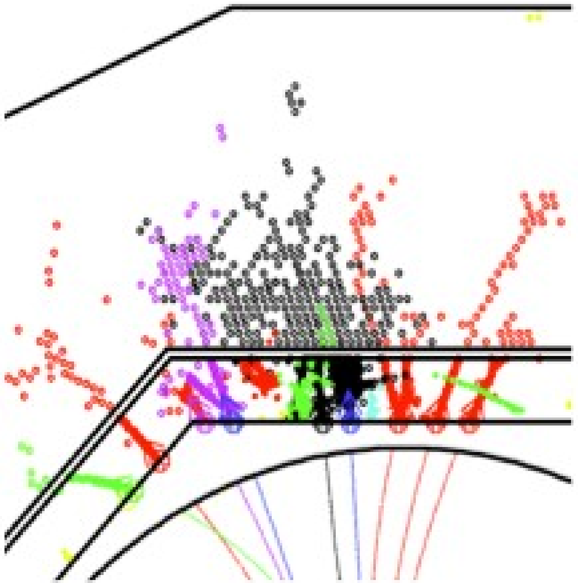
- GT14 -
Prospectives for calorimeter development



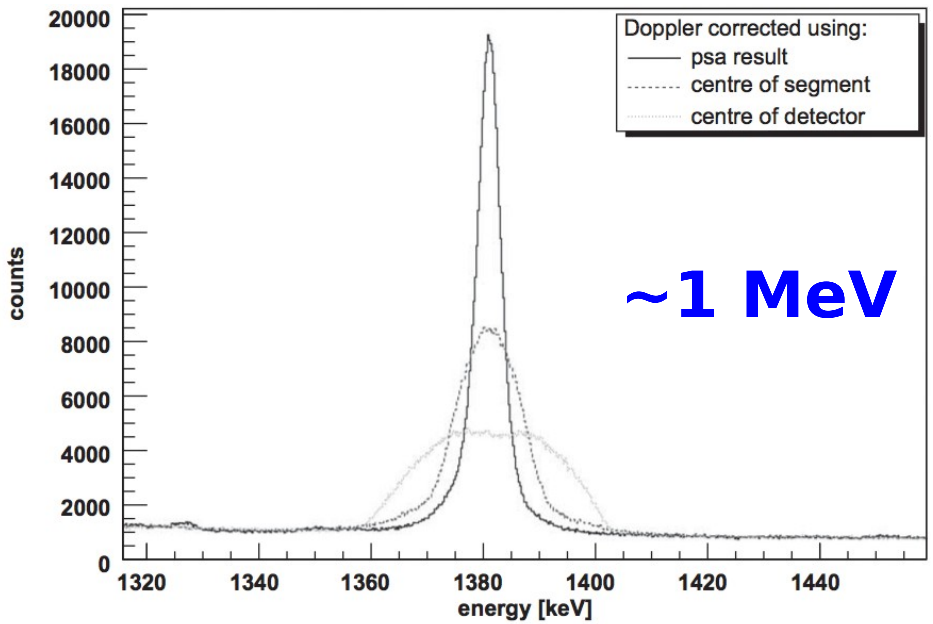
Roman Pöschl

Remerciements: Membre du groupe GT14
et
G. Duchene, C. Finck, Y. Sirois, D. Fournier,
I. Laktineh, A. Peyre, F. Machefert, A. Straessner

Journées de prospectives IN2P3/IRFU – Giens April 2012

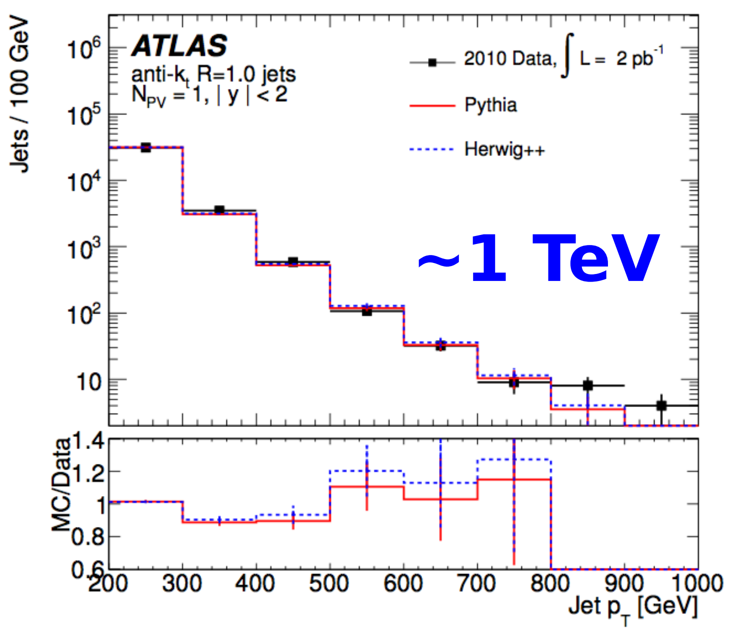
Calorimeters

Devices to measure the energy of particles



Energy of photons emitted by recoiling exotic nuclei as measured by AGATA experiment

- Nuclear physics -



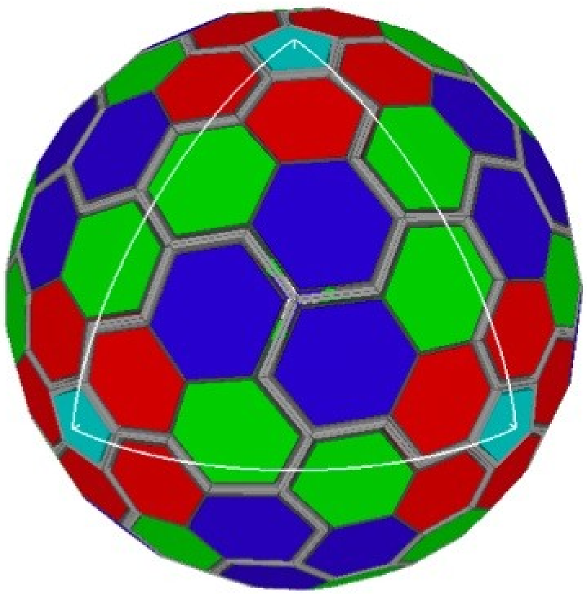
Jet energy spectrum as measured by the ATLAS experiment

- Particle physics -

Dimensions of Calorimeters

4 π 'Germanium Ball' of AGATA Experiment

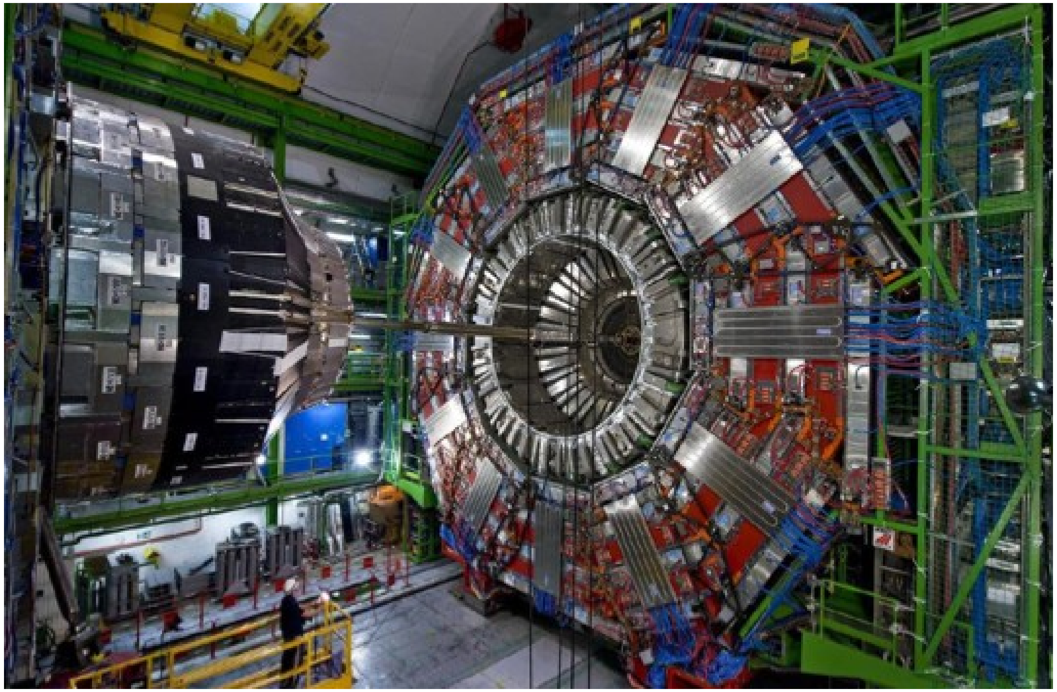
Going on tour now



~1m

LHC experiment e.g. CMS

Taking data now

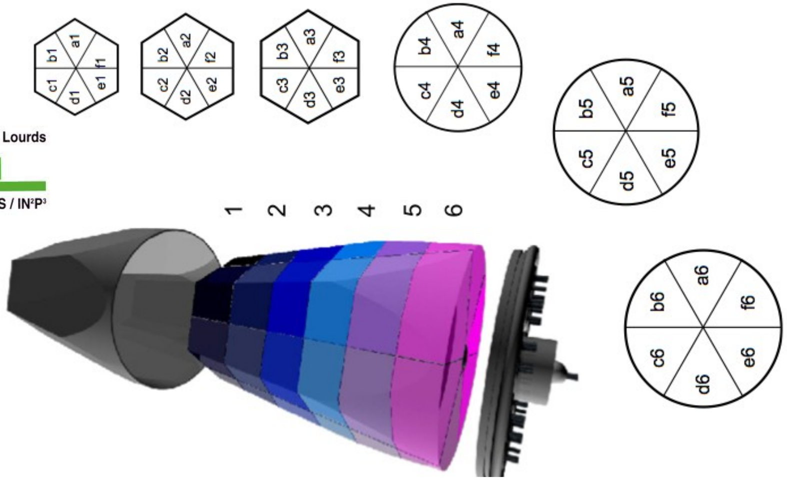


~20m

Calorimeters are employed in 'table top' experiments and in huge experimental apparatuus

AGATA – New horizons in nuclei spectroscopy

Tapered HP-Ge Crystal
Electrically segmented



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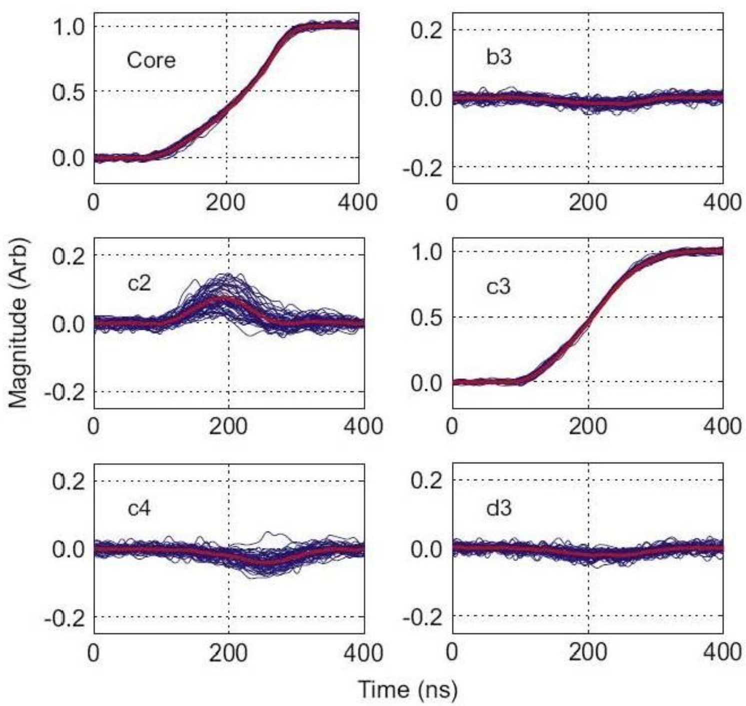
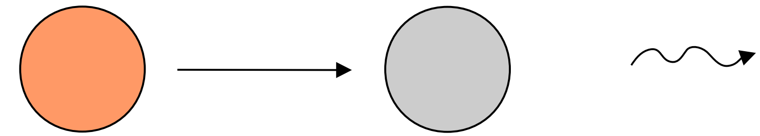
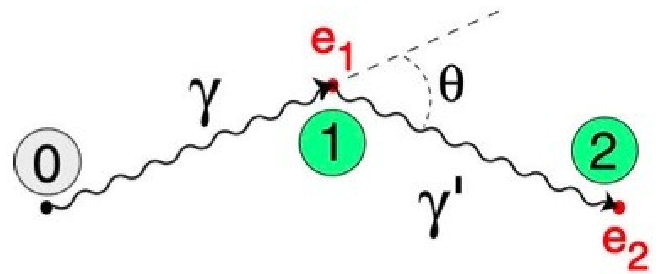


De-excitation of a nucleus:



Nucleus A* Nucleus A Photon

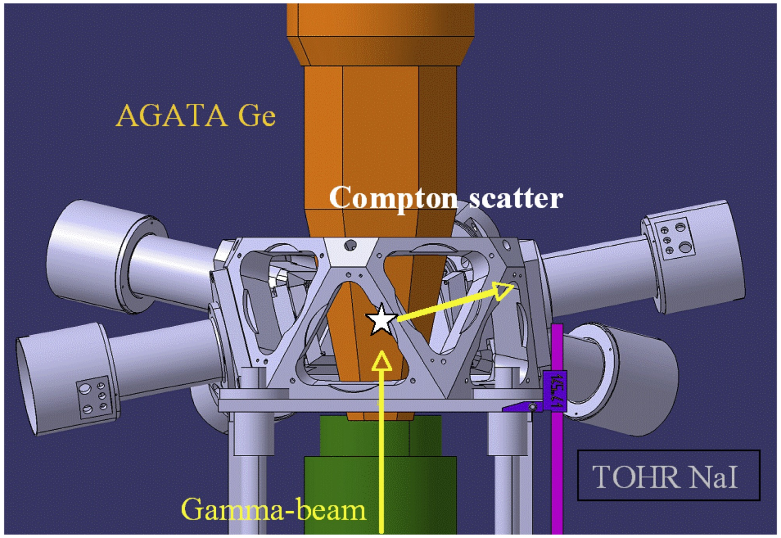
Compton scattered photons



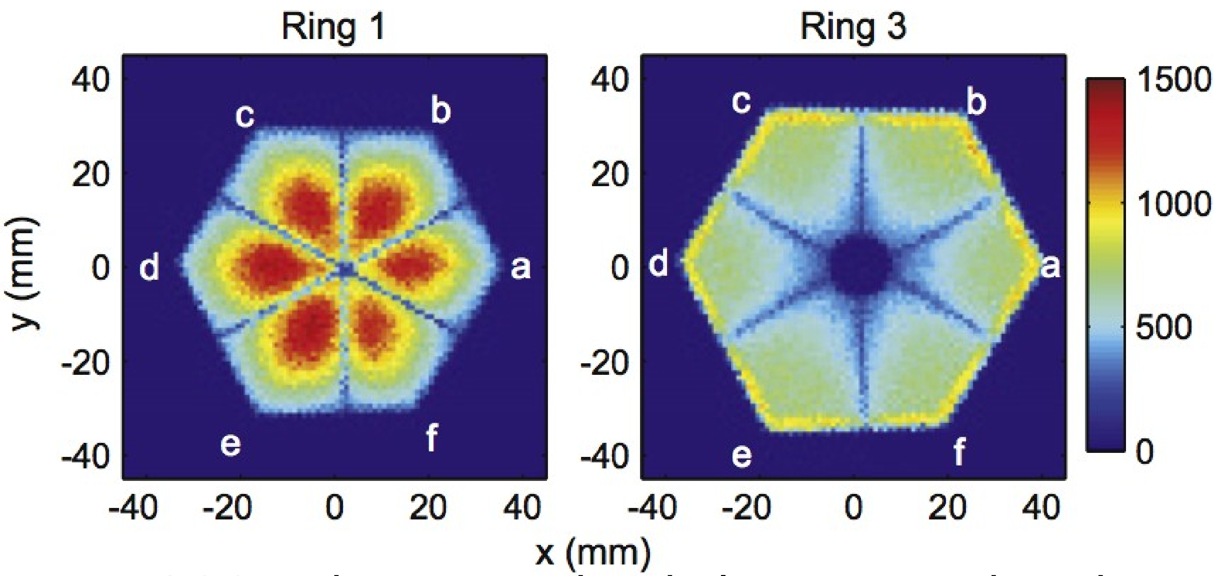
Challenge(s):
- Reconstruct photon trajectory
  Spatial resolution to be better than **5 mm**
- Make use of characteristic signal for each point in the volume of the crystal
  Pulse Shape Analysis
- Use of NARVAL as DAQ

AGATA - Xtal scanning

Example for scanning table

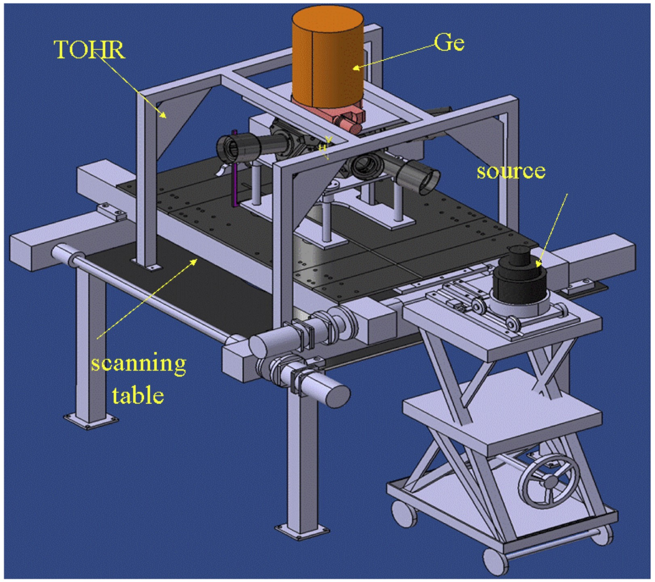


Intensity distribution of scattered 661 keV γ

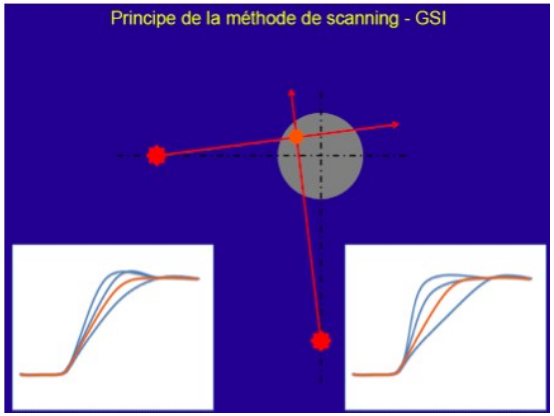


- **1200** points scanning is long procedure in Liverpool **(~3 months)**

- Faster scanning techniques (**few days for 40000 points**) being tested and installed a GSI and IPHC – **P**ulse **S**hape **C**omparison **S**can

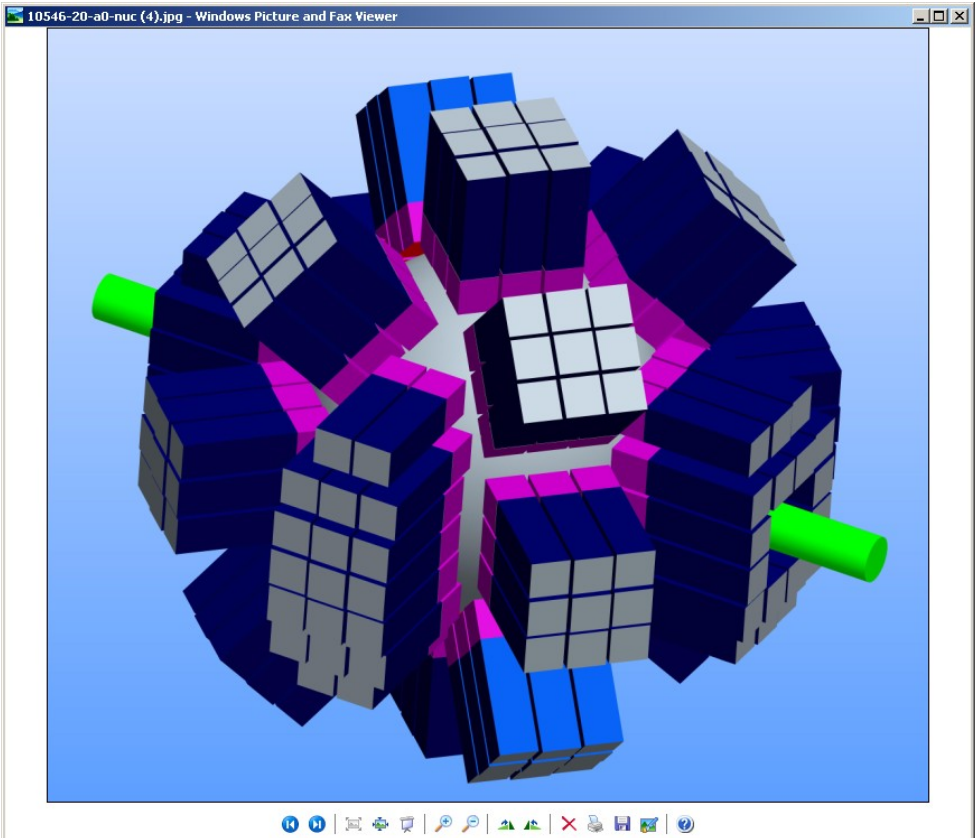


Xtal rotation to create point pairs



PARIS: Gamma Calorimeter

Possible design



IPNL

IPN INSTITUT DE PHYSIQUE NUCLÉAIRE ORSAY

IPHC Institut Pluridisciplinaire Hubert CURIEN STRASBOURG

Grand Accélérateur National d'Ions Lourds
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Goal : 50keV < E_γ < 40 MeV
with < 4% @ 660 keV.

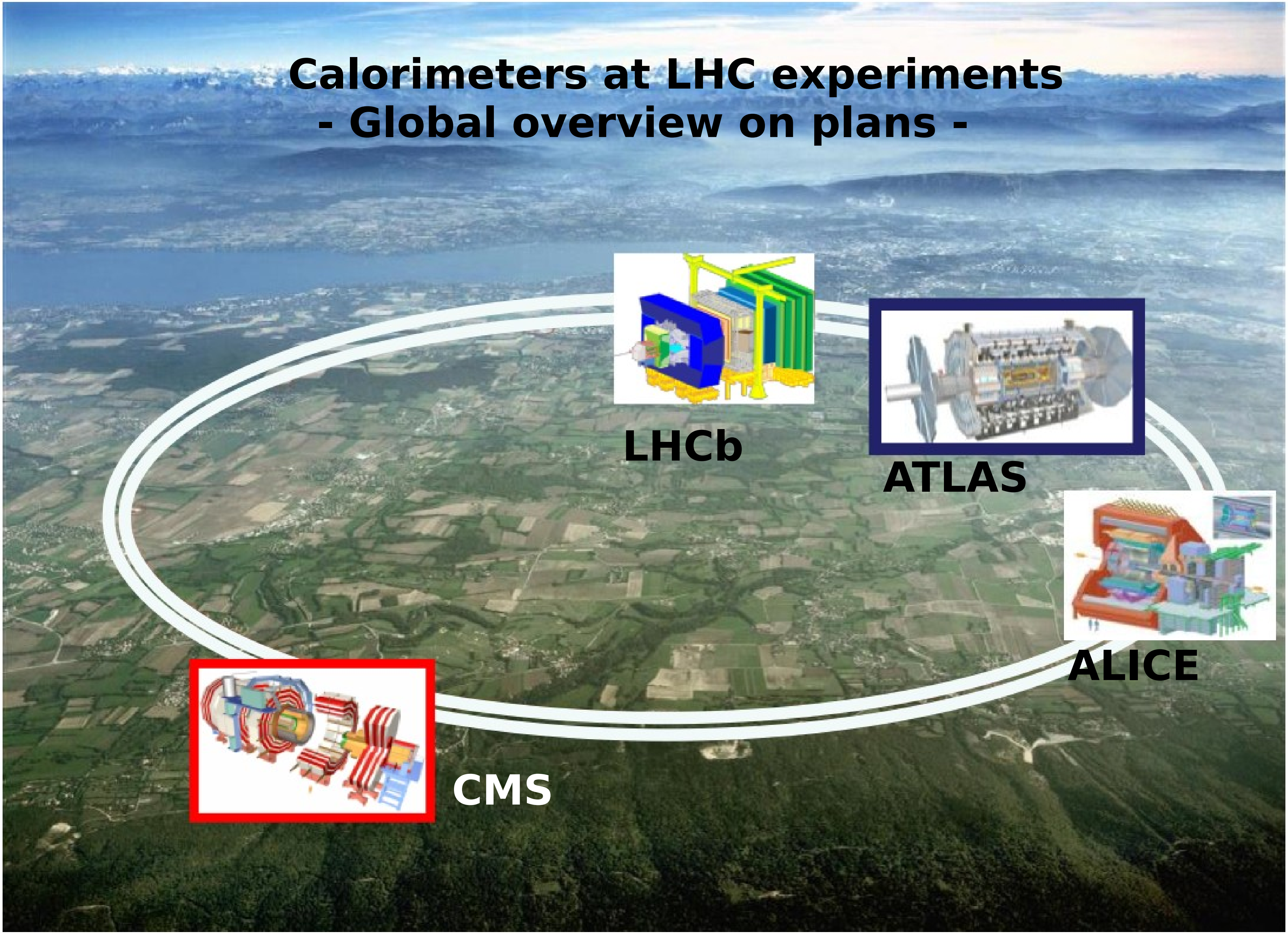
4π calorimeter :
~ 18 clusters of 9 phoswich (PW).
PW: $LaBr_3$ (2"x2"x2") + NaI (2"x2"x6")

Resolutions @ 660 keV:
E_γ: $LaBr_3$ 4-5%, NaI 7-8%
Time : $LaBr_3$ 170ps

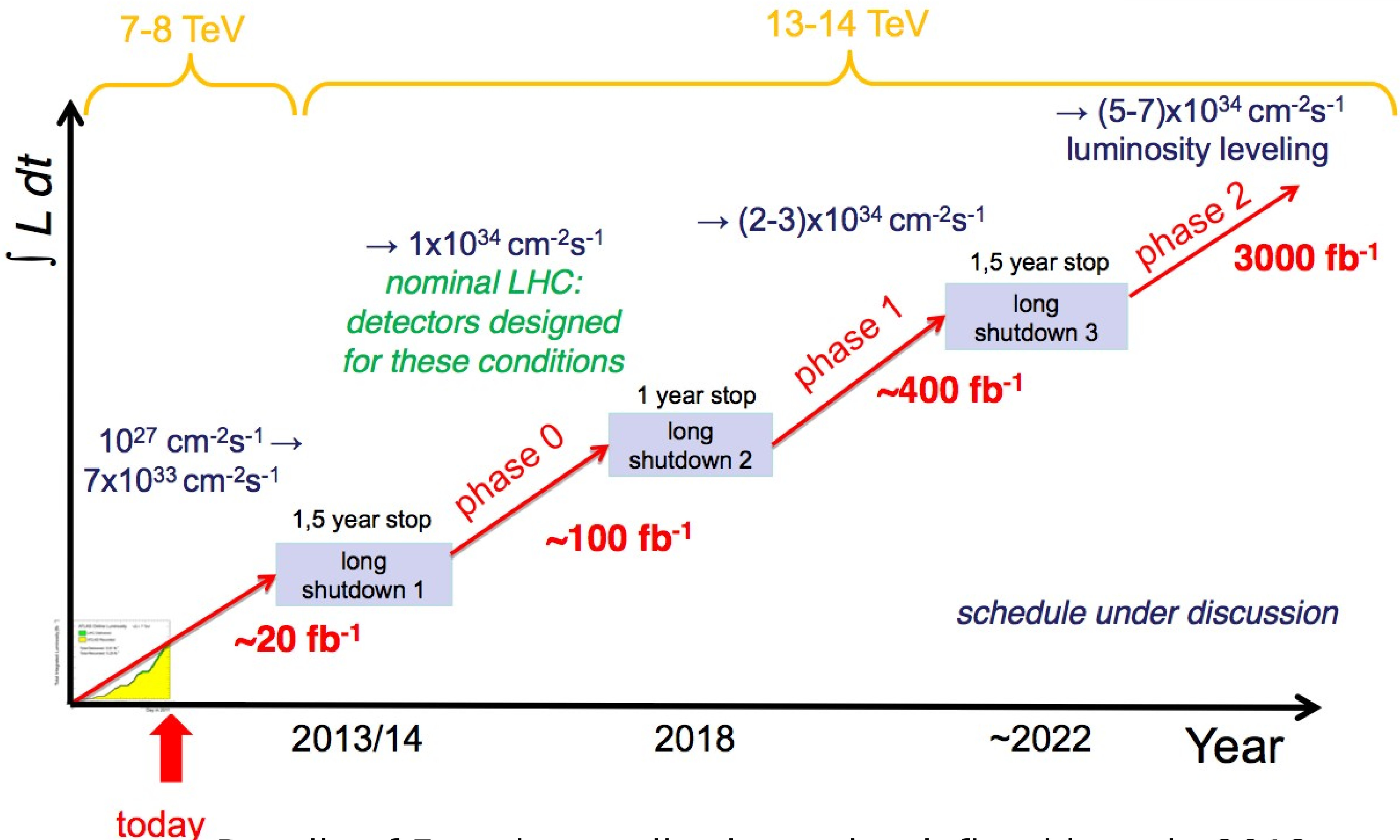
Test of 2 clusters (18 PW): 2012
2π construction: 2016
4π construction: > 2018

Further developments with new scintillators : $CeBr_3$ or SrI_2

Calorimeters at LHC experiments
- Global overview on plans -



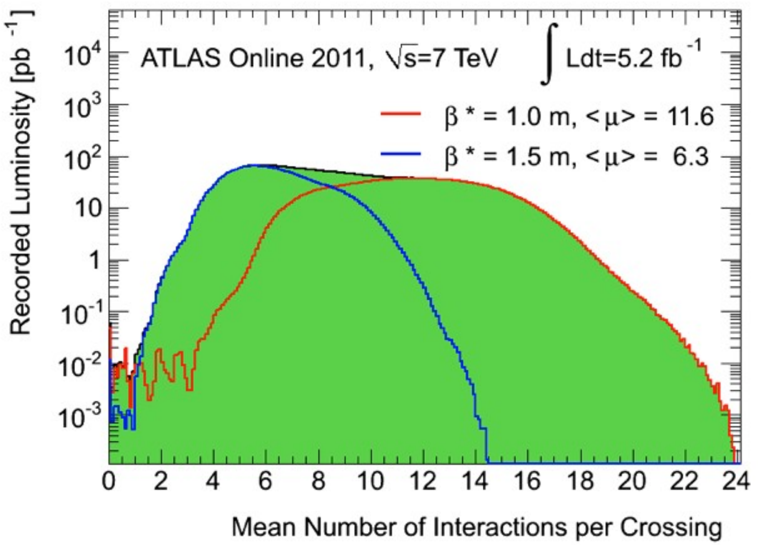
Evolution of LHC into high luminosity phase



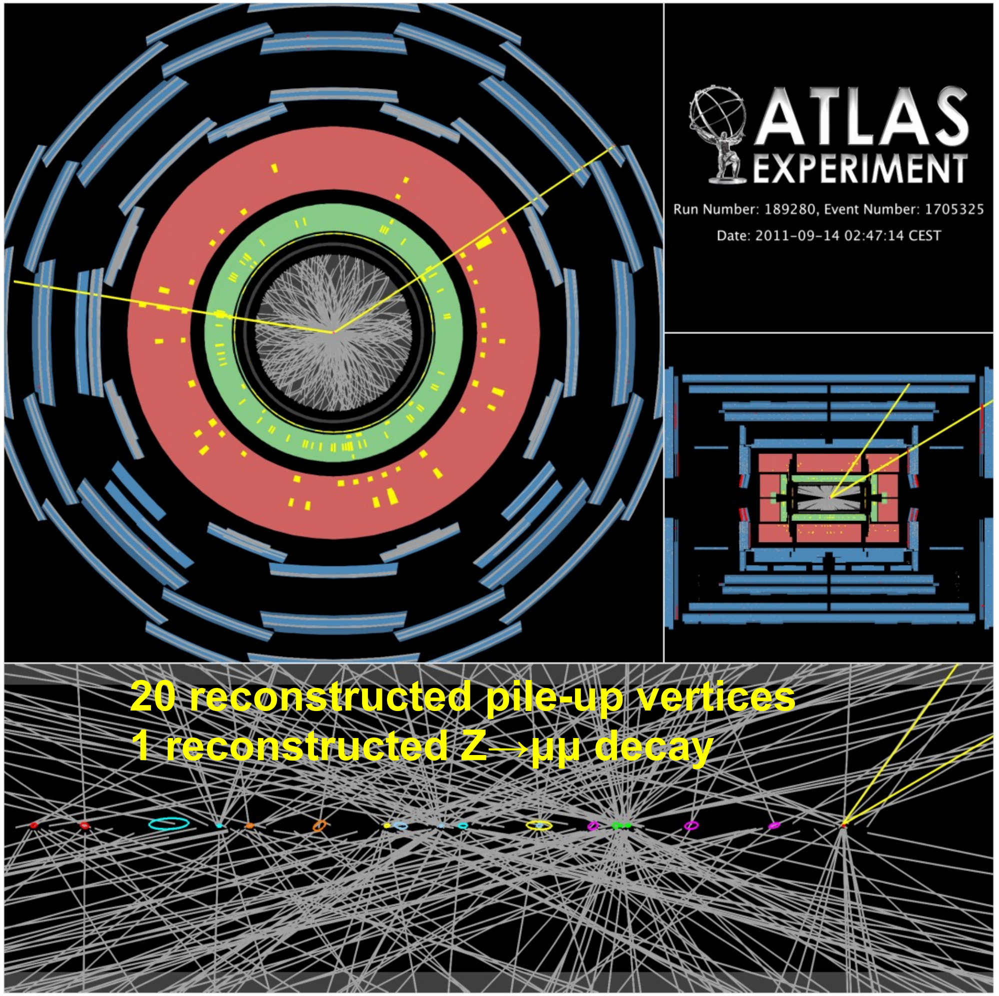
Details of French contribution to be defined later in 2012
Today flavor on things which need to be done

Challenges at High Instantaneous Luminosities

- Reconstruction of physics objects already deals with pile-up of proton-proton collisions: up to 24 events in 2011



- Poisson mean at nominal LHC: 25 events



- Increased instantaneous luminosity
  → increased flux of particles
  → pile-up events dilute trigger performance
  → trigger energy and momentum thresholds are raised accordingly

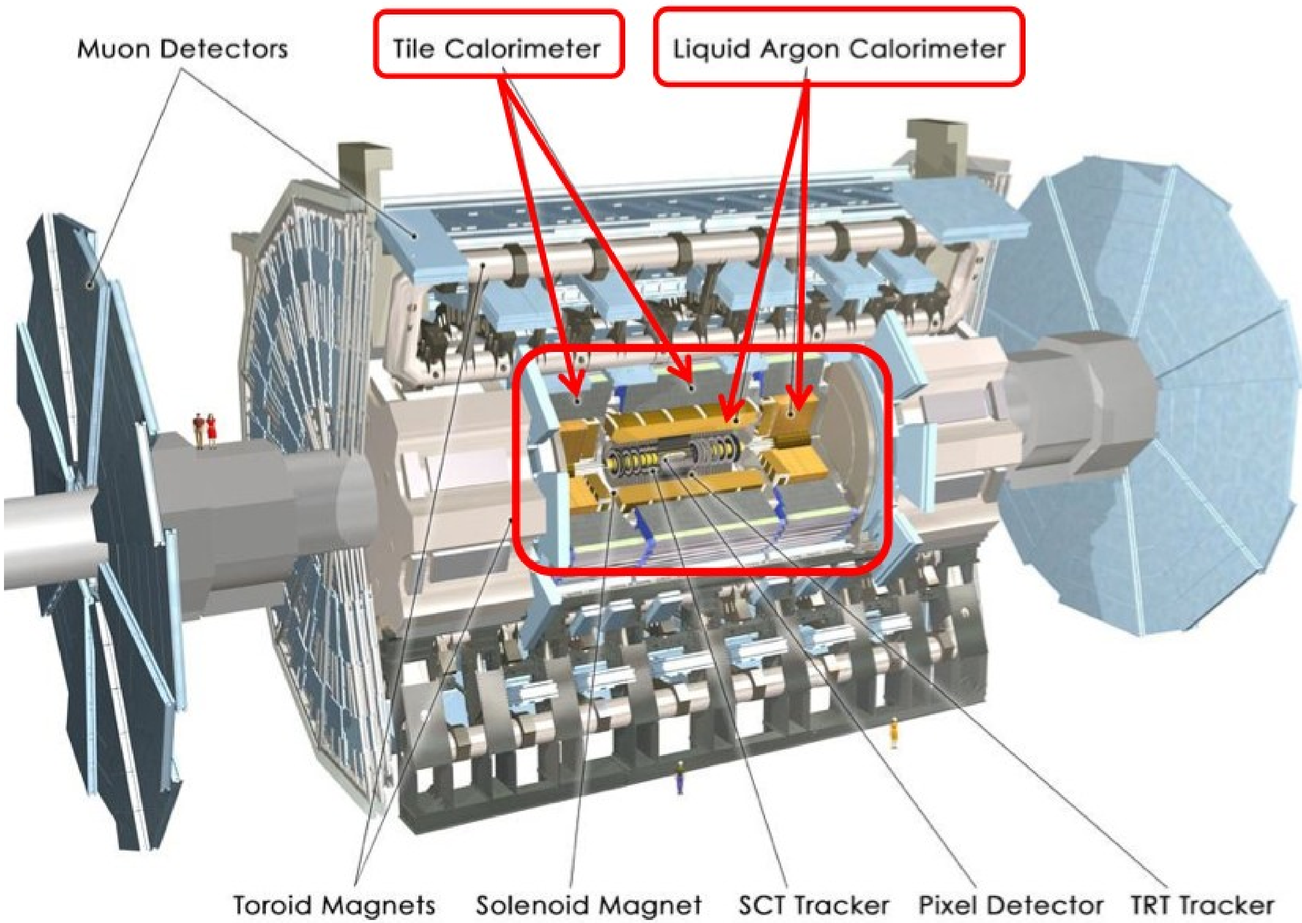
- Pile-up in HL-LHC Phase-1: 55-80 events Pile-up in HL-LHC phase-2: ~200 or more events

Slide courtesy of A. Straessner

ATLAS – Calorimeter Upgrade Plans

- LHC phase-0 (2013/14):
- Consolidation work on LAr front-end electronics: replacement of low-voltage power supplies

- LHC phase-1 (2017/18):
- New calorimeter read-out electronics and additional calorimeter trigger logic



- LHC phase-2 (2022):

- Free-running readout electronics for calorimeters
- New digital calorimeter trigger electronics

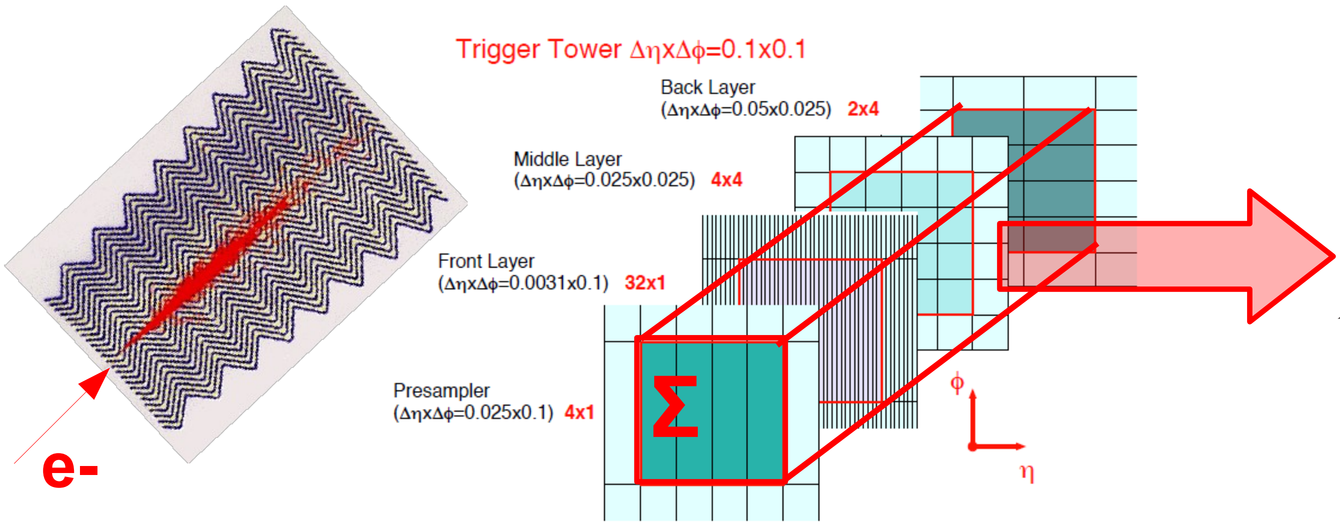
- Possible replacement of cold electronics in LAr Hadronic Endcap (HEC)

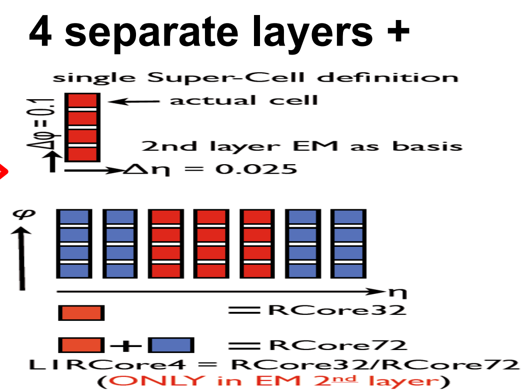
- Possible replacement of Forward Calorimeter (FCal) or additional forward MiniFCal

Slide courtesy of A. Straessner

Higher Granularity for L1 Trigger

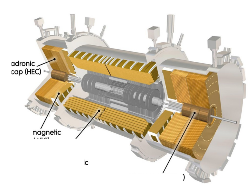
- Calorimeter trigger prepares analog 4-layer sums into trigger towers → $\Delta\eta \times \Delta\varphi = 0.1 \times 0.1$
- Finer longitudinal and transverse granularity allows better rejection of background with pile-up

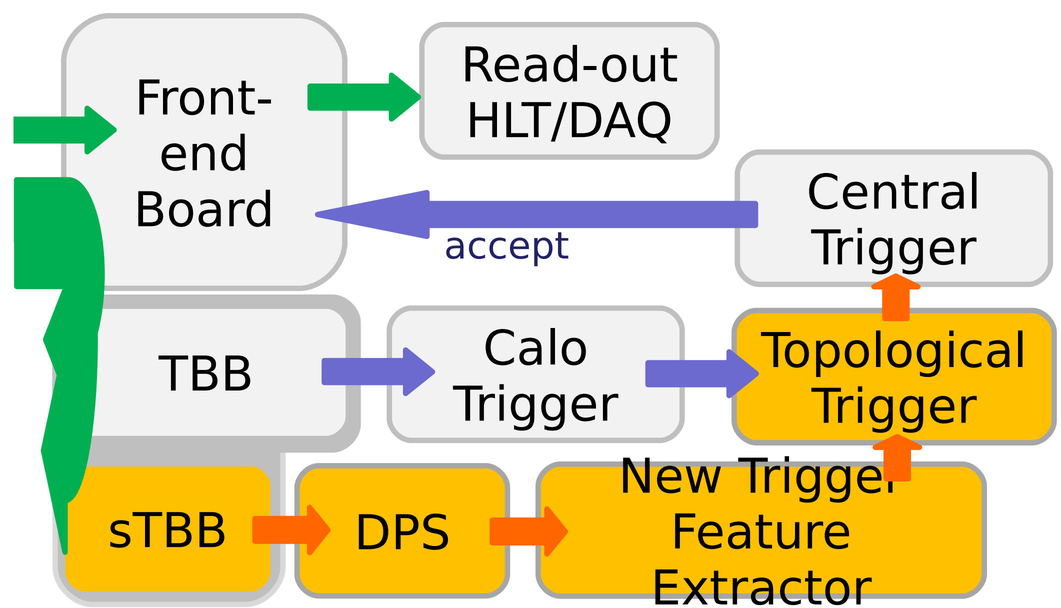




New trigger readout concept:

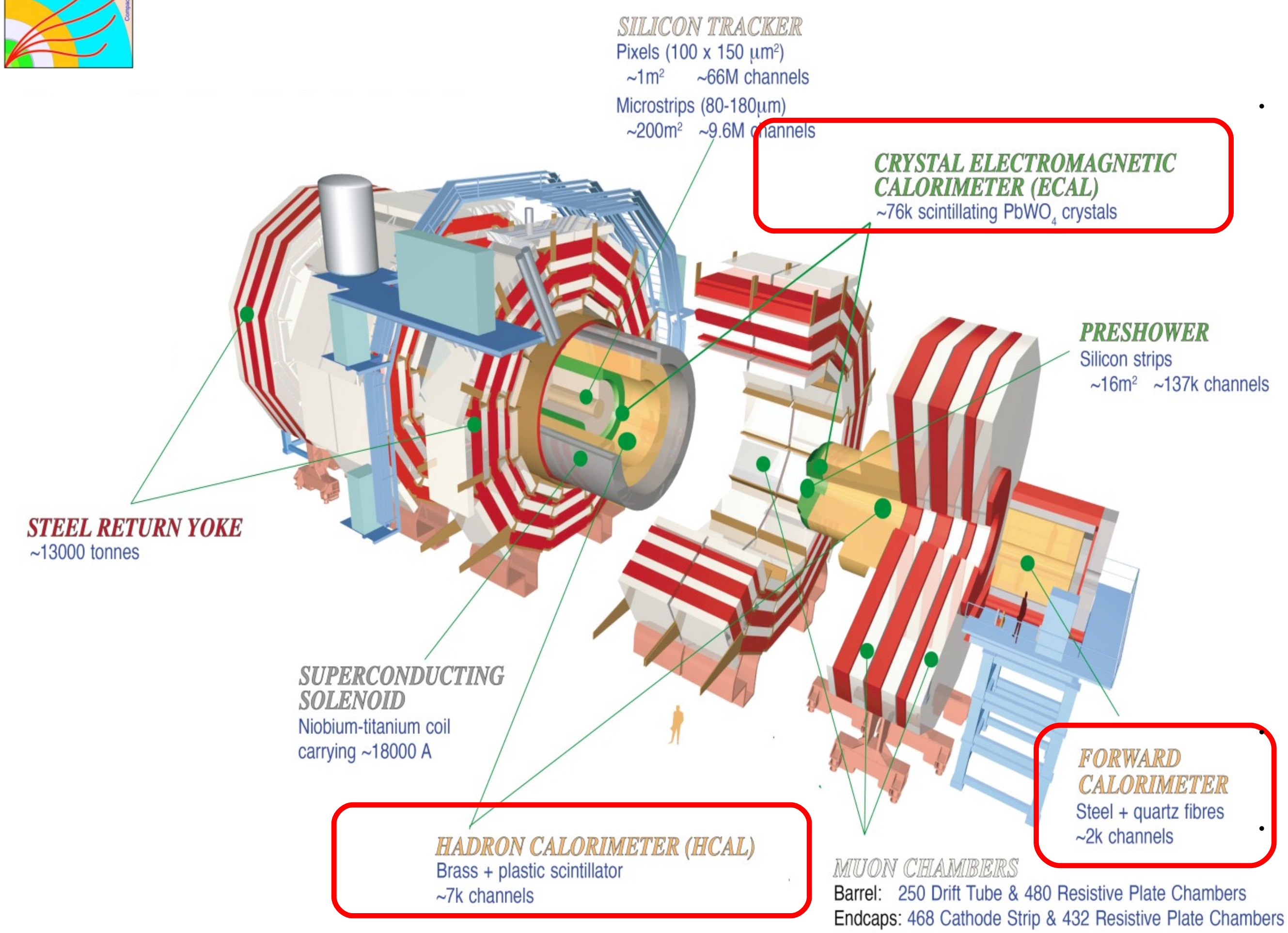
- Send analog signal to addition. front-end electronics
- New Tower Builder Board (sTBB) with digital trigger signal input
→ radiation tolerance to 3000 fb-1
- New Digital Processing System (DPS)
- Additional trigger logic





Slide courtesy of A. Straessner

CMS – Calorimeter Upgrade Plans



- possible modification of Avalanche Photo Diode readout (phase-2)
- possible replacement of PbWO4 endcaps (phase-2)

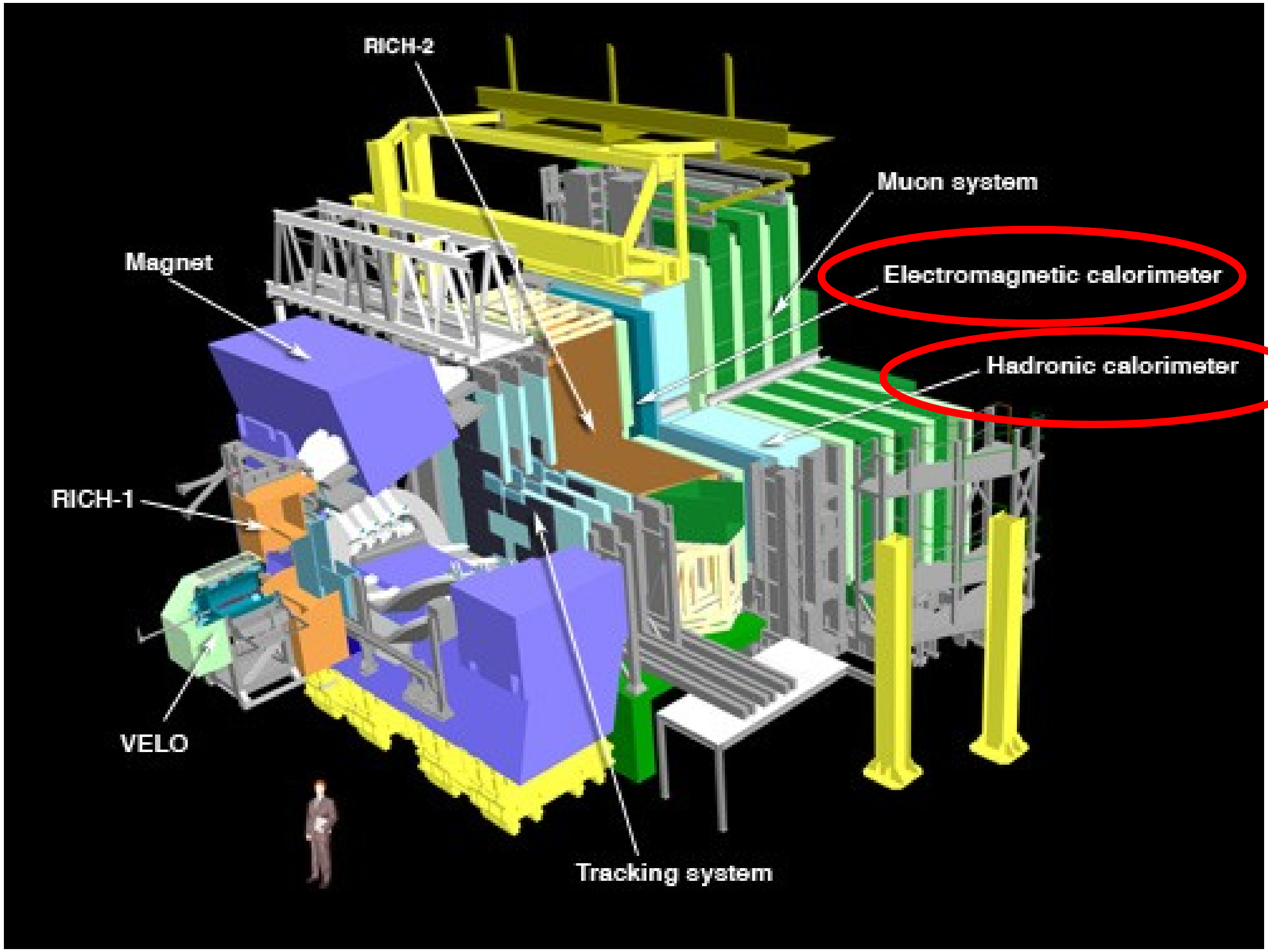
- new photo-detectors for scintillator light collection
- new quartz fibers (phase-2)

- new photo-detectors for scintillator light collection
- new quartz scintillator (phase-2)

+ Upgrade of readout and trigger systems and DAQ

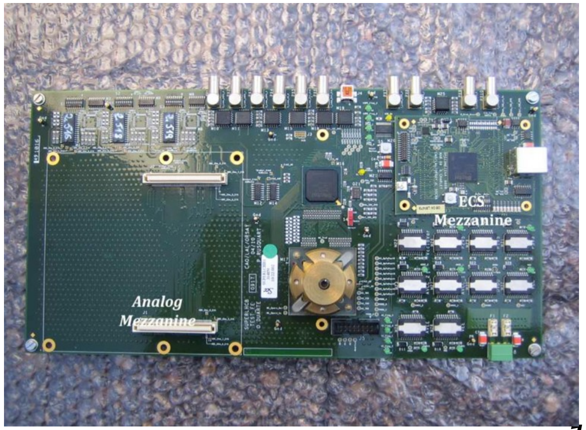
LHCb upgrade - Calorimeter

Main goal of upgrade: Increase readout to 40 MHz



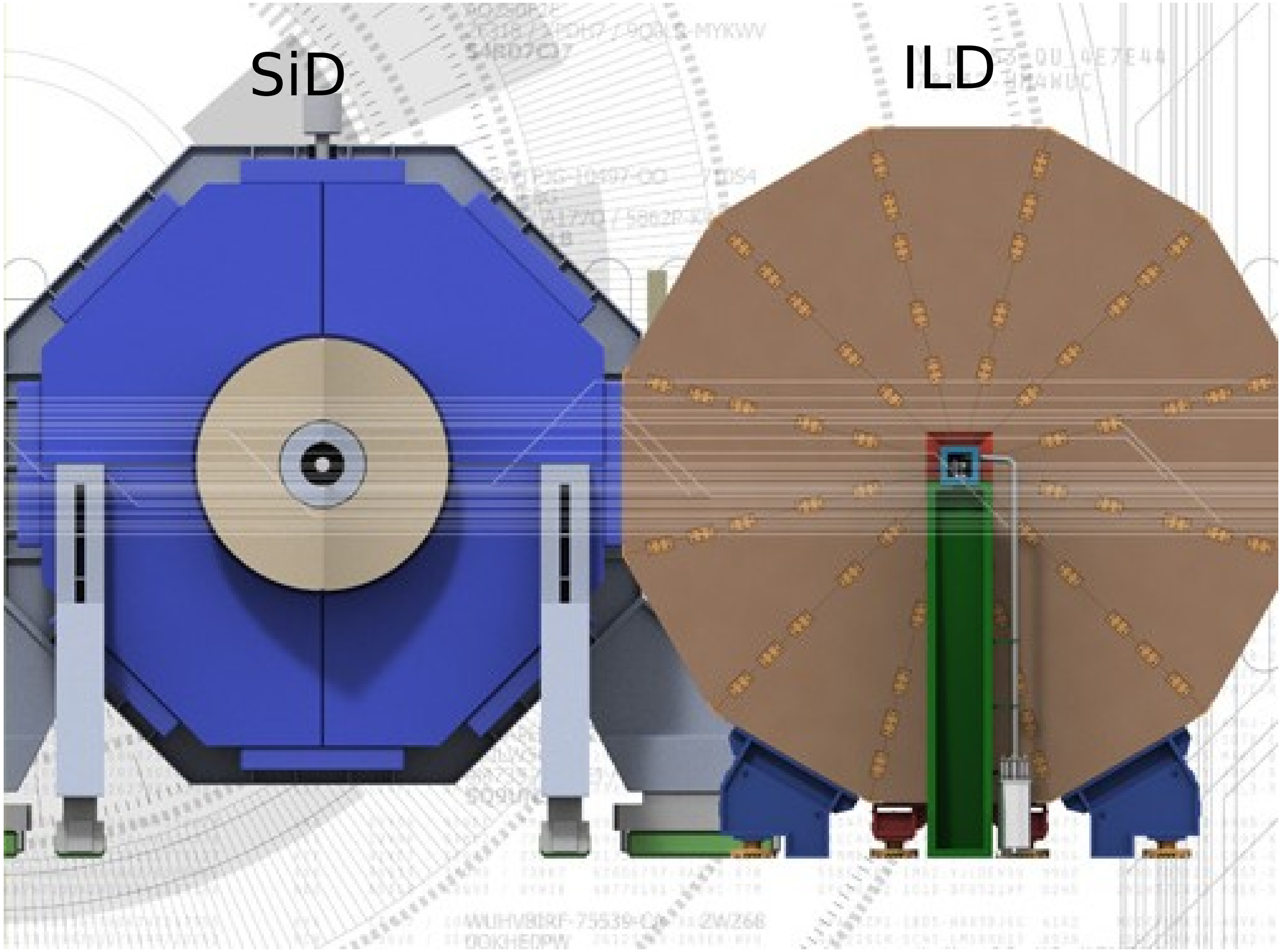
Examples for upgrade projects:
- First level Trigger
L0 → LLT
Trigger Rate
1.1 MHz → (up to) 40 MHz

Front End electronics
- Need to cope with Reduction of PMT amplification
- Digital part



The upgrade target rather 2018 than 2013

Calorimeter R&D for LC detectors



Detectors for e+e- - collisions around $\sqrt{s}$ ~ 500GeV

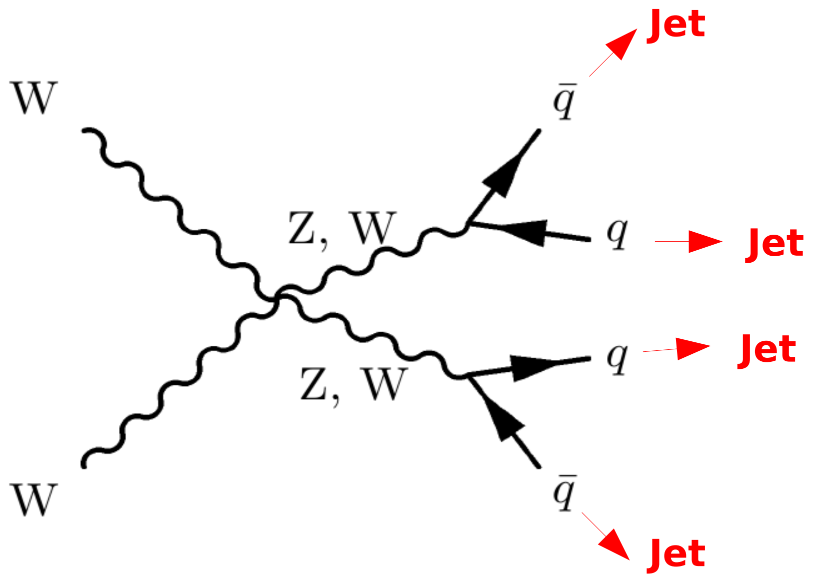
(and up to 3 TeV)

Detector **B**aseline **D**esign in 2012 – Together with machine TDR

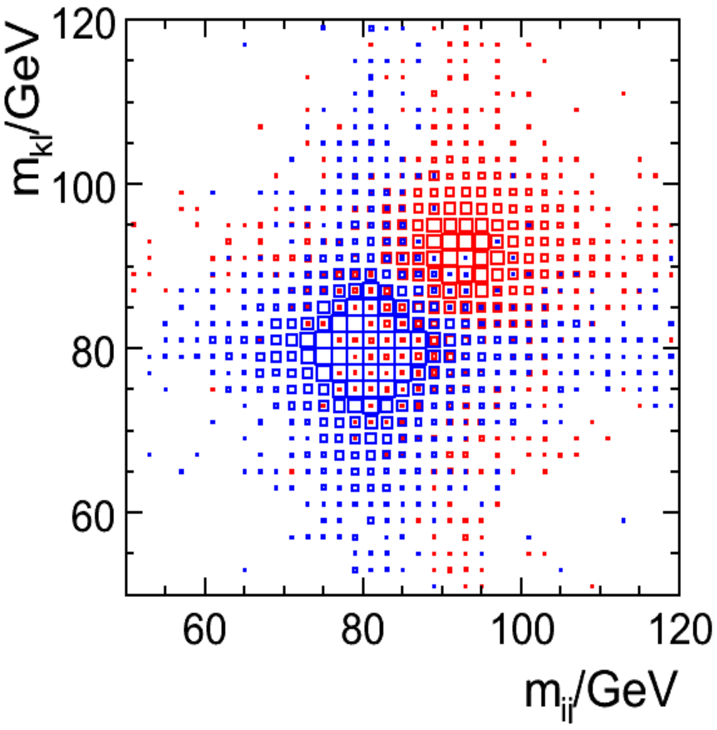
Hadronic Decays of W and Z Bosons

Boson Boson Scattering

Example for multi-hadron final state



W, Z separation in the ILD detector



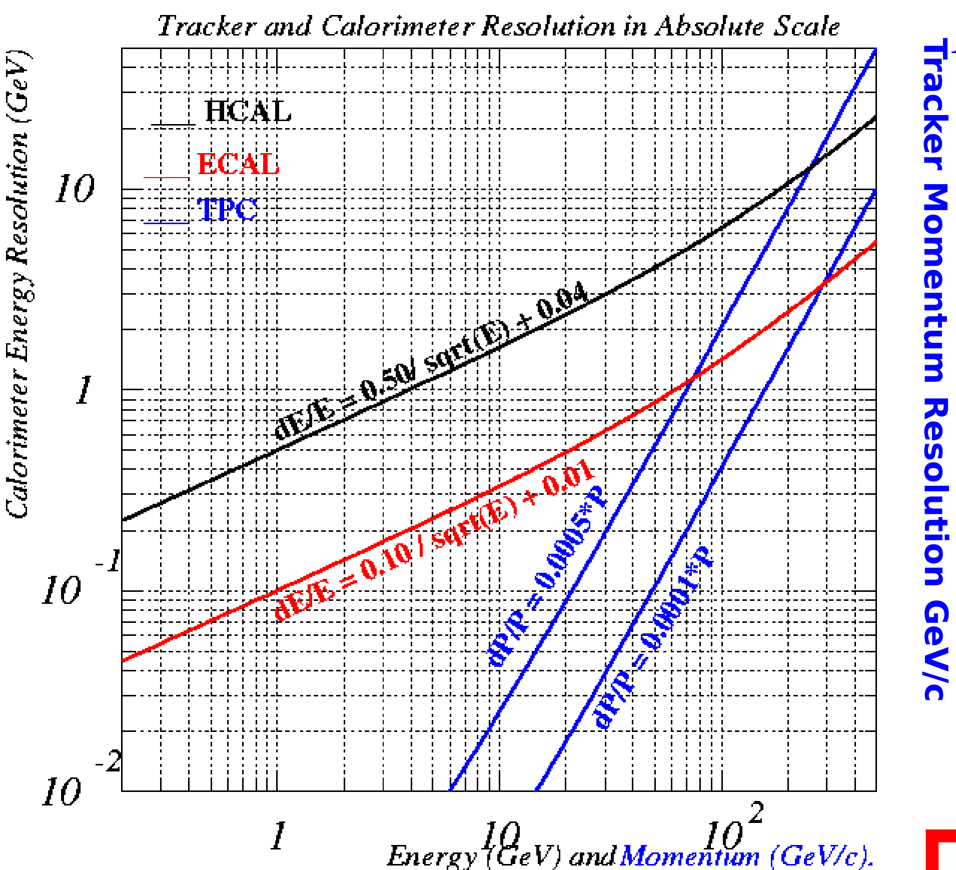
Remember: M_z-m_w ≈ 10 GeV

- Need excellent jet energy resolution to separate W and Z bosons in their hadronic decays

Goal 3% - 4% for jets between 45 GeV and 500 GeV

Jet Energy Resolution

Final state contains high energetic jets from e.g. Z,W decays
Need to reconstruct the jet energy to the <u>utmost</u> precision !



Jet energy carried by …

- Charged particles (e±, h±,μ±)): 65%
  Most precise measurement by Tracker
  Up to 100 GeV

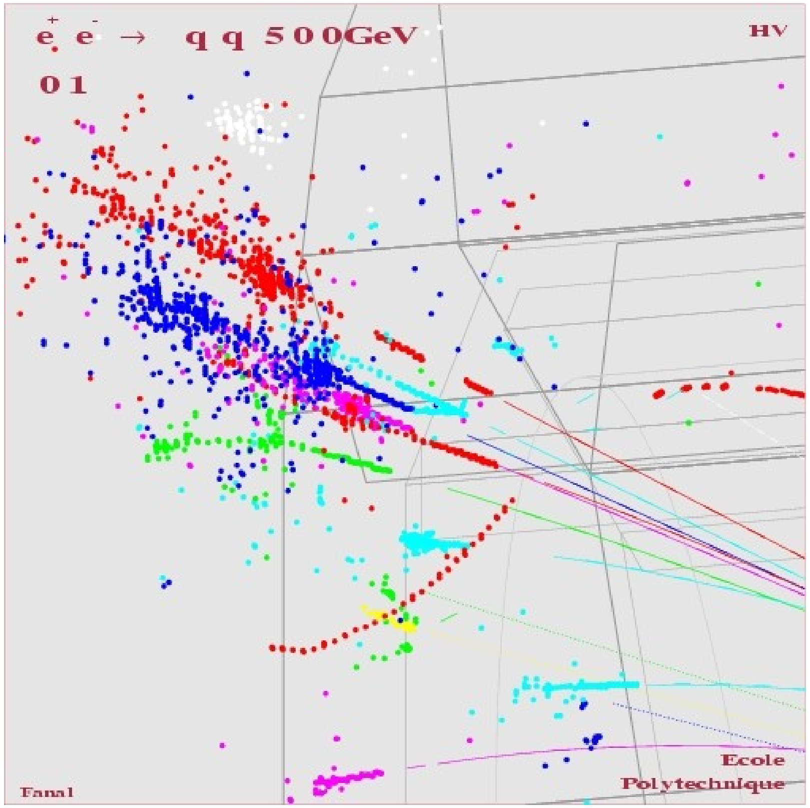
- Photons: 25%
  Measurement by Electromagnetic Calorimeter (ECAL)

- Neutral Hadrons: 10%
  Measurement by Hadronic Calorimeter (HCAL) and ECAL

$$\sigma_{Jet} = \sqrt{\sigma^2_{Track} + \sigma^2_{Had.} + \sigma^2_{elm.} + \sigma^2_{Confusion}}$$

Confusion Term

- Base measurement as much as possible on measurement of charged particles in tracking devices
- Separate of signals by charged and neutral particles in calorimeter



- Complicated topology by (hadronic) showers

- Correct assignment of energy nearly impossible

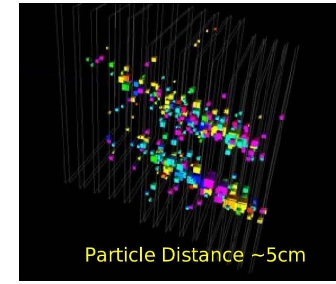
$\Rightarrow$ Confusion Term

Need to minimize the confusion term as much as possible !!!

Reconstruction of every single particle of final state
Particle Flow
Introduced for LC adopted by e.g. CMS

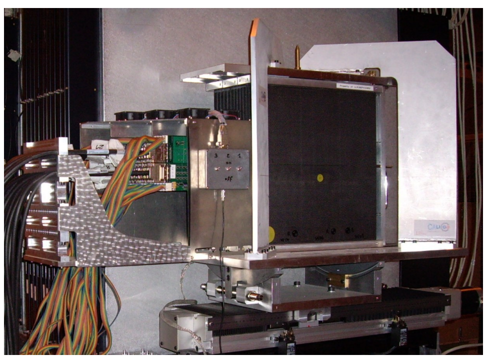
Detector R&D

Precision physics at LC require highly granular calorimeters

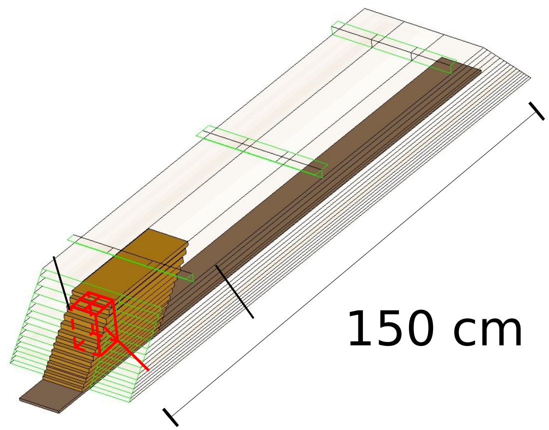


Physics prototypes
Proof of principle
2003 - 2011

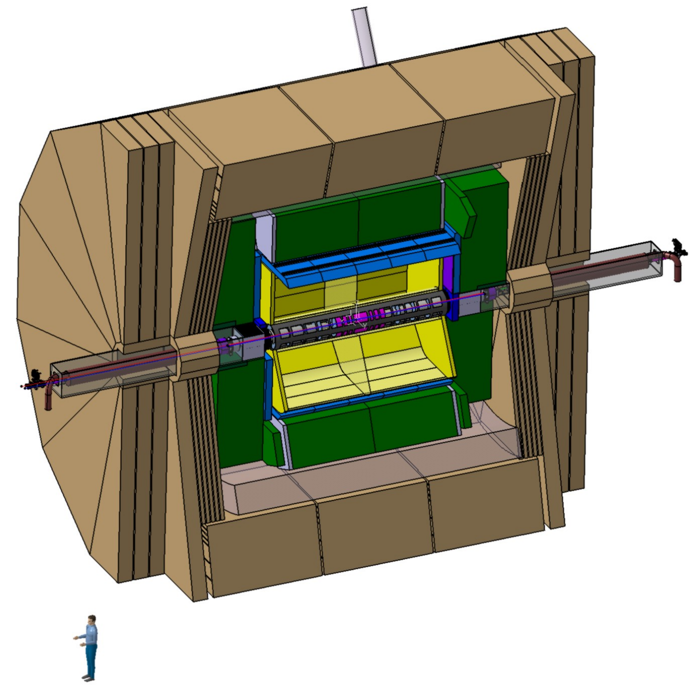
30cm



Technological prototypes
Engineering challenges
2009 - ...



LC detector

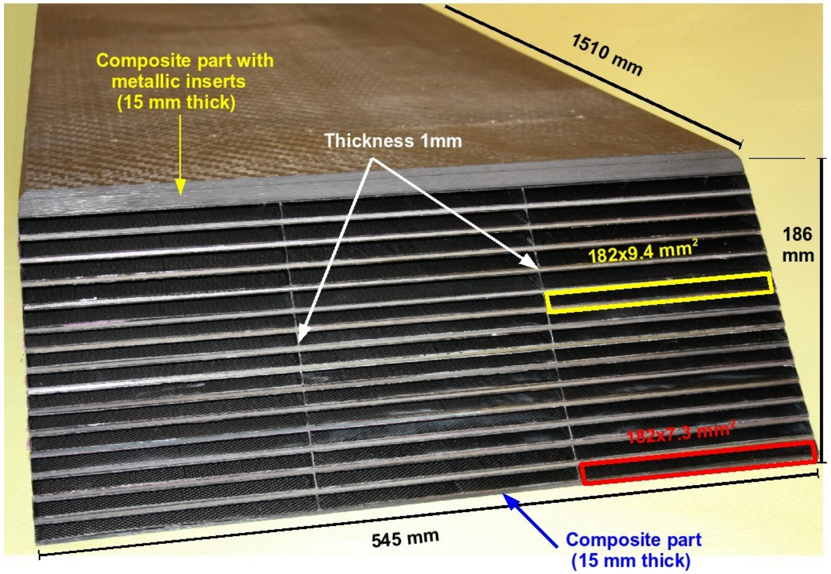


- **Calorimeters for full detector**

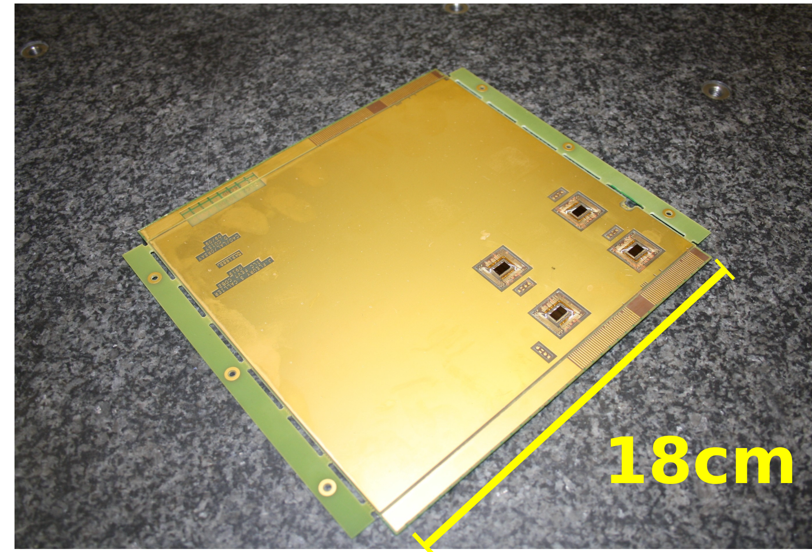
Future: Step from first prototypes to full calorimeter systems
R&D oriented towards LC but major synergies with other projects!!

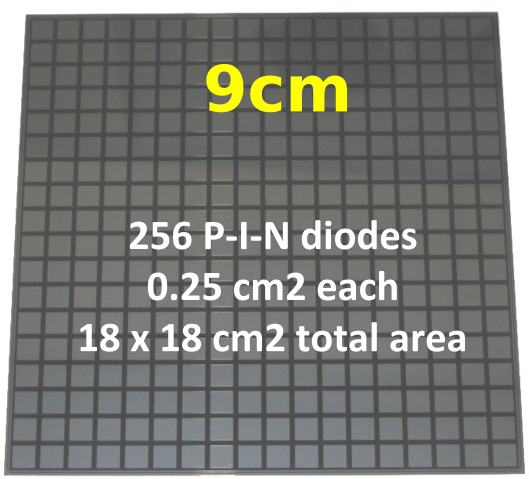
C'est le moment de remercier tous les ingénieurs/techniciens qui sont engagés dans les projets

Technologies under study I – SiW Ecal



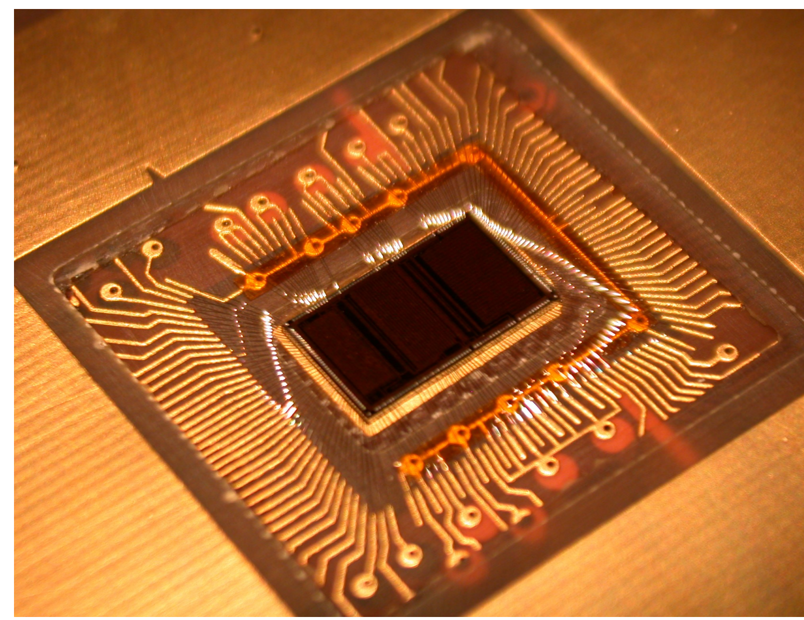
Alveolar strucuture to house layers
(self supporting)





Silicon sensors

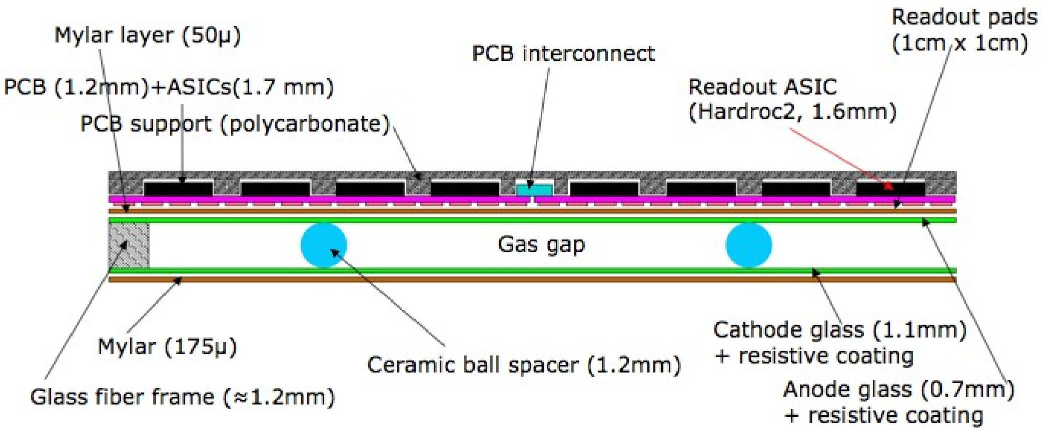
- Si allows for pixelisation
- Good signal over noise ratio (goal 10/1)
- Cost is an issue

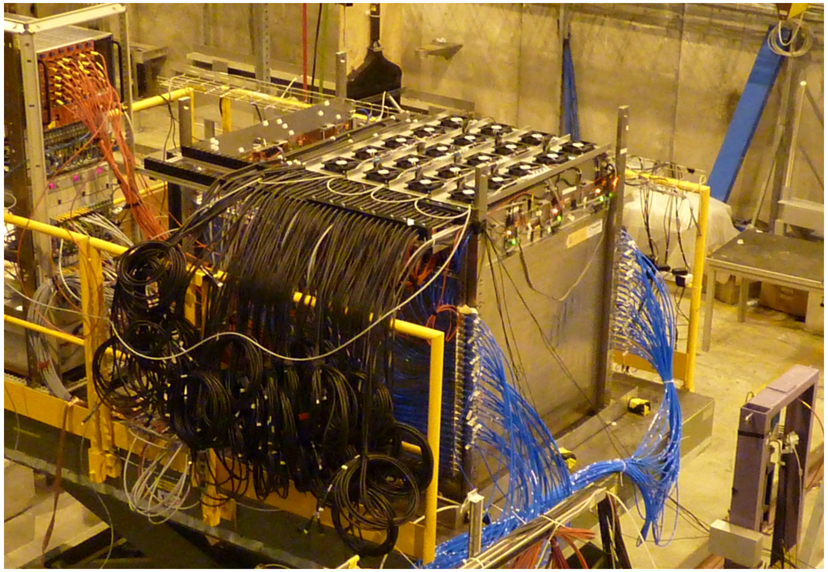


Front end electronics
Embbeded in calorimeter layers

Goal: Construction of technological prototype until 2015

Technologies under study II – Glass RPCs





Glass RPCs as sensitive medium
- Cost effective
- Acceptable resolution at high efficiency
- Allow for fine subdivision

=> High granularity which allows for

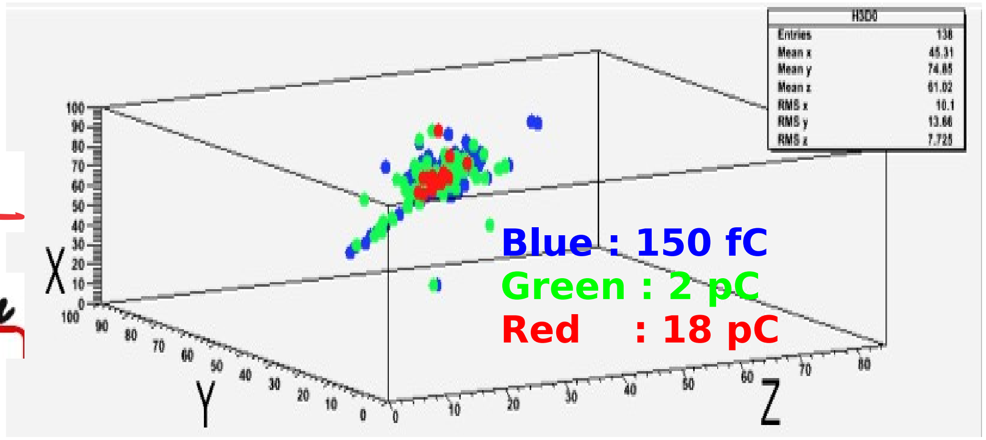
(semi) digital calorimetry

=> SDHCAL

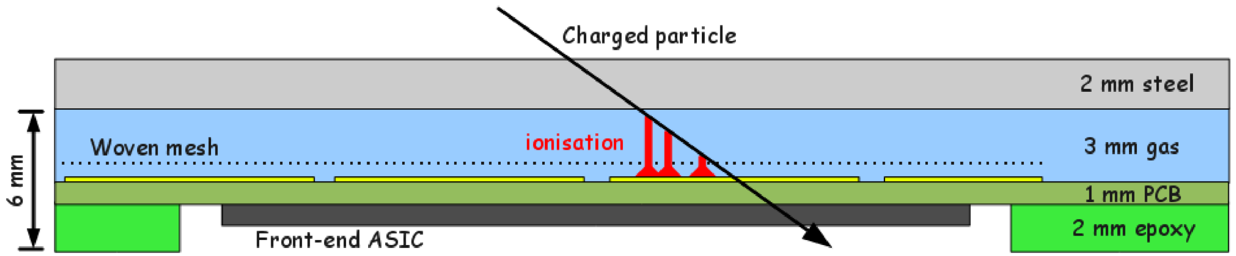
$1m^3$ technological prototype of SDHCAL
- 52 x 10000 cells
- Commissioned in 2011
- Tested in beams in coming years

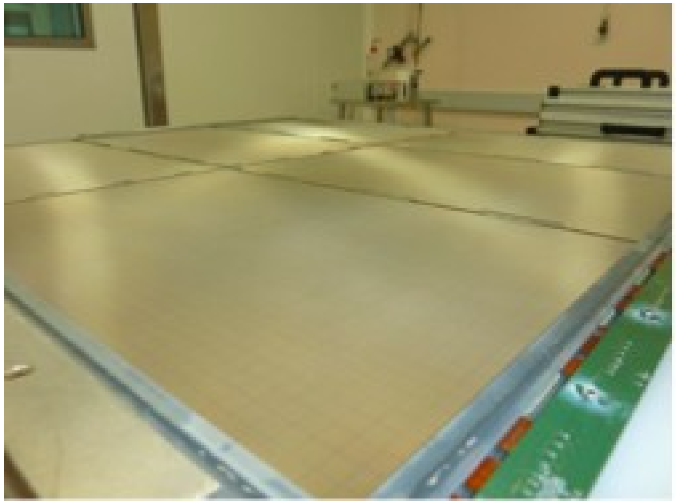
Technology to be validated for
- Homogeneity
- Feasibility to master thin (and large) GPRC chambers
- Embedded electronics

Common development for all LC calorimeter prototypes



Technologies under study III - Micromegas





Micromegas as sensitive medium

- Bulk technique allow for large surfaces
- operation in proportional mode
- Fast response time

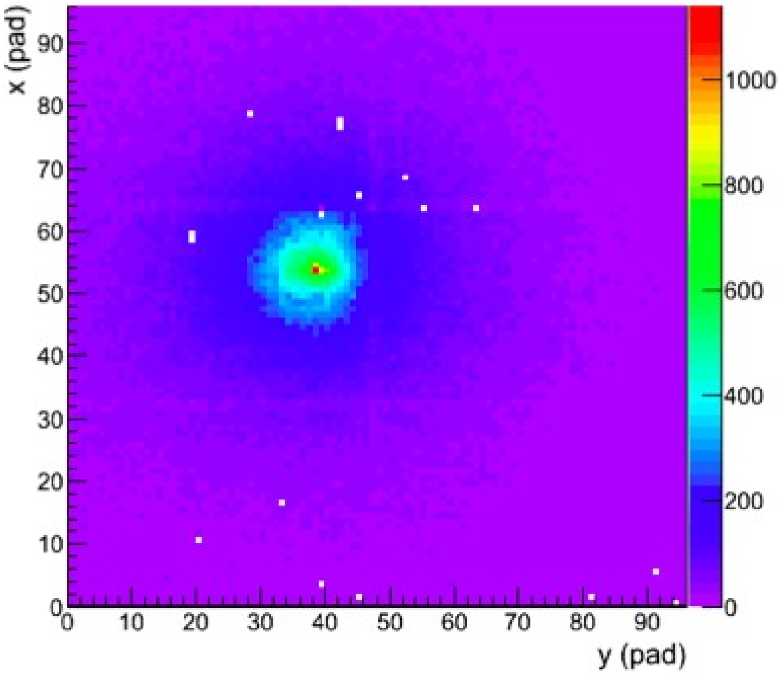
- Successful R&D program

  Tested Micromegas chamber exhibit small noise level
- Progressive increase of number of chambers,

  => Studies of shower development In micromegas
- Synergies with GRPCs and SiW Ecal

  e.g. DAQ for large number of channels

  Readout electronics
- Study of Micromegas for LC is part of a large scale R&D program around Micromegas RD51 collaboration



Major issues of R&D

- Master current technological prototypes with up to 500000 channels

  e.g. Power management of considerable systems

- Establish contacts to industrial partners

  Development of cost effective solutions

- Prepare the step towards 'real' detectors

  Prototypes now: up to 500000 channels

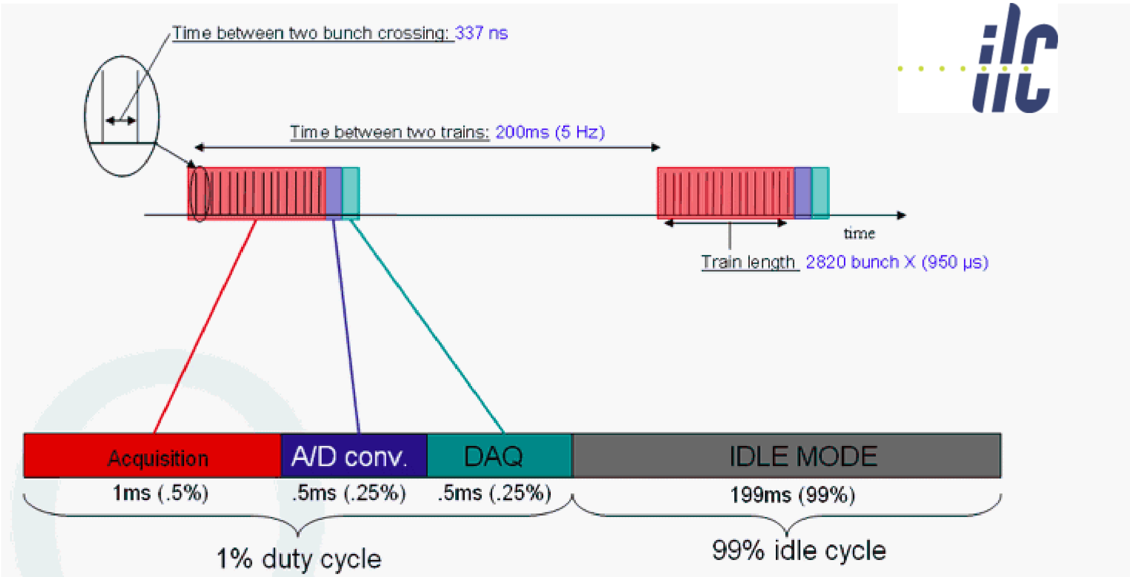
  Final detector: > 10^8 channels

- Development of system simulation tools

- Invent procedures to assure utmost reliability of detector equipment
- Prepare procedures for mass production of detectors

- (To say the least) Difficult to conduct with current resources (funding and manpower)

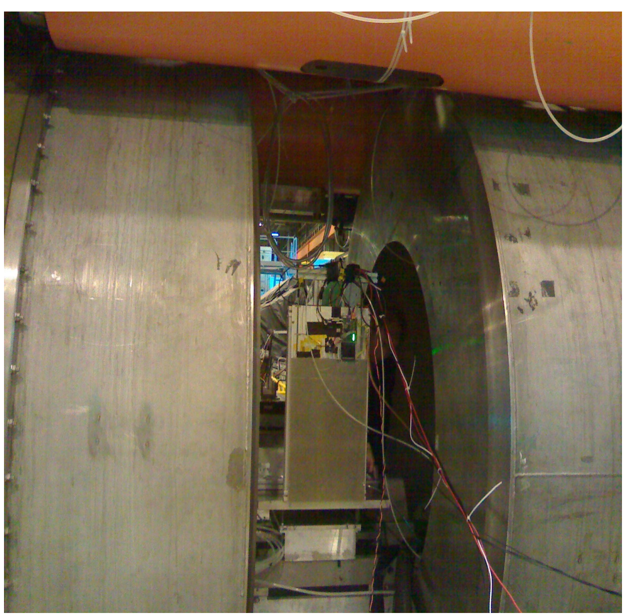
Power pulsing (better power gating)



- **Electronics switched on during 1ms of ILC bunch train and data acquisition**
- **Bias currents shutdown between bunch trains**

Aim: power consumption of few 10 muW/channel
Additional difficulty: Calorimeters will be embedded in ~4T B-Field

Mastering of technology is essential for operation of LC detectors



Short test of power pulsing with SDHCAL prototype in 2010

-> Encouraging results
e.g. little up to no drop in efficiency of pads

As we speak: 1m^3 of SDHCAL operated in power pulsed mode

Summary and outlook

- Coming years will see realisation of challenging calorimeter projects

- New horizons in gamma spectroscopy
  AGATA and PARIS

- LHC calorimeters are preparing for high luminosity phase

- LC needs pixelised calorimeters
  No 'traditional' calorimeters
  Will require mastering of systems with more than 100 000 000 calorimeter cells
  Not mentioned: Beam tests with hadrons will lead to new quality in the understanding of hadron showers
  → Beneficial for the entire (HEP and Nuclear) community
  → Synergies with applied mathematics and other fields of science