Bundesministerium für Bildung und Forschung

HIGH-D

AP 2.1 – 2.3

1-Cell WOM-LS Prototype:

DESY Test Beam Exposure 2022/10

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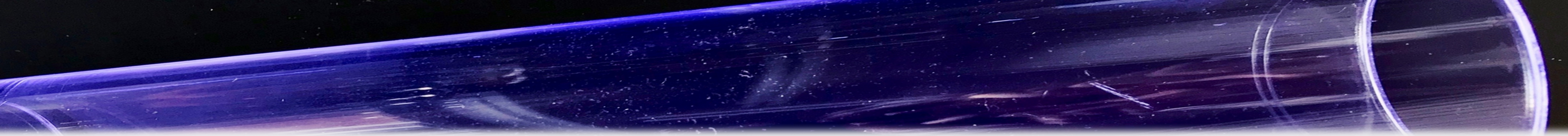
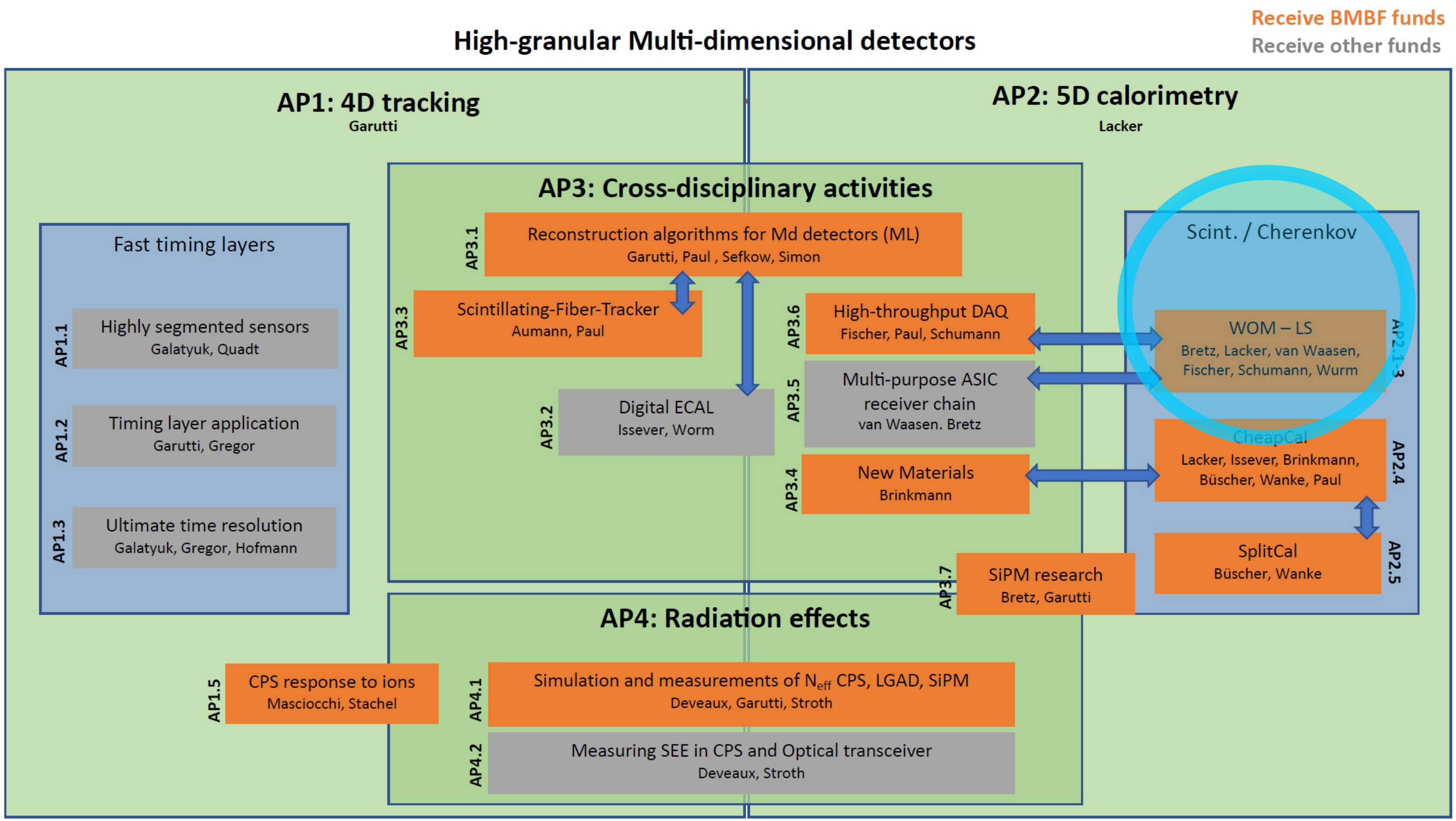


WOM-based LS Detectors @HIGH-D

HIGH-D

WOM-LS @HIGH-D



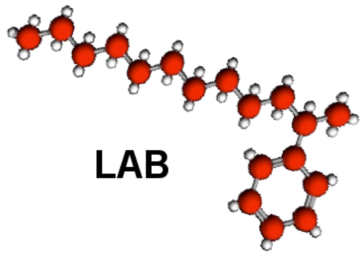
R&D for a new generation of high-precision detectors with unprecedented spatial, time, and energy resolution

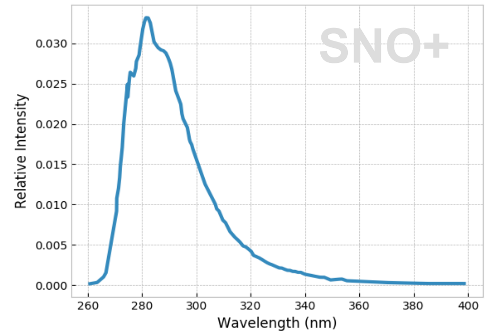
JOHANNES GUTENBERG UNIVERSITÄT MAINZ JG|U

Liquid Scintillator (LS)

HIGH-D

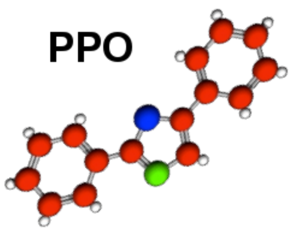
Solvent: Linear **A**lkyl**B**enzene **(LAB)**

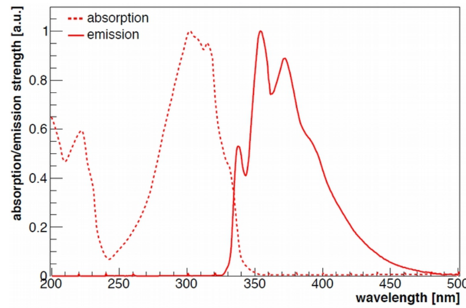




$\lambda_{scat} \sim 20\text{m}$ @400nm

Fluor: 2,5-diphenyl-oxazole **(PPO)**

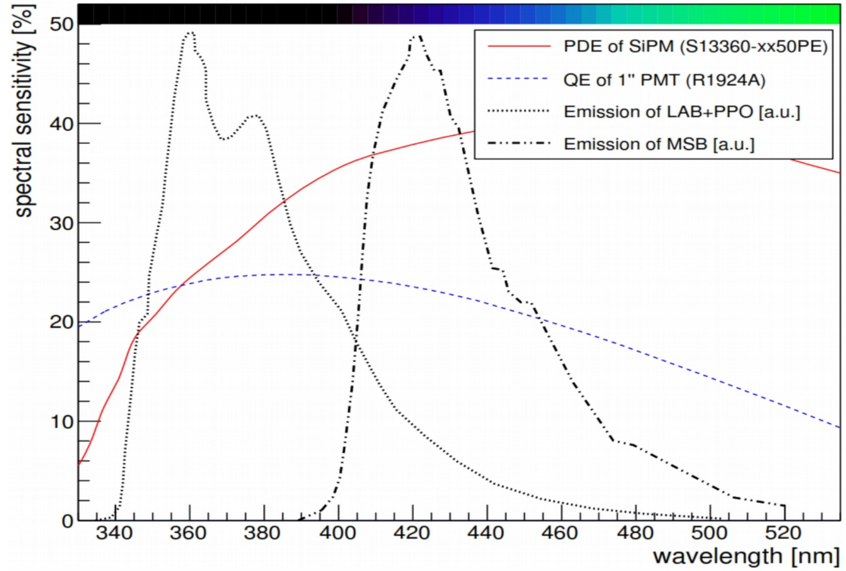




$\tau_{PPO} \sim 1.6\text{ns}$, $\tau_{LAB+PPO} \sim 5\text{ns}$

Scintillator emission spectrum:

- **LS:** LAB + 2.0 g/l PPO [350 – 380 nm]
- **WLS paint:** Bis-MSB [420 nm]



Photodetector quantum efficiency (QE):

- **PMT:** e.g. R1924A [350 – 420 nm]
- **SiPM:** e.g. S13360-xx50PE [400 – 520 nm]

Wavelength-Shifting Optical Module (WOM)

Transparent PMMA tube:

60mm ⌀, 200mm length, 3mm wall

- **Large effective area** (w.r.t. photo sensor)
- Low material budget

WLS paint coating:

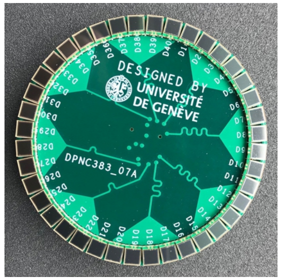
Bis-MSB (+ p-Terphenyl)

- **UV / blue absorption** [290 - 390 nm]
- **Isotropic visible light emission** [420 nm]

▸ **Internal total reflection:** Up to 75% collection efficiency

▸ Instrumentation of **large detector volumes**

▸ Ideal for **Cherenkov & scintillation** detectors



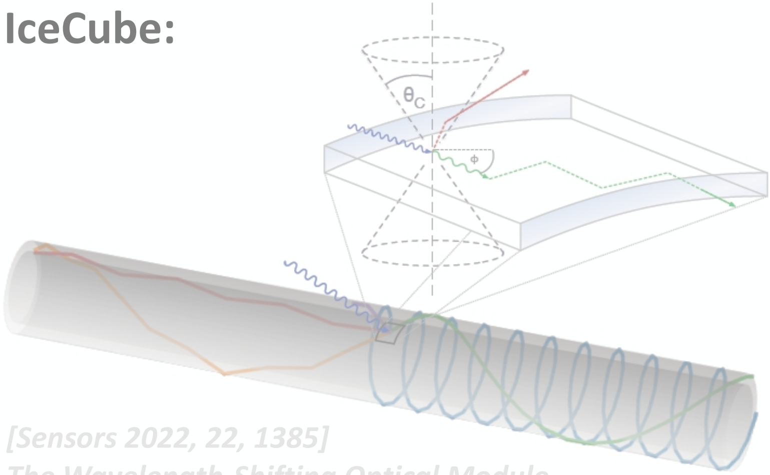
SiPM readout:

Hamamatsu S14160-3050PE [450 nm]

- 40x 3x3 mm² SiPM on PCB array

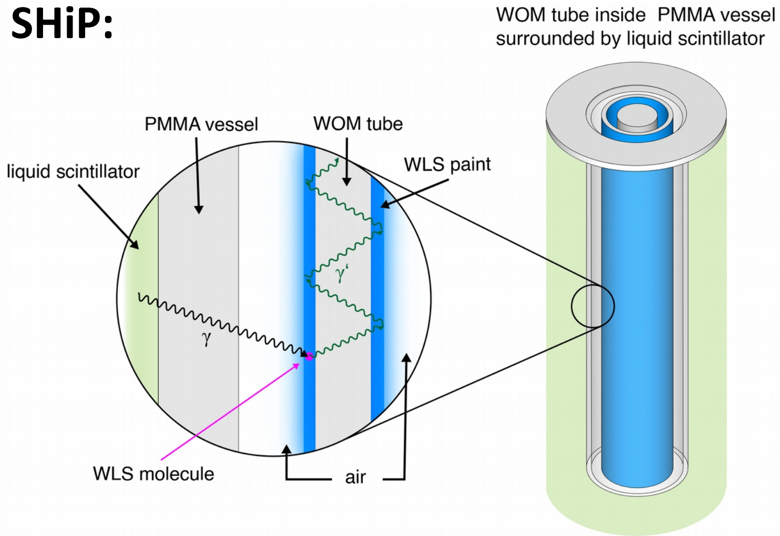
Insulation from LS: PMMA vessel

IceCube:



[Sensors 2022, 22, 1385]
The Wavelength-Shifting Optical Module

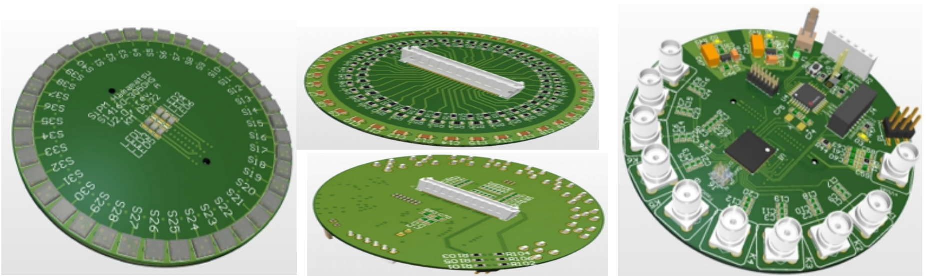
SHiP:



Readout & Electronics

40-SiPM PCB:

Hamamatsu S14160-3050HS / SENSL J30035



eMUSIC readout PCB:

8x 5 SiPMs combined to one analog output

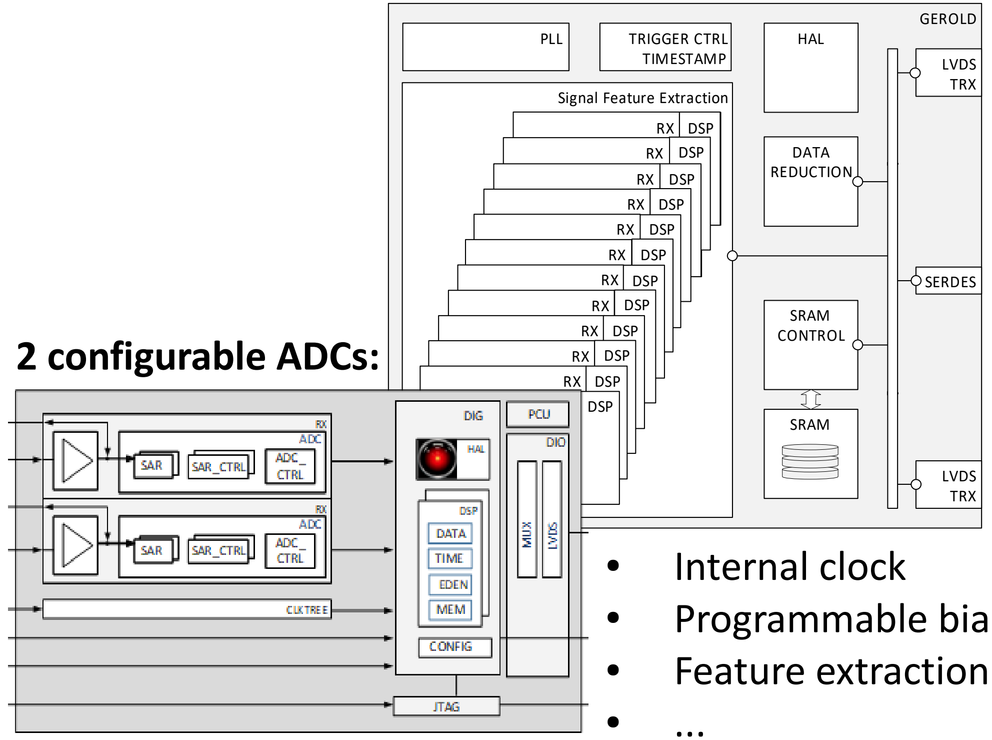
- One common **fast OR** of all 40 SiPM
- One **analog sum** of all 40 SiPM

3 preamplifier options:

- **eMUSIC:** 8 channels (analog) + Wavecatcher
- **CITIROC 1A:** 32 channels (digital)
- **Triroc 1A:** 64 channels (digital)

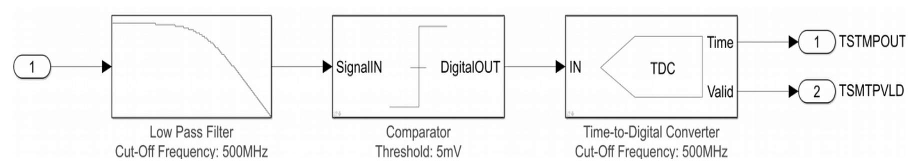
Frontend: Signal feature extraction hub (**GEROLD**)

2 configurable ADCs:

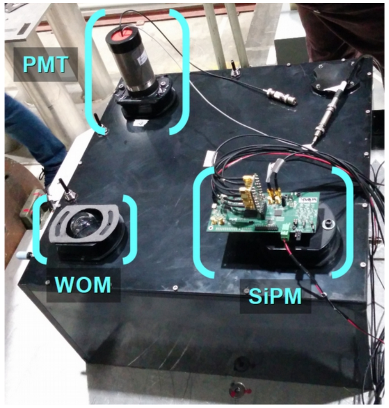


- Internal clock
- Programmable bias
- Feature extraction
- ...

System modeling & simulation



Detector Prototypes & Test Beam Measurements

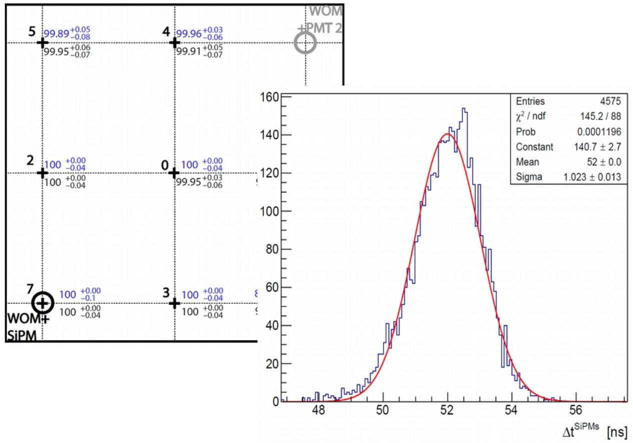


Proof-of-principle: [2019 JINST 14 P03021]

- **60l cell:** Black **ABS plastic**, Tyvek lining
- **LAB + PPO (1.5 g/l)**

- **3 WOMs** with light guide (**PMT / SiPM** readout)
- 1x 8-channel **MUSICboard**

▸ **2017 CERN SPS:** $e^- / \mu^+ / \pi^+$

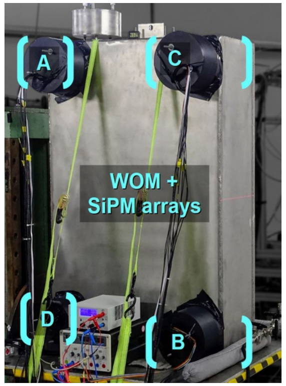


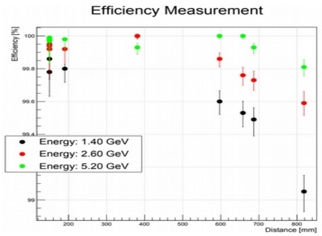
Large 1-cell prototype 1:

- **300l cell: Stainless steel**
- **LHS prototype**
- LAB + **PPO (2.0 g/l)**
- **4 WOMs** (**SiPM readout**)
- 4x 8-channel **miniMUSIC**

▸ **2018 CERN PS:** $e^+ / \mu^+ / \pi^+$
▸ **2019 DESY:** e^-

▸ **> 99 % efficiency for m.i.p.**



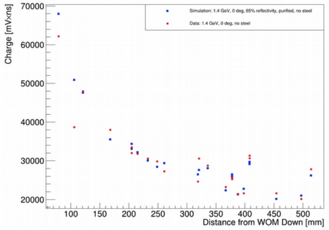


Large 1-cell prototype 2:

- **240l cell: Corten steel**
- **BaSO4 reflective coating**
- LHS prototype
- **Improved** mechanical & optical **coupling**
- LAB + PPO (2.0 g/l)

- **2 WOMs** (**SiPM readout**)
- 2x 8-channel **eMUSIC**

▸ **2022 DESY:** e^-

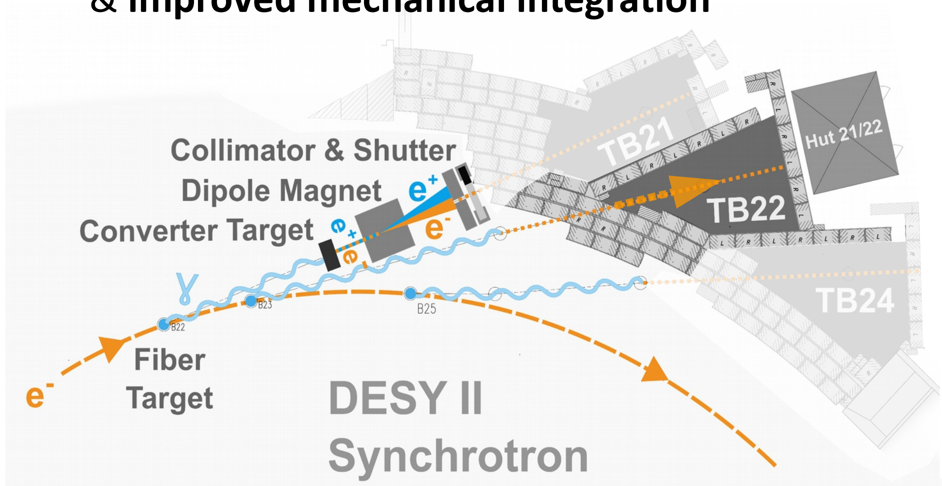


Test Beam Exposure
@DESY 2022/10

DESY Test Beam Exposure 2022

Large 1-cell prototype 2: 120cm x 80cm x 25cm, upper / lower surface at slight angle

- **Corten steel** with **$BaSO_4$ reflective coating**
- **240l LS: Purified LAB** + PPO (2.0 g/l)
  + Liquid Handling System
- **2 WOMs**
  + **SiPMs** with 2x 8-channel **eMUSIC** readout
- **Rotation platform**
  & **improved mechanical integration**



Detector Prototype: Light Yield Optimisation

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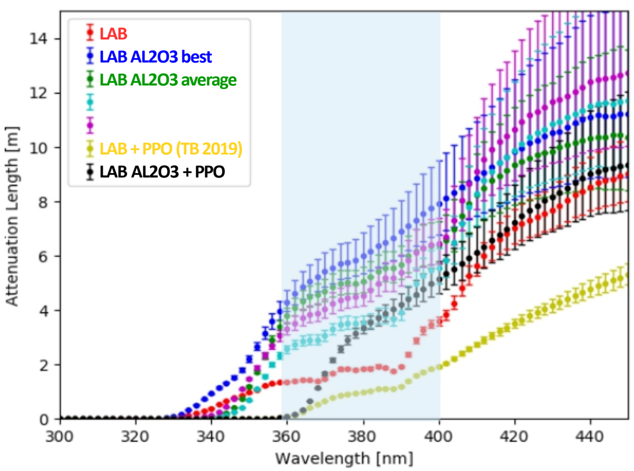
LAB purification:

- **Al_2O_3 column**
- **250l LAB purified** (batches of 5x 5l)
- ~ 65g Al_2O_3 / l LAB

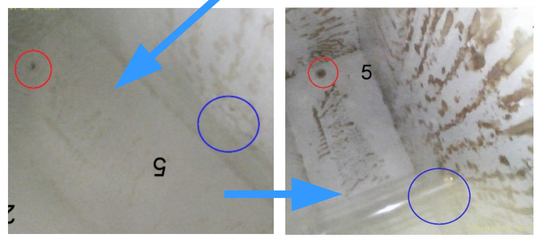
► **Transparency increase:**



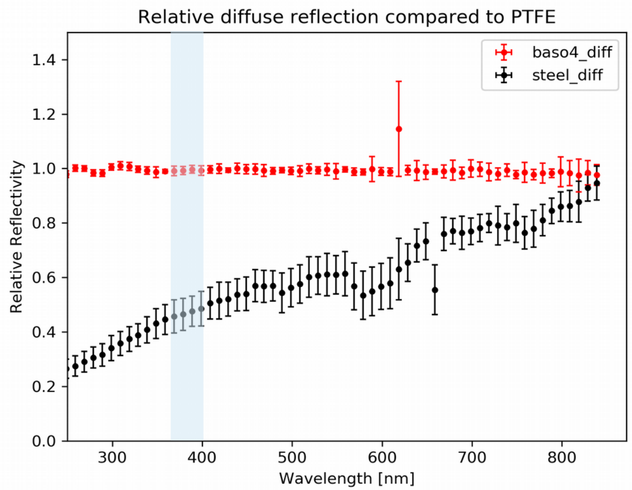
Reflective cell coating:

- **Corten steel:**

- Acrylic primer & **$BaSO_4$ coating:**

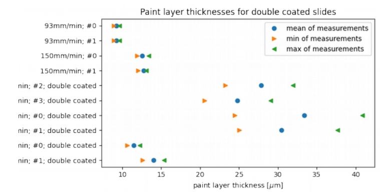


► **Reflectivity increase: 50 – 75 %**

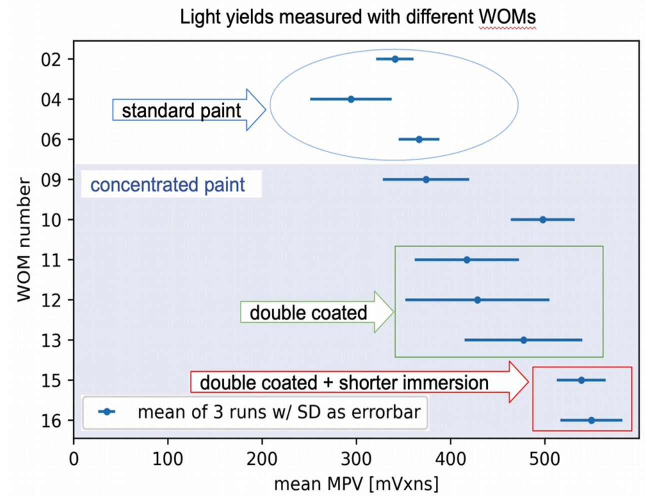


WOM WLS paint & dip coating:

- Fluor **concentration**
- **Coating speed & immersion time**



► **Light yield increase: up to 50 – 100 %**



Detector Prototype: Mechanical Integration

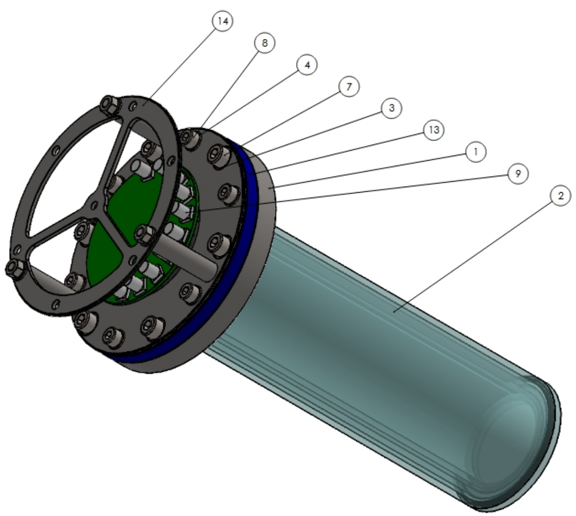
Improved, ultrasound-welded PMMA vessels

Mounting, alignment & coupling of:

- PMMA vessel – detector cell
- WOM – PMMA vessel
- SiPM PCB – WOM
- eMUSIC PCB – SiPM PCM

- Readout cable relief

▸ **Prevention of light leaks**

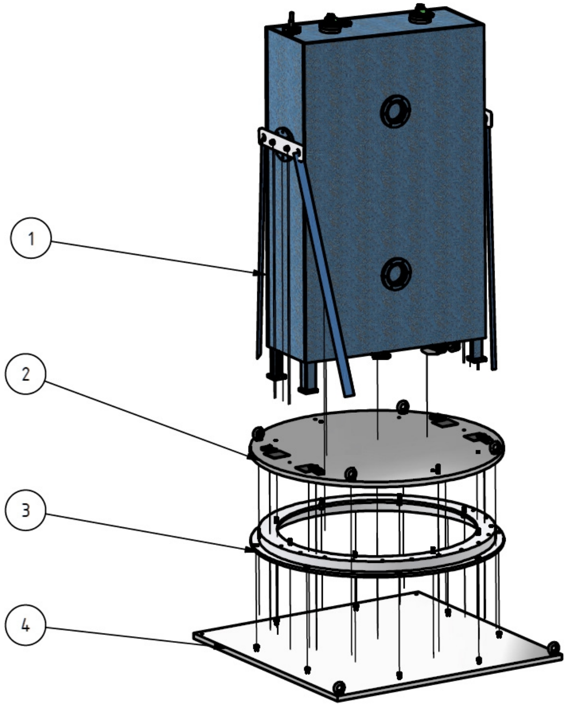


Rotation platform:

Safe rotation of **whole detector** wrt. Beam

- Realisation of angles **0° – ±90°** [15° steps]

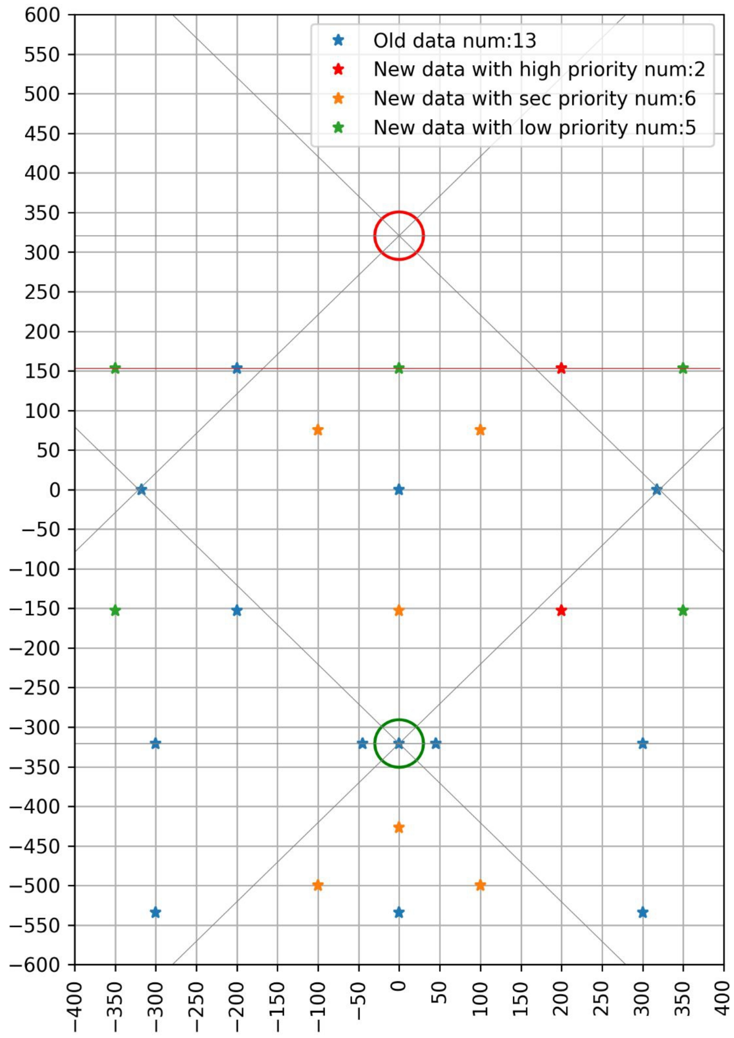
▸ **Precursor to 4-cell detector holding structure**



Test Beam Exposure: Measurements

DESY II TB 22: 2022-10-17 – 2022-10-23

# recorded events / measurement	10 000
e energies [GeV]	1.4 / 2.4 / 3.4 / 4.4 / 5.4
Measurement points	> 40
Box rotation ± [°]	0 / 15 /30 / 45 / 60 / 75 / 90
Steel plate	+ / -
# recorded events total	**> 2 250 000**

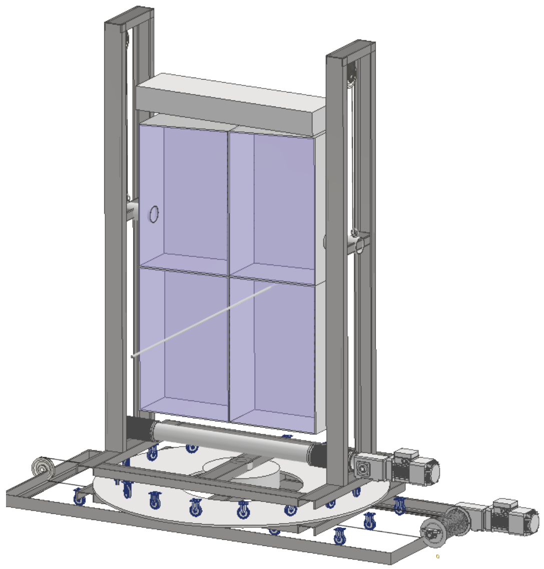


Further variations / measurements:

- Fixing of **light leaks**
- Optical coupling: **Gel pads vs. optical gel**
- Electronics settings: **Digitiser impedance**, **SiPM HV**
- SiPM boards: **SENSL J30035** vs. **Hamamatsu S14160-3050HS**
- **Dark count** measurement

Outlook & Summary

Outlook (2023)

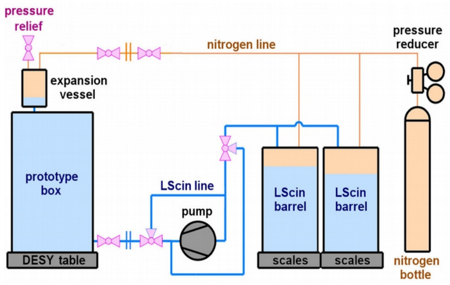


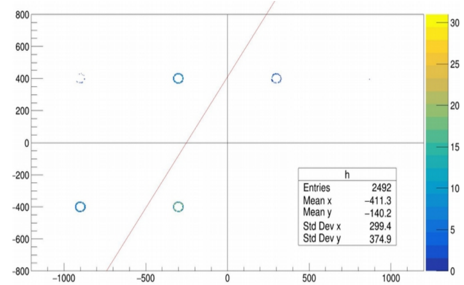
Large 4-cell prototype (AP 2.1):

- **Support structure** & **Liquid handling system**
- Improve **mechanical integration**
- Optimise **cell reflective coating**
- Update **readout & DAQ**

- **Multi-dimensional particle reconstruction:** Light yield, energy deposition, spatial information, incidence angle...

- **CERN test beam:** 2023-Q4





Readout:
- Direct coupling of **SiPMs to coaxial cables**?
  - **1 FE chip for 4 WOMs**
  - Mechanical integration & **signal quality**

Primer & cell reflective coating:
- **Chemical compatibility** with corten steel
- Improve **coating procedure**

LAB quality:
- Switch of manufacturers (SASOL → **CEPSA**)
  - **No need for purification**?

Small 1-cell prototypes (AP 2.2 + AP 2.3):
- Different cell **inner surface / coating**
- **New WOM geometries** & **WLS coatings**
- Cosmics & test beams

HIGH-D

Summary

Backup

WOM-LS: Institutes & Work Packages

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AP 2.1

Multi-dimensional particle reconstruction using a WOM-based liquid scintillator detector

AP 2.2

Improving the spatial (+time?) resolution of a WOM-based liquid scintillator detector

AP 2.3

Separation of Cherenkov and scintillation light via wavelength selection

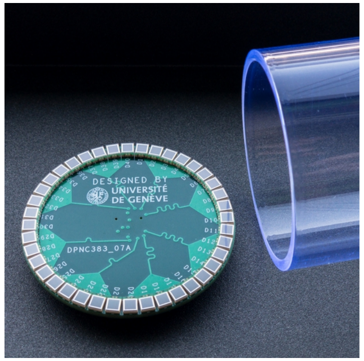
AP 2.1

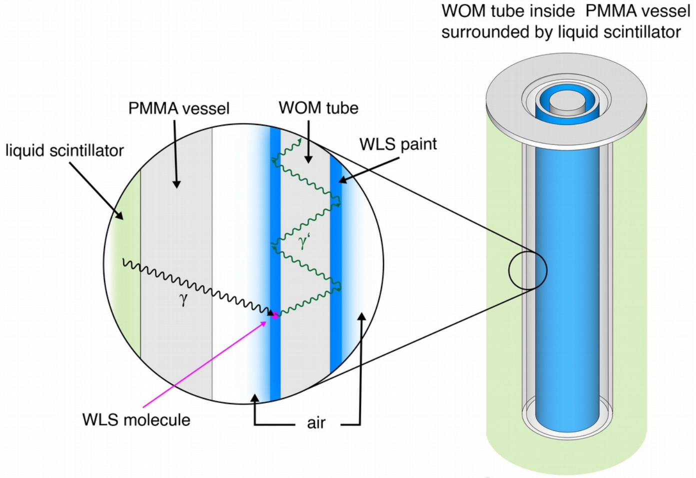
HIGH-D

AP 2.1: ***Multi-dimensional particle reconstruction using a WOM-based liquid scintillator detector***

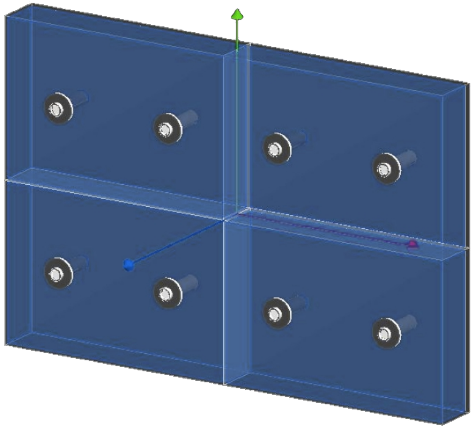
WOM-LS detector with SiPM readout:

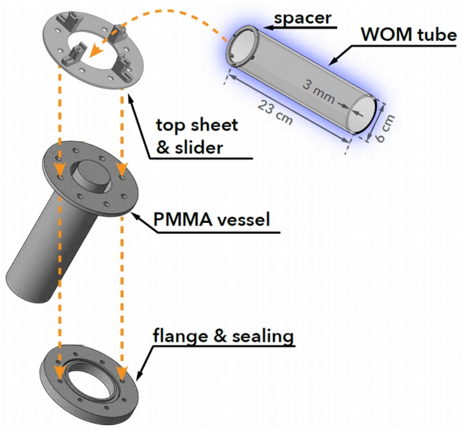
- Liquid Scintillator
- WOM & WLS
- SiPM readout
- DAQ & frontend electronics





- Proof-of-principle: (2019 JINST 14 P03021) -





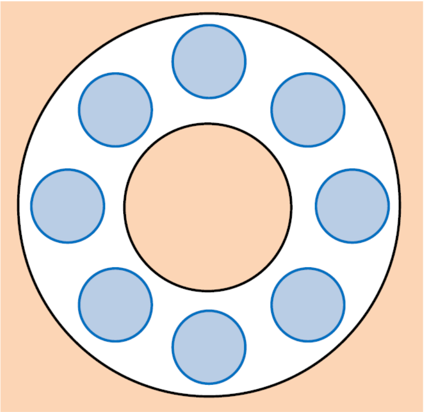
4-cell WOM-LS prototype detector:

- PMMA vessel & WOM / PCB integration
- Support structure & LS filling system
- CERN test beam exposure
- ▸ **Multi-dimensional particle reconstruction**

AP 2.2 + AP 2.3

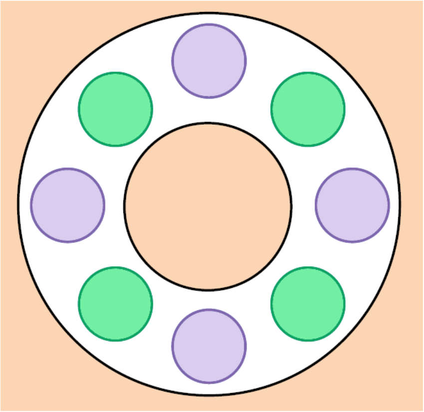
AP2.2: ***Improving the spatial (+time?) resolution of a WOM-based liquid scintillator detector***

- **Increase detector granularity: 8 WOM rods** in circular array
  - **Individual readout:** 6x6 mm^2 SiPM
  - **Improved directional information:** Resolving left-right ambiguities
  - Improved time resolution (?)
- Installation in **small 1-cell LS prototypes**, measurement **of cosmic μ**



AP2.3: ***Separation of Cherenkov and scintillation light via wavelength selection***

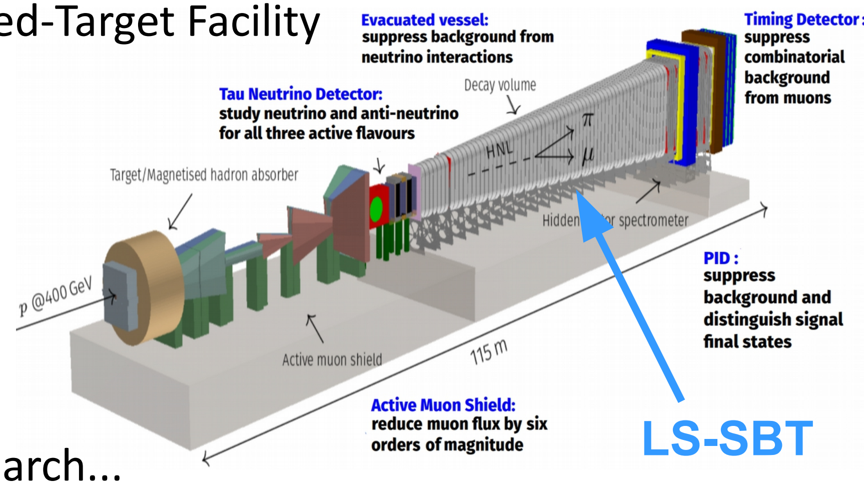
- Employing the WOM rod array of 2.2:
  - **Alternating rod coating with different WLS** (e.g. BPEA)
  - Sensitivity to **Cherenkov** light **OR scintillation** light
  - **Adjustment of LS fluors necessary:** Blue → green
- Installation in **small 1-cell LS prototypes**, measurement **of cosmic μ**

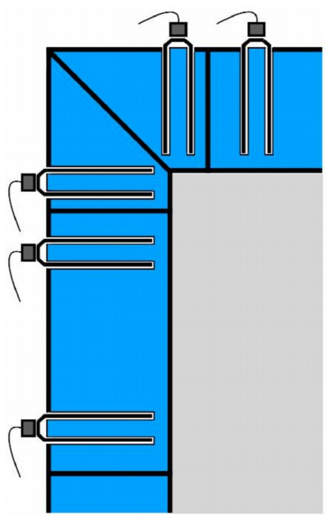


Usecase: The SHiP LS-SBT

Search for Hidden Particles (SHiP): General-Purpose Fixed-Target Facility

- Part of the **CERN Physics Beyond Colliders** initiative
- **SPS NorthArea:** 400 GeV protons
  - Search for weakly interacting particles ($m \leq 10$ GeV/c^2): HNL, dark γ, light scalars, SUSY, axion-like particles...
  - ν_τ physics, lepton flavour-violation, direct Dark Matter search...





Liquid Scintillator-Surrounding Background Tagger (LS-SBT):

- **Tagging of μ- and ν-induced BG:**
  - **High efficiency:** 99.9% for m.i.p.
  - **Good time resolution:** $\mathcal{O}$(1 ns)
- Segments $\mathcal{O}$(2000): Filled with ~200 m^3 **LS** (LAB + PPO)
- Instrumentation with **WOMs** $\mathcal{O}$(4000) & **SiPM readout**