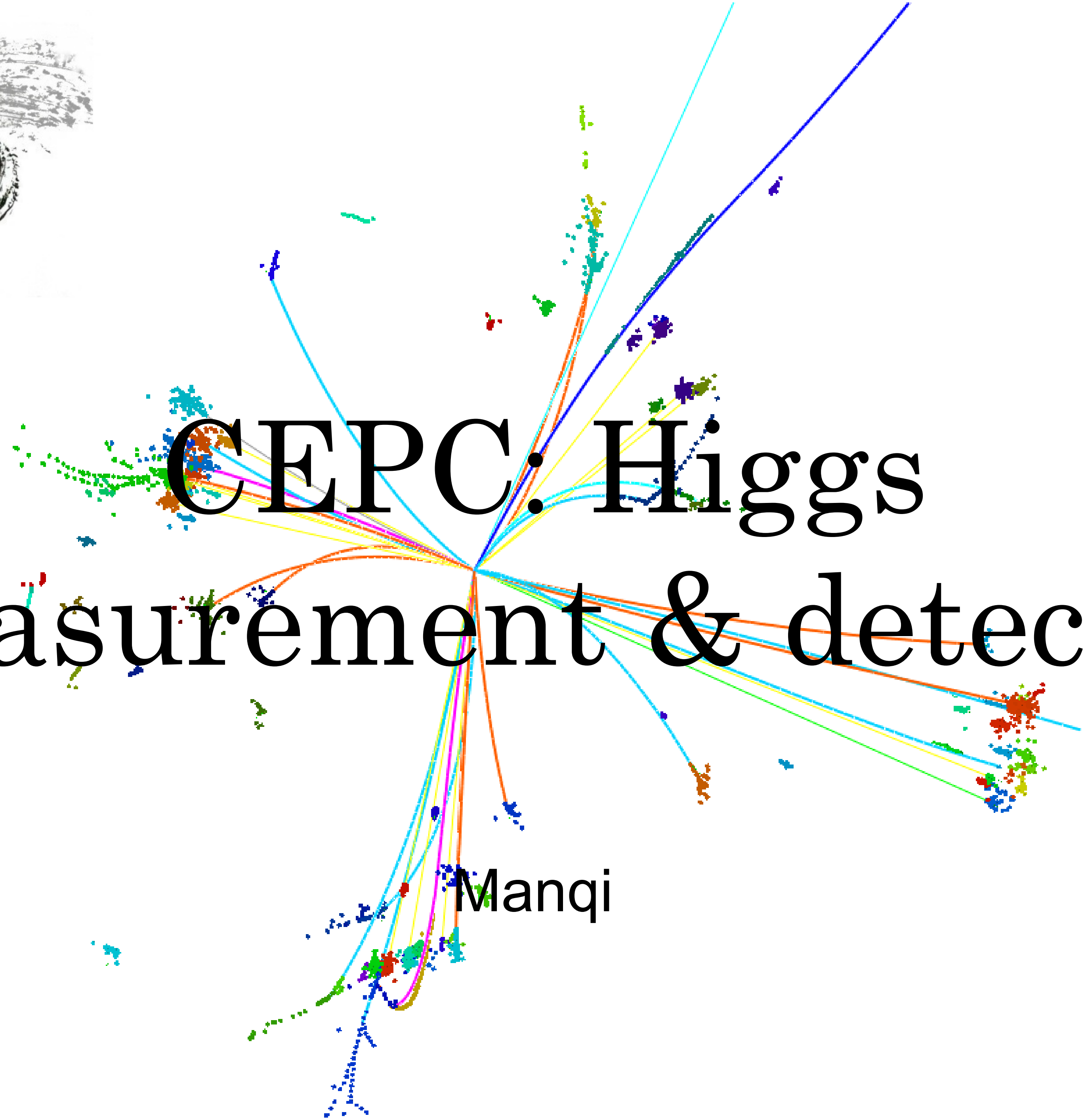
CEPC: Higgs Measurement & detector



Manqi

Remark

Higgs measurement is **NOT** the only motivation for CEPC

SM Lagrangian

$$\mathcal{L} = -\frac{1}{4}B_{\mu\nu}B^{\mu\nu} - \frac{1}{8}tr(\mathbf{W}_{\mu\nu}\mathbf{W}^{\mu\nu}) - \frac{1}{2}tr(\mathbf{G}_{\mu\nu}\mathbf{G}^{\mu\nu}) \qquad \text{(U(1), SU(2) and SU(3) gauge terms)}$$

$$+(\bar{\nu}_L, \bar{e}_L)\,\tilde{\sigma}^\mu i D_\mu \begin{pmatrix} \nu_L \\ e_L \end{pmatrix} + \bar{e}_R \sigma^\mu i D_\mu e_R + \bar{\nu}_R \sigma^\mu i D_\mu \nu_R + (\text{h.c.}) \qquad \text{(lepton dynamical term)}$$

$$-\frac{\sqrt{2}}{v}\left[(\bar{\nu}_L, \bar{e}_L)\,\phi M^e e_R + \bar{e}_R \bar{M}^e \bar{\phi} \begin{pmatrix} \nu_L \\ e_L \end{pmatrix}\right] \qquad \text{(electron, muon, tauon mass term)}$$

$$-\frac{\sqrt{2}}{v}\left[(-\bar{e}_L, \bar{\nu}_L)\,\phi^* M^\nu \nu_R + \bar{\nu}_R \bar{M}^\nu \phi^T \begin{pmatrix} -e_L \\ \nu_L \end{pmatrix}\right] \qquad \text{(neutrino mass term)}$$

$$+(\bar{u}_L, \bar{d}_L)\,\tilde{\sigma}^\mu i D_\mu \begin{pmatrix} u_L \\ d_L \end{pmatrix} + \bar{u}_R \sigma^\mu i D_\mu u_R + \bar{d}_R \sigma^\mu i D_\mu d_R + (\text{h.c.}) \qquad \text{(quark dynamical term)}$$

$$-\frac{\sqrt{2}}{v}\left[(\bar{u}_L, \bar{d}_L)\,\phi M^d d_R + \bar{d}_R \bar{M}^d \bar{\phi} \begin{pmatrix} u_L \\ d_L \end{pmatrix}\right] \qquad \text{(down, strange, bottom mass term)}$$

$$-\frac{\sqrt{2}}{v}\left[(-\bar{d}_L, \bar{u}_L)\,\phi^* M^u u_R + \bar{u}_R \bar{M}^u \phi^T \begin{pmatrix} -d_L \\ u_L \end{pmatrix}\right] \qquad \text{(up, charmed, top mass term)}$$

$$+\overline{(D_\mu \phi)} D^\mu \phi - m_h^2 [\bar{\phi}\phi - v^2/2]^2 / 2v^2. \qquad \text{(Higgs dynamical and mass term)} \quad (1)$$

Higgs

- 9 fermion masses (+ 3 m_ν)
- 3 CKM mixing angles + 1 phase (+ 3+1 for $m_\nu \neq 0$)
- 1 electromagnetic coupling constant α
- 1 strong coupling constant α_s
- 1 weak coupling constant $G_F = 1.16637(1) \times 10^{-5}$ GeV^{-2}
- 1 Z^0 mass $m_Z = 91.1876(21)$ GeV/c^2
- 1 Higgs mass

Only scalar particle in SM

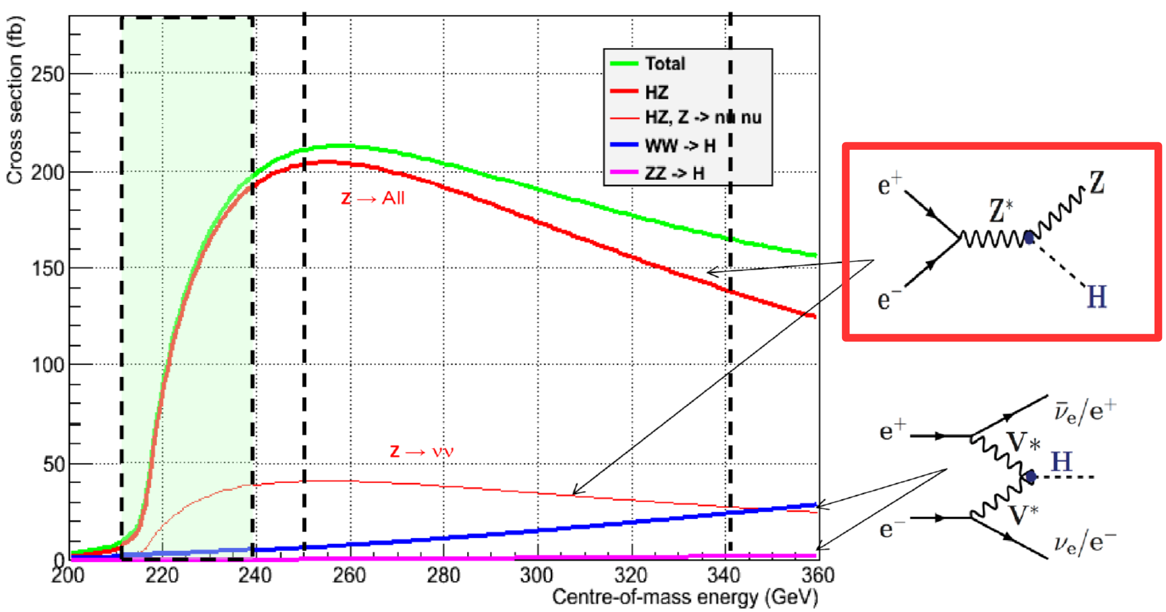
Most free SM parameters

MANY theoretical difficulties


Higgs, the focus,
the gate

The key: e^+e^- Higgs factory

$$g/g_{SM} \sim 1 + \delta(1\text{TeV}/\Lambda_{NP})^2$$



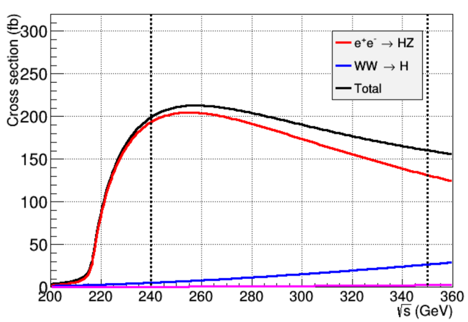
NP model	δ(hVV)	δ(htt)	δ(hbb)
Extra Higgs	<1%	<1%	1.7%
Composite Higgs	8%	~ 10%	~ 10%
Mixed in Singlet	6%	6%	6%
MSSM	< 1%	3%	10%-100%
Top parter	0.8 – 2.9%		
...			

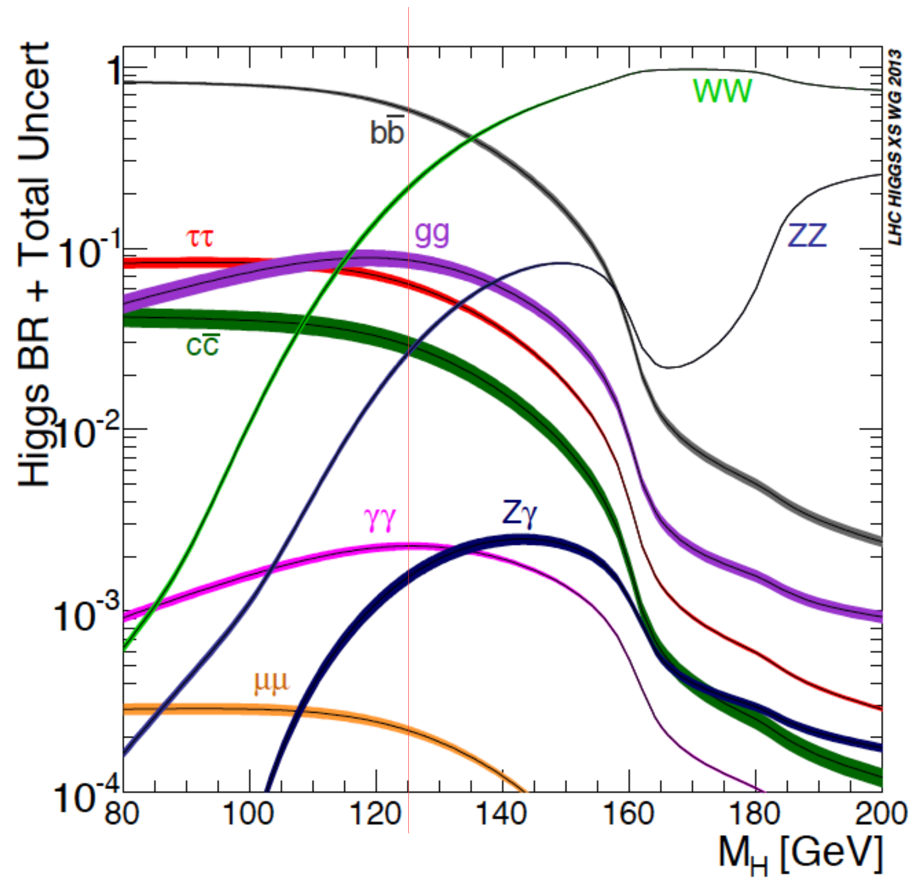
ILCTDR, 1310.8361 [hep-ex]...

...Higgs couplings: **absolute** measurements to percentage level...
... a vision of New Physics Landscape at TeV era...

SM Higgs observables

- Mass, spin, σ(ZH): model independent measurement of g(HZZ)
- σ(ZH)/σ(ννH)*Br(H→X)
- Access to the absolute value of Higgs width, Br(H→inv) and all the couplings

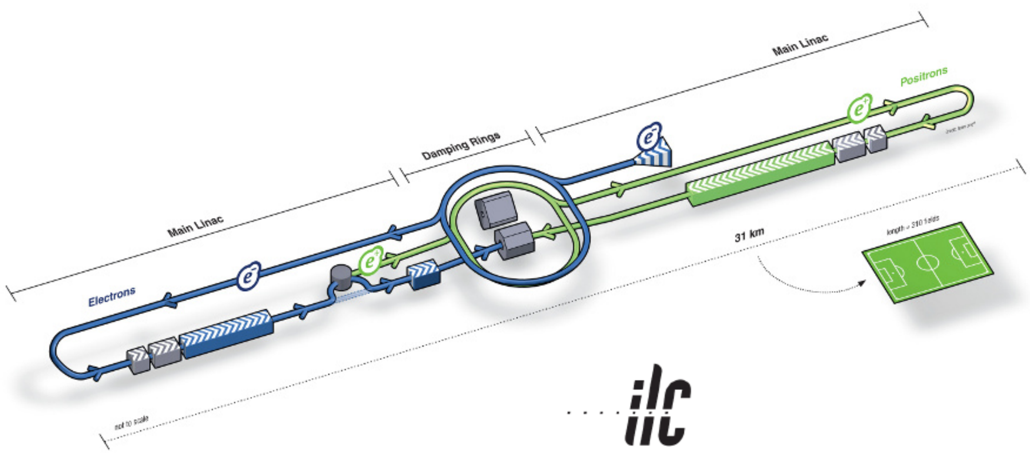


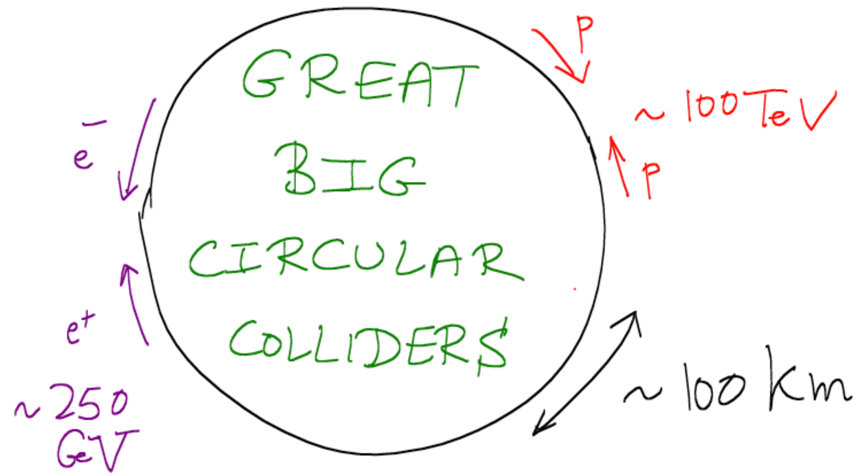


Mode	$b\bar{b}$	$c\bar{c}$	gg	WW^*	$\mu^+\mu^-$	$\tau^+\tau^-$	ZZ^*	$\gamma\gamma$	$Z\gamma$
BR (%)	57.8	2.7	8.6	21.6	0.02	6.4	2.7	0.23	0.16

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

Linear or Circular

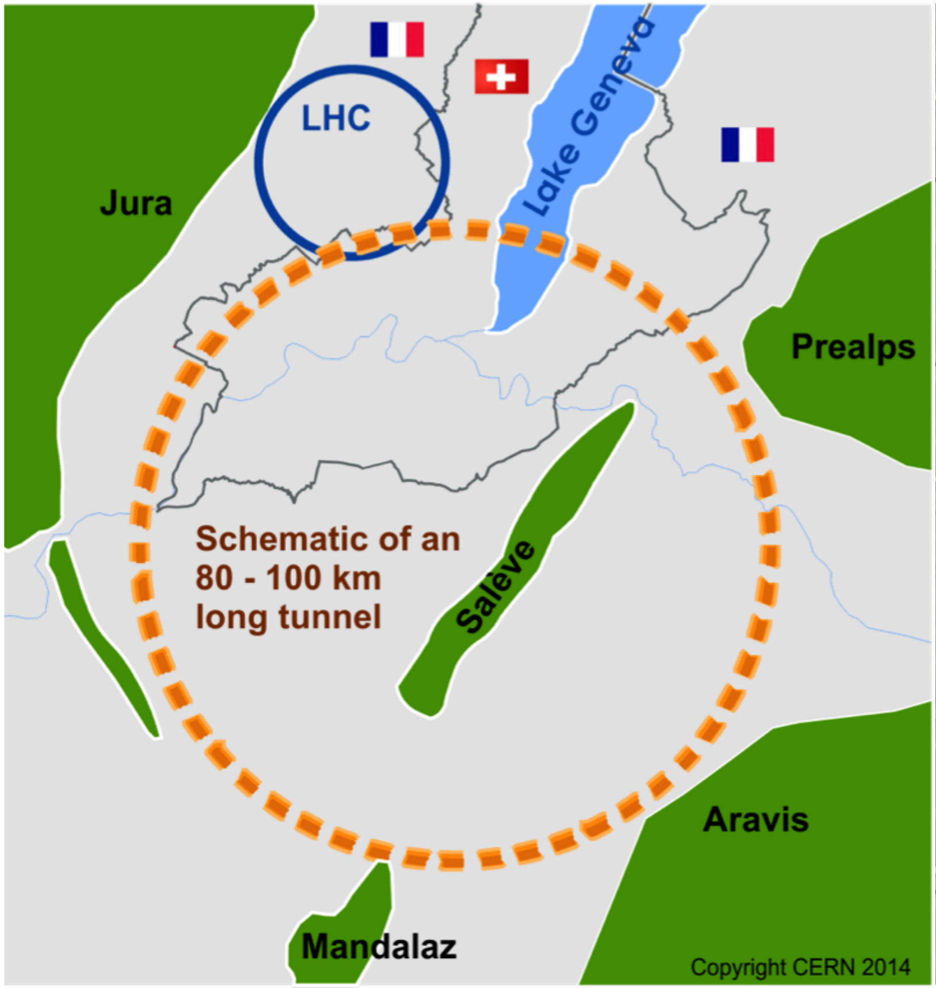




	Linear: ILC, CLIC	Circular: CEPC, TLEP
Pro	Center of mass energy can be upgraded to 1-3 TeV Longitudinal polarized beam Power pulsed detector	Cost-efficient, mature technology Multiple interaction point High luminosity & beam quality
Con	Expensive (~ 8 – 10 B euros) Single interaction point, might need push-pull	Center of mass energy limited in e^+e^- phase (but can be upgraded to ~ 100 TeV in pp phase) No beam polarization at high energy No power pulse

Muon & photon colliders are also possible Higgs factories, but...

FCCee & CEPC


LHC
Jura
Lake Geneva
Prealps
Schematic of an
80 - 100 km
long tunnel
Salève
Aravis
Mandalaz
Copyright CERN 2014


S363
S251
G1
高能所
秦皇岛市
G102
抚宁县
S267
G205
Image © 2013 DigitalGlobe
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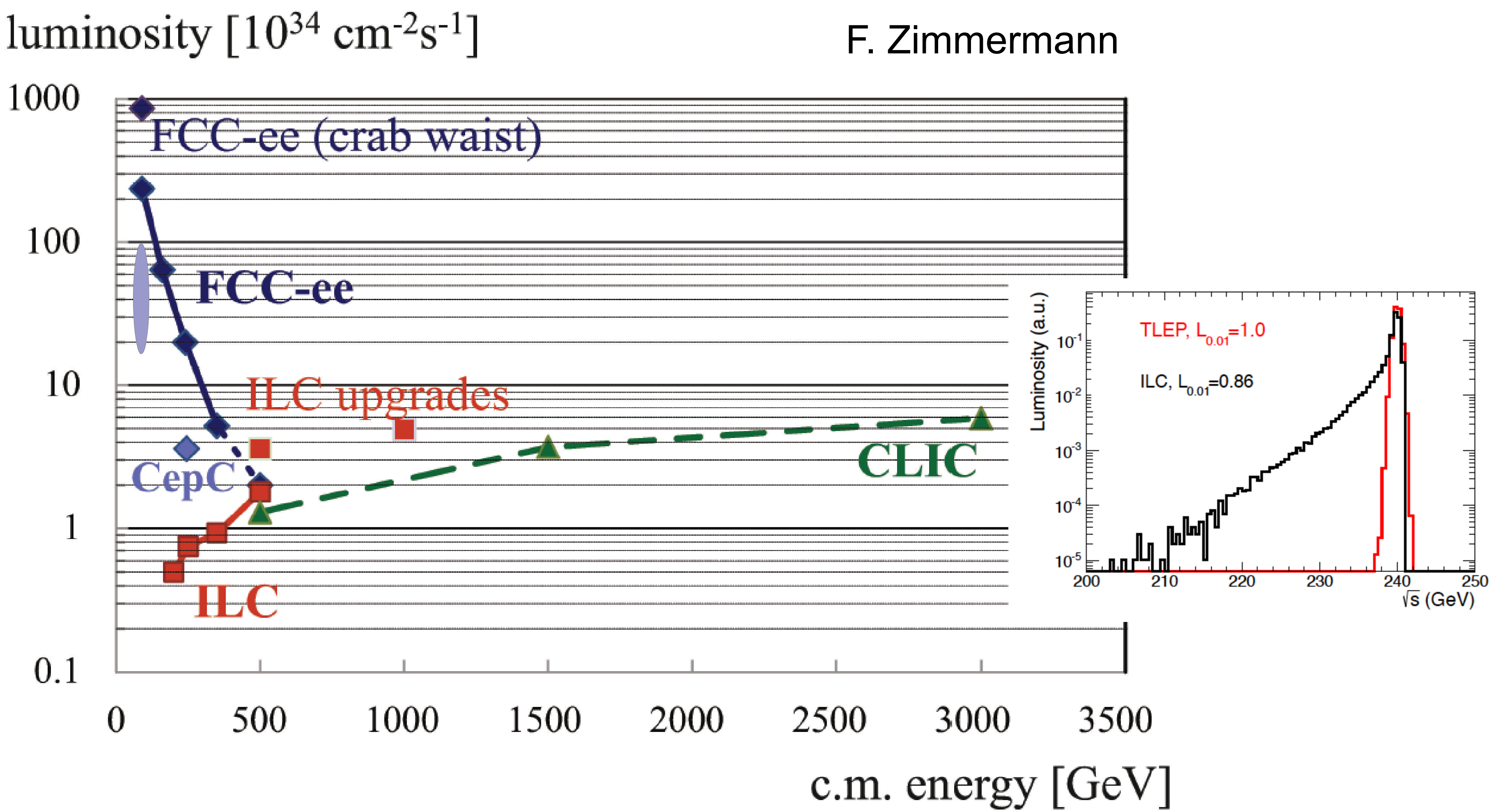
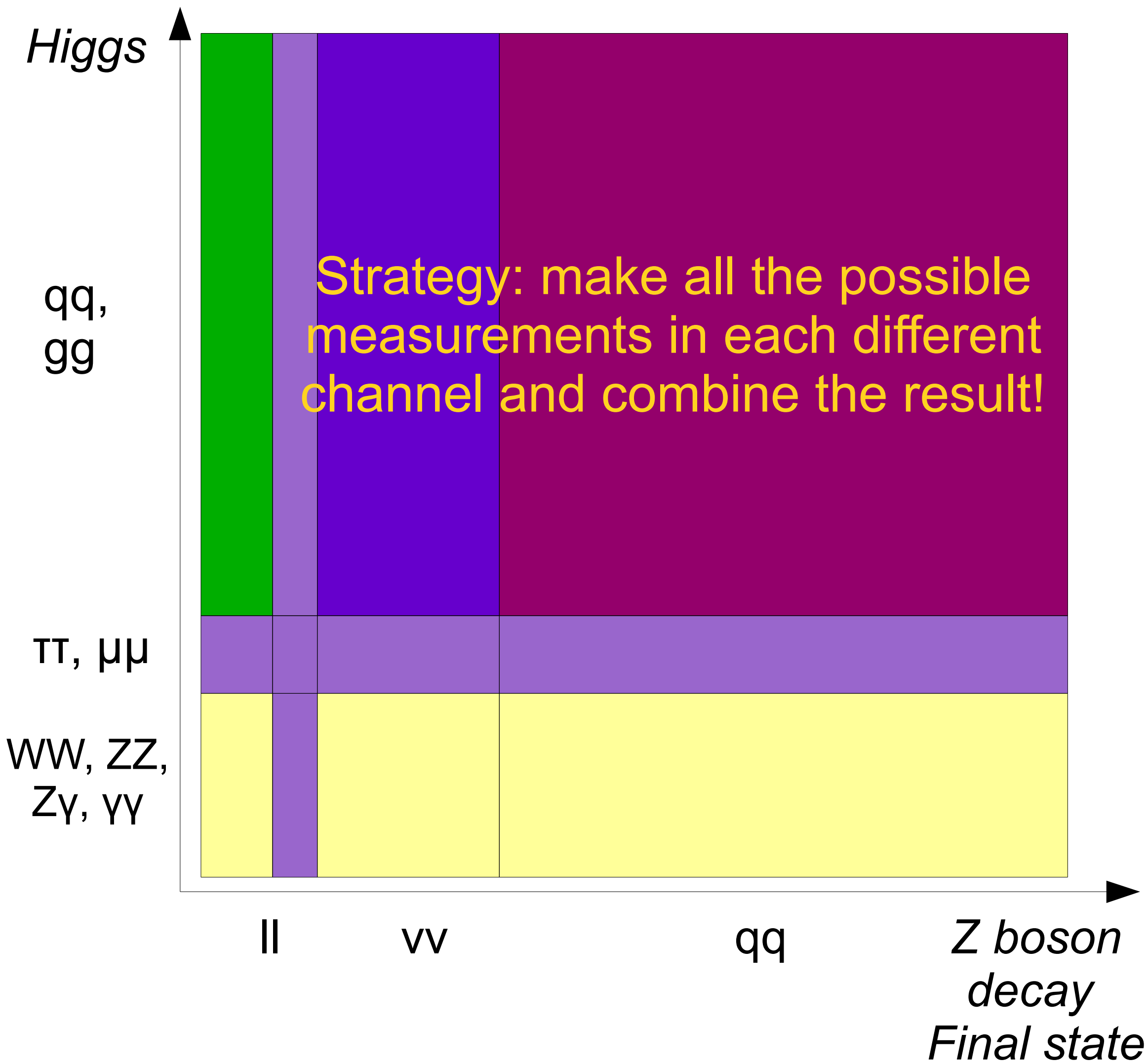
e^+e^- luminosity vs energy



	FCCee 240 (10 ab^{-1})	FCCee 350 (2.6 ab^{-1})	CEPC 250 (5 ab^{-1})
Higgs from HZ	500 k/IP * 4 IP	85 k/IP * 4 IP	500 k/IP * 2 IP
Higgs from fusion	12.5 k/IP * 4 IP	17.5 k/IP * 4 IP	18.7 k/IP * 2 IP

FCCee: 5 year of operation at each point, 1 year ~ 10^7 sec;
*CEPC: 10 year of operation, 1 year ~ 1.25*10^7 sec*

ZH event: requirement on detector and critical algorithms



Vertex: Flavor tagging, tau tagging;

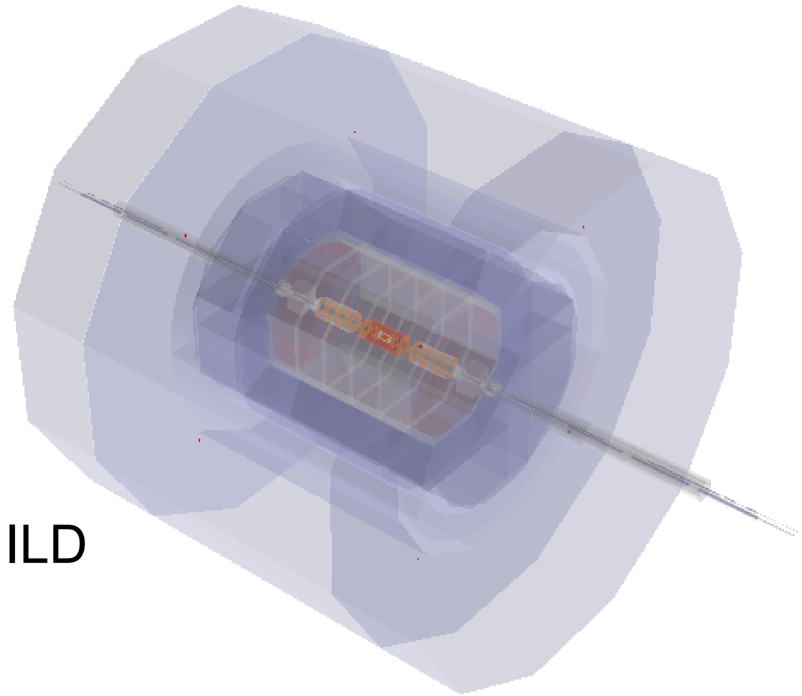
Tracker: momentum measurement of charged particle;

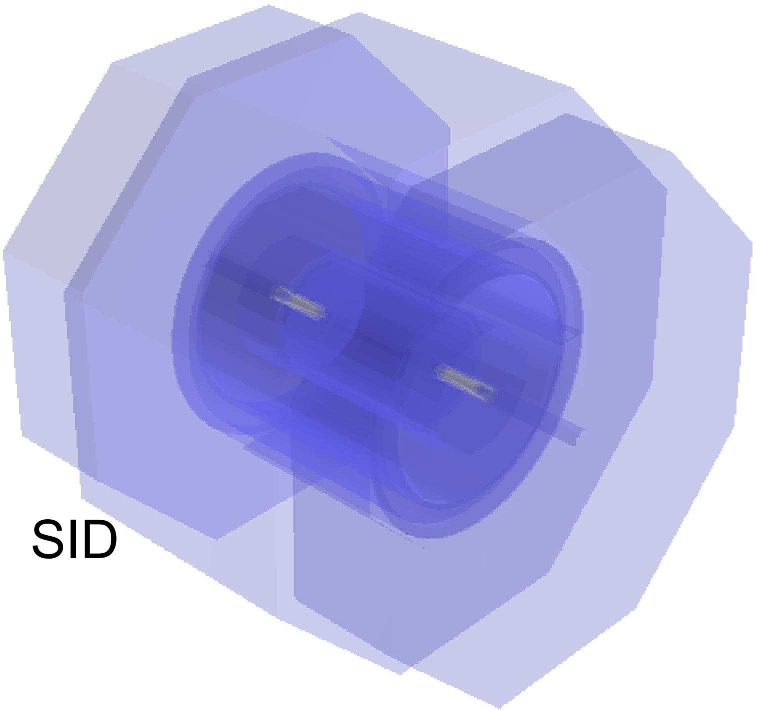
Calorimeter:
Particle Flow Algorithm(PFA): separation/ reconstruction of particle showers,
PID – lepton tagging,
Jet/Missing energy measurements;

Critical algorithms:
H→2 jets: Flavor tagging
H→2 taus: Tau tagging
H→ZZ*, WW*: VV* events tagging

Reference detectors: ILD, CMS,...

PFA Oriented LC detectors





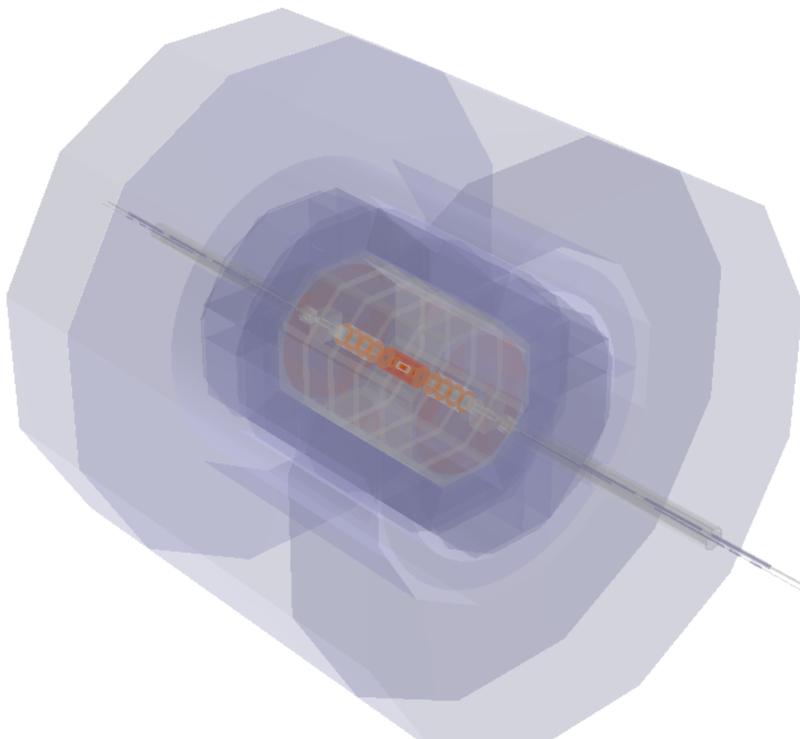
- PFA: Jet energy resolution
  less confusion ~ good separation ~ high granularity
  Granularity > Energy Resolution for the Calorimetry...

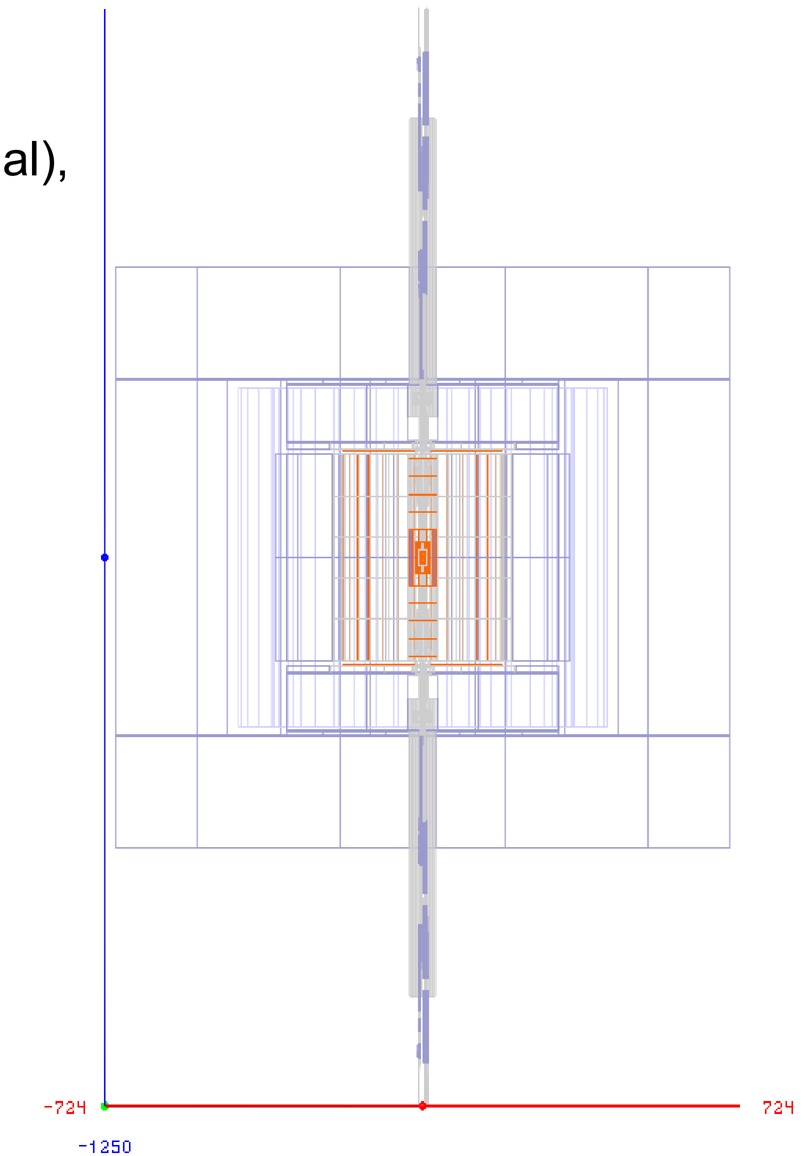
- PFA Oriented detector (both have ILC/CLIC Versions):
  - ILD (European + Asia, International Large Detector): TPC (+ Silicon inner detectors) tracking with B = 3.5T
  - SiD (US, Silicon Detector): Silicon tracking with B = 5T

Reference detector for CEPC: ILD

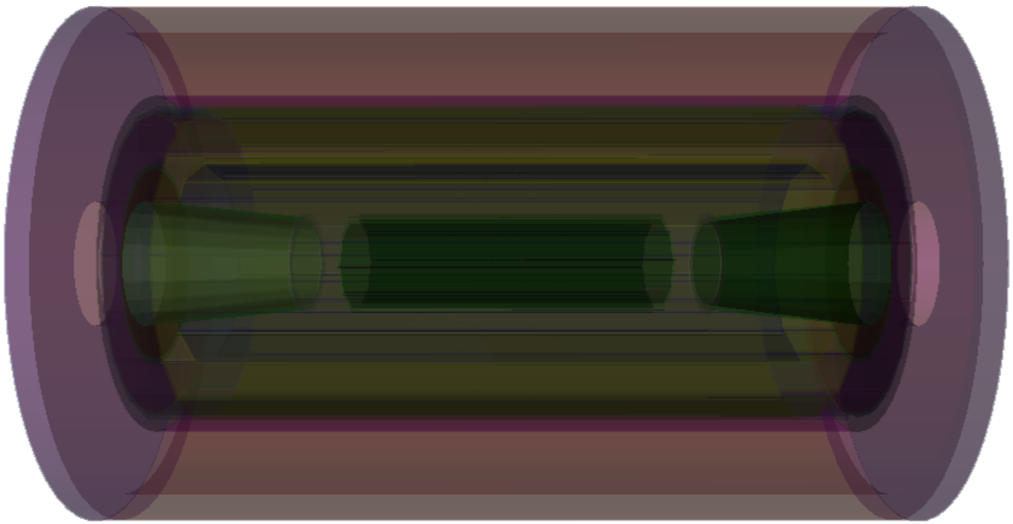
Scale: half_Z: 12.5/6.62 meter, radius 7.24 meter

Sub detectors: VTX, SIT, FTD, TPC, SET/ETD(optional),
Ecal, Hcal, Coil, Muon

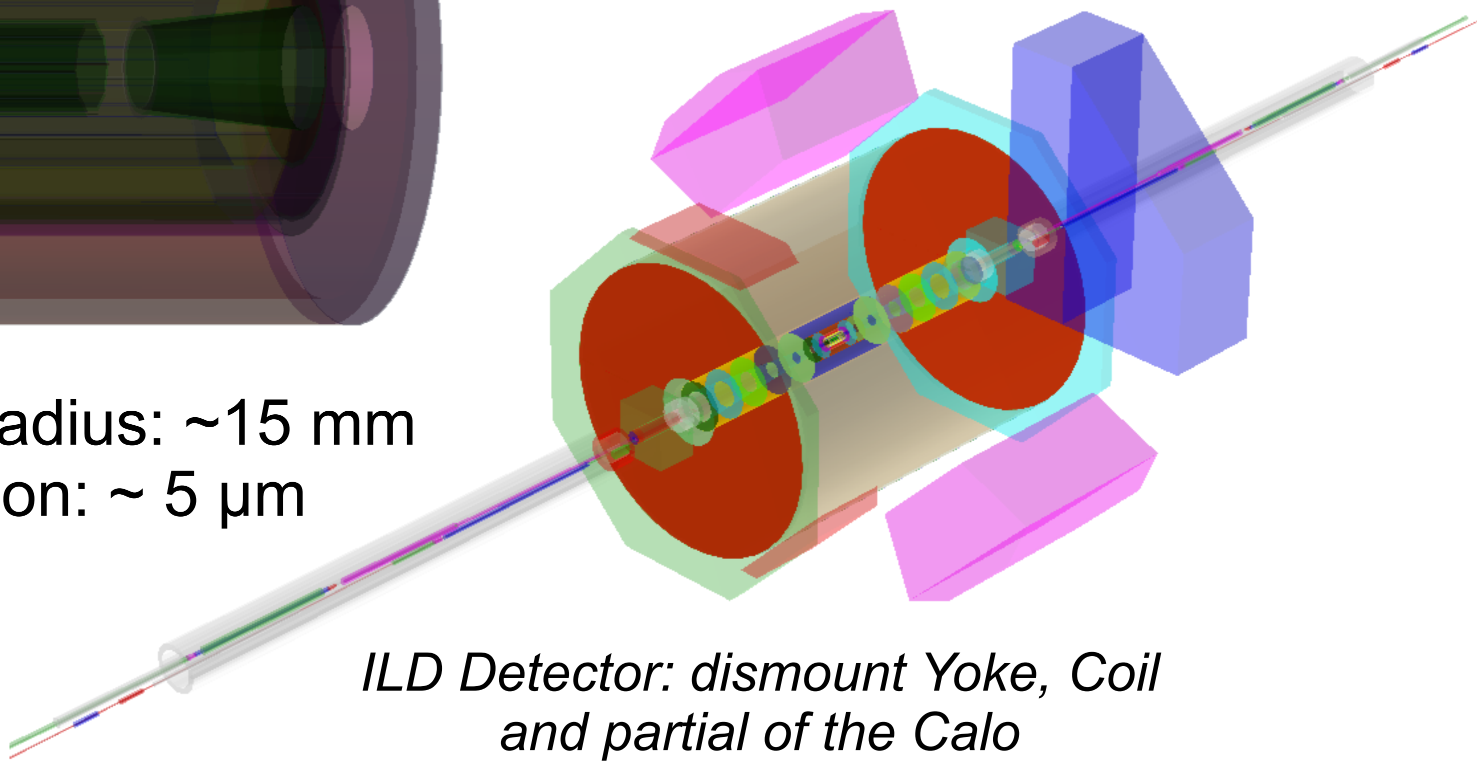




Vertex detector

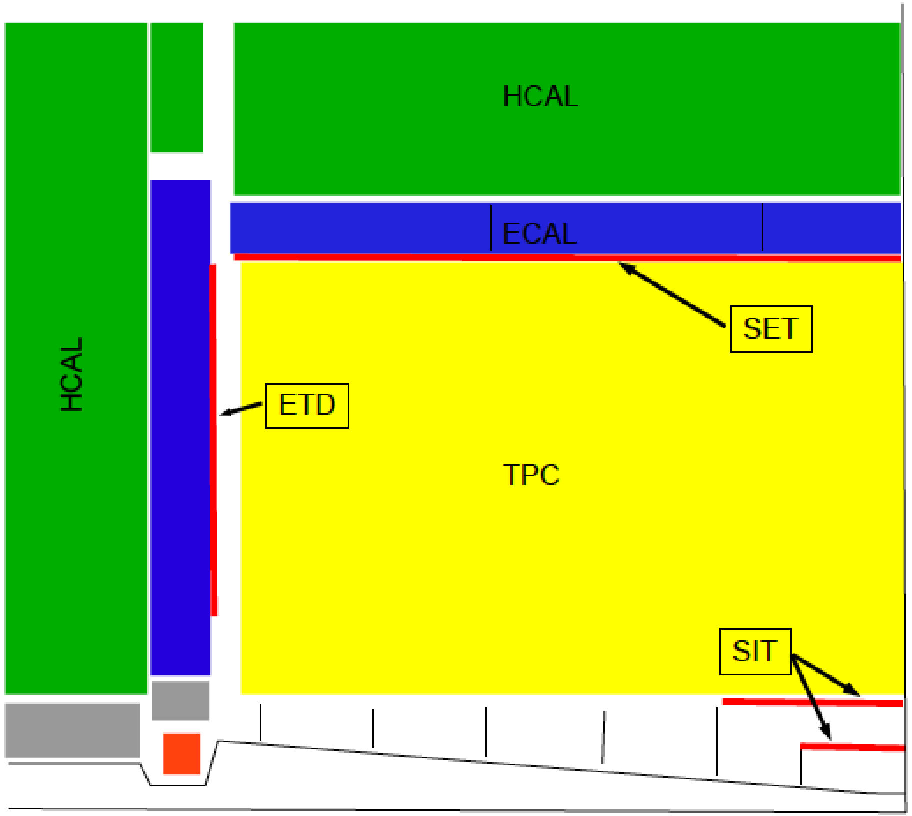


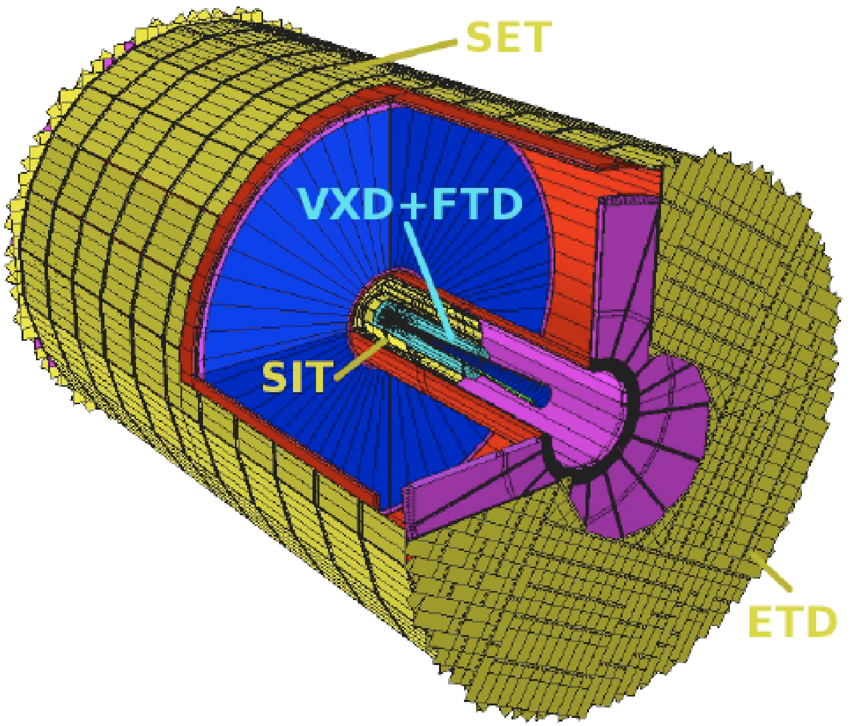
Inner most layer Radius: ~15 mm
Spatial resolution: ~ 5 μm



ILD Detector: dismount Yoke, Coil and partial of the Calo

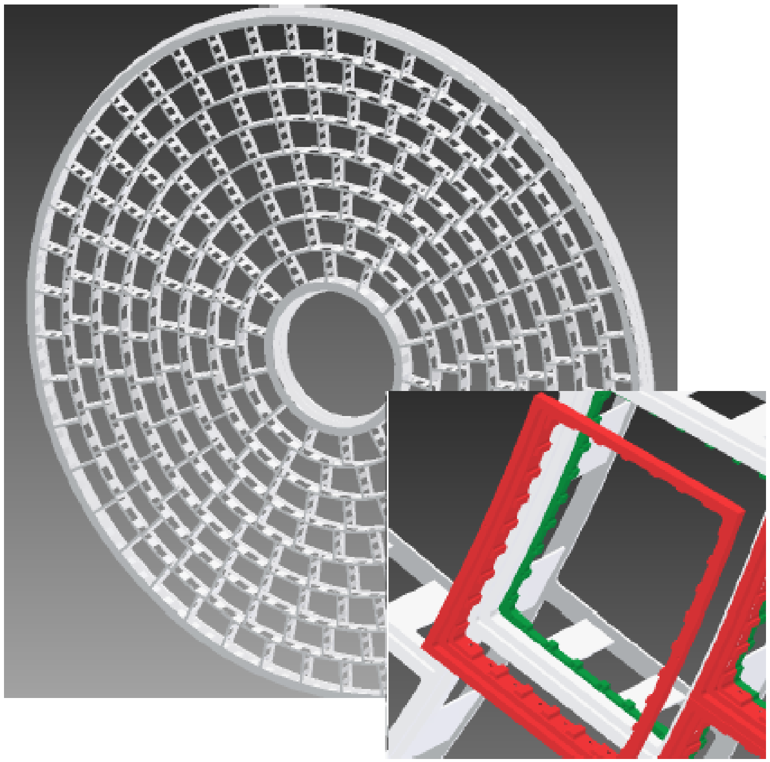
Silicon Tracking at ILD





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

ILD Main Tracker: TPC



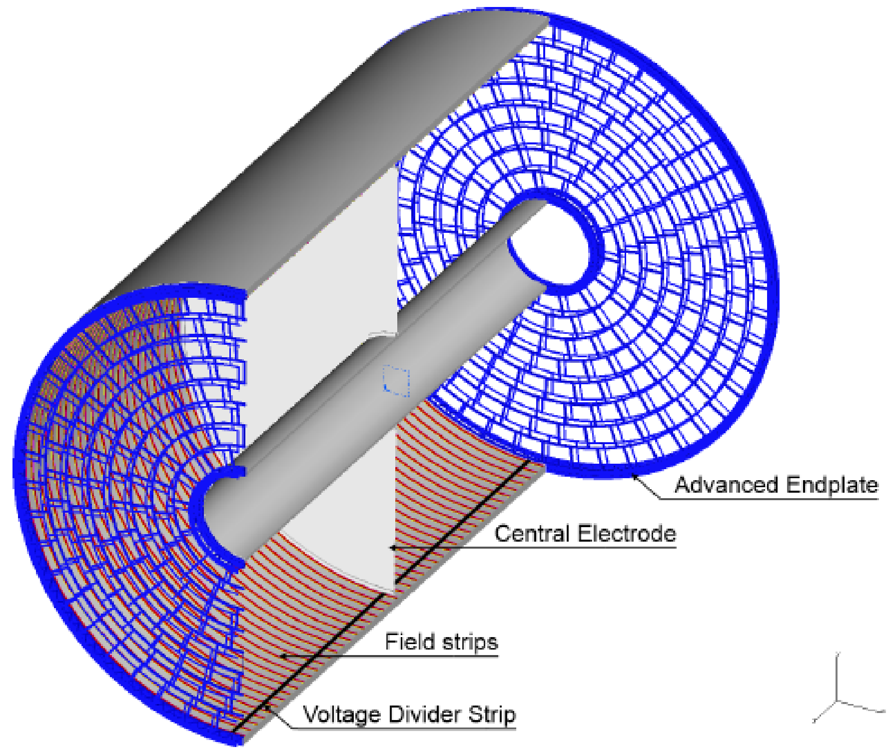
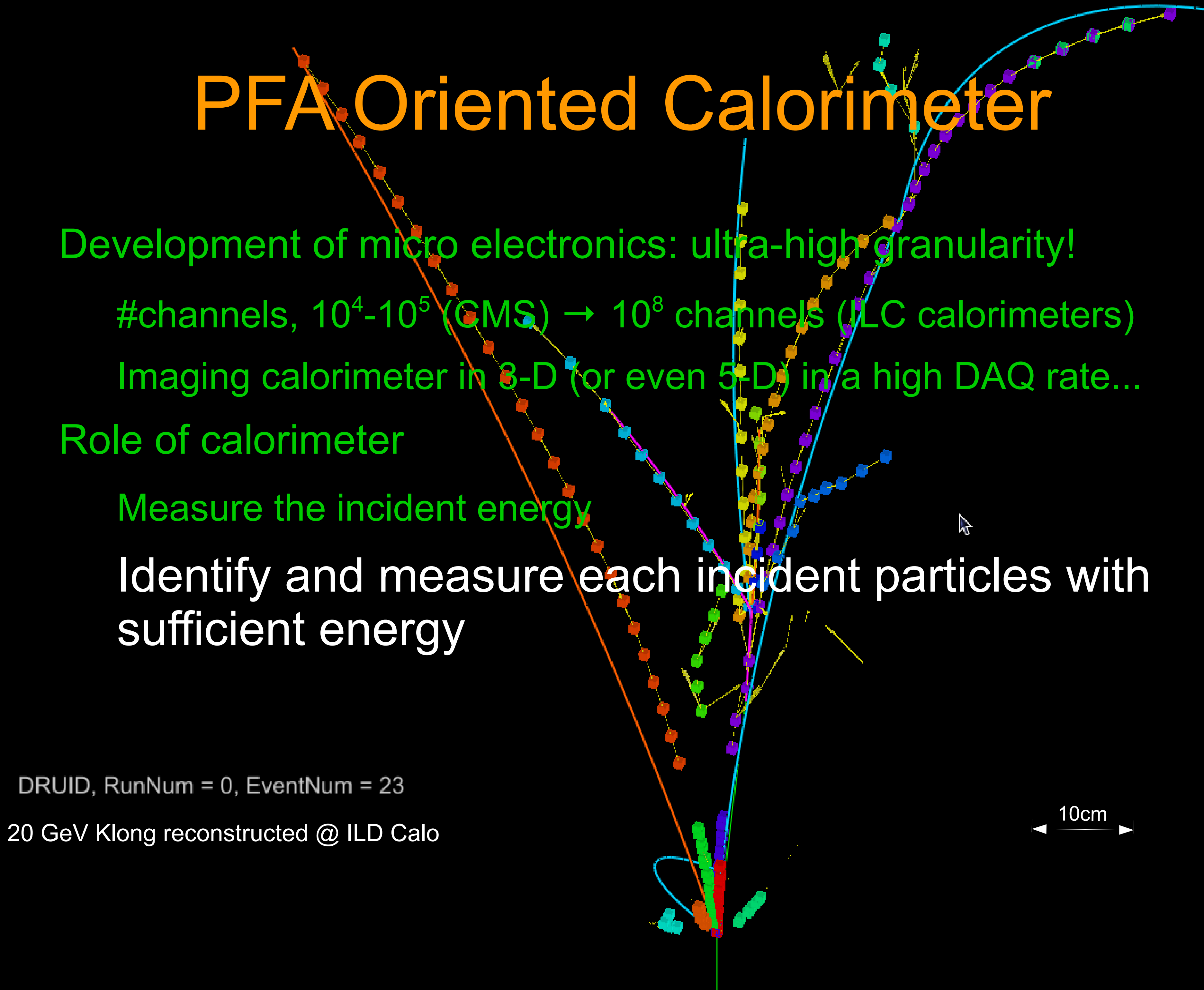


Figure III-2.11. Left: Drawing of the proposed end-plate for the TPC. In the insert a backframe which is supporting the actual readout module, is shown. Right: Conceptual sketch of the TPC system showing the main parts of the TPC (not to scale).

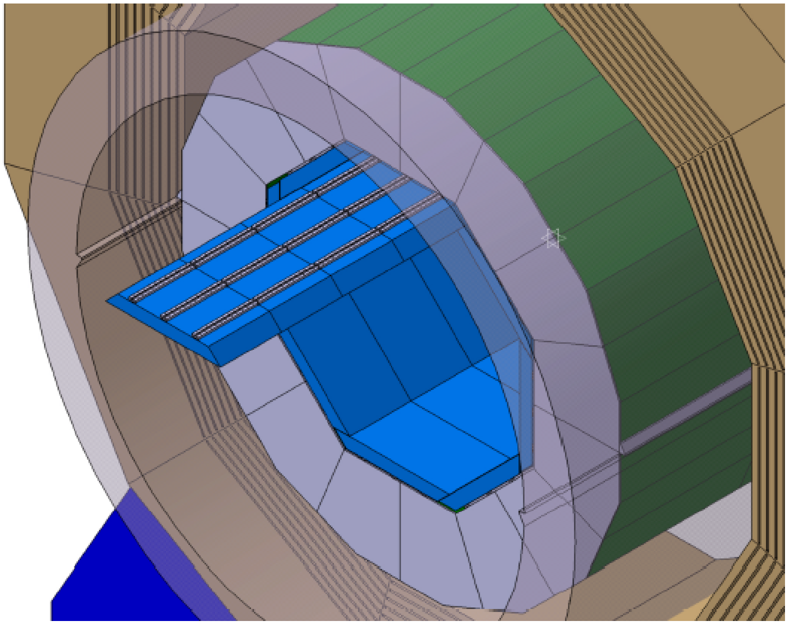
PFA Oriented Calorimeter

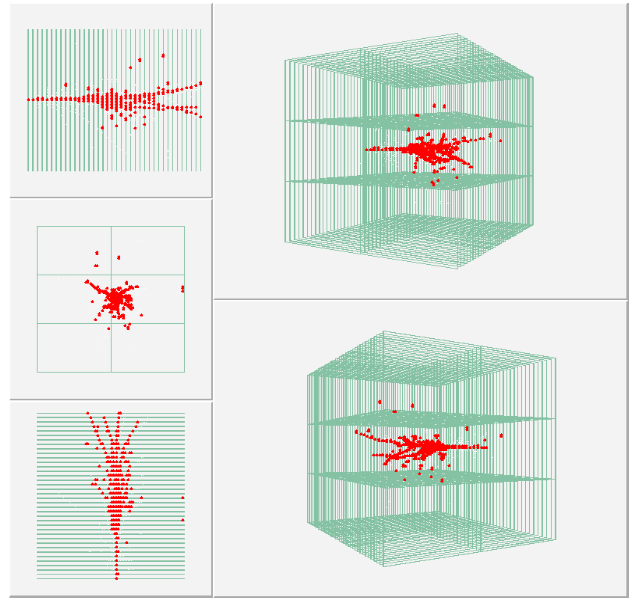
- Development of micro electronics: ultra-high granularity!
  - #channels, 10^4-10^5 (CMS) → 10^8 channels (ILC calorimeters)
  - Imaging calorimeter in 3-D (or even 5-D) in a high DAQ rate...
- Role of calorimeter
  - Measure the incident energy
  - Identify and measure each incident particles with sufficient energy

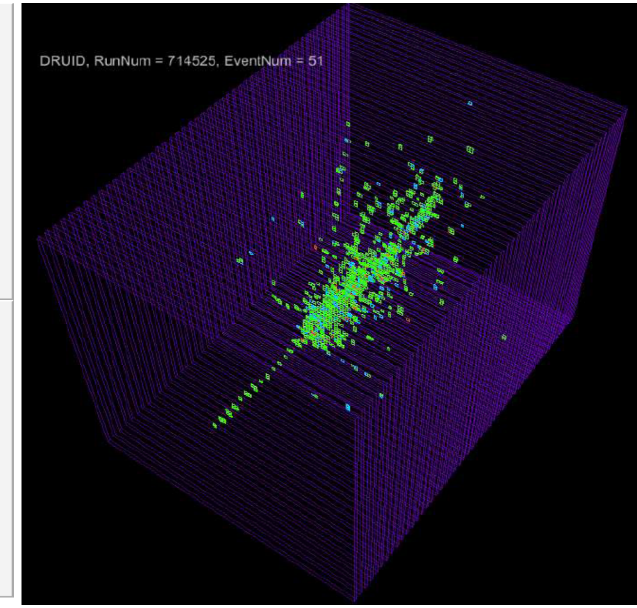


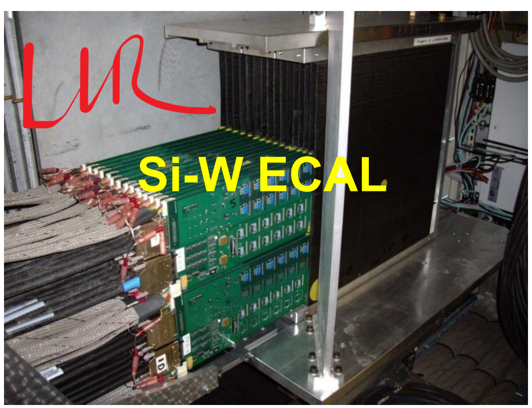
20 GeV Klong reconstructed @ ILD Calo

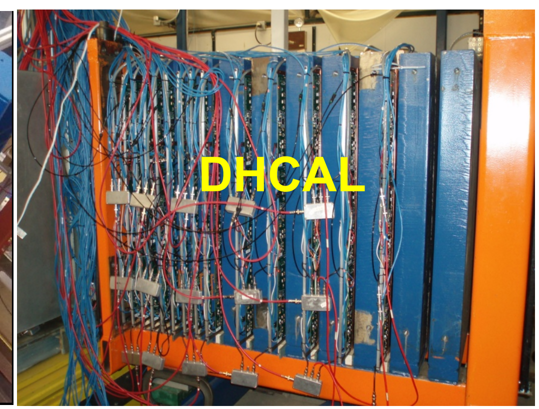
Calorimeter R&D for ILD







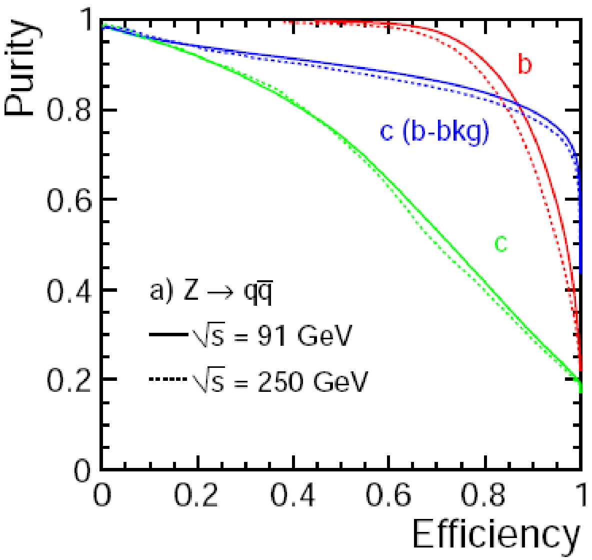


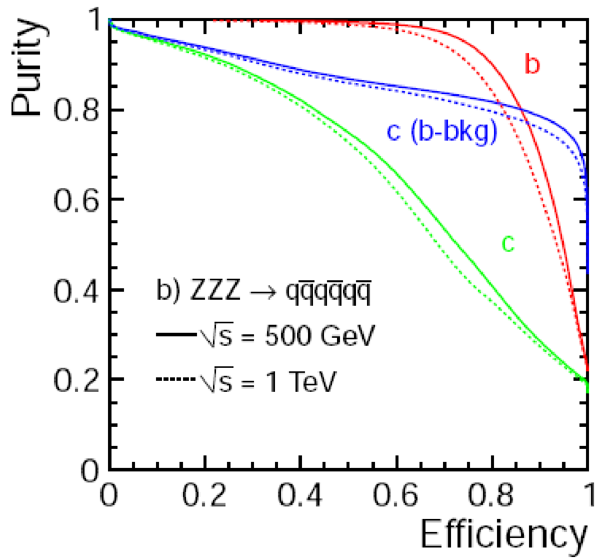


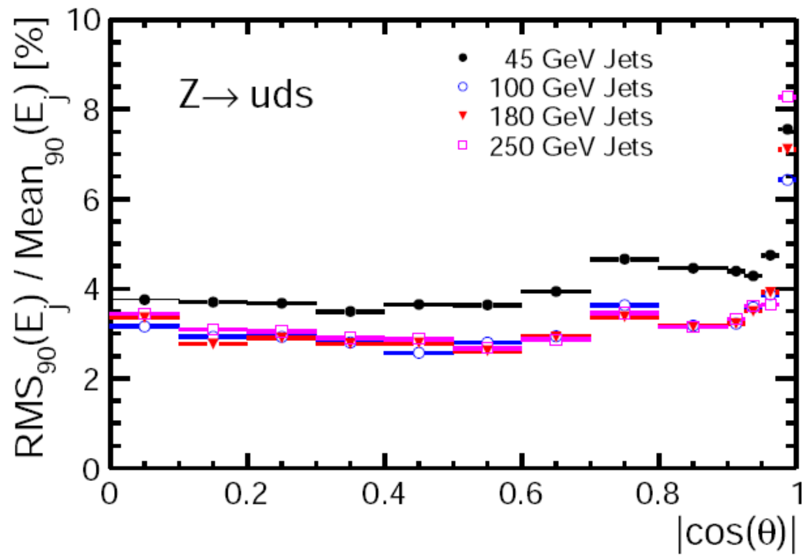
Ultra high granularity ~ 1 channel cm^{-3}. 3d, 4d or 5d image...

ILD Performance

b Vs udsc; c Vs b; c Vs udsb







Flavor tagging: eff = 80%, purity > 90% for b-tagging (Impact parameter resolution ~ 5 μm)
Algorithm: LCFIPlus, Tokyo University (Tomohiko Tanabe)

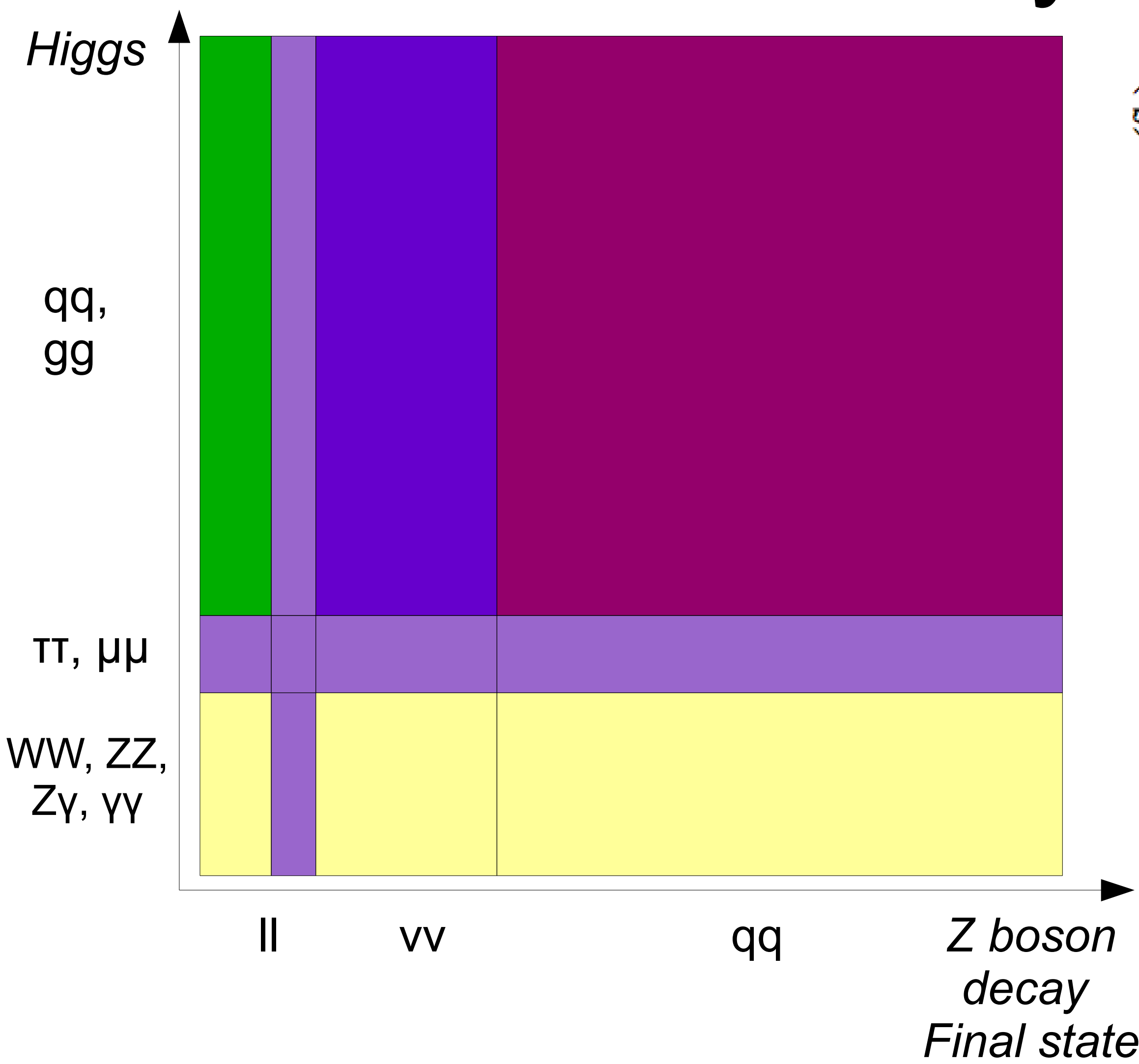
Tracking: $\delta(1/P_T) \sim 2\text{-}5{*}10^{-5}$(1/GeV)
Algorithm: Clupatra, DESY (Frank Gaede); KalTest, KEK (Keisuke Fujii), etc

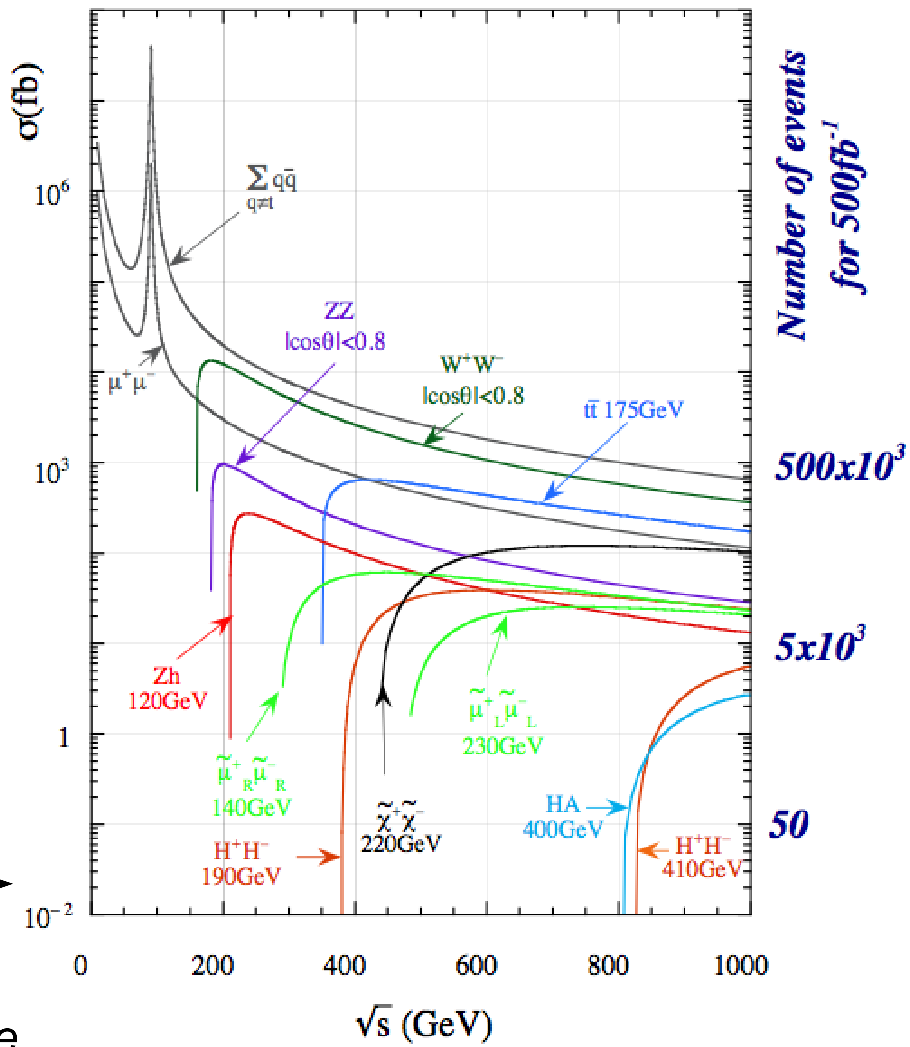
PFA： $\delta E_J/E$ = 3 - 4%
Algorithm: PandoraPFA, Cambridge (Mark Thomson); Arbor, LLR & IHEP(Manqi, Henri)

How detector works:

Take a snapshot of the physic event!

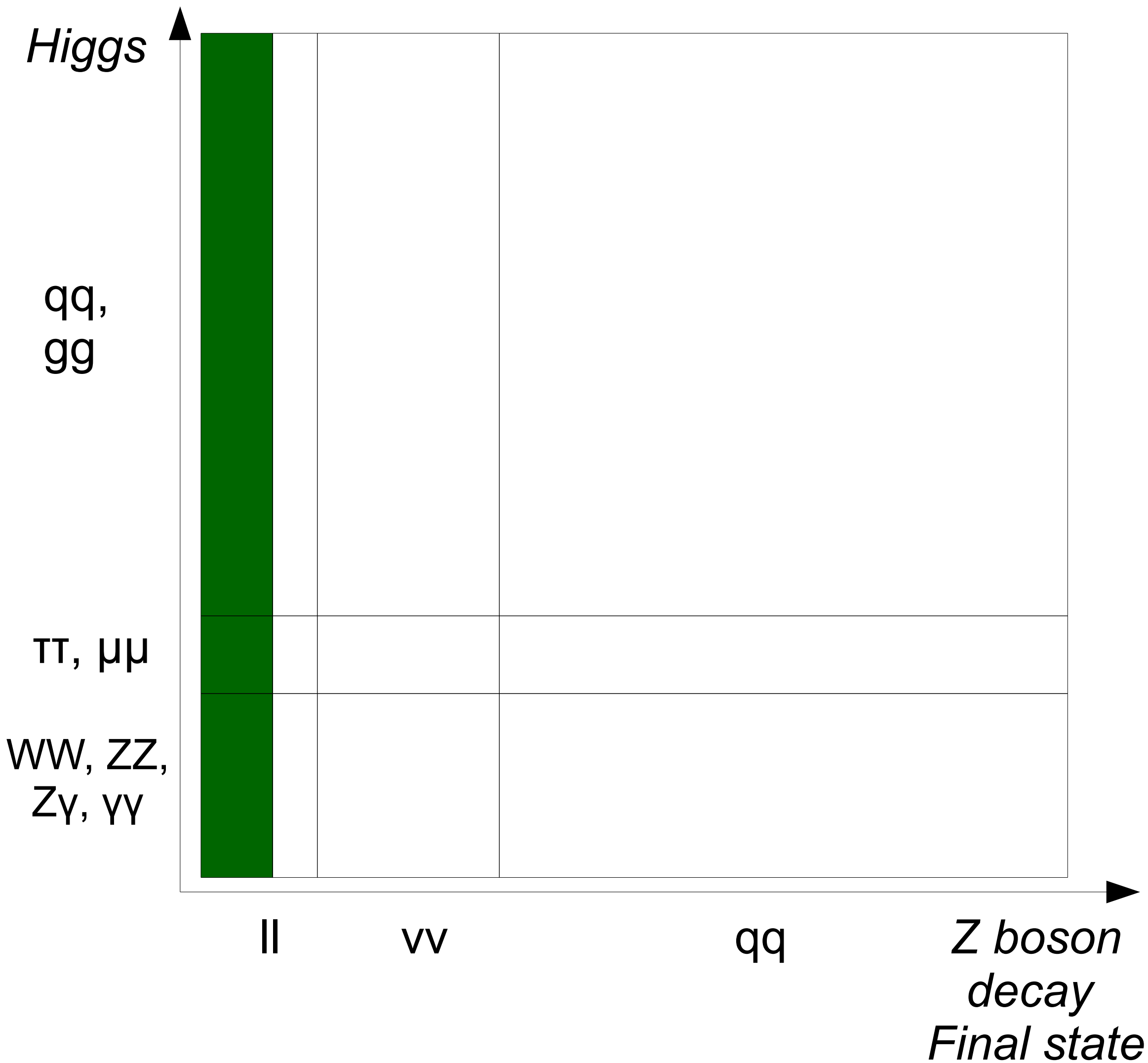
Higgs Measurement: Physics Analysis





Main background: WW, **ZZ**, qq/ll, Single W, Single Z...

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

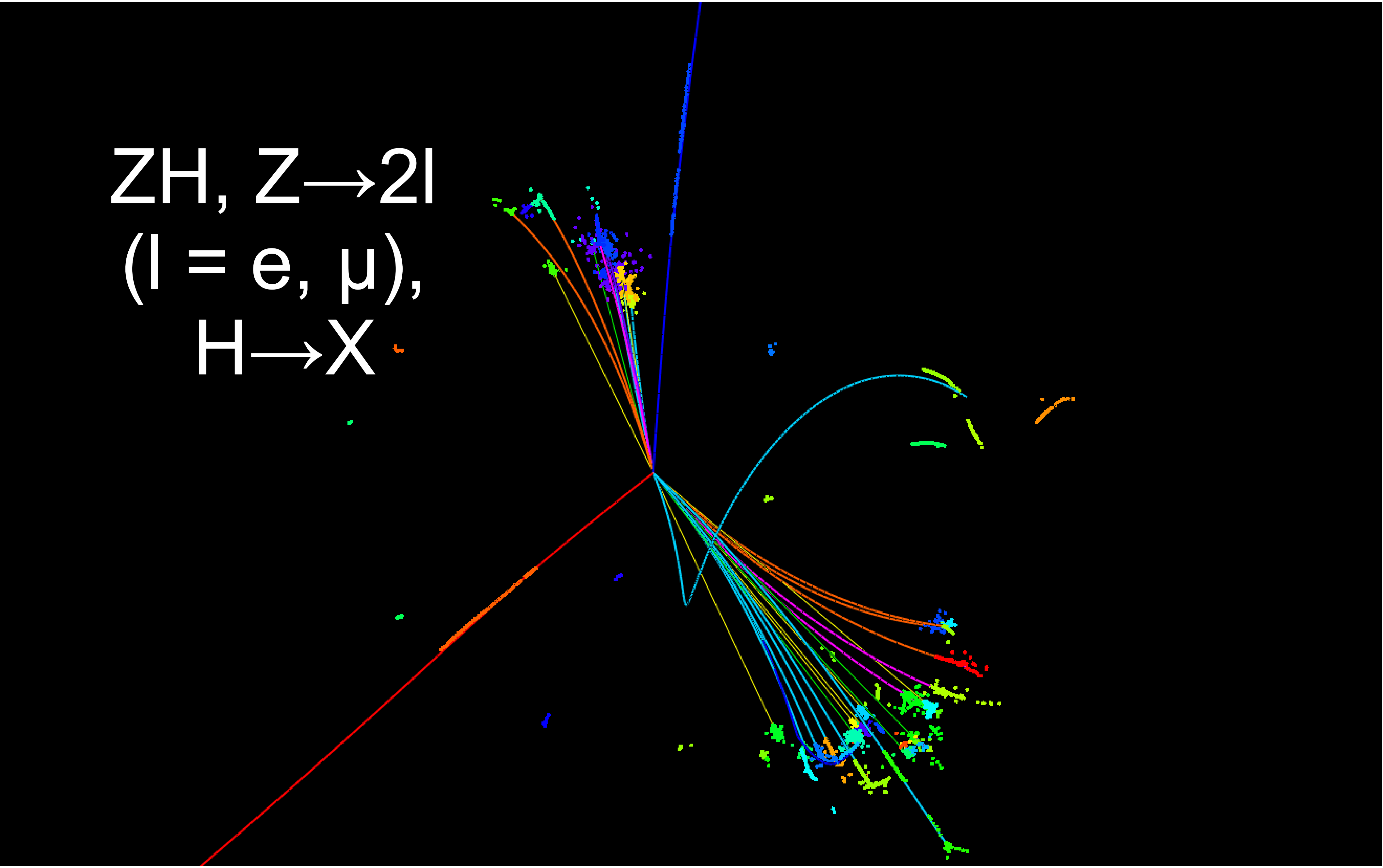
Objective Observables:

Recoil mass spectrum:
Higgs mass, σ(HZ)

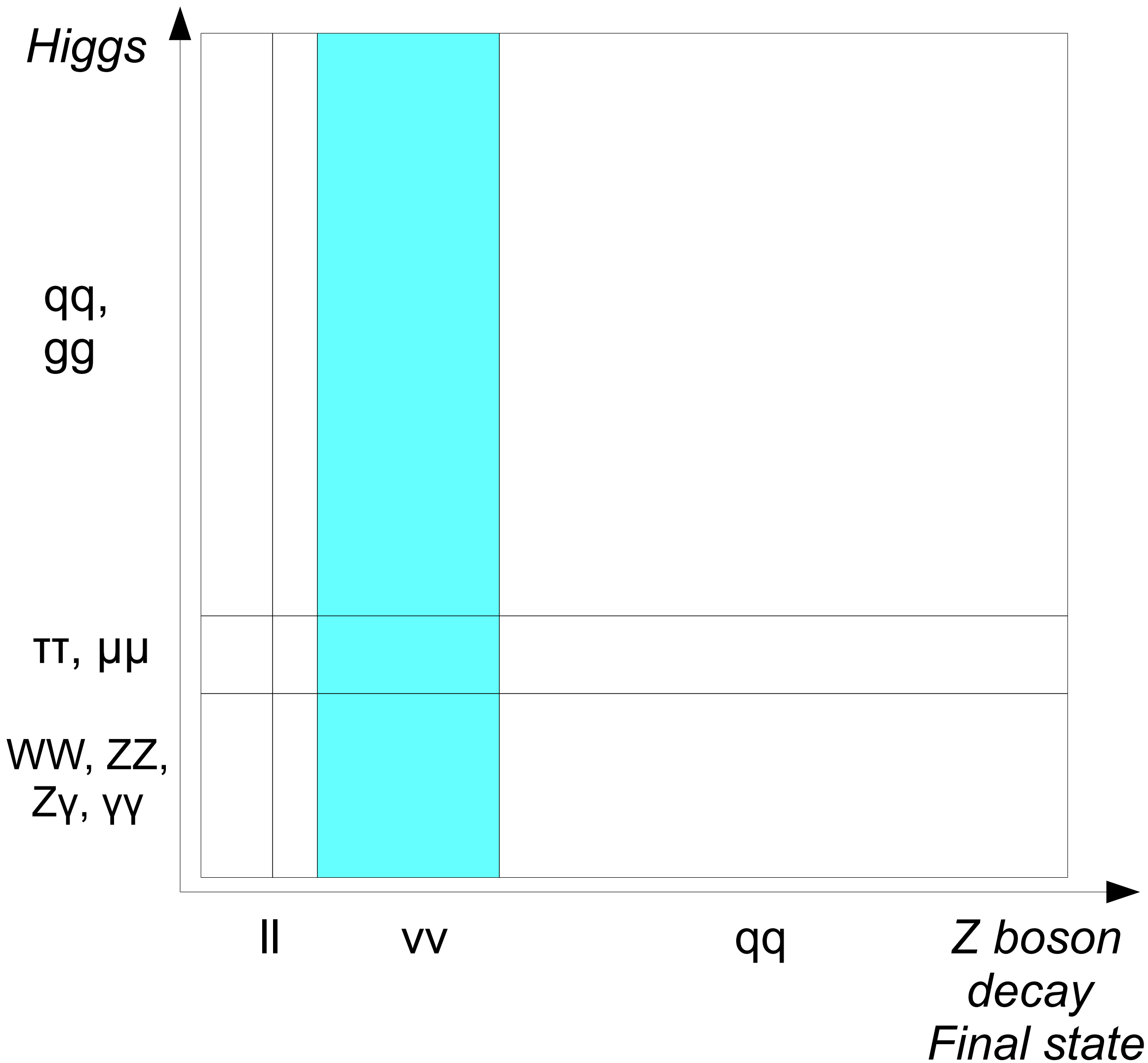
Tagged ZH events + Higgs final states classification:
Br(H→X)*σ(HZ)

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



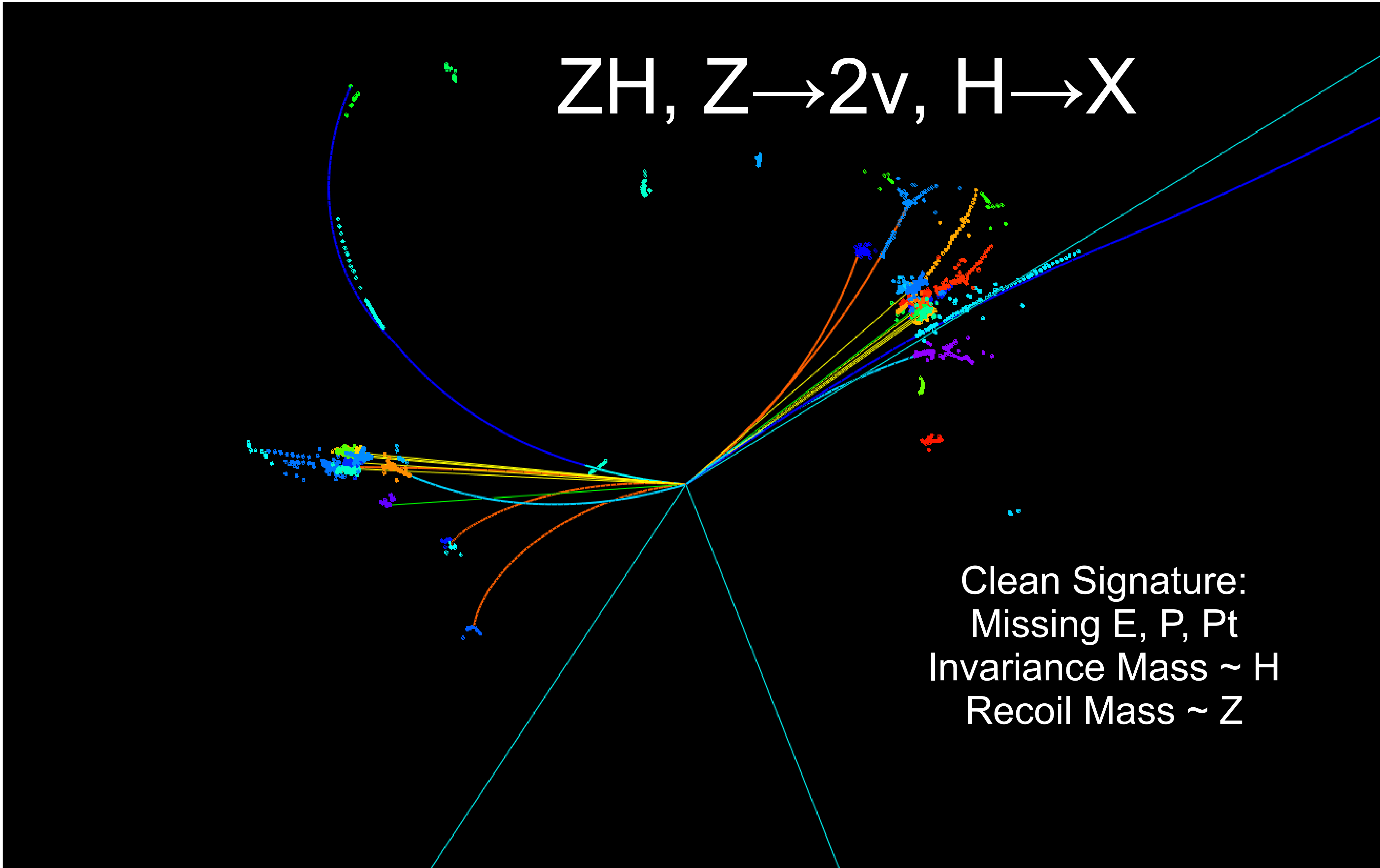
Tag the ZH events from di-jet Invariant mass. Statistic ~ 20k evts

Objective Observables:

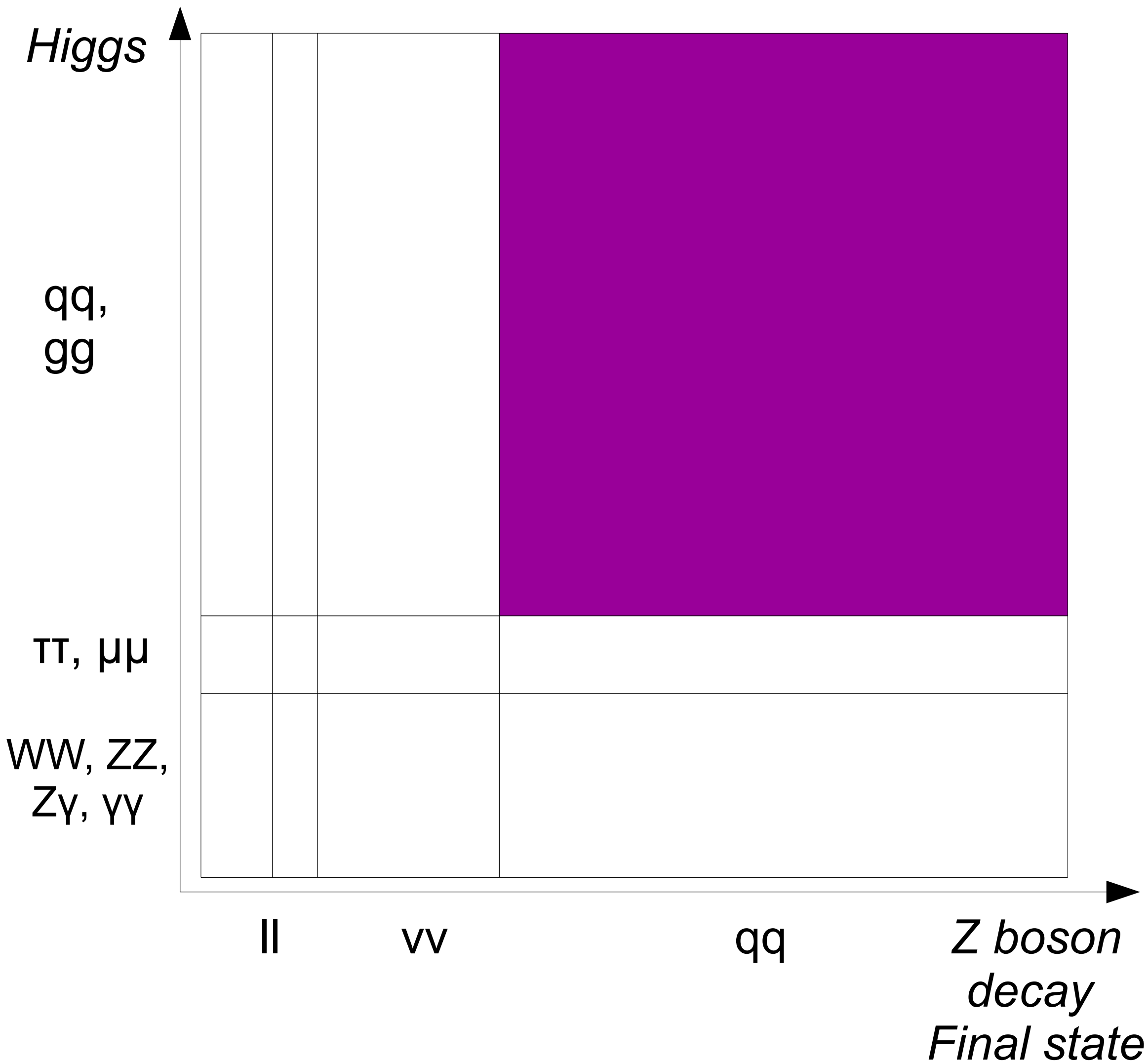
Higgs mass, σ(HZ)*Br(H→X)

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



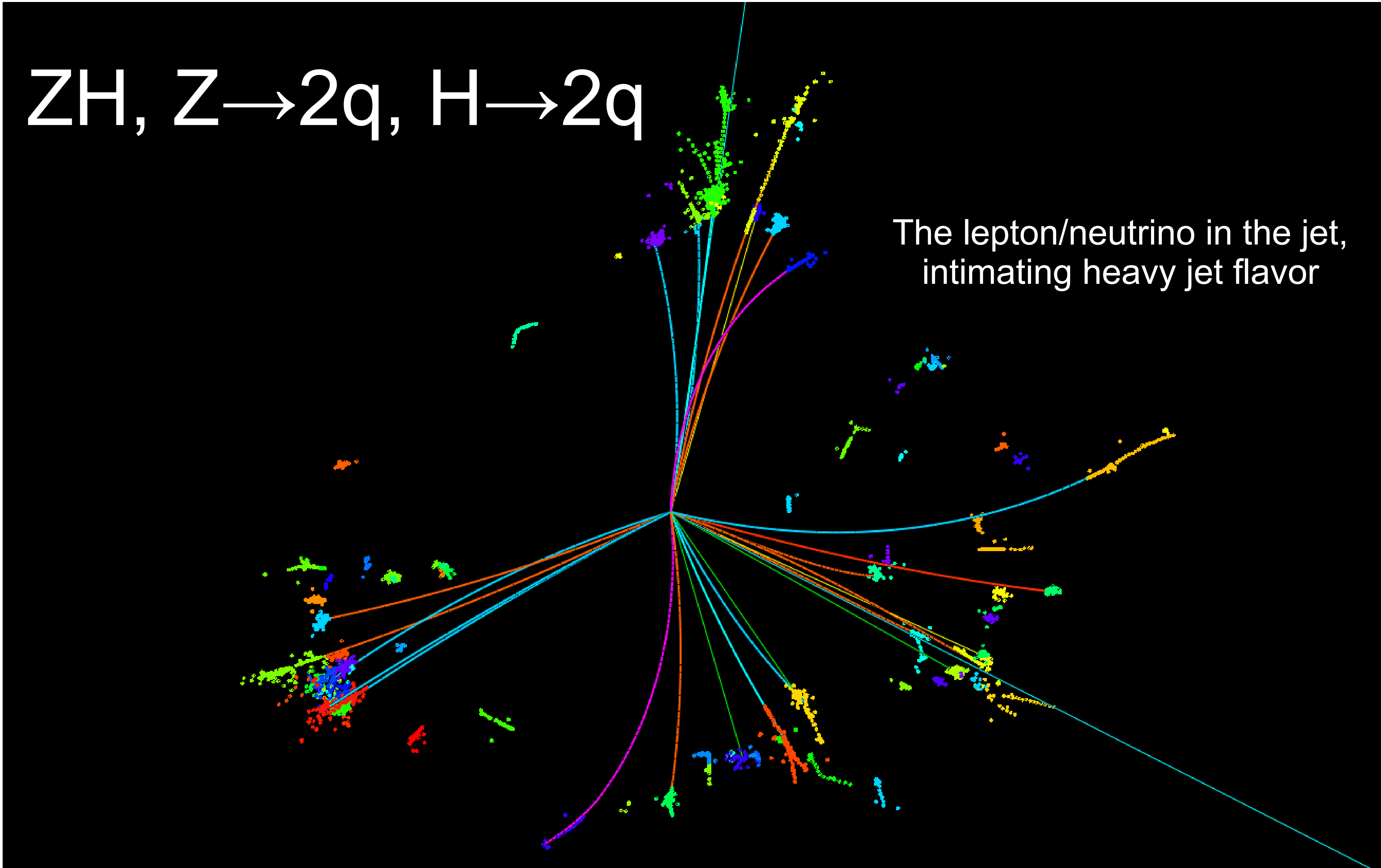
Tag the ZH events from invariant Mass of all 2-jets combinations.
Statistics ~ 50k evts

Objective Observables:

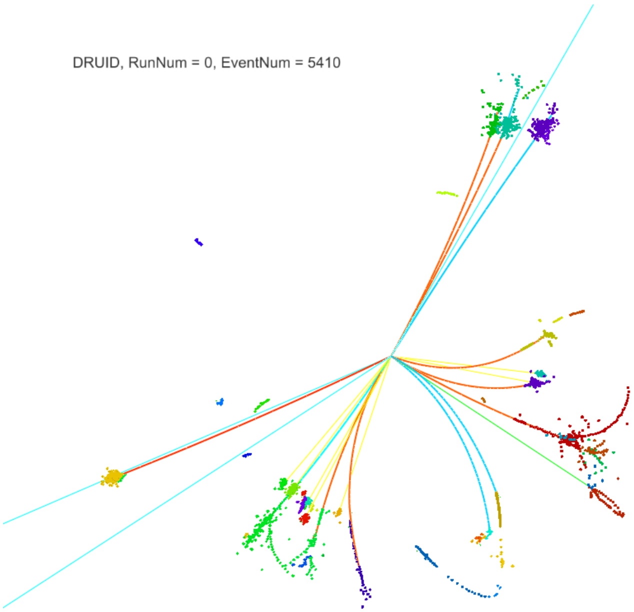
Higgs mass, σ(HZ)*Br(H→2j), σ(HZ)*Br(H→2b, 2c, 2g),

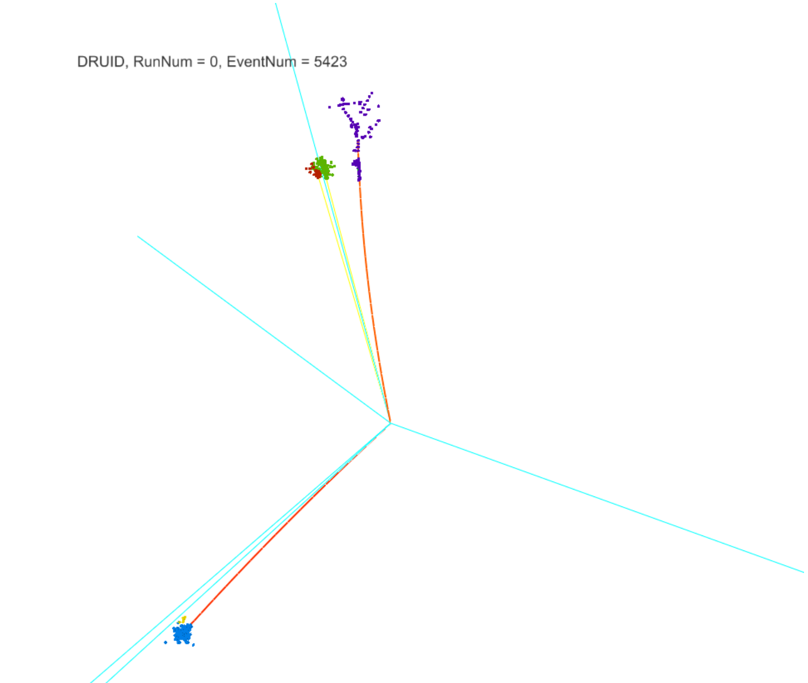
Critical performances:
Jet clustering,
Jet energy resolution (PFA),
Flavor tagging

ZH, $Z \to 2q$, $H \to 2q$



Taus...


DRUID, RunNum = 0, EventNum = 5410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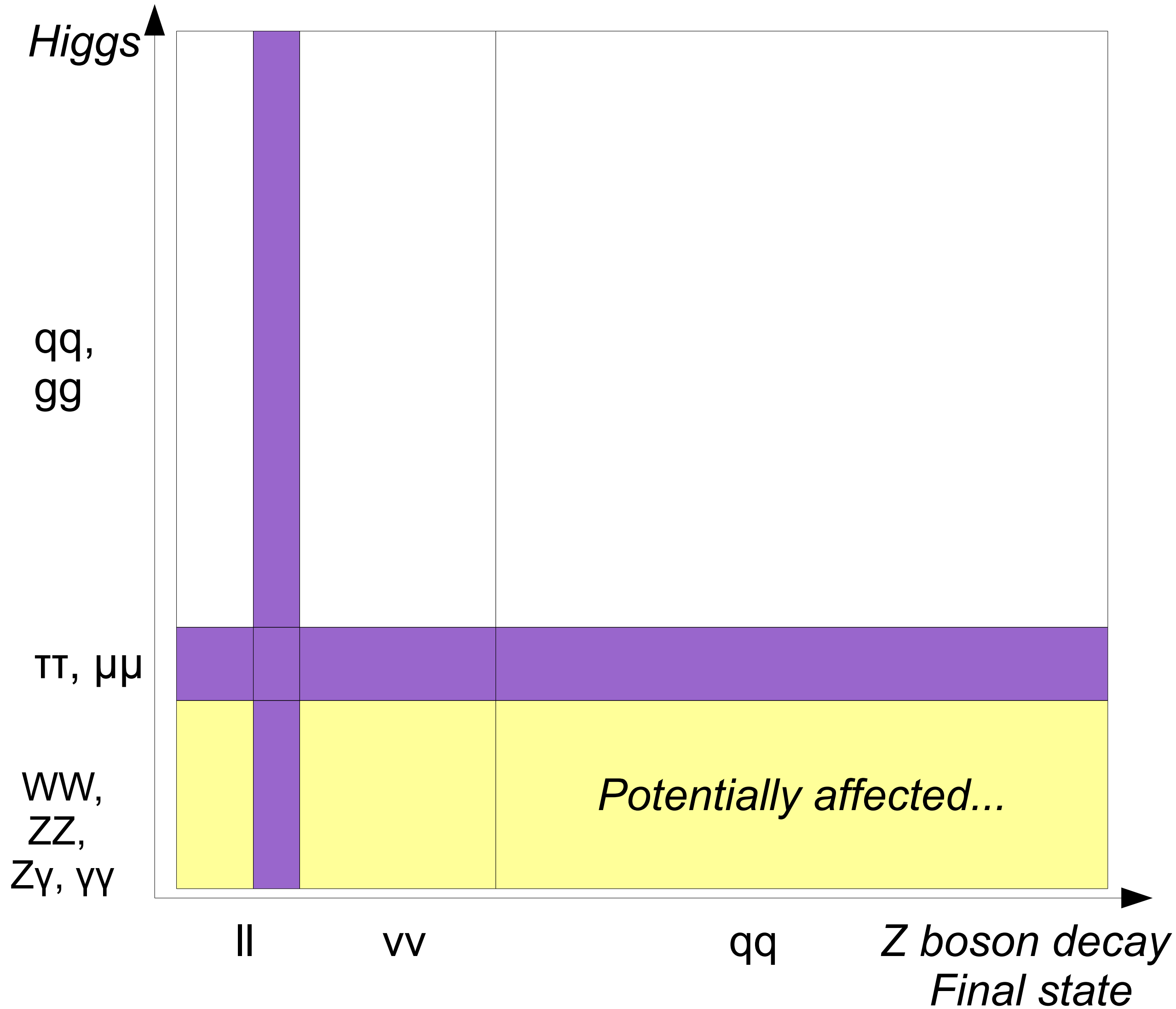
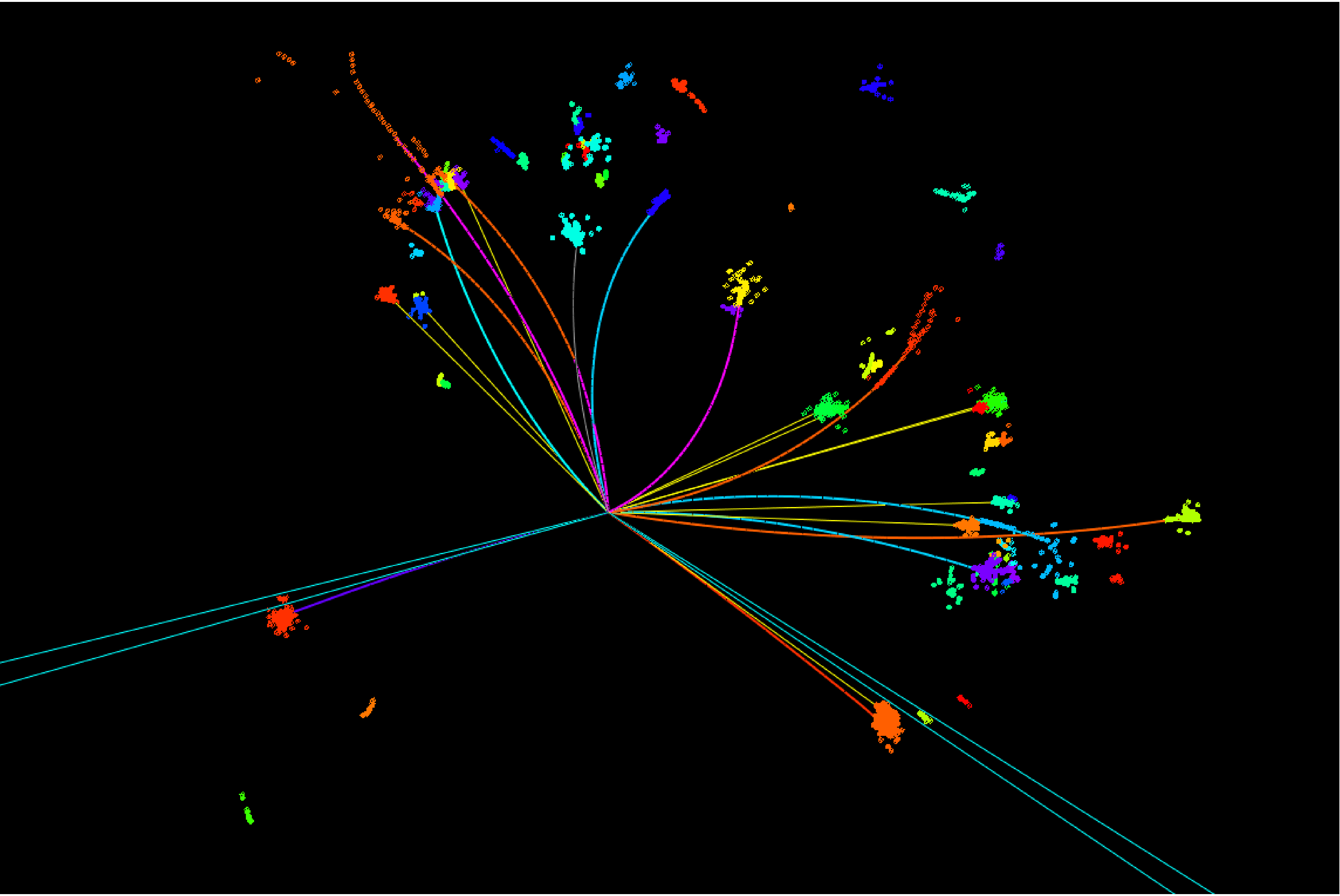
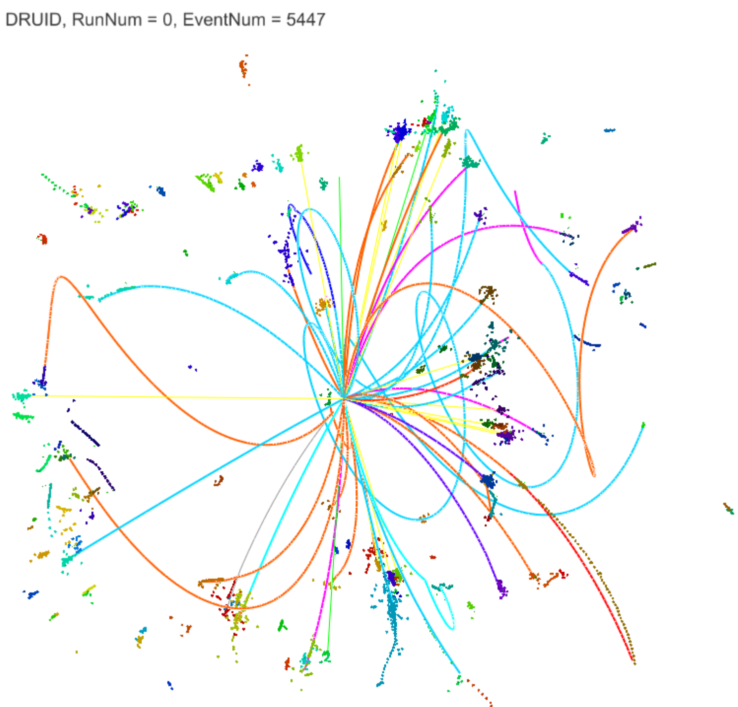
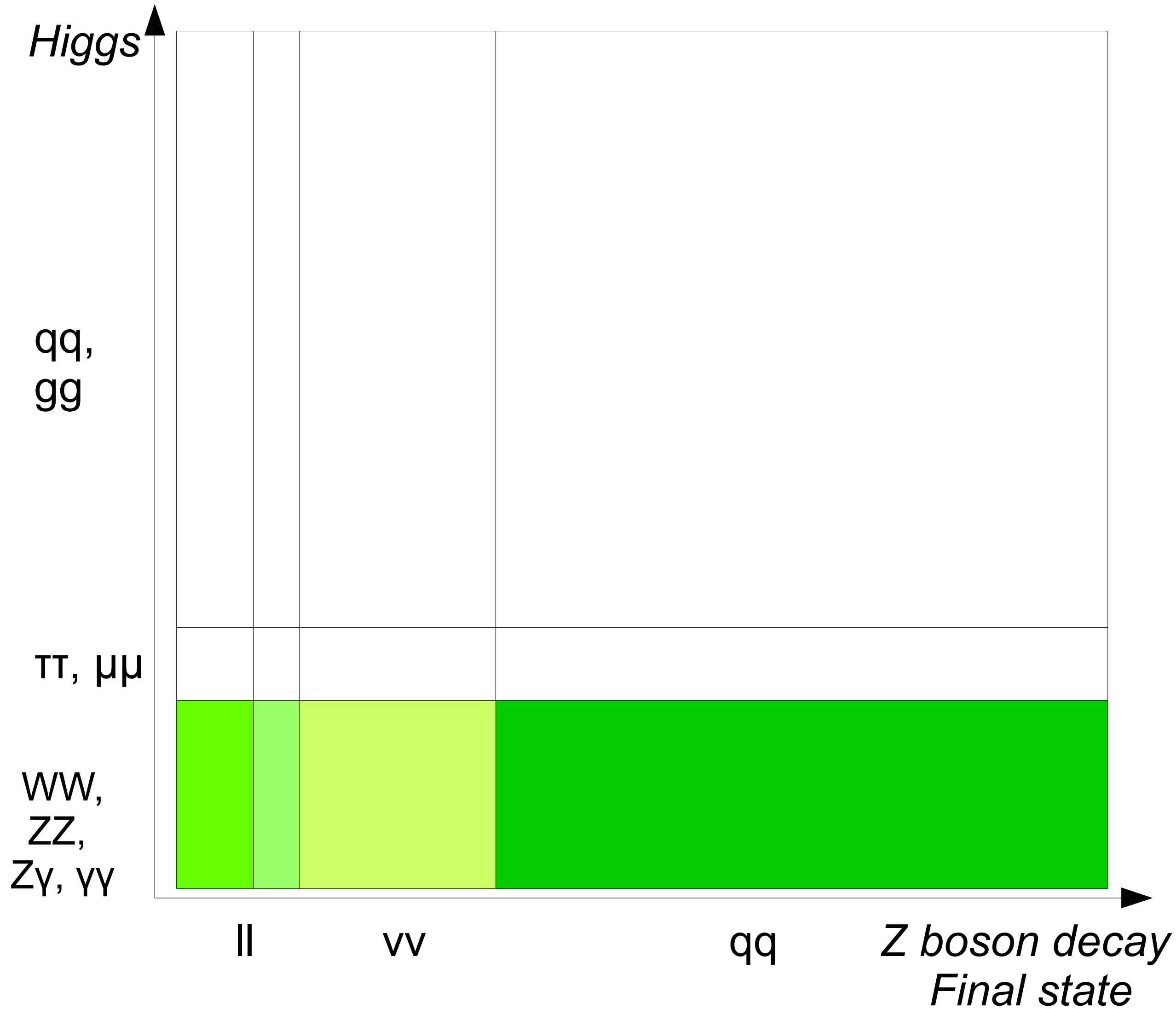

Higgs
qq,
gg
ττ, μμ
WW,
ZZ,
Zγ, γγ
Potentially affected...
ll
νν
qq
Z boson decay
Final state

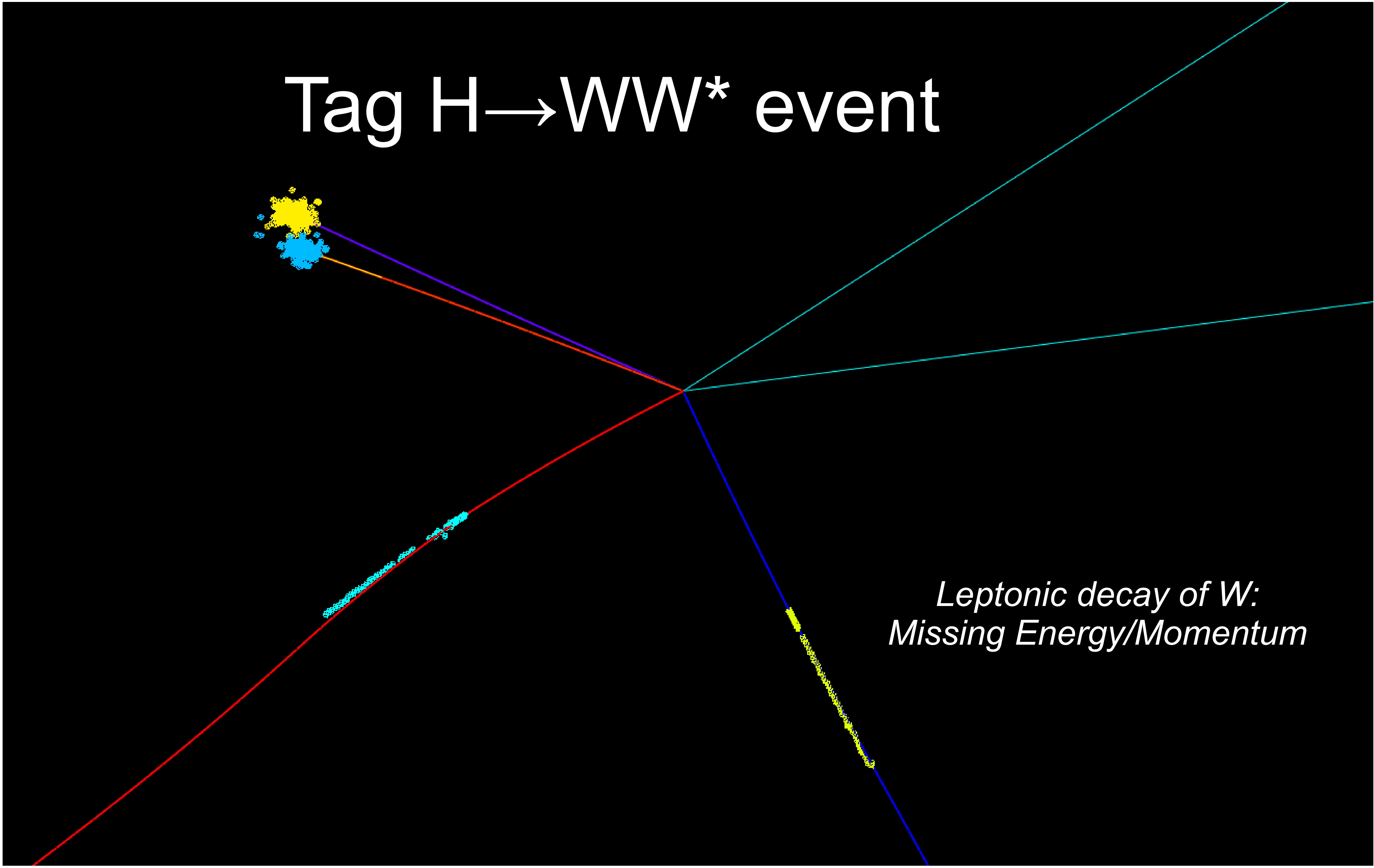


Br(H→WW, ZZ) ~ Width Measurement

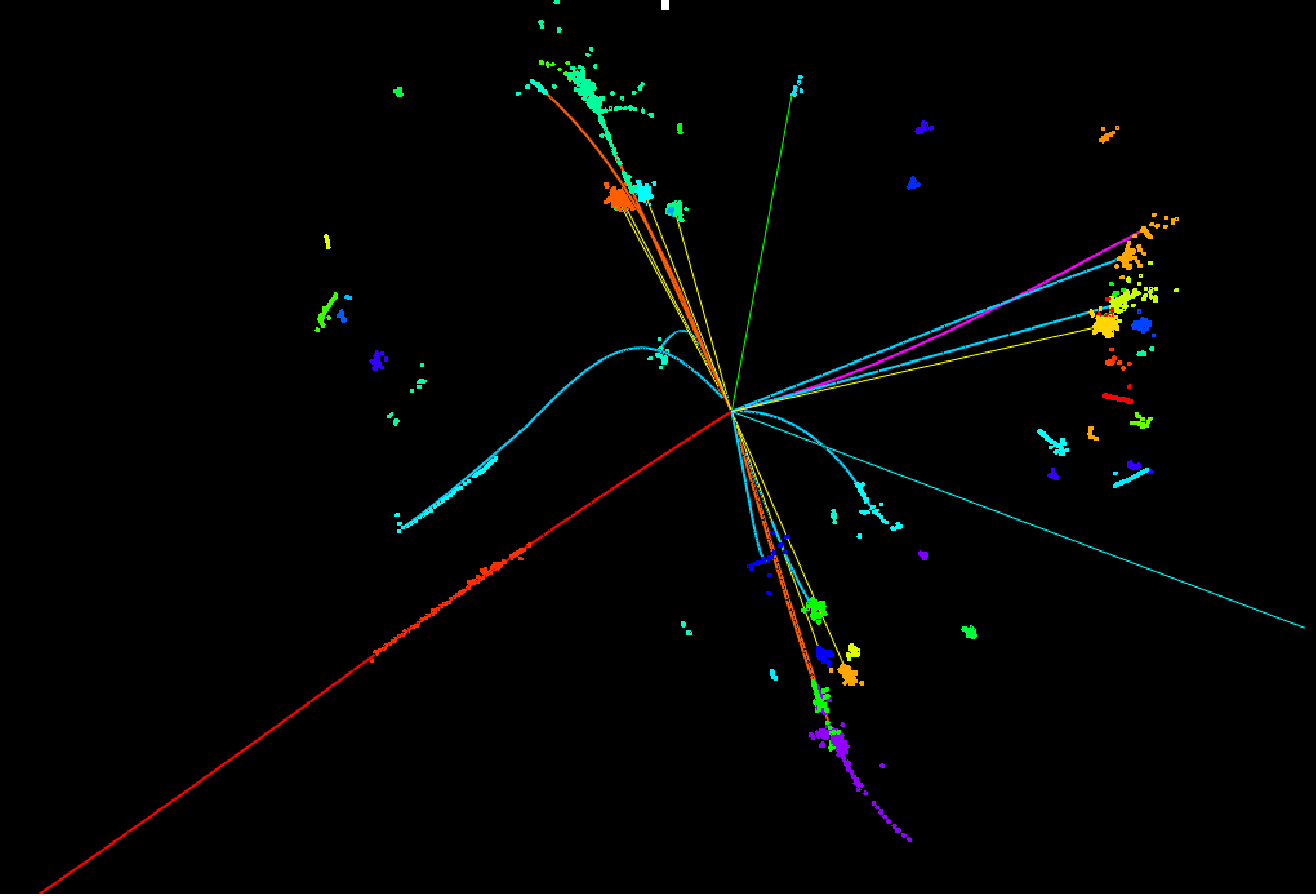


Important,
challenging,
Exciting.




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

H→WW*→2qlν



Higgs analysis at CEPC

	CEPC @ 5 ab^{-1}	Current Status	Responsable & perspective
mH (MI)	8 MeV	12 MeV (μμH)	IHEP, CCNU
σ(ZH)	0.7 %	1.2 %	IHEP, CCNU
Higgs CP		Theoretically Investigated	THU, HKUST
Δ(σ*Br)/(σ*Br)			
ZH, H→bb	1.0%	0.22% (qqH channel)	SJTU, IHEP
H→cc	2.1%	2.2 – 2.8%	SJTU, IHEP
H→gg	1.8%	1.8 – 2.4%	SJTU, IHEP
H→WW*	**1.3%**		IHEP, PKU
H→ττ	1.2%	Efforts initialized	IHEP, USTC
H→ZZ*	5.1%		SDU
H→γγ	8%	~ 12% (ννH)	WhU, IHEP
H→μμ	?		UCAS
H→Inv.	0.3%		IHEP, HKUST
ννH, H→bb	**3.8%**		PKU, IHEP

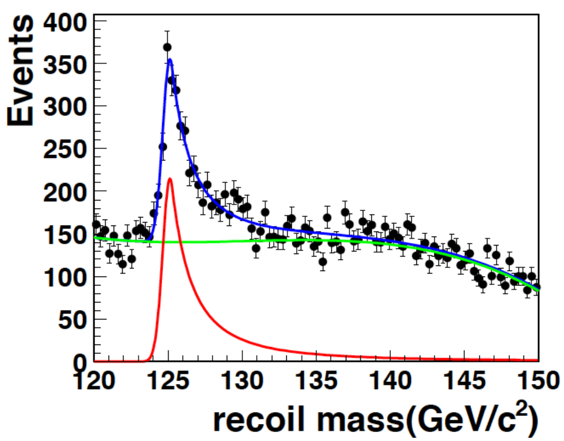
Optimistic Perspective
By the end of 2014

To be validated by Full Simulation

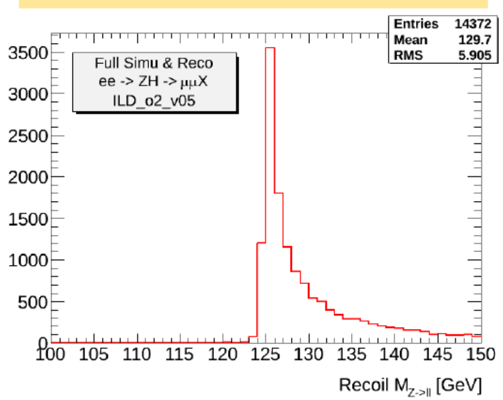
Stat at Fast Simulation Level

Some analysis on Higgs measurements

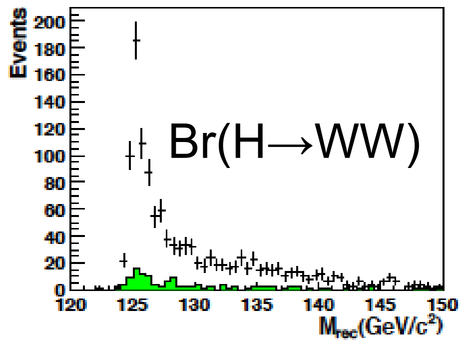
Higgs Recoil mass and Xsec

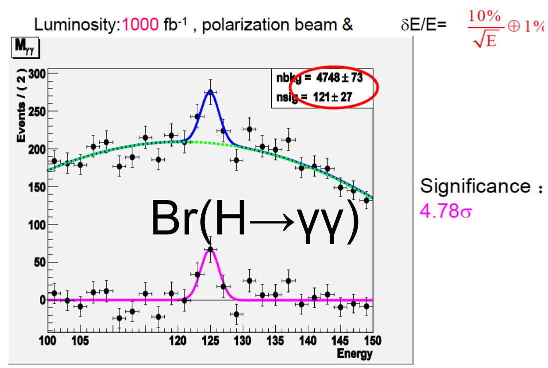


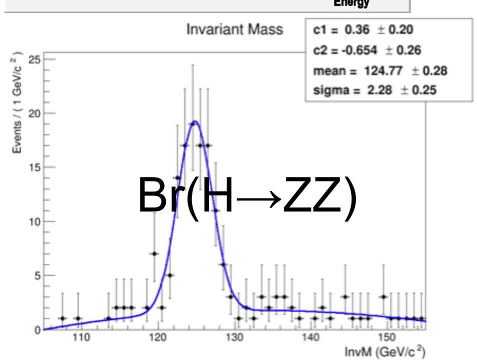
→Recoil Mass of Z → μμ
Mean = 129.7 GeV
RMS = 5.9 GeV



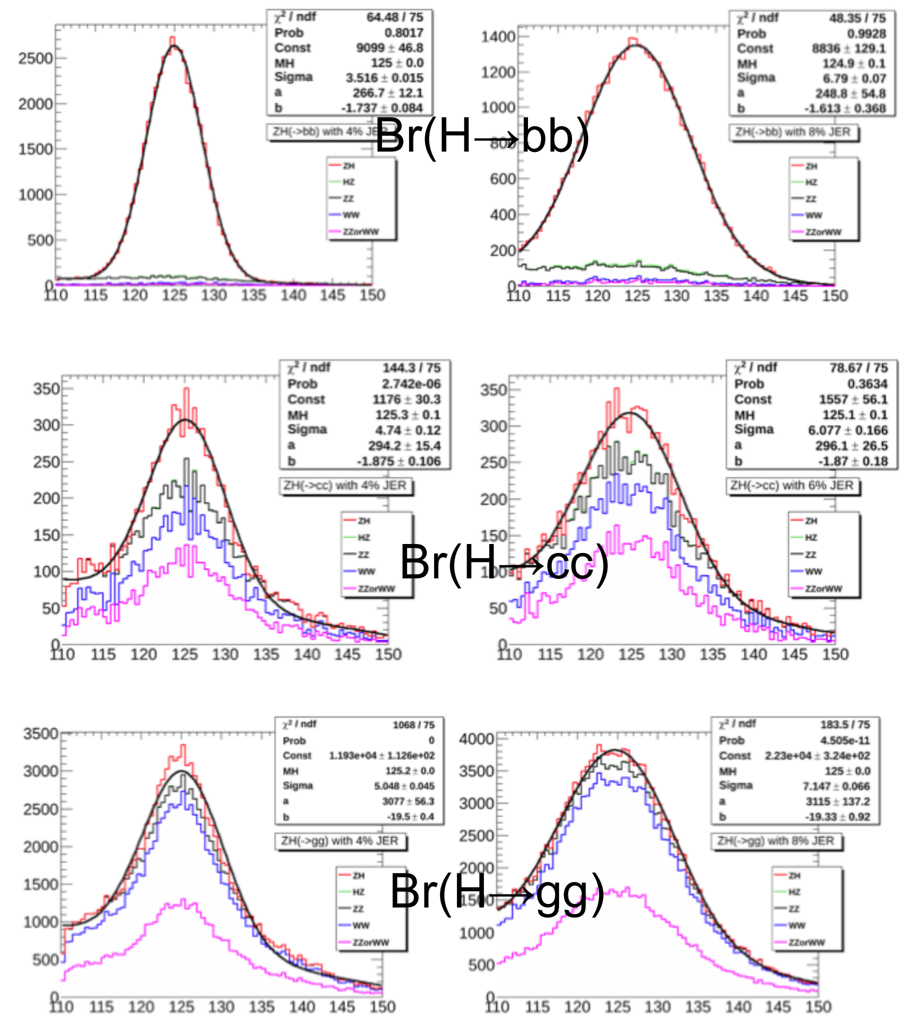
Br(H→bosons)



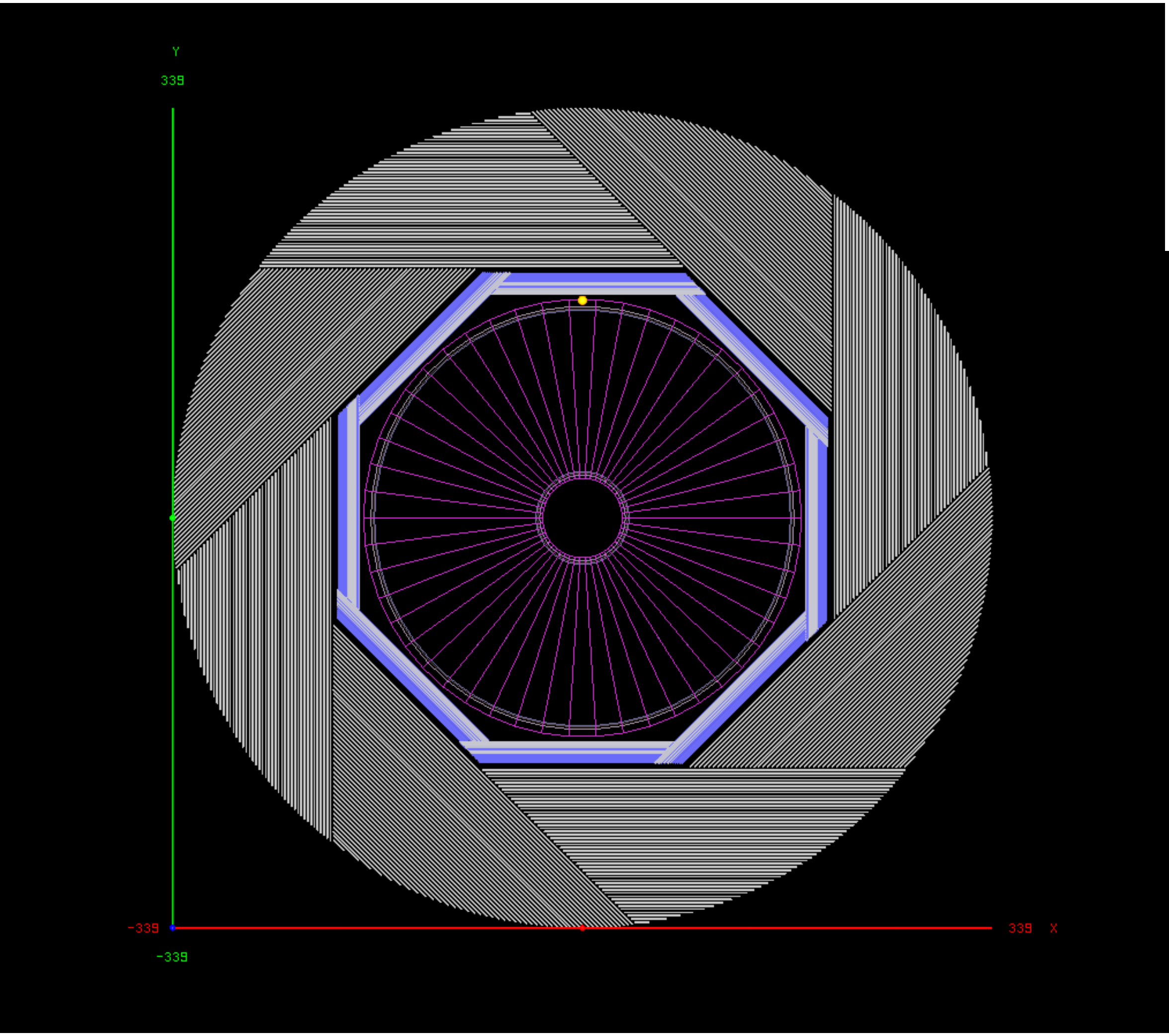




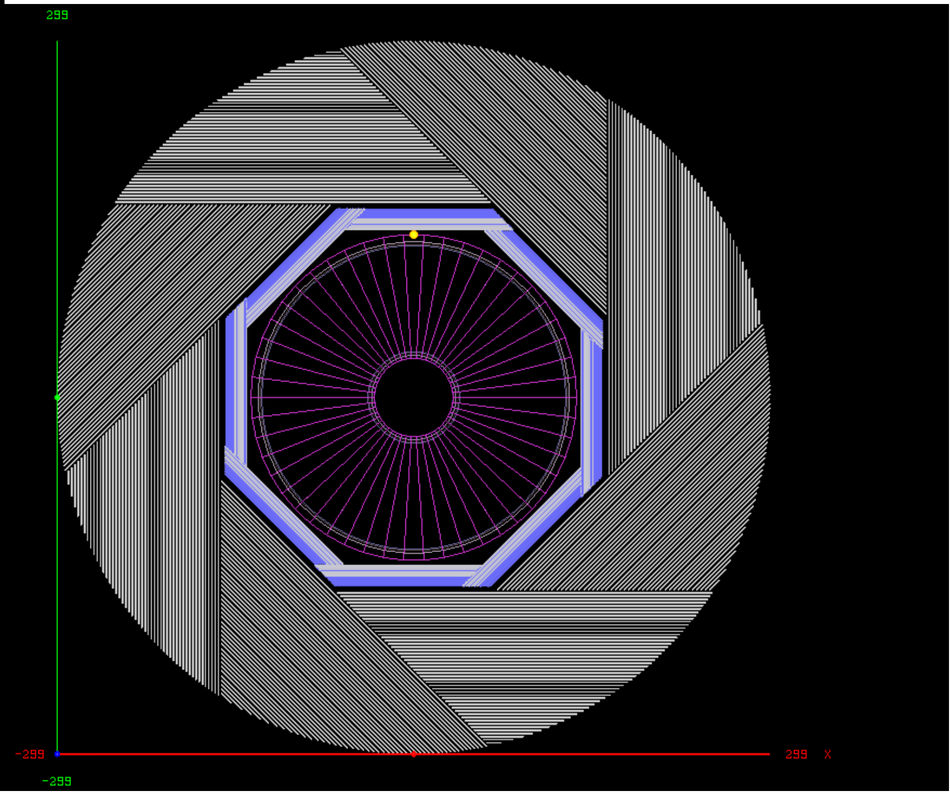
Br(H→2 jets)



From ILD to ILD_v2

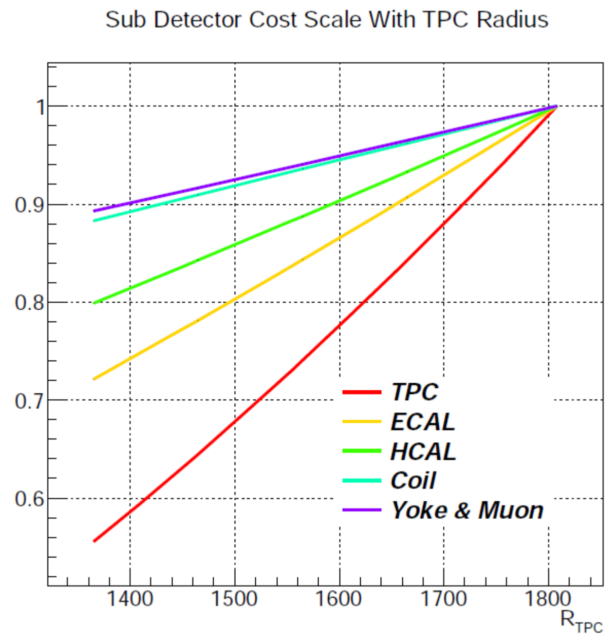


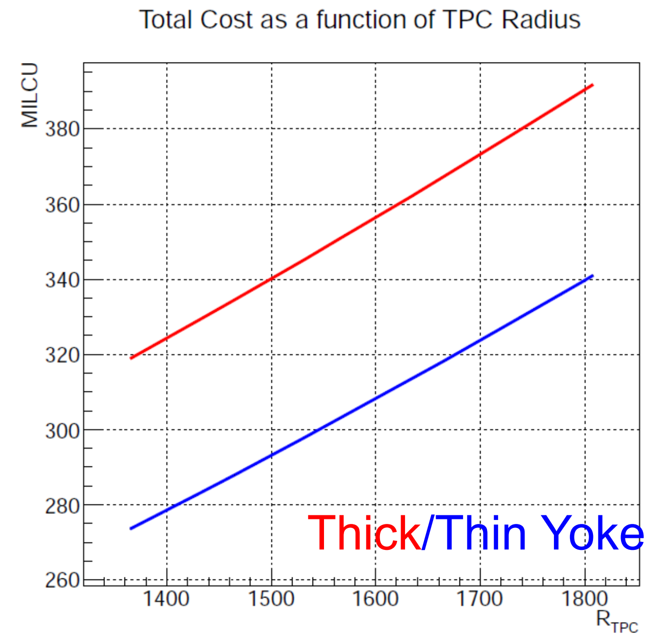
Scaled (~ 75%) length & radius of TPC
Reduced #Calo Layer



Geometry optimization and cost

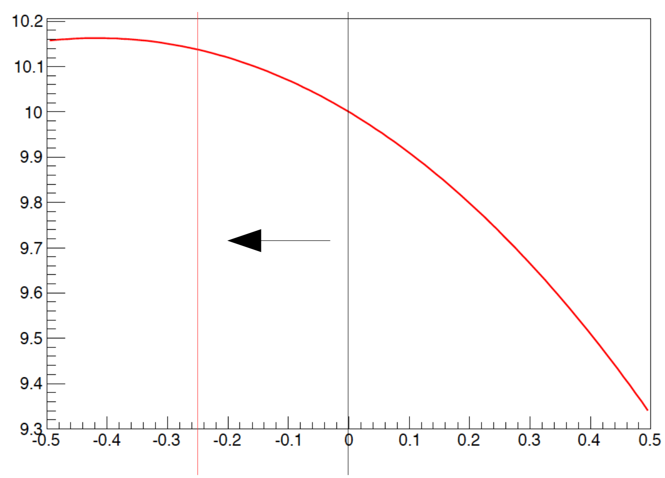
- Optimized geometry with ILD as reference: reduce the total radius by 25%
- Assumption: 5 yr/1 detector & 10 yr/2 detector
- Total efficiency will be increased by ~ 1%

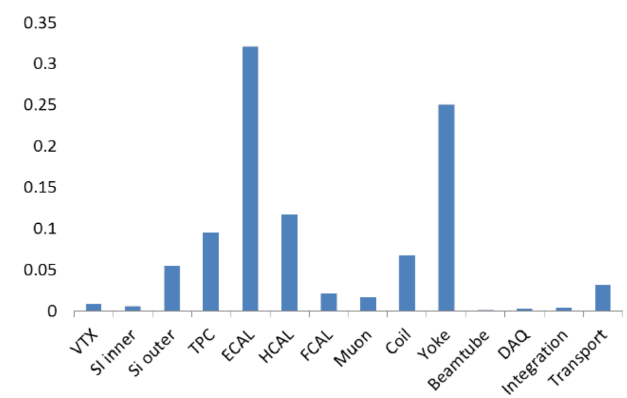




ILD Cost ~ 400 MILCU (PPP)
CEPC detector ~ 270 MILCU
~ 1.6 Billion CNY
~ 3 B CNY for 2 detectors;

Without manpower





From ILD to CEPC detector

- Many new designs
  - Changed granularity (no power pulsing)
  - Changed L* & MDI
  - Changed VTX inner radius
  - Changed TPC outer Radius
  - Changed Detector Half Z
  - Changed Yoke/Muon thickness
  - **Changed Sub detector design**
  - …
- All Changes need to be implemented into simulation, develop/adjust adequate reconstruction, iterate with physics analysis and cost estimation

We need

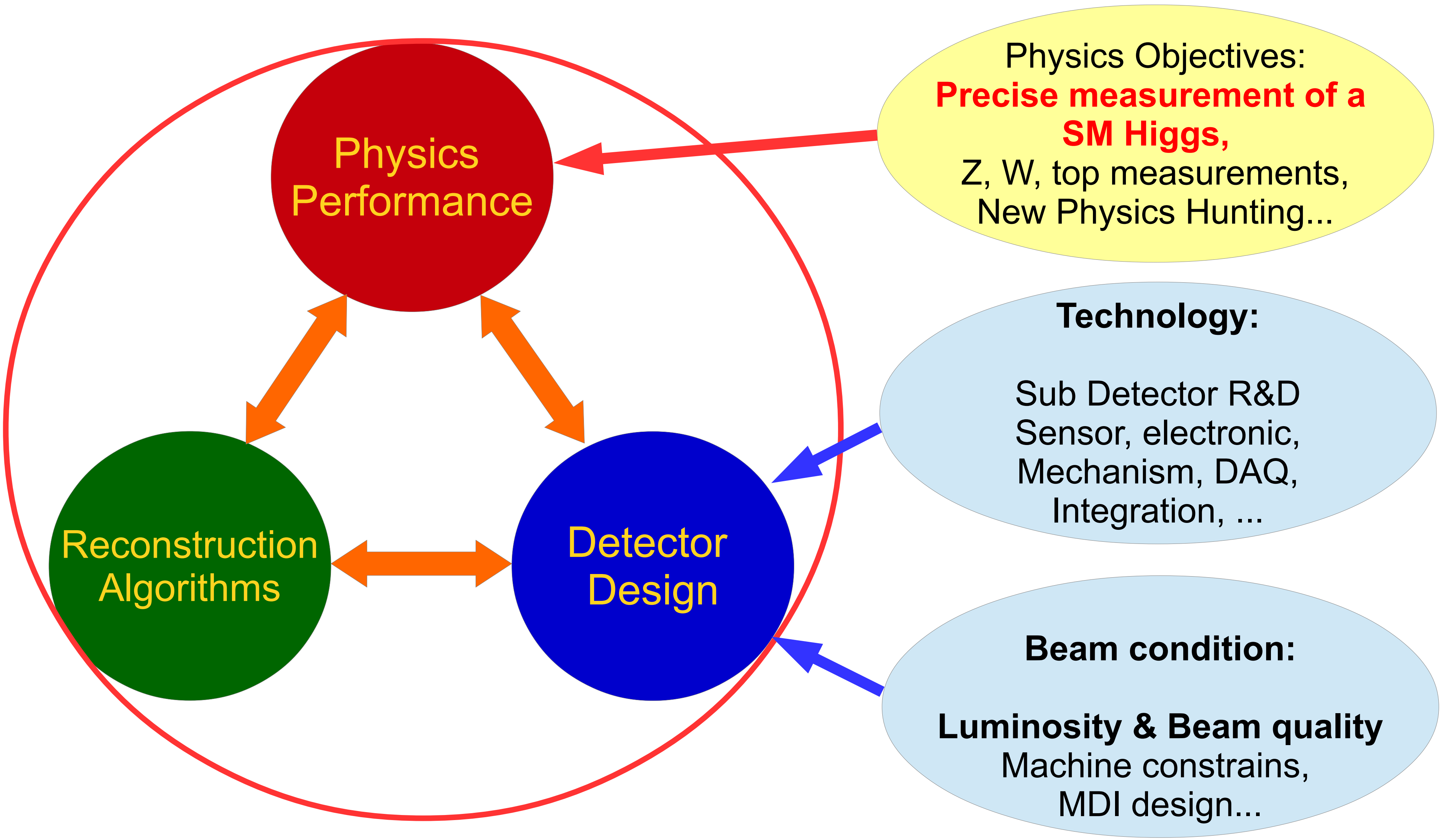
- Through understanding of detector system
  - Physics requirement, performance & cost... to sub detector level
- Correct implementation of detector geometry into the central simulation framework
  - G4 coding
  - Central Standard, Plugin-Communication
  - Validation
- Adequate Reconstruction Algorithms: Calibration, Alignments & Performance Estimation
  - Tracking (Kalman)
  - Calorimeter (Particle Flow)
  - Vertex: Jet Clustering & Flavor tagging
- Future trends to software framework...
  - Generic, transparent, efficient, flexibility...


WE WANT YOU!


NEED
WE WANT YOU!

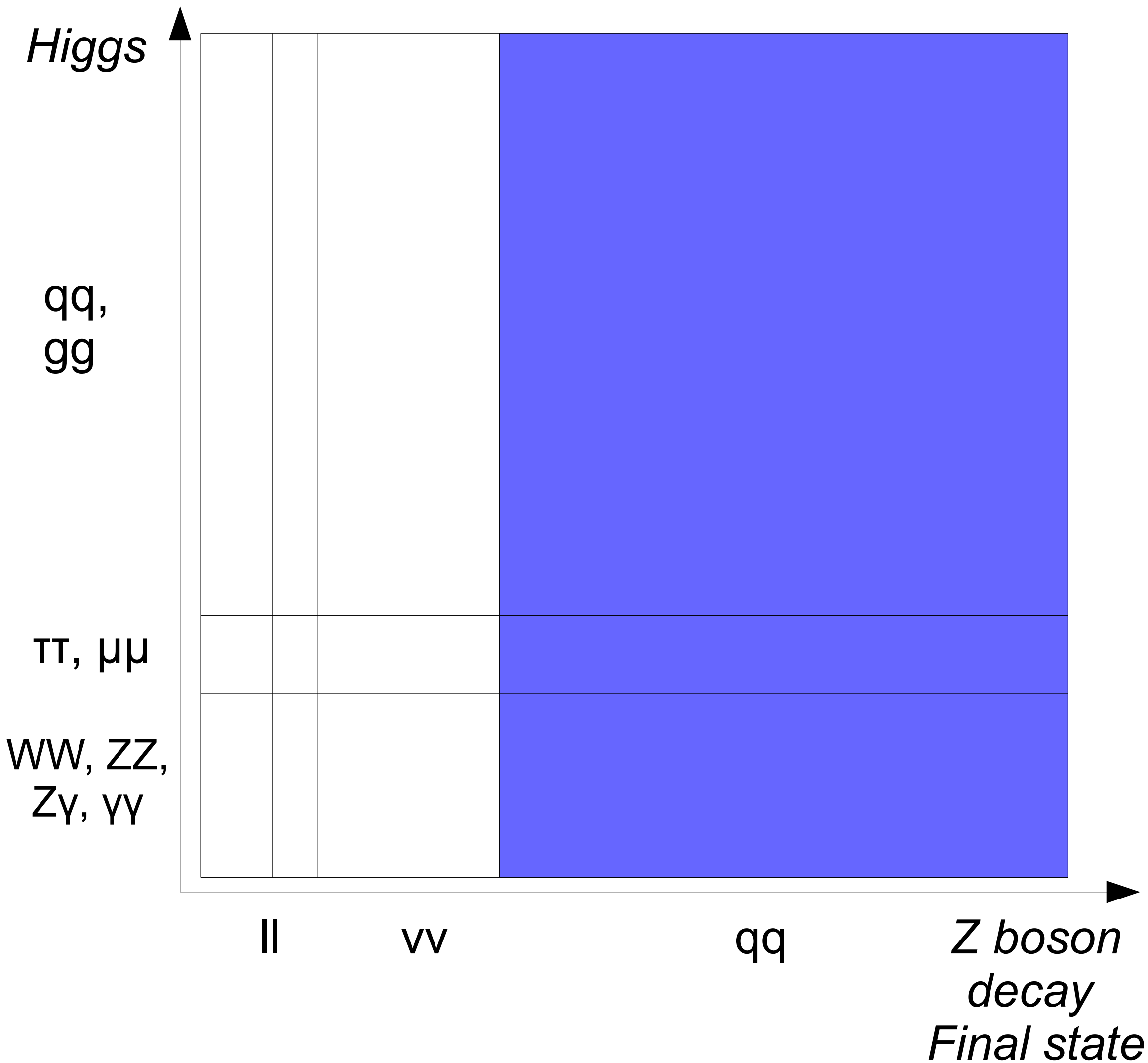
Spared

Detector optimization: Basic ingredients




Higgs, the focus,
the gate
CEPC, the KEY

ZH, Z→2q, H→X



Model independent tagging of ZH events from recoil mass spectrum to di-jet system. Statistic ~ 70k evts

Objective Observables:

Recoil mass spectrum:
Higgs mass, σ(HZ)

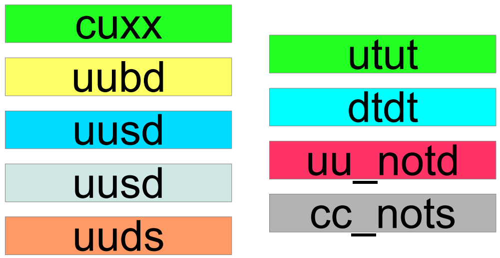
Tagged ZH events + Higgs final states classification:
Br(H→X)*σ(HZ)

Critical performance/algorithms:
PFA (jet energy resolution),
Jet clustering &
final states classification:

All 4-fermion back grounds

Type	ID	LL (n)	LR (n+1)	RL (n + 3)	RR (n+2)	non-pol	Final states
sw_l	6585-88	40	3335	29.1	40	861	$\nu_e e \nu_l l$ (l:μ,τ)
sw_sl	6563-66	119.7	10000	85.6	119.3	2581.2	ν_eeUD
sze_l	6555-58	1009.6	1084.1	1019.5	1008.4	1030.4	eell(l:μ,τ) $ee\nu_l\nu_l$
sze_sl	6559-62	259.8	459.1	316.5	259.0	323.6	eeUU, DD
szeorsw_l	6567-70	27.7	922.1	21.6	27.6	249.8	$ee\nu_e\nu_e$
sznu_l	6589(LR)-90		192.8	39.3		58.0	$\nu_e\nu_e$ll, (l:μ,τ)
sznu_sl	6571-72		456.8	130.8		146.9	$\nu_e\nu_e$UU, DD
ww_h	6551-52		14874.3	136.4		3752.7	
ww_l	6581-82		1564.2	14.7		394.7	$\nu_\mu \mu \nu_\tau \tau$
ww_sl	6577-78		18781.0	172.7		4738.4	UDν_ll (l:μ,τ)
zz_h	6573-74		1402.1	605.0		501.8	
zz_l	6579-80		158.0	99.5		64.4	2l2l (l:μ,τ) 2l'2ν_l,
zz_sl	6575-76		1422.1	713.5		533.9	
zzorww_h	6553-54		12383.3	224.8		3152.0	
zzorww_l	6721-22		1636.0	54.0		422.5	2l2ν_l (l:μ,τ)

Background: WW & ZZ, hadronic



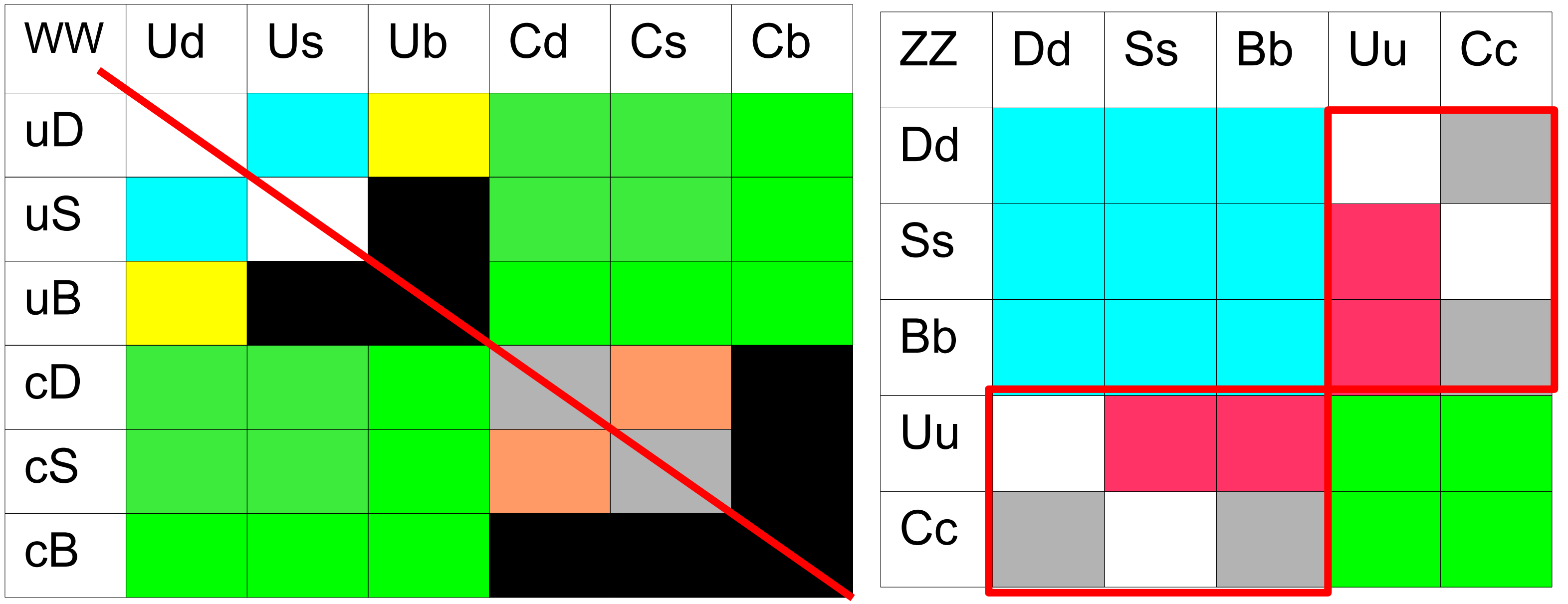
Single W:

V Br

Ud ~ 0.974 ~ 0.475
Us ~ 0.225 ~ 0.025
Ub ~ 0.004 ~ 0

Cd ~ 0.23 ~ 0.025
Cs ~ 1.006 ~ 0.475
Cb ~ 0.04 ~ 7e-4

Single Z:
Uu ~ 15%
Dd ~ 12%



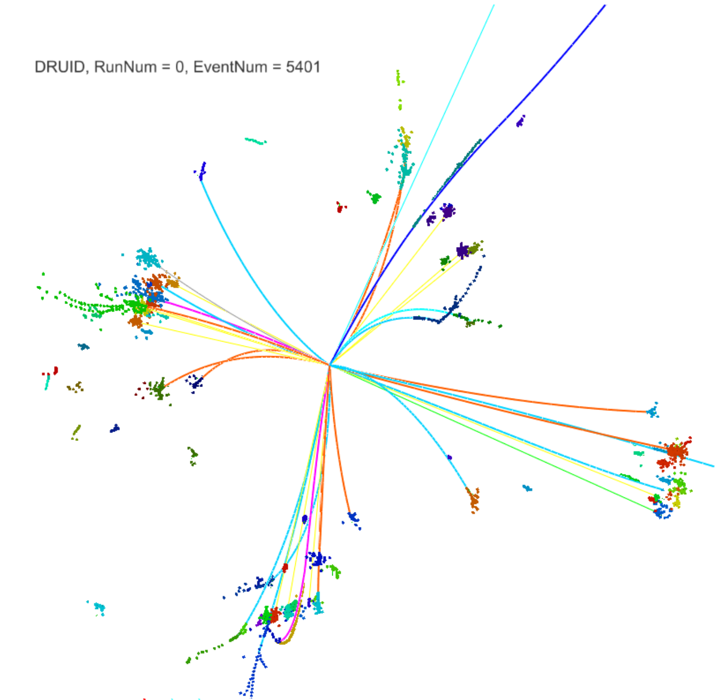
Xsec/fb	LL	LR	RL	RR	Non-pola/evts at 500 fb^{-1}
ww_h		14874	136.4		3752 fb ~ 1.87 M
zz_h		1402	604		502 fb ~ 250 k
zzorww_h		12383	225		3152 fb ~ 1.58 M

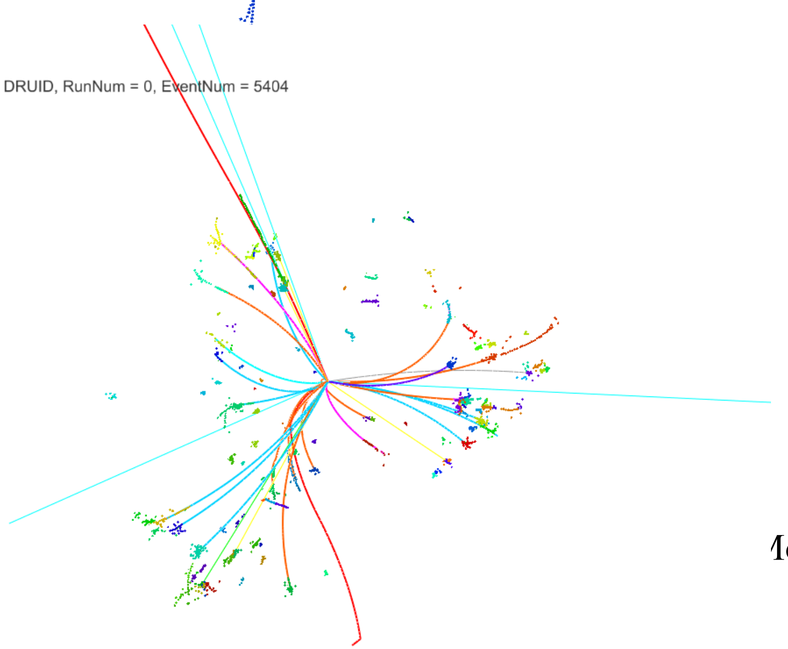
Signal, ZH with Z to qq and Higgs to qq or gg ~ 48.6 k

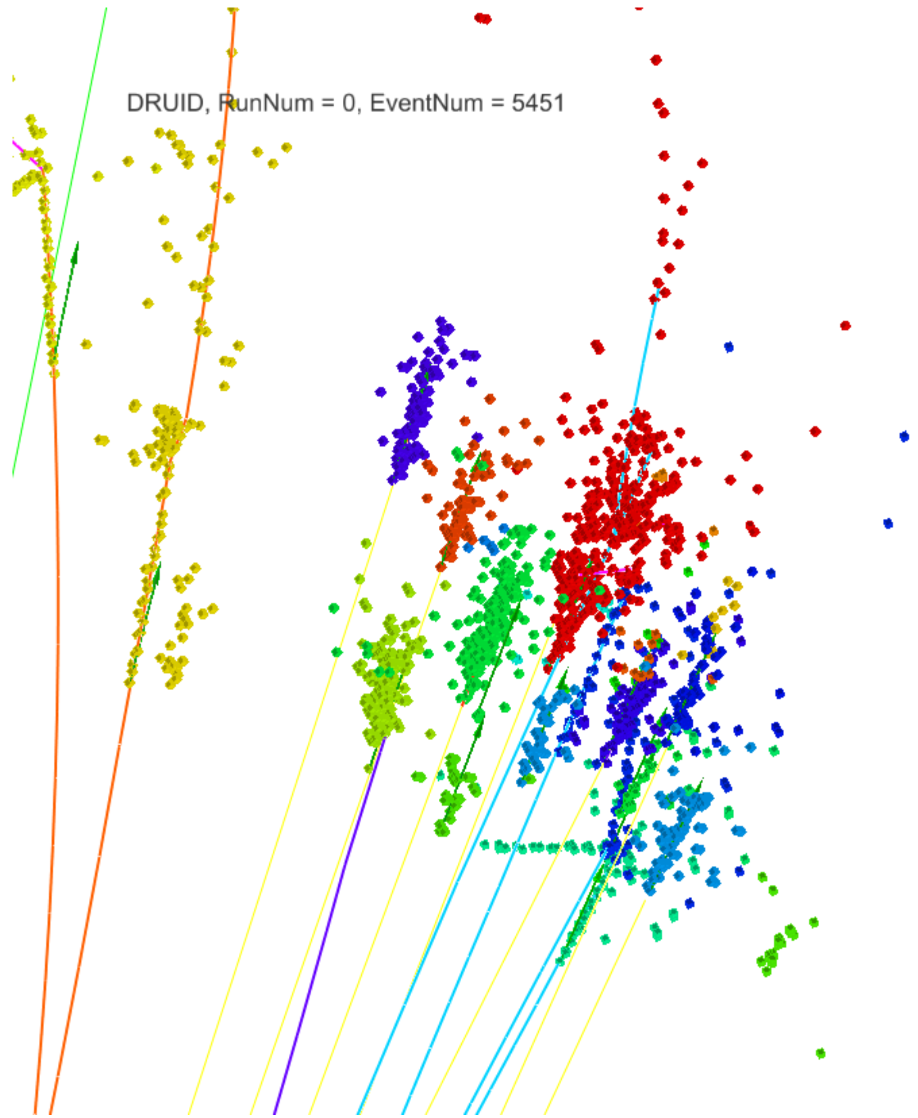
Background & Analysis: general remark

- Without any selection, the statistic total background is roughly 2 orders higher than Signal
  - Dominated by WW
  - ZZ, irreducible background ~ 5 times larger than ZH
- Event Selection should reduce the background to the same order of magnitude as the Signal
  - Tagging different final state: lepton ID & Flavor tagging
  - Kinematic selection: rely on PFA
- Good statistic:
  - Detector should be efficiency oriented

Reconstruction with Arbor



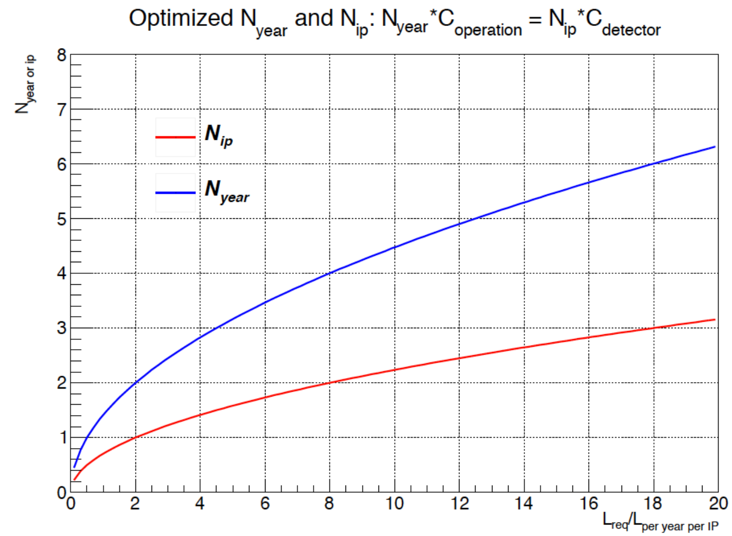




Principle: reconstruct every energetic final state particle

Open discussing

- *Operation program: 100 k Higgs, or more?*
  - *Electricity cost ~ 10^9 CNY/y (half a detector)*
    - *Site power 200 MW, $2*10^7$ s/y, 0.5 CNY/kwh*
  - *Objective: 100k Higgs, or more?*
    - *200 - 400 fb^{-1} per IP per year?*
    - *ILC: 250 fb^{-1}/5 year;*
    - *LEP3: 100 fb^{-1}/(year*IP), 2 ab^{-1} with 4 IP.*
    - *TLEP: 10 ab^{-1}*
- *Detector: as precise as possible*
  - *hardware + reconstruction*
- ***Detector geometry**: tell me your concern!*
- ***Logo & Name?***



	ILC-250	TLEP-240
σ_{HZ}	2.5%	0.4%
$\sigma_{HZ}\times BR(H\to bb)$	1.0%	0.1%
$\sigma_{HZ}\times BR(H\to cc)$	6.9%	1.3%
$\sigma_{HZ}\times BR(H\to gg)$	8.5%	1.4%
$\sigma_{HZ}\times BR(H\to WW^*)$	8.0%	0.9%
$\sigma_{HZ}\times BR(H\to \tau\tau)$	5.0%	0.9%
$\sigma_{HZ}\times BR(H\to ZZ^*)$	28%	3.1%
$\sigma_{HZ}\times BR(H\to \gamma\gamma)$	27%	3.0%
$\sigma_{HZ}\times BR(H\to \mu\mu)$	–	13%
Γ_{INV} / Γ_H	< 1.5%	< 0.3%
m_H	40 MeV	8 MeV
	ILC-350	TLEP-350
$\sigma_{WW\to H}$	3%	0.5%
Γ_H	5.5%	1.1%