IceCube-Gen2
Technical developments

J.P. Yanez for the **IceCube-Gen2 Collaboration**

NNN workshop

Beijing, November 2016

UNIVERSITY OF ALBERTA

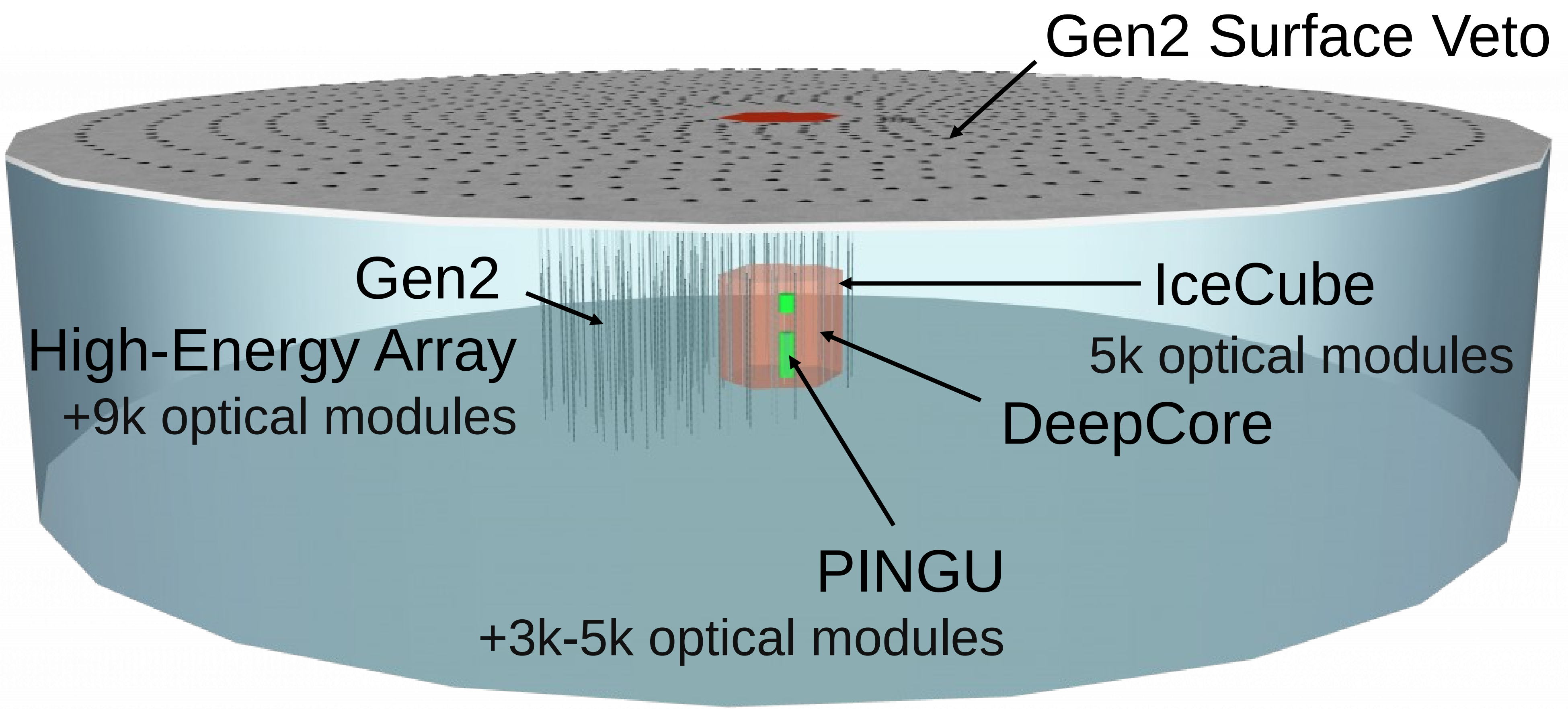
Bourses postdoctorales Banting Postdoctoral Fellowships

j.p.yanez@ualberta.ca

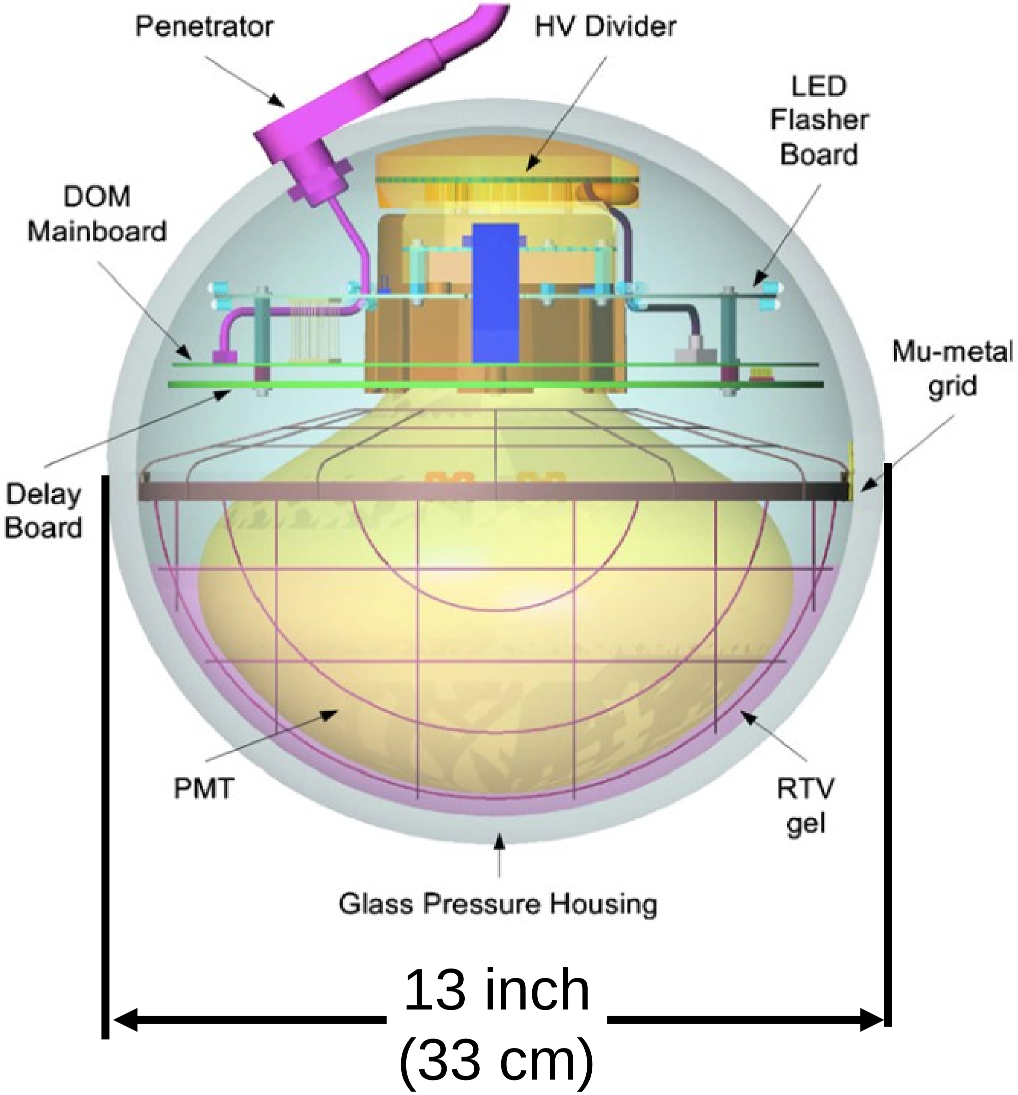
The IceCube-Gen2 facility

A wide band neutrino observatory

- Optical, radio & surface veto
- MeV to EeV ν detection range → supernovae … astrophysical
- Requires additional 13k to 15k optical modules



IceCube Digital Optical Module



*NIM A **601** (2009) 294*

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IceCube Digital Optical Module

» IceCube DOM

- » Single, large (10”) PMT per module
- » Full waveform digitization
- » Glass transmissivity of 0.5 at ~350 nm
- » Calibration LEDs on-board
- » Power consumption ~3W
- » Discriminator
- » Local coincidence logic for readout
- » Delay line: 75ns
- » Redundant digitizers
- » Photon counting capabilities to high charge (1-thousands pe)
- » Withstand > 550 bar freeze-in pressure
- » Survive shock vibration
- » Gel cushioning for optical coupling, electronics

IceCube Digital Optical Module

» IceCube DOM

Improve

» Single, large (10”) PMT per module

» Full waveform digitization

» Glass transmissivity of 0.5 at ~350 nm

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Get rid of

Keep

» Photon counting capabilities to high charge (1-thousands pe)

» Withstand > 550 bar freeze-in pressure

» Survive shock vibration

» Gel cushioning for optical coupling, electronics

IceCube Digital Optical Module

» Gen2 wish list

- Simpler, cleaner electronics
- Segmented modules, more but smaller PMTs
- Uniform angular coverage
- Directional information from single modules
- Dynamic digitization scheme
- Lower photon wavelength threshold
- Better understood LEDs
- Reduce power consumption to ~1W per OM

- Photon counting capabilities to high charge (1-thousands pe)
- Withstand > 550 bar freeze-in pressure
- Survive shock vibration
- Gel cushioning for optical coupling, electronics

Consider designs which improve these points

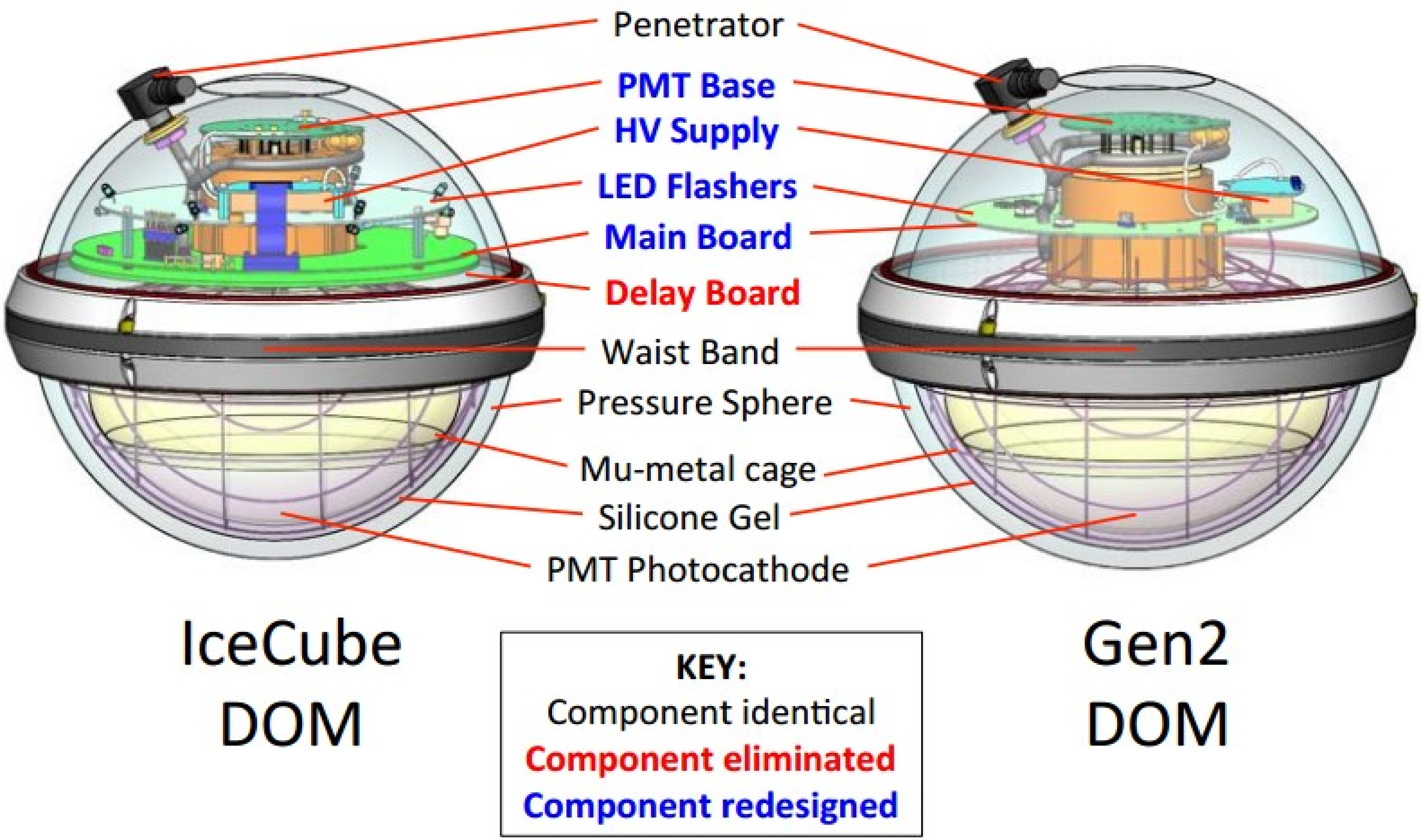
IceCube-Gen2 modules

Design of new sensors - Baseline

» Same performance, simpler design

» Mechanical design tested, reliable

» Performance in-situ well understood



Design of new sensors - D-Egg

- 2x8” PMTs – Up/down = 12” diameter
- Strain measurement @ 700bar
- Towards uniform acceptance
- Self-veto potential
- Benefits from glass + higher QE

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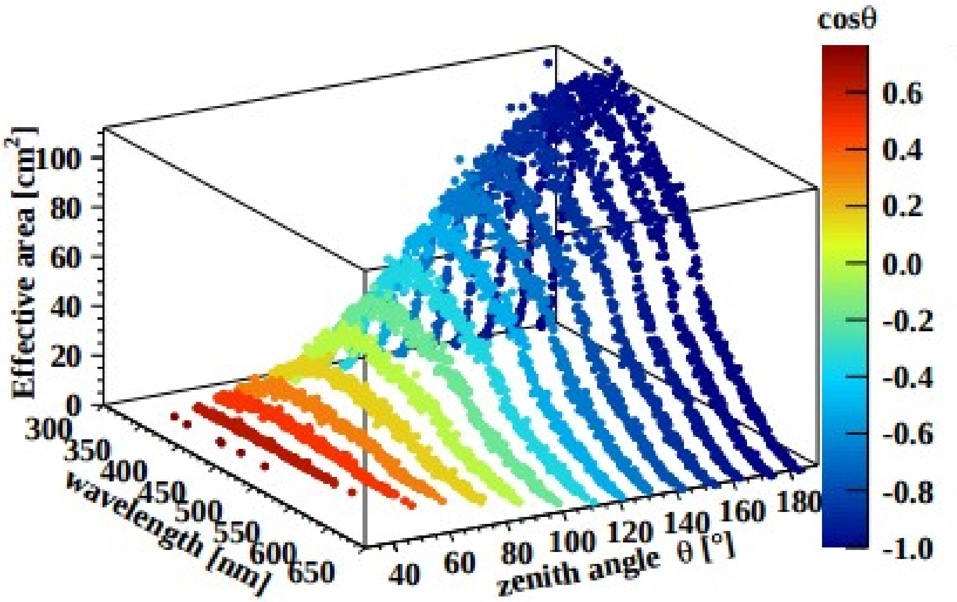

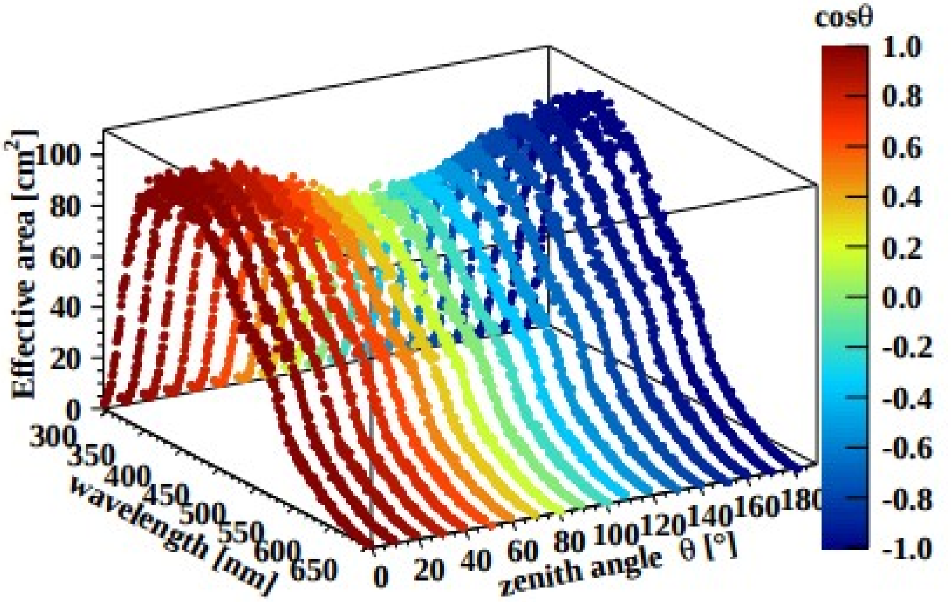

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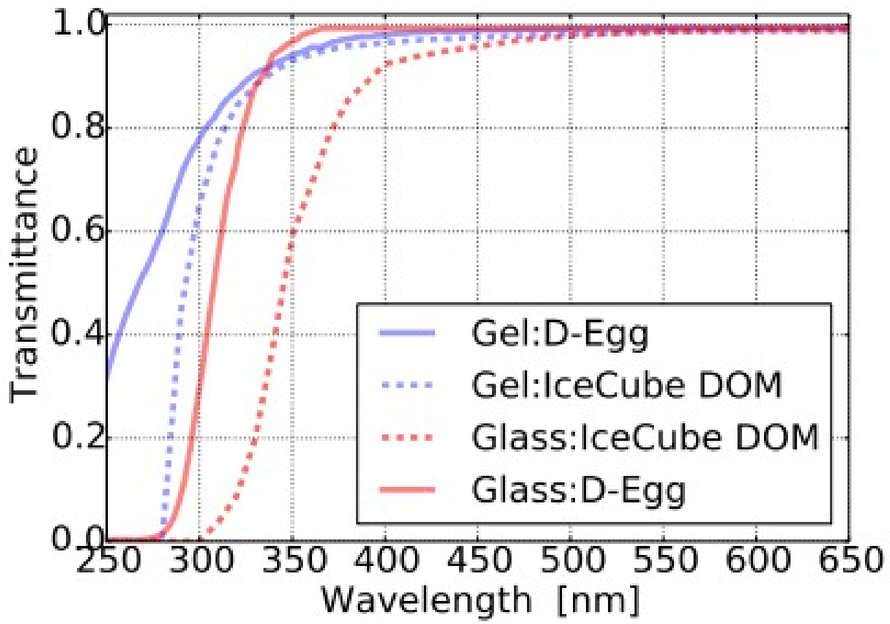

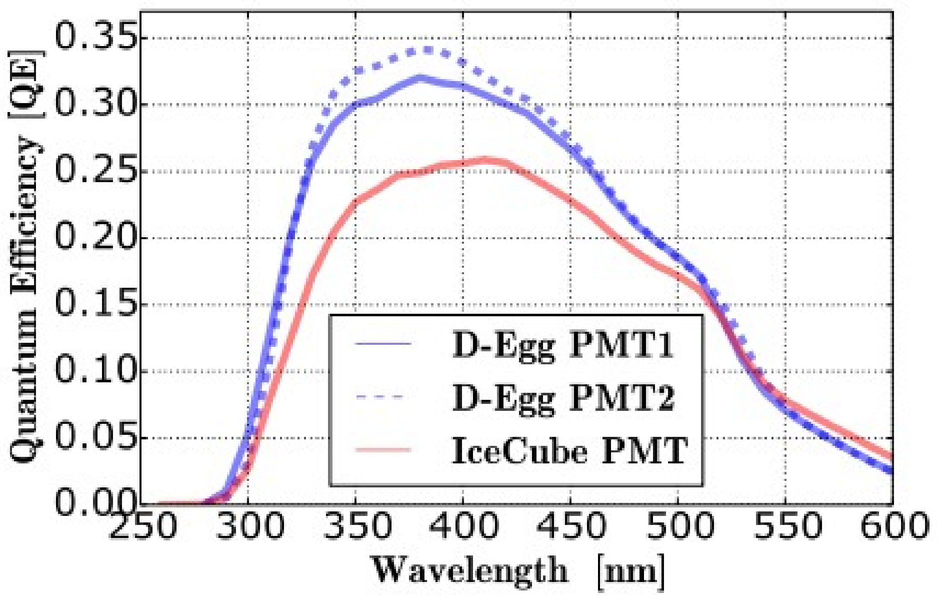

*Transmittance cutoff of the D-Egg glass appears to be very sensitive to impurities

Design of new sensors - mDOM

- Adapted from KM3NeT mDOM
- 24 x 3-inch PMTs
- Diameter 14 inch = 355 mm
- Pressure rating 700 bar
- 3D printed PMT holding structure
- 4π angular coverage
- Reflectors
- Main challenge: power for sampling complex waveforms

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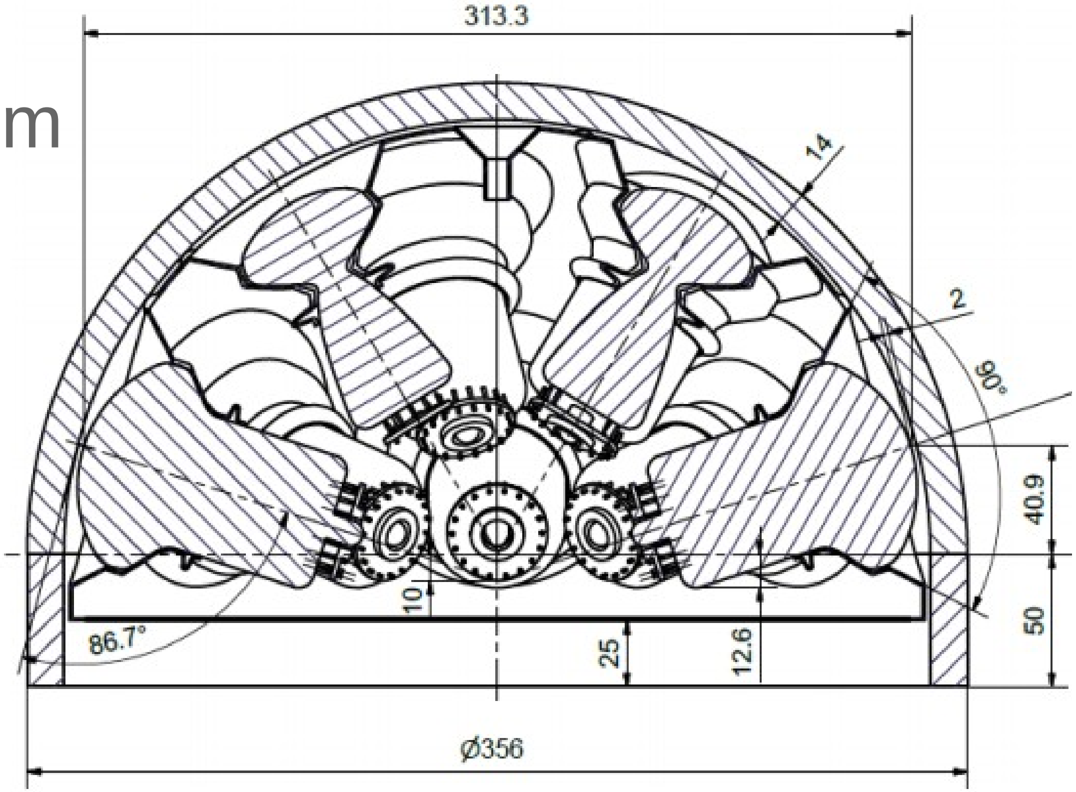

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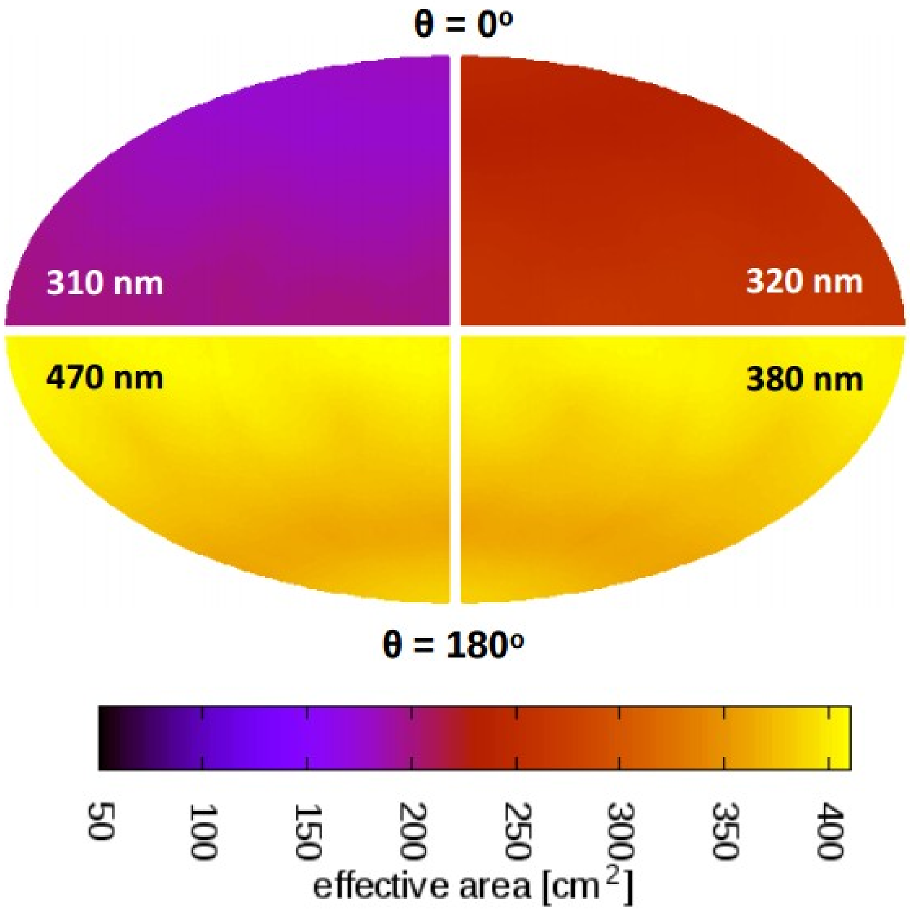

3x IceCube DOM eff area – very uniform

Design of new sensors - mDOM

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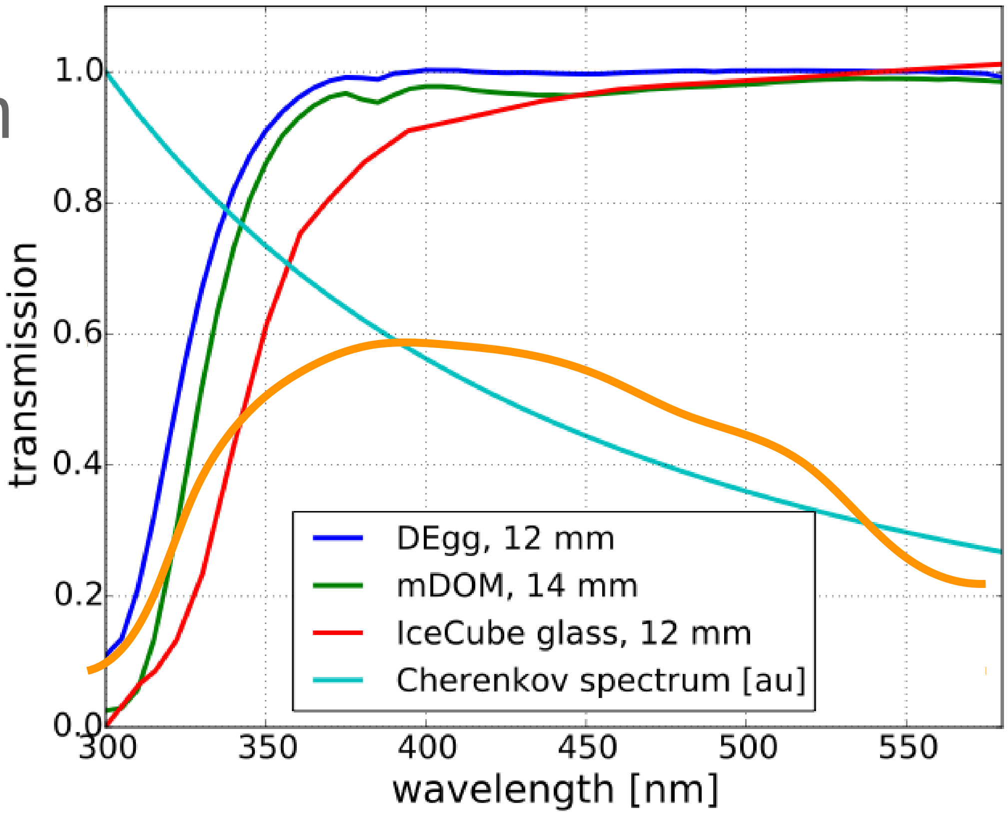
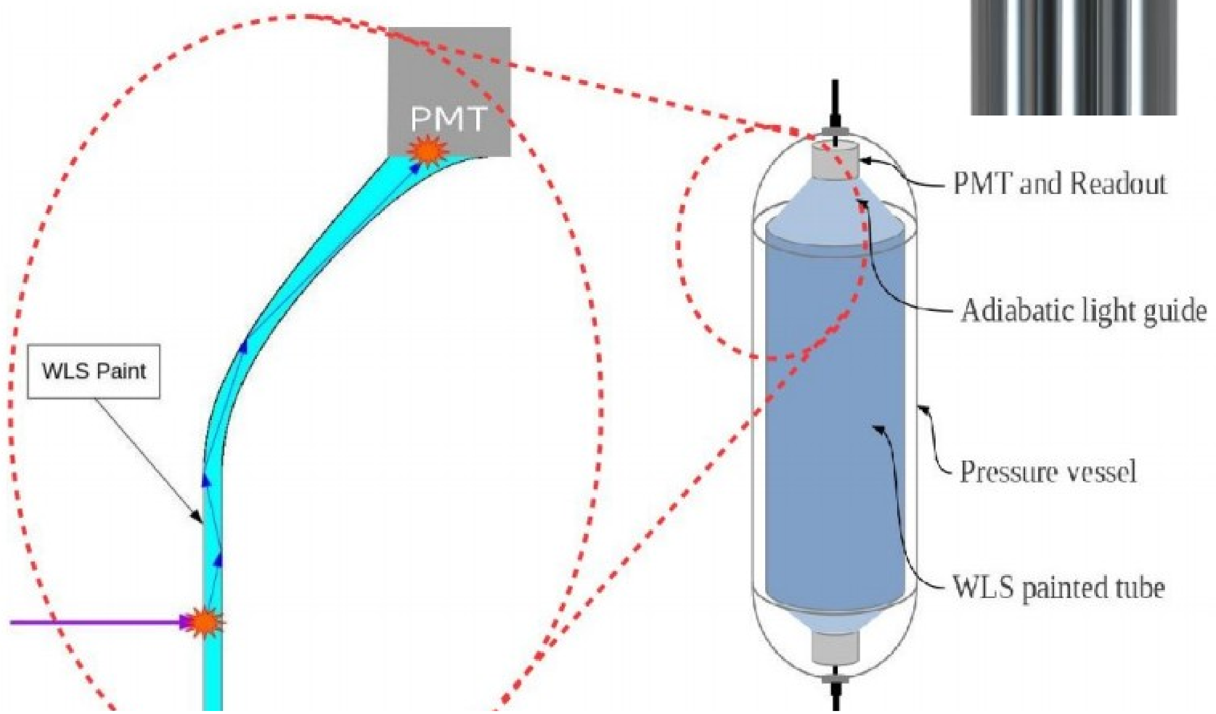


Glass of mDOM and D-Egg becoming comparable

*Transmittance cutoff of the D-Egg glass appears to be very sensitive to impurities

Design of new sensors - WOM

- » Wavelength-shifter optical module
- » Custom paint shifts light from UV (250-400nm) to blue (>400nm)
- » Light captured travels in tube
- » 2 small (1.5”) PMTs at the ends
- » Low threshold
- » Directionality lost



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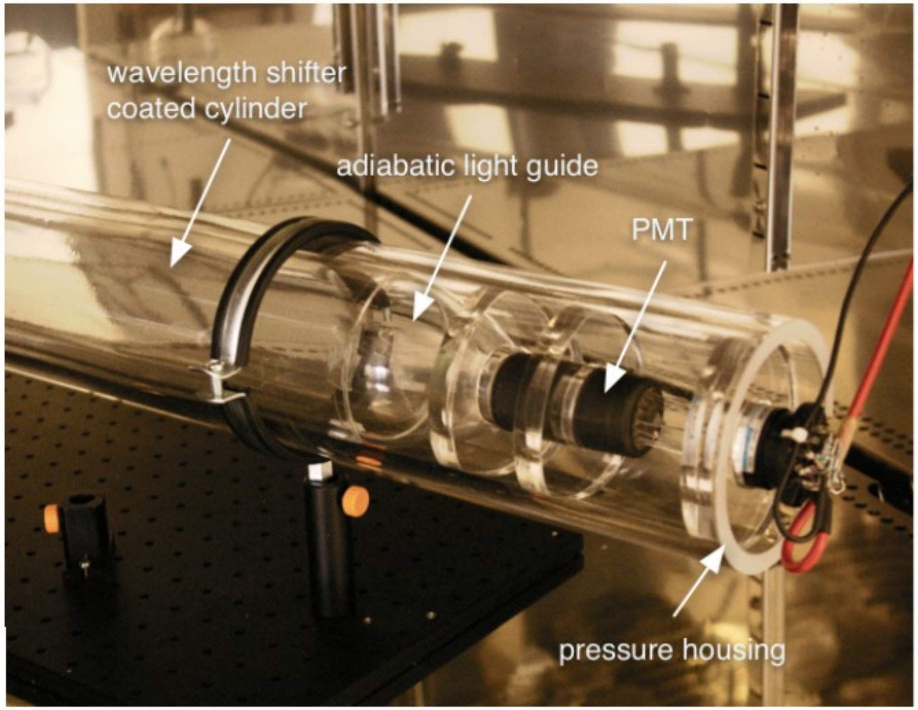
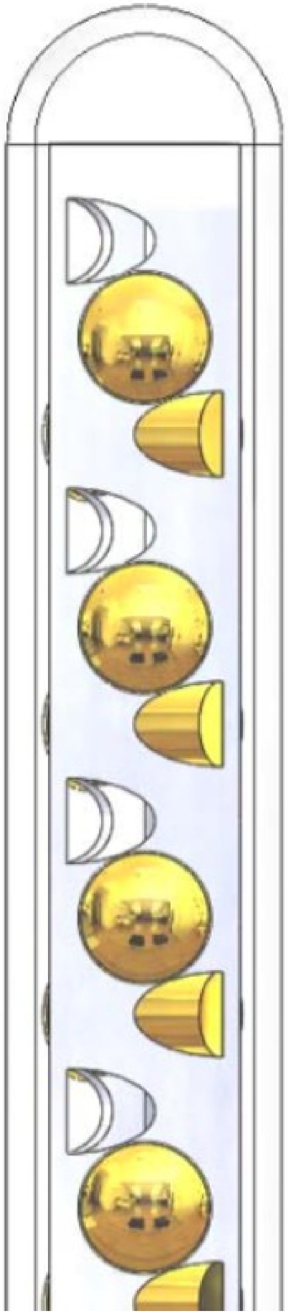


Initial attempt to assemble a prototype for noise measurements

Design of new sensors - LOM

- Wavelength-shifter optical module
- Move UV (250-400nm) to blue (>400nm
- Multiple PMTs inside the tube
- Keep directional information
- Acceptance higher at horizon



Summary of new sensors

mDOM

36 cm

- Directional information
- More sensitive area per module
- Precise timing

PoS(ICRC2015)1147

D-Egg

30 cm

- Directional information
- More sensitive area per module
- Smaller geometry

PoS(ICRC2015)1137

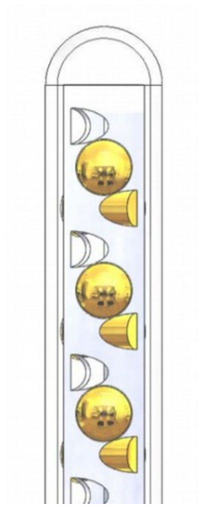
WOM

~26 cm

- More sensitive area per $
- Small diameter
- Lower noise rate
- Lower UV threshold

PoS(ICRC2015)1134

LOM



13 cm

- Small diameter
- Directional info.
- More area per module

IceCube-Gen2 readout

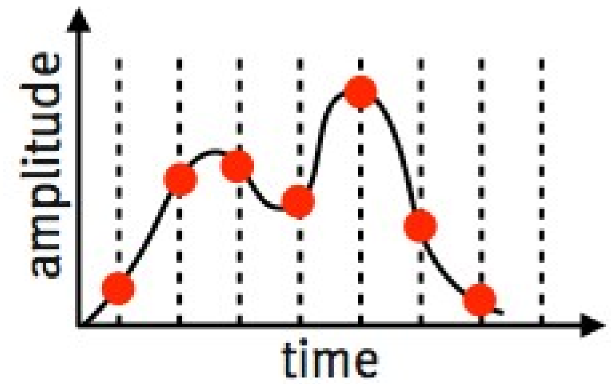
Readout schemes

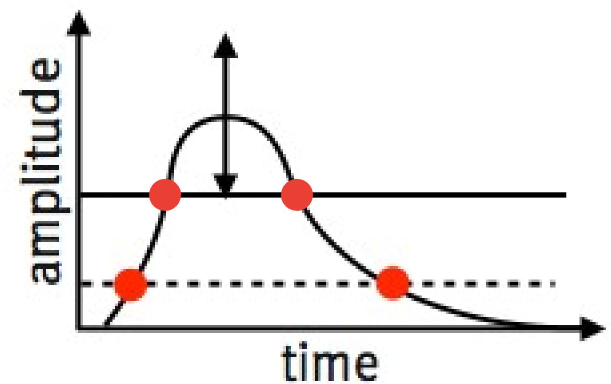
ADC

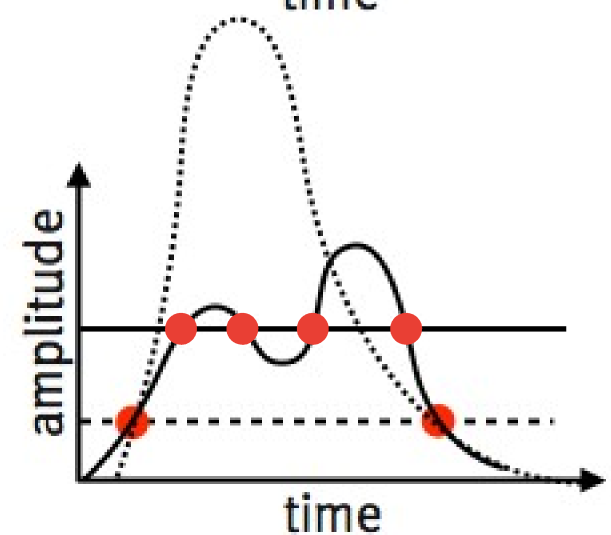
- Measure amplitude at fixed times
  - Conventional approach, used in IceCube
  - Power consumption too high for multiple PMTs

Leading edge time and time-over-threshold*

- Measure at a fixed amplitude
  - Low power, no current flow below threshold
  - Need multiple thresholds/discriminators

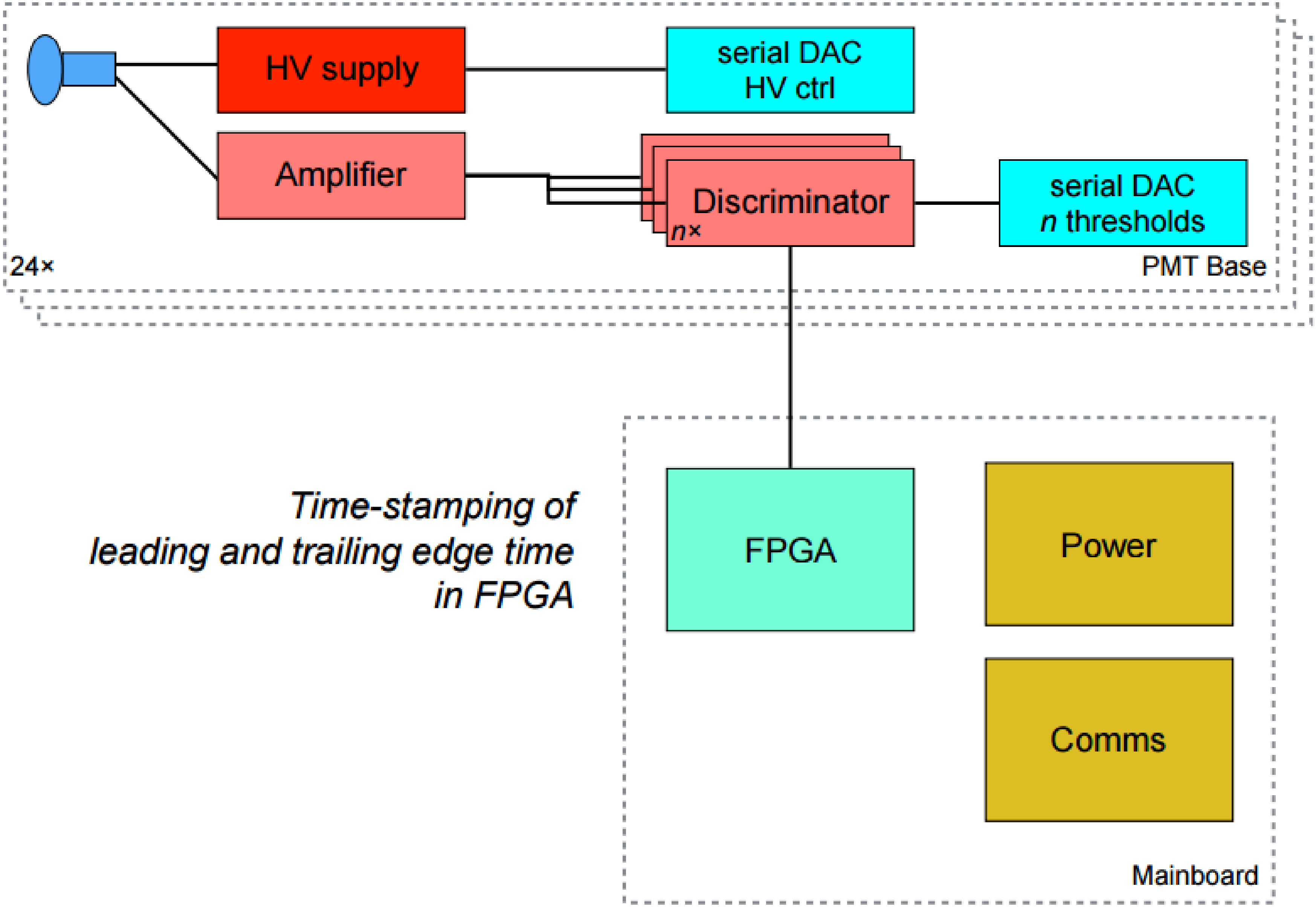






*Readout scheme designed for mDOM, but the idea is applicable to all modules

Readout block diagram

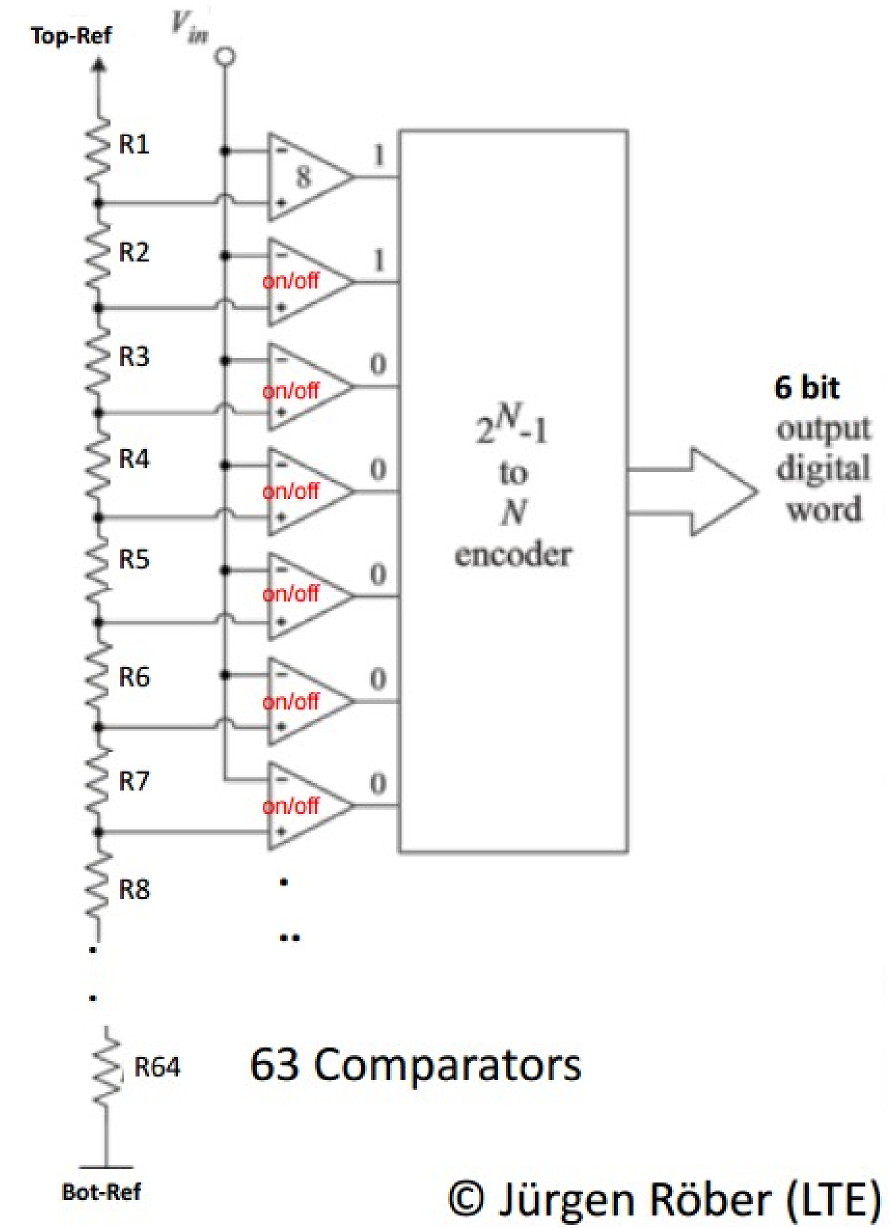


Time-stamping of leading and trailing edge time in FPGA

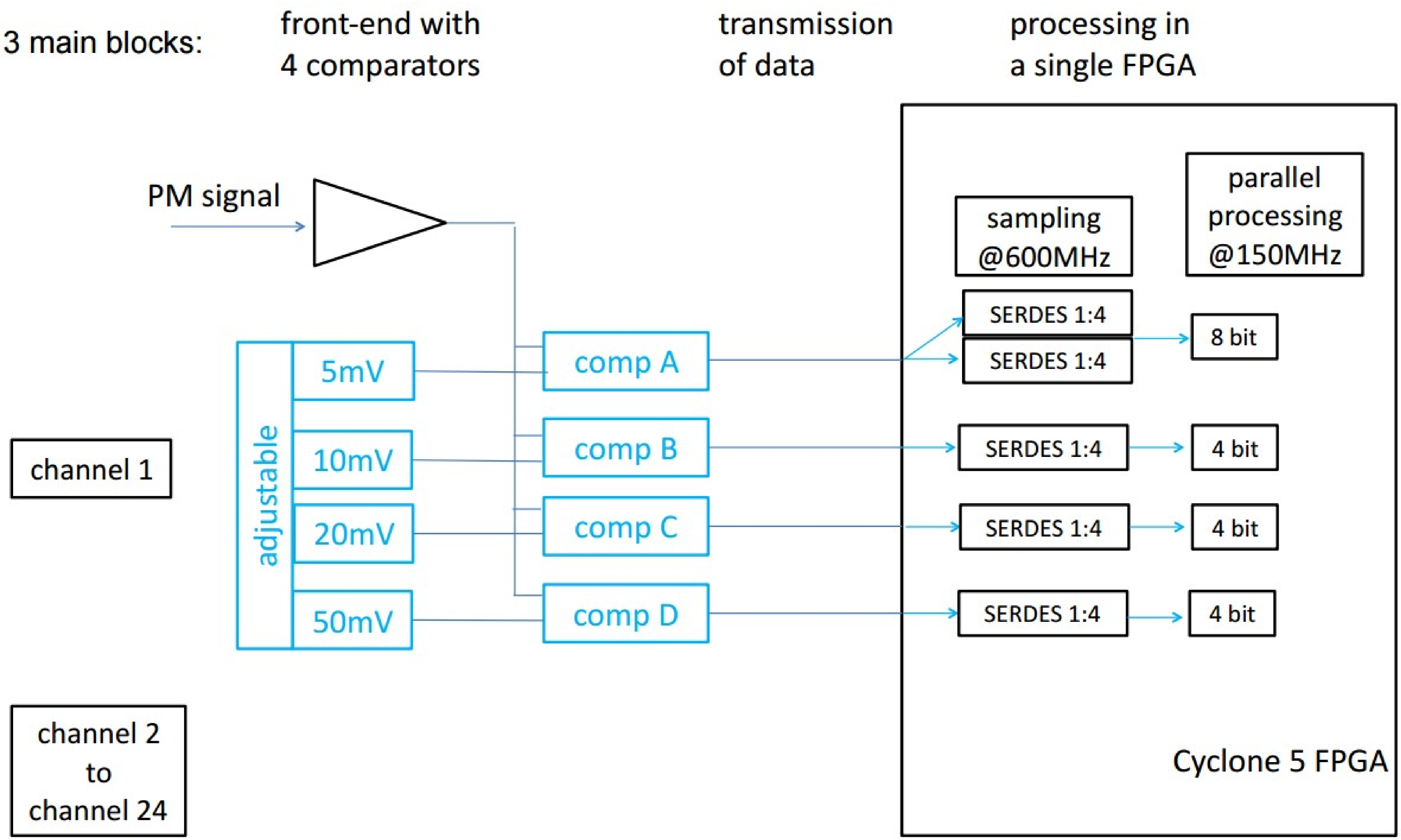
From T.Karg

Discriminators

- Multi-comparator design
- Pseudo-digital comparator output from base to mainboard
- Time-stamping of leading- and trailing- edge in FPGA
- Two-fold strategy
  - ASIC design: 63 comparators w/6-bit encoder
  - Four comparator discrete design
- Output: pseudo-digital singal



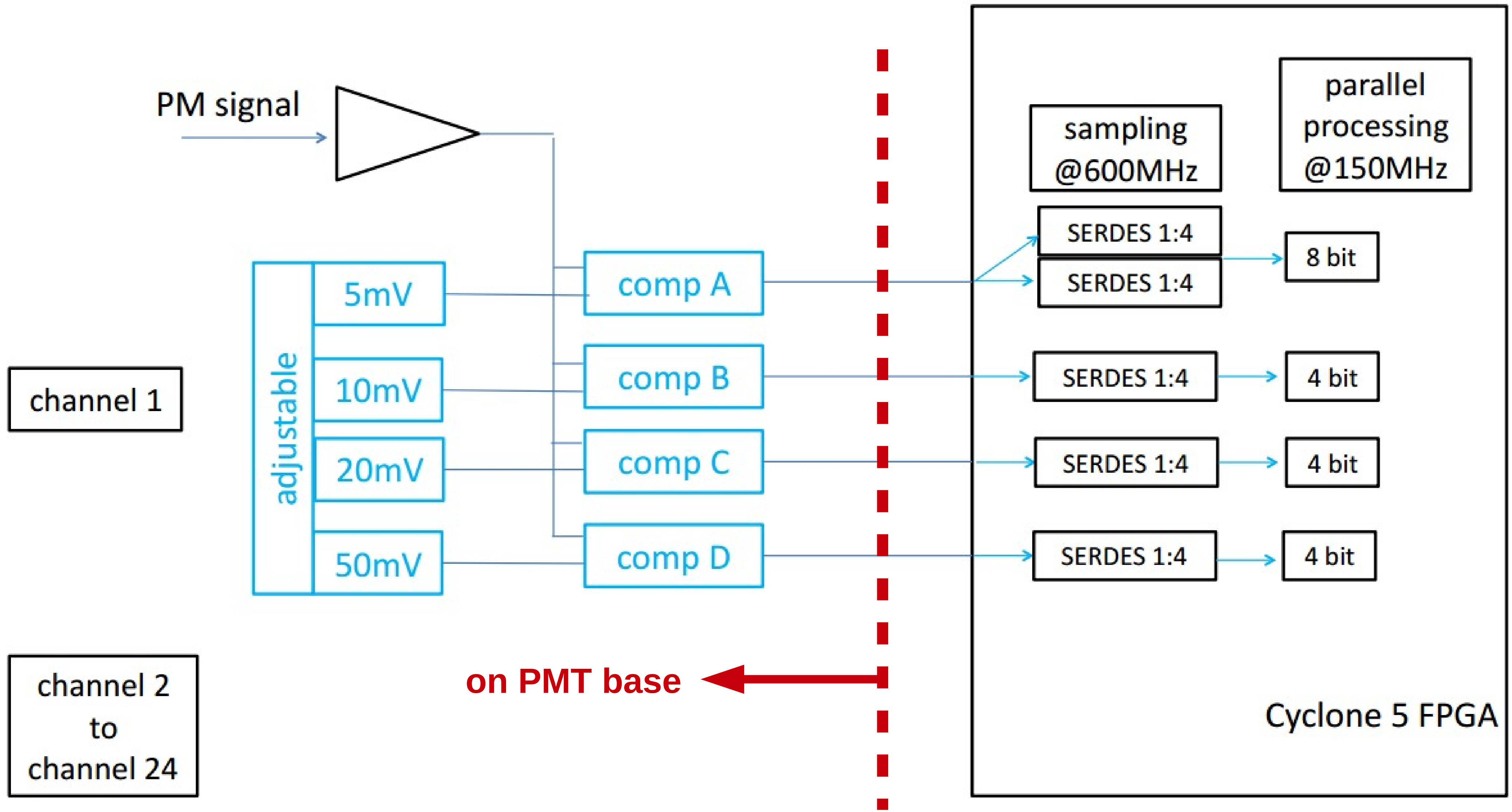
Readout chain



From T.Karg

Readout chain

3 main blocks: front-end with 4 comparators | transmission of data | processing in a single FPGA



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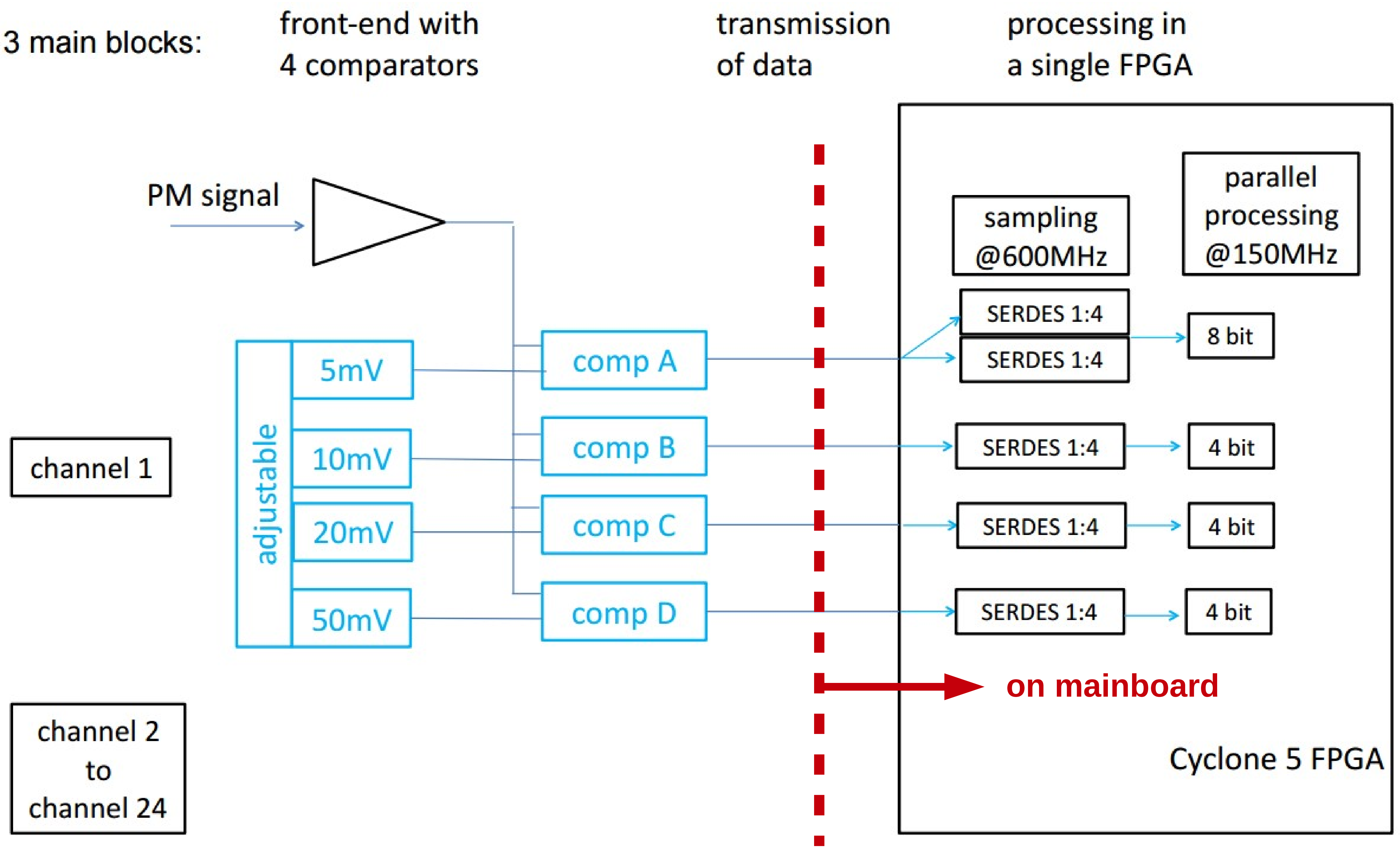

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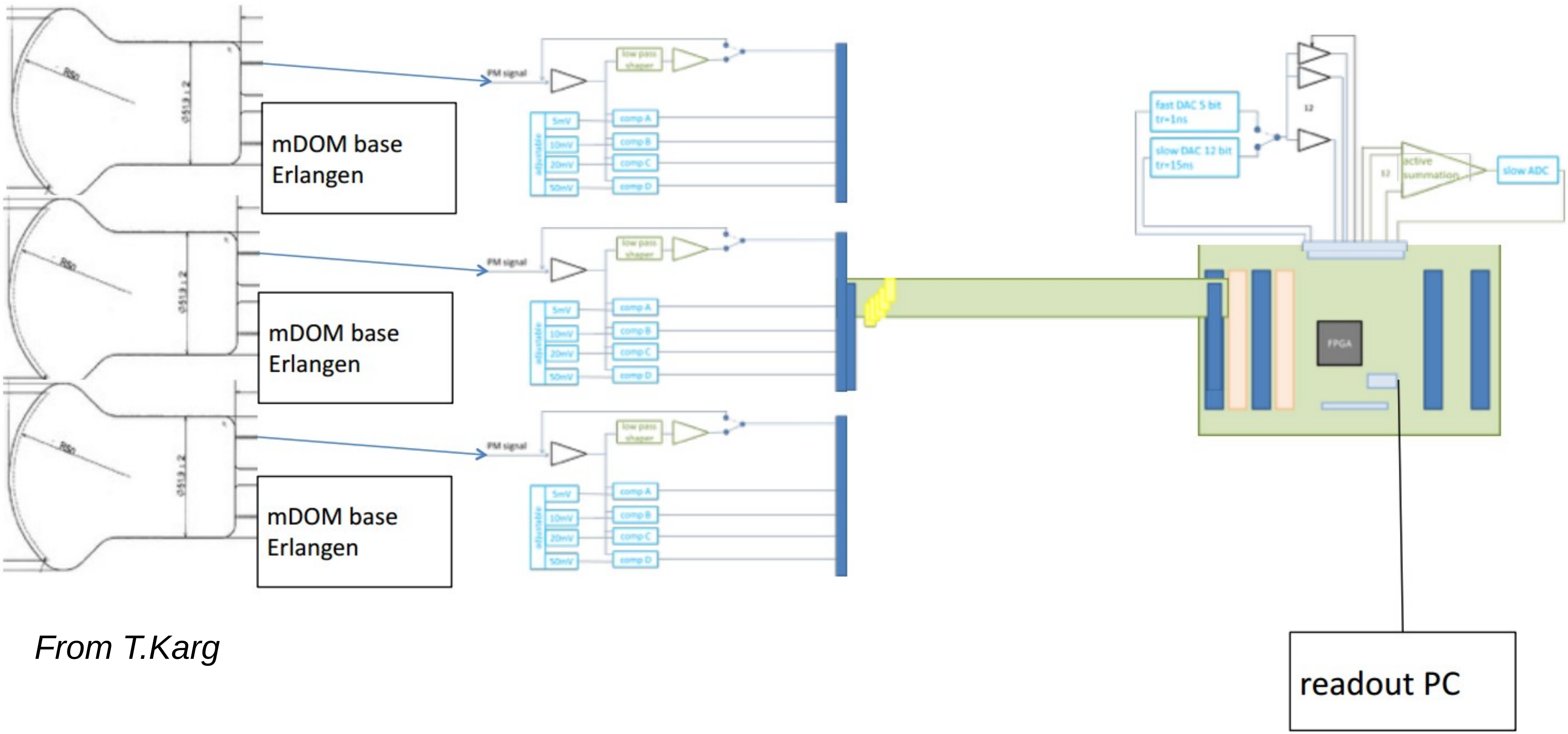
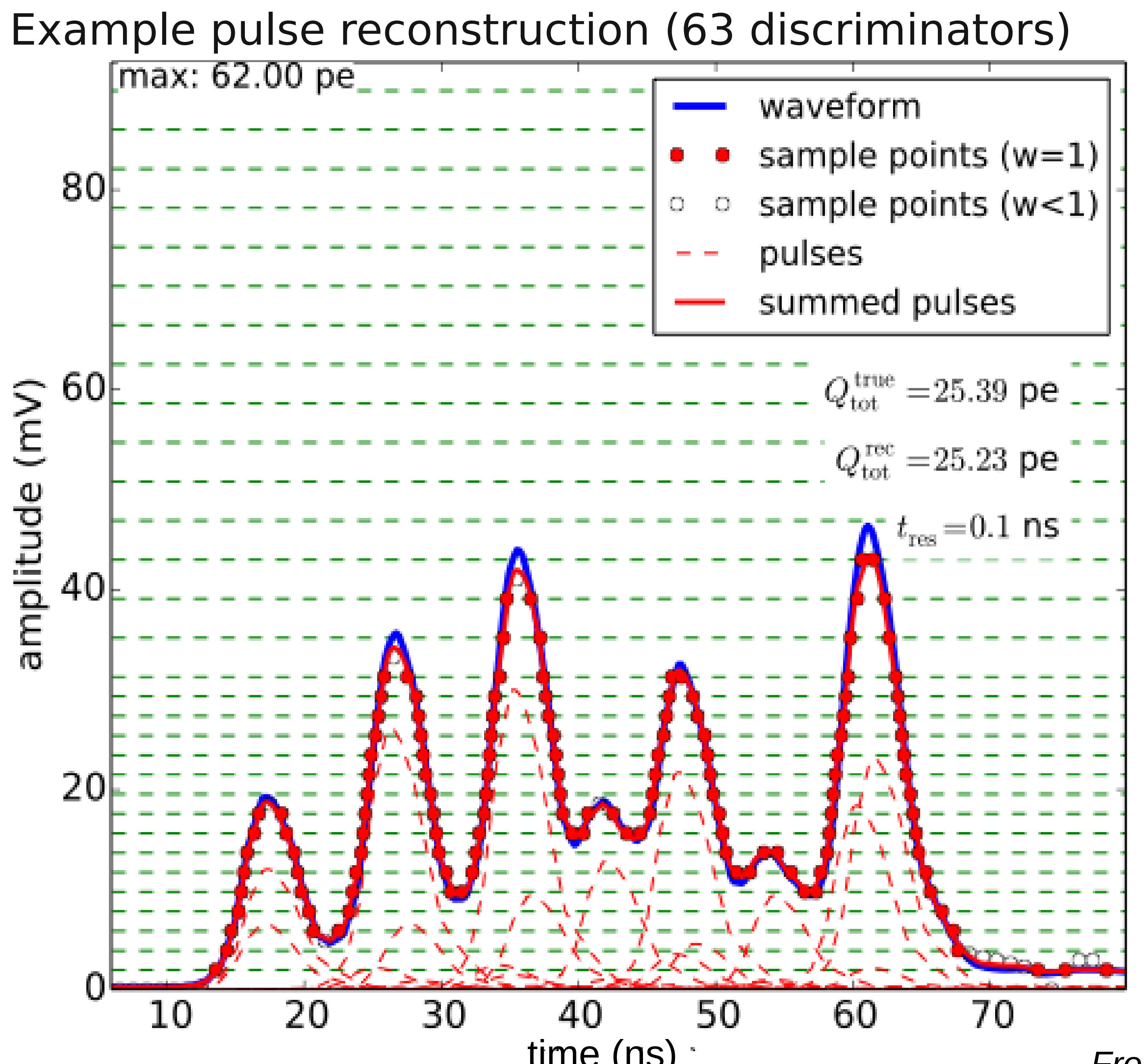


From T.Karg

Pulse reconstruction example



From A.Kappes

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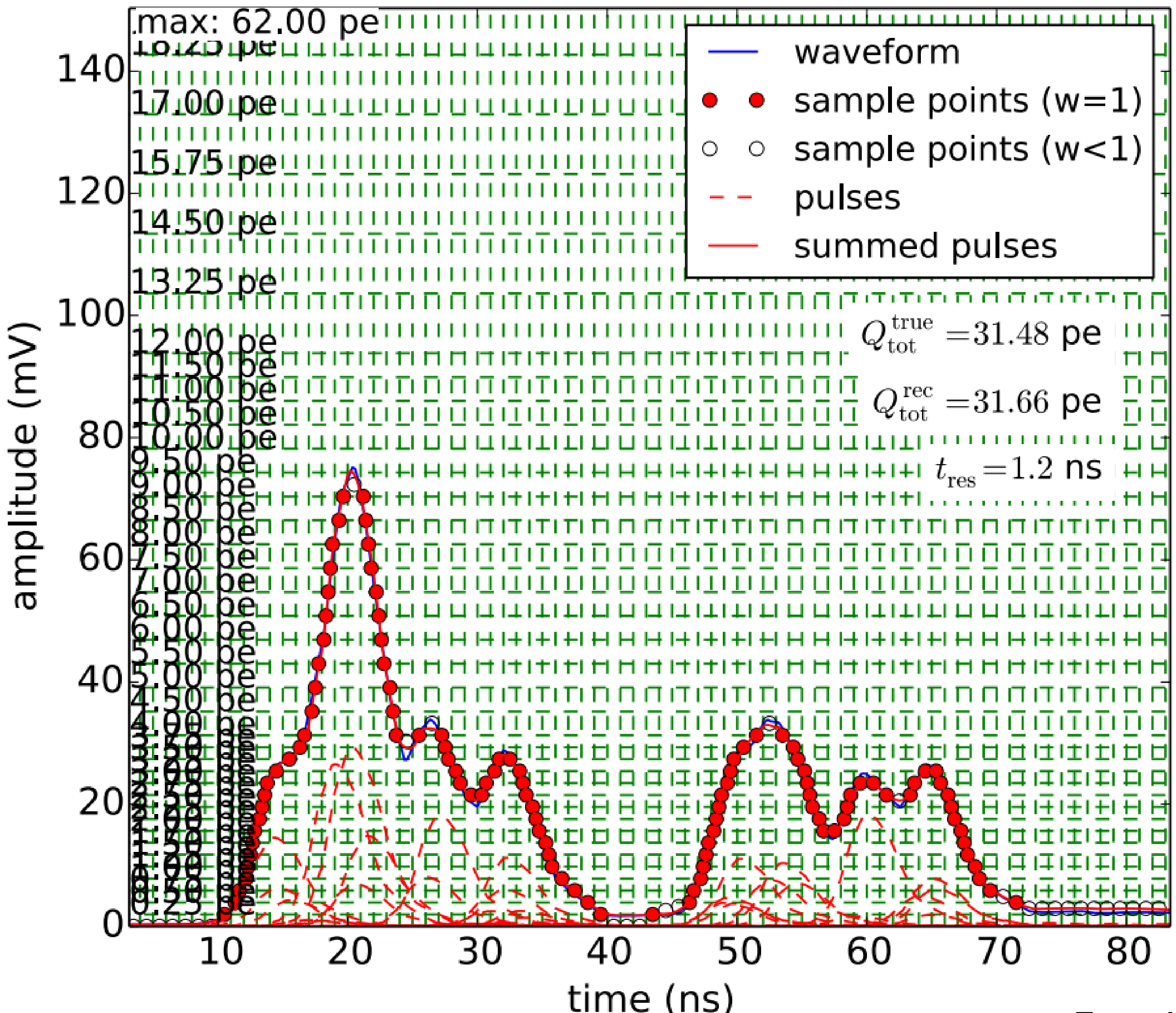
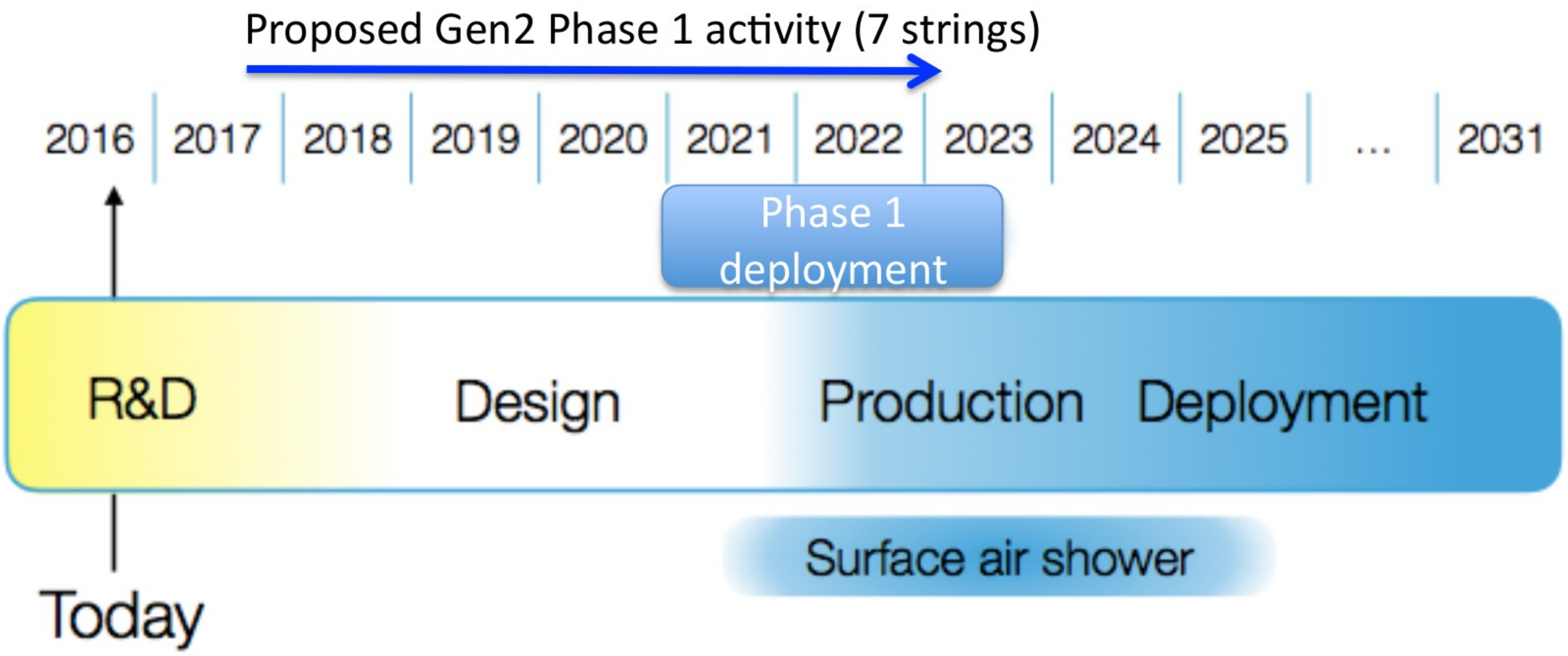


From A.Kappes

IceCube-Gen2 schedule



Conclusions

» IceCube-Gen2 science can benefit from new optical sensors

  » Baseline: IceCube revamped
  » New designs and adaptations under study

» Mechanical & partial prototypes built

  » Characterization of properties underway
  » Functional devices expected within a year

» Simulation, reconstruction with new modules ongoing

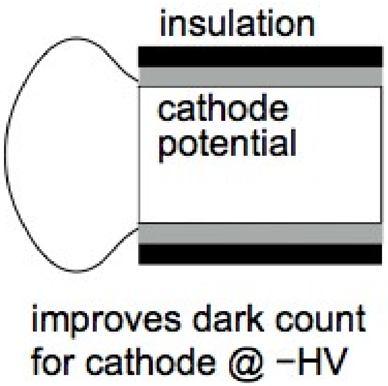
» Promising low-power readout for mDOM developed

  » No physics losses, applicable to other modules

Backup slides

mDOM PMT Properties

TTS (FWHM)	< 4 ns
QE @ 470 nm	22%
QE @ 404 nm	27%
dark rate @ 20C	400 – 1500 Hz
dark rate @ -30C	< 100 Hz
supply voltage	< 1400 V
gain	3 x 10^6
peak-to-valley ratio	> 3.5



based on KM3NeT spec’s / measurements

mDOM effective area