Claude Vallée
CPPM/DESY

“Highlights and Visions of LC Detectors”

LC detector specifications
Subdetector technologies
Global detector concepts
Towards detector Collaborations

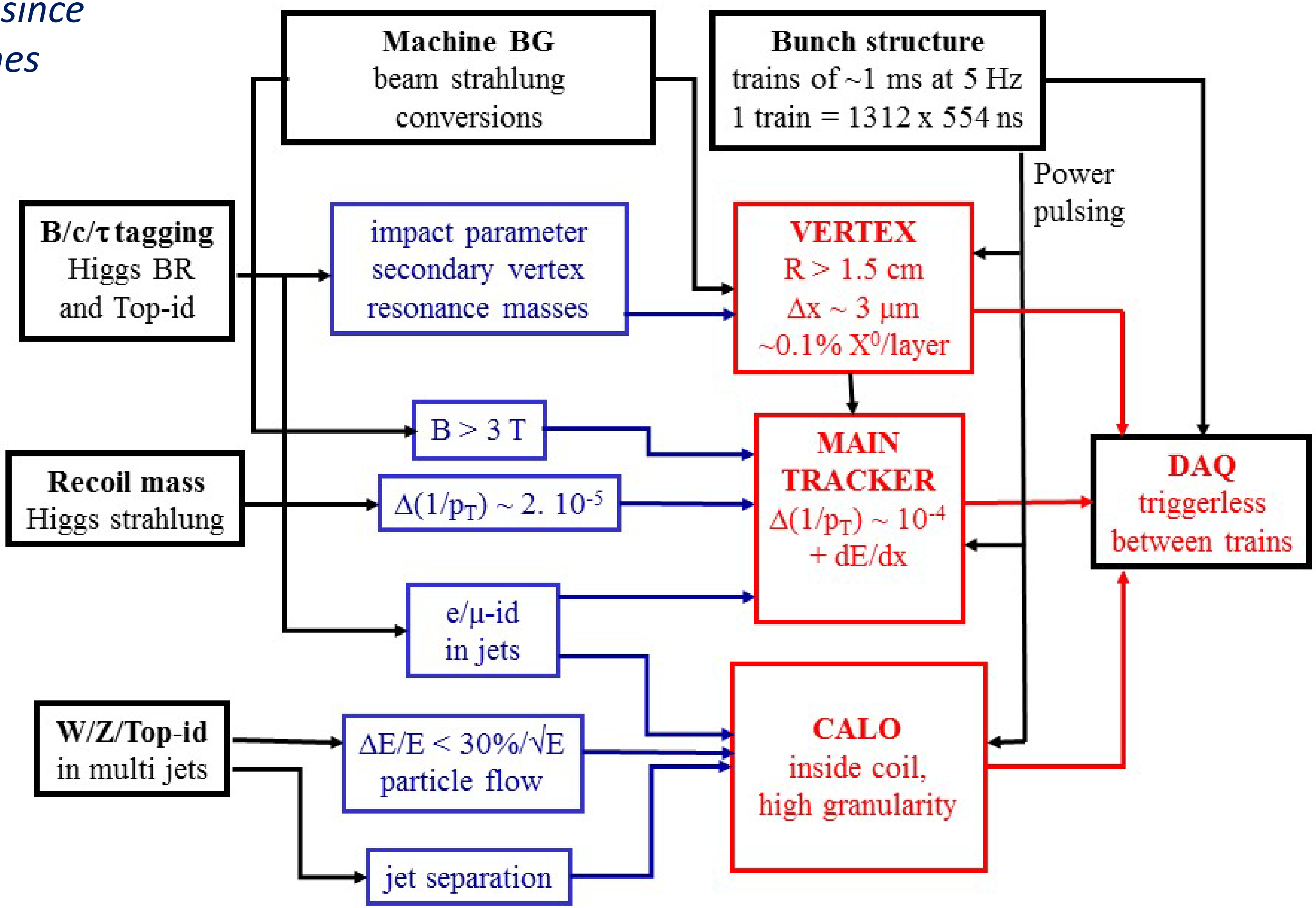
Disclaimer: not a technical expert review, but a personal view on the main issues.

[nn] refers to parallel session speakers for details

LC DETECTORS SPECIFICATIONS

ILC CASE

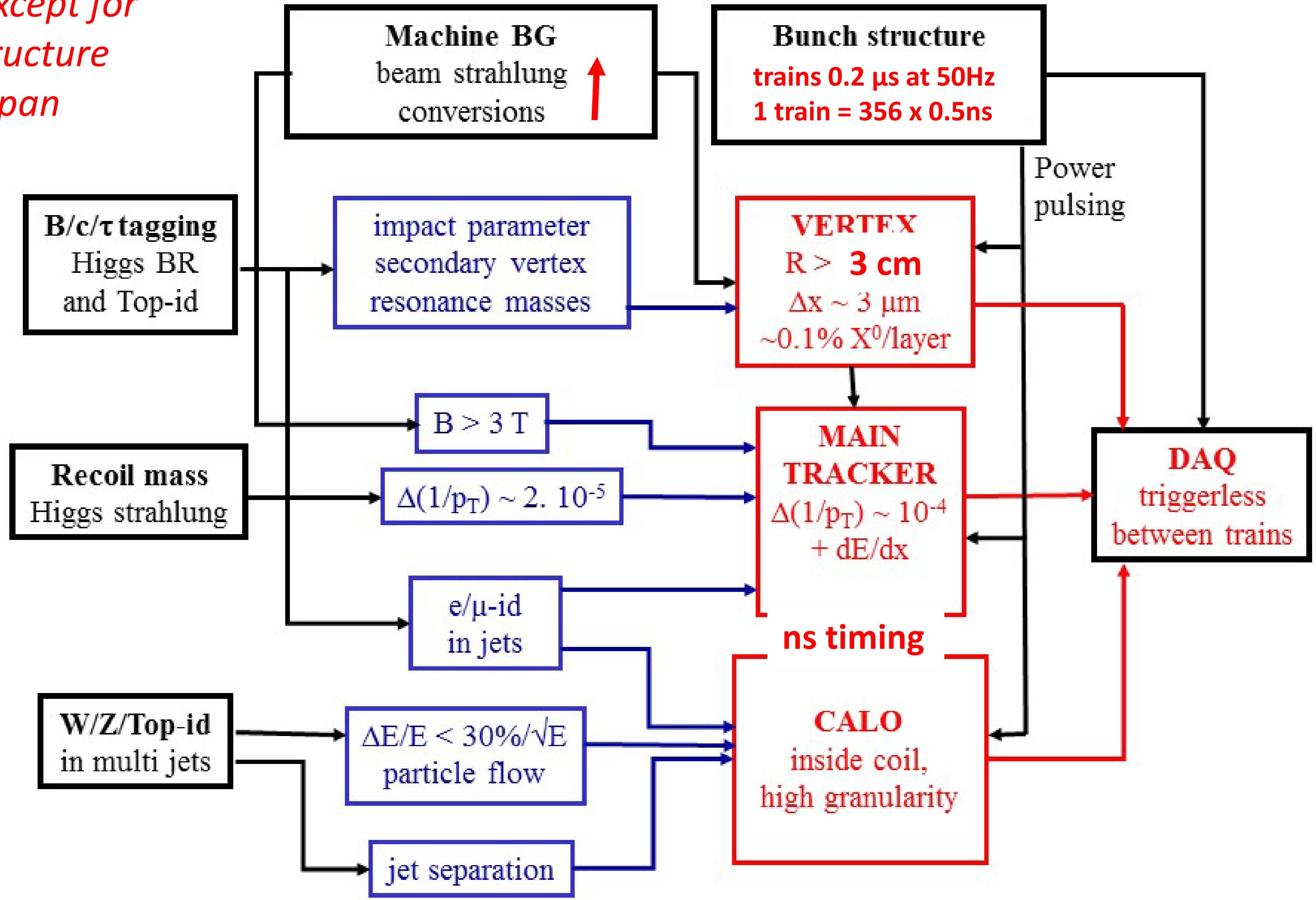
~unchanged since TESLA times



LC DETECTORS SPECIFICATIONS

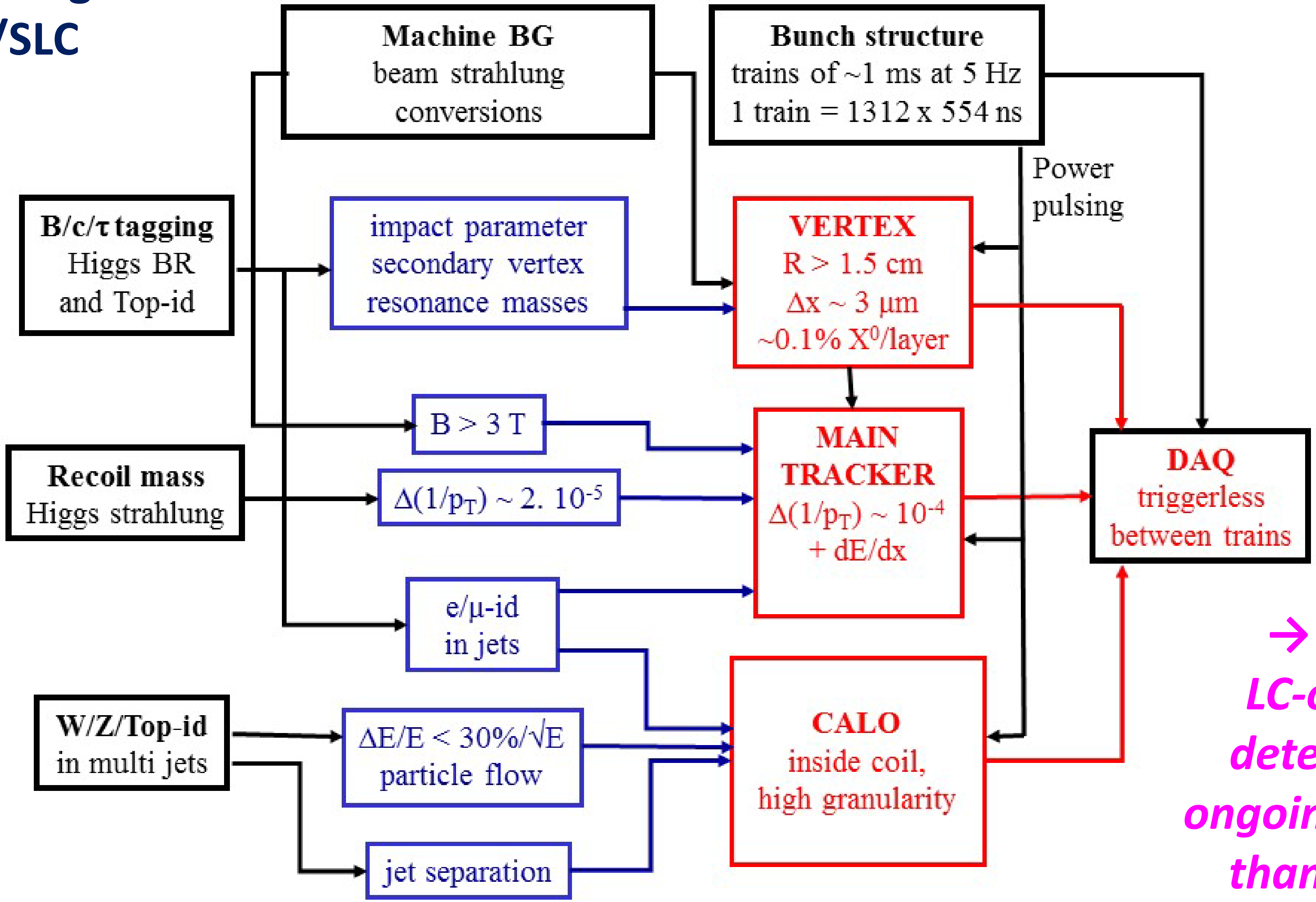
CLIC CASE

similar to ILC except for beam BG&structure + energy span



LC DETECTORS SPECIFICATIONS

Very different from LHC, much more stringent than LEP/SLC



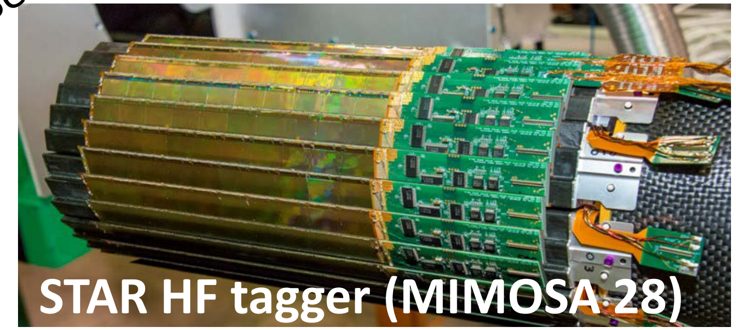
→ steady LC-oriented detector R&D ongoing for more than 15 years

SUBDETECTOR TECHNOLOGIES: SILICON for VERTEX

ILC-oriented long-standing R&D getting mature within many experiments worldwide

[Besson]

CMOS pixels



<u>CMOS developments</u>:
ALPIDE (ALICE upgrade)
MIMOSIS (CBM)
PSIRA (ILD)
…

<u>CMOS critical</u>: RO speed (BC tagging)/power/material

[Marinas]

DEPFET pixels

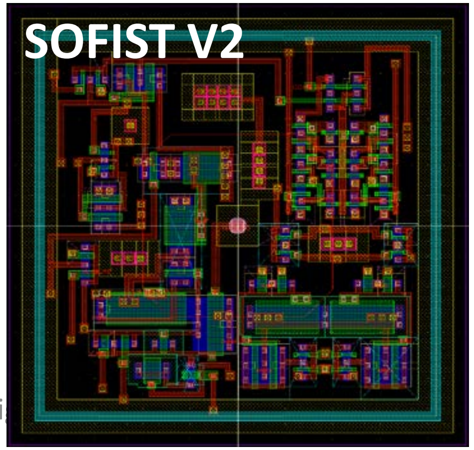
<u>DEPFET critical</u>: Large scale production & integration

Many other options under study

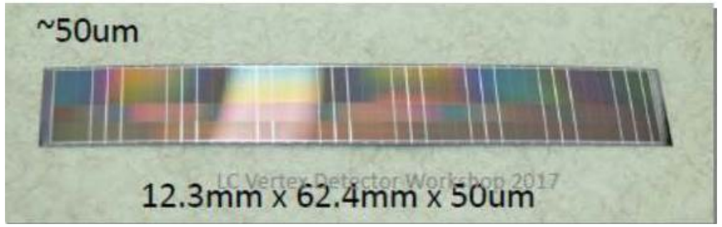
SiD CMOS Chronopixels
for ILC BC time stamping
V3 under test

Thinned SOI pixel for both x&t resolution
Beam tests show o(μs) time resolution

[Yamada]



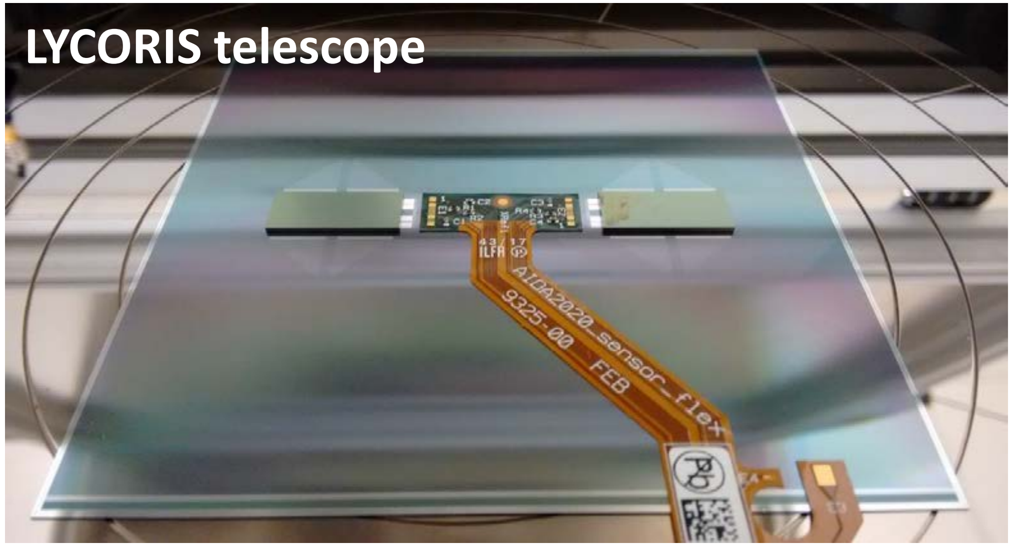
… and also FP-CCD
Large prototype ladder



SUBDETECTOR TECHNOLOGIES: SILICON for VERTEX&TRACKING

[Wu] **SiD strip tracker**

Sensors and KPIX ASIC implemented in DESY testbeam telescope

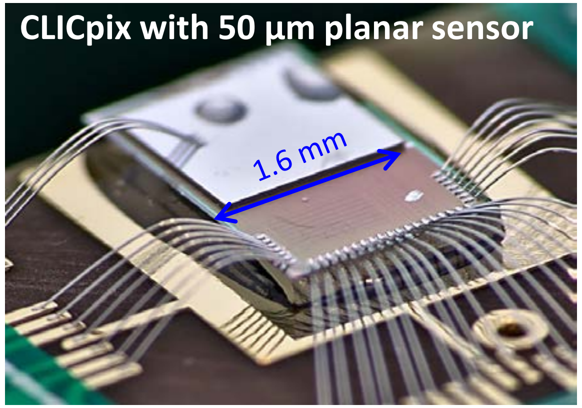


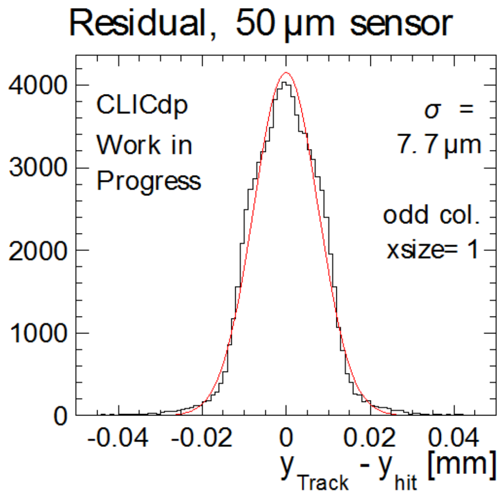
KPIX: universal Si-chip with ~0.5µs BC tagging for tracker&calo

CLIC-oriented R&D

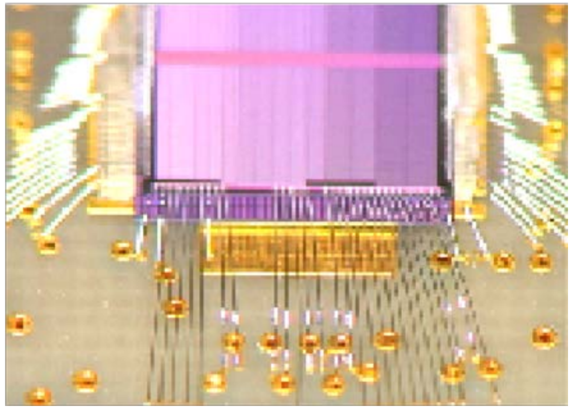
focus on HV/HR/SOI Si for timing purpose

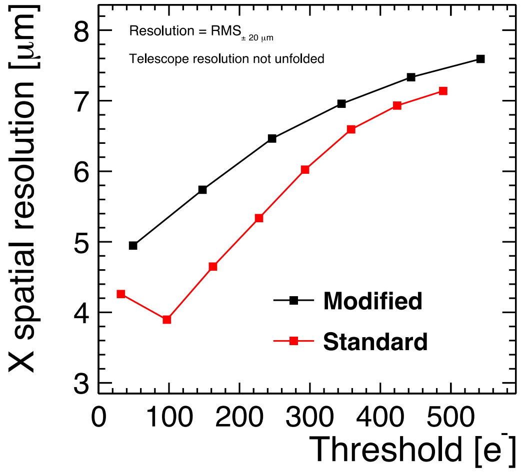
Hybrid pixels





INVESTIGATOR HR-CMOS test chip





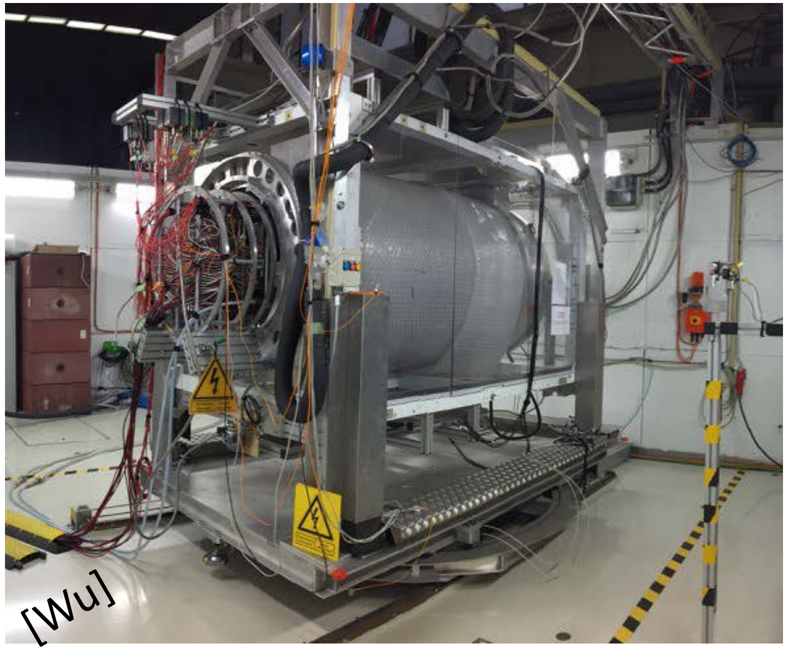
NB: frontier between pixels and strips not frozen, general trend towards more pixelization

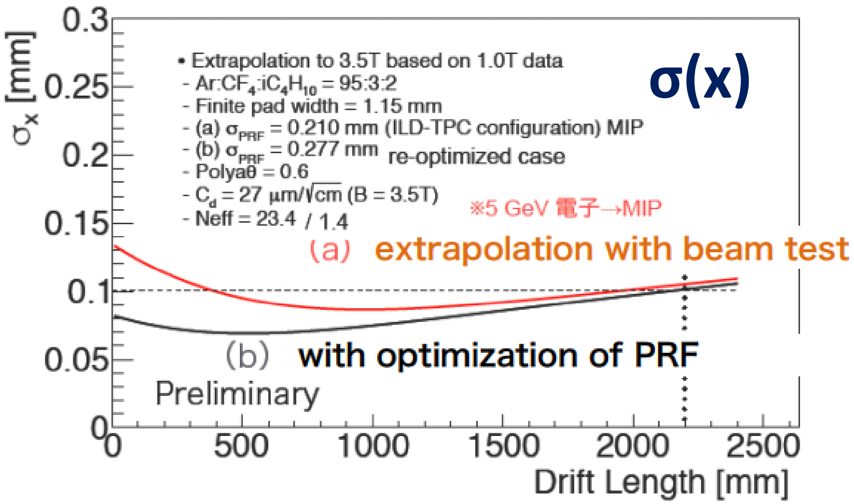
SUBDETECTOR TECHNOLOGIES: TPC for TRACKING

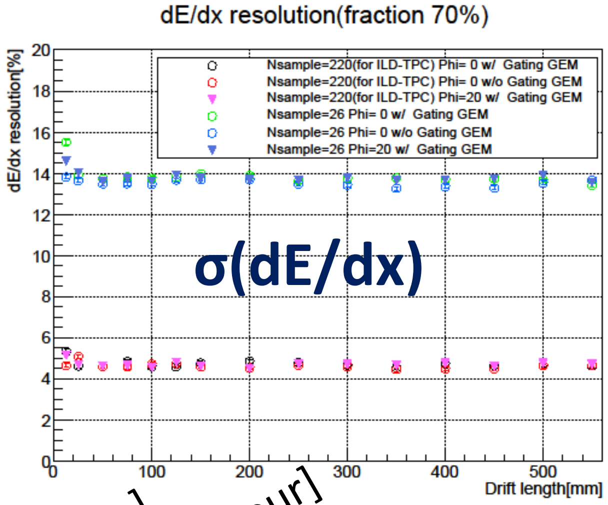
LC-TPC permanent setup available at DESY in test beam →

Micromegas/GEM/pixel RO options under development

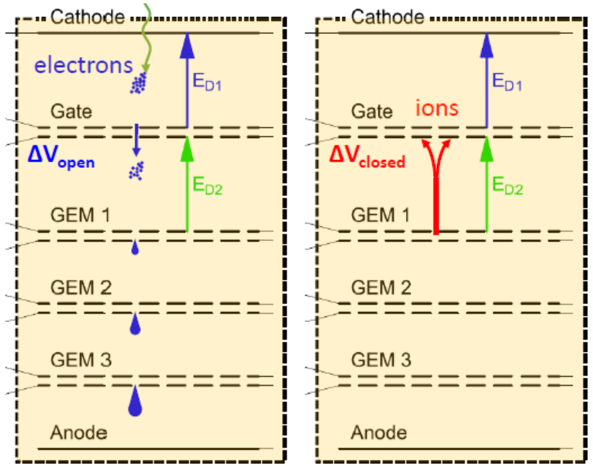
Required 100 µm spatial and 5% dE/dx resolutions achieved





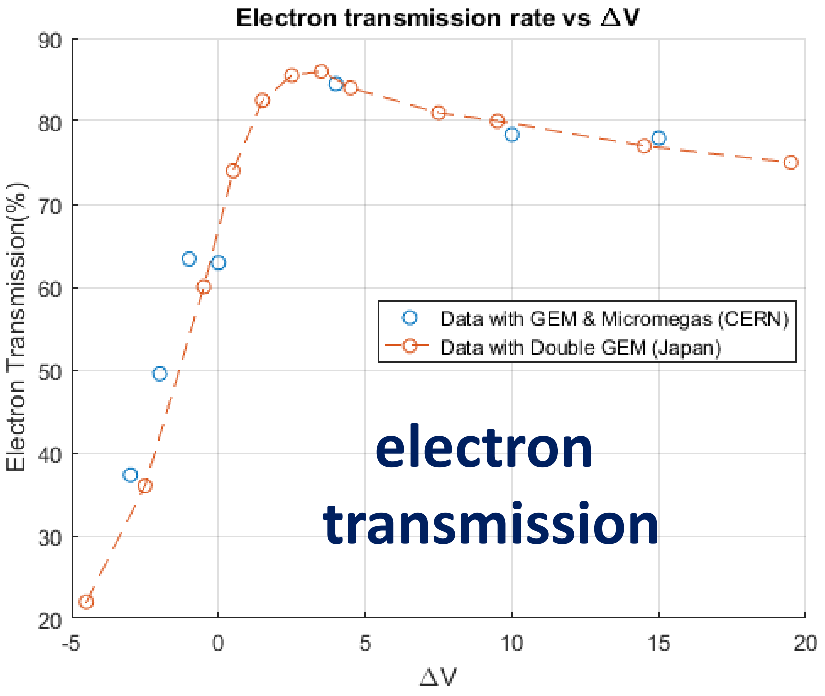


[Shoji] [Colas] [Ganjour]



Ion gating scheme with GEMs validated with good electron transparency

[Aoki]

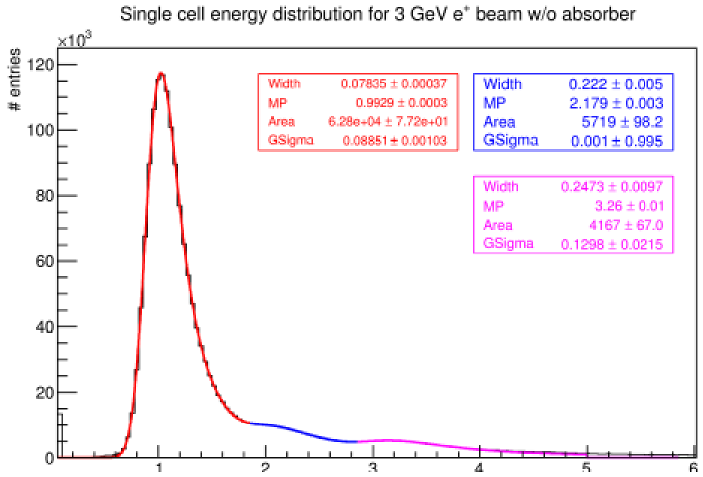


SUBDETECTOR TECHNOLOGIES: ELECTROMAGNETIC CALORIMETRY

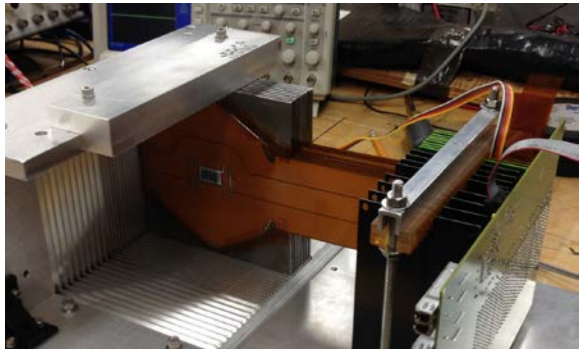
Si-W is the baseline option of all 3 consortia (scintillator also considered [Yoshimura])

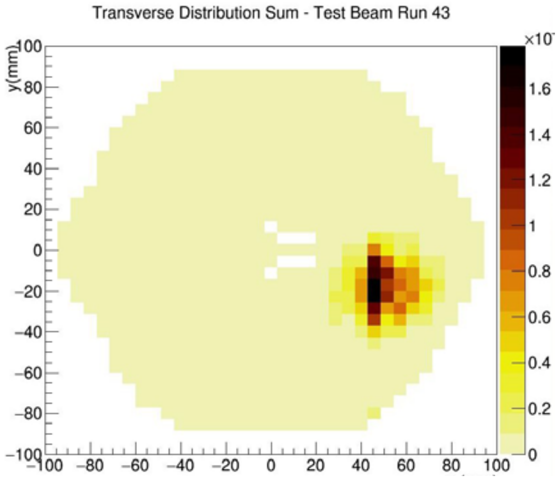
CALICE (ILD/CLICdp) technological prototype

[Sekiya]



SiD prototype





Very good signal/noise achieved in beam tests, *adopted by CMS HGCAL*

Technological solutions for large calo (long slabs) under development

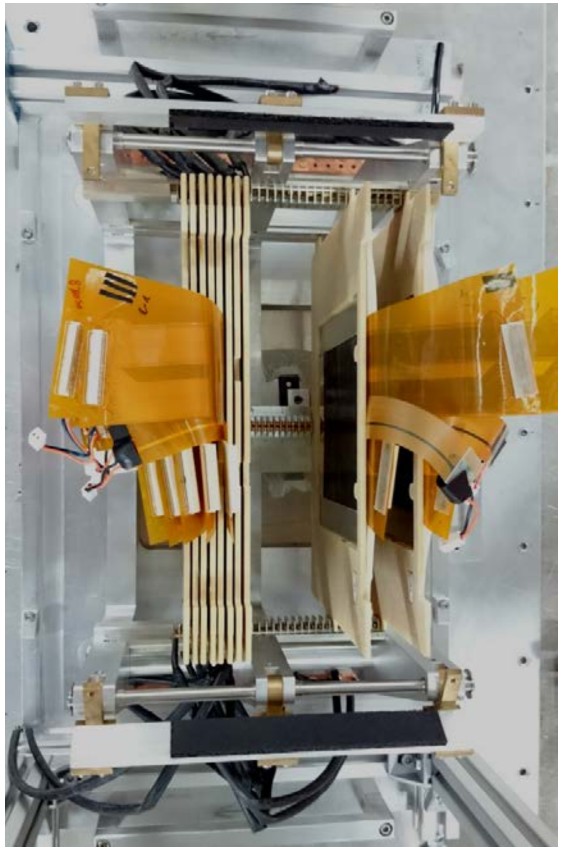
Industrial challenge: large arrays of low cost Si sensors (cost driver)

SUBDETECTOR TECHNOLOGIES: ELECTROMAGNETIC CALORIMETRY cont'd

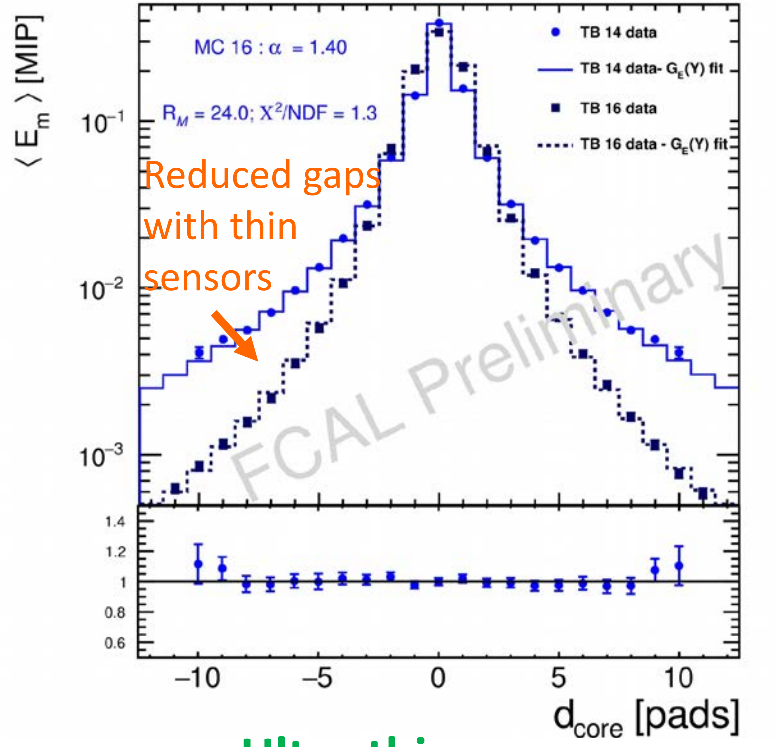
Similar solutions as for central ECAL foreseen with Si/GaAs/sapphire/diamond sensors for the very forward LUMICAL&BEAMCAL monitors

[Borysova]

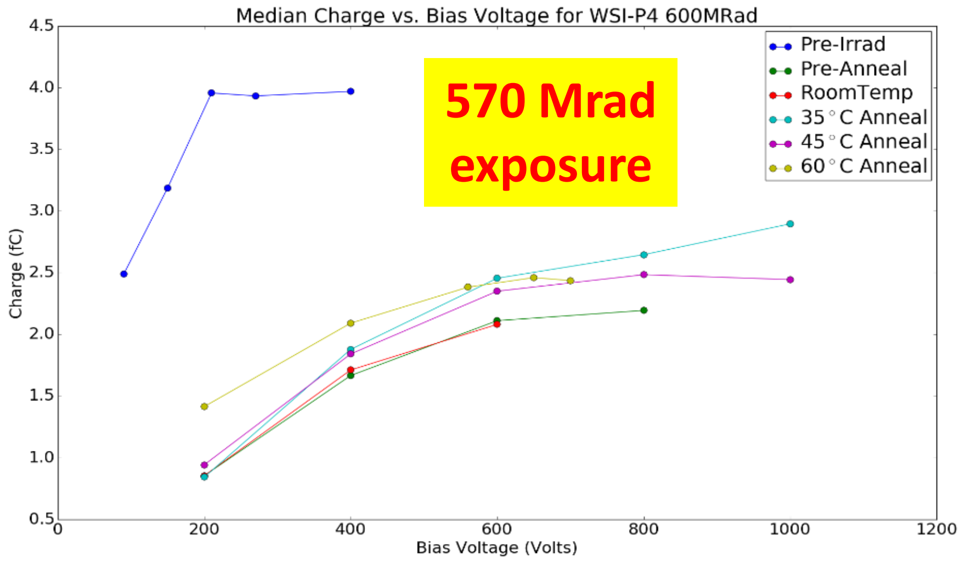
Critical in this region: EM shower compactness, radiation hardness



FCAL Si-prototype



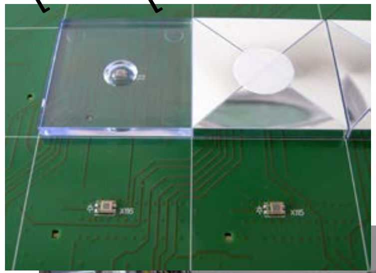
Ultra-thin sensors allow sharpening of the EM shower

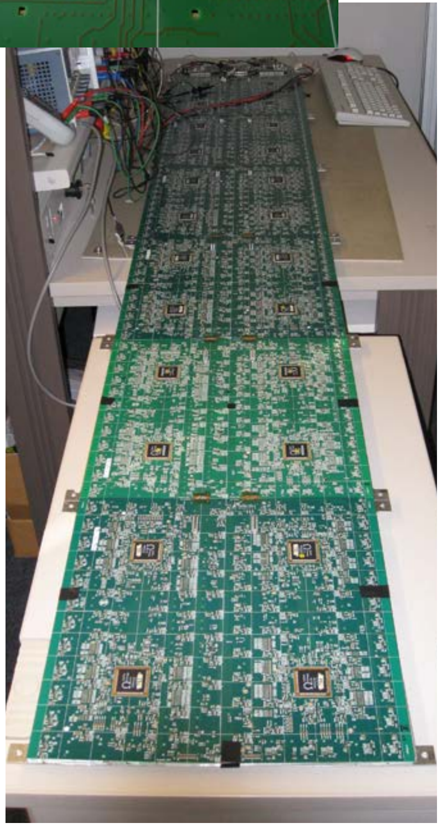


Irradiation measurements performed at SLAC by SiD

SUBDETECTOR TECHNOLOGIES: HADRONIC CALORIMETRY

[Sefkow] [Tsuji]

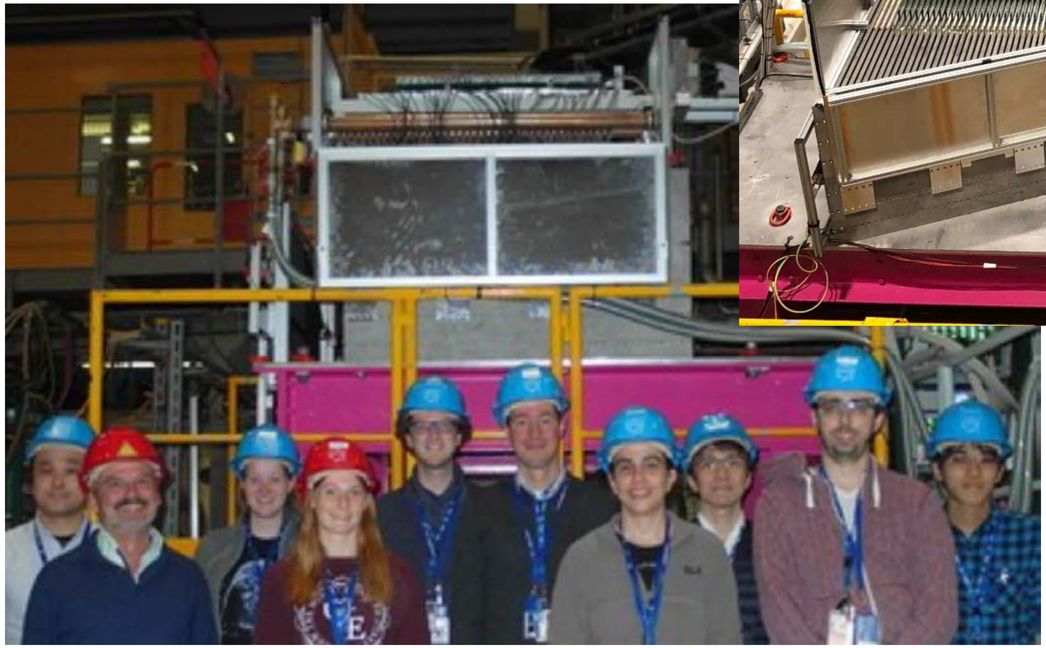




Scintillator pads+SiPM considered by all 3 consortia

~1m^3 technological prototype (22000 channels!) built by CALICE: very promising results from ongoing beam test at CERN validate scalability.

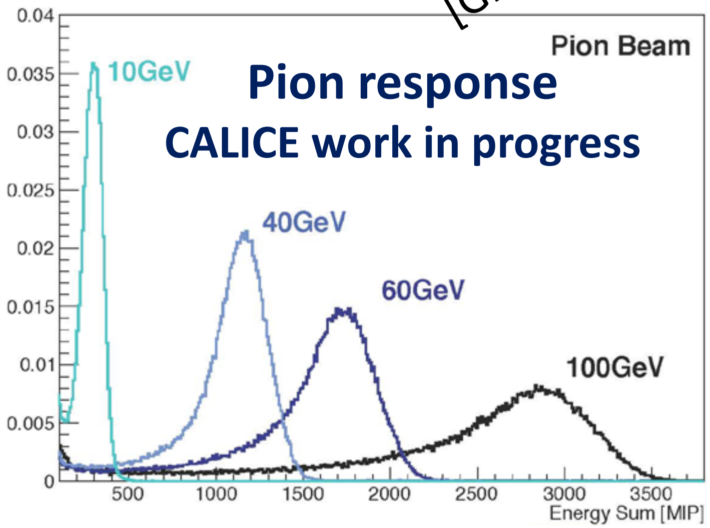
Technology adopted by CMS HGCAL

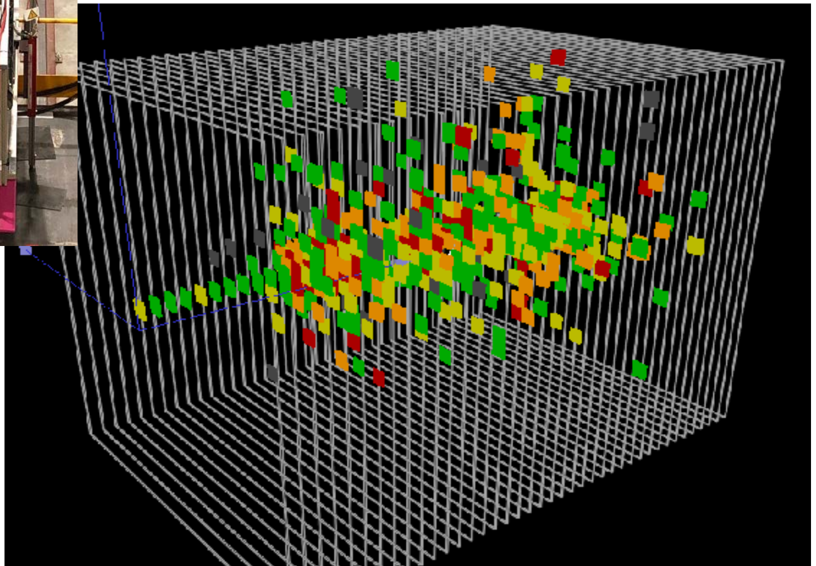


[Graf]

Pion response

CALICE work in progress



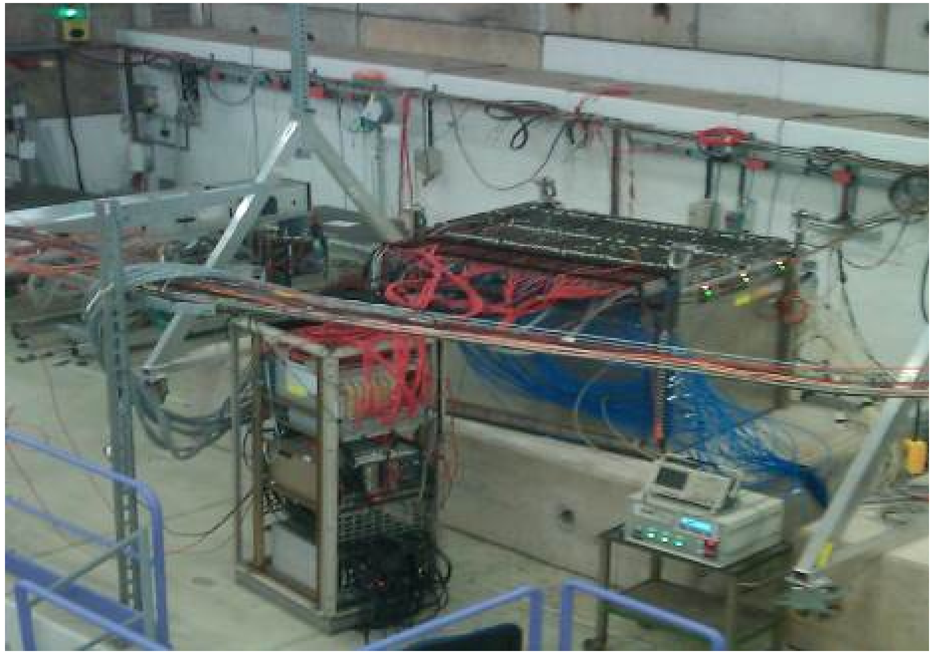


Pion shower in 1m^3 prototype

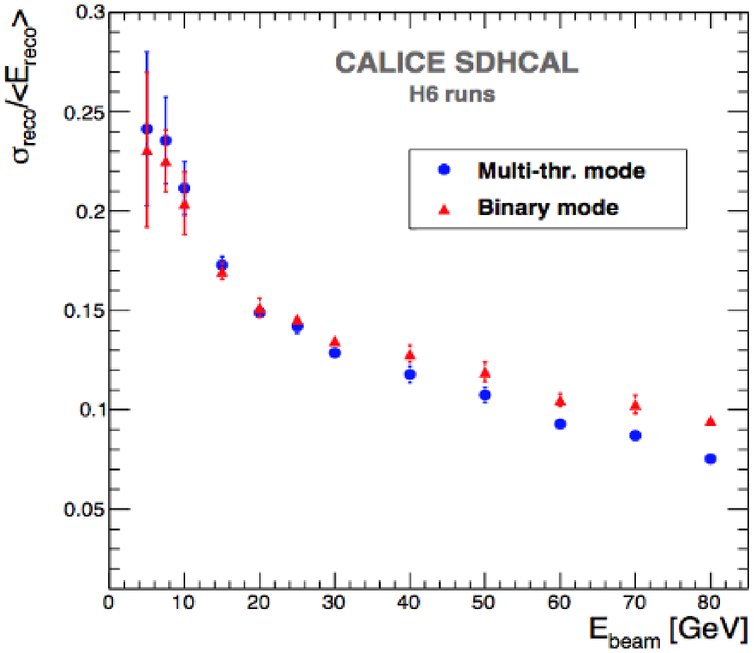
Industrial challenge: low cost SiPMs

SUBDETECTOR TECHNOLOGIES: HADRONIC CALORIMETRY cont'd

RPC option also considered by ILD



~1m³ technological prototype beam-tested at CERN



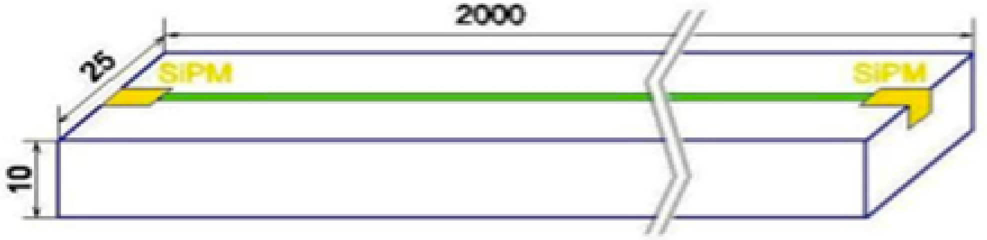
Semi-digital RO improves energy resolution vs digital RO

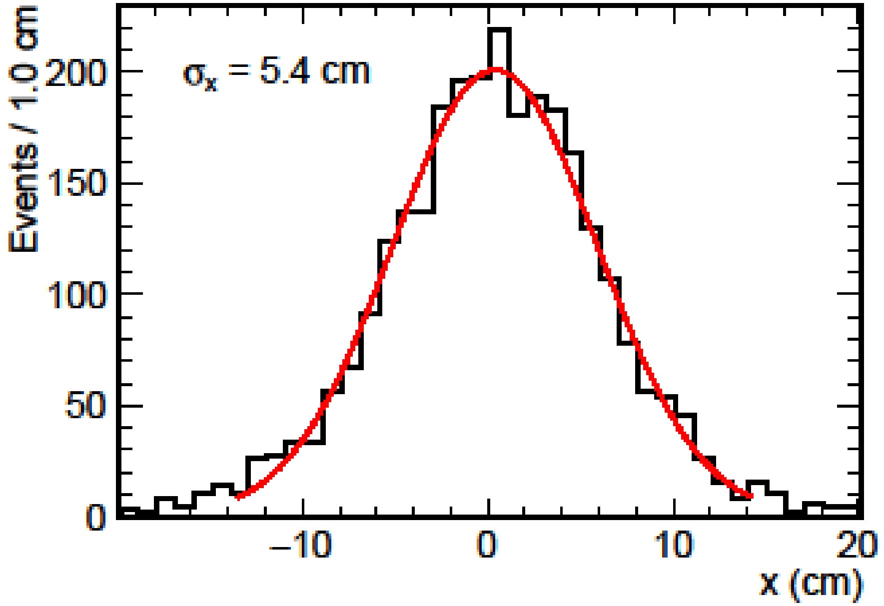
Large RPC planes being developed for full calorimeter

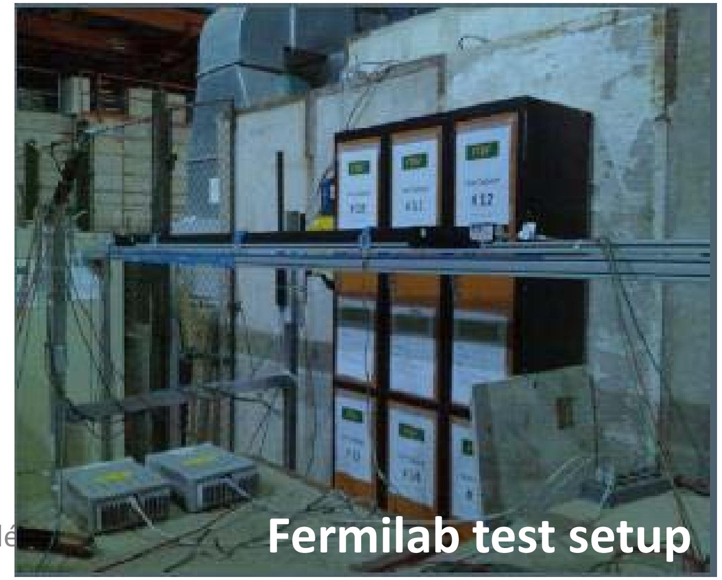
Semi-digital RPC 1cm pads equivalent to analog Scintillator 3cm pads for particle flow

SUBDETECTOR TECHNOLOGIES: IRON YOKE INSTRUMENTATION

Scintillator bars+SiPM considered by all 3 consortia (RPCs also an option [Sun])



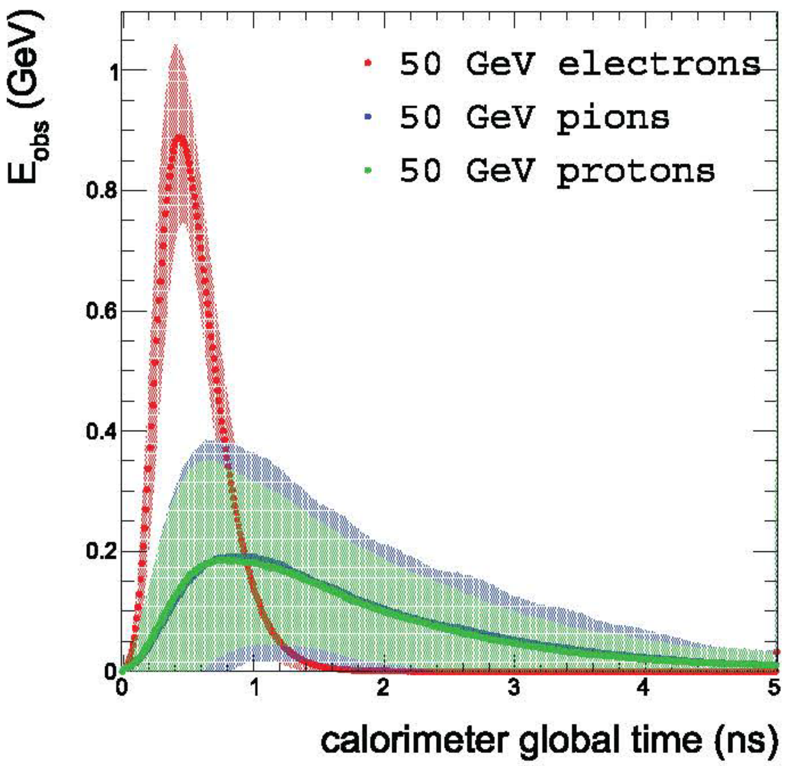


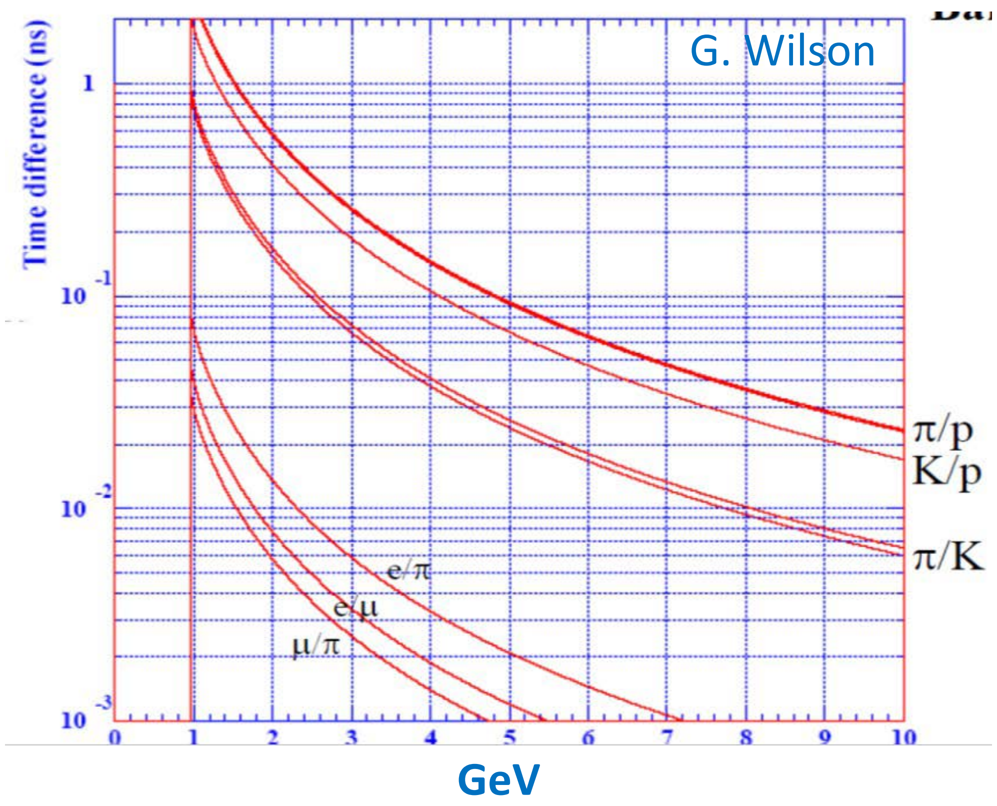

Fermilab test setup

Prototypes built by SiD and tested at Fermilab
Light division shown to provide
the required longitudinal resolution

SUBDETECTOR TECHNOLOGIES: POSSIBLE NEW FEATURES

Example: high precision timing on top of high granularity ?





ns timing in calorimeter may reduce confusion term in particle flow

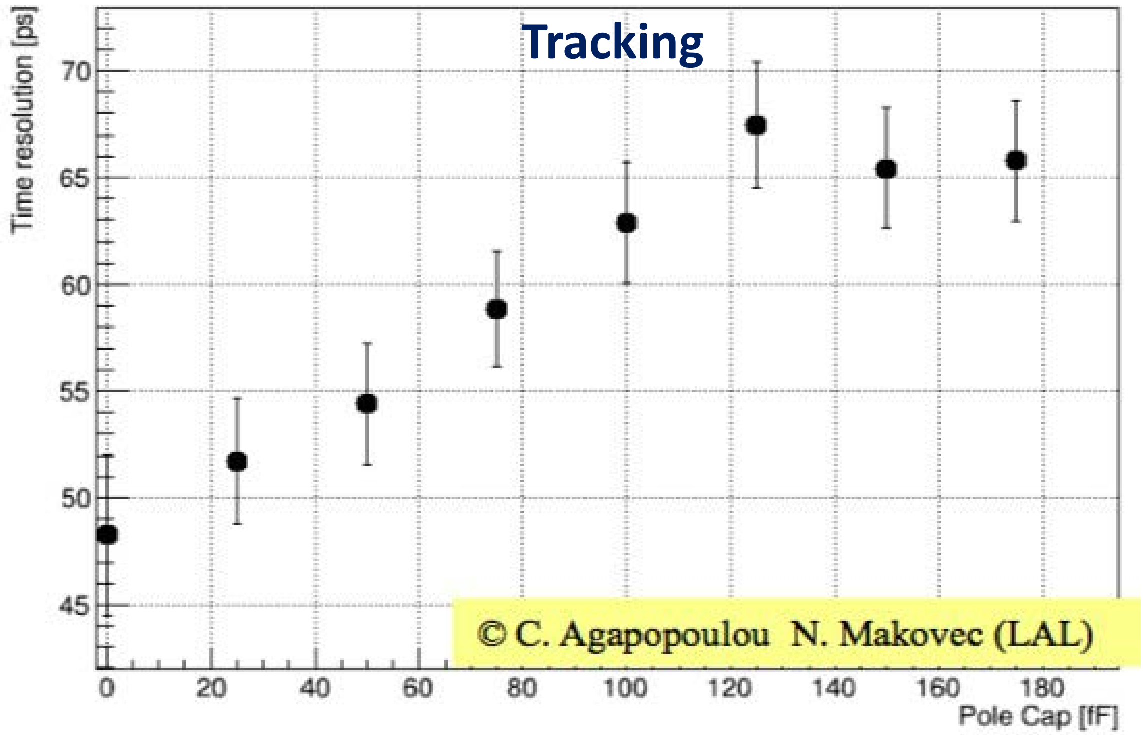
Few 10 ps timing in tracker/calo would allow hadron-Id from TOF in the few GeV range

SUBDETECTOR TECHNOLOGIES: HIGH PRECISION TIMING AT LHC

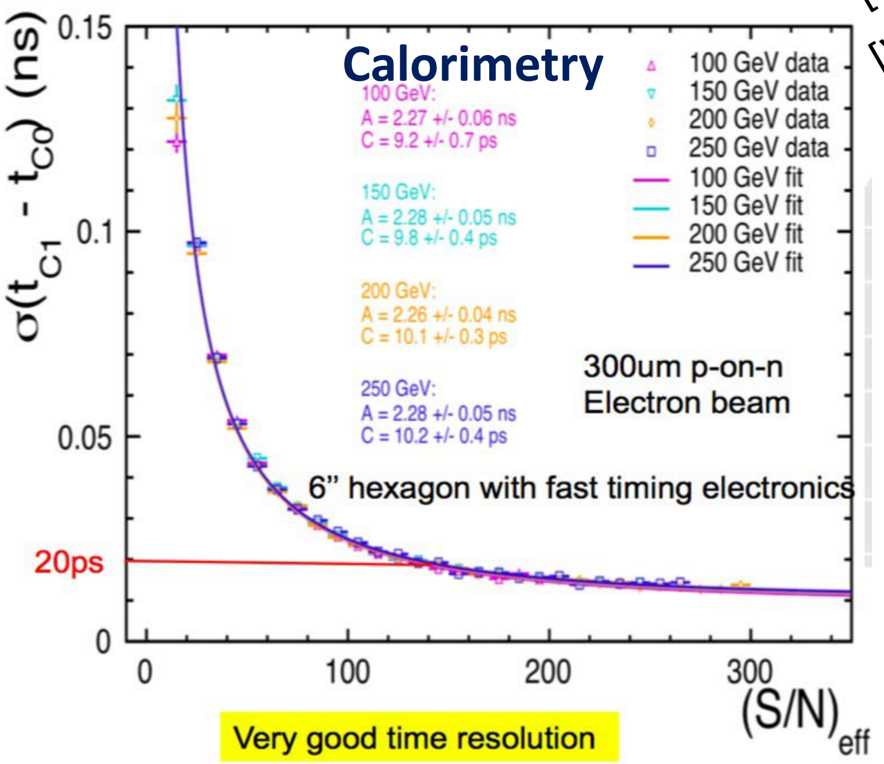
Many LC-oriented R&Ds being implemented in LHC upgrades (e.g. CMS HGCAL) with involvement of some groups of the LC consortia

New precision timing features being added to LHC detectors for HL-LHC

[Paganis]
[Wang]



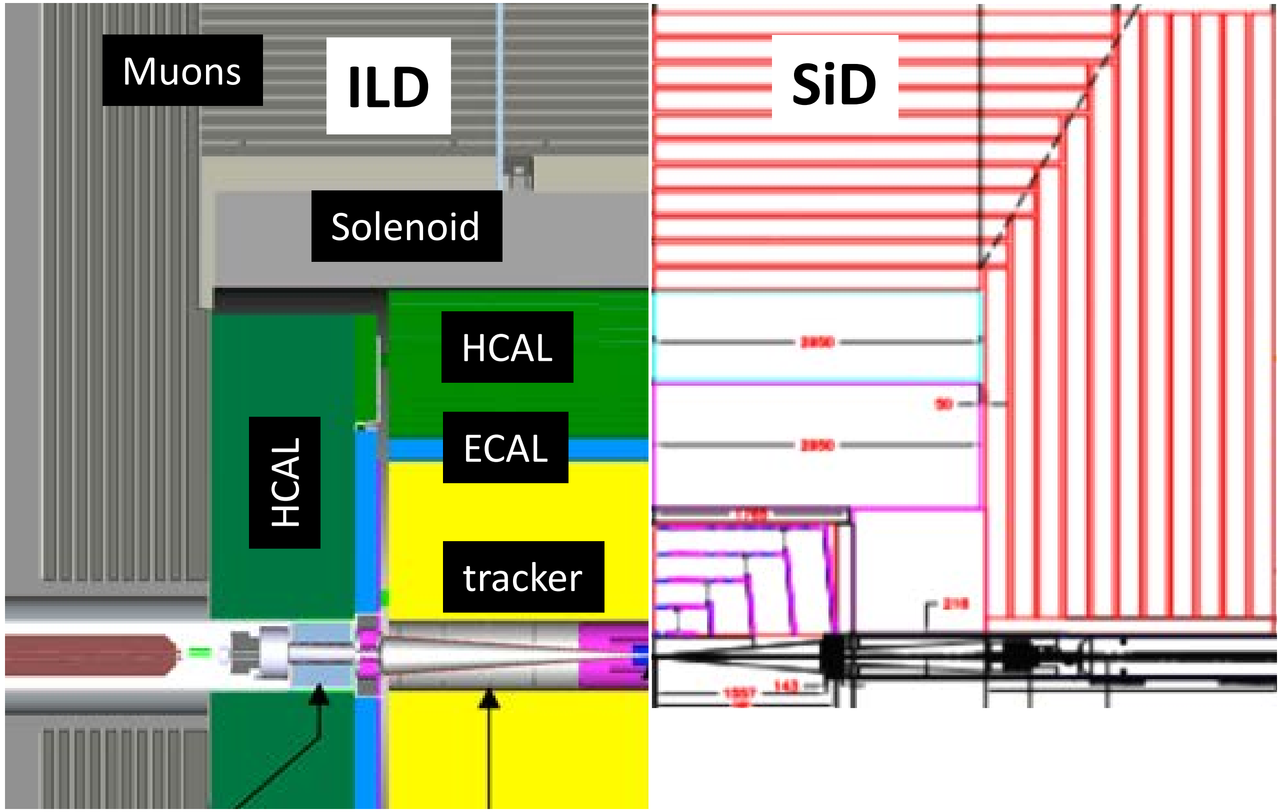
ATLAS Si Low Gain Avalanche Detectors (LGAD)

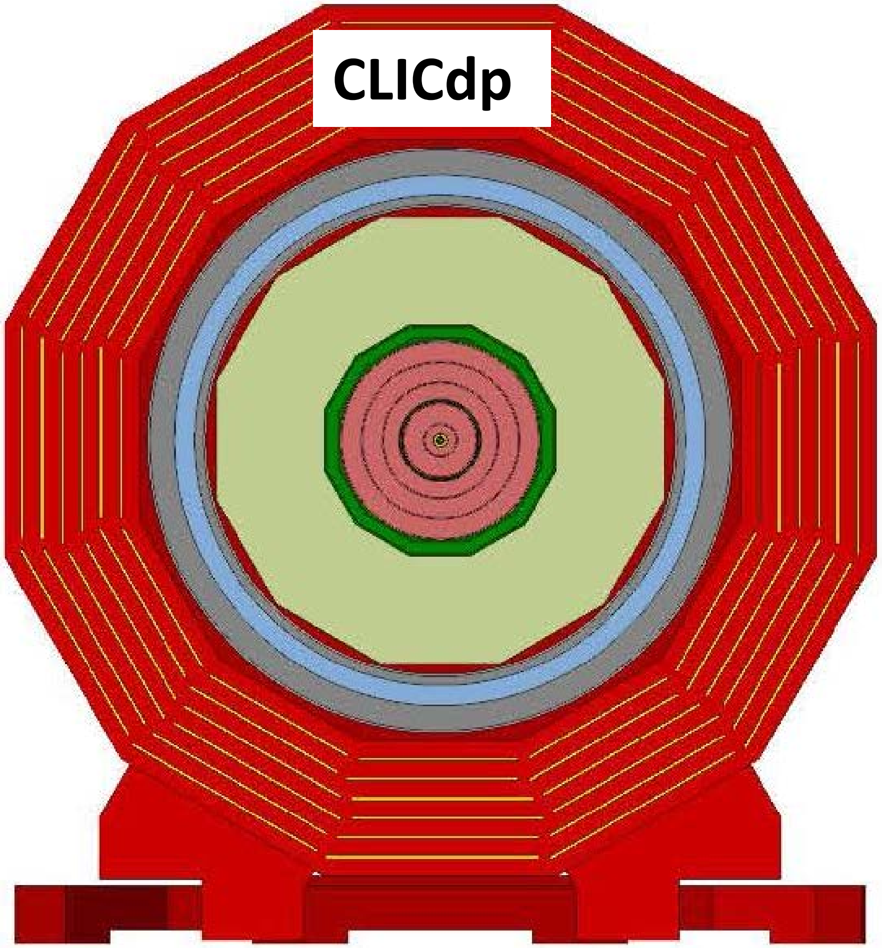


CMS HGCAL Si sensors

NB: at a LC, timing performance will result from a different optimization between power consumption, sensor material and RO speed than at LHC

GLOBAL DETECTOR CONCEPTS





Similar subdetector technologies under consideration by the 3 consortia,
→ strong consortia mixing within the R&D collaborations (CALICE, FCAL.,…)
Main difference: TPC (ILD) ↔ Si tracker (SiD/CLICdp)
Also different starting points for sizes, B fields and mechanical structures

GLOBAL DETECTOR CONCEPTS: sizes

CMS	Inner Radius	SiD (DBD)	ILD_L (DBD)	CLICdp
40	**Vertex (mm)**	14	16	31
1.3	**ECAL (m)**	1.3	1.8	1.5
3.0	**Coil (m)**	2.6	3.4	3.5
3.8	**B-field (T)**	5	3.5	4.0
For reference		**Compact design**	**Expanded design**	**Intermediate tracker size, deeper calo for up to 3 TeV**

NB: all 3 consortia now use the same software environment
→ *should ease comparison of performances*

GLOBAL DETECTOR CONCEPTS: sizes

CMS	Inner Radius	SiD (DBD)	ILD_L (DBD)	CLICdp	ILD_S
40	Vertex (mm)	14	16	31	16
1.3	ECAL (m)	1.3	1.8	1.5	1.5
3.0	Coil (m)	2.6	3.4	3.5	3.1
3.8	B-field (T)	5	3.5	4.0	4.0
For reference		**Compact design**	**Expanded design**	**Intermediate tracker size, deeper calo for up to 3 TeV**	**Same B and tracker size as CLICdp,** ***should allow comparison of TPC and Si tracker***

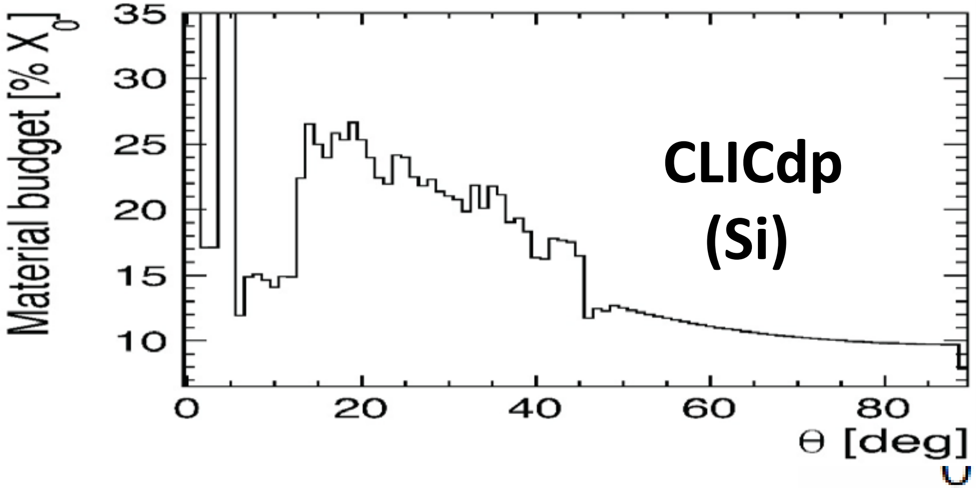
NB: all 3 consortia now use the same software environment

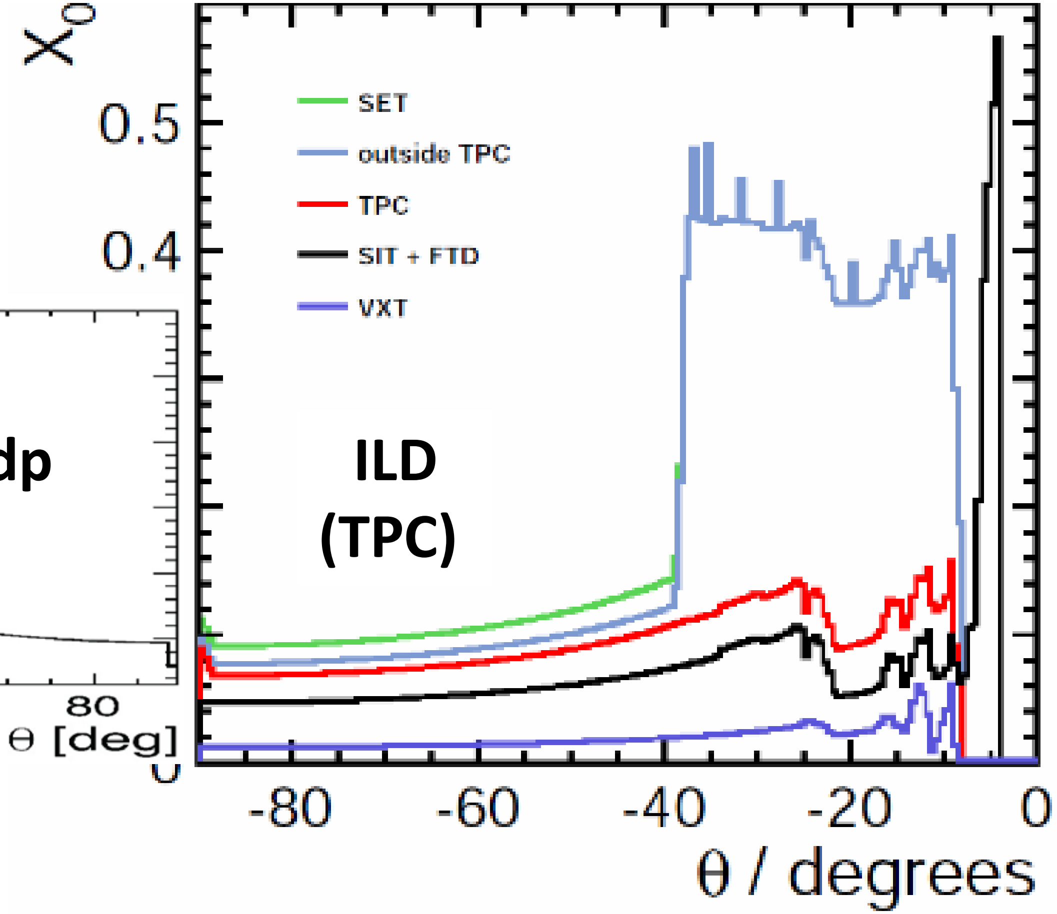
→ *should ease comparison of performances*

GLOBAL DETECTOR CONCEPTS: tracker material

Total tracker material

rescaled to same scale





Ambitious Si tracker design comparable to TPC in barrel

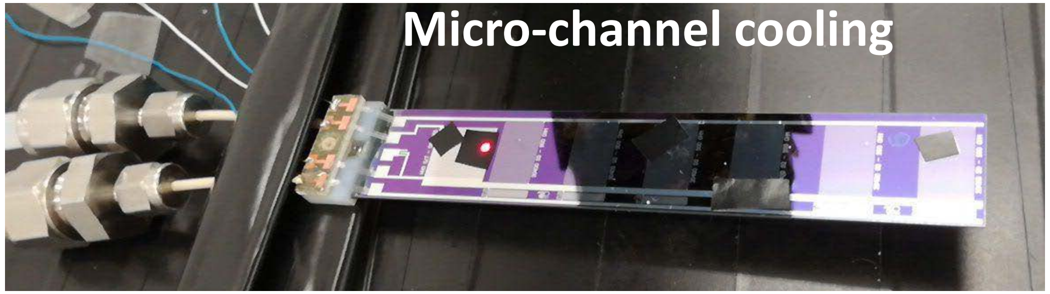
But this may change with final services and supports…

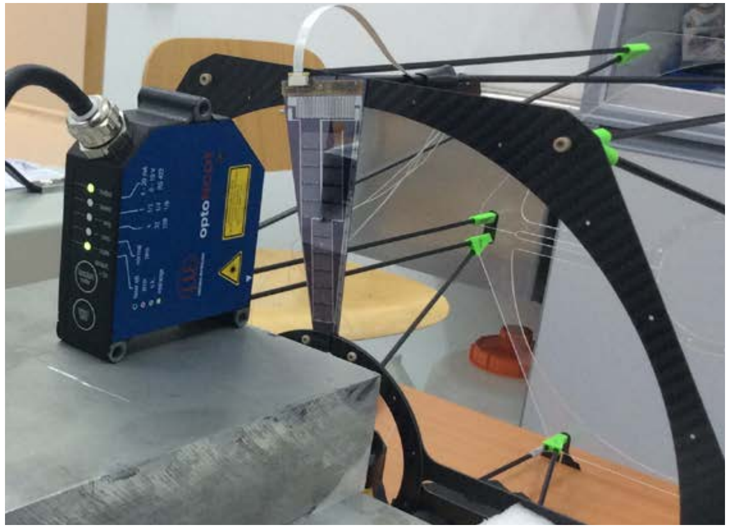
Significant TPC material in endcap

…but a less critical region

GLOBAL DETECTOR CONCEPTS: R&D for low material tracker integration

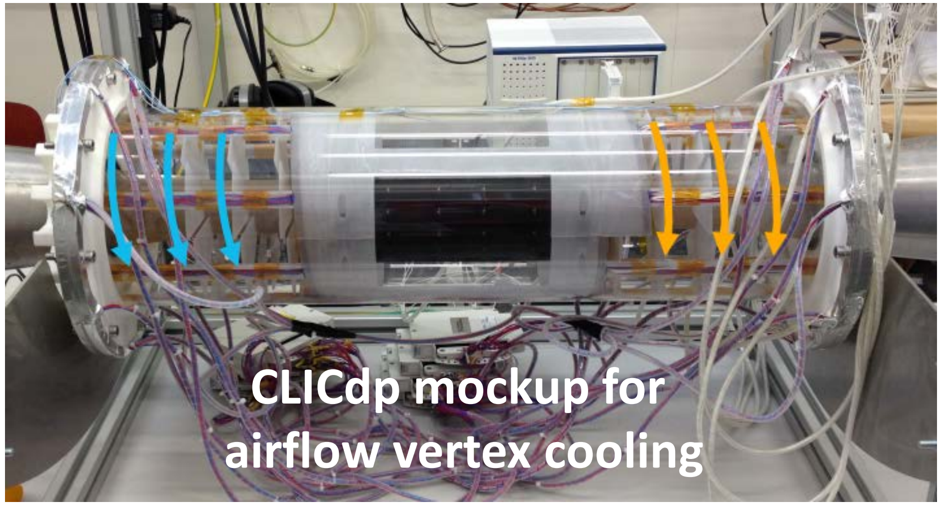
In use for BELLE-II beam commissioning [Baudot]





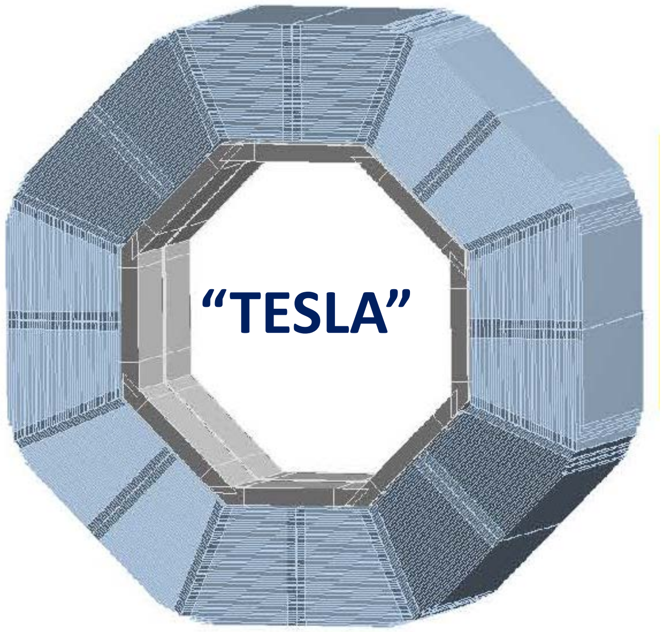
[Villarejo]

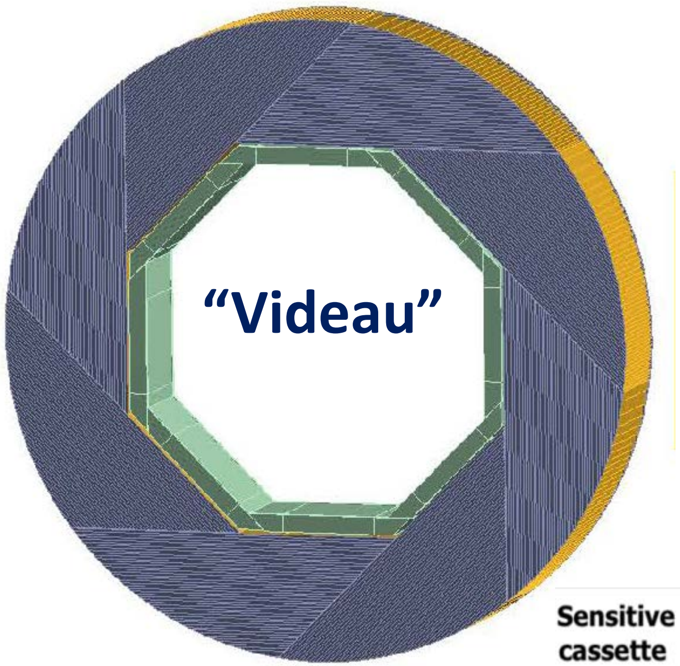
Airflow cooling test for ILD Forward Tracker



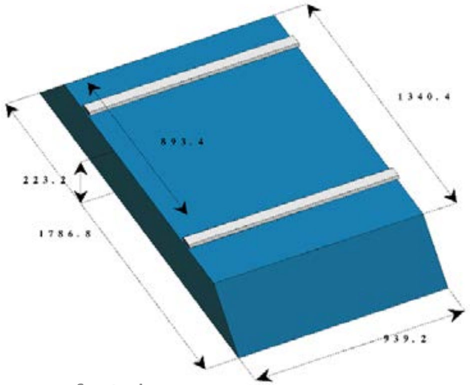
GLOBAL DETECTOR CONCEPTS: calorimeter mechanical structures

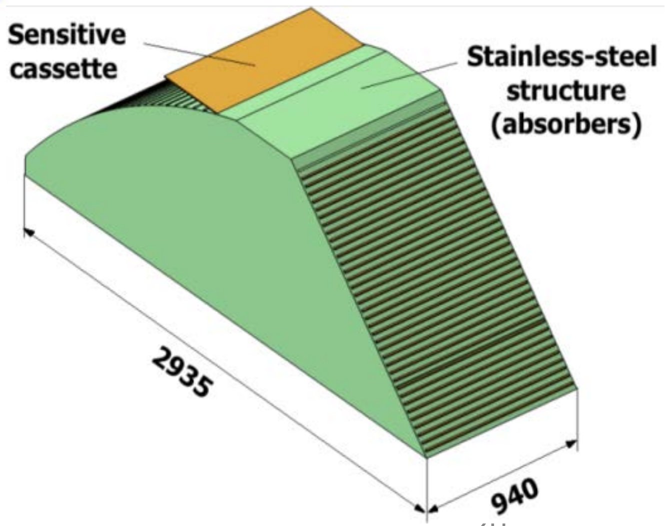
Innovative concept under study within ILD aside of more conventional structure





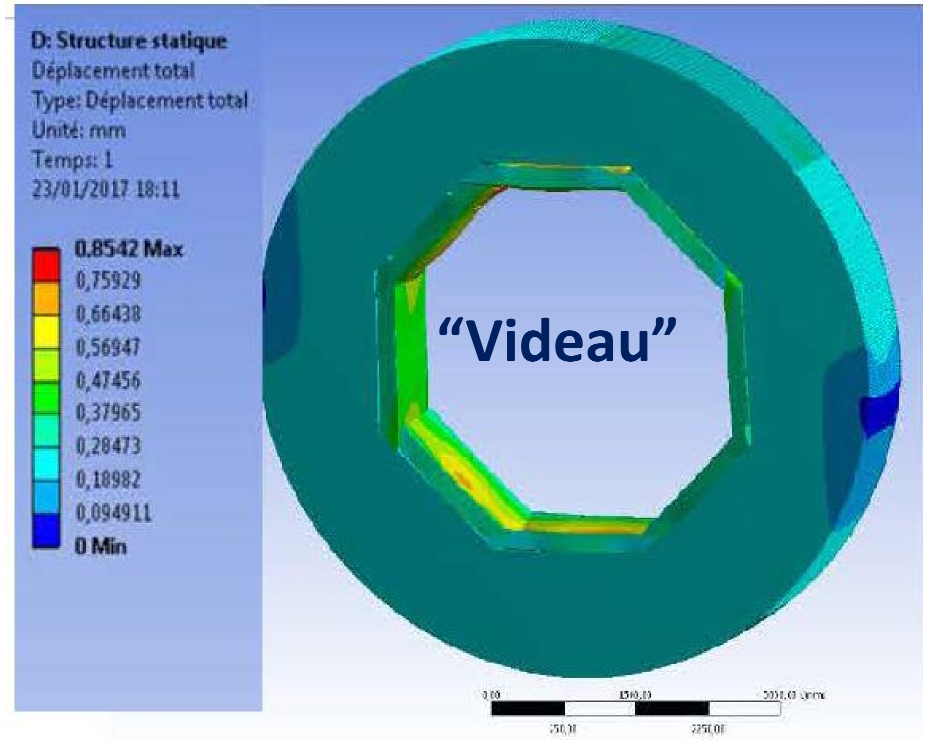
“Videau” layout avoids φ cracks and routes signals directly to the outside, at a cost of reduced accessibility to the front-end electronics

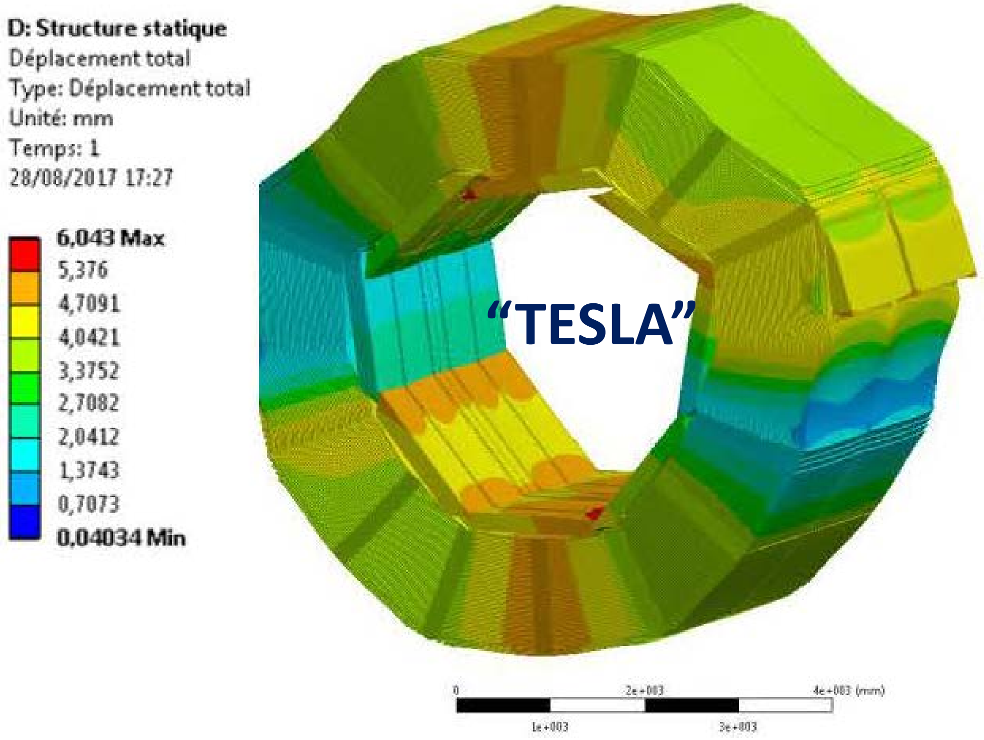


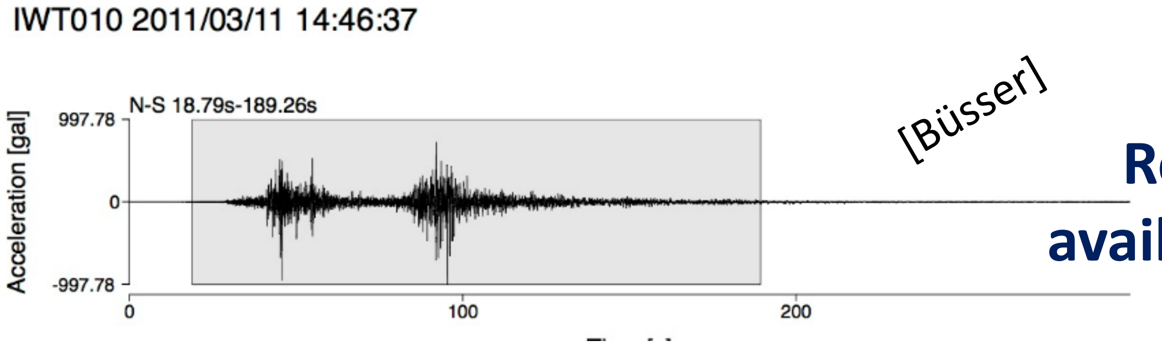


GLOBAL DETECTOR CONCEPTS: calorimeter mechanical structures cont’d

Important ingredient for mechanical structures: simulation of static and dynamic behaviours







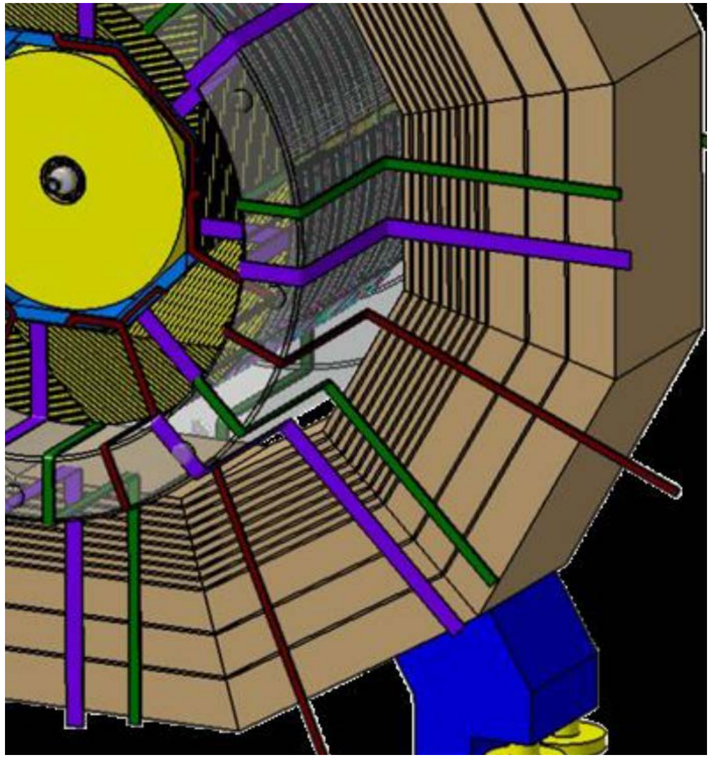
[Büsser]

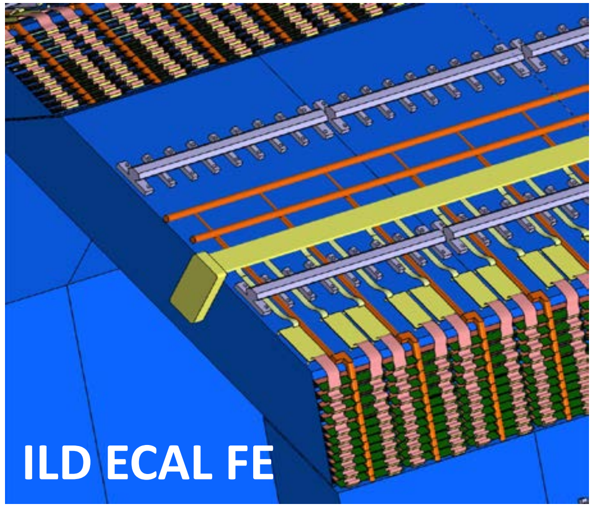
Reference earthquake spectra in Japan available and used for dynamical simulations

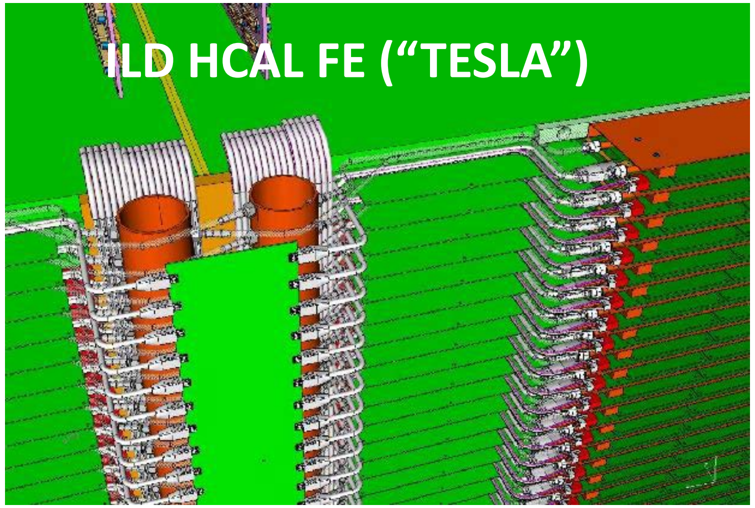
GLOBAL DETECTOR CONCEPTS: internal integration

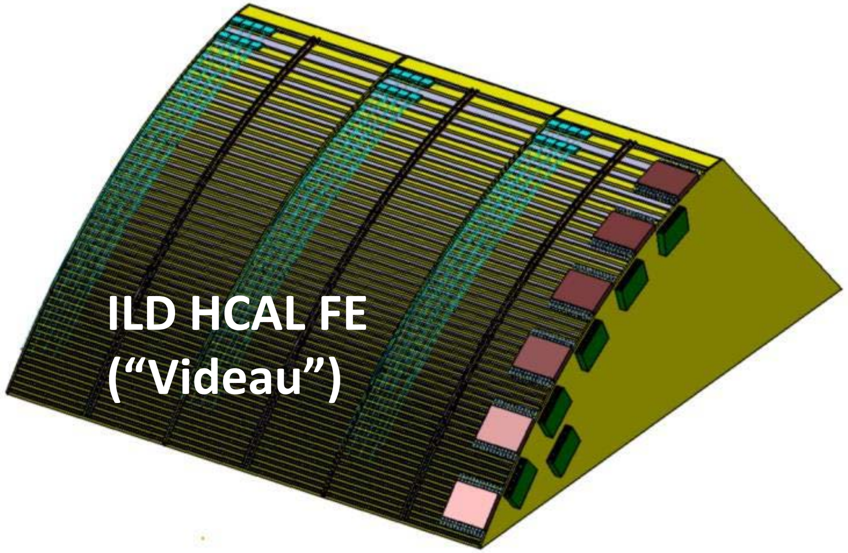
Detector structure and segmentation also drives the organization of supports, services and cabling,
with a potential strong impact on physics (crack sizes, dead materials, etc…)

→ ***should now be given more attention***



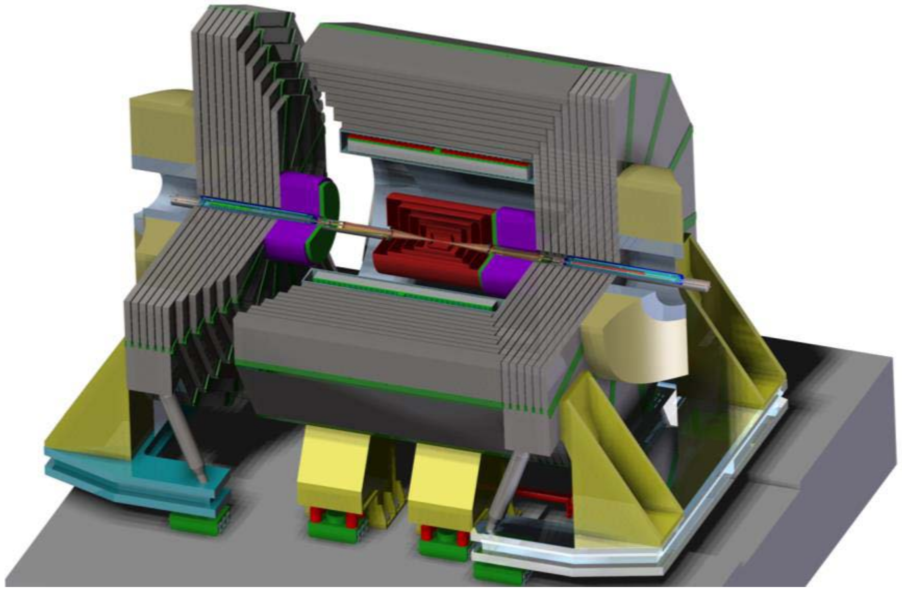




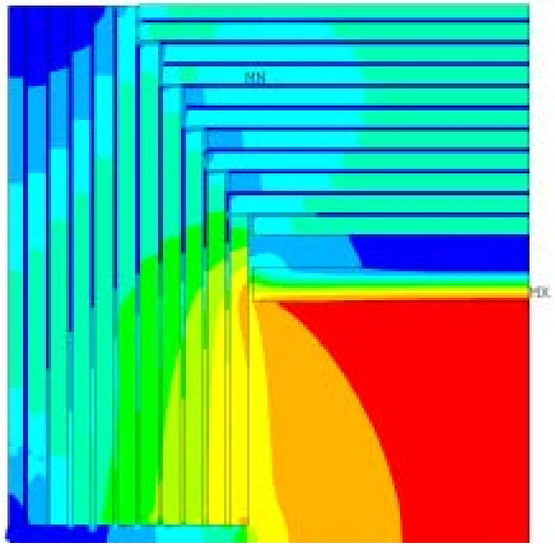


GLOBAL DETECTOR CONCEPTS: coil and yoke

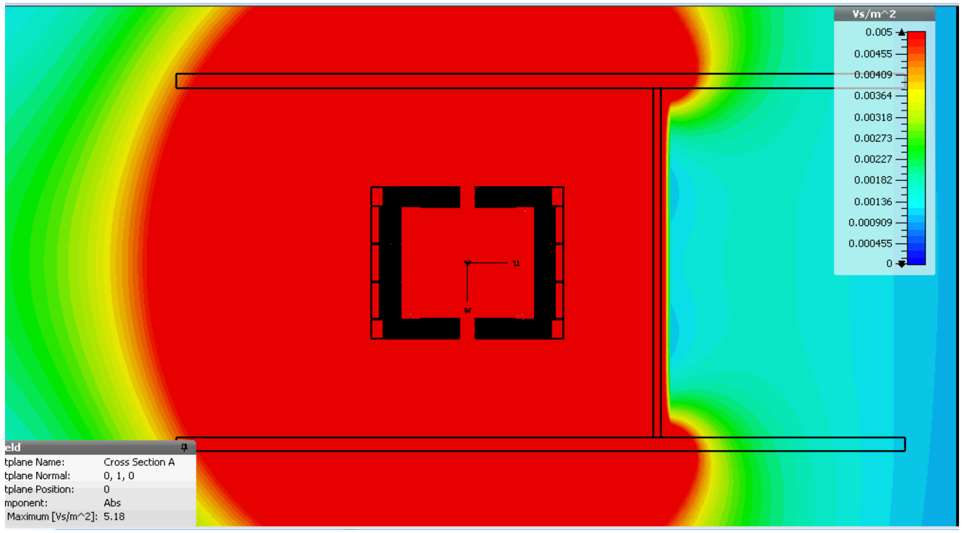
SiD updated yoke



SiD inner field



ILD stray fields with separation wall

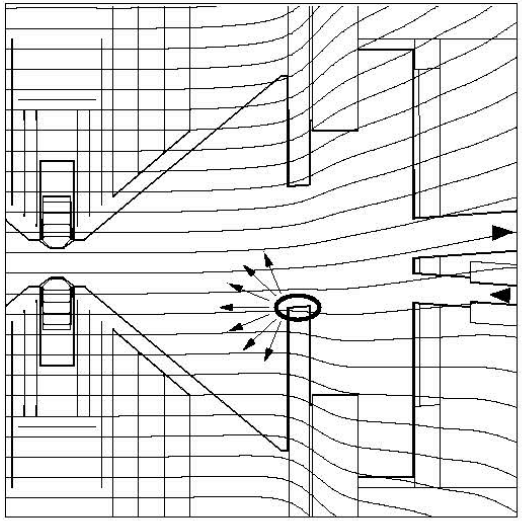


Ongoing work to minimize the yoke size (an important cost driver):

- **Separation wall option to minimize stray fields in the push-pull option**
- **Compensating external magnets to reduce return fields also considered and in the baseline design of SiD/CLICdp yokes**

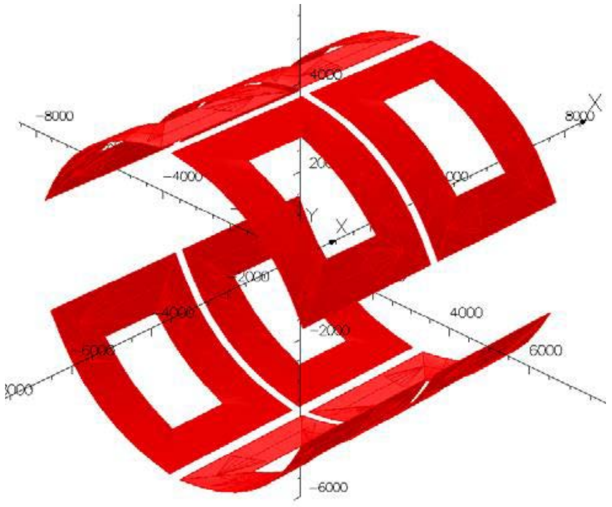
→ The coil/yoke design is strongly related to the final decision on the push-pull option !

GLOBAL DETECTOR CONCEPTS: coil cont'd



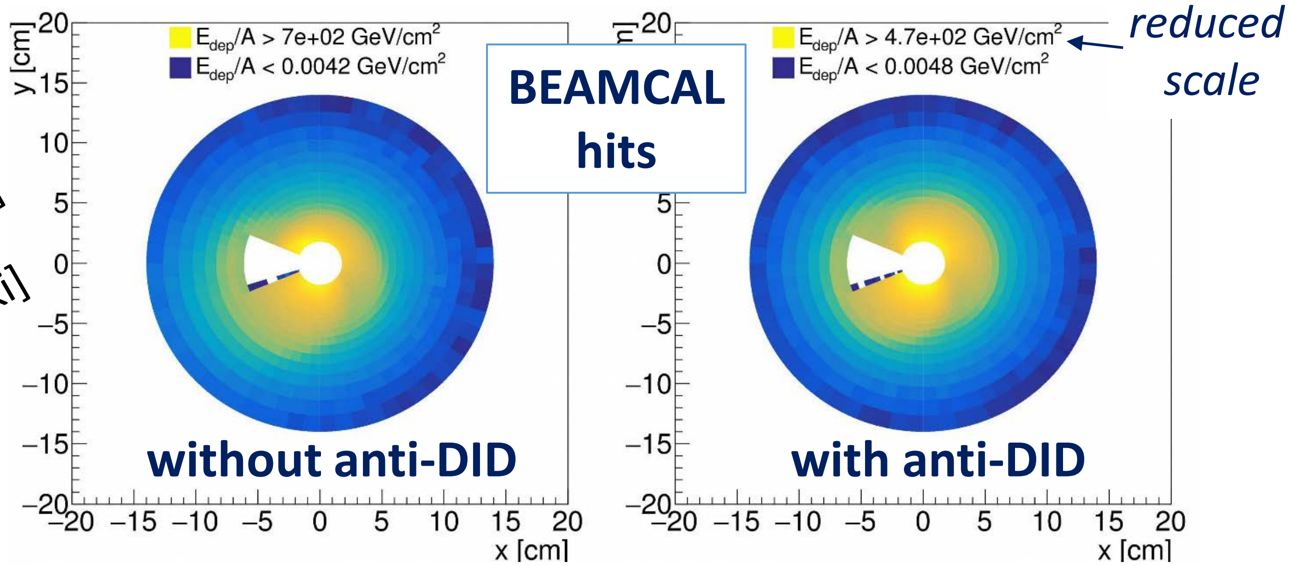
Open issue: "Anti-DID" option to mitigate beamstrahlung BG:

a small dipole field added to the main solenoid field in order to guide direct beamstrahlung pairs to the in/outgoing beam pipes and the backscattered particles within the beam pipe.



[Jeans]

[Arominski]

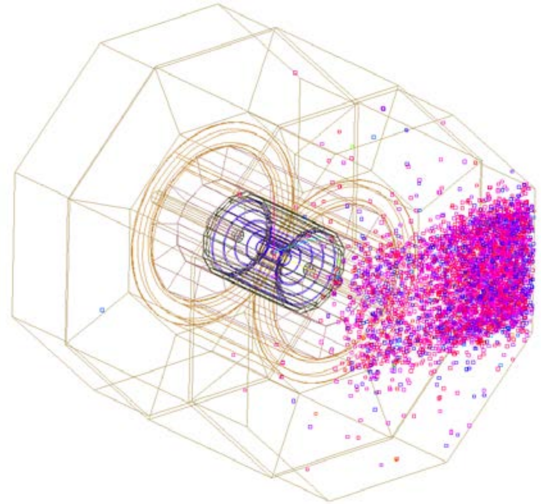


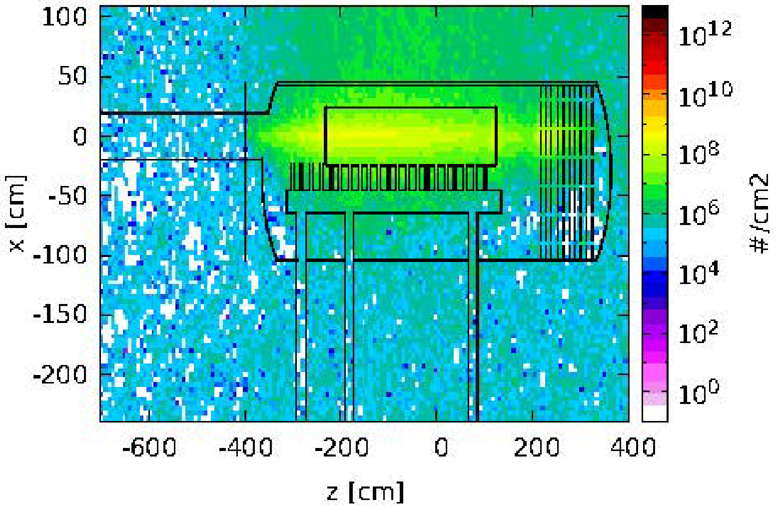
Progress on design of realistic options by coil manufacturers (Toshiba/Hitachi)

SiD&ILD ongoing studies indicate moderate improvement → *not yet clear whether this is worth the anti-DID complication*

GLOBAL DETECTOR CONCEPTS: other beam-induced backgrounds

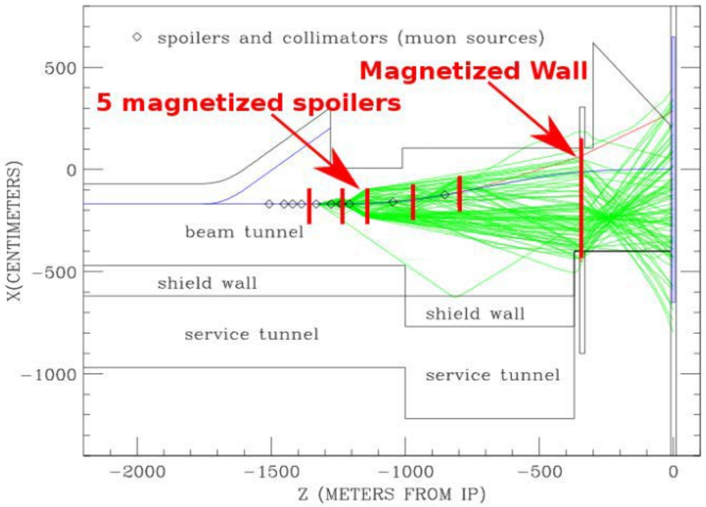
Flux of neutrons backscattered from the e-beam dump and from μ-halos studied by SiD&ILD

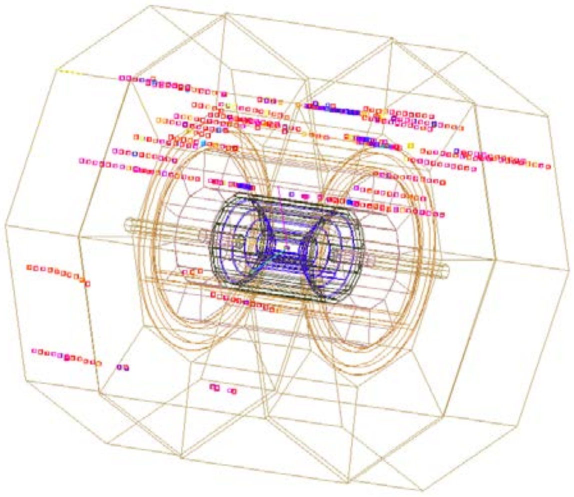




[Jeans]

[Tauchi]



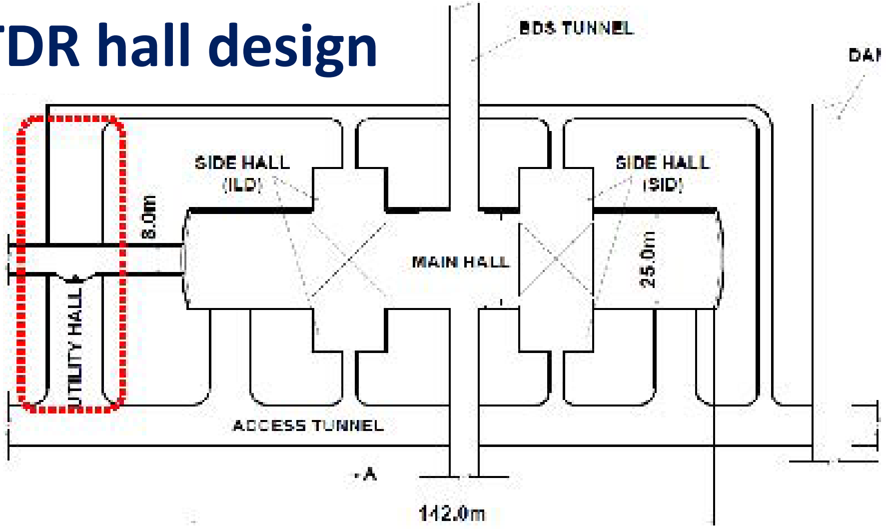


These important aspects of machine-detector interface should get more attention in the future

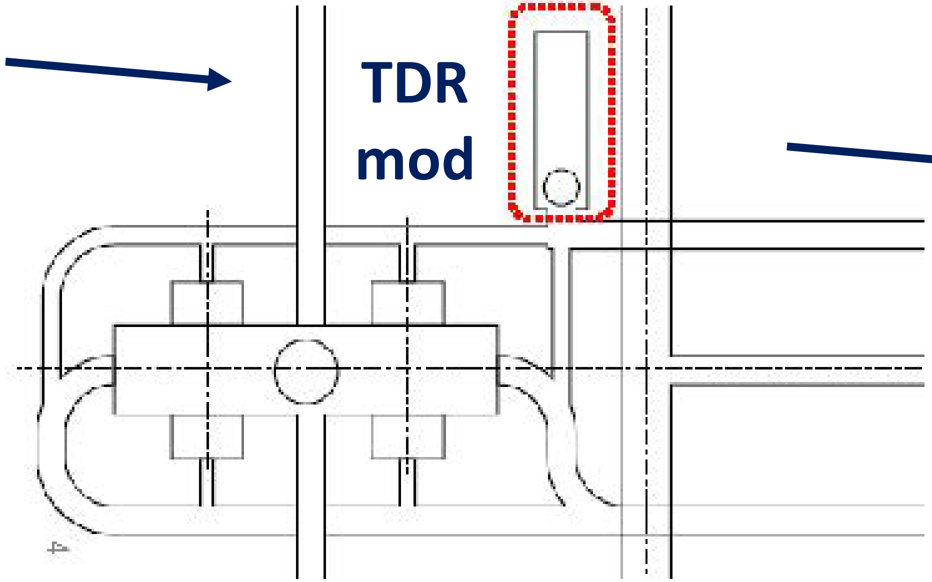
GLOBAL DETECTOR CONCEPTS: integration in the cavern (ILC case)

[Sugimoto]

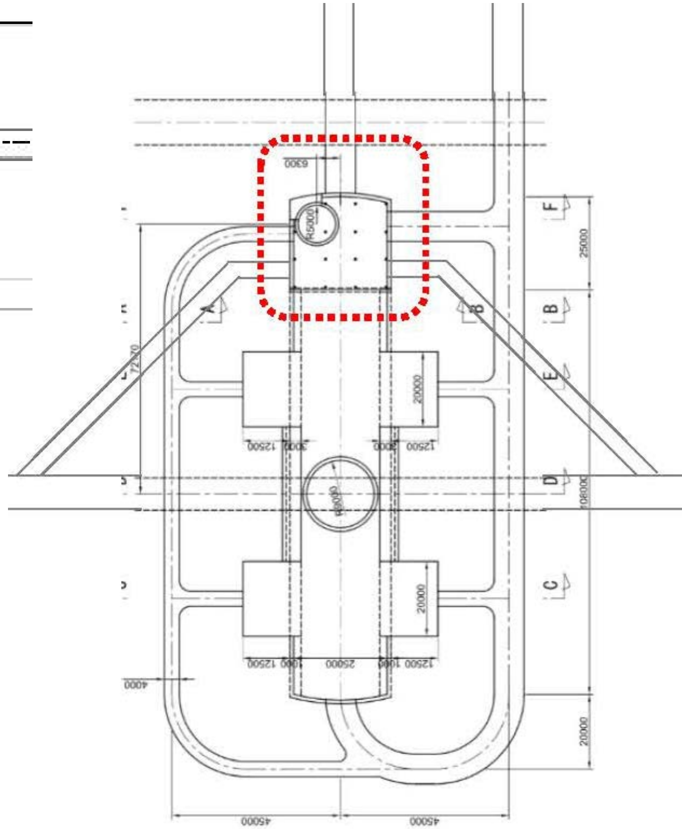
TDR hall design



TDR mod



Tohoku hall design

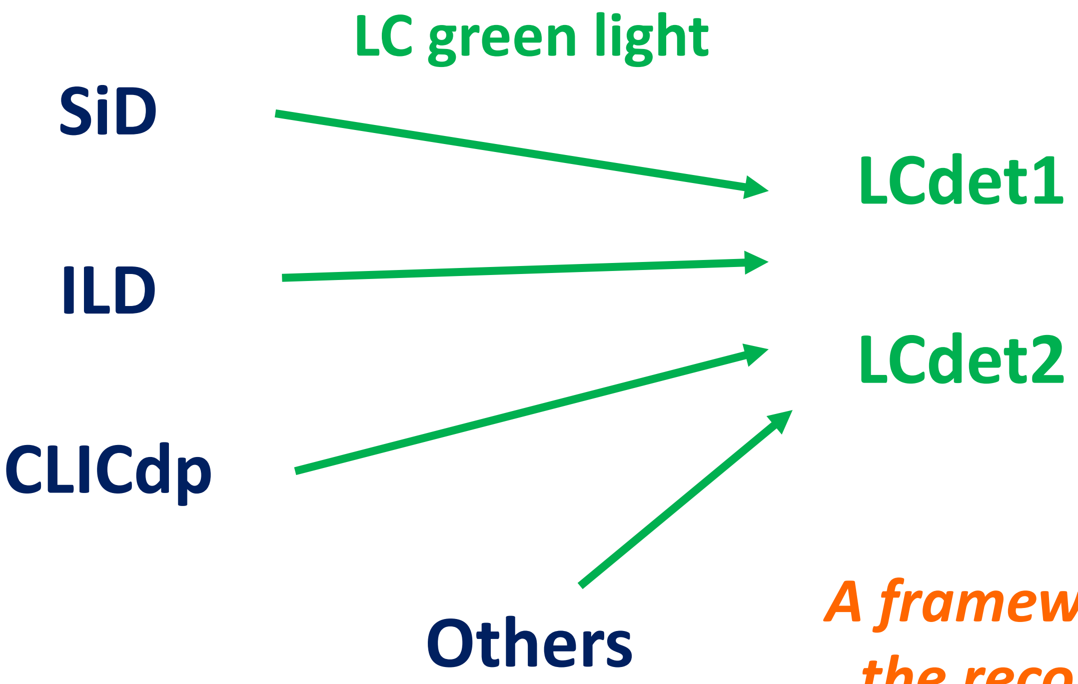


A general trend to shrinkage of space allocated to detector services in the successive cavern designs…

Transfer of information on detector utility needs to cavern designers should be improved.

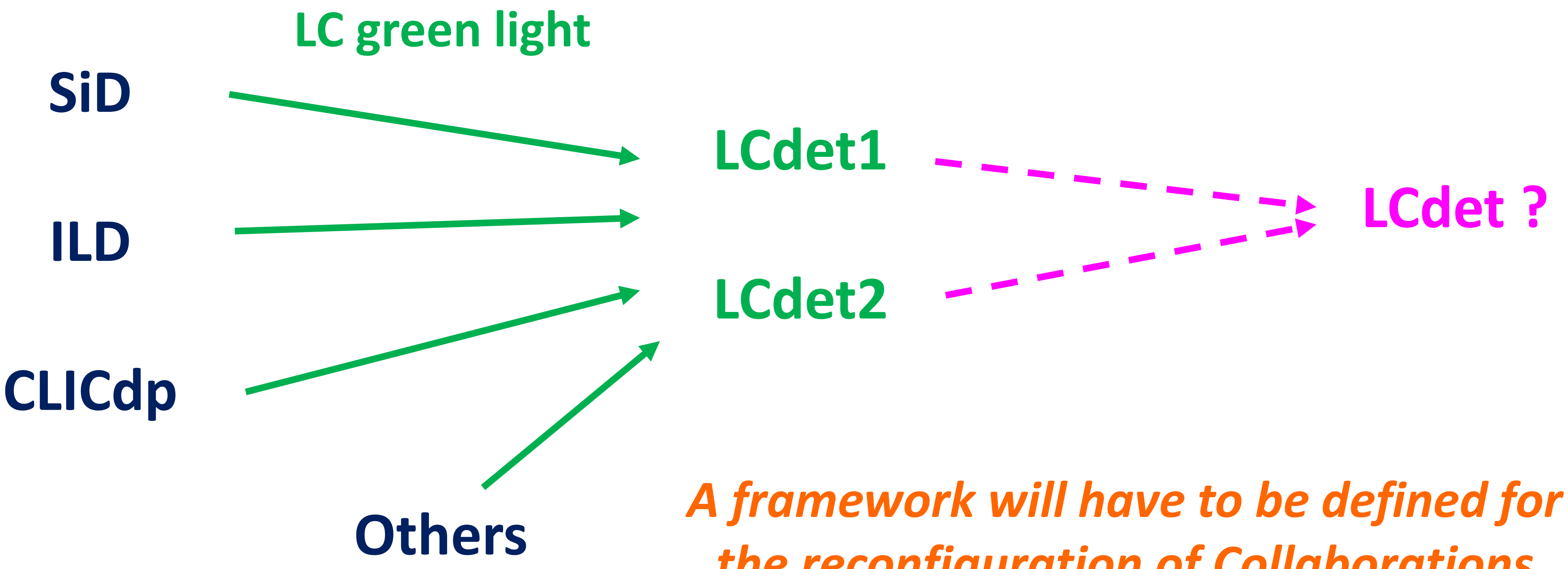
An issue also strongly related to the final decision on push-pull

TOWARDS DETECTOR COLLABORATIONS



A framework will have to be defined for the reconfiguration of Collaborations

TOWARDS DETECTOR COLLABORATIONS



A framework will have to be defined for the reconfiguration of Collaborations

TOWARDS DETECTOR COLLABORATIONS: 1 or 2 detectors ?

2 detectors

- Fully independent hardware for mutual crosschecks
- More room for collaboration of groups with different culture
- Mutual emulation from competition

- Push-pull technical overheads (alignment, stray fields, integrated luminosity)
- Detectors cost increase by > 2 incl. overheads

1 detector

- Concentrate all resources on the best single state-of-the-art detector
- Twice more luminosity for systematics
- Simpler and cheaper cavern design

- Requires more convergence on technologies from existing collaborations
- Less hardware redundancy for cross-checks of results

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Competition and cross-checks are important for reliability of results, however:

Hardware redundancy is weakened if many technologies are common to both detectors

Software@Analysis redundancy is at least as important but in tension with using the same software tools

→ Room for innovative organization of the detector&physics collaborations at a LC, getting inspired from e.g. space experiments

OUTLOOK

Subdetector baseline technologies are mature for LC detectors
and start to be implemented in LHC upgrades and other projects worldwide
There is room for further performance improvements and implementation of new features

Global detector concepts have been validated by the LC consortia

In case of positive momentum towards a LC:

More attention should be given to detector integration and to machine interfaces
detector global structure, dead materials, services, calibration procedures,
beam induced backgrounds, cavern utilities

Finalization of the interaction layout (including #detectors)
should come soon after LC green light
to allow both technical and political convergence of the detector Collaborations