Instrumentations & Computing

CERN Council Open Symposium

Update on the European Strategy for Particle Physics

May 12-17, 2019, Granada, Spain

https://cafpe.ugr.es/eppsu2019/

XinChou Lou

Institute of High Energy Physics, Beijing

Outline

Introduction

- ESPPU
- Open Symposium
- Briefing Book, ESG, CERN Council Decision

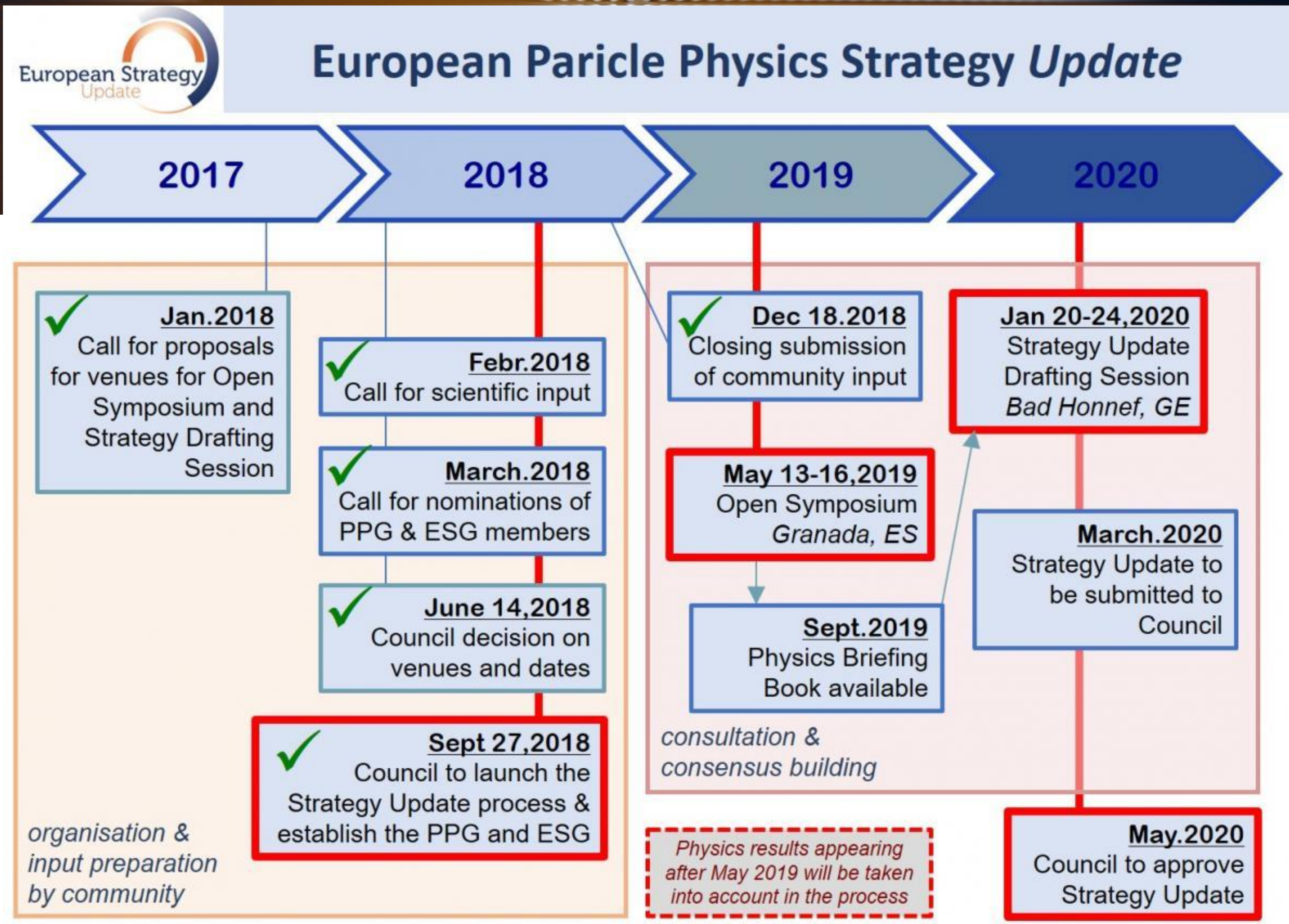
OS: Instrumentation-Computing

- Presentations, Panel Discussion and Debate
- Instrumentation: Highlights and Essence
- Computing： Evolution, Model, Challenges & Possible Solutions

European Strategy for Particle Physics 2018-2020

- The European Strategy for Particle Physics is the cornerstone of Europe's decision-making process for the long-term future of the field.
- Mandated by the CERN Council, it is formed through a broad consultation of the grass-roots particle physics community, it actively solicits the opinions of physicists from around the world, and it is developed in close coordination with similar processes in the US and Japan in order to ensure coordination between regions and optimal use of resources globally.
- Input from global HEP community
- Open Symposium results in a Briefing book to be presented to the ESG for further deliberations

European Strategy for Particle Physics 2018-2020



The composition of the ESG and the PPG is established by the CERN Council

European Strategy for Particle Physics 2018-2020

Main document: Please prepare a pdf file containing a cover page (title, abstract, name of the contact person and his/her e-mail address) and a comprehensive and self-contained description of the proposed input (maximum 10 pages). This document should address (when applicable) the scientific context, objectives, methodology, readiness and expected challenges.

Addendum: Please also prepare a pdf file containing information on the following topics (where relevant): interested community, timeline, construction and operating costs, computing requirements. The name of this pdf file should be as follows: "Addendum-NN.pdf", where NN is the file-name of your main document.

submission themes (tracks) to which your input relates:

- Large experiments and projects
- National road maps
- Accelerator Science and Technology
- Beyond the Standard Model at colliders (present and future)
- Dark matter and dark sector (accelerator and non-accelerator dark matter, dark photons, hidden sector, axions)
- **Instrumentation and computing**
- Electroweak physics (physics of the W, Z, H bosons, of the top quark, and QED)
- Flavour Physics and CP violation (quarks, charged leptons and rare processes)
- Neutrino physics (accelerator and non-accelerator)
- Strong interactions (perturbative and non-perturbative QCD, DIS, heavy ions)

160+ inputs

For confidential addenda: If you wish the addendum to be treated as confidential (i.e. limited to the PPG and ESG), you should send it to the following email address eppsu.addenda@espace.cern.ch by 18 December 2018

Organization of the Symposium

https://indico.cern.ch/event/808335/sessions/306790/#20190514

- Granada Symposium: Plenary sessions, eight discussion sessions.

- The parallel sessions be convened by two members of the Physics Preparatory Group. The sessions are organized around topics covered by the submission tracks.

Accelerator Science and Technology
Caterina Biscari
Lenny Rivkin

Instrumentation and Computing
Xinchou Lou
Brigitte Vachon

Electroweak Physics
Keith Ellis
Beate Heinemann

Strong interactions
Jorgen D'Hondt
Krzysztof Redlich

Neutrino Physics
Stan Bentvelsen
Marco Zito

BSM at colliders
Gian Giudice
Paris Sphicas

Dark Matter and Dark Sector
Shoji Asai
Marcela Carena

Flavour Physics and CP violation
Belen Gavela
Antonio Zoccoli

more than 600 attendants

Instrumentation

340 minutes of presentations, discussions and debates

similar for computing

Plenary Session - García Lorca Room

12:20	[12] Technological challenges of particle physics experiments	FORTI, Francesco (INFN Sezione di Pisa, Universita' e Scuola Normale Superiore, P)

B8 - Instrumentation and Computing: Instrumentation - Picasso Room (09:00-13:30)

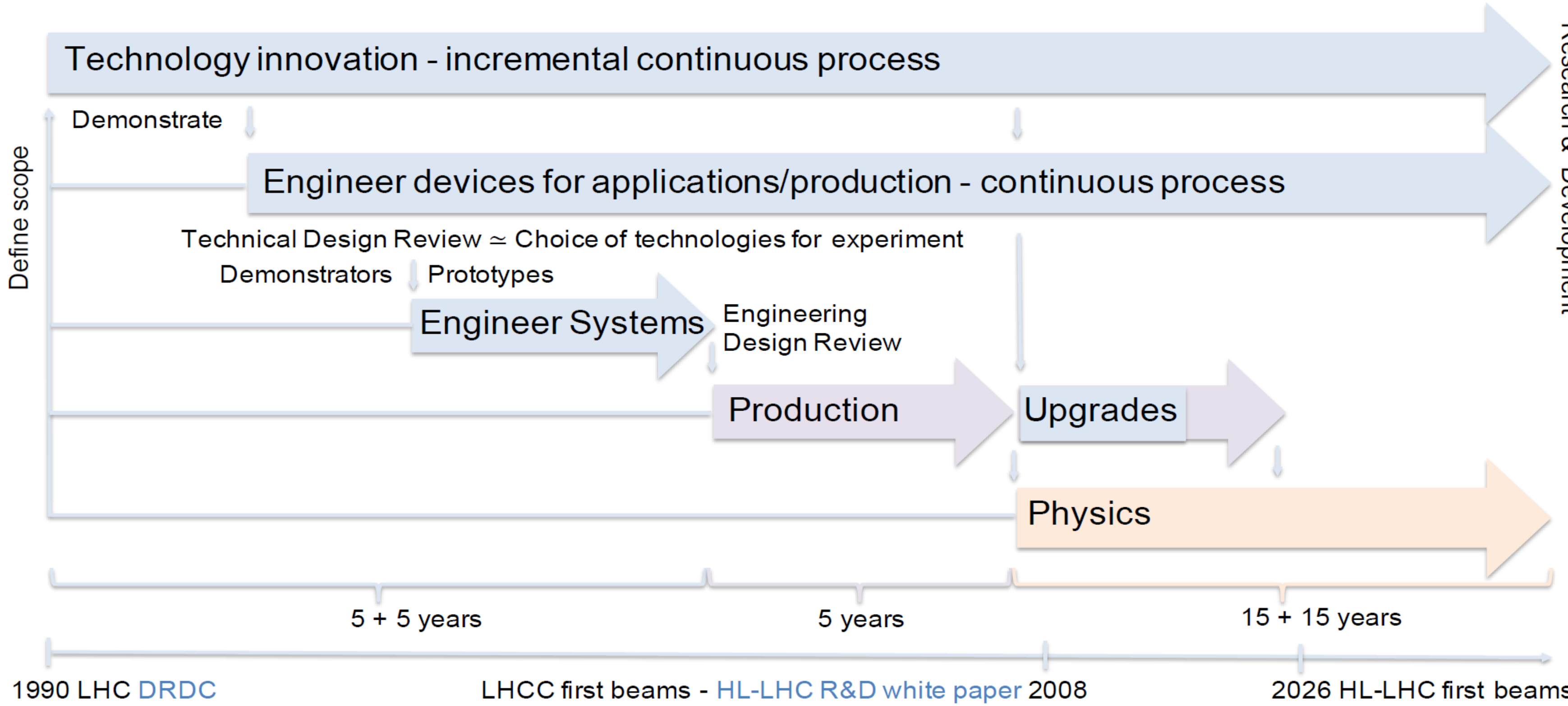
09:00	[127] Lessons learned from past instrumentation R&D (20+10 min)	CONTARDO, Didier Claude (Centre National de la Recherche Scientifique (FR))
09:30	[128] Detector challenges of future HEP experiments (30 + 10 min)	LINSSEN, Lucie (CERN)
10:10	[129] Detector R&D for future HEP experiments (30+10 min)	SEFKOW, Felix (Deutsches Elektronen-Synchrotron (DE)) SEFKOW, Felix (Deutsches Elektronen-Synchrotron (DE))
10:50	Coffee break	
11:20	[130] Technological synergies in instrumentation R&D with non-HEP experimental programs and industry (20+10 min)	DA VIA, Cinzia (University of Manchester (GB))

Plenary Session: Summaries, Discussion and Closeout - García Lorca Room (14:15-16:00)

time	[id] title	presenter
14:15	[141] Instrumentation and Computing	VACHON, Brigitte (McGill University, (CA)) LOU, Xinchou (Chinese Academy of Sciences (CN))

Instrumentation – lessons learned from past R&D

Typical HEP program timeline (R&D in blue)



R&D timescale is ≃ 10 years, approved experimental programs are natural drivers for techniques and resources, technology innovation can suffer cycle/migration effects

D. Contardo - IPN Lyon CNRS/IN2P3

Instrumentation – lessons learned from past R&D

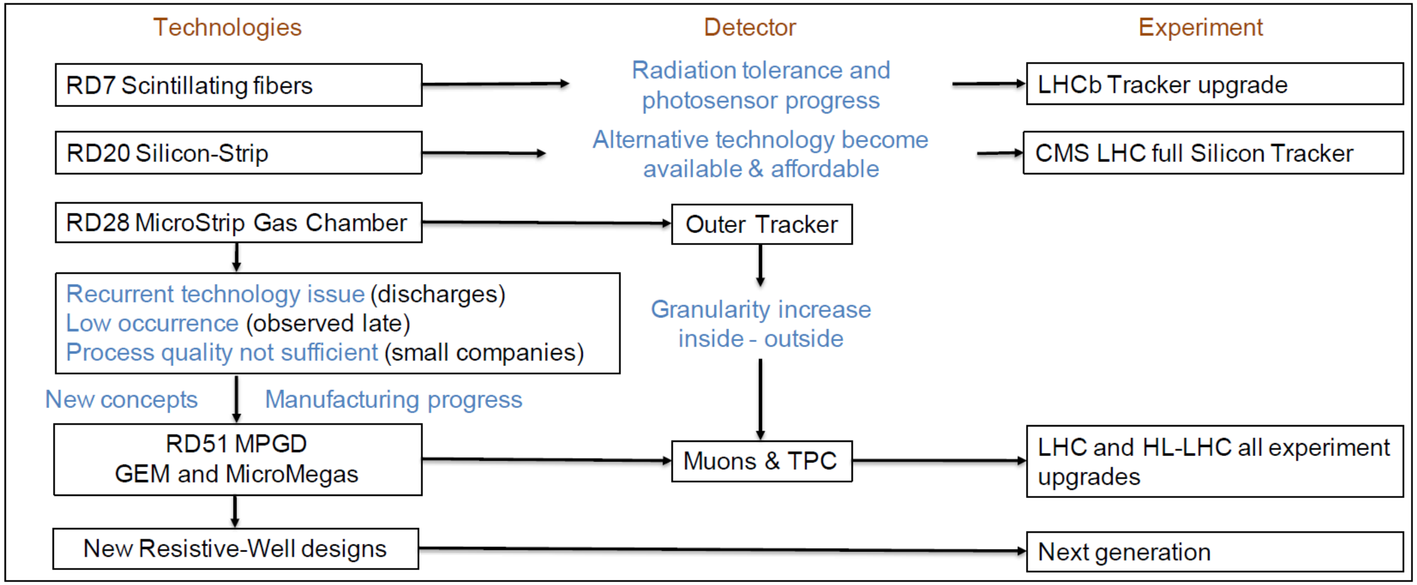
LHC preparation R&D programs

"Cell" approach, a technology a detector, oriented to select the different experiment technologies

- CERN DRDC program http://committees.web.cern.ch/Committees/obsolete/DRDC/Projects.html
  - 50 proposals approved, however with large focus on calorimetry and tracking

Successful approach to provide detectors operating efficiently since ≃ 10 yrs

- Efforts in techniques not retained was not necessarily fully wasted
  - ex below of some tracker R&D and evolution toward HL-LHC



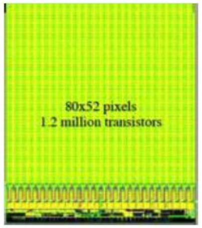
Instrumentation – lessons learned from past R&D

R&D example of evolution and diversity

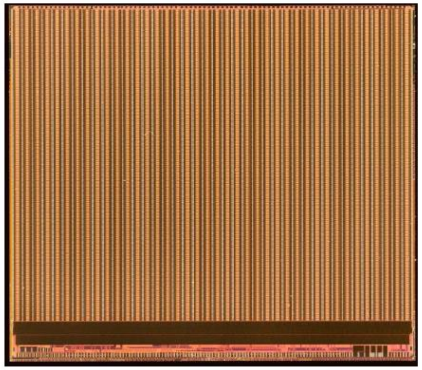
Ex. ASIC chips: 67 ASIC chips of various complexity identified for LHC upgrades

- RD53 for a common ATLAS and CMS Pixel chip:
  - Too complex chip design for a single team
  - 24 institutes - 5 years work
  - Investigated variants and anticipated specific ATLAS/CMS features implementation
  - Complex organization, but allowed to built expertise in 65 nm technology (used for other ASIC

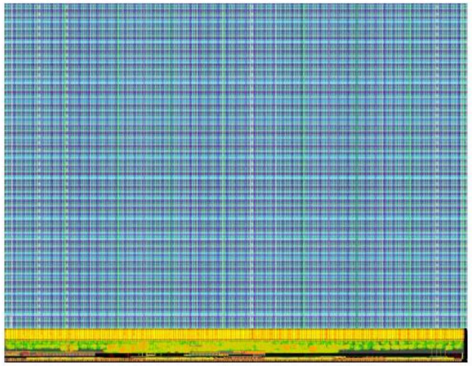
≃ x10 transistors at each step
Pixel size /6



CMS pixel chip
250nm CMOS
80 x 52 pixels
100 x 150 μm²
7.9 x 9.8 mm²
1.2 10^6 transistors
2005



FEI4 ATLAS IBL
130nm CMOS
80 x 336 pixels
50 x 250 μm²
20 x 19 mm²
80 10^6 transistors
2010



RD53 ATLAS/CMS
65nm CMOS
384 x 400 pixels
50 x 50 μm²
21.6 x 19 mm²
700 10^6 transistors
2019

Instrumentation – lessons learned from past R&D

Technology development process

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- We usually do not produce components, and rely on partners interested in other fields using similar devices (mostly imaging) or general public industry (electronics, mechanics…)*
  - Medical, space, nuclear, military, homeland security, automotive, computing, telecommunication…

- HEP devices have specific requirements and constraints
  - High precision performance
  - Complex and highly reliable systems with high channel density, compactness & ultra light (trackers)
  - Operation in high radiation environment and magnetic field (at low temperatures & high voltages…)

- HEP R&D is both a driver and beneficiary of progress in several external applications
  - It qualify technologies, develop/exploit new process/features - integrate systems readout & mechanics
    - Crystals were originally developed in HEP, we now benefit from developments for medical imaging (ex. LYSO)
    - ASIC developed for CMS crystal timing layer is based on ASIC developed for European project EndoTOFPET
    - APDs where developed for HEP, the new LGADs are based on a merge of APDs and SiPM processes

Technology transfer/tracking and privileged partnerships outside HEP are essential

Instrumentation – lessons learned from past R&D

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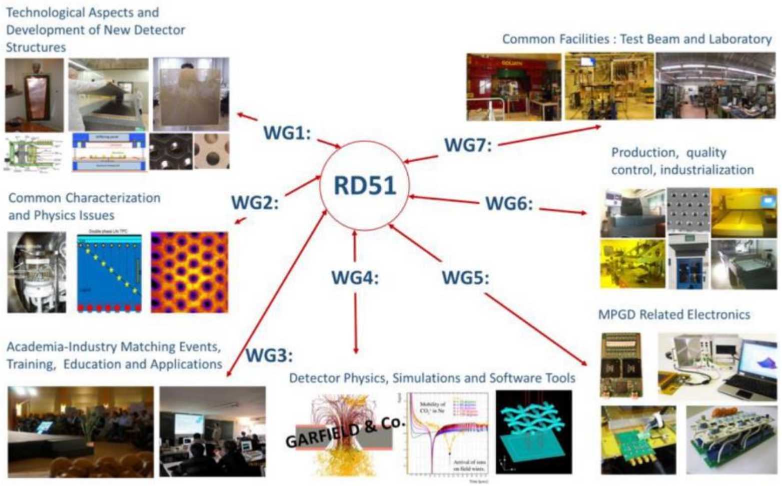
International R&D program offer

- Gather worldwide expertise in all aspects and provide visible framework for institutions
  - HEP involved in innovation and various experimental programs, but also material science and device producers
- Develop/provide access to common tools (sharing cost and work)
  - Modelling, ex. TCAD (RD50)
  - Characterization, ex. TCT technique (RD50), source (laser/particles), test benches, readout systems
- Possibility of common order of samples
- Common test protocols, documentation, data bases of results and beam test infrastructures
- Work structure and coordination
  - To limit duplication (dead-ends) and share work per areas
  - Can include non HEP developments
    - ex. medical imaging in RD18 (Crystal Clear)
  - Collaboration Boards can streamline activities and make recommendations while preserving diversity approach
- Wide dissemination of knowledge and approved results
  - Publications, conferences, dedicated workshops, schools
- Large network for exchange of information
- Active environment for training and to create new expertise



RD51: 400 members, 90 institutes in 29 countries institutes

Instrumentation – Detector challenges of future HEP

circular: FCC-ee /CEPC beam parameters

	FCC-ee			CEPC	
	Z	Higgs	ttbar	Z (2T)	Higgs
$\sqrt{s}$ [GeV]	**91.2**	**240**	**365**	**91.2**	**240**
Luminosity per IP ($10^{34}cm^{-2}sec^{-1}$)	**230**	**8.5**	**1.7**	**32**	**1.5**
no. of bunches / beam	16640	393	48	12000	242
Bunch crossing separation (ns)	**20**	994	3000	**25**	680
Beam size at IP σ_x/σ_y (μm)				6.0/0.04	20.9/0.06
Bunch length (SR / BS) (mm) Beam size at IP σ_z (mm)	3.5 / 12.1	3.3 / 5.3	2.0 / 2.5	8.5	4.4

Beam transverse polarisation => beam energy can be measured to very high accuracy (~50 keV)

CEPC CDR

FCC-ee slides, CDR

At Z-peak very high luminosities and **very high e^+e^- cross section (40 nb)**

- ⇒ **Statistical accuracies at 10^{-4}-10^{-5} level** ⇒ **drives detector performance requirements**
- ⇒ **Small systematic errors required** to match
- ⇒ This also drives requirement on **data rates** (physics rates 100 kHz)
- ⇒ Triggerless readout likely still possible

Beam-induced background, from beamstrahlung + synchrotron radiation

- Most significant at 365 GeV
- Mitigated through MDI design and detector design

Main e^+e^- collider detector challenges

Vertex detectors:

- Very **high spatial resolution**, **very low mass** + O(5 ns) hit timing (CLIC)
- Linear Colliders: Engineering challenge to combine low mass with air cooling
- Circular Colliders: Maintain low mass for position resolution without power pulsing

Combination makes it challenging

PFA calorimetry:

- Much experience gained through CALICE; CMS HGCal will be a benchmark
- **Very large area of silicon** for ECAL => cost driver
- Engineering challenge overall

Power pulsing:

- Much experience gained with laboratory set-ups, and with system tests of CALICE prototypes
- **Power pulsing not yet tested at system level for vertex/tracker**
- Power pulsing can become an obstacle for e.g. cosmic ray calibration

Systematics on energy scale, luminosity measurement, calibration:

- **Keep systematics below level of statistical errors**

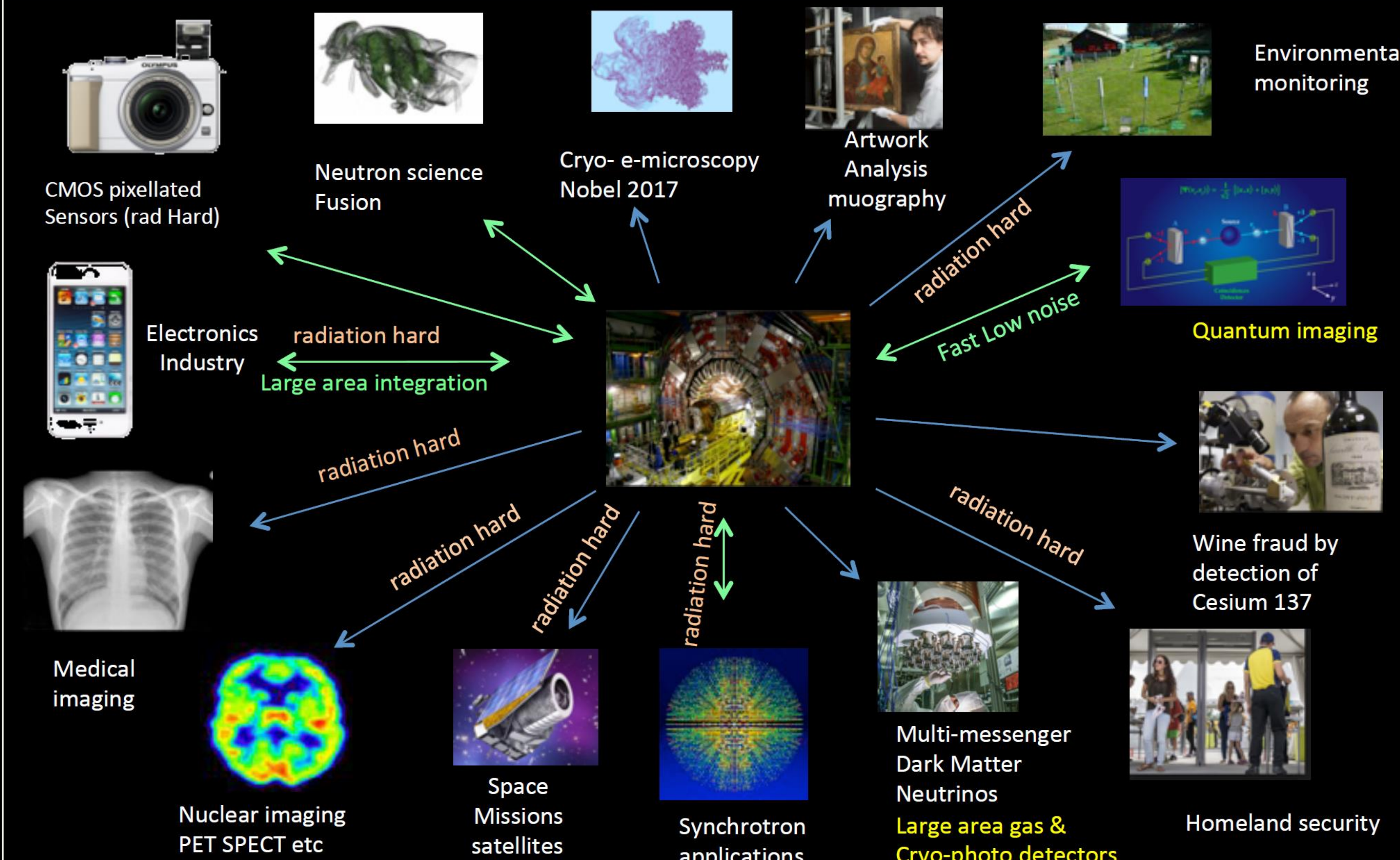
  => most challenging at Z-peak, but also for top quark mass and per-mille level Higgs couplings

Instrumentation – Technological synergies in R&D with non-HEP experimental programs and industry

Detector R&D for future HEP experiments

Non-HEP Synergy with Particle Detectors

High Precision Radiation Detection and Imaging – Test Facilities



Evidence of Converging Detector Requirements and R&D needs among disciplines →The ERDIT Platform

ERDIT
www.erdit.eu
European Radiation Detectors and Imaging Technology

	HEP	SYNC	Neutron ESS	Beam monitoring	Astronomy	Hadron Therapy	Medical Imaging Pre-clinical Imaging	Electron Microscopy	Environmental radiation monitoring IAEA
Radiation type	p, n, γ	X-rays	n	p, n, γ, e^-	λ=300nm to 28μm	N, p, γ, light ions (protons to oxygen)	X-rays	e	γ
Max Intensity	12×10^{15} ncm^{-2}	2700 pulses	10^{8} ncm^{-2}	10^{17} ncm^{-2} (p, n) 10MGy (e^-)	from 1 photon/ hour/pixel to 1E9 photons/s/ pixel	conventional accelerator up to 10^10 ions /s Laser > 10^7/cm2 (ps pulses, low repetition rate ~ 1/s)	CT: 10^9 g/mm²/s, General X-ray: 10^8 g/mm²/s Angiography: 10^8 g/mm²/s Mammography: 10^7 g/ mm²/s	20 Mrads	100 μSv/h (~100,000 cts/s)
timing	25ns 10ps	4.5 MHz 10ps	1us	Sub ns	from 2000 frames/s to 1 frame/ hour	Up to MHz (singles rate) 10ps	CT: 5000 frames/s General X-ray: - Angiography: 1-60 frames/s Mammography: - 10ps	1000 frames/s	
Pixel size (Min)	50x50 um²	10x10 um²	50x50 um²	50x50 um²	10x10 um²	50x50 um²	CT: 1000 mm General X-ray: 150-200 mm Angiography: 150-200 mm Mammography: 85 mm	10x10 um²	
Spectral resolution	yes	yes	no	yes	no , moderate possible with APD	yes	Today: not used, Future: yes	yes	< 1.5% @ 662 keV
Detector size (max)	2500m² (ILC cal)		80m²	100 cm²	Optical 9Kx9K NIR 4Kx4K	40x40 cm2	CT: 10 x 100 cm² (segmented), General X-ray : 43x43 cm² Angiography: 30x40 cm² Mammography: 24x30 cm²	8k x 8k pixels	6 cm³

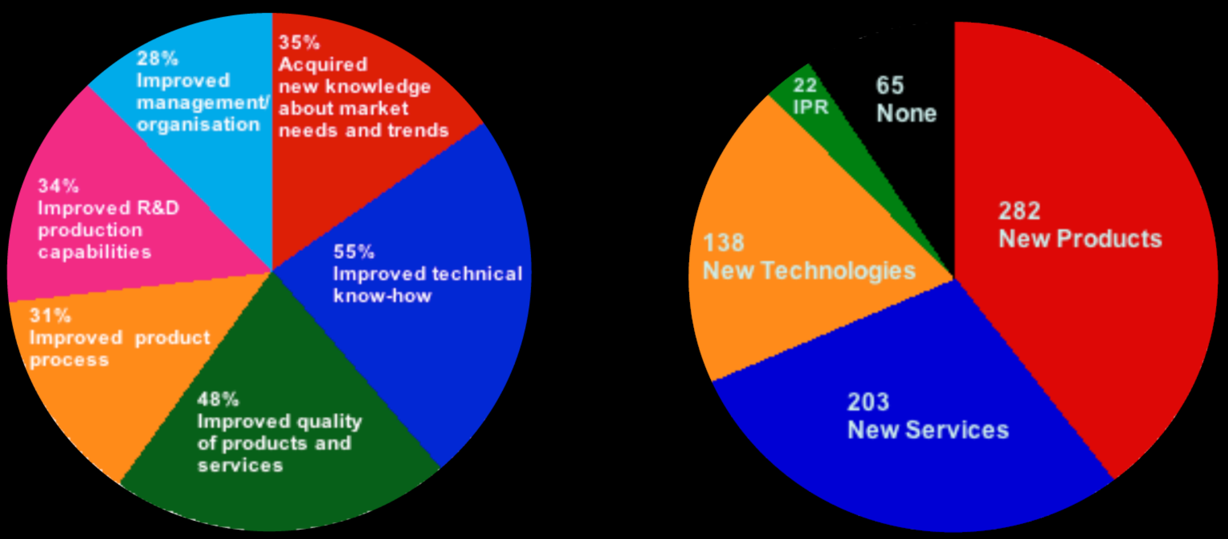
Cinzia Da Via, The University of Manchester, UK & SUNY USA– 2019

HEP & Industry

Data from Florio, Giffoni, Giunta, Sirtori
ISSN 2279-6916 Dpt Economia, Roma Tre

2017 Survey on 668 SME suppliers from 33 EU Countries working with CERN from 1995-2008

Thanks to CERN: | Because of the work with CERN:



"The estimated coefficients of this "CERN effect" are statistically significant for the whole sample but higher for high-tech firms. As expected,… in most cases the coefficients are not significant for firms receiving orders for "off-the-shelf" products".

R&D Coordination involving Industry from the start is more efficient

→ FUNDS ←

Instrumentation – Panel Discussion

Scope of panel discussion

European Strategy Update

- As part of the preparation work leading up to the Open Symposium:
  - All inputs submitted to the EPPSU were reviewed.
  - EPPSU-PPG, EPPSU-ESG and ECFA initiated discussions with colleagues, communities and heads of collaborations.
  - ECFA initiated several European community surveys.
- Three topics were identified as important to further discuss:
  1. **Generic —> Guided detector R&D activities**
  2. **Coordination of detector R&D activities**
  3. **Knowledge preservation, training and career perspectives**
- Organization of today's discussion:
  - Recurring questions associated to each of the three topics will be presented.
  - Brief summary of data collected as part of the preparation work will be presented (A. Cattai)
- Goal:
  - **Make progress towards formulating constructive answers/suggestions to these questions, to bring forward to the European Strategy.**
    - Today's discussion will provide input to the writing of the "Briefing Book"

Instrumentation – Panel Discussion

1. Generic —> Guided R&D

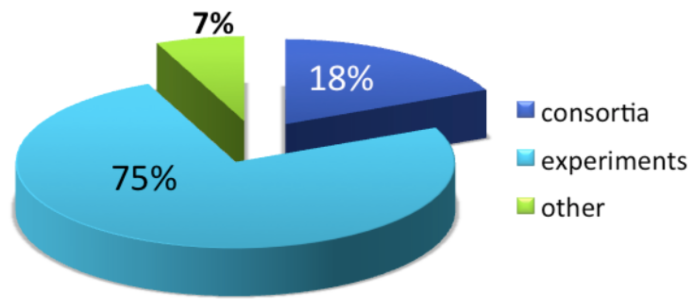
European Strategy Update

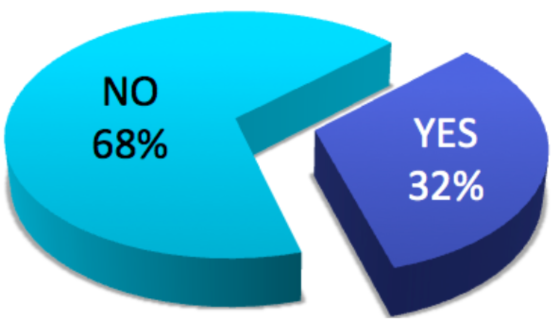
Data collected from ECFA survey, 700 respondents representing 2900 FTE

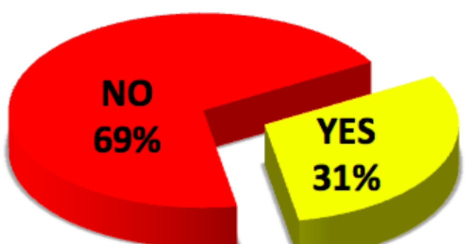
75% R&D performed in present/future experiments (CMS, ATLAS, FAIR….)

18% R&D performed within a consortium (AIDA, RDx,…)

7% Generic R&D







32% of R&D activities are linked to Tech. Transfer but the large majority (70%) do not get enough support to solve: financial, manpower, technical and legal challenges.

Instrumentation – Panel Discussion

According to the ECFA survey:

- At present there is a strong indication of major interest for R&D around semi-conductors technologies and related electronics & mechanics

Detectors technologies	% of FTE
Gaseous detectors	13
Semi-conductors	**30**
Scintillators and crystals	11
Photo-detectors	10
Cryogenic (liquid) detectors	2
Cerenkov detectors	2
Highly specialized mechanics	**7**
Detector specific electronics	**14**
Detector specific software	9
Other	2

Other (TES – RF related - bolometers, opto-mechanical sensors – MEMS, laser, photonics, magnets, quantum sensors ……..)

Instrumentation – Panel Discussion

According to the ECFA survey:

Most promising areas of R&D

Most promissing future R&Ds	% respondents to ECFA survey
Precision timing	56
Precise position resolution	17
Rad Hard	8
Precise energy measurements	7
CMOS HV-MAPS monolithic	6
High granularity imaging calorimetry	6
Artificial intelligence / Machine Learning	4
Fast (tracker) triggers (online)	4
4D tracking	4
High rate capability	4
Low power consumption systems/electronics	4
Fast detectors/electronics	3
High energy resolution	3
PID TOF	3
Low mass detectors & services	3
Silicon photomultipliers	3

Instrumentation – Big Questions

"Big questions"

European Strategy Update

Instrumentation:

(a) What **areas of instrumentation R&D** should be supported, and how, in order to meet the needs of future experimental programs?

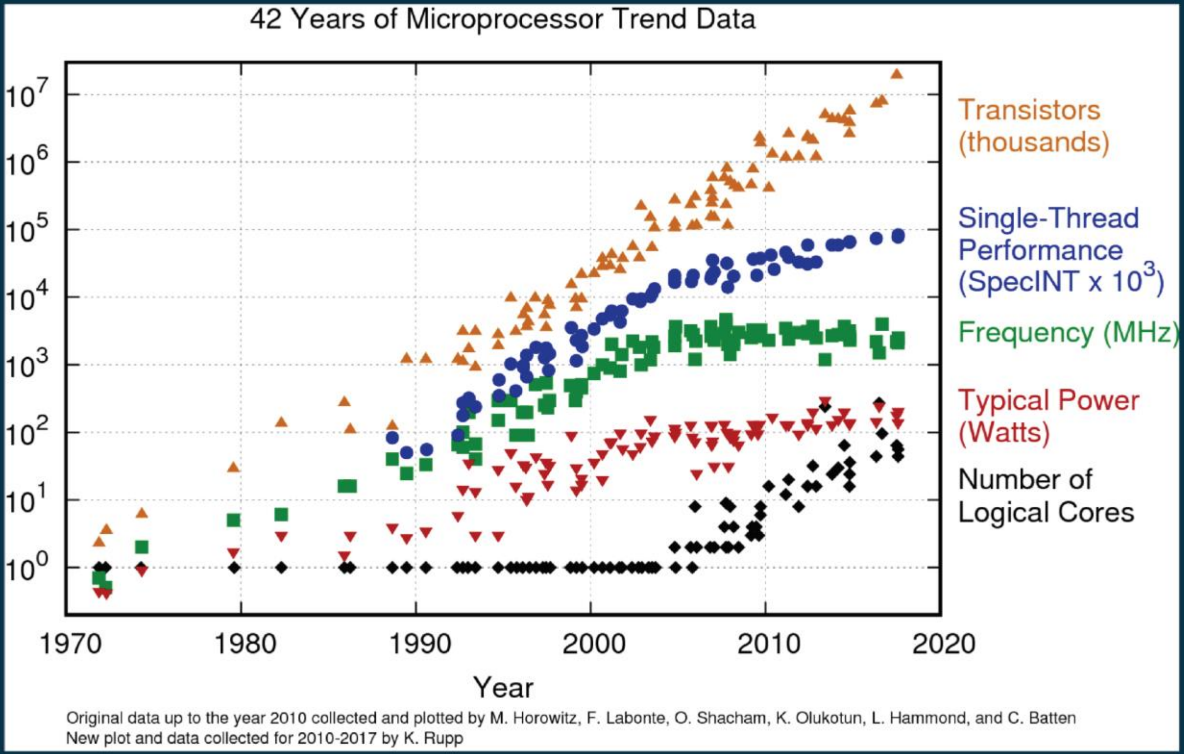
(b) How to preserve knowledge, technical expertise and train the future generation of experts in detector R&D?

Instrumentation – Big Questions

Human factor

- **Career recognition/opportunities**: Instrumentation and C&S activities need to be recognized as fundamental to research activities and bearing a large impact on the final physics results.
- Detector/computing R&D needs strong support.
- Maintain/develop proper mixture of activities related to "**now, next, horizon**" (yes, even for computing)

Computing – evolution and current model



- Moore's law is barely holding on
  - CMOS technology approaches fundamental limits
- Clock speed has been largely flat since 2007
- Number of cores continues to increase

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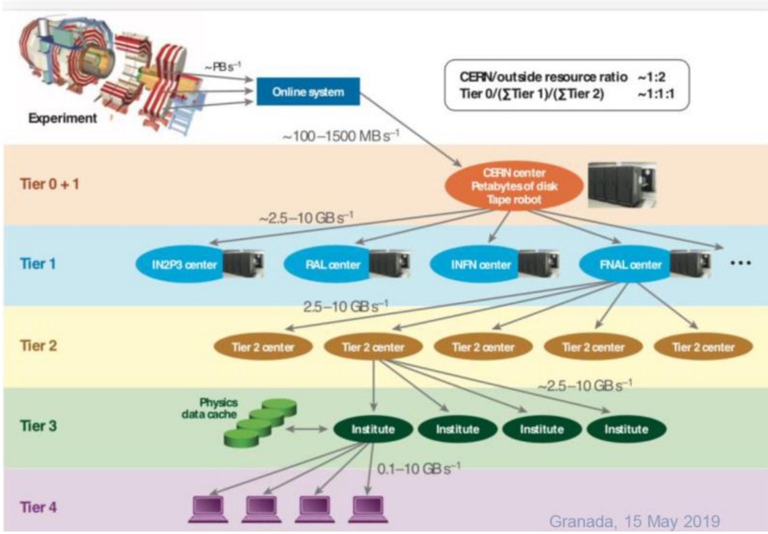
CERN openlab

Computing – evolution and current model

Today's computing models

- HEP has always done distributed computing
- Scale of the challenge for LHC forced a more organized and formal structure
- Built a federated system – grid – to integrate and make easily usable pledged resources



WORLDWIDE LHC COMPUTING GRID COLLABORATION

CERN-C-RRB-2005-01/Rev. 1
28 April 2015

WLCG Collaboration

Memorandum of Understanding

for Collaboration in the Deployment and Exploitation of the Worldwide LHC Computing Grid

between

The EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH ("CERN"), an intergovernmental Organization having its seat at Geneva, Switzerland, as the Host Laboratory of the Worldwide LHC Computing Grid, the provider of the Tier0 Centre and the CERN Analysis Facility, and as the coordinator of the LCG project,

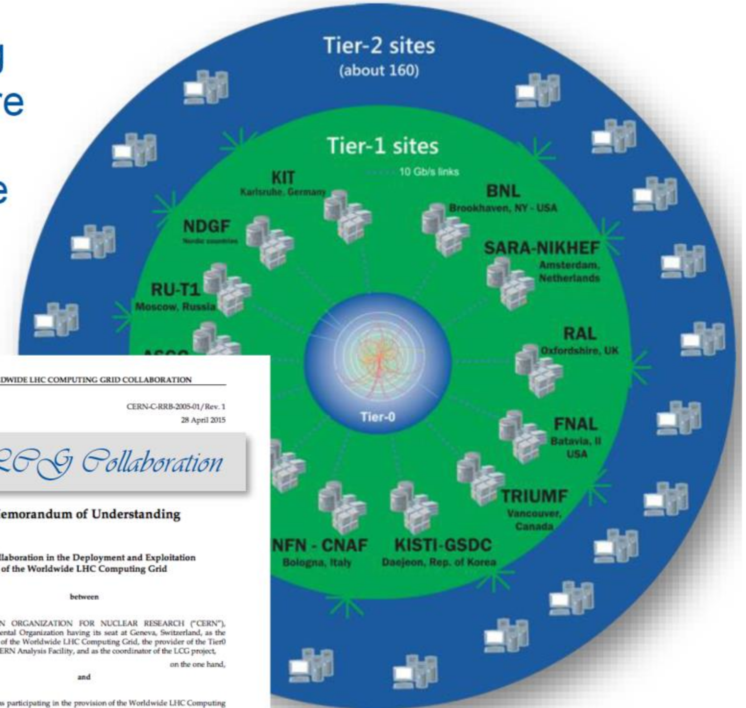
on the one hand,

and

all the Institutions participating in the provision of the Worldwide LHC Computing Grid with a Tier1 and/or Tier2 Computing Centre (including federations of such Institutions with computer centres that together form a Tier1 or Tier2 Centre), as the case may be, represented by their Funding Agencies for the purposes of signature of this Memorandum of Understanding,

on the other hand,

(hereafter collectively referred to as "the Parties").



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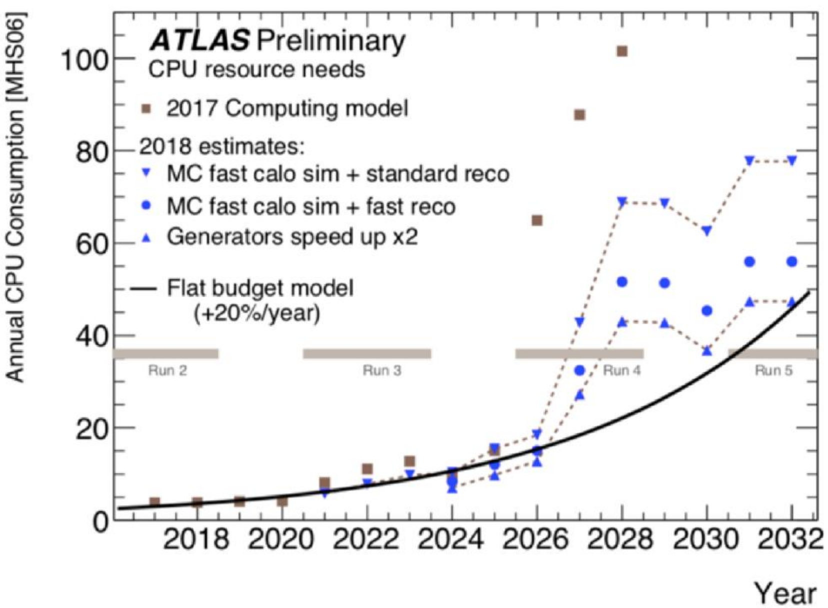
Commodity components, distributed system (WLGC), other resources

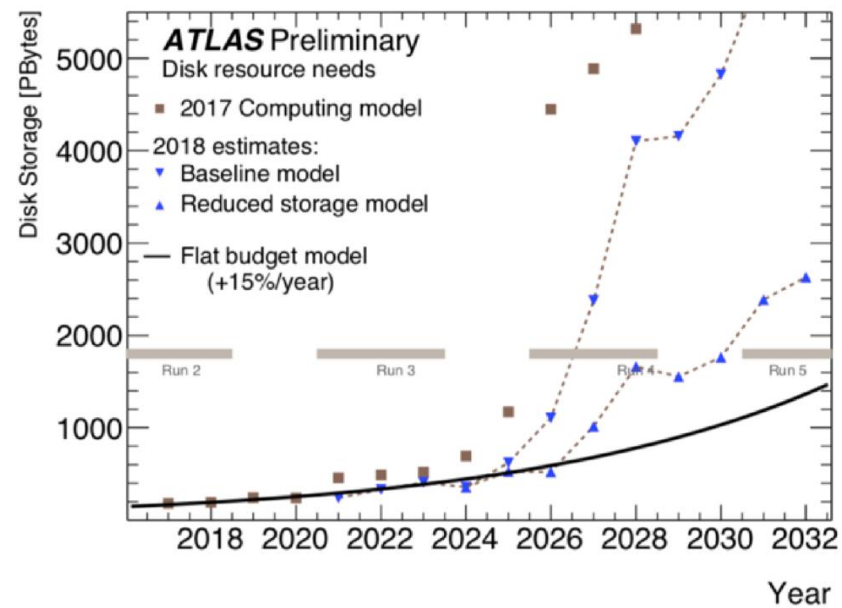
Computing – challenges

LHC upgrade to High Luminosity

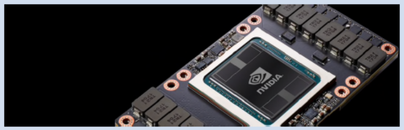
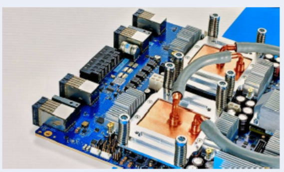
- The accelerator will be upgraded to provide ~3-4 times higher luminosity by 2026
  - Luminosity:
    Phase I: < 2.2×10^{34} $cm^{-2}s^{-1}$
    Phase II: (5)7.5×10^{34} $cm^{-2}s^{-1}$
  - Planned to deliver 3-4000 fb^{-1} until 2037

	LHC	HL-LHC
Pileup	~60	~140-200
Dataset	300/fb	3000-4000/fb
Instantaneous Lumi	~2x10^{34}	5-7.5x10^{34}





Computing – industry and HEP applications

Technology		Industry Applications	HEP Experiments R&D (see backup slides)
GPUs		Machine learning, AI, block chain, signal processing, voice recognition, etc.	Online pattern recognition, object reconstruction, fast simulation, data quality monitoring, computing resource optimization, machine learning training and inference
TPUs		Machine learning inference and training, data processing, matrix multiplication	Machine Learning inference and training
FPGAs		Pattern recognition, inference application, low latency real-time applications	Triggering, machine learning inference, image recognition
ARM		Mobile applications, embedded systems, low power highly parallelized many core systems	Alternative low power general purpose architectures

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Start with the detector-trigger, real time, online, AI, + software improvement

Computing – R&D

Likely take-aways from Granada

Carry out carefully planned and coordinated R&D programs that will adopt new hardware, take advantage of industrial trends and emerging technologies:

- Develop tools and applications for effective use of capacity provided by heterogenous hardware and specialized architectures.
- Improve the software: There are great opportunities for HEP to improve and generate new software by organizing the community, reaching out to industry, software engineers and other sciences.
- Continue R&D on data organization, infrastructure, management
- Application development and data access tools at HPC facilities and using commercial clouds, which will deliver extra capacity to HEP
- To effectively carry out the above activities, the field needs more skilled developers, and a significant investment here is required.
- position HEP computing and software for the revolutionary and disruptive technologies.

Instrumentations and Computing

A chapter on Instrumentation and Computing, intended for the Briefing Book for the European Strategy Group, is being prepared.

The ESG group will take the delivery of the Briefing Book, and will work with CERN Council and CERN management to develop the European Strategy for the next cycle.

Additional Material

Computing – R&D

Far Future Ideas: Quantum Computing, Neuromorphic…

- Intensely active area of research
  - Europe have invested 1B€ in Quantum Flagship Program; US invest heavily as well (including for HEP)
- Certainly a game changer if engineering of sufficient, stable q-bits can be achieved
  - Rapid progress in the last 5 years, but still far from being practical and useful
  - Even with some spectacular breakthroughs commercialisation would take time
- Maria's talk gave some specific projects
- How should HEP be involved? And at what level?
  - Are these with extra resources or some effort that we dedicate from our pool?
  - Mapping QC to current HEP algorithms? New algorithms enabled by QC? Programmable? Maintainable?

#162, 150, 59, 128, 88, 148, 157

Instrumentation – lessons learned from past R&D

HL-LHC preparation R&D programs

6

Adapted to upgrade circumstances, building on LHC experience and existing communities; a "row" approach with consortium to develop technologies for all experiments, extending to ancillary components and qualification facilities

- RD50 continued from RD48 in 2001, RD18 (Crystal Clear) continued
- CERN R&D white paper in 2008 https://indico.cern.ch/event/36149/
  - 3 Electronics Work Packages - 4 Detector Work Packages - Material engineering and cooling
  - RD51 formed in 2008, RD53 common ATLAS-CMS Pixel ASIC chip formed in 2013

Successful approach to streamline effort/resources, and compress timescales to handle new techniques and common components to on-going detector engineering developments or production

- RD50 radiation tolerant n-in-p Si-sensors (ATLAS/CMS/LHCb), LGADs (Timing ATLAS/CMS)
- RD51 MPGD GEMs, Micromegas (ATLAS/CMS/LHCb/ALICE)
- RD18 Crystals (Barrel Timing Layer CMS)
- Electronics common components: 130 & 65 nm radiation tolerant technologies for ASICs, LpGBT, Optical Links, DCDC & serial powering
- RD53 Pixel detector ASIC first version with all features fully functional (ATLAS/CMS)
- Mechanics: new light material structure for trackers, CO_2 cooling with modularity toward detector needs
- Qualification: GIF^{++} Irradiation and rate facility

Instrumentation – lessons learned from past R&D

Other R&D programs

- ILC and CLIC

LCTPC

  - CALICE high granularity electromagnetic and hadronic calorimeters
    - Formed in 2001 for ILC, evolved to joint ILC-CLIC R&D and now extend also to e-e circular colliders
  - Developments of Monolithic Active Pixels (MAPs) was initiated for ILC in 1998
  - CLIC R&D started in 2008 focusing on effect of different beam conditions (particularly for tracking)

Other R&D programs

- And several other host laboratories, experiments and national R&D programs*
  - Belle-II at SuperKEK, ex. DEPFET fully depleted CMOS active pixels, TOP Cerenkov, ARICH…
  - Several developments of liquid noble gas TPCs for Dark Matter and Neutrino experiments also requiring cryogenic developments
    - DarkSide Liquid Argon TPC with SiPMs, DARWIN Liquid Xenon two Phase TPC with PMTs (LNGS)
    - ProtoDune two phase liquid Argon TPC with THGEM (FNAL)
  - Liquid scintillator for JUNO neutrino experiment with PMTs (Jiangmen)
  - Pure water Cerenkov with PMTs for SuperKamiokande neutrino experiment (T2K)
  - Cryogenic and ultra-vacuum developments for gravitational wave interferometers
  - …

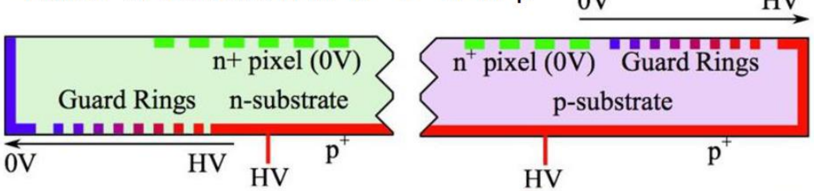
Instrumentation – lessons learned from past R&D

R&D example of evolution and diversity

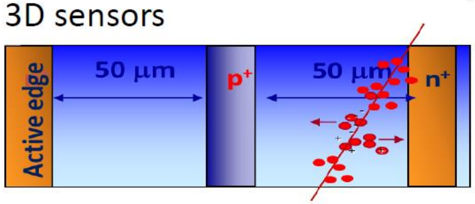
Ex. Si-sensor main designs

Most radiation tolerant

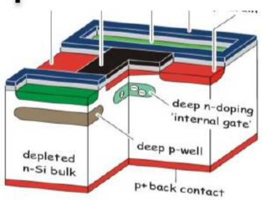
Planar Si-sensors n-in-n → n-in-p



3D sensors

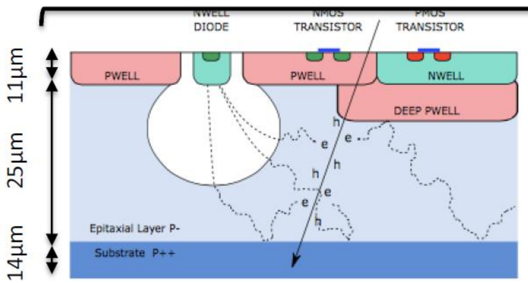


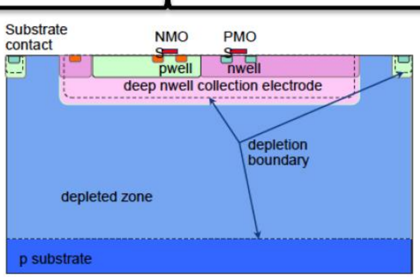
Full depletion monolithic

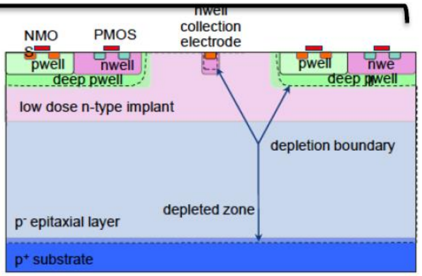


Belle-II Pixel DEPFET

Most precise position





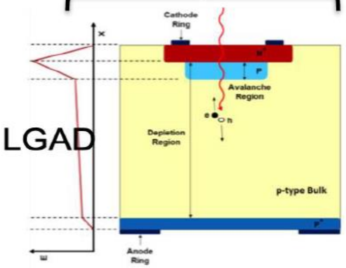


MAP CMOS Tower Jazz Techno. (0.18 μm)

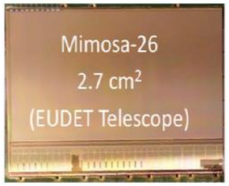
HV CMOS modified large (left) small (right) collection electrodes

Most precise timing

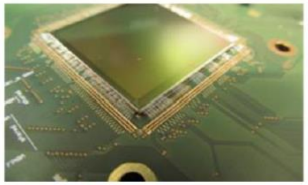
LGAD



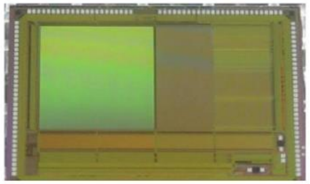
MAP Devices



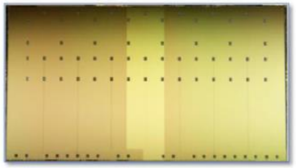
PIMMS – for TOF mass spectroscopy



CHERWELL – Calorimetry/Tracking



ALPIDE – Tracking



... Mimosis CBM

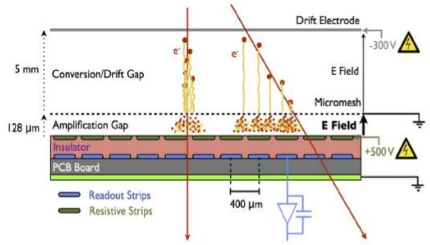
Instrumentation – lessons learned from past R&D

R&D example of evolution and diversity

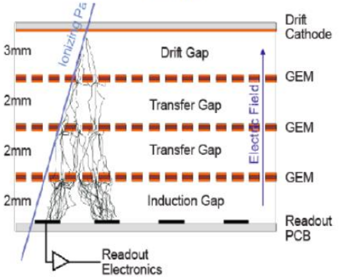
Ex. MPGD main designs

- Enabling progress in PCB photolithography techniques - unique facility at CERN to develop process
- Transfer of technology to industrial companies, ex. GEM fabrication at KODEL in Korea
- Increasing muon chamber size and improving assembly techniques, adaptations to TPCs
  - ex. GEM scheme to avoid ion feedback for ALICE TPC…

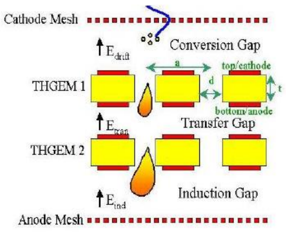
MicroMegas



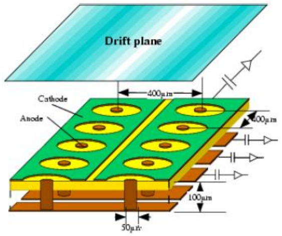
GEM



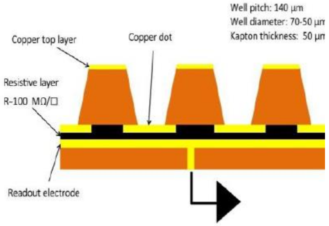
THGEM



µPIC

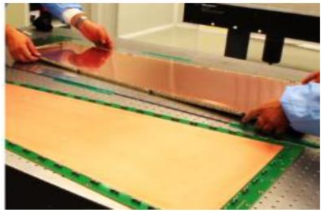


µ-Resistive-Well design

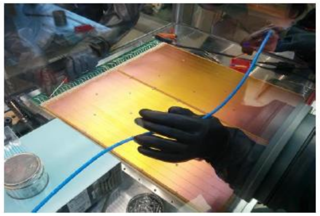


ATLAS new small wheels

CMS GEM



COMPASS RICH

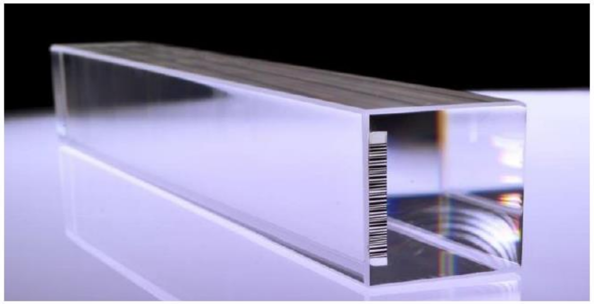


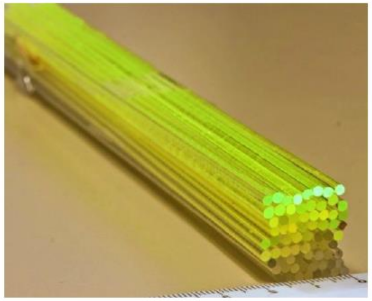
Instrumentation – lessons learned from past R&D

R&D example of evolution and diversity

Ex. Scintillating devices

- Several PVT, PS scintillator materials for optimization of light yield, attenuation length, emission wave lengtl (to match photosensor), speed… and related R&D on wave length shifting, clear fibers for transmission…
    - Some difficulties in improving radiation tolerance of plastic scintillators
- Crystals similarly large phase space of options depending on performance optimization





From CMS LHC Crystals to Time Imaging Calorimetry (TICAL ERC)

Instrumentation – lessons learned from past R&D

R&D practice considerations

15

- Precise specifications are important to avoid under-over designing
  - Considering all factors: performance, operating conditions (regular/abnormal), compatibility with other systems, production capabilities, cost… they must be well documented and re-visited as relevant
    - Physics MC simulations are important and require substantial effort
      - Benchmark device performance considering all elements: sensitive captors, electronics, material; and entire detector configuration with physics event fluctuations
    - Margins need to be well defined considering all uncertainties, and possible operation mitigations
      - ex. simulation of doses needs accurate detector representations, specifications could be different due to gradient in a same detector ex. specs for sensors… transition from one technology to another (Si-sensors to Scintillator + SiPMs in CMS HGC)
      - ex. voltages, temperature limits need to be foreseen accordingly
    - Also calibration aspects need to be considered
      - ex. mechanical structure precision, alignment better achieved with particles
      - ex. effect of environment variations temperature, voltages…
    - Known features such as discharges, saturations, need to be properly quantified
      - ex. discharge effects increase in large scale muon detectors with more occurrence and/or large charge
      - ex. Highly Ionizing Particle effects in tracker electronics
  - Common parameters for cross-systems/experiments components need to be anticipated particularly to allow implementing (cost effective) adaptation to specific system performance need and configurations
    - ex. generic components GBTs, Optical Modules, Cooling plants, and also RD53 common CMS/ATLAS Pixel ASIC

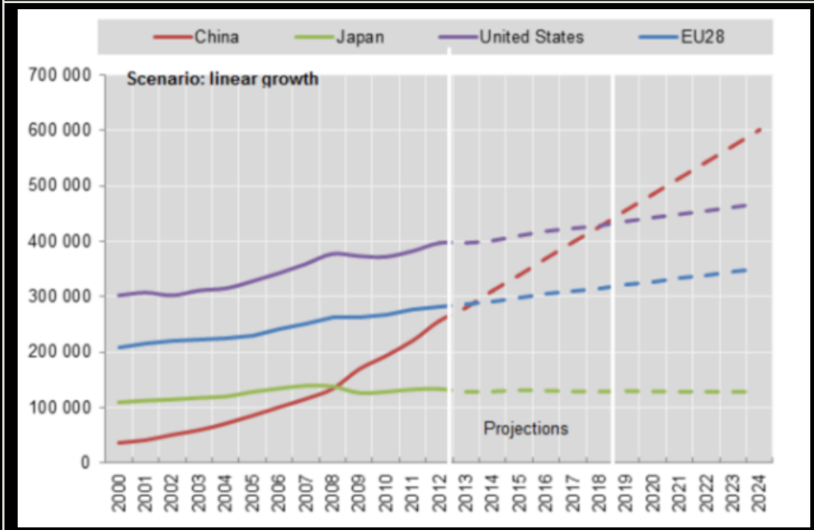
Instrumentation – lessons learned from past R&D

R&D practice considerations

- Developing design and characterization tools is essential to minimize prototype iterations
  - Modelling software developments
    - Signal formation to study configurations
      - ex. TCAD electric field simulation continuously improved to study Si-sensors configurations in RD50, implemented in GEANT MC simulation by CLIC to add event fluctuations
      - And also several other codes: AllPix, PixelAV, KdetSim, Garfield++, Allpix Squared
    - Radiation effects to predict long term behavior
    - Design and validation of electronic systems and mechanical components
      - ex. improved simulation tools for ASICs (Digital on Top technique) enable reduced number of (expensive) iterations; mostly 2 iterations of complete ASIC chips expected to provide production version
      - ex. mechanical FEA simulations to ensure thermomechanical compatibility and evaluate stability and cooling performance of detector elements and large structures
      - ex. CO_2 cooling modeling to develop performance studies and distribution to detectors
  - Infrastructure needs and special equipment to characterize devices are required with substantial cost
    - ex. clean rooms, probe stations, bonding/packaging tools, radioactive/laser sources, electronics and DAQ…
    - ex. equipment for impurity/dopant, content and profiles in solid state devices, spectro-photometer spectro-fluorometers to measure transmission/emission spectra in scintillators…

Funding: Forecast on Science and Technology spending from OECD

Organization for Economic Cooperation and Development



OECD Science, Technology and Industry Outlook 2014 - © OECD 2014

European countries are diverging in R&D as some move closer to their R&D/GDP targets (Denmark, Germany) and others (Portugal, Spain) fall further behind.

In most countries, 10% to 20% of business R&D is funded with public money, using various investment instruments and government targets.

Current special funding programs available in specific subjects
→ Quantum information, Robotics

12/11/14 - Squeezed R&D budgets in the EU, Japan and US are reducing the weight of advanced economies in science and technology research, patent applications and scientific publications and leaving China on track to be the world's top R&D spender by around 2019, according to a new OECD report.

The OECD Science, Technology and Industry Outlook 2014 finds that with R&D spending by most OECD governments and businesses yet to recover from the economic crisis, the OECD's share in global R&D spending has slipped from 90% to 70% in a decade.

Annual growth in R&D spending across OECD countries was 1.6% over 2008-12, half the rate of 2001-08 as public R&D budgets stagnated or shrank in many countries and business investment was subdued. China's R&D spending meanwhile doubled from 2008 to 2012.

Gross domestic expenditure on R&D (GERD) in 2012 was USD 257 billion in China, USD 397 billion in the United States, USD 282 billion for the EU28 and USD 134 billion in Japan.

Reflections & Conclusions

- Synergies between HEP and other fields and industry are an evidence nowadays since many programs (scientific and societal) have converging requirements and goals

- One possible way to better exploit these synergies is by "lowering" historical (with exceptions, e.g. medicine, electronics) inter-disciplinary barriers and invest in common technology centered research together with discipline driven goals.

- This approach can solve some of the questions this symposium addresses like identifying the best practices to retain technological know-how and boost careers in instrumentation. → Important role of Instrumentation schools, consortia, meetings

- In my view the organization of this common work is possible if Researchers, together with Industry and Policymakers (Funding Agencies, Research Labs, EU) would seat together to efficiently identify funding schemes in dedicated common areas

- With a special mention to the support of innovative "impossible" ideas.

Instrumentation – Panel Discussion

ECFA inputs and recommendations regarding **training**:

- Many effective schools for PhD/PostDocs exist.
- It would be profitable to enhance, already at University level the basic knowledge required for applied physics activities
- Discussion could start with academia such that PhD students in experimental physics would include in their PHD thesis the basic knowledge in detectors.
- R&D shall not be centralized exclusively in large-scale facilities or in the major labs but should be encouraged and supported in local institutions and Universities.

ECFA European Committee for Future Accelerators

Instrumentation – Panel Discussion

knowledge preservation and career perspective:

The success and future of our field depends:

- on our strength to attract the *most talented researchers* (physicists and engineers)
- in our ability to foster *them*, recognizing individual achievements especially within large collaborations
- in our ability to provide *them* with sufficient and adequate career opportunities

How to achieve all this?

Maybe difficult to succeed since, at present, it is resented that detector technology research is less valued than physics data analysis & interpretation (already at level of PhD)

Detector development needs to be fully recognized as a research field leading to a valuable PhD degree,