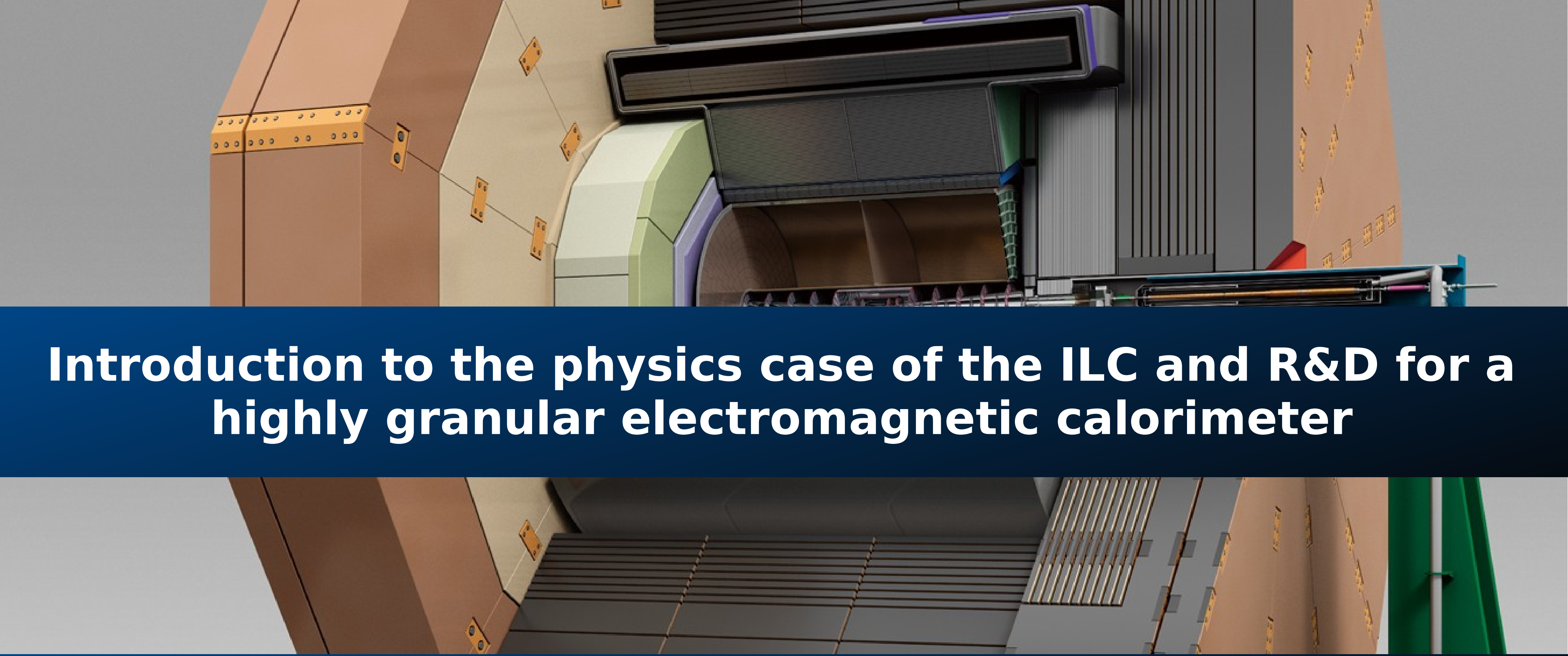
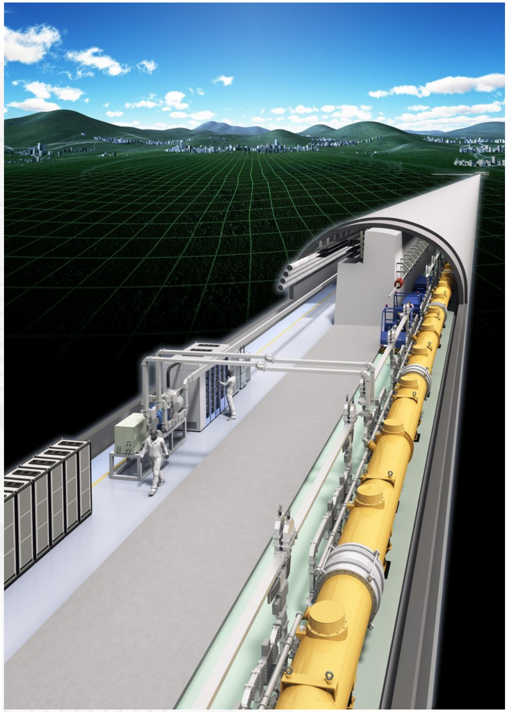


Introduction to the physics case of the ILC and R&D for a highly granular electromagnetic calorimeter

A. Irles, 30th January 2018, IPHC Strasbourg

CALICE AIDA 2020 HIGHTEC P2IO Physique des 2 Infinis et des Origines PRESTIGE Postdoctoral Research Fellowships in France MARIE CURIE ACTIONS CNRS IN2P3 Les deux infinis LABORATOIRE DE L'ACCÉLÉRATEUR LINÉAIRE

Outline of the talk



- Motivation: towards high precision measurements
- The International Linear Collider (ILC)
  - The machine
  - Physics benchmarks
- Detector R&D for the ILC
  - Particle Flow Detectors
- Highly granular electromagnetic calorimeter for the ILC

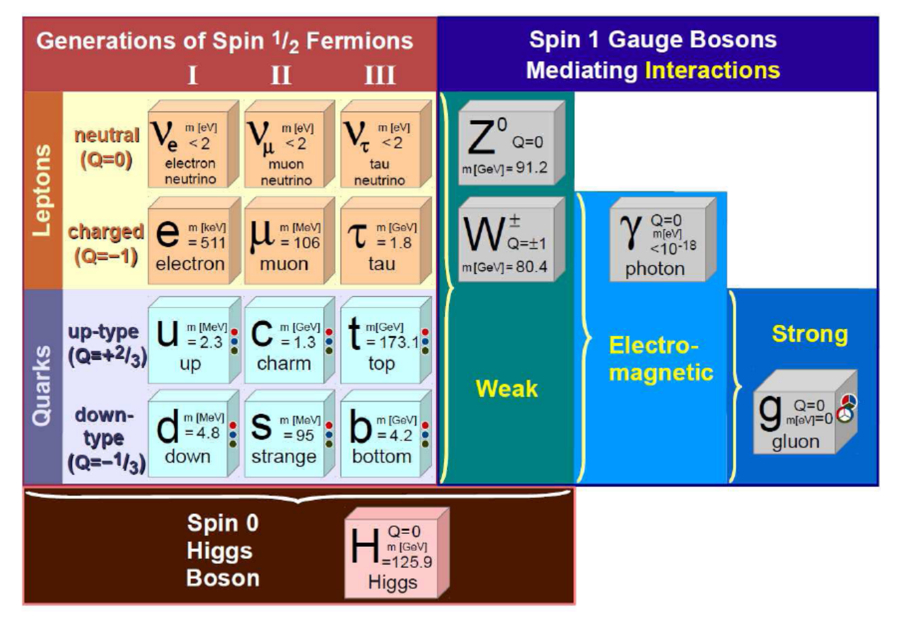
- Summary

LINEAR COLLIDER COLLABORATION
Designing the world's next great particle accelerator

ilc

PRESTIGE
POSTDOCTORAL RESEARCH FELLOWSHIPS IN FRANCE

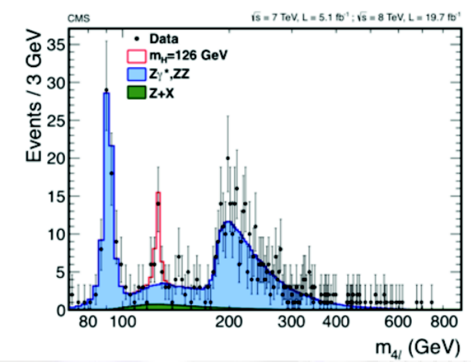
LABORATOIRE DE L'ACCÉLÉRATEUR LINÉAIRE

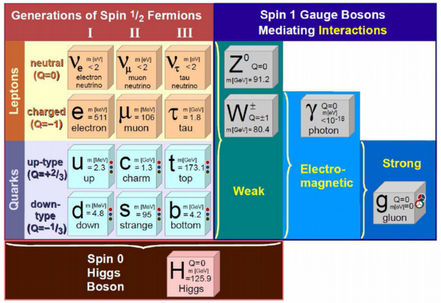


Physics Motivations : towards high precision measurements

Motivation I

- The Standard Model **(SM)** is a **successful theory** proven at many experiments.
- **Higgs discovery completes** the **SM** particle content and describes the origin of the **particle masses**.

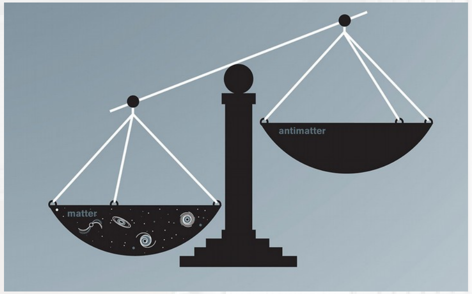


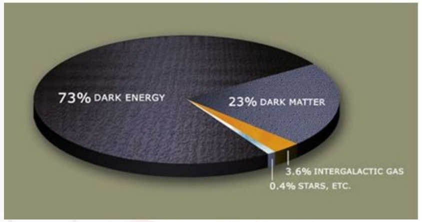


Few important questions remain open, . *i.e.*:

- What is the origin of the **large matter-antimatter asymmetry ?**
  - SM CP-violation is not enough
- The **SM only explains ~15% of the matter** content of the universe…
  - what is the composition of the rest (dark matter) ?

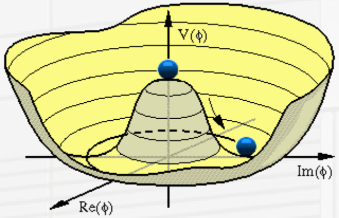
Very weakly interacting NEW particle (and/or new interaction)

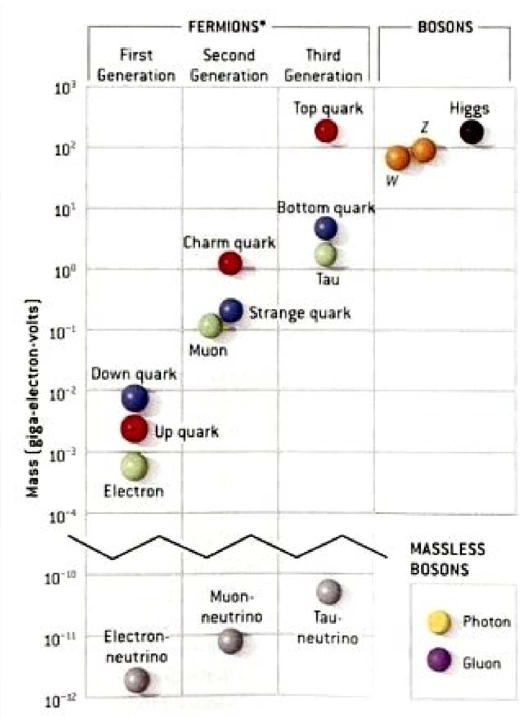




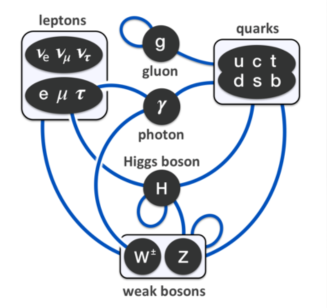
Motivation II

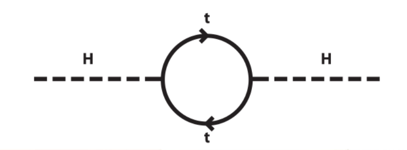
- **Higgs discovery completes the SM** particle content, but **the Higgs mechanism is introduced *ad-hoc*.**
  - why the quantum field associated to the Higgs Boson field creates a condensate that fills the space and gives masses to the elementary particles?

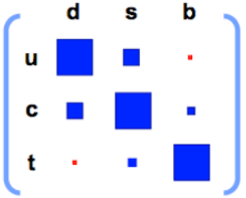




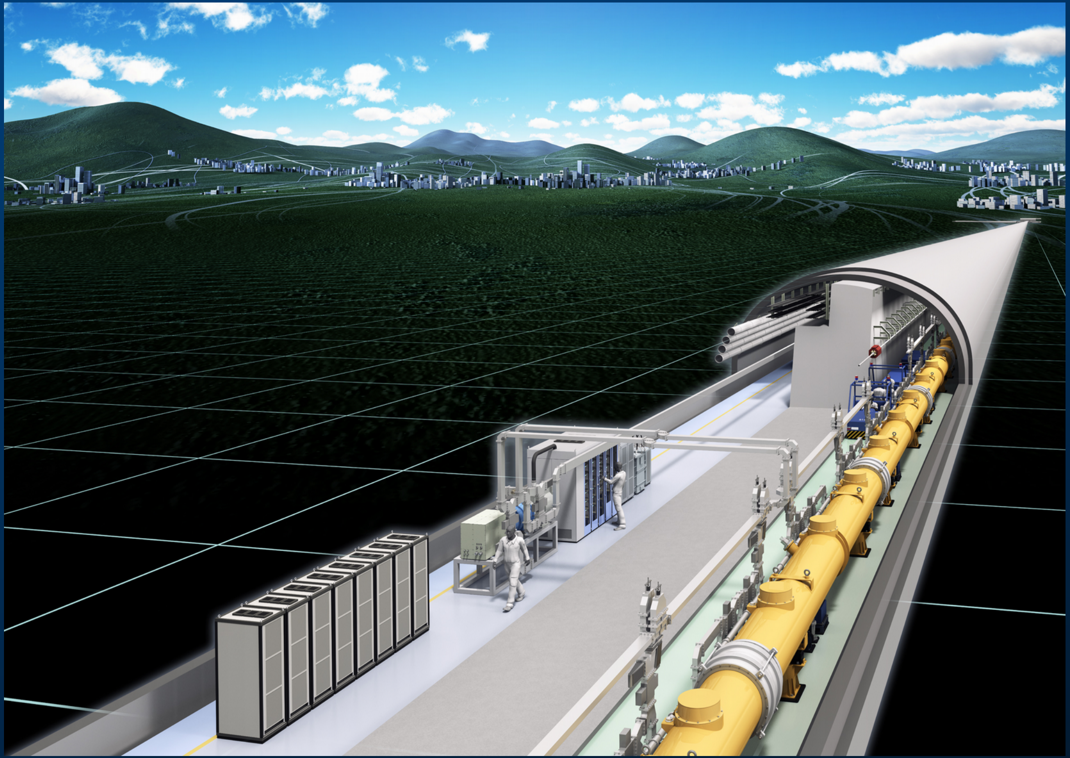
- Higgs **coupling** to X **proportional to mass** of X.
  - why the fermion masses are spanned in a range of **several orders of magnitude** with only one value for the vacuum expectation ??
  - Hierarchy, naturaleness problem → hints of hidden mechanisms BSM Compositeness ? SUSY ?





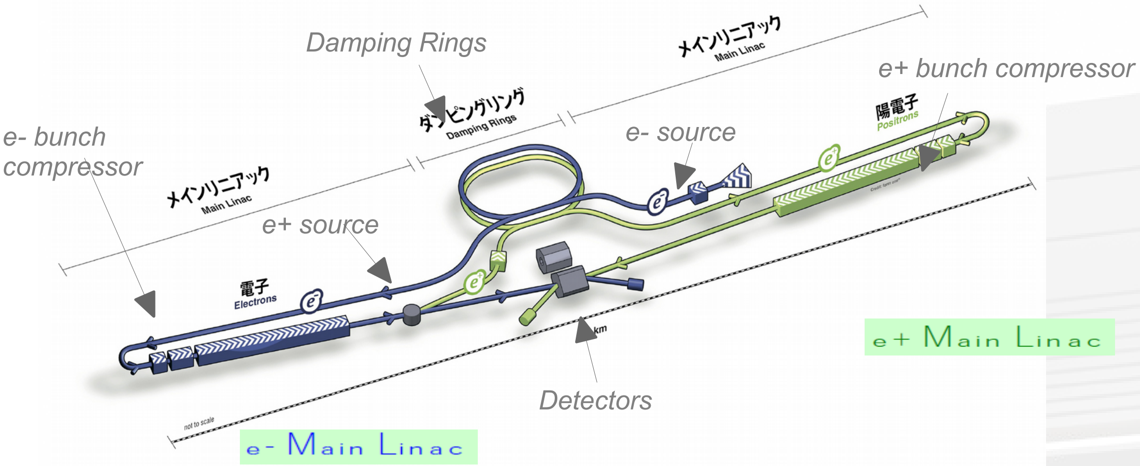


Are these couplings **compatibles** with the **SM** ?

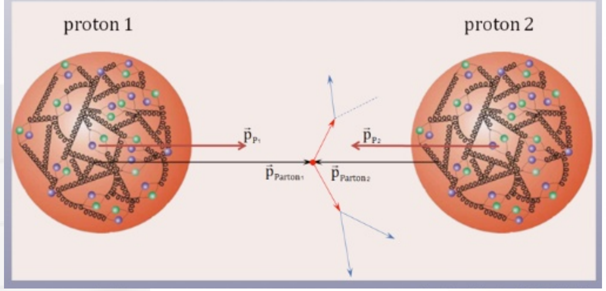


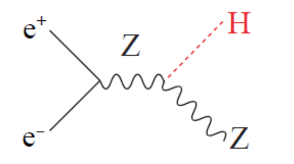
The International Linear Collider : accelerator, physics cases

The ILC: https://www.linearcollider.org/ILC

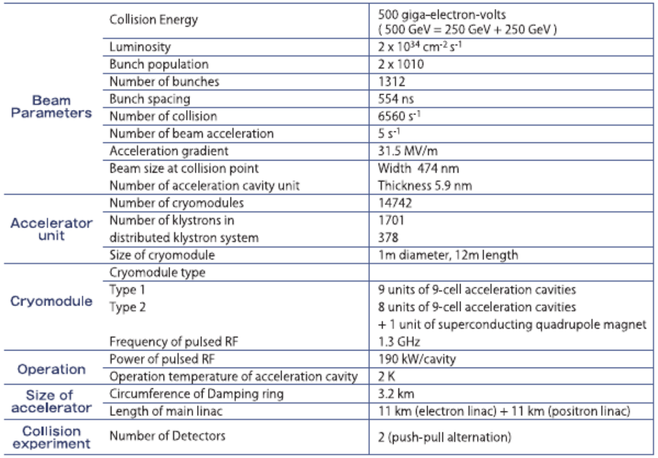


ILC Scheme | ©www.form-one.de



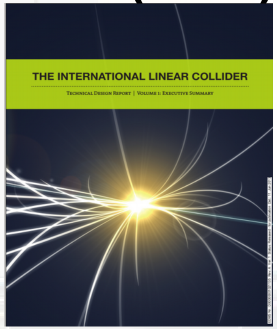


- **e+e- collider,** Energy **250**-500 **GeV** **upgradable** using **polarized beams**
  - Based on superconducting RF cavities
  - Gradient: 32 MV/m
  - Length of 31 Km
- Luminosities ~ 10^{-34} cm^{-2} s^{-1}



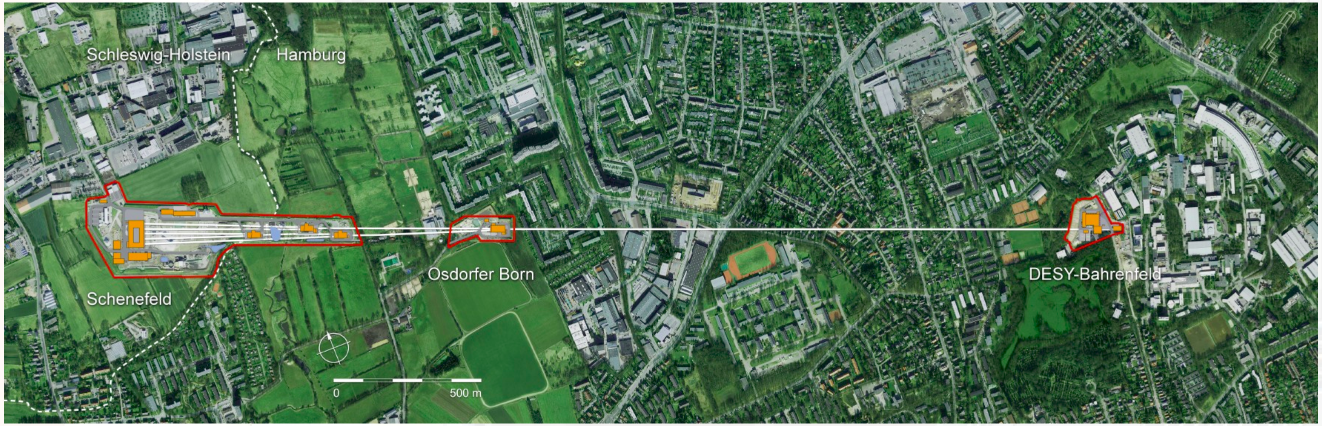
Beam Parameters	Collision Energy	500 giga-electron-volts (500 GeV = 250 GeV + 250 GeV)
	Luminosity	2 x 10^{34} cm^{-2} s^{-1}
	Bunch population	2 x 1010
	Number of bunches	1312
	Bunch spacing	554 ns
	Number of collision	6560 s^{-1}
	Number of beam acceleration	5 s^{-1}
	Acceleration gradient	31.5 MV/m
	Beam size at collision point	Width 474 nm
	Number of acceleration cavity unit	Thickness 5.9 nm
Accelerator unit	Number of cryomodules	14742
	Number of klystrons in	1701
	distributed klystron system	378
	Size of cryomodule	1m diameter, 12m length
Cryomodule	Cryomodule type	
	Type 1	9 units of 9-cell acceleration cavities
	Type 2	8 units of 9-cell acceleration cavities + 1 unit of superconducting quadrupole magnet
	Frequency of pulsed RF	1.3 GHz
Operation	Power of pulsed RF	190 kW/cavity
	Operation temperature of acceleration cavity	2 K
Size of accelerator	Circumference of Damping ring	3.2 km
	Length of main linac	11 km (electron linac) + 11 km (positron linac)
Collision experiment	Number of Detectors	2 (push-pull alternation)

TDR (2013)

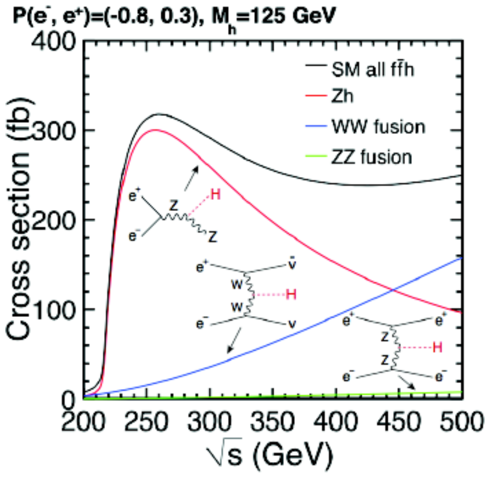


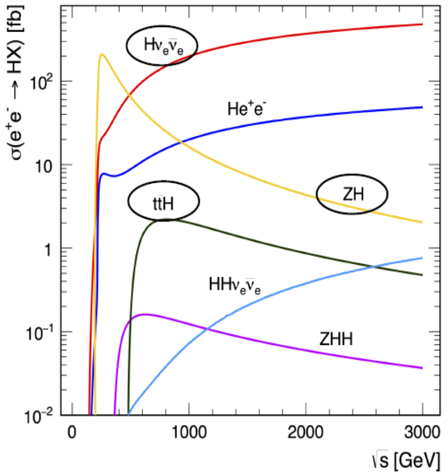
The ILC: https://www.linearcollider.org/ILC

- Existing technollogy.
- The European X-ray free-electron laser (European XFEL) for multidisciplinary research
  - **commissioned** during 2017
  - **first great mass production** of the superconducting radio frequency TESLA technology → **shared technology with the ILC**
  - In the **scope of the ILC, the European XFEL acts as a prototype** for technical design, project planning and construction phase.
  - Strong participation of **French groups and industry**

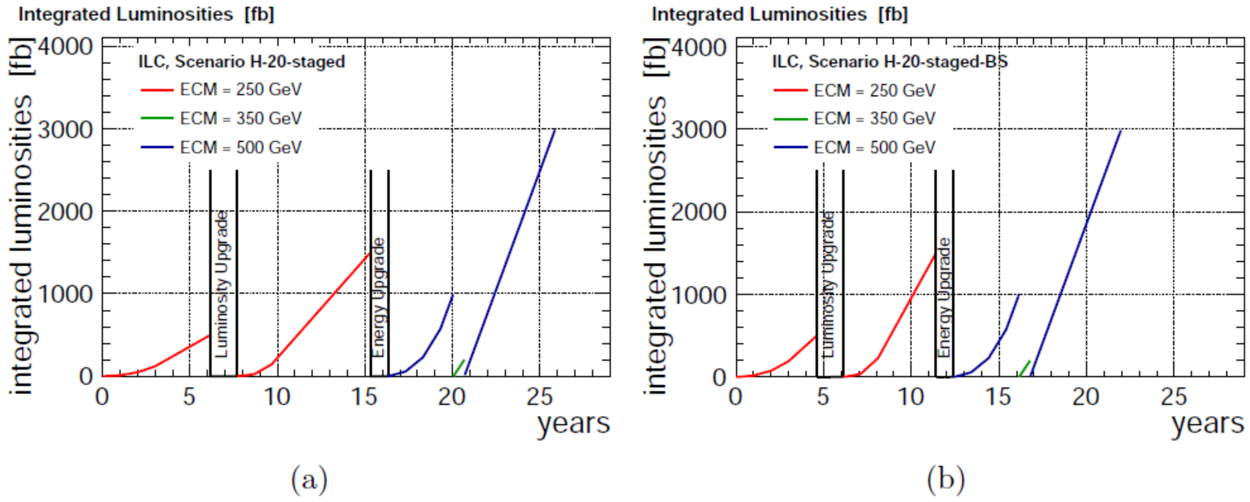


Physics case





- Tentative scenarios for staged ILC



(a) (b)

- 250 GeV: access to Zh, WW, $f\bar{f}$
- 350 GeV: $t\bar{t}$ threshold
- 500 GeV: $t\bar{t}H$, ZHH

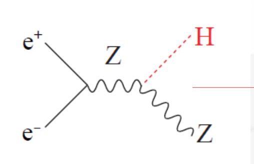
ILC is a H/top/W/Z factory

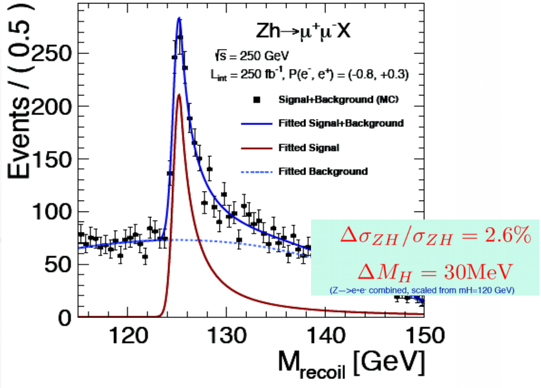
Polarized beams gives:

- Effective luminosity improvement
- Allow to separate g^{γ} of g^{Z}
- Provides robusteness against systematic uncertainties
- Minimize higher-order corrections

Benchmark analysis: Higgs couplings

- Golden channel: ee→ zH, use Z->ee/μμ to **isolate a very clean Higgs signal** mass
  - high momentum resolution
  - Sensitive to invisible decay modes.





$\Delta\sigma_{ZH}/\sigma_{ZH} = 2.6\%$

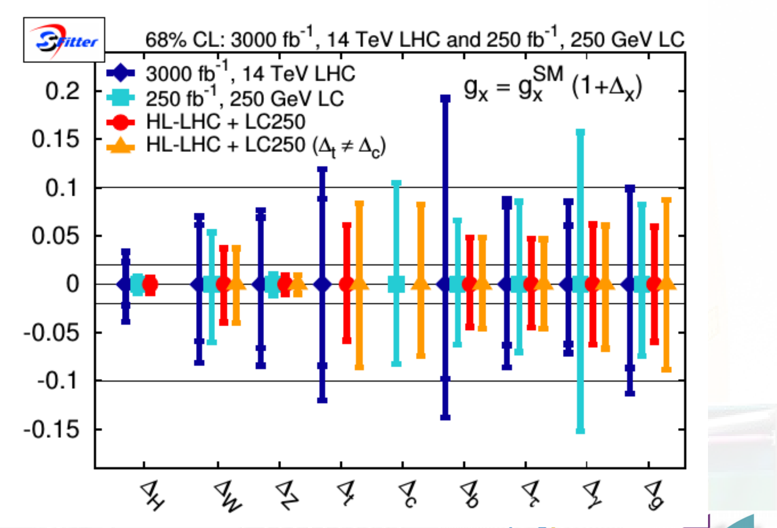
$\Delta M_H = 30\text{MeV}$

(Z->e+e- combined, scaled from mH=120 GeV)

- ILC can measure the full **width of the Higgs coupling using a** combination of σ and σ x Br measurements
  - Direct access to the couplings !

- **ILC can improve HL-LHC** measurements of Higgs couplings in **~ 1 order of magnitude**
  - Smaller theory uncertainties: EW corrections at ILC (~1%) vs PDF + QCD at LHC (~ 10%)
  - Access to unreachable measurements at LHC (c-quark coupling)
  - Model independent !

- **HL-LHC + ILC** will make the determination of the Higgs couplings more precise than any machine.

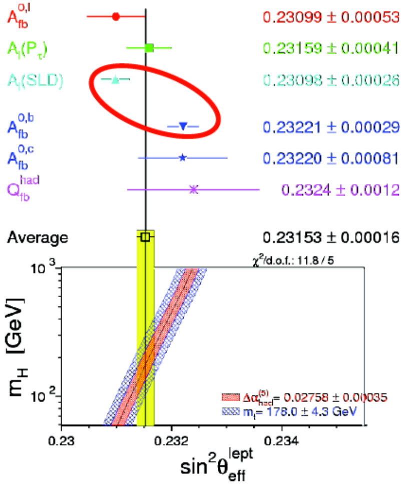


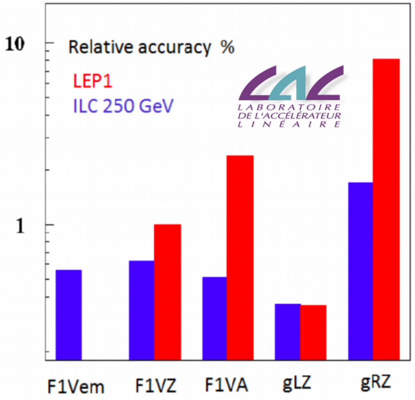
Benchmark analysis: heavy quarks physics

- 3rd generation of quarks
  - is heaviest, with closest connection to EW symmetry breaking
  - composite?
- Electroweak couplings: **b-quark**
  - Current LEP measurements show tension with the SM in the Afb measurement
  - Many **composite models predict deviations** in the fermion **electroweak couplings** (specially in the heavy flavors)

    → can be observed in the cross sections and Afb measurements if measured at the % level
- Polarization allows to **separate Z and γ couplings.**

- ILC will be able to **resolve the LEP issue** on Afb and **test compositeness** theories.

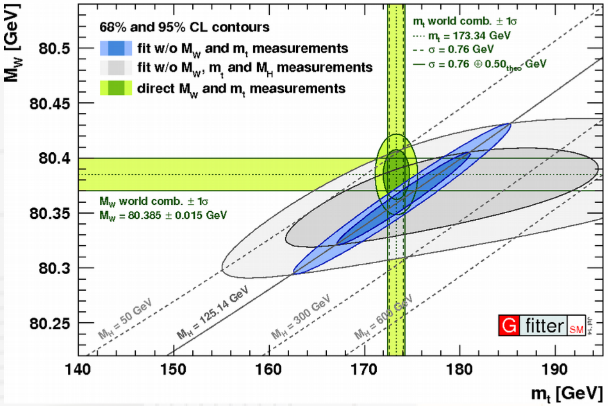




500 fb^{-1} at 250 GeV with polarized e- (80%) and e+ (30%)
(Bilokin, Poeschl, Richard)

Benchmark analysis: top-quark mass

- **Top-quark mass is a key parameter of the SM**
- **Quark masses are not observables** (quarks are bounded in color singlet states)
  - are renormalized couplings (like α_s) that must be inferred from hadronic observables (i.e. cross section)



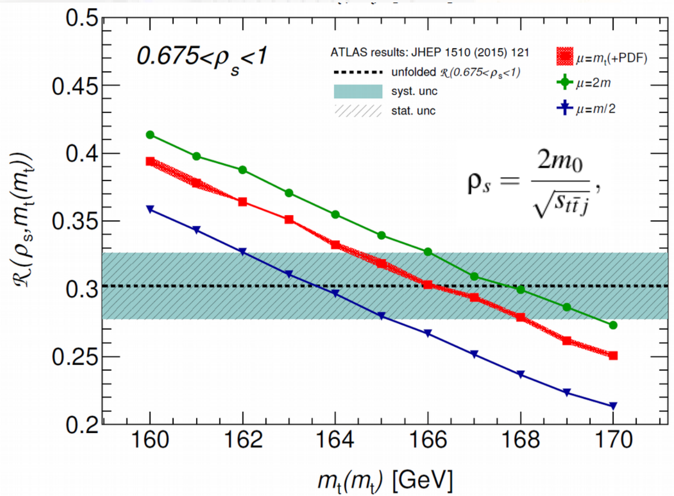
- The most precise **well defined top-quark mass** measurements at **hadron colliders** are based in cross section measurements :
  - example. the R-observable Eur.Phys.J. C73 (2013) 2438 (Alioli, Fernández, Fuster, A.I., Moch, Uwer, Vos)

Pole mass (ATLAS measurement, 7 TeV) $m_t^{\text{pole}} = 173.7^{+2.3}_{-2.1}$ (total) GeV.

JHEP 1510 (2015) 121 (Atlas Collab)

Running mass (using ATLAS data, 7 TeV) $m_t(m_t) = 165.9^{+2.4}_{-2.0}$ (total) GeV.

Eur.Phys.J. C77 (2017) no.11, 794 (Fuster, A.I., Melini, Uwer, Vos)

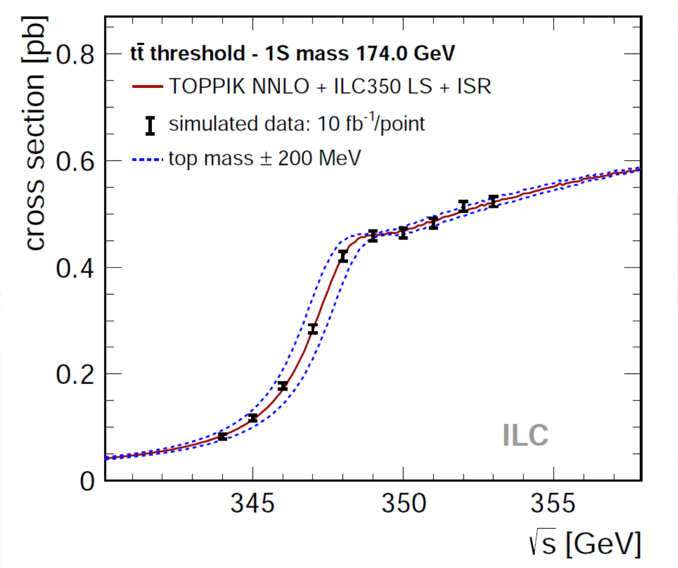


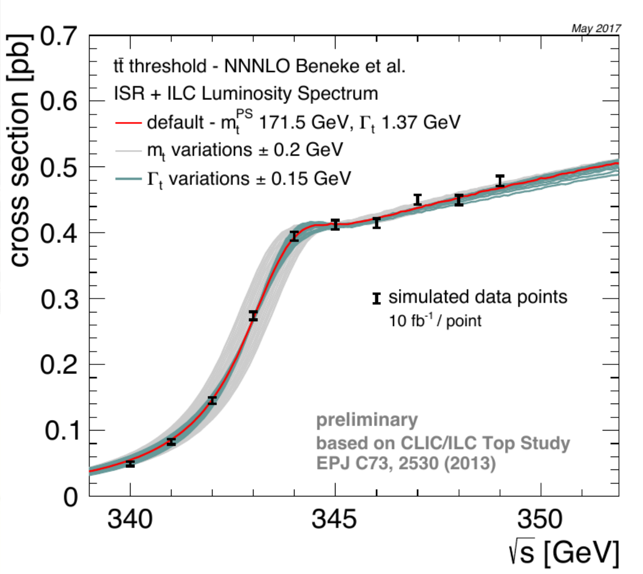
- Prospects (LHC) ~ 1 GeV, limited by theory (scale, PDF), luminosity, modeling uncertainties ….

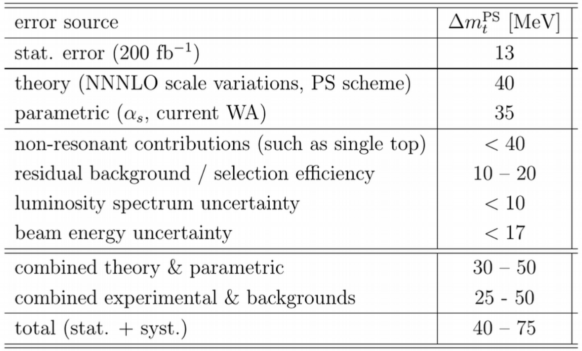
Benchmark analysis: top-quark mass

Linear Collider measurement: threshold scan

- Clean final state (look for leptons and missing energy) → the analysis can be done in simple way (cut & count)
- Well defined observables and mass interpretation



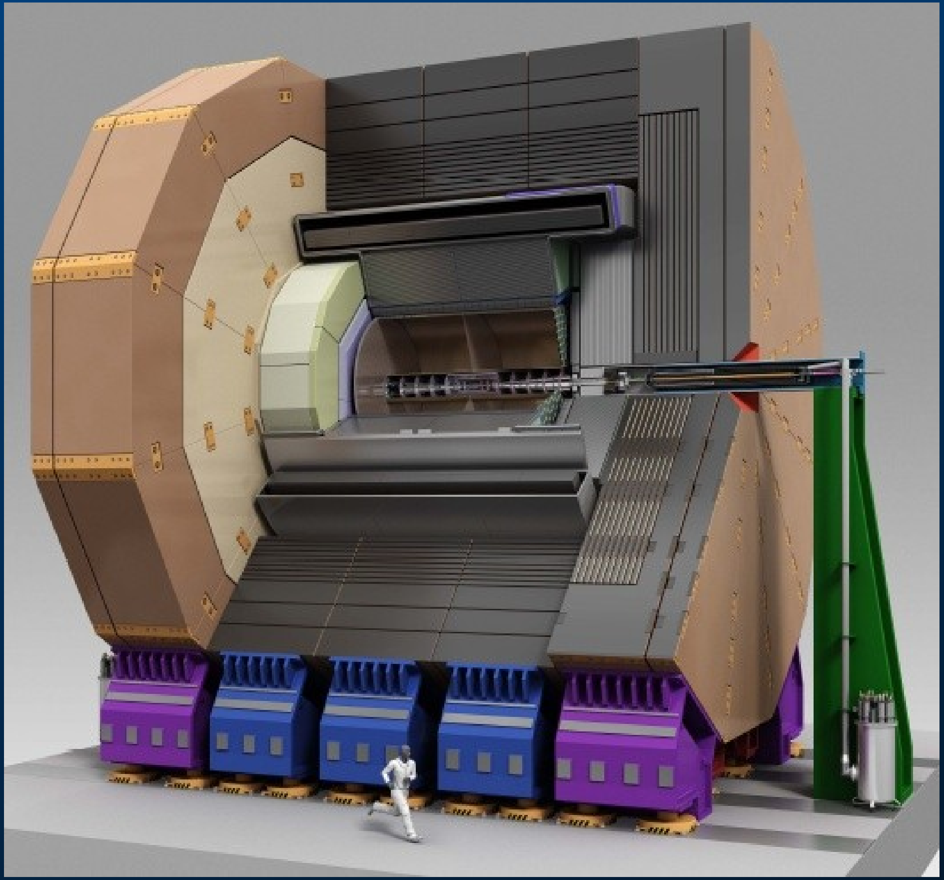




error source	Δm_t^{PS} [MeV]
stat. error (200 fb^{-1})	13
theory (NNNLO scale variations, PS scheme)	40
parametric (α_s, current WA)	35
non-resonant contributions (such as single top)	< 40
residual background / selection efficiency	10 – 20
luminosity spectrum uncertainty	< 10
beam energy uncertainty	< 17
combined theory & parametric	30 – 50
combined experimental & backgrounds	25 - 50
total (stat. + syst.)	40 – 75

In **one year** of data taking we can **improve by x10** the **LHC** results

Possible at **different mass schemes**, with small uncertainties in the conversion from one to other



Detector R&D for the ILC :

These final states require **highly performance detectors**:

- b(c,s)-charge determination using micro vertex information

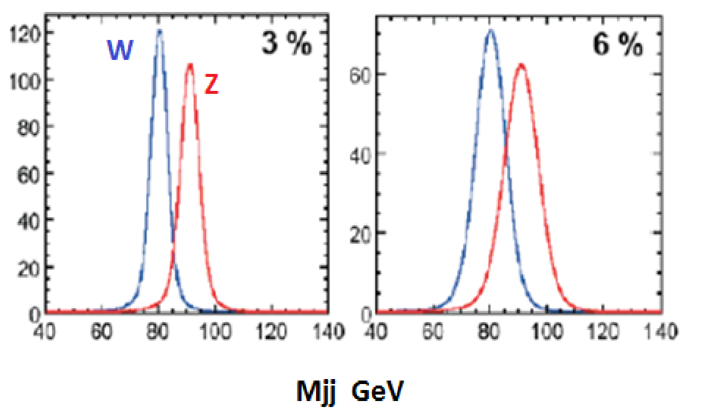
- Charge particle identification using trackers

- High resolution in jet reconstruction

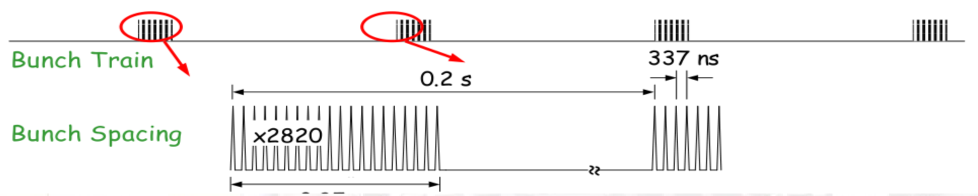
The detector concepts: requirements

- Known (and speculated) **physics channels dictate detector properties**.
  - The detectors should be able to resolve hadronic heavy boson decays

$$M^2 = 2E_1E_2(1-\cos\theta_{12}) \longrightarrow \sigma_M/M = (1/\sqrt{2})\sigma_E/E$$

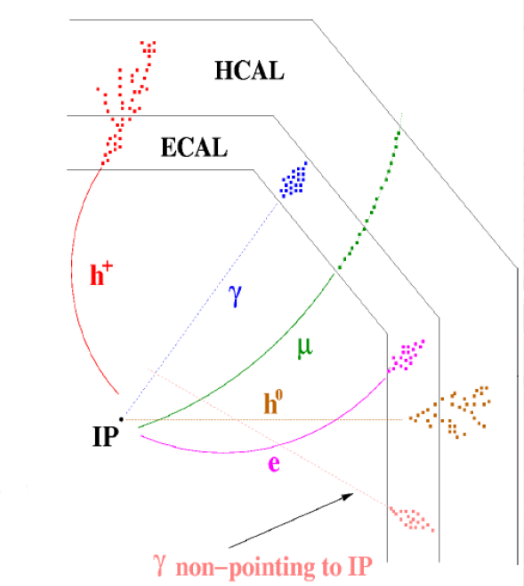


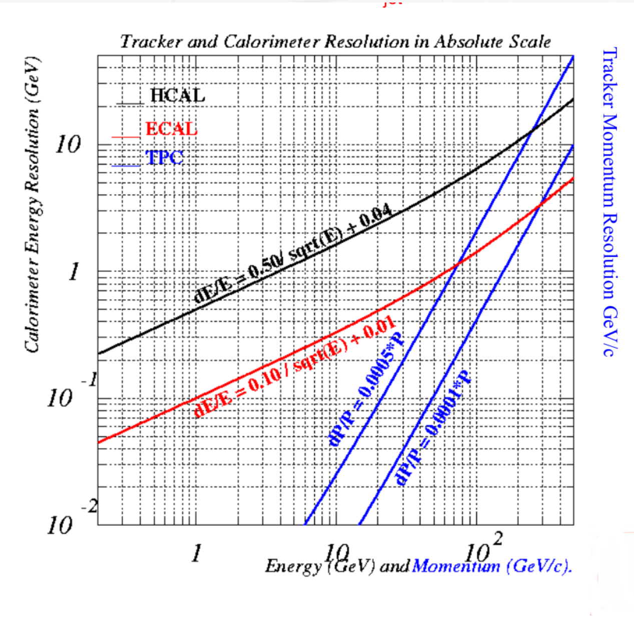
  - A 3-4% jet energy resolution is needed for W/Z separation
  - Roughly: factor 2 better than LEP resolution and factor 3 better than LHC resolution
- A bias **free selection** is essential to cover any unforeseen physics scenario
  - The beam time structure (~1 ms bunch trains separated by ~200 ms) allows to not use a central trigger and record all collisions recorded in each bunch train (self triggering detectors working in zero suppression mode).



Particle Flow and Imaging calorimetry

- A typical jet is formed by ~65% of charged particles, ~25% of photons and ~10% of neutral hadrons
  - In classical calorimetry, the resolution is limited by our capability to measure the energy of neutral hadrons in HCAL but also in ECAL (~50% of neutral hadrons convert in ECAL)

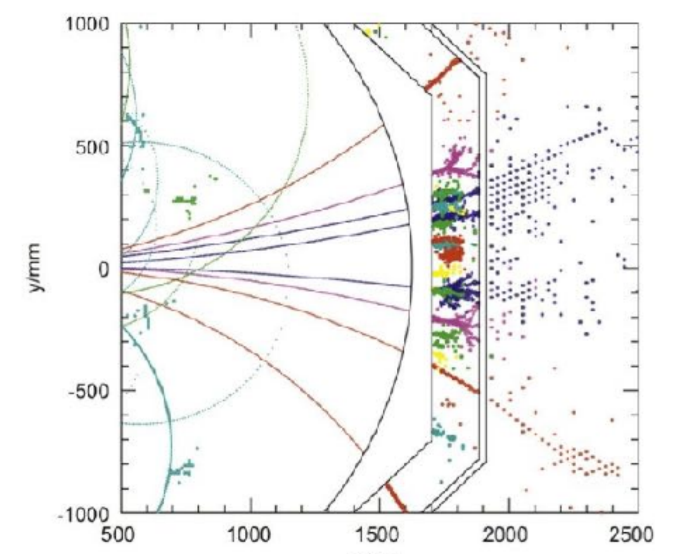


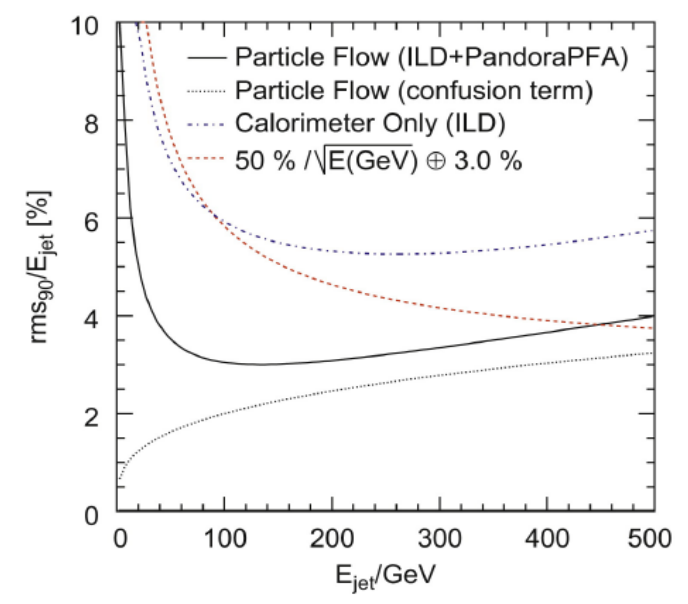


- Need to perform separation of single particle signals in the calorimeters
- The Particle Flow approach that uses the best information in the detector to measure particle energies, **to meet the required level of precision**

Particle Flow and Imaging calorimetry

- The limiting factor for the energy resolution is not the classical calorimeter resolution but the overlap between showers that compromises the correct assignment of calorimeter hits (**confusion term**)
  - Need to **minimize** this term as much as possible !



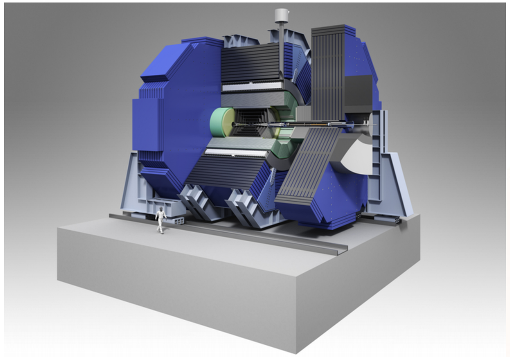


The detector optimization for Particle Flow

- **Detectors optimized for PF require:**
  - Excellent tracking efficiency (>99%)
  - Large radius and lengths & Large magnetic fields (to separate particles)
  - Low material budget in front of the calorimeters (calorimeters confined inside the magnets)
  - Imaging calorimetry: high granularity, compact (limited shower radial expansion) and hermetic calorimeters to maximize the capabilities of the pattern recognision algorithms.

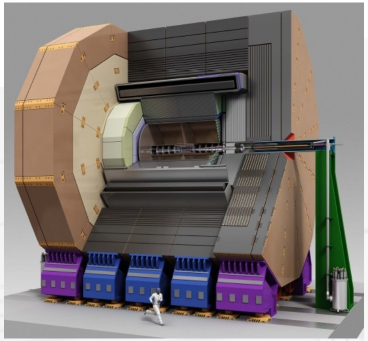
- Particle flow-like algorithms were applied at **ALEPH, ZEUS, CDF.**
  - Much lower level of granularity and optimization for PF
- **Nowadays PF is being used by CMS** (but in a detector not optimized for PF).

The detector concepts: SiD and ILD



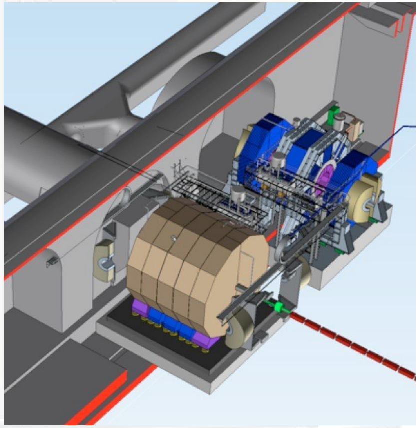
SiD:

ILC Silicon Detector



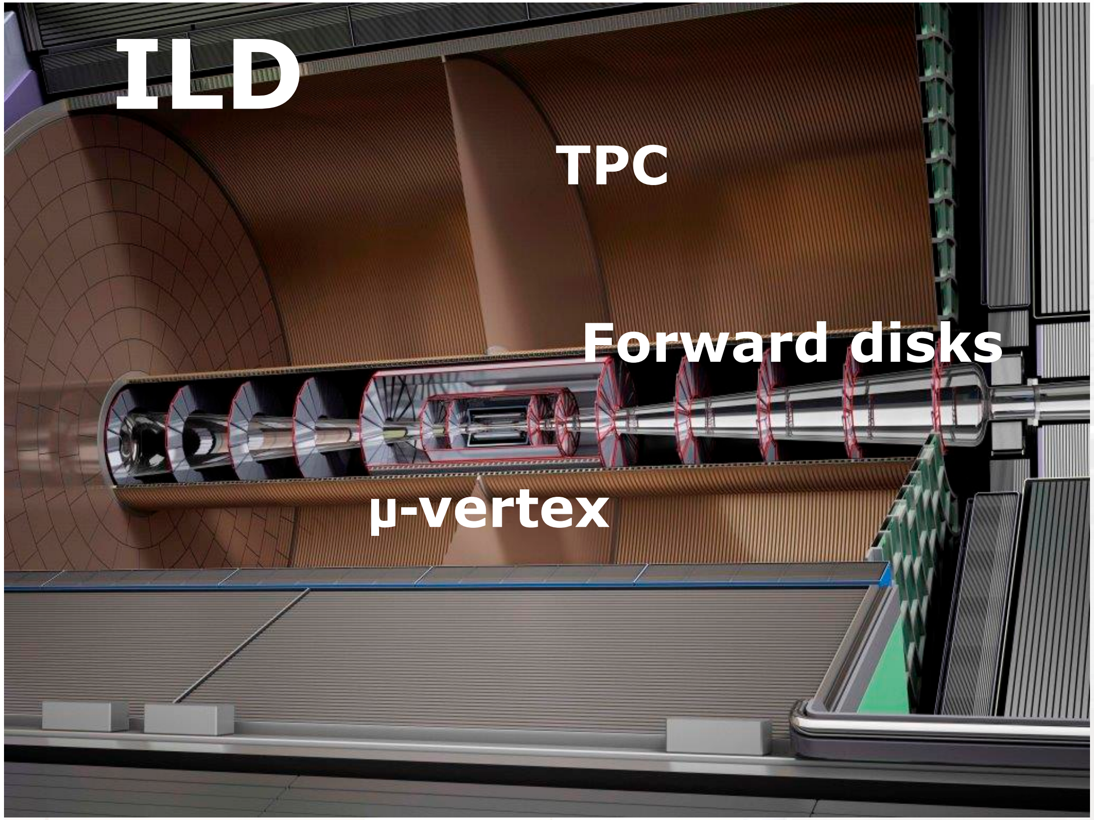
ILD:

ILC International Large Detector

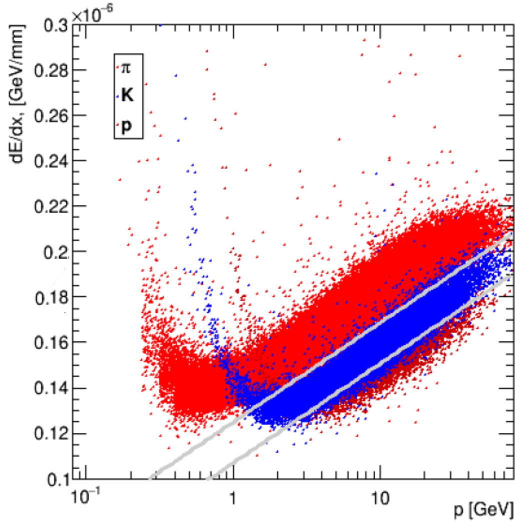


- **‘Full’ angular coverage** including for flavor tagging
- **Large SC solenoidal magnetic** field à *la CMS* (B>3 T) ensuring excellent momentum resolution.
- Almost **‘transparent’ trackers** with calorimeters included inside the coil minimizing material effects
- **Imaging calorimetry** for PF with **>10^8** of electronic **channels**
- Both use **low power consumption** systems
- **Push-pull** philosophy insuring scientific and technical safety

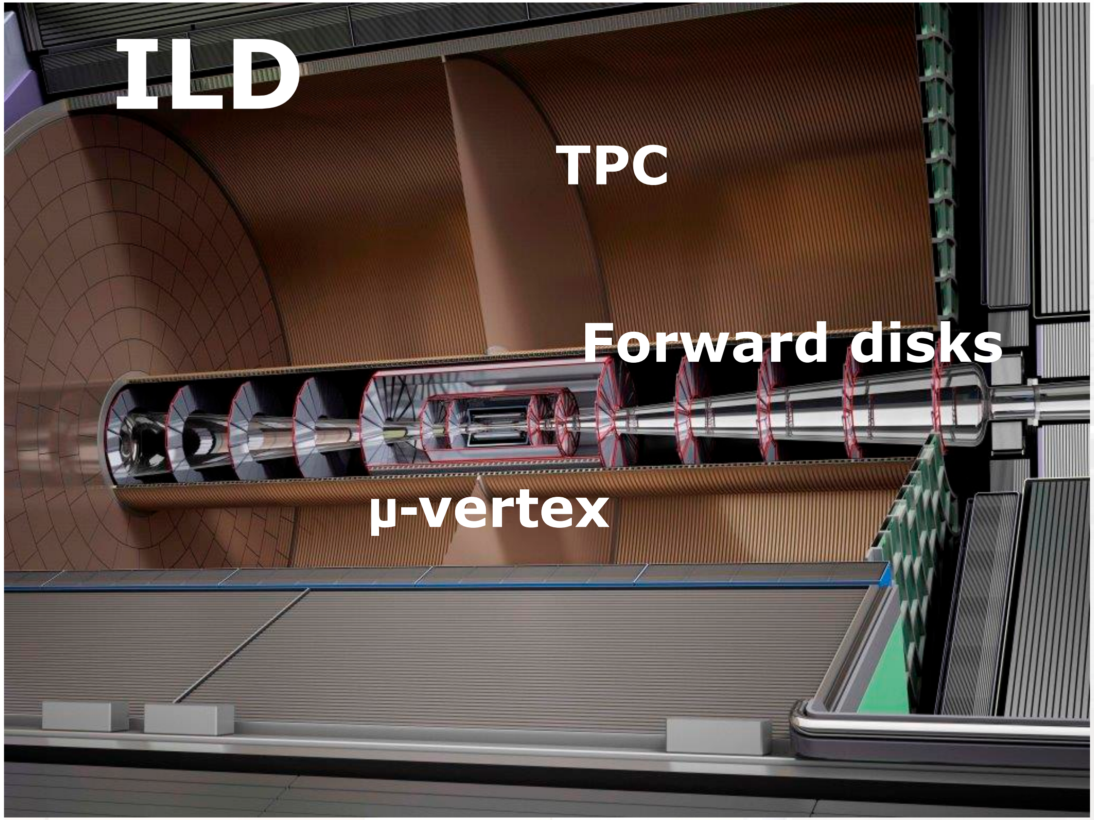
Tracking & Vertexing



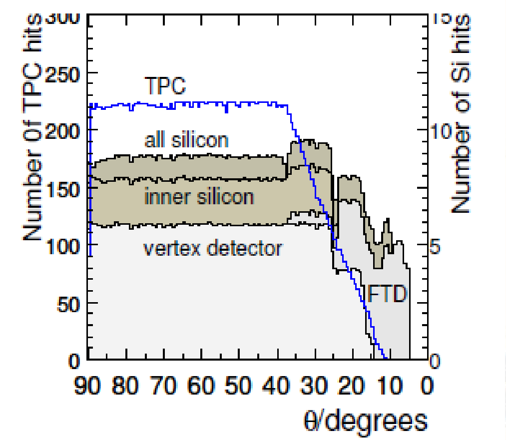
- The use of a TPC is one of the identity marks of the ILD:
  - Large power of separation of particles (large volume)
  - Low material budget
  - Particle identification.



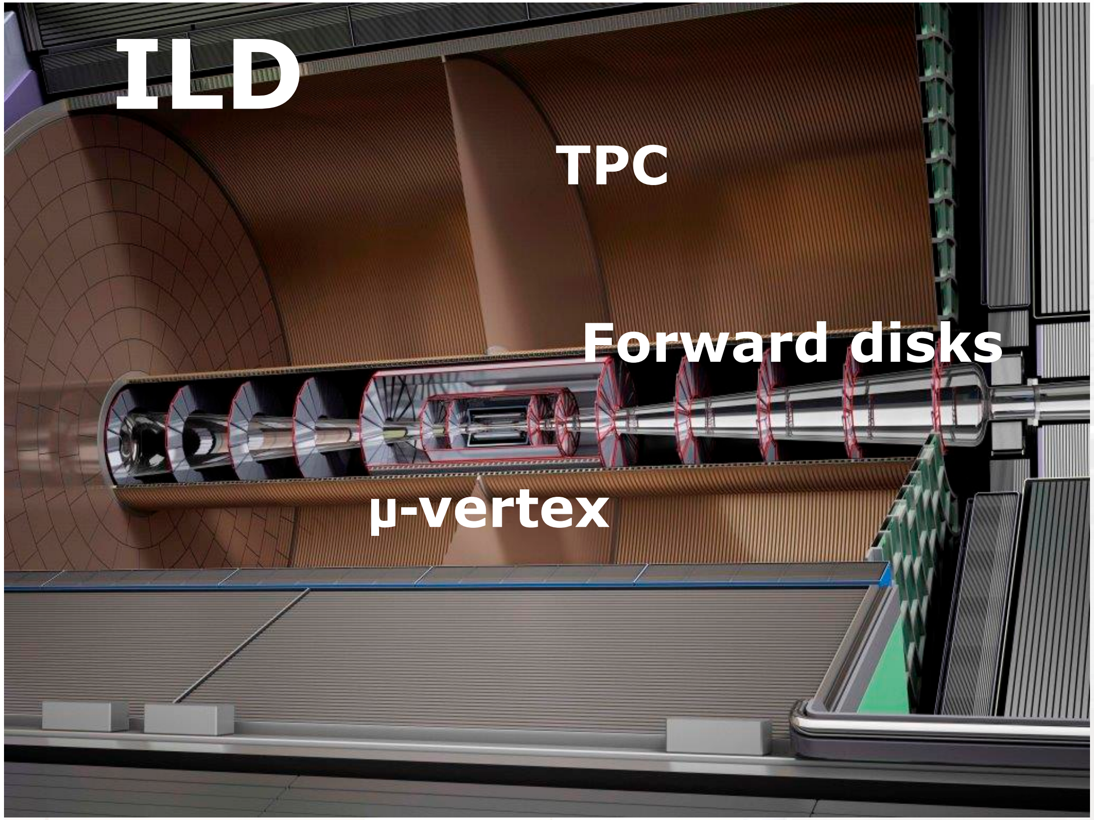
Tracking & Vertexing



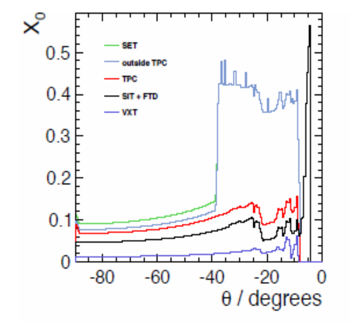
- Major breakthroughs with respect to existing detectors with many available new technologies for the Silicon detectors.
  - CMOS Pixel Sensors (IPHC)
  - Fine Pixel CCD and DEPFET
- 1st layer at R<2cm (5cm at LEP)
- High coverage

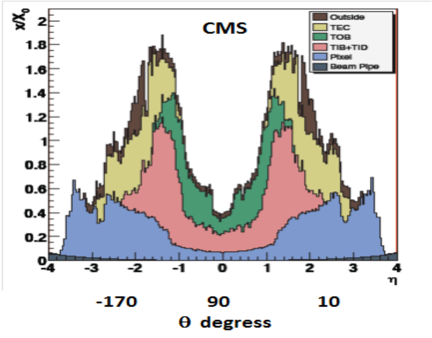


Tracking & Vertexing

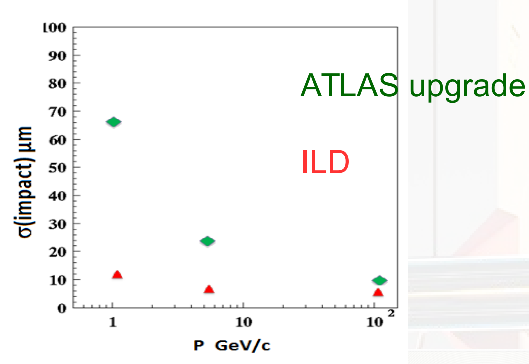


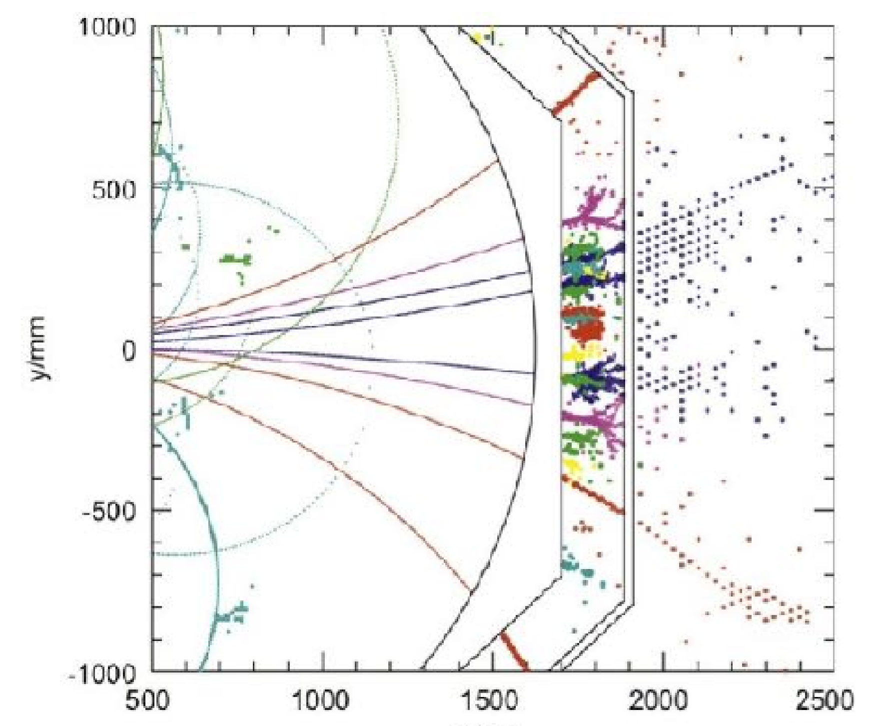
- Low material budget





- Excellent vertexing performance



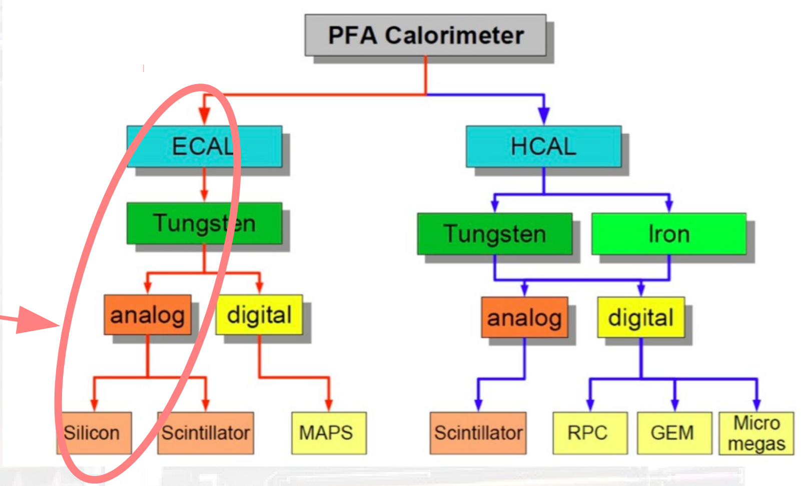


Imagin calorimetry

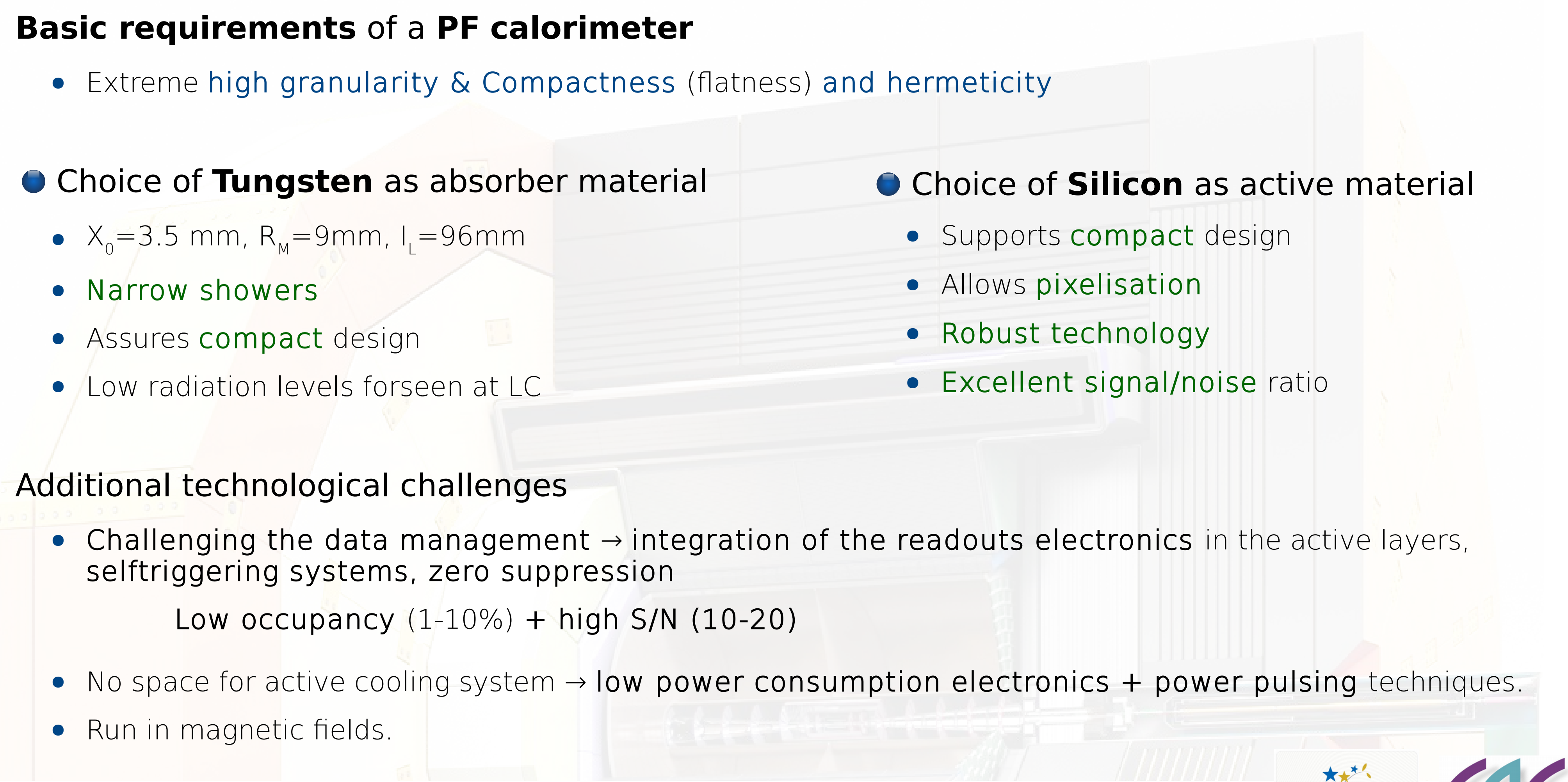
The SiW-ECAL :
an electromagnetic calorimeter for a Particle Flow detector

Calorimetry for the future linear colliders

- The R&D in high-granularity calorimeters for the ILC is being conducted by the **CALICE** collaboration
- Goal: **construct highly granular calorimeters optimised for PF** measurement of multi-jet final states at the **ILC**
- Intermediate step: **build prototype calorimeters to**
  - Establish the technology
  - Collect hadronic showers with unprecedented granularity to tune and test PF and MC algorithms → great interest shown by the Geant4 collaboration.
- The **SiW ECAL R&D** is tailored to meet the specifications for the **ILD** **ECAL** **baseline** proposal



SiW-ECAL for the ILC



Basic requirements of a **PF calorimeter**

- Extreme high granularity & Compactness (flatness) and hermeticity

Choice of Tungsten as absorber material

- X_0=3.5 mm, R_M=9mm, I_L=96mm
- Narrow showers
- Assures compact design
- Low radiation levels forseen at LC

Choice of **Silicon** as active material

- Supports compact design
- Allows pixelisation
- Robust technology
- Excellent signal/noise ratio

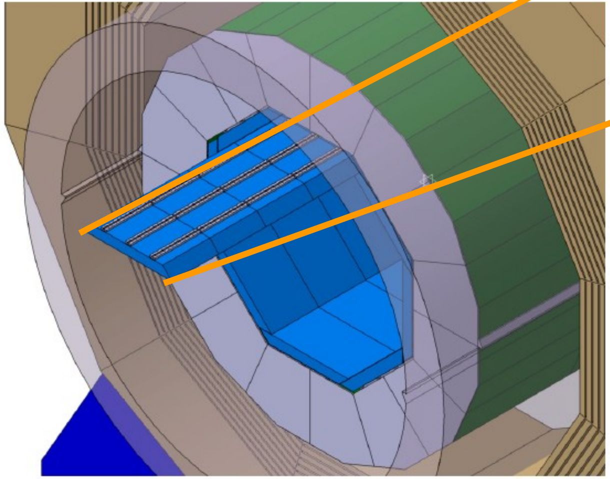
Additional technological challenges

- Challenging the data management → integration of the readouts electronics in the active layers, selftriggering systems, zero suppression

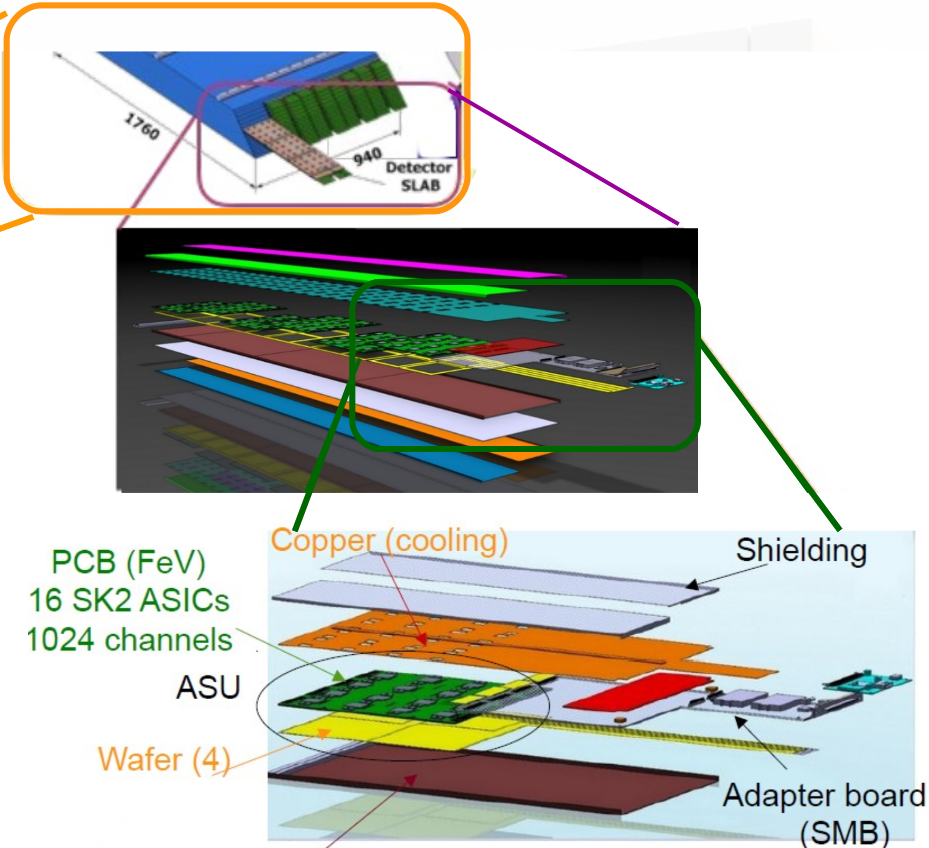
  Low occupancy (1-10%) + high S/N (10-20)

- No space for active cooling system → low power consumption electronics + power pulsing techniques.
- Run in magnetic fields.

SiW-ECAL for the ILC

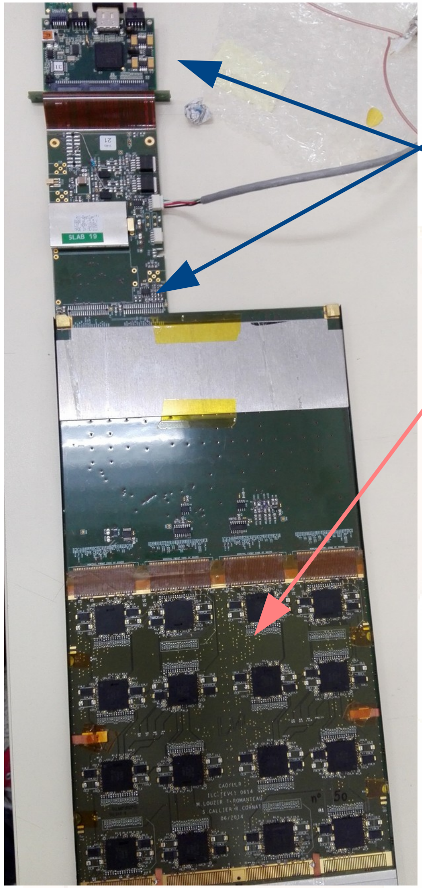


The SiW ECAL in the ILD Detector



U layout of a **short slab**

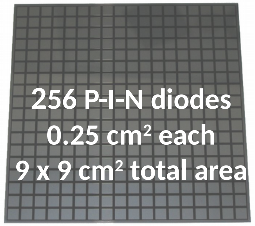
SiW-ECAL technological prototype: active units



DIF + SMB

ASU

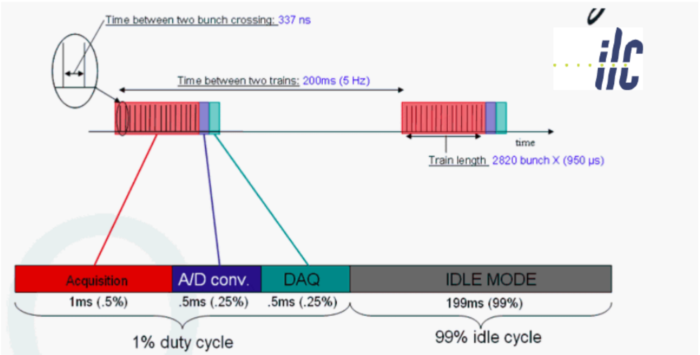
equipped with 4 Si-wafers



256 P-I-N diodes
0.25 cm^2 each
9 x 9 cm^2 total area

Short slab:

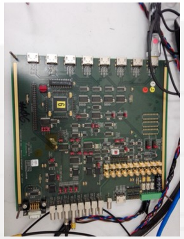
- Adapter board (**SMB**) and Detector Interface (**DIF**)
- **ASU (Active Sensor Unit)**,
  - PCBs (FEV10/11) with glued silicon P-I-N diodes as active material (325um, 4 kΩcm, N-type)
  - 1024 channels per slab
- VFE electronics: 16 **Skiroc ASICS** (in the ASU)
  - Auto trigger, double gain ADC
  - Low power consumption & power pulsing (25µW/ch)

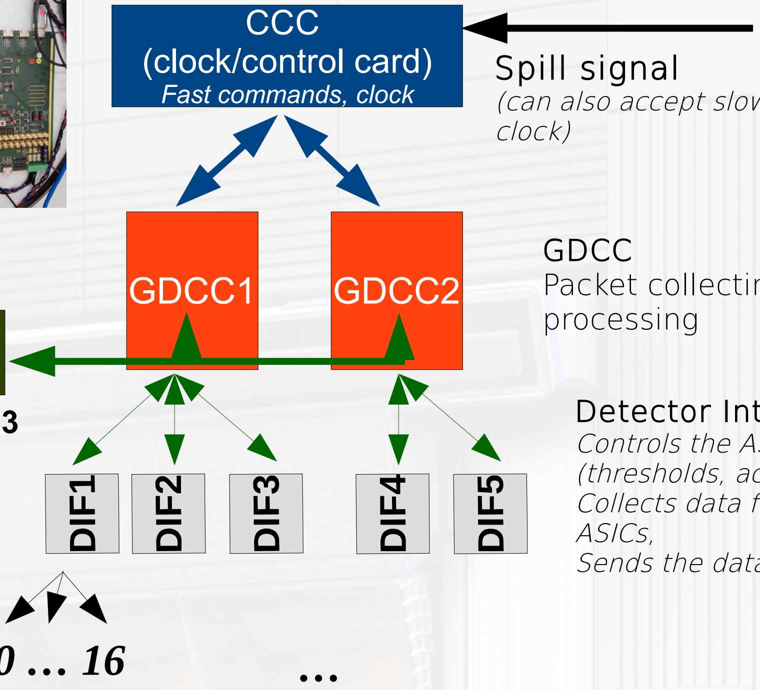


N.B. Final numbers may vary

SiW-ECAL technological prototype: DAQ

- Compact **DAQ designed for standalone beam test**
  - Standard (to facilitate compatibility with other ILC prototypes),
  - Modular
  - scalable to ILD

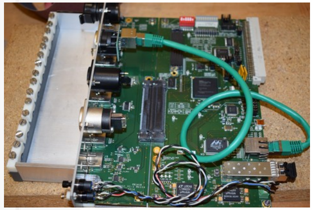




Spill signal
(can also accept slow clock)

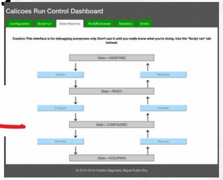
DAQ PC

GDCC
Packet collecting, processing



Detector InterFaces
Controls the ASICs (thresholds, acq. State),
Collects data from all ASICs,
Sends the data to GDCC

Pyrame Calicoes 3



Calicoes Run Control Dashboard

Lur

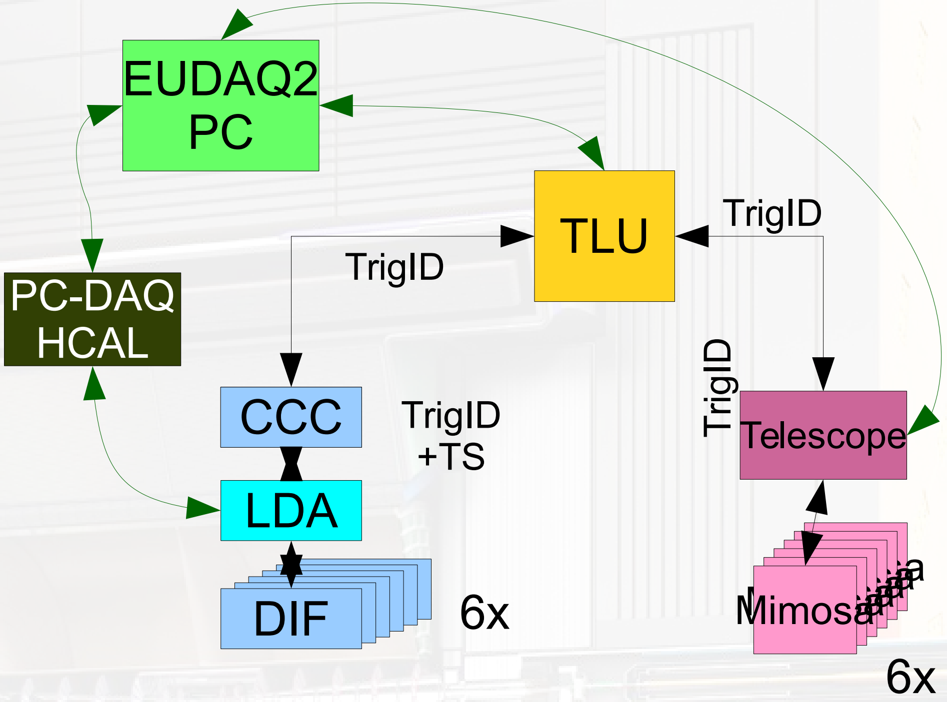
SiW-ECAL technological prototype: DAQ

Current efforts:

- Preparation of future **common beam test** with other ILC prototypes using the **AIDA2020 WP5** standards, software, hardware and support.
- The AIDA-2020 project brings together the leading European research infrastructures in the field of detector development
- AIDA2020 WP5 is dedicated to DAQ developments for LC-detectors common tesbeams.

Towards Combined beam tests

- Example case of combined beam test architecture followed by the AHCAL (analogue hadronic calorimeter prototype for the ILC) within the AIDA2020 standards.



Towards Combined beam tests

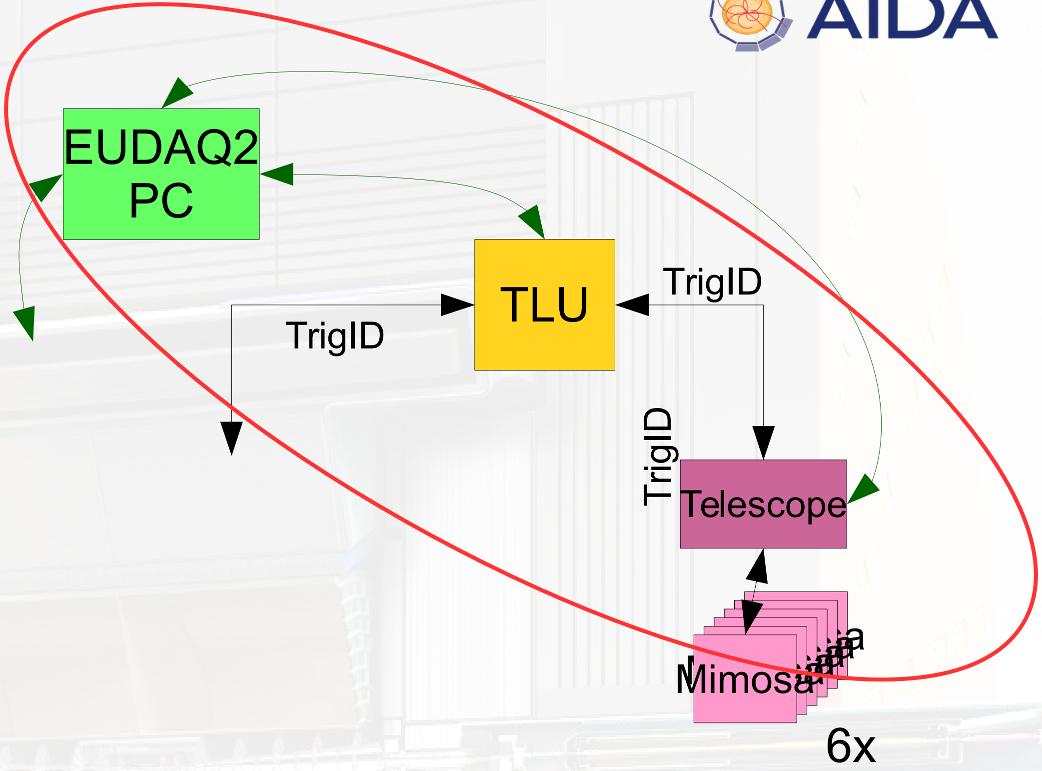
- Example case of combined beam test architecture followed by the AHCAL (analogue hadronic calorimeter prototype for the ILC) within the AIDA2020 standards.

Provided by AIDA2020 and beam lines:

TLU: Trigger Logic unit masters the beam test by delivering trigger signals (and managing busies) through different subsystems.

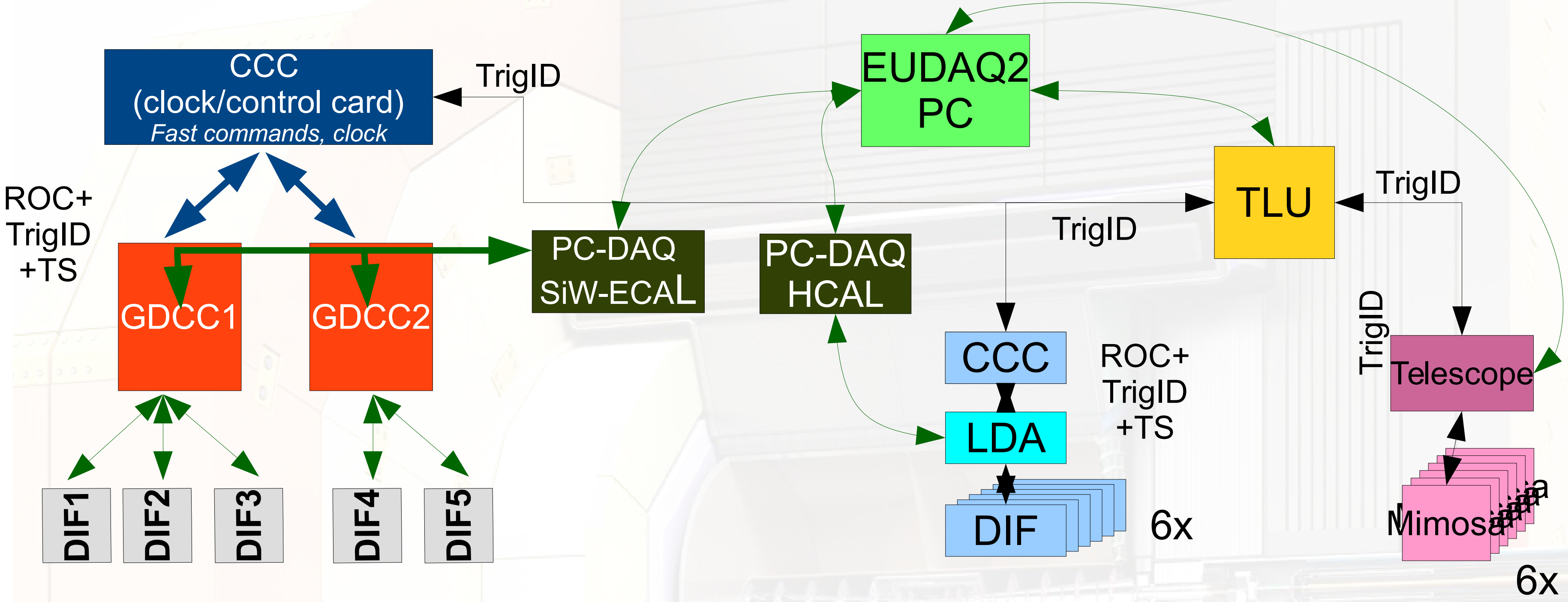
EUDAQ: modular and **generic DAQ software** used as run control and data collector (including event building)

Telescope (optional): for track finding and geometric event building.



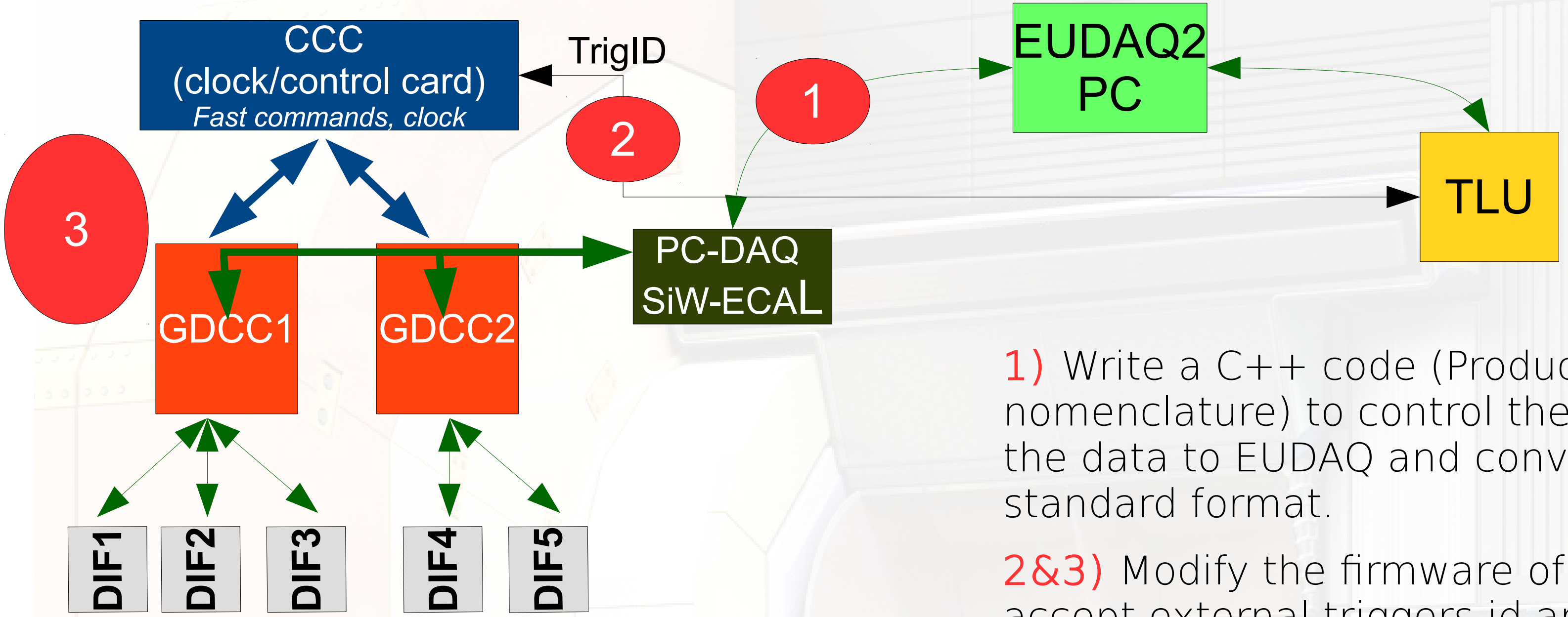
Towards Combined beam tests

- How to join to these devices in beam test?



Towards Combined beam tests

- To be done by the SiW-ECAL to go in common beam tests with another AIDA2020 prototype.

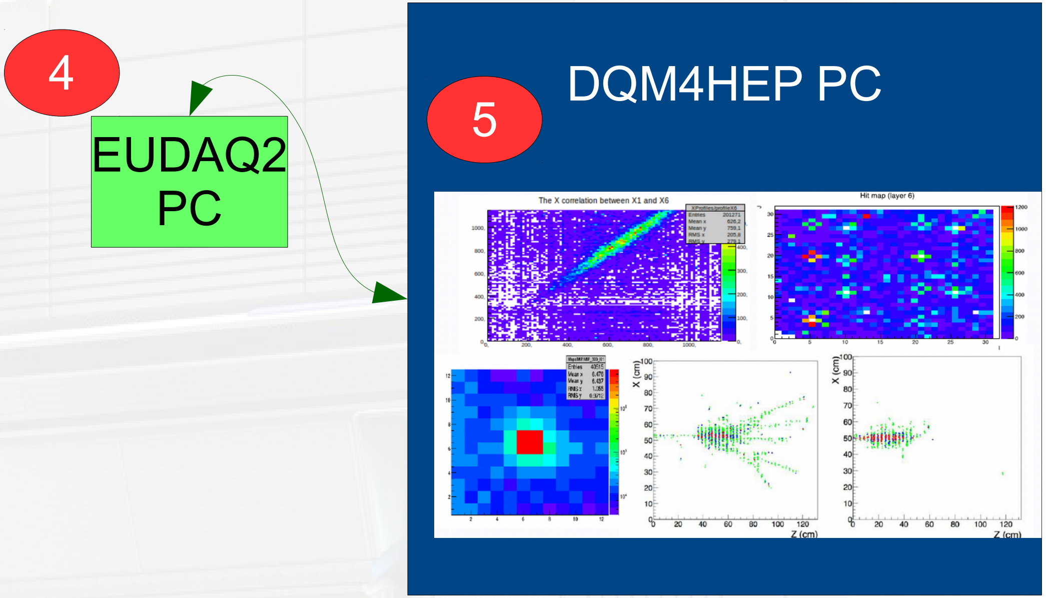


1) Write a C++ code (Producer, in EUDAQ nomenclature) to control the SiW-ECAL DAQ, send the data to EUDAQ and convert them to a standard format.

2&3) Modify the firmware of CCC and GDCC to accept external triggers id and deliver them through the system

Towards Combined beam tests

- To be done in collaboration by all experiments in the common beam test.



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EUDAQ2 PC

5

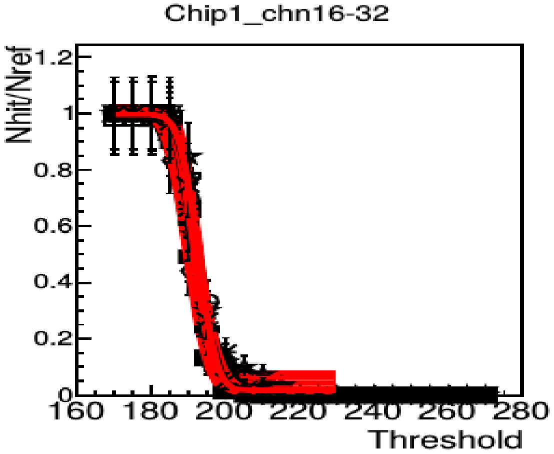
DQM4HEP PC

4) **Build the events in EUDAQ**: for that the different experiments should save the needed information (timestamp, trigger id, etc)

5) Write the monitoring analysis in **DQM4HEP: generic, modular and flexible** monitoring tool developed by the **SDHCAL** (Semi Digital Hadronic Calorimeter) and supported now by AIDA2020

Preparation of a (standalone) Test Beam at DESY (2017)

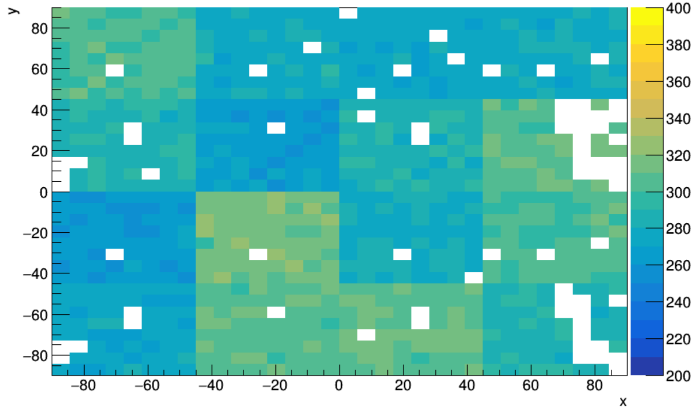
- Define a **commissioning procedure**
  - **Optimal** auto **trigger Threshold value** determination through fit of **scurves** to data taken in noise runs.
  - Find **noisy channels**: **7-8%** masked channels (can be reduced by individual threshold settings, sk2A)
  - 7 shorts slabs passed it, the other 3 were rejected for lower performance: under investigation



- Noise sources found and isolated:
  - **Repetitive patterns** on the localization of **noisy channels. Solution: mask these channels**

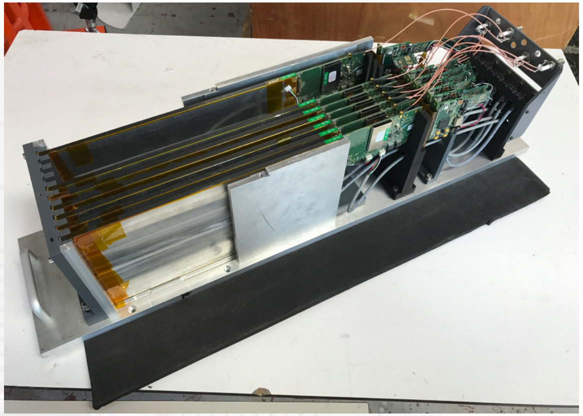
→ ***issues on the routing*** *of pad2ASIC in the PCB have been found after beam test (currently under study)*

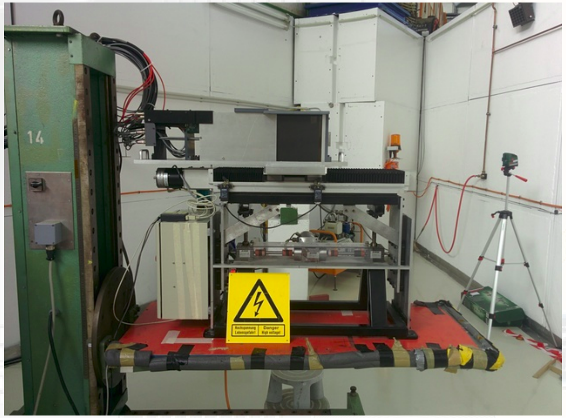
  - Noise bursts due to grounding loops (isolation issues). Solution: improve slab isolation.



Test Beam at DESY

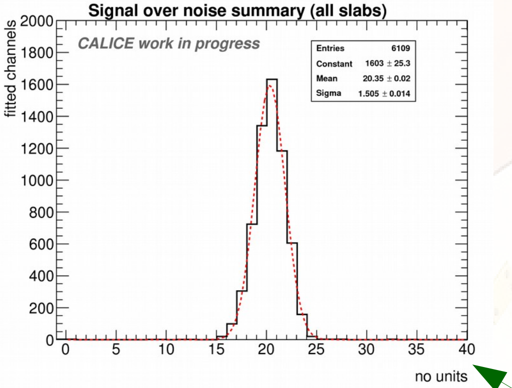
- **Setup** :
  - **7 short slabs:** 6 FEV11, 1 FeV10 each equipped with 4 325um Si wafers and 16 Skiroc2
  - **Power pulsing and ILC mode** (emulated ILC spill conditions)
- **Physics program:**
  - **Calibration** run with 3 GeV positrons perpendicular beam without tungsten absorber plates
  - **Electromagnetic showers program.**
  - **Calibration** run with 3 GeV positrons in **~45 degrees** (6 slabs)
  - **Magnetic field tests** with 1 slab (up to **1 T**) in the PCMag



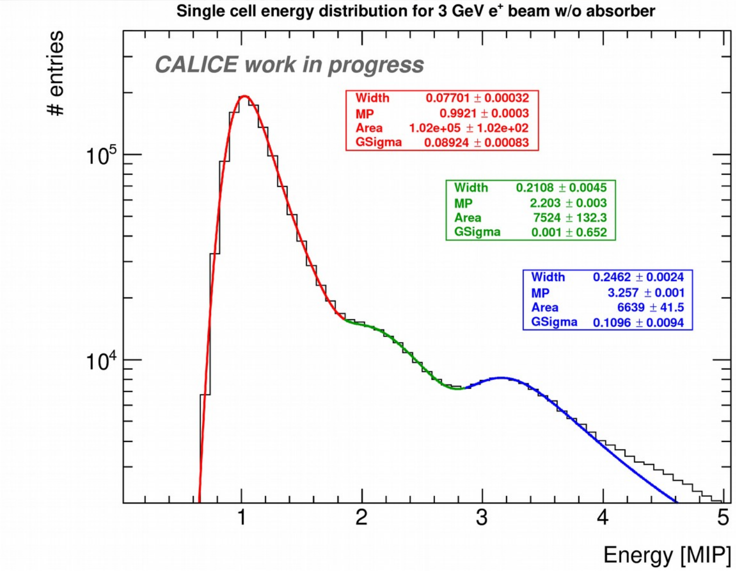


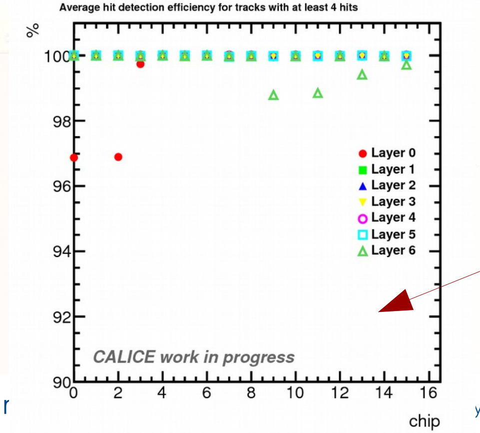
Calibration

- MIP scan: Si - ECAL **(w/o the W)**
  - Positrons of 3 GeV (~2 kHz rate, beam spot with slightly irregular shape and size <2cm diameter)
- Data used for pedestal subtraction and energy calibration for following runs:



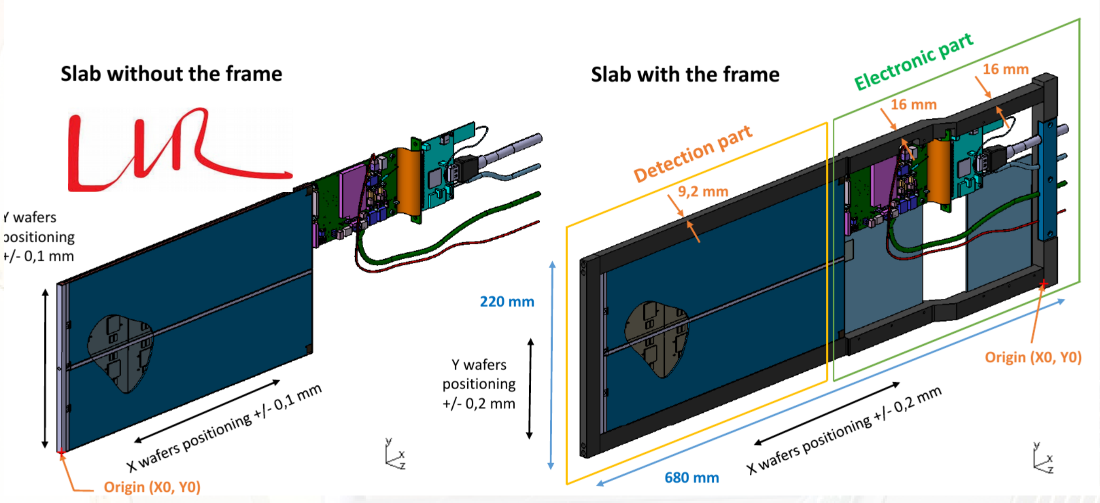
- We fit the 98% of available channels
- MPV = 62.2 ADC, sigma= 3.2 ADC (dispersion of 5.1 %)
- S/N = 20.3, sigma = 1.5 (7.4 % dispersion)
  (MIP position – pedestal position) / pedestal width
- Track detection efficiency ~100%





Data taking program

- Magnetic field tests
  - One slab in a special plastic support
  - Magnetic field from 0 to 1 T.
  - With and without beam.
- **No failure/loss of performance during visual inspection on the web cam & online monitor.**
  - ~20 hours of data in total.

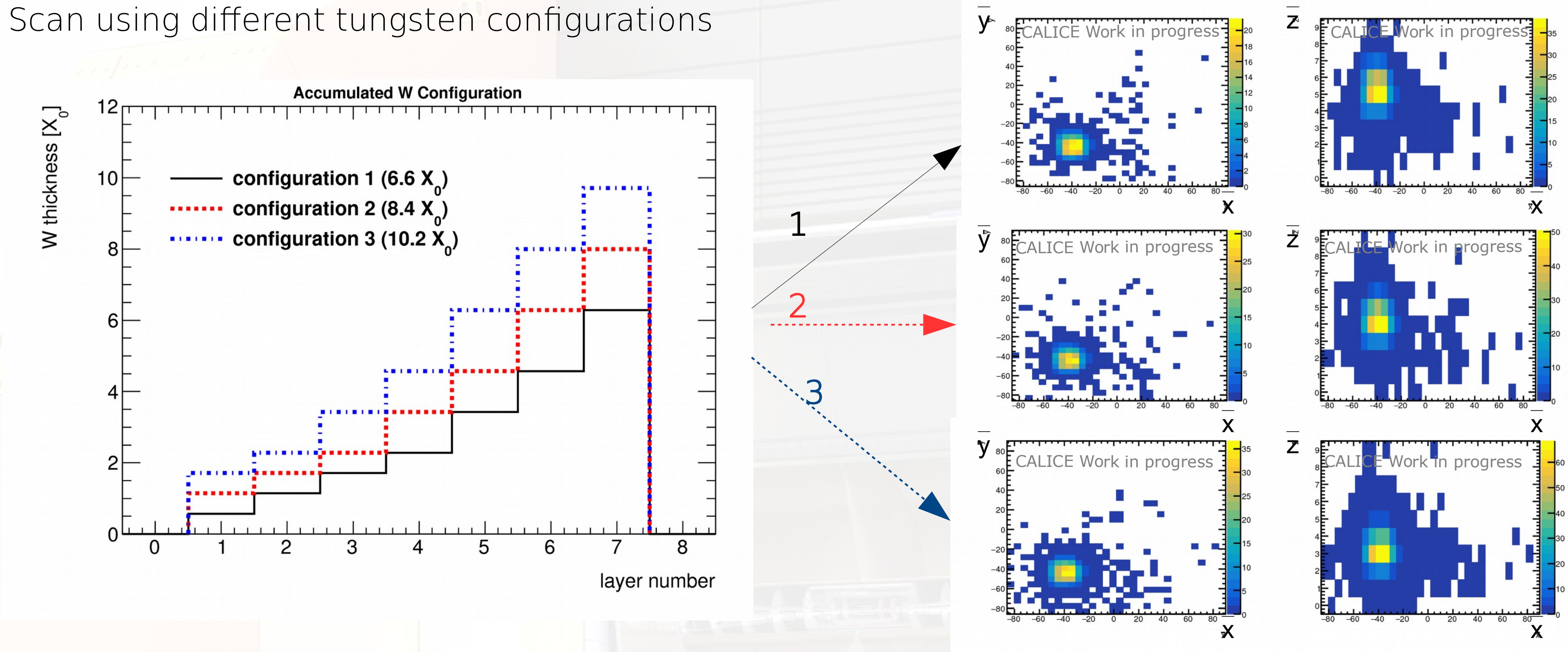


SiW-ECAL performance for electromagnetic showers

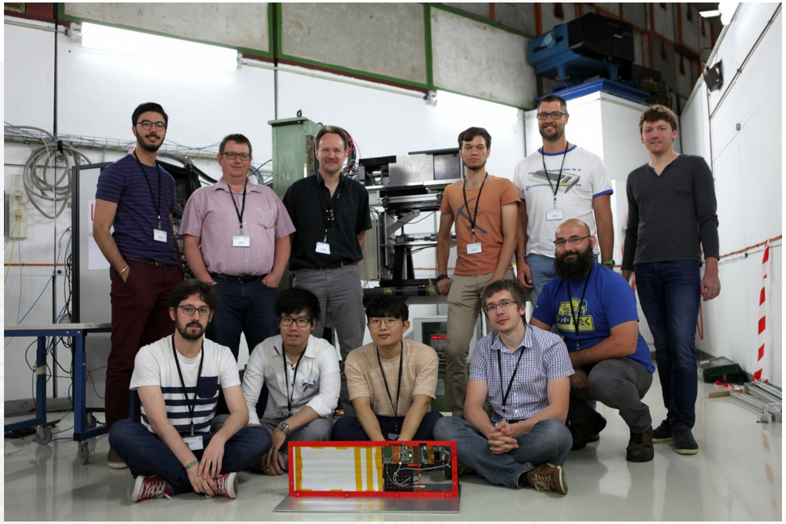
- Tungsten program
  - Scans of various energies (from 1-5.8 GeV).
  - Scan using different tungsten configurations

Raw shower barycenter maps

$$\bar{x} = \sum_{i=cells,\, j=layer\ number} x^i w_0^j E_i \Big/ \sum_{i=cells,\, j=layer\ number} w_0^j E_i$$



Test beam performance summary



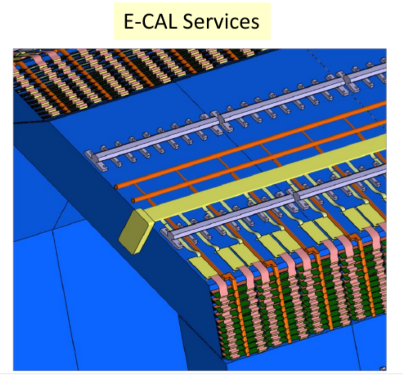
- Successful beam test of the SiW-ECAL technological prototype.
  - first time with fully assembled detectors elements (first 7 of 10000 needed for ILD)
- **Very good S/N** performances in all the SLABs of (20±1.5)σ on mips
- Raw calibration achieved at the **5% level.**
- First looks at **shower response are very promising**
- **Operating in 1T magnetic field**
  - Also nice and consistent calibration results

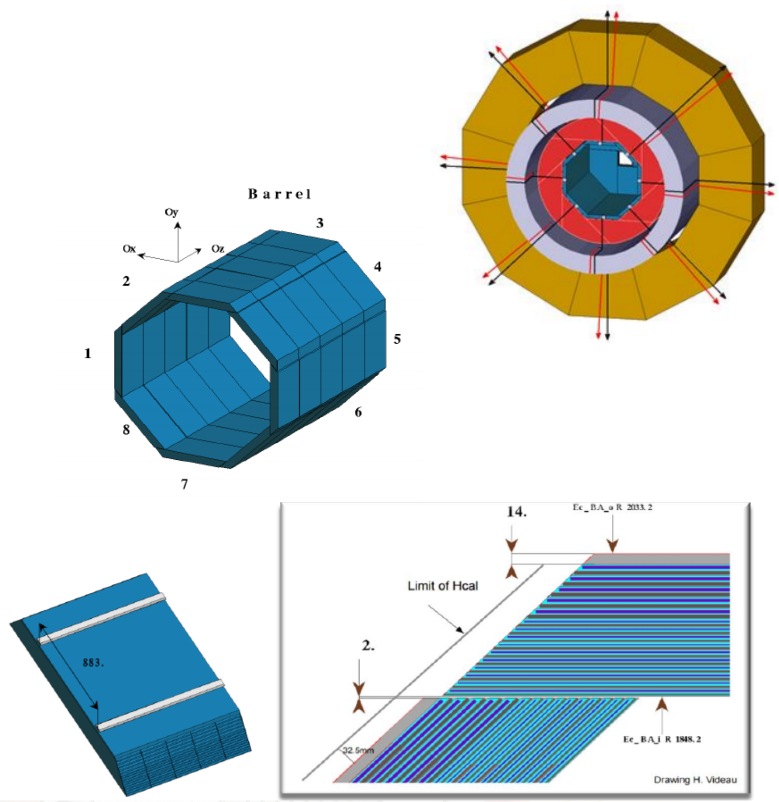
- Presentations + proceedings for **CHEF2017, IEEE2017, LCWS2017**
- Construction & beam test **technical paper ongoing**.

- Excellent prospects for next beam tests in 2018 !!

Towards ILD: challenges

- **Long slabs** : up to ~15 ASU **(2-3m)**.
  Mechanically and electronically complex object.
- **Spatial constraints**
  - Minimization of passive material thickness
  - limited space between layers and between ECAL and AHCAL
- **Low power consumption.**
- **Thermal uniformity**
- **Mechanical Assembly process**





Lot of integration efforts being done

See back-up slides

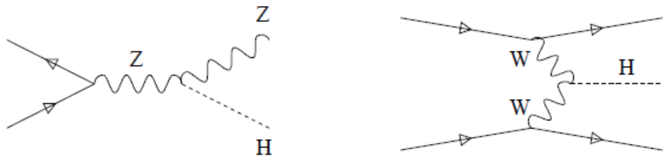
Summary

- The discovery of the **Higgs boson at the LHC** has been a major success of the field but it leaves **few questions open**.
- **The ILC** is the perfect experiment to **seek for answers** !
  - currently, the only e+e- at the energy frontier at the engineering phase.
- It will provide excellent **probe of the SM and BSM through precision measurements** but this requires **excellent detector performances**.
- The required level of performance will be acquired with detectors optimized for **Particle Flow reconstruction.**
- The PF requires **highly granular calorimeters and minimum material in front of them** (among other things). The R&D on such calorimeters is driven by the **CALICE collaboration**.
- One of these calorimeters is the **SiW-ECAL** fr the ILC which is in a **very exciting phase of R&D** and **prototyping** for the ILC.

Thanks for your attention.

Back-up

Higgs Factories: Higgs–Strahlung versus W–Fusion



$$\Gamma_{\text{tot}} \leftarrow \frac{\sigma_{\nu\nu bb}/\sigma_{Zbb}}{\sigma_{ZWW}/\sigma_{ZH}} \times \sigma_{ZH} \; .$$

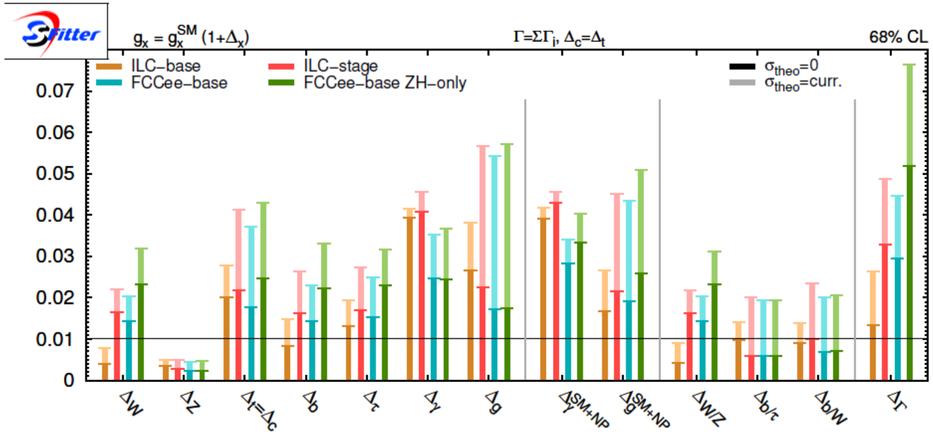


Figure 2. Precision of the Higgs couplings extracted in the linear and circular baseline scenarios using the current theoretical errors and assuming negligible theory errors. We also show results assuming a staged low-energy operation of the ILC and the impact of the W-fusion process by restricting the FCCee measurements to ZH production. We assume that the total Higgs width is constructed from all observed partial widths.

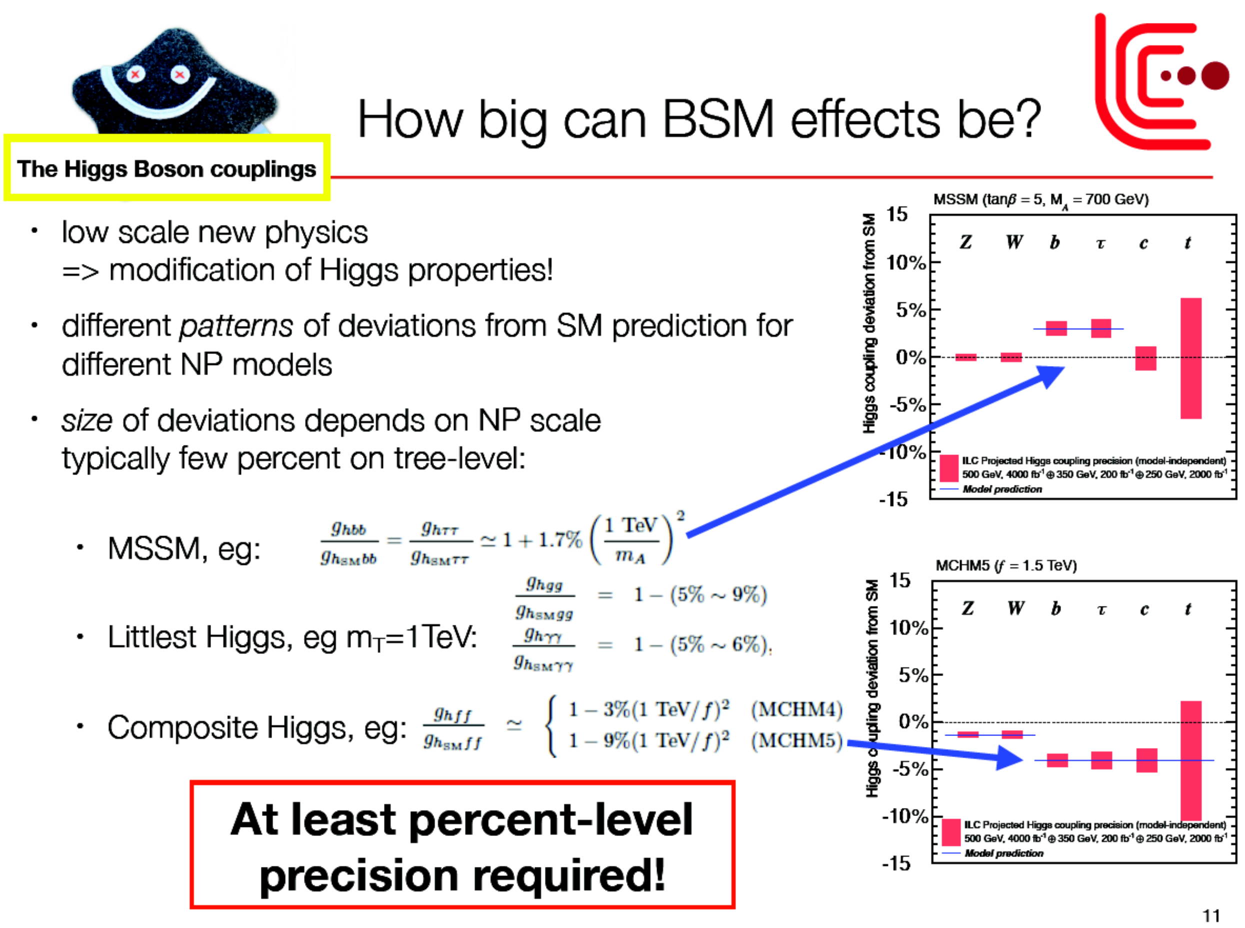
Higgs precision studies:

- **Theory errors are important!**
- **FCC-ee ZH-only wrt FCC-ee shows the impact of VBF**
- **High stat is balanced by high energy**
- **Key: total width**

collider	$\sqrt{s}$ [GeV]	luminosity [ab^{-1}]
HL-LHC	14000	3
FCC-ee/CEPC–240	240	4
FCC-ee/CEPC–350	240/350	4/1
ILC	250/350/500	0.5/0.2/0.5
ILC Upgrade	250/350/500	2/0.2/4

Lafaye, Plehn, Rauch, Zerwas
Phys. Rev. D 96, 075044 (2017)

Higgs Factories: Higgs–Strahlung versus W–Fusion



The Higgs Boson couplings

How big can BSM effects be?

- low scale new physics
  => modification of Higgs properties!
- different *patterns* of deviations from SM prediction for different NP models
- *size* of deviations depends on NP scale typically few percent on tree-level:
  - MSSM, eg: $\frac{g_{hbb}}{g_{h_{\mathrm{SM}}bb}} = \frac{g_{h\tau\tau}}{g_{h_{\mathrm{SM}}\tau\tau}} \simeq 1 + 1.7\% \left(\frac{1\ \mathrm{TeV}}{m_A}\right)^2$
  - Littlest Higgs, eg m_T=1TeV: $\frac{g_{hgg}}{g_{h_{\mathrm{SM}}gg}} = 1 - (5\% \sim 9\%)$, $\frac{g_{h\gamma\gamma}}{g_{h_{\mathrm{SM}}\gamma\gamma}} = 1 - (5\% \sim 6\%)$.
  - Composite Higgs, eg: $\frac{g_{hff}}{g_{h_{\mathrm{SM}}ff}} \simeq \begin{cases} 1 - 3\%(1\ \mathrm{TeV}/f)^2 & (\mathrm{MCHM4}) \\ 1 - 9\%(1\ \mathrm{TeV}/f)^2 & (\mathrm{MCHM5}) \end{cases}$

At least percent-level precision required!

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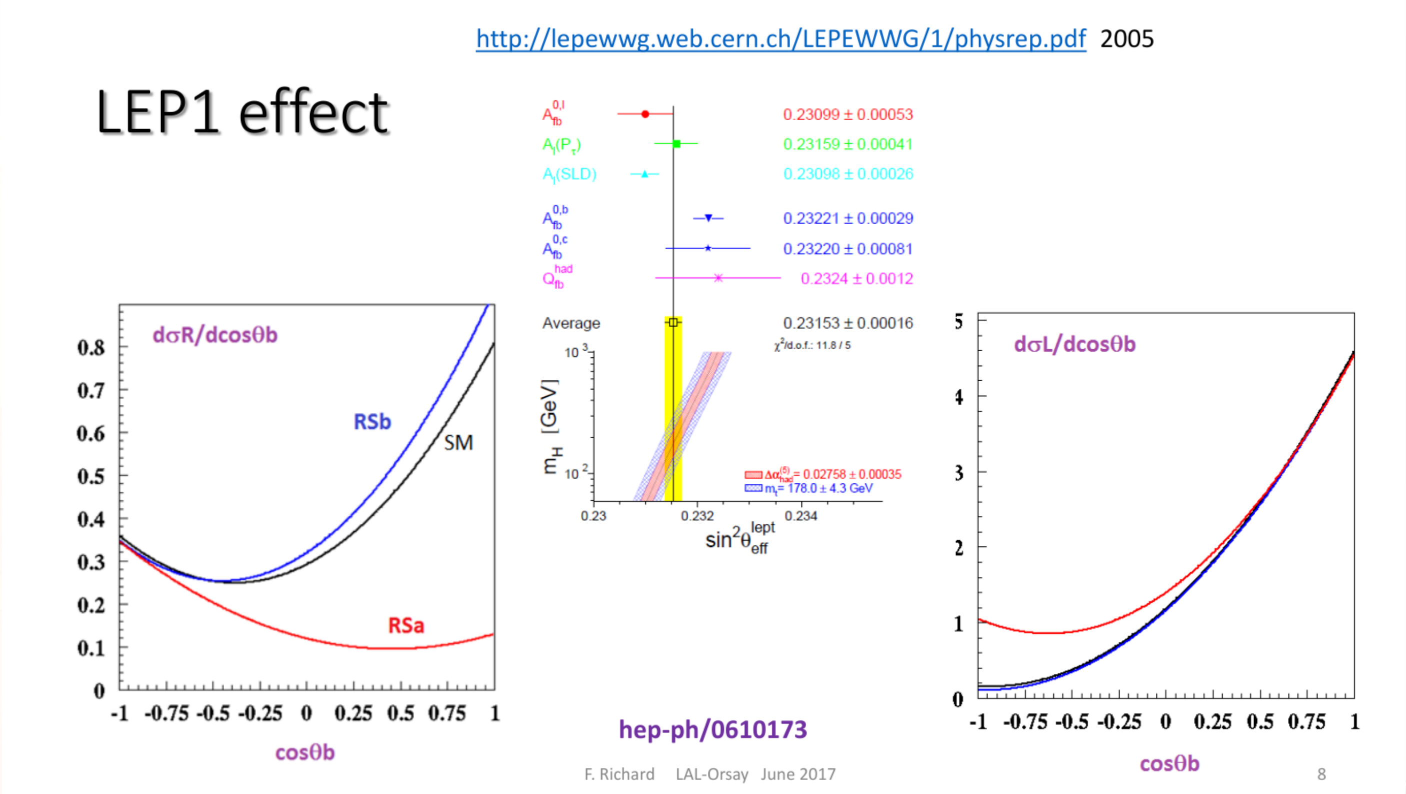
J. List, LCWS 2017

Benchmark analysis: heavy-quark physics



http://lepewwg.web.cern.ch/LEPEWWG/1/physrep.pdf 2005

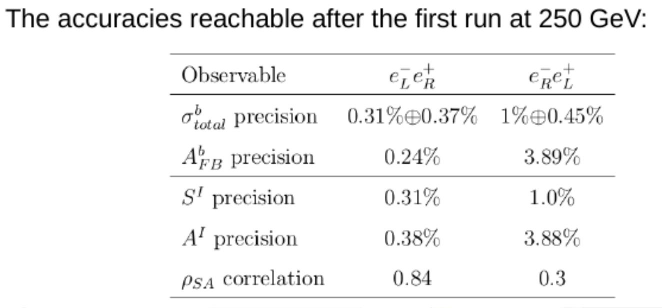
LEP1 effect

hep-ph/0610173

F. Richard LAL-Orsay June 2017

8

Benchmark analysis: heavy-quark physics



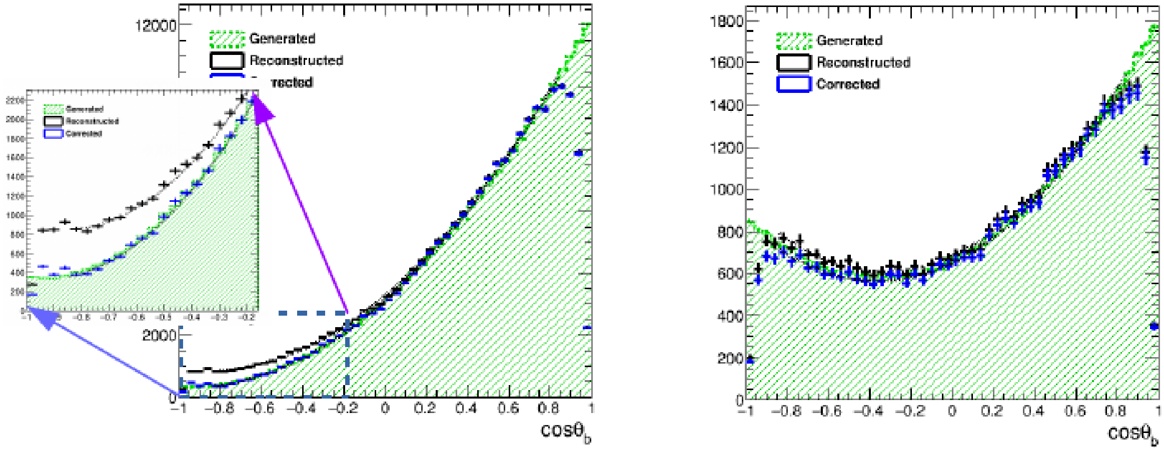
The accuracies reachable after the first run at 250 GeV:

Observable	$e^-_L e^+_R$	$e^-_R e^+_L$
σ^b_{total} precision	$0.31\% \oplus 0.37\%$	$1\% \oplus 0.45\%$
A^b_{FB} precision	0.24%	3.89%
S^I precision	0.31%	1.0%
A^I precision	0.38%	3.88%
ρ_{SA} correlation	0.84	0.3

Polar angle reconstruction

$$\mathcal{L} = 250\,\mathrm{fb}^{-1}$$

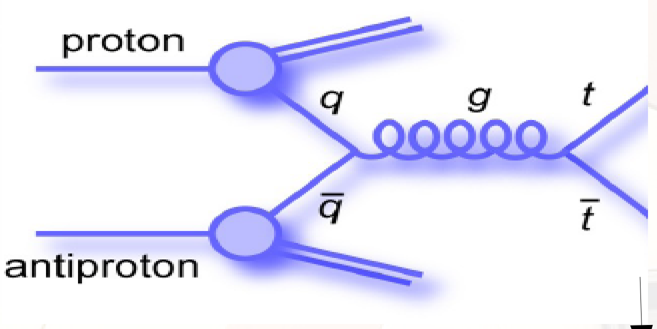
$e^-_L e^+_R \rightarrow b\bar{b}$ $\quad$ $e^-_R e^+_L \rightarrow b\bar{b}$

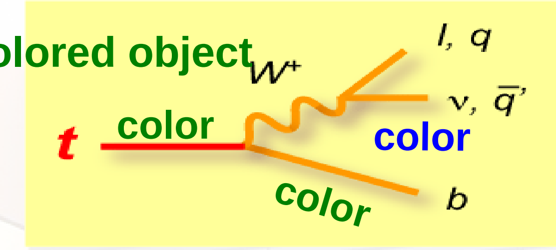


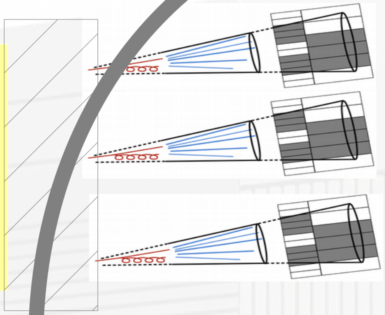
$$A^{rec}_{fb}/A^{gen}_{fb} = 100.7\% \pm 0.2\%$$

$$A^{rec}_{fb}/A^{gen}_{fb} = 103.8\% \pm 2.1\%$$

Top quark mass measurements: observables







Non colored objects

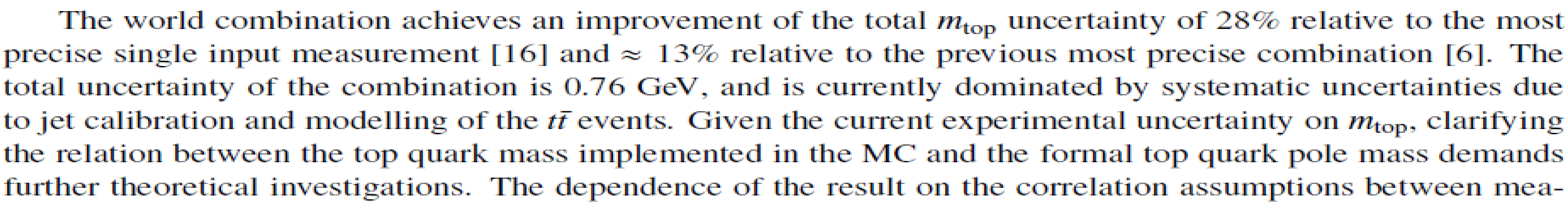
Calculation / Simulation

tt production
LO/NLO

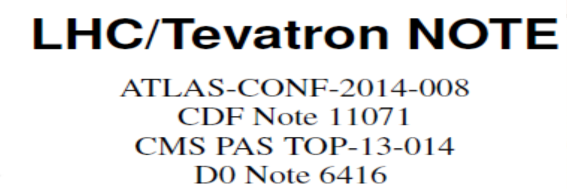
Top decay
LO

Hadronization + detector effects

Top quark mass measurements: observables



The world combination achieves an improvement of the total m_{top} uncertainty of 28% relative to the most precise single input measurement [16] and ≈ 13% relative to the previous most precise combination [6]. The total uncertainty of the combination is 0.76 GeV, and is currently dominated by systematic uncertainties due to jet calibration and modelling of the $t\bar{t}$ events. Given the current experimental uncertainty on m_{top}, clarifying the relation between the top quark mass implemented in the MC and the formal top quark pole mass demands further theoretical investigations. The dependence of the result on the correlation assumptions between mea-



LHC/Tevatron NOTE

ATLAS-CONF-2014-008
CDF Note 11071
CMS PAS TOP-13-014
D0 Note 6416

There is no well defined prescription that relates $\mathbf{m_t^{MC}}$ and $\mathbf{m_t^{pole}}$

Is the same MC mass for both colliders? And for the four experiments?

Current estimation of the uncertainty ~O(1) GeV

Current precision in $\mathbf{m_t^{MC}}$ ~ 0.7 GeV

- S. Moch et al., arXiv:1405.4781,
- ATLAS, CDF, CMS and D0 Collaborations, arXiv:1403.4427,
- A. H. Hoang and I. W. Stewart, 500 Nouvo Cimento B123 (2008) 1092–1100,
- A. Buckley et al., arXiv:1101.2599
- A. H. Hoang, arXiv:1412.3649.

Top quark mass measurements: observables

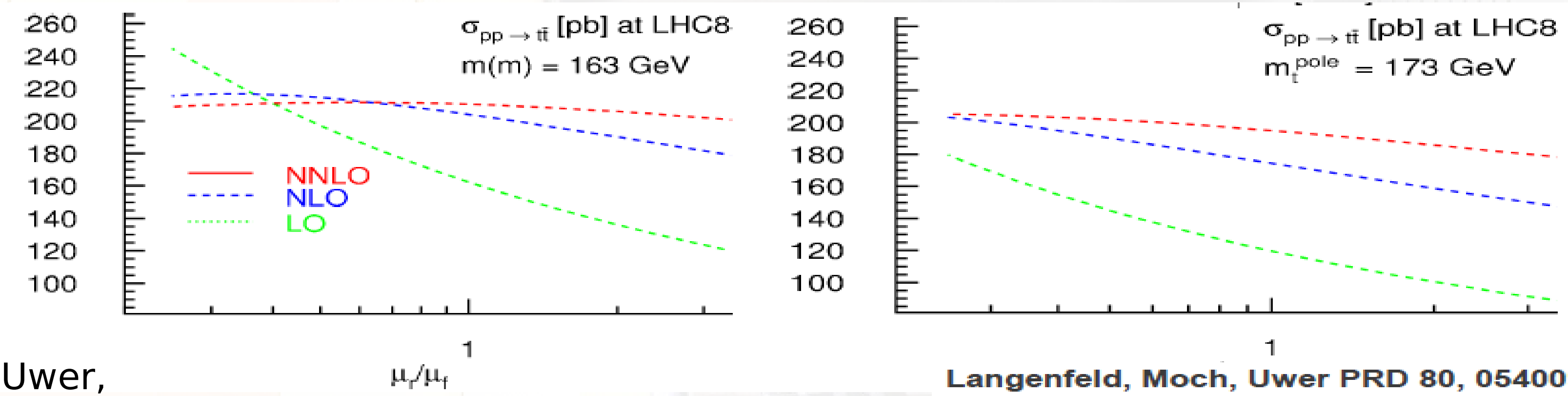
$$\frac{\Delta O}{O} \leftrightarrow \frac{\Delta m_t}{m_t}$$

1) Define an observable which should show **good sensitivity**

2) Small theoretical uncertainties.

3) Well defined **mass scheme** → **NLO calculations!**

4) Measured observables are corrected to the parton level where they are compared with calculations



P. Uwer,
La Thuile, Feb. 2013

Langenfeld, Moch, Uwer PRD 80, 054009 (2009)

Czakon, Fiedler, Mitov hep-ph/1303.6254

Top quark mass measurements: R-observable

$$\mathcal{R}(m_t^{\mathrm{pole}},\rho_s) = \frac{1}{\sigma_{t\bar{t}+1\text{-jet}}}\frac{d\sigma_{t\bar{t}+1\text{-jet}}}{d\rho_s}(m_t^{\mathrm{pole}},\rho_s), \quad \rho_s = \frac{2m_0}{\sqrt{s_{t\bar{t}j}}}$$

m_0=170 GeV

- **$t\bar{t}$+1-jet**

  The production of extra gluons(quarks) depend on the top-quark mass

- **differential**

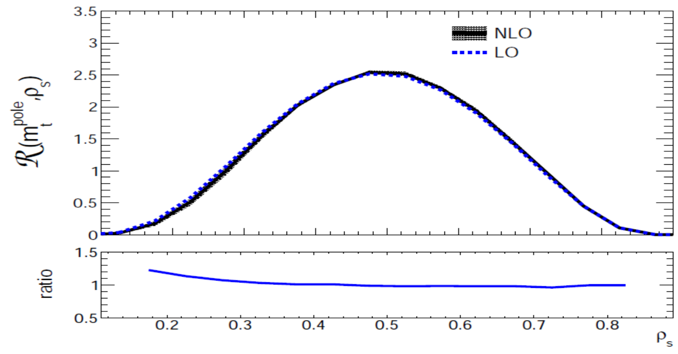
  Mass dependence enchanced in certain regions of the phase space

- **normalized**

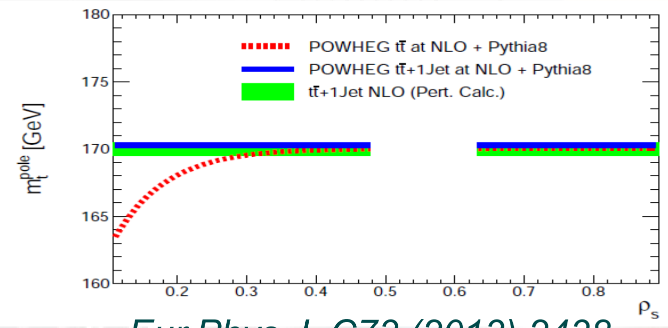
  Cancelation and reduction of systematic uncertainties (theoretical and experimental)

- **Large event rates at LHC ~ 30% of the inclusive cross section**

- **NLO & NLO+PS corrections available.**



NLO → small corrections



Eur.Phys.J. C73 (2013) 2438

Alioli, Fernández, Fuster, A.I., Moch, Uwer, Vos

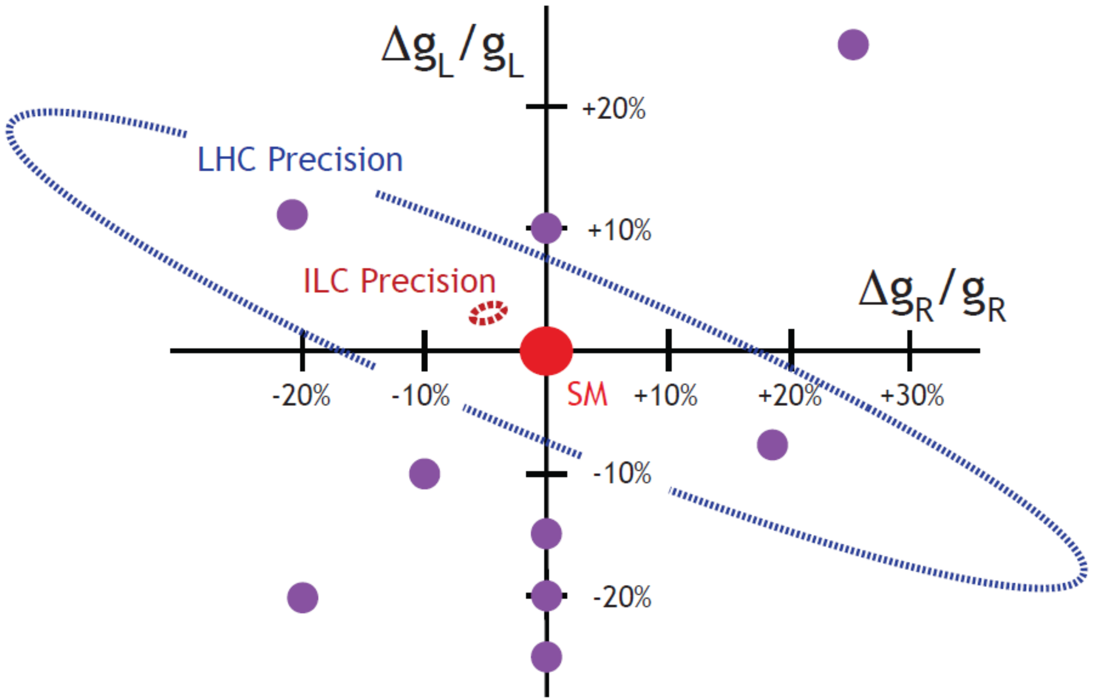
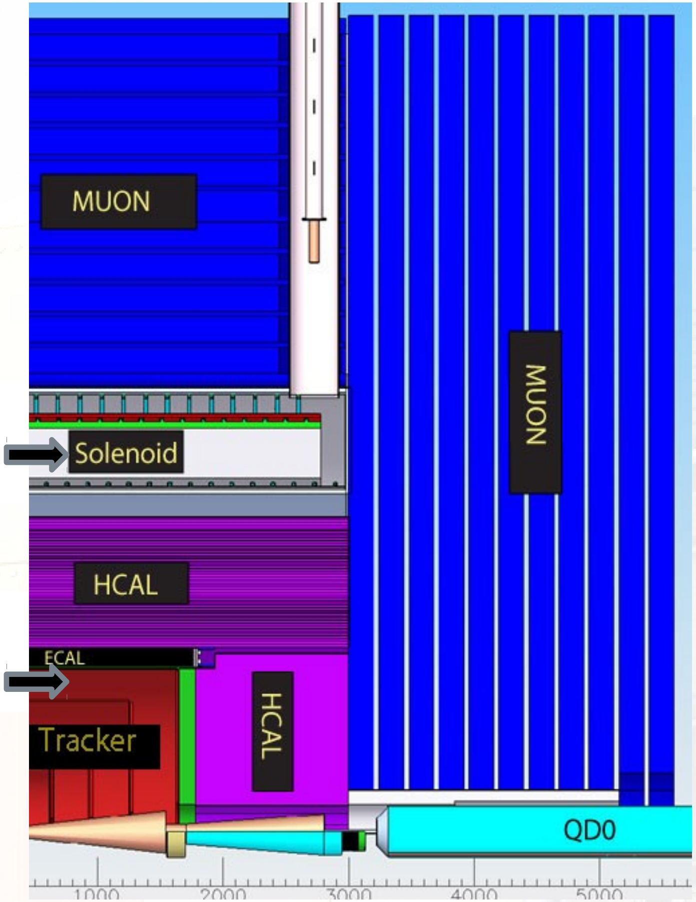


Figure 9: The heavy dots display the shifts in the left- and right-handed top quark couplings to the Z boson predicted in a variety of models with composite Higgs bosons, from Ref. [41]. The ellipses show the 68% confidence regions for these couplings expected from the LHC [36,43] and the ILC [42].

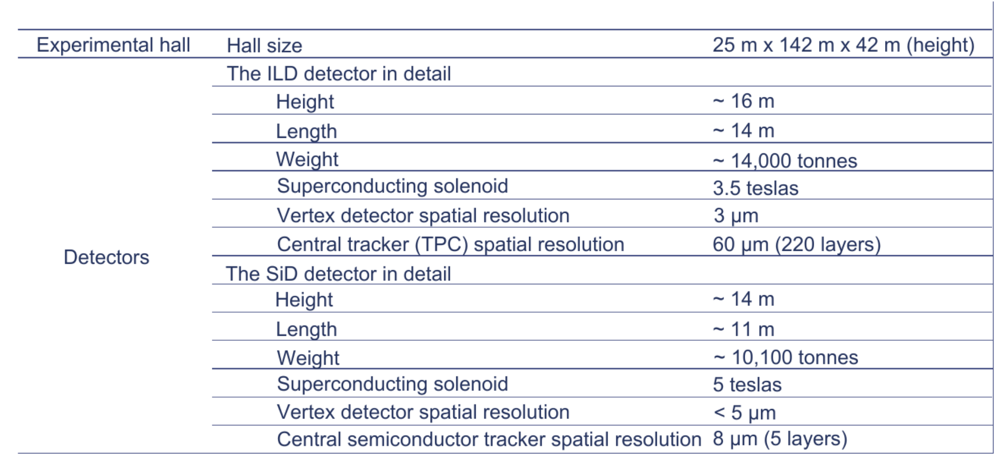
SiD and ILD: differences

SiD 5T
ILD 3.5T

SiD 1.2m
ILD 1.8m



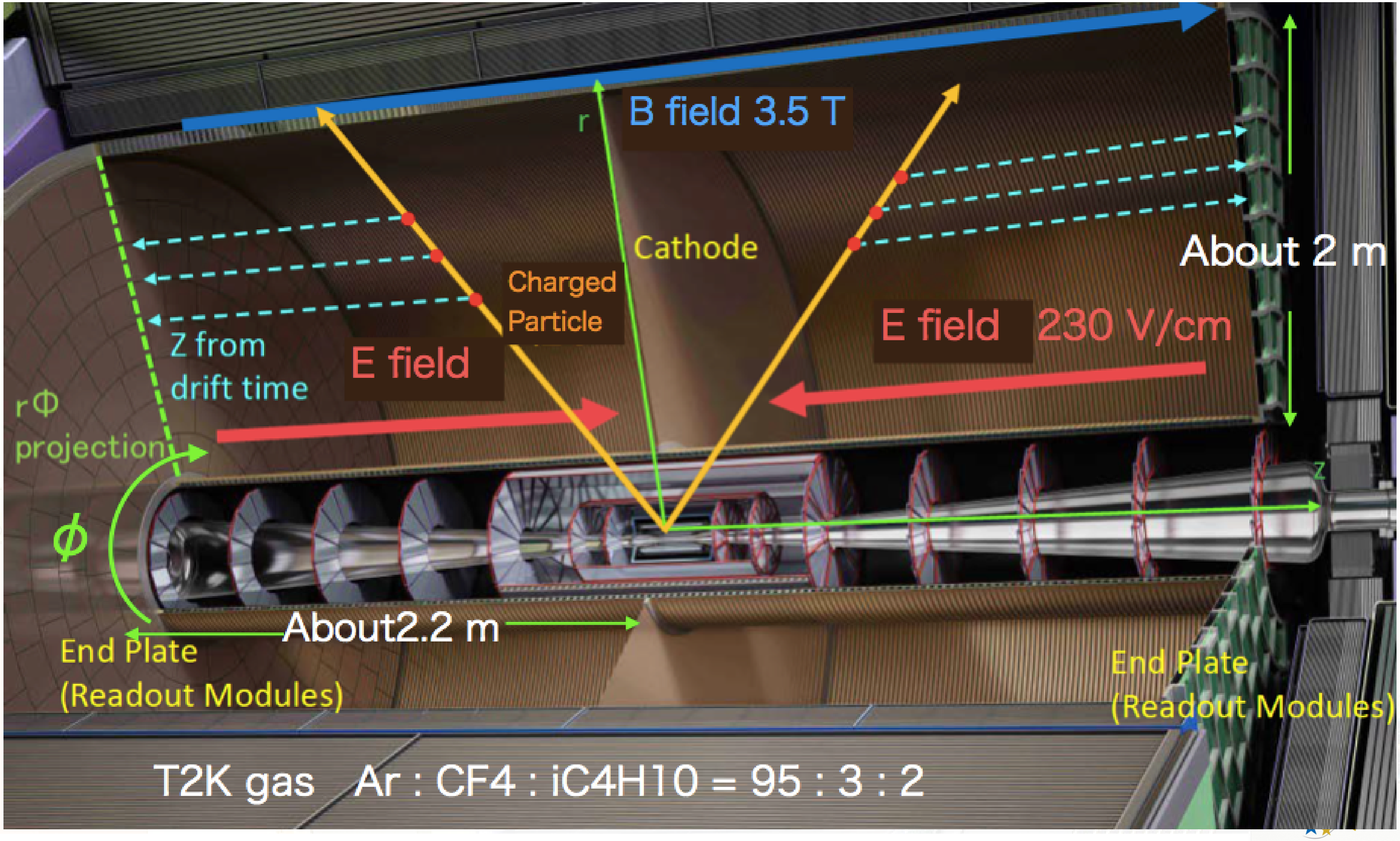
- Different B field & tracker radius achieving similar energy/momentum resolution.
- 100% Silicon tracker for SiD
- ILD has a large volume gaseous tracker (TPC >>LEP) supplemented by silicon tracking.
- Various calorimeter technologies are considered.
- Both will profit from



Experimental hall	Hall size	25 m x 142 m x 42 m (height)
Detectors	The ILD detector in detail	
	Height	~ 16 m
	Length	~ 14 m
	Weight	~ 14,000 tonnes
	Superconducting solenoid	3.5 teslas
	Vertex detector spatial resolution	3 µm
	Central tracker (TPC) spatial resolution	60 µm (220 layers)
	The SiD detector in detail	
	Height	~ 14 m
	Length	~ 11 m
	Weight	~ 10,100 tonnes
	Superconducting solenoid	5 teslas
	Vertex detector spatial resolution	< 5 µm
	Central semiconductor tracker spatial resolution	8 µm (5 layers)

F. Richard June 2013

The TPC



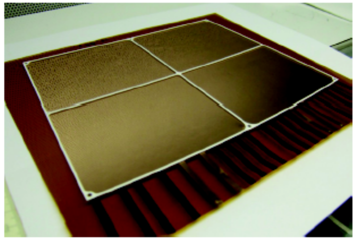
T2K gas Ar : CF4 : iC4H10 = 95 : 3 : 2

The TPC

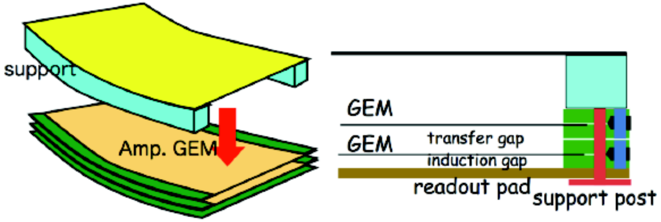
Four read-out technologies studied

European GEM

Standard kapton triple GEM with ceramic spacers

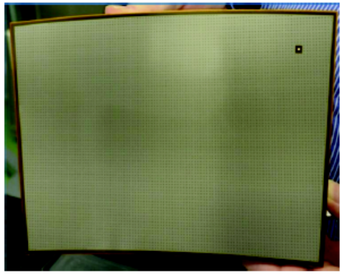


Asian GEM



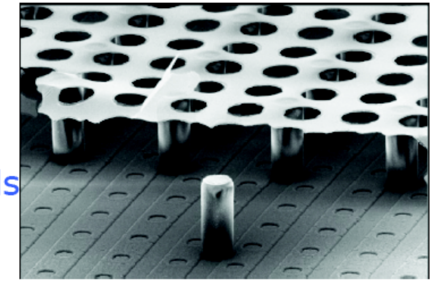
Micromegas

Mesh on top of a charge dispersing resistive anode

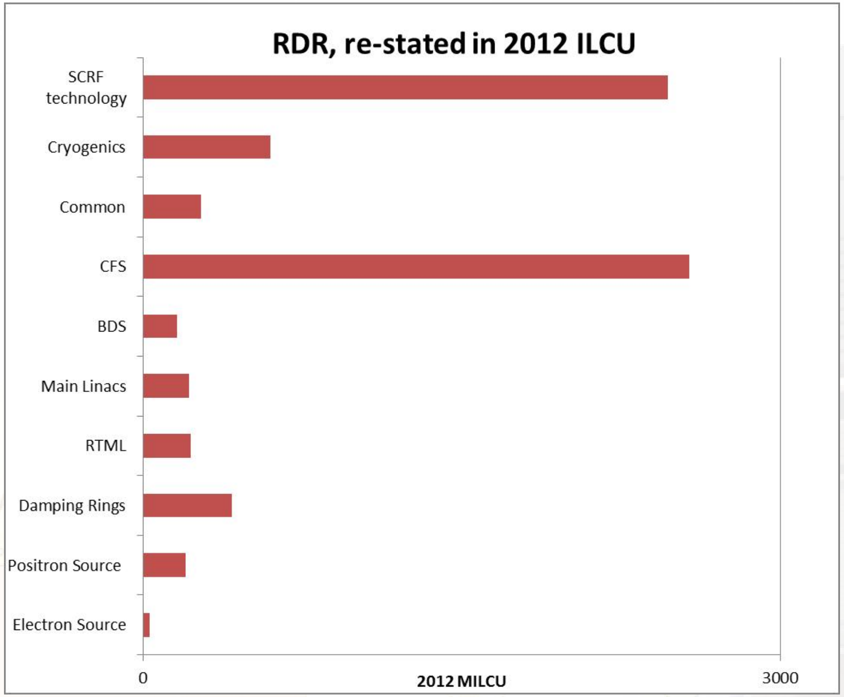


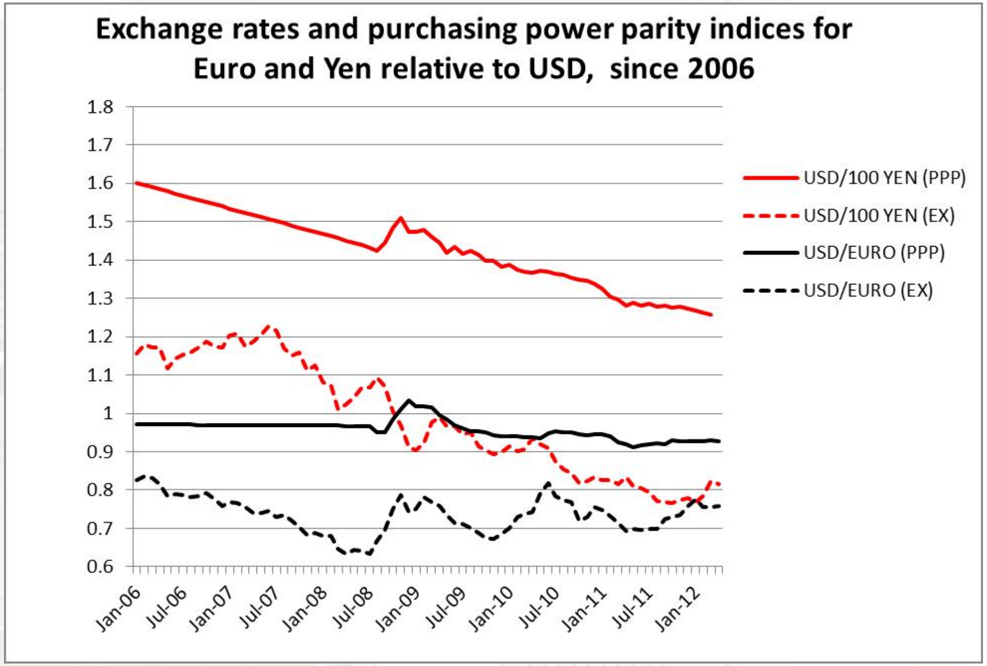
GridPix

Integrated grid on 55x55 µm² digital pixels



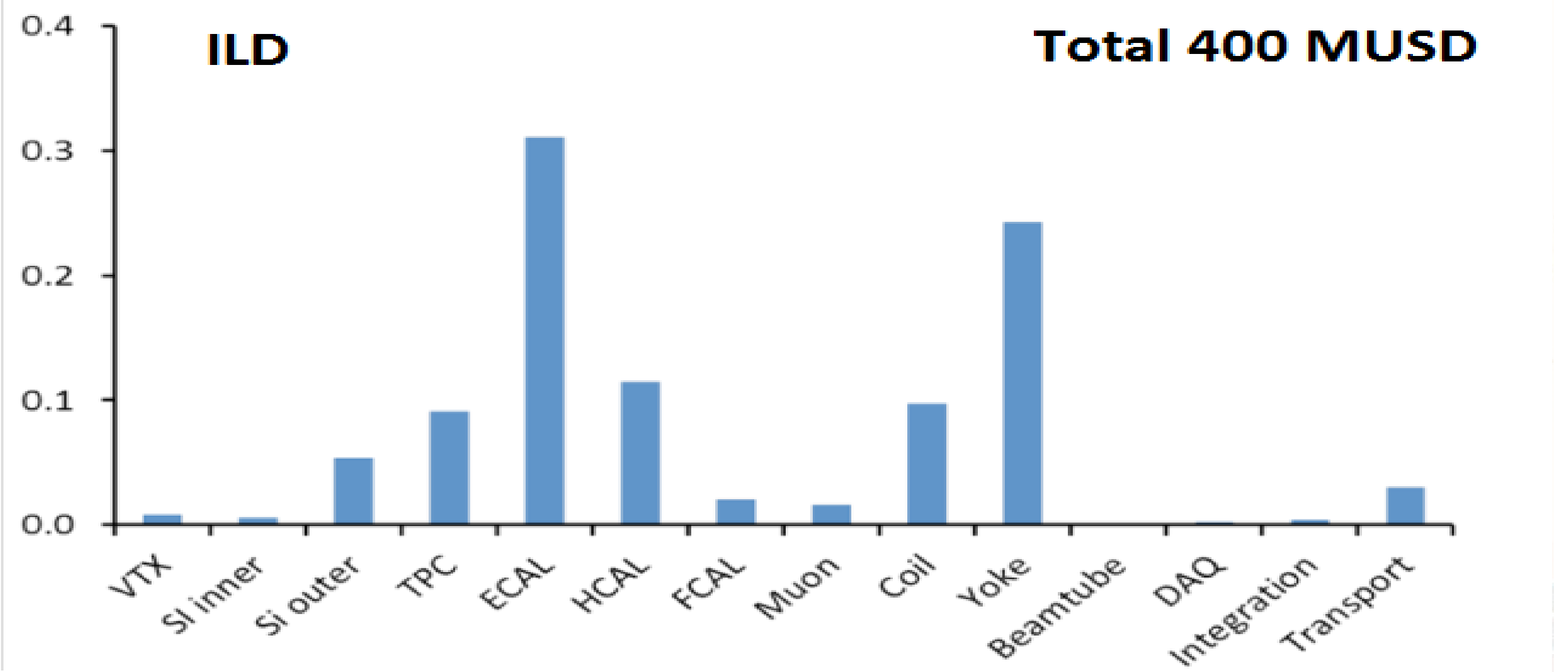
ILC cost estimates





Costs

- ☐ Cost drivers : coil+yoke and calorimetry



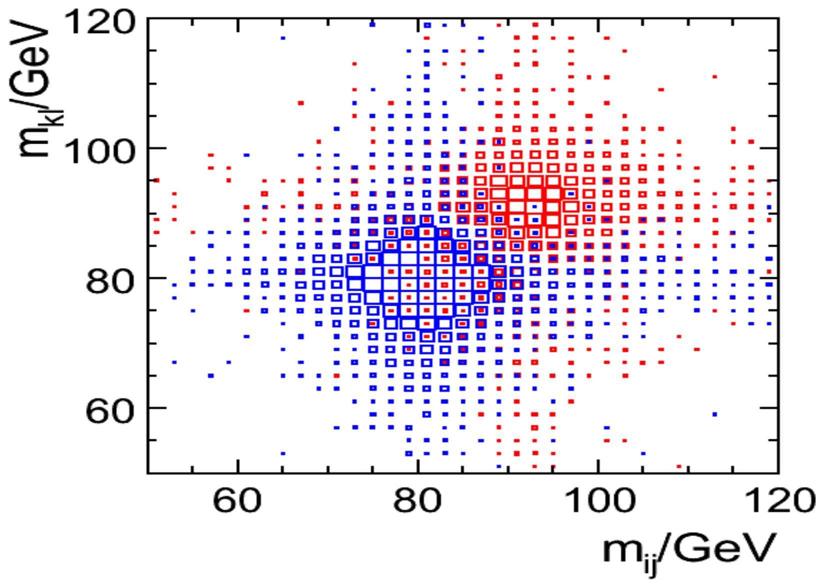
CALICE: Calorimeter R&D for future LC and beyond

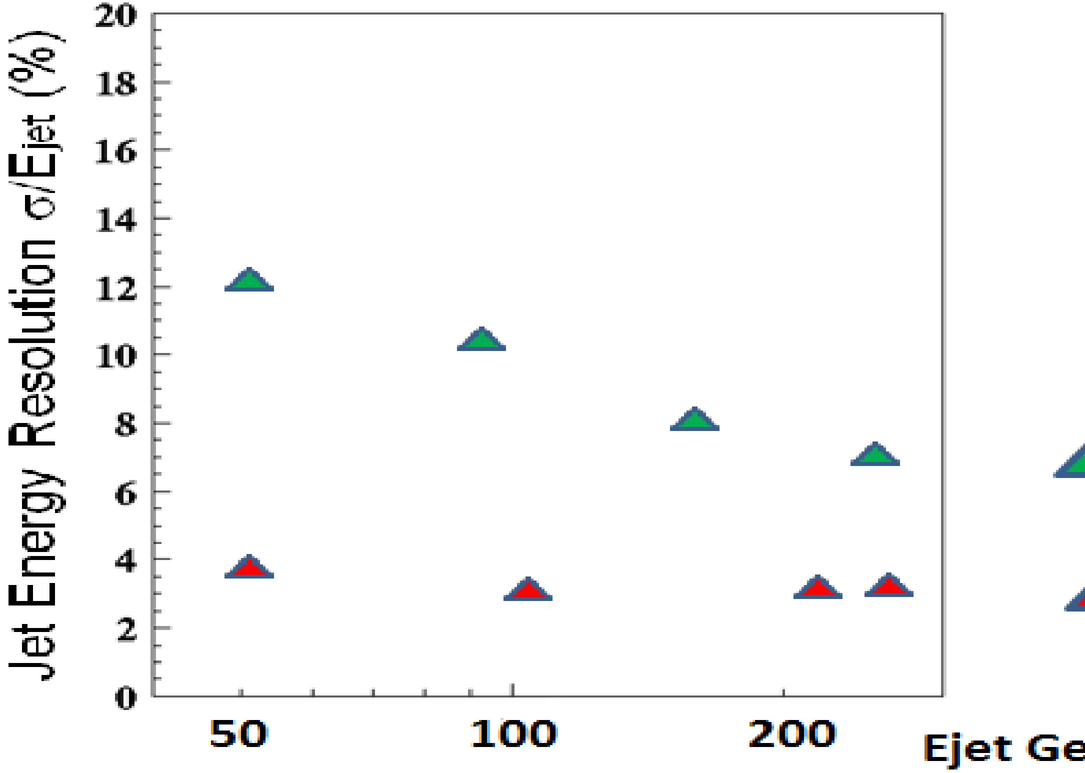
- International collaboration: ~360 physicist from 60 institutes and 19 countries

Calorimeter for ILC

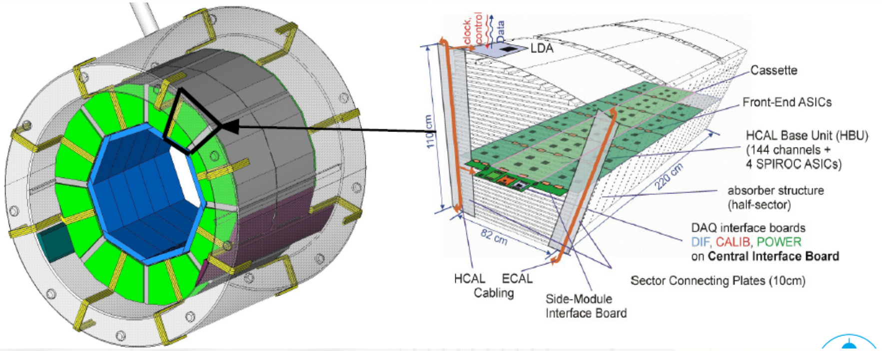
- Initial step: build physics prototypes to prove the PF algorithm performance. (done)
- Intermediate step: build prototype calorimeters to
  - Establish the technology
  - Collect hadronic showers with unprecedented granularity to tune and test PF and MC algorithms → great interest shown by the Geant4 collaboration.
- Goal: **construct highly granular calorimeters optimised for PF** measurement of multi-jet final states at the **ILC**

Particle Flow





The Analogue Hadronic Calorimeter for ILC



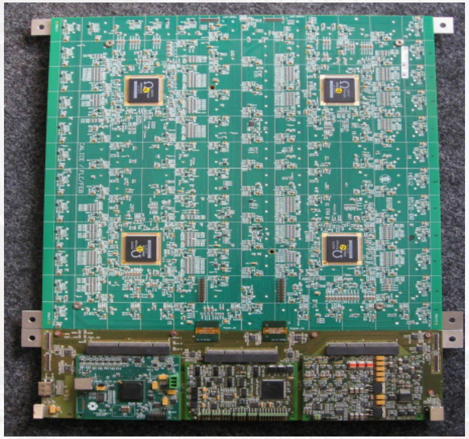
Analog HCAL detector:

- Scintillator tiles (3x3 cm^2) +SiPMs
- SPIROC ASIC (designed by Omega group)

  36 channels
  Autotrigger (signal must pass a threshold)
  16 analogue memory cells
  Optional Trigger validation (unvalidated events are discarded): only in beam test mode
  Runs until 16 memory cells are full, then it needs long time to convert and readout (~10 ms)

- Base unit: HBU

  4 ASICs, 144 channels, 36x36 cm2
  Scalability: 6 HBU in row (called "slab")
  Up to 3 slabs read out by single HDMI cable

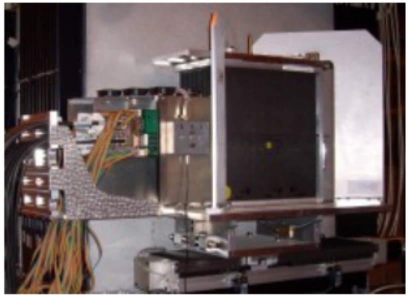


Road towards an SiW-ECAL for ILC

Physics Prototype

Proof of principle

2003 - 2011



Number of channels : 9720

Pixel size: 1x1 cm2

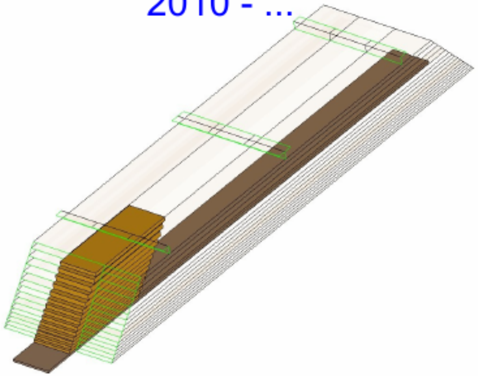
$R_{M,eff}$: ~ 1.5cm

Weight : ~ 200 Kg

Technological Prototype

Engineering challenges

2010 - ...



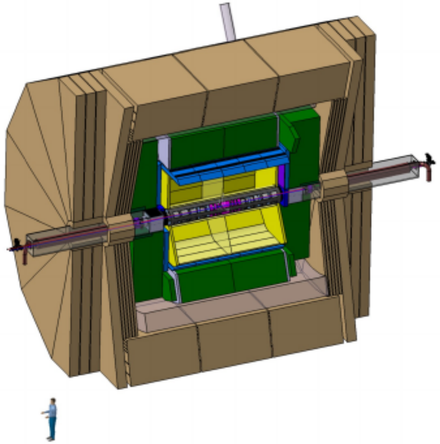
Number of channels : 45360

Pixel size: 0.55x0.55 cm2

$R_{M,eff}$: ~ 1.5cm

Weight : ~ 700 Kg

LC detector



ECAL :

Channels : ~100 10^6

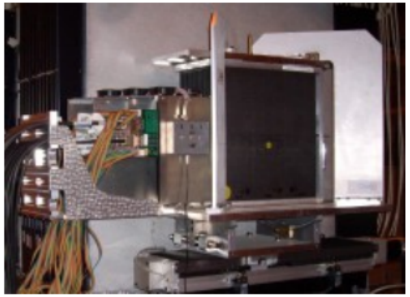
Total Weight : ~130 t

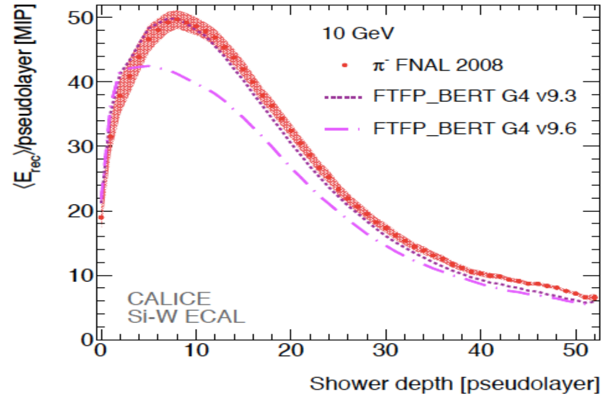
Road towards an SiW-ECAL for ILC

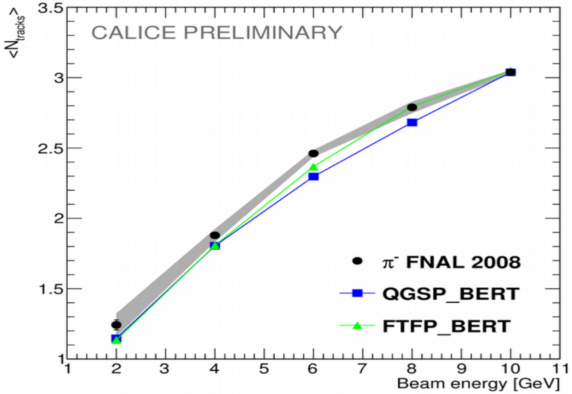
Physics Prototype

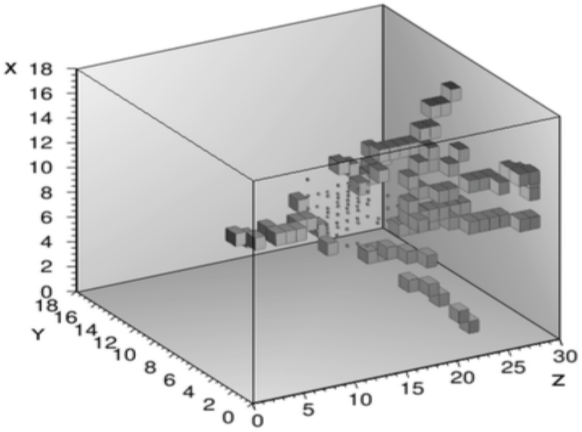
Proof of principle

2003 - 2011









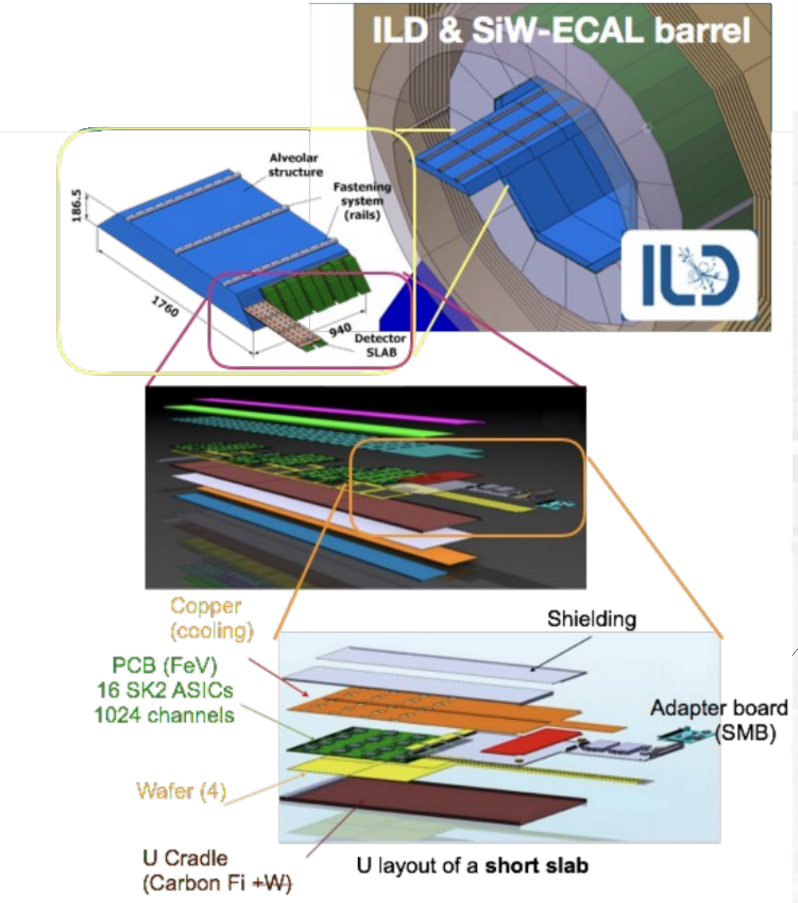
Number of channels : 9720

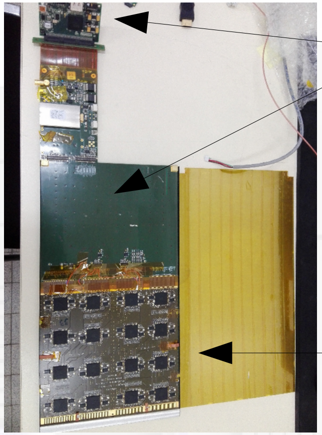
Pixel size: 1x1 cm2

$R_{M,eff}$: ~ 1.5cm

Weight : ~ 200 Kg

SiW-ECAL technological prototype





ILD SiW-ECAL	Prototyped*
~10,000 SLAB's	~0.1
100,000 ASU's	~20
400,000 Wafers	~350
1,600,000 ASIC's	~1000
100,000,000 channels	~20000

* incl. Physical Prototype

+ Mechanics , Cooling, Integration, ...

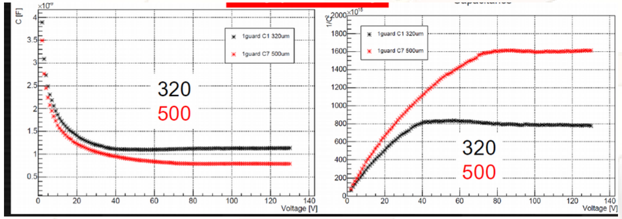
Si wafers

Designed for ILC : Low cost, 3000 m2

Minimized number of manufacturing steps

Target is 2.5 EUR/cm2

Now : 10 EUR/cm2 (Japan)



I(V) and C(V) characterization

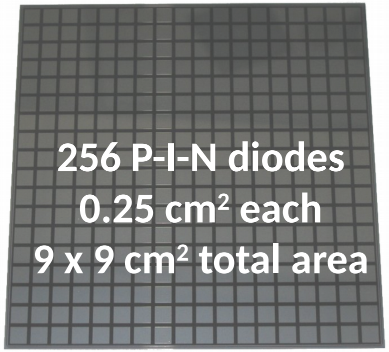
Breakdown voltage >500V

Current leakage <4 nA/pixel (chip is DC coupled)

Full depletion at <100 V

(~40 V with 320 um, ~70 V with 500um)

Null C(V) slope to avoid dC/dV noise



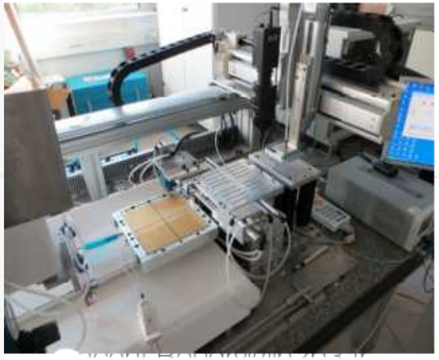
256 P-I-N diodes

0.25 cm² each

9 x 9 cm² total area

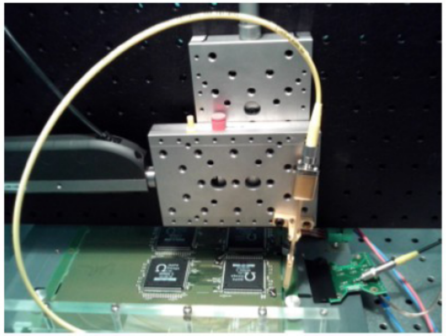
EUDET layout

Prototype from Hamamatsu



Wafers are glued to PCB (robot, LPNHE)

Segmented guard-rings layout as an option



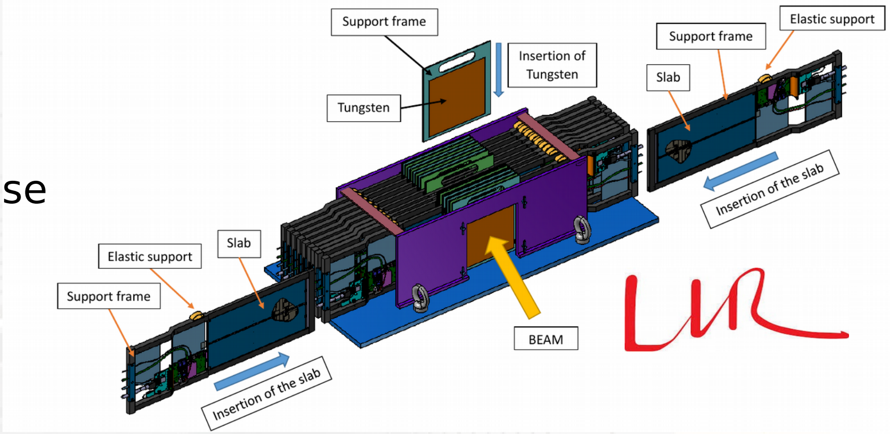
R&D on crosstalk

Segmented guard-rings layout as an option. Systematics studies with laser systems and simulation.

Beam test at DESY, Summer 2018

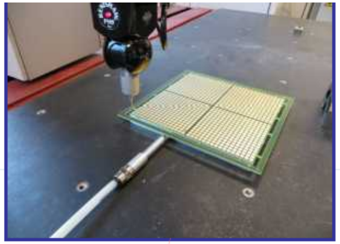
2 weeks in June 2018 for the SiW-ECAL of ILD/CALICE.

- Using a **new compact structure** allowing for 0 to 24 X0 of Tungsten and 10-20 sensor layers:
  - Test new PCB & Si Wafers & DAQ developments
- A long structure (3.2m) chaining 12 detector units, mounted on a support on wheel, to test the response of a long layer.

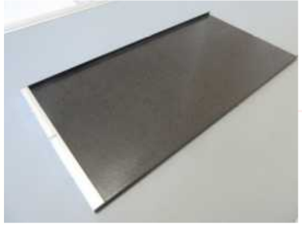


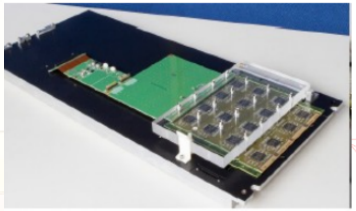
Physics program:
- MIP calibration
- Electromagnetic showers
- If possible: photon/electron separation studies (key for Particle Flow understanding)
- Tests with and w/o B field.

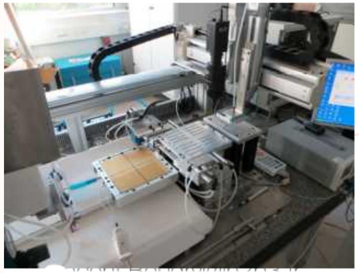
Assembly chain

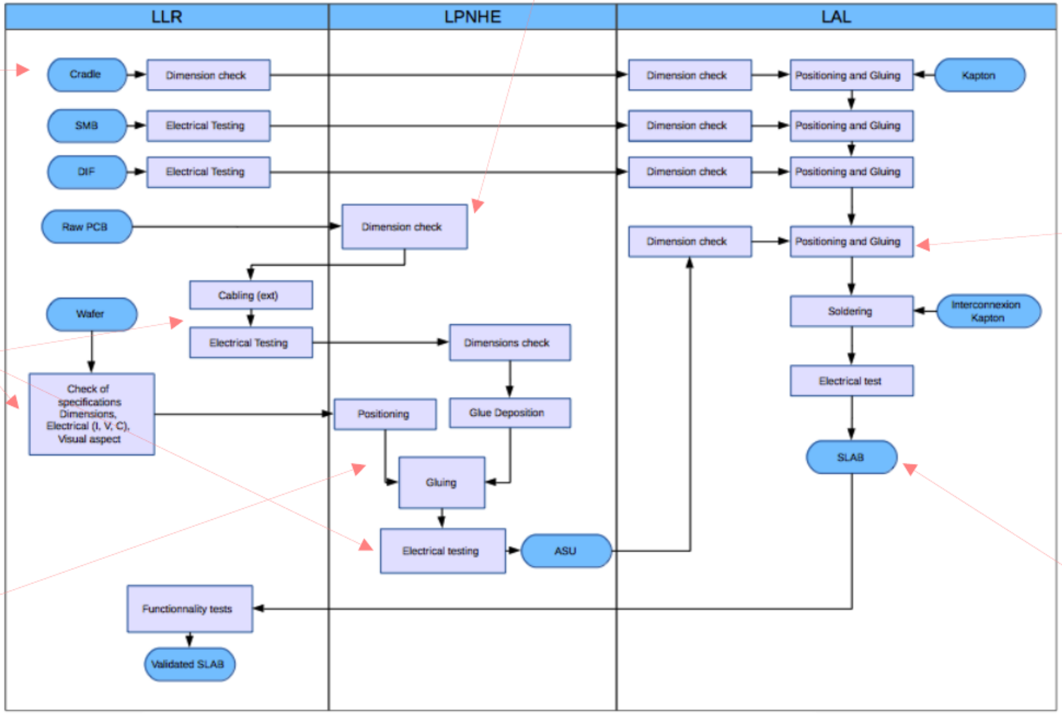


‘Simplified view’









LLR

LPNHE

LAL

Cradle

Dimension check

SMB

Electrical Testing

DIF

Electrical Testing

Raw PCB

Wafer

Cabling (ext)

Electrical Testing

Check of specifications Dimensions, Electrical (I, V, C), Visual aspect

Functionnality tests

Validated SLAB

Dimension check

Dimensions check

Positioning

Glue Deposition

Gluing

Electrical testing

ASU

Dimension check

Dimension check

Dimension check

Dimension check

Positioning and Gluing

Positioning and Gluing

Positioning and Gluing

Positioning and Gluing

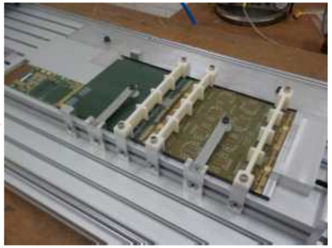
Kapton

Soldering

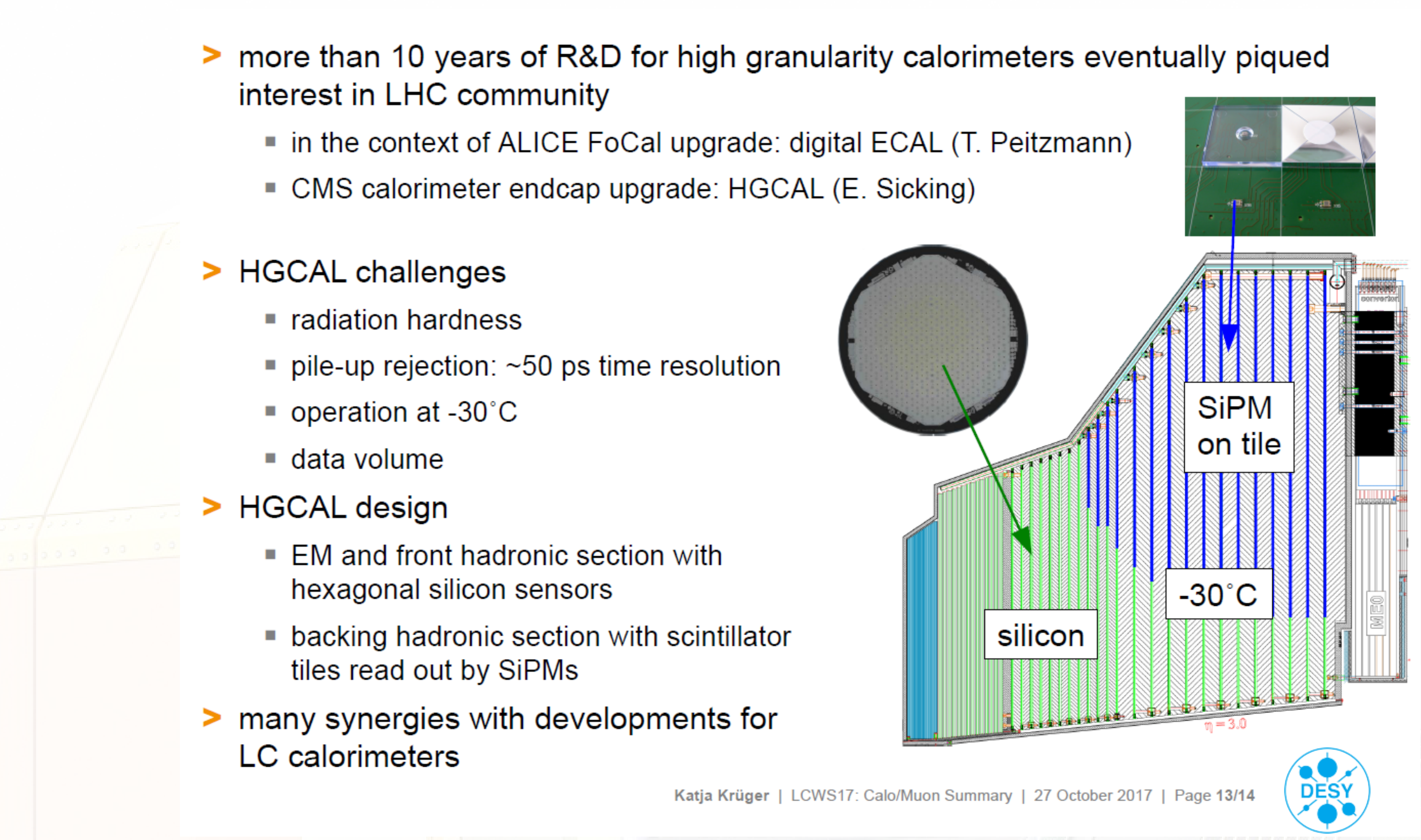
Interconnexion Kapton

Electrical test

SLAB



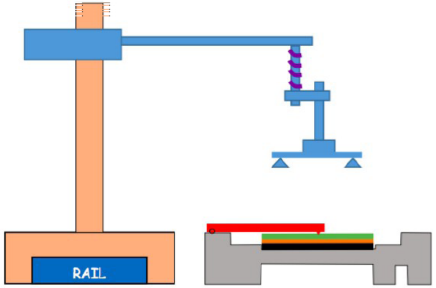
CALICE: Calorimeter R&D for future LC and beyond



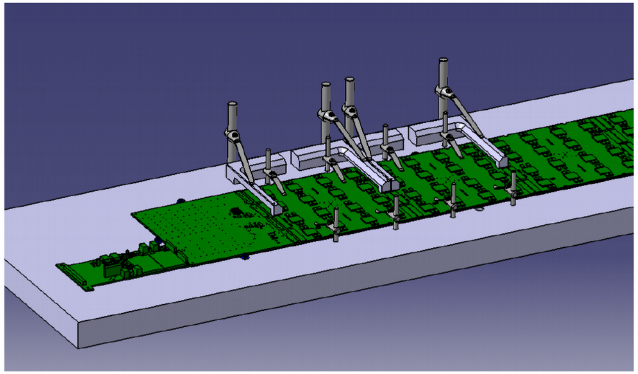
- more than 10 years of R&D for high granularity calorimeters eventually piqued interest in LHC community
  - in the context of ALICE FoCal upgrade: digital ECAL (T. Peitzmann)
  - CMS calorimeter endcap upgrade: HGCAL (E. Sicking)
- HGCAL challenges
  - radiation hardness
  - pile-up rejection: ~50 ps time resolution
  - operation at -30°C
  - data volume
- HGCAL design
  - EM and front hadronic section with hexagonal silicon sensors
  - backing hadronic section with scintillator tiles read out by SiPMs
- many synergies with developments for LC calorimeters

Katja Krüger | LCWS17: Calo/Muon Summary | 27 October 2017 | Page 13/14

Long slab: assembly bench



- 2nd generation of manipulator:
  - Pick-up by vacuum aspirator, pressure protection by springs
  - Motorization along longitudinal and vertical axes is envisaged.
- Different assembly scenarios under study, all with different possibilities to intervene in case of damaged ASUs.
- Final layout to be defined after decision on assembly scenario.
- Work done by the mechanics department in close collaboration with the electronic department (SERDI)

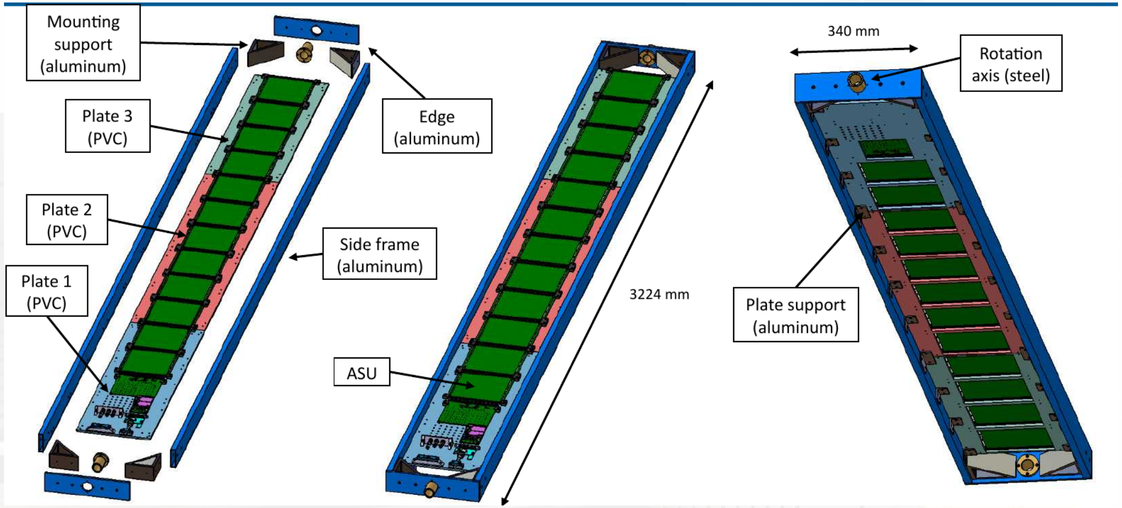


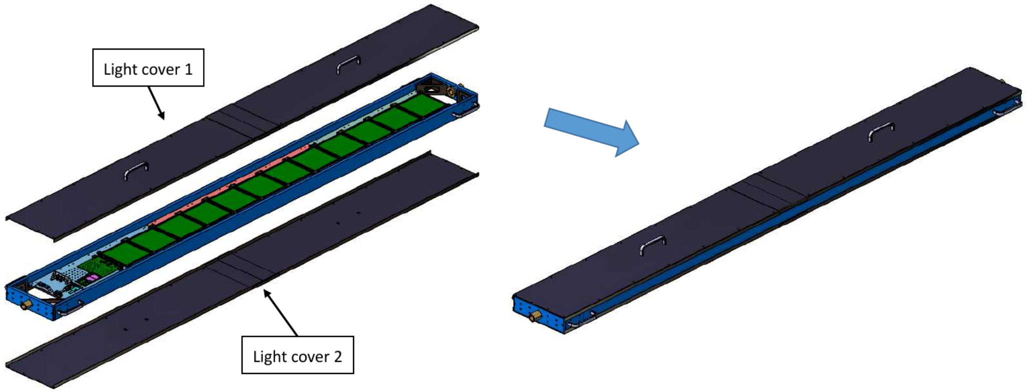
- Preparation of upgraded testbench (In step from drawing to fabrication)

Electric long slab prototype

- Scale to support electronics
  - 2+6+4 ASUs = ~3.2 m
  - Support of SMB
  - Total access to upper and lower parts

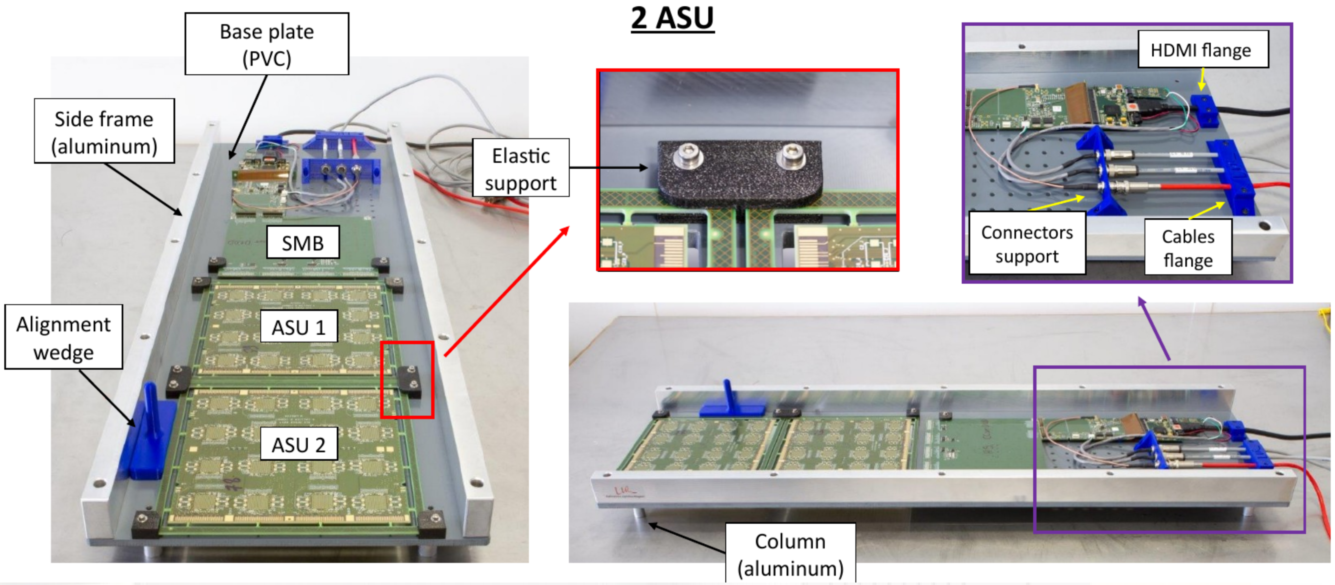
    Baby wafers (4×4 pixels) on the bottom
- Mechanical characteristics
  - Movable: table and to beam test
  - Rotatably along long axis (for beam test)
  - Rigidity : ≤ ~1 mm per ASU
  - No electrical contacts scale / cards
- Shielding
  - vs Light and CEM

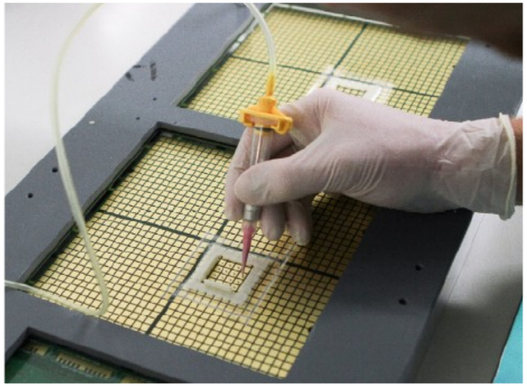


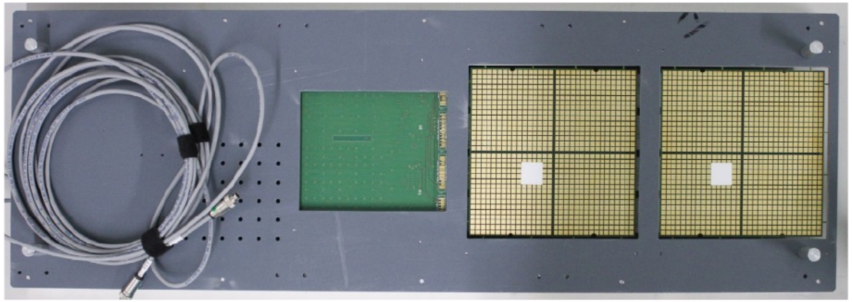


Electric long slab prototype

- 2 ASUs prototype.
  - FEV11, sk2.
- Equipped with baby wafers
  - Calibration with RA sources ^{90}Sr, ^{137}Cs.
  - Beam test in summer 2018

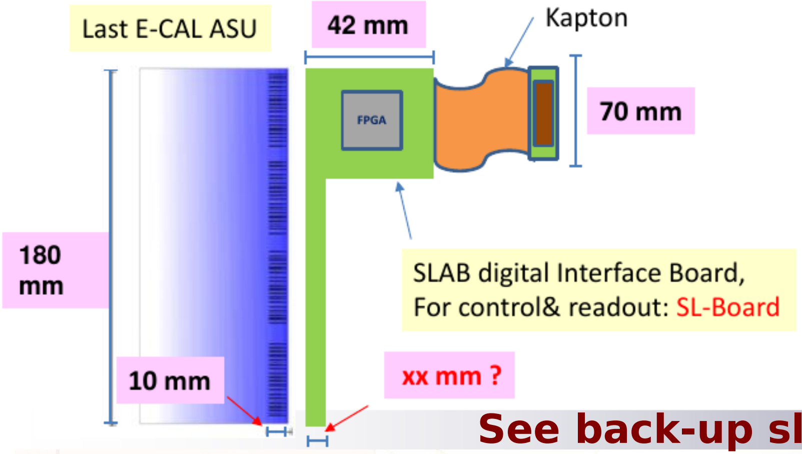


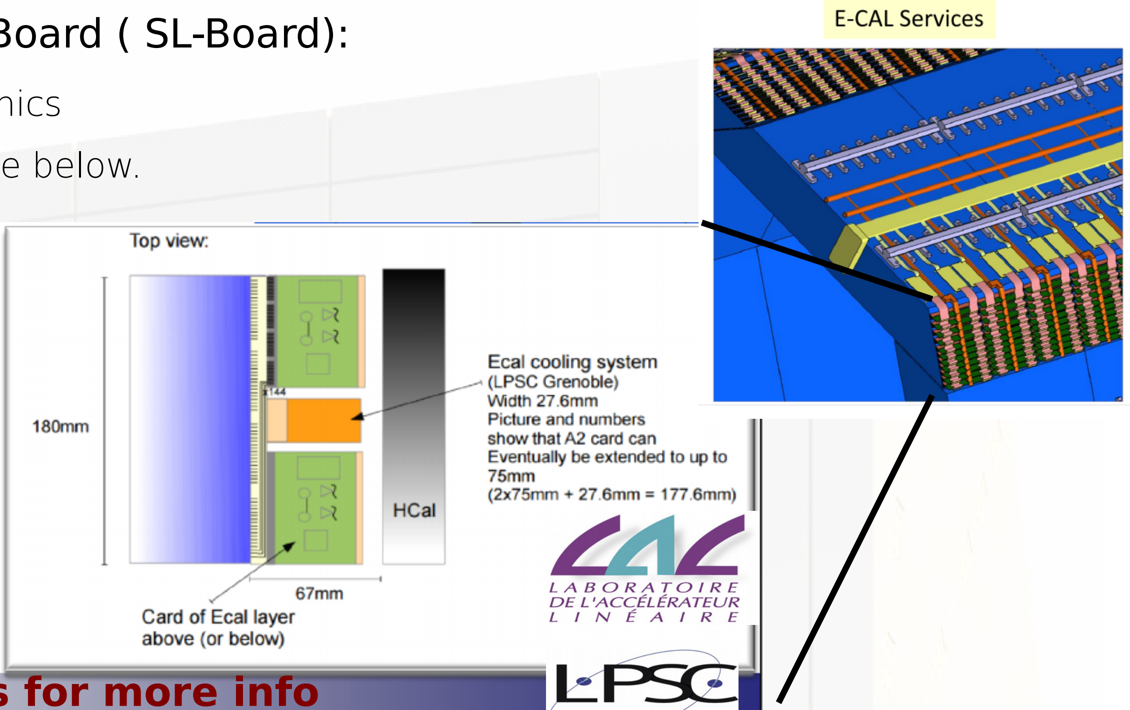




Compactifying the DAQ and passive components of the ASU

- Space constraints for the Slab Interface Board (SL-Board):
  - Power and signal cables and read-out electronics
  - L-shape (even and odd ASUs) Dimensions: see below.





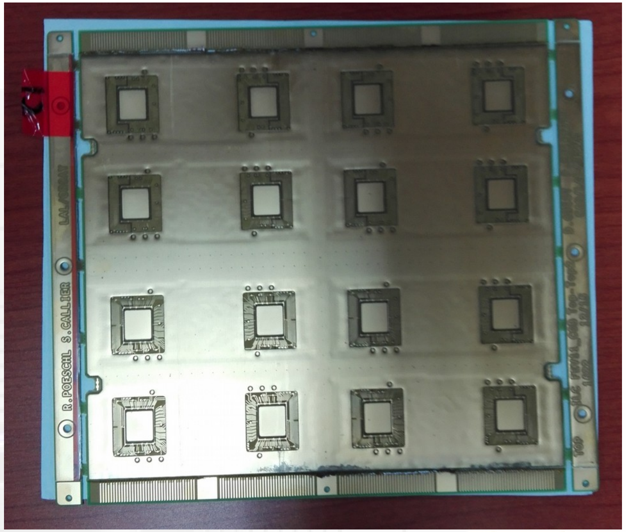
See back-up slides for more info

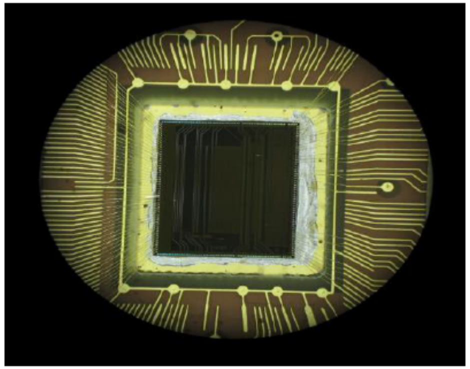
- Space constraints for the Active Sensor Units (ASUs):
  - Maximum Height for Electronics (including PCB): 1.7 mm (depends on number of layers ~20-30?)
  - Current values for prototype: (PCB + components for the SKIROC-2 BGA option) : ~ 3mm

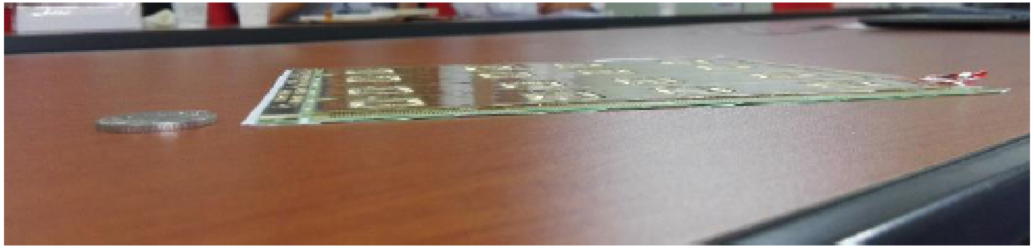
    nex slides →

Compactifying the passive components of the ASU

- Investigating **ultra thin PCB**, with chip on board **COB**
  - Semidonductor packaging, wire bonded.
- LAL/OMEGA collaboration with Corean Group of SKKU, EOS company for the PCB and Kale company for the wire bonding)
  - Strong synergies between university and local companies
  - Testbenchs at LAL and SKKU, training of students done at LAL.
- FEV11_COB production ready (**10 boards of 1.1mm,** good planarity and good electrical response). **3 sent to LAL**
  - Skiroc2a being **wire bonded** at **CERN** Bond Lab
  - To be tested in beam this year.



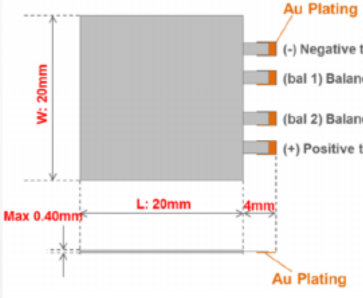


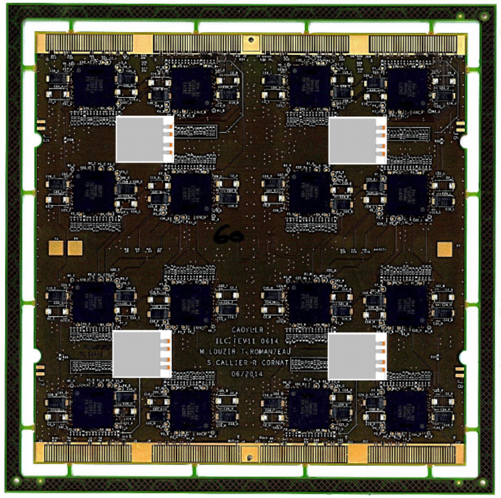


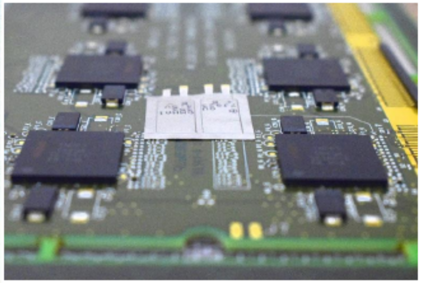
Compactifying the passive components of the ASU

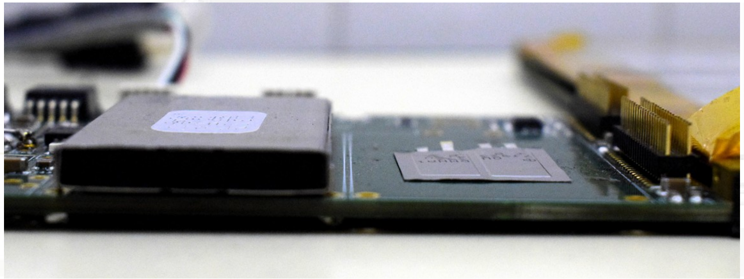
- Proposal to use new ultra-flat capacitors to distribute over the ASUs. This will permit:
    - Peak current reduction: especially through the connectors
    - No more voltage drop along the slab
    - Homogeneous peak power dissipation during power pulsing.
- We go from the 400 mF capacitor/ 12A (peak Current) for the whole SLAB to 140 mF / 1.2 A per ASU.

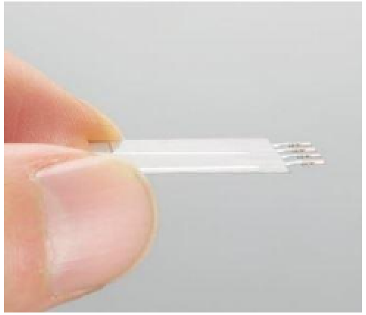
Brand new product, appeared few months ago









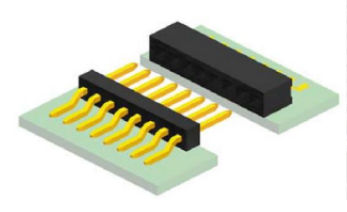


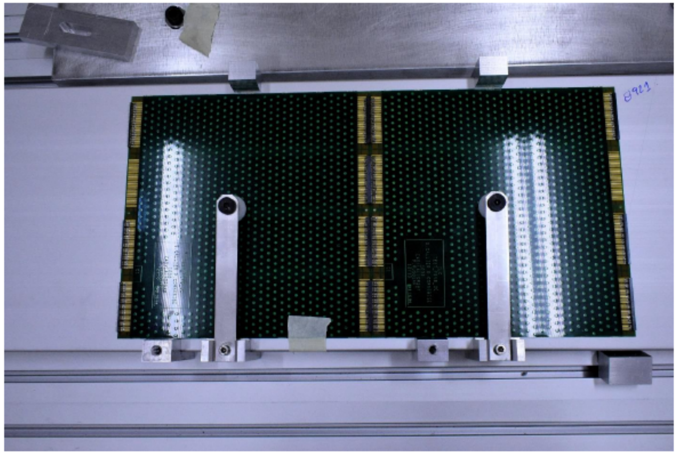
Interconnection with flat kapton cables

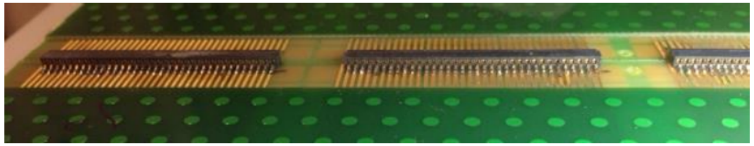
- Interconnection is maybe the most involved piece of the assembly
- Current solution with Flat Kapton + Iron Soldering works
  - Proven for short slabs
  - But… Interconnection so far made by hand & Delicate work
- Application for long slab requires automatised (robust) procedure
  - difficulties to find supplier for developing such a procedure…
- Intensive brainstorming at LAL over summer to find solution that
  - is robust, “easy” to implement on short notice and that can be extrapolated
  - Remember also that long slab is electronics/electrotech and mechanical object
  - Tight communication and between LAL electronics and mechanics departments

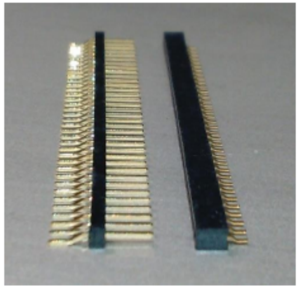
Compactifying the passive components of the ASU

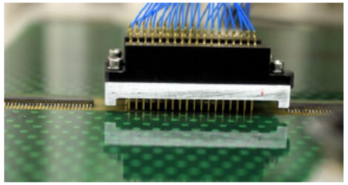
- New interconnection proposal for the ASU with the SKIROC-BGA option
  - old approach based in flat kapton cables seems not feasible at production scales (see back-up slides)
- Gradconn connector BB02-YN
  https://www.gradconn.com/Products/BoardToBoard/MatingHalves/BB02-YN/BB02-WF
  - 35 pins, Height : 1,5 mm possibly 1,27 mm.
  - Pitch 1mm compatible with existing ASUs
  - Current rating : 1 A., AC 300 Volts
- Still ongoing tests to perform:
  - Connectors resistivity measurement
  - Only one board so far → long slabs? Check ASU alignment.
  - Emulate power-pulsing and measure the effect on the AVDD power supply on the ASUs all along the slab.
  - Signal integrity along the slab: we may need to add buffers on the ASUs
  - Mechanical stress test.







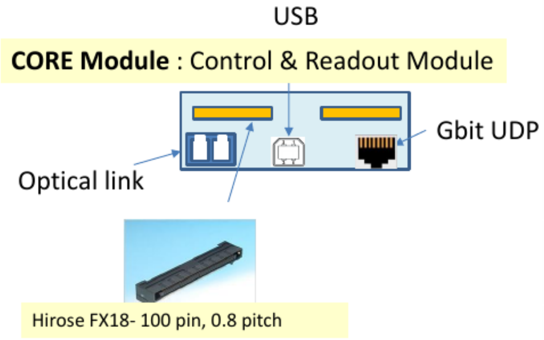


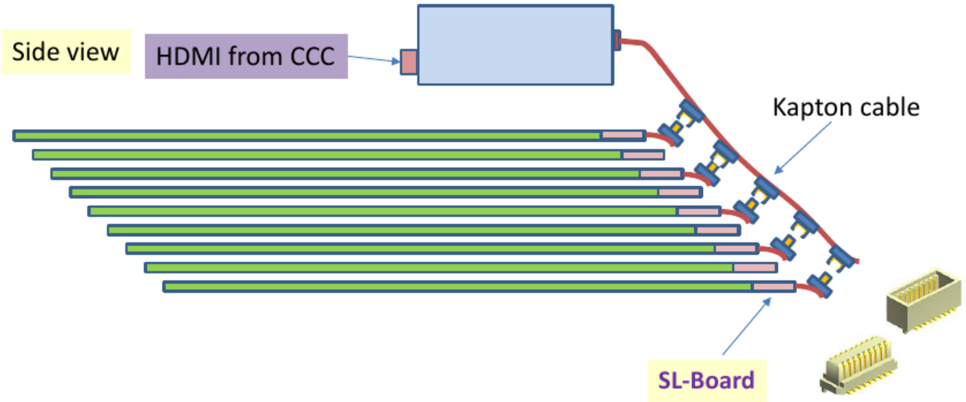


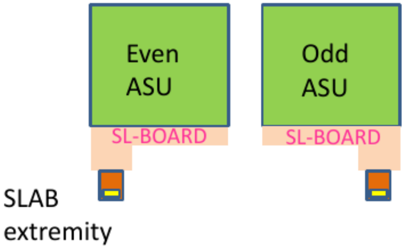
Compactifying the DAQ

The new developments for the control and readout electronics are based on :

- **SL-Board:** It’s the digital interface board situated at the extremity of the Slab, based on a MAX10 FPGA, which handles:
    - Control & readout of the chained ASUs (SKIROC interface)
    - Interface to the CORE acquisition module through a kapton cable in order to have flexibility for the connection inside the detector (45° angle constraint)
- **CORE-Module:** Control & Readout module that handles a column of Slabs, for the prototype phase.







More info in back-up slides