Detectors for HET Factories: Calorimeters and PID Systems

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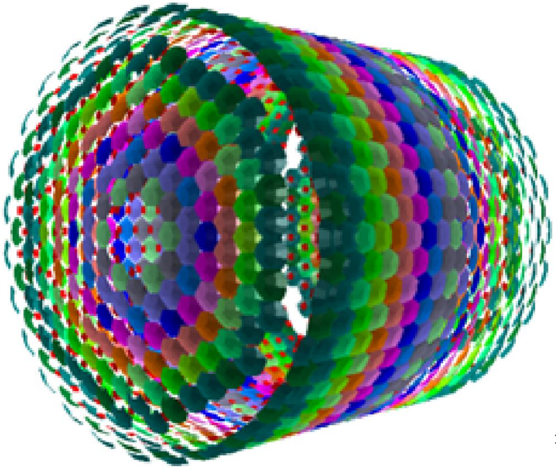
Calorimeters and PID Systems: Introduction

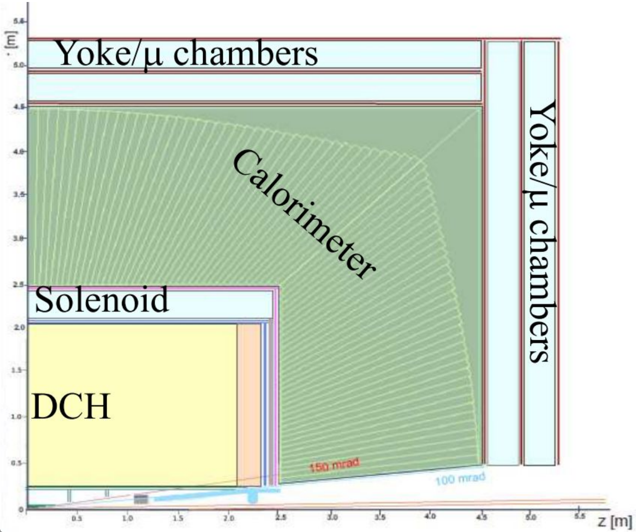
Calorimeters: central elements of Detector Concepts for HET factories

- Very active R&D programs ongoing to explore different technologies
- And cope with the challenges of HET Factories physics requirements

High-performance PID crucial for many measurements in HET physics program

- Use PID capabilities of detectors
- Build dedicated PID systems





Calorimeters

Calorimeters for HET factories

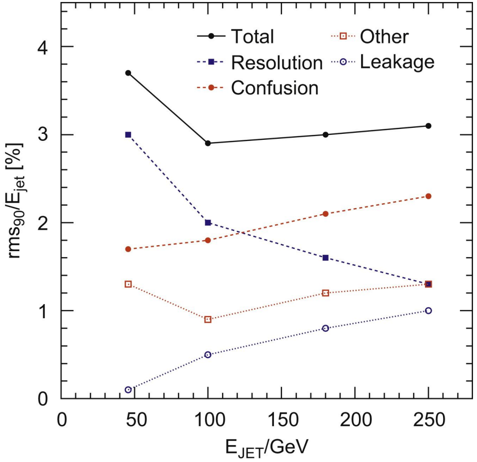
An extensive set of requirements

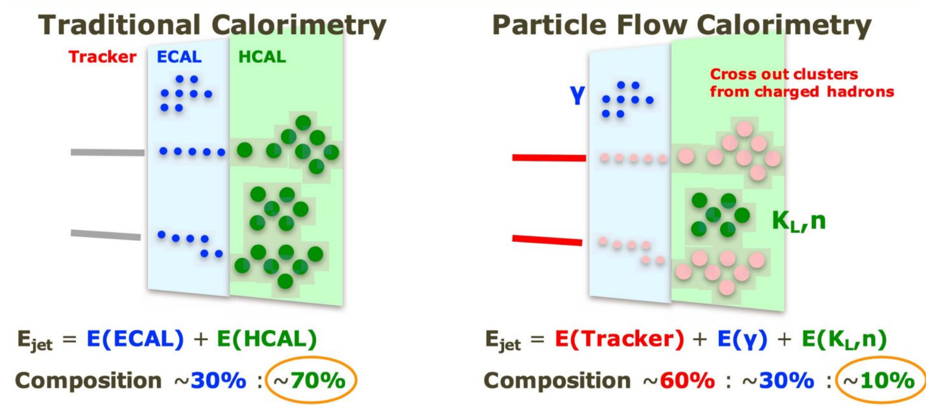
- Energy resolution: “only” for photons and neutral hadrons
  - But: ideally photons as low as 200 – 300 MeV
- Dynamic range: 200 MeV – 180 GeV
  - vs LHC: 6 TeV jets !
- Granularity: PID, disentangle showers for PFlow
  - But: how granular exactly ?
- Hermeticity, uniformity, calibrability, stability
  - Low systematics for precision measurements
  - Complex system-level engineering questions
- No need to be particularly fast
  - But: can precise timing help in reconstructing showers more accurately ?

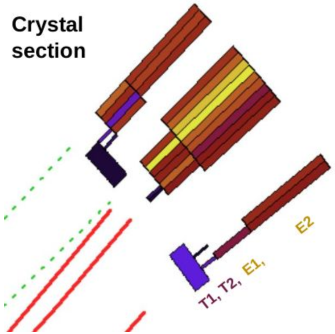
A quest for ultimate jet energy resolution

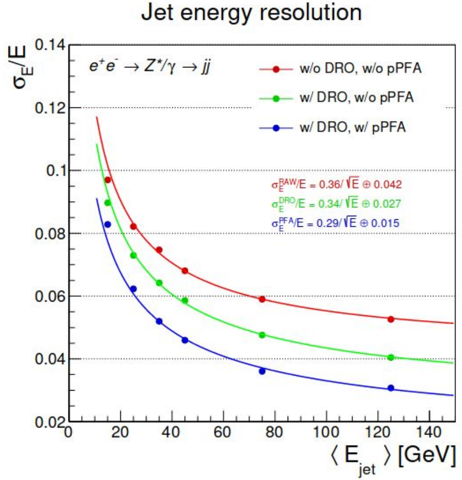
PFlow PFlow PFlow

- Basic principles well known
- What granularity do we really need at HET Factories ?
- New calos concepts bring new ideas (crystals DR study)









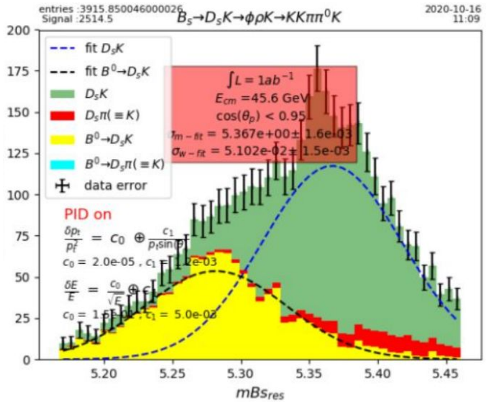
EW factories unique challenges

FCC-ee: O(10^{11}) B and τ at 45 GeV !!!

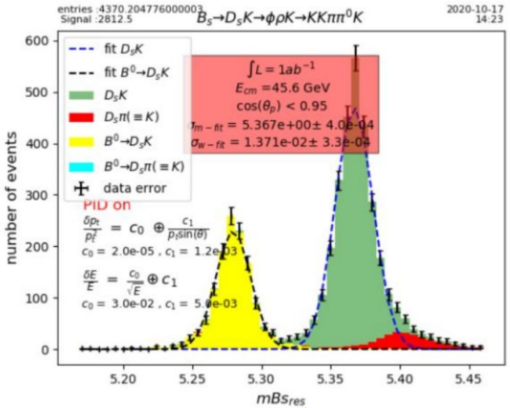
- Some physics channels require very high EM resolution

- τ physics: reconstructing the decays
  - Means π^0 reconstruction and ID
  - Count close-by π^0
  - Granularity

- BSM, e.g ALP searches
  - Photon resolution, photon pointing



15%/√E



3%/√E

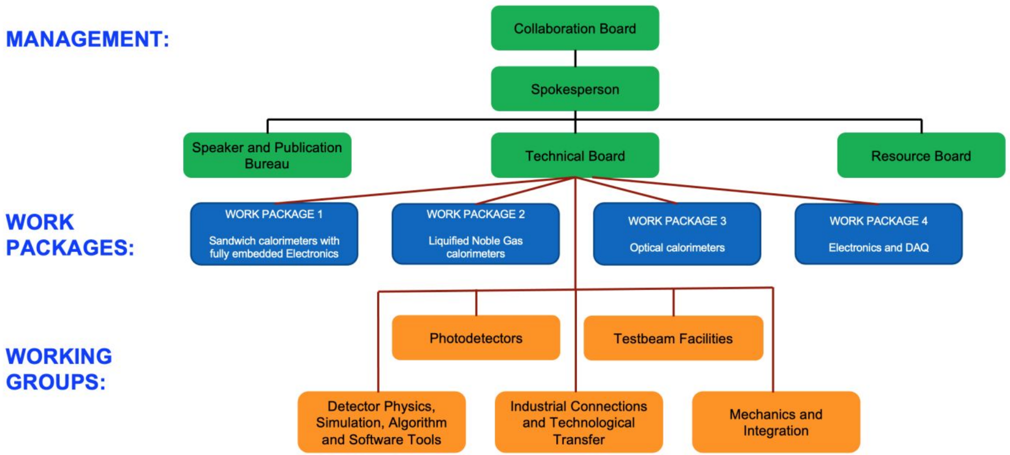
Recon → / Gen ↓	$\pi^\pm\nu$	$\pi^\pm\pi^0\nu$	$\pi^\pm 2\pi^0\nu$	$\pi^\pm 3\pi^0\nu$	$\pi^\pm 4\pi^0\nu$
$\pi^\pm\nu$	**0.9560**	0.0425	0.0010	0.0003	0.0002
$\pi^\pm\pi^0\nu$	0.0374	**0.9020**	0.0586	0.0016	0.0002
$\pi^\pm 2\pi^0\nu$	0.0090	0.1277	**0.7802**	0.0808	0.0022
$\pi^\pm 3\pi^0\nu$	0.0036	0.0372	0.2679	**0.5972**	0.0910

Table: Each row shows the fraction of e.g. $\tau \to \pi^\pm\nu$ decays classified as each of the considered channels

HET Factories calorimeters landscape: DRD6

Detector R&D (DRD) collaborations implement the ECFA Detector R&D Roadmap

- DRD6 on Calorimetry with 4 work packages and several transversal activities (TB, Materials, SW, …)
  - First Collaboration meeting: April 9-11 at CERN
- Most DRD6 calo projects aim HET factories
  - Presenting only **selected examples** to highlight main R&D directions



- Mission:
  - Bring a diverse set of calorimeter technologies to a level of maturity such that they can be considered for a technology selection of future experiments
  - Maturity demonstrated with **full-scale prototypes**

DRD6 Workpackages

WP1: Sandwich calos with fully embedded electronics

- Focus on hermeticity and compactness of designs
- Emphasis on system-level designs and challenges
- Adapting linear colliders designs to circular collider challenges
- Ultra-compact calos for lumi measurements

WP2: Liquified noble gas calorimeters

- Reviving R&D on noble liquid calos
- Scaling concepts to O(millions) readout cells

WP3: Optical calorimeters

- Many calorimeter concepts based on scintillation / Cerenkov light
- Strong link with R&D on crystals / scintillating materials

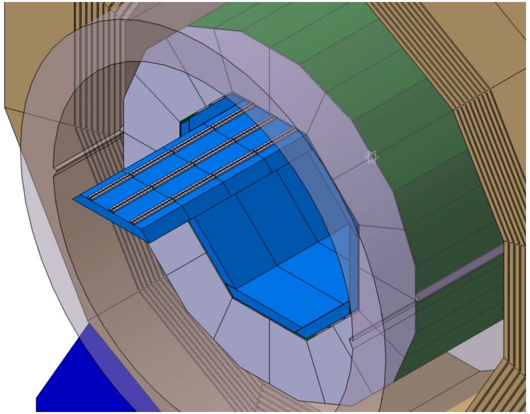
WP1: SiW Ecal

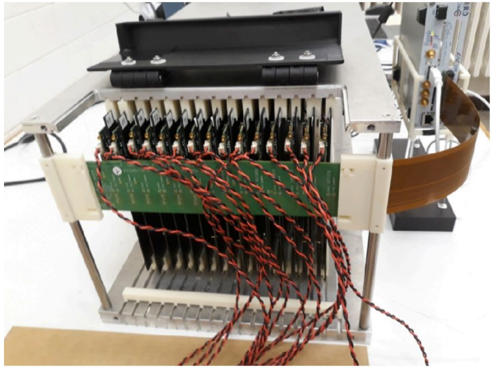
Vincent Boudry's Talk

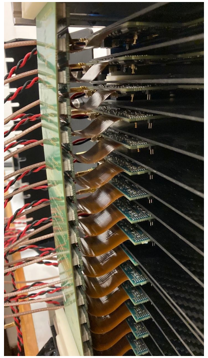
Baseline Ecal in ILD, CLD

- 30 layers, 2.8 mm tungsten absorber, 24 X_0
- 0.5 mm thick silicon sensors with 5×5 mm^2 granularity
- $O(10^8)$ cells
  - Super high granularity for PFlow reconstruction
  - Tight integration: compact and hermetic
- EM resolution ~17%/√E

- Challenges:
  - Adaptation to FCC-ee (cooling, power)
  - Granularity re-optimisation ?
  - Study addition of timing
  - System aspects: design engineering module





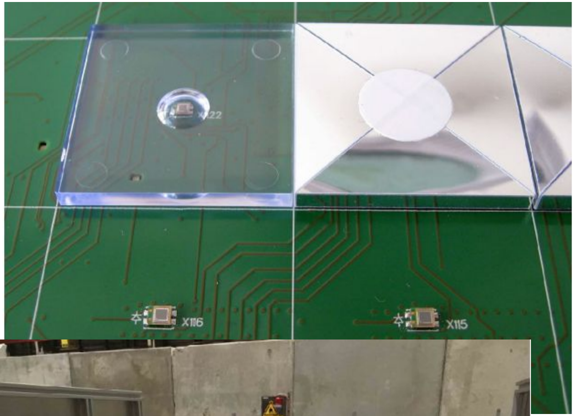


WP1: SiPM-on-Tile AHCAL

Baseline HCal in ILD, CLD. Same technology as used in CMS HGCal.

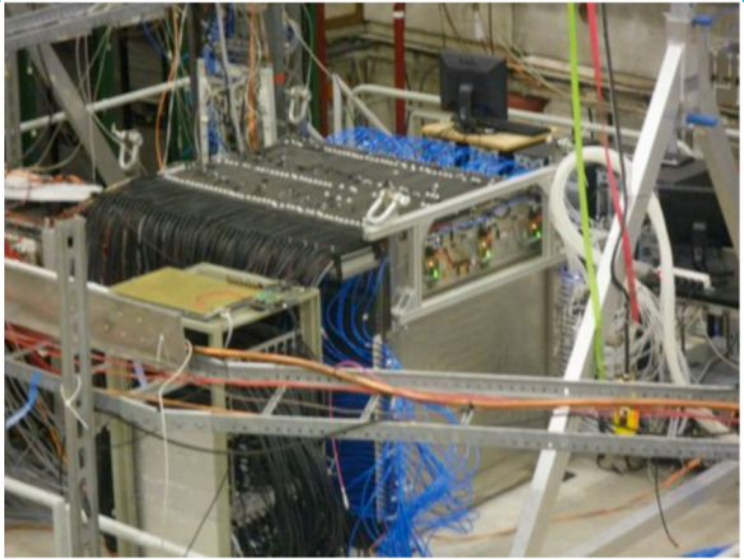
- SiPM-on-tile / steel HCAL
  - Builds on CALICE AHCAL prototype
  - Wrapped scintillator tiles directly read by SiPM

- Main R&D topics
  - Adaptation of detector concept to circular colliders with continuous readout
    - Data rates, cooling
  - Corresponding hardware developments: ASICs, readout, thermal and mechanical designs, scintillator geometry



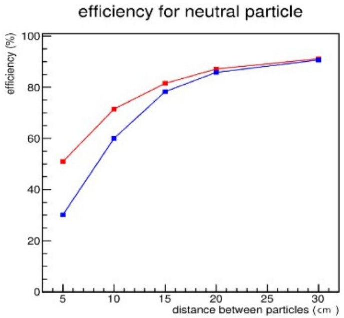
WP1: T-SDHCAL

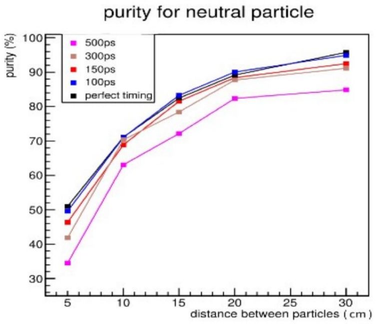
[Tanguy Pasquier's Poster]



- A RPC-based semi-digital HCAL with timing capability → MRPC
  - Builds on CALICE SDHCAL technological prototype, but reaching 100 ps resolution
  - Use of more eco-friendly gases (HFO)

- Main R&D directions
  - Simulation studies extending to time information
  - Study and development of cooling and cassette concepts
  - Fast timing electronics, DAQ system
  - Aim to conclude initial R&D to propose a concept by 2026





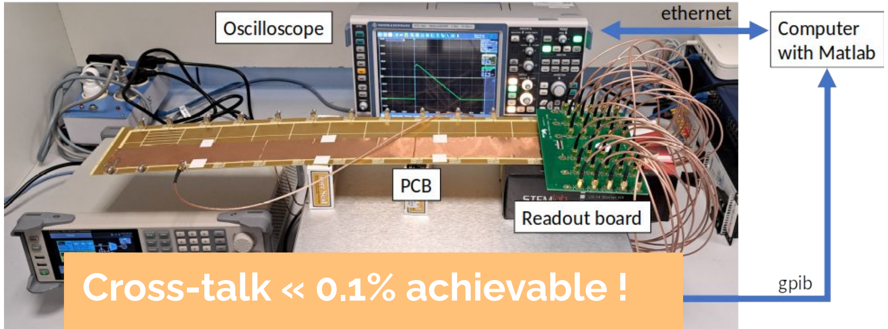
WP2: ALLEGRO ECal

Farès Djama's Talk

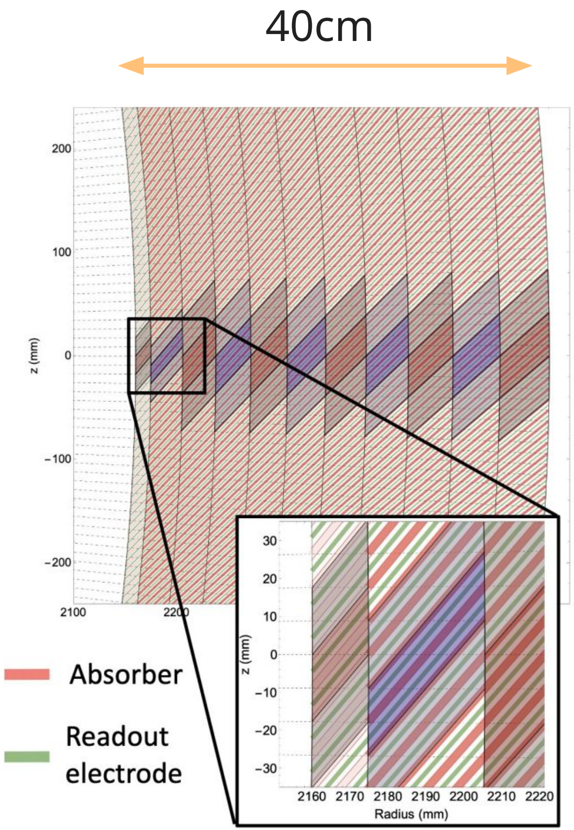
Ecal for ALLEGRO Detector Concept

- High granularity (O(10^6) cells) noble liquid (LAr/LKr) Ecal using straight readout electrodes
  - Good compromise for granularity, resolution (5-8%/√E), stability, uniformity

- Main R&D topics
  - Optimise design for performance based on simulations
  - R&D on electrodes and absorbers
  - Mechanical design
  - Cold and warm frontend electronics
  - Aim: testbeam module in 2028



Cross-talk « 0.1% achievable !

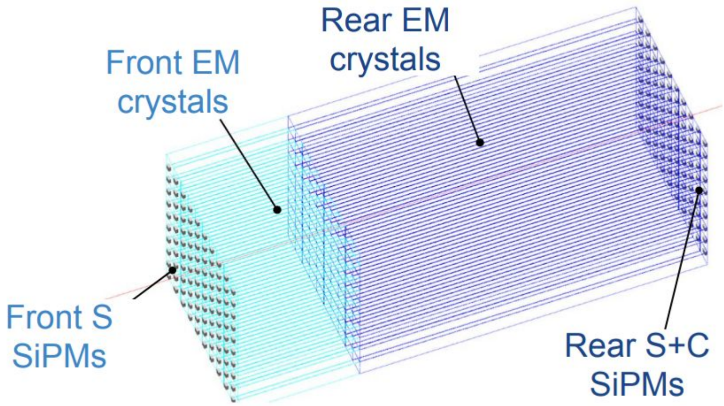


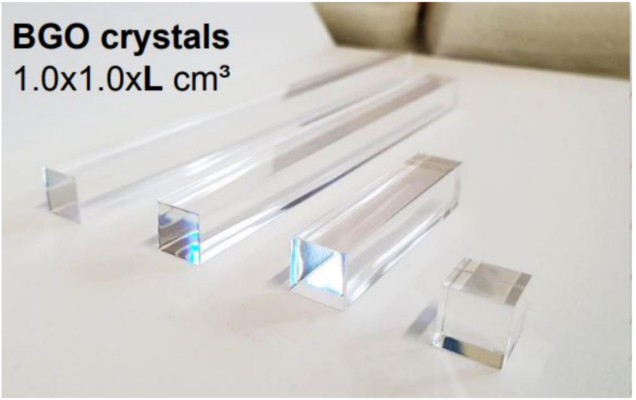
WP3: MAXICC / CalVision

Ecal for IDEA detector concept

- Homogeneous EM calorimeter based on segmented crystals with dual-readout
  - High density scintillating crystals with good cherenkov yield
  - Dedicated optical filters and SiPMs to readout S and C from same active element
  - Promise 3%/√E + DR capability
  - Synergies within Calvision, IDEA and CERN Crystal Clear collaborations

- Main R&D Topics
  - Identification of optimal crystals, optical filters and SiPM candidates
  - Proof-of-concept with lab measurements and prototypes
  - EM scale prototype for beam test



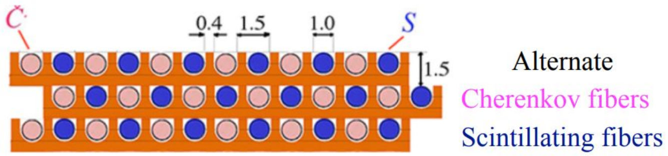


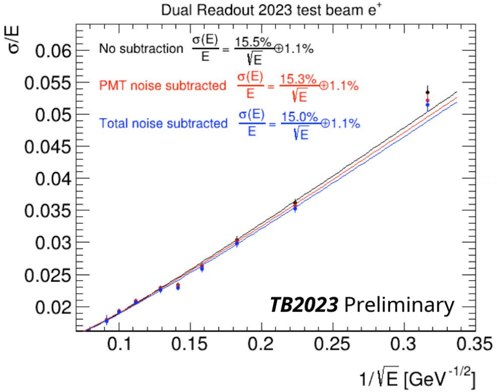
WP3: Dual Readout calorimeter

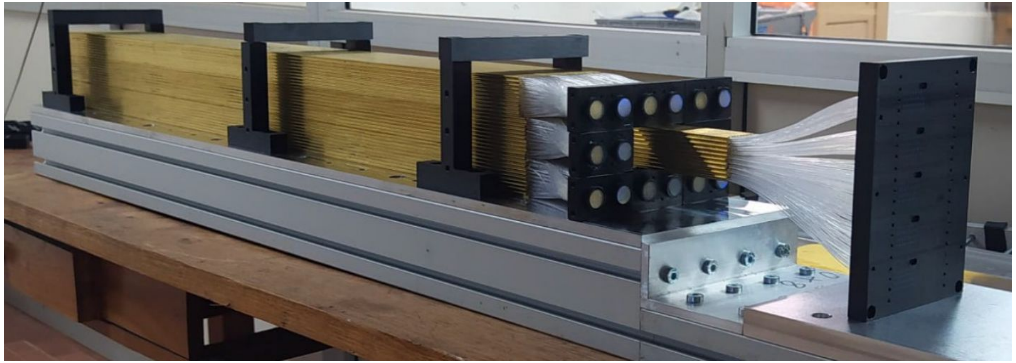
Ruggero Turra's Talk

Main / Hcal calorimeter for IDEA detector concept

- Longitudinally unsegmented dual-readout sampling calorimeter
  - Scintillation and Cherenkov fibres inside an absorber groove
  - Reaches 30%/√E for single hadrons ⇒ ultimate resolution for jets
  - O(130 M) fibers for O(15 M) channels
- Main R&D Topics
  - Develop scalable readout electronics: analog/digital SiPM ?
  - Optimize metal matrix mechanics for large production
  - Develop mechanical model of full system with services
  - Testbeam with Hidra2 prototype







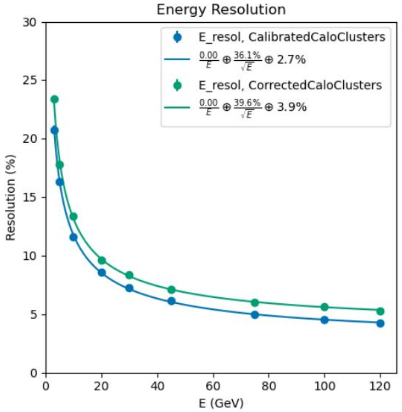
WP3: TileCal

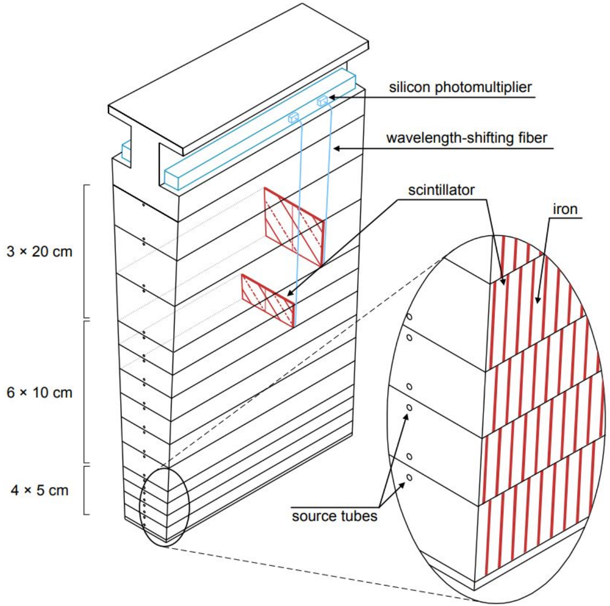
Michaela Mlynarikova's Talk

Used in ALLEGRO concept

- High-granularity version of ATLAS TileCal hadronic calorimeter
  - 5mm steel absorber plates alternating with 3mm Scint.: 8 - 9.5λ
  - SiPM readout through WLS
  - Cost-effective solution

- Main R&D topics
  - Exploration of scintillators
  - Optimisation of WLS and SiPMs for readout efficiency
  - Build testbeam module



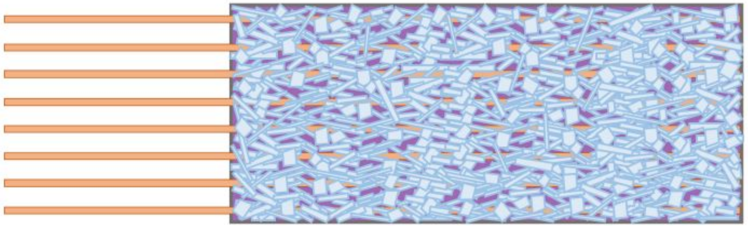


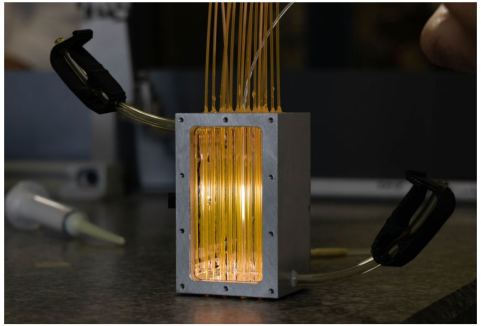
WP3: GRAiNITA

Marie-Hélène Schune's Talk

A novel type of calorimeter ~ next-gen shashlik

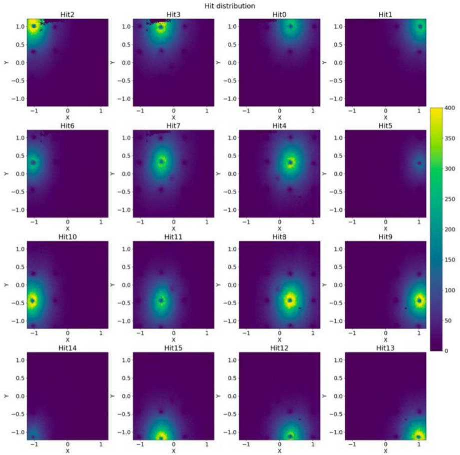
- Use grains of inorganic scintillating crystal readout by wavelength shifting fibers
  - Light spatially confined by refraction/reflections





- Excellent expected EM resolution: 2-3%/√E
  - Using BGO or $ZnWO_4$ crystals
  - 16-channel prototype tested with cosmics
  - First test beam of small proto at CERN

- Main R&D topics
  - R&D on crystal grains
  - Aim for larger prototype to validate on testbeam



Confirmation of light confinement

PID Systems

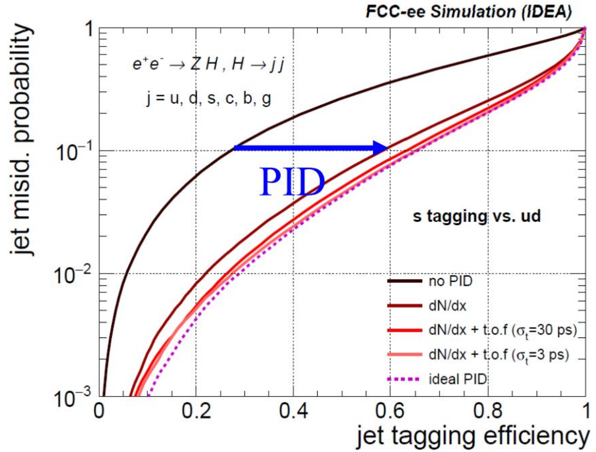
Why PID ?

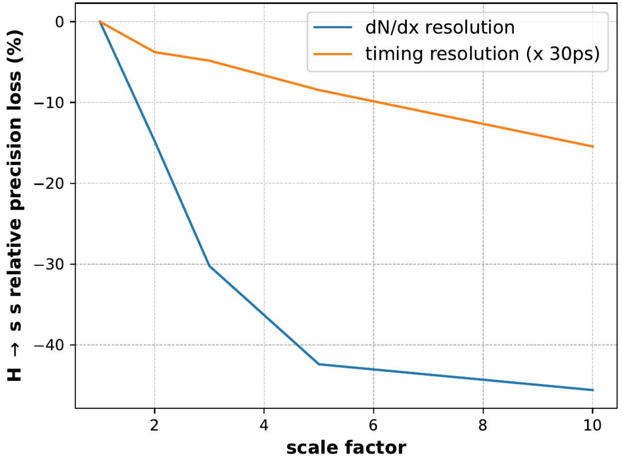
A must-have to complete the full HET programme

- Higgs physics
  - H → ss sensitivity driven by strange-tagging perf, depends a lot on PID performance
  - Flavour violating modes, e.g H → bs
- SM parameters
  - Also depend on K identification / strange tagging
  - See Uli Einhaus' talk: V_{ts}, V_{bs}
- B physics
  - $B^0_s \to D^{\pm}_s K^{\mp}$, $B \to K^* \nu\nu$, $B_s \to \phi\nu\nu$, ...

Variable		$\ln(E_{ch.})$	isPhoton	$K^{\pm}$ID	m^{SV}	p^{V^0}	z_0	D_0/σ_{D_0}
$\epsilon_{bkg} = 10\%$	b vs c	3.5%	0.3%	0.2%	3.0%	0.1%	7.8%	11.6%
	c vs s	23.8%	0.7%	0.5%	0.3%	0.2%	20.9%	39.1%
	s vs ud	12.8%	16.6%	38.8%	0.0%	9.2%	23.3%	26.7%
$\epsilon_{bkg} = 0.1\%$	b vs c	13.8%	1.3%	0.9%	67.2%	0.8%	34.1%	45.0%
	c vs s	57.6%	0.9%	4.8%	7.0%	0.3%	56.2%	79.5%
	s vs ud	35.0%	28.0%	59.0%	0.4%	34.7%	60.5%	80.1%

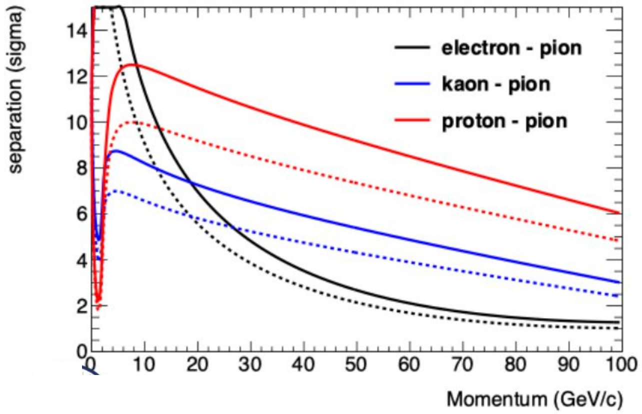
Freya Blekman's Talk

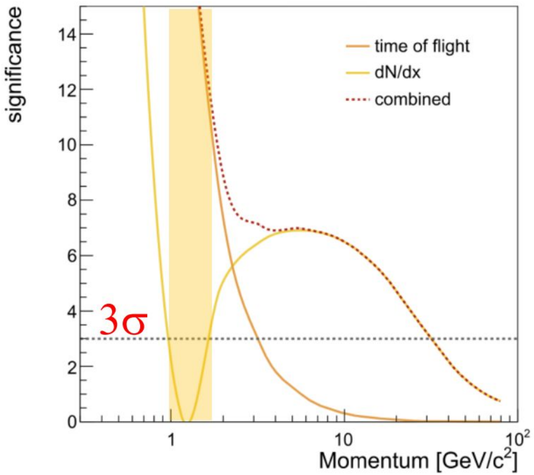




PID embedded in trackers

- Gaseous detectors
  - dE/dx or cluster counting measurements
  - Good progress shown in studies of TPC, Straw Tracker, Drift chamber
  - Need dedicated electronics / signal processing
- Fast detectors for time-of-flight measurements
  - Using e.g LGAD technologies
  - few ps – 10 ps resolution
  - Used in “silicon wrapper” layers after gaseous tracker, in front of calorimeter
- Great complementarity between two measurements
  - p/K/π separation over large momentum range



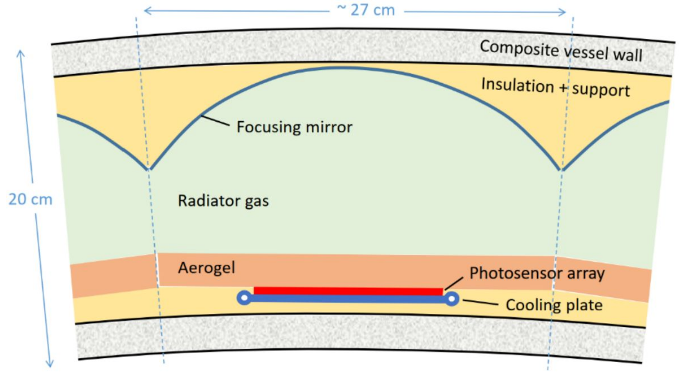


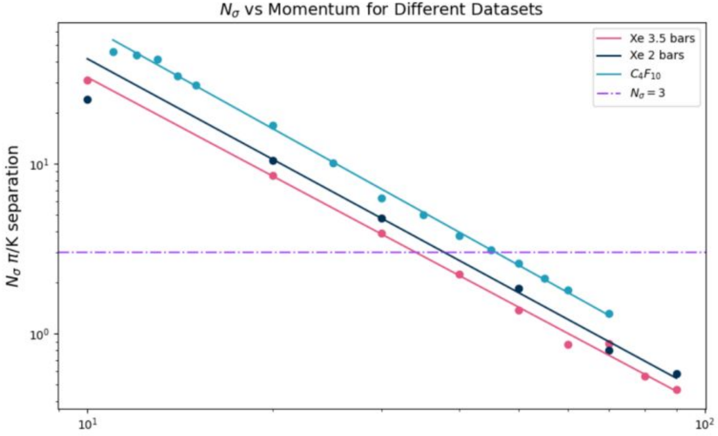
The ARC (Array of Rich Cells) concept

Serena Pezzulo's Talk

Dedicated RICH detector, developed for the CLD Detector Concept (Silicon main tracker)

- Detector = array of independent RICH cells
  - 20cm depth between main tracker and Ecal
  - Cerenkov light from radiators focused by a mirror on a SiPM array
- New detector concept
  - R&D part of DRD4
  - Aim to build first prototype cell within 3 years
- Very promising expected PID performance
  - 3σ K/π separation up to 45 GeV
  - Study ongoing to evaluate performance of replacing HFC with greenhouse-friendly gases (pressurized Xe)





Conclusions

- Large diversity of calorimeter concepts for HET Factories
  - Some building on proven technologies
    - Pushing those technologies to their limits
  - Some coming to fruition after years of R&D
    - e.g Challenge for calorimeters tailored for ILC: adaptation to FCC-ee conditions
  - Some brand new ideas
  - In all cases:
    - Long road ahead to get to large scale prototypes
    - System-level concerns and engineering challenges are numerous
- Good PID is mandatory for various physics cases
  - Can be achieved as a additional measurements in tracking detectors
  - Or with new concepts of Cerenkov detectors

Backup

DECAL – Digital ECAL based on MAPS

- A MAPS-based digital Silicon-Tungsten ECAL, building on current DECAL and EPICAL projects

- Fully digital (no energy measurement / cell)
  - 30×30 μm^2 Si pixels

- Main R&D topics
  - Establish requirements of a sensor dedicated for digital calorimetry
  - Design of next-generation sensor with calorimeter-specific optimisation and evaluation of sensor design
  - Aim for small-scale digital ECAL prototype in 2026