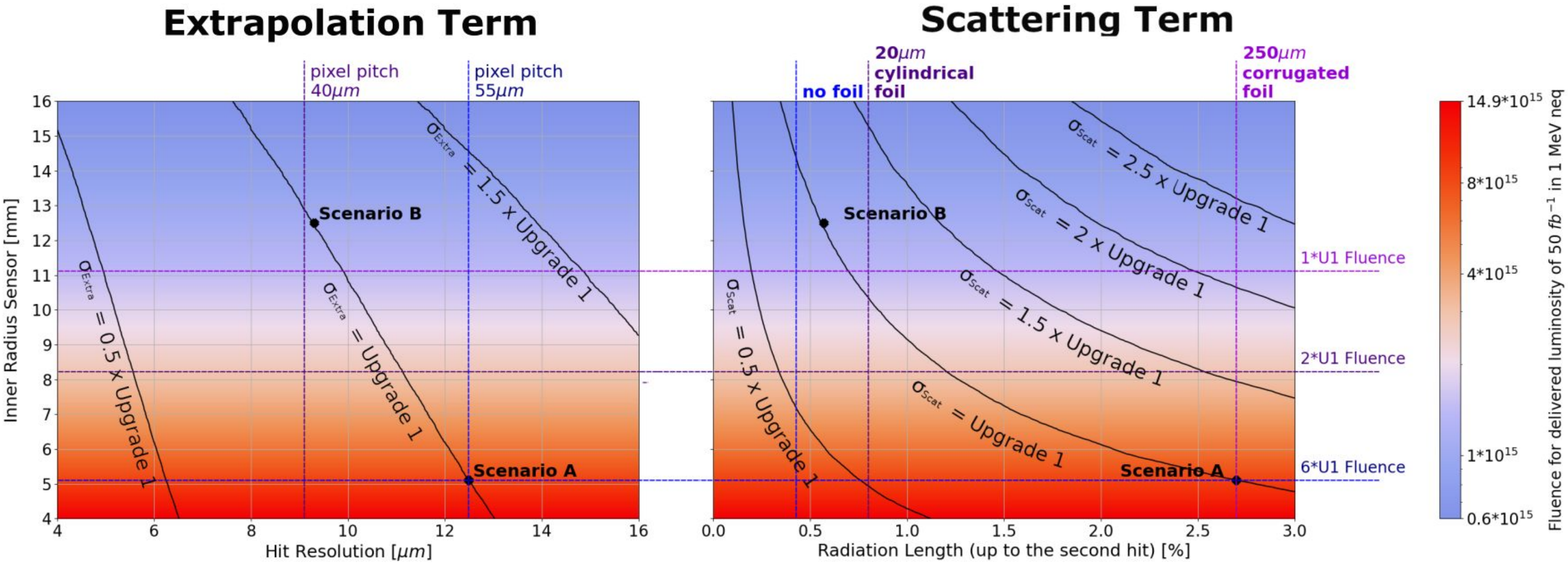
The VELO Upgrade II

Kazu Akiba - 29 . March . 2023

The "original" Scenarios



A successful LHCb @ $1.5 \times 10^{34}\ cm^{-2}s^{-1}$

Main assumption:

U1 IP Resolutions will yield same signal selection performance
IF timing resolution of **20 ps/track** is achieved.

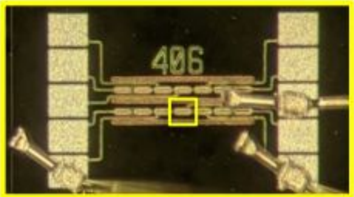
Timing of 50 ps/hit is a global requirement.

Radiation Hardness needs to be up to 6 times larger than U1

An extensive R&D program was launched to find the achievable limits

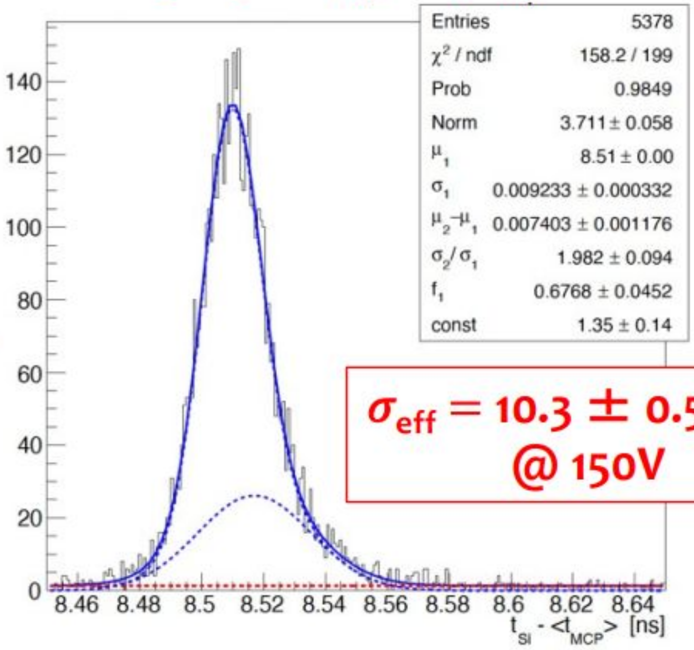
Radiation Hardness

Irradiated sensors: timing performance

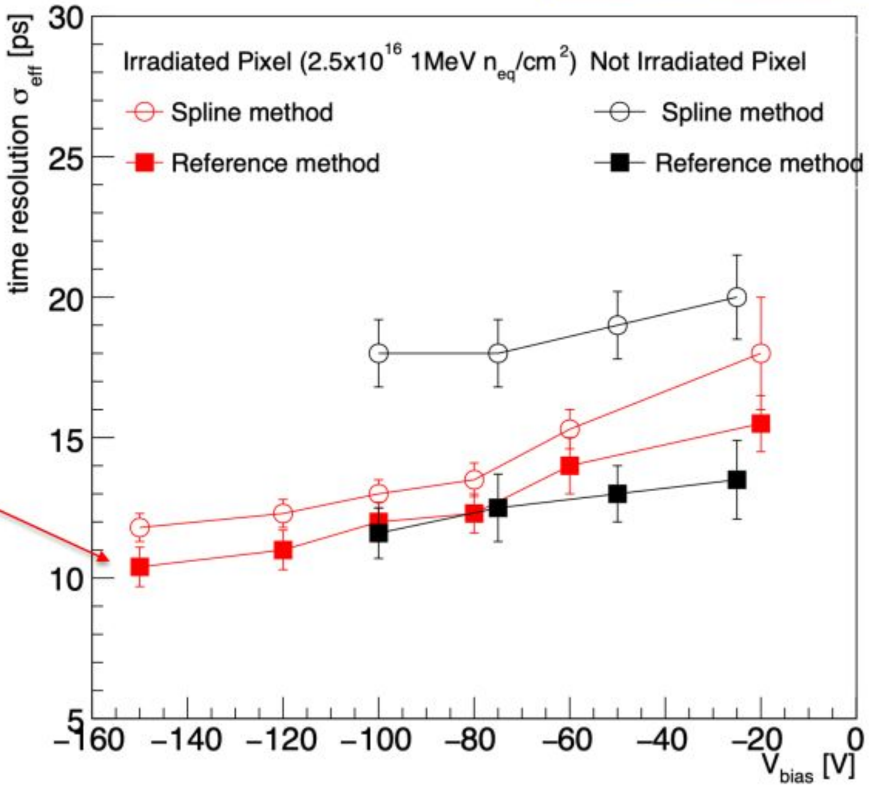


Irradiated @ 2.5 10^{16} n_{eq}/cm^2 , $\alpha_{tilt} = 0°$

$\sigma_1 \approx 9$ ps
$\sigma_2 \approx 18$ ps



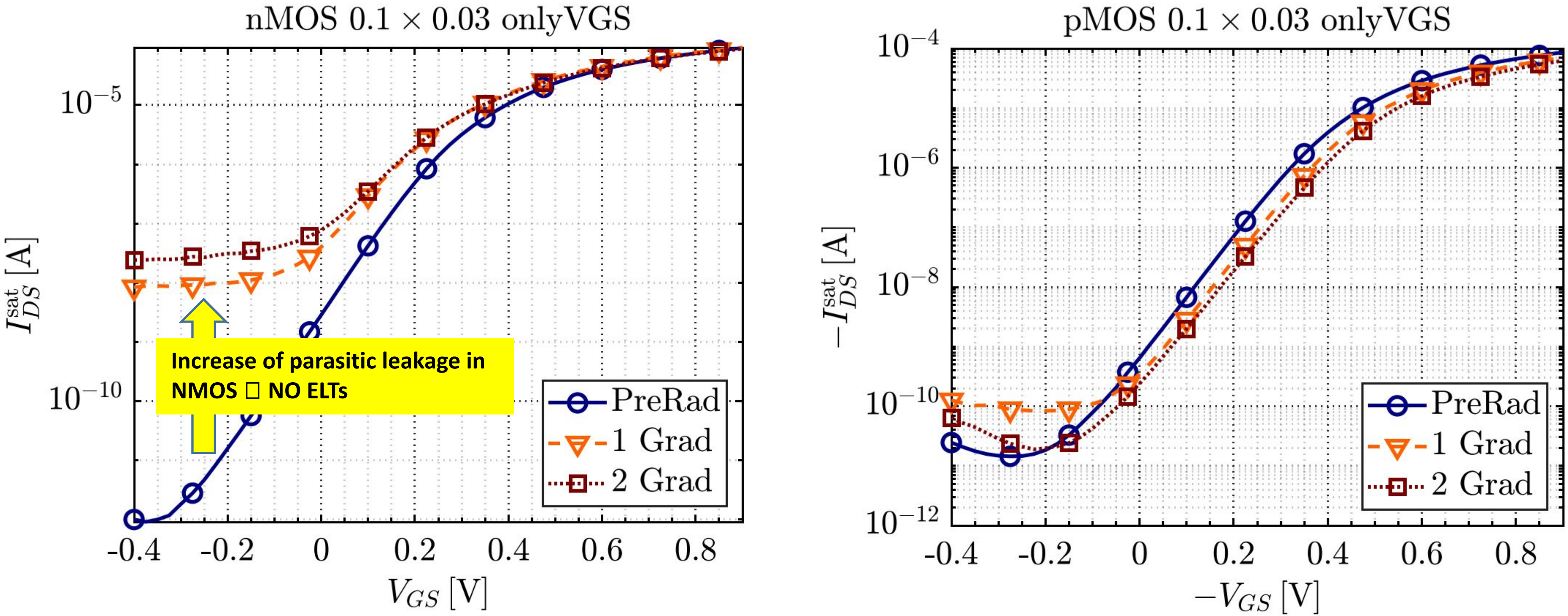
$\sigma_{eff} = 10.3 \pm 0.5$ ps @ 150V



Pre-irradiation performance is already recovered at $\Delta V_{bias} \approx$ 10-15 V

Radiation hardness of TSMC HPC+ 28nm

X. Llopart
G.Borghello



28 nm tech should be tolerant to some ~1 Grad

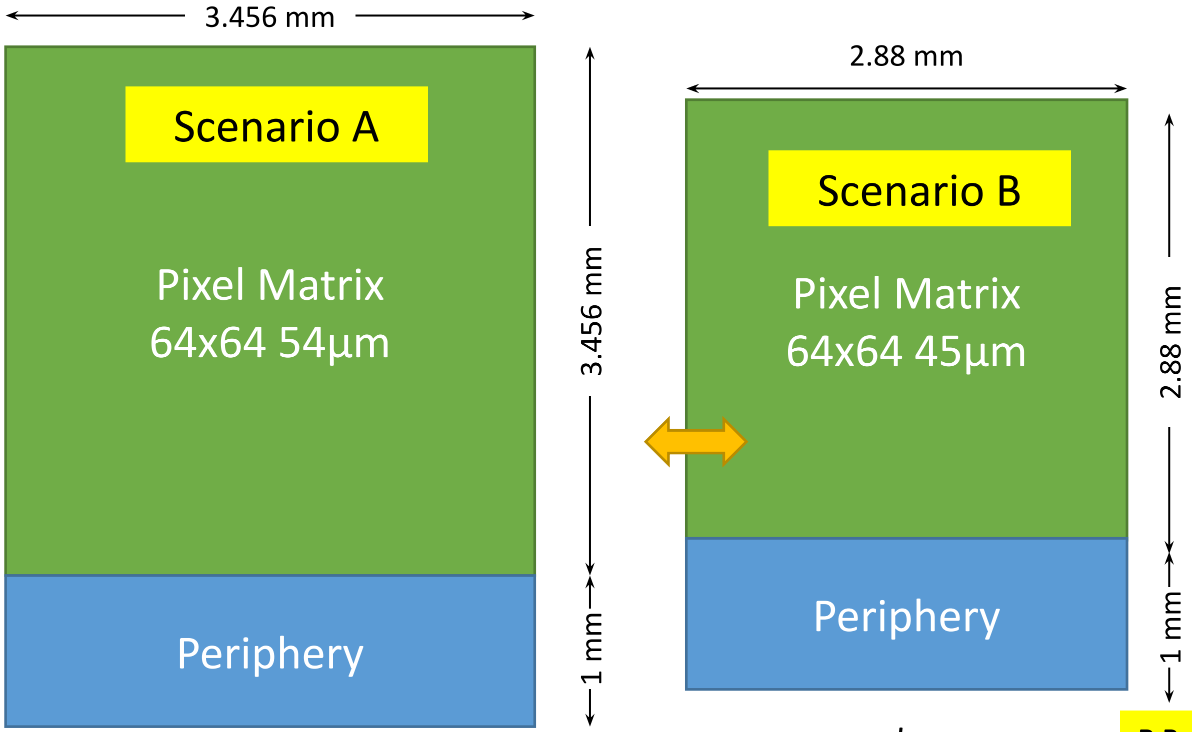
Radiation Hardness

This points to the limit of **1.2 Grad** equivalent to **2.5×10^{16} 1MeV n_{eq}/cm^2**

Smaller pixels

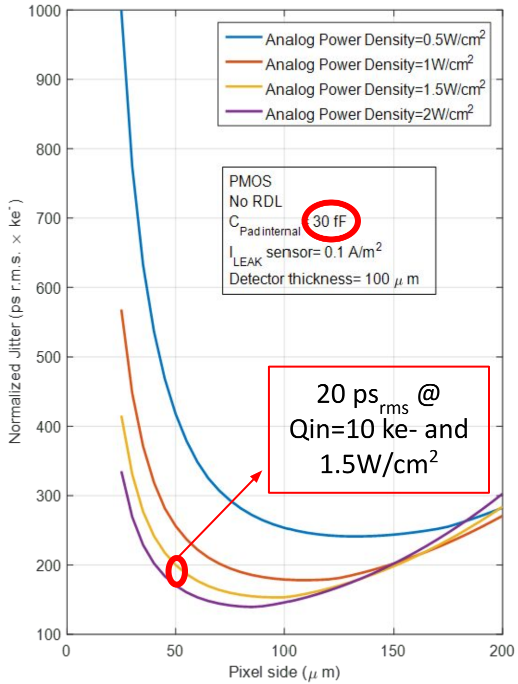
Pico-challenge-pix

40µm scenario B already ruled out!



~120 K$

~75 K$

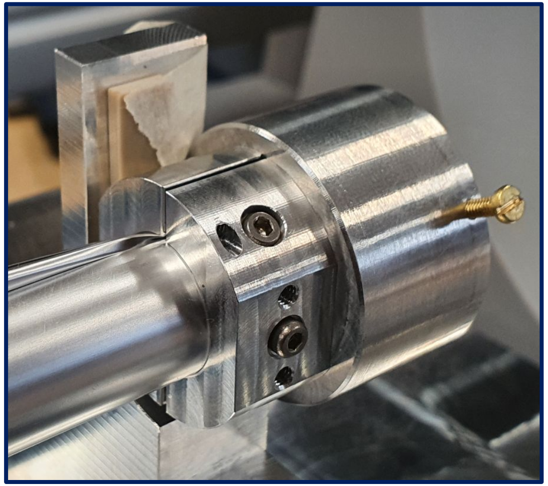


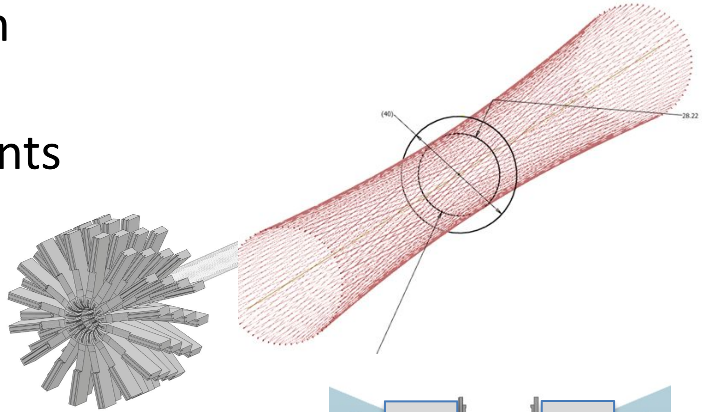
R.Ballabriga, The Timepix4 analog front-end design: Lessons learnt on fundamental limits to noise and time resolution in highly segmented hybrid pixel detectors
https://doi.org/10.1016/j.nima.2022.167489

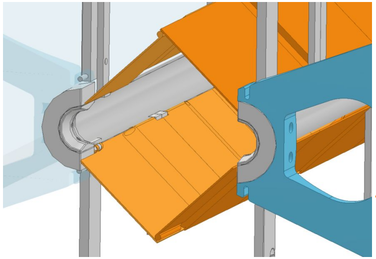
Minimising material

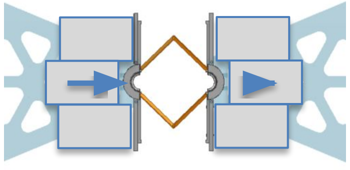
- Thin-foil Shield
    - Tension tests, conclusions & possible next steps
- Wire/Fibre Shield
    - Proposed layout, feasibility & prototyping option
- Open/Closed Position Mechanics
    - Concept mechanism, linkage & setup requirements

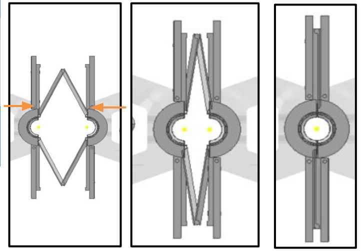
M. Booth
Oxford











Should we Replace?

NO.

Downscoping the VELO Upgrade II Scenario

Detector defined by **65 nm** technology

Innermost active @11.5 mm ⇒ 66 Mrad/year or **400 Mrad**/284fb.

400 Mrad is the limit for 65 nm technology.

No Replacement by construction.

Max pixel rate 69 kHz (>110 Gb/s/2cm2)

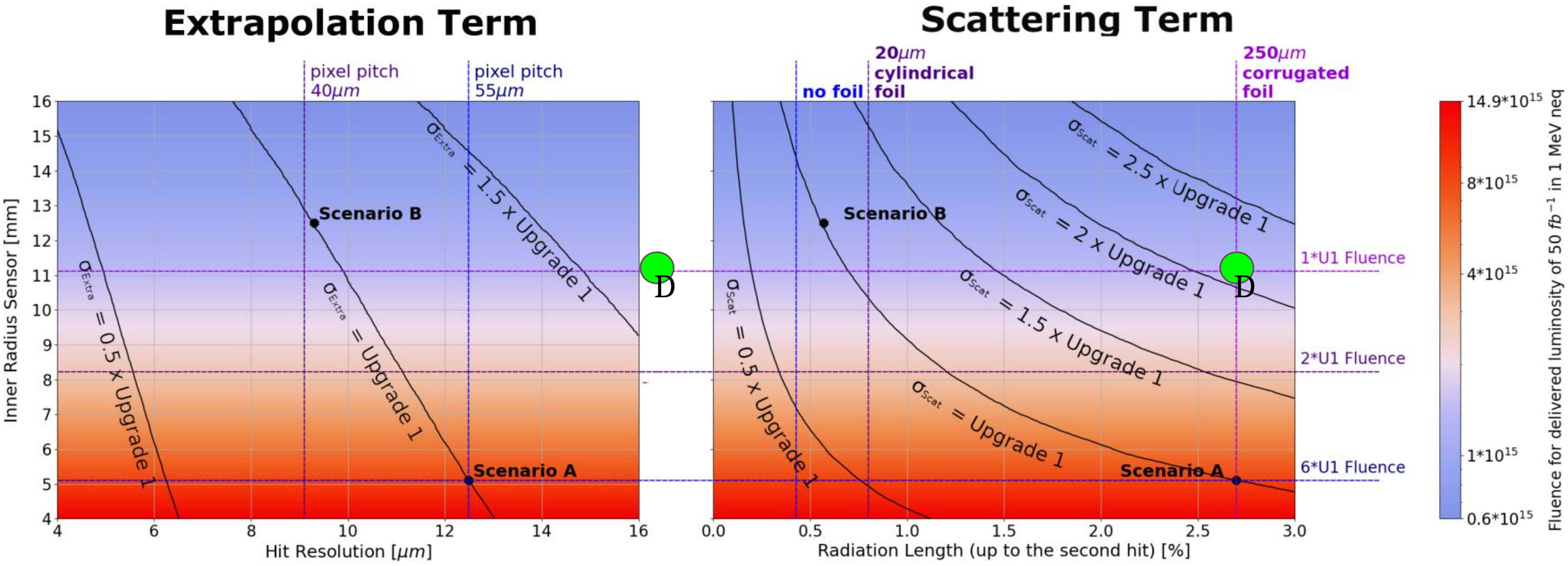
Assume the reduced luminosity scenario: particle rates of **L=1e34/cm2/s**

Radiation damage equivalent to integrated fluence of **43/fb/year**

Consequences

- We need to make a compromise between physics reach and cost.
  ⇒ This means not fulfilling the IP resolution constraints outlined in previous discussions.
- Feature size of 65 nm gives much less space for digital processing, but cheaper ASIC technology.
  - Increase the pixel size → worse spatial resolution
  - Thin Planar sensors
  - Inner radius set at Max radiation fluence of 400 Mrad or 8e15 1MeV neutron equivalent
  - Conservative module design and assembly
  - Minimal mechanical upgrade.
- We make concessions across the whole costs table as the average data rates will be smaller.

Scenario "D"ownscoped



Detector Constraints

Timepix4 is taken as baseline: but pixel size must be larger to fit the TRL and faster rate readout.

Pixel pitch **60 µm** ⇒ hit resolution = **17µm** ⇒ 100-200 µm thick planar sensors

Temporal resolution ⇒ **200 ps** ⇒ assume Timepix4 as baseline and thin planar at very best resolution. This is optimistic!

R&D needed to find balance between spatial and temporal resolutions.

Material budget:

Foil -- 200µm thick, as a conservative approach. Same cost as in 2019.

Sensor + ASIC =0.3% X0, Module substrate 0.45 %X0

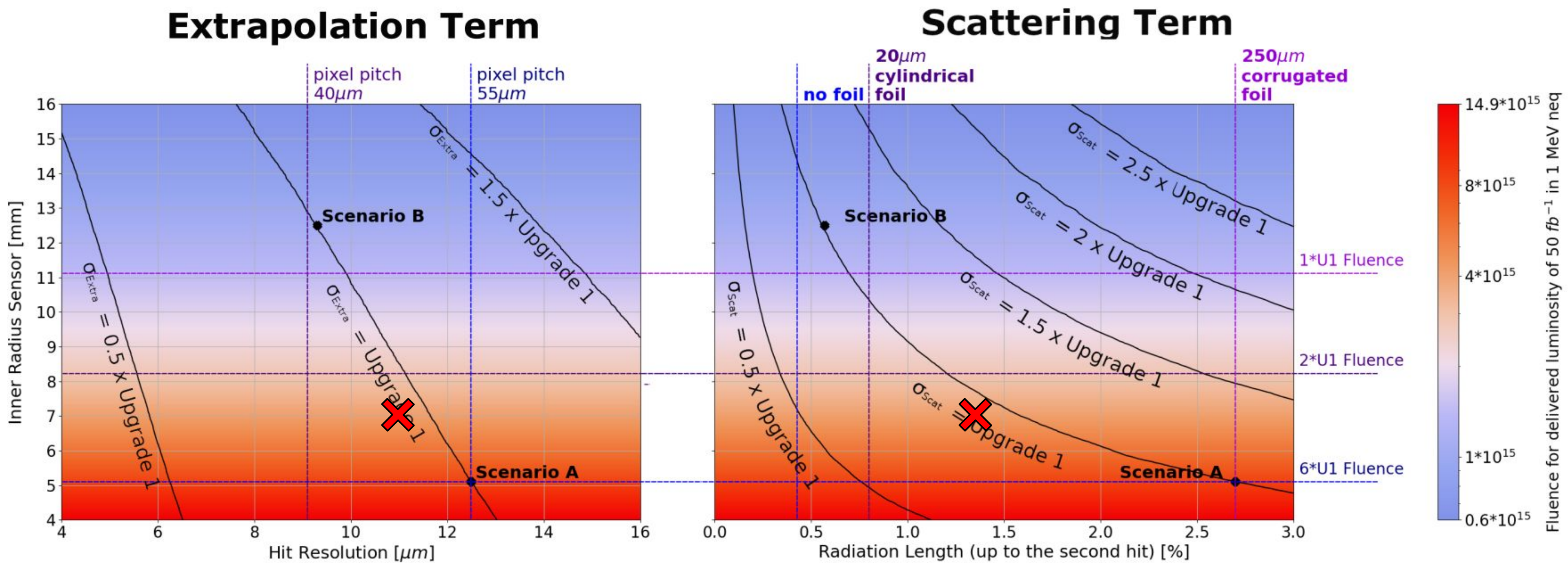
Savings

- Sensors - same cost of U1 inflation adjusted (U1ia)
- ASICs - estimating 2 submissions at the same price as Timepix4.
- Hybridization costs - more expensive due to higher industry prices
- Data/Optical links and feed throughs: 3x U1ia → more data than U1…
- Opto power boards, DAQ, ECS: 1.5 M → a little higher than U1ia, but needs to cope with higher data bandwidth…
- RF boxes, cooling plant, vacuum, Motion, Cooling = U1ia.
- Modules: 50% higher than U1ia
- Mechanics: 2x U1ia (original VELO was 1.4M = 2.3M @20y ia).

	original estimate	FTDR estimate	U1 MoU Cost	U1 inflation adjusted	Downscoped Estimate
Sensors	1872	1100	620	833	833
ASICS	4310	**3000**	1598	2148	1950
Interconnecting (bump bonds)	878	400	160	215	**430**
Optical links and feedthroughs	1763	**800**	239	321	**900**
Opto and Power boards	1763	800	452	607	800
DAQ and ECS boards	1938	1000	497	668	700
Power Supplies	449	400	345	464	400
RF foil	702	500	400	538	500
cooling plant	585	500	270	363	375
Vacuum and Motion	585	500	181	243	243
Cooling	1183	800	403	542	542
Modules	2730	2000	786	1056	1500
Mechanics (inc. vac vessel)	3250	3000	505	679	1500
total	22006	14800	6456	8676	10673

These were too low at the FTDR

Scenario "X" -- Marks the spot



Should we do better?

Based on the limit of 28 nm technology, the innermost radius can be set ~7.2 mm beam.

Constraints for Scenario X:

Assume reduced luminosity scenario: particle rates of **L=1.5**x10^{34}**/cm2/s**

Radiation damage equivalent to integrated fluence of **50/fb/year**

Innermost active @7.2 mm ⇒ 200 Mrad/year or 1200 Mrad/300fb. Fluence: **2.5**x10^{16} **1MeV neq**

Max pixel rate 175 kHz (>200 Gb/s/2cm2)

1200 Mrad taken as operational limit for 28 nm technology, and also operational limit for 3D detectors (2.5x10^{16} 1MeV neq) .

No Replacement by design (or desire).

Requirements: 50 ps timing/hit. Hit resolution better than 11 µm.

Details and work assumptions of Scenario X

Moderately challenging goal of a 50 µm foil ⇒ roughly estimate of 0.6% X0

This also limits the sensor + ASIC plus substrate to ~0.8% X0, to be below 1.4%. If we assume the first 2 points can on an overhang, this allows sensor and ASIC to have a headroom for material (up to some 400+400 µm, but preferably below 200+200 µm), with a cue for TSVs

Innermost radius of 7.2 mm ⇒ Reduction of a factor 2 in Radiation and peak data rate; Bandwidth reduction is modest wrt SA.

Pixel pitch <= 49 µm ⇒ binary resolution at the expected angle will probably not reach the 10.5-11 µm hit resolution, required. (reminder that at 8 mm, strip-VELO had some 5 µm resolution.

Summary

Replacing 2 old scenarios by 2 new ones

Previous scenarios were equivalent in performance.

The new ones have **technology or cost** as limitations.

Scenario D has large, negative impact on physics performance:

See Dan's talk how for much!

Scenario X has BETTER performance than A and/or B!

Because, **we SHALL NOT build a worse detector than Upgrade 1!**