R&D for Future Detectors and Accelerators : ILC, CALICE and Accelerators

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Project Review 2009

Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)

Excellence Cluster Universe

Overview

- **Accelerator Projects**
  - Muon Cooling: Progress and new ideas

- **Linear Collider Projects**
  - ILC & CLIC
  - ILC Detector Status
  - TPC Development
  - Imaging Calorimeters

The Team

- **Proton-Driven Plasma Wakefield Acceleration**
  A. Caldwell, O. Reimann, F. Simon, G. Xia

- **Muon Cooling**
  Y. Bao, C. Blume, A. Caldwell, A. Ianus, D. Greenwald, B. Mackenzie
  and lots of help by S. Tran (Electronics) and from the technicians in the Mechanics Group

- **ILC / CALICE**
  L. Andricek, C. Kiesling, P. Klenze, S. Lu, H.-G. Moser, O. Reimann, R. Richter, S. Rummel, K. Seidel, R. Settles, F. Simon, C. Soldner, L. Weuste
  and help from the Electronics and Mechanics Department

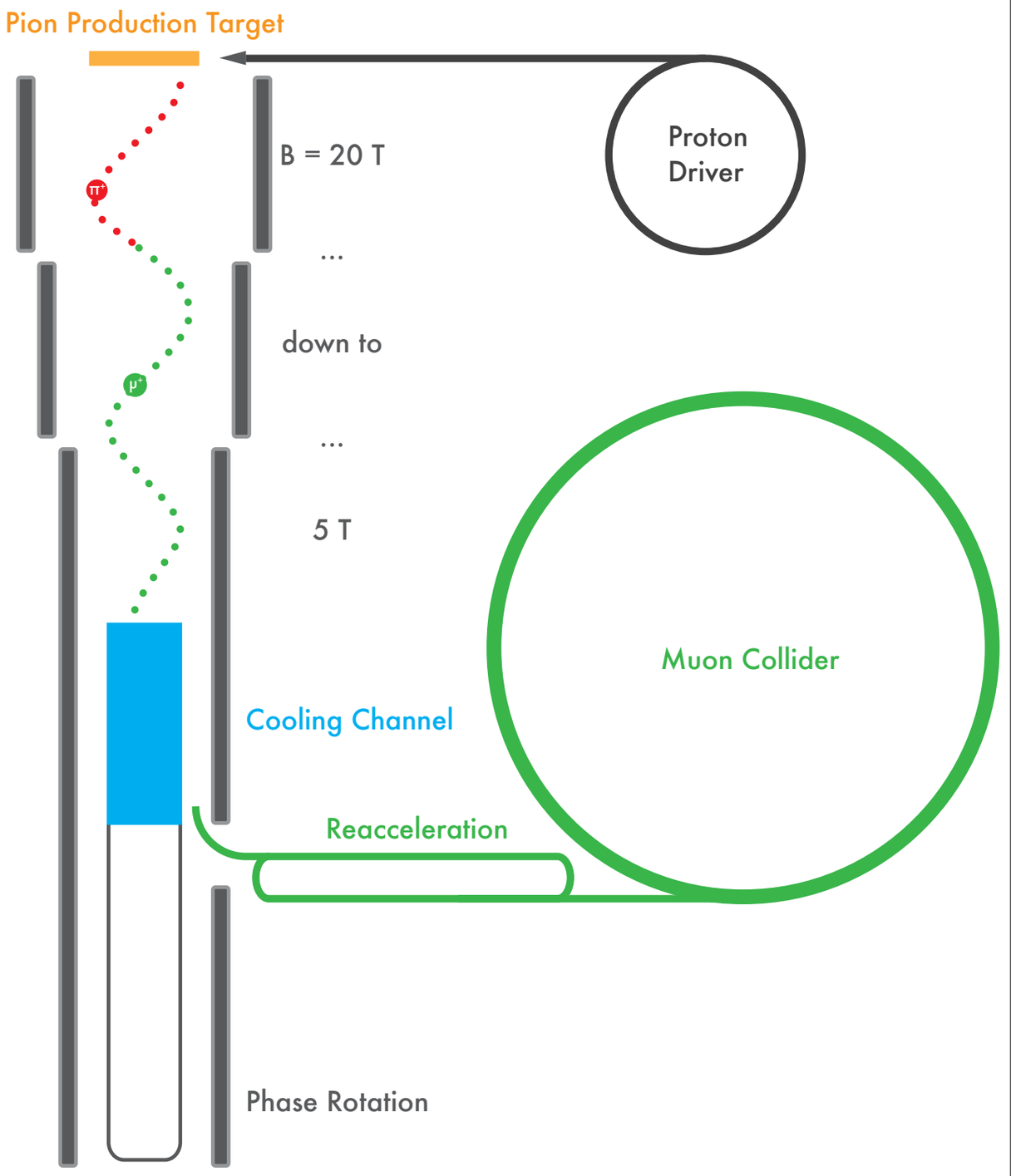
Accelerator Projects

Concepts for Future Accelerators

- High precision studies of physics at the Terascale need a complementary lepton collider in addition to the LHC

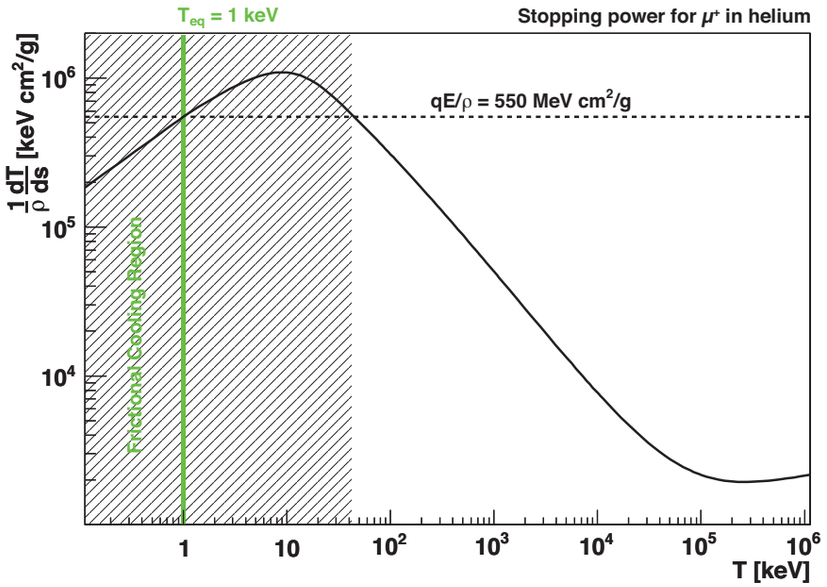
- Proton-Driven Plasma Wakefield Acceleration for a high energy e^+e^- collider: Paper on the concept published in Nature Physics, for a detailed overview about the project see Allen Caldwell's Colloquium tomorrow afternoon

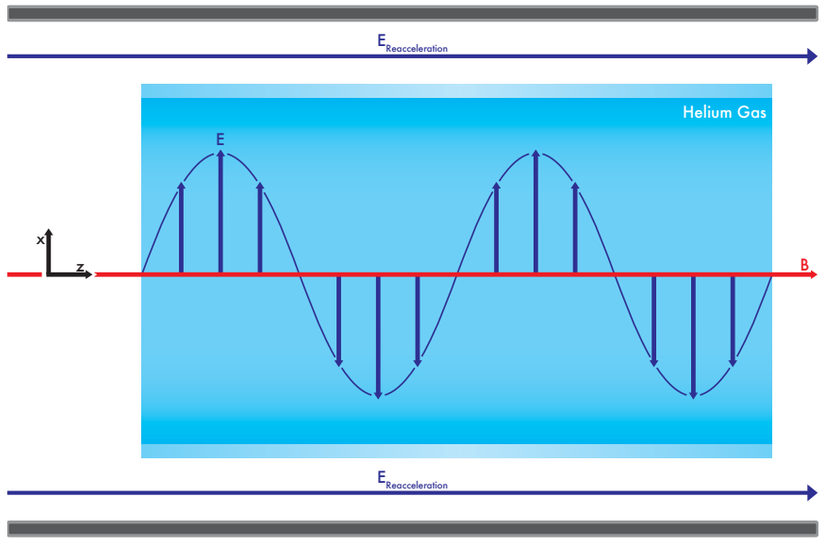
- Muon Collider: Exploring possibilities to provide "cold" muons necessary to achieve the phase space reduction needed for a collider: Frictional cooling



Frictional Cooling

- Muons brought to a fixed energy by balancing energy loss in He gas and gain in an electrical field, the cold muons are then extracted and reaccelerated





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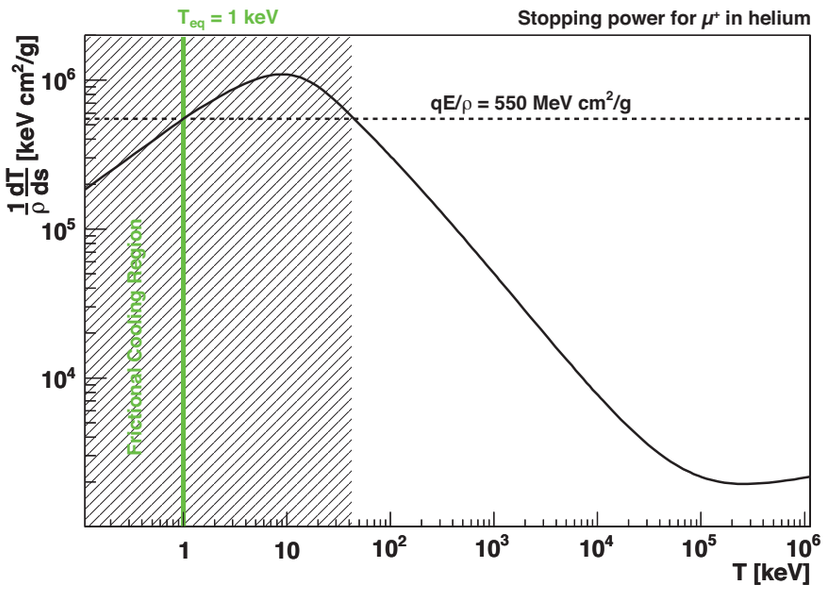
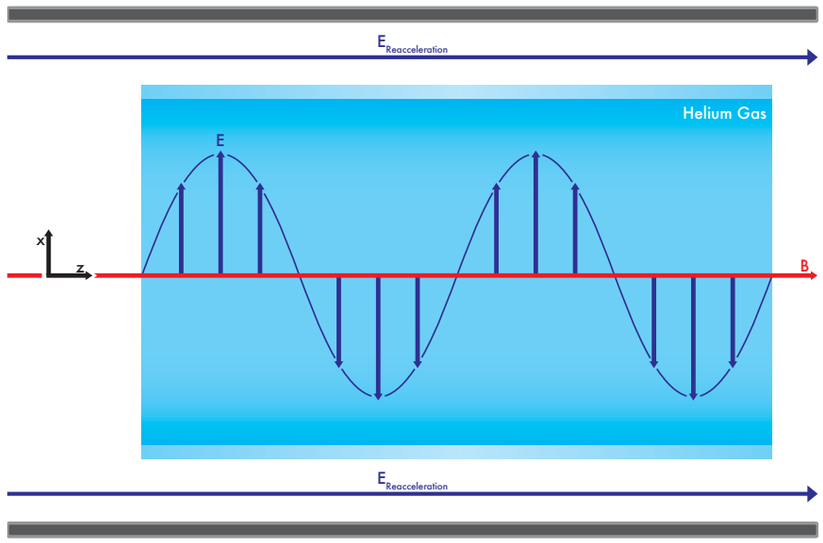
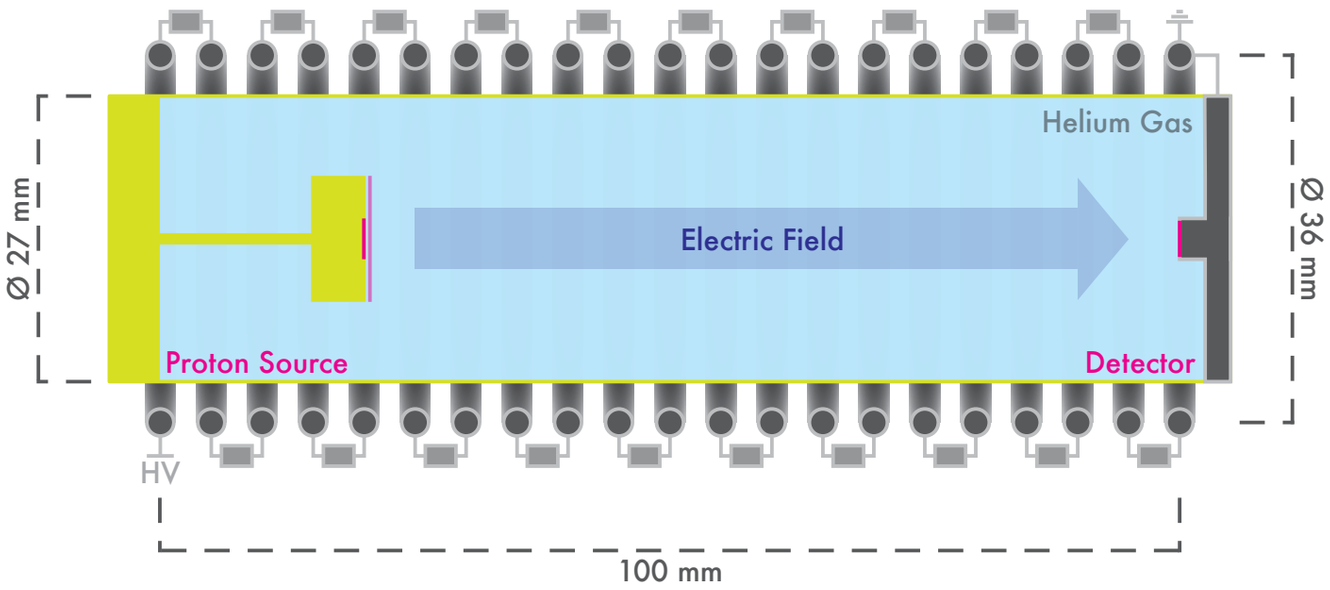


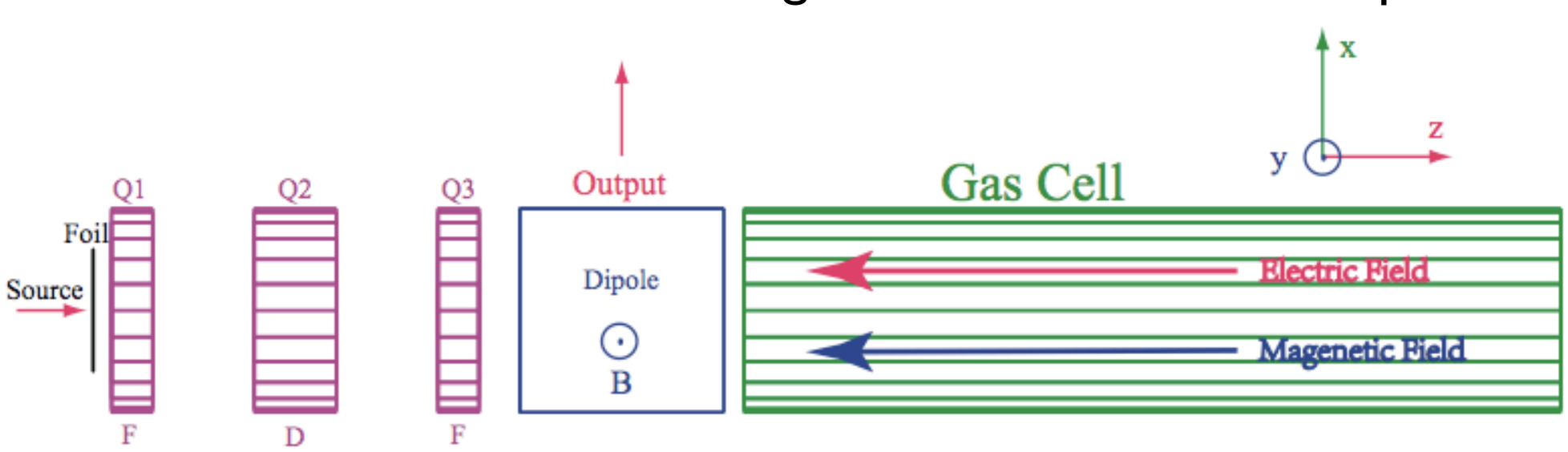




- Experimental test: Low energy protons in a He cell with electric field
- Proton energy measurement with HLL Si detector, operation in He gas being investigated
- Coming up: Measurements of proton energy as a function of pressure and field

Possible Application: Slow Muons at PSI

- PSI's new μE4 beam line delivers the world's highest flux surface muon beam.
- The surface muons are used to produce a slow muon beam at PSI using moderation technology.
- The slow muon production efficiency at PSI is 10^{-5} to 10^{-4}
- Using frictional cooling, we simulated a scheme with a slow muon production rate of 1%, two to three orders of magnitude increase over the present scheme



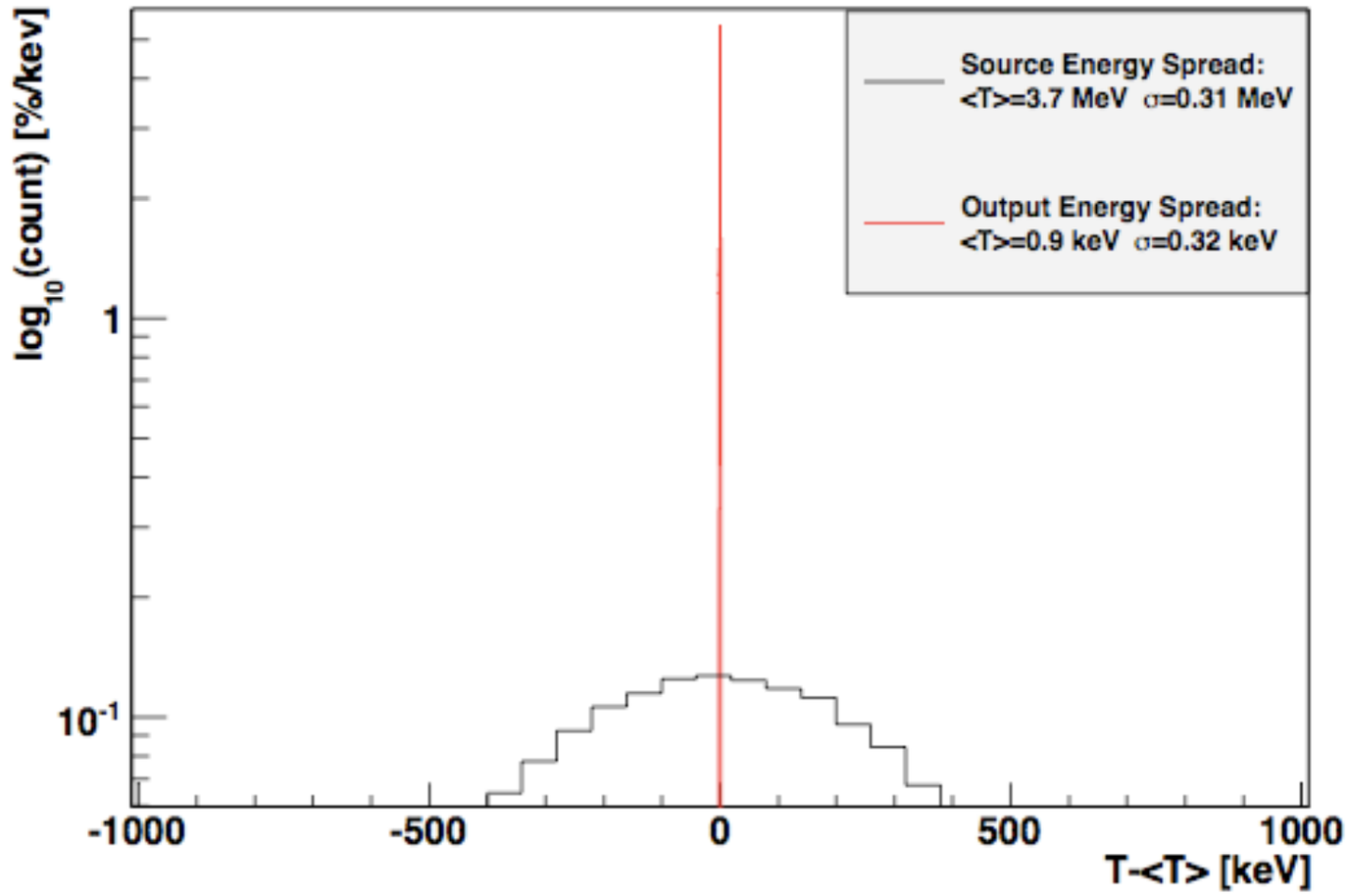
- The concept: fast surface muons enter a He cell, run against an electric field and get cooled, then get extracted in a weak dipole field

Slow Muons at PSI: Expected Performance

Simulation Results:

- Muons are cooled to 1 keV with an energy spread of 320 eV
- With a surface muon rate of 2.2 x10^8/mAs, the slow muon production rate is over 2×10^6/mAs
- 3 orders of magnitude increase over present rate at PSI!

⇨ Paper in preparation

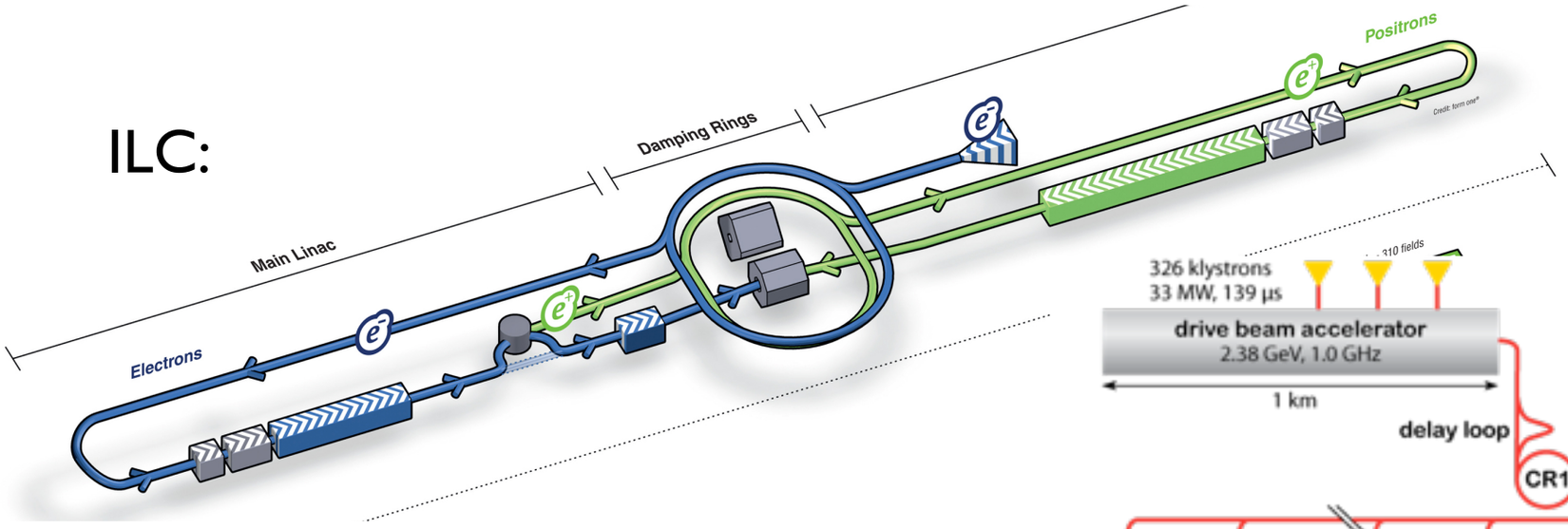


Linear Collider Projects

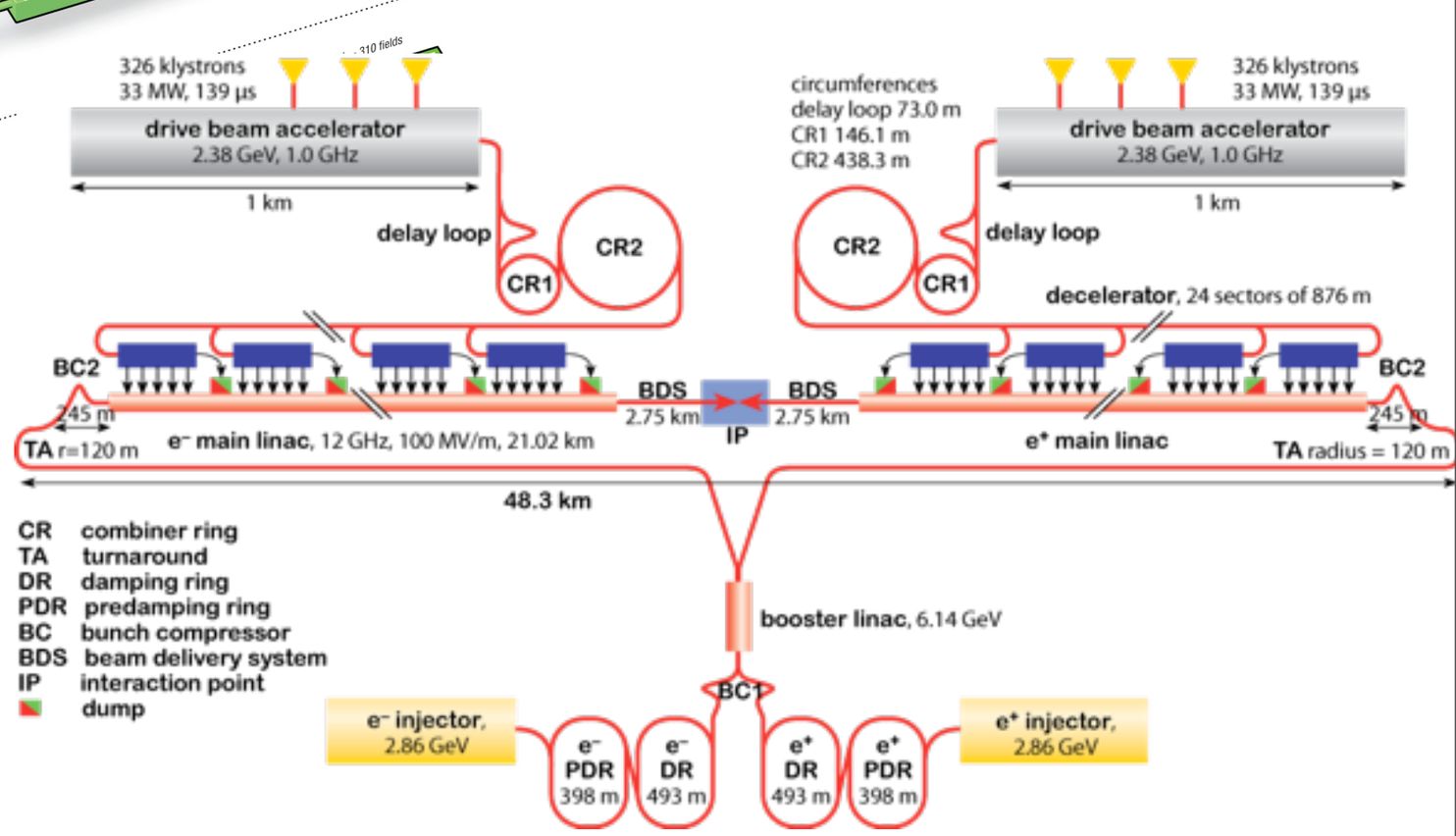
Linear Collider: A Question of Energy

- LHC results will show which energy is needed for a future e^+e^- collider
  - Two options:
    - Low energy (initially 500 GeV) with superconducting RF: ILC
    - High energy (3 TeV) with a two beam acceleration scheme: CLIC

ILC:



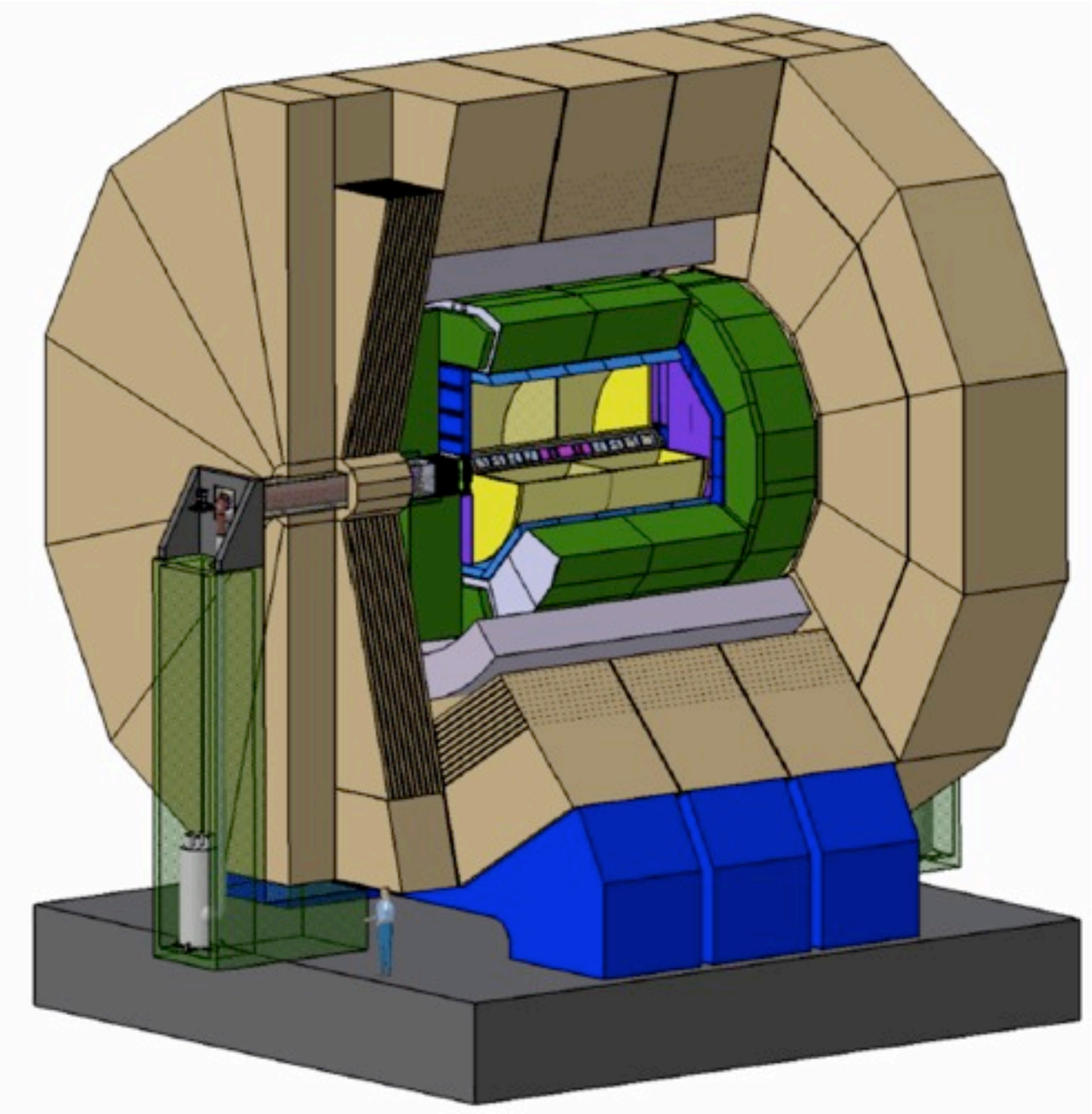
CLIC:



- Different technologies but similar challenges: Increasingly close collaboration on machine and detector issues

Validation of ILC Detector LoIs

- Submission of Detector Letter of Intents to IDAG end of March 2009
  - Significant MPI contributions to the ILD LoI (Vertex, TPC, HCAL, Physics)



- Coherent layout of the detector
  - High performance, low mass vertexing
  - High resolution, low mass main tracker (TPC)
- Highly granular calorimeters, optimized for Particle Flow

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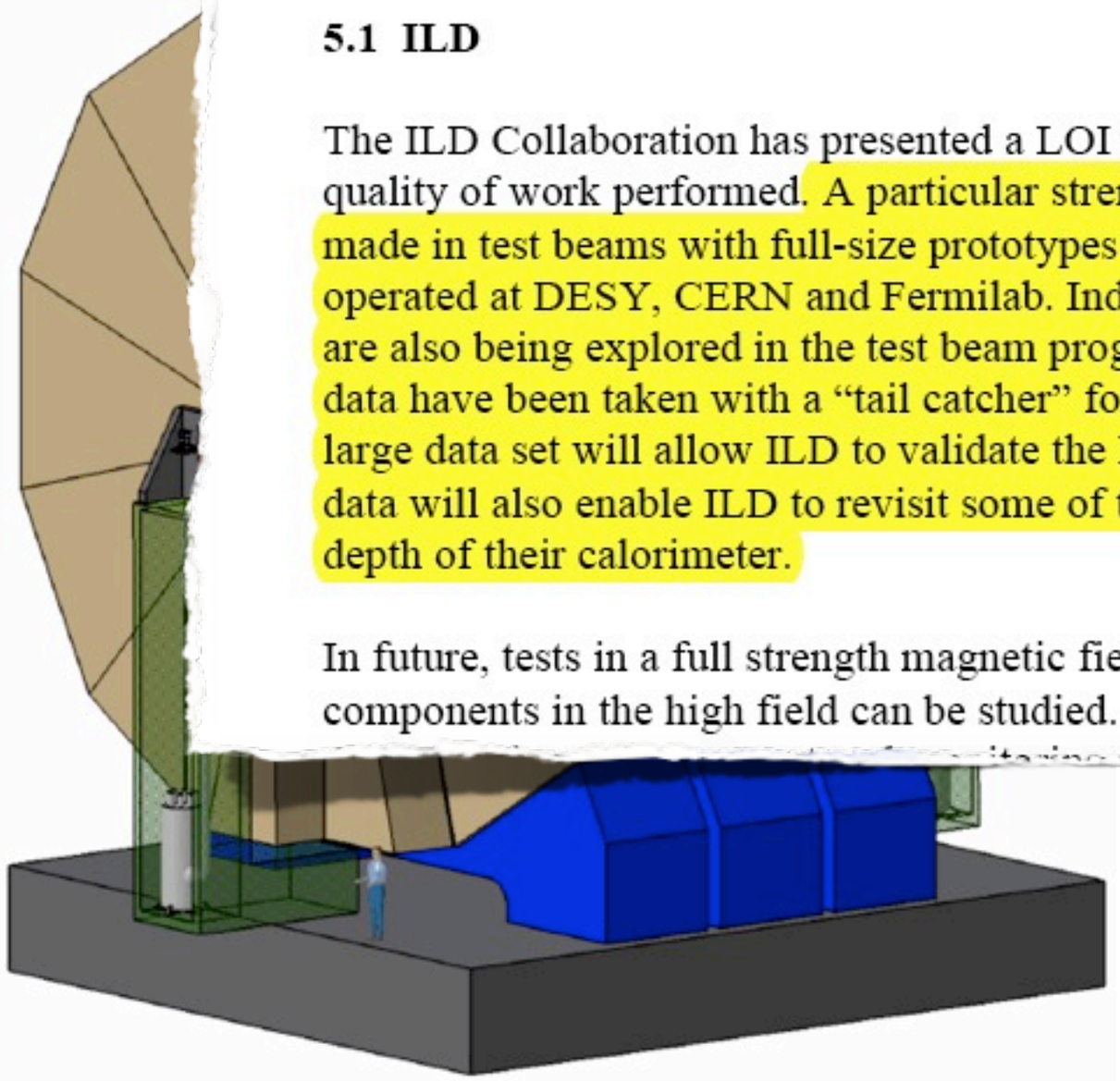


5. EVALUATION OF THE THREE CONCEPTS

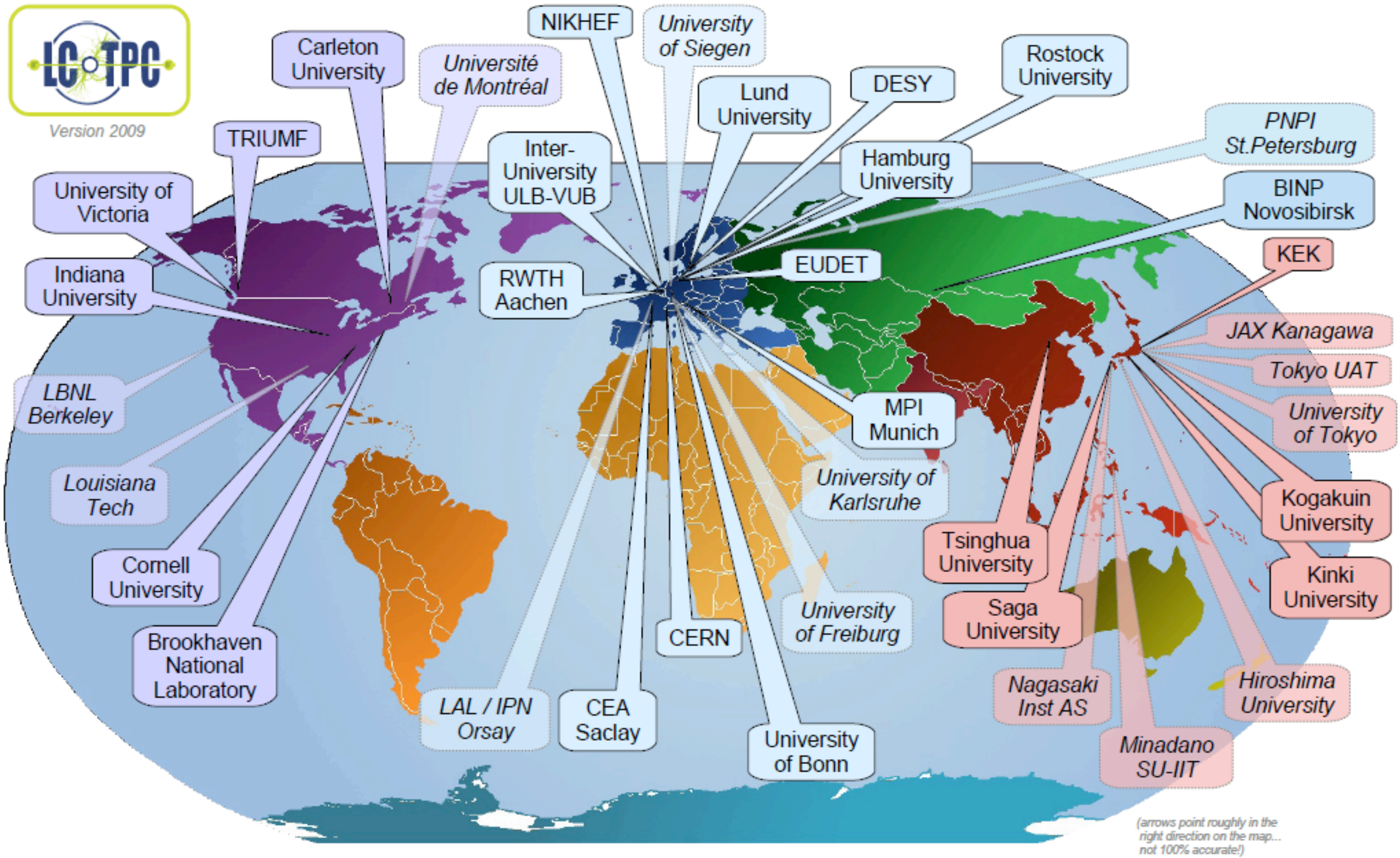
5.1 ILD

The ILD Collaboration has presented a LOI which documents the impressive quantity and quality of work performed. A particular strength of the LOI is the very extensive R&D effort made in test beams with full-size prototypes of the calorimeter having been constructed and operated at DESY, CERN and Fermilab. Indeed, alternative technologies for the calorimetry are also being explored in the test beam program. Integrated with these calorimeter tests their data have been taken with a "tail catcher" for one of the possible muon system options. This large data set will allow ILD to validate the PF strategy which is central to their design. The data will also enable ILD to revisit some of their parameter choices, for example the total depth of their calorimeter.

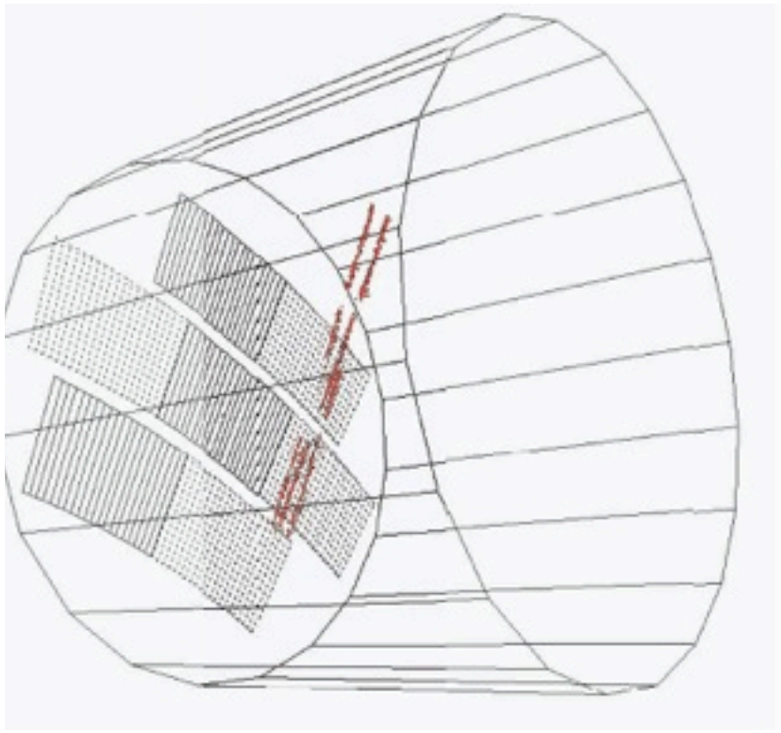
In future, tests in a full strength magnetic field will be made. Initial layout of power and other components in the high field can be studied. Prototyping of the TPC is ongoing in other tests.

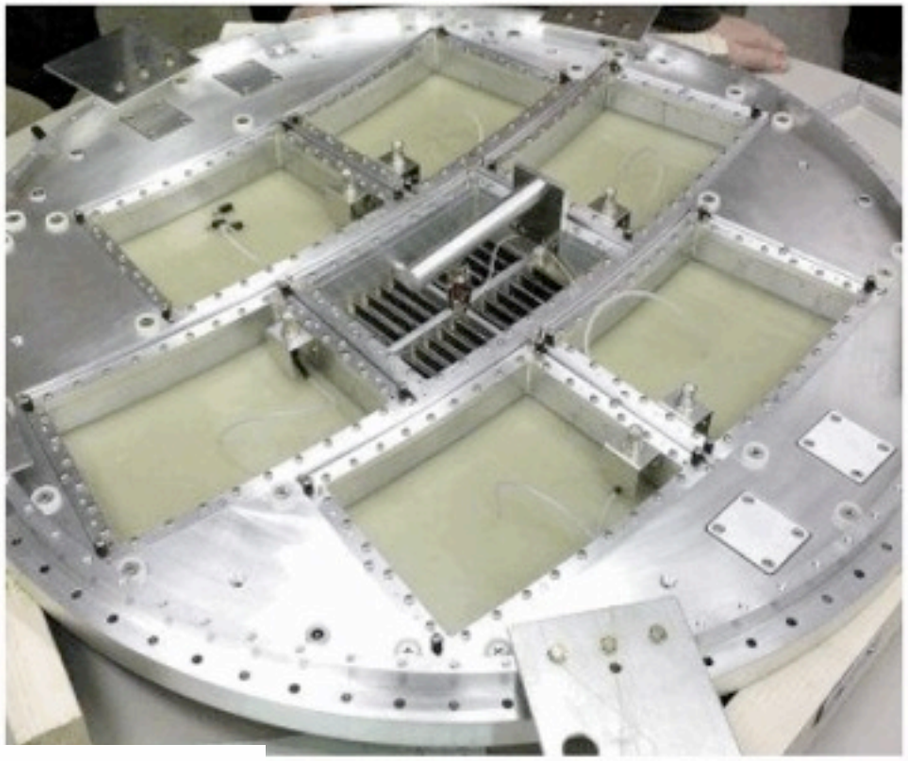
The detailed studies on calorimetry with a strong MPI participation played a crucial role in the validation of the ILD concept!

LCTPC: The main Tracker

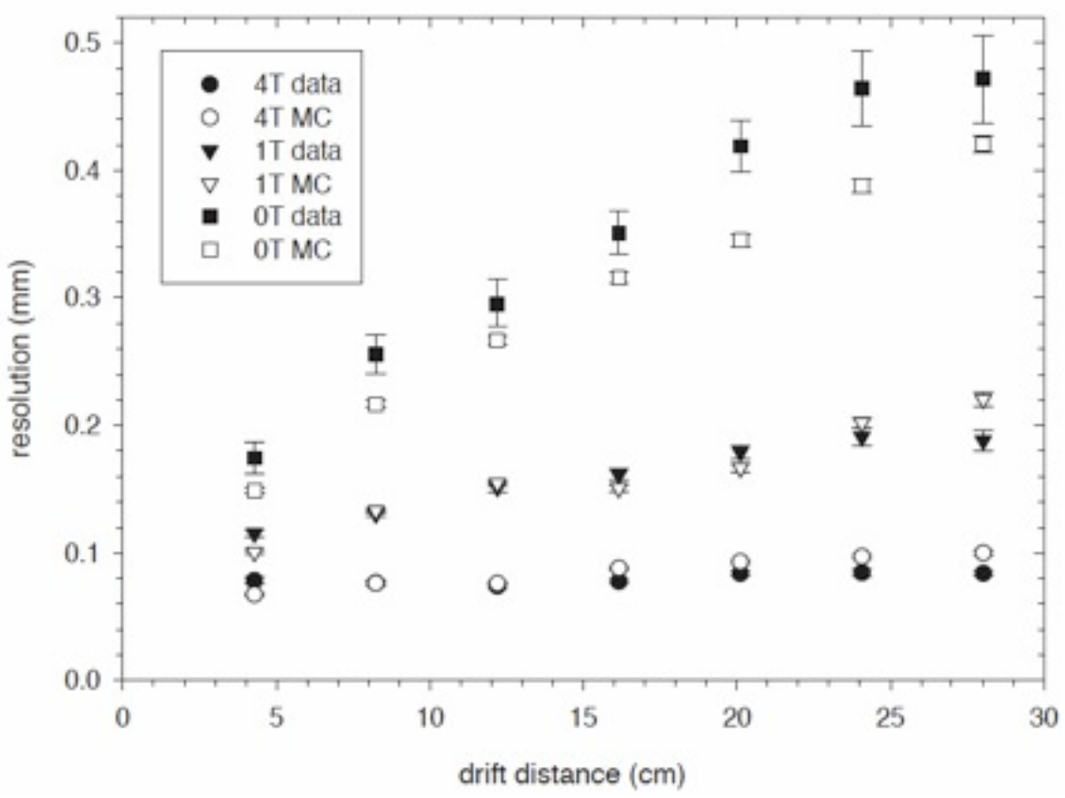


LCTPC





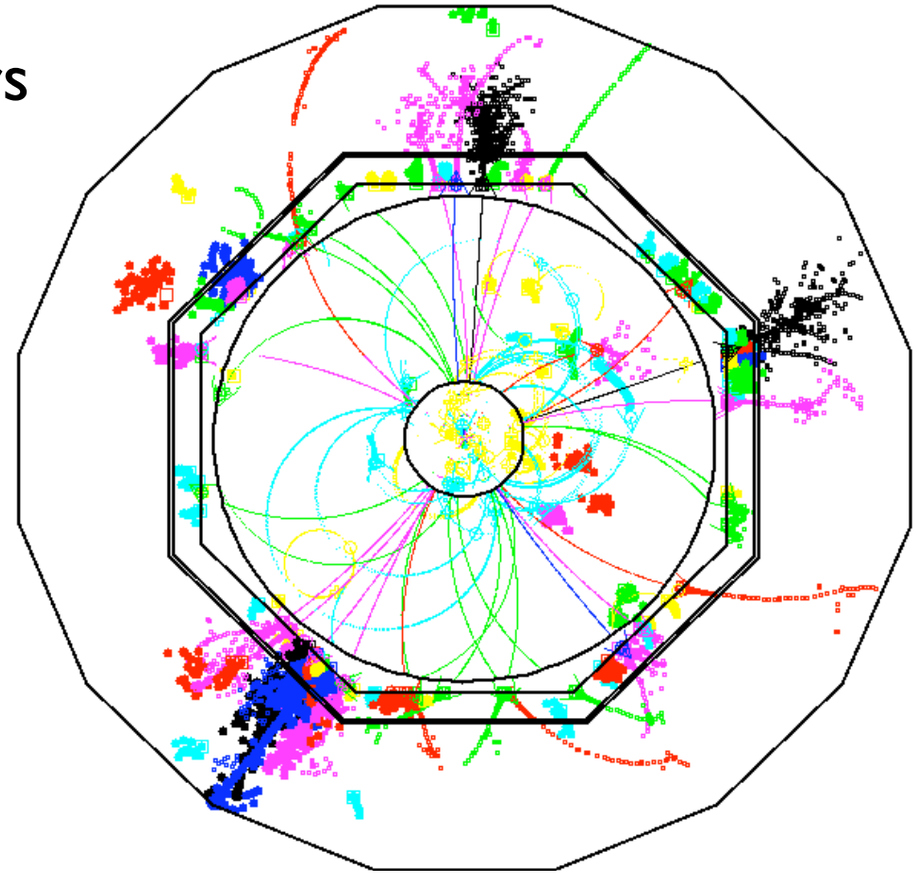
- Large prototype: Evaluate different readout technologies
- First test beam events recorded



- Measurement of resolution as a function of drift distance with the small prototype (partially built at the MPI)
  - Gas: $ArCH_4CO_2$ (95-3-2)

CALICE: Imaging Calorimetry

- Development of highly granular "imaging" calorimeters for detectors at a future Linear Collider
  - Evaluate different technologies to find the best solution for a future experiment
- The physics benefit: Unprecedented 3D resolution of hadronic showers, will help to improve hadronic shower models in simulations



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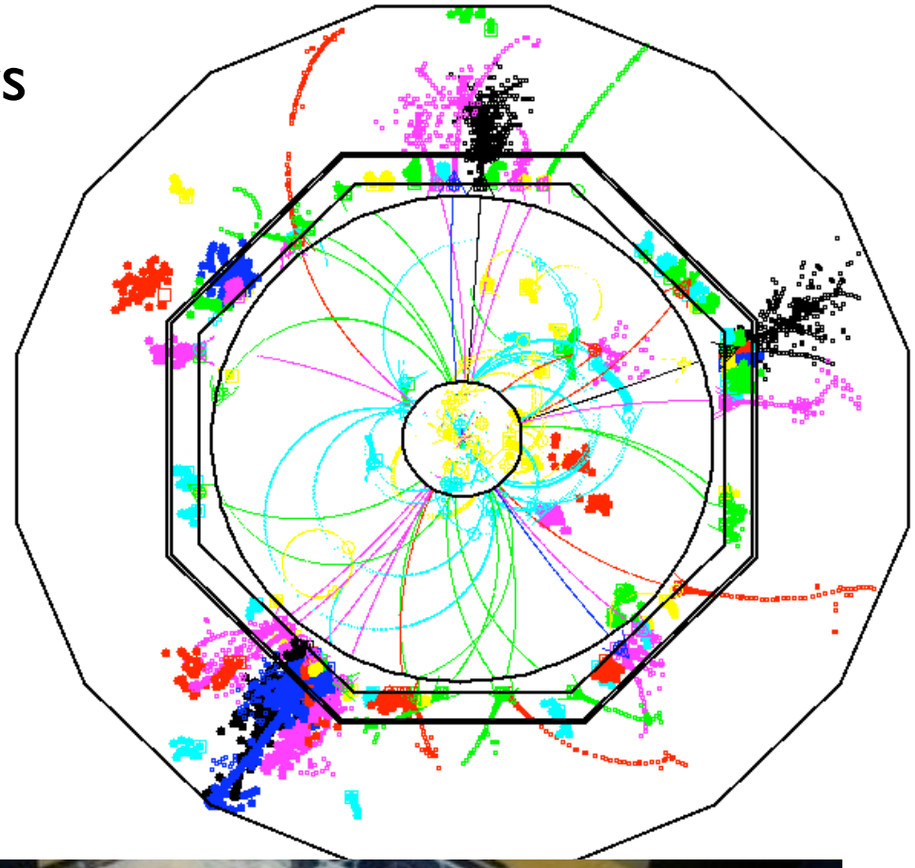
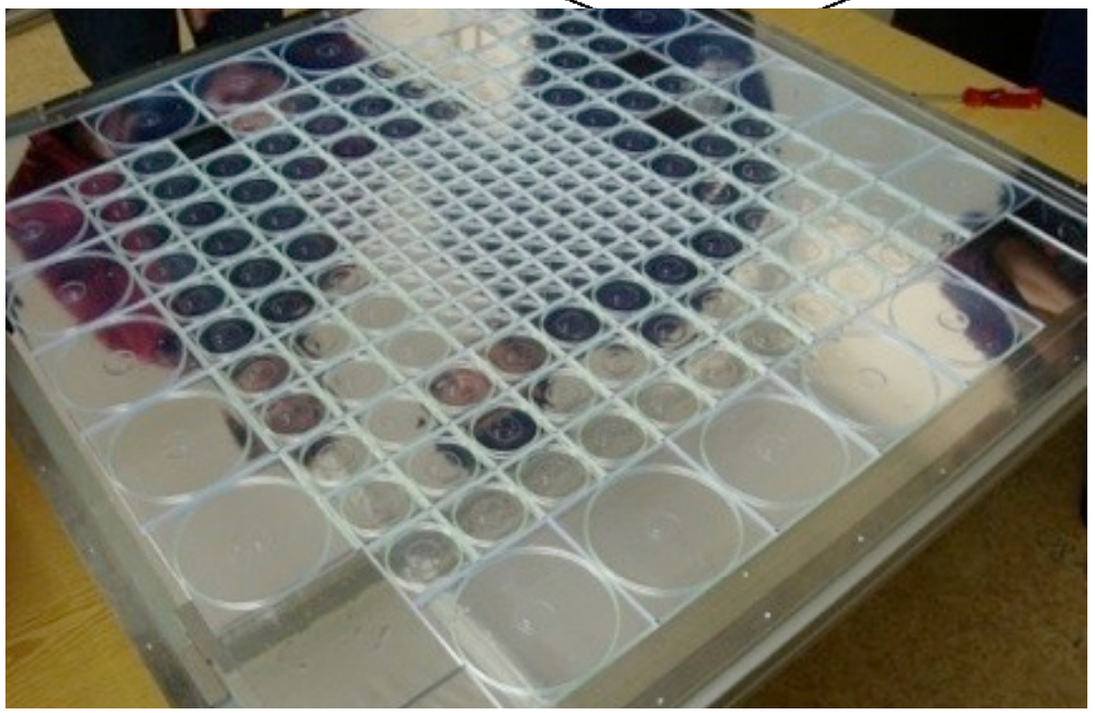
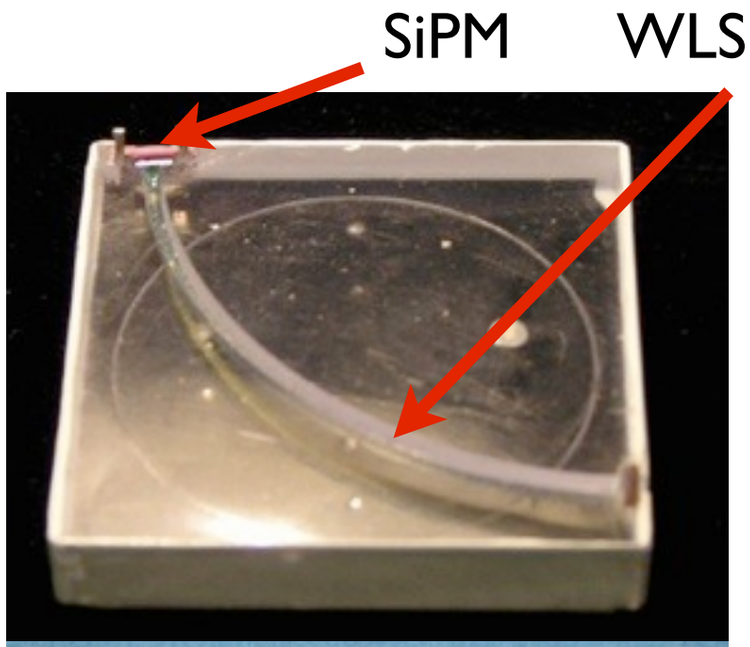
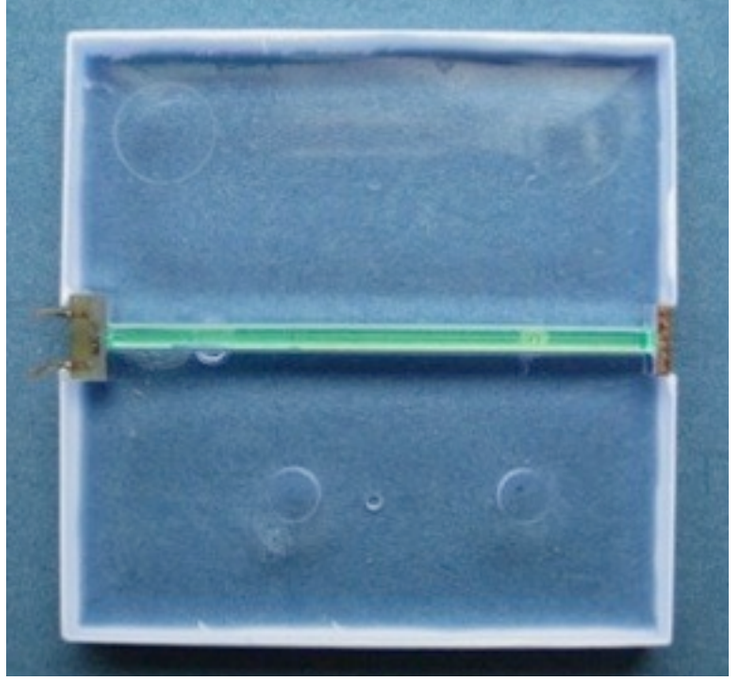


- The first generation analog HCAL completed data taking at Fermilab in May 2009
- Technology: Small scintillator tiles individually read out with SiPMs



New Ideas for Scintillator Tiles



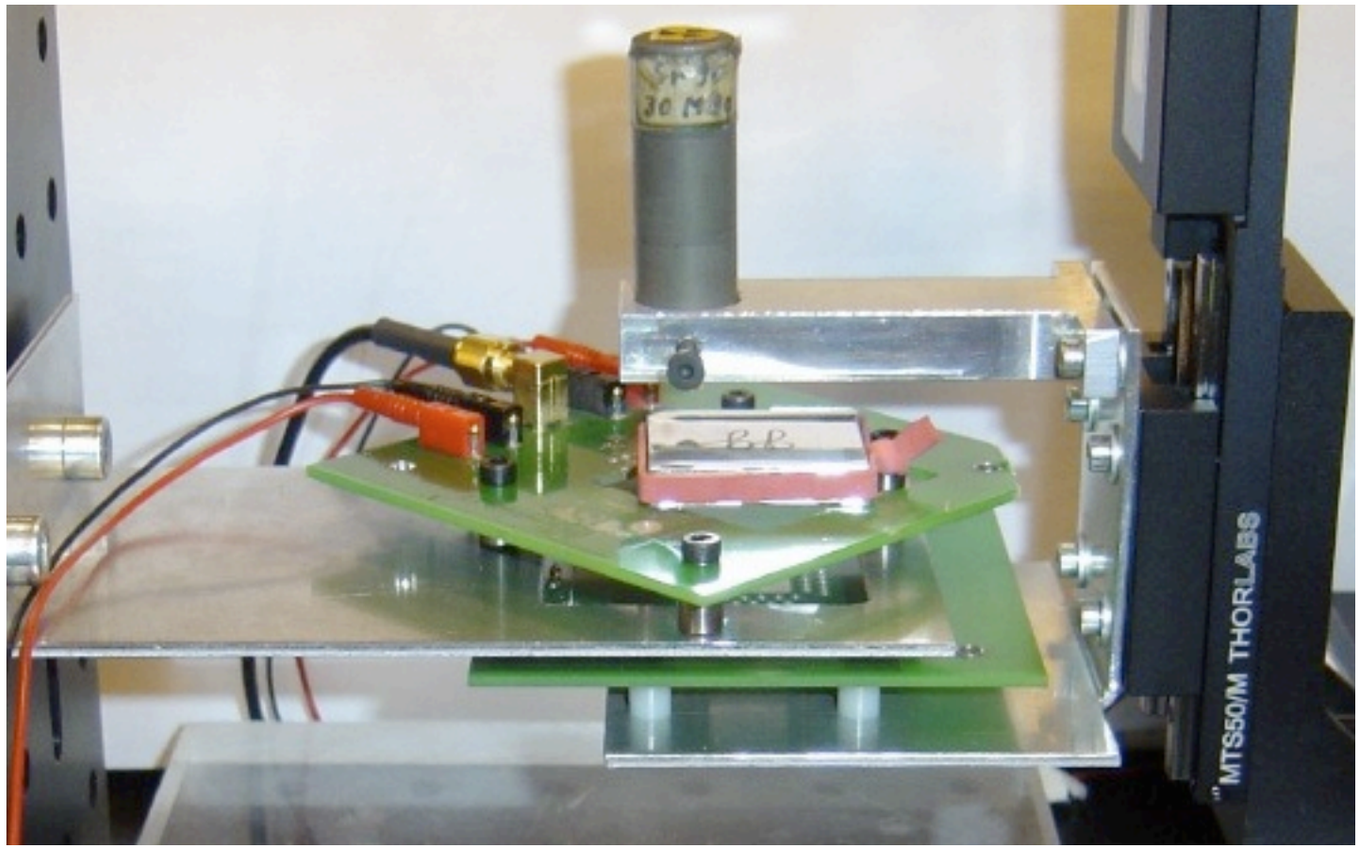


- Present prototype: SiPM coupled to WLS fiber in the scintillator
  - Was needed since maximum efficiency of the first generation SiPMs is in the green spectral range
  - Added benefit: Fiber improves light collection uniformity

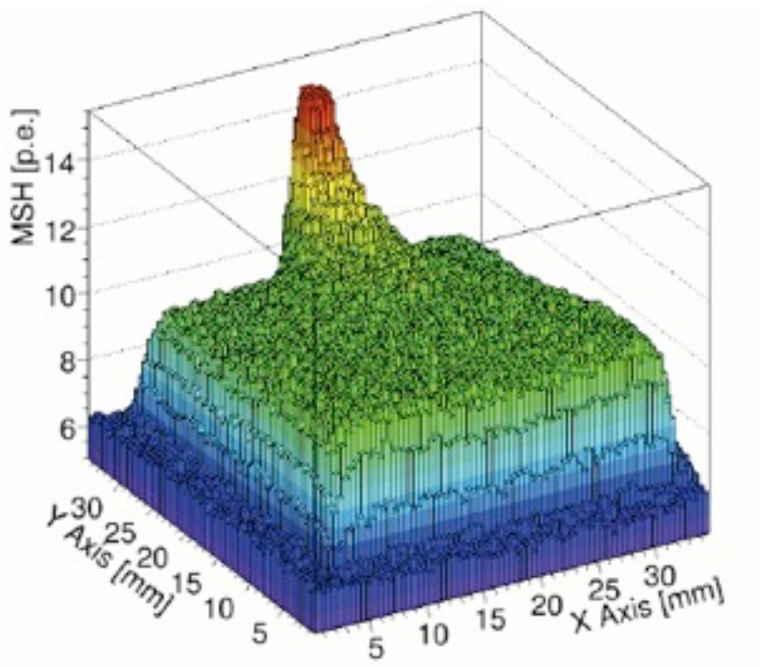
- SiPM + Fiber also used as baseline for the next generation prototype, but:

- New SiPMs are blue sensitive: Fiber not needed, is an added mechanical complication
  - Uniformity of response over the tile area challenging without fiber!

Direct Coupling of SiPMs with Optimized Uniformity



- Scanning of the response of scintillator tiles with SiPM readout
- ^{90}Sr source, XY stage



Large non-uniformity with directly coupled SiPM

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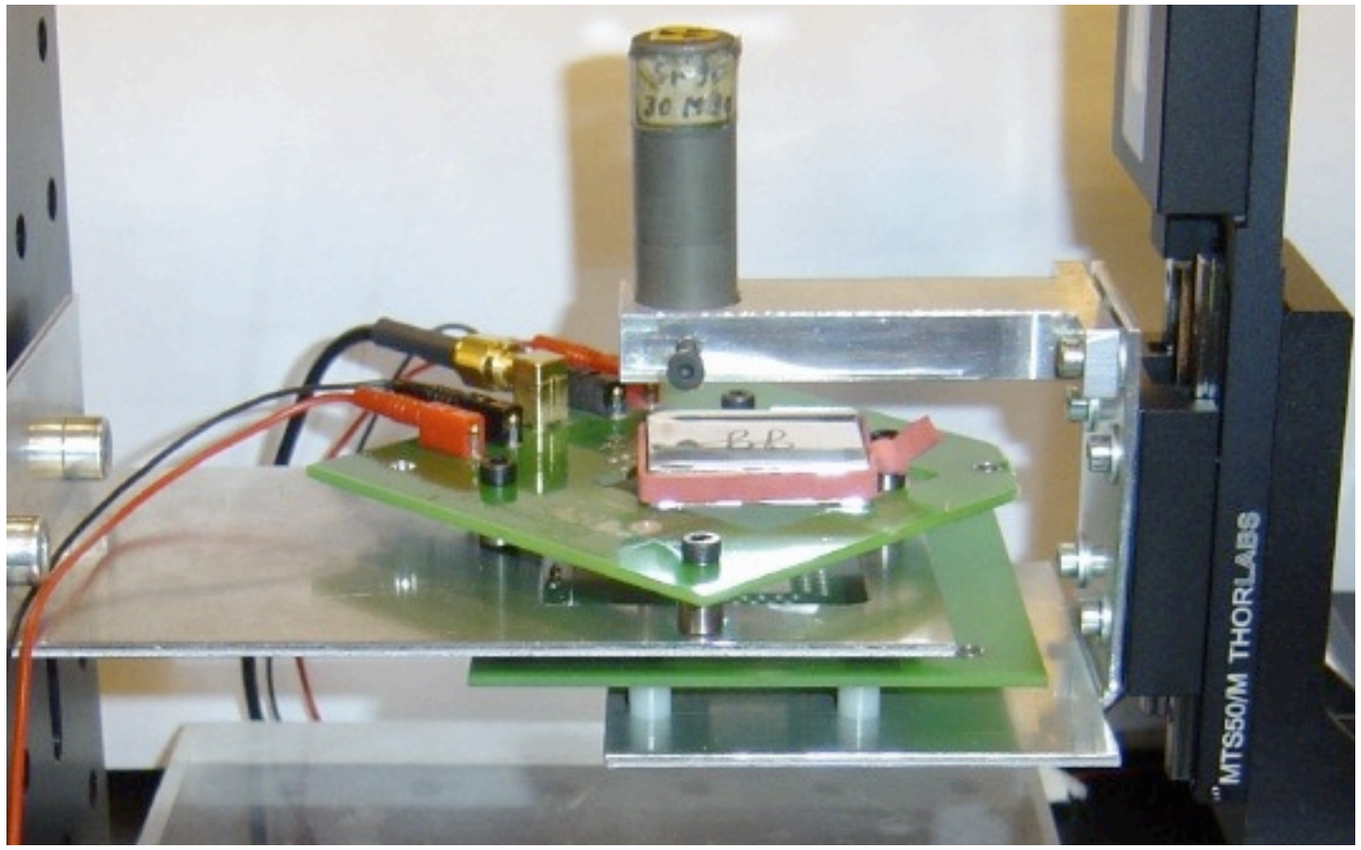

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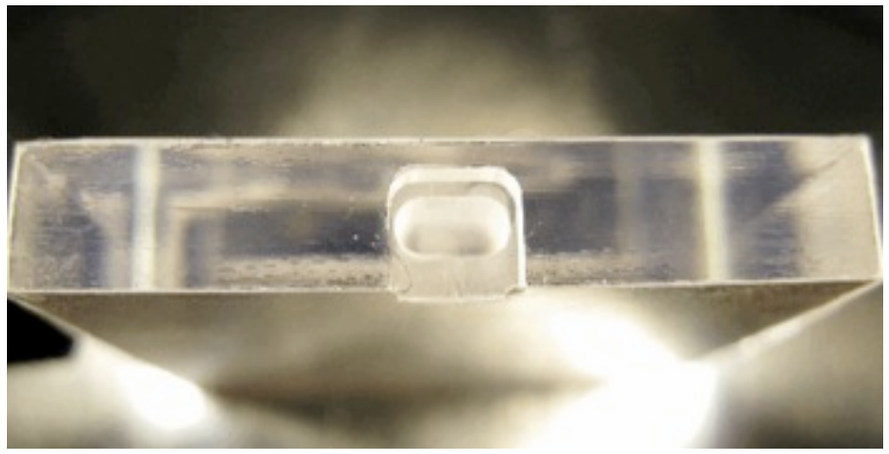
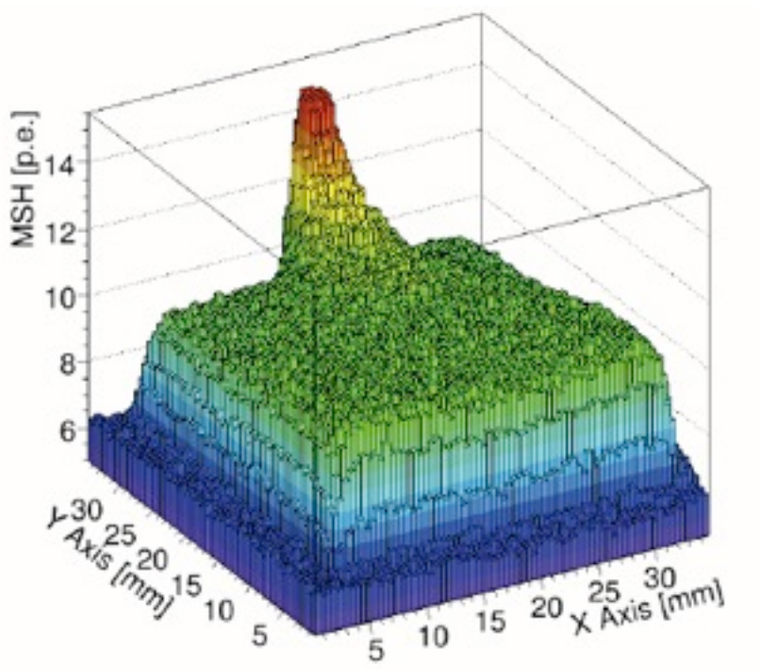
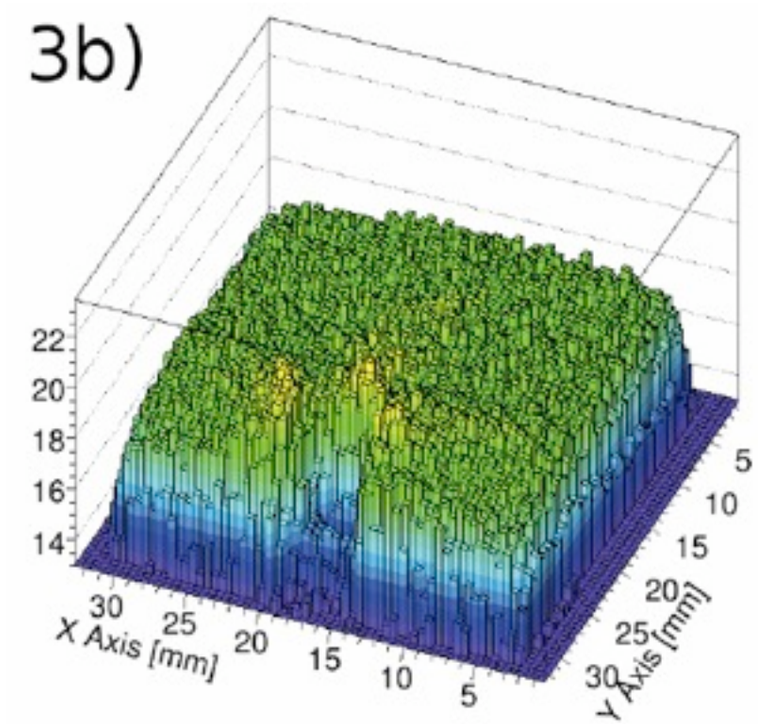




Large non-uniformity with directly coupled SiPM

Substantial improvement with "dimple" at the SiPM coupling



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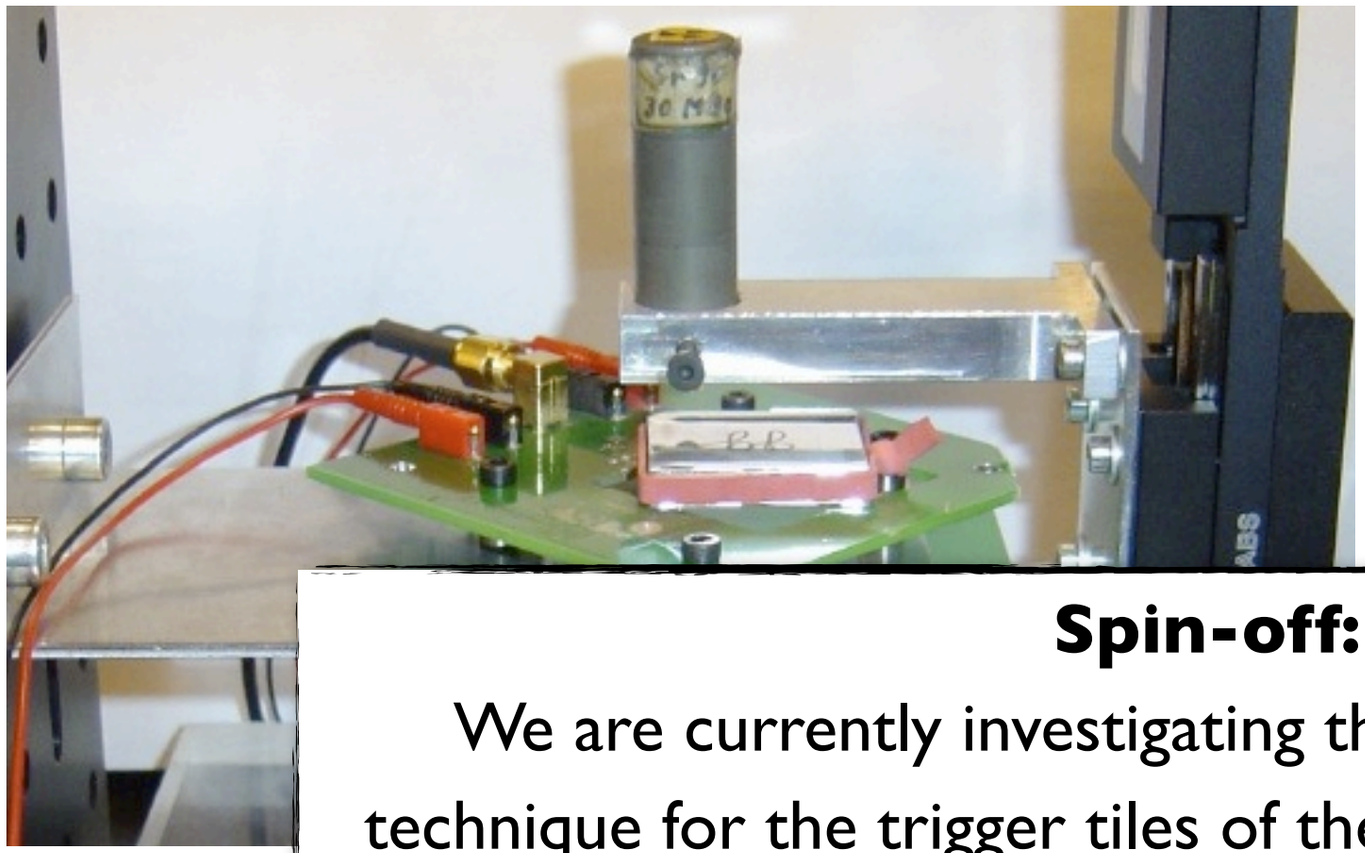

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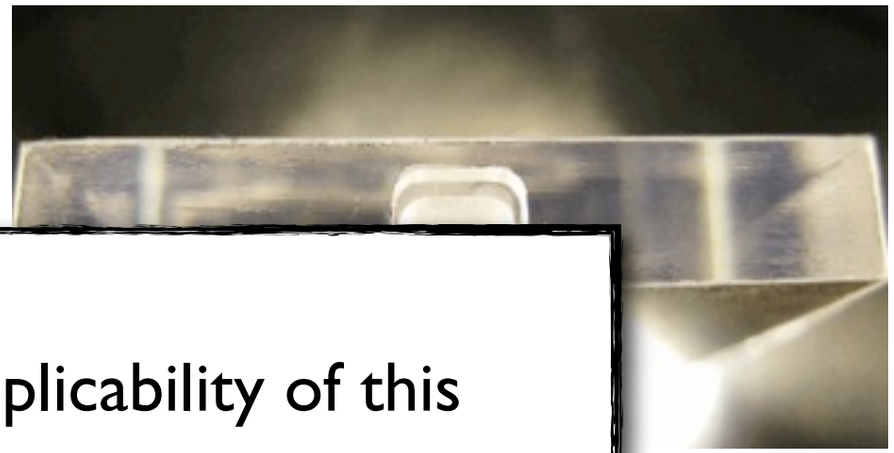
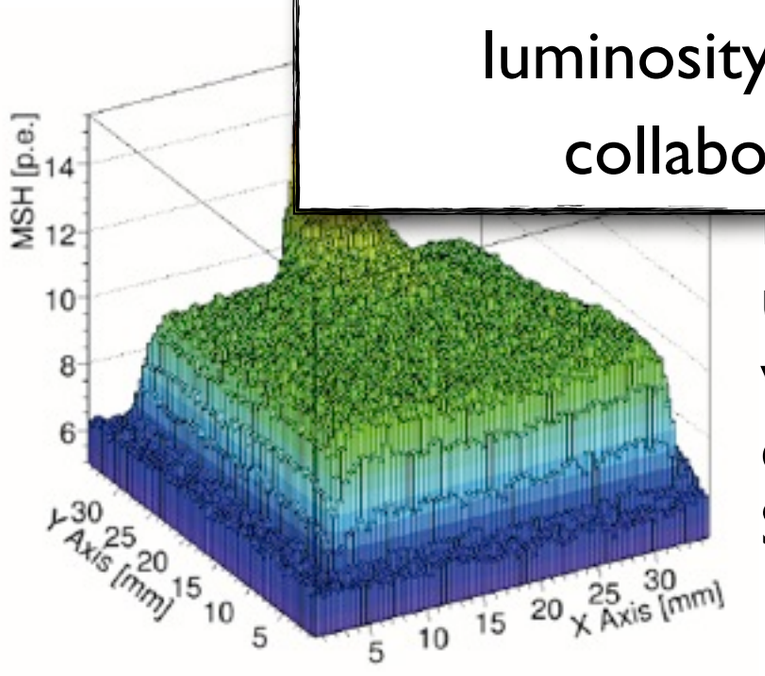


Spin-off:

We are currently investigating the applicability of this technique for the trigger tiles of the ATLAS ALFA (absolute luminosity measurement for ATLAS) experiment in collaboration with the CERN detector group



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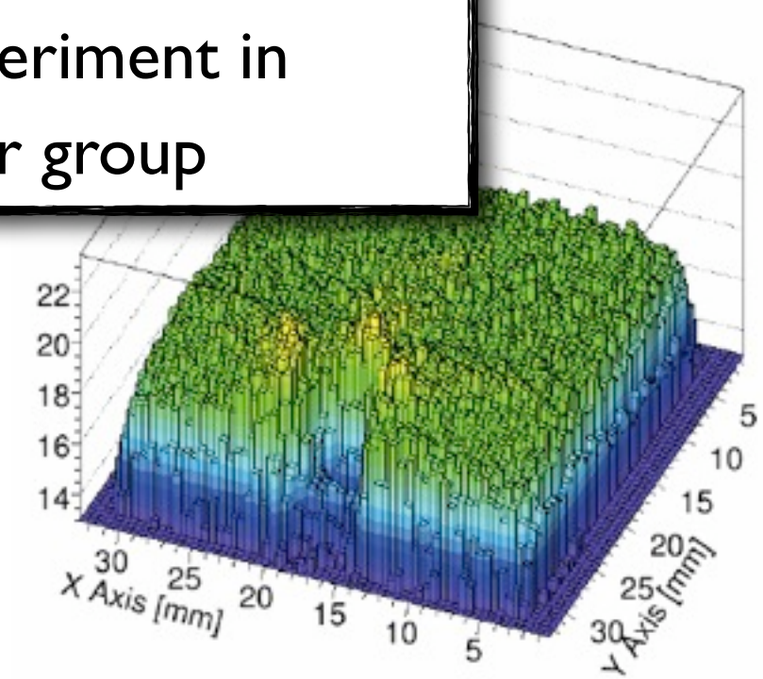
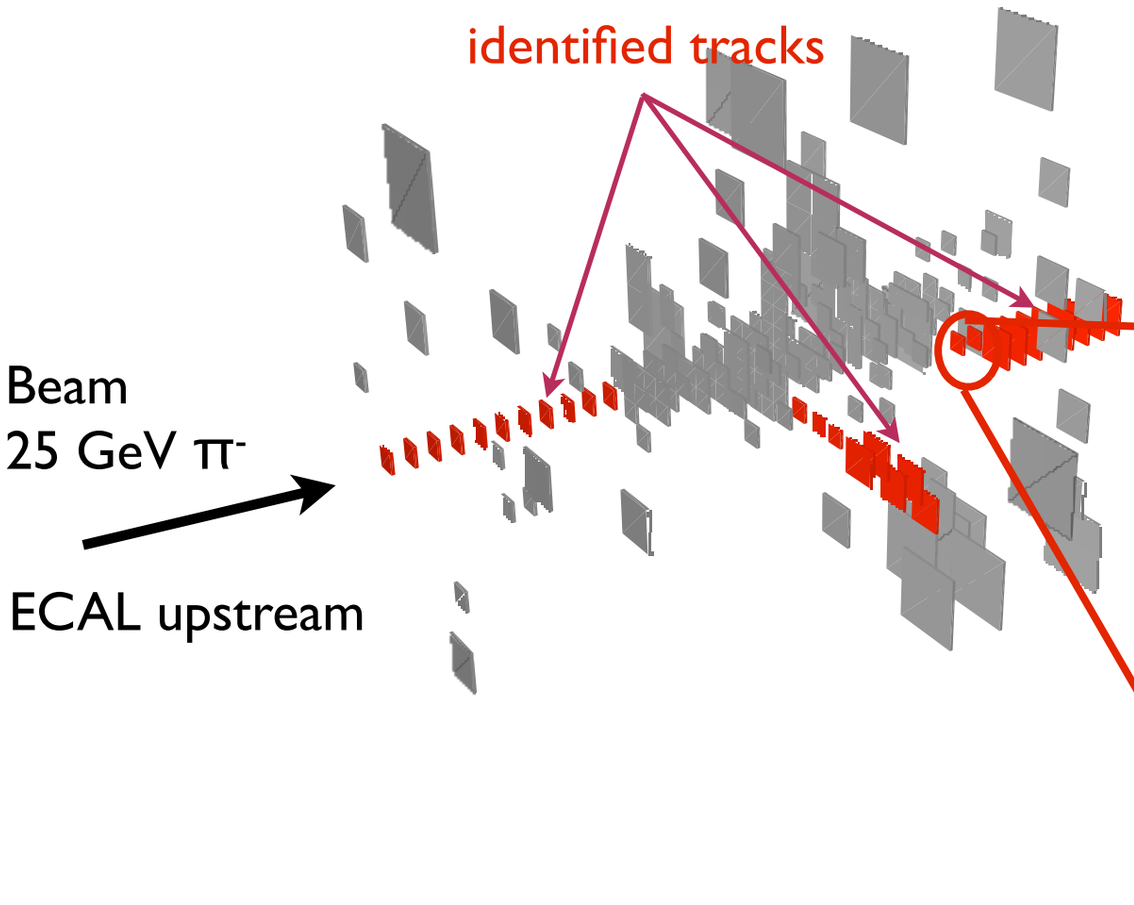
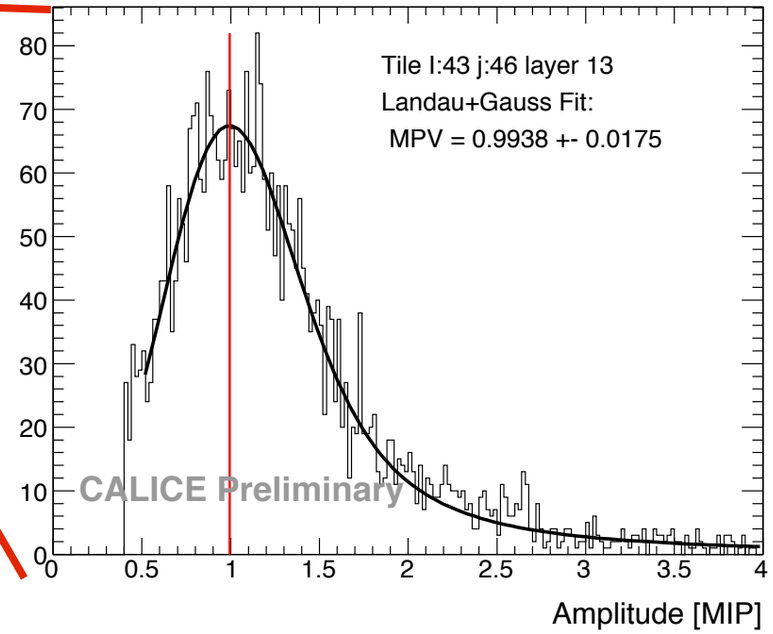


CALICE: Shower Substructure and Calibration



- Imaging capability of detector allows the identification of individual MIP-like tracks within hadronic showers



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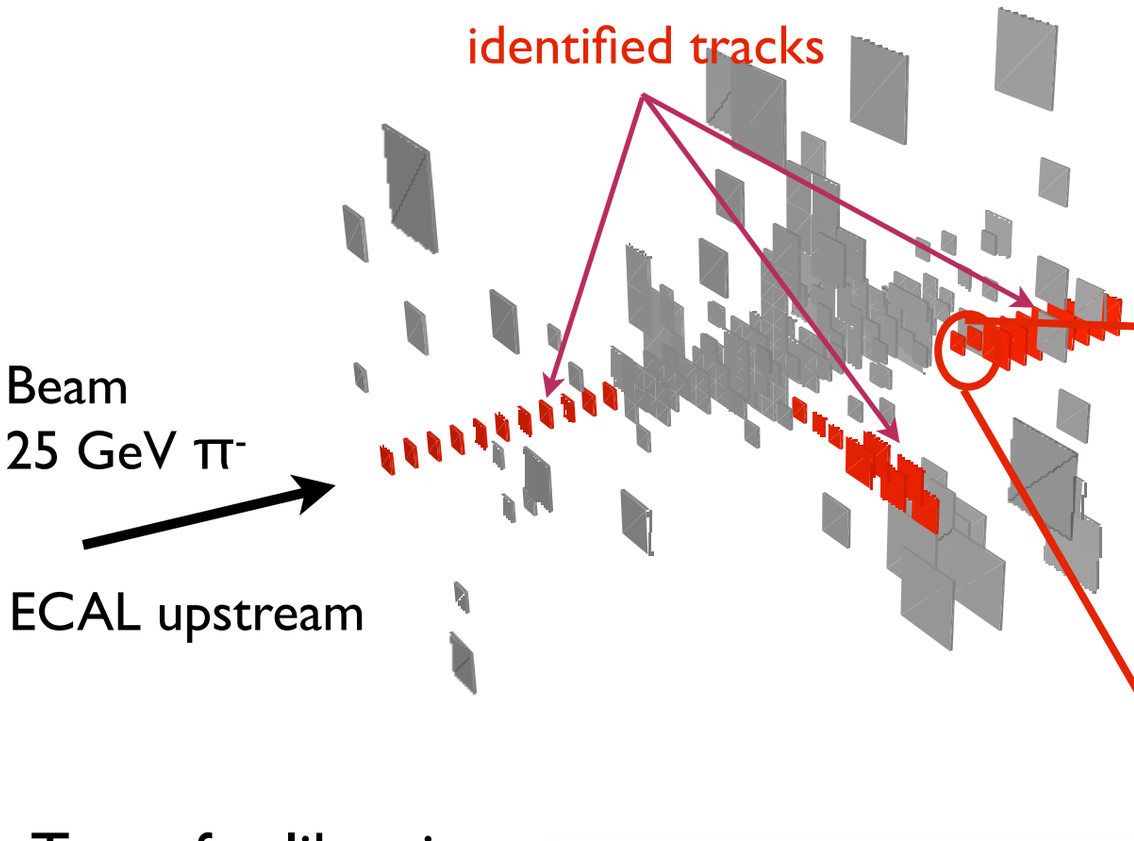

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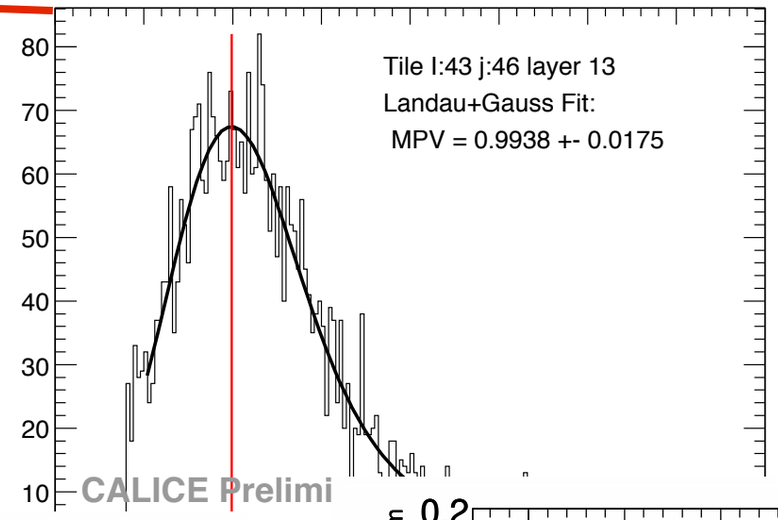
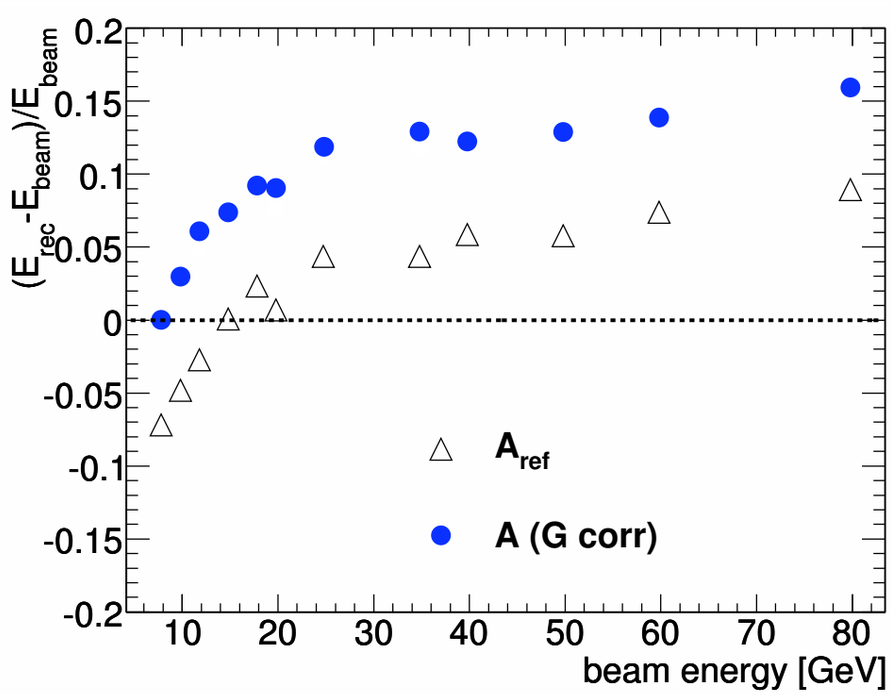
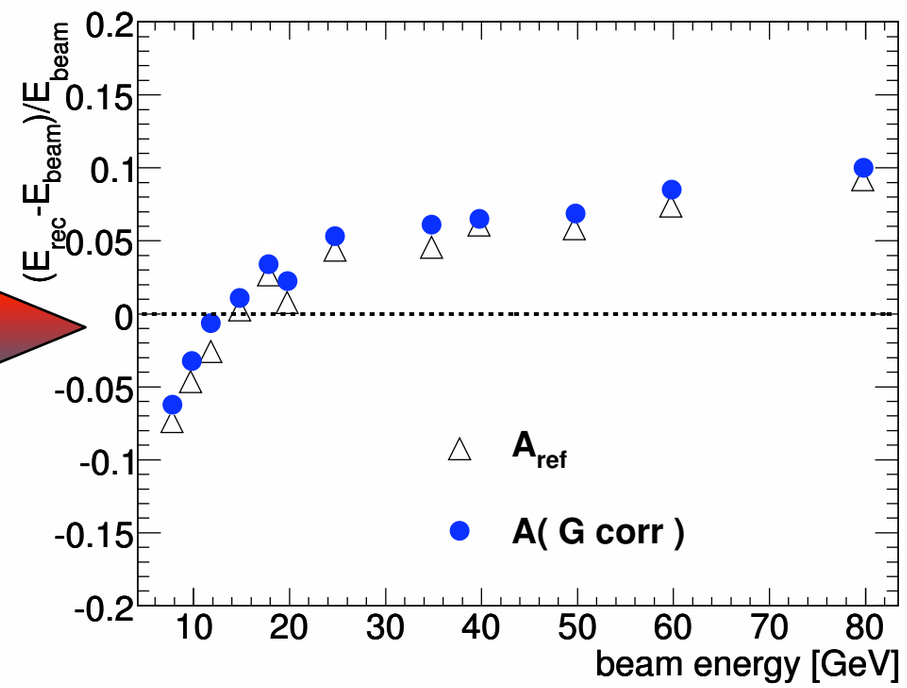


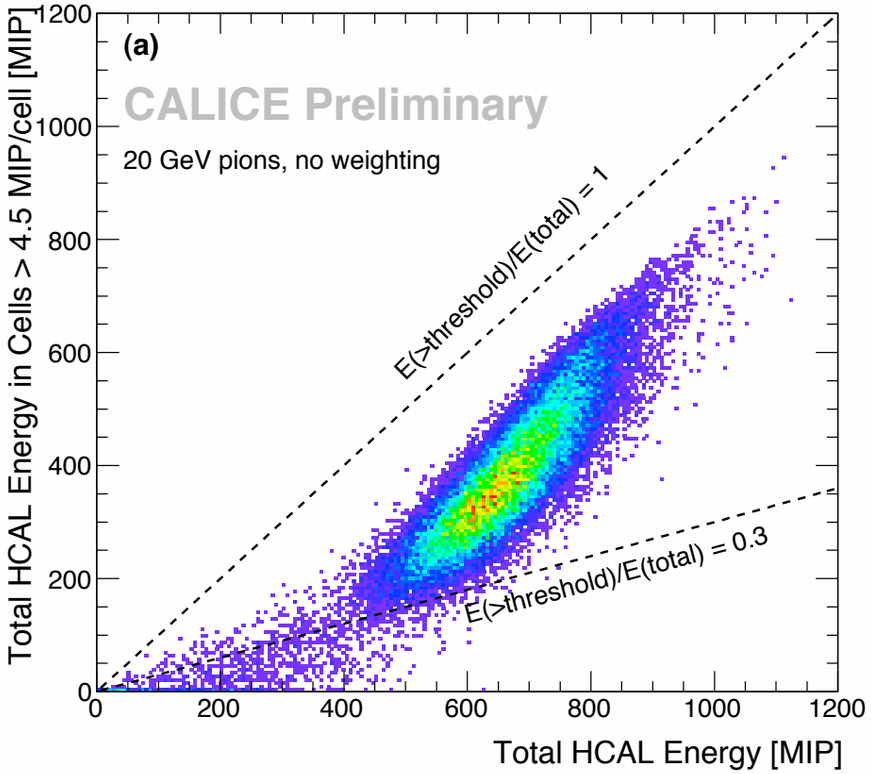
- Test of calibration strategy: Transport of constants from FNAL to CERN, correction with track segments



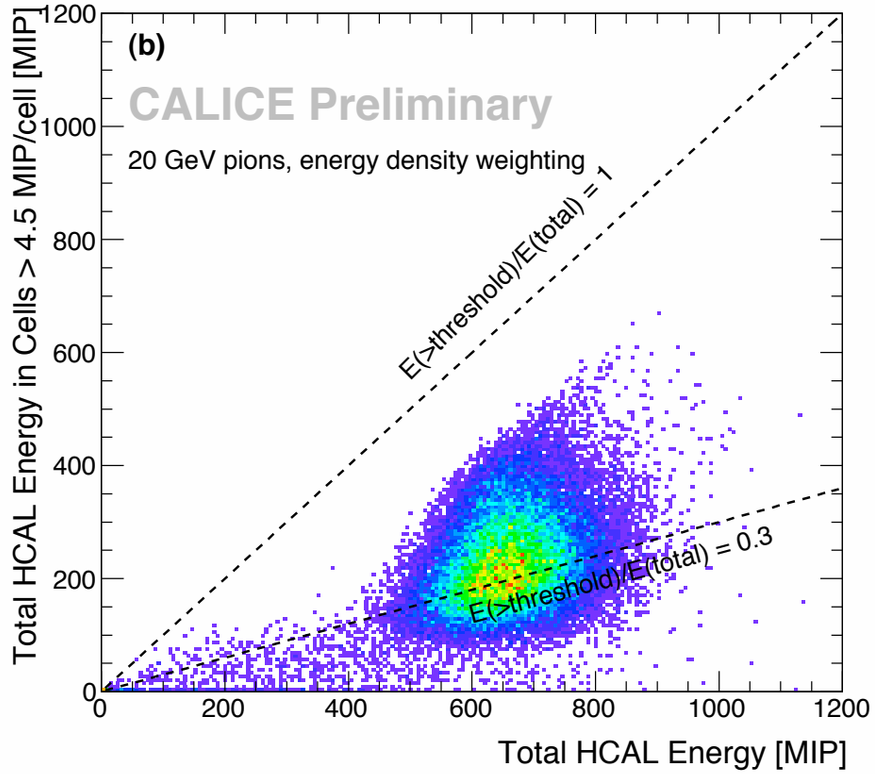


CALICE HCAL: Energy Reconstruction

- High granularity used for software compensation, several techniques under study
  - Weighting based on local energy density, cells with a high energy content (predominantly em subshowers) get assigned a lower weight in the energy sum



cell-by-cell weights



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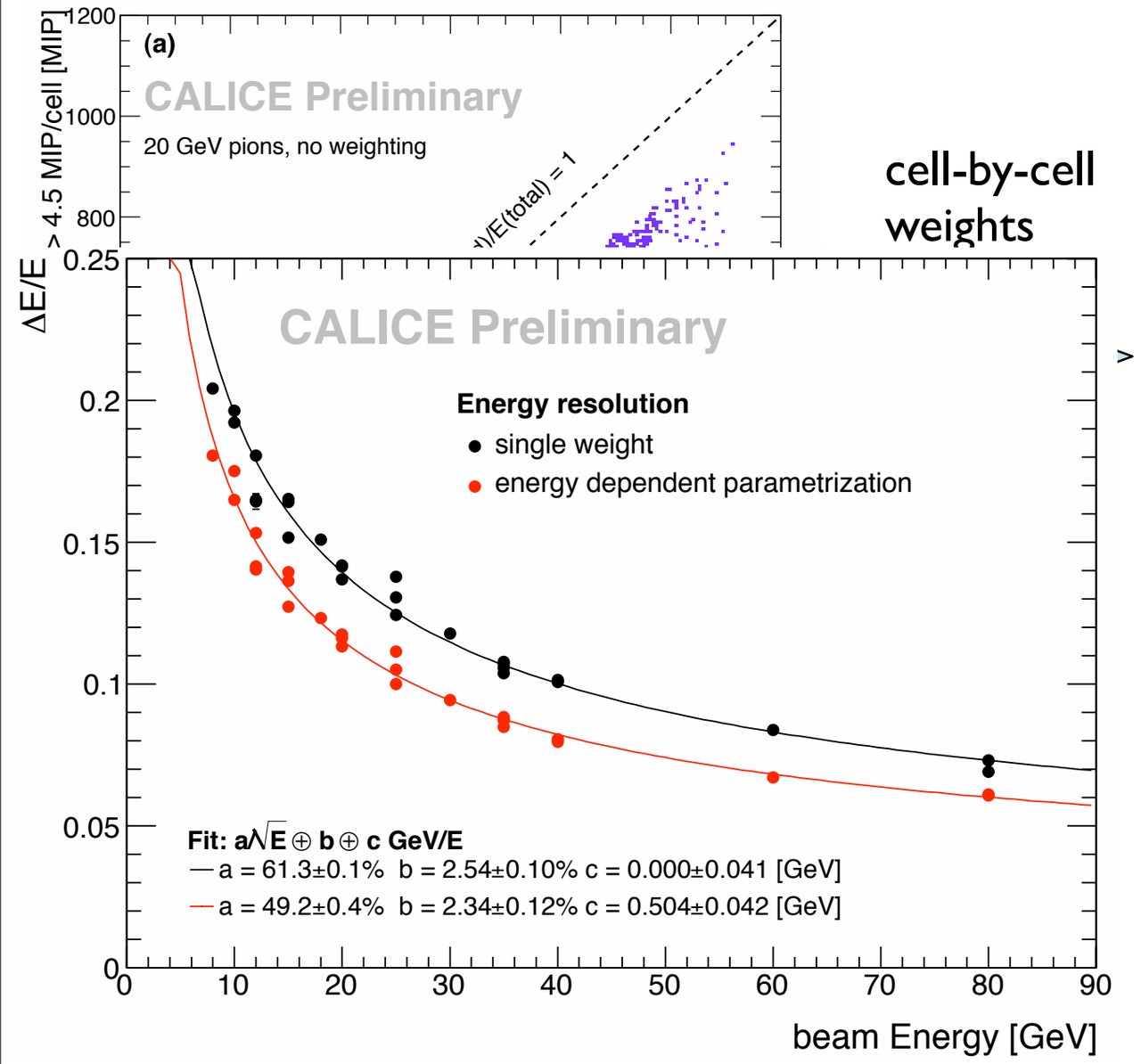
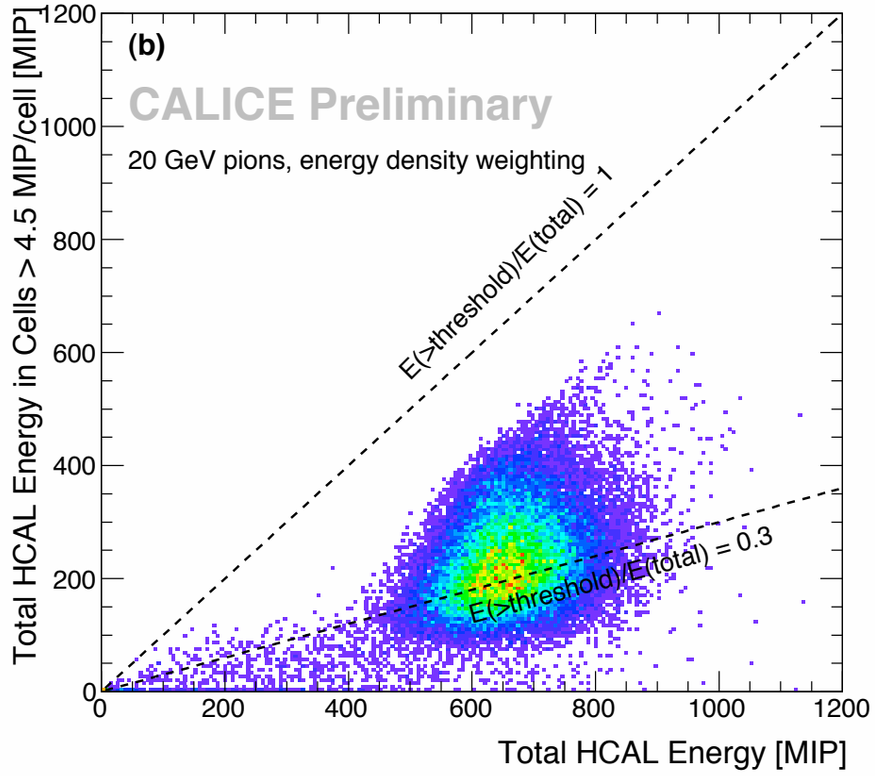
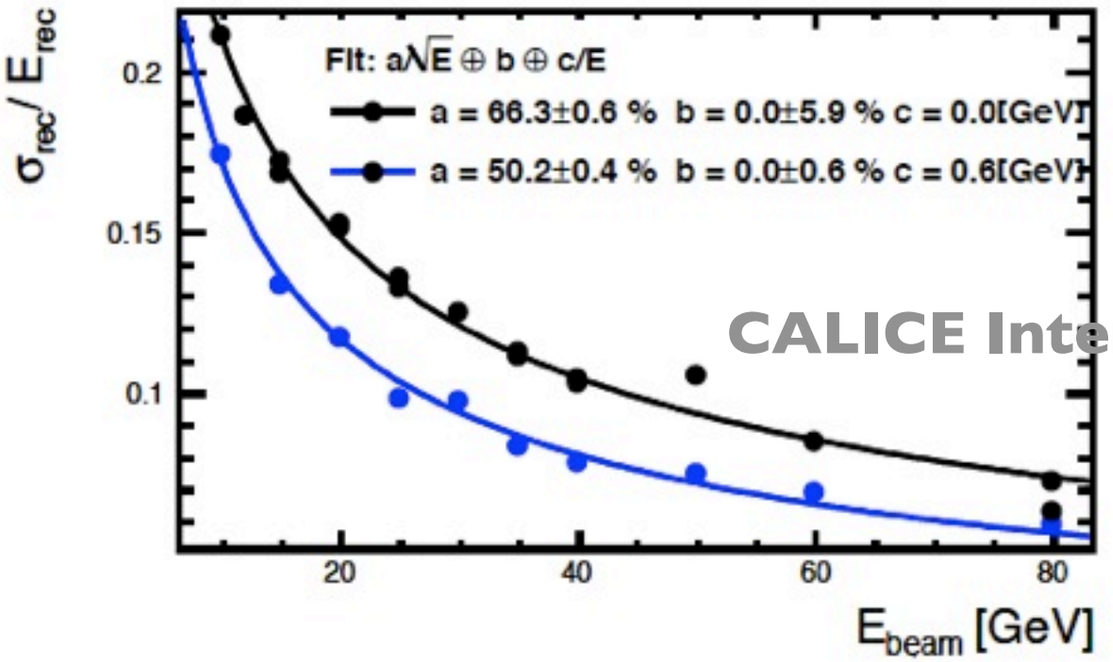




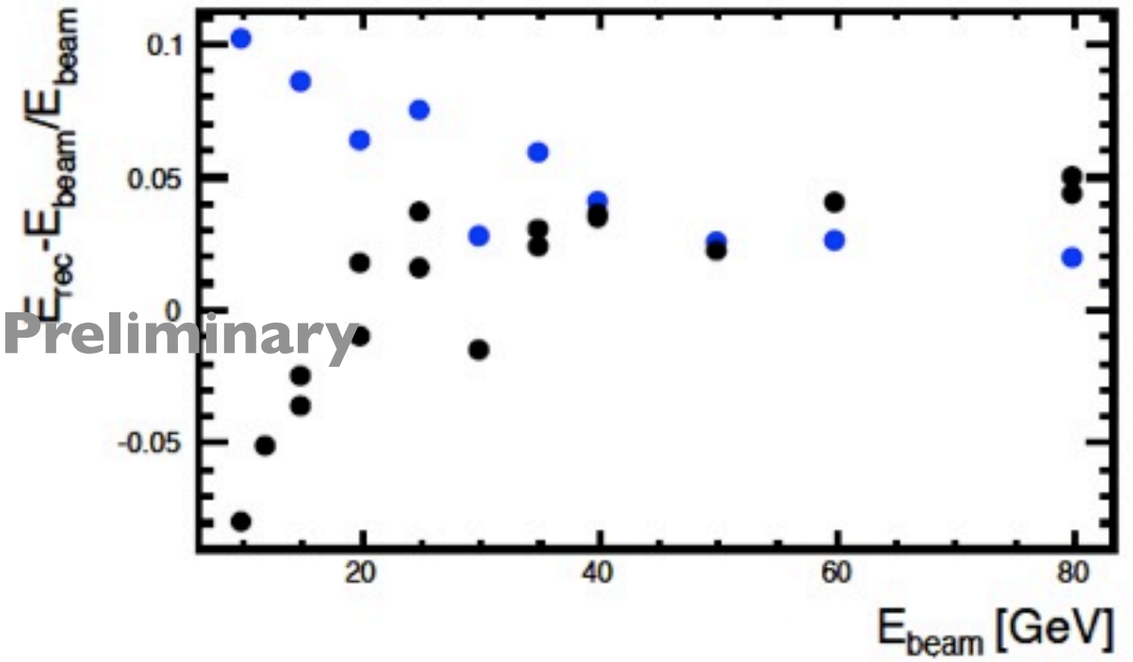
- Improved linearity of the detector response
- 20% improvement of energy resolution: ~50%/$\sqrt{E}$ stochastic term

CALICE HCAL: Energy Reconstruction

- Neural Networks under study, in combination with shower clustering
- Use a large MC sample with quasi-continuous energy distribution for training



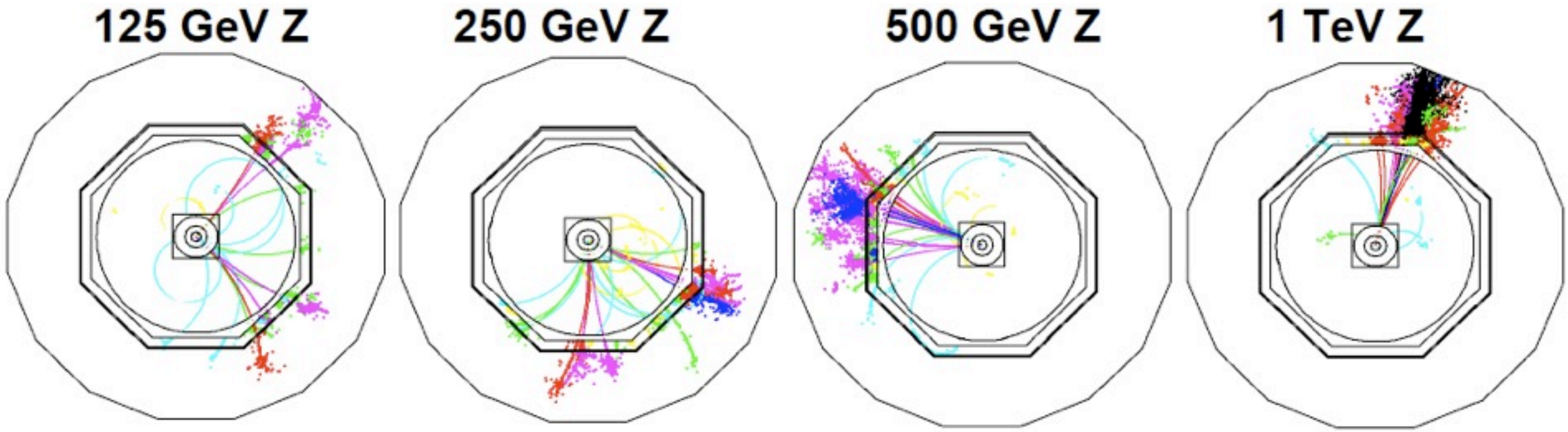
CALICE Internal Preliminary



- First promising steps: 50%/$\sqrt{E}$ stochastic term achieved
- Problems with linearity at low energies: Partially due to missmatch between data and MC distributions

Challenges at High Energy

- Calorimetry at a Multi-TeV Linear Collider brings new Challenges
  - Now an integral part of the CALICE Program



ILD-like detector, with 8 λ deep HCAL (M. Thomson, ALCPG09)

A key issue: Leakage! ⇨ Deep HCAL required, potentially with a very dense absorber to satisfy the space constraints: Investigate Tungsten

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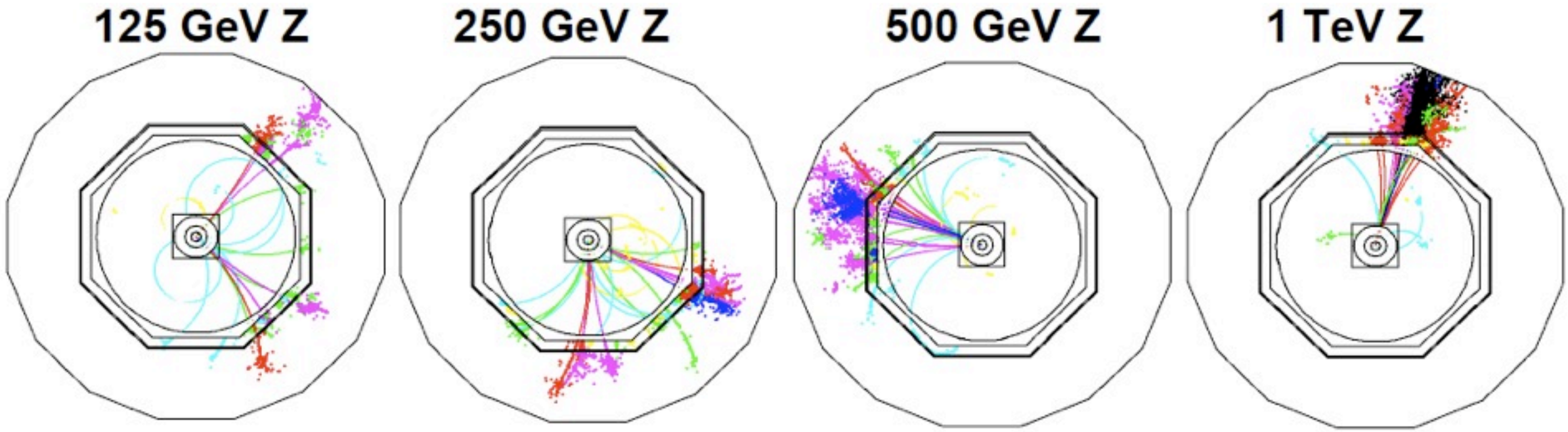
- Calorimetry at a Multi-TeV Linear Collider brings new Challenges
  - Now an integral part of the CALICE Program



ILD-like detector, with 8 λ deep HCAL (M. Thomson, ALCPG09)

A key issue: Leakage! ⇨ Deep HCAL required, potentially with a very dense absorber to satisfy the space constraints: Investigate Tungsten

Tungsten different from Steel: Very different X_0/λ, much more neutrons (affects time structure!)

⇨ Beam tests needed to understand the suitability of Tungsten for PFA Calorimetry

The Road Ahead

- Next milestones for the overall projects:
  - CLIC CDR: End of 2010
  - ILC TDR: End of 2012
  - Physics driven technology decision

- CALICE HCAL next steps
  - Test of a digital HCAL at Fermilab starting Summer 2010
  - First test beams with a Tungsten Analog HCAL at CERN in Fall 2010, potentially also first shower time structure measurements
  - Construction of next-generation electronics modules: Evaluate different scintillator tile technologies

- Publication of analysis results: Several papers planned for 2010

Summary

- Broad program for future lepton colliders:
  Accelerator studies and detector development

  - Muon Cooling:
    - Progress towards a demonstration experiment with protons
    - Possible application for PSI slow muon beam

  - Linear Collider:
    - Validation of ILD letter of intent: Calorimetry played an important role
    - First results from TPC large prototype
    - Hardware and analysis progress within the CALICE collaboration
    - Increased activities for a detector at a multi-TeV linear collider

More tomorrow: