Tracking Technology

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Many thanks to Hans Dijkstra, Christian Joram, Blake Leverington, Marcel Merk, Jeroen van Tilburg and Stephie Hansmann-Menzemer, and others for useful discussions!

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Disclaimer:
1) More questions than answers…
2) Aimed to collect *existing* information

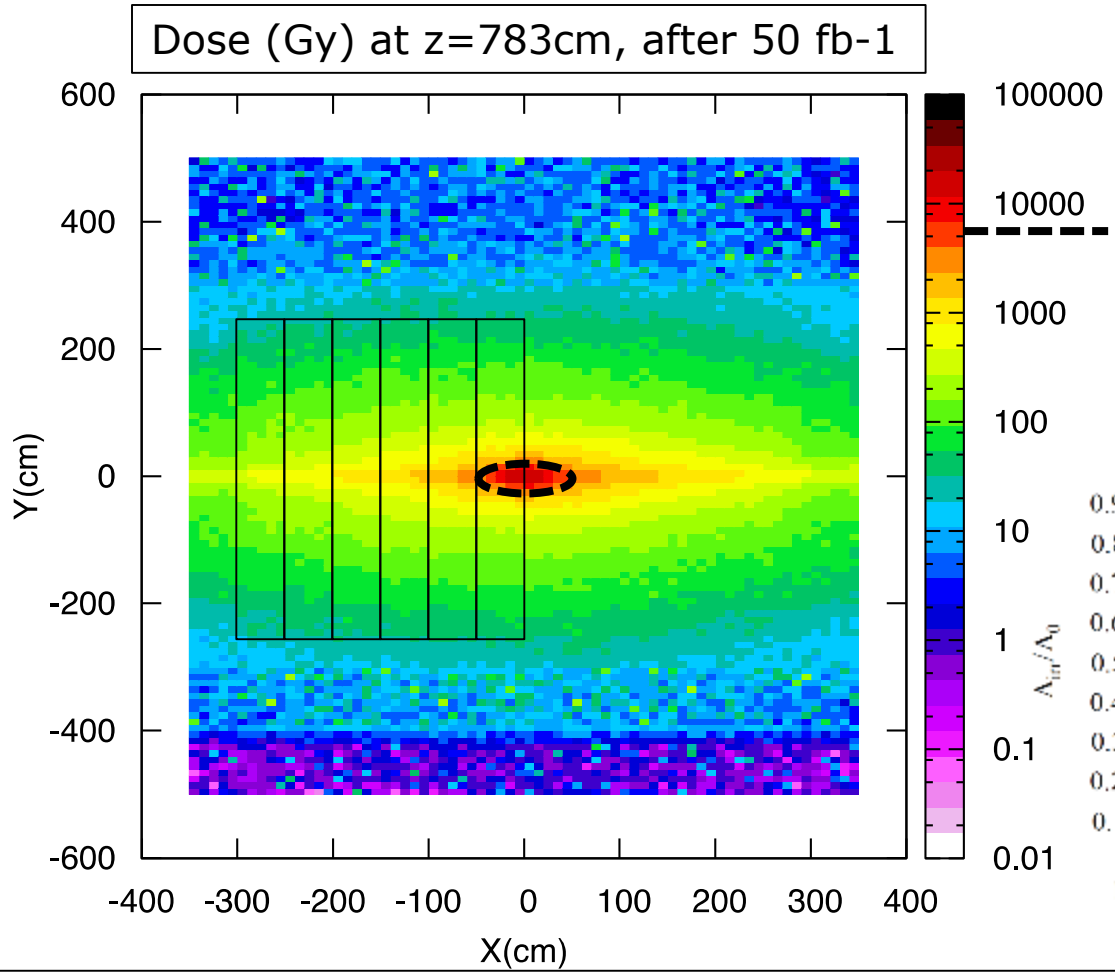
Previous Upgrade Considerations

- 1st Upgrade Workshop, Edinburgh, 11 Jan 2007
  - M.Needham: Occupancy estimates

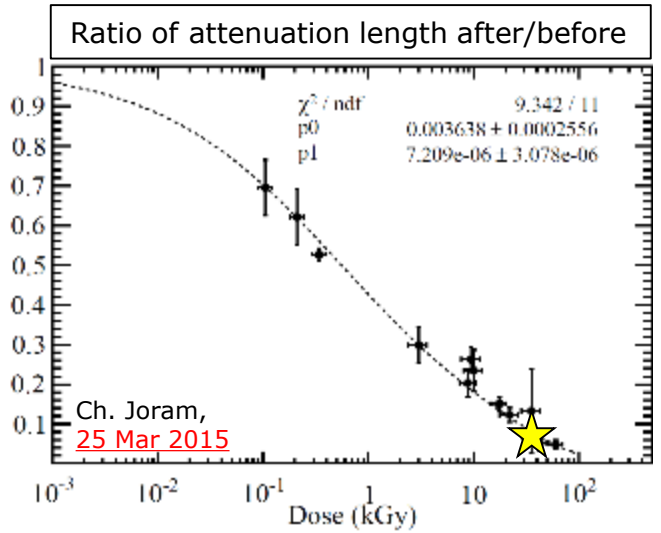
- More recent talks:
  - M. Ferro Luzzi: Tracker Upgrade Overview (Nov 2011)
  - M. Merk: Past Experience with Tracking Opt (Mar 2012)
  - H. Dijkstra: IT for the upgrade (Nov 2013)
  - U. Uwer: Challenges for SciFi at high lumi (Apr 2015)

- TDRs:
  - Letter of Intent: CERN-LHCC-2011-001 (Mar 2011)
  - Framework TDR: CERN-LHCC-2012-007 (Apr 2012)
  - Tracker TDR: CERN-LHCC-2014-001 (Feb 2014)

SciFi: Radiation on fibers

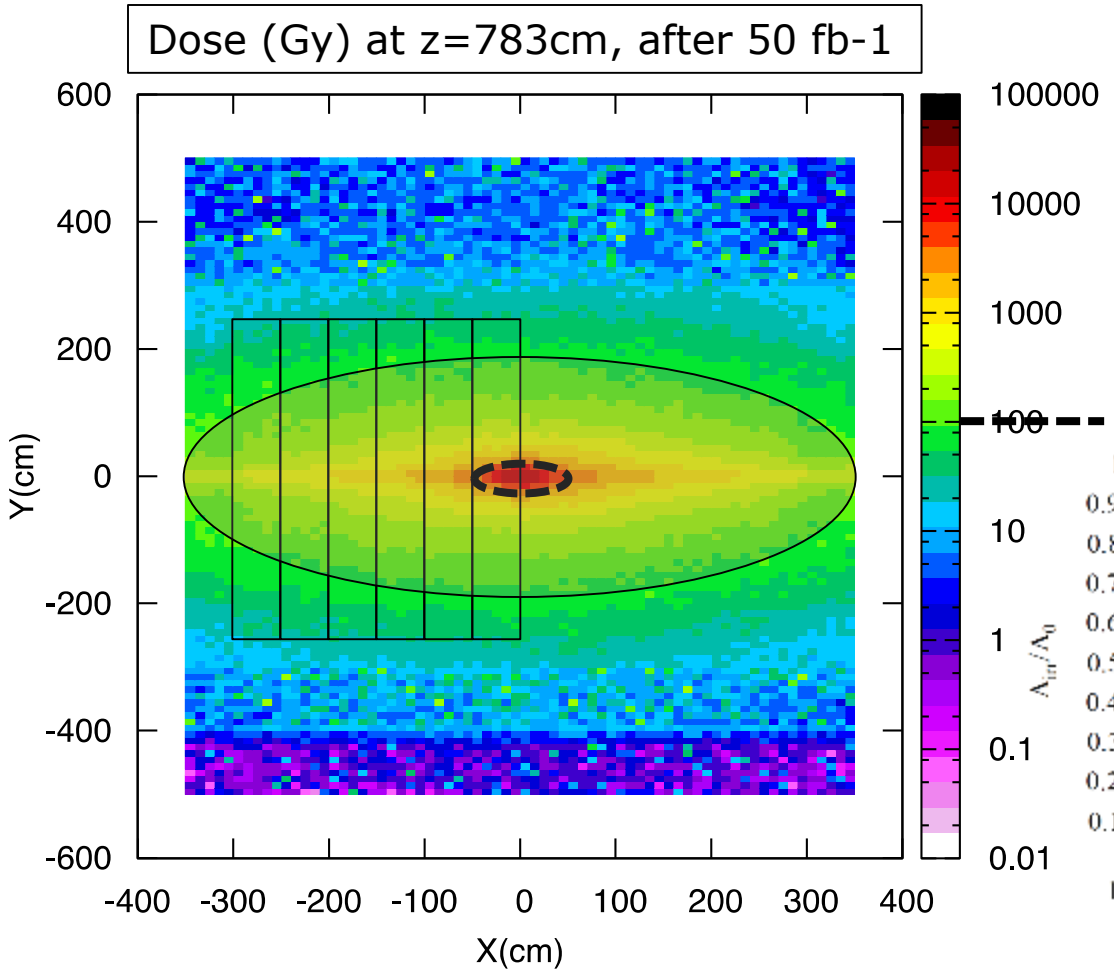


35 kGy after 250 fb^{-1}
= 7 kGy after 50 fb^{-1}



- Maximum dose on fibers: 35 kGy after 50 fb^{-1}
- Dose(1st module) ~ 5-10 x Dose(2nd module) ?
  - 2nd mod under similar conditions as 1st mod in current upgrade?

SciFi: Radiation on fibers



500 Gy after 250 fb^{-1}
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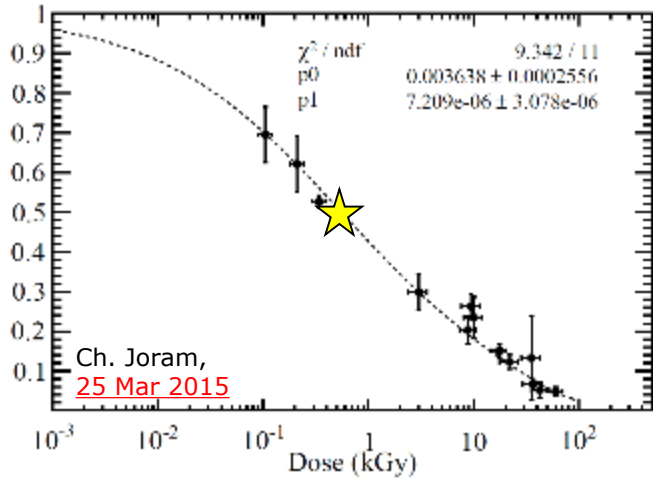
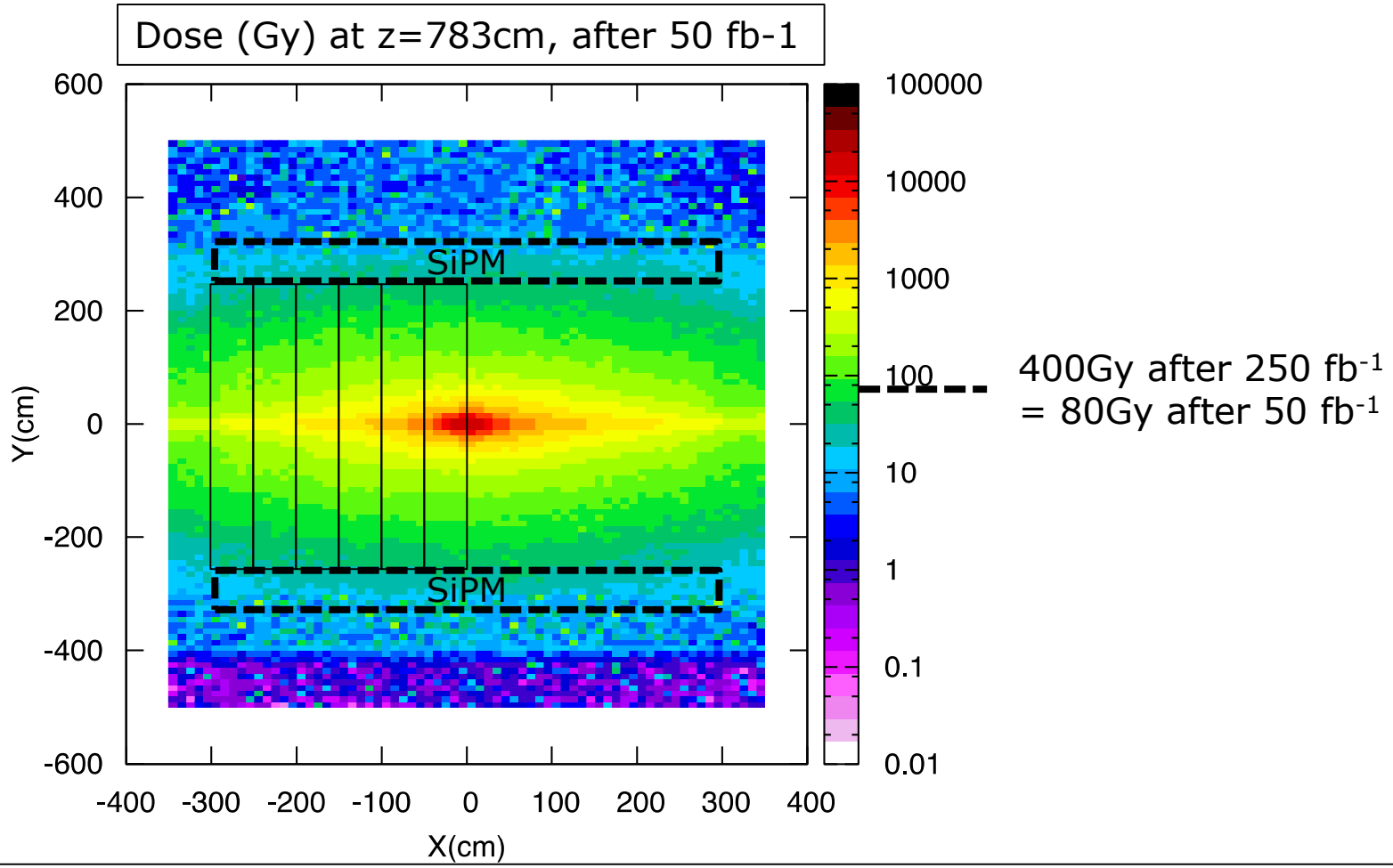


- Significant light loss also in outskirts
  - Challenge….

SciFi: Radiation on SiPM



- Dose on SiPM: 80 Gy after 50 fb^{-1}
- Neutron flux SiPM (~10^{12} n_{eq}/cm^2) causes large dark count rates
  - Challenge…

SiPM operation beyond 50 fb^{-1}

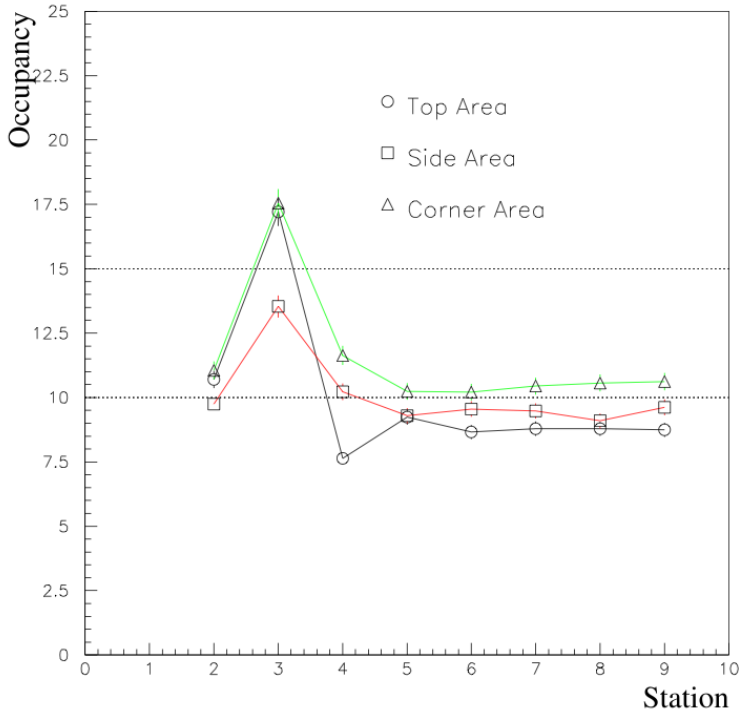
- The neutron fluence scales with the integrated luminosity. I am hesitating to assume a significant improvement of the shielding w/r to what we are currently planning.

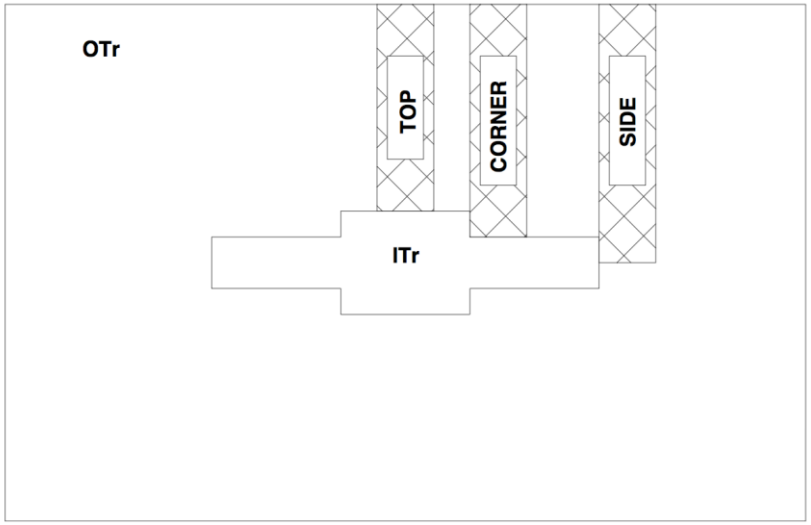
- At neutron fluences larger $1.2 \cdot 10^{12}$ the SiPMs will have DCRs of 40 MHz and more (noise HITS in every channel for every BX). A further decrease of the operation temperature seems difficult.

- Even if the cluster rate will be significantly lower it is not obvious how to operate today's SiPMs under these conditions.

Historical note: occupancy < 10%

Occupancy in OT stations: IT/OT boundary





OTTDR in 2001

Many occupancy distributions were studied. Final design requirement was simple:

- For the seeding stations 10% average occupancy in hottest areas was tolerated
- For the track-following stations (magnet) 15% occupancy in hottest area was tolerated

M. Merk 19 Mar 2012

Historical note: occupancy < 10%

OT Occupancy rule of thumb

- Occupancy spec is difficult to make an exact science:
  - Pattern recognition: 5% average occupancy is easy while 50% occupancy is impossible.
  - Alternative approach to make a spec: relate occupancy to efficiency
- Spec_1 (Occupancy-tail)
  - Calculate the fraction of events with occupancy larger then 40% and set a spec for average occupancy
- Spec_2 (Inefficiency-effect)
  - Inefficiency due to multiple hits should not dominate the detector efficiency for a good design
  - For a given OT straw with a hit, the probability to be hit by a second particle is equal to the occupancy
  - *To first order in occupancy* that efficiency is given by:
    - Eff_straw = 1 – (0.5 x Occ)
- This resulted in the spec for the ***average*** occupancy: Occ < 10%
  - Local occupancy fluctuations can be significantly higher

M. Merk 19 Mar 2012

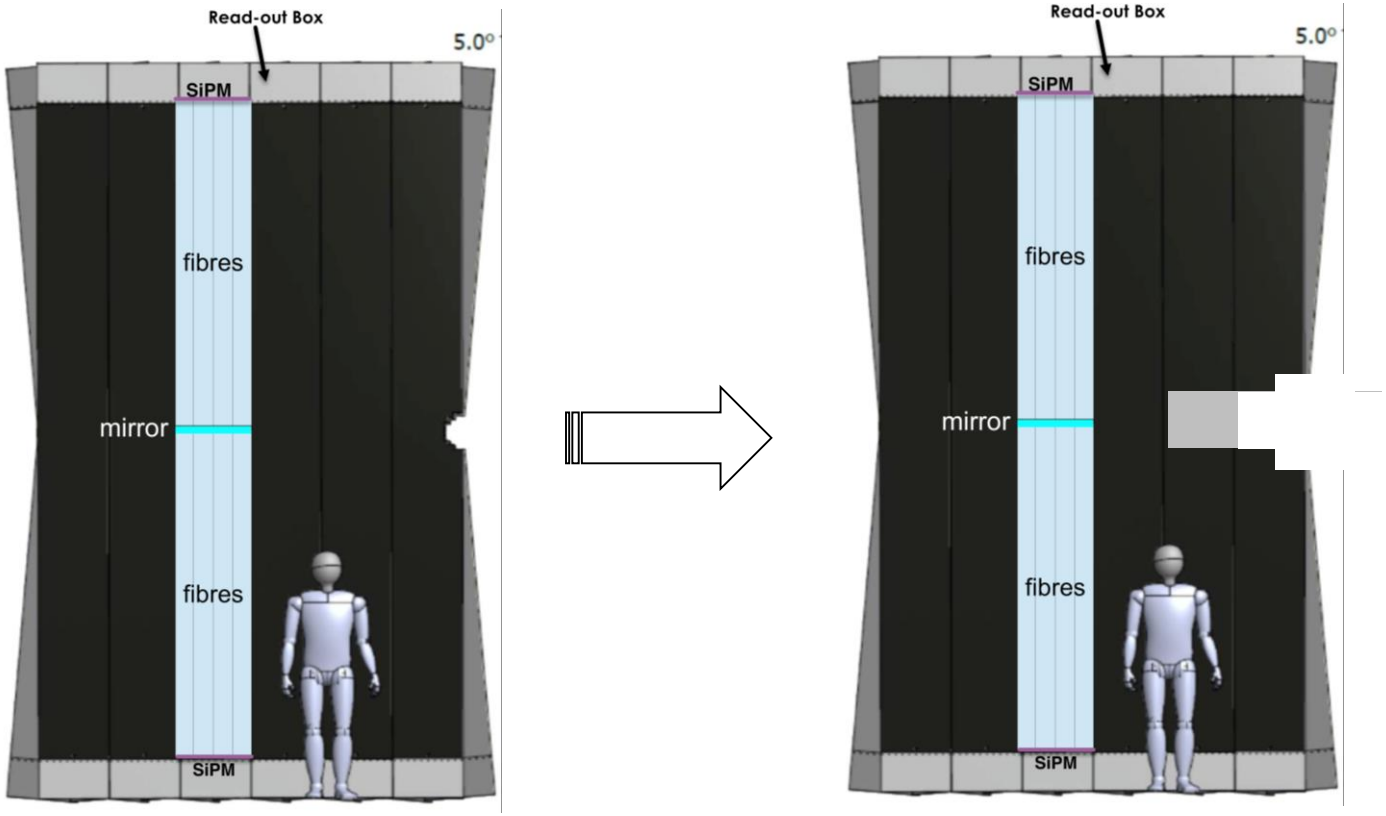
➢ **NB**: a maximum occupancy of 10% is probably too ambitious for SciFi:

A. The resolution over pitch ratio
   - Straws can accommodate a higher occupancy than Si strips

Mechanical considerations

Would need shorter SciFi modules to limit occupancy

- Is it affordable to produce 15% extra mats+modules ?
- Would just a modified central module suffice? (→ see Greg)

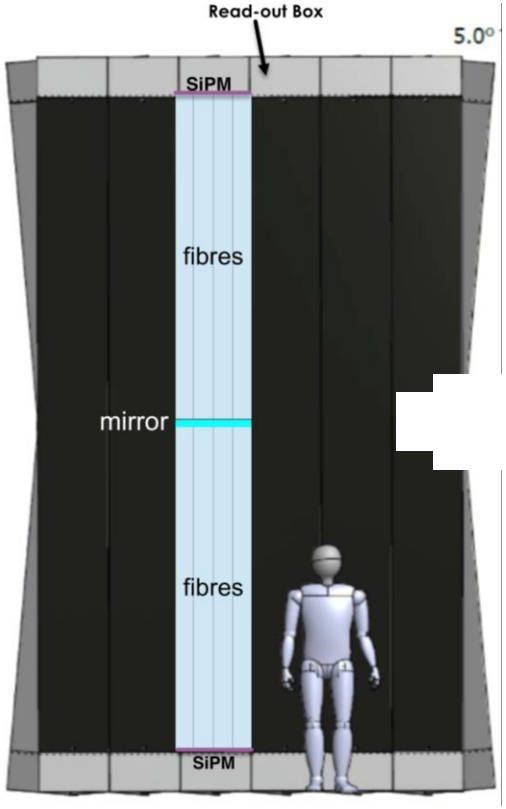


Larger beamhole

- Effect of reduced acceptance on tracking?
  - Loose 20% of B-tracks
  - Reduce Seed ghost rate 19% → 1%
  - Reduce Forward ghost rate 39% → 30%

	No IT coverage	Full SciFi
Seed ghostrate	1.3 %	19.4 %
Seed eff (fromB)	64.6 %	83.2 %
Forward ghostrate	30.4 %	38.6 %
Forward eff (fromB)	71.5 %	90.5 %

$B_s \rightarrow \phi\phi$, ν=7.6, no spillover
Jacco de Vries 19 Feb 2014



Mechanical considerations

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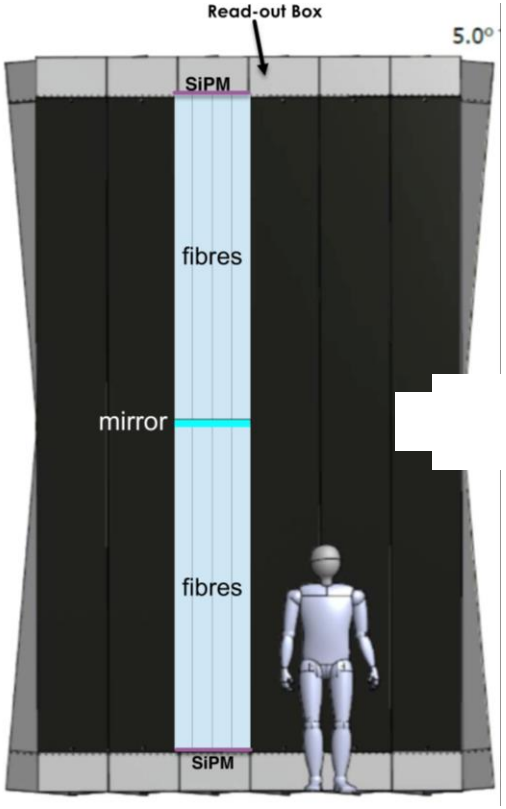
- Is it affordable to produce 15% extra mats+modules ?



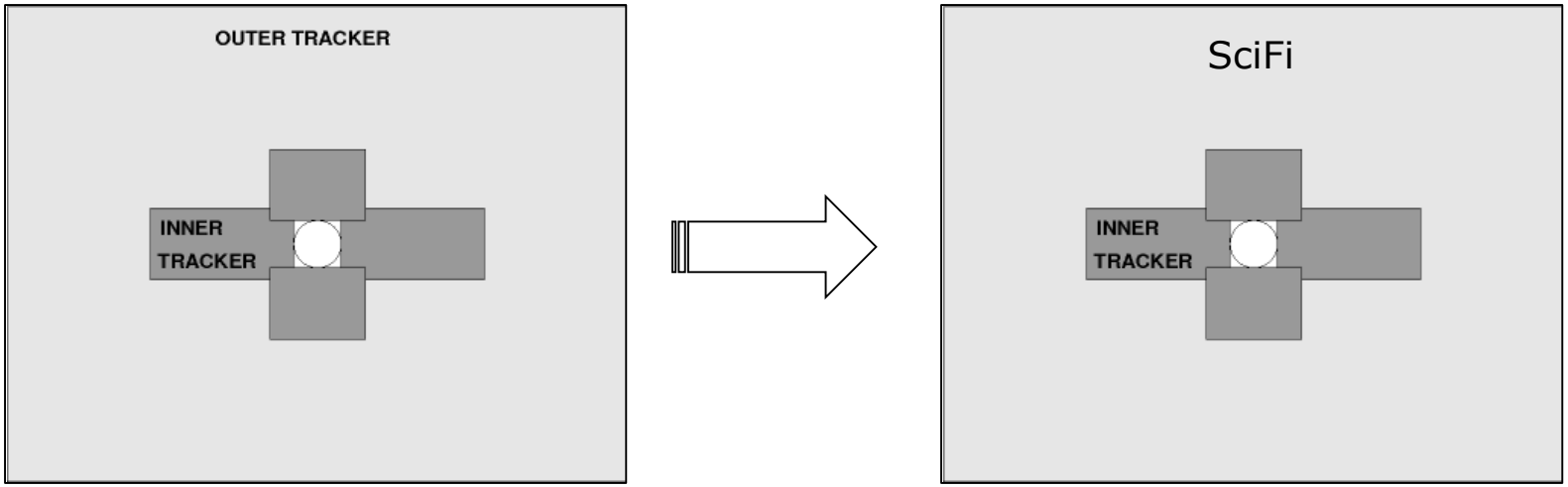
Intermezzo: OT assembly > 2010 ?

From OT experience, we know it is very difficult to resume detector construction 5 years later…

- Cleanroom: demolished at Nikhef and HD
- Materials: procurement of wire, straws, wirelocator, PCB ?
- Support panels: made in house (Cracow), difficult
- Quality: software, measurement tools?
- Expertise: leaves
- Tooling: we tried to keep it…

High occupancy in the center

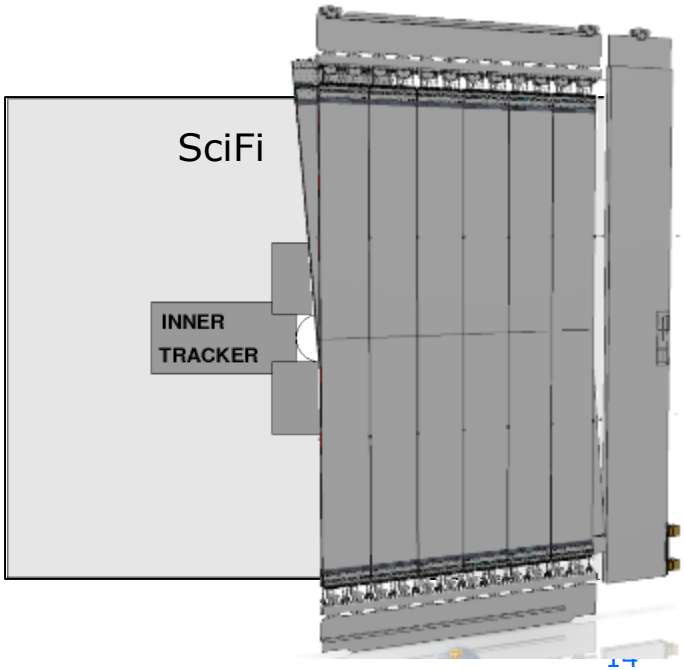
- Consider SciFi + light-IT option?
- Analogy of OT + light-IT option for current upgrade



High occupancy in the center

- Consider SciFi + light-IT option?
- Analogy of OT + light-IT option for current upgrade

- Occupancy? Tracking? (→ see Greg)
- Radiation tolerance fibers?
- Radiation tolerance SiPMs?
- Mechanical considerations?
- Light-IT?



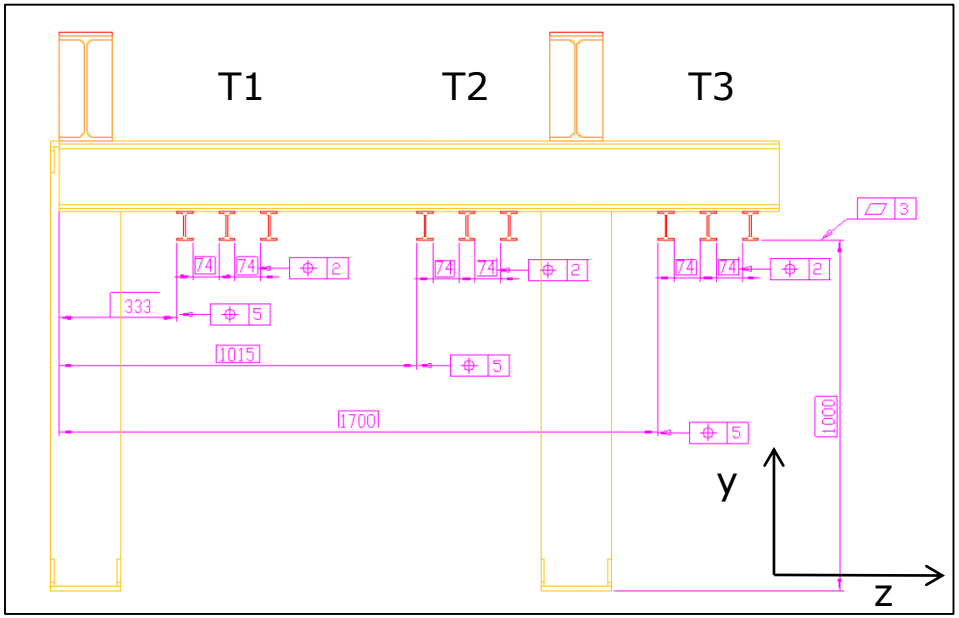
Mechanical considerations

Would need shorter SciFi modules to limit occupancy

Would need space in z to mount a new IT

- Is there space for a 3rd rail, next to the 2 SciFi rails?
- No…: space is consumed by SciFi

OT and IT Rails:

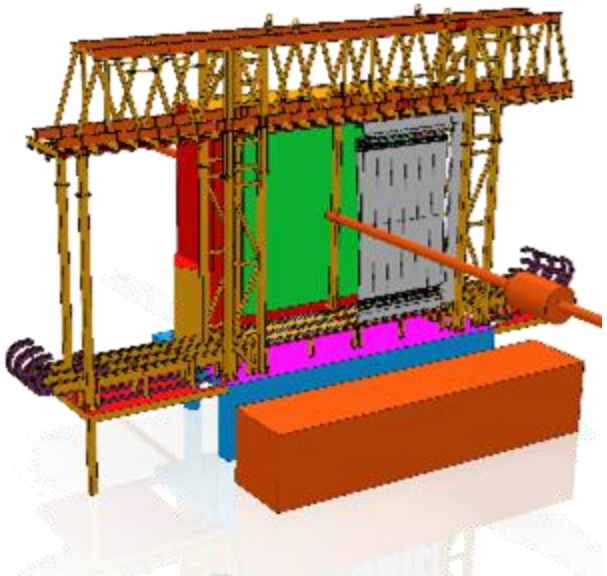


Mechanical considerations

Would need shorter SciFi modules to limit occupancy

Would need space in z to mount a new IT

- Is there space for a 3rd rail, next to the 2 SciFi rails?
- Or could we mount an "IT-light" on the SciFi ?
  - Possibly an IT-*light* is thinner/lighter/compatible ?



“IT-light” R&D

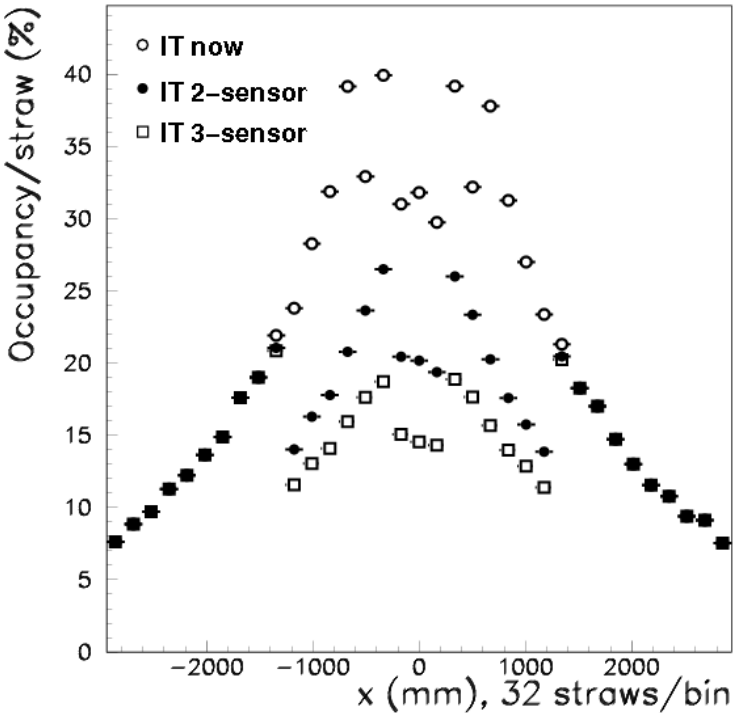
- Documentation (Hans Dijkstra et al.)
  - LHCb-INT-2016-011 Assembling and testing of silicon prototype module for the fall-back solution of the LHCb Tracking upgrade
  - LHCb-INT-2014-006 Airflow induced vibration of the Si-IT prototype
  - LHCb-INT-2014-005 Radiation environment and cooling of the Si option for the IT upgrade
  - LHCb-INT-2013-063 Report on SI-IT Prototype Modules R&D for the LHCb Upgrade
  - LHCb-INT-2013-048 Simulation and tracking performance of the Si IT light detector

Hans Dijkstra, Sergii Kandybei, Eric van Herwijnen, …, …

Why IT-light?

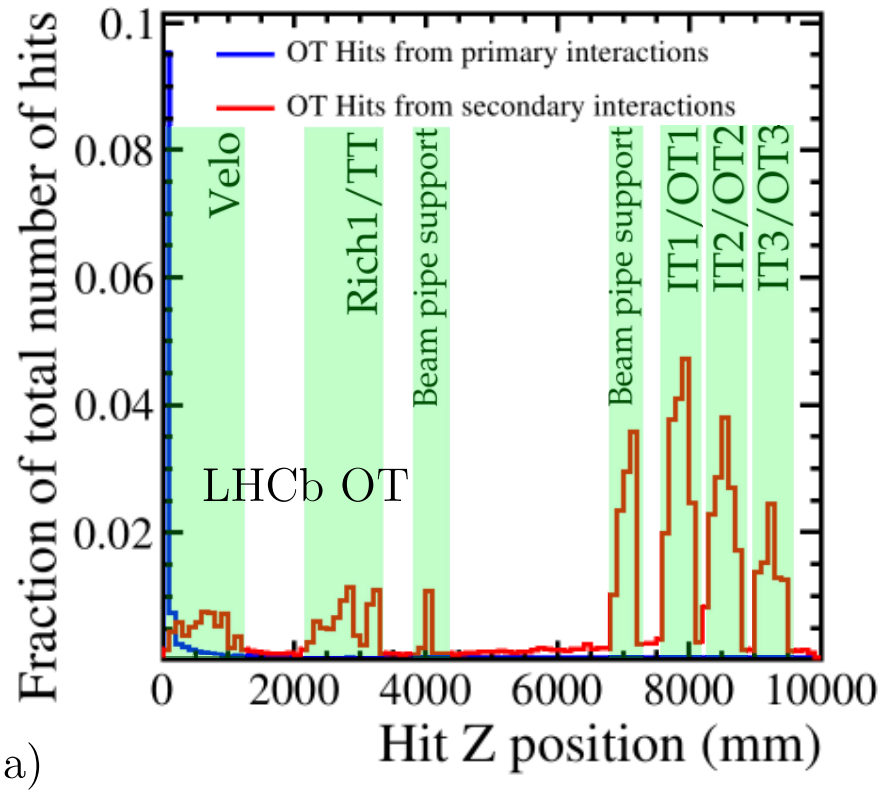
- Many hits from secondary interactions in IT material:

OT occupancy



H. Dijkstra et al., Framework TDR, LHCC-2012-007

"Origin" of OT hits

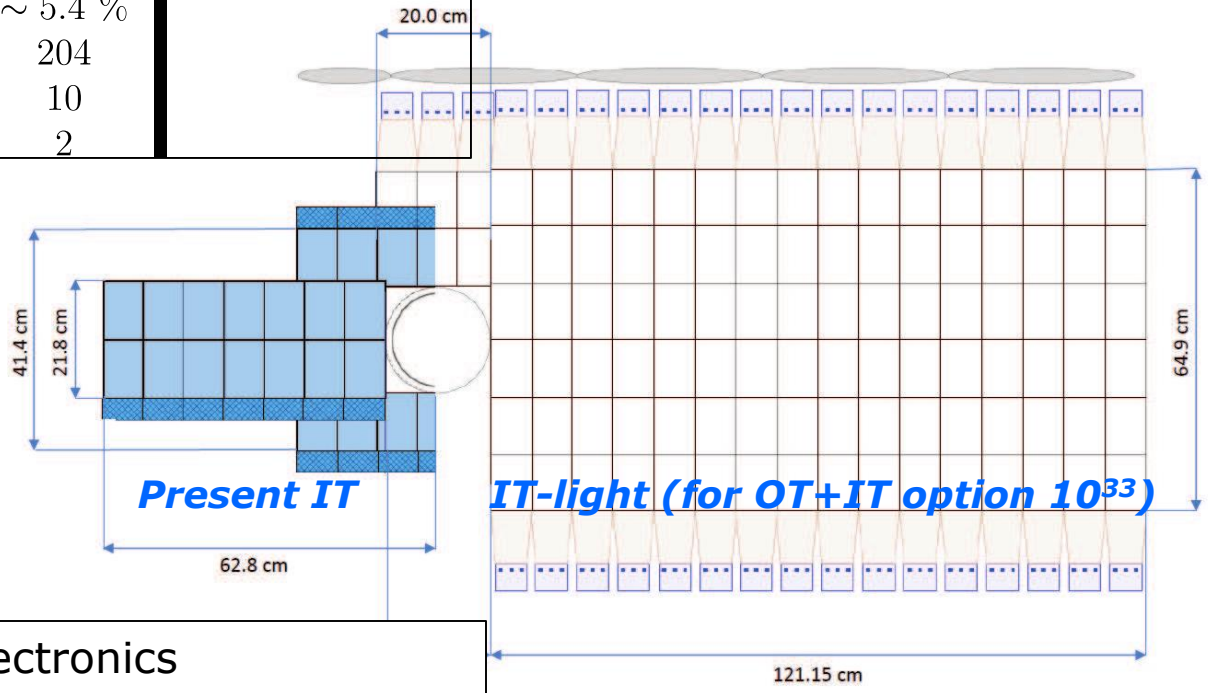


(a)

V. Coco et al., OT performance, arXiv:1311.3893

Original IT-light: big

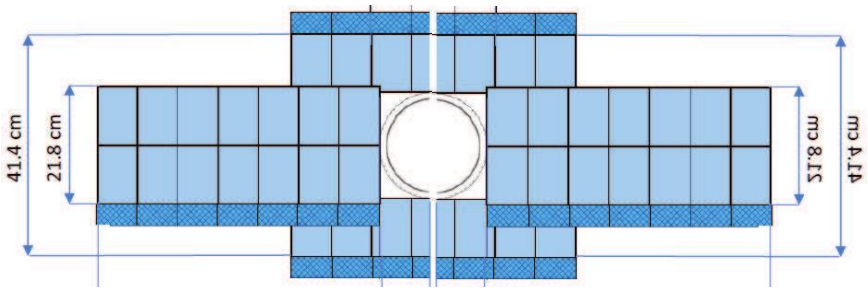
	IT-now	SiIT light	
coverage B decay tracks	28 %	47 %	
Max OT-occupancy	~ 43 %	~ 22 %	$B_s \to \phi\phi$, $\nu = 7.6$
Max IT-occupancy	~ 7.5 %	~ 3.4 %	$B_s \to \phi\phi$, $\nu = 7.6$
X/X0 for $\eta > 3.5$	~ 15 %	~ 5.4 %	
Nr sensors/layer	42	204	
Nr layers	12	10	
Nr stations	3	2	



- Cool only sensors, not electronics
  - Air cooling, checked for vortex induced vibrations
- Light-weight (vertical) carbon support
- Aluminum flexible microcables (no bonds)
- ~10 kg per full station large IT-light (4 layers)

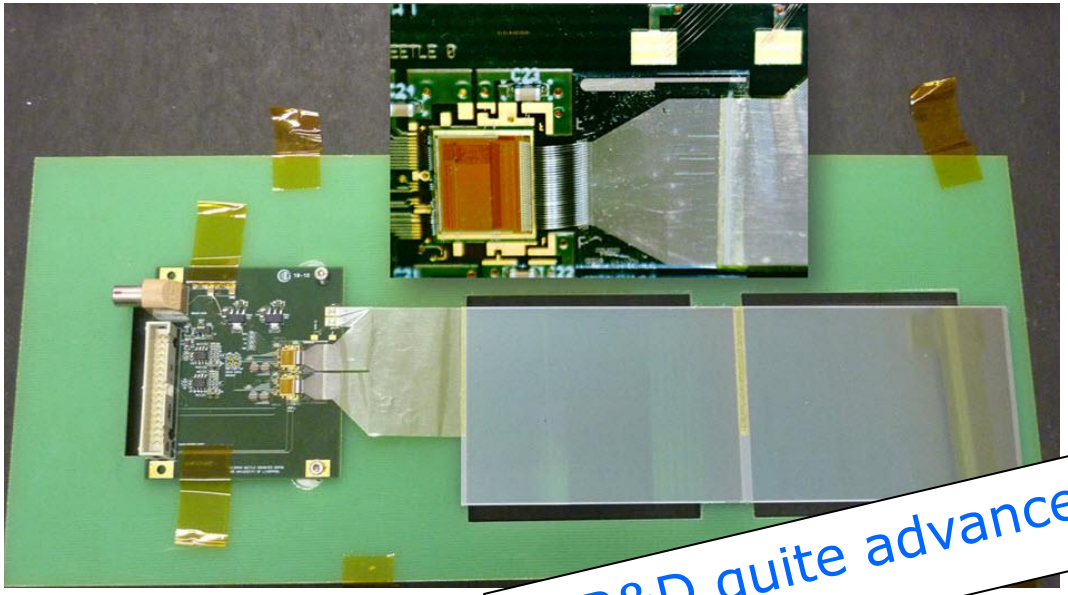
Small IT-light?

IT-light at present-IT dimensions?
(see Greg)



- Cool only sensors, not electronics
  - Air cooling, checked for vortex induced vibrations
- Light-weight (vertical) carbon support
- Aluminum flexible microcables (no bonds)
- Weight of full station small IT-light (4 layers)?

IT-light



➤ R&D quite advanced ?

6 Conclusions

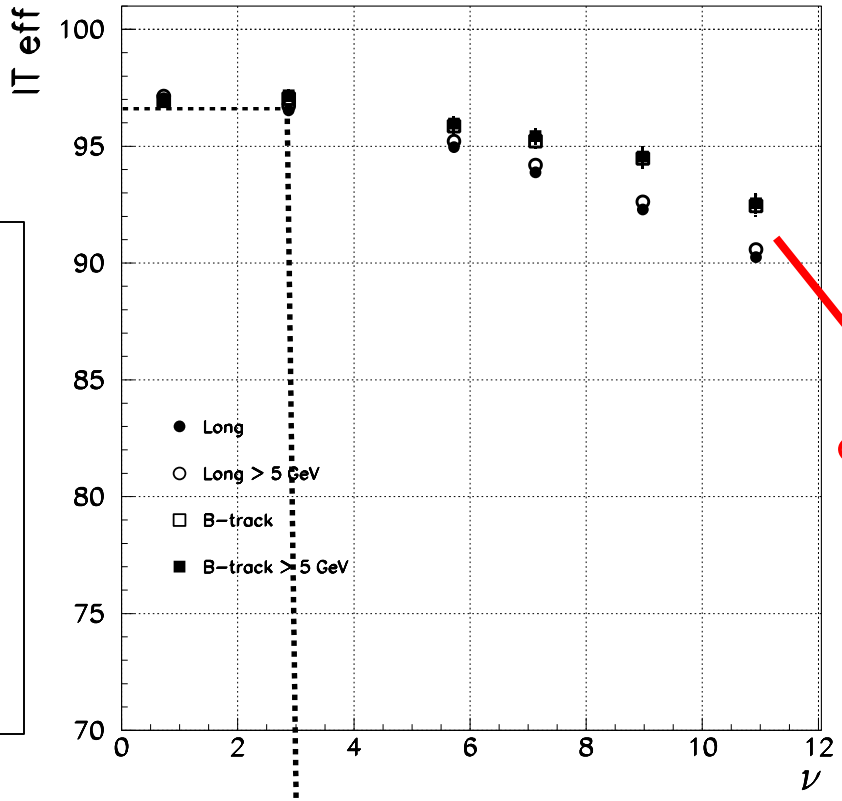
The prototype module for the fall-back solution of the LHCb Tracker upgrade was successfully assembled using TAB-flex connections and Alibava Si pitch adapters. The design of the module is very similar to the final version that could be used in the "SiIT-light" detector. The basic properties of silicon sensors such as leakage current and capacitance were measured. The tests with β^--source were carried out and demonstrated a signal to noise ratio S/N $\sim$ 14, while the noise level is uniformly distributed over the channels. The obtained results show that chosen prototype assembly technology is a good approach for large area silicon trackers construction.

Hans Dijkstra & Sergeii Kandibey, LHCb-INT-2016-011
Assembling and testing of silicon prototype module for the fall-back solution of the LHCb Tracking upgrade

Tracking efficiency?

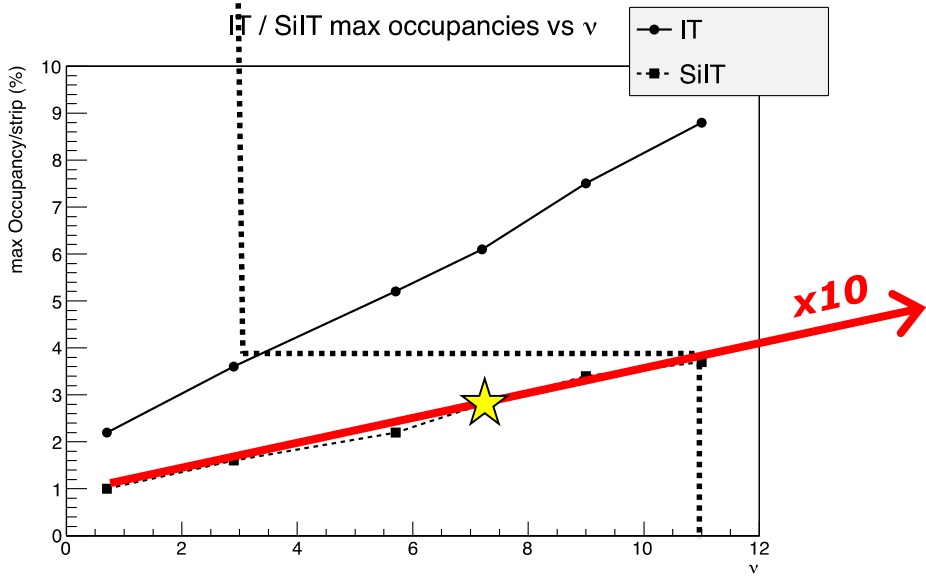
- At L=2x10^{34}, ν=76
- Max occ: ~24%
  - Corresponds to ν=30 for current IT

➢ ie. what is track eff. at ν=30? (for current IT)



➢ Quantify performance in terms of occupancy

- Where is boundary of 5% occ ?
- ➢ See Greg



Conclusions

- Present SciFi limited to 2 10^{33}
  - Radiation levels
  - Occupancy, combinatorics
- Higher lumi would require an Inner Tracker
  - Size of IT?
    - Between present IT and "IT-light" ?

- Construction of shorter SciFi modules ?
  - Best done as continuation of present SciFi construction
- Construct new light-weight IT ?
  - Less secondary particles
  - Smaller and lighter: easier to mount
  - Significant R&D has been done

Historical note… (M.Merk) :

(My) Conclusions

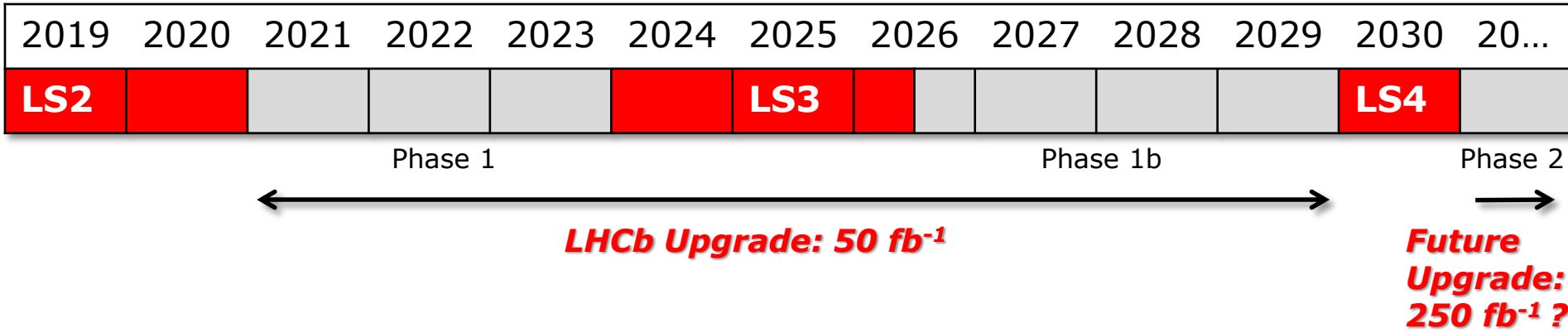
- LHCb upgrade must be ambitious
- Status of technology is important
  - Success of a detector also depends on dedication to details in the design
  - Push material thickness to absolute minimum
  - Invest effort on mechanical stability and alignability
- Design must include safety margin to allow for future improvements
- Optimisation: usefull to have “robust” estimators for different options
  - Occupancy
  - Combinatorics
- Where pattern recognition is used try to find “honest” comparison
  - Algorithms don’t have to be fully tuned to make relative comparisons
- Decisions often based on straightforward arguments (“common sense”)
  - E.g. An upgrade cannot have worse resolution (I.P. or δp/p) than the original

M. Merk 19 Mar 2012

Timeline?

- "Future upgrade: LS4"
- "Enhanced capabilities: LS3"

- SiPM and fibers suffer from high dose (even with larger hole)
  - Personal opinion: intermediate ambition, with new IT in LS3 ?



See talk by Nicola Neri for tracking ideas at very high lumi

From: F. Brodry LHC roadmap (MTP 2016-2020) Link