SHiP-TD inspired design for the ToF system of the ND280 upgrade

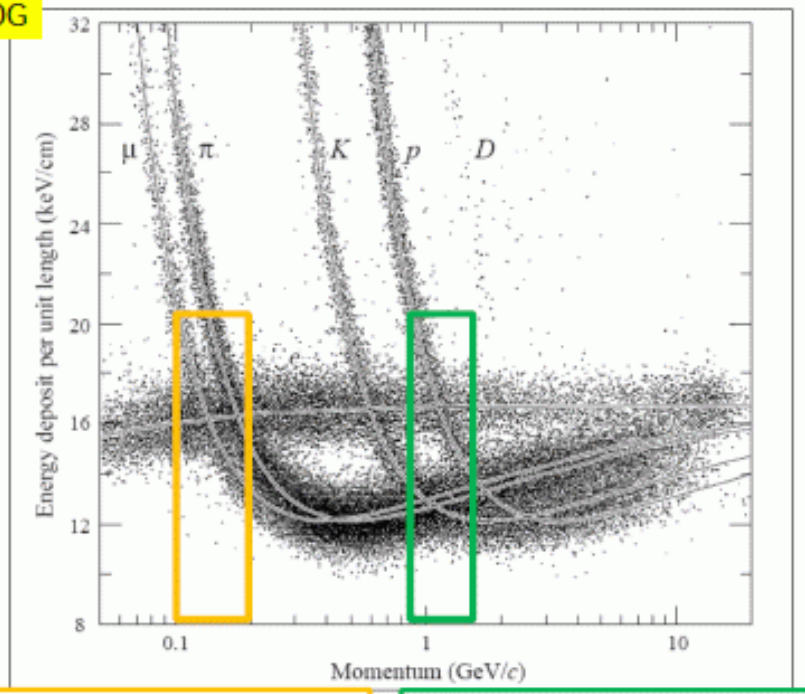
A.Blondel, A.Korzenev, P. Mermod, D.Sgalaberna / Uni Geneva
D.Gascon, S.Gomez / Uni Barcelona

3-rd workshop on ND280 upgrade
Tokai, May 20, 2017

Motivation for the ToF detector in ND280

dE/dx

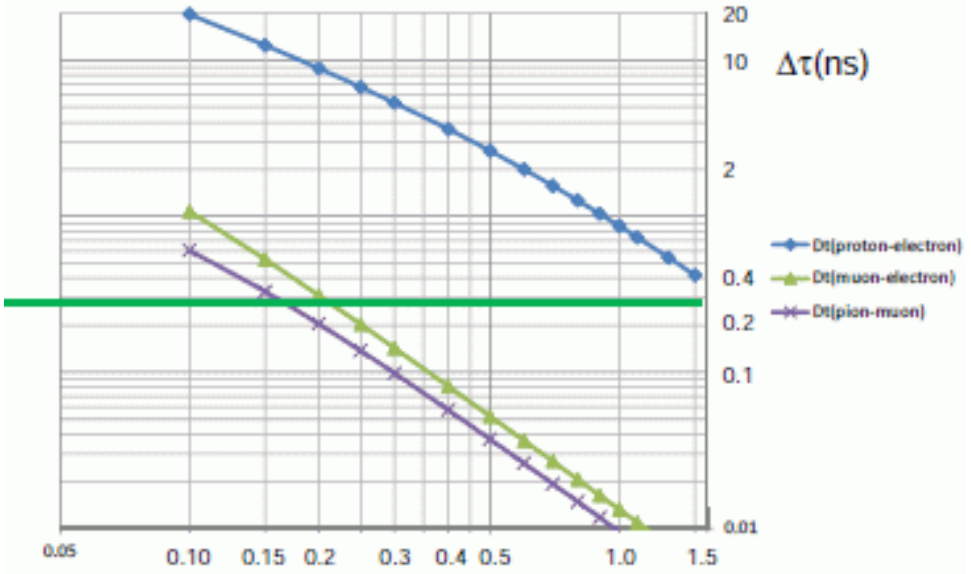
Plot from PDG



mu/e confusion zone : 100-200 MeV/c

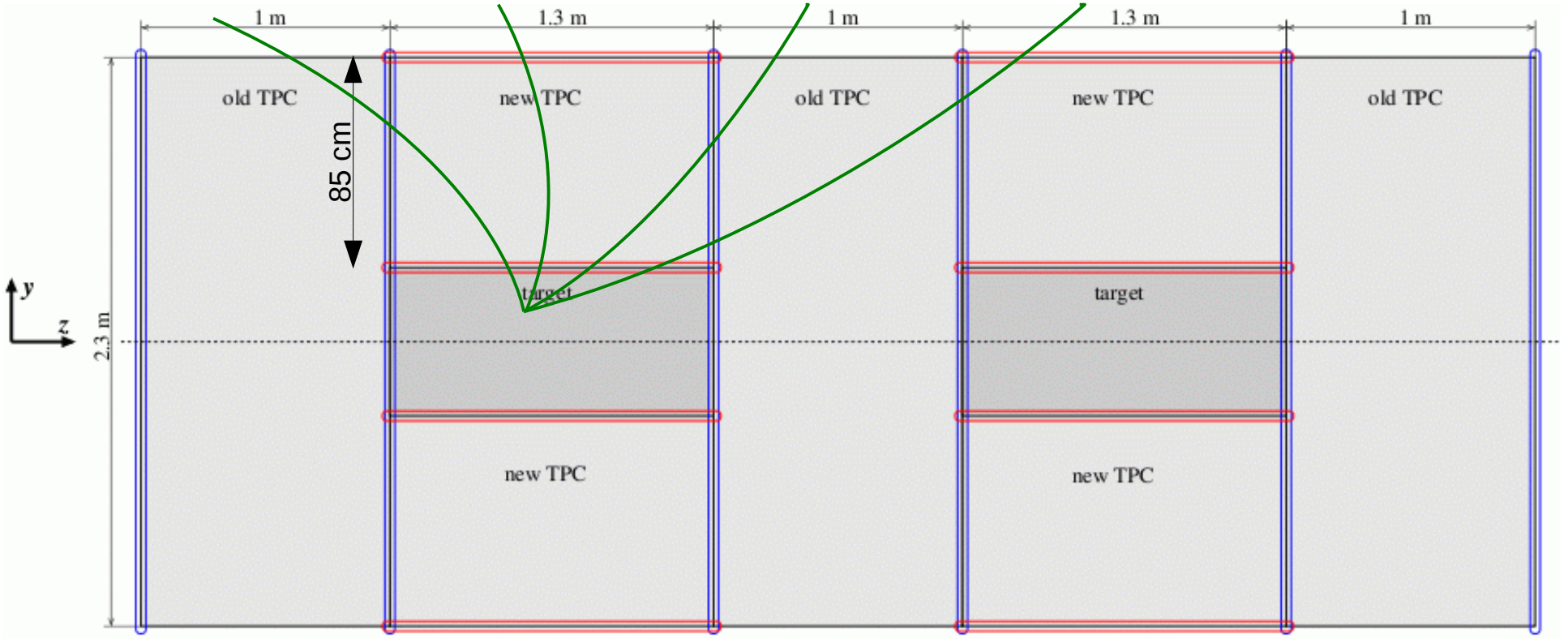
p-e confusion zone 0.9 -1.5 GeV/c

Minimum difference in time of flight between e/mu/pi/proton for a flight of 70cm as function of momentum (not taking into account of bending or angles)



Δτ of 300ps gives 1σ or more in all cases where needed

Proposal for the use of ToF based on a cast plastic



- 6 modules **XY** with dimensions 230 cm x 230 cm each
- 12 modules (**YZ+XZ**) with dimensions 130 cm x 230 cm each
- All modules can be assembled with bars of 230 cm long
- No space for plastic around old TPCs (???)

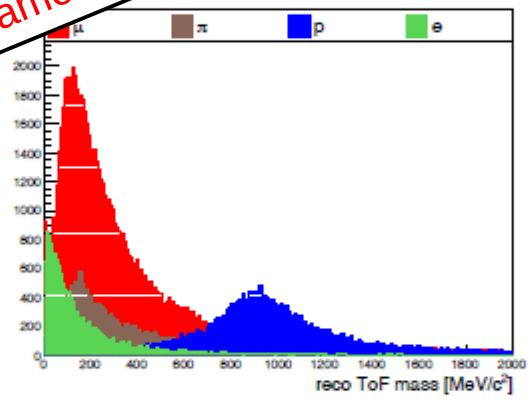
ToF mass

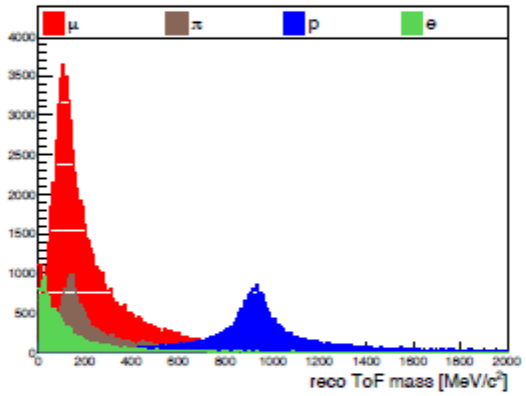
$$m_{ToF} = p \times \sqrt{\frac{c^2(\Delta t_{reco})^2}{L^2} - 1}$$

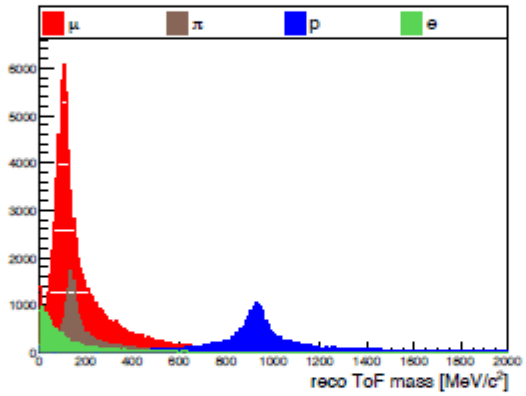
Sample of preselected ν_μ events
Look at all particles with ToF information (not only highest momentum)

For details see slides of M. Lamoureux

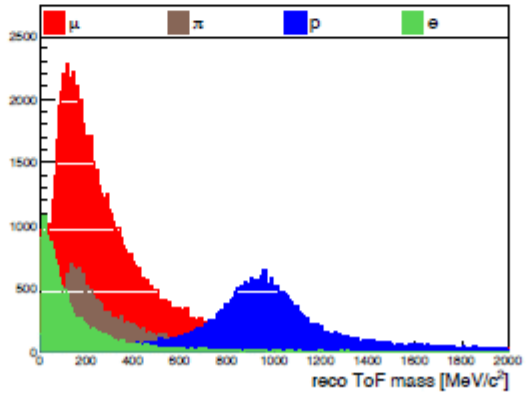
reference configuration

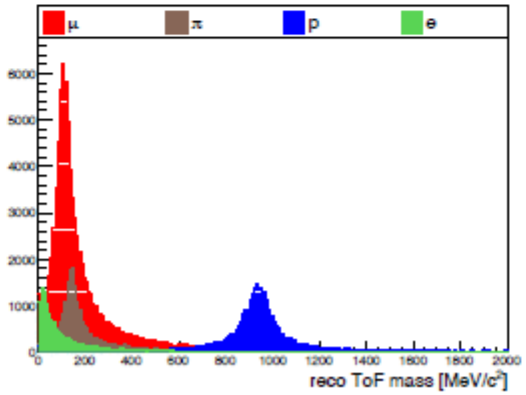


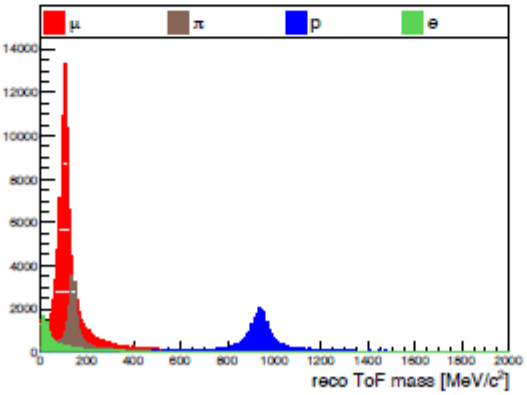




adding new ToF between Target and HTPC

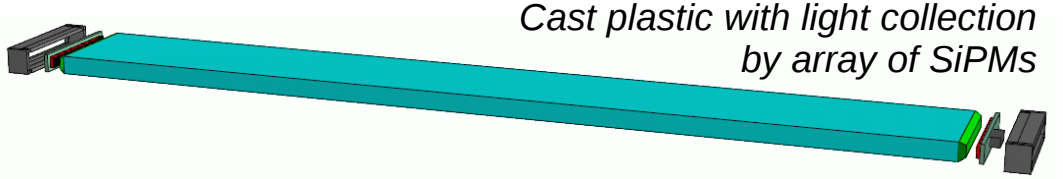




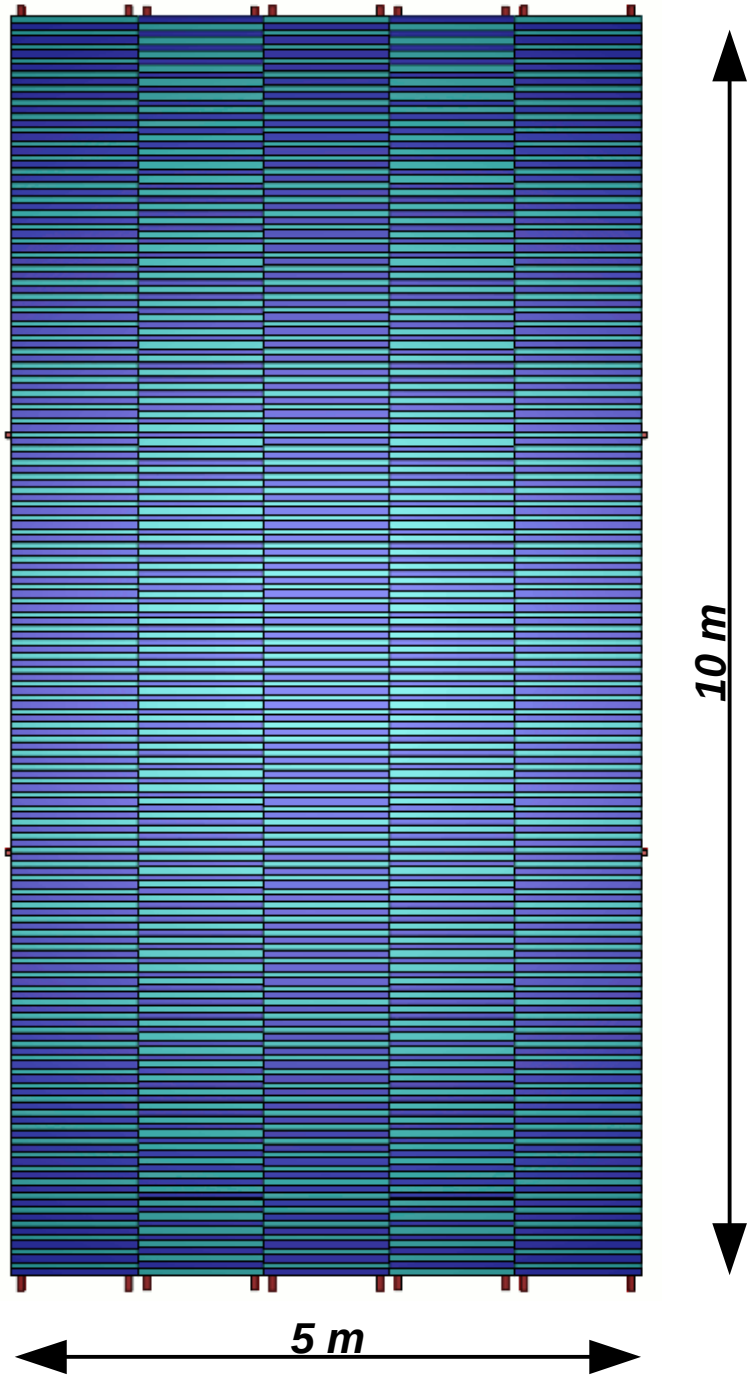


$\sigma_{ToF} = 600$ ps ↑ $\sigma_{ToF} = 150$ ps ↑ $\sigma_{ToF} = 50$ ps ↑

Timing Detector in SHiP

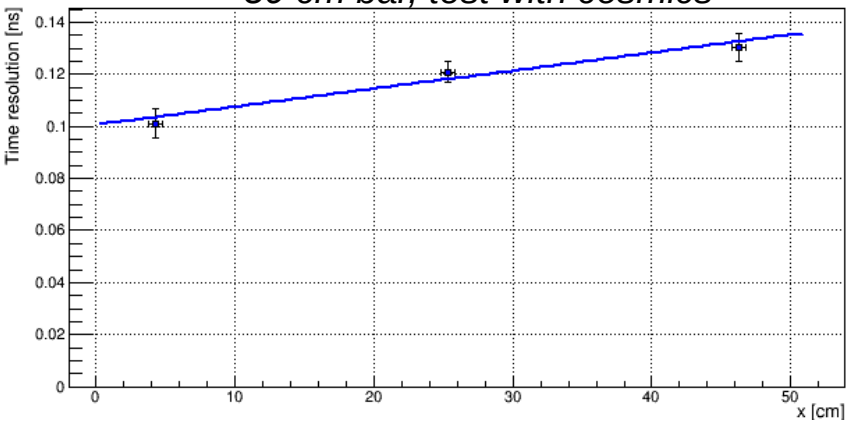


Cast plastic with light collection by array of SiPMs



- For the TD of size 5 m x 10 m with a bar ***100 cm x 6 cm x 1 cm***
  - 5 col x 182 row = 910 bars =>
  - 910 bars x 2 = 1820 ch =>
  - 1820 x 8 = 14560 SiPMs
- The resolution at 50 cm is ~140 ps => we can use with 1 m bar and 2-side readout to be within 100 ps.

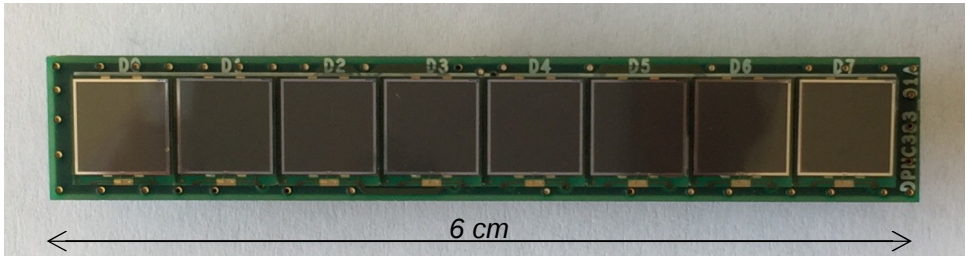
50 cm bar, test with cosmics



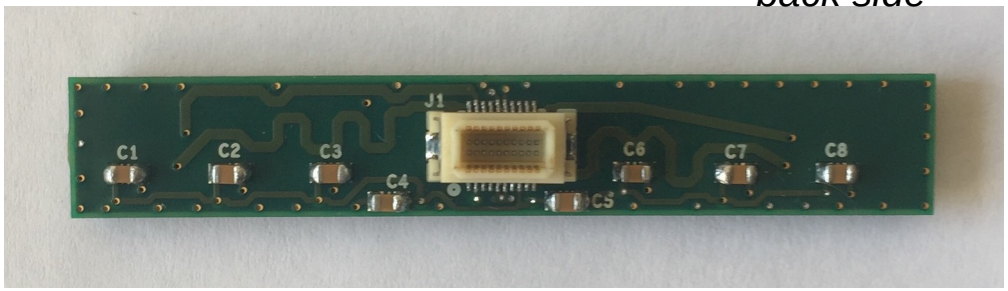
Bar and sensors for ToF/ND280

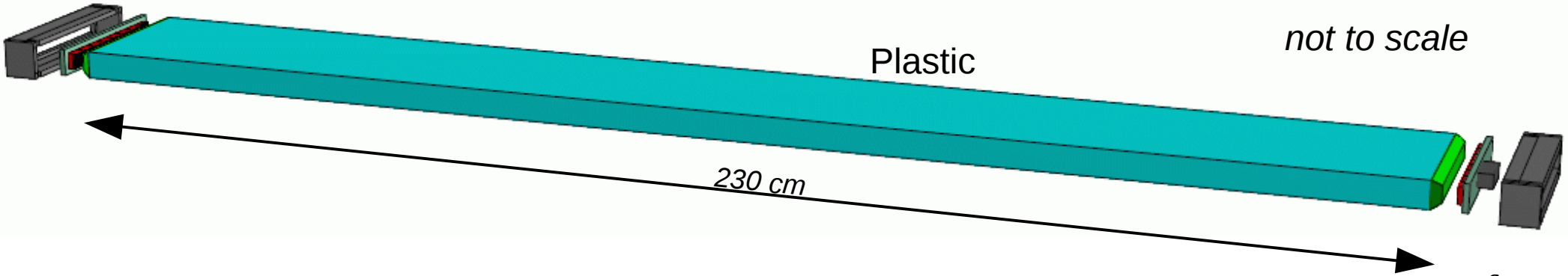
- Bar: 230 cm x 6 cm x 1 cm
- Plastic material:
  - EJ200 (BC408) or EJ208(BC412)
  - Attenuation length ~4 m
  - 1.42 kg/bar
- Readout from both ends
  - 8 sensors of 6 mm x 6 mm
  - Example: S13360-6050PE

front side



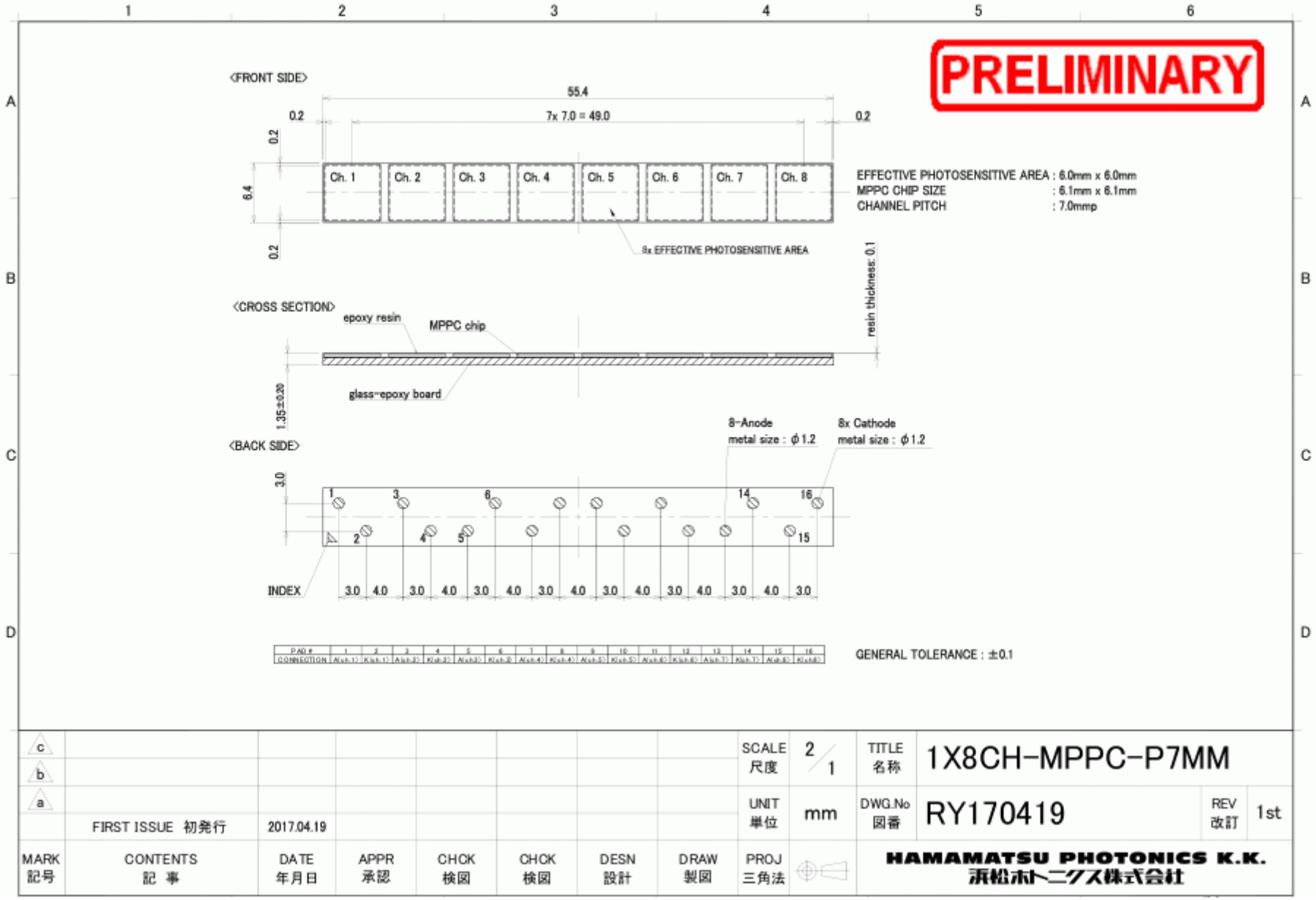
back side



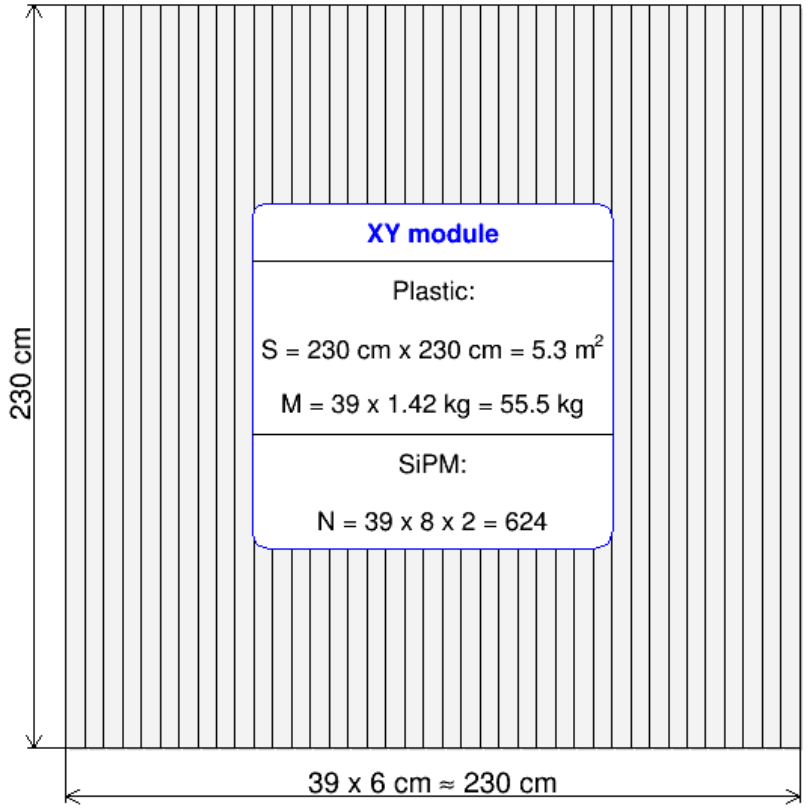


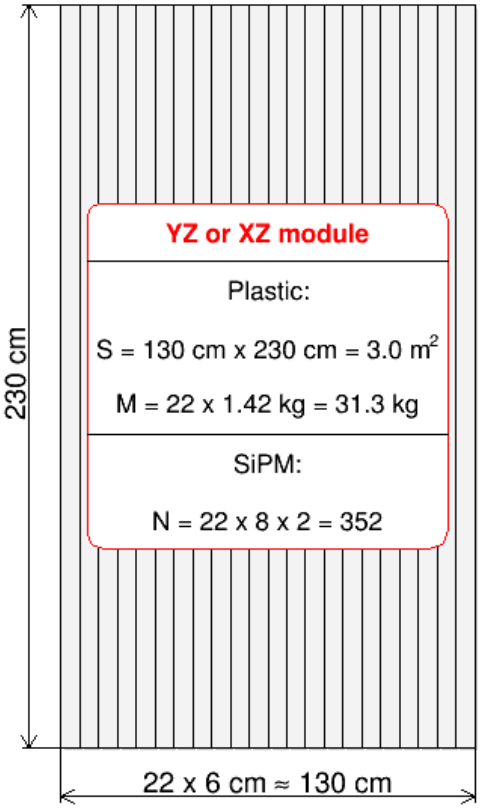
not to scale

Array of SiPMs (10% cheaper)



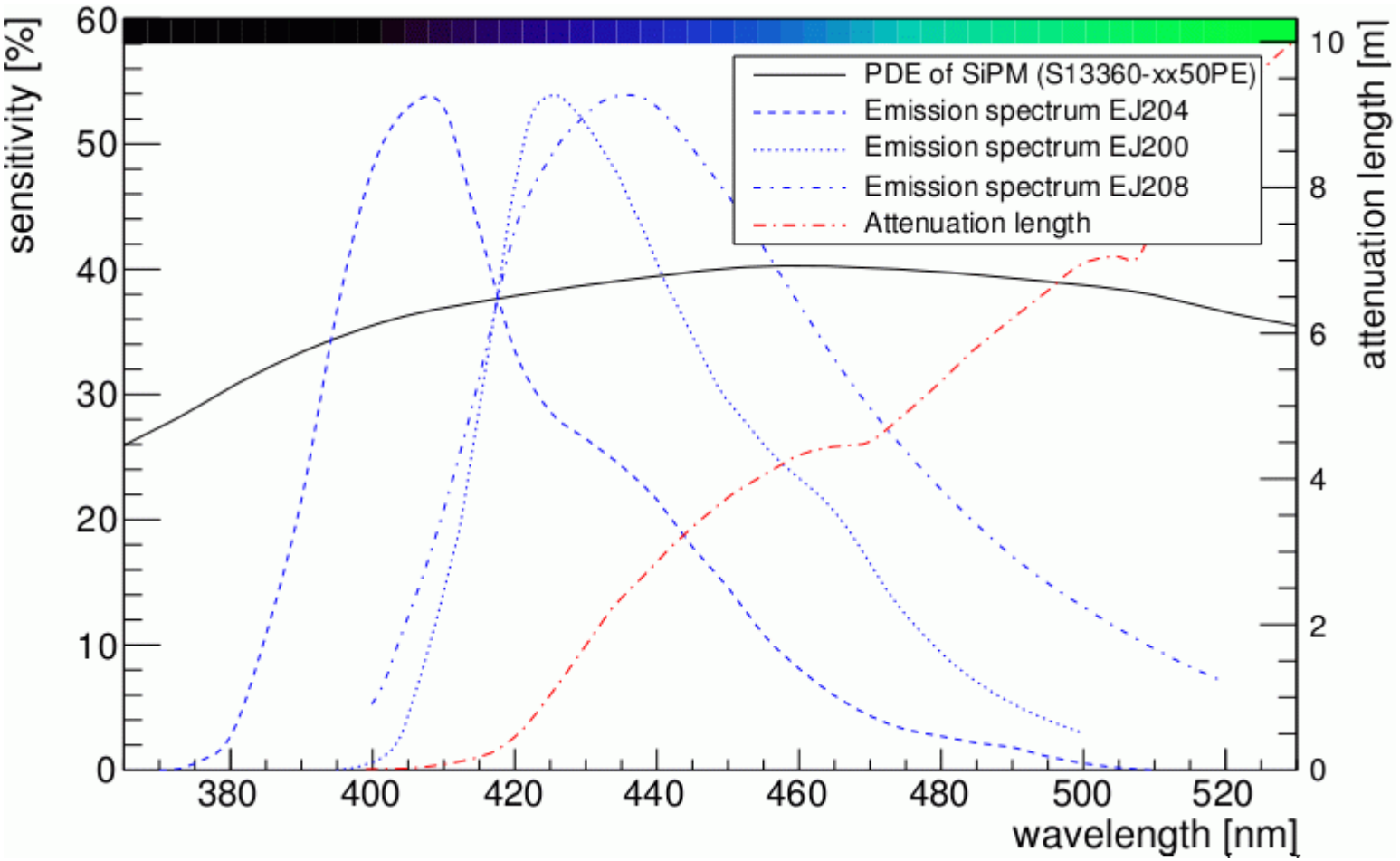
Modules





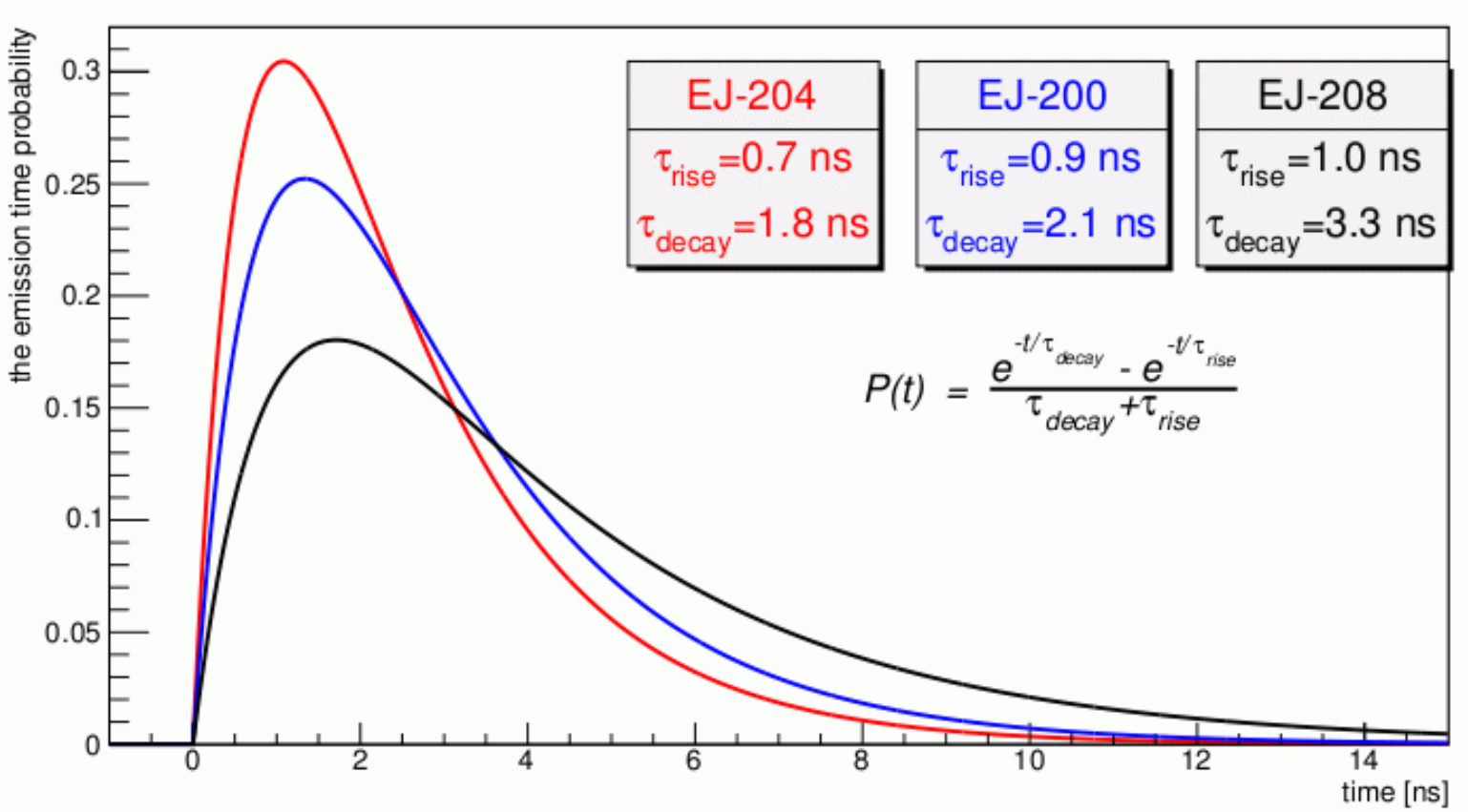
- 6 modules XY and 12 modules (YZ+XZ)
- Surface 6 x 5.3 m^2 + 12 x 3 m^2 = 67.6 m^2, weight 0.7 ton
- Number of bars (230 cm) = 498. Number of SiPMs = 498 x 2 x 8 = 7968
- In case of the 5 mm overlap between bars all estimates to be increased by 5/60=8.3%

Choice of plastic material (1)



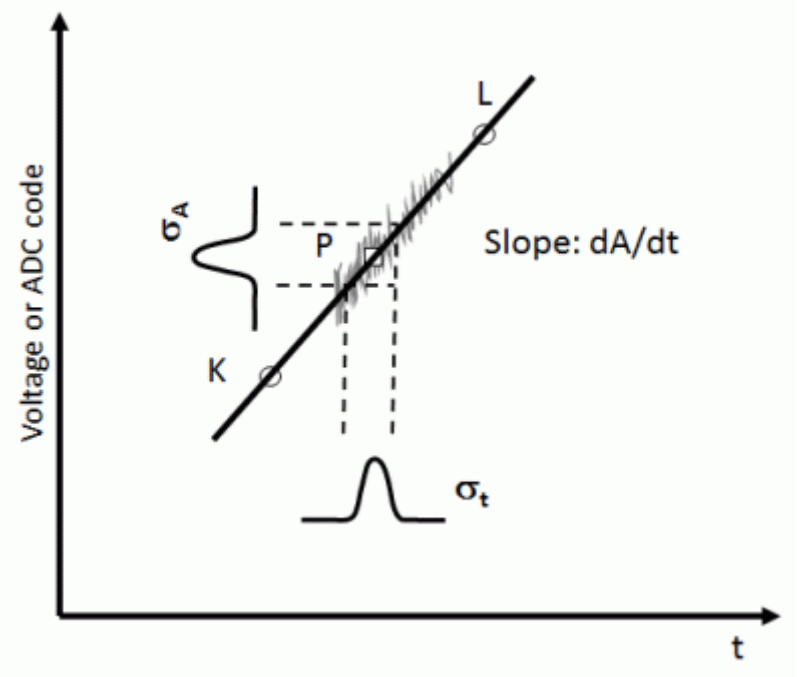
ELJEN Technology	SAINT-GOBAIN CRYSTALS	γ /1 MeV e⁻	Wavelength	Rise time	Decay const	Att. length
EJ-204	BC-404	10.4k	408 nm	0.7 ns	1.8 ns	1.6 m
EJ-200	BC-408	10k	425 nm	0.9 ns	2.1 ns	~3.8 m
EJ-208	BC-412	9.2k	435 nm	1.0 ns	3.3 ns	~4.0 m

Choice of plastic material (2)



ELJEN Technology	SAINT-GOBAIN CRYSTALS	γ /1 MeV e⁻	Wavelength	Rise time	Decay const	Att. length
EJ-204	BC-404	10.4k	408 nm	0.7 ns	1.8 ns	1.6 m
EJ-200	BC-408	10k	425 nm	0.9 ns	2.1 ns	~3.8 m
EJ-208	BC-412	9.2k	435 nm	1.0 ns	3.3 ns	~4.0 m

Choice of plastic material (3)



- Time precision measurement

$$\sigma_t^2 = \left(\frac{\sigma_A}{dA/dt}\right)^2 + Const$$

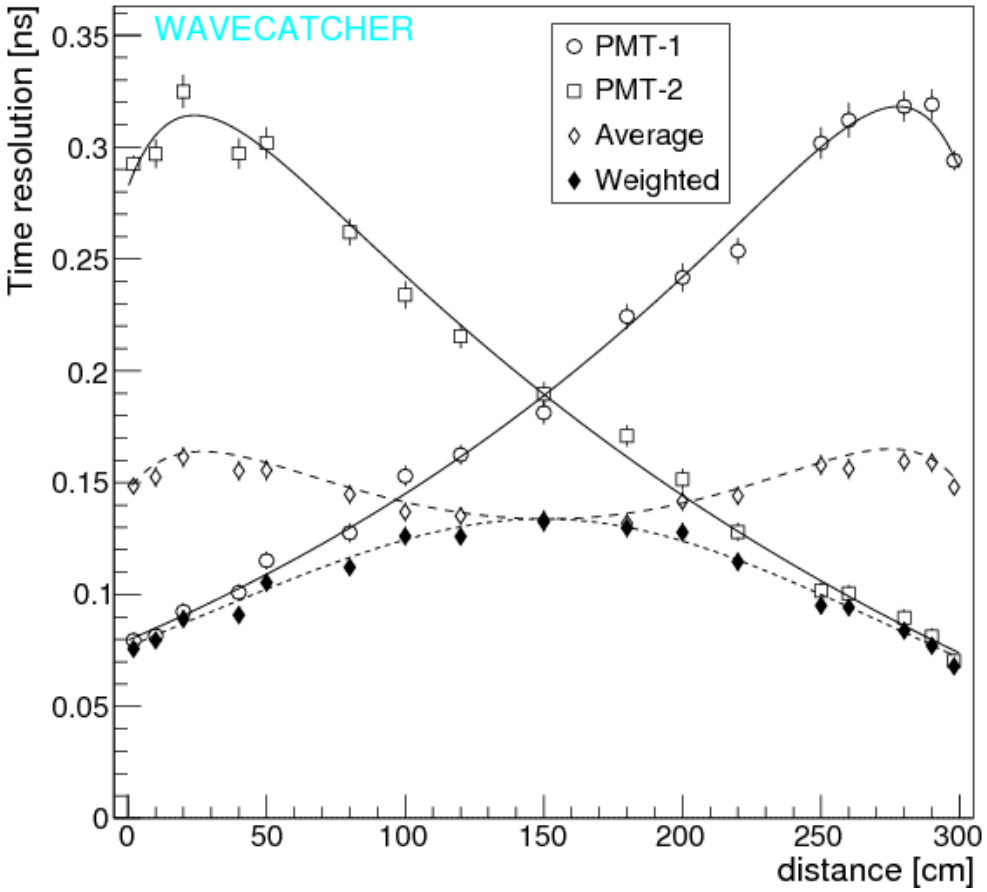
- 'Fast' plastic (steep slope) should be chosen only if there are no other contributions smearing the front edge of a signal

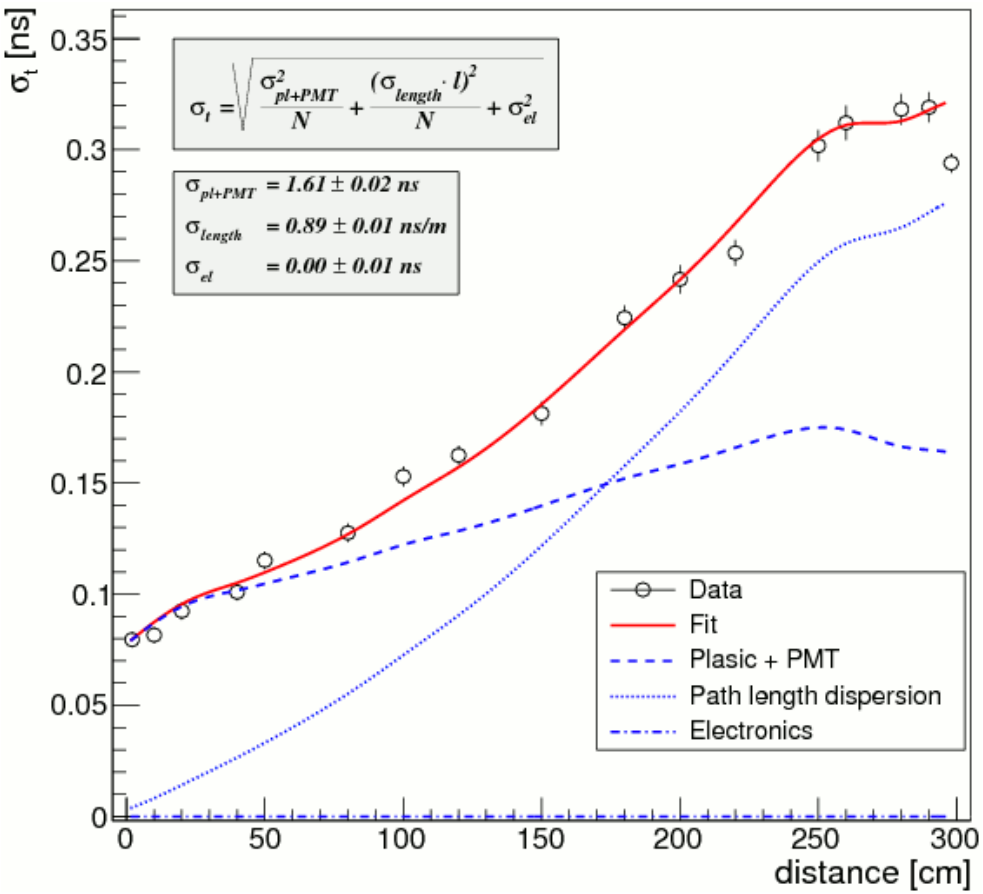
Time resolution of a scintillator counter

$$\sigma_t(l) = \sqrt{\frac{\sigma_{sci+PMT}^2}{N(l)} + \frac{(\sigma_{length} \cdot l)^2}{N(l)} + \sigma_{el}^2}$$

- $\sigma_{sci+PMT}$ is a decay time of the scintillator and a time jitter of PMT
- σ_{length} is a time spread of the light transmission
- σ_{el} is an uncertainty due to electronics
- N_e is the number of p.e. $N_e = N_0 e^{-l/\lambda}$

Example of counter based on cast plastic

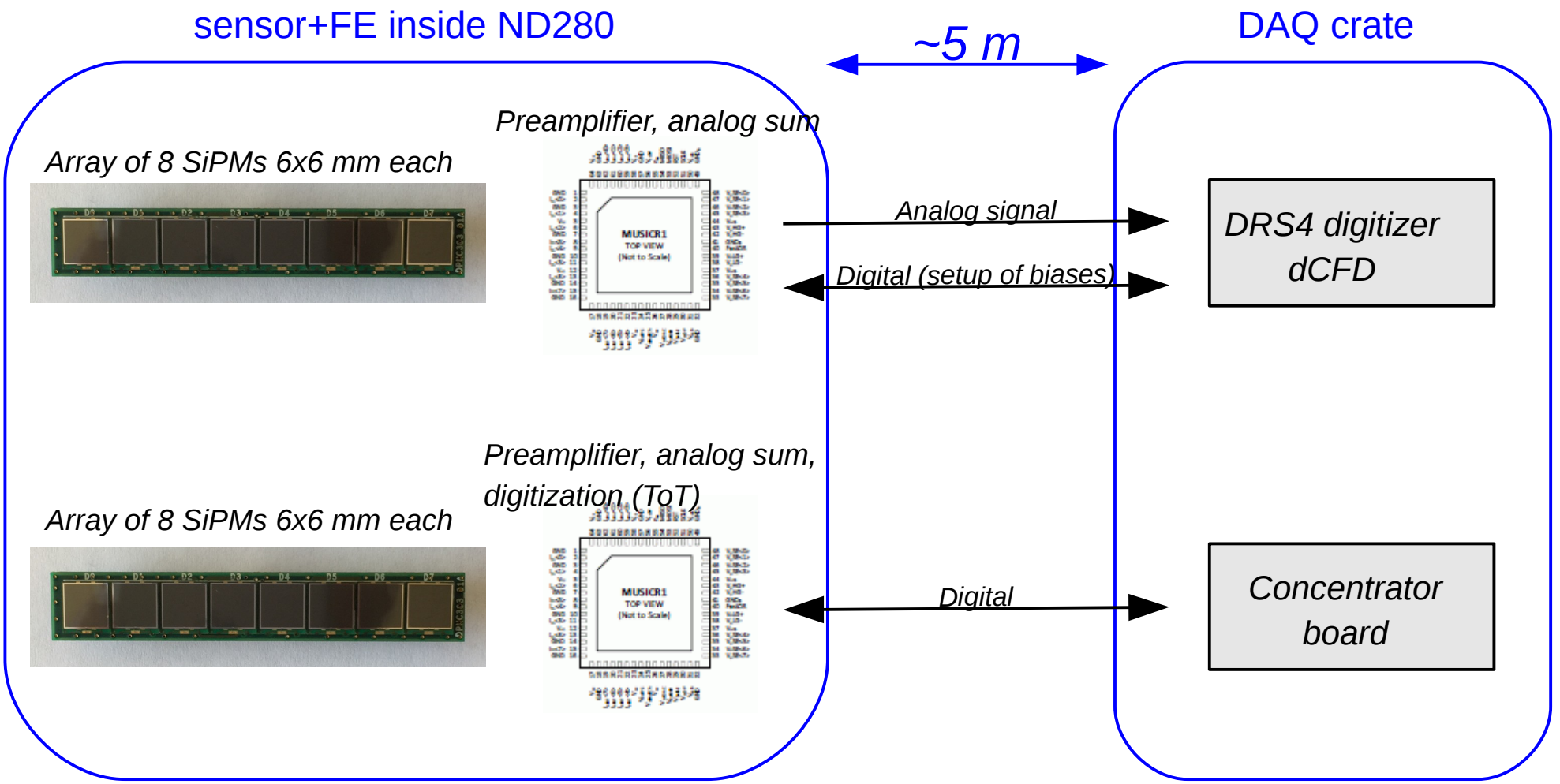




- Data collected last summer with a ***EJ-200*** counter ***3 m x 11 cm x 2.5 cm***
- Light collected by 2" PMTs (not SiPMs), readout by a digitizer
- Contribution from the dispersion of γ length paths σ_{length} is dominant at larger distances

arXiv:1610.05667

Options for electronics

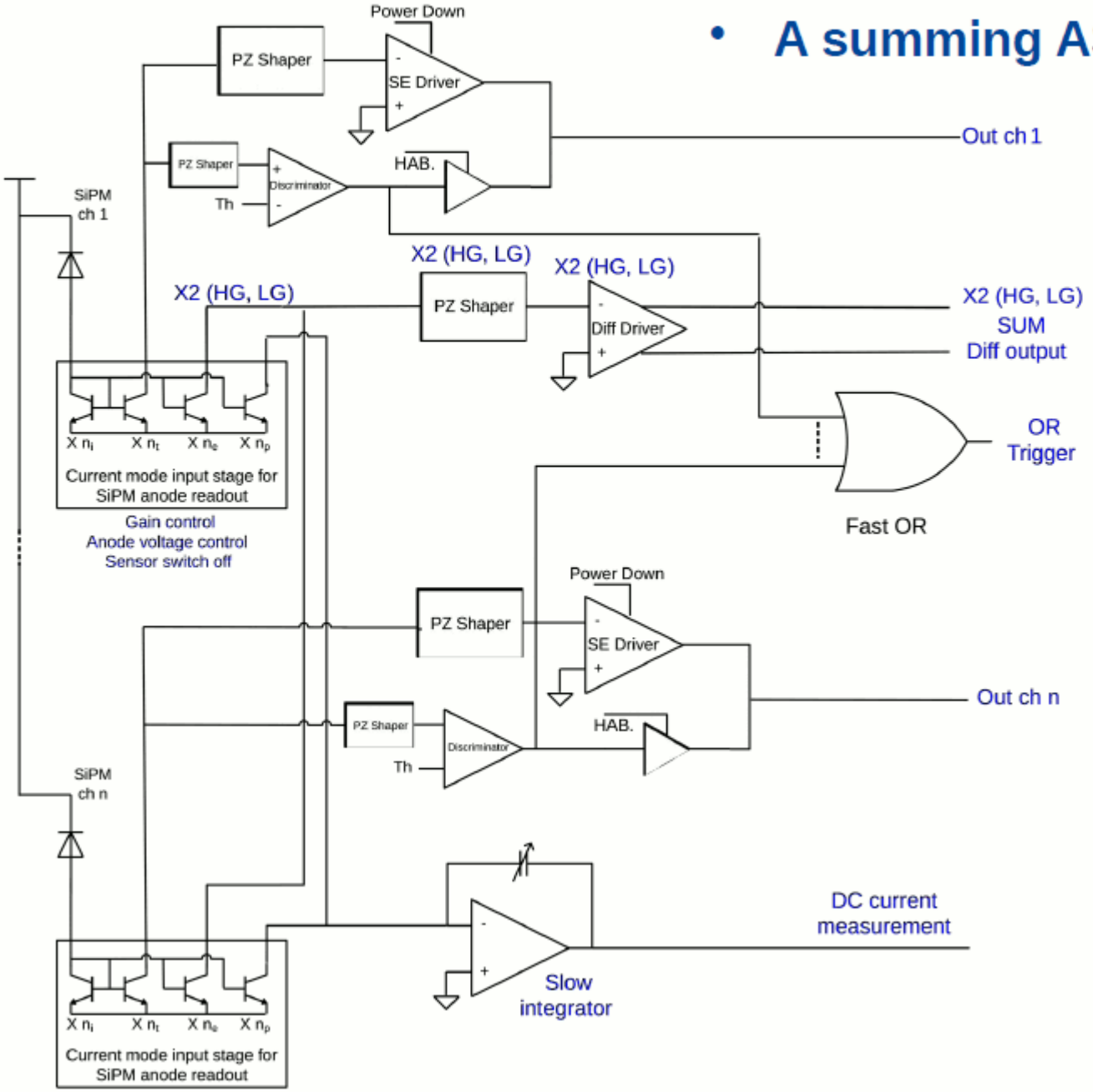


- Price per ASIC (MUSIC R1) is 80 EUR. Total: 1000 x 80 EUR = 80 kEUR
  - Including connectors, PCBs and so on 120 kEUR (estimate by Barcelona Uni)
- In general, UniGe can also contribute with electronics

Electronics: ASIC *vs* discrete circuit

- Light collected by *large area SiPMs*
  - Capacitance increases with the surface of SiPM => rise time increases => time resolution degrades. Solution: readout sensors in parts, amplify and sum
- Advantage of ASIC (*MUSIC R1*) as compared to the discrete circuit
  - MUSIC (Multiple Use SiPM Integrated Circuit) developed in Uni Barcelona
  - Amplification, summation and discrimination within a single chip
  - Occupied space is much smaller
  - Power consumption is an order of magnitude lower => lower heating => less constraints for the cooling system
  - 'current buffer' is used for the input stage of MUSIC => minimum input impedance which is the best for the readout of a large capacitance

MUSIC (Multiple Use SiPM IC)



- **A summing ASIC and more…**

- Input
  - Up to 8 pixels (6x6 mm² SiPMs)
  - Possible to disable each input reducing overvoltage by 4V

- Outputs:
  - High Gain SUM
    - Diff, 100 Ω, 500 MHz
  - Low Gain SUM
    - Diff, 100 Ω, 500 MHz
  - OR trigger
  - Per channel, choose between:
    - Analog (S.E, 50 Ω,, 100 MHz)
    - Digital
  - "DC current"
    - Sum output
    - Per channel mux output
    - Integrator: 1 ms time constant

- Control
  - Every block and channel can be disabled (power down)
  - Many config parameters

Cost estimate: Plastic

- Bars with dimensions: **230 cm x 6 cm x 1 cm**
  - Scintillator EJ-200 (BC-408), attenuation length 380 cm.
    - 500 pcs: 290 EUR each
    - Total: 500 x 290 EUR = **145 kEUR**
  - Scintillator EJ-208 (BC-412), attenuation length 400 cm.
    - 500 pcs: 295 EUR each
    - Total: 500 x 295 EUR = **147.5 kEUR**
- UVT PMMA Light-Guide (optional)
  - Dimensions: 60 mm x 10 mm by 4 mm thick tapered to 56 mm x 6 mm
  - 1000 pcs: 45 EUR each
  - Total: 1000 x 45 EUR = **45 kEUR**
- Quotation by Scionix (NL) on Apr 11, 2017

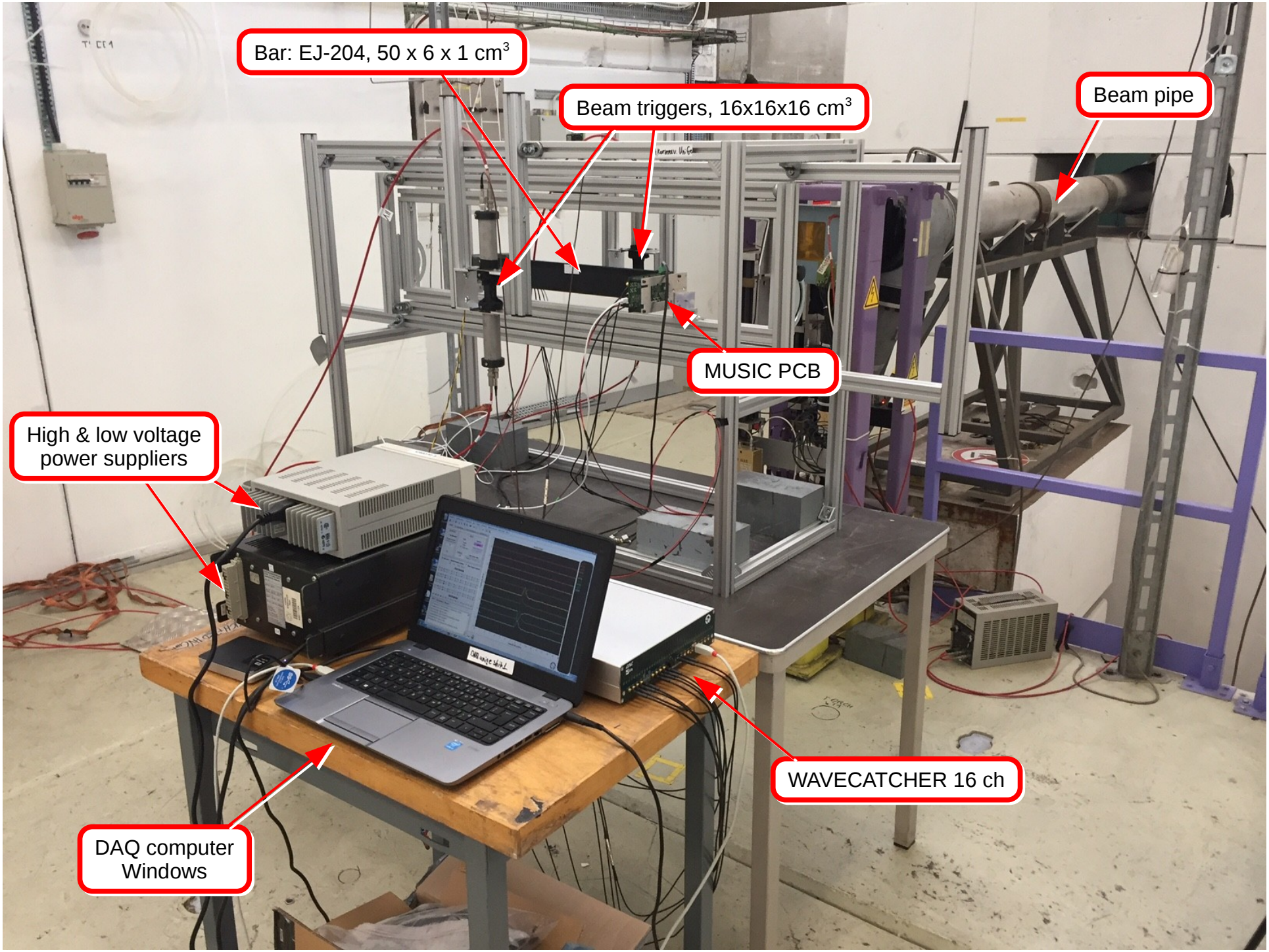
Cost estimate: SiPMs

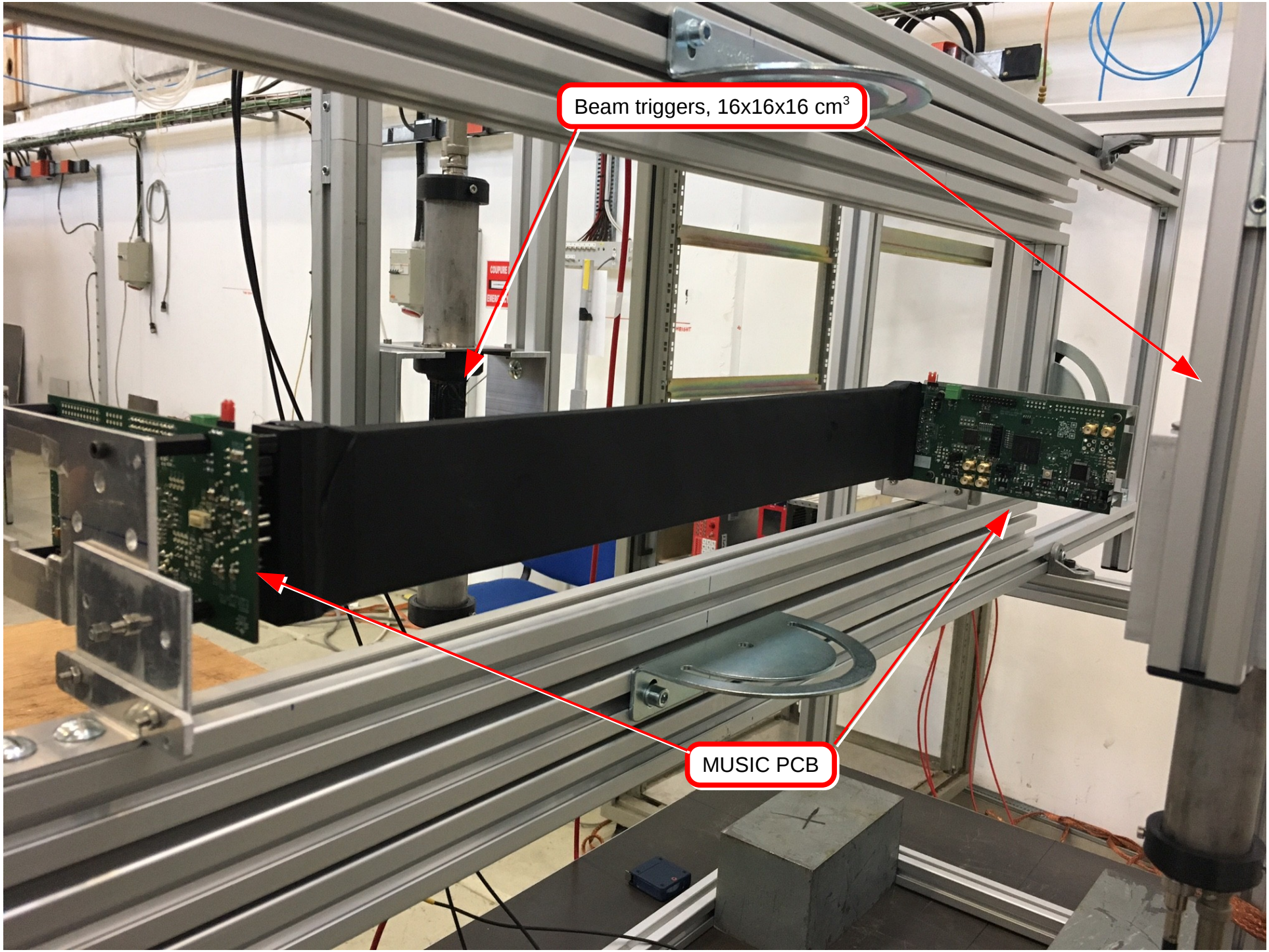
- based on **S13360-6050PE** : 6x6mm, 50 μm pixel, low xtalk & afterpulse, epoxy resin
- Stand-along SMT packages
  - 8000 pcs: 2'990 JPY = 27.5 CHF/MPPC
    - Total: 8000 x 27.5 CHF = **220.0 kCHF**
  - 10 kpcs: 2'420 JPY = 22.2 CHF/MPPC
  - Pricebreak: 10-49 / 100-299 / 5k-9'999 / 10k – 49'999 pcs
- Array 6X6MM-1X8CH-MPPC
  - NRE COST SSD: 625 kJPY = 5.8 kCHF
  - 1000 pcs: 21'450 JPY = 197.1 CHF/array => 24.3 CHF/MPPC
    - Total: 1000 x 197.1 CHF = **197.1 kCHF**
  - 2000 pcs: 17'420 JPY = 160.1 CHF/array => 20.0 CHF/MPPC
  - Pricebreak: 10 (MOQ) – 49 / 1k – 1'999 / 2k -4'999 pcs
- Quotation by Hamamatsu on Apr 11, 2017
- Exchange rate assumed: 1 CHF = 108.8 JPY

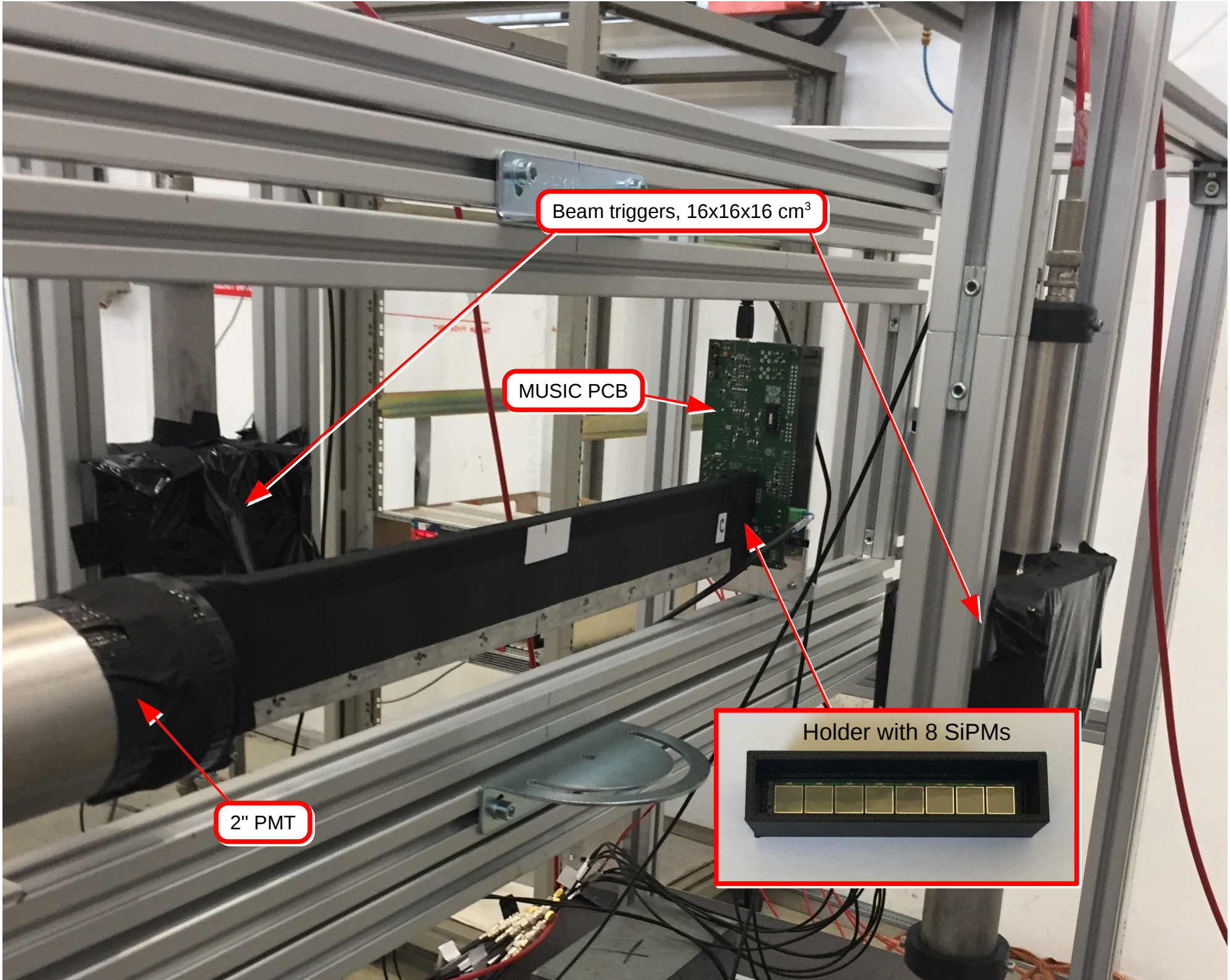
Summary for the cost estimate

- ToF system based on a cast plastic (EJ-200 or EJ-208)
  - 500 bars of dimension 230 cm x 6 cm x 1 cm
  - Light collection by arrays of large area SiPMs (6x6 mm2)
  - Expected time resolution 100 – 200 ps
- Main contributes to the *overall cost* of the 'cast' version of ToF
  - Plastic: 145 kEUR
  - SiPM arrays: 197.1 kCHF
  - Electronics: 120 kEUR
  - Together: 1.1x(120+145)+197.1 = 489 kCHF
- If DRS is used one adds: 1000 ch x 50 CHF = 50 kCHF
- Reduction of the number of channels (Electronics+SiPMs) => square root reduction of the time resolution
- Time resolution with a long bar will be measured at the **test-beam at the end of June**

backup


Bar: EJ-204, 50 x 6 x 1 cm3
Beam triggers, 16x16x16 cm3
Beam pipe
MUSIC PCB
High & low voltage power suppliers
WAVECATCHER 16 ch
DAQ computer Windows


Beam triggers, 16x16x16 cm3
MUSIC PCB


Beam triggers, 16x16x16 cm^3
MUSIC PCB
Holder with 8 SiPMs
2" PMT