ECFA Detector R&D Roadmap Introduction - TF6 Symposium

TF6 Task Force

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+ Introduction to Roadmap by

Phil Allport

TF6 Symposium – May 2021

European Particle Physics Strategy Update

"Organised by ECFA, a roadmap should be developed by the community to balance the detector R&D efforts in Europe, taking into account progress with emerging technologies in adjacent fields."

"The roadmap should identify and describe a diversified detector R&D portfolio that has the largest potential to enhance the performance of the particle physics programme in the near and long term."

"Detector R&D activities require specialised infrastructures, tools and access to test facilities."

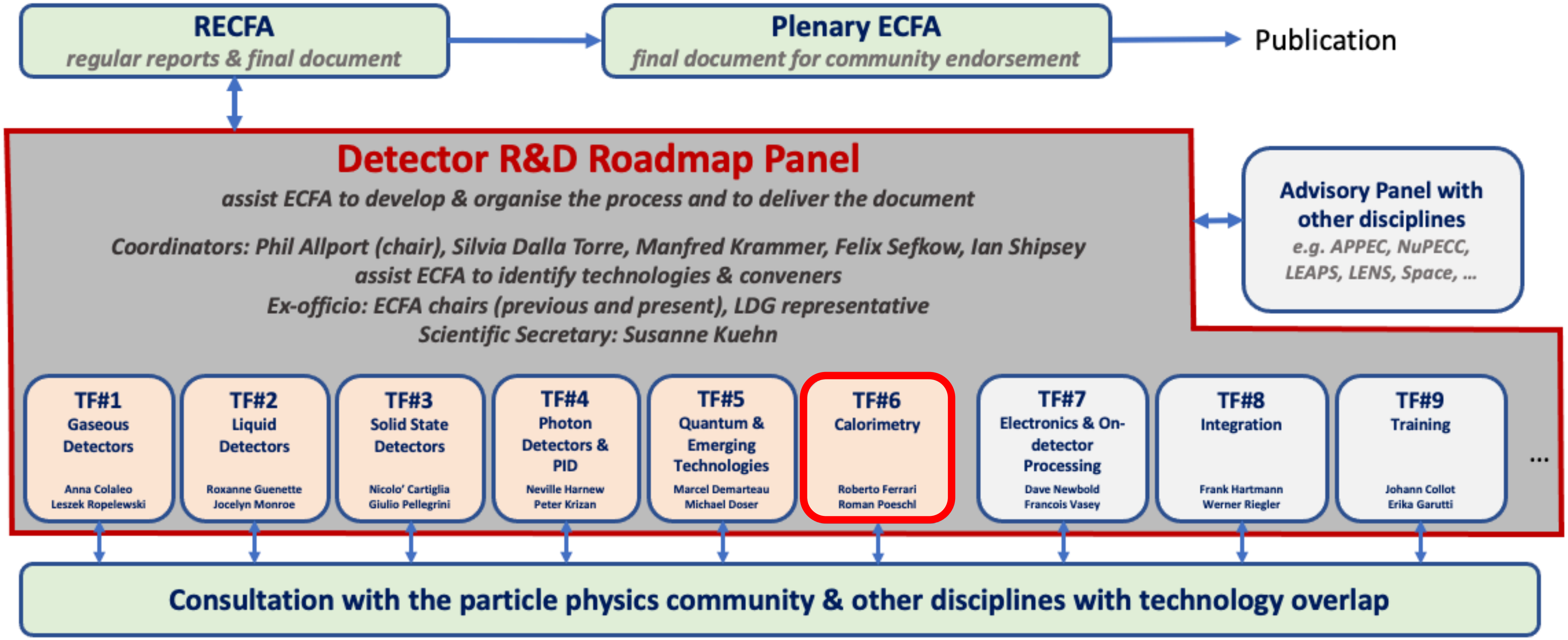
"The community should define a global detector R&D roadmap that should be used to support proposals at the European and national levels."

Extracted from the documents of 2020 EPPSU, https://europeanstrategyupdate.web.cern.ch/

For previous presentations on the Detector R&D Roadmap see Plenary ECFA: Jorgen D'Hondt (13/7/20) & Susanne Kuehn (20/11/20) (https://indico.cern.ch/event/933318/ & https://indico.cern.ch/event/966397/)

More roadmap process details at: https://indico.cern.ch/e/ECFADetectorRDRoadmap

Organization for Consultation of Relevant Communities



https://indico.cern.ch/e/ECFADetectorRDRoadmap

Organization for Consultation of Relevant Communities

- Focus on the technical aspects of detector R&D requirements given the EPPSU deliberation document listed "*High-priority future initiatives*" and "*Other essential scientific activities for particle physics*" as input and organise material by Task Force.
- Task Forces start from the future science programmes to identify main detector technology challenges to be met (both mandatory and highly desirable to optimise physics returns) to estimate the period over which the required detector R&D programmes may be expected to extend.
- Within each Task Force create a time-ordered technology requirements driven R&D roadmap in terms of capabilities not currently achievable.

Grouped targeted facilities/areas emerging from the EPPSU

1. **Detector requirements for full exploitation of the HL-LHC (R&D still needed for LS3 upgrades and for experiment upgrades beyond then) including studies of flavour physics and quark-gluon plasma (where the latter topic also interfaces with nuclear physics).**
2. **R&D for long baseline neutrino physics detectors (including aspects targeting astro-particle physics measurements) and supporting experiments such as those at the CERN Neutrino Platform.**
3. **Technology developments needed for detectors at e^+e^- EW-Higgs-Top factories in all possible accelerator manifestations including instantaneous luminosities at 91.2GeV of up to $5\times10^{36}cm^{-2}s^{-1}$.**
4. **The long-term R&D programme for detectors at a future 100 TeV hadron collider with integrated luminosities targeted up to $30ab^{-1}$ and 1000 pile-up for 25ns BCO.**
5. **Specific long-term detector technology R&D requirements of a muon collider operating at 10 TeV and with a luminosity of the order of $10^{35}\,cm^{-2}\,s^{-1}$.**

ECFA
European Committee for Future Accelerators

Broad Topic Areas

Grouped targeted facilities/areas emerging from the EPPSU

6. Detector developments for accelerator-based studies of rare processes, DM candidates and high precision measurements (including strong interaction physics) at both storage rings and fixed target facilities, interfacing also with atomic and nuclear physics.
7. R&D for optimal exploitation of dedicated collider experiments studying the partonic structure of the proton and nuclei as well as interface areas with nuclear physics.
8. The very broad detector R&D areas for non-accelerator-based experiments, including dark matter searches (including axion searches), reactor neutrino experiments, rare decay processes, neutrino observatories and other interface areas with astro-particle physics.

9. Facilities needed for detector evaluation, including test-beams and different types of irradiation sources, along with the advanced instrumentation required for these.
10. Infrastructures facilitating detector developments, including technological workshops and laboratories, as well as tools for the development of software and electronics.
11. Networking structures in order to ensure collaborative environments, to help in the education and training, for cross-fertilization between different technological communities, and in view of relations with industry.

12. Overlaps with neighbouring fields and key specifications required for exploitation in other application areas
13. Opportunities for industrial partnership and technical developments needed for potential commercialisation

ECFA
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Process and Timeline

Organisation

May 2020
EPPSU mandate to ECFA to develop a roadmap for detector R&D efforts in Europe

Sep 2020
Structure in place with **Detector R&D Roadmap Panel**

Dec 2020
Task Forces active

Website:
https://indico.cern.ch/e/ECFADetectorRDRoadmap

Expert & Community Consultation

Feb 2021
Collection of requirements of future facilities & projects

Feb/March 2021
Questionnaires of Task Forces to national contacts

Task Forces liaise with experts in
- ECFA countries
- adjacent disciplines
- industry

March-May 2021
Open Symposia

Drafting Roadmap & Feedback

May 2021
Task Forces collate input from symposia

25-28 May 2021 **Drafting sessions**
- opening session with all experts involved
- plenary & parallel sessions with Task Force members
- final session of Roadmap Panel

July 2021
Near final draft shared with RECFA*

30 July 2021
Presentation at Joint ECFA-EPS session

Until Sep 2021
Collect final community feedback*

Oct 2021
Detector R&D Roadmap Document submission to RECFA and afterwards to PECFA and Council

*community feedback via RECFA delegates and National Contacts

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European Committee for Future Accelerators

Process and Timeline

Input session of Future Facilities I

Friday 19 Feb 2021, 13:00 → 18:00 Europe/Zurich

- 13:00 → 13:30 **Detector R&D requirements for HL-LHC**
  Speaker: Chris Parkes (University of Manchester (GB))
  ECFA_RD_Parkes_1...
- 13:30 → 14:00 **Detector R&D requirements for strong interaction experiments at future colliders**
  Speaker: Luciano Musa (CERN)
  MUSA_ECFA_IS_20...
- 14:00 → 14:30 **Detector R&D requirements for strong interaction experiments at future fixed target facilities**
  Speaker: Johannes Bernhard (CERN)
  Detector R&D requir...
- 14:30 → 14:45 Coffee-Tea Break
- 14:45 → 15:15 **Detector R&D requirements for future linear high energy e+e- machines**
  Speaker: Frank Simon (Max-Planck-Institut fuer Physik)
  LC_DetRoadmapInp...
- 15:15 → 15:45 **Detector R&D requirements for future circular high energy e+e- machines**
  Speaker: Mogens Dam (University of Copenhagen (DK))
  ECFA_Detector_R&D...
- 15:45 → 16:15 **Detector R&D requirements for future high-energy hadron colliders**
  Speaker: Martin Aleksa (CERN)
  20210219-ECFA-Det...
- 16:15 → 16:35 **Detector R&D requirements for muon colliders**
  Speaker: Nadia Pastrone (Universita e INFN Torino (IT))
  MuonColliders_Dete...

Input session of Future Facilities II

Monday 22 Feb 2021, 14:00 → 18:00 Europe/Zurich

- 14:00 → 14:30 **Detector R&D requirements for future short and long baseline neutrino experiments**
  Speaker: Marzio Nessi (CERN)
  21-02-22-ECFA-Neut... 21-02-22-ECFA-Neut...
- 14:30 → 15:00 **Detector R&D requirements for future astro-particle neutrino experiments**
  Speaker: Maarten De Jong (Nikhef National Institute for subatomic physics (NL))
  ECFA - Maarten de ... ECFA - Maarten de ...
- 15:00 → 15:30 **Detector R&D requirements for future dark matter experiments**
  Speaker: Laura Baudis (University of Zurich)
  baudis_ecfa_feb21....
- 15:30 → 15:40 Coffee-Tea Break
- 15:40 → 16:10 **Detector R&D requirements for future rare decay processes experiments**
  Speakers: Cristina Lazzeroni (University of Birmingham (GB)) , Cristina Lazzeroni (University of Birmingham (GB))
  ECFA_Lazzeroni.pdf
- 16:10 → 16:40 **Detector R&D requirements for future low energy experiments**
  Speaker: Dr Alexandre Obertelli (TU Darmstadt)
  ECFA_LowEnergyFa...

Expert & Community Consultation

Feb 2021
Collection of requirements of future facilities & projects

Feb/March 2021
Questionnaires of Task Forces to national contacts

Task Forces liaise with experts in
- ECFA countries
- adjacent disciplines
- industry

March-May 2021
Open Symposia

May 2021
- 07 May ECFA Detector R&D Roadmap Symposium of Task Force 6 Calorimetry
- 06 May ECFA Detector R&D Roadmap Symposium of Task Force 4 Photon Detectors and Particle Identification Detectors

April 2021
- 30 Apr ECFA Detector R&D Roadmap Symposium of Task Force 9 Training
- 29 Apr ECFA Detector R&D Roadmap Symposium of Task Force 1 Gaseous Detectors
- 23 Apr ECFA Detector R&D Roadmap Symposium of Task Force 3 Solid State Detectors
- 12 Apr ECFA Detector R&D Roadmap Symposium of Task Force 5 Quantum and Emerging Technologies
- 09 Apr ECFA Detector R&D Roadmap Symposium of Task Force 2 Liquid Detectors

March 2021
- 31 Mar ECFA Detector R&D Roadmap Symposium of Task Force 8 Integration
- 25 Mar ECFA Detector R&D Roadmap Symposium of Task Force 7 Electronics and On-detector Processing

Materials from past Symposia, Input Sessions and other components of the ECFA Detector R&D Roadmap Process can be found at https://indico.cern.ch/e/ECFADetectorRDRoadmap

Links for Roadmap Process

https://indico.cern.ch/e/ECFADetectorRDRoadmap

https://indico.cern.ch/event/957057/page/21633-mandate (Panel Mandate document)

https://home.cern/resources/brochure/cern/european-strategy-particle-physics

https://arxiv.org/abs/1910.11775 (Briefing Book)

https://science.osti.gov/-
/media/hep/pdf/Reports/2020/DOE_Basic_Research_Needs_Study_on_High_Energy_Physics.pdf

https://ep-dep.web.cern.ch/rd-experimental-technologies (CERN EP R&D)

http://aida2020.web.cern.ch/aida2020/ (linking research infrastructures in detector development and testing)

https://attract-eu.com/ (ATTRACT: linking to industry on detection and imaging technologies)

https://ecfa-dp.desy.de/public_documents/ (Some useful documents from the ECFA Detector Panel)

This Symposium – Welcome

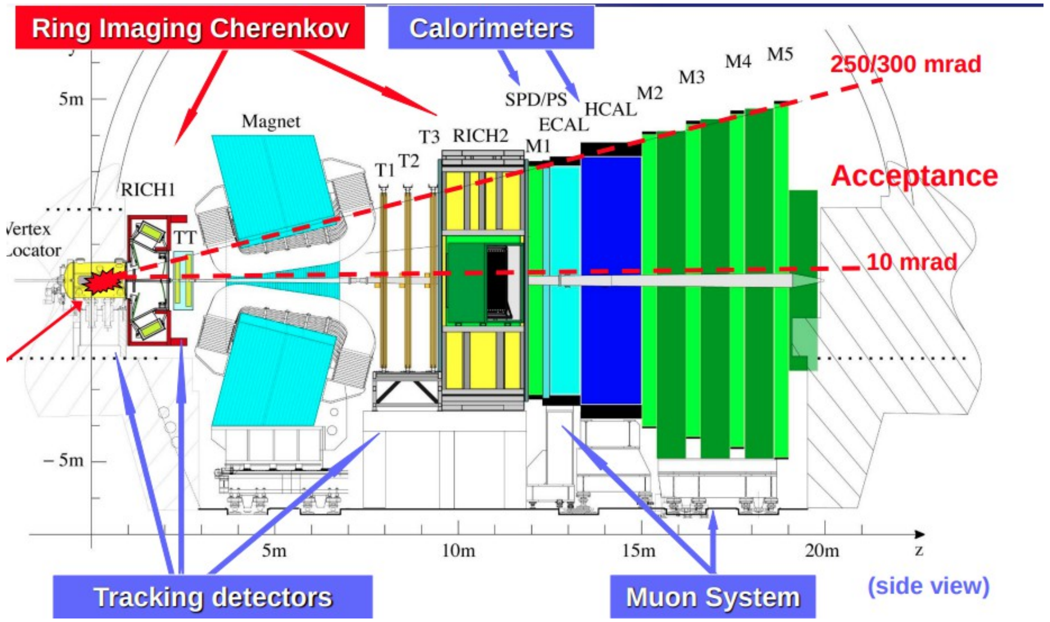
- **Welcome to the TF6 Symposium**
- **Thanks to the coordination team and in particular to Susanne Kühn for guidance and help with setting up the symposium**
- **Thanks to the Speakers for having agreed to the challenging task of summarising their corresponding topic**
- *The symposium will be recorded*
- Your questions and answers in the chat will be made available to the taskforce for the drafting of the Roadmap
  - If possible state your name and institute before asking a question
  - Note that we have reserved ample time for discussion in the agenda
- Questions and answers to the talks can be also put in the *questionnaire*
  - Questionnaire will be open until May 14th 2021
- You can also send a mail to the taskforce
  - ECFA-DetectorRDRoadmap-TF6Calorimetry@cern.ch

ECFA

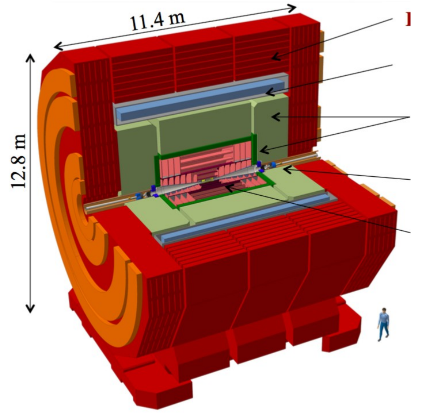
TF6 (Main) Target Projects

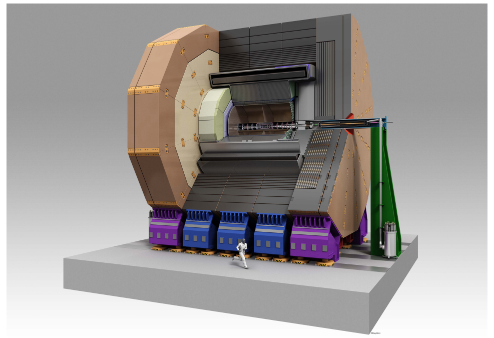
European Strategy Update

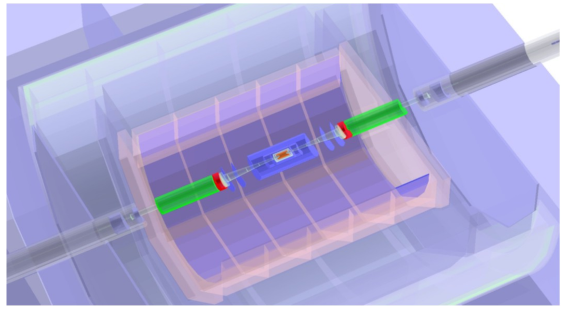
HL-LHC after LS4

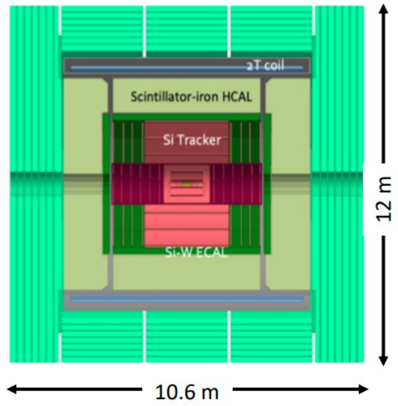


Higgs Factories

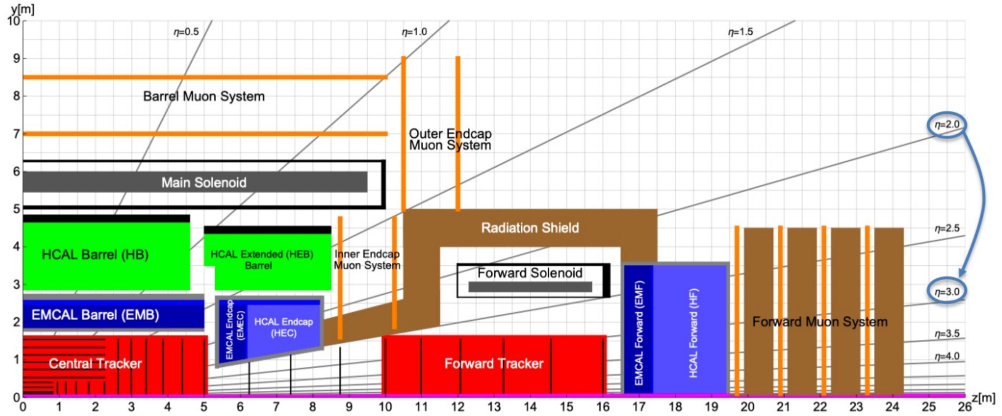




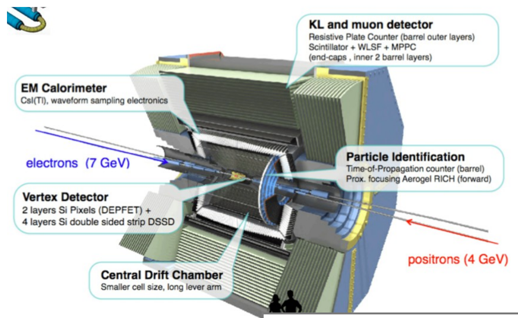


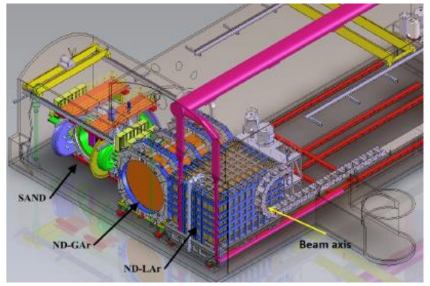


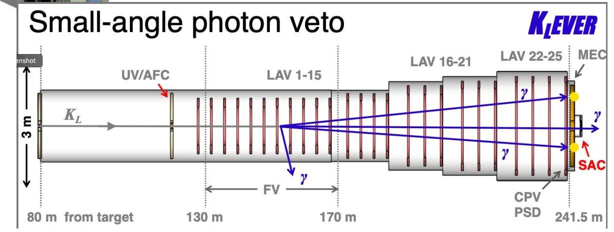
Future hadron colliders (including eh colliders)



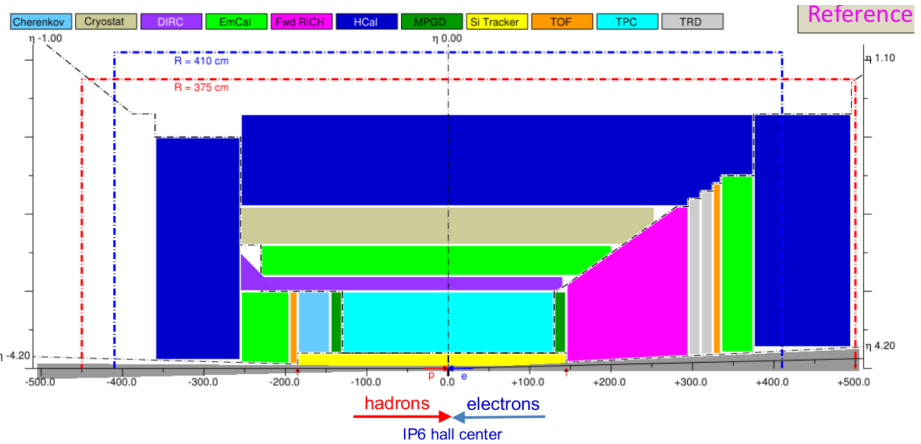
SuperKEKB, DUNE ND and Fixed Target



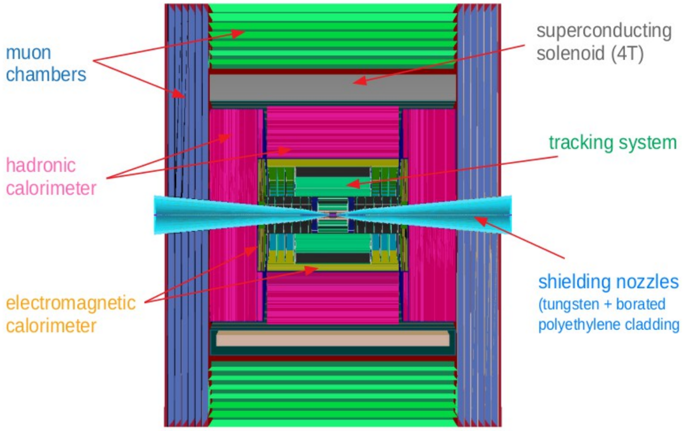




EiC



Muon Collider



ECFA

Review Input Sessions – Overview Table

European Strategy Update

Project	~Earliest Start of data taking	Current Calorimeter options					
		Solid state	Scintilling tiles/strips	Crystals	Fibre based r/o (including DR)	Gaseous	Liquid Noble Gas
HL-LHC (>LS4)	2030			✔	✔		
SuperKEKb (>2030)	2030			✔			
ILC	2035	✔	✔			✔	
CLIC	2040	✔	✔				
CEPC	2035	✔	✔	✔	✔	✔	✔
FCC-ee	2040	✔	✔	✔	✔	✔	✔
EiC	2030		✔	✔	✔		
FCC-hh (eh)	>2050	✔	✔				✔
Muon Collider	> 2050	✔	✔	✔	✔	✔	
Fixed target	“continous”		✔	✔	✔		✔
Neutrino Exp.	2030		✔				(✔)

In most of the cases final choices have still to be made

Future projects – Some general considerations

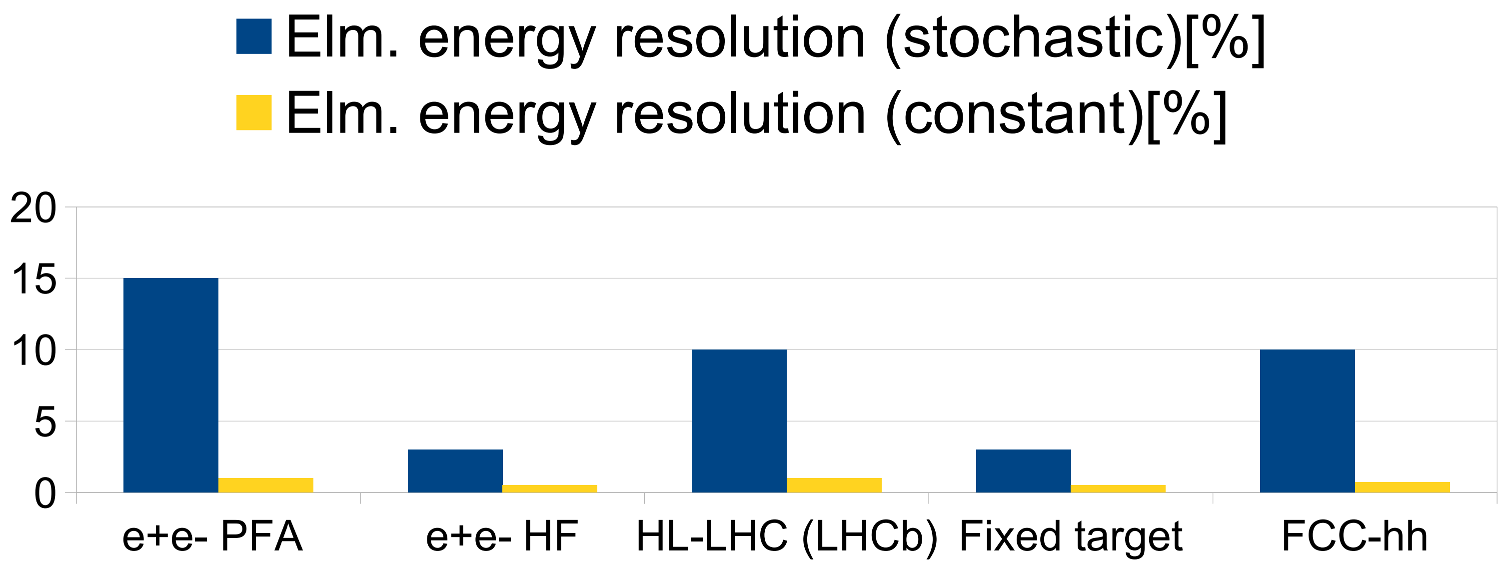
- Detectors at future high energy e+e- colliders
  - Relative benign environment in terms of radiation (well, maybe less true for Muon Collider)
  - Physics program span between Z-pole and few TeV
    - At same machine in case of LC
  - Consequences for detector design?
  - This is particularly important for calorimeters since calorimeters require significant human resources and material during construction and during maintenance

- Detectors at future hadron colliders
  - No strong change in centre-of-mass energy within one project
  - However,
    - Harsh radiation environments from the beginning
    - ... amplified by potential luminosity upgrades
  - Requires calorimeters that can stand severe conditions w/o degradation (or upgrades are priced in from the beginning)
  - Again calorimeters are huge and require sustained long term support

- Most other projects have constraints that are subsets of the above but in different combinations and on different time scales

Requirements on Energy Resolution

- Electromagnetic energy resolution (stochastic term):
  - HL-LHC (LHCb LS4): 10%
  - Linear e+e- Colliders: 10-15% (Particle Flow Based Approach)
    - May require another look
  - Circular e+e- Colliders: 3-15% (ranging from Heavy Flavour Programme to PFA requirements)
  - EiC: 2-10% depending on angular range
  - FCC-hh: 10% (Order of current ATLAS LAr-Calorimeter)



- Electromagnetic energy resolution (constant term):
  - Requirements formulated in input sessions range from ~0.5% to 3%

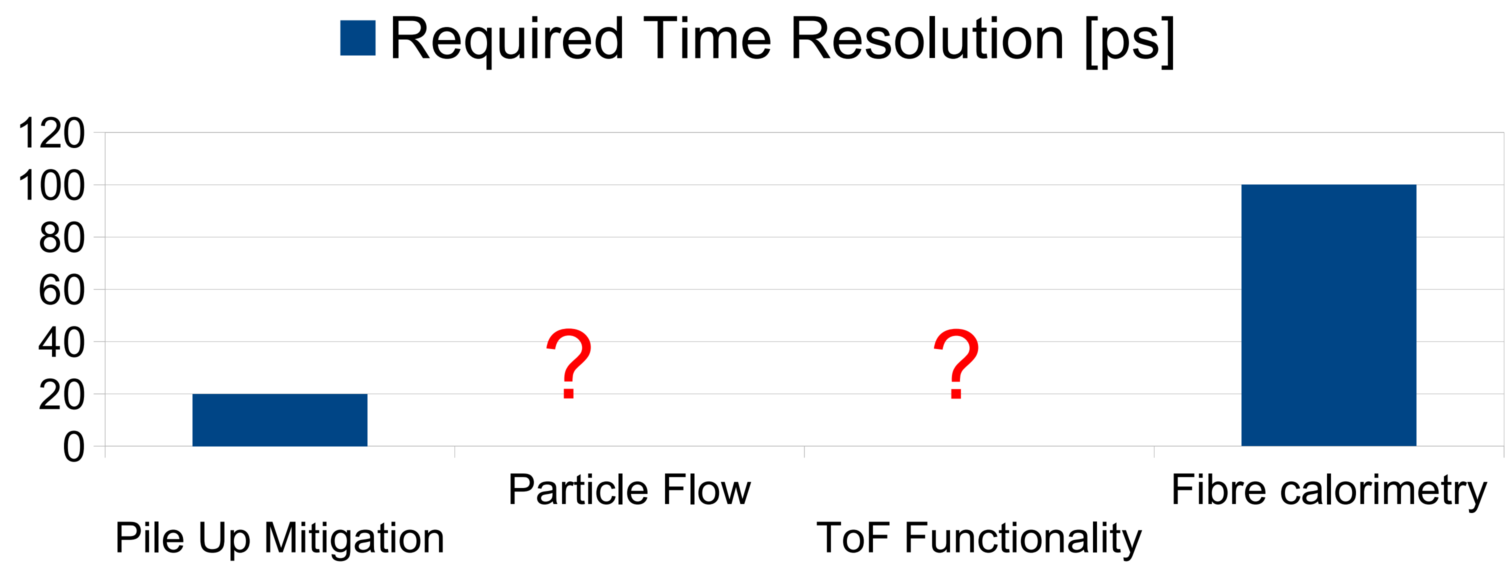
- Hadronic or rather jet energy resolution
  - Linear e+e- Colliders: 3-5% (Particle Flow Based Approach)
  - Circular e+e- Colliders: Same as Linear Colliders, however LC may have to cover larger jet energy range (45 GeV – O(1 TeV))
  - Current R&D proves/targets O(30%-40%)/$\sqrt{E}$ for hadronic energy resolution of individual particles

- Other projects (e.g. Fixed target experiments, Muon Collider) are roughly in the same ball park as above

- In future calorimeters ultimate energy resolution may not be the key metric

Requirements on Timing

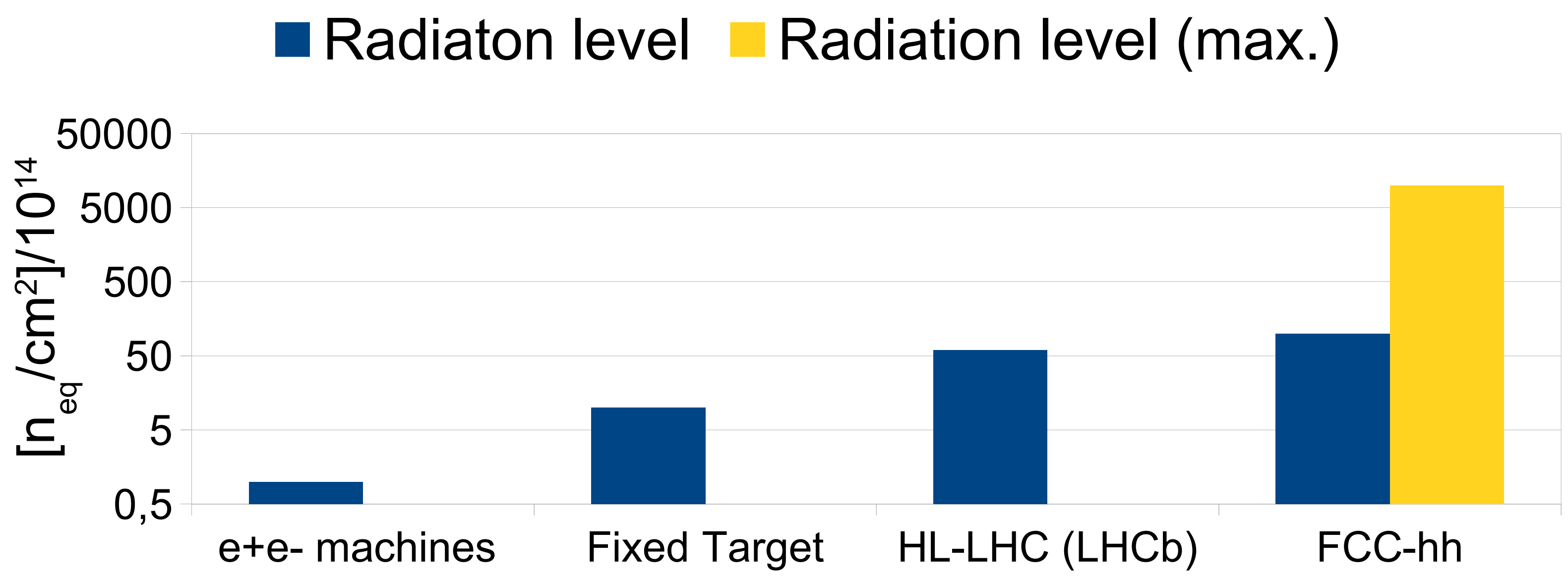
- Timing is a wide field
- A look to 2030 make resolutions between 20ps and 100ps at system level realistic assumptions
- At which level: 1 MIP or Multi-MIP?
- For which purpose ?
  - Mitigation of pile-up (basically all high rate experiments)
  - Support of PFA – unchartered territory
  - Calorimeters with ToF functionality in first layers?
    - Might be needed if no other PiD detectors are available (rate, technology or space requirements)
    - In this case 20ps (at MIP level) would be maybe not enough
  - Longitudinally unsegmented fibre calorimeters



- Input sessions presented a wide field of application for precision timing
- A topic on which calorimetry has to make up it's mind
  - Remember also that time resolution comes at a price -> High(er) power consumption and (maybe) higher noise levels
- See also talk by Nural

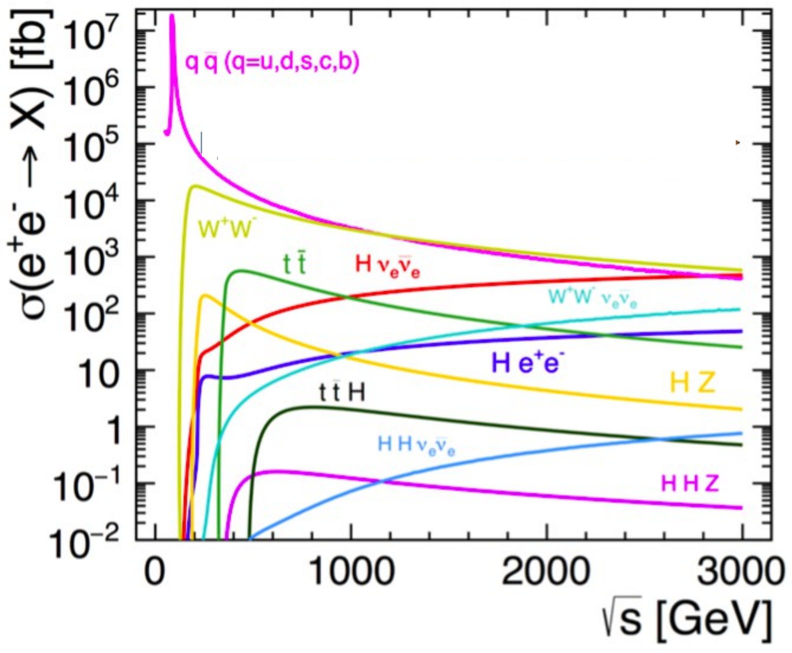
Requirements on Radiation Hardness

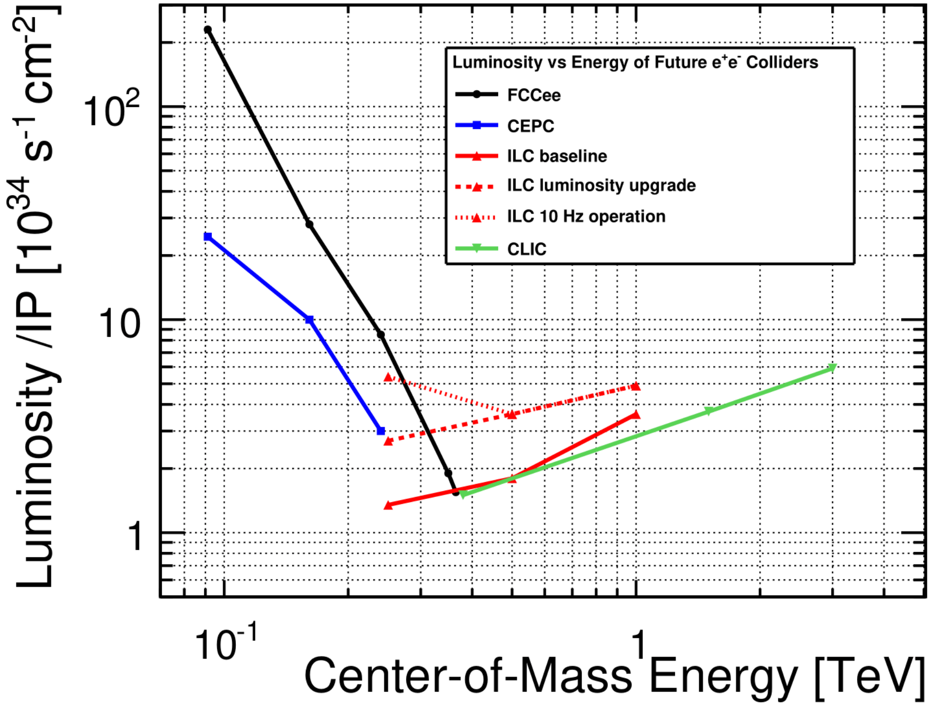
- The Radiation Frontier: Future Hadron Colliders
  - Have to count with $10^{16} – 10^{18}$ neq/cm^2 (1 MeV neutron equivalent flux)
    - i.e. around a factor 30 more than at HL-LHC
  - A bit more relaxed in barrel region
  - R&D for these extreme doses may start with covering HL-LHC (LHCb) and fixed target (e.g. NA62/Klever) needs
  - R&D will cover needs for eh-colliders



- Future Lepton Colliders
  - Much more relaxed conditions
  - Energy frontier e+e- Colliders: e.g. 10^{14} n_{eq}/cm^2 in forward region of ILC, CLIC Detectors
  - Surely more challenging at circular e+e- colliders at max. Luminosity and at Muon Collider

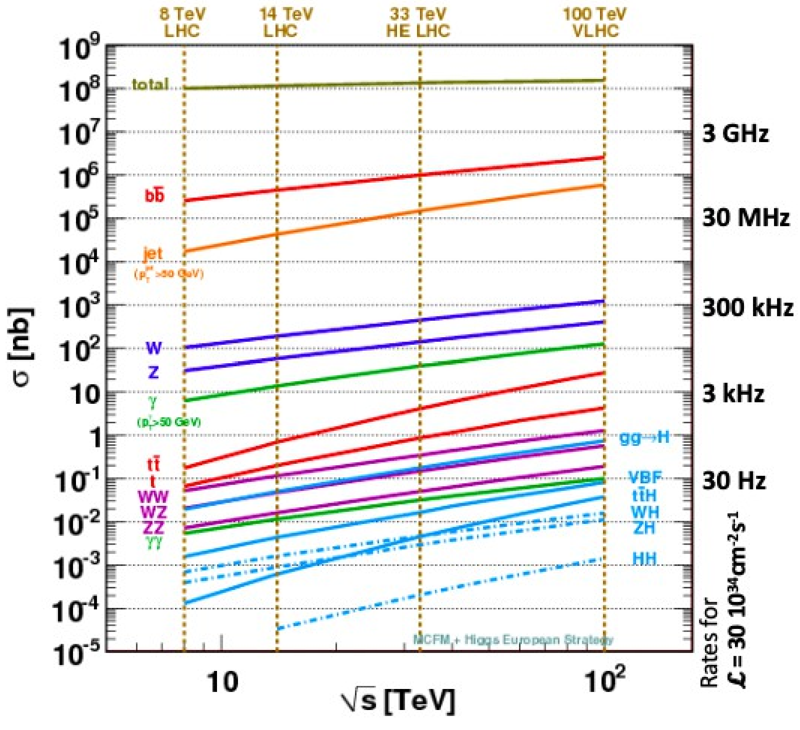
Impact of "Rates"





High energy e+e- colliders:

- Physics rate is governed by strong variation of cross section and instantaneous luminosity
- Ranges from 100 kHz at Z-Pole (FCC-ee) to few Hz above Z-Pole
- (Extreme) rates at pole may require other solutions than rates above pole
  - strong active cooling, calo trigger and feature extraction in front-end elx.
- Rates in Beam Calorimeters comparable to Z-Pole rate



Hadron collisions/colliders

- Interesting physics processes are only small fraction of total cross section
- Event filtering motivates implementation of sophisticated algorithms (PFA) in or close to front-end electronics
- Pioneering work by current LHC experiments and fixed target experiments
  - ... in particular LHCb

See also talk by Andre David

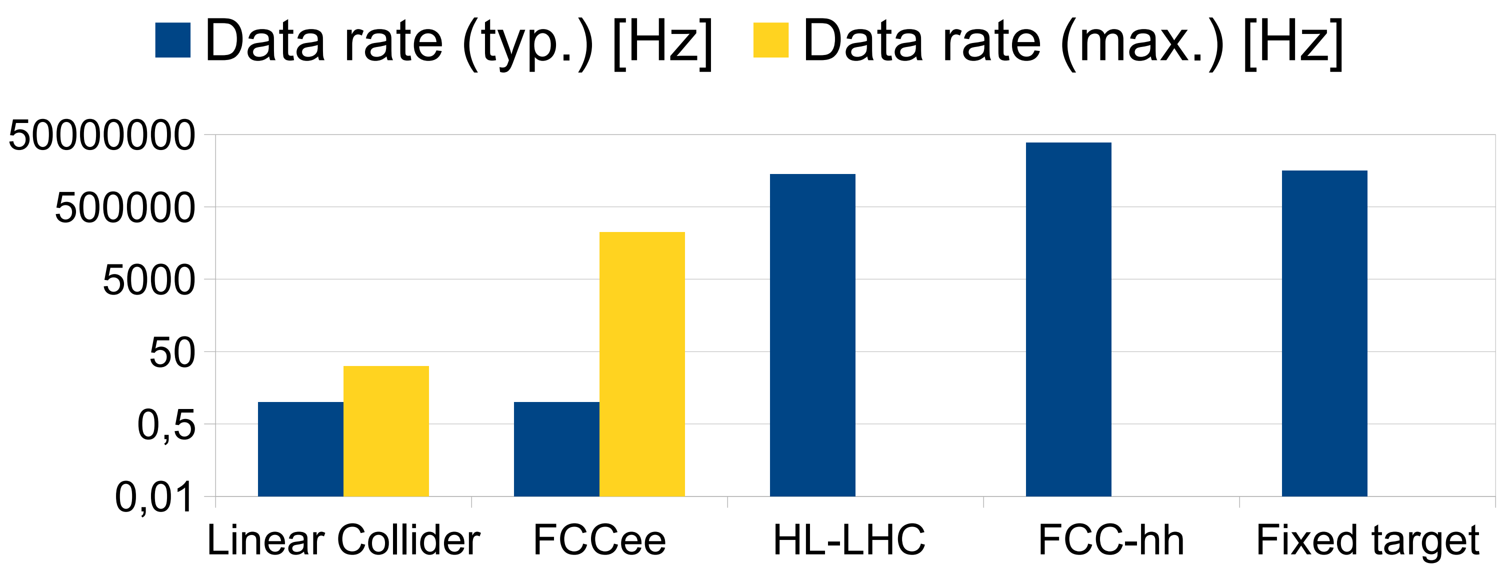
Hit rates (largely my estimations)

- Future hadron collider will have hit rates of the order of 0.1 – 10 GHz/cm^2 In the calorimeter
  - This about a factor of 10 higher than for HL-LHC Experiments
- Upper limit of hit rates for fixed target (non LHCb) is around 160 Mhz/cm^2 (estimated from NA62 Numbers)
- Future lepton colliders cover a broad spectrum of occupancies
  - e.g. Hit rates at CLIC (CERN Yellow Report https://doi.org/10.23731/CYRM-2019-001)

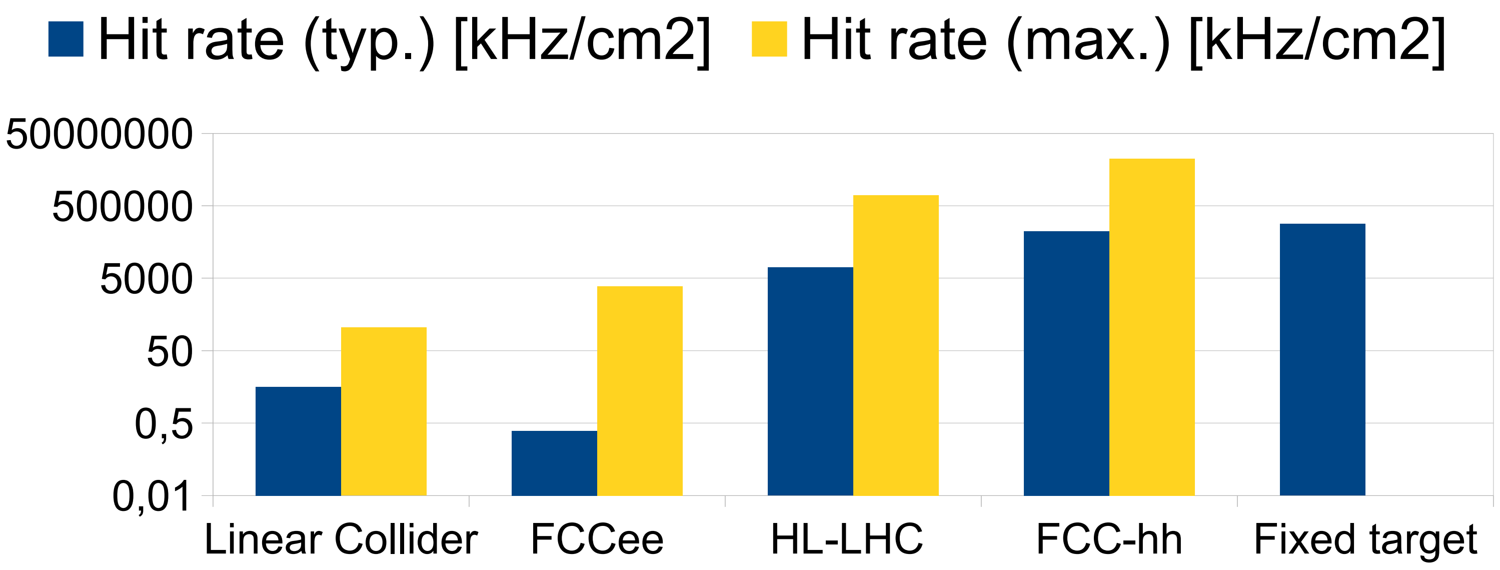
Detector region	time sampling period [ns]	hit time resolution [ns]	cell size [mm^2]	number of channels [10^6]	average to max. train occupancy [%]	number of bits per cell [bits]	data volume per train [MByte]
ECAL barrel	25	1	5×5	72	0.36 / 2.4	16 × 8	5.0
ECAL endcap	25	1	5×5	29	1.1 / 33	16 × 8	6.1
HCAL barrel	25	1	30×30	4.8	0.11 / 0.86	16 × 8	0.10
HCAL endcap	25	1	30×30	4.5	5.4 / 100	16 × 8	4.6
HCAL rings	25	1	30×30	0.4	0.010 / 1.4	16 × 8	0.00075
LumiCal	10	5	3.75×13–44	0.25	90 / 100	16 × 20	9.3
BeamCal	10	5	8×8	0.093	100	16 × 20	3.7

- One train in CLIC is 352 bunches over 200 ns
- Large variety of hit rates
- Extreme rates in Hcal endcap may be remedied with shielding

Date rates and Hit rates



- pp collision rate at HL-LHC and FCC-hh
- Physics rates at e+e- colliders



- Here LC=CLIC
  - Background only in Ecal Barrel
  - ILC has less hit rate due to less collimation and larger bunch spacing
- FCCee under (unrealistic) assumption that around 30 particles of a jet impinging within 1cm^2
- Still hit rate on pole much higher than above pole

Disclaimer: The numbers have been roughly estimated from the literature.
All mistakes are mine

Requirements on Compactness

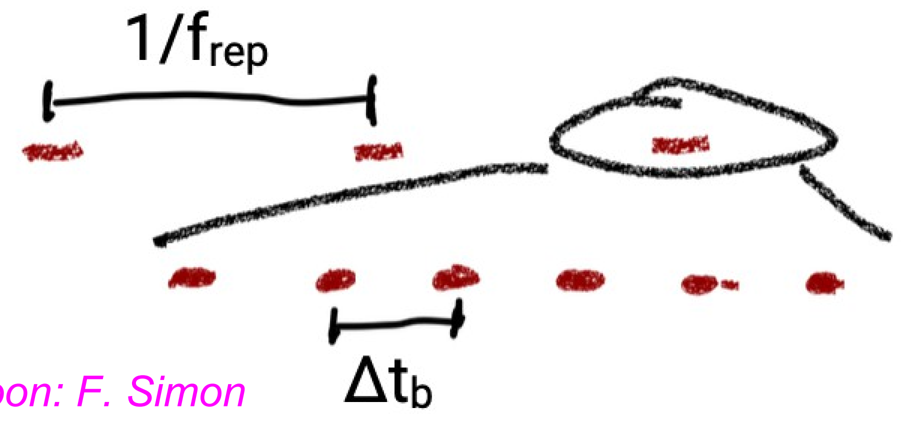
- Particle Flow Approach puts tight requirements on compactness and hermiticity
  - Careful layout to maximise acceptance
  - Shower separation in calorimeter must not be compromised by gaps needed for services or passive material

- Fulfilling these requirements is most likely more important for collider detectors than for fixed target detectors
- Notable dedicated efforts
  - Construction of CMS-HGCAL
  - Compact electronics and mechanics for Higgs-Factory Detectors (mainly CALICE)
    - May need to integrate timing requirements in the future
  - Innovative PCBs for Liquid Noble Detectors, thin cryostats

- The upshot is that the quest for compactness requires close collaboration between physicists and engineers for the detector design (see also talk by Dave)

A distinct feature at Linear Colliders – Power Pulsing

- Linear Colliders operate in bunch trains



Cartoon: F. Simon

CLIC: Δt_b ~ 0.5ns, frep = 50Hz

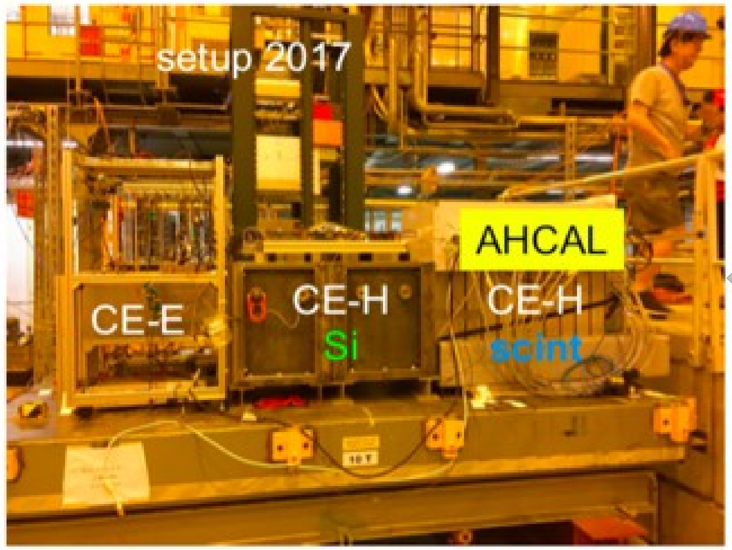
ILC: Δt_b ~550ns, frep = 5 Hz (base line)

- Power Pulsing reduces dramatically the power consumption of detectors
  - e.g. ILD SiECAL: Total average power consumption 20 kW for a calorimeter system with 10^8 cells
- Power Pulsing has considerable consequences for detector design
  - Little to no active cooling
  - => Support compact detector design
- Have to avoid large peak currents
- Have to ensure stable operation in pulsed mode

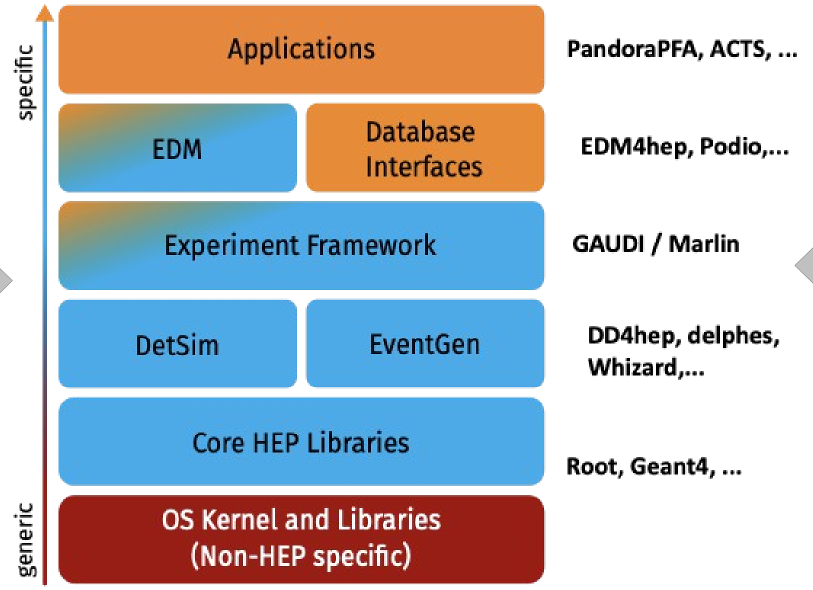
- Upshot: Pulsed detectors face other R&D challenges than those that will be operated in “continuous” mode

Software

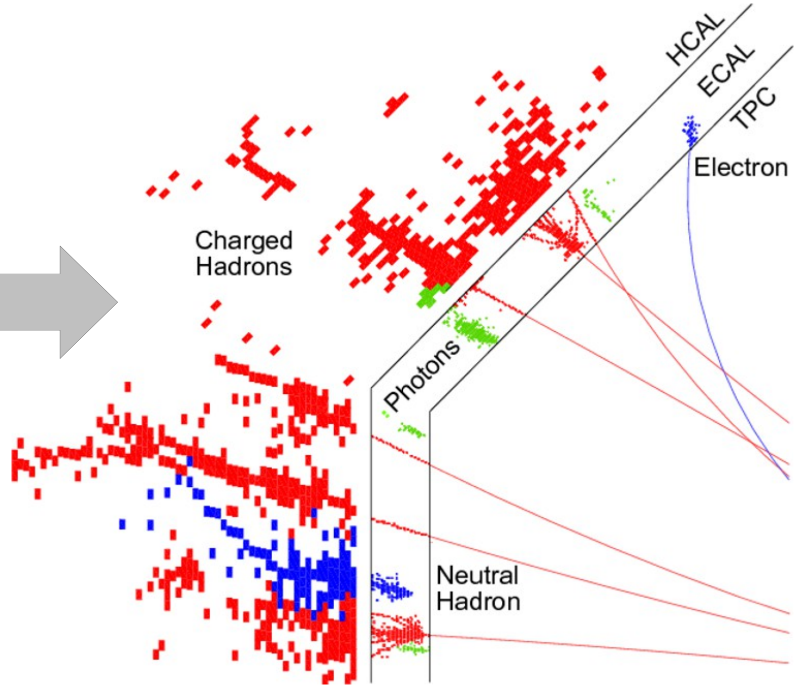
Beam test



Software framework



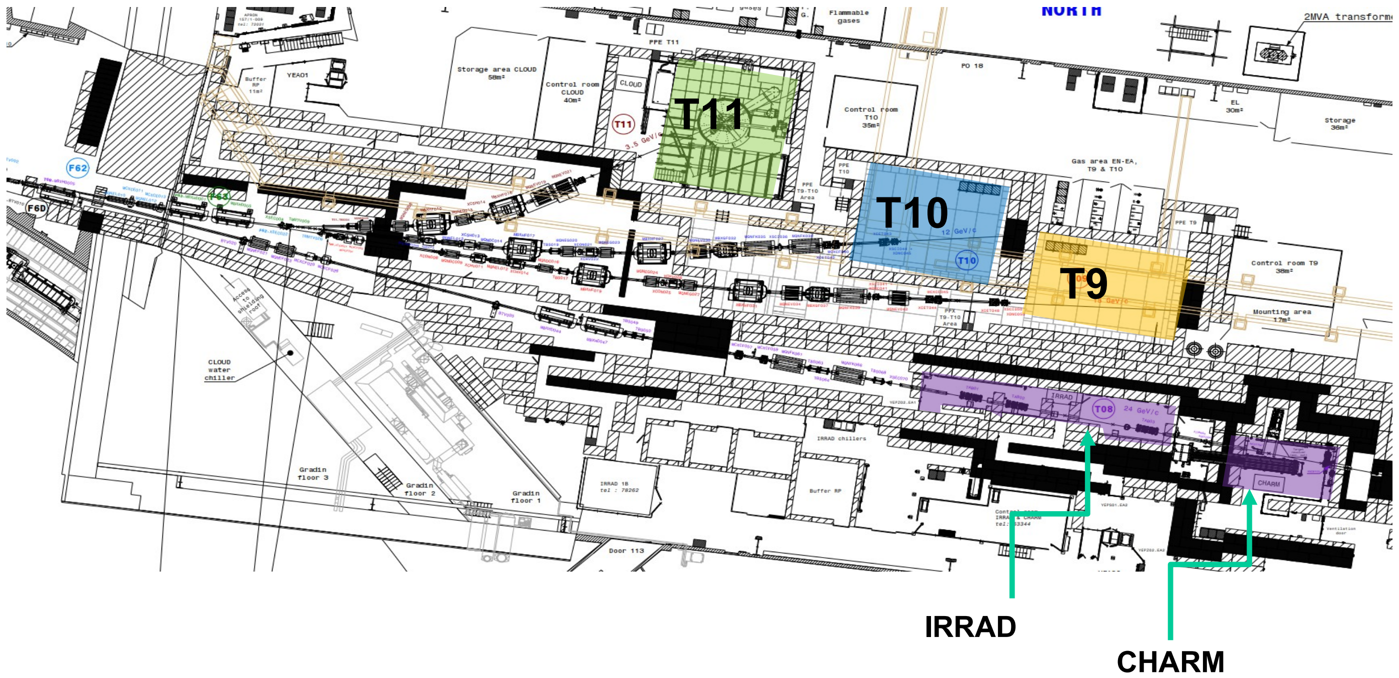
Detector/physics studies



- Software plays a central role in calorimeter development
- Validation of hadronic cascades in beam tests to guide full detector/full simulation studies
- In turn, realistic event reconstruction guides the technical choices
- It is important that Calorimeter R&D projects integrate into common software frameworks as Key4HEP
  - Better comparability of results
  - Facilitates porting of e.g. beam test results to full simulation studies
  - Facilitates switching between beam test studies and physics studies

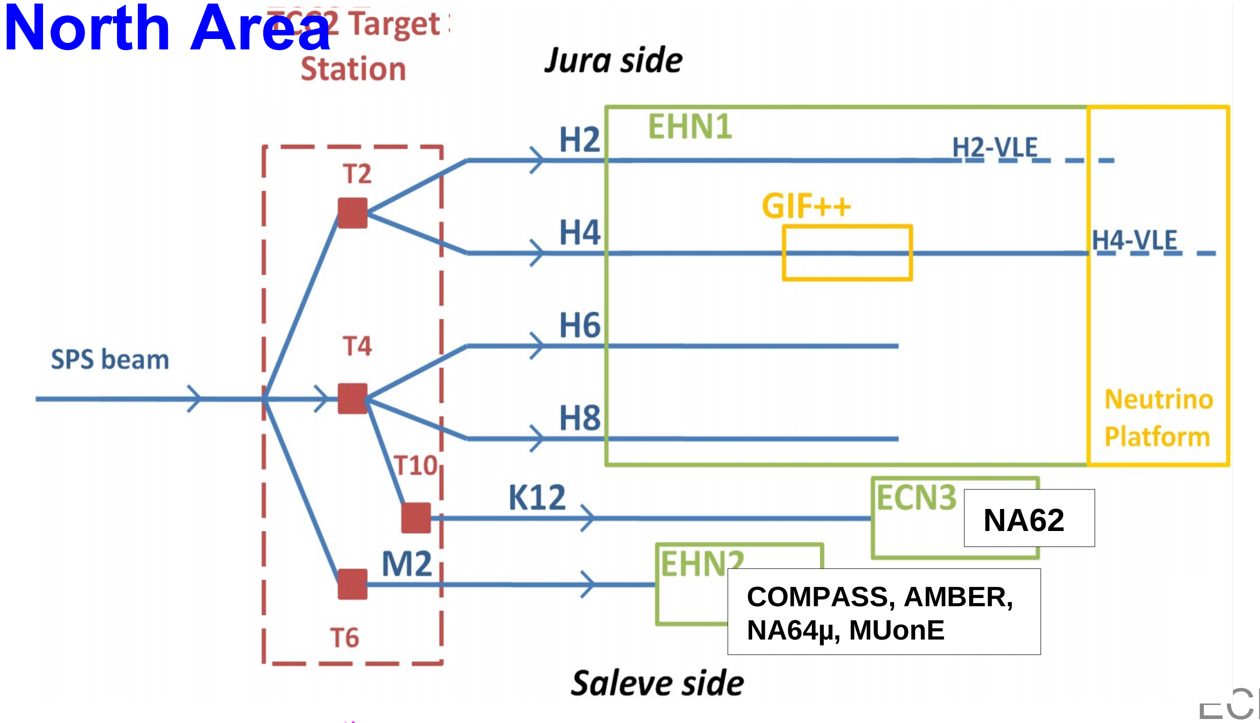
Testbeam facilities – CERN

New East Area



Parameters		
Secondary Beam Line	T9	T10
Momentum [GeV/c]	0.3 – 15 GeV/c	0.3 – 12 GeV/c
Maximum p/p [%]	± 15 %	± 15 %
Maximum Intensity / spill	$5 \cdot 10^6$	$5 \cdot 10^6$
Particle Types	(pure) electrons, hadrons, muons	

North Area

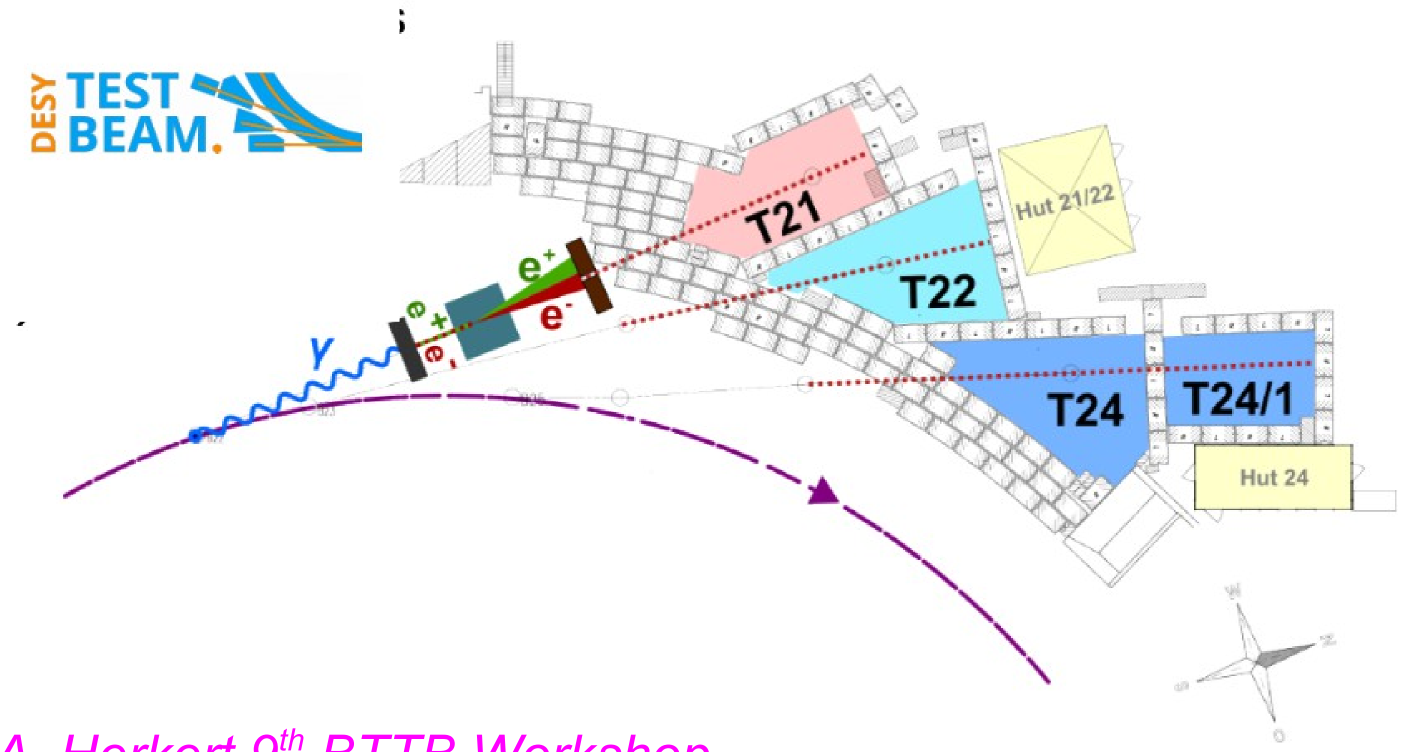


Parameters	T2		T4	
Beam Line	H2	H4	H6	H8
Maximum Momentum [GeV/c] primary p beam / secondary beam	400 / 10–380	400 / 10–380	n.a. / 10–205	400 / 10–360
Beamline Maximum Acceptance [µSr]	1.5	1.5	2	2.5
Beamline Maximum p/p	± 2.0 %	± 1.4 %	±1.5 %	±1.5 %
Maximum Intensity / Spill * (Hadrons / Electrons / Muons)	107 / 105 / 104	107 / 106 / 104	107 **/105/104	107 ** / 105/104
Primary Beams (ions in certain years)	p, ions	p, ions	n.a.	p, ions
Derived Beams (from p beams)	electrons OR muons OR mixed hadrons (/K/p)			
Secondary Ion Beams (in certain years)	fragmented ions	fragmented ions	n.a.	fragmented ions

* Imposed by Radio Protection, and not available to every zone
** In some zones can be elevated up to 108 subject to certain restrictions

E.B. Holzer 9th BTTB Workshop

Testbeam facilities – DESY and other facilties



A. Herkert 9th BTTB Workshop

- Three beam lines T21, T22, T24
  - Extracted independently via Bremsstrahlungstargets
  - From DESY II Storage Ring
- e+ or e- beams, 1-6 GeV
- Rate O(1kHz), dependent on energy

- Further facilities
  - Irradiation facilities (GIF++, IRRAD, JSI Triga, U.o.B Cyclotron)
  - Small(er) energy facilities (e.g. ELSA/Bonn, BTF@LNF)
  - Oversea facilities
    - **Fermilab**, SLAC (?)
    - Tohoku

Testbeam facilities – General remarks

- Let us first thank the beam test and radiation facilities operators and the lab and institute managements for the availability of the facilities

- The importance of beam tests during detector development cannot be overrated
  - Recent refurbishment of various beam test sites witness that this is recognised by the lab managements

- Maybe more than other detectors calorimeters need a large variety of particle momenta, particle types and beam rates

- The portfolio of the EPPSU comprises projects supposed to run between now and 2080-2090
  - During all these decades we need versatile beam test and radiation facilities to accompany the R&D program
  - ... including competent staff to run these facilities (-> investment in accelerator and instrumentation experts)
  - Maybe some steps can be executed with powerful computing, AI or whatever the future brings
  - However, it can never be desirable that the first beam a detector sees is the beam in the final experiment
    - Despite the fact that the return vessel of Apollo 11 has also never been tested before ;-)

- A future hadron collider would require to make a test beam facility part of the LHC programme

From TF1 Symposium - Recognition

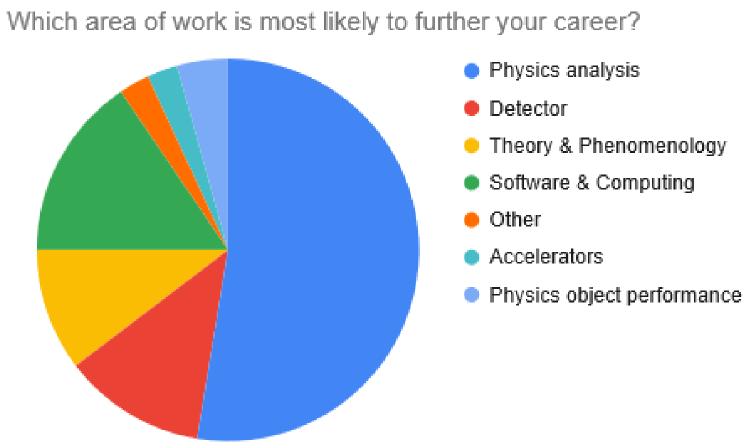
- Hard to preserve knowledge and know-how, people, equipment, infrastructures,..
- Difficulties on being funded if not well attached to a project …
- When attached to a project, sometime difficult to preserve the investment done because of a different project phases (moving from instance from R&D to “installation, commissioning, operation”)…
- End of a project can be the end, i.e. everyone busy (lost) in new proposal/applications/calls…
- Difficulties on getting people and offering a perspective: not the best entry point for a career (*) – sometimes hard to get students or post-doc - trained researchers have often to leave…
- Note also that in CMS only 1/3 of the students are involved in the upgrade projects

Report on the ECFA Early-Career Researchers Debate on the 2020 European Strategy Update for Particle Physics

The ECFA Early-Career Researchers

February 6, 2020

https://cds.cern.ch/record/2708708/files/2002.02837.pdf



(*) Early-Career Researcher (PHD and post-DOC) perception

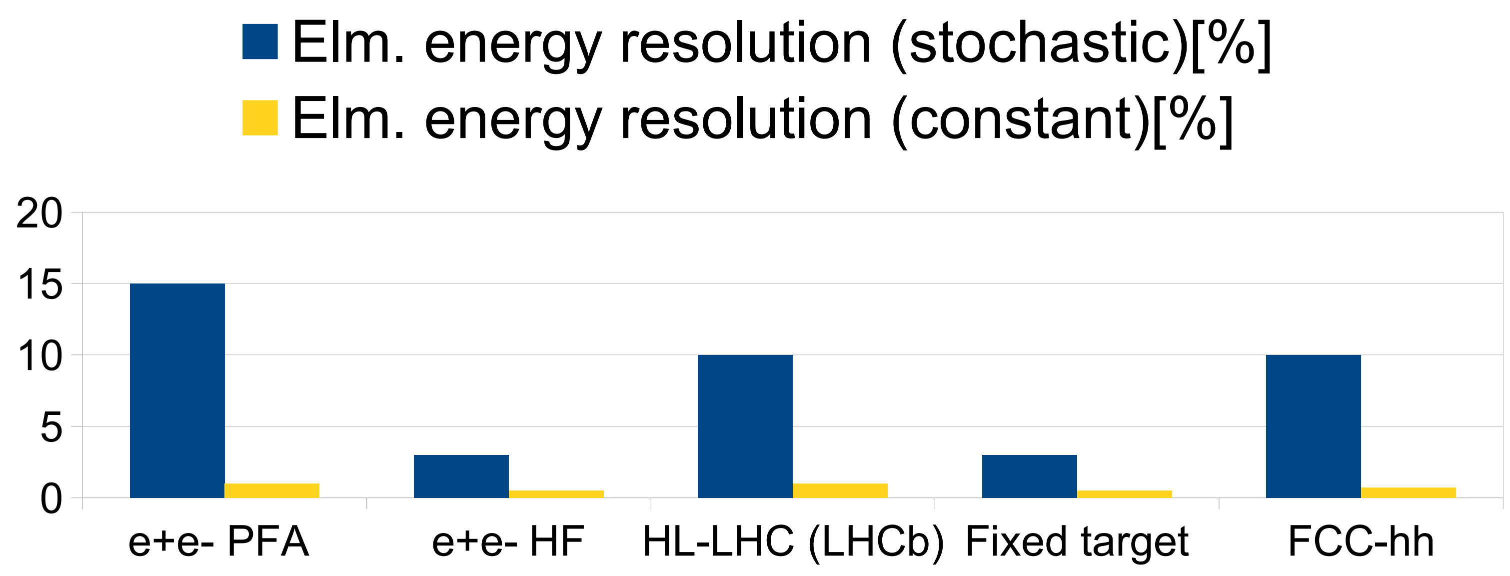
Eraldo Oliveri, TF1 Symposium
+ supplementary remark on CMS

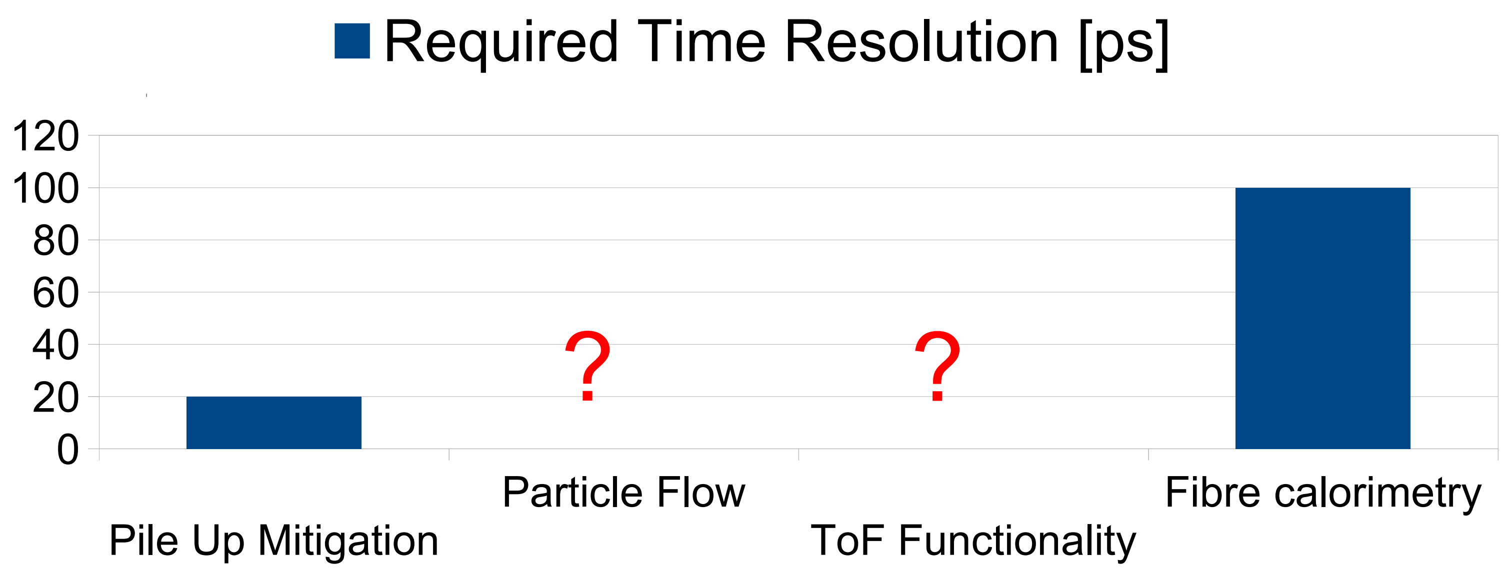
Collaborations and Networks

- European projects such as AIDAinnova (start 4/2021)
- CERN EP-Programme
- Existing collaborations (LHC Experiments, Belle II, DUNE, NA62, KLEVER, ...)
- R&D Collaborations (CALICE, FCAL, CrystalClear, ...)
- Proto collaborations (ILD, SiD, CLICdp, FCC, IDEA, EiC)

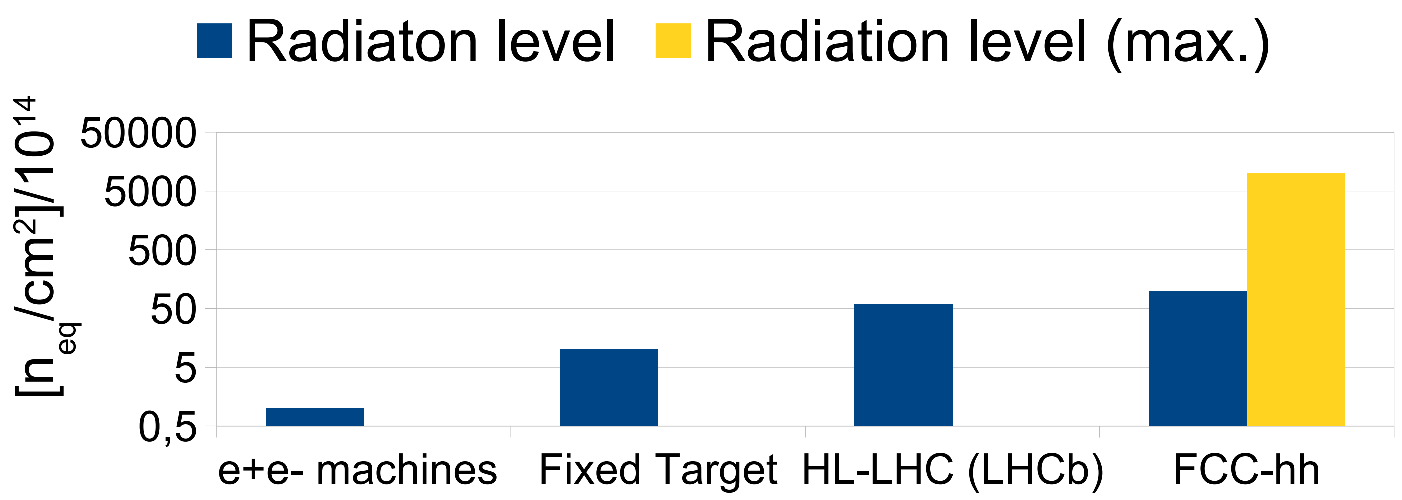
Backup

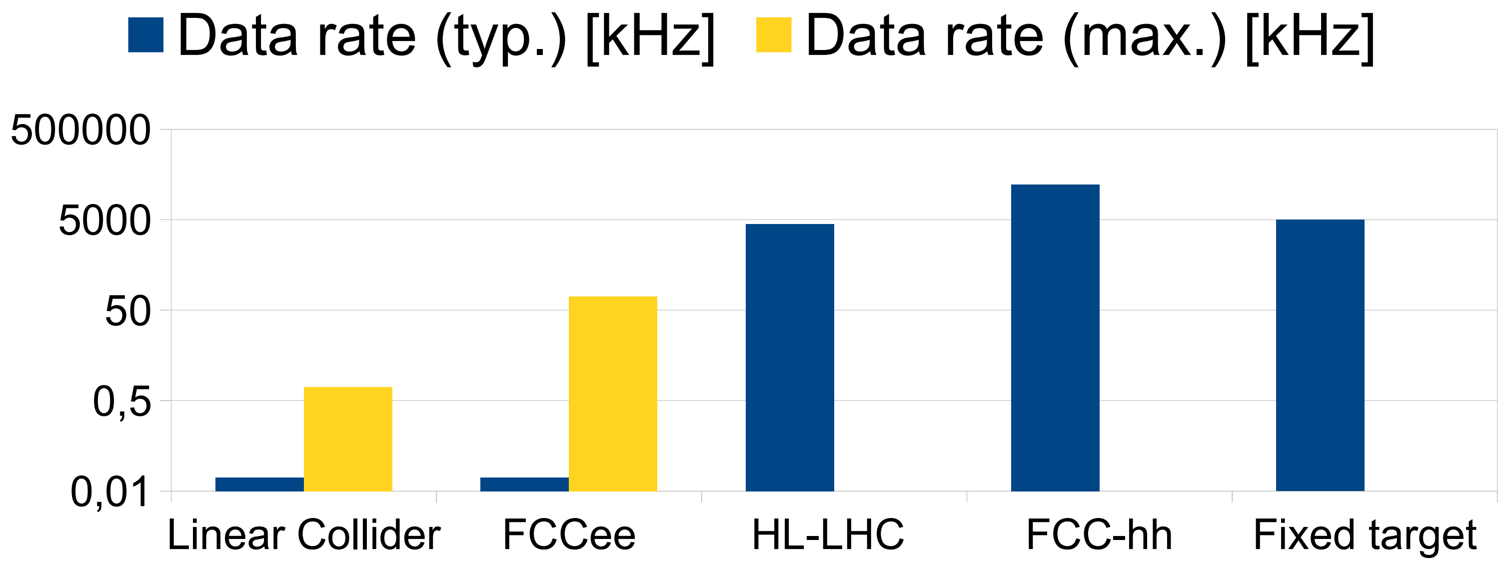
ECFA Summary tables on Requirements and Running Conditions– An Attempt





- Hadronic energy resolution must not compromise PFA performance
- Current R&D proves/targets O(30%-40%)/√E





- pp collision rate at HL-LHC and FCC-hh
- Physics rates at e+e- colliders
  - Note bunch train structure at Linear Colliders