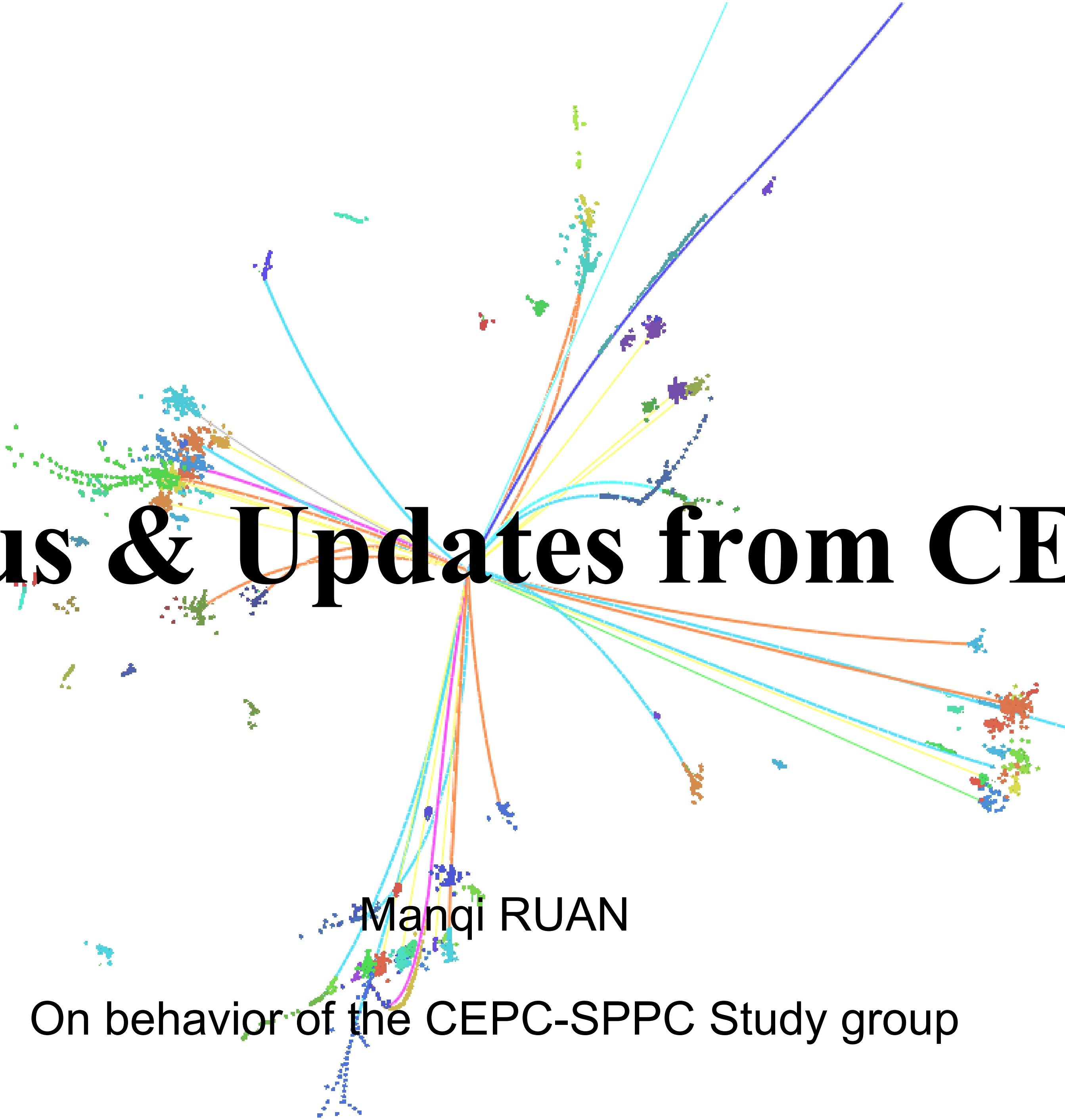


Status & Updates from CEPC

Manqi RUAN

On behavior of the CEPC-SPPC Study group

Outline

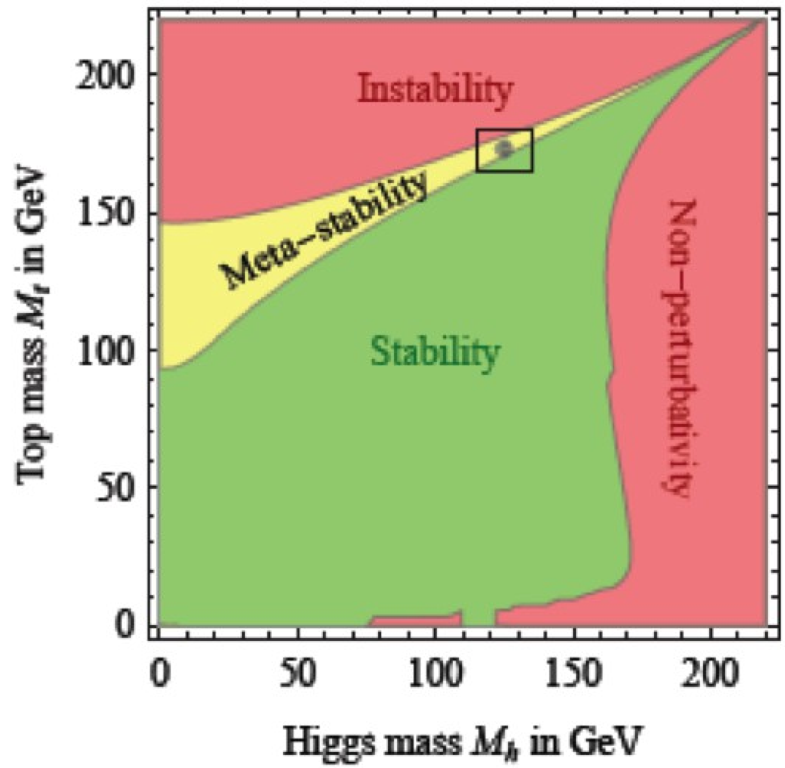
- Introduction
  - Time Line & Milestones
  - Funding
- High Lights
  - Accelerator
  - Detector
  - Theory
- Summary

SM is **NOT** the end!!

- Hierarchy: From neutrinos to the top mass, masses differs by 13 orders of magnitude
- Naturalness: Fine tuning of the Higgs mass
- Masses of Higgs and top quark: meta-stable of the vacuum
- Unification?
- Dark matter candidate?
- Not sufficient CP Violation for Matter & Antimatter asymmetry

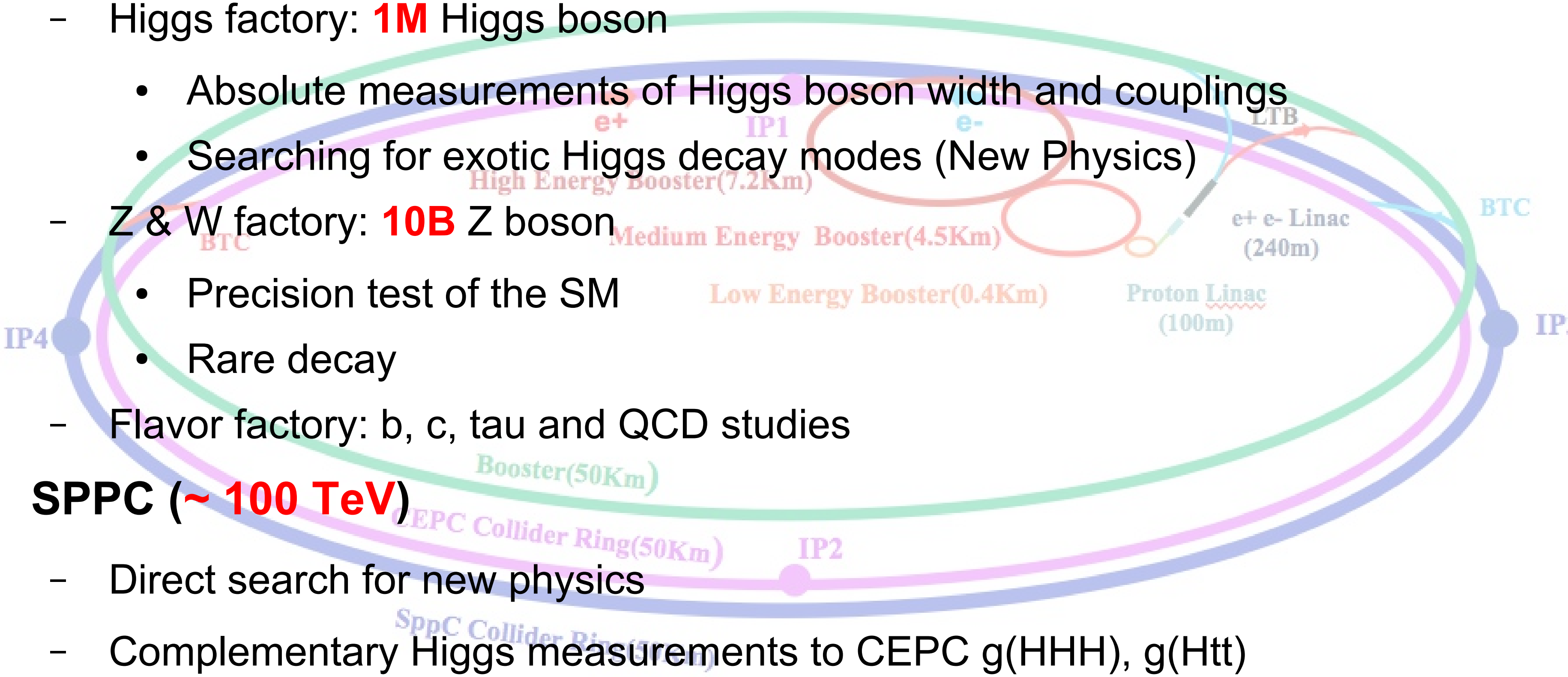
- **Most issues related to Higgs**

$$m_H^2 = 36{,}127{,}890{,}984{,}789{,}307{,}394{,}520{,}932{,}878{,}928{,}933{,}023$$
$$-36{,}127{,}890{,}984{,}789{,}307{,}394{,}520{,}932{,}878{,}928{,}917{,}398$$
$$= (125\ \text{GeV})^2 \ ! \ ?$$



Science at CEPC-SPPC

- **Tunnel ~ 100 km**
- **CEPC (90 – 250 GeV)**
  - Higgs factory: **1M** Higgs boson
    - Absolute measurements of Higgs boson width and couplings
    - Searching for exotic Higgs decay modes (New Physics)
  - Z & W factory: **10B** Z boson
    - Precision test of the SM
    - Rare decay
  - Flavor factory: b, c, tau and QCD studies
- **SPPC (~ 100 TeV)**
  - Direct search for new physics
  - Complementary Higgs measurements to CEPC g(HHH), g(Htt)
  - ...
- **Heavy ion, e-p collision...**



Complementary

Timeline

Milestones

1st, PreCDR (end of 2014)

2nd, R&D funding from MOST (Middle 2016, 35 M CNY/5yr for the 1st phase)

3rd, CDR (end of 2017)

...

IHEP-CEPC-DR-2015-01

IHEP-EP-2015-01

IHEP-TH-2015-01

IHEP-CEPC-DR-2015-01

IHEP-AC-2015-01

Can be downloaded from

http://cepc.ihep.ac.cn/preCDR/volume.html

CEPC-SPPC

Preliminary Conceptual Design Report

Volume I - Physics & Detector

403 pages, 480 authors

The CEPC-SPPC Study Group

March 2015

CEPC-SPPC

Preliminary Conceptual Design Report

Volume II - Accelerator

328 pages, 300 authors

The CEPC-SPPC Study Group

March 2015

Status & plan

- Pre-CDR delivered
  - No show-stopper
  - Technical challenges identified
  - Preliminary cost estimate

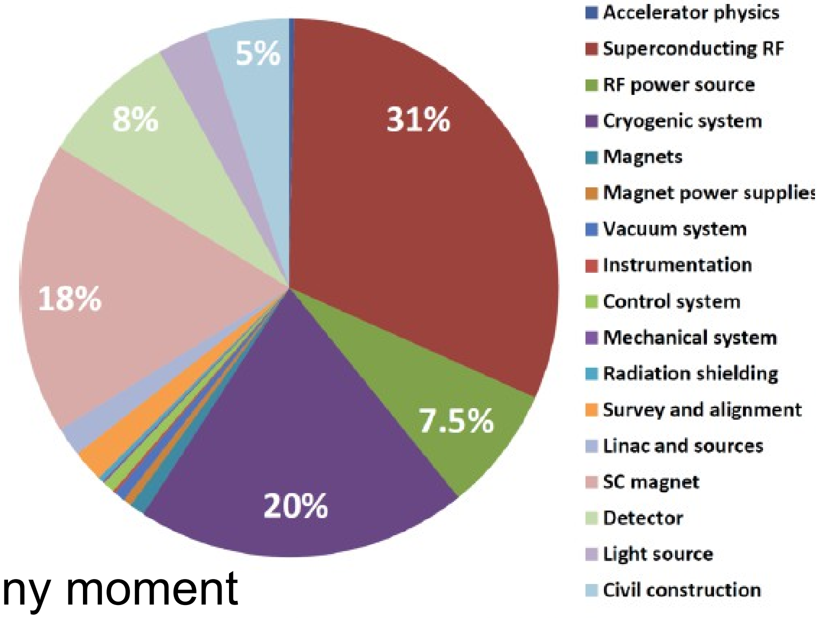
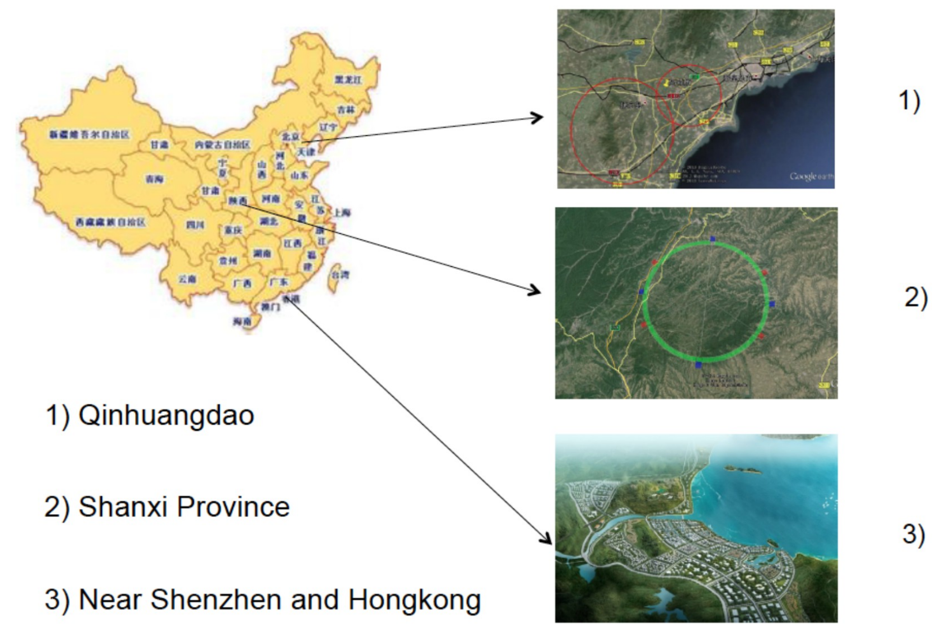


Figure 12.4: Breakdown of the R&D budget of each system.

- Towards CDR
  - Working machine on paper
  - Get ready to be reviewed by government at any moment

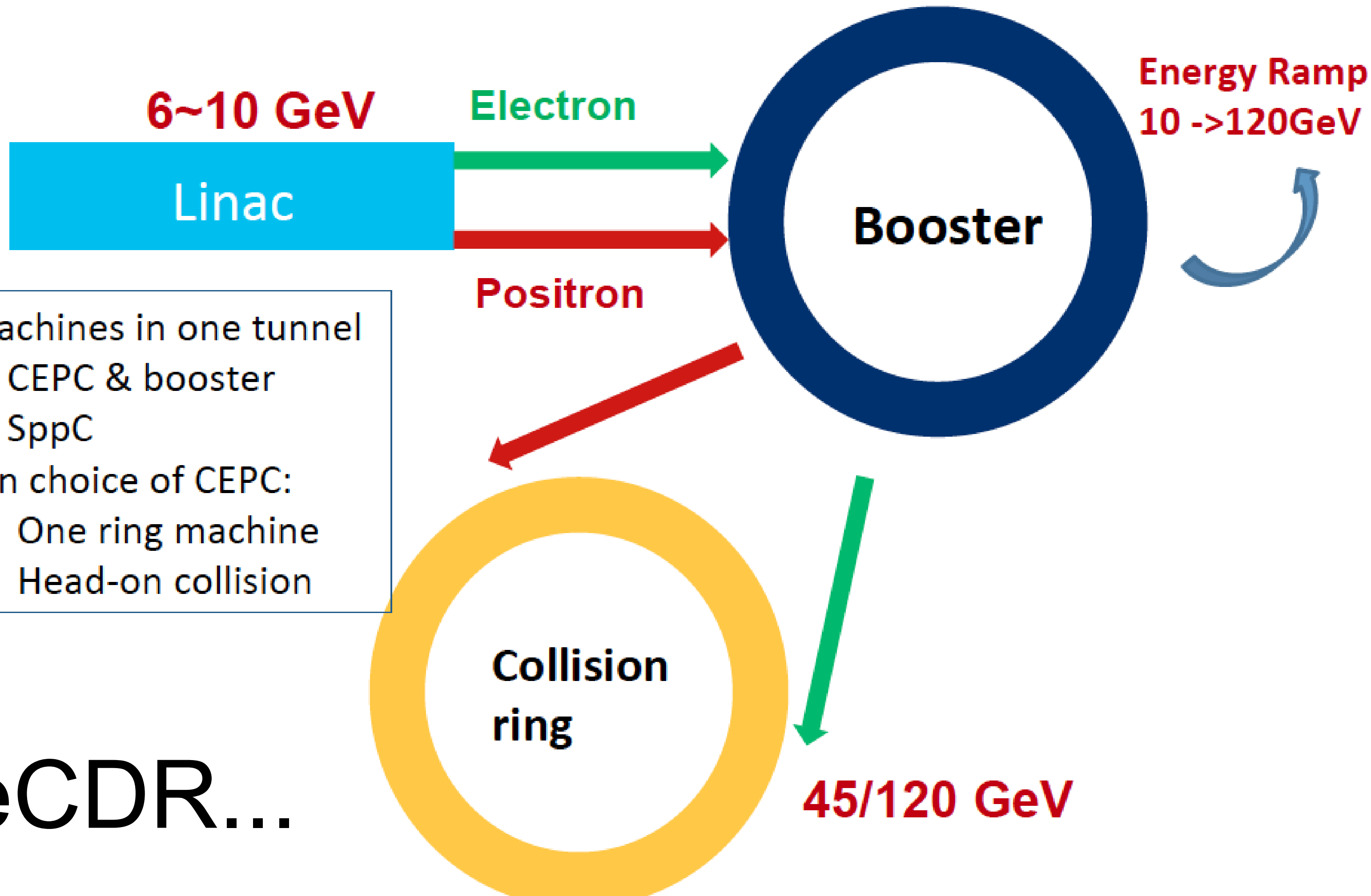
- R&D issues identified & funding request underway
  - IHEP **seed** money: 12 M CNY/3 years
  - MOST: 35 M/5 yr **approved**, ~ 40 M to be asked next year
  - NCDR (13^{th} 5 year plan): ~ 0.8 B/5 yr, **failed** in voting process
  - CAS & CNSF: **under discussion**, hopefully ~ 50 M/y

Accelerator Highlight 1: **100 km**



- **Reference Circumference 100 km**
  - *Preliminary Cost estimation: 25/36 Billion CNY at 50/100km*
- PreCDR: design starts at 50 km eventually converge to 60 km
- Public debate - Feedbacks: No direct objection on 100 km

CEPC Accelerator

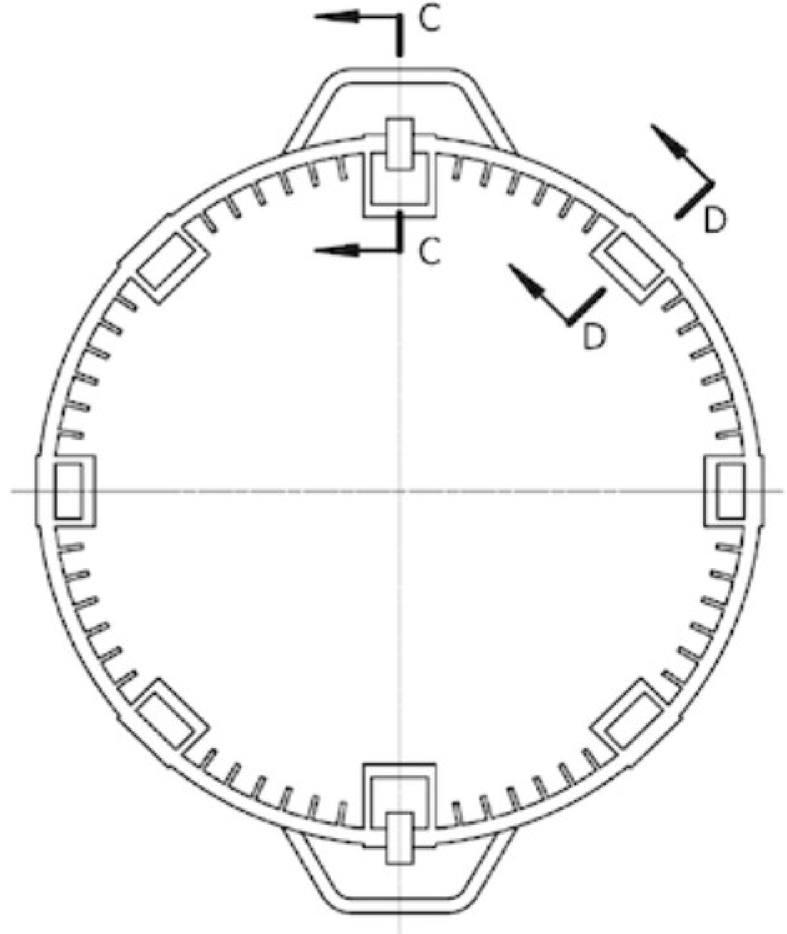


- 3 machines in one tunnel
  - CEPC & booster
  - SppC
- Main choice of CEPC:
  - One ring machine
  - Head-on collision

At PreCDR...

Compatibility: The Key Issue

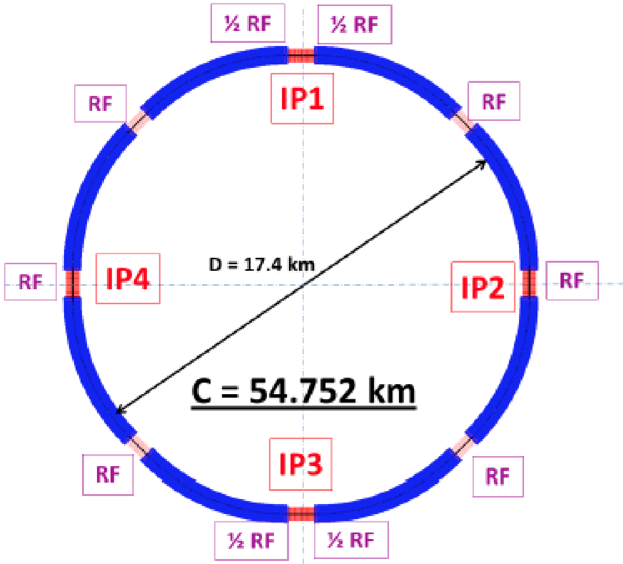
- CEPC Injector
- SPPC injector
- Beam pipe detour for detectors
  - CEPC booster avoid storage ring
  - CEPC avoid SPPC detectors
  - SPPC avoid CEPC detectors
- SR beamlines
- Predict what SPPC needs
  - Collimators
  - Straight sections
  - Tunnel dimensions
  - Access tunnel
  - ....
- To be fully understood in the next 5 years



隧道俯视示意图

CEPC Design

- Critical parameters:
  - SR power: 51.7 MW/beam
  - 8*arcs, 2*IPs
  - 8 RF cavity sections (distributed)
  - RF Frequency: 650 MHz
  - Filling factor of the ring: ~70%



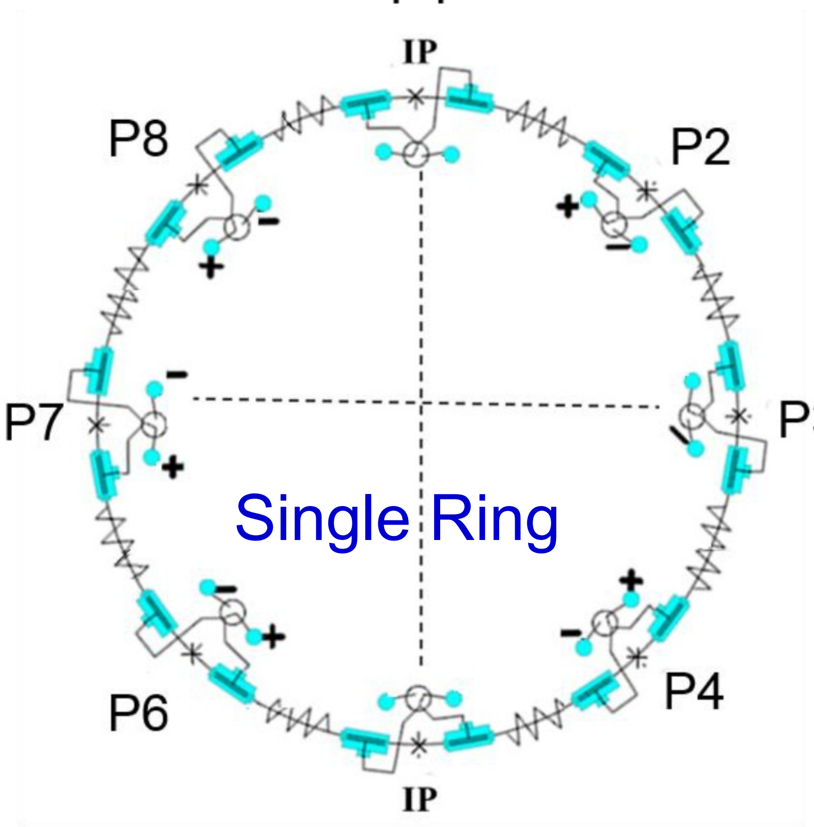
Parameter	Unit	Value	Parameter	Unit	Value
Beam energy [E]	GeV	120	**Circumference [C]**	m	54752
Number of IP[N_{IP}]		2	**SR loss/turn [U_0]**	GeV	3.11
Bunch number/beam[n_B]		50	**Energy acceptance RF [h]**	%	5.99
SR power/beam [P]	MW	51.7	**Beam current [I]**	mA	16.6
emittance (x/y)	nm	6.12/0.018	**β_{IP}(x/y)**	mm	800/1.2
Transverse size (x/y)	μm	69.97/0.15	**Luminosity /IP[L]**	$cm^{-2}s^{-1}$	2.04E+34

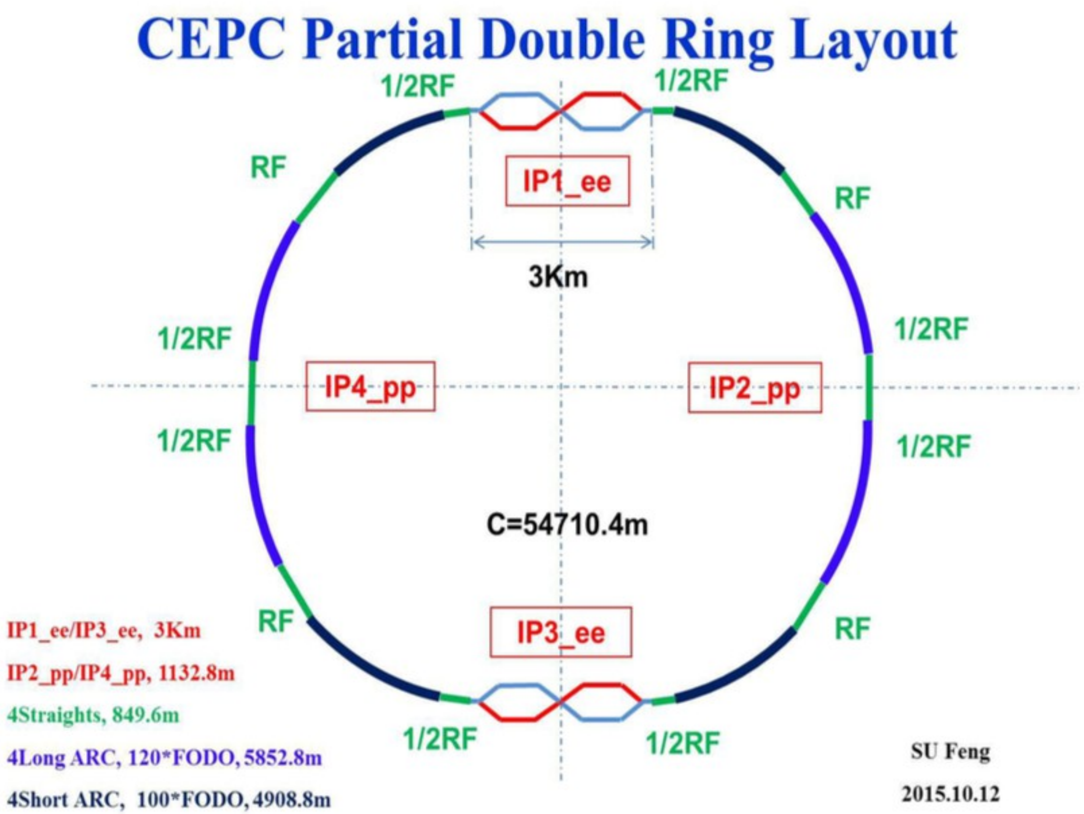
Main Problems left in Pre-CDR

1. Pretzel scheme is difficult to design and operate, with little flexibility and stability
2. Too high AC power consumption (~ 500 MW)
3. Very low luminosity for Z
4. Booster with very too low magnetic field (30 Gauss for 6GeV injection in a background field of 3 Gauss, say in the BEPCII tunnel) and too small dynamic aperture
5. Very small Dynamic Aperture at 2% energy spread with beam-beam effects and magnetic errors

- **Goal of CEPC CDR:** a "design" working on paper

Highlight 2: Single Ring to Partial Double Ring



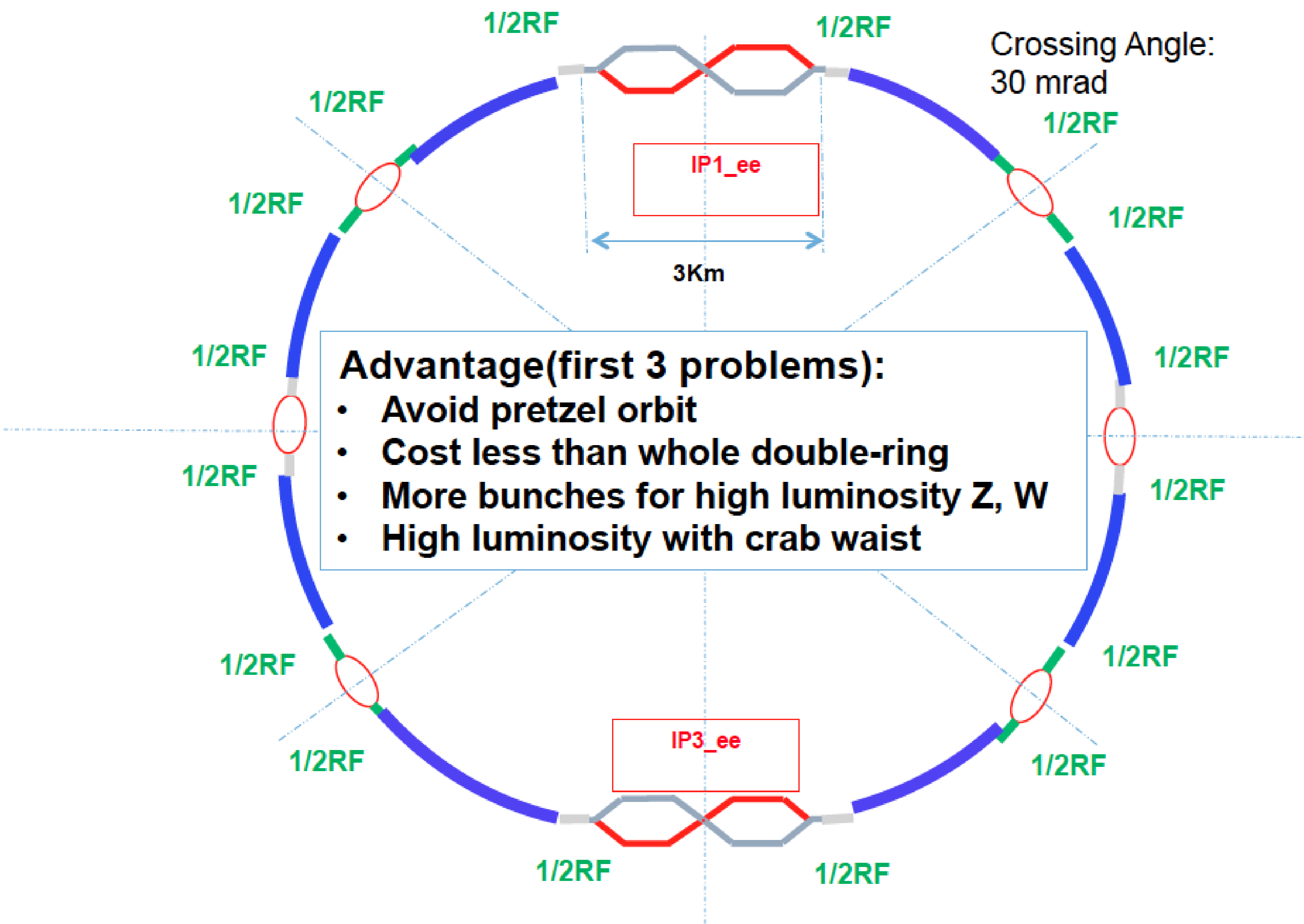


Since Oct 2012

Since May 2015

Bunch time structure

New Idea: Partial Double Ring



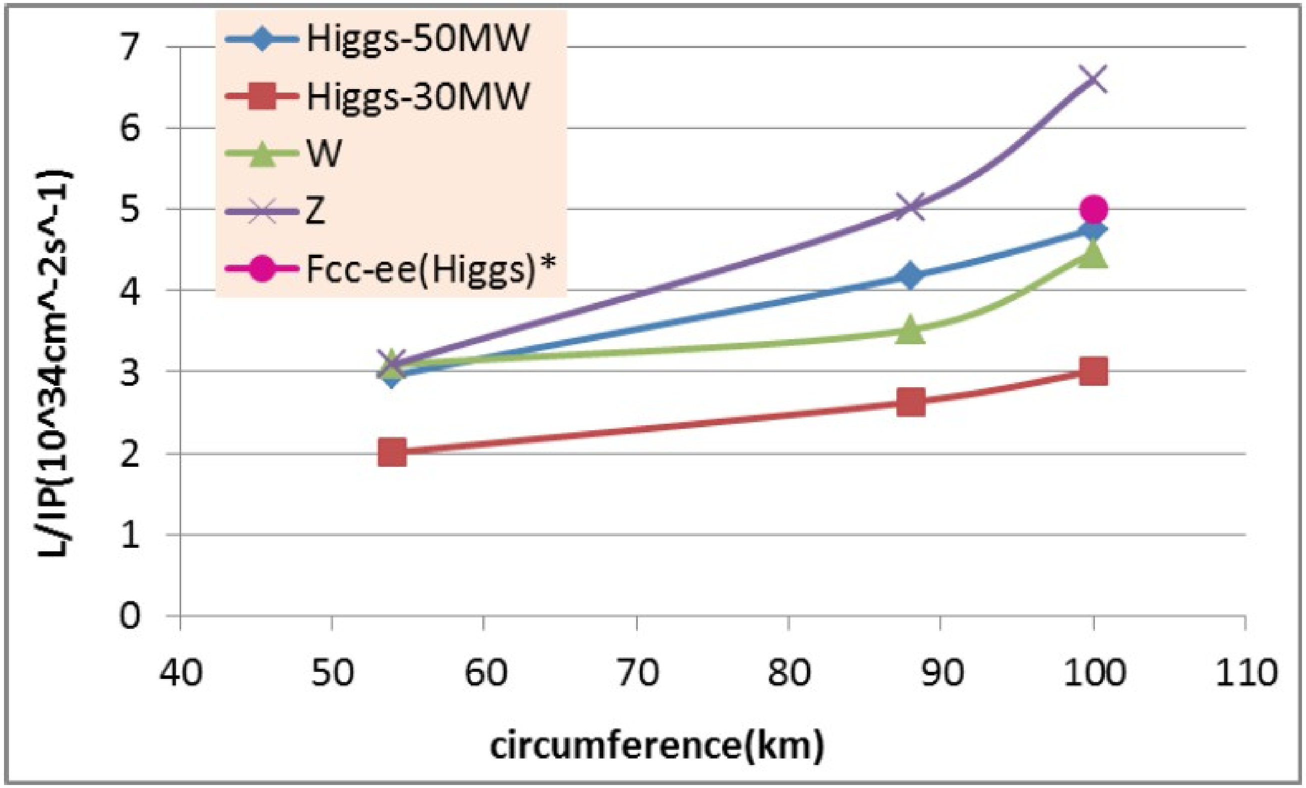
Advanced PDR: 8 PDR sector

Parameter for CEPC Partial Double Ring

（wangdou20161109-61km）

	Pre-CDR	*H-high lumi.*	*H-low power*	*W*	*Z*	*Z-5cell*
Energy (GeV)	120	120	120	80	45.5	45.5
Circumference (km)	54	61	61	61	61	61
SR loss/turn (GeV)	3.1	2.96	2.96	0.58	0.061	0.061
N_e/bunch (10^{11})	3.79	2.0	1.98	0.85	0.6	0.6
Bunch number	50	107	70	400	1100	700
SR power /beam (MW)	51.7	50	32.5	15.7	3.2	2.0
β_{IP} x/y (m)	0.8/0.0012	0.272/0.0013	0.275 /0.0013	0.16/0.001	0.12/0.001	0.12/0.001
Emittance x/y (nm)	6.12/0.018	2.05/0.0062	2.05 /0.0062	0.93/0.003	0.87/0.004 6	0.87/0.0046
ξ_x/IP	0.118	0.041	0.042	0.0145	0.0098	0.0098
ξ_y/IP	0.083	0.11	0.11	0.084	0.073	0.073
V_{RF} (GV)	6.87	**3.48**	**3.51**	**0.7**	**0.12**	**0.12**
f_{RF} (MHz)	650	650	650	650	650	650
Nature σ_z (mm)	2.14	**2.7**	**2.7**	**3.23**	**3.9**	**3.9**
Total σ_z (mm)	2.65	2.95	2.9	3.35	4.0	4.0
HOM power/cavity (kw)	3.6	0.74	0.48	0.47	0.59	0.93
Energy acceptance (%)	2	2	2			
Energy acceptance by RF (%)	6	**2.3**	**2.4**	**1.3**	**1.1**	**1.1**
Life time due to beamstrahlung_cal (minute)	47	37	37			
L_{max}/IP (10^{34}cm^{-2}s^{-1})	2.04	3.1	2.01	3.5	3.44	2.2

Partial Double Ring Luminosity

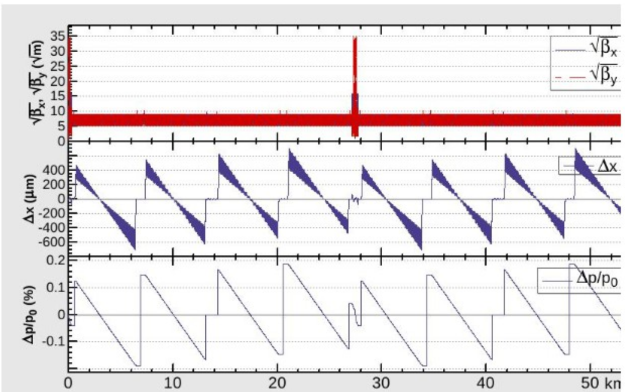


* Fabiola Gianotti, Future Circular ColliderDesign Study, ICFA meeting, J-PARC, 25-2-2016.

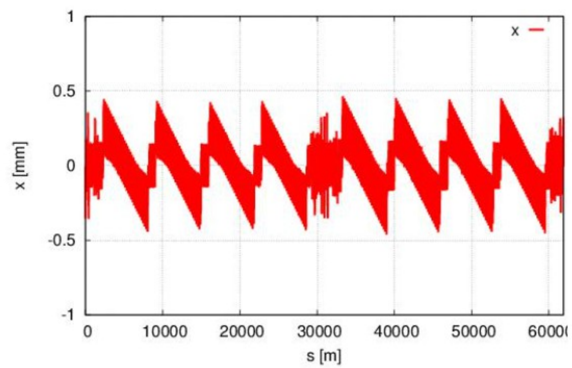
Two important issues on single ring and partial double rings

1) Sawtooth effects induced DA reductions

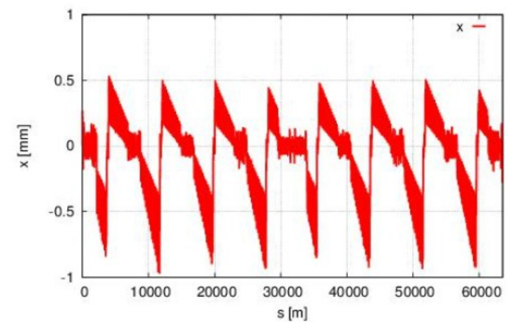
The potential bottle necks for single ring and partial double rings!



Single ring Huiping Geng

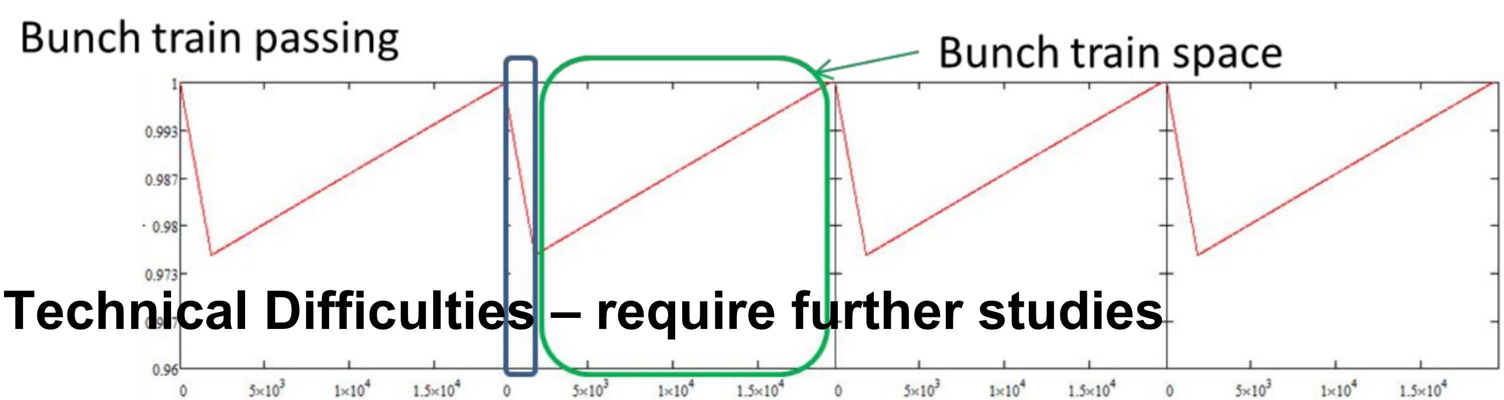


Partial double ring



Advanced Partial double ring
Sha Bai

2) Beam loading effects induced DA reduction



Many Technical Difficulties – require further studies

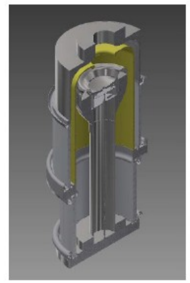
Z.C. Liu

Key R&D issues

RF power source: Efficiency

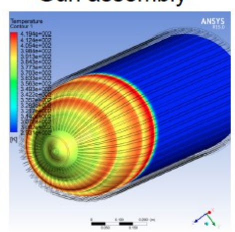
Key parameters of NEW klystron design

Parameters mode	Now	Future
Centre frequency (MHz)	650+/-0.5	650+/-0.5
Output power (kW)	800	800
Beam voltage (kV)	80	70
Beam current (A)	16	15
Efficiency (%)	65	80



Gun assembly

- ➢ **Key factors for the cost and the power consumption**
- ➢ **Used by radar, radio and television broadcasting, ...**



Collector design

SRF System: three key issues

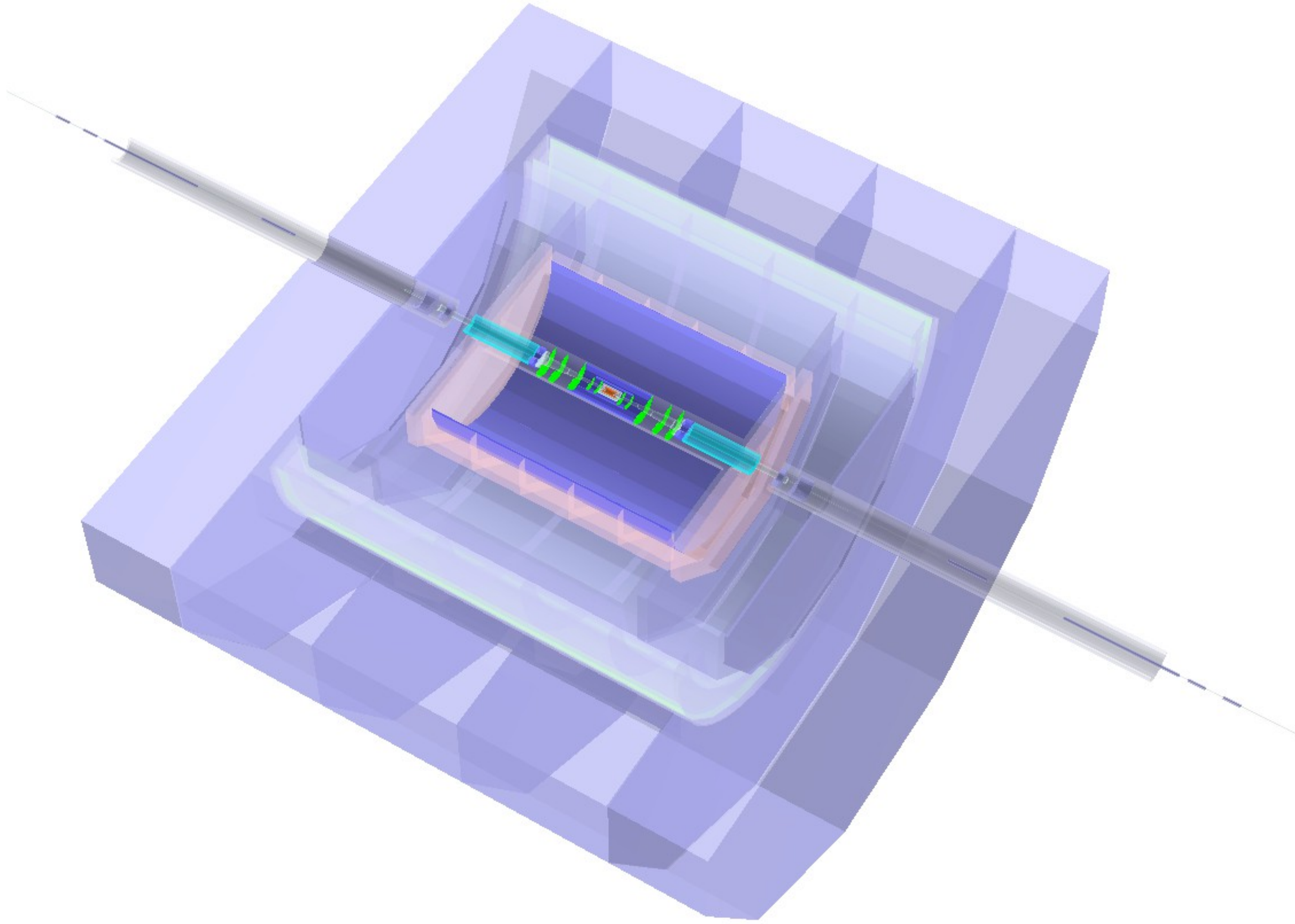
- Extremely high Q_0 cavities
  - New technology: N-doping to improve Q_0 by a factor ~ 4
- Efficient thermal power extraction
  - SR power
  - HOM power
- Mass production

- ➢ **Largest SRF system next to ILC**
- ➢ **Technically challenge**
- ➢ **Used by all future acclerators**
- ➢ **Key factors for the cost**

- High power Cryogenic system
- Beam Monitoring and Diagnostics
- High field SC magnets

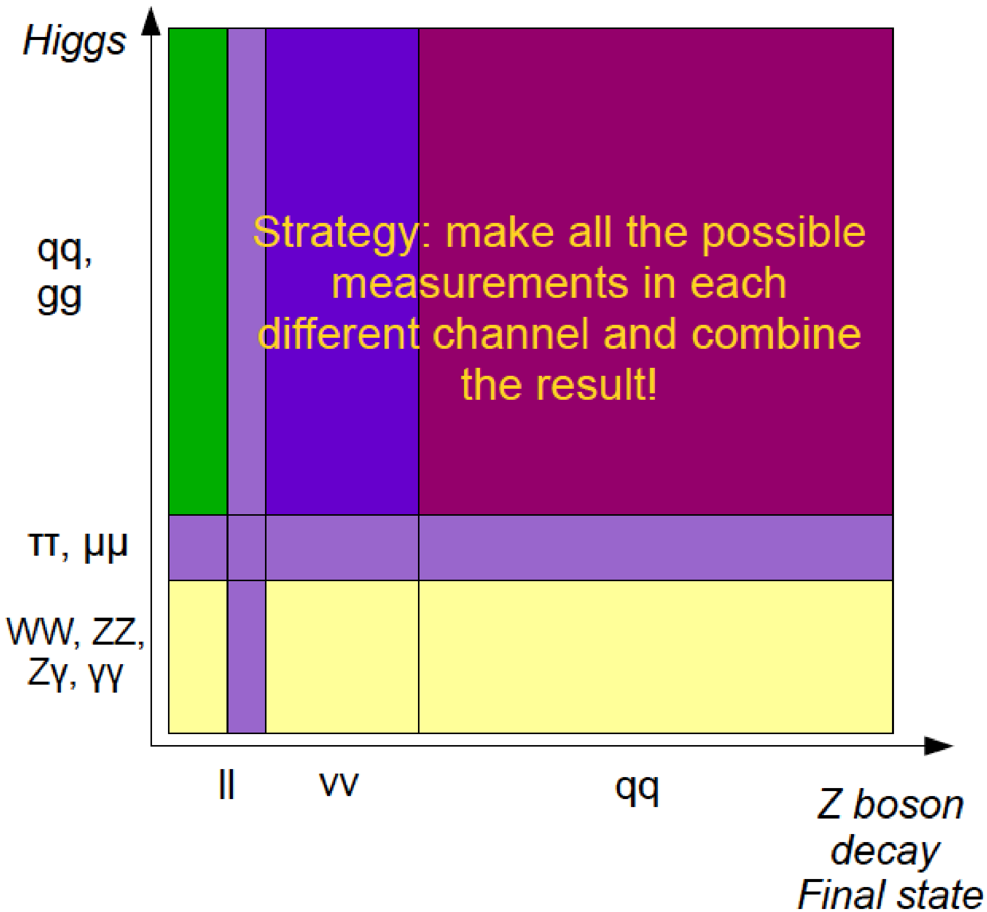
  ...
- Site selection & Civil design

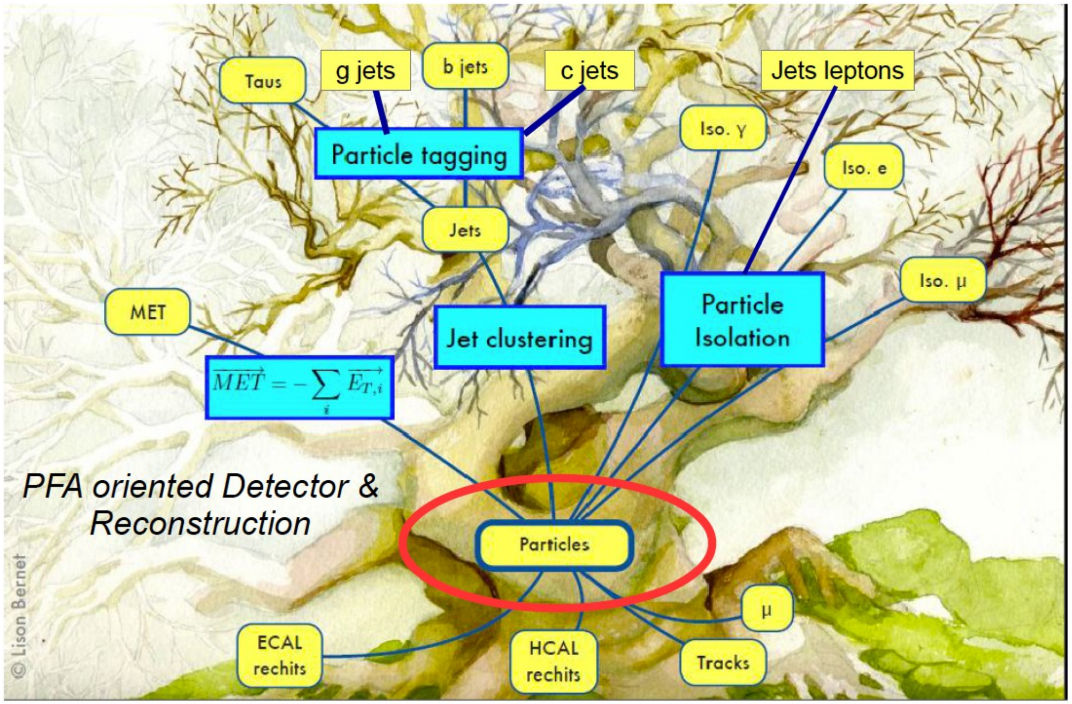
Detector Design & Optimizations



CEPC_v1, Conceptual detector designed from ILD...
Multiple IP - New ideas are always welcome

CEPC detector: PFA oriented

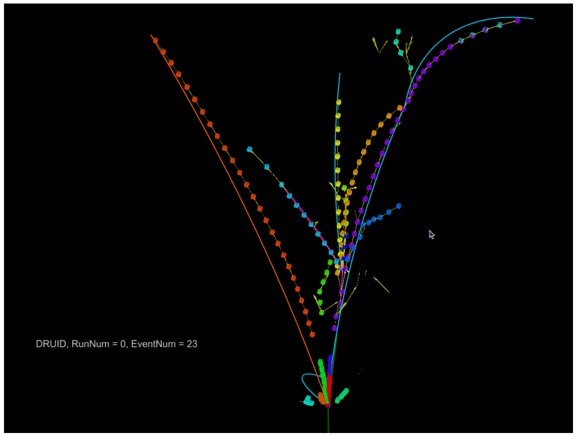


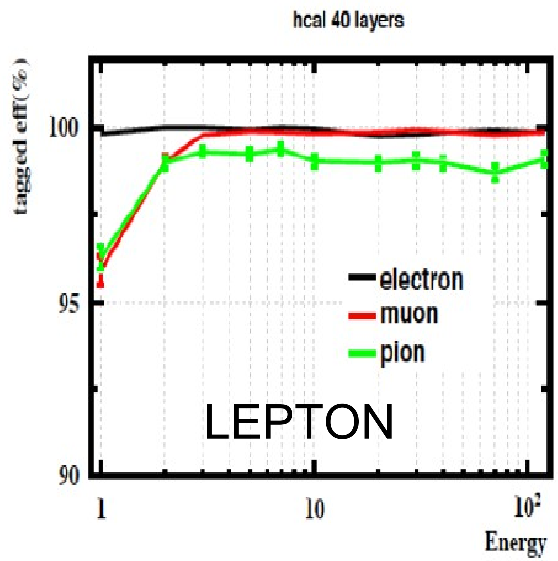


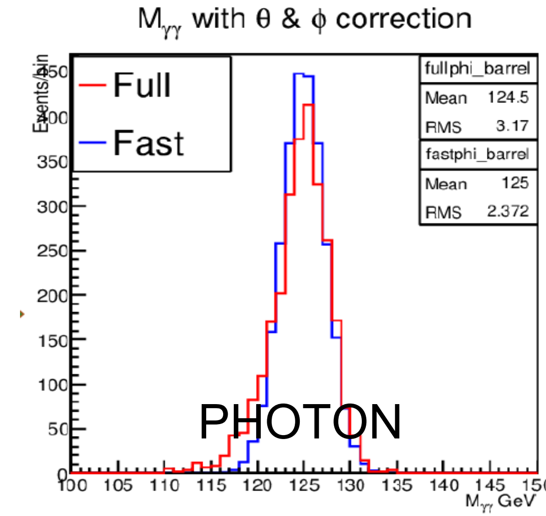
Reconstruct **ALL** the physics objects (lepton, γ, tau, Jet, MET, ...) with high efficiency/precision

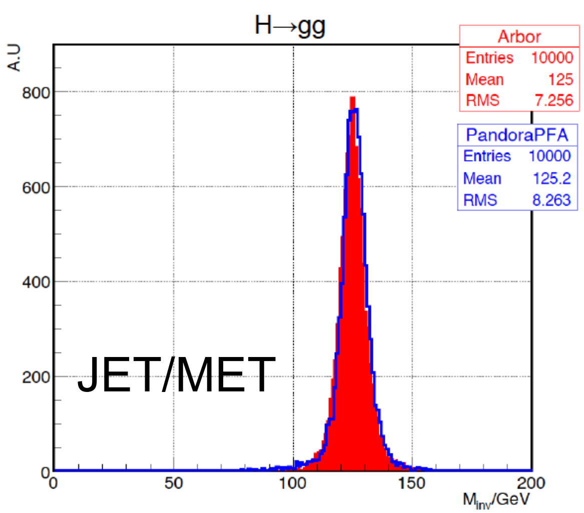
High Precision VTX close to IP: b, c, tau tagging
High Precision & light Tracker:
PFA *oriented Calorimeter: Tagging, ID, JER, etc*

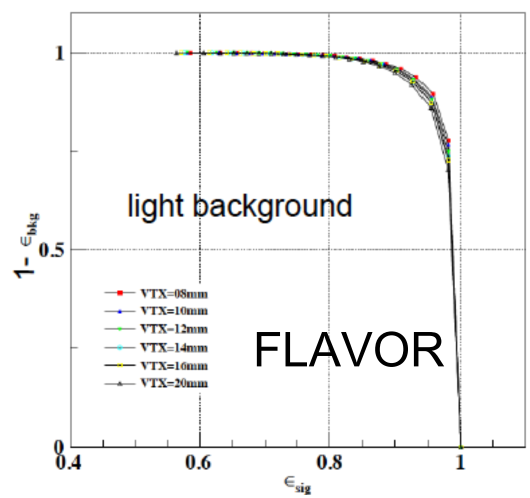
Highlight 1: Reconstruction

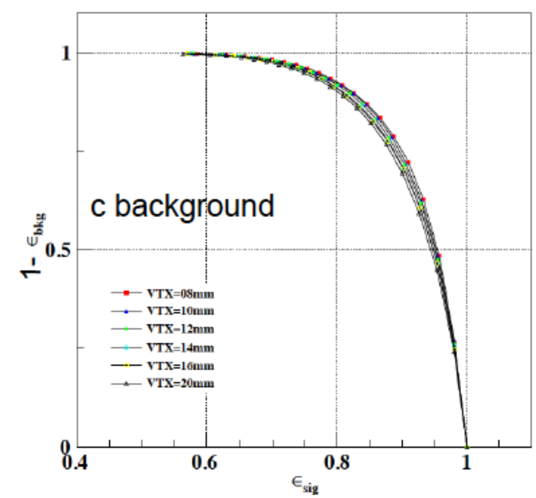






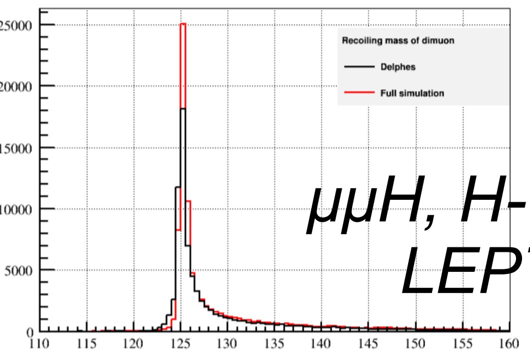






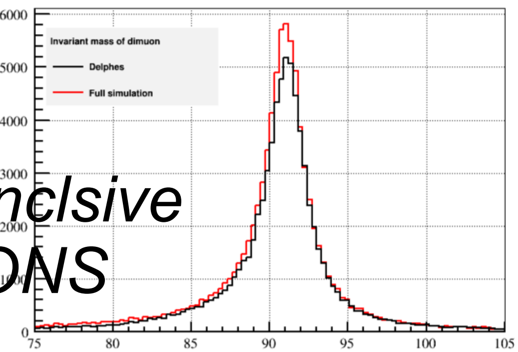
Reconstructed by Arbor Particle Flow Algorithm, 1403.4784

A preliminary validated CEPC Delphes Card



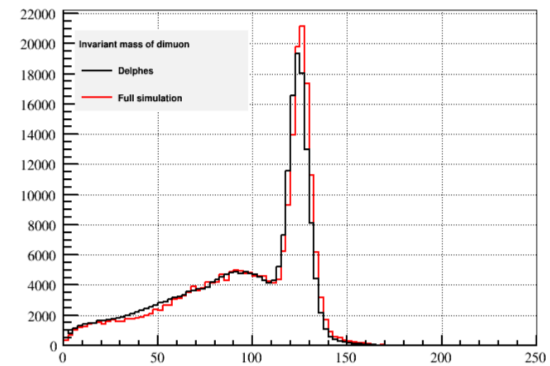
(a) Recoiling mass against $\mu^+\mu^-$

μμH, H->inclsive
LEPTONS



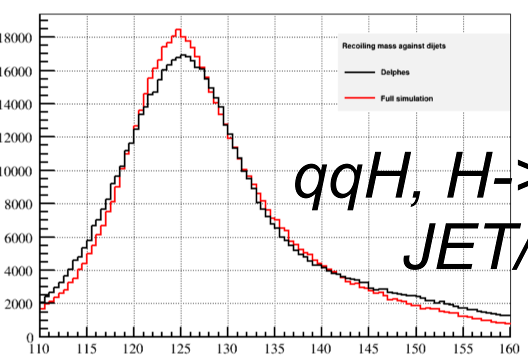
(b) Invariant mass of $\mu^+\mu^-$

Figure 1: The comparison for $\mu^+\mu^-h$ channel.



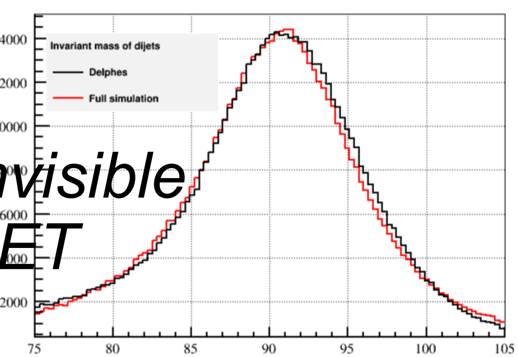
(b) Visible mass in $\nu\bar{\nu}h \rightarrow WW^*$

vvH, H->WW LEPTONS + JET/MET*



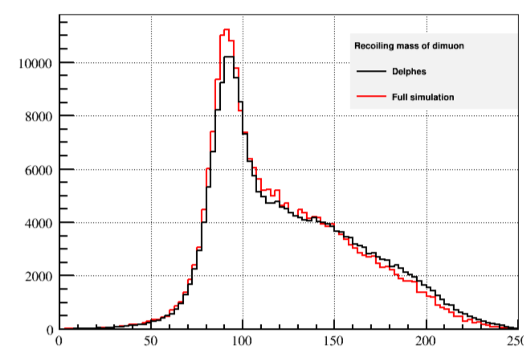
(a) Recoiling mass against $q\bar{q}$

qqH, H->invisible
JET/MET



(b) Invariant mass of $q\bar{q}$

Figure 2: The comparison for $q\bar{q}h$ invisible channel.



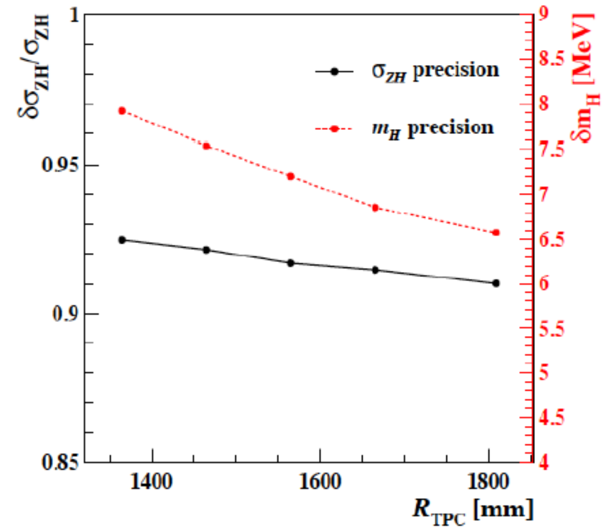
(a) Recoiling mass against WW^* in $\nu\bar{\nu}h \rightarrow WW^*$

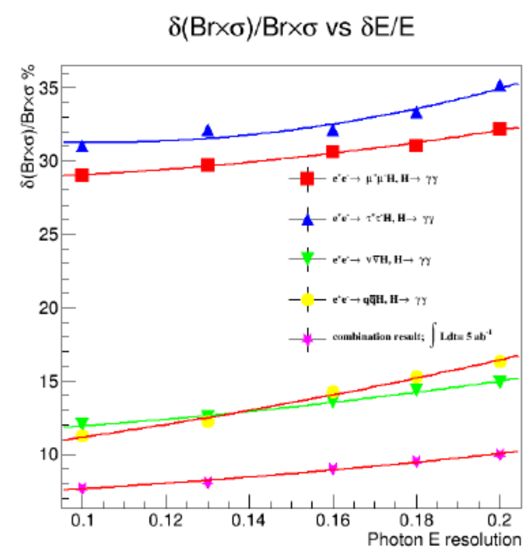
Thanks Michele!

- *https://github.com/delphes/delphes/blob/master/cards/delphes_card_CEPC.tcl*

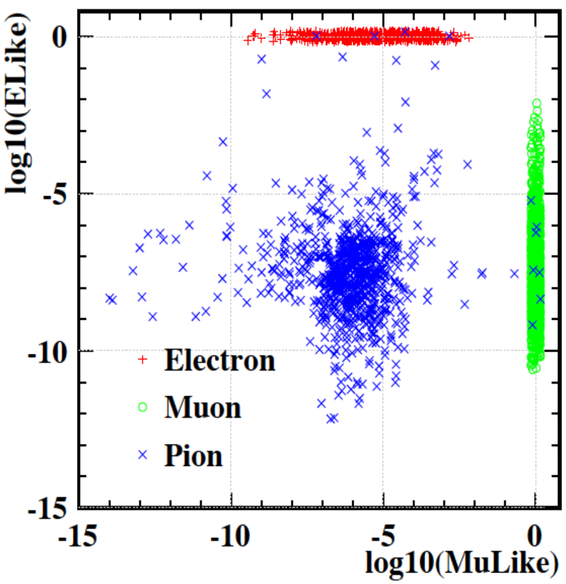
Highlight 2: Optimization

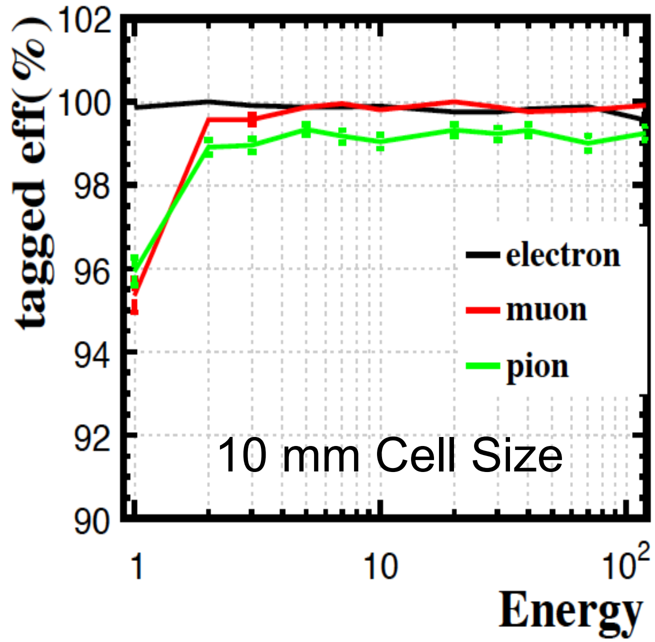
- Collision environment is very difficult from Linear Collider
- Lower E: Smaller Detector & B Field:
  - m_H & σ(ZH) at μμH: accuracy reduced by 20%/3% with 25% smaller Radius
- Without Power pulsing or Active Cooling
  - Granularity reduced ~ 1-2 order of magnitudes
  - Br(H->WW/ZZ) & Higgs recoil analysis@llH: event reconstruction efficiency reduced by ~2%
- Different technology options:
  - ECAL: Scintillator vs. Silicon Sensor compared
  - Tracking: Full Silicon Tracker - TPC

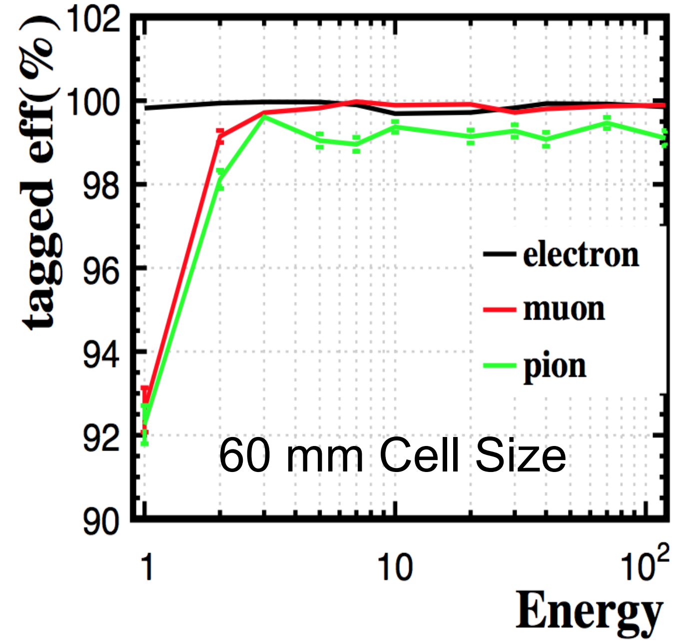




Generic Lepton ID for Calorimeter with High granularity (LICH)







Migration Matrix at 40 GeV (Barrel1)

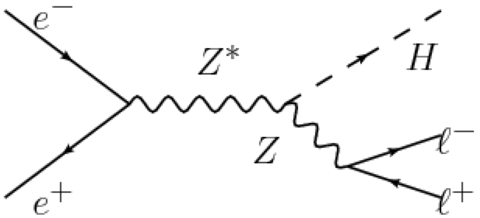
	e^-	μ^-	π^+
e^-	99.91 ± 0.08	0.08 ± 0.03	0
μ^-	0	99.60 ± 0.19	0.39 ± 0.19
π^+	0.34 ± 0.17	0.25 ± 0.14	99.39 ± 0.22

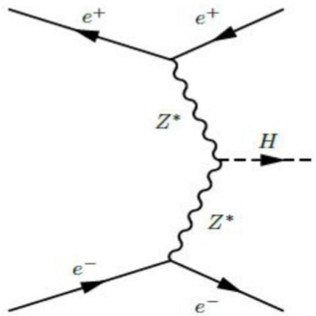
DanYu: BDT based

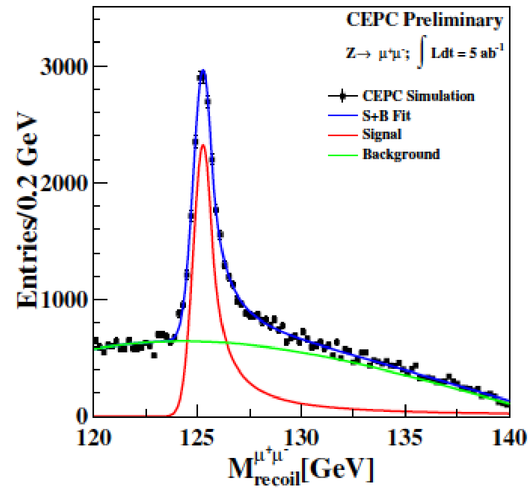
Performance close to physics limit

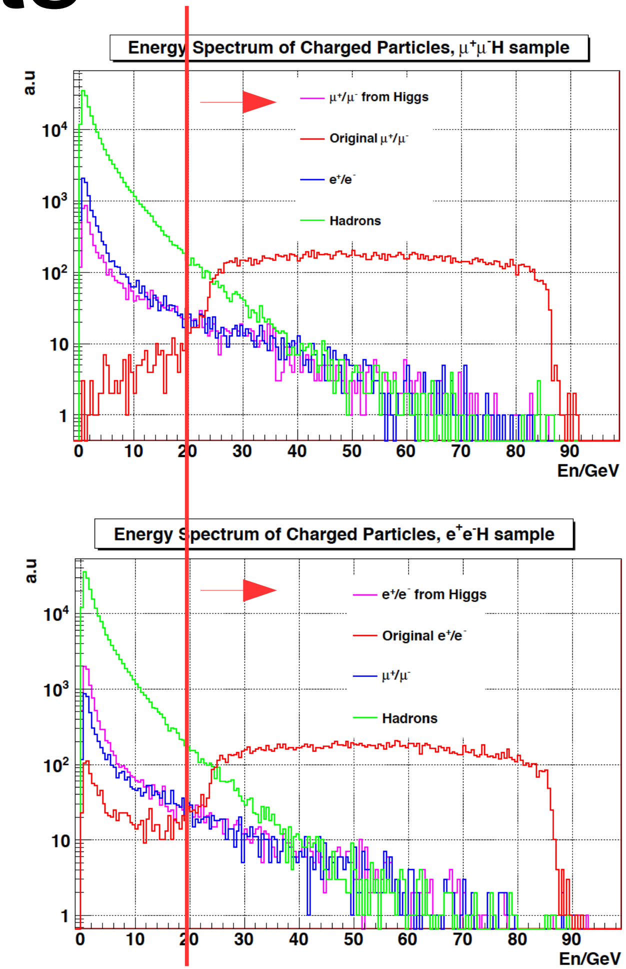
Stable performance even reduce Granularity by two orders of magnitude: only slightly degraded at low energy

LICH @ llH events









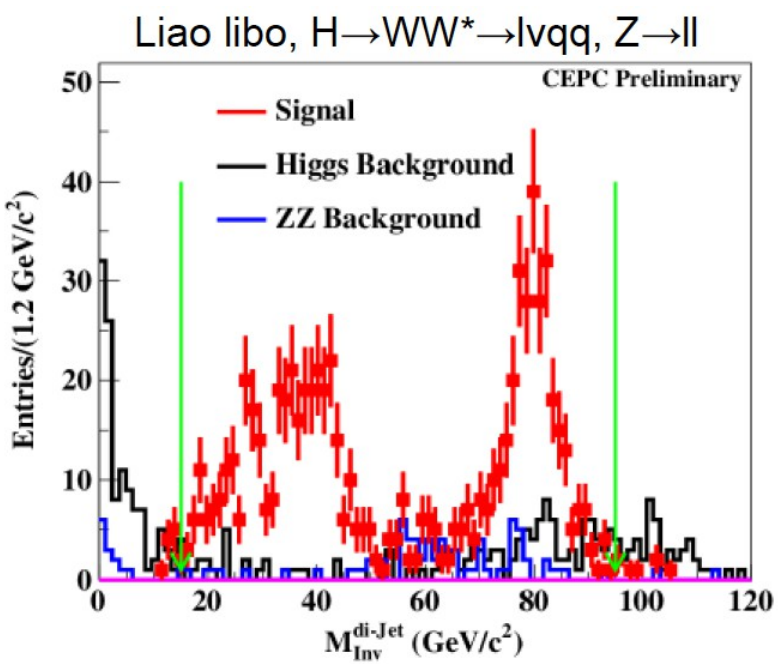
	Geom 1		Geom 2	
	$\mu\mu$H	eeH	$\mu\mu$H	eeH
Cut_μ	0.1	0.1	0.1	0.1
Cut_e	0.01	0.001	0.01	0.001
ε_E	93.41 ± 0.92	**98.64 ± 0.08**	91.60 ± 1.02	**97.89 ± 0.11**
η_E	92.02 ± 1.00	**99.74 ± 0.04**	89.89 ± 1.10	**99.67 ± 0.04**
ε_μ	**99.54 ± 0.05**	95.53 ± 0.76	**99.19 ± 0.06**	86.48 ± 1.26
η_μ	**99.60 ± 0.04**	96.31 ± 0.70	**99.83 ± 0.03**	95.38 ± 0.81
ε_{event}	98.53 ± 0.13	97.06 ± 0.19	97.24 ± 0.18	95.40 ± 0.24

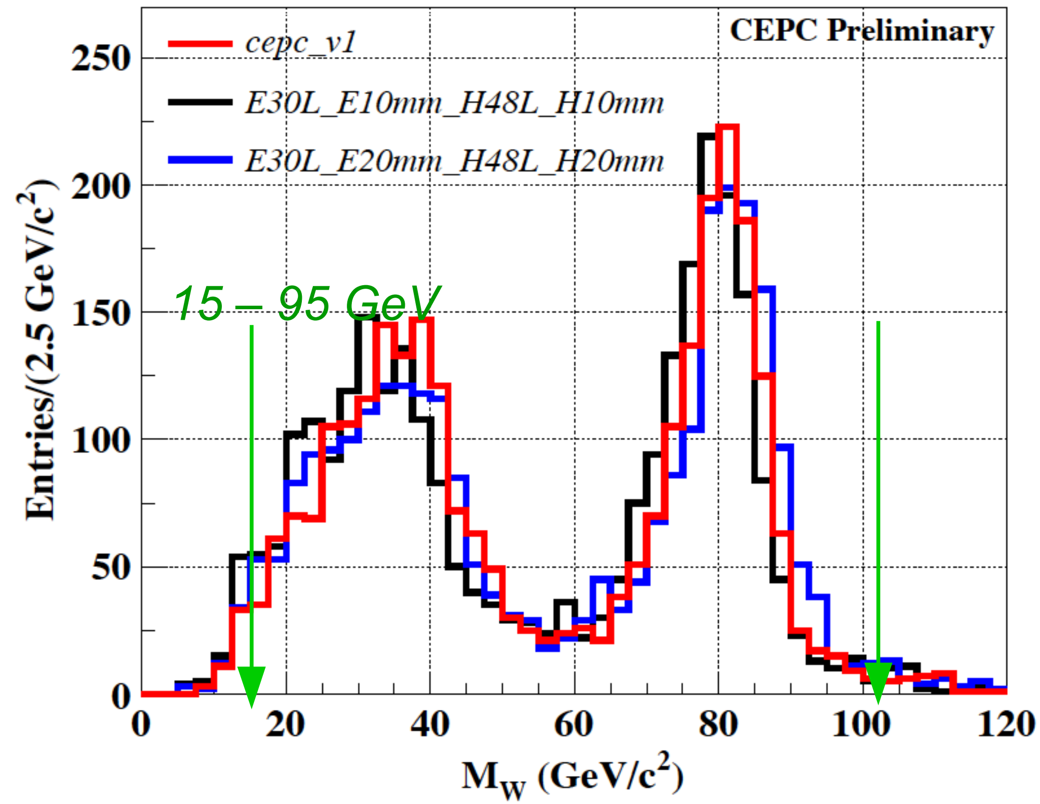
Original Design (5 mm Cell) and test Geometries: 10 - 20 mm Cell

High energy leptons identification: high efficiency & purity (limited by shower overlap)

More stringent requirement arises from jet leptons and pi0 reconstruction...

Lepton + Jets: Br(H→WW)





Br(H→WW) via vvH, H→WW*→lvqq

No lose in the object level efficiency;
JER slightly degraded, ~ 5/10% at 10/20 mm
(*ill. behaviors: stay to be tuned*)

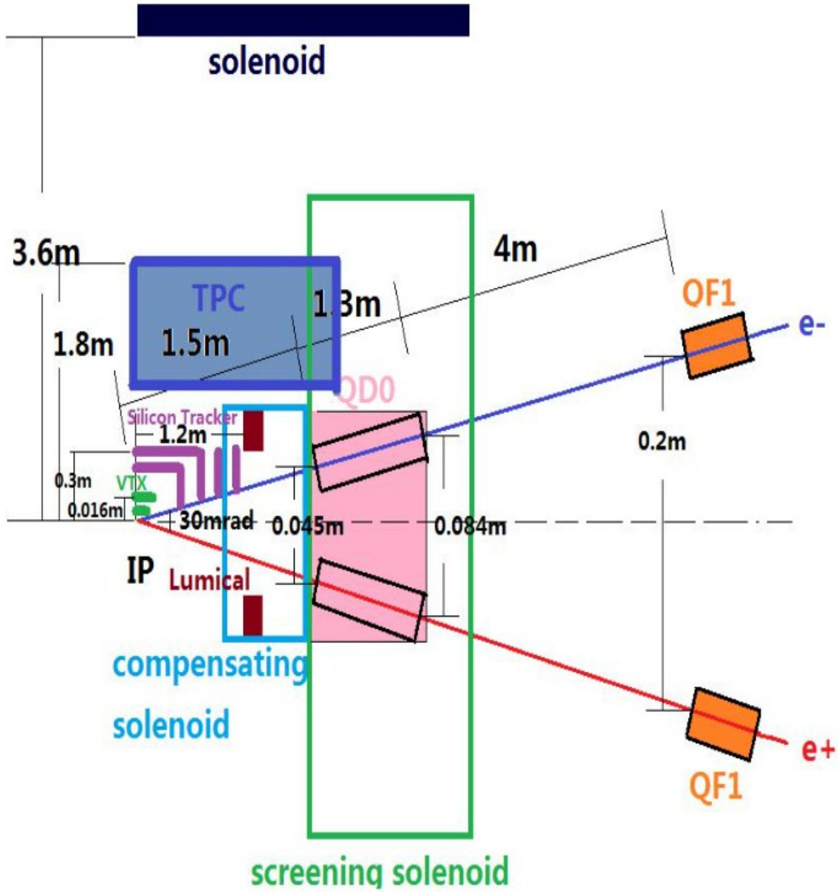
Over all: event reco. efficiency varies ~1%

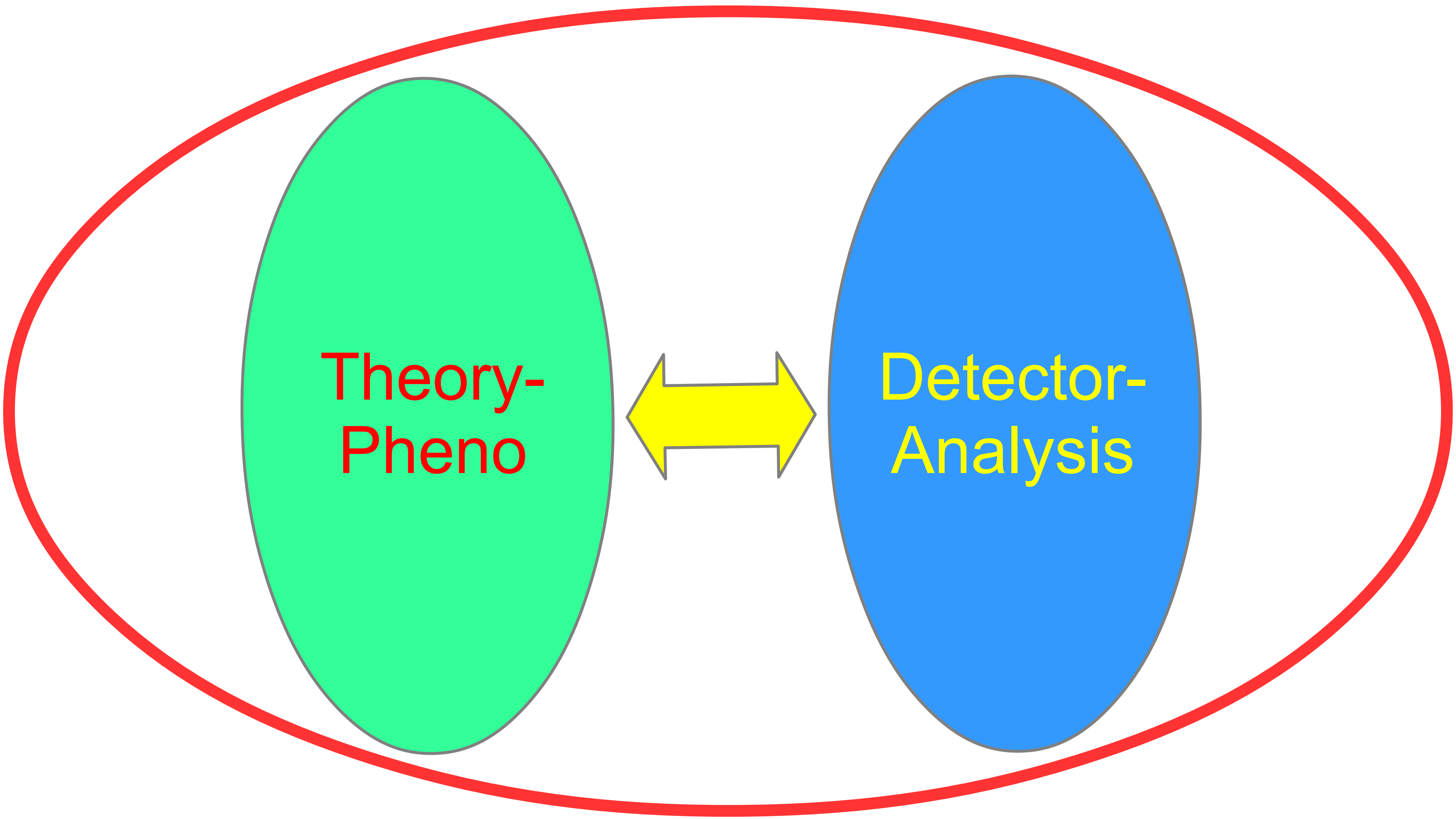
	Simu.	Recon.	Efficiency
CEPC_v1	2885	2783	96.5%
TG1	2878	2814	97.8%
TG2	2878	2807	97.5%

TG1: E30L_H48L_10mm, TG2: E30L_H48L_20mm

Key R&D issues

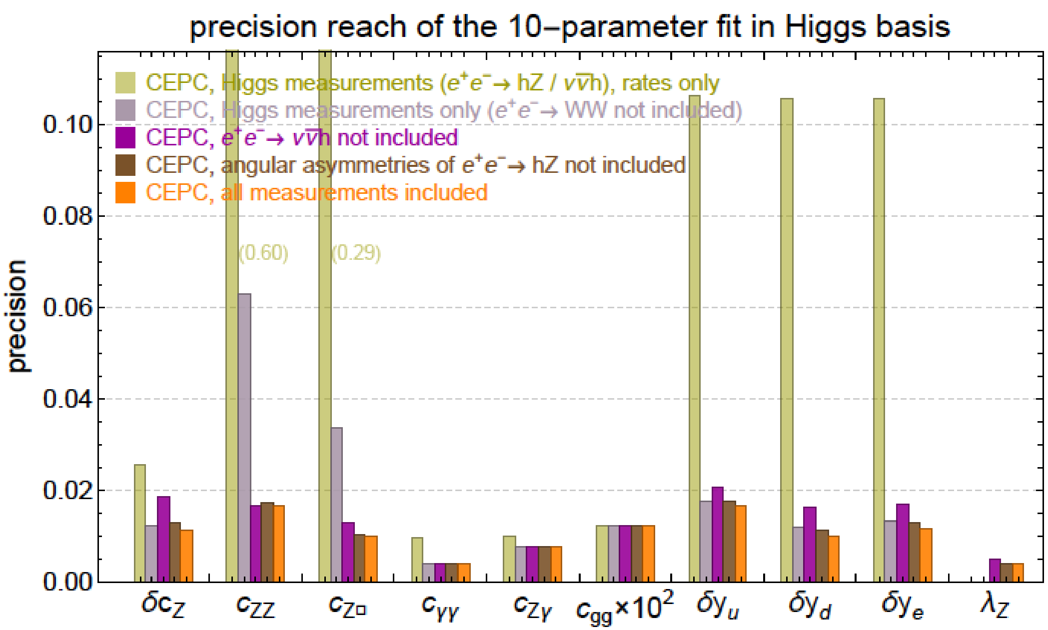
- Beam Energy Calibration
- MDI:
  - Partial double ring
  - L* optimization & beam background
- VTX & Main Tracker
  - Large area silicon detector R&D
  - TPC feasibility studies:
    - Hit occupation;
    - Ion feedback-charge distortion;
    - dEdx
- Calorimeter & B-Field
  - *Less demanding in Jet Energy Resolution + no power pulsing*




Theory-
Pheno
Detector-
Analysis

Highlight 1: Impact of EW, TGC & Differential measurements

Jiayin Gu (顾嘉荫)   G. Durieux, C. Grojean, K. Wang



The "10-parameter" framework in the Higgs basis

- Starting with all the D6 operators that can contribute to the above measurements.
- Assuming new physics is CP-even, flavor universal.
- Assuming no corrections to Z-pole observables and W mass. (More justified if the machine will run at Z-pole.)
- We are left with 10 operators, parameterized in the Higgs basis by:

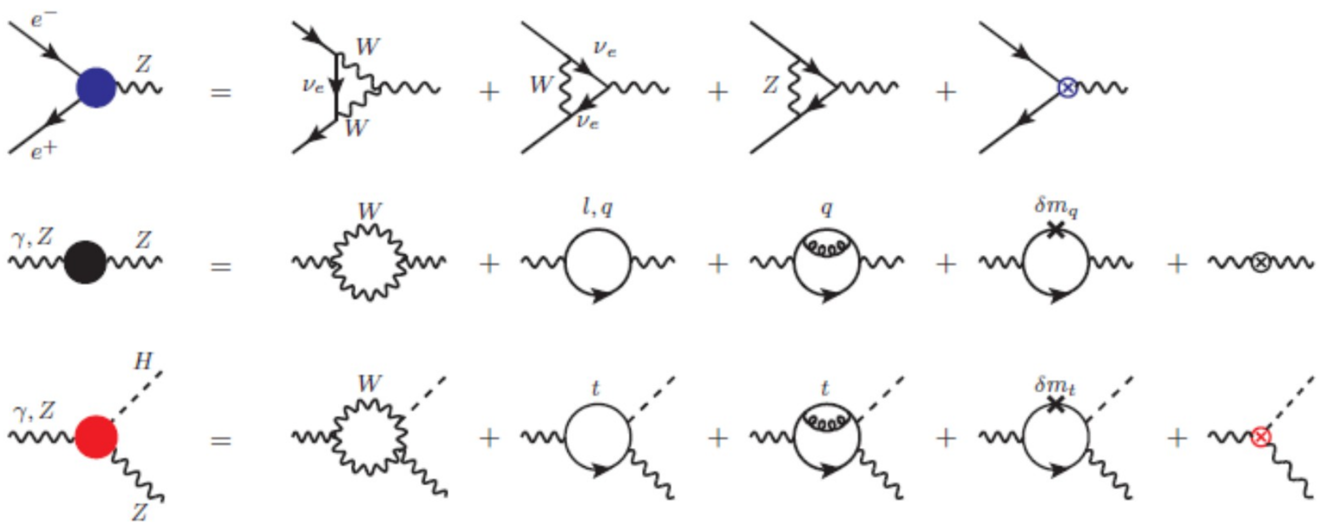
$$\delta c_Z\,,\quad c_{ZZ}\,,\quad c_{Z\Box}\,,\quad c_{\gamma\gamma}\,,\quad c_{Z\gamma}\,,\quad c_{gg}\,,\quad \delta y_u\,,\quad \delta y_d\,,\quad \delta y_e\,,\quad \lambda_Z\,.$$

- Strong independent constraints can be obtained for all 10 coefficients!
- [1505.00046] Falkowski
  [1508.00581] Falkowski, Gonzalez-Alonso, Greljo, Marzocca

http://indico.ihep.ac.cn/event/6495/session/3/contribution/44/material/slides/0.pdf

Higgs + EW, etc is significantly better...

Highlight 2: NNLO correction to σ(ZH) ~ 1%



$\sqrt{s}$ (GeV)		LO (fb)	NLO Weak (fb)		NNLO mixed EW-QCD (fb)				
		$\sigma^{(0)}$	$\sigma^{(\alpha)}$	$\sigma^{(0)}+\sigma^{(\alpha)}$	$\sigma_{eeZ}^{(\alpha\alpha_s)}$	$\sigma_{Z}^{(\alpha\alpha_s)}$	$\sigma_{\gamma}^{(\alpha\alpha_s)}$	$\sigma^{(\alpha\alpha_s)}$	$\sigma^{(0)}+\sigma^{(\alpha)}+\sigma^{(\alpha\alpha_s)}$
240	Total	**223.14**	6.64	229.78	0.84	1.59	0.008	2.43	232.21
	L	88.67	3.18	91.86	0.33	0.63	0.003	0.97	92.82
	T	134.46	3.46	137.92	0.50	0.96	0.005	1.46	139.39
250	Total	**223.12**	6.08	229.20	0.83	1.58	0.009	2.42	231.63
	L	94.30	3.31	97.61	0.35	0.67	0.004	1.02	98.64
	T	128.82	2.77	131.59	0.48	0.91	0.005	1.40	132.99

Q. SUN et. Al, 1609.03995

Y. Gong et. Al, 1609.03955

ISR correction not included

NNLO accuracy is worse than statistical error (~ 0.5%)
Higher order calculation and new method/tools is needed

Summary

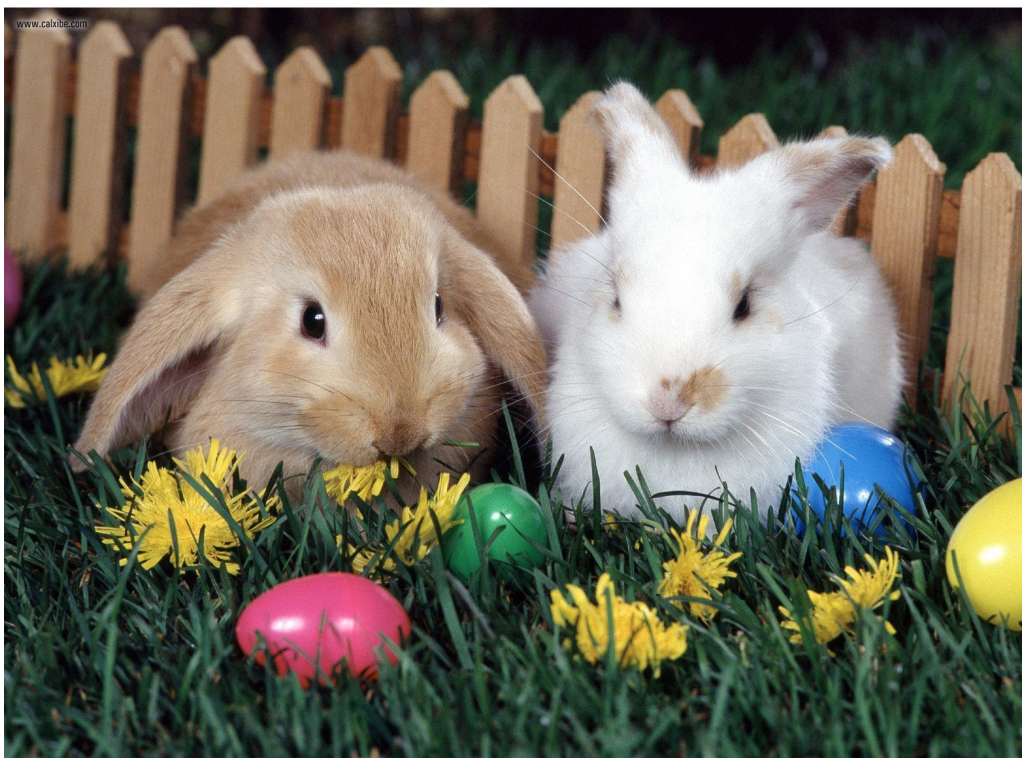
- Given the importance of Higgs, we expect that at least one of them, FCC-ee, ILC, or CEPC, can be realized
- CEPC is the first Chinese effort for a science project at such scale: challenges every where
- Tremendous progresses up to now, but still long way to go
  - Accelerator
    - Reference circumference of **100 km**
    - PDR: attractive & challenge
  - Detector: Reconstruction & Optimization
  - Theory-Phenomenology: Theoretical control & Interpretation. etc
- Toward CDR: a working design for the machine & detector
  - Key R&D issues identified and pushed forward

CEPC Workshop

19-21 April 2017

Central China Normal University

http://indico.ihep.ac.cn/event/6433/



8-10 Nov 2017

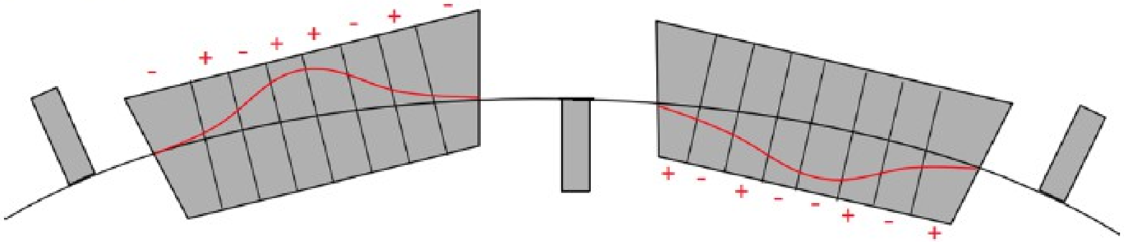
Backup

CEPC Booster Design

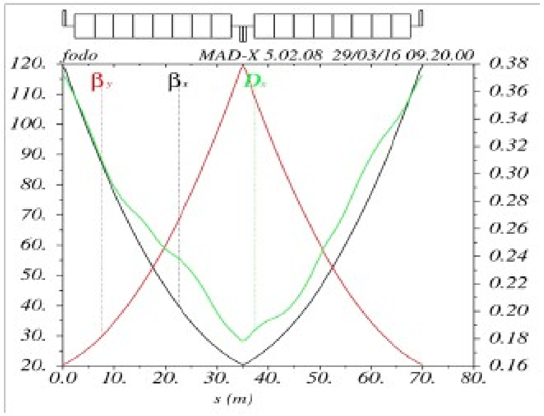
1) Normal Low field Bend Scheme

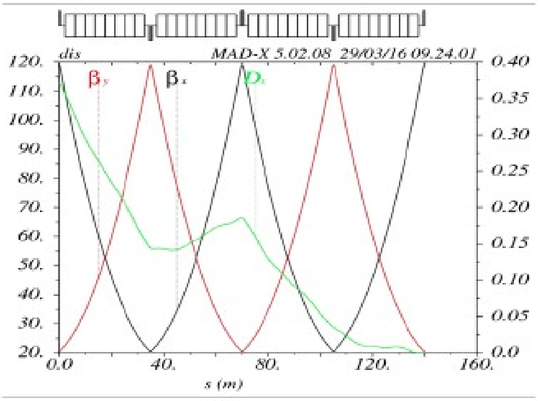
Solution to the 4th problem

2) Wiggling Bend Scheme



- **90 degree FODO**
- **FODO length:70 meter**





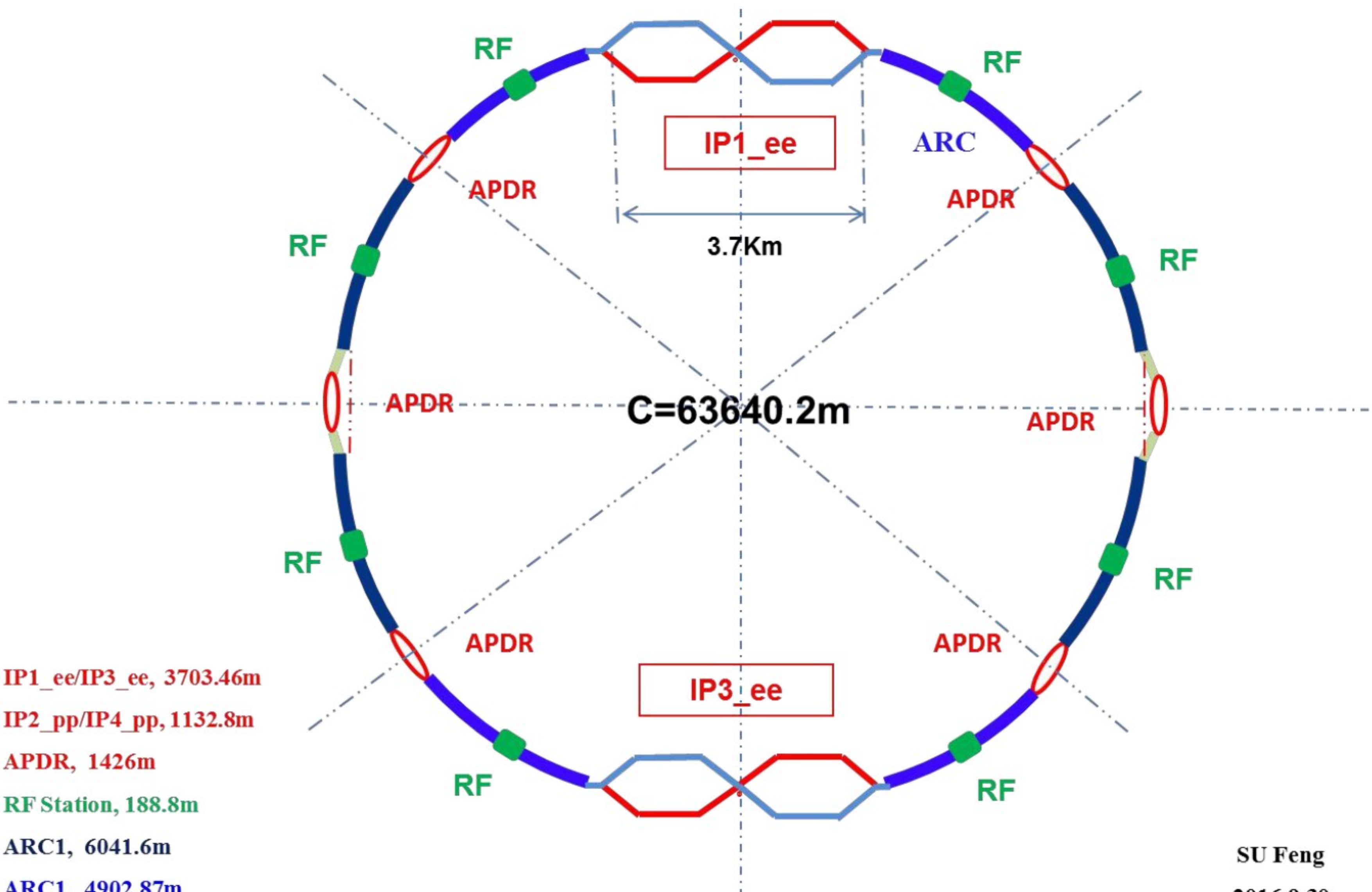
Main Problems left in Pre-CDR

1. Pretzel scheme is difficult to design and operate, with little flexibility and stability
2. Too high AC power consumption (~ 500 MW)
3. Very low luminosity for Z
4. Booster with very too low magnetic field (30 Gauss for 6GeV injection in a background field of 3 Gauss, say in the BEPCII tunnel) and too small dynamic aperture
5. Very small Dynamic Aperture at 2% energy spread with beam-beam effects and magnetic errors

- **Goal of CEPC CDR:** a "design" working on paper

Addressed by PDR	Addressed by Wiggler	Progressing

CEPC Advanced Partial Double Ring Layout



IP1_ee/IP3_ee, 3703.46m

IP2_pp/IP4_pp, 1132.8m

APDR, 1426m

RF Station, 188.8m

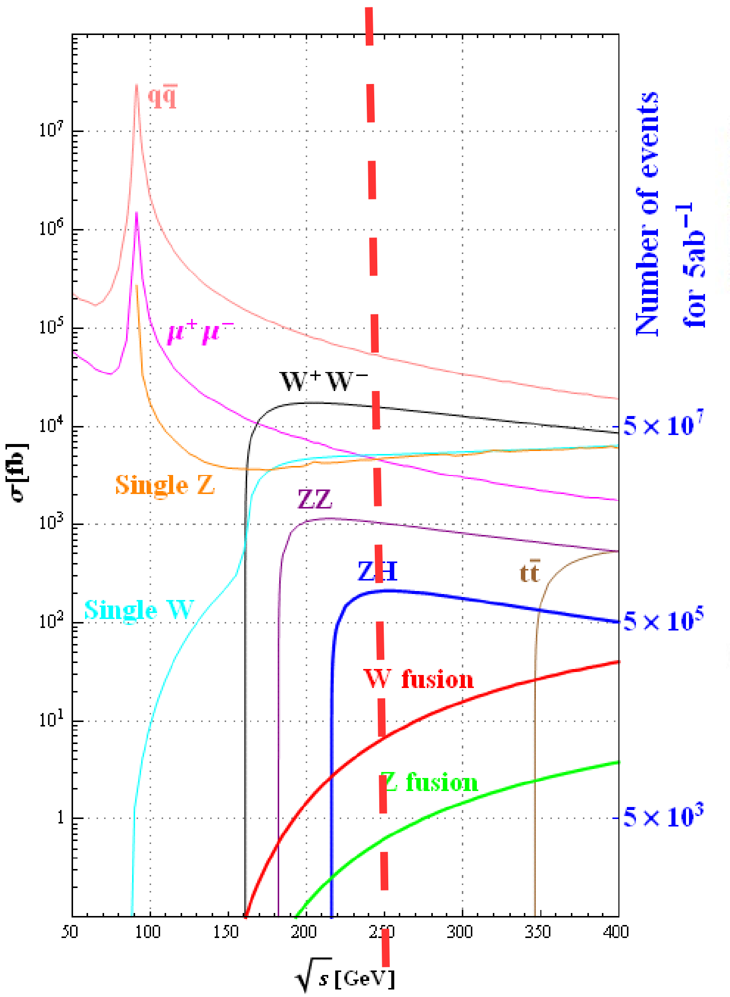
ARC1, 6041.6m

ARC1, 4902.87m

SU Feng

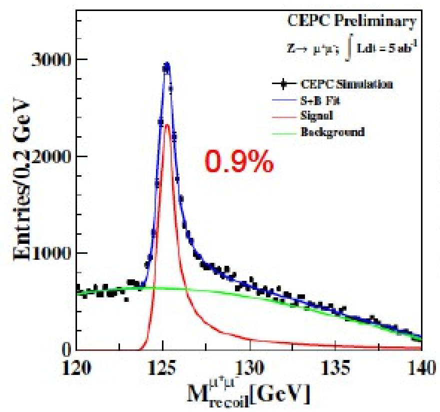
2016.9.30

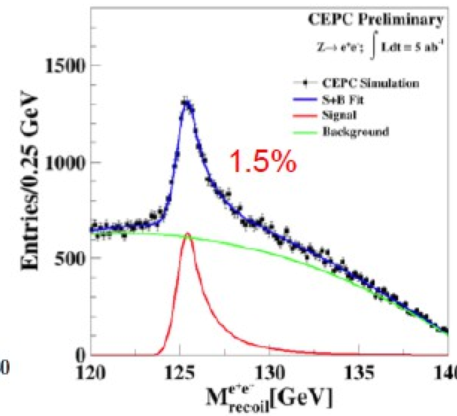
CEPC: absolute Higgs measurements

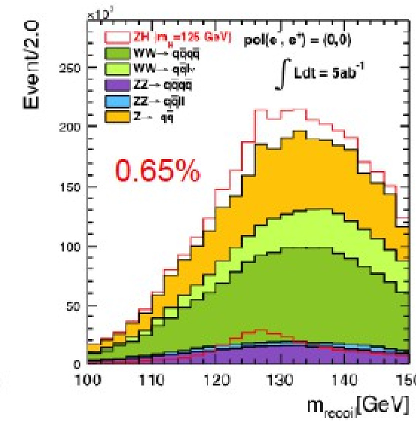


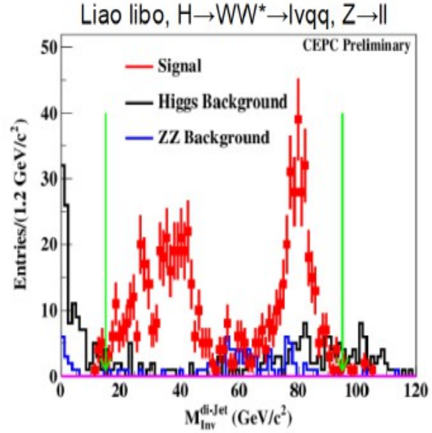
Zhenxing Chen & Yacine Haddad

σ(ZH) measurements

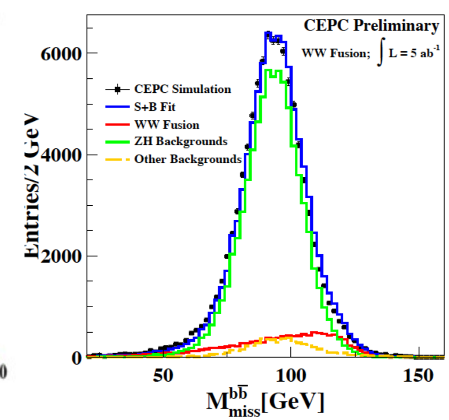




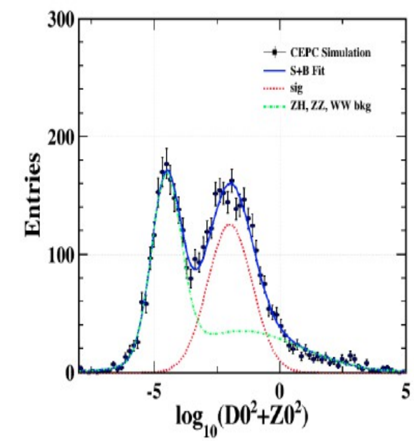




Br(H→WW)

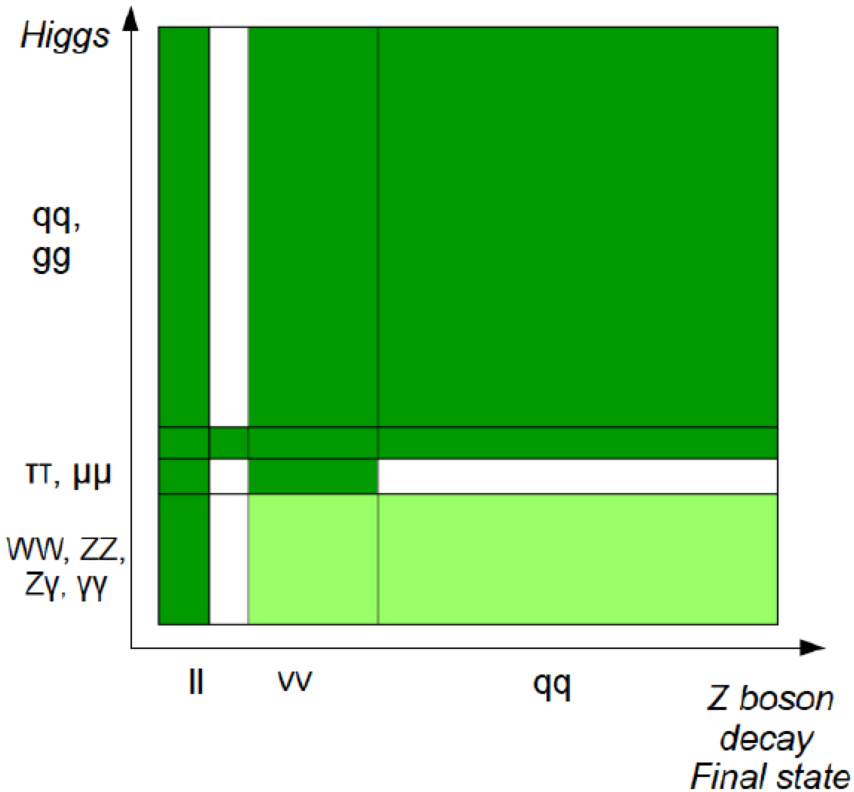


σ(vvH)*Br(H→bb)



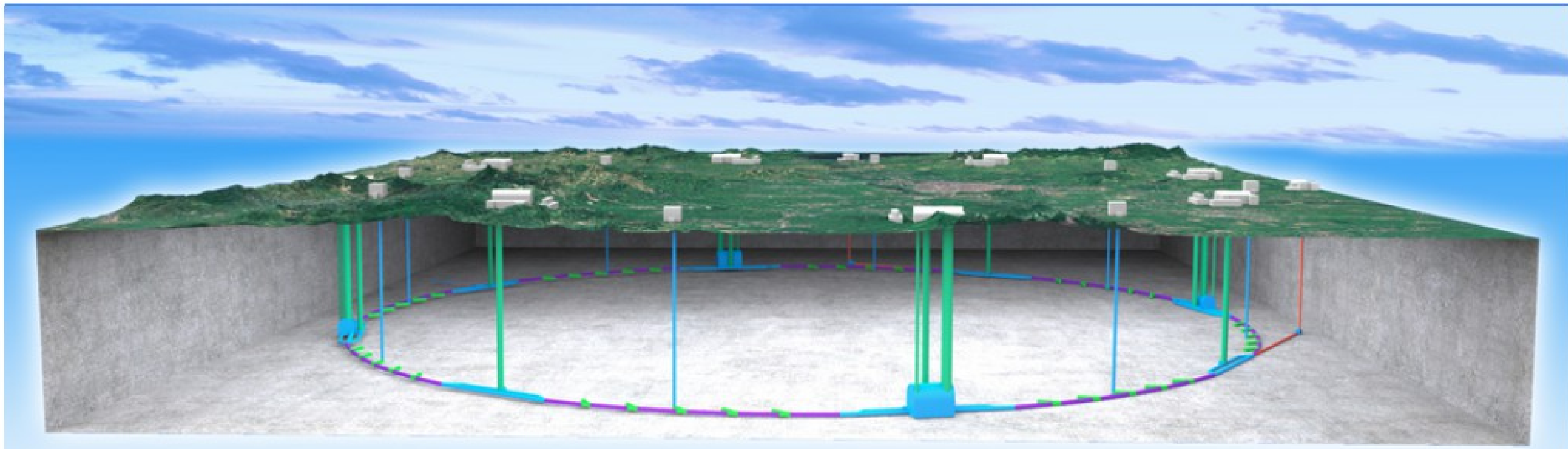
Br(H→ττ)

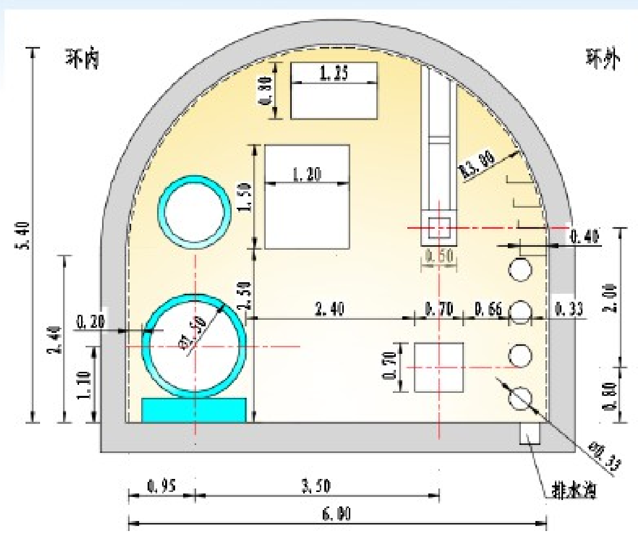
CEPC: Simulation Studies

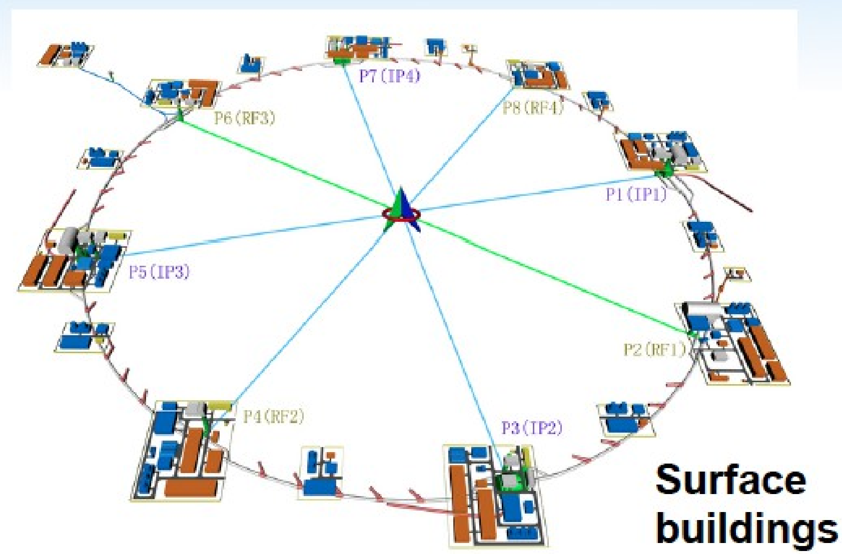


	PreCDR (Jan 2015)	Now (Aug 2016)
σ(ZH)	0.51%	0.50%
σ(ZH)*Br(H→bb)	0.28%	0.21%
σ(ZH)*Br(H→cc)	2.1%	2.5%
σ(ZH)*Br(H→gg)	1.6%	1.3%
σ(ZH)*Br(H→WW)	1.5%	1.0%
σ(ZH)*Br(H→ZZ)	4.3%	4.3%
σ(ZH)*Br(H→ττ)	1.2%	1.0%
σ(ZH)*Br(H→γγ)	9.0%	9.0%
σ(ZH)*Br(H→Zγ)	-	~4 σ
σ(ZH)*Br(H→μμ)	17%	17%
σ(ννH)*Br(H→bb)	2.8%	2.8%
Higgs Mass/MeV	5.9	5.0
σ(ZH)*Br(H→inv)	95%. CL = 1.4e-3	1.4e-3
Br(H→ee/emu)	-	1.7e-4/1.2e-4
Br(H→bbχχ)	$<10^{-3}$	3.0e-4

Civil Construction

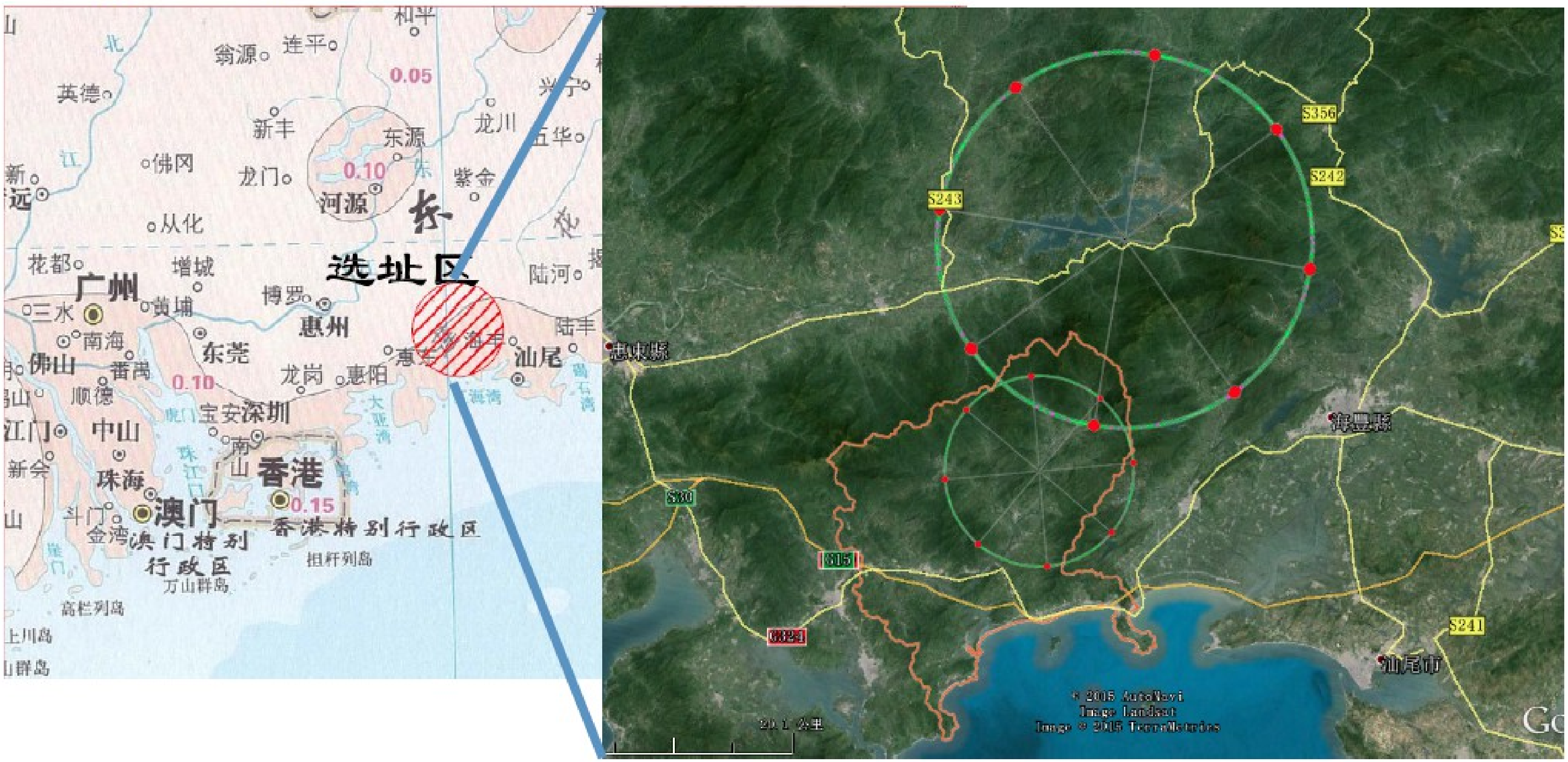




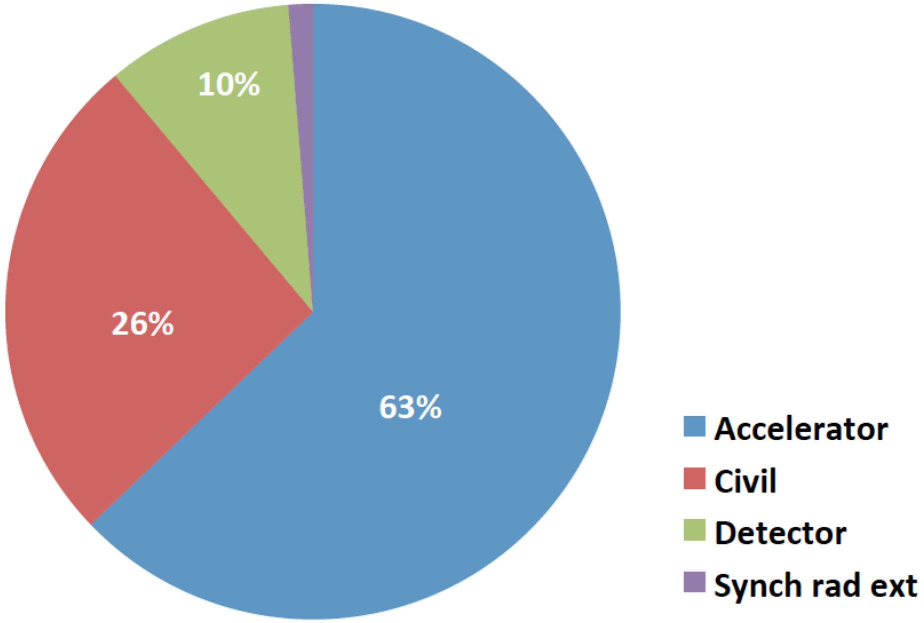


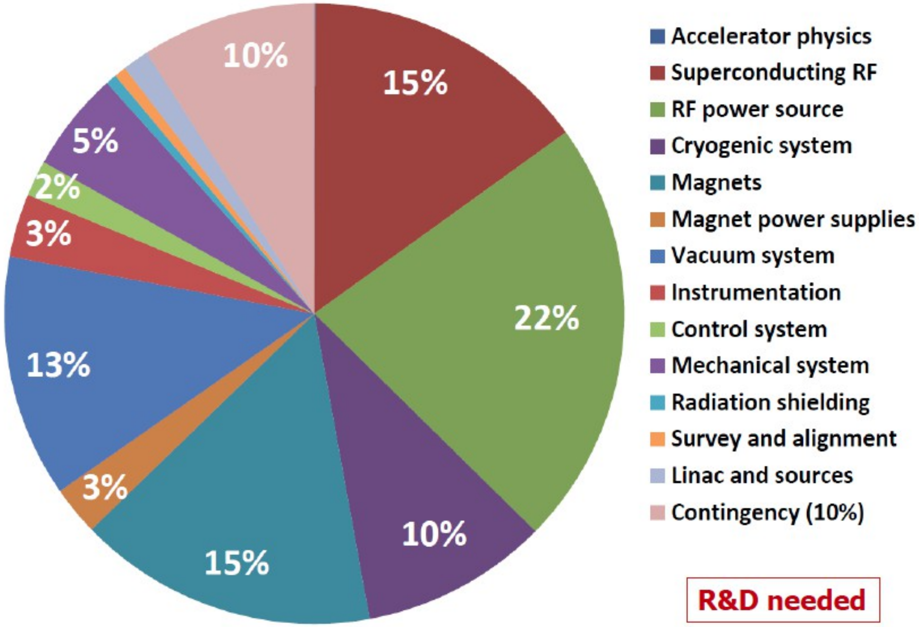
Site Selection

- Continue to work on site selection
- Previously investigated: 300 km north-east of Beijing
- A new possibility close to Hong Kong, invited by the local government



Cost estimation





- Preliminary: 25/36 Billion CNY at 50/100km Circumference
- Accelerator: Key technology development on going (budget + power)
  - *RF source (efficiency)*
  - *High Q SRF cavities*
  - *...*

Theory-Pheno: Physics motivation

- Unique/distinguishable advantage of electron-positron Higgs factory
- Higgs:
  - Event Number Counting
    - Absolute Higgs measurements
      - Total generation Xsec
      - Higgs width, Decay branching ratio & absolute couplings
    - Exotic decay mode searching via recoil mass method
  - Differential distribution measurements
    - Higgs CP
    - O5, O6 Higgs interaction operators
- EW:
  - Z pole observables, etc

International Collaboration

- A new international organization for CEPC will be organized after (at least some) funding is available
  - A new format: not ITER, CERN, ILC, …
- An international advisory board is formed to discuss in particular this issue, together with others
- Many MOU and meeting minutes signed with collaborating institutions/organizations:
  - UChicago, BNL, SLAC, BINP, Oxford, INFN, …
  - More will be signed
- Seeking international coordination

ICFA Statements

- **ICFA meeting of Feb. 2014 at DESY, Hambourg, stated:**

ICFA supports studies of energy frontier circular colliders and encourages global coordination

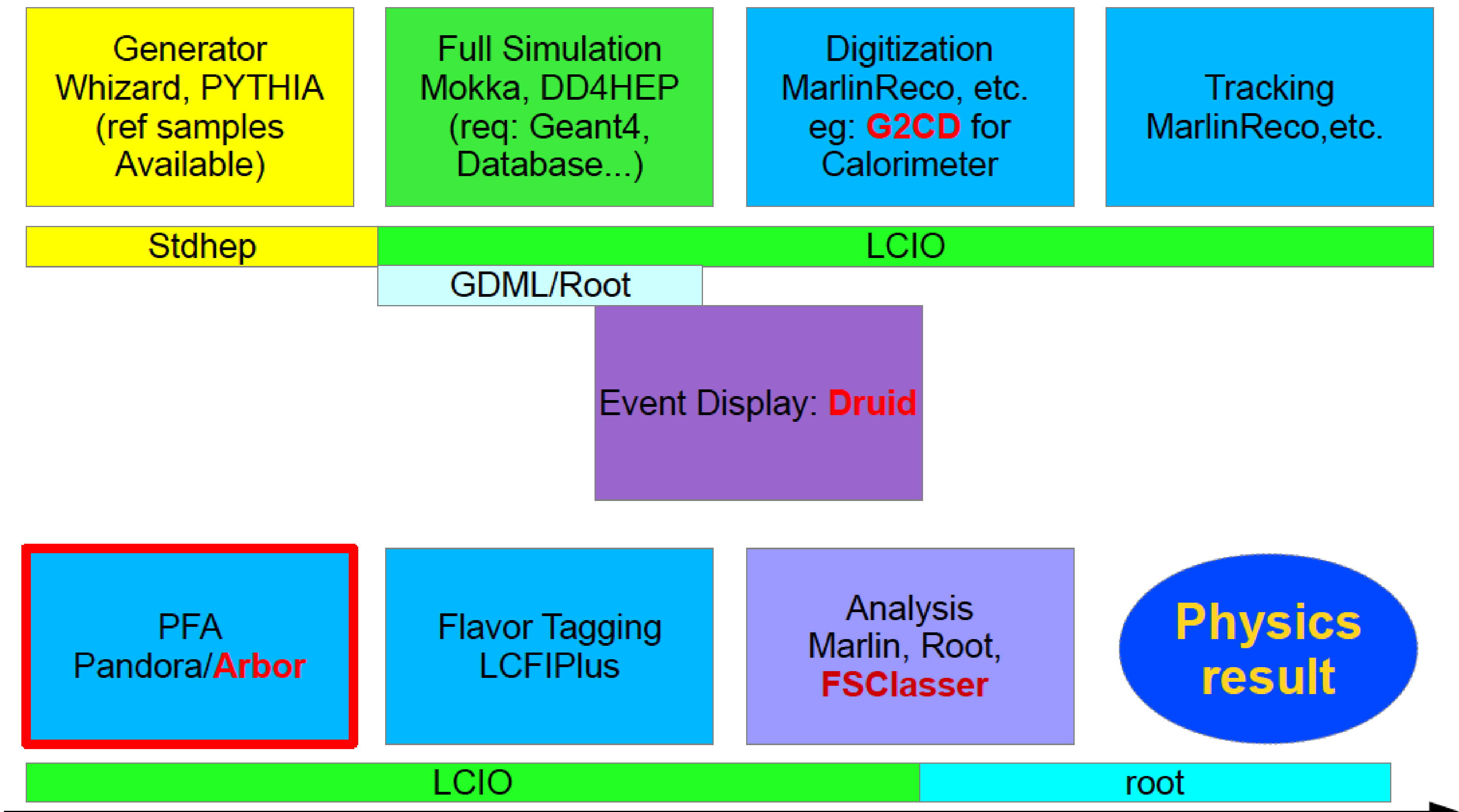
- **ICFA meeting of July 2014 in Spain, stated:**

… ICFA continues to encourage international studies of circular colliders, with an ultimate goal of proton-proton collisions at energies much higher than those of the LHC.

AsiaHEP/ACFA Statement on ILC + CEPC/SPPC

AsiaHEP and ACFA reassert their strong endorsement of the ILC, which is in a mature state of technical development. The aim of ILC is to explore physics beyond the Standard Model by unprecedented precision measurements of the Higgs boson and top quark, as well as searching for new particles which are difficult to discover at LHC. The Higgs studies at higher energies are especially important for measurement of WW fusion process, to fix the full Higgs decay width, and to measure the Higgs self-coupling. In continuation of decades of world-wide coordination, we encourage redoubled international efforts at this critical time to make the ILC a reality in Japan. The past few years have seen growing interest in a large radius circular collider, first focused as a “Higgs factory”, and ultimately for proton-proton collisions at the high energy frontier. We encourage the effort lead by China in this direction, and look forward to the completion of the technical design in a timely manner.

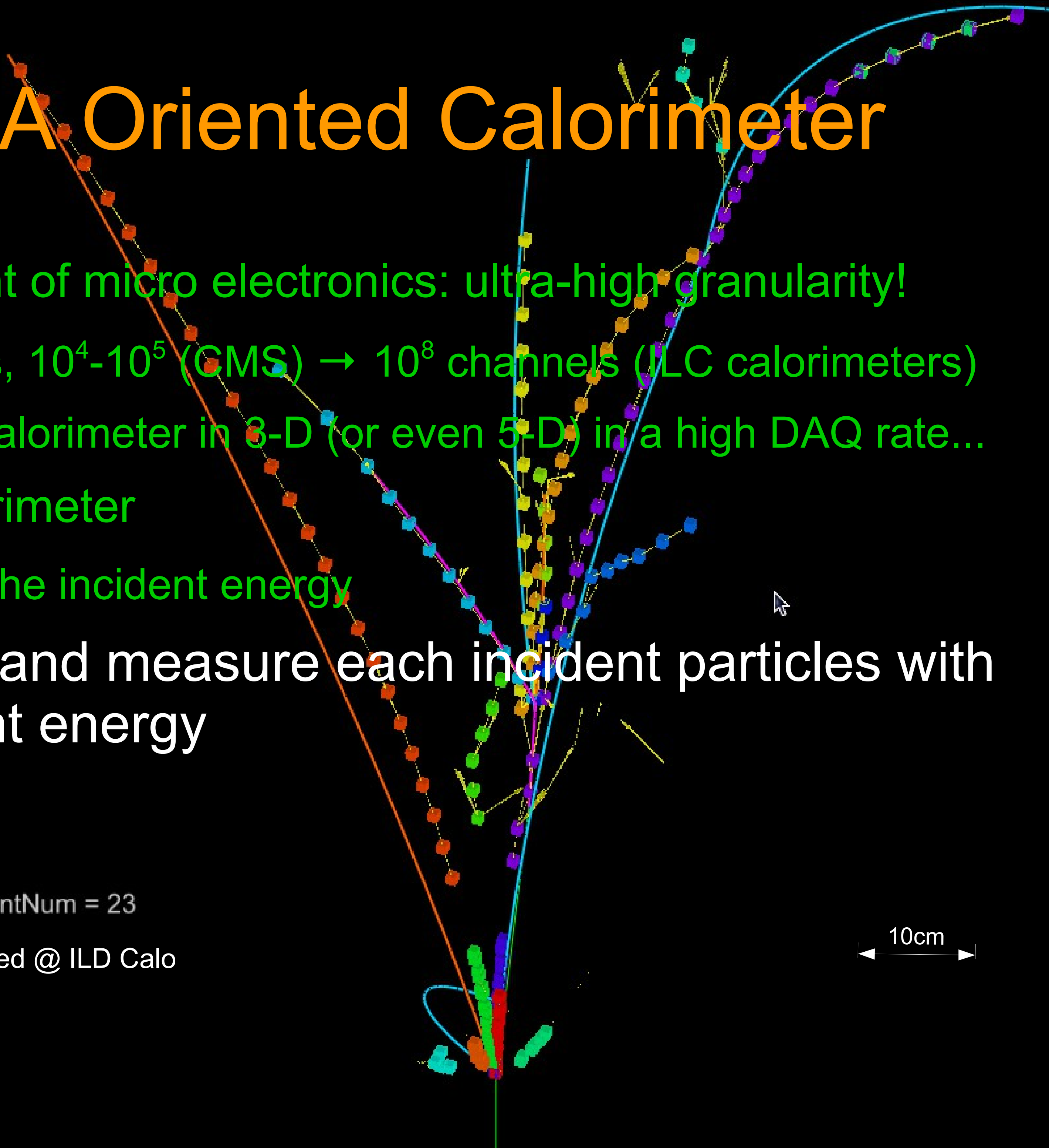
SCRAC



07/04/2016 *Simulation Calibration Reconstruction Analysis Chain* 3

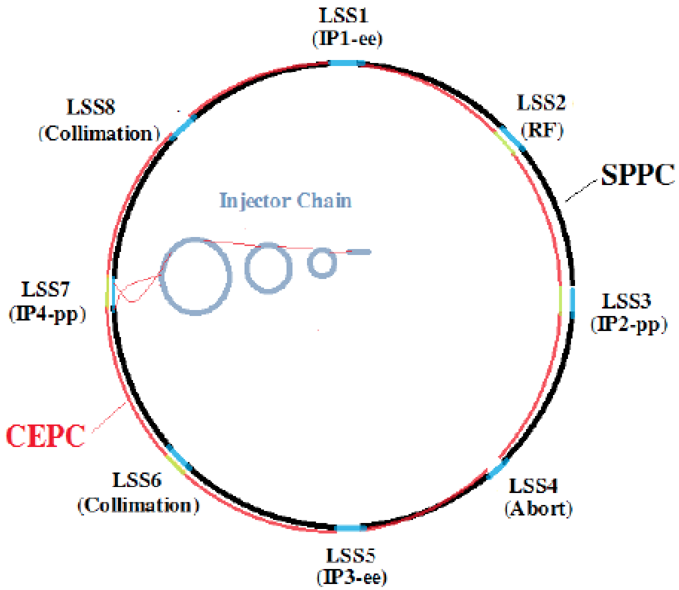
PFA Oriented Calorimeter

- 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

SppC General design



- 8 arcs (5.9 km) and long straight sections (850m*4+1038.4m*4)

Parameter	Value
Circumference	54.36 km
Beam energy	35.3 TeV
Dipole field	20 T
Injection energy	2.1 TeV
Number of IPs	2 (4)
Peak luminosity per IP	**1.2E+35 $cm^{-2}s^{-1}$**
Beta function at collision	0.75 m
Circulating beam current	1.0 A
Max beam-beam tune shift per IP	0.006
Bunch separation	25 ns
Bunch population	2.0E+11
SR heat load @arc dipole (per aperture)	56.9 W/m