PHOTODETECTORS AND READOUT FOR PICOCAL: R&D OPTIONS AT UMD

WORKSHOP ON US CONTRIBUTION TO LHCB UII
UNIVERSITY OF MARYLAND

FRIDAY MARCH 17TH 2023

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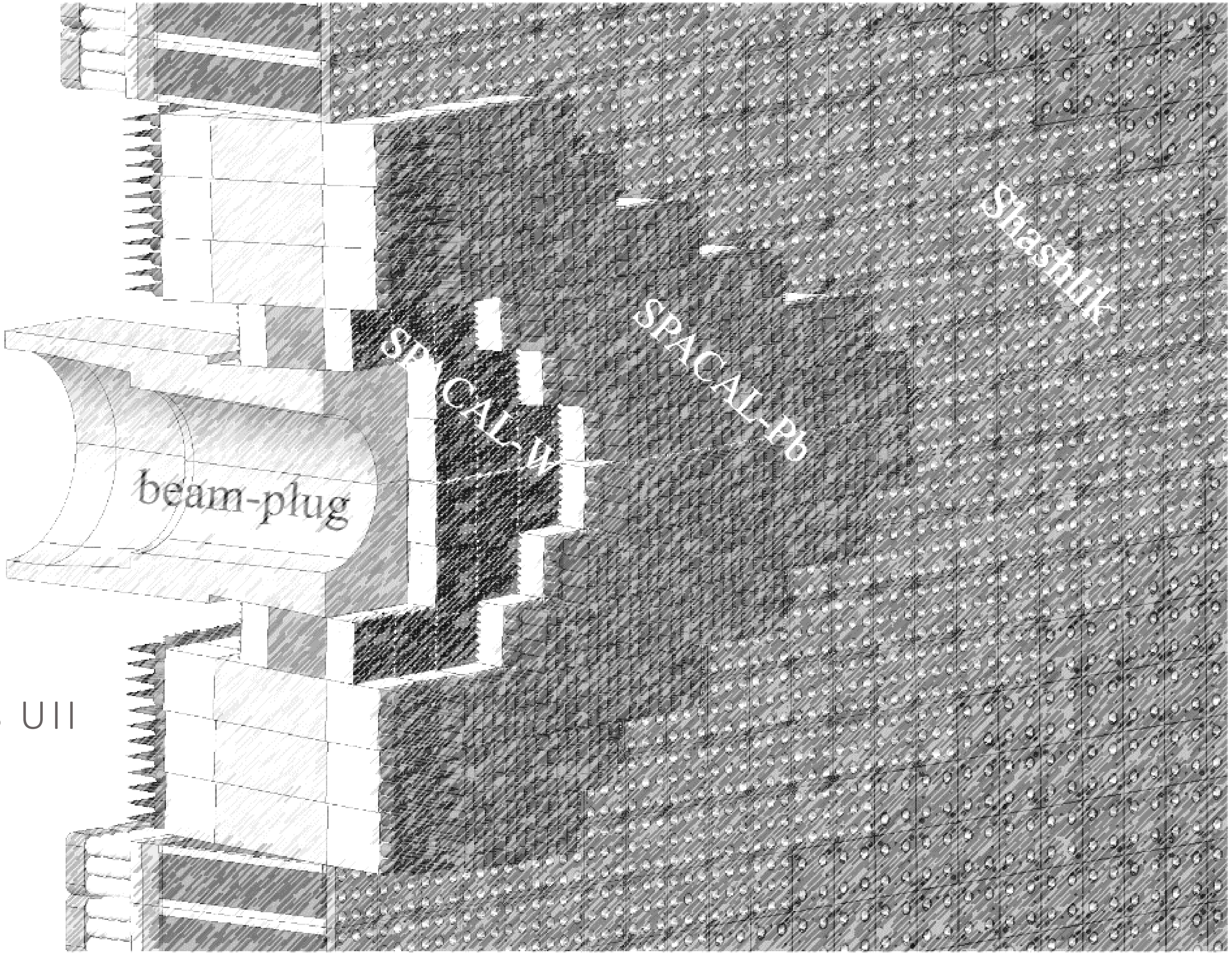
(UNIVERSITY OF MARYLAND)



Up-front Caveats

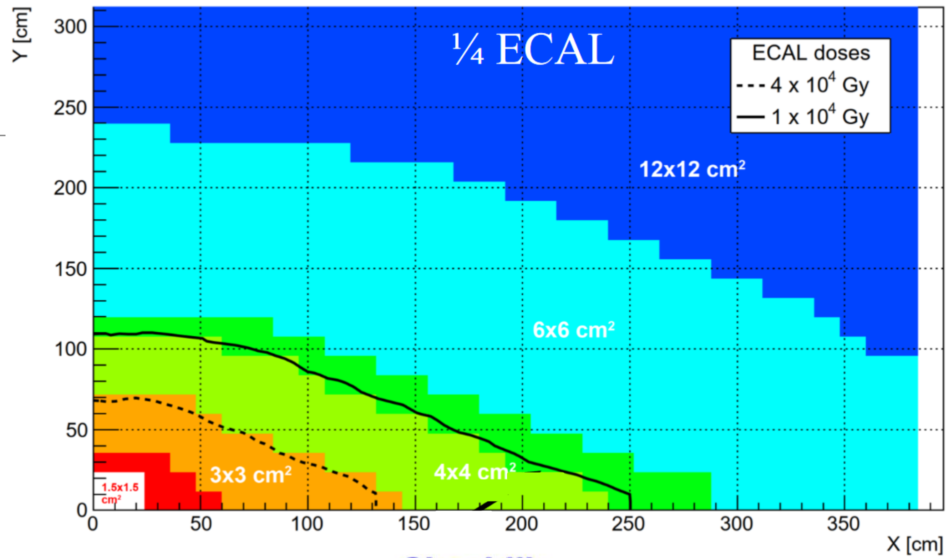
- This is largely an outsider perspective
  - Mostly gathered from zoom meetings and Orsay workshop

- Any misstatements, misunderstandings, or glaring omissions are my own

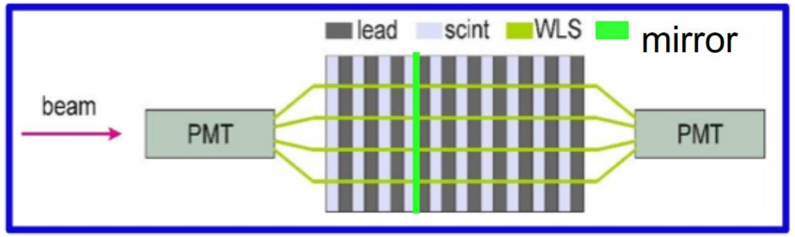
- Goal here: open up thinking on UMD or broader US contributions to photodetectors and their readout
  - If targets and paths were crystal clear we could skip the workshop and go straight to writing

Numerology Reminders

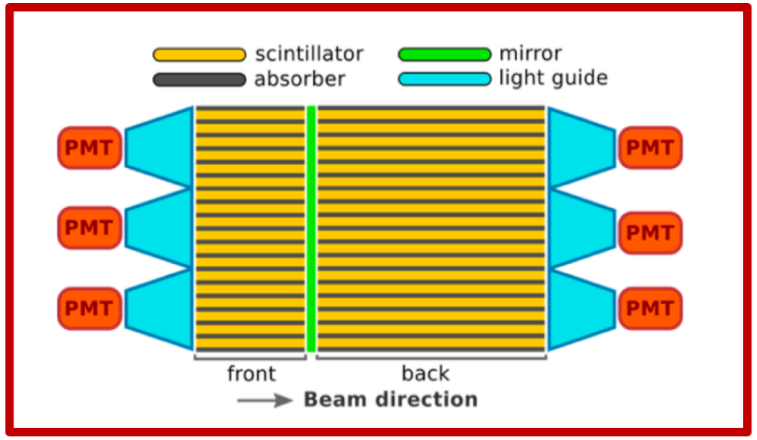
- 6016ch Current -> 30 208 ch U2
  - 32x 64-cell SPACAL-W
  - 144x 16-cell SPACAL-Pb
  - 272x 9-cell Shashlik
  - 896x 4-cell Shashlik
  - 1344x 1-cell Shashlik
- Baseline: double-sided Shashlik readout (right)
  - Downscope: Shashlik single-sided only -> 19 456
- PMTs:
  - 1 PMT/ch (OR 1 anode/ch?? MaPMT option)
  - Single type ideal
  - Split by SPACAL/Shashlik probably more costly in time/R&D/logistics than would be saved from relaxed spec.....



Shashlik

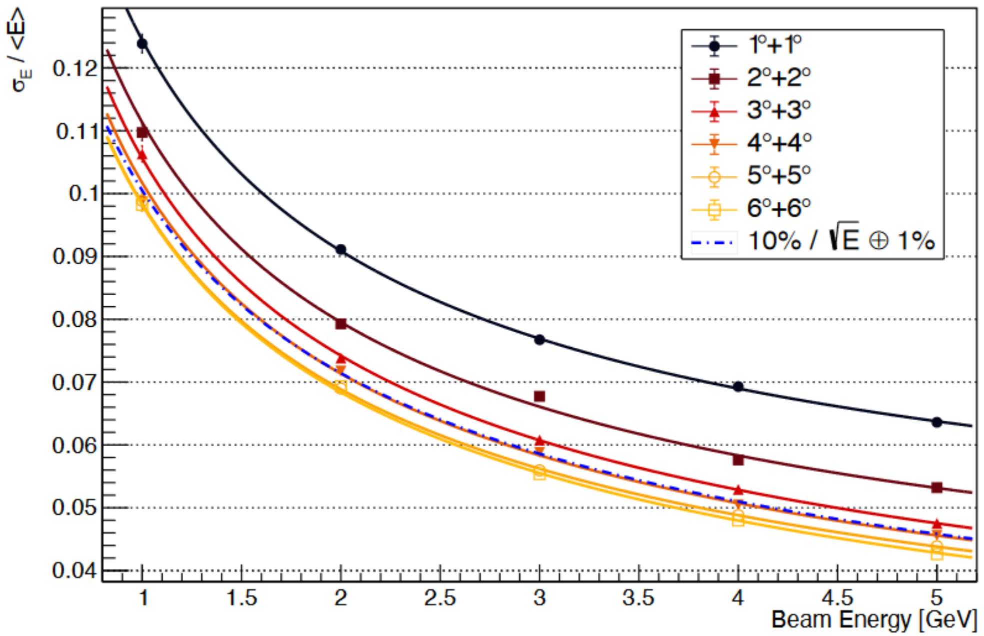


SPACAL

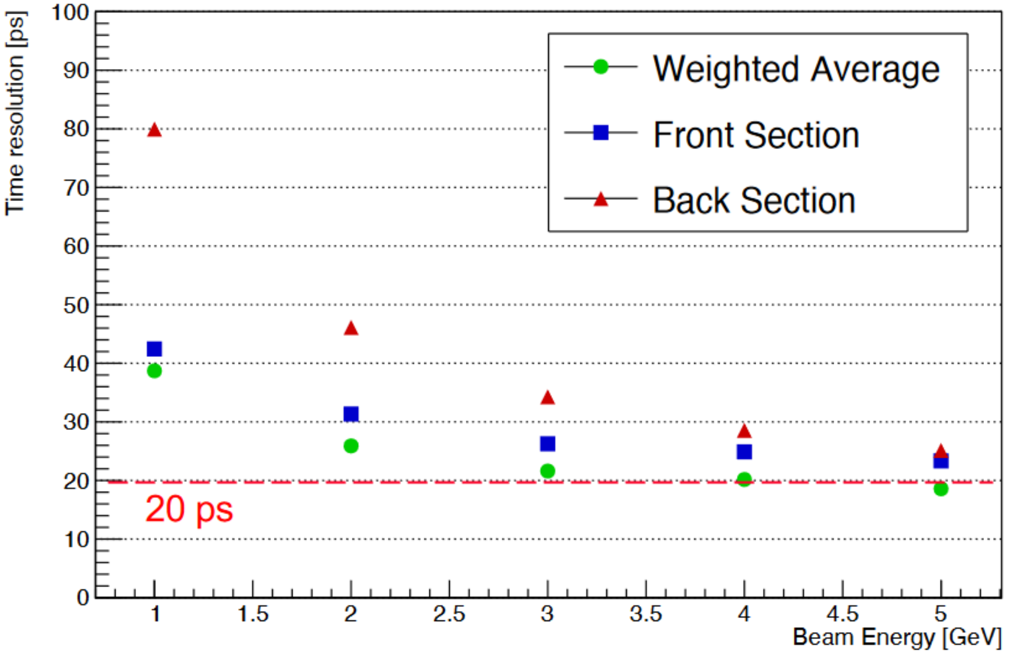


Performance goals

Energy resolution (DESY 2020 , R12421)



Time resolution (DESY 2020 , R7600-20)



- Maintain $\sigma(E)/E \approx 10\%/\sqrt{E} \oplus 1\,\%$
- Occupancy mitigation via improved granularity
- Pile-up mitigation via $O(10\ ps)$ time precision

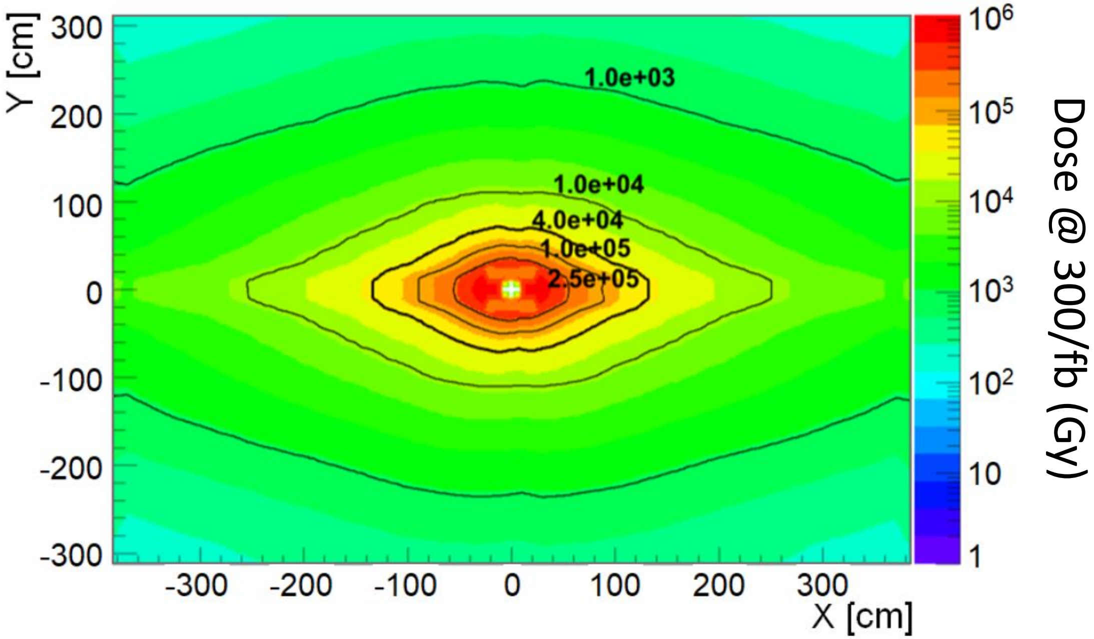
- Need photodetectors that keep up with or optimize this performance and satisfy the tough environmental and aging constraints

PMT conditions

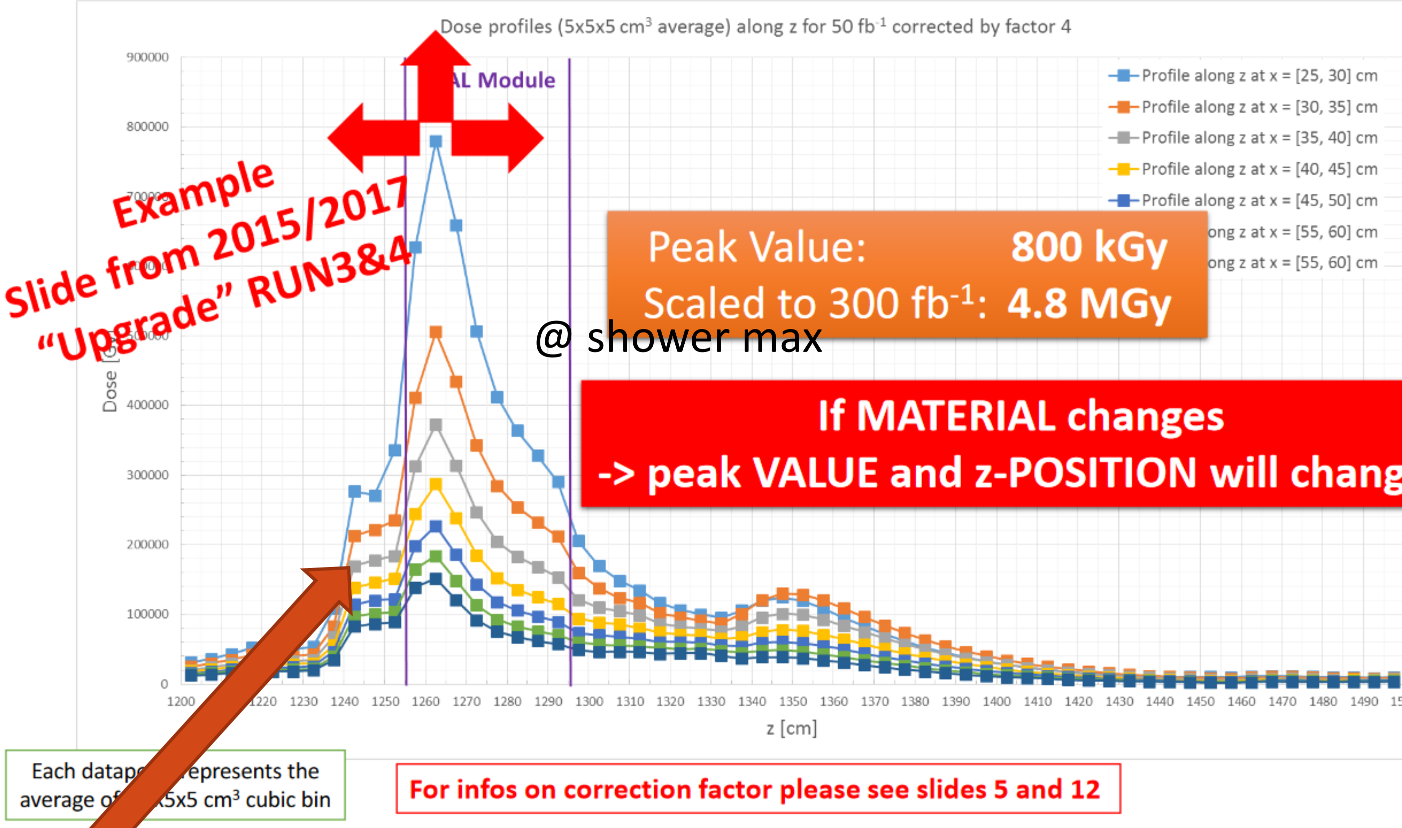
- Upgrade 2
  - Expect $\lesssim 1\ \mathrm{MGy}$ in center
  - 20 000 γ/GeV (undoped GAGG)
    - Hopefully will come down naturally with faster crystals
  - 5 mT B field
    - Shielding needs dependent on TTS
  - Remote HV (stability? noise?)
  - Integrated charge > 10^3C/year
  - Emission:
    - 550nm GGAG
    - 450nm PS
    - 500-550nm Sashlik WLS
    - -> Varying decay times, varying light yields, varying (?) intrinsic rise

- *c.f.* Run1-2
  - $\approx 1\ \mathrm{kGy/fb^{-1}}$
  - 3000 γ/GeV
    - Calibration follows E^T_{max}
    - Gain factors $(1-15)\times 10^3$
  - 5 mT B field – shielding used
  - Local HV derviation (CW base)
  - Y11 peak at 476 nm
  - Y11 WLS $\rightarrow$ 7ns decay time

Radiation Detail



Dose profiles along z for the upgrade (50 fb^{-1} at 14 TeV)



Aside: Important region to understand for PMTs on front side, depends sensitively on material model

Matthias Karacson @ Orsay wkshp
Profile shape in z w/module boundaries

Readout Architecture

QUICK REFRESHER

Electronics for the upgrade1b&2

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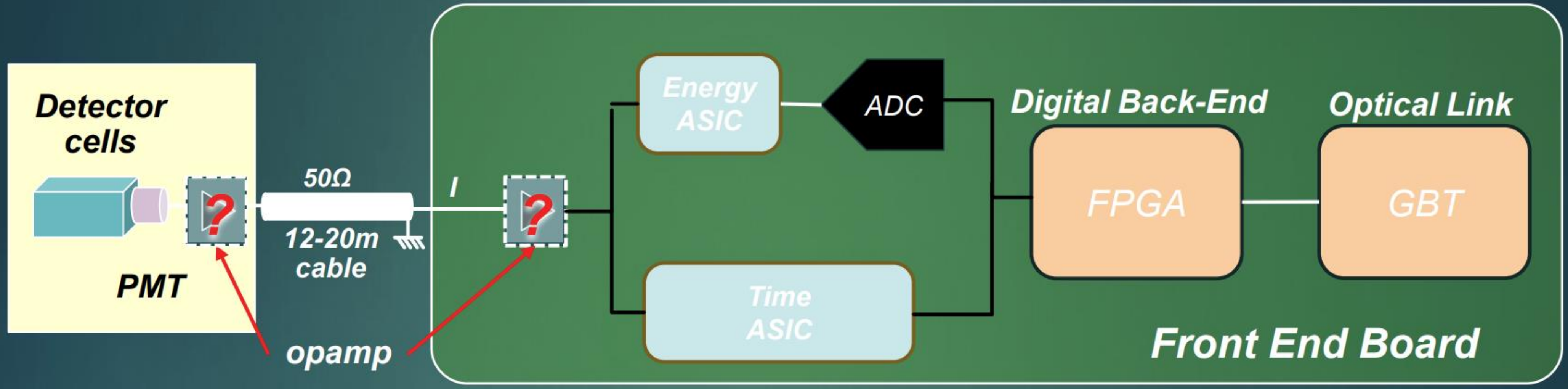
- Chosen architecture

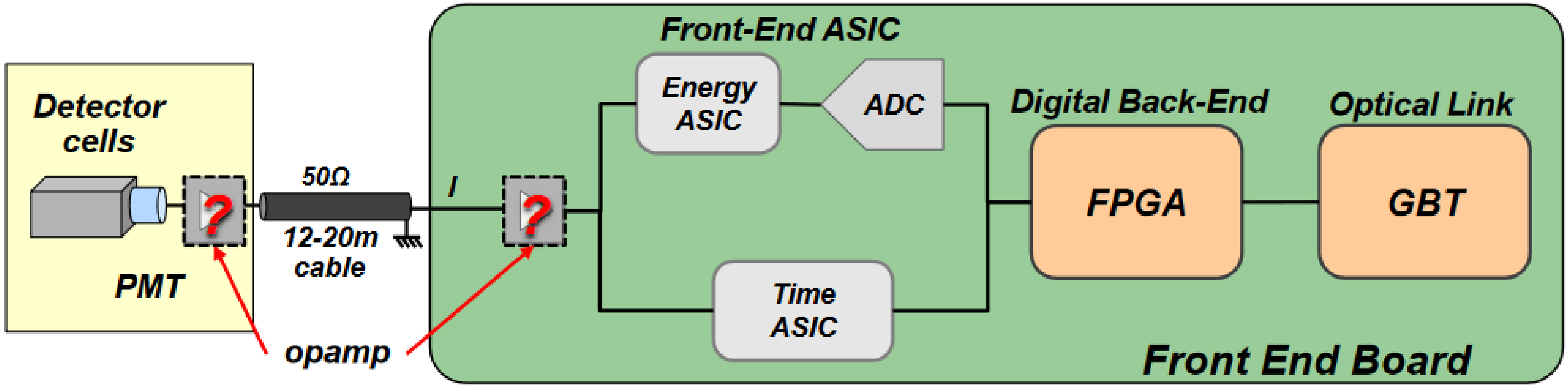
Slide stolen from Christophe Beigbeder-Beau



- Two separate processing paths with dedicated Asics in the same techno 65 nm :
  - Energy path close to the current ICECAL scheme (mostly analog processing)
  - Timing path based on a waveform TDC.
  - For dynamic range compatibilities, cable attenuation, Signal range Gain , noise, BW requirements:
    - Amplification and shaping either at the PM level or on the FEB
    - Opamp stage + dedicated passive attenuator for each ASIC could provide the optimal signal conditioning (see Edu's talk)

PMT Signal Conditioning

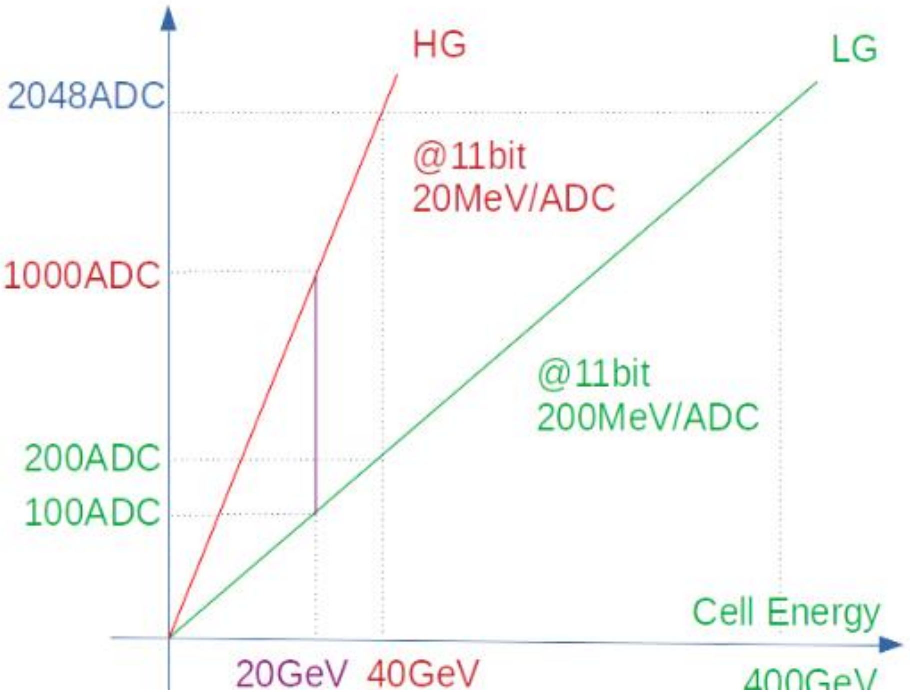
- Photodetectors readout solution follows the same scheme as in current ECAL:
  - Minimal light transport with PMT sensors near modules,
  - All electronics in crates on top of the detector (reduced radiation),
  - Connection via analog link (coaxial) ~12m long (up to 20m considered).
- ASIC/chipset in TSMC 65nm with separate energy and timing processing paths



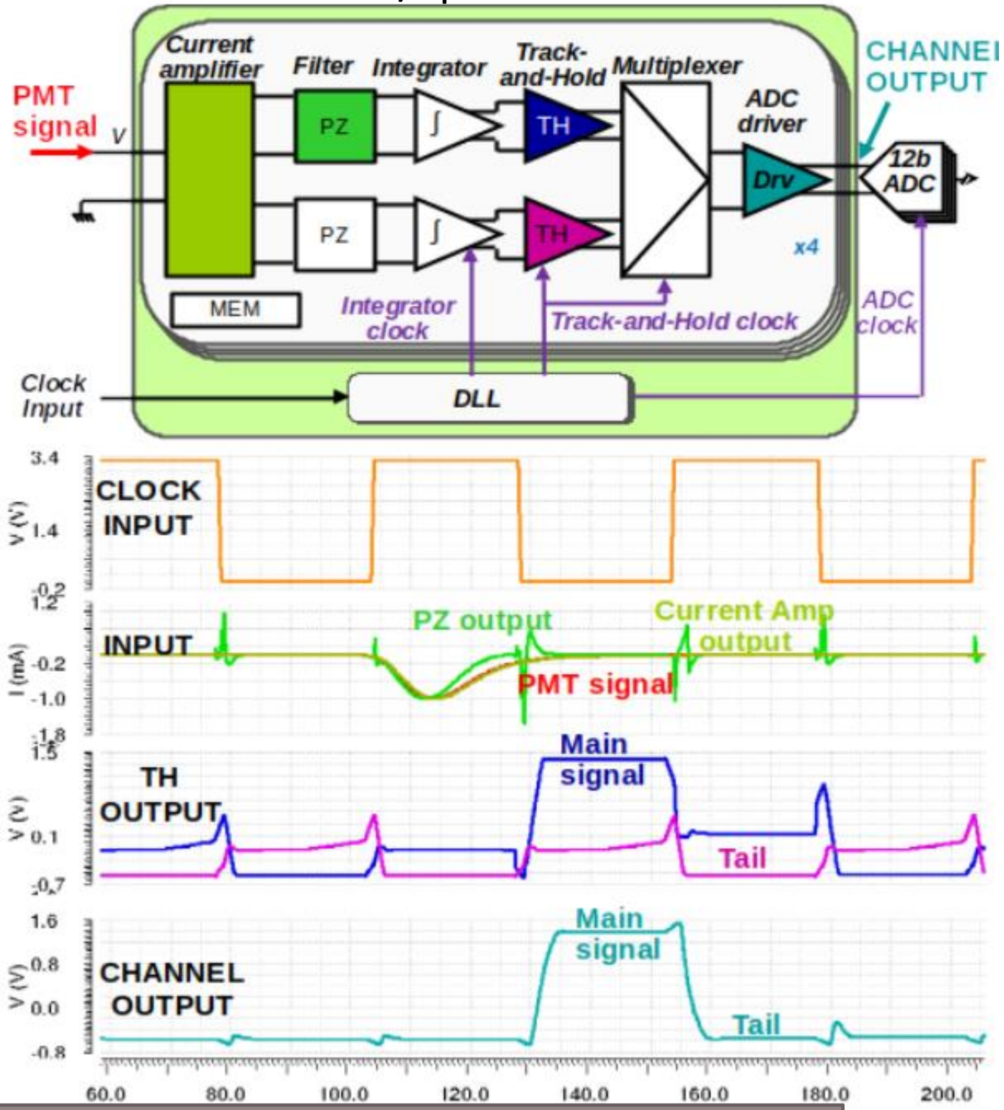
- Amplifier + Shaper circuit included on the PMT base or FEB under consideration
  - To compensate cable attenuation, improve SNR, if necessary, and reduce spill-over effort
  - To act as a buffer to help split the signal between paths
  - Different ASIC requirements (signal range, gain, noise, BW): add dedicated passive attenuator for each path.
  - If at FEB, use differential outputs to ASICs

Energy measurement: ICECAL II

- Dual-gain scheme to allow for larger dynamic range
  - Need to keep one eye on input/conditioning requirements
- PMT performance: linearity, gain stability, aging, rate effect



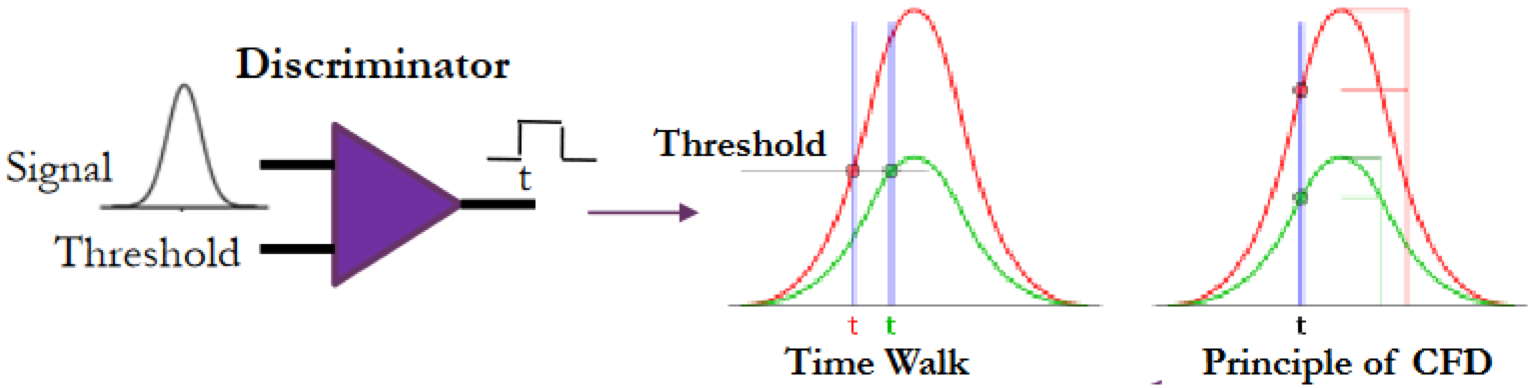
IFIC/Spanish labs



Figures clipped from talk by Jose Mazorra De Cos

Time measurement

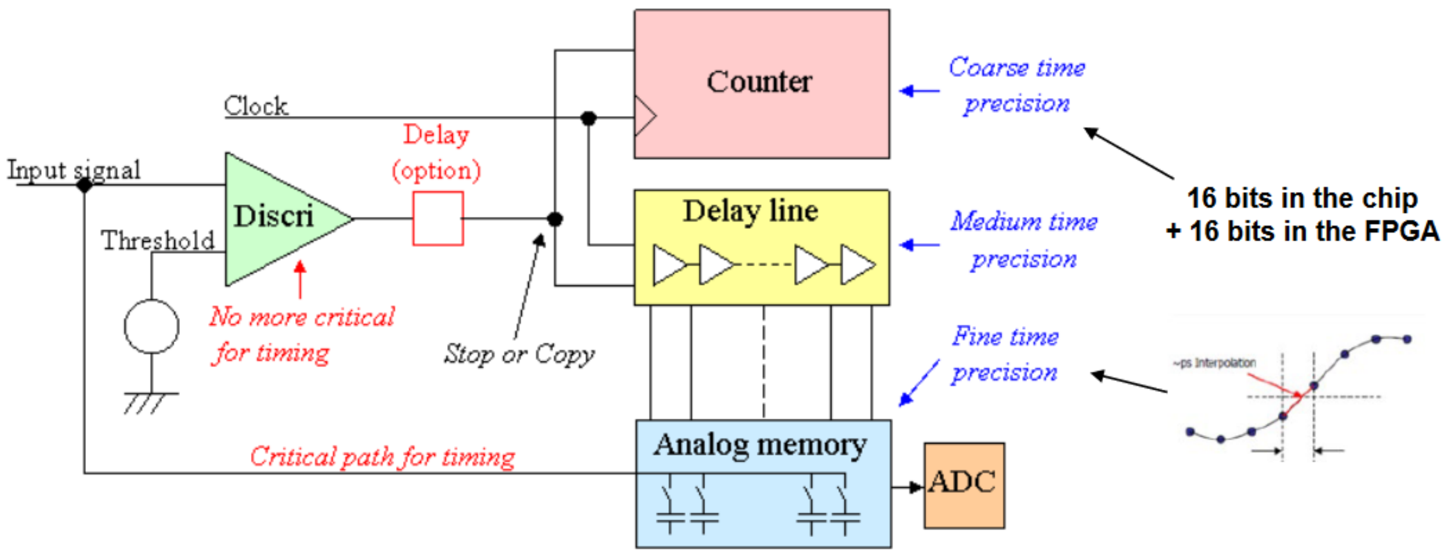
Figures clipped from talks by Philippe Vallerand, Dominic Breton, and Christophe Beigbeder-Beau

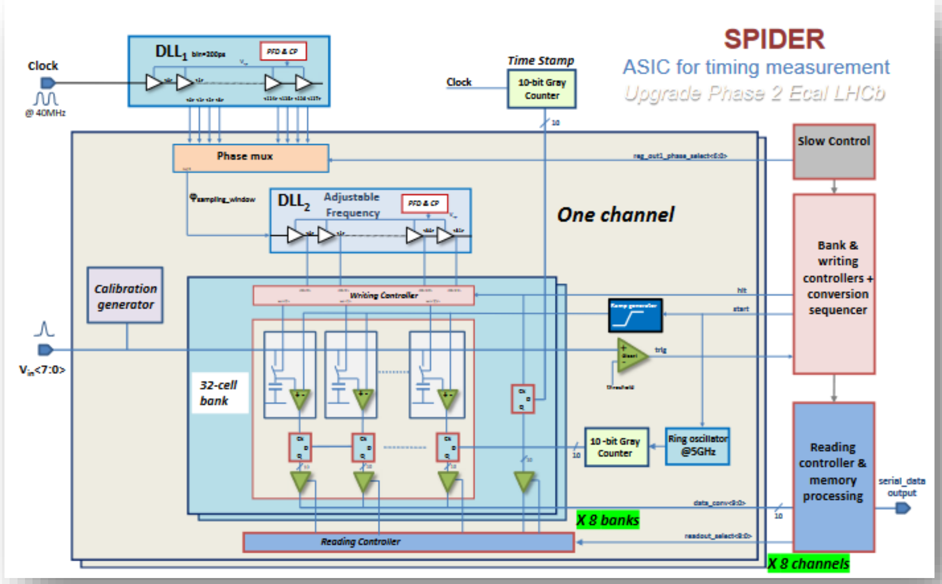


- Fundamental problem: need to derive timestamps from waveforms very quickly
  - Fastest simple structure, discriminator+TDC, creates time-walk effect ✖
  - Constant-fraction discrimination is more stable vs amplitude, harder to do in real-time
    - Analog implementation introduces delay lines that degrade performance in front of ASIC
    - Much easier “after the fact” with digitized waveform

Waveform TDC

Figures clipped from talks by Philippe Vallerand, Dominic Breton, and Christophe Beigbeder-Beau





IJCLab + other IN2P3

- Use analog memory to buffer waveform and use constant-threshold discriminator for timing only
  - Pass along waveform for interpolated CFD timing measurement in FPGA
- Looks rather like an oscilloscope timing measurement on-a-chip!

Waveform TDC timing capability

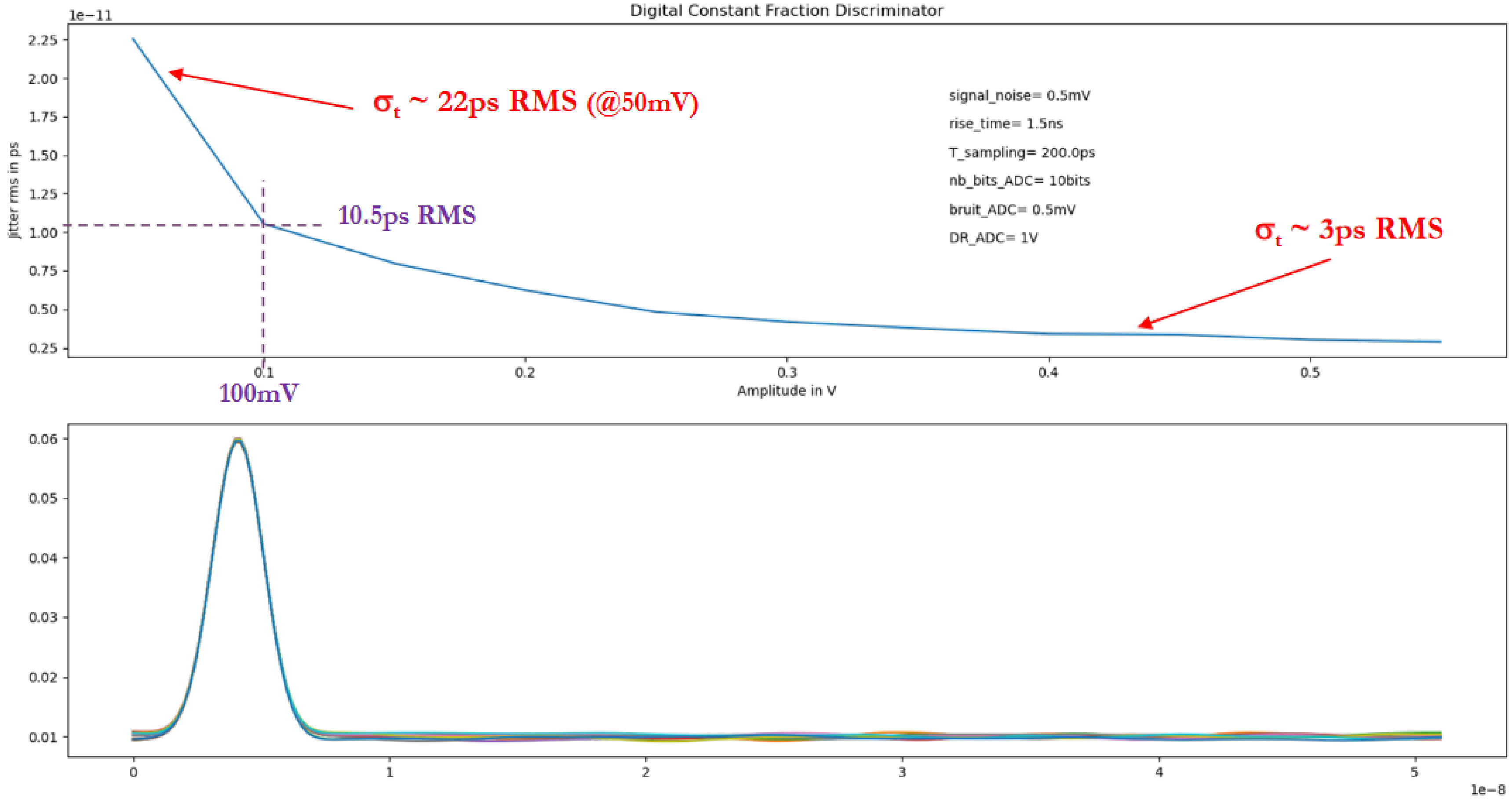
Figures clipped from talks by Philippe Vallerand, Dominic Breton, and Christophe Beigbeder-Beau

- Plot from Dominique @ Orsay workshop
- Timing measurement exceptionally good at high end of dynamic range
  - Low end may be an issue – dynamic range may extend below 50mV
  - Compensation options:
    - Lower noise
    - Higher Vmax
    - Faster rise time (jitter ~ noise/slope)
- PMT performance: TTS, uniformity, rise time

Timing jitter versus signal amplitude :

rise time = 1.5ns ; σ_{noise}= 500µVRMS ; σ_{SCA}= 500µVRMS

Just to compare, here we use a reduced dynamic range of 20
=> Vin ranges from 50mV to 1V



R&D targets

Rise time and TTS

- TTS represents an intrinsic limitation on time performance, need to understand and optimize
  - Possible trade-off against other desirable features, e.g. magnetic field tolerance vs TTS for fine-mesh
- Fast rise time may help with time resolution at lower energies
  - What is intrinsic limit of the modules?
  - What is the trade-off with TTS?

Hammamatsu

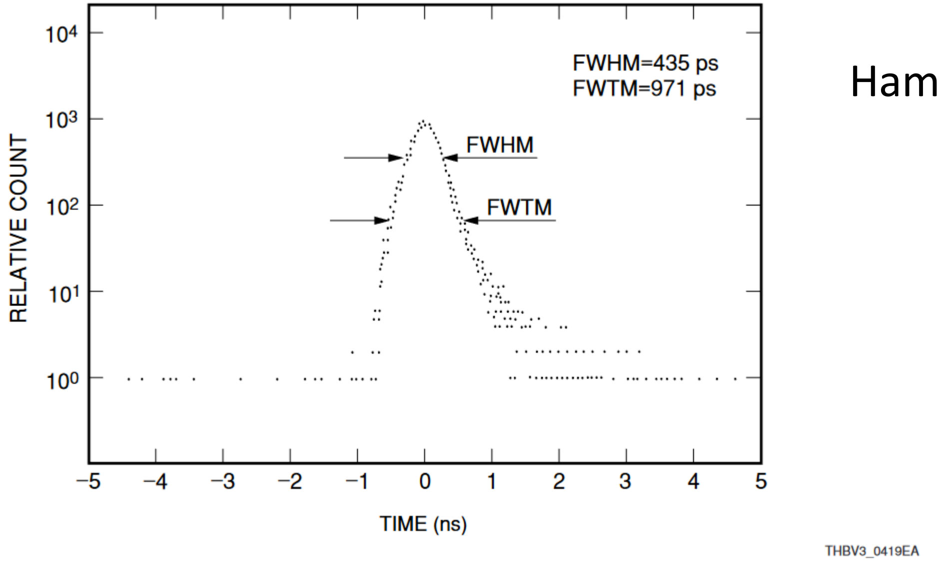
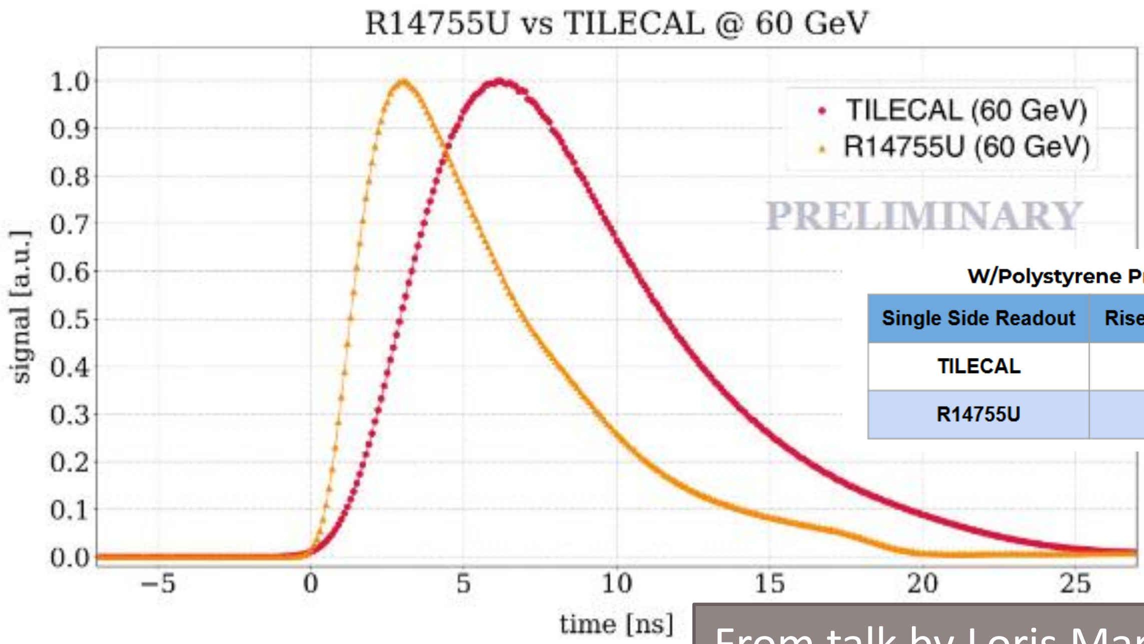


Figure 4-19: TTS (transit time spread)



W/Polystyrene Prototype

Single Side Readout	Rise Time (10-90%) [ns]
TILECAL	3.6
R14755U	1.8

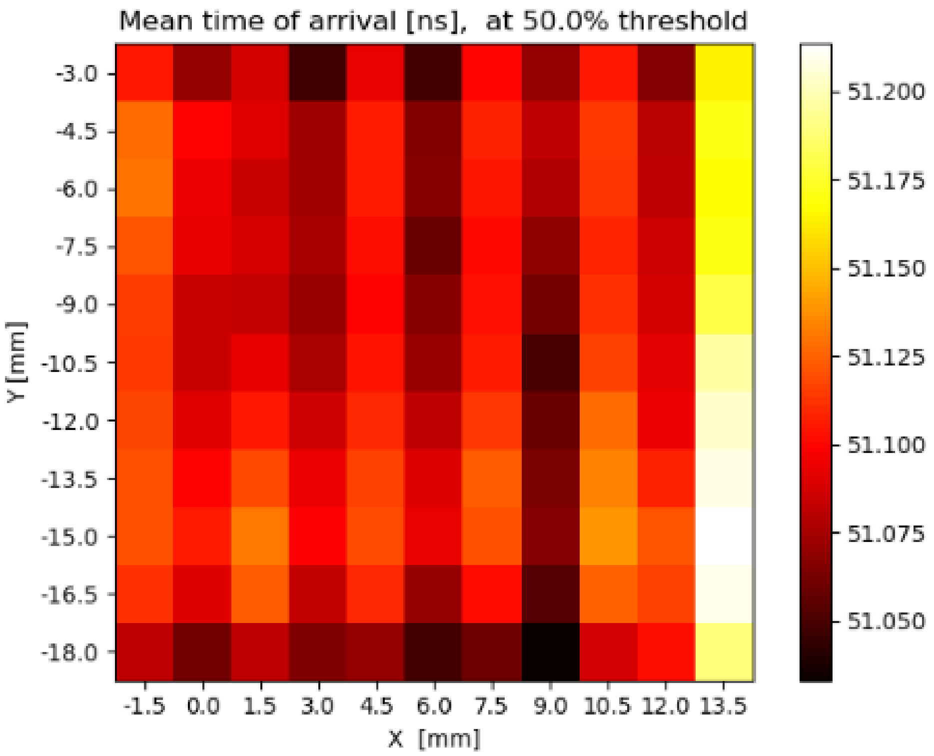
From talk by Loris Martinazzoli

Time response uniformity

- Spread due to different timing for signal build up starting at different positions on photocathode

- Needs to be understood well for each candidate model
  - Possible to mitigate/minimize with mfg cooperation?
  - Part of QA characterization?
  - Possible to reduce with lightguide?

- Option to use MaPMT brings in a similar uniformity discussion, but now between-cell uniformity!



Example Measurements for R7600U-20

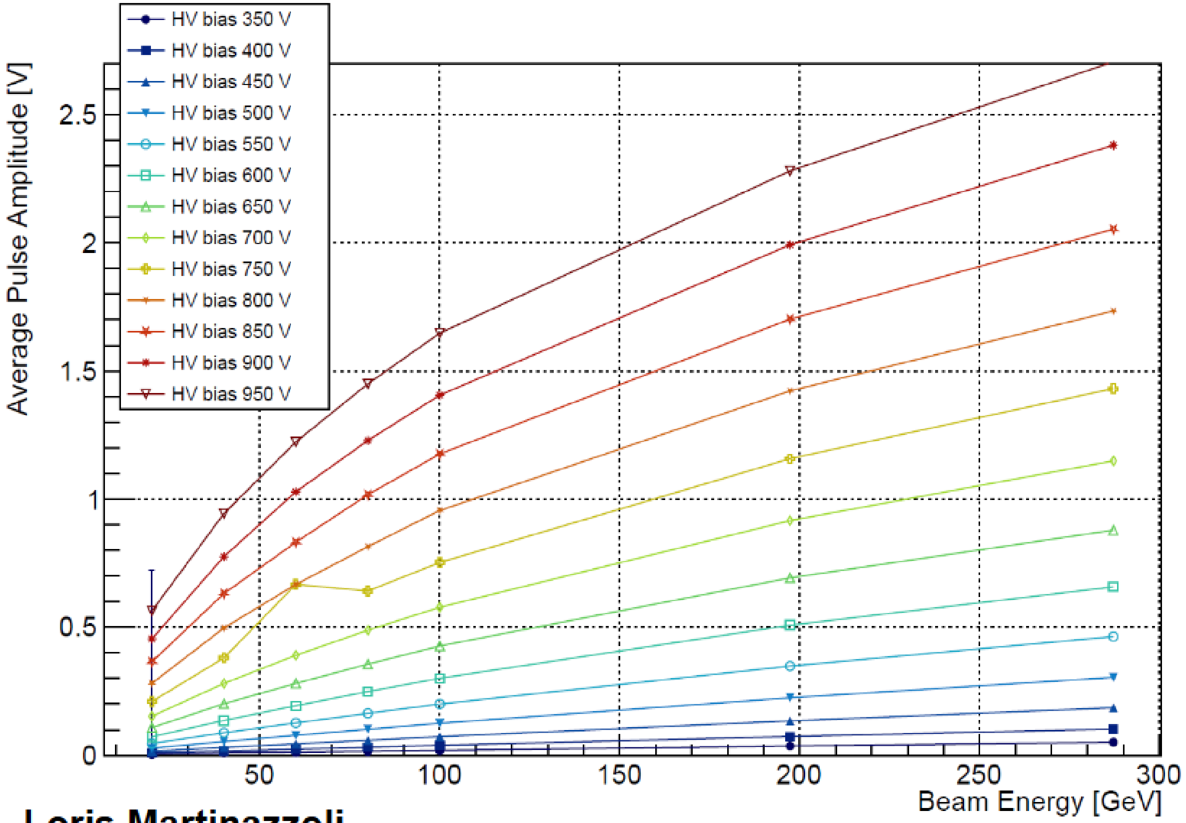
total σ_t = 41 ps

E. Picatoste, ECAL U2 R&D Meeting 2 March

Linearity

- Currently some non-optimal behavior from round PMT candidates
  - Would like to understand how to reproduce and investigate on bench so mitigation strategies can be validated without relying on test beam time

Round PMT amplitudes Vs. HV Vs. E

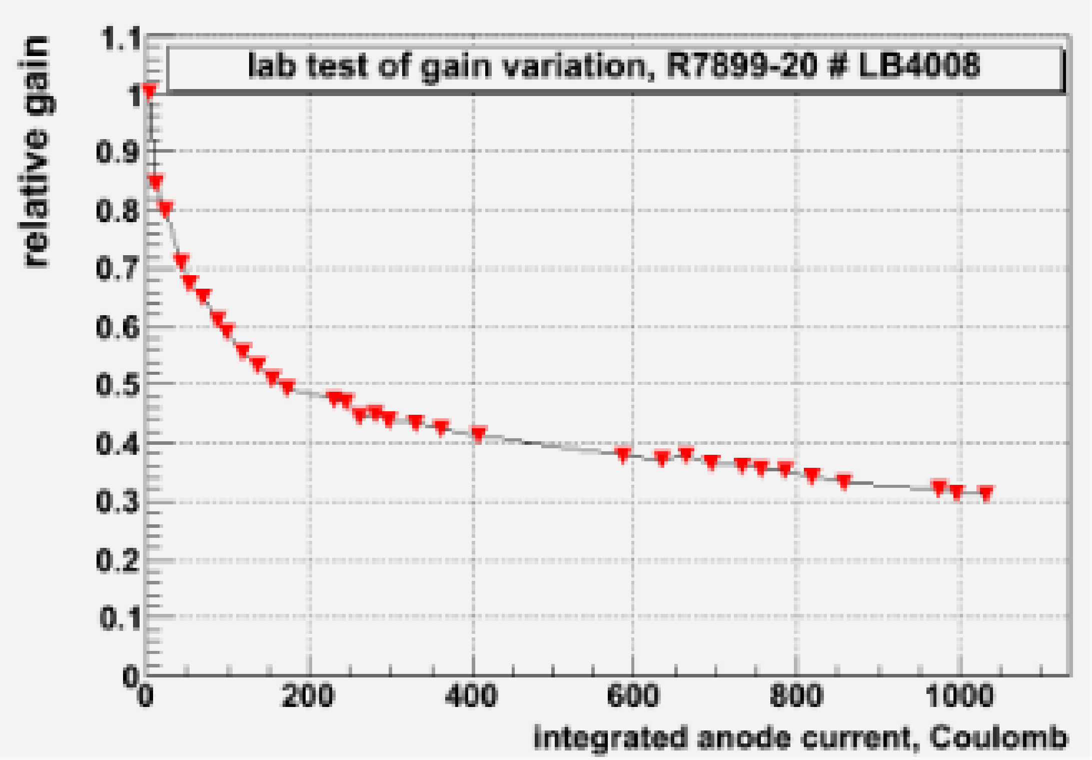


Loris Martinazzoli

Aging

- Even if reduced light yield GAGG is chosen, still many system-level decisions influenced by aging behavior

- Crucial to study behavior out to end-of-life (+irradiated?)



Studies for original ECAL
Dug up from old meetings by Iouri Guz

Optimization with MFG

- Expect that optimal PMT solution will require iteration with manufacturers
  - UMD involvement can allow for parallel testing, cross-validation of results, faster convergence on solutions

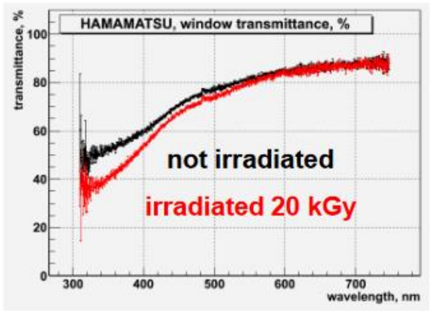
R7899-20

Main modification wrt the original R7899:

- spherical photocathode → flat (HAMAMATSU UV glass)
  - reduces price
  - improves radiation tolerance (thin)
  - but increases transit time spread
- photocathode: made green-extended
  - improved QE for Y11 light
    - from HCAL beam tests of 2003, the photoelectron yield was 60/GeV with Photonis XP3102 and 100/GeV for HAMAMATSU R7899-20
- reduced rate effect
  - probably via special treatment of dynode holders

final
R7899-20

Intermediate
R7899-11



2023-02-03

From talk by Iouri Guz

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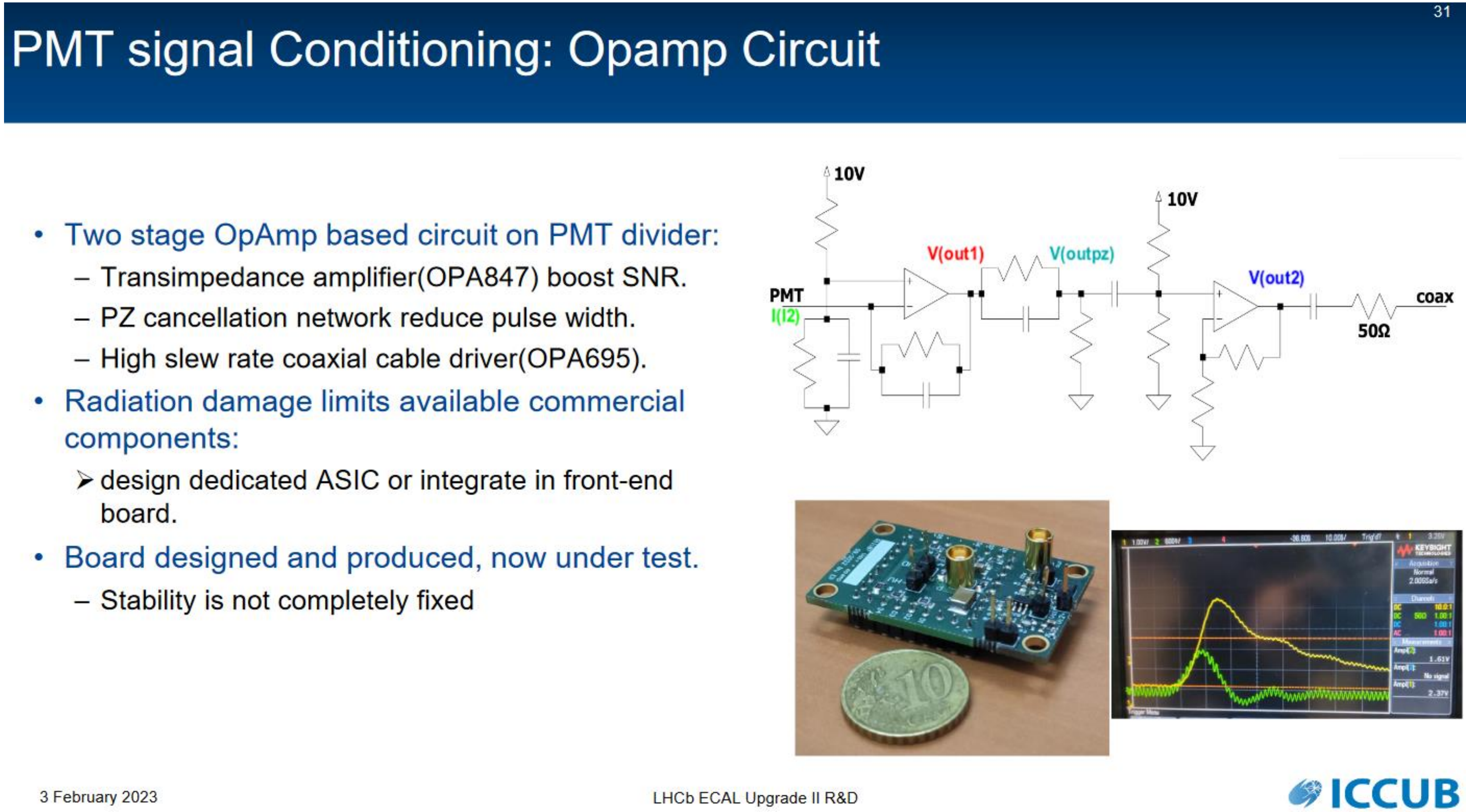
Example: PMTs for Run1/2 ECAL
(Iouri Guz @ 2 March R&D MTG)

Conditioning Electronics

- UMD electronics experience opens possibilities for contributions to signal conditioning circuit R&D, in addition to characterization



Slide from Eduardo Picatoste

UMD lab ideas

Lab needs

- Starting point: similar setup to Barcelona group
- Will need to source laser, light box, optical table, collimator, diffuser, other optics
- Acquisition and digitization, power, control likely doable with materials on-hand
- TBD: what additional/unique capability do we want to try to build out from there?

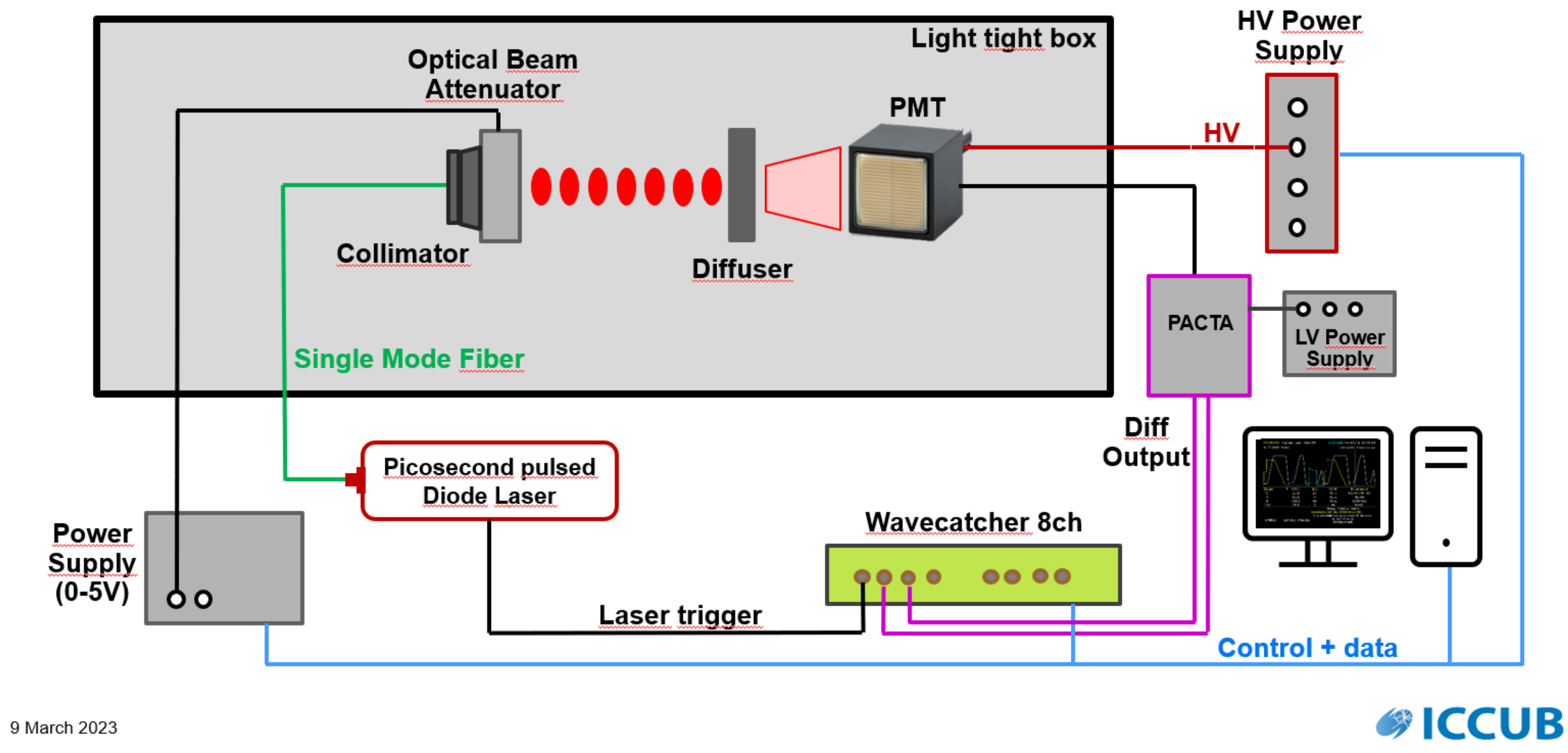
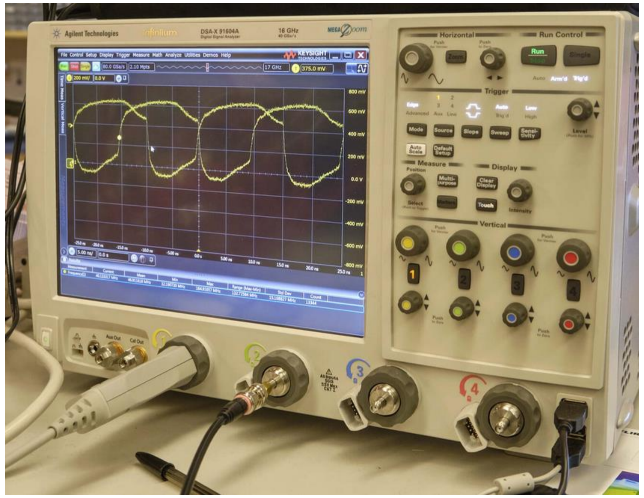


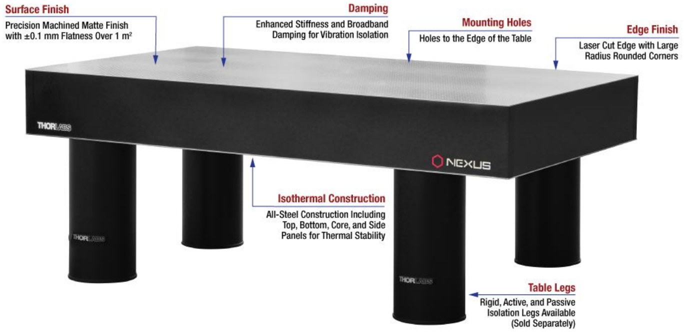
Figure from Eduardo Picatoste

Lab costs

Item	Approx Cost (kUSD)
Laser	22
Laser shutter	1.5
Optical table top	9-10
Optical table support	1-2
HV Supply	4.5
Light box frame	0.5
Light box breadboard	0.2
Misc through-wall connectors	?
Opto & mech hardware	<~1?
Total	**~42**

- On hand:
  - LV supplies (various)
  - 16 GHz / 40 GSa scope
    - Differential mid- and high-bandwidth active probes
    - Automated acquisition and signal processing needed
      - Very possible using PC control up to modest rep rates
      - Excellent student project





Summary

- Possible R&D path at Maryland involves characterization and development of PMT
  - Potentially very sensitive to many different parameters of performance and robustness
  - Hope to work at UMD on optimization of the PMTs in close collaboration with readout design

- Interesting possibilities to interface with colleagues at Barcelona and CERN, potentially culminating in development of custom solutions with industry