IMPROVING HF GFLASH SIMULATIONS AT CMS

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August, 2014

OUTLINE

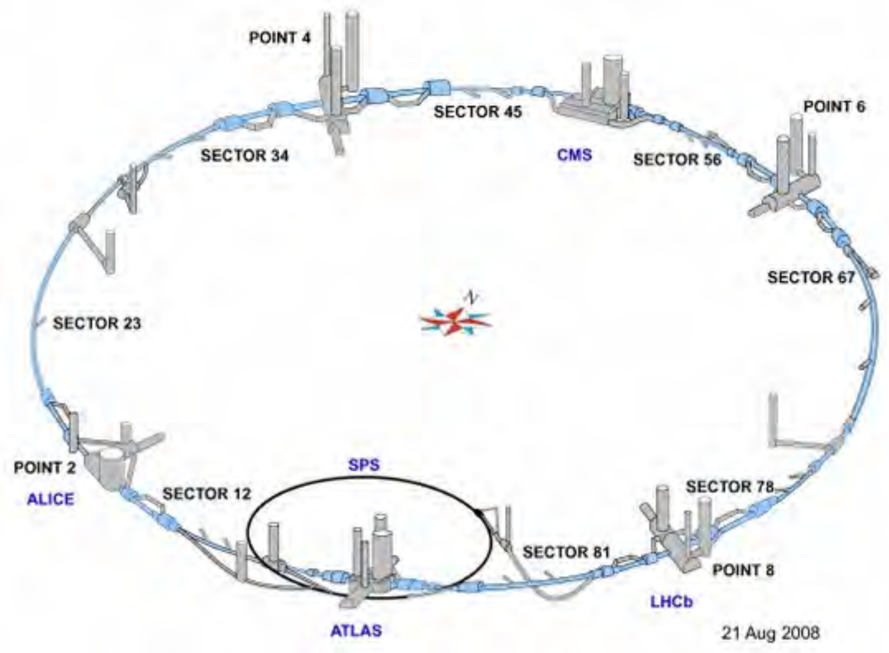
- LHC and CMS
- Hadron Forward Calorimeter
- EM Showers
- GFlash
- Improving speed
- Tuning GFlash

INTRODUCTION

- LHC
- CMS
- HF Calorimeter
- EM Showers
- GFlash

Located at CERN Switzerland-France.

ALICE, ATLAS, CMS, LHCb



LHC four experiments scheme

LHC NOW

- LHC
- CMS
- HF Calorimeter
- EM Showers
- GFlash

- Proton-Proton collisions
- Center of mass energy: 8 TeV
  - Signatures of the Higgs boson
  - Super-symmetric particles
  - Extra dimensions
  - Dark matter
  - Etc…

LHC ring

LHC FUTURE

- LHC
- CMS
- HF Calorimeter
- EM Showers
- GFlash

- 2019
- Center of mass energy: 14TeV
  - Better measurement techniques
  - Faster and more accurate simulations

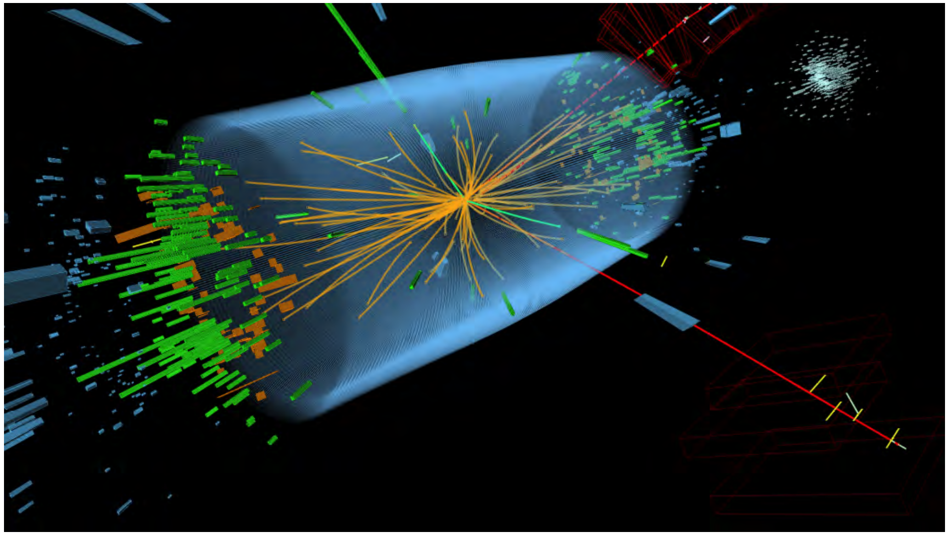
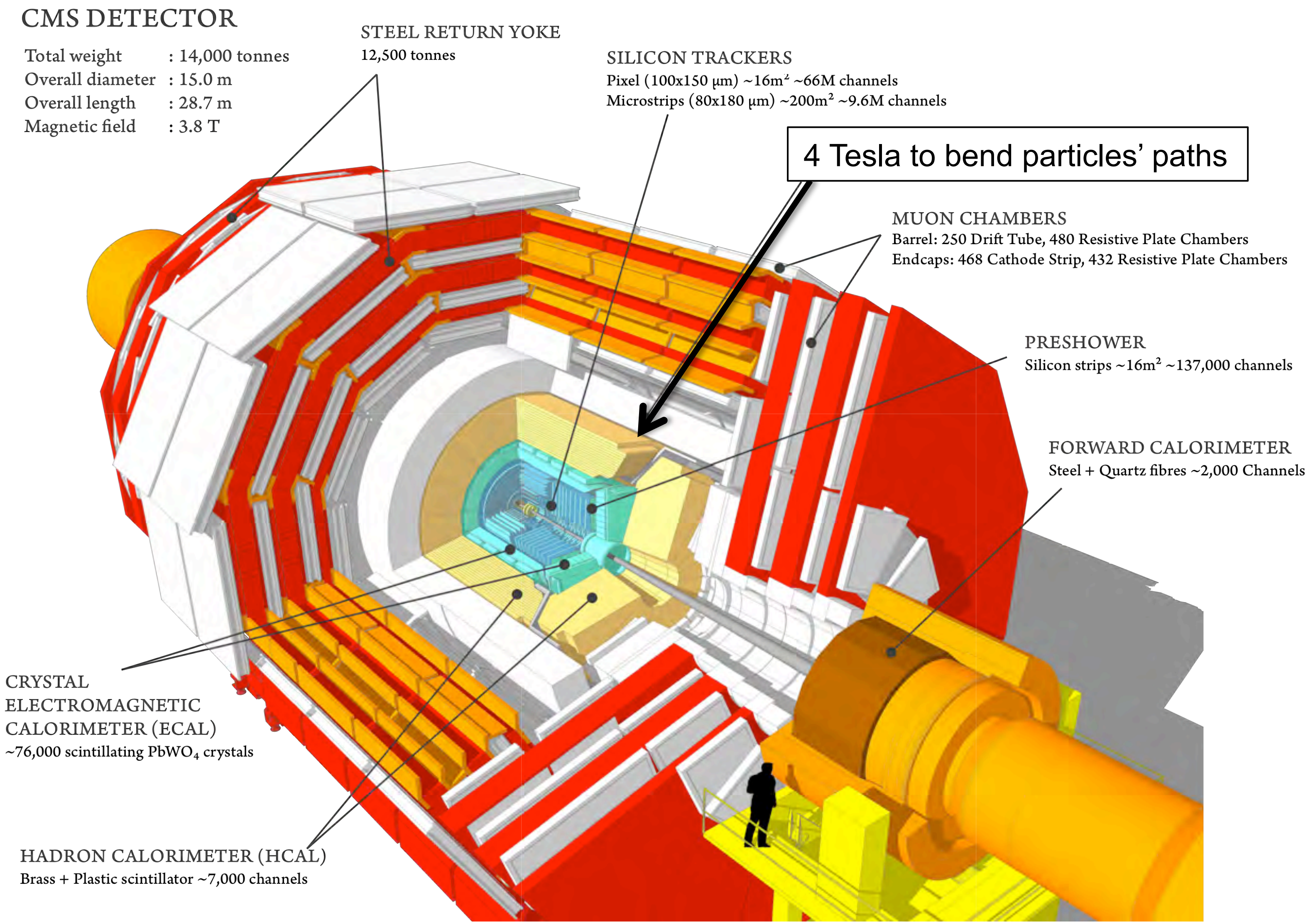


Illustration of a result from the CMS experiment at the LHC, gathered on May 27, 2012.

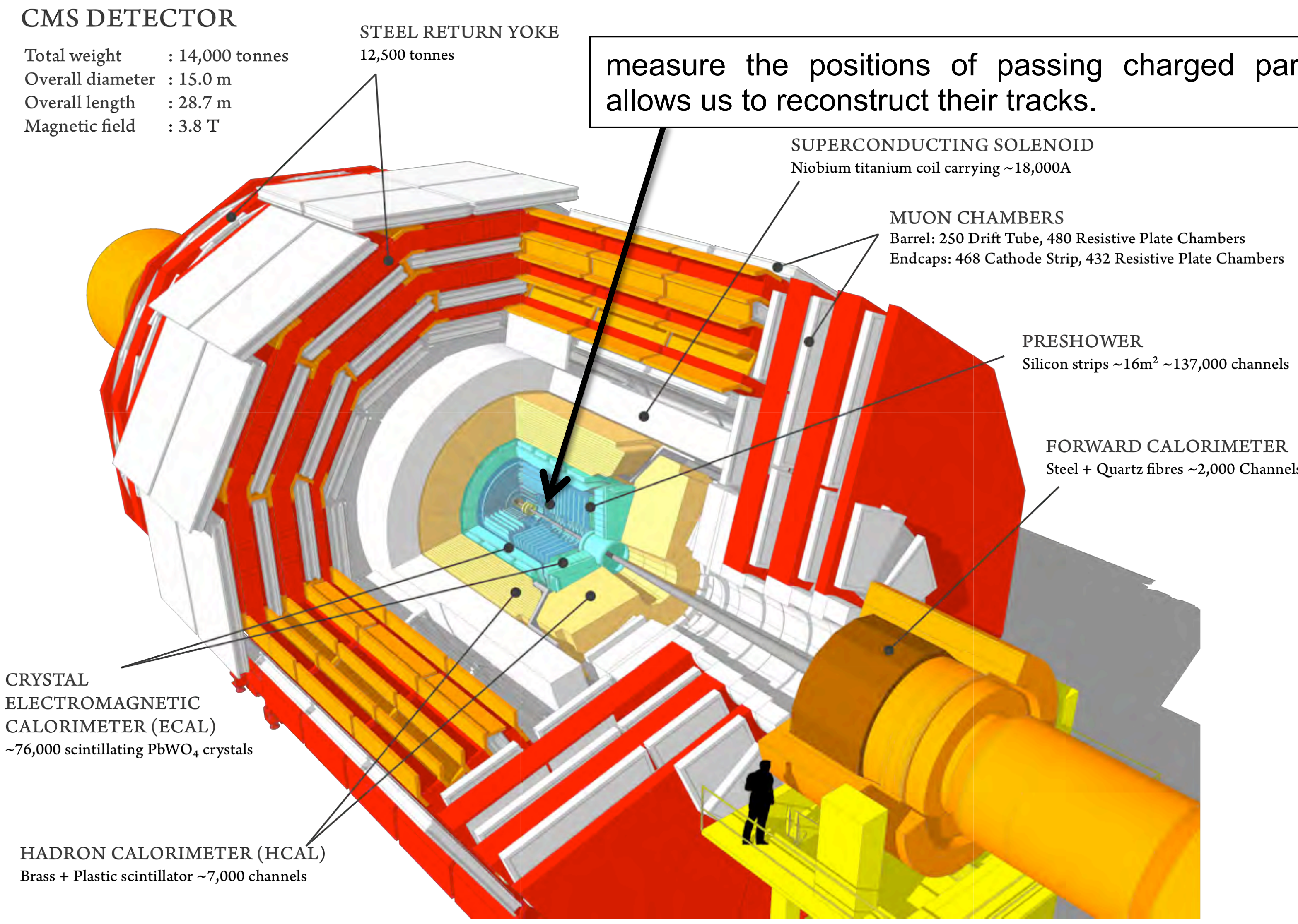
SOLENOID



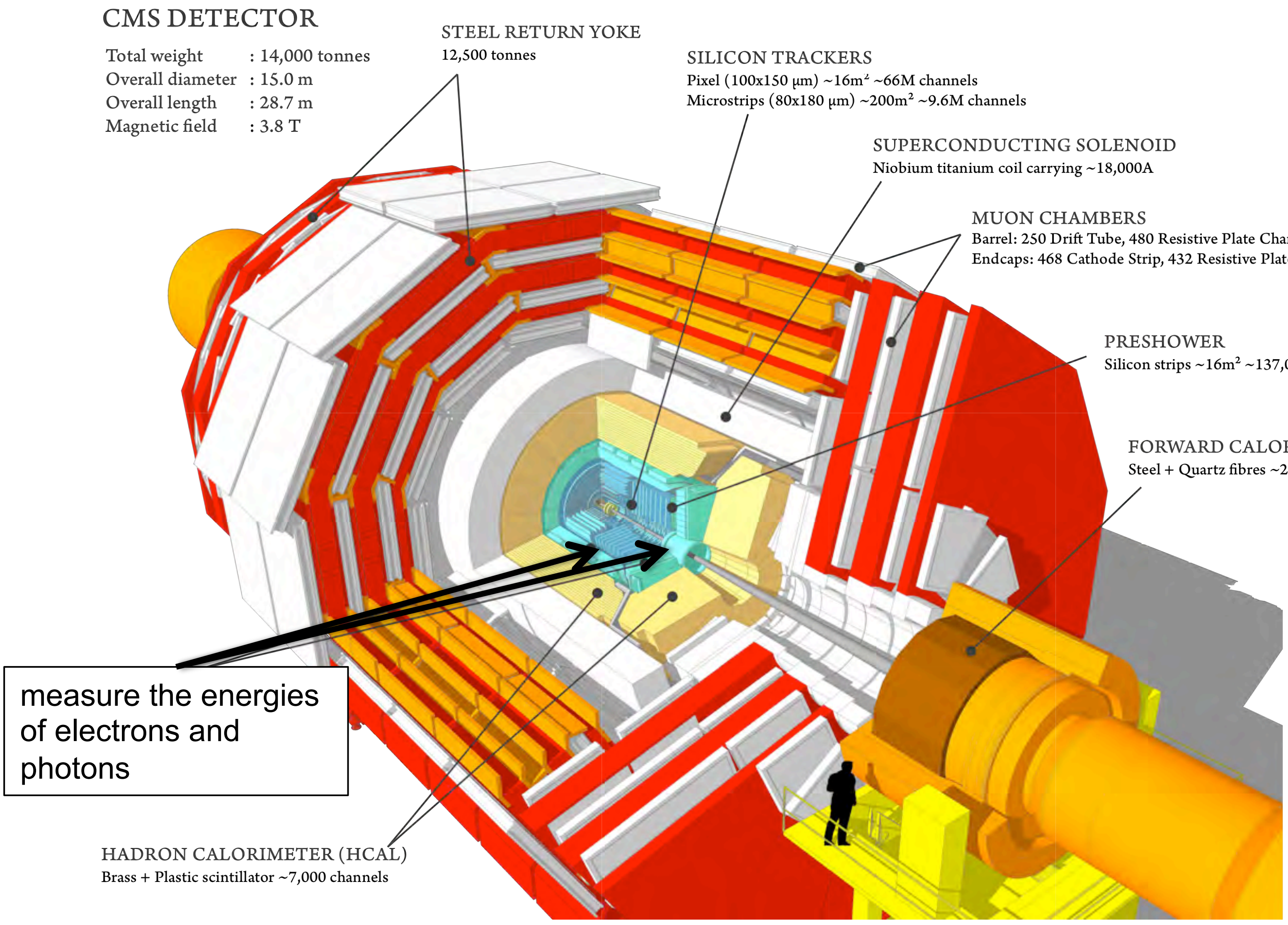
CMS DETECTOR
Total weight : 14,000 tonnes
Overall diameter : 15.0 m
Overall length : 28.7 m
Magnetic field : 3.8 T
STEEL RETURN YOKE
12,500 tonnes
SILICON TRACKERS
Pixel (100x150 μm) ~16m² ~66M channels
Microstrips (80x180 μm) ~200m² ~9.6M channels
4 Tesla to bend particles' paths
MUON CHAMBERS
Barrel: 250 Drift Tube, 480 Resistive Plate Chambers
Endcaps: 468 Cathode Strip, 432 Resistive Plate Chambers
PRESHOWER
Silicon strips ~16m² ~137,000 channels
FORWARD CALORIMETER
Steel + Quartz fibres ~2,000 Channels
CRYSTAL ELECTROMAGNETIC CALORIMETER (ECAL)
~76,000 scintillating PbWO4 crystals
HADRON CALORIMETER (HCAL)
Brass + Plastic scintillator ~7,000 channels

SILICON TRACKER

measure the positions of passing charged particles allows us to reconstruct their tracks.



ECAL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Niobium titanium coil carrying ~18,000A
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measure the energies of electrons and photons
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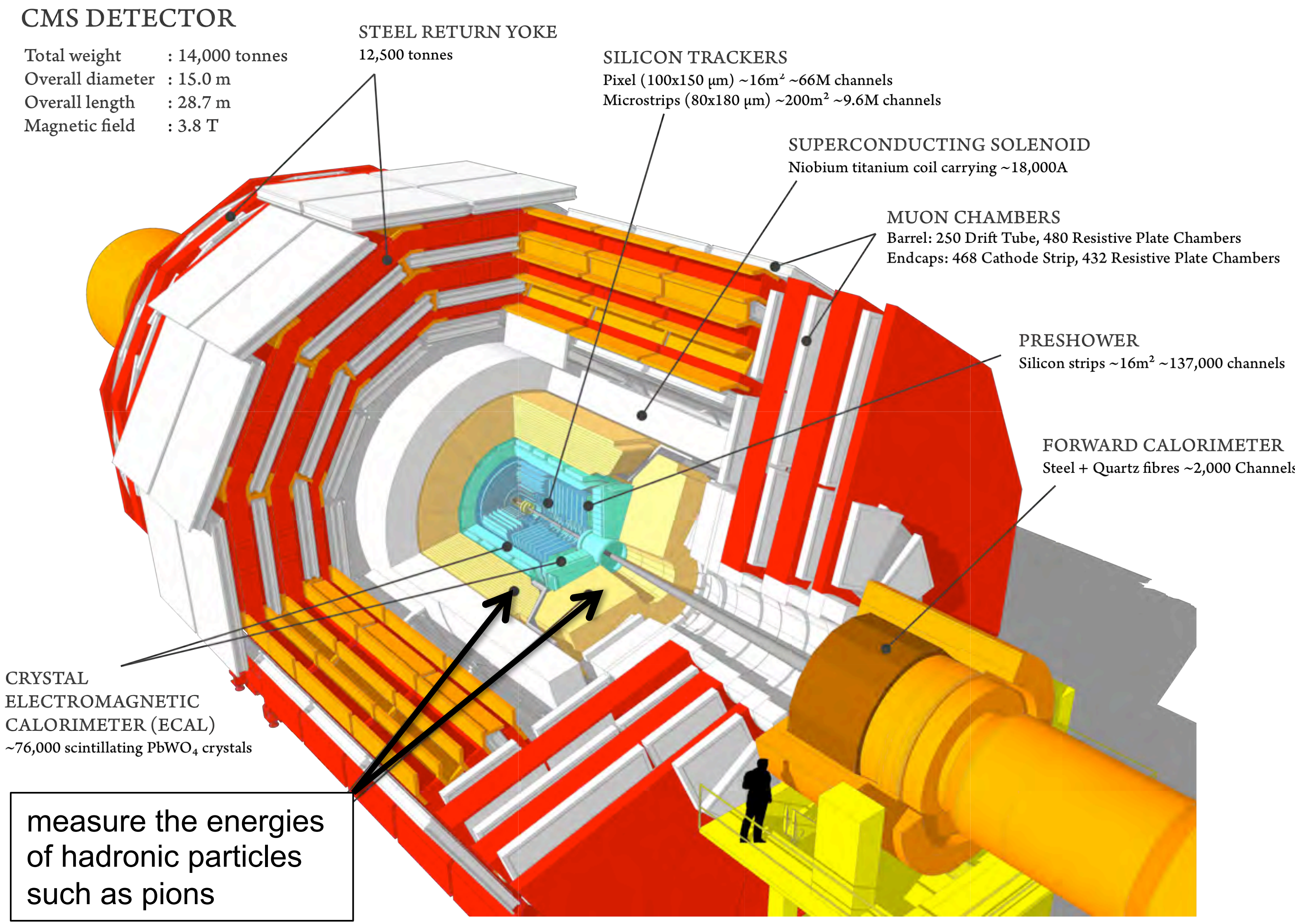
HCAL



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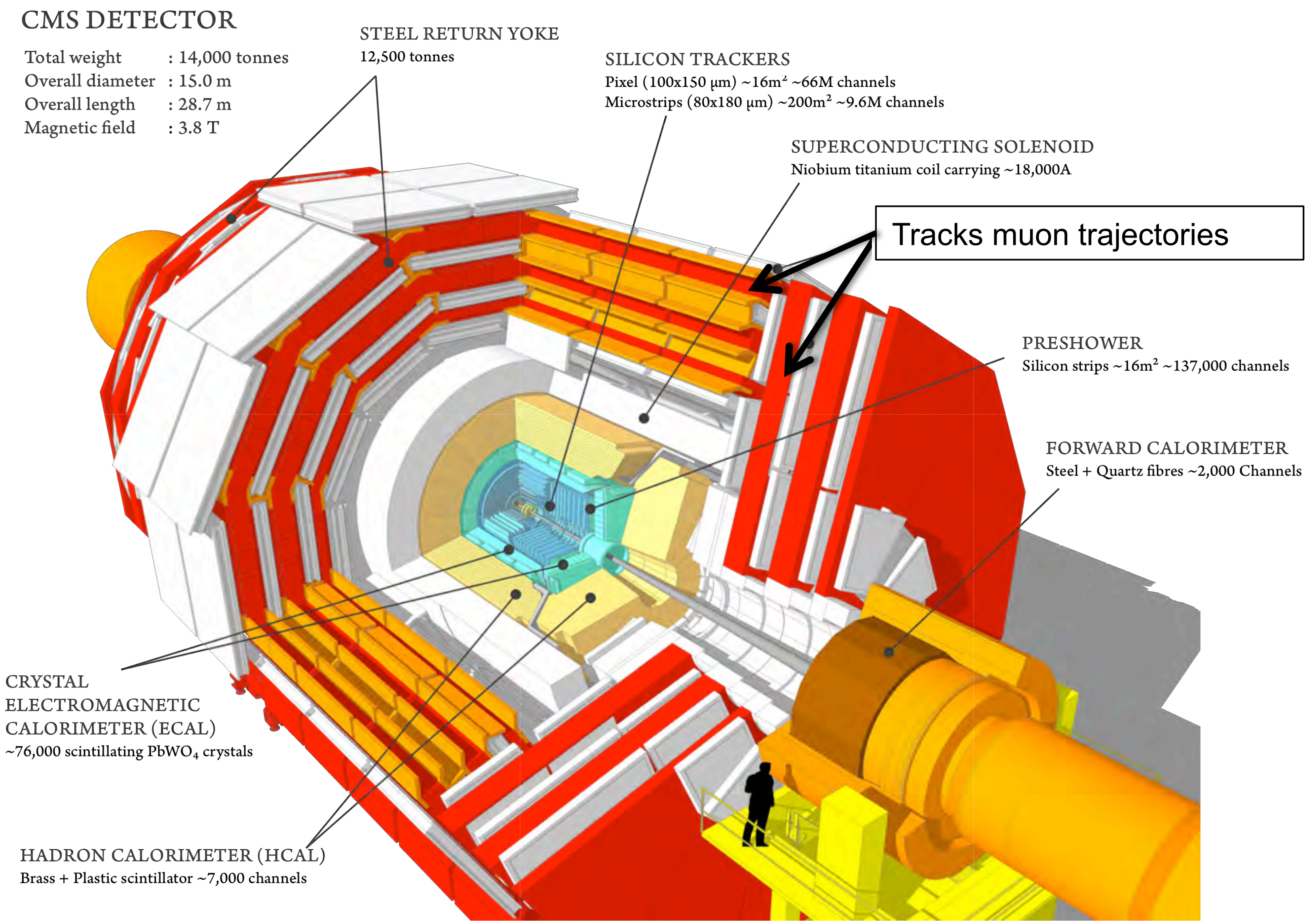
measure the energies of hadronic particles such as pions

MUON CHAMBERS



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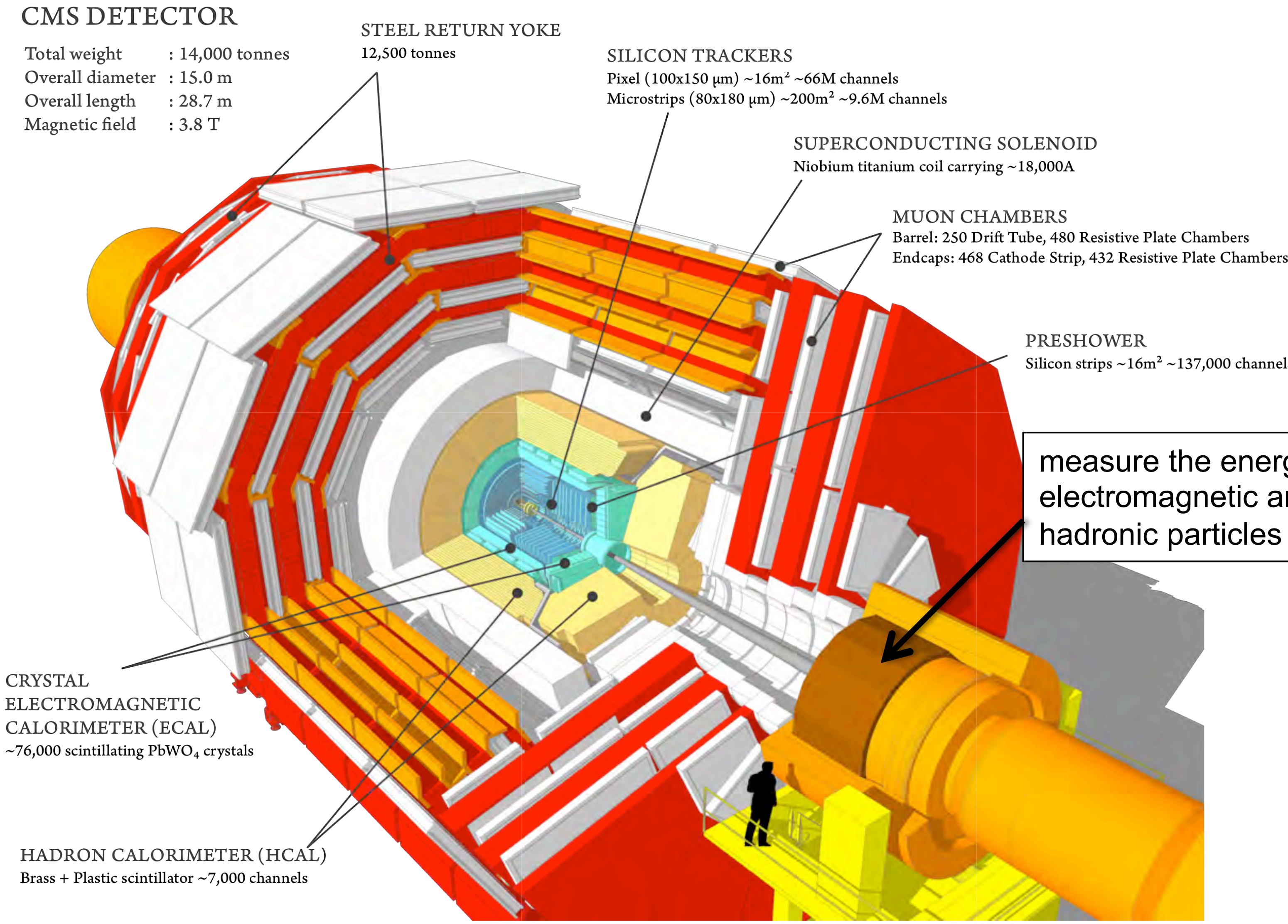
HF CAL



measure the energies of electromagnetic and hadronic particles

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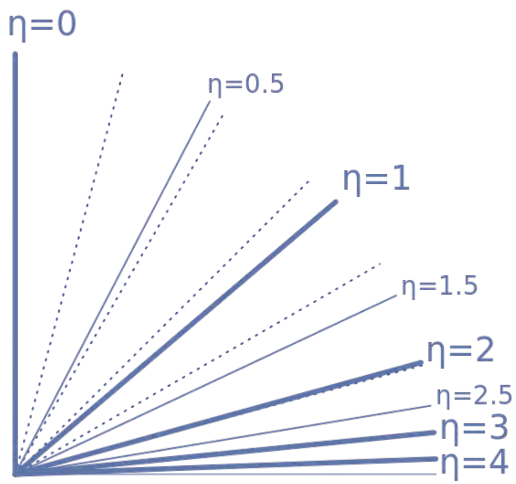
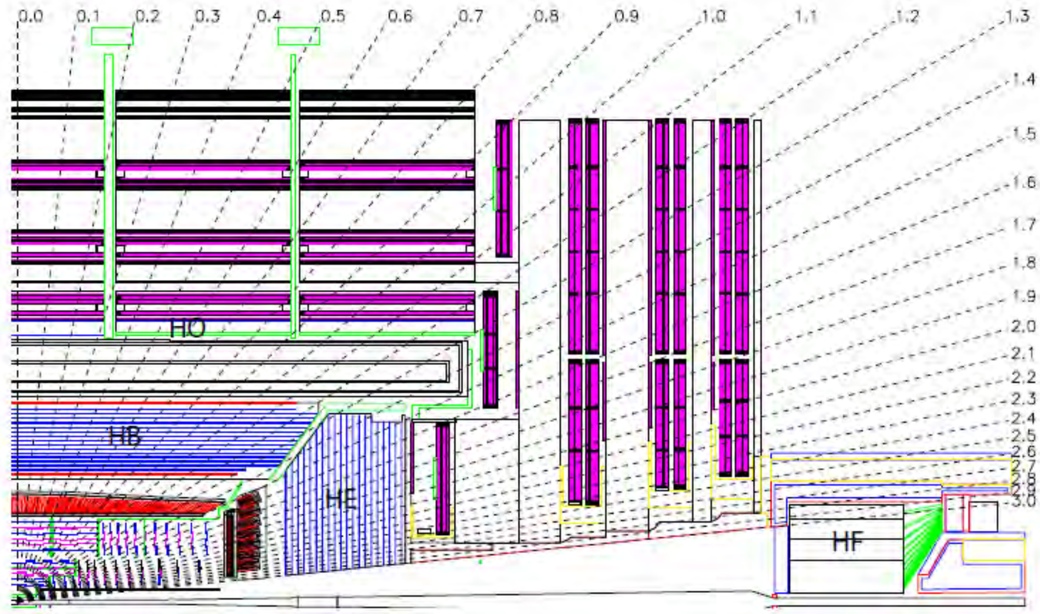
HF CALORIMETER

- **LHC**
- **CMS**
- **HF Calorimeter**
- **EM Showers**
- **GFlash**

- 11.15m away from the interaction point
- Pseudorapidity region 3 < |η|< 5.
- Steel absorbers and quartz fibres





Pseudorapidity diagram and location of HF Calorimeter

HF CALORIMETER

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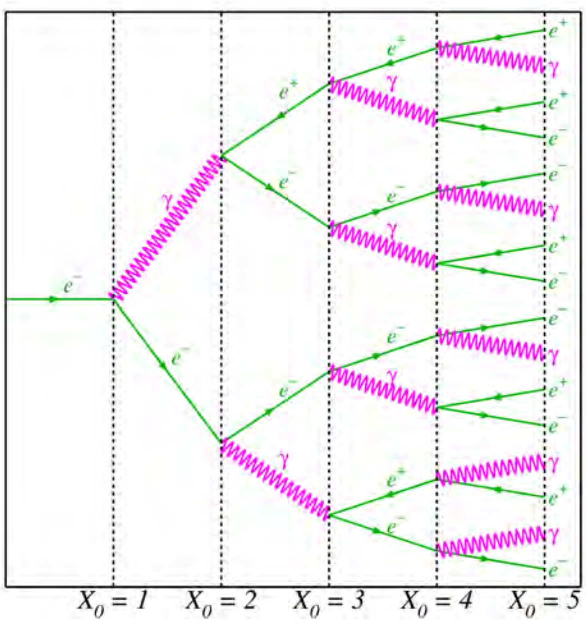
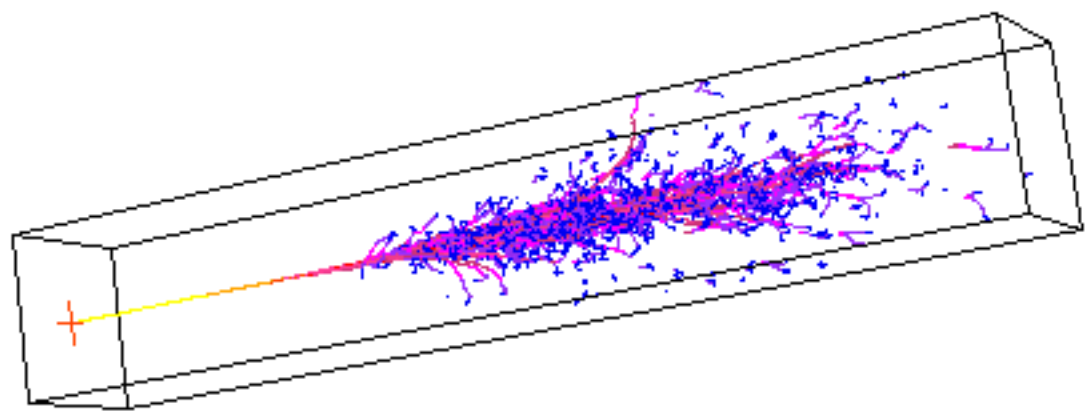
HF Calorimeter wedges. In white, PMT's.

EM SHOWERS

- LHC
- CMS
- HF Calorimeter
- EM Showers
- GFlash

- Electrons radiate photons
- Photons pair produce
- Number of particles increases exponentially.
- Each pair production and Bremsstrahlung radiation the energy of the particles reduces.



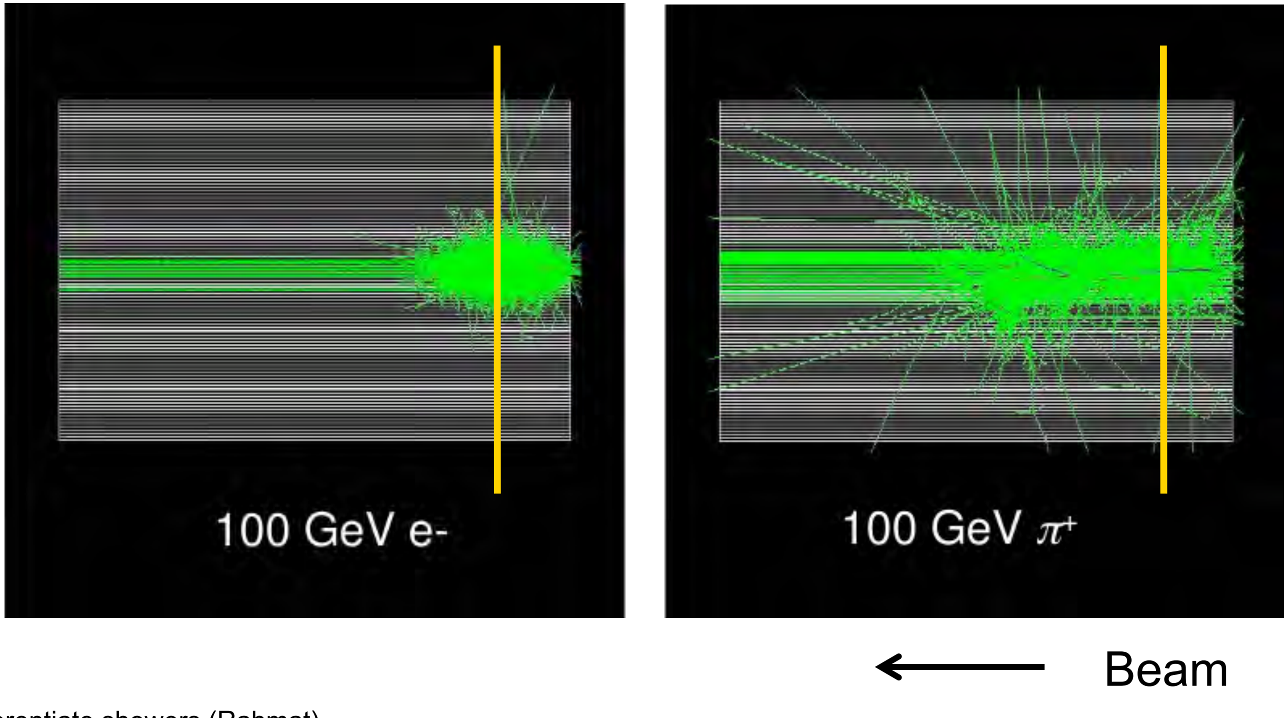


Electron EM Shower diagram and EM Shower profile simulation

EM SHOWERS & HF CAL

- **LHC**
- **CMS**
- **HF Calorimeter**
- **EM Showers**
- **GFlash**

- Long (L) and short (S) fibres to differentiate showers from electromagnetic and hadronic particles
- 165 cm (L) and 143 cm (S)



Long and Short fibres to differentiate showers (Rahmat)

GFLASH

- LHC
- CMS
- HF Calorimeter
- EM Showers
- GFlash

- Why do we need GFlash?

- Full Geant4 simulation → might need days to simulate 1 event.

- Previous CMS Simulation has a problem to simulate HF Noise because it killed particles immediately when they entered detectors and replaced them with Shower Library.

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GFLASH

- The spatial energy distribution of EM Showers is given by 3 Probability Distribution Functions (pdf)

$$dE(\vec{r}) = Ef(t)f(r)f(\phi)dtdrd\phi$$

- t = Longitudinal shower distribution
- r = Radial shower distribution
- Φ = Azimuthal shower distribution (assumed to be distributed uniformly)

- The average longitudinal shower profile (in units of radiation length):

$$\left\langle \frac{1}{E}\frac{dE(t)}{dt} \right\rangle = f(t) = \frac{(\beta t)^{\alpha-1}\beta\exp(-\beta t)}{\Gamma(\alpha)}$$

- The average radial energy profile (in units of Moliere radius):

$$f(r) = \frac{1}{dE(t)}\frac{dE(t,r)}{dr}$$

GFLASH 2012

- **LHC**
- **CMS**
- **HF Calorimeter**
- **EM Showers**
- **GFlash**

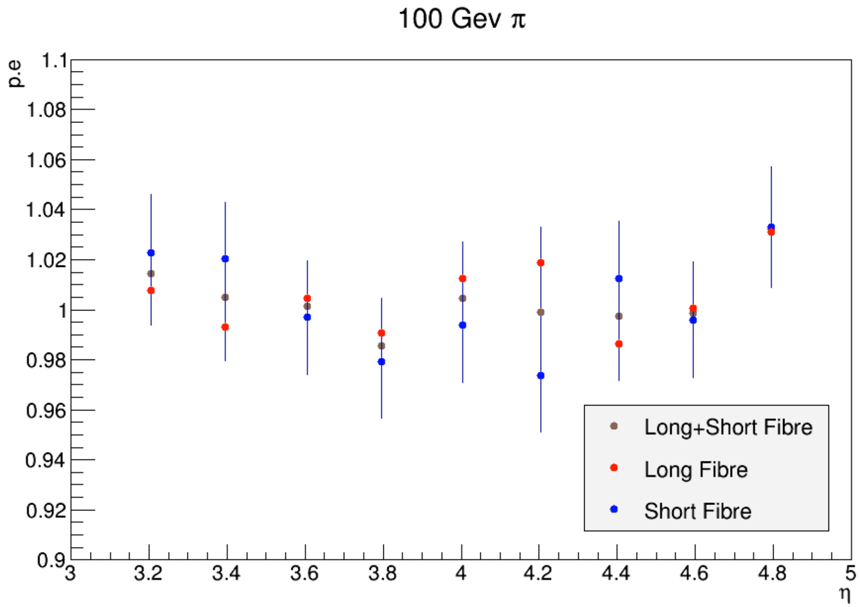
- Tested against:
  - Test Beam Data
  - Collision Data
  - Shower Library (previous HF CMS Simulation)
- Noises simulation
- Very high energy particles
- Better agreement to Test Beam Data
- Good agreement to CMS Collision Data
- 10000 times faster than Geant4.
- **Aim → Faster and more precise**

METHODOLOGY

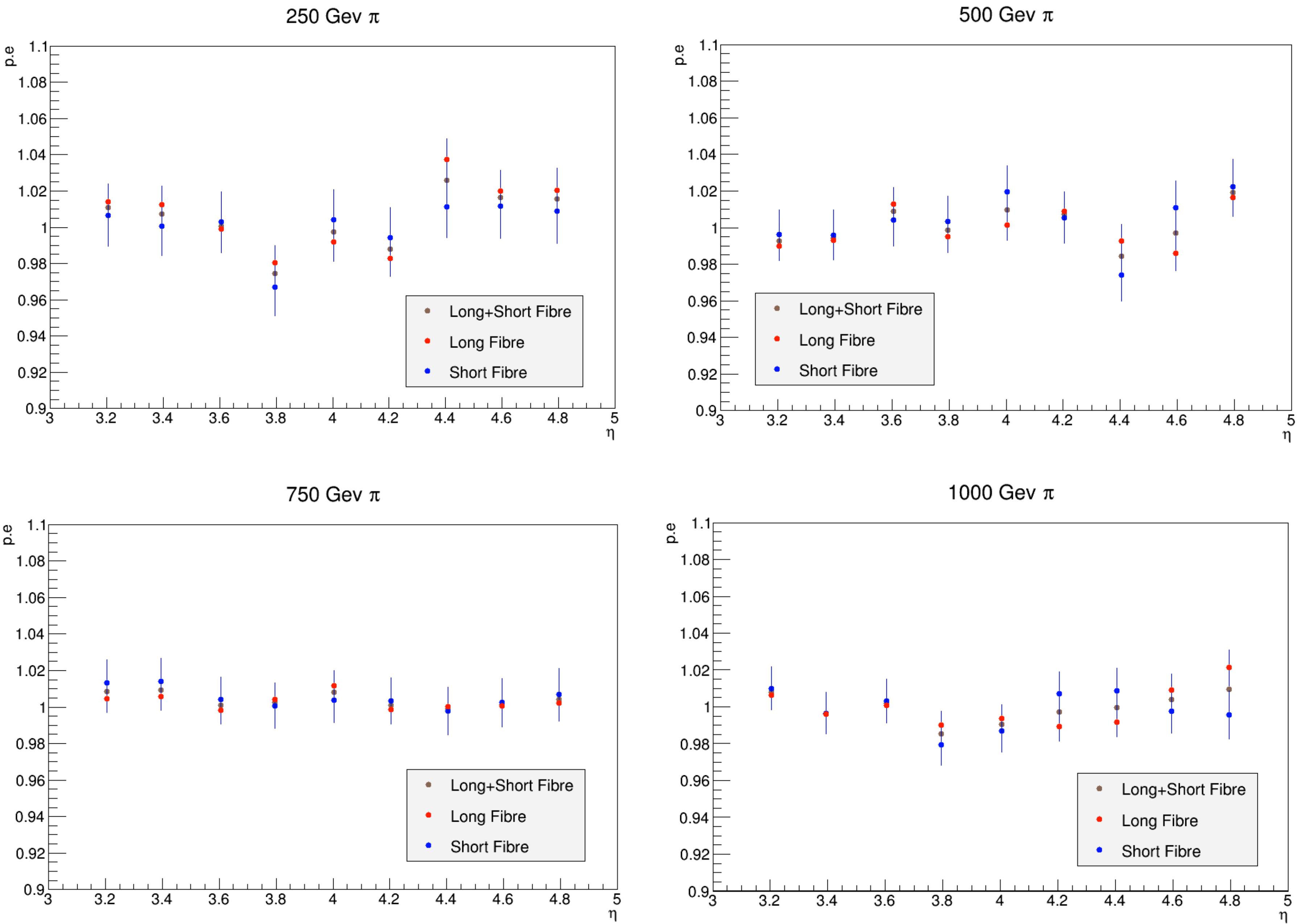
1 Gathering previous results of GFlash simulations.
   1 Photoelectron (p.e.) counts varying the incoming energy of the particle Eo.
   2 p.e. counts varying the η of entrance.
   3 p.e. counts for both e^- and π^+.
2 Set a soft neutron threshold. We varied the energy of this threshold from 1.0 GeV to 1.5 GeV.
3 Comparing the obtained data we determined the threshold that is more convenient.
4 Compare average computing times with and without the cut and test the results obtained with the 1.2 cut vs Test Beam Data.
5 Tune the simulation using the Test Beam Data.

1.2 GEV CUT RESULTS

- Plot the ratio:
  - p.e. (1.2 cut)/p.e. (no cut) vs η
  - 100 to 1000 GeV
  - π^+
- % Discrepancies < 4%
- Simulation runs 76% faster



Plot p.e. ratio vs η for 100 GeV pions



Plot p.e. ratio vs η for 100, 250, 500 and 1000 GeV pions

SOFT NEUTRON THRESHOLD RESULTS

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Energy [GeV]	1.0	1.1	1.2	1.3	1.4	1.5
% Faster	30	45	76	81	84	86
Mean Ratio	1.000	1.003	0.999	0.997	1.002	0.997
Mean Relative Error %	1.15	1.04	1.24	1.36	1.34	1.32
Std. Dev. RE	0.59	0.49	0.32	0.42	0.80	0.87

Table 1: Soft Neuton Threshold results

TUNING THE SIMULATION

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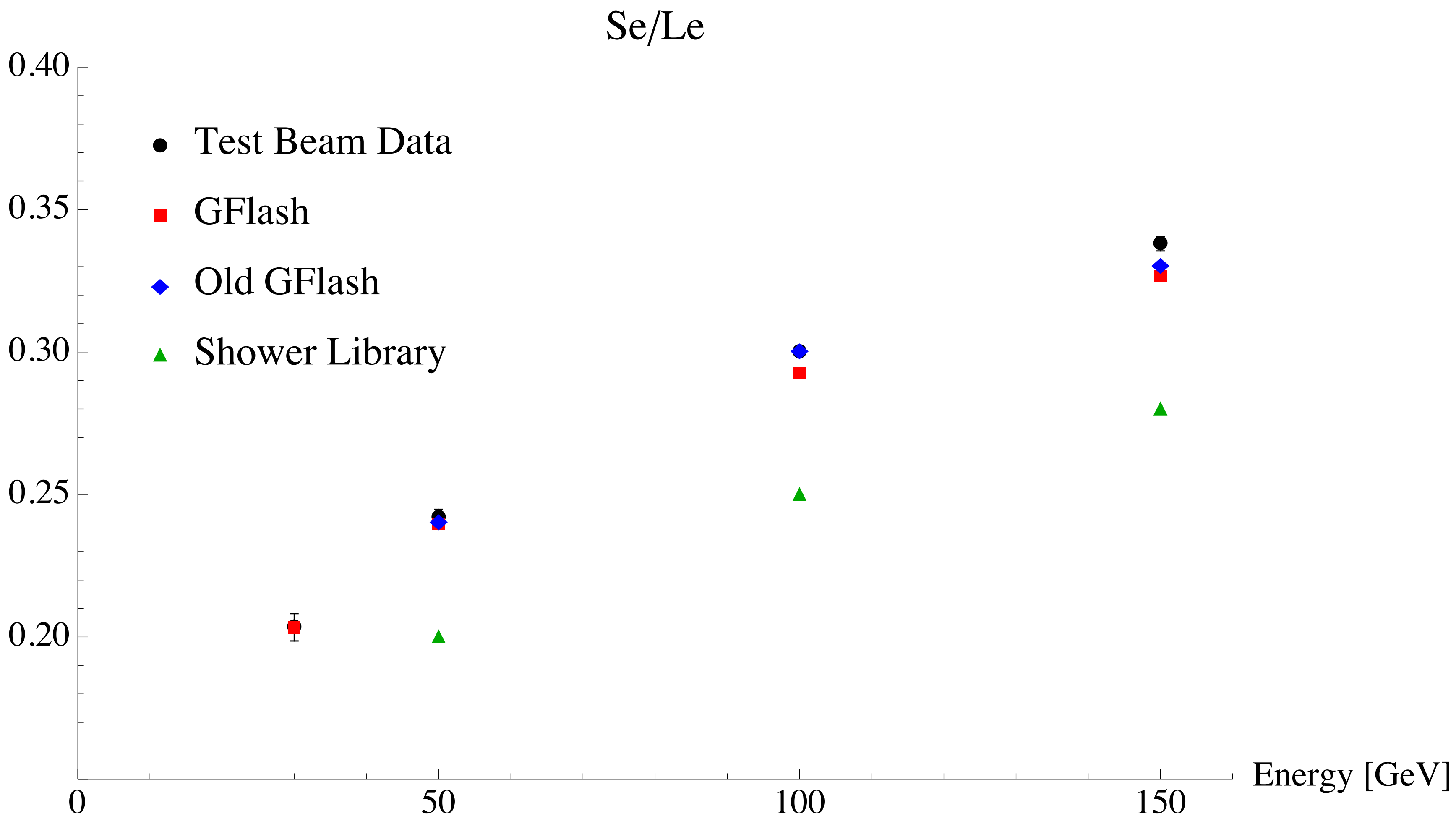
- 4 responses:
  - Ratios of the energies deposited in Long and Short fibres for electrons and pions.
    - Se/Le
    - Lp/Le
    - Sp/Le
    - Sp/Lp
- e→ electron, p→ pion, S→ short fibres, L→ long fibres

TUNING THE SIMULATION

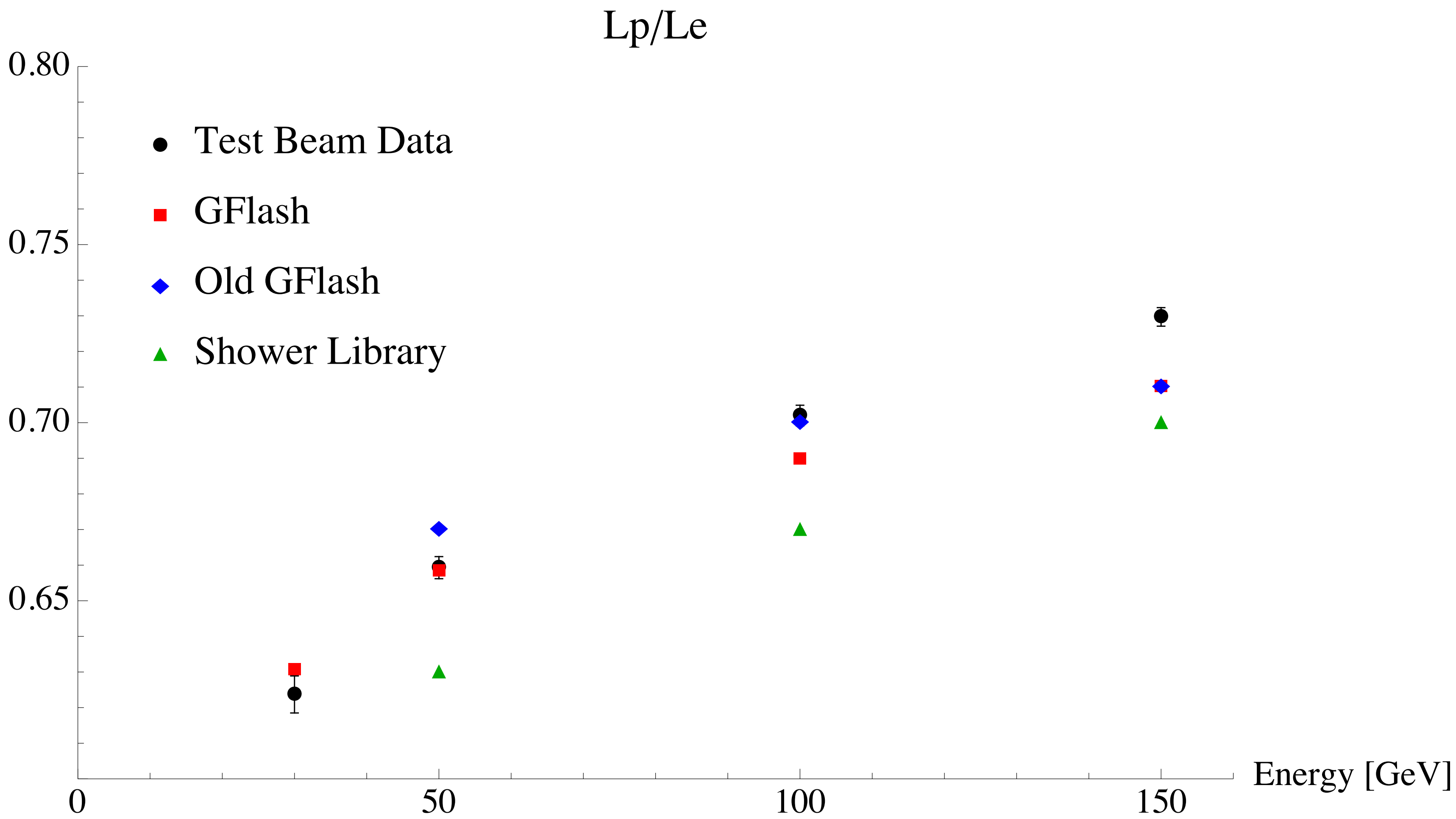
- 10 parameters
- 3^k Factorial design experiment:
  - Define 3 levels for each factor (+,=,-)
  - 3^{10} experiments to be done!!!!
- Defined 3 blocks (3,4,3)
  - Do all possible combinations per block and find correlations between those parameters.
- Define new levels and blocks. Repeat.
- Wrote a program that aided us in doing statistical analysis.
- **1.15% mean discrepancy when compared to Test Beam Data.**
- **Reduced the error by 55% after tuning.**

TUNING THE SIMULATION



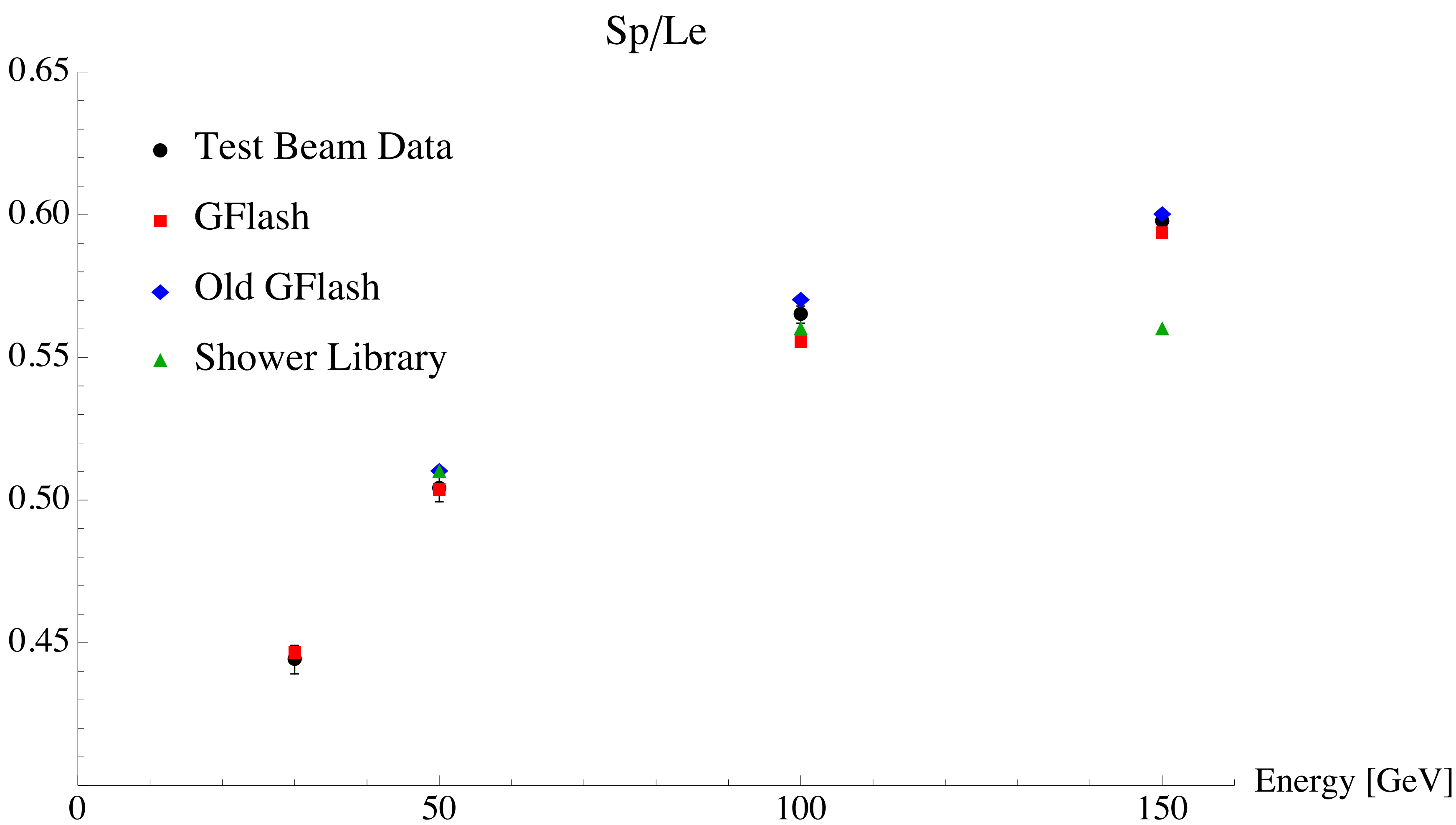
Se/Le Ratio plot

TUNING THE SIMULATION



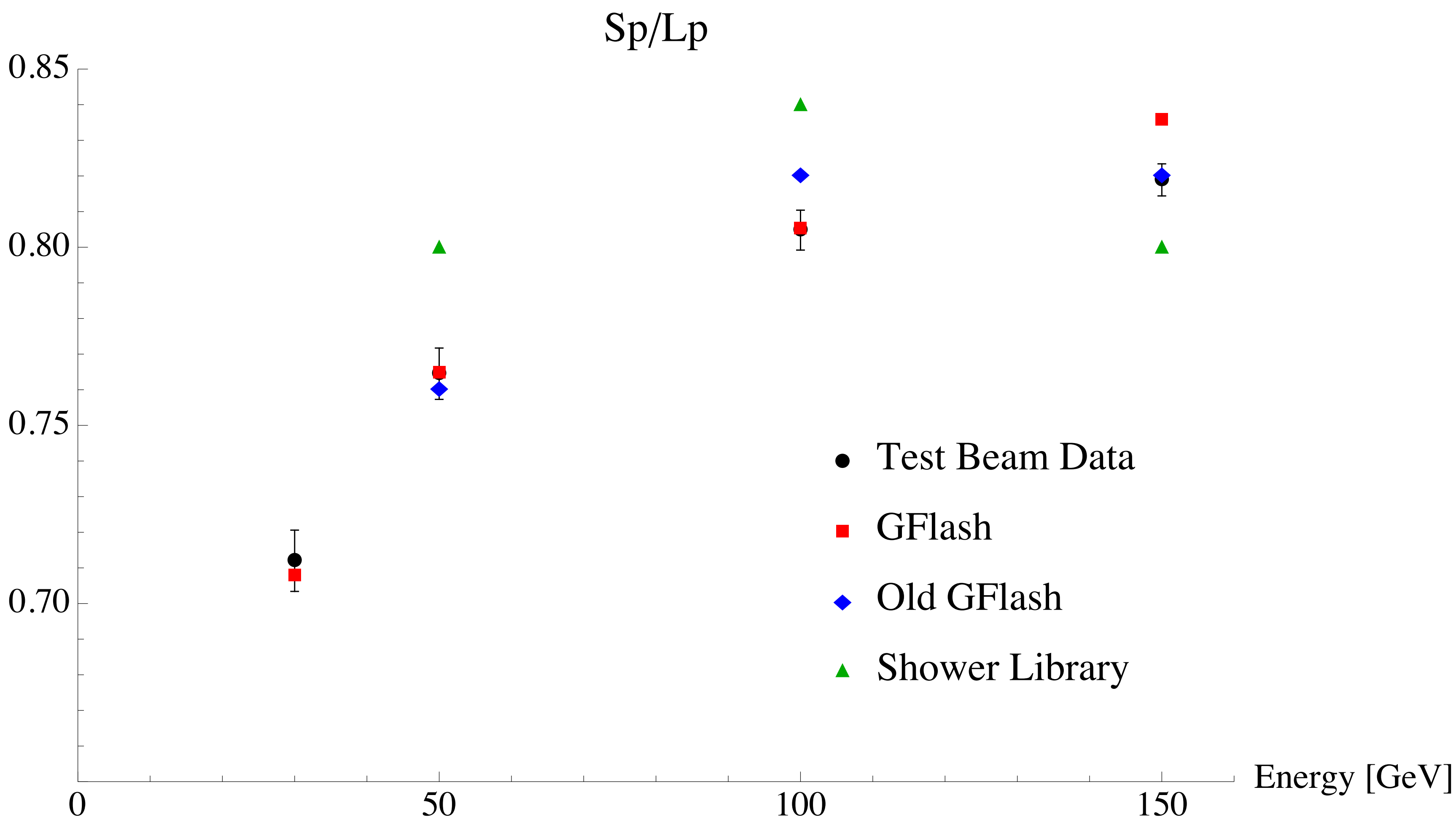
Lp/Le Ratio plot

TUNING THE SIMULATION



Sp/Le Ratio plot

TUNING THE SIMULATION



Sp/Lp Ratio plot

TUNING THE SIMULATION

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30 GeV				
Ratio	**HF GFlash**	**Test Beam**	**Old HF GFlash**	**Shower Library**
Se/Le	0.2032	0.2034	--	--
Lp/Le	0.6307	0.6237	--	--
Sp/Le	0.4464	0.4441	--	--
Sp/Lp	0.7079	0.7120	--	--

50 GeV				
Ratio	**HF GFlash**	**Test Beam**	**Old HF GFlash**	**Shower Library**
Se/Le	0.2395	0.2419	0.24	0.20
Lp/Le	0.6584	0.6593	0.67	0.63
Sp/Le	0.5036	0.5040	0.51	0.51
Sp/Lp	0.7648	0.7645	0.76	0.80

Tables 2,3: Comparison of energy response ratio between HFGFlash, Old HFGFlash, Test Beam (reference) and Shower Library using 10000 electrons and pions at 30 and 50 GeV

TUNING THE SIMULATION

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100 GeV				
Ratio	**HF GFlash**	**Test Beam**	**Old HF GFlash**	**Shower Library**
Se/Le	0.2924	0.3000	0.30	0.25
Lp/Le	0.6898	0.7020	0.70	0.67
Sp/Le	0.5554	0.5650	0.57	0.56
Sp/Lp	0.8052	0.8048	0.82	0.84

150 GeV				
Ratio	**HF GFlash**	**Test Beam**	**Old HF GFlash**	**Shower Library**
Se/Le	0.3264	0.3380	0.33	0.28
Lp/Le	0.7102	0.7297	0.71	0.70
Sp/Le	0.5936	0.5976	0.60	0.56
Sp/Lp	0.8358	0.8189	0.82	0.80

Tables 4,5: Comparison of energy response ratio between HFGFlash, Old HFGFlash, Test Beam (reference) and Shower Library using 10000 electrons and pions at 100 and 150 GeV

SANITY CHECK

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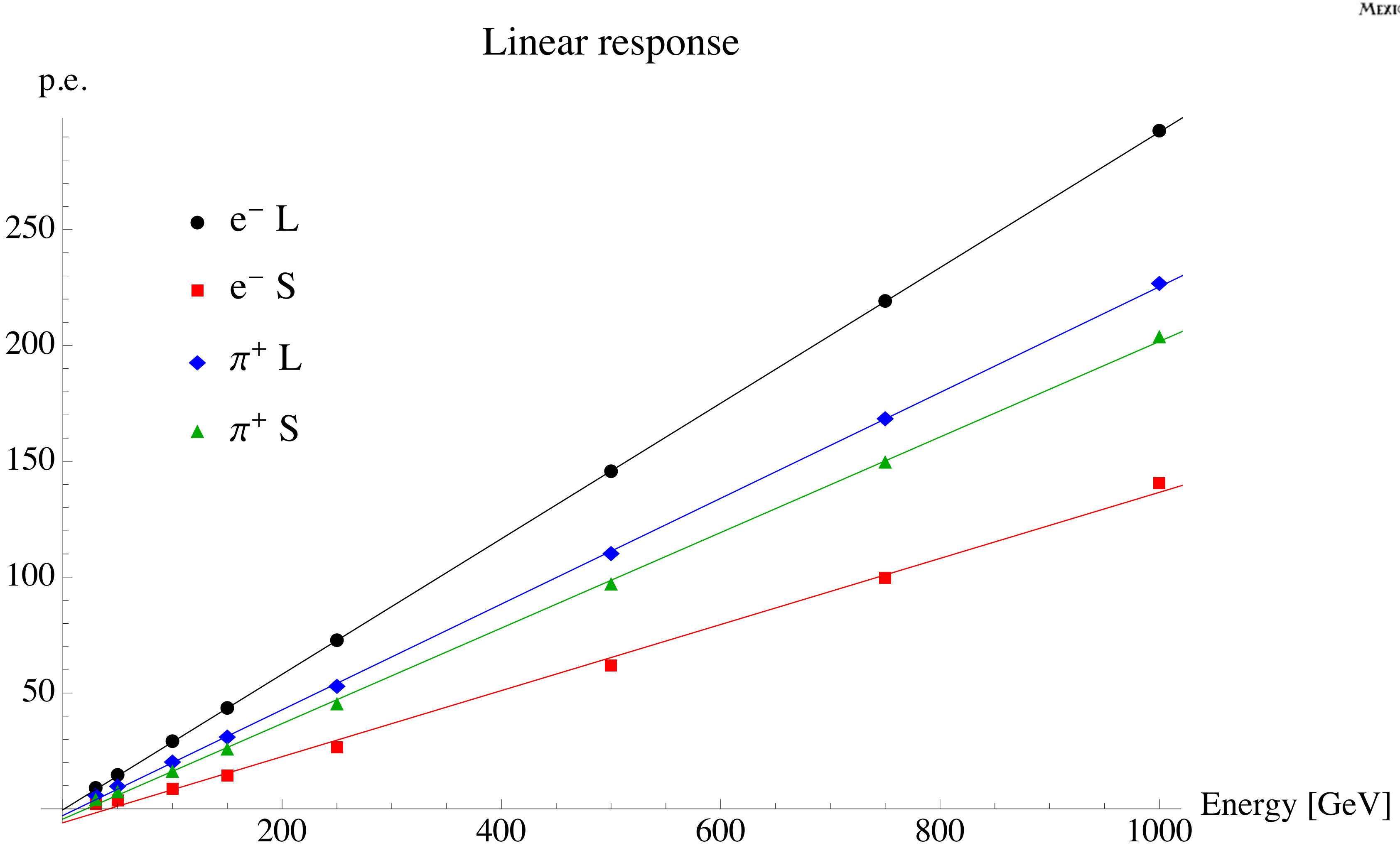
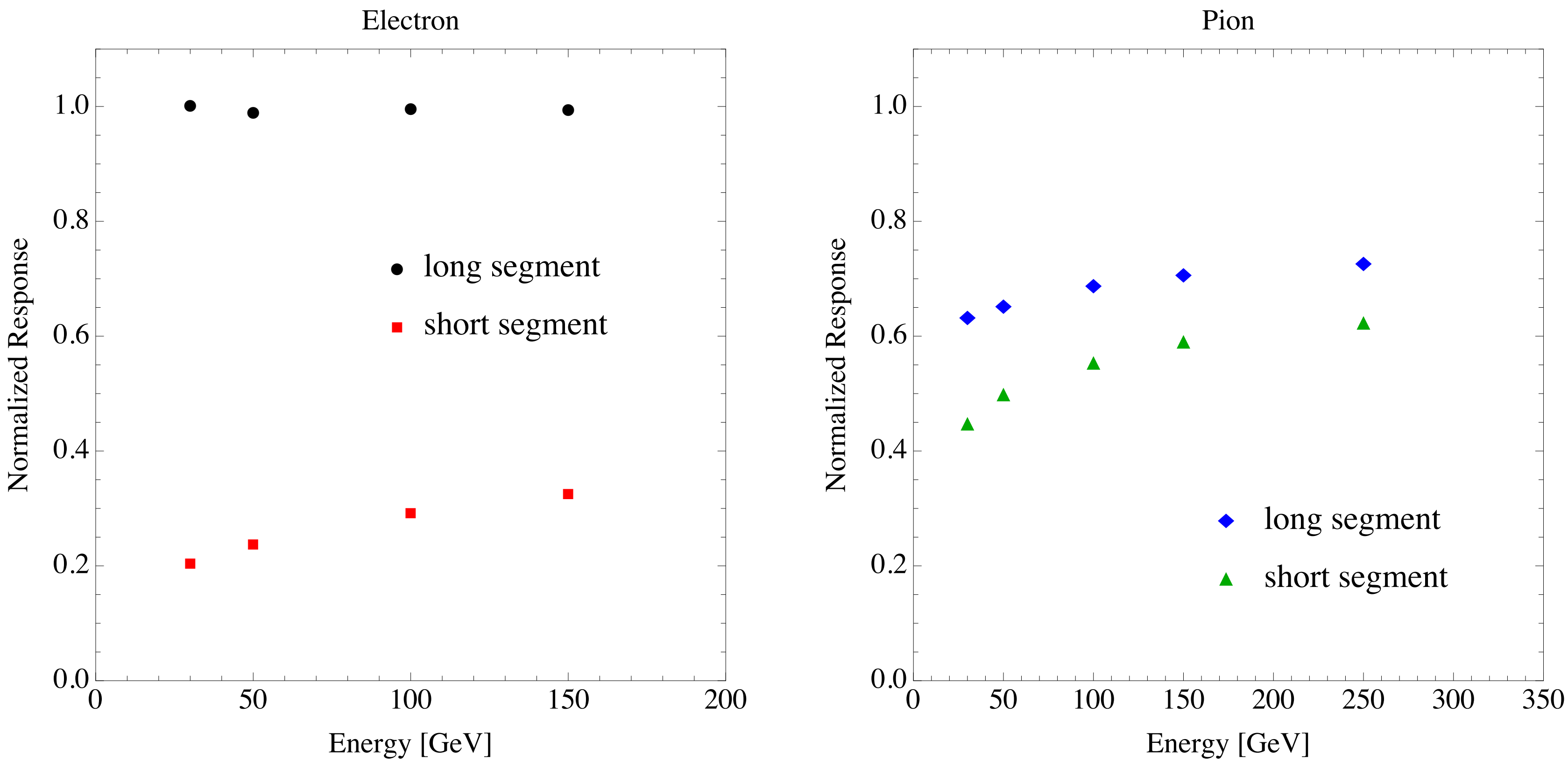


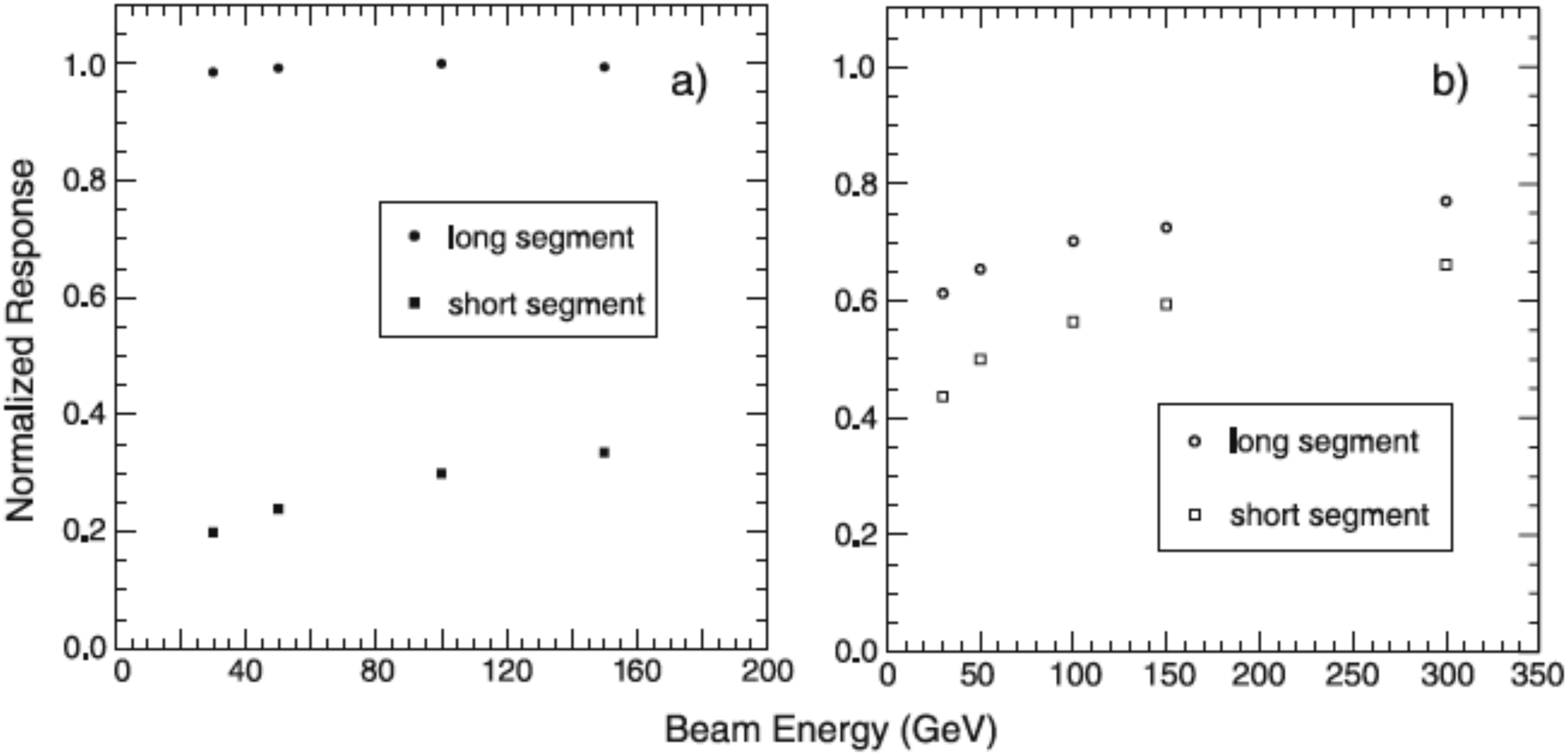
GFlash has a linear energy response for electrons and pions with energies from 30 to 1000 GeV

SANITY CHECK



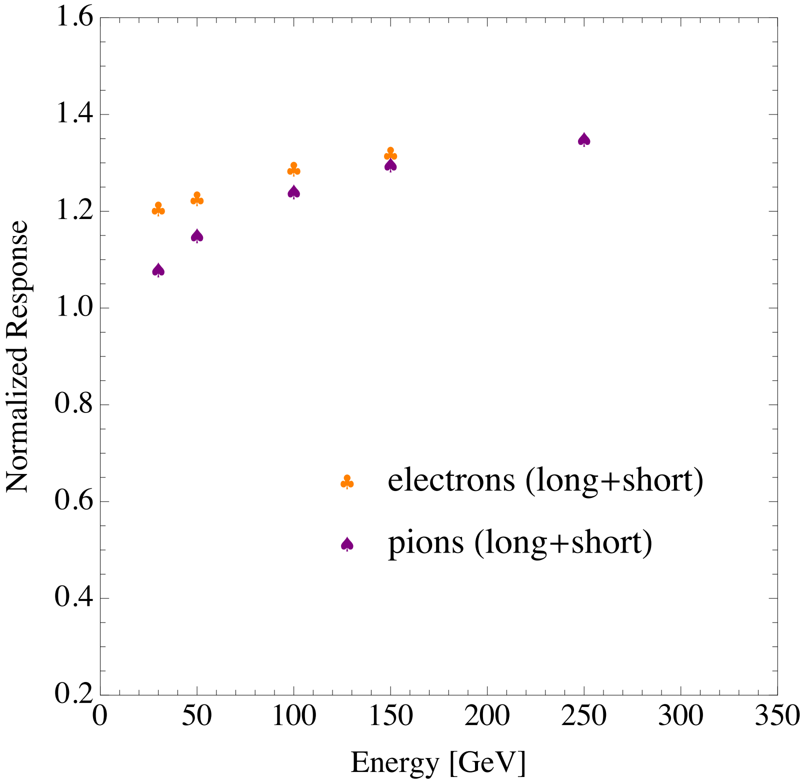
The normalized response for electrons and pions as a function of beam energy for our simulation.

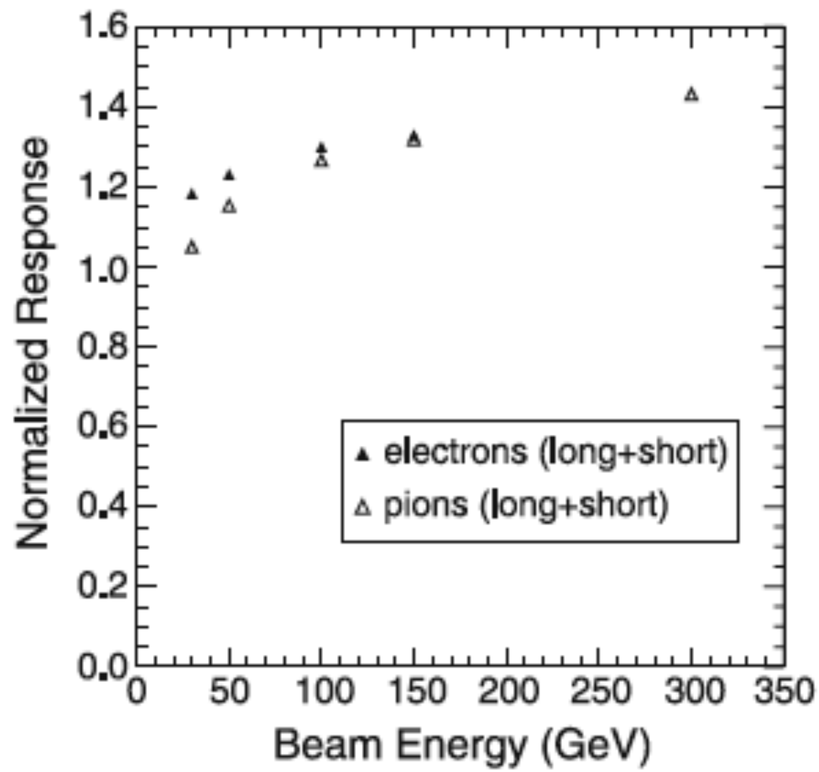
SANITY CHECK



The normalized response for electrons and pions as a function of beam energy test beam data results.

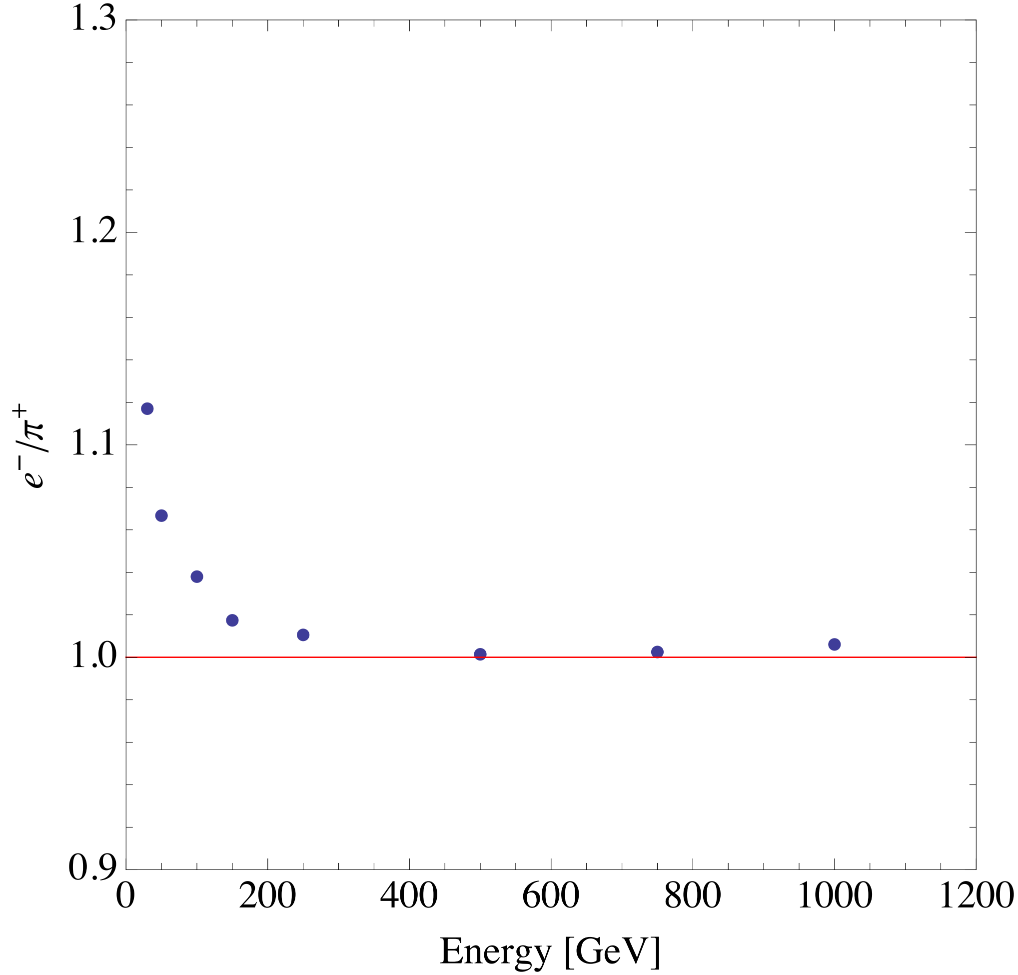
SANITY CHECK





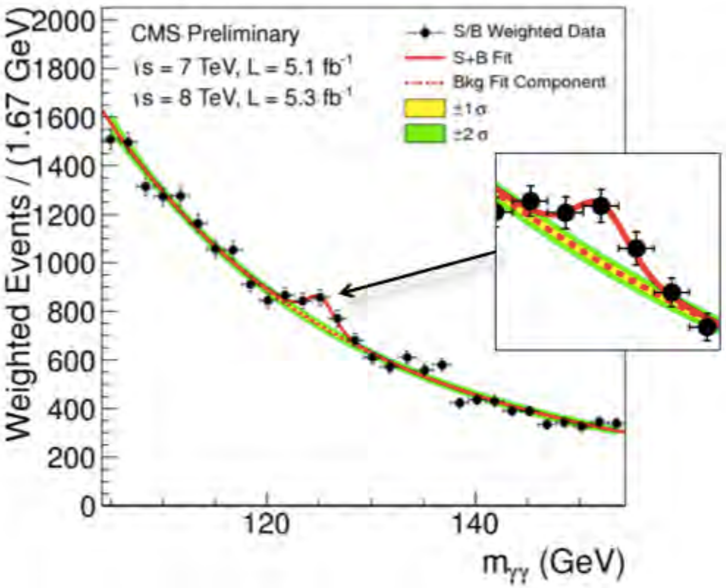
The L+S response of the detector for electrons and pions are shown as a function of beam energy. In the left our simulation, in the right test beam data results.

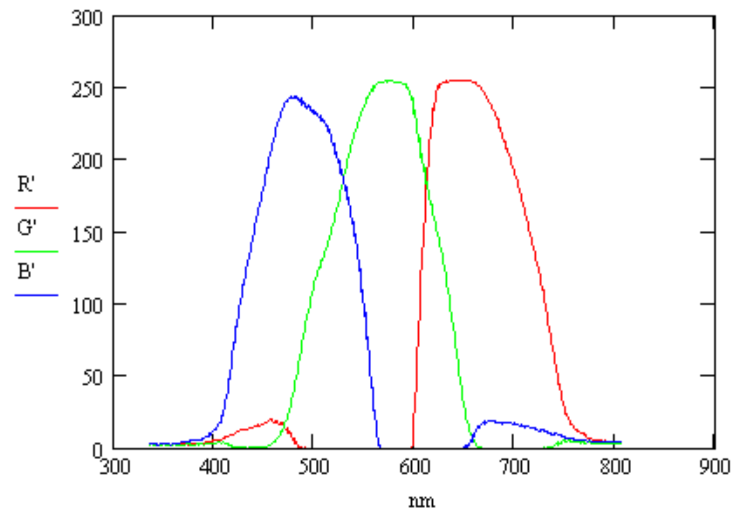
SANITY CHECK

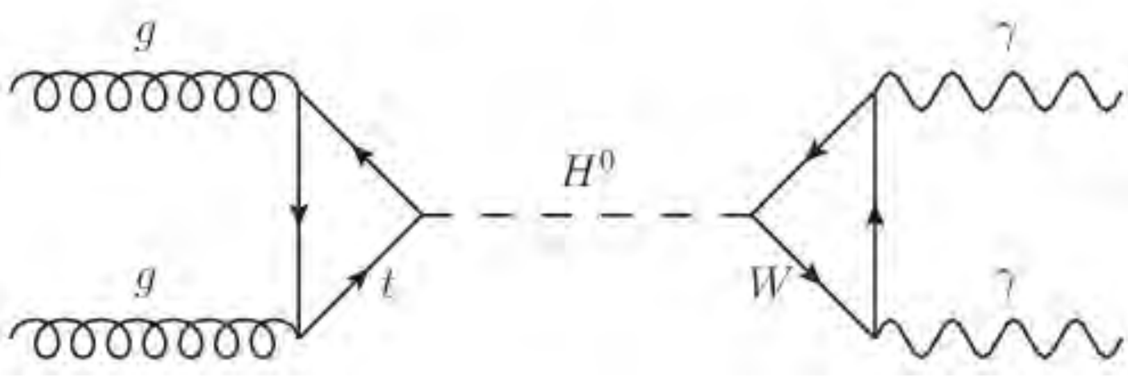


The e/π ratio varies from 1.14 to 1.01 in the tested energy range, and is essentiallyflat at high energies

LOOKING FOR NON SM HIGGS







Higgs "bump", What if the bump is a superposition of several Higgs bosons? Feynman diagram of a typical diphoton decay

CONCLUSIONS AND FORTHCOMING RESEARCH

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- We were able to tune HF Gflash simulations:
  - Reduced the error by 55%.
  - Runs 76% faster.
  - With 1.15% mean discrepancy when compared to Test Beam Data.

- Extend the simulation to the other calorimeters.
- Span a wider η range.
- Aim for a better precision.

ACKNOWLEDGMENTS

- Rahmat Rahmat
- Jeff van Harlingen
- Sheri López, Brian Allgeier, Todd Seiss and Tina Nelson
- Erik Ramberg and Roger Dixon
- Tanja Waltrip, Kappy Sherman

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