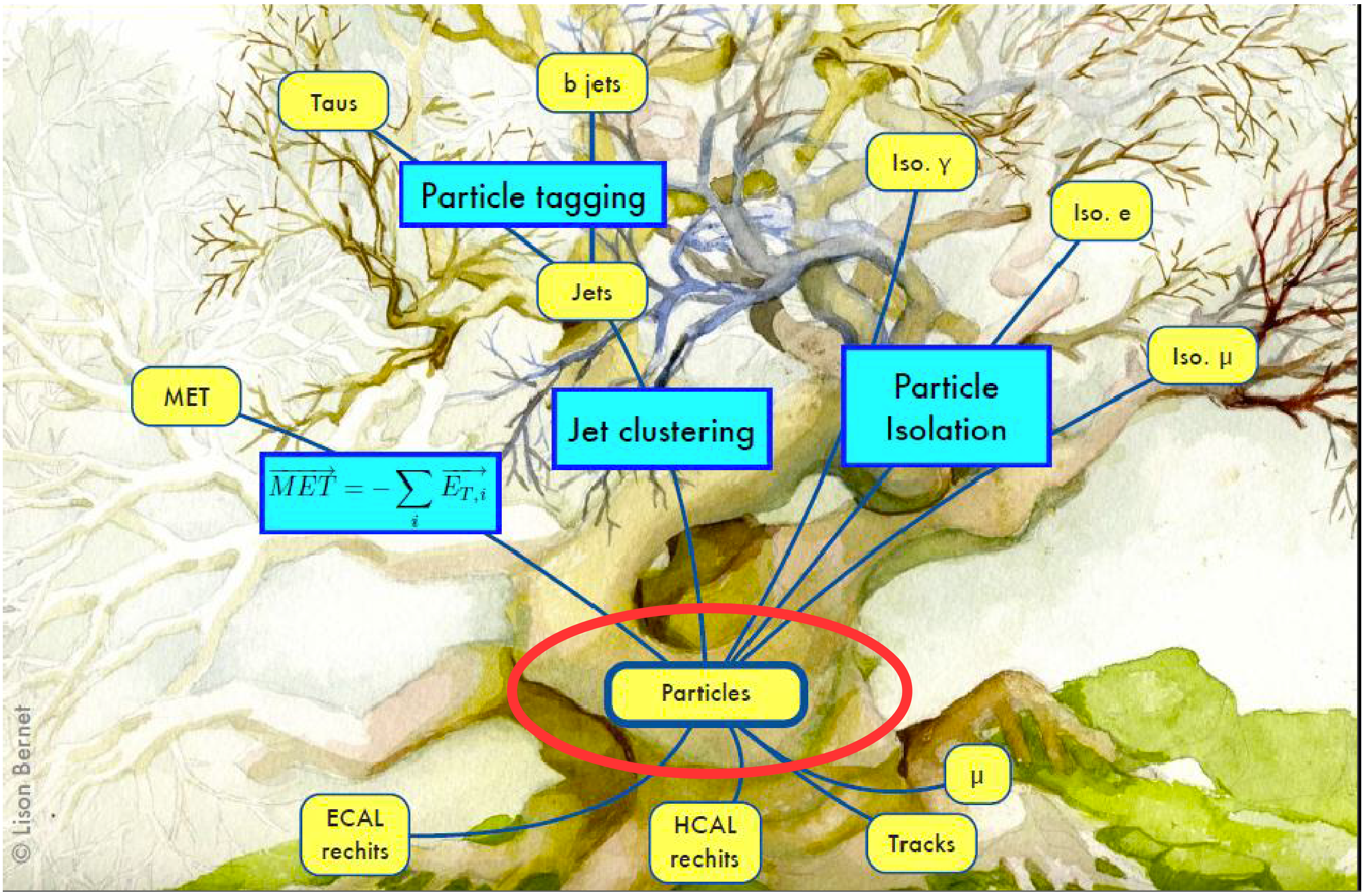
request excellent knowledge of **ALL** the sub-detectors

Originated from ALEPH

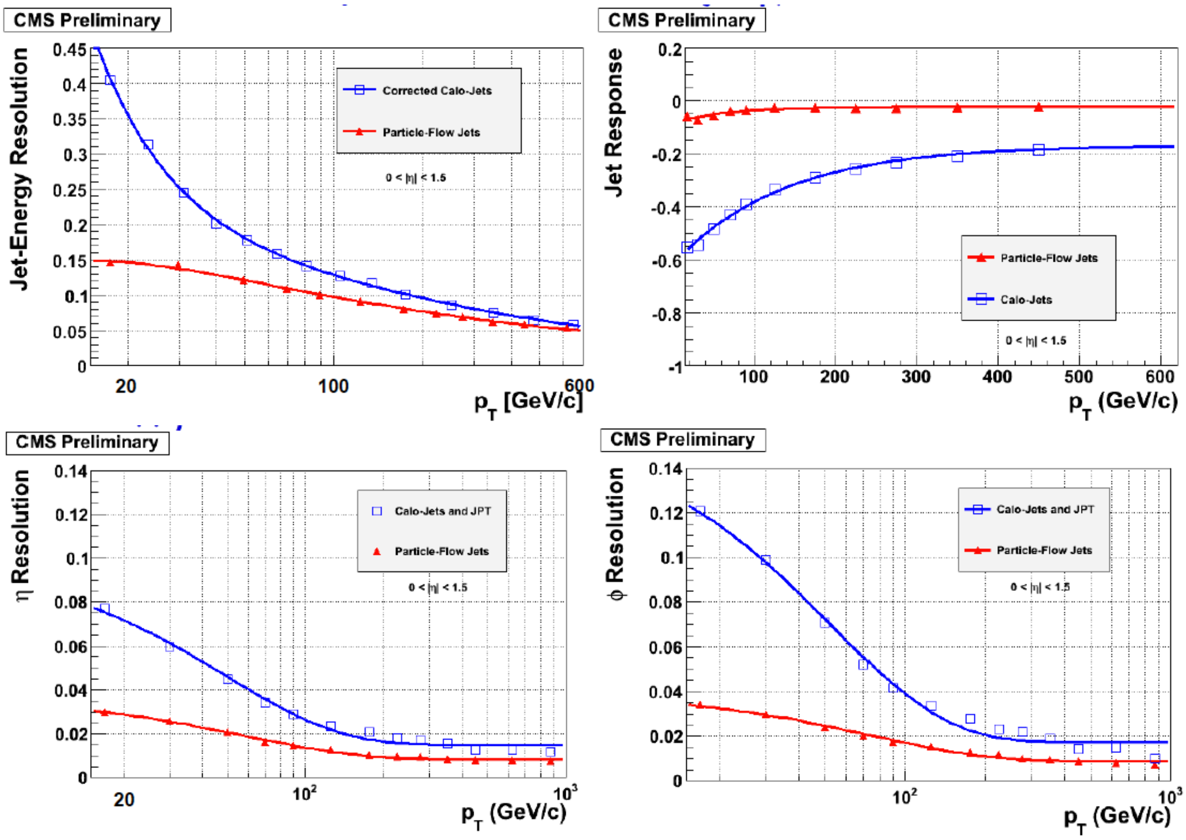
Provide the same basis for finding all physics object: final state particles!

Provide excellent jet energy resolution.

Key requirement: Separate showers & understand patterns

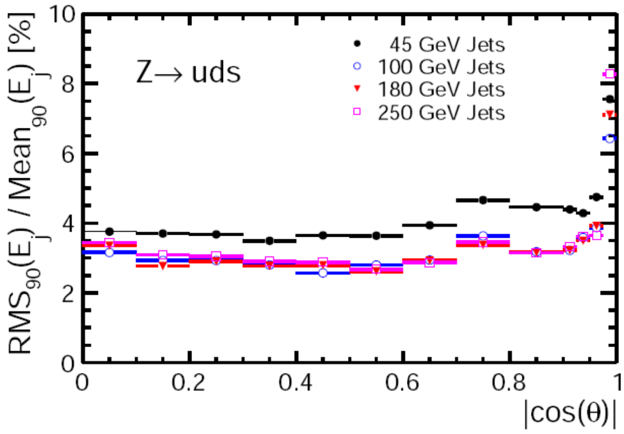

b jets
Taus
Particle tagging
Iso. γ
Iso. e
Jets
Iso. μ
MET
Particle Isolation
Jet clustering
$\overrightarrow{MET} = -\sum_i \overrightarrow{E_{T,i}}$
Particles
μ
ECAL rechits
HCAL rechits
Tracks
© Lison Bernet

PFA Performance at CMS

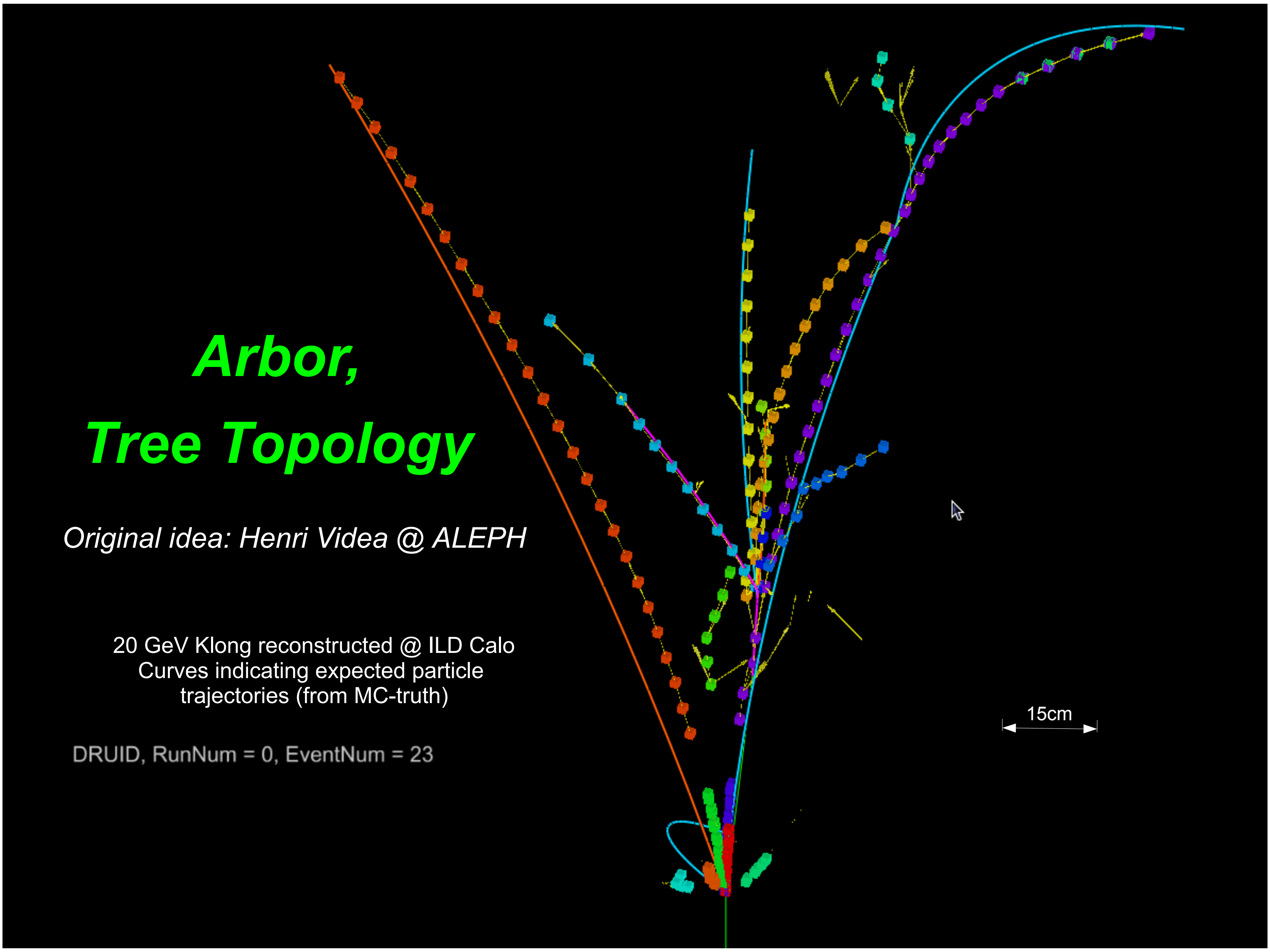


PFA @ ILC

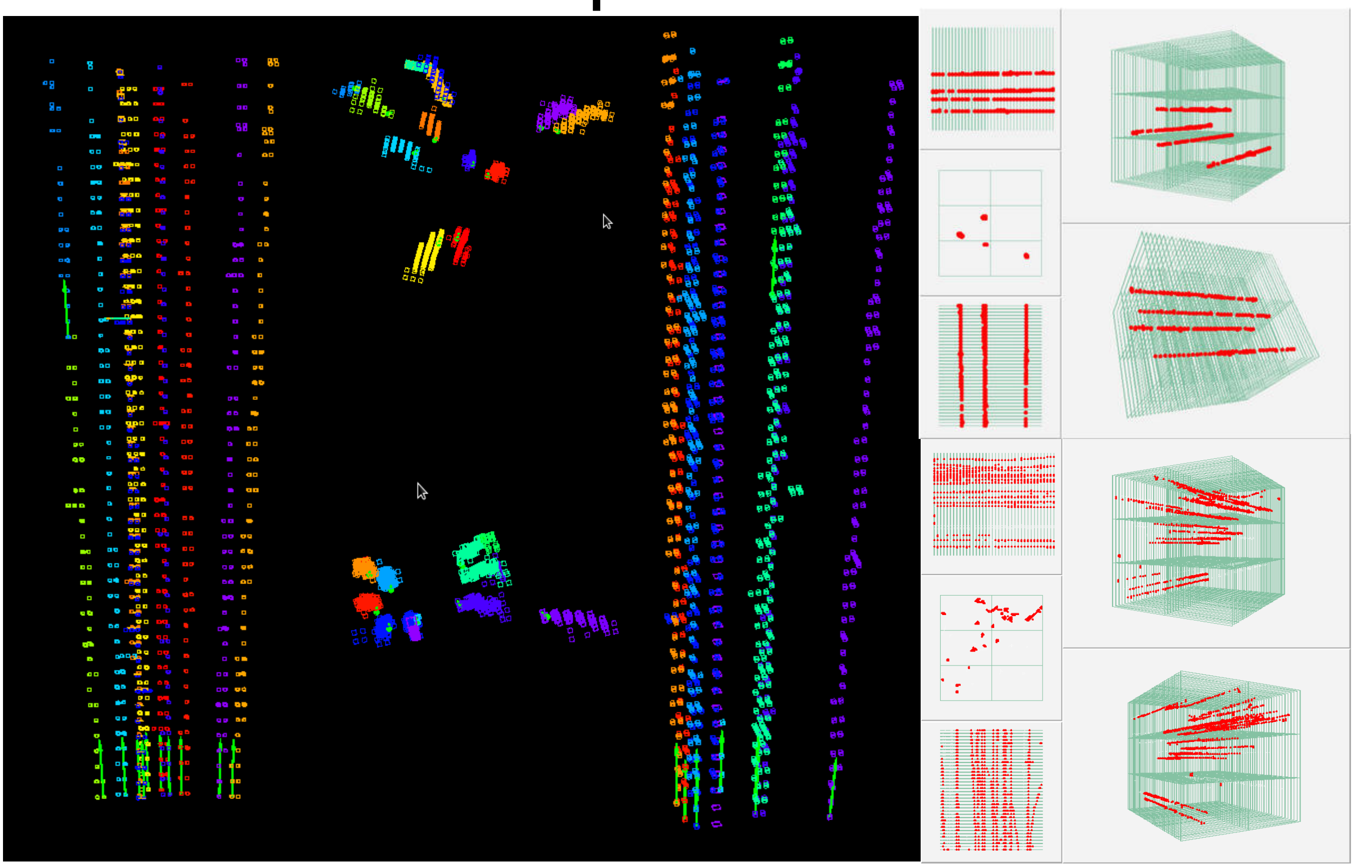
Multi bosons	Multifermions + Boson(s)
ZH	e^+e^- H , e+e- Z
WW	νν H , νν Z
ZZ	ttH
ZHH	e ν W
ZZZ	νν WW, νν ZZ
ZWW	ttbar



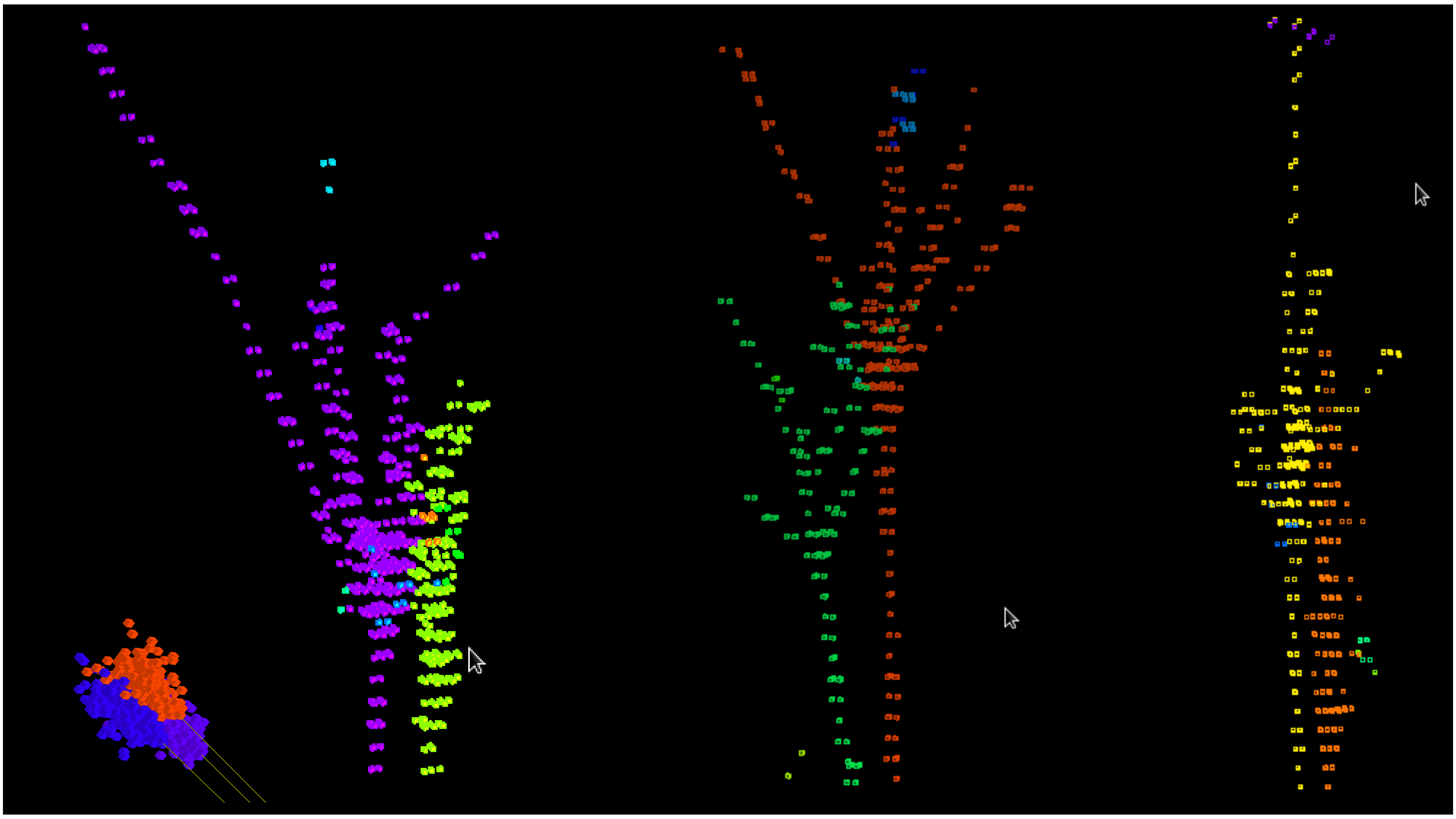
- LC detector: precisely identify and measure final state particles (*visible*)
  - Calorimeter: jet energy, PID
- Available:
  - *Pflow, SiD-IowaPFA, Trackwise Clustering...*
  - **PandoraPFA**: achieves the Benchmark requirement: δE/E ~ 3%


Arbor,
Tree Topology
Original idea: Henri Videa @ ALEPH
20 GeV Klong reconstructed @ ILD Calo
Curves indicating expected particle
trajectories (from MC-truth)
DRUID, RunNum = 0, EventNum = 23
15cm

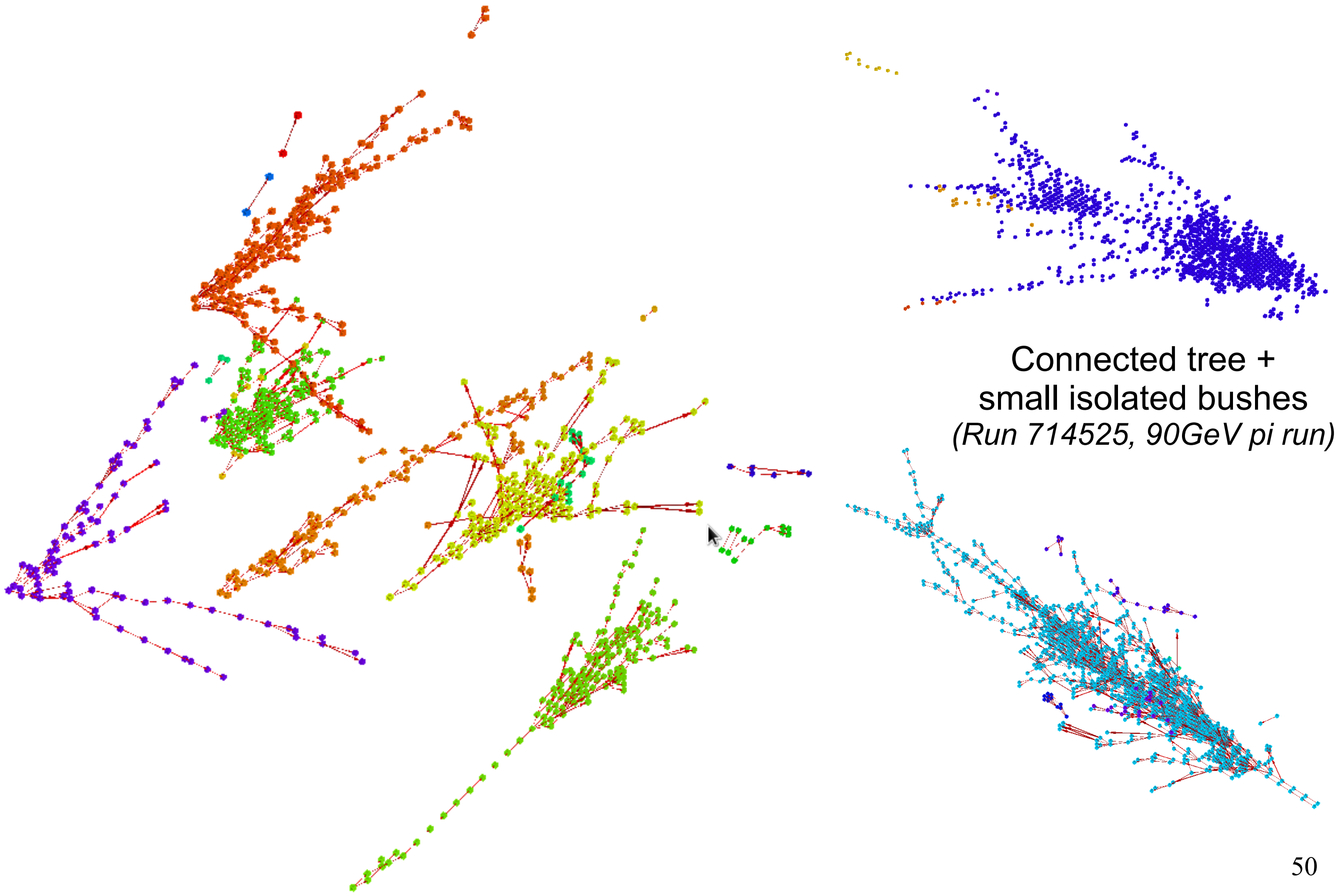
Separation: multiple muon



Separation:
overlay showers

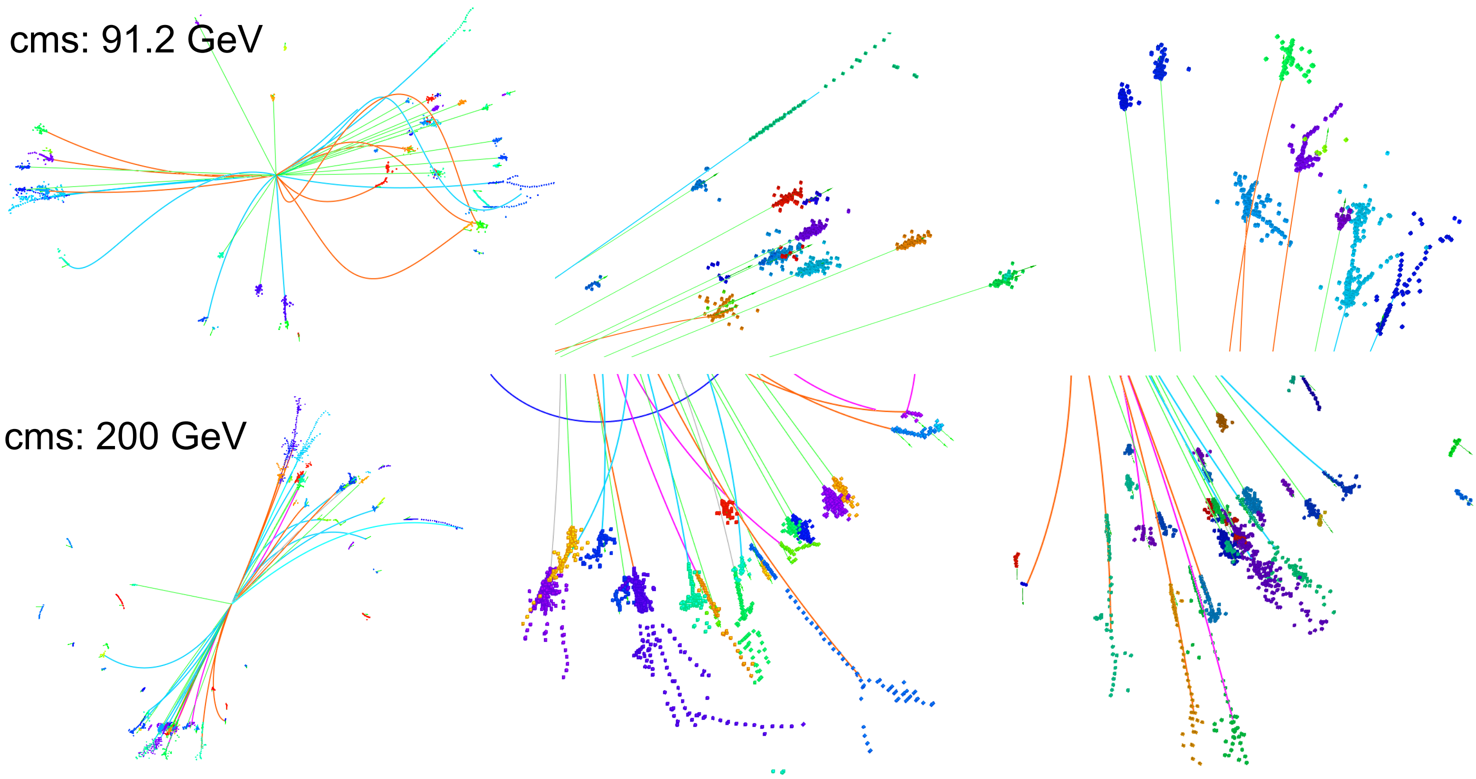


Test beam data

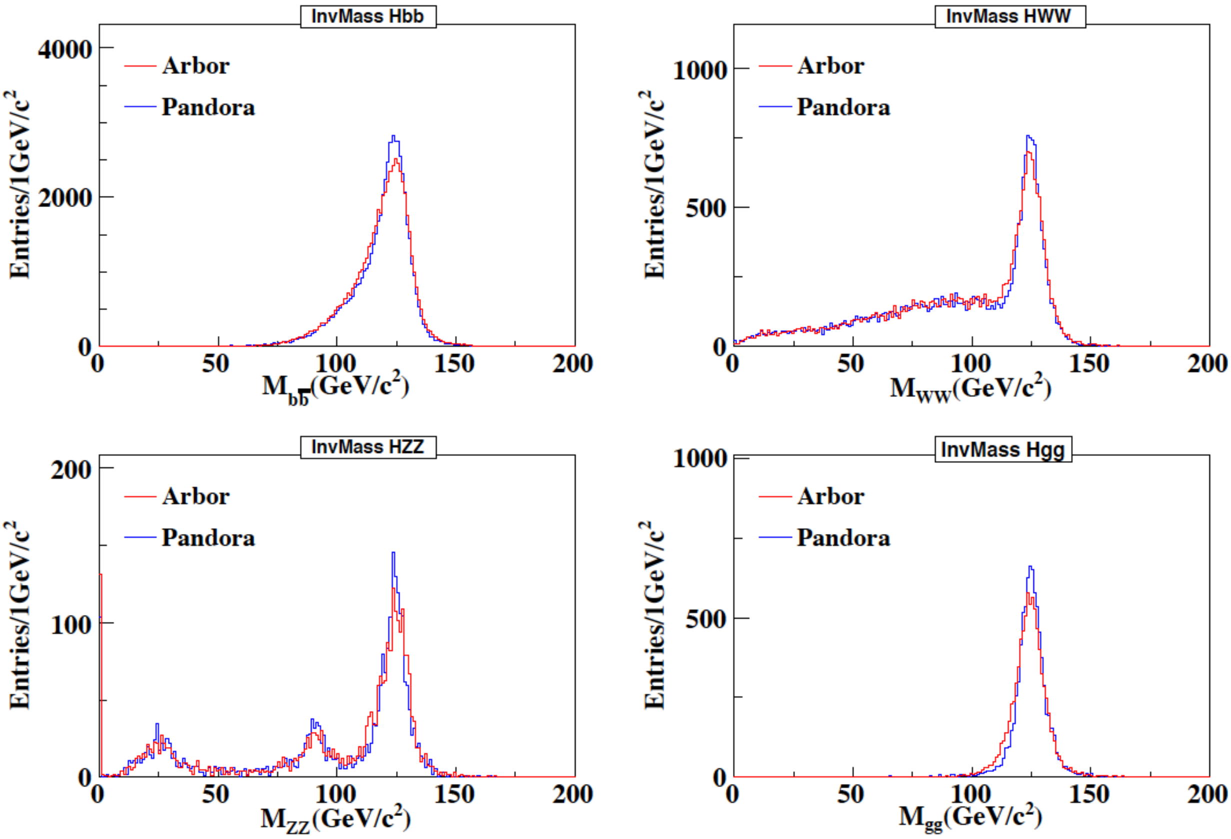


Connected tree +
small isolated bushes
(Run 714525, 90GeV pi run)

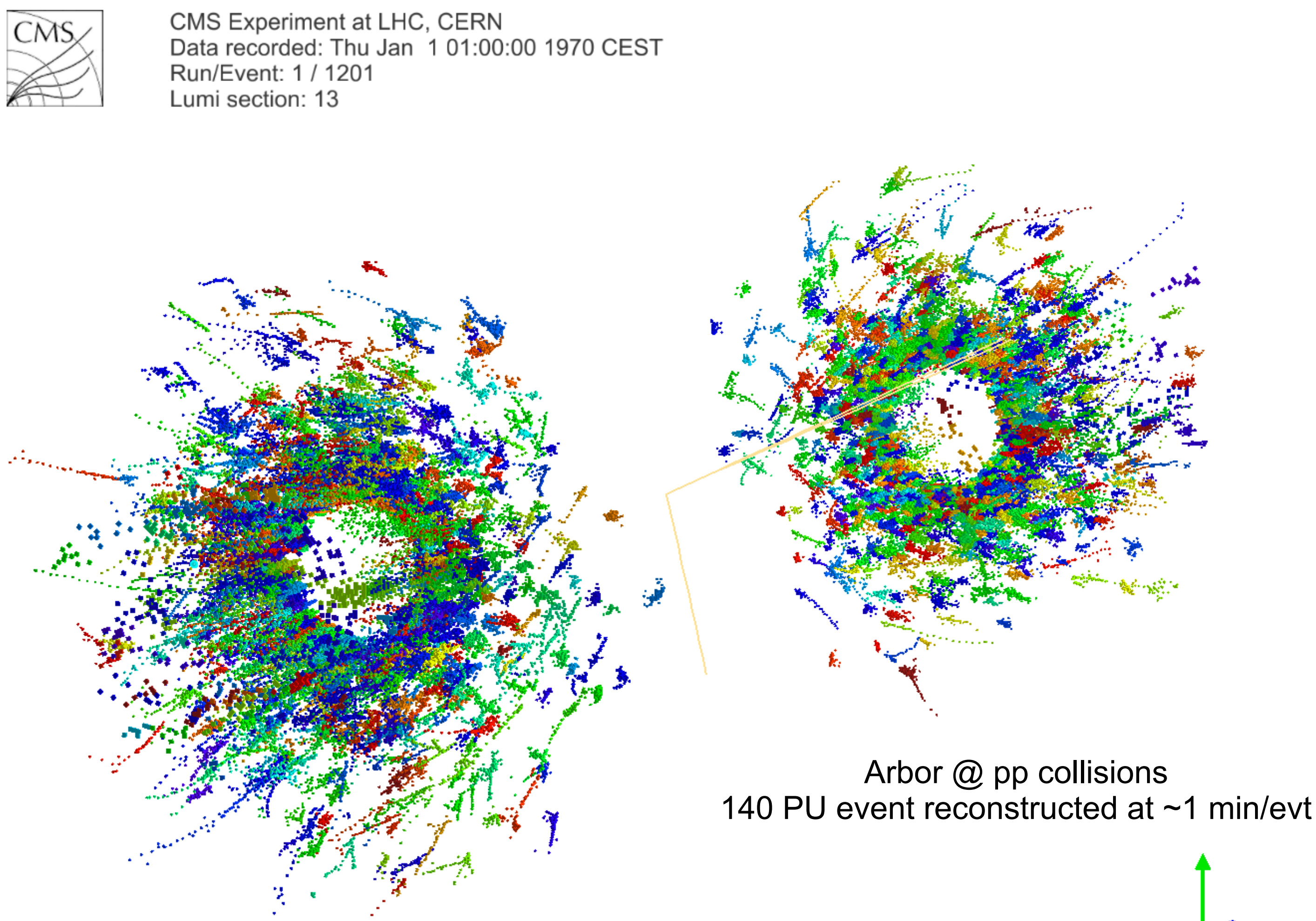
Jet: qq event



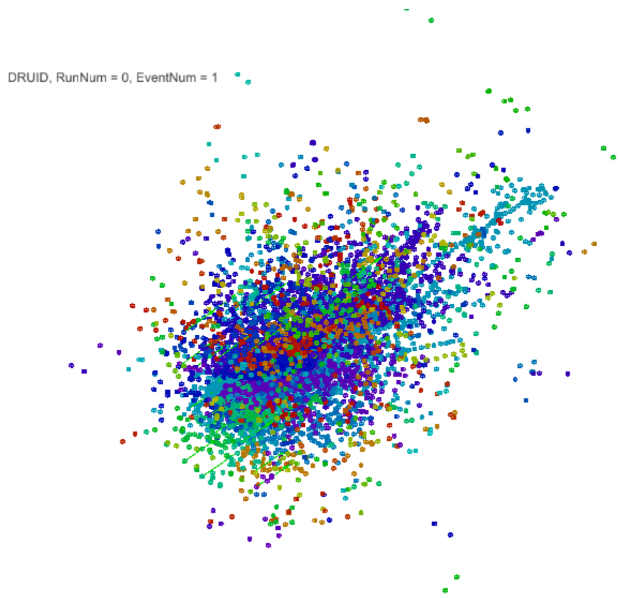
Energy Resolution



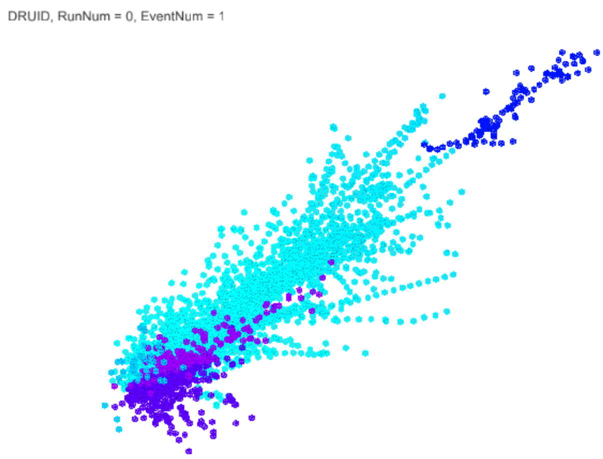
Invariant mass of vvH events: Still tuning...


CMS
CMS Experiment at LHC, CERN
Data recorded: Thu Jan 1 01:00:00 1970 CEST
Run/Event: 1 / 1201
Lumi section: 13
Arbor @ pp collisions
140 PU event reconstructed at ~1 min/evt

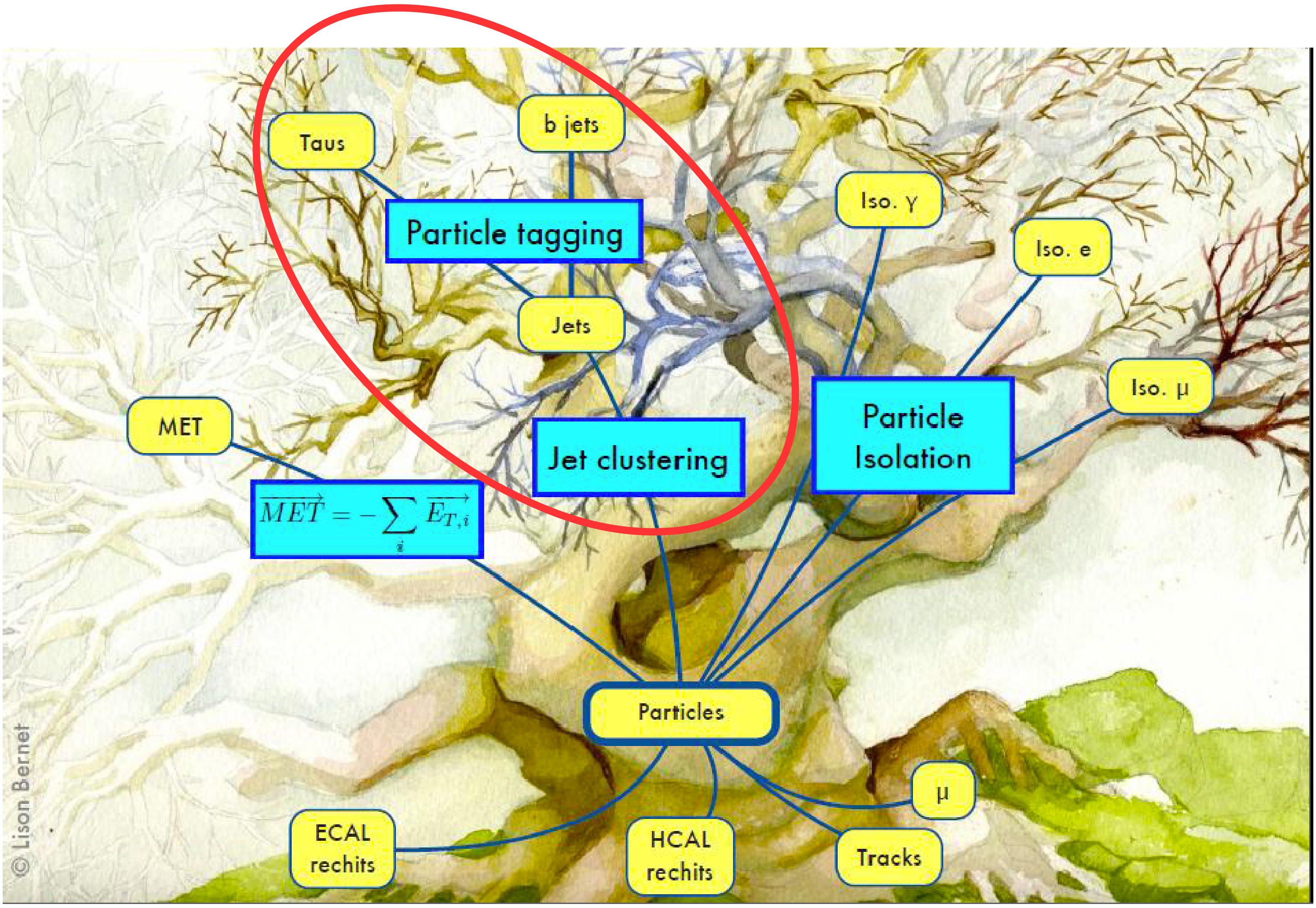
1 TeV pion reconstruction



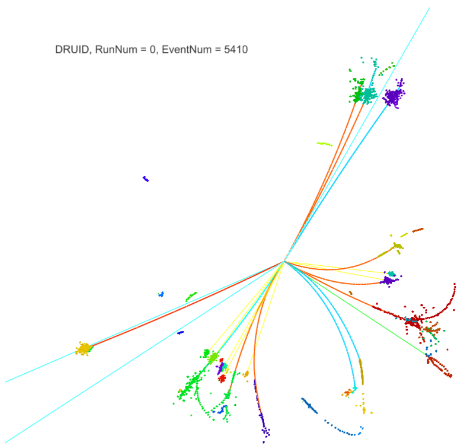
Original Version

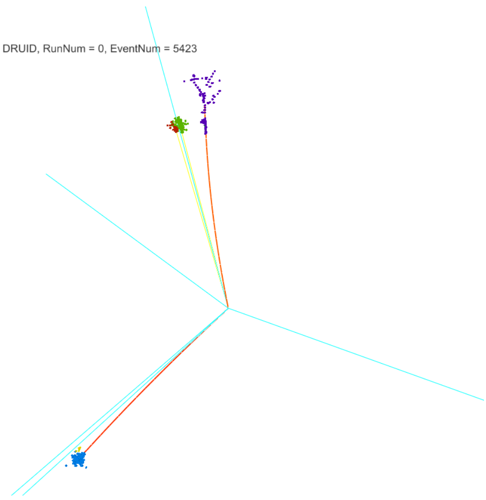


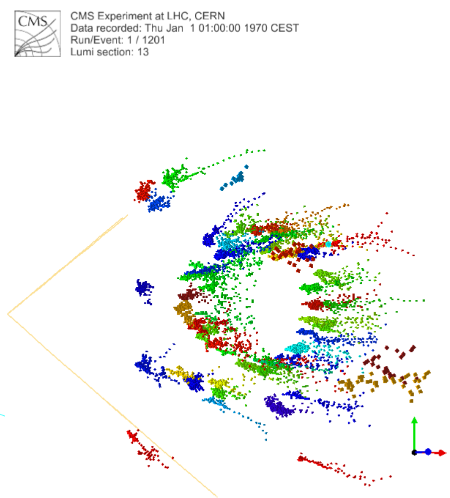
Cleaned with hit energy/time information


Taus
b jets
Particle tagging
Jets
Iso. γ
Iso. e
Iso. μ
MET
Jet clustering
Particle Isolation
$\overrightarrow{MET} = -\sum_i \overrightarrow{E_{T,i}}$
Particles
μ
ECAL rechits
HCAL rechits
Tracks
© Lison Bernet

Finding Tau: hints







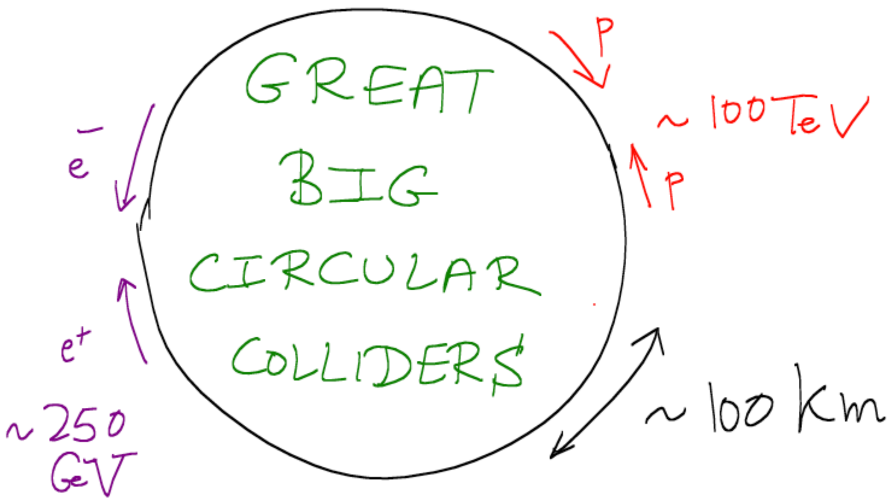
Tau decay

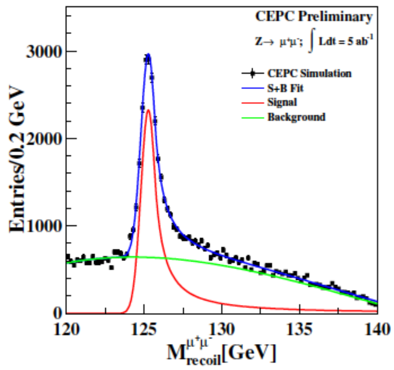
One Prong:

E + 2V	*18%*
Mu + 2V	*17%*
H + V	*11.5%*
H+pi0+V	*26%*
H+2pi0+V11%	
H+3pi0+V1%	

Three Prong: *15%*

Event Reconstruction at CEPC

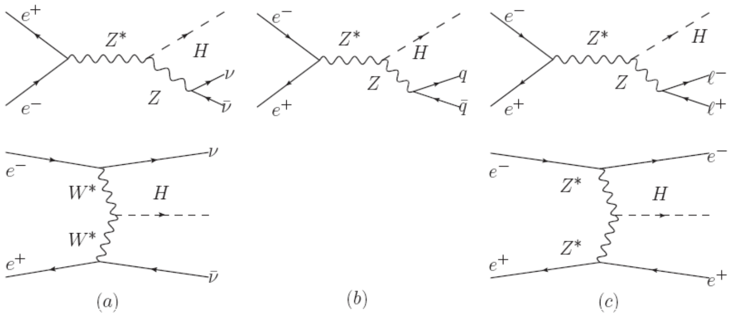




14 SM Higgs observables

- From 100k – 1M Higgs: Direct observables
  - Mass, spin, σ(ZH)
  - Branching ratios (b, c, tau, g, W, Z)
  - Branching ratios (gamma, mu)

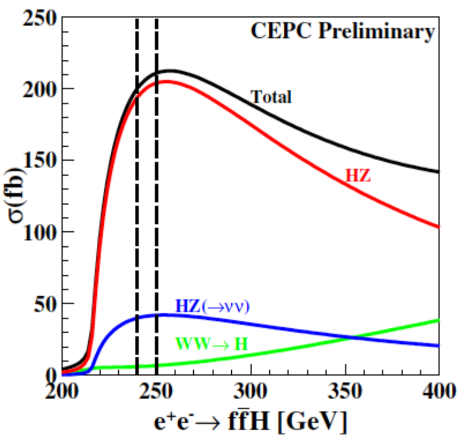
    +
  - Invisible Branching ratio
  - σ(vvH)*Br(H→bb)
- Measured from all sub-channels..
- Calculate: width – coupling

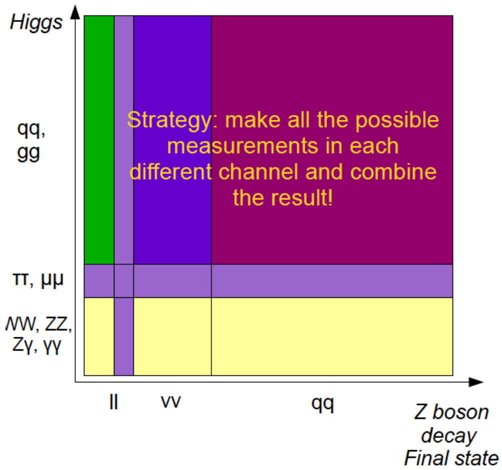


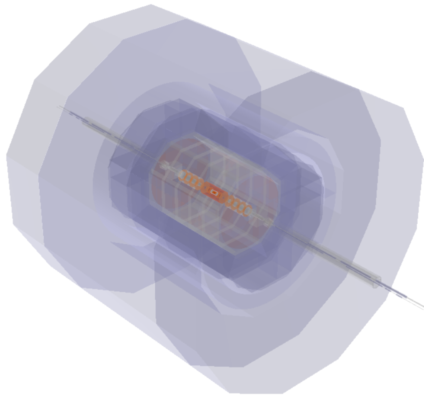
Mode	$b\bar{b}$	$c\bar{c}$	gg	WW^*	$\mu^+\mu^-$	$\tau^+\tau^-$	ZZ^*	$\gamma\gamma$	$Z\gamma$
BR (%)	57.8	2.7	8.6	21.6	0.02	6.4	2.7	0.23	0.16

g(Hbb), g(Hcc), g(Htt), g(HWW)/Γ_H, g(Hμμ), g(Hττ), g(HZZ)/Γ_H, g(HWW)/g(Htt)

ILD detector, the starting point of CEPC detector







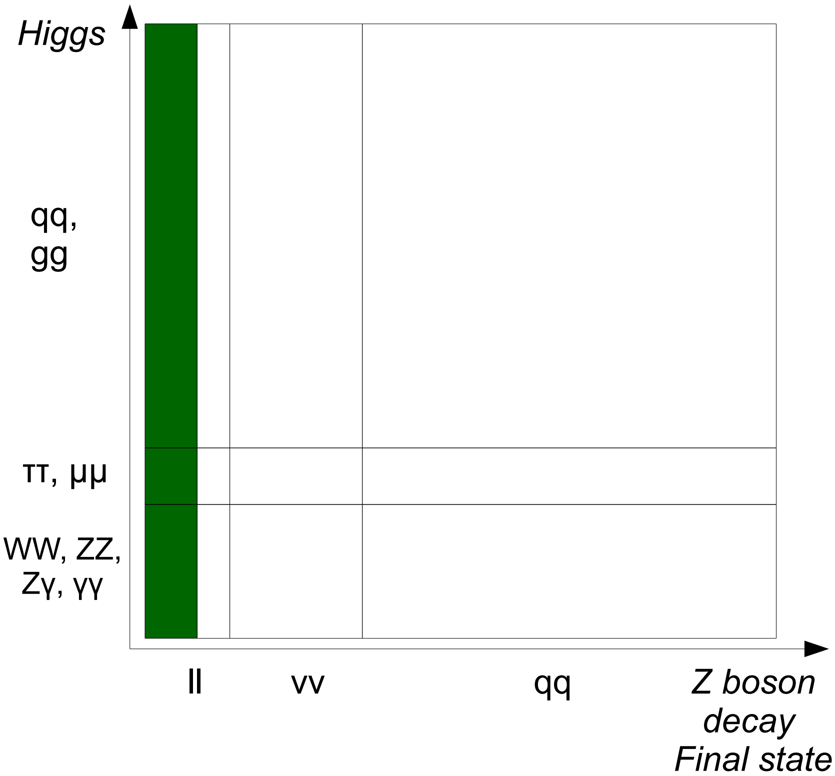
A detector reconstruct all the physics object (lepton, photon, tau, Jet, MET, ...) with high efficiency/precision

High Precision VTX located close to IP: b, c, tau tagging

High Precision Tracking system: $\delta(1/Pt) \sim 2*10^{-5}(GeV^{-1})$

PFA oriented Calorimeter System (~$o(10^{8})$ channels): Tagging, ID, Jet energy resolution, ect

ZH, Z→2l (l = ee, μμ), H→X



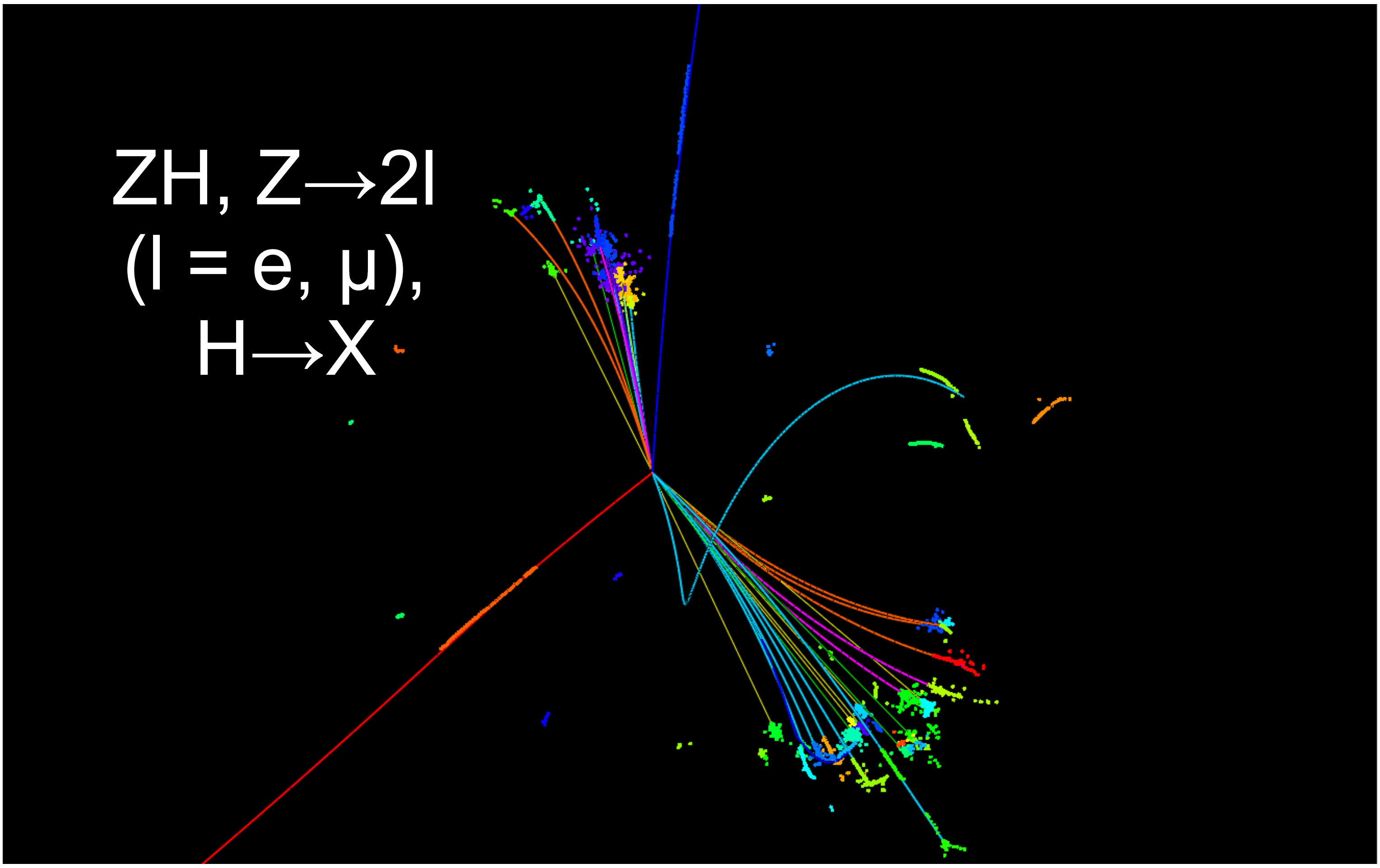
Model independent tagging of ZH events from recoil mass spectrum to di-lepton system. Statistic ~ 6.7k evts

Objective Observables:

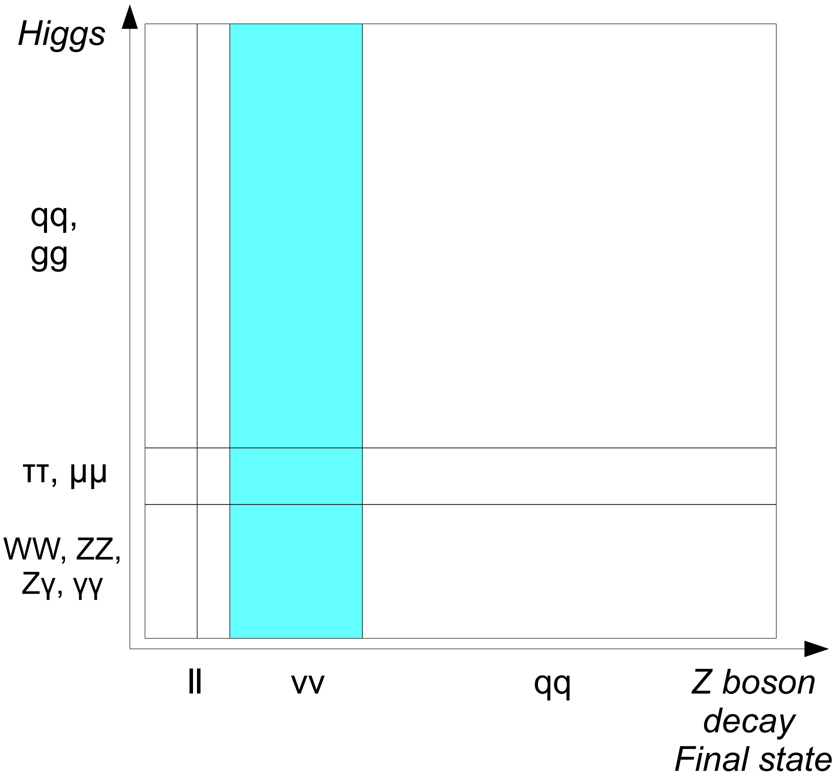
Recoil mass spectrum:
Higgs mass, σ(HZ)

Tagged ZH events + Higgs final states classification:
Br(H→X)*σ(HZ)

Critical performance/algorithms:
Tracking & final states Classification (Tagging of Tau, WW*/ZZ*, jet flavor):


ZH, Z→2l
(l = e, μ),
H→X

ZH, Z→2ν, H→X



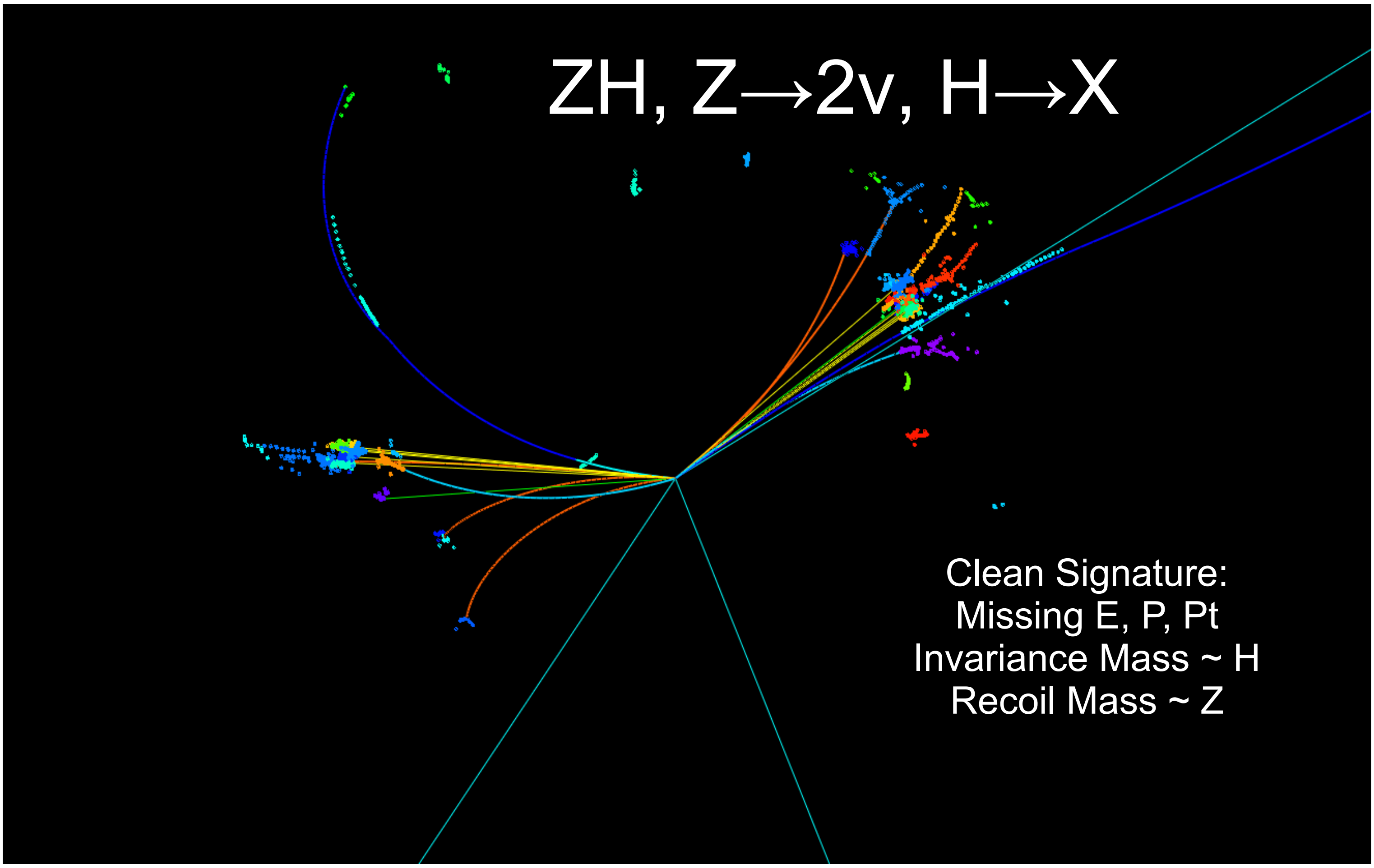
Tag the ZH events from di-jet Invariant mass. Statistic ~ 20k evts

Objective Observables:

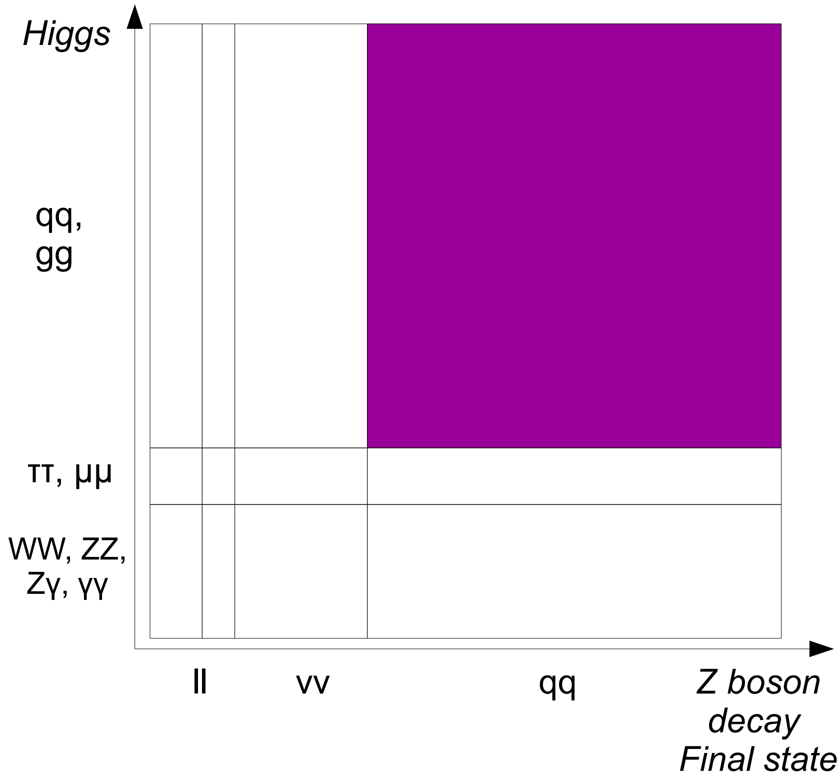
Higgs mass, σ(HZ)*Br(H→X)

Critical performances/algorithms:

Jet clustering,
PFA (Jet energy resolution,
Missing energy reconstruction)
Final states classification


ZH, Z→2v, H→X
Clean Signature:
Missing E, P, Pt
Invariance Mass ~ H
Recoil Mass ~ Z

ZH, Z→2q, H→2q

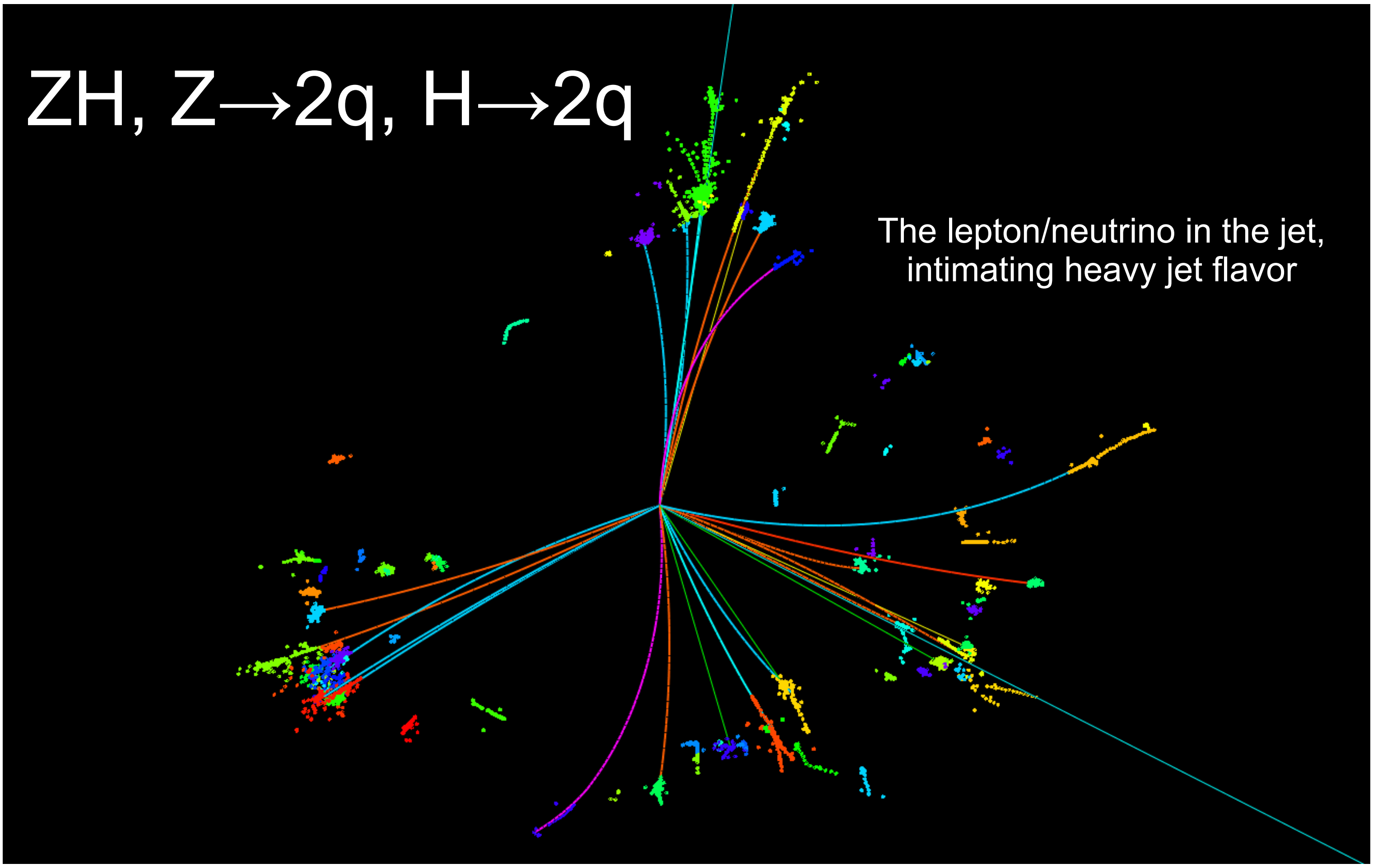


Tag the ZH events from invariant
Mass of all 2-jets combinations.
Statistics ~ 50k evts

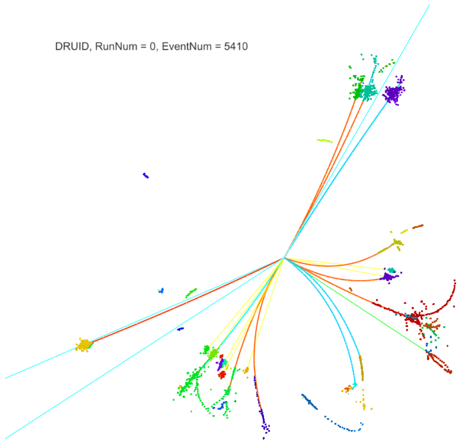
Objective Observables:

Higgs mass, σ(HZ)*Br(H→2j),
σ(HZ)*Br(H→2b, 2c, 2g),

Critical performances:
Jet clustering,
Jet energy resolution (PFA),
Flavor tagging


ZH, Z→2q, H→2q
The lepton/neutrino in the jet,
intimating heavy jet flavor

Taus...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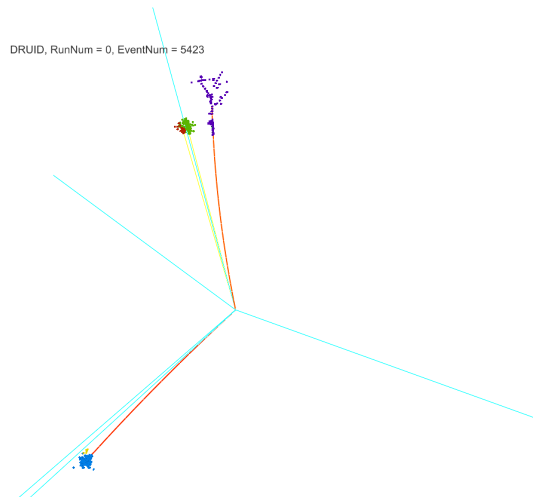
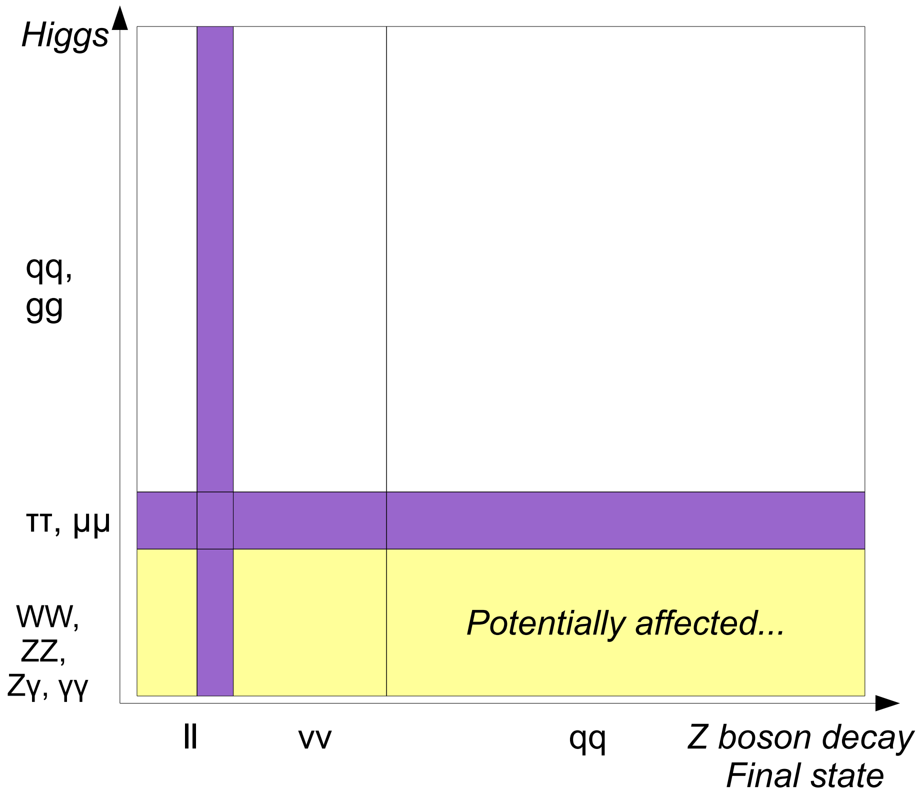
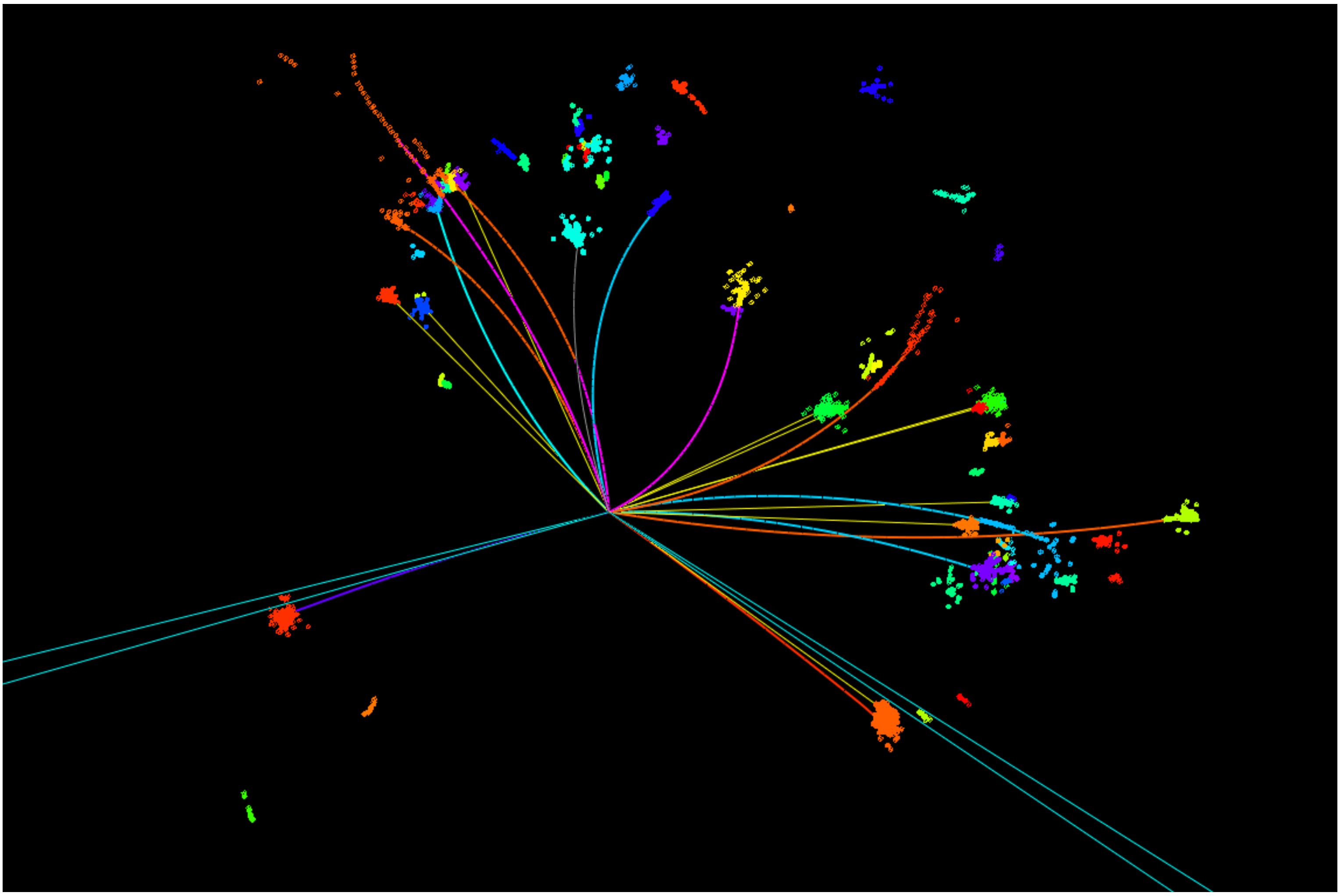
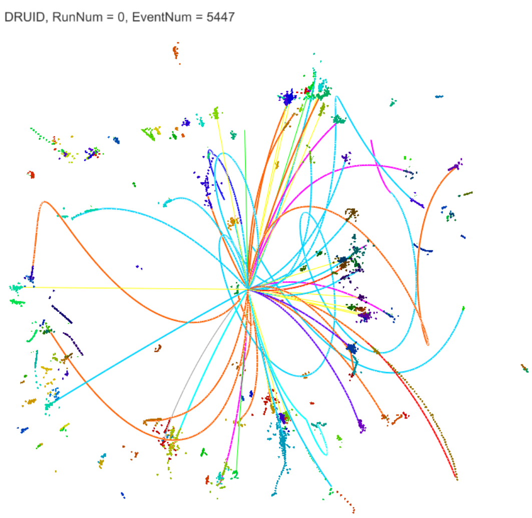

DRUID, RunNum = 0, EventNum = 5423

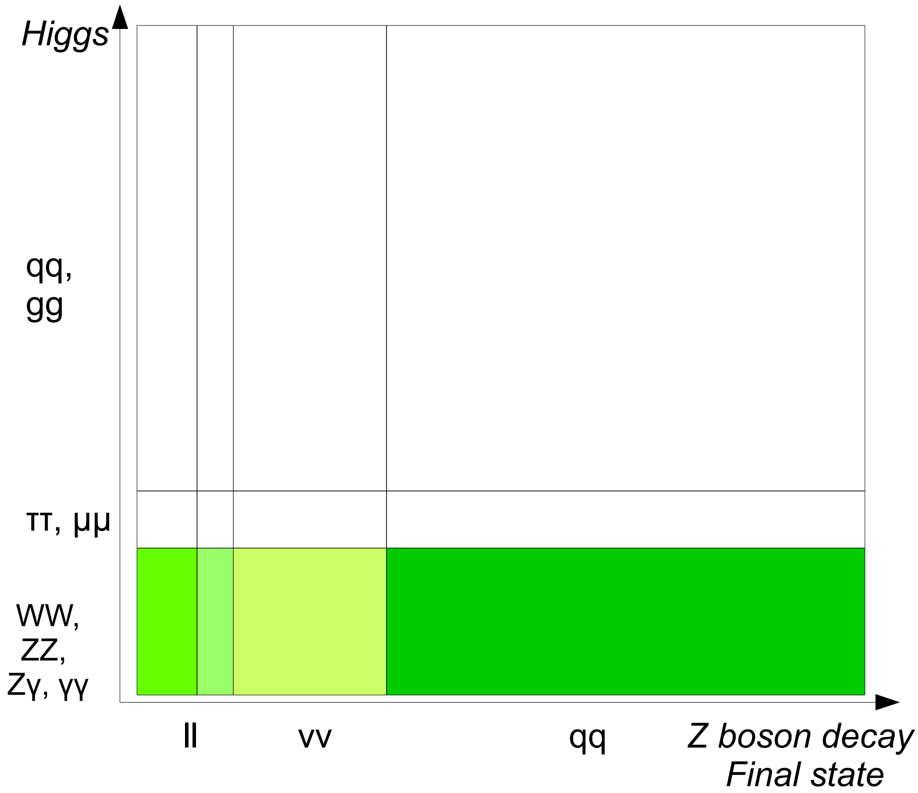

Higgs
qq,
gg
ττ, μμ
WW,
ZZ,
Zγ, γγ
Potentially affected...
ll
νν
qq
Z boson decay
Final state

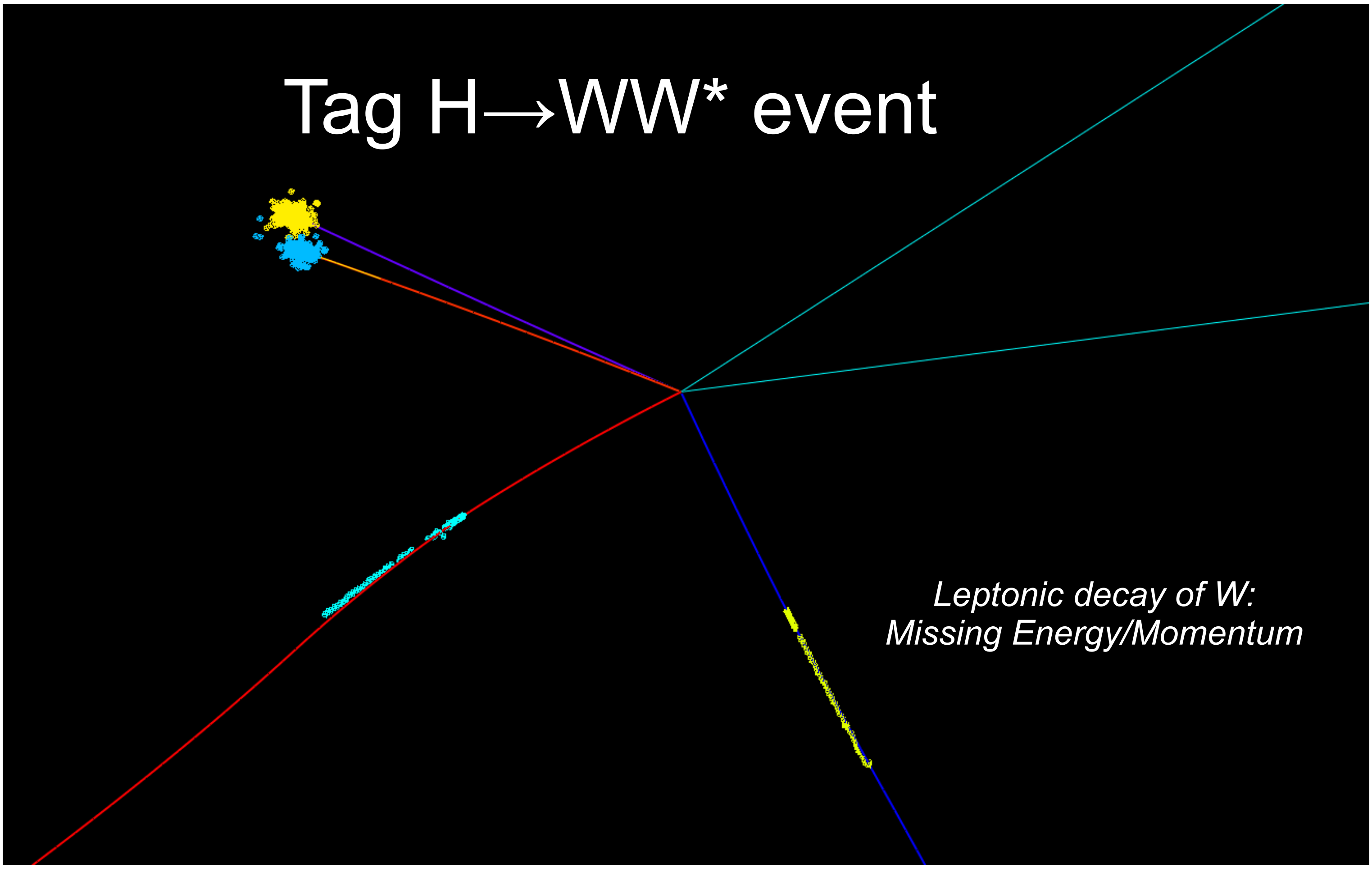


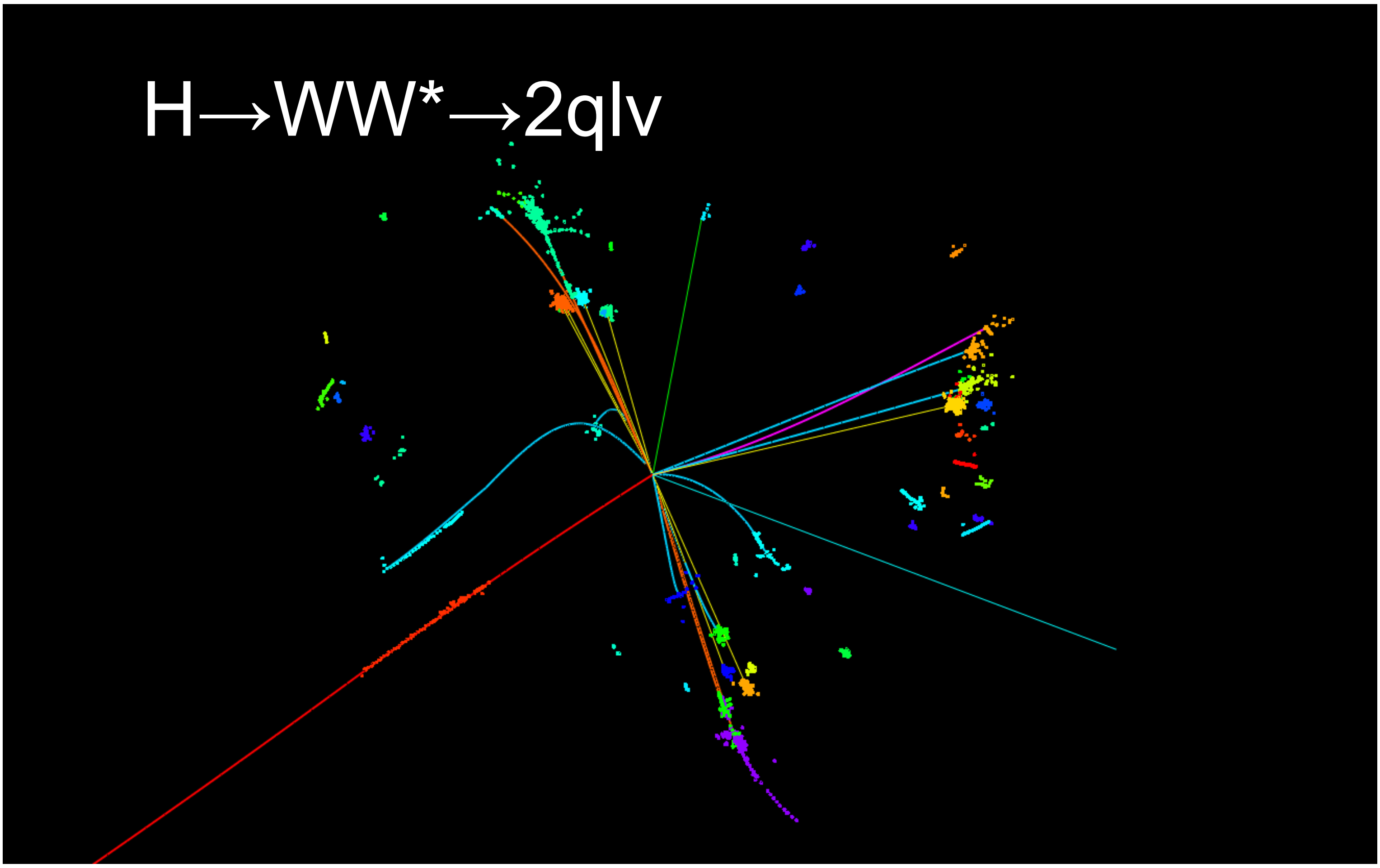
Br(H→WW, ZZ) ~ Width Measurement



Important,
challenging,
Exciting.




Tag H→WW* event
Leptonic decay of W:
Missing Energy/Momentum


H→WW*→2qlν

Summary

- SM Particles
  - Stable & Quasi stable: those able to make hits in the detectors directly
- Detector
  - Very light tracker, and very dense calorimeter
  - Loooots of hits & patterns
- Tracker: fit tracker hits into helix, measure the momentum, charge and even type of the incident charged particle
- Calorimeter: energy measurement, and
  - exhibit the fractal nature of shower, with high granularity
- PFA, ultimately, find, separate and measure every final state particles in the detector
- Reconstruction at CEPC, various of different event configuration
  - Tau and Jet Clustering: interesting topic, need lots of work & optimization

Internal | Events | Contact Us

CEPC

Circular Electron Positron Collider

HOME | ABOUT CEPC | ORGANIZATION | RESULTS | WHY SCIENCE | JOIN US | pre-CDR Author

Future High Energy Circular Colliders

The Standard Model (SM) of particle physics can describe the strong, weak and electromagnetic interactions under the framework of quantum gauge field theory. The theoretical predictions of SM are in excellent agreement with the past experimental measurements. Especially the 2013 Nobel Prize in physics was awarded to F. Englert and P. Higgs "for the theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles, and which recently was confirmed through the discovery of the predicted fundamental particle, by the ATLAS and CMS experiments at CERN's Large Hadron Collider".

After the discovery of the Higgs particle, it is natural to measure its properties as precise as possible, including mass, spin, CP nature, couplings, and etc., at the current running Large Hadron Collider (LHC) and future electron positron colliders, e.g. the International Linear Collider (ILC). The low Higgs mass of ~125 GeV makes possible a Circular Electron Positron Collider (CEPC) as a Higgs Factory, which has the advantage of higher luminosity to cost ratio and the potential to be upgraded to a proton-proton collider to reach unprecedented high energy and discover New Physics.

CEPC preCDR volumes

Manqi.ruan@ihep.ac.cn

Particle Physics

- Goal:
  - Find the building blocks of the world
  - Understand the interactions between them

- How
  - Propose theories/models
  - Need instruments/apparatus to test/verify the theories