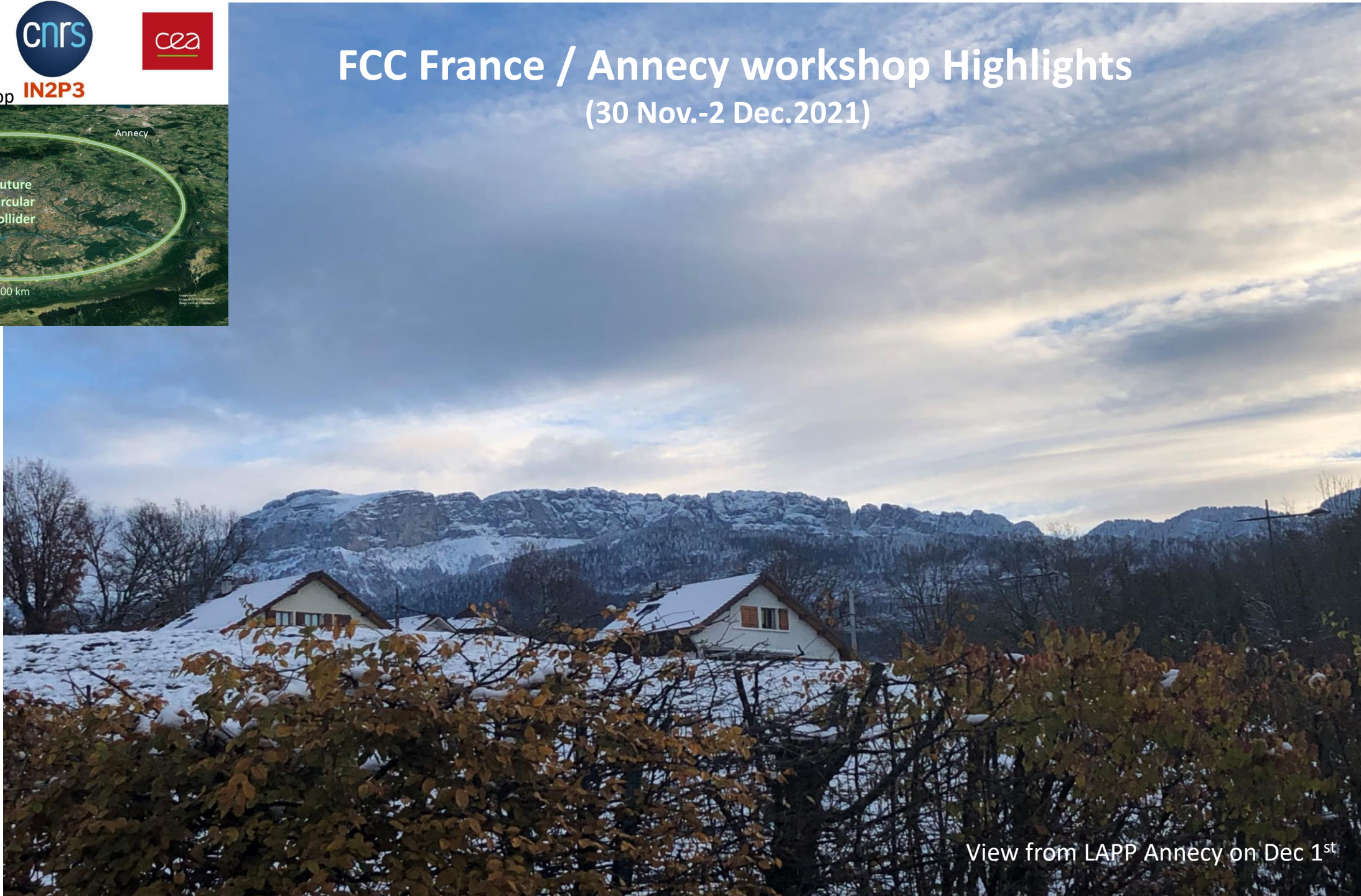


FCC France / Annecy workshop Highlights

(30 Nov.-2 Dec.2021)

G. Bernardi
15/12/2021

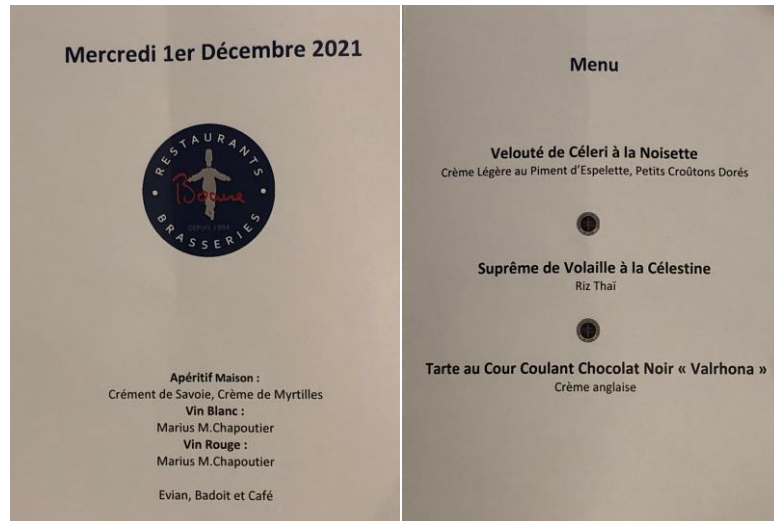
- Overview of the program
- Highlights
- Next steps



View from LAPP Annecy on Dec 1st

Welcome (and temporary goodbye ?) to the Hybrid world !

- 155 registered participants (90 where Zoom-only participants, and 90% of them connected to at least one session)
- Of the 65 planning to come to LAPP/Annecy, 58 made it : 2/3 from France, 1/3 from CERN/Danemark/Italy/Germany
- ~40 made it to the banquet, less on the last day photo ;)



- THANKS to the LAPP for inviting us at this excellent banquet, at Irma Bocuse !
...and also for the Cocktail/Raclette on the first day



Overall, it was very successful !! good balance between presentations/questions from the room and from video, and good discussions during coffee breaks and lunches/dinners

The Intro Session



Overall R&D Effort @ IN2P3

Accelerators (A&T portfolio):

- 2 main scientific programs related to FCC/Higgs+EW factory:
 - SCPL: Superconducting RF cavities & high-power Proton Linac
 - LPAC: Laser-Plasma Acceleration & high-energy Colliders
- 10 master-projects

Technologies (A&T portfolio):

- ITIN: Innovative Technologies & Instrumentation for NP & PP
- 7 master-projects linked with FCC/Higgs Factory

Detector R&D (P&H portfolio):

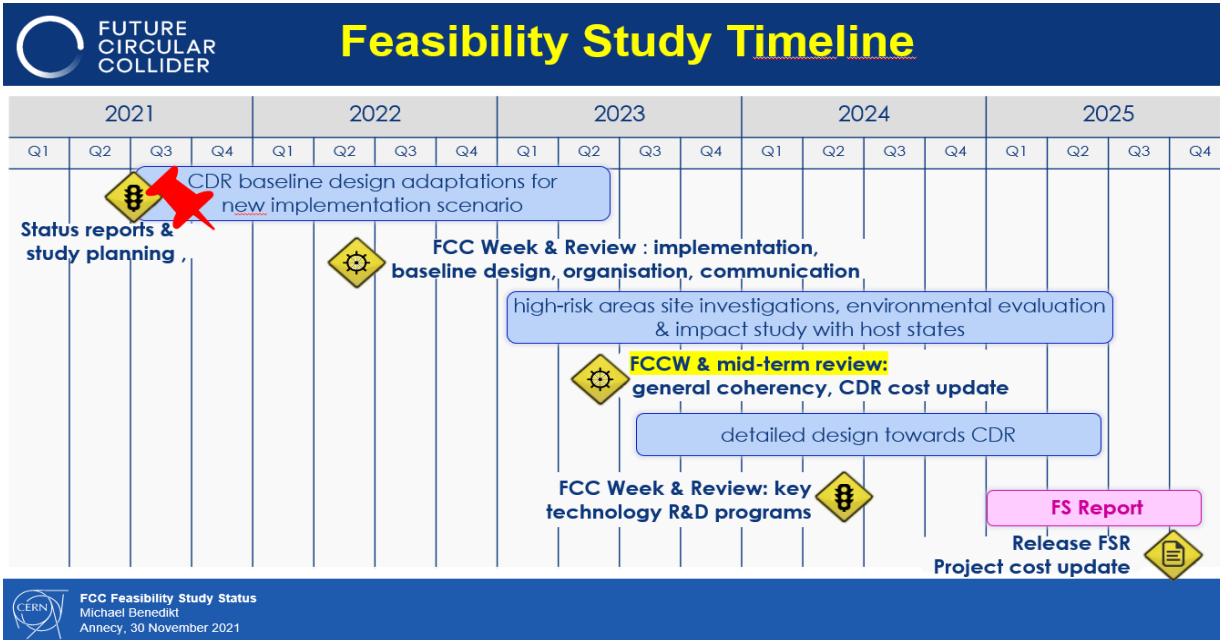
- INDE: INnovative DEtectors

Prospective physics, simulation, detector optim (P&H portfolio):

- FCC-Phys MasterProject

Rough estimate of IN2P3 effort on FCC/Higgs+EW factory in 2021:

- 100 FTE
- 1.2M€ investment + extra sources
- 4.5M€ manpower



13:35

e+e- collider efforts in France ¶

Orateur: Laurent Vacavant (IN2P3)

13:45

Potential role of Annecy in FCC

Orateur: Giovanni LAMANNA (LAPP - IN2P3/CNRS)

GLamanna_FCCAnn...

13:55

The FCC Feasibility and Innovative Studies

Orateur: Michael Benedikt (CERN)

211130_FCC-Feasib...

14:25

FCC Innovative Study socio-economic impact

Orateur: Leslie Alix

FCCIS Socio-econo...

14:45

FCCIS: Engagement and Communication Strategy

Orateur: Claire Adam (LAPP)

ClaireAdam-WP5rep...

15:05

FCC as a global collaboration

Orateur: Emmanuel Tsesselis (CERN)

Tsesselis FGC.pptx

15:20

FCC-ee Physics potential and the PED organization

Orateur: Patrick Janot (CERN)


Accelerator session

Thanks Angeles, Pierre, Giacomo, Benjamin

Président de session: Angeles Faus-Golfe (IJCLab)


16:10 Introduction to the accelerator sessions


Orateur: Angeles Faus-Golfe (IJCLab)

 FCC_France_2021_...

16:15 High Field Magnets R&D status update:


Orateur: Etienne Rochepault (CEA Paris-Saclay)

 FCCWorkshop21_M...

 FCCWorkshop21_M...


16:33 Stability and positioning for FCCee

Orateur: Eva Montbarbon

 2021-11-30_Stabilit...


16:50 SRF R&D for FCCee

Orateur: Mohammed Fouaidy (IPNO)

 Meeting-FCC-Franc...

17:07 Optimization of e⁺ sources for FCCee

Orateur: Salim Ogur (IJCLab)

 FCC-France_Positro...

Theory @ FCC(ee) and (hh)

Président de session: Giacomo Cacciapaglia (IP2I Lyon)

09:00 Introduction to the theory session ¶

Orateur: Giacomo Cacciapaglia (IP2I Lyon)

 FCCTHIntro.pdf


09:10 MadGraph5_aMC@NLO for ee colliders

Orateur: Olivier Mattelaer (FNRS - CP3)

 21_11_30_eecollider...

09:30 Determination of Dark Matter Properties at e⁺e⁻ colliders

Orateur: Alexander Belyaev (Southampton University)

 Belyaev-FCC-2021-...

09:50 A Z-portal to the dark sector at FCC-ee

Orateur: Ennio Salvioni (CERN)

 Talk_FCC_France_u...


10:10 Neutrino physics in high-energy proton-proton collisions

Orateur: Richard Ruiz (Institute of Nuclear Physics (IFJ) PAN)

 rruiz_FCCfrance_Nu...

10:30 Testing new-physics models with global comparisons to collider measurements

Orateur: Mohammad Mahdi AITakach

 FCC-France-1-12-21...

10:50 Testing charge-radius coupling of the composite Higgs boson at hadron colliders

Orateur: Antoine LESAUVAGE

First presentation of the plans of the detector concepts working group

- ◆ Develop, study and evaluate DCs: Make sure DCs are capable of delivering the detector requirements
 - Main tool: Detailed simulation studies
- ◆ Optimize compatibility of DCs with operation at FCC-ee:
 - MDI layout; timing and background conditions
- ◆ Identify and encourage necessary R&D in the direction of the requirements for FCC-ee
- ◆ Gather and engage a wide community around the DC effort; foster collaboration towards the common goal of developing FCC-ee DCs
- ◆ Function as a forum, where progress, ideas and results from individual R&D efforts and test-beam activities are presented, discussed and reviewed in view of FCC-ee detector requirements and physics.
 - Follow technological developments that could lead to new physics opportunities

+ detailed report of the ECFA R&D roadmap + overview of unified SW R&D Overview for the Higgs Factories

Synergies Dominate

Detector Technology	Linear & Circular Colliders common R&D	Differences
All	test infrastructure prototype electronics software for reconstruction and optimisation	readout rates power and cooling requirements
Silicon Vertex and Track Detectors	highest granularity and resolution, timing ultra-thin sensors and interconnects simulation and design tools low-mass support structures cooling micro-structures	emphasis on timing (background) and position resolution
Gaseous Trackers and Muon Chambers	ultra-light structures for large volumes industrialisation for large area instrumentation eco-friendly gases	DC and TPC presently considered only at some colliders
Calorimeters and Particle ID	highly compact structures and interfaces advanced photo-sensors and optical materials ps timing sensors and electronics	emphasis on granularity and stability DR and LAr presently only considered for circular

Detectors Concepts and Software

Président de session: Mogens Dam

17:35

The Detector Concepts working group plans

Orateur: Mogens Dam (Niels Bohr Institute, Copenhagen)



20211130-FCCFran...

17:55

The ECFA R&D roadmap

Orateur: Felix Sefkow (DESY)



ECFA-RM4FCC.pdf

15:40

Examples of detector concept for FCC-ee: CLD & IDEA

Orateur: Paolo Giacomelli (INFN Bologna)



Detector-concepts-...

18:15

Software for detector concepts development

Orateur: Valentin Volkl (CERN)



2021-11-30-FCCAnn...

18:35

Software for e+e- analysis

Orateur: Thomas Madlener (DESY)



edm4hep_analysis_...

18:55

Overview of the Software for FCC

Orateur: Clement helsens (CERN)

R&D session

On going R&D will lead to additional Detector concepts.
R&D Developments in Tracking and Calorimetry, many of these Projects having been encouraged by Linear Colliders, which can now also be adapted for Circular ones.



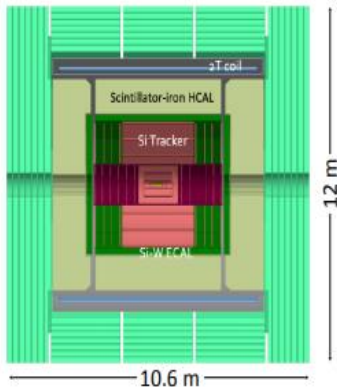
CDR: 2 Detector concepts



"Proof of principle concepts"

- Not necessarily matching (all) detector requirements, which are still being spelled out

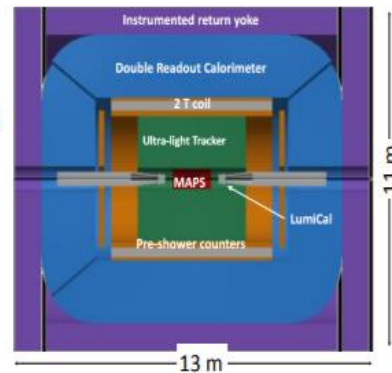
CLD



- Based on CLICdet detector design; profits from technology developments carried out for LCs
 - ▢ All silicon vertex detector and tracker
 - ▢ 3D-imaging highly-granular calorimeter system
 - ▢ Coil *outside* calorimeter system
 - ▢ Muon system made of RPC layers embedded in the iron yoke

<https://arxiv.org/abs/1911.12230>, <https://arxiv.org/abs/1905.02520>

IDEA



- New, innovative, possibly more cost-effective concept
 - ▢ Silicon vertex detector
 - ▢ Short-drift, ultra-light wire chamber
 - ▢ Dual-readout calorimeter
 - ▢ Thin and light solenoid coil *inside* calorimeter system
 - ▢ Muon system made of 3 layers of μ RWell detectors in the return yoke

<https://pos.sissa.it/390/>

R&D projects

Président de session: Jessica Leveque (LAPP)

14:00

CMOS status

Orateur: auguste besson (Institut Pluridisciplinaire Hubert Curien)

FCC_2021_12_Anne...

14:20

DICE status

Orateur: Marlon Barbero (CPPM)

20211201_FCC_DIC...

14:40

Update of R&D on fast detector for ToF using Micromegas

Orateur: Thomas Papaevangelou (CEA Saclay)

PICOSECMF_FCC-F...

15:00

Calice for FCC

Orateur: Vincent Boudry (LLR - CNRS, École polytechnique/IPP Paris)

2021-12-01_CALICE...

15:20

Powder-O Calorimetry

Orateur: Jacques Lefrançois (IJCLab)

Annecy_5.pptx

11:40

LAr Calorimeter for FCC-ee

Orateur: Nicolas Morange (CNRS/UMR9012)

LAr-FCC-Workshop....

16:05

Combining dual-readout crystals and fibers in a hybrid calorimeter for the IDEA

Orateur: Marco Toliman Lucchini (INFN & University of Milano-Bicocca)



What is a Calice Calorimeter

1) It is not a single calorimeter

- Calorimetric system : **ECAL+HCAL** + (X_0 -thin) High Performance Tracker (system) complementary and well associated \rightarrow small distance (NO MAGNET on the way)

2) Optimised for Particle Flow

- NOT the best calorimeter system (= Best Raw Energy measurement of single part.)
- Measurement and Identification of all particles \supset (esp) in jets, τ , ...

best Boson mass measurement $H \rightarrow ZZ, WW; Z, W \rightarrow jj$.

$$\Delta(M_Z, M_W) \Rightarrow \sigma(E_j)/E_j \sim 30\%/\sqrt{E} \sim 3.5\text{--}5\%$$

3) CALICE = R&D on detectors (prototypes)

SiD, ILD, CLICdet, CECF_{Baseline} = detector concepts implementing CALICE

physics performances, \supset PFA ('physics' prototypes) \Rightarrow 'technological' prototypes

Particle Flow Approach

Full Reconstruction of single particles

- Charged mostly from tracker
- Neutrals only from calorimeters

Large Tracker

- Precision and low X_0 budget
- Pattern recognition

High precision on Si trackers

- Tagging of beauty and charm

Large acceptance

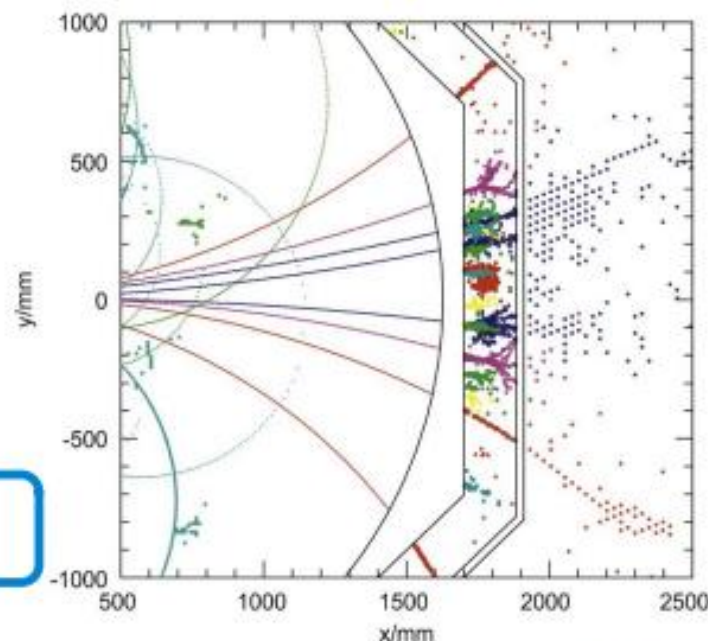
HG Imaging Calorimetry

Particle Flow Algorithms :

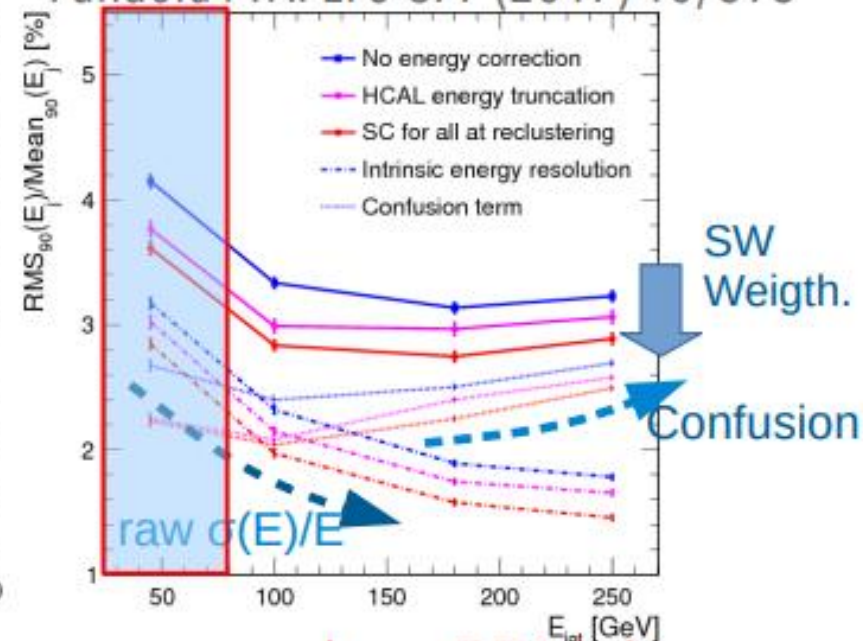
- Jets = 65% charged Tracks + 25% γ ECAL + 10% h^0 E+HCAL
- TPC $\delta p/p \sim 5 \cdot 10^{-5}$; VTX $\sigma_{x,y,z} \sim 10 \mu\text{m}$

+ timing

H. Videau and J. C. Brient, "Calorimetry optimised for jets," (CALOR 2002)



Pandora PFA: EPJ C77 (2017) 10, 698



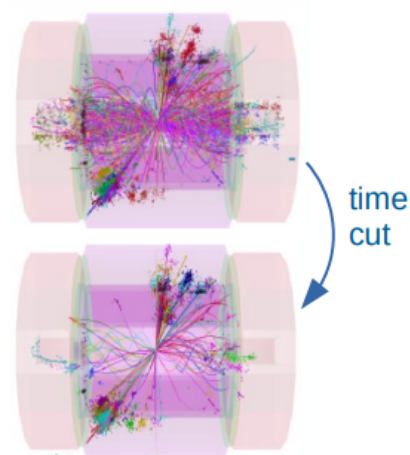
4,5 prototypes, 15+ years of R&D, all tested

personal opinion,
not the collaboration's

Si-W ECAL	(ALICE FoCAL)	Scint-W ECAL	AHCAL	SDHCAL
				
0,5×0,5 cm ² ×15 (→30) Si layers + W	0,003×0,003 cm ² × 24 MIMOSA layers + W	0,5×4,5 cm ² ×30 Scint+SiPM lay. + SS	3×3 cm ² × 38 Scint+SiPM lay. + SS	1×1 cm ² × 48 layers GRPC + SS
Resolution – R _M ✓ Intégration ✓ Cost – Calibration ✓	Resolution ✓ R _M ✓✓ Intégration ?? Cost ?? Calibration ?	Resolution ✓ R _M ? Intégration ✓ Cost ✓ Calibration –	Resolution ✓ λ ✓ Intégration ✓ Cost ✓ Calibration –	Resolution ✓ λ ✓ Intégration (Gaz) – Cost ✓ Calibration –
LLR, IJCLab, LPNHE, (LPSC) IFIC, Kvushu, KEK. ...	DE, NL, CERN	Shinshu, IHEP (CN)	DESY + DE	IP2I, LPC, (LAPP) CIEMAT, Shanghai

Timing in calorimeters: 0.1-1ns range

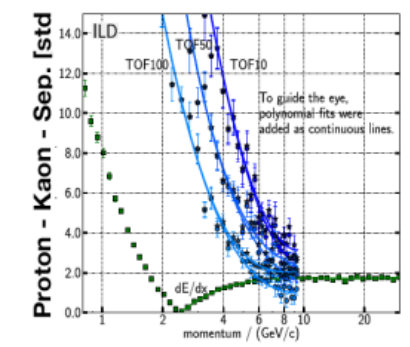
Cleaning of Events



[CLIC CDR: 1202.5940]
adapted from L. Emberger

Particle ID by Time-of-Flight

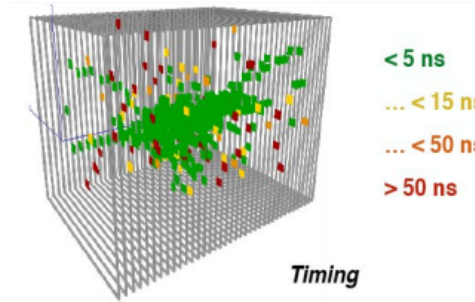
- Complementary to dE/dx
- here with 100ps on 10 ECAL hits



S. Dharani, U. Einhaus, J. List

Ease Particle Flow:

- Identify primers in showers
- Help against confusion
better separation of showers
- Cleaning of late neutrons & back scattering.



Ch. Graf

Detector Parameters

- Cell lateral size
 - Shower separation (EM $\sim 2 \times$ cell size)
 - Cell time resolution (1 cm/c ~ 30 ps)
 - Time performance for showers
 - ParticleID, easier reconstruction
- Longitudinal segmentation
 - sampling fraction
 - E resolution (ECAL $\sim 15\%/\sqrt{E}$)
 - shower separation/start
- ECAL inner radius; Barrel Z_{Start}
- ECAL-HCAL distance
- Barrel-Endcap distance
- Dead-zones sizes (from Mechanics, Cooling)

Number of cells $\nearrow \Rightarrow$ Cost \nearrow
Cell density $\nearrow \Rightarrow$ Power consumption \nearrow
Time resolution $\searrow \Rightarrow$ Power \nearrow

thr. passive vs active cooling
dead-zones \nearrow

NEED TO BE FULLY RE-EVALUATED
for EW region

Inner Radius $\nearrow \Rightarrow$ Tracking performance \nearrow
Cost \nearrow^2 (\supset Magnet, Iron)
Gaps $\nearrow \Rightarrow$ PFlow performances \searrow

Review of physical implication (from TeV): see [Linear collider detector requirements and CLD, F. Simon @ FCC-Now \(nov 2020\)](#)
Physics Requirement studies @ 250 GeV: see [Higgs measurements and others, M. Ruan @ CEPC WS, \(nov 2018\)](#)

Conclusion

CALICE enters a new phase :

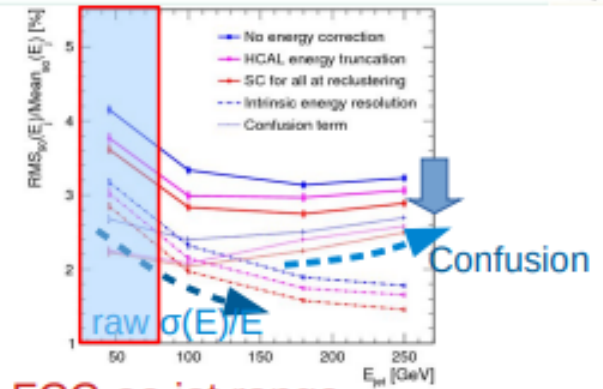
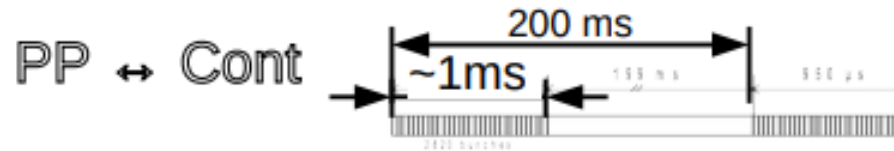
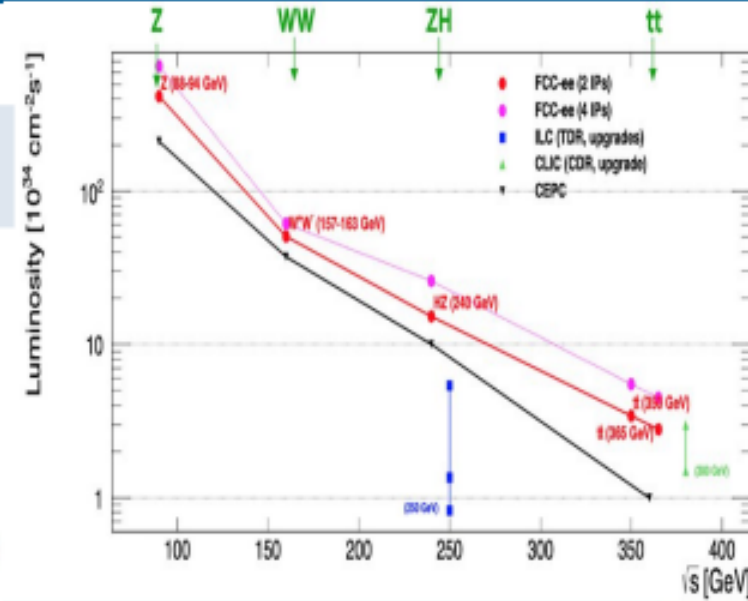
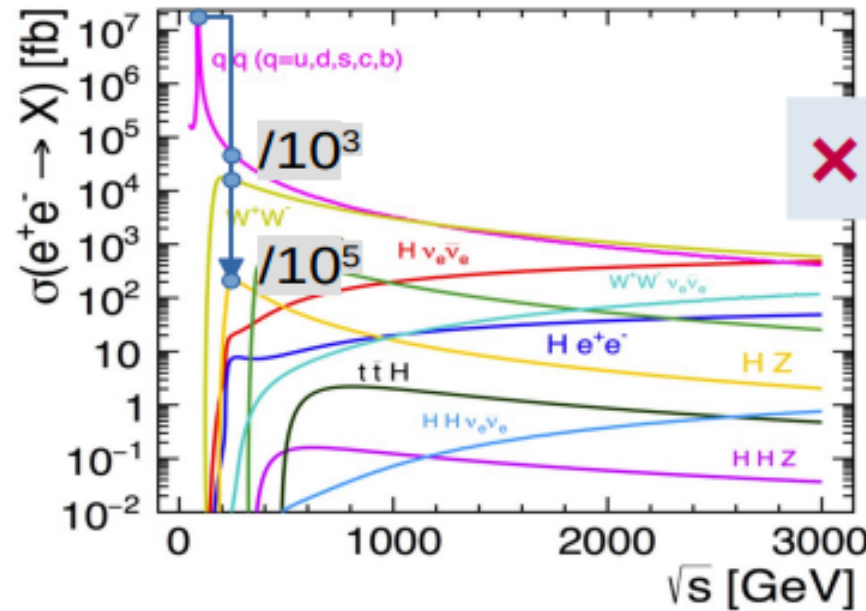
- Construction of 1st large HG calorimeter (HGCal : 6M vox)
- R&D ``final rush'' for ILC
 - Construction = ~8 years
→ 3 years of R&D + 5y for FCC-ee...

Still many element to be thought of

- stability, fiability (MTBF) → redondance
- Power & Cooling (HL scheme)
- Performances (Z peak ≠ WW & Higgs Hill)
 - RAW (single particle) Resolution E, t → (PID, Reco) → Jets, FS

FCC-ee :

- Need to fix parameters & det. philosophy for a large range of conditions → **Think large / complementary**
 - **Technology ↔ Performances** : Trigger/DAQ ↔ noise, noise ↔ detection efficiency, cooling ↔ granularity, ...
- Time for new techno: Timing, ML optimisation, other sensors (Crystal), μ-cooling, Digital sensors (dSiPM)
 - Change of constraints ?



FCC-ee jet range

Progress on R&D on granular Noble Liquid Calorimeters

Nicolas Morange, thanks to the work of:

Ronic Chiche, Daniel Fournier (IJCLab),

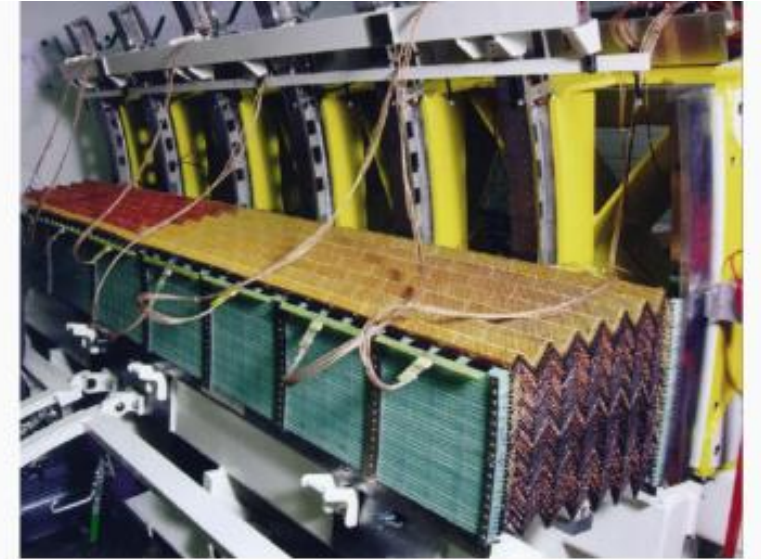
Martin Aleksa, Brieuc François, Maria Soledad Molina Gonzalez, Clément Helsen, Maria Asuncion Barba Higuera, Olivia Reinicke, Valentin

LAr Calorimeters

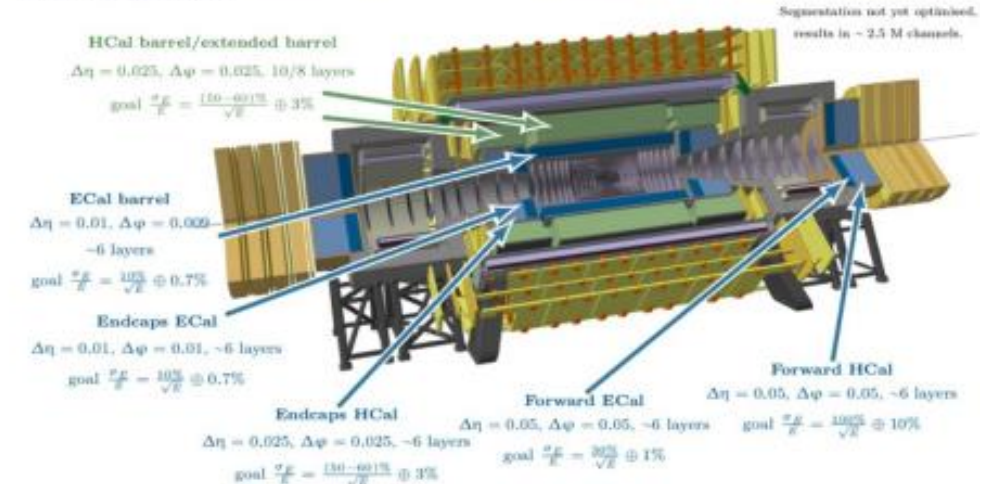
- LAr Calorimeters very successful at particle physics experiments: HERA, D0, NA31, ATLAS
- Sampling calorimeters, e.g Lead/LAr for ATLAS
- Excellent linearity, stability
- EM energy resolution $\frac{10\%}{\sqrt{E}} \oplus \frac{0.25}{E} \oplus 0.3\%$
- e/γ identification through 3D shower shapes

LAr Calo for ee machine ?

- Concept developed for FCC-hh can work very well at e^+e^-
- With e^+e^- conditions allowing for significant optimisations
 - On noise for low energy measurements
 - On segmentation for PID/PFlow use



FCC-hh detector



Granular L.Ar Calo for ee machines: How ?

Optimizing granularity for PFlow

- High granularity electrodes
- High density feedthroughs
- Add timing to the mix ?

High energy resolution

- Minimize dead material (cryostat)
- Low noise electronics

General design

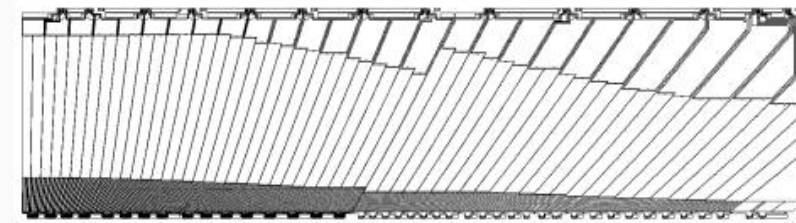
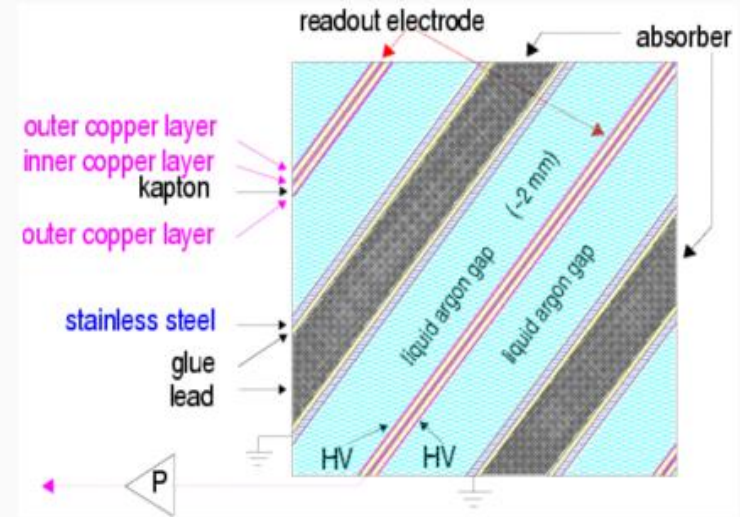
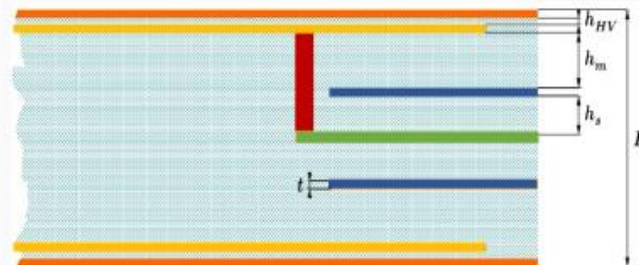
- Choice of absorber (Pb, W) and active

Reaching $10\times$ ATLAS granularity

- 200000 cells \rightarrow few million cells
- Readout in ATLAS uses simple copper/kapton electrodes
- Issue: traces to route signals to front or back of electrode take space !
- For $10\times$ more granular: go to multilayer PCB to route signals in a deep layer

Basic design

- Multi-layer PCB cannot be bent to accordion as ATLAS Kapton electrode
- \Rightarrow Straight planes inclined around the barrel
- Simulation in a specific IDEA-LAr setup

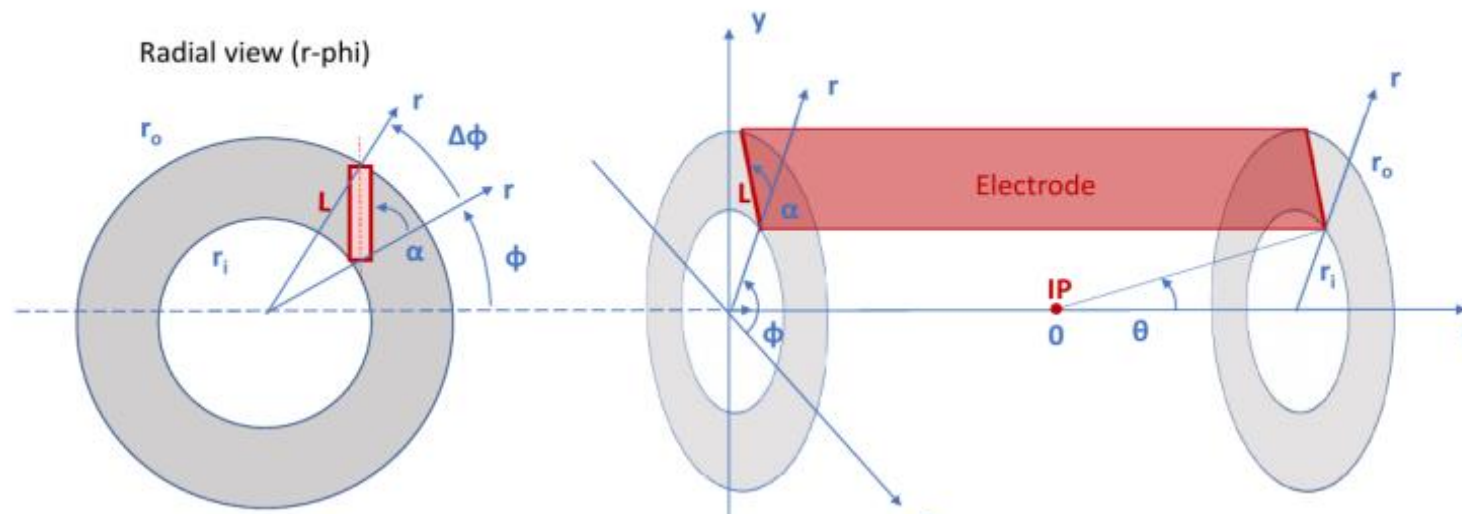
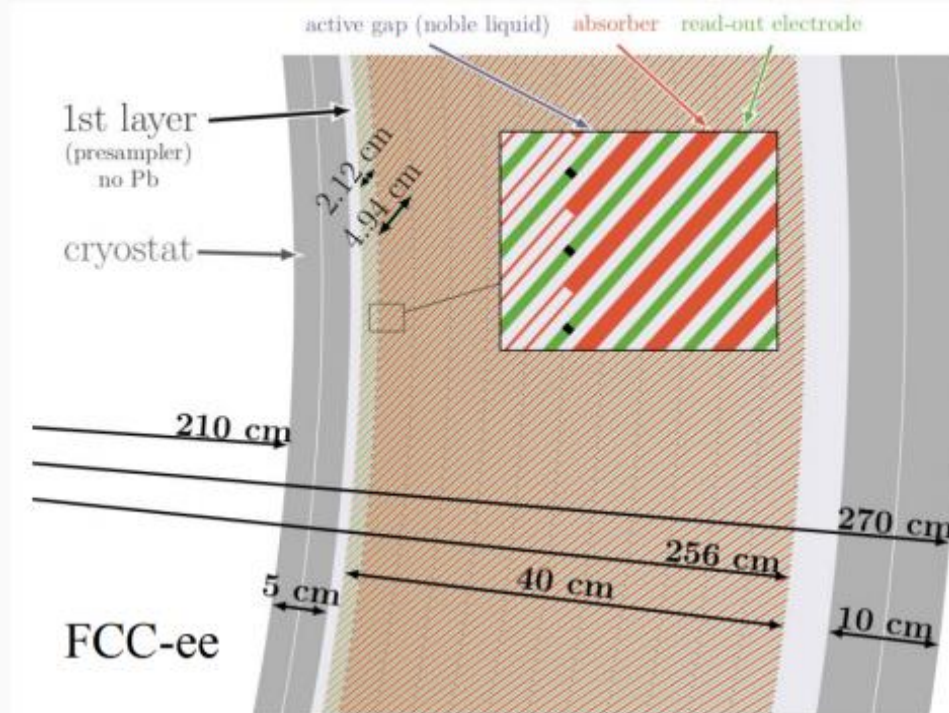


Design of ATLAS electrodes

Detector Geometry

Tilted planes around cylinder: non-trivial geometry !

- Very flexible grouping and splitting
 - Segmentation where needed, i.e 'strips' in ATLAS for π^0 rejection
- Projective cells along η and ϕ
- Gap widening at high radius
 - Non-constant sampling fraction within a cell
 - Mitigated by high longitudinal segmentation

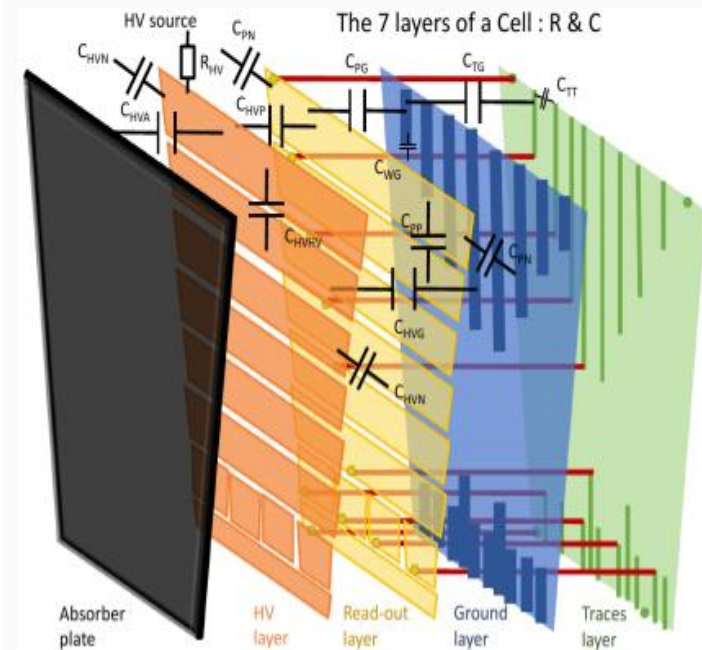


Electrode Design and Properties

/ R&D on Electrodes

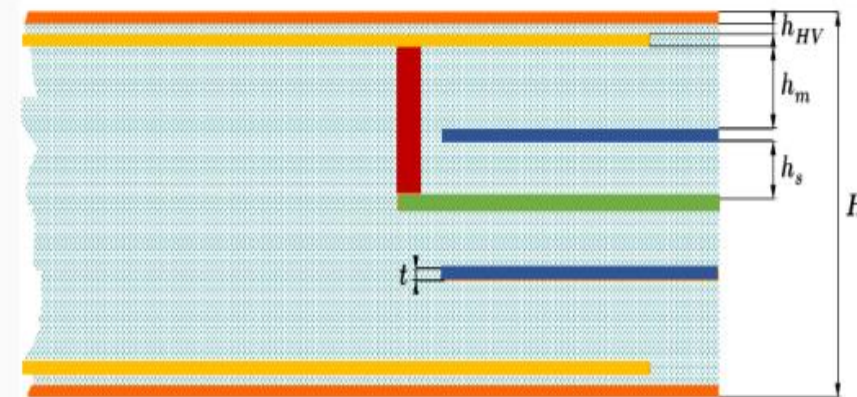
Principle

- HV layer capacitively coupled to readout layer
- Signal transferred from both sides to read-out trace through a via
- Shielding traces reduce cross-talk from other segments



Calculation of cell properties

- Cell capacitance: $C_{cell} \sim C_{HVA} + C_{PG}$
 - Estimation by analytical calculations and Finite Element Methods: 25 – 250 pF
- Transmission line capacitance adds up for noise and signal shape
- Multi-parameter optimisation:
 - Trade-off capacitance (noise) / cross-talk ?
 - What is the maximum density of signal traces ?
 - Can we readout all cells at the back, or do we have to route the first segments to the front ? (as in ATLAS)



Confronting simulation

- PCB studies done on simulation so far
- Concerns that we can take for granted extractions of capacitances and cross-talk
 - Although succeeded to have agreement between SPICE and Sigrity on simple examples
- Getting ready to build prototypes
 - Very simple ones to do detailed checks of accuracy of simulation
 - More complex ones to get a hint of performance with many neighbouring cells

Thin Cryostats

Minimizing dead material in front of calo

- Crucial for low energy measurements at FCCee
- Ongoing R&D for cryostats using new materials and sandwiches
 - See talk in [ECFA TF8 meeting](#)
 - Test microcack resistance, sealing methods, leak and pressure tests
- Promises for 'transparent' cryostats: few % of X_0 !

	Sandwich			Baseline	
	UHM CFRP	HM CFRP	IM CFRP	Al	Ti
Avg. Th. [mm]	3.5	3.8	4.9	4.0	1.5
Material budget X/X_0	0.0134	0.0147	0.0189	0.045	0.034
$X_0 + \%$	-70%	-67%	-58%	X_0	-24%
Skin Th. [mm]	1.2	1.2	1.6	1.7	
Core Th. [mm]	25	33	40	40	
Total Th. [mm]	27.4	35.4	43.2	43.4	101
Thickness + %	-37%	-18%	0%	T	+133%



NASA's lineless cryotank

Magnet

- If magnet in front of calorimeter (IDEA), can be put in same cryostat
- Try to minimise X_0 of cold mass as well

Readout Electronics

Specifications

- Low noise:
 - Must "see" MIPs
 - Small noise term even for low energy photon clusters
- Cross-talk at % level
- Dynamic range ~ 14 bit for FCCee

Master formula

- Dominant noise term goes as $C\sqrt{4kT/(g_m\tau_p)}$
- Where C depends on cell capacitance and on the transmission line
- τ_p can be much larger than in ATLAS: 50 \rightarrow 400 ns

Cold electronics ?

- Gain on g_m , T and C (short transmission line) !
 - Noise requirements can be achieved
- No radiation hardness issue at FCCee, could simplify feedthrough design
- Challenges are heat dissipation and difficulty of repairs

Warm electronics ?

- A la ATLAS, with longer shaping
- First calculations indicate low enough noise levels achievable ($S/N > 3$ for MIPs)

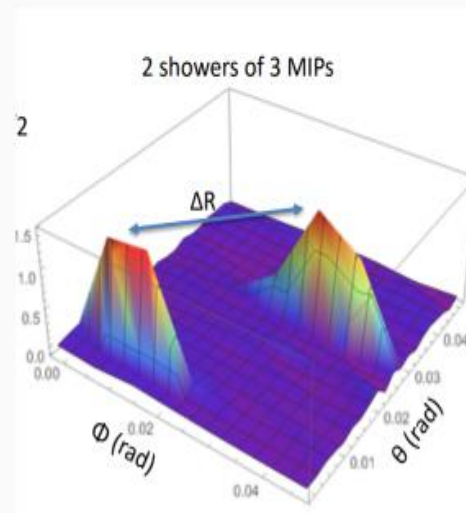
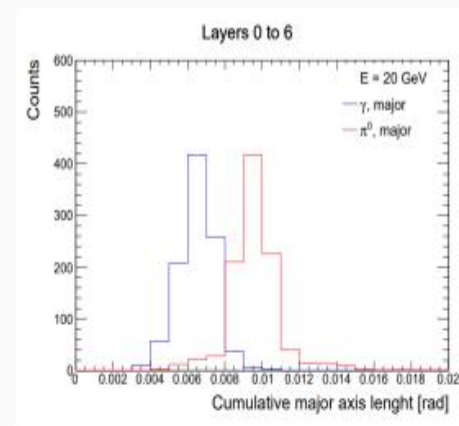
Detector Optimisation

Many open design questions

- Choice of absorber (Pb, W), active material (LAr, LKr) and gap sizes
 - Implications on sampling term (baseline $\sigma \sim 8\%/\sqrt{E}$), compactness, cost
 - First studies done in 2021
- Optimization of granularity
 - Use of PCBs gives large flexibility

End-to-end detector optimisation

- Ideally perform optimization by computing figures of merits for physics analyses
- Photon energy resolution and EM shower shape discrimination can be studied with the calo design alone
 - Studies ongoing/starting: τ physics, ALPs...
- But evaluation of electrons, jets, MET performance requires PFlow and full detector design
 - Goal for 2022 !



L.Ar conclusions

Good progress achieved in 2021

- R&D on feedthroughs progressing well
- Expected noise studied with educated simulations
 - Excellent performance with cold electronics
 - Warm electronics can provide adequate performance
 - Plus 8% sampling from baseline design
- First PCB designs ready to be built

Challenges for 2022

- PCB measurements and progress on electronics
- Studies on absorber / liquid choice
- Explore performance in physics channels with photons
- Obtain fullsim and integrate with PFlow to study jet performance
- Endcaps design

First workshop on noble liquid granular calorimeters

IJCLab, April 6-8 2022

New collaborators welcome !

CMOS pixels sensors R&D for the vertex detector in a Higgs factory

Auguste Besson

On behalf of the PICSEL group & C4PI Platform
@IPHC – Strasbourg

- Introduction: requirements & strategy
- MIMOSIS chip development (IPHC-IKF-GSI Collaboration)
- 65 nm R&D (with CERN EP R&D WP 1.2 & ALICE ITS-3)

Strategy: on the road to Higgs factories

CMOS Master Project

Design, build and exploit CMOS pixels sensors
with low material budget & high granularity

In order to contribute to the construction of a vertex & a tracking detector in a Higgs factory.

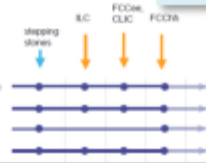
Approach the Higgs factories
vertex detector requirements

MIMOSIS chip family (180 nm)



Example:
Solid State Detectors

- DSIT 1.1: Achieve full integration of sensing and microelectronics in monolithic CMOS pixel sensors
- DSIT 1.2: Develop solid state sensors with 4D capabilities for tracking and calorimetry
- DSIT 1.3: Extend capabilities of solid state sensors to operate at extreme fluences
- DSIT 1.4: Develop full 3D interconnection technologies for solid state devices in particle physics



Input for detector simulations

Optimize the parameters
of the technology
(e.g. sensitive layer)

Maintain & develop the
know how to build sensors
to be installed in real
experiments

Exploit fully the potential
of the CMOS technology

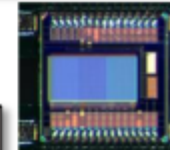
R&D 65 nm

Large surfaces
(stitching)

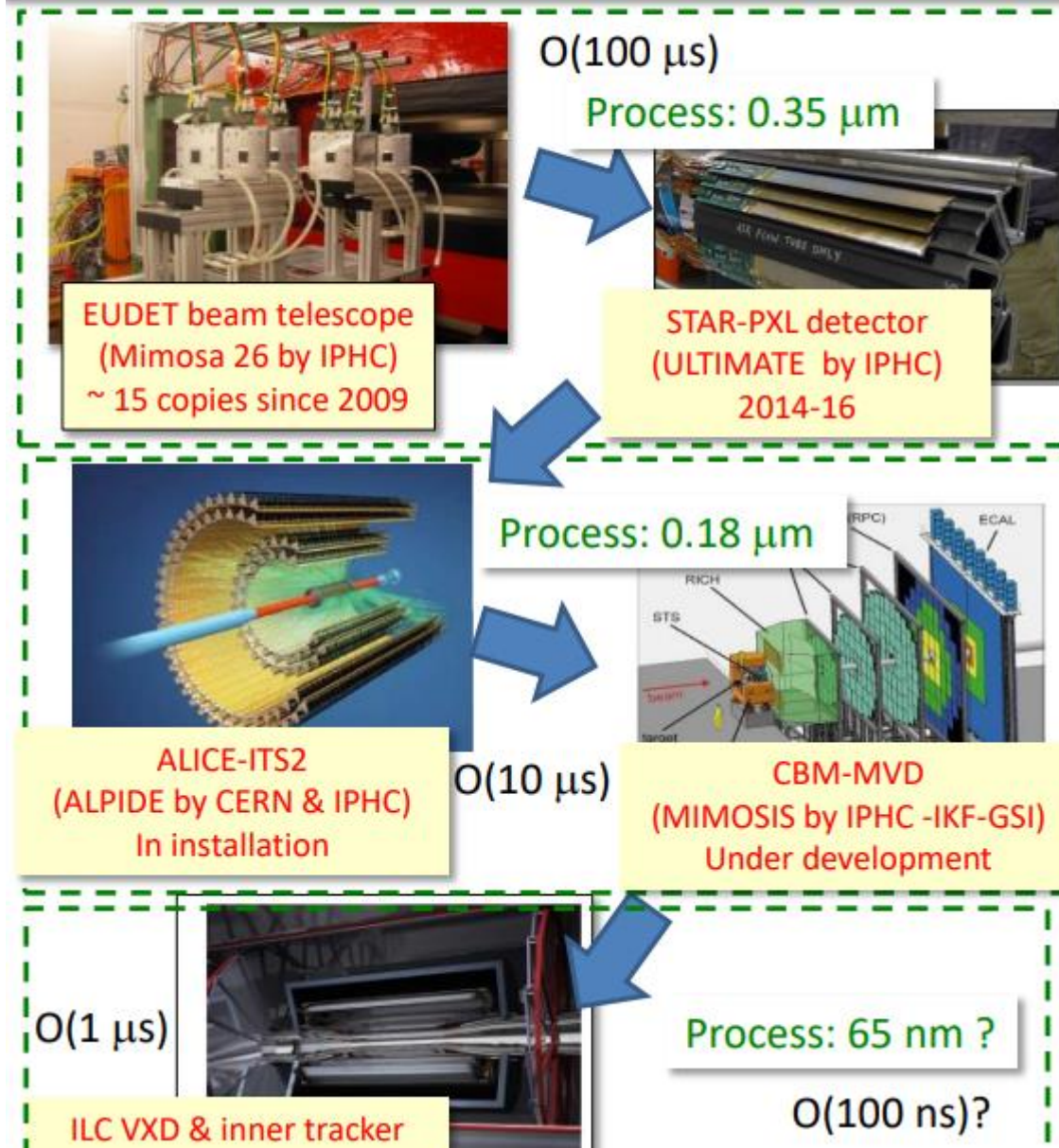
Bent sensors

Integration

Emerging technologies
(e.g. double tier)

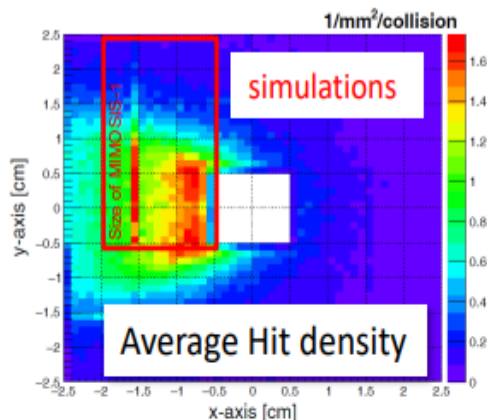
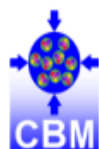


History & Future: On the road to Higgs factories

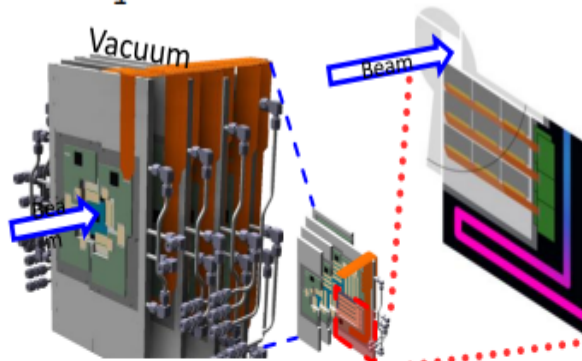


- IPHC: R&D started in ~1999
 - ✓ Take advantage of mid-term projects to get closer to ILC vertex detector requirements
- Today (\Rightarrow ~2023)
 - ✓ CBM-MVD: MIMOSIS chips
 - ✓ 65 nm technology exploration with CERN
 - + stitching
- Long term (> 2025 \Rightarrow 2035)
 - ✓ Higgs factories development line

MIMOSIS requirements



Physics parameter	Requirements
Spatial resolution	$\sim 5 \mu\text{m}$
Time resolution	$\sim 5 \mu\text{s}$
Material budget	$0.05\% X_0$
Power consumption	$< 100 - 200 \text{ mW/cm}^2$
Operation temperature	-40°C to 30°C
Temp gradient on sensor	$< 5\text{K}$
Radiation tol* (non-ion)	$\sim 7 \times 10^{13} \text{ n}_{\text{eq}}/\text{cm}^2$
Radiation tol* (ionizing)	$\sim 5 \text{ MRad}$
Data flow (peak hit rate)	@ $7 \times 10^5 / (\text{mm}^2\text{s})$ $> 2 \text{ Gbit/s}$



CBM-MVD@FAIR



- 4 double-sided thin planar detector stations
- 100 kHz Au+Au @ 11 AGeV and 10GHz p+Au @ 30 AGeV
- Non uniform hit density in time and space
- High radiation environment, operating in vacuum

MIMOSIS chip

- ✓ Based on ALPIDE architecture
- ✓ Discriminator on $27 \times 30 \mu\text{m}^2$ pixel
- ✓ Multiple data concentration steps
- ✓ Elastic output buffer
- ✓ 8 x 320 Mbps links (switchable)
- ✓ Triple redundant electronics

Parameter	Value
Technology	TowerJazz 180 nm
Epi layer	$\sim 25 \mu\text{m}$
Epi layer resistivity	$> 1 \text{ k}\Omega\text{cm}$
Sensor thickness	$60 \mu\text{m}$
Pixel size	$26.88 \mu\text{m} \times 30.24 \mu\text{m}$
Matrix size	1024×504 (516096 pix)
Matrix area	$\approx 4.2 \text{ cm}^2$
Matrix readout time	$5 \mu\text{s}$ (event driven)
Power consumption	$40-70 \text{ mW/cm}^2$

MIMOSIS = a milestone for Higgs factories ($5 \mu\text{m}$ / $\leq 5 \mu\text{s}$)

MIMOSIS roadmap

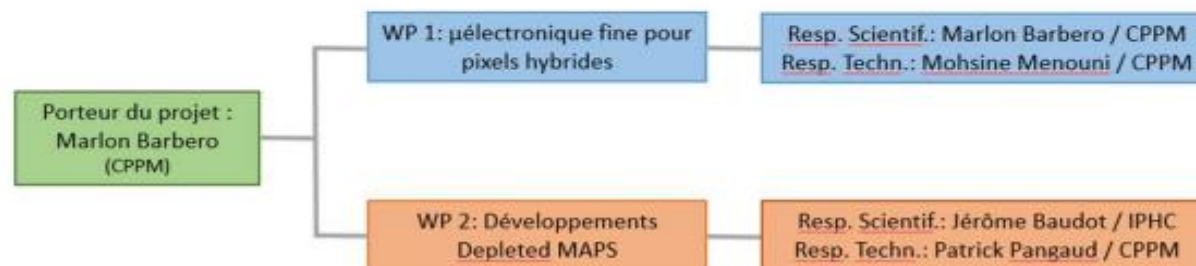
- 4 prototypes:
- MIMOSIS-0: = 2 regions
 - ✓ Tests (2018-2019)
 - Testability
- **MIMOSIS-1: 1st full size prototype**
 - ✓ Elastic buffer, SEE hardened
 - ✓ Fabricated in 2020
 - ✓ Lab/beam test campaign in 2021
- MIMOSIS-2:
 - ✓ On-chip clustering
 - ✓ Q4 2021 \Rightarrow tests in 2022
- MIMOSIS-3: final pre-production sensor
 - ✓ ≥ 2023

Summary: Synergies in CMOS R&D

- CMOS Pixel Sensors are the baseline for Higgs factories
 - ✓ Requirements are within reach
- Strong dynamic of CMOS pixel Sensors R&D:
 - ✓ 180 nm : MIMOSIS series
 - (5 μ m spatial res./ \leq 5 μ s time res./ 60 μ m thickness / < 70 mW/cm²)
 - MIMOSIS-1 \Rightarrow full size prototype being tested
 - MIMOSIS-2 to be submitted (Q4 2021)
 - ✓ 65 nm technology exploration
 - First submission dec.2020 (MLR1)
 - Techno validation: first indices are encouraging (DPTS)
 - First test beam on CE_65 chips ongoing @ CERN/DESY
 - 2nd submission (ER1, Q1 2022): Stitching
 - ✓ Stitching & large surfaces for very low mass detectors \Rightarrow Priority for Higgs factories in the future
 - Bent sensors test beam performed by ALICE
 - Material budget & Large pixelated surfaces
 - ✓ Synergies with
 - CERN R&D (ALICE ITS upgrades and EP R&D WP1.2)
 - R&D programs (e.g. AIDA-Innova, CREMLIN+, etc.)
 - Heavy ion experiments (e.g. ALICE beyond LS3/4 proposal, CBM, EIC)
 - Other experiments: Belle-II, etc.
 - DICE MP (see Marlon's talk)

DICE project

- A project involving CPPM and IPHC, carried by M. Barbero / CPPM (+ involvement IPHC -J. Baudot et al-). Start: beginning 2021.
- General theme :
 - Tracking / vertexing with pixel detector in relevant technologies for futures projects with main emphasis on:
 - High counting rates/ high hit rates.
 - Radiation hardness middle to high.
- 2 Work Packages:
 - **Hybrid Pixels:** Exploring advanced process nodes technologies -e.g. 28 nm- (RS: Barbero / RT: Menouni)
 - **Monolithic Pixels:** Focus on Depleted MAPS technologies Depleted MAPS in two main directions → exploitation of mature R&D and potential of new technologies (RS: Baudot / RT: Pangaud)



Heavy Flavour, Taus, and QCD: Physics and Detector Constraints

Président de session: Stephane Monteil (Laboratoire de Physique de Clermont - UCA/IN2P3)

11:40

Introduction to the Heavy Flavour, Tau and QCD session

Orateur: Stephane Monteil (Laboratoire de Physique de Clermont - UCA/IN2P3)

 FCC_France_2021_...

11:50

CP violation and determination of the b_s "flat" unitarity triangle at FCCee


Orateur: Emmanuel PEREZ (CERN)

 2021_12_01_CPV_s...

12:10

Opportunities to measure semileptonic asymmetries


Orateur: Dennis Arogancia (MSU-ILIGAN INSTITUTE OF TECHNOLOGY)

 AslsUncertainty_up...

12:30

Perspectives for high-precision $\alpha_S(m_Z^2)$ determinations @ FCC


Orateur: Luc Poggioli (LPNHE Paris)

 Annecy_Poggioli.pdf

18:05

Tau Physics at Future e^+e^- colliders

Orateur: Jean-Claude brient (LLR)

 talk fcc 2021.pdf

QCD:

- α_S from *hadronic τ & Z decays*
- α_S from *(ISR) jet production*
- *Jet substructure opportunities*

Heavy Flavour/tau programme makes use of the very large statistics: 10^{12} bb, cc, $2 \cdot 10^{11}$ tautau

CKM matrix, CP measurements, flavour anomaly studies, Rare decays, LFV, Lepton universality....

Some example of tau physics

Tau decays
Search for NP

Tau neutrino mass

High lumi. allows to have a large stat. of tau decays to $5\pi^\pm$ (or $7\pi^\pm$?)

Tau CC universality , Michel parameters

e vs μ , even at very low energy

Control sample of PID efficiency (easy with Z decays)

Tau as polarimeter

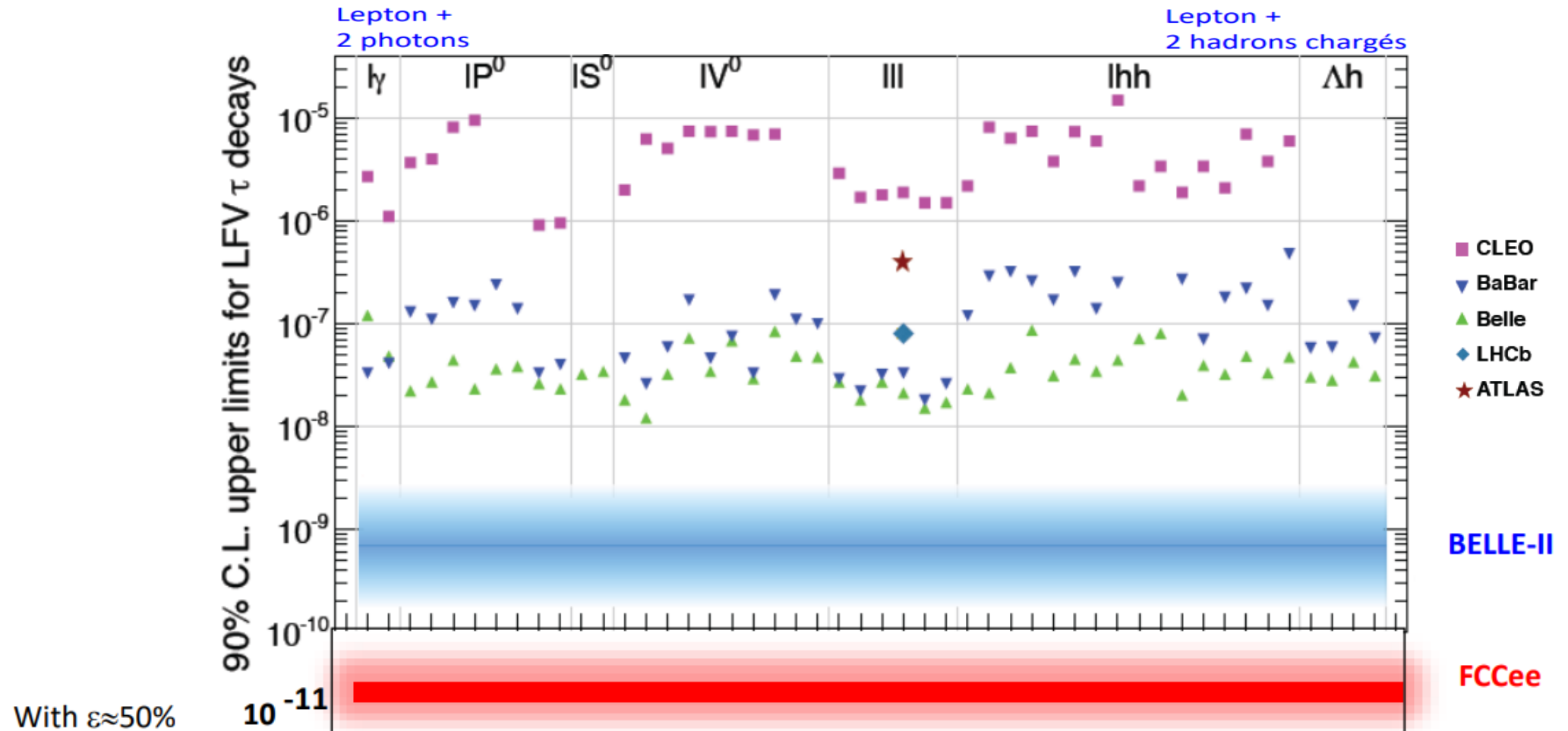
for Z decays to $\tau\tau$, polarization and AFB(Pol) , which could be affected by Z' somewhere BUT ALSO for a very important piece of the program at FCCee : the CP violation in Higgs decays

Tau physics and EW physics with taus

Rare tau decays , search for NP

With the right detector, FCCee can do it much better

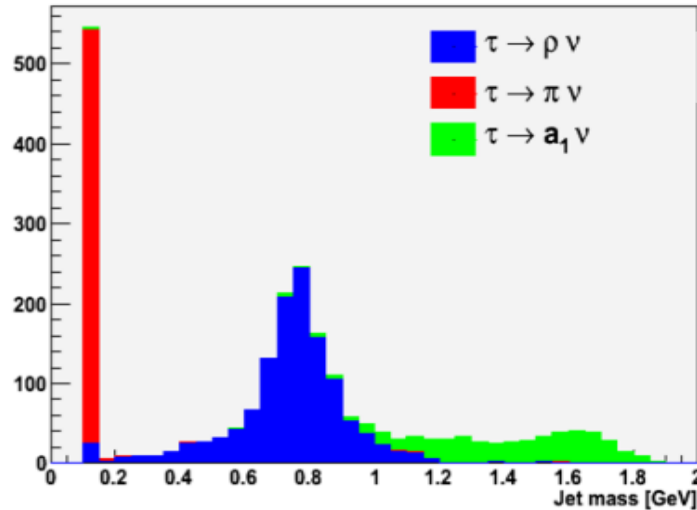
(more stat. and very clean environment ≥ 1 order of magnitude better)



τ^\pm as a polarisation analyser

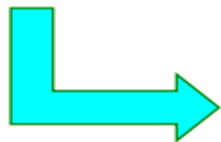
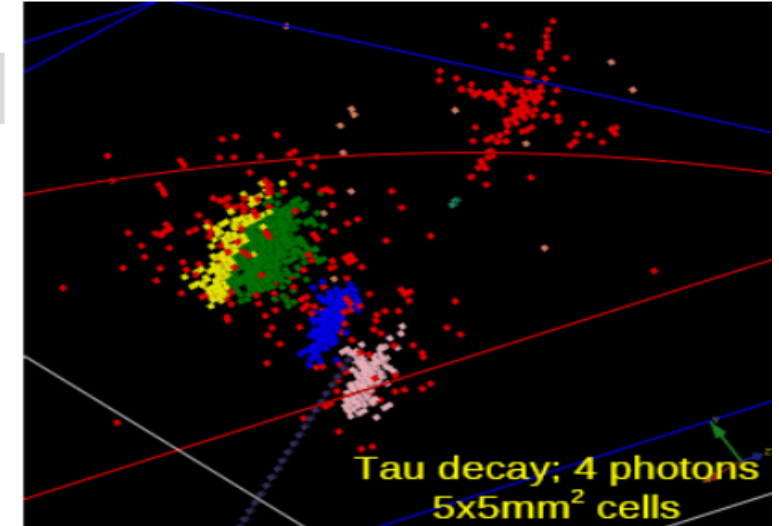
→ Need to reconstruct photon(s) in dense environment.... **Even at Z peak**

Full Simulation GEANT4
& Reconstruction with PFA
Invariant Mass from τ decays



Cluster energy cut at 200 MeV

Is there photon(s) or not
in the hemisphere ?



	Jet mass < 0.2	Jet mass in 0.2-1.1	Jet mass >1.1
$\tau \rightarrow \pi \nu$	90.2 %	1.7 %	8.1 %
$\tau \rightarrow \rho \nu$	1.7 %	87.3 %	7.4 %
$\tau \rightarrow a_1 \nu$	0.6 %	7.4 %	92.0 %

Performances depends
strongly on
ECAL granularity

17


some conclusions on taus

- FCCee could do much better than BELLE-II or HL-LHC for many measurements
- The purity of the selected tau pairs is very high (nothing to do with BELLE-II or LHCb)
- FCCee can address rare decays as well as other aspects , like EW measurements (tau polar)
- The systematics are “probably” easier to control (vs BELLE or LHC)
- Pay attention to ECAL imaging performances (not so much to the stochastic term of energy resolution of ECAL)


Electroweak Physics: Physics and Detector Constraints

Président de session: Lucia di Ciaccio (LAPP)


17:00 **EW measurements: comparing theory and experiments**
Orateur: Ayres Freitas (Pittsburg)

 fccfrance21_freitas...


17:25 **Energy calibration and Polarization : where do we stand ?**
Orateur: Alain Blondel (LPNHE Paris-Sorbonne)

 Blondel-EPOL-FCC-F...


17:45 **Angular analysis of $e^+e^- \rightarrow W^+ W^-$ final states**
Orateur: Jean-Loup RAYMOND (LAPP)

 Angular analysis ee ...

18:25 **Study of the Z-boson couplings to heavy fermions**
Orateur: Marina Cobal (Udine)

 Annecy_cobal-final_...

18:45 **Searches for LLP at FCC-ee**
Orateur: Marcin Chrzaszcz (University of Zurich)

 mchrzasz.pdf


Top Physics and R&D

Président de session: Jeremy Andrea (IPHC)

10:40 **top-antitop production in ee collisions at threshold**
Orateur: Jürgen Reuter (DESY Hamburg, Germany)

 2021_FCCee_Franc...

11:00 **Latest top analyses in FCC framework**
Orateur: Patrizia Azzi (INFN)

 TopTools-FCCFranc...

11:20 **Top and (Heavy) quark studies at linear colliders**
Orateur: Roman Poeschl (LAL Orsay)


In the EW session,
TeraZ and LLP
searches potential
were presented

Contributions in
Higgs and Top
coming from cases
studies performed
in both FCC & ILC


Higgs: Physics and detector constraints

Président de session: Suzanne GASCON-SHOTKIN (IPN Lyon)

08:30 **The total $e^+e^- \rightarrow ZH$ cross section σ_{HZ} and mass measurement from the recoil**
Orateur: Ang Li (APC Paris)


 2021_12_02_FCC_F...

08:50 **The total $e^+e^- \rightarrow ZH$ cross section and the Higgs self-coupling σ_{HZ}**
Orateur: Roberto Salerno (LLR)

 RobertoSalerno_FC...

09:10 **Higgs boson coupling measurements to charm quarks at FCC-ee**
Orateur: Giovanni Marchiori (APC Paris)

09:30 **A combined fit of the Higgs branching ratio using ILD detector at Higgs Factory**
Orateur: Jonas Kunath (LLR)

 fcc_higgs_combine...

Measurement of $e^+e^- \Rightarrow \nu\bar{\nu}H$ at future lepton colliders
Orateur: Guillaume Garillot (IPNL)

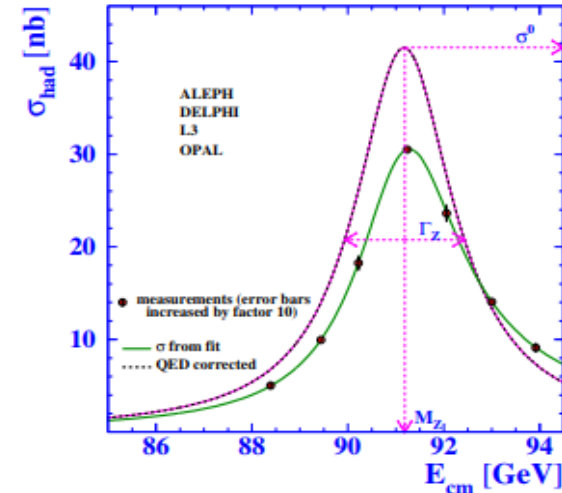


Electroweak measurements: Comparing theory and experiments

A. Freitas

University of Pittsburgh

- Electroweak precision at Z pole & WW
- EW precision tests at future colliders
- SM input parameters

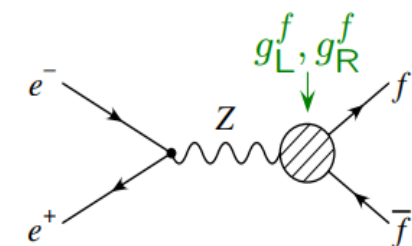


Z cross section and branching f

$e^+e^- \rightarrow f\bar{f}$ for $E_{\text{CM}} \sim M_Z$:

- Mass M_Z
- Width $\Gamma_Z = \sum_f \Gamma_{ff}$
- Branching ratio $R_f = \Gamma_{ff}/\Gamma_Z$
- $\sigma^0 \approx \frac{12\pi \Gamma_{ee} \Gamma_{ff}}{(s-M_Z^2)^2 + M_Z^2 \Gamma_Z^2} = \frac{12\pi}{M_Z^2} R_e R_f$

$$\Gamma_{ff} = C[(g_L^f)^2 + (g_R^f)^2]$$



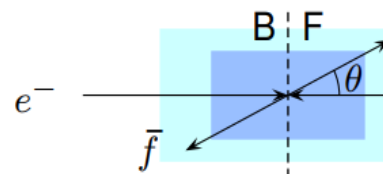
Z -pole asymmetries

Forward-backward asymmetry:

$$A_{\text{FB}} \equiv \frac{\sigma_F - \sigma_B}{\sigma_F + \sigma_B} = \frac{3}{4} \mathcal{A}_e \mathcal{A}_f$$

$$\mathcal{A}_f = \frac{2(1 - 4\sin^2 \theta_{\text{eff}}^f)}{1 + (1 - 4\sin^2 \theta_{\text{eff}}^f)^2}$$

$$\sin^2 \theta_{\text{eff}}^f = \frac{g_R^f}{2|Q_f|(g_R^f - g_L^f)}$$



Left-right asymmetry:

With polarized e^- beam: $A_{\text{LR}} \equiv \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R} = \mathcal{A}_e$

Polarization asymmetry:

Average τ pol. in $e^+e^- \rightarrow \tau^+\tau^-$: $\langle \mathcal{P}_\tau \rangle = -\mathcal{A}_\tau$

Z lineshape

■ Deconvolution of initial-state QED radiation:

$$\sigma[e^+e^- \rightarrow f\bar{f}] = \mathcal{R}_{\text{ini}}(s, s') \otimes \sigma_{\text{hard}}(s')$$

■ Subtraction of γ -exchange, γ - Z interference, box contributions:

$$\sigma_{\text{hard}} = \sigma_Z + \sigma_\gamma + \sigma_{\gamma Z} + \sigma_{\text{box}}$$

■ Z -pole contribution:

$$\sigma_Z = \frac{R}{(s - M_Z^2)^2 + M_Z^2 \Gamma_Z^2} + \sigma_{\text{non-res}}$$

$\sigma_\gamma, \sigma_{\gamma Z}, \sigma_{\text{box}}, \sigma_{\text{non-res}}$ known at NLO

→ need consistent pole expansion framework

→ leading NNLO may be needed for future e^+e^-

- To probe new physics, compare EWPOs with SM theory predictions
- Need to take theory error into account:

	Current exp.	Current th. [†]	CEPC	FCC-ee
M_W [MeV]	15	4*	1	1
Γ_Z [MeV]	2.3	0.4	0.5	0.1
$R_\ell = \Gamma_Z^{\text{had}} / \Gamma_Z^\ell$ [10^{-3}]	25	5	2	1
$R_b = \Gamma_Z^b / \Gamma_Z^{\text{had}}$ [10^{-5}]	66	10	4.3	6
$\sin^2 \theta_{\text{eff}}^\ell$ [10^{-5}]	16	4.5	<1	0.5

* computed from G_μ † full NNLO and leading NNNLO

Common methods:

- Count prefactors (α , N_c , N_f , ...)
- Extrapolation of perturbative series
- Renormalization scale dependence
- Renormalization scheme dependence

- **Electroweak precision tests** at future e^+e^- colliders require 1–2 orders improvement in SM theory calculations and tools

- **Z-pole**: 3-loop & leading 4-loop EW + multi-loop/leg merging for QED MC
- **off Z-pole / backgrounds**: (≥ 2)-loop EW
- **WW** 2-loop EW for $2 \rightarrow 2$ processes (+ 4-loop QCD)
(≥ 1)-loop for backgr. and non-resonant terms

- M_Z , Γ_Z : From $\sigma(\sqrt{s})$ lineshape; δM_Z , $\delta \Gamma_Z \sim 0.1$ MeV at FCC-ee
→ Main theory uncertainties: **QED ISR**

Summary EW theory

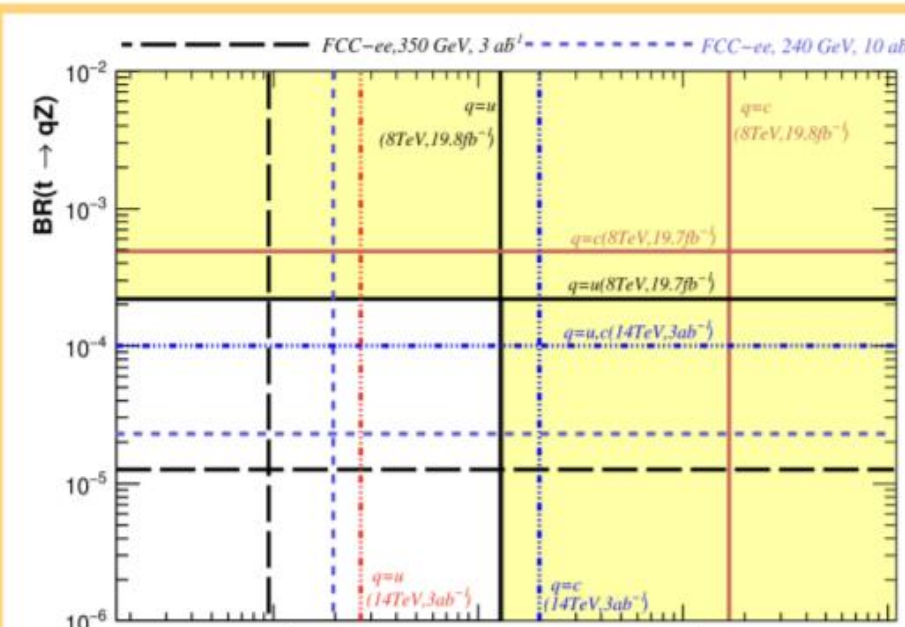
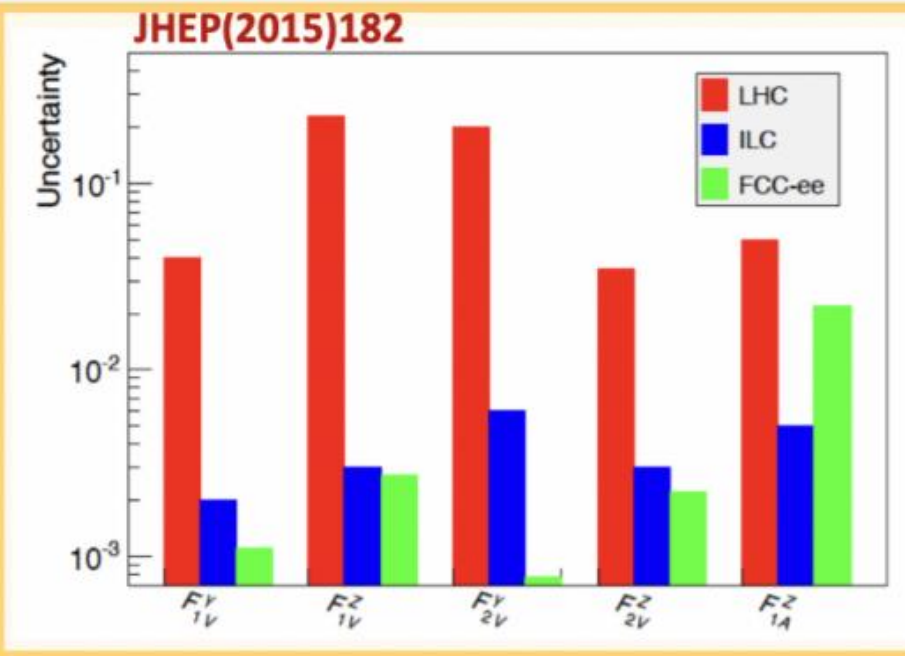
- Electroweak precision tests require theory input for **measurements of pseudo-observables** (BRs, widths, masses, cross-sections, ...) and their **SM/BSM interpretation**
- **Future e^+e^- colliders** improve precision by 1–2 orders of magnitude
- Uncertainties from **perturbative** and **non-perturbative** theory and **input parameters** require much work, but can also be mitigated through choice of measurements and analysis
- Theory progress needed both for **fixed-order loop corrections** as well as **MC tools**
- **Direct determination** of α_s , m_t , $\Delta\alpha$ at e^+e^- colliders is important
- Other lower-energy experiments can provide additional input:
BELLE II, BES, ...

Top physics case studies

See also Snowmass LOI

P. Azzi

- **Measurements at threshold:** precision top mass, width, (indirect) Y_t . But also, differential distributions, A_{fb} , top polarisation important for EFT fits need to be explored.
 - To fully profit of the hadronic channel statistics will help set requirements on jet reconstruction and kinematical fits
- **EWK couplings:** $\sqrt{s}=365\text{GeV}$ optimal to extract sensitivity on (anomalous) EWK couplings below the % using optimal variables (lepton energy and polar angle). Need to extend the analysis to more variables and extract detector requirements.
- **FCNC:** preliminary results at 240GeV and 365GeV show sensitivity 10^{-5} - 10^{-6} . Need to fully optimise the analysis, combine the energies and extract the requirements on jet flavour tagging.



On-Shell process: $e^+e^- \rightarrow t\bar{t}$

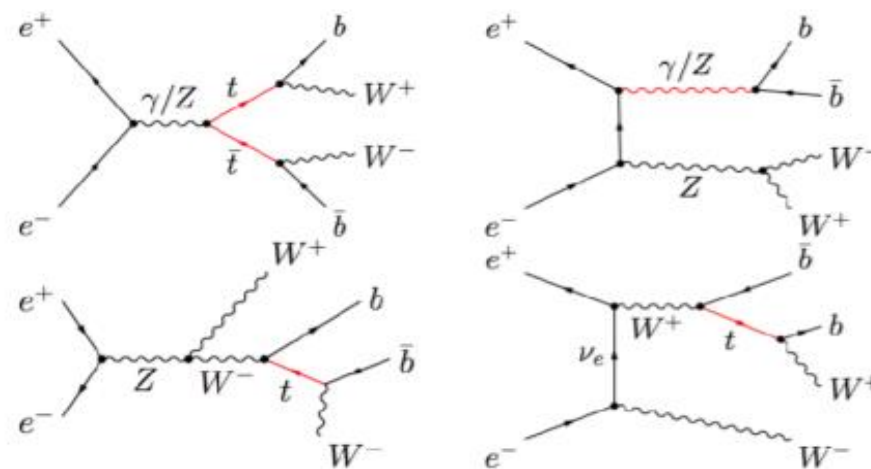
- 🕒 NLO QCD [Jersak/Laermann/Zerwas, 1982]
- 🕒 NNLO QCD [Chetyrkin/Kühn/Steinhauser, 1996; Harlander/Steinhauser, 1998; Chen/Dekkers/Heisler/Bernreuther/Si, 2016]
- 🕒 NLO EW [Beenakker/von der Marck/Hollik, 1991; Beenakker/Denner/Kraft, 1993; Akhundov/Bardin/Leike, 1991]
- 🕒 Threshold enhancement [Fadin/Khoze, 1987; Strassler/Peskin, 1991; Jezabek/Kühn/Teubner, 1992; Sumino et al., 1992]

Off-Shell process: $e^+e^- \rightarrow W^+\bar{b}W^-b$

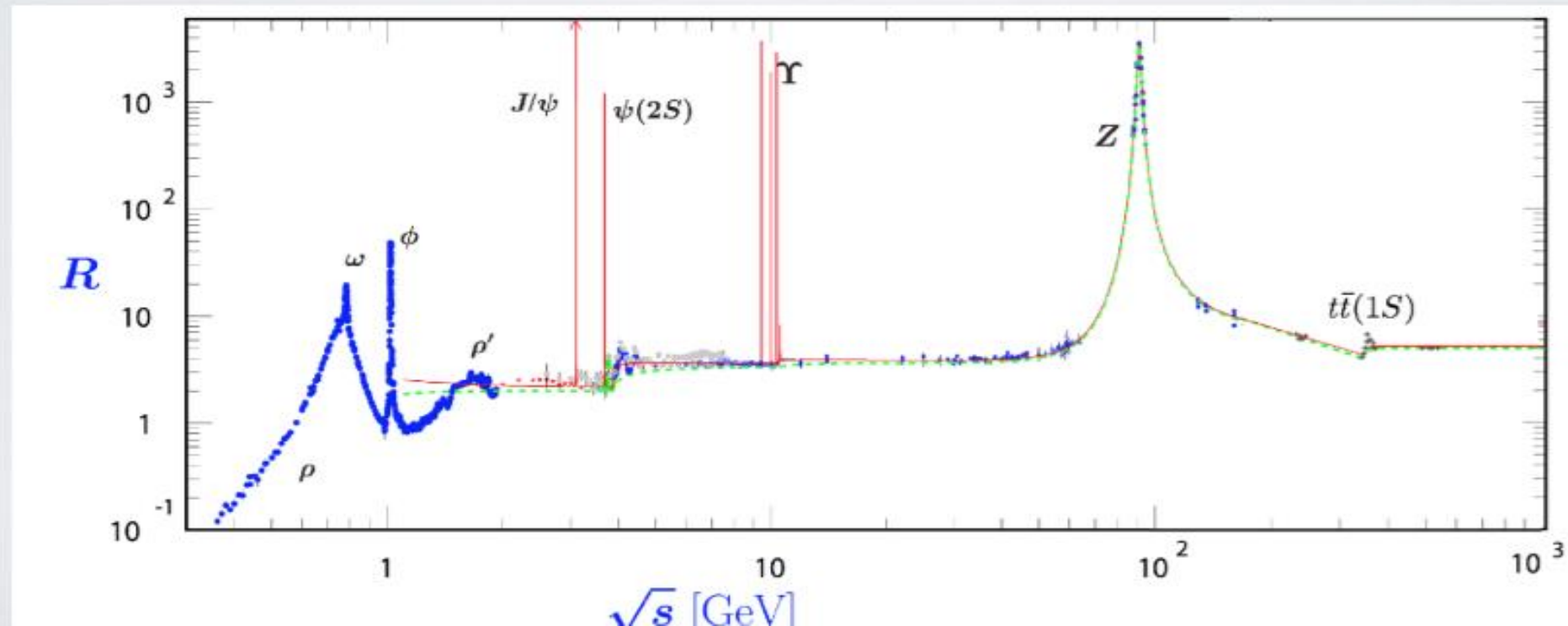
- 🕒 NLO QCD [Guo/Ma/Wang/Zhang, 2008] ✗
- 🕒 NLO QCD diff. [Chokoufe/JRR/Weiss, 2015; Liebler/Moortgat-Pick/Papanastasiou, 2015; Chokoufe/Kilian/Lindert/JRR/Pozzorini/Weiss, 2016]

Top width: $t \rightarrow W^+b$

- 🕒 NLO QCD [Jezabek/Kühn, 1989]
- 🕒 NNLO QCD [Guo/Li/Zhu, 2012]



- * Top physics precision program: top mass, top width, top Yukawa, α_s
- * Top threshold scan: **high precision mass measurement** ($\Delta M_t \approx 30\text{-}70\text{ MeV}$)
- * Severe theory challenges (!)
- * High precision top Yukawa measurement (needs $\sim 550\text{ GeV}$)
- * Top: telescope to BSM physics \hookrightarrow Backup slide
- * Top electroweak couplings: deviations guideline to distinguish BSM models



The total $e^+e^- \rightarrow ZH$ cross section σ_{ZH} and mass measurement from the recoil

➤ Signal: $e^+e^- \rightarrow ZH \rightarrow l\bar{l} + X$

ZH is the dominant Higgs production process @ 240 GeV e^+e^- machine

➤ M_{recoil} from the Z production without measuring the Higgs production final state

$$m_{recoil}^2 = (\sqrt{s} - E_{l\bar{l}})^2 - p_{l\bar{l}}^2 = s - 2E_{l\bar{l}}\sqrt{s} + m_{l\bar{l}}^2$$

➤ Sensitive to the precise knowledge of the centre-of-mass energy (\sqrt{s})

and Initial State Radiation (ISR)

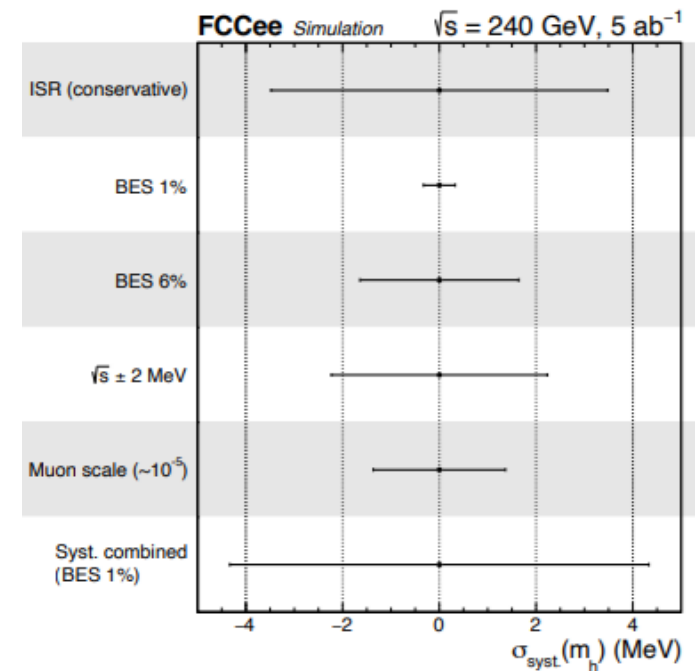
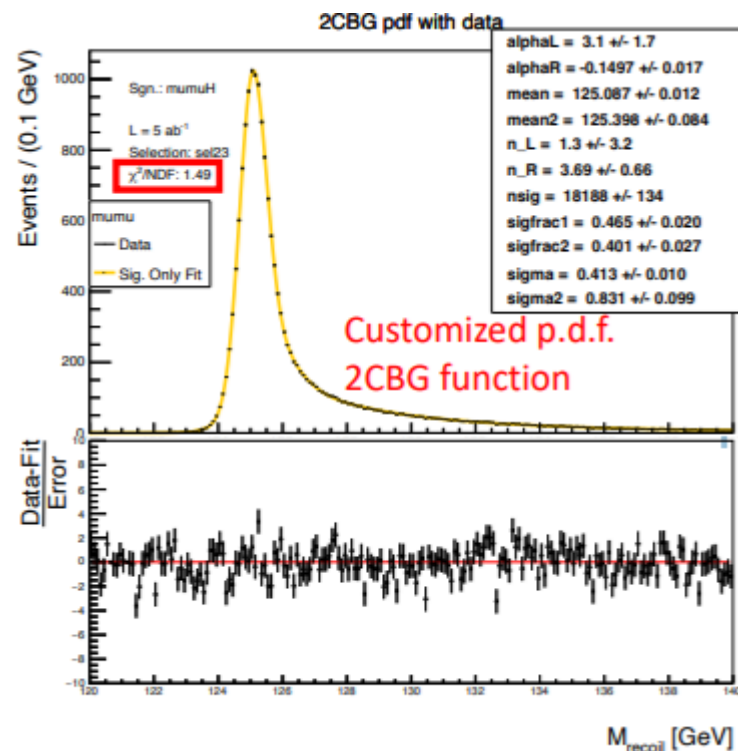
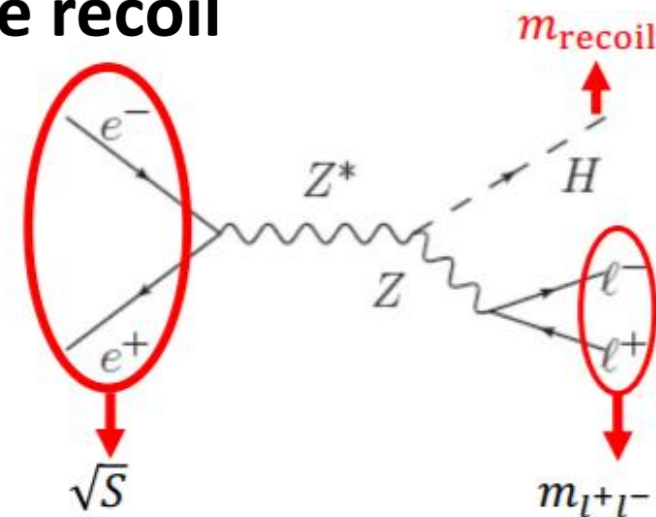
➤ Model-independent study

Signals:

1. $Z(\mu^+\mu^-)H$ (Whizard)
2. $Z(\tau^+\tau^-)H$ (Whizard)
3. $Z(q\bar{q})H$ (Whizard)

Backgrounds:

1. ZZ (inclusive), (Pythia)
2. $W^+(\nu\mu^+)W^-(\bar{\nu}\mu^-)$, (Pythia)
3. $Z \rightarrow l^+l^-$, (Pythia)
4. $Z \rightarrow q\bar{q}$, (Pythia)
5. eeZ , (Whizard)
6. $\gamma\gamma \rightarrow \mu^+\mu^-$, (Whizard)



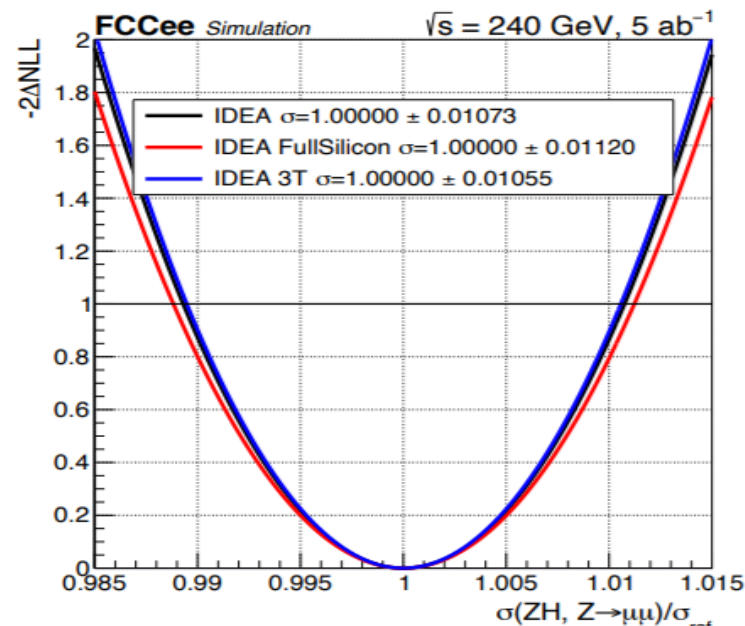
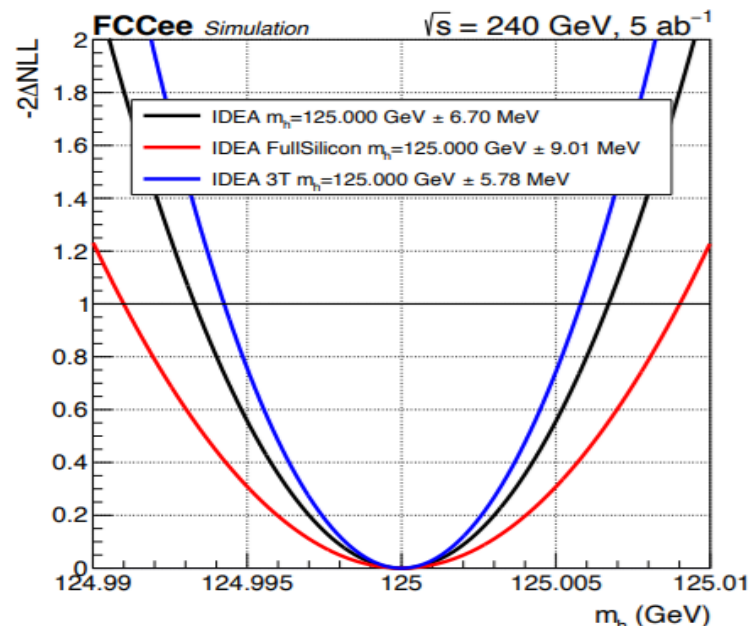
Higgs Mass (MeV)

Conclusion:

- In the Higgs measurements at the e^+e^- colliders, the “ZH recoil mass” allows for the measurement of m_H with an uncertainty down to a few MeV
- The Higgs boson width ($\Gamma = 4.1$ MeV in the SM), will also be measured directly for the first time
- Measurement of the HZZ coupling will be a “standard candle” for other Higgs coupling measurements
- Statistical analysis yields Higgs mass uncertainty 6.7 MeV, cross-section 1.1% (stat-only)

Examples of Systematic studies

1. Magnetic field increased from 2T to 3T → expected better momentum resolution
2. FullSilicon tracker instead of drift chamber → degraded resolution due to enhanced multiple scattering, especially at low p_T and in the range relevant for this analysis
3. Effect on mass scales with resolution, impact on cross-section uncertainty is limited

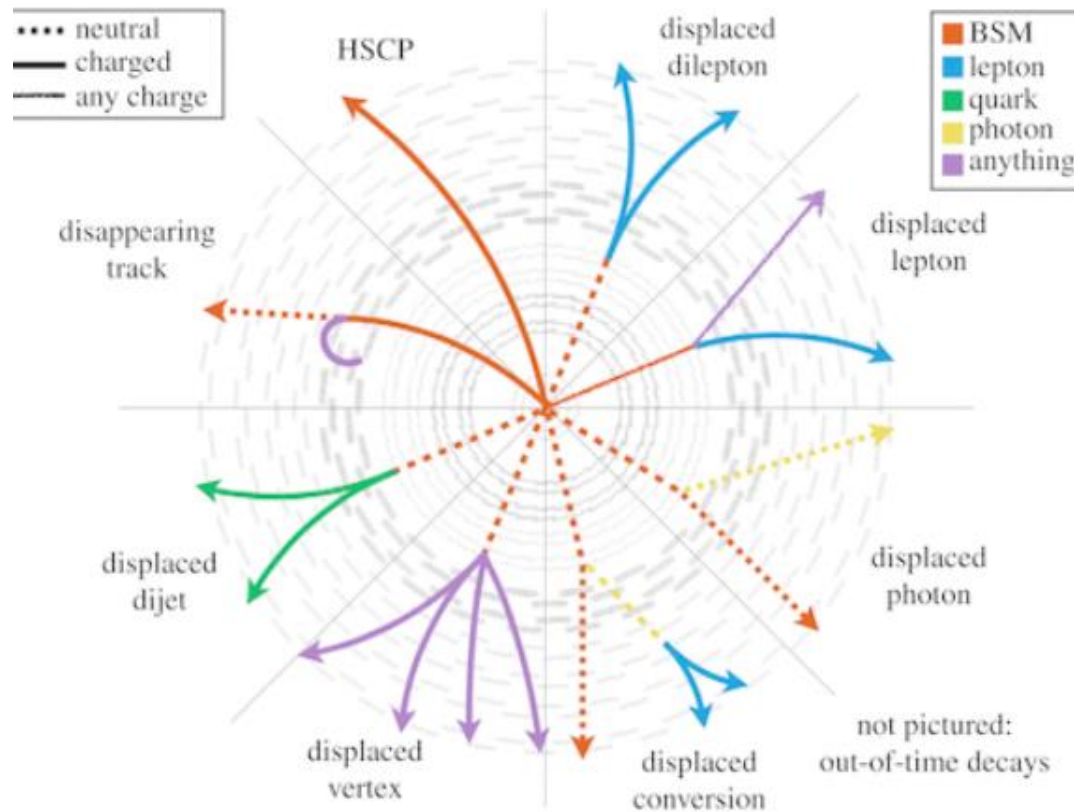


Stat-only results

IDEA	Δm_H (MeV)	$\Delta\sigma$ (%)
Nominal	6.7	1.07
FullSilicon	9.0	1.12
3T	5.8	1.06

→ « low mass » drift chamber is a better choice than full silicon tracker

Searches for LLP at FCC-ee



- Displaced tracks/vertices
 - Disappearing/kinded tracks
 - Anomalous tracks (dE/dX)
 - Slow/stopped particles (out of time)
 - Emerging signatures
- ⇒ But this also means:
- Non or small background.

Need dedicated techniques. Many experiments being built.

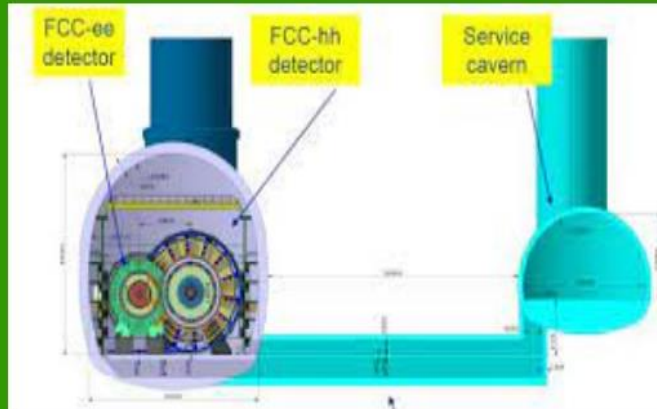
All current searches have something in common → they need to fit into existing infrastructure

Design a detector ahead of time for FCC

HECATE

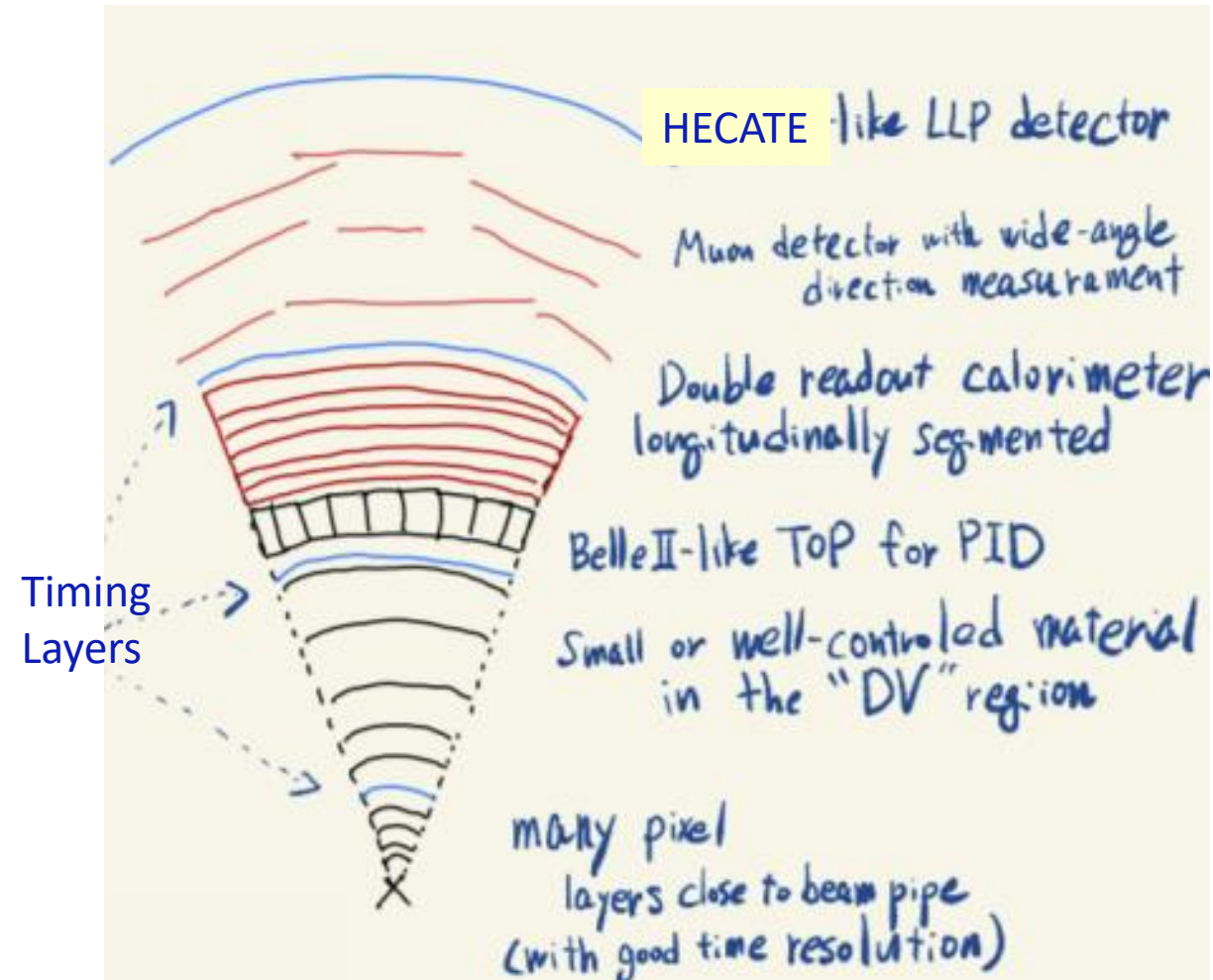
HErmetic CAvern TrackEr (HECATE), arxi:2011.01005, Jan Hajer, Marco Drewes, MC

- Use the HUGE FCC caverns and cover them detectors.
- Most space & cost efficient design.

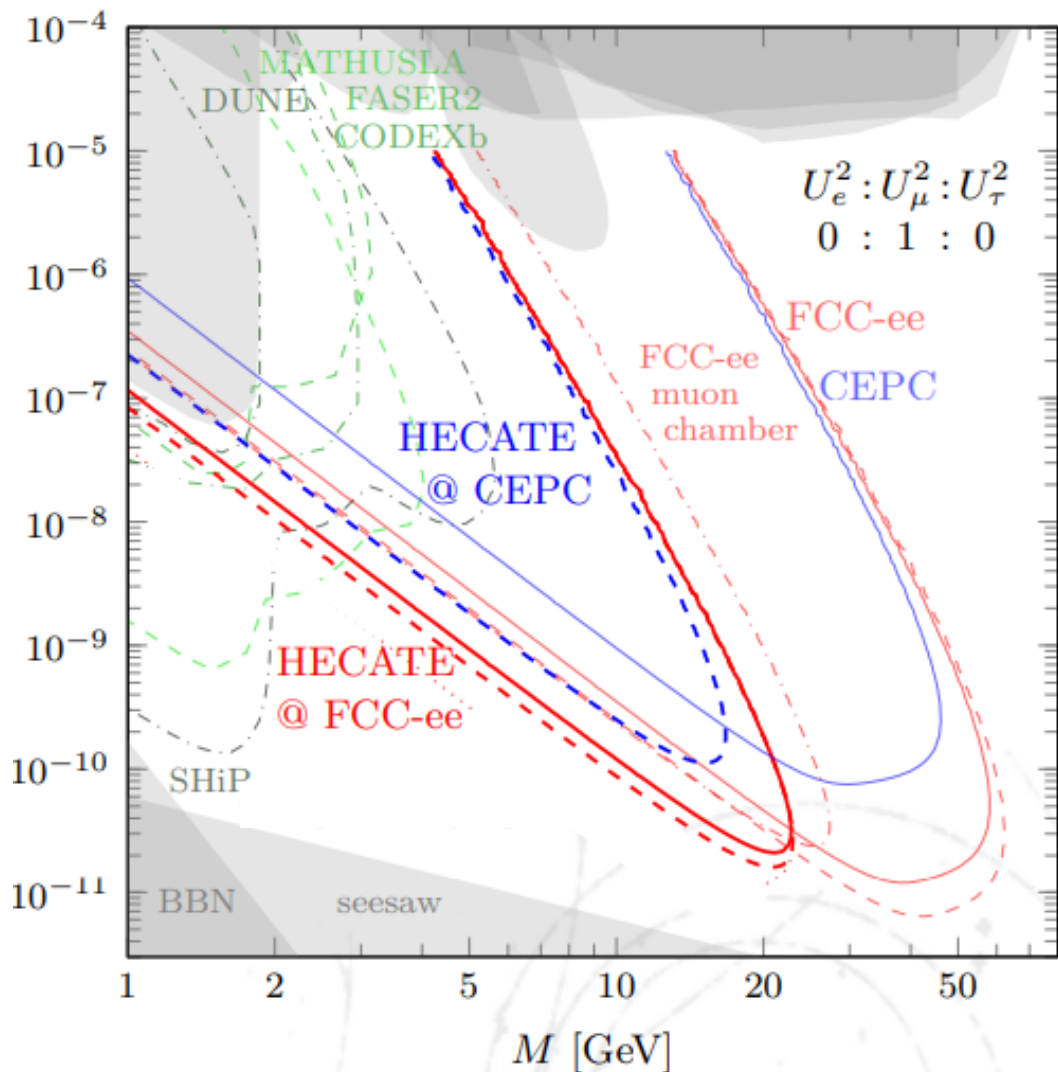


The sweat spot

- Hermetic 4π detector.
- No additional civil engineering.
- Cheap: 10MCHF.
- Needs timing.
- Scintillators, RPC
- Discussion with Imad Laktine started



Heavy Neutral Lepton sensitivity



Model which can be tested @ FCC

- Hidden Valley models with neutral, long-lived p Higgs boson can decay to (arXiv:1812.05588) .
- Higgs portal, dark glueball(arXiv:1911.08721)
- Neutral naturalness (arXiv:1506.06141)
- Folded SUSY (arXiv:1911.08721)
- Neutralinos (arXiv:1904.10661)
- ALPs (arxiv:1808.10323)
- Dark photon (arxiv:1906.10608)

Conclusions

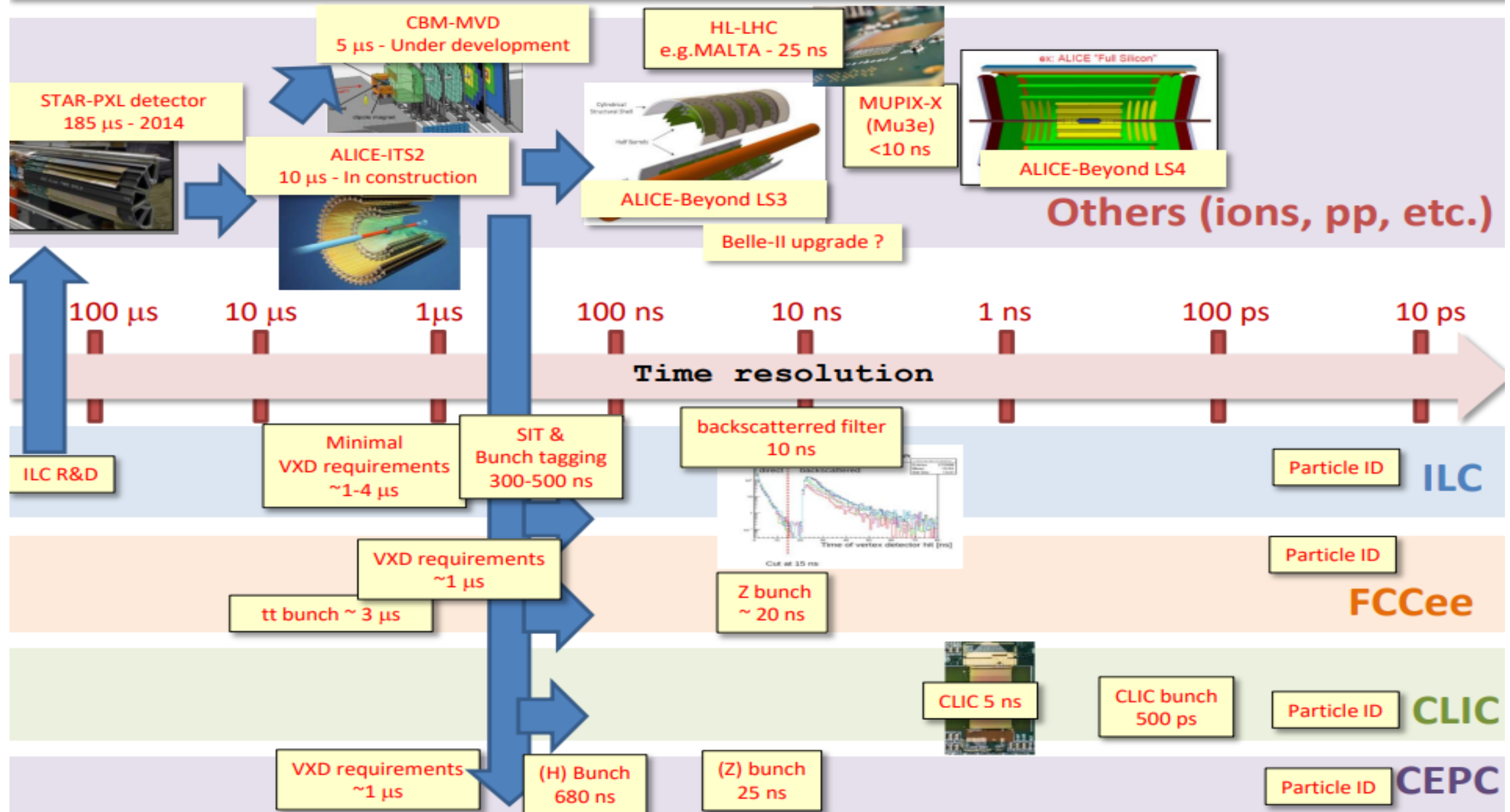
- ⇒ FCC is an ideal environment to look for LLP.
- ⇒ We are in unique spot to start thinking about them
- ⇒ Possible Majorana - Dirac distinction.
- ⇒ Complementarity with hadron machines.
- ⇒ We cannot waste this opportunity!!

Next Steps, next workshop

- New paths have been presented in this workshop
 - Build on these, strengthen the collaborations, in particular between FCC and ILC
→ Higgs/EW factory approach,
but also, possibly, with neighbouring countries !
 - Follow up on detector concepts, using already advanced R&D developed in particular for ILC
 - Merge developments in Physics cases, and in Theory progress
- ➔ Organize in November 2022 another Workshop (funding already requested by IP2I Lyon)

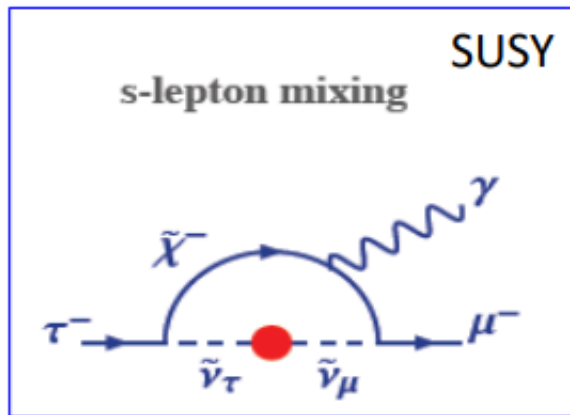
Thanks for your attention !

Time resolution in the context of e^+e^- colliders



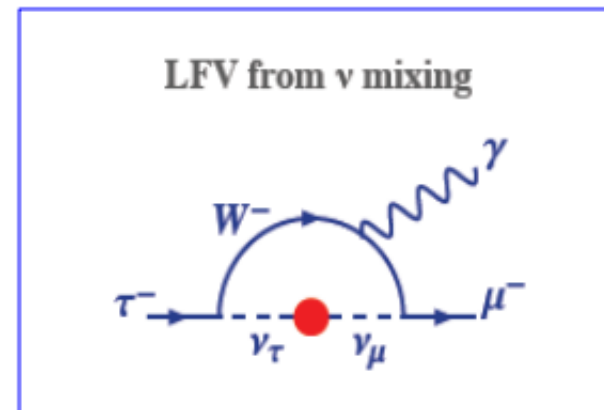
Another rare decays $\tau^{\pm} \rightarrow \mu^{\pm} \gamma$

BSM



Any signal means NP

SM



$$\mathcal{B}(\ell_1 \rightarrow \ell_2 \gamma) = \frac{3\alpha}{32\pi} \left| \sum_{i=2,3} U_{\ell_1 i}^* U_{\ell_2 i} \frac{\Delta m_{i1}^2}{M_W^2} \right|^2$$

Unmeasurable small rates (10^{-54} - 10^{-49})

● α_S :

- Most precise determination using Lattice QCD:

$$\alpha_S = 0.1184 \pm 0.0006 \quad \text{HPQCD '10}$$

$$\alpha_S = 0.1185 \pm 0.0008 \quad \text{ALPHA '17}$$

$$\alpha_S = 0.1179 \pm 0.0015 \quad \text{Takaura et al. '18}$$

$$\alpha_S = 0.1172 \pm 0.0011 \quad \text{Zafeiropoulos et al. '19}$$

→ Difficulty in evaluating systematics

- e^+e^- event shapes and DIS: $\alpha_S \sim 0.114$

Alekhin, Blümlein, Moch '12; Abbate et al. '11; Gehrmann et al.

→ Subject to sizeable non-perturbative power corrections

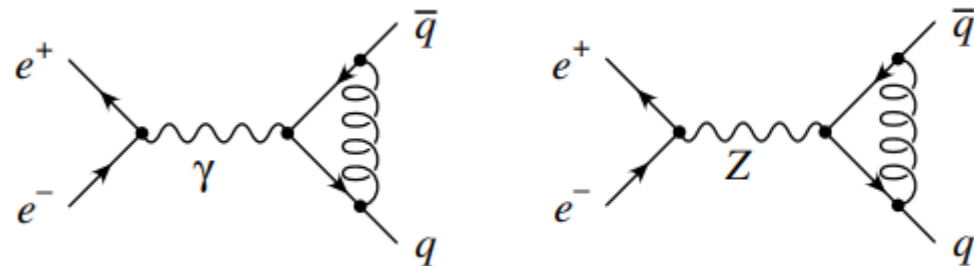
→ Systematic uncertainties in power corrections?

- Hadronic τ decays: $\alpha_S = 0.119 \pm 0.002$

PDG

→ Non-perturbative uncertainties in OPE and from duality violation

Pich '14; Boito et al. '15



● α_S :

- Electroweak precision ($R_\ell = \Gamma_Z^{\text{had}} / \Gamma_Z^\ell$):

$$\alpha_S = 0.120 \pm 0.003 \quad \text{PDG '18}$$

→ No (negligible) non-perturbative QCD effects

FCC-ee: $\delta R_\ell \sim 0.001$

$$\Rightarrow \delta \alpha_S < 0.0002 \text{ (subj. to theory error)}$$

Caviat: R_ℓ could be affected by new physics

- $R = \frac{\sigma[ee \rightarrow \text{had.}]}{\sigma[ee \rightarrow \mu\mu]}$ at lower \sqrt{s}

e.g. CLEO ($\sqrt{s} \sim 9 \text{ GeV}$): $\alpha_S = 0.110 \pm 0.015$

Kühn, Steinhauser, Teubner '07

→ dominated by s -channel photon, less room for new

→ QCD still perturbative

naive scaling to 50 ab^{-1} (BELLE-II): $\delta \alpha_S \sim 0.0001$