Mighty Tracker: Simulation Status and Plans

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Barcelona Meeting

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Outline

- Reminder of FTDR studies
- Descoping options
- Tools
- Some recent results
- Plans

See also talks here: https://indico.cern.ch/event/1251283/

Mighty Tracker baseline for U2

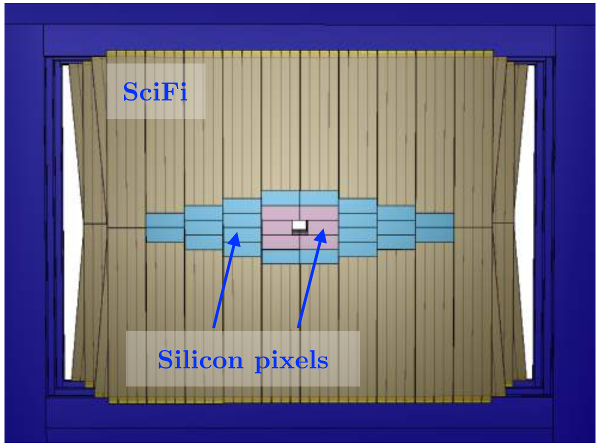
- The high track density in Upgrade 2 is a challenging tracking environment
- The occupancies in the inner part of the SciFi reach up to 20 %
- There will be significant radiation damage to the Scifi even after Run3
  - Need a detector that can stand 300 fb^{-1} in inner part

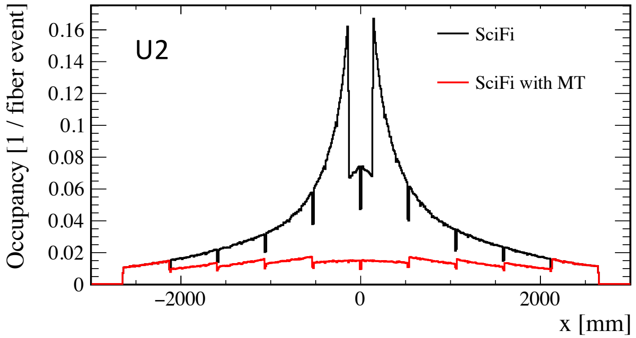
Baseline layout described in https://cds.cern.ch/record/2658015?ln=en

- 6 layers of HV-CMOS pixels. Each layer 3m^2 (18 m^2 in total)
- Each layer divided into 28 modules 54 x 20 cm^2
- Default pixel size 50 x 150 μm (100 x 300 μm ok from physics perspective)

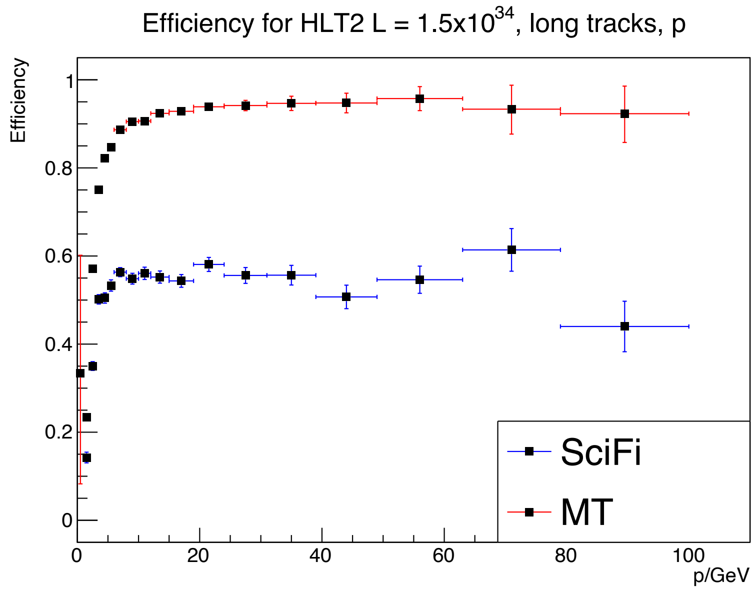
Design driven by SciFi occupancies and radiation damage

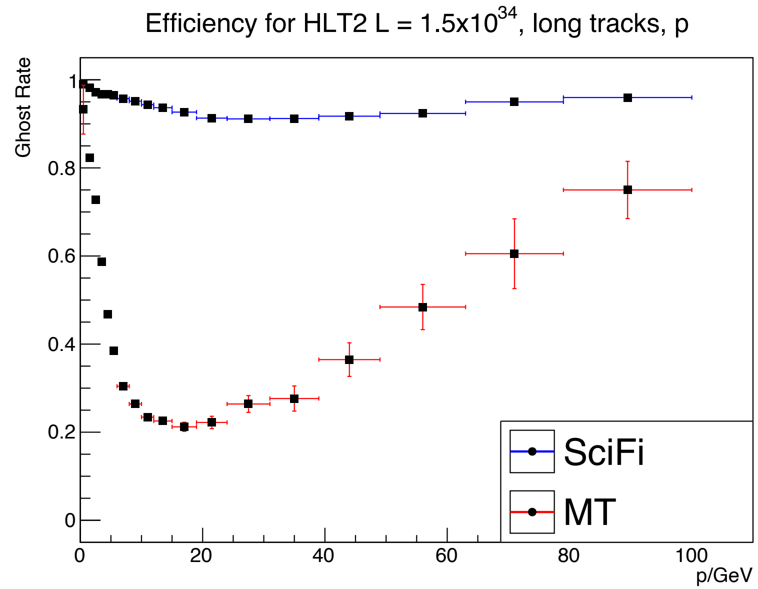
- Assumes SciFi as in the U1 (ie no gains from better SiPMs or Cryo cooling)
- Occupancies in SciFi outer part in this design similar to inner part in U1





Tracking studies for FTDR





From the FTDR

Assuming an efficiency about 95% for the tracks passing through the MT MAPS, as discussed above, an overall long-track efficiency of above 90% can be achieved, for tracks with momentum above 5 GeV/c, which are used by the majority of physics analyses. A ghost rate of below 30% is estimated from the current studies and substantial improvements are expected with algorithm optimisation. This performance is comparable with the track reconstruction performance expected in Upgrade I [155], and is much improved as compared with the case of a SciFi detector covering the full acceptance, with the additional benefit of reducing the reconstruction time by an order of magnitude. Further improvements are expected by using the new 4-D reconstruction algorithms which are being developed for the VELO, and by exploiting the improved pixelation in the UT.

These plots were made patching together existing software and standalone studies

For a TDR we need to prove these statements and do things properly

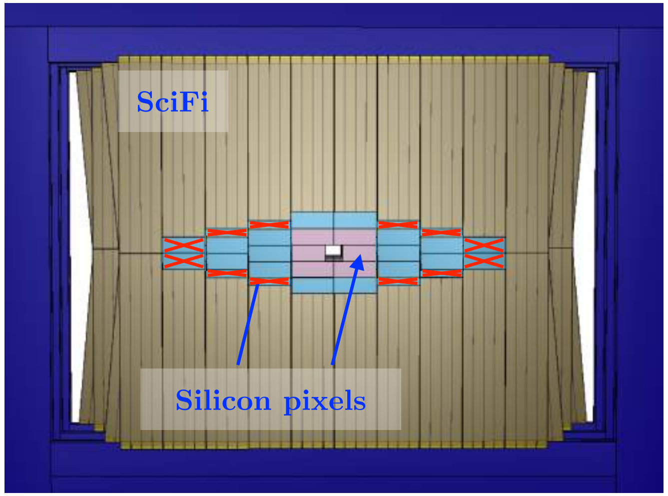
Descoping scenarios

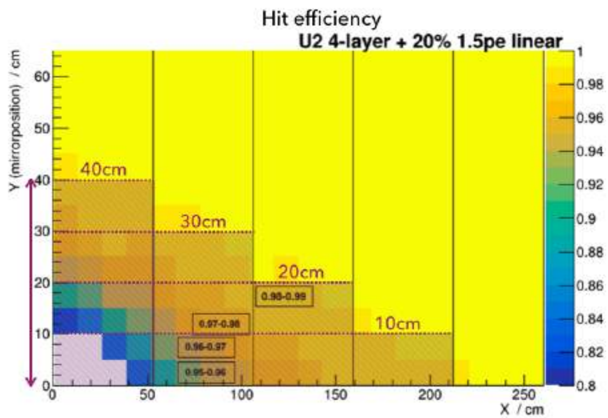
The rules of the game are reasonably clear

- Need to reduce cost by 15 – 30 % (conservative - optimistic)
- Having two detector technologies doubles the cost compared to Upgrade I
- For SciFi costs are well known (largest unknown is cryogenic cooling cost)
- Obvious way to reduce costs is to reduce silicon area in x-y or reduce number of layers
- Small savings on SciFi side possible by reducing number of fiber layers per mat from 6 to 4, other possibility is to reduce SciFi outer acceptance
- Running at lower instantaneous luminosity could help tracking, but SciFi radiation damage driven by total integrated luminosity.

Downscoping: A modest tracker

- In FTDR main descope option discussed is reducing the silicon area: assume we gain from cryo cooling on the SciFi side.
- Also reduce to 5 silicon layers
- Silicon area reduces to 11 m^2
- Reduces cost of Silicon by 40 %
- With 4 fiber layers for SciFi total system cost also reduces

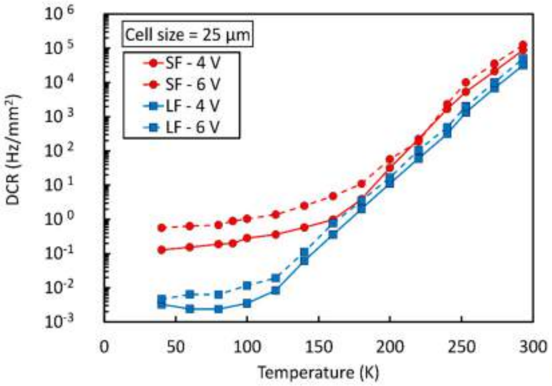


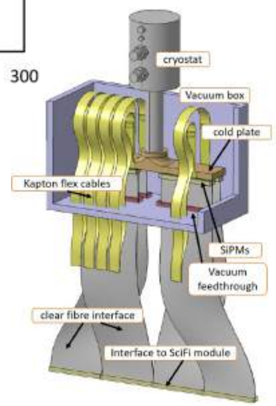


SciFi Enhancements

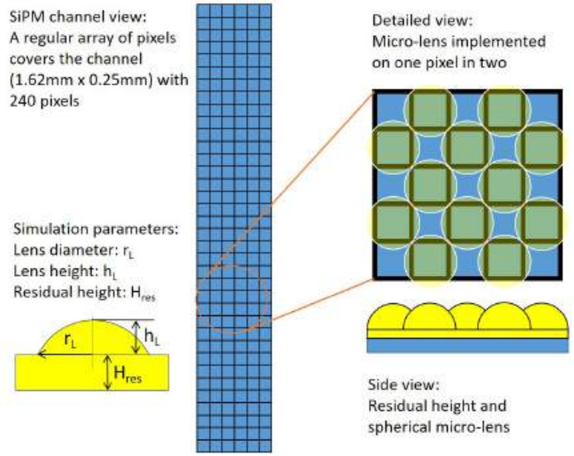
Major improvement seen cryogenic cooling to allow to run below -120 °C

- Essential to maintain reasonable noise rate for SiPMs after irradiation
- Should allow to reduce the cluster thresholds while keeping acceptable dark count rate





Additional interface
~ 16 % loss in light

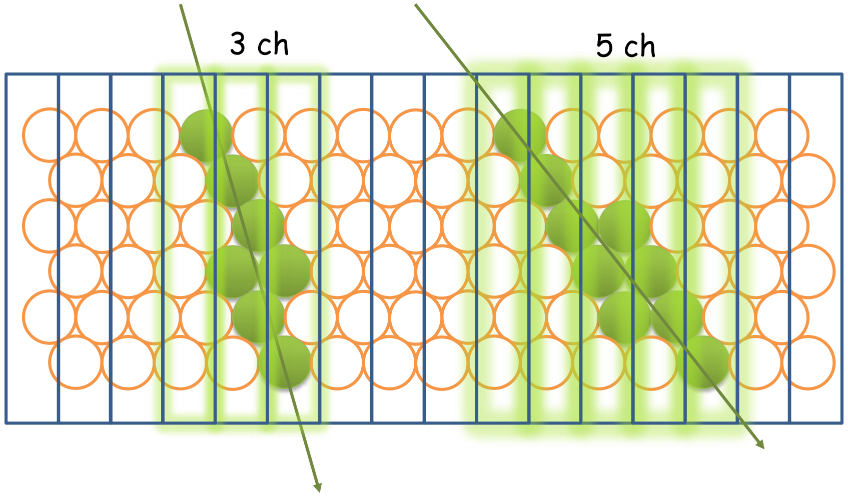


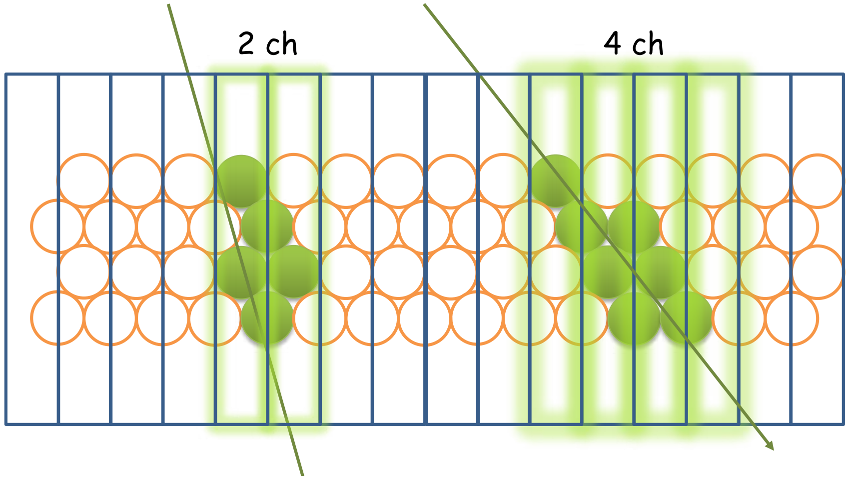
Better SiPMs and micro-lensing should compensate for light loss

SciFi Enhancements

Investigate reducing number of fiber layers per mat from 6 to 4

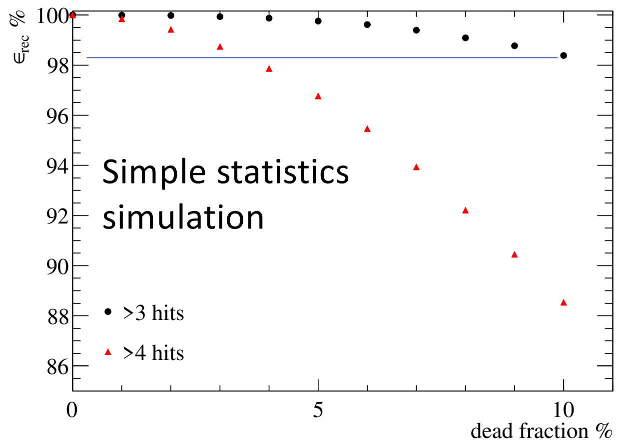
- Reduce detector size in z, reducing occupancy (though not track density) from high angled tracks
- Less material
- Lower light yield but may be ok with cryo cooling
- Need to understand if this works





How many layers of Silicon needed ?

- Since tracks are in magnetic field, standalone tracking needs 3 pixel measurements minimum
- With three hits, you have little redundant information: ghost rate will be high
  - Nothing to confirm the triplet is real
- 4 or 5 hits minimum needed
  - With 4 or 5 hits candidates can be ranked according to χ^2 and number of hits
- Are 5 layers enough ? Depends on the detector efficiency
  - Inactive sensor areas (guard ring/periphery)
  - Non-functional pixels
  - Dead pixels
  - Loss due to tagging to beam crossing
  - Radiation damage
- If you can keep the sum of all these down to 4-5 % level 5 layers might be feasible for track finding, may lose a bit in momentum resolution



A modest Tracker

Describe this modest scenario as a possibility in the FTDR. Work is needed to prove its performance

Where we got for FTDR

Criteria	Status
SciFi occupancies	Study was done, looked ok
Radiation damage	Studies in progress. Looks promising. We need to complete and carefully review to be sure assumptions are solid since a lot of factors are in play – e.g. improvement from Cryo cooling SciFi (next slides)
Tracking	First studies show tracking is equally bad with both modest and full Mighty layouts. We also need to be more careful with dead areas/inefficiencies if we move to 5 layers

New ideas

Barcelona preparation meeting generated some new ideas

Reduce SciFi acceptance

- Removing outer modules saves electronics/fiber costs
- Reduced acceptance in y, reduces fiber costs, frees up space (Cryo cooling/more neutron shielding)
- Quick RapidSim simulation: reducing size in |y| by 20 cm and removing outer module lose ~ 10 % of $B_s \rightarrow \phi\phi$ events (while cost reduced by 20-30 %)

MightyPix: Can we gain by reducing links/data rates by reducing coverage at high rapidity?

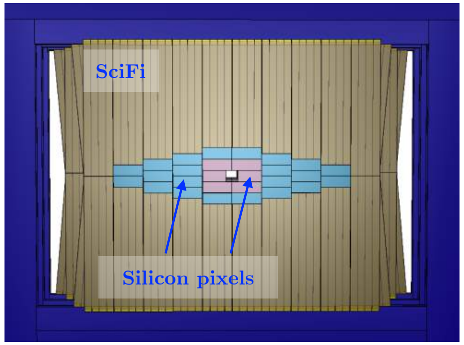
Possibility to add ~ 4 bit TDC to SciFi (time resolution ~ 1.5 ns)

- Gate readout window and reduce occupancy/storage requirements?
- Reduce combinatorics for tracking?

Add threshold information in SciFi (Mighty Tracker)

- Allow identification of Helium-3

LS3 Enhancements



The SciFi is designed to survive 50 fb^{-1}

- Baseline for Run 4 is full SciFi as in Run 3
- FTDR describes possibility of adding MPix in Run 4
- Originally six layers inner tracker enhance performance + allowing to compensate for loss of SciFi performance beyond 50 fb^{-1}

Addition of MPix after LS3 needs to justified by simulations:

- Tracking performance of Upgrade detector at end of life (SciFi and global tracking)
- What we gain by adding silicon (resolutions, ghost rates, timing) versus losses (more material)

Since the FTDR understand LS enhancement is a highly constrained parameter space

- Likely can only fit 2 layers (after T2, front of T3), covering inner part of detector
- Bolt on to current detector – simplest use would be bolt on to current tracking to validate tracks

What we need to do

For the next TDRs/scoping document we need a detector configuration that is demonstrated to give good tracking performance. **That means optimizing existing or developing new tracking algorithms**

Reducing the cost means we push the envelope/accept some lost of physics: **we need to sure of our assumptions in both SciFi and Pixels and have them in the MC.**

Global tracking system should work as a whole. Pixel UT should help downstream, material budget of all elements needs to be under control. Momentum resolution of whole detector needs to be estimated.

Reasonable concern expressed by RTA project. Reducing silicon part may make reconstruction time larger, meaning more trigger resources needed with non-negligible cost and carbon footprint

Tools in hand: Old ways

Run 3 SciFi Geometry exists

- Used to kludge together FTDR studies
- Still useful for LS3 enhancement studies, useful to evaluate geometric losses

Toy studies

- Still useful
  - Evaluating geometric losses in case of reduced detector acceptance
  - e.g Momentum resolution studies of Renato that will be presented after coffee by Fred
  - For SciFi we need to have full simulation details

Tools in hand: Geometry

We have a DD4Hep geometry for the silicon

- Does not make sense to develop a DetDesc geometry. Assume Upgrade 2 studies will be done with DD4Hep. For global tracking studies need all tracking detectors simulated/digitized in DD4Hep
- There are hacks around to port DD4Hep to DetDesc (allowing to run Gauss) which allow to do simple things like radiation scans/occupancies but to do tracking we would need old style detector elements
- Can simulate both Run 4 and Run 5 geometries

For the SciFi

- SciFi will is ready in for simulation in DD4Hep for Run 3?
- Need to cut holes for default and modest layouts, decide on number of Fiber layers in a mat etc

Global detector envelopes need to be defined (e.g. no space to put layer between last z of current SciFi and RICH2) and z-positions of layers adjusted

Tools in hand: Digitization

First digitization chain for MPix in place

- Classes to go from MCHits to Deposits to Digits with basic functionality
- For now dummy channel numbering scheme with Extended LHCbID
- Need to code proper xyz to channel mapping function

First algorithms to populate these classes + monitoring code

- Starting point for further development both both Run 4 and Run 5 detectors

Missing RawBank/DAQ encoding/decoding: we will need this for e.g accurate data rate estimates

Tools in hand: Digitization

Fiber digitization for Run 3 exists

- Parameters need adjusting for Run 5 studies: e.g. less noise with Cryo cooling, radiation damage

Also developed smeared MCHit class (could be interesting for fast studies)

- Ideas in simulation group to have some ‘fast’ smeared MCHit digitization for studies. For pixels can be quick way forward (no need for Raw data format), for SciFi (performance critical) full digitization needed

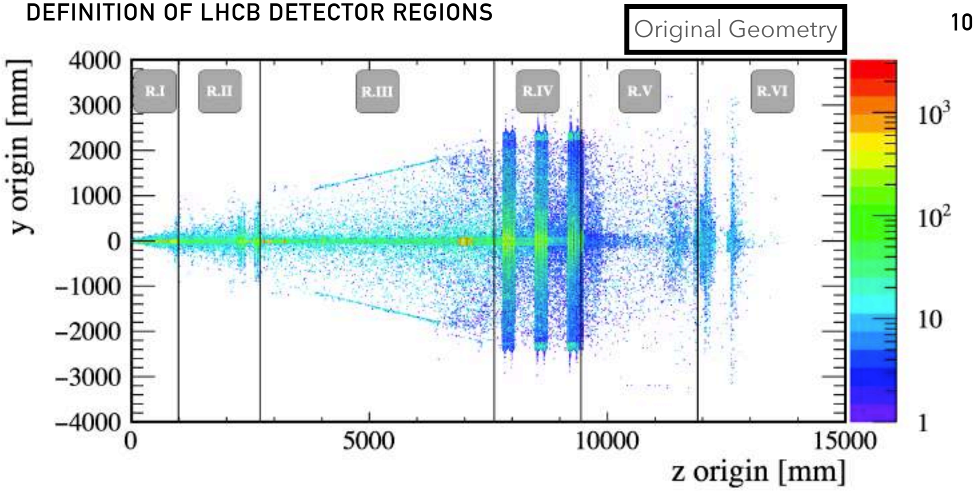
V. Bellée, T. Hume, O. Steinkamp

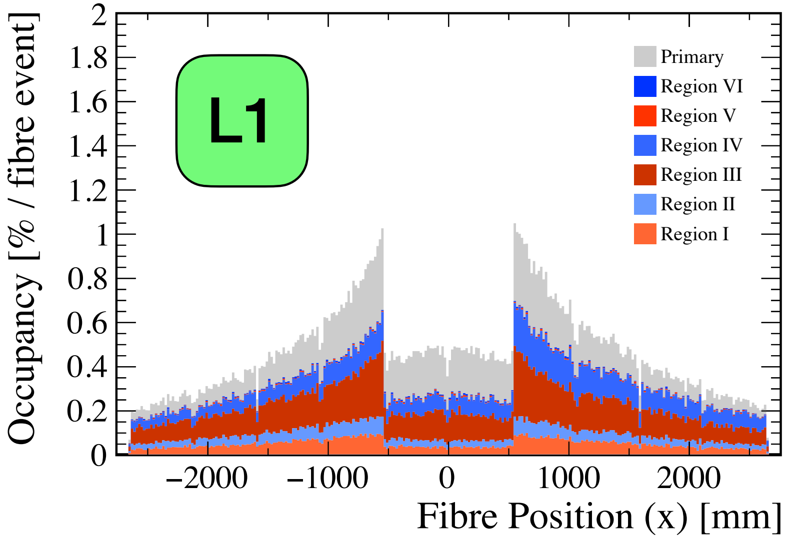
IT Occupancy Study

Study focused on Run 3 detector and impact of extra material of Inner Tracker

In particular DCDC convertors will add a lot of material

DEFINITION OF LHCB DETECTOR REGIONS



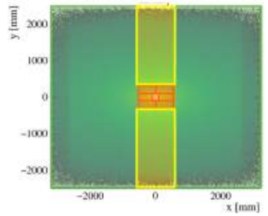


~75 % of the occupancy in 1st layer of SciFi is generated upstream in material interactions

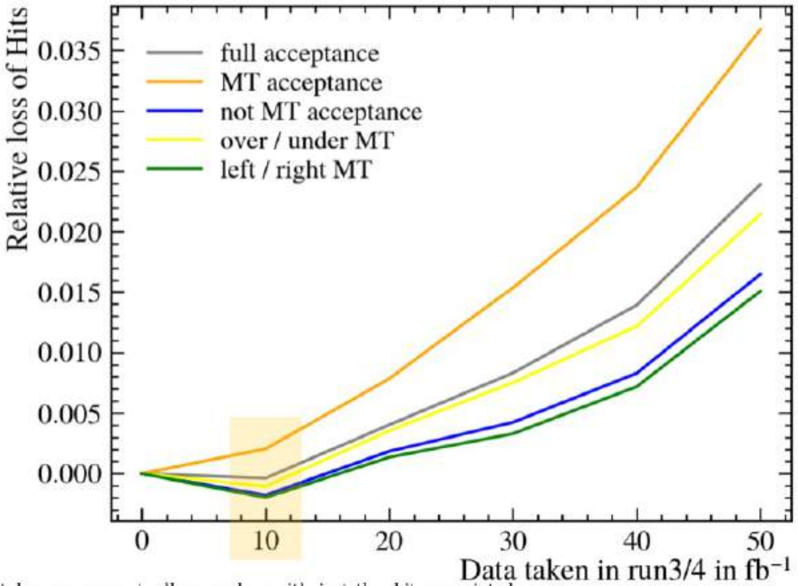
https://tinyurl.com/2p8kwr24

SciFi radiation study

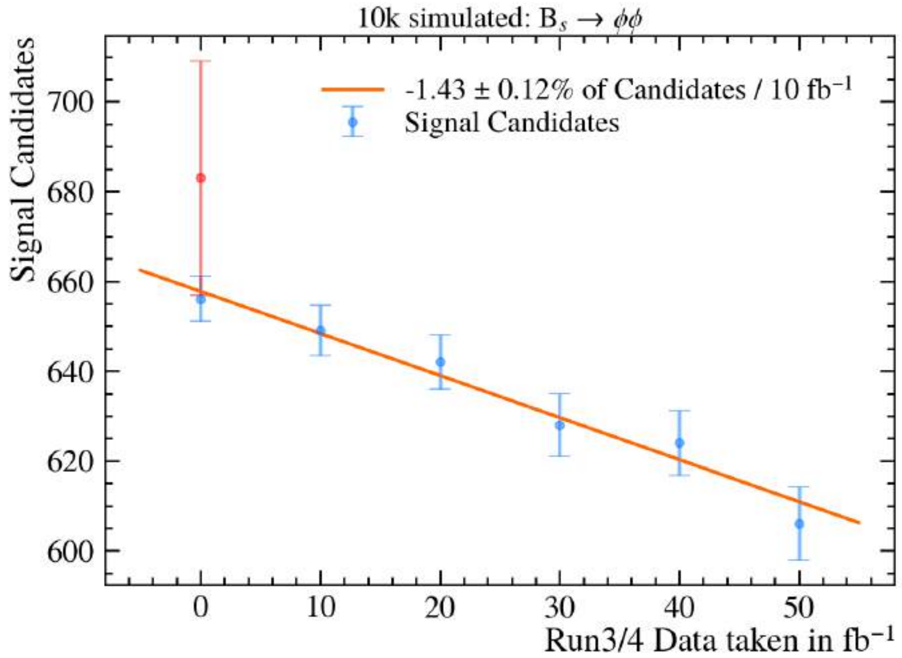
Marian Stahl[1], Lennart H. Uecker[2]



Studies of effect of radiation damage in Run 3 on Scifi



Total occupancy actually goes down, it's just the hits associated with the MCParticles' that go up. → Statistics?

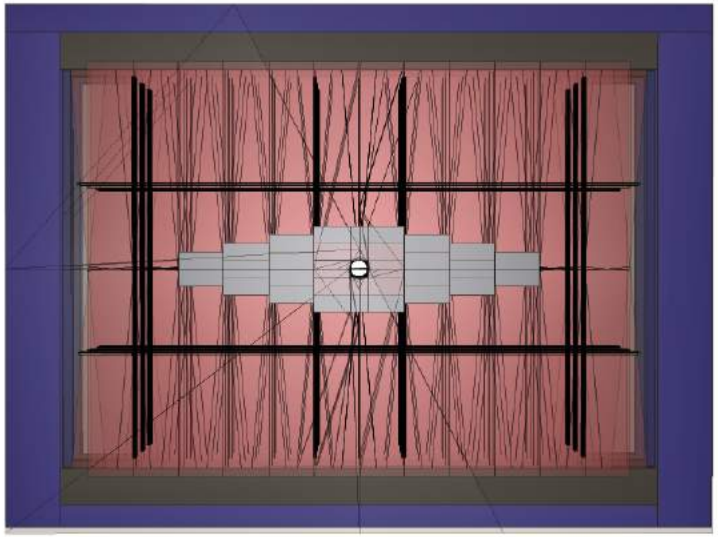


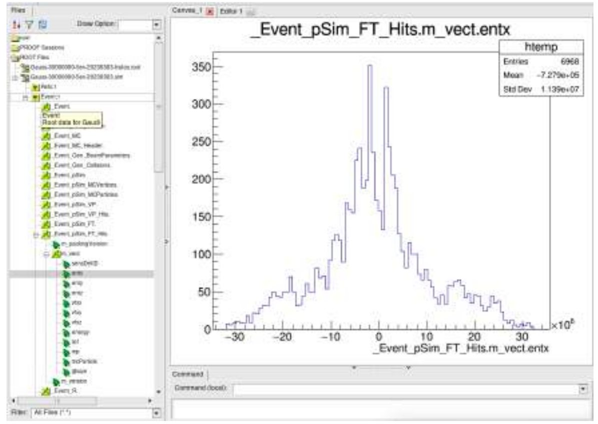
Next step what does MPix bring ?

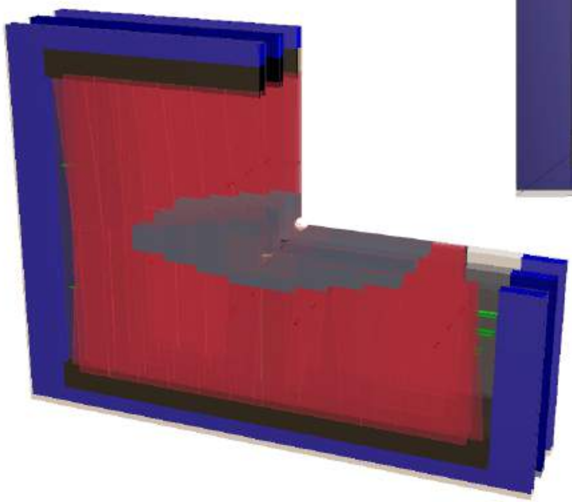
https://tinyurl.com/2p9enuhz

DD4Hep Geometry

Tai-Hua Lin







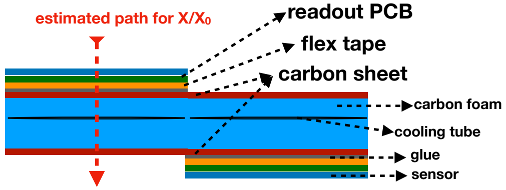
DD4Hep geometry for MPix exists and gives Geant hits

Tai-Hua Lin

Material budget

Material Budget - per layer (apply filling factors)

Material Unit	Thickness μm	Filling Factor (%)	Layers	X_0 (cm)	X/X_0 (%)	composite
Silicon	150	100	1	9.37	0.160	Si
Cooling tube	50	12	2	28.6	0.004	Kapton Polymide
Carbon foam	4200	100	1	185.65	0.226	C, Allcomp K9 130pp
Carbon sheet	1000	100	2	23.70	0.843	C, K13C2U/EX1515
Flex tape	340	100	1		0.428	Cu + Dielectric + FR4
Glue	150	100	1	35.49	0.042	TenCate EX-1515
PCB	2360	20	1	17.0	0.278	FR4
Armacell	31200	100	2	801.27	0.779	-30 degree
SUM					2.761	



- **Option 3**
- **with total X/X_0 = 2.761 %**

Material Unit	Thickness μm	Filling Factor (%)	Layers	X_0 (cm)	X/X_0 (%)	composite
Silicon	120	100	1	9.37	0.128	Si
Cooling tube	50	12	2	28.6	0.004	Kapton Polymide
Carbon foam	3200	100	1	185.65	0.172	C, Allcomp K9 130pp
Carbon sheet	300	100	2	23.70	0.253	C, K13C2U/EX1515
Flex tape	340	100	1		0.356	Cu + Dielectric + Polymide
Glue	120	100	1	35.49	0.033	TenCate EX-1515
PCB	1570	20	1	17.0	0.184	FR4
Armacell	12300	100	2	801.27	0.307	0 degree
SUM					1.439	

- **Option 2**
- **with total X/X_0 = 1.439 %**

Material Unit	Thickness μm	Filling Factor (%)	Layers	X_0 (cm)	X/X_0 (%)	composite
Silicon	100	100	1	9.37	0.106	Si
Cooling tube	50	12	2	28.6	0.004	Kapton Polymide
Carbon foam	2200	100	1	185.65	0.118	C, Allcomp K9 130pp
Carbon sheet	100	100	2	23.70	0.084	C, K13C2U/EX1515
Flex tape	340	100	1		0.356	Cu + Dielectric + Polymide
Glue	100	100	1	35.49	0.028	TenCate EX-1515
PCB	780	20	1	17.0	0.009	FR4
Armacell	2200	100	2	801.27	0.055	15 degree
SUM					0.845	

- **Option 1**
- **with total X/X_0 = 0.845 %**

Operating temperature has large impact on material budget

And we need to worry about DCDC convertors

Tai-Hua Lin

How much material is too much?

Clearly tracking, occupancy, electron reconstruction studies are important but in my experience never give a clear answer

Better baseline for judging to much? Original LHCb (we have some feeling for what this means for electrons, hadronic interactions)

- **For all combined (SciFi + Mighty Tracker): between 28.81% ~ 17.31%**

- **Estimation of the material budget of the LHCb detector (LHCb note 2007-025)**

Region	z_{min}/cm	z_{max}/cm	X_0/%
VELO	0	83	16.2
VELO-RICH1 interface	83.0	97.8	6.8
RICH1	97.8	225	9.5
TT	225	275	5.1
Magnet	275	760	5.3
T	760	930	17.8

Judging this way: amount of material is already a serious concern, especially this early in the project

Aside: it would be good if somebody updated LHCb-2007-025 for Upgrade I

https://tinyurl.com/s7p64zbx

Next steps

We have reasonable tools in hand for the Mighty Tracker to allow us to to do studies

- More detail to be added but have a first chain

On our side we have to define a matrix of detector configurations and study priorities

- At moment we give priority to Run 4 studies

Need for better global coordination

For descoping and detector TDRs need realistic pattern recognition:

- TDR timescale defines set of milestones to be met

Tracking system as a whole needs to work and to have minimal material

- We need a framework where we can run all tracking detectors at the same time with a magnetic field

DD4Hep has clearly been difficult but we need operational clarity and strong strategic decision making needed going forward

Next steps

Studies to be done (for matrix of scenarios)

- Material budget
- Occupancies
- Digitization level: efficiencies, dead time, ...
- Momentum resolution
- Pattern recognition
- Standalone tracking
- Long tracks (forward/matching)

Timeline

Next months scenario defining:

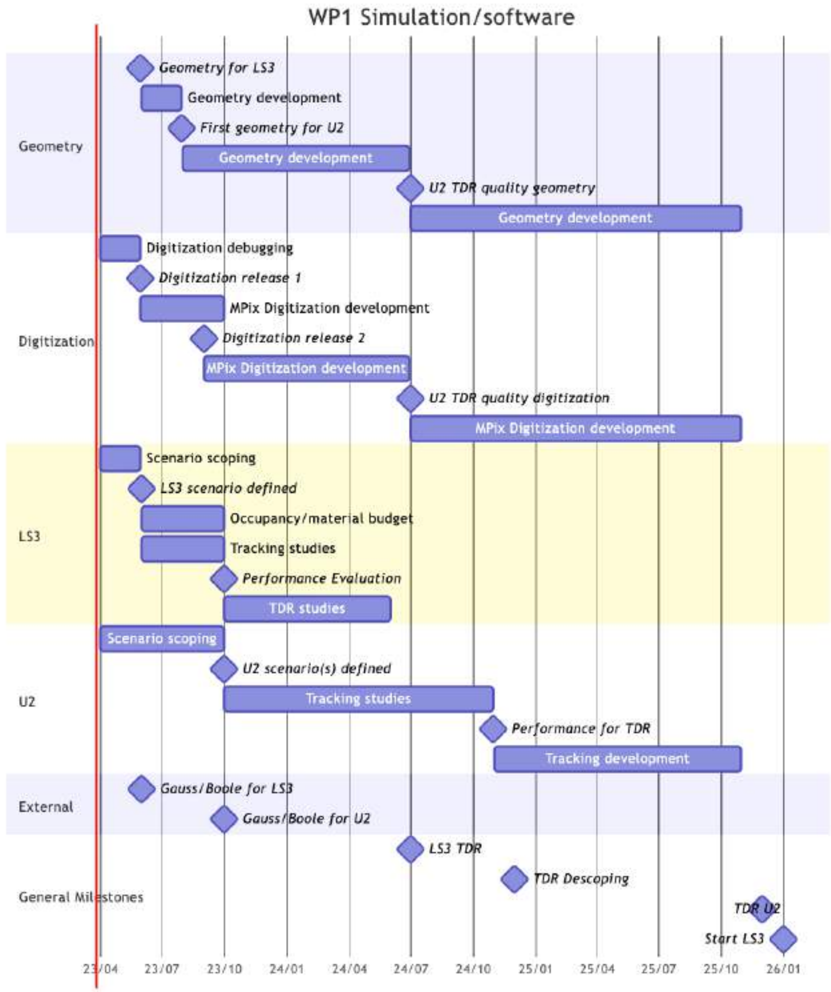
- Define matrix of geometries and options to be studied

Geometry, digitization development

- Iterative process

- Assume priority in short-term is LS3

Global studies dependent on availability of framework/other detectors



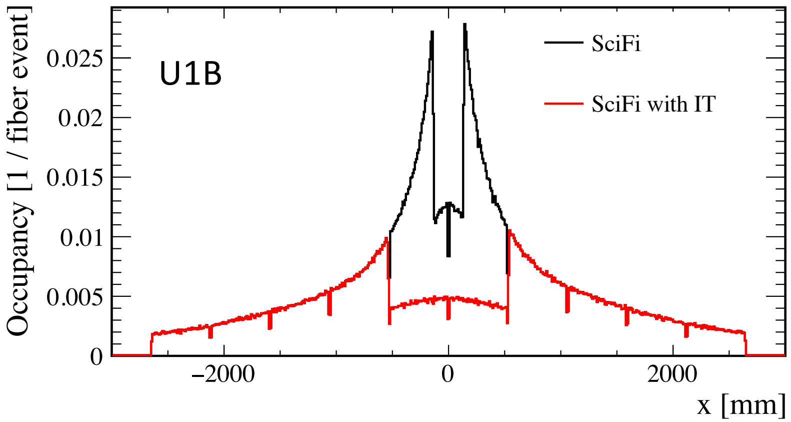
Summary

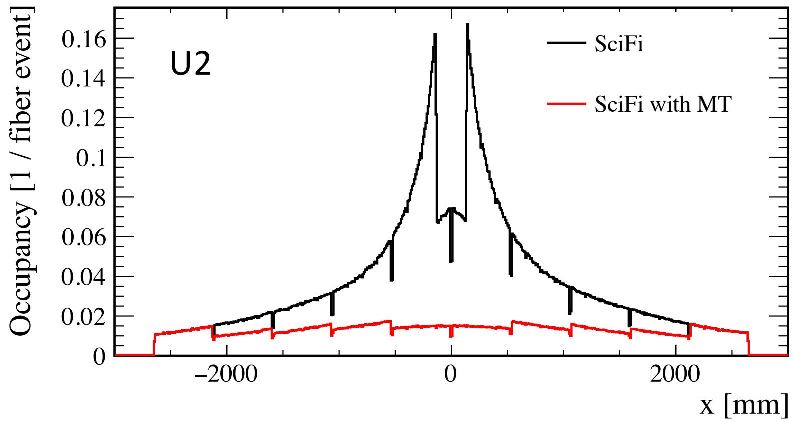
- Mighty Tracker geometry ready in DD4Hep for some time
- First version of digitization code exists, needs to be debugged
- Global tracking studies will need framework and good coordination

Backup

Occupancies

Occupancies studied at Geant4 level – ie not digitization, no noise, no spillover
Documented in https://cds.cern.ch/record/2743056?ln=en (V. Denysenko)





With silicon, peak occupancy will be similar to Run 3, but not that the average occupancy is comparable to peak

Tracking Strategy

For FTDR we won't have a full pattern recognition,

- First time we have pixel detectors in UT and T: time to develop new strategies
  - y segmentation is a game changer
- We don't have a digitization for Mighty Tracker yet
- We do have a DD4HEP detector description but not all detectors are so advanced on migration to this

Tracking strategy is to divide problem up

Imagine a two-stage strategy, first finding tracks in Mighty Tracker, matching these with VELO and cleaning out, the go back and match Velo/SciFi, means in parallel. Look at

- Standalone tracking in Mighty Tracker
- Forward tracking for SciFi
- Cheated matching of segments