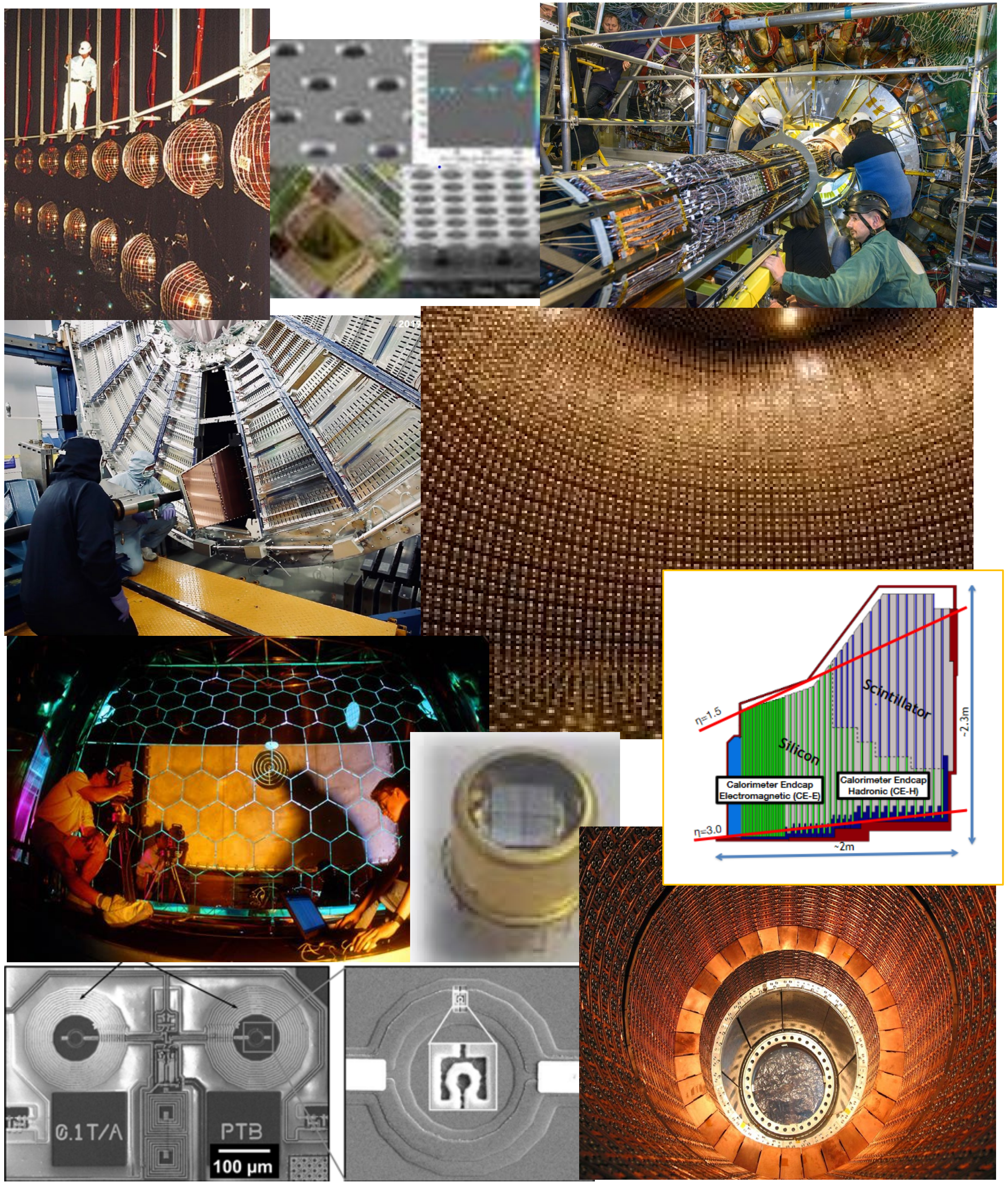
Highlights on detectors R&D



S. Dalla Torre
INFN - Trieste

ICHEP2022, Bologna, 6-13/7/2022

Detector R&D

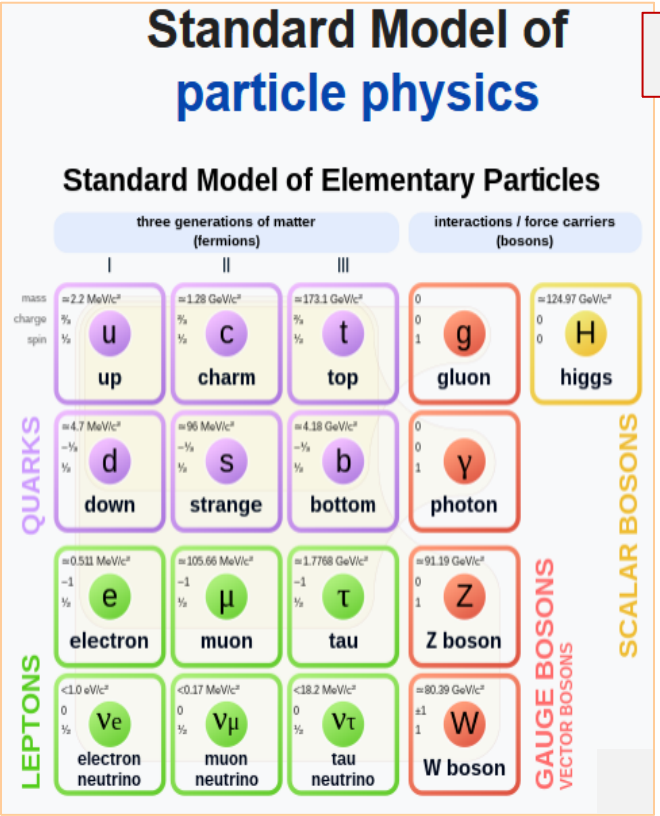
The present context

The context

Major processes of **global planning** recently concluded or ongoing

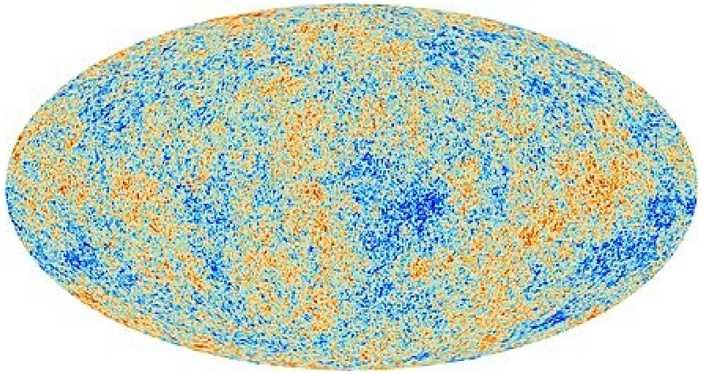
- The **European Particle Physics Strategy Update** (EPPSU)
  - 2018-2020
  - In charging ECFA to organize the **Detector R&D Roadmap (2020-2021) process**
- The ongoing **Snowmass Community Planning Exercise** (2020-2021, going to culminate in July with the Community Summer Study Workshop)
  - Including complementary areas, among which: the **instrumentation frontier**

The context, more

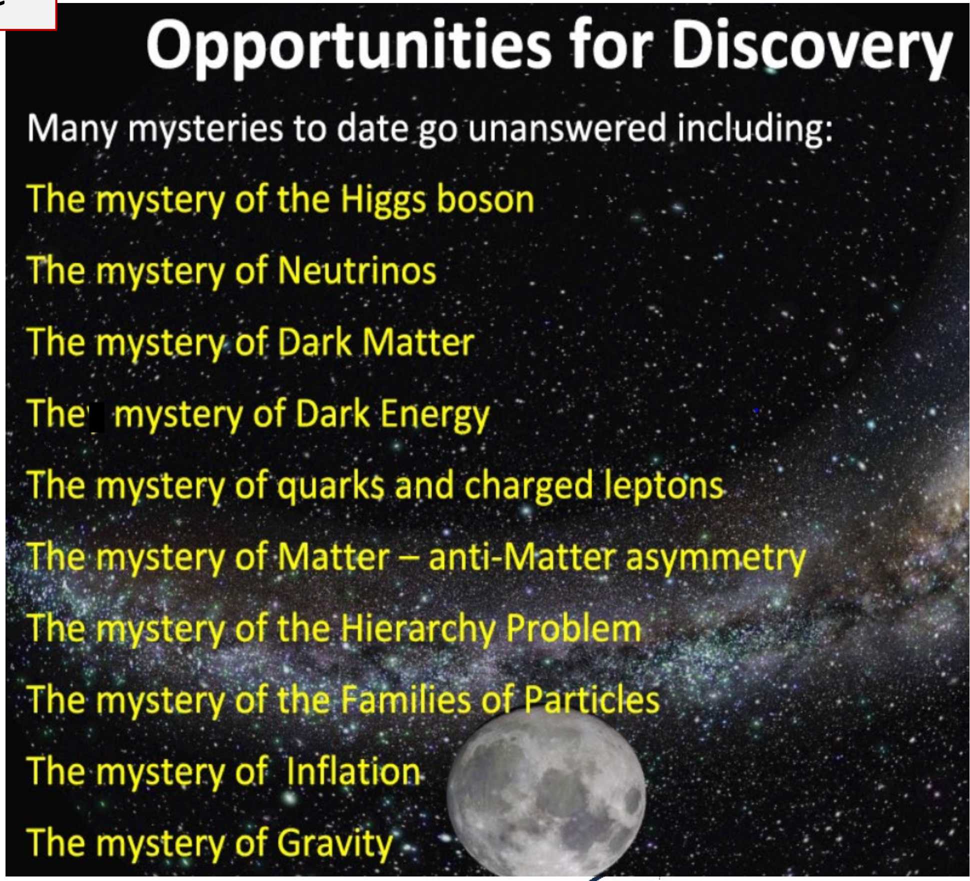


Present → Future

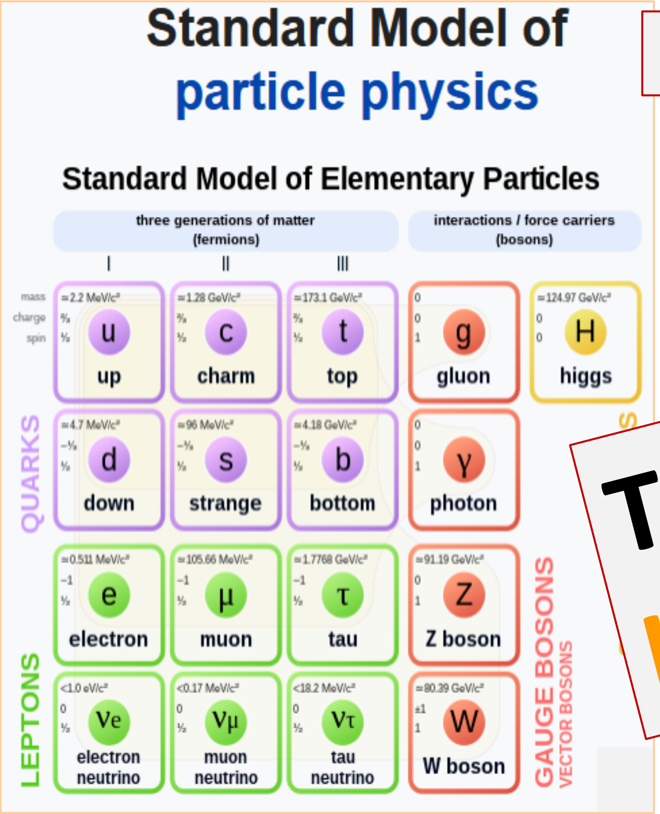
Cosmology Standard Model (Lambda-CDM model)



From a recent compilation by I. Shipsey, PDM 2022c



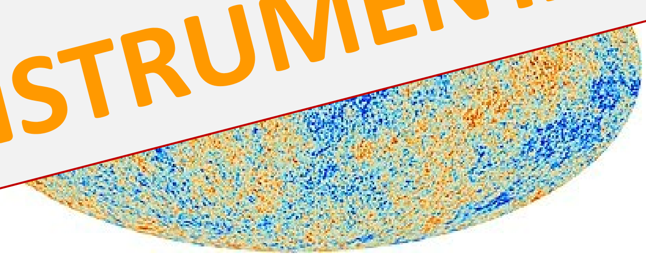
The context, more



Present → Future

Cosmology Standard Model

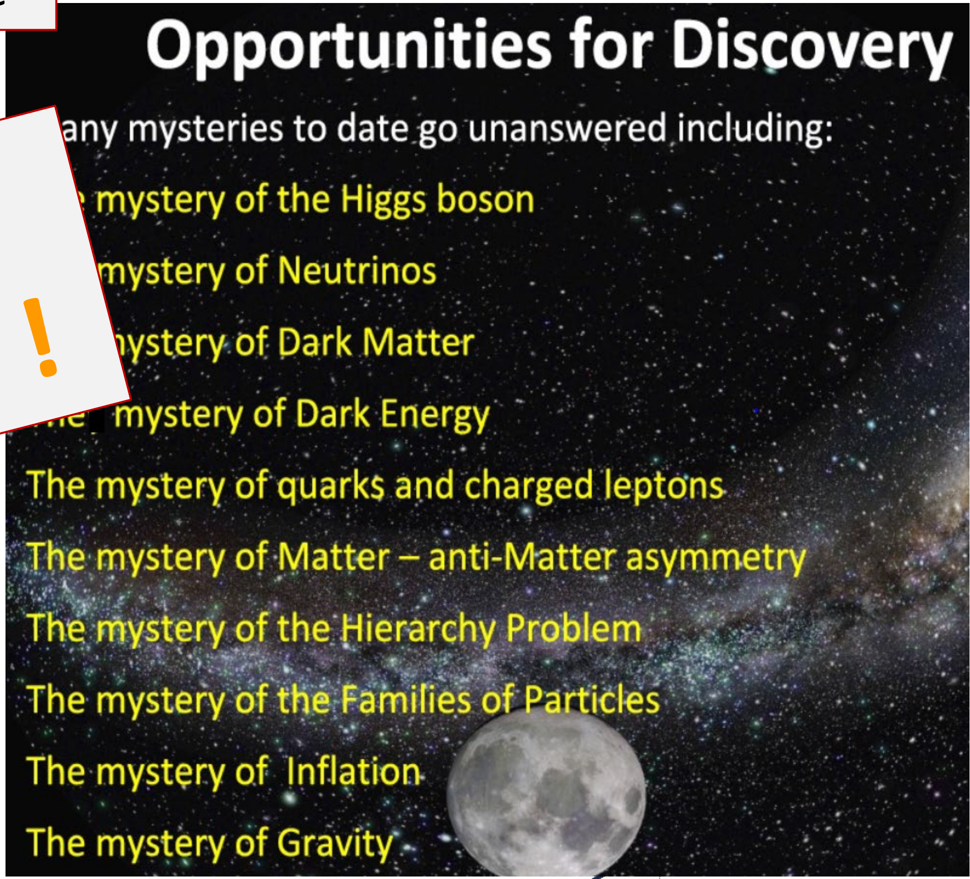
(Lambd



TO INABLE ALL THIS:

INSTRUMENTATION !

From a recent compilation by I. Shipsey, PDM 2022



Detectors
@ ICHEP2022

Parallel Session :

Detectors for Future Facilities, R&D, novel techniques

68 talk & poster contributions

- the distribution among areas also reflects the typical attendance of the ICHEP Conference series

	PP & high energy NP	**APP**	**ν, DM, 0νββ decay**	**others**
contributions (talks & posters)	48	3	15	2

Detectors @ ICHEP2022

ICHEP 2022 BOLOGNA

Parallel Session :

Detect

In the following :

A quick tour in trends and perspective in detector R&D

- **mainly illustrated by examples from contributions to ICHEP2022**
- **NO ranking intent between quoted/non quoted efforts**

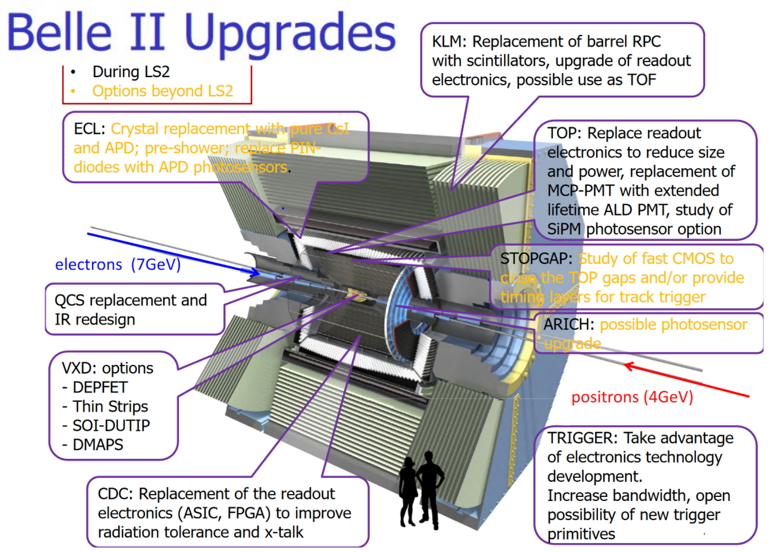
	high energy NP	APP	ν, DM, $0\nu\beta\beta$ decay	others
contributions (talks & posters)	48	3	15	2

Which requests to detectors?

Which requests to detectors?

Hints @ ICHEP2022

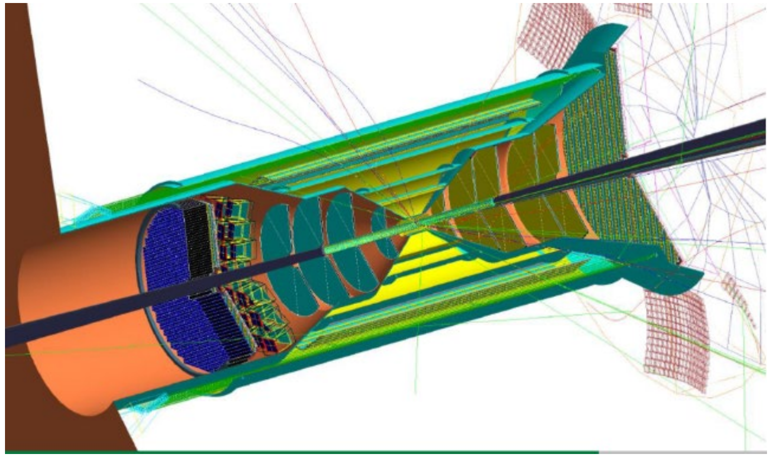
Belle II Upgrades



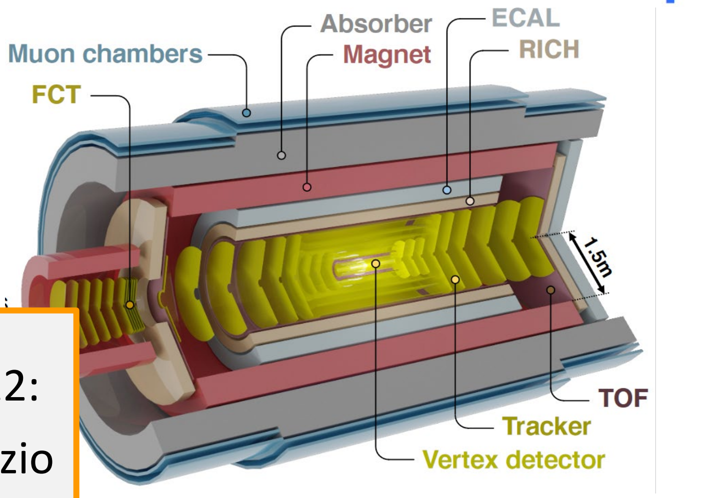
BELLE II upgrade
@ICHEP2022:
Peter Krizan

Detector for the EIC

EIC detector
@ICHEP2022:
Xuan Li
Nicolas Schmidt

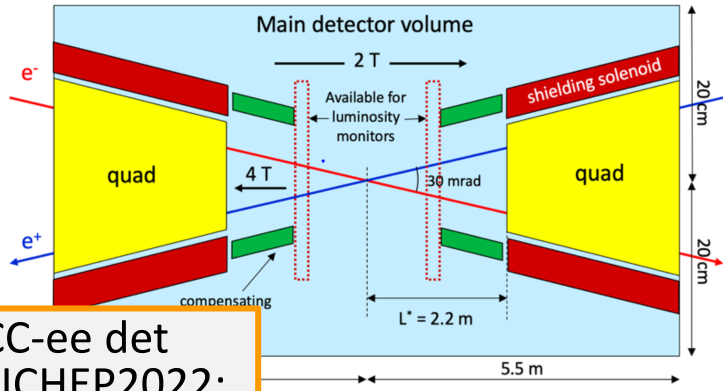


ALICE 3 detector concept



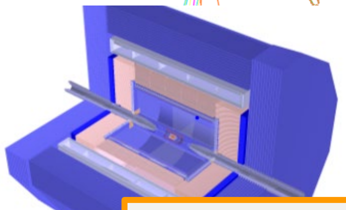
ALICE 3
@ICHEP2022:
Nicolo' Jacazio

Detector Requirements for FCC-ee



FCC-ee det
@ICHEP2022:
Marina Cobal

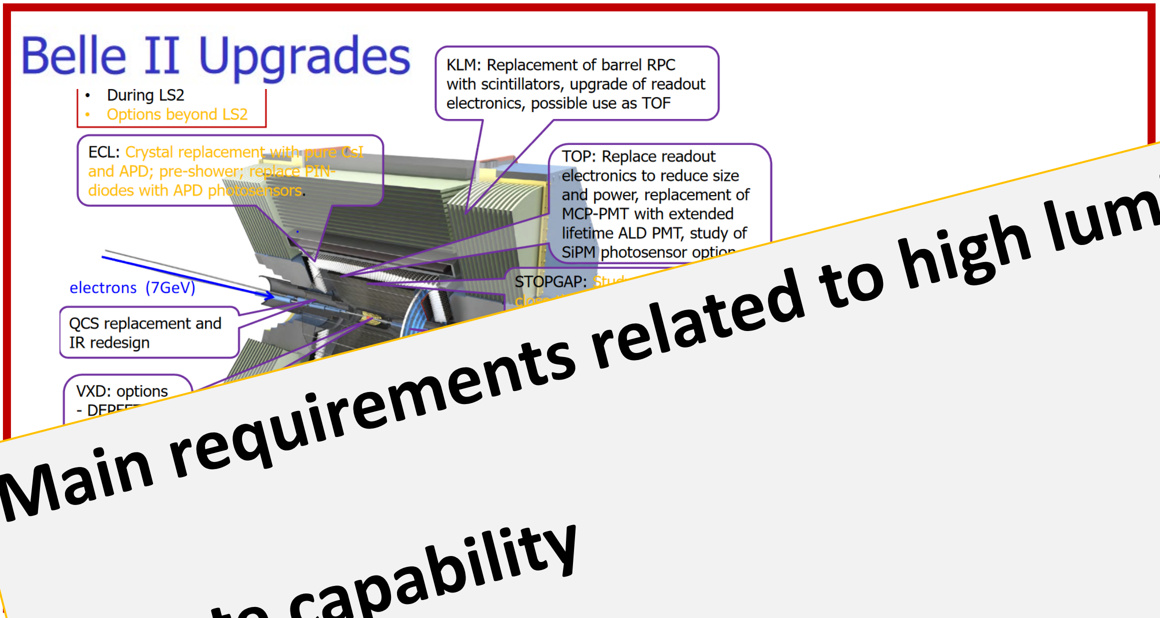
detector requirements at the CEPC

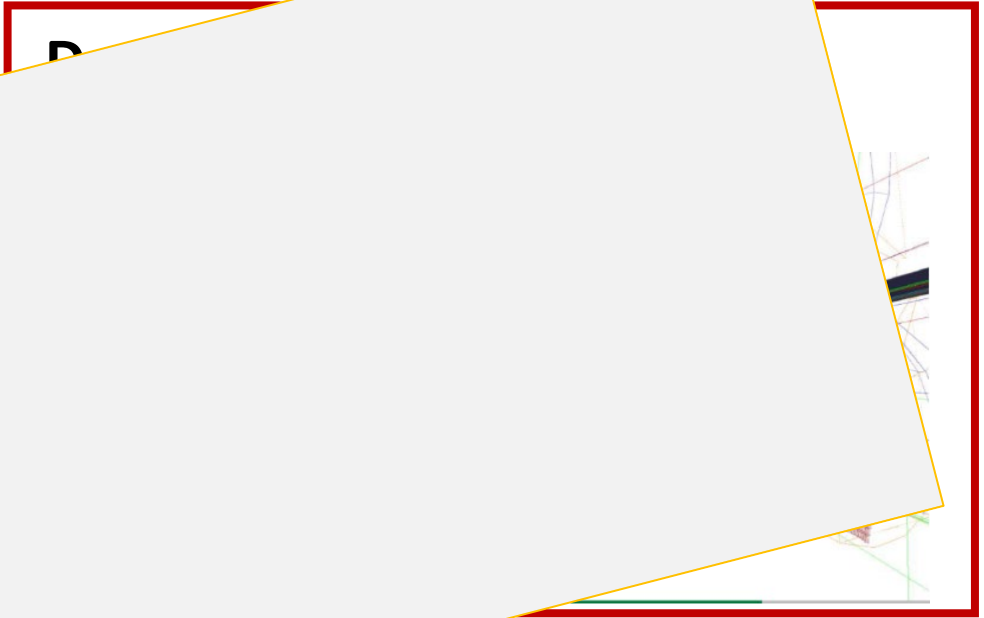


CEPCdet.
@ICHEP2022:
Manqi Ruan

Which requests to detectors?

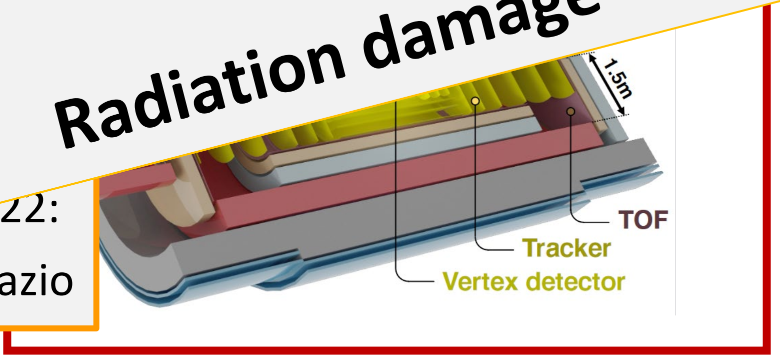
Hints @ IC 022





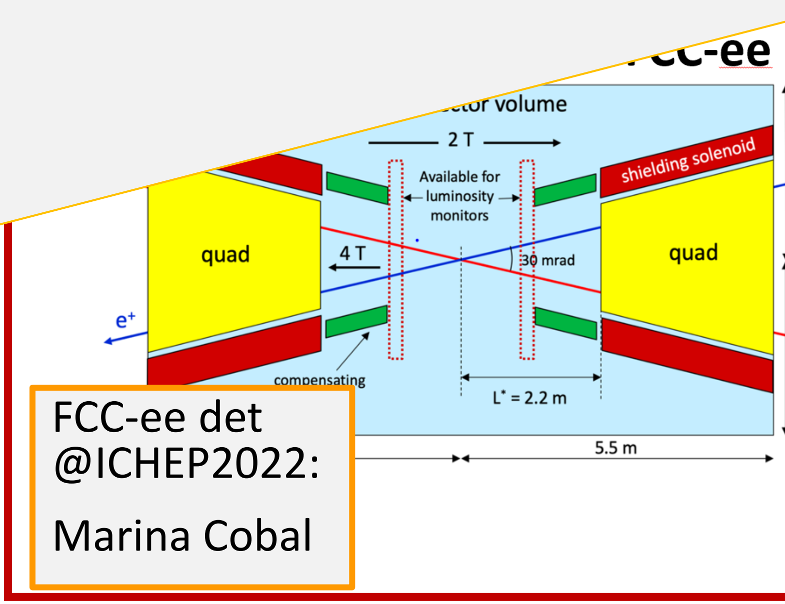
Main requirements related to high luminosity:

- **Rate capability**
- **Occupancy**
- **Radiation damage**



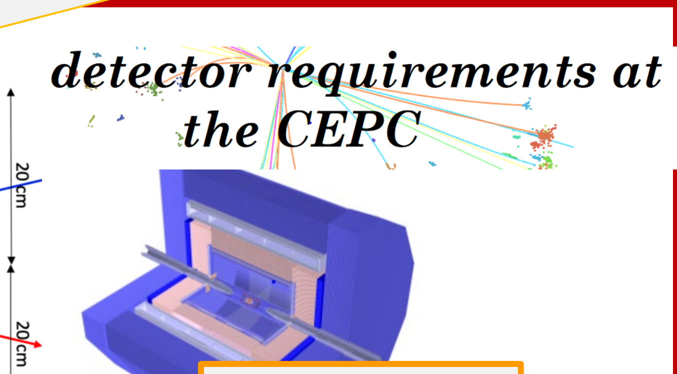
ALICE 3 @ICHEP2022:

Nicolo' Jacazio



FCC-ee det @ICHEP2022:

Marina Cobal



CEPCdet. @ICHEP2022:

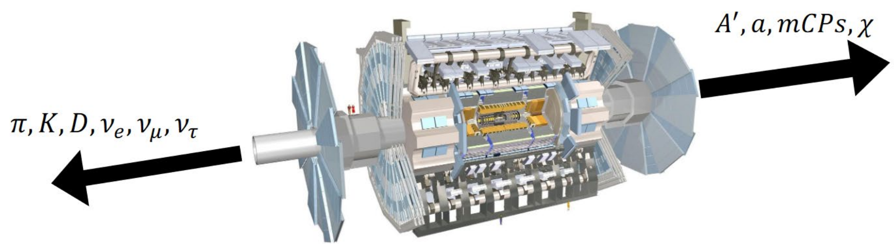
Manqi Ruan

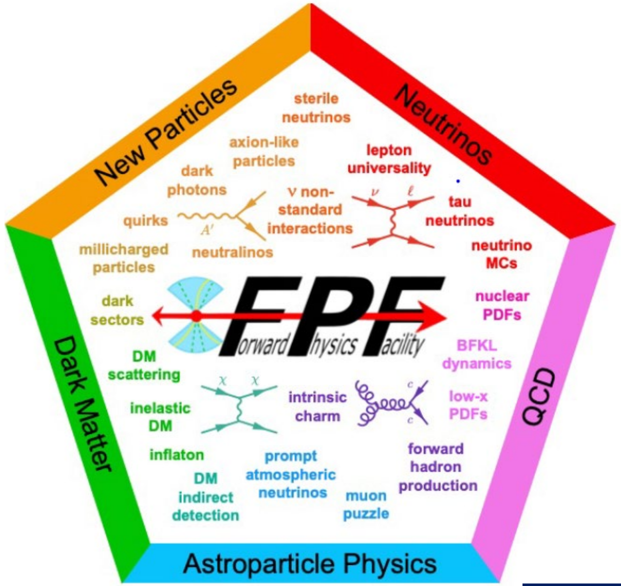
Which requests to detectors?

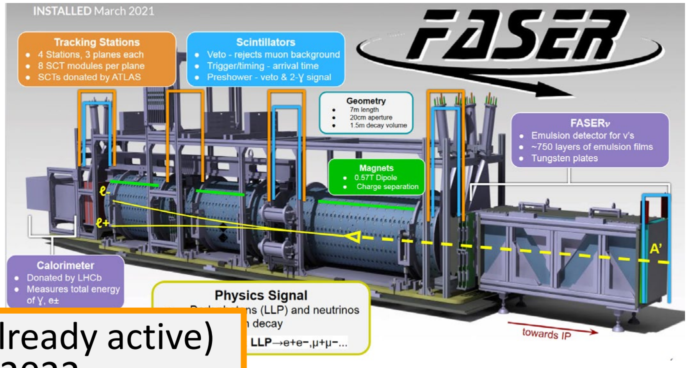
Hints @ ICHEP2022

DM and ν and more at LHC

What are we missing ?







FASER(already active) @ICHEP2022:

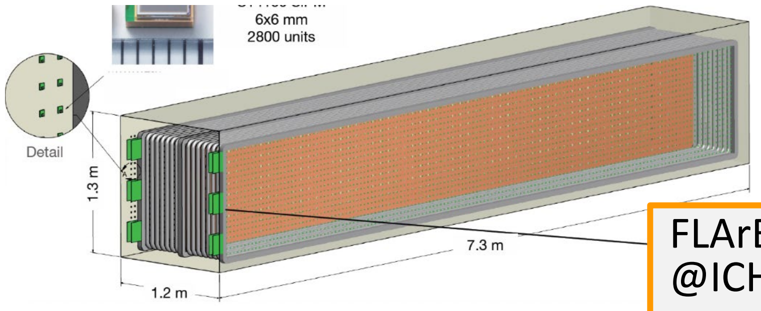
Savannah Shively

Forward Physics Facility (FPF)

Experiment	Science Priority	Technology
Faser 2	Long-live neutral particles decay	Large decay volume (super-conducting) magnetic spectrometer
FASERnu2	Neutrino Interactions	Tungsten/Emulsion 20 tons. Veto and interface tracker for muons
AdvSND	Neutrino Interactions on/off axis	Hybrid electronic and tungsten/emulsion detector with had. cal.
FORMOSA	Milicharged particles	Scintillation bars with photomultiplier readout.
FLArE	DM scattering and neutrino interactions	Liquid Argon TPC 10-20 tons

FLArE: Forward Liquid Argon Experiment for High Energy Neutrino and Dark Matter Searches at LHC

Starting operation after LS3 and upgraded for ultimate performance after LS4



FLArE @ICHEP2022:

Jianming Bian

Which requests to detectors?

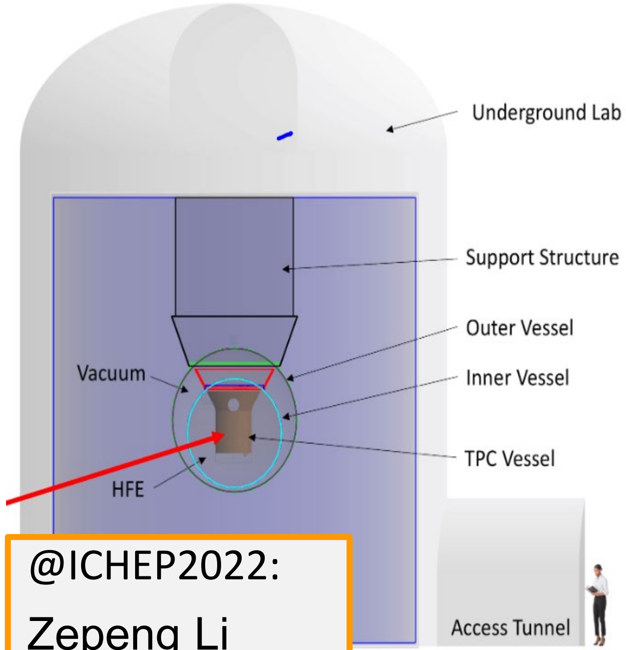
Hints @ ICHEP2022

nEXO

Search for $0\nu\beta\beta$ decay with liquid xenon TPC

2D readout of ionization charge and scintillation light to achieve full 3D event reconstruction.

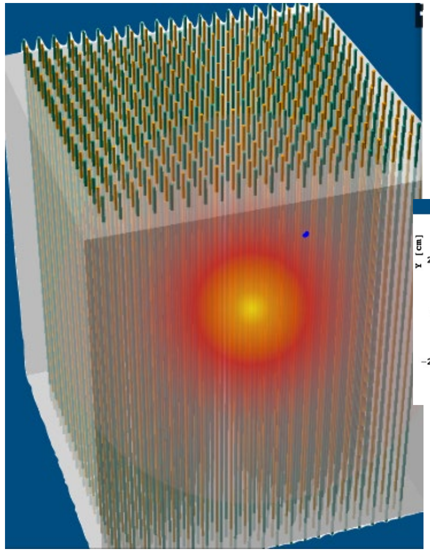
Light detection: 4.5 m^2 of VUV SiPMs with ASIC readout in LXe



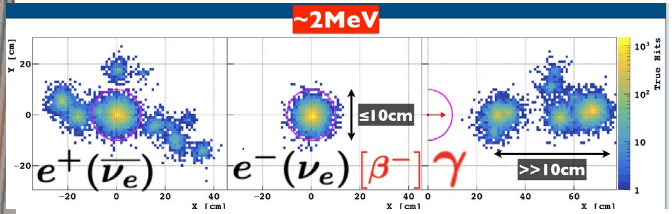
@ICHEP2022:
Zepeng Li

LiquidO

Stochastic light confinement



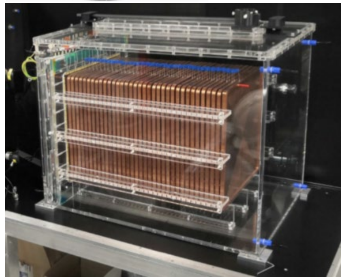
Opaque (scintillating) liquid and optical fibers



@ICHEP2022:
Stefano Dusini

CYGNO Experiment

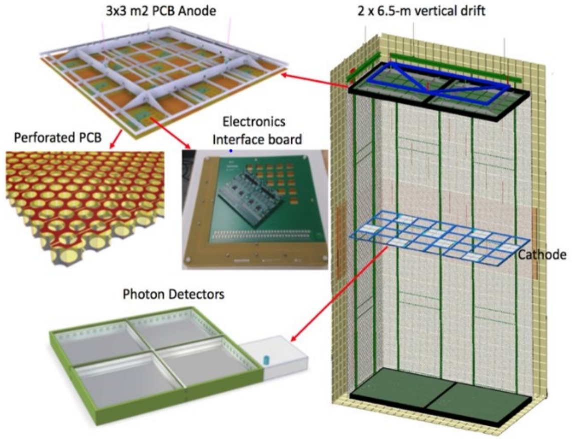
gaseous TPC with optical readout
LIME: 50l → 30 m^3



GEM
Electro-luminescence

@ICHEP2022:
Stefano Piacentini

The DUNE vertical drift TPC



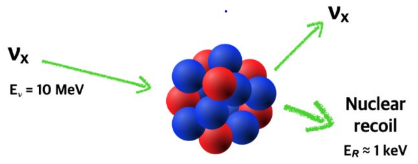
@ICHEP2022:
Oliver Lantwin
Nitish Nayak

Which requests to detectors?

Hints @ ICHEP2022

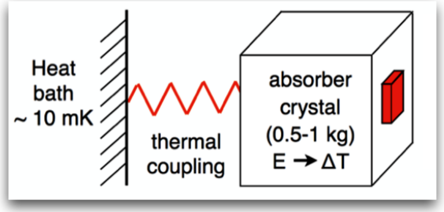
RES-NOVA

Detecting Supernova neutrinos with archaeological Pb-based cryogenic detectors



Thermometer at mK
Transition Edge Sensor
low-threshold DM technology

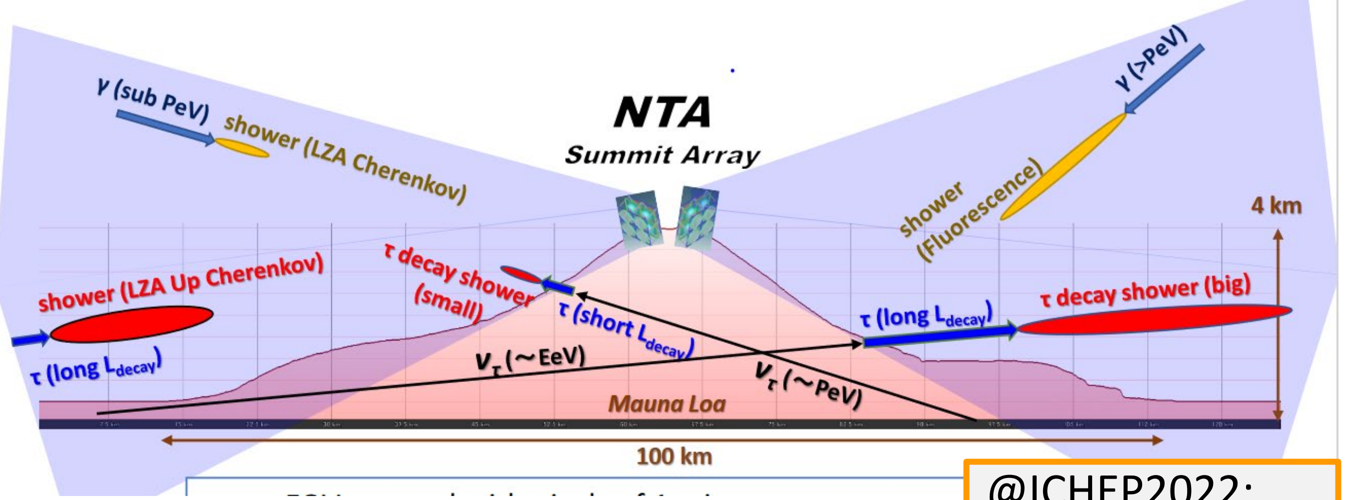
High-radiopurity crystal
$PbWO_4$
low-background DBD technology



@ICHEP2022: Luca Pattavina

NTA

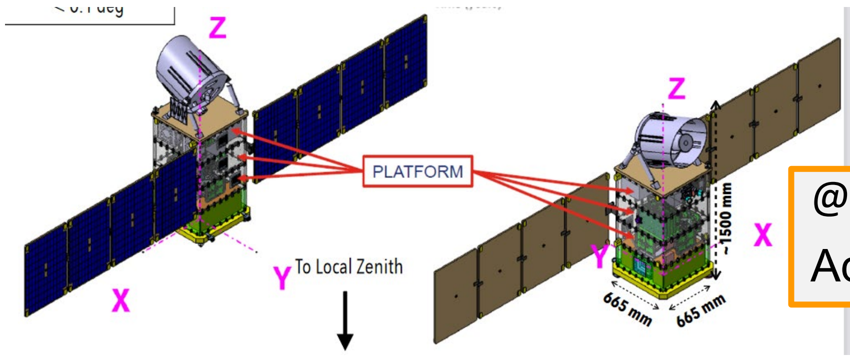
Very High Energy Physics and Astronomy with Tau and Photon Probes



@ICHEP2022: Makoto Sasaki

The NUSES space mission

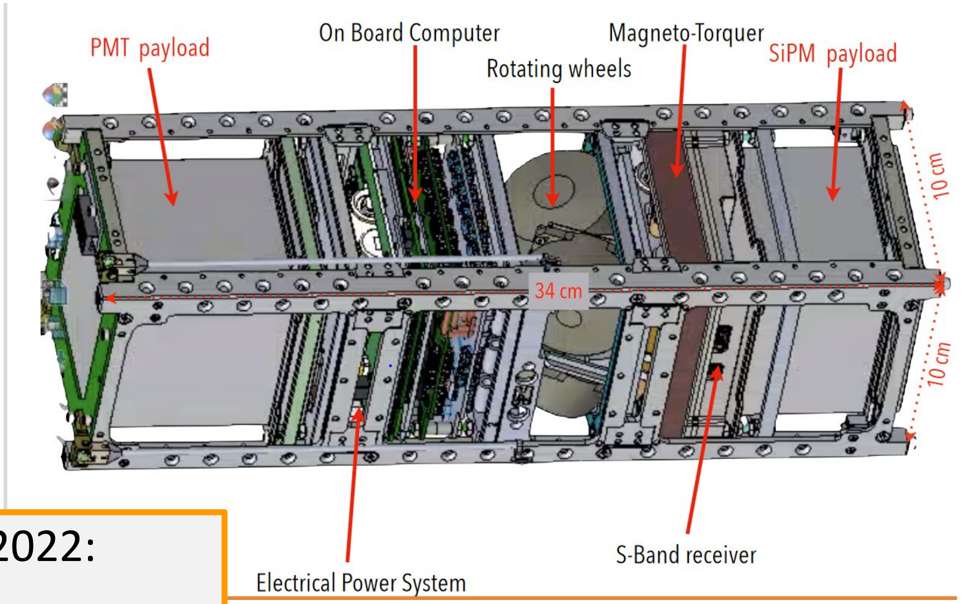
CR via Cherenkov light and 1-10 MeV photons



@ICHEP2022: Adriano Di Giovanni

EXOTIC DETECTOR FLAVOURS @ ICHEP2022

LIGHT-1: *A 3U Cubesat Mission for the detection of Terrestrial Gamma-Ray Flashes*

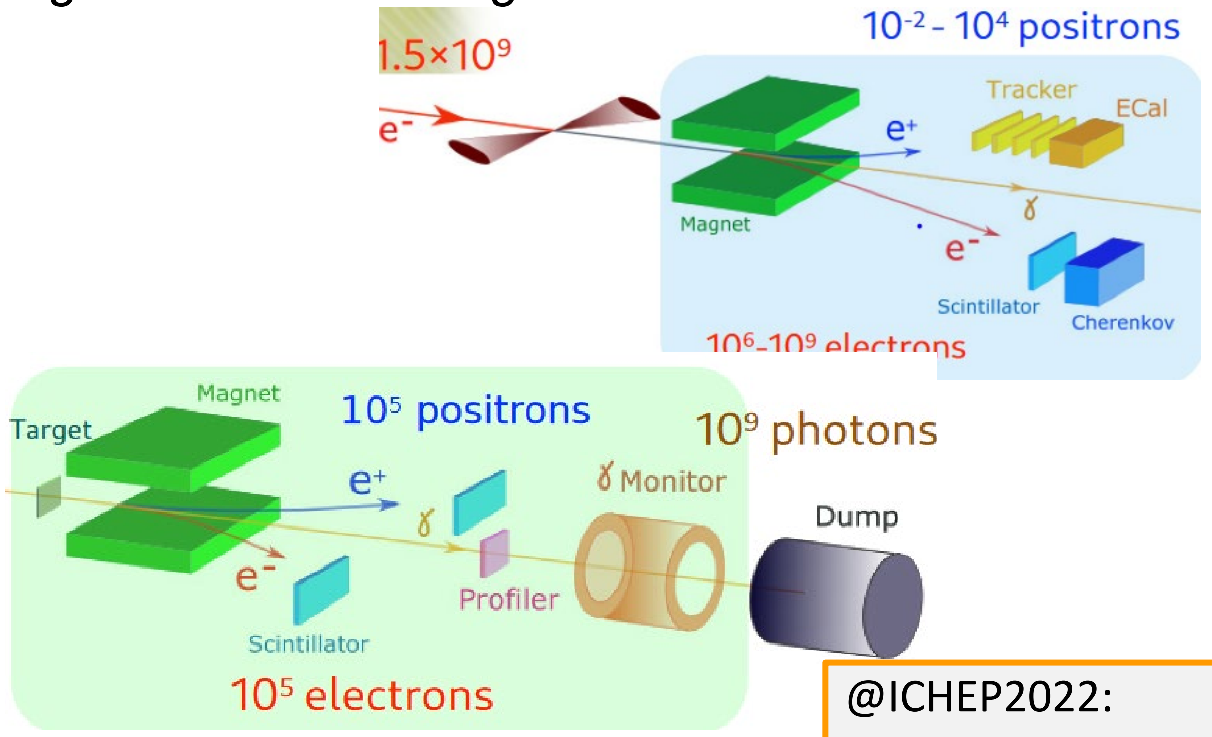


@ICHEP2022:

Adiano Di Giovanni

Detector Challenges of the strong-field QED experiment LUXE at the European XFEL

Need of X-ray and e detectors in a context of high rates and brackgound level



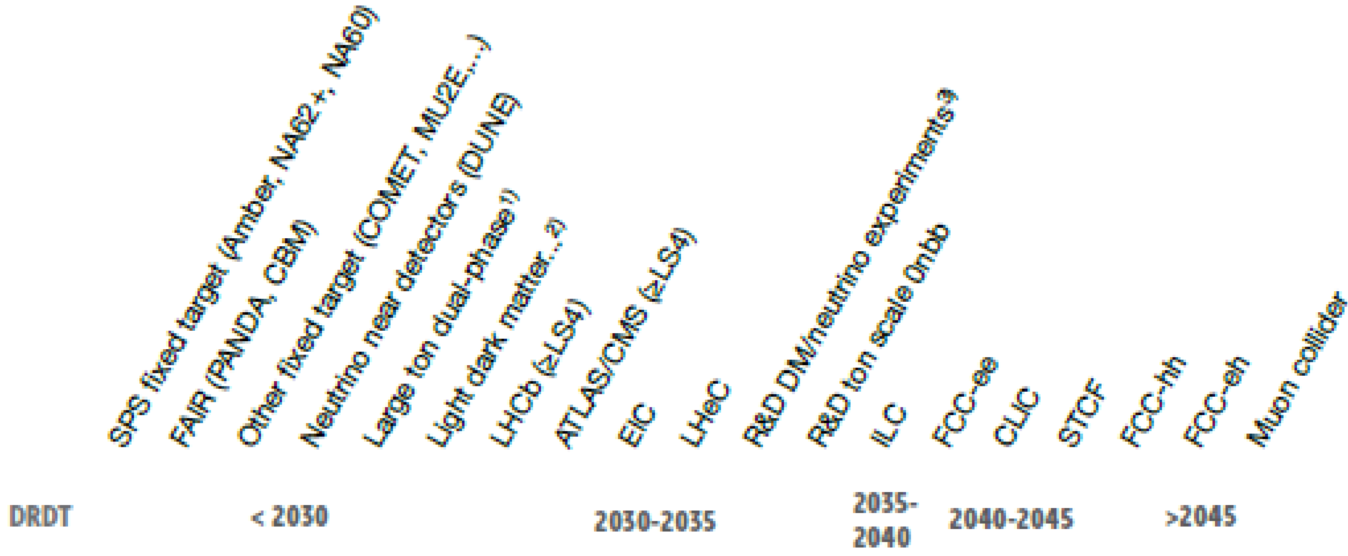
@ICHEP2022:

Oleksandr Borysov

A tour among detectors

Gaseous Detectors

- Extremely **wide range** of applications **including highest energies and luminosities**, long term projects
  - ubiquitous in **collider**
  - Largely needed in **fix target**
  - key also for **ν-physics** and **dark matter**
  - Even if not included in the Roadmap timelines, also **low energy NP, applications beyond fundamental research**
- 4 major families
  - **MPGDs**
  - **RPC & mRPC** for fine time resolution
  - Large volume: **TPCs & Drift Chambers**
  - and more: **Straw Tubes, Cathode Strip & Thin Gap Chambers**

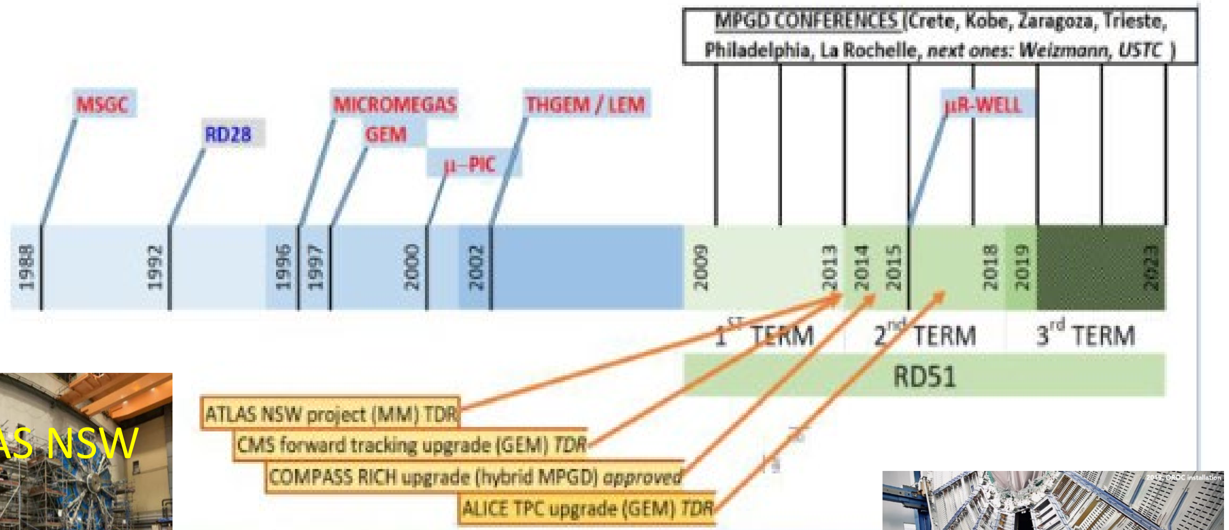


Facilities requiring Gaseous Detectors
(Final Report of the ECFA DETECTOR R&D RoadMap)

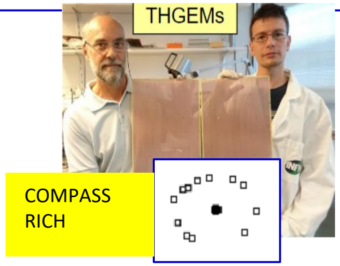
Gaseous Detectors

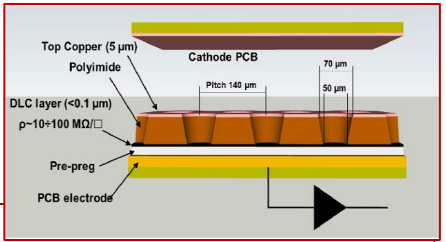
NOVEL TECHNOLOGIES AND THEIR APPLICATION (examples 2 ICHEP 2020)

- A **wide family** of detectors : **MPGDs**
  - **Key role of the RD51 technological Collaboration, CERN-based, world-wide, dedicated to MPGD developments and dissemination**
  - **Dissemination proven by the MPGD adoption in all the LHC experiments**
  - **Wide targeted & blue-sky R&D on-going**



@ICHEP2022:
Paolo Iengo





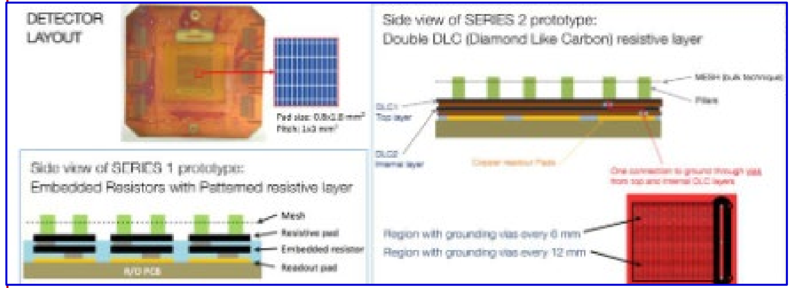
μR-WELLs:

- **LHCb Muon system** phase-2 upgrade
- The **IDEA** concept FCC-ee

μR-WELL @ICHEP2022:
Gianfranco Morello,
Riccardo Farinelli

Message: μR-WELL industrial production is reaching maturity

- **Small-pad resistive Micromegas** for high-rates



RHUM @ICHEP2022:
Roberto Di Nardo

Gaseous Detectors

- **large volume drift chambers and TPCs**

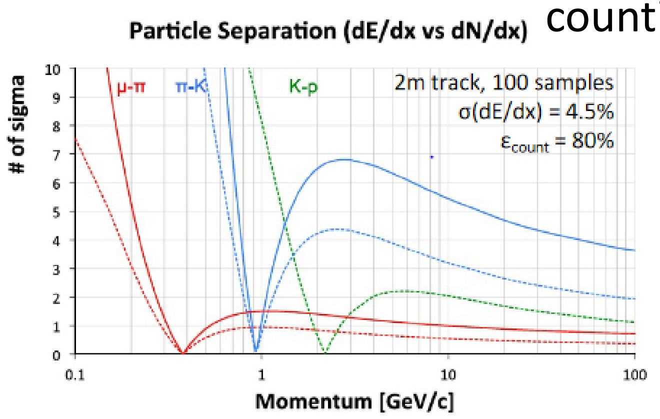
IDEA DC @ICHEP2022:

Gabriella Gaudio,

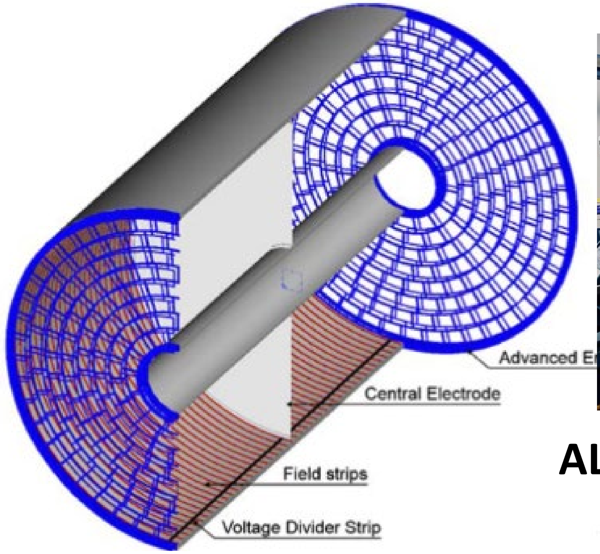
Federica Cuna

IDEA large volume drift chamber

Improved dE/dx with cluster counting



MPGD-based TPC with continuous readout



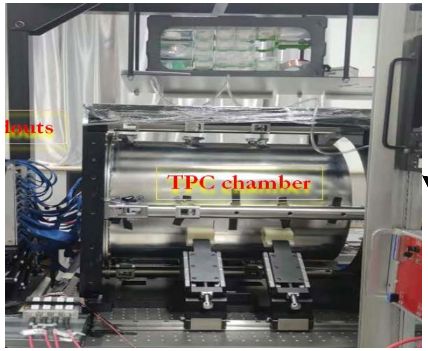
ALICE TPC

ILC-ILD concept

Read-out with

- GEMs
- MMs
- GridPix

TPC for CEPC



@ICHEP2022:

Huirong Qi

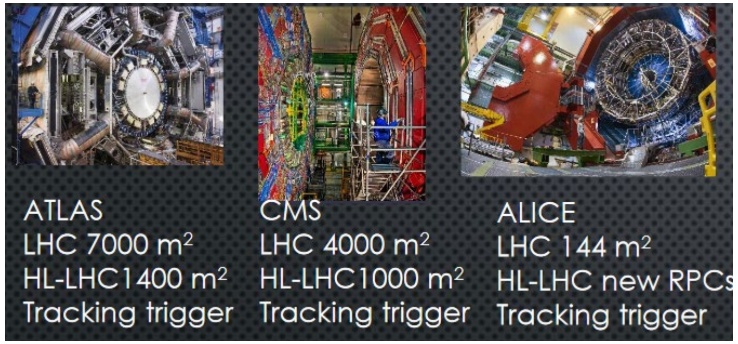
Message: cluster counting is making its way also in TPCs !

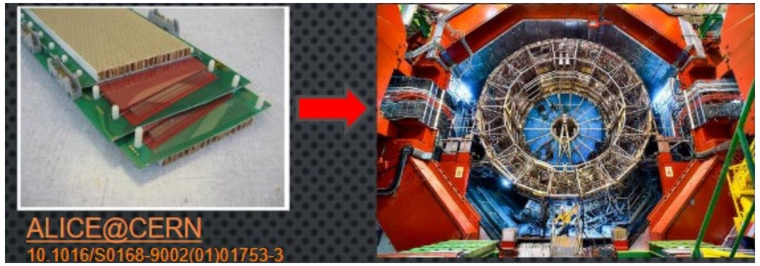
@ICHEP2022:

Maxim Titov

Gaseous Detectors

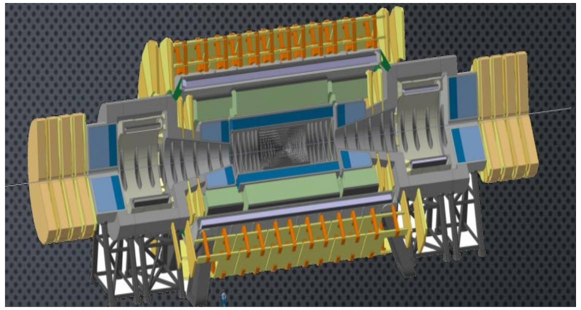
RPCs and mRPCs
ATLAS, CMS, ALICE triggers
ALICE, STAR ToF



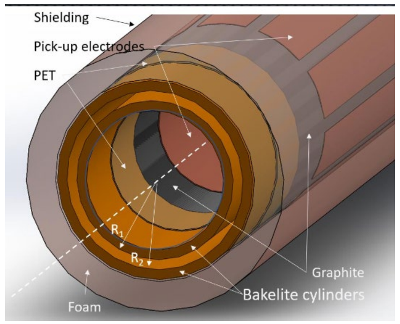


RPCs in future projects with improved rate capabilities (low resistance glass) and novel architectures

The quest for FCC-hh



RESISTIVE CYLINDRICAL CHAMBER (RCC)



Eco-gasses @ICHEP2022:

Giorgia Proto

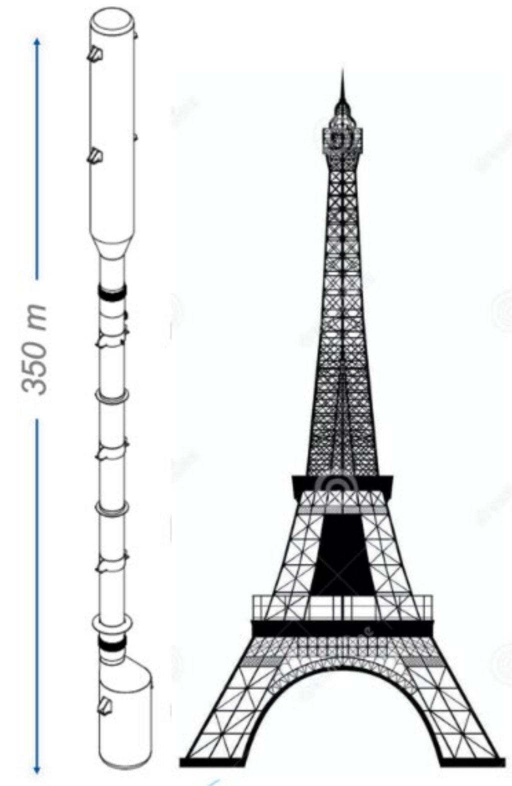
Liquid Detectors

Radio-Purity

- Which liquids ?
  - **Noble liquids (LAr, LXe)**
    - Combination of their **scintillation properties** and the **high ionization yield**
  - **Liquid scintillators, Water detectors**

  - **Examples @ ICHEP2020: nEXO, LiquidO, Dune**
    - In differerence conference sections: **JUNO, Kamiokande**

ARIA project (Darkside Collab.), production of depleted argon, below the UAr levels



ARIA -distillation column

Aria is **a 350 m tall cryogenic distillation column**, the tallest distillation column in the world, capable of isotopic enrichment. Operating in a mine shaft on the island of **Sardinia in Italy**, Aria will be able to further reduce the concentration of 39Ar by a factor of 10 per pass and at a rate of several kg/day. Beyond argon isotopic enrichment, the column has **commercial applications in the production of isotopes for nuclear energy and medicine.** For DarkSide-20k, however, Aria will not be used to reduce ^{39}Ar, but rather **to chemically purify the crude UAr** from Urania (99.9% pure) to produce detector-grade UAr. **For this chemical purification Aria will produce on the order of 1000 kg/day of purified UAr.**

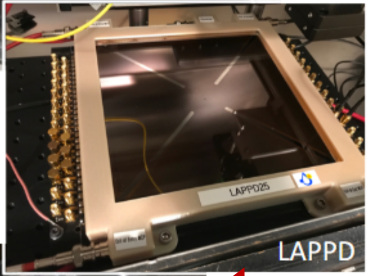
Required purity: 99.9999%

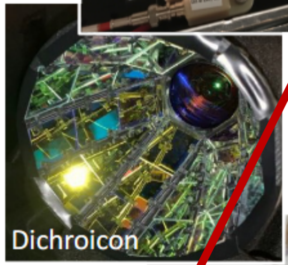
Liquid Detectors

- Photodetectors

Optical Module for IceCube-Gen2 @ICHEP2022:

Yuya Makino





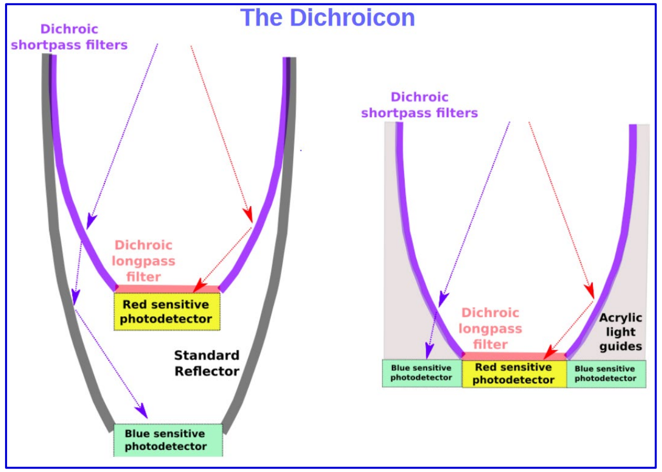
Photosensor	Features
Large-area PMTs (high-QE & MCP-PMT)	Enhanced light collection
M-DOMs, Multi-PMT modules in water	Exploit granularity for reconstruction
LAPPDs in water/WbLS	ps-timing for improved vertex reco and č/S separation
Dichroicons in WbLS Separate Cherenkov/Scintillation light	Wavelength-separation for hybrid-reconstruction
WOMs in water/LS Wavelength-shifting Optical Modules	Large light collection area optical coupling and emission/absorption spectra
SiPMs in LS	High QE/granularity but cooling for dark noise

+ enhanced light collection:
mirrors/cones, (active) light guides, fibres, metalenses …

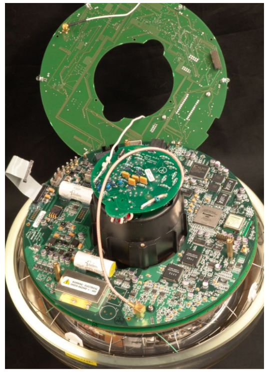
LAPPDs @ICHEP2022:

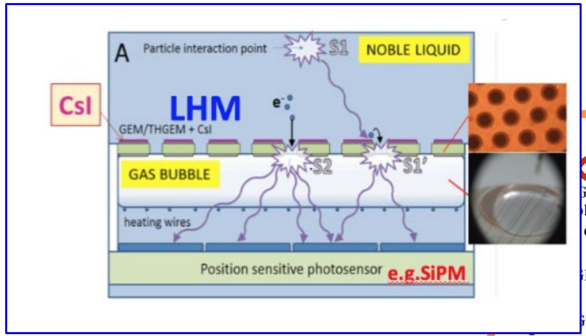
Shwan Shin

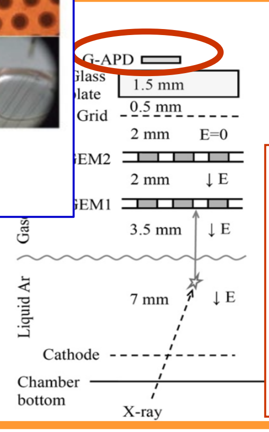
Alexander Kiselev



Digital Optical Module

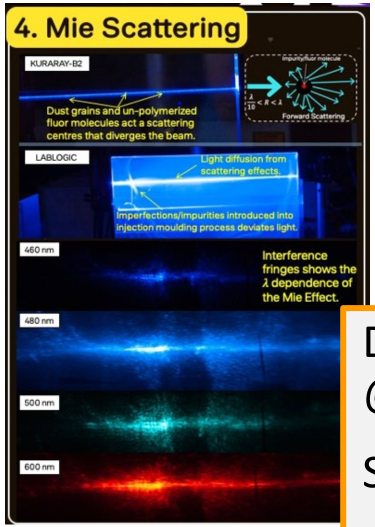






A. Bondar et al., NIMA 628 (2011) 364

THGEM + G-APD
Detect luminescent light



Deeper studies of WLS @ICHEP2022:

Sonyia Samani

Solid State Detectors

Project timescales for new solid sate devices

Discussed within Calorimetry

From RoadMap symposia, Didier Contardo

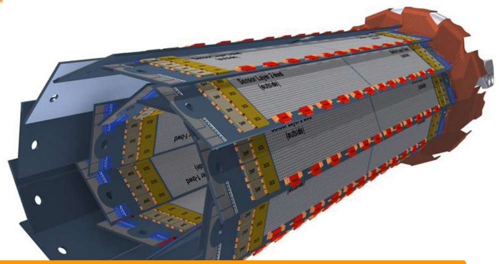
Projects	Timescale	Vertex Det.	Tracker	Calorimeter	Fine time res.
Panda (Fair/GSI)	2025	✓			
CBM (Fair/GSI)	2025	✓			
NA62/KLEVER	2025	✓			
ALICE	2026-27 (LS3) – 2031 (LS4)	✓	✓	✓	✓
Belle-II*	2026	✓			✓
LHCb	2031 (LS4)	✓	✓		
ATLAS-CMS	2031 (LS4) - 2035 (LS5)	✓			✓
EIC	2031	✓	✓	✓	✓
ILC	2035	✓	✓	✓	✓
CLIC	2035	✓	✓	✓	✓
FCC-ee	2040	✓	✓	✓	✓
Muon-collider	> 2045	✓	✓	✓	✓
FCC-hh	> 2050	✓	✓	✓	✓

- R&D completion typically ≃ - 5 years for construction, and including typically ≃ 5 years system engineering on top or in // to technology demonstration***
- Upgrade programs earlier than future colliders provide opportunities to iterate technologies and mature systems in real operation environments

ECFA roadmap detector R&D, TF3 solid state devices symposia
D. Contardo, 23/04/2021

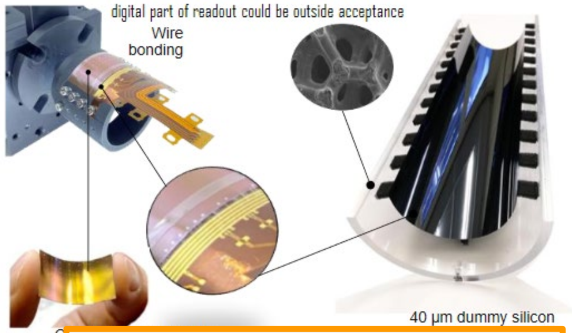
Solid State Detectors – **vertex**

- **high position precision**
  - ALICE, ILC, CLIC, FCC-ee, EIC
  - ALICE ITS2: **ALPIDE** 30 µm pitch, 50 µm thick, $\sigma_{hit} \simeq 5$ µm, X/X0 $\simeq$ 0.3% / layer
  - ALICE ITS3 target: $\sigma_{hit} \simeq 3$ µm, $X/X_0 \simeq 0.05\%$ / layer
    - **MAPs** with stitching process in 65 nm node (TowerJazz)
      - 10-20 µm pixel pitch, thickness down to 20 µm
      - 12” wafers (10 x 28 cm sensors), power $\simeq$ 20 mW/cm^2 for gas flow cooling



BELLEII vertex @ICHEP2022:

Klemens Lautenbach



ITS3 @ICHEP2022:

Magnus Mager

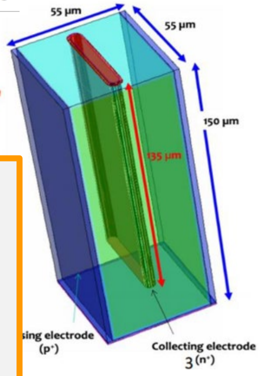
- **Not specifically discuss at ICHEP2020, even if needed for future facilities:**
  - **Position, and time requirements**
  - **high rates, and timing requirements**
  - **Stringent requirements of <u>radiation hardness</u>**
    - ***a part diamond detectors for BELLE II***

Diamonds @ICHEP2022:

Yifan Jin

Solid State Detectors – **timing**

3D – for timing detectors

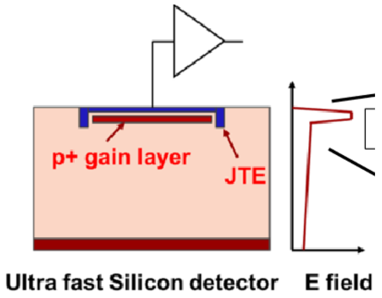


- **Particle Identification (PID) dedicated layer(s)**
  - ALICE 3 (post LS4), targeting $\boldsymbol{\sigma_t \simeq}$ **20 ps** for 3σ π/K up to 5 GeV/c
  - Belle-2, FCC-ee similar requirement to cover dE/dx crossing at low p (cluster counting)

TimeSPOT (3D trench silicon pixel)

@ICHEP2022:

Federica Borgato



- **4D tracking for track collision time association**
  - Dedicated layer(s) or implementation in VD and/or tracking layers
    - ATLAS/CMS $\boldsymbol{\sigma_t \lesssim}$ **30 ps** (pile-up mitigation)
      - desirable for high η LGADS replacement in LS4-LS5 (for rad. tol.)
  - LHCb pile-up mitigation for vertex precision **(≲ 50 ps)**
    - Options for e-e colliders to reduce beam backgrounds and improve 1st, 2nd, 3rd vertices identification
  - Muon collider: $\boldsymbol{\sigma_t \simeq}$ **10 ps** to eliminate out of time hits
  - FCC-hh pile-up: $\boldsymbol{\sigma_t \simeq}$ **5 ps**
  - FCC-ee at $\boldsymbol{\sigma_t \simeq}$ **6 ps** can allow to correct √s variation within bunches

(AC-)LGAD

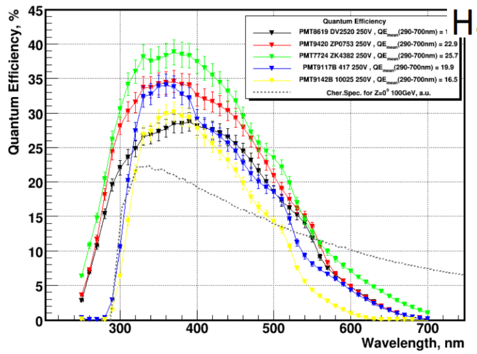
@ICHEP2022:

Xuan Li

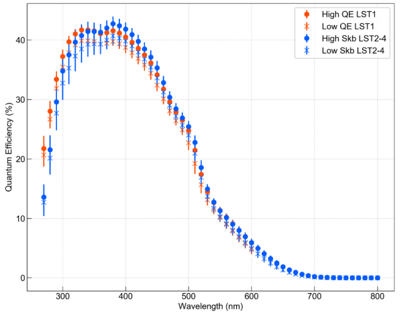
PhotoDetectors

PMT

Progress in QE

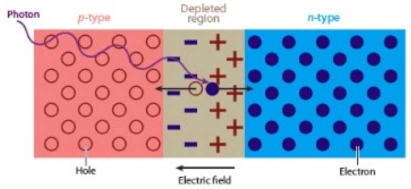


Hamamatsu
Type: R12992-100-05



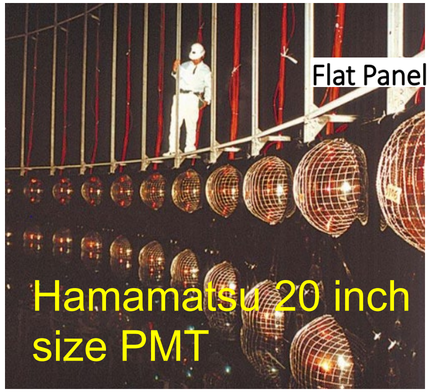
SiPM

An array of APDs operated in Geiger mode – above APD breakdown voltage (microcells or SPADs – single photon avalanche diodes)

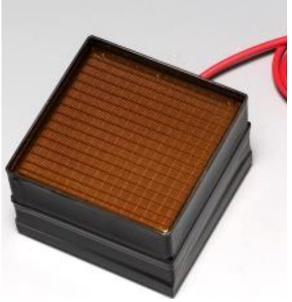


The PD family, something more

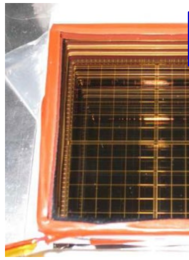
- ***Vacuum-based***
  - PMTs, MAPMTs, MCP-PMTs and large-size LAPPD, Hybrid (HAPD)
- ***Solid-state***
  - SiPMs
- ***Gaseous***
  - MWPCs, MPGDs
- ***Superconducting*** *(all cryogenic)*

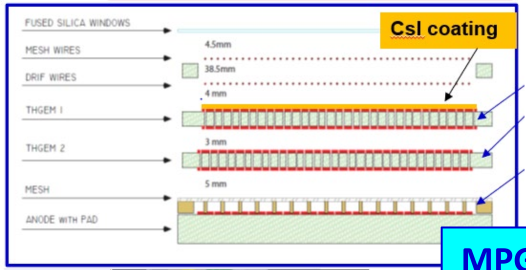


Flat Panel Multi-anode PMT Hamamatsu H9500

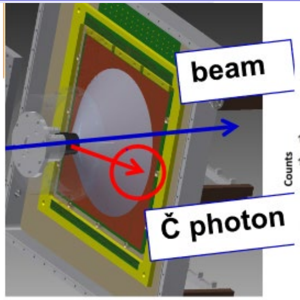


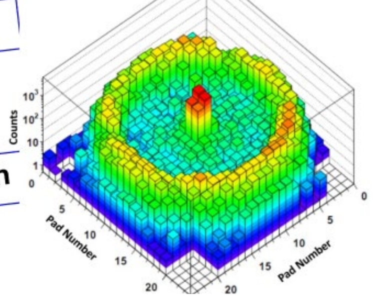
HPD



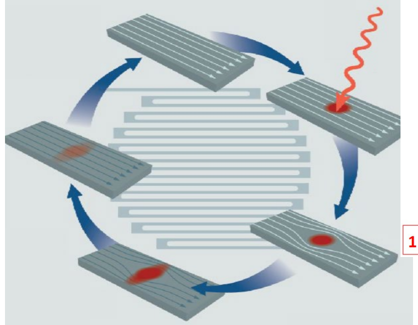


MPGD-based PDs

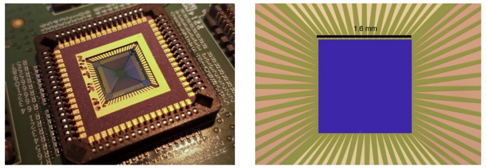




Superconducting Nanowire Single Photon Detectors:



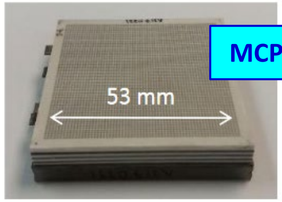
Larger Areas: N^2 pixels with 2N readout



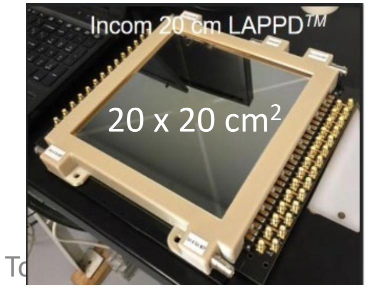
1 kilopixel today, new architectures for 1 Megapixel, 100 Megapixel...

- ultra-thin (4 to 8nm, 2nm)
- Anomolously large kinetic inductance (non-linear)

MCP-PMT



MCP-PMT by Photek



PhotoDetectors

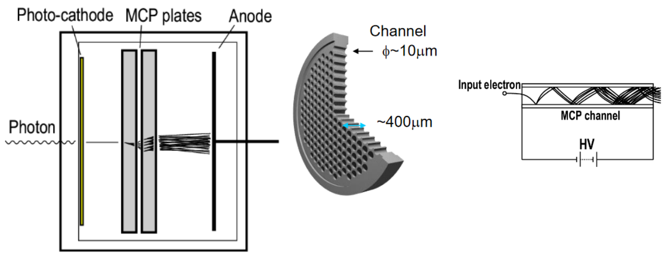
Future needs in photodetection

Projects	Timescale	SiPM technology	MCP-PMT technology	Large diameter PMT technology	CCDs & superconducting devices
Panda/CBM (Fair/GSI)	2025	✓	✓		
NA62/KLEVER/TauFV	2025	✓	✓		
ALICE	2026-27 (LS3) – 2031 (LS4)	✓	✓		
Belle-II	2026		✓		
Neutrino long baseline	2027	✓		✓	
LHCb	2031 (LS4)	✓	✓		
ATLAS-CMS	2031 (LS4) - 2035 (LS5)	✓			
Non accelerator & particle astro	--	✓		✓	✓
EIC	2031	✓	✓		
ILC	2035	✓			
CLIC	2035	✓			
FCC-ee	2040	✓	✓		
Muon-collider	> 2045	✓			
FCC-hh	> 2050	✓			

From RoadMap symposia, Didier Contardo

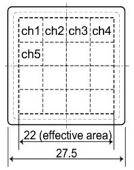
PhotoDetectors

MCP-PMTs



Square-shaped MCP-PMT

for Belle II TOP

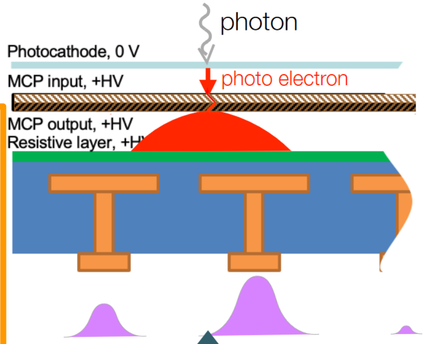


2-inch square MCP-PMTs

- PMTs with 2-inch square are being available.
  - Photonis Planacon
  - Photek AuraTek MAPMT253
  - (Hamamatsu in R&D)

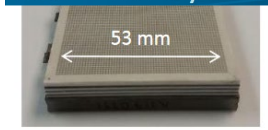
TORCH @ICHEP2022:

Jonas Rademacker



Prototype developed by our industrial partner, Photek

MCP-PMT by Photek



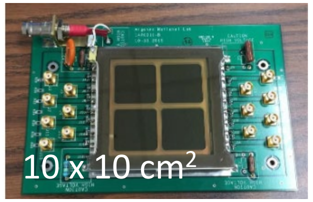
- 64 x 8 readout pads
- Required 128x8 resolution achieved through charge sharing.

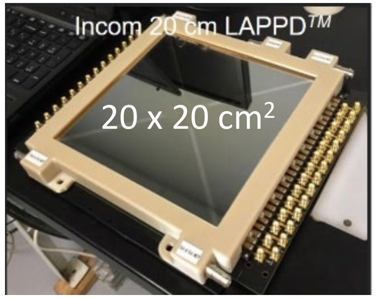
ICHEP2022

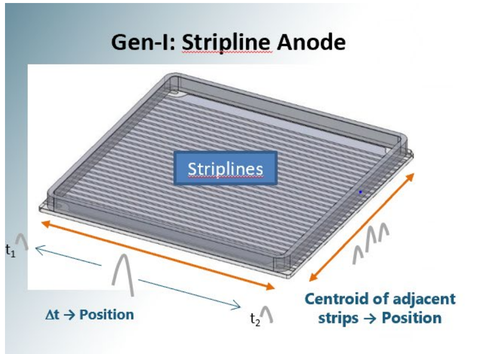
JINST 10 (2015) 05, C

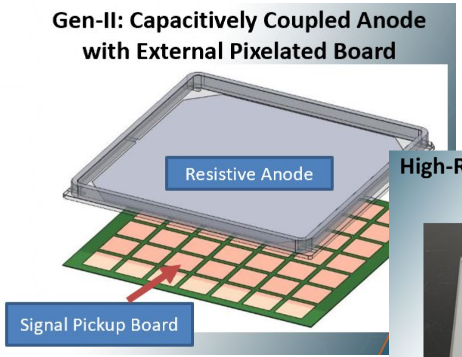
LAPPD (Large Area Picosecond Photodetector)

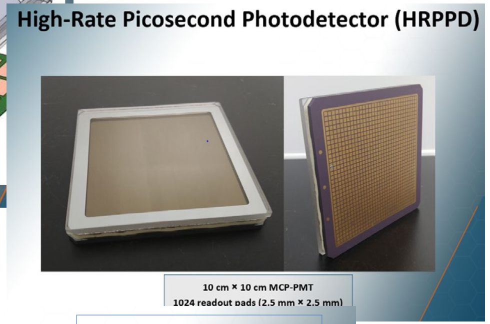
A joint effort of academy and industry

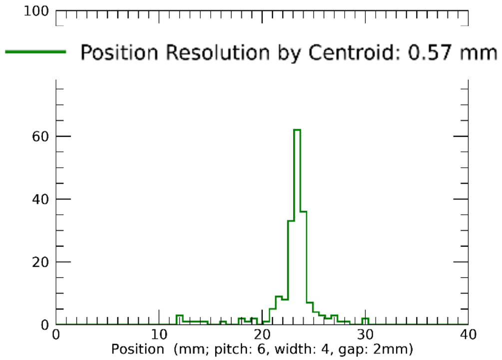


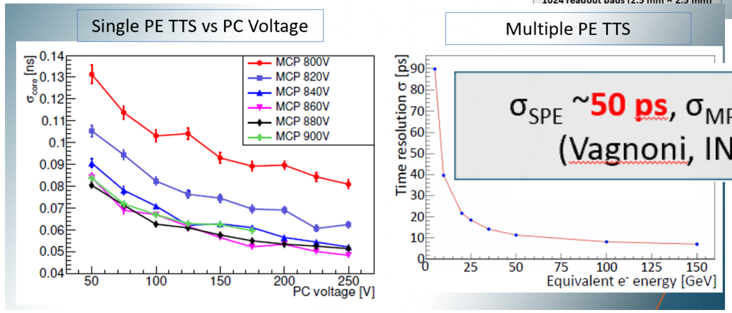












σ_{SPE} ~**50 ps**, σ_{MPE} ~**8 ps** (Vagnoni, INFN)

LAPPDs @ICHEP2022:

Shwan Shin (INCOM),

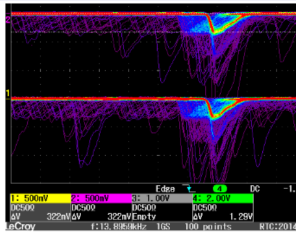
Alexander Kiselev

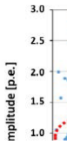
PhotoDetectors

Si-PMs

SiPM: noise

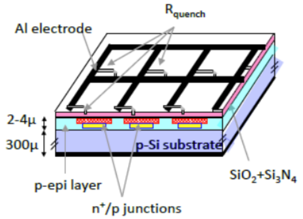
- dark counts are produced by thermal generation of carriers, trap assisted tunneling or band gap tunneling
- signal equal to single photon response
- typical rate went from $\approx 1MHz/mm^2$ to below $\approx 100kHz/mm^2$ for more recent devices
- roughly halved for every 8^oC
- increases linearly with fluence
- optical cross-talk produced when photons emitted in avalanche initiate signal in neighboring cell, reduced by screening – tranches
- after-pulses produced by trap-release of carriers or delayed arrival of optically induced carrier in the same cell





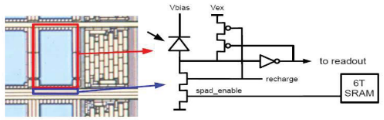
Analoge, digital, 3D

Analoge SiPM:



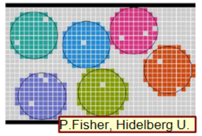
- common output with passive quenching
- custom process with more flexibility in optimization of SiPM parameters
- higher fill factor – higher PDE
- lower DCR

Digital SiPM, SPAD arrays:



Y. Haemisch et al. Phys. Proc. 37(2012)1546

- integration of SPADS into CMOS standard process (p^+ in n-we-l or n^+ in p-well
- allows integration of active quenching and readout electronics (comparator, TDC ...) at micro-cell level
- improved spatial and timing resolution
- higher DCR, possibility to disable noisy channels, enable only used channels (fibre matching)

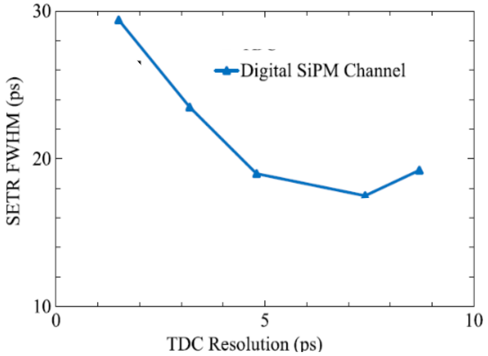


P. Fisher, Hidelberg U.

- reduced fill factor - need for compromise between electronics and SPAD area ...

ICHEP202

The best time resolution so far from single SPAD; FWHM ~ 17. 5 ps



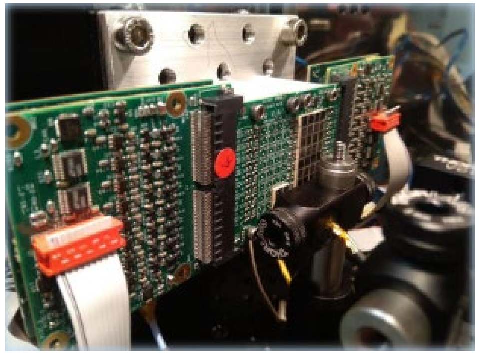
SiPMs in CALORIMETRY:

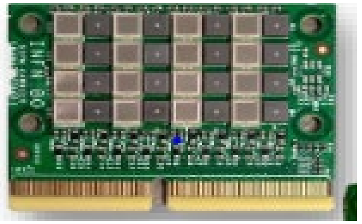
- Sensors for **crystals** and **scintillators**
- **Sever radiation up to NIEL**(non-ionizing energy loss)~ $\mathbf{10^{14}}$ **neq/cm²**

SiPms for Cal @ICHEP2022:

- Considered for a number of cal developments that we are going to meet in the dedicated session

R&D to recover radiation damage by thermal annealing cycles ongoing (image related to an effort for PID at EIC)





SiPms for single ph.s

@ICHEP2022:

Luigi Pio Raganese

PID

Cherekov

Projects	Timescale	RICH (high and low momentum PID)	Time of flight and DIRC	RPC technologies	TRD & dE/dx
Panda/CBM (Fair/GSI)	2025	✓	✓	✓	
NA62/KLEVER/TauFV	2025	✓	✓		
ALICE	2026-27 (LS3) – 2031 (LS4)	✓	✓	✓	✓
Belle-II	2026	✓	✓		
Neutrino long baseline	2027				
LHCb	2031 (LS4)	✓	✓		
ATLAS-CMS	2031 (LS4) - 2035 (LS5)				
Non accelerator & particle astro	--				
EIC	2031	✓	✓		
ILC	2035				
CLIC	2035				
FCC-ee	2040	✓	✓		✓
Muon-collider	> 2045				
FCC-hh	> 2050				

Future needs in PID

Summarizing about the fundamental physics domain of application:

- **Flavour physics**
- **Hadron physics**

photon detectors for BELLE II upgrade @ ICHEP2022:

Peter Krizan

TORCH @ICHEP2022:

Jonas Rademacker

Tof for Higgs factories @ICHEP2022:

Bohdan Dudar

PID – no Cherenkov at ICHEP2022

Everyone invite to:

Important progress in concepts and technologies

11th International Workshop on Ring Imaging Cherenkov Detectors (RICH2022)

Sep 12 – 16, 2022
University of Edinburgh

PID – ToF

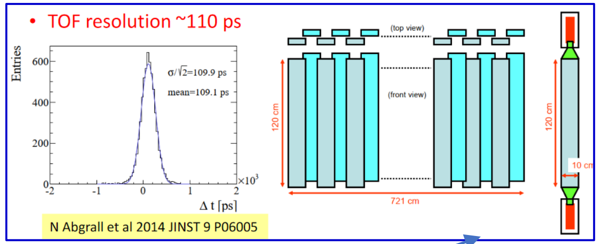
TOF

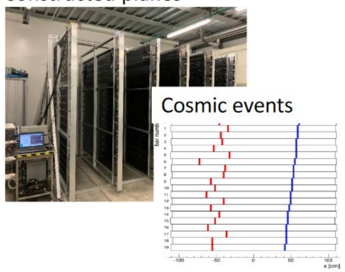
Conceptually easy, but …   some major issues:

- **Energy loss + multiple scattering** between the IP and TOF detector
- **Start time** (t0) needed
- System issues: **synchronization over a large area** is challenging

Present trend: Timing layers

NA61 Fast-Hamamatsu R1828





~ 130 ps resolution

T2K near Detector Upgrade

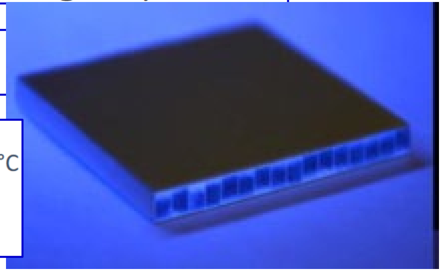
SiPMs (6 × 6 mm2 Hamamatsu S13360-6050PE MPPC)

1. Scintillator
2. Crystals
3. Gaseous
4. Silicon
5. Cherenkov

CMS Barrel Timing Layer

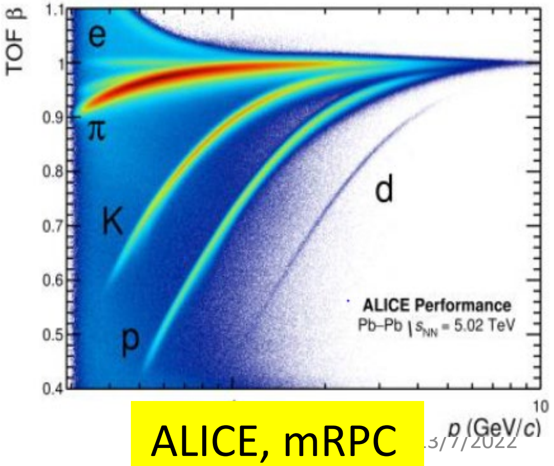
Fast scintillator: LYSO:Ce

- Thermoelectric coolers to improve SiPM radiation tolerance: run at -45°C
- Time resolution: 35 ps at start and 60 ps by the end of HL-LHC



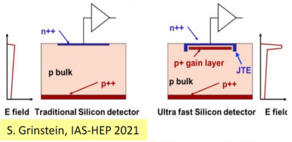
mRPC & MPGD (picosec, FTM)

F. Carnesecchi, arXiv:1806.03825

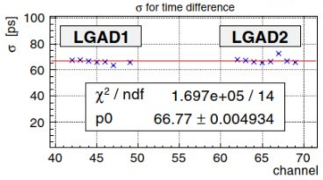


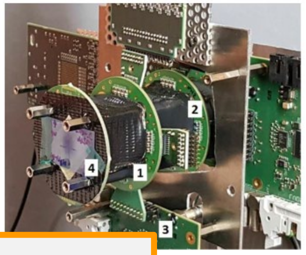
ALICE, mRPC

LGADs, low gain avalanche diodes, for end-cap timing, adopted by ATLAS/CMS layers a family of detectors



Corresponds to 47 ps/hit

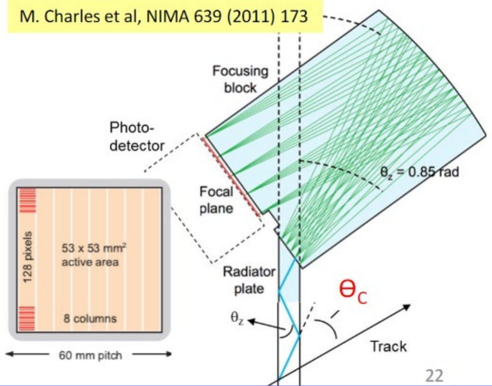




Coupled to MCP-PMTs

TORCH concept

Target: ~ 50 ps
π/K sep up to
10 Gev/c



TORCH @ICHEP2022:

Jonas Rademacker

ToF for Higgs factories @ICHEP2022:

Bohdan Dudar

NOVEL EMERGING TECHNOLOGIES

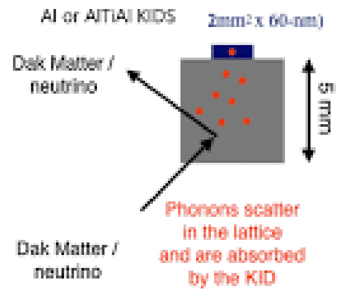
A **rich panorama** of technologies with still largely **<u>unexplored potentialities</u>**

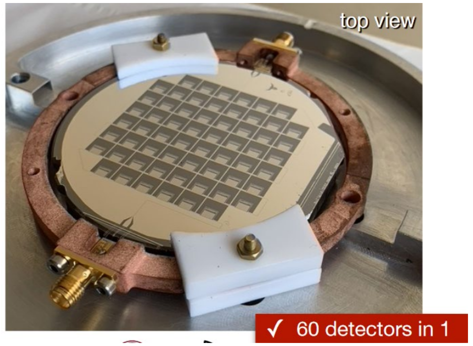
- *Tentatively: CP-violation, EDM, ν, DM, 5th force, QM*
- spin-based sensors, magnons
- superconductive approaches
  - Superconductor Insulator Superconductor (SIS) mixers, Hot Electron Bolometer (HEB) and Cold Electron Bolometer (CEB), **Transition Edge Sensors (TES)**, **Kinetic Inductance Detectors (KID),** Superconducting Nanowire Single Photon Detectors (SNSPD), Superconducting Quantum Interference Device (SQUID), Josephson Junction Parametric Ampliers (JJPA), Travelling Wave Parametric Amplifiers (TWPA), 3-D microwave cavities
- Optomechanical technologies
- Atoms, molecules, ions and atom-interferometric probes
- Metamaterials, low-dimensional materials, quantum materials

BULLKID @ICHEP2022:

Marco Vignati

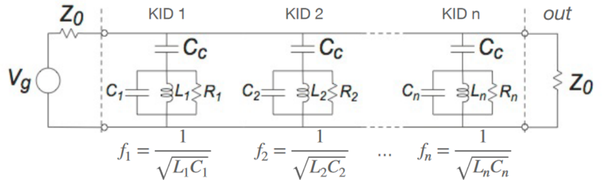
BULLKID: DM and ν interactions by KIDs with high granularity and low mass aiming at future large mass scale

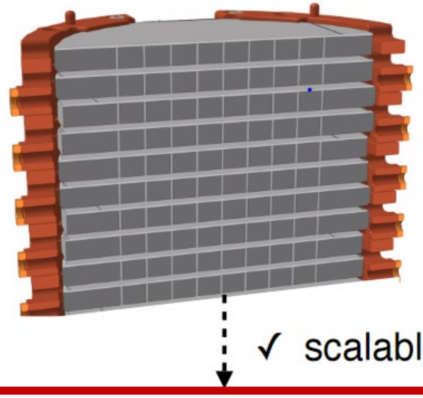




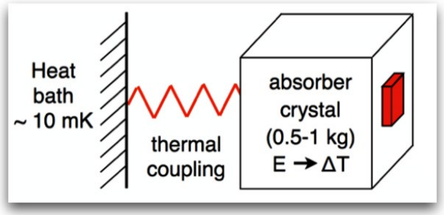
unique feature of KIDs: multiplexed readout

several KIDs coupled to the same feedline at different frequencies





✓ scalable



TES for RES-NOVA @ICHEP2022:

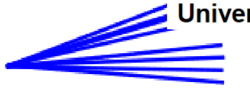
Luca Pattavini

CALORIMETRY – a needed introduction

★ **In a typical jet :**

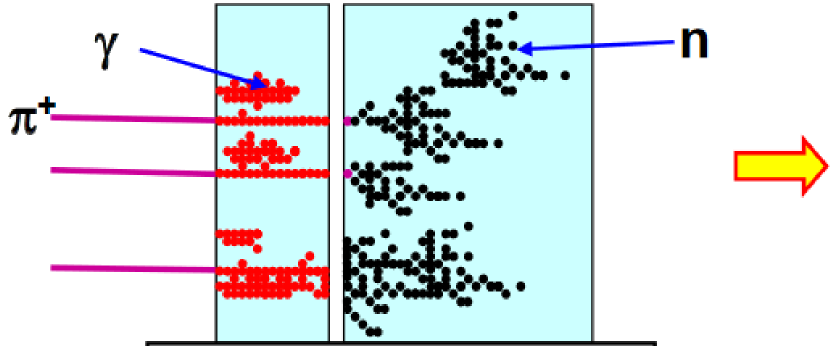
- **60 % of jet energy in charged hadrons**
- **30 % in photons (mainly from $\pi^0 \to \gamma\gamma$)**
- **10 % in neutral hadrons (mainly n and K_L)**

Credit:
Mark Thomson
University of Cambridge



★ **Traditional calorimetric approach:**

- **Measure all components of jet energy in ECAL/HCAL !**
- **~70 % of energy measured in HCAL: $\sigma_E/E \approx 60\,\%/\sqrt{E(\mathrm{GeV})}$**
- **Intrinsically "poor" HCAL resolution limits jet energy resolution**



$E_{JET} = E_{ECAL} + E_{HCAL}$

$E_{JET} = E_{TRACK} + E_{\gamma} + E_{n}$

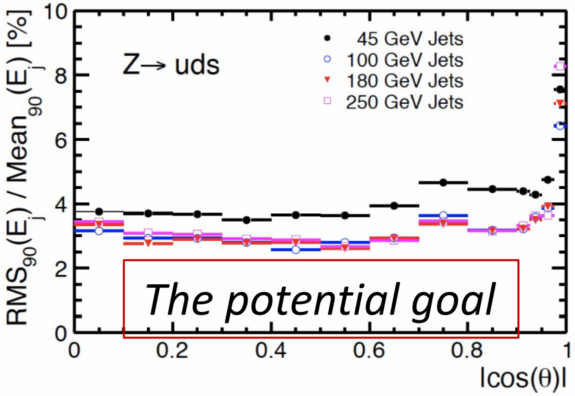
★ **Particle Flow Calorimetry paradigm:**

- **charged particles measured in tracker (essentially perfectly)**
- **Photons in ECAL: $\sigma_E/E < 20\,\%/\sqrt{E(\mathrm{GeV})}$**
- **Neutral hadrons (ONLY) in HCAL**
- **Only 10 % of jet energy from HCAL ⟹ much improved resolution**

PARTICLE FLOW CALORIMETRY:

Needed:

- HIGH GRANULARITY
- PDF reconstruction



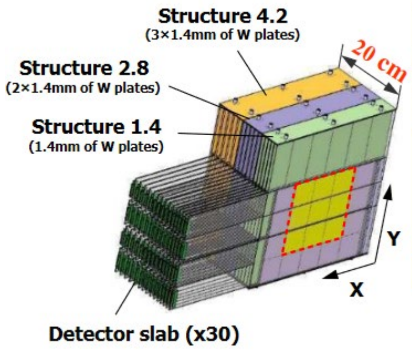
ILCTDR

PFA reconstruction

@ICHEP2022:

Fabricio Jimenez Morales

CALORIMETRY – Si-based highly granularity



Calice calo review @ICHEP2022:

Adrian Irles

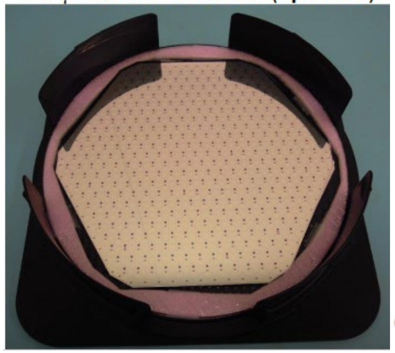
Imad Laktineh

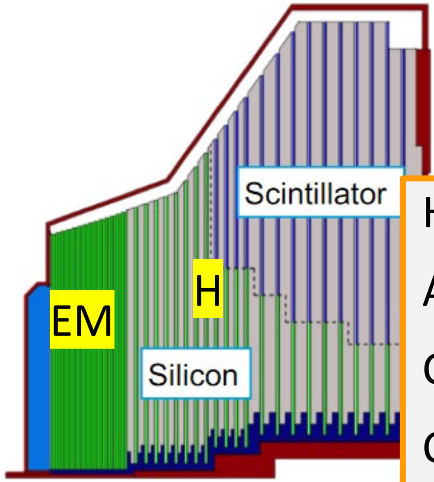
Fabricio Jimenez Morales

CMS HGCAL:

8” silicon sensors

High-density 8” sensor
~450 cells of area ~0.5cm²
120μm active thickness (**epitaxial**)





HGCAL @ICHEP2022:

André David

Chaochen Yuan

Chaochen Yuan

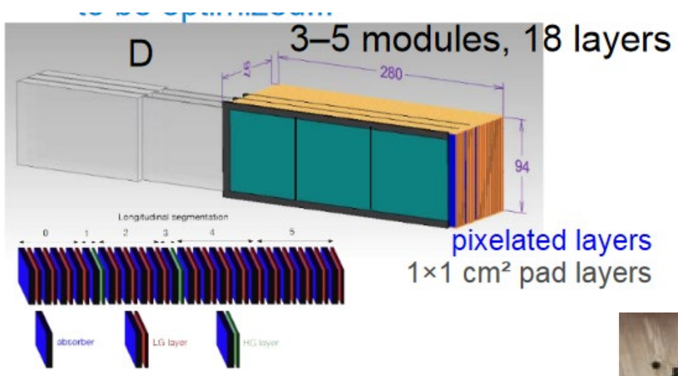
Simon Rothman (software)

FOCAL-E @ ALICE

Goal: measure of the (n)PDFs at low x_{Bj}

FOCAL @ICHEP2022:

Max Rauch



CALORIMETRY – Scintillator-based granularity

"Classical" scintillator tile calorimeters

ATLAS TileCal
CMS HCAL

Scintillating Glass *gaining momentums: EIC, CEPC*

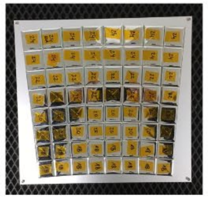
Scint. Glass @ICHEP2022:

Dejing Du

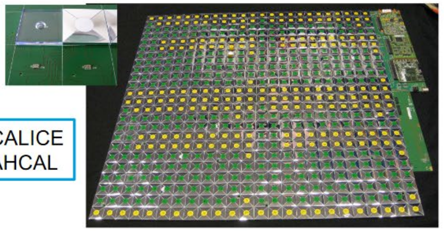
"Integrated" scintillator tile and strip calorimeters

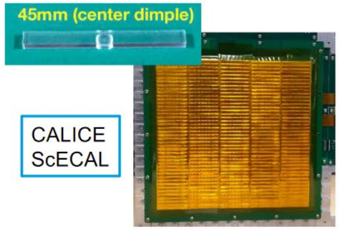
Also photodetector and electronics in radiation area

CMS HGCAL



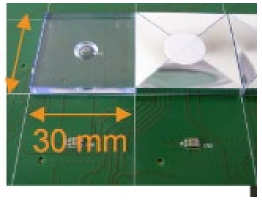
CALICE AHCAL





CALICE ScECAL

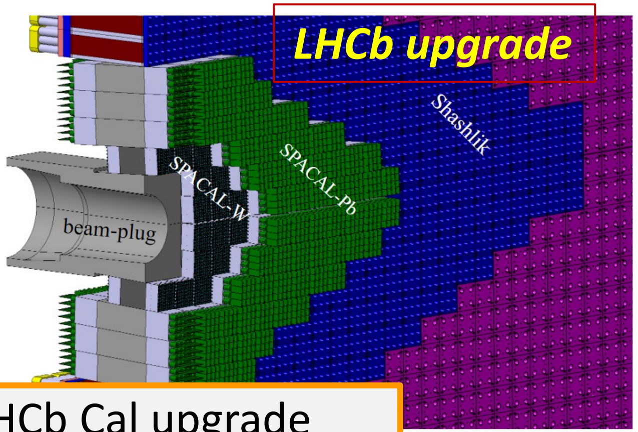
Granularity:
2.5 * 2.5 to 5.5 * 5.5 cm²

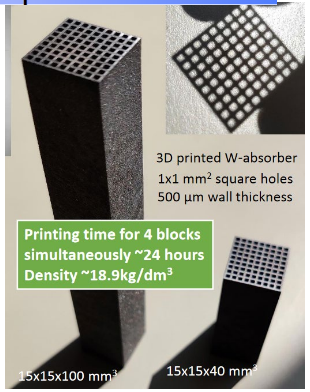


Scintillator and silicon share the same (cold) volume
- Operation at -30° C beneficial for SiPM noise
- Limited possibility to warm up for annealing

Radiation damage of photodetector (SiPM): neutron fluence
- State of the art: CMS BTL plans use up to 3 * 10^14 neq/cm²

LHCb SPACAL: excellent recent experience with 3D-printed tungsten absorber for ultra-compact calorimeter



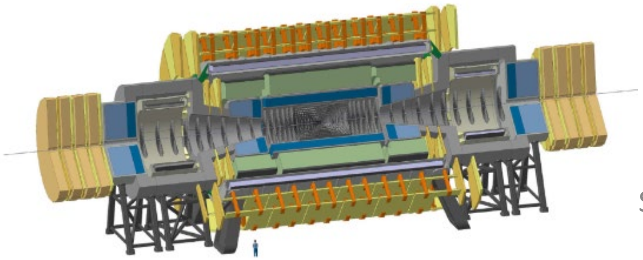


LHCb Cal upgrade @ICHEP2022:

Andreas Schopper

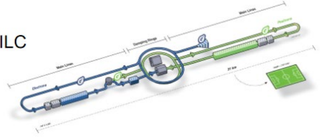
Further in the future

FCC-hh

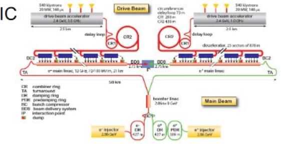


e^+ - e^-

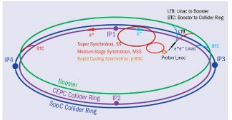
ILC



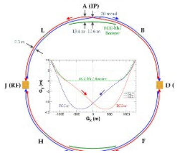
CLIC



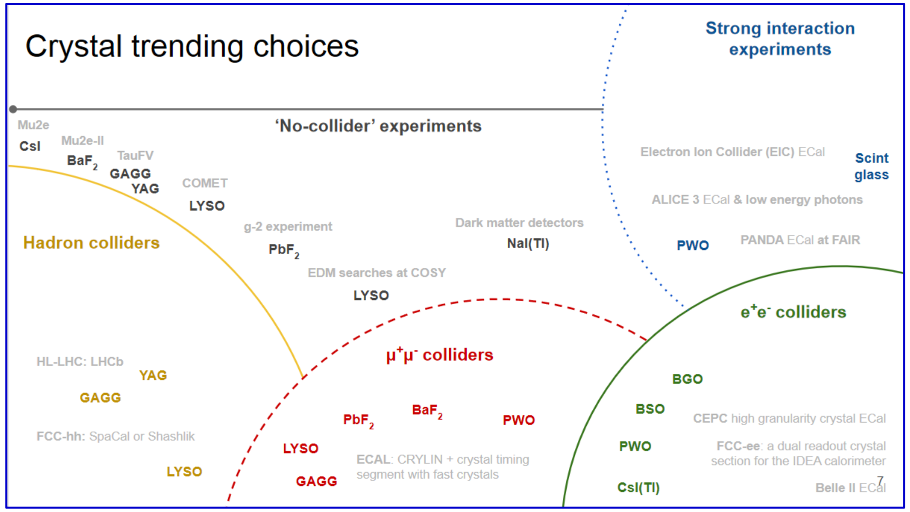
CEPC

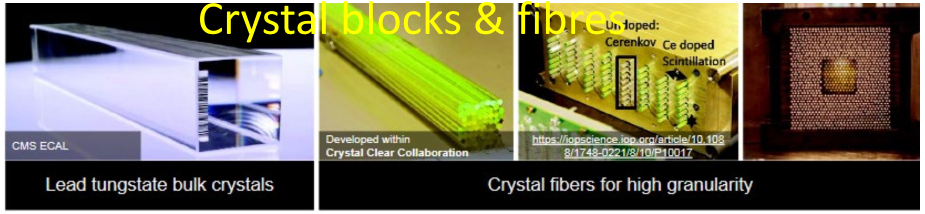


FCCee



CALORIMETRY – granularity with crystals



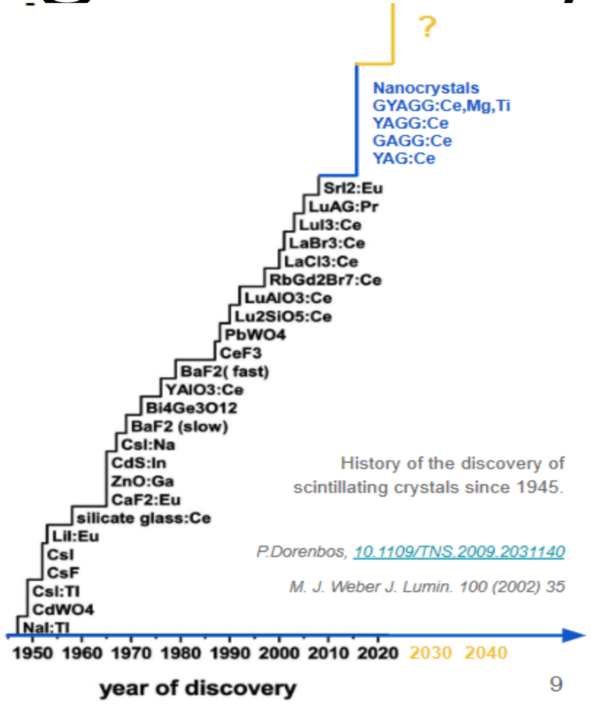


The Crilin Calorimeter: an alternative solution for the Muon Collider barrel

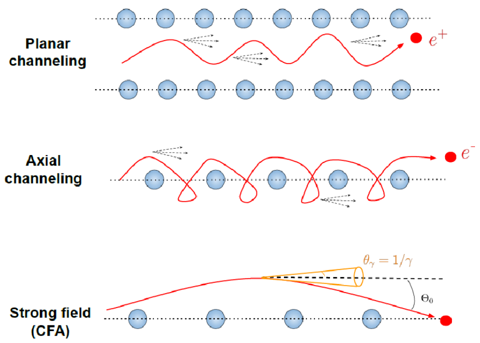
calorimeter by Lead Fluoride (PbF2) with longitudinal information

Crilin @ICHEP2022:

Eleonora Diociaiuti



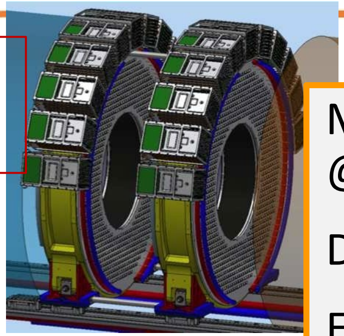
Beam test characterization of oriented crystals in strong field conditions



Crystal in strong field @ICHEP2022:

Pietro Monti-Guarnieri

mu2e crystal calorimeter

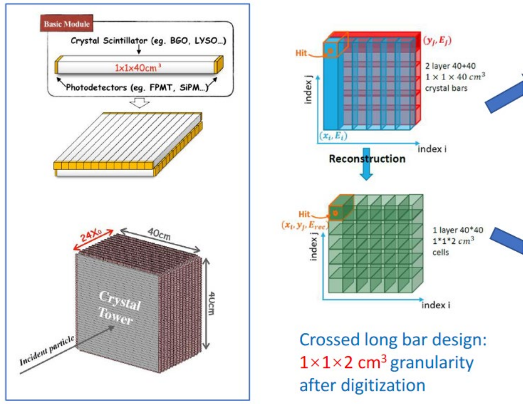


Mu2e crystal Cal @ICHEP2022:

Daniele Paesani

Elisa Sanzani

- Adapted from CEPC baseline detector
- Application and optimization of Arbor-PFA



Crossed long bar design: 1×1×2 cm³ granularity after digitization

Crystal Cal for CEPC @ICHEP2022:

Baohua Qi

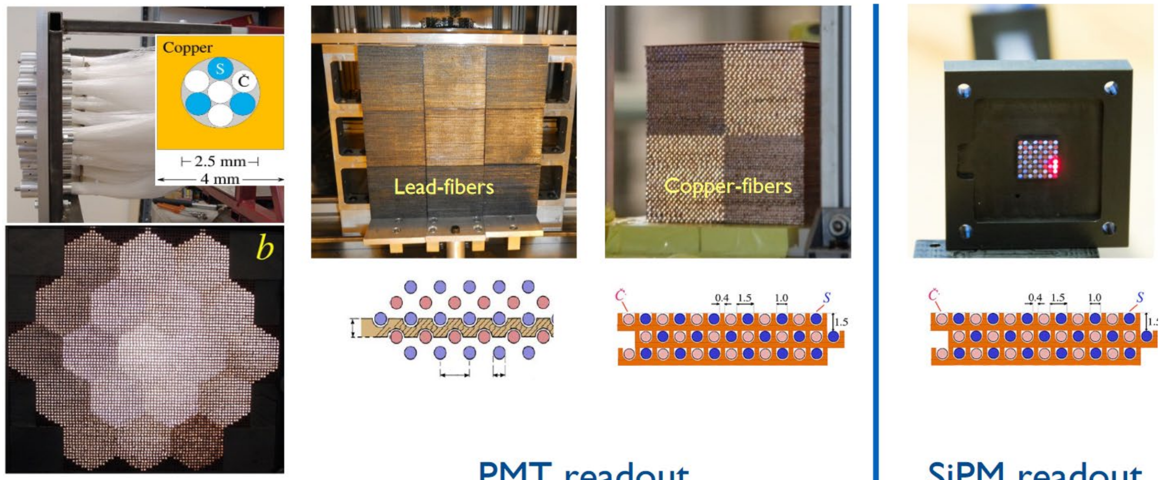
CALORIMETRY – the concepts

Dual-Readout fibre-sampling calorimetry

Dual-readout in a nutshell

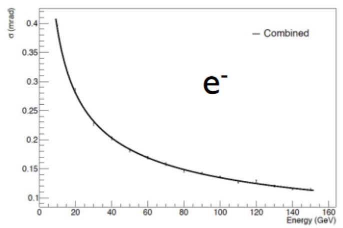
- f_{em} **fluctuations** dominate the hadronic calorimeter resolution
- **Dual Readout:**
  - Scintillation (all particles) and Cherenkov (electrons) signals have **different h/e** ⟹ allow the event-by-event extraction of f_{em}

State of the Art – DREAM & RD52 collaboration



Dual Readout in IDEA@FCC (CepC)

GEANT4 – IDEA / e⁻ 15-150 GeV

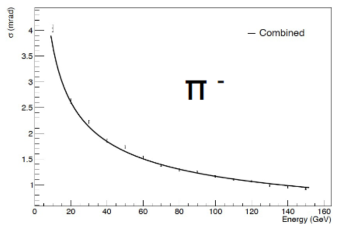


High granularity

good angular resolution

$$\sigma(mrad) = \frac{1.23}{\sqrt{E}} \oplus 0.05$$

GEANT4 – IDEA / π⁻ 15-150 GeV



$$\sigma(mrad) = \frac{11.6}{\sqrt{E}}$$

Dual-readout calorimetry @ICHEP2022:

Giacomo Polesello

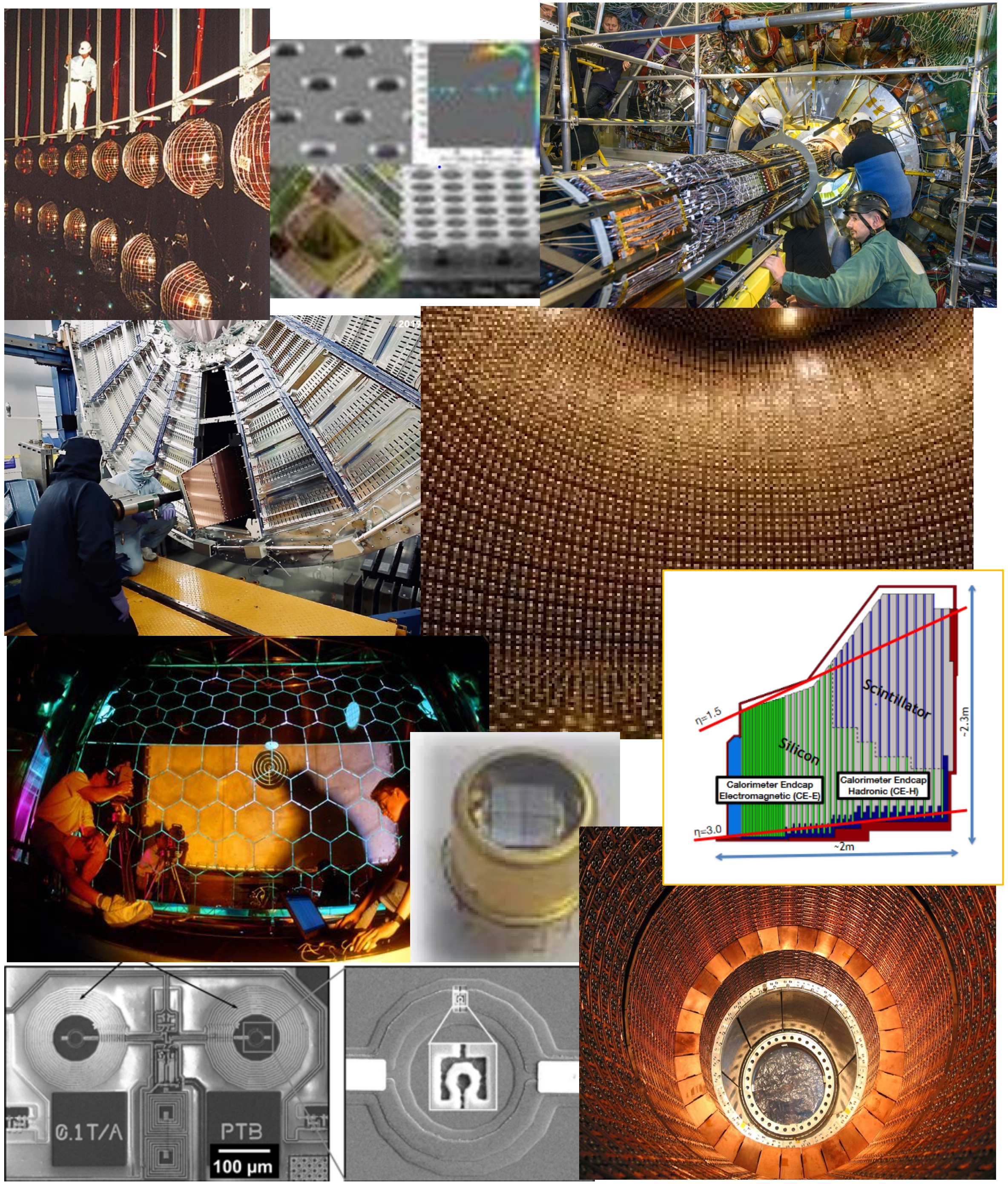
Bobae Kim

Iacopo Vivarelli

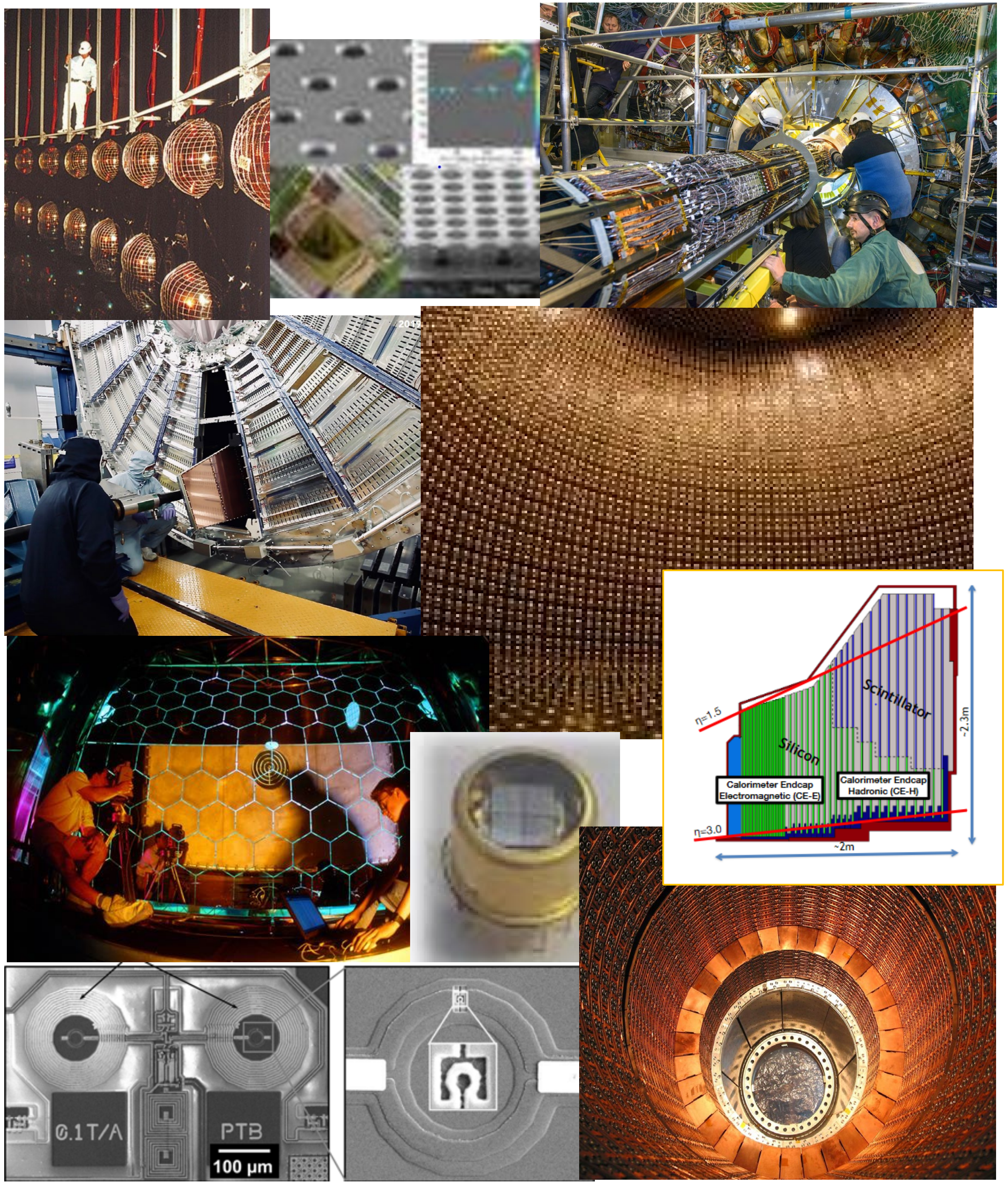
Concluding

CONCLUSIONS

- Detectors & detector R&D **key** for the progress in fundamental research
  - To be better and concretely recognized
- A **rich panorama** of development, worldwide
- A more and more **holist approach** in the detector design
  - Also because of increased challenges
- Detectors & detector R&D **@ ICHEP2022**
  - Even if not in a systematic approach, a significative sample of the ongoing effort has been presented



THANK YOU



Scintillator
Silicon
Calorimeter Endcap Electromagnetic (CE-E)
Calorimeter Endcap Hadronic (CE-H)
η=1.5
η=3.0
~2m
~2.3m
0.1T/A
PTB
100 µm