The Surround Background Tagger (SBT)

SHiP
Search for Hidden Particles

Heiko Lacker (HU Berlin)
On behalf of the SHiP SBT groups

SHiP and BDF workshop, Berlin
27.03.2020

Overview

* Groups involved

* Purpose of the Surround BG Tagger (SBT)

* SBT and Decay Vessel

* Photodetection Principle

* Liquid Scintillator

* Wavelength-Shifting Optical Modules (WOMs)

* Performance goals and achievements

* Electronics (dedicated talk on FEE: D. Arutinov)

* Areas to contribute during TDR phase

Groups involved

- **Humboldt University of Berlin (Germany): H. Lacker**
- **Johannes Gutenberg University Mainz (Germany): M. Wurm**
- **Forschungszentrum Jülich, ZEA2 (Germany): S. Van Waasen**
- **Taras Shevchenko National University of Kyiv (Ukraine): O. Bezshyyko**

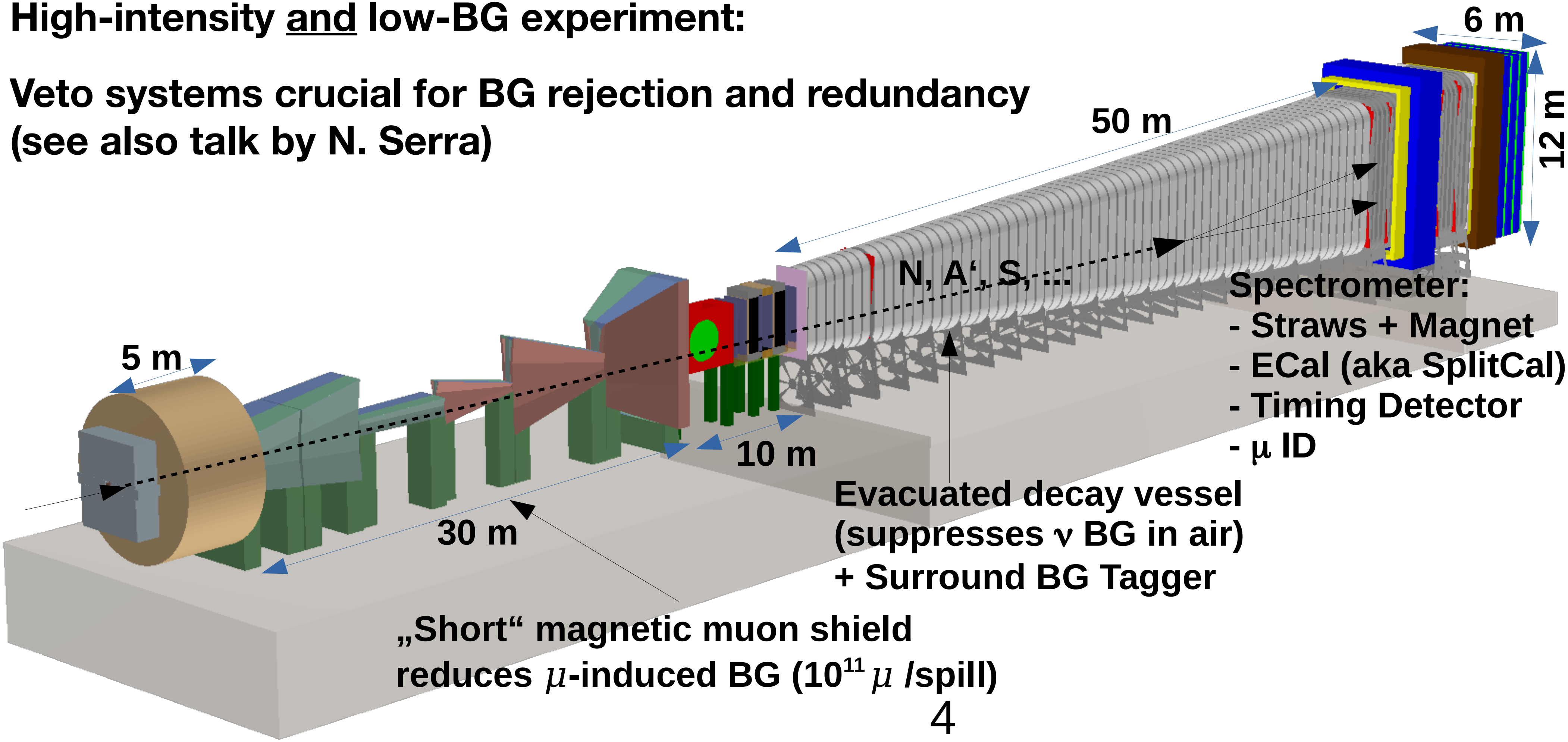
- **Vaccum Vessel construction:**
  University of Naples Federico II (Italy): A. Prota

- **Filling and empyting of the Surround BG Tagger:**
  University of Naples Federico II (Italy): M. Giugni and other Profs.

SHiP: Detector Overview

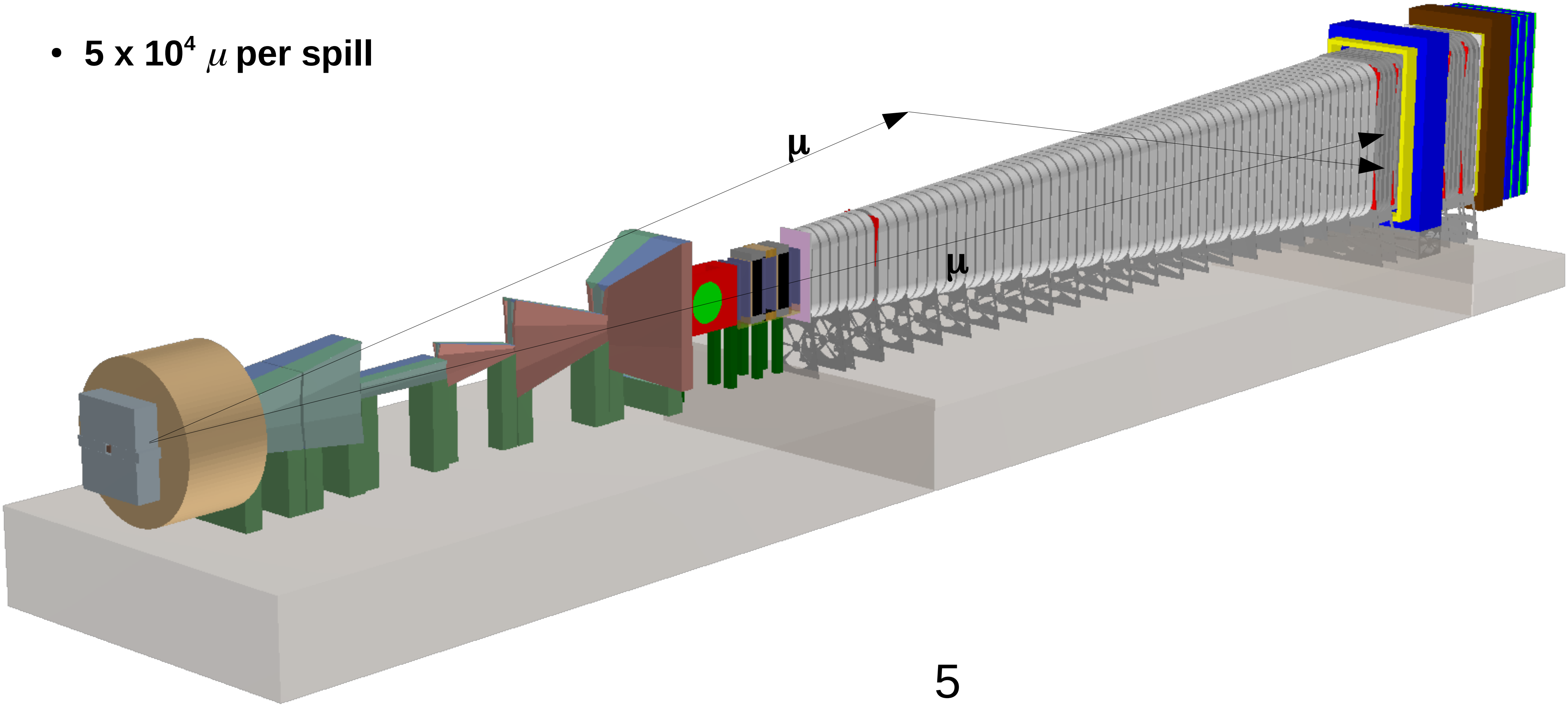
High-intensity and low-BG experiment:

Veto systems crucial for BG rejection and redundancy (see also talk by N. Serra)



Purpose 1: Detect μ entering the decay vessel

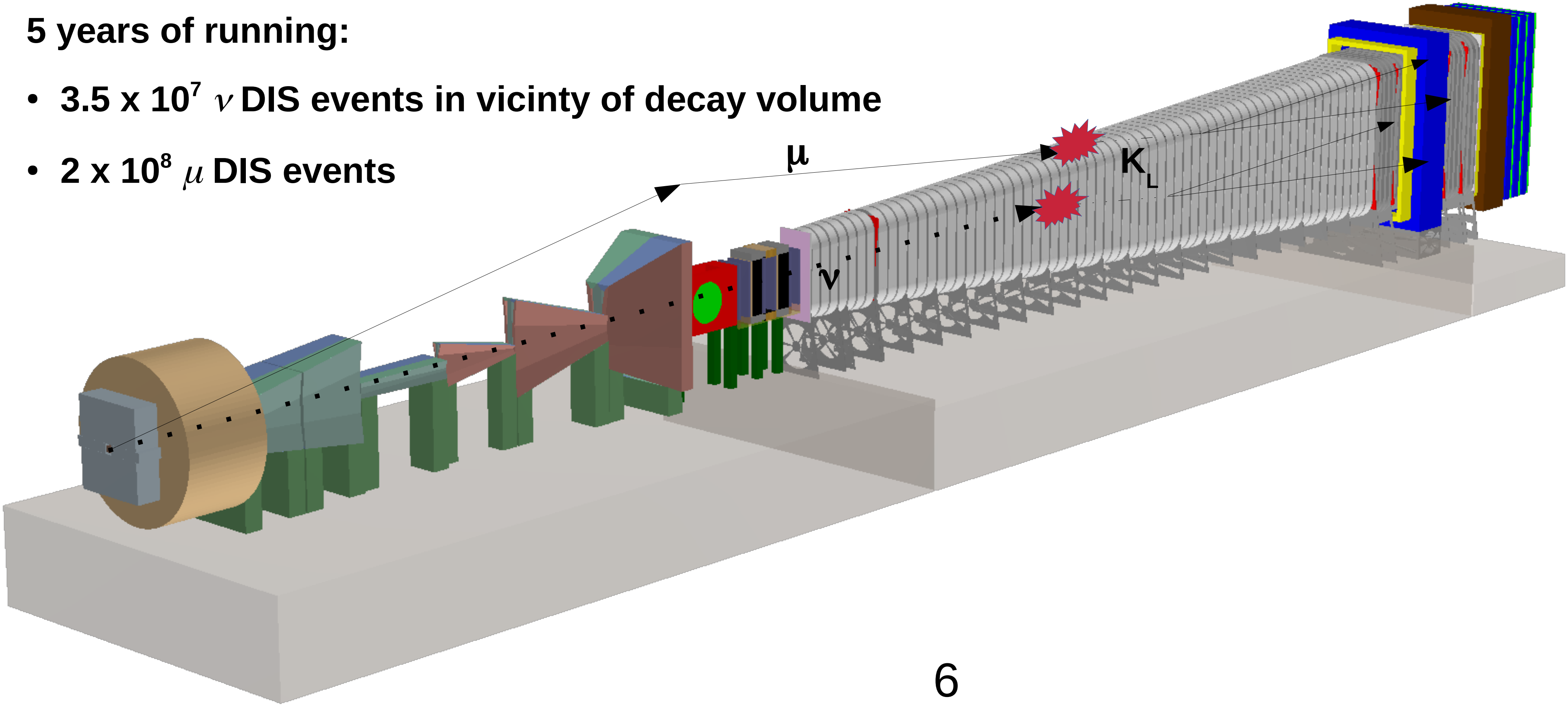
- **5 x 10^4 μ per spill**



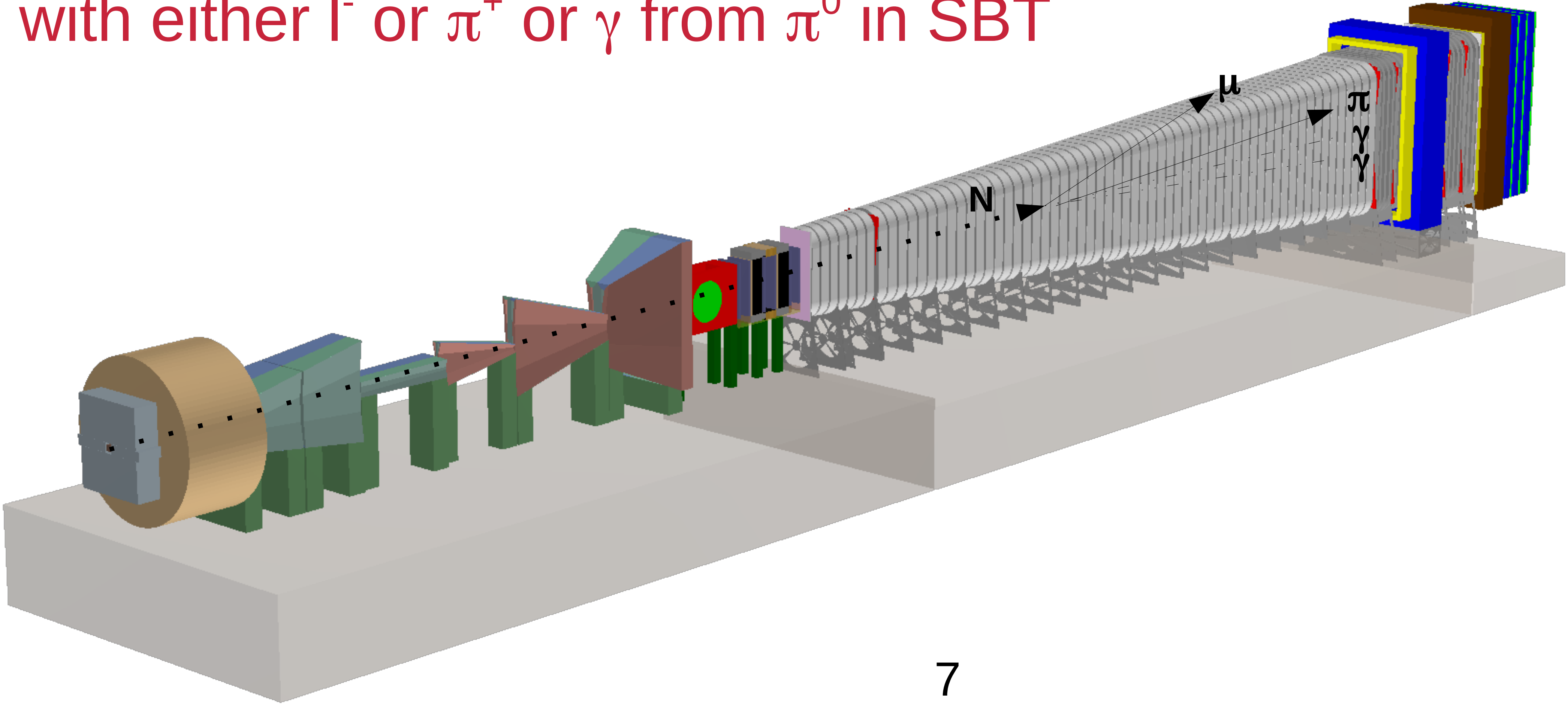
Purpose 2: Detect μ and ν DIS in decay vessel walls and surroundings

5 years of running:

- **3.5×10^7 ν DIS events in vicinty of decay volume**
- **2×10^8 μ DIS events**



Possible add-on (to be explored):
Extend signal reconstruction of $N \rightarrow l^{-}\rho^{+} \rightarrow (\pi^{+}\pi^{0})$
with either l^{-} or π^{+} or γ from π^{0} in SBT



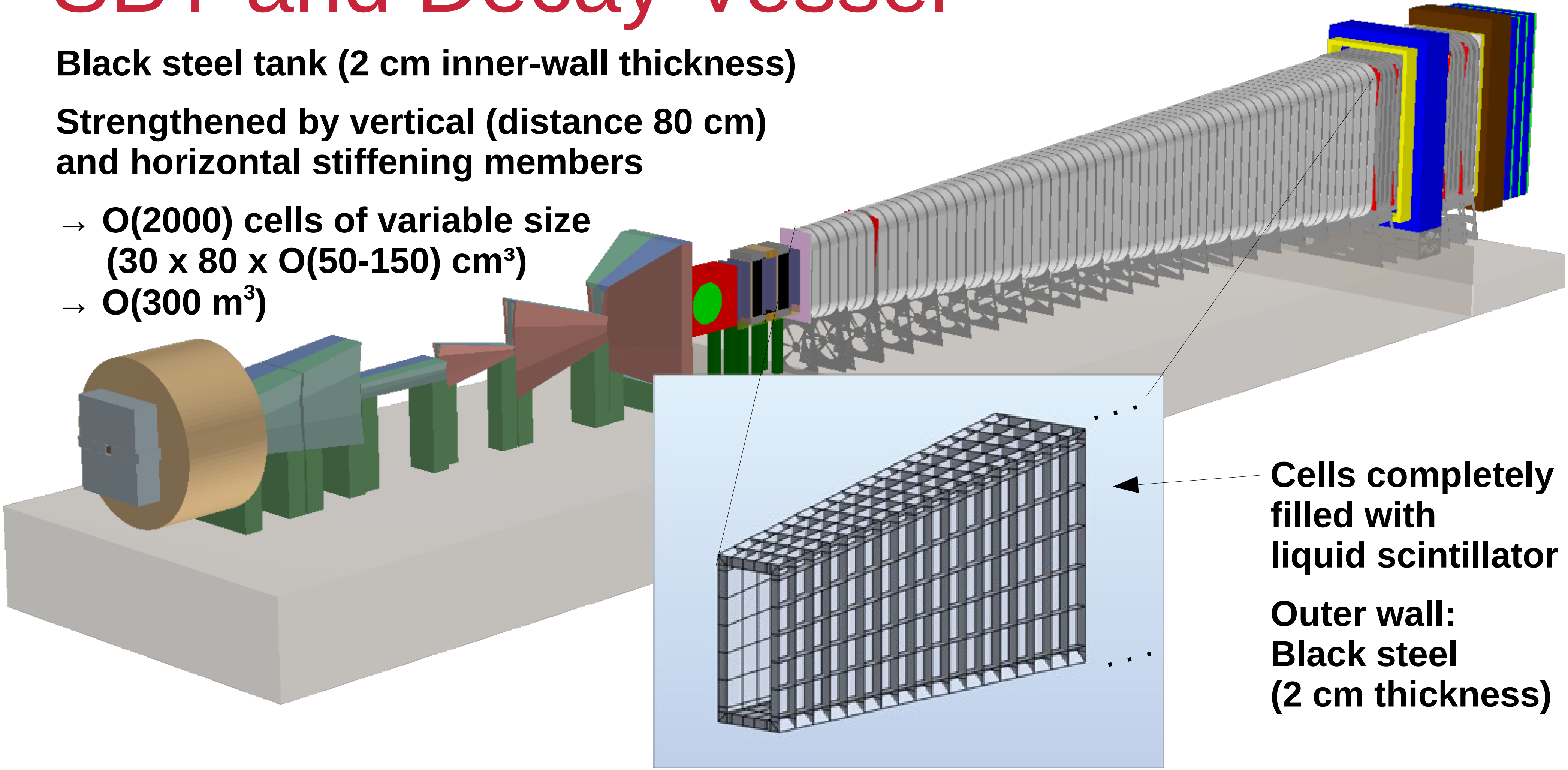
SBT and Decay Vessel

Black steel tank (2 cm inner-wall thickness)

Strengthened by vertical (distance 80 cm) and horizontal stiffening members

→ O(2000) cells of variable size (30 x 80 x O(50-150) cm³)

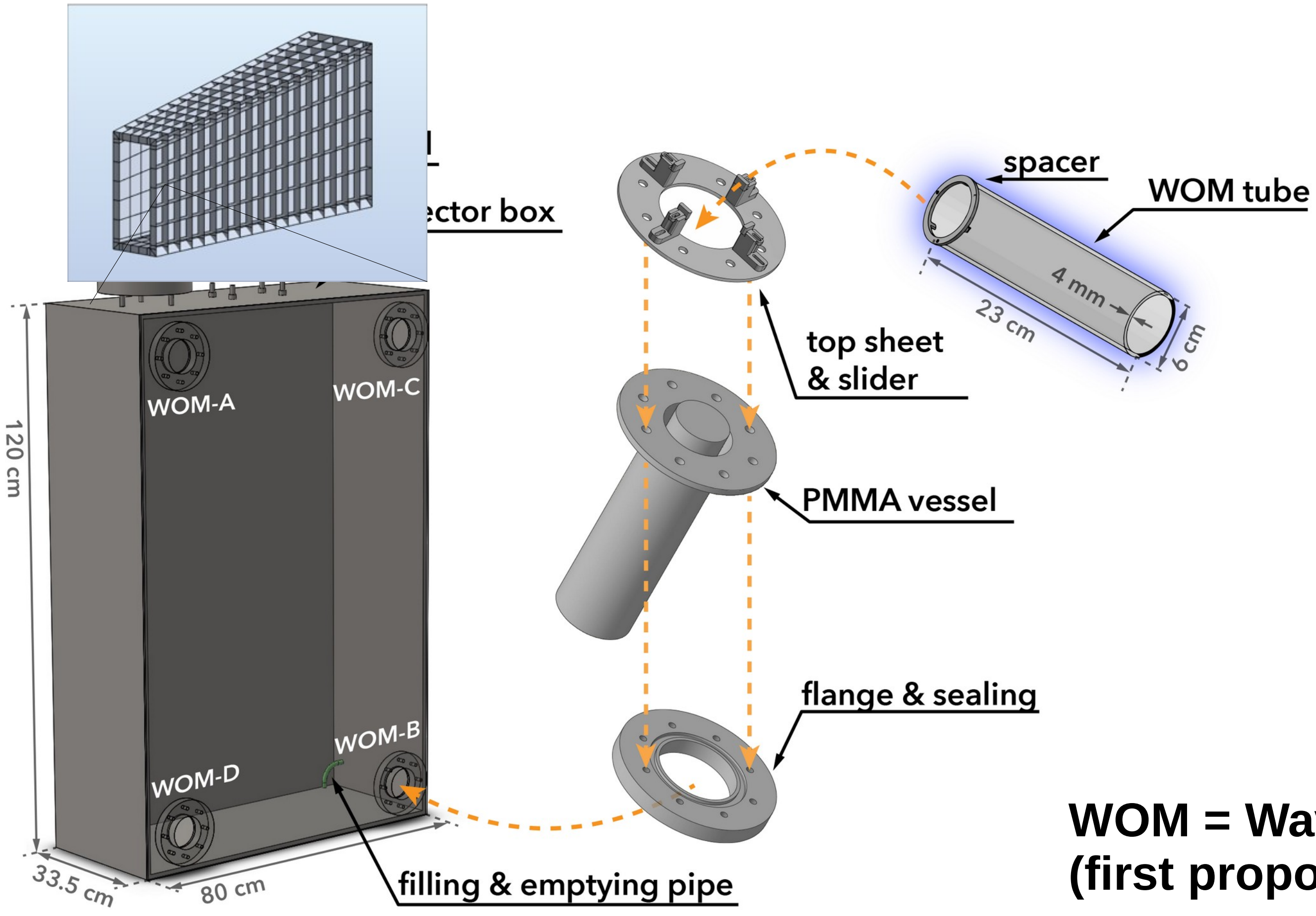
→ O(300 m³)

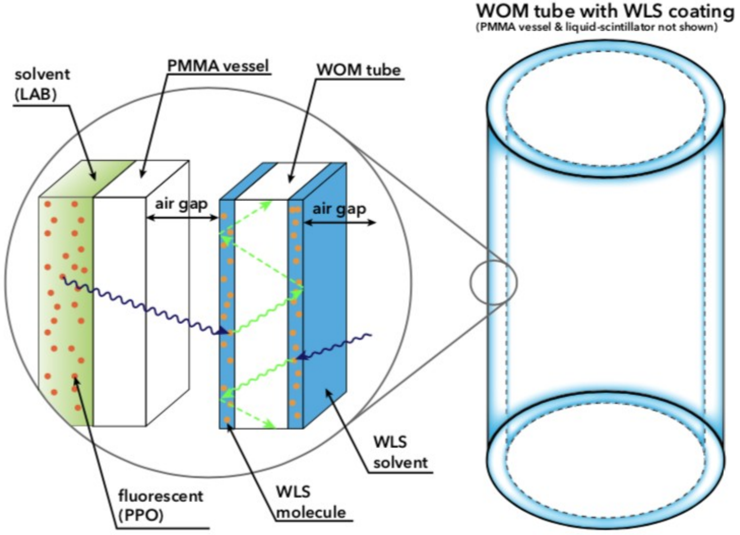


Cells completely filled with liquid scintillator

Outer wall: Black steel (2 cm thickness)

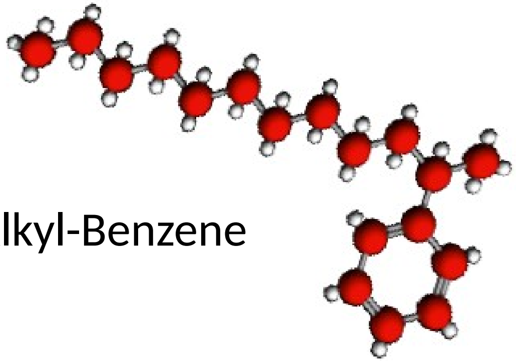
Detection principle (here for a test detector)





WOM = Wavelength-Shifting Optical Module
(first proposed for IceCube extension)

SBT: Liquid Scintillator

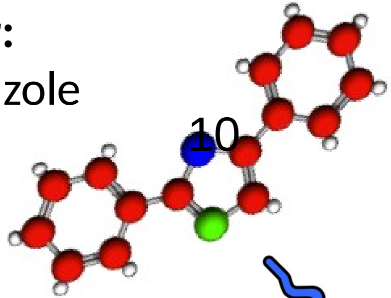


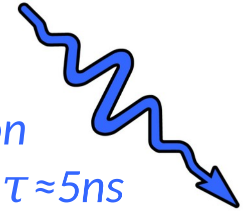
solvent:
Linear Alkyl-Benzene (LAB)

\+

non-radiative
→ 280nm

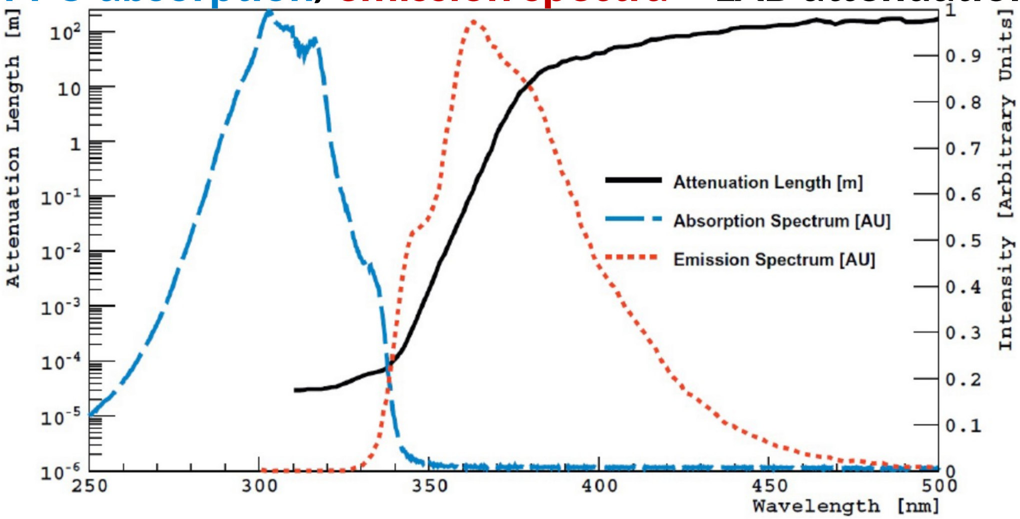
primary fluor:
di-phenyl-oxazole (PPO), ~2 g/l





light emission
→ ~380nm, τ≈5ns

PPO absorption/emission spectra + LAB attenuation



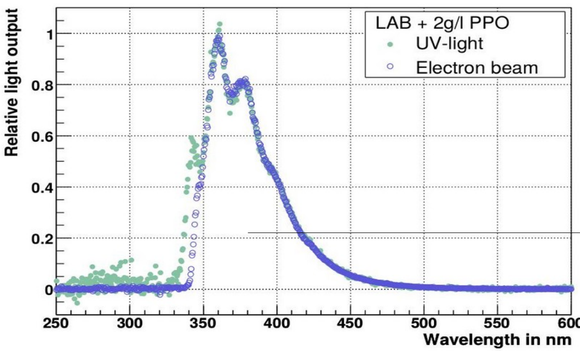
Light yield: ~10^4 photons/MeV

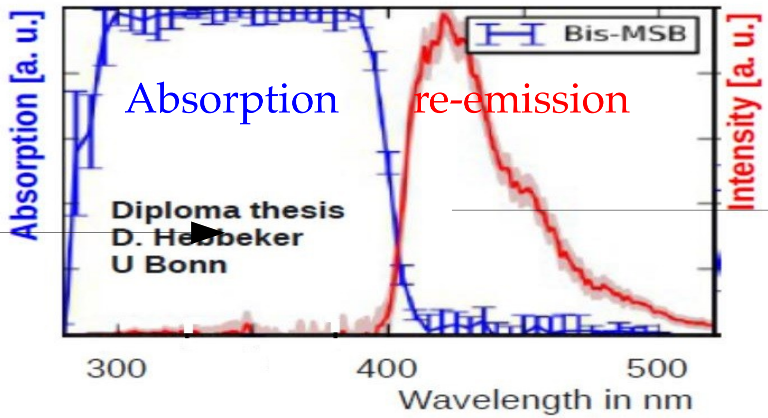
Composition:

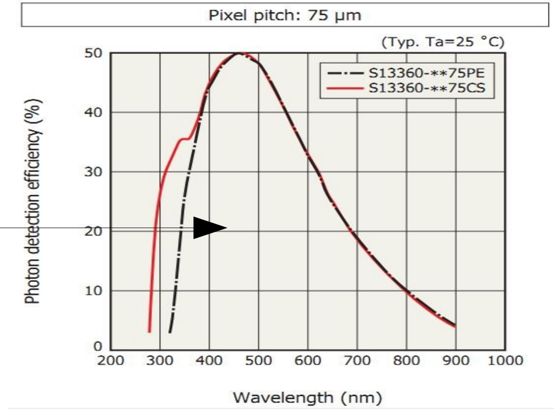
→ **Solvent: LAB**
- high transparency: λ_{scat}~20m @ 400nm

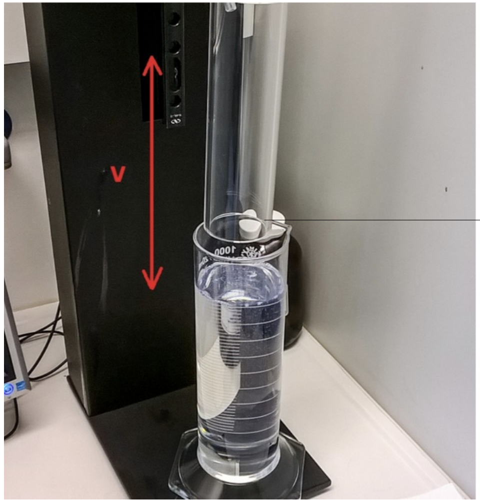
→ **Fluor: PPO**
- fast timing: O(ns)
- high efficiency: ε_{PPO} > 90-95%
- high solubility: ~100g/l okay

Wavelength-Shifting Optical Modules (WOMs)

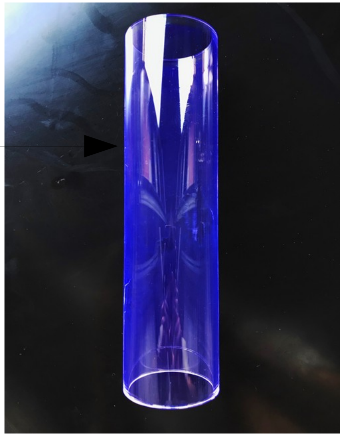




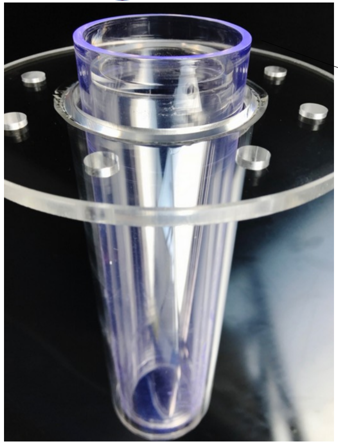




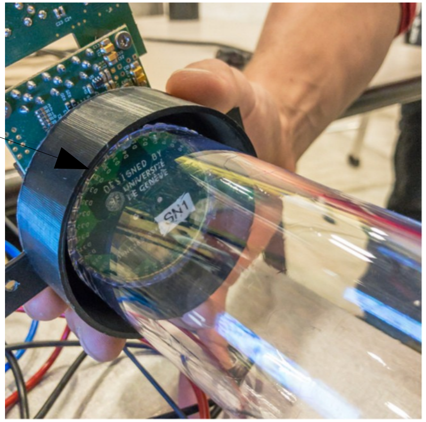
WOM dip-coating with WLS dye



Dip-coated WOM tube



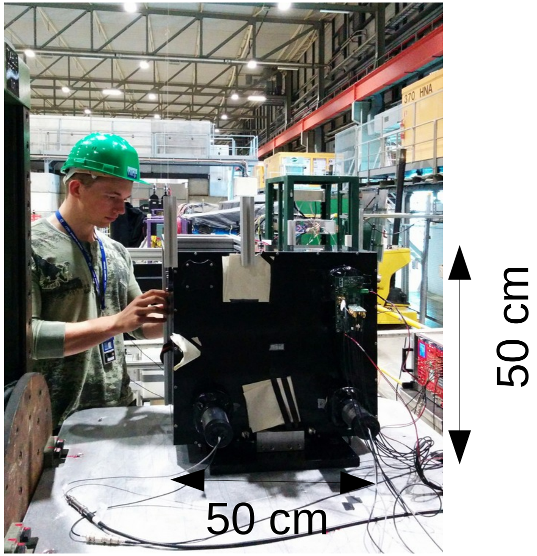
Vessel separating WOM from LS



Optical coupling to 40-SiPM ring array

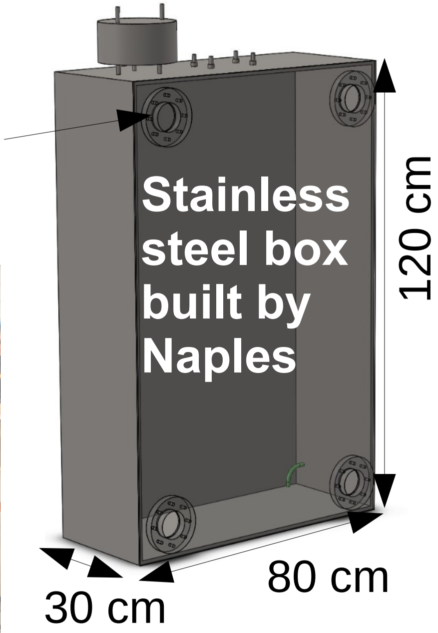
Test-beam campaigns

- **2017: CERN SPS; small protype (black ABS walls)**



- **2018/2019: CERN PS/DESY) large prototype**

Photodetector position (WOM + SiPM array)



Small-scale LS handling system with LS under N_2 atmosphere (Mainz)

Performance Goals and Achievements

- **High detection efficiency for a particle passing through one detector cell**

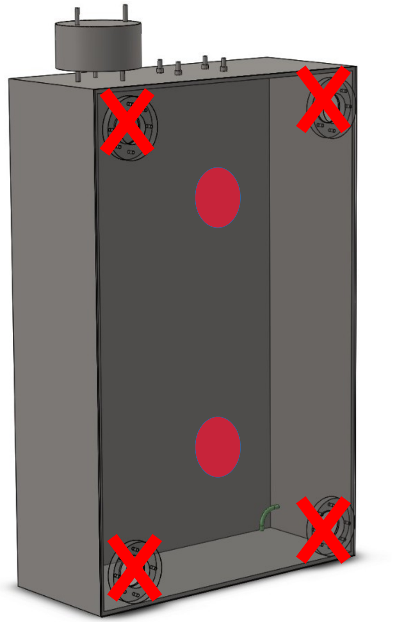
  Sensitivity studies assume 99.9% efficiency for > 45 MeV energy deposition (equivalent to a μ traversing 30 cm of LS)

- **Good homogeneity**

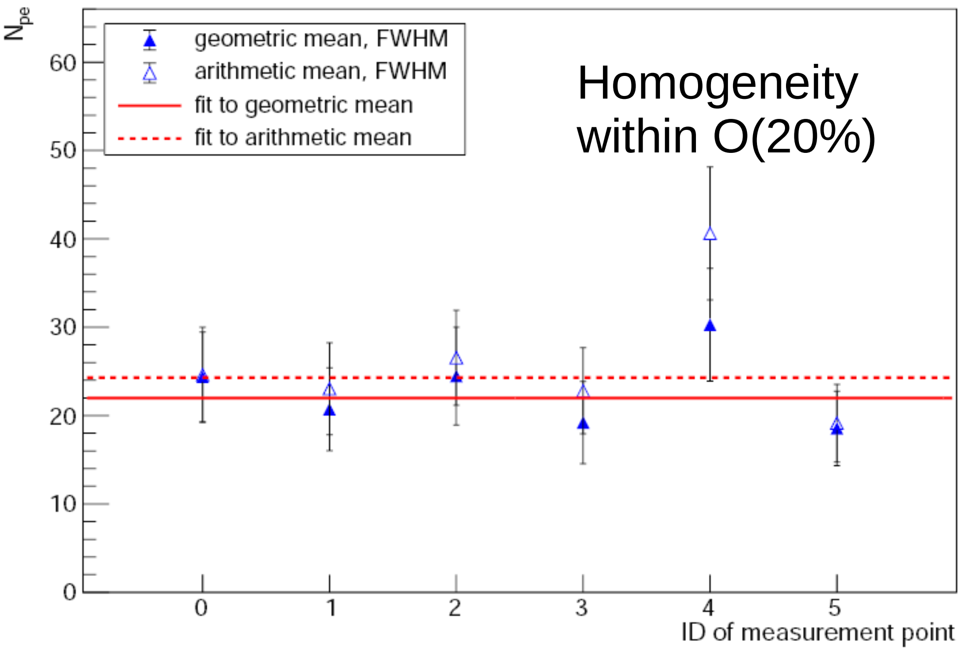
- **Good time resolution and small deadtime**

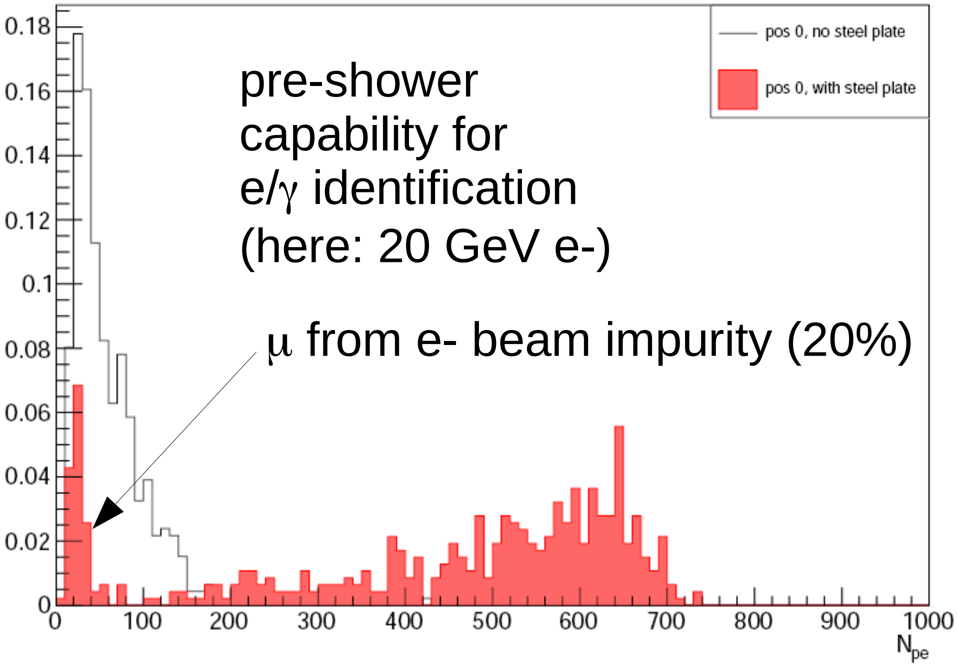
- **Good spatial resolution**

  → Each cell to be instrumented with 2 WOMs;
  WOM positions to be optimized
  (x 2000 cells → 4000 WOMs)



Performance Goals and Achievements





JINST 14 (2019) no.03, P03021, arXiv:1812.06460

M. Ehlert[a], A. Hollnagel[b], I. Korol[a], A. Korzenev[c], H. Lacker[a],
P. Mermod[c], J. Schliwinski[a], L. Shihora[a], P. Venkova[a], M. Wurm[b]

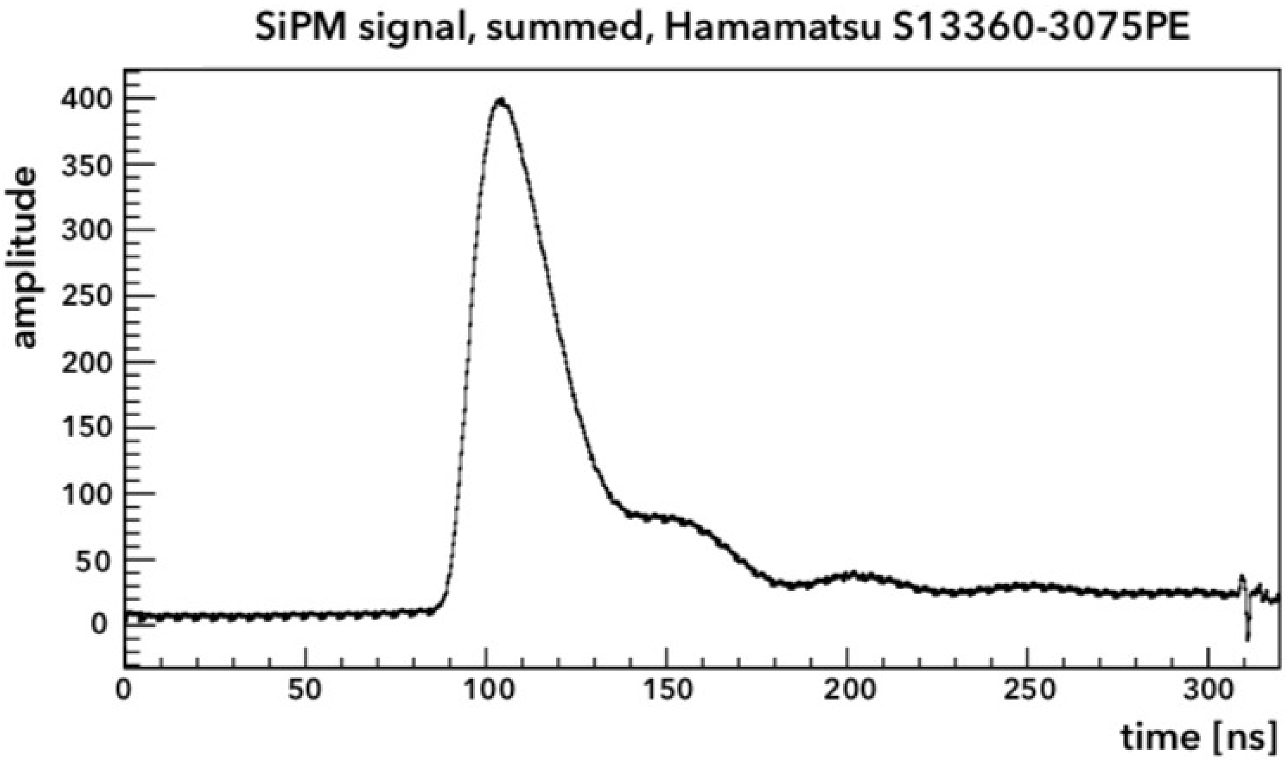
Proof-of-principle measurements with a liquid-scintillator detector using wavelength-shifting optical modules

CERN SPS Testbeam 2017

Performance Goals and Achievements

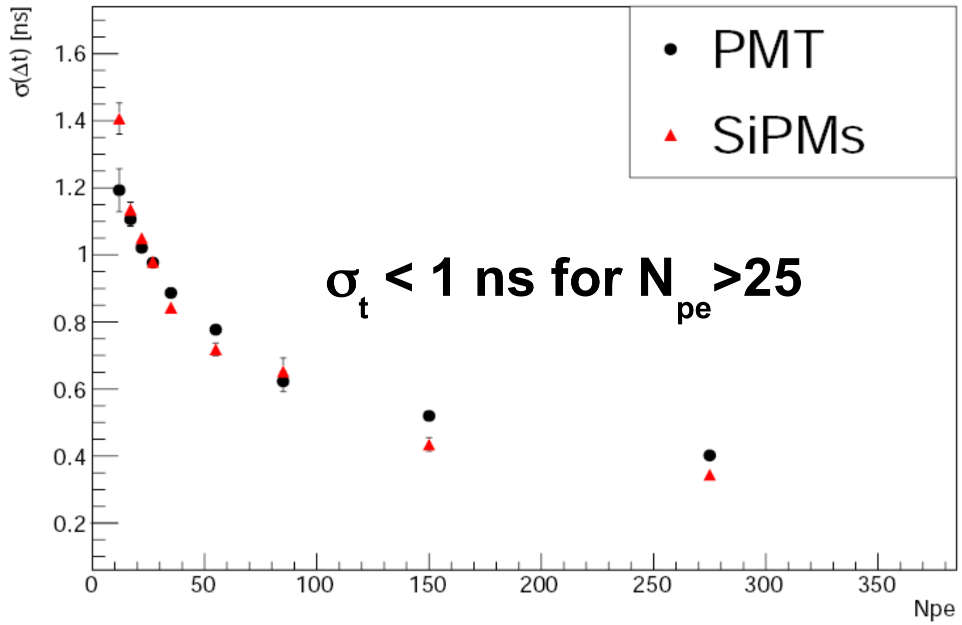
- **Fast rising edge**
  → good time resolution

- **Main light yield within O(50 ns)**
  → small dead time



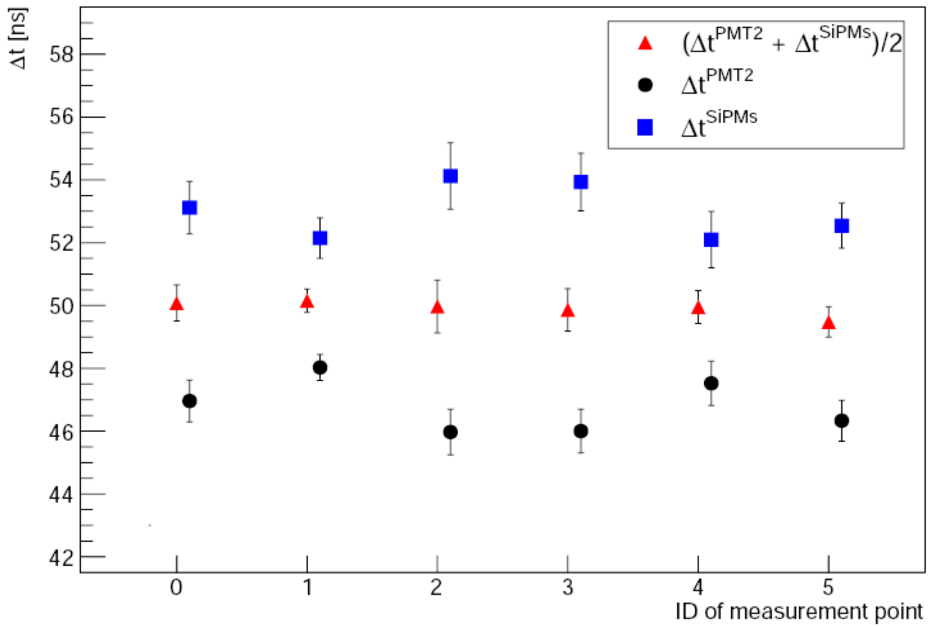
Performance Goals and Achievements

- **Time resolution with small protoype for one WOM as function of N_{pe}**



σ_t < 1 ns for N_{pe}>25

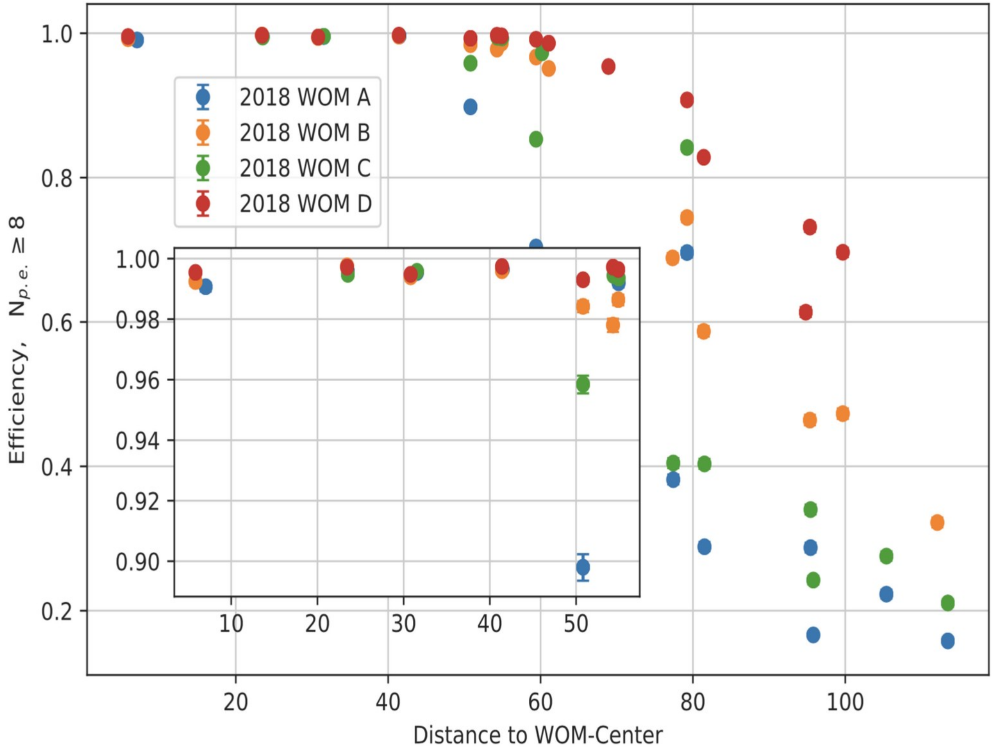
- **Time resolution with small prototype for two WOMs**



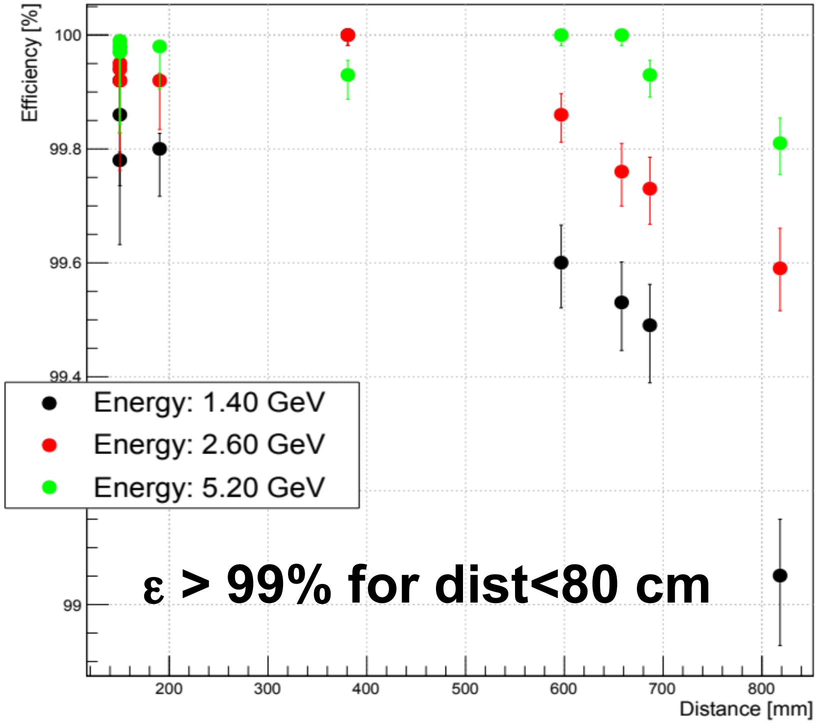
CERN SPS Testbeam 2017

Performance Goals and Achievements

- **Efficiency(Particle–WOM distance) measured with μ at CERN PS (2018)**



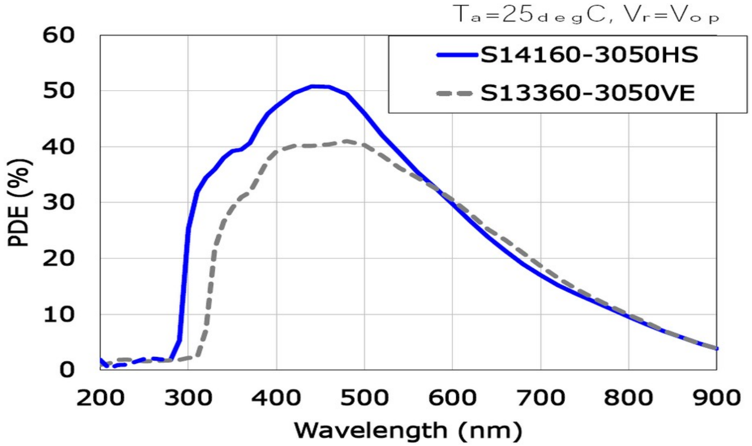
- **Efficiency(Particle–WOM distance) measured with e⁻ at DESY (2019)**

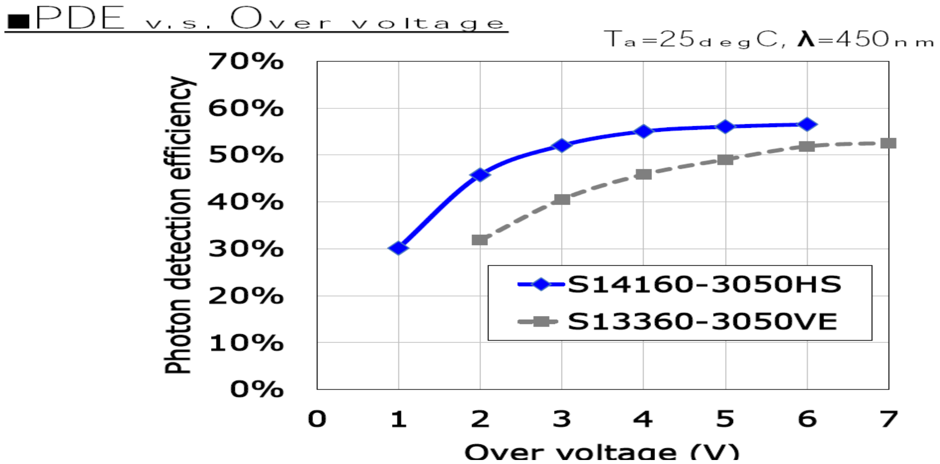


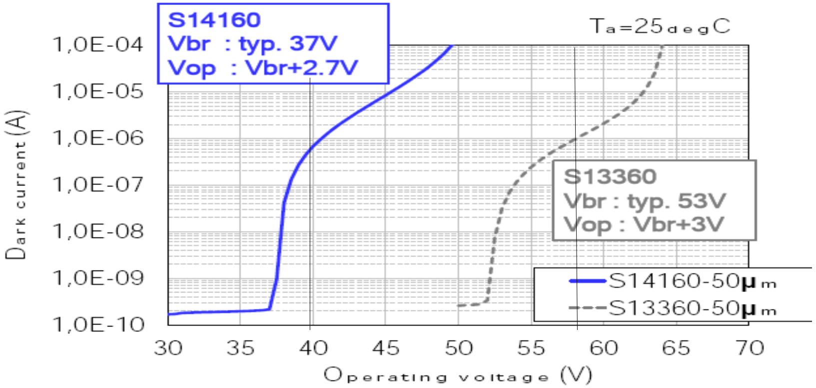
Increase of Signal-over-BG: 1

- **Replace Hamamatsu S13360-3075 SiPMs e.g. by S14160-3050**

  → higher SiPM efficiency at reduced overvoltage,
  reduced dark current+correlated noise
  reduced price (25%)





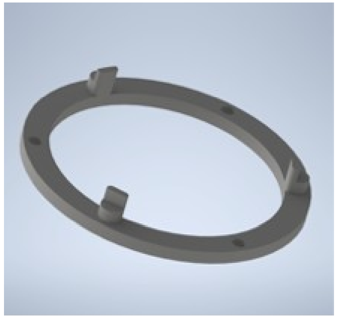


Increase of Signal-over-BG: 2

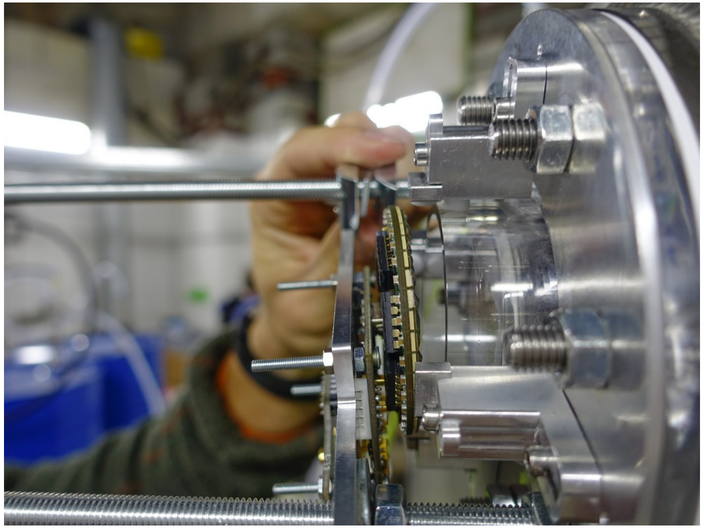
- **Defined WOM position inside PMMA vessel**
  Better & controllable optical SiPM-WOM coupling

  → 1st solutions at DESY 2019 testbeam
  → „engineer“ solution for TDR needed

- **„Mechanics“ in general (SiPM→ FEE; cabling; heat removal; light-tight cover)**



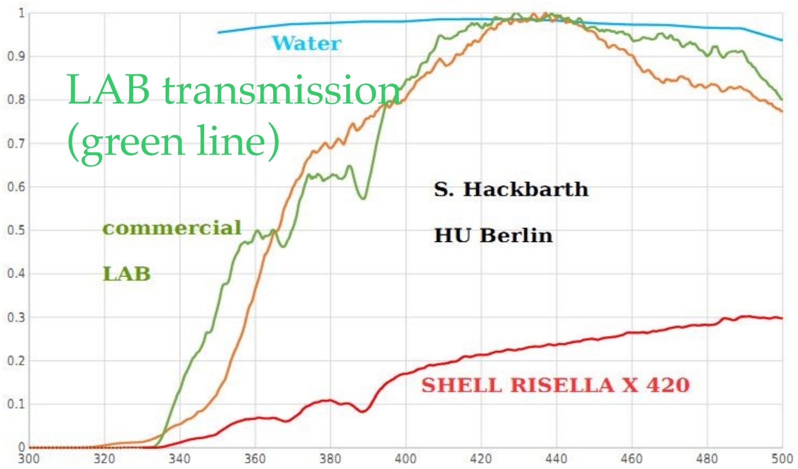
Bottom fixation of WOM



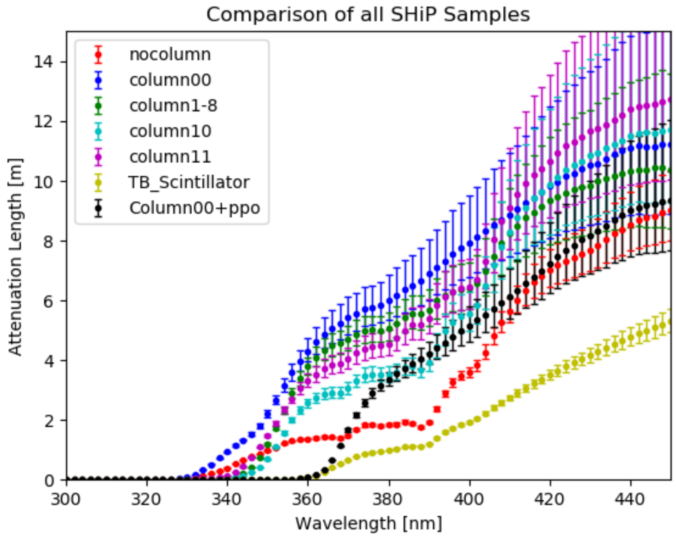
Top fixation of WOM, SiPM PCB and Music-board

Increase of Signal-over-BG: 3

- **Liquid-Scintillator Quality → TDR phase**



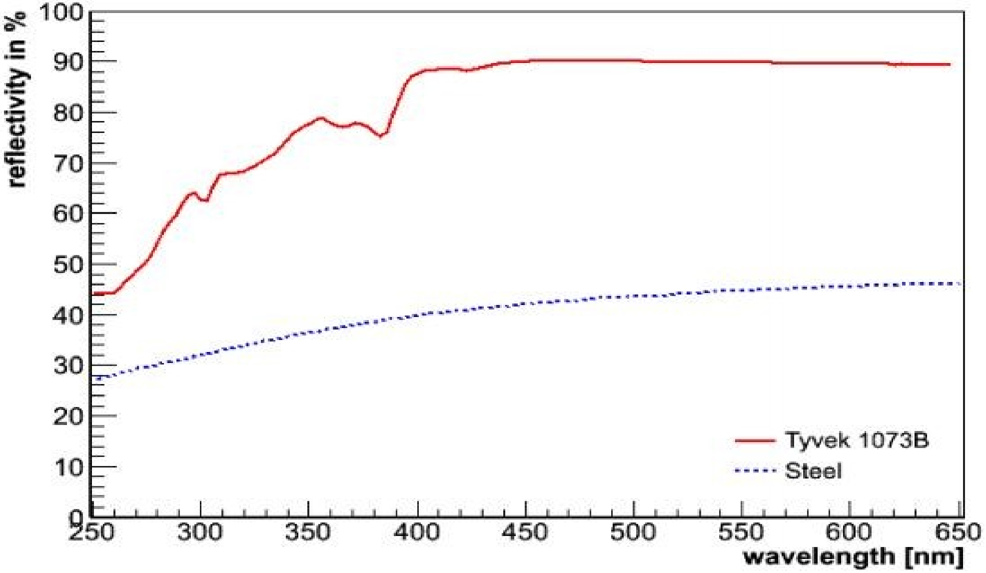
Al_2O_3 purification column in Mainzz

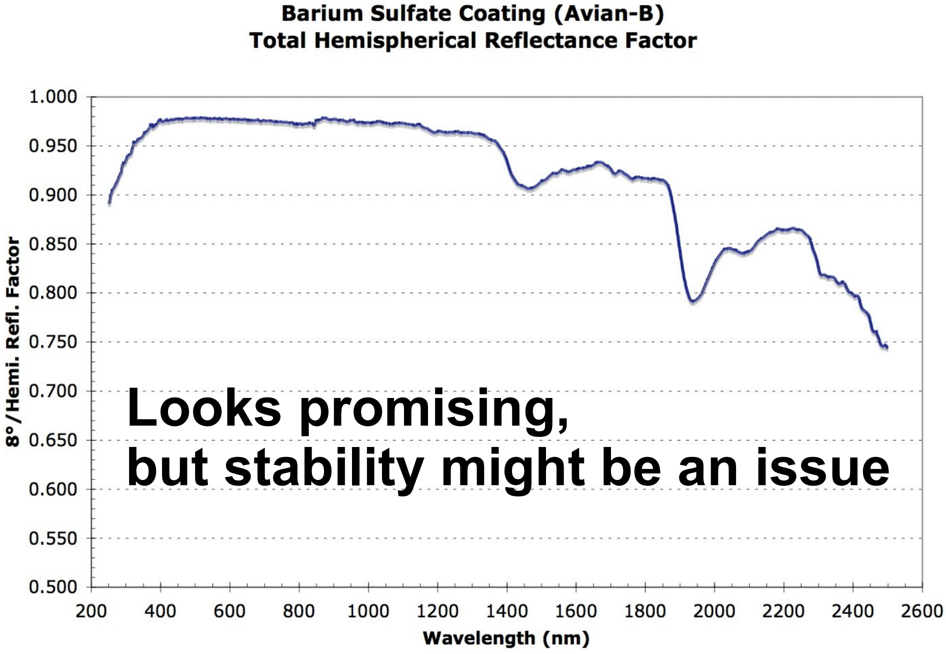


- **LAB purified (with Al_2O_3) by Mainz just arrived @ HU Berlin**
  → cosmics test: bachelor thesis will start after 1st corona wave
- **Usage of higher-quality LAB (→ JUNO, SNO) and PPO from the beginning**
- **Add small amount of bis-MSB to LS**
  and change WOM-WLS from blue to green (→ R&D)

Increase of Signal-over-BG: 4

- **Coating of inner cell walls with reflecting acrylic-paint (Mainz) → TDR phase**
- **Always to consider: Mechanical stickiness; Chemical compatibilty with LS**
- **Coating after welding of the cells through WOM vessel holes**

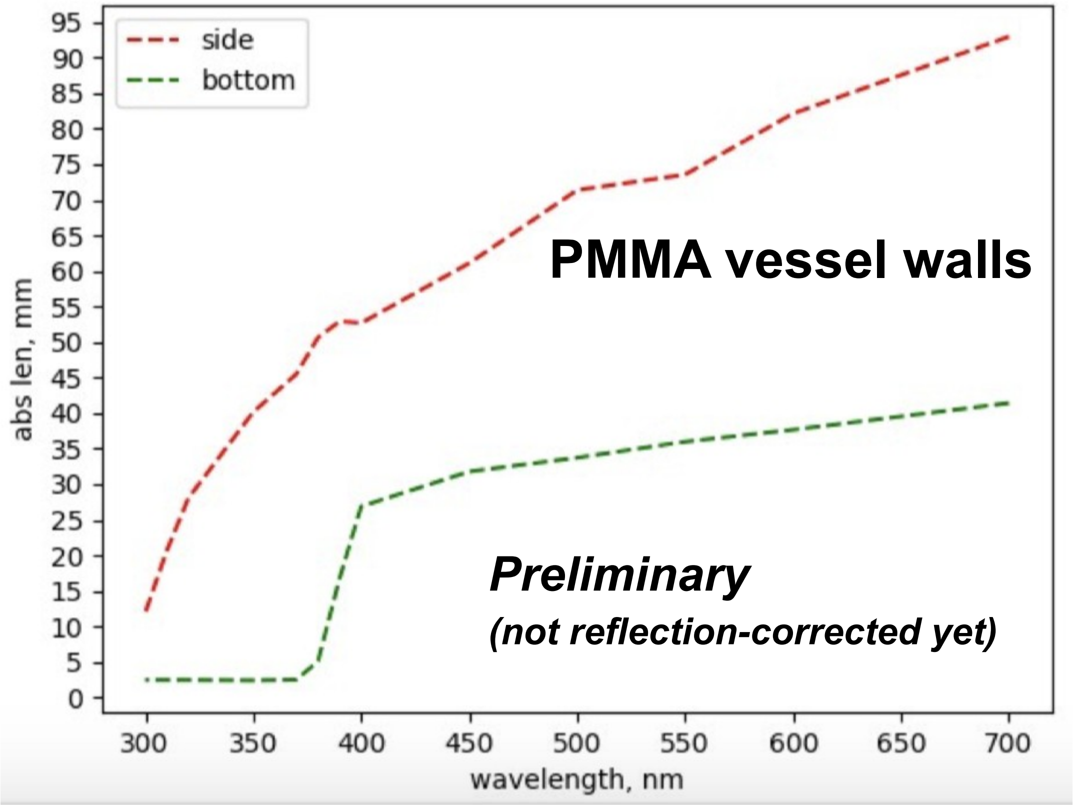


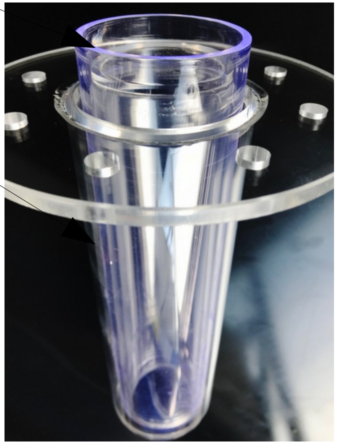


Looks promising,
but stability might be an issue

Increase of Signal-over-BG: 5

- **Transparency of WOM tube for visible light**
- **UV-transparency of PMMA vessel material**

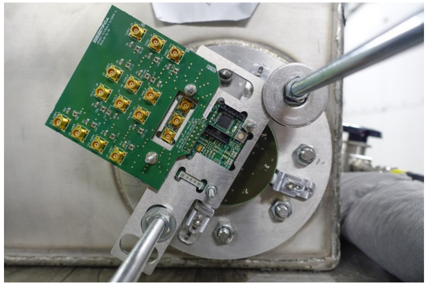




Electronics

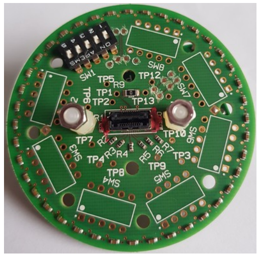
- **Up to now & during the next couple of years):**

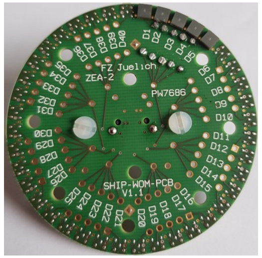
  Readout board with MUSIC ASIC for amplification of 8 SiPM channels (individual & sum) (Barcelona; too expensive for complete experiment)

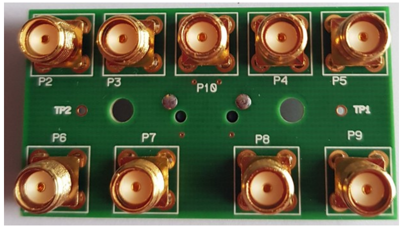


- **WaveCatcher (LAL Orsay) for digitization plus ROOT-based analysis software (HU Berlin)**

- **Improved PCB developed by ZEA2 Jülich for new S14160-3050 Hamamatsu SiPMs**







- **Ideas for FEE and also Concentrator Electronics: Dedicated talk by D. Arutinov**

TDR phase: areas for contributions

- **Pre-Claimer:**

  Contributions possible and welcome in all areas

  Red color: contributions particularly highly welcome!

TDR phase: areas for contributions

- Increasing the light collection (see slides before)
- Reflectivity and absorption measurements of materials
- Design and construction of the WOMs/PMMA vessels
(material, shape → transparency; chemical compatibility;
pressure resistance of PMMA vessel)

  In contact with possible partner: IKV RWTH Aachen

- WOM dip-coating and quality assurance/control,
e.g. coating thickness, efficiency measurements,
preparation of large-scale production
- LS handling
- Integration, e.g. how to fill and empty the LS-SBT?
(tests with various transparent Mock-Ups in close collaboration with Naples)

TDR phase: areas for contributions

- **Light calibration system (LED or laser-based) for LS and SiPMs**

- **FEE (ZEA2 is planning to develop a FE card based on a new chip building on their expertise with VULCAN(Gerold))**

- **Concentrator electronics (collection and selection of signals for DAQ), e. g.: sum of two WOM signals/cell and adjacent cells > defined threshold**
  → suppress dark current + correlated noise of SiPMs as well as upstream μ-induced electromagnetic BG

- **Powering (LV and HV)**
  e.g. FE-onboard „HV“ powering using already developed concepts (possible collaboration with Thomas Bretz, RWTH Aachen ?)

TDR phase: areas for contributions

- **MC simulations:**

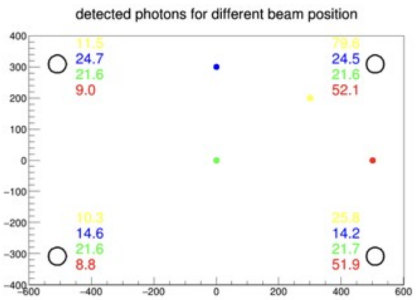
  - Light transport

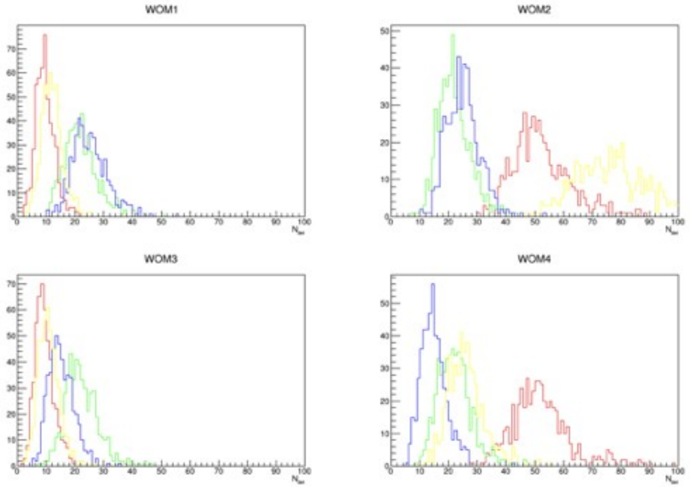
  - WOM position optimization

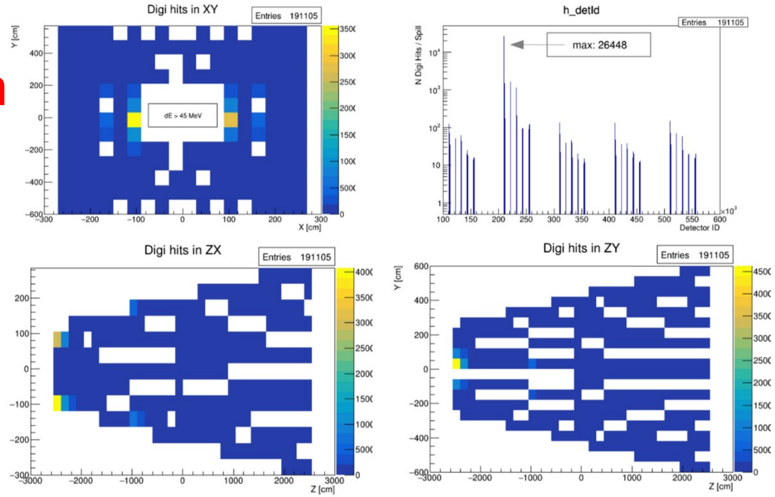
  - FairSHiP
  (geometry; detector response parameterisation; BG rates from μ + e.m. showers and its mitigation

  - Radiation level @ SIPM and electronics location

- **Physics analysis studies with FairSHiP: e.g. μ/ν DIS BG; $N \to l^- \rho^+ \to (\pi^+ \pi^0)$ with SBT**

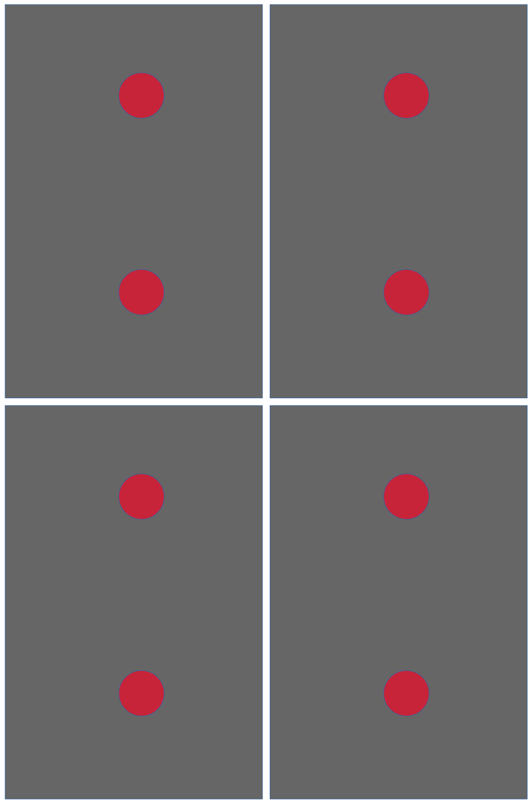






TDR phase: areas for contributions

- **4-cell demonstrator detector (incl. movable/rotatable support structure!)**



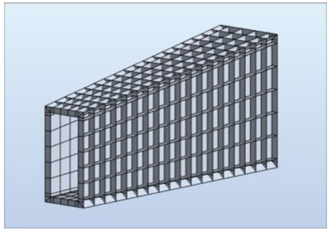
- **Cosmics measurements from 2022 onward**
  → requiring a large scintillator hodoscope with good coverage and decent granularity to reduce measurement times

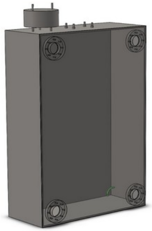
- **Testbeam measurement in 2022 (2023) (with test versions of FEE, concentrator electronics and powering)**

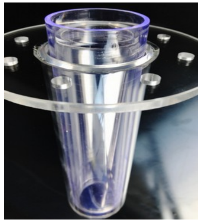
- **TDR delivery: End of 2023**

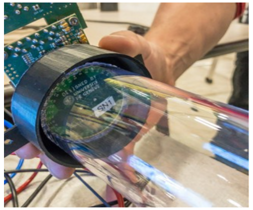
Summary

- **SBT: → crucial veto system for SHiP with strong German participation**
  → potential for extending signal sensitivity to be explored
- **Baseline option: Liquid Scintillator with WOM+SiPMs as photodetectors**
- **Proof-of-Principle demonstrated**
- **TDR phase (this year – end of 2023):**
  Many opportunities to contribute (impact even with moderate personpower)



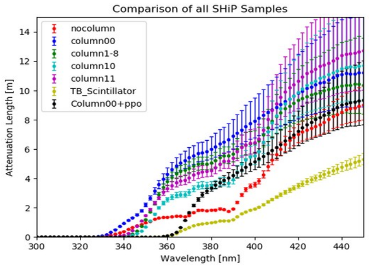


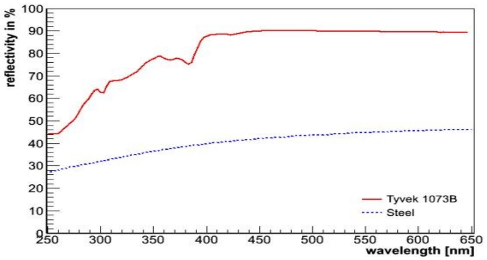


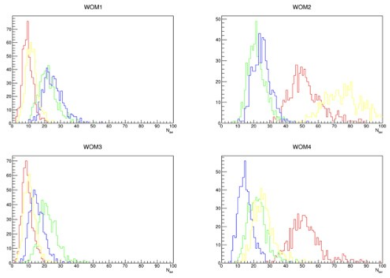


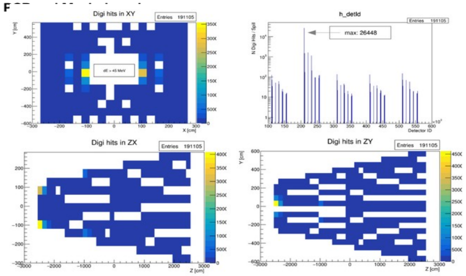
Top fixation of WOM,

Al_2O_3 purification column in Mainzz



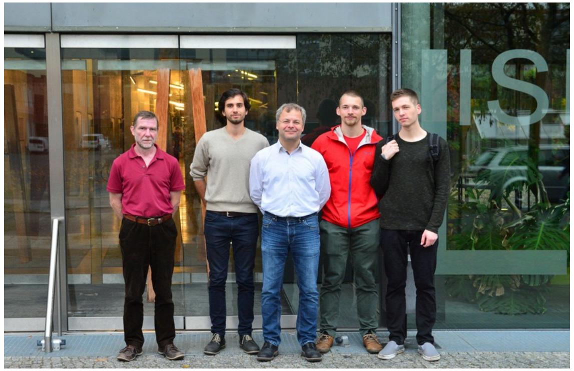






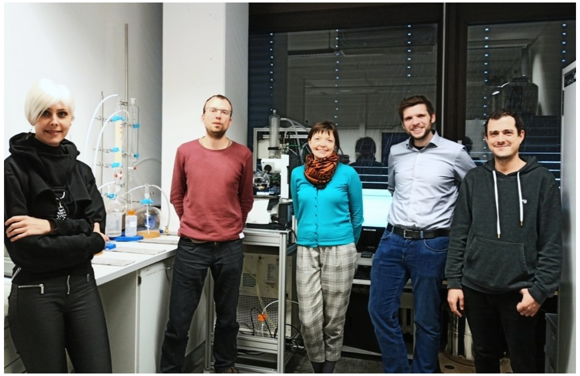
Looking forward to welcome you!

Humboldt-Universität zu Berlin



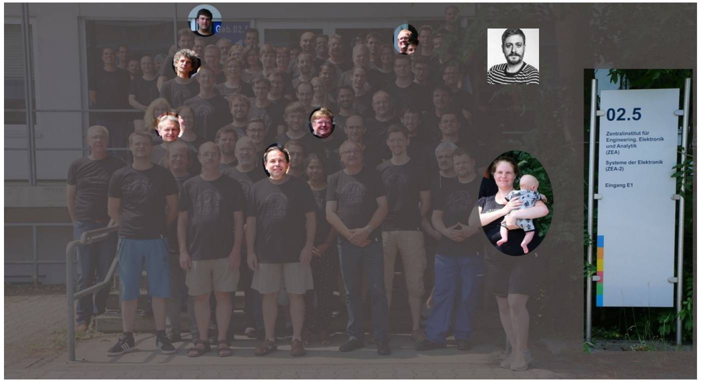
„WOMs, Data Analysis“

Johannes Gutenberg-Universität Mainz



„Scintillator“

ZEA2 FZ Jülich



„Electronics“

Taras Shevchenko National University of Kyiv

„Photon propagation simulation“

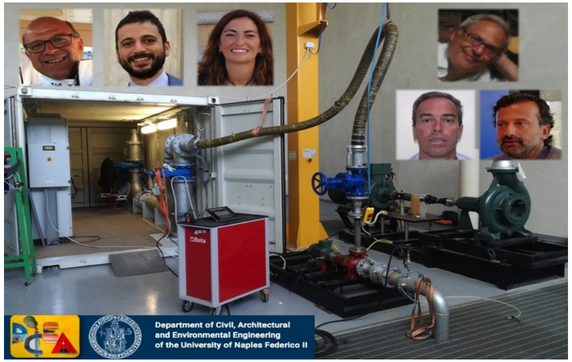
University of Naples Federico II

Dipartimento di Strutture per l'Ingegneria e l'Architettura

„Decay Vessel Design & Construction“

University of Naples Federico II

Dipartimento di Ingegneria civile, edile e ambientale



„Hydraulics: Filling and emptying SBT“