Test beam for Detector Qualification In HEP

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Outline

- Current detector R&D in HEP
- Typical Observables
- Testing Tracking Detectors
- Testing Calorimeters
- Full System Tests
- How and where to do a test beam ?
- Summary

Scotty, beam me up !

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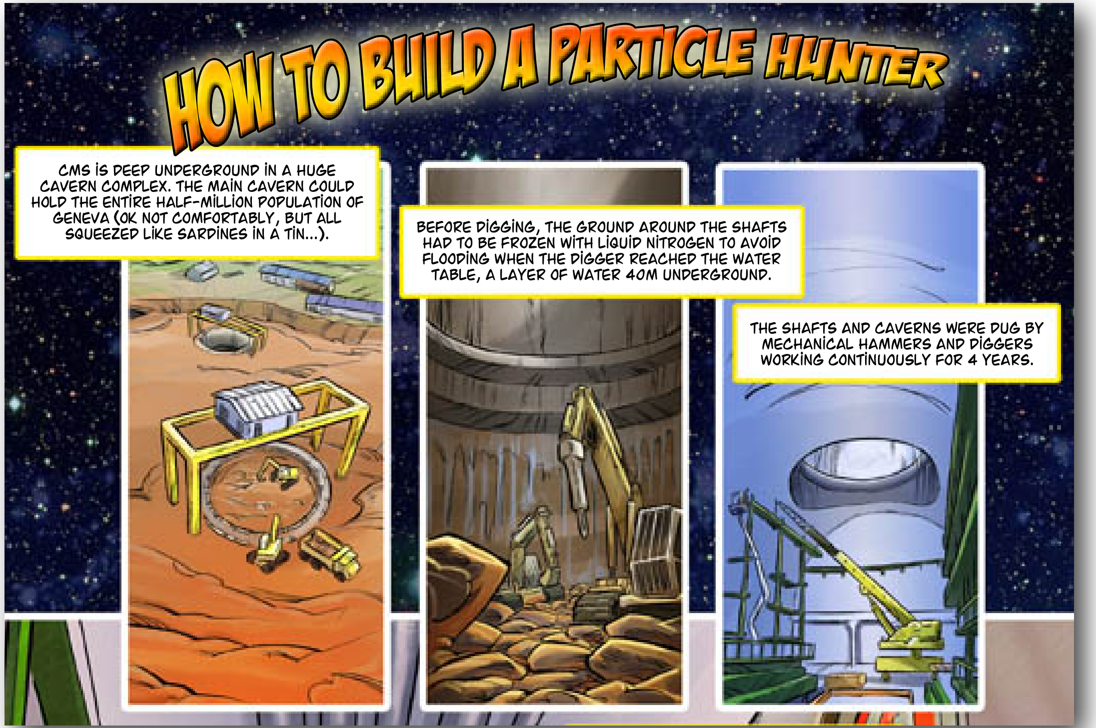
Current Detector R&D in HEP

(very biased abbreviated list)

Current HEP Detector R&D

- Detector development is always an important topic in high energy physics
- Technical demands are constantly increasing due to new challenges in particle physics
  - higher occupancy, smaller feature size, larger trigger rates, radiation level, …..

- New HEP detector projects are planned for
  - Detector upgrades during different LHC phases up to HL-LHC (ATLAS, CMS, ALICE, LHCb)
  - Detector R&D for a future linear collider (ILC and CLIC)
  - Belle II (construction phase starting)
  - PANDA and CBM @Fair
  - …..

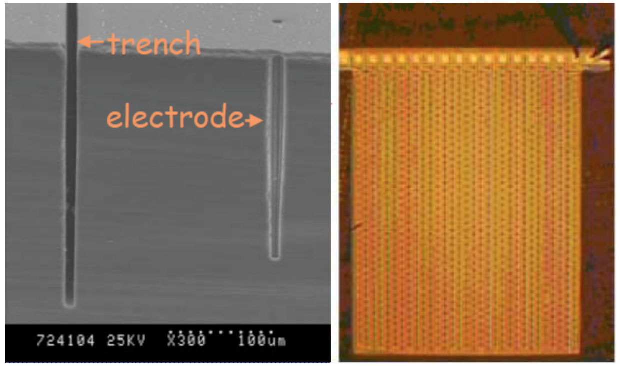


source: “CMS Particle Hunter”

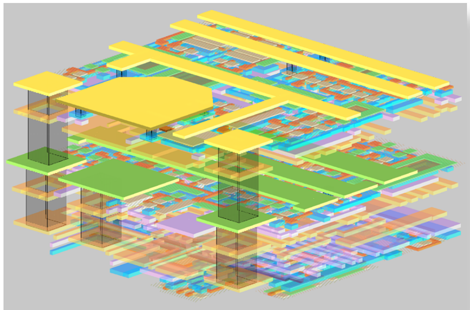
HEP Detector R&D

- Many different new or advanced detector technologies are under investigation:
  - radiation hard silicon sensors (x10 of LHC)
  - new pixel sensor technologies (planar, 3D sensors, diamond, CMOS)
  - new silicon strip technologies
  - silicon photomultipliers (SiPM)
  - micro-pattern gas detectors
  - heavy fibers, new scintillating crystals
  - new diamond devices for luminosity monitoring,
  - use of quartz plates in calorimetry
  - high resolution calorimetry (EM and Hadronic; PFA, analog vs. digital ….)
  - optimal detector geometry
  - magnetic field configurations...

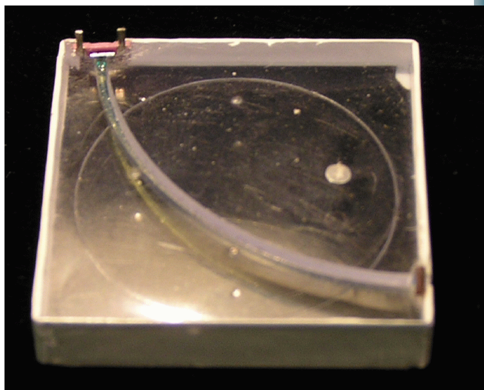
- Extensive amount of studies of all this new technologies to qualify them

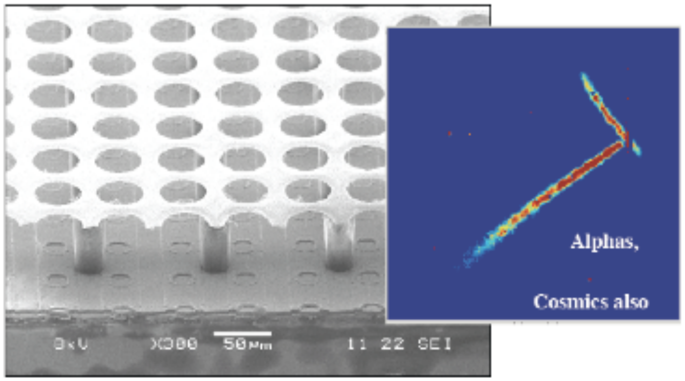


3D sensors



vertical integration





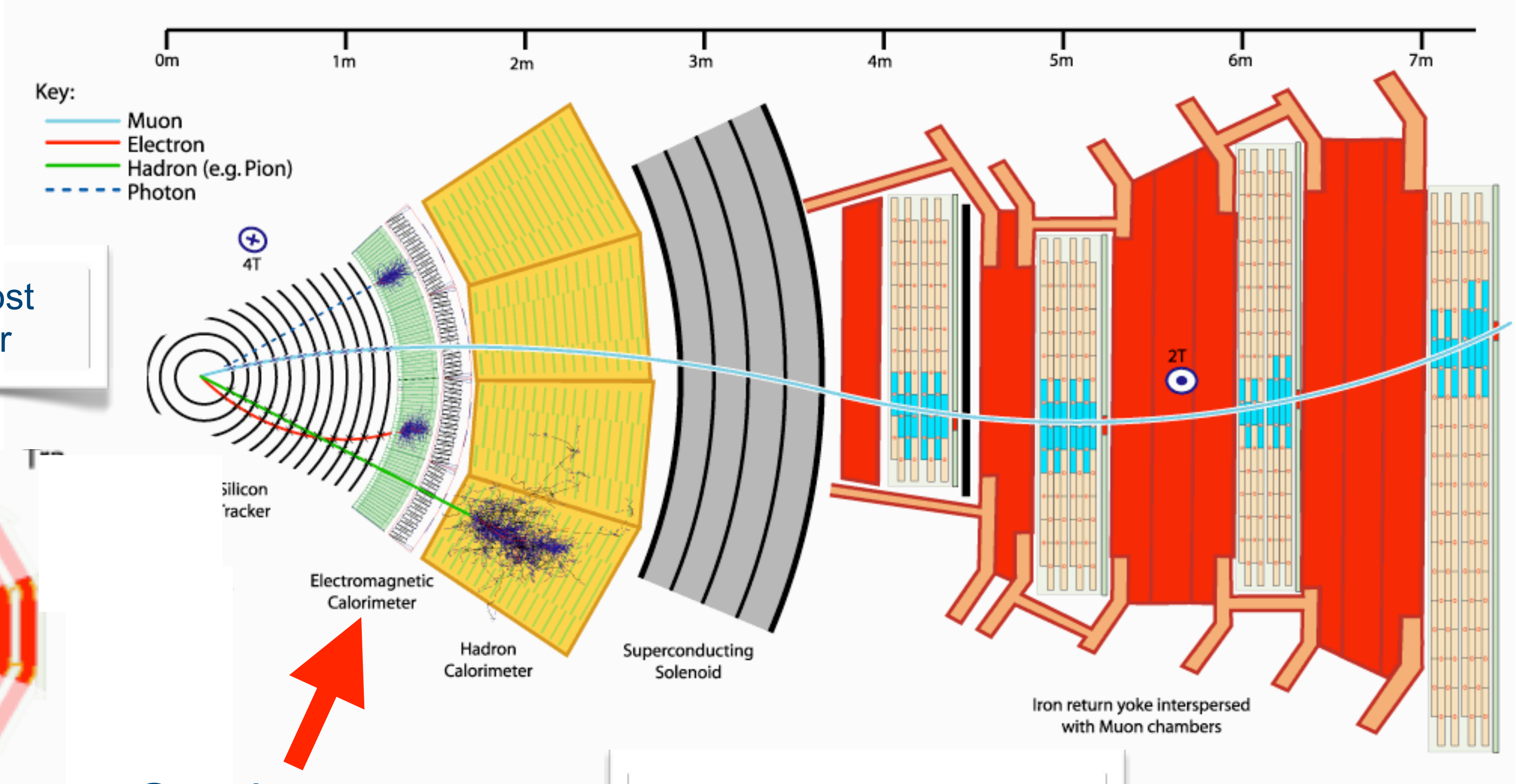
HEP Detector Overview

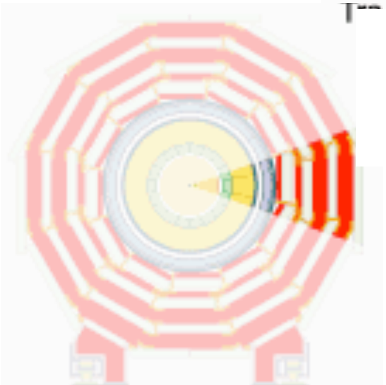
Tracker: Precise measurement of track and momentum of charged particles due to magnetic field.

Calorimeter: Energy measurement of photons, electronics and hadrons through total absorption

Muon-Detectors: Identification and precise momentum measurement of muons outside of the magnet

Vertex: Innermost tracking detector





Transverse slice through CMS

Good energy resolution up to highest energies

Radiation hard (hadron collider)

see talk from Phil Allport

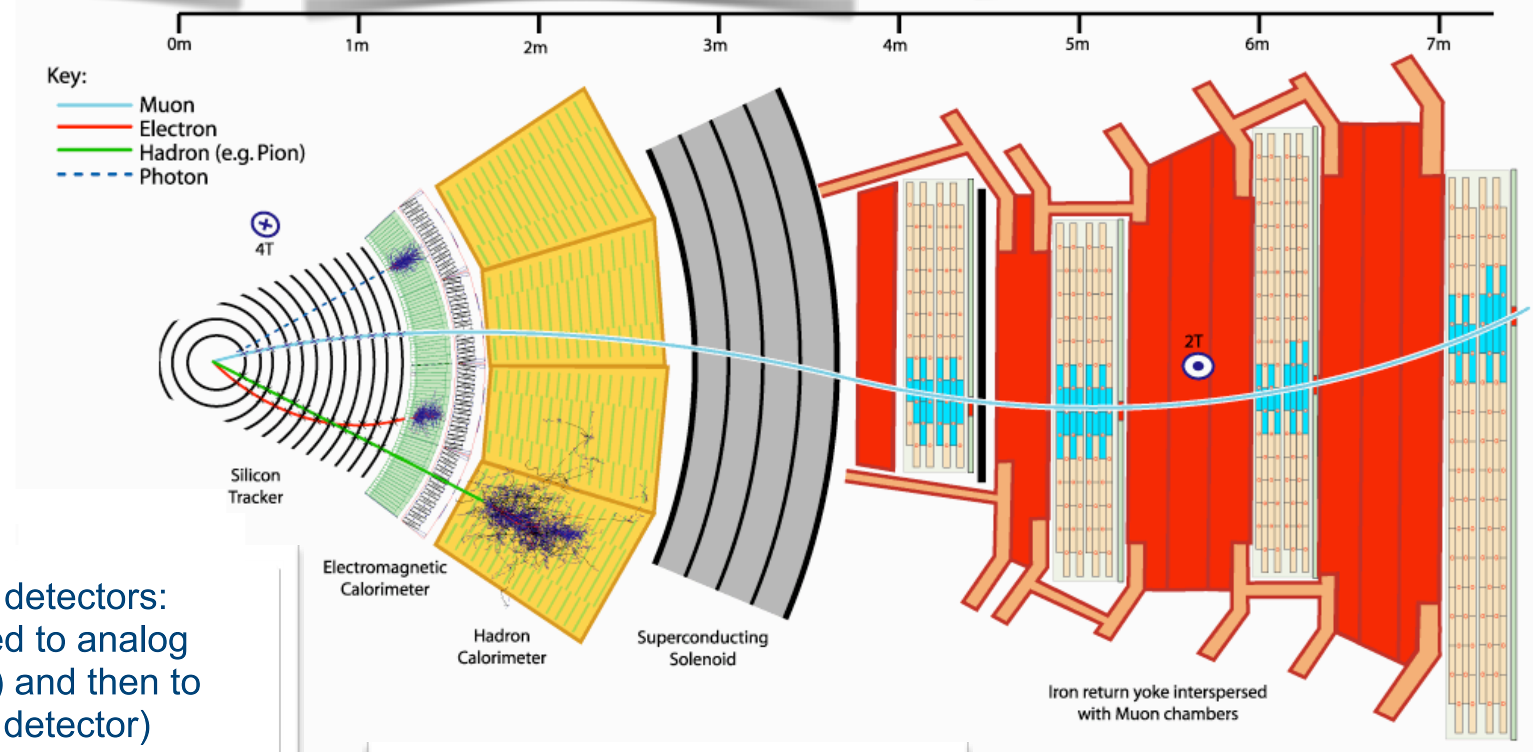
picture: CMS@CERN

HEP Detector Signal Types

Calorimeter: ionisation -> charge measurement -> electrical signal (analog or digital)

Calorimeter: ionisation -> light signals from crystals or scintillators converted into electrical signals (analog or digital)

Muon-Detectors: charge in gas detected by wires -> electrical signal converted into digital signals

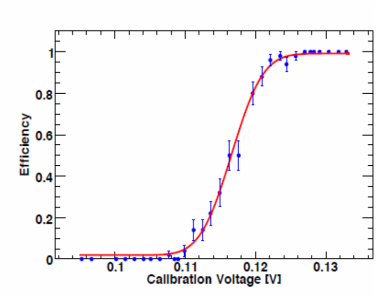


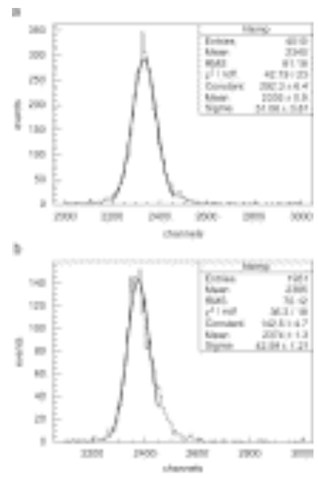
Tracker: silicon detectors: charge converted to analog (amplifier stage) and then to digital (on or off detector)

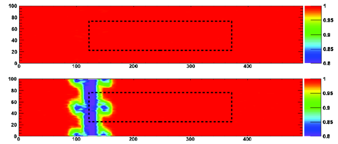
Tracker: gas detectors: charge converted to digital (on detector or off detector)

Important Figures of Merit

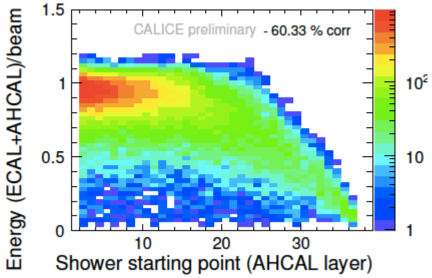
- Tracking Detector (Systems)
  - Signal-over-Noise ratio (before and after irradiation)
  - Detector resolution
  - Efficiency (depending on parameters as thresholds, voltages, ….)
  - Charge collection efficiency (before and after irradiation)

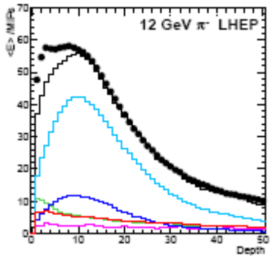


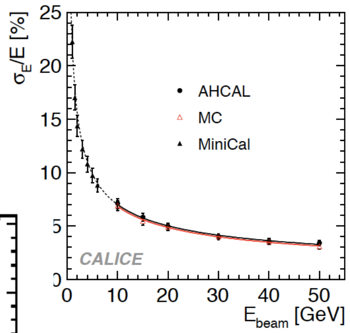




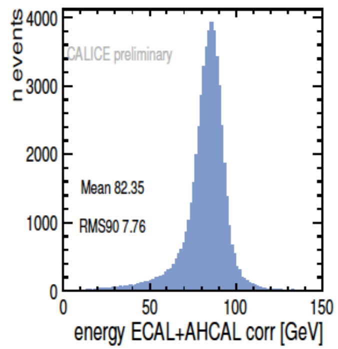
- Calorimeter
  - Signal-over-noise ratio
  - Energy resolution
  - Single photon peak
  - Electron/hadron ratio







- Other important aspects:
  - Running full system with a real trigger/conditions might be tricky
  - Combined test beams
  - ….



Life is a Test Beam ...

- Detectors for High Energy Physics need to go through a very extensive test beam program during R&D phase, conception and commissioning.
- All physical properties have to be measured precisely at least at one beam line.
  - R&D and Detector conception
  - Conceptual design, choice of detectors/ technologies
  - Technical design, prototypes construction and testing
  - Detector construction
  - Calibrations
  - Commissioning
  - Data taking
  - Analysis, systematics studies

Test Beams

Test Beams

Test Beams

Test Beams

Test Beams

This presentation gives an overview of what kind of studies are performed to qualify new technologies and detectors.

Testing Tracking Detectors

HEP Detector Overview

Tracker: Precise measurement of track and momentum of charged particles due to magnetic field.

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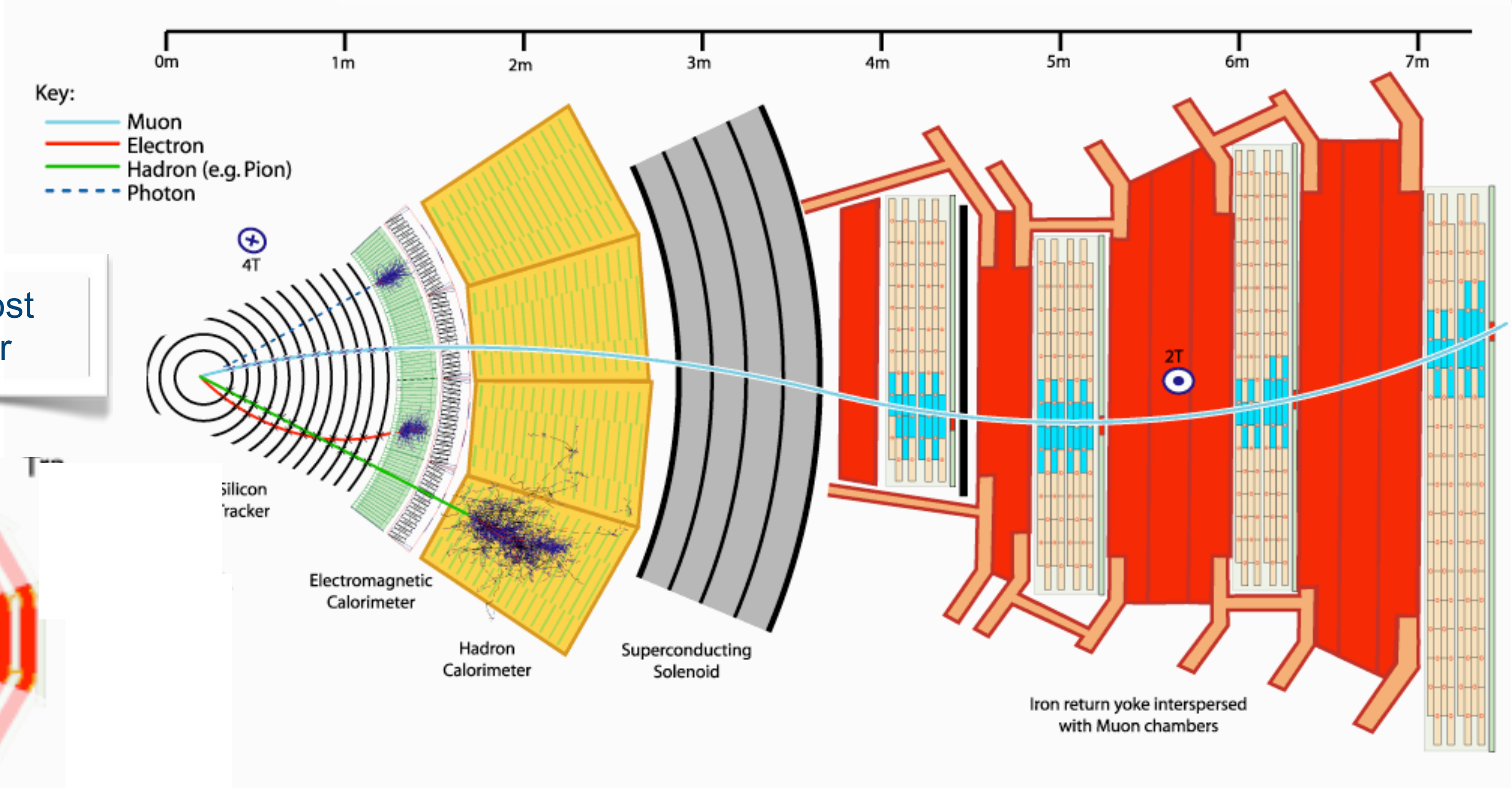
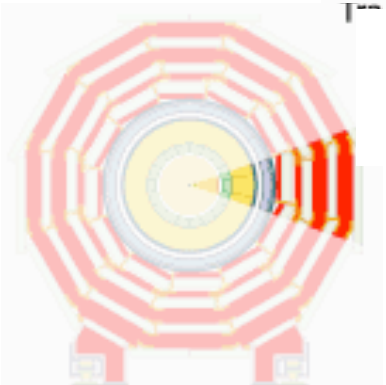
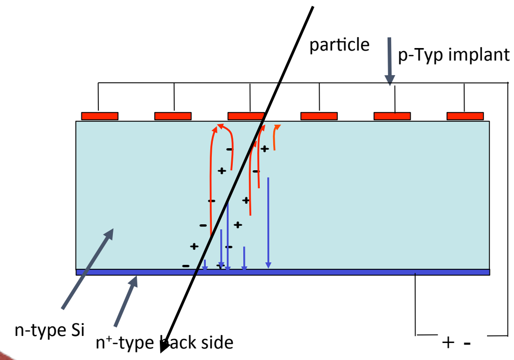


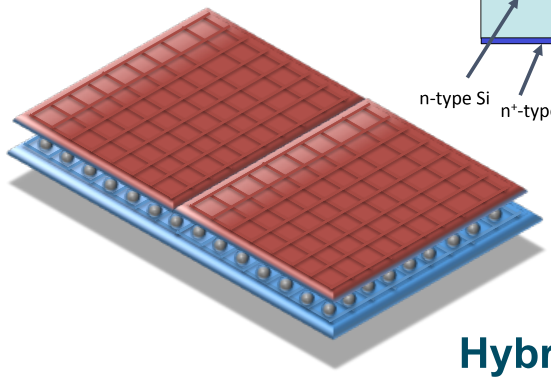


Transverse slice through CMS

Silicon Detector Types

- Pixel detector: deposited charge sensed by small pixels on one side of sensor
  - many channels
  - relatively expensive
  - more material (in case of hybrid pixels)
  - easy pattern recognition

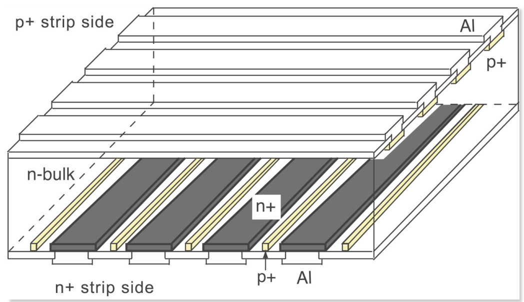




Hybrid pixel detector

see talk from Cinzia DaVia

- Strip detector: deposited charge sensed by long narrow strips
  - fewer channels
  - less expensive
  - less material
  - pattern recognition difficult!

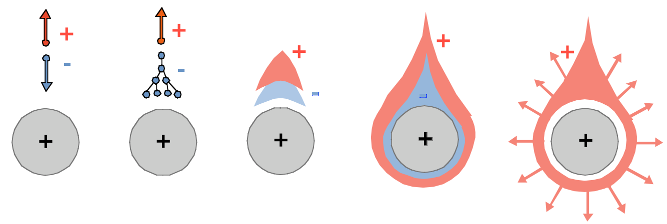


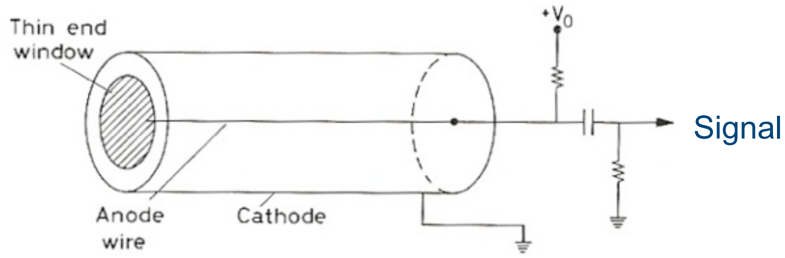
Double sided strip sensor

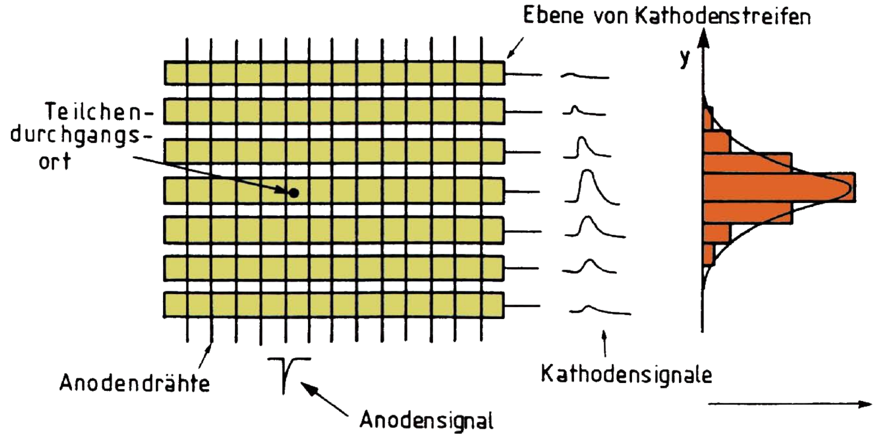
see talk from Nobu Unno

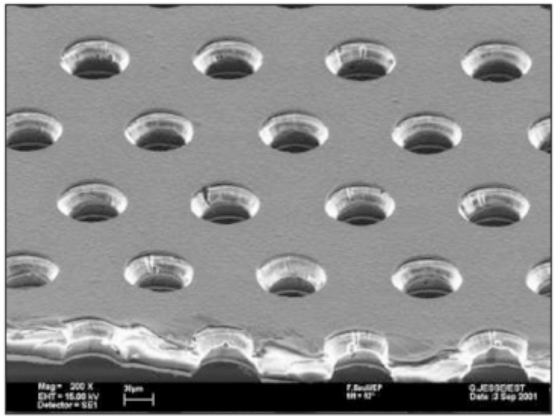
Gas Detectors for Tracking

- Passage of particles creates within the gas volume electron-ion pair
- Electrons are accelerated in a strong electrics field -> amplification
- The signal is proportional to the original deposited charge or is saturated (depending on the voltage)
- Many different types and sizes possible
- Segmentation of sensitive volume into smaller volumes improves the spacial resolution.





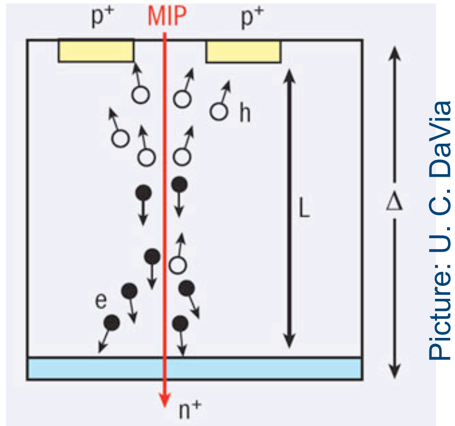




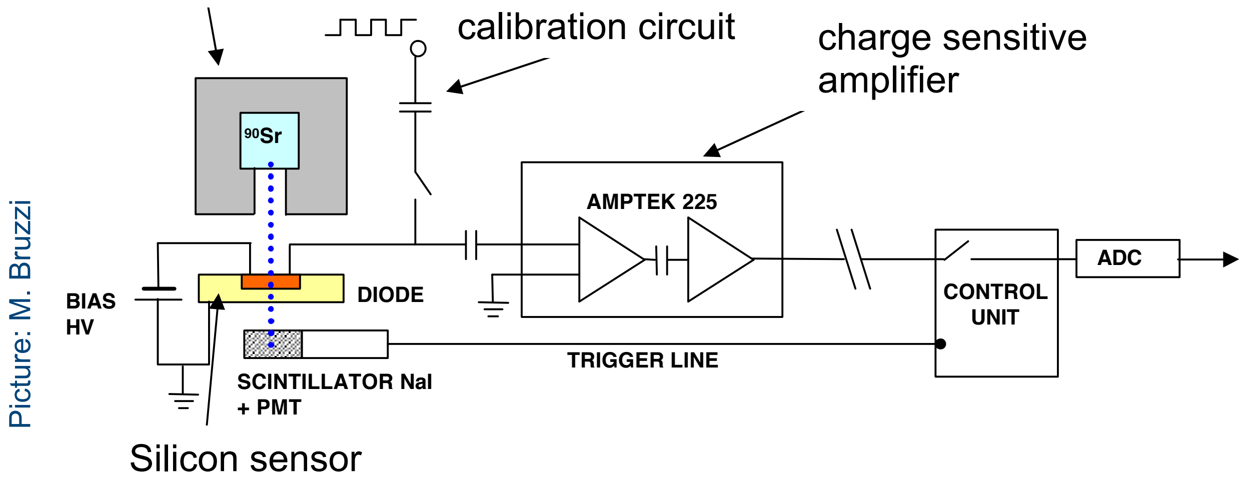
next slides are more for silicon detectors but mostly also applicable for gas detectors

Tracker: Important Parameter (1)

- **Charge collection** CC: collected charge in a detector volume
  - important parameter which shows effects with radiation damage or other effects
  - charge induced by particles from a radioactive source, by a laser or test beam particles
  - measurement of CC in comparison to optimal value versus different parameters (**CC efficiency**)
    - bias voltage
    - radiation level
    - ….



Example: with ^{90}Sr source



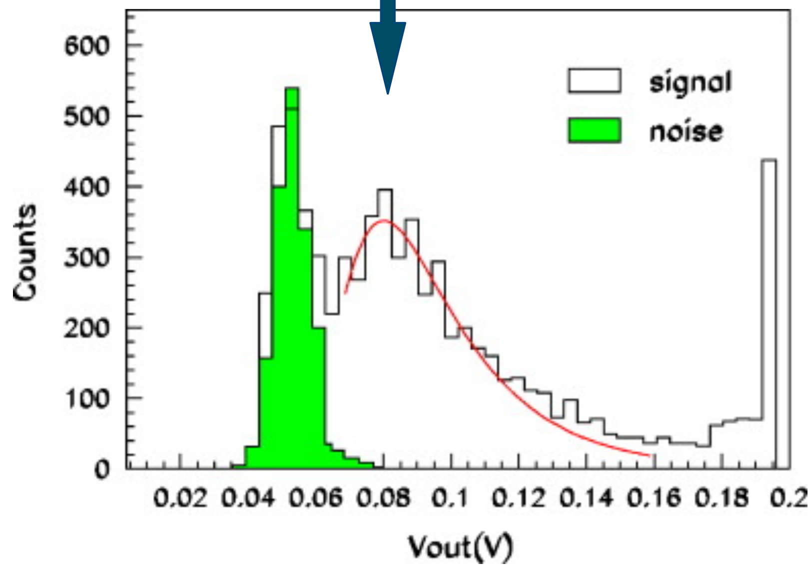
Can be measured with bench top setup in a laboratory

Tracker: Important Parameter (2)

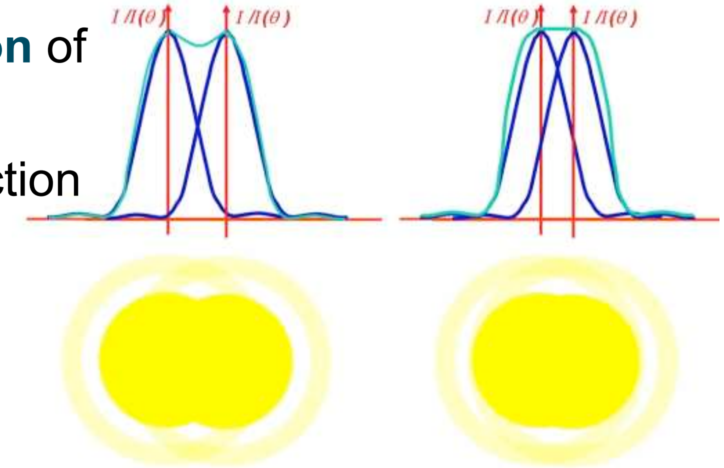
- **Signal/noise ratio**: signal size for a certain input signal over the intrinsic noise of the detector
  - parameter for analog signals
  - good understanding of electrical noise needed
    - noise measurements
    - noise simulations
  - signal induced by source or laser (or test beam particles)
  - optimal S/N is larger than 20

Can be measured with bench top setup in a laboratory

most probable peak!



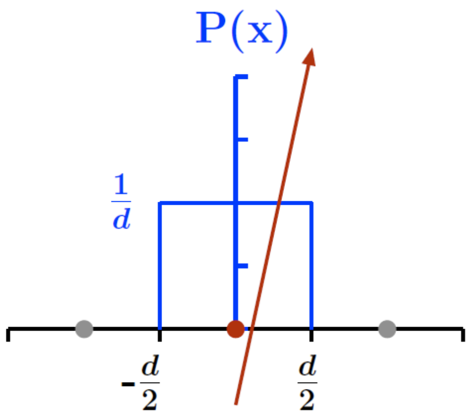
Tracker: Important Parameter (3)



- An important figure of merit is the **spatial resolution** of a tracking detector
- Depending on detector geometry and charge collection
  - Pitch (distance between channels)
  - Charge sharing between channels

  - Simple case: all charge is collected by one strip
  - Traversing particle creates signal in hit strip
  - Flat distribution along strip pitch; no area is pronounced

➔ Probability distribution for particle passage:



$$P(x) = \frac{1}{d} \qquad \Rightarrow \int_{-d/2}^{d/2} P(x)\,dx = 1$$

The reconstructed point is always the middle of the strip:

$$\langle x \rangle = \int_{-d/2}^{d/2} x\,P(x)\,dx = 0$$

Tracker: Important Parameter (4)

- Calculating the resolution orthogonal to the strip:

$$\sigma_x^2 = \langle (x - \langle x \rangle)^2 \rangle = \int_{-d/2}^{d/2} x^2 \, P(x) \, dx = \frac{d^2}{12}$$

- Resulting in a general term (also valid for wire chambers):

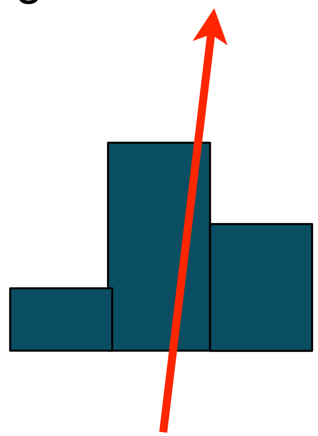
$$\sigma = \frac{d}{\sqrt{12}}$$

very important !

- For a silicon strip detector with a strip pitch of 80 µm this results in a minimal resolution of ~23µm
- In case of charge sharing between the strip (signal size decreasing with distance to hit position)
  - resolution improved by additional information of adjacent channels

Needs to be measured in test beam ….

$$\sigma = \frac{d}{1.5 \cdot (S/N)}$$



Tracker: Important Parameter (2)

- **Detector efficiency** ϵ: probability to detect a transversing particle
  - should be as close to 100% as possible
  - i.e. 12 layer silicon detector with 98% efficiency per layer -> overall tracking efficiency is only 78%
  - needs to be measured in test beam

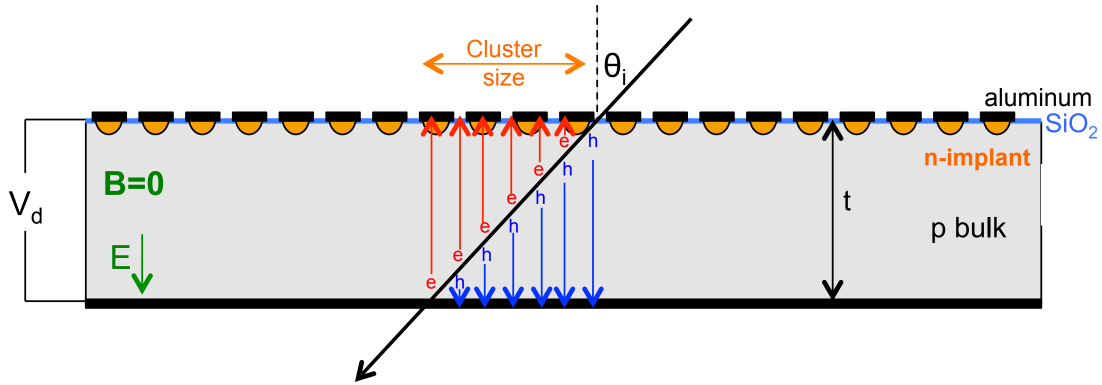
$$\epsilon_{\text{track}} = (\epsilon_{\text{layer}})^n$$

n = number of layer is tracking system

$$\epsilon_{\text{track}} = (\epsilon_{l1}) \cdot (\epsilon_{l2}) \cdot (\epsilon_{l3}) \cdot \ldots \cdot \epsilon_{l12})$$

- **Cluster size** : number of hit pixels/strips belonging to one track
  - usually given in unit of strips or pixels
  - depending on angle of incidence

Needs to be measured in test beam ….

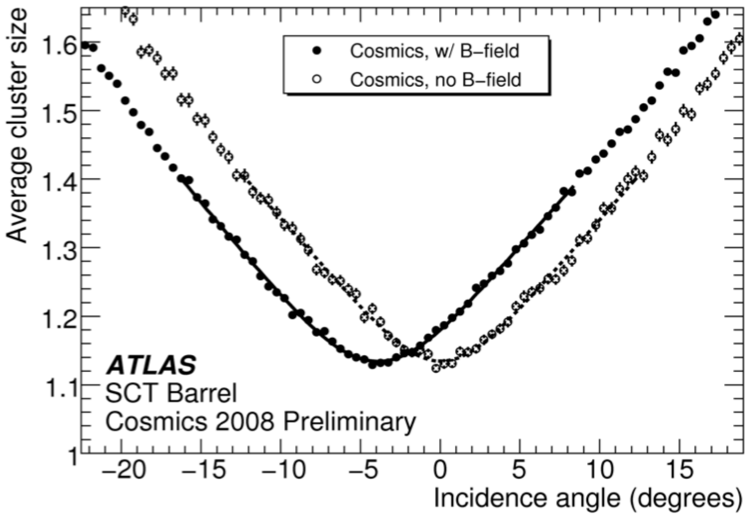


Tracker: Important Parameter (2)

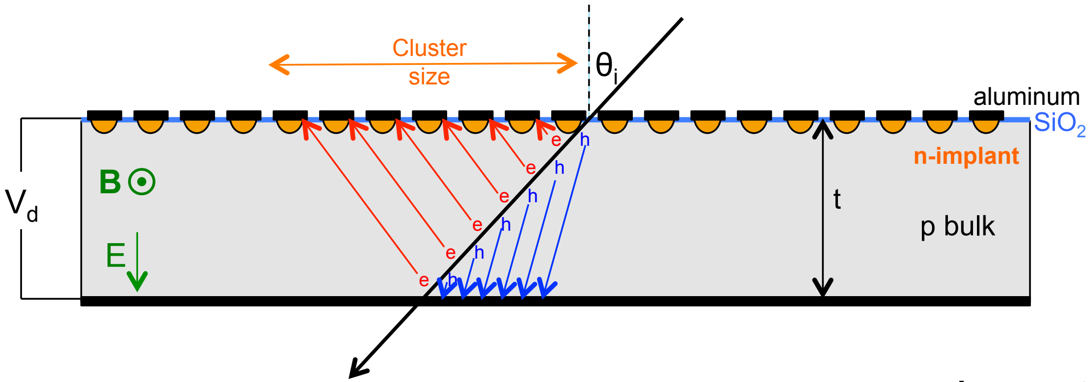
- **Lorentz angle**: increase of cluster size due to Lorentz drift in a magnetic field
- Important parameter in particle physics as most tracking detectors operate in a magnetic field

$$\tan\theta_L = \mu_H B = r_H \mu_d B$$

Hall mobility Hall factor Drift mobility



Measurement in ATLAS after full installation

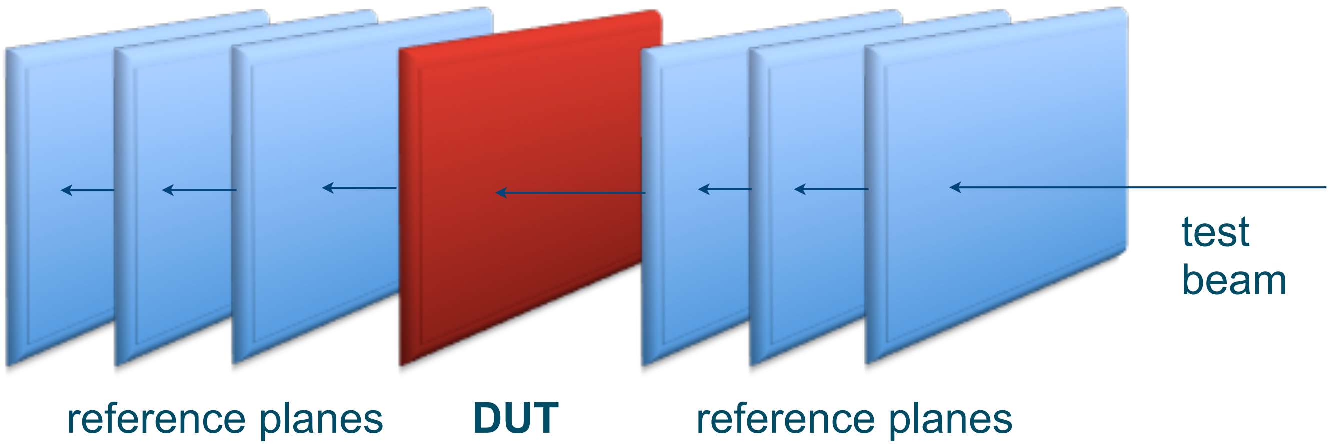


Needs to be measured in test beam AND magnetic field ….

- as cluster size, drift velocity and depletion voltage are depending on radiation damage this changes with the accumulated irradiation (fluence)

Tracker Studies at Test Beam

- How to study a tracking device in a test beam?
- Reference frame to define the particle tracks of the test beam very precisely is needed
  - usually in front of and behind the device under test (DUT)
  - reference system should have at least the same or better resolution
- Two possibilities
  - a layer system of the detectors under test
  - an independent reference system
  - typically referred to as beam “telescope”



Track of test beam particle is measured precisely with the reference system. DUT results compared to result from telescope.

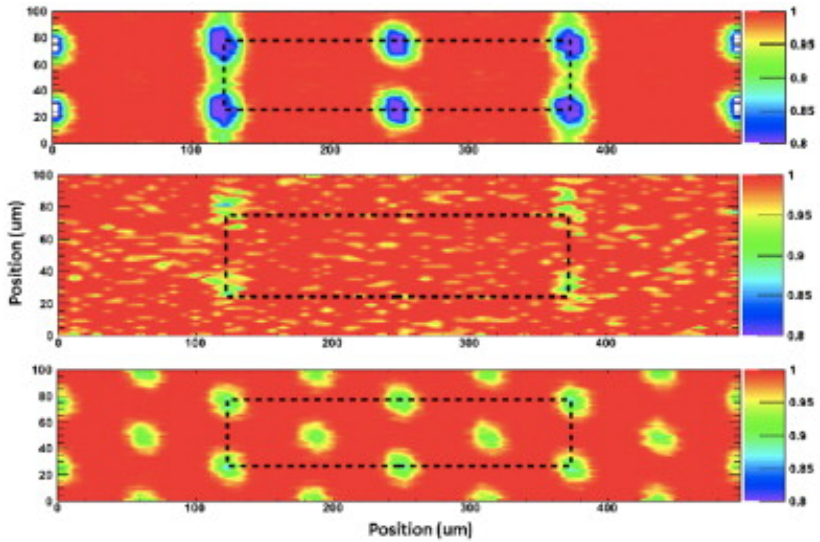
Measuring some Figure of Merits

- **Detection efficiency:**
  - require a track in the reference system (hit in all layers)
  - count how many of these are detected by the DUT detects

  - one has to be very careful that the reference system is synchronous to the DUT and has the same time window for detection
    - central clock and trigger distribution
    - if reference system is different one can add a further reference plate of the DUT type

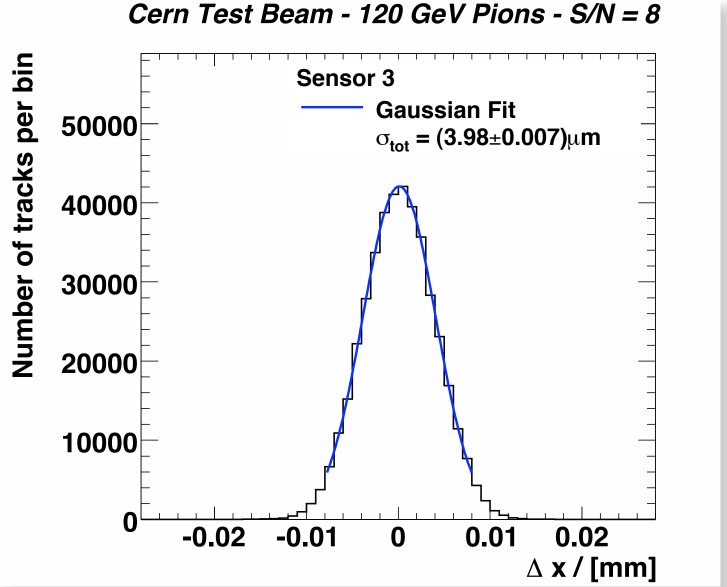
```
if n<max:
    if (track_reference = 1):
        hit_reference ++
        if (hitDUT = 1)
            hitDUT ++
efficiency = hit_DUT/hit_reference
```

- Example: 3D pixels for HL-LHC
  - different irradiation levels and processes
  - vertical implants are clearly visible
  - effect will be smeared due to inclined tracks



Measuring some Figure of Merits

- **Spatial resolution**
  - Measure particle track very precisely with reference system (telescope)
  - Extrapolate track to z position of device under test (expected track coordinate)
  - Difference between expected track and measured hit coordinate -> residual distributions
  - Resolution per plane: sigma of Gaussian Fit



Difference between expected track and measured hit coordinate (residuals) for one MIMOSA plane in the EUDET telescope.

$$\sigma^2_{meas} = \sigma^2_{DUT} + \sigma^2_{Tel} + \cancel{\sigma^2_{MS}}$$

Multiple scattering term -> can be neglected at high energy beams
at lower energy the multiple scattering has to be taken into account in the track fit

$$\sigma^2_{DUT} = \sigma^2_{meas} - \sigma^2_{Tel}$$

$$\sigma^2_{Tel} = k \cdot \sigma_{ref.plane}$$

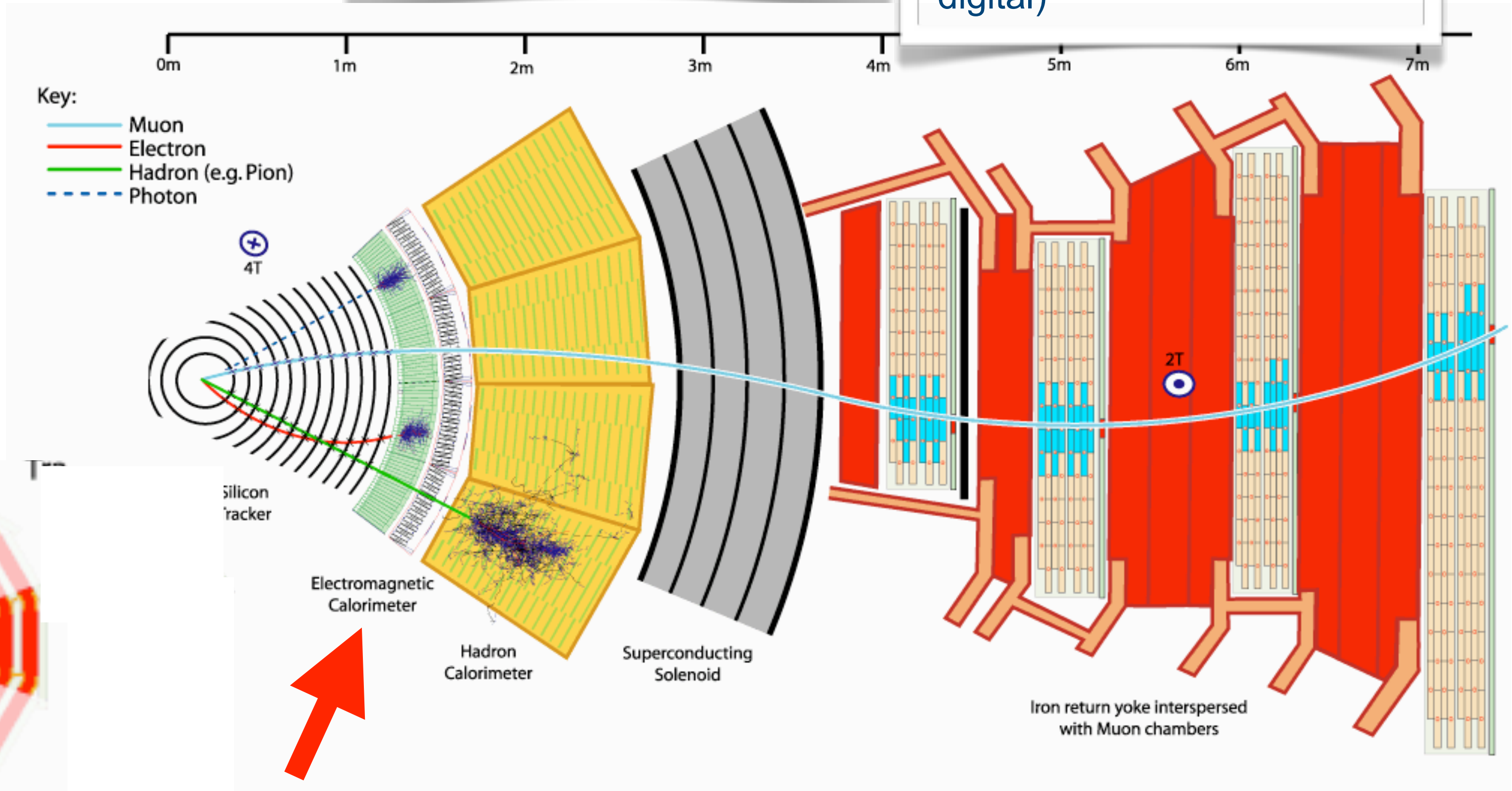
geom. factor $$k = \frac{\sum_i^N z_i^2}{N\sum_i^N z_i^2 - (\sum_i^N z_i^2)^2}$$

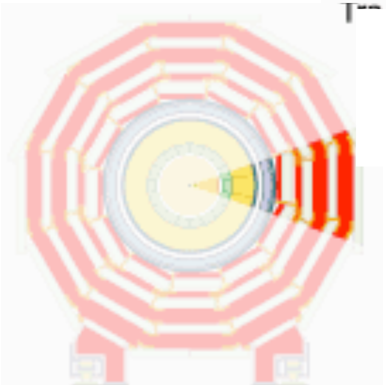
Calorimeter Tests

HEP Detector Overview

Calorimeter: Energy measurement of photons, electronics and hadrons through total absorption

Calorimeter: ionisation -> light signals from crystals or scintillators converted into electrical signals (analog or digital)



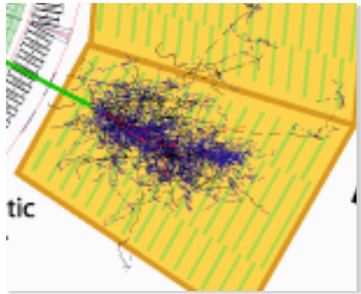


Transverse slice through CMS

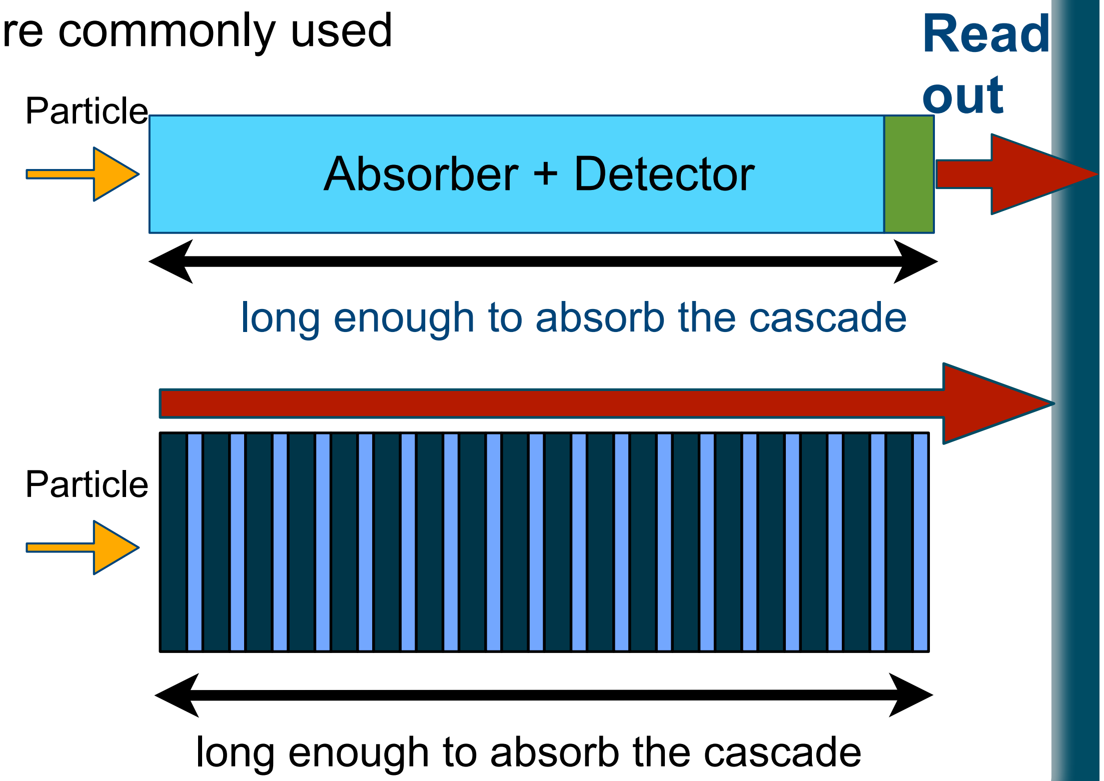
Good energy resolution up to highest energies

Calorimeter in a nutshell

- Energy measurement of photons, electrons and hadrons through total absorption
  - Particles release their energy in matter through production of new particles => shower
  - Number of particles in shower is proportional to the energy of the incidental particle



- Two different types of calorimeters are commonly used
- **Homogeneous Calorimeter**
  - The absorber material is active
  - The overall deposited energy is converted into a detector signal
- **Sampling Calorimeter**
  - A layer structure of passive material and an active detector material
  - Only a fraction of the deposited energy is “registered”



Calorimeter: Important Parameter (1)

- The **energy resolution** of a calorimeter is parametrized:

$$\frac{\sigma}{E} = \frac{a}{\sqrt{E}} \oplus \frac{b}{E} \oplus c$$

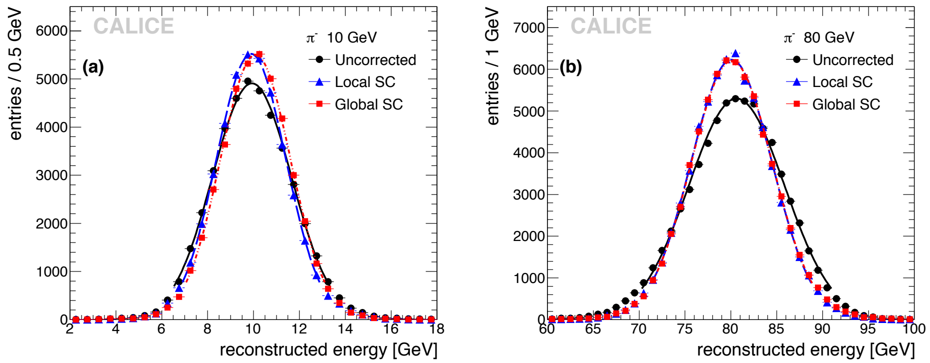
- Stochastic term **a**
  - the resolution depends on the number of particles and the number of reactions, proportional of the energy
- Noise term **b**
  - Electronic noise, radioactivity, i.e. dependent of the energy
- Constant term **c**
  - Energy independent term contributing to the resolution: due to inhomogenities with in the detector sensitivity etc.

Losses of Resolution:

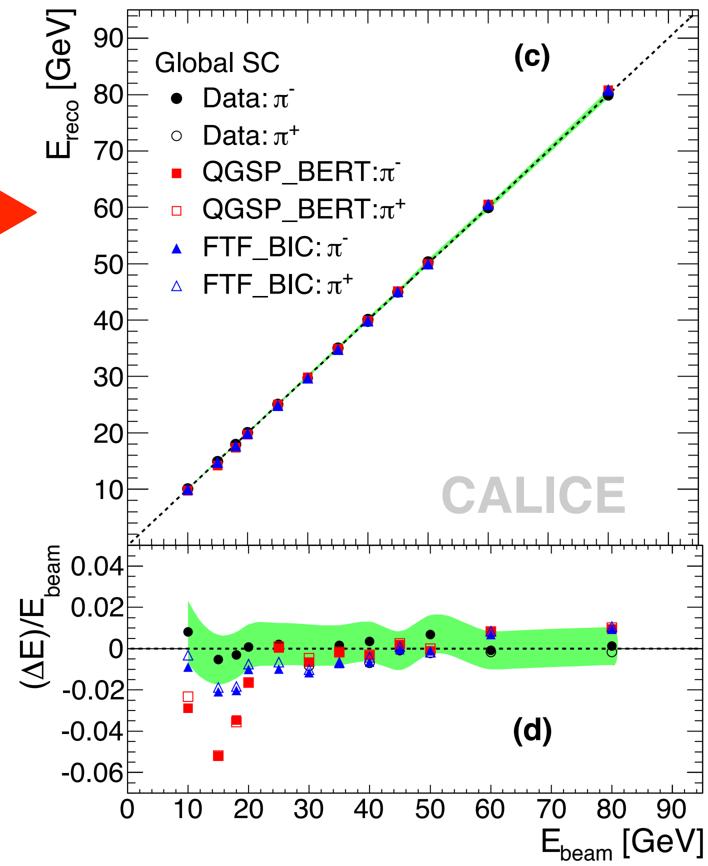
- **Shower not contained** in detector → fluctuation of leakage energy; longitudinal losses are worse than transverse leakage.
- **Statistical fluctuations** in number of photoelectrons observed in detector.
- **Sampling fluctuations** if the counter is layered with inactive absorber.
- ….

Needs to be measured in test beam ….

Calorimeter R&D for the LC: CALICE



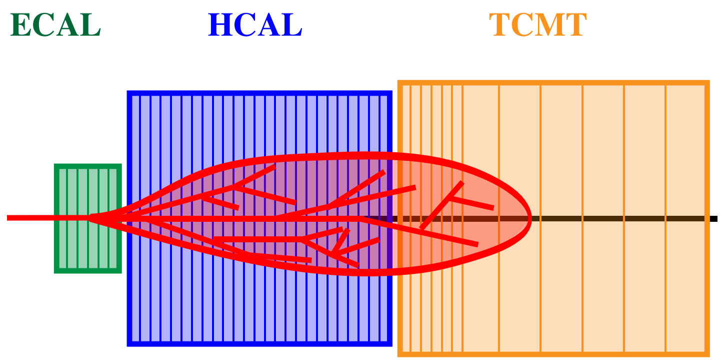
Reconstructed energy resolution for 10 and 80 GeV

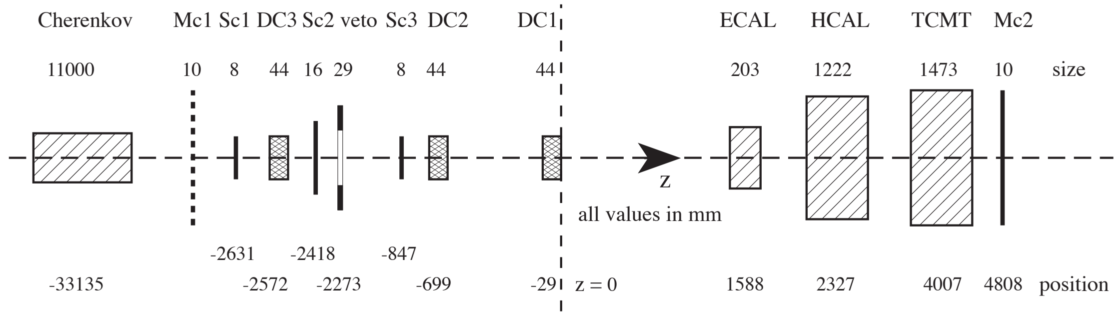


- Many studies need to be done with test beam to be ready for the production of a large scale detector
- energy resolution and linearity of response
- Check that calibration is under control
- Understand what level of detail is required in simulation (e.g. noise, saturation, cross-talk, gaps) so that this knowledge can be transferred to full detector studies.
- Electrons (and muons) are particularly useful for this; well understood electromagnetic physics; dense showers.

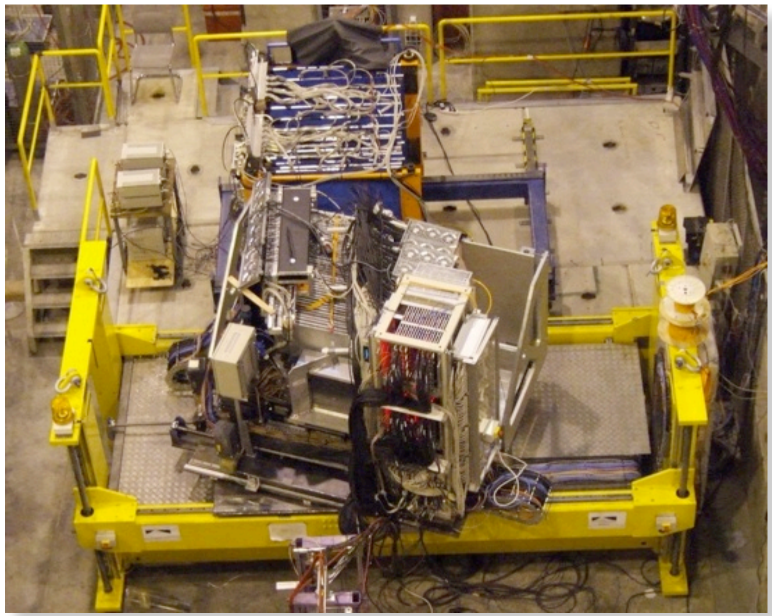
Plots: 2012 JINST 7 P09017

Measuring the Energy Resolution



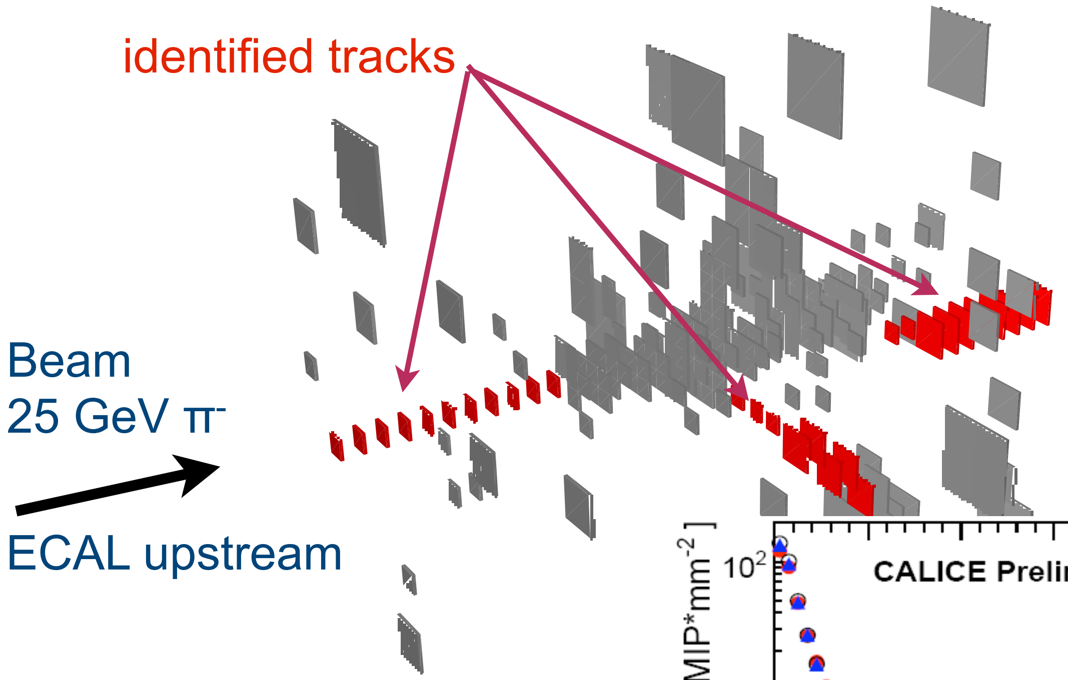


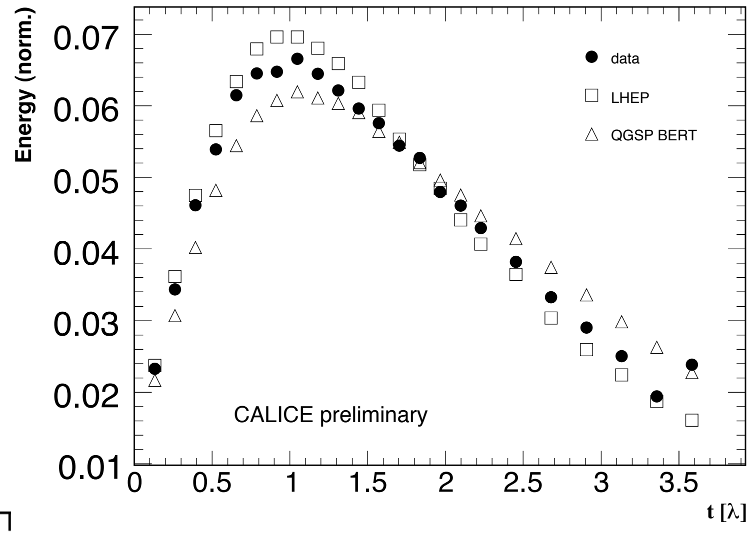
- Main issue: the prototype has to be large enough to contain the energy
- Hadron Calorimeter downstream of ECAL: electrons and photons do not reach the HCAL
- Special studies without the ECAL to test HCAL with electrons
- Tail Catcher behind HCAL to measure shower leakage, important for energy measurements

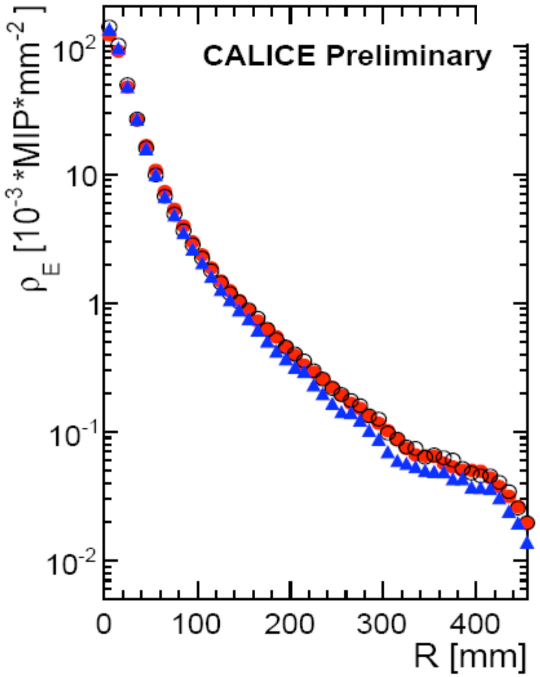


ECAL & HCAL can be rotated

Detailed Studies of Hadronic Showers





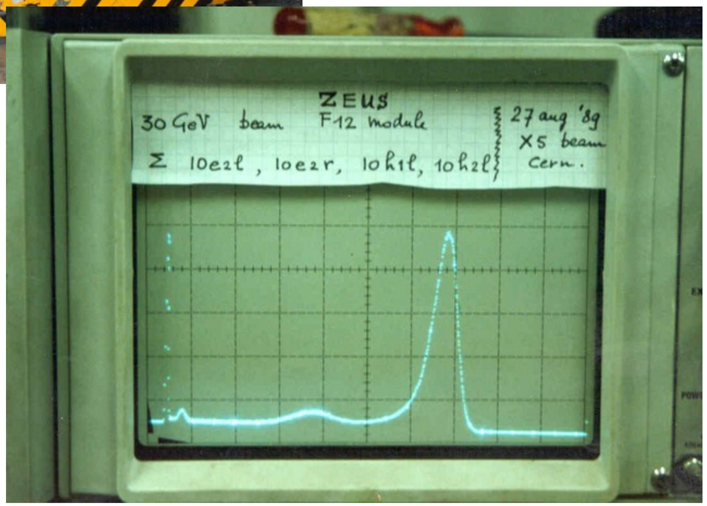


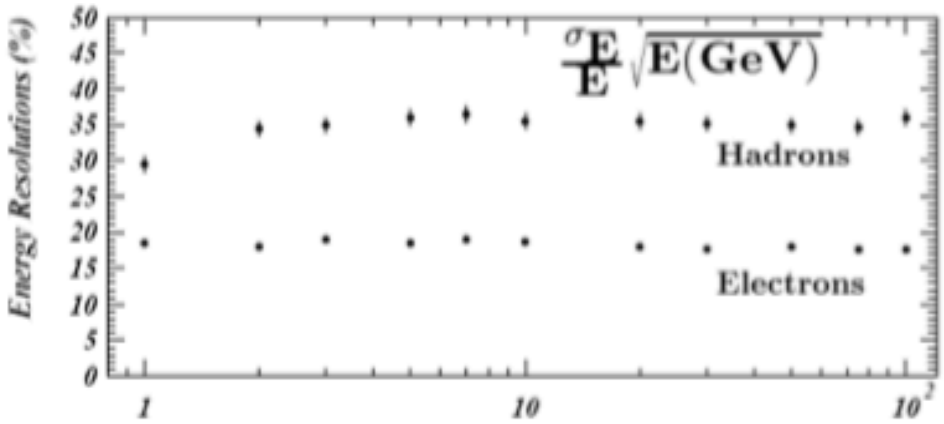
- Comparison of detailed test beam studies with simulations: improvement of existing shower models

ZEUS Calorimeter at CERN SPS

1989

- The ZEUS calorimeter was a uranium scintillator sandwich calorimeter
- Intrinsic Uranium radioactivity allowed “easy” calibration during running
- Operation characteristics were determined in test beams at CERN (prototype detector and all production modules)





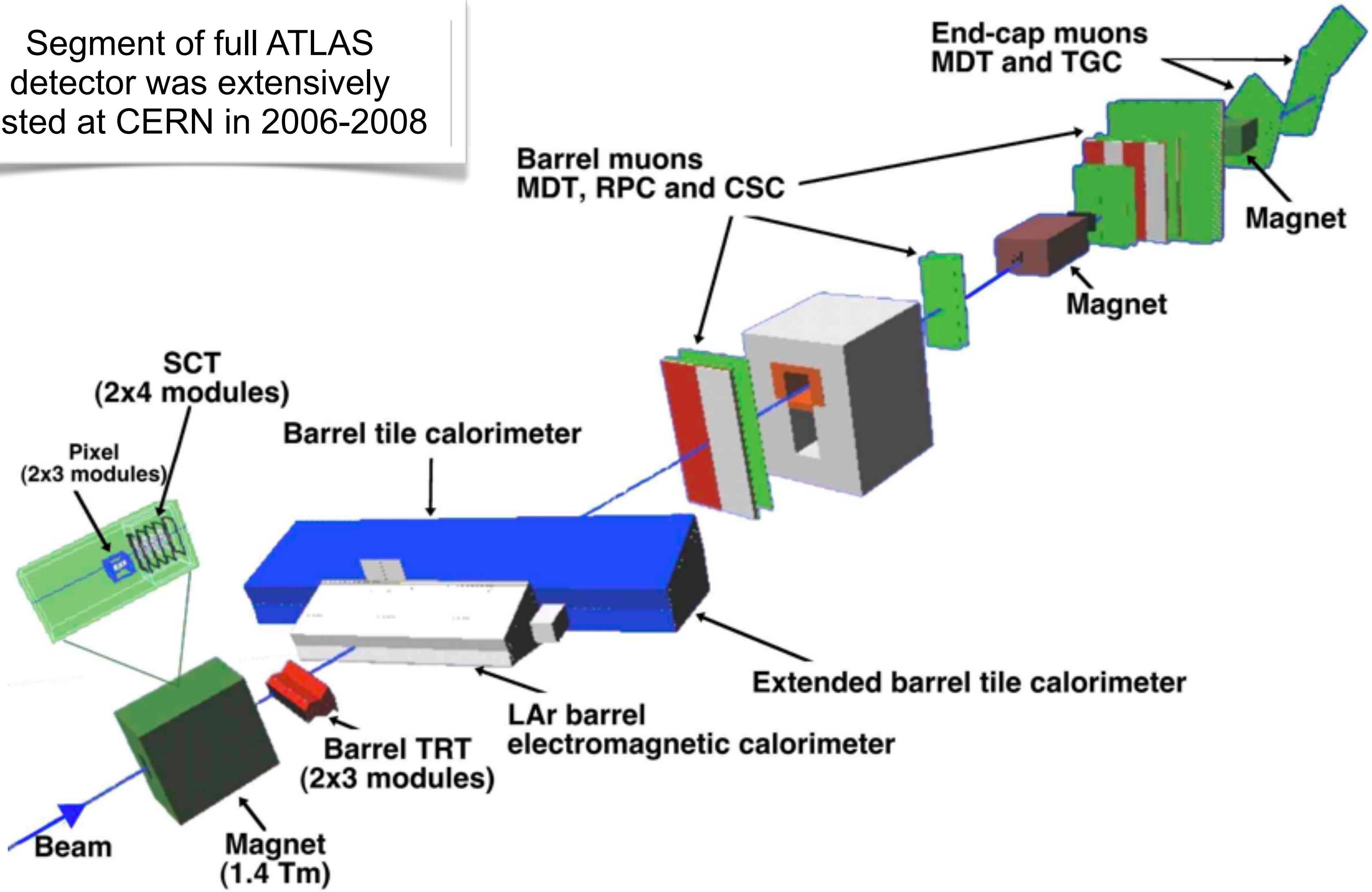
Electrons: $$\frac{\sigma(E)}{E} = \frac{18\%}{\sqrt{E(GeV)}}$$

Hadrons: $$\frac{\sigma(E)}{E} = \frac{35\%}{\sqrt{E(GeV)}}$$

Full System Tests

ATLAS Combined Test Beam

Segment of full ATLAS detector was extensively tested at CERN in 2006-2008



Picture: ATLAS@CERN

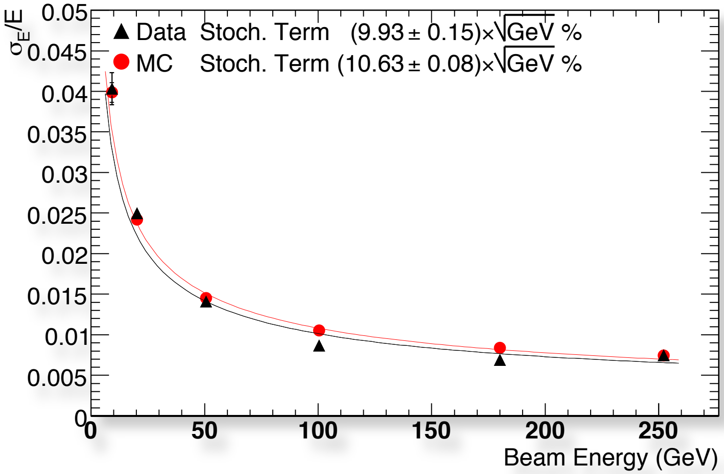
ATLAS Combined Test Beam

- Several important objectives in the test:
  - Calibrate the calorimeters at a wide range of energies.
  - Finalize the trigger studies with the level 1 Muon and Calorimeter,
  - Study commissioning aspects and get experience with the readout,
  - Study the detector performance of an ATLAS barrel slice,
  - Gain experience with the latest offline reconstruction and simulation tools,
  - Gain experience with the latest Trigger and data acquisition (DAQ) programs.

- $e^{\pm}/\pi^{\pm}$ at 1...250 GeV
- $\mu^{\pm}, \pi^{\pm}, p$ up to 350 GeV
- γ at $\sim$ 20...100 GeV
- Inner Detector (ID) collected **22 M "good" events**

Picture: ATLAS@CERN

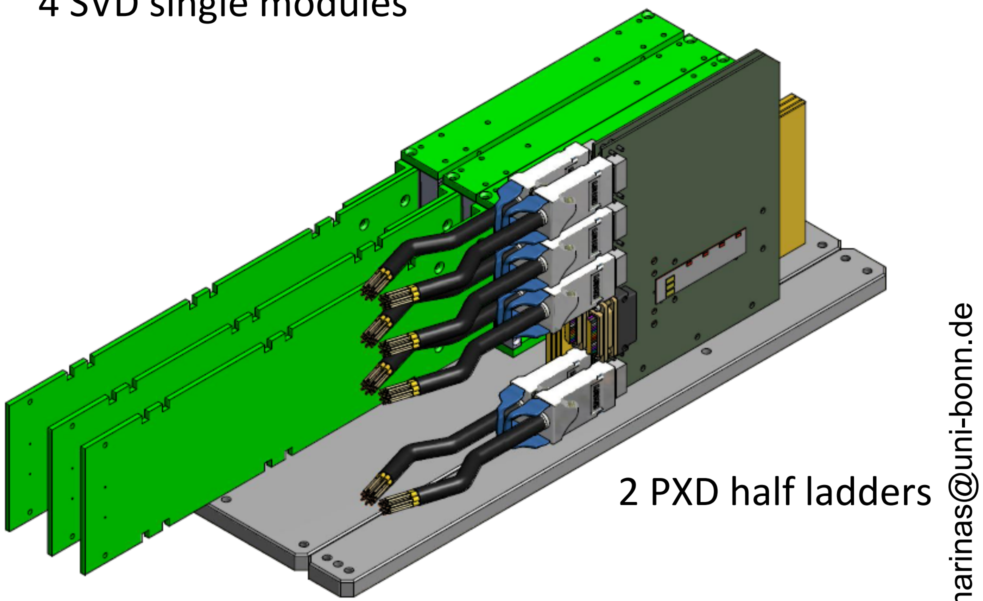
Example: Energy resolution of LAr Calorimeter



Belle II VXD Combined test beam

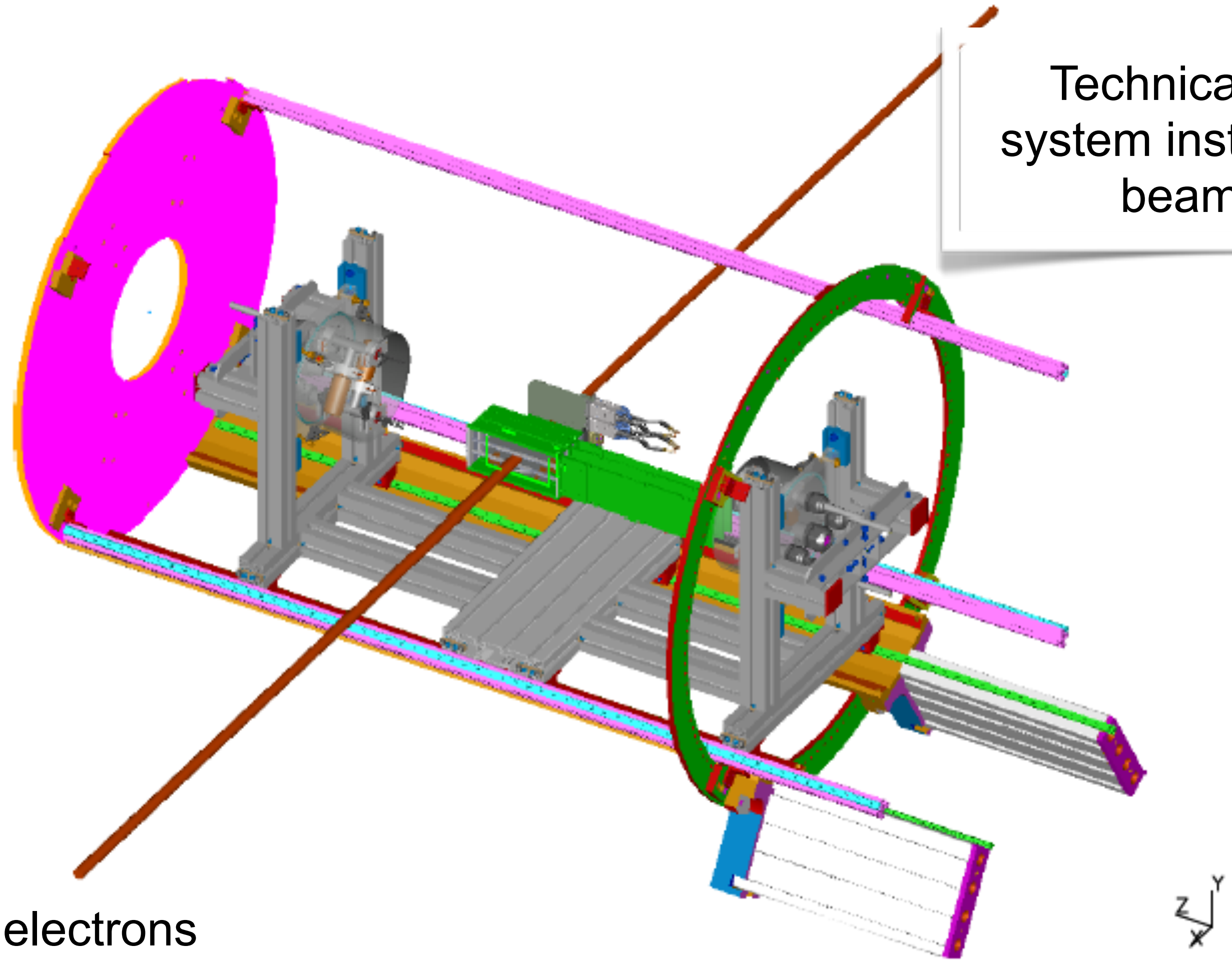
- Example for another rather complex test beam in preparation
- Full test beam before installation of the detector in Japan
- System test in magnetic field (PCMAG, 1T, DESY test beam facility)
- Planning started about half a year ago, the beam period is assigned for January 2014

- Small sector of the Belle II Vertex Detector (VXD=PXD+SVD)
- PXD=Pixel Detector (i.e. DEPFET)
- SVD=Silicon Vertex Detector (i.e. DSSD)
- Final DAQ, Slow Control and High Level Trigger
- Alignment, tracking and ROI (Region of Interest) generation
- CO_2 cooling



Design still evolving

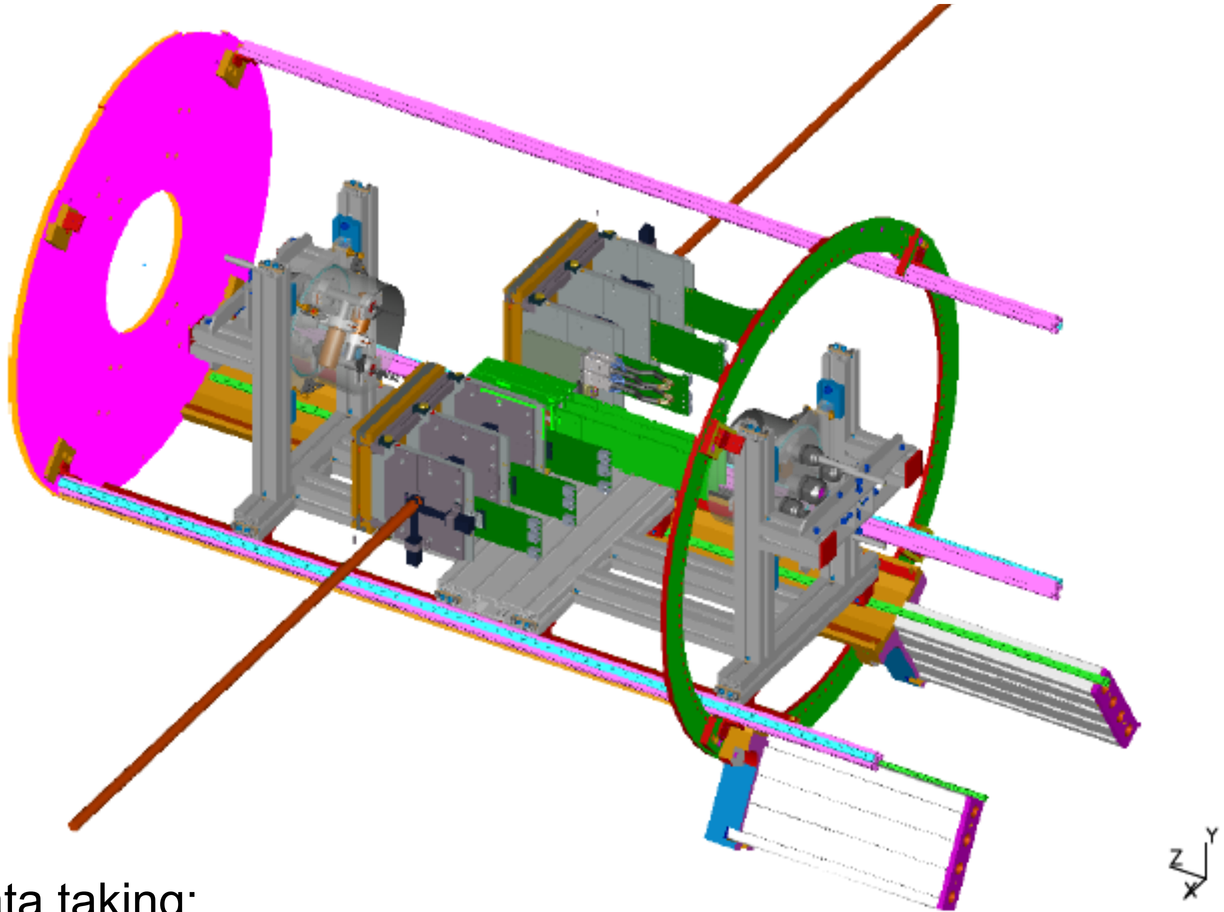
Integration into the PCMAG



Technical drawing of system installation in test beam magnet

Integration into the PCMAG

6 telescope planes
Trigger: PM + FE-I4



Two stage data taking:
1.- Run with telescope: low trigger rate and momentum definition
2.- Standalone run: high data rate (>1 kHz) VXD

How to do a test beam ?

How to Plan a Test Beam Study (1)

- What do you want to measure ?
  - Is really test beam needed ? Use all alternative tests (sources, laser, …)
- What kind of particles are useful ?
  - A lot of studies do not require highest energy
  - Lower energy machine also give great possibilities for studies
- Apply for test beam time early one (sometimes a year in advance)!
- Test your system very carefully before moving it to a test beam hall
  - Recommendable: run the system in the lab **at least** twice as long as it has to run during the test beam campaign.
  - Often groups end up debugging their electronics, DAQ or software instead of taking data (waste of valuable beam time!)
  - You can only solve problems if you know your setup really well
  - Expect the unexpected !

How to Plan a Test Beam Study (2)

- Prepare, prepare, prepare ….
  - Visit test beam facility before !
  - Make sure one person is in charge (too many bosses can make a big mess) !
  - Make lists of the needed hardware and packing lists
  - Bring all tools along which you might need
    - Most important: cable binders and tape
  - Bring spare parts !
  - Bring enough people to help, but not too many ...
  - Ship your equipment well in advance
  - Make a detailed list of the needed measurements and put priorities
    - There is always one measurement one can not finish ...

- Coffee and candy helps that people stay put

Where to do a test beam ?

Test Beams in The World

Test Beams in The World

Beam lines with beam of energies higher than 100 MeV/c

Test beams* in the world, status June 2013						
Laboratory	**Number of beam lines**	**Particles**	**Energy range**	**Diagnostics etc.**	**Availability**	**Information, contacts & comments**
CERN / PS (CH)	4	p (prim.) e, h, μ (sec.)	24 GeV/c 0.6 - 12 GeV/c	Threshold Cherencov, scintillators, MWPCs, delay wire chambers, scintillators, magnet, movable platform	9 months per year, continous except winter shutdown Duty cycle depends on PS / SPS / LHC operation mode and is typical * PS ~1-3% * SPS: 20-40%	contact beam time request and scheduling: Sps.Coordinator@cern.ch http://spsschedule.web.cern.ch/SPSschedule/pindex.html contact beam lines: sba-physicists@cern.ch http://sba.web.cern.ch/sba/
CERN / SPS (CH)	4	p (prim.) e, h, μ (sec.) e, h (tert.) Pb ions (prim) other ion species (out of fragmentec primary Pb ions)	400 GeV/c 10 - <400 GeV/c 10 - 200 GeV/c 20 - 400 GeV/c proton equivalent (z=1)	delay wire chambers, filament scanners, XEMC calorimeters, Threshold & CEDAR, hodoscopes, magnet, movable platform		
DESY (D)	3	e+, e- (sec.) e- (prim., planned for 201X)	1 - 6 GeV/c 6.3 GeV/c	Trigger systems and beam telescopes, magnet (~1T)	10 months per year, 2014: presumably 8 - 10 months Duty cycle ~ 50%	contact: Testbeam-Coor@desy.de http:// testbeam.desy.de
FERMILAB/FTBF (US)	2	p (prim.) e, h, μ (sec.) h (tert.)	120 GeV/c 1-66 GeV/c 200-500 MeV	Cherencov, TOF, pb-glass calorimeters, MWPC, Si Tracker, see website for more	24 hrs/day 10% duty cycle	contact: FTBF_Co@fnal.gov http://www-ppd.fnal.gov/FTBF/
FERMILAB/MTA (US)	1.00	H^- ions	400 MeV Flux of $1*10^{12}$/minute	SEM for beam flux measurement	T. b. d.	contact: Aria Soha (aria@fnal.gov) Erik Ramberg@fnal.gov
IHEP Bejing (CN)	2	e (prim.) e (sec.) p, π (sec.)	1.1 - 2.5 GeV/c 100 - 300 MeV/c 0.4 - 1.2 GeV/c	MWPC, TOF Cherencov, CAMAC system, platform	Availability: 3 mouths per year, duty cycle depends on BEPCII operation mode	contact: Hu Tao (hut@ihep.ac.cn)

Christoph Rembser

Test Beams in The World

Beam lines with beam of energies higher than 100 MeV/c

Test beams* in the world, status June 2013						
Laboratory	**Number of beam lines**	**Particles**	**Energy range**	**Diagnostics etc.**	**Availability**	**Information, contacts & comments**
IHEP Protvino (RU)	5	p (prim), p, K, π, μ, e (sec.) C-12 (prim)	70 GeV/c 1-45 GeV/c 6-300 GeV/c	Cherenkov, TOF, MWPC	two months per year	contact: Alexandre Zaitsev (alexandre.zaitsev@cern.ch)
KEK / JPARC (JP)	1	p,π,K,e(sec.)	<1GeV/c	Cherenkov, TOF		contact: Masaharu Ieiri (masaharu.ieiri@kek.jp) http://j-parc.jp/researcher/Hadron/en/index.html
KEK / Tsukuba (JP)						Fuji beam line in KEKB main ring unavailable until Super KEKB will resume operation (~2015) http://www.kek.jp/ja/Facility/IPNS/K11BeamLine/
PSI / piE1, piM1, etc. (CH)	2-4	π+-, μ+-, e+-, p	50-450 MeV/c, rate $<10^9$ sec^{-1} 20nsec structure continuous beam at very high rate		6-8 months per year	beam time allocated by programme committee (twice per year) contact: Peter Kettle (peter.kettle@psi.ch)
PSI / PIF (CH	1	p	5 - 230 MeV/c ax. current 2 - 5 nA, rate $<10^9$ sec^{-1}, typ. flux 10^8 cm^{-2} sec^{-1} for wide beam, energy, beam spot and flux selectable by user		11 months per year, mostly during weekends	contact: Wojtek Hajdas (wojtek.hajdas@psi.ch)
SLAC (US)	1	e (prim.) e (sec.)	2.5 - 15 GeV/c 1 - 14 GeV/c		Starting July 2012, 9 months per year, 50% duty cycle	contact: Carsten Hast (hast@slac.stanford.edu) https://slacportal.slac.stanford.edu/sites/ard_public/tfd/
SPRING-8, Compton Facility (JP)	1	photons (tagged) :+, e- (conversions	1.5 - 3.0 GeV/c 0.4 - 3.0 GeV/c		>60 days per year	contact: Takashi Nakano (nakano@rcnp.osaka-u.ac.jp) http://www.spring8.or.jp/en/

*Beam lines with beams of energies higher than 100 MeV/c

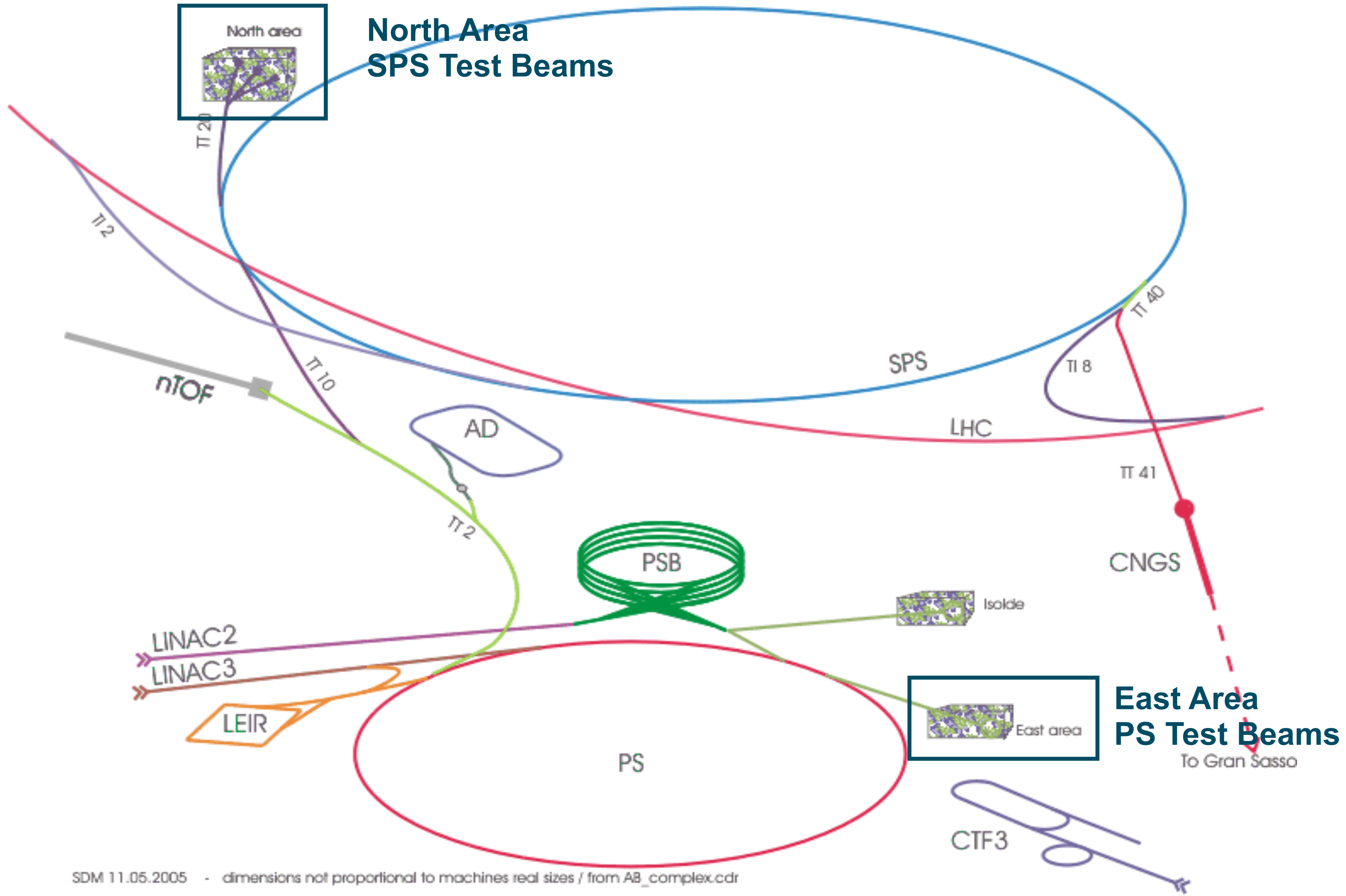
CR, 29 June 2013

A few more details on the main European facilities on the next slides

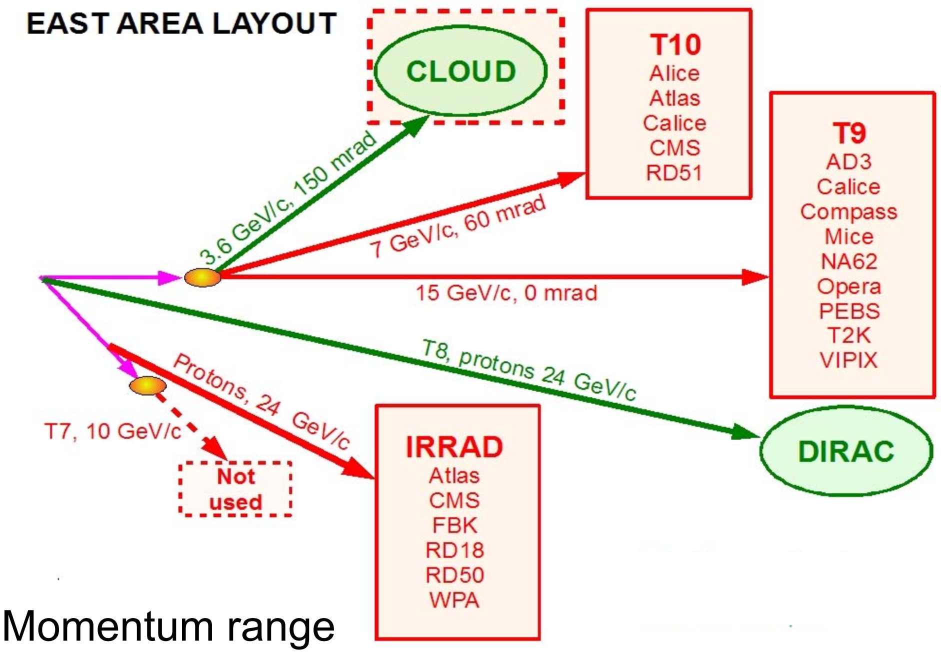
Christoph Rembser

CERN Test Beam Facility

Beam Facilities at CERN



East Area Test Beams: PS

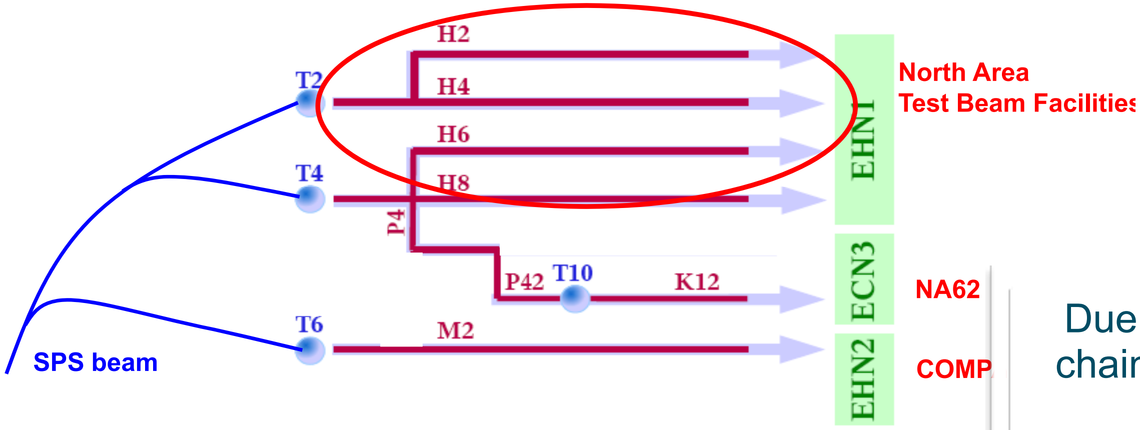


- 5 beam lines
- total length 300m
- 300 scientists / year performing experiments and tests

- Momentum range
  - Secondary beam: 1GeV/c – 15 GeV/c
- Particle type and intensity
  - electrons, hadrons, muons
  - max. 1-2*10^6 particles per spill; typically 10^3 - 10^4 used
- Spill structure from PS
  - 400ms spill length
  - typically 1 spill every 33.6 s, more on request

North Area Test Beams: SPS

- Momentum range
  - H2, H4, H8: 10–400GeV/c (secondary beam)
  - primary proton beam at 400(450)GeV/c
  - H6: 5–205GeV/c
- Particle type
  - electrons, hadrons, muons (secondary target -> tertiary beam)
- Particle intensity
  - max. $2*10^8$ particles per spill



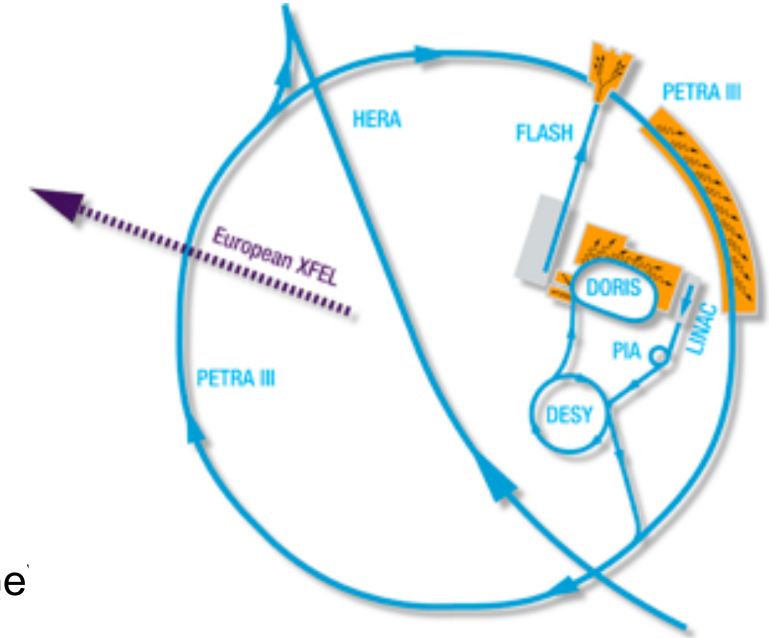
E. Gschwendtner, CERN

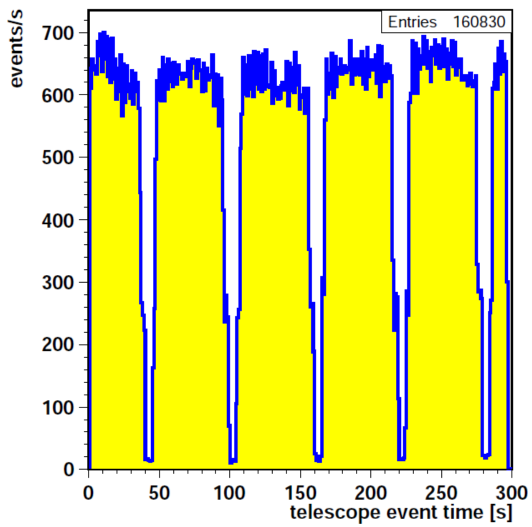
Due to the ongoing shutdown of the accelerator chain at CERN PS and SPS test beams are only available late 2014/ beginning of 2015.

The DESY Electron Test Beam

DESY II

- Synchrotron for electrons and positrons
- Since 1987 used as pre-accelerator for
  - DORIS (until 2012)
  - PETRA
  - HERA (until 2007)
- For PETRA 3
  - single bunches with 1*10^{9} positrons at 6.0 Ge
    every minute (Top-Up mode)
- Test beam runs in PETRA 3 mode with extraction on the falling slope
  - extraction at 6 GeV
  - reduced beam current during Top-Up (10%)
- Top-Up mode allows 24/7 running of DESY II
  - test beam usage possible at any time

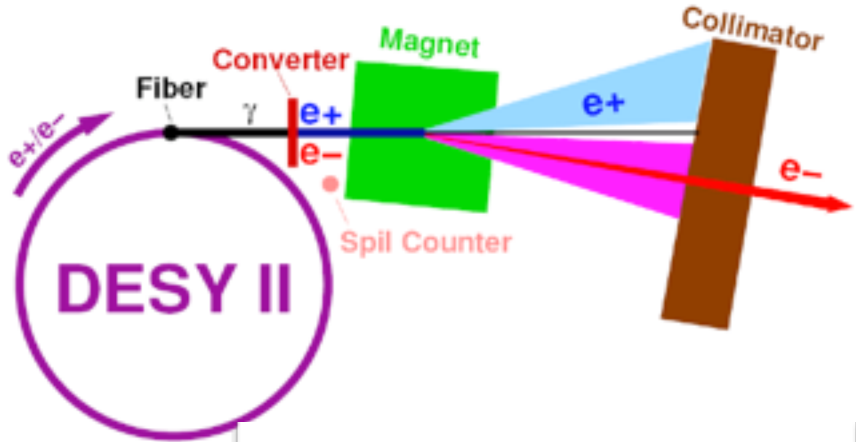




Example:
4.4 GeV with 8E9:
650 Hz peak trigger rate
intensity drop every 60 s for 12 s: filling PETRA

Test Beam at DESYII

- For test beam no extraction is used
- Inserting a carbon fibre in the circulating electron/positron beam -> Bremsstrahlung.
- Bremsstrahlung photons are converted to electron/positron pairs with a metal plate.
- Beam is spread out into a horizontal fan with a dipole magnet. Collimator cuts out final beam.
- No beam optics, very simple to use

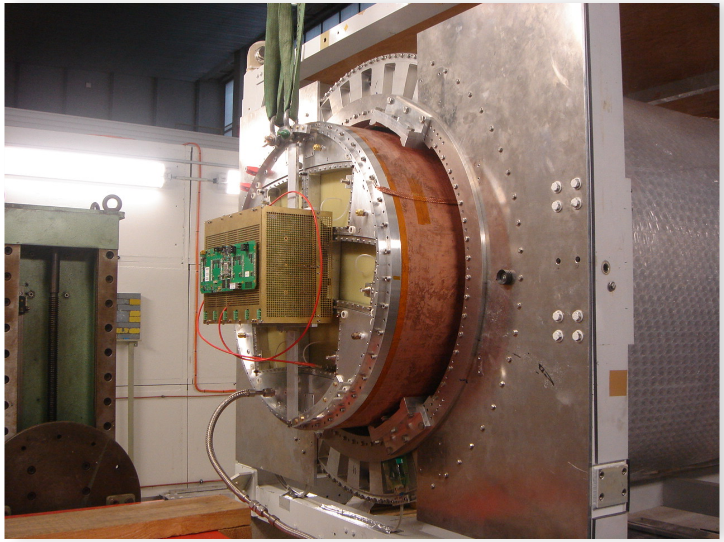


DESY II:
revolution frequency: 1 MHz,
RF frequency: 500 MHz
bunch length: ~30 ps.
average radius: 46.6 m

- With this concept DESYII provides three test beam lines with 1-5 GeV/c electrons.
- Test beam was developed during HERA detector preparation and used by all HERA experiments
- Recent years -> newly increase in usage due to LC and HL-LHC detector R&D

Facilities for Test Beam User

- All three test beam lines have
  - Interlock systems
  - Magnet control to select momentum
  - Patch panels with pre-installed cables
  - Gas warning systems
  - Fast internet connection (DHCP)
  - Trigger scintillators
- The user can ask for:
  - Translation stages
  - Premixed gases
  - Superconducting Magnet (1T)
  - Beam Telescopes:
    - Pixel Beam Telescope
- The users typically bring:
  - Data Acquisition incl. computers
  - Trigger scintillators



Beam Telescope Requirements

What is a beam telescope?

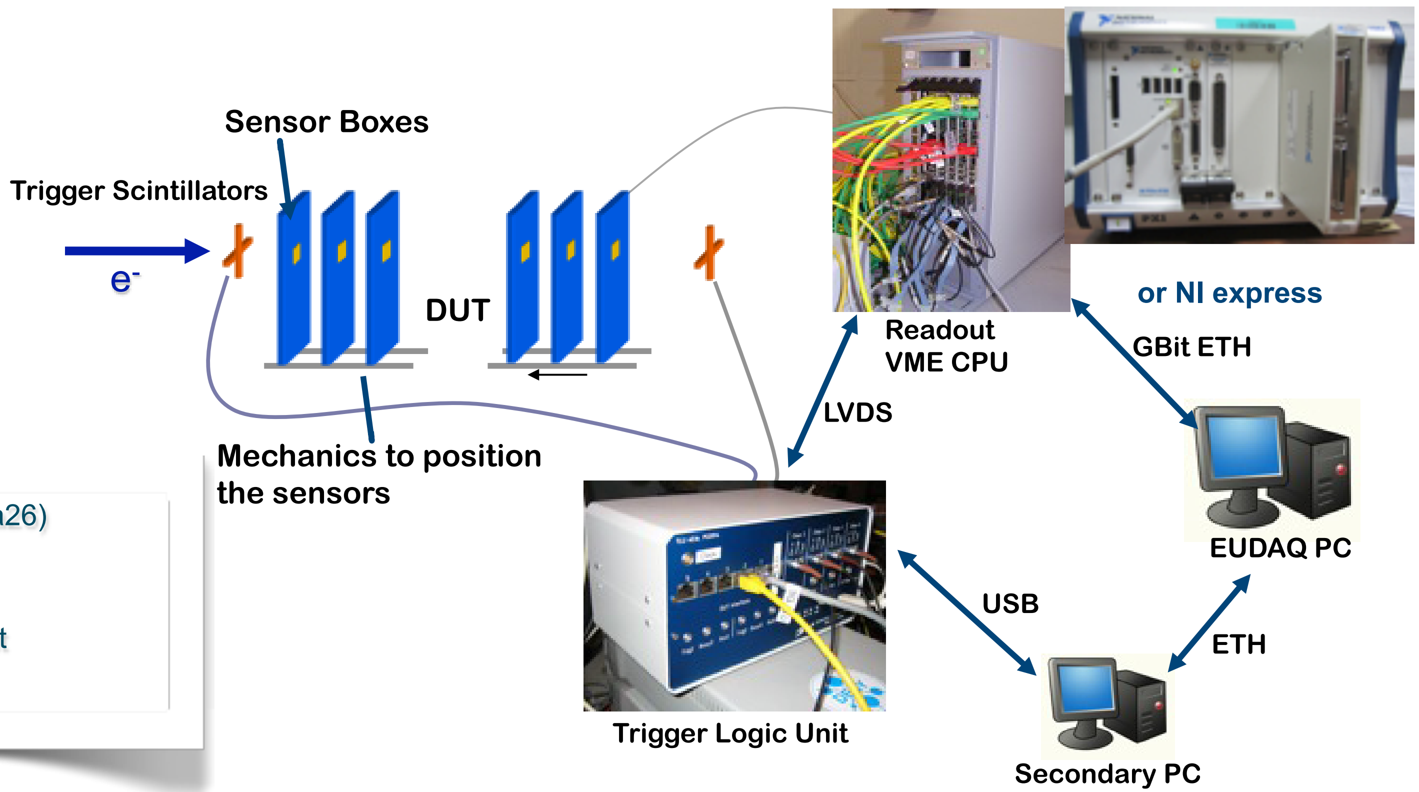
- A tool to define the exact track of a particle in a test beam very precisely.
- Used for detailed studies of newly developed detectors.
- Pointing resolution should be better than the expected intrinsic resolution of the device under test (DUT).

Generally applicable:

- DUTs: from small pixel sensors to larger detectors
- Movement of device under test (DUT) to scan larger surface
- Large range of conditions: cooling, positioning, (B-Field)
- Easy to use: well defined/described interface
- Very high precision: <3 µm precision even at smaller energies (DESY)
- Mobile !

… plan when we started out with the EUDET telescope in 2006 …..

Telescope Ingredients



- ✓ Sensors (Mimosa26)
- ✓ Readout System
- ✓ EUDAQ
- ✓ Trigger Logic Unit
- ✓ Mechanics

Important

- Use of DAQ software and analysis software which is also general applicable and easy to use
- EUDAQ -> highly modular multi threaded software to implement existing DAQ "easily"
- EUTelescope -> Generic Pixel Telescope Data Analysis Software based on ILCSoft
- developed for our telescope but much more versatile

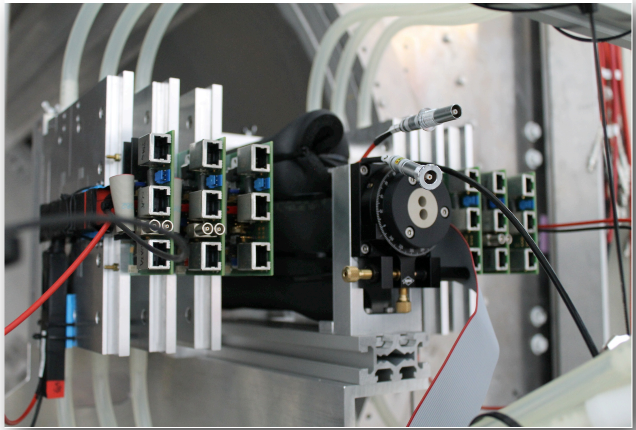
Telescopes !!

- More successful than anticipated
- Already 5 telescope copies built and are planning #6
- EUDET
  - the original !
- ANEMONE
  - copy for Bonn (ELSA test beam)
- ACONITE
  - copy for ATLAS collab. currently in TB22
- DATURA
  - copy for DESY currently in TB21
- CALADIUM
  - copy for Carlton, recently commissioned in Canada
- DURANTA
  - copy for DESY

- Pixel telescope allows high precision measurements also at low momentum test beam (<5 um)
- Relative easy use for many user groups
- Exact same system can be found at different test beam facilities

Education !!

- Nowadays education of young scientists in all aspects of particle physics is more difficult
  - Preparatory phases for detectors are getting longer; only a few aspects can be studied
  - Data taking periods are longer -> generations of students never see the real detector
- Test beam studies allow education in many aspects
  - Experimental preparation
  - Trigger
  - Data Acquisition
  - Data taking (shifts, on-call)
  - Reconstruction, alignment, tracking
  - ….



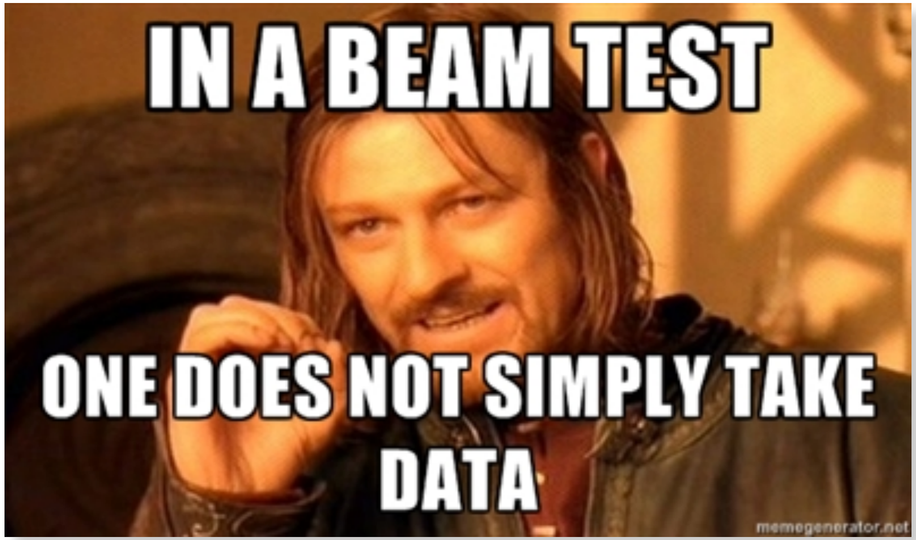
Setup for Lorentz angle measurements: telescope installed in 1T magnet.

If you ever get the chance to be part of a test beam campaign
-> don't run away ! You will learn a lot in an intensive but effective way !!

Summary

- Testing a new detector system for high energy physics is most likely involving test beam studies
- Tracking detectors: efficiency, spatial resolution are important parameters to be measured with a reference telescope
- Calorimeters test beam involve more than one test beam facility

- Test beam facilities are available around the world
  - PS/SPS at CERN are currently shut down -> back in 2015
  - Only European facility in 2013/14 is the DESY electron beam
- Being part of a test beam campaign is a lot of work, but very exciting



Many thanks for your attention!