3rd Workshop on LHCb Upgrade II

LAPP

UNIVERSITÉ
SAVOIE
MONT BLANC

21 - 23 March 2018

Detectors:

Summary & Outlook

Alessandro Cardini / INFN Cagliari

The LHCb Path to the Future

Chris Parkes

- Long program ahead of us
- Increasing difficulties in time
- Requires to be carefully planned in advance

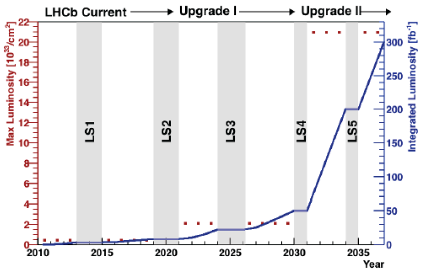
LHCb Timeline

- LHC Run-I (2010-2013)
- LHC Run-II (2015-2018)
  - Trigger computing increased.
- LHC Run-III, Run-IV (2021-2023, 2026-2029)
  - Major 'New' Experiment: **LHCb Upgrade [I(a), I(b)]**
  - L = 2×10^{33} $cm^{-2}s^{-1}$, integrated $50fb^{-1}$
- LHC Run-V (2031-)
  - Major 'New' Experiment

    LHCb Upgrade II

    L = 2×10^{34} $cm^{-2}s^{-1}$, integrated $300fb^{-1}$

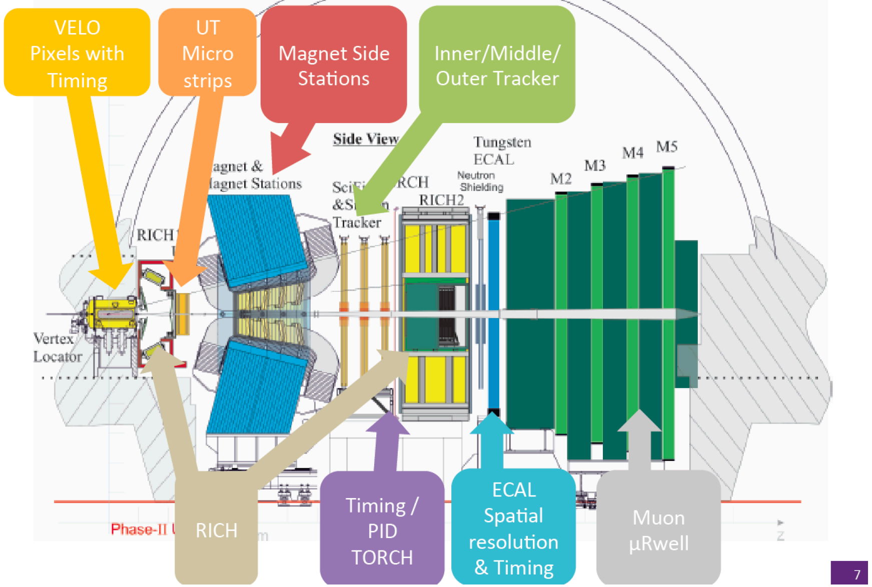
    – May be only general heavy flavour expt on this timescale



Chris Parkes

U2

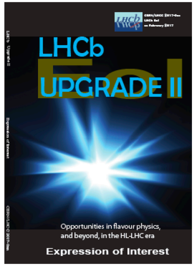
Upgrade II Detector



LHCC response to EOI

From LHCC minutes: May 2017

- The **LHCC notes** the submission of the EoI for LHCb upgrades beyond Phase-I, and **encourages** LHCb to pursue the physics studies and collaboration with the LHC experts to motivate these upgrades with a solid physics case, taking into account the expected results from LHCb Phase-I and Belle II, and establish feasible running conditions that do not interfere with other LHC experiments. The **LHCC urges** the LHCb management to ensure that these activities have no impact on the on-going Phase-I upgrades, which must take priority.



Interpret as:
- Physics case document required
  - Emphasis of this meeting
- Increase interaction with LHC accelerator experts

  from LHCb Eric Thomas
  - Talk: Riccardo de Maria
  - Attending: Beniamino Di Girolamo

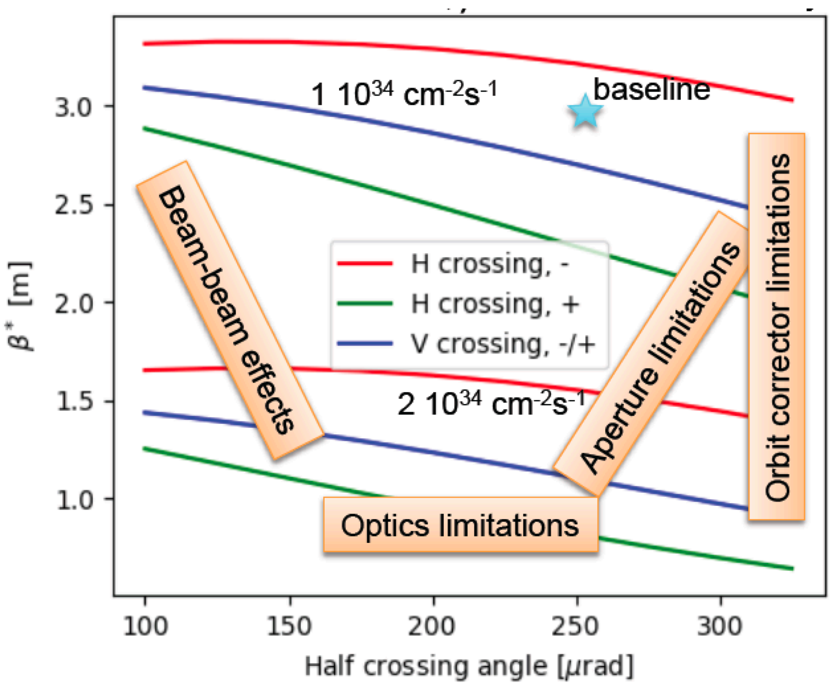
Detector Sessions

Machine	LHC studies
Tracking	VELO@U2 overview Use of timing in tracking (Use of timing in ATLAS) CMOS Pixel Sensors for Inner Tracker Magnet-side chambers
PID	RICH Upgrade TORCH CALO Upgrade Muon Upgrade
TDAQ	Towards an U2 Data Processing Model

LHC studies

Riccardo de Maria

- Many ways to increase instantaneous luminosity, but machine has limits
- The need to change the LHCb magnet polarity further complicates the situation, implying possible LHC commissioning operation (➔ extra time) at polarity reversal



What can we get from LHC

Riccardo de Maria

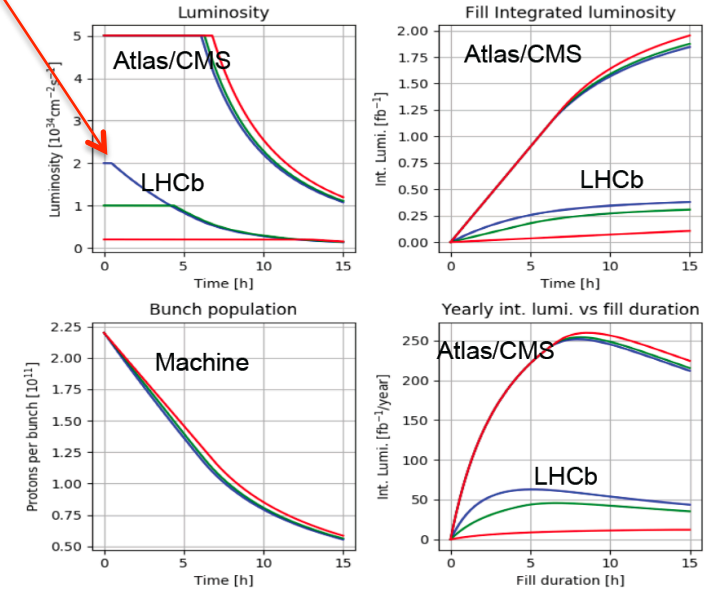
- Will not be able to operate continuously at a leveled luminosity of 2E+34 cm^{-2}s^{-1}

- Design for 2E+34 cm^{-2}s^{-1} will allow us to
  - Increase overall statistics
  - Better perform at lower instantaneous luminosity

- LHCb prefers shortest fills with respect to ATLAS/CMS

- LHC concern: lifetime of our triplets, due to radiation damage
  - Better estimate will come from ATLAS/CMS
  - Consider <u>improving their shielding</u>, in particular for the one behind muon stations

Example of Luminosity evolution

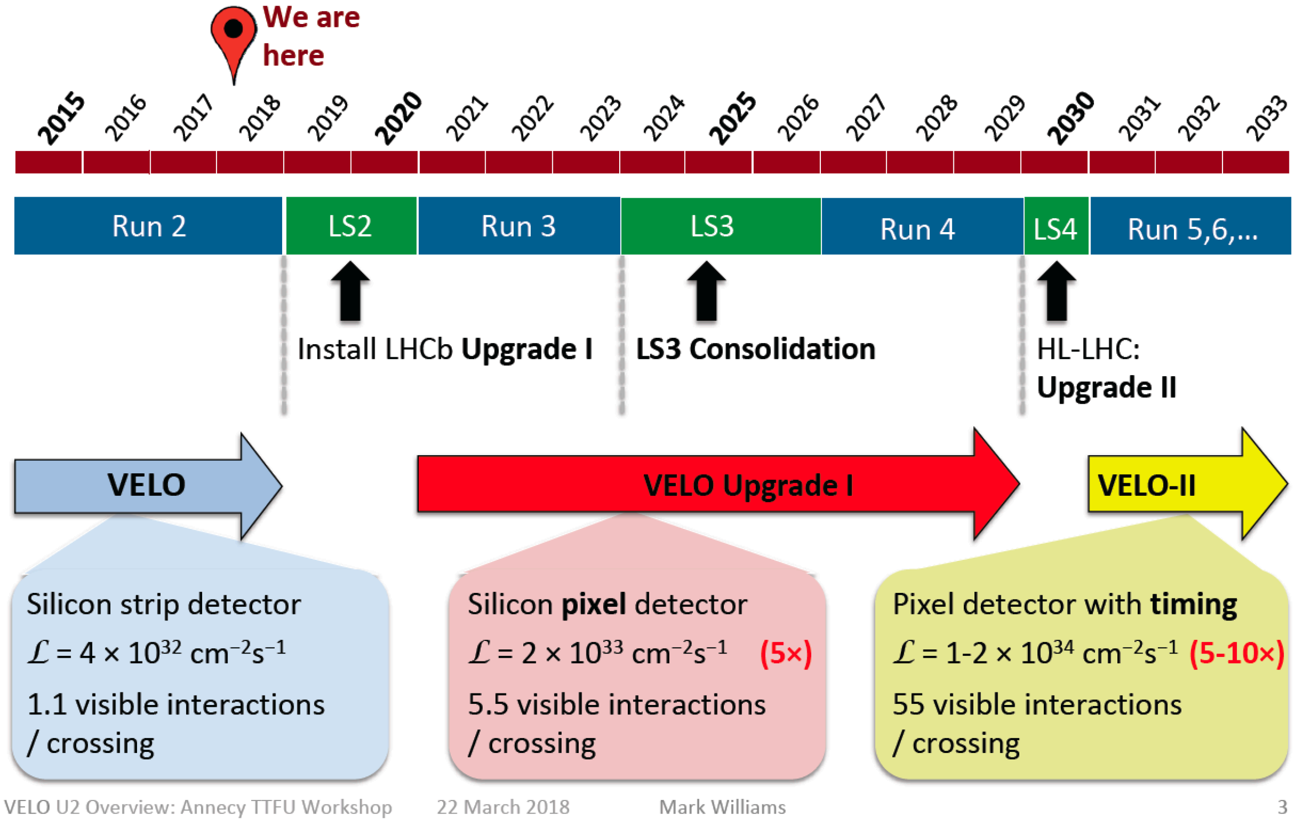


Case with LHCb virtual luminosity of 2.16 10^{34} cm^{-2}s^{-1} with three levelling scenarios.

Simple model used for illustration only and not for quantitative estimates.

The VELO Timeline

Mark Williams



Install LHCb **Upgrade I**

LS3 Consolidation

HL-LHC:
Upgrade II

VELO

Silicon strip detector

$\mathcal{L} = 4 \times 10^{32}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$

1.1 visible interactions / crossing

VELO Upgrade I

Silicon **pixel** detector

$\mathcal{L} = 2 \times 10^{33}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$ **(5×)**

5.5 visible interactions / crossing

VELO-II

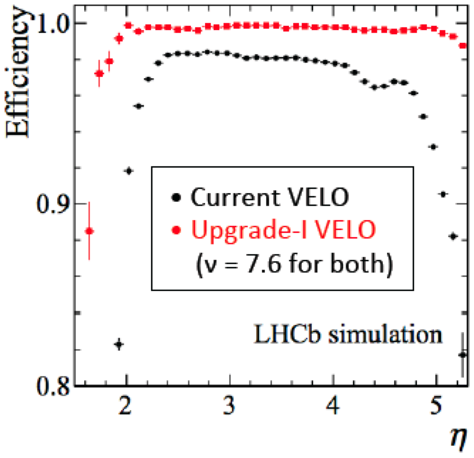
Pixel detector with **timing**

$\mathcal{L} = 1\text{-}2 \times 10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$ **(5-10×)**

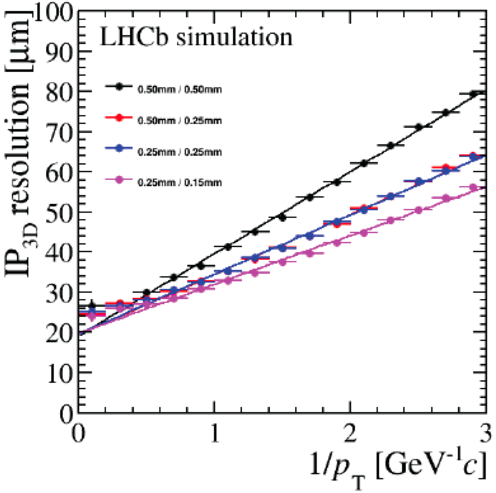
55 visible interactions / crossing

VELO Requirements

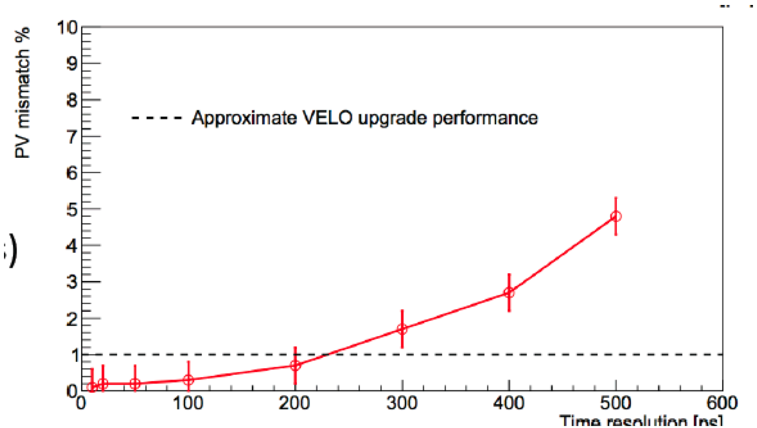
Mark Williams



Maintain the Upgrade-I efficiencies



Possibly improve impact parameter resolution



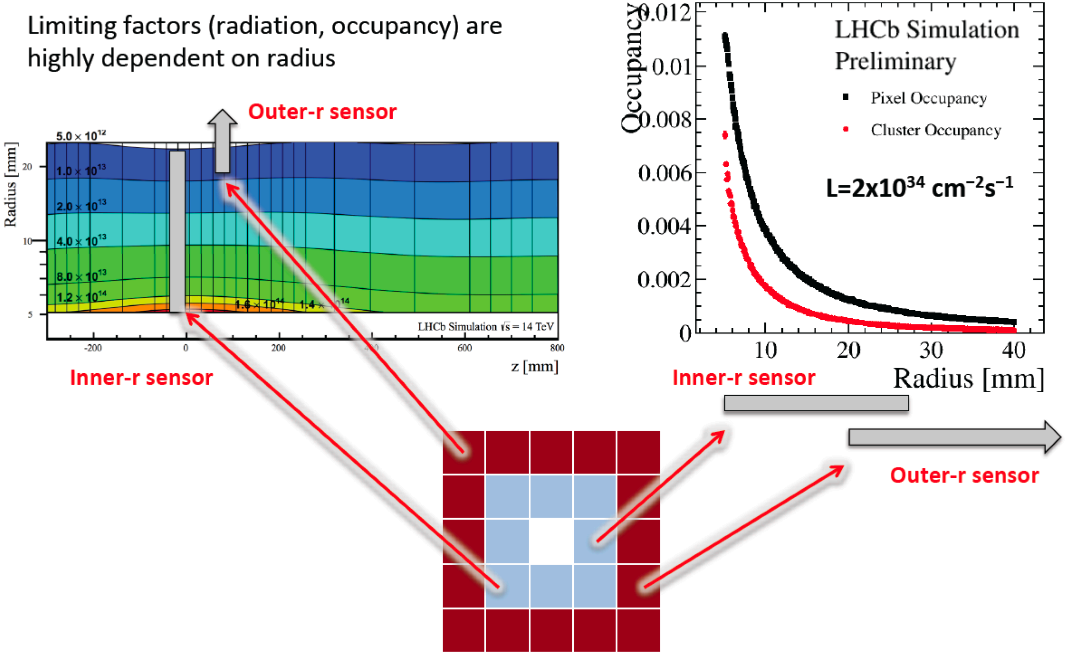
Reduce wrong associations to PV using time information

10x multiplicities, 10x occupancies, 10x rad. damage: <u>can it be done and how?</u>

Implications of occupancy to design

Mark Williams

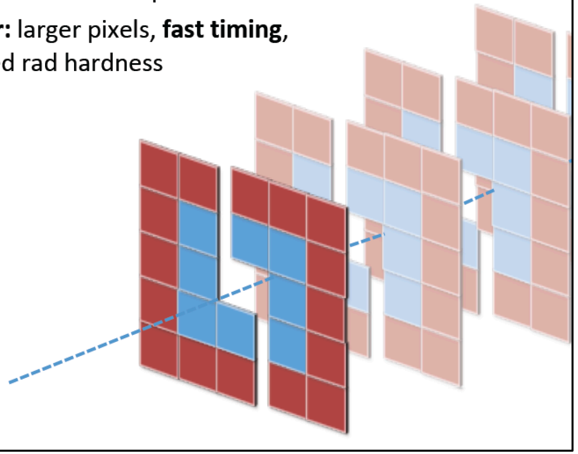
Limiting factors (radiation, occupancy) are highly dependent on radius



Radial dependence motivates a dual-technology design

🟦 **Small-r:** small pixels, radiation hard, timing information optional

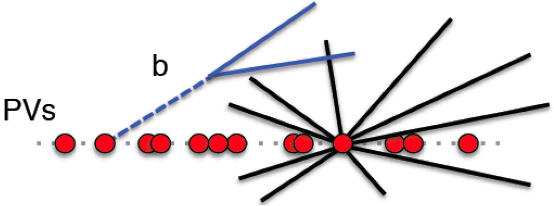
🟥 **Large-r:** larger pixels, **fast timing**, reduced rad hardness

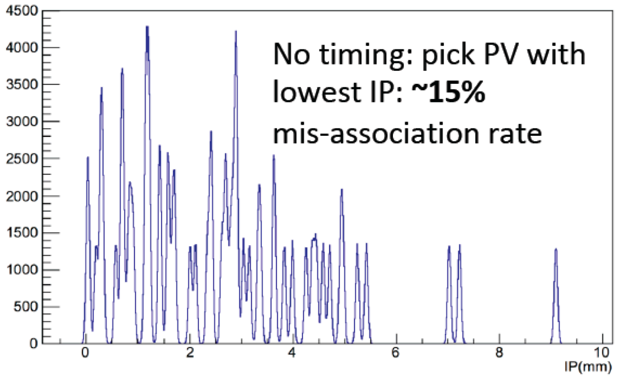


Time info reduces spatial occupancy

Mark Williams

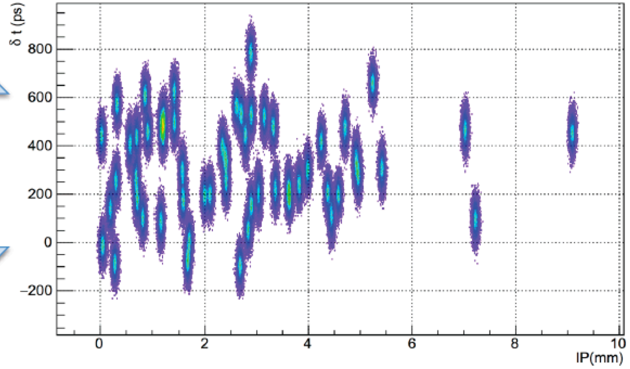
Run toy simulations of two-body B decays to assess PV mis-association rate from dual-technology design





No timing: pick PV with lowest IP: **~15%** mis-association rate

+ timing



With timing: additional power to select correct PV using both IP and timing information:
2-4% mis-association rate

PV mis-association fraction

Mark Williams

At $\mathcal{L} = 2.0 \times 10^{34}$ /cm²/s,
PV mis-association rate (~~PV~~%):

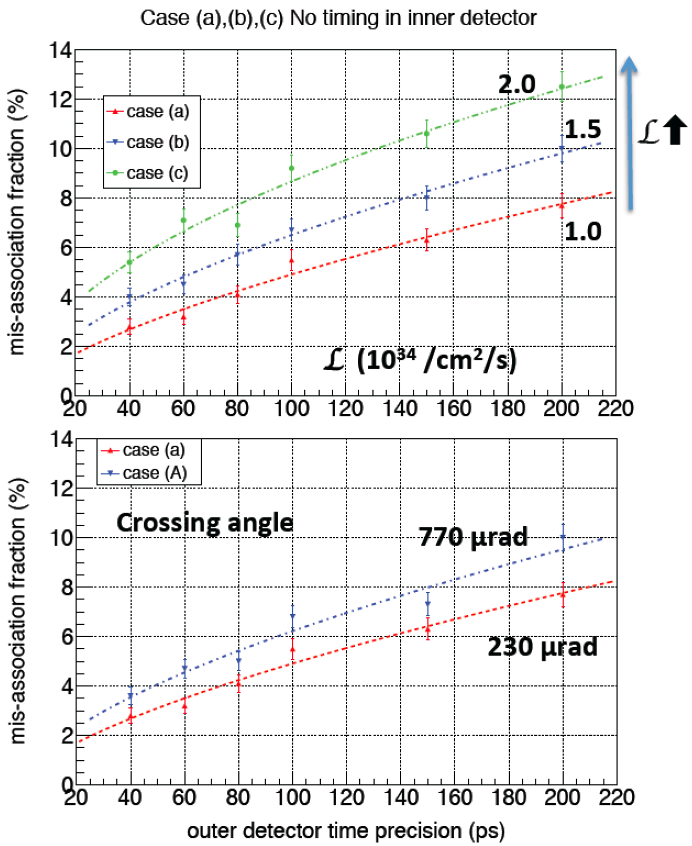
- No timing: **20%**
- Timing only in inner detector: **5-13%**
- +200ps timing in outer region: **4-9%**

As expected, ~~PV~~% scales ~linearly with luminosity

No strong effect from β* value

Significant degradation for larger crossing angle (i.e. for one choice of LHCb magnet polarity)

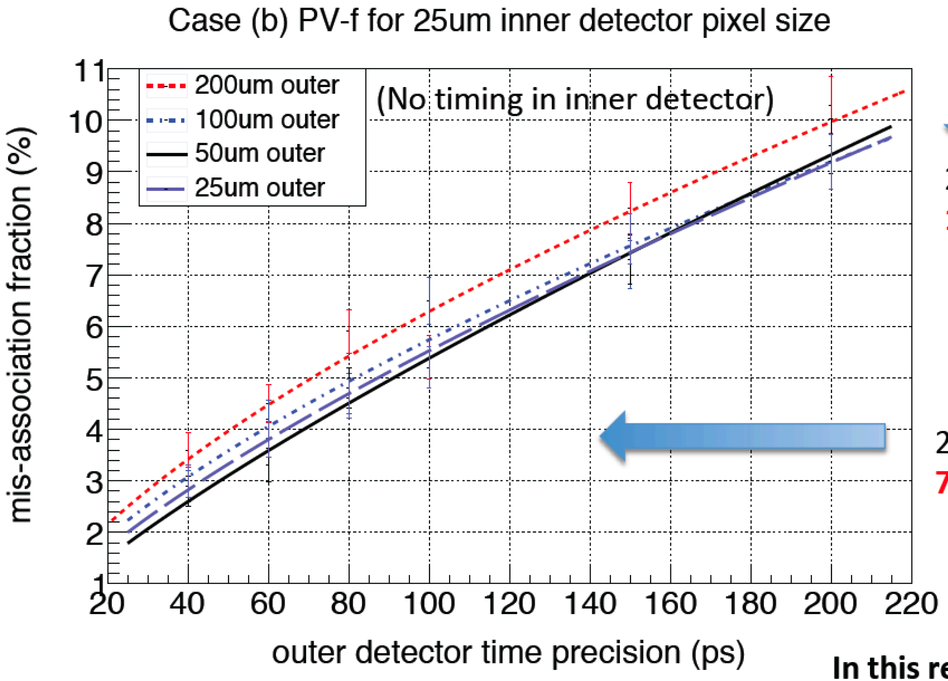
Significantly different performance for different polarities… no longer obvious that instrumental effects cancel



Faster is Better than Smaller

Mark Williams

Pixel size versus timing precision: what matters most for outer radial region?



200→25µm pixels:
10% lower ~~PV~~%

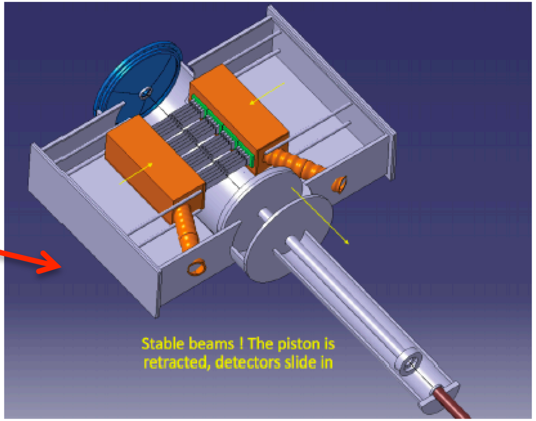
200→40ps timing:
70% lower ~~PV~~%

In this realm, timing more important for PV association

Mark Williams

(Many) Open Questions

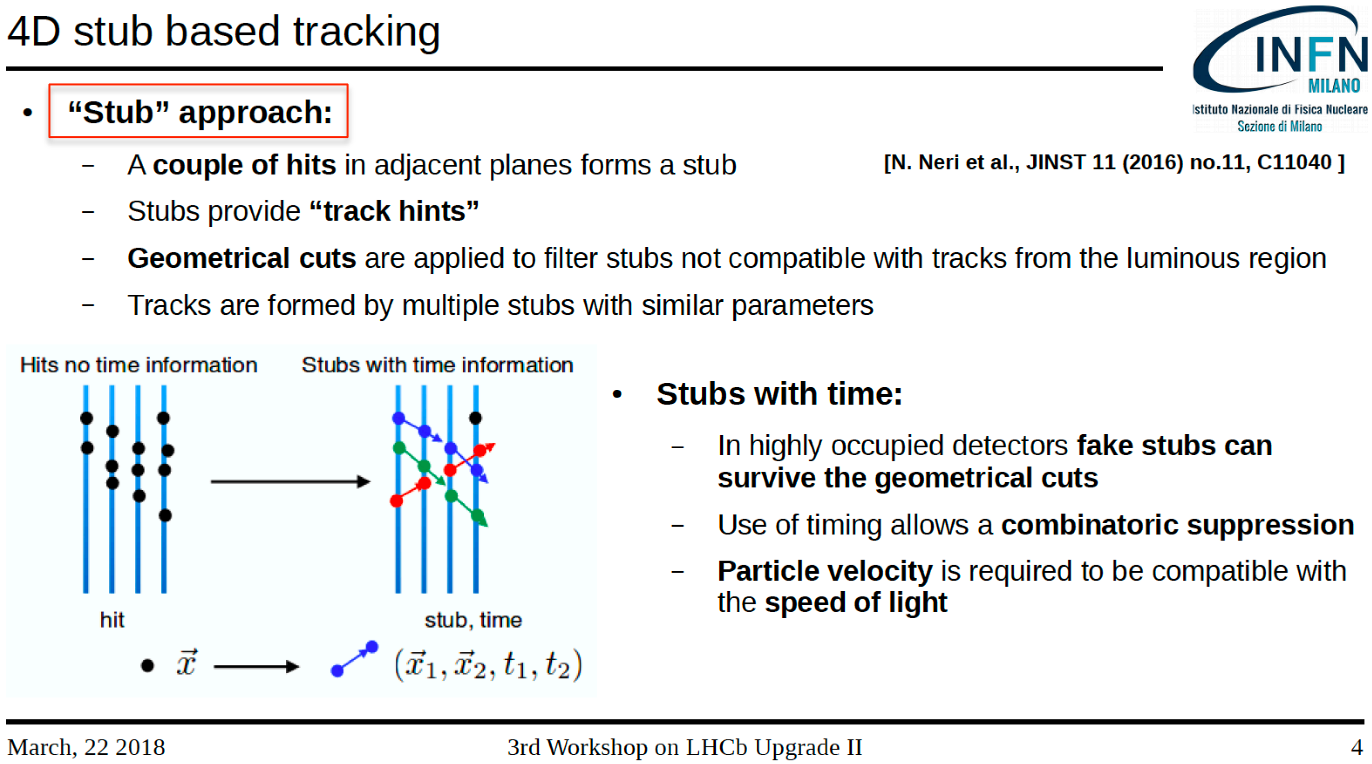
- How we will deal with radiation damage?
- Can we remove RF foil?
- How will timing information be used?
- Will (and how will) reconstruction needs and limitation influence VELO design?



Conclusion →

Tracking using Time Info

Marco Petruzzo



4D stub based tracking

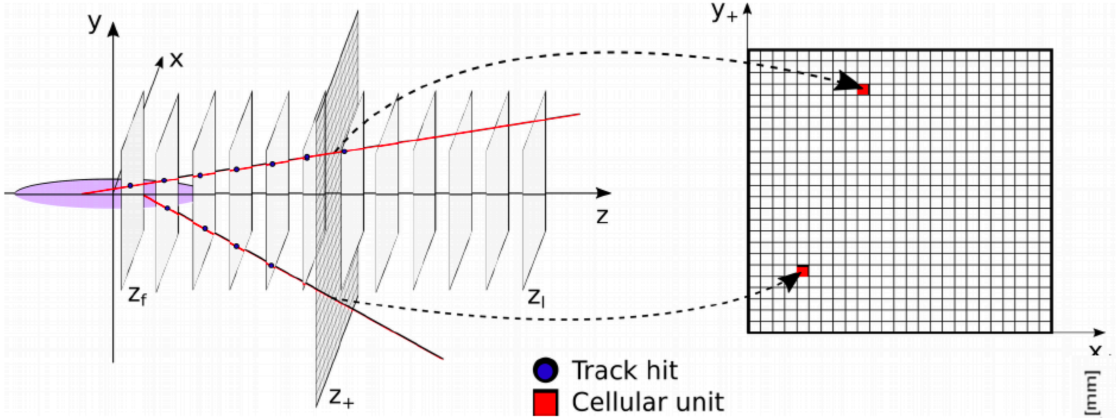
INFN MILANO
Istituto Nazionale di Fisica Nucleare
Sezione di Milano

- **"Stub" approach:**
  - A **couple of hits** in adjacent planes forms a stub
  - Stubs provide **"track hints"**
  - **Geometrical cuts** are applied to filter stubs not compatible with tracks from the luminous region
  - Tracks are formed by multiple stubs with similar parameters

[N. Neri et al., JINST 11 (2016) no.11, C11040]

- **Stubs with time:**
  - In highly occupied detectors **fake stubs can survive the geometrical cuts**
  - Use of timing allows a **combinatoric suppression**
  - **Particle velocity** is required to be compatible with the **speed of light**

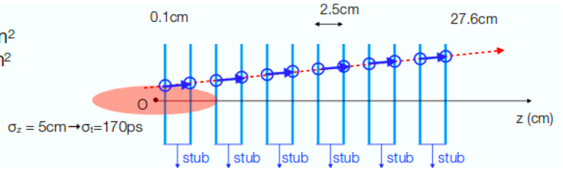
Marco Petruzzo

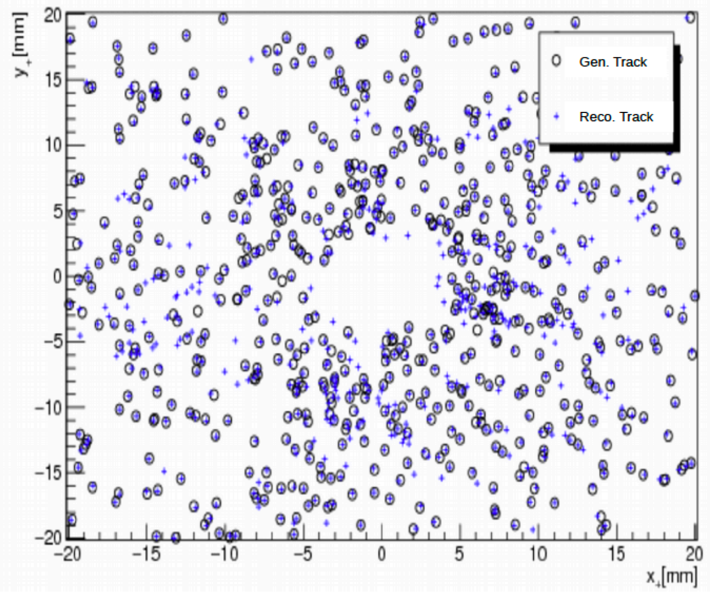


Simulation conditions

- **VELO-like tracking device:**
  - 12 planes of silicon pixel detectors in the forward region.
  - Pile-up ~**40**
  - ~**1200** tracks/event
  - Luminous region Gaussian distributed: σ_z=5cm, σ_t=167ps

Sensor area = 6x6cm^2
pixel size = 55x55μm^2
thickness = 200 μm
time res σ_t=30 ps

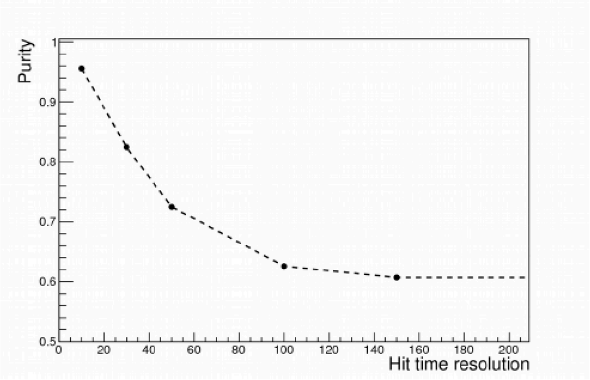


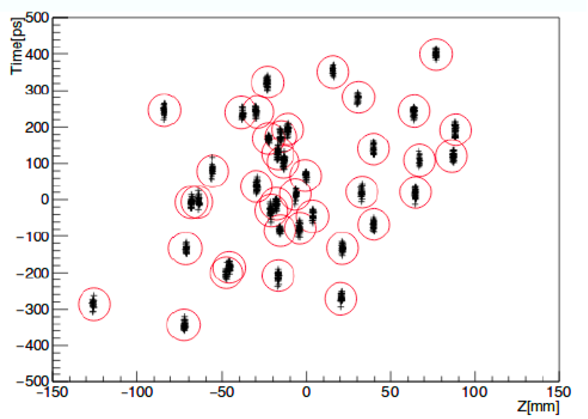


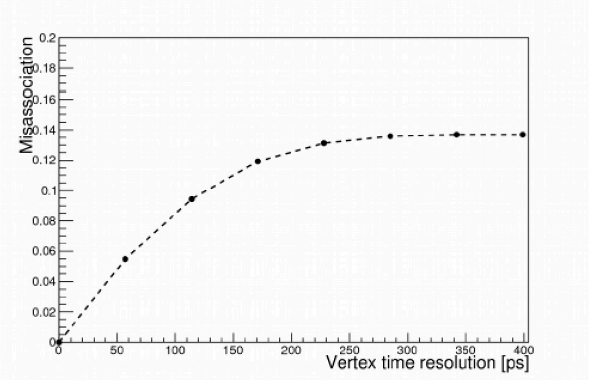
Marco Petruzzo

Istituto Nazionale di Fisica Nucleare
Sezione di Milano

Benefits of timing on track purity and PV association







- The track **purity improves with improved time** resolution, as expected
- The track timing allows to **“clusterize” the tracks** in a 2D (z,t) space
- The **PV mis-association reduces**, with improved time resolution

Tracking with Timing Summary

Marco Petruzzo

- Timing in tracking helps − however more detailed studies required
- Stub-based approach is an interesting option − how to make stub?
- Doing tracks at hardware level
  - Might not necessarily reduce total amount of data sent to event builder
  - Will definitely speed-up HLT
- FPGA-based system is a possibility that matches well the expandability our event-builder scheme − but it's not the only one

CMOS Pixels (Inner Tracker)

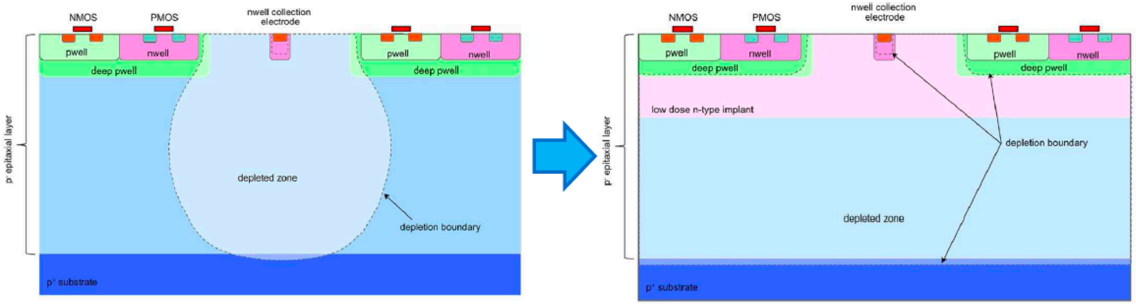
M. Winter

Advantages:

- Detector and FEE on the same substrate
- Commercially available
- Low cost per cm^2
- Granular (<10 um)
- “Fast” (timestamping <25ns)
- Radiation Hard (10^{15} n_{eq}/cm^2)
- Low Power

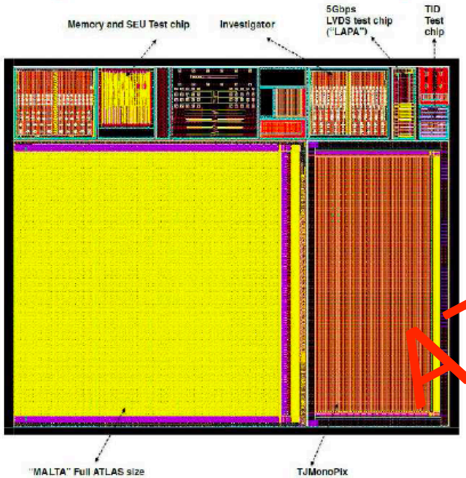
TowerJazz 180 nm Modified Process

- ☐ Modified process developed in collaboration of CERN with TJ foundry, originally developed in context of ALICE ITS
- ☐ Adding a planar n-type layer significantly improves depletion under deep PWELL
  - ✓ Increased depletion volume → fast charge collection by drift
  - ✓ better time resolution reduced probability of charge trapping (radiation hardness)
  - ✓ Possibility to fully deplete sensing volume with no significant circuit or layout changes

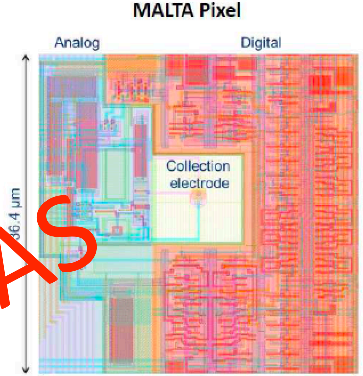


M. Winter

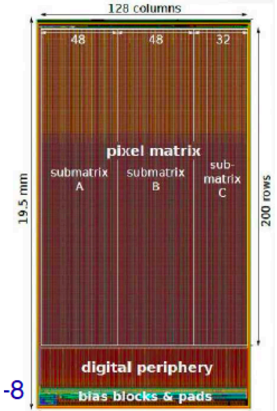
CMOS & HVCMOS



ATLAS


MALTA Pixel

T. Kugathasan et al. TWEPP 2017



MuPix8

- **MALTA**
  Asynchronous readout architecture to reduce digital power consumption and increase hit rate capability in the matrix.
  No clock distribution over the pixel matrix - (power reduction)

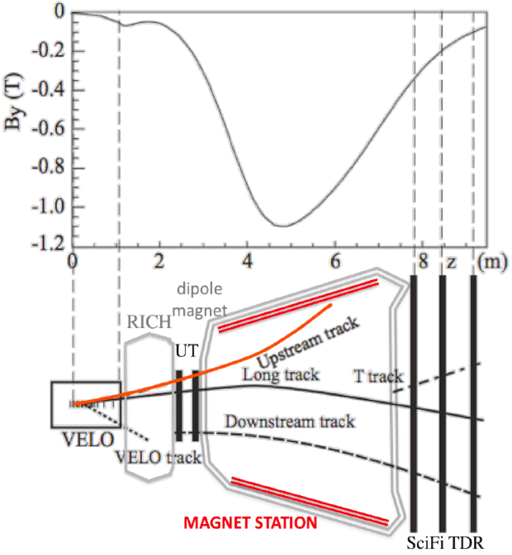
- **TJ-Monopix**
  Synchronous readout architecture. Uses the well-established column drain readout architecture (experience from LF-Monopix design)

- **First large scale sensors :**
  MuPix-7 and MuPix-8:
  - process: AMS-H18
  - triple well, no epitaxy
  - thinned to 50 μm
  - light doping substrate:
    $\rho \sim$ 20/80 Ω·cm for MuPix-7/-8
  - depletion depth: $\simeq$ 9/15 μm for MuPix-7/-
  - pixels : 80 x 81 μm^2
  - fluence: 1.5·10^{15}p/cm^2 (CERN-PS)

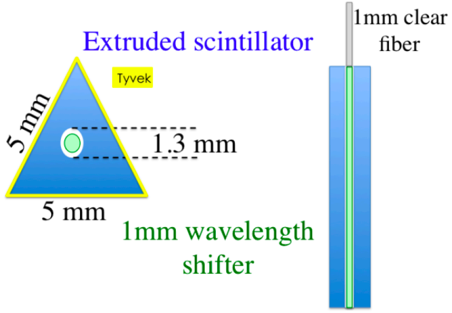
MONOLITHIC CMOS PIXEL SENSORS OFFER A PROMISING FUTURE FOR LHC TRACKERS

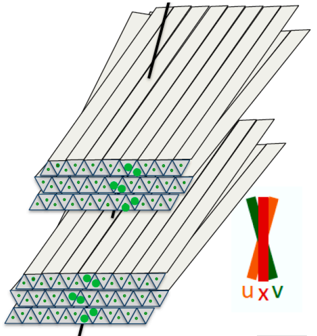
Magnet Stations

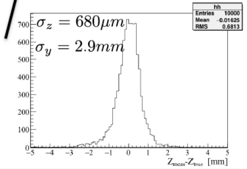
C. Da Silva



- δp/p~15%-20% for upstream tracks
- A 1mm z resolution tracker inside the magnet provides momentum resolution similar to long tracks
- See Marcin's presentation for physics possibilities







- Leverage R&D from D0 preshower
- Easier WS-clear fiber coupling
- Fewer number of channels

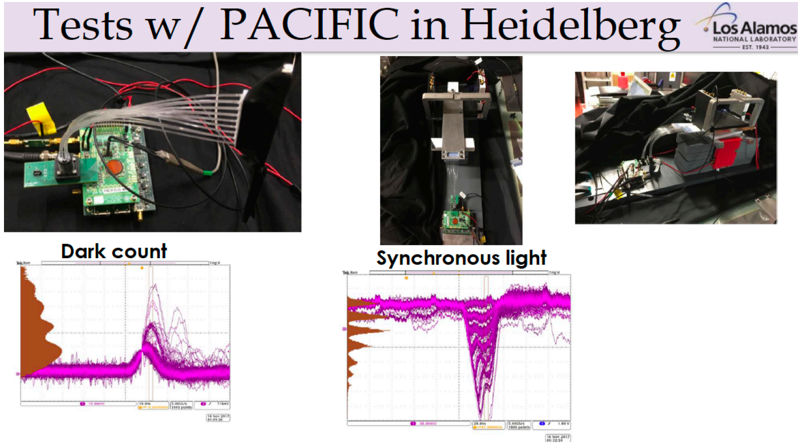
C. Da Silva

R&D for triangular bars

- 500 m of triangular bars produced by Fermilab extruded scintillator factory
- smallest extruded bar ever produced in that facility, had to develop new tooling for 5mm triangular bars

- Wavelength shifter -> clear fiber -> SiPM couplers developed at LANL

- First version of SiPM array board developed at LANL
- Using 2 commercial 4x4 SiPM arrays (2x2 mm^2 each channel, but will change to 1.3x1.3 mm^2)
- Second version with 4 SiPM arrays (64 channels) under development



Tests w/ PACIFIC in Heidelberg

Dark count

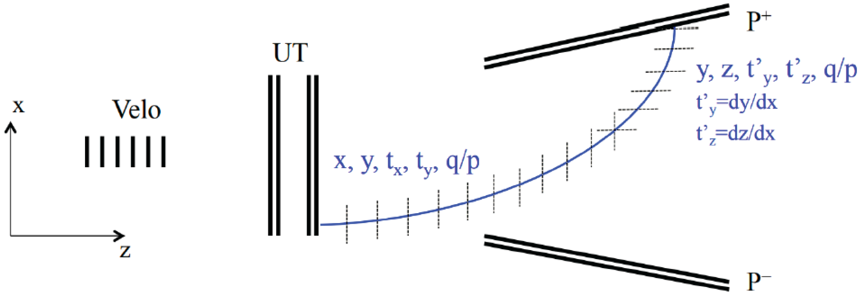
Synchronous light

Use a simplified version of SCIFI electronics

Tracking and MC studies

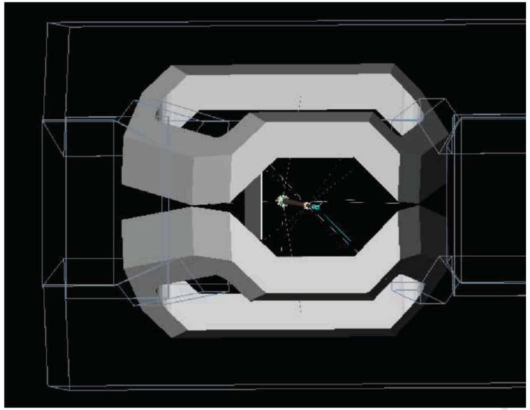
M. Chrzaszcz

2-fold Runge-Kutta for MS, P.Billoir



- ⇛ We start from „standard" Runge-Kutta method.
- ⇛ If $|t_x| > 1$ we switch steps to x.
- ⇛ With VELO + UT we know precisely: x, y, t_x, t_y. We poorly know: $\frac{q}{p}$ → MS can help.
- ⇛ Runge-Kutta method has to be inverted with the Newton-Raphson method.

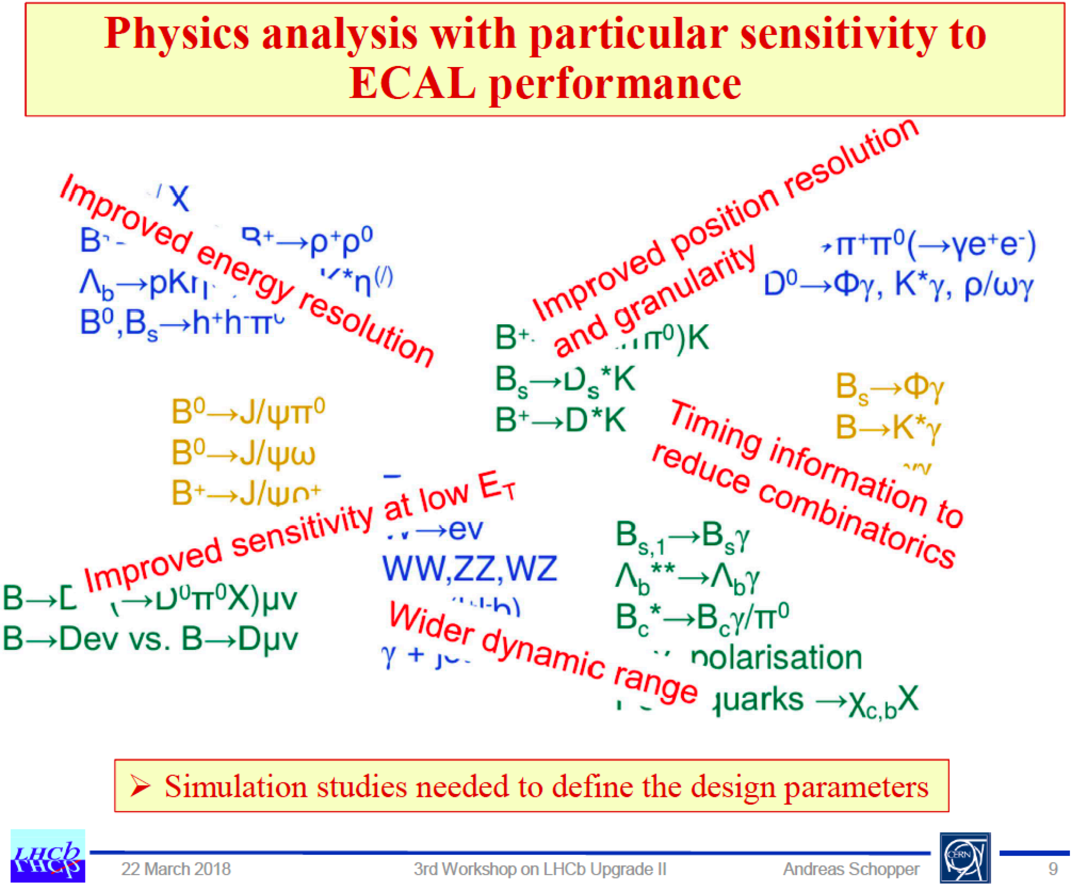
Gauss implementation, M. Pikies



- ⇛ Currently cloning structures of the SciFi.
- ⇛ Plans to implement Cesars proposal.
- ⇛ Run full MC simulations.

ECAL Requirements for U2

A. Schopper



Physics analysis with particular sensitivity to ECAL performance

Improved energy resolution

/ X

B

$B^+ \to \rho^+ \rho^0$

$\Lambda_b \to pK$

$*\eta^{(\prime)}$

$B^0, B_s \to h^+ h^- \pi$

Improved position resolution and granularity

$\pi^+ \pi^0 (\to \gamma e^+ e^-)$

$D^0 \to \Phi\gamma$, $K^*\gamma$, $\rho/\omega\gamma$

B^+ $\pi^0)K$

$B_s \to D_s^* K$

$B^+ \to D^* K$

$B_s \to \Phi\gamma$

$B \to K^*\gamma$

$B^0 \to J/\psi\pi^0$

$B^0 \to J/\psi\omega$

$B^+ \to J/\psi$

Timing information to reduce combinatorics

Improved sensitivity at low E_T

$\to e\nu$

WW,ZZ,WZ

$h)$

$\gamma +$

$B_{s,1} \to B_s\gamma$

$\Lambda_b^{**} \to \Lambda_b\gamma$

$B_c^* \to B_c\gamma/\pi^0$

$B \to$ $\to D^0\pi^0 X)\mu\nu$

$B \to De\nu$ vs. $B \to D\mu\nu$

Wider dynamic range

polarisation

uarks $\to \chi_{c,b} X$

- Simulation studies needed to define the design parameters

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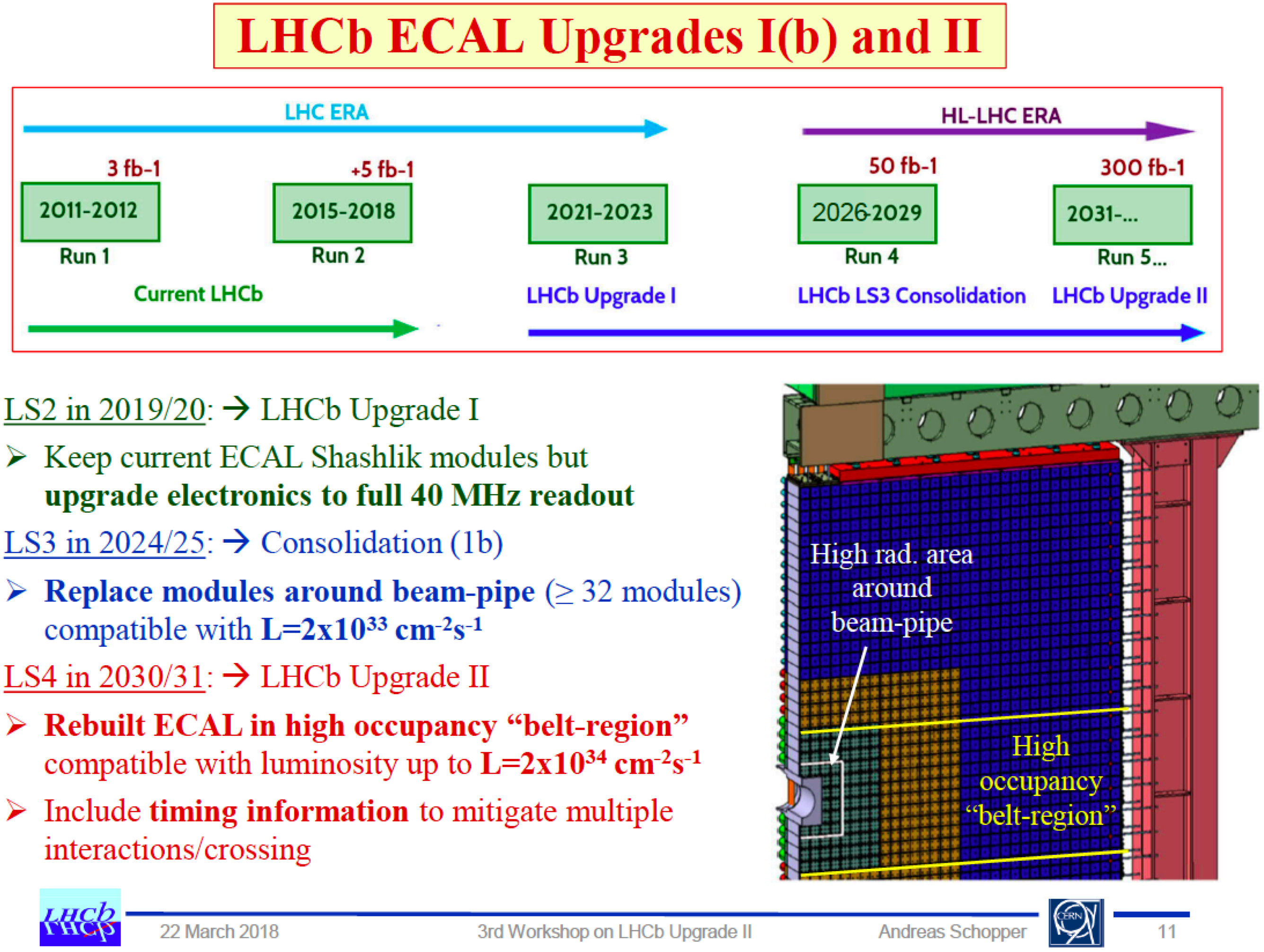
A. Schopper



LHCb ECAL Upgrades I(b) and II

LS2 in 2019/20: → LHCb Upgrade I

- Keep current ECAL Shashlik modules but **upgrade electronics to full 40 MHz readout**

LS3 in 2024/25: → Consolidation (1b)

- **Replace modules around beam-pipe** (≥ 32 modules) compatible with **$L=2x10^{33}$ $cm^{-2}s^{-1}$**

LS4 in 2030/31: → LHCb Upgrade II

- **Rebuilt ECAL in high occupancy "belt-region"** compatible with luminosity up to **$L=2x10^{34}$ $cm^{-2}s^{-1}$**
- Include **timing information** to mitigate multiple interactions/crossing

A. Schopper

ECAL requirements for Upgrade II

Rad. Hardness

Energy resolution

Occupancy

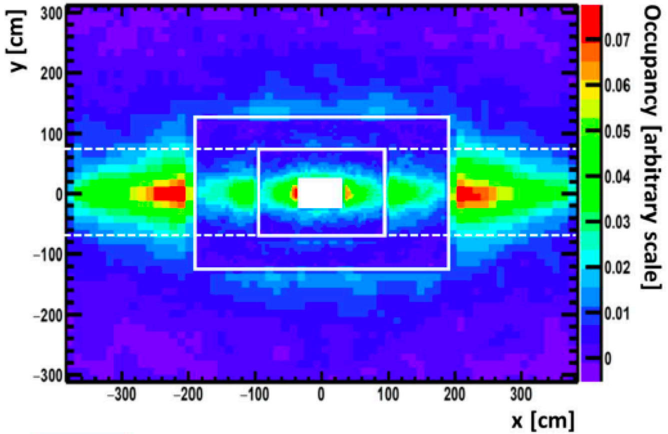
Timing

Constraints

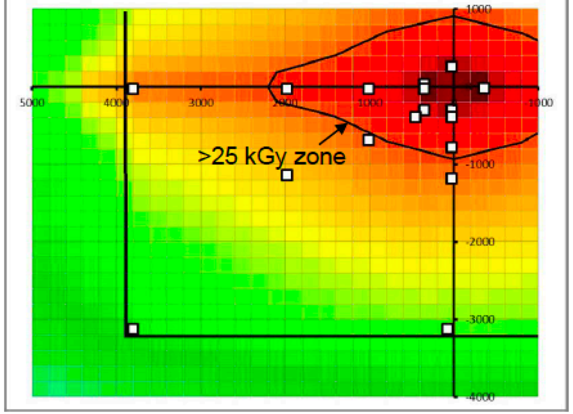
Overall requirements:

- ✓ **Sustain radiation doses of up to ~3 MGy and ~$3\cdot10^{15}$cm^{-2} for 1 MeV n eq. at 300 fb^{-1}**
  (in hottest region of the central part, decreasing quickly with distance from beam-pipe)
- ✓ Keep good energy resolution of order $\sigma(E)/E \sim 10\%/\sqrt{E} \oplus 1\%$
- ✓ Reduce occupancy and improve spatial resolution in inner region
  (reduce Moliere Radius (to ~2-3cm) and cell size (inner region) to ~ 2cm x 2cm)
- ✓ Include a very fast (crystal) component (~20ps) for pile-up mitigation into sampling module or add "pre-shower timing layer" in front of module (crystal, silicon, …?)
- ✓ Respect dimensional constraints of a module: 12 x 12 cm^2 outer dimension

Occupancies in different ECAL regions

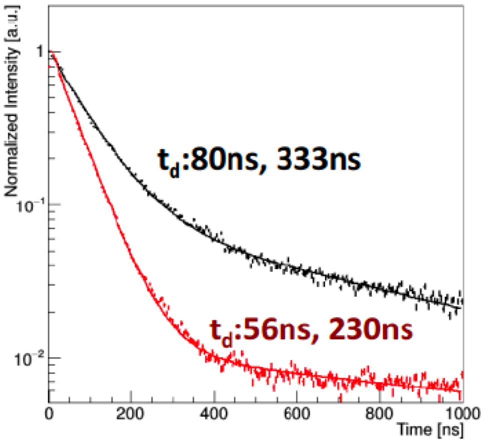


Radiation dose on ECAL front

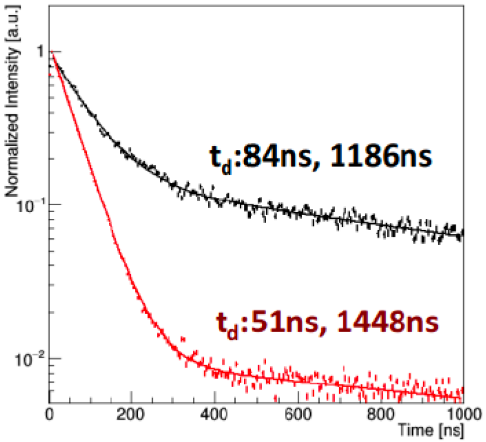


Radiation hard and fast scintillators

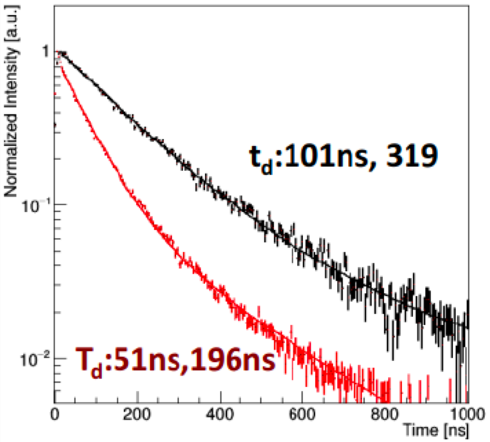
Y. Guz



YAG



LuAG



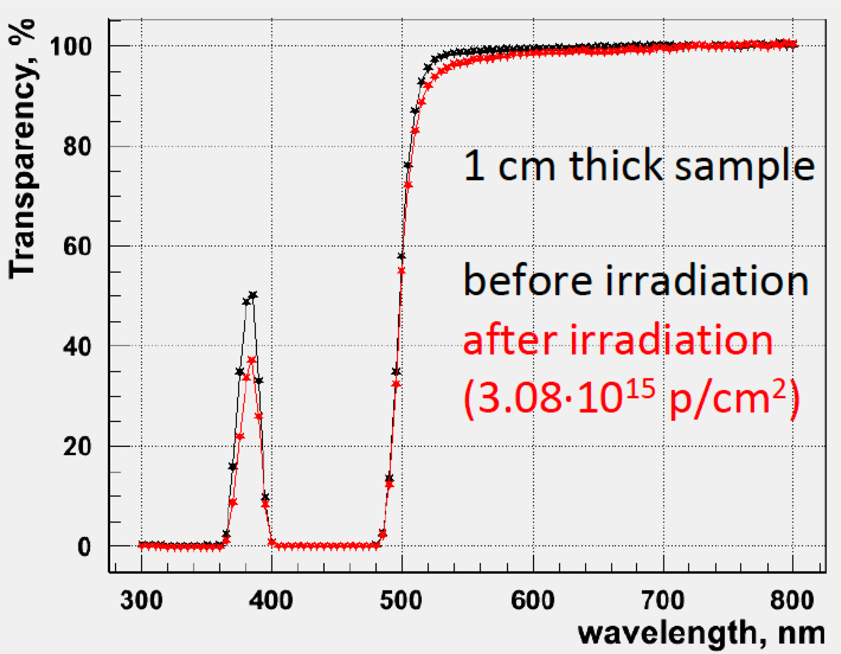
GAGG

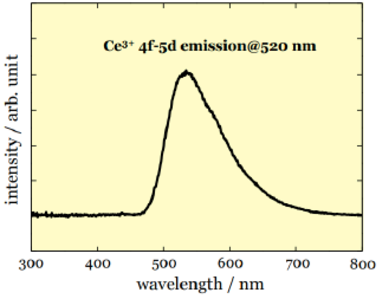
with Mg codoping: shorter decay time and strong decrease of slow component

E.Auffray, Upgrade Ib/II calorimeter meeting, 23-Feb-2018

Y. Guz

Transparency degradation after 3E+15 p/cm^2



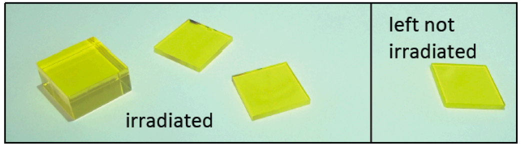


Radioluminescence spectrum of Ce:GAGG excited by Cu K$_\alpha$ X-ray.

At important wavelengths:

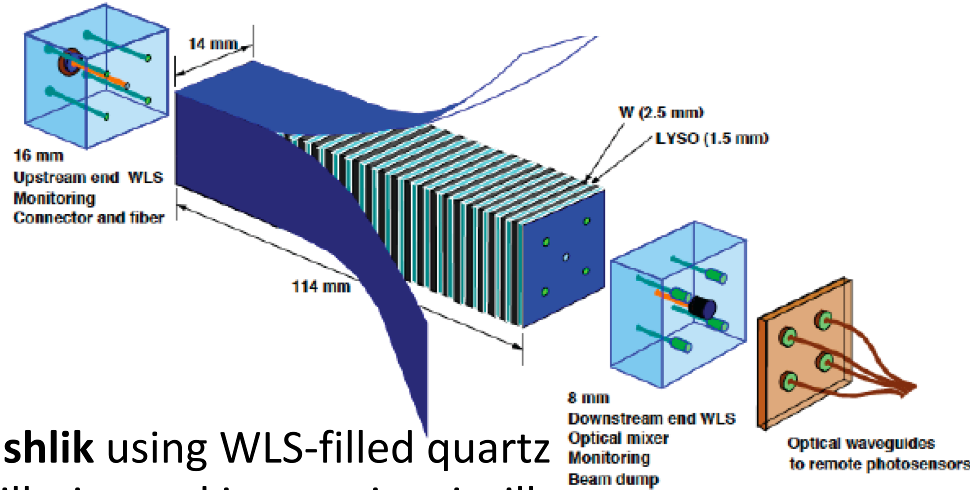
-3.6% @520nm
-2.5% @540nm
-1.8% @560nm

Excellent radiation hardness !



Possible ECAL Technologies

Y. Guz



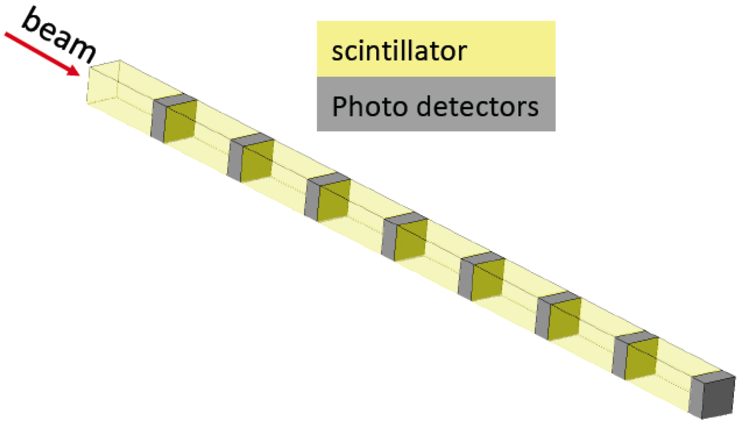
Shashlik using WLS-filled quartz capillaries and inorganic scintillator slabs

+ Rad. Hard. / low Moliere radius / reasonable E_{res}

- Complex construction

Homogeneous calorimeter

With longitudinal segmentation as an option.

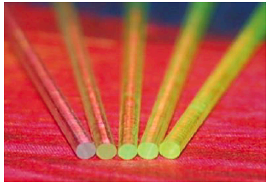


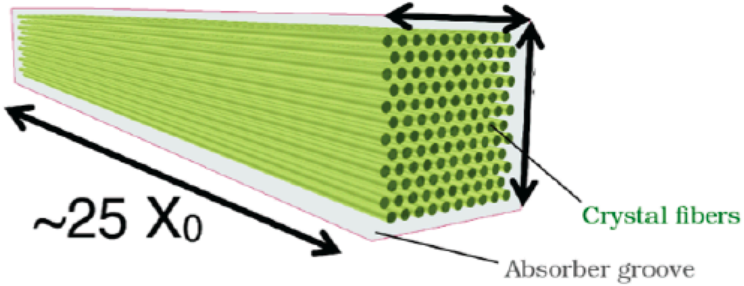
+ Rad. Hard. / low Moliere radius / longitudinal segmentation / t@shower_max

- Cooling? Calibration? ….

Possible ECAL Technologies

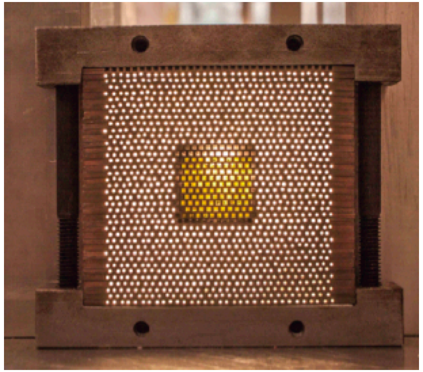
Y. Guz

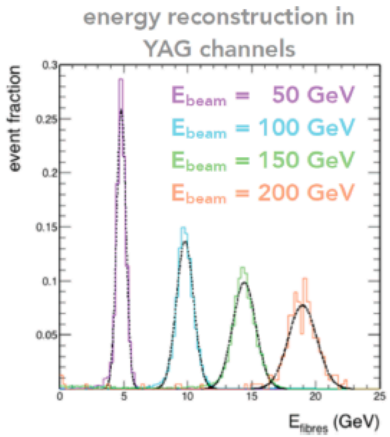


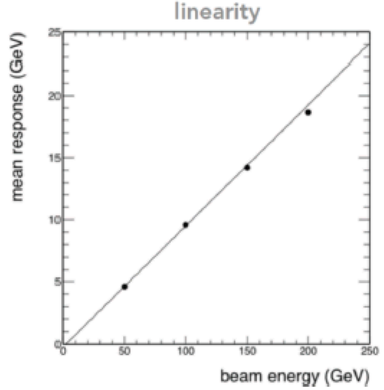


Crystal SpaCal

+ Smaller Moliere radius possible
- Long light path



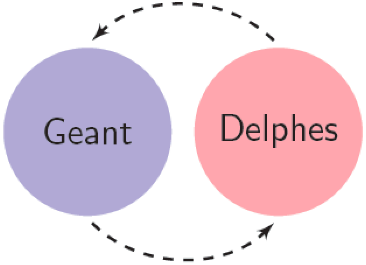




ECAL Performance Simulations

A. Davis

- Simultaneous development in two directions:
  - Full simulation in Geant 4
  - Fast simulation using Delphes
- Fast and full simulation have a symbiotic relationship
- Pushing both projects at once is of utmost importance
- Main questions to answer:
  - How does performance scale with occupancy?
  - How does timing influence the ability to separate signal from background, especially given HL-LHC environment?
  - What detector granularity and response maximizes the physics output while minimizing the cost?
- Goal: Dream big, understand limitations quickly



Fast feedback on physics response

Accurate parameterization of timing response, shower development and energy deposition

Let’s not forget that electron reconstruction will much benefit of material reduction before the magnet

Challenges in RICH Upgrade

S. Easo

- Improve single photon resolutions and yield

$$\sigma_{\mathrm{p}} = \sigma_{\mathrm{chromatic}} \oplus \sigma_{\mathrm{emission\ point}} \oplus \sigma_{\mathrm{pixel}}$$

$$\sigma_{\mathrm{t}} = \frac{\sigma_{\mathrm{p}}}{\sqrt{\mathrm{N}}} + \mathrm{Const.}$$

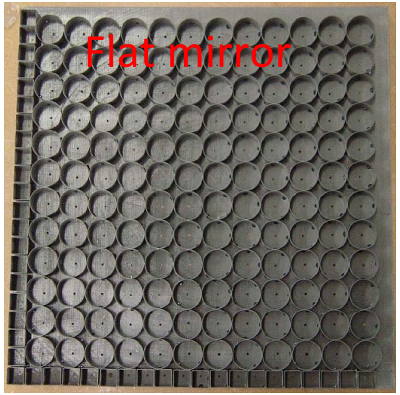
- Cope with high occupancy expected in Phase2
  - *Phase 1a and 1b: nominal ν=7.6*
  - *phase2 onwards : nominal ν=35 : RICH1 > 100 % occupancy*
- Upgrade the coverage at low and high momenta
  - *No signal from Kaons < 9.3 GeV/c and Protons < 18 GeV/c : Many charged tracks in this range*
  - *Above ~ 70 GeV/c close to saturation from all particle types*

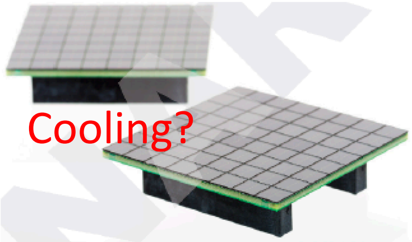
RICH Plans

C. D'Ambrosio

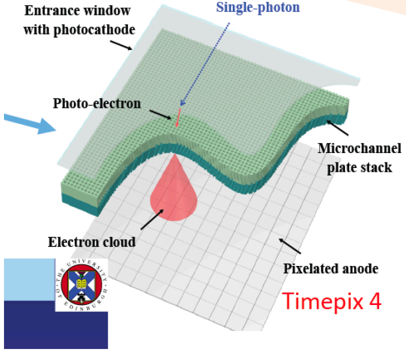
- Recipe for U2
  - Keep occupancy <30%
  - Improve single photon Č angle precision to <0.5mrad

- How
  - Improve optical error → flat light mirrors (in acceptance)
  - Further reduce chromatic error → green-enhanced detectors
  - Increase granularity
  - Add timing


Flat mirror

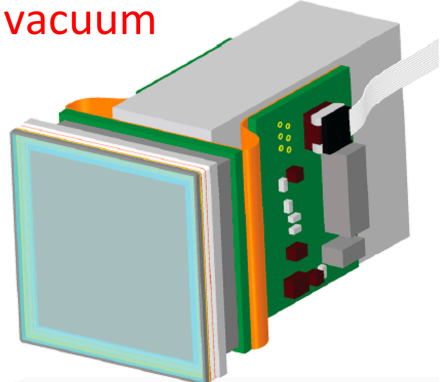

Cooling?

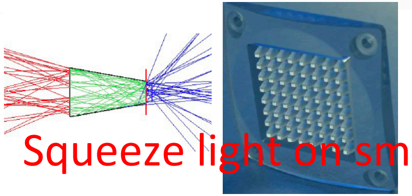
Synch 1ns gating!



Timepix 4

ASICs in vacuum

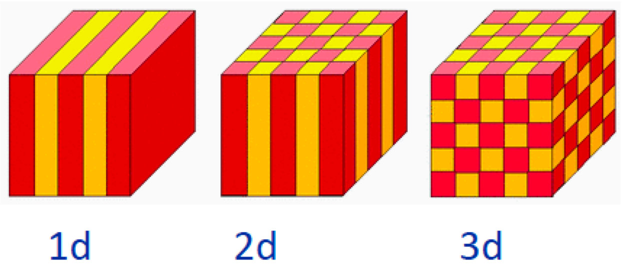



Squeeze light on smaller area

Improved RICH Radiators

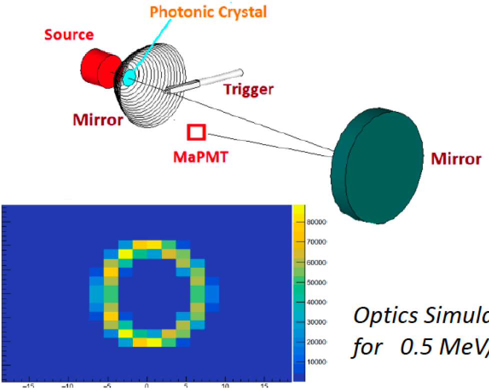
S. Easo

Design photonic crystals from transparent dielectrics

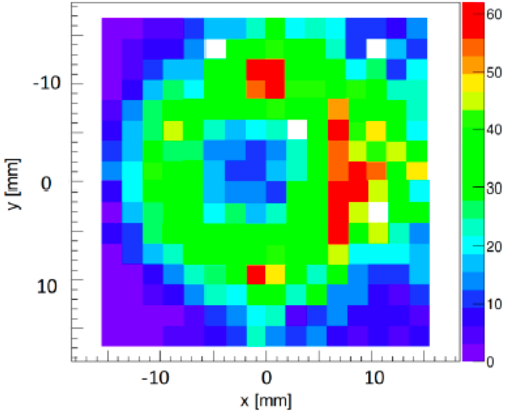


- R&D work in very early stages:
  - Few 1d samples obtained from industry

    PVDF n_1=1.414 + PET n_2=1.567
    1024 layers, each with 250 nm thickness



Optics Simulation for 0.5 MeV/c



Michele

Real Data 0.2 → 0.7 MeV/c

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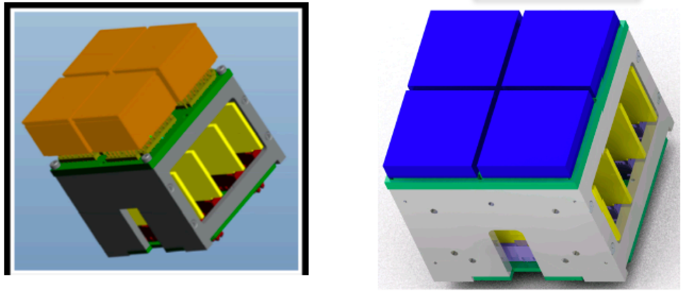
(Near) Future Work Directions

C. D'Ambrosio

Seen the enthusiastic response of present and future collaborators,
we could propose before LS3 to:

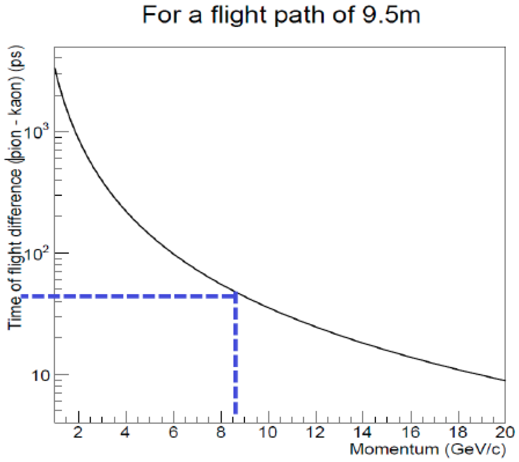
- Develop and characterize a few Elementary Cells instrumented with SiPM arrays (MCPs could also be thought of)

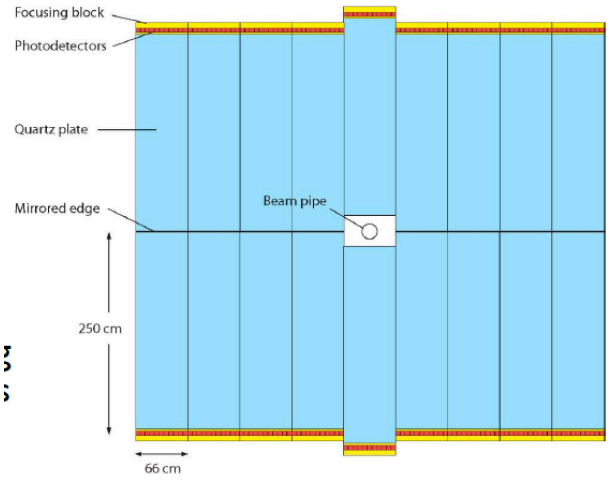


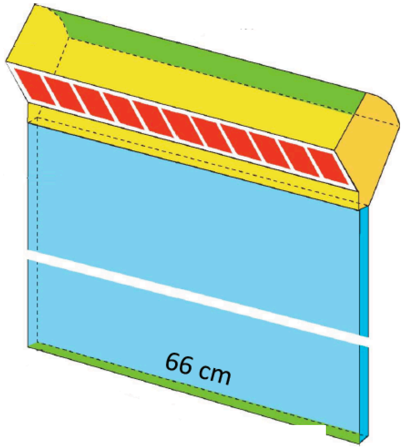
- Develop a cooling system (in vacuum?);
- Provide a ns gating and time resolution;
- Study the long-term behavior and characteristics of the system
- DAQ is a challenge; compress/reduce data on detector.
- Work on new and specific pattern recognition algorithms.

The TORCH TOF Detector

N. Harnew

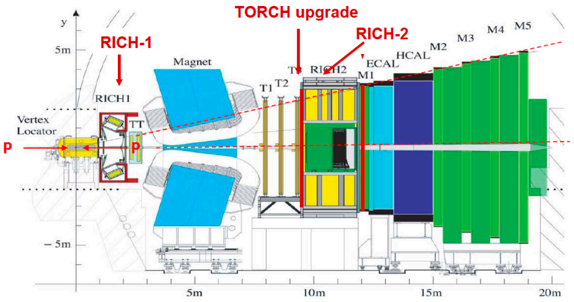

For a flight path of 9.5m

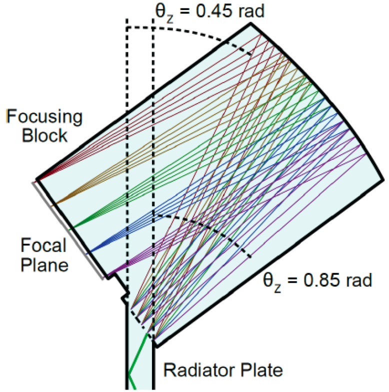




Aim: 10-15ps time resolution per track, or 70ps single photon time resolution

1mrad precision required to achieve 50ps

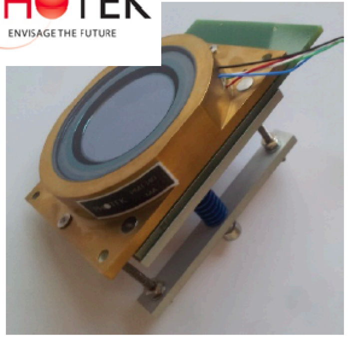


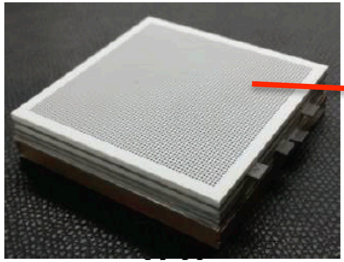


ERC-funded 5 years R&D Program

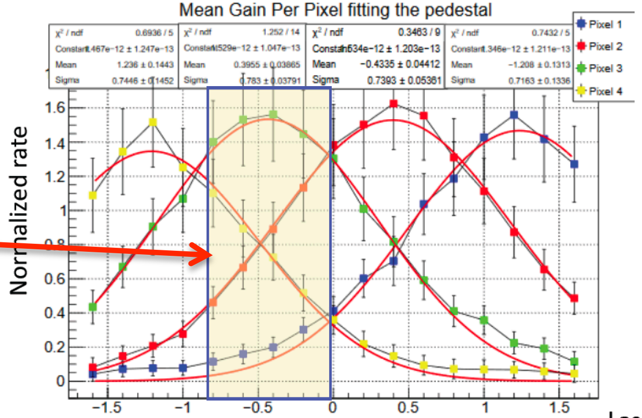
N. Harnew

PHOTEK
ENVISAGE THE FUTURE





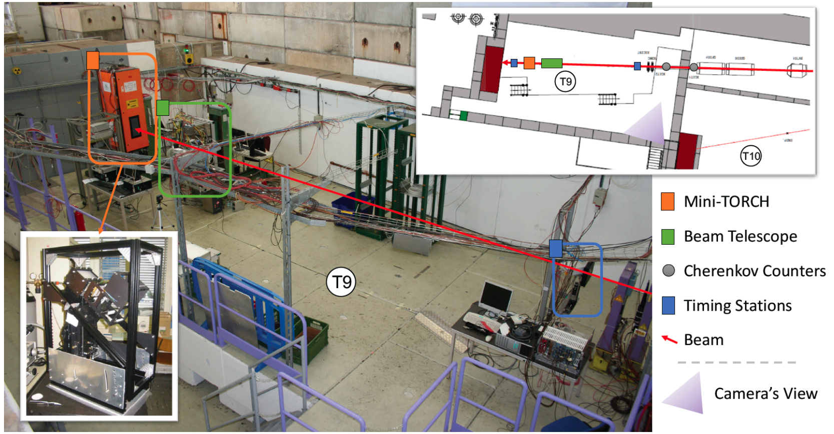
(1) New photodetectors
(2) Demonstrator



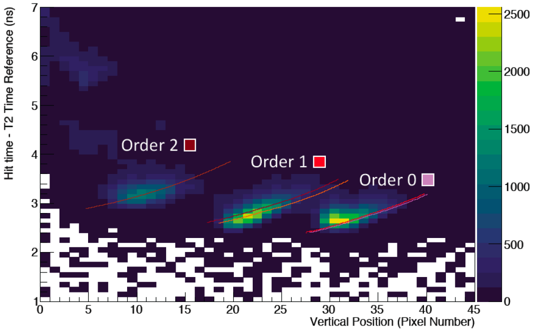
Laser position cm

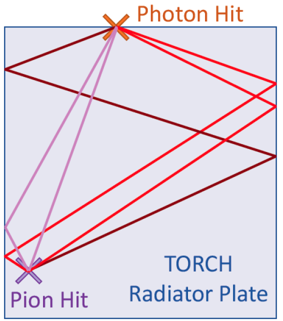
TORCH Demonstrator Test Beam

T. Hancock

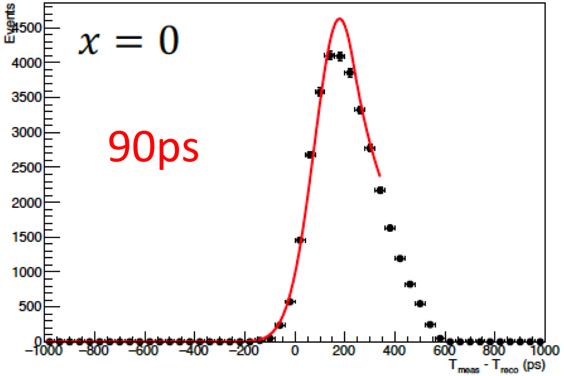


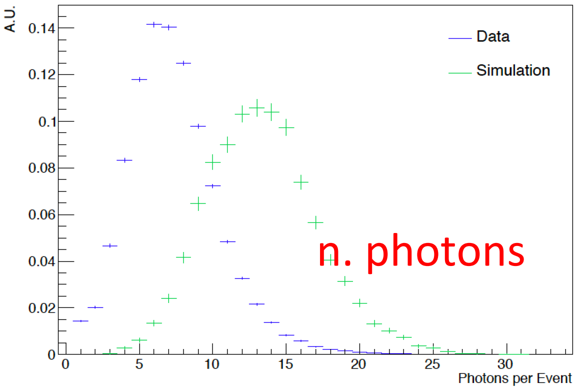
Time Resolution – Separating Reflections

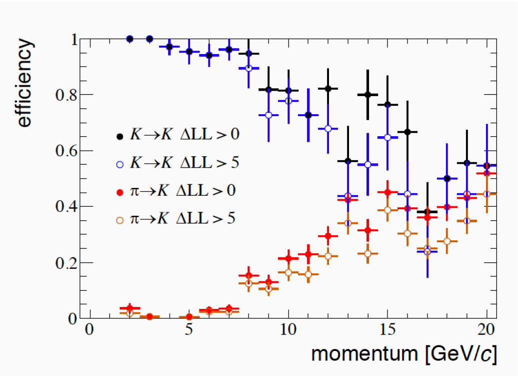




Beam striking radiator close to the edge results in superposed patterns



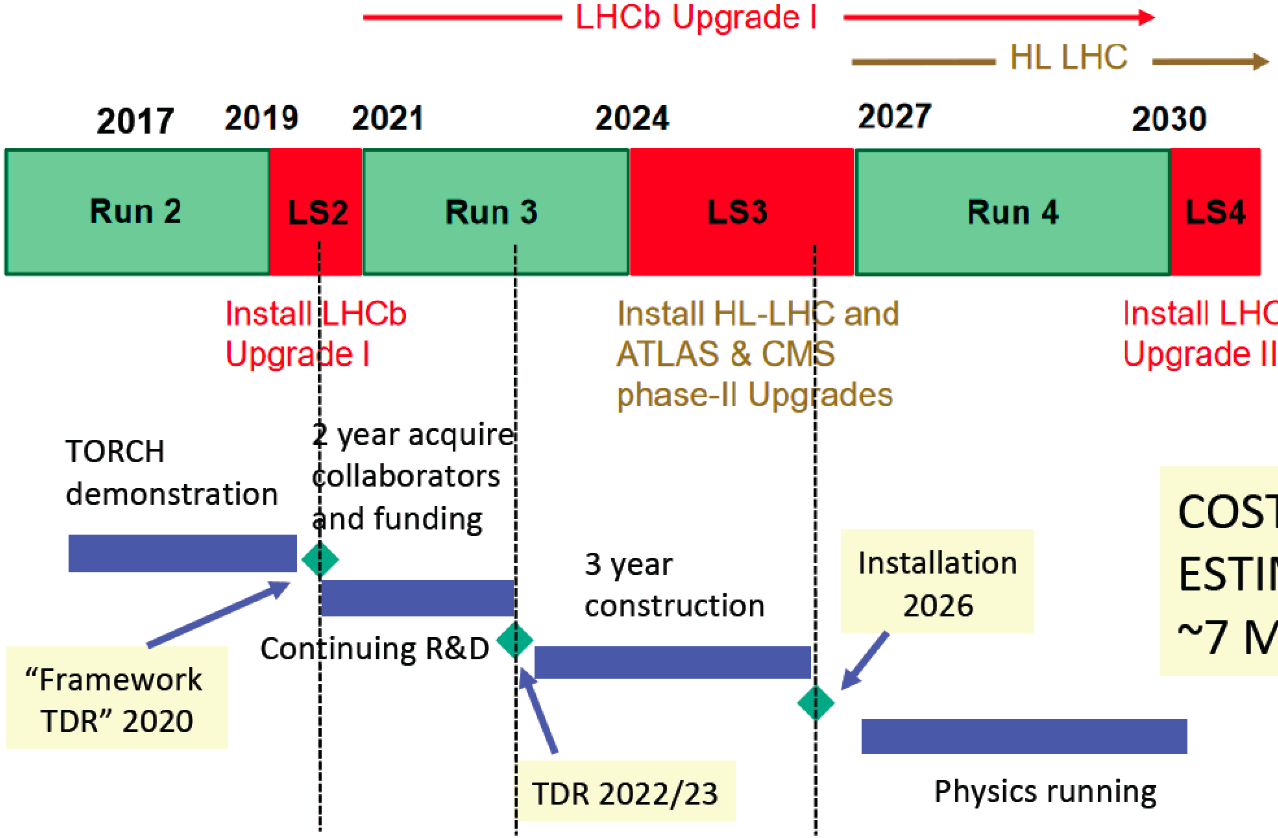




Inclusive B Events, $\mathcal{L} = 2\times10^{33}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$

N. Harnew

Possible TORCH timeline



"Framework TDR" 2020

TDR 2022/23

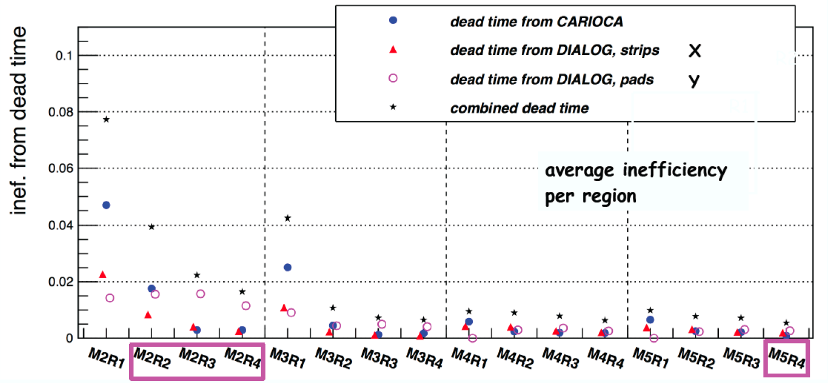
Installation 2026

COST ESTIMATE ~7 MChF

Muon System LS2 Upgrades

M. Palutan

Mitigation strategy at LS2



average inefficiency per region

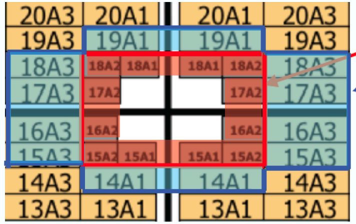
At LS2: beside the aforementioned improved beam pipe shielding, we plan to increase the granularity of X and Y strips by removing the OR of contiguous channels (IB boards) in M2R2 (dialog ineff /2), in M2R3 (/24), and in M2R4 (/24), and in M5R4 (/6)

The expected loss on dimuon events becomes 8%

LHCb-INT-2017-019

Further mitigation strategy for Run3

At LS2 or immediately after: install PAD chambers in M2R1, M2R2 and M3R1, to increase readout granularity and reduce CARIOCA induced dead time

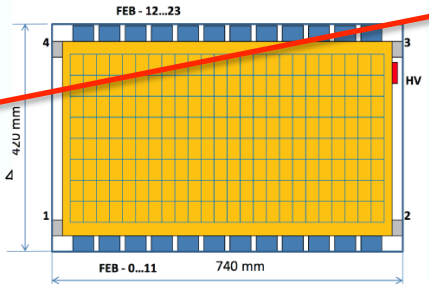


M2R1 and M3R1:12+12 PAD chambers

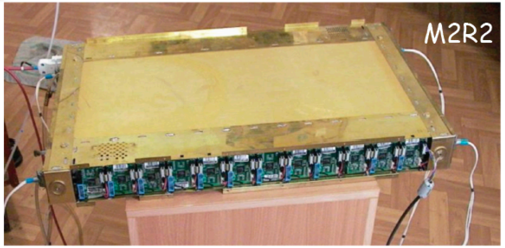
half M2R2: 12 PAD chambers

- A total of 360 additional FEBs, 12 additional nODEs, 6 additional TELL40 are needed: **all available within the planned LS2 resources**

The expected loss on dimuon events becomes 4.5%



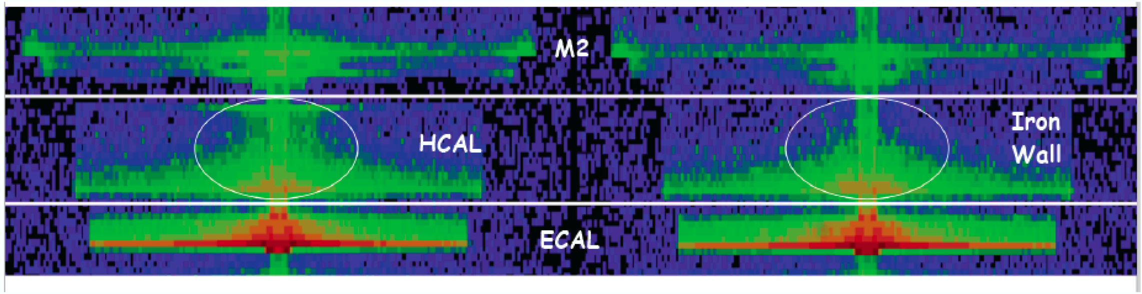
N.Bondar, B.Bochin, et al.



Increase Muon Shielding @ L=2E+34

M. Palutan

Idea: Replace HCAL with thicker (in terms of λ_{int}) iron shielding



Average rate reduction for inner regions

M2R1	M2R2	M3R1	M3R2
46%	77%	6%	20%

Muon losses

3<p<6 GeV	6<p<10 GeV	p>10 GeV
17%	2,7%	0,6%

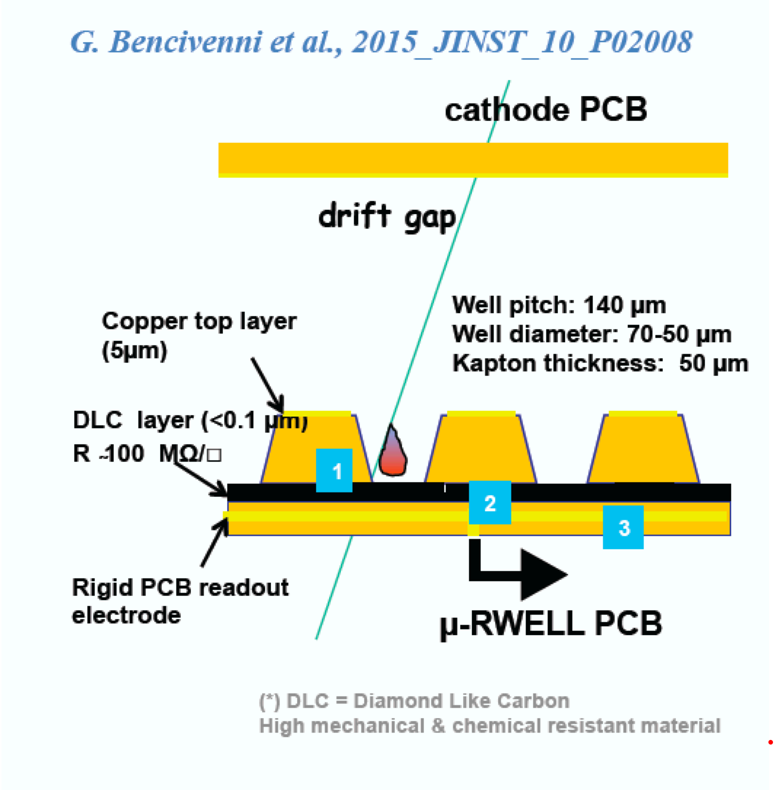
2-3% on $B_s\to\mu^+\mu^-$, $B_s\to J/Psi\ \varphi$, $D^0\to\mu^+\mu^-$

11% on $K_s\to\mu^+\mu^-$, $\tau\to3\mu$

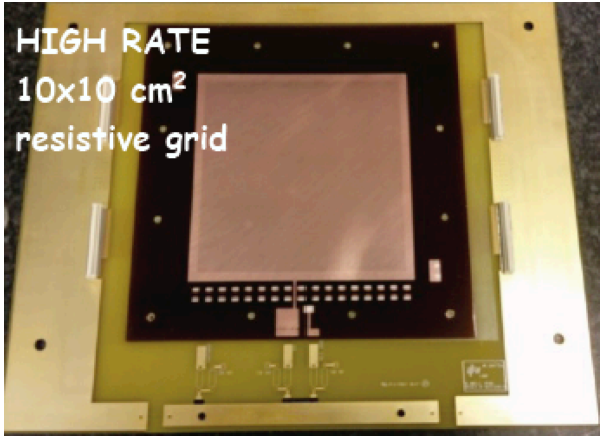
PID performance loss due to HCAL removal to be carefully assessed

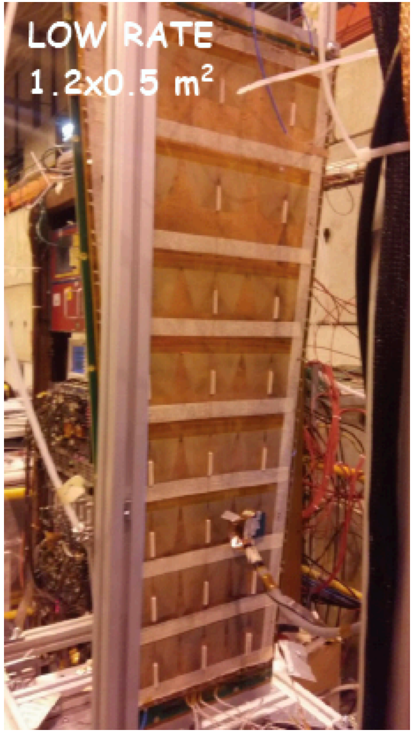
New detectors needed

M. Palutan


G. Bencivenni et al., 2015_JINST_10_P02008

(*) DLC = Diamond Like Carbon
High mechanical & chemical resistant material





… and a new electronics too!

M. Palutan

Muon Upgrade Summary

- @LS3 (2024 - 5)
  - additional Fe shielding (and no HCAL) → impact on PID and low E muons to be carefully evaluated

- @LS4 (2030 - …)
  - New detectors for all inner regions, with new FEE
  - New FEE, but we might also need new chambers in R34, the ones installed were built in ~2005…

Data Taking in the U2 Era

V. Gligorov

Everyone agrees on the fact that

- Almost all bunch crossing will contain interesting physics signal
- Most of the particle produced in these bunch crossing are not interesting

The biggest data processing challenge in history of HEP

==> Try to cleanup the event as early as possible

Vava assumes an untouched DAQ model…

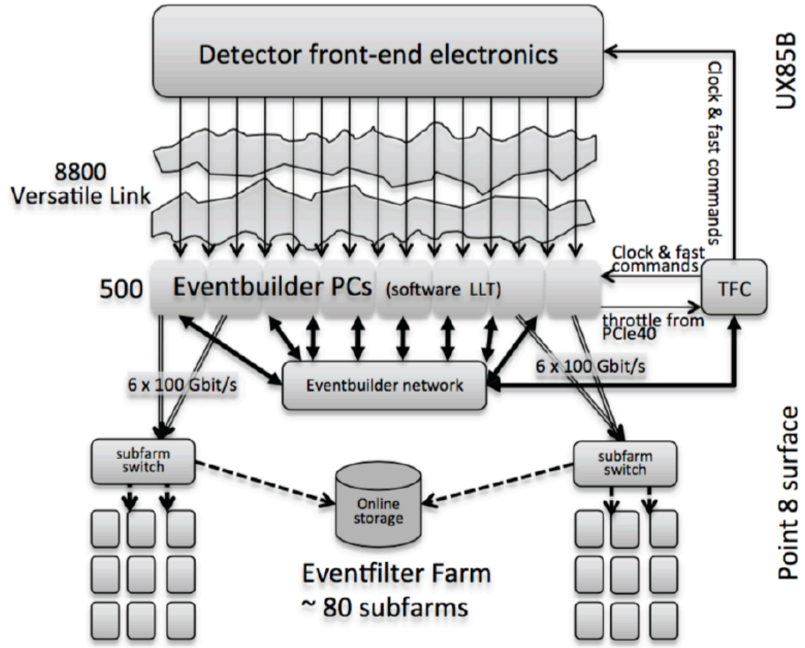
V. Gligorov

✗ No possibility of a hardware trigger based on tracking because of the breadth of the physics case.

✗ Cannot save significant bandwidth with reconstruction in front-end as cannot send a subset of interesting objects for each individual detector (see backups for details why)

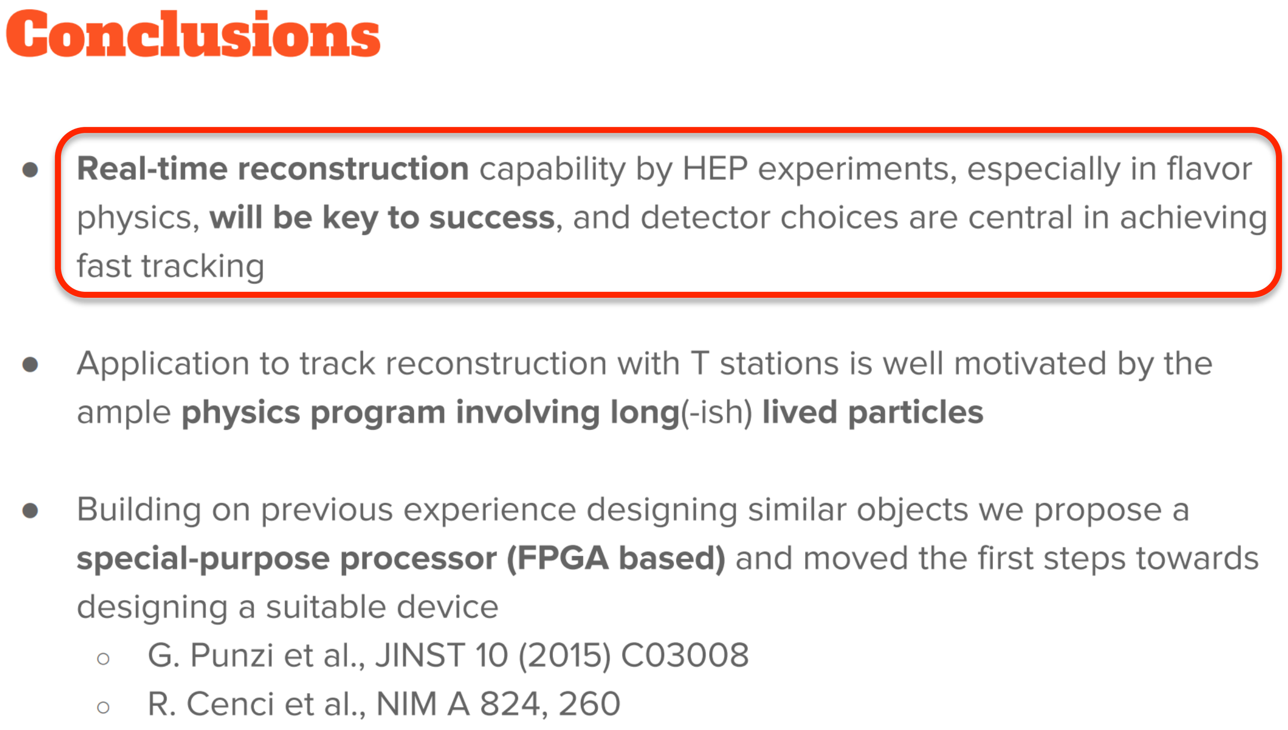
✓ Therefore DAQ architecture should stay the same as in Upgrade I. Implement zero-suppression and clustering in front-end electronics, sort & transform to global LHCb coordinates (?) in back-end.

LHCb Upgrade I DAQ



… others have different ideas

S. Stracka
TTFU 2017



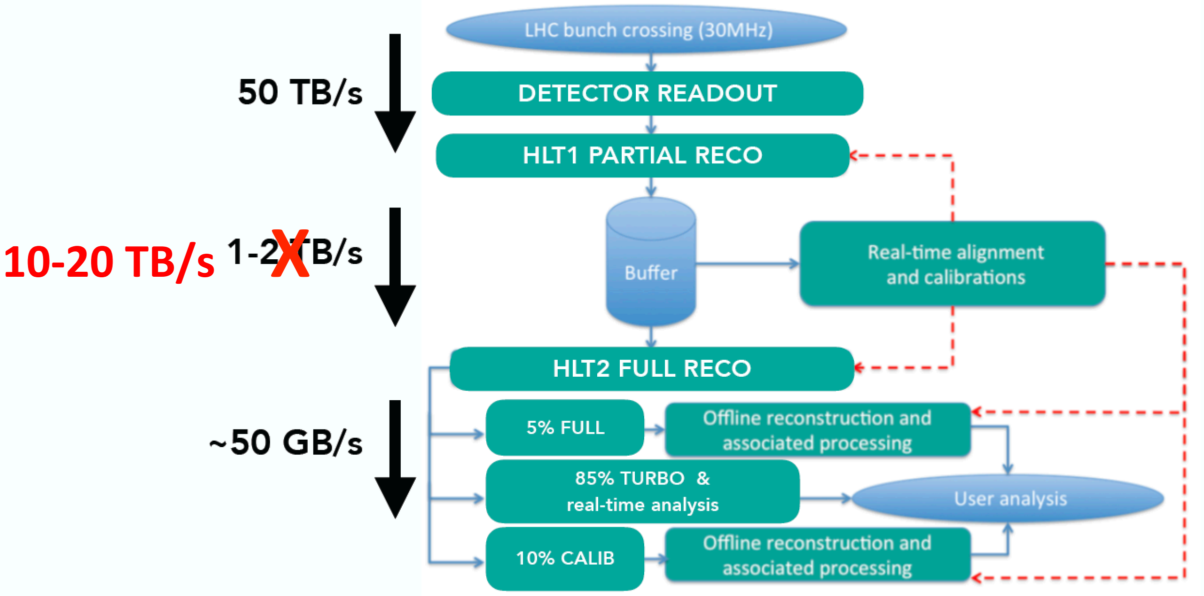
Conclusions

- **Real-time reconstruction** capability by HEP experiments, especially in flavor physics, **will be key to success**, and detector choices are central in achieving fast tracking
- Application to track reconstruction with T stations is well motivated by the ample **physics program involving long**(-ish) **lived particles**
- Building on previous experience designing similar objects we propose a **special-purpose processor (FPGA based)** and moved the first steps towards designing a suitable device
  - G. Punzi et al., JINST 10 (2015) C03008
  - R. Cenci et al., NIM A 824, 260

Towards an U2 Data Processing Model

Data and signal rates at $2\cdot10^{34}$

V. Gligorov



LHC bunch crossing (30MHz)

50 TB/s

DETECTOR READOUT

HLT1 PARTIAL RECO

10-20 TB/s ~~1-2 TB/s~~

Buffer

Real-time alignment and calibrations

HLT2 FULL RECO

~50 GB/s

5% FULL

Offline reconstruction and associated processing

85% TURBO & real-time analysis

User analysis

10% CALIB

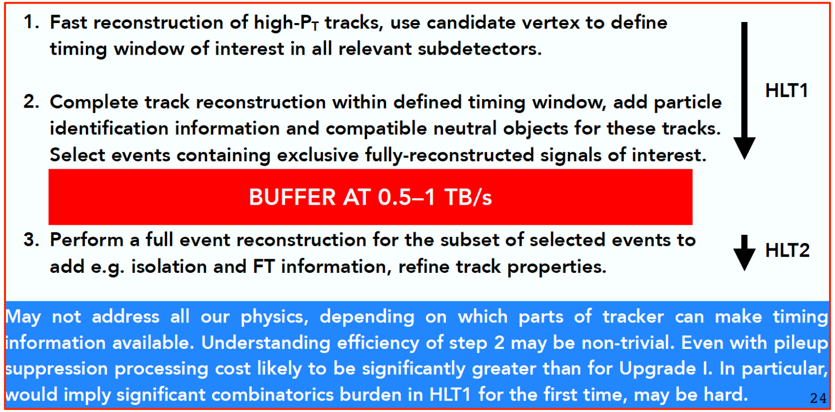
Offline reconstruction and associated processing

Everything should scale by ~10 from U1… but HLT1 output rate cannot scale because of signal saturation! (1) What could we do at HLT1? OR (2) Could we run HLT2 at 5-10 MHz?

Possible HLT1 Strategies

V. Gligorov

HLT1 finds an interesting signal based on a high-p_T subset of decay product, then uses timing to to suppress pile-up in full event reconstruction



1. Fast reconstruction of high-P_T tracks, use candidate vertex to define timing window of interest in all relevant subdetectors.
2. Complete track reconstruction within defined timing window, add particle identification information and compatible neutral objects for these tracks. Select events containing exclusive fully-reconstructed signals of interest.

HLT1

BUFFER AT 0.5–1 TB/s

3. Perform a full event reconstruction for the subset of selected events to add e.g. isolation and FT information, refine track properties.

HLT2

May not address all our physics, depending on which parts of tracker can make timing information available. Understanding efficiency of step 2 may be non-trivial. Even with pileup suppression processing cost likely to be significantly greater than for Upgrade I. In particular, would imply significant combinatorics burden in HLT1 for the first time, may be hard.

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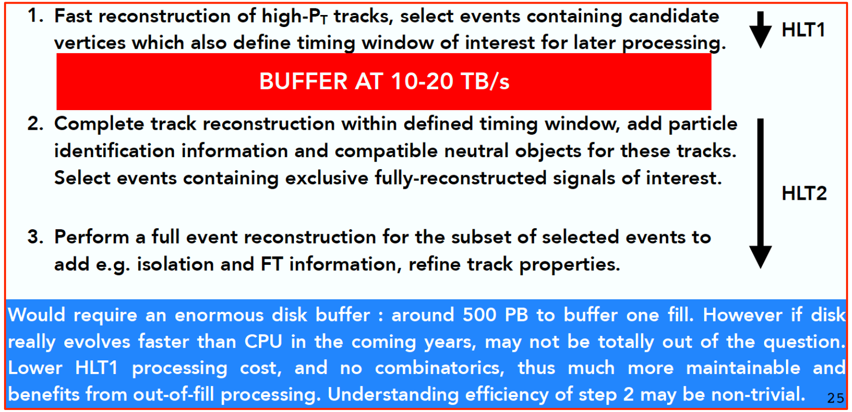


1. Fast reconstruction of high-P_T tracks, select events containing candidate vertices which also define timing window of interest for later processing.

HLT1

BUFFER AT 10-20 TB/s

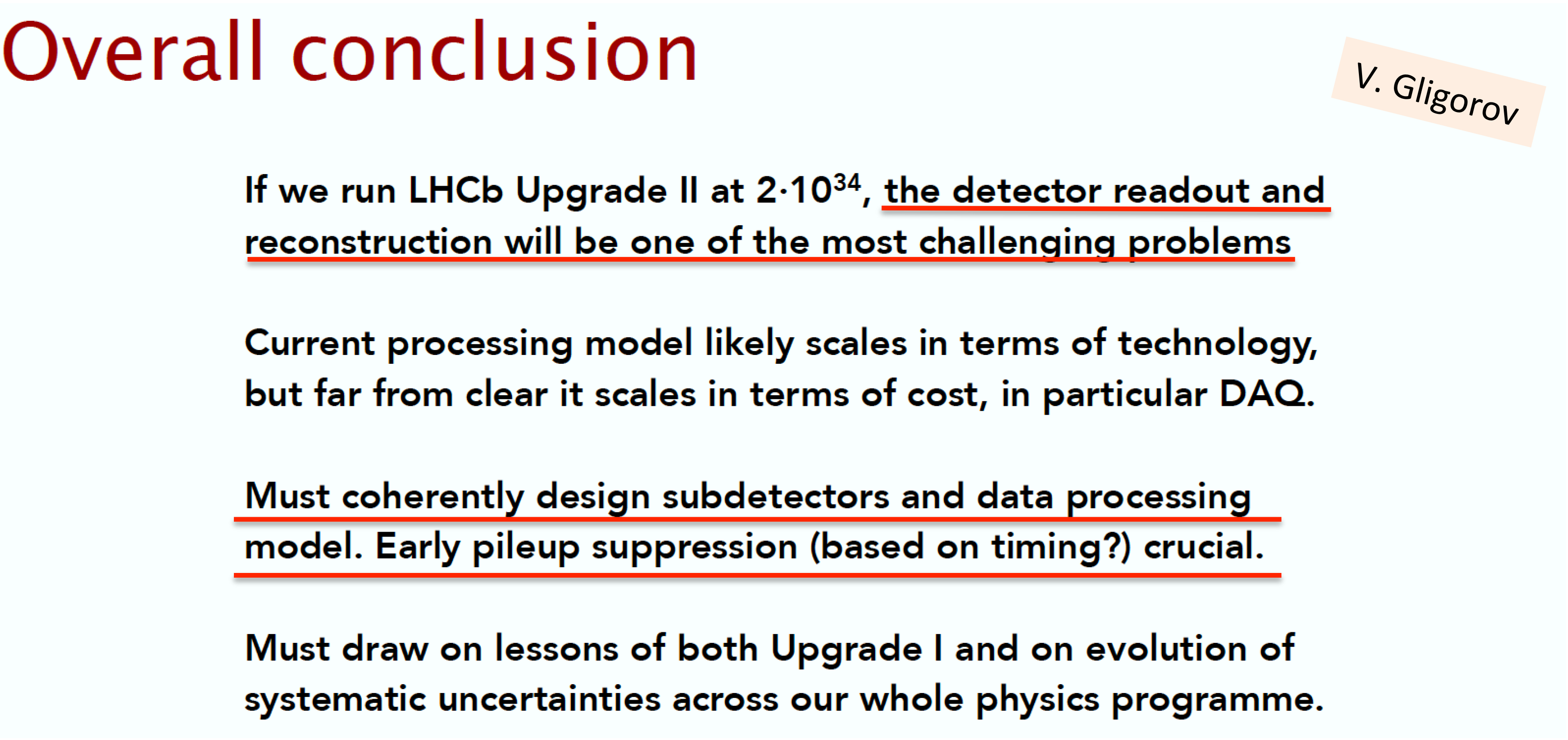
2. Complete track reconstruction within defined timing window, add particle identification information and compatible neutral objects for these tracks. Select events containing exclusive fully-reconstructed signals of interest.
3. Perform a full event reconstruction for the subset of selected events to add e.g. isolation and FT information, refine track properties.

HLT2

Would require an enormous disk buffer : around 500 PB to buffer one fill. However if disk really evolves faster than CPU in the coming years, may not be totally out of the question. Lower HLT1 processing cost, and no combinatorics, thus much more maintainable and benefits from out-of-fill processing. Understanding efficiency of step 2 may be non-trivial.

25

… but we can all agree on this



Overall conclusion

V. Gligorov

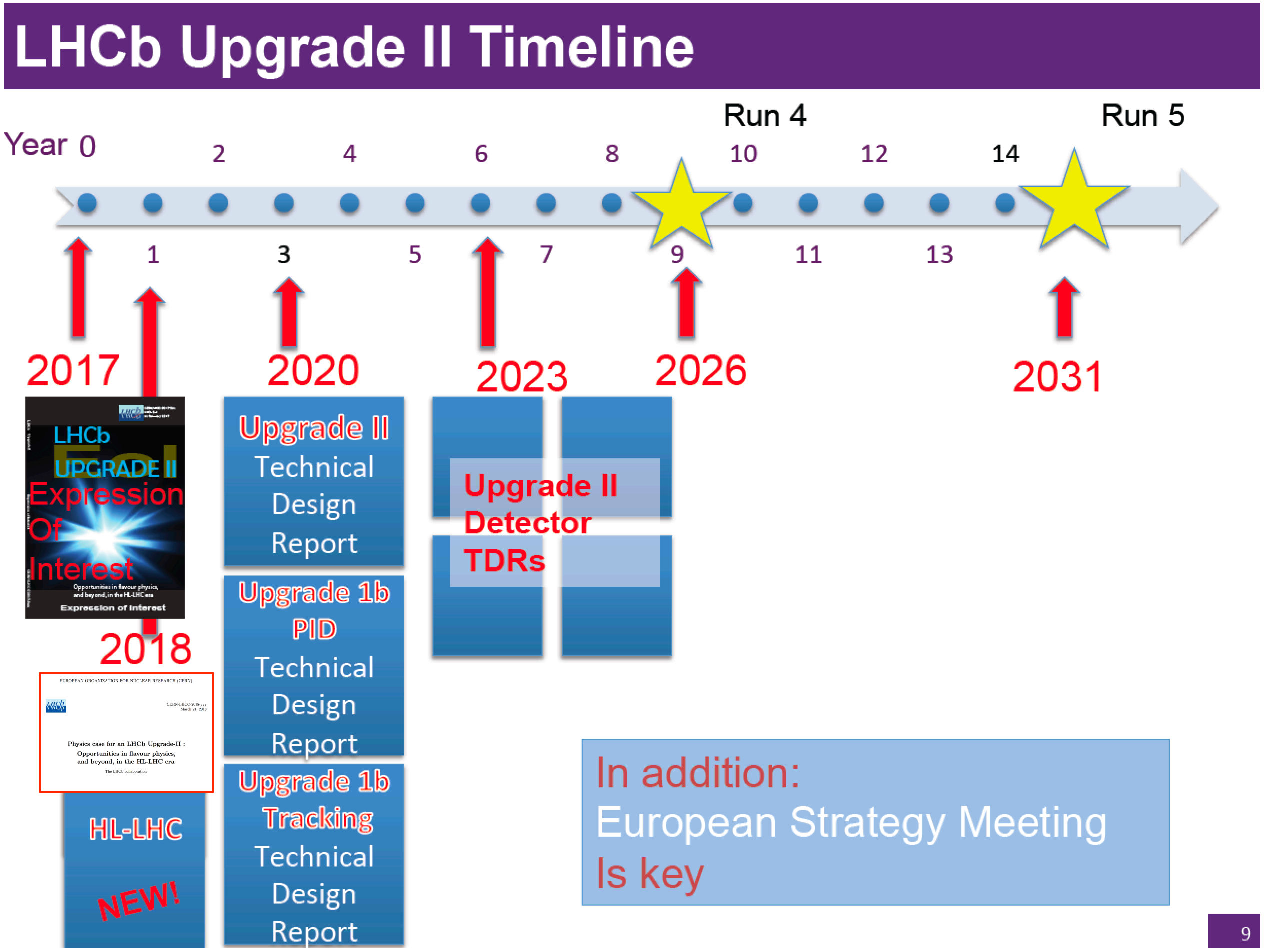
If we run LHCb Upgrade II at $2{\cdot}10^{34}$, the detector readout and reconstruction will be one of the most challenging problems

Current processing model likely scales in terms of technology, but far from clear it scales in terms of cost, in particular DAQ.

Must coherently design subdetectors and data processing model. Early pileup suppression (based on timing?) crucial.

Must draw on lessons of both Upgrade I and on evolution of systematic uncertainties across our whole physics programme.

Conclusion



LHCb Upgrade II Timeline

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)

CERN-LHCC-2018-xxx
March 21, 2018

Physics case for an LHCb Upgrade-II : Opportunities in flavour physics, and beyond, in the HL-LHC era

The LHCb collaboration

HL-LHC

NEW!

Upgrade II Technical Design Report

Upgrade 1b PID Technical Design Report

Upgrade 1b Tracking Technical Design Report

Upgrade II Detector TDRs

In addition:
European Strategy Meeting
Is key

U2: a final remark

(From Wednesday 21st afternoon session)

- (Vava) We will be going to extremely difficult data taking conditions with Upgrade II…

- (Mitesh) … but it's worth it!

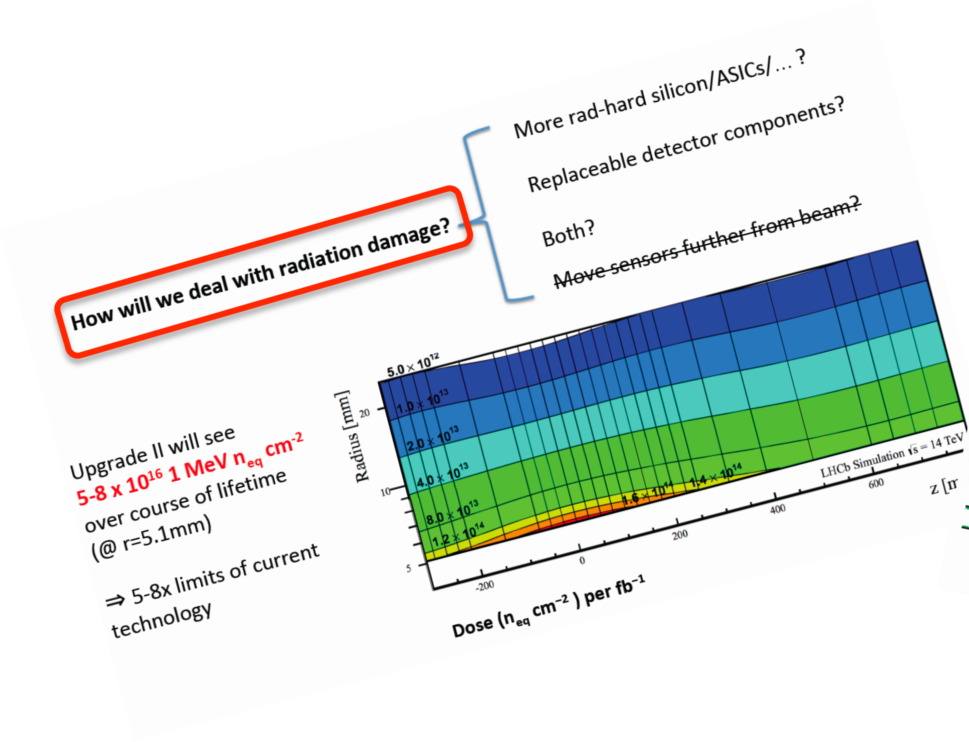
A big THANKS to the LAPP team for their kind hospitality and for the excellent organization

(P.S.: Any volunteers for 2019 TTFU?)

Spares Slides

(Many) Open Questions…

Mark Williams

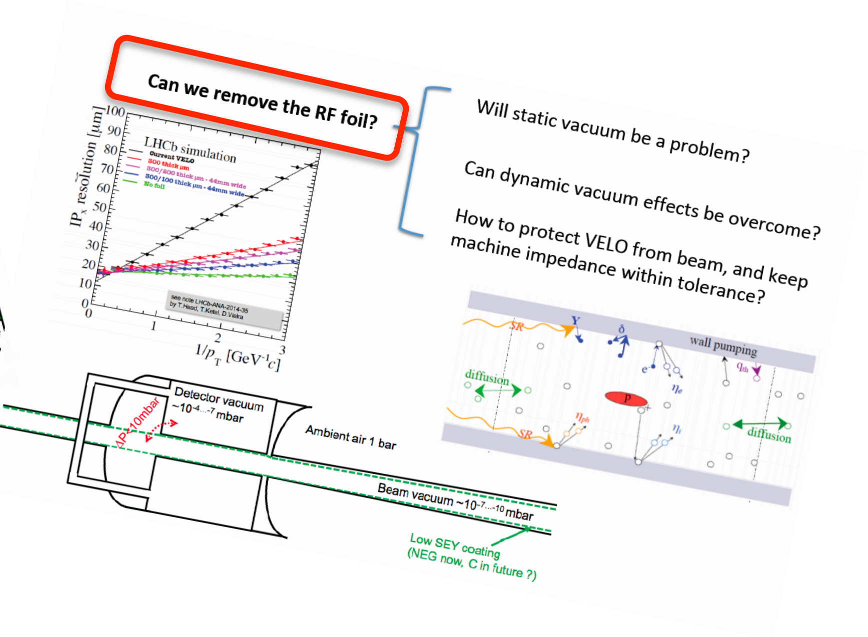


How will we deal with radiation damage?

- More rad-hard silicon/ASICs/… ?
- Replaceable detector components?
- Both?
- ~~Move sensors further from beam?~~

Upgrade II will see **$5\text{-}8 \times 10^{16}$ 1 MeV n_{eq} cm^{-2}** over course of lifetime (@ r=5.1mm)

⇒ 5-8x limits of current technology



Can we remove the RF foil?

- Will static vacuum be a problem?
- Can dynamic vacuum effects be overcome?
- How to protect VELO from beam, and keep machine impedance within tolerance?

… and more

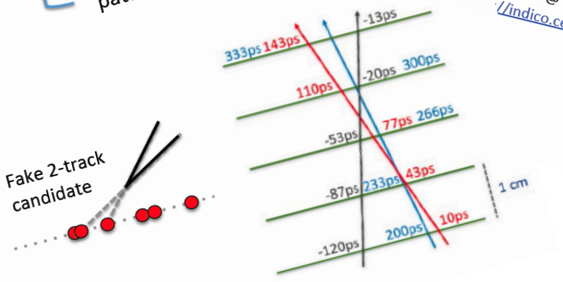
Mark Williams

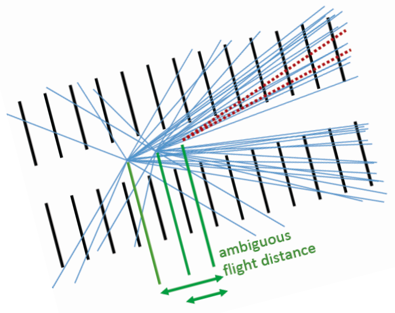
How will timing information be used?

Time **per vertex** for improved PV association?

+Time **per track** for improved background rejection?

+Time **per hit** for improved pattern recognition?

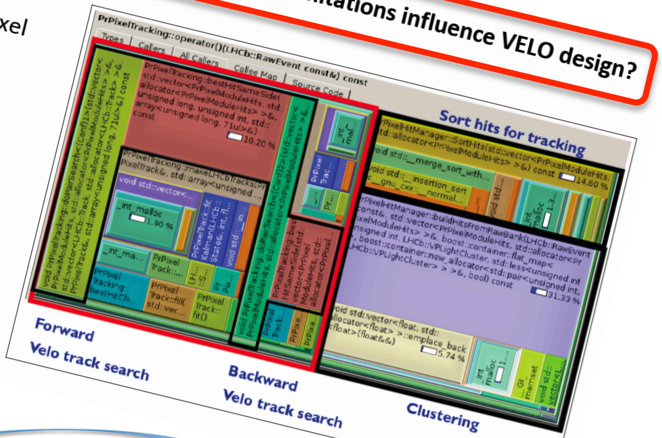




Will (and how will) reconstruction needs and limitations influence VELO design?

50% of resource use in pixel tracking goes into data preparation (sorting hits & clustering)

. Fitzpatrick @ VELO U2 retreat 2/3/2018
ps://indico.cern.ch/event/681201/
uagliani @ T&A meeting 20/2/2018
/indico.cern.ch/event/691555/



Conclusion →


Analysis needs

Motivate & Guide

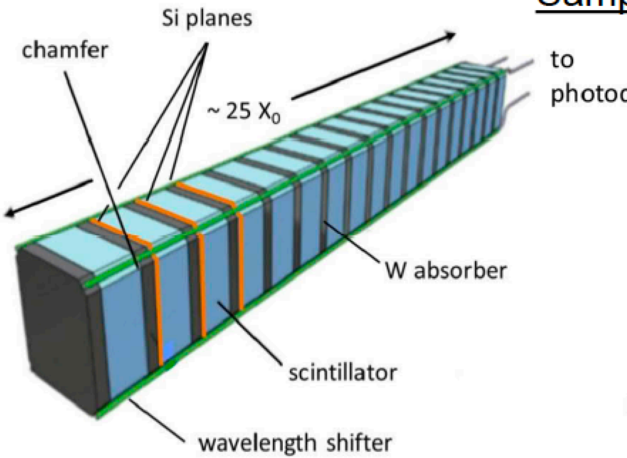
Detector design

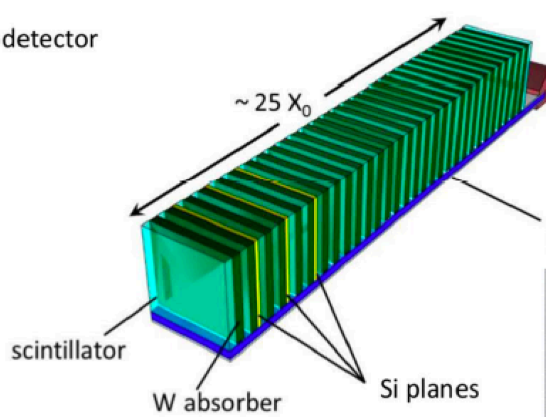
Solves & inspires

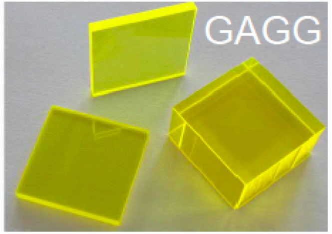
Ideas “on the market” for LHCb ECAL upgrade

A. Schopper

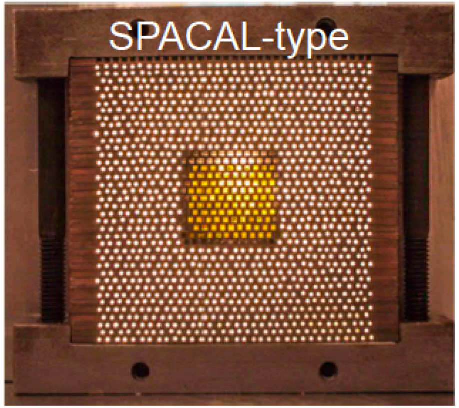
Sampling calorimeters of various type



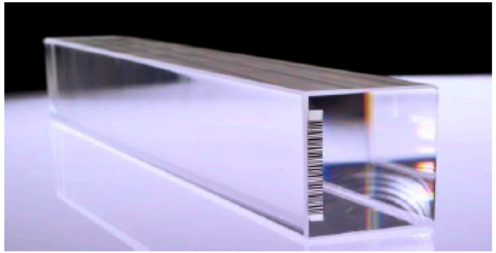




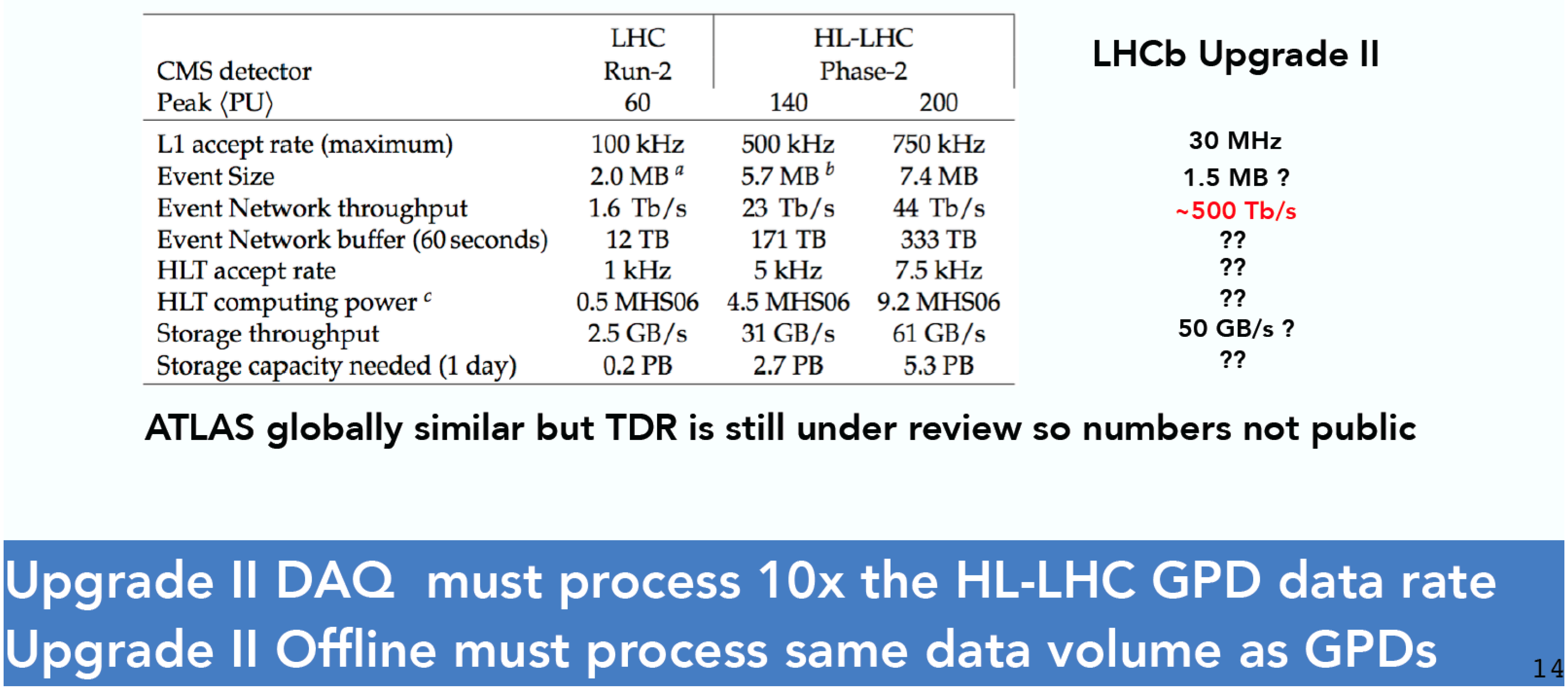

Shashlik type
(e.g. W/LYSO)


SPACAL-type

Homogeneous Crystals



CMS vs. LHCb data rates



CMS detector	LHC Run-2	HL-LHC Phase-2		LHCb Upgrade II
Peak ⟨PU⟩	60	140	200	
L1 accept rate (maximum)	100 kHz	500 kHz	750 kHz	30 MHz
Event Size	2.0 MB [a]	5.7 MB [b]	7.4 MB	1.5 MB ?
Event Network throughput	1.6 Tb/s	23 Tb/s	44 Tb/s	~500 Tb/s
Event Network buffer (60 seconds)	12 TB	171 TB	333 TB	??
HLT accept rate	1 kHz	5 kHz	7.5 kHz	??
HLT computing power [c]	0.5 MHS06	4.5 MHS06	9.2 MHS06	??
Storage throughput	2.5 GB/s	31 GB/s	61 GB/s	50 GB/s ?
Storage capacity needed (1 day)	0.2 PB	2.7 PB	5.3 PB	??

ATLAS globally similar but TDR is still under review so numbers not public

Upgrade II DAQ must process 10x the HL-LHC GPD data rate
Upgrade II Offline must process same data volume as GPDs

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Implement neutron plastic shields: **RICH1 will be "wrapped" in plastic, instead of iron!**

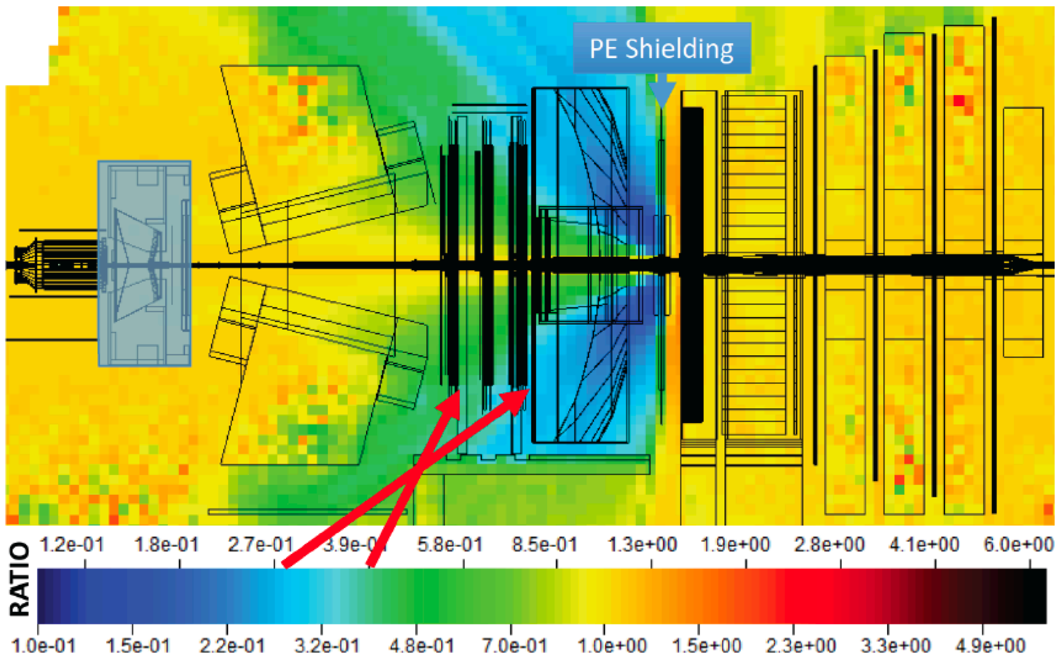
C. D'Ambrosio

Factor 2 to 4, 20/30 cm thick Polyethylene

Could already ask

Mathias to do a

simulation …

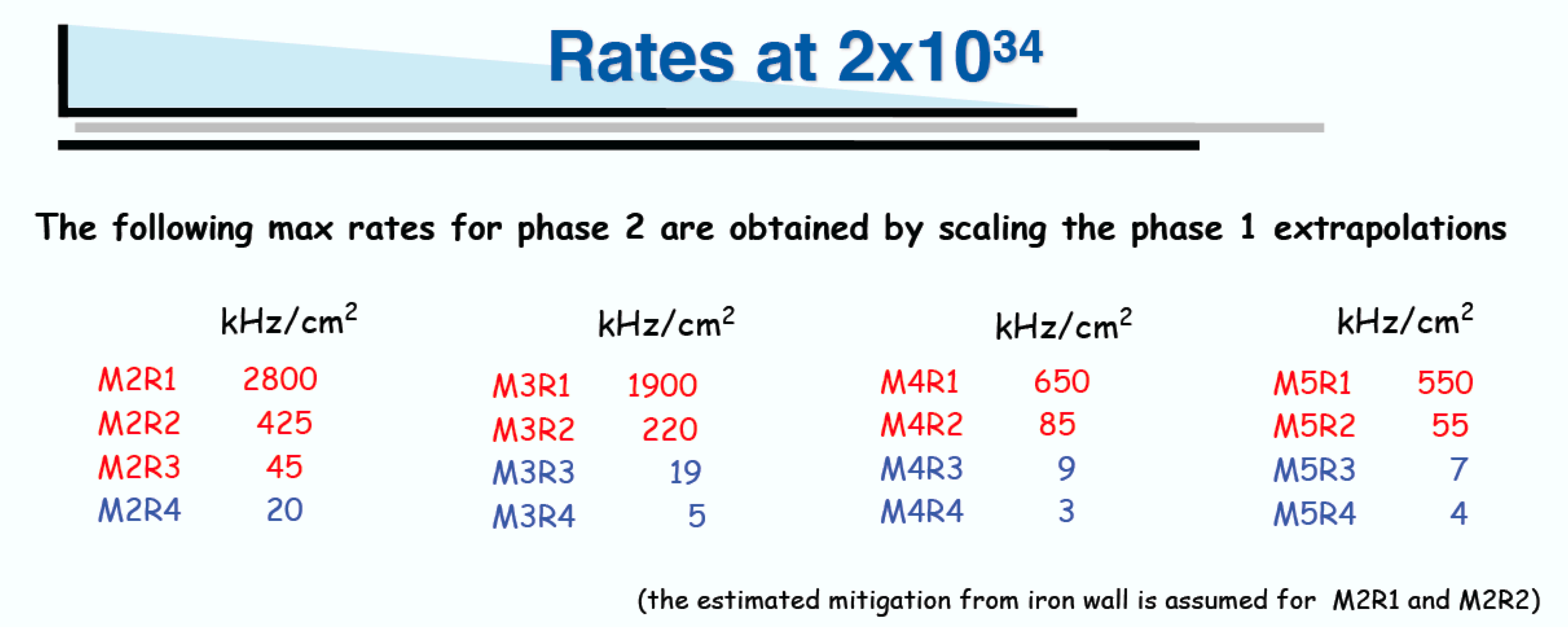


1 MeV n. equ. fl.: RATIO between final 30 cm Shielding VS No Shielding

M. Karakson et al.

Still, strong requirements on detectors…

M. Palutan



Rates at 2x10^{34}

The following max rates for phase 2 are obtained by scaling the phase 1 extrapolations

	kHz/cm^2		kHz/cm^2		kHz/cm^2		kHz/cm^2
M2R1	2800	M3R1	1900	M4R1	650	M5R1	550
M2R2	425	M3R2	220	M4R2	85	M5R2	55
M2R3	45	M3R3	19	M4R3	9	M5R3	7
M2R4	20	M3R4	5	M4R4	3	M5R4	4

(the estimated mitigation from iron wall is assumed for M2R1 and M2R2)