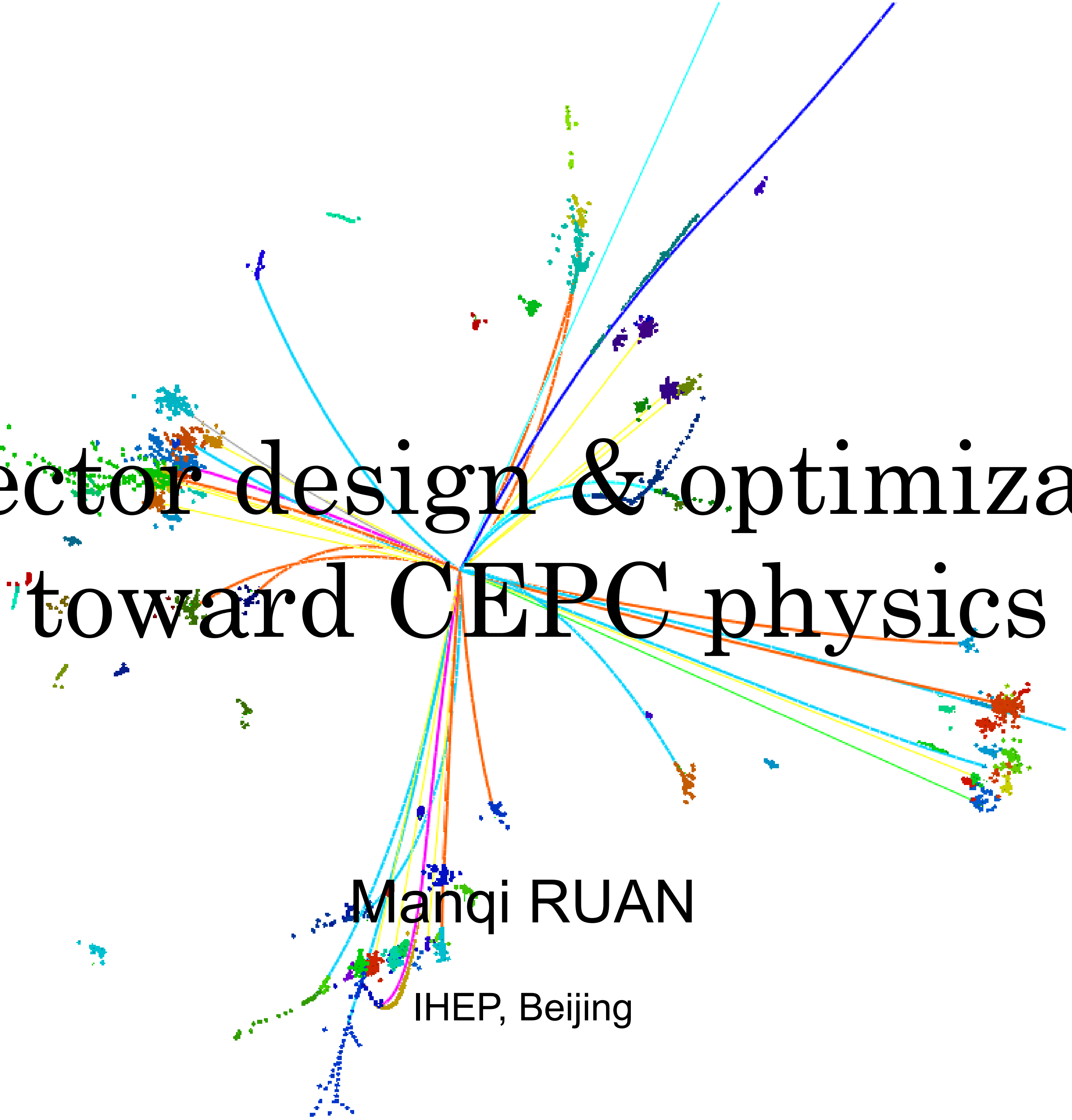
Detector design & optimization toward CEPC physics



Manqi RUAN

IHEP, Beijing

Why an e^+e^- Higgs factory

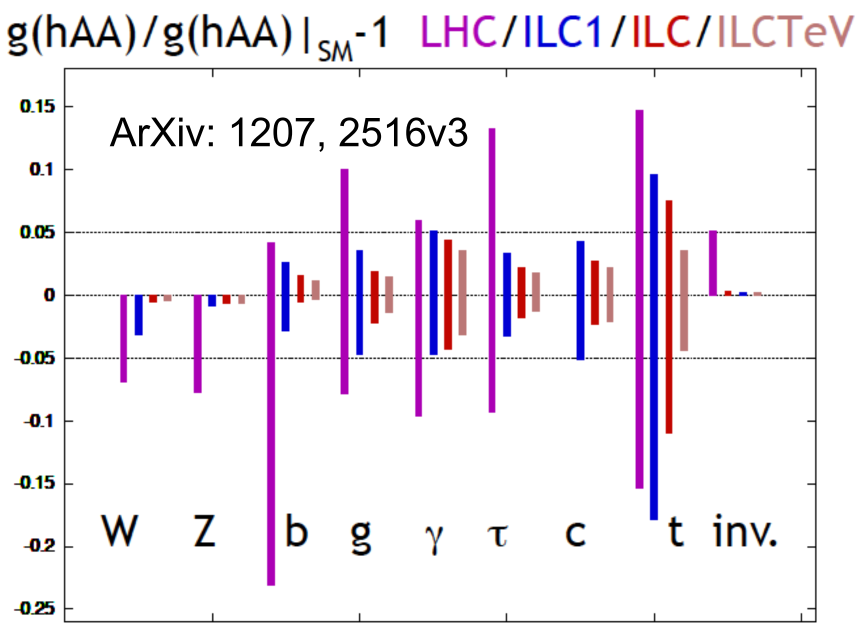
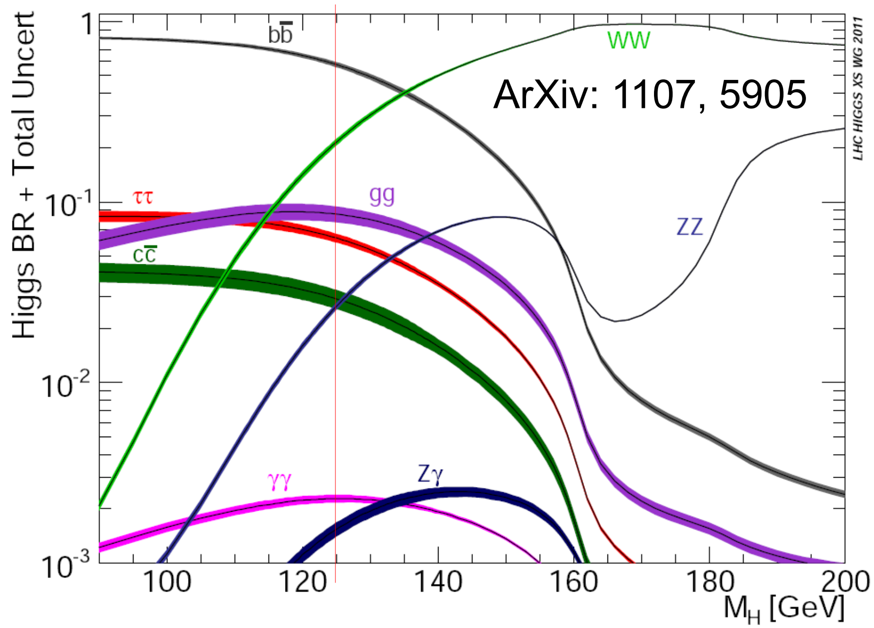


Figure 2: Comparison of the capabilities of LHC and ILC for model-independent measurements of Higgs boson couplings. The plot shows (from left to right in each set of error bars) 1 σ confidence intervals for LHC at 14 TeV with 300 fb^{-1}, for ILC at 250 GeV and 250 fb^{-1} ('ILC1'), for the full ILC program up to 500 GeV with 500 fb^{-1} ('ILC'), and for a program with 1000 fb^{-1} for an upgraded ILC at 1 TeV ('ILCTeV'). More details of the presentation are given in the caption of Fig. 1. The marked horizontal band represents a 5% deviation from the Standard Model prediction for the coupling.

SM Higgs Branching ratio



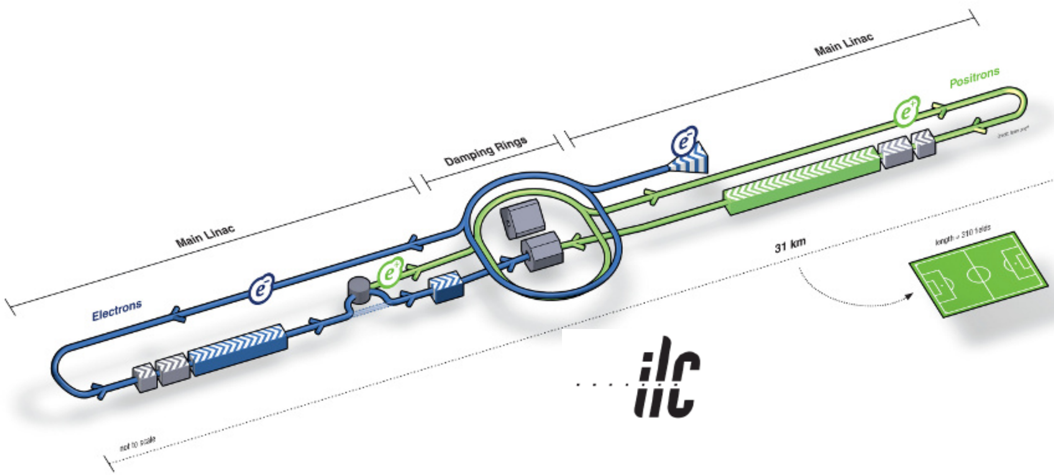
Bb: 58%; WW, 21%; gg, 9%; ττ, 6%; cc, 3%; ZZ + others, 3%

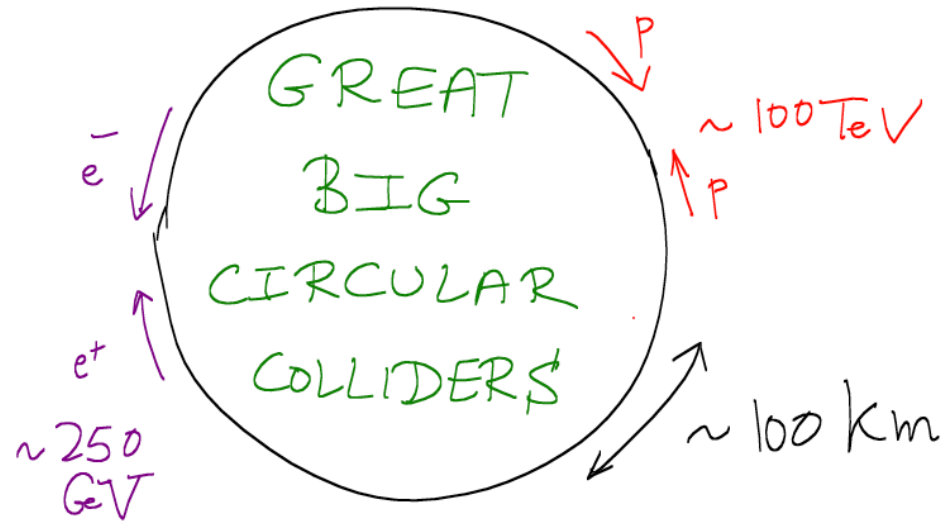
Precisely verify the standard model – searching for possible new physics
Higgs couplings must be measured to at least 10% to reveal TeV scale new physics

$$\frac{g_{HXX}}{g_{HXX}^{SM}} \approx 1 + \delta \times \left(\frac{1\,\mathrm{TeV}}{\Lambda_{NP}}\right)^2$$

LHC: high productivity, no tagging signal, huge backgrounds & systematics.
Ultimate precision in Higgs coupling limited
e^+e^- machine: low background – triggerless mode, precisely known/adjustable initial state, allowance of model independent measurement...
a precise Higgs factory must be a lepton machine (ILC/CLIC, TLEP/FCC, **CEPC**...)

Higgs factory: Linear or Circular

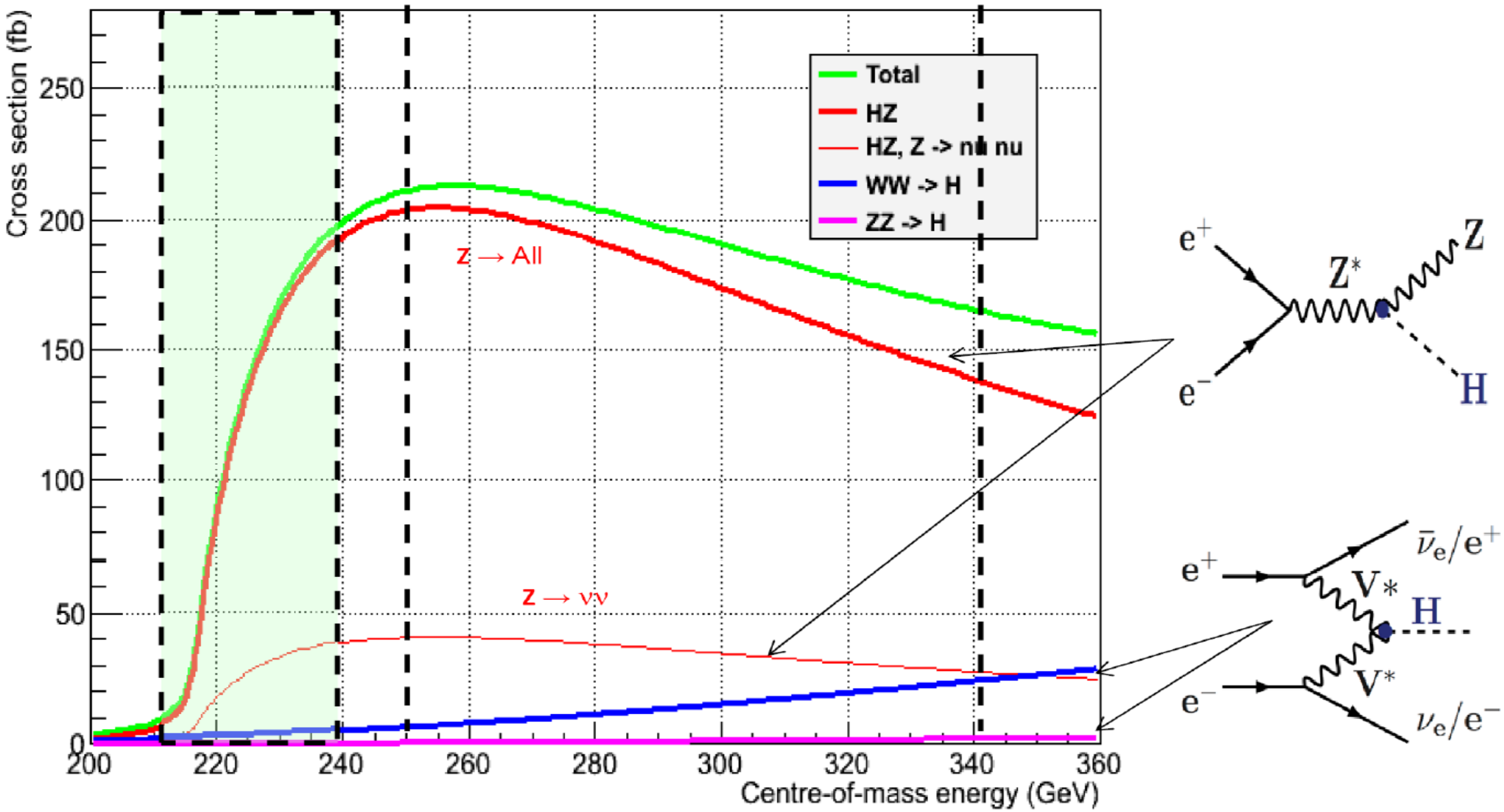




	Linear: ILC, CLIC	Circular: CEPC, TLEP, FCC
Pro	C.o.M energy can be upgraded to 1-3 TeV Longitudinal polarized beam Power pulsed detector	Cost-efficient, mature technology Multiple interaction point High luminosity & beam quality
Con	Expensive ($\sim$ 8 – 10 B euros) Single interaction point, might need 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...

Higgs productivity at e^+e^- machine



σ(HZ, 240 GeV) ~ 200fb with non-polarized beam

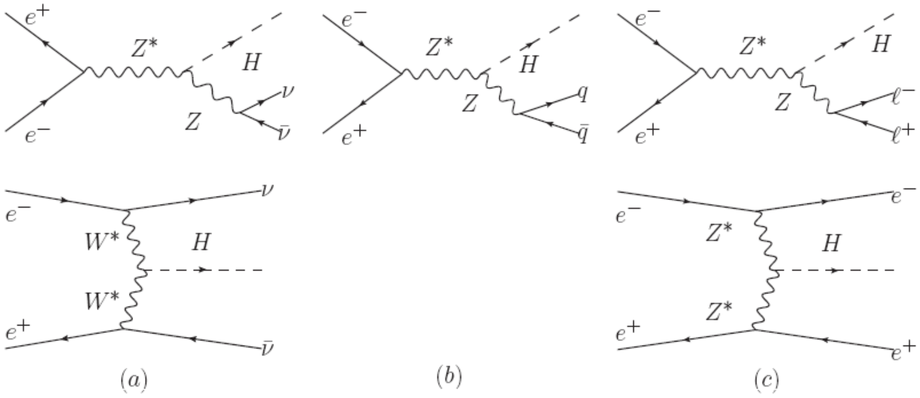
L $\sim 10^{34}\ cm^{-2}s^{-1} \sim 100fb^{-1}/y$: Nominal luminosity $500fb^{-1}$ ~ 10^5 Higgs/IP

Benchmark: 100 k Higgs, but can be (largely) increased

Beam polarization can enhance the Higgs productivity by ~ 50% at ILC, and reduce the SM Background at the same time. However, it's not crucial for Higgs measurement

CEPC: 8 + 2 measurements for SM higgs

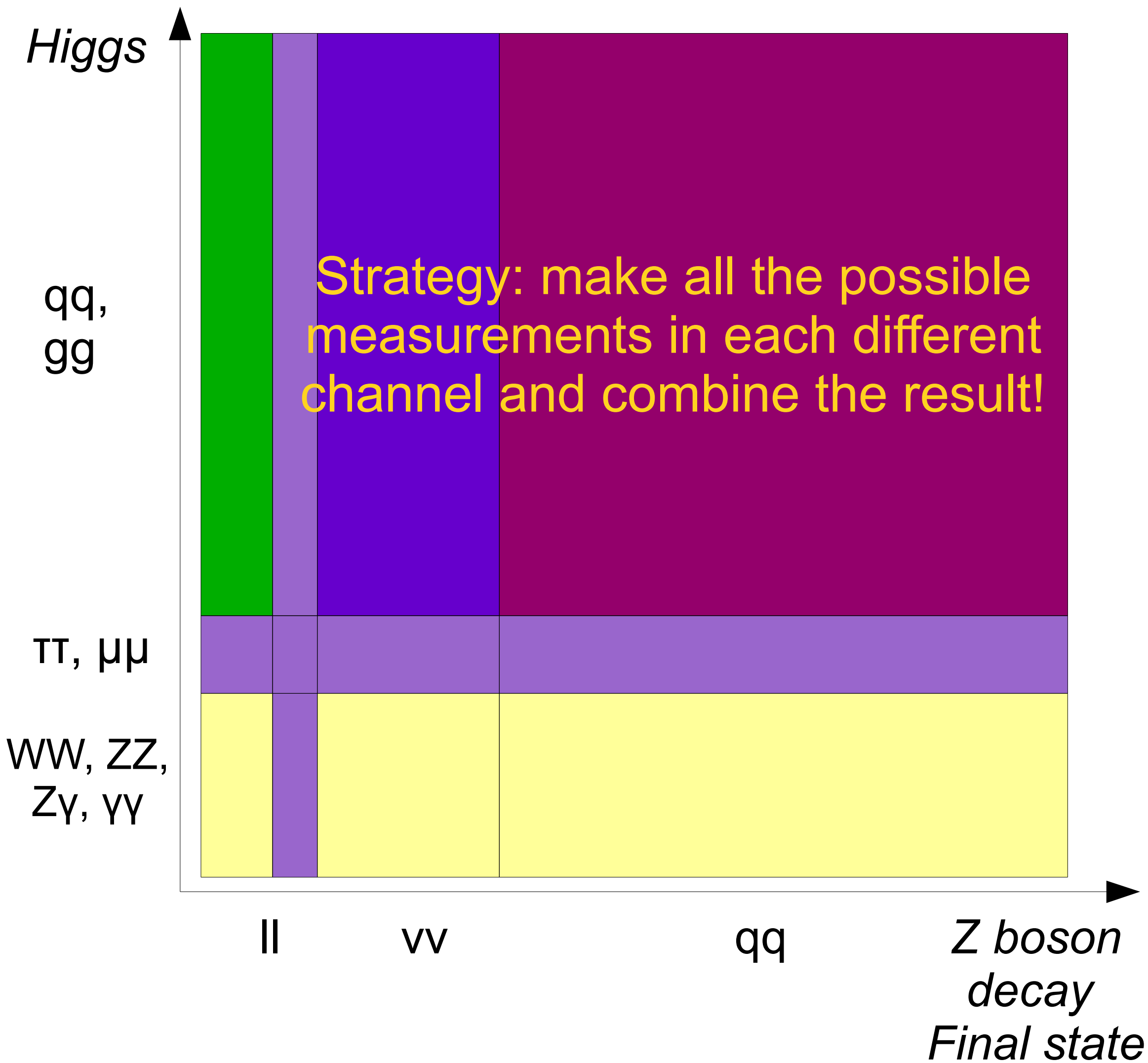
- Mass, spin, total cross section
- Branching ratios (b, c, tau, g, W)
- Branching ratios (gamma, mu)
- Calculate: width – coupling
- Other measurements, SM & exotics...

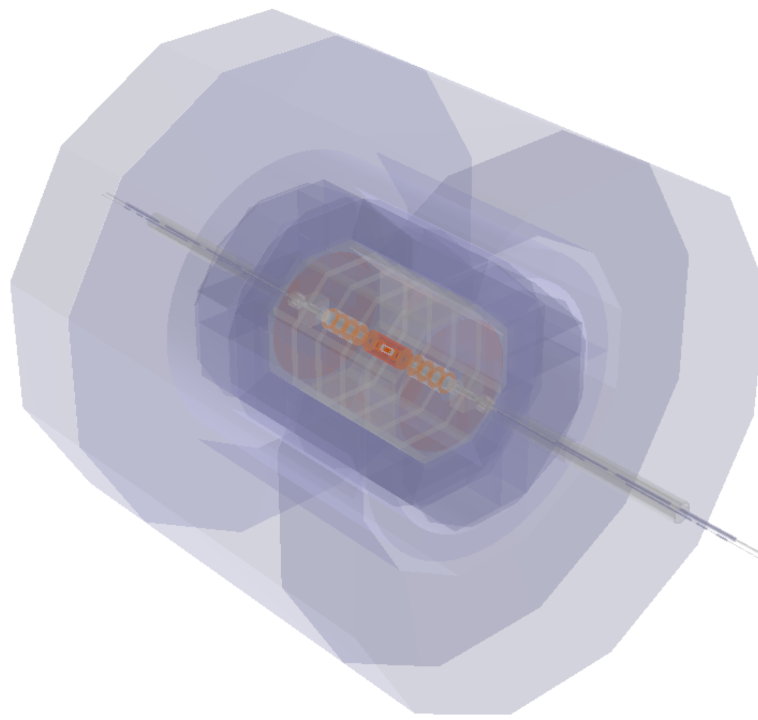


Mode	$b\bar{b}$	$c\bar{c}$	gg	WW^*	$\mu^+\mu^-$	$\tau^+\tau^-$	ZZ^*	$\gamma\gamma$	$Z\gamma$
BR (%)	57.8	2.7	8.6	21.6	0.02	6.4	2.7	0.23	0.16

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

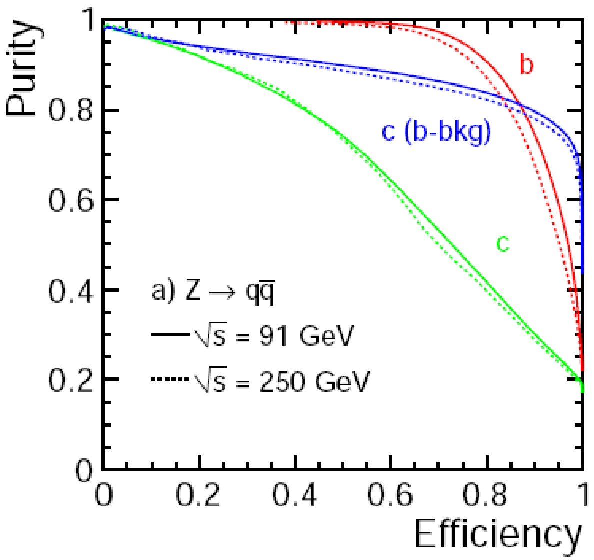
ZH event: requirement on detector

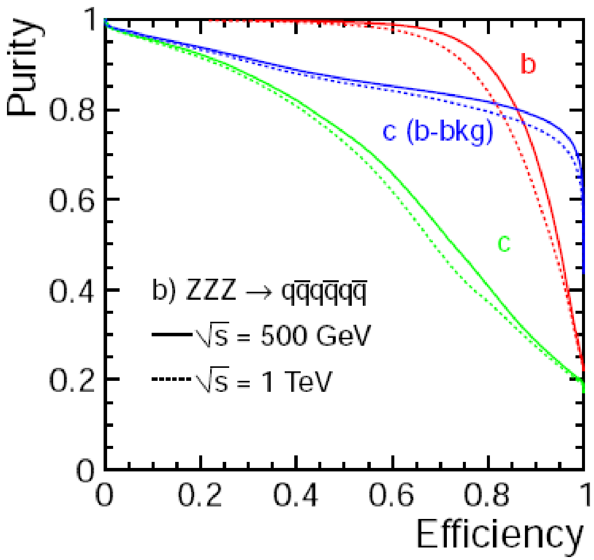


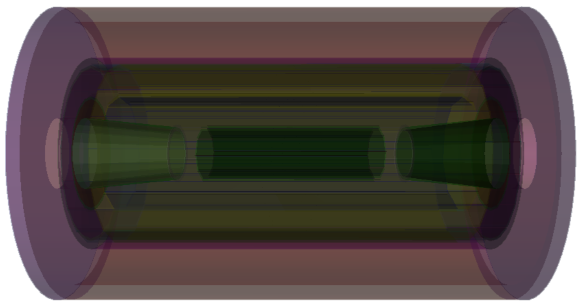


Sub detector & performance: VTX

b Vs udsc; c Vs b; c Vs udsb







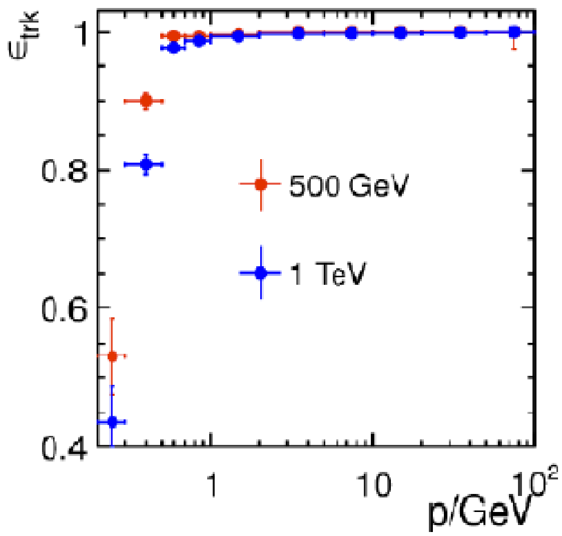
VTX detector: spatial resolution ~ 5 μm, located with inner radius of 15 mm

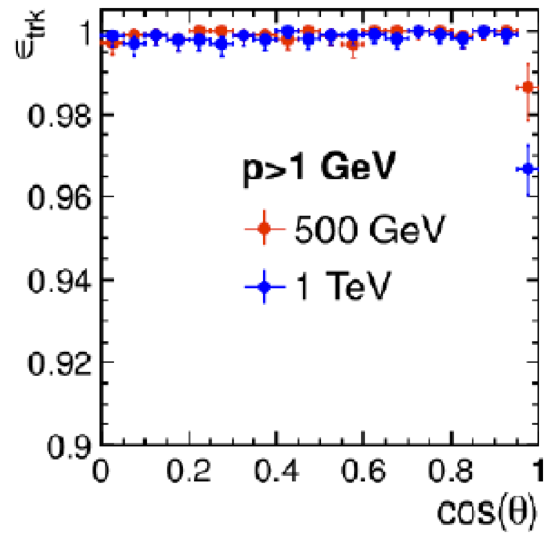
Flavor tagging performance:

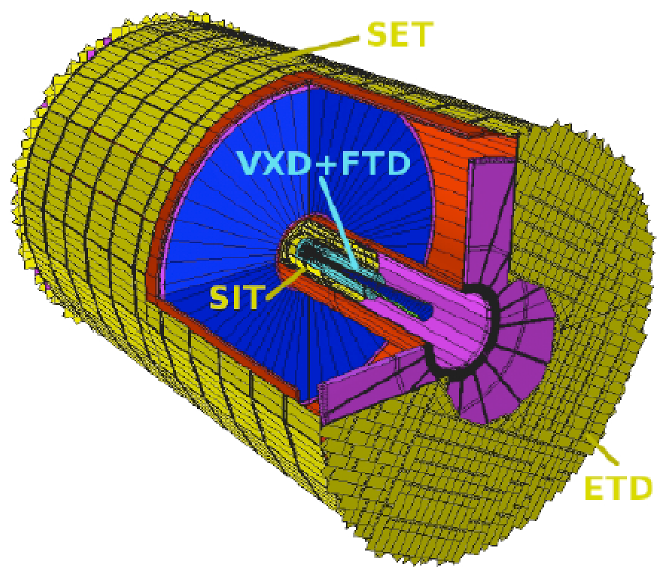
- Eff = 80%, purity > 90% for b-tagging
- Capability for c tagging

Algorithm: LCFIPlus, Tokyo University (Tomohiko Tanabe. etc)

Tracker





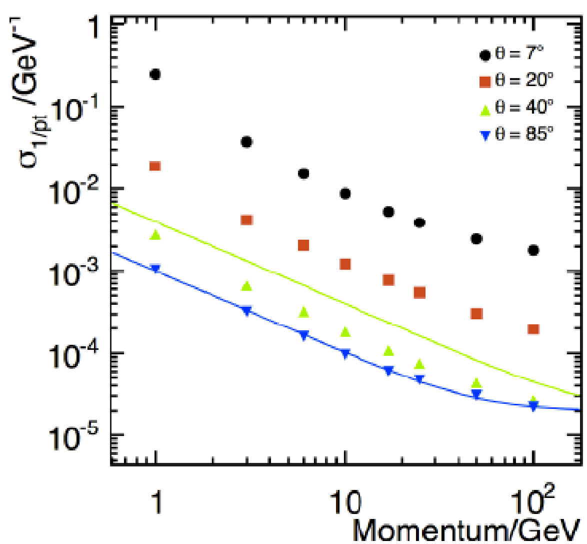


Tracking:

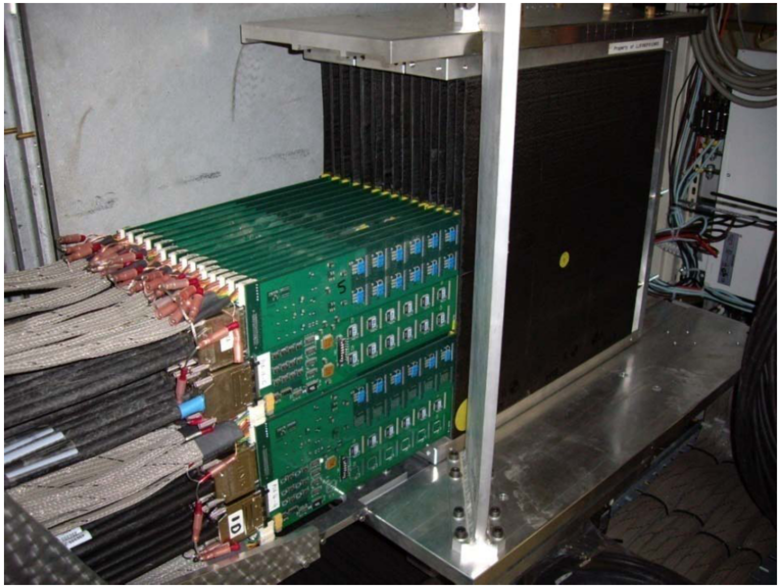
Barrel: TPC + Inner Silicon (VTX, SIT)
Forward: Front Tracking Disks;
Optional: External Silicon Tracker

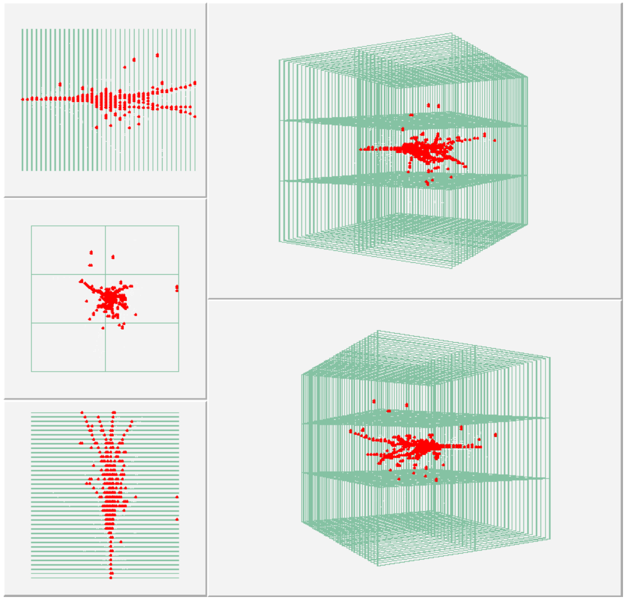
Performance: $\delta(1/P_T) \sim 2\text{-}5*10^{-5}(1/\text{GeV})$

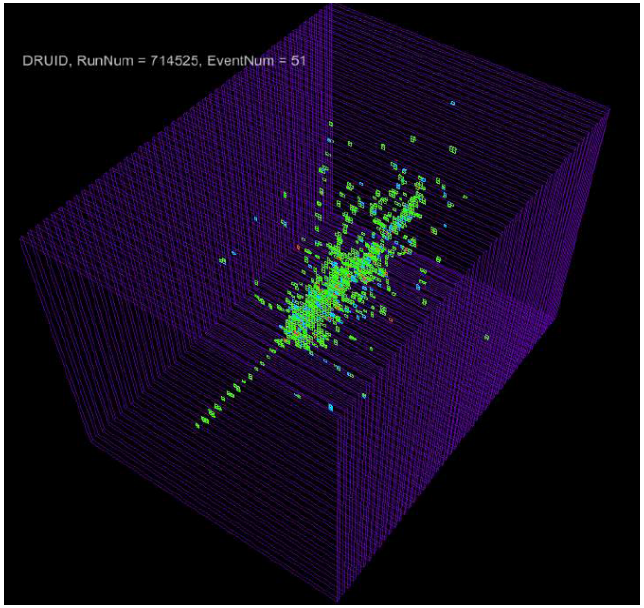
Algorithm: Clupatra, DESY (F. Gaede);
KalTest, KEK (K. Fujii), Tsinghua (B. Li)



Imagine Calorimeter

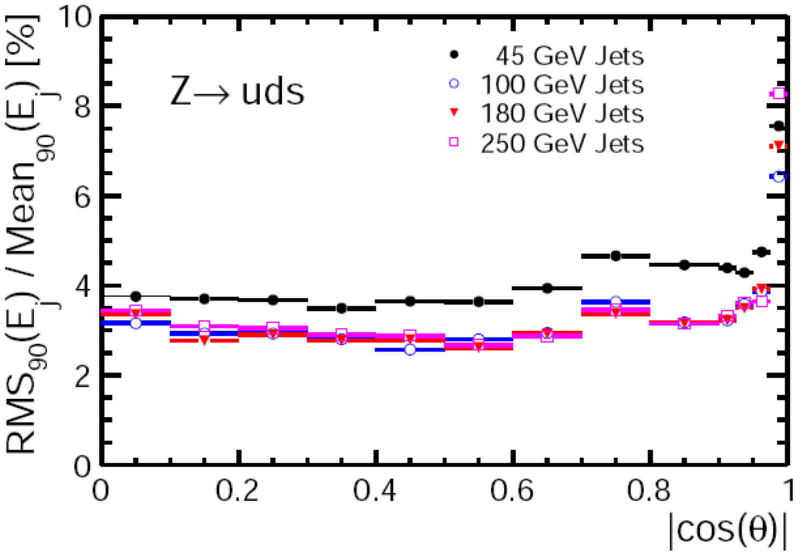






Ultra high granularity ~ 1 channel cm^{-3}.
3d, 4d or 5d image...

PFA： δEJ/E = 3 - 4%
Algorithms:
PandoraPFA, Cambridge (M. Thomson);
Arbor, LLR & IHEP(Manqi, Henri)



Higgs Measurement at ILD

ILC Higgs Measurement:

Well understood,

But for sure potential

to improve

	$\Delta(\sigma \cdot BR)/(\sigma \cdot BR)$				
$\sqrt{s}$ and $\mathcal{L}$ (P_{e^-}, P_{e^+})	$250\,\text{fb}^{-1}$ at 250 GeV (-0.8,+0.3)		$500\,\text{fb}^{-1}$ at 500 GeV (-0.8,+0.3)		$1\,\text{ab}^{-1}$ at 1 TeV (-0.8,+0.2)
mode	ZH	$\nu\bar{\nu}H$	ZH	$\nu\bar{\nu}H$	$\nu\bar{\nu}H$
$H \to b\bar{b}$	1.2%	10.5%	1.8%	0.66%	0.32%
$H \to c\bar{c}$	8.3%	-	13%	6.2%	3.1%
$H \to gg$	7.0%	-	11%	4.1%	2.3%
$H \to WW^*$	6.4%	-	9.2%	2.4%	1.6%
$H \to \tau^+\tau^-$	4.2%	-	5.4%	9.0%	3.1%
$H \to ZZ^*$	19%	-	25%	8.2%	4.1%
$H \to \gamma\gamma$	29-38%	-	29-38%	20-26%	7-10%
$H \to \mu^+\mu^-$	-	-	-	-	31%
$H \to$ Inv.(95% $C.L.$)	$< 0.95\%$		-		-
$t\bar{t}H, H \to b\bar{b}$	-		28%		6.0%

TABLE I: Expected accuracies for cross section times branching ratio measurements for the 125 GeV H boson by the canonical scenario.

couplings	250 GeV	250 GeV + 500 GeV	250 GeV + 500 GeV + 1 TeV
g_{HZZ}	1.3%	1.3%	1.3%
g_{HWW}	4.8%	1.4%	1.4%
g_{Hbb}	5.3%	1.8%	1.5%
g_{Hcc}	6.8%	2.9%	2.0%
g_{Hgg}	6.4%	2.4%	1.8%
$g_{H\tau\tau}$	5.7%	2.4%	1.9%
$g_{H\gamma\gamma}$	18%	8.4%	4.1%
$g_{H\mu\mu}$	-	-	16%
g_{Htt}	-	14%	3.2%
Γ_0	11%	5.9%	5.6%

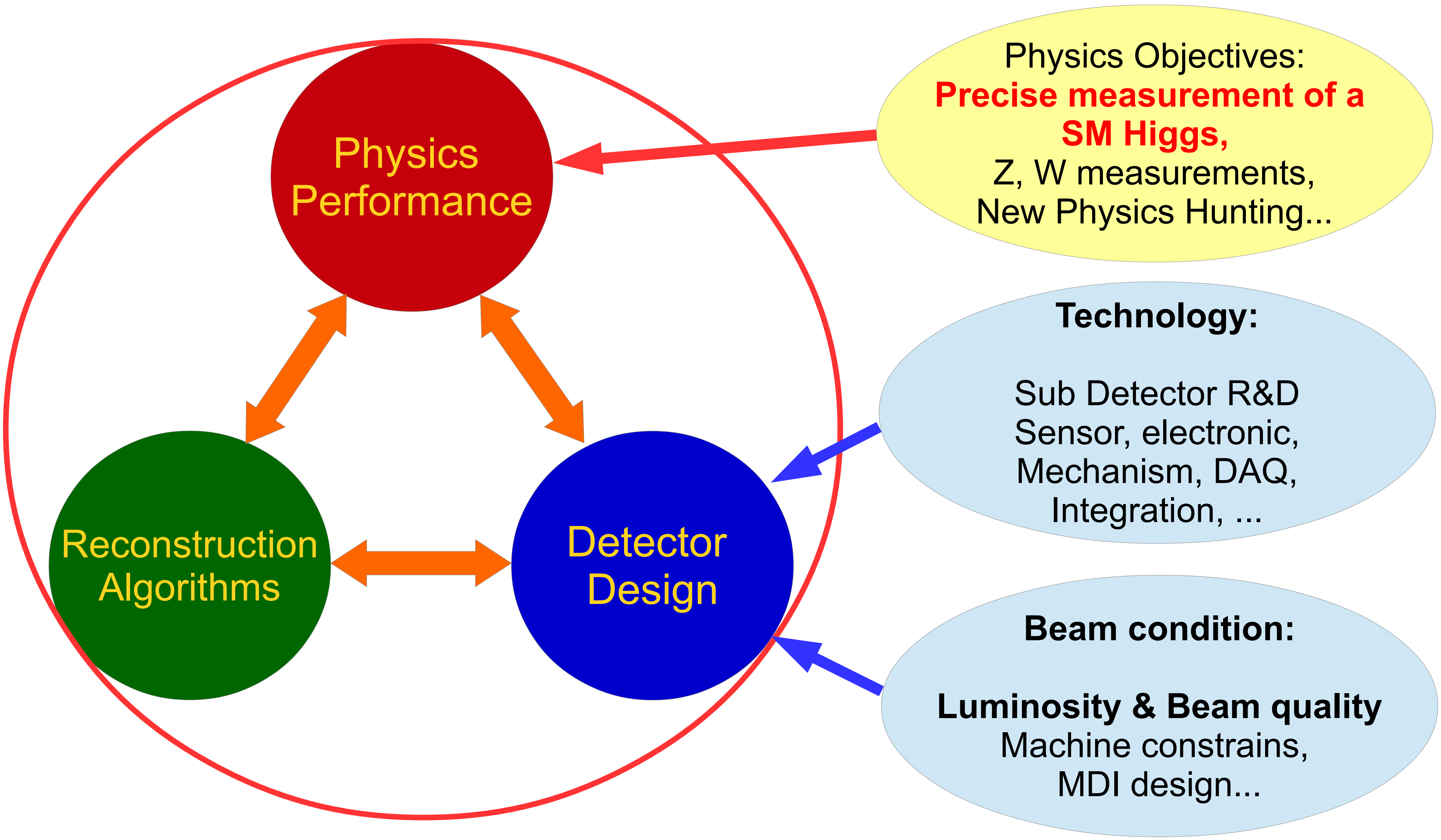
J. Tian & K. Fujii
LC-REP-2013-021

TABLE II: Expected accuracies of Higgs couplings and total Higgs width by the canonical scenario.

From ILD to CEPC detector

- Many new designs
  - Changed granularity (no power pulsing)
  - Changed L*
  - 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, iterate with physics analysis (Fast – Full Simulation) and cost estimation

Detector optimization: Basic ingredients



Kick-off @ Sep 2013

Training @ Oct 2013

Regular meetings, communications

Physics and Detector Meetings

November 2013

- 29 Nov CEPC Calorimeter Group Meeting 3rd New!
- 20 Nov CEPC Physics & Detector 5th New!
- 18 Nov - 19 Nov Franco-Chine Detector Discussing
- 15 Nov CEPC Tracking Group Meeting 2nd
- 07 Nov Simulation - Physics Analysis Meeting 1st
- 07 Nov CEPC Physics & Detector 4th
- 04 Nov CEPC Vertex Working Group Meeting 1st
- 01 Nov CEPC Tracking Group Meeting 1st
- 01 Nov CEPC Calorimeter Group Meeting 2nd

October 2013

- 23 Oct CEPC Physic & Detector 3rd
- 18 Oct CEPC Calorimeter Group Meeting 1st
- 09 Oct CEPC Physics & Detector 2nd

CEPC

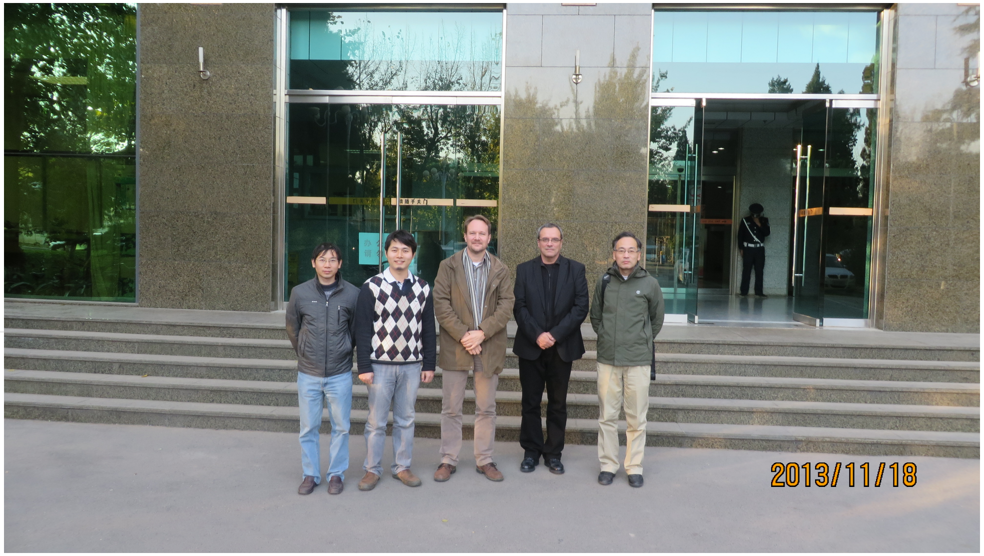
CEPC + SppC events

Managers: WEN, S.; Zhu, H.; Yang, H.; Hu, T.; Ruan, M.; QI, H.

General Meetings 2 events

Physics and Detector Meetings 13 events

Training 1 event



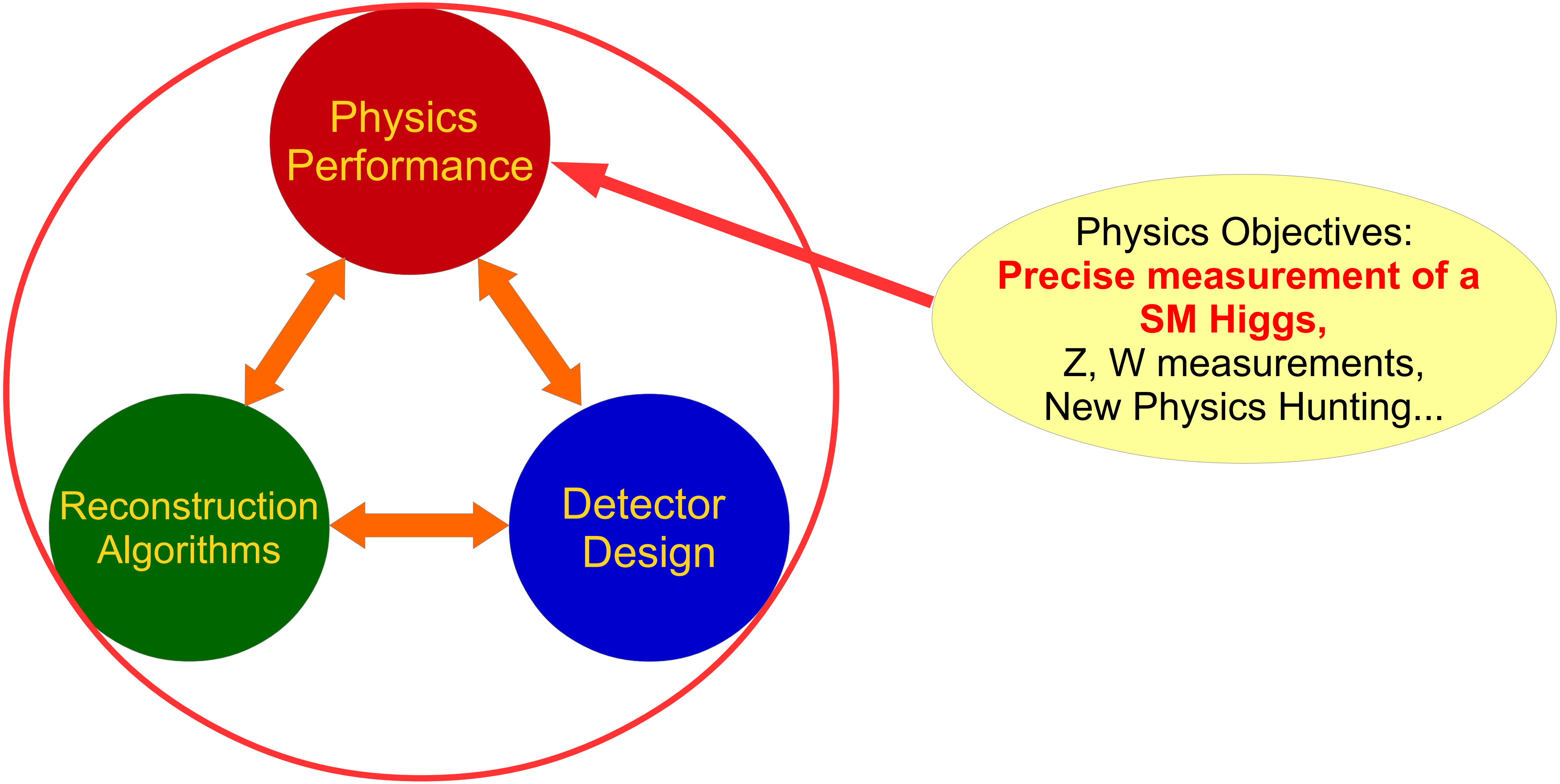
CEPC Detector: Institutes

Theory

VTX	TPC	Calo	Physics Requirement
ShanDong University (SDU) IHEP ...	Tsinghua University (THU), University of Chinese Academic of Science (UCAS), IHEP ...	University of Science and Technology of China (USTC), Shanghai Jiaotong University (SJTU), Wuhan University (WhU), Nanjing University IHEP ...	Nankai University, Pekin University (PKU), Beihang University, Center China Normal University (CCNU), IHEP ...

Machine

Perspective of CEPC Physics Measurement

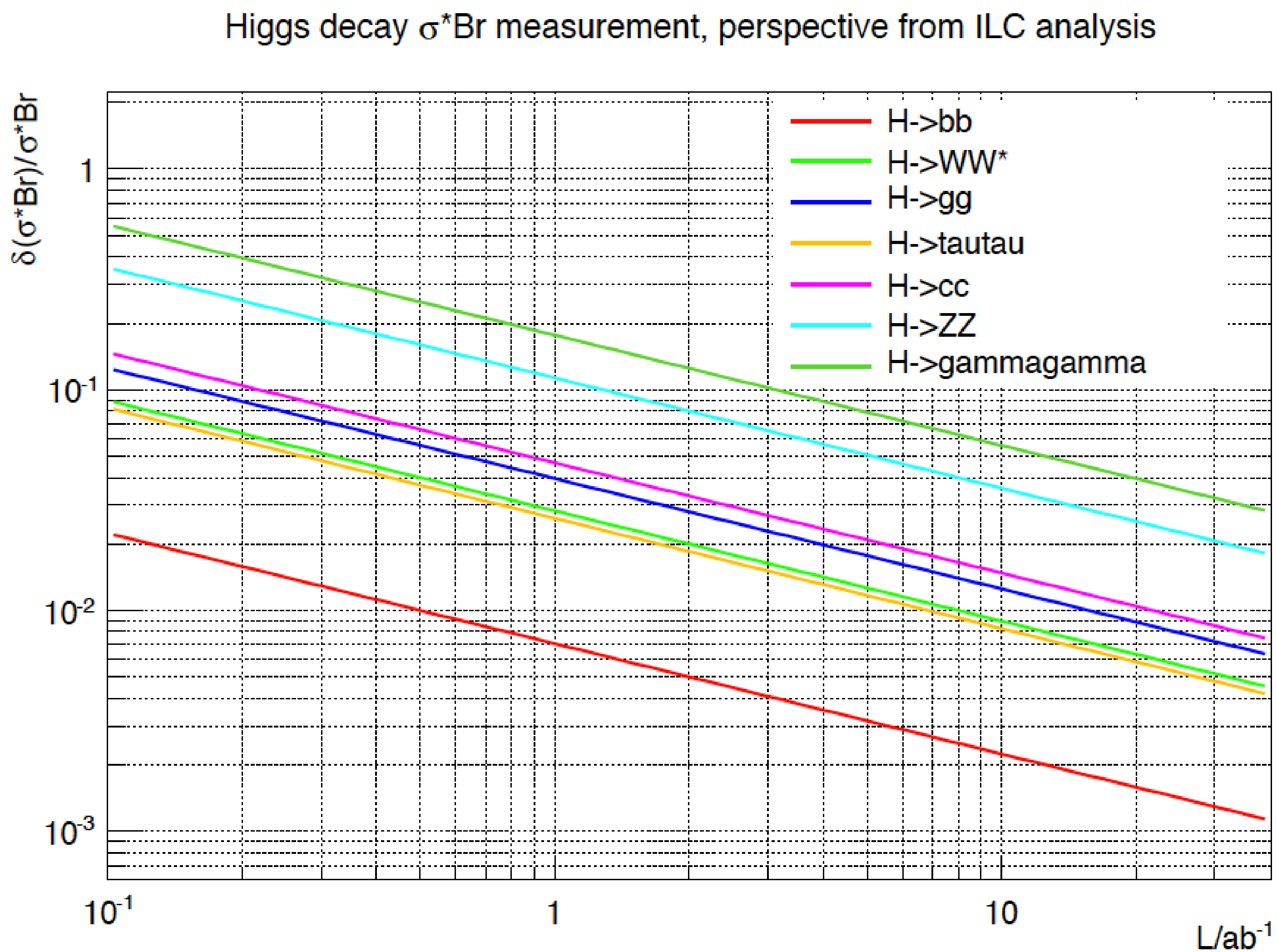


Extrapolation/Verification from ILC Studies

	ILC @ 250 fb^{-1} (-0.8, 0.3)	CEPC @ 500 fb^{-1} (0, 0)	Status
mH (MI)	29 MeV	25 MeV	FS Validated
σ(ZH)	2.6%	2.2%	
Δ(σ*Br)/(σ*Br)			
ZH, H→bb	1.2%	1.0%	FS Estimated
H→cc	8.3%	6.6%	
H→gg	7.0%	5.6%	
H→WW*	6.4%	**4.0%**	Efforts started (PKU, SJTU)
H→ττ	4.2%	3.7%	USTC
H→ZZ*	19%	16%	
H→γγ	29-38%	25%	IHEP, WhU
H→μμ	-	?	IHEP
H→Inv.	0.95%	0.8%	
vvH, H→bb	10.5%	**12%**	

Scale the signal and all the background accordingly

Scaled with total luminosity

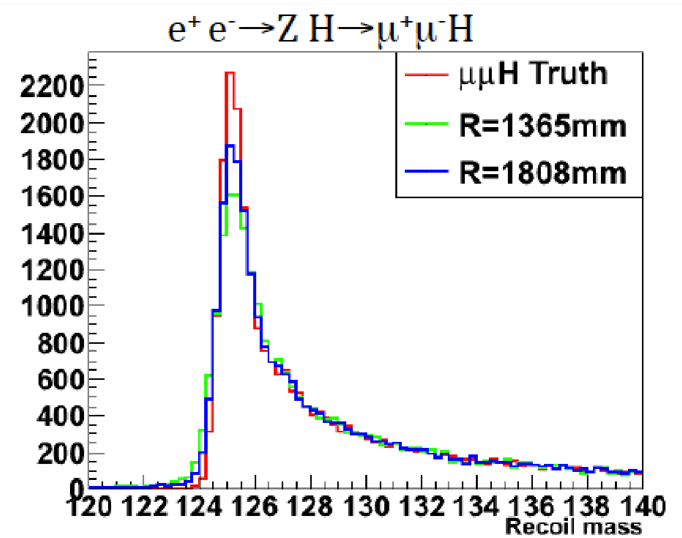


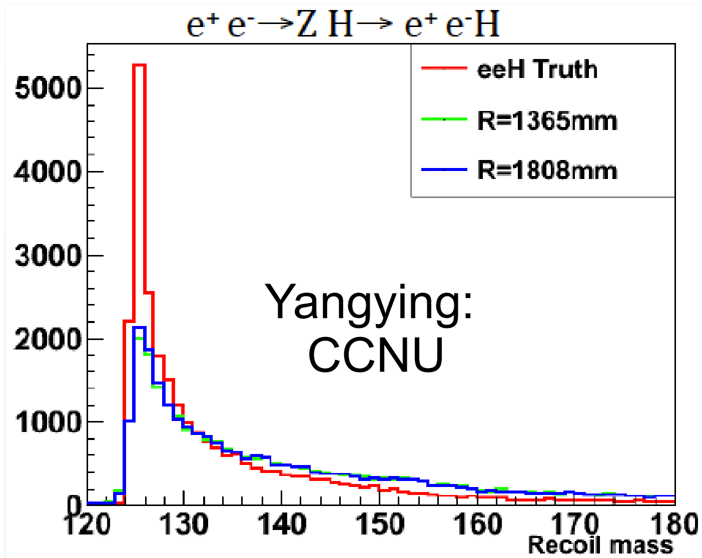
Frequent communication
With machine group
On beam parameter,
Power consumption
Achievable luminosity

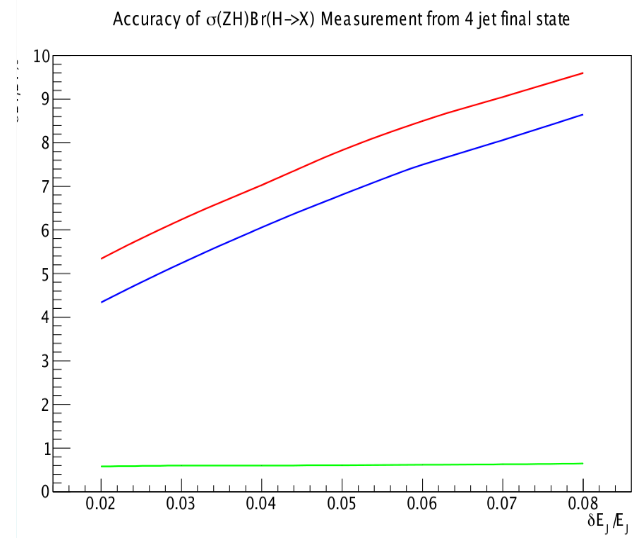
Beam condition:

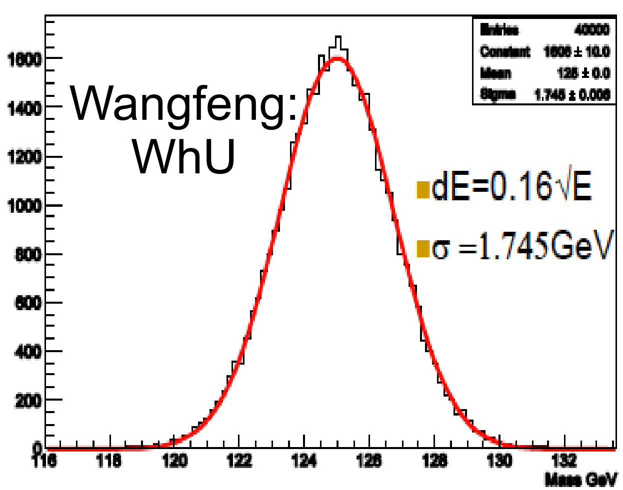
Luminosity & Beam quality
Machine constrains,
MDI design...

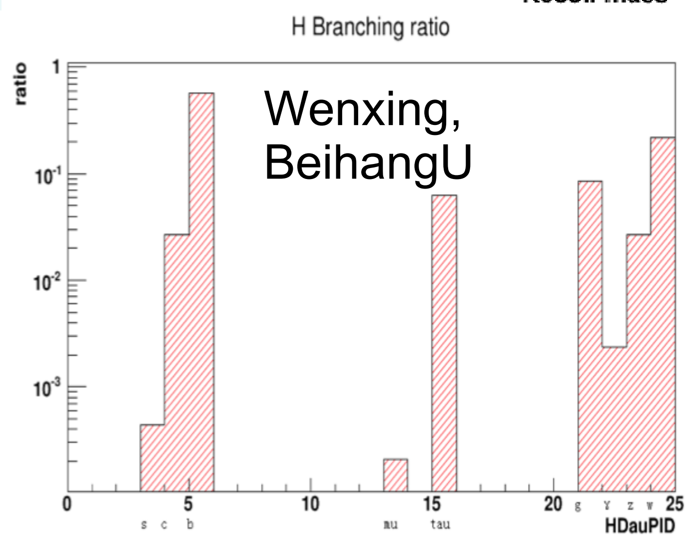
Ongoing Physics Analysis

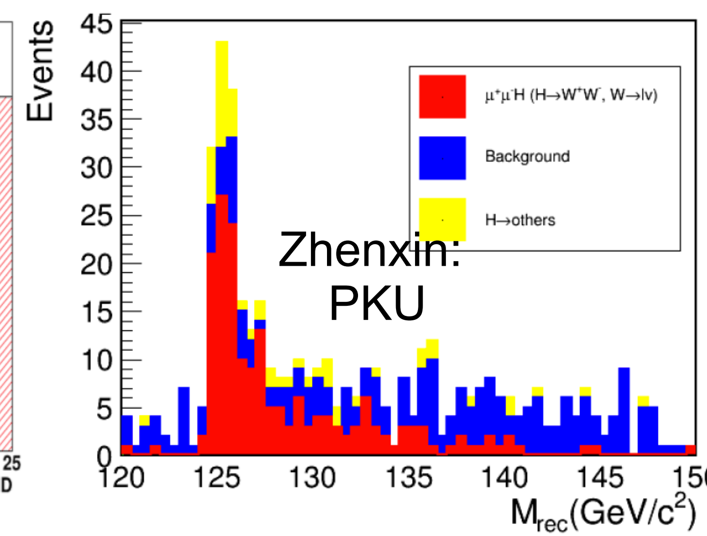






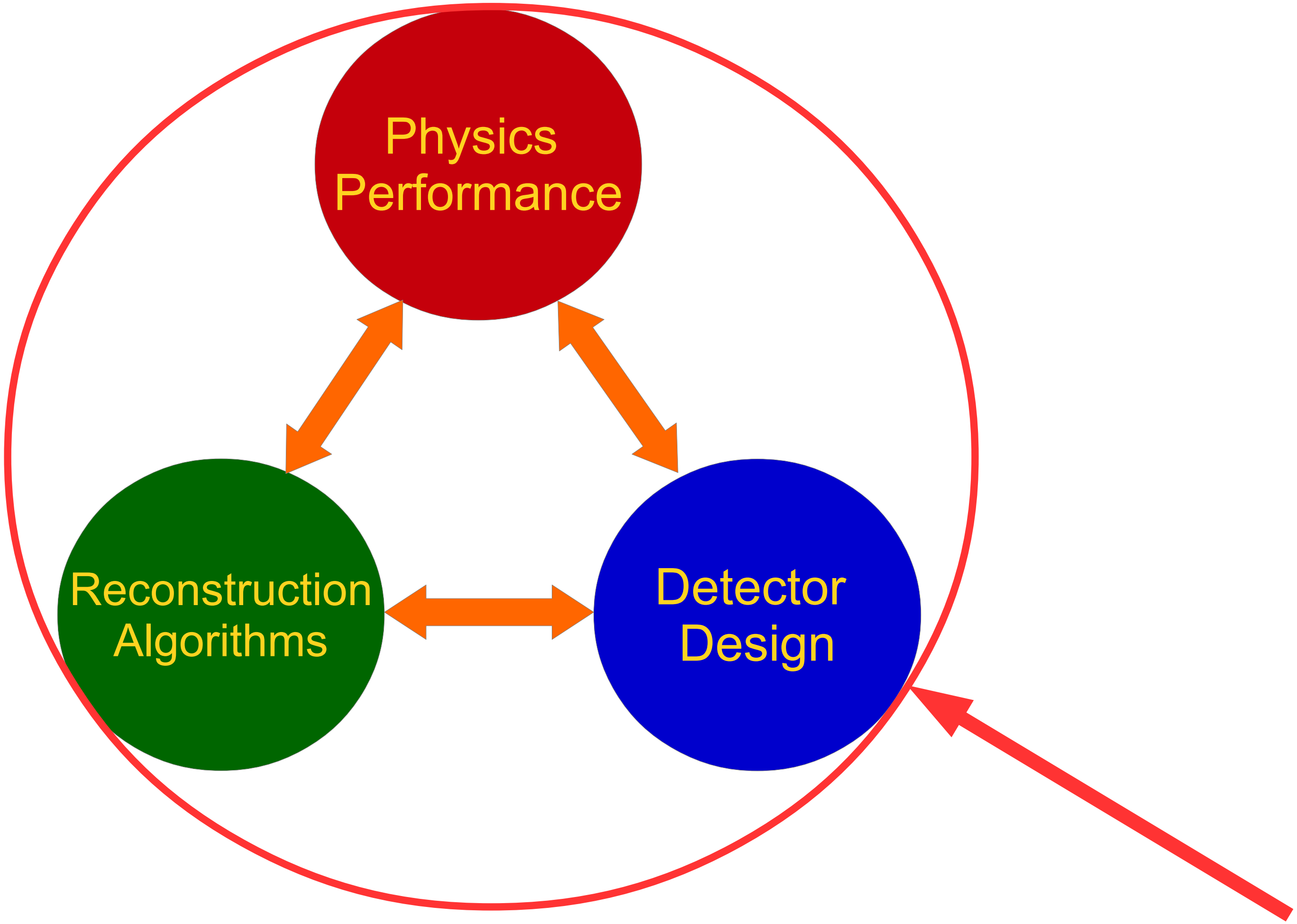






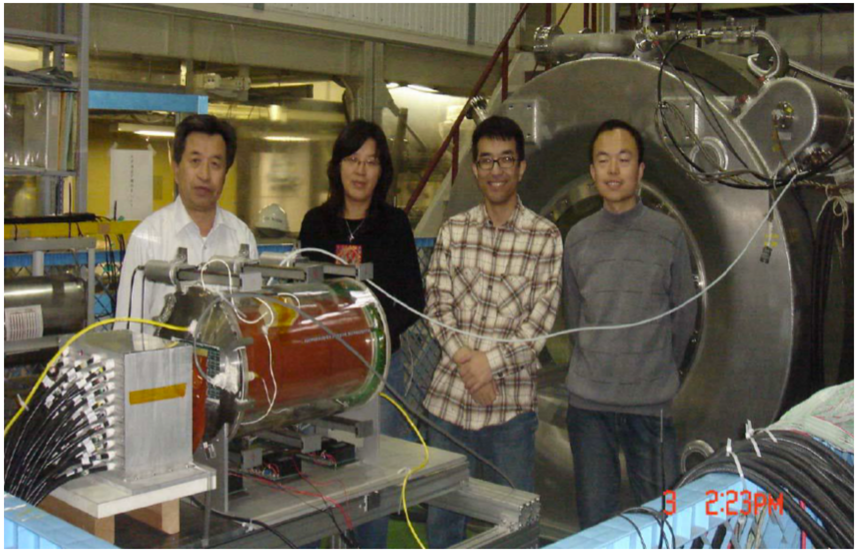
Duchun(IHEP): generator development/comparison

Detector Design



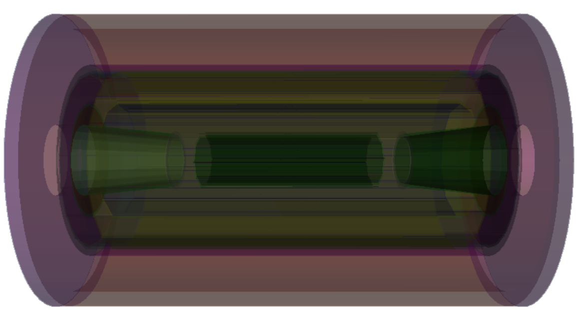
Detector R&D

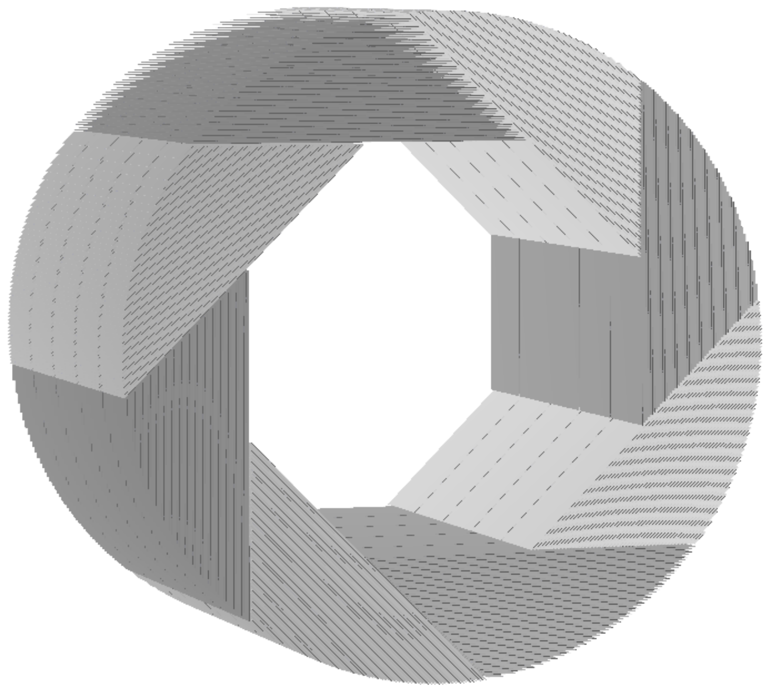
- Status:
  - TPC: Tsinghua & IHEP have participated in LCTPC (*See Prof. Y.L. Li's talk*)
  - VTX: Investigating into the technology Market, lots of related projects
  - Calorimeter: cooperation with CALICE collaboration
- *Long termly: prototype design, construction, test, integration...*



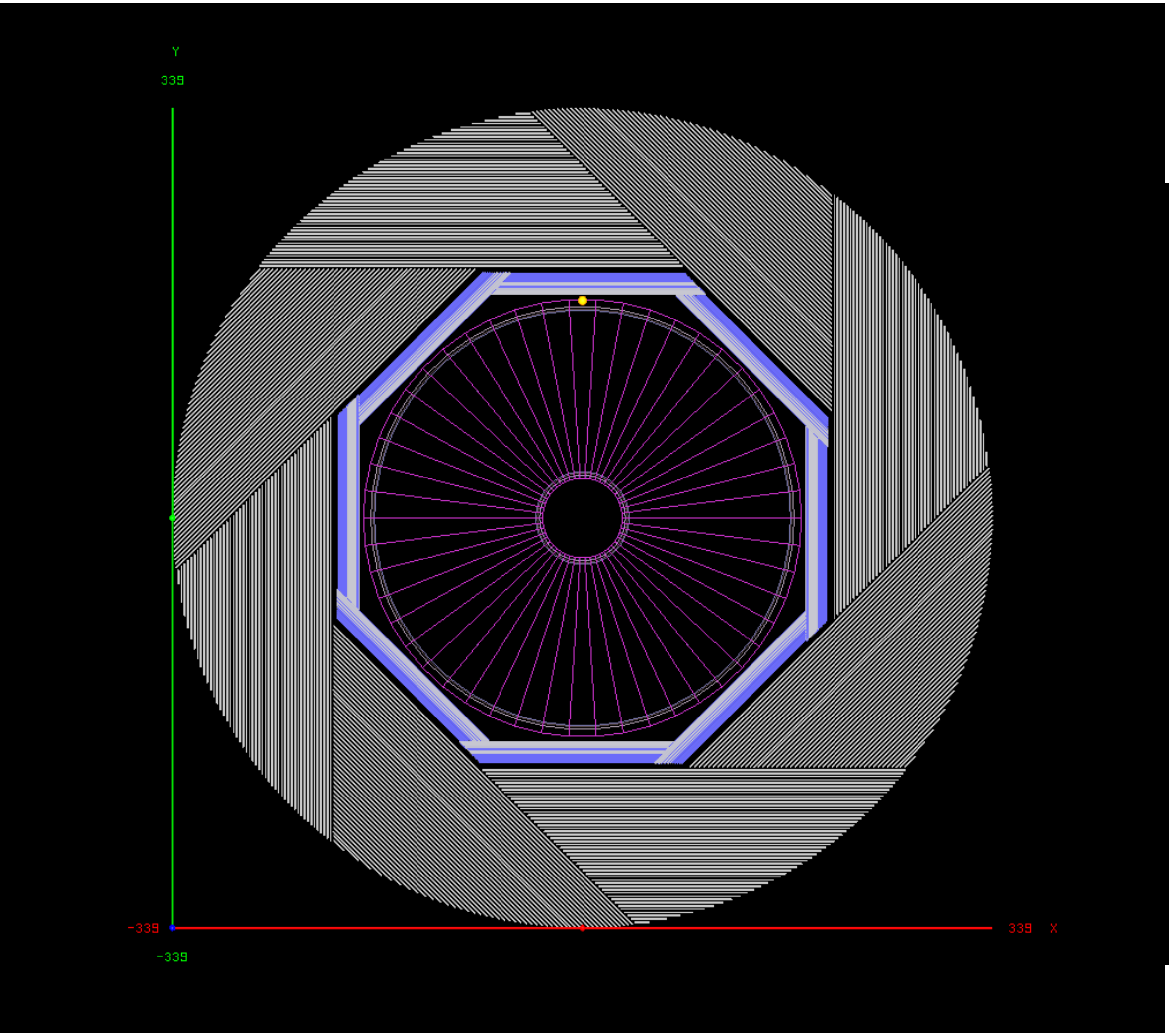
Detector simulation studies

- Center simulation support: Nankai University (2 faculty + 2 students)
  - Cooperating with Ecole polytechnique (France)
- Sub detector simulation development
  - TPC: UCAS (binglong Wang)
  - VTX: SDU (Qingyuan Liu)
  - Calo: SJTU & IHEP

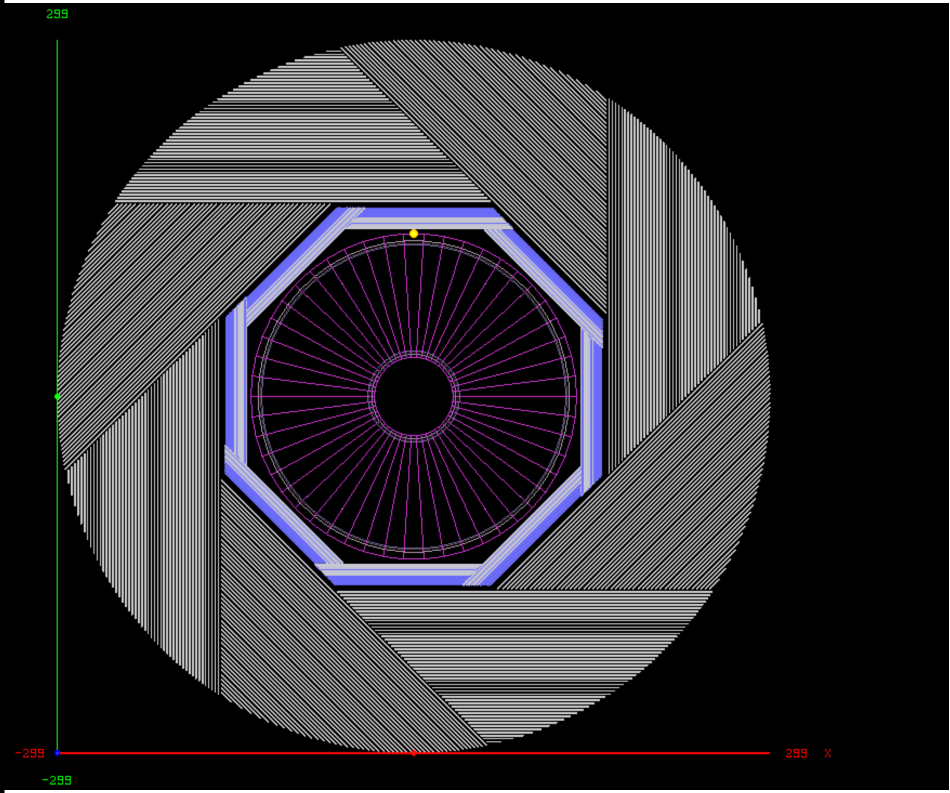




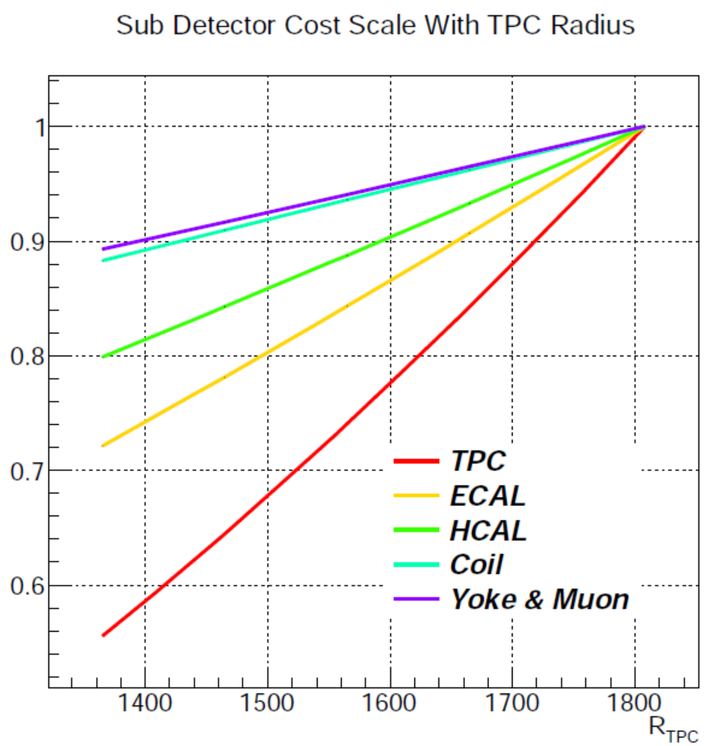
Design new geometry

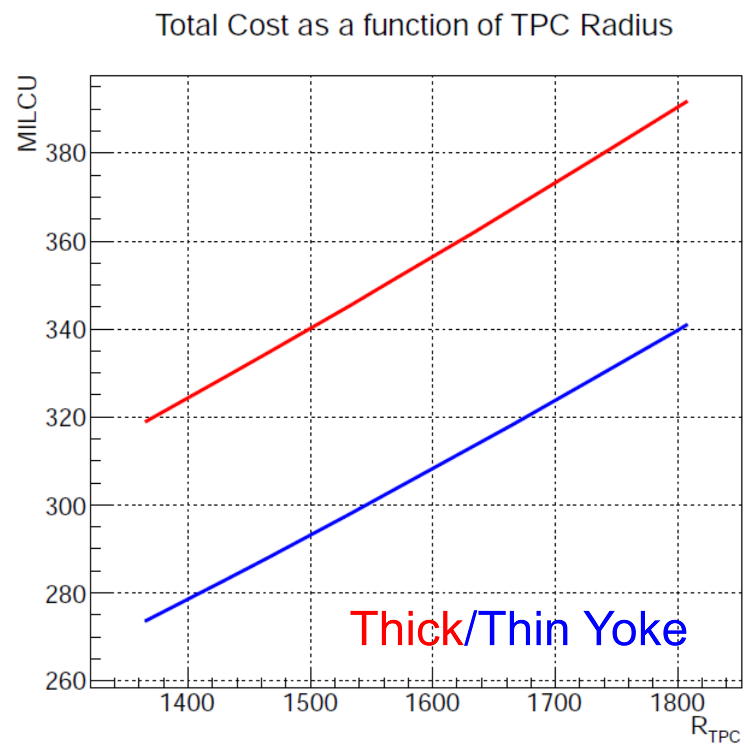


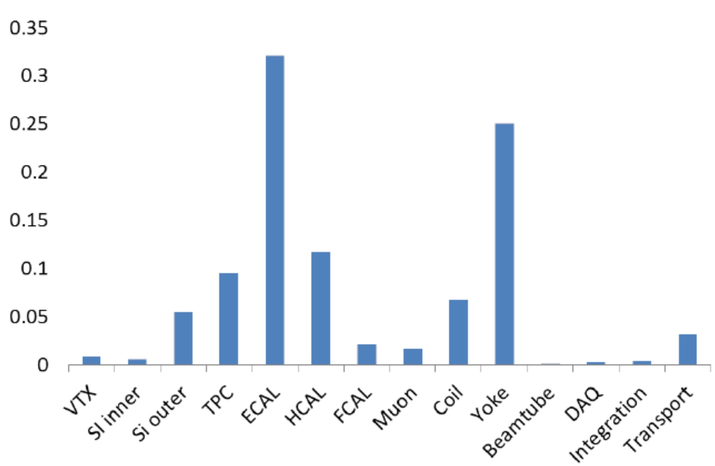
Reduce TPC Radius by 25%
Why not?



Cost estimation: extrapolate from ILD



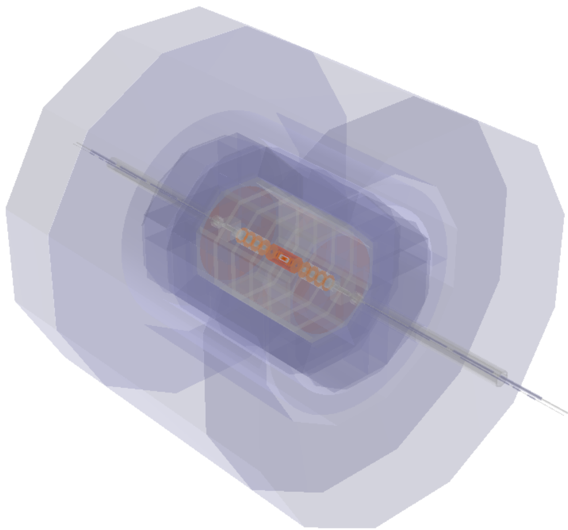


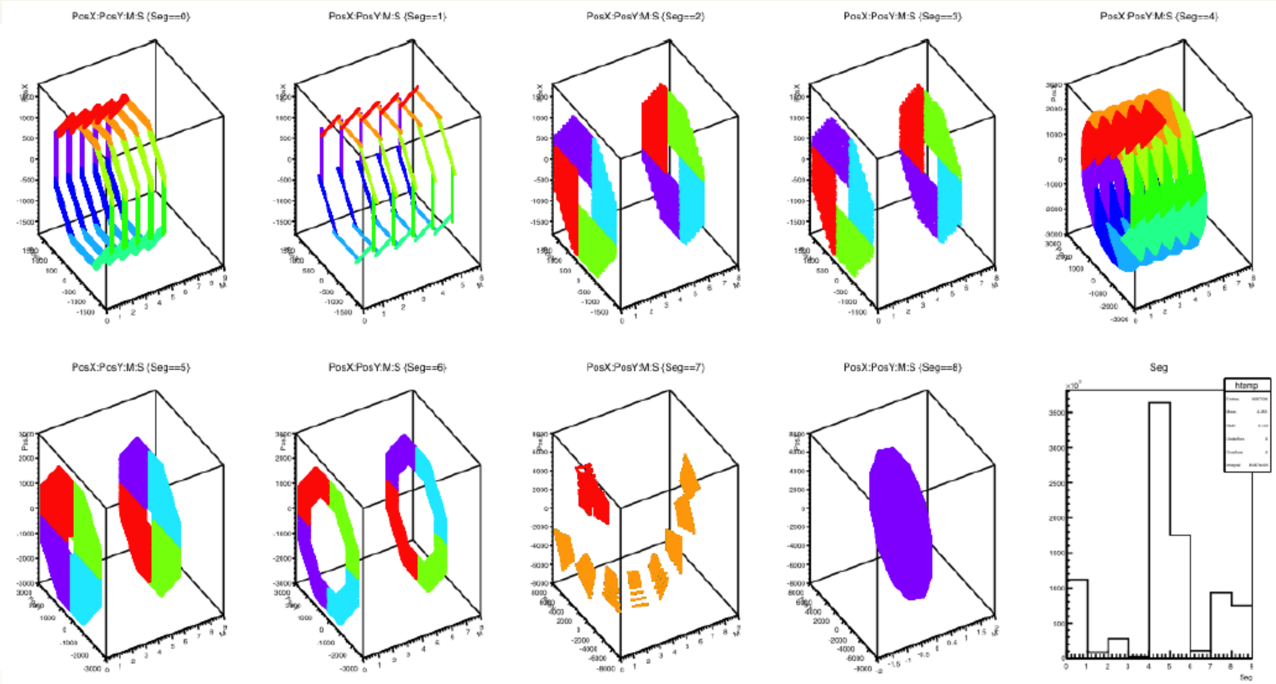


ILD Cost ~ 400 MILCU
CEPC detector ~ 270 MILCU
~ 1.6 Billion CNY
~ 3 B CNY for 2 detectors;

Without manpower

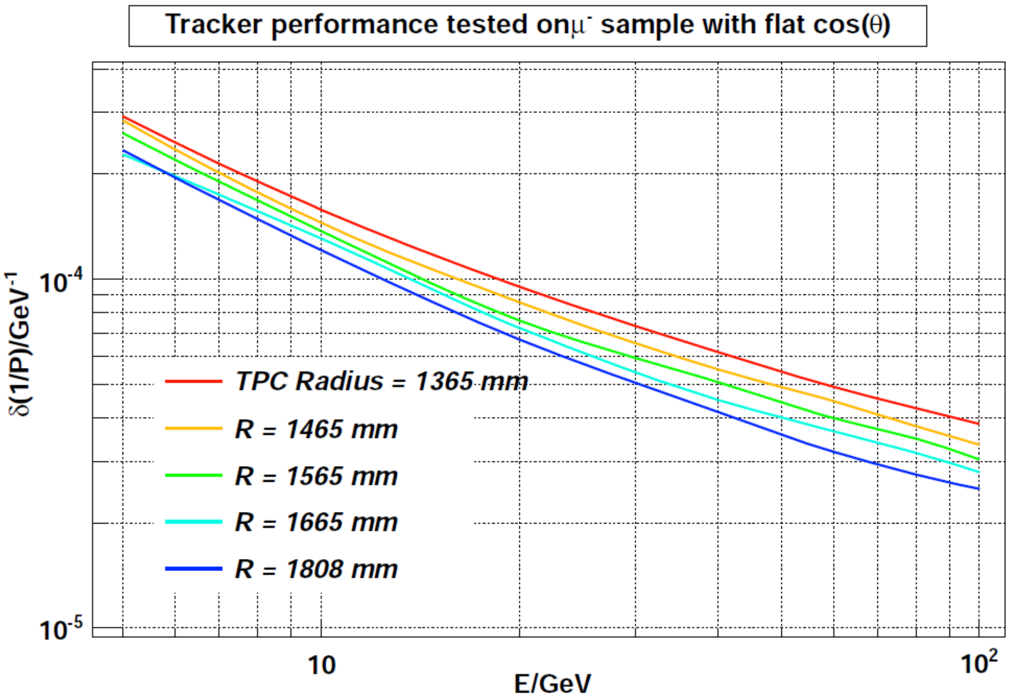
Validation of new geometry

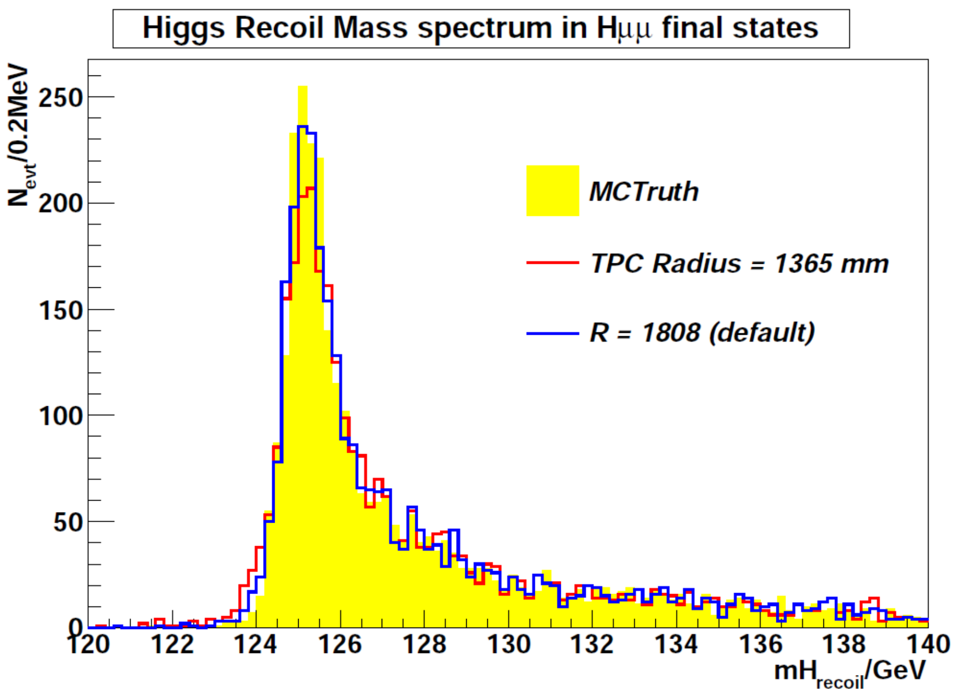




- Hit map validation: NanKai University
- Sub detector performance analysis:
  - Tracks: IHEP (finished)
  - Photons: WhU
  - Neutral Hadrons: SJTU

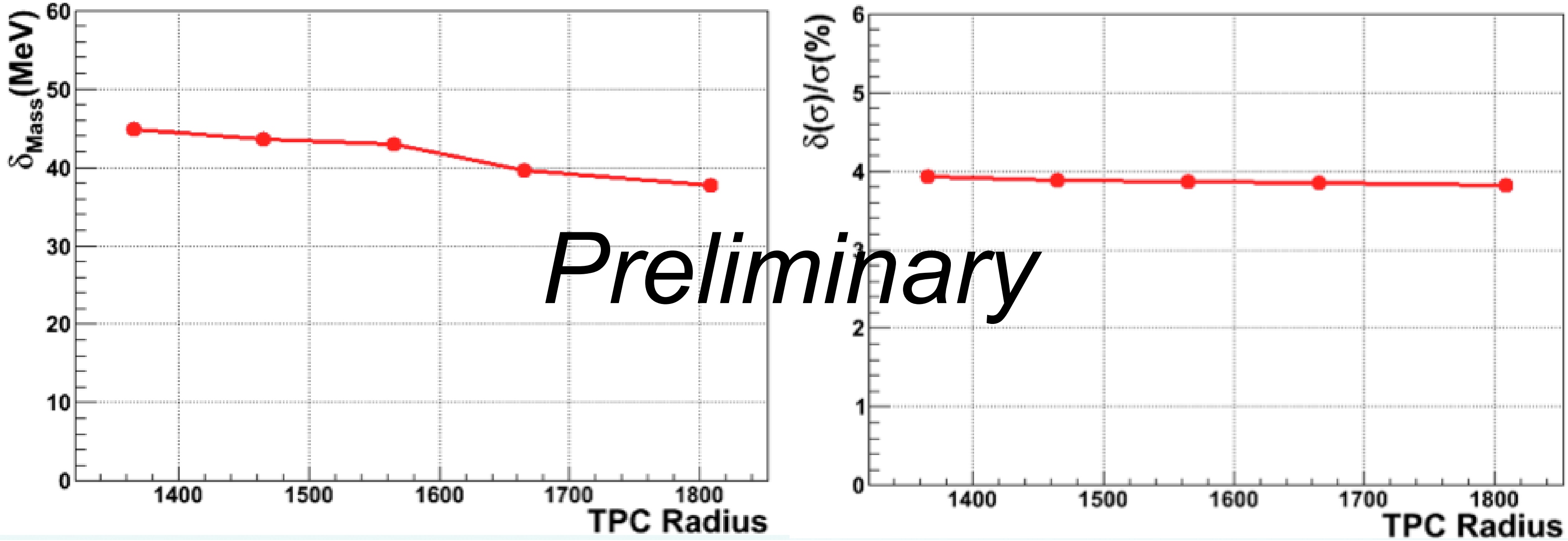
Fast simulation of recoil mass spectrum





Large intrinsic width: from beam energy spread & radiation effects (Beamstrahlung, etc)

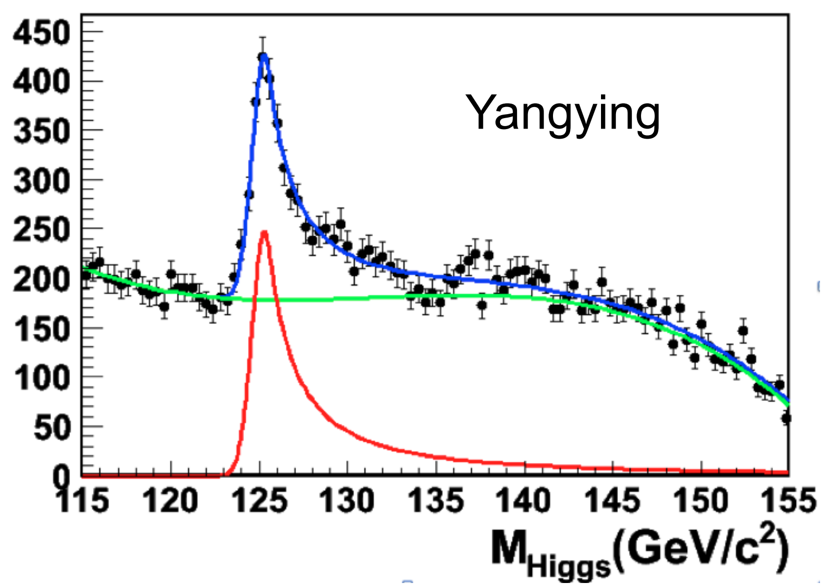
Fast simulation of recoil mass spectrum



Mass resolution worsen ~ 10%,
Xsec resolution almost flat

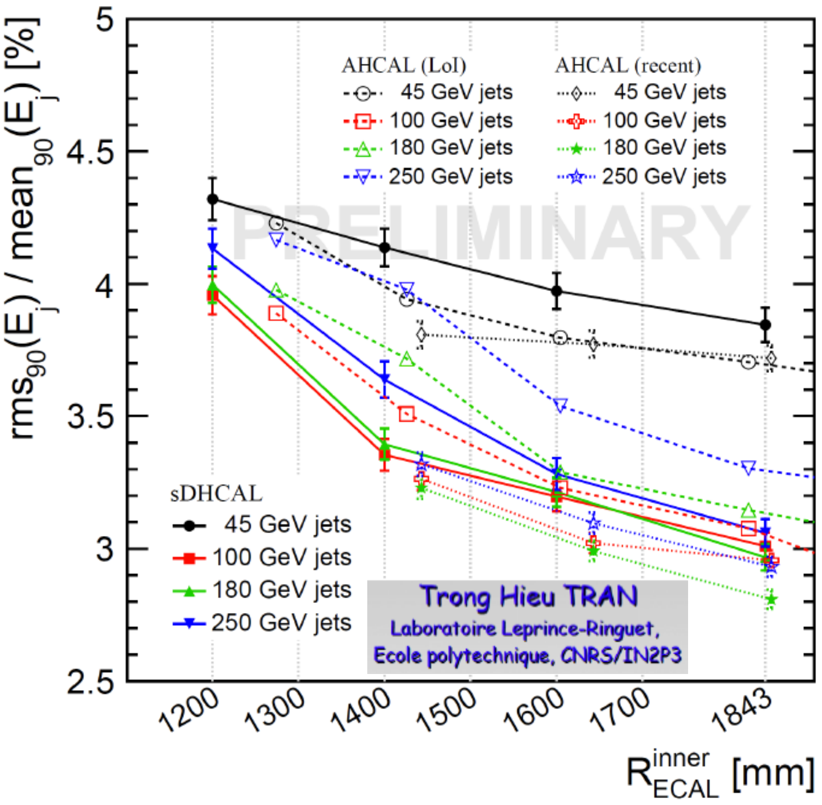
Cut chain/Fit not finalized

Result obtained with ZH, Z→μμ channel
Z→ee will be added soon

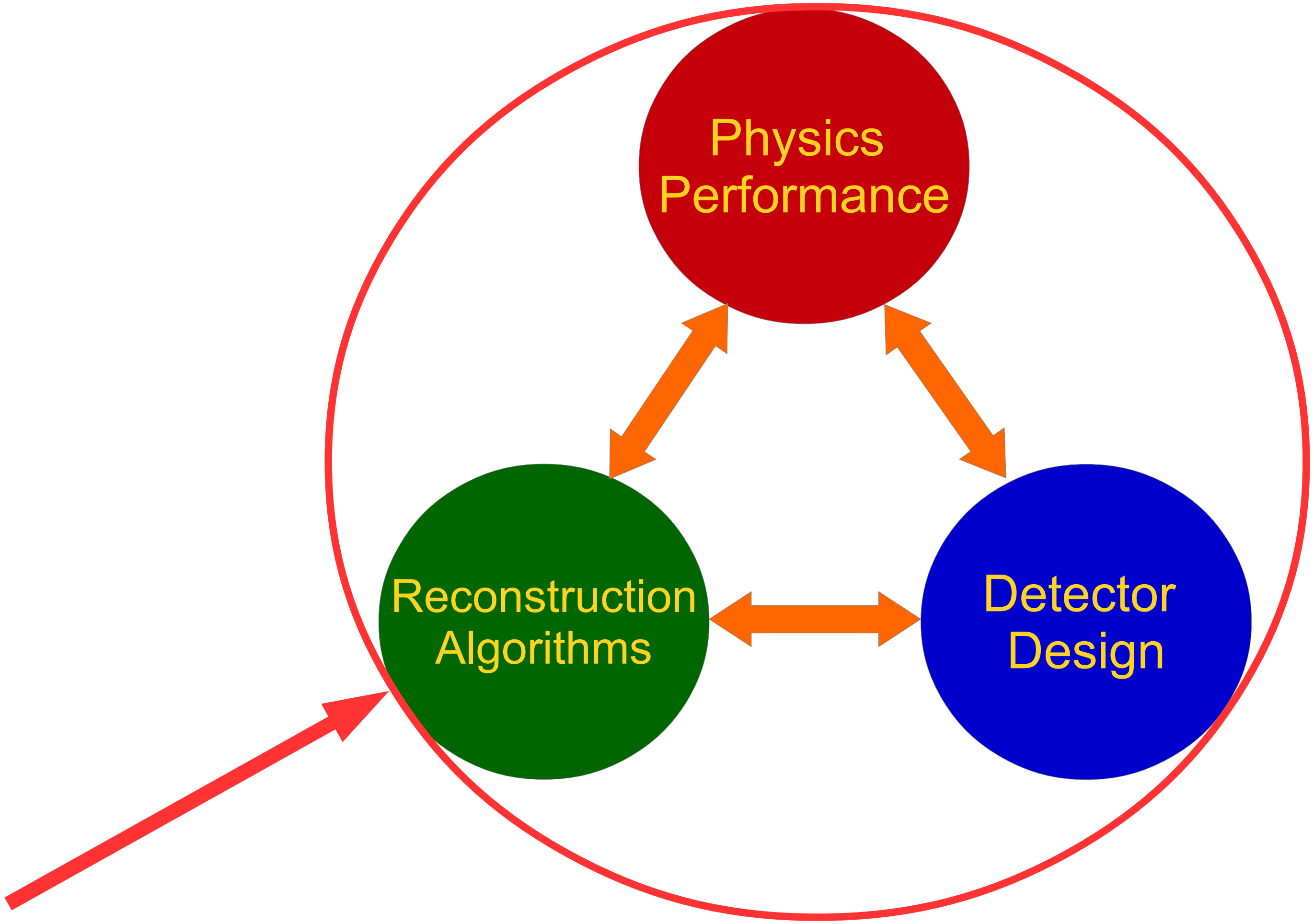


Reduce the size/cost

- Mass, total cross section: understood
  - The beam condition can be changed
  - Software/analysis chain is ready
- Need to investigate the influence on other measurements (Branching ratios)
  - Based on adequate reconstruction, analysis
  - One Hint: Jet energy resolution: 10% worse with TPC radius be reduced by 25% (agrees with ILC studies)

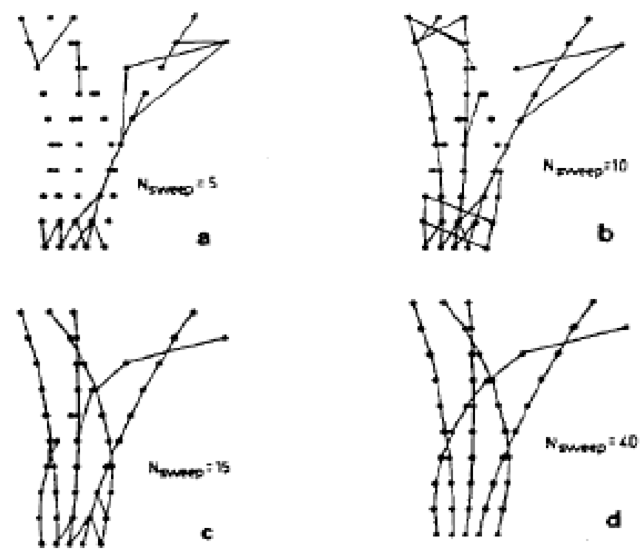


Reconstruction chain developments



Reconstruction Algorithms: Status

- Starting point: ILD reconstruction chain
  - Tsinghua University: Track reconstruction for LCTPC
  - IHEP: PFA & Calorimeter reco-algorithm development
- A long wish list:
  - Calorimeter Cluster Pattern Identification
  - Particle identification, especially lepton ID
  - Cluster energy estimation
  - Track-Clustering match, track hierarchic
  - Tau tagging algorithm
  - Jet clustering
  - …
- Advanced Analysis Algorithms



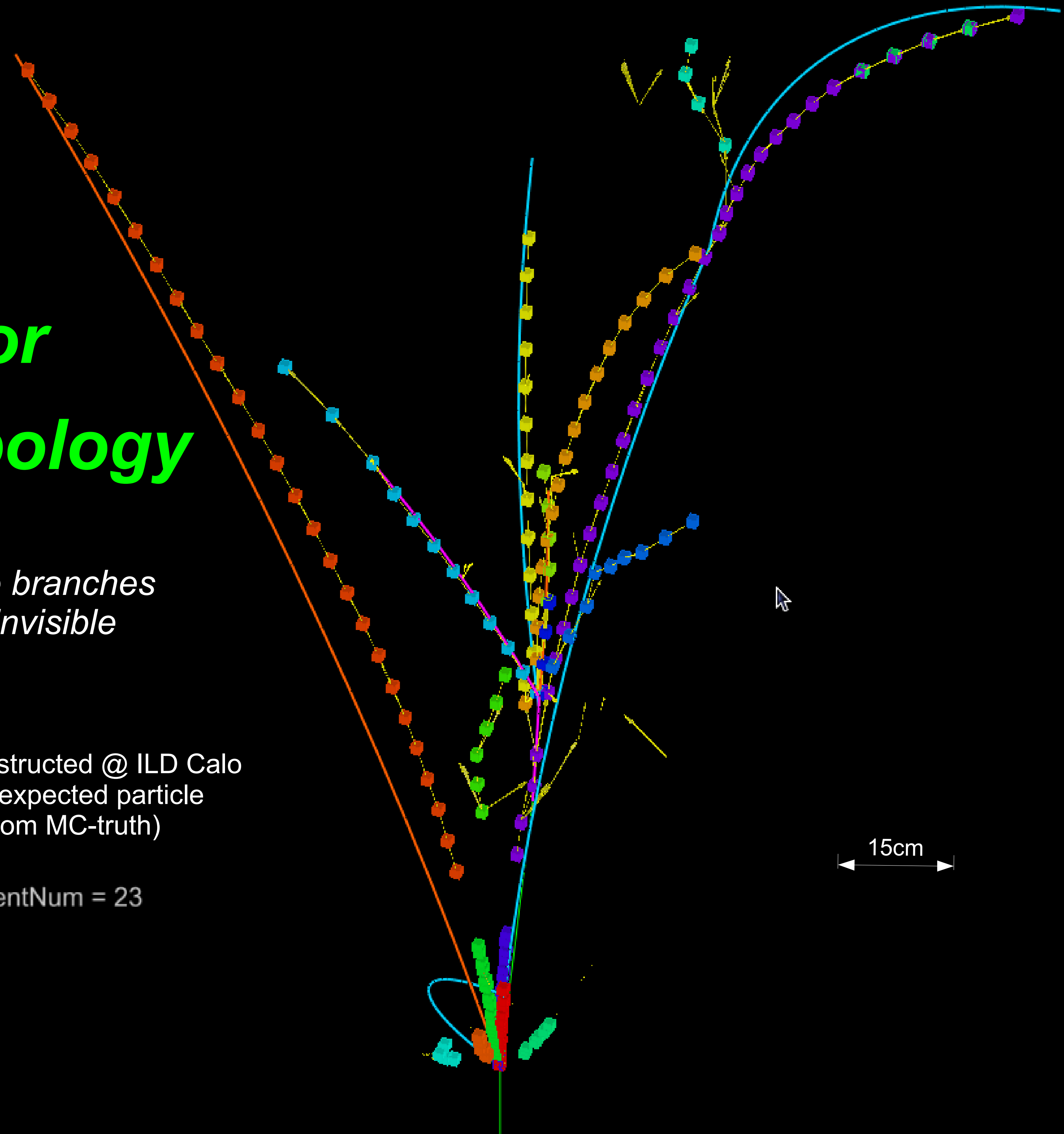
Tracking algorithm: B. Li

Arbor
Tree Topology

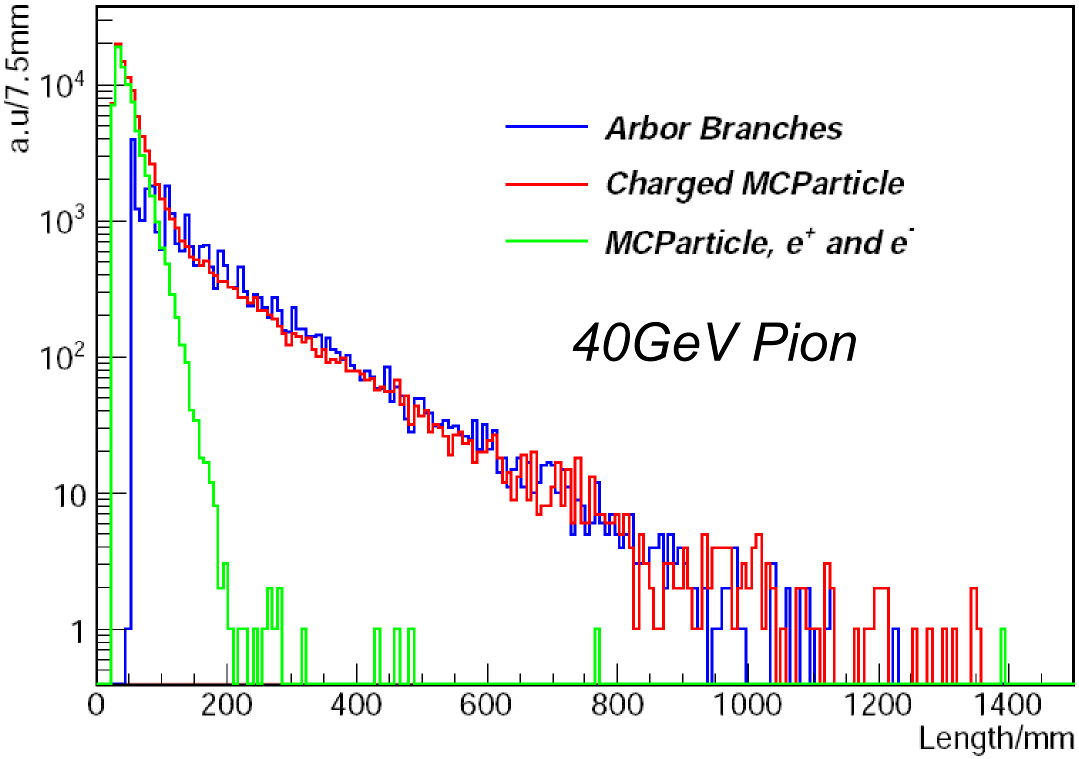
Except some branches might be invisible

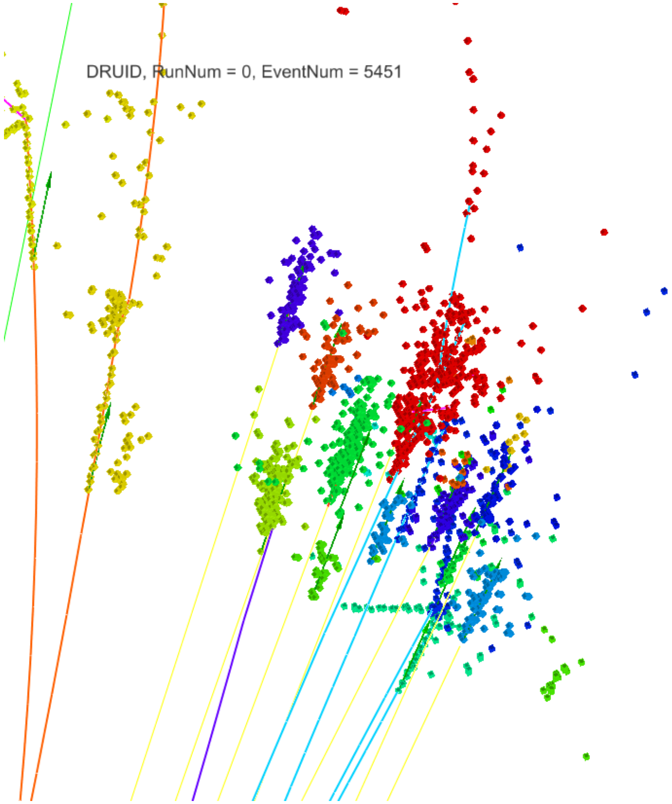
20 GeV Klong reconstructed @ ILD Calo
Curves indicating expected particle trajectories (from MC-truth)

DRUID, RunNum = 0, EventNum = 23



Arbor: Validation & Goal





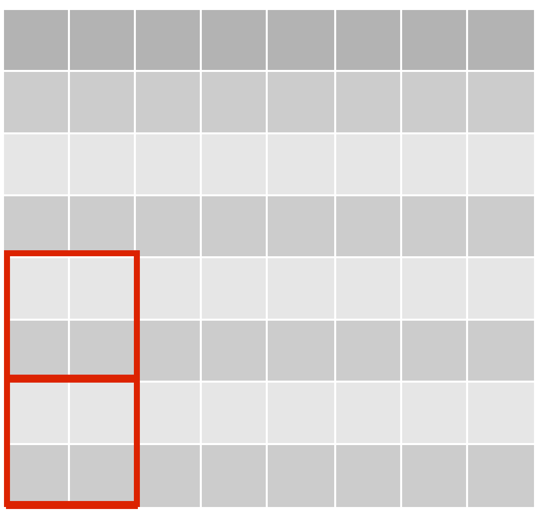
Arbor: successfully tag sub-shower structure
Ultimate goal: reconstruct every energetic final state particle

Samples: Particle gun event at ILD HCAL (readout granularity 1cm^2 & layer thickness 2.65cm)
Length: Charged MCParticle: spatial distance between generation/end points
Arbor branch: sum of distance between neighboring cells

Fractal dimension of particle shower

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

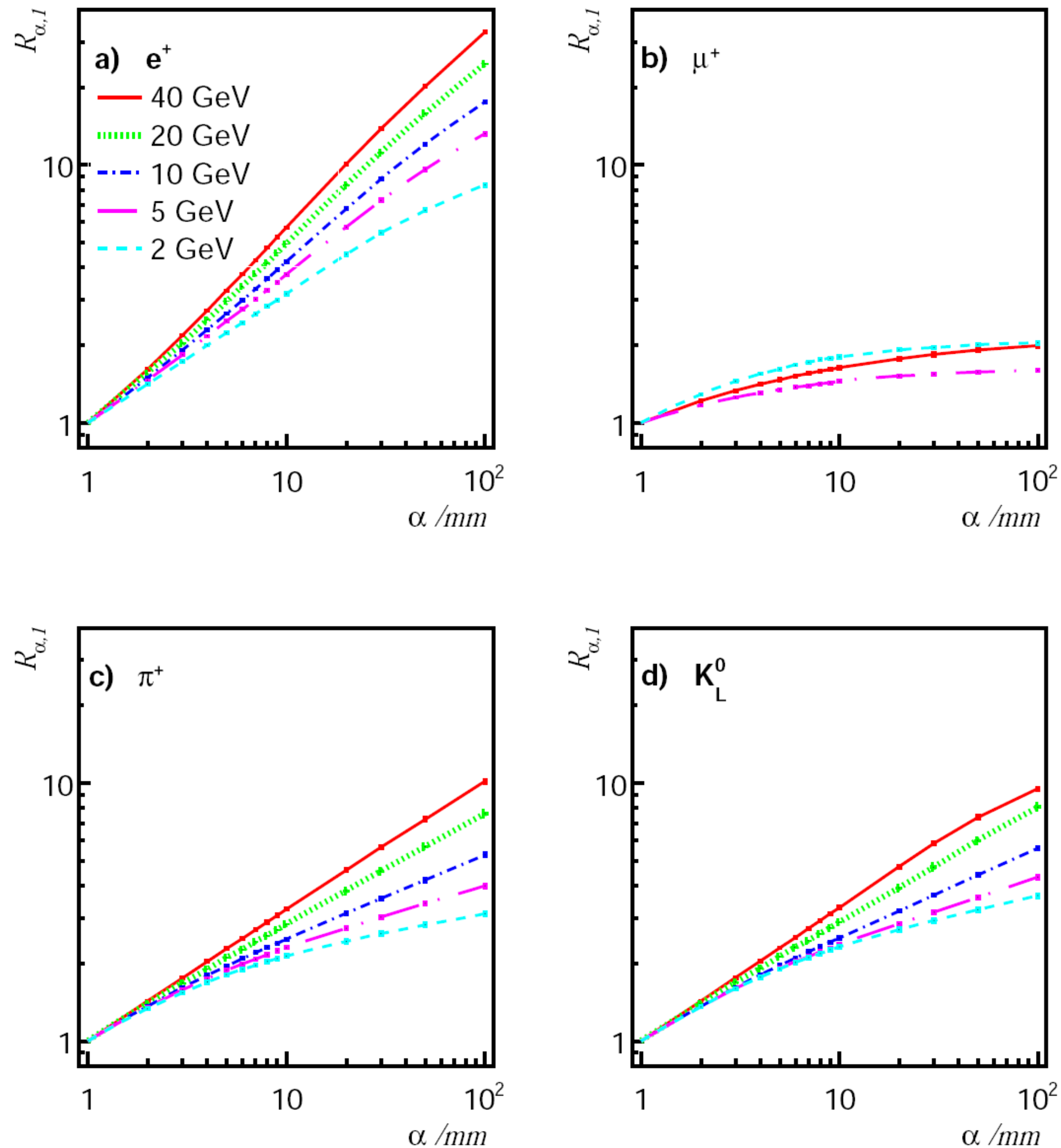
$$R_{\alpha,\beta} = N_\beta / N_\alpha.$$



Ultimate cell size: 1mm

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

Sample: particle gun events at ILD SDHCAL

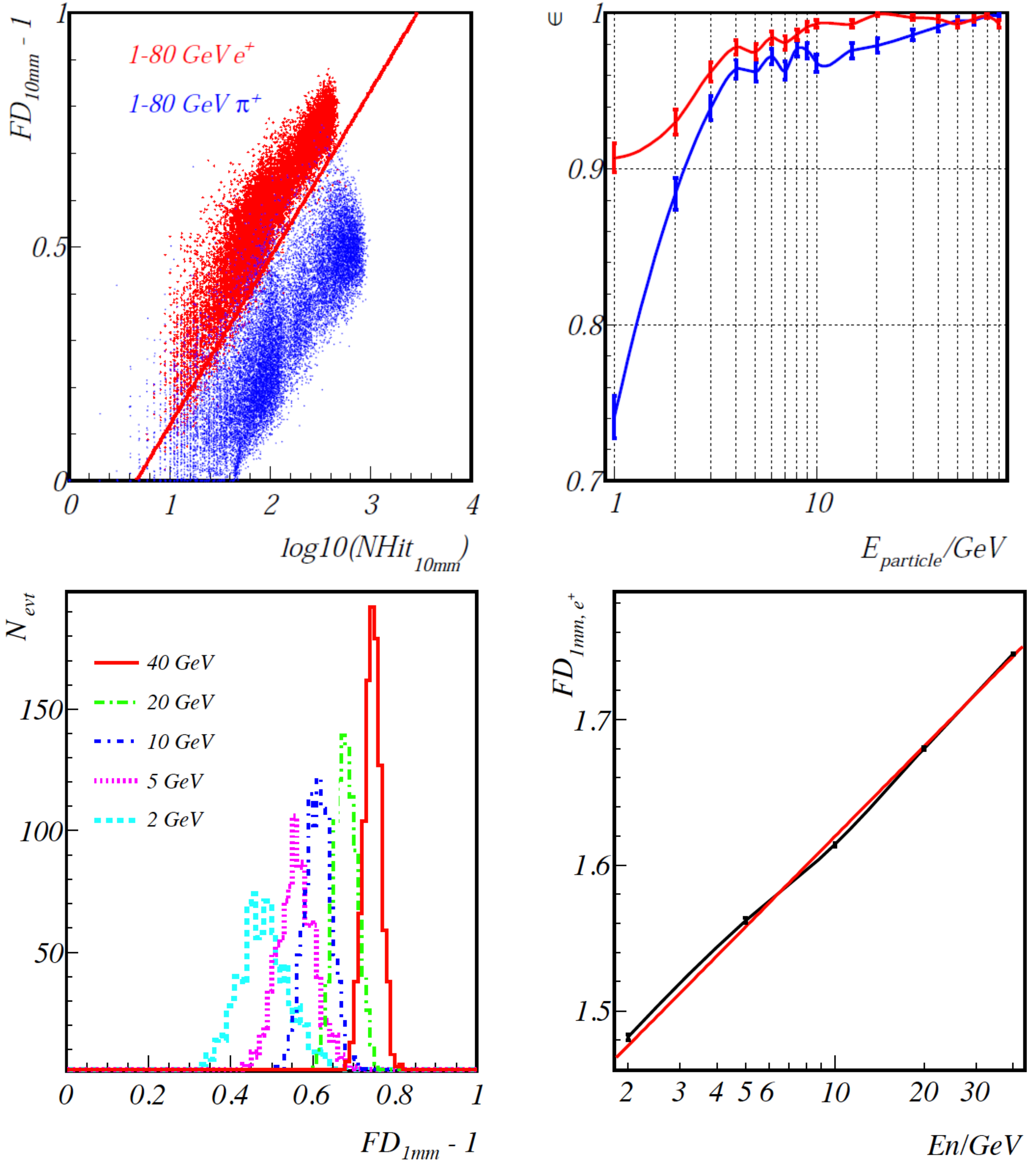


Impaction

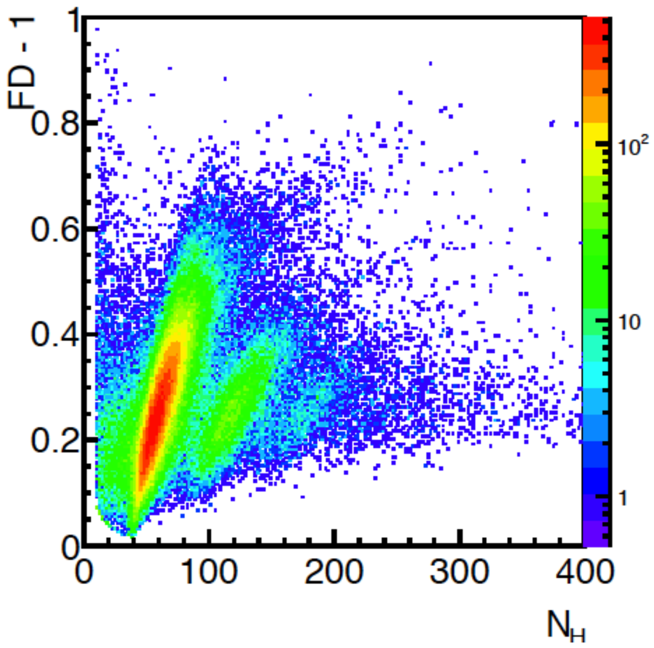
Remark: FD uses only the transverse shower information...

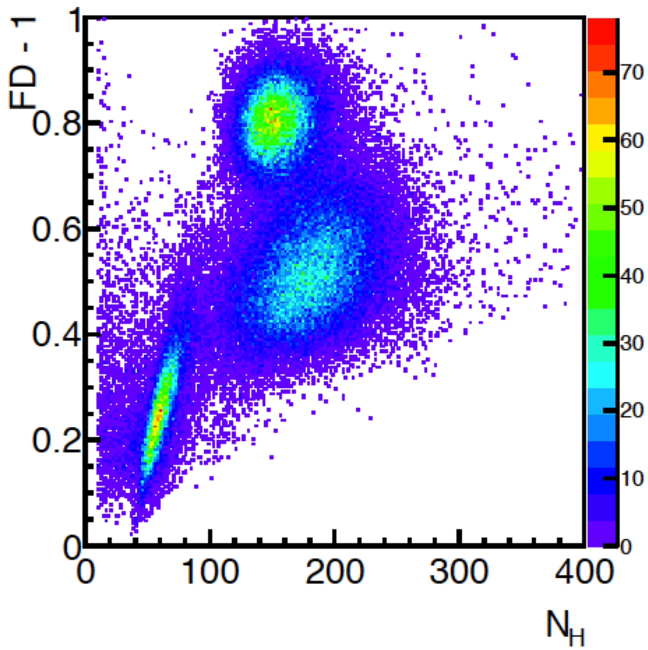
Promising PID over
the full energy range

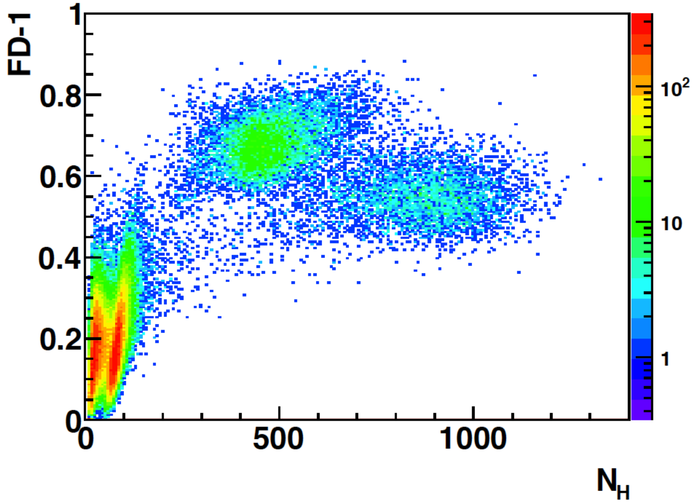
$$FD^{em}_{1\mathrm{mm}}(E) = 1.41 + 0.21 \times \log_{10}(E/\mathrm{GeV})$$
$$FD^{had}_{1\mathrm{mm}}(E) = 1.24 + 0.15 \times \log_{10}(E/\mathrm{GeV})$$
$$FD^{mip}_{1\mathrm{mm}}(E) = 1.2$$



Validated with CALICE TB data





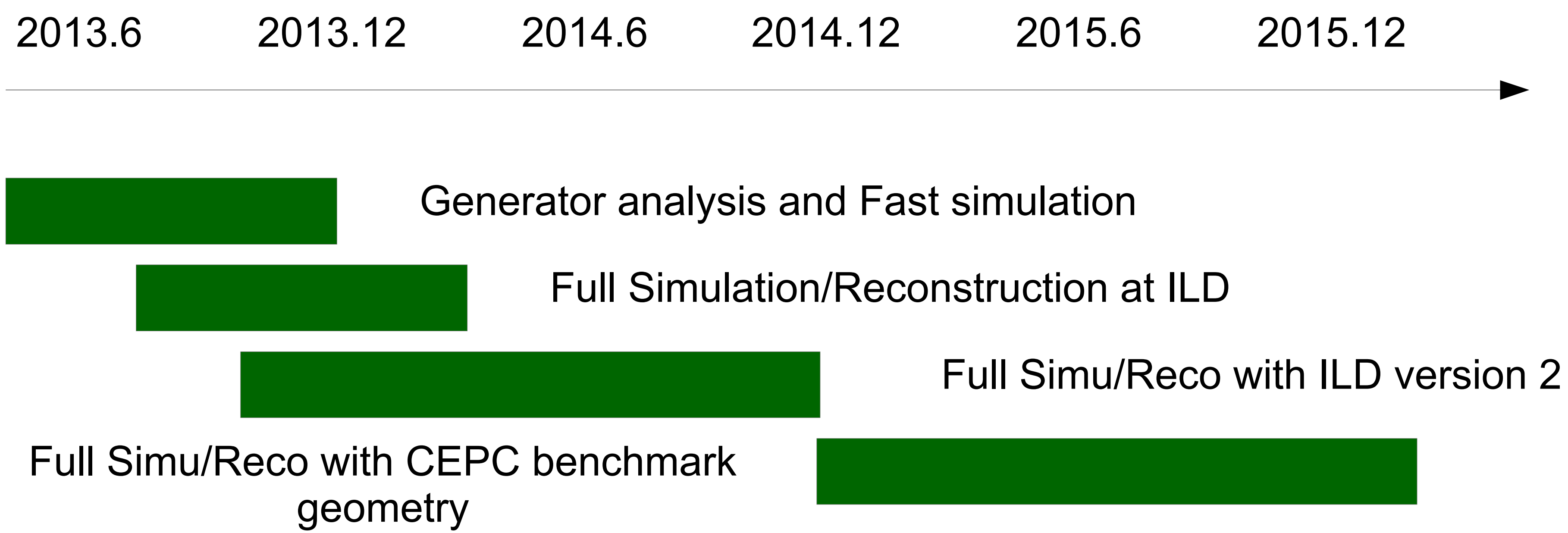


Sensitive to group behavior

Also be used to tag noise pattern

Personal Perspective: A Tentative Time Line

4 Steps...



Summary

- Lots of activities toward Detector R&D & Physics analysis at CEPC
  - 120 ppl from 19 institutes at Kick off meeting
  - 80 ppl from 12 institutes participated the Training
  - Phone meeting: 10 ~ 30 participates
  - **Key point: get people trained**
- Parallel Studies on going
  - Generator: ILD official sample, Validation – fast simulation, nearly finished
  - Detector geometry: changing TPC radius, model validation & cost estimation
  - Full simulation: ILD Version 2 to be validated
  - Reconstruction - Analysis: developing & testing
- Communications: with machine, theory group and foreign experts
- Long to do list: especially at detector R&D side
  - Needs lots of manpower, computing resources and International Cooperation

* End of 20'th Century
[1895 — 2012]

* Dawn of a New Era in Fundamental Physics

Thank you!

Spared slides

CEPC Activities

- Sep 2012, Proposed
- May – Aug, 2013
  - Computing environment, queue, software & tools settled
  - Generator samples obtained, Fast/Full Simulation launched
- *12 – 16 Aug, 2013: International Symposium on Higgs Physics (related)*
- 13 – 14 Sep, 2013: CEPC Kickoff meeting
  - 100+ participants from 19 institutes
  - Collaboration established
- 19 – 20 Oct, 2013: CEPC Training on physics analysis & detector optimization
  - 80 participants from 12 institutes
  - Task sharing & working plan clarified, studies initialized at different institutes
- 18 – 19 Nov, 2013: Franco-Chine CEPC detector discussing
- 16 – 17 Dec, 2013: Workshop on Future High Energy Circular Colliders

Higgs Measurement at ILD: Luminosity Upgrade scenario

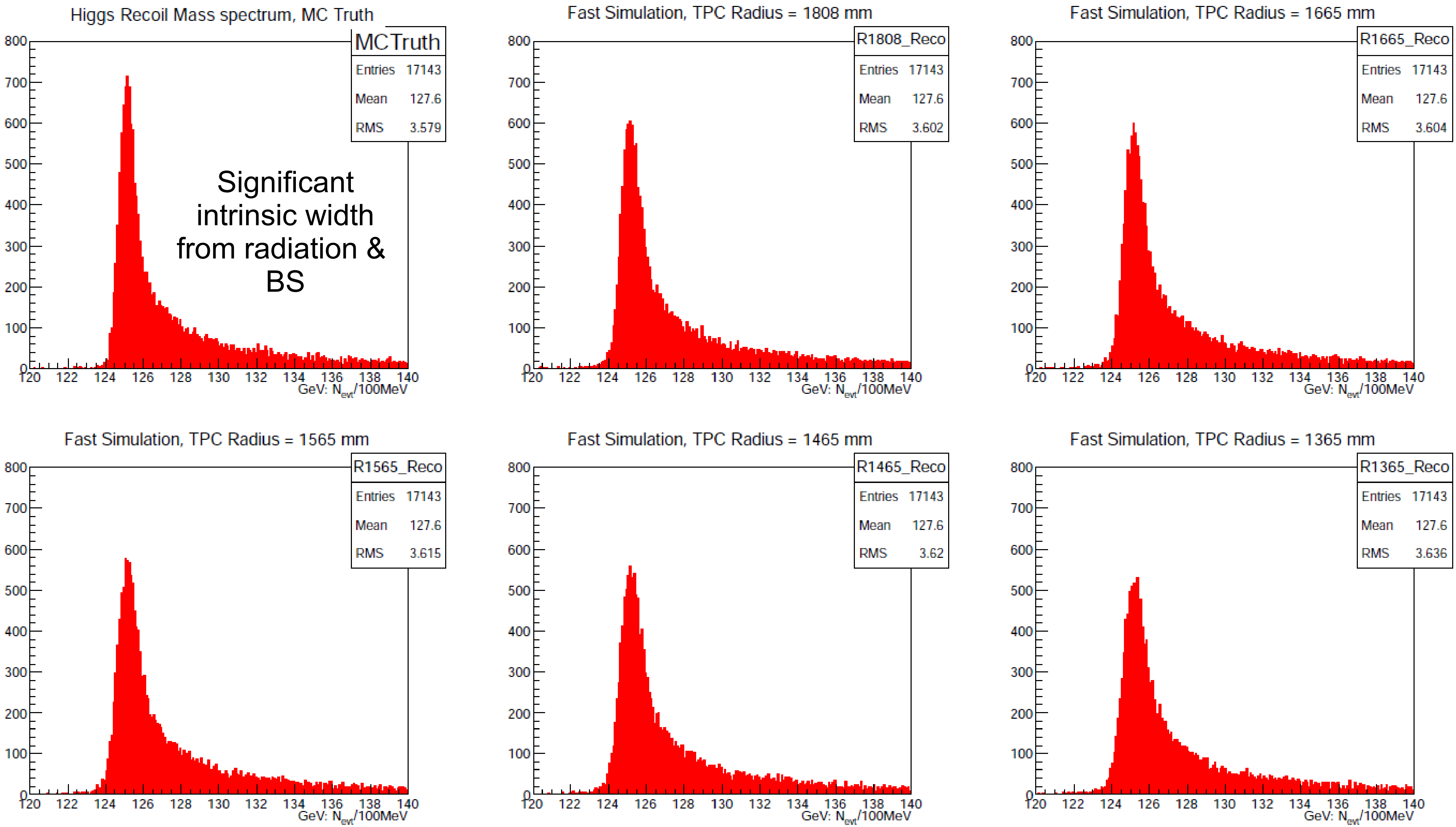
	$\Delta(\sigma \cdot BR)/(\sigma \cdot BR)$				
$\sqrt{s}$ and $\mathcal{L}$	1150 fb^{-1} at 250 GeV		1.6 ab^{-1} at 500 GeV		2.5 ab^{-1} at 1 TeV
(P_{e^-}, P_{e^+})	(-0.8,+0.3)		(-0.8,+0.3)		(-0.8,+0.2)
mode	ZH	$\nu\bar{\nu}H$	ZH	$\nu\bar{\nu}H$	$\nu\bar{\nu}H$
$H \to b\bar{b}$	0.56%	4.9%	1.0%	0.37%	0.20%
$H \to c\bar{c}$	3.9%	-	7.2%	3.5%	2.0%
$H \to gg$	3.3%	-	6.0%	2.3%	1.4%
$H \to WW^*$	3.0%	-	5.1%	1.3%	1.0%
$H \to \tau^+\tau^-$	2.0%	-	3.0%	5.0%	2.0%
$H \to ZZ^*$	8.8%	-	14%	4.6%	2.6%
$H \to \gamma\gamma$	16%	-	19%	13%	5.4%
$H \to \mu^+\mu^-$	-	-	-	-	20%
$H \to$ Inv.(95% $C.L.$)	$< 0.37\%$		-		-
$t\bar{t}H, H \to b\bar{b}$	-		16%		3.8%

TABLE IV: Expected accuracies for cross section times branching ratio measurements for the 125 GeV H boson by the luminosity upgrade scenario.

couplings	250 GeV	250 GeV + 500 GeV	250 GeV + 500 GeV + 1 TeV
g_{HZZ}	0.61%	0.61%	0.61%
g_{HWW}	2.3%	0.67%	0.65%
g_{Hbb}	2.5%	0.90%	0.74%
g_{Hcc}	3.2%	1.5%	1.1%
g_{Hgg}	3.0%	1.3%	0.93%
$g_{H\tau\tau}$	2.7%	1.2%	0.99%
$g_{H\gamma\gamma}$	8.2%	4.5%	2.4%
$g_{H\mu\mu}$	-	-	10%
g_{Htt}	-	7.8%	2.0%
Γ_0	5.4%	2.8%	2.7%

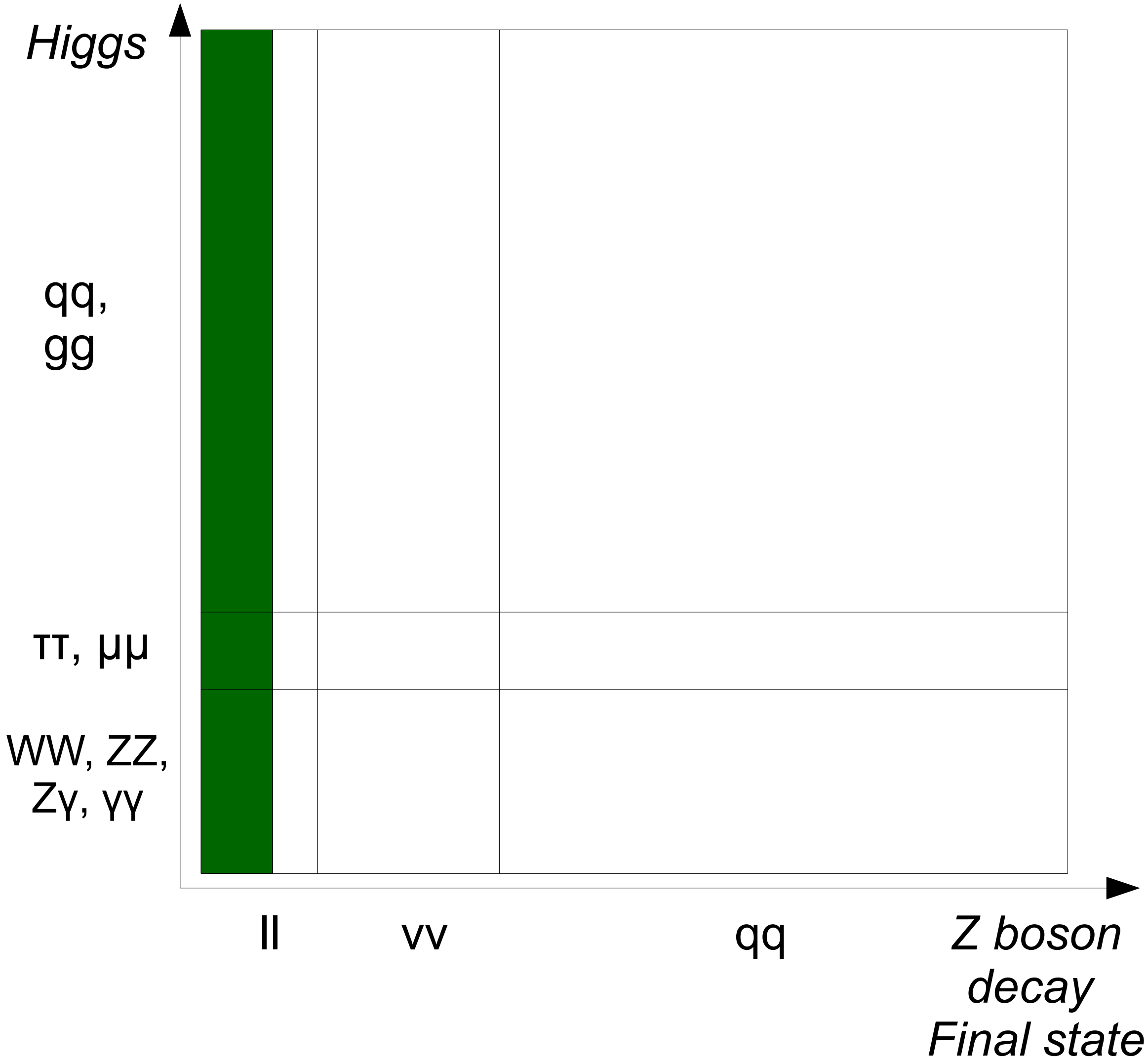
TABLE V: Expected accuracies of Higgs couplings and total Higgs width by the luminosity upgrade scenario.

Recoil mass at different TPC Radius



Nevts scaled by a factor of ~ 5

Measurements at different final states: 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

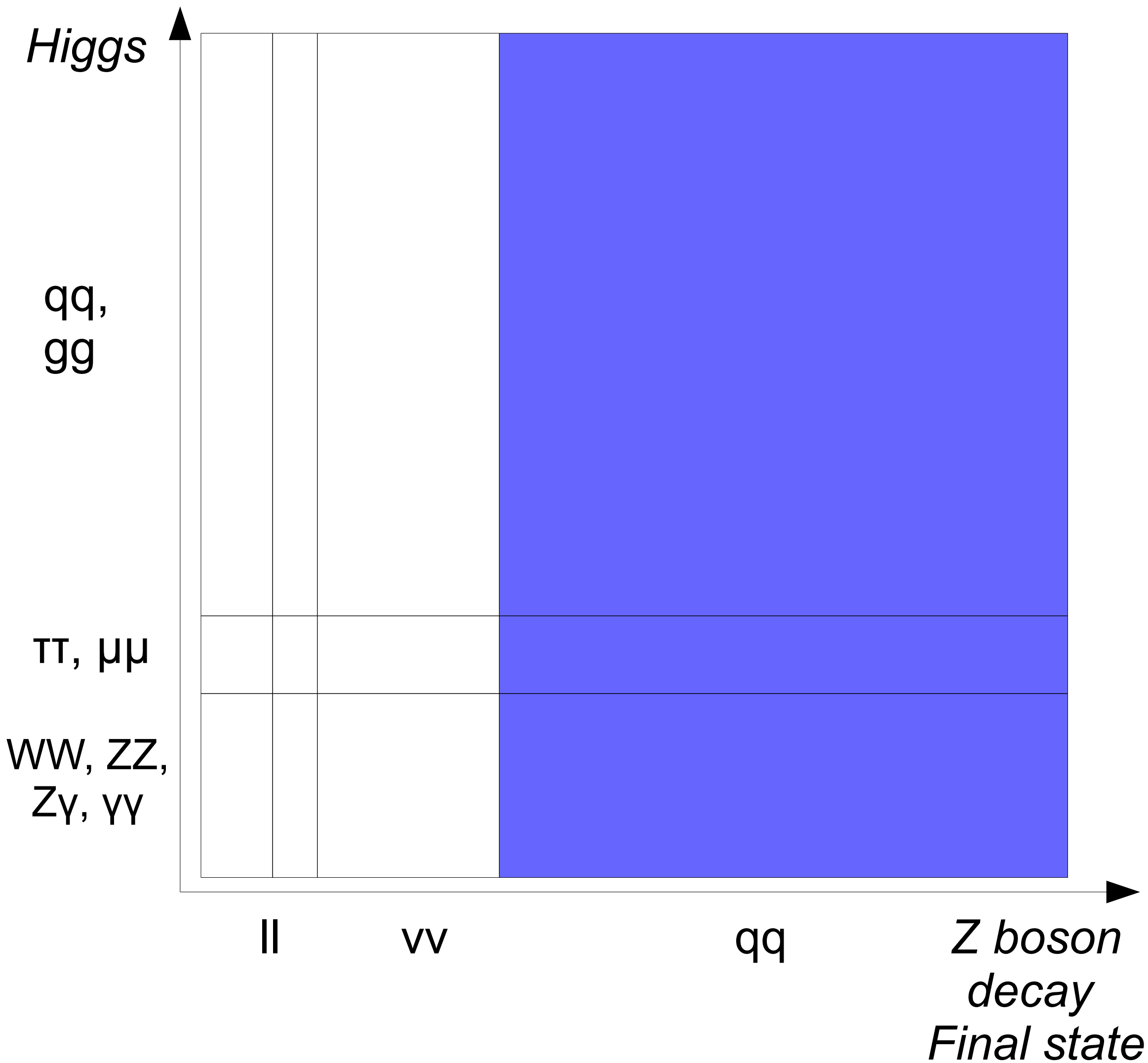
Objective Observables:

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



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

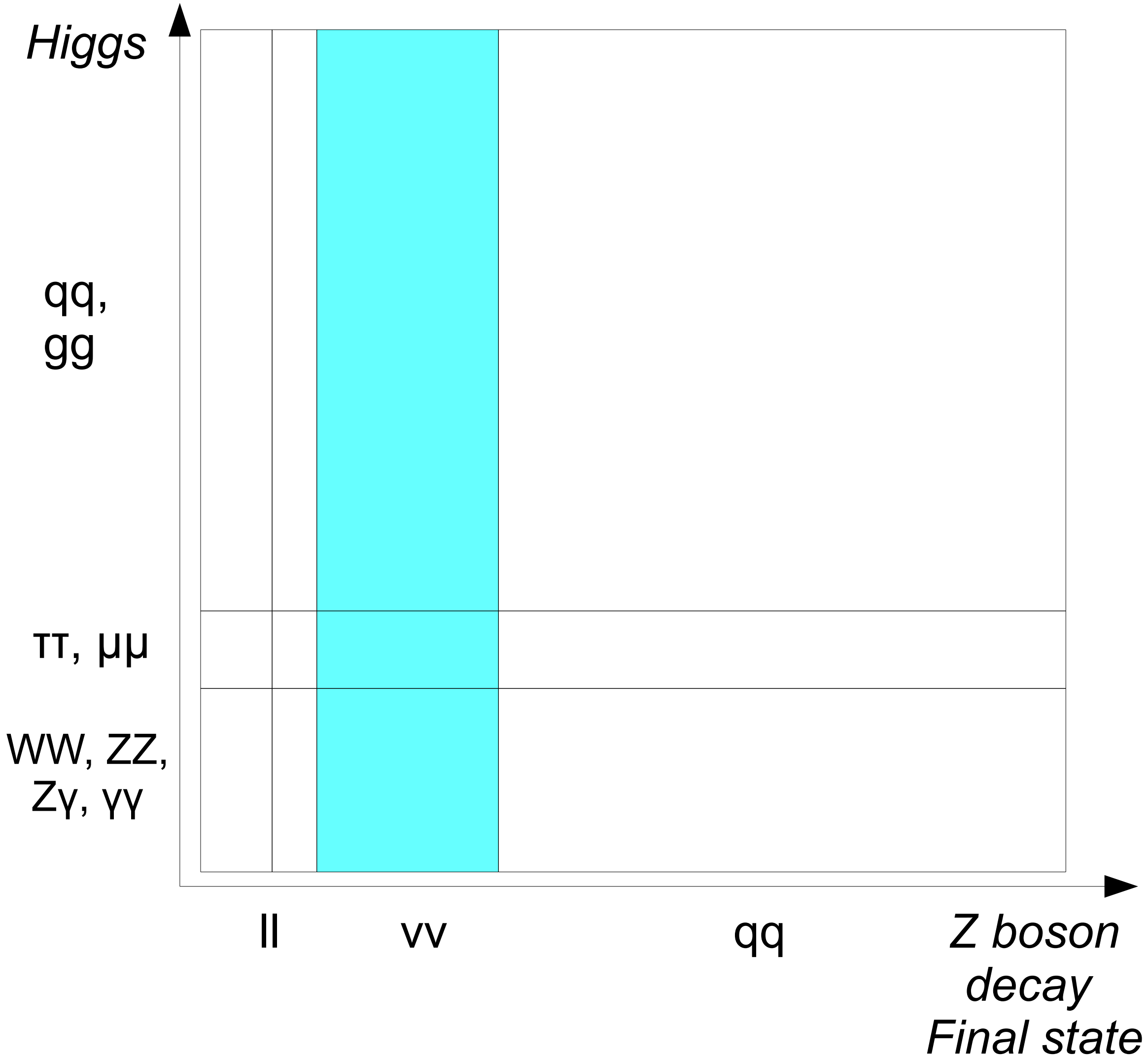
Objective Observables:

Recoil mass spectrum:
Higgs mass, $\sigma(HZ)$

Tagged ZH events + Higgs final states classification:
$Br(H \to X) * \sigma(HZ)$

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

ZH, Z→2ν, H→X



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

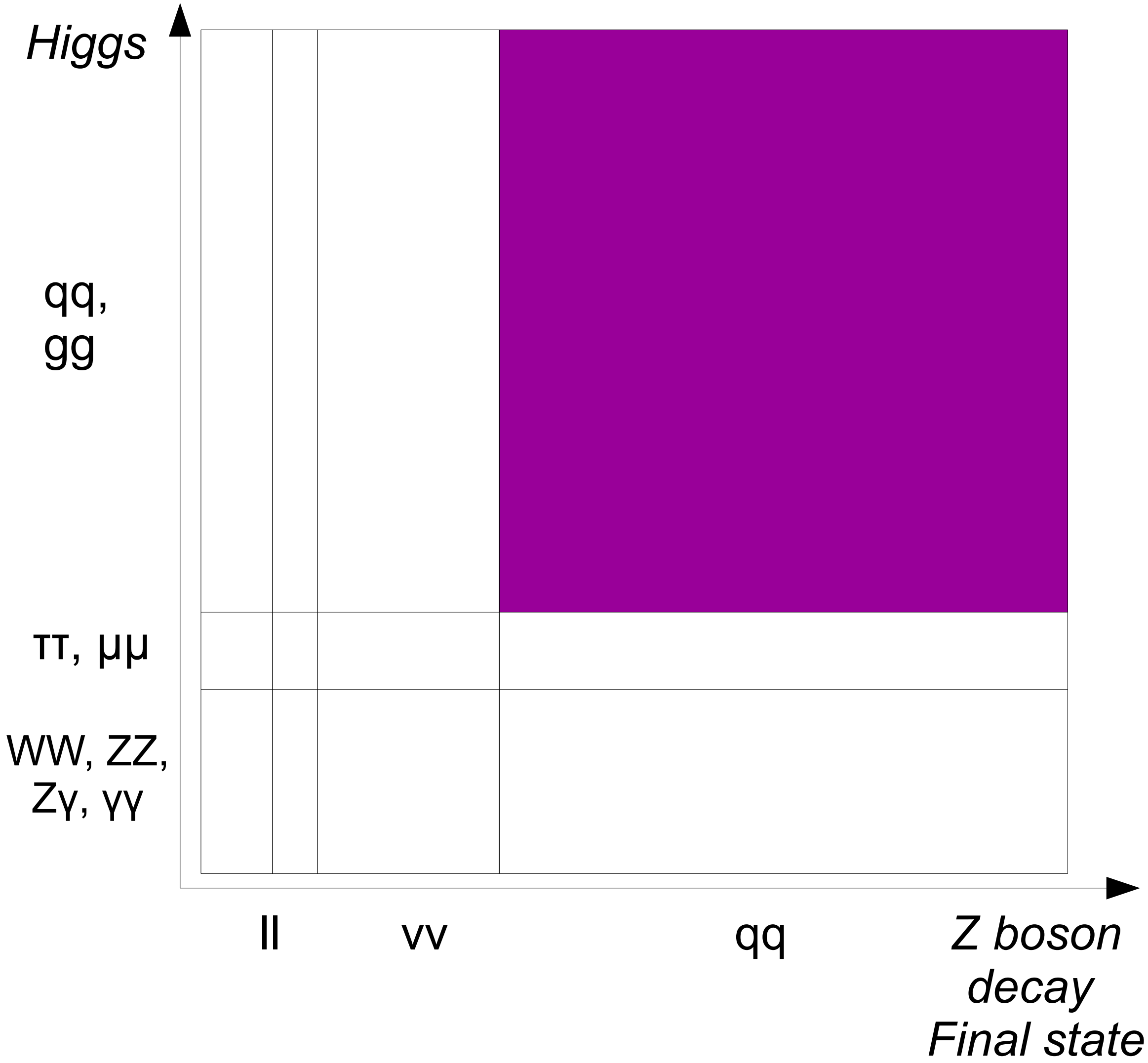
Objective Observables:

Higgs mass, σ(HZ)*Br(H→X)

Critical performances/algorithms:

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

ZH, Z→2q, H→2q



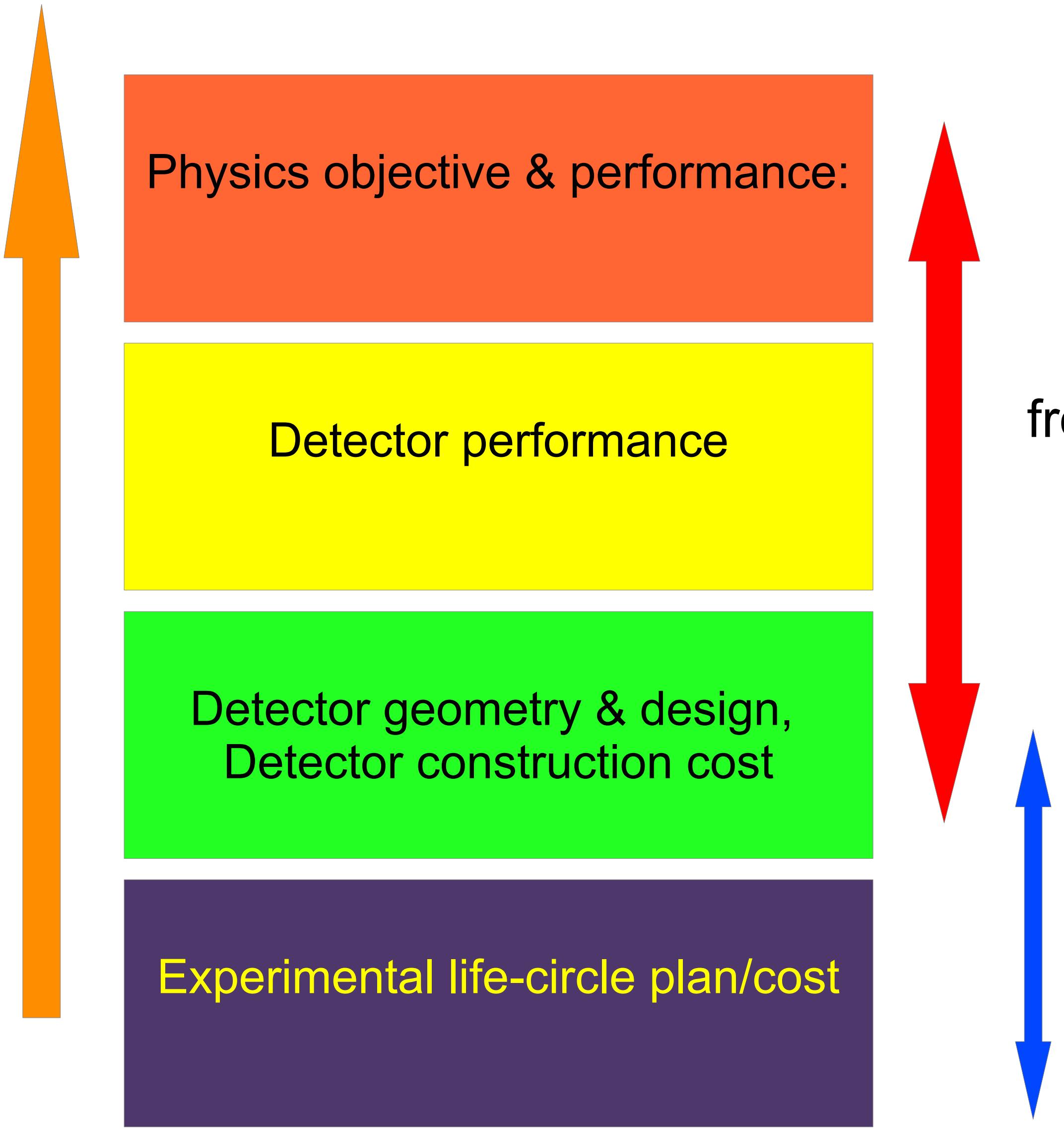
Tag the ZH events from invariant Mass of all 2-jets combinations.
Statistics ~ 50k evts

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

Detector optimization: objective

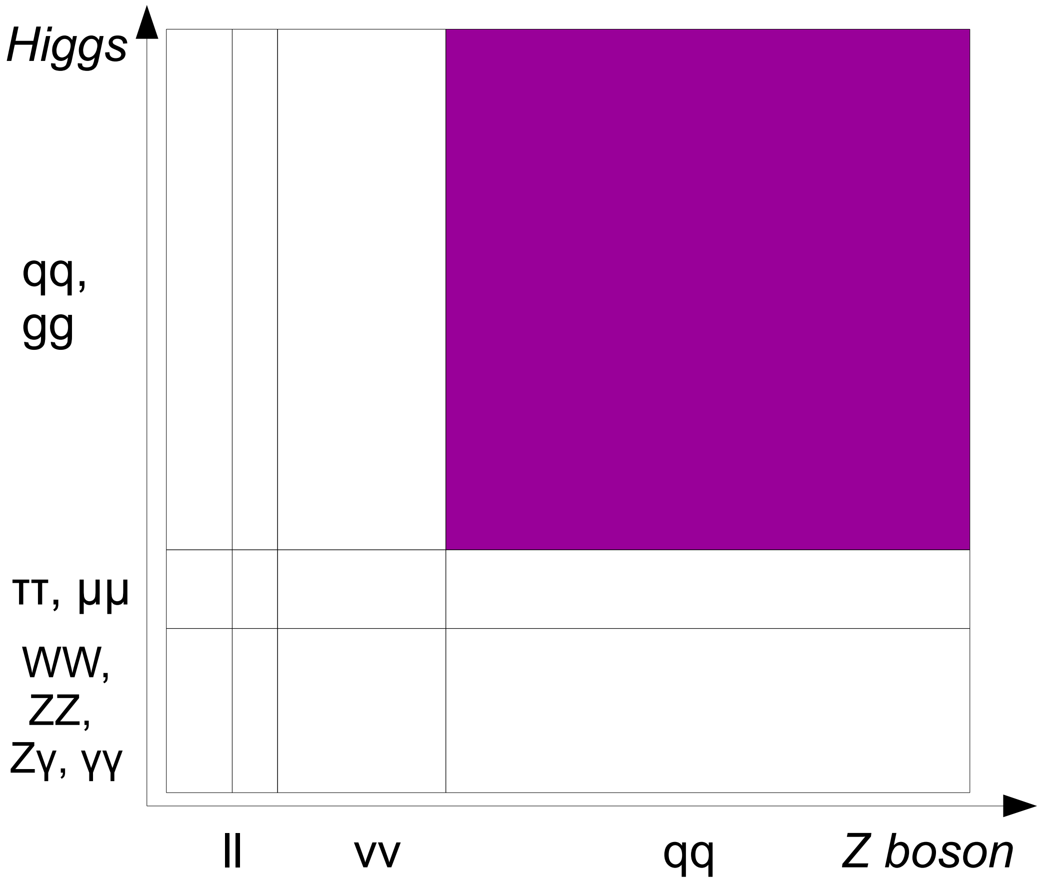


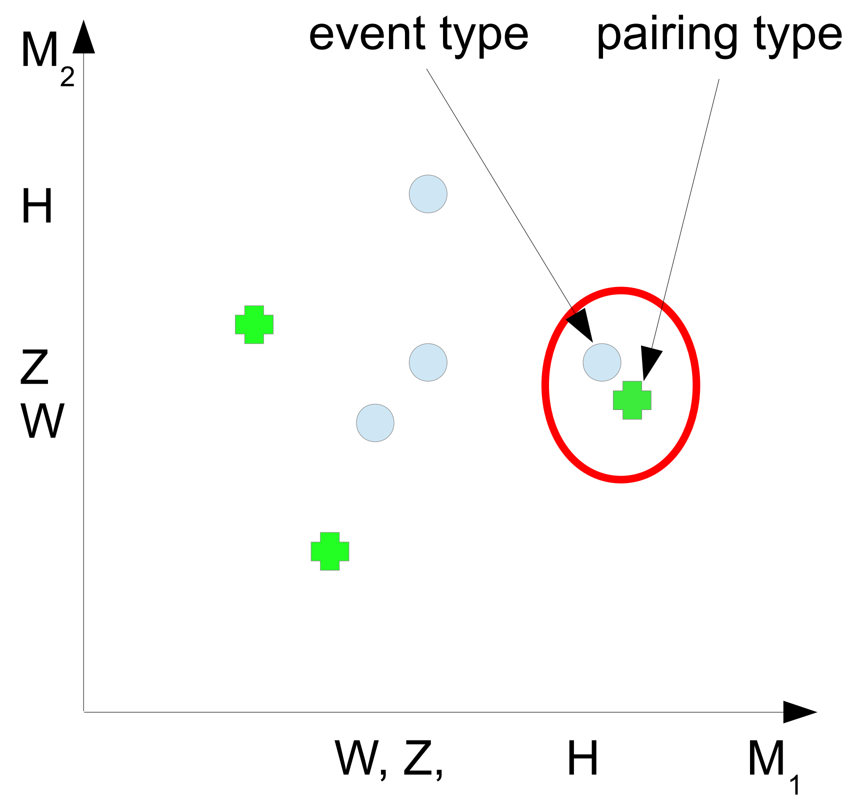
Full & Fast simulation:

from generator to physics performance, parametrized the performance to detector design/cost...

Profound understanding, reliable reference, Communication, PR, decision making...

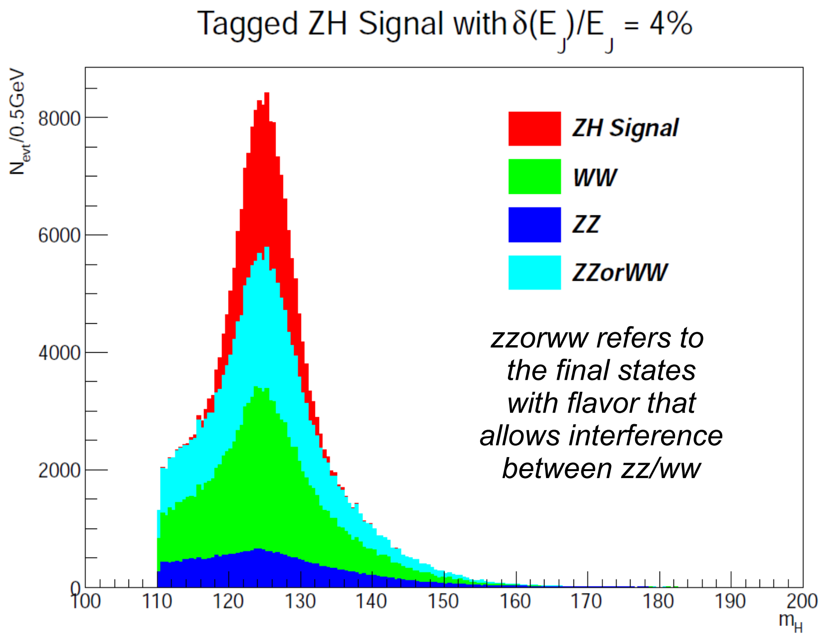
Measurement of σ(HZ)*Br(H→2j)

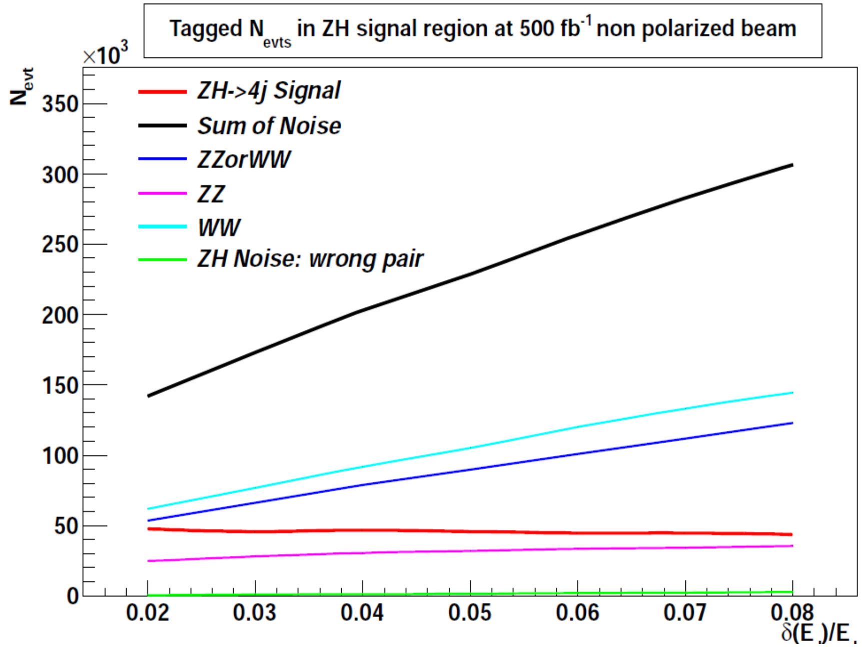




- Represent reconstructed jets by MC Truth quark * percentage energy smearing
- Main backgrounds ZZ, WW events into 4 jets
- Define Chi2 = $((M_{i,j} – MB_1)/\sigma_1)^2 + ((M_{k,l} – MB_2)/\sigma_2)^2$, Ijkl runs over all 3 combinations
- The minimal chi2 indicates both event type and jet pairing

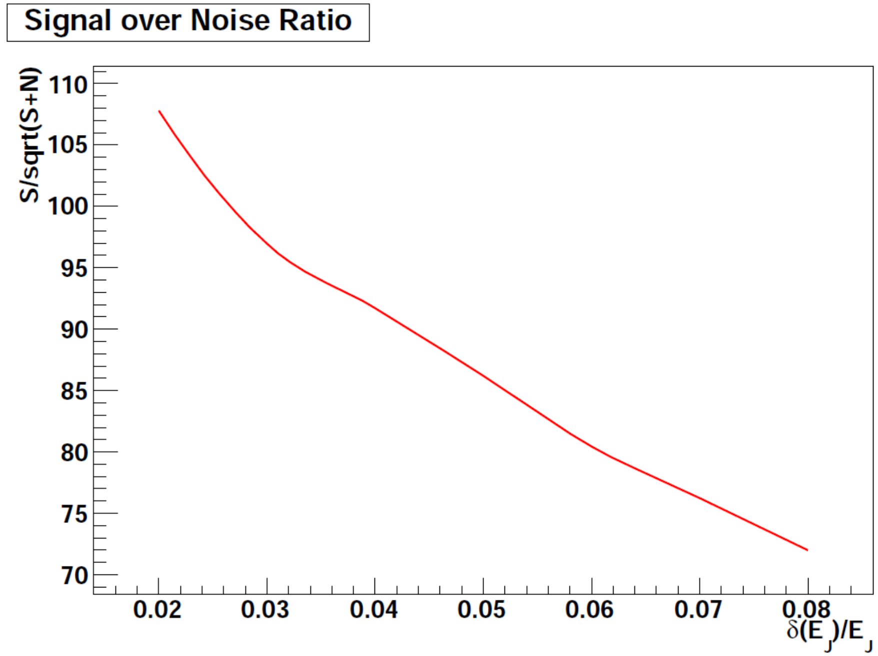
Performance at different Jet E resolution





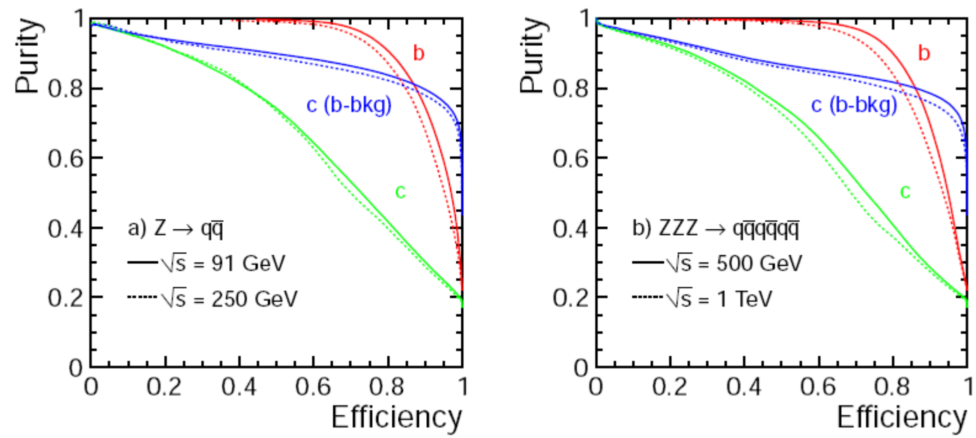
$\sigma(H\rightarrow 2j)$ measurement easily reaches percentage level accuracy;

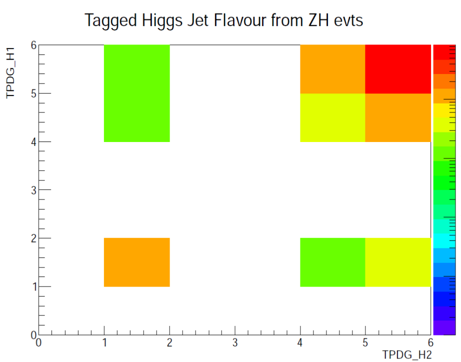
Performance weakly depends on the jet Energy resolution: $\delta\sigma/\sigma \sim$ 1-1.5 %

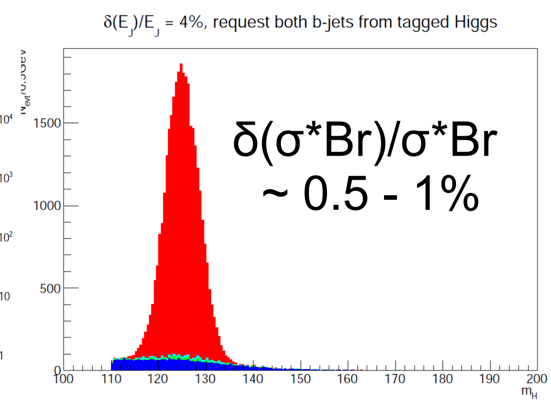


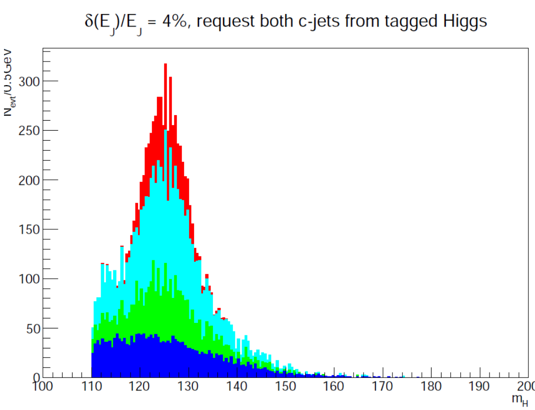
Modeling of Flavor tagging

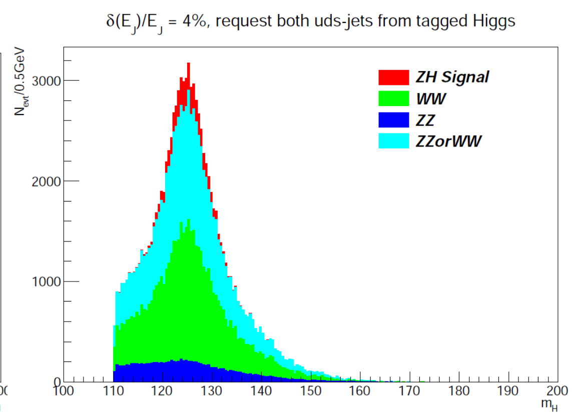
	b	c	uds	undef
b	0.90	0.08	0.02	
c	0.25	0.70	0.05	
uds	0.03	0.06	0.91	





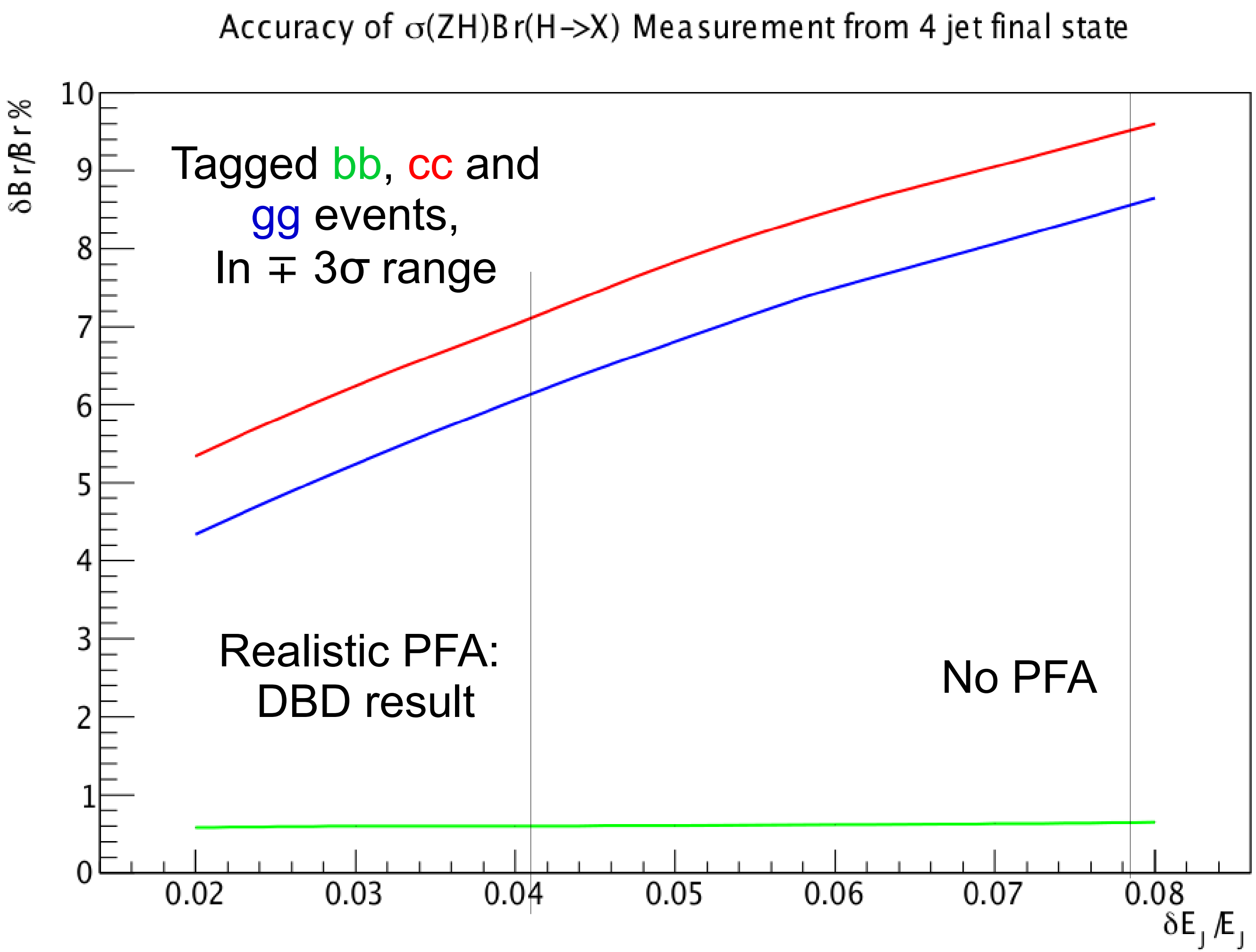






*O = M*T; M, Migration Matrix*
O, T: vector of number of events in each final state, Observed & Truth
T = T(Branching ratios)

Measuring σ(HZ)*Br(H→2j), j = b, c, g



Remarks:

Measurements from HZ, Z→ll, νν Can be combined to Improve the result

Fit range and event Selection can be improved

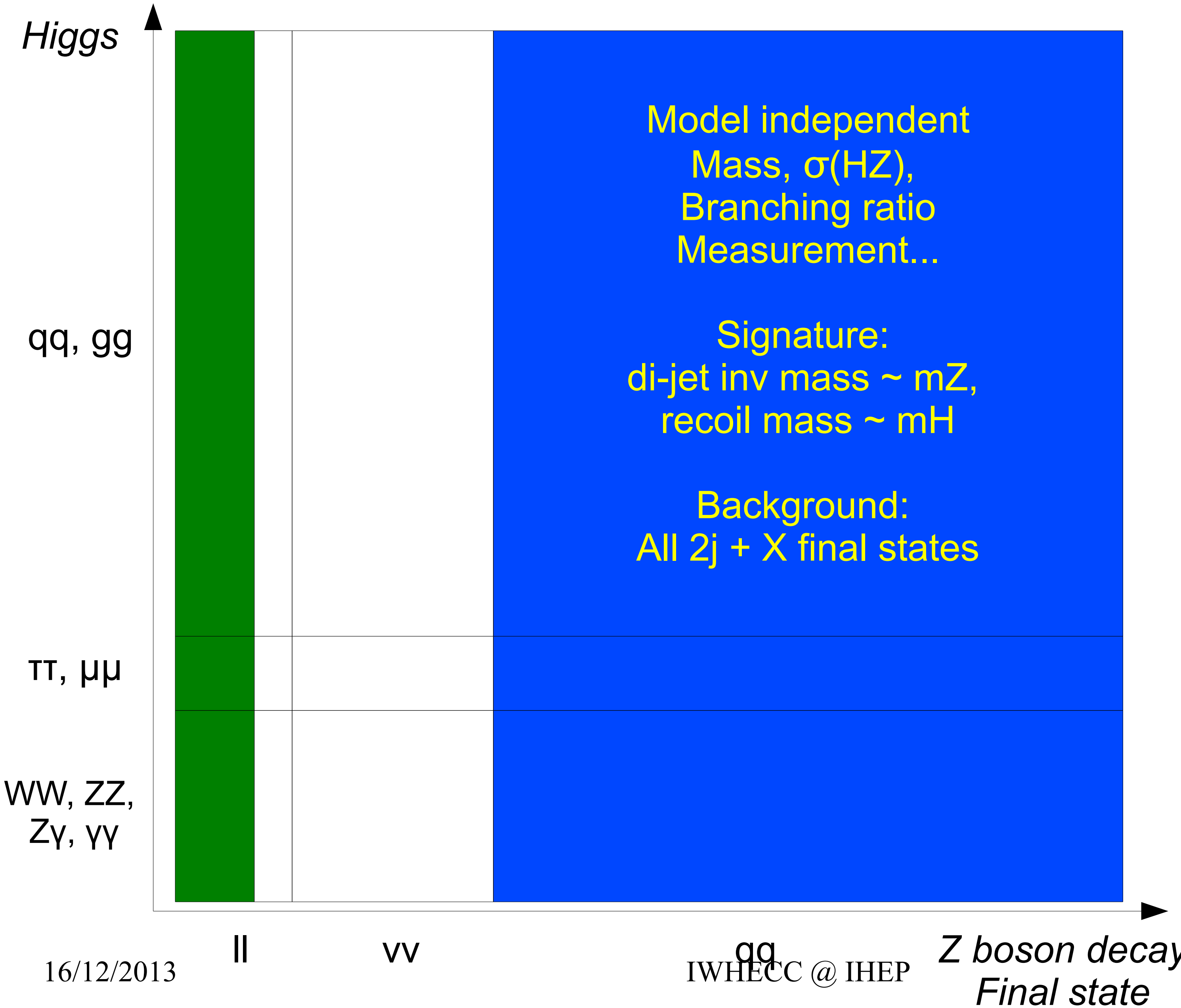
Migration Matrix information Should be used

bb, cc accuracies Should be worse in realistic because of Neutrinos

Trends shall not be Changed after including All above effects

PFA is critical for Br(H→gg, cc) measurement...

Model - independent tagging of ZH

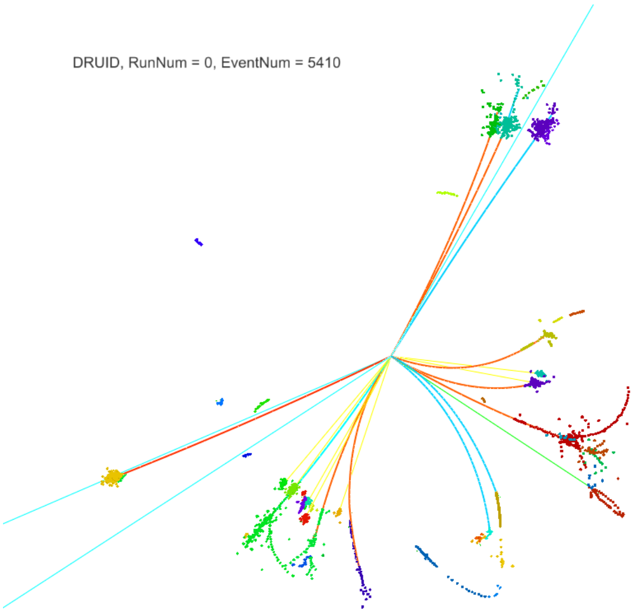


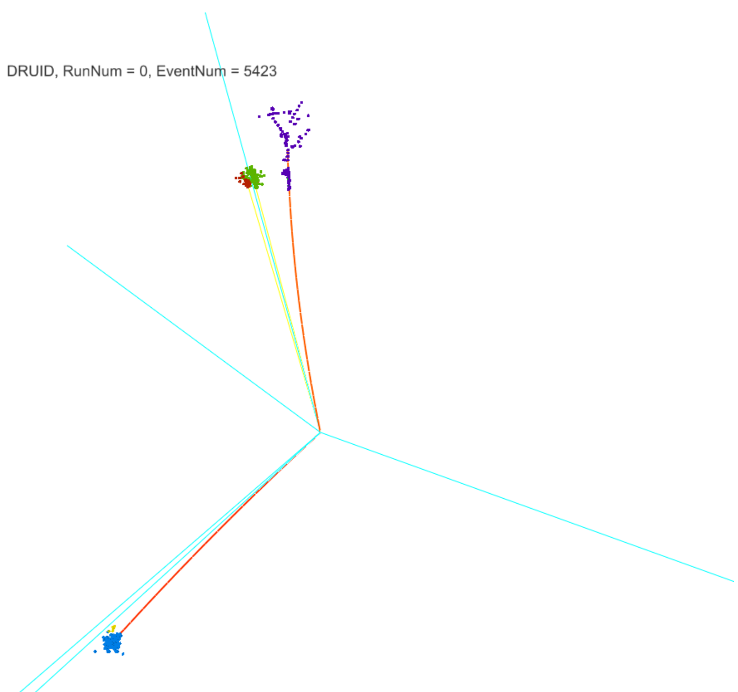
Algorithm:

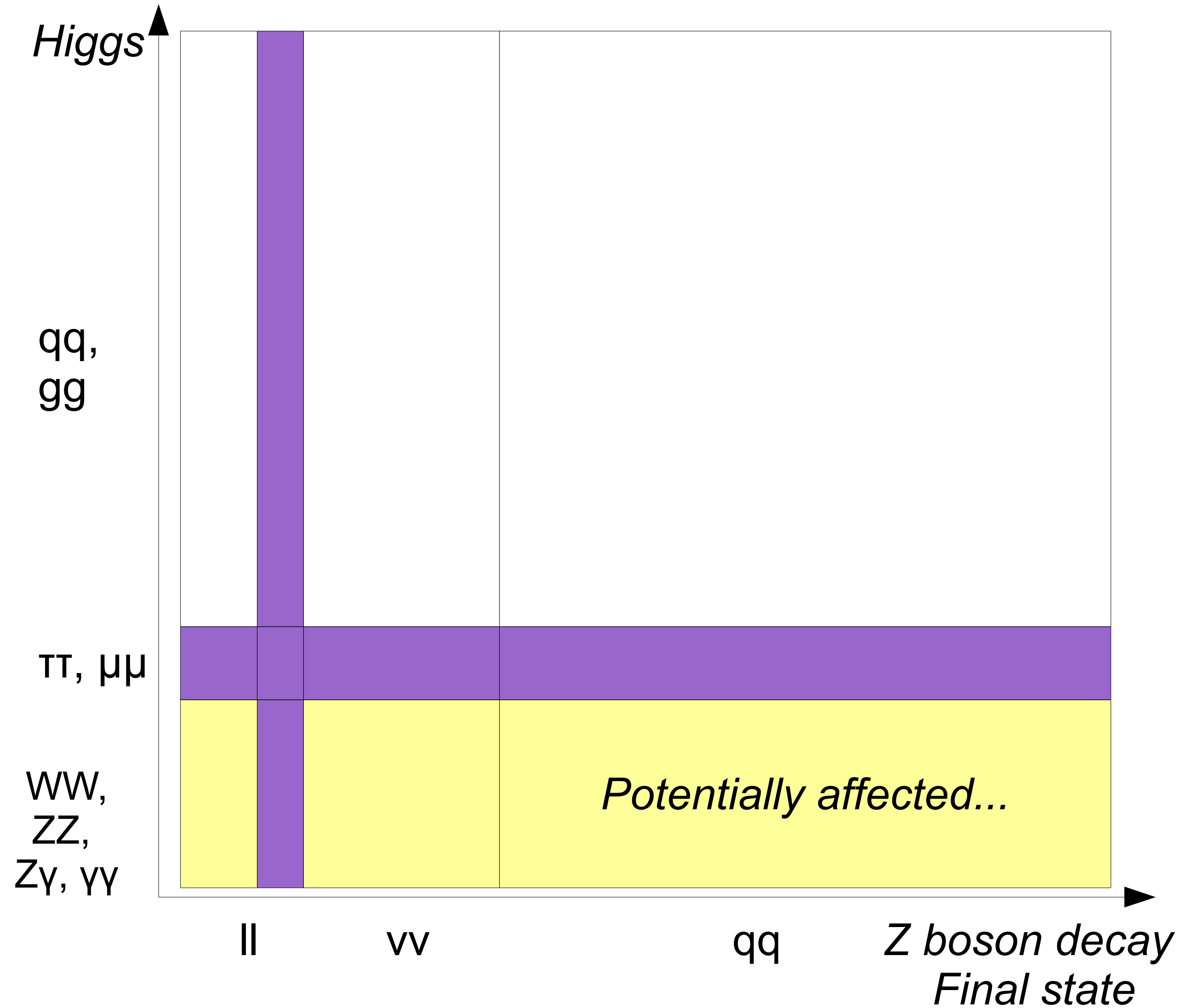
If 2f: calculate
M_inv & M_recoil

If 4f:
Pairing as before,
After pairing,
Define the pair
Closer to mz as Z
pair..

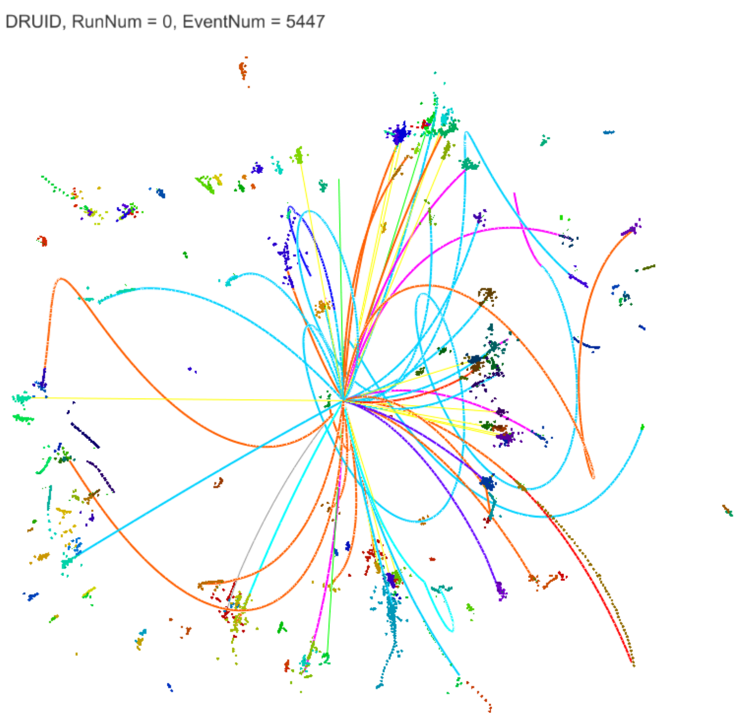
To do: PFA Tau tagging & Reconstruction



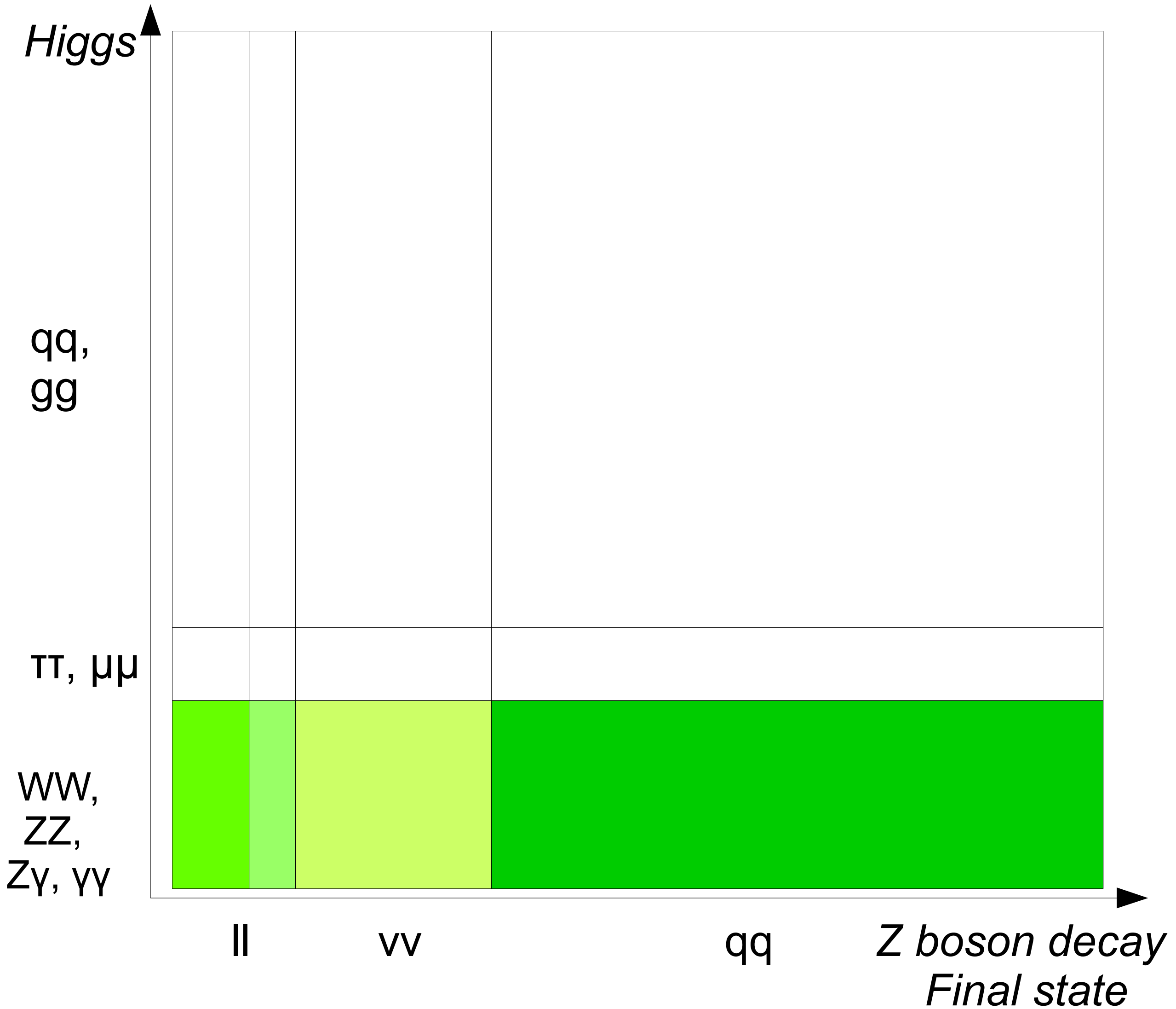




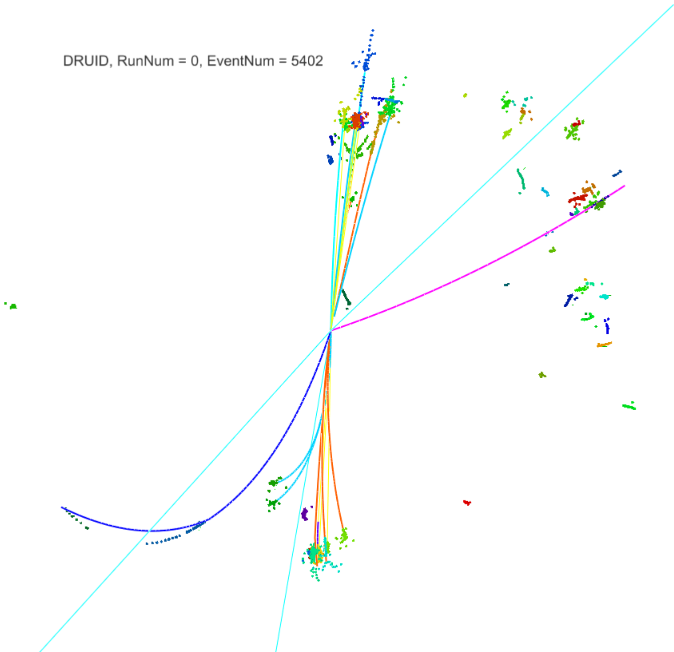
To do: Br(H→WW, ZZ) ~ Width Measurement

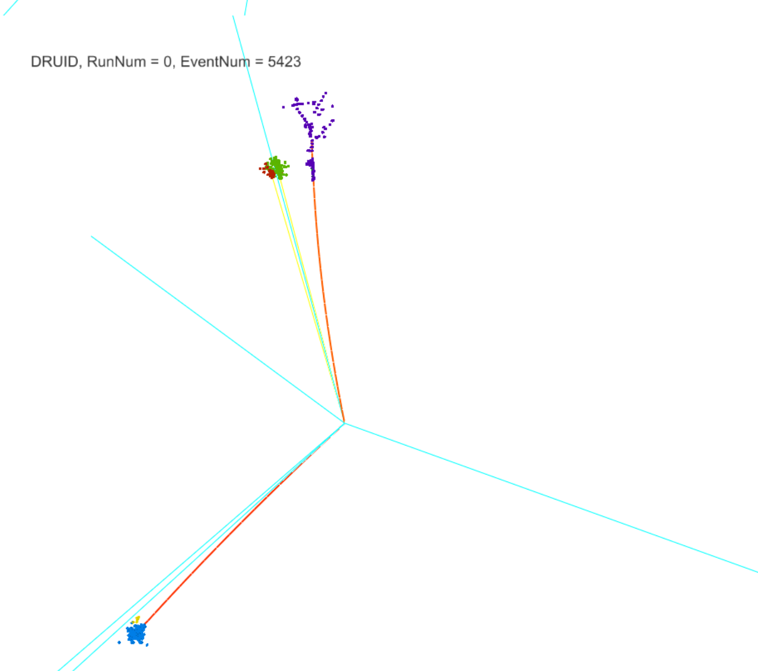


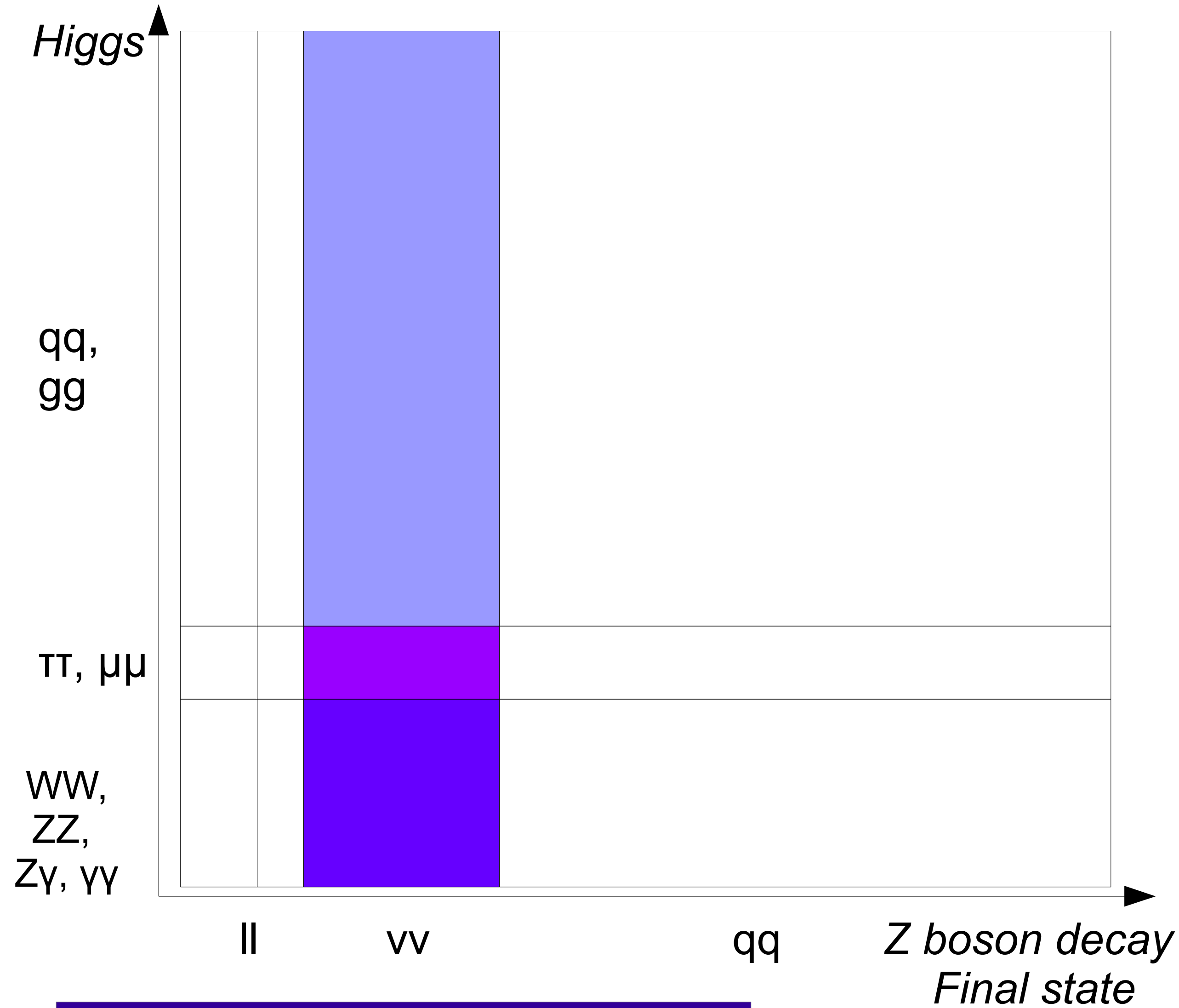
Important,
challenging,
Exciting.



To do: ZH, Z→νν channel







I guess relatively easy...
Test bed for VV event tagging*