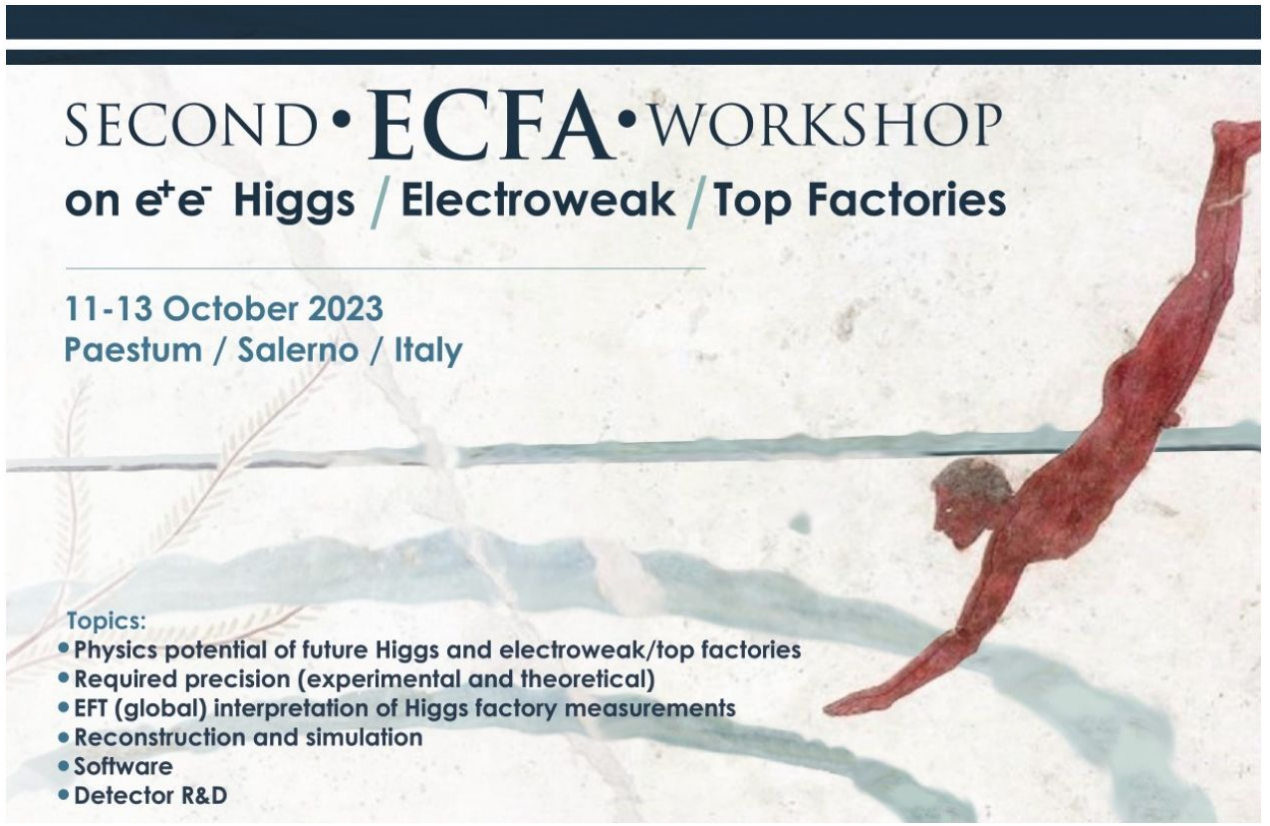
Report from the ECFA higgs factory meeting: analysis and software



ILD group meeting

Thomas Madlener

Nov 07, 2023

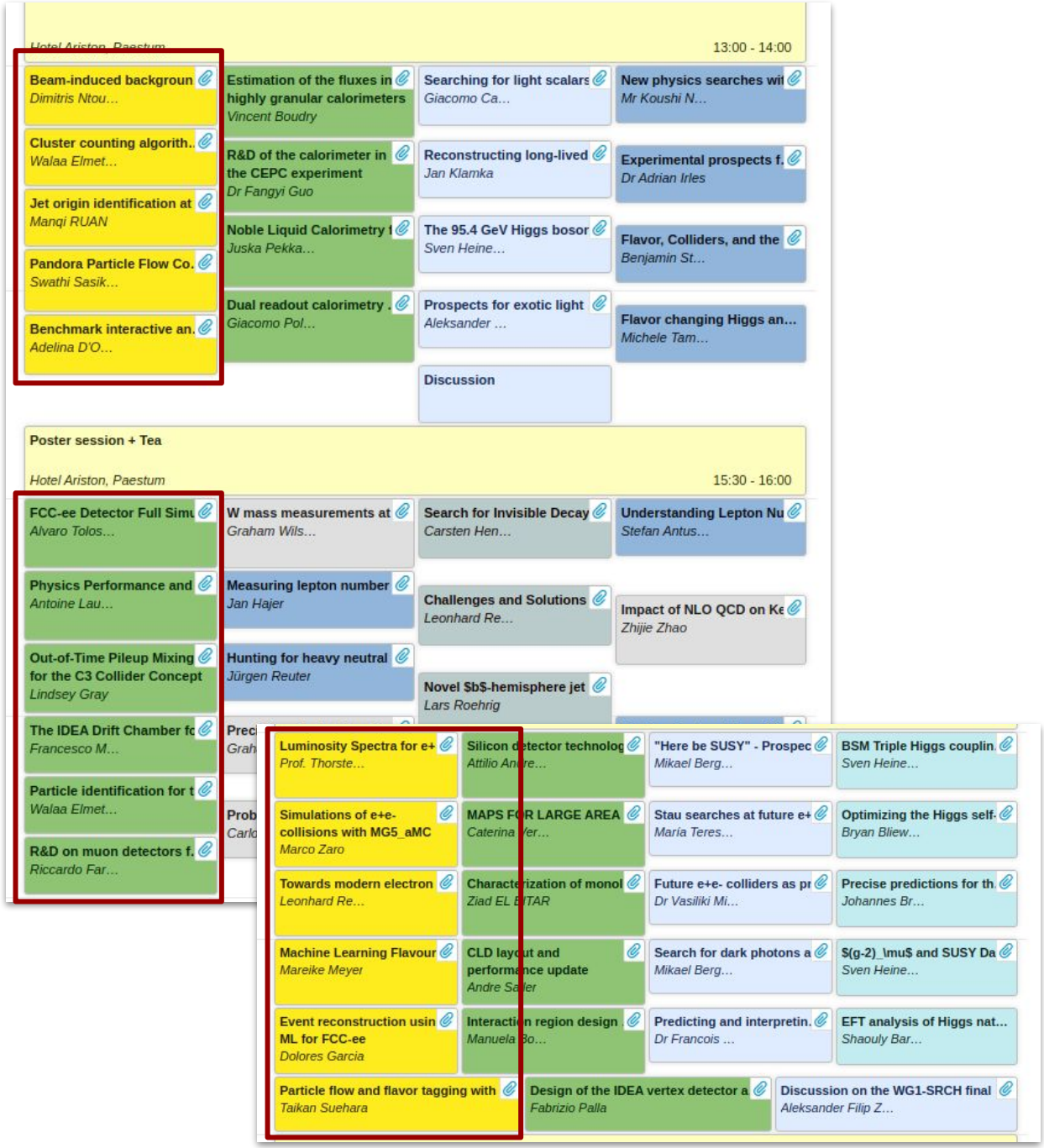
HELMHOLTZ

DESY.

What to expect

The usual disclaimers

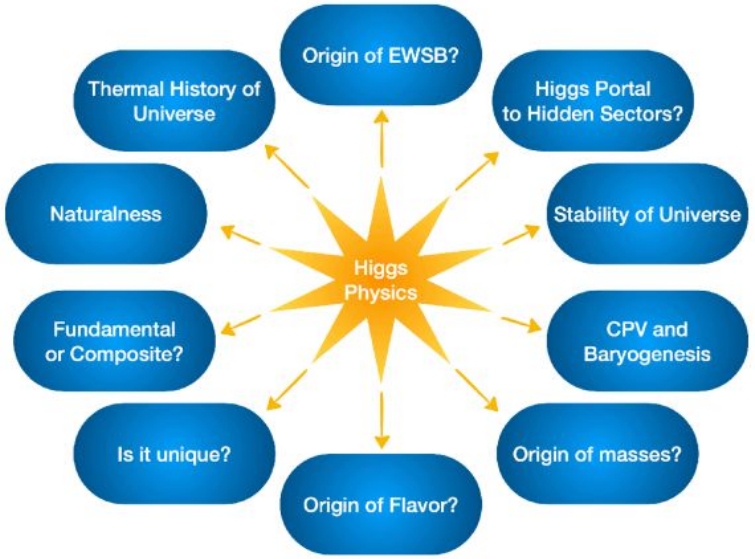
- https://agenda.infn.it/event/34841/
- Focus on software, detectors and reconstruction
  - Selection biased by personal preferences and the sessions I attended
- Try to give an overview and a few highlights
- Report on the ECR session (and the ECR workshop in Sep)
- Few slides stolen from J. Reuters recap at FC@DESY meeting (Nov 03)

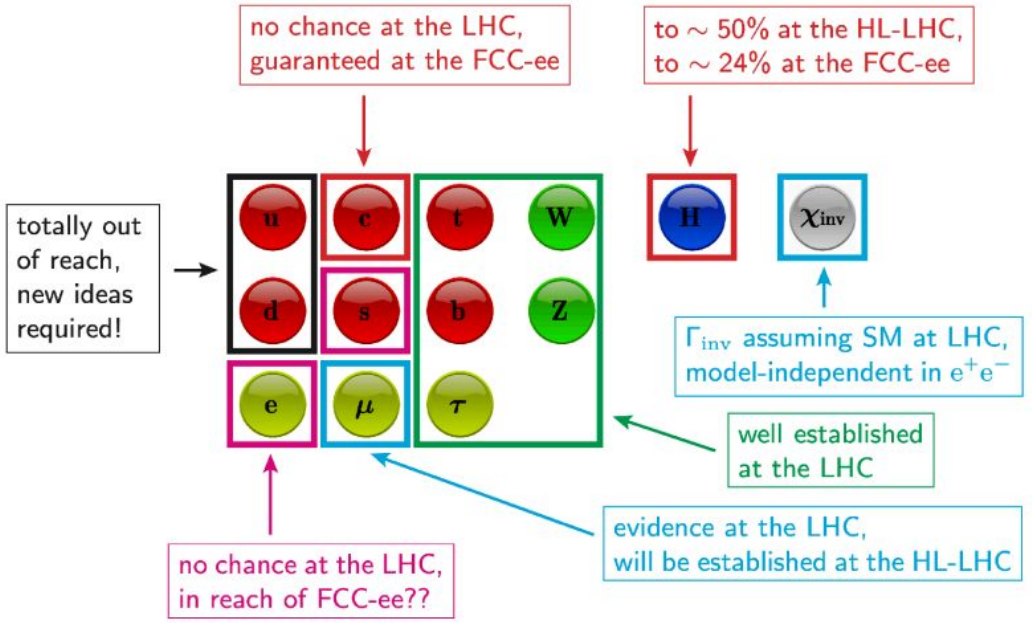


Physics landscape and vision

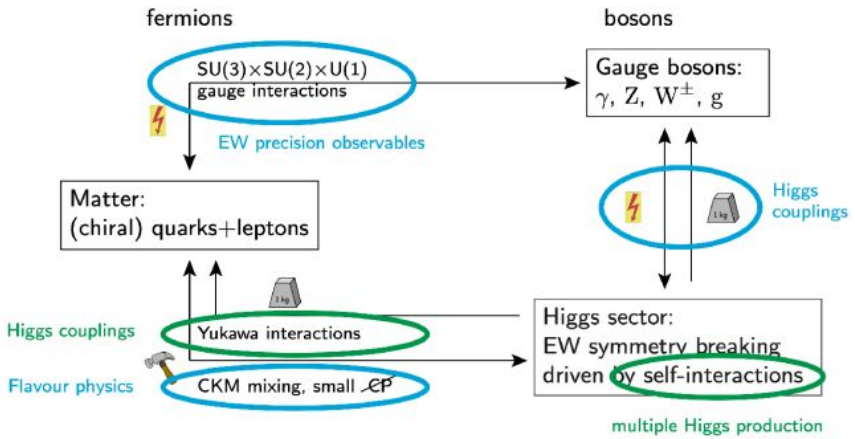
Mystery Higgs sector

Snowmass 2021 US Community Study on the Future of Particle Physics



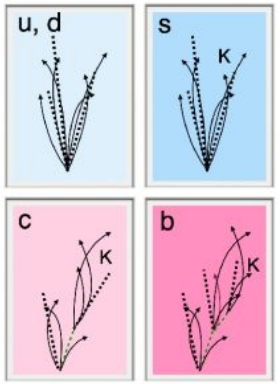


The Standard Model – establishing its dynamics (with precision)

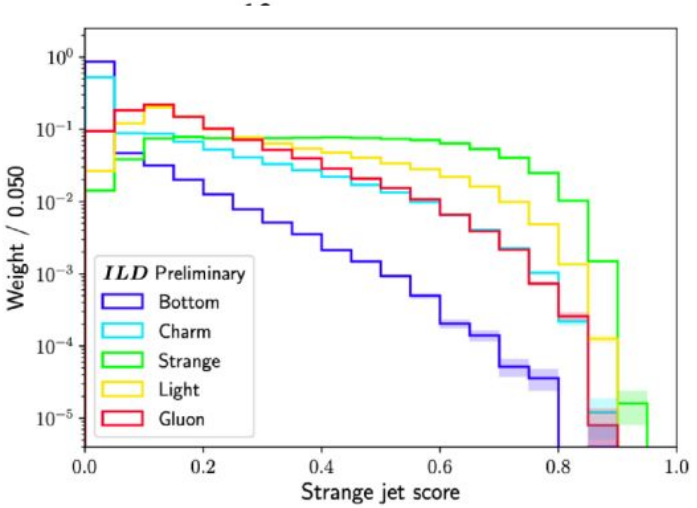


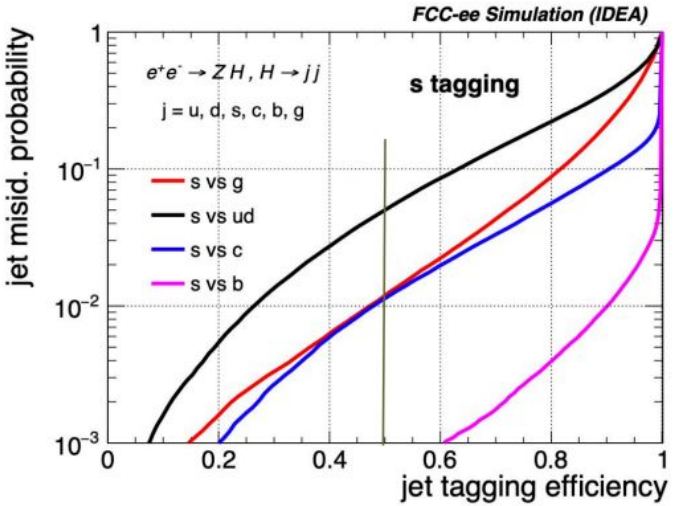
Strange tagging / NP in top decays / Higgs self-coupling

Talk Caterina Vernieri



Jet flavour	Number of secondary vertices (excluding V^0s)	Number of strange hadrons (e.g., $K^{\pm}$, $K^0_{L/S}$, and Λ^0)
Bottom	2	≥ 1
Charm	1	≥ 1
Strange	0	≥ 1
Light	0	0





- As b,c, and s jets contain at least one strange hadron
- Strange quarks mostly hadronize to prompt kaons which carry a large fraction of the jet momentum
- Strange hadron reconstruction:
  - $K^{\pm}$ PID
  - K^0_L PF (neutral)
  - $K^0_S \to \pi^+\pi^-$ (~70%) / $\pi^0\pi^0$ (~30%)
  - $\Lambda^0 \to p\pi^-$ (~65%)

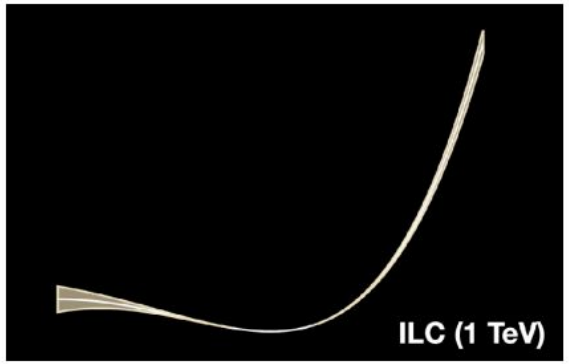
Distinctive two-prong vertices topology

- ILD results in full simulation vs. IDEA results in Delphes fast simulation
- 4 different methods charged hadron ID: ToF, dE/dx, dN/dx, RICH
- Phenomenological targets BSM models with modif. $H \to s\bar{s}$ or $H \to sc$
- provide detector benchmarks (also for $s/\bar{s}$ separation)

Strange tagging / NP in top decays / Higgs self-coupling

Talk Junping Tian

- Higgs self-coupling *experimentum crucis* for EWSB
- Only possible with severe model assumptions at circular machines
- Might be the one major selling point for linear colliders
- Guideline: precision in λ_{HHH} as function of achievable FCC-hh energy



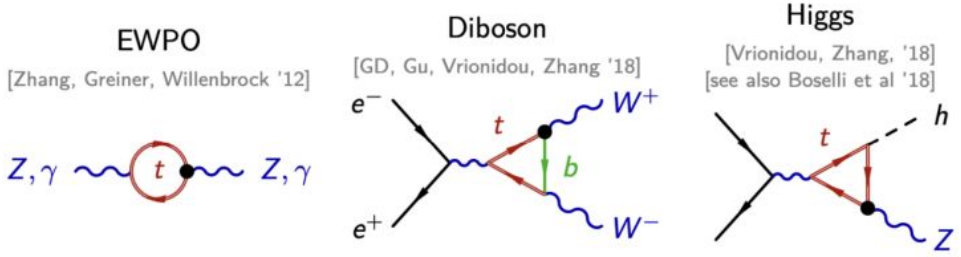
Nathaniel Craig, LCWS 2023

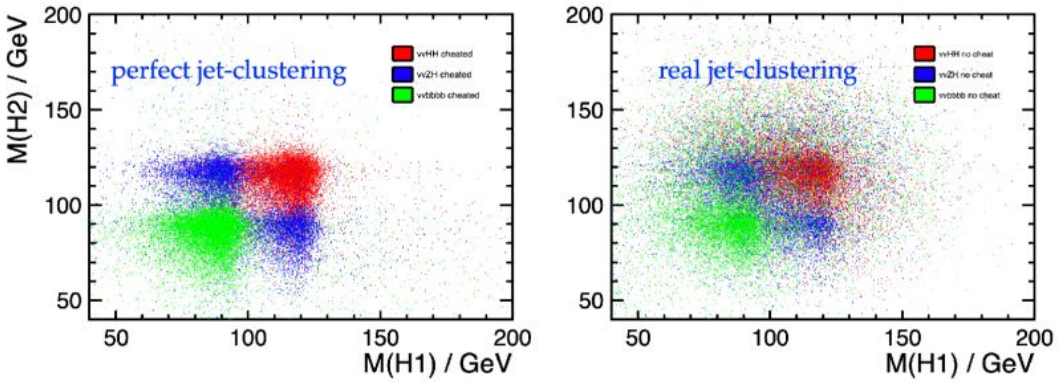
Double Higgs:

- O(20%) precision possible at 500 GeV [C. Dührig, 2016]
- Improvements: flavor tagging, kinematic fitting, jet clustering, ML, ME
- Talks in Paestum: B. Bliewert, T. Suehara, M. Ruan
- Perfect jet clustering would improve $\delta\lambda/\lambda$ by 40%
- Would ~550 GeV improve over 500 GeV (more boosted jets) ??

Single Higgs:

- Single Higgs contaminated: δZ vs. δh vs. δt
- Lift degeneracies: — diff. measurements (?)
  — energy scan 240-250 GeV (?)
  — radiative return from 365 GeV (?)

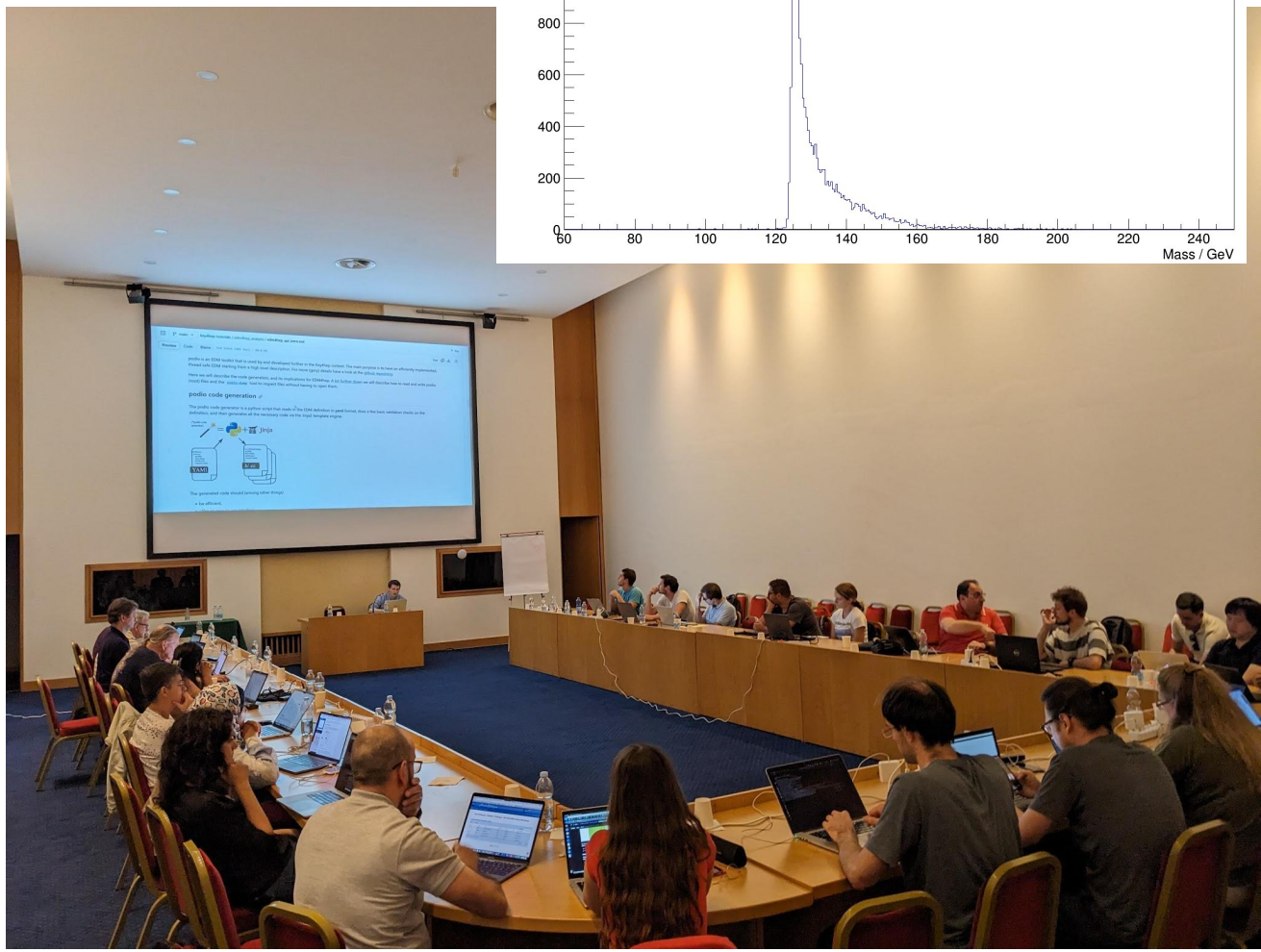




Key4hep software tutorial

Spreading the word

- 5 hours of tutorial on Tuesday before workshop start
- Introduction of existing tools & exercises for using them
  - Full chain from running the generator over simulation and reconstruction and making plots
  - key4hep-tutorials on github
- Focus on Key4hep and EDM4hep and how to run existing Marlin processors in Gaudi
- Introduce Gaudi Functional (i.e. how to write thread safe algorithms)
- **~25 participants from various communities**
- **Major update to the Key4hep documentation**
- **Positive feedback throughout**



Key4hep in Paestum

… (almost) everywhere

- Plenary talk on Thursday by J. M. Carceller
  - Nice progress since last workshop
  - Overview of ongoing developments
- (Almost) anything simulation or reconstruction related mentioned Key4hep
- **Also mentioned in quite a few plenary talks**
- Community fully supporting this common effort

Plenary by S. Rajagopalan

Software Support

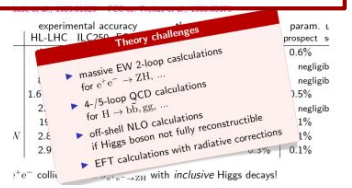
- While we agree with the prioritization of benchmark physics processes as laid out by ECFA, we must be able to support other ongoing studies:
  - Ongoing studies at Z-pole (*b* and τ factory!), WW (EW and top precision measurements), light and top Yukawa couplings, Higgs self-couplings, rare/exotic decay modes and other studies accessible only at higher energies. This helps to add value to the ECFA planned studies.
- Software tools and related support are essential to allow contributions to physics studies and in turn detector optimizations.
- Close coordination with ECFA WG2 and FCC software team, building on the developments in Key4HEP is essential. U.S. has significant pool of expertise to engage here.
- U.S. interests in the near-term leverage expertise at the LHC and focus primarily on:
  - Immediate Near Term (starting now):

Plenary by K. Jakobs

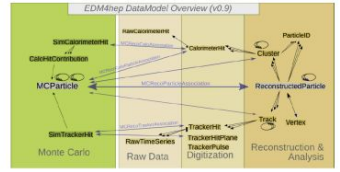
Where do we stand?

After a rather slow start, the activities are ramping up!

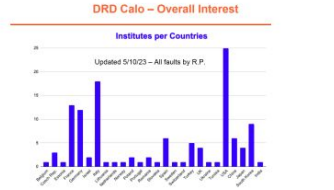
Excellent work of the working group conveners!



+ **Theory involvement** ramping up, good progress on generators,
  … but still a lot of work required e.g. on precision calculations
  (→ stronger participation welcome, ECFA study provides a forum!)



+ Lot of progress on **software tools (key4hep)!**
  Full simulation and reconstruction on the way,
  appreciate tutorials & documentation



+ **Detector interface** group started activities;
  Good to see integration in detector R&D;

+ Definition of **Focus Topics** was a good idea, ramping up,
  but definitely room for more people to join;
  This would also allow to extend the topics and broaden the physics coverage towards the next ESPP.

ECFA European Committee for Future Accelerators

2nd ECFA Workshop, Paestum, 12th October 2023

20

Key4hep in Paestum

… (almost) everywhere

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  - Nice progress since last workshop
  - Overview of ongoing developments
- (Almost) anything simulation or reconstruction related mentioned Key4hep
- **Also mentioned in quite a few plenary talks**
- Community fully supporting this common effort
  - Necessity for success given resource limitations
- Many ongoing efforts in making recent developments available in Key4hep
  - Migration of FCC detectors to common k4geo geometry package
  - Integration of reconstruction algorithms and ML
  - …

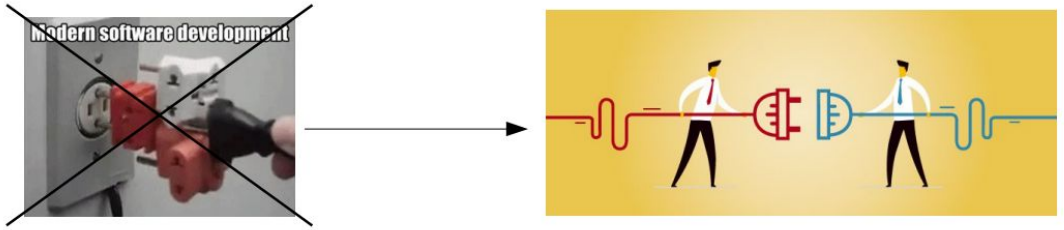
Plenary by S. Rajagopalan

Software Support

- While we agree with the prioritization of benchmark physics processes as laid out by ECFA, we must be able to support other ongoing studies:
  - Ongoing studies at Z-pole (*b* and τ factory!), WW (EW and top precision measurements), light and top Yukawa couplings, Higgs self-couplings, rare/exotic decay modes and other studies accessible

Plenary by B. Francois

Community Effort



- Prospective studies have limited man power (w.r.t. operating experiments)
  - Important to exploit synergies through a common effort
- The Future Collider community decided to develop a **common software ecosystem**
  - **Key4hep** guiding principles
    - **Interoperability**
      - "What was developed by some should be useable by others" (with minimal modifications)
    - **Versatility:** should cover large spectrum of needs (serves diverse facilities and detectors)
    - **Flexibility:** everything is under development, need to adapt to evolving detector configurations, experimental conditions, etc

Simulation Brieuc Francois 5

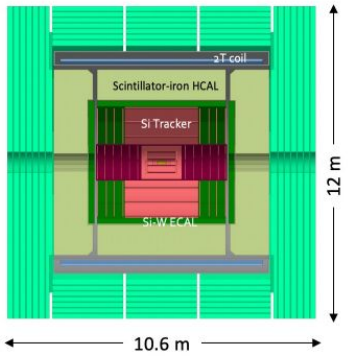
Detector concepts updates

with a strong focus on FCC-ee

FCC 12/10/2023 2nd ECFA Workshop Manuela Boscolo INFN LNF 23

FCC-ee Detector Concepts

CLD

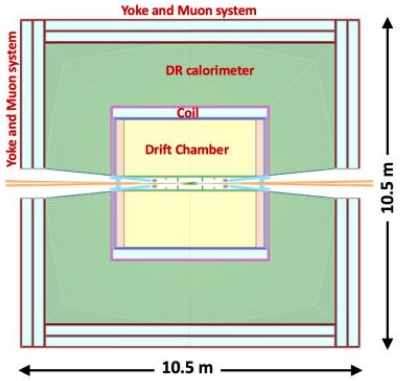


- Full Silicon vertex detector + tracker;
- Very high granularity, CALICE-like calorimetry;
- Muon system
- Large coil outside calorimeter system;

- Possible optimization for
  - Improved momentum and energy resolutions
  - PID capabilities

CDR

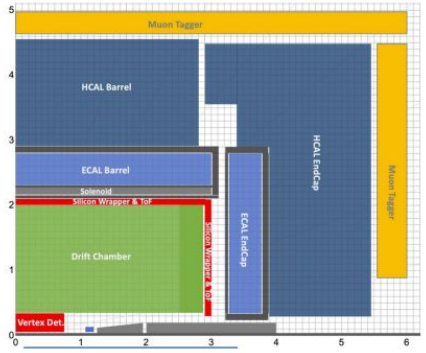
IDEA



- Si vertex detector;
- Ultra light drift chamber w. powerfull PID;
- Monolitic dual readout calorimeter;
- Muon system;
- Compact, light coil inside calorimeter;

- Possibly augmented by crystal ECAL in front of coil;

ALLEGRO



- High granularity Noble Liquid ECAL as core;
  - PB+LAr (or denser W+LCr)
- Drift chamber (or Si) tracking;
- CALICE-like HCAL;
- Muon system;
- Coil inside same cryostat as LAr, possibly outside ECAL.

new

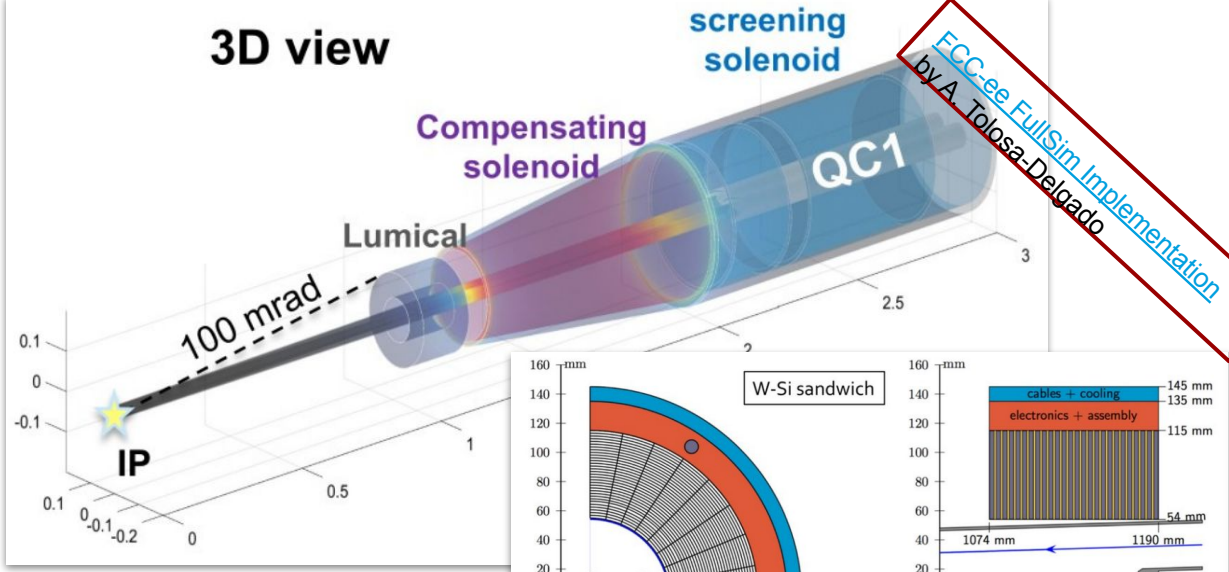
Find details in these talks:

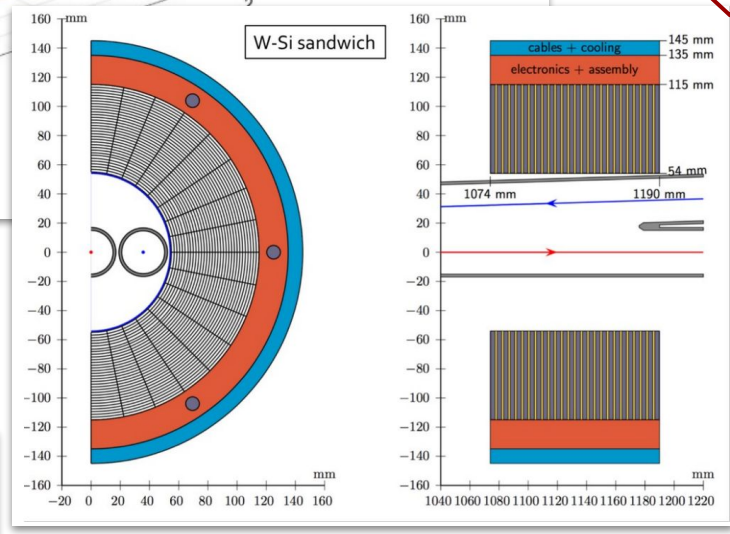
- FCC-ee FullSim Implementation by A. Tolosa-Delgado
- CLD Update by A. Sailer
- IDEA Drift Chamber by F. M. Procacci
- FCC-ee IR and MDI by M. Boscolo
- Noble Liquid calo by J. Pekkanen
- Dual readout calo by G. Polesollo
- IDEA vertex detector by F. Palla
- CEPC calo R&D by F. Guo

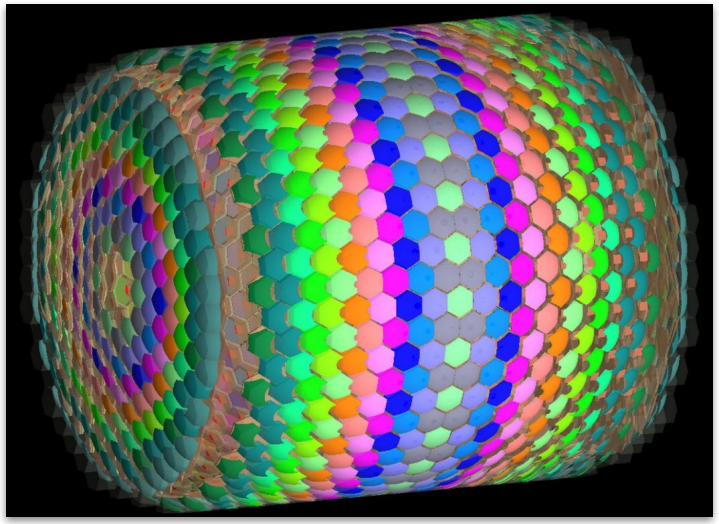
Recent & ongoing developments

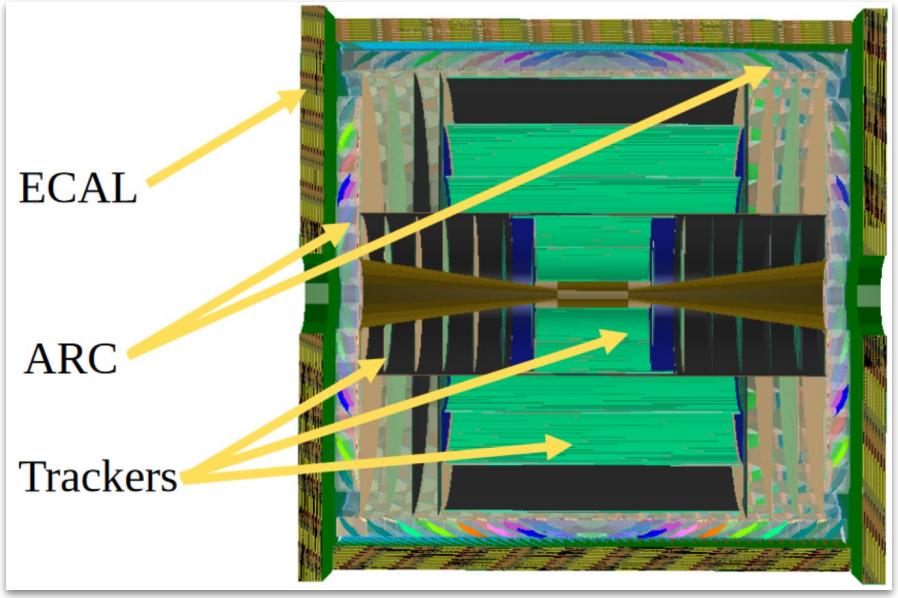
Towards Fully Simulated FCC-ee detector concepts

- **Common beam pipe for all concepts**
  - DD4hep implementation based on CAD design
  - Lumical from ILD
- Evolution of CLD
  - Testbed for full simulation of complete detector concept
  - Option with ALLEGRO ECAL (LAr)
  - Option with Array of RICH Cells (ARC)







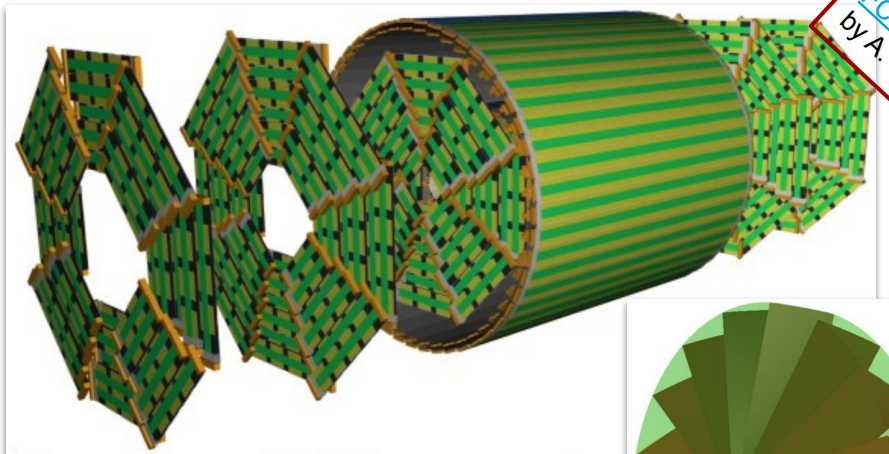


CLD Update by A. Sailer

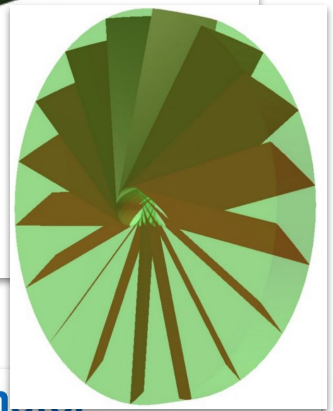
Recent & ongoing developments

Towards Fully Simulated FCC-ee detector concepts

- **Common beam pipe for all concepts**
  - DD4hep implementation based on CAD design
  - Lumical from ILD
- Evolution of CLD
  - Testbed for full simulation of complete detector concept
  - Option with ALLEGRO ECAL (LAr)
  - Option with Array of RICH Cells (ARC)
- IDEA developments
  - DD4hep models for vertex detector and dual readout calorimeter advancing
  - Drift chamber reconstruction under development
- ALLEGRO status
  - Tracker from IDEA concept
  - Barrel calorimeter implementations ready
  - Work in progress for endcaps
- **Necessity for beam tests to validate simulation**



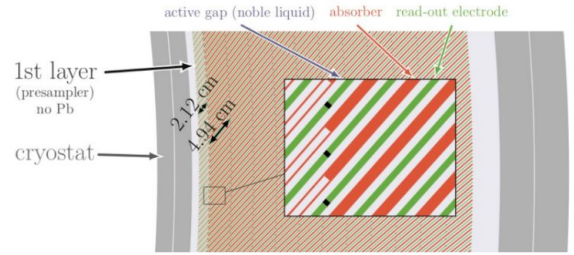
FCC-ee FullSim Implementation by A. Tolosa-Delgado

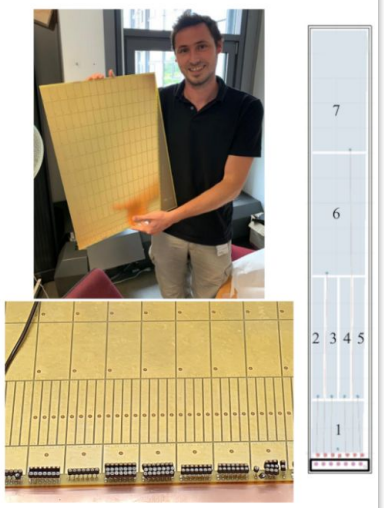


Noble Liquid calo Endcap "turbine" concept

Highly granular noble-liquid calorim

- Printed circuit board (PCB) technology allows "arbitrarily" high granularity
  - Signal traces inside the electrode
- Prototype PCB 58 cm $\times$ 44 cm $\rightarrow$
  - 50° inclination, 40 cm (22 χ_0) thick
  - Split to 16 θ-towers & 12 depth layers
  - Narrow strips in front for π^0 detection
- 7-layer PCB, complex internal structure
- 240 cells in total in the first prototype
- Read-out from inner and outer edge



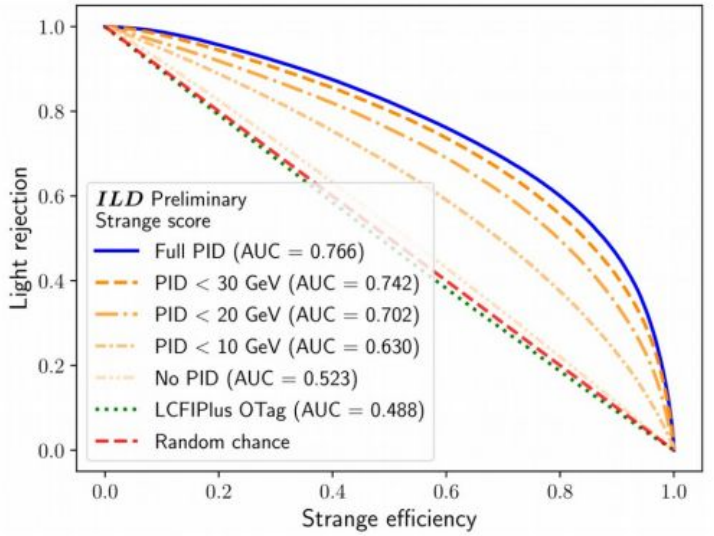


Noble Liquid calo by J. Pekkanen

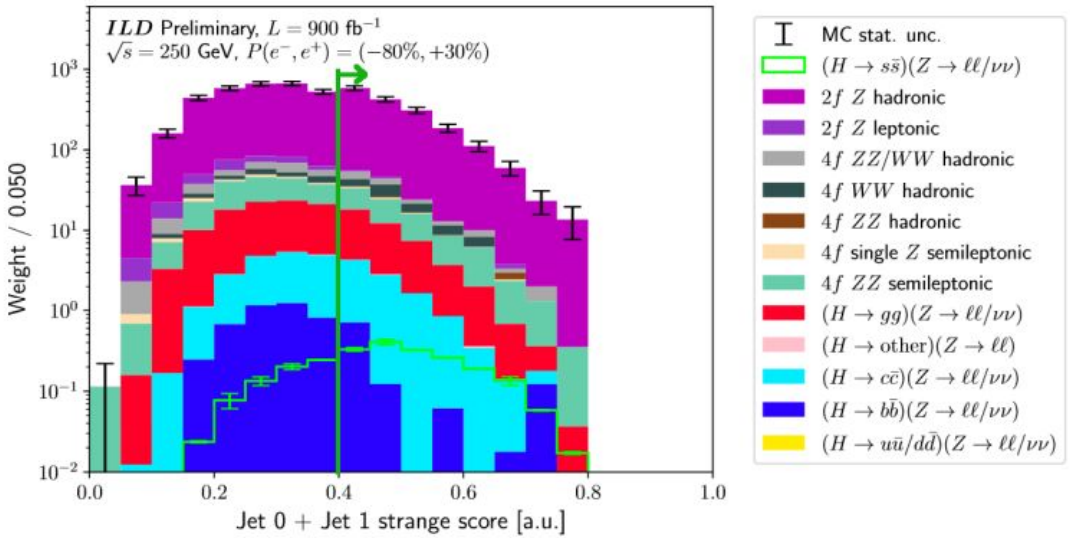
Reconstruction

The key to physics from collisions

- Plenary by U. Einhaus for a much more comprehensive summary
  - Covers pretty much everything
- A lot of existing software from LC communities **usable in Key4hep via the MarlinWrapper**
  - Working horse for many studies
- See also L. Reichenbach's talk on the challenges and possibilities of moving to ACTS for tracking
- Many new developments pushing physics potential of the different proposals
- A lot of ongoing efforts to support new detector concepts



arXiv:2203.07535



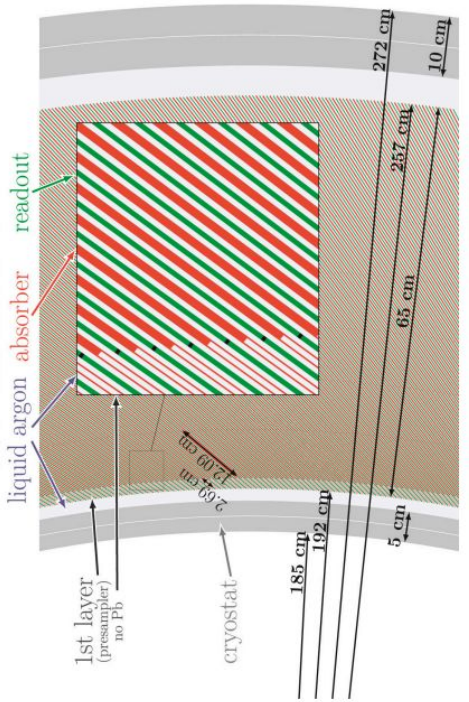
Particle Flow in LAr calorimeter

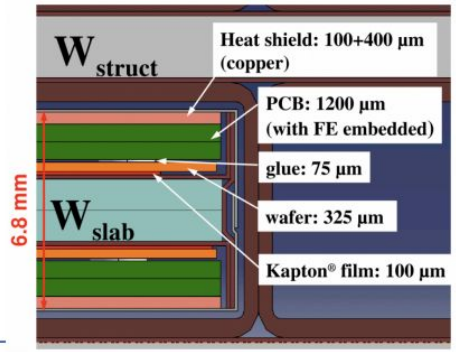
New concepts, new challenges

Pandora in Key4hep by S. Sasikumar

Material properties for PandoraPFA

- DDMarlinPandora designed for high granularity CALICE sandwich calorimeters
- LAr calorimeter has a very different structure : an ensemble of different materials in a cell varying in density and homogeneity
- Density of material also varies from the inner radius to the outer radius of the barrel
- Moreover, the inclination of the segments play a role
- Challenging to calculate radiation length or interaction length for LAr

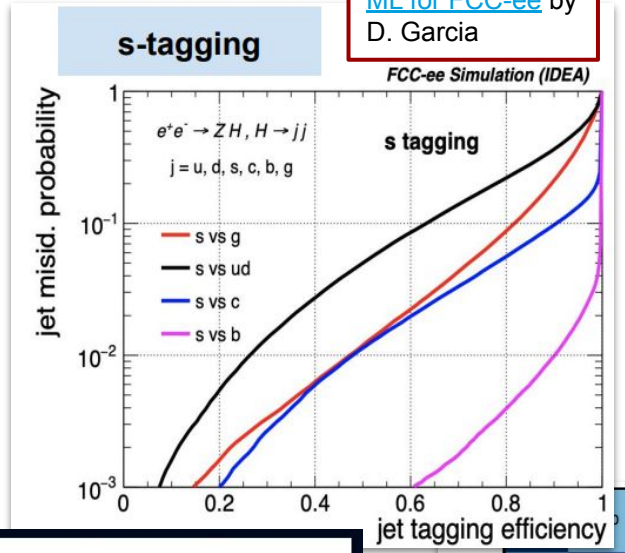




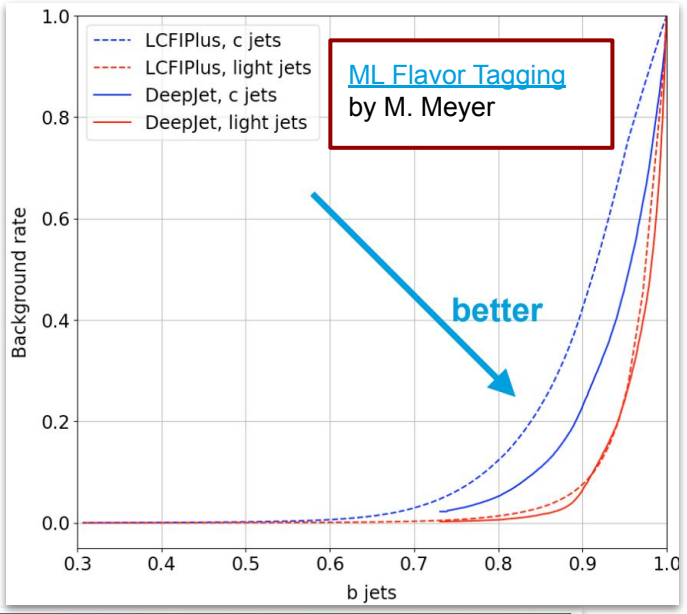
Flavor Tagging and Event Reco

The latest ML developments

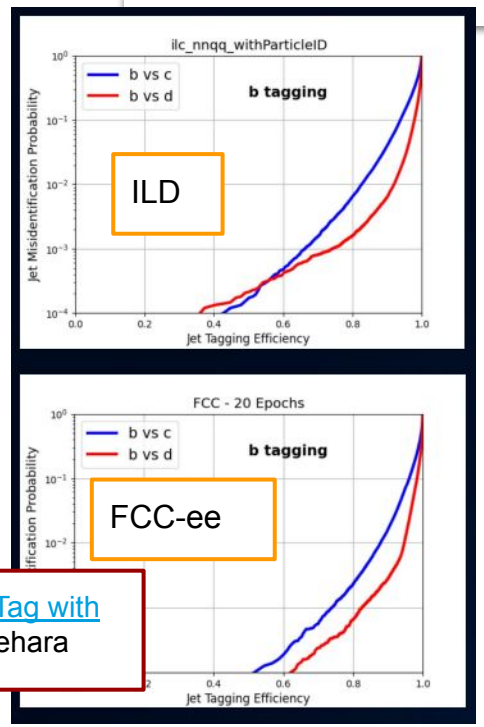
- Flavor Tagging & Jet origin identification using *Particle Net*, *DeepJet*, *Particle Transformer*, *Particle Clouds*, …
  - Significant improvements over LCFIPlus
  - *Tagging everything*
- Many results for various detector concepts (and simulation approaches)
- Next step: Consolidation of these results
  - Understand what causes the performance differences

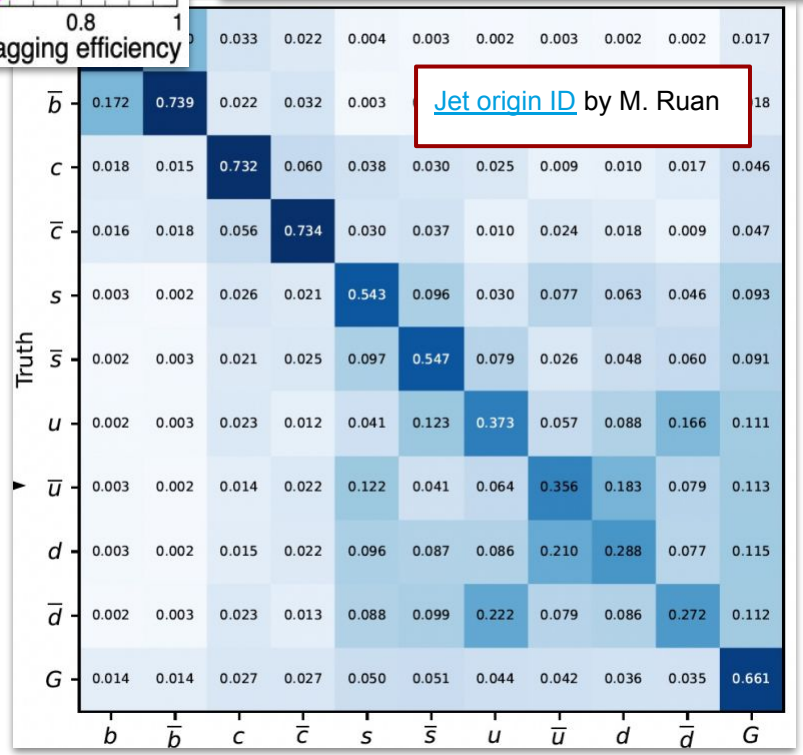


ML for FCC-ee by D. Garcia



ML Flavor Tagging by M. Meyer





Jet origin ID by M. Ruan

PF and Flavor Tag with GNNs by T. Suehara

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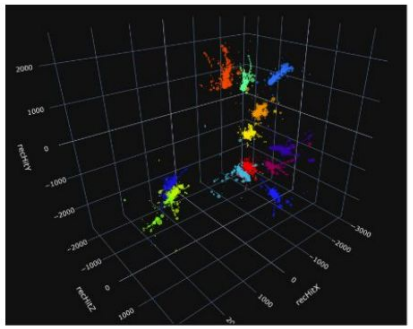
  - Significant improvements over LCFIPlus
  - Tagging everything
- Many results for various detector concepts (and simulation approaches)
- Next step: Consolidation of these results
  - Understand what causes the performance differences
- ML for Particle Flow
  - Using object condensation
  - Raw detector inputs clustered into particles in embedding space
  - Next steps: Add track info
- **Ultimate Goal: Integration into Key4hep**

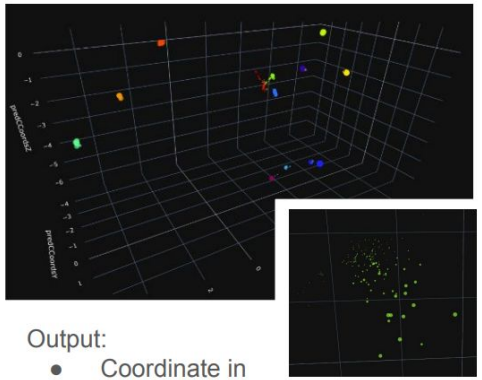
Architecture: Object condensation (End-to-End approach)

ML for FCC-ee by D. Garcia



CP

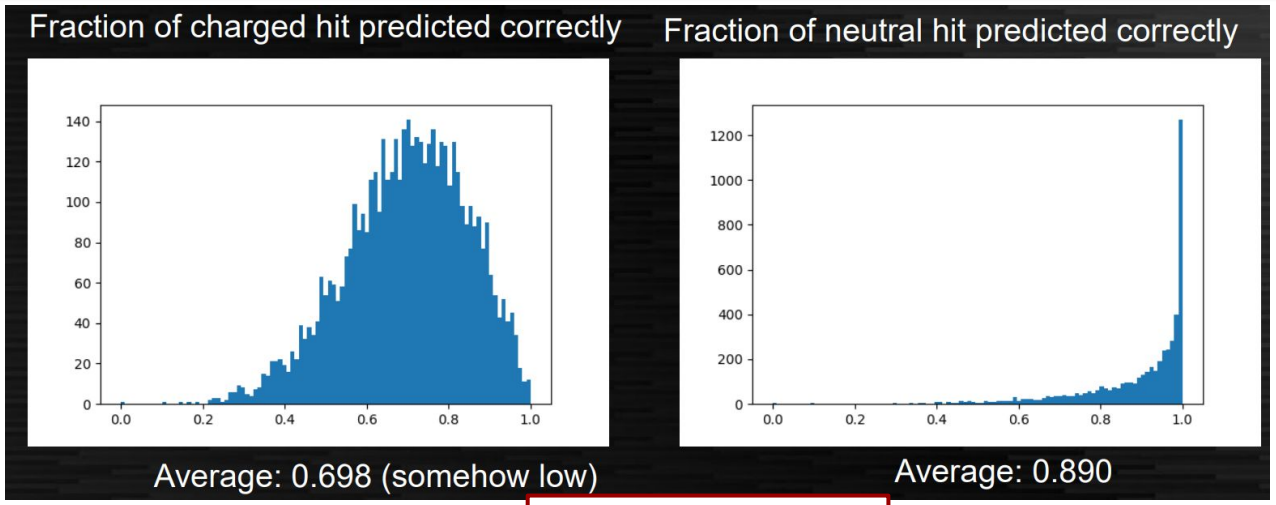
$$q_{\alpha k} = \max_i q_i M_{ik}.$$
$$\check{V}_k(x) = \|x - x_\alpha\|^2 q_{\alpha k}, \text{ and}$$
$$\hat{V}_k(x) = \max(0, 1 - \|x - x_\alpha\|) q_{\alpha k}.$$
$$L_V = \frac{1}{N} \sum_{j=1}^{N} q_j \sum_{k=1}^{K} \left(M_{jk} \check{V}_k(x_j) + (1 - M_{jk}) \hat{V}_k(x_j) \right).$$



Input:
- A set of hits from different sensors (coordinates, type of hit, energy, A)
- Each one node in the graph O(600) per particle

- **Each object 1 condensation point (CP)**
- **Repulsive +Attractive potentials for each CP**

Output:
- Coordinate in embedding space (3D>)
- Beta (q)
- Use clustering space to build showers



PF and Flavor Tag with GNNs by T. Suehara

The ECFA and the ECR Panel

Talk by E. A. Bagnaschi

ECR Panel

The objective of the ECFA Early-Career Researchers (ECR) Panel is for its members to discuss all aspects that contribute in a broad sense to the future of the research field of particle physics. In its advisory role to ECFA, the panel reports to ECFA on a regular basis. An annual report of the ECFA ECR Panel is added as a standing item to the agenda of Plenary ECFA meetings.

Role

- ECR community link to the update of the European Strategy via the ECFA
- Activity divided in various working groups. For a full overview, see https://arxiv.org/abs/2212.11238
- You should get involved!

Composition

- 3 representatives for each ECFA country, +1 for the major laboratorities
- Composed of researchers going from PhD to assistant professors
- Theorists/phenomenologists and experimentalists work together with the aim of representing the diverse viewpoints of the community
- 3-4 panel meetings per year, handled by Organization Committee (3 members)
- 5 ECR delegates in Plenary ECFA, 1 delegate in Restricted ECFA

ECR Session & Panel Discussion

Talking about the future of FCs

- Introduction of ECFA ECR Panel
- Report on recent ECR workshop at CERN
  - Follow up with national events
- (Open) panel discussion with 4 ECR panelists
  - Antoine Laudrain (DESY)
  - Rebeca Gonzalez Suarez (IFCA - U. Oviedo)
  - David Marzocca (INFN Trieste)
  - Thomas Madlener (DESY)
  - Karl Jakobs*
- Mixed attendance
- Cut short by delays

*second part of the discussion (not exactly ECR)

too busy discussing to take a picture

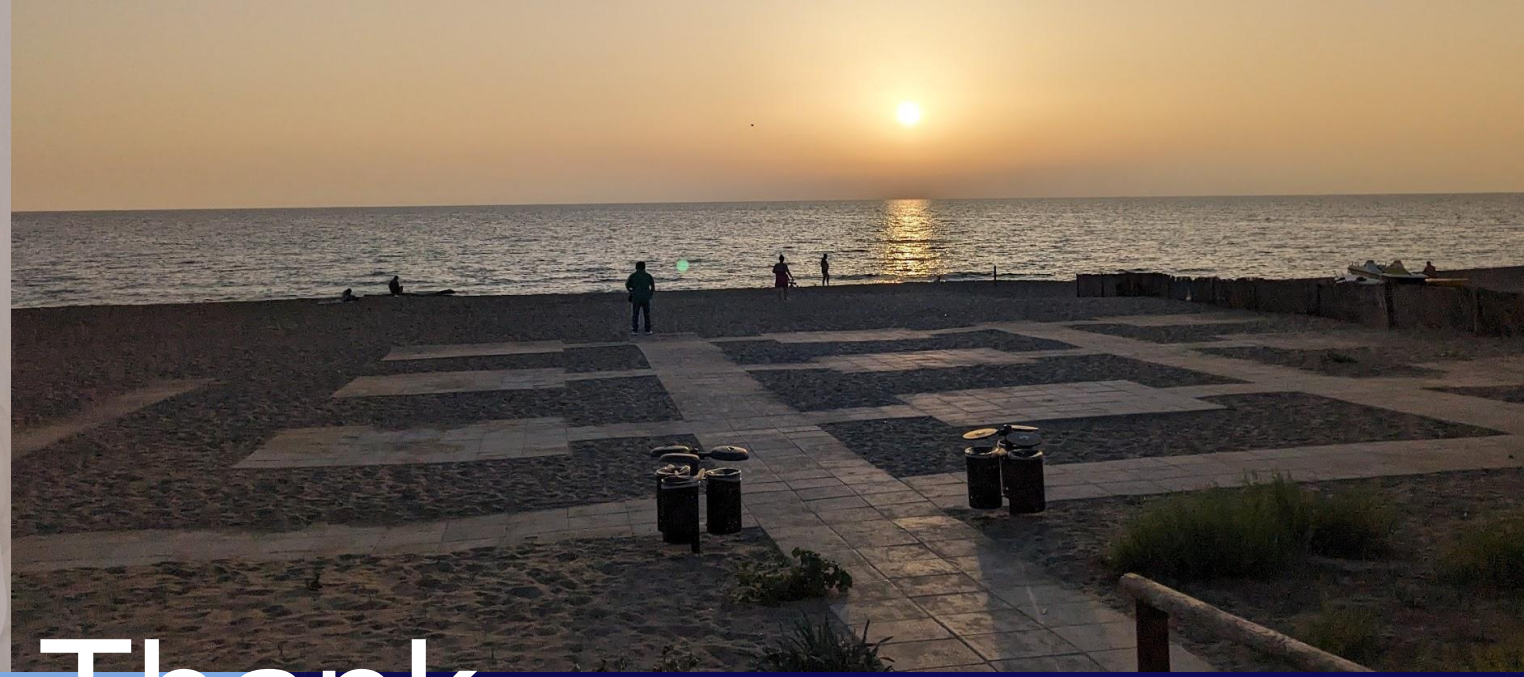
- No real preference for a specific project from panelists
  - Location might matter more than form factor
- Timelines might be an issue
  - (Not really discussed in Panel, but coffee break talk)
  - Not sure if people will come back if they switched to another (smaller) project
- General feeling that ECRs are being heard in ECFA
  - … and that contributions are appreciated
- … but also that there is always room for more involvement (from both sides)
- Cautious optimism(?)

Summary

…and final thoughts

- Key4hep is everywhere and all developments are converging towards it
- Progress towards full simulation for FCC-ee concepts
- New detector concepts come with new challenges in simulation and reconstruction
- Many Machine Learning approaches for high level reconstruction
  - Strange tagging becomes a thing
- Cautious optimism among ECRs
- Intense 2.5 days (3.5 incl. Key4hep tutorial)
  - With lots of things I didn't tell you about
- FCC is gathering steam
  - Many ECRs from CERN
- Still a lot of work ahead


SECOND • ECFA • WORKSHOP
on e⁺e⁻ Higgs / Electroweak / Top Factories
11-13 October 2023 Paestum / Salerno / Italy
INFN

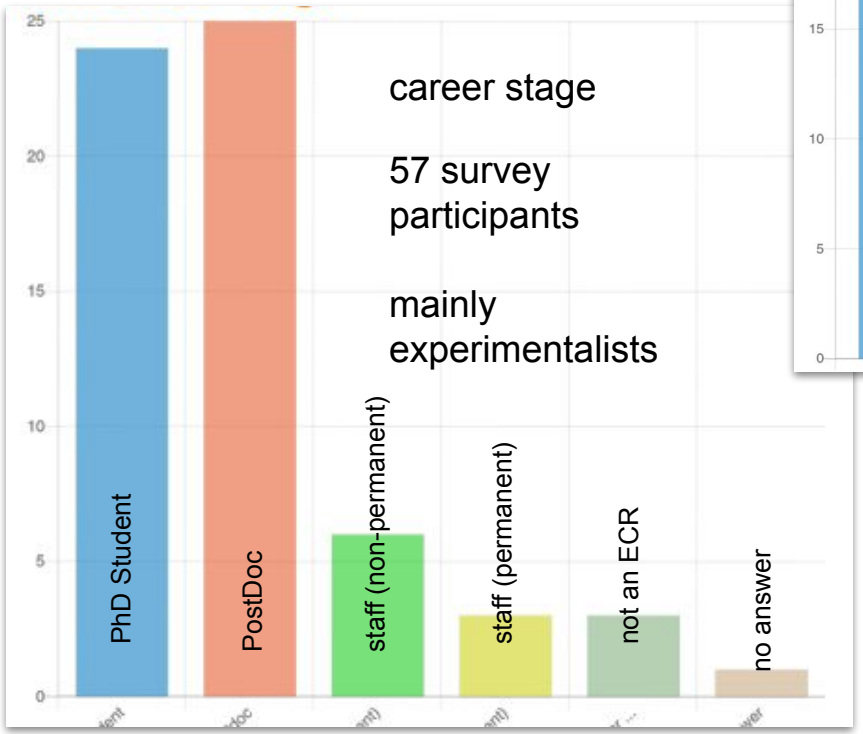


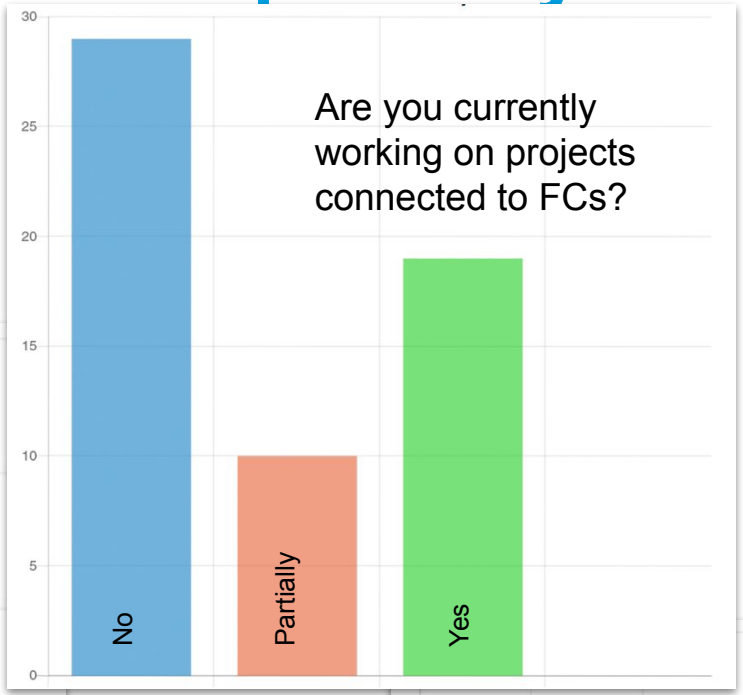
Thank You

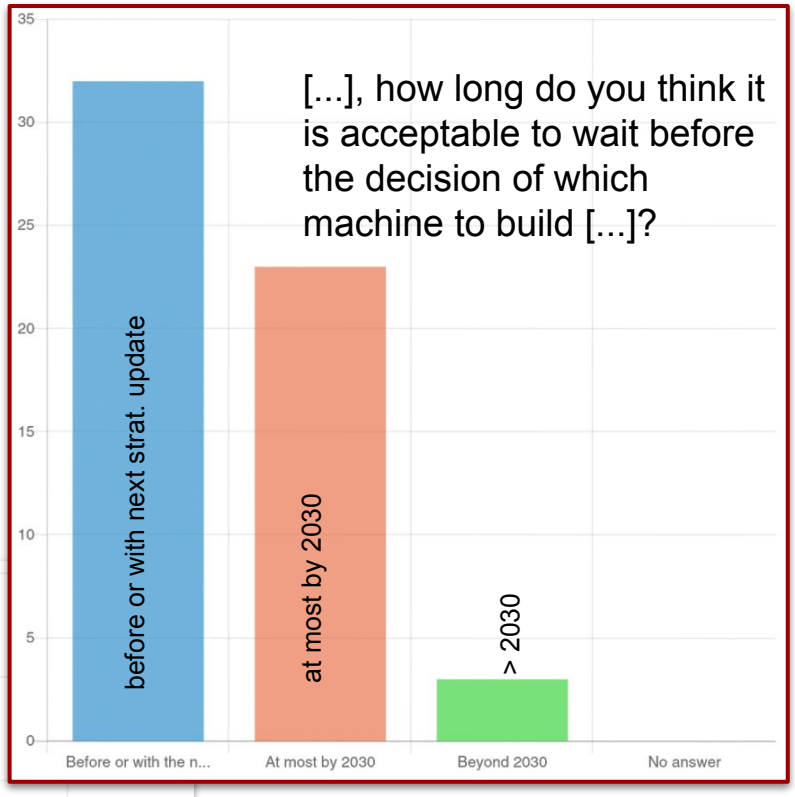
Preliminary ECR workshop survey results

An extremely limited overview

See the full presentation for more (preliminary!) results



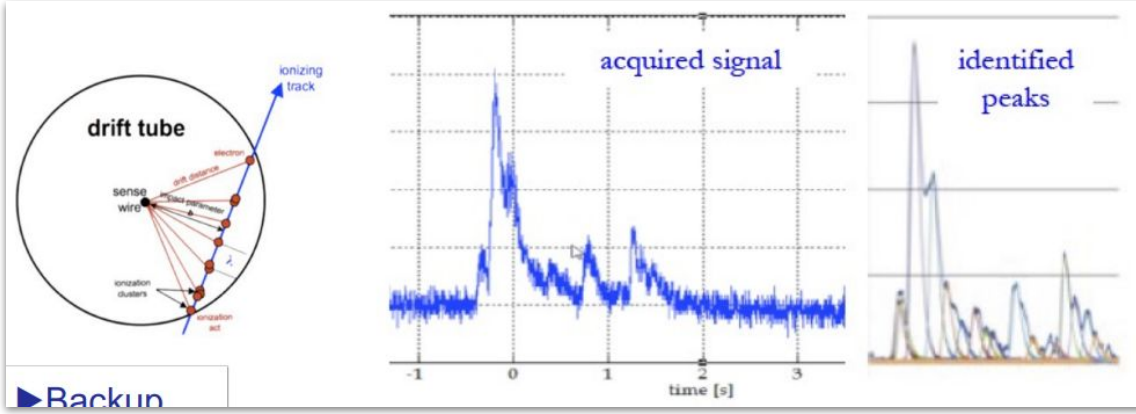


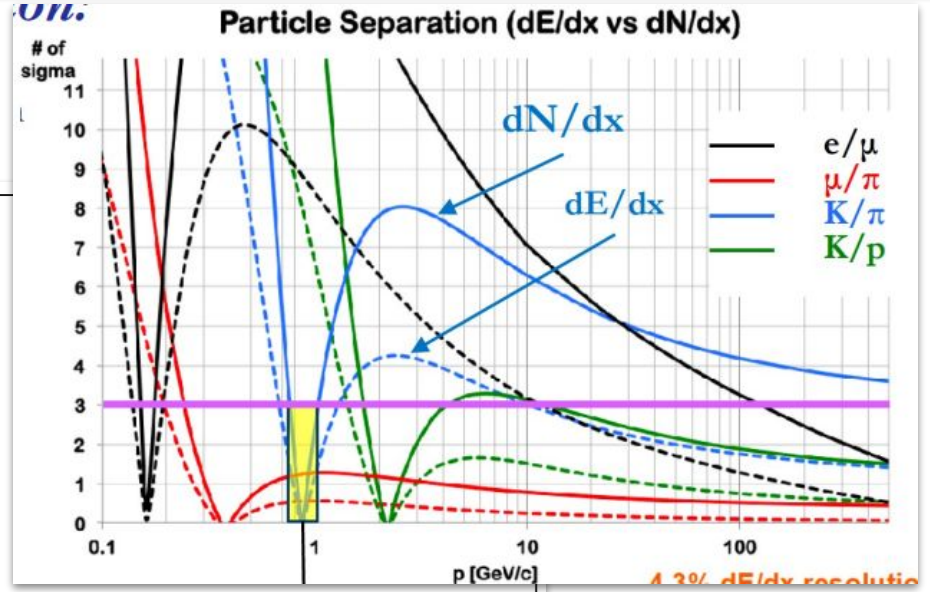


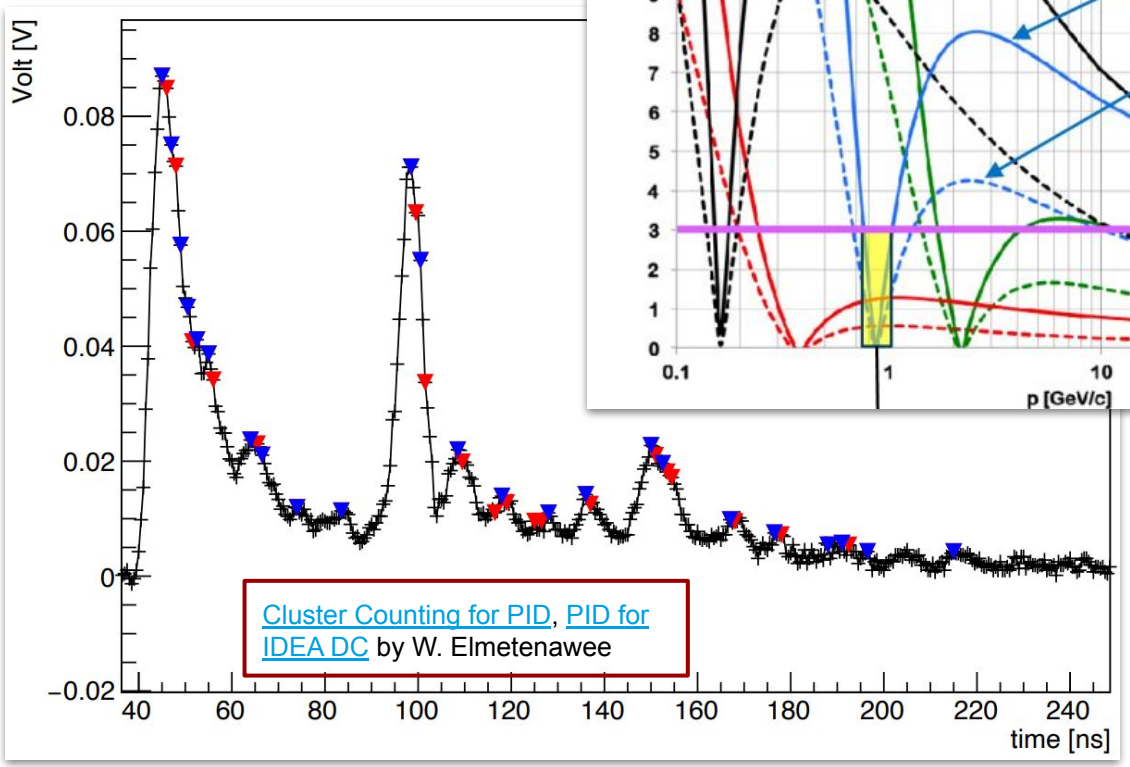
Cluster counting for PID

Simulation & reconstruction

- Cluster counting (dN/dx) with prospect of improved PID capabilities wrt dE/dx
- Updated simulation based on Garfield++ and Geant4
  - Simulate single drift cells precisely
  - Parametrize response for full simulation
  - Some discrepancies
- Promising beam test results
- Develop algorithms to reconstruct dN/dx
  - Applied to test beam data
  - Match expectations
  - Further testing ongoing
- More beam tests to come







ECFA embedding and next steps

- A larger fraction of theorists / phenomenologists start working on e^+e^- !
- Transition of ECFA chair: Karl Jakobs ➠ Paris Sphicas
- Deliverables / timeline:
  - ☑ Focus topics reports Nov./Dec. 2023
  - ☑ Dec 5/6, 2023: P5 recommendations from US Snowmass Study
  - ☑ FCC feasibility study (end of 2025)
  - ☑ Final report on ECFA study (end 2024-mid 2025) [CERN Yellow Report?]
  - ☑ New CERN management 1.1.2026
  - ☑ European Strategy Update 2026/27

- Thoughts and plans for next European strategy
- Next ESU should endorse a single project (if nothing happens in Asia): huge streamlining needed!
- Expectance of project approval soon after: construction at CERN could start early 2030s
- Early reach of deliverables at HL-LHC ($HHH, H \to \mu\mu$) could shorten HL-LHC (2/ab ?, 2037?)
- Would boost large person power to Higgs factory at CERN