The Scintillating Fibre Tracker for the LHCb Upgrade

TIPP 2014
Amsterdam

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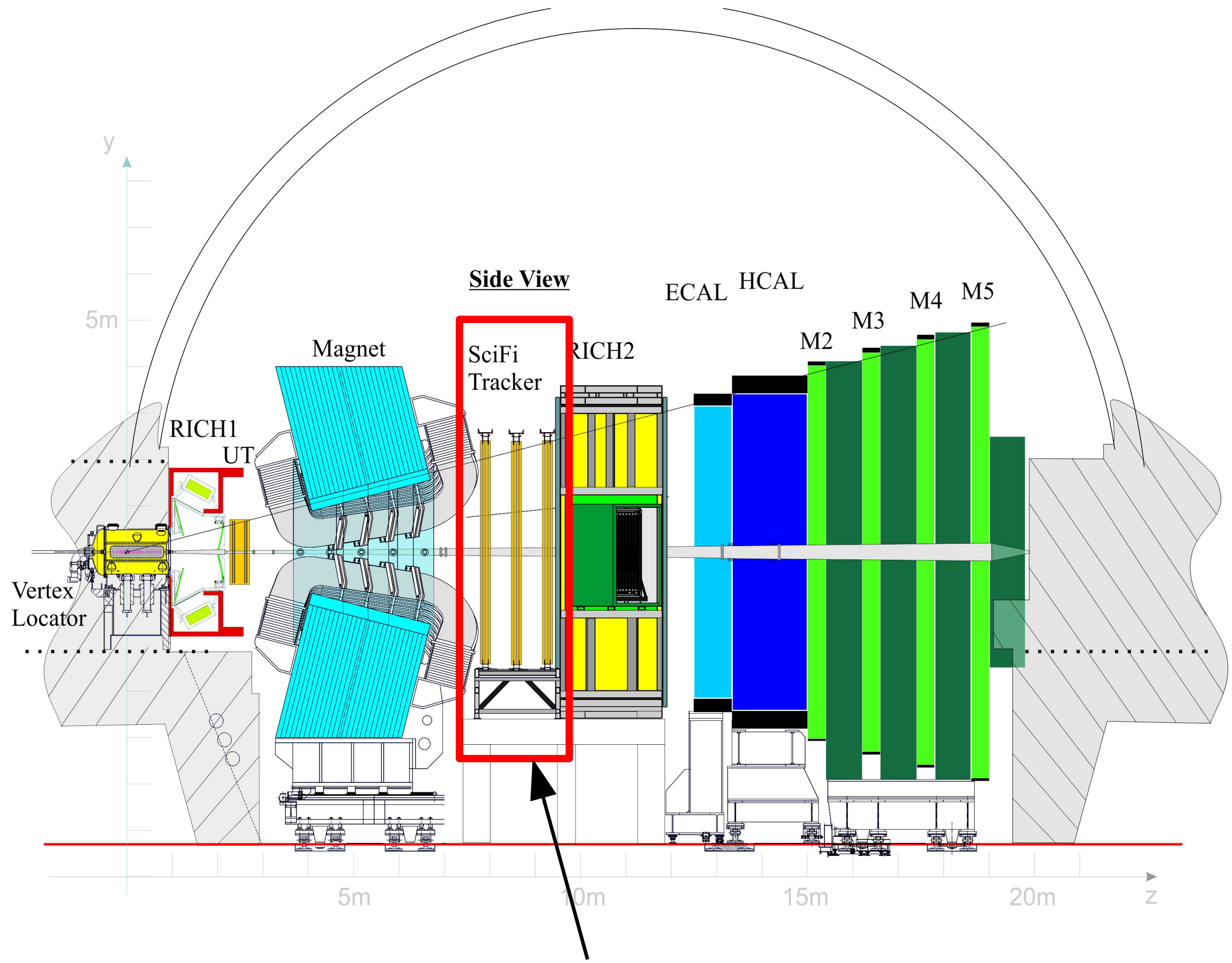
on behalf of the LHCb SciFi Tracker group

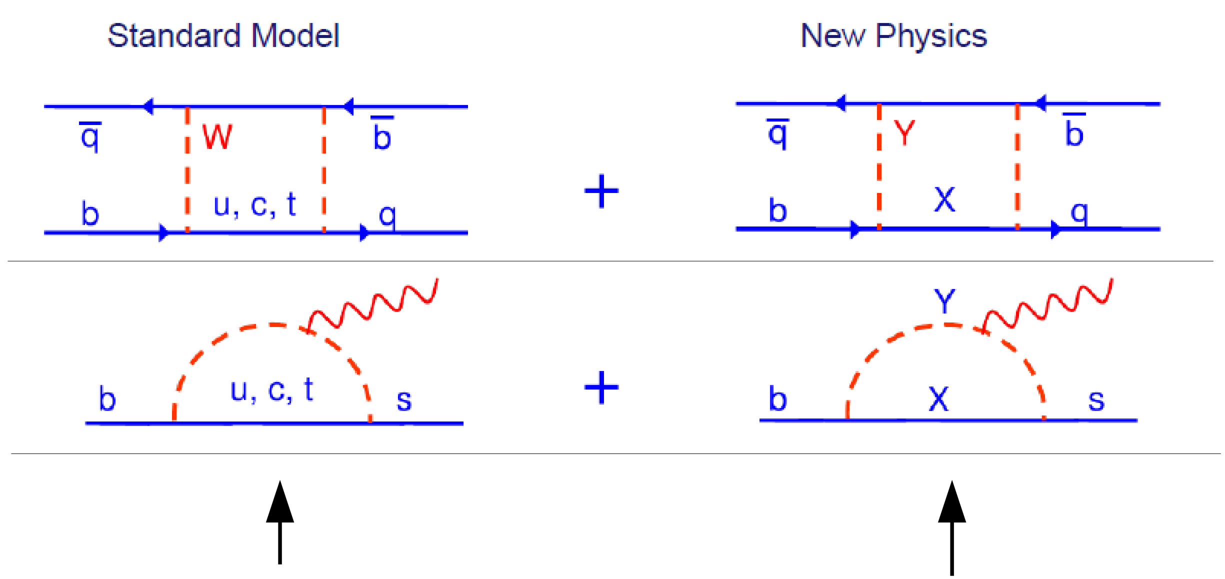
Outline

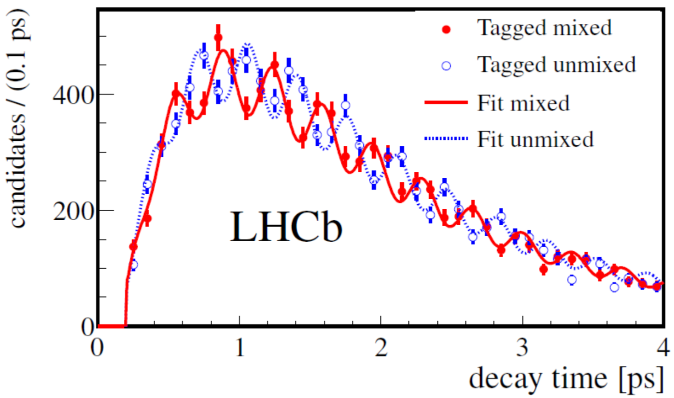
- LHCb and the Upgrade overview
- The SciFi Tracker
  - Detector basics
  - Challenges



The LHCb detector

- Built for indirect searches for new physics via precision measurements of quantum loop induced processes in the b- and c-quark systems
  - Rare decays
  - Particle/anti-particle asymmetry

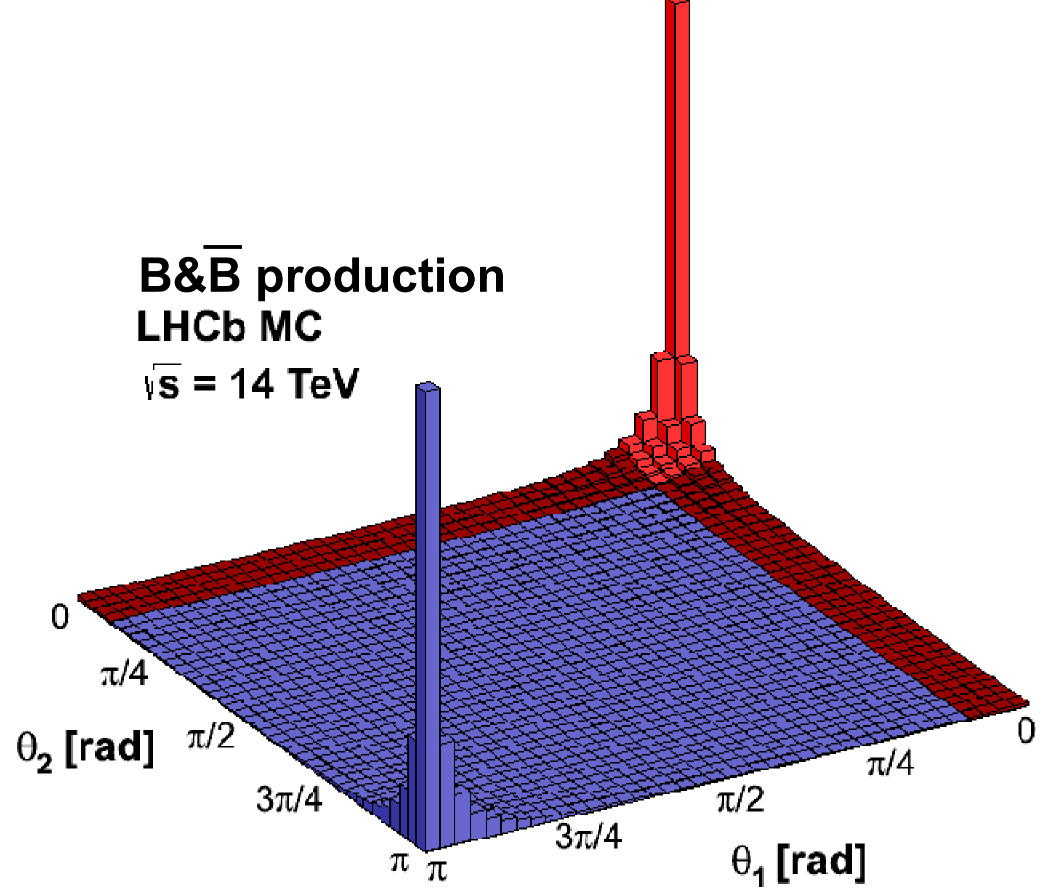


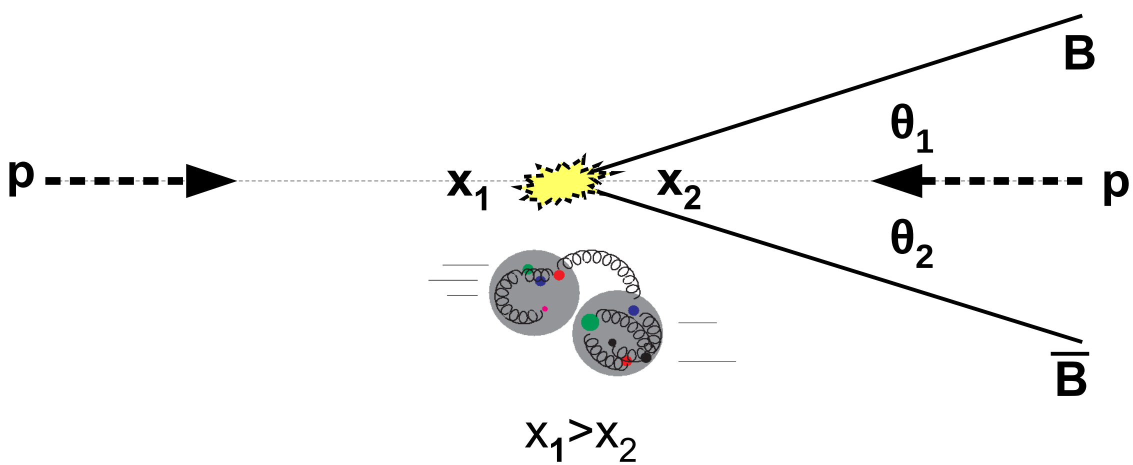


Theoretical predictions

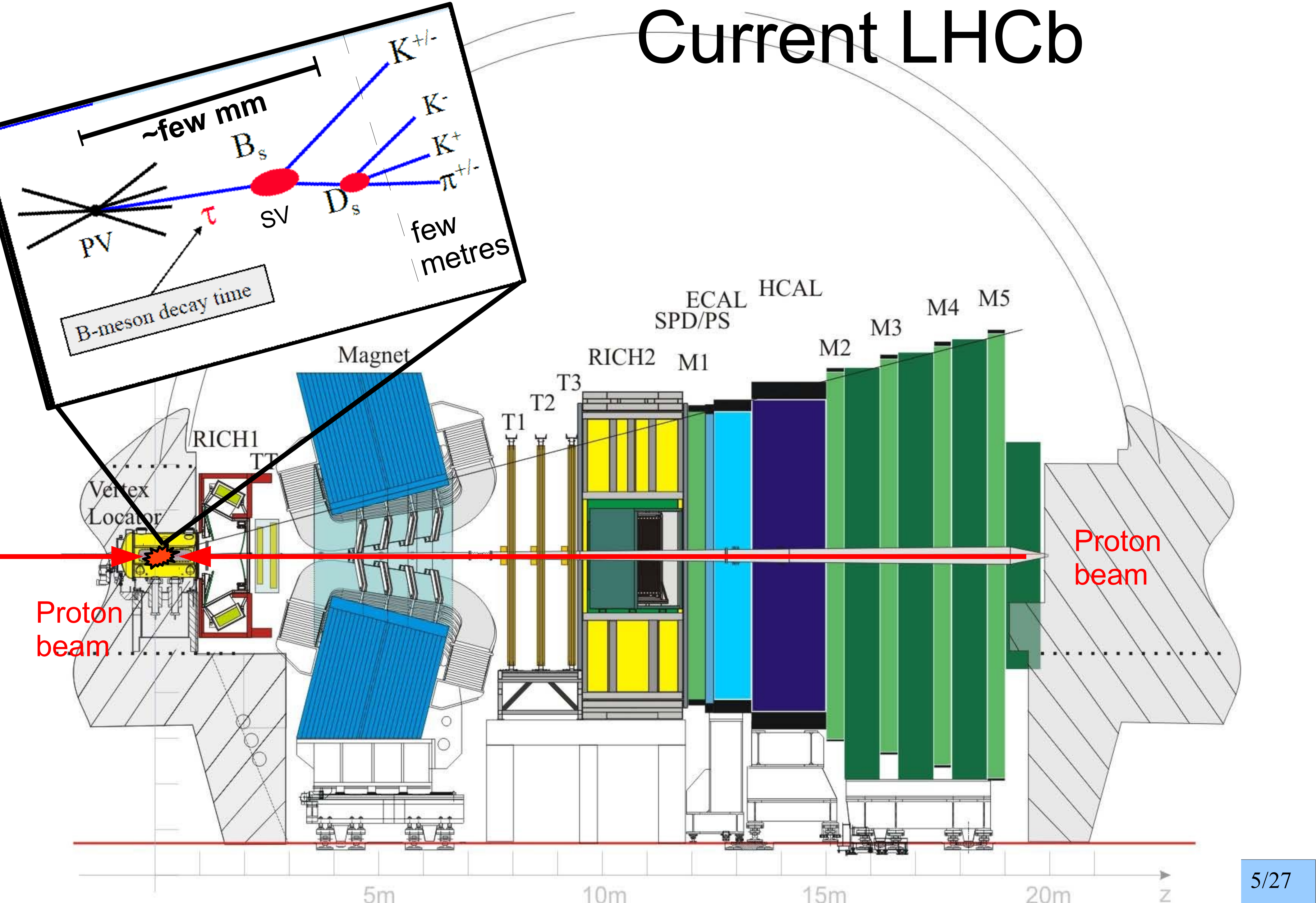
Deviations from predictions

b-mesons are produced in the forward direction at the LHC

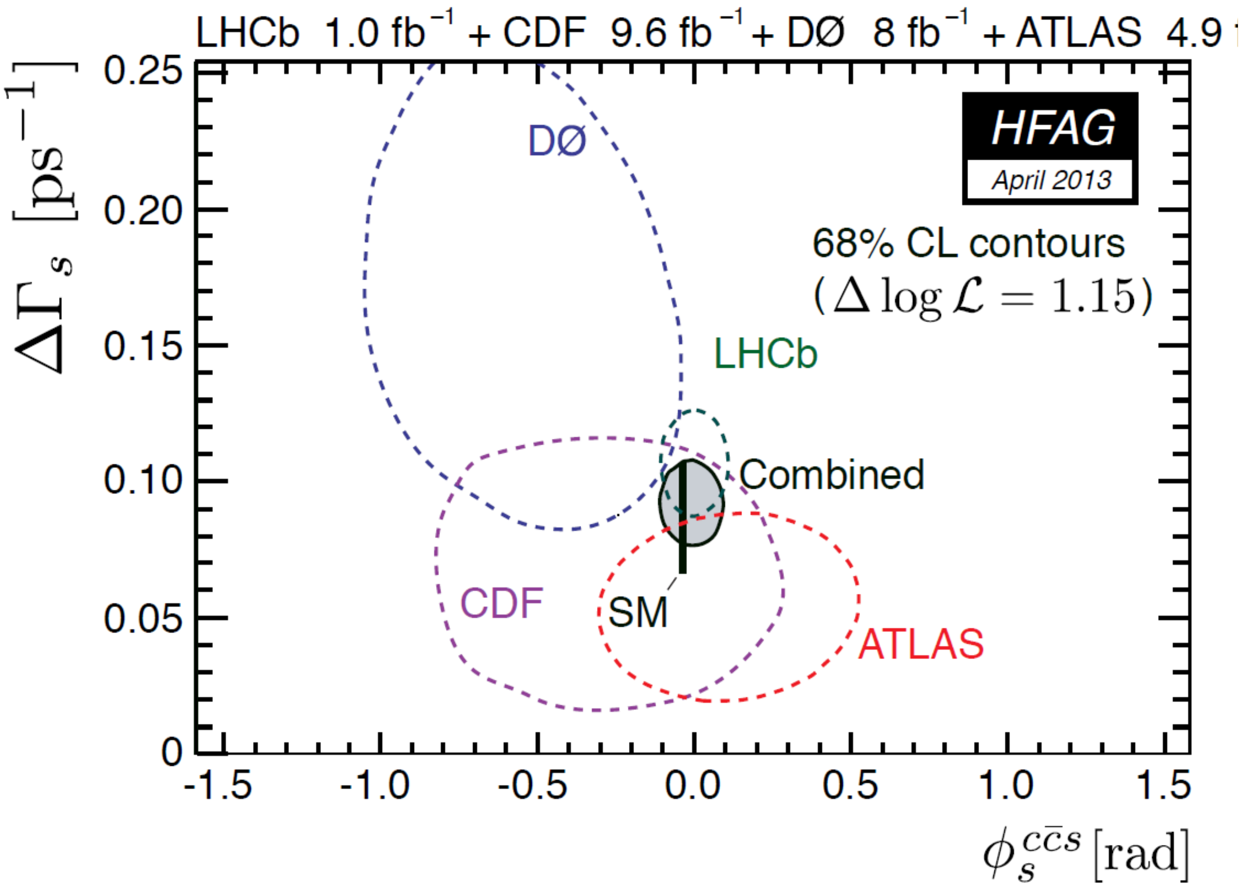




Current LHCb



- LHCb is running at twice its design value (~2x10[12] $b\bar{b}$/year), 180+ papers published

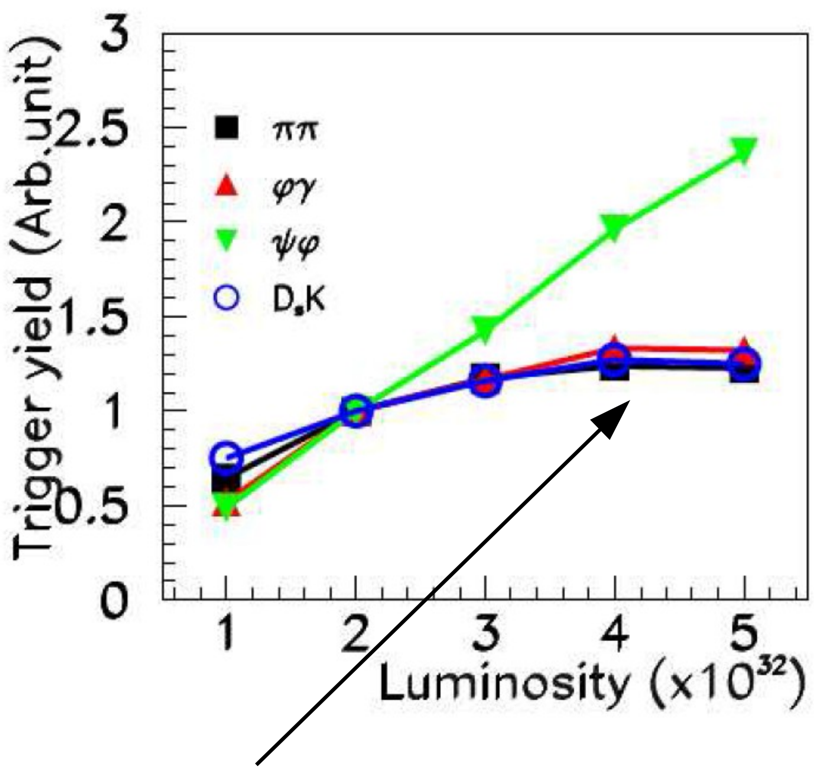


- Almost every physics measurement in LHCb is limited by statistical uncertainties, not systematic

→ We need more data!!

Limitations

- LHCb collision rate is tuned to manage data rate (can be increased), but...
- Statistics are limited by the 1MHz hardware trigger rate and then detector occupancy

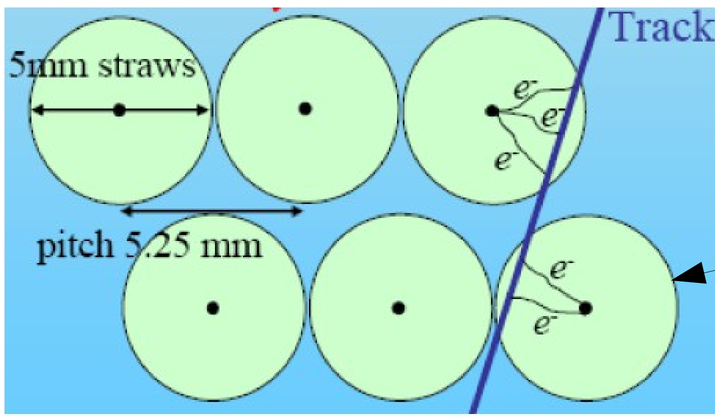


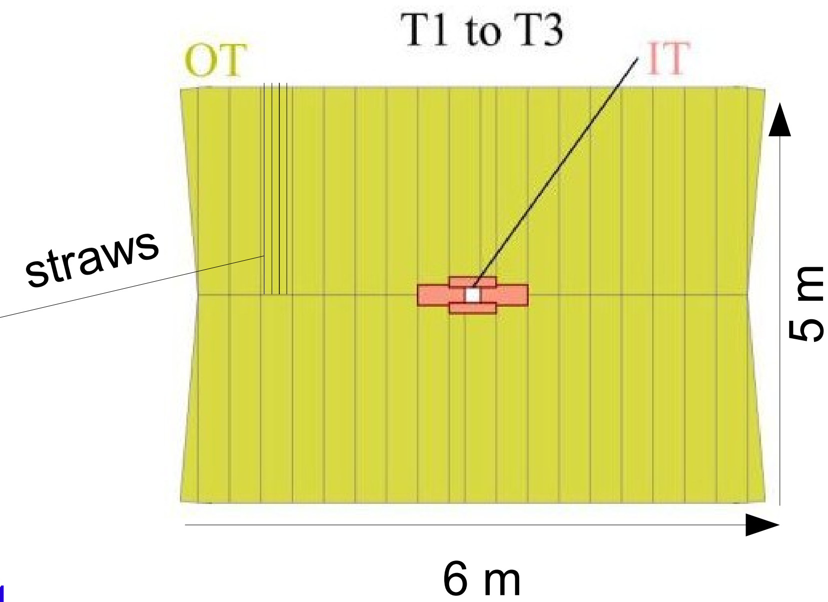
Saturation of hadronic modes with L0-hardware trigger

Detector Occupancy and Efficiency

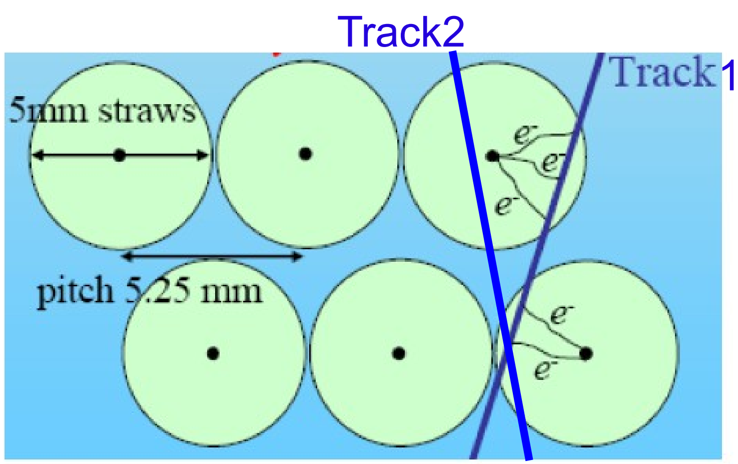
Outer Tracker = 5 mm straw gas drift tubes (2.5m long)
- Detector is insensitive to multiple tracks per tube (35ns drift time)

Good!!





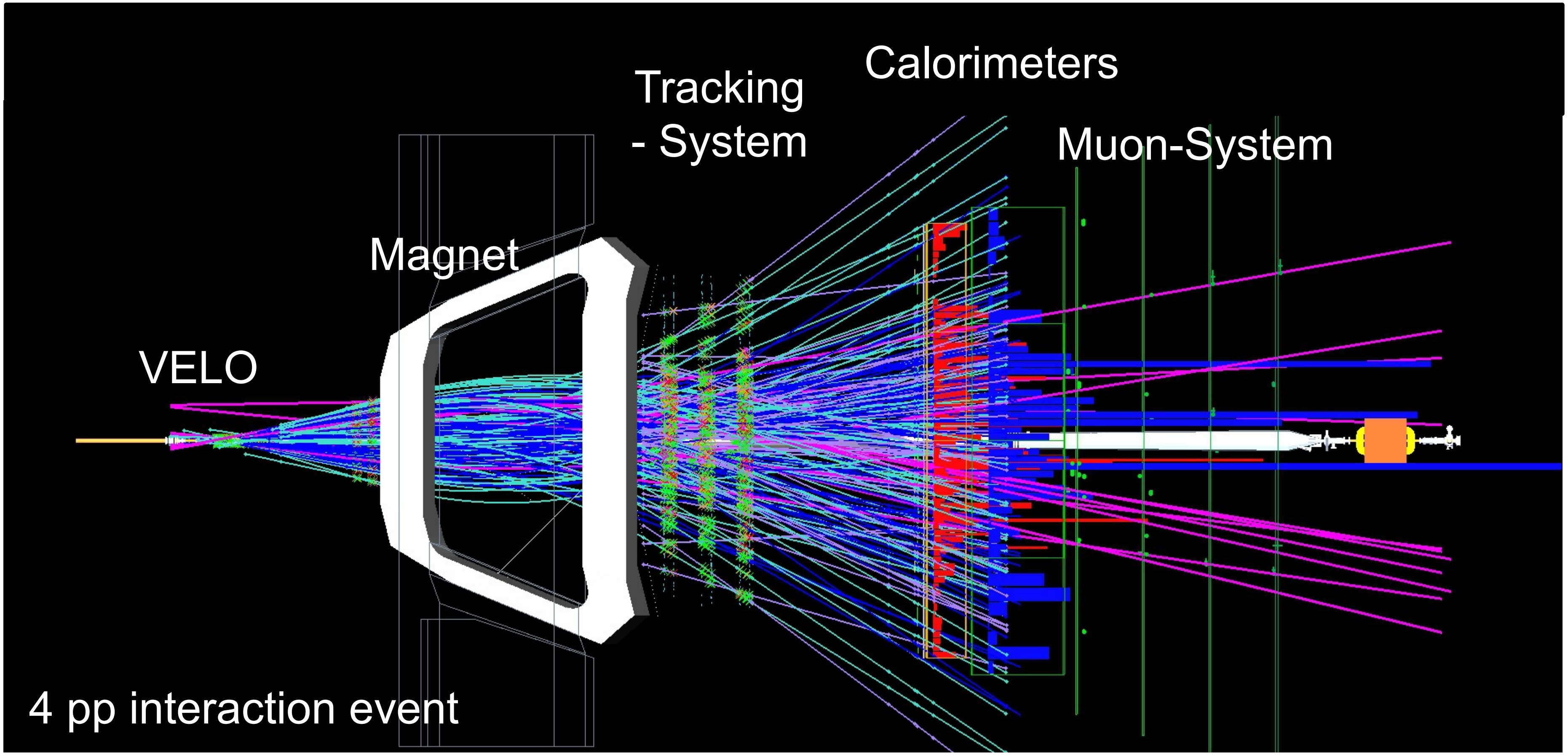
BAD!!



Outer Tracker tracking efficiency decreases above 25% occupancy → 40% expected in the upgrade

Beam bunch spacing will be 25ns in 2015+

Detector Occupancy and Efficiency



Current visible pp interactions/event:

Poisson distribution with $\mu \approx 2$;
Upgrade is at $\mu \approx 5$

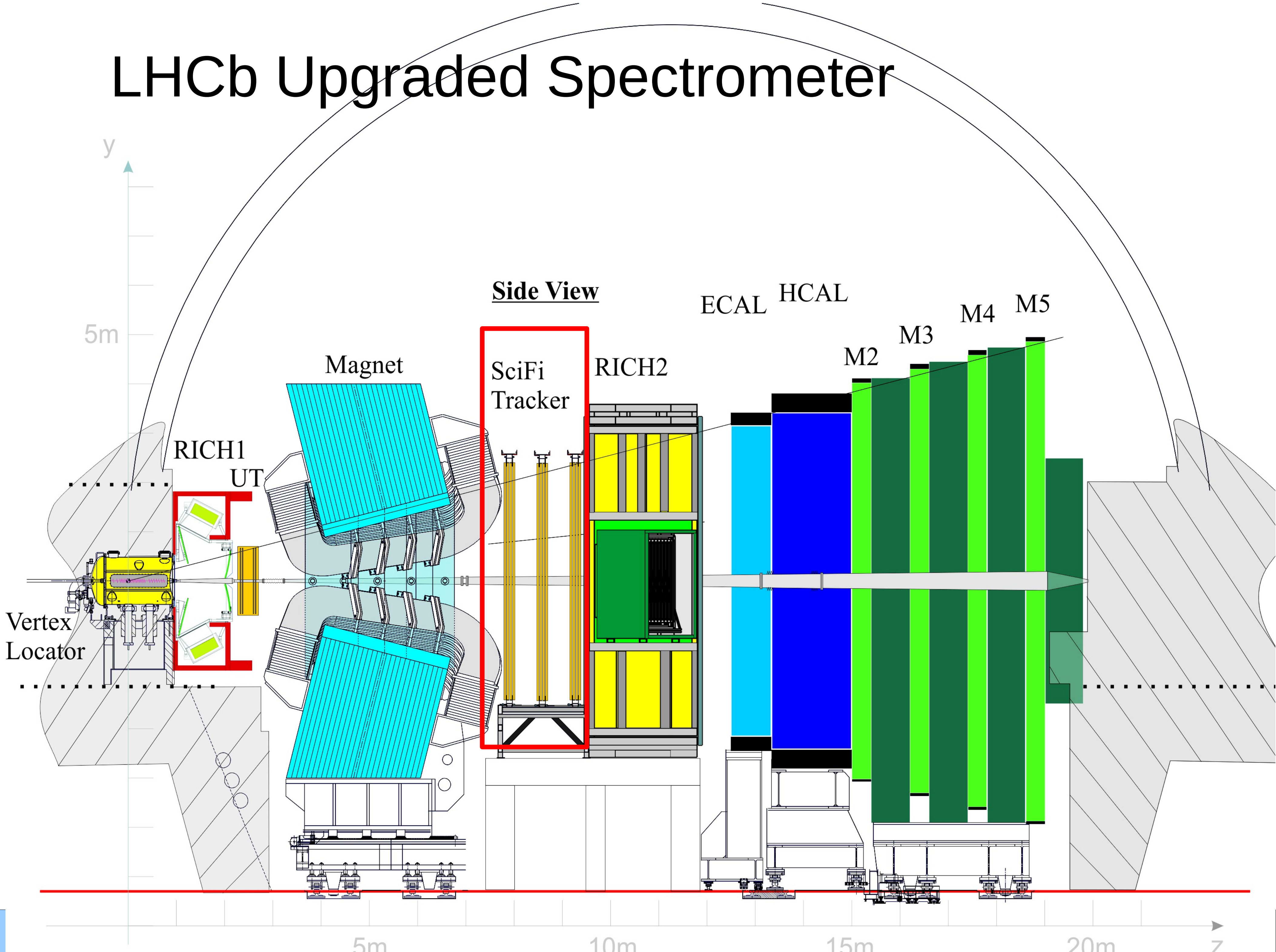
72 tracks, on average for a B-Bbar event;
180 in upgrade

→ We need a high hit detection efficiency (98+%)

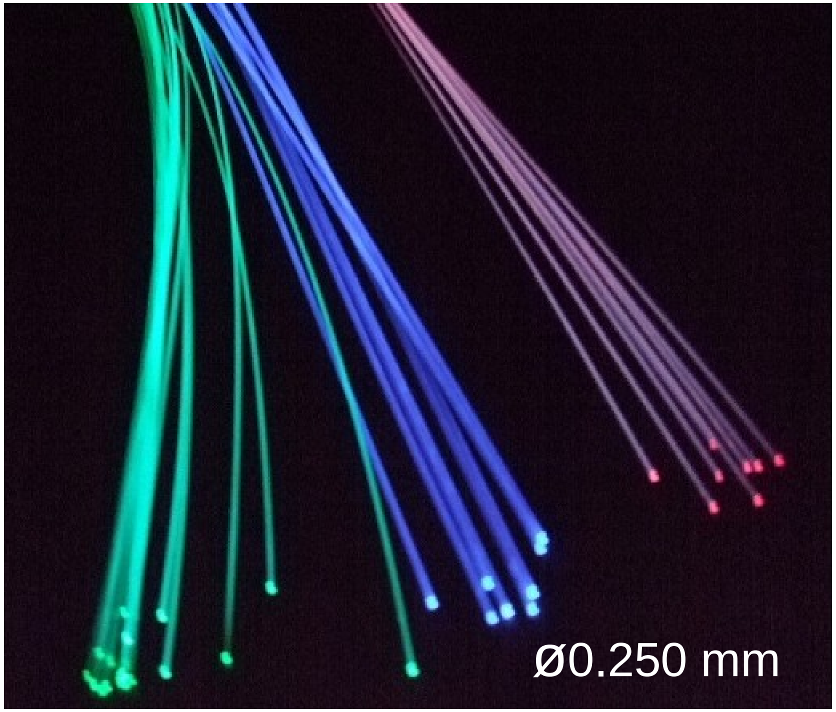
LHCb Detector Upgrade

- Replace 1 MHz hardware trigger → 40MHz software trigger, all front-end electronics to 40 MHz
- Visible interactions per bunch crossing increase to mu = 2.5 – 5 (from 1.8)
- Expected **annual** physics yields increase (with respect to 2011)
  - 14 Tev cross section (x2), trigger rate (≥ x4), luminosity (≥ x2.5)
    - **x10** in muonic channels
    - more than **x20** in hadronic channels
- 10 times smaller uncertainties after 10 years

LHCb Upgraded Spectrometer

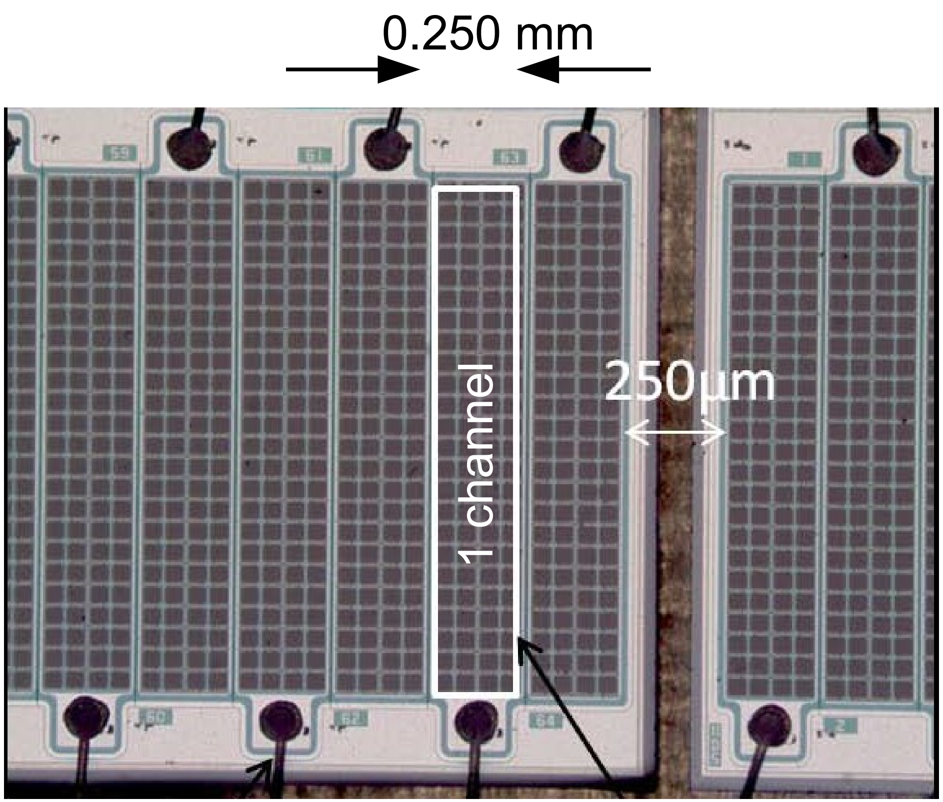


The SciFi Tracker



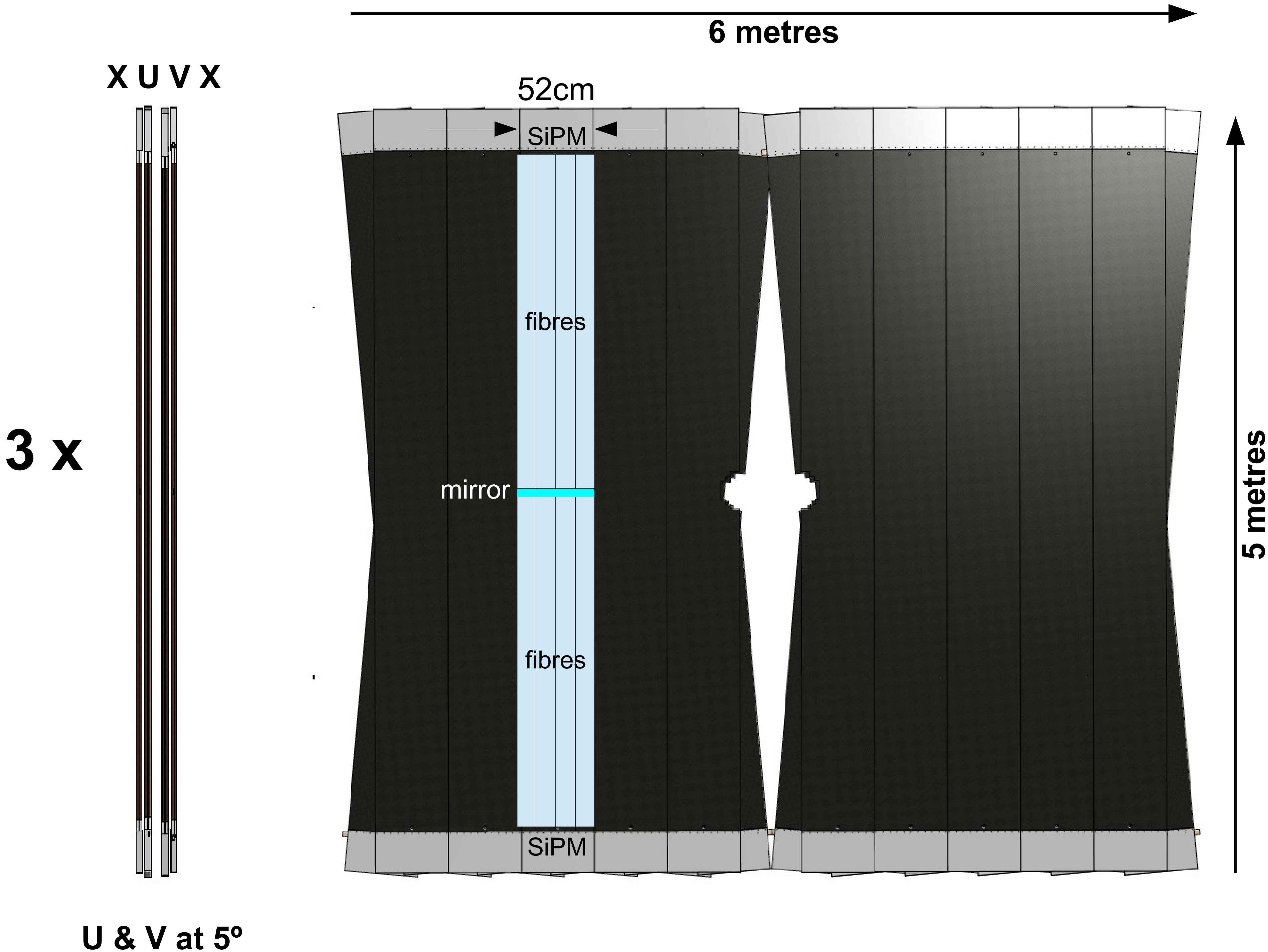
Scintillating fibres

- fast scintillation decay time (2.8ns)
- good light yield and attenuation length



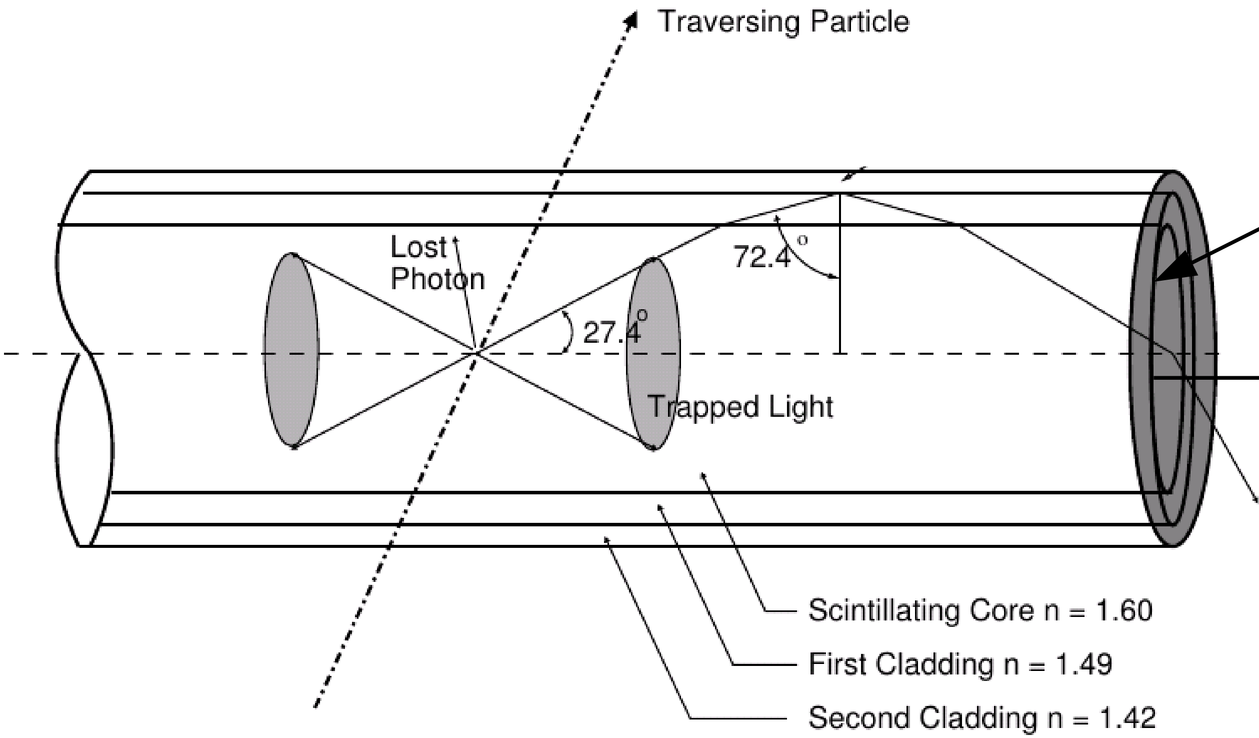
An array of pixelated silicon photomultipliers

- fast signals
- high photon detection efficiency (40+%)
- compact channel size



6 metres
X U V X
52cm
SiPM
fibres
3 x
mirror
fibres
SiPM
5 metres
U & V at 5º

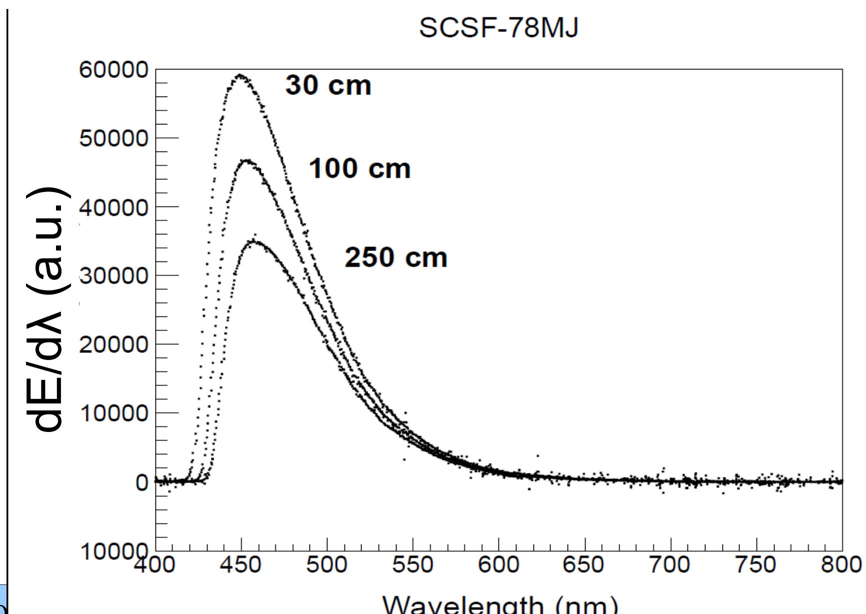
Scintillating Fibres

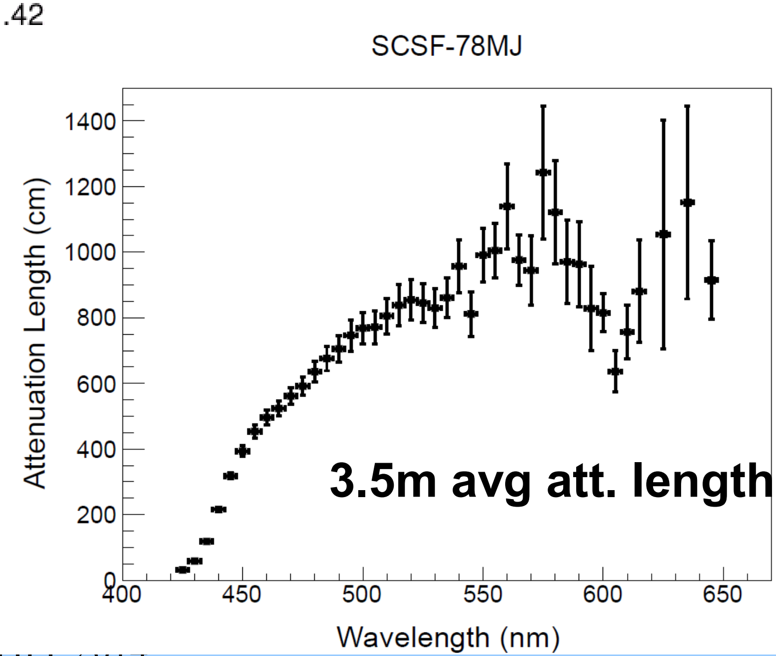


(scintillator)
Polystyrene core with 2 dyes

Only a few photons after 2.5m

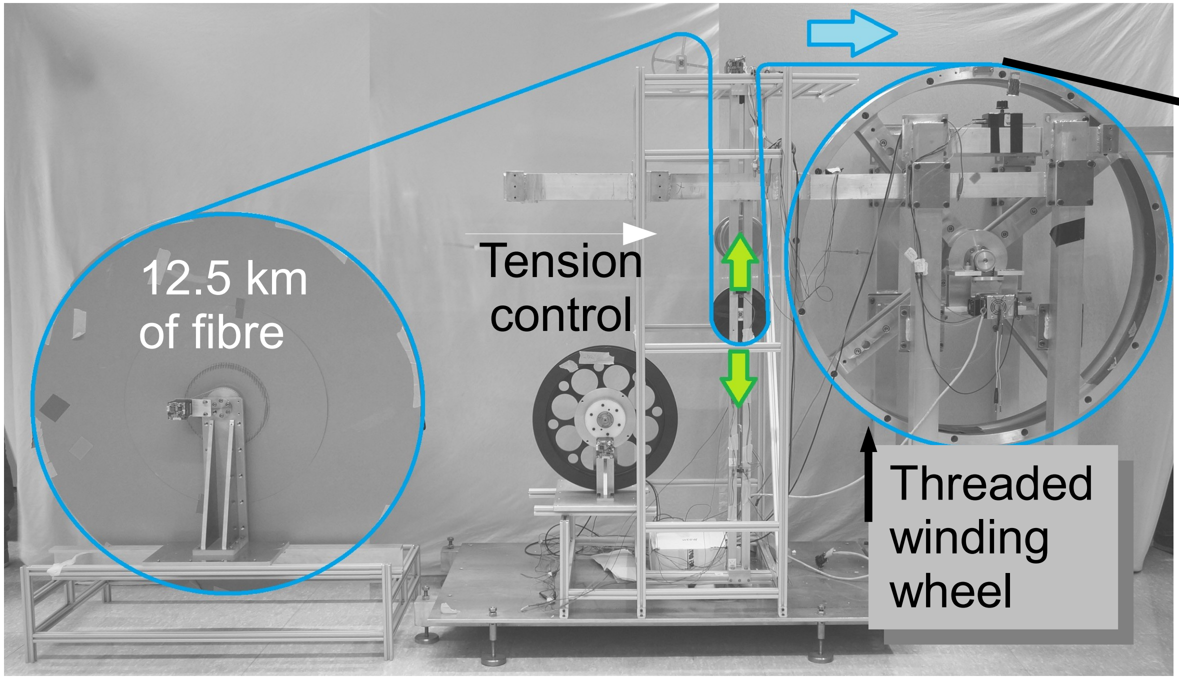
300 photons per MIP produced (only 5% captured)

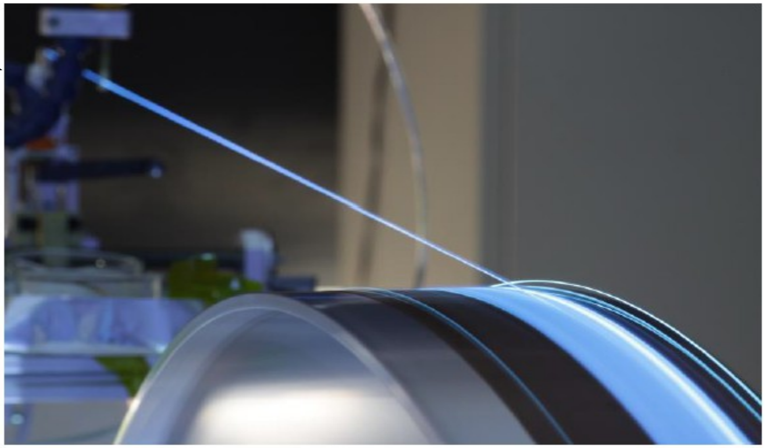


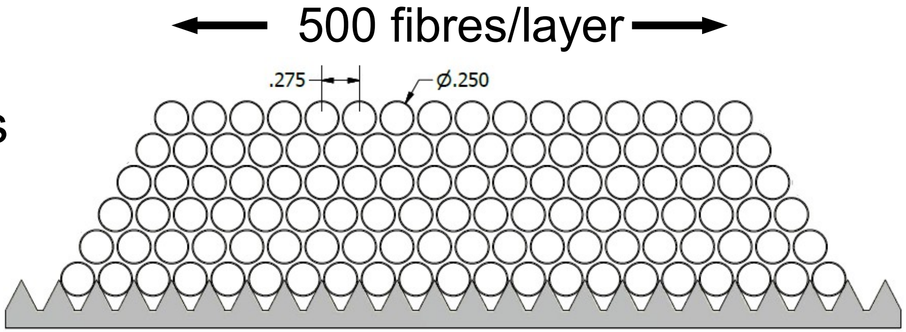


Fibre Mats

Fibre mats are produced from winding a single fibre onto a threaded wheel.

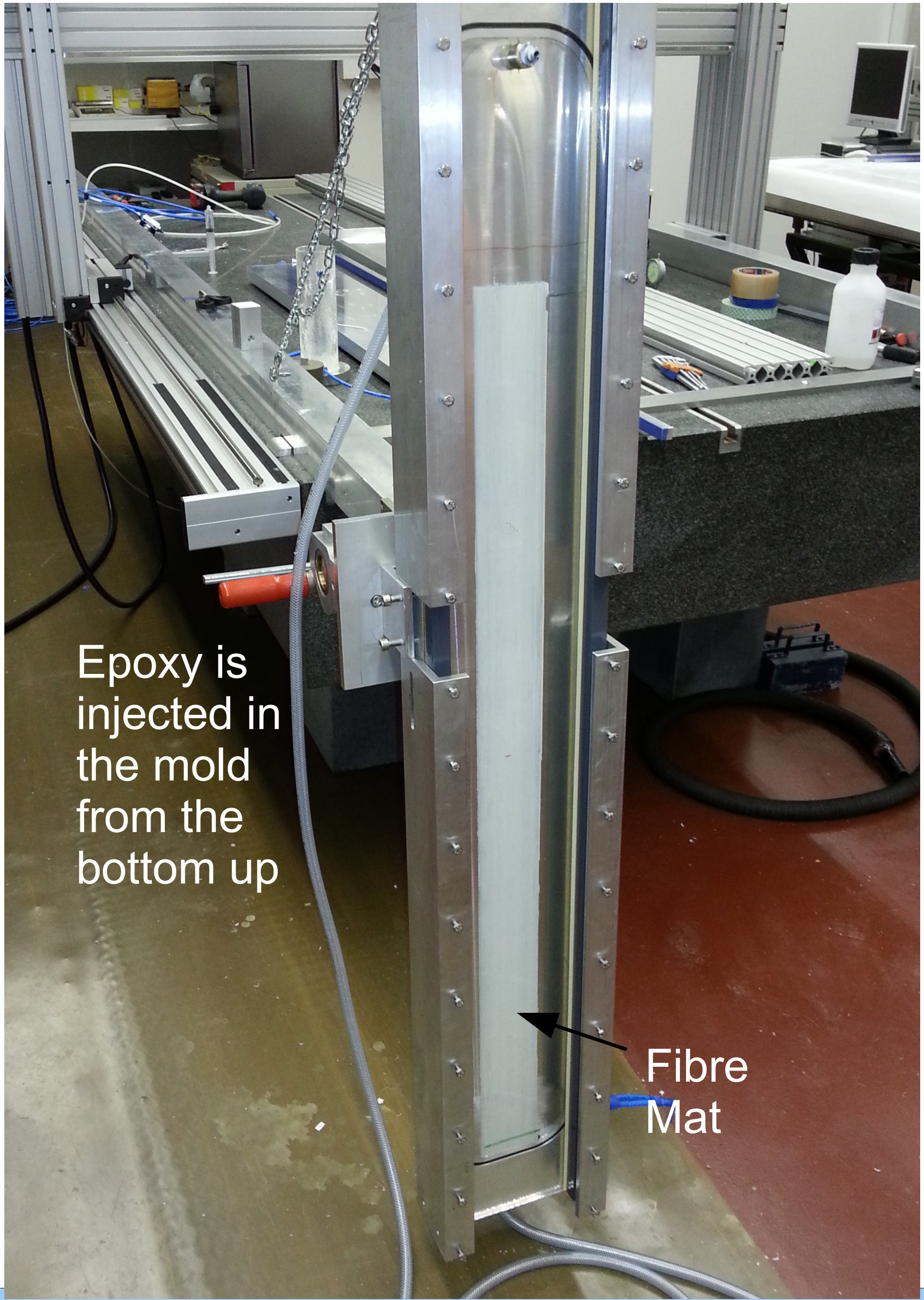




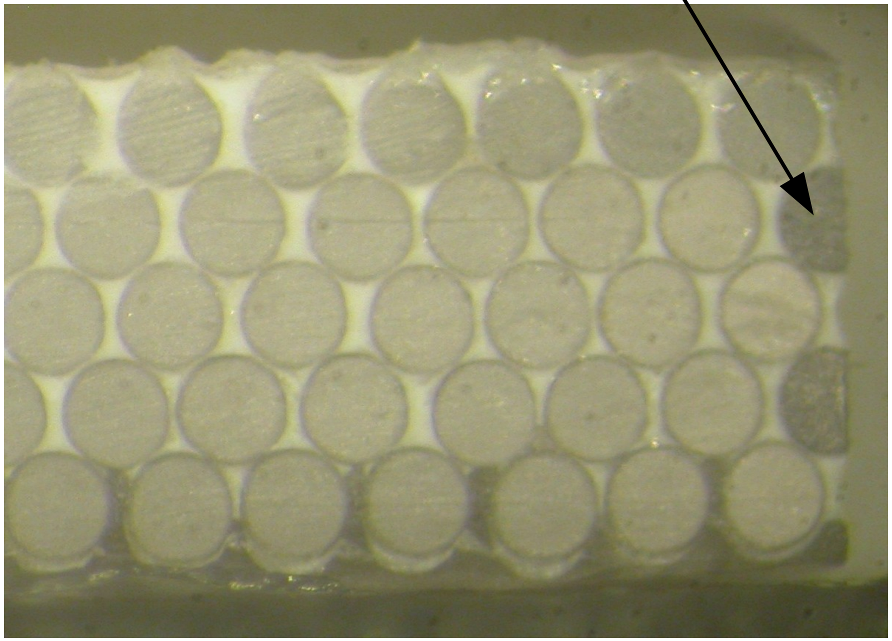


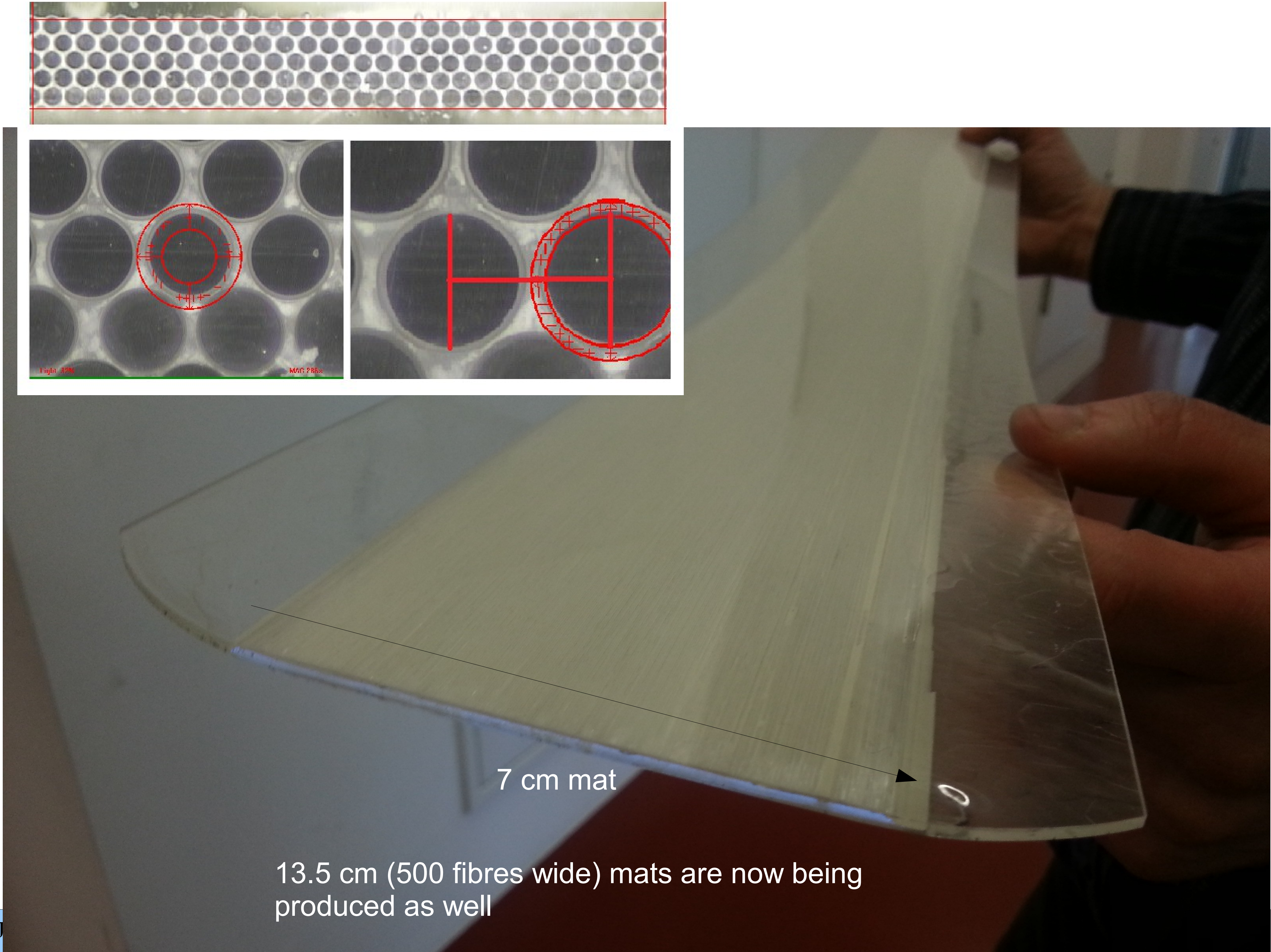
- Need about 8km of fibre for one mat of 6 layers 2.5 metres long
- 10,000 km of fibre in total ...

Fibre Mats



Cutting will create dead fibres on the edges

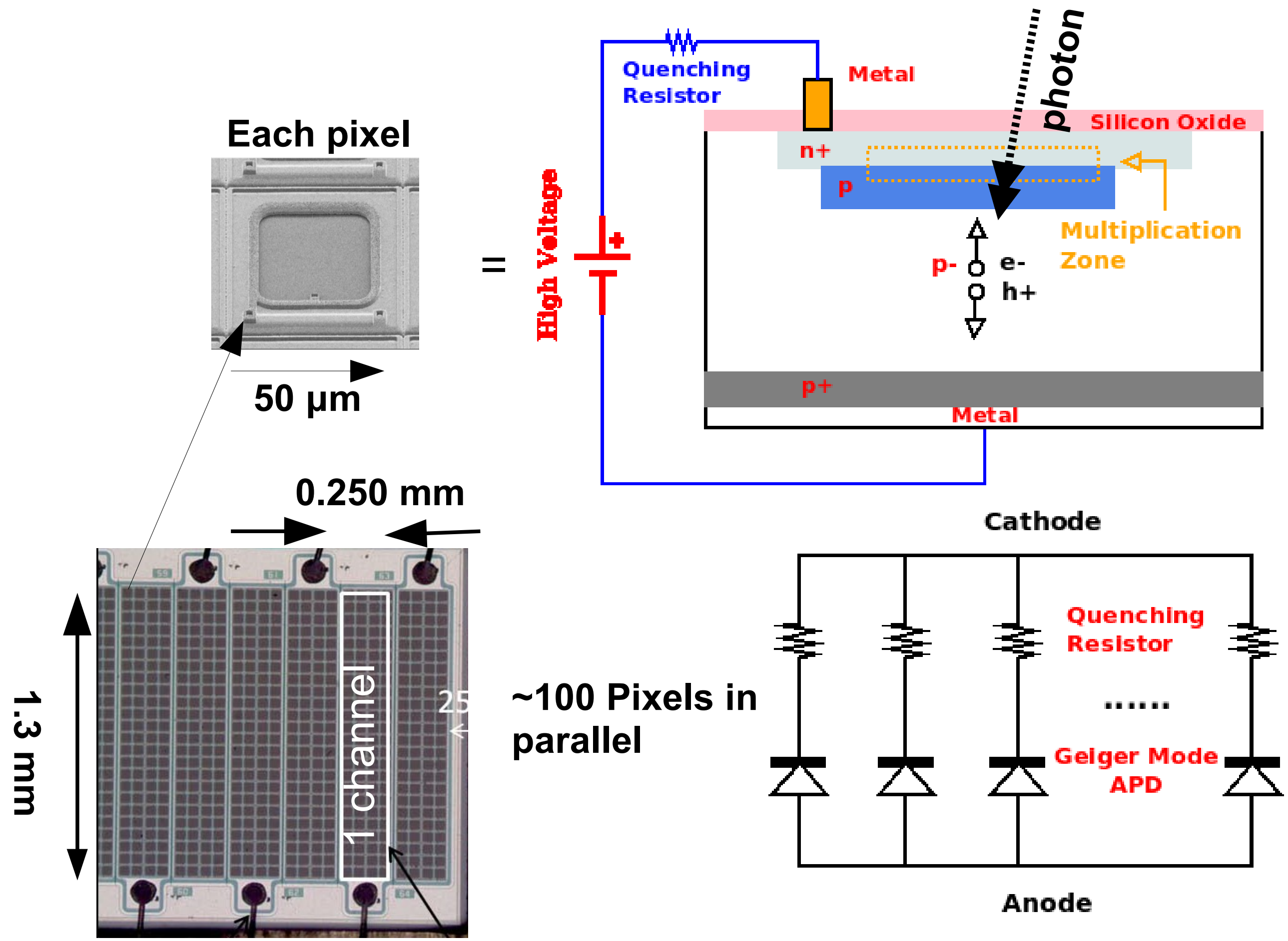




13.5 cm (500 fibres wide) mats are now being produced as well

SiPMs

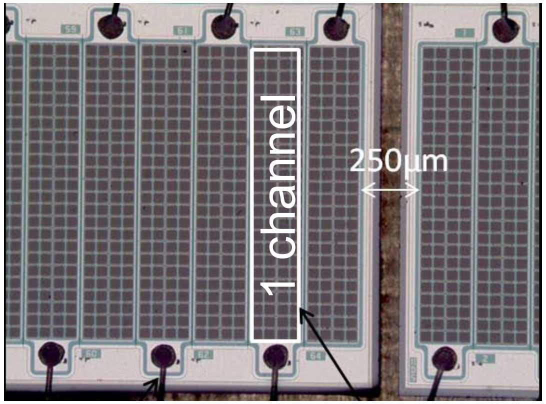
- The SiPM pixel is a photo-diode (reverse-biased, above breakdown)
- a single free electron/hole-pair can trigger an avalanche of electrons
- 10^6—10^7 gain
- 40-50% photon detection efficiency



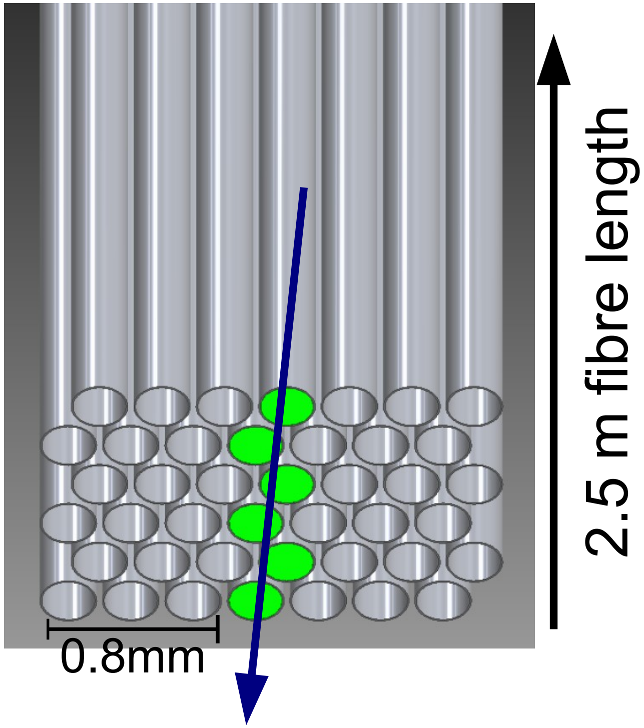
Sketches from Wei Shen, PhD Thesis Uni Heidelberg

Basic principle

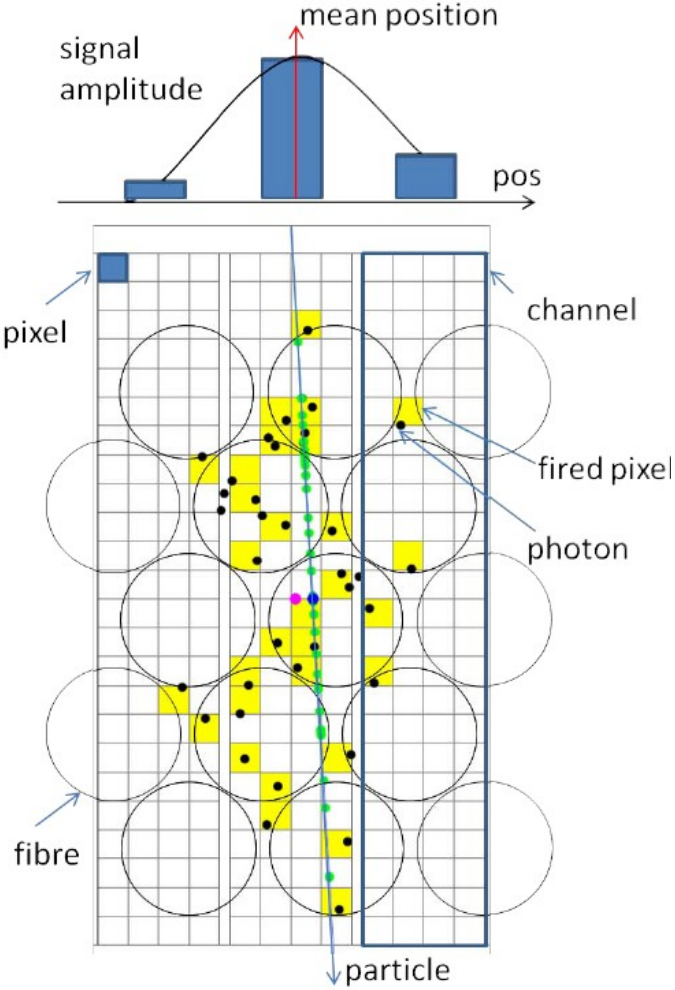
SiPM array



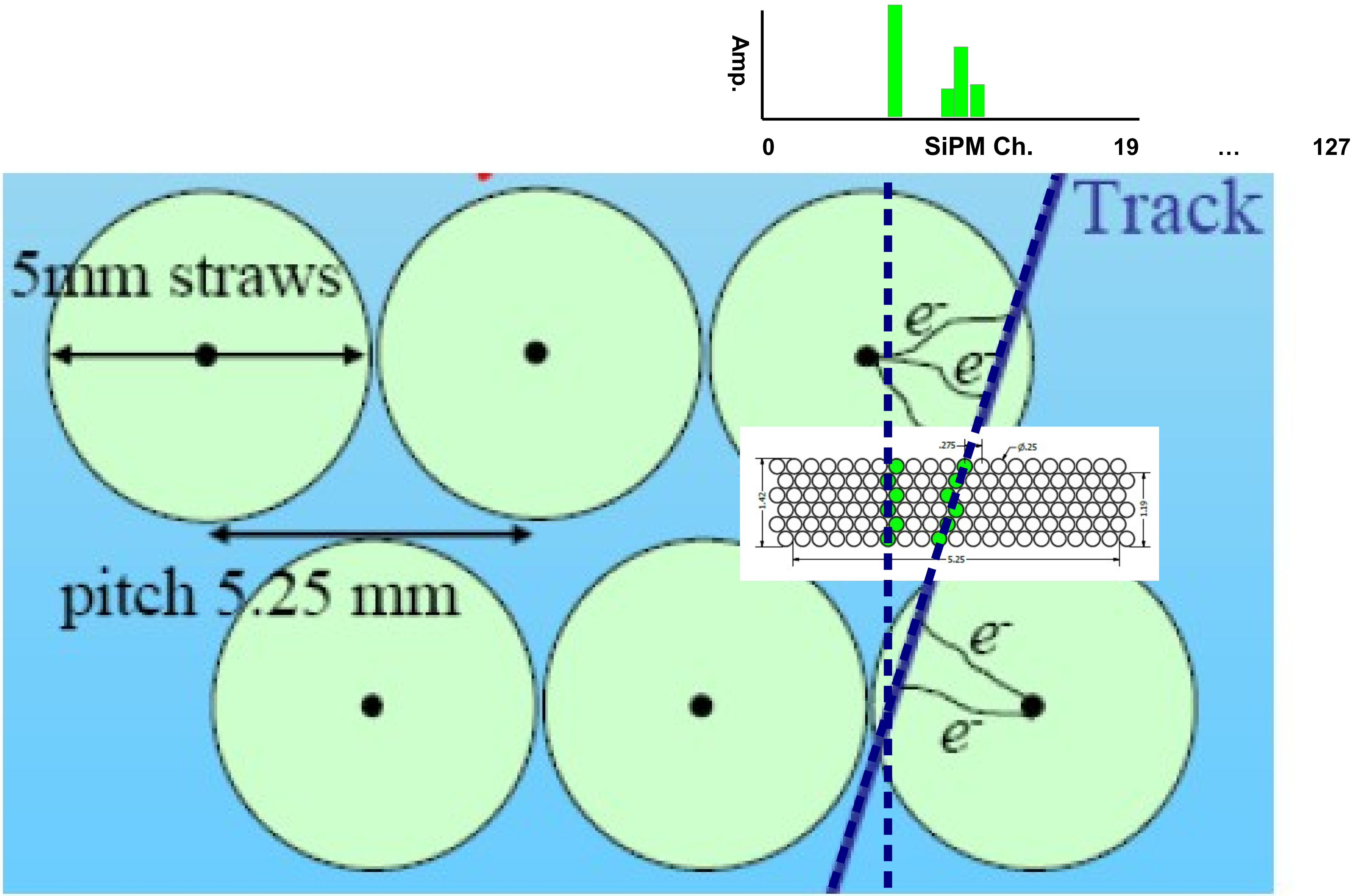
Scintillating Fibres (0.250mm diameter)



Signal cluster



Typically one observe 15-20 photoelectrons for 5 layers of fibre


Amp.
0
SiPM Ch.
19
...
127
Track
5mm straws
pitch 5.25 mm
e-
e-
e-
e-
.275
ø.25
1.42
1.19
5.25

Challenges

<u>Previous Presentations at TIPP 2014:</u>

- **Scintillating Fibre and Radiation Damage Studies for the LHCb Upgrade**
  - Mirco Deckenhoff on June 4th, 2014
- **Silicon Photomultipliers for the LHCb Upgrade Scintillating Fibre Tracker**
  - Zhirui Xu on June 4th, 2014
- **Cooling for the LHCb Upgrade Scintillating Fibre Tracker**
  - Petr Gorbounov on June 2nd, 2014

<u>Posters at TIPP 2014:</u>

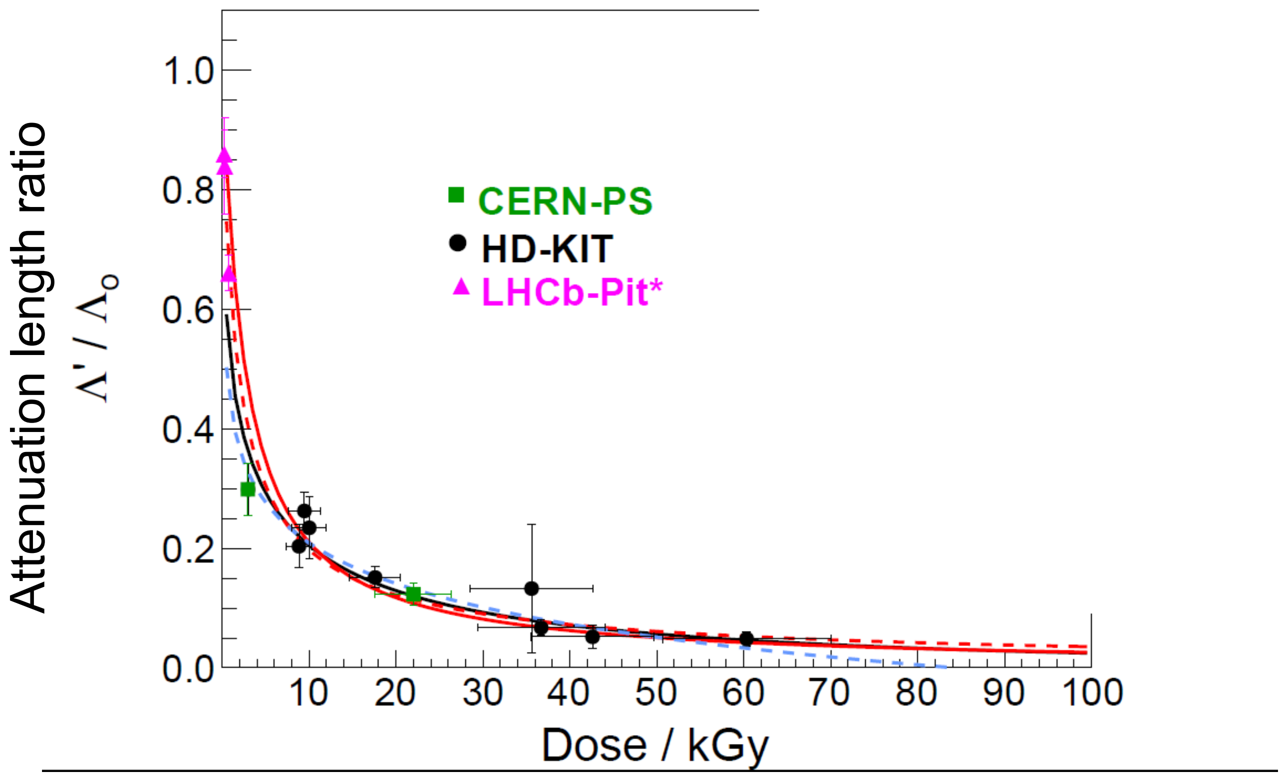
- **Detector Module Design, Construction and Performance for the LHCb SciFi Tracker**
  - Robert Ekelhof
- **Front-End Electronics for the LHCb Upgrade Scintillating Fibre Tracker**
  - Herve Chanal

<u>Technical Design Report:</u>

- **LHCb Tracker Upgrade Technical Design Report**,
  - LHCb Collaboration, 2014: LHCB-TDR-015, CERN-LHCC-2014-001

Challenges: Fibre irradiation

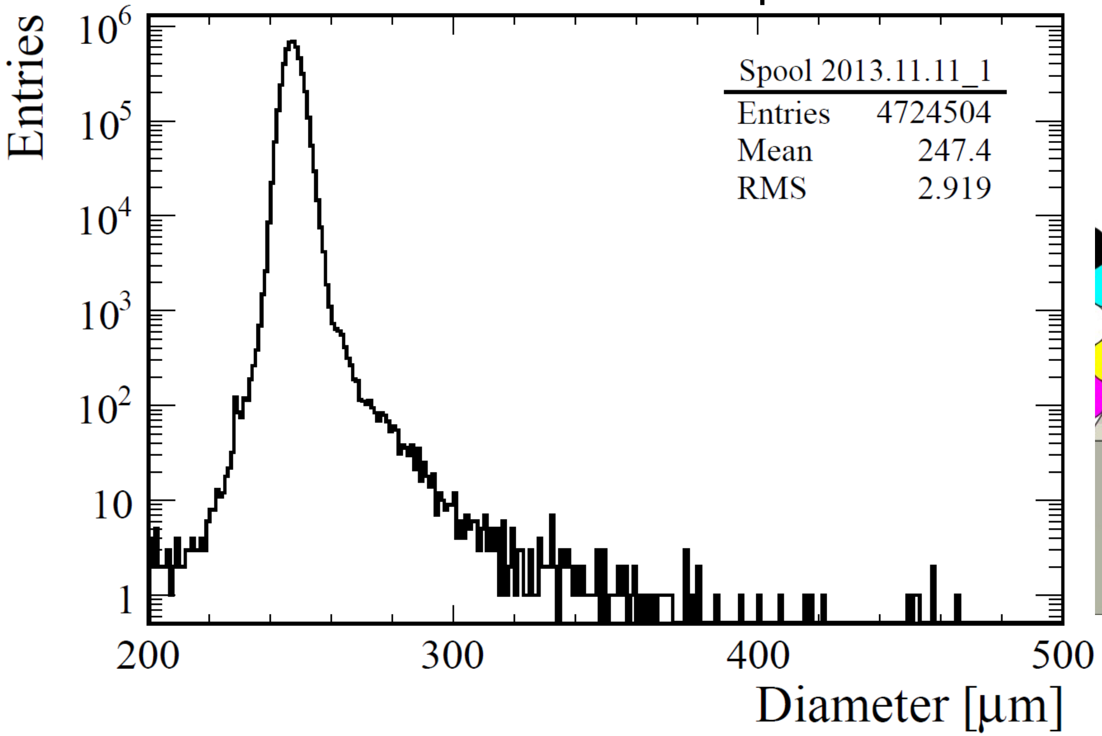
- The scintillating fibres darken with radiation (up to 35 kGy expected near the beam pipe over the upgrade lifetime)



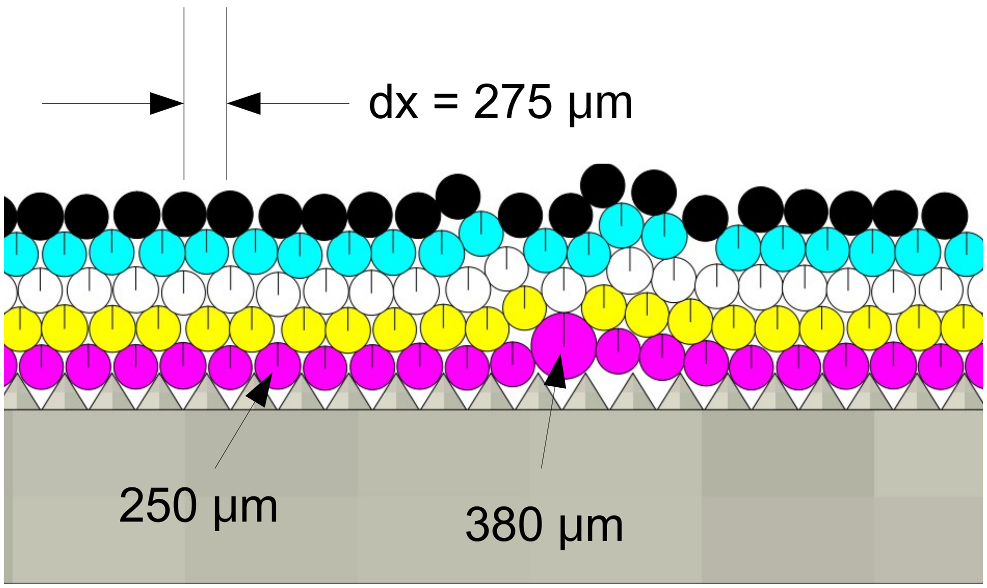
Challenges: Fibre bumps

- Defects of the fibre can be created during the extrusion process making “blobs”

Fibre diameter over one spool

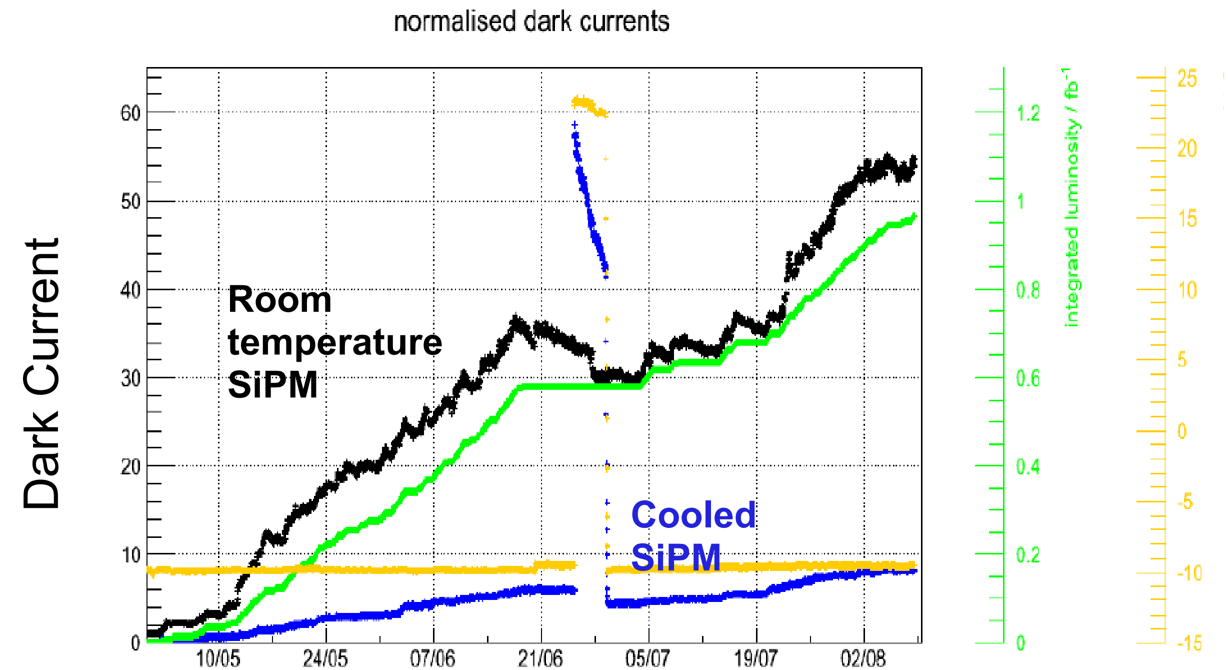


For a good mat
rms(dx) = 8-15 μm



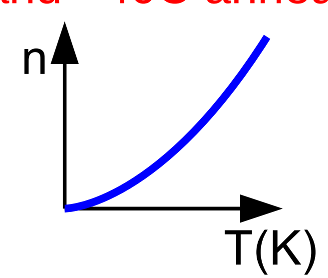
Challenges: Neutrons and Cooling

- SiPMs create single photo-electron signals from thermal electrons, cross-talk between pixels makes 1 photo-electron look like 2+
- Neutron damage to silicon worsens thermal problem, expect 10^{12} neutrons/cm^2



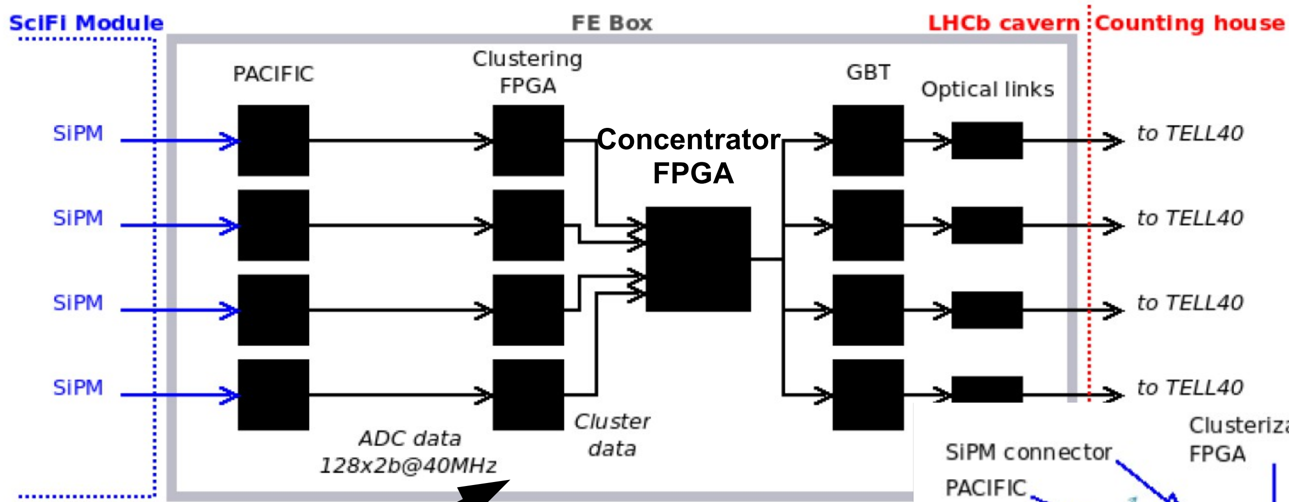
- Acceptable cluster rates require -40C cooling and +40C annealing

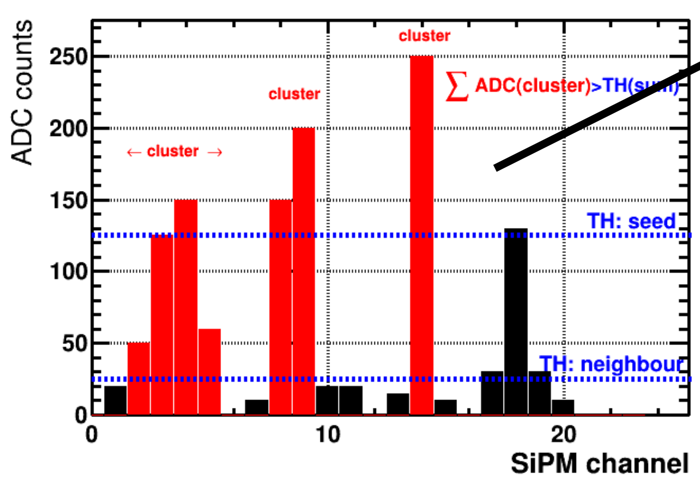
$$dark\ noise \propto T^2 \exp\left(\frac{-E_g}{2k_B T}\right)$$

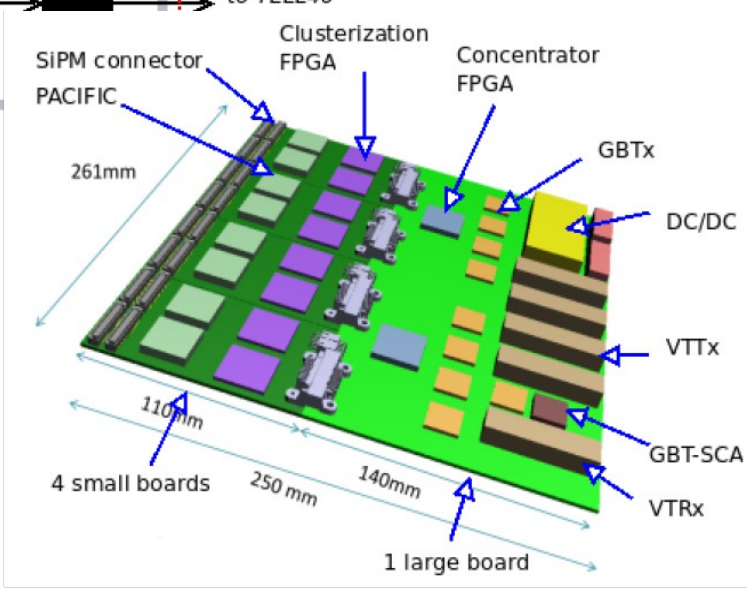


Challenges: Electronics

- Digitizes the 560,000 SiPM signals and forms the clusters and hit positions
- ASIC (PACIFIC) and front-end board development



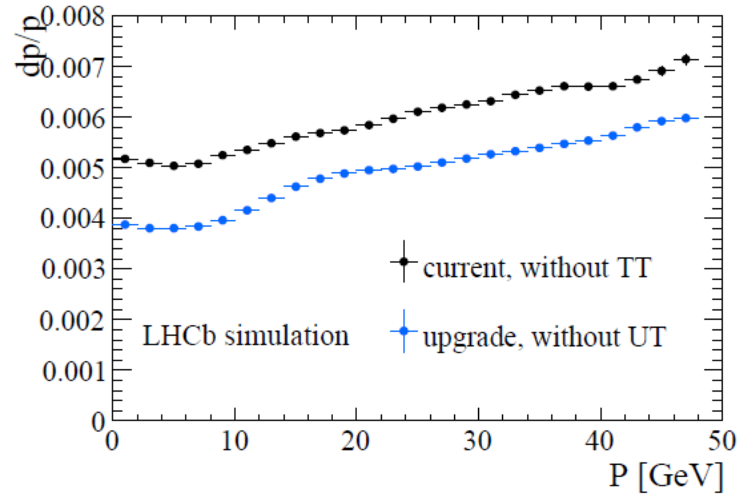


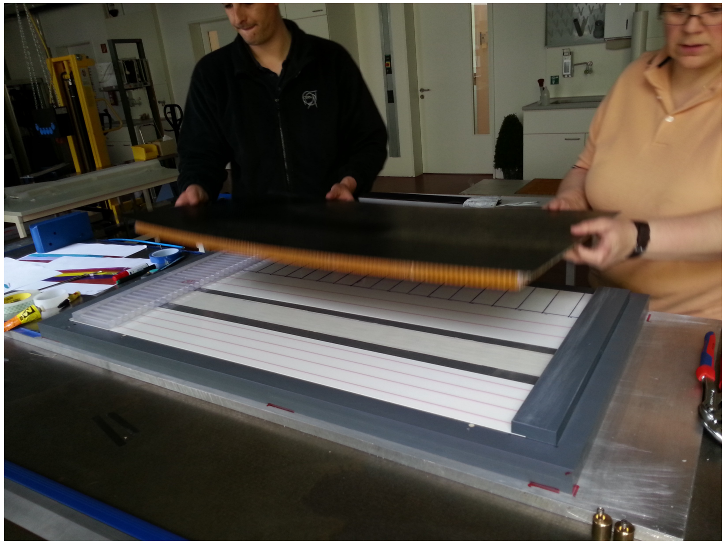


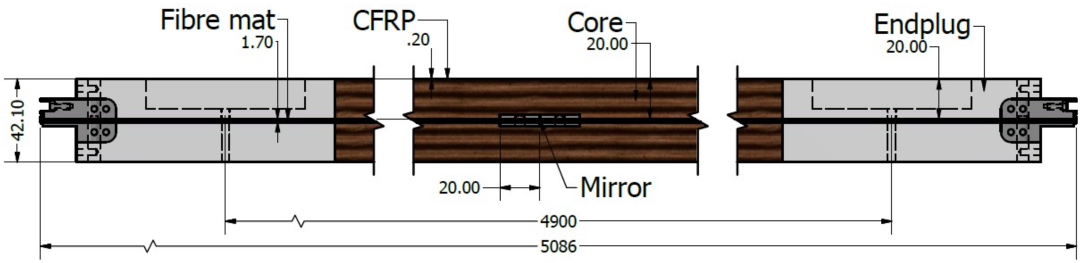
Challenges: Detector design

- Stability and alignment of the detector must be ~100μm
- Must be <1% of a radiation length per detector layer (4mm equiv. of plastic)

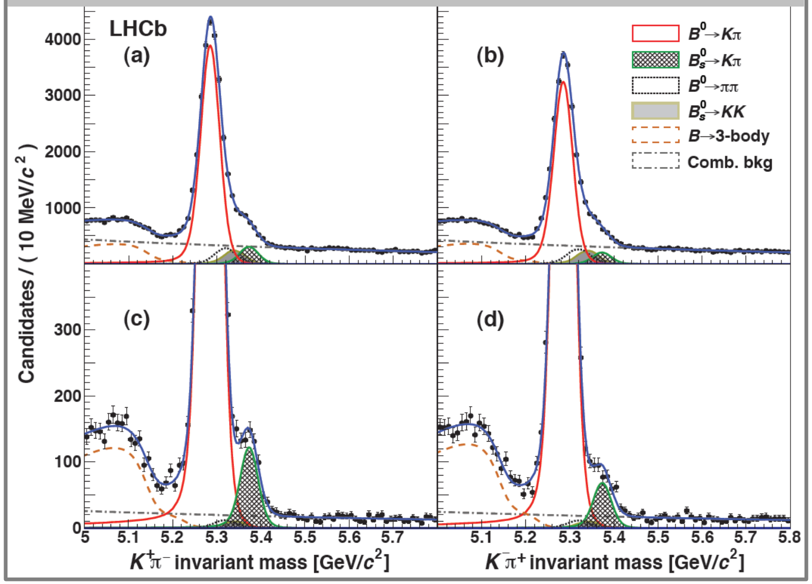
Less material + stable detector = improved momentum resolution = better mass resolution







Phys.Rev.Lett. 110 (2013) 22, 221601



Summary

- The order of magnitude increases in precision will allow new physics searches down to Standard Model theoretical uncertainties
- The SciFi tracker is crucial to scope with the upgrade requirements
- SciFi collaboration with 10 countries in 20 institutions
- Begin construction in end of 2015; Ready for installation in 2018