# Future Accelerator R&D
# -
# ILC, CALICE and Plasma Wakefield Acceleration

**Frank Simon, MPI für Physik & Excellence Cluster ‘Universe’**

MPI Project Review, December 2008

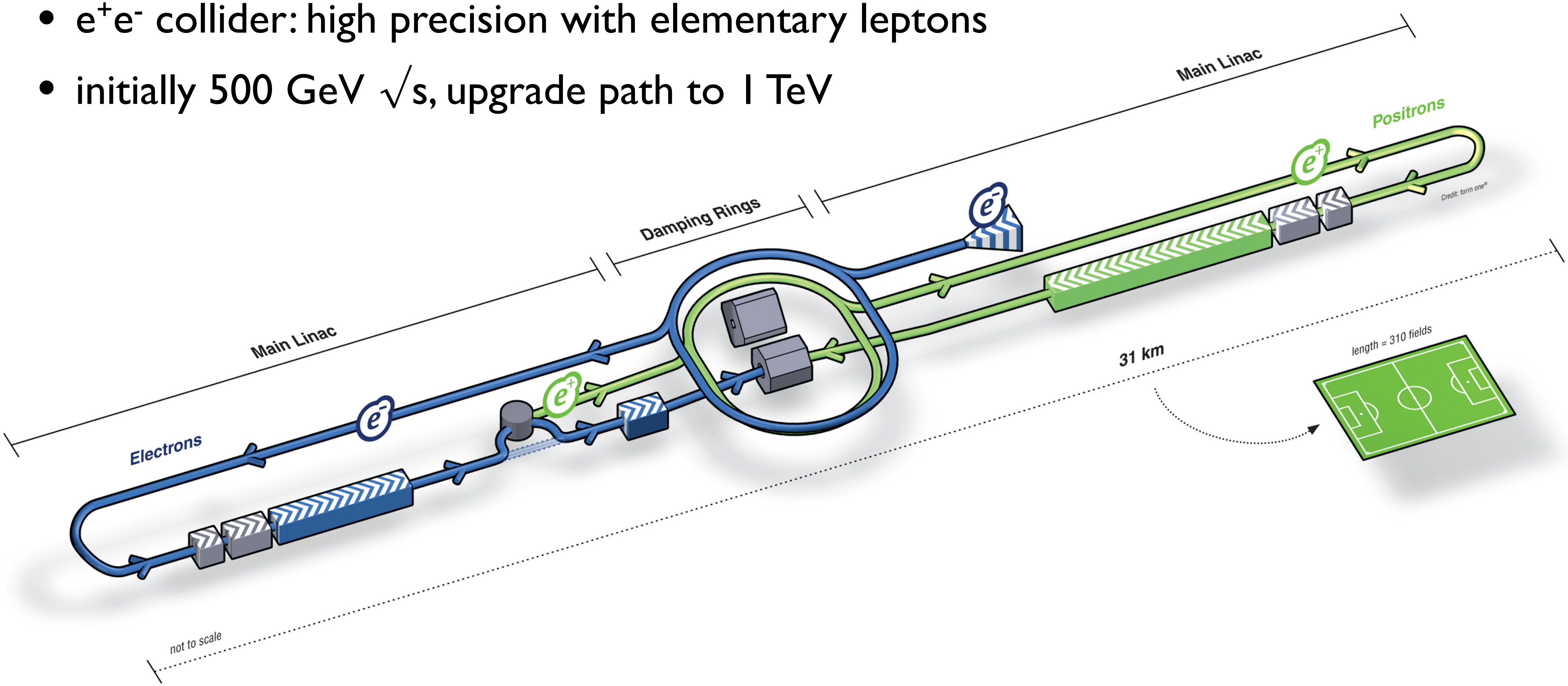
# Overview

- **ILC**
  - ILC status
  - The ILD detector concept
  - Vertex Detector
  - LC-TPC Developments
- **CALICE**
  - The CALICE project
  - SiPM & Tile coupling studies
  - First Analysis Results
- **Plasma Wakefield Acceleration**
  - The Concept
  - Ideas for a proton driver

# ILC: The International Linear Collider

# The International Linear Collider

- The next big machine in high energy physics, currently under discussion
- $e^+e^-$ collider: high precision with elementary leptons
- initially 500 GeV $\sqrt{s}$, upgrade path to 1 TeV




- 2 Detectors, share one interaction region in a push-pull scheme
- Letters of Intent in preparation for the experiments, deadline March 2009

# ILC: The Status

- Despite funding disasters in the US and UK ("black December 2007"): Global Design Effort (GDE) and World Wide Study (WWS) back on track
- Formation of the CLIC/ILC Collaboration: A linear $e^+e^-$ collider as a common goal
  - CLIC: up to 3 TeV center of mass energy, achieved with (so far unproven) accelerating scheme delivering higher gradients, powered with a high intensity electron drive beam
  - ▸ Many common issues, ILC in many aspects more advanced use common schemes for costing to allow a comparison of both machines
- Time line:
  - ILC TDP interim report 2010
  - ILC TDP / proposal 2012
  - CLIC CDR 2010
  - CLIC TDR 2012
  - ILC - CLIC decision ~ 2012

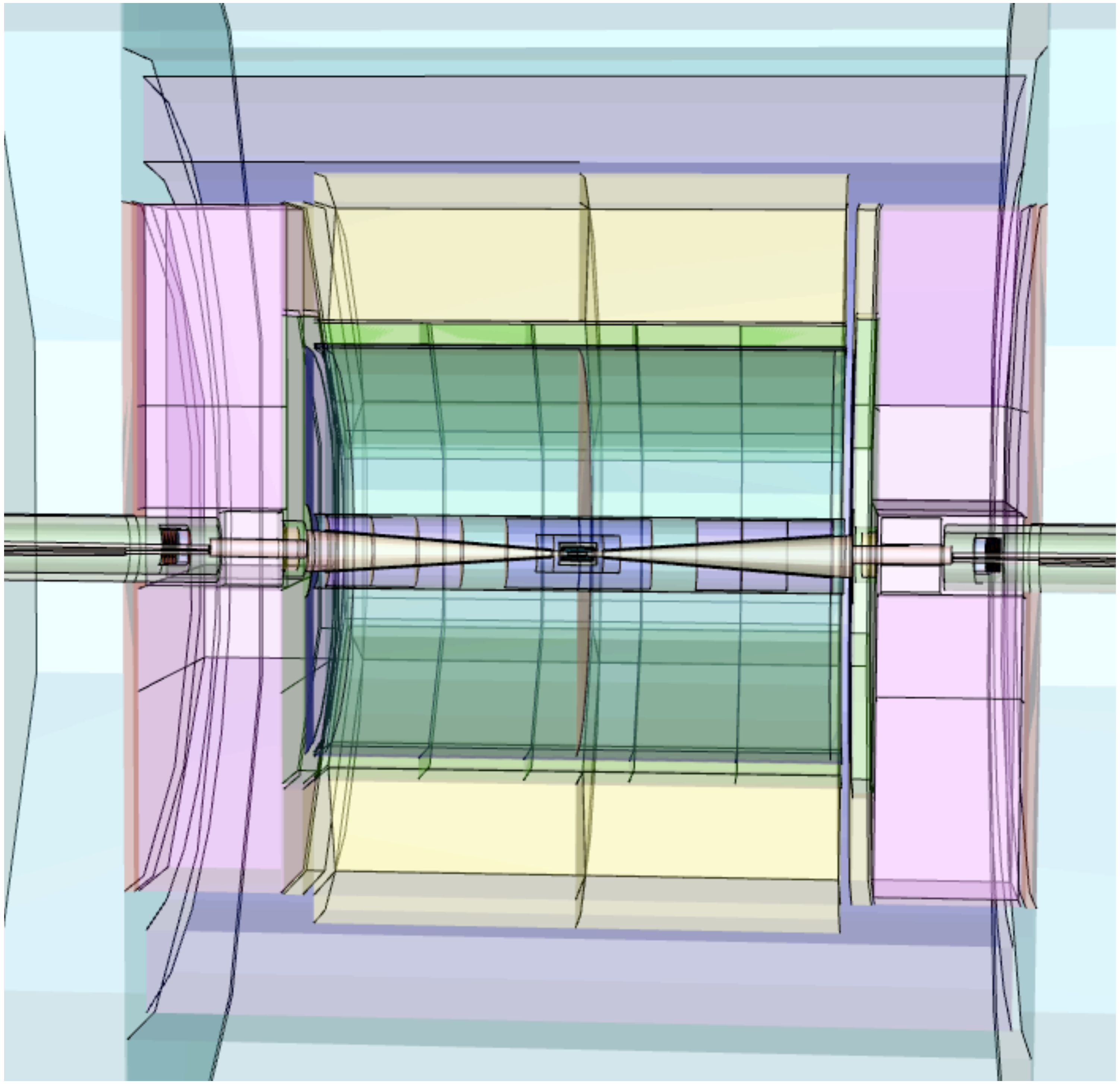
# ILC Activities

- Very active world-wide work on:
  - accelerator development and study
  - detector technology development, organized in R&D Collaborations; MPI contributions to:
    - LC-TPC: TPC development
    - CALICE: calorimeter development
    - Vertex: pixel - vertex tracker development
  - these MPI R&D efforts are also part of EUDET (EU FP6 R&D support)

  - detector concepts:
    - currently three concepts under discussion: ILD, SiD, 4$^{th}$
    - detector R&D collaborations mostly extend across concepts

# ILC Detector Concepts: ILD

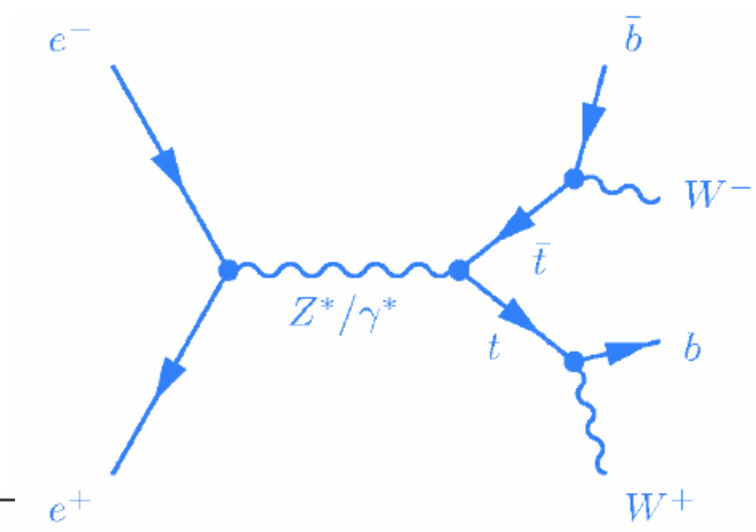
- A merger of the mostly Asian and and the mostly European Concepts GLD and LDC, baseline design defined in September 2008



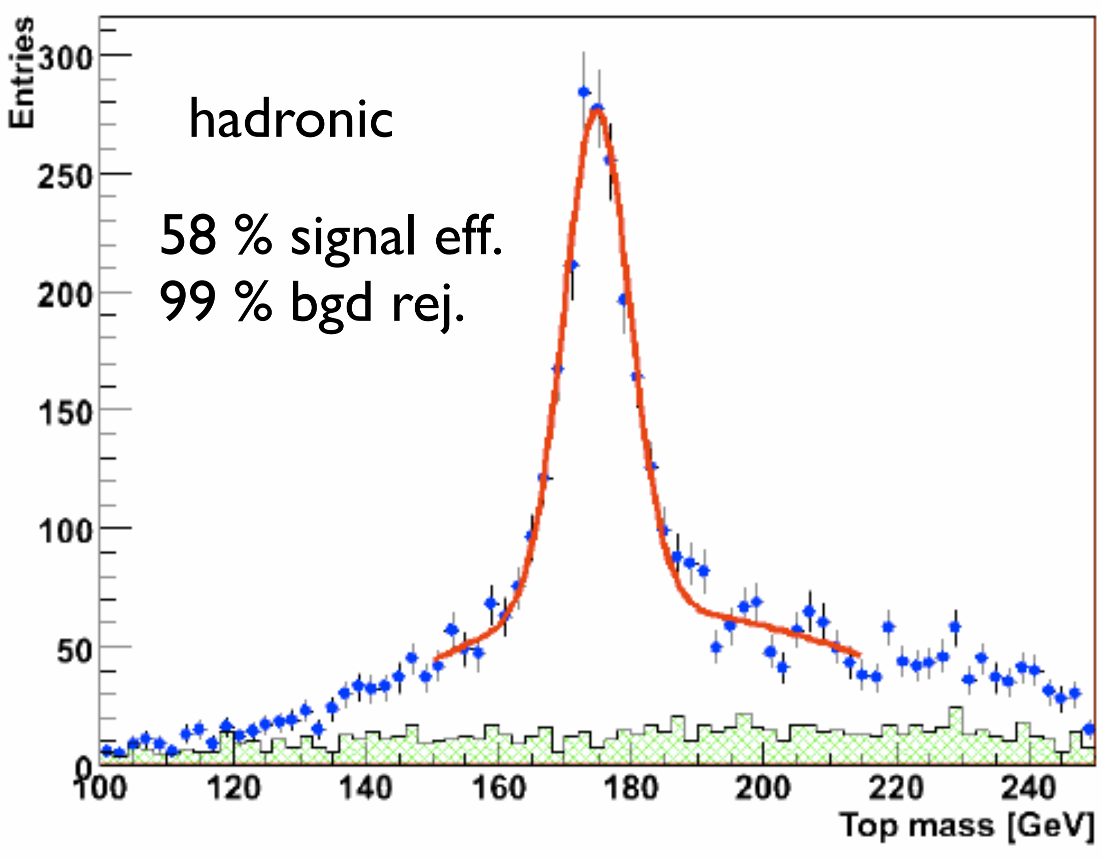
- thorough MC study of physics performance for the LOI, with participation from MPI (X. Chen, A. Raspereiza, A. Moll)

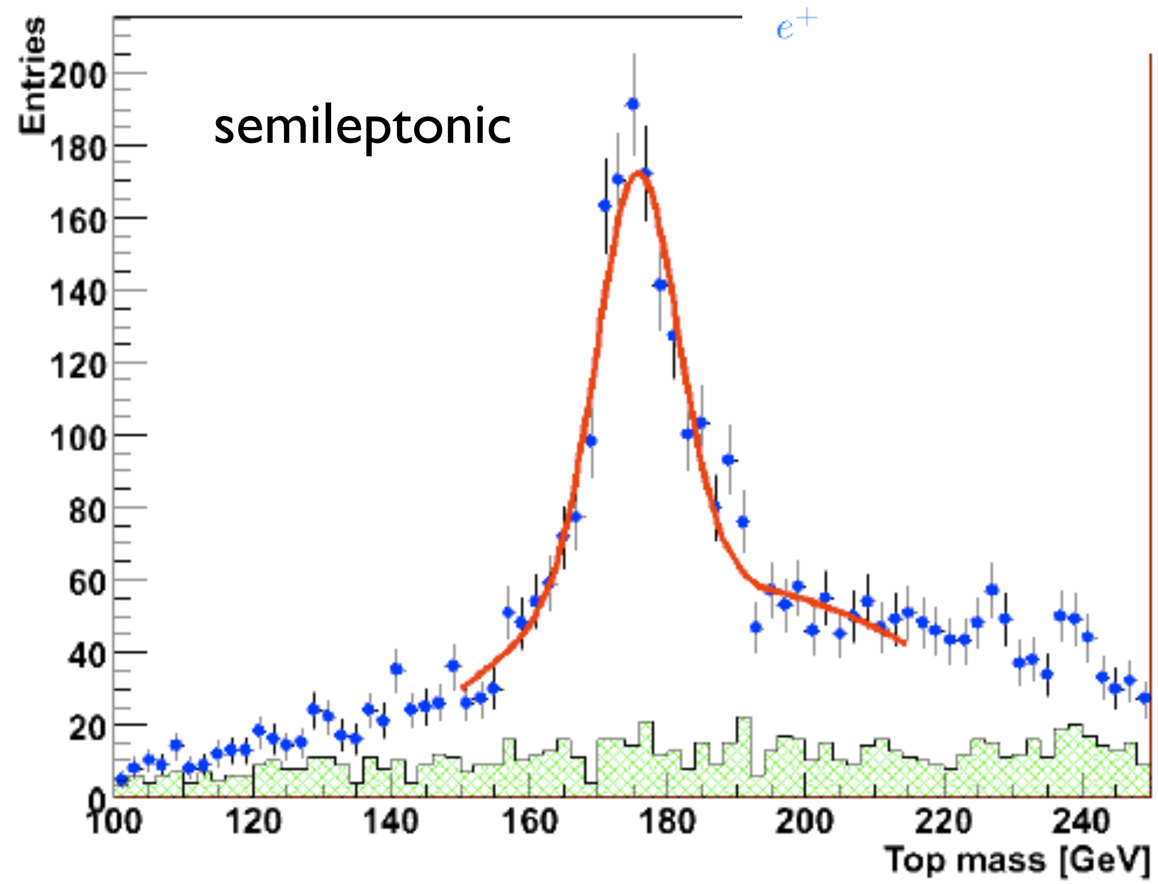
# Physics Studies: Top Pair Production

- Study of top pair production with full MC simulation of ILD, inclusion of background processes, binned likelyhood to identify background




Full hadronic and semi-leptonic decay (one W → lν)
MC input: Mass 175 GeV, width 1.5 GeV



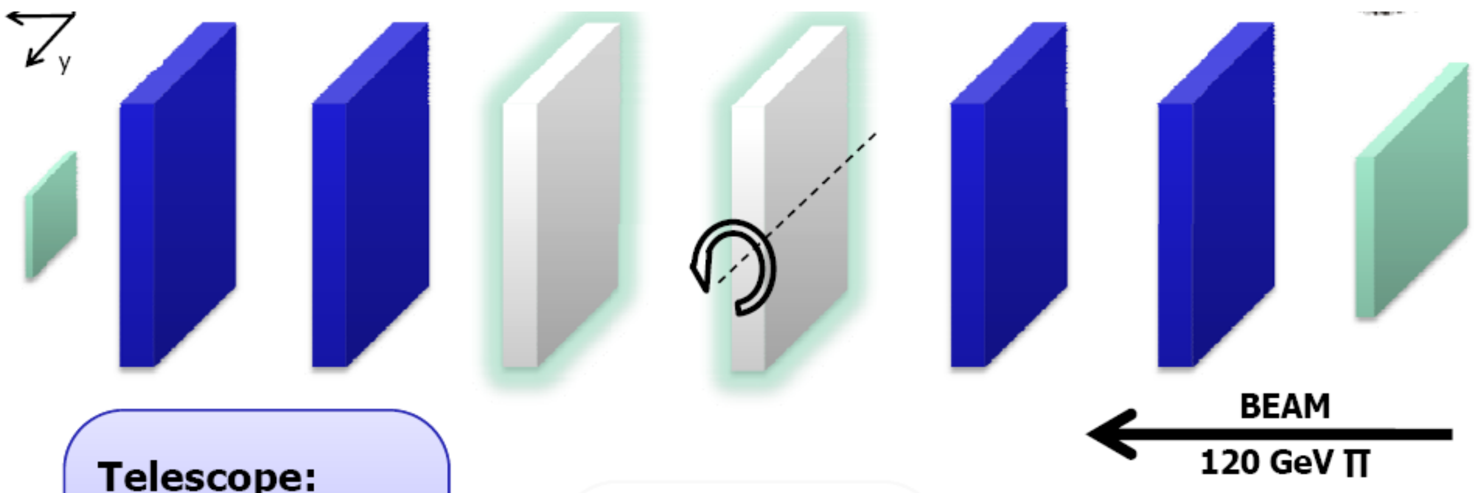

combined result with kin. fitting:

$$m_t = 175.02 \pm 0.17\,(stat.)\,GeV \quad (for\ 20\,fb^{-1})$$
$$\Gamma_t = 1.67 \pm 0.10\,(stat.)\,GeV$$

A.Moll

# ILC Vertex Detector: DEPFET Option

- DEPFET active pixel sensors in discussion for pixel vertex detector for ILD, SID
- Beam Test at CERN in 2008:

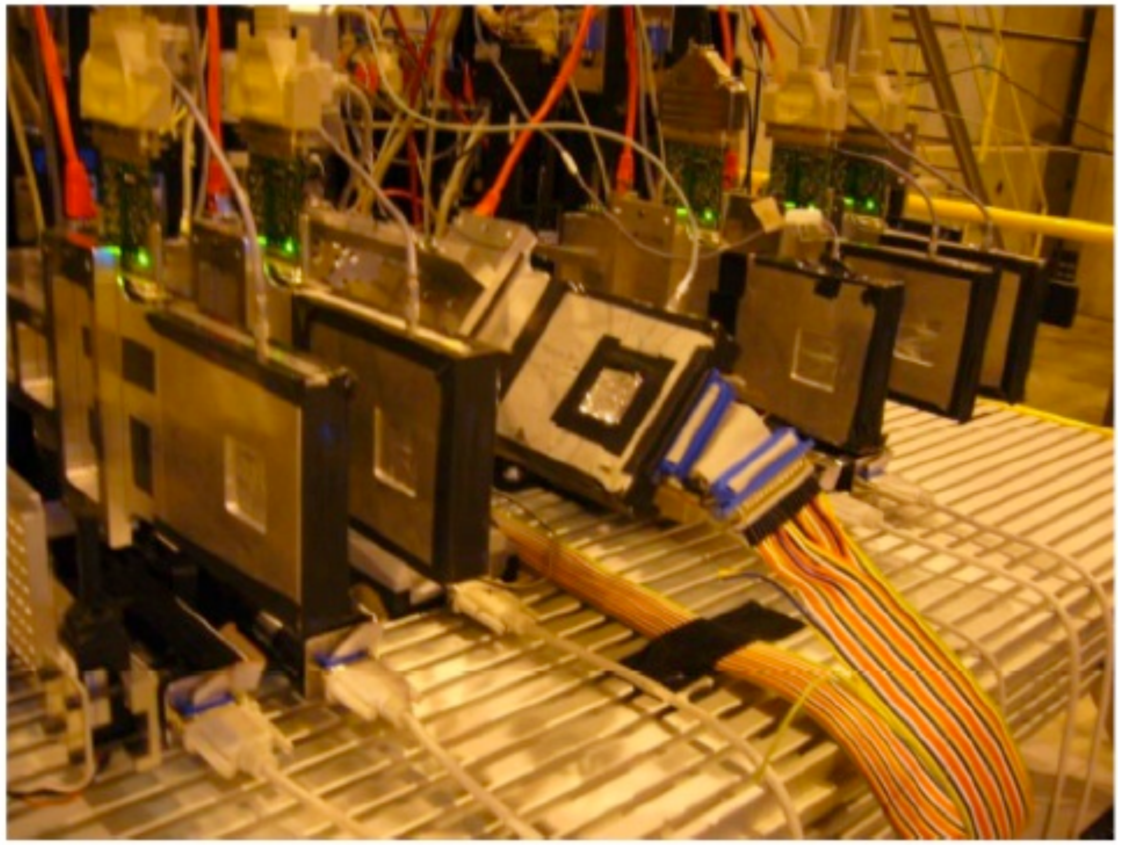



**Telescope:**
- 4 DEPFET planes
- 33x24μm²
- CCG
- 450 μm thick

**DUT:**
- 2 DEPFET modules
- Various pixel sizes
- 450 μm thick
- 1 rotating motorstage

**Scintillators:**
- 1 Big "Beam finder"
- 1 Finger "Beam allignment"
- Triggering

**Trigger Synchronization**
via TLU[1] (Trigger Logic Unit)



DEPFET Collaboration, led by MPI

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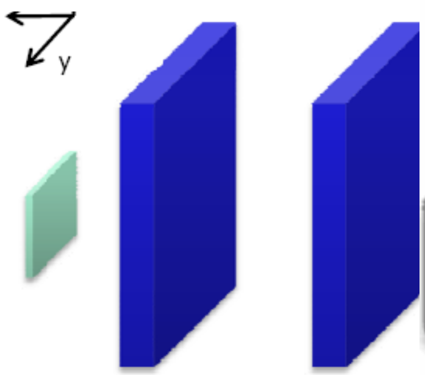


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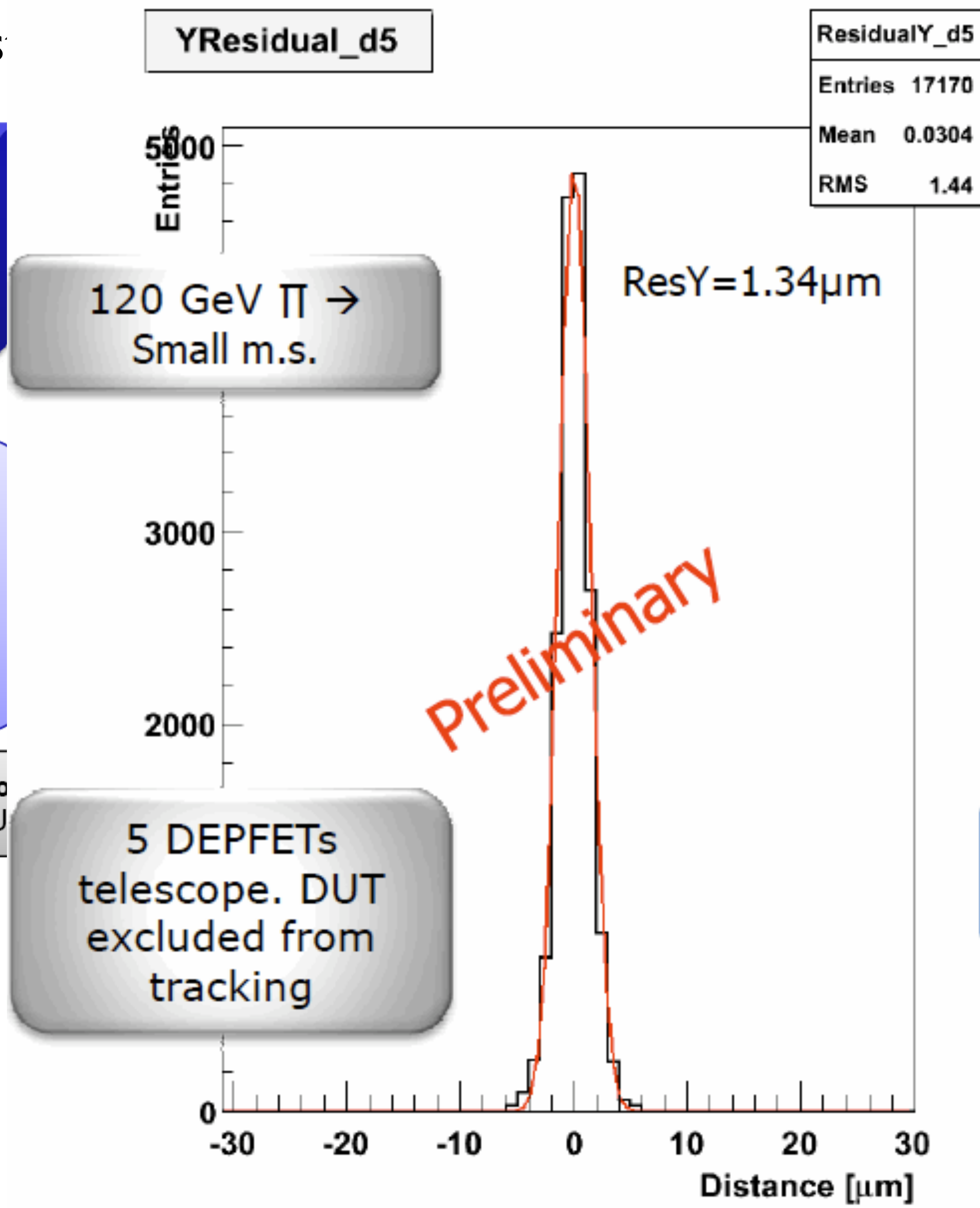
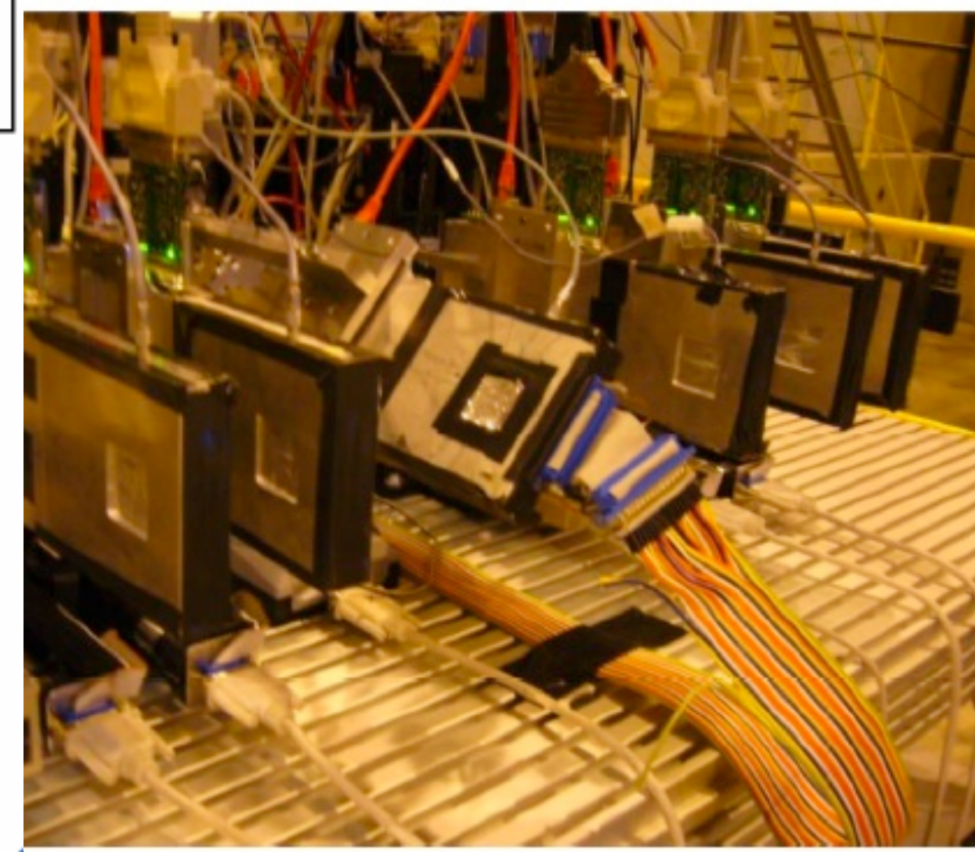
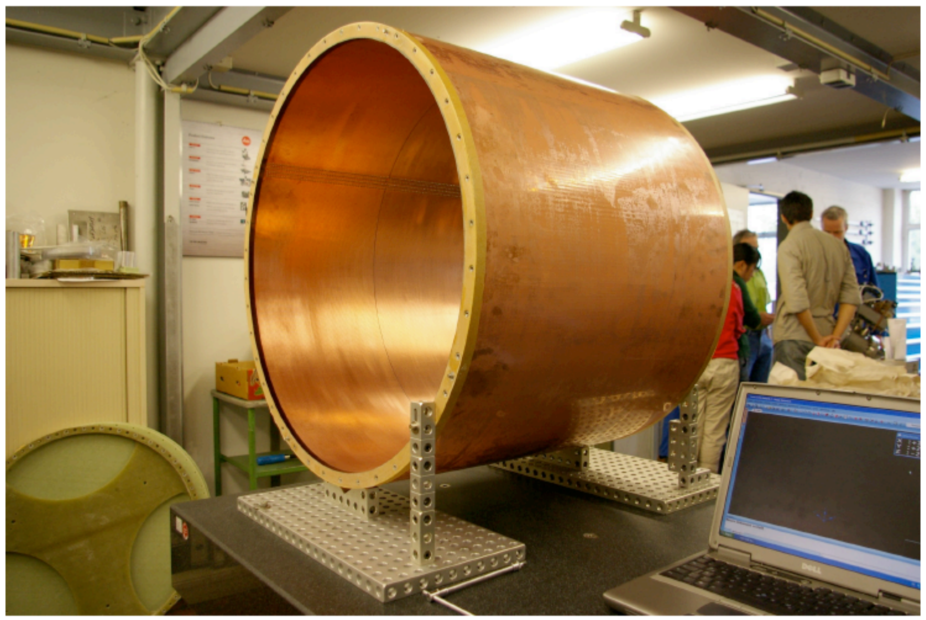


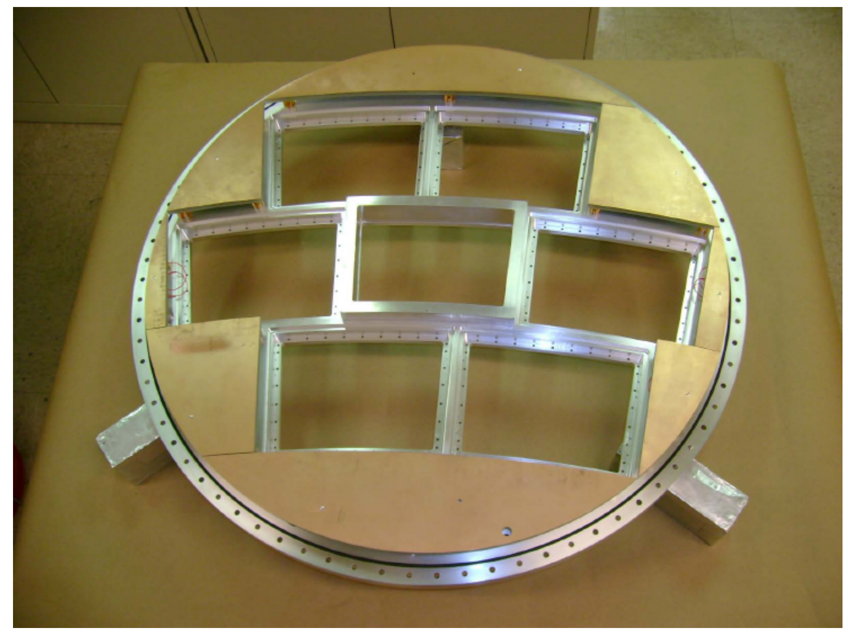



DEPFET Collaboration, led by MPI

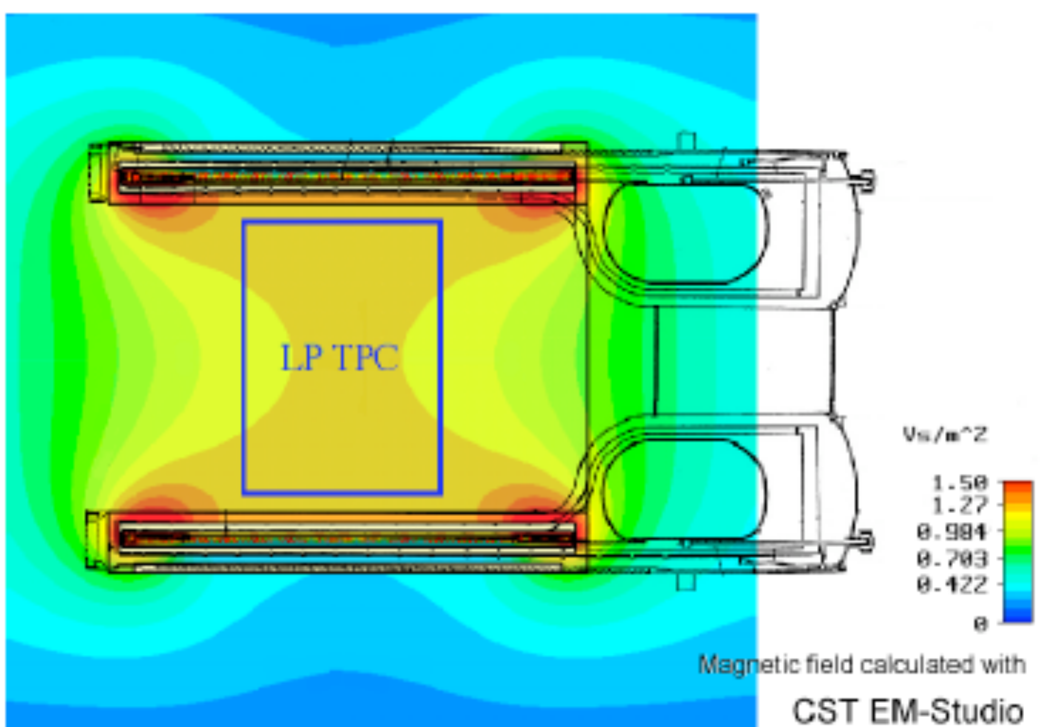
# LC-TPC: The Large Prototype

- Large Prototype of TPC now available, installed and taking data at DESY (6 GeV e⁻ beam): Contributions from R. Settles





endplate designed to evaluate different readout & ampification technololgies: MicroMegas currently installed




installed in 1T Magnet (loan from KEK)

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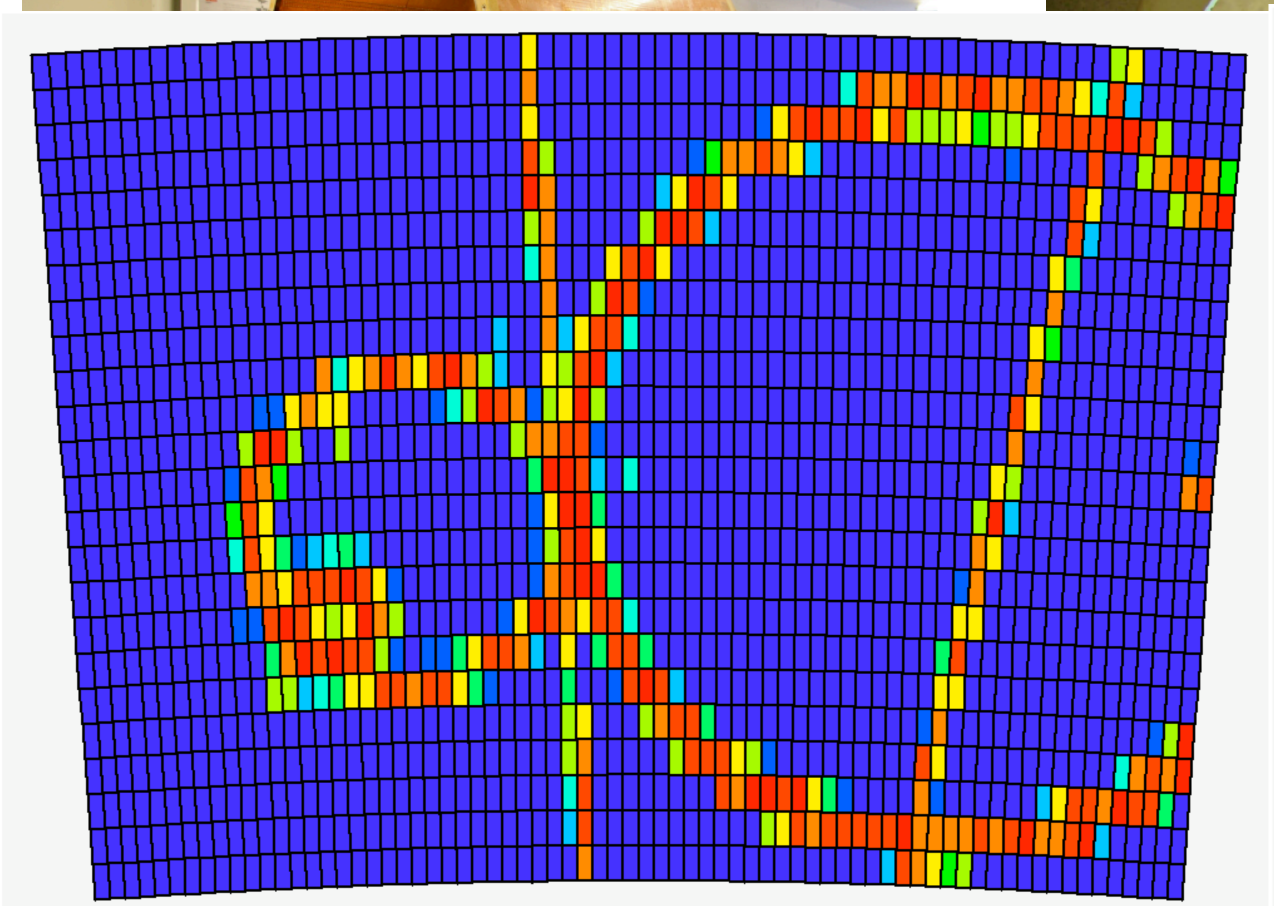
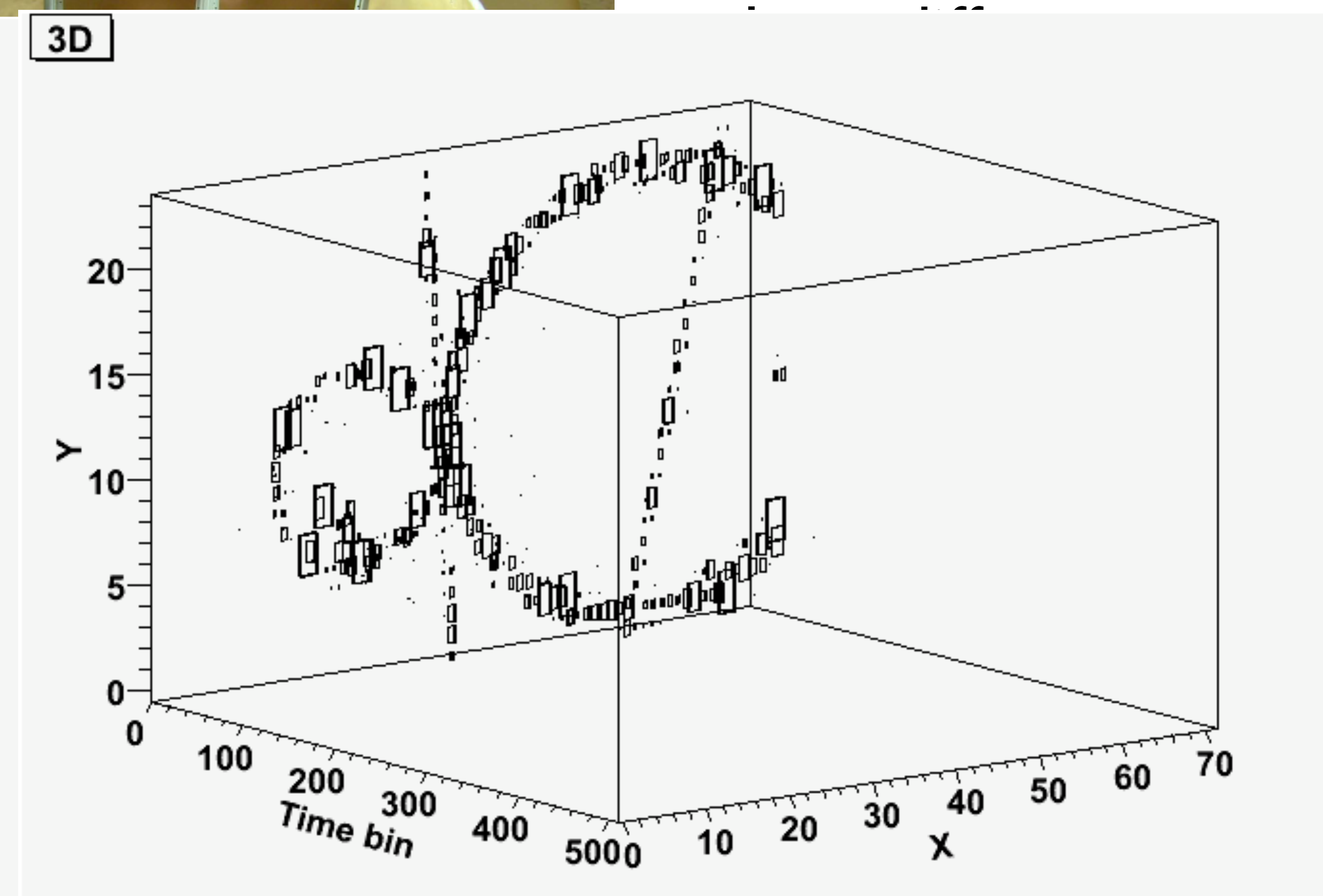
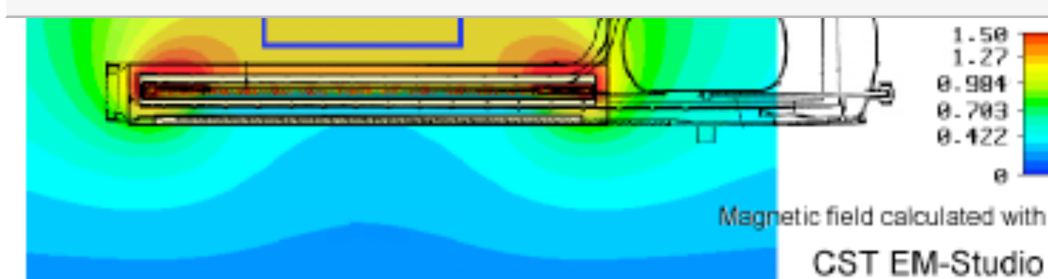
endplate designed to





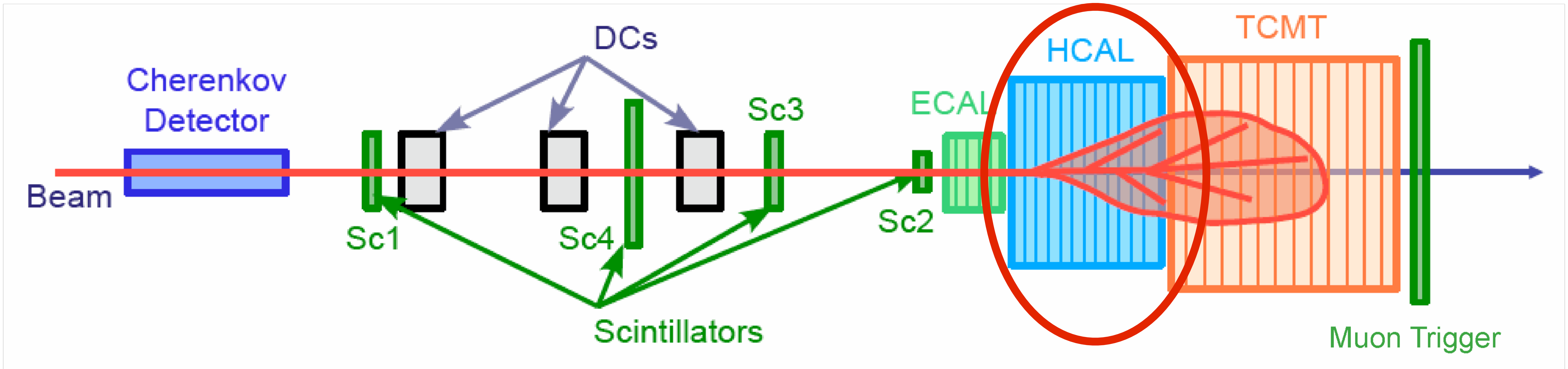




first beam events with large prototype

# CALICE: Calorimeter Development

# The CALICE Program

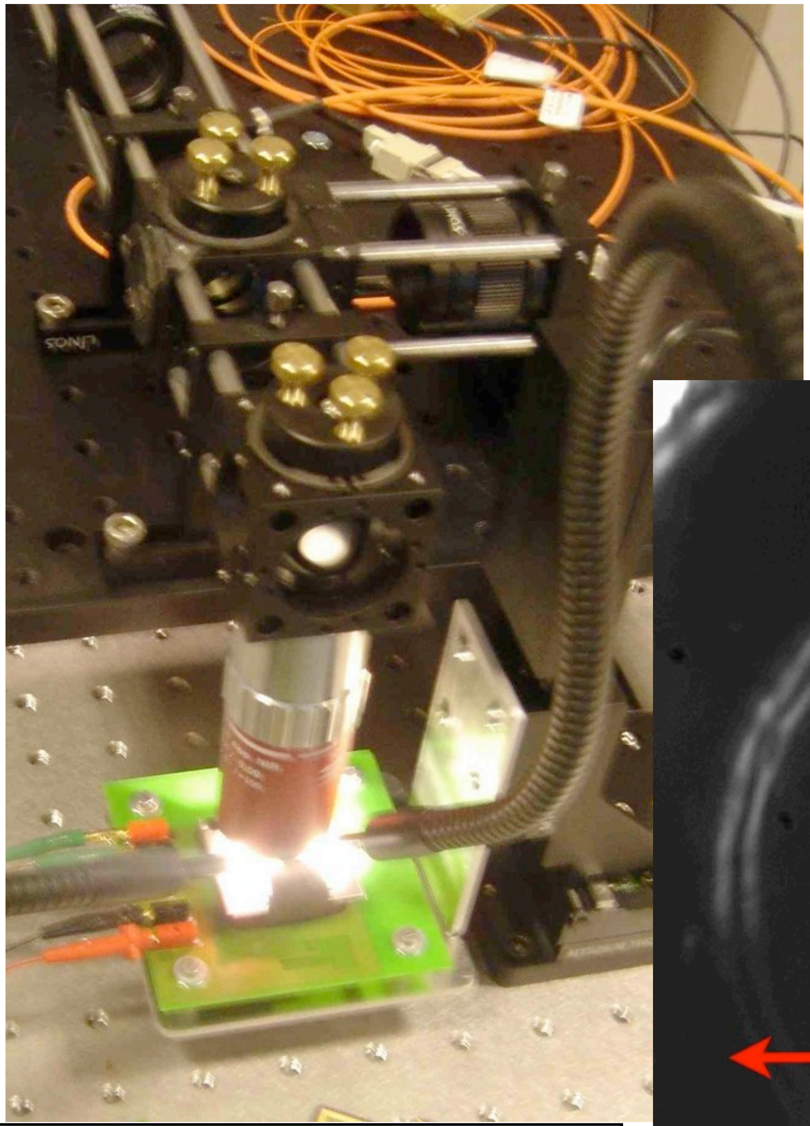
- Development and study of highly granular electromagnetic and hadronic calorimeters, comparison of different detector technologies
  - Extensive test beam campaign: CERN 2006 and 2007, FNAL 2008

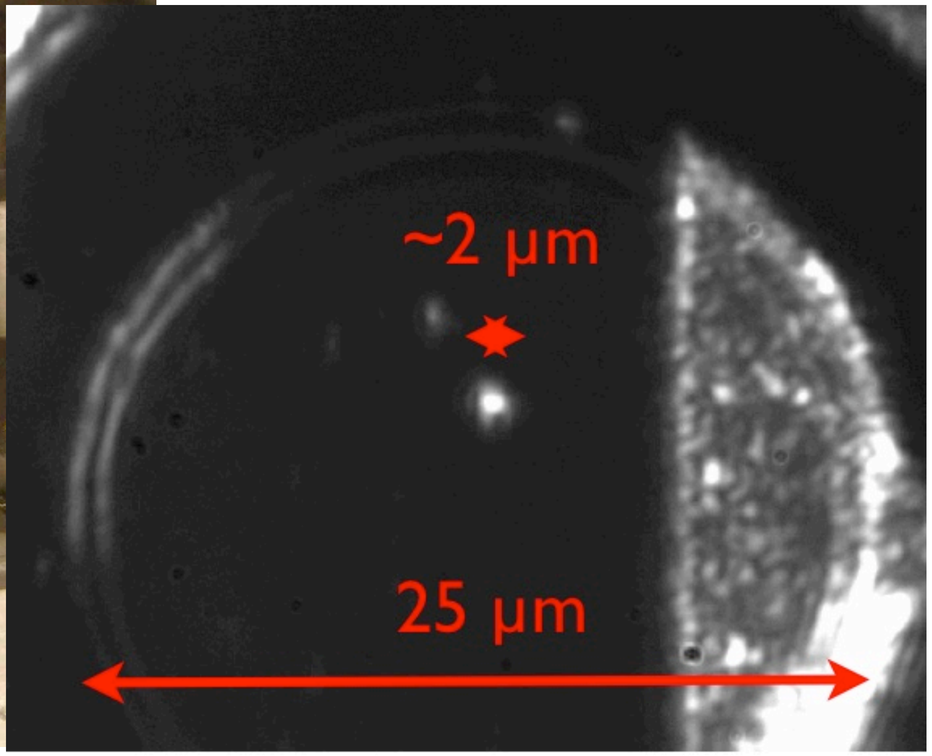



- Si/W ECAL: pad size 1 x 1 $cm^2$, 30 layers, ~30 $X_0$, 0.9 $\lambda$, 10k channels
- Scintillator/Fe HCAL: Cell size 3 x 3 $cm^2$ in the center, 6 x 6 $cm^2$ and 12 x 12 $cm^2$ on the outside, each cell separately read out by SiPM, 38 layers, 4.5 $\lambda$, 8 k channels
- Scintillator/Fe Tailcatcher, long scintillator strips with SiPM readout, 16 layers, first 8 with fine sampling , then coarse sampling, 300 channels

# SiPM studies

- Detailed studies of SiPM properties with focused laser and precision scanning:
  - crosstalk, afterpulses, relative efficiency, ...

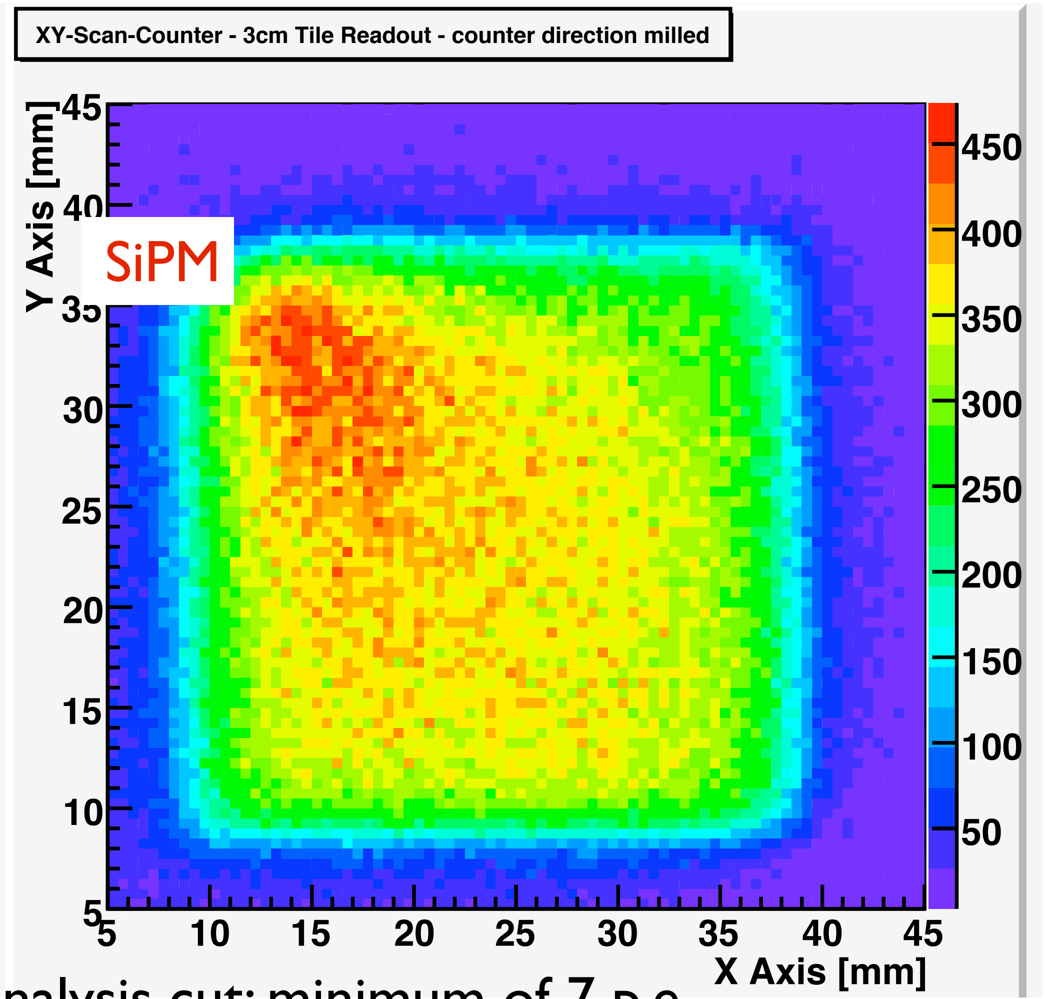





K. Prothmann, C. Soldner

- With blue sensitive SiPMs, the WLS fiber is not necessary, except for light collection
- First performance studies with direct coupling of SiPMs to scintillator tile:

raw count rate, $^{90}Sr$ source

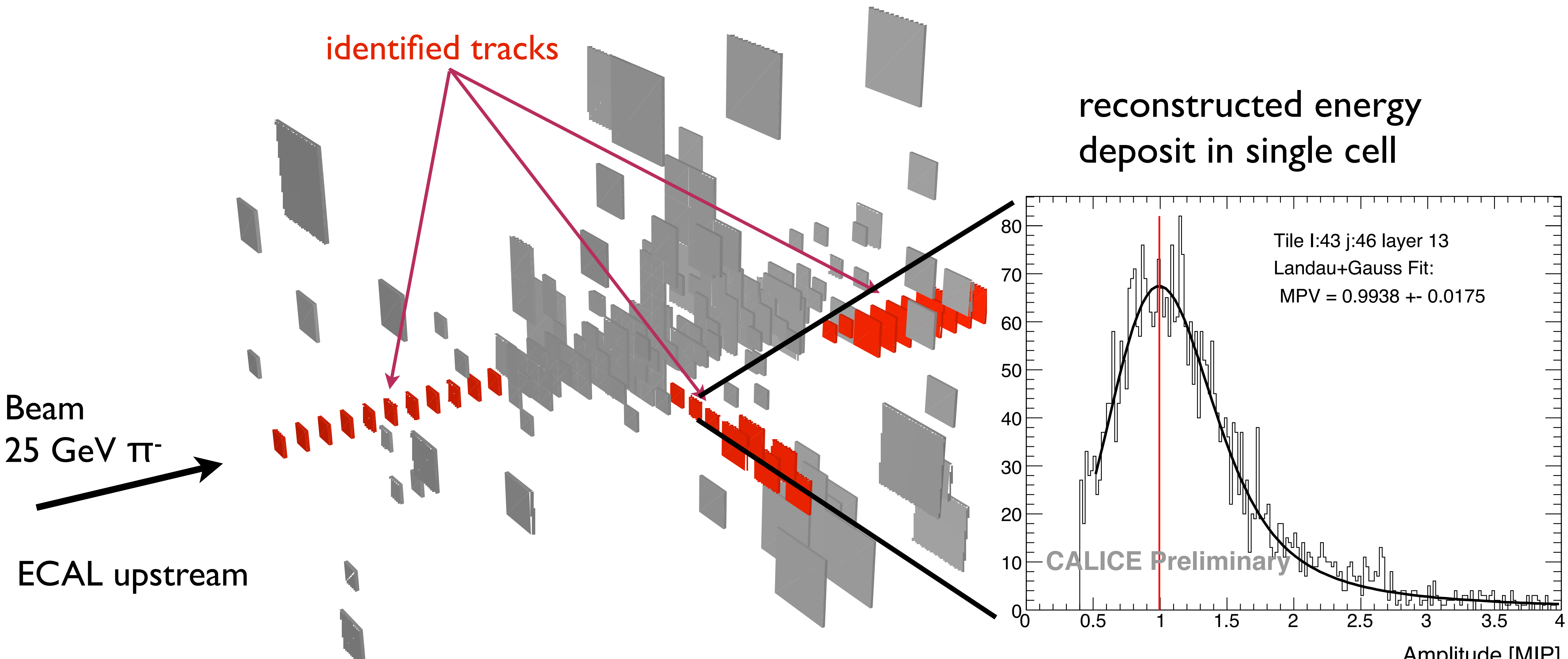



analysis cut: minimum of 7 p.e.

# Data Analysis: Track Segments



- High granularity of the HCAL allows identification of minimum-ionizing track segments within hadronic showers
  - Useful for detailed detector studies (temperature dependence, ...)
  - Possible cell-by-cell calibration strategy for a full detector without muons




S. Lu, F. S., C. Strege, L. Weuste

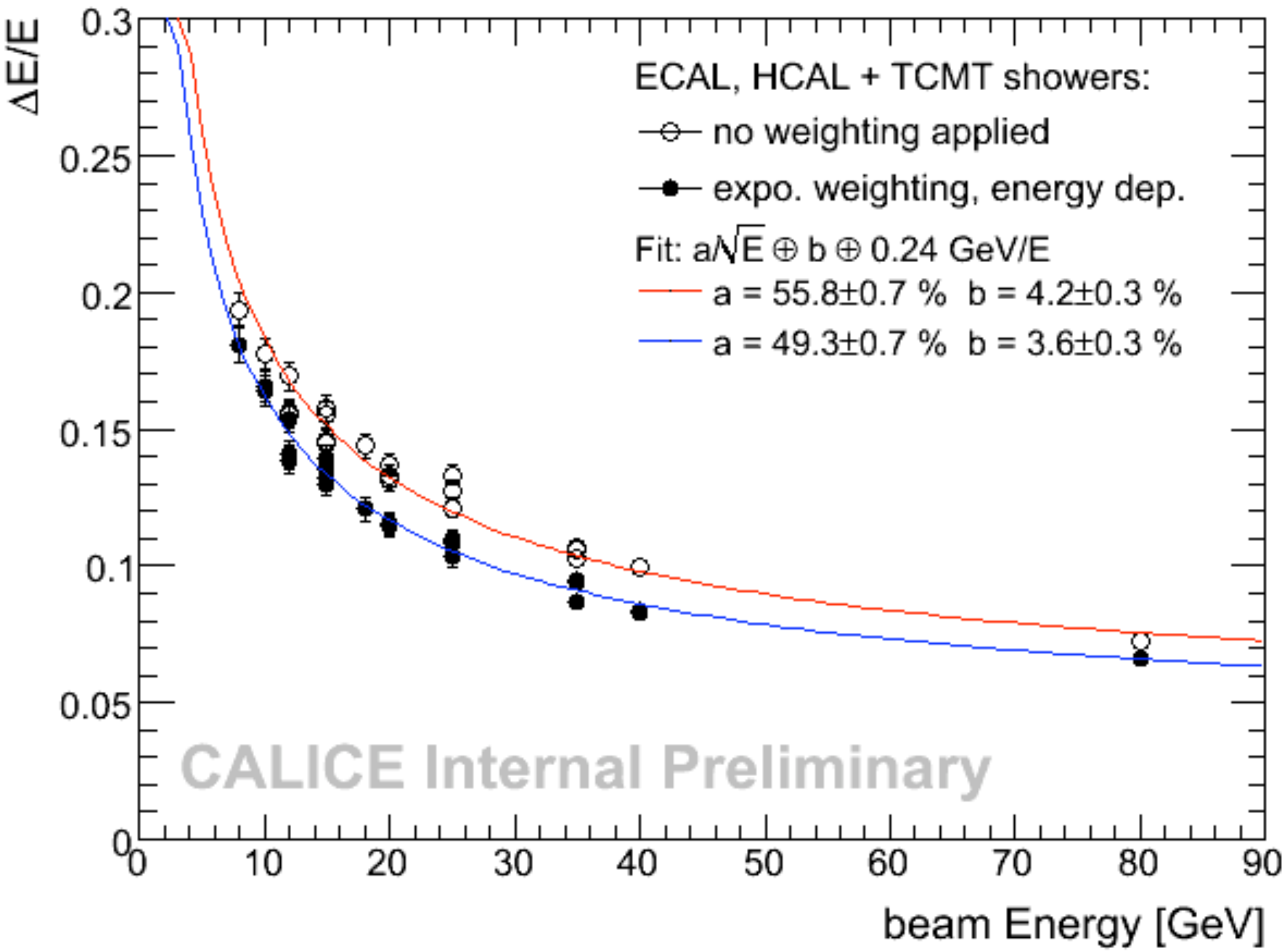
# Resolution for Hadrons: The Physics

- Hadronic showers are complicated beasts:
  - Electromagnetic subshowers due to neutral pion production in the cascade
  - charged hadrons
  - isolated neutrons
  - ...
- The calorimeter responds differently to different components of the shower:
  - A higher signal is seen for electromagnetic subshowers than for hadronic subshowers of the same energy

$$\frac{e}{h} > 1$$

- Large fluctuation of relative contributions event by event, limits energy resolution
- Weight energy deposit according to its nature: lower weight for em deposits
  - Identify type of deposit: EM showers tend to be denser than hadronic showers
  - First (easiest) approach: Cell-by-cell weighting according to cell energy ("local density")

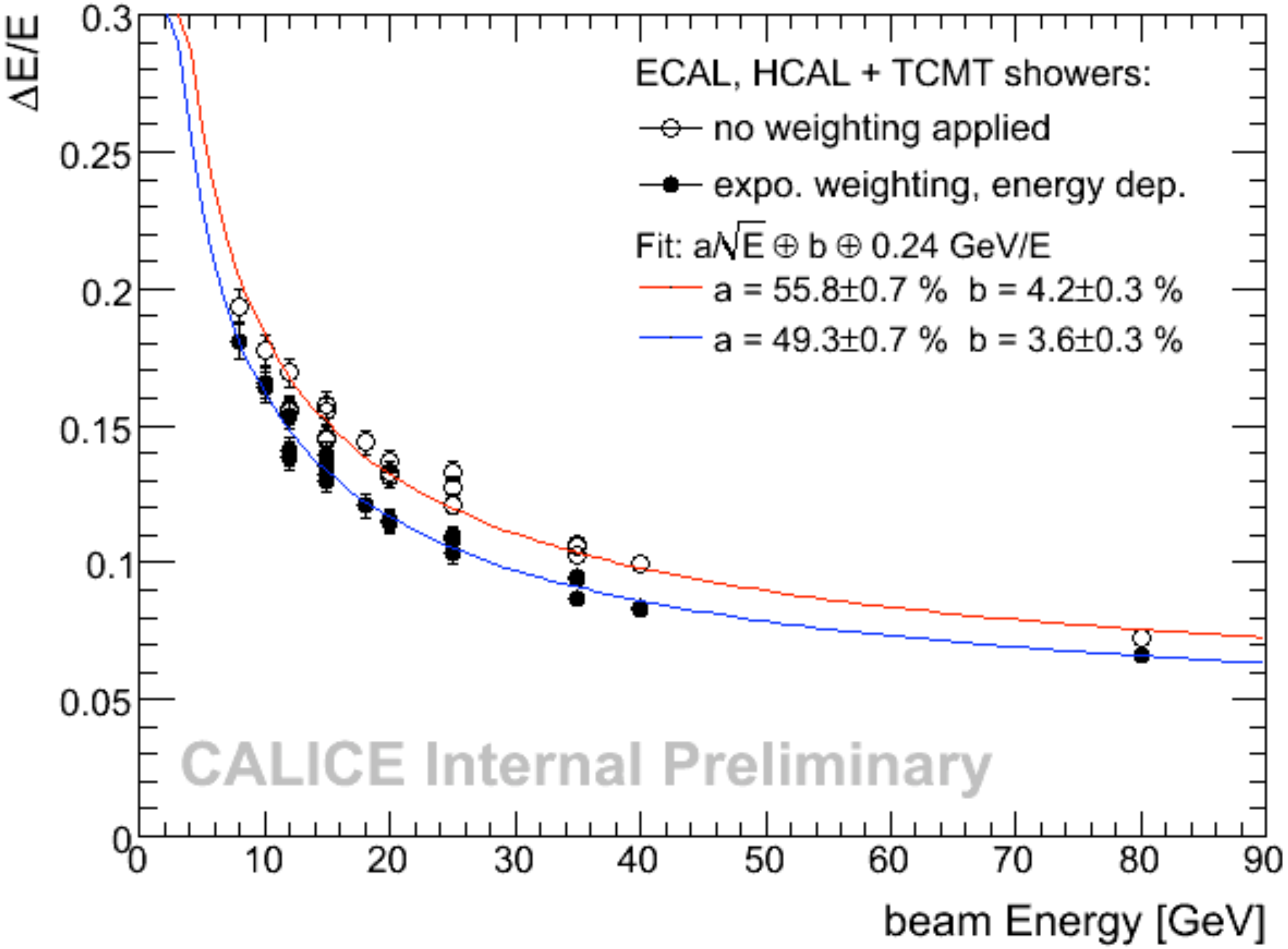
# Resolution & Linearity with simple Parametrization

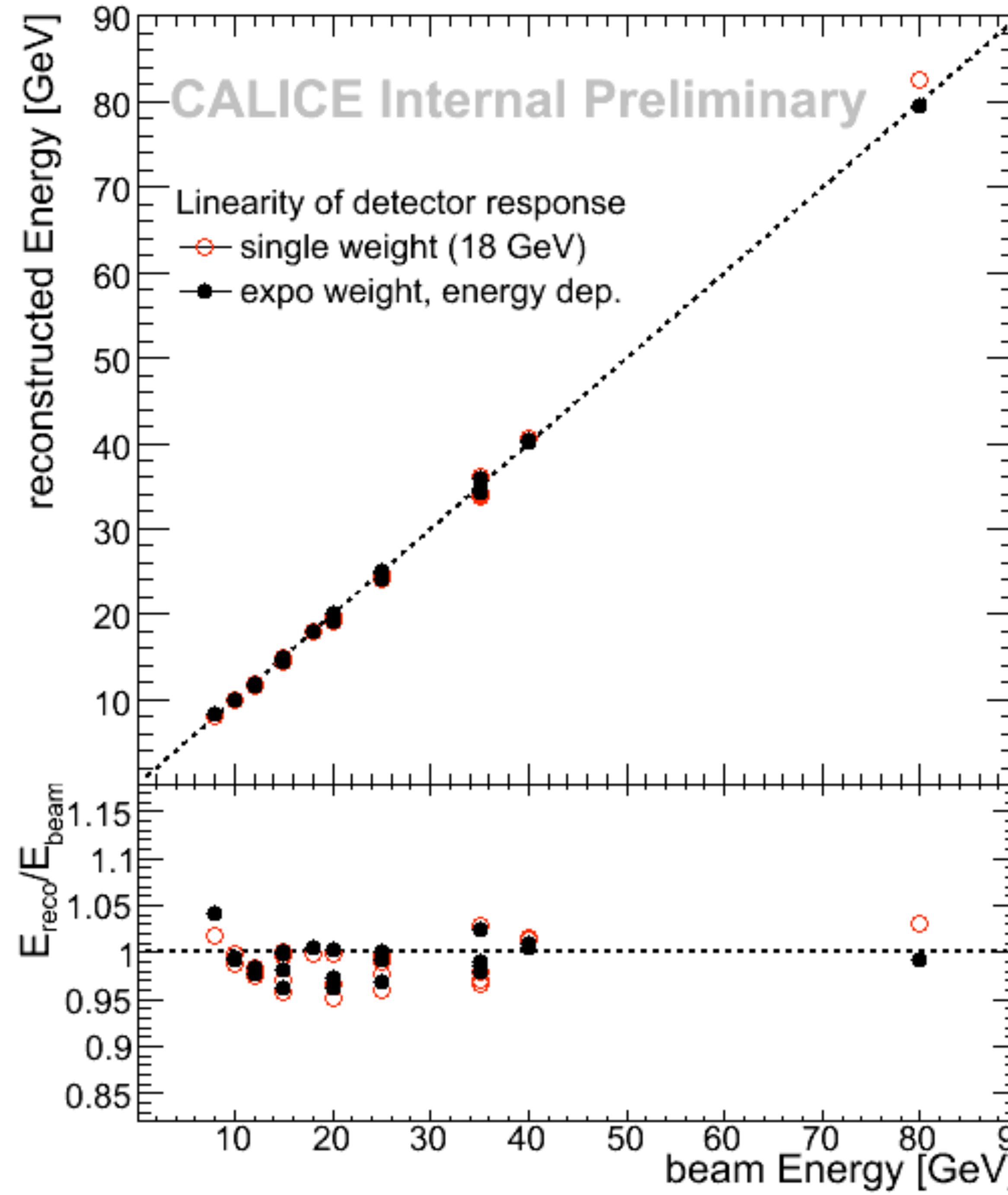



- Simple model for density weights (only β is energy dependent): $\omega(x) = \alpha\, e^{-\beta\, x} + \gamma$
- Moderate improvement of resolution: ~ 10%

F. S.

# Resolution & Linearity with simple Parametrization




- Simple model for density weights (only β is energy dependent): $\omega(x) = \alpha\, e^{-\beta\, x} + \gamma$
- Moderate improvement of resolution: ~ 10%

- Linearity of detector response is improved compared to the unweighted case, better than 5% over the full energy range (no correction for temperature!)

F. S.

# Proton Driven Plasma Wakefield Acceleration

# The Dream: Compact Accelerators

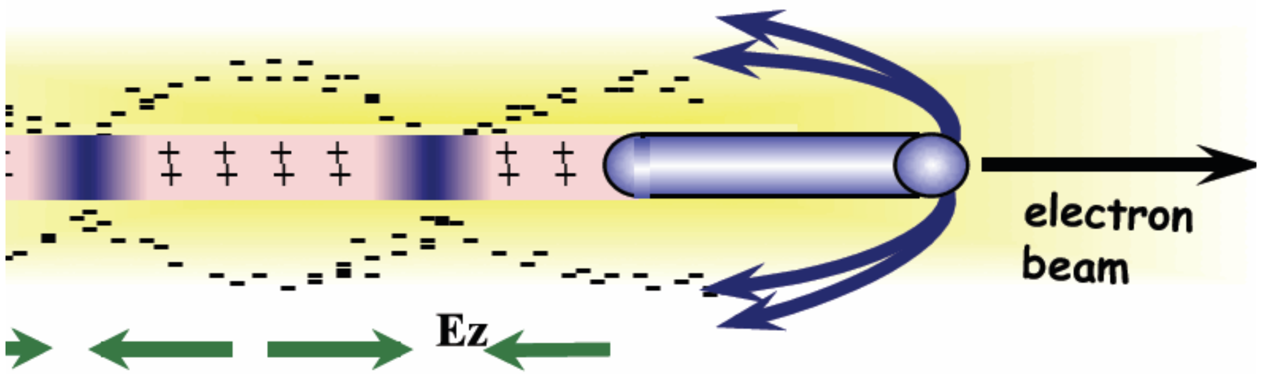
**PDPWFA**

- High energy accelerators and colliders are huge and extremely expensive facilities:
  - Size (and cost) to a large extend dictated by achievable accelerating gradient, in particular for electron machines
  - Current technologies deliver ~ 31.5 MV/m (ILC SC cavities), CLIC promises ~100 MV/m
  - Limited mostly by electrical breakdown in the cavities
  - Potential solution: Plasma Wakes: extremely high gradients are achievable, no breakdown or damage problems

# Plasma Wakefield Acceleration: Achievements

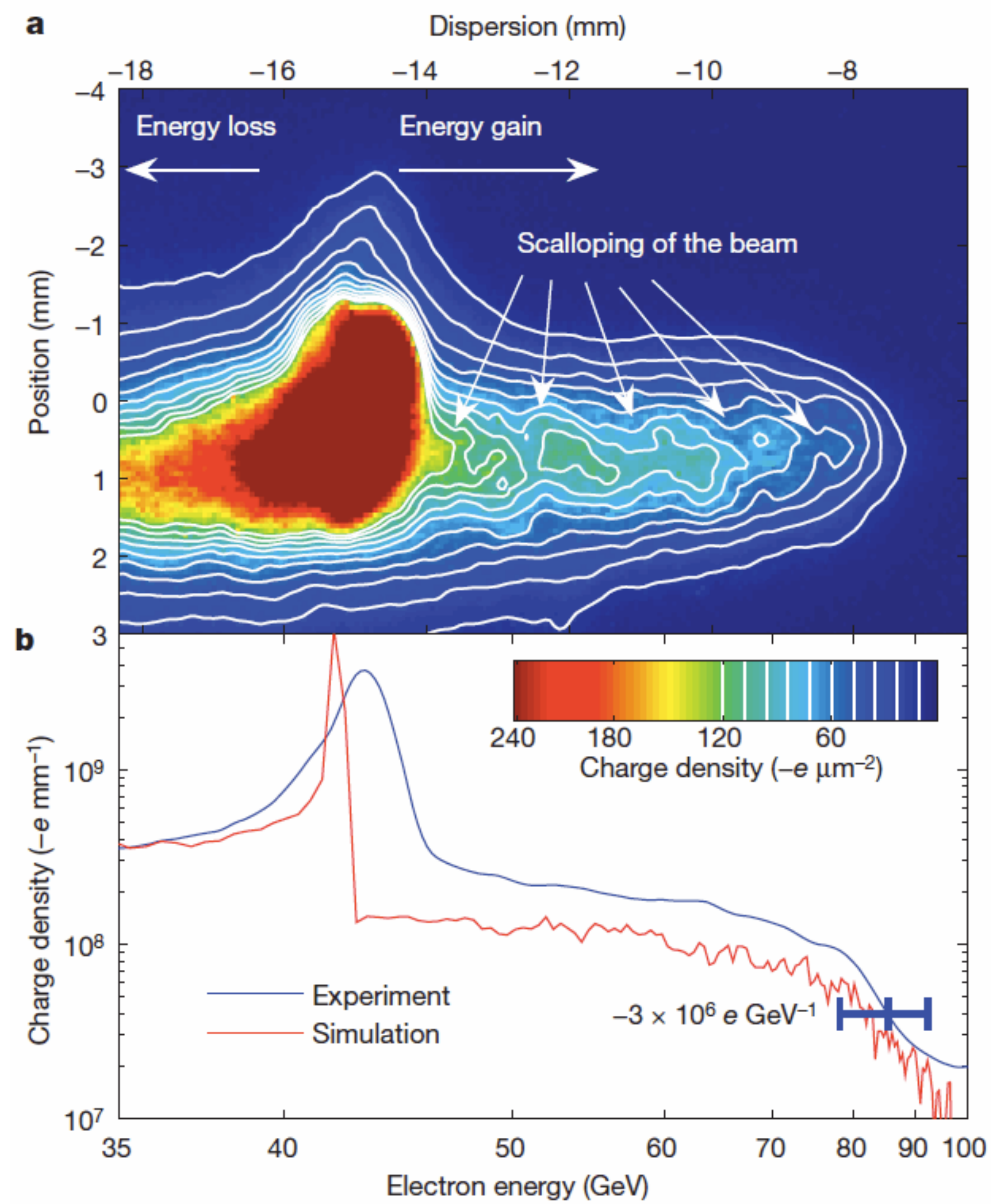
**PDPWFA**

- Demonstration of high energy acceleration of electrons at SLAC: E-164X
  - doubling of beam energy observed




electrons are expelled from central axis by strong electric field of the relativistic drive beam, zones with accelerating and decelerating fields from in the wake of the drive bunch

Nature 445, 741 (2007)



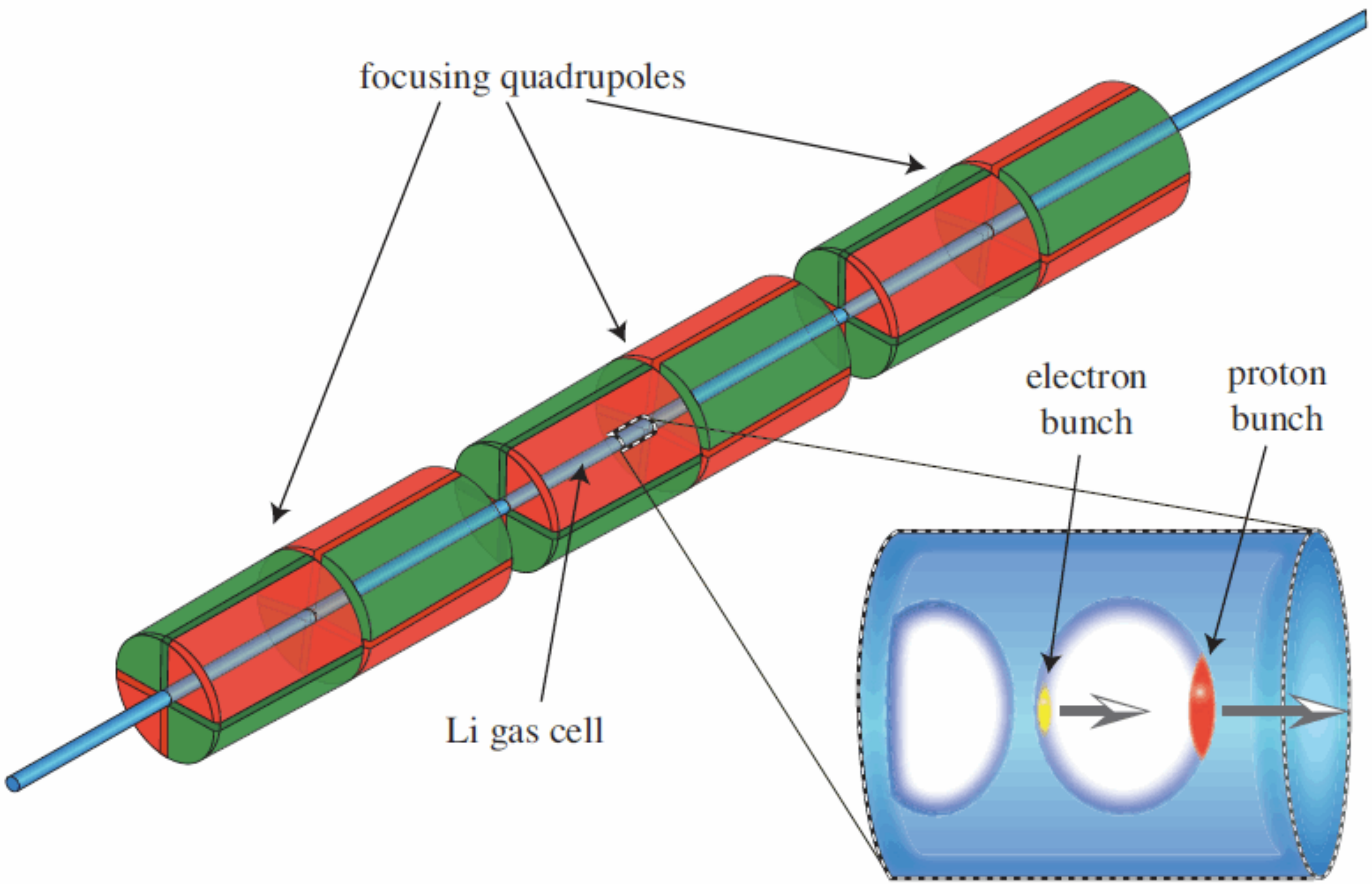

- Energy gain in one acceleration stage limited to 2 x $E_{drive}$ (energy of the beam driving the plasma) [“transformer ratio”]

▸ Use higher energy drive beams? Protons!

# Proton Driven Plasma Wakefield Acceleration

**PDPWFA**

- High energy proton beams exist ➩ beat the transformer ratio, get high energy electrons out of a plasma accelerator driven by protons




simulations indicate that long acceleration stages are possible, gradients well above 1 GV/m can be achieved

A major challenge:
to excite the wake, a very short pulse is needed (~ 100 μm), usual proton bunches are long (LHC 7.5 cm, SPS ~30 cm)

- study bunch compression

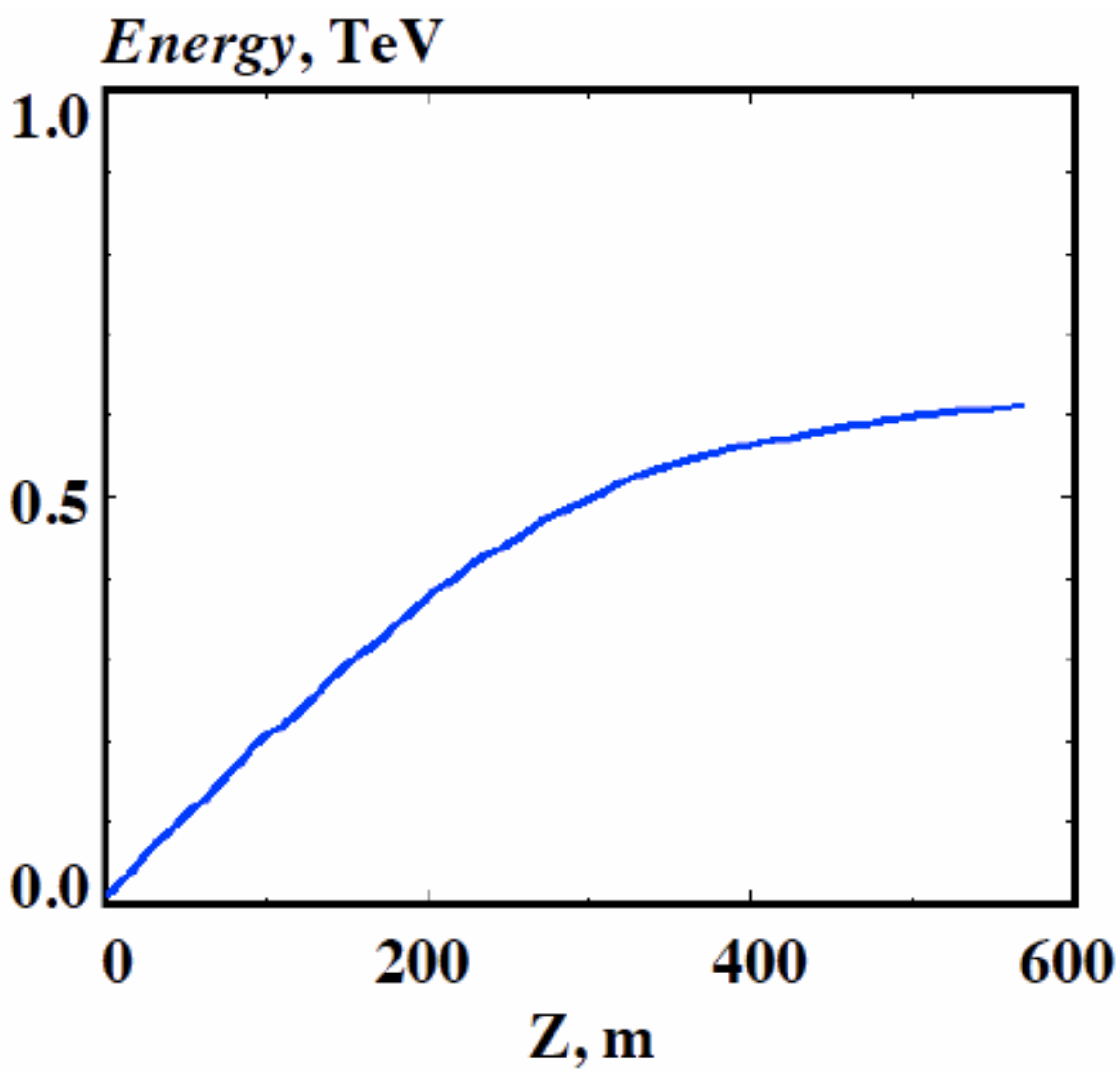
A. Caldwell, F. S., G. Xia

first paper: arXiv:0807.4599 [physics.acc-ph]

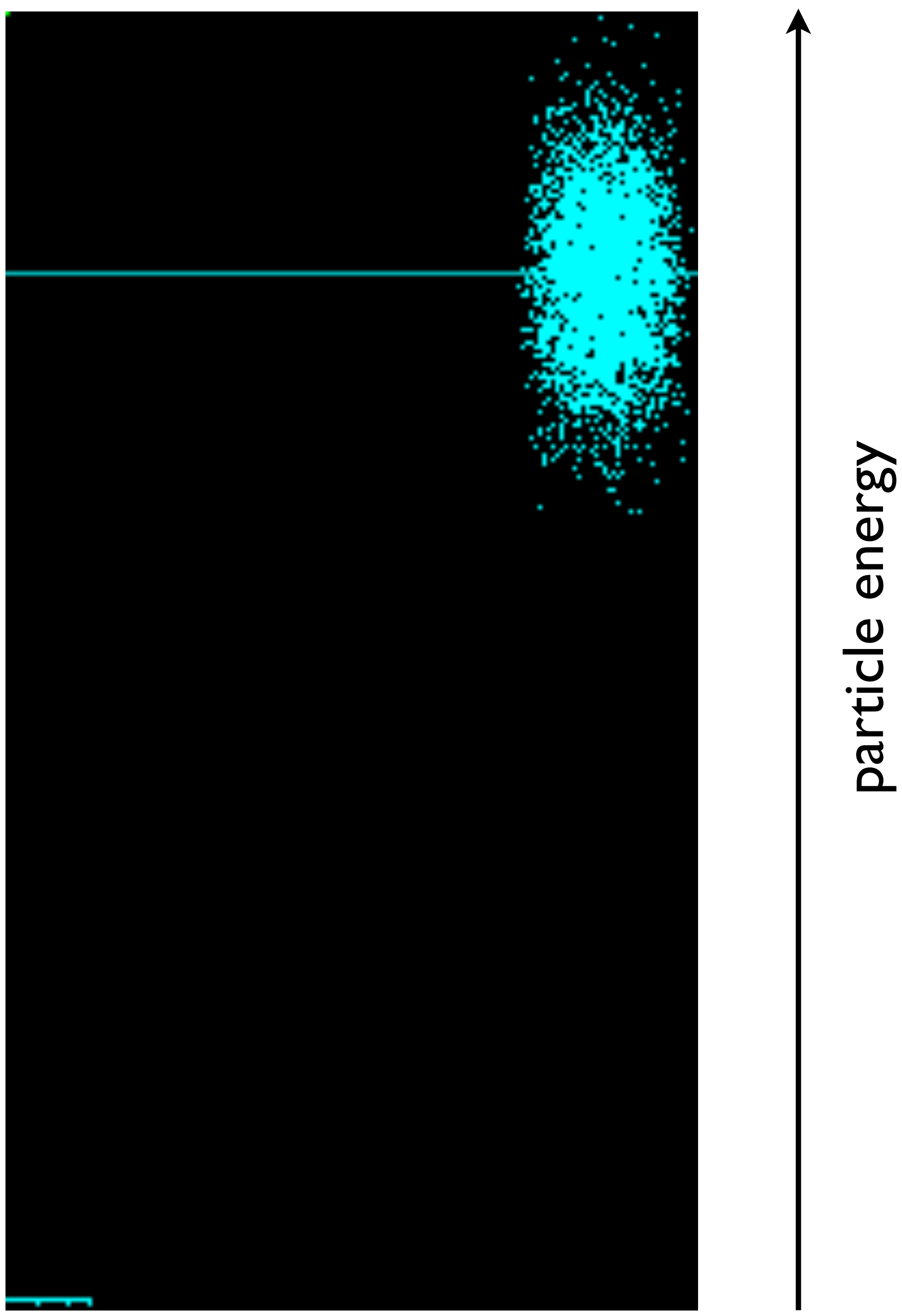
# Simulation Studies

PDPWFA

- Simulations done with PIC simulations




Energy gain of e⁻ in a thin Li plasma driven by 1 TeV protons:
~ 600 GeV after ~ 450 m

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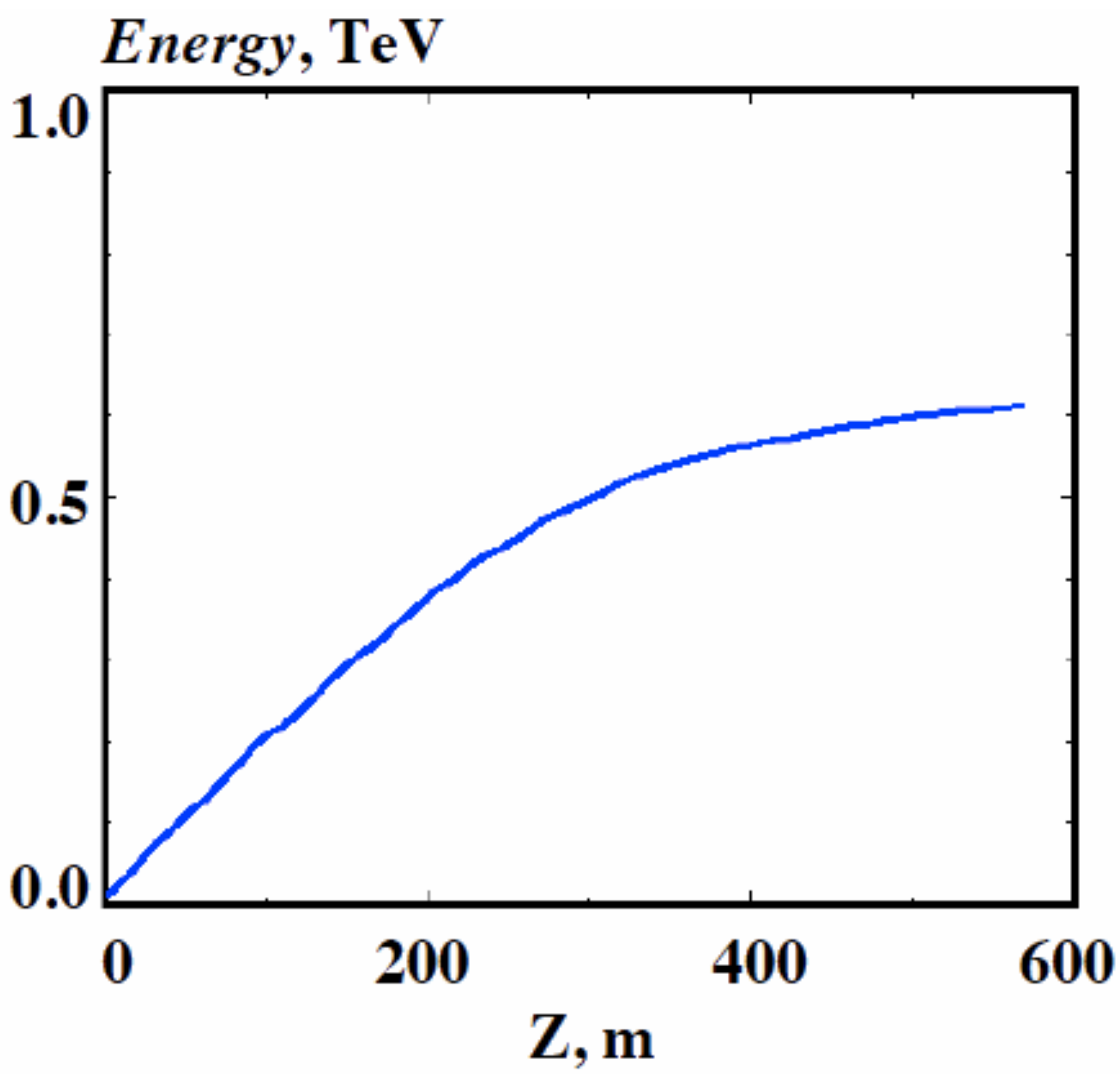


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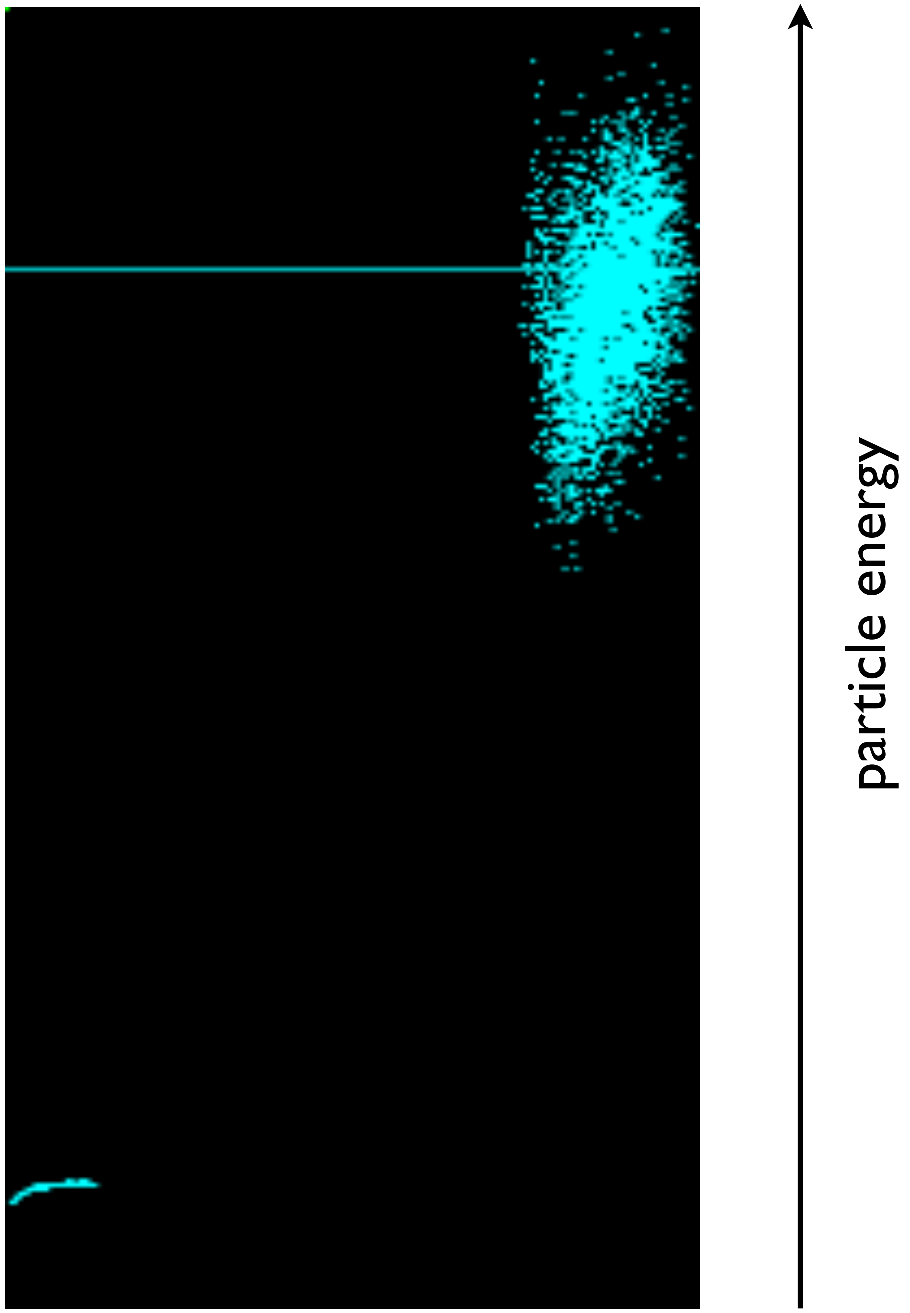


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*PDPWFA*

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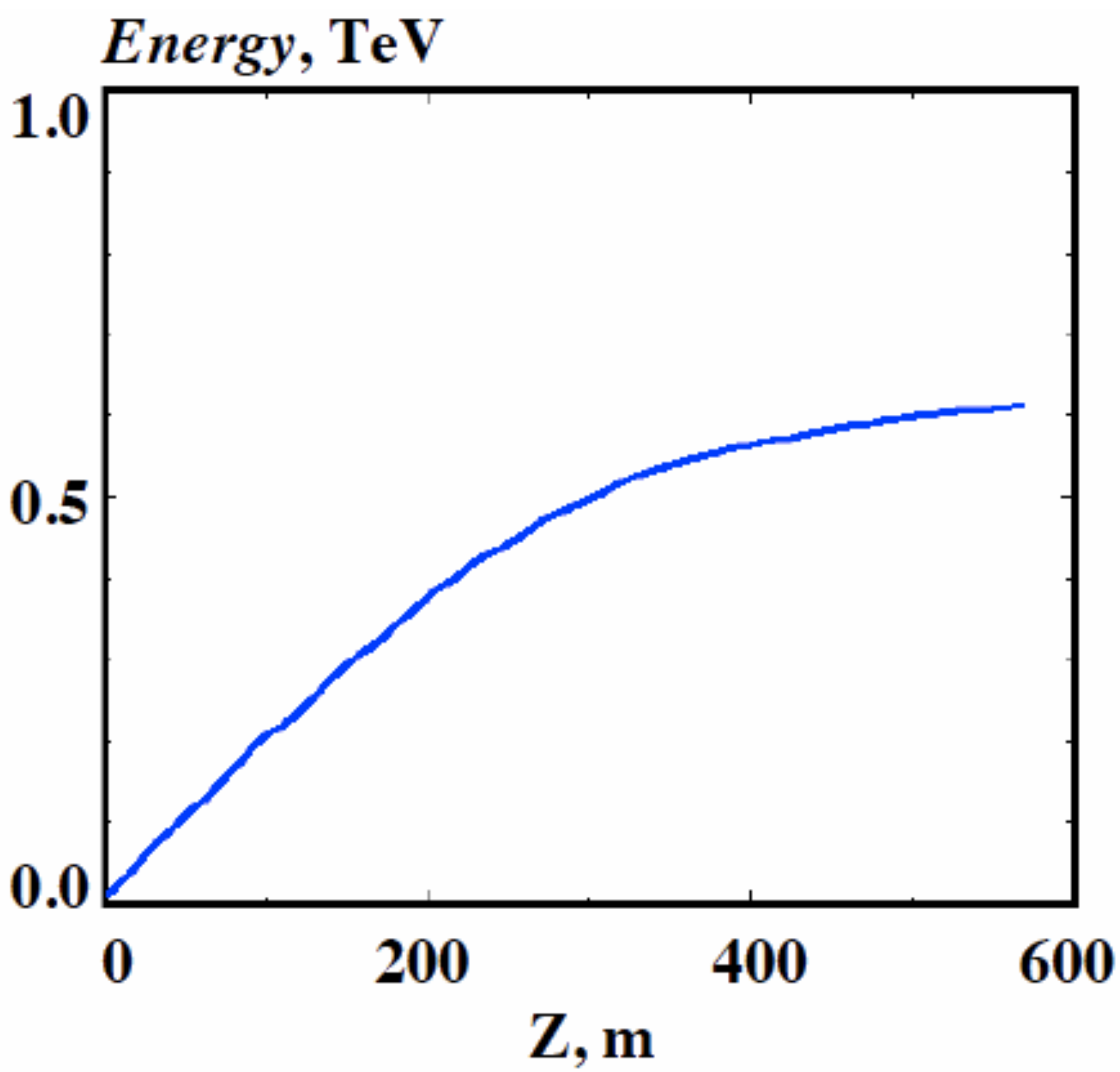


Energy gain of e- in a thin Li plasma driven by 1 TeV protons:
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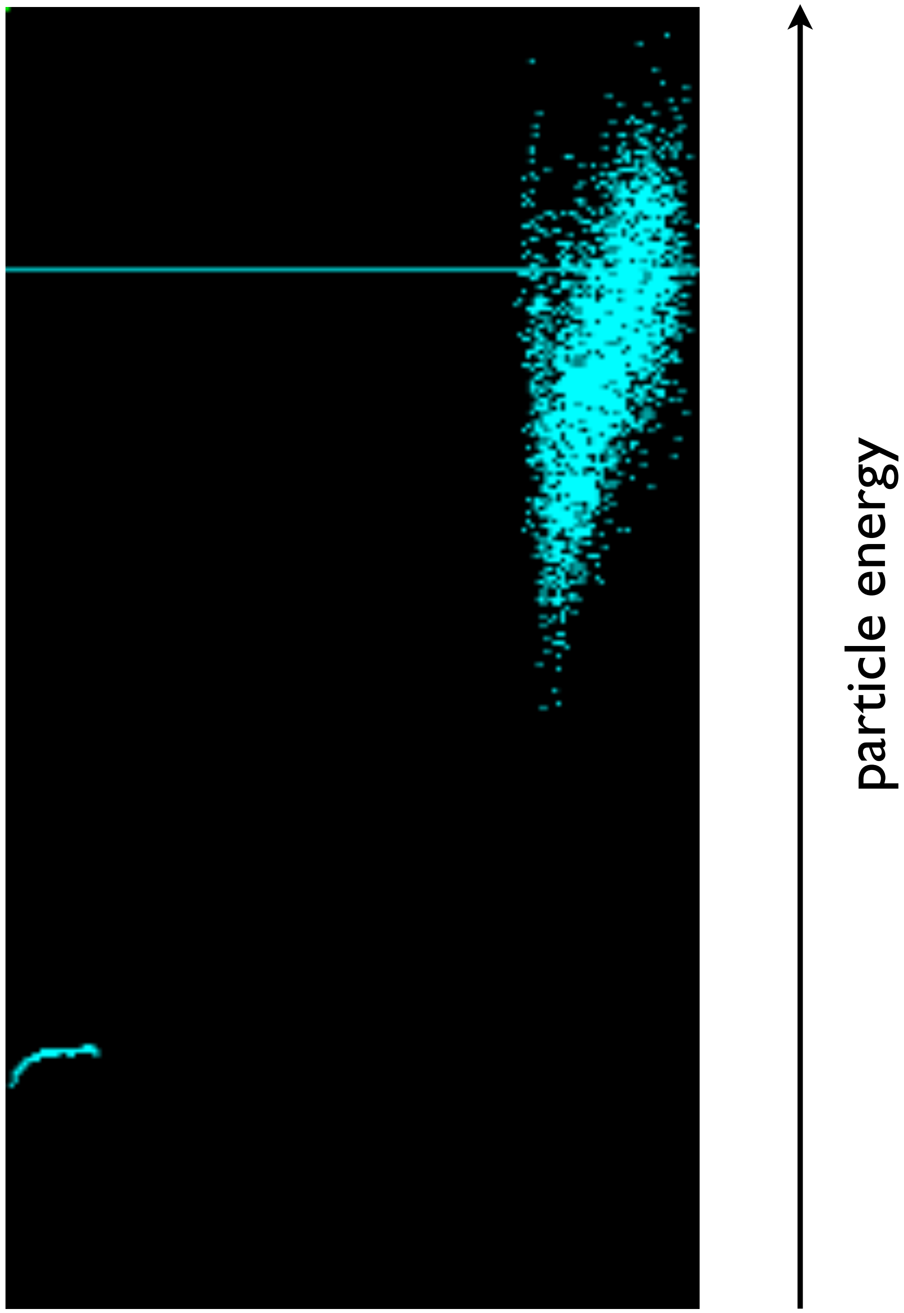


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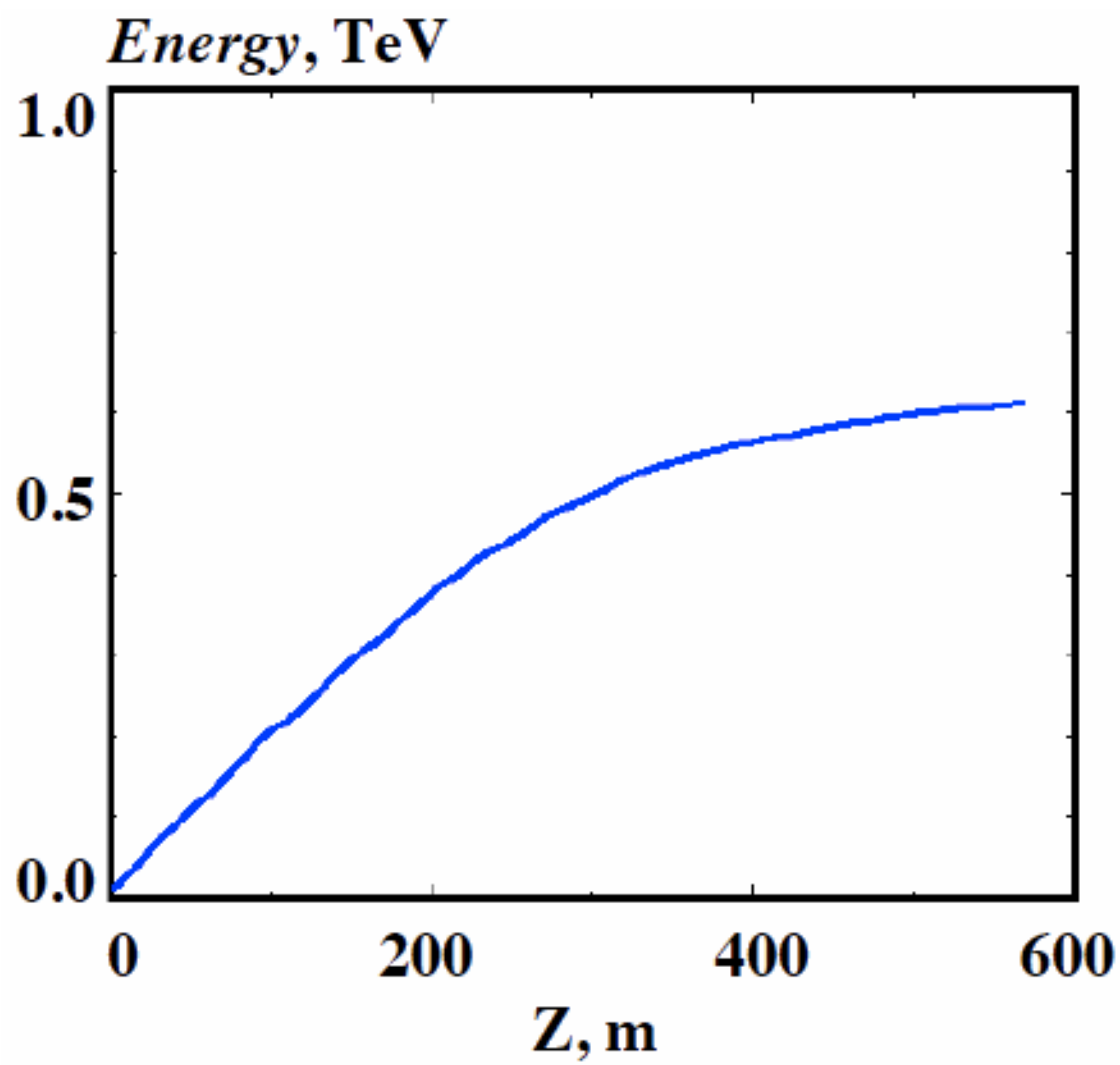


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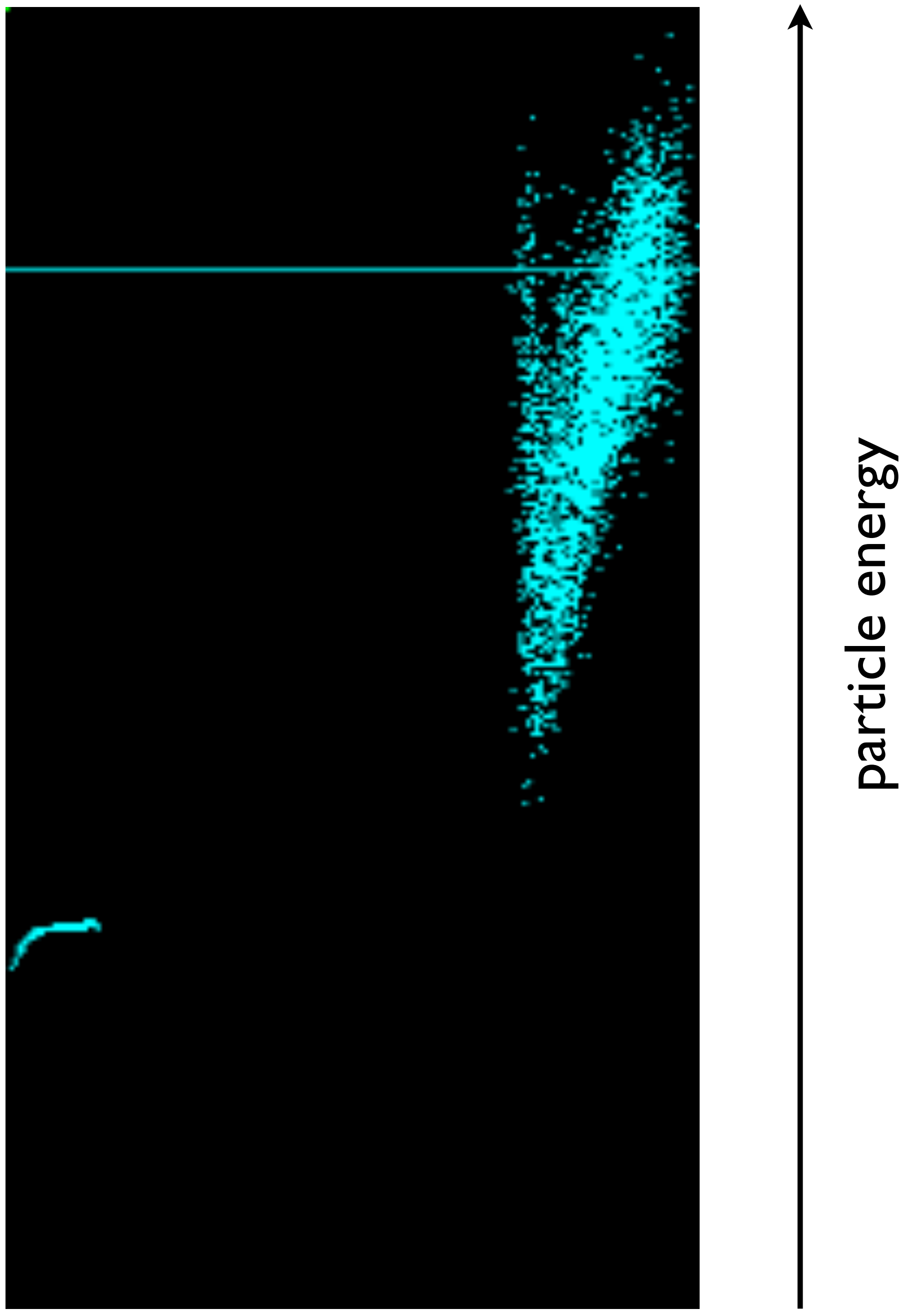


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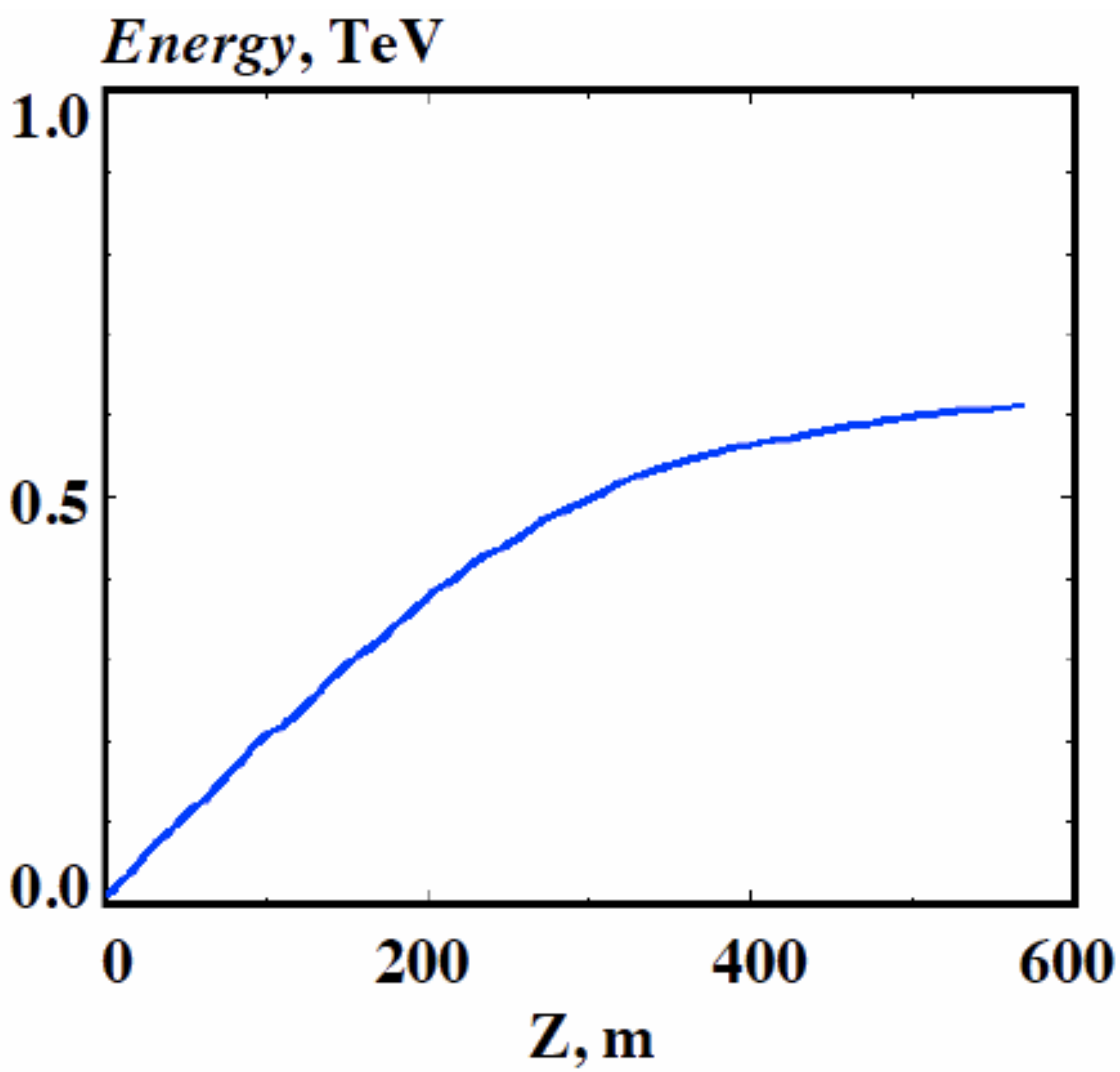


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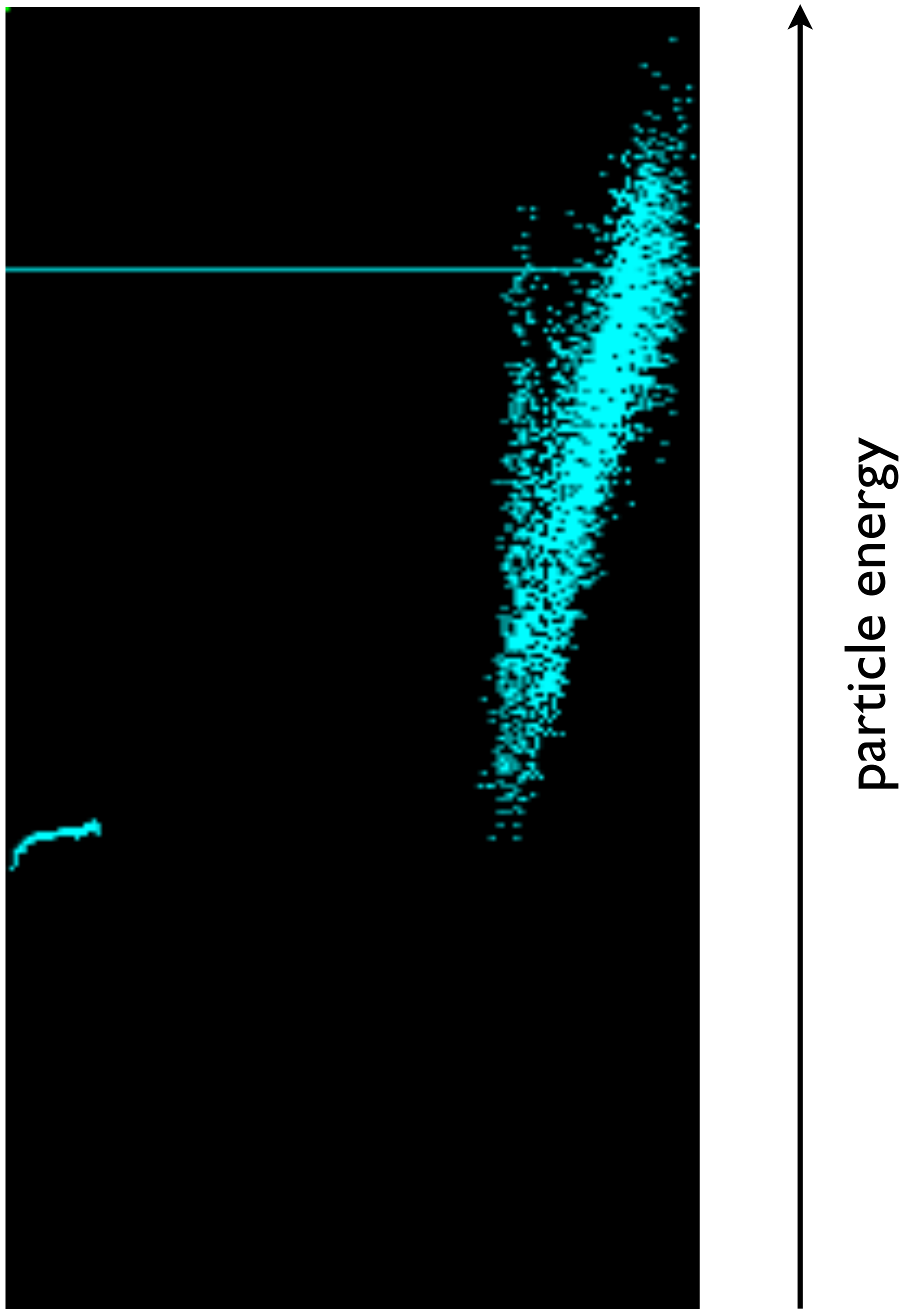


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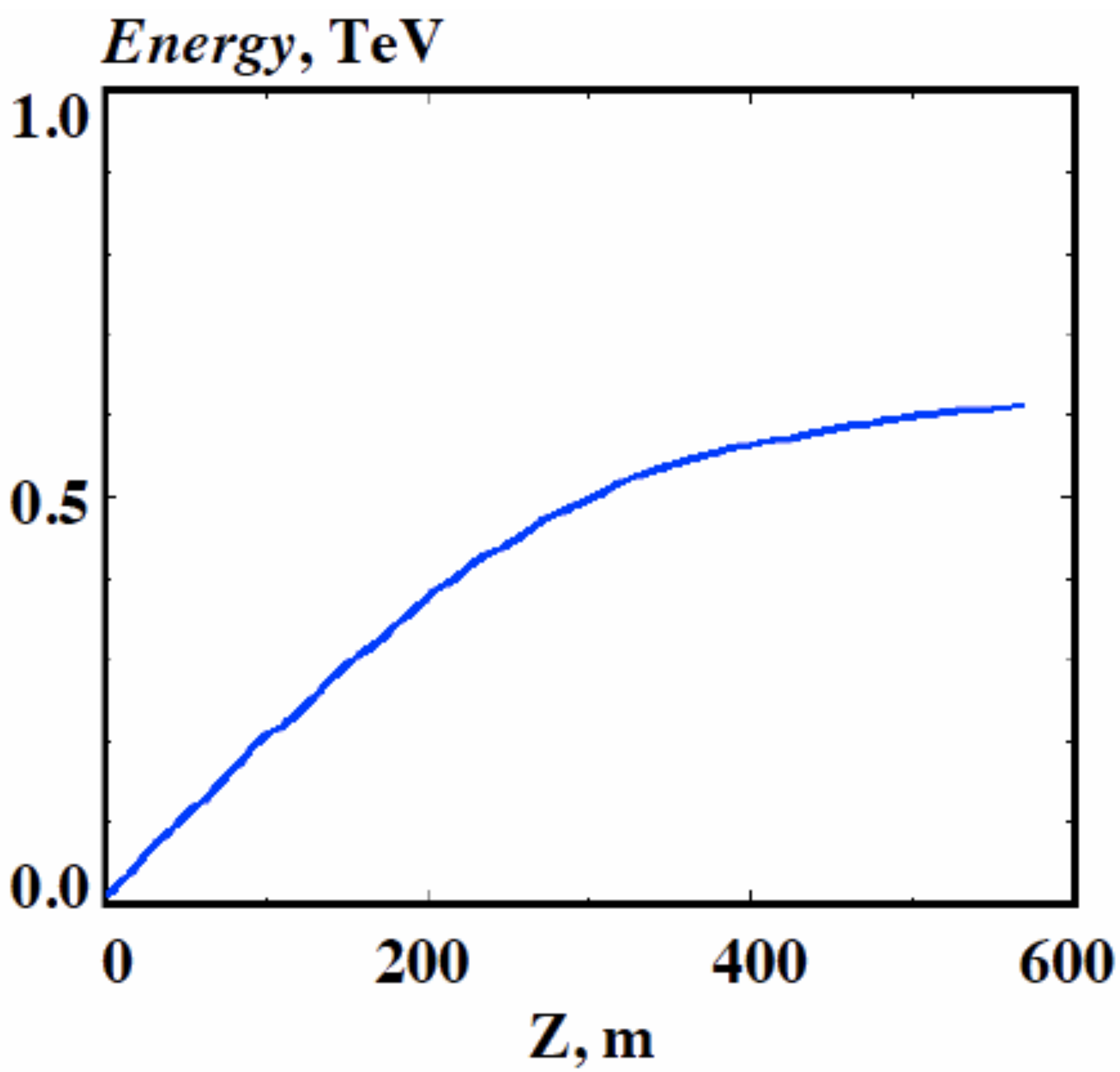


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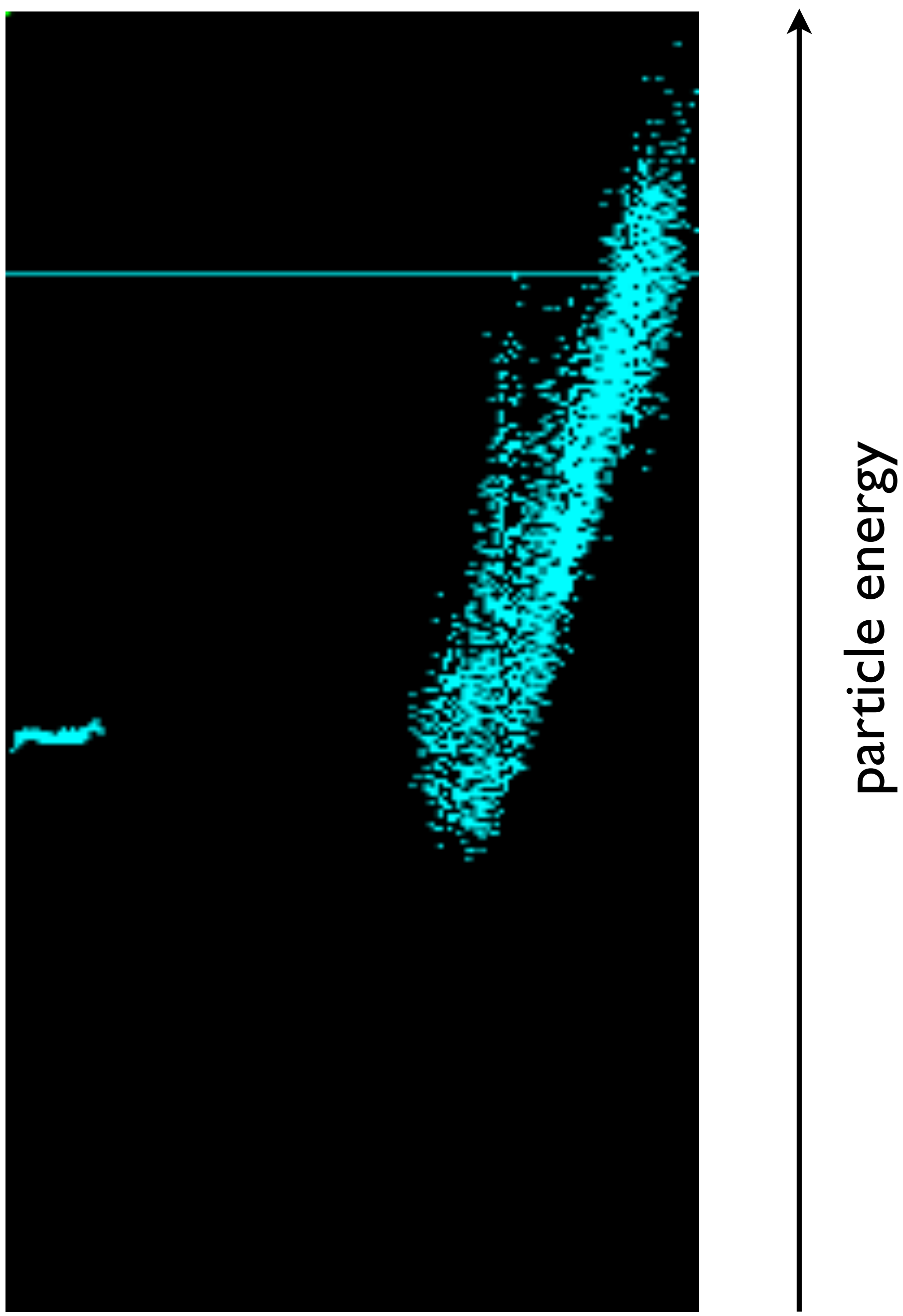


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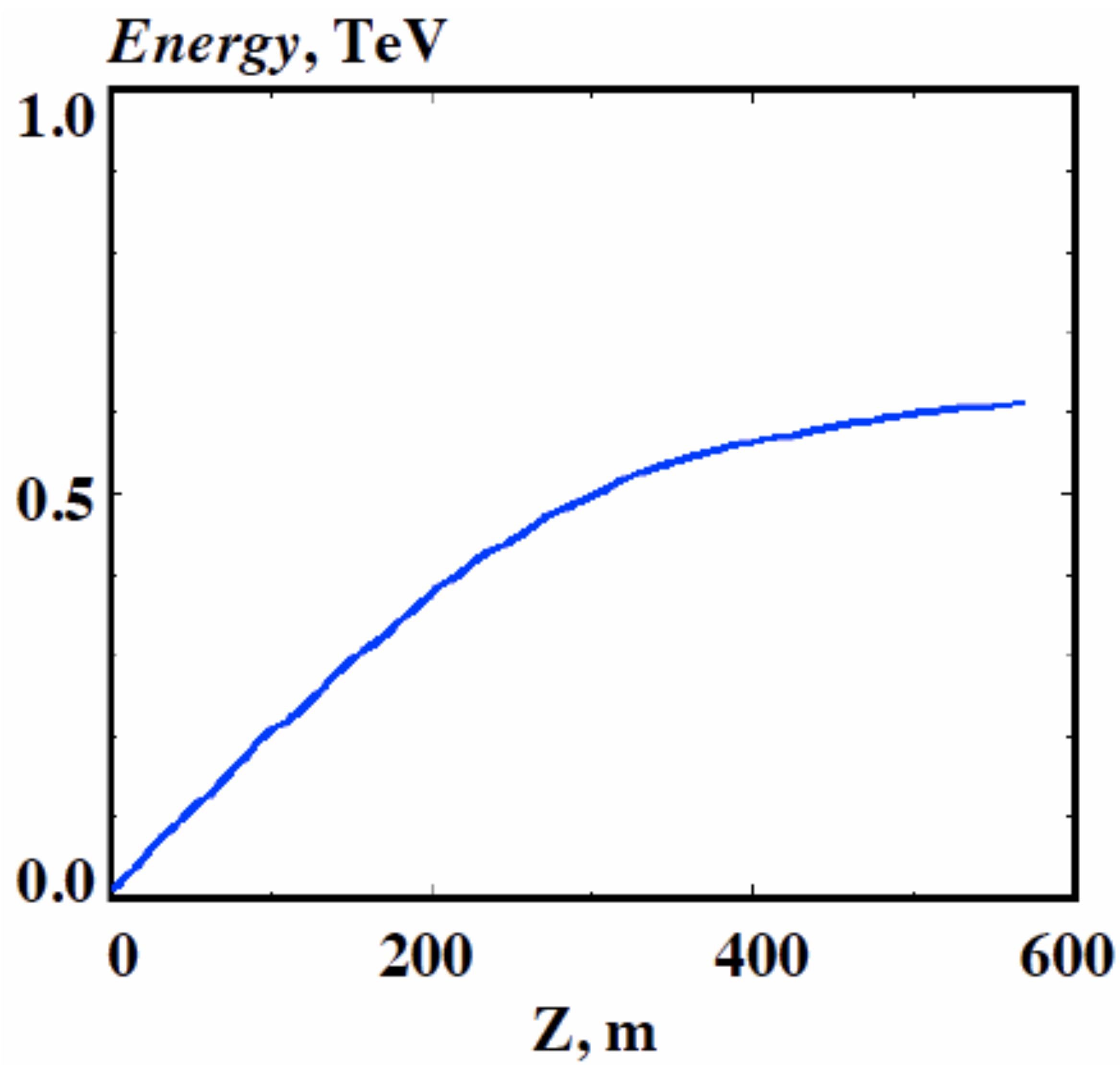


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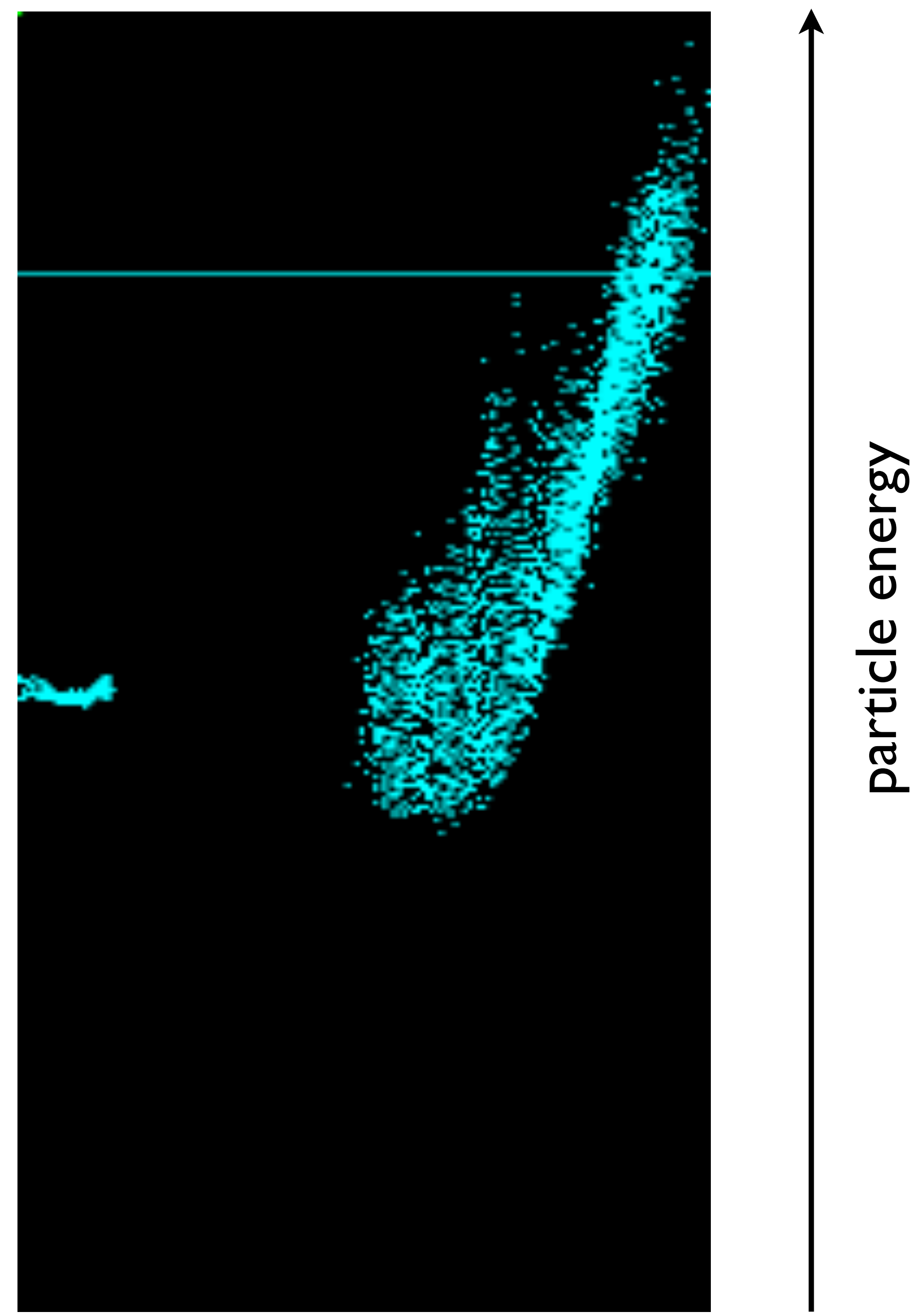


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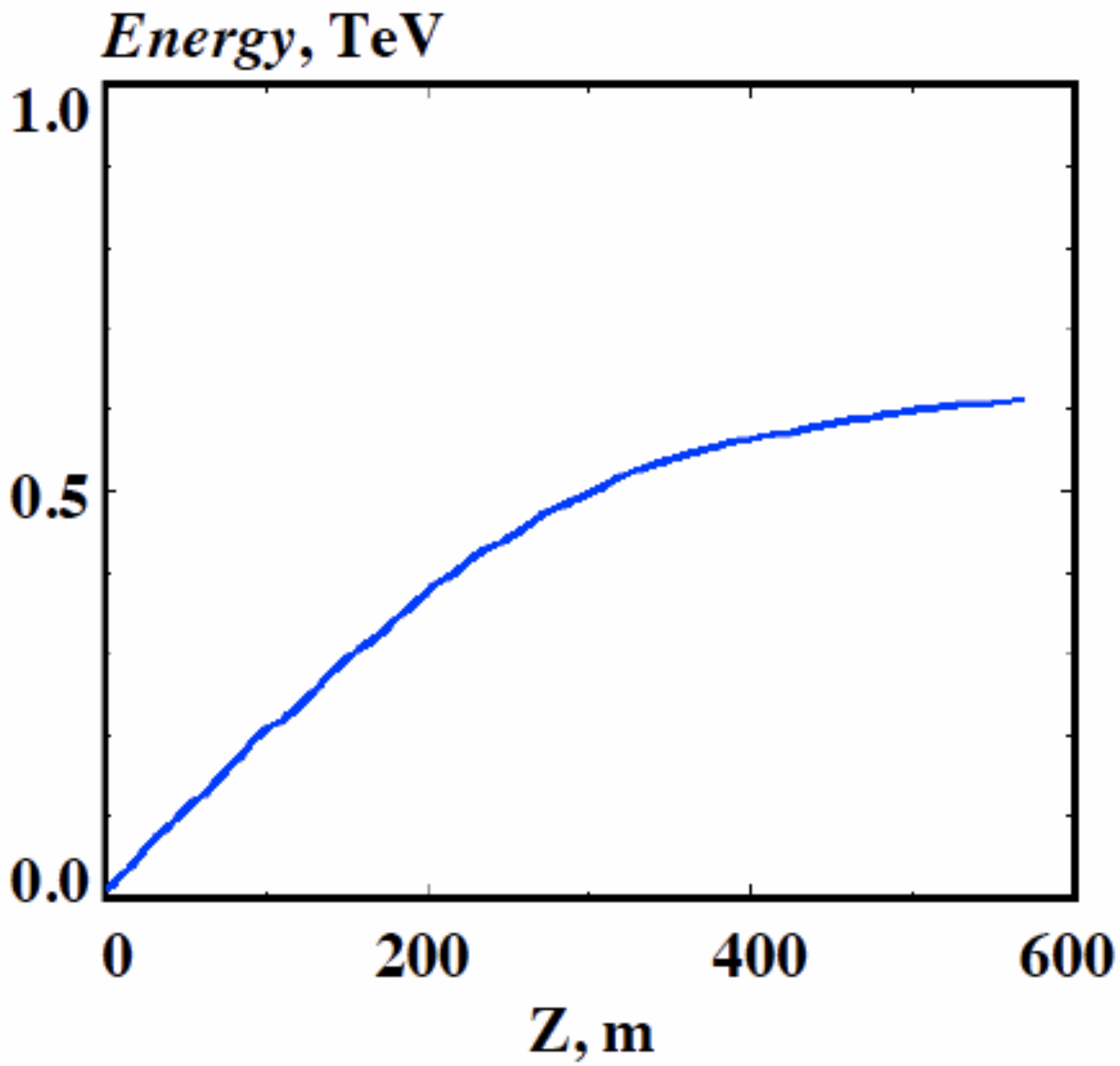


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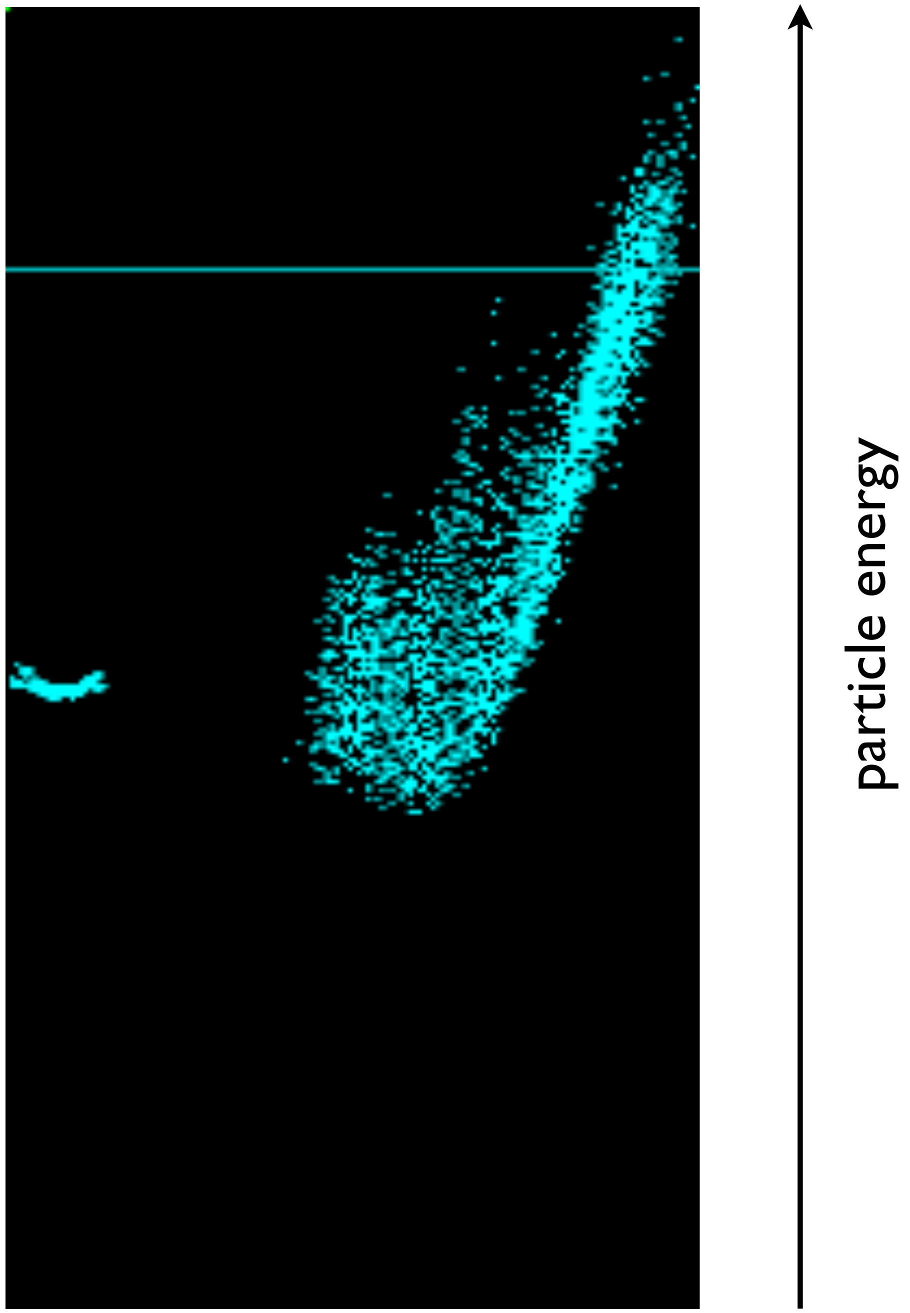


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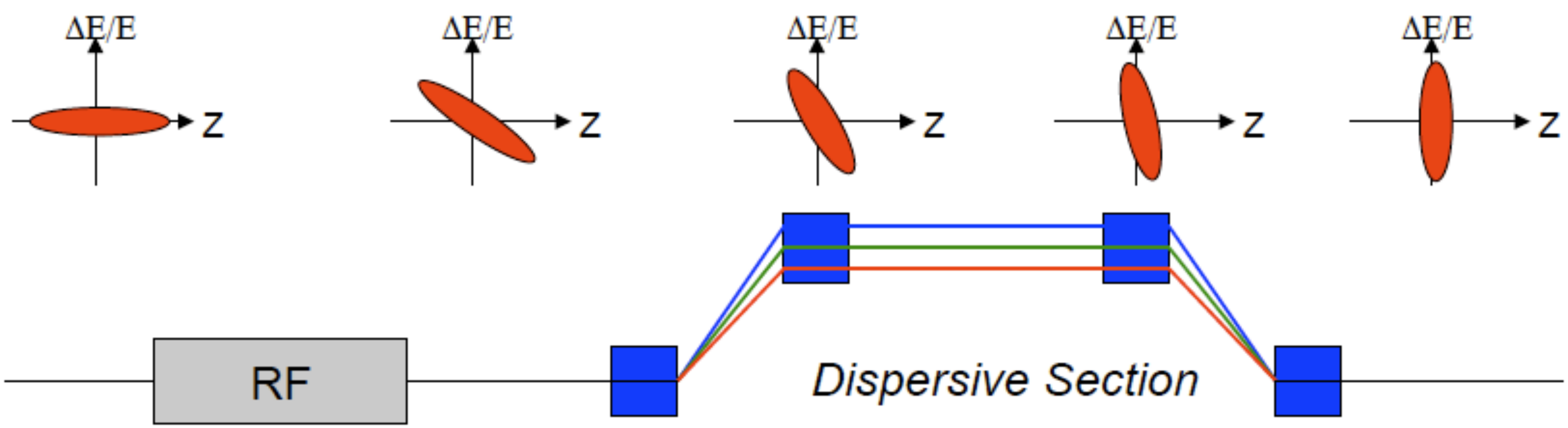
# Ideas for Bunch Compression

**PDPWFA**

- Strategies to create short proton bunches currently under investigation
  - No obvious simple solution!
  - For example: magnetic compression




need strong RF section to introduce "energy chirp", position dependent energy deviation in the bunch, which is then used to reduce longitudinal bunch size in a magnetic chicane

- 1 TeV protons need 2.7 km standard RF, 800 m long chicane... further ideas needed.

G. Xia

# Summary

- ILC development internationally strong despite recent funding challenges
  - collaboration with CLIC now ongoing
- ILC detector concepts preparing for LOIs (03/2009), with contributions from the Institute to ILD on physics simulations, TPC, Calorimetry, Vertex (SiD also)

- Growing activities on calorimeter development within the CALICE collaboration: HCAL with small scintillator cells and SiPM readout
- Hardware studies & data analysis: properties of hadronic showers, calibration strategies, optimization of energy resolution...

- Investigation of novel technologies for high-gradient acceleration: plasma wakefield
- Use of a proton beam to drive the plasma allows high energies in one acceleration stage due to availability of high energy protons
  - Very short proton bunches needed, bunch compression extremely challenging

# The Team

- L. Andricek, A. Caldwell, X. Chen, C. Kiesling, S. Lu, A. Moll, H.G. Moser, K. Prothmann, A. Raspereza, O. Reimann, R.H. Richter, S.Rummel, R. Settles, F. Simon, C. Soldner, L. Weuste, G. Xia

  with a lot of help from the electronics and the mechanical department