LS3 enhancements (the project formerly known as Upgrade Ib)

Guy Wilkinson
University of Oxford
31/3/23

Welcome to Manchester !

Welcome to Manchester !

First Upgrade II workshop;
7 long years ago.

Man Utd vs Barcelona – a random selection

Man Utd 3 Barcelona 0
Cup Winners' Cup,
¼ final, 2nd leg, 1984

Man Utd 1 Barcelona 0
Champions' League
semi final, 2nd leg, 2008

Man Utd 2
Barcelona 1

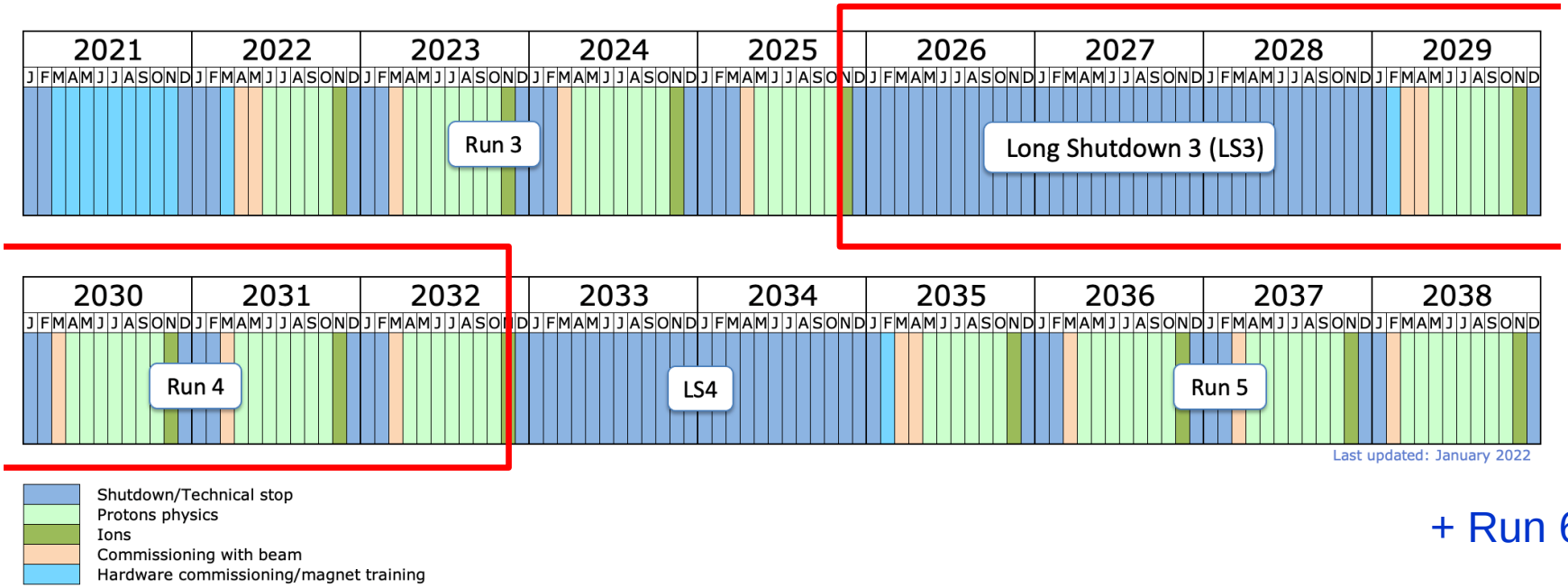
Cup Winners
Cup Final, 1991

Man Utd 2 Barcelona 1
Europa Cup 2nd leg, 2023

Outline

- The LS3 / Run-4 opportunity
- Criteria for LS3 enhancements
- What was on the table in Manchester
- What could be on the table this year
  - RICH, ECAL: under review / now or very soon
  - HCAL: a special case
  - Tracking system
  - RETINA
- Things not to forget
- Conclusions

The LS3 / Run-4 opportunity



+ Run 6

- LS3 is very long (and may get longer) – an opportunity to lay the foundations for Upgrade II, and strengthen performance of Upgrade I.
- Run 4 is when the majority of Upgrade I data will be collected – conceivably > 30 fb^{-1} [caveats: i) start up of HL LHC could be slow, ii) energy crisis].
- Maybe the luminosity can be pushed a *little* above the Upgrade I 2×10^{33} $cm^{-2}s^{-1}$ baseline? Need first to see how detectors perform in Run 3.

My criteria for LS3 enhancements

IMO there are four essential tests a proposed LS3 enhancement *has* to pass:

- Must improve Run-4 physics overall * ;
- Cannot endanger start of Run-4 operation;
- Must be coherent with Upgrade II;
- Must be modest in required resources, & not compromise Upgrade-II efforts.

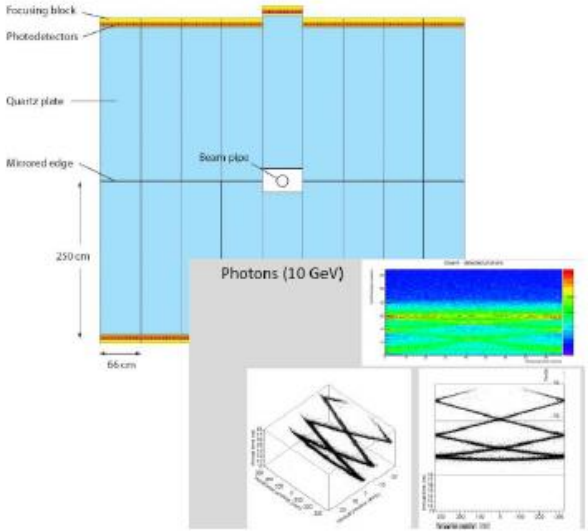
If it doesn't satisfy these, we should not discuss it further. If it does, then there are further desirable attributes we may consider:

- Technologically interesting;
- Good for group building.

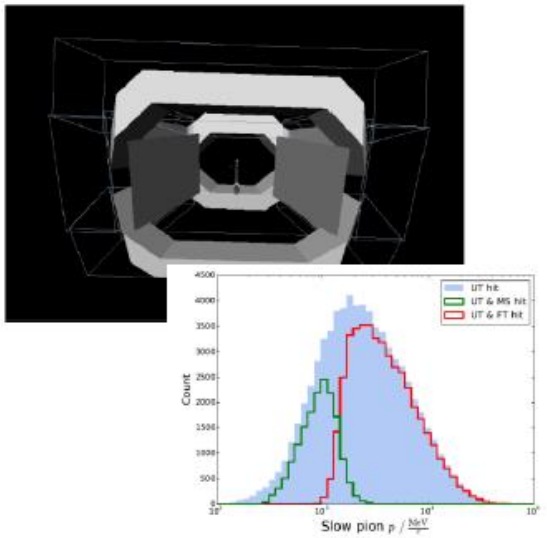
- there may be one exception to this requirement – see later

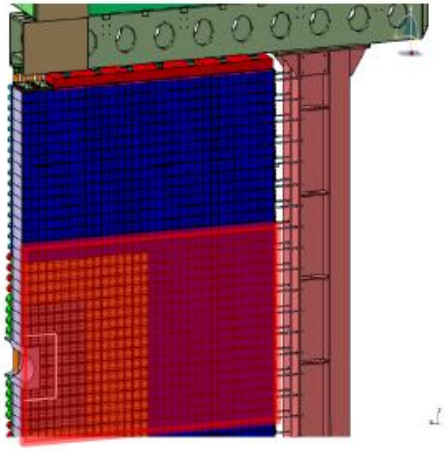
LS3 enhancements – under discussion in Manchester

TORCH – for PID, general timing, or in hybrid CALO ?



Side chambers – conceptually simple but in practice an interesting challenge.

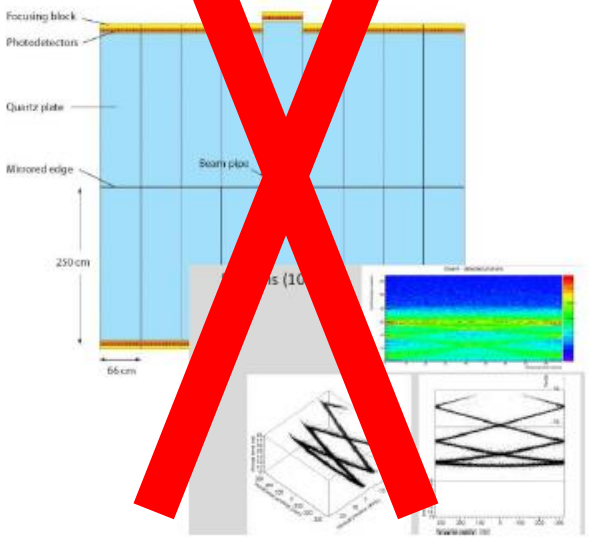




Replace a significant region of the ECAL with a new technology.

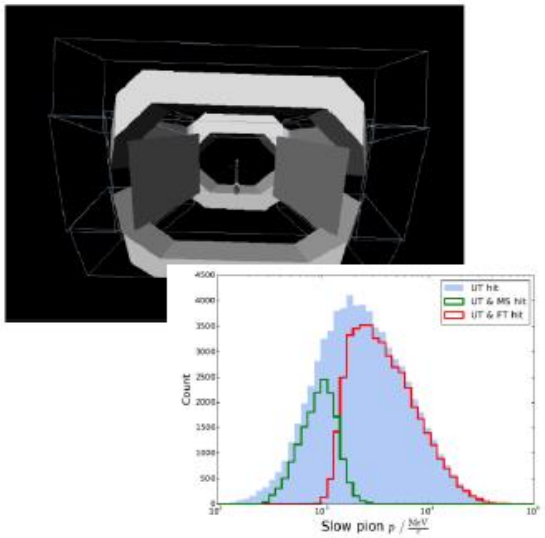
LS3 enhancements – under discussion in Manchester

TOPCH – for PID
gen al timing, c
hybr CALO ?

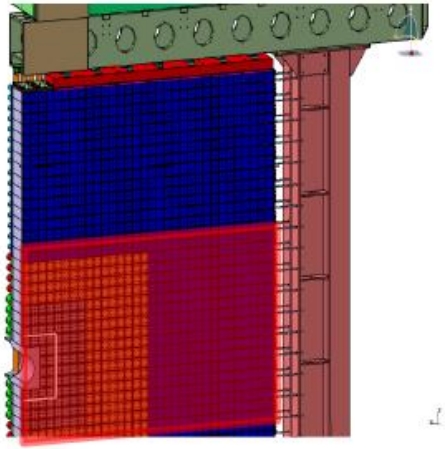


Now a UII project

Side chambers –
conceptually simple but in
practice an interesting challenge.



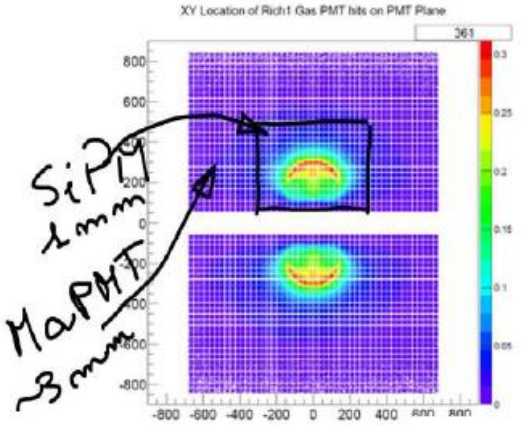
Still in play – remains
an 'interesting challenge'



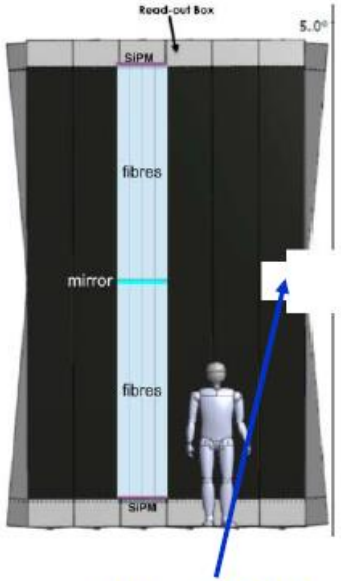
Replace a significant
region of the ECAL
with a new technology.

Being pursued

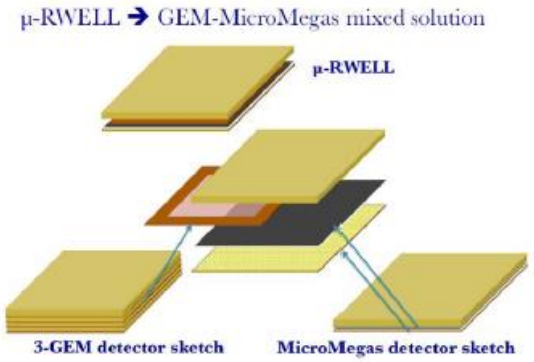
LS3 enhancements – under discussion in Manchester



Develop SiPMs for phase-2 operation. Already populate hot area of R1 in LS3

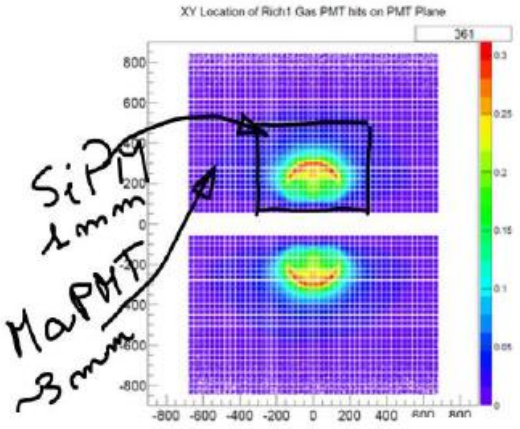


small (for LS3) silicon IT in this region ?



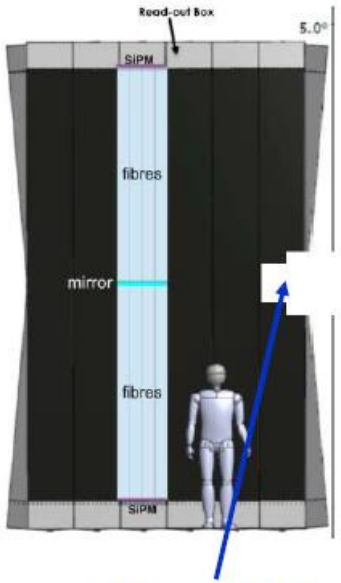
New muon chamber technology for hot regions. Already install first chambers during LS3 ?

LS3 enhancements – under discussion in Manchester



Develop SiPMs for phase-2 operation. Already populate hot area of R1 in LS3

LS3 focus is now on timing rather than granularity



small (for LS3) silicon IT in this region ?

Still being discussed

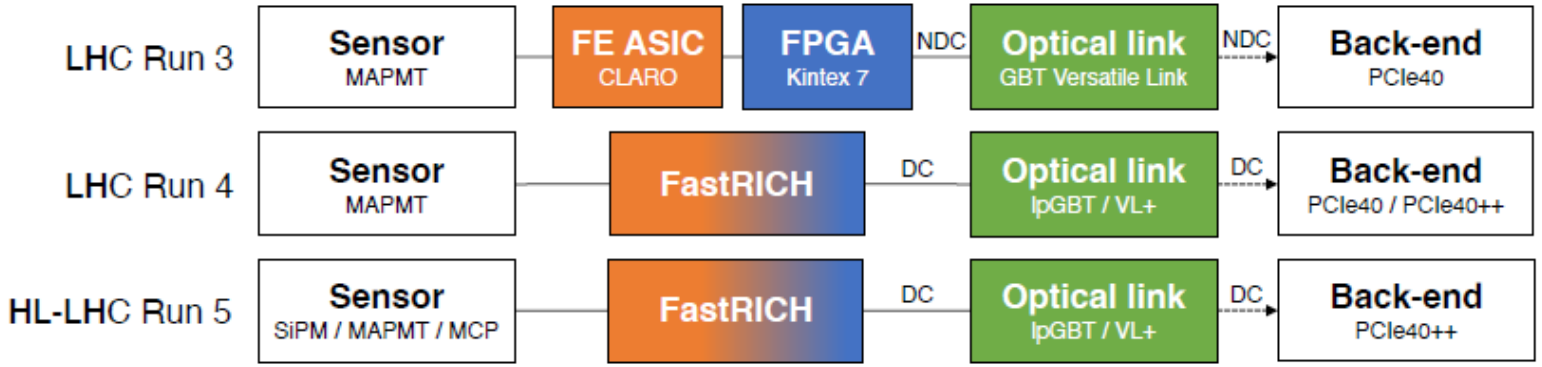
New mu cham r technology for hot r ions. Al ady install first ch bers duri LS3 ?

Now a UII project

RICH LS3 aspirations

Key ingredients

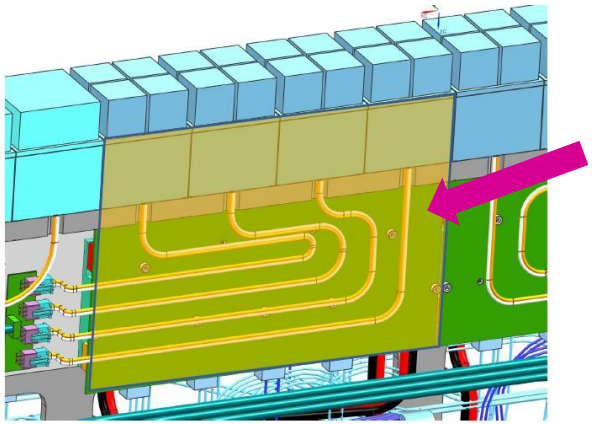
- FastRICH replaces CLARO and FPGA . Allows for s/w time gate and (in principle) compatible with UII.
- Change to data compressed (DC) format at front end.
- Introduce lpGBT/VL+.
- Small expansion in requirements at back end.



	Sensor	ASIC timewalk	FE time gate	TDC time bin
LHC Run 3	150 ps	< 4 ns	6.25 ns	None
LHC Run 4	150 ps	CFD correction	2 ns	25 ps
HL-LHC Run 5	~ 50 ps	CFD correction	2 ns	25 ps

In Run 4 narrowness of time gate limited by sensor (MaPMT) not electronics.

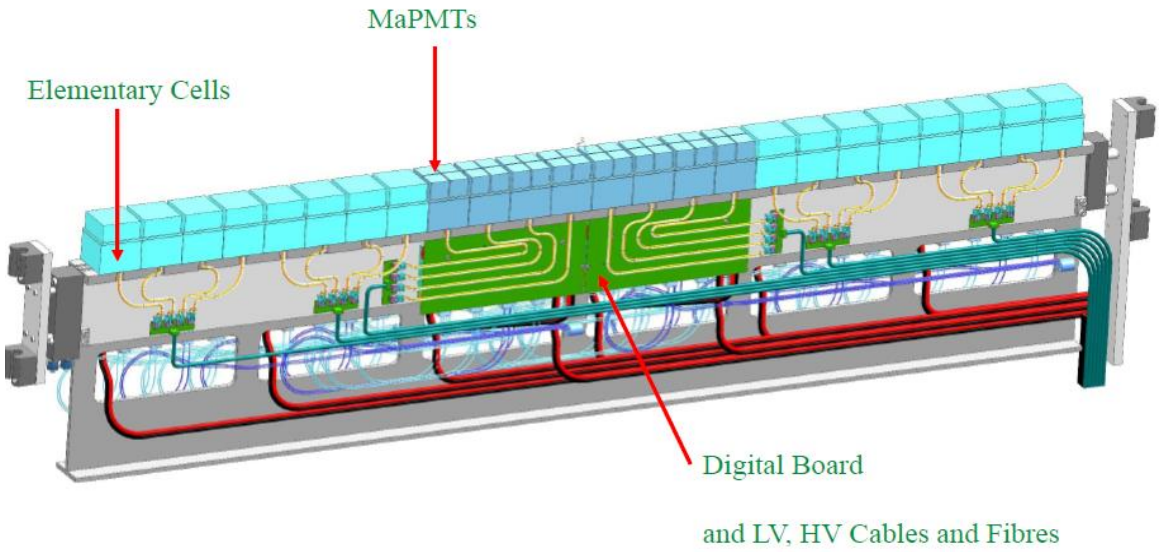
RICH LS3 aspirations



Replace all this, *i.e.* front-end ASIC (CLARO) and digital board hosting FPGA, with new FastRICH-based electronics.

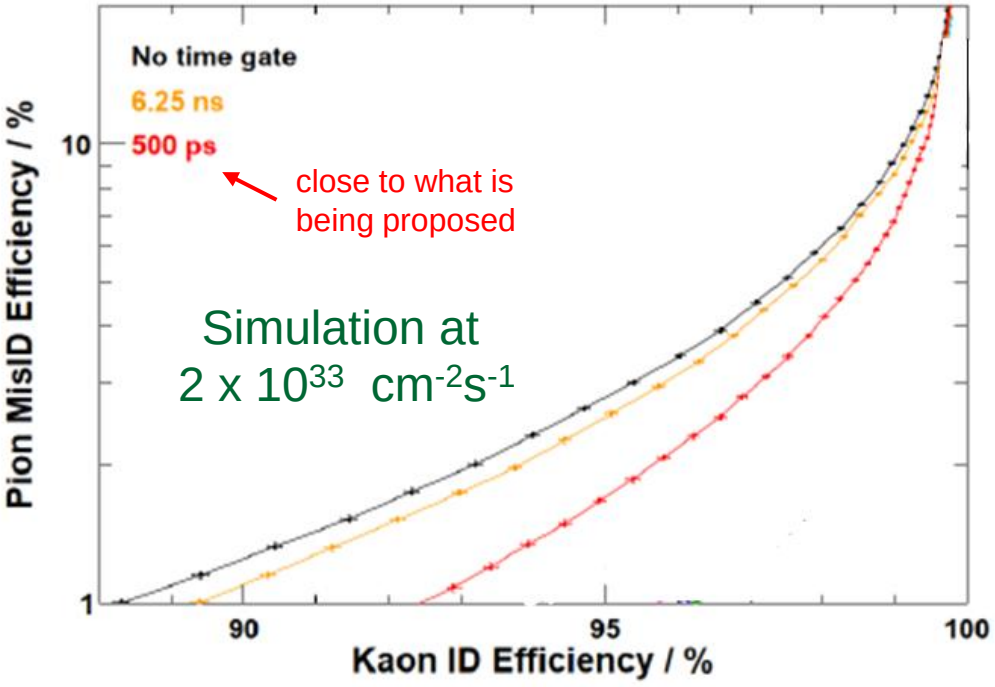
Some changes to back end.

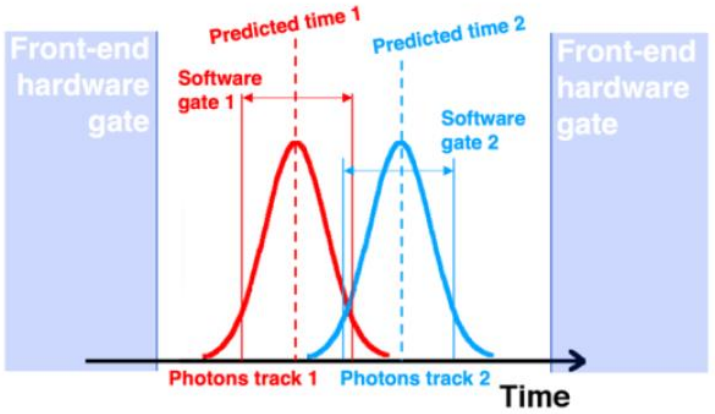
Cost: 2.3 MCHF + 15% contingency. Dominated by electronics, with FastRICH making up 0.9 MCHF.



RICH LS3 enhancements – physics gains

Place hardware gate of ~2ns to reject out-of-time photons and reduce data rate, then place software gate of around 600 ps in width (~ ±2 x MAPMT transit time spread).





Potential for significant physics gain.

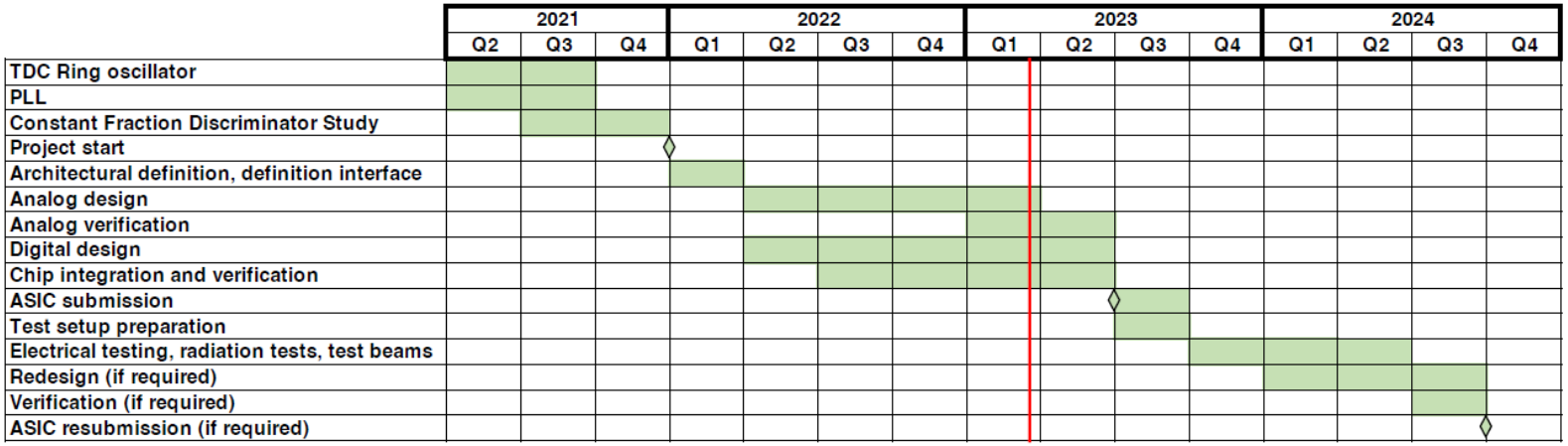
Would be interesting to see how improvement varies with momentum, RICH1 vs RICH2, event multiplicity *etc.*

Also what is performance with slightly wider gates ?

RICH LS3 enhancements – risks

At heart of proposal is the FastRICH ASIC, which is based on the FastIC (FastIC+ also under development), designed by Barcelona (ICCUB) and CERN. Great team ! But LHC history tells us that the ASIC is usually the critical-path item.

From RICH LS3 review:

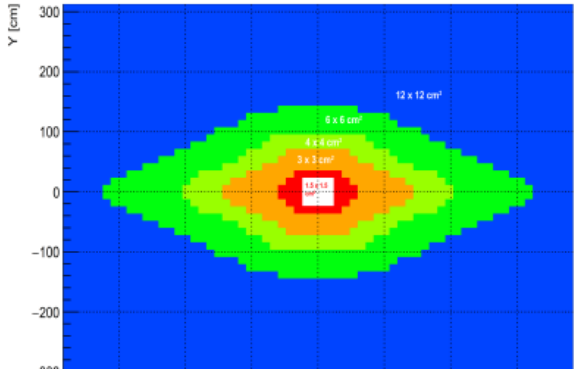


Robustness and realism of plan being assessed by LS3 review team.

Questions:
- what impact would having a working ASIC later than Q1 2025 have on overall schedule ?
- how would this impact be softened, if enhancements were limited to one RICH rather than both ?
- what further developments, if any, needed for Upgrade II ?

L3 enhancements: ECAL

Starting point: innermost region needs replacing due to radiation damage.



No longitudinal segmentation

Cell size:	Modules:
2 x 2 cm²	32 *new* SpaCal-W modules
3 x 3 cm²	144 *new* SpaCal-Pb modules
4 x 4 cm²	176 existing modules in rhombic configuration
6 x 6 cm²	448 existing modules in rhombic configuration
12 x 12 cm²	2'512 existing modules in rhombic configuration

Solution: replace with new SpaCal-W modules (granularity suitable for UII).
With Upgrade II in mind, further improvements are being proposed:

- new SpaCal-Pb modules, leading to 9,344 cells in total (*c.f.* 6,064 now);
- rearrangement of existing modules into occupancy-motivated rhombus shape;
- new electronics (perhaps even with timing);
- modifications of infrastructure required for LS4.

~4 MCHF project

Will be reviewed on May 3 and 4.

L3 enhancements: ECAL

Starting point: innermost region needs replacing due to radiation damage.

Do not wish to prejudice the review, but here are some personal impressions:

- Impressive, well organised and huge amount of work, which looks to plausible as optimum cost vs. performance option for Upgrade II;
- LS3 plans are very ambitious. We will need reassurance they can be accomplished without significant risk;
- We need to be honest about the LS3 physics gains. Would welcome a clearer demonstration of what these are;
- With the LS3 TDR imminent, we must understand what we are keeping open for Upgrade II (timing layer ?) and what we are excluding (Si-W option).

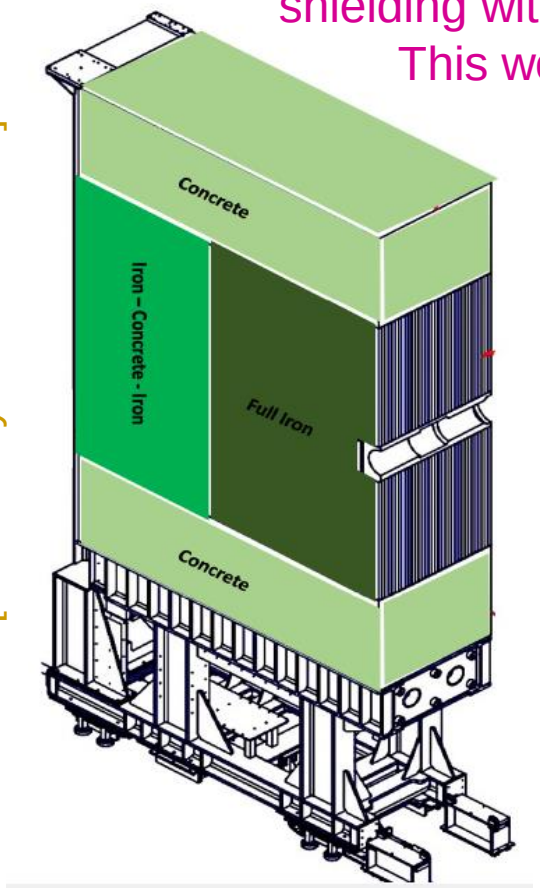
- modifications of infrastructure required for LS4.

Will be reviewed on May 3 and 4.

Getting ready for Upgrade II: HCAL removal

Known since Upgrade-II EoI: flux in much of M2 will be unacceptably high.
One solution is to remove the HCAL (main purpose was L0 triggering) & to install shielding with greater interaction thickness, making use of OPERA iron.
This would approximately halve occupancy in critical M2 regions.

[see talk by M. Santimaria]



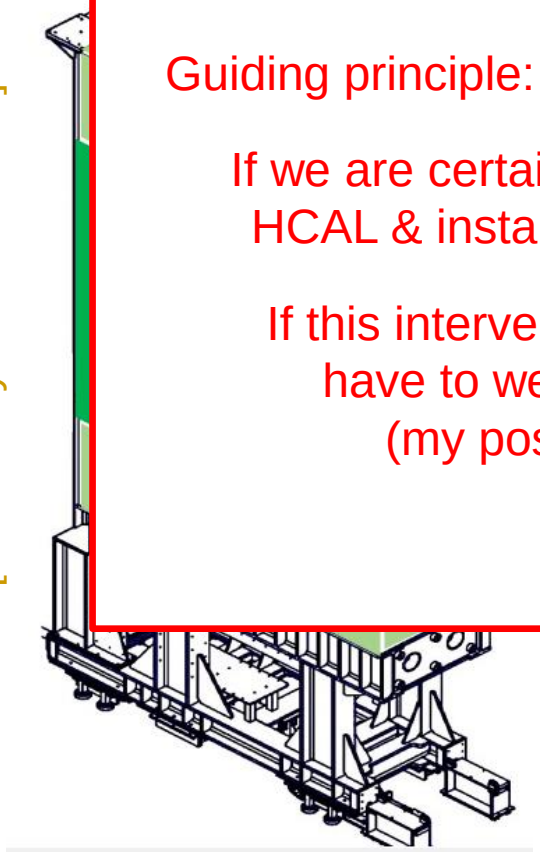
- Performing this intervention is a huge job.
  Feasible for LS3, inconceivable for LS4.
- Some worries for Run 4 physics w/o HCAL:
  - HCAL brings some useful orthogonal information to the muon identification, but it is not clear how essential this is in Run 4.
  - Some benefits also in Run 4 for electron and jet physics, but these need to be quantified better.

These points were discussed in first meeting in February, and summarised by Miriam this week.

Getting ready for Upgrade II: HCAL removal

Known since Upgrade-II EoI: flux in much of M2 will be unacceptably high.
One solution is to remove the HCAL (main purpose was L0 triggering) & to install shielding with greater interaction thickness, making use of OPERA iron.

[see talk by M. Santimaria]



Guiding principle: LHCb physics requires the best possible muon id.

If we are certain that for Upgrade II this requires removing the HCAL & installing more shielding, this must be done in LS3,

If this intervention degrades Run-4 muon physics, we then have to weigh up this loss against gains in Run 5 & 6 (my possible one exception to the four criteria).

More studies needed !

gions.

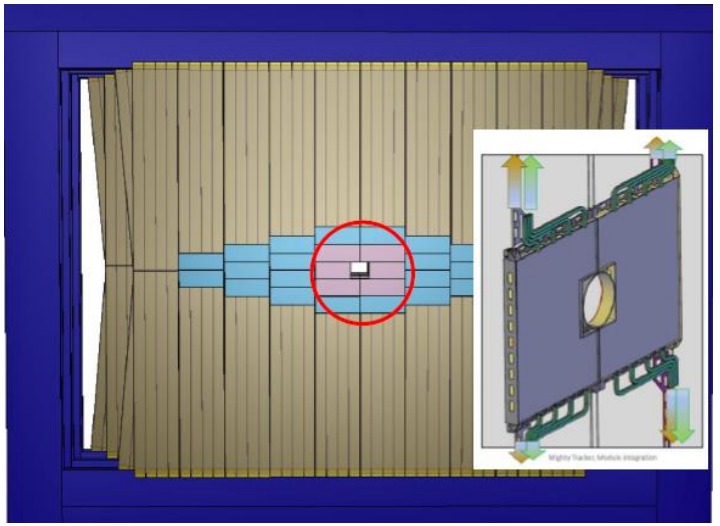
ation

jet

physics, but these need to be quantified better.

These points were discussed in first meeting in February, and summarised by Miriam this week.

Tracking enhancements ? Proto Mighty Tracker



Early thinking:

- Replace damaged SciFi modules.
- Add silicon pixels in innermost region.

Current thinking:

My simplistic interpretation. See Pascal's talk for more discussion.

- Don't touch the SciFi.
- If add silicon, do so as a "bolt on". Space constrained – two layers maximum.

"Addition of MPix needs to be justified by simulation" (M. Needham)

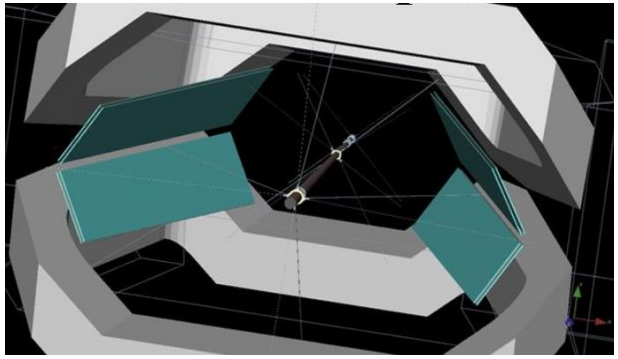
Agree ! And simulation needs to *show physics gain* (heavy ions ?).

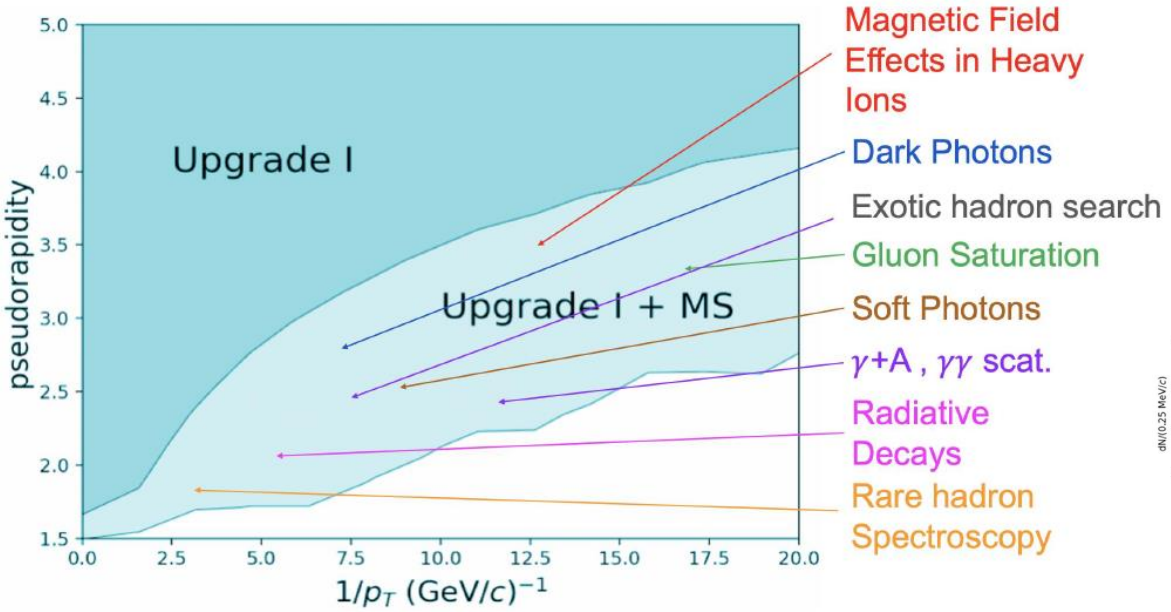
The clock is ticking. Much depends on how the current SciFi behaves…

Tracking enhancements ? Magnet Stations

Ingenious idea to recover low p_T tracks.

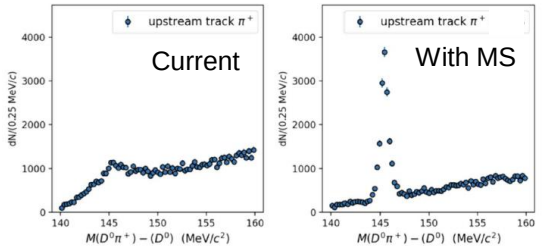
First proposed by Sheldon Stone, now being pursued with great determination by Los Alamos and Krakow institutes (PAN, AGH & PK).





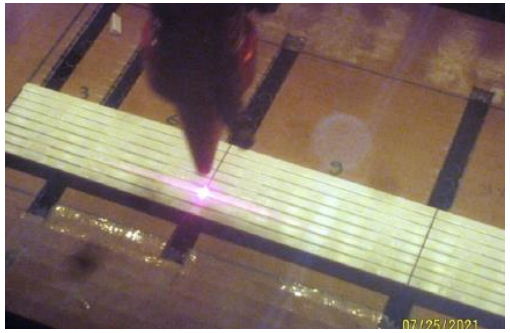
Clear and significant physics gains, in both Run 4 and beyond.

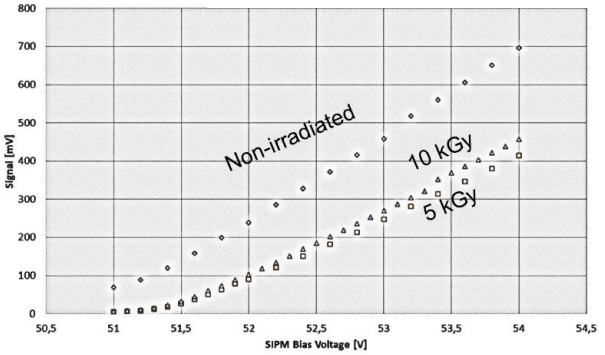
p_T < 1 GeV/c

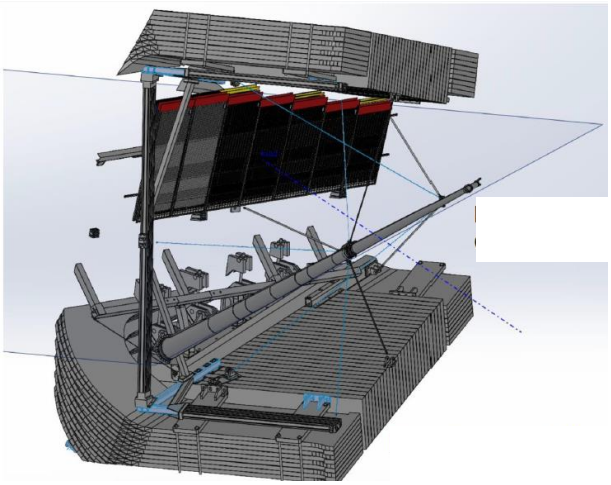


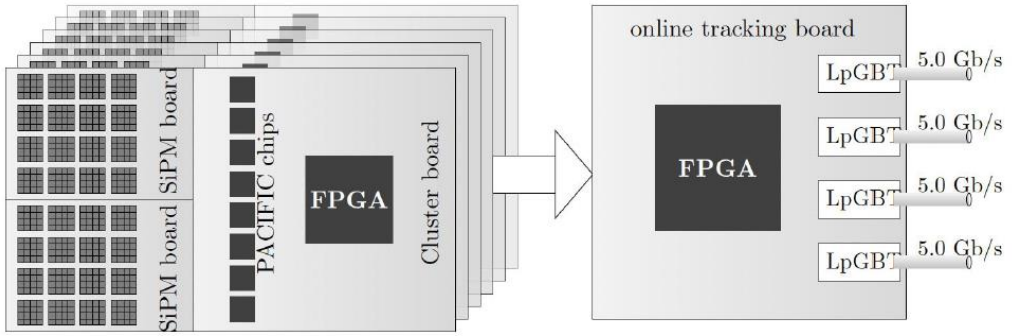
Tracking enhancements ? Magnet Stations

Enormous amount of work performed, underway, and foreseen (C. da Silva).









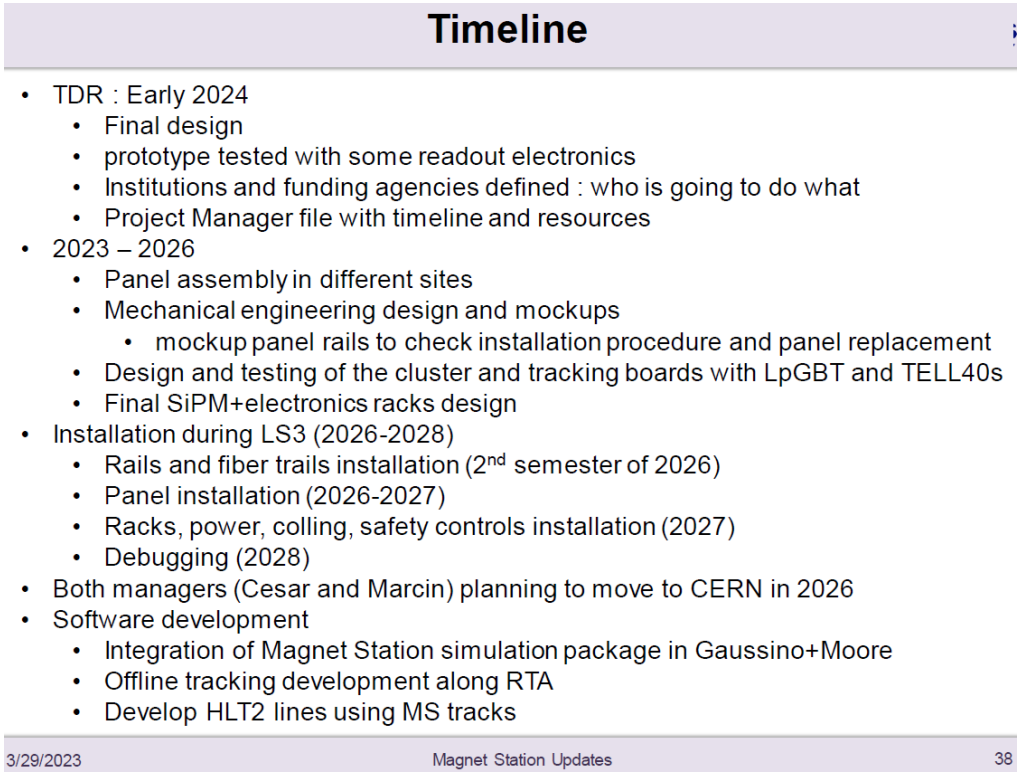
Magnet Stations – open questions

Tight timeline, and limited resources.

Many open questions (*e.g.* ghost rate).

We are all highly enthusiastic about the gains this can bring LHCb physics…

…but we must help involved groups do everything right. Look forward to constructive discussions within U2PG, and within wider collaboration.



Timeline

- TDR : Early 2024
  - Final design
  - prototype tested with some readout electronics
  - Institutions and funding agencies defined : who is going to do what
  - Project Manager file with timeline and resources
- 2023 – 2026
  - Panel assembly in different sites
  - Mechanical engineering design and mockups
    - mockup panel rails to check installation procedure and panel replacement
  - Design and testing of the cluster and tracking boards with LpGBT and TELL40s
  - Final SiPM+electronics racks design
- Installation during LS3 (2026-2028)
  - Rails and fiber trails installation (2nd semester of 2026)
  - Panel installation (2026-2027)
  - Racks, power, colling, safety controls installation (2027)
  - Debugging (2028)
- Both managers (Cesar and Marcin) planning to move to CERN in 2026
- Software development
  - Integration of Magnet Station simulation package in Gaussino+Moore
  - Offline tracking development along RTA
  - Develop HLT2 lines using MS tracks

3/29/2023 Magnet Station Updates 38

[C. da Silva]

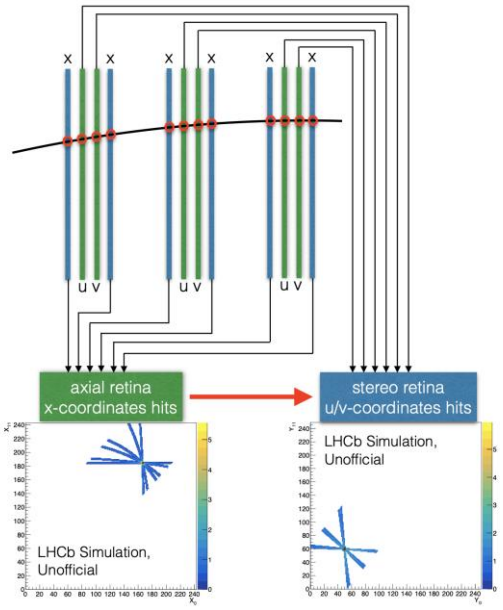
L3 enhancements: RETINA

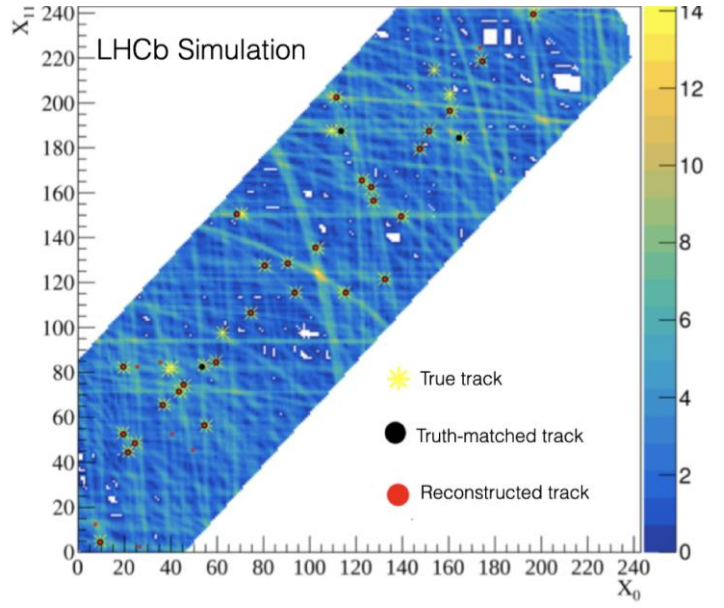
RETINA goal: make event reconstruction primitives (VELO, T-tracks, MuonID) found by FPGAs immediately available to event-building, freeing resources for other tasks.

Two main ongoing activities:

LS3 proposal

- Reconstruct VELO track primitives in real time at 30 MHz;
- Realise a downstream tracking unit (DWT) using hits from SciFi at 30 MHz.





L3 enhancements: RETINA

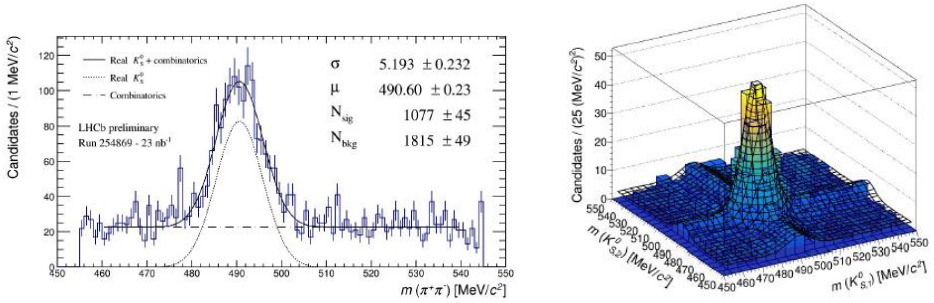
RETINA goal: make event reconstruction primitives (VELO, T-tracks, MuonID) found by FPGAs immediately available to event-building, freeing resources for other tasks.

Two main ongoing activities:

LS3 proposal

- Reconstruct VELO track primitives in real time at 30 MHz;
- Realise a downstream tracking unit (DWT) using hits from SciFi at 30 MHz.
  Clear physics benefits for downstream K_S and for long-lived particle searches.

K_S vs K_S signal in Run 3 (not RETINA)



Possible physics gains

Sample	Efficiency gain factor
$D^0 \to K^0_S K^0_S$	3.7
$D^0 \to K^0_S \pi^+ \pi^-$	4.1
$B^0 \to K^0_S K^0_S$	6.7
$B^0 \to K^0_S \pi^+ \pi^-$	2.5

Claimed gains in throughout, bandwidth (less raw data), power consumption.

For more info see Feb meeting. U2PG review to be scheduled in coming months.

L3 enhancements: *not* to be overlooked

Any L3 enhancement will have implications in terms of:

Software and simulation

We should insist all code written, commissioned and operational well before start of Run 4 ! Any project review must demonstrate this can be done.

Infrastructure, cavern and online

Remember no common fund available for LS3 enhancements.
Need realistic estimate for number of additional optical fibres by summer.

L3 enhancements: *not* to be overlooked

Any L3 e

Softw

We ell before
sta one.

Infra

Re
Ne mmer.

What we need from sub-detectors

- Amount of links (DAQ & ECS/TFC)
- Throughput (IN and OUT of the DAQ boards)

→ Contact: me

- Optical fibers plans
- DCS plans → Contact: Clara Gaspar, Luis Granado Cardoso
- Data formats
- Firmware plans

→ Contact: Guillaume Vouters, Paolo Durante

PLANNING AND PROCUREMENT
ALWAYS TAKE LONGER THAN EXPECTED.
2026 IS AROUND THE CORNER.

T. Colombo ▸ Online system for U1b and U2 Barcelona, 30 Mar 2023 9

L3 enhancements: *not* to be overlooked

Any L3 enhancement will have implications in terms of:

Software and simulation

We should insist all code written, commissioned and operational well before start of Run 4 ! Any project review must demonstrate this can be done.

Infrastructure, cavern and online

Remember no common fund available for LS3 enhancements.
Need realistic estimate for number of additional optical fibres by summer.

RTA and HLT

Surely, many implications here also.

Furthermore, let us not forget much consolidation of trigger system will be required in LS3 anyway, *e.g.* replacement of aging CPUs.

Conclusions

LS3 presents a golden opportunity to:

- consolidate Upgrade I;
- enhance physics performance for Run 4 (which will be one of the most important data harvests for LHCb);
- lay foundations for Upgrade II.

But opportunities often carry risks, and this is no different. We cannot endanger prospects of Run 4, nor interfere with preparations for Upgrade II.

Important that all proposals are reviewed carefully and we make right decisions.