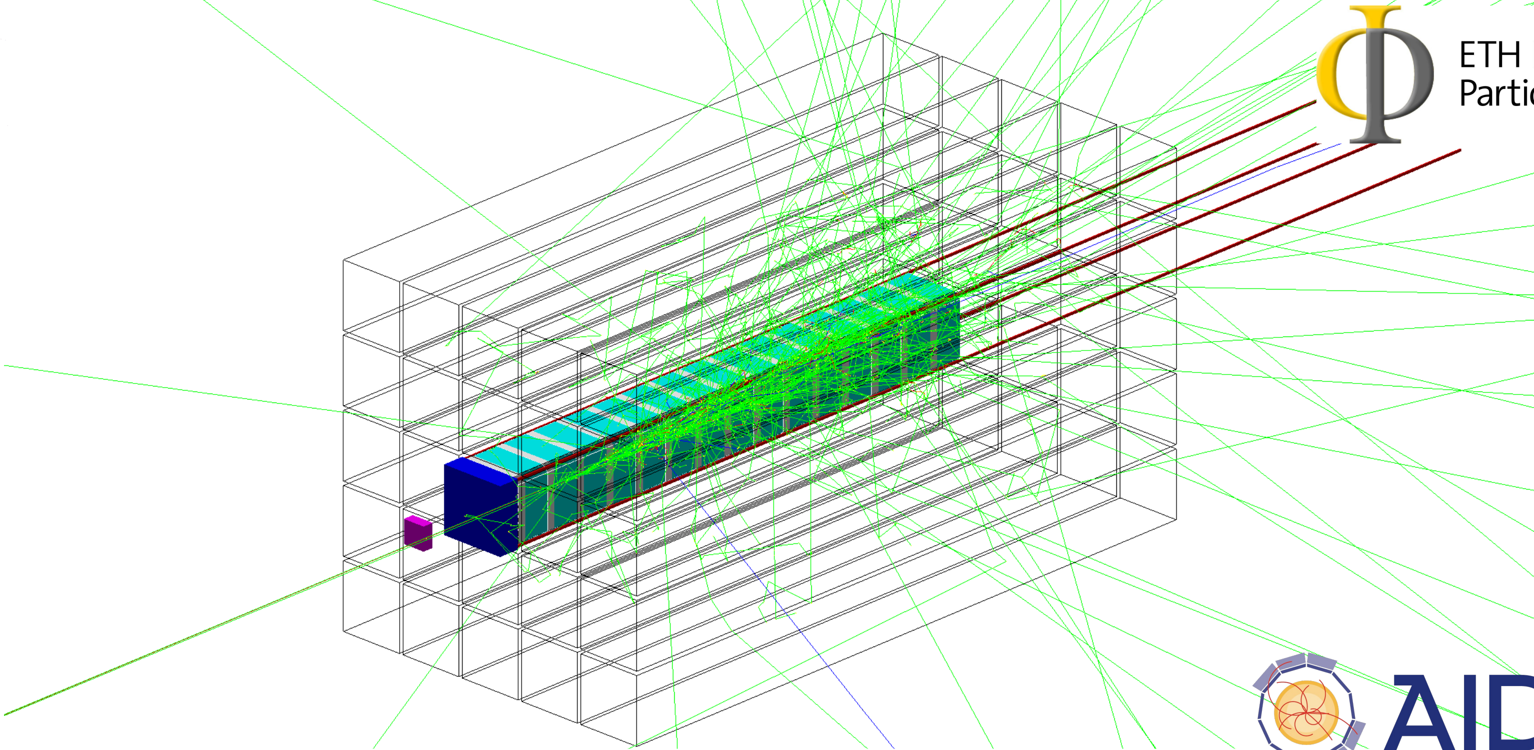

Performance Studies of a Tungsten-CeF_3 Sampling Calorimeter

Myriam Schönenberger - ETH Zürich on behalf of the W-CeF_3 R&D group:

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Rome University 'Sapienza' and INFN
Milano University 'Bicocca' and INFN
Torino University and INFN
Trieste University and INFN
Texas Tech University, Lubbock, Texas, USA

CALOR2016
Daegu, South Korea
05.19.2016

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Challenges at the LHC

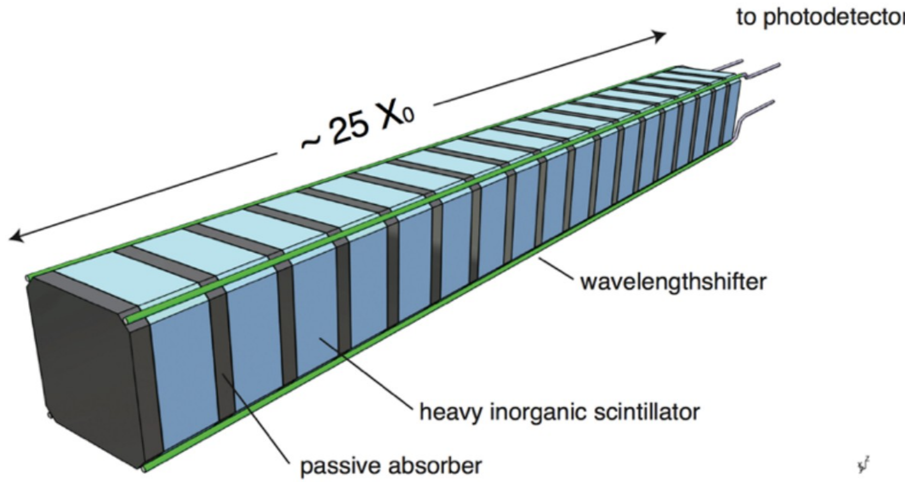
- **High particle fluence** at LHC: accumulated dose forseen to be problematic at the end of Run2 in forward direction

  → need **radiation hard** detector elements & **short optical path lengths**
- **High pileup** (from average 25 in Run1 to 140-200 at HL-LHC)

  Need:
  - **Small module size**
  - **Timing information**
- **Excellent energy resolution**

	Run1	**Run2**	**HL-LHC**
$\sqrt{s}$ [TeV]	7-8	13	13
L [cm^{-2} s^{-1}]	7×10^{33}	1×10^{34}	$> 5 \times 10^{34}$
Int. L [fb^{-1}]	25	300	3000
γ dose rate [Gy/h]	0.2 (η=0) 4 (η=3)	0.3 (η=0) 10 (η=3)	1.5 (η=0) 50 (η=3)
Hadron fluence [cm^{-2}]	4×10^{10} (η=0) 10^{13} (η=3)	4×10^{11} (η=0) 10^{14} (η=3)	4×10^{12} (η=0) 10^{15} (η=3)

Challenges at the LHC
Our Approach



- Cerium Fluoride (CeF_3):
  - **Fast** enough for LHC bunch crossing: 30ns decay time
  - Suitable for WLS: emission length 300nm
  - Can be grown radiation hard[1][2]
- Sampling calorimeter of CeF_3 &Tungsten
  - minimizes the light path in CeF_3
  - **High granularity**
- **Simple design**: depolished chamfers for WLS fibers along the edges[3]

Datataking campaigns:

- 2014: Proof of principle & **energy resolution** studies
- 2015: Radiation-hard fibres & **timing** studies
- 2016: 3x5 matrix tests

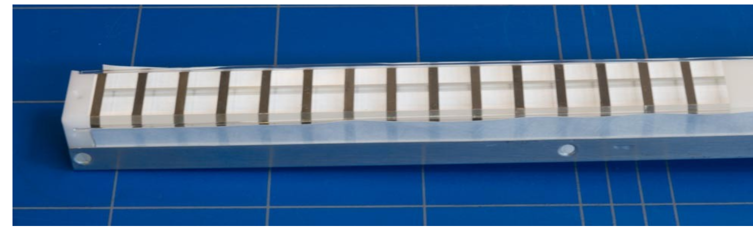
[1] E. Auffray et al. NIM A 383 (1996) 367-390
[2] G. Dissertori et al. NIM A 745 (2014) 1-6
[3] F. Nessi-Tedaldi et al., J. of Phys. Conf. Ser. 587 (2015) 012039

W-CeF_3: Single Channel Prototype

- **(10mm CeF_3 + 3mm W) x 15 layers = 25X_0** for longitudinal containment
- Effective **R_M = 23mm**

  → 24x24mm² lateral size of the channel
- 4 WLS fibers: **3HF single-clad** (Kuraray, *not* radiation hard)

  later also **Cerium doped quartz fibres** (where specified)
- Fibres read out independently by PMTs
- Surrounded by BGO crystals for shower containment



Data-Taking Campaigns

- **Frascati BTF**

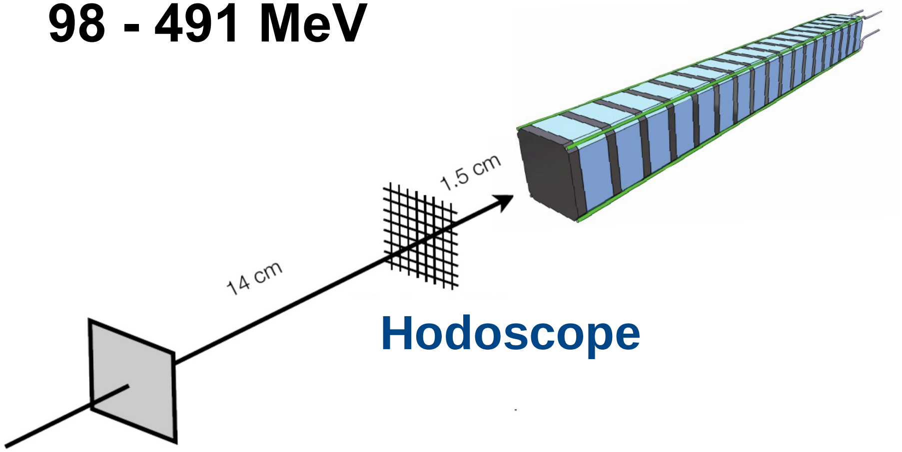
- **CERN SPS**

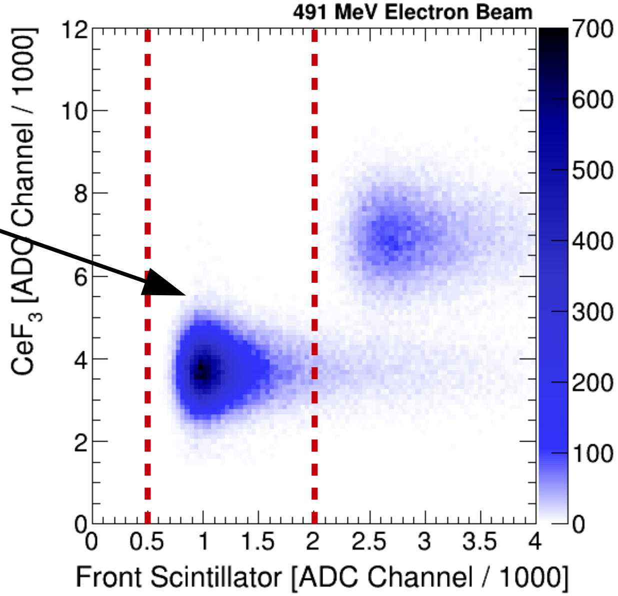
Beam Lines

- **Frascati BTF**

Bunched electron beam

98 - 491 MeV



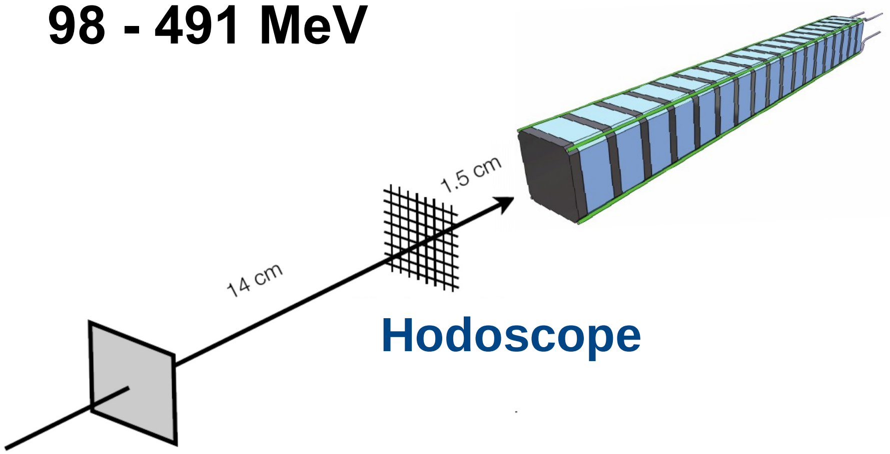


Beam Lines

- **Frascati BTF**

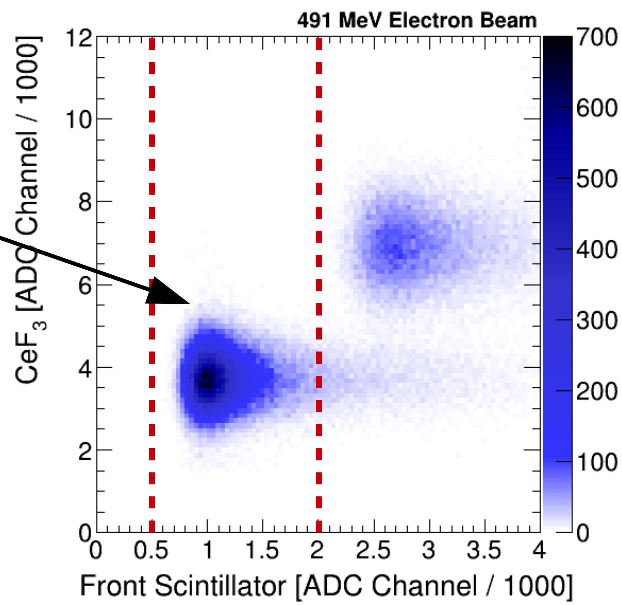
Bunched electron beam

98 - 491 MeV



Front Scintillator

→ for selection of single electrons



- **CERN SPS**

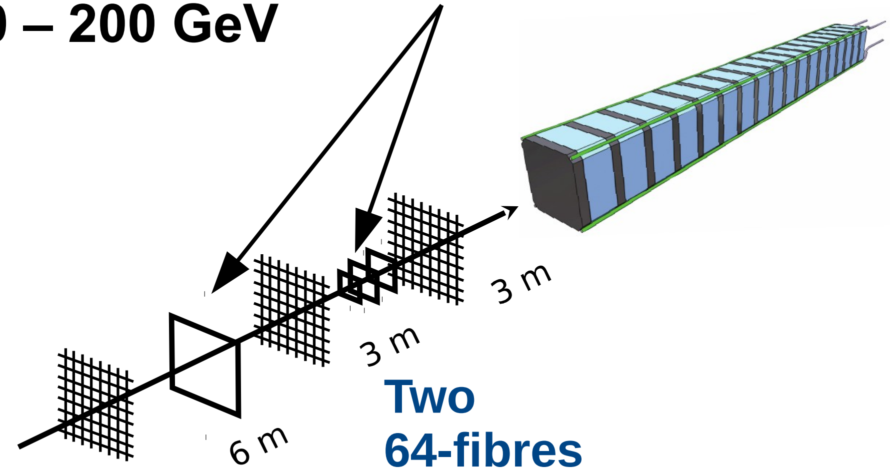
Electron beam

20 – 200 GeV

Scintillators

For triggering

Smallest one 1cm²



Two 64-fibres Hodoscopes

Wire Chambers

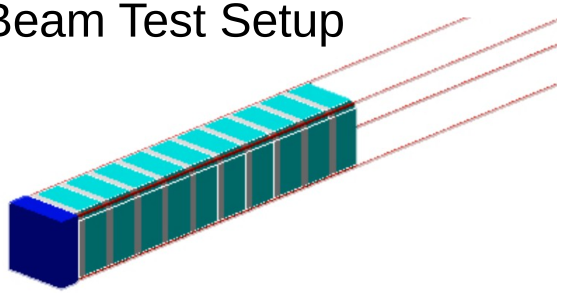
Allows for precise tracking → impact point known within < **0.5mm**

Simulation Setup

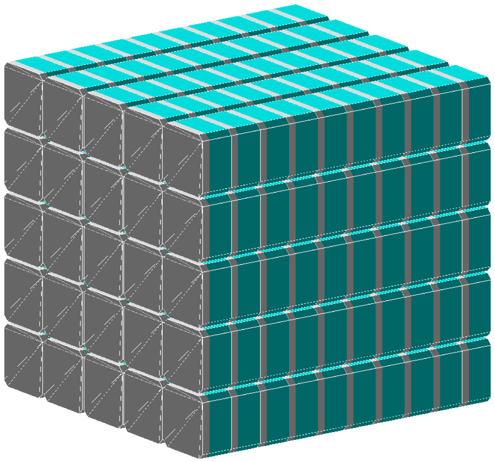
- Simulated using GEANT4
  - Single channel setup corresponding to the beam test setup
  - 5x5 matrix setup

    → no limitations due to lateral containment
- Includes
  - Upstream material
  - Beam profile
  - Photostatistics

Single Channel
Beam Test Setup

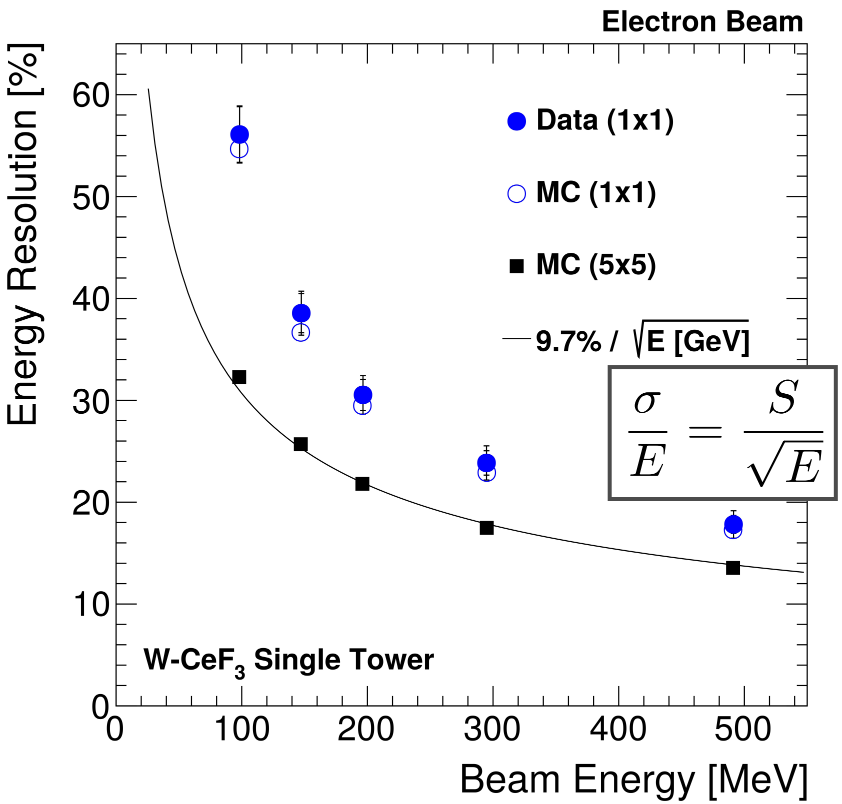


5x5 Matrix
Future detector

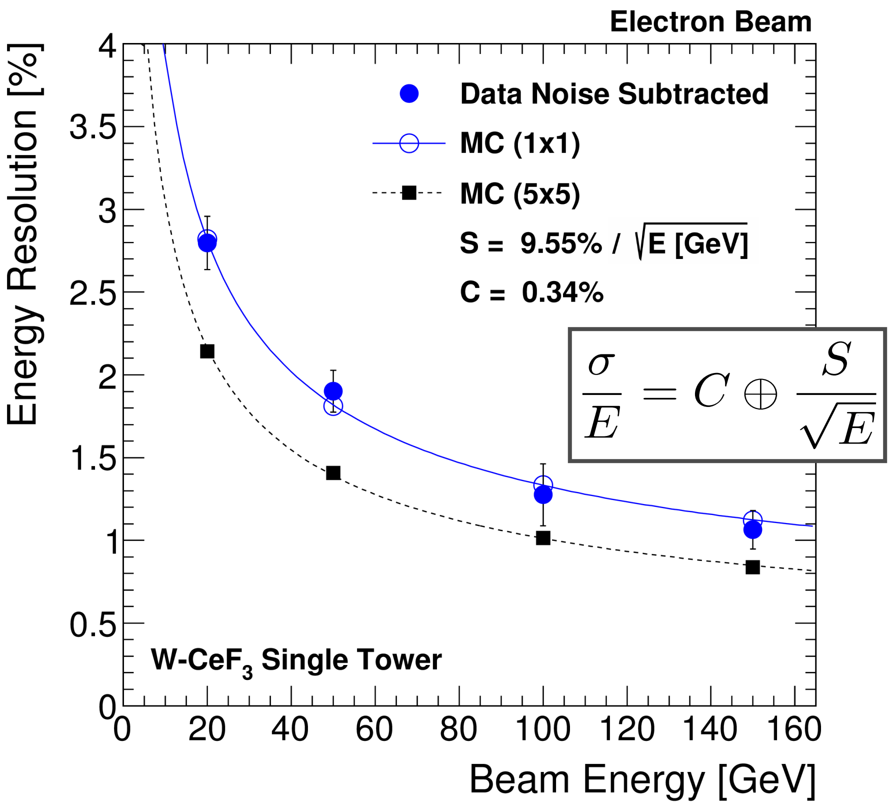


Energy Resolution

- **Frascati BTF [1]**



- **CERN SPS [2]**

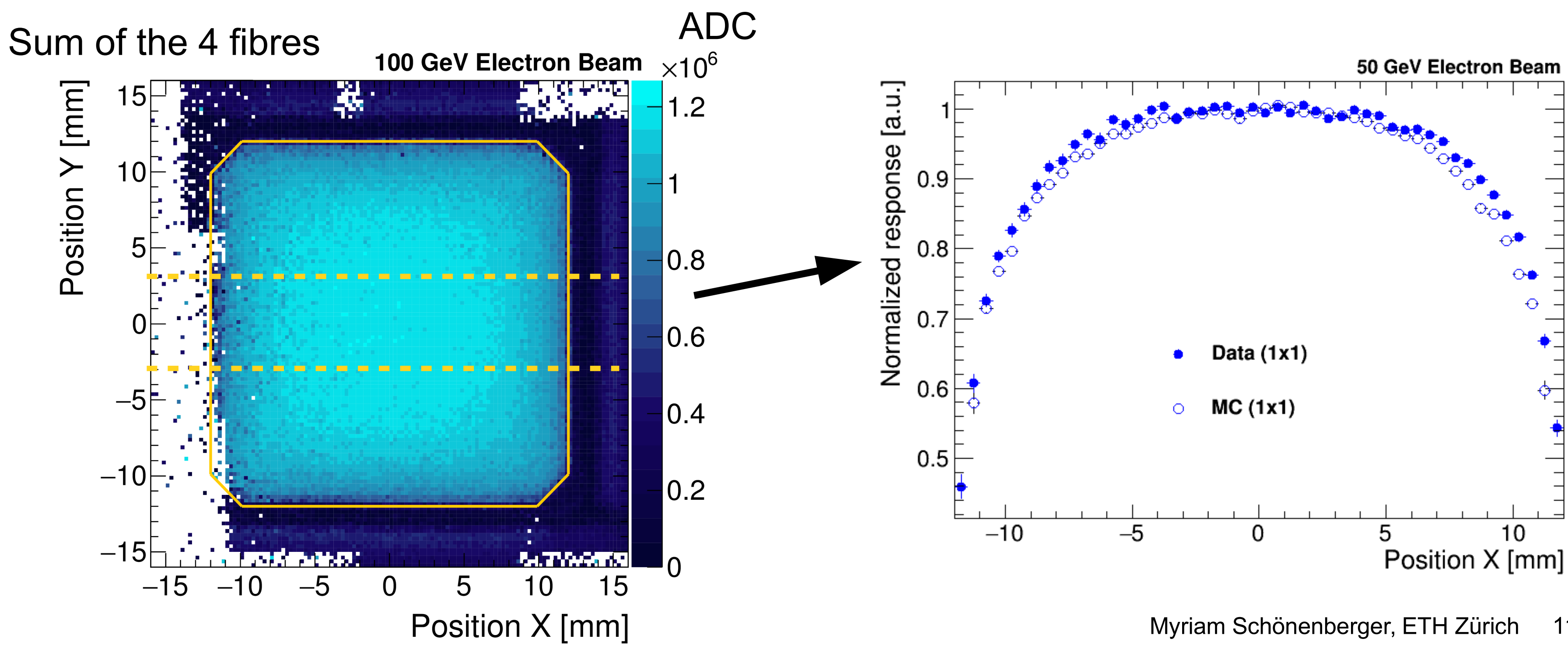


- Energy resolution of **~1% at 150GeV**
- **Stochastic term < 10%** achievable for 5x5 matrix

[1] R. Becker, et al., 2015 JINST 10 P07002
[2] R. Becker, et al., NIM A 804 (2015) 79 - 83

Uniformity of the Response

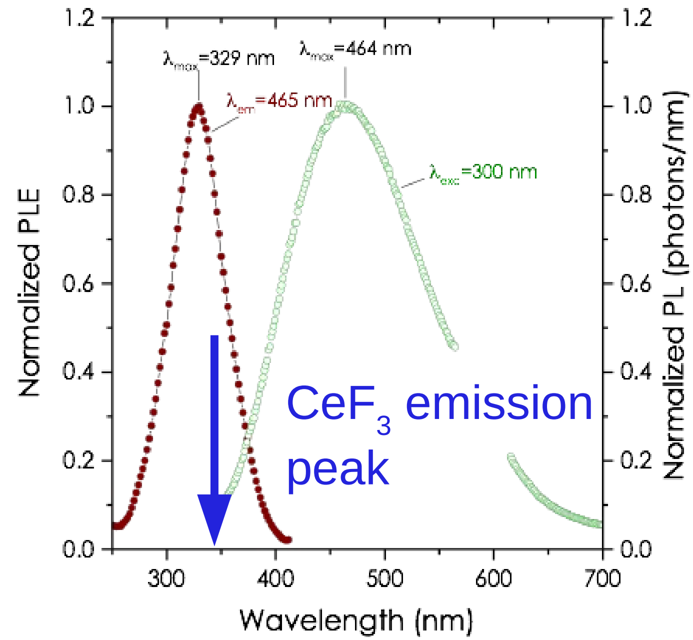
- Clearly distinguishable **nominal dimensions of the channel** (overlayed in orange), Gaps & Chamfers
- Single channel → Decrease of response towards edges due to **shower containment**
- Uniformity will be measured in the 2016 matrix



Towards radiation hard WLS Fibers

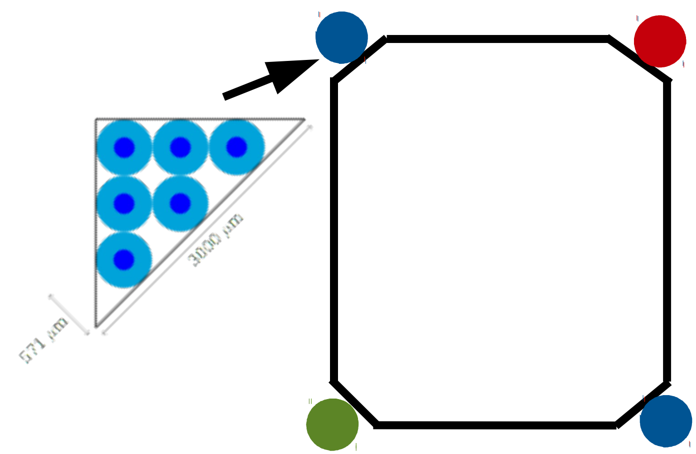
Photoluminescent Ce doped quartz fibres ($Ce:SiO_2$):

- **Can be made radiation hard** to fluences of $>10^{15} cm^{-2}$
- **Suitable for WLS:** absorption spectrum matches CeF_3 emission
- **Fast** time response ~30ns
- Factor ~10-20 less light than plastic fibres



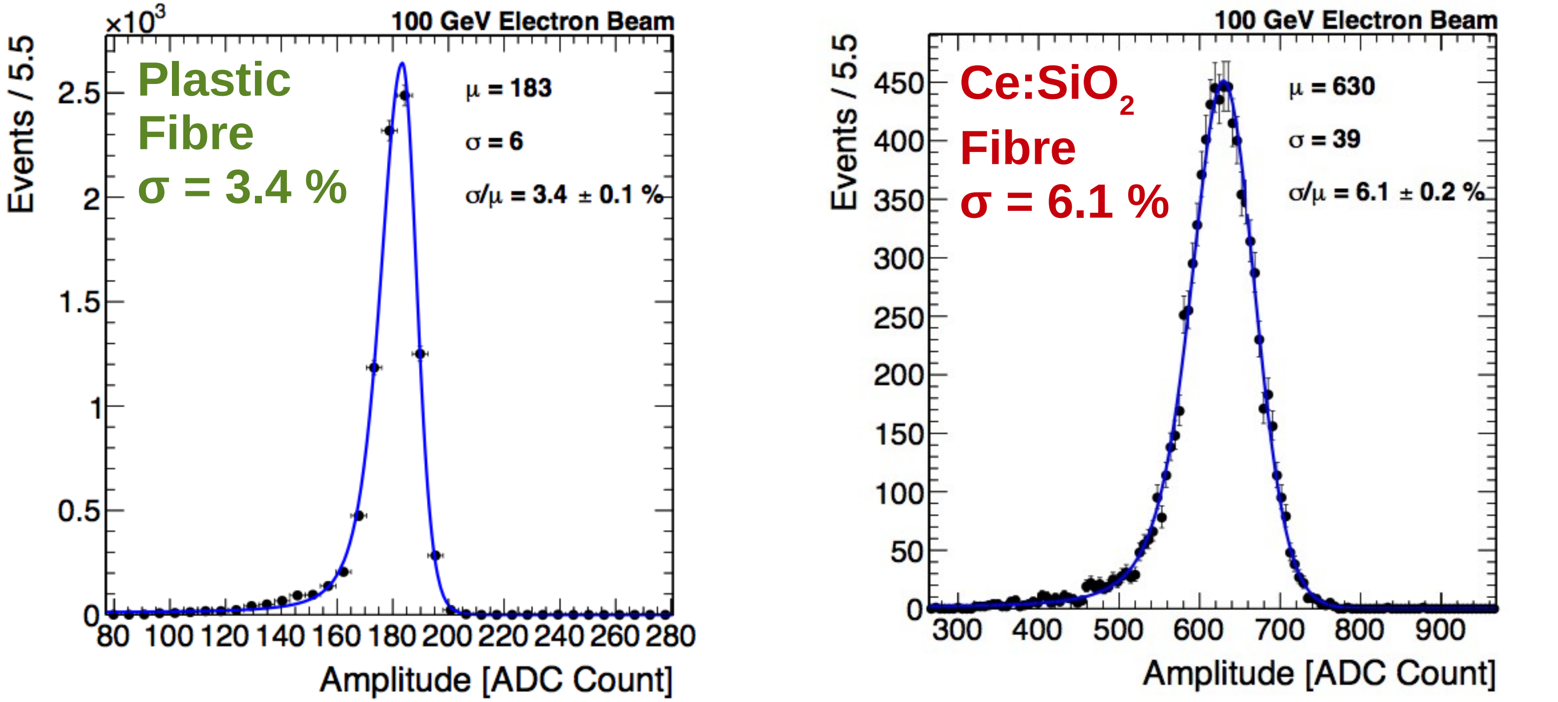
Test different fibres with the same channel:

- 1x reference plastic fiber
- 1x bundle (3 fibers) $Ce:SiO_2$ from U. Milano-Bicocca[1]
- 2x bundles (6 fibres) $Ce:SiO_2$ of Polymicro[2]



[1] A. Vedda, N. Chiodini, M. Fasoli et al., Appl. Phys. Lett., Vol. 85 (2004) 6356 and priv. comm.
[2] Jordan Damgov, Proc. SCINT2015, Berkeley (USA)

Energy Resolution for Plastic and Ce:SiO_2 WLS Fibres



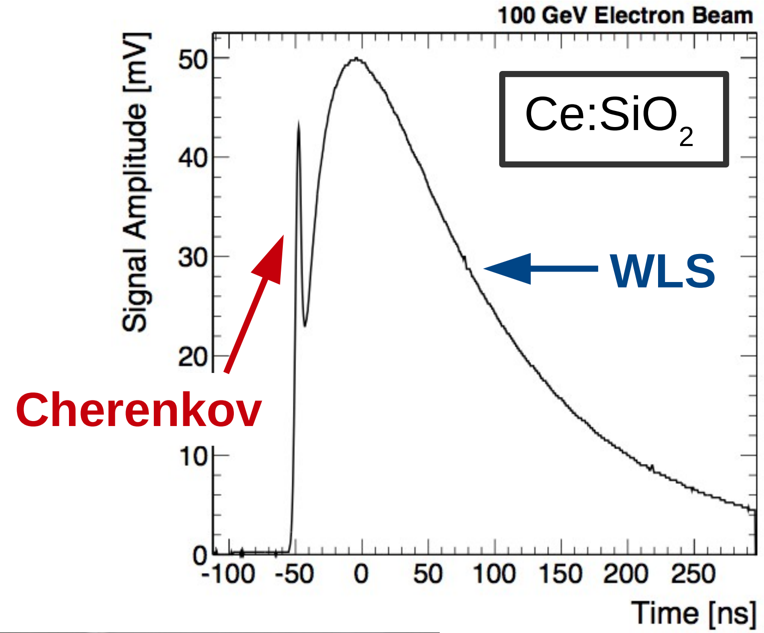
- Signal spectrum from signle fibre, for central electrons
- Ce:SiO_2 shows worse resolution wrt to plastic fibres, consistent with a factor ~10 less light

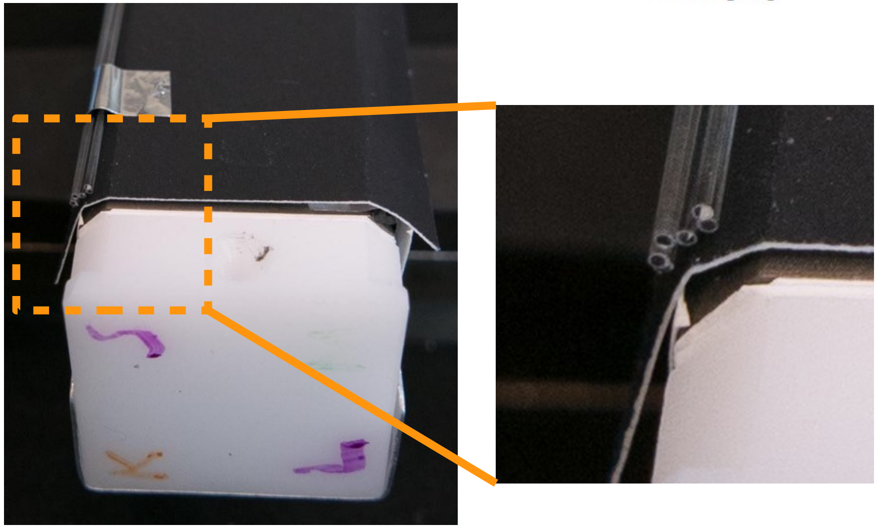
$Ce{:}SiO_2$: WLS & Cherenkov Component

- Fibres read out by SiPM & preamplifier boards developed by ETH
- Digitizer @ 2.5Gs/s, 400ns window

  → **full waveform** acquired
- Fast Cherenkov component, rising within a few ns for $Ce{:}SiO_2$ fibres

  → interesting for **timing studies**
- Blinded fibre: Place black screen between one $Ce{:}SiO_2$ fibre bundle and CeF_3 samples to study the **Cherenkov** part indipendently of the **WLS** component

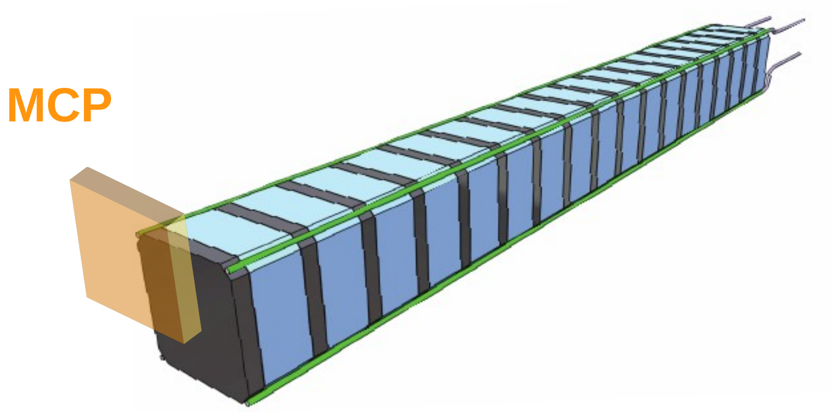


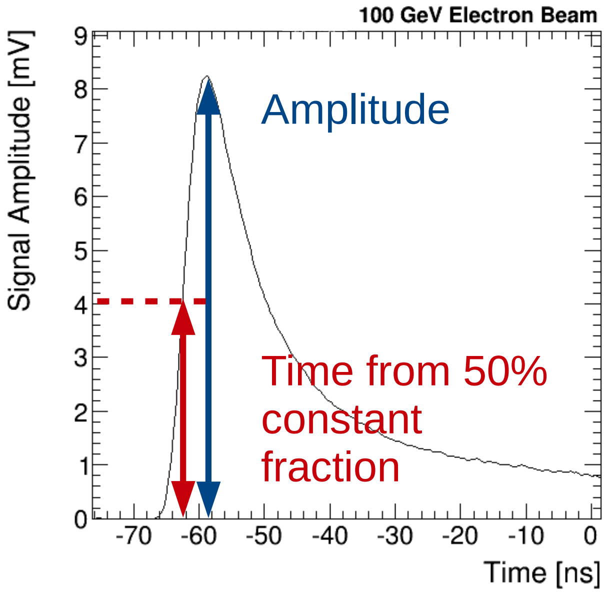


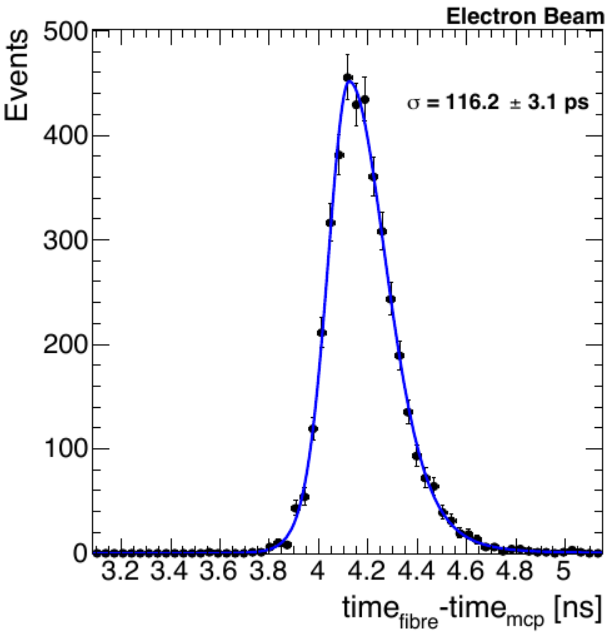
Time Resolution of blinded Fibre

- Time of fibre signal
  = time at 50% amplitude
- Reference time: **Micro Channel Plate** (MCP)[1] in front of fibre
  - **Resolution of 20-30ps**

  (see also A. Bornheim's talk on Tuesday)
- Time resolution estimated using time(fibre) - time(MCP)

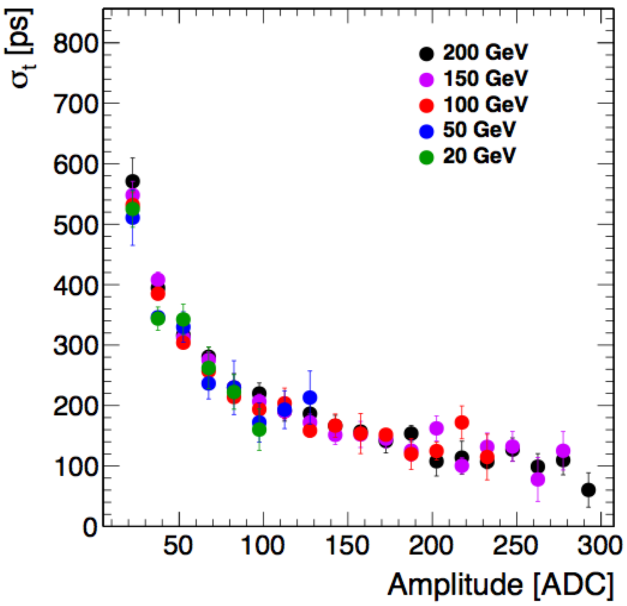


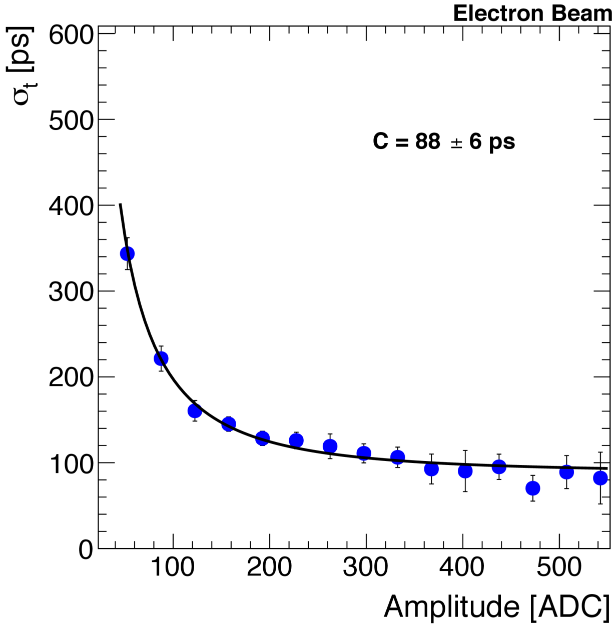




[1] Nucl.Instrum.Meth. A797 (2015) 216-221, L. Brianza et al.

100ps Timing Resolution possible

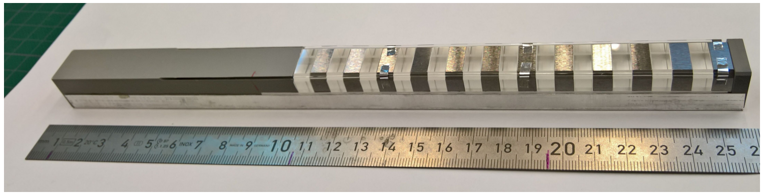


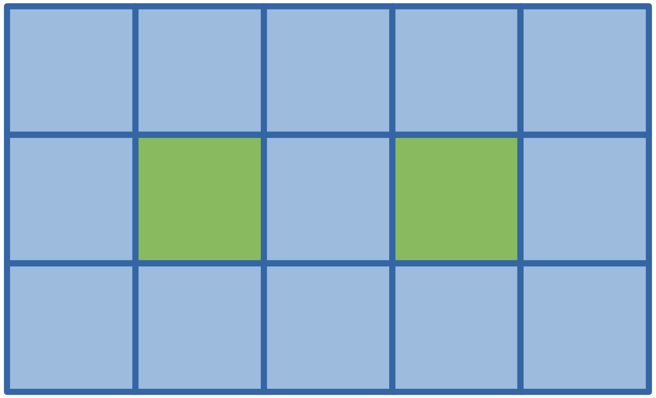


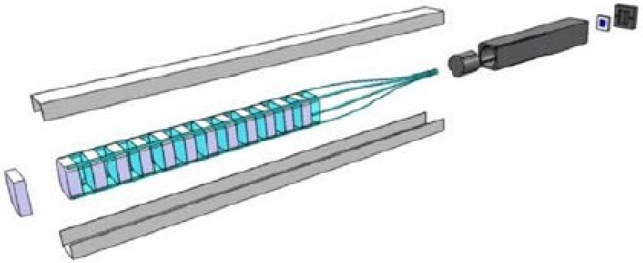
- Resolution dependent on amplitude, not on beam energy
- For amplitude >100 ADC counts, timing reaches a resolution $\sigma_t < 100$ ps for electrons on the fibre

Outlook – 2016 Matrix Test in Beam

- **5x3 channel matrix**
  - Energy resolution as a function of the impact angle
  - Containment studies
- **(6mm CeF_3 + 6mm W) x 12 layers = $25X_0$**
- **Higher granularity,** as necessary for high pileup environment: **R_M = 17mm** (previous configuration 23mm)
- WLS fibres: Kurarary 3HF-SC
- **4 fibres** of a channel into **one photo-detector**
  - **Fibers of two inner channels** read out independently
- APDs: Hamamatsu S8664-55, 5x5mm²
- Matrix build, to be tested next month with electrons at the SPS







Conclusions

Tested a W-CeF_3 sampling calorimeter read out by WLS fibres

- Can be produced to withstand high particle fluences & doses as expected at the HL-LHC
  - CeF_3 can be grown radiation hard
  - Ce:SiO_2 fibres suitable for WLS & can be made radiation-hard
  - short optical path lengths
- Allows to mitigate pileup effects:
  - Small module size
  - Timing resolution of < 100ps possible for Ce:SiO_2 fibres with SiPM read-out
- Good energy resolution
  - Resolution ≈ **1%** at 150 GeV
  - Resolution of simulated 5x5 matrix: stochastic term S < 10%
- further tests of new Ce:SiO_2 fibres with the existing single channel prototype
- Results with 5x3 matrix to come soon

BACK UP

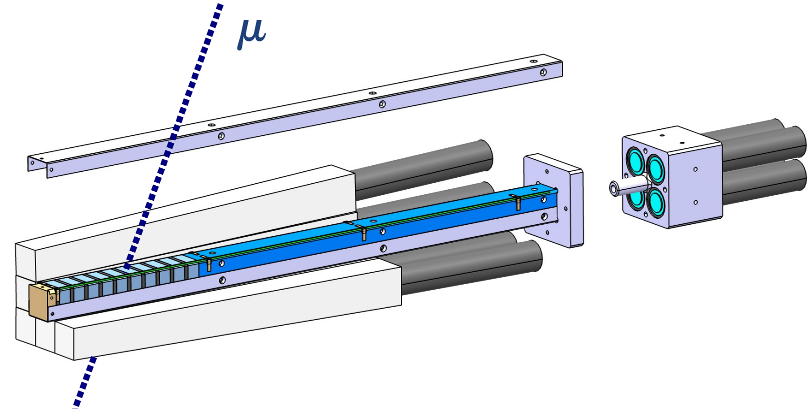
Material Specifications

- **CeF_3 crystals**
  - Produced by Tokuyama, Japan
  - 0.5% Ba doping
- **PMTs**
  - Hamamatsu R1450
  - Hamamatsu R5380
- **WLS Plastic Fibers:**
  - Produced by Kuraray (Japan)
  - 3HF single-clad, 1mm diameter

WLS Fibers: Ce:SiO_2:

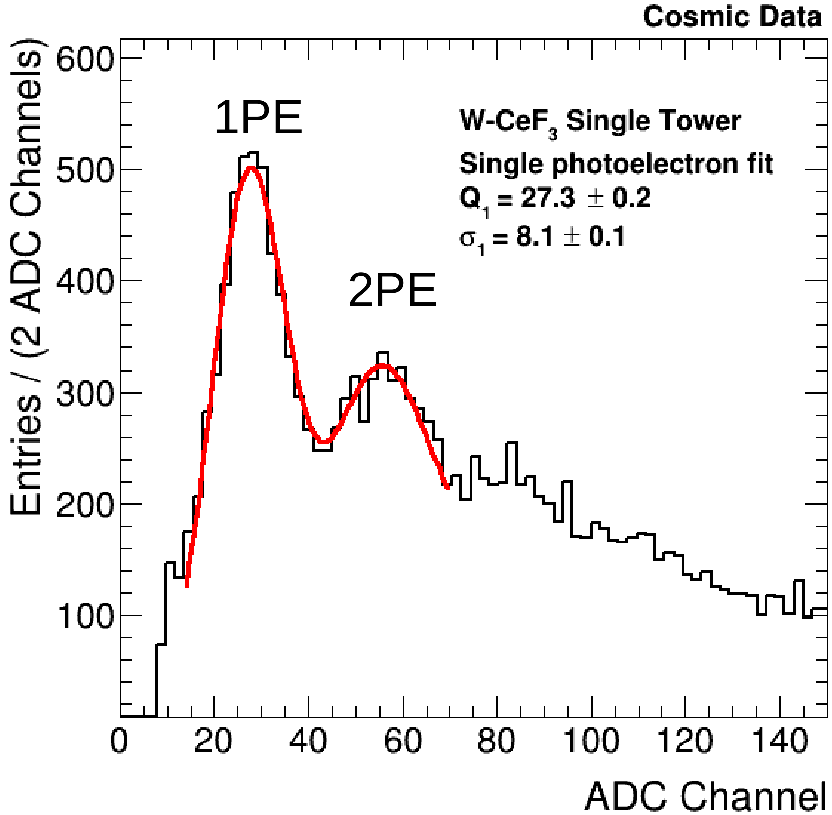
- **Milano-Bicocca** (from A. Vedda, M. Fasoli, N. Chiodini):
  - Diameter ~750 µm
  - 600 µm Ce-doped quartz core
  - Fluorinated-glass cladding (radiation hard, very transparent)
- **Polymicro + Texas Tech** (from N.Akchurin):
  - Diameter ~550 µm
  - 150 µm Ce-doped quartz core
  - fluorinated hard polymeric buffer
  - Acrylate cladding

Single Photo-Electrons from Cosmic Muons



- Trigger on the concidence of the BGO crystal above and below the central channel
- Fit to extract single photo-electron

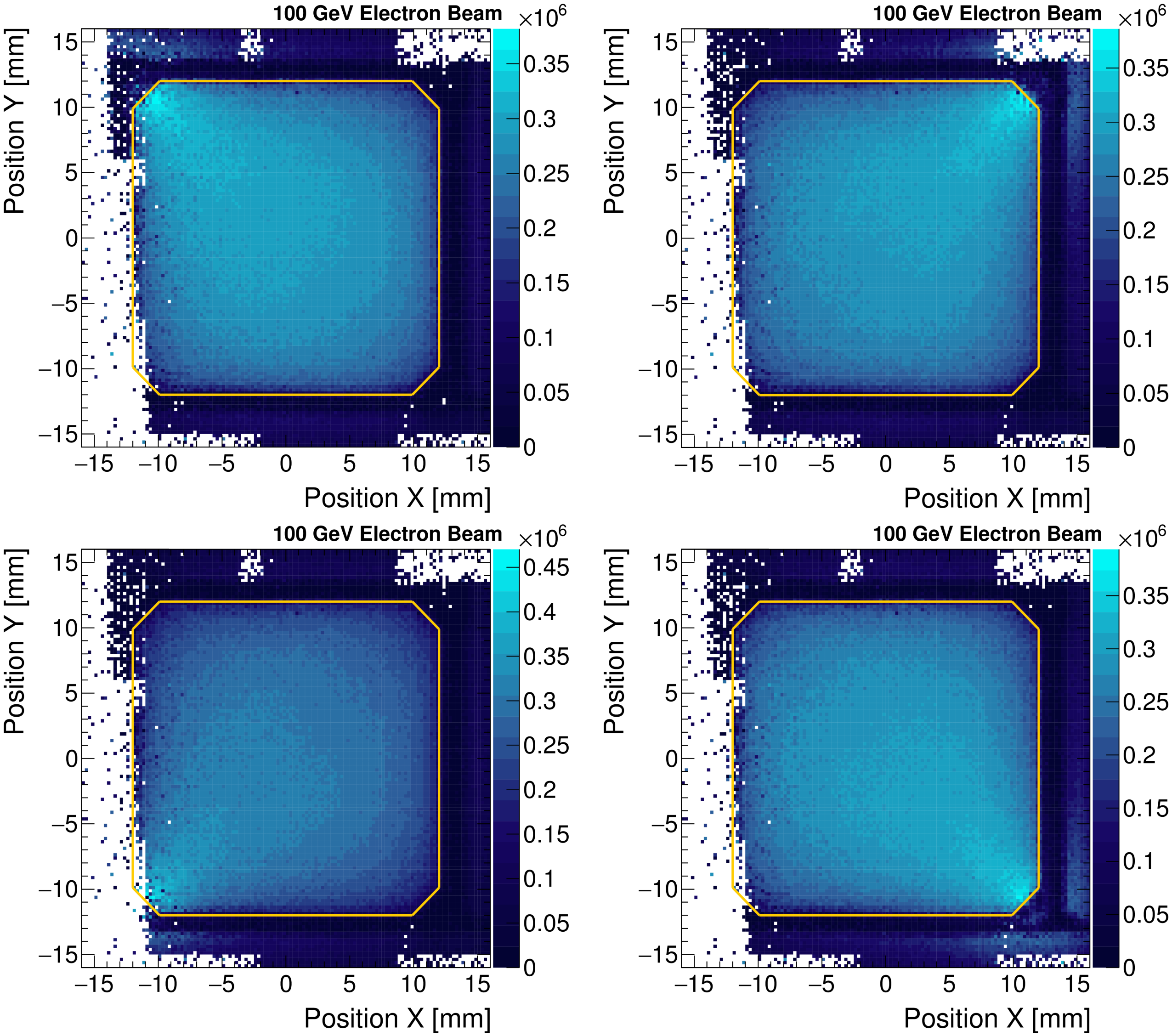
$$\sum_{n=1}^{2} \frac{\mu^n e^{-\mu}}{n!} \frac{1}{\sigma_1\sqrt{2\pi n}} \exp\left(-\frac{(x-nQ_1)^2}{2n\sigma_1^2}\right)$$



- ADC ↔ photo-electron conversion

  → input for simulation

Single Fiber Response Dependence on Impact Point Position



Slight contribution from light collection visible