ILD and CLD

Roman Pöschl

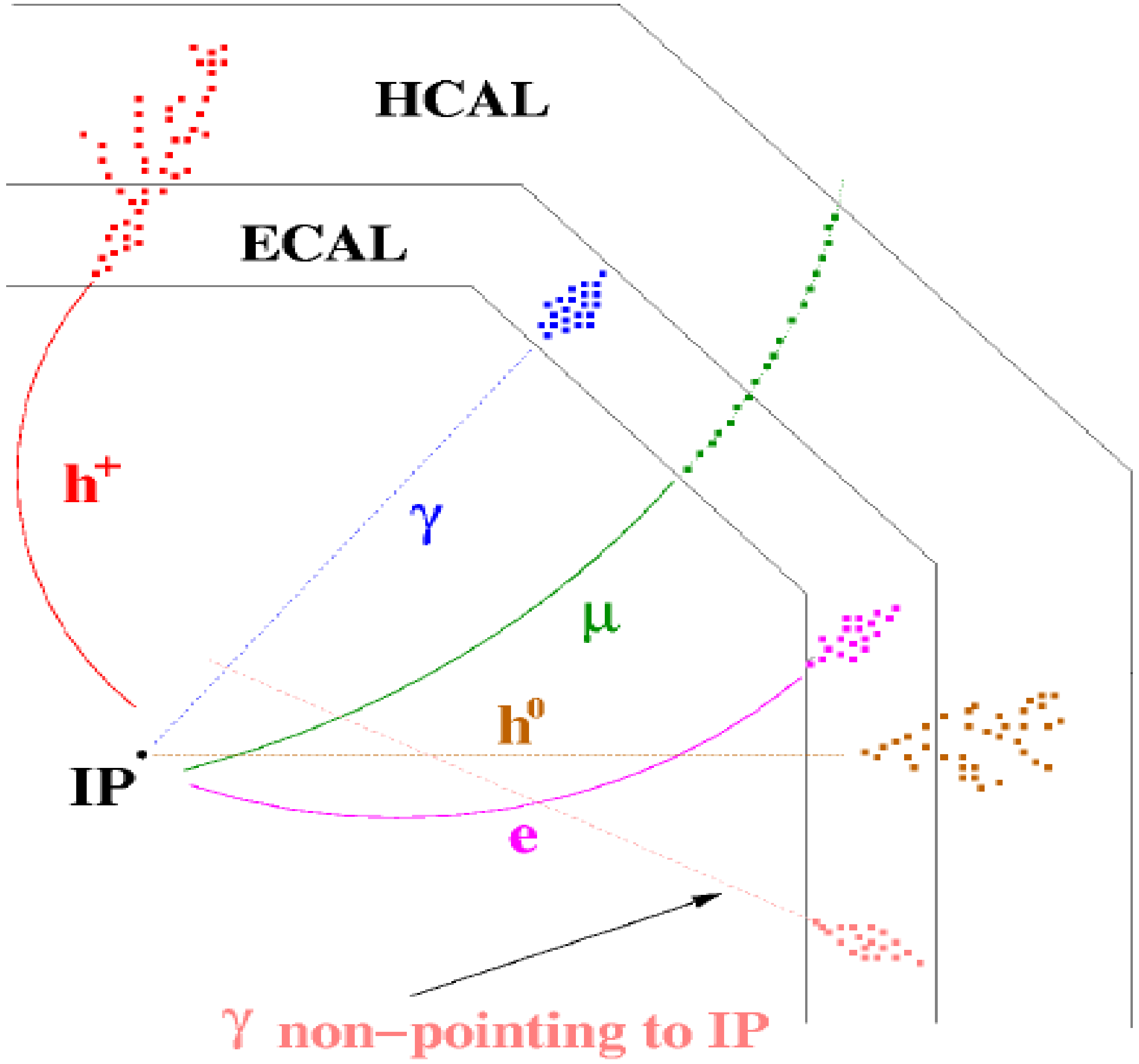
Supported by

French FCC Meeting – November 2023 Strasbourg

Particle Flow Detector Layout

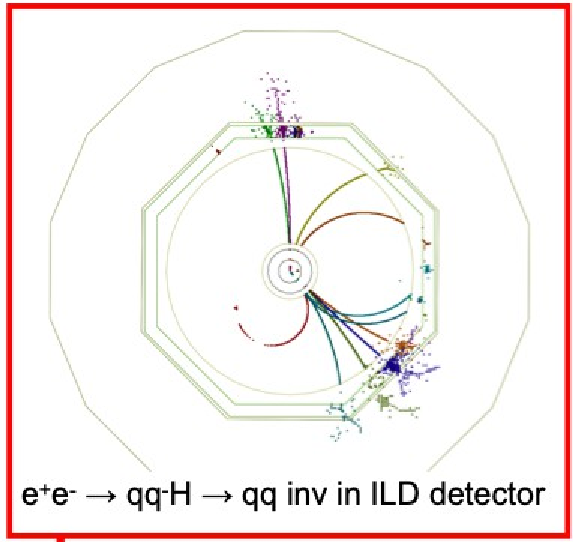
- Jet energy measurement by measurement of **individual particles**
- Maximal exploitation of precise tracking measurement

- Large radius and length
  - ➔ to separate the particles
- Large magnetic field
  - ➔ to sweep out charged tracks
- “no” material in front of calorimeters
  - ➔ stay inside coil (the puristic viewpoint)
  - ➔ see later discussion
- Minimize shower overlap
  - ➔ Small Molière radius of calorimeters
- **high granularity of calorimeters**
  - ➔ to separate overlapping showers



Detector Hermeticity

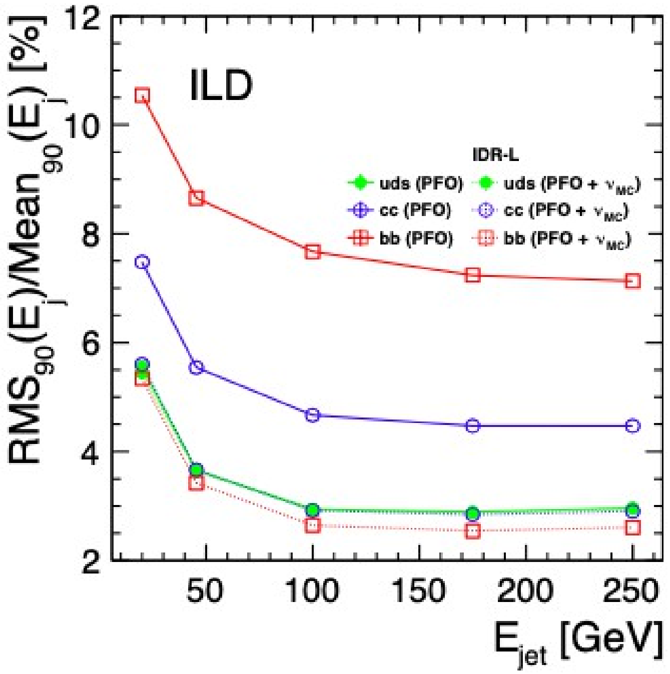
Invisible Higgs decays



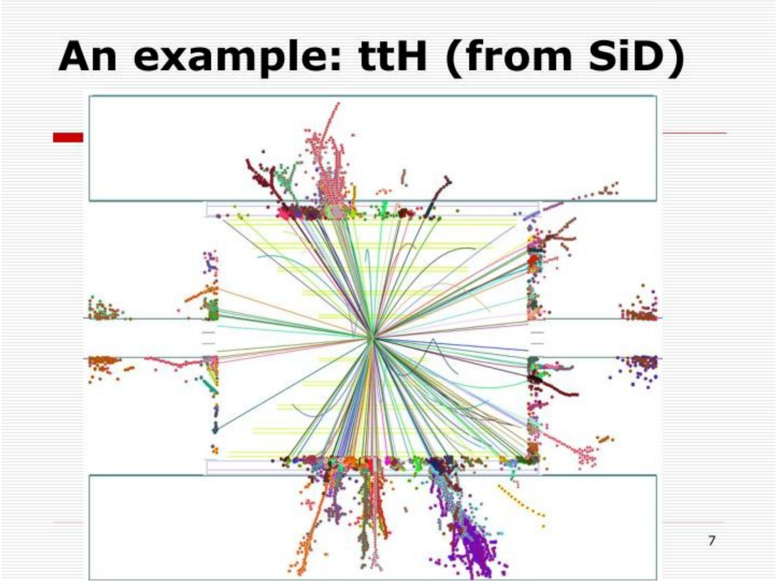
e⁺e⁻ → qq-H → qq inv in ILD detector

Hermeticity = Acceptance down to the beam pipe and no acceptance holes!

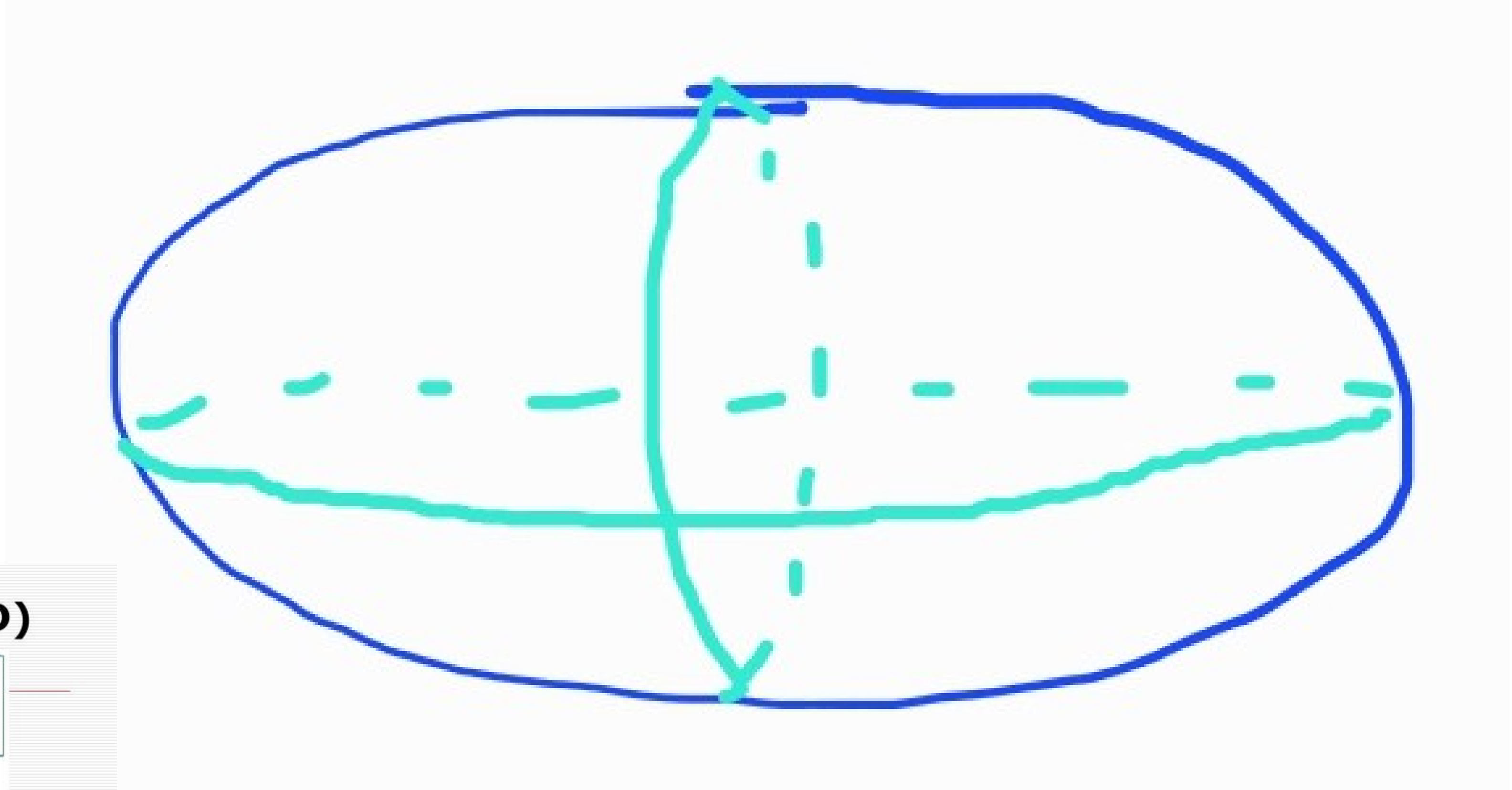
Missing Energy



Rich events:

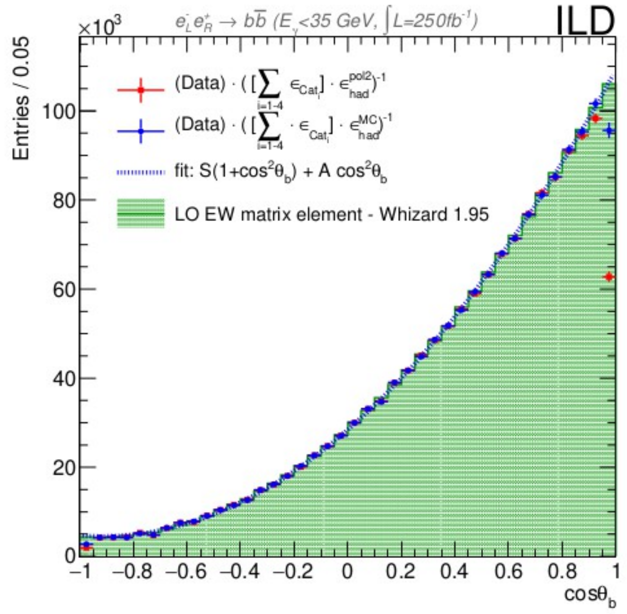


An example: ttH (from SiD)



Detector Hermeticity requires is team effort
Vertex Detectors, Central Tracking and
of course
Calorimeters

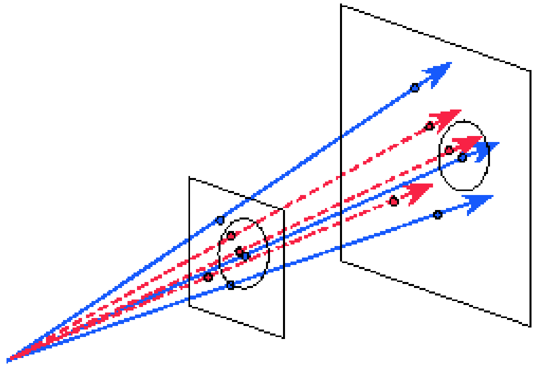
Heavy Quark asymmetries



Detectors for e+e- Colliders – Main Parameters

Concepts currently studied differ mainly in SIZE and aspect ratio

	ILD	SiD	CLICdp	CLD
Rin [mm] Vertex Detector	16	14	31	17.5
$R_{in, Ecal}$ [mm]	1805	1270	1500	2150
$R_{out,tot}$ [mm]	7755	6042	6450	6000
$Z_{min, ECAL}$ [mm]	2411	1657	2310	2310
$Z_{max,tot}$ [mm]	6712	5763	5700	5300
B [T]	3.5	5	4	2



- Figure of merit (ECAL):

  Barrel: $B R_{in}^2 / R_m^{effective}$

  Endcap: $"B" Z^2 / R_m^{effective}$

  R_{in} : Inner radius of Barrel ECAL

  Z : Z of EC ECAL front face

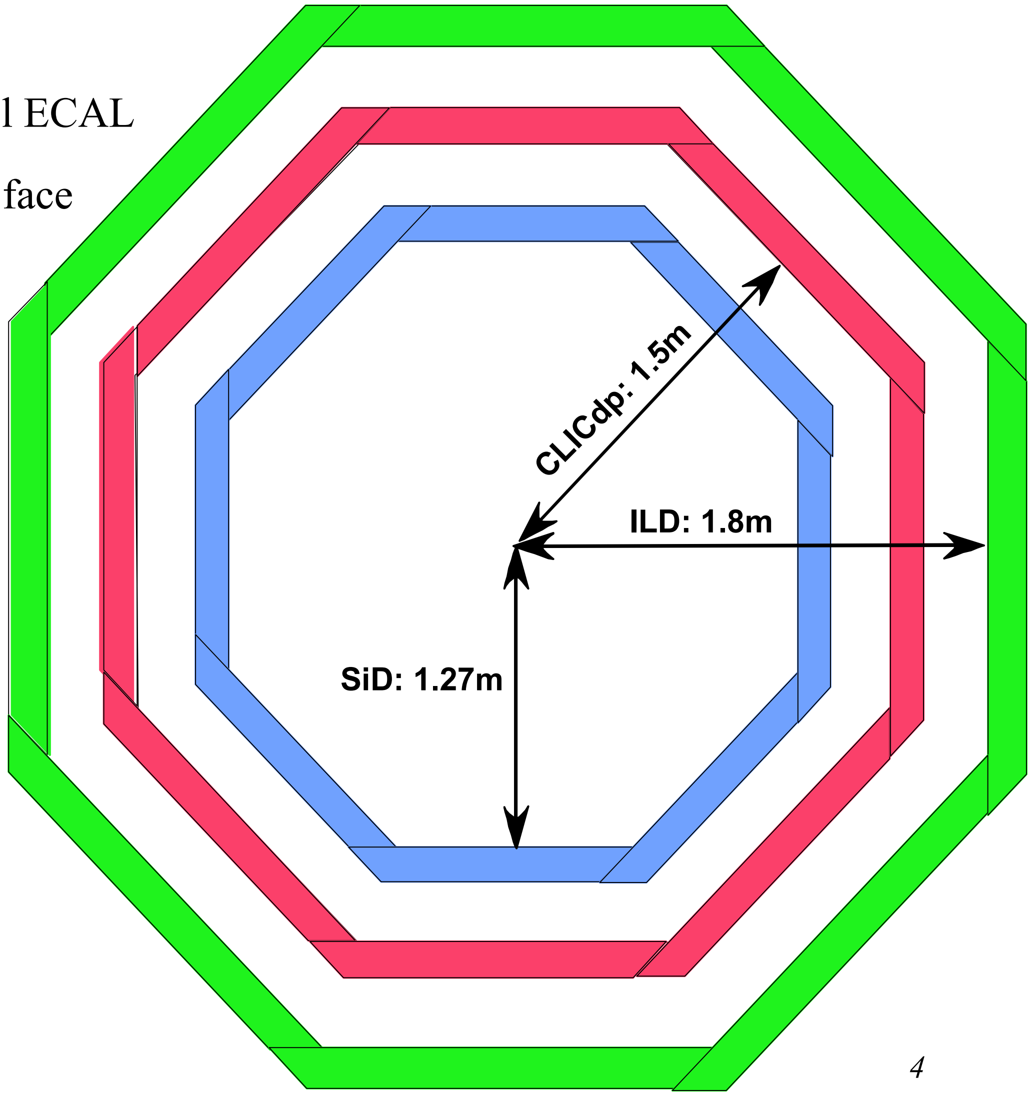
- Different approaches

  SiD: $B R_{in}^2$

  CLICdp: $B R_{in}^2$

  ILD $B R_{in}^2$

  CLD: $B R_{in}^2$



- Roughly: The smaller B the bigger $R_{in,Ecal}$ has to be
- Overall outer radius will depend on required Hcal thickness
- ... and details of return yoke design
  - Cost, safety considerations ...

Detector requirements

Track momentum: $\sigma_{1/p} < 5 \times 10^{-5}/\mathrm{GeV}$ (1/10 x LEP)

(e.g. Measurement of Z boson mass in Higgs Recoil)

Impact parameter: $\sigma_{d0} < [5 \oplus 10/(p[\mathrm{GeV}]\sin^{3/2}\theta)]\ \mu\mathrm{m}$ (1/3 x SLD)

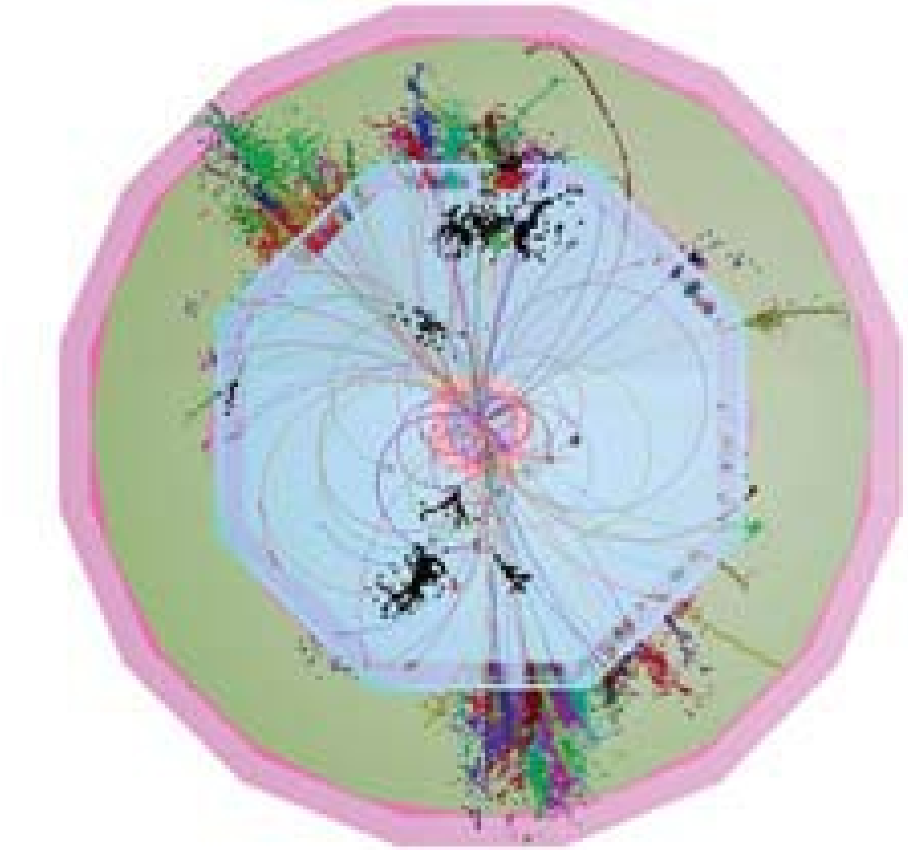
(Quark tagging c/b)

Jet energy resolution : $dE/E = 0.3/(E(\mathrm{GeV}))^{1/2}$ (1/2 x LEP)

(W/Z masses with jets)

Hermeticity : $\theta_{min} = 5$ mrad

(for events with missing energy e.g.dark sector/ invisible decays)

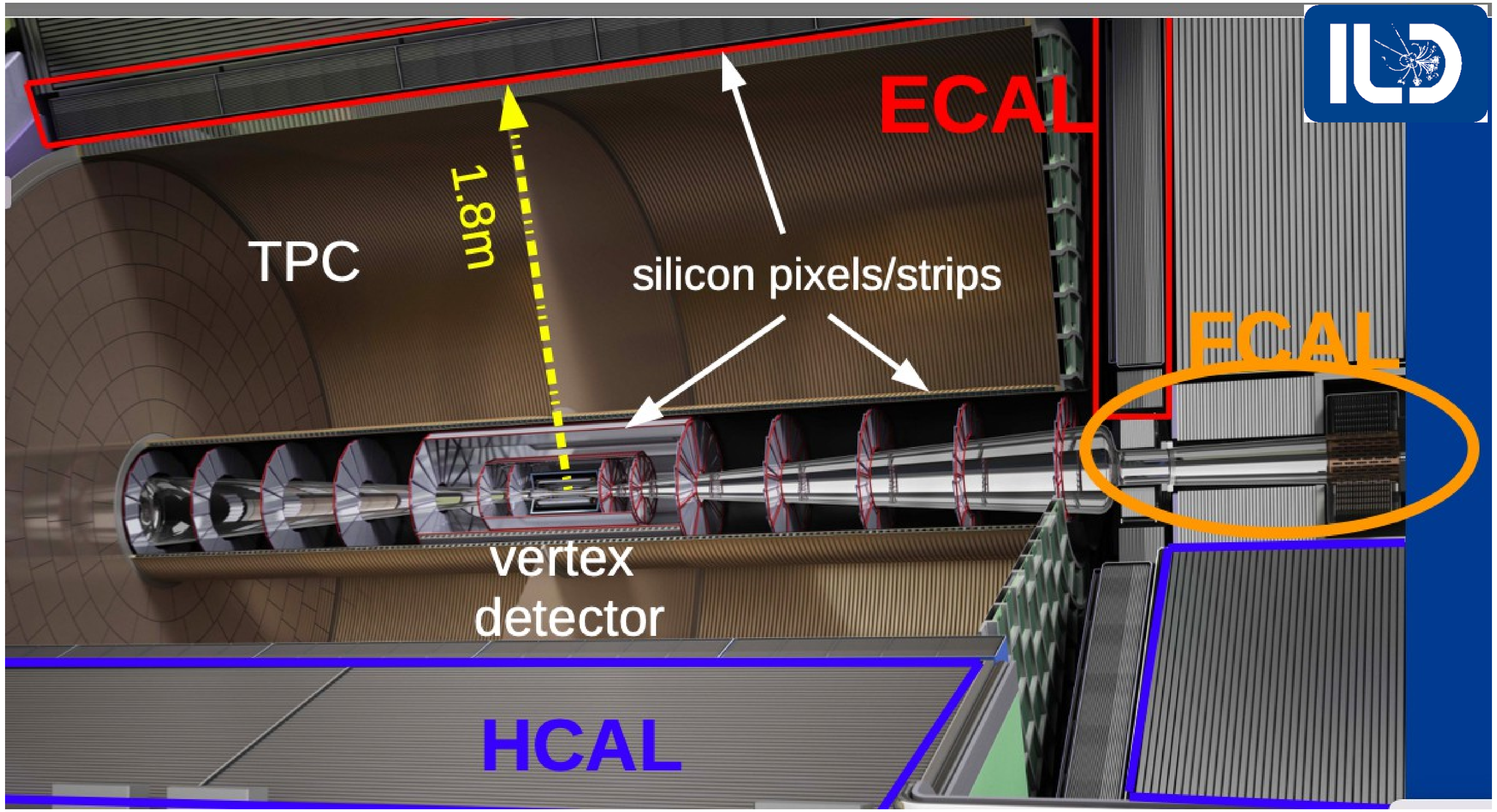


Final state will comprise events with a large number of charged tracks and jets(6+)

- High granularity
- Excellent momentum measurement
- High separation power for particles

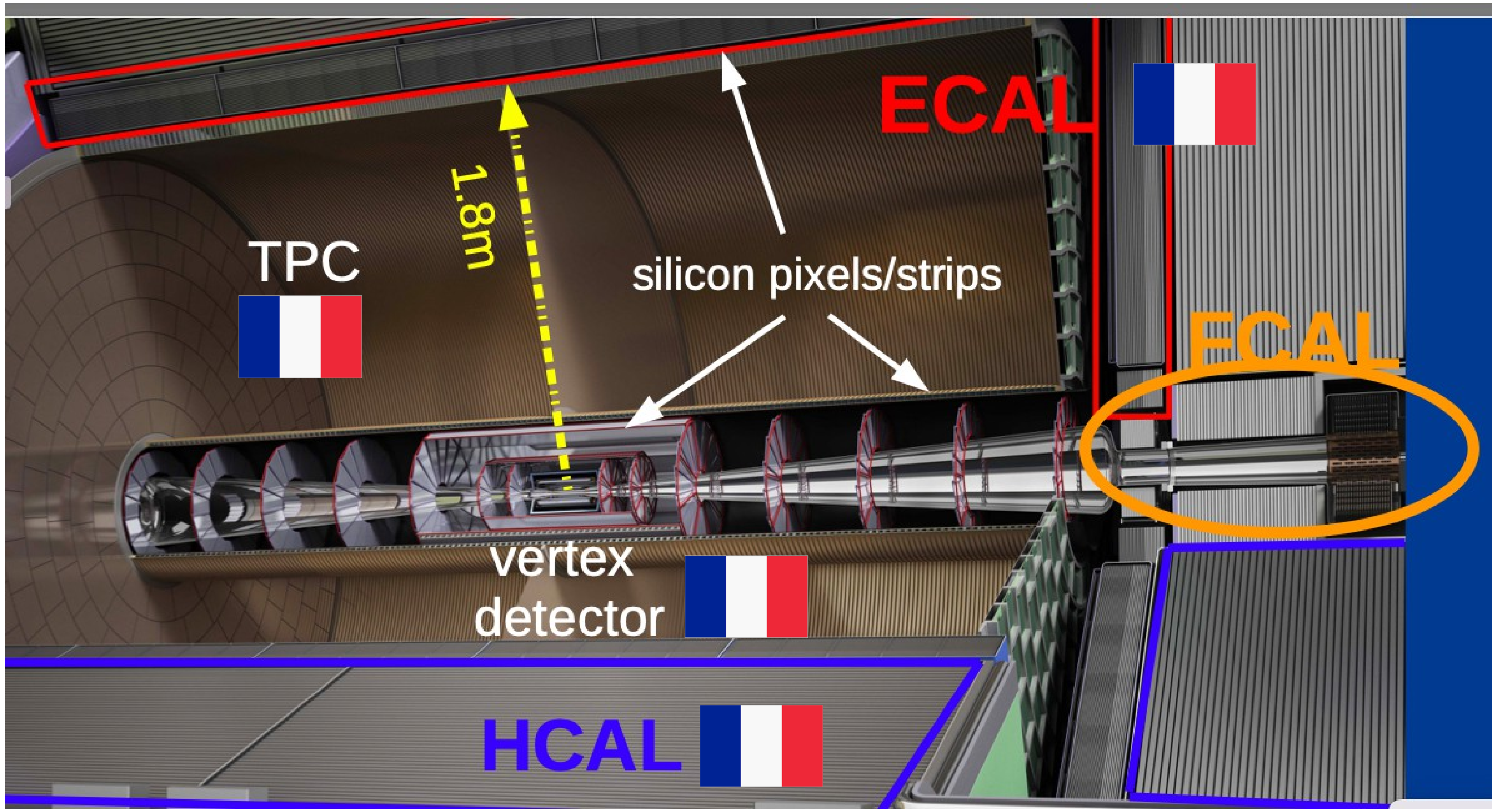
Particle Flow Detectors

ILD Concept

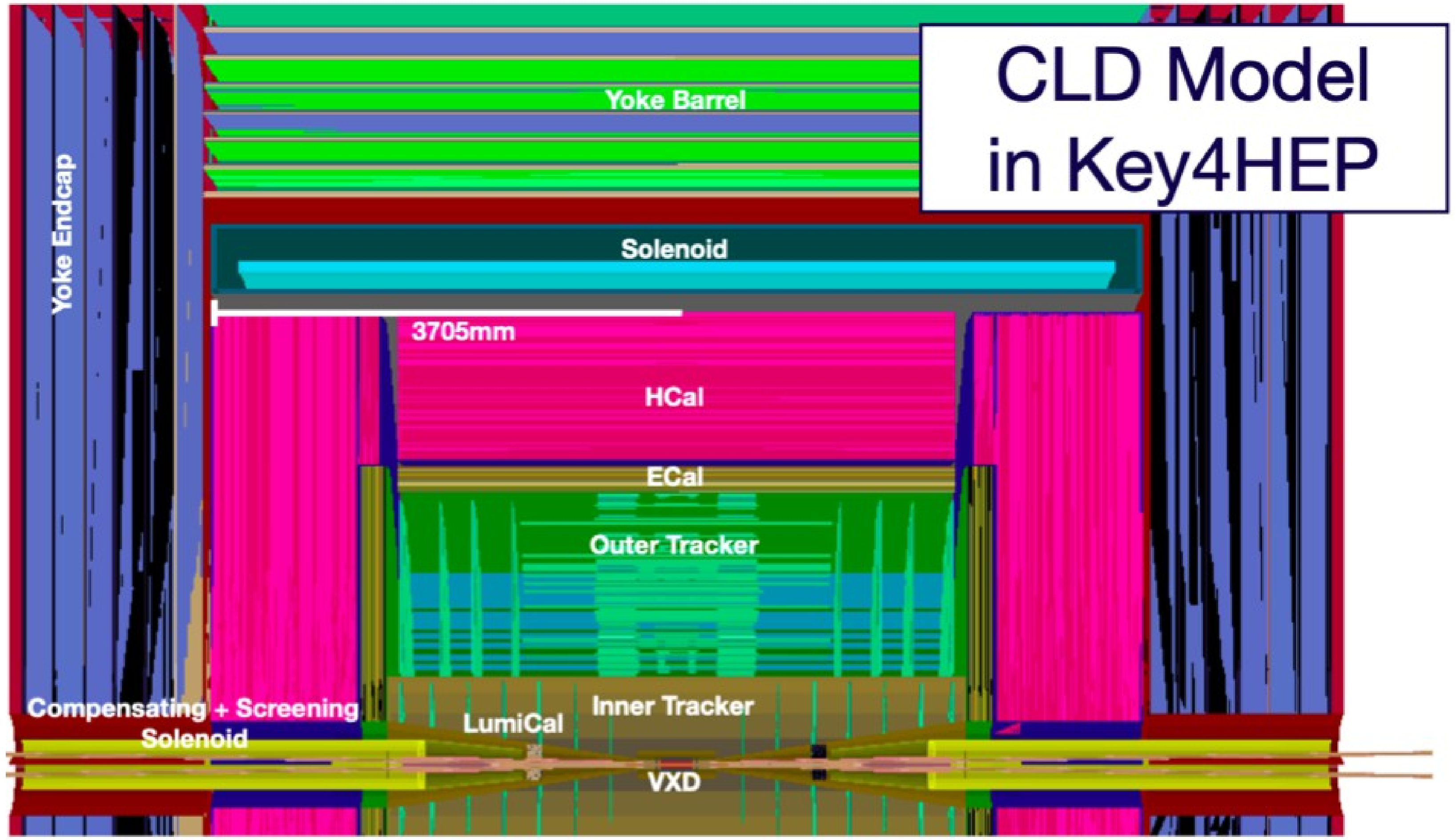


- Initiated in 2008 as merger between (European) Large Detector Concept (LDC) and the Gaseous Large Detector (GLD)
- Concept to measure e+e- collisions between the Z-Pole and 1 TeV
- Documents are
  - Letter of Intent (2009),
  - Detector Baseline Design (2013) as accompanying document to ILC TDR
  - Intermediate Design Report (2019)

ILD Detector Participation of French Groups

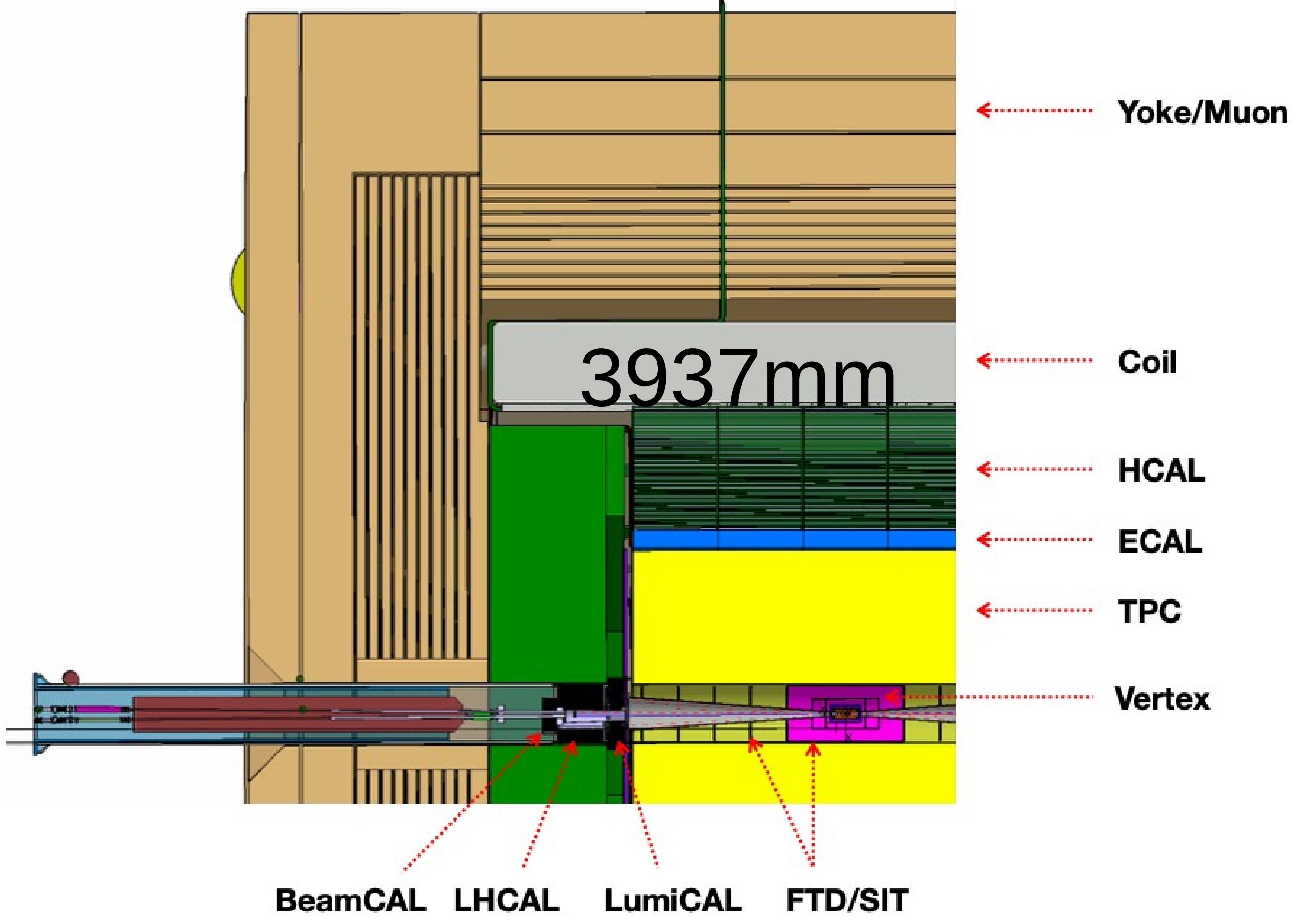


CLD and ILD Concept


CLD Model in Key4HEP

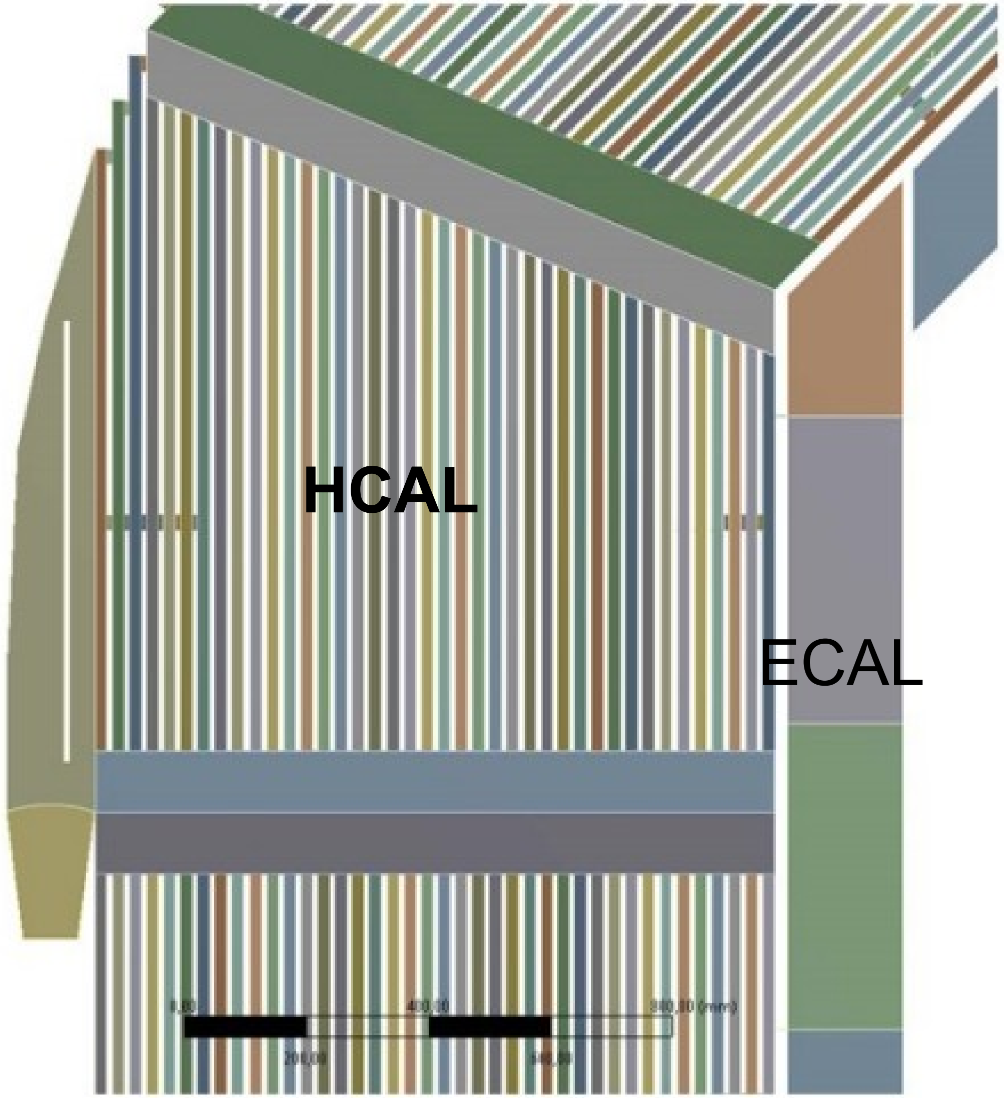
Central Silicon Tracking

For reference: ILD



Central Tracking with TPC

ILD/CLD concept and highly granular calorimeters I



- ILD/CLD are particle flow detectors
  - Implies goal to measure every particle of hadronic final state
  - Key components for PFA are highly granular calorimeters

- Calorimeter options in ILD
  - Silicon-Tungsten Ecal (LLR, IJCLab, LPNHE, OMEGA)
    - 26-30/40 layers
    - Cell size 5.5x5.5mm^2, layer depth 0.6-1.6 X_0
  - Scintillator-Tungsten Ecal
    - 30 layers
    - Strip size 5x45 mm^2, layer depth 0.7 X_0
  - Analogue Hcal
    - 48/44 layers
    - Scintillating tiles: 30x30mm^2, layer depth 0.11λ_I
    - Absorber stainless steel
  - Semi-Digital Hcal (I2PI, LPC CF, OMEGA)
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    - GRPC: 10x10mm^2, layer depth 0.12 λ_I
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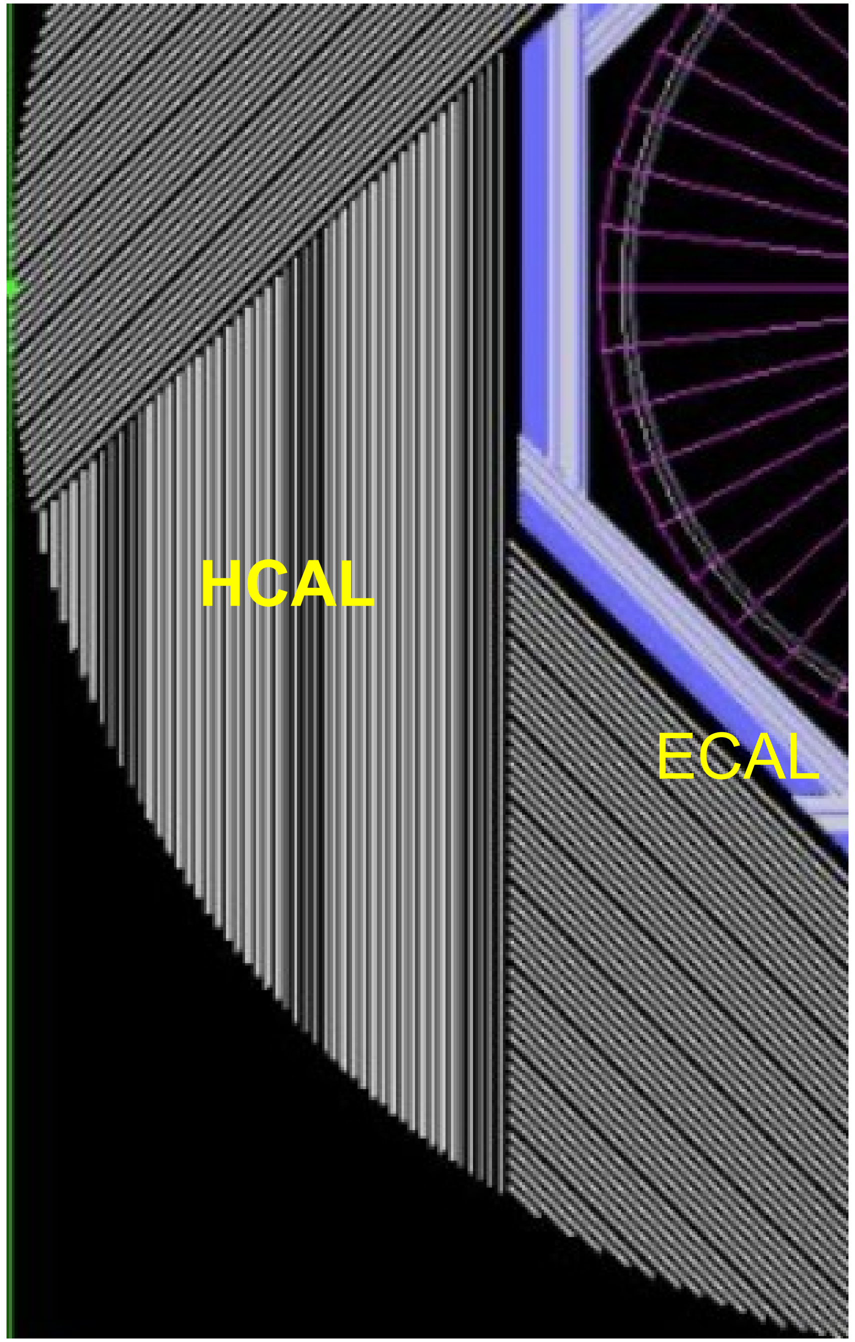
ILD/CLD concept and highly granular calorimeters II



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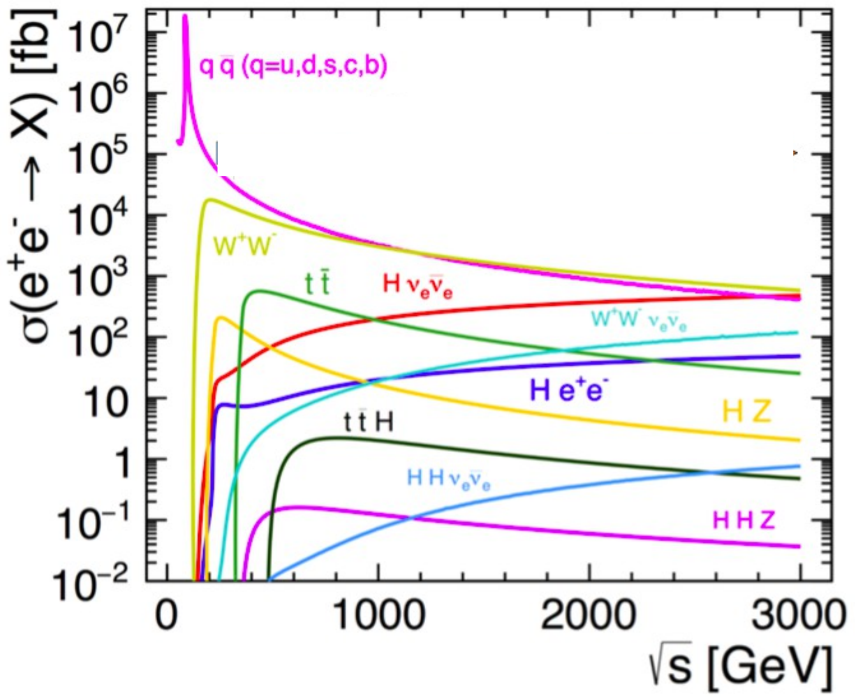
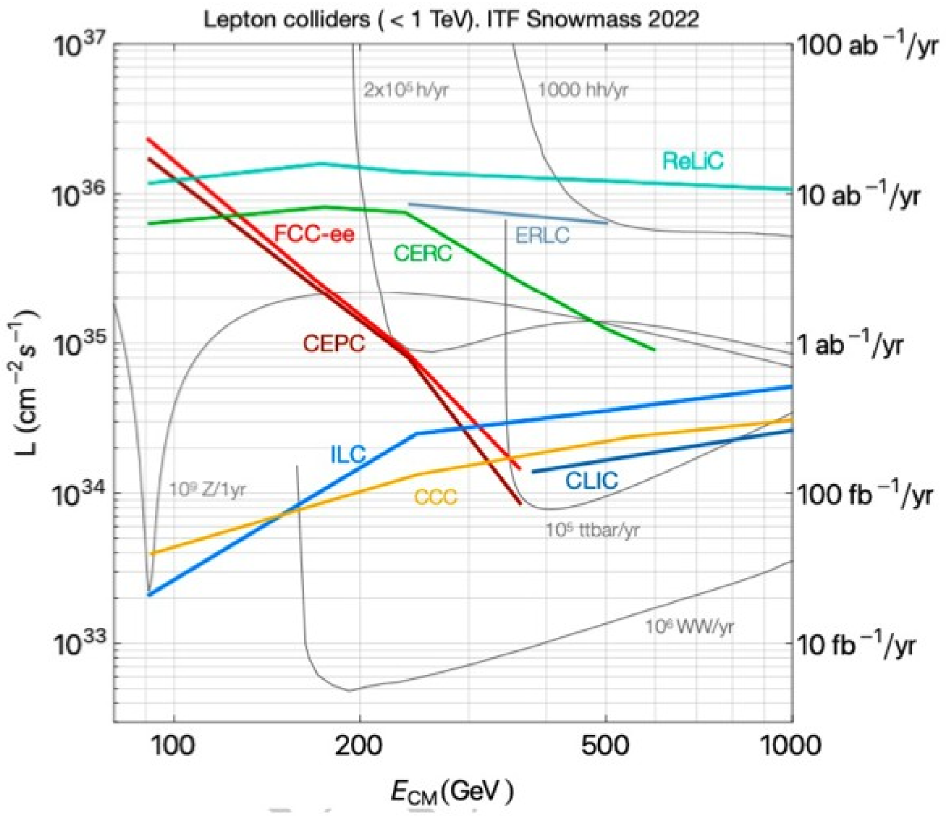
Future direction of R&D - Impact of event rates





High energy e+e- colliders:

- Physics rate is governed by strong variation of cross section and instantaneous luminosity
- Ranges from 100 kHz at Z-Pole (FCC-ee) to few Hz above Z-Pole
- (Extreme) rates at pole may require other solutions than rates above pole

- Event and data rates have to looked at differentially
  - In terms of running scenarios and differential cross sections
  - Optimisation is more challenging for collider with strongly varying event rates
    - Z-pole running must not compromise precision Higgs physics

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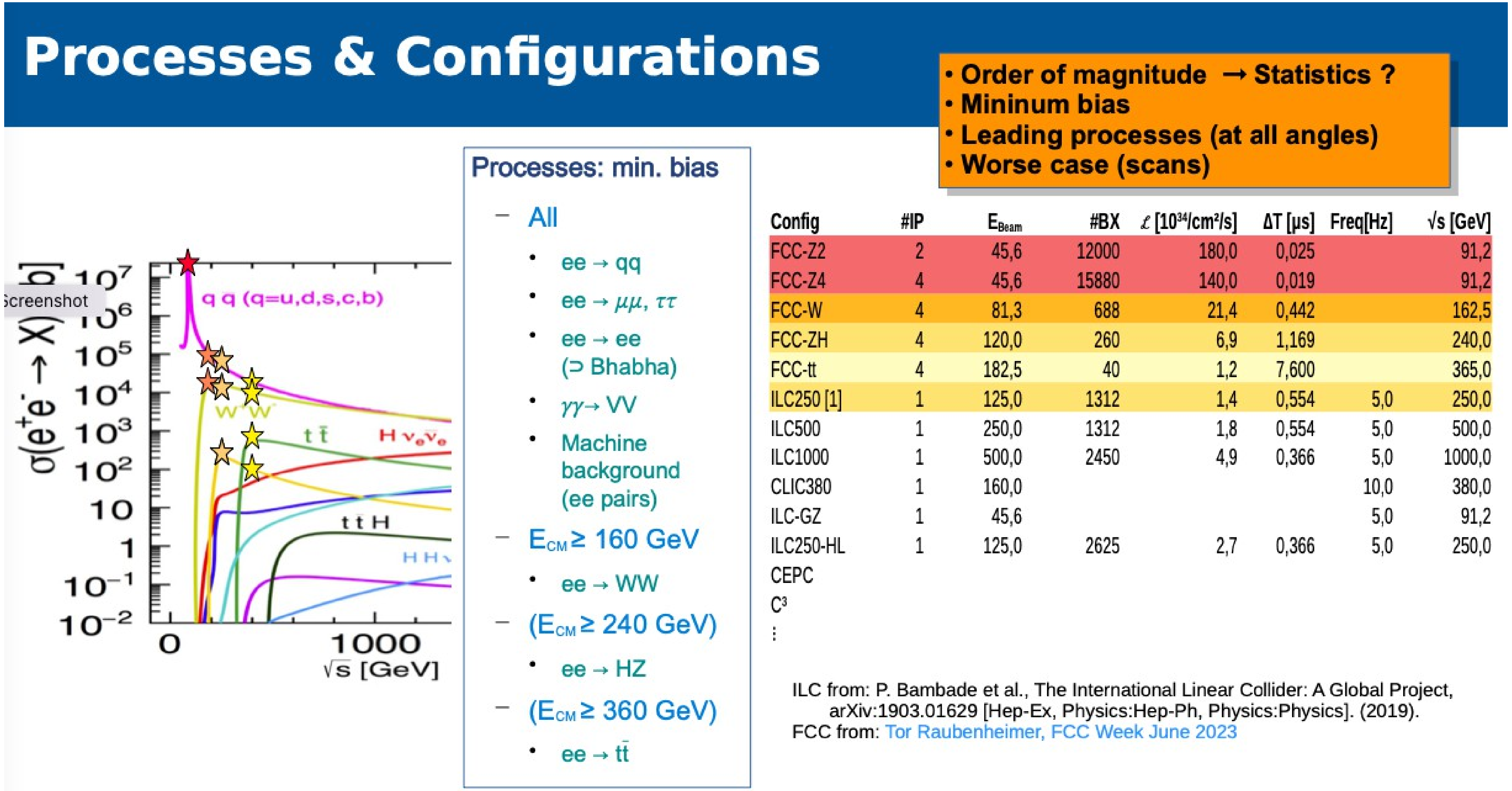


Processes & Configurations

- **Order of magnitude → Statistics ?**
- **Mininum bias**
- **Leading processes (at all angles)**
- **Worse case (scans)**

Processes: min. bias

- All
  - ee → qq
  - ee → $\mu\mu$, $\tau\tau$
  - ee → ee (⊃ Bhabha)
  - $\gamma\gamma$→ VV
  - Machine background (ee pairs)
- E_{CM} ≥ 160 GeV
  - ee → WW
- (E_{CM} ≥ 240 GeV)
  - ee → HZ
- (E_{CM} ≥ 360 GeV)
  - ee → tt̄

Config	#IP	E_{Beam}	#BX	$\mathcal{L}$ [10^{34}/cm²/s]	ΔT [μs]	Freq[Hz]	√s [GeV]
FCC-Z2	2	45,6	12000	180,0	0,025		91,2
FCC-Z4	4	45,6	15880	140,0	0,019		91,2
FCC-W	4	81,3	688	21,4	0,442		162,5
FCC-ZH	4	120,0	260	6,9	1,169		240,0
FCC-tt	4	182,5	40	1,2	7,600		365,0
ILC250 [1]	1	125,0	1312	1,4	0,554	5,0	250,0
ILC500	1	250,0	1312	1,8	0,554	5,0	500,0
ILC1000	1	500,0	2450	4,9	0,366	5,0	1000,0
CLIC380	1	160,0				10,0	380,0
ILC-GZ	1	45,6				5,0	91,2
ILC250-HL	1	125,0	2625	2,7	0,366	5,0	250,0
CEPC							
C^3							
⋮							

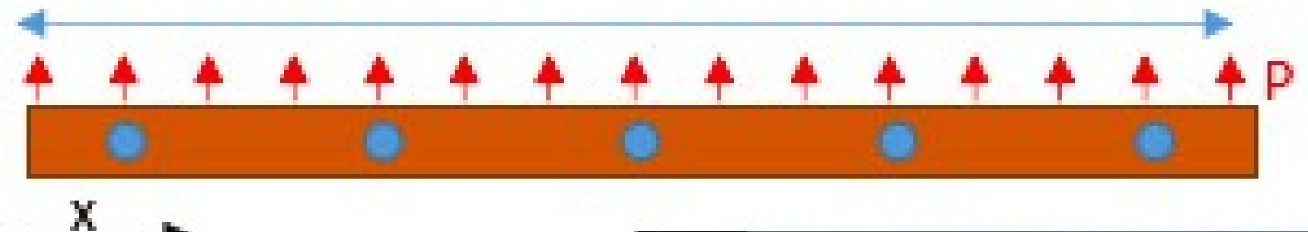
ILC from: P. Bambade et al., The International Linear Collider: A Global Project, arXiv:1903.01629 [Hep-Ex, Physics:Hep-Ph, Physics:Physics]. (2019).
FCC from: Tor Raubenheimer, FCC Week June 2023

Update in talk by Vincent Boudry

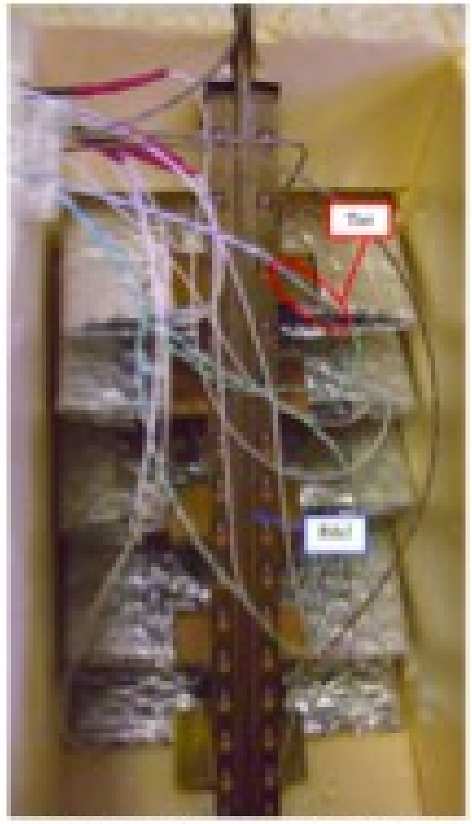
Active cooling?

Passive cooling

Active cooling




Passive cooling ramp example


Passive cooling ramp set up test


Active cooling test layout (400mm x 300mm x 3mm thick copper plate with 1,800 pipes embedded)


Active cooling set up test with water at room temperature

Large SDHCAL Module

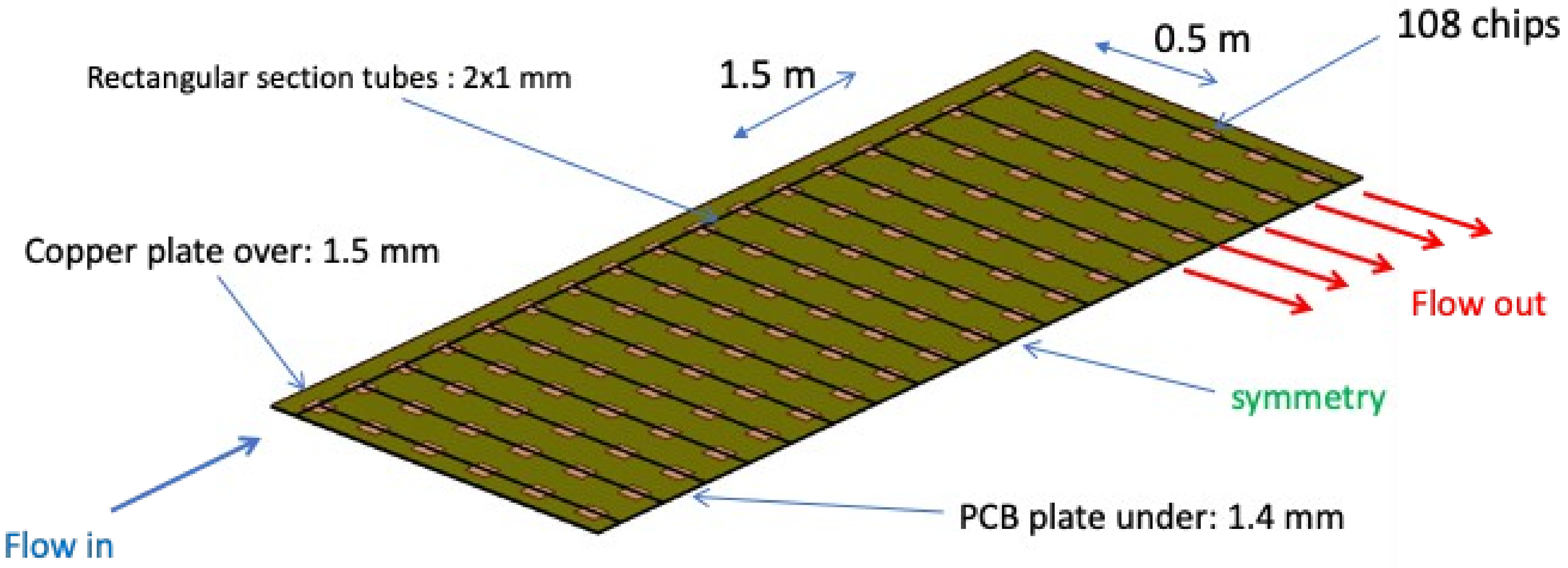
SDHCAL power consumption and cooling

The duty cycles of CEPC/FCCee are different from that of ILC and no power pulsing is possible.

The power consumption is therefore increased by a factor of 100-200 with respect to ILC and active cooling is needed.

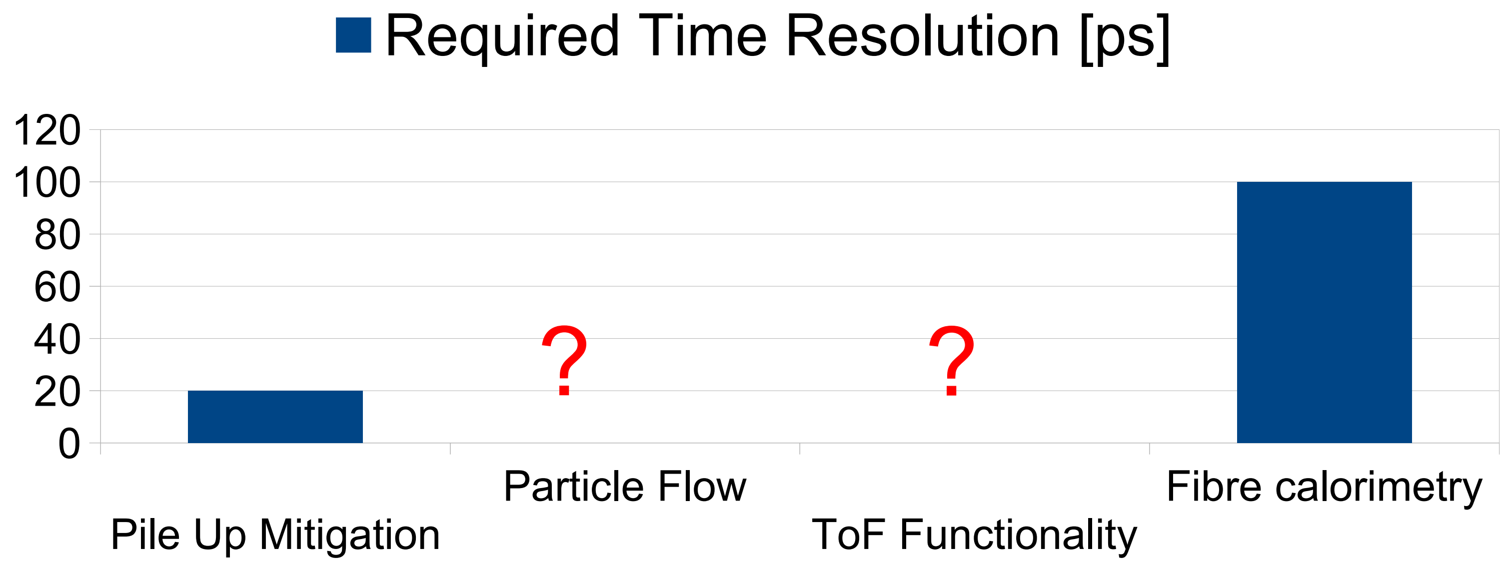
Lyon and Shanghai groups worked on a simple cooling system for SDHCAL based on using water circulating into copper pipes

0.8 mW/chips with power pulsing → 80 mW/chips without power pulsing



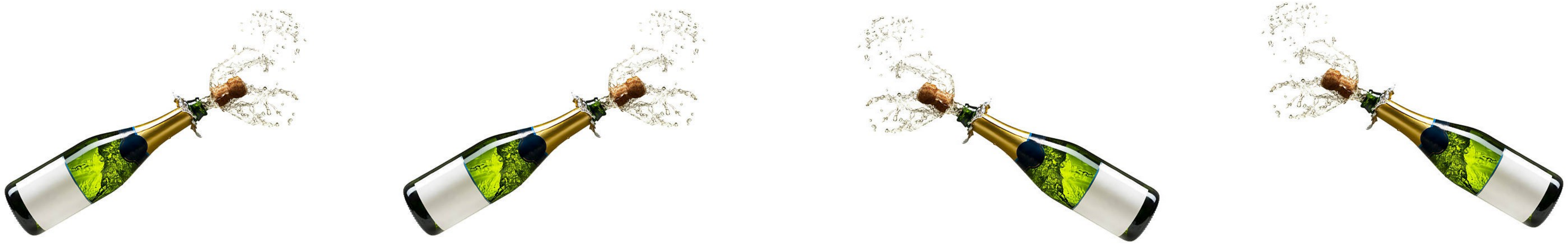
Timing ?

- Timing is a wide field
- A look to 2030 make resolutions between 20ps and 100ps at system level realistic assumptions
- At which level: 1 MIP or Multi-MIP?
- For which purpose ?
  - Mitigation of pile-up (basically all high rate experiments)
  - Support of PFA – unchartered territory
  - Calorimeters with ToF functionality in first layers?
    - Might be needed if no other PiD detectors are available (rate, technology or space requirements)
    - In this case 20ps (at MIP level) would be maybe not enough
  - Longitudinally unsegmented fibre calorimeters



- A topic on which calorimetry has to make up it's mind
  - Remember also that time resolution comes at a price -> High(er) power consumption and (maybe) higher noise levels

CALO5D

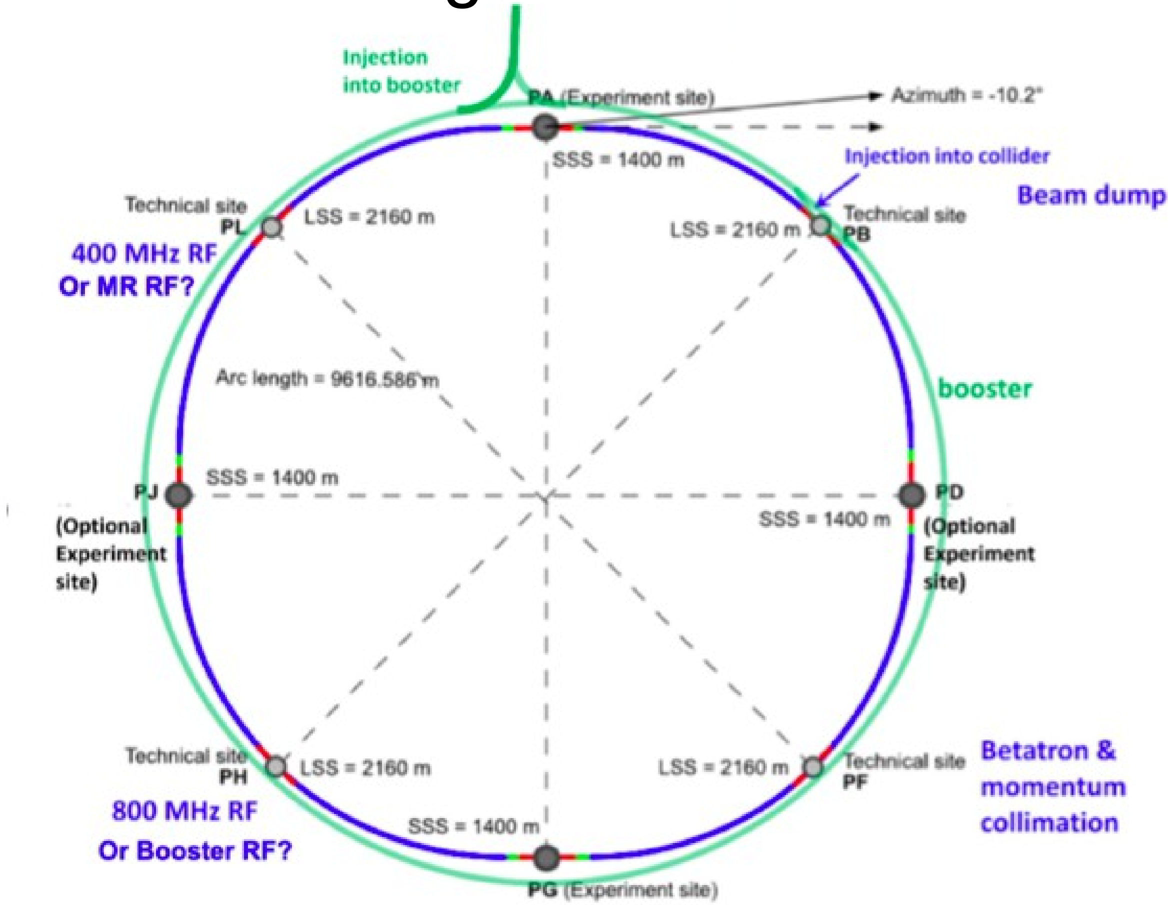


- Joined French ANR – German DFG Project on “CALOrimetry in 5 Dimensions

- French ANR: T-CALO

FCC MDI Nutshell (and poor man's) Introduction

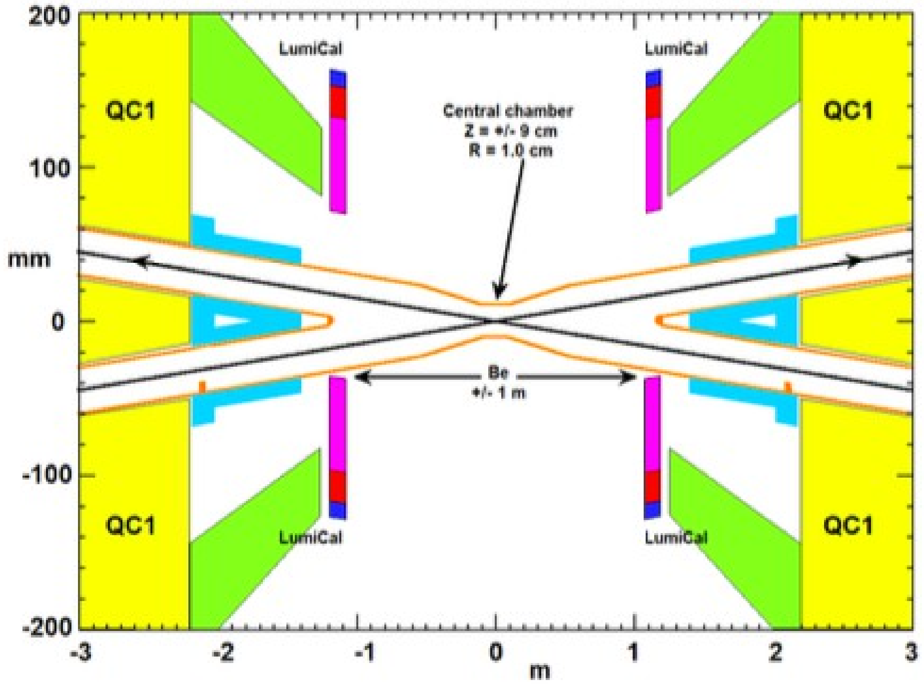
Machine layout
as shown during FCC Week 2023 Cracow



- Circumference 90,6 km
- 4IP (FCC-ee = FCC-hh)

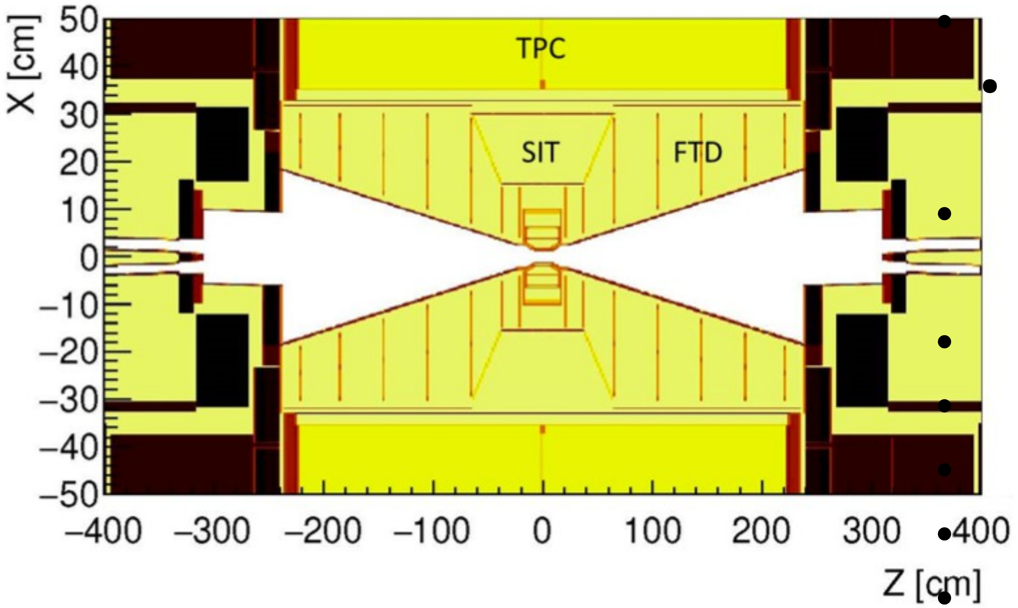
M. Boscolo, FCC Week Cracow

Typical MDI



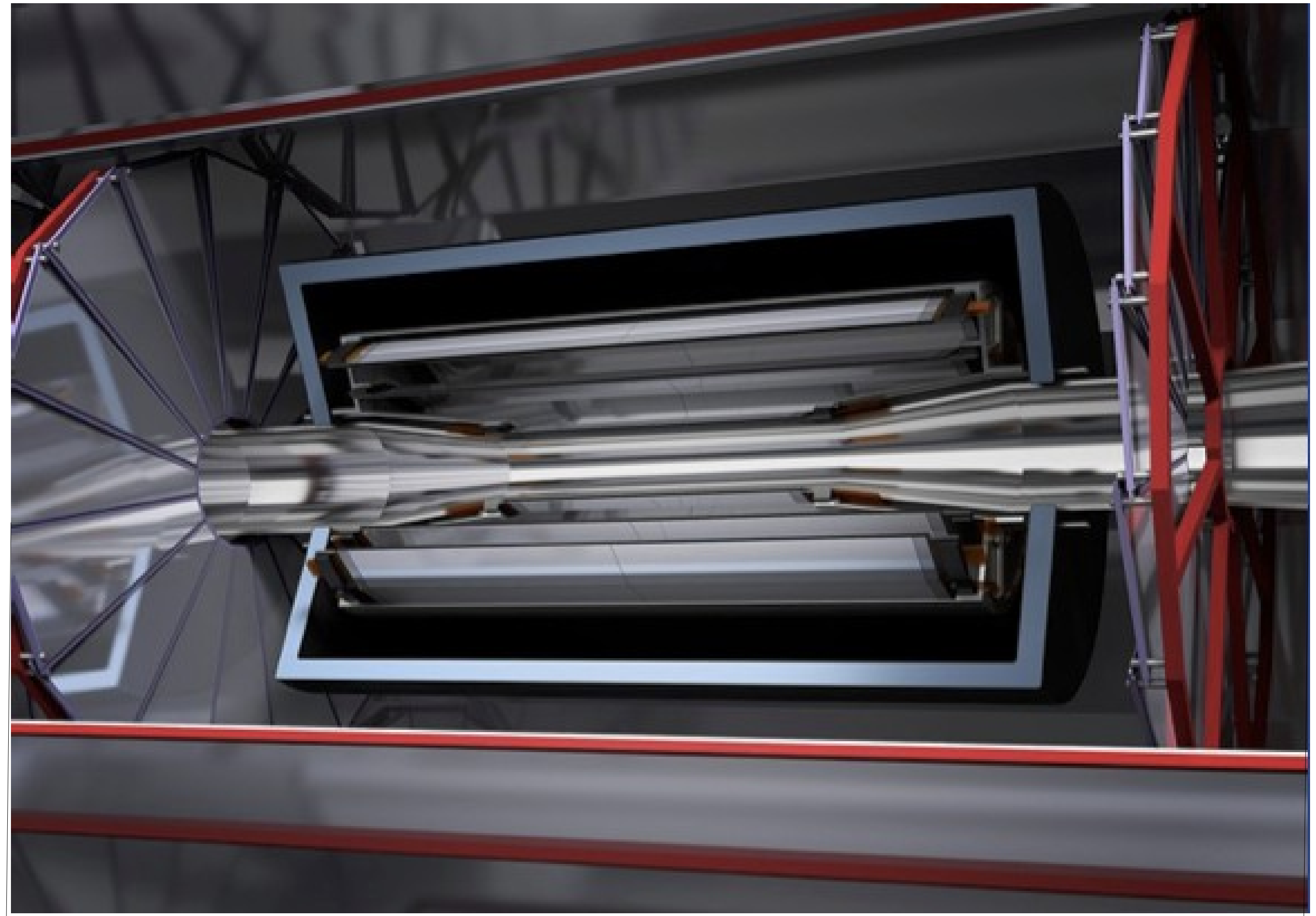
- L* = 2.2m
- Final quadropole inside detecto
  region
(and is background source)
- LumiCal at 1000mm
- => defines tracker acceptance
  cos? ~0.984
- Inner beampipe radius 10mm
- Magnetic Field 2 T
- Crossing angle ~30 mrad

Compare with ILC MDI region



- L* = 4.1m
- Final quadropole outside of detector region
- Tracker Acceptance defined by conic beam pipe(due to blown-up beam)
- cos? ~0.995
- LumiCal at ~2500mm
- Inner beampipe radius 16 mm
- Magnetic Fiels 3.5-4 T
- Crossing angle 14 mrad

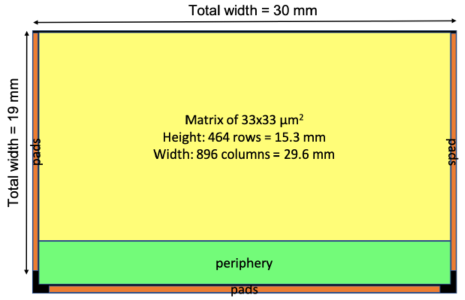
Vertex Tracking

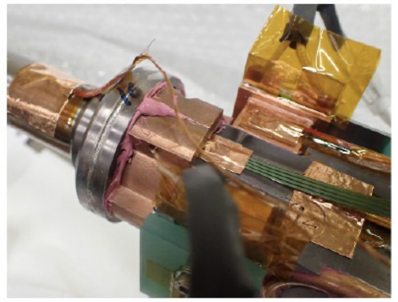


Big question: Radius of beam pipe

- Groups in France on ILD: IPHC, IJCLab
  - Profits from ANR recently obtained (?)
- Low material is overall challenge

- Experience on Belle II





- Introduction of novel ideas from ALICE III
  - “bent” Si layers

Summary and outlook

- French groups are involved in many detector components of ILD
  - In some cases the step to CLD would not be that big

- In all cases MDI is a big challenge

- Activities well matched to international DRD programm
  - ... benefit from recently obtained ANR + DFG Grants

- All activities have potential to be developed to full system level
  - .... for any Higgs Factory including FCC

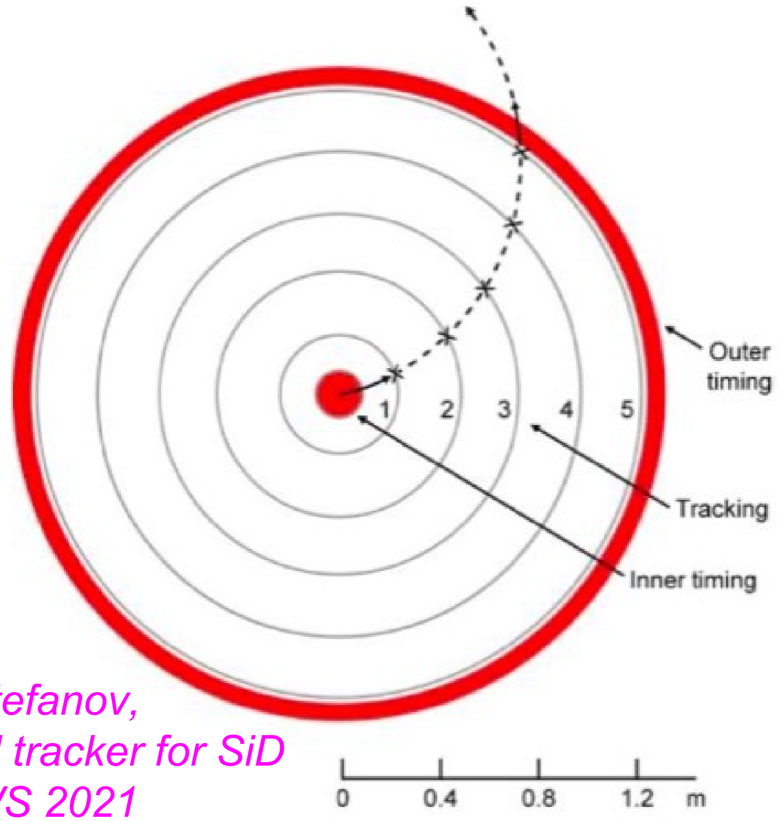
- For ILD it is/was always beneficial to closely tie detector R&D and detector integration
  - ... requires sustained engineering support

Backup

In absence of gaseous tracking

Two options (not mutually exclusive)

ToF System



K. Stefanov,
Pixel tracker for SiD
LCWS 2021

(With two closed eyes)
ToF systems might work
up to 10 GeV

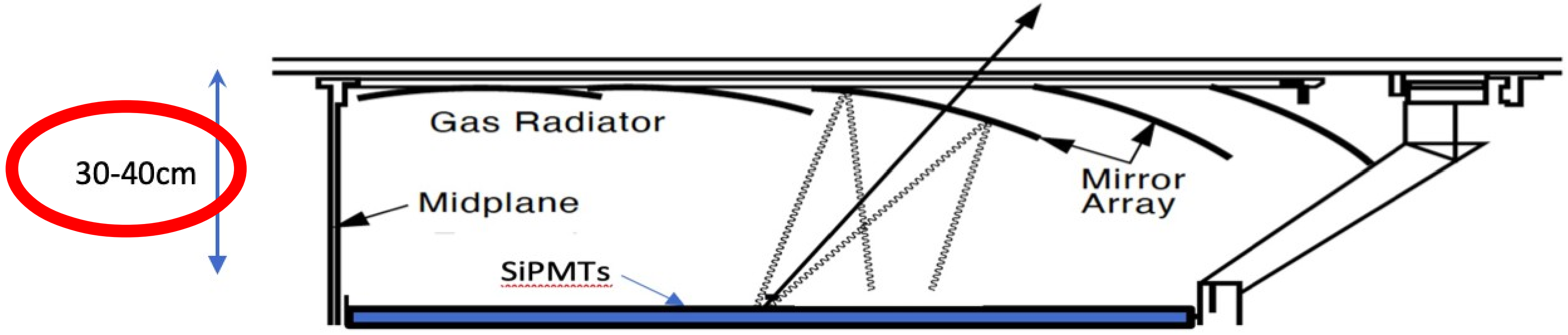
Cerenkov Detector

à la J. Vavra

Three options:

- DIRC: 6- 7 GeV/c
- Focusing Aerogel RICH: 9-10 GeV/c
- Gaseous RICH: 10-30 GeV/c

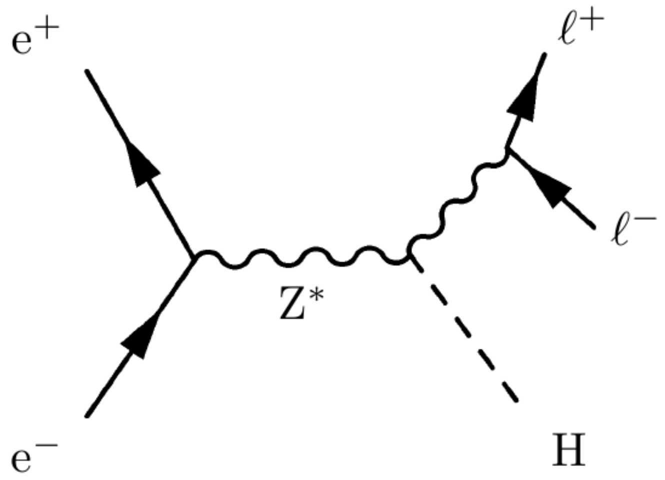
Gaseous RICH looked at for SiD:

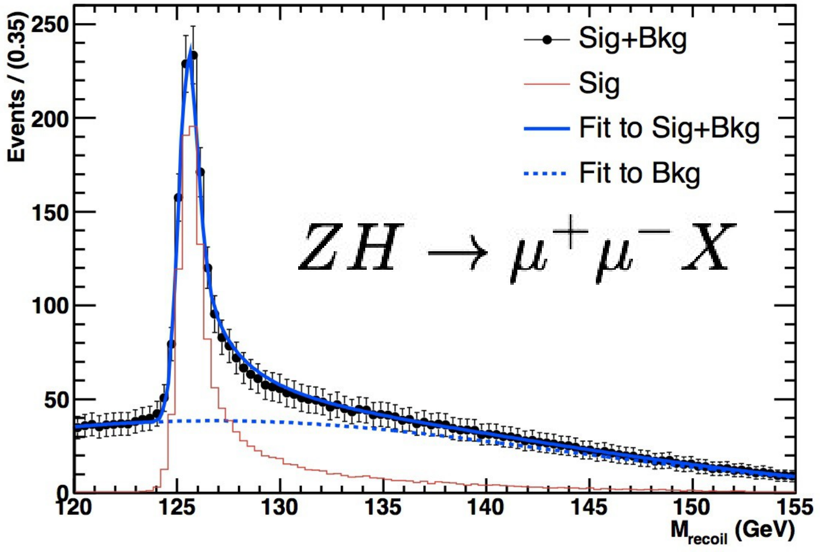


- ToF and Cherenkov are options for PiD systems
- Cherenkov most likely needed to go to high momenta
- Both lead to ” compressed tracking systems
- New ideas to minimise this compression might be needed
- ... and material is added in front of the calorimeter

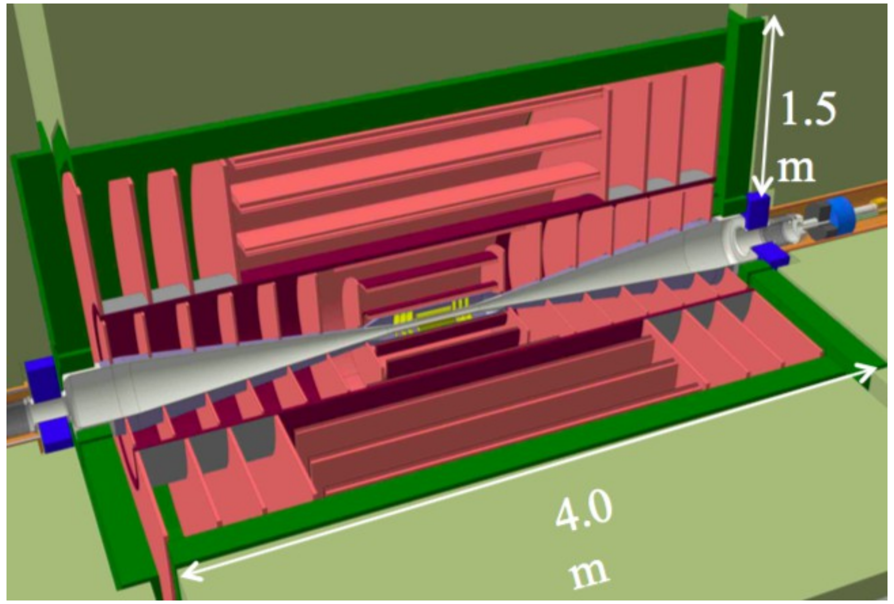
Central Tracking

"Royal" task of central tracking system
Precise measurement of charged particles in e.g.

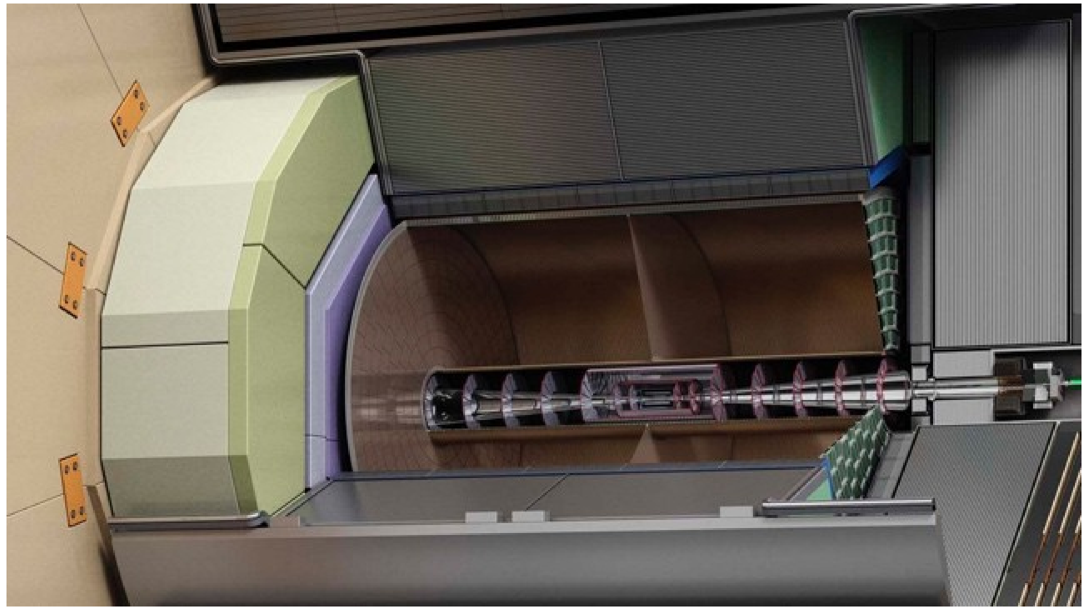




Option 1: All silicon tracking



Option 2: Gaseous tracking

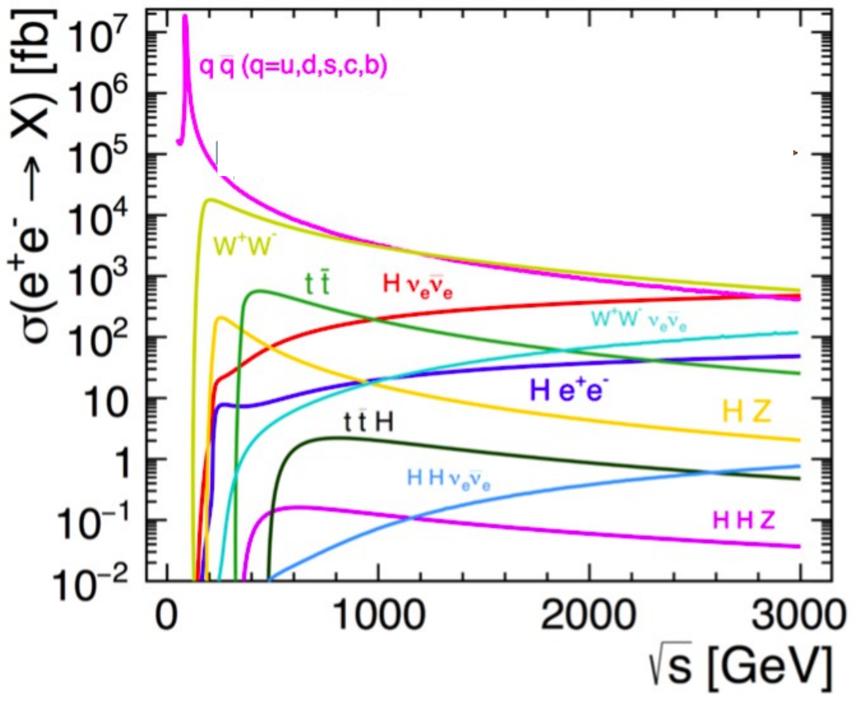


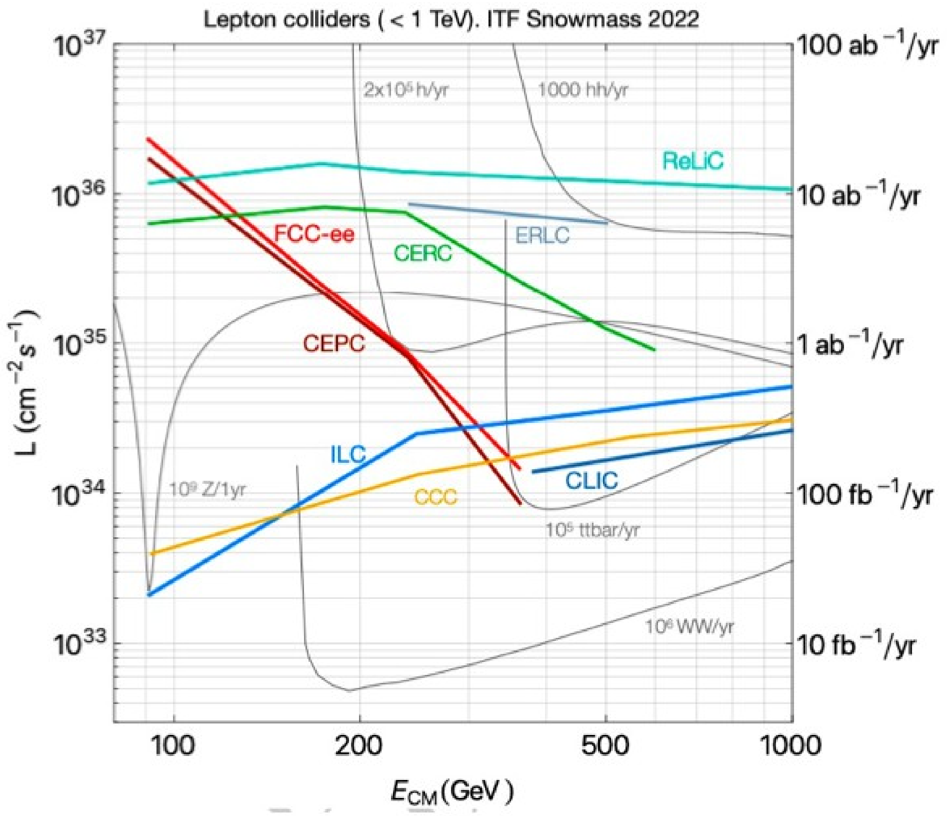
Gluckstern Formula:

$$\frac{\Delta p_t}{p_t^2} = \frac{\sigma_{r\phi}}{0.3\,L^2\,B}\sqrt{\frac{720}{N+4}}$$

Relates track momentum resolution with single point resolution **σ** with **N**umber of hits and track length **L** and magnetic Field **B**

Future direction of R&D - Impact of event rates





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