Community challenges and opportunities for detector R&D

Outcome from the European Particle Physics Strategy Open Symposium in Granada

A.Cattai –CERN–

ECFA
European Committee for Future Accelerators

European Strategy Update

Inputs & disclaimer

- Documents submitted by the communities for the European Particle Physics Strategy Update *https://indico.cern.ch/event/765096/contributions/*
- Talks and round table discussion @ R&D session in Granada
- Results from 2 surveys → status of R&D in Europe *by the ECFA detector panel*

  representing ~2900 FTE

  → recognition of individual achievements

  by ECFA 1355 participants
- Discussions & inputs from Colleagues and ECFA Detector Panel

.... but selection of topics & critical views are my own

with apologies to all interesting R&Ds not covered

160 submissions gave an overview of the different researches in different environments

Dealing with detectors:

14 submissions Future colliders *(CLIC, FCC, ILC, μ Coll…..)*

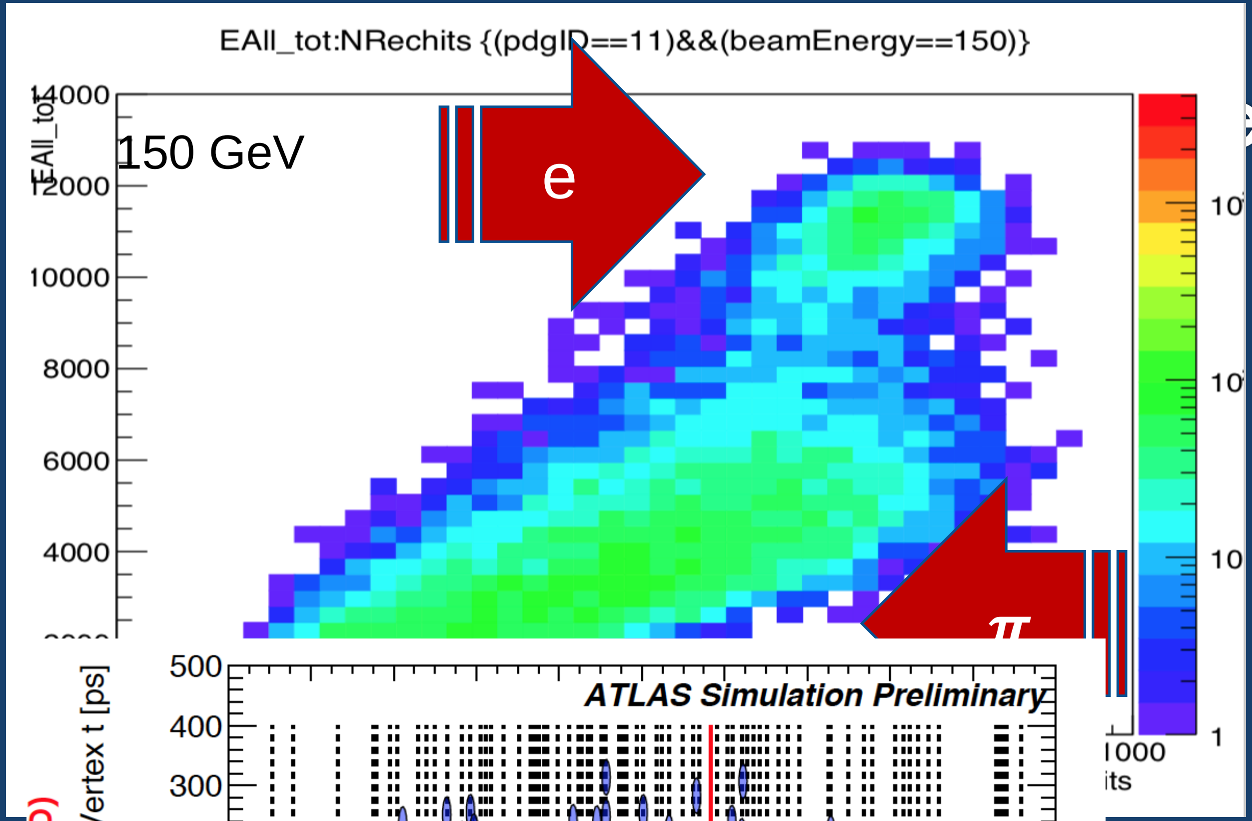
7 submissions " *The invisible*" elusive particles

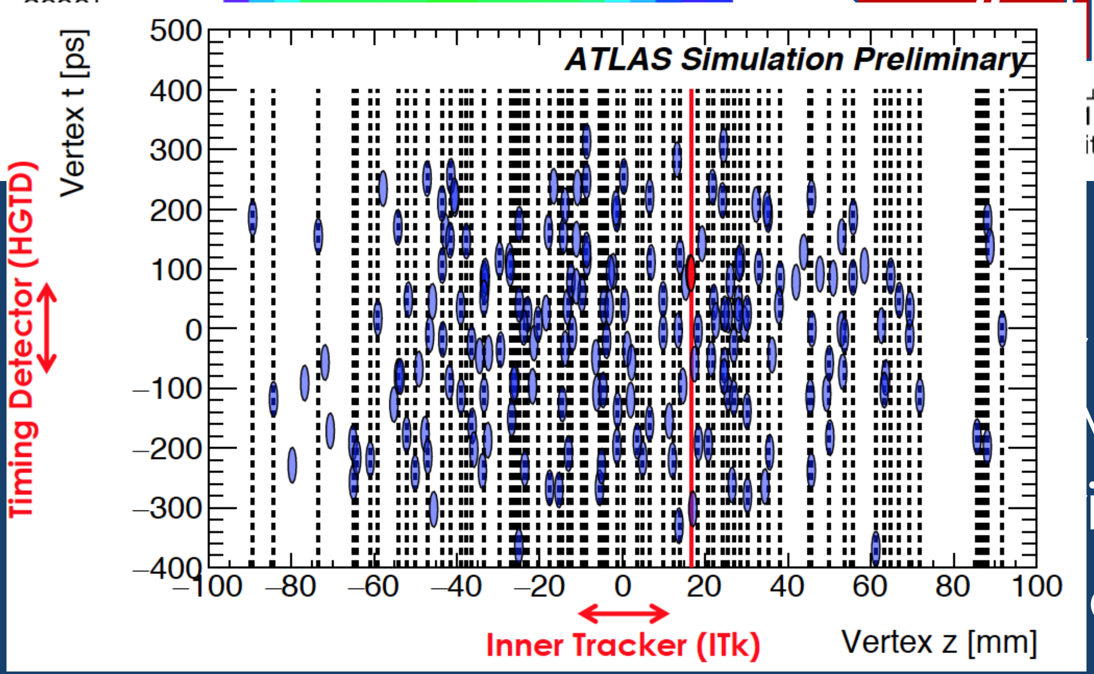
* Neutrinos near and far detector - Reactor neutrinos
* Low energy high sensitivity *(0v2β, g-2, EDM, ...)*

7 submissions Astro-particle and cosmology

* Dark matter detectors
* Cosmic rays - Gravitational waves- Satellite experiments

Very different requirements from many fundamental detector technologies





e experime

ext

$10*10\ \mu m^2$ @ ALIC

~10 ps per hit @ FCC

~30 ps per track @ HL-LHC

~0.05% X_0 per layer @ ALICE++

$10^{17-18}\ n_{eq}/cm^2$ @ FCC

detector (5D imaging)

very high readout speed

v cost

ing challenges: powering, extreme

e mechanics and production techniques

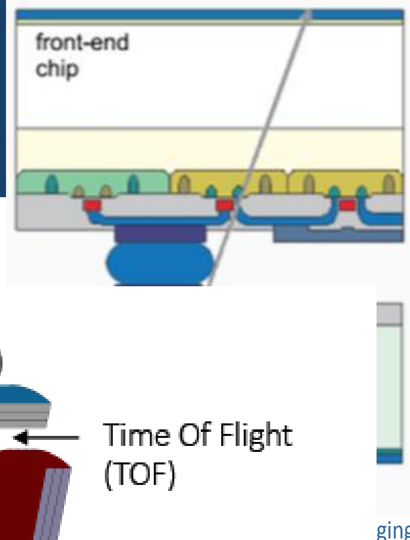
image
calorimetry
PFA
Rad Hard LiAr

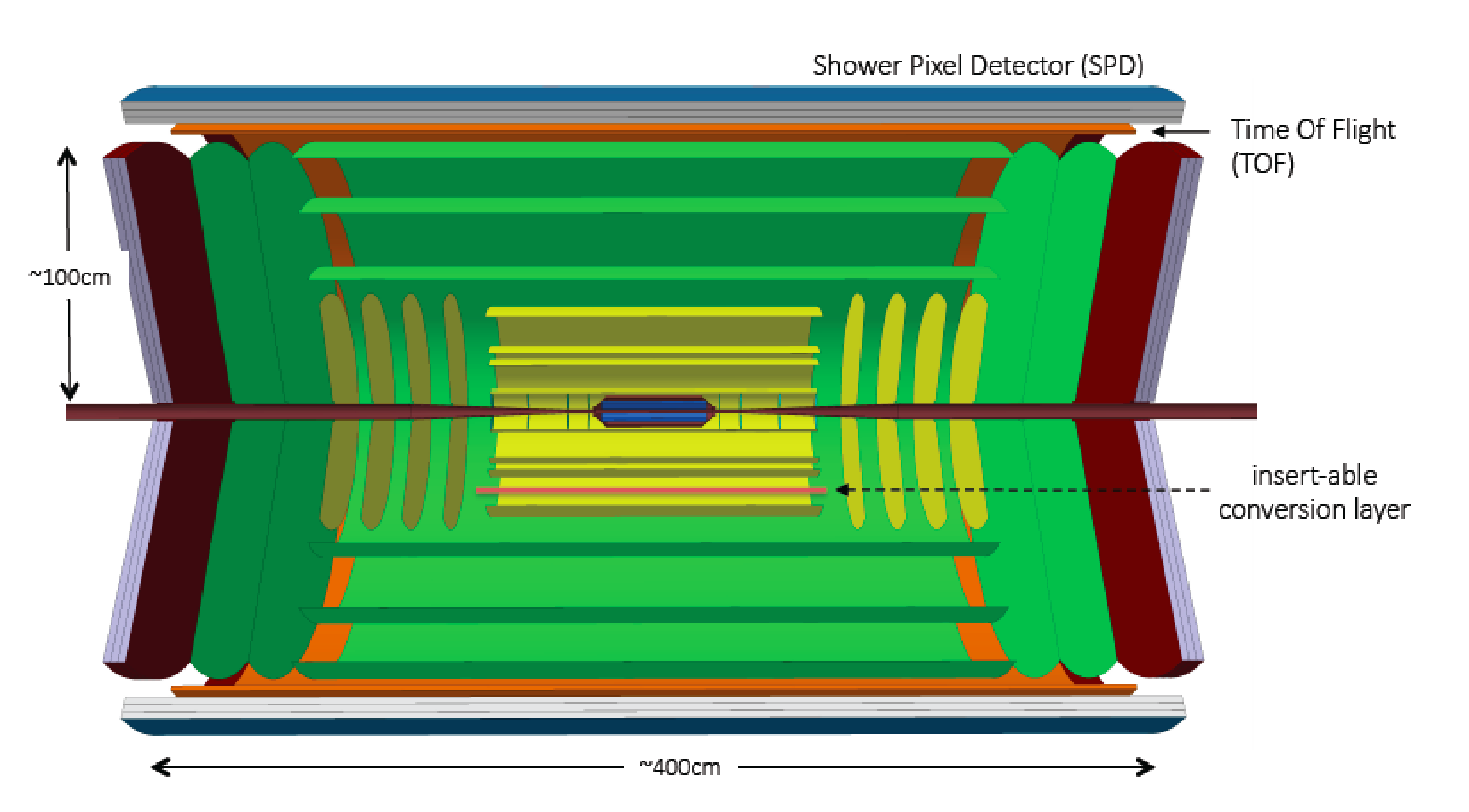
40% FTE

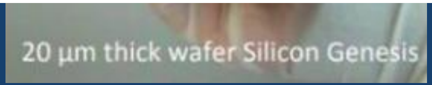
Challenges	Solid state **Vertex** 3D, (HV-)CMOS, MAPS, FPCCD, LGAD μ-electronics @ 65nm-28nm	Solid state **Trackers** HV-CMOS, SoI, (D)MAPS, LYSO tiles+SiPM, LGAD timing layers	Gaseous **Trackers** GEM, MM, THGEM, μ-RWELL, μ-PIC, GEMpix, TPC, Drift Chambers, sTGC, RPC	**Scintillating fibre tracking & calorimetry** NOL Nano-Organo-Si-Luminophores, Crystal fibers	**Calorimetry** à la CALICE Si/W, MAPS, LiA,r LYSO, Dual RO, Shower Pixel Detector, Metamaterial	**Particle Identification** RICHs, TORCH,ToF, ToP
Granularity --> space resolution	100x150μm - ALPIDE:27μm*29μm Hybrid: 50x50 μm - CLIC&CLD:25*25… ALICE++ μ… 10*…	CLIC: 1 mm t… m for 50 …	>100μm ILC: 100μm in r ~ 1mm in z **50 μm** ->10μm ILD: TimePix with 55μmX55μm	**LHCB Scifi: 80μm,** PEBS:55μm ATLAS alpha~25μm SPACAL:1x1 or 2x2 cm2	ECAL 5*5mm**2 HCAL 3*3 cm**2 for PFA with CALICE HL-LHC: 0.5 or 1cm2 Challenge for LiAr 5x20mm2	LHCb single-γ 0.7 mrad **LHCb: single-γ 0.2 mrad**
Fast & precise timing	…	…amp …c ILC 300 ns-ms **Timing Layer: LGAD ~30ps/track**	~10nsec 25 ps@PICOSEC	**Mu3e: 0.5 - 1ns** SPACAL: 20-40ps	25 ps timing 5D calorimetry **HL-LCH, μColl: Timing Layer: Lyso+SiPM ~30ps/track**	LHCb &TauFV RICH:10ps - TORCH:10-15ps/track **ALICE++ ToF: CMOS MAPS or LGAD with time res. ~ 20 ps**
Rate capability	…0--> 4000 MHz/cm2	FCC-hh: pile-up/bunch Xing O(1000)	2.5 MHz/cm2 **μ-RWELL 10MHz/cm2**	40 MHz SPACAL: up 3MHz/cm2	FCC-hh 8 charged particles per rapidity unit.	
Rad Hard of detectors & electronics, cables…..	10^15 neq/cm2 - 3D hyb: 10^16 neq/cm2 FCC-hh:10^17-18 neq/cm2 & 220 Mgy	**10^15 neq/cm2** - 10^17 neq/cm2 **timing layer 2x10^14-15 neq/cm2**	10^16 neq/cm2 1.6 C/cm2	**NOL:~10^13 neq/cm2 @-14C ~10^14 neq/cm2 kGy->10kGy SiPMS10^12neq/cm2 @-4C** SPACAL:~1MGy & 6-10^15 neq/cm2 at 300 fb-1	CLIC~ 20 Mrad/ year in the FWD FCC-hh: 2x10^16 neq/cm2 in EndCap **LiAr**	~50 kGy
Low material budget	**ALICE: 0.35%** CLIC: 0.2% CLD:0.3% ALICE++0.05% X0	**~2% X0 per layer**	CEPC IDEA: Drift chamber: 1.5% X0 & 3%X0 before the pre-shower	1% X0 /layer (complete module) 0.25% (fibre only)		**thinner radiators**
System integration	**mechanics,** truly cylindrical sensor, cooling, power, cables	**mechanics,** cooling, power, cables	eco-gas, optical read-out	**mechanics,** cooling, power, cables	**mechanics, large area,** cooling, power, cables	light carbon-fibre based mirrors - cooling for SiPM - **operation in B field, photondet.**

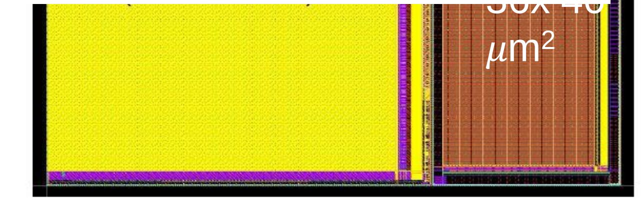
- Enormous effort in many directions *(40% FTEs are involved in R&D on solid state detectors for vertexing and tracking)*
  - Planar ?
  - 3D ?
  - Hybrid ?
  - Monolithic ?

- CMOS MAPS most a
  - Can be thinned to b
  - Can be stitched to c
  - Inherently high gran
  - *MALTA →$10^{15} n_{eq}/cm^2$ c hit-rate capabilities of*





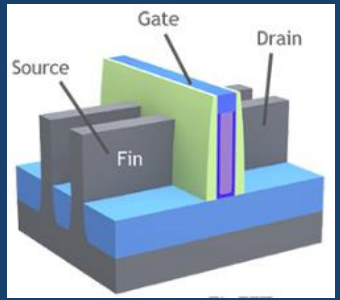




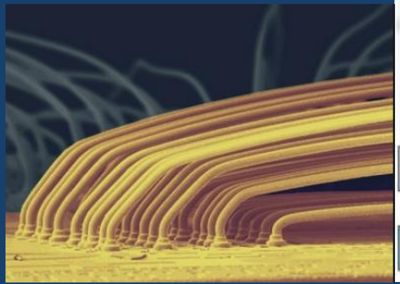
The real challenge: RO electronics !!!!!!

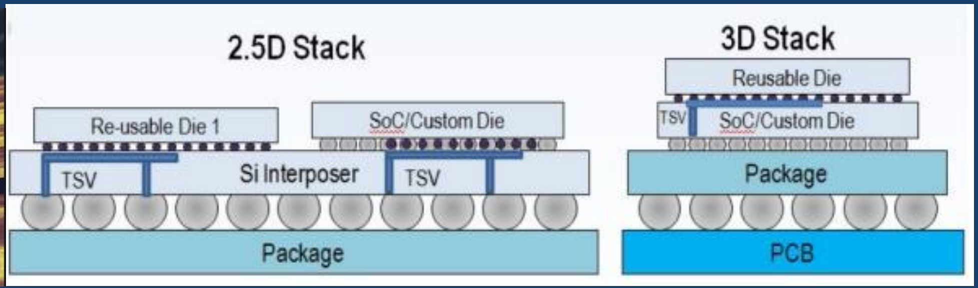
- Crucial role in all systems

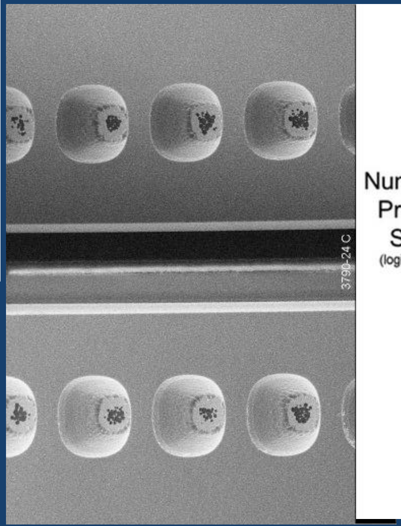
- Technical challenges *and more……*:
  - If down to pitches <20 μm, high density, rad hard, fast ~10 ps
    → You need to use electronics in 28 nm node or less
    → Exploits 3D VI geometries **NEW** to our community

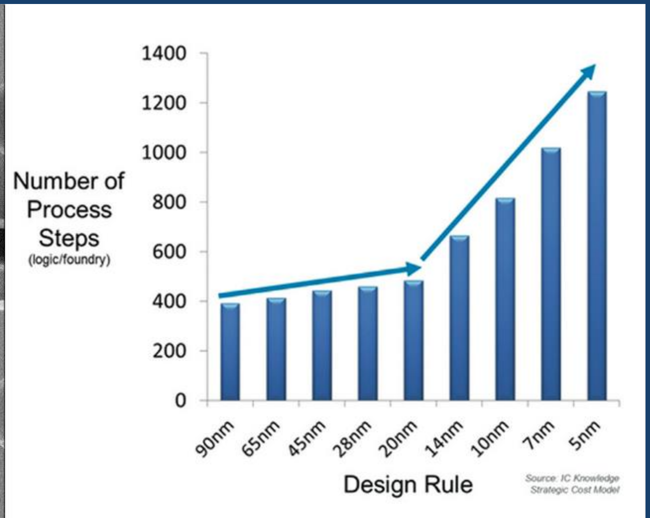


FinFet @ 14,10,7 nm



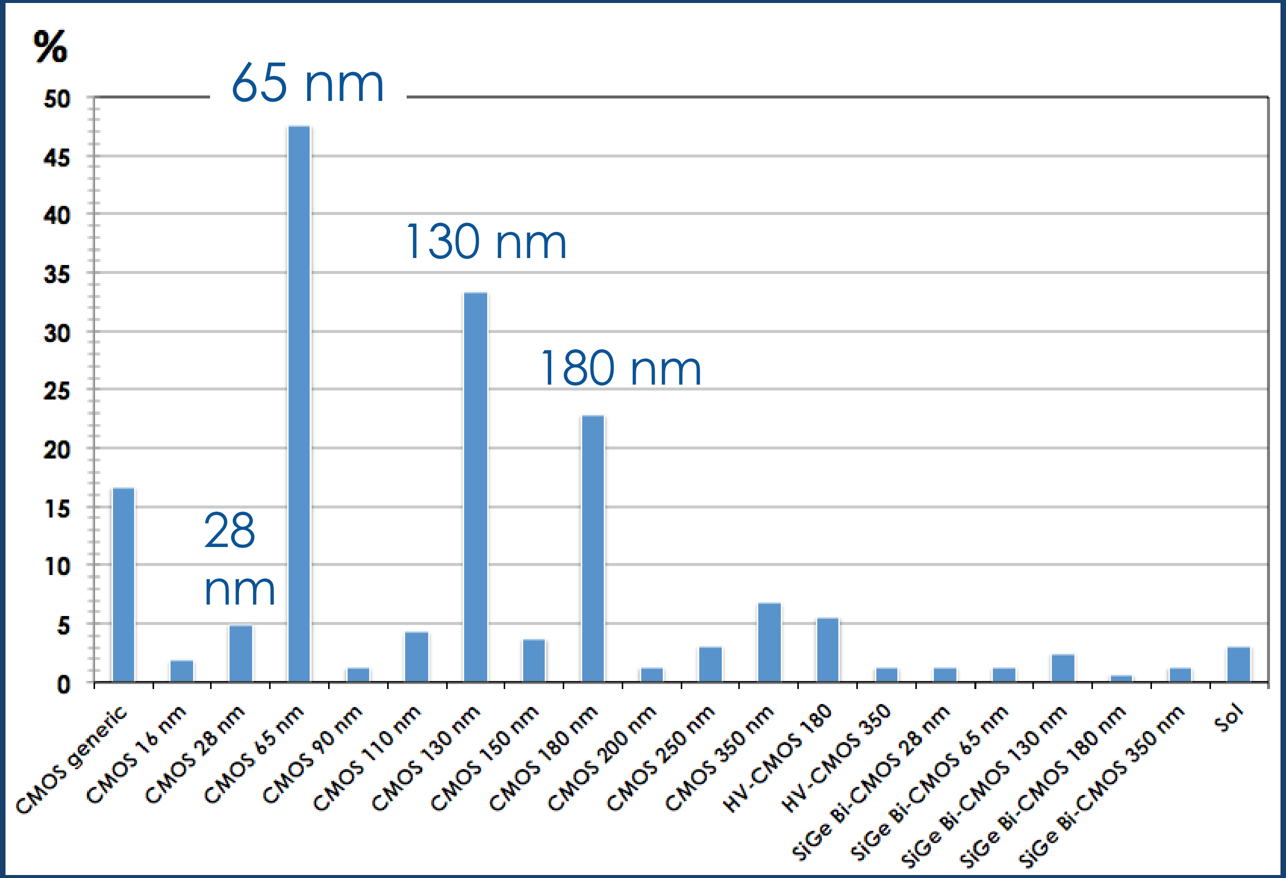




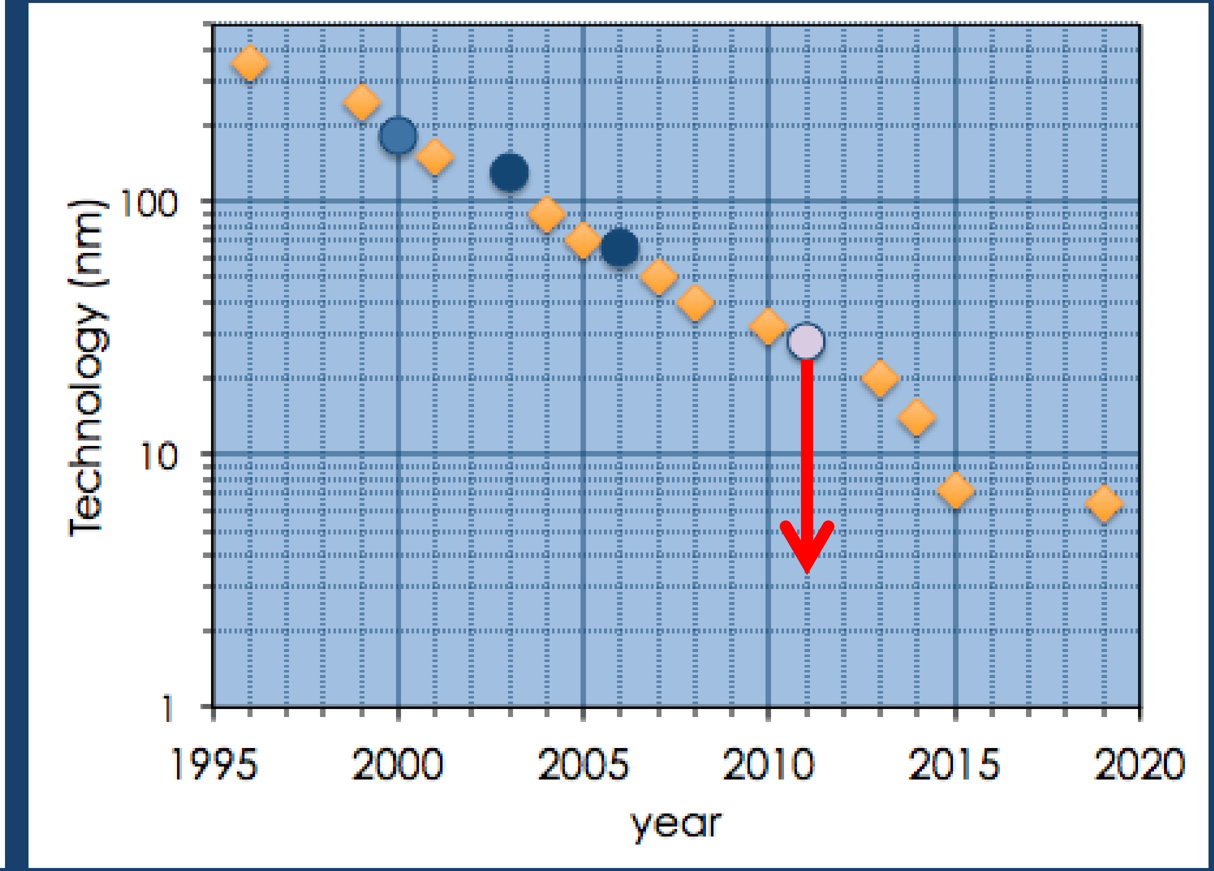


- Complexity of the design increases
- Industry-driven technology

Involvement of FTEs in μ-electronics



Technologies exploited by industry



The μ–electronic real challenges

- Many years behind industry
  → we risk to become obsolete
- The cost of the engineering runs are outrageous !!!!!
  → We can afford to invest only on a limited amount of technologies
  → which one ???? strategic choice !
- We are small clients *(see D. Contardo talk @Granada)*

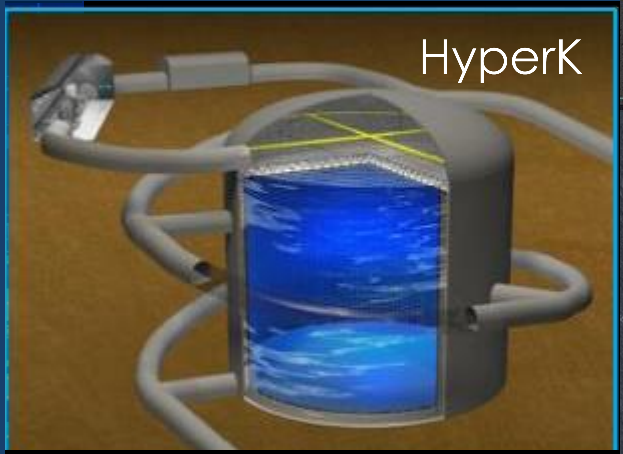
→ Cross-experiments collaboration mandatory
→ Expensive tools and corresponding user support must be set up in a central way for the entire community
→ Common submissions to foundries need to be organised through central frame contracts
→ Urgency of international coordination & adequate resources for shared programs

ν, Dark Matter and known unknowns

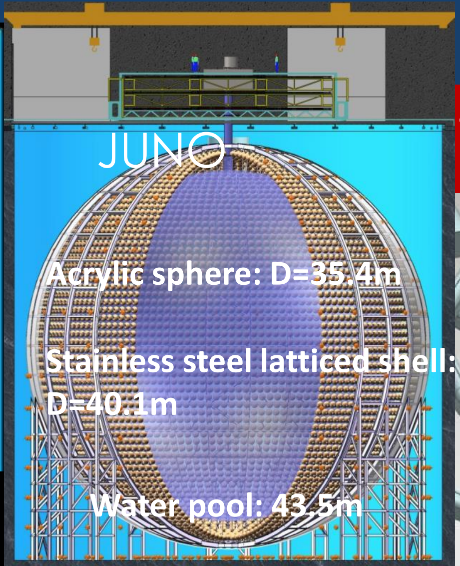
Demand for stronger CERN engagement in astroparticle Physics

Challenges & *synergy with accelerator Physics*

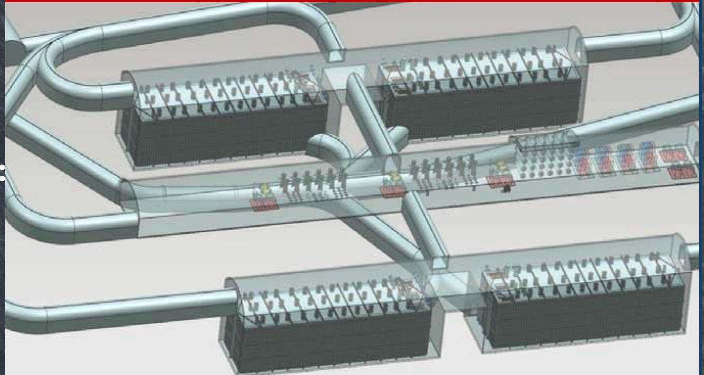
- *"Radio purity"* , huge mass, active shielding, large cryogenic infrastructure
- Dual phase operation
- Huge number photo detectors → many progresses SiPM & LAPPD



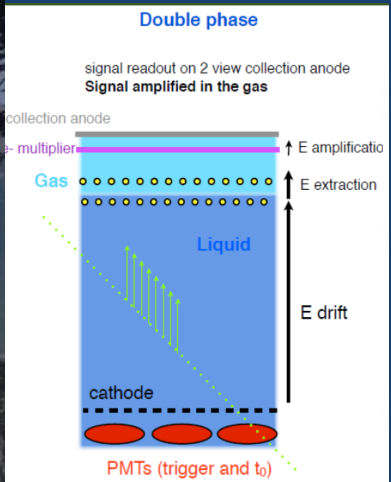
- 260 kton ultrapure water
- 190 kton fiducial mass: 10×SK



40 kton Liquid Argon Time Projection Chamber (LArTPC)



DUNE



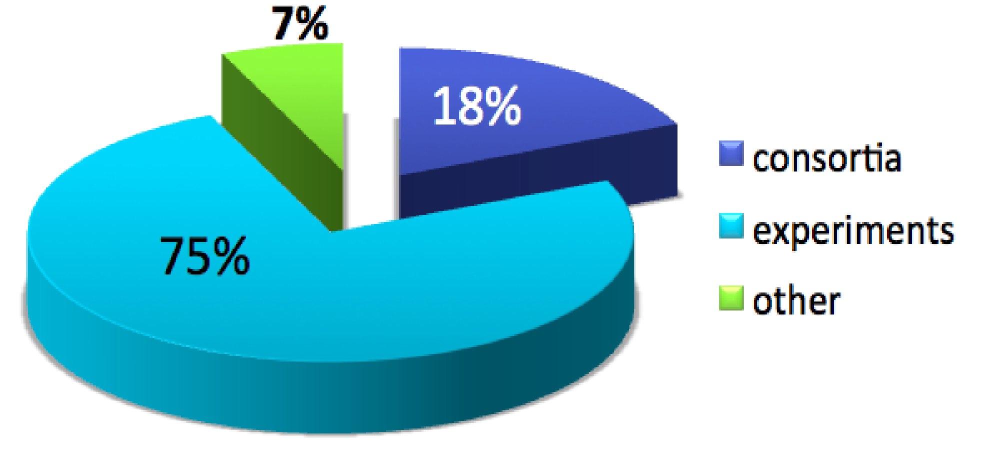
- Complex technologies have long *(and costly)* R&Ds

- Experiments that last a lifetime with thousands of people
  → Carry along a palette of ineluctable challenges

Discussions in Granada were organized around 3 major R&D themes

- **Coordination of R&D** Distributed everywhere in independent way ?
  Centralized in laboratories and consortia ??
- **Human factor** How to give recognition to young people? Foster recruitment ?
  How to be effective with long term training ?
- **Technical^{++}** R&D guided by existing experiment ?? Blue sky R&D ??

Blue sky R&D?



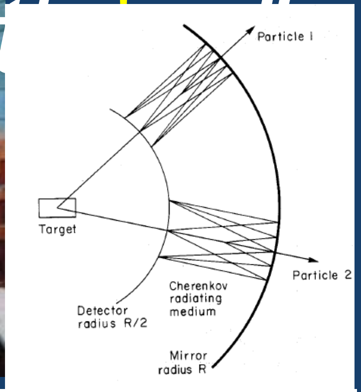
- large majority → R&D driven by well defined requirements of experiments
- minority → consortia (AIDA…..)
- very small minority → driven by what today is impossible but ……… tomorrow will be the new ?????

Maybe linked to the funding scheme ?

Funding agencies	% of respondents
International funding program	13
EU funding program	32
National funding agency	**71**
Home Institute	**52**
Other *(Mainly private or industry)*	1

a touch of history..........

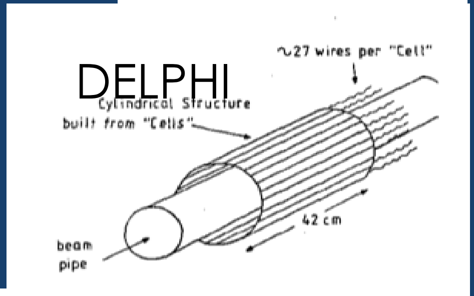
TPC Nygren 1974 *"….. it was a question of aesthet*



RICH Seguinot, Ypsilantis, *Ekelof* 1977

Si strip many….1970-80

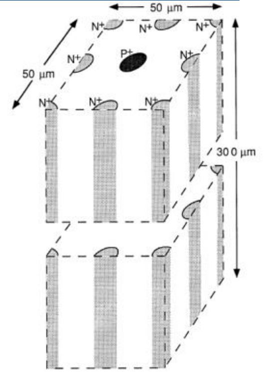
Blue sky R&D pays



RPC Santonico, Cardarelli 1981

MPGD Charpak, Giomataris, Sauli ~1995

3D Si pillars Parker, *Da Via'* 1997



*private communication

Coordination of R&D activities

Obvious evidence → Expertise is distributed in many institutions

General opinion → R&D should not be centralized exclusively in large-scale facilities and/or in major labs

that remain key places for exchanges of ideas and their unique technical support

	YES (%)	NO(%)
Need to be coordinated among Physics communities	**77**	**23**
Need to be better and/or more centrally organized	**50**	**50**

Coordination of R&D activities

- Extend working relationships

  → Organize "exchange of idea" platforms with a multidisciplinary approach, sources of new technologies, industry

- Current R&Ds collaborations (eg. RD#, AIDA2020, CALICE, etc.) are effective models of collaboration *(Develop, provide access & distribute common tools → Most effective framework to share resources with small institutes/users)*

  → Strength and establish new ones

  → Need to optimise the reviewing process and implement regular reassessments in addition to the collaboration internal procedures

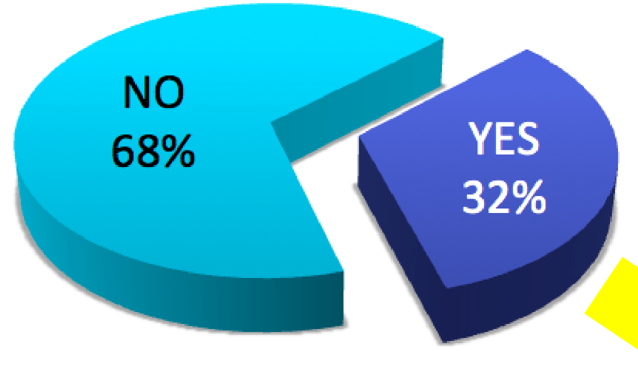
- Reflect on how to support and strength the community doing R&D suited for application outside HEP

~80% of respondents perceive that their R&Ds are suited for applications outside fundamental physics

	% of respondents
Dosimetry	26
Civil security	18
Cultural heritage	10
Medical	65 %
Nuclear control	25
Other **	18 %
	>> 100 %

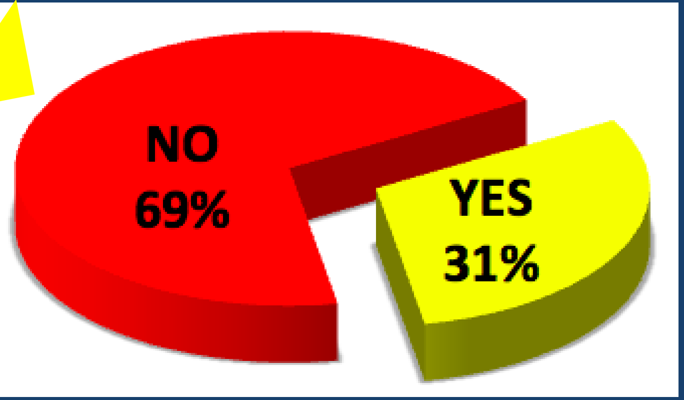
*** Photon science, geophysics, volcanology, industry, magnets related, muon & large tomography, data handling, space, agriculture, optics, precision metrology, marine biology, environmental, high-tech engineering, telecommunications,….*

Only ~30% of the projects engage in technology transfer programmes



The majority of them have not enough support to solve:

- financial problems
- manpower
- technical
- legal problems



→ Reflect on how to obtain adequate effectiveness in the process of technology transfer from detector R&D to society applications

Human factor

Perceived perspective for job/career opportunities for detector experts

	YES (%)	NO (%)
In research field	39	**61**
In industry	**66**	34
In tertiary sector, requiring advanced software development skills	**80**	20

Expertise acquired by young researchers @ labs/institutes is *GREAT !!!!!*

BUT our current career model, to keep the researchers in house, doesn't work very well !!!

R&D activities are not considered as rewarding as physics analysis and they do not grant equal career opportunities

The success and future of our field depend on our ability and strength:

- to attract the most talented researchers
- to recognize individual achievements especially within large collaborations
- to provide adequate career opportunities

→ Instrumentation activities must be recognized as a fundamental research

→ Career opportunities for detector experts must be greatly strengthened

F. FORTI → at recruiting time need to change the attitude: "this person only knows about detectors, should we really hire him/her ? "

Education & training

- PhD/postdocs often lack basic knowledge because University courses are often insufficiently oriented towards technical aspects

@ University

→ Need to enhance basic knowledge required for applied physics activities

→Need to recognized instrumentation activities as granting valuable PhD thesis

after University

→Strength the specialized training platforms in large lab/institutes

(EDIT school on Detectors: https://indico.desy.de/indico/event/22513/)

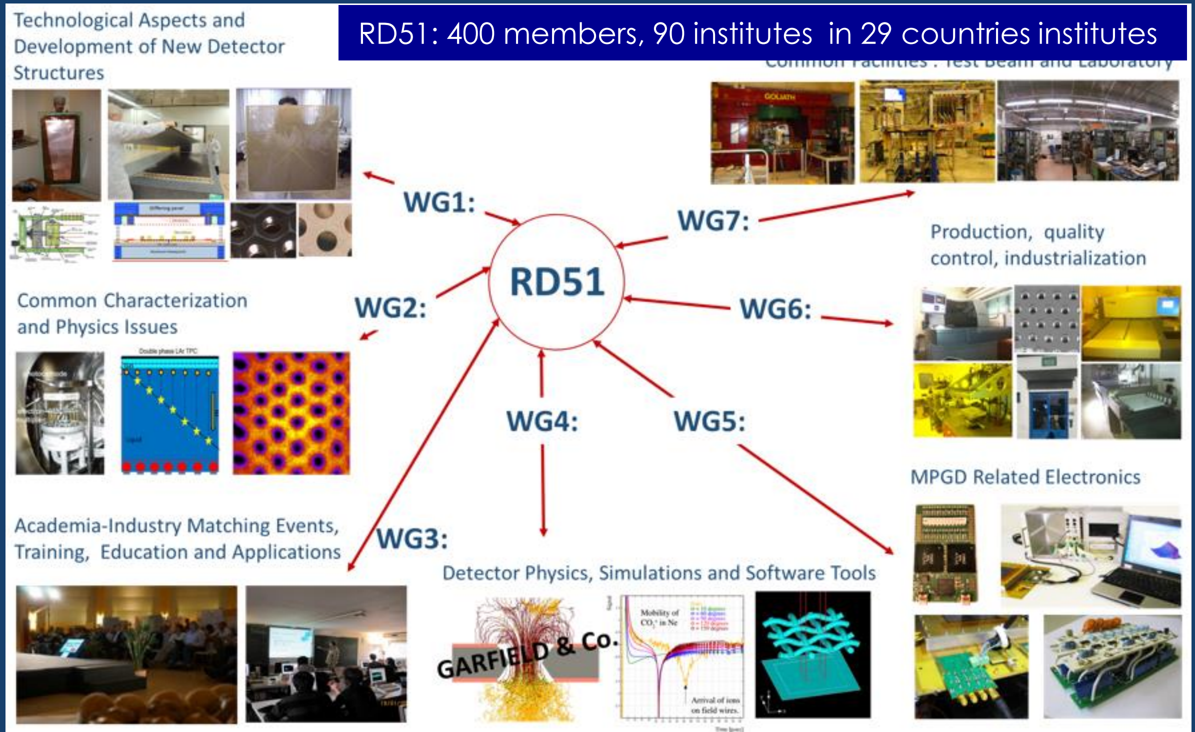
Granada take away messages

- There are many promising developments → Fast detectors, precise in time and space, ideally linked with energy determination, exploiting in-situ artificial intelligence → *The future is going towards multi-functional detectors !!!*
- Blue sky R&D can provide breakthrough technologies but it's a long process → *Need strong support*
- We can & it is necessary to bring fundamental research closer to the needs of the whole of society → *Review and strength our tech transfer model*
- In the μ-electronics realm → *Urgency for an international coordination & adequate resources for shared programs*
- R&D coordination → *Need to enhance collaboration and exchange of information between physics fields and technology specialisations*
- Instrumentation activities need to be recognized as a fundamental research
- Career opportunities for detector physicists must be greatly strengthened

BACKUP

example RD51 : μpattern gaseous detectors

- Gather worldwide expertise in all aspects and provide visible framework for institutions
- Inherent large network for exchange of information
- Limit duplication and share work per areas
- Can include non HEP developments
- Develop, provide access & distribute common tools → Most effective framework to share resources with small institutes/users
- Gives the possibility of common orders
- Define and adopt common test protocols, documentation, data bases ….
- Active environment for training and creating new expertise
- Provide door to industry relations



FTEs doing R&Ds in the major detectors categories

Detectors categories	% of FTEs
Vertex detectors	15
Trackers	23
Detectors for Particle Identification	14
Calorimetry	15
Timing detectors	12
Highly specialized instrumentation for Neutrino searches	7
Highly specialized instrumentation for Astroparticle	7
Other**	5

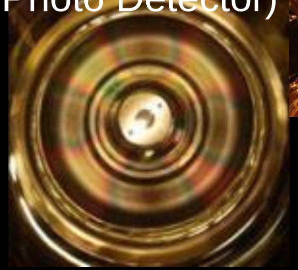
~40%

*** gamma spectrometry, neutron detection, dosimeters, beam monitors, luminometers, gravitational waves……..*

Photon detectors

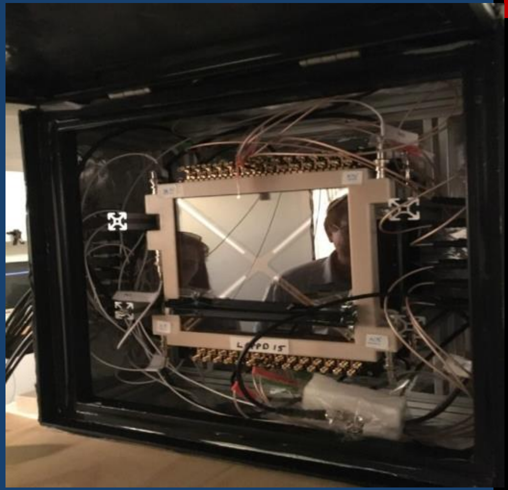
- Photon detection is key to many detection systems in HEP and in “invisible”
- **SiPM**, PMT, APD, **LAPPD**, Vacuum SiPM Tube
- Challenges:
  - Quantum efficiency > 35%
  - Spectral response
  - Radiopurity
  - Speed
  - Noise

Hamamatsu R12860 Box and line PMT



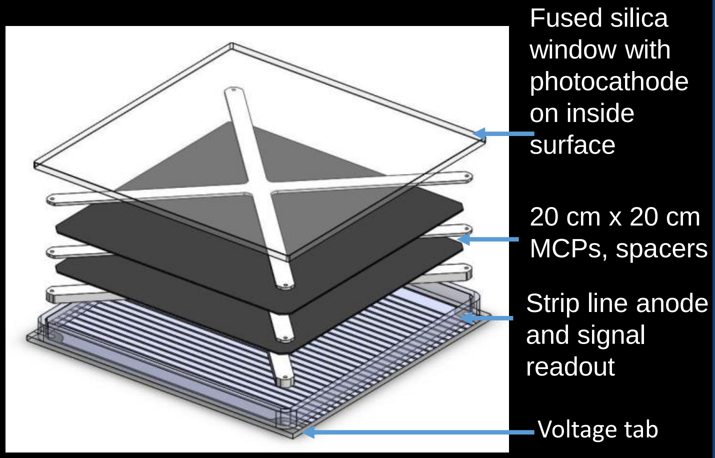
Hamamatsu R12850 HPD (Hybrid Photo Detector)

LAPPD



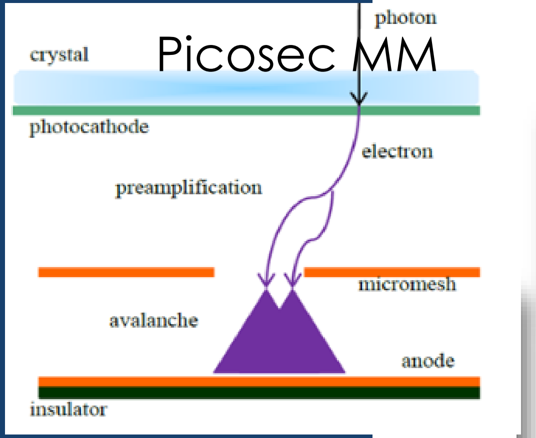
Large Area Picosec Photo Detectors

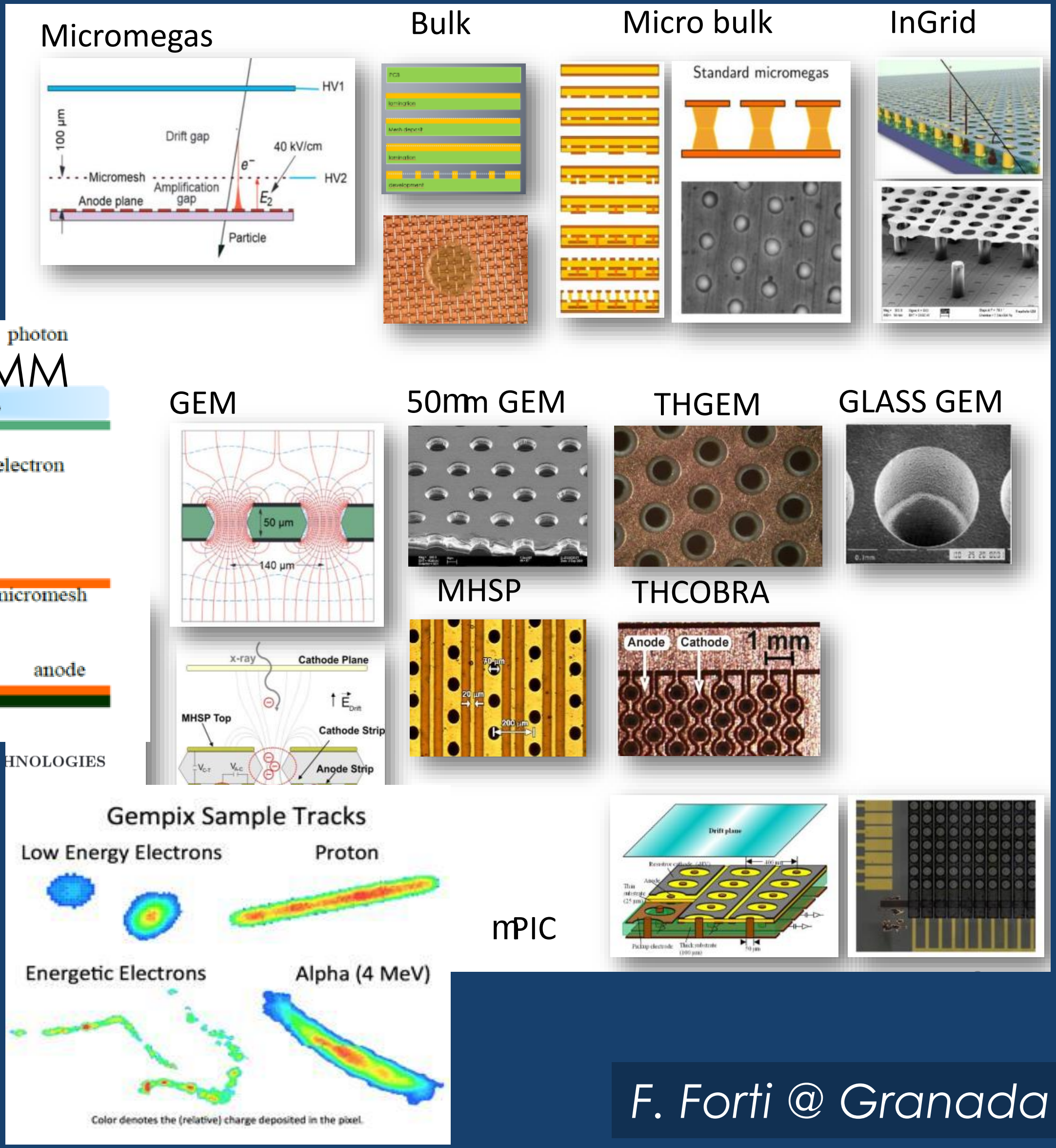
- Use Atomic Layer Deposition (ALD) Coating to Convert Glass Capillary Arrays into MCPs



Micro Pattern Gas Detectors

- Very active field. Good coordination through RD51
- Future directions:
  - Resistive materials and architectures
  - Fast and precise timing
  - New materials and technologies
  - Hybrid detectors
- Challenges
  - Granularity
  - Time resolution
  - Large area, Large volume
- Reliability of industrial production still to be optimized for large surfaces
- Many applications, for instance treatment plans

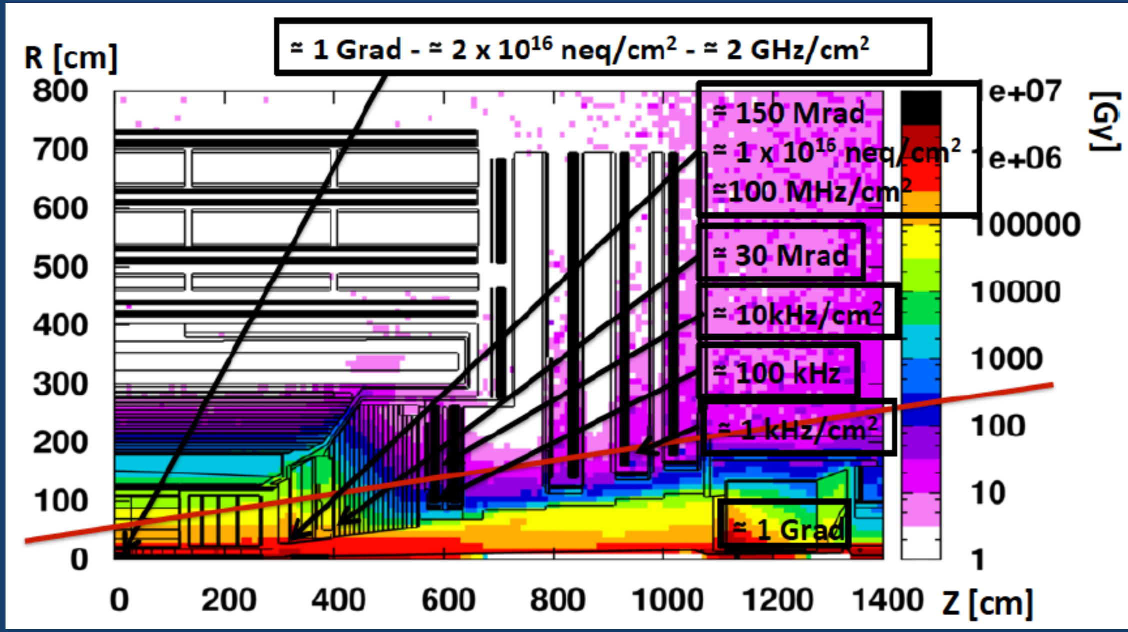




F. Forti @ Granada

Radiation

- Radiation resistance considerations are omni-present in detectors
- Huge progress in identifying materials and design techniques
- Next accelerators might increase the radiation level by more than a factor 10-100
  - FCC
  - Muon collider
- Solutions are not in hand today



1. Increasing radiation levels

- **Semiconductor detectors will be exposed to hadron fluences equivalent to more than 10^{16} n_{eq}/cm^2 (HL-LHC) and more than $7x10^{17}$ n_{eq}/cm^2 (FCC)**
  ➔ detectors used now at LHC cannot operate after such irradiation

2. New requirement and new detector technologies

- New requirements or opportunities lead to new technologies (e.g. HV-CMOS, LGAD,…) which need to be evaluated and optimized in terms of radiation hardness

G.Casse and M.Moll, RD50 Status Report,