CERN Compact Linear Collider: physics goals and detector challenges

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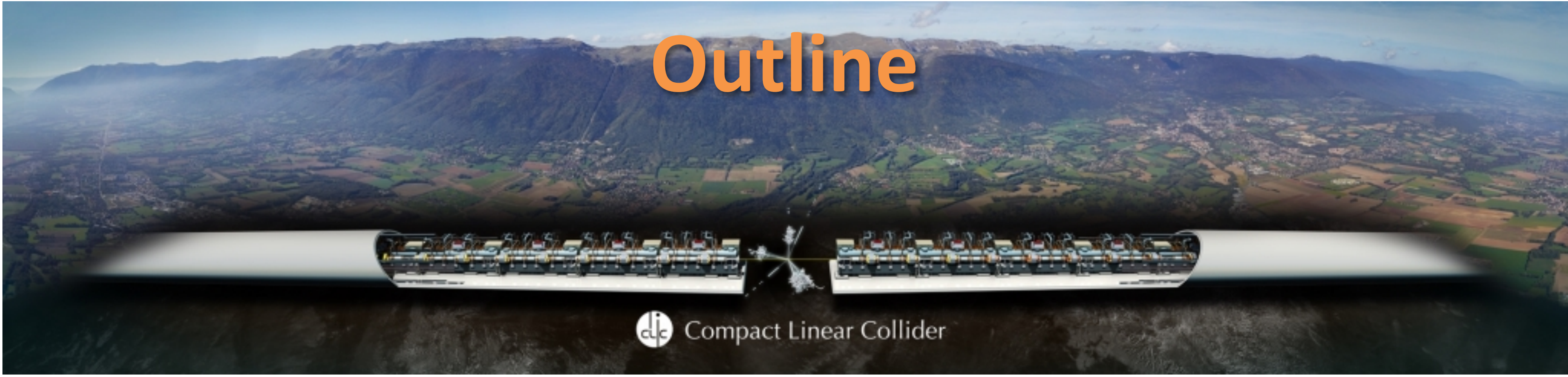
International School of Subnuclear Physics,
Erice, 24th June – 3rd July 2015

Outline

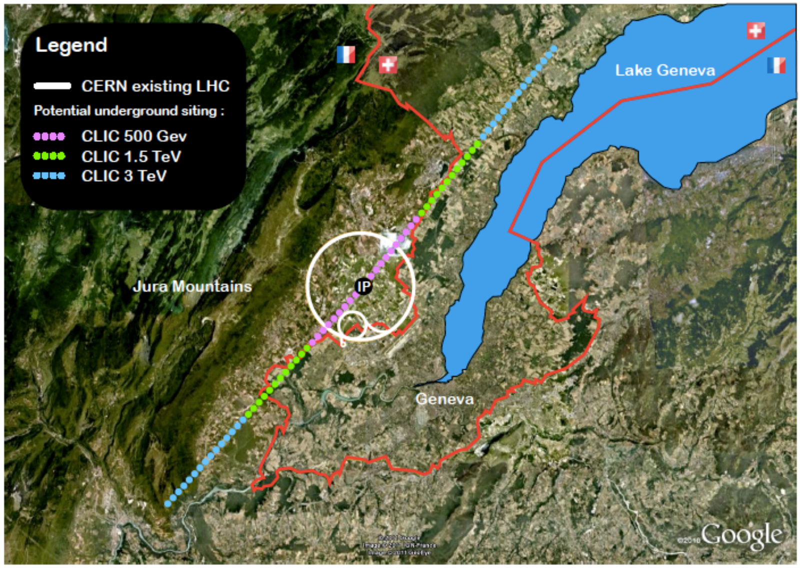


- Project for the Compact Linear Collider (CLIC) at CERN
- Motivations for a linear electron-positron collider
  - Prospects of physics analyses
- Requirements for the detector optimisation & RD
  - Vertex
  - Main tracker
  - Calorimeter system
- Conclusion

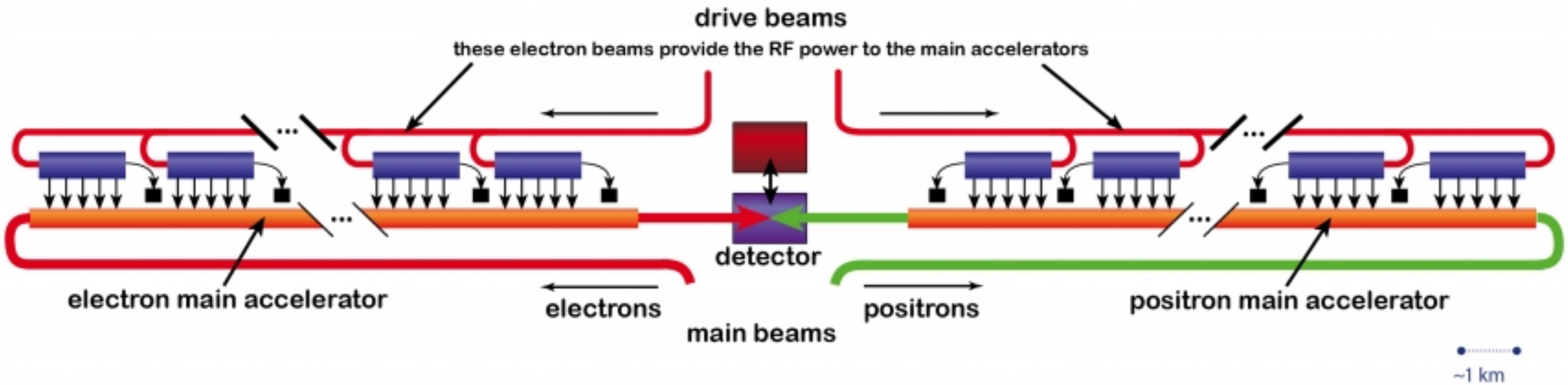
CLIC

- **CLIC = C**ompact **LI**near **C**ollider, $e^- e^+$
- High accelerating gradient 100MV/m:
  - dual beam scheme at room temperature
- Up to high energy and luminosity

$\sqrt{s}$ [GeV]	length [km]	$\mathcal{L}$ [$cm^{-2}s^{-1}$]
350	11	1.5×10^{34}
1400	27	3.5×10^{34}
3000	48	6.0×10^{34}

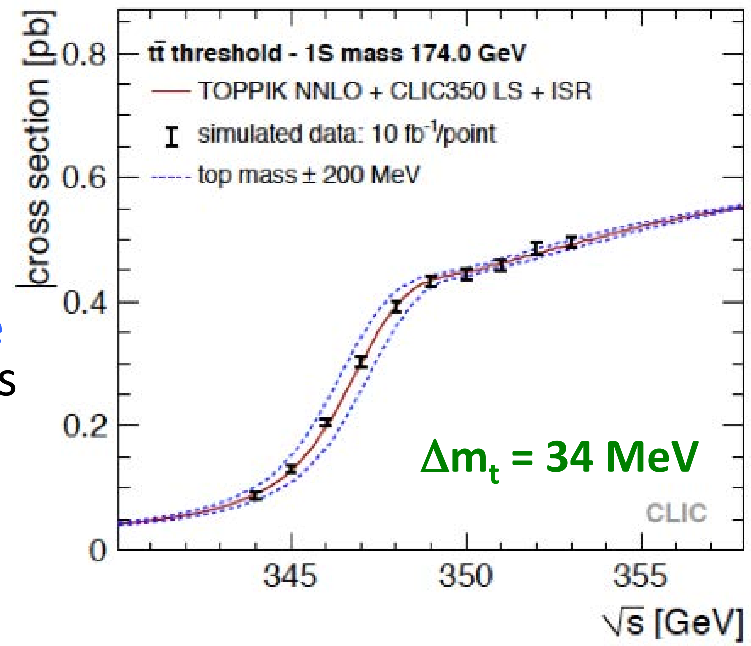


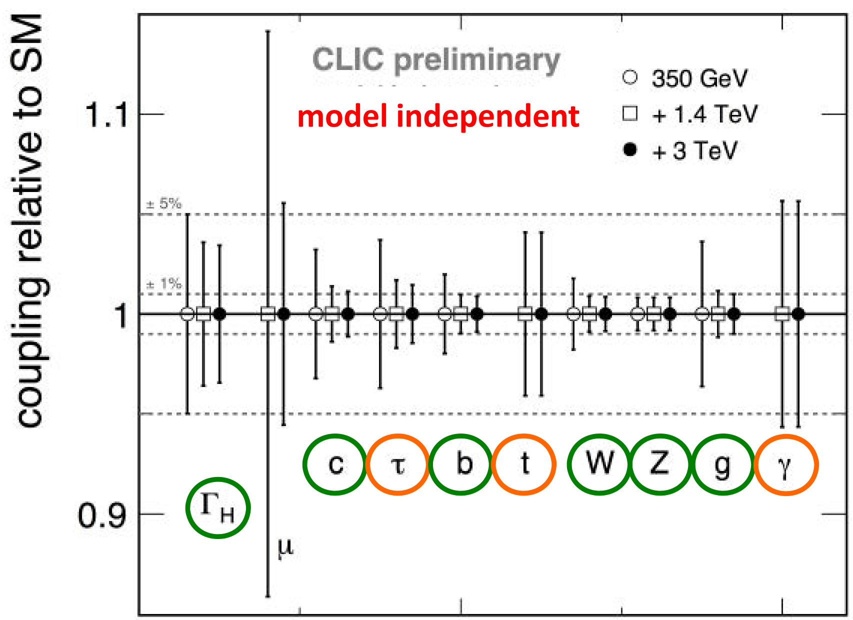
- Small bunch size: σ_{xyz}(40 nm, 1 nm, 44 µm) → beamstrahlung

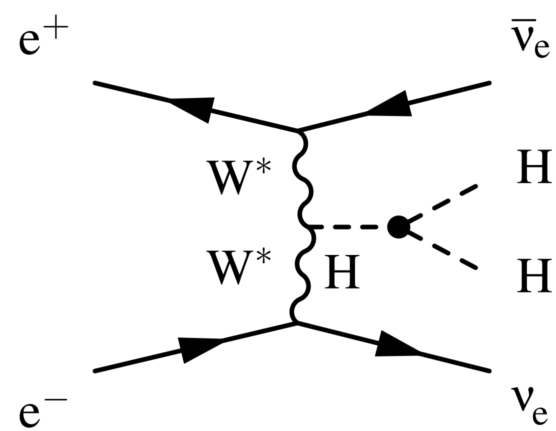


Motivation for a linear e^-e^+ collider

- Defined initial state, beam polarization possible → high precision studies:
  - Top mass and asymmetry (stage 1)
  - Higgs properties → model independent coupling determination (stage 1-2-3)
- Complementary info w.r.t. hadron colliders (stage 2-3) → higher sensitivity to electroweak processes
- CLIC → high energy: access to rare process, i.e.: Higgs self coupling (stage 2-3)







Precision on g_{HHH} ~ 10% at 3 TeV

Performance requirements

- Momentum resolution

$$\sigma_{p_T}/p_T^2 \sim 2 \times 10^{-5}\ \mathrm{GeV}^{-1}$$

- Jet Energy resolution

$$\frac{\sigma_E}{E} \sim 3.5 - 5\ \%$$

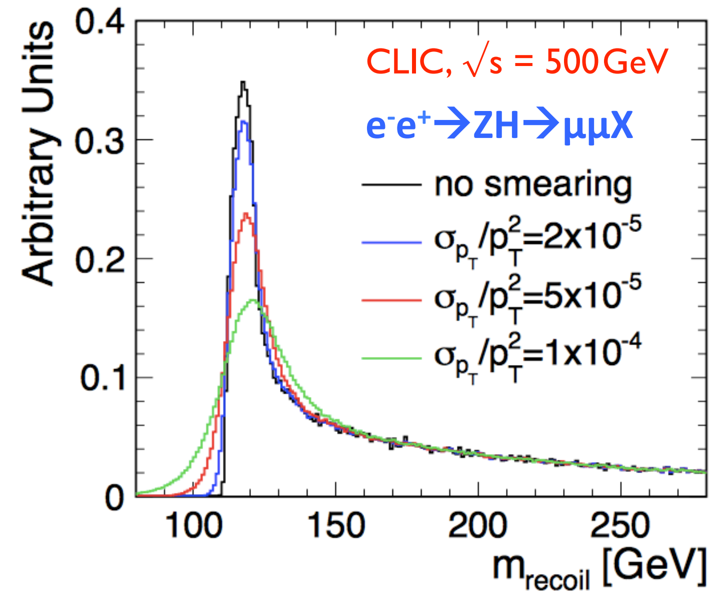
- Impact parameter resolution

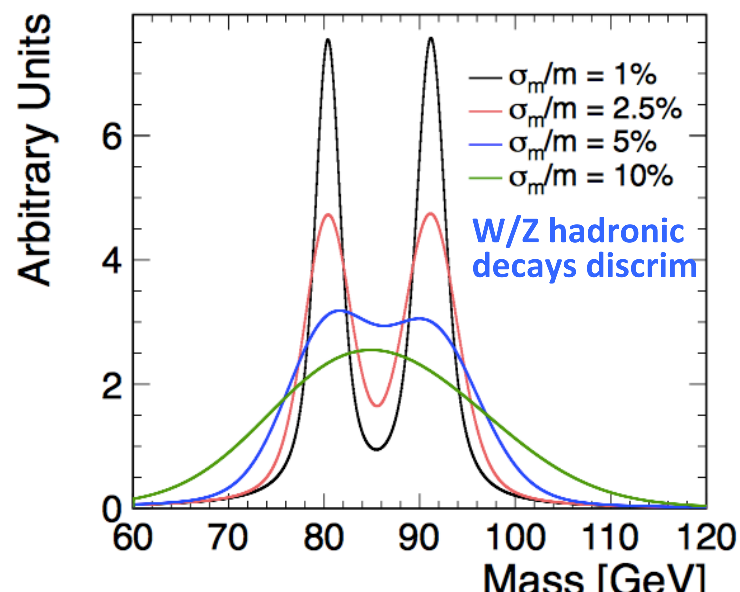
$$\sigma_{r\phi} = \underbrace{5}_{\text{single point resolution}} \oplus \underbrace{15/(p[\mathrm{GeV}]\sin^{\frac{3}{2}}\theta)}_{\text{multiple scattering}}\ \mu\mathrm{m}$$

- Excellent determination of secondary vertices for b/c-tagging and tau reco

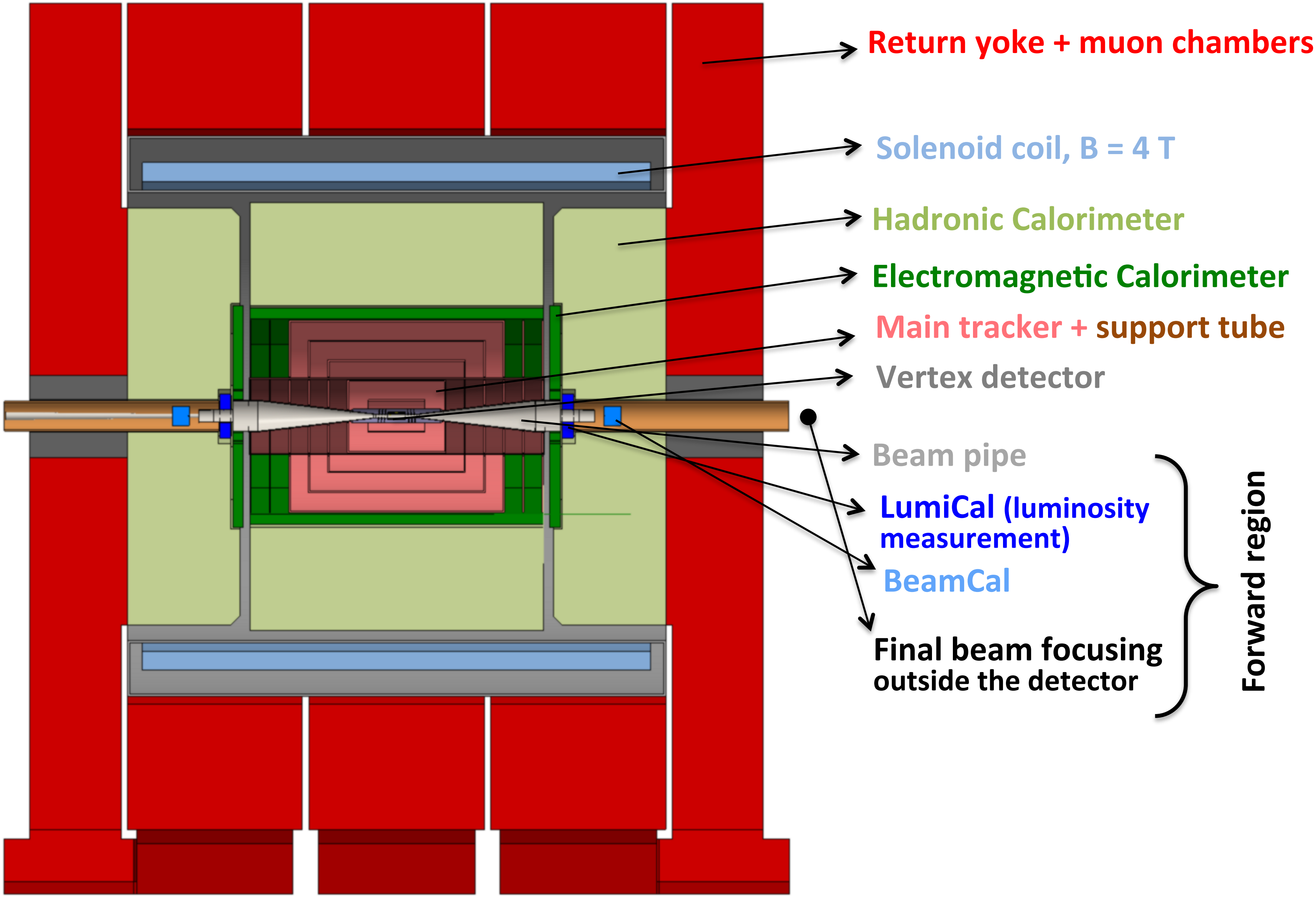
- Lepton identification efficiency > 95% over full range of energies

- Detector coverage in forward region



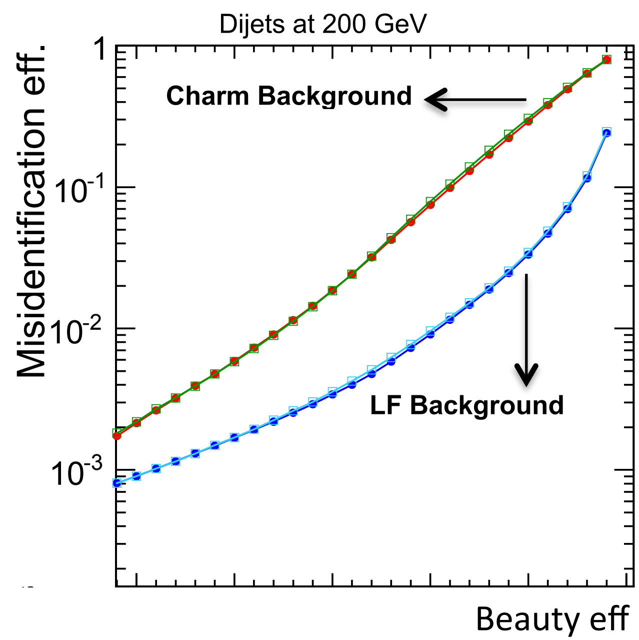


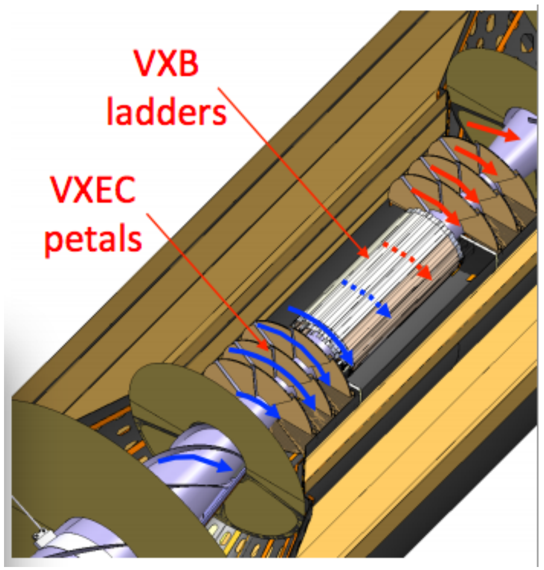
Detector Overview



Vertex detector

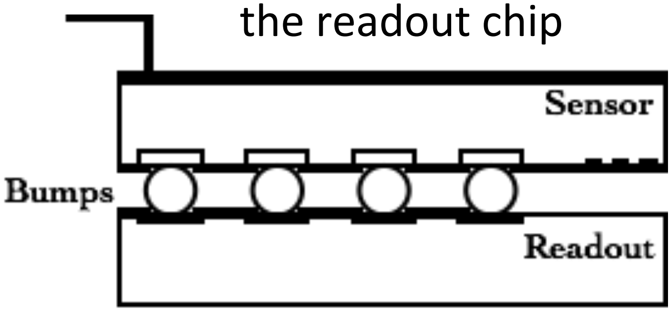
- **Physics aim: excellent identification of secondary vertices for b/c-tagging → excellent impact parameter resolution**
- **Single point resolution of 3µm**
  - 25µm pixel pitch
  - 2 billion pixel
- **Ultra light detector: 0.2%X_0 per layer**
  - Air coiling: spiral geometry to force air flow → 50mW/cm^2
  - Ultra thin sensor and readout: 0.1%X_0
  - Low mass supports: 0.05%X_0
  - Double layers geometry to maximise the number of measurements minimazing the support material
- **Occupancy of few %** → first layer layout R = 31 mm



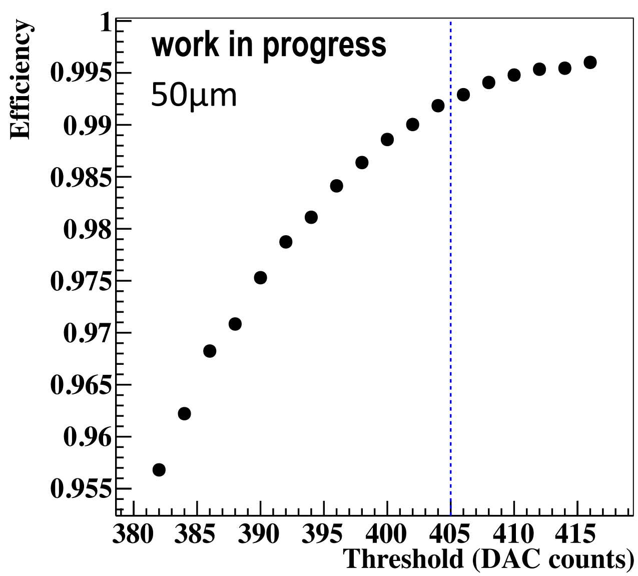


Vertex: sensor + readout options

- **50-300 μm sensor bump-bonded to Timepix chips, 55 μm pixel pitch**
- DC-coupling with amplifier input on the readout chip

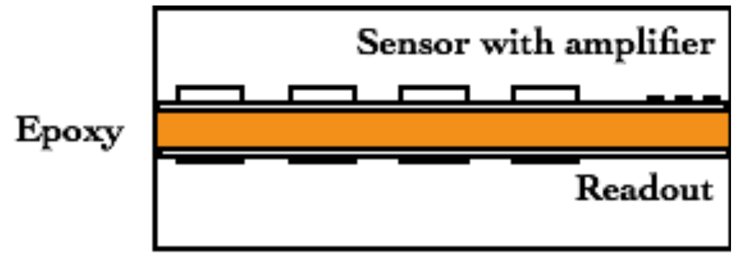


Bump-bonded assembly

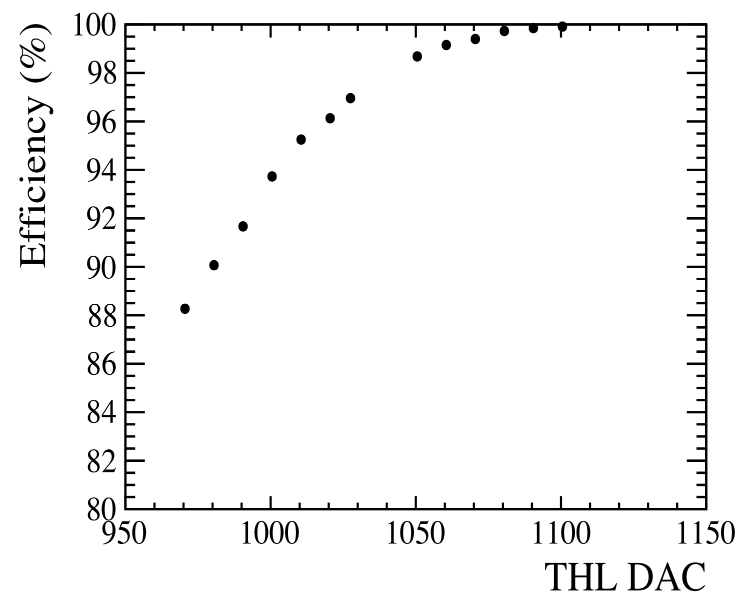


- Resolution: 4-18 μm

- **HV-CMOS sensor glued on CLICpix ASIC, 25 μm pixel pitch**
- AC-coupling → amplification of the signal on the sensor side



AC-coupled assembly

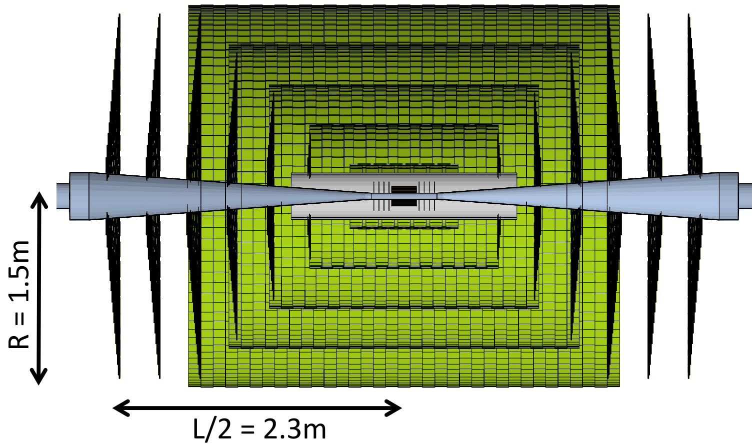


Main Tracker and B field

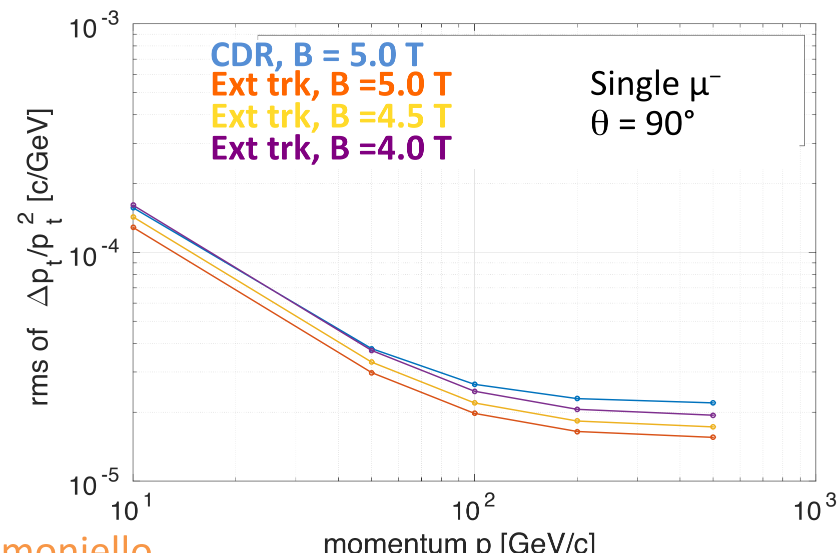
- **Physics aim: excellent track momentum resolution**

$$\frac{\sigma(p_\mathrm{T})}{p_\mathrm{T}^2} \propto \frac{\sigma}{\sqrt{N+4}BR^2}$$

- **High B field (B = 4 T) and determination of the overall size of the tracker**
- 7µm single point resolution
- Very light detector: 1%X_0 per layer
- Air flow not possible → liquid cooling
- Technology: **all Si, short strip or large pixel** → size from occupancy studies

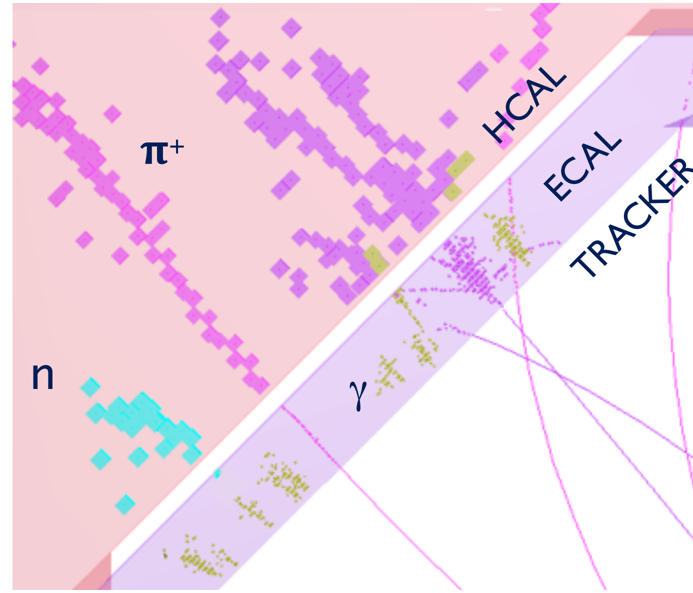


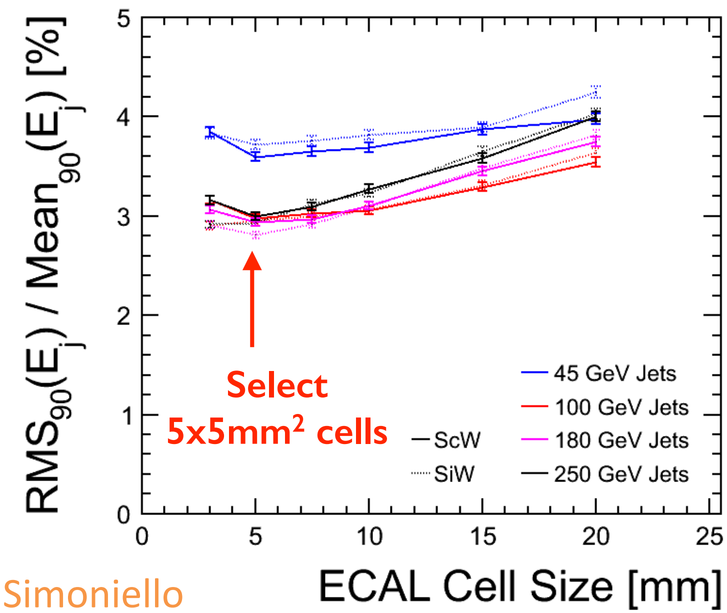
Place	Hits/ mm^2/BX	max strip length / mm
B1	1.0e-4	2
F1	5.0e-5	3
B2	3.6e-5	5
F2	1.5e-5	13
B3	1.2e-5	15
F3	6.0e-6	31
B4	6.0e-6	30
F4	2.4e-6	76
B5	4.0e-6	43
F5	1.5e-6	120
F6	1.3e-6	140
F7	1.3e-6	140

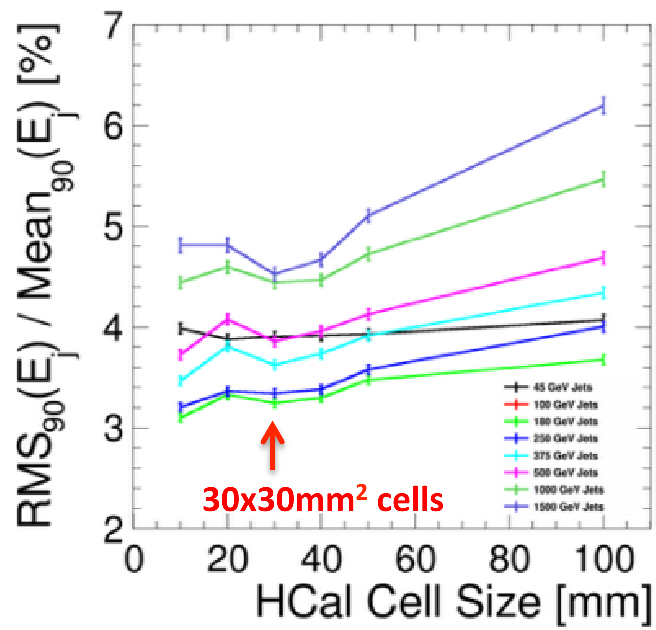


Calorimeter system

- **Physics aim: excellent jet resolution**
- Typical Jet composition:
  - 60% charged particles
  - 30% photons
  - 10% long-lived neutral hadrons
- **Employment of particle flow techniques**
  → large impact on the detector design
- High granularity calorimeter
- Forward acceptance

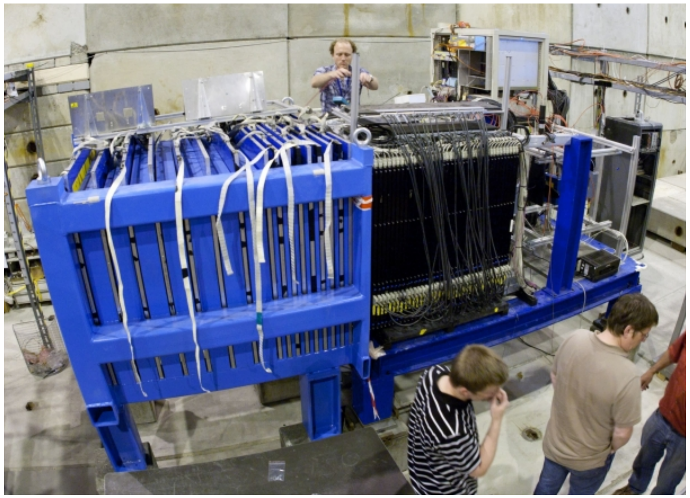


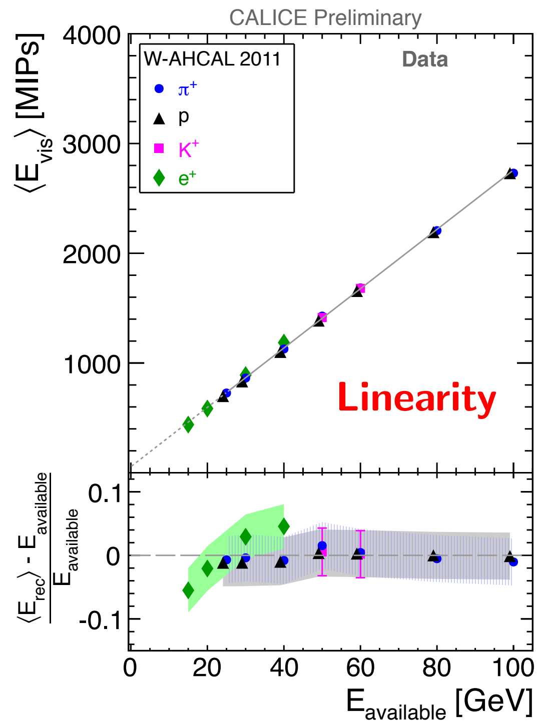


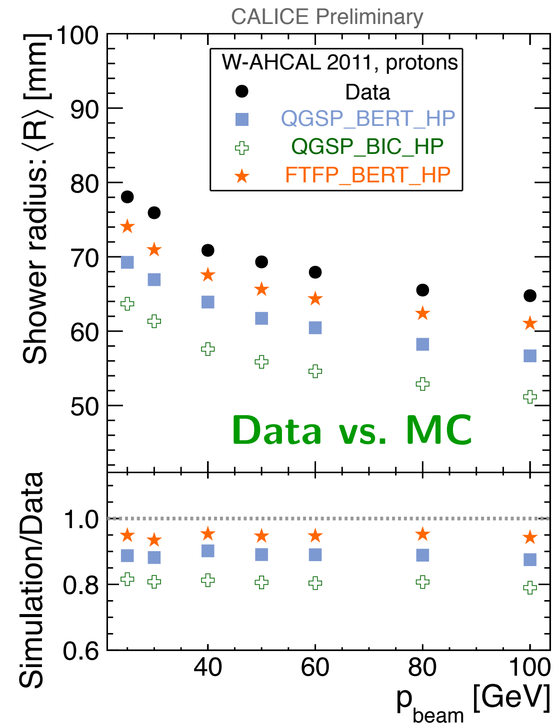


Tungsten Analogue Hcal

Test beam data : e, π, K and p at 1-300GeV







- Analogue readout: scintillator + SiPM
- *Good linearity, resolution:* $\frac{\sigma_E}{E}(\pi^+, E = 3-10GeV) = \frac{(61.8 \pm 2.5)\%}{\sqrt{E[GeV]}} \oplus (7.7 \pm 3.0)\% \oplus \frac{0.070GeV}{E[GeV]}$
- *Data-simulation* in general in *agreement*
  - room for improvement in shower shape description
- Comprehensive study of all relevant *systematic uncertainties*

Digital W Hcal option also considered → analysis of the test beam data on going

Software

- **DD4hep: Detector Description for High Energy Physics**
  - *Complete and consistent description* → Single source of detector information for display, simulation, reconstruction, analysis, alignment, etc.

- **Tracking reconstruction (under development):**
  - Based on detector geometry, i.e.: specific algorithm to exploit double layer structure of the vertex detector

- **Pandora: particle flow**
  - Sophisticated software framework for developing pattern-recognition algorithms. Large numbers of independent algorithms address specific event topologies.
  - Used also in neutrino experiments (LAr TPC)

Collaboration

CLICdp collaboration: 25 institutes

- CLICdp web site: http://clicdp.web.cern.ch/
- CLICdp CDR: http://arxiv.org/abs/1202.5940

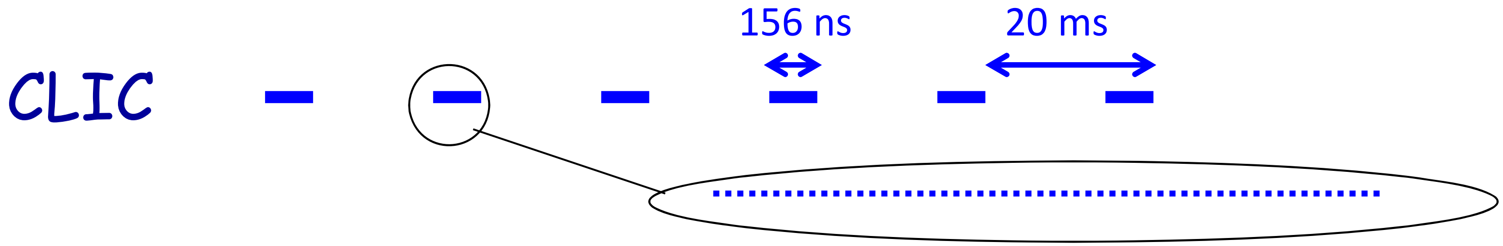
You are welcome to join!

Conclusion

- High energy e+e- linear collider aiming to precision studies
- Demanding requirements on detector layout and hardware
  - Intense (and successful) R&D activities
- Sophisticated software and reconstruction algorithms
  - Fully exploit the best information from each subdetector

Thanks for your attention!

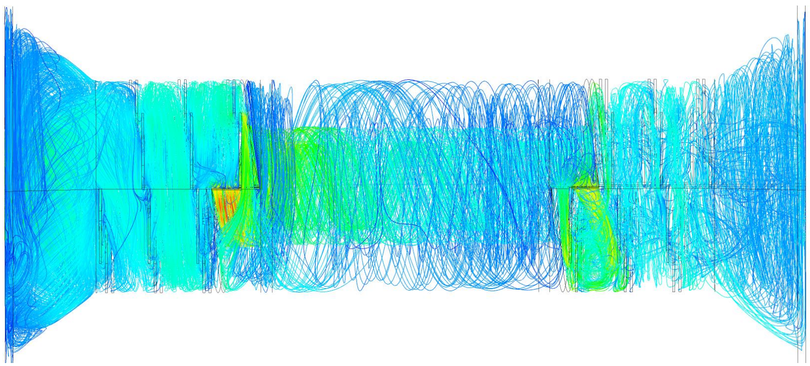
BACK-UP

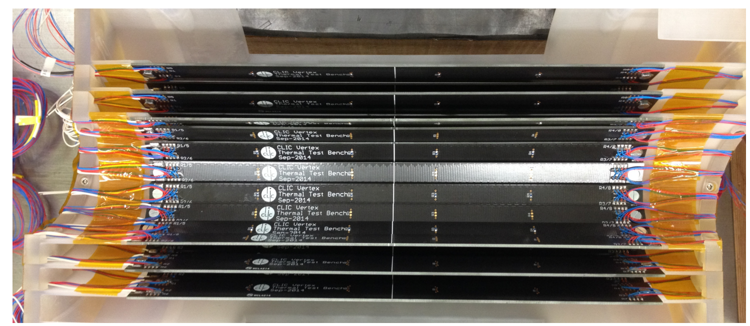


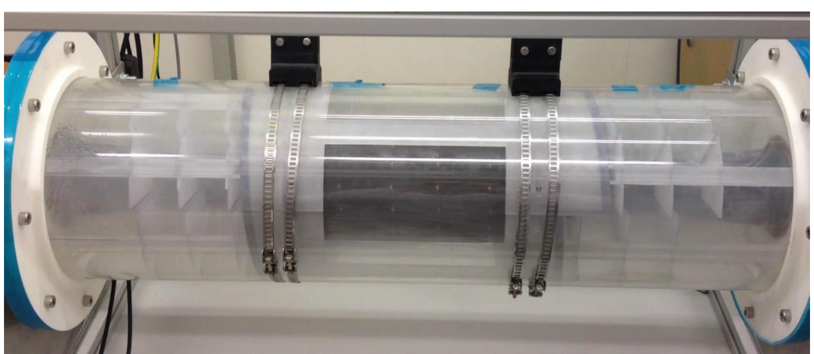
1 train = 312 bunches, 0.5 ns apart

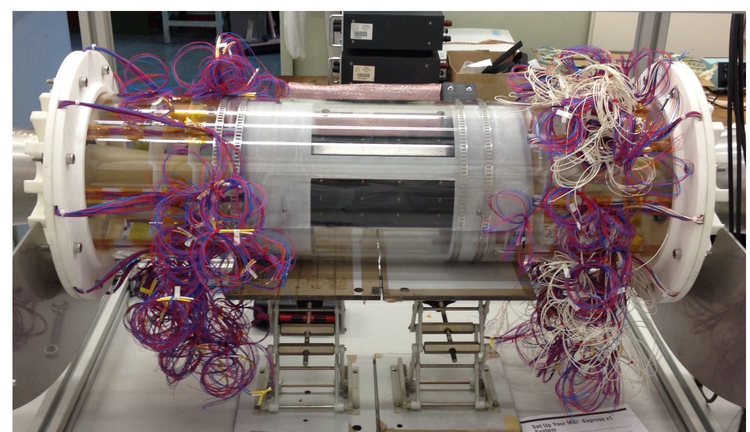
Forced-air and thermal mock-up

- Real-size mock-up to verify simulation and study air-flow feasibility, vibrations and temperature
  - ~500 W heat load to extract (50mW/cm^2) → T^{Si} < 40°C after power pulsing
  - Vibration acceptable at 1-2 μm RMS amplitude
- Bending/stiffness of low mass supports (0.05%X_0)









Cooling: simulations

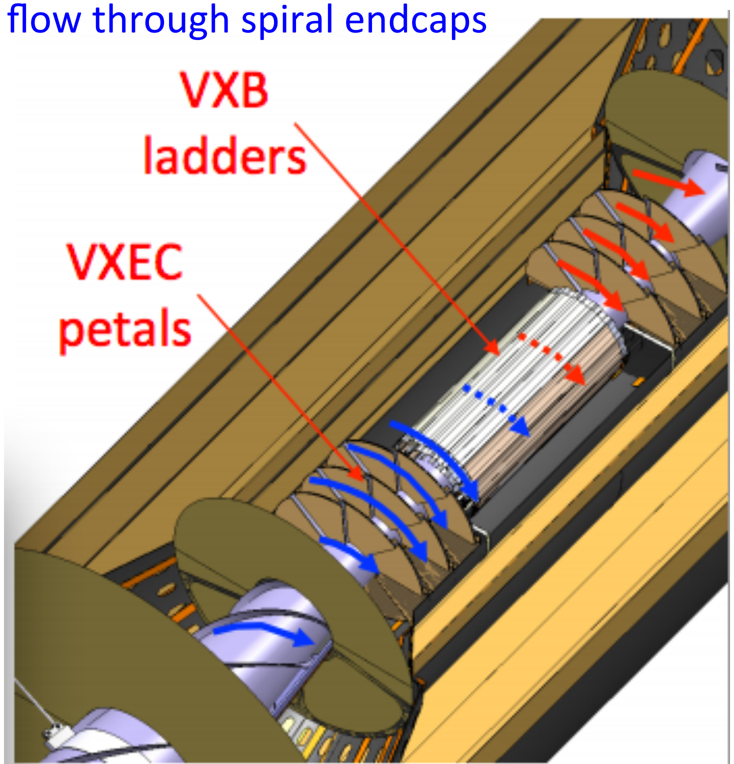
Cooling studies for CLIC vertex detector

- ~500 W power dissipation in CLIC vertex area
- spiral disks allow air flow through detector
- ANSYS Computational Fluid Dynamic (CFD) finite element simulation

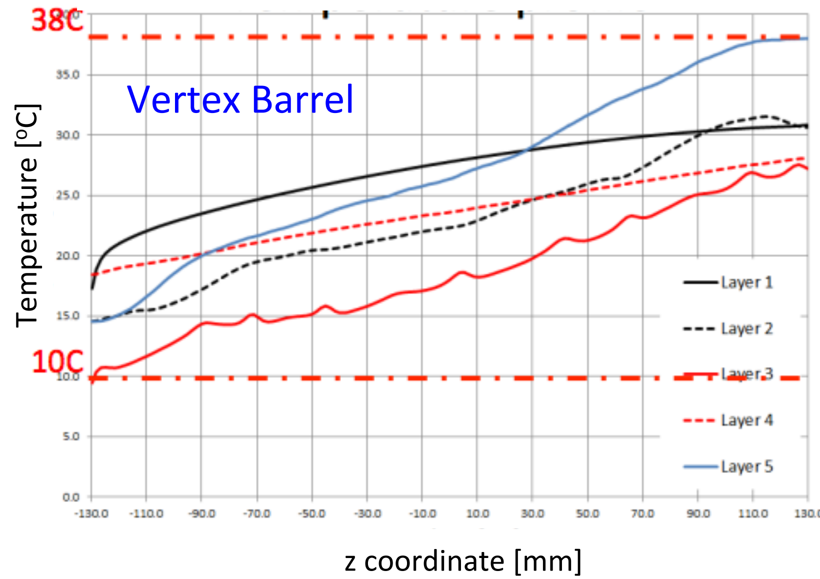
→ air cooling seems feasible

- 5-10 m/s flow velocity, 20 g/s mass flow

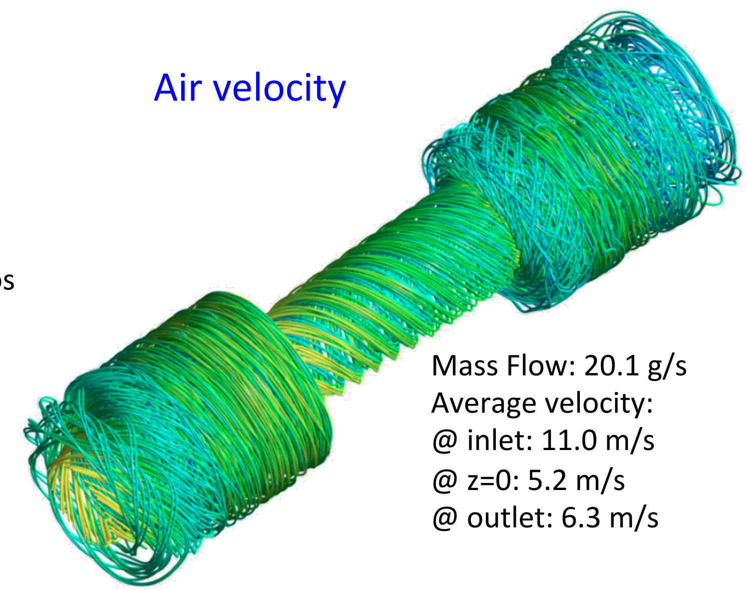
Air flow through spiral endcaps



Temperature profile (FE simulations)



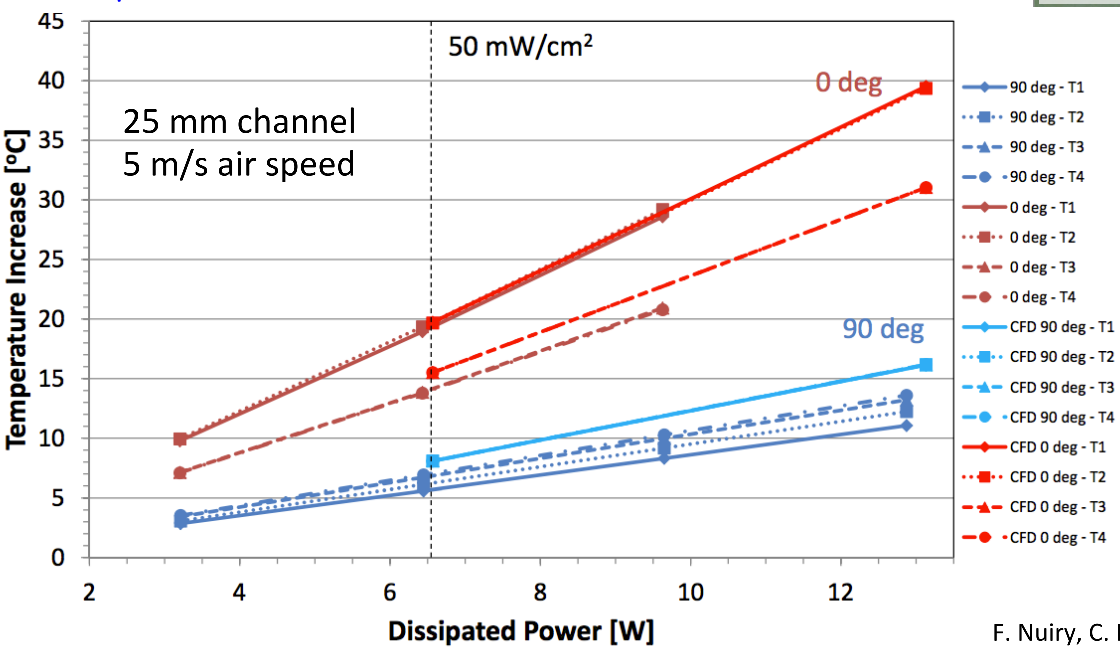
F. Duarte Ramos

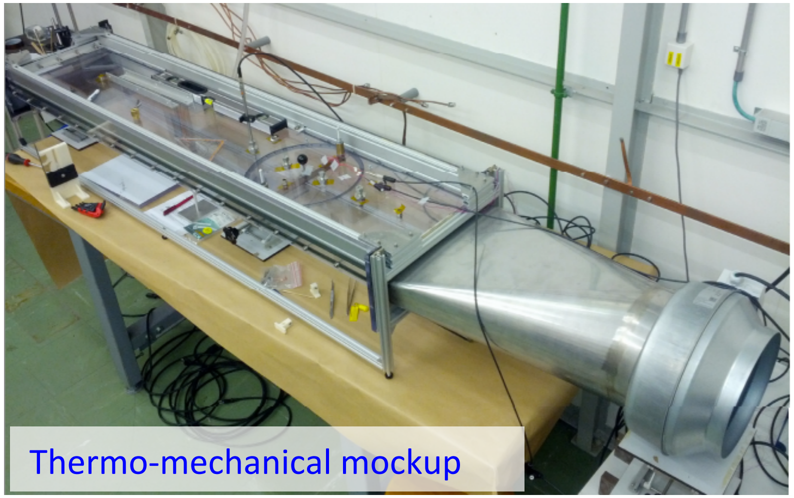


Cooling: experimental verification

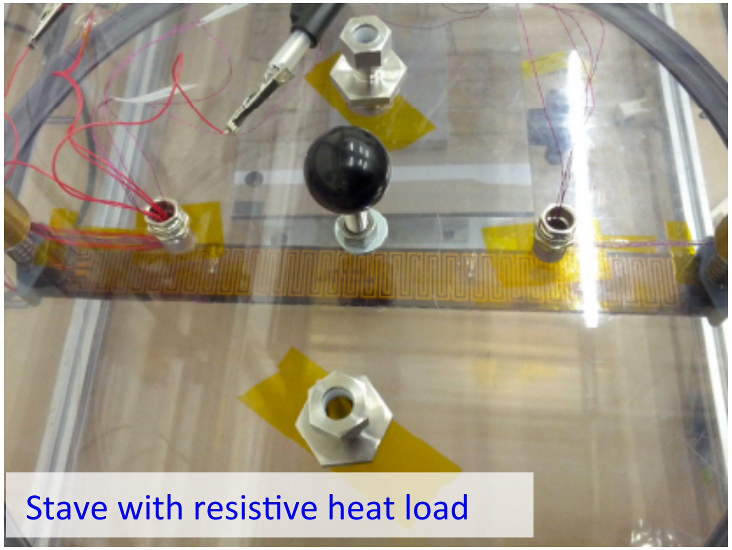
- built mock-up to verify simulations (temperature, vibrations)
- measurements on single stave equipped with resistive heat loads:
  - air flow
  - temperature
  - vibrations (laser sensor)
- comparison with simulation

Temperature increase: measurement + CFD simulation





Thermo-mechanical mockup

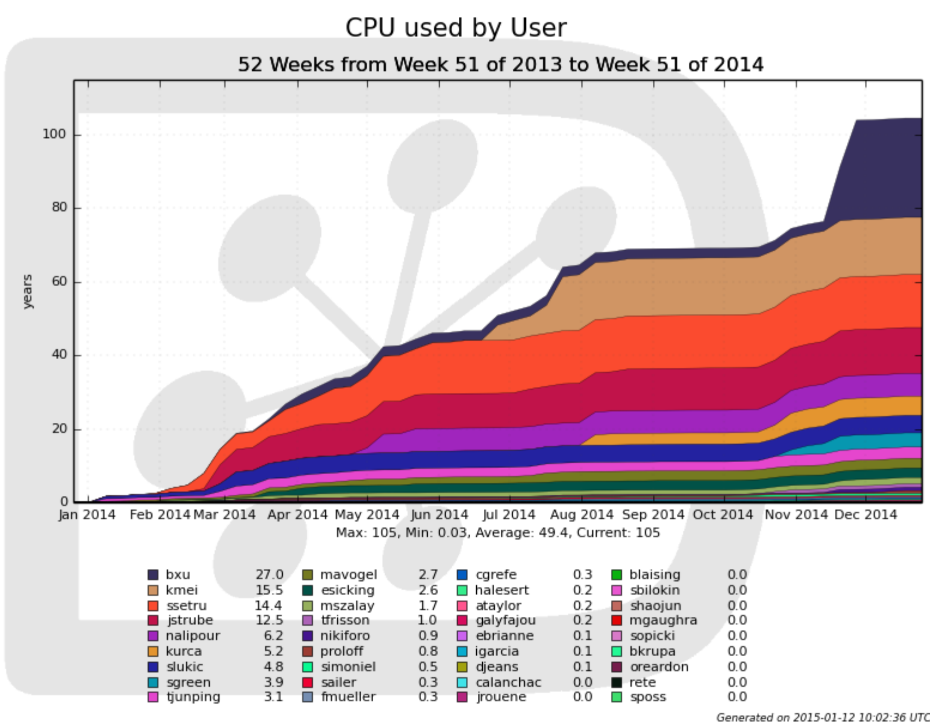


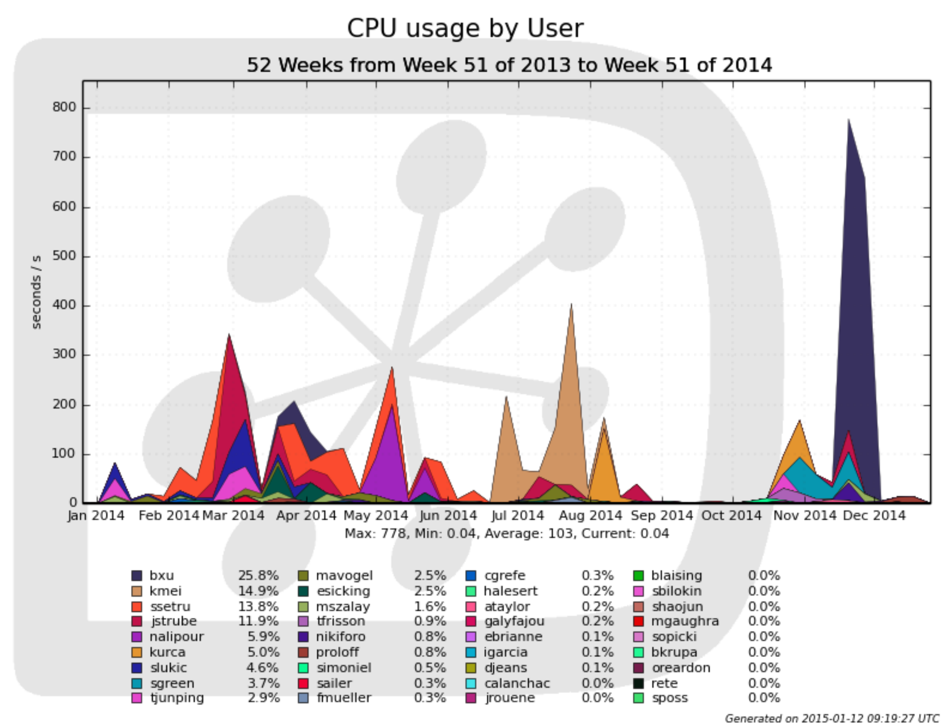
Stave with resistive heat load

F. Nuiry, C. Bault, F. Duarte Ramos, M.-A. Villarejo Bermudez, W. Klempt

ILCDirac

- ILCDirac: Complete Grid Solution
- Workload management, data storage, production system, bookkeeping
- Used by CLICdp, SiD, ILD, CALICE
  - Grid interface for users and production to run any LC software
- https://twiki.cern.ch/twiki/bin/view/CLIC/DiracUsage





DD4Hep

- *Full detector description*: geometry, materials, visualization, parameters for readout, alignment, calibration, etc.
- *Consistent Description*: Single source of detector information for display, simulation, reconstruction, analysis, alignment, etc.
- Detector Palette for CLIC based on SiD model → example detector model for testing and to be updated with the most recent subdetectors
- *Validation* of simulation and reconstruction interface on-going