The Belle II upgrade program

HQL2023 Mumbai

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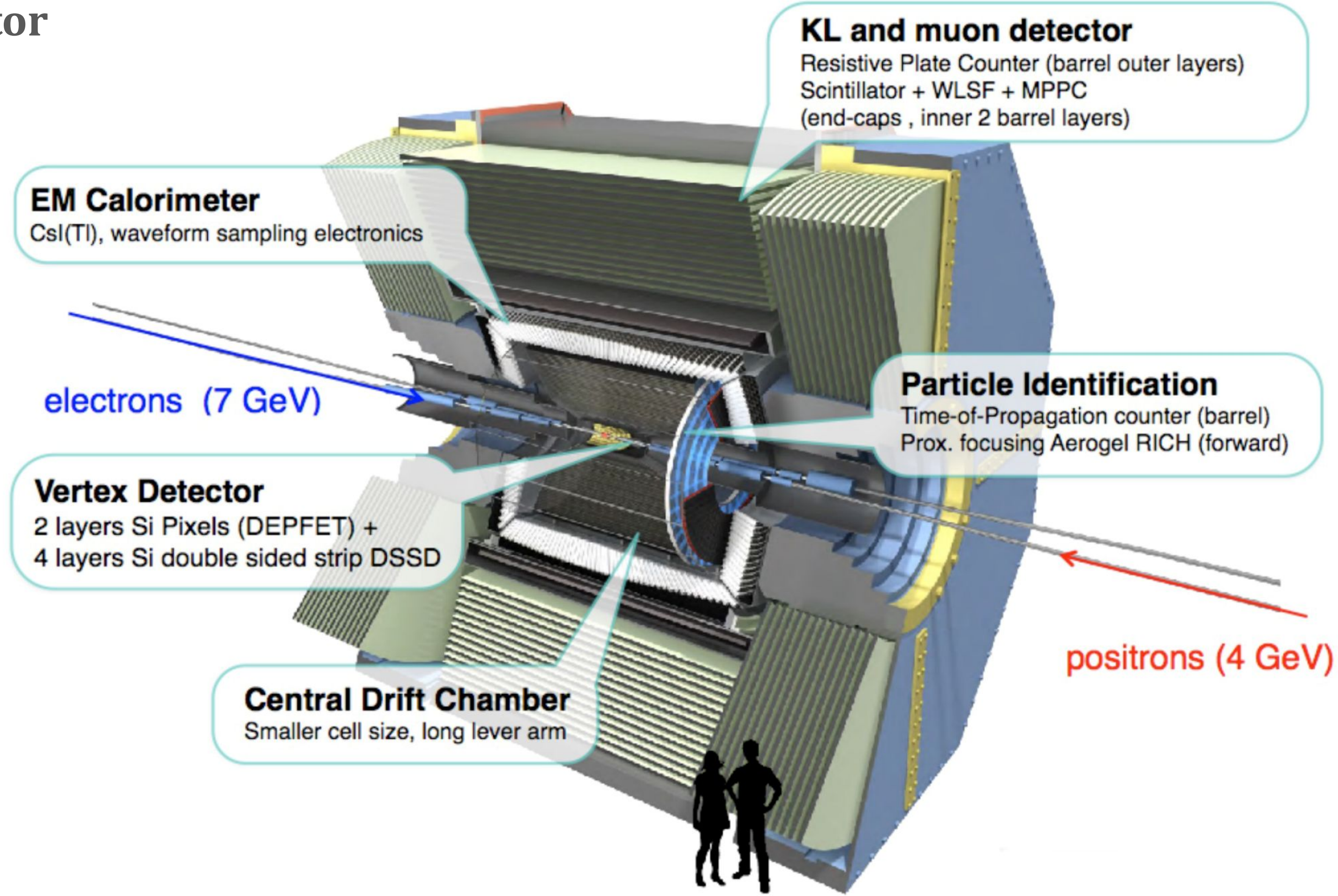
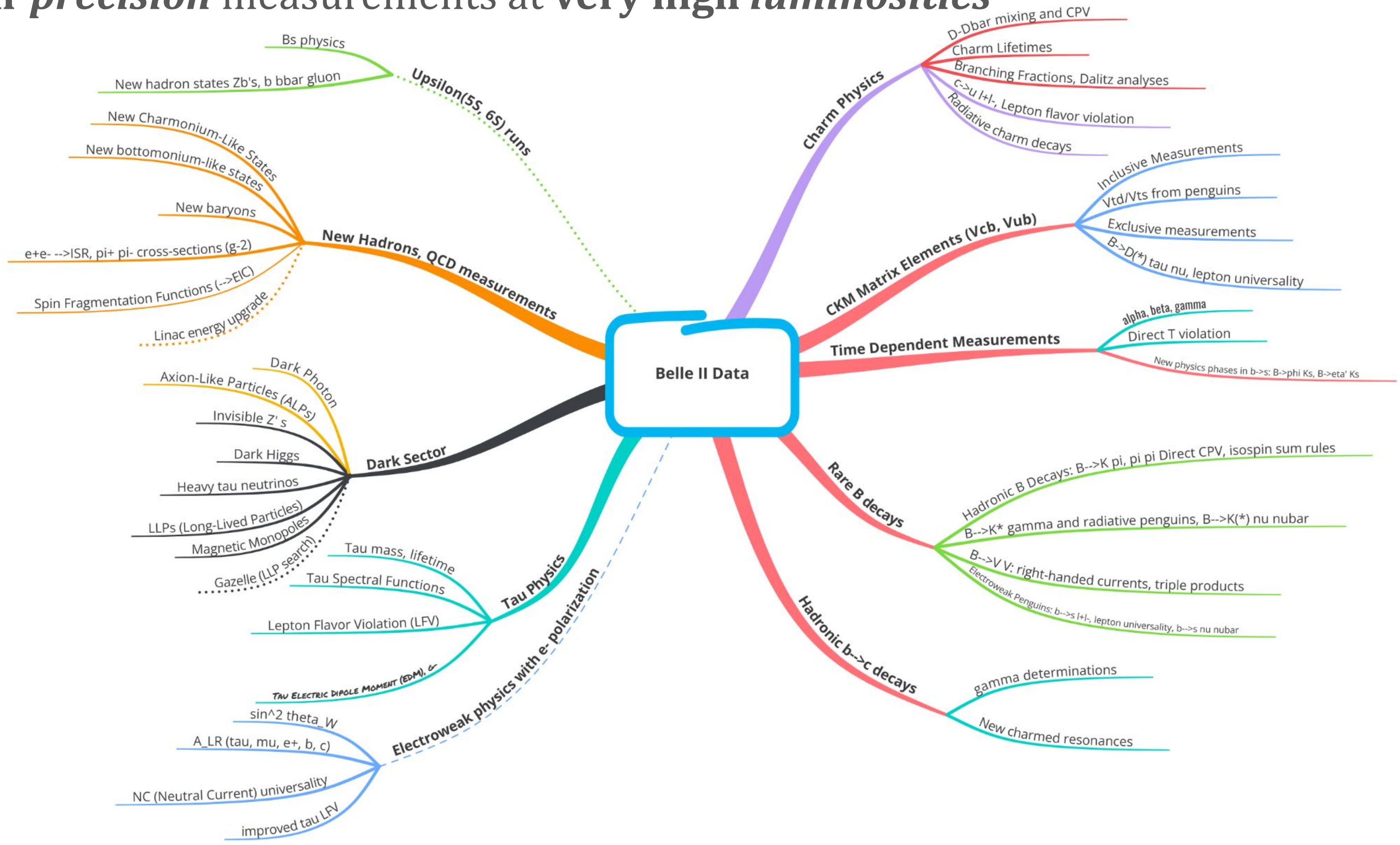
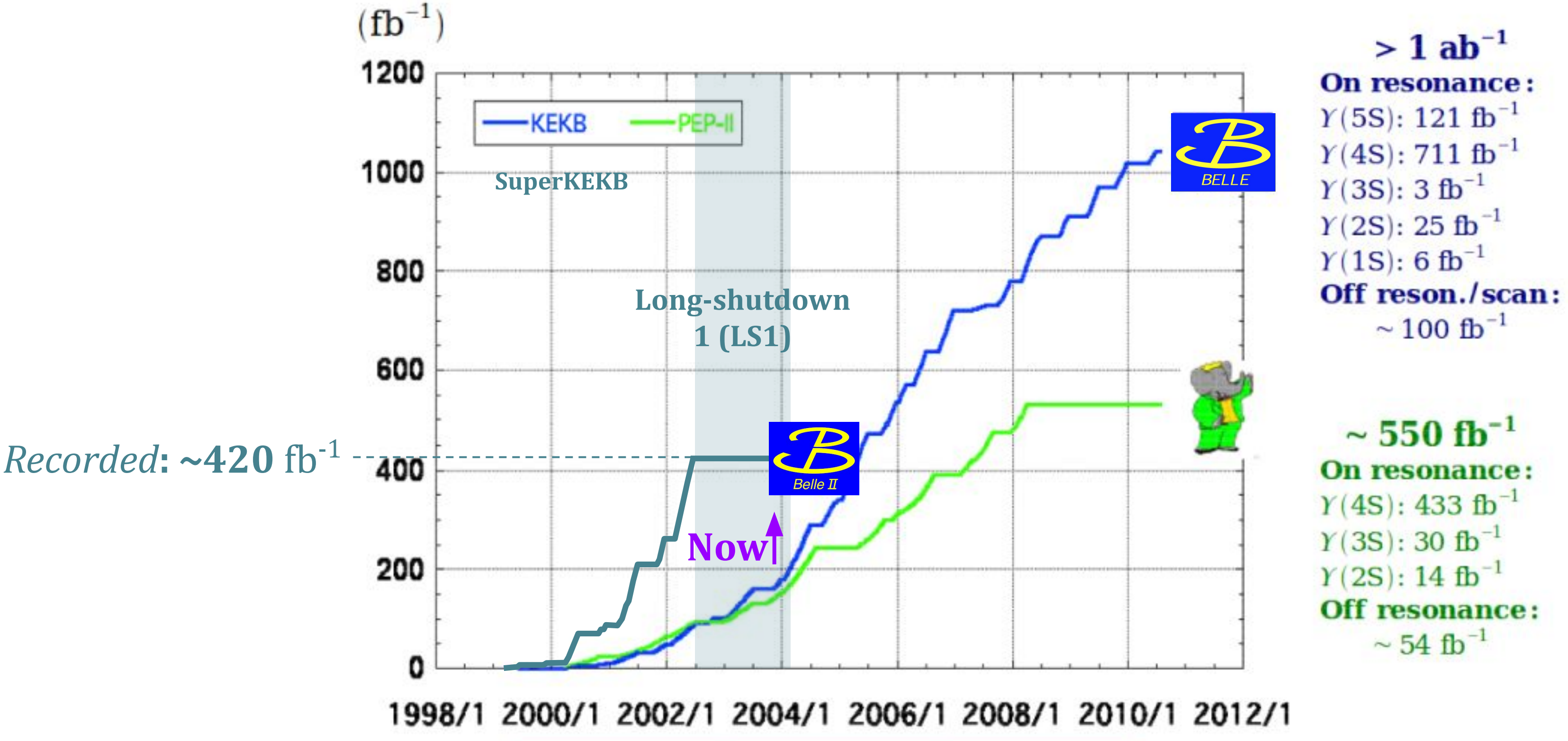
on behalf of the Belle II collaboration

Detector


KL and muon detector
Resistive Plate Counter (barrel outer layers)
Scintillator + WLSF + MPPC
(end-caps , inner 2 barrel layers)
EM Calorimeter
CsI(Tl), waveform sampling electronics
electrons (7 GeV)
Particle Identification
Time-of-Propagation counter (barrel)
Prox. focusing Aerogel RICH (forward)
Vertex Detector
2 layers Si Pixels (DEPFET) +
4 layers Si double sided strip DSSD
positrons (4 GeV)
Central Drift Chamber
Smaller cell size, long lever arm

High-*precision* measurements at **very high *luminosities***





+ 20 years

…but there's still a long way to go…

We need:

- **120-fold** increase in integrated luminosity ($0.4 \rightarrow 50\ ab^{-1}$) *via*…
- **16-fold** increase in instantaneous luminosity ($0.4 \rightarrow 6{\times}10^{35} cm^{-2}s^{-1}$)

This is an enormous challenge for the **accelerator** and **detector**…

…and **backgrounds** are higher than anticipated

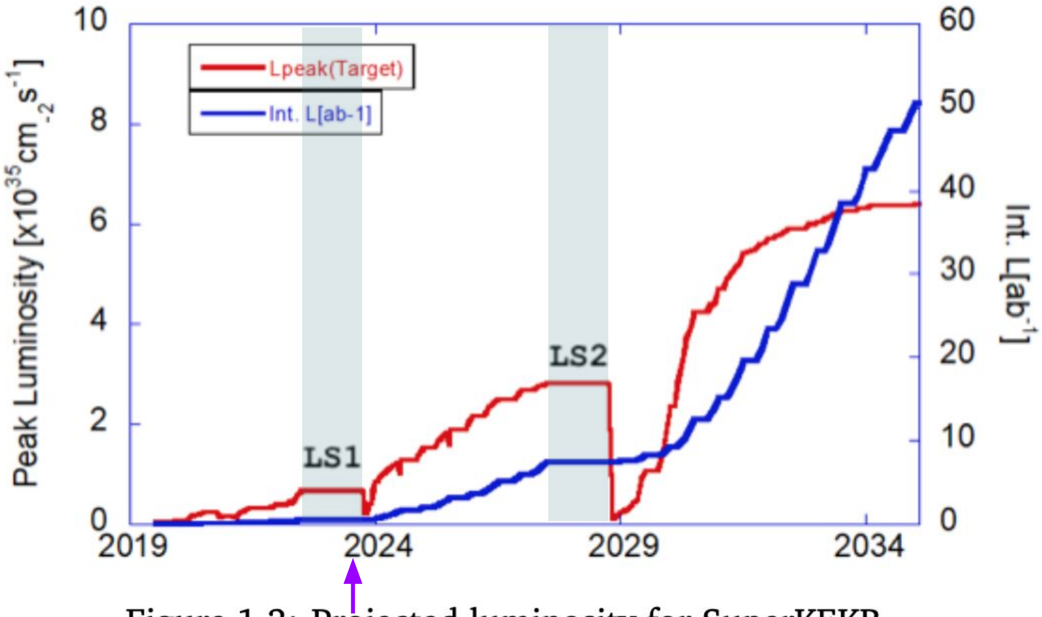


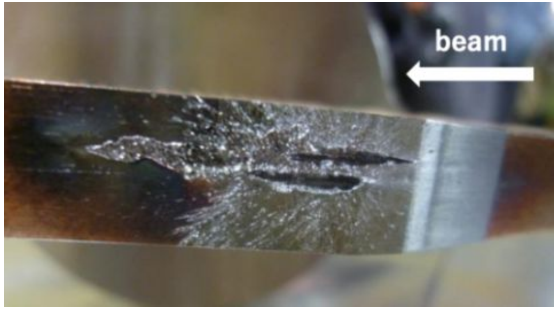
Figure 1.3: Projected luminosity for SuperKEKB.

Here's what we're doing to meet this challenge…

LS1 upgrades (now)

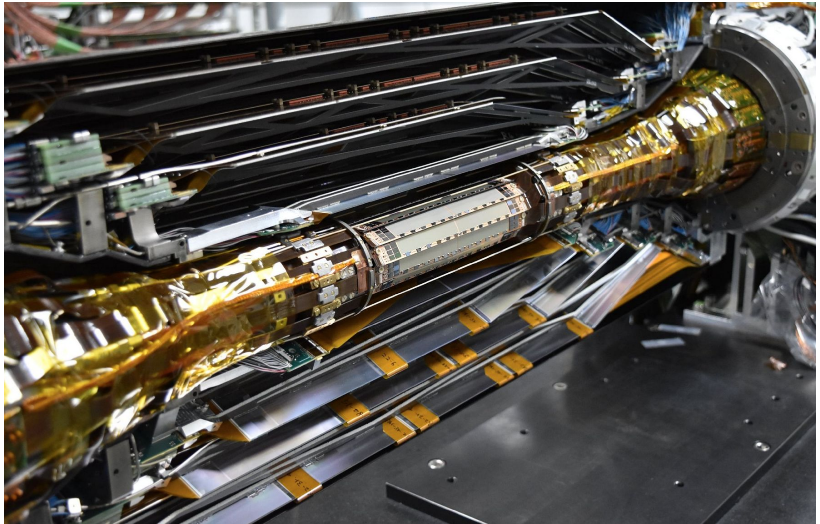
Machine

- New beam-loss monitors
- **More-resilient collimators**
- Improved neutron shielding
- RF cavity replacement, faster kicker magnets at injector
- …

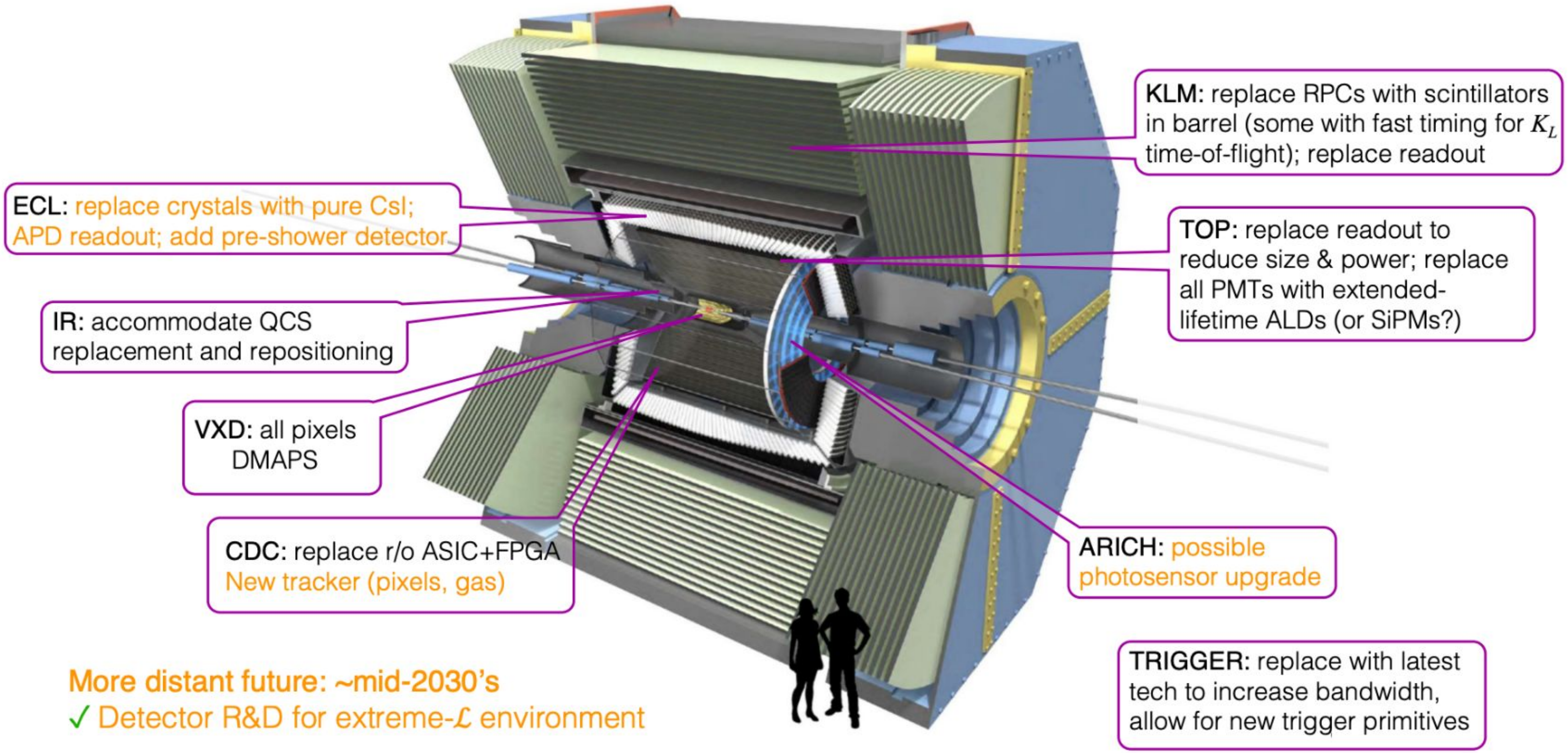


Detector

- Installation of **complete pixel detector**
- Replacement of TOP PMs
- Improved CDC gas distribution and monitoring
- DAQ system upgrade to PCIe40

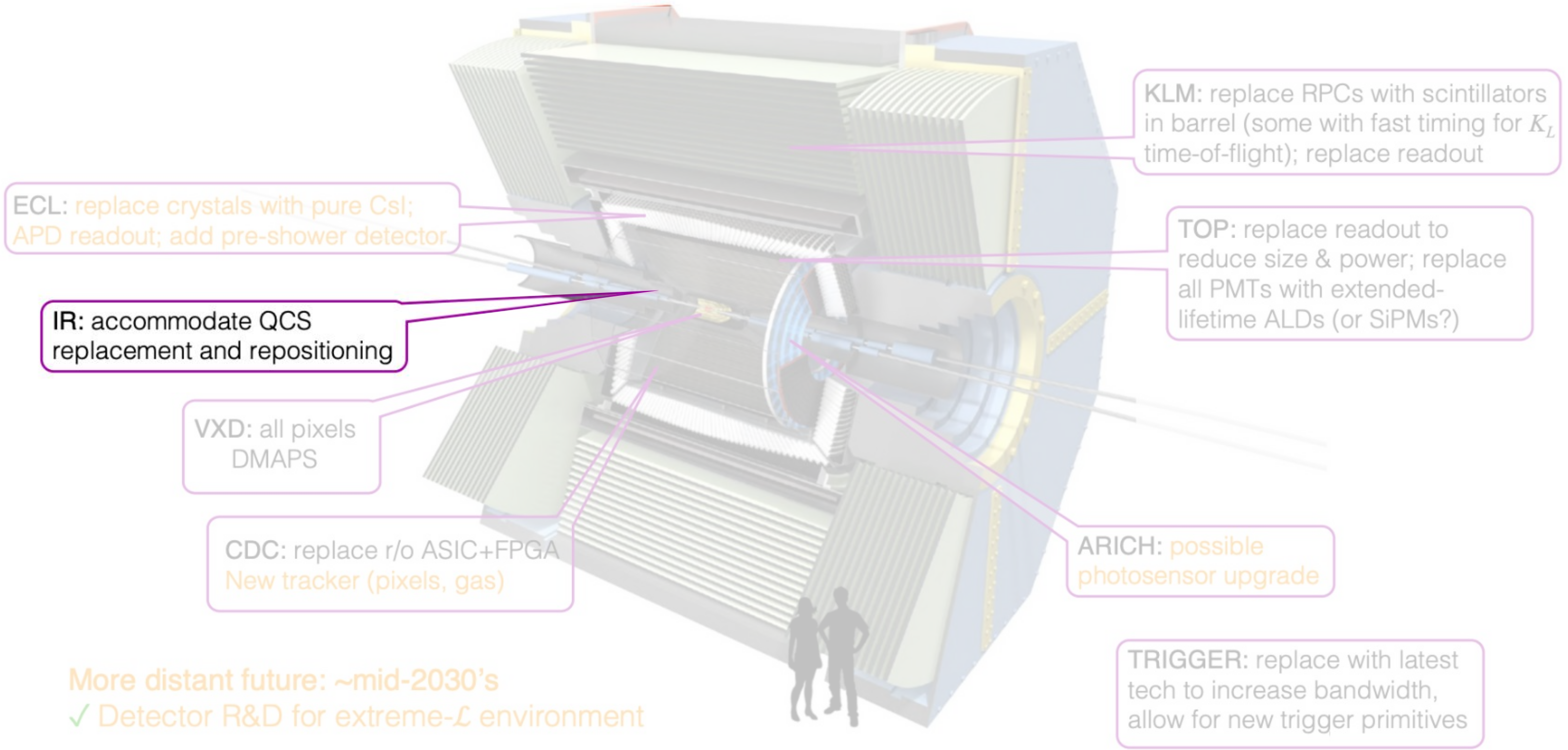


LS2 and longer-term upgrades



More distant future: ~mid-2030's
✓ Detector R&D for extreme-$\mathcal{L}$ environment

LS2 and longer-term upgrades



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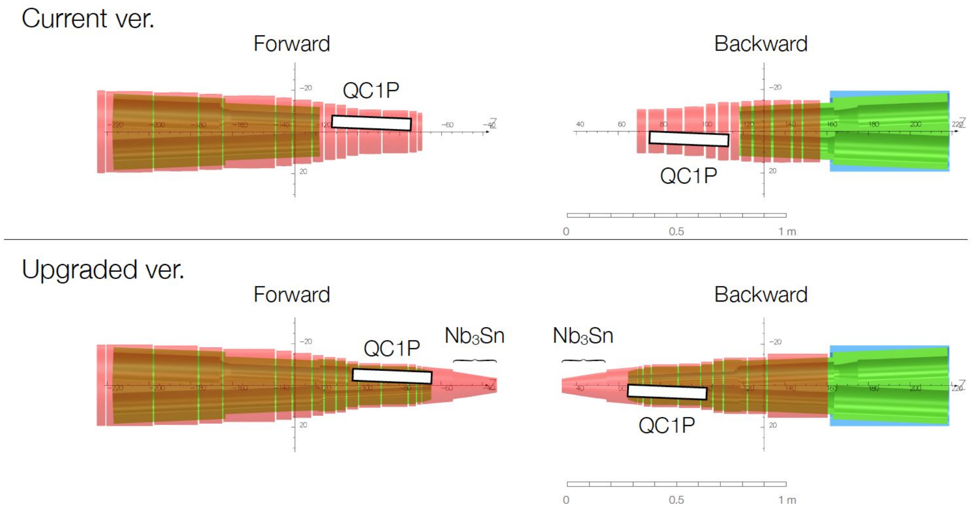
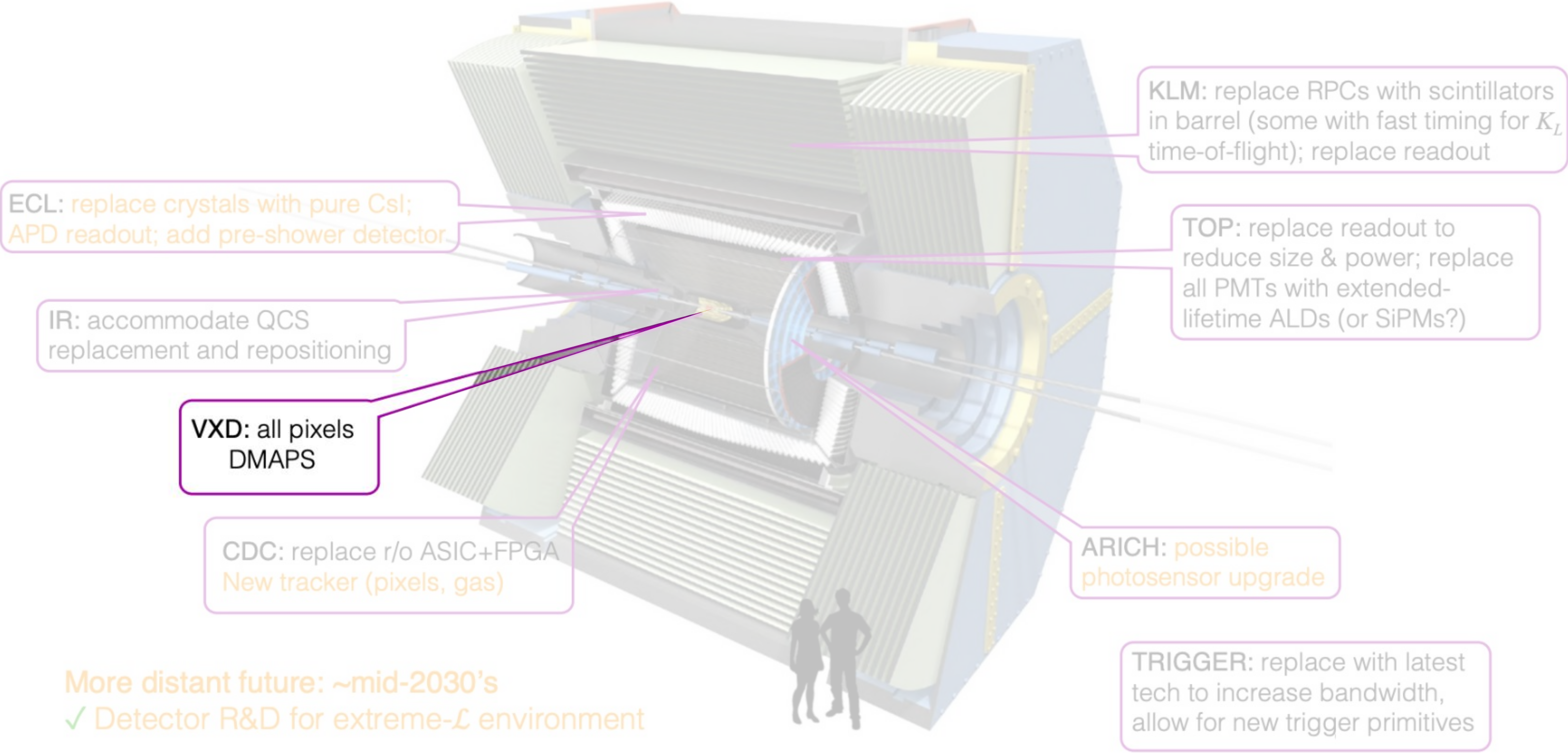
Interaction region

- Limit beam-beam effects, preserve beam lifetime
- Redesign final focus:
  - Extend final magnet closer to IP
  - New anti-solenoid coil placed between final magnet and IP
  - Overall: nearly **double the Touschek lifetime**



→ the envelope for inner detector services will change

LS2 and longer-term upgrades



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VXD upgrade

Motivation

- Handle high background rates
- *Improved* tracking and vertex resolution
- Simplify vertex system (pixels + strips → pixels)
- Contribute to L1 trigger
- Operation without data reduction

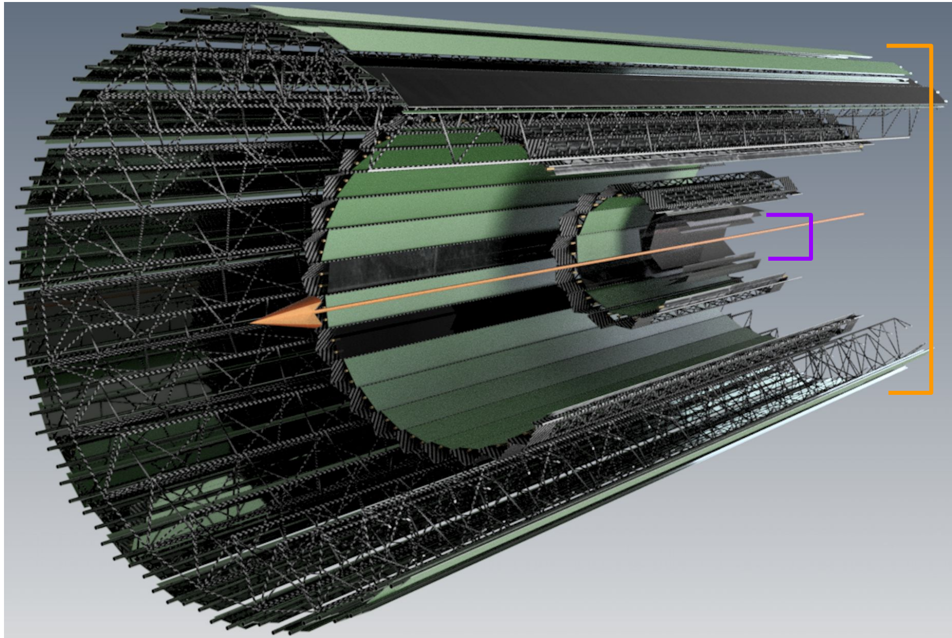
Specifications

Chip	
Pixel pitch	30-40 µm
Integration time	≲ 100 ns
Performance	
Single-point resolution	< 15 µm
Material budget	0.2%/0.7% X_0 inner-/outer-layer
Environment	
Hit rate	~600 MHz/cm^2 (120 read out)
Total ionizing dose	~10 Mrad/year
NIEL fluence	~5x10^{13} n_{eq}/cm^2/year

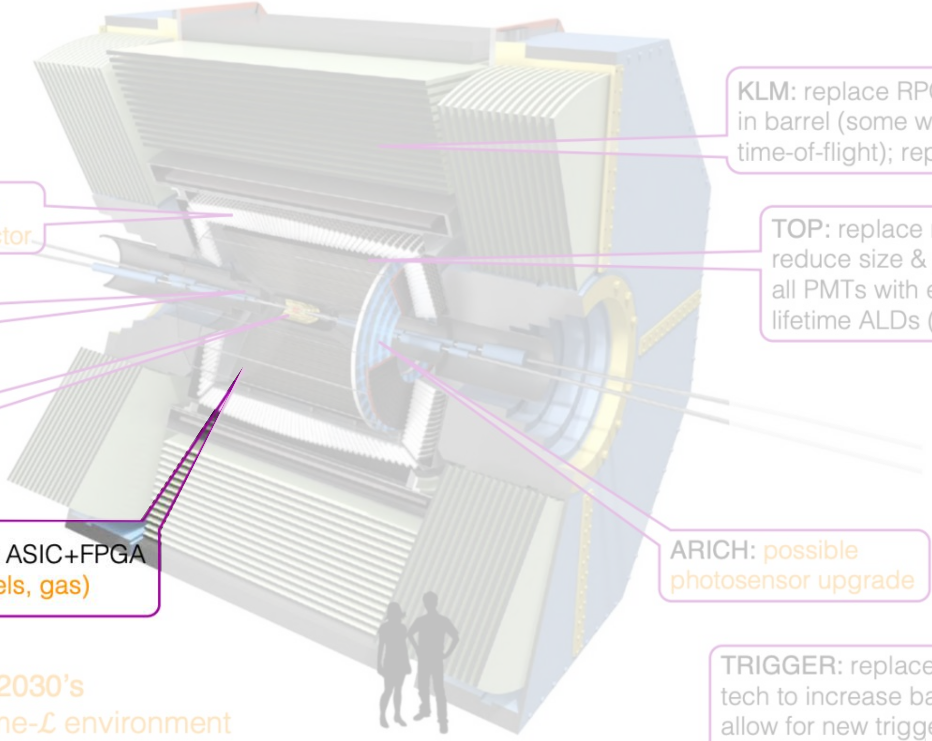
VTX

All-layer DMAPS pixel detector

- Monolithic active CMOS pixels in 5 layers
- Sensitive layer thickness < 50 μm (~1000e from MIPs vs. 100-200e noise)
- Sensor thickness < 100 μm
- **iVTX**: innermost 2 layers, self-supported, air-cooled
- **oVTX**: outer 3 layers, CF structure, water-cooled
- Prototype (TJMonopix2) has largely met these specifications



LS2 and longer-term upgrades



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L2 upgrades (2027-2028)

CDC front-end electronics

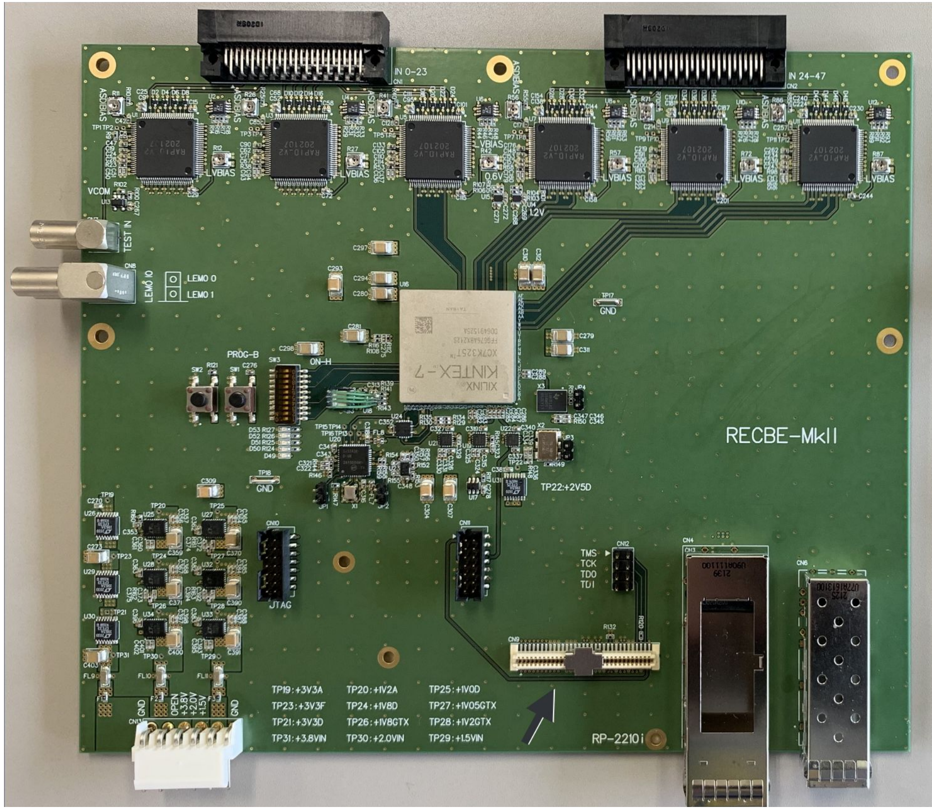
Toward better tracking performance

- Reduce cross-talk, power consumption, and increase output bandwidth
- Improve radiation tolerance

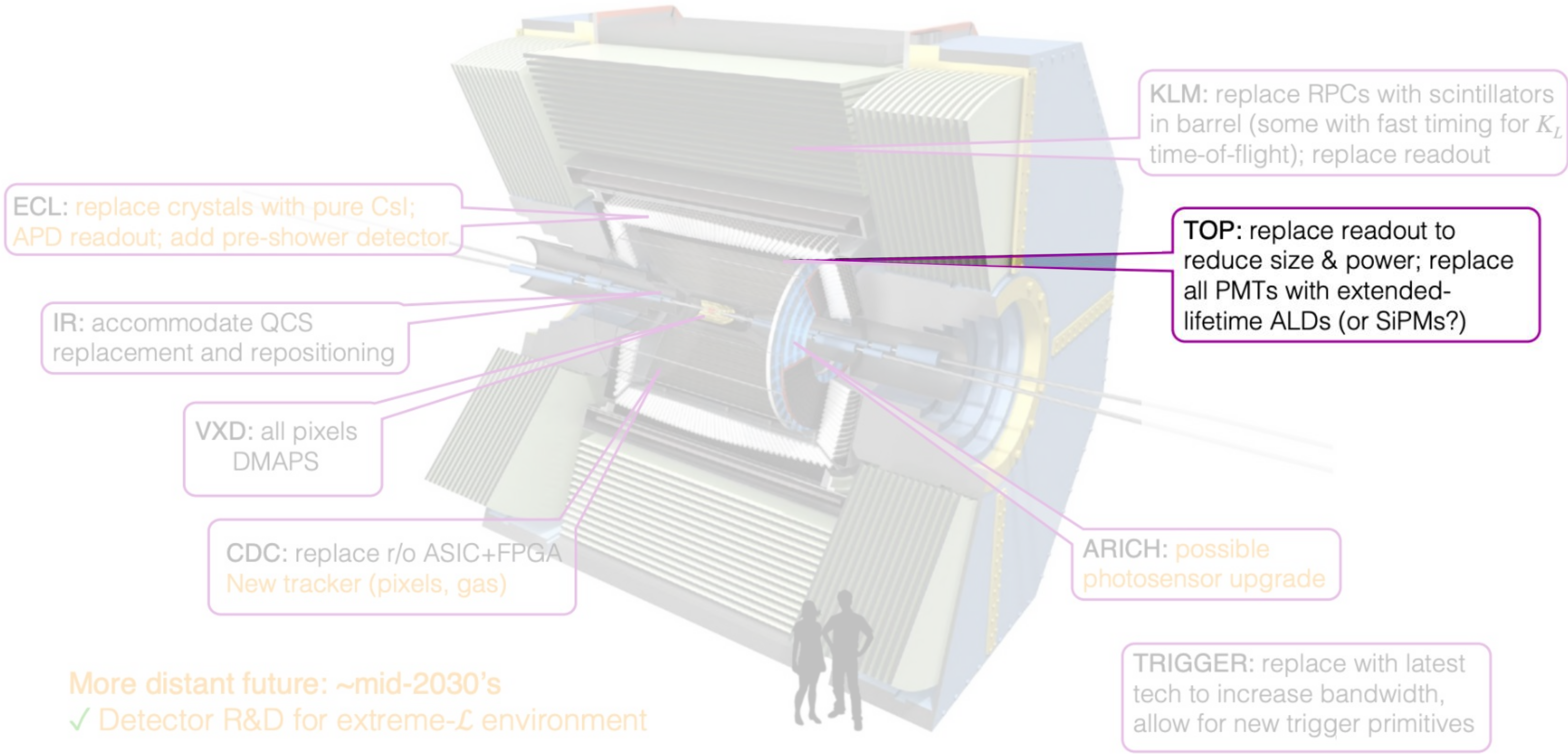
New ASICs, new FPGA, optical module

- ASIC: timing and waveform digitization
- FPGA: online data processing for trigger and DAQ
- Rad-hard fiber transceivers

Prototype front-end board upgrade



LS2 and longer-term upgrades



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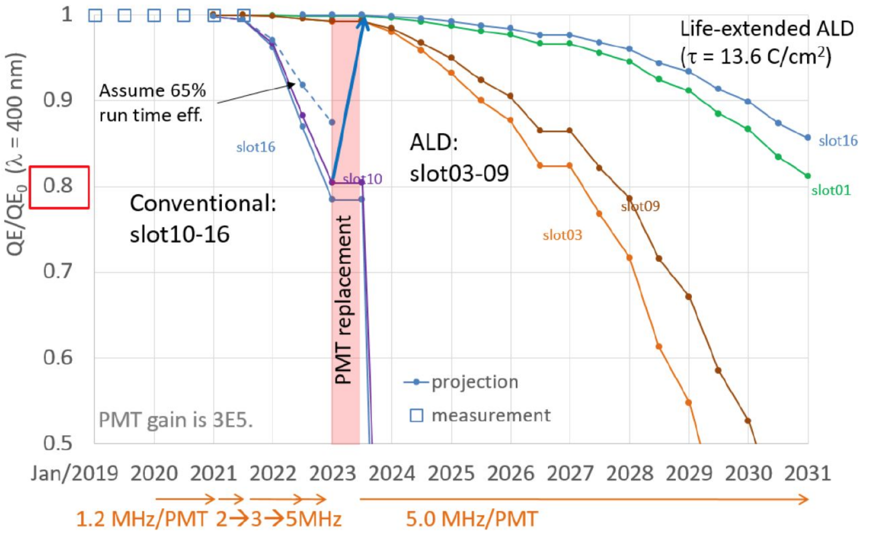
PID: Time of Propagation

Photosensor upgrade

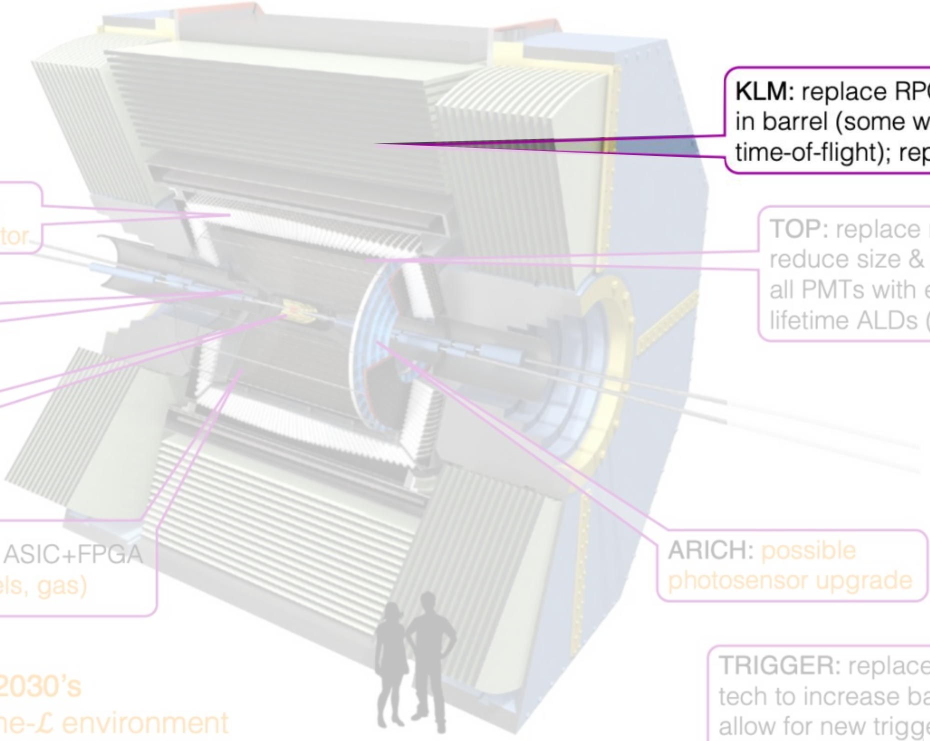
- MCP-PMTs degrading under **higher-than-expected backgrounds**
- Replacement with lifetime-extended ALD-PMT's
- (potential SiPM replacement?)



Readout upgrades

- Frontend board: reduce size and power (to accommodate potential SiPM's)
- ASoC on ASIC boards with Gpbs to FPGA

LS2 and longer-term upgrades



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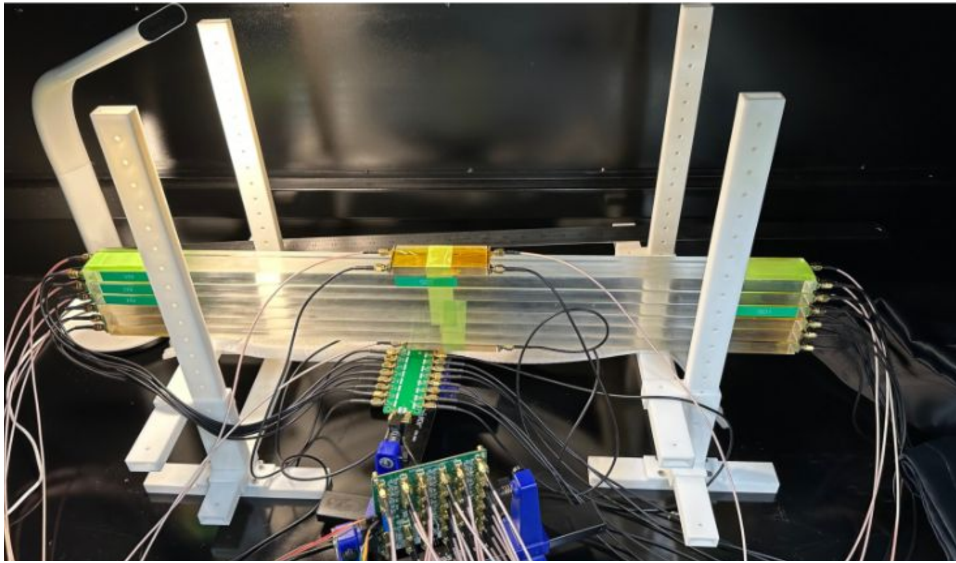
KLM: K_L^0 and muon detector

New capability: K_L^0 energy measurement

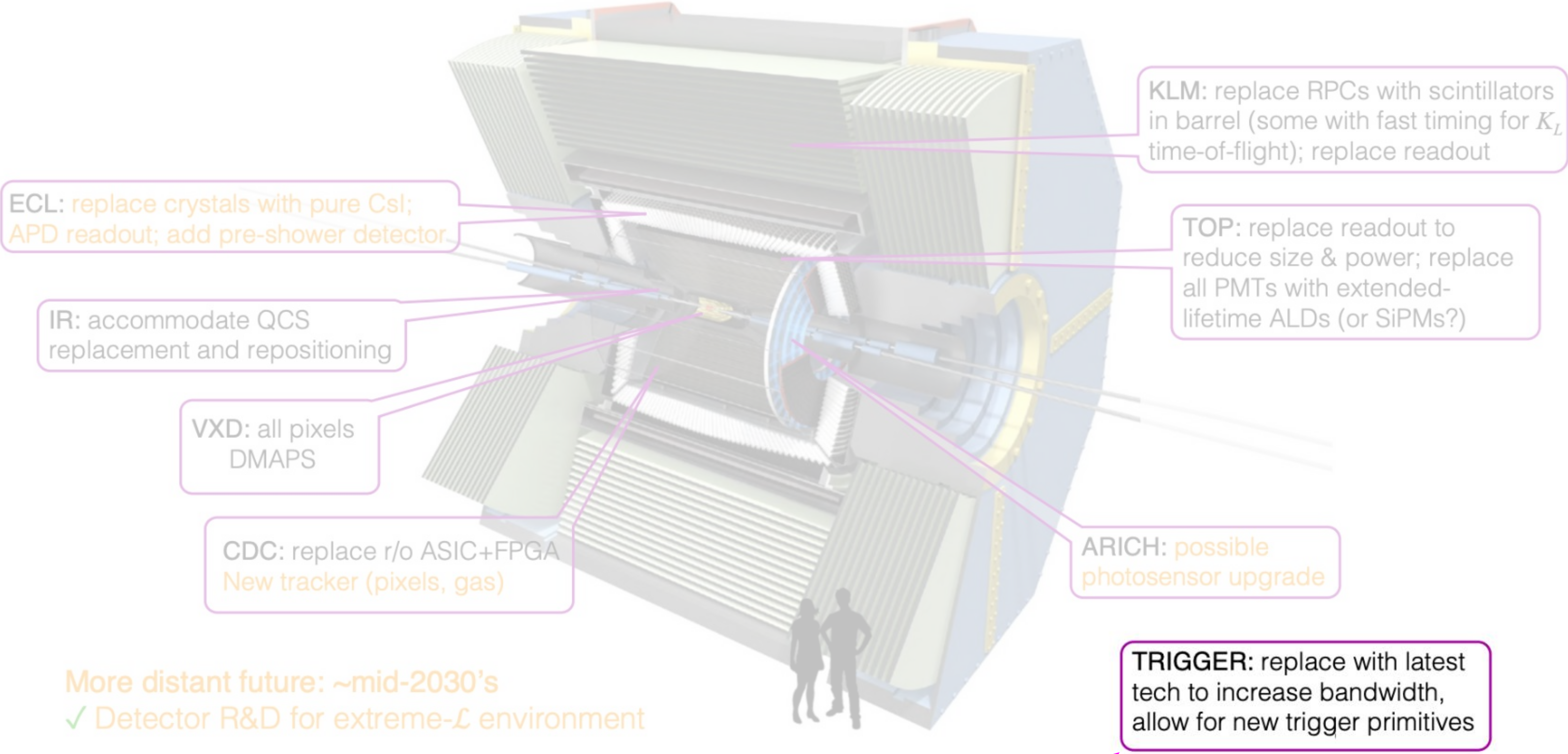
- Replace remaining RPC’s with scintillators + SiPM’s
- **Fast timing** (~100ps) gives K_L^0 E via TOF



Readout upgrades

- Move feature extraction to frontend ASIC
- Replace many km of twisted-pair ribbon cables with a few fibers

LS2 and longer-term upgrades



More distant future: ~mid-2030's

✓ Detector R&D for extreme-$\mathcal{L}$ environment

TRIGGER: replace with latest tech to increase bandwidth, allow for new trigger primitives

LS1, LS2, and beyond

- At Belle II, **(physics output) $\propto$ (luminosity)×(detector performance at high lumi.)**
- Achieving **both** is an iterative process…
- … we have a rich set of short-, medium-, and long-term upgrades in the works

Look for the Belle II Upgrades CDR soon

Thank you!