Calorimeter systems for linear collider experiments

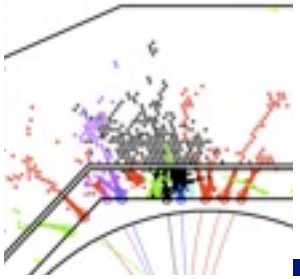
Felix Sefkow

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

DESY

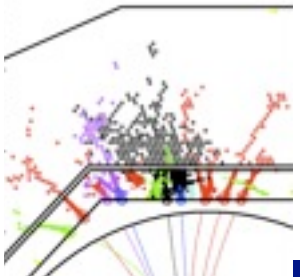
CALICE

ILC Meeting at DESY, July 8, 2016



Outline

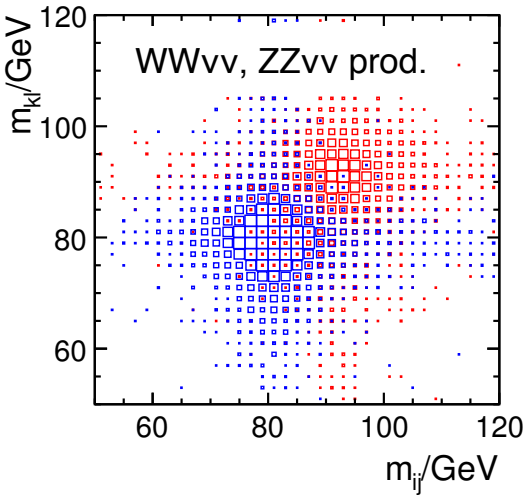
- Absorber materials
- Active layer technologies
- Geometries and services
- Segmentation

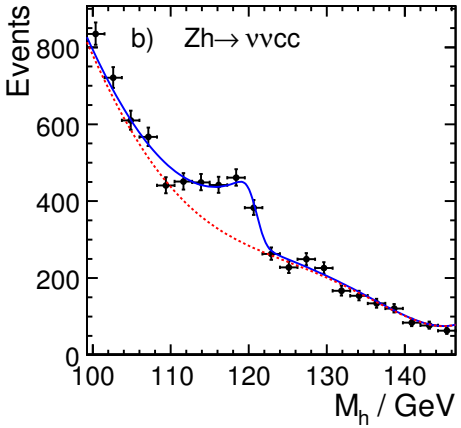


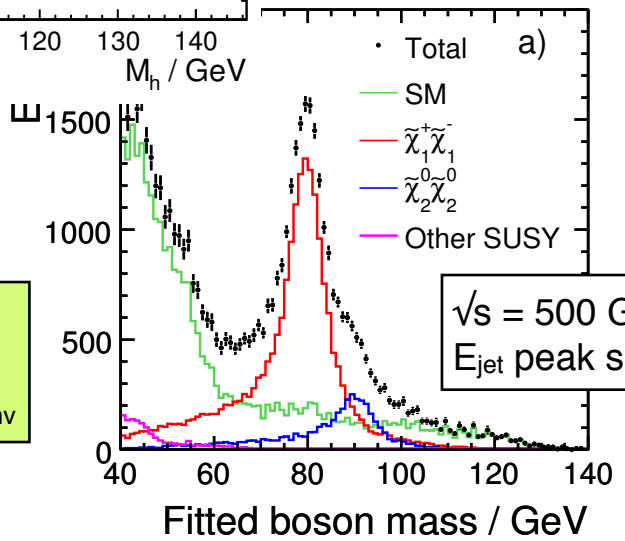
LC physics with jets: M_{inv}

- W - Z separation
  - study strong e.w. symmetry breaking at 1 TeV
- Other di-jet mass examples
  - H → cc, Z → νν
  - Higgs recoil with Z → qq
  - invisible Higgs
  - WW fusion → H → WW
    - total width and g_{Hww}
- SUSY example:
  - Chargino neutralino separation

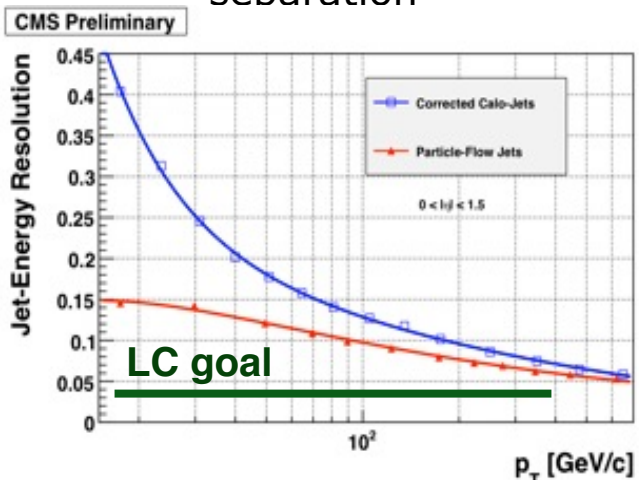
typical jet energies at √s = 500 GeV 50-150 GeV



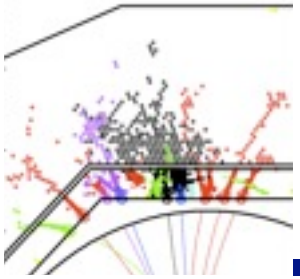




√s = 500 GeV
E_{jet} peak s @ 35 GeV



Fragmentation effects dominate at low E_{jet} - but largely cancel in M_{inv}

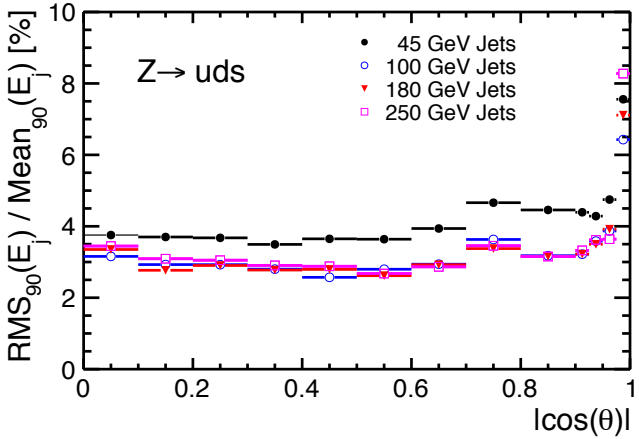


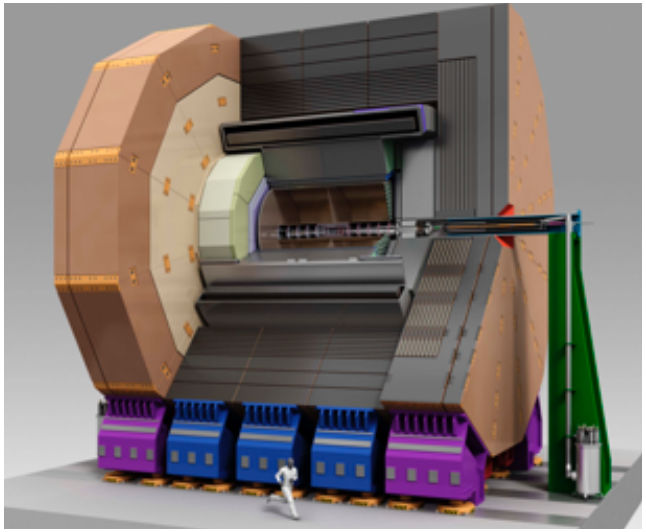
Calorimeter optimisation

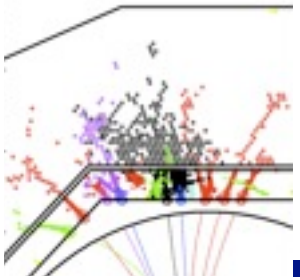
- Mostly driven by jet energy performance and particle flow

- Large radius, high magnetic field, calorimeters inside coil
- Dense and compact design
- Very high granularity

- ECAL also studies tau identification
- Less well or not at all studied
  - photon energy resolution
  - electron and muon identification

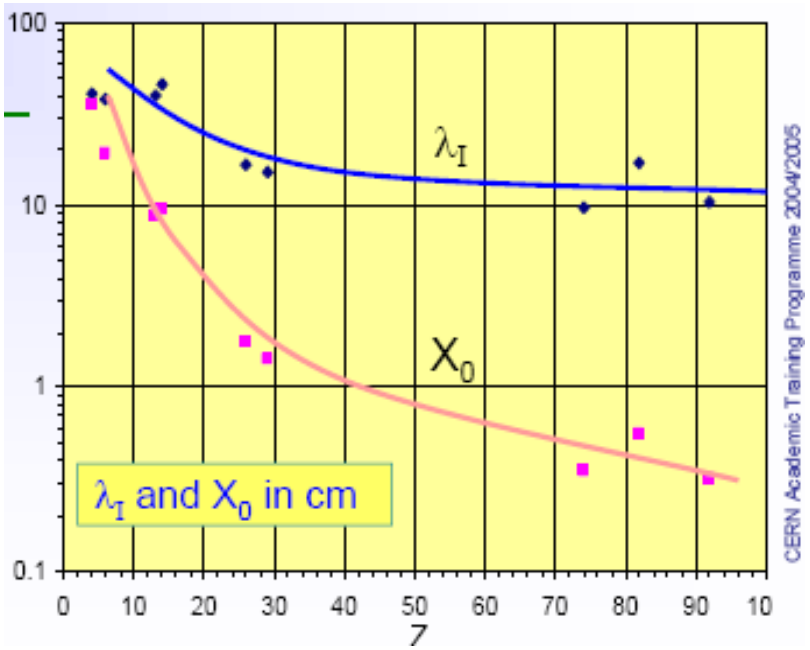


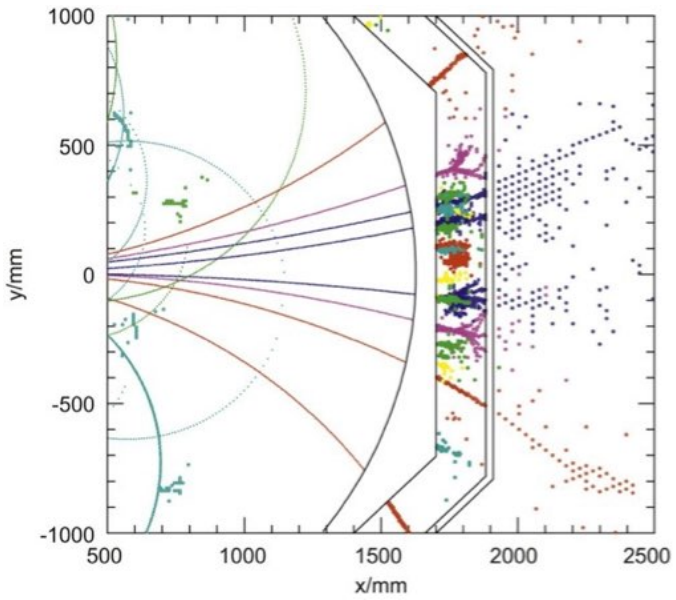




Absorber materials

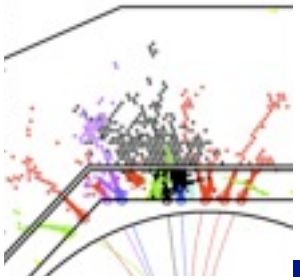
- Electromagnetic showers: X_0
- Hadronic showers λ_I (and X_0)
- Photon photon separation $R_M \sim X_0$
- Photon hadron separation: λ_I / X_0
  - ECAL "transparent" for hadrons
- W preferred for ECAL





	(cm)	λ_I	X_0	λ_I / X_0
Fe		16,8	1,8	10
W		9,9	0,35	28
Pb		17,6	0.56	31

GLD had a Pb ECAL and a Pb HCAL option



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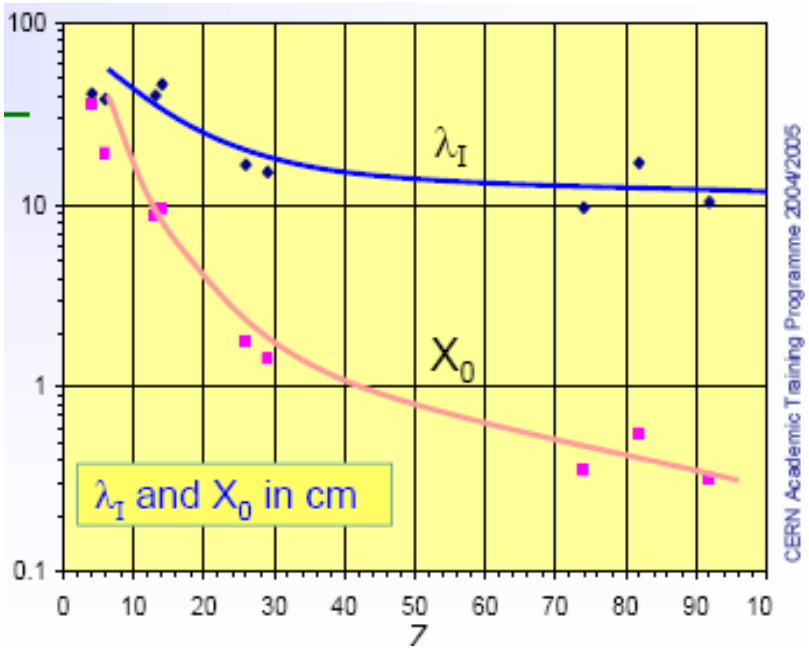

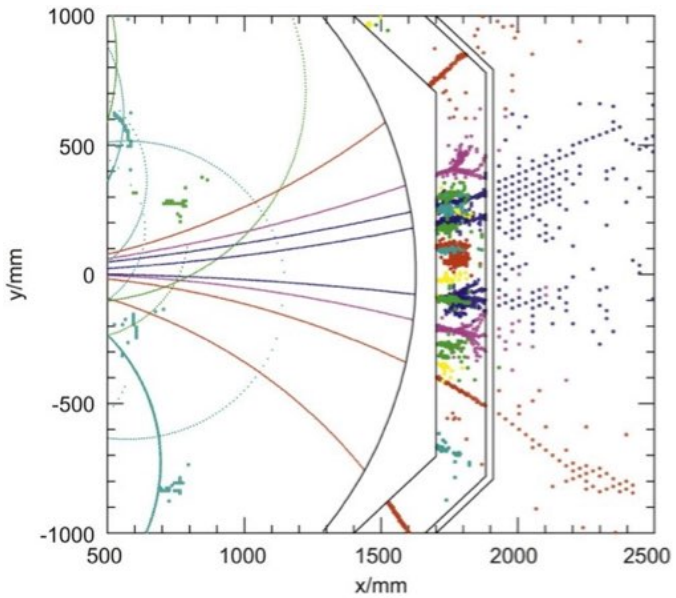

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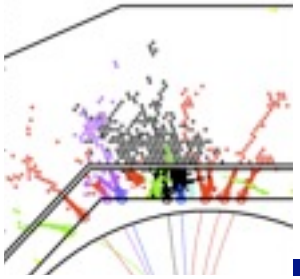

HCAL absorber

- Want reasonable sampling for hadronic **and** electromagnetic part of shower: avoid too large λ_I / X_0
- Fe preferred for the HCAL

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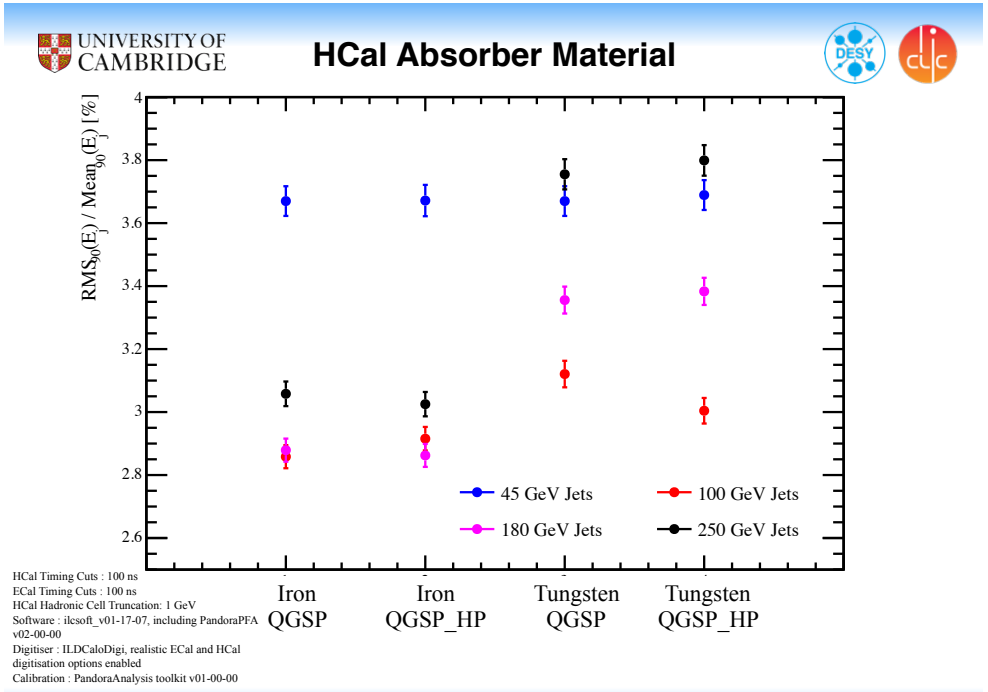
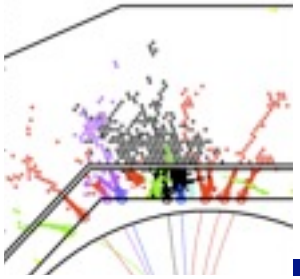
- CLICdp had considered W
  - to fit enough λ_I inside coil
  - performance gain at high E for same ΔR
- With new model back to Fe
  - more space due to smaller tracker
  - Performance superior for same number of $\lambda_I \sim 7.5$
    - W: 70 layers, ΔR = 1.2m
    - Fe: 60 layers, ΔR = 1.6m





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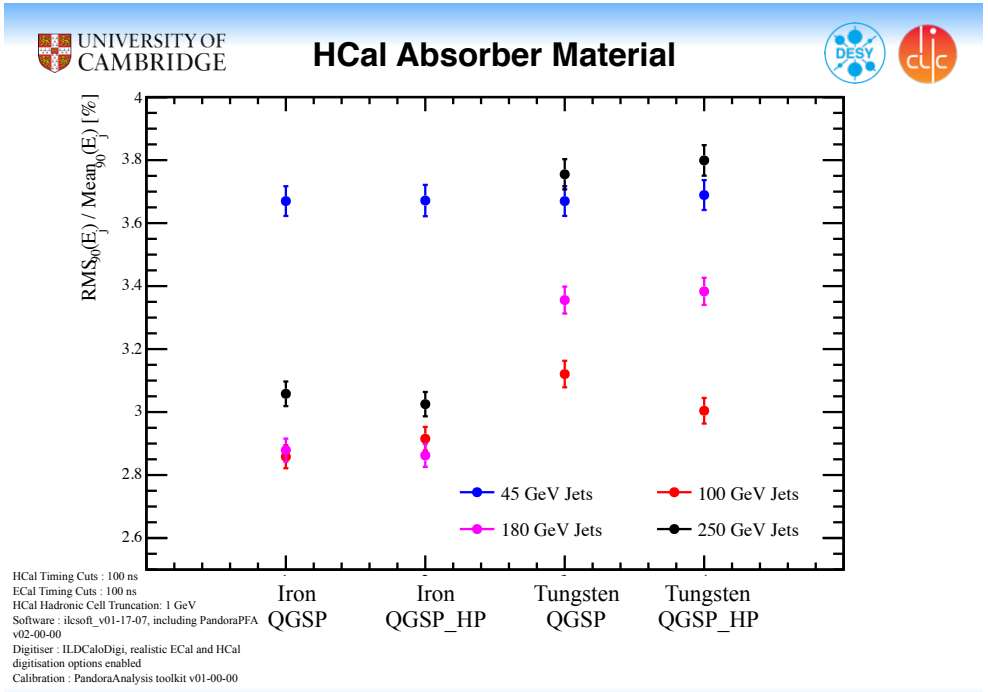
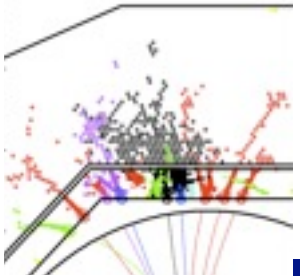
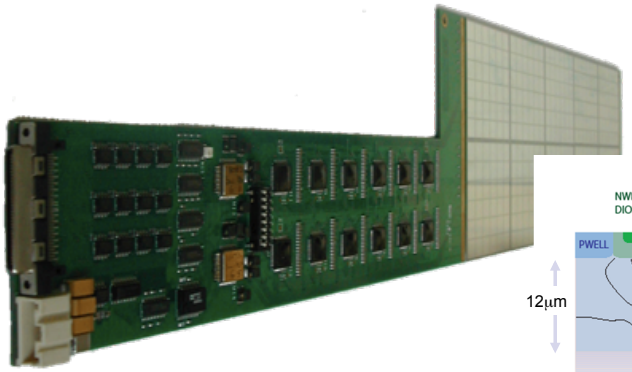
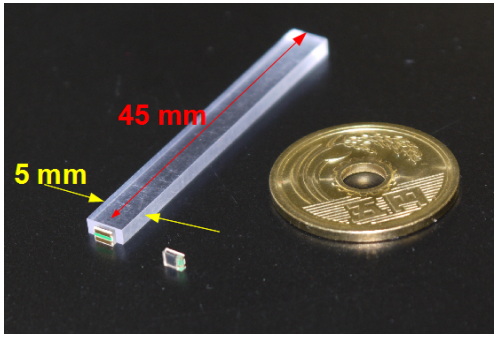


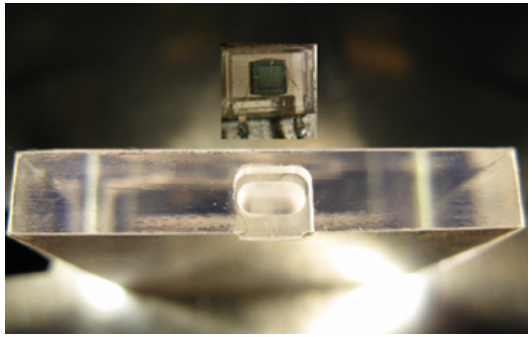


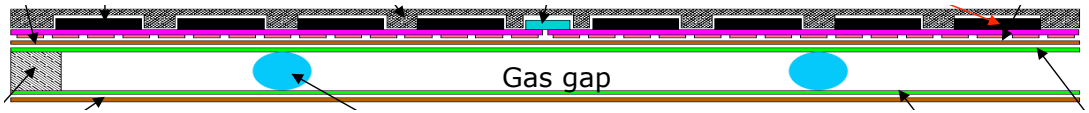
Particle flow technologies

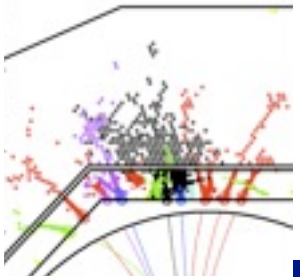
- Silicon (ECAL)
  - most compact solution, stable calibration
  - 0.5 - 1 cm^2 cell size
  - MAPS pixels also studied
- Scintillator SiPM (ECAL, HCAL)
  - robust and reliable, SiPMs..
  - ECAL strips: 0.5 - 1 cm eff.
  - HCAL tiles: 3x3 cm^2
- Gaseous technologies
  - fine segmentation: 1 cm^2
  - Glass RPCs: well known, safe
  - MPGDs: proportional, rate-capable
    - GEMs, Micromegas





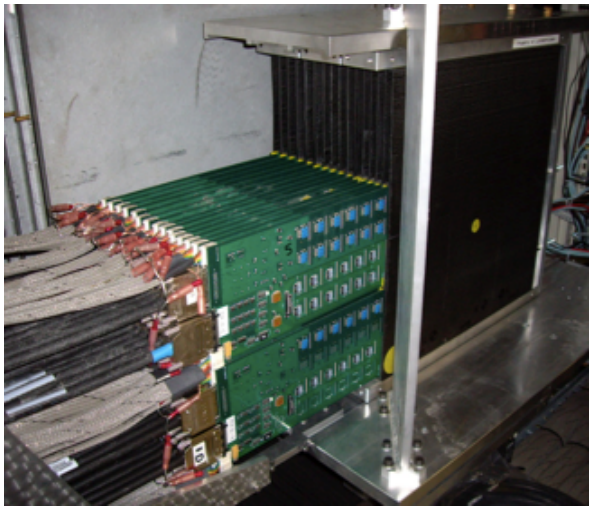




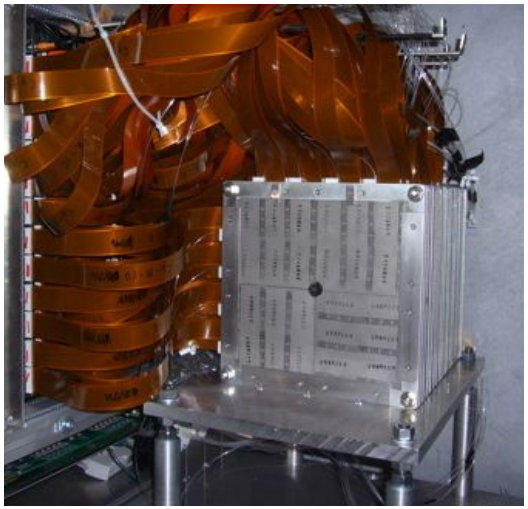


Test beam prototypes

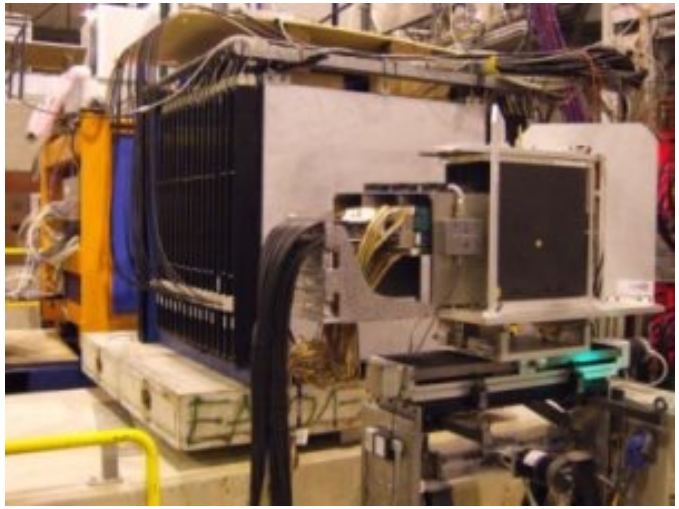
SiW ECAL



ScintW ECAL

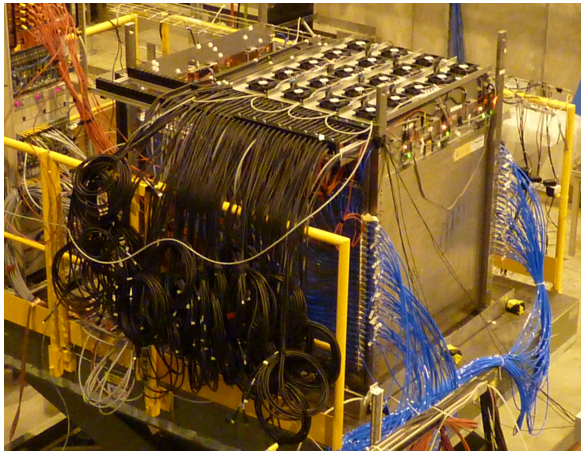


Scint AHCAL, Fe & W



RPC DHCAL, Fe & W

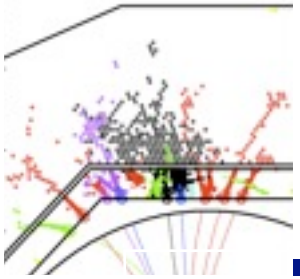
RPC SDHCAL, Fe



plus tests with small numbers of layers:

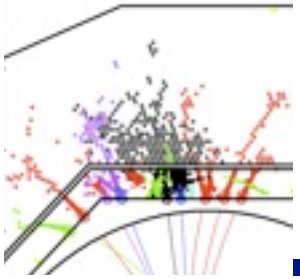
- ECAL, AHCAL with integrated electronics

- Micromegas and GEMs



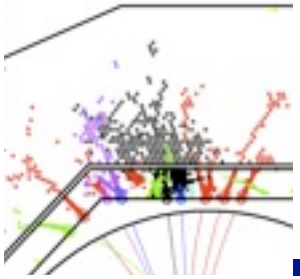
Choices

	ILD	SiD	CLICdp
SiW Ecal	(✔)	✔	✔
Sci W Ecal	(✔)		(✔)
Sci Fe Hcal	(✔)	✔	✔
Gas Fe Hcal	(✔)	(✔)	



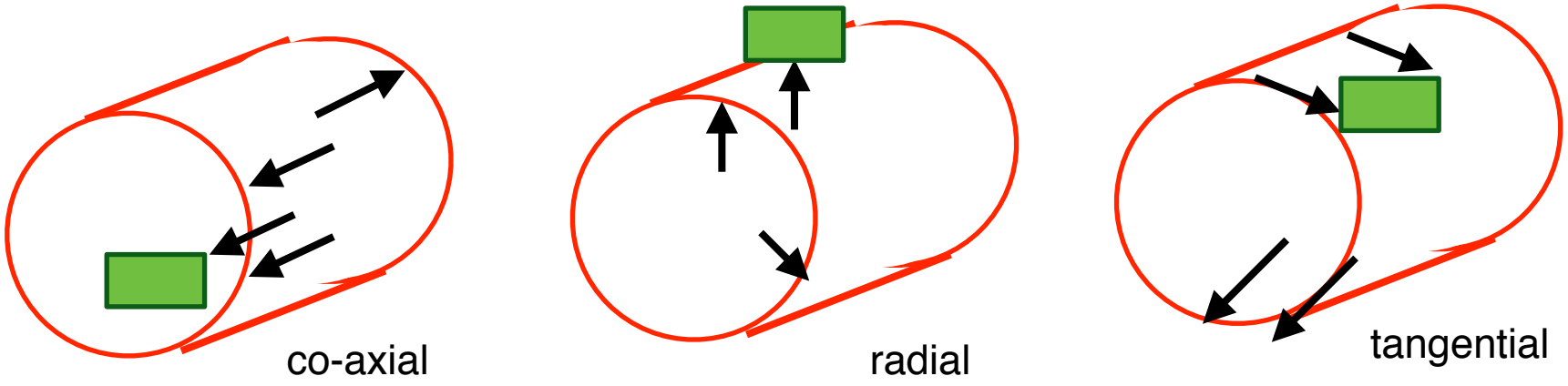
SiD HCAL baseline

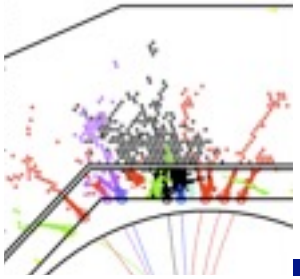
- SiD recently changed their HCAL baseline from Gas to scintillator
- Internal review including external expertise
  - J. Brau, M. Breidenbach, R.Rusack
- In favour of scintillator: progress in SiPM
- Concerns with respect to RPCs
  - calibration not simple, no reference signal
  - no redundancy for monitoring (equiv. to LED)
  - but stability required since response varies with gain
  - large cell-to-cell cross-talk, non-uniformities
  - non-linear response
  - ageing
  - fragility
  - gas flow uniformity over large area, gas recovery system
- Not final, of course



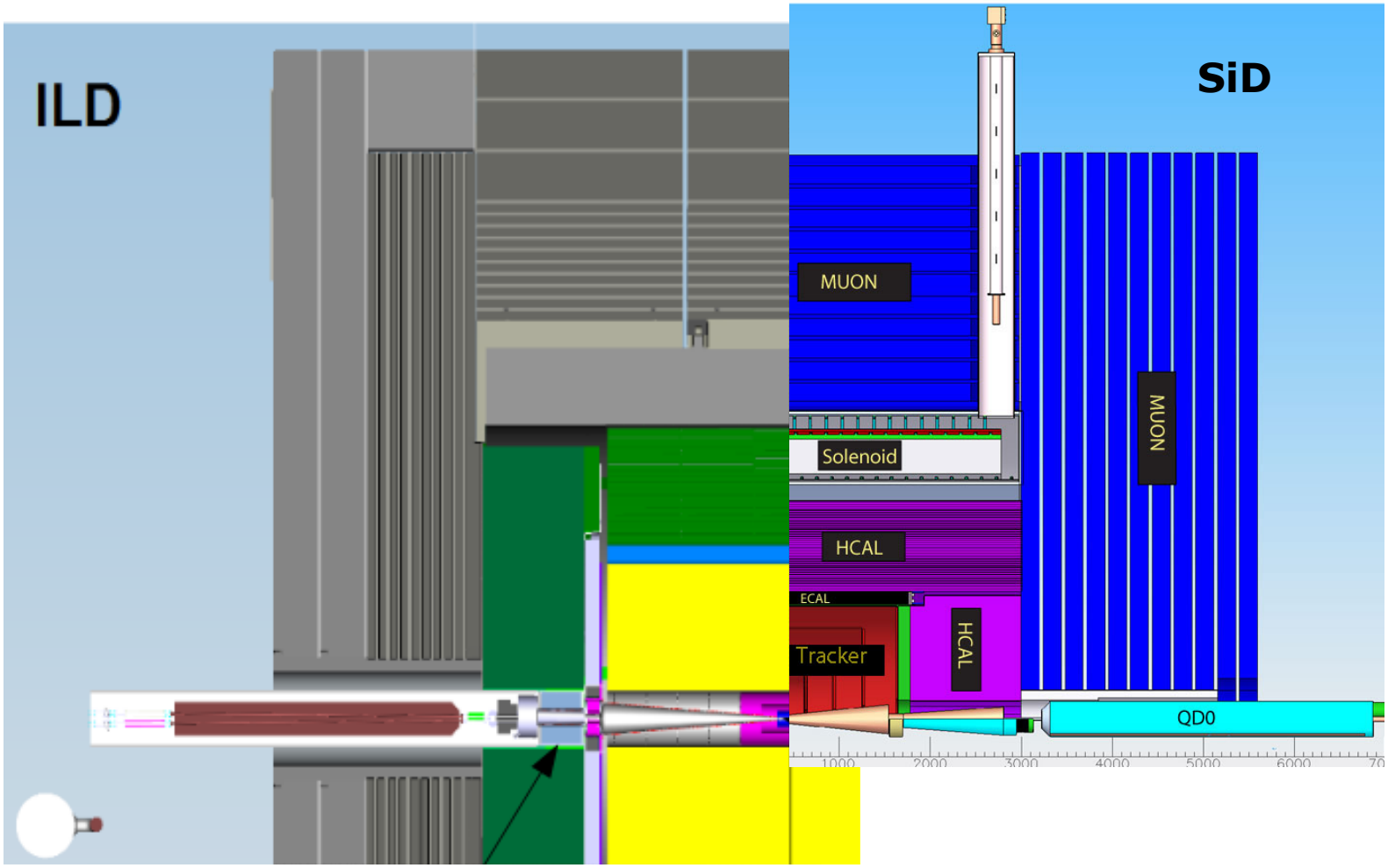
Geometries

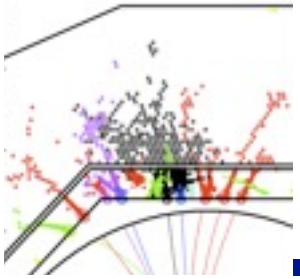
- Basic choices:
- Barrel endcap
- Routing of signals





Basic layouts





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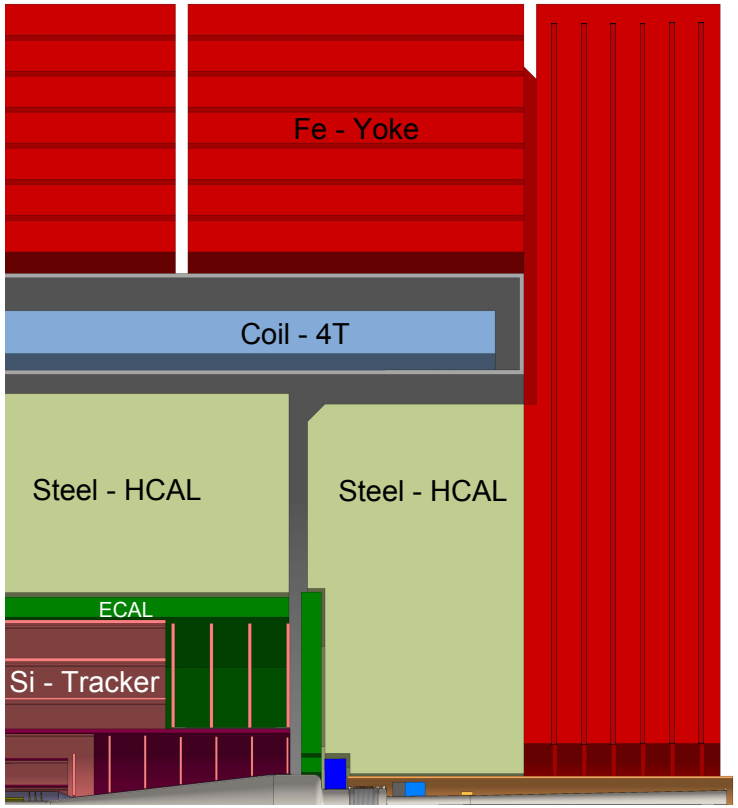


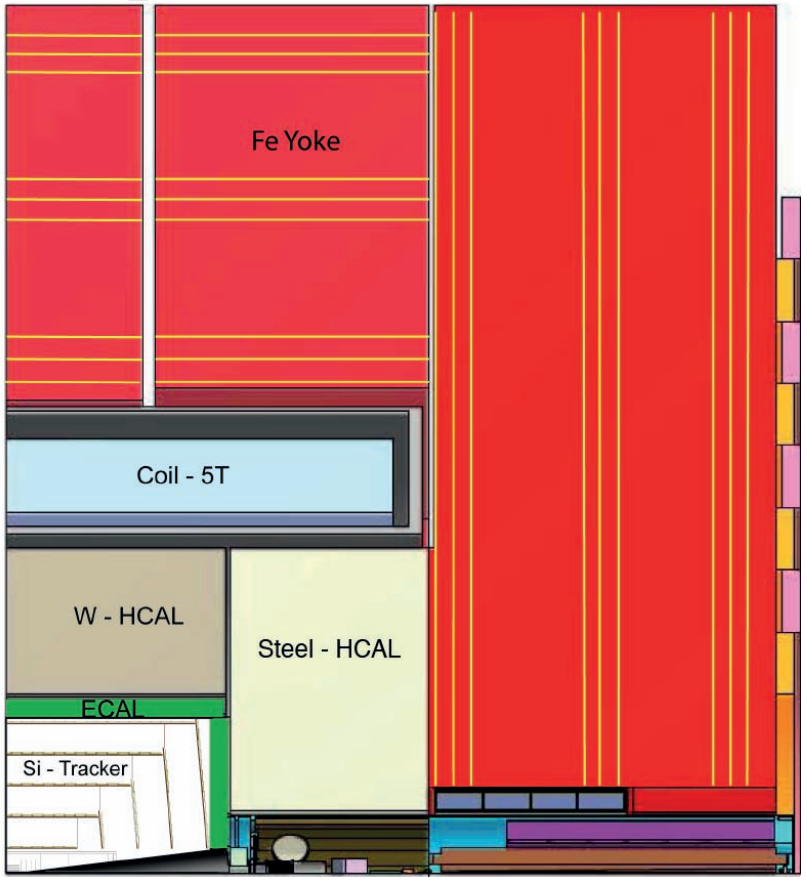
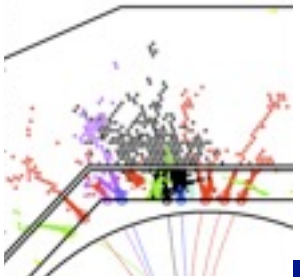
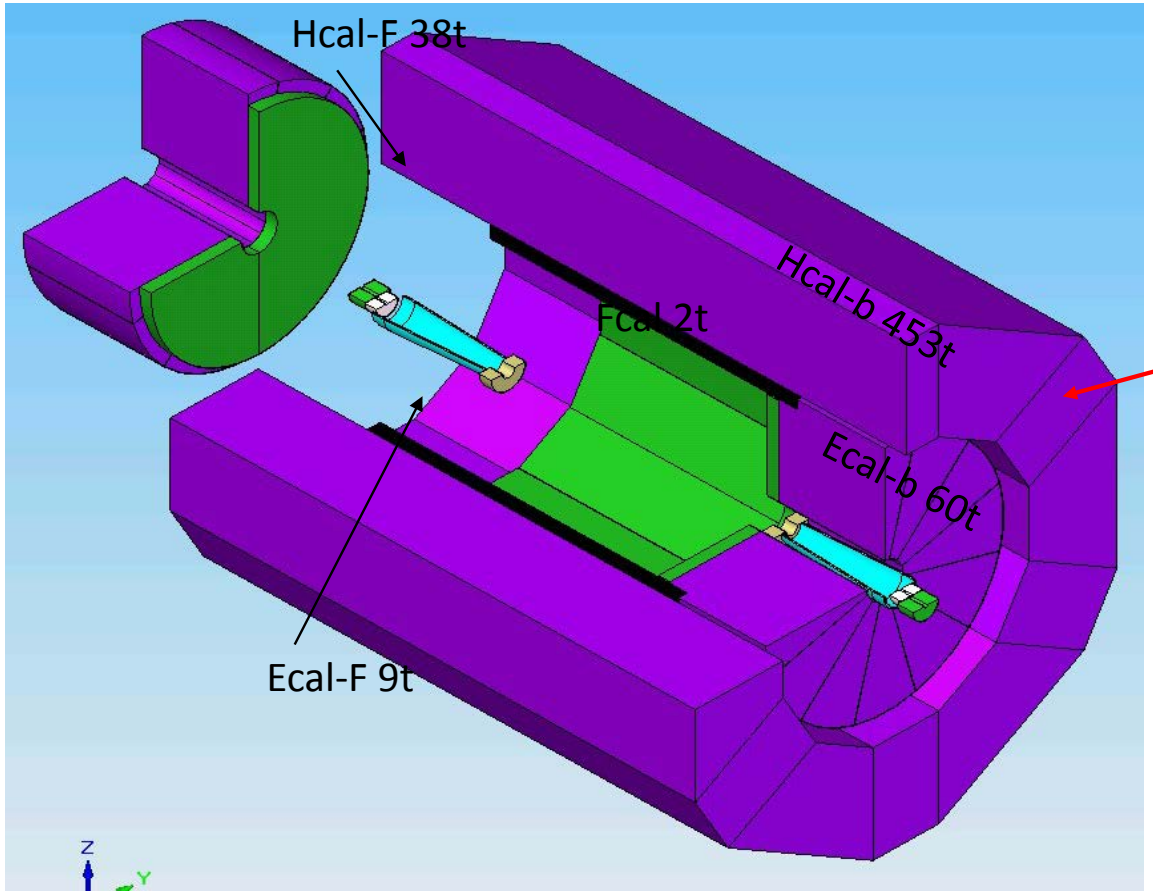


Figure 1: Longitudinal (YZ) cross section of the top right quadrant of CLICdet_2015 (left) and CLIC_SiD (right).

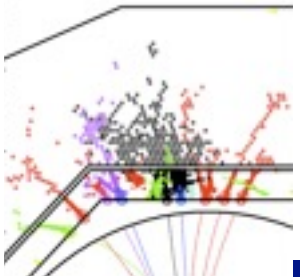


SiD HCAL update



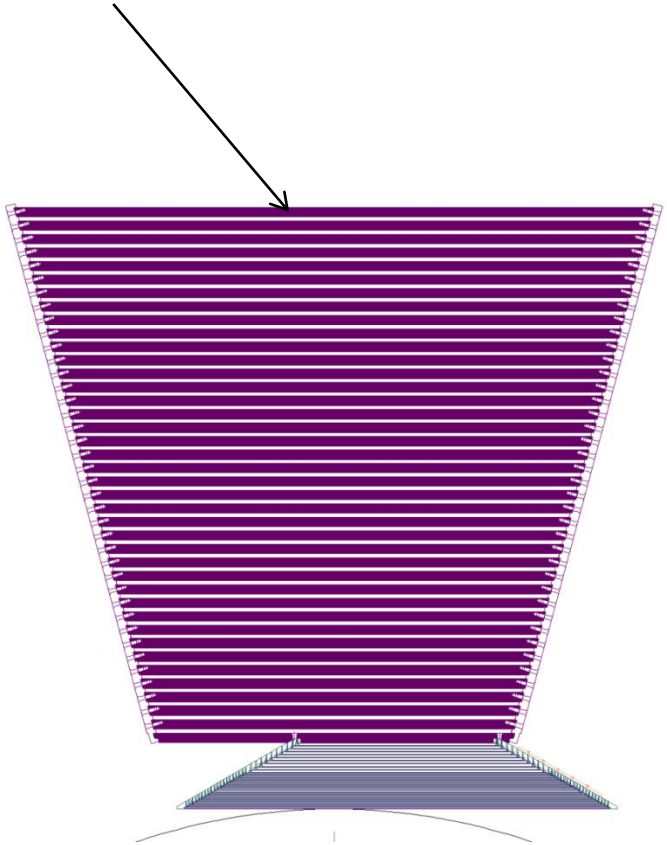
Note: "old" non-projective HCal geometry

- give up non-pointing phi sectors
- tapered iron provides better magnetic field containment

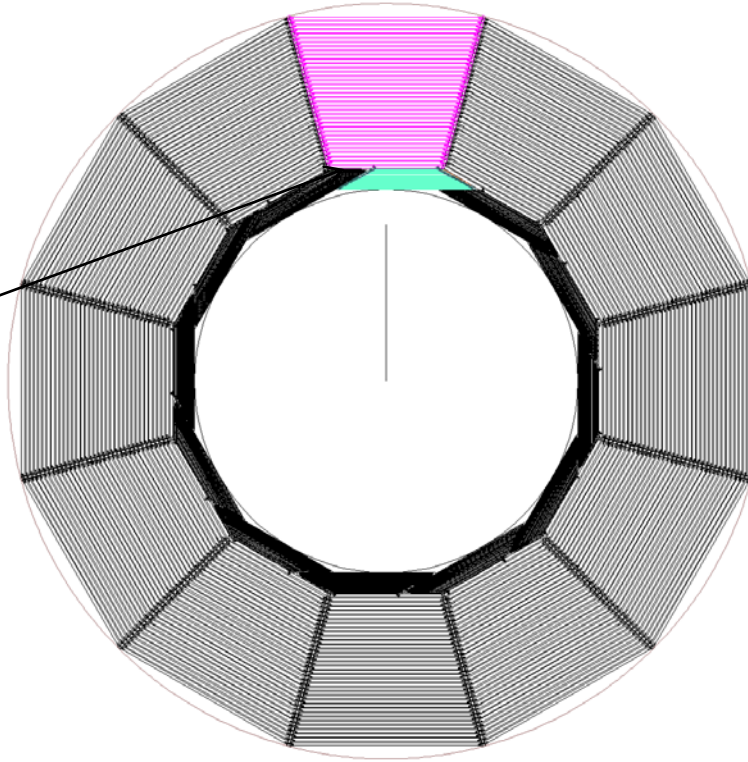


SiD HCAL update

HCAL module supports ECAL module



Note module overlap: No gaps; service cables at ends.



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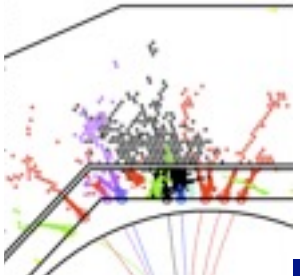
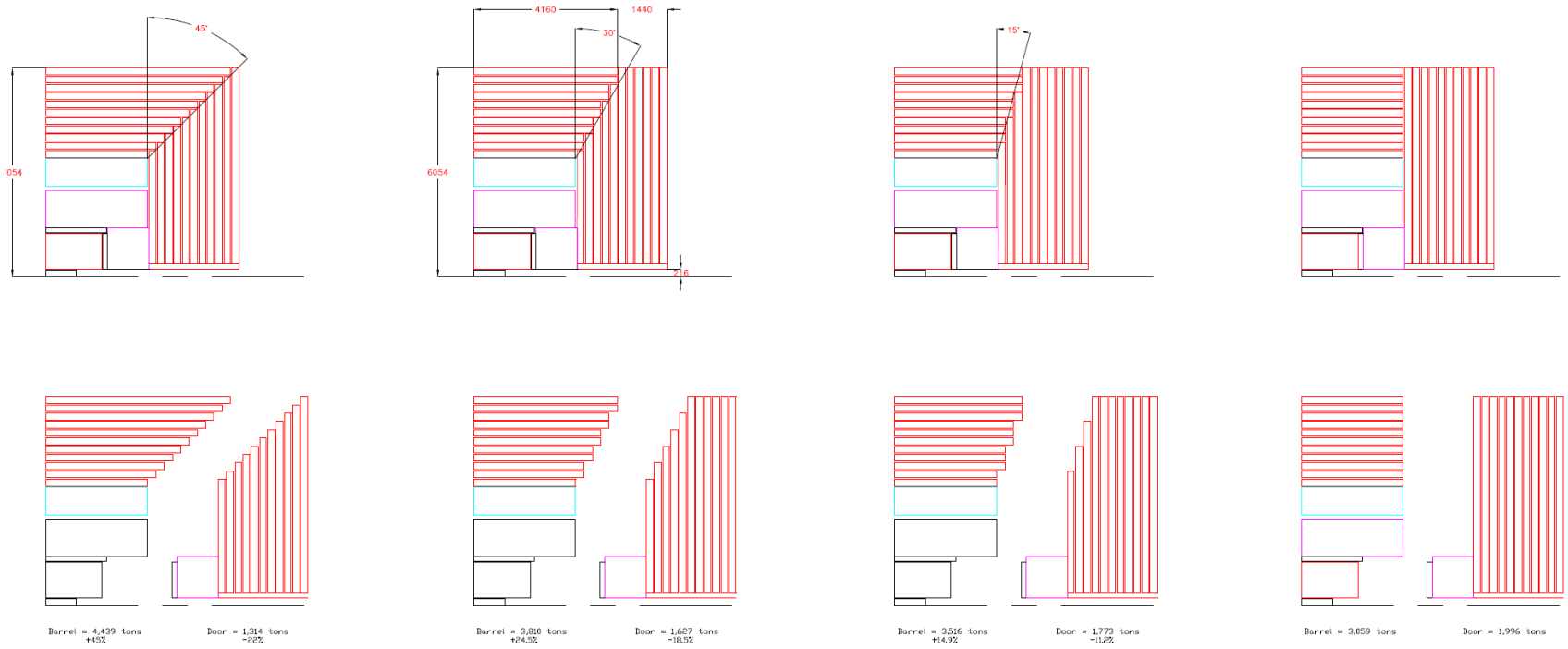


SiD HCAL update

Barrel-Door partitions



45 deg | 30 deg | 15 deg | 0 deg Baseline

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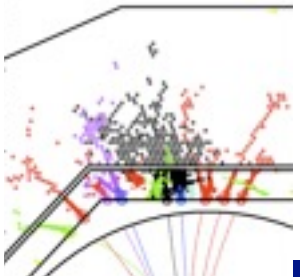

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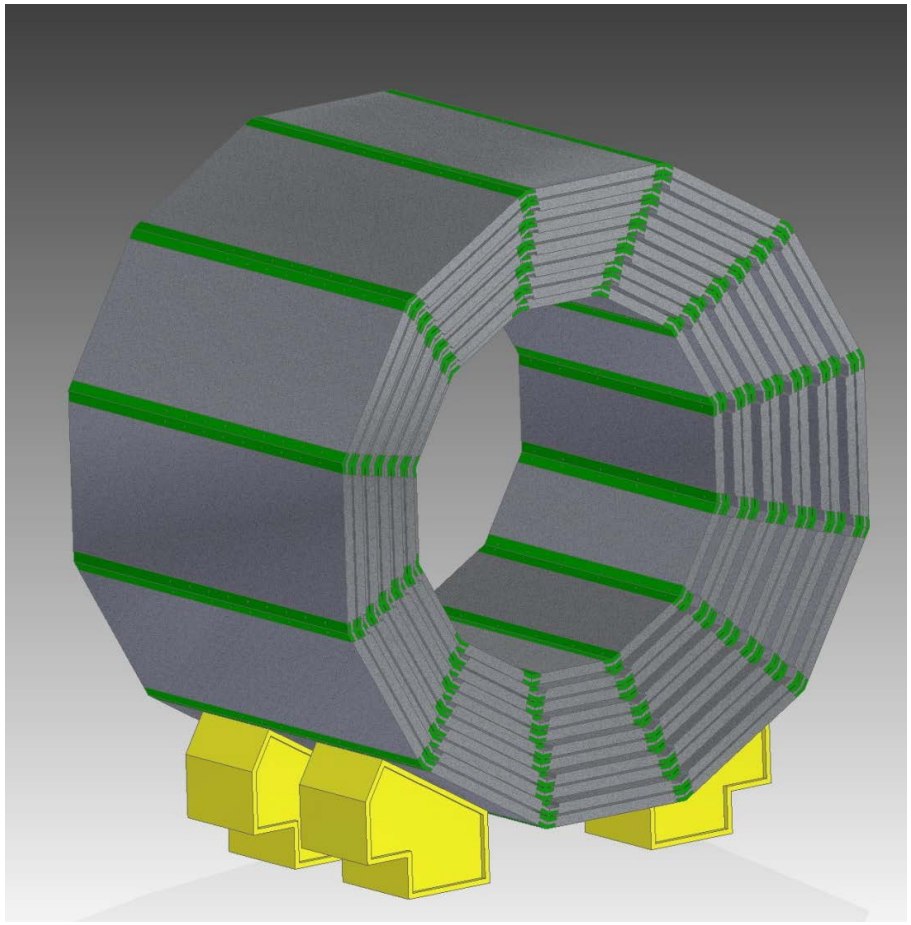

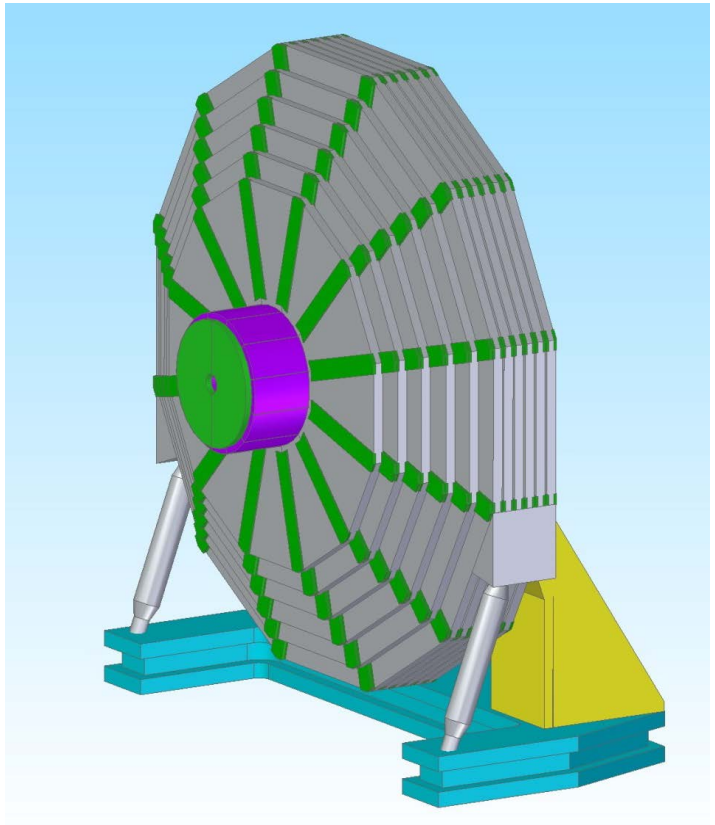

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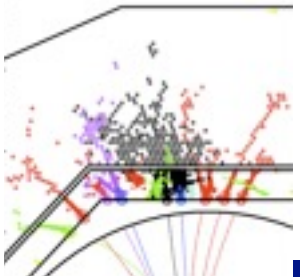
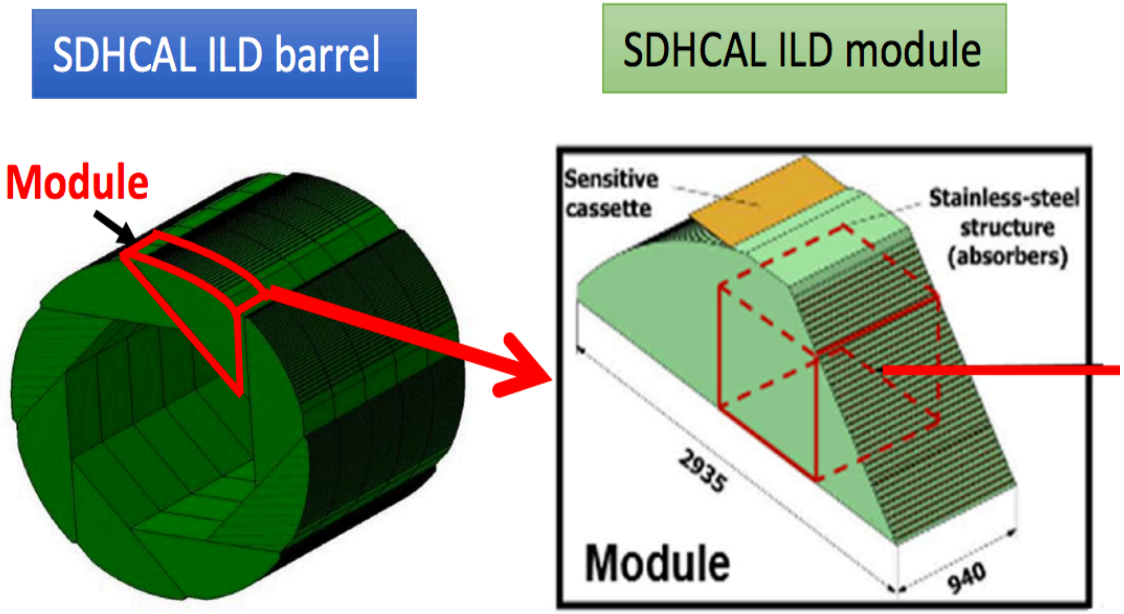
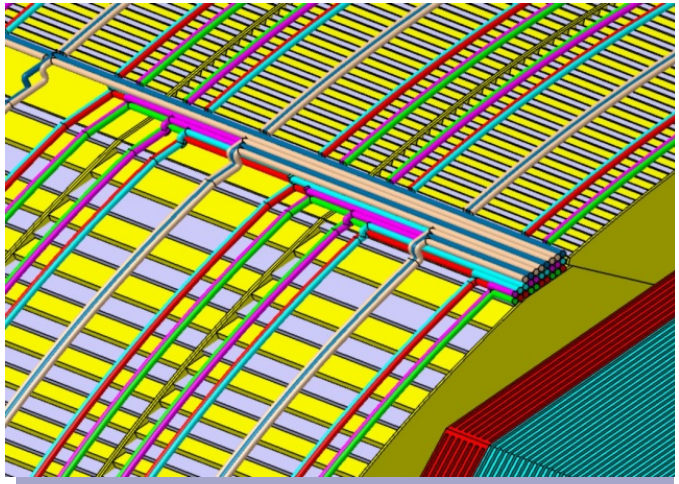
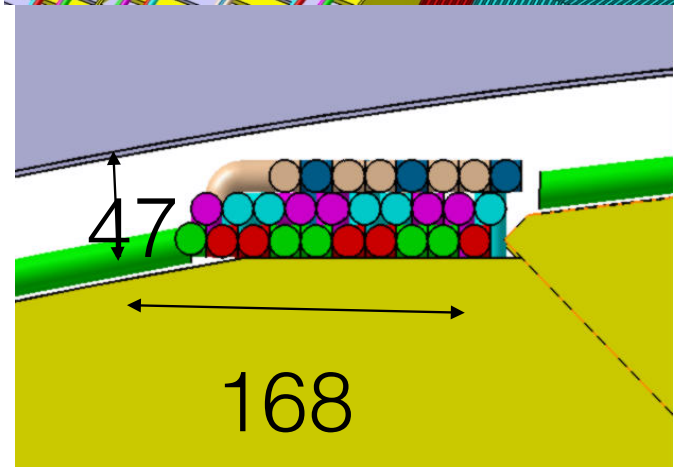


ILD HCAL

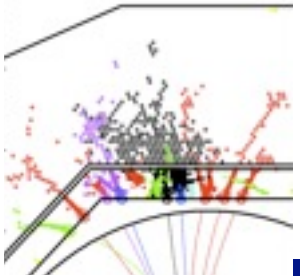
- TESLA: coaxial, interfaces and services between barrel and endcap
- Videau: tangential, interfaces and services between HCAL and coil





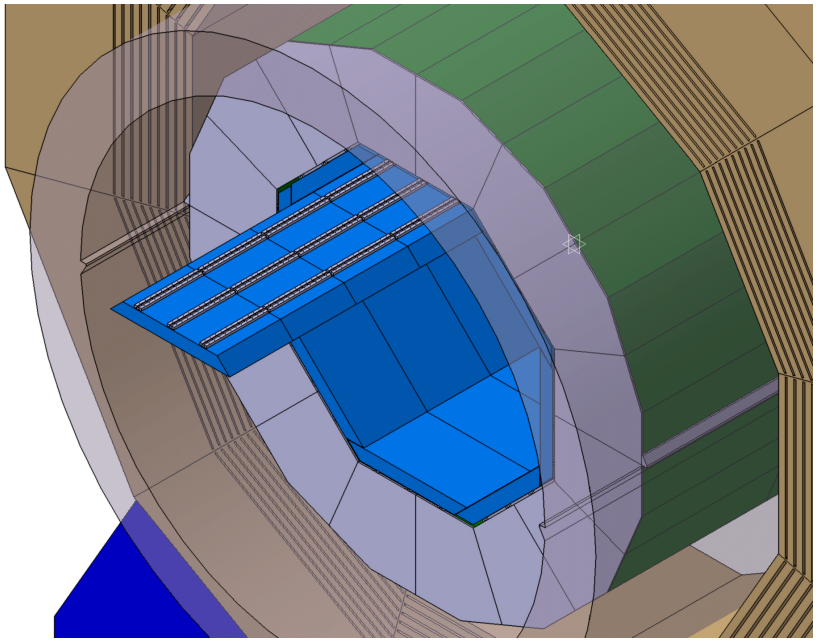


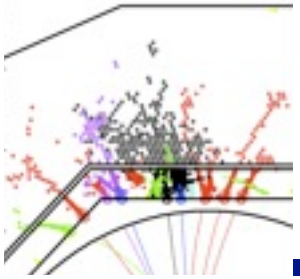
This geometry would be good for the HCAL ring.



ILD ECAL geometry

- tangential
- read-out interfaces and services between ECAL and HCAL





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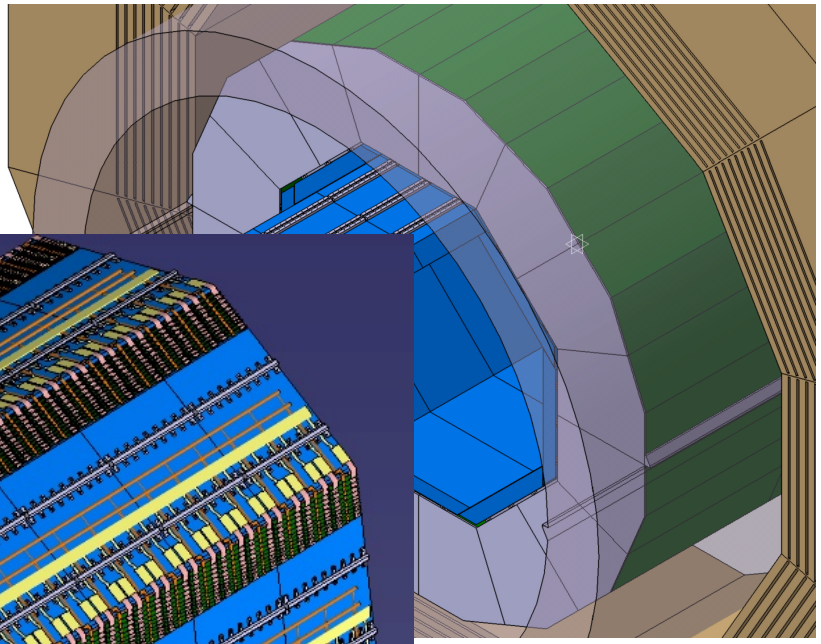

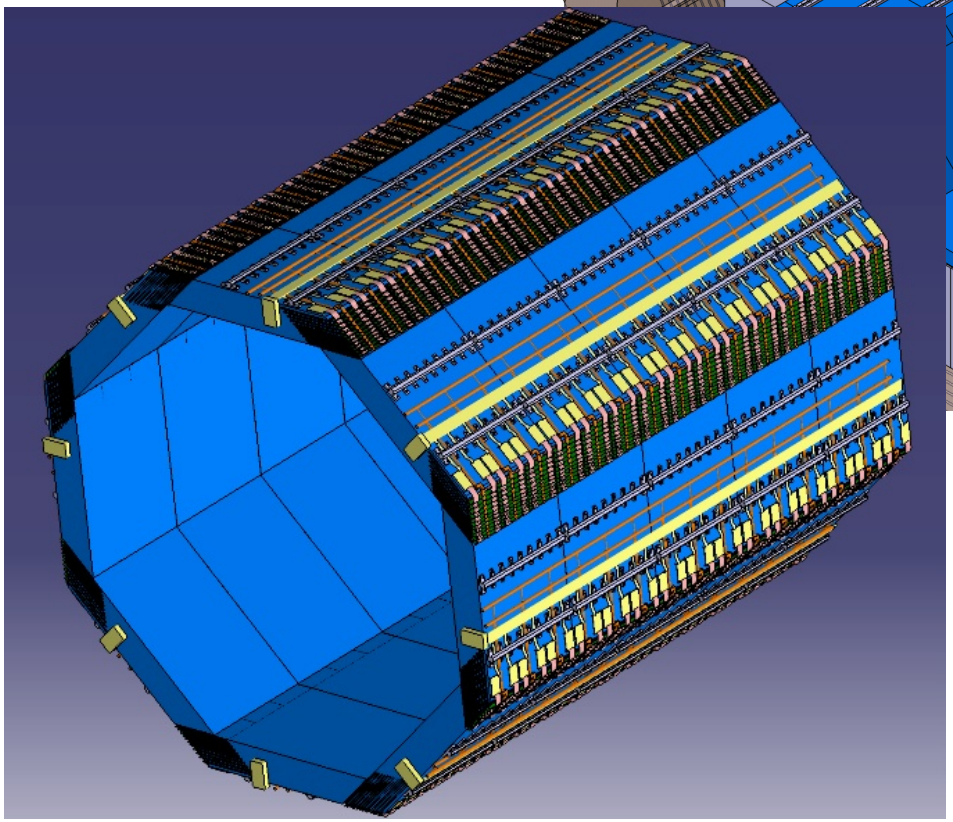

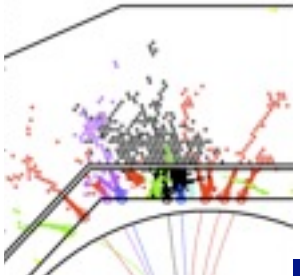

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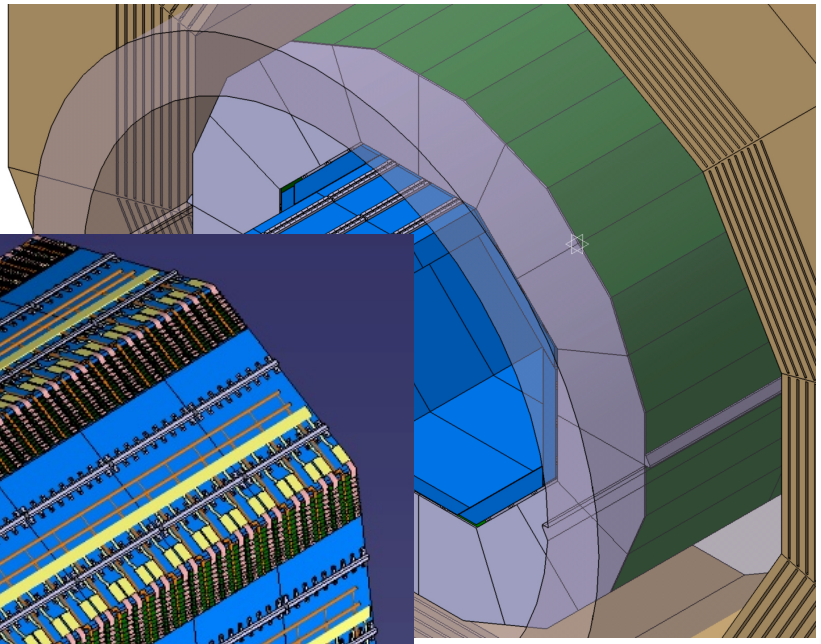

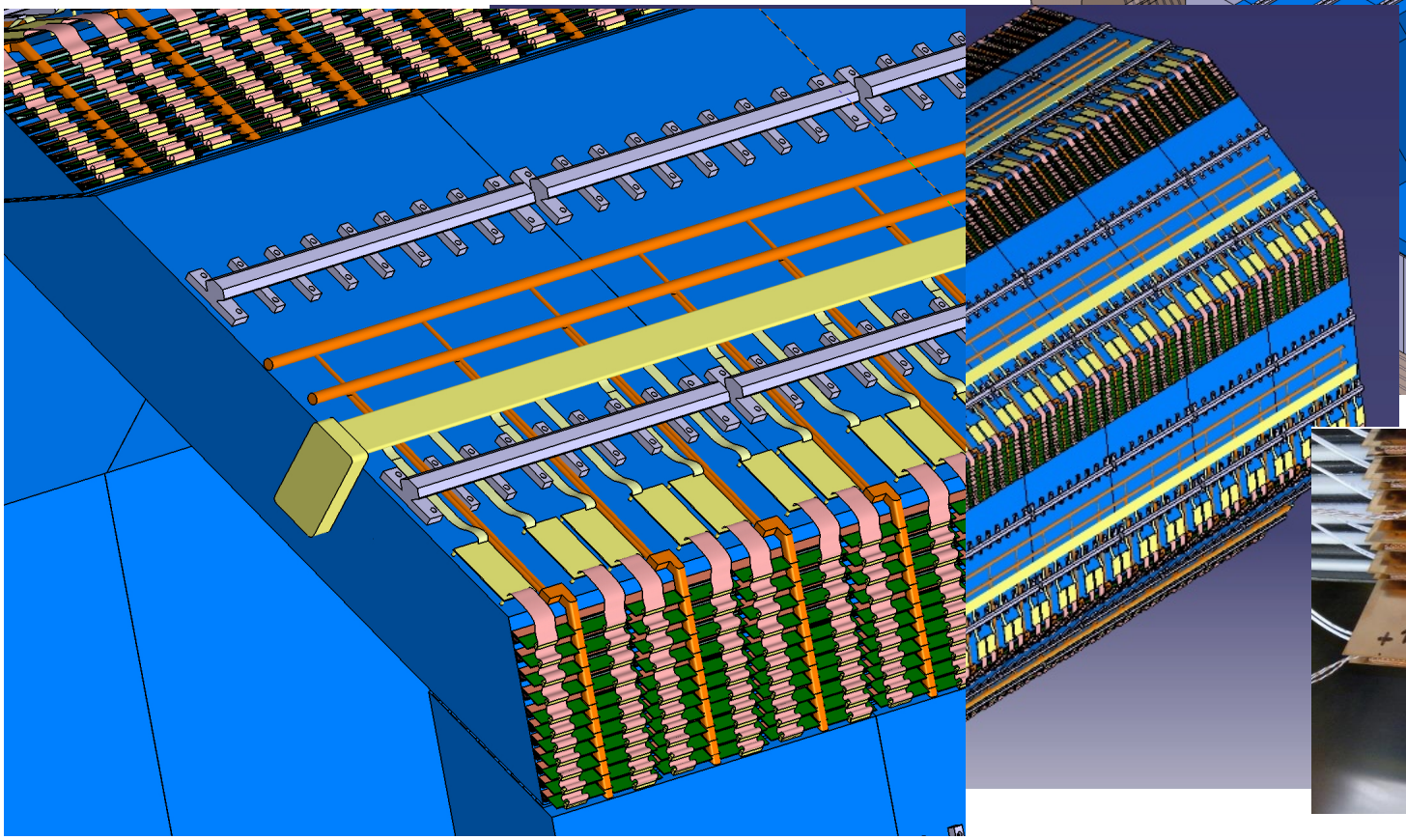

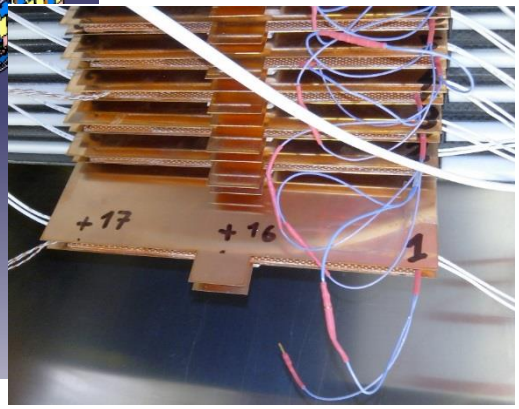

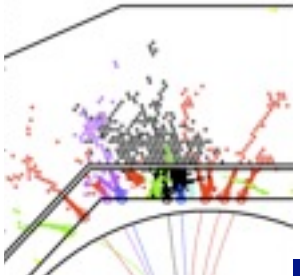

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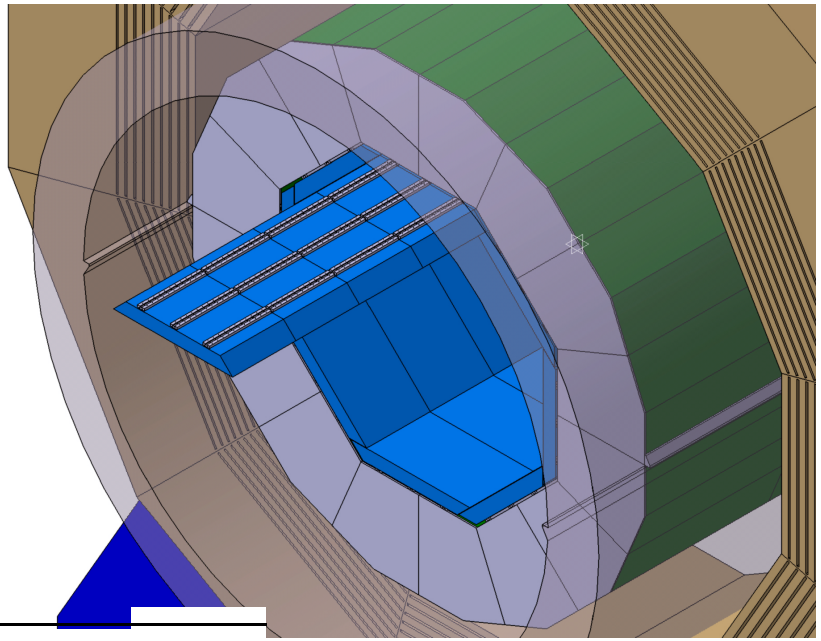
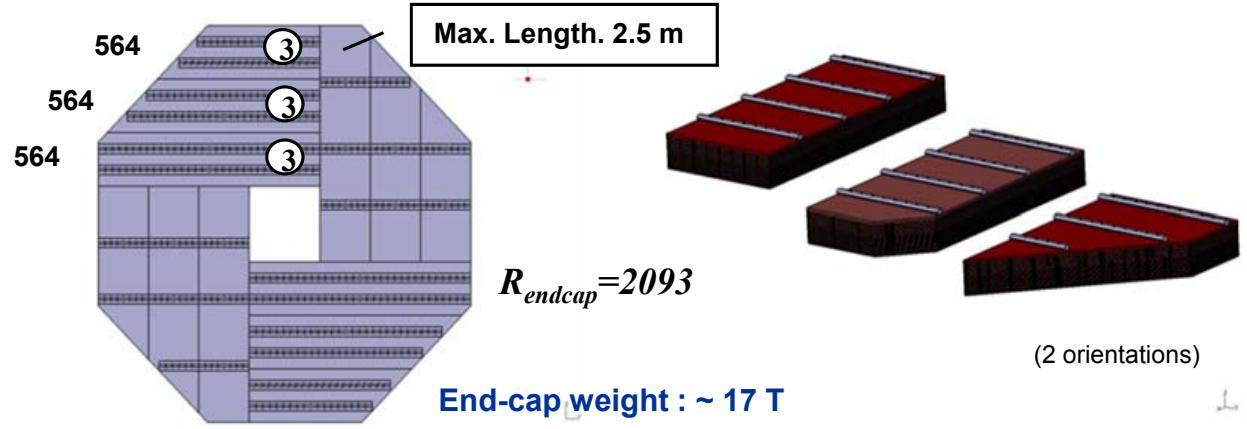
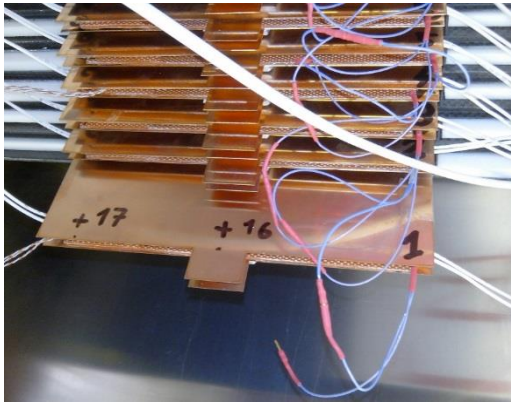
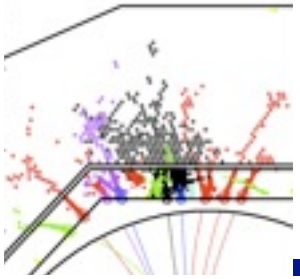


End-Caps: 4 x 3 modules each

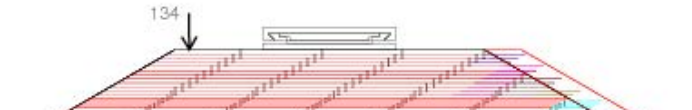


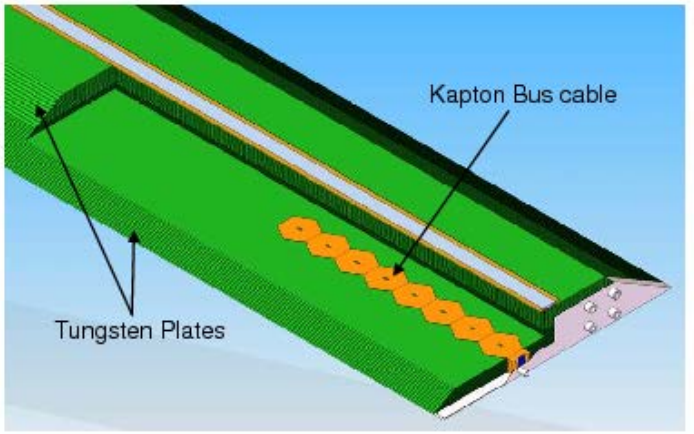


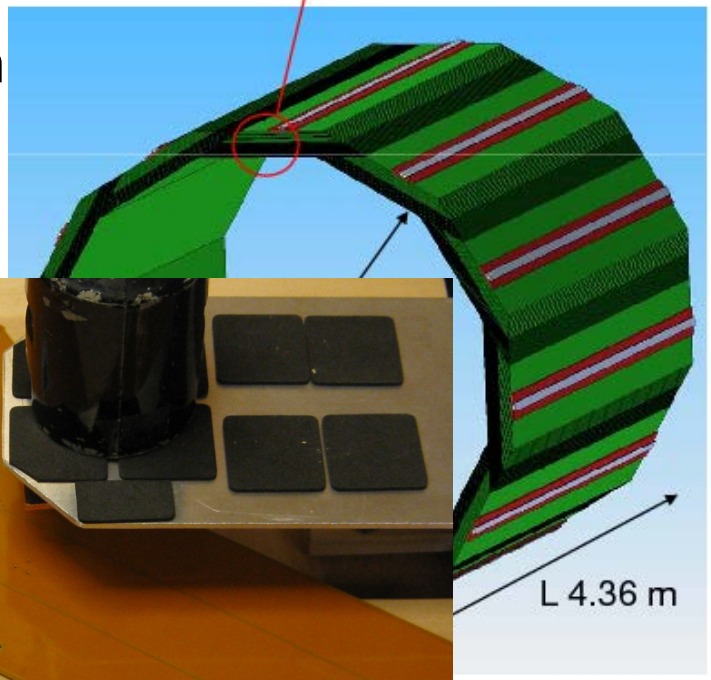


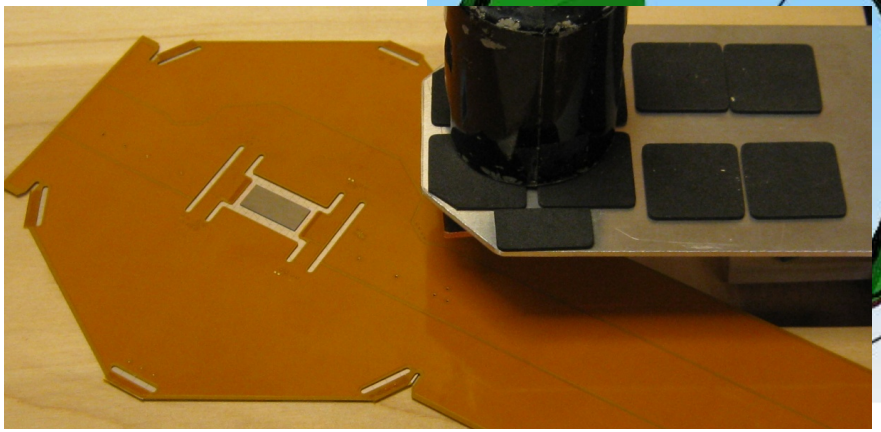
SiD ECAL

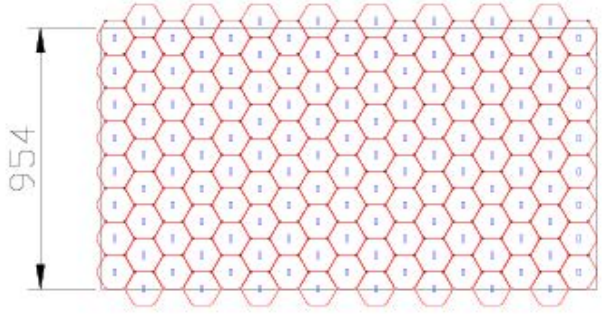
- co-axial
- interfaces between barrel and endcap
- 1mm gap
- R_M=1.3mm



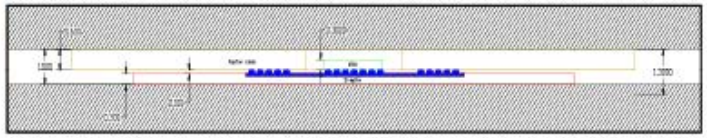




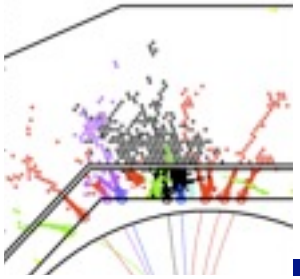




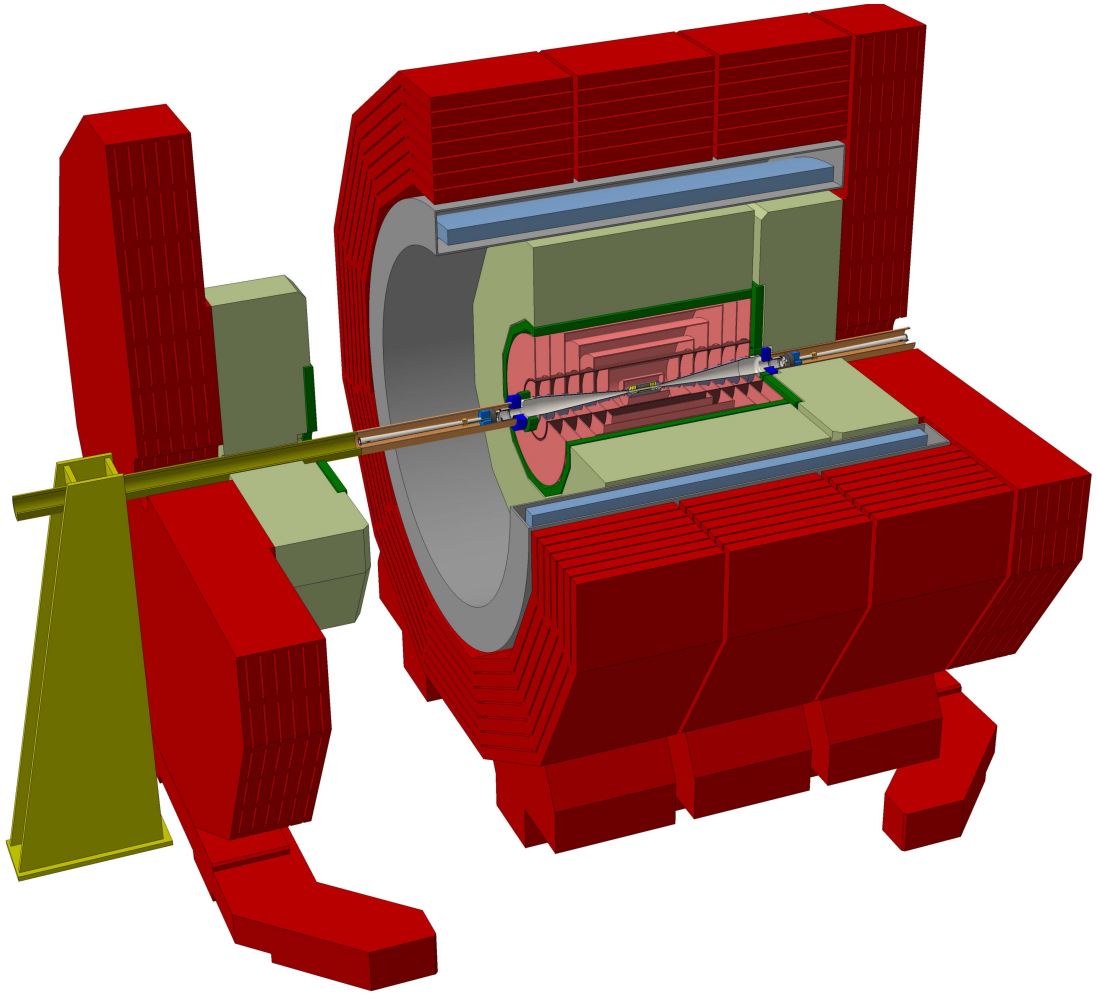
Hexagon sensors arrangement



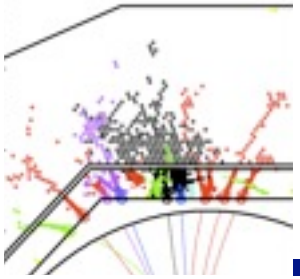
detector module between tungsten plates



CLICdp

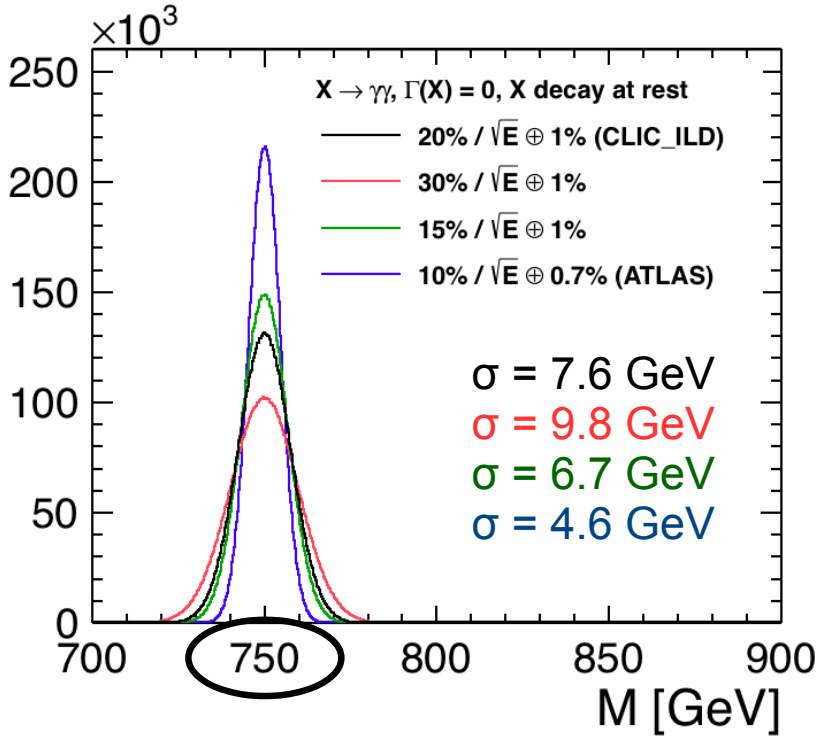


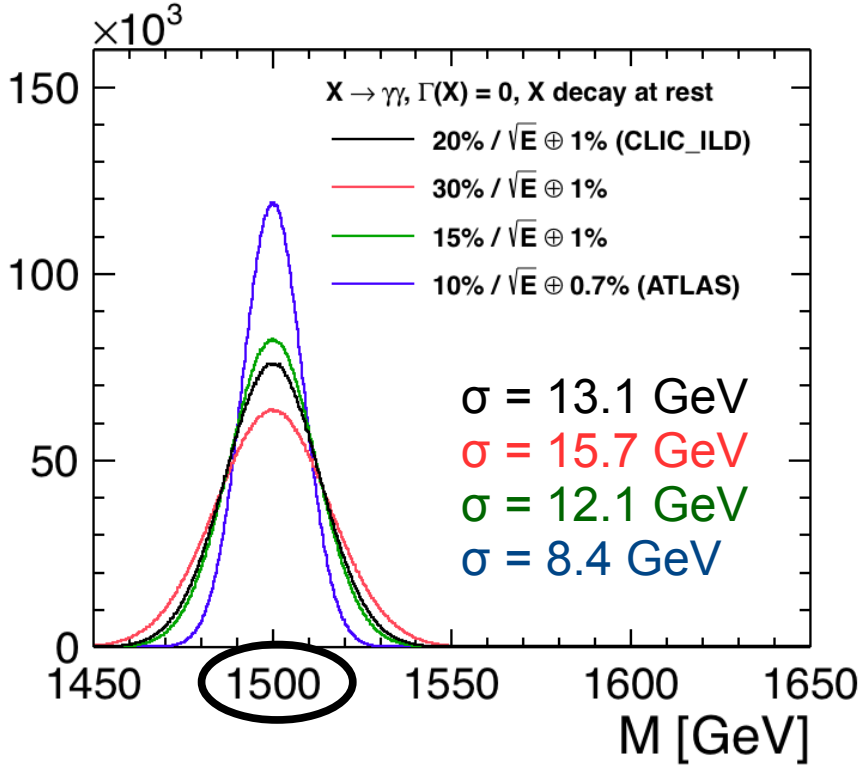
- no decision on calorimeter signal routing taken yet

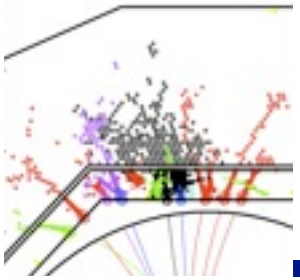


ECAL optimisation

- (HCAL cell sizes, see back-up slides)
- X750 real or not, reminder that X→γγ is a discovery channel
- Stochastic term does matter also for heavy resonances

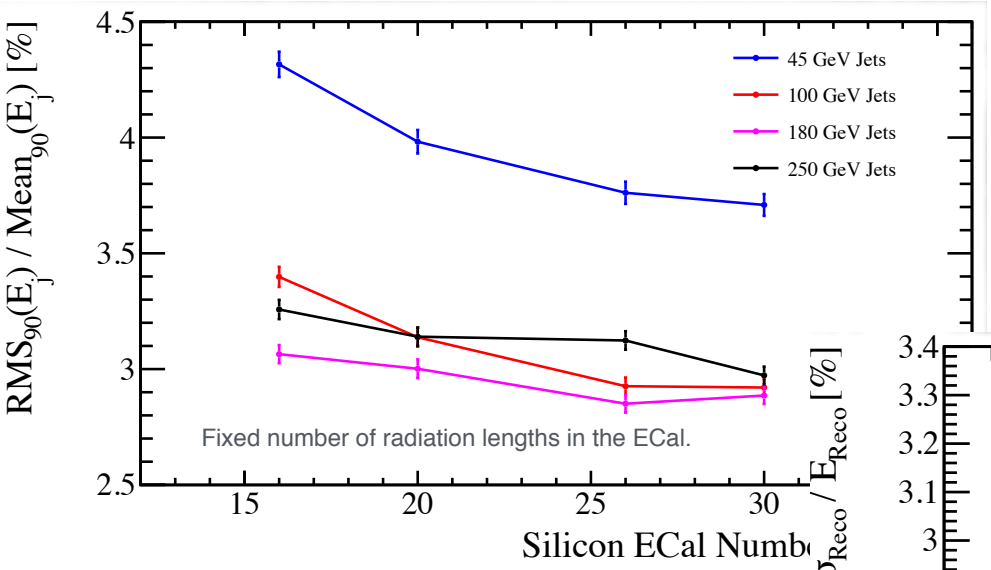


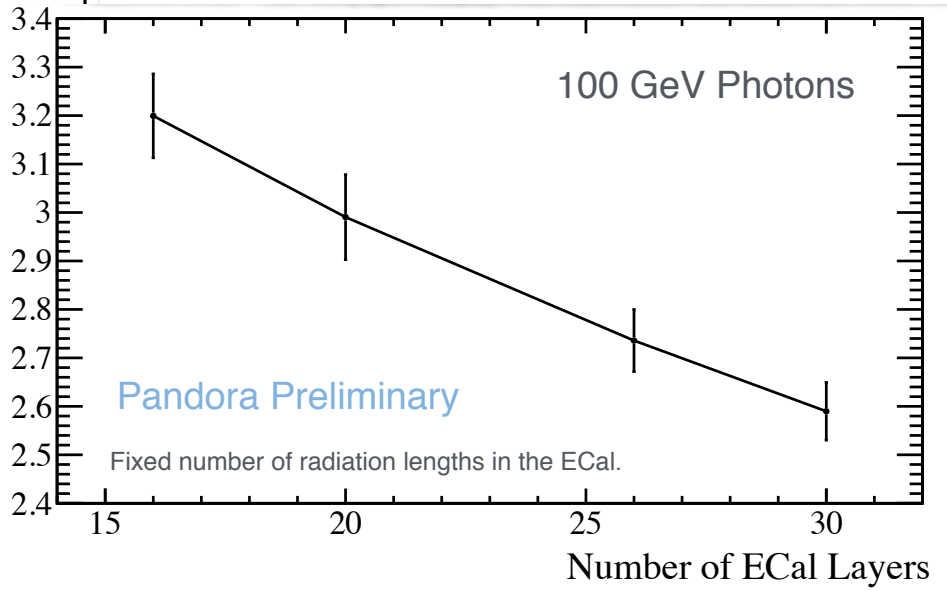


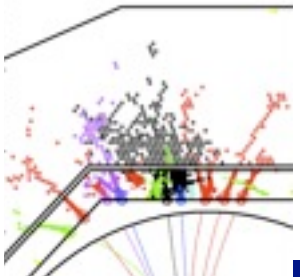


ECAL longit. segmentation

- Jets: sensitive mostly for low jet energies
- Photons: more direct impact

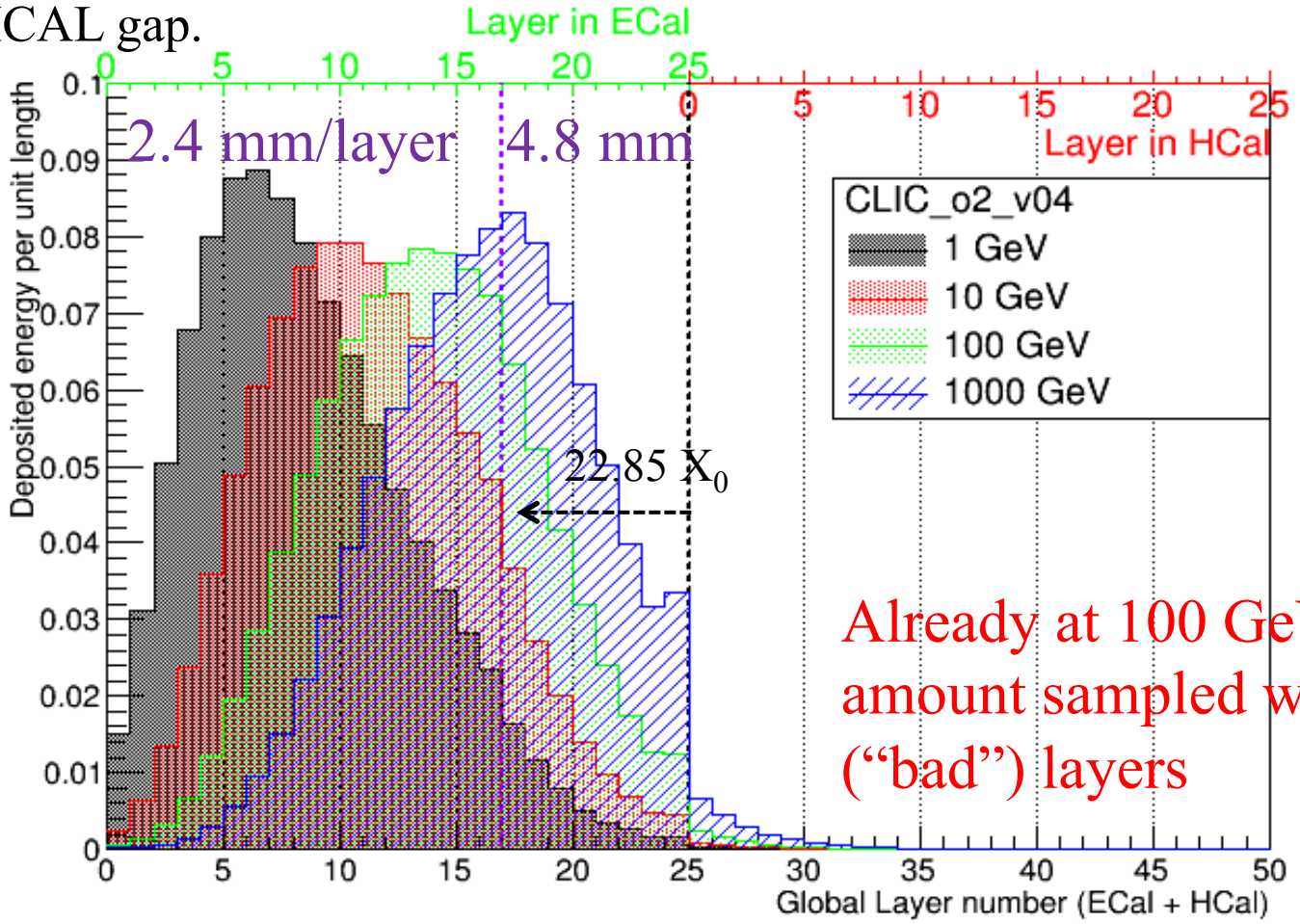




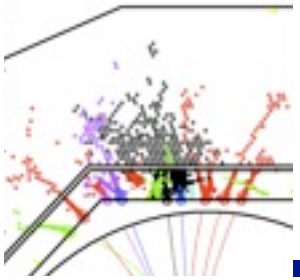


Profiles and resolution

ECAL-HCAL gap.



Already at 100 GeV sizable amount sampled with the larger ("bad") layers



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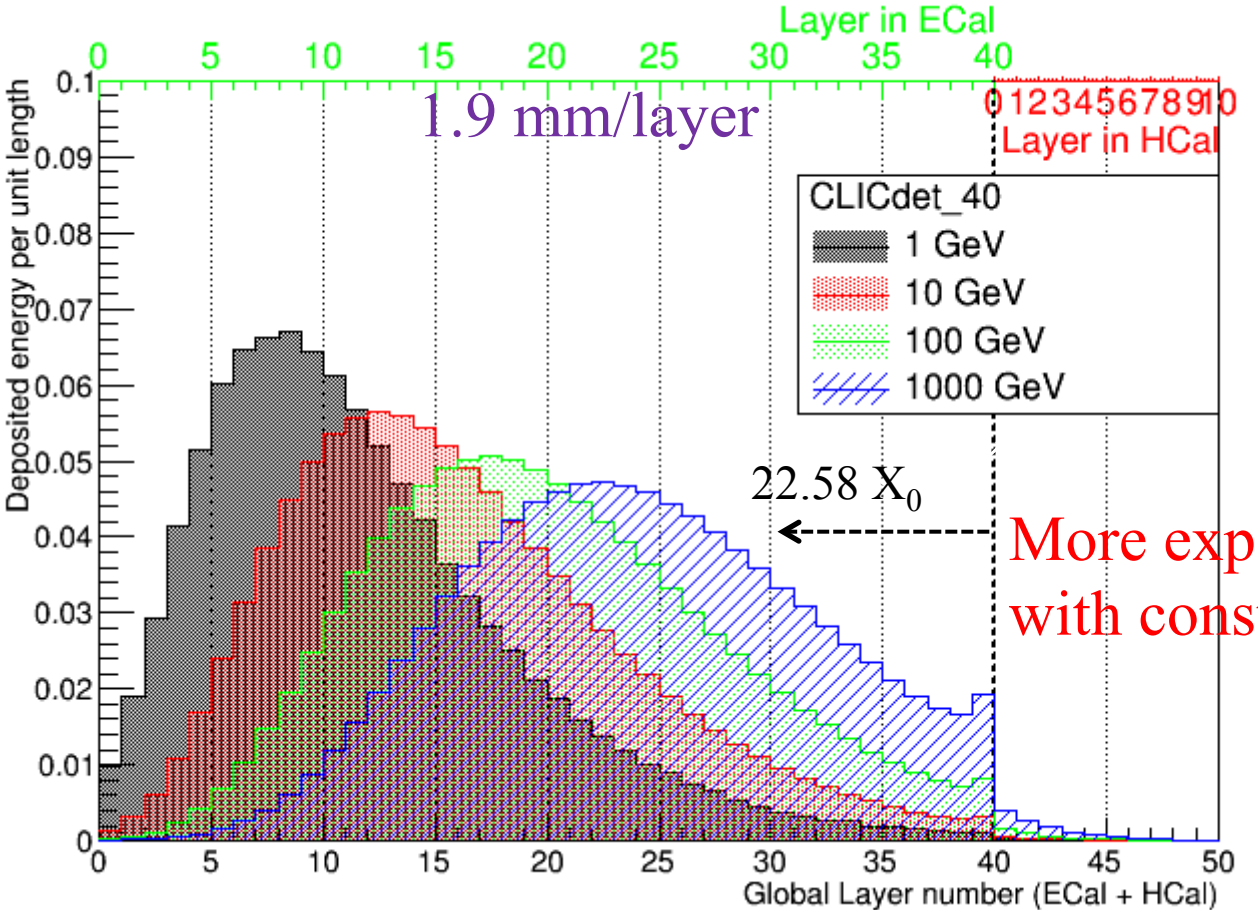
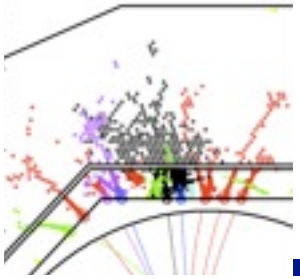
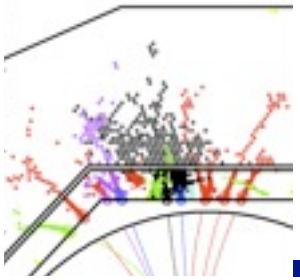


More expensive option with constant sampling

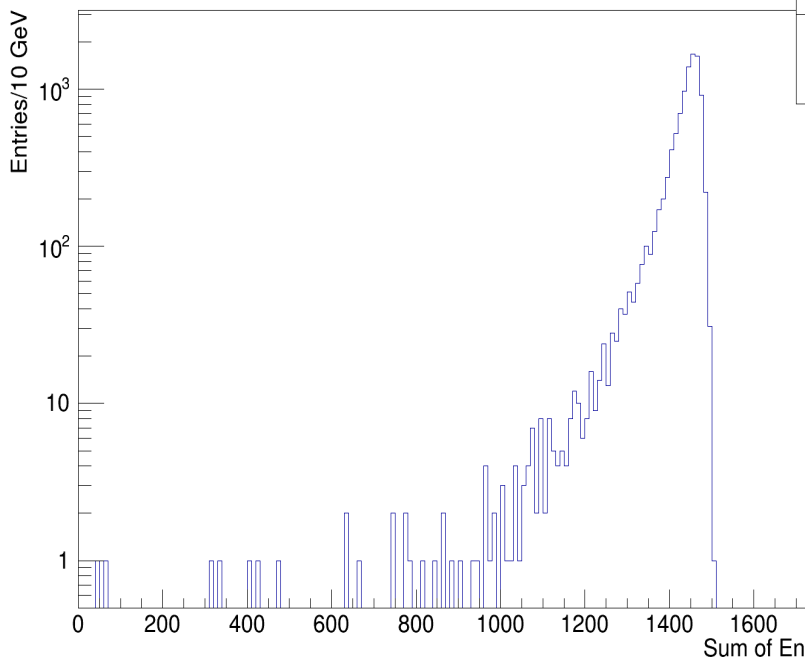


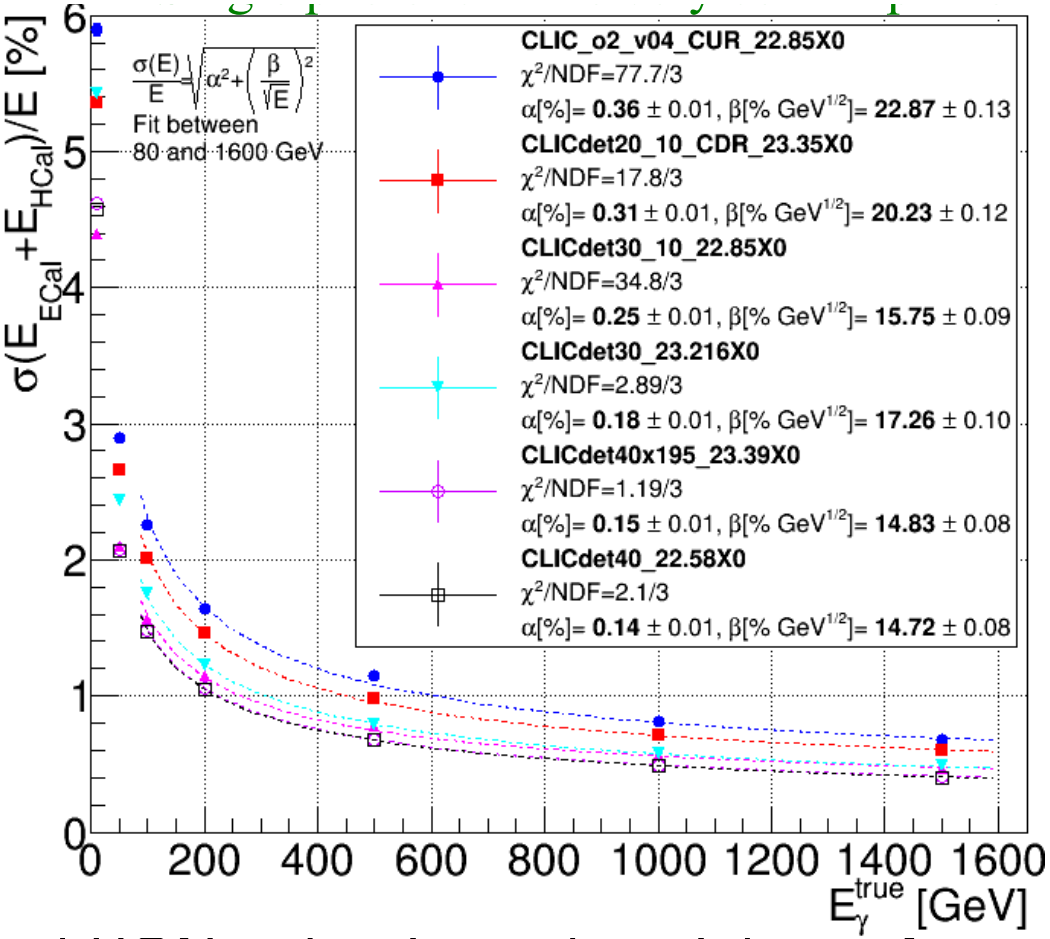
Profiles and resolution

Better performance with larger segmentation

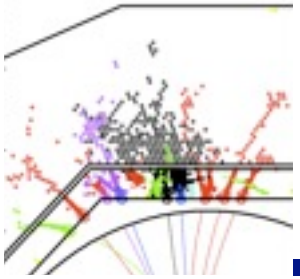


ECAL leakage





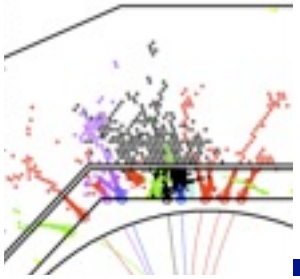
- ECAL HCAL combined
- Material between ECAL and HCAL: stay impact on jets **and** photons



Summary

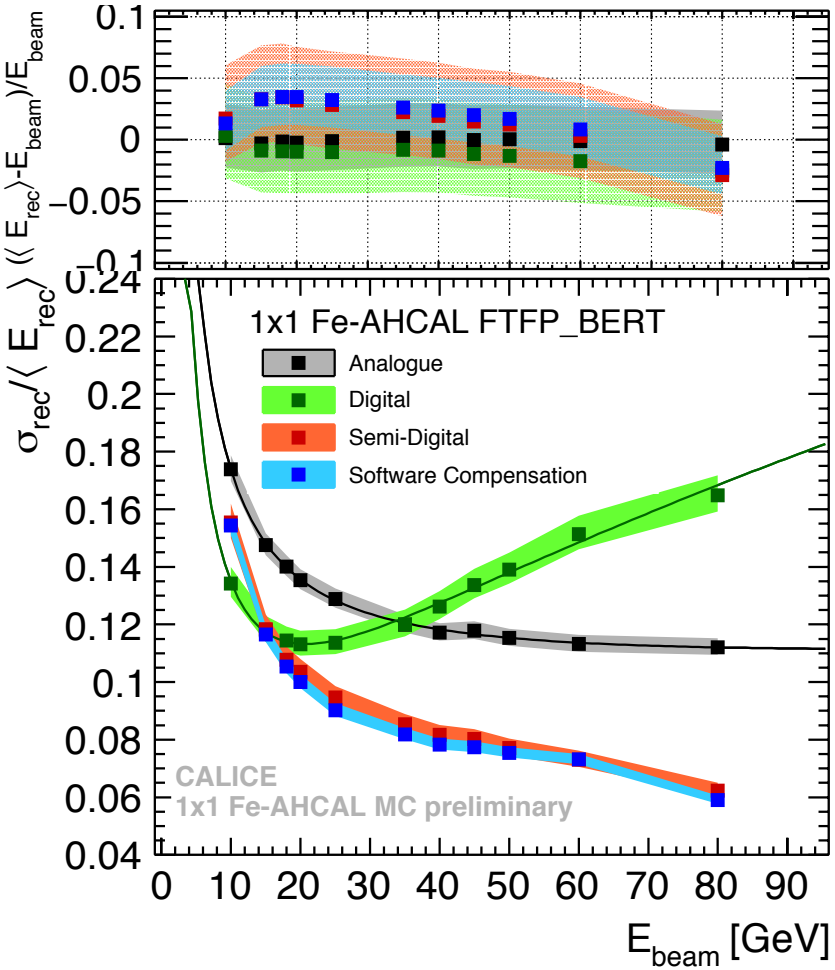
- Consensus on absorber materials
- Technologies: some signs of slow convergence
- Basic calorimeter geometries still under discussion (everywhere)
- Photon energies back in focus
  - ECAL segmentation, ECAL HCAL combination

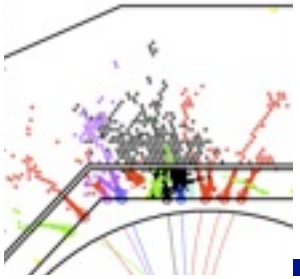
Back-up slides



Simulate smaller granularities

- Simulate with same degree of realism as in AHCAL test beam
  - except noise (not an issue with present SiMs)
  - and adjust threshold in order to obtain similar linearity
- Apply digital and (re-optimised) semi-digital reconstruction
- For 1x1cm^2 case, semi-digital (2-bit) information is sufficient
- With full analogue information, 1x1 not better than 3x3





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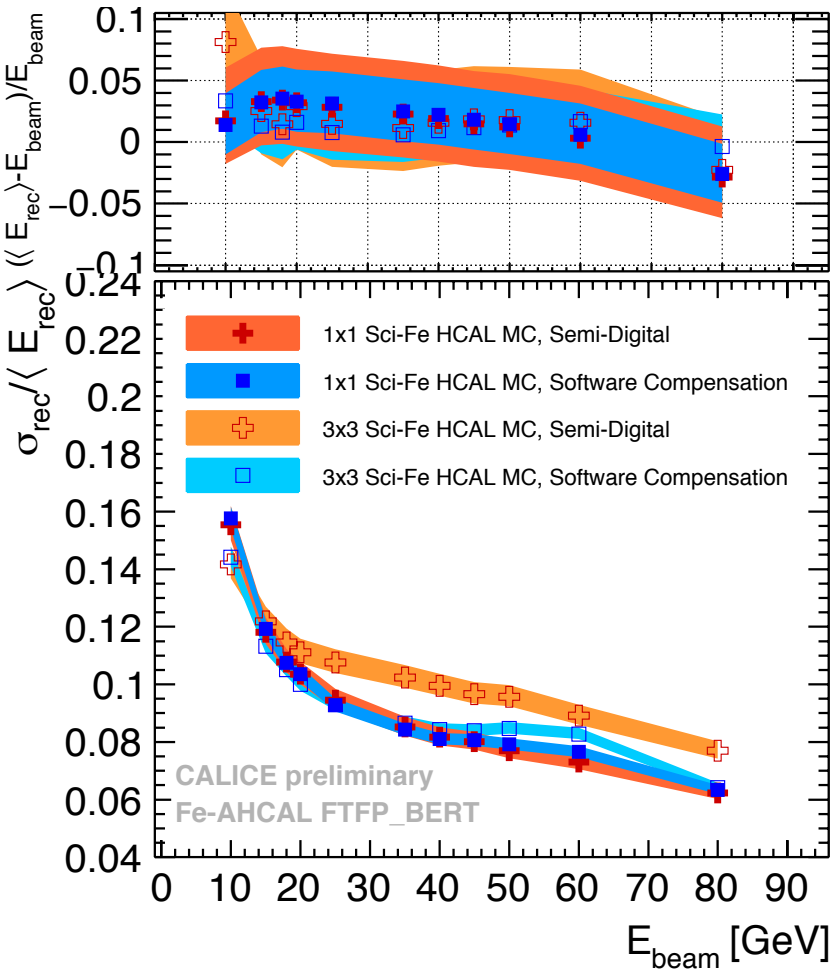

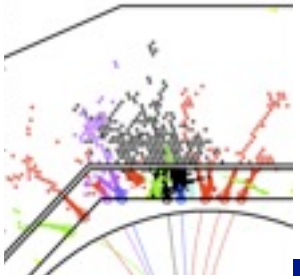

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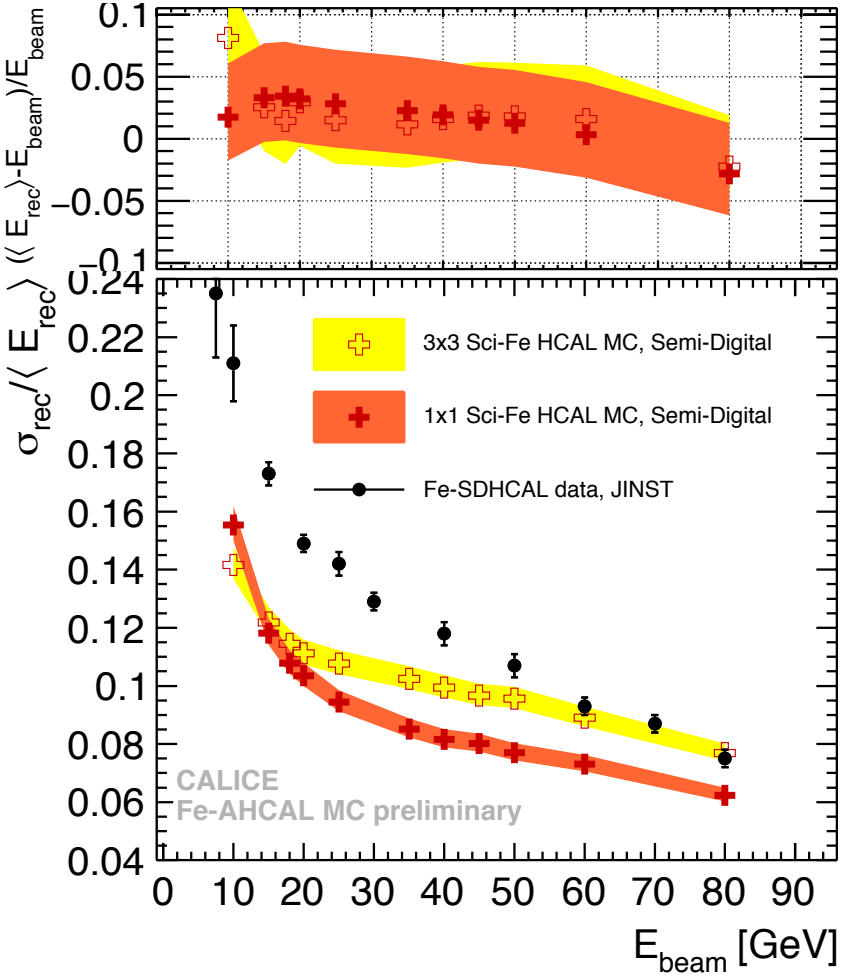
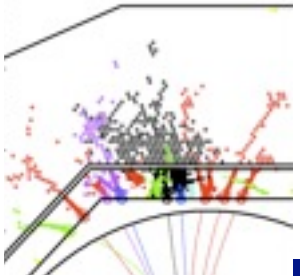
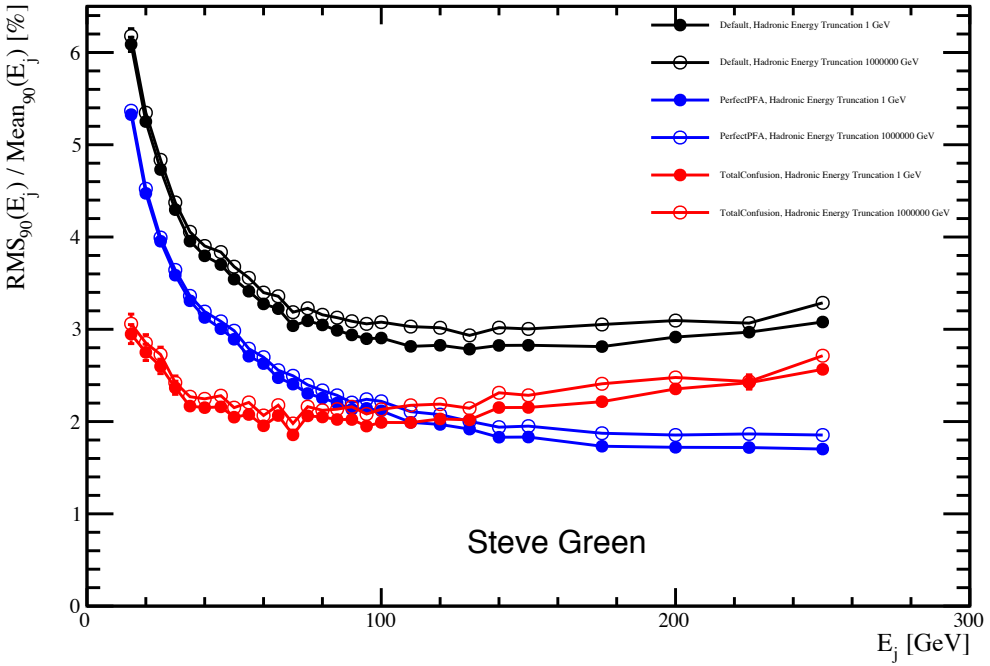


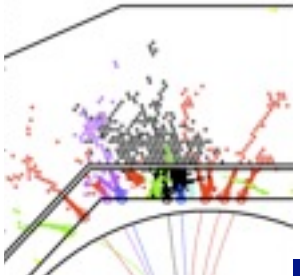


s/w compensation and PFLOW

- Jet energy resolution is the goal
- In principle can benefit in two-fold way:
  - improve resolution for neutral objects
  - improve cluster energy estimators for track-cluster association -

studies with Pandora PFA





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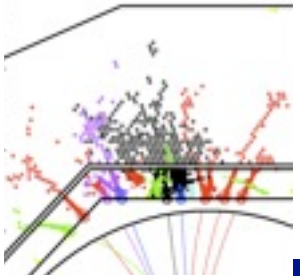

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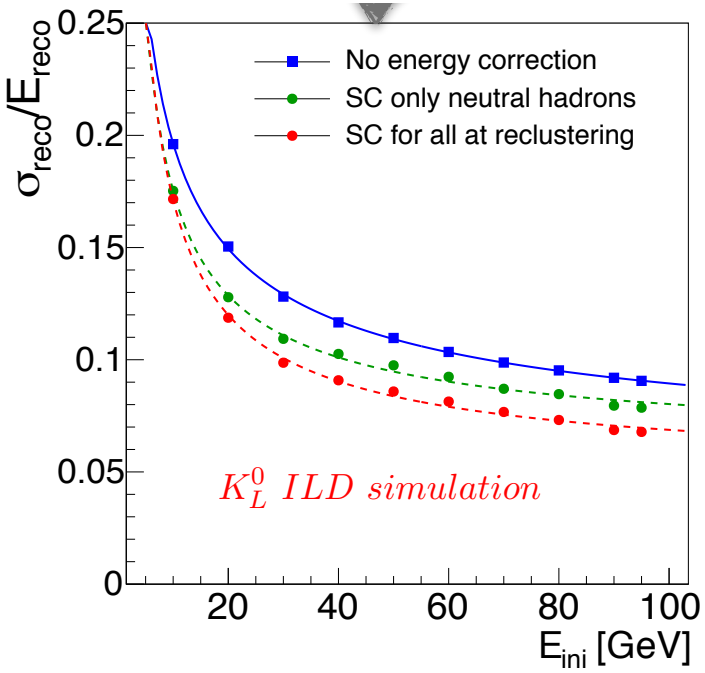

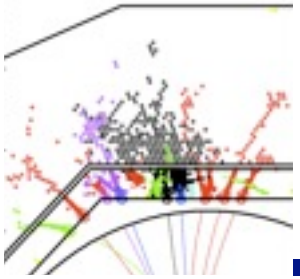

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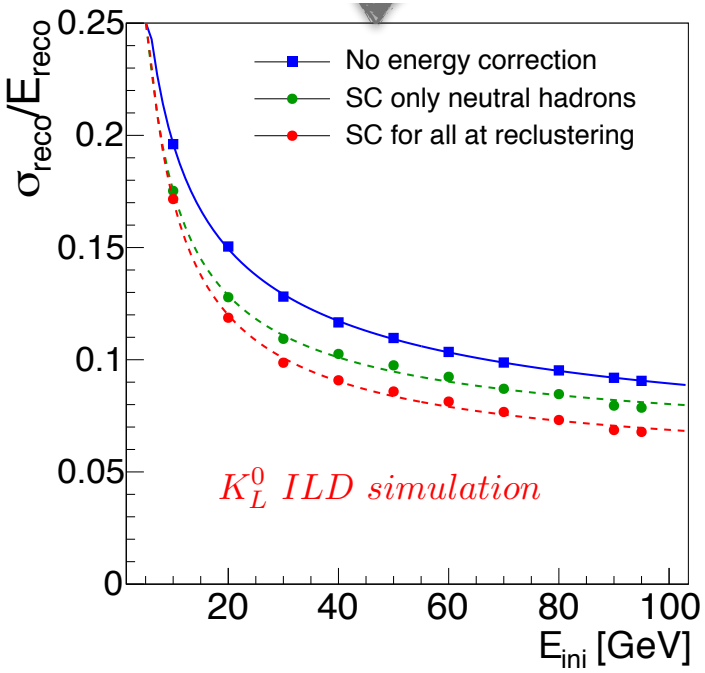
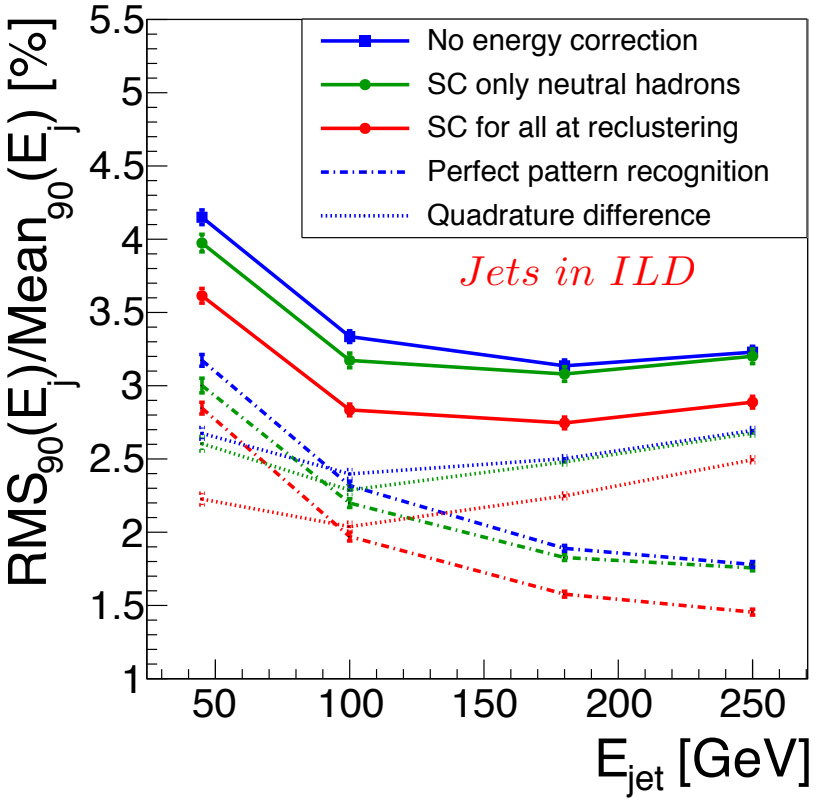
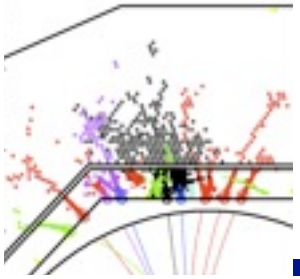
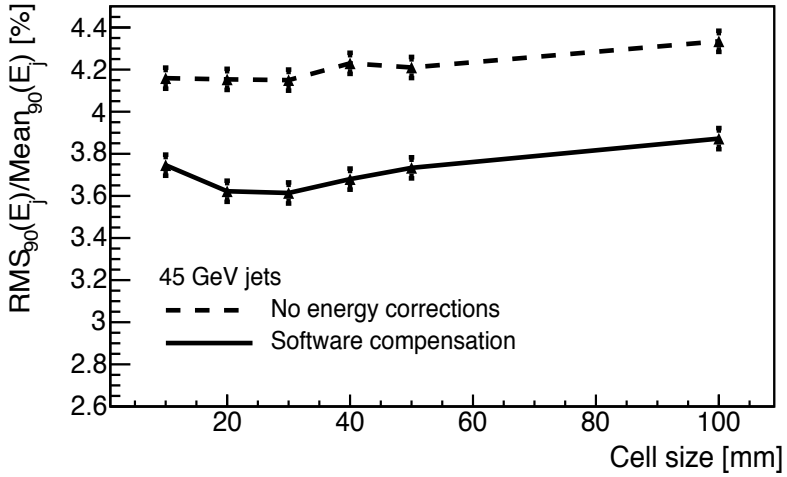


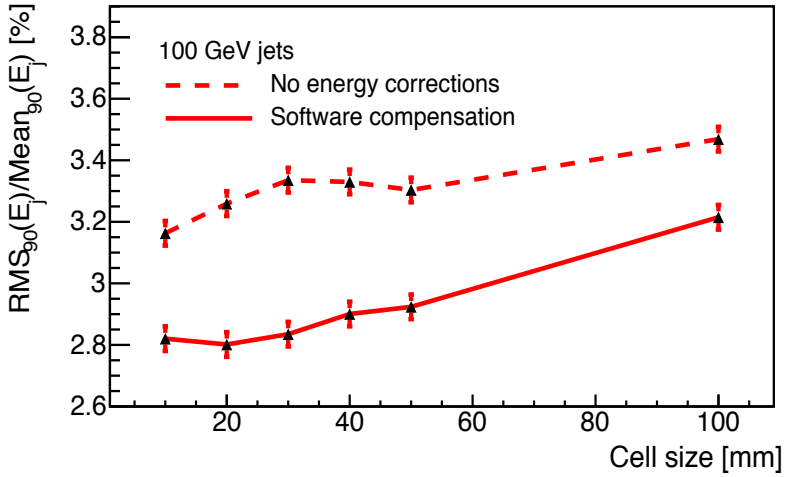
studies witl

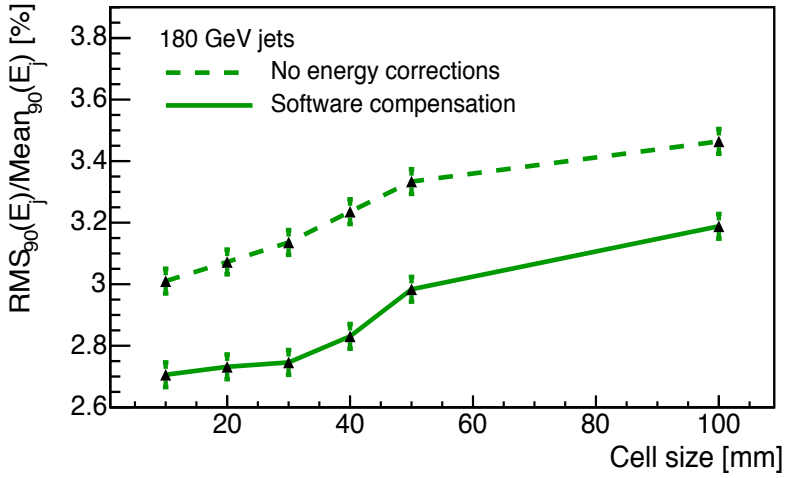


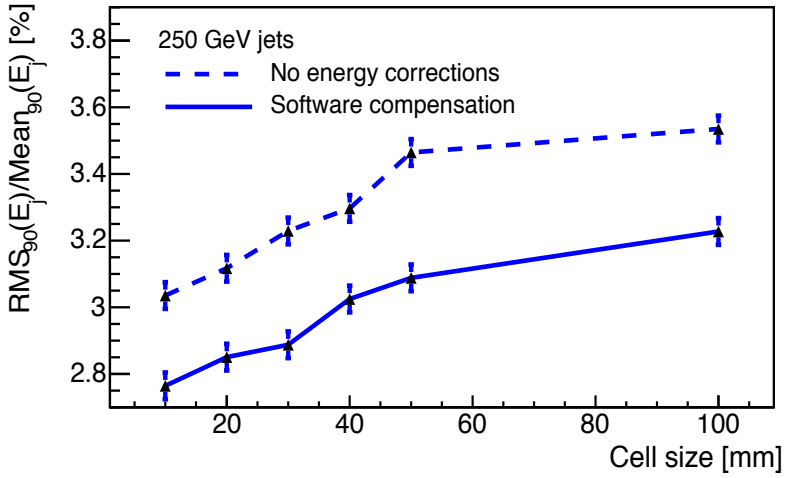


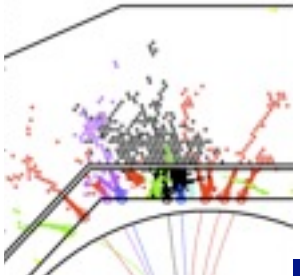
Granularity and resolution 2



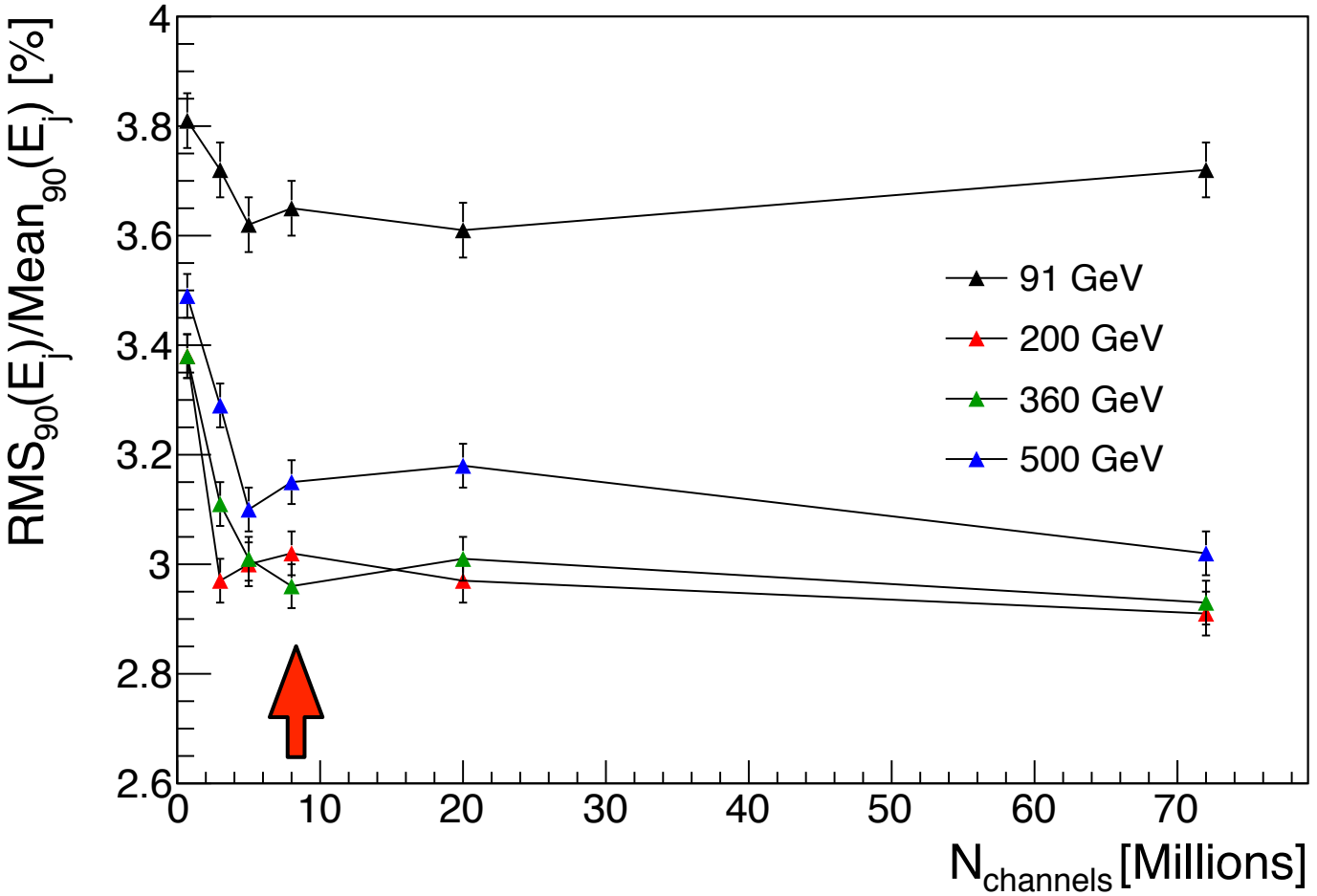








Granularity and resolution 2



- 3 cm still a very reasonable choice