Upgrade options and R&D for the LHCb tracking system

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

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CHIPP workshop on the high-energy frontier
University of Zürich
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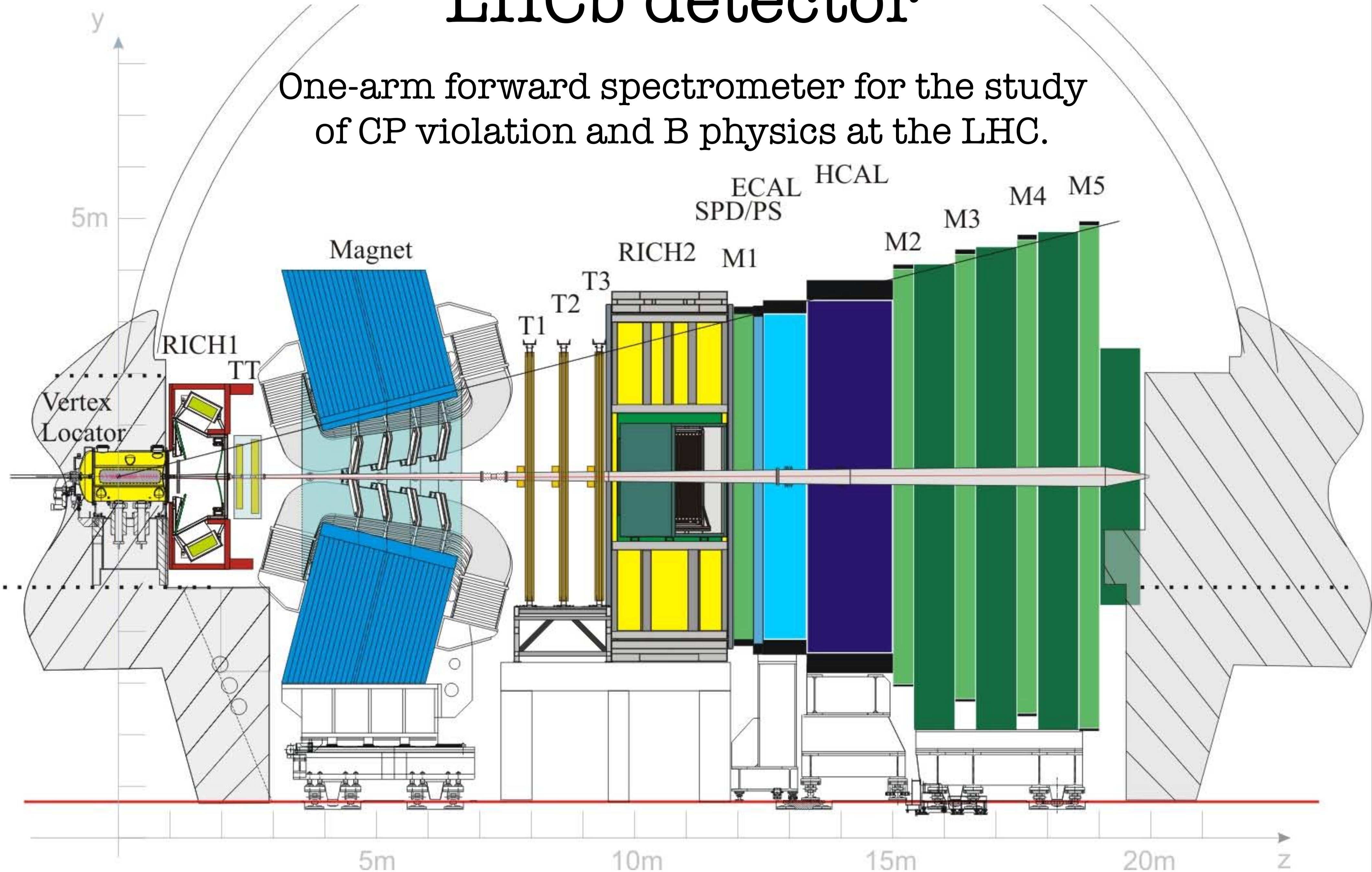
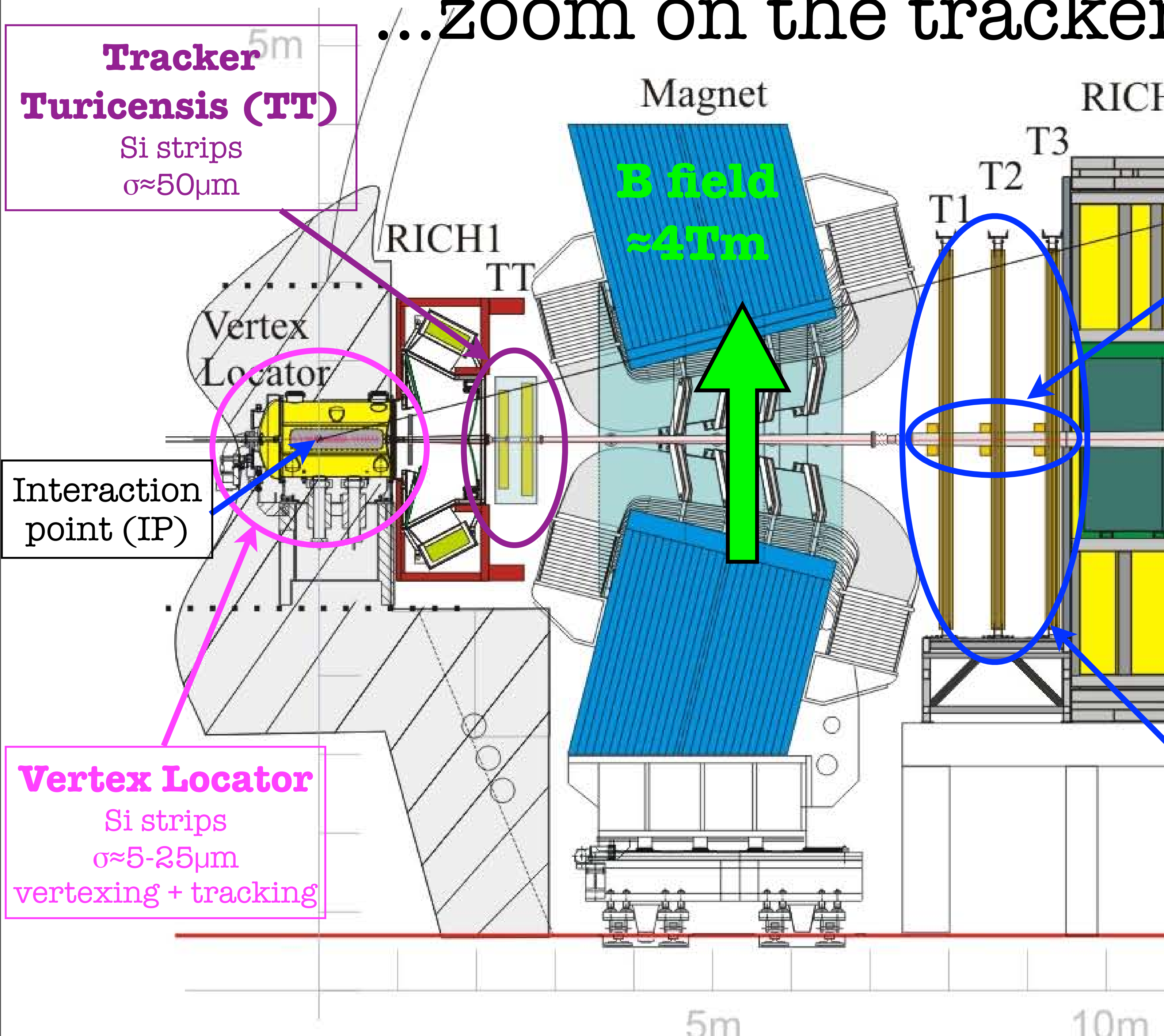
LHCb detector

One-arm forward spectrometer for the study of CP violation and B physics at the LHC.

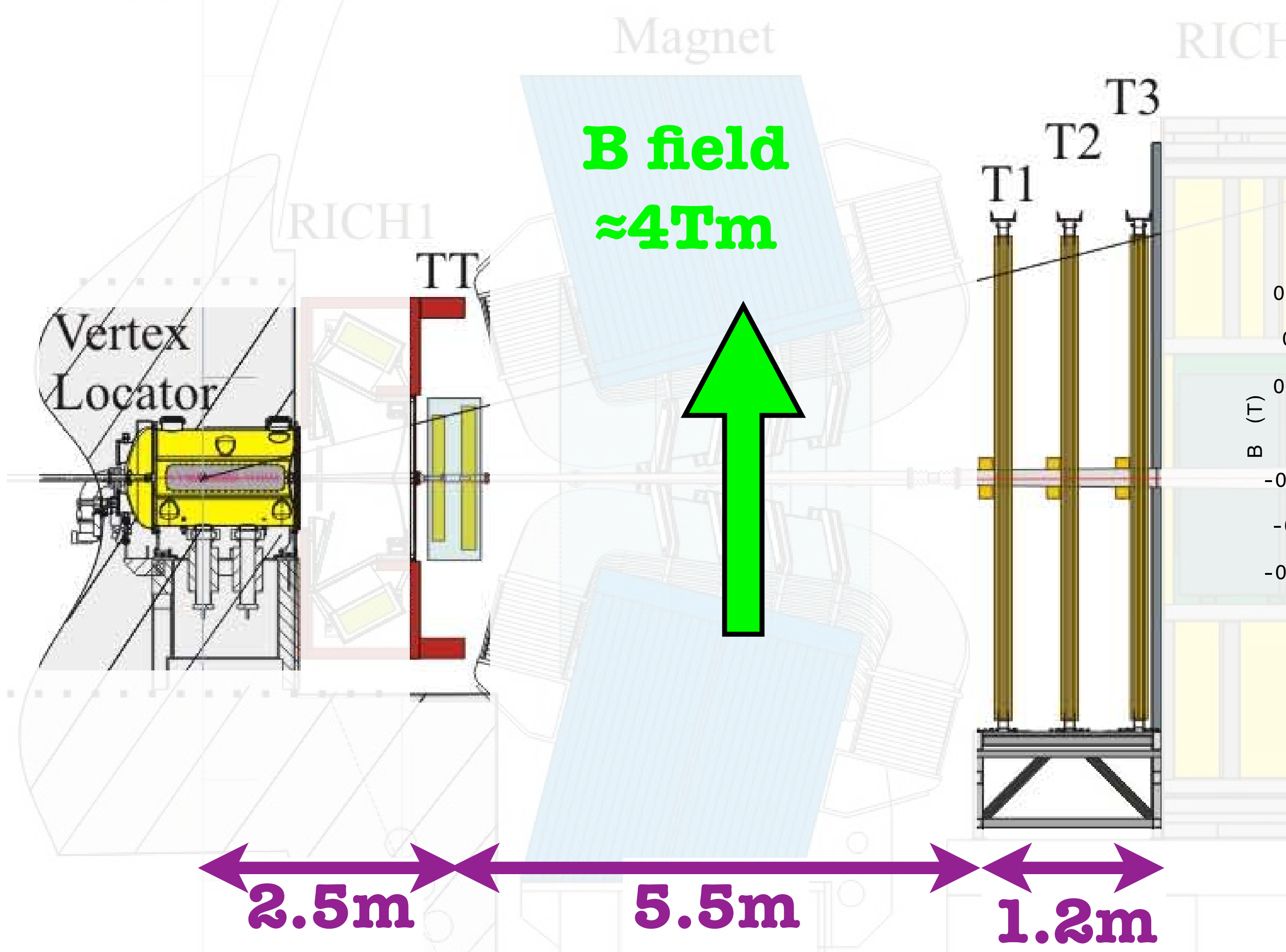


...zoom on the tracker

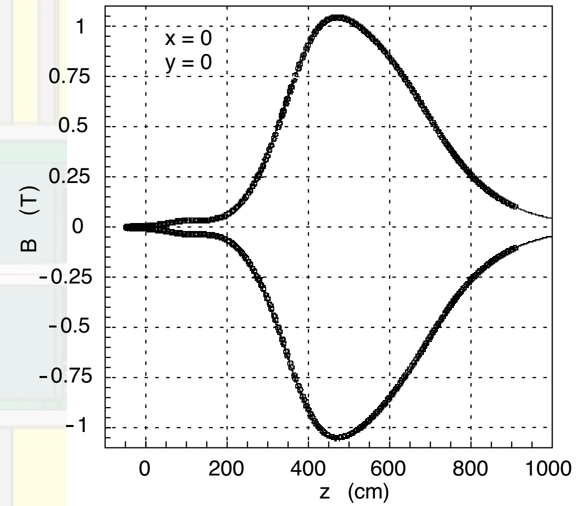


In this talk: consider only TT, IT and OT

Tracker only (VELO, TT, IT/OT)

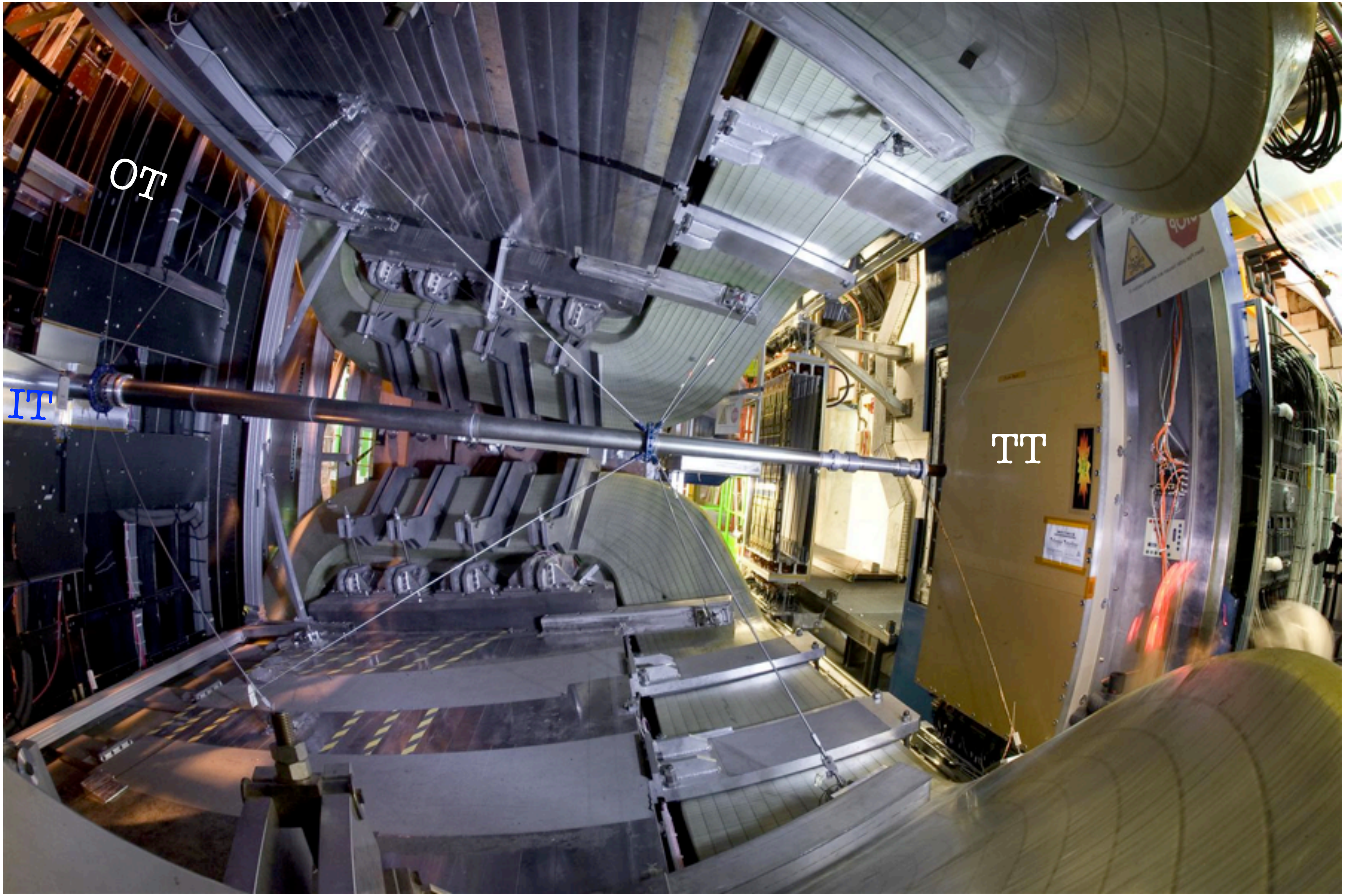


B field vs z



B field equivalent to 1T over 4m

Hypothesis: keep identical geometry for upgrade


OT
IT
TT

Tracking sub-detectors

- 4 tracking stations: 1 upstream (TT) and 3 downstream (IT+OT) of magnet
- 4 layers in each station: X_1UVX_2 (±5° stereo angle for U and V)

1. Tracker Turicensis (TT)

- 1.5m×1.3m ; 183μm pitch Silicon strips

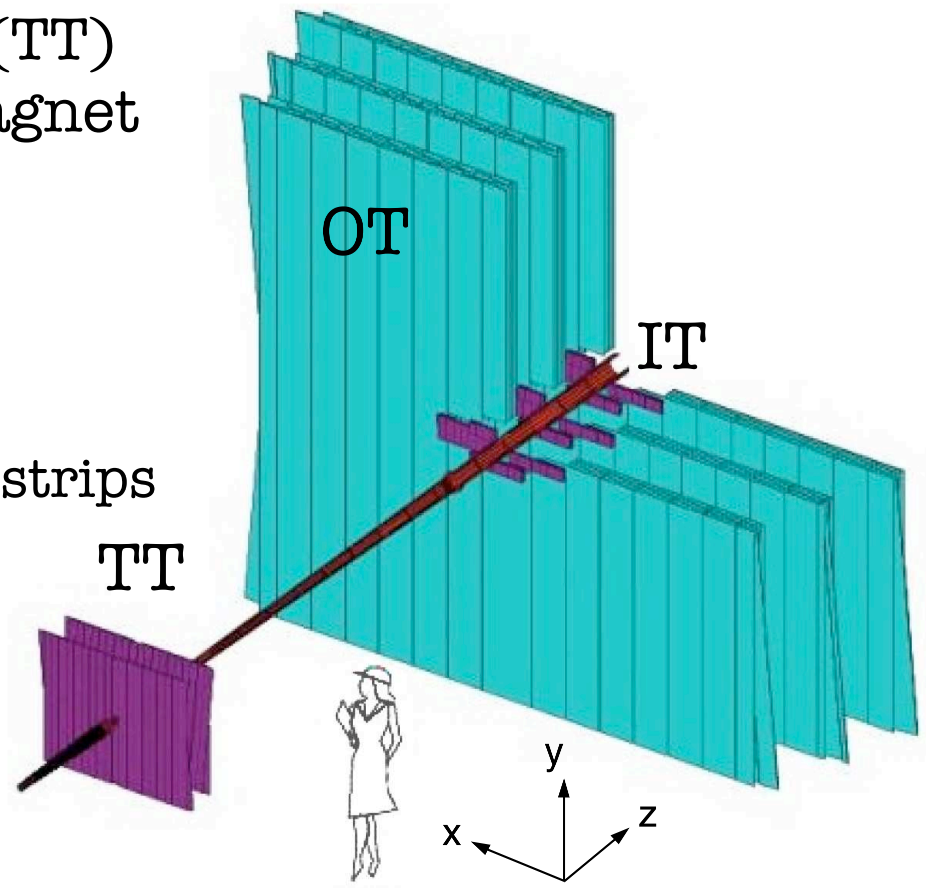
2. Inner Tracker (IT)

- 1.2m×0.4m cross around beam pipe
- Si strip detector; 198μm pitch

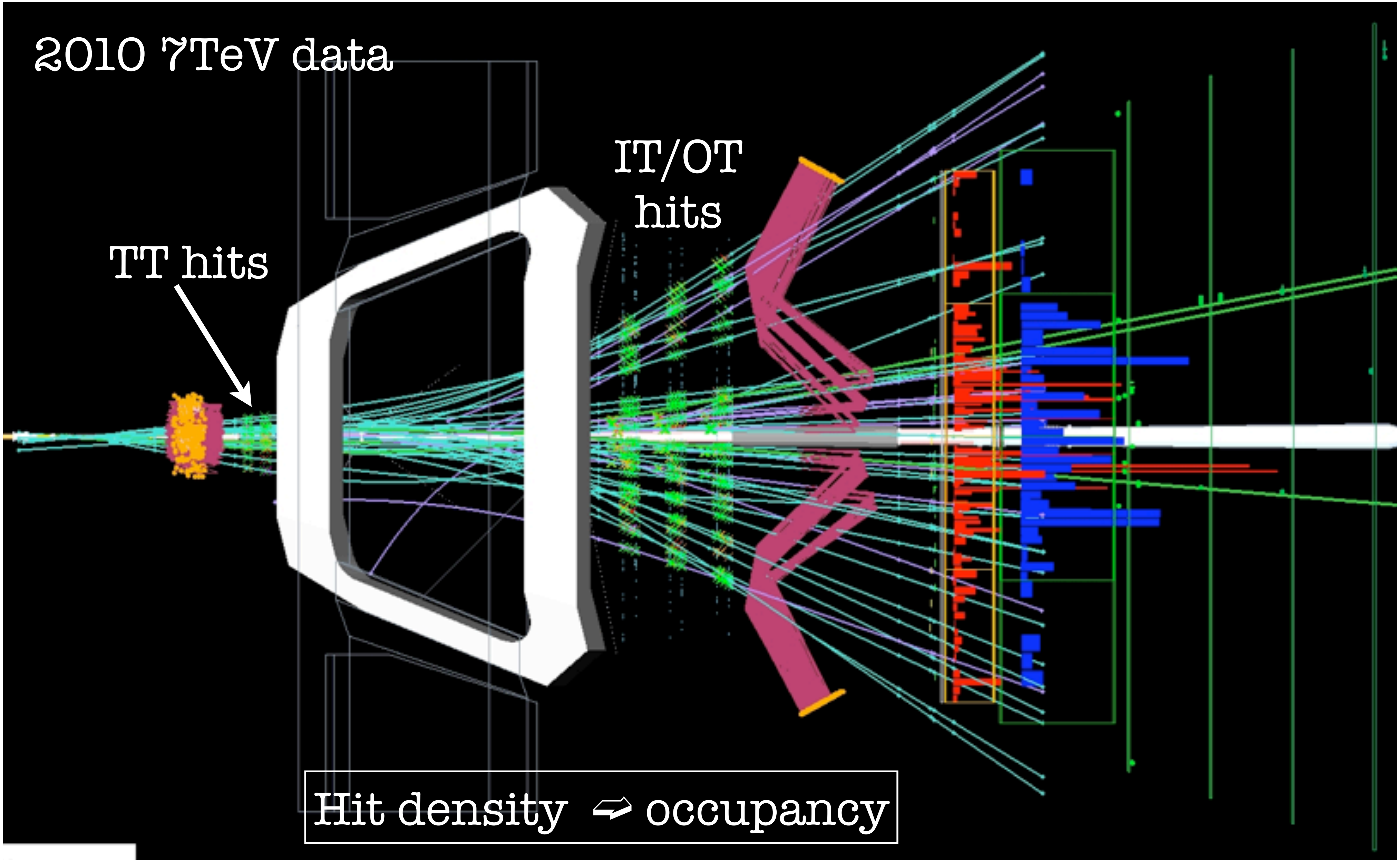
3. Outer Tracker (OT)

- 6m×5m area for full outer acceptance coverage
- Straw tubes; 70%Ar; 30%CO_2 ; <50ns drift time

- Ratio of IT and OT area driven by occupancy (see later)



LHCb event display

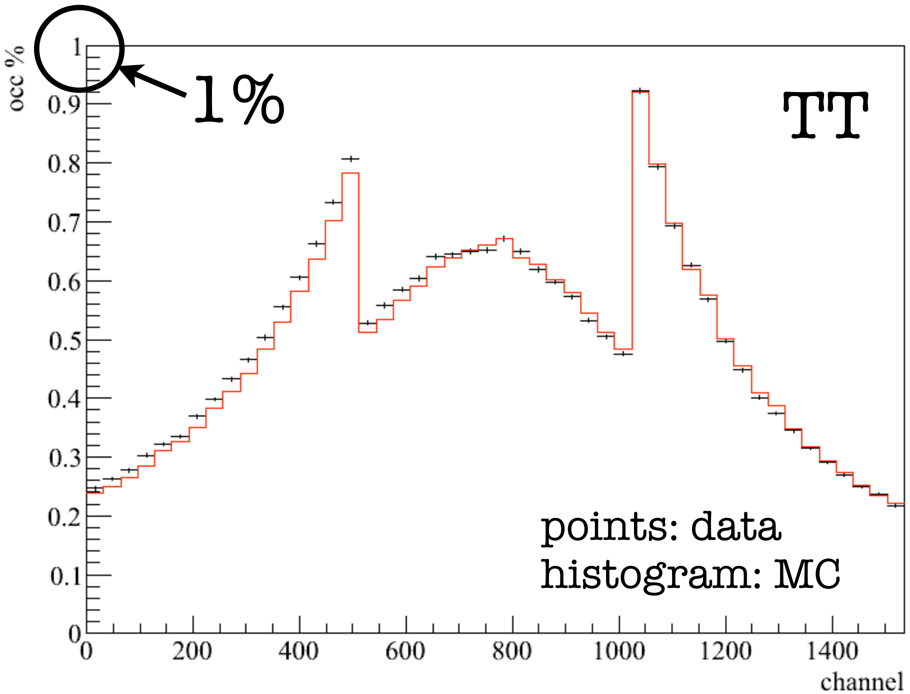


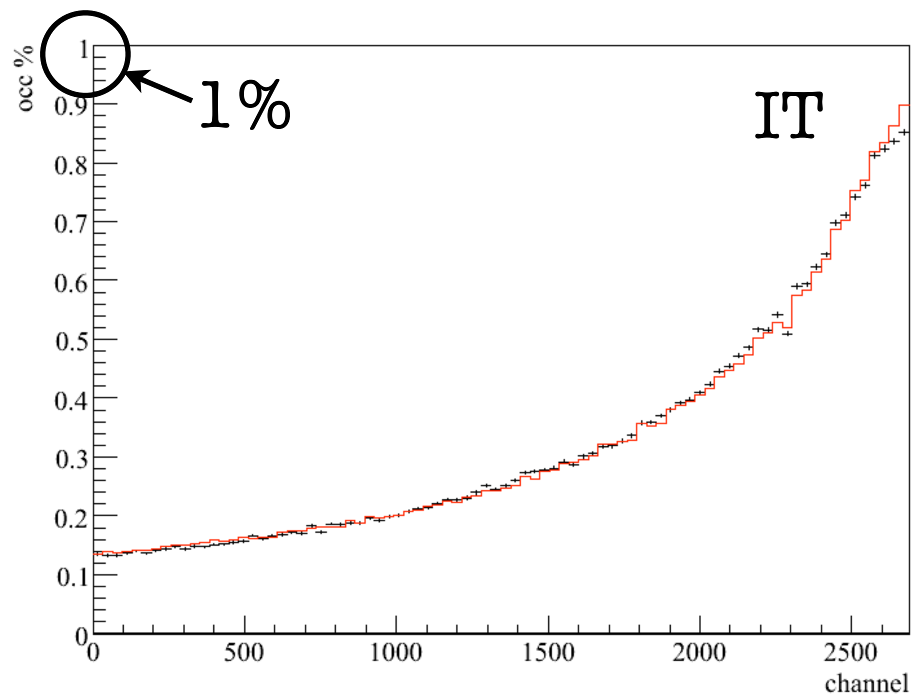
TT and IT occupancy

- with early 2010 data (no pile-up, micro-bias trigger), strip occupancy below 1% for both IT and TT detectors

strip occupancy =
(particle occupancy × cluster size)
+ noise

- now reaches approximately 2% occupancy





(See M.Needham's presentation for other performance results)

$L=2\times10^{33}$ upgrade conditions I

- What will be different at $L=2\times10^{33}\ cm^{-2}s^{-1}$?
  - higher average number of pp interactions per crossing (parameter ν)
    - the luminosity is related to the number of bunches $N_{bunches}$ and to ν

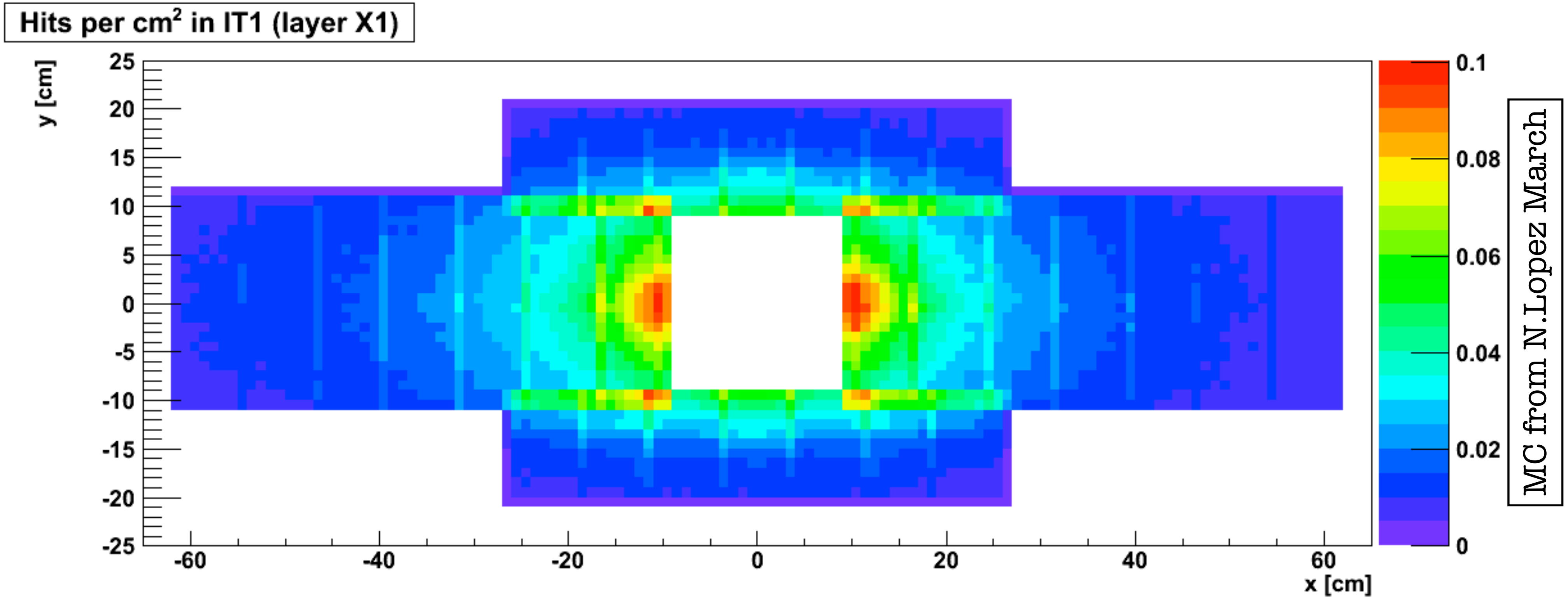
$$\nu \propto \frac{\mathcal{L}}{N_{\text{bunches}}}$$

We obtain **$\nu \approx 7$ @ $L=2\times10^{33}\ cm^{-2}s^{-1}$**

  - A larger value for ν implies an increase in occupancy...

L=2×10^{33} upgrade conditions II

- ...higher occupancy (MC studies)
  - In IT, up to 0.1 particle per cm^2 and per event
    (1 strip area = 0.02cm × 20cm = 0.4cm^2)



  - TT strip occupancy also increases to about 10% in hottest spots

$L=2\times10^{33}$ upgrade conditions III

- What will be different at $L=2\times10^{33}$ $cm^{-2}s^{-1}$?
  - LHCb will design its electronics for readout at 40MHz

    => develop new fast front-end electronics

    => new “TELL-40” acquisition board able to read events at 40MHz

Tracking requirements

A. **50μm resolution** (driven by multiple scattering)

- each station (TT, IT, OT): $x/X_0 \approx 3\text{-}4\%$
  => multiple scattering angle θ_{ms} (cf. PDG)

$$\theta_{\rm ms} = \frac{13.6\,{\rm MeV}}{\beta cp}\sqrt{x/X_0}\left[1 + 0.038\ln(x/X_0)\right]$$

- $p \approx 20$GeV/c ; $\beta \approx 1$ => $\theta_{ms} \approx 0.12$mrad
- 0.12mrad×0.6m = 72μm uncertainty due to multiple scattering from a T-station to the next
  => do not need better than ≈50μm measurement accuracy
- 0.12mrad×5.5m = 660μm in 1st T station due to TT

B. **low occupancy** (at a few the percent level)
=> implies lower bound on granularity

C. **fast signal shaping time** (minimize pile-up)

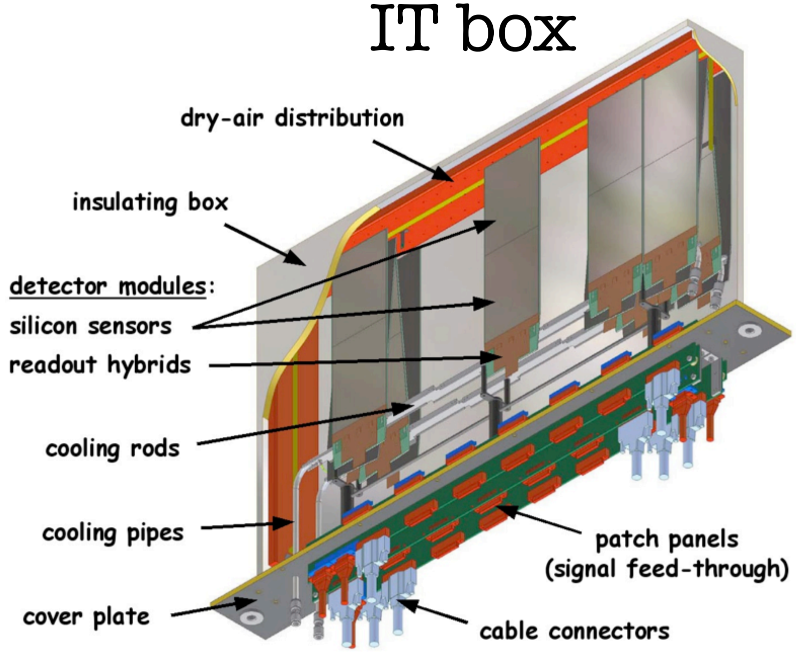
$L=2\times10^{33}$ tracker upgrade options

- Consider combinations of
  1. **Silicon strips**
  2. **Straw tubes**
     - Larger gas detectors (TPC, drift chamber) not fast enough as soon as the drift time >>25ns
  3. **Scintillating fibers**

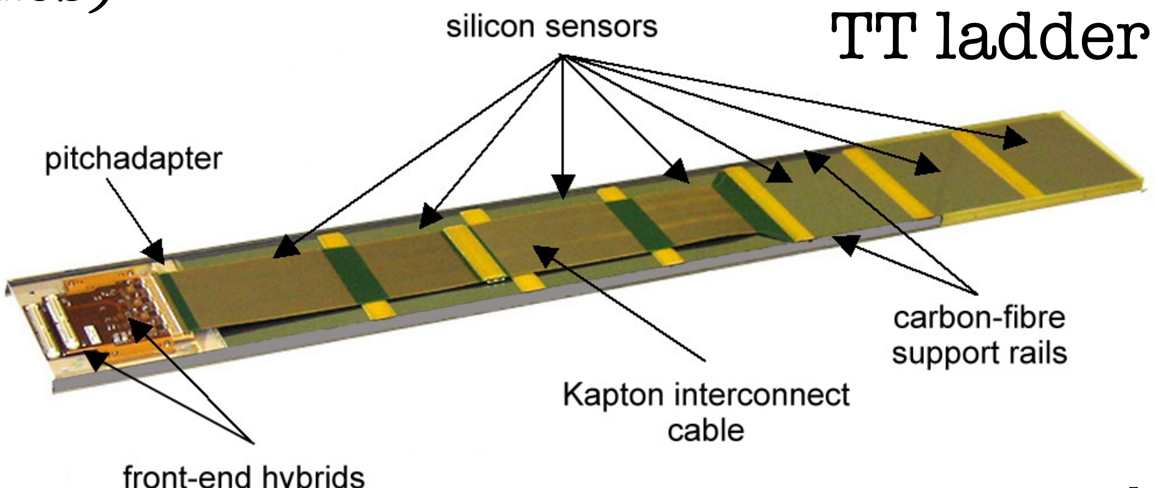
Silicon

- Silicon strips
  - resolution => pitch≈200μm
  - occupancy => strip length
- Fast shaping time
- Cost is a function of
  - Silicon area ($N_{channels}$ × pitch × length)
  - $N_{channels}$ (electronics)

IT box

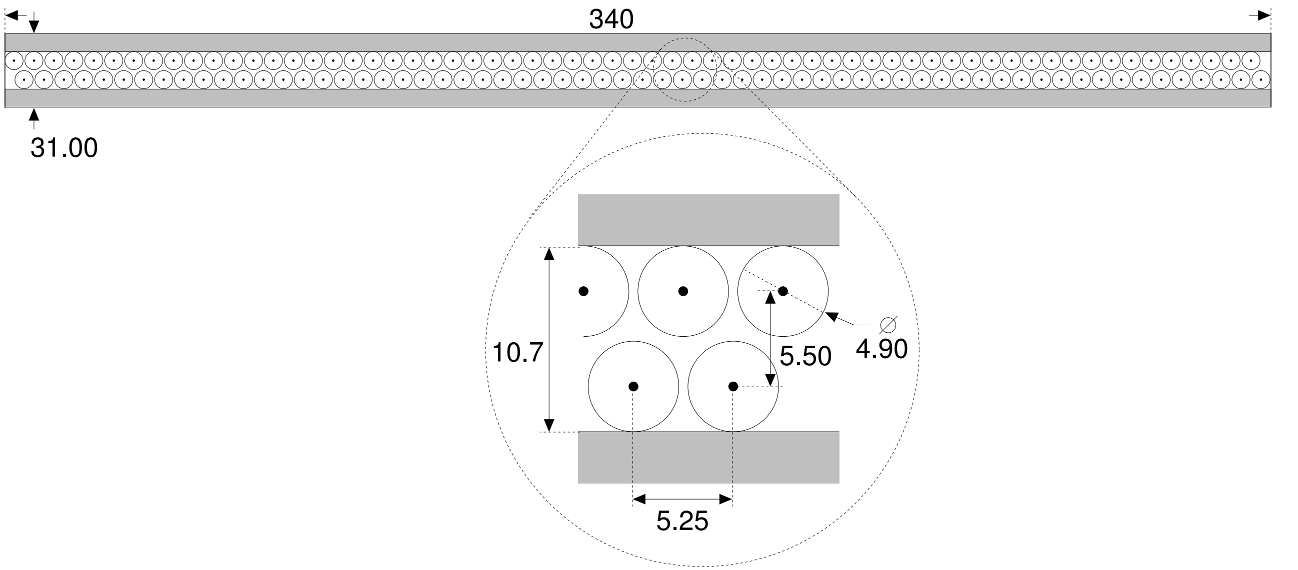


TT ladder



Straw tubes

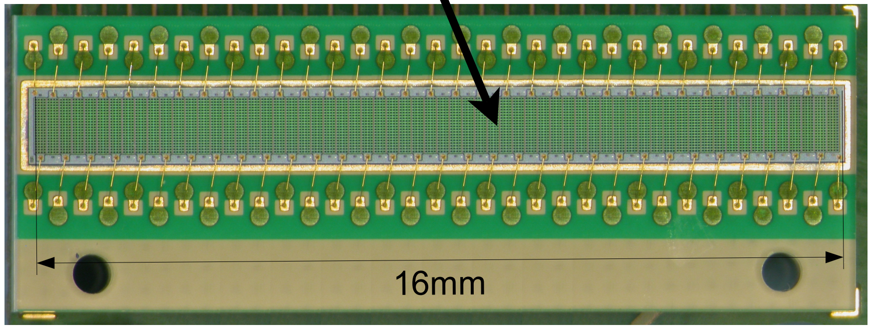
- Array of ∅=5mm straw tubes to cover large acceptance area



- Use fast drift gas mixture
  - currently 70% Ar + 30% CO_2 => <50ns
  - might need faster gas for upgrade
- Resolution ≈200μm

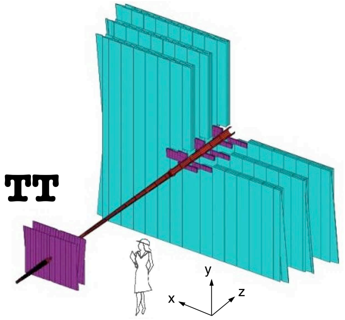
Scintillating fibers

- Array of densely packed 250μm scintillating fibers (SciFi)
- Readout with Silicon photo-multiplier (SiPM) [0.25mm×1.1mm channels]

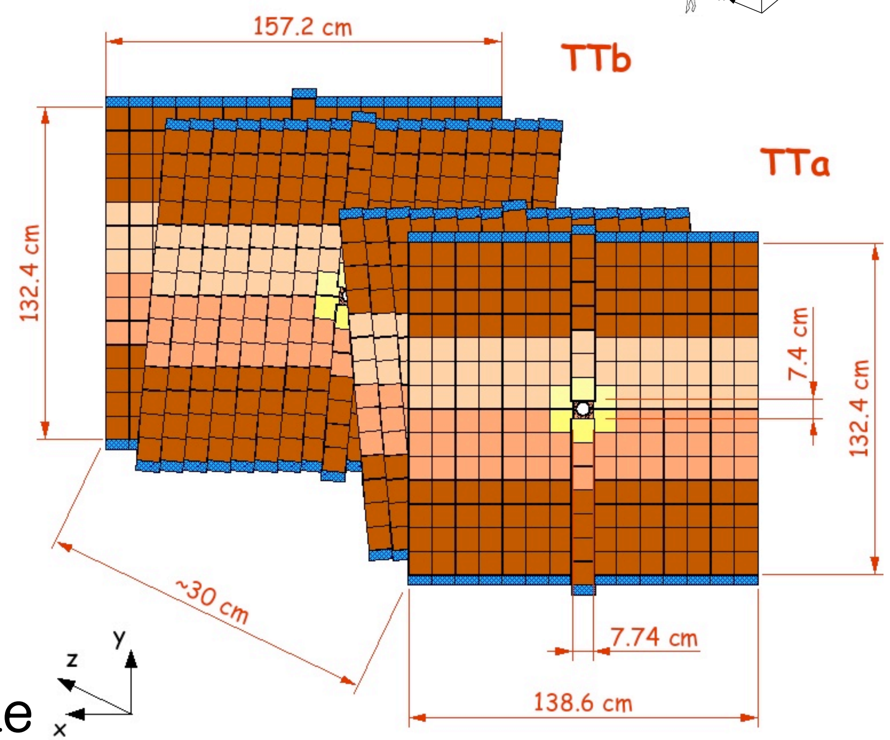


- can achieve 50μm resolution
- high efficiency
- cost dominated by SiPM and electronics
  => $N_{channels}$ is the critical parameter
  => fiber length is not a dominant contribution to the cost!

Options for TT

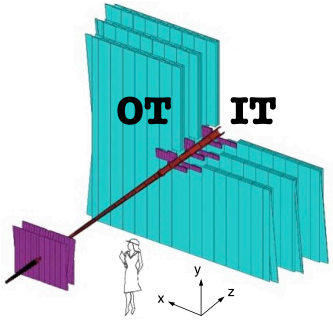


- R&D for upgrade:
  - higher granularity near beam to keep occupancy at a low level
  - lower material budget
    => better extrapolation to T1
    => impact of 3 TT layers U+X+V?
- Silicon fulfills all the requirements for TT
  - 50µm resolution, etc...
  - infrastructure can be kept outside of acceptance (FE-electronics, cooling, HV)



- SciFi detector could also be considered:
  - would necessitate R&D (combined with IT R&D)
  - Single technology in LHCb if SciFi used for IT too

Options for IT+OT



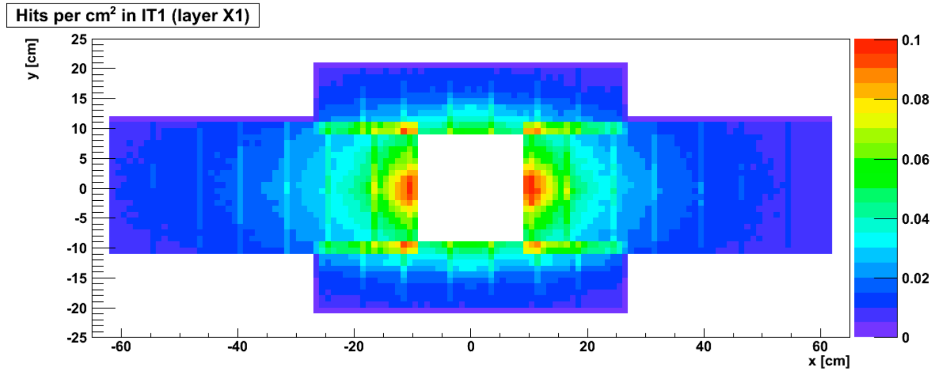
A. revisit relative size of IT and OT active area to minimize occupancy

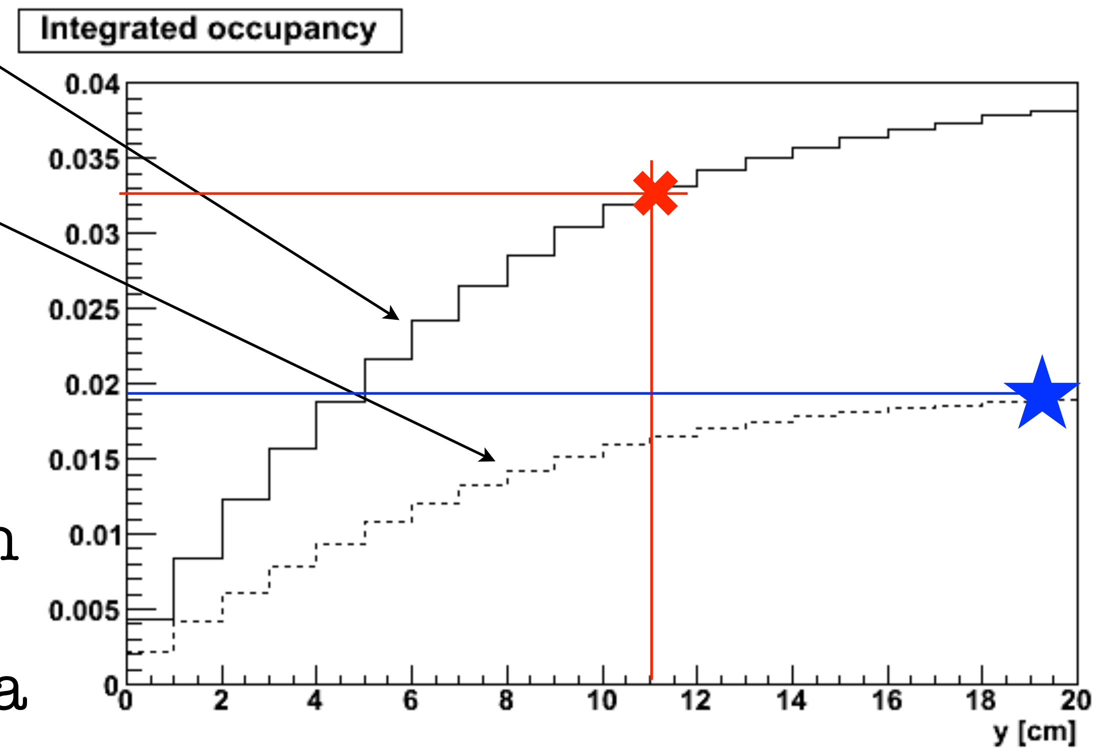
B. detector technology configurations:

	IT	OT
1.	Silicon	Straw tubes
2.	SciFi	Straw tubes
3.	SciFi	SciFi

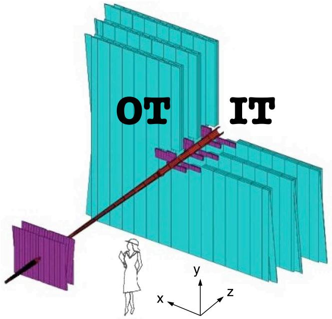
Optimizing IT/OT area ratio

- Hit occupancy from 2D plot
- Determine the hit occupancy at closest points left and right of beam pipe as a function of the length of the strips
  - single long strips [-y,+y]
  - two shorter strips [-y,0] and [0,+y]
- ≈3.3% occupancy with current geometry (✖)
- occupancy divided by 2 if IT detector split between y<0 and y>0 (★) => can cover twice the area of current design!



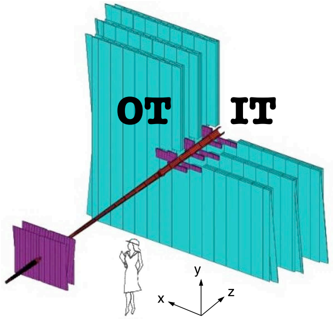


Silicon IT + straw tubes OT



- Advantage:
    - well known technology
      => little R&D needed
- Difficulties:
    - significant material in acceptance from IT
        - electronics, readout cables, HV cables
    - cooling of Si sensors is difficult
    - Straw tube gas might be too slow => R&D

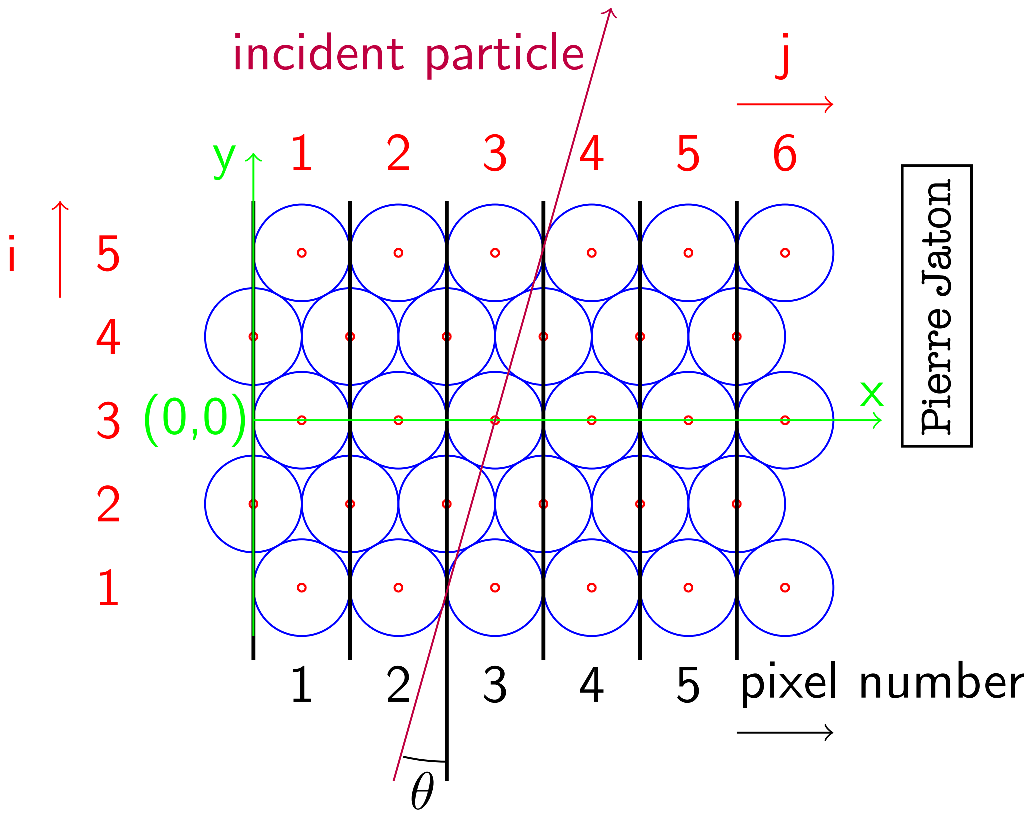
SciFi IT + straw tubes OT

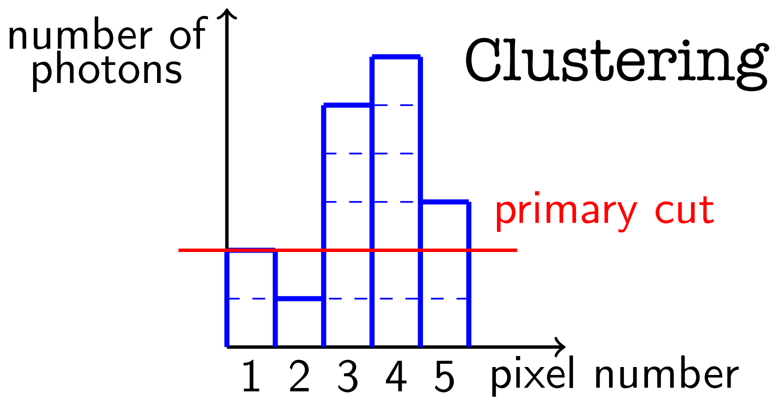


- OT: straw tubes (cf. previous slide)
- IT: R&D at EPFL and Dortmund to replace IT Silicon detector boxes with SciFi detectors (acting as spares)
  - mechanical and electronics constraints for compatibility with current detector (not relevant for upgrade)

SciFi R&D

- 5 layers of densely packed 250μm fibers
- readout in 250μm x 1100μm channels
- standalone simulation to study effects of:
  - integrated photon efficiency (assume 20pe/mm)
  - noise (assume 0.3pe/channel)
  - track angle (up to ±10°)
  - gaps / dead regions
  - saturation

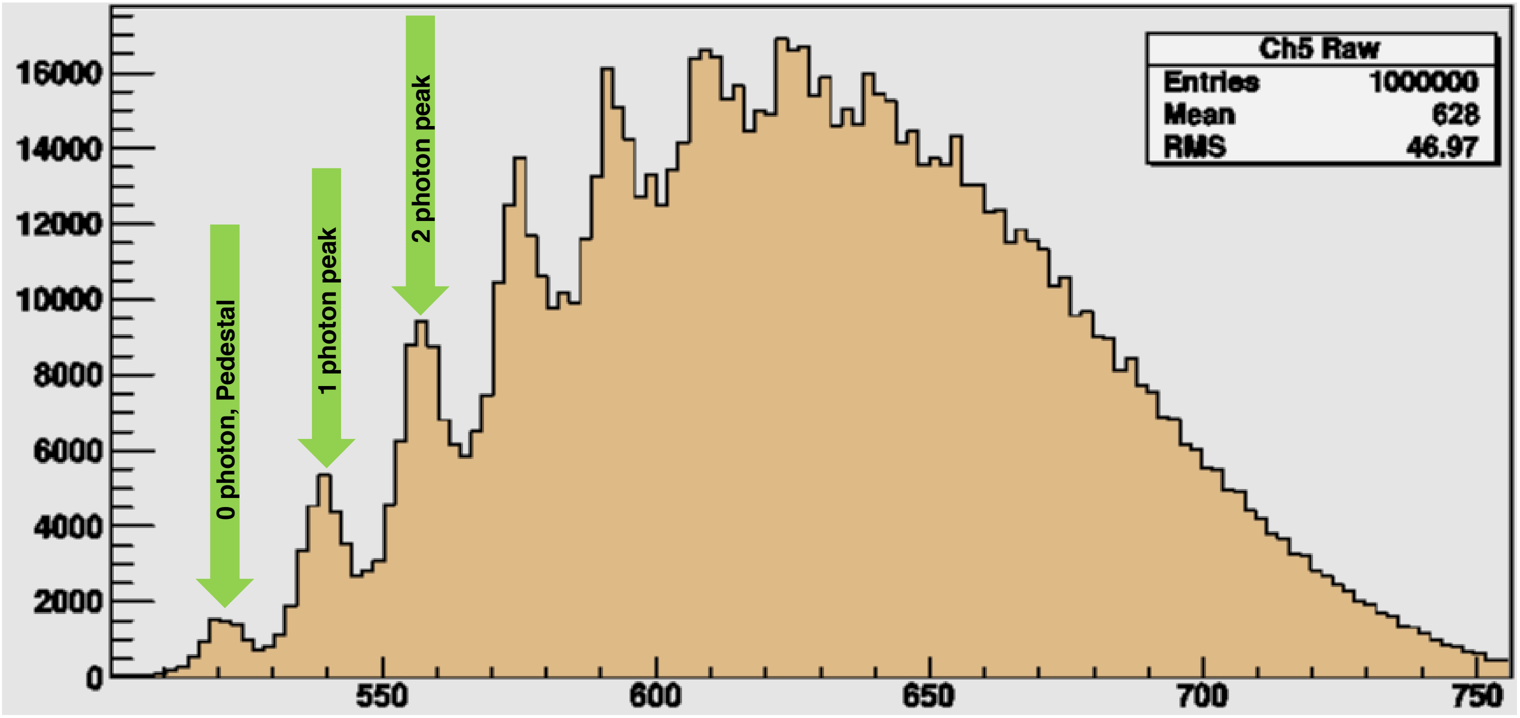




- **Efficiency >99.9%** with 1 noise / 1000 signal clusters

SciFi R&D: S/N

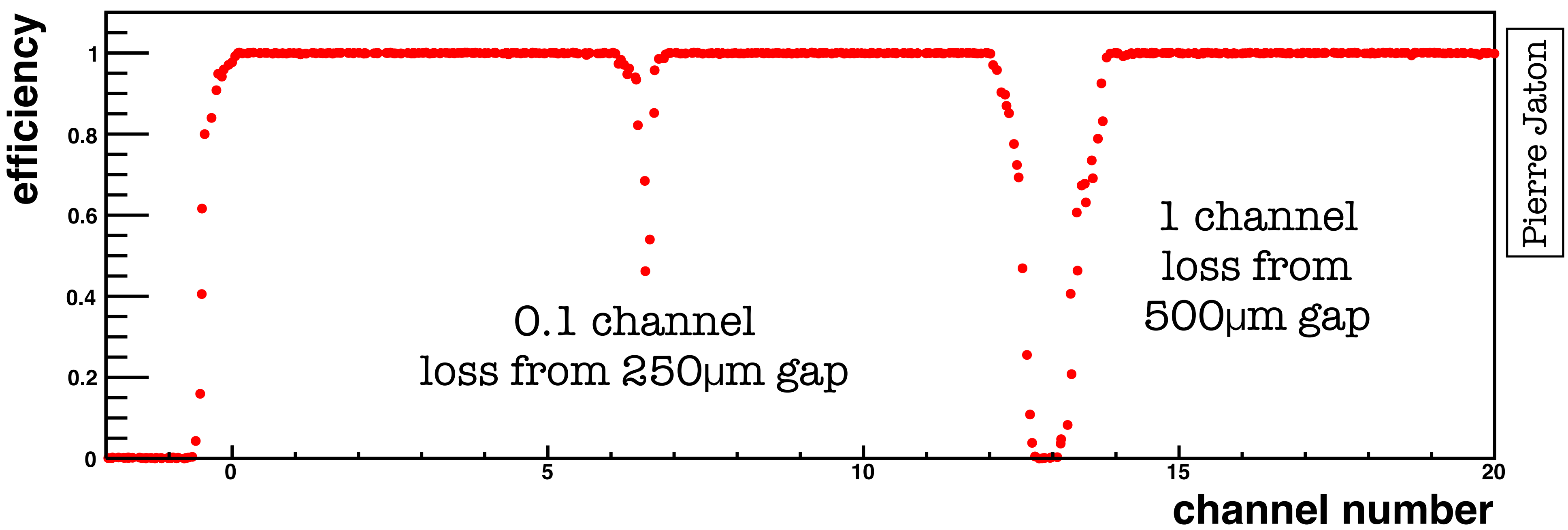
- For IT replacement detector:
  - must adapt strong signal from Silicon PM to high-gain Beetle chip
  - use passive current divider (~1/40)
    - S/N ≈ 30 for 1MIP (≈15 photo-electrons)
    - dynamics ≈30 photo-electrons



Guido Haefeli

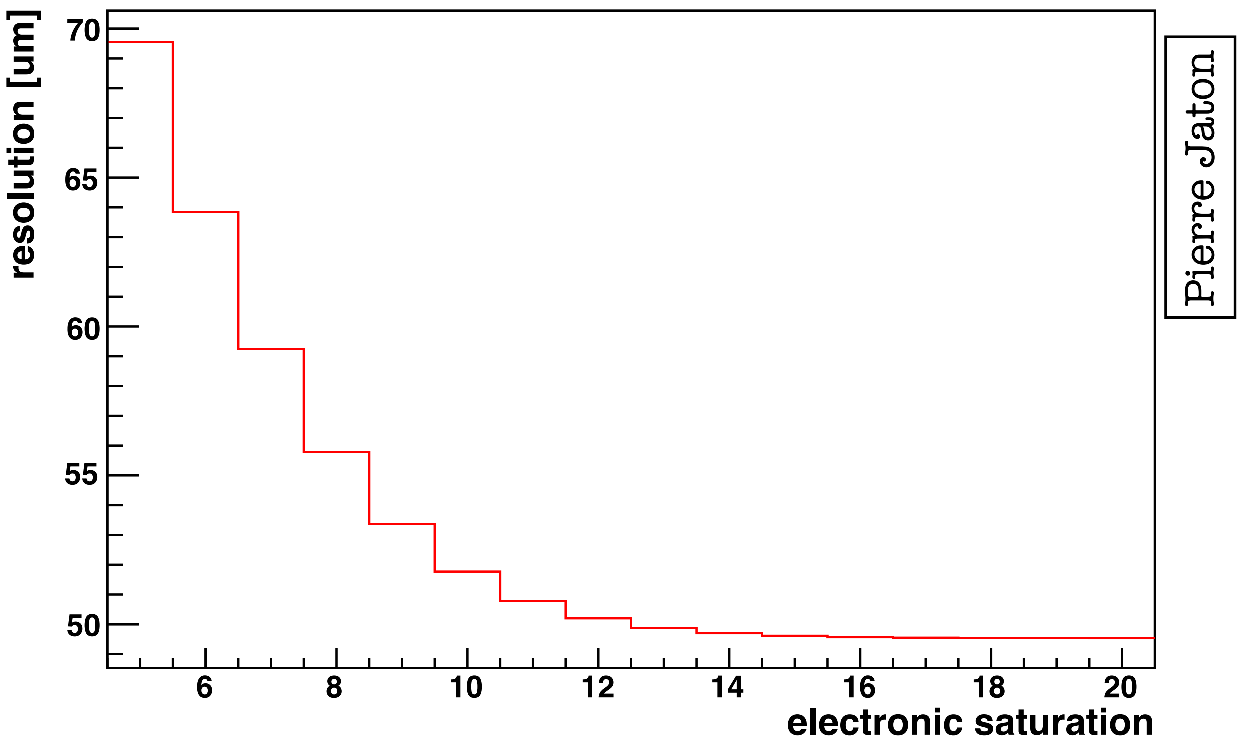
SciFi R&D: efficiency in gaps

- Simulated inactive SiPM channels:
  - 250μm gaps built in SiPM (≡1 channel)
  - 500μm gaps between adjacent sensors (≡2 channels)



SciFi R&D: resolution

- PEBS test beam (2009):
  - 25pe/MIP/1.1mm
  - 50μm resolution
- Resolution depends on electronics saturation and cluster size
- **Average resolution ≈50μm**
  (compare to binary resolution of $250/\sqrt{12} = 72\mu m$)



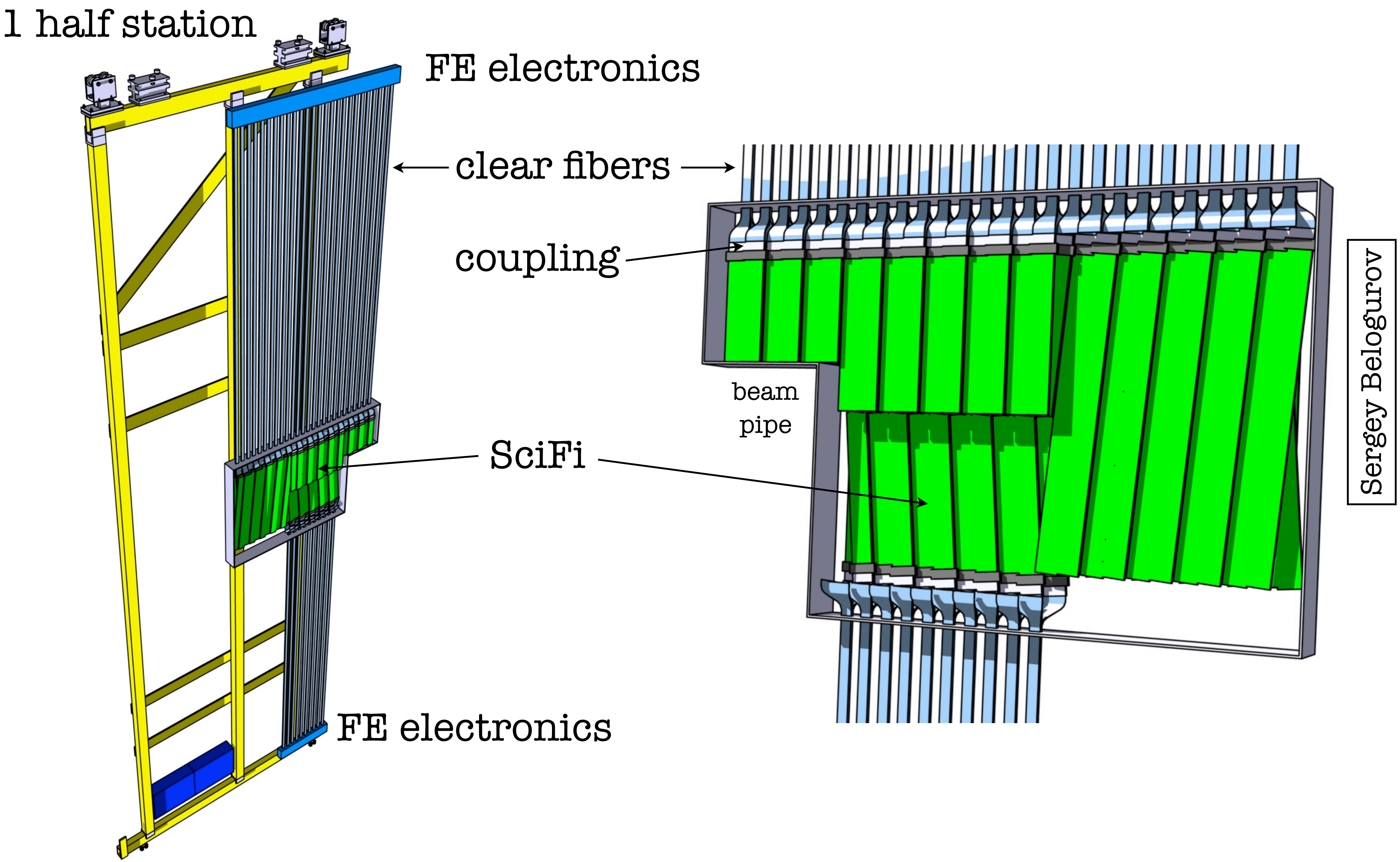
SciFi R&D: radiation hardness?

- SiPM possibly not sufficiently radiation hard to survive in high flux region
  - currently testing SiPM samples with neutron source
  - MC of neutron fluxes in LHC @$2\times10^{33}cm^{-2}s^{-1}$
  - can be a show stopper for replacement
  - for upgrade, will consider shielding SiPMs outside of acceptance

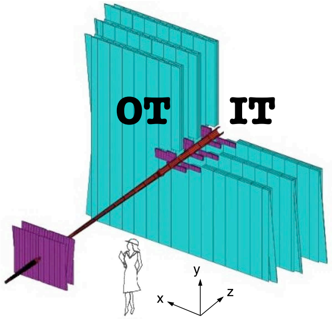
IT SciFi upgrade option

- Scintillating fibers satisfy the requirements for resolution, efficiency, signal shaping time, etc...
- Several advantages:
  1. signal can be sent outside of acceptance via clear fibers for readout
     => keep electronics outside of acceptance
     => SiPM radiation hardness is not critical
  2. no active cooling of the sensors (only for electronics)
  3. no HV => no cables in acceptance
- Main difficulty:
  - **R&D for SciFi to clear fiber coupling!**

IT SciFi: possible layout



IT + OT SciFi



- 250μm IT channels and 750μm OT channels
- IT signal sent out of acceptance with clear fibers
- Advantages:
  - uniform technology for entire tracker
  - all electronics, cooling, cables outside of acceptance
  - same technology for both IT and OT (and TT?)
- R&D needed for
  - mechanical structure
  - electronics
  - SciFi to clear fiber coupling

Conclusion

- Presented upgrade options for the LHCb tracker to run at $L=2\times10^{33}cm^{-2}s^{-1}$
- From status quo "hybrid" option

  Silicon TT + SciFi IT + straw-tubes OT

- ...to more elegant "uniform" option

  Scintillating Fiber TT + IT + OT

- Dedicated global design of the tracker is now necessary to converge to the optimal solution