The Surround Background Tagger (SBT)

SHiP
Search for Hidden Particles

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

SHiP Decay Vessel workshop
12.02.2021

Overview

* 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

* Important areas for R&D

Groups involved

LS-SBT:

- **Humboldt University of Berlin (Germany): H. Lacker**
- **Albert Ludwigs Universität Freiburg (Germany): M. Schumann, H. Fischer**
- **Johannes Gutenberg University Mainz (Germany): M. Wurm**
- **Forschungszentrum Jülich, ZEA-2 (Germany): S. Van Waasen**
- **Taras Shevchenko National University of Kyiv (Ukraine): O. Bezshyyko**

+ RWTH Aachen (Germany): T. Bretz → Generic R&D (SiPM-WOM)

Vaccum Vessel construction:

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

Filling and empyting of the Surround BG Tagger:

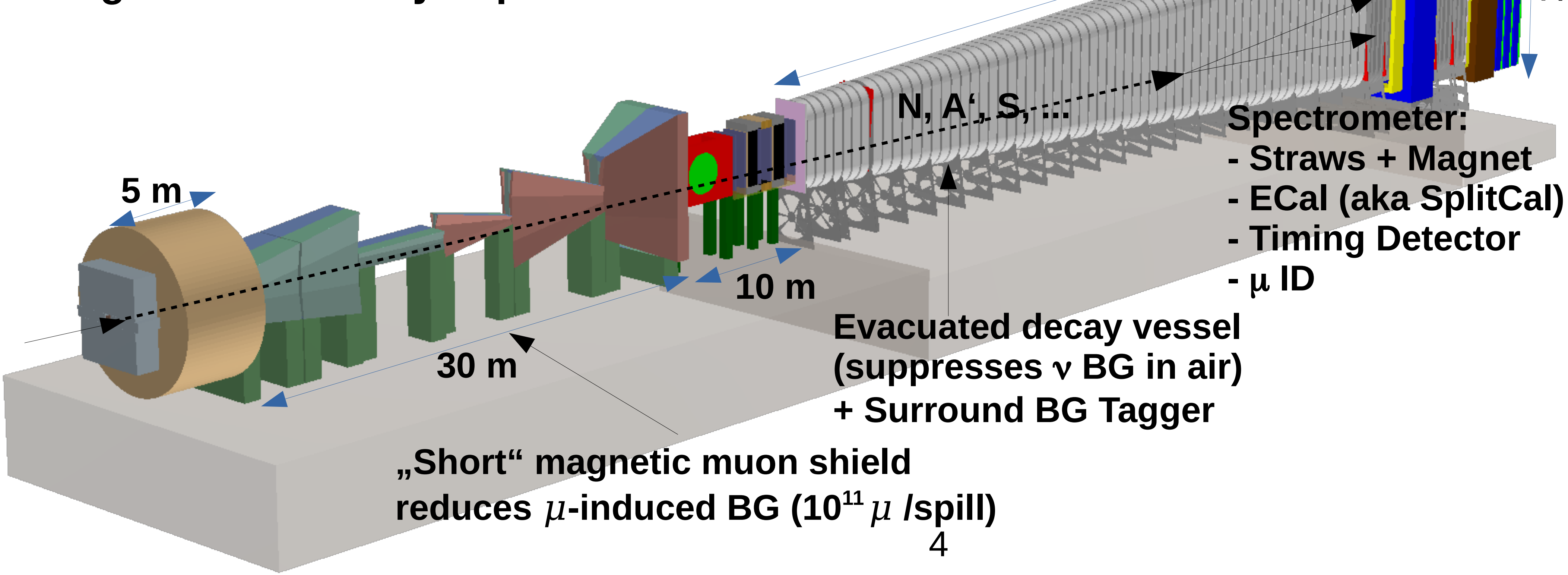
- **University of Naples Federico II (Italy): C. Di Cristo and other Profs.**

SHiP: Detector Overview (not fully up-to-date)

High-intensity and low-BG experiment:

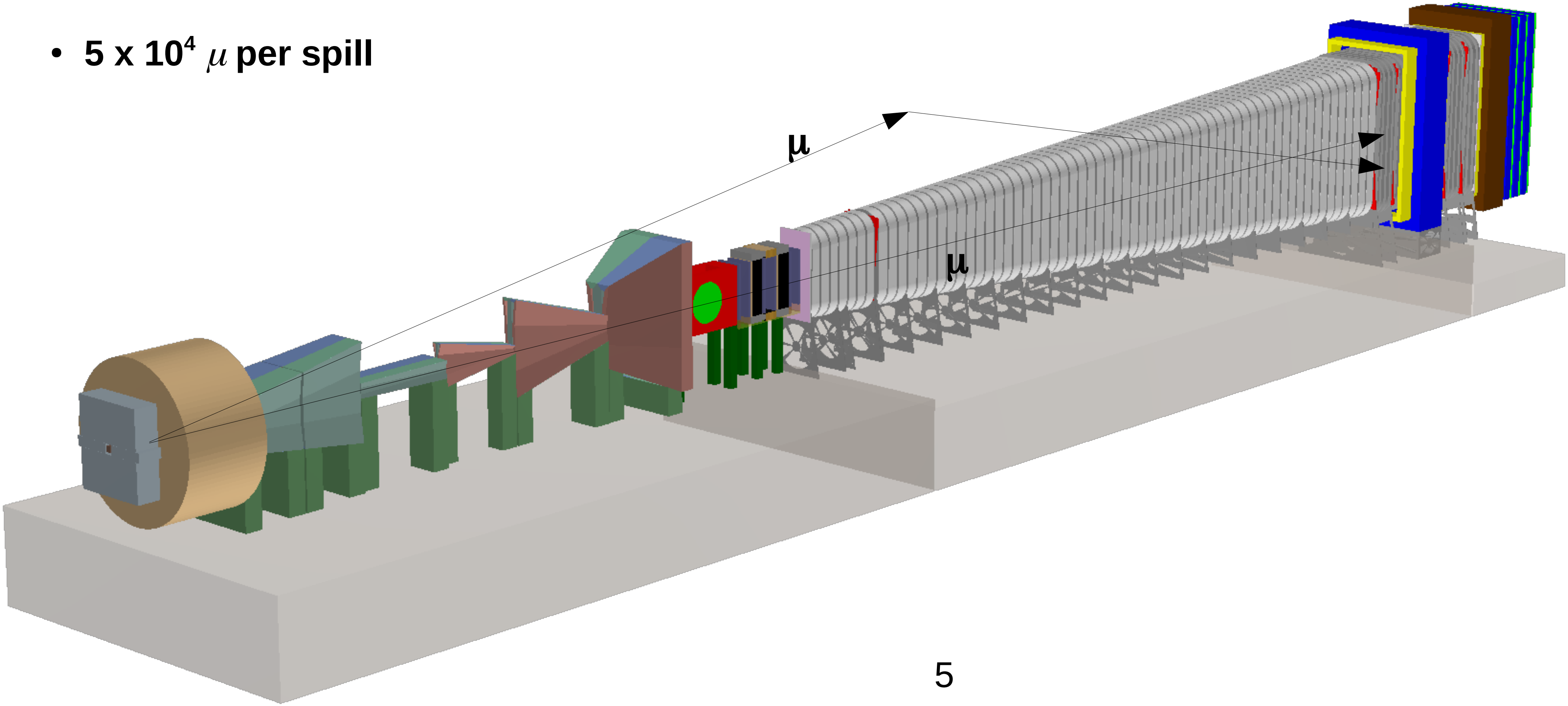
Veto systems crucial for BG rejection and redundancy

→ High veto efficiency required



Purpose 1: Detect μ entering the decay vessel

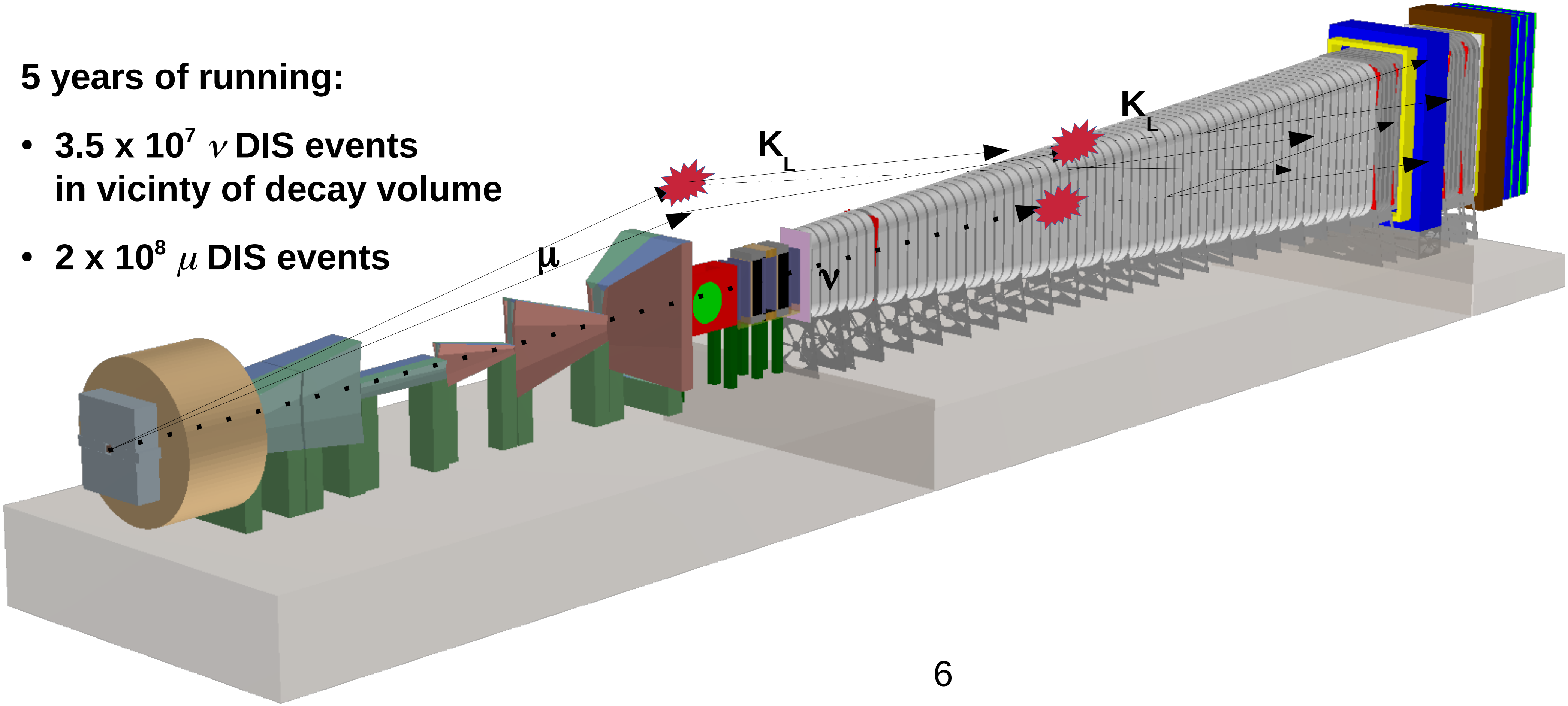
- **5 x 10^4 μ per spill**



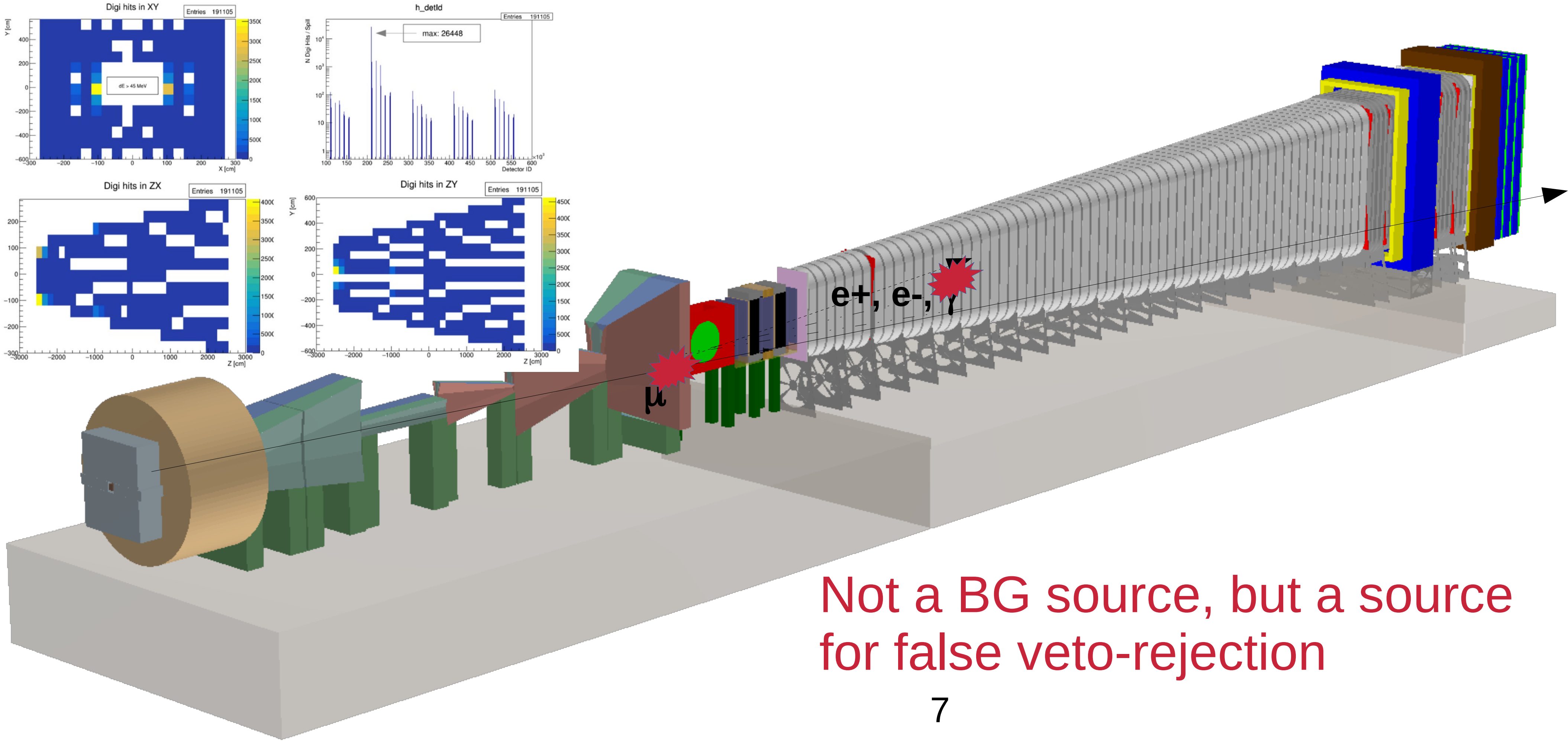
Purpose 2: Detect μ and ν DIS in decay vessel walls and surroundings

5 years of running:

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



Challenge:
Electromagnetic debris from muon-interactions with upstream materials generate a hit rate in the SBT (for the current geometry layout) much higher than the muon hit rate



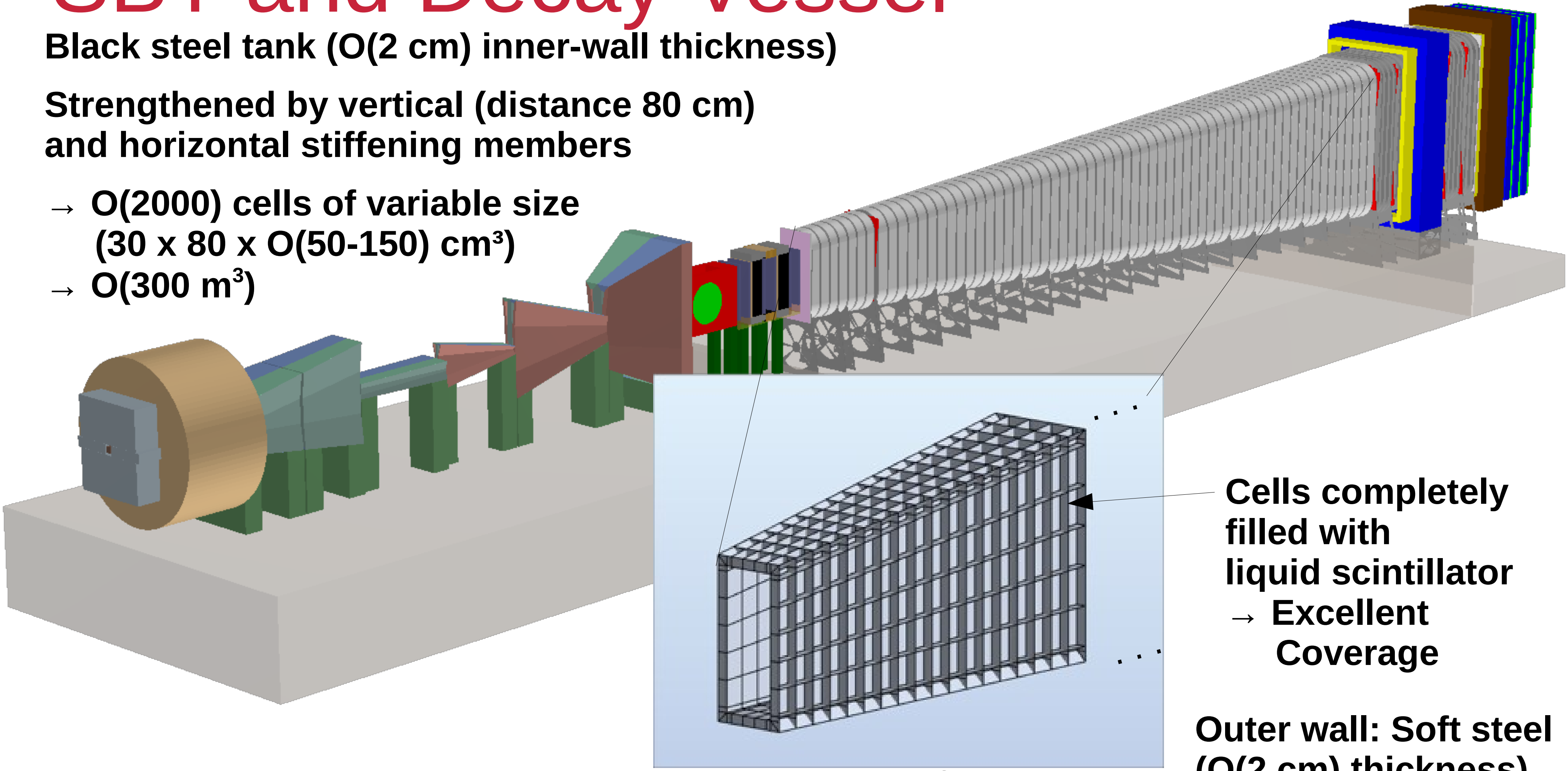
Not a BG source, but a source for false veto-rejection

SBT and Decay Vessel

Black steel tank (O(2 cm) inner-wall thickness)

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

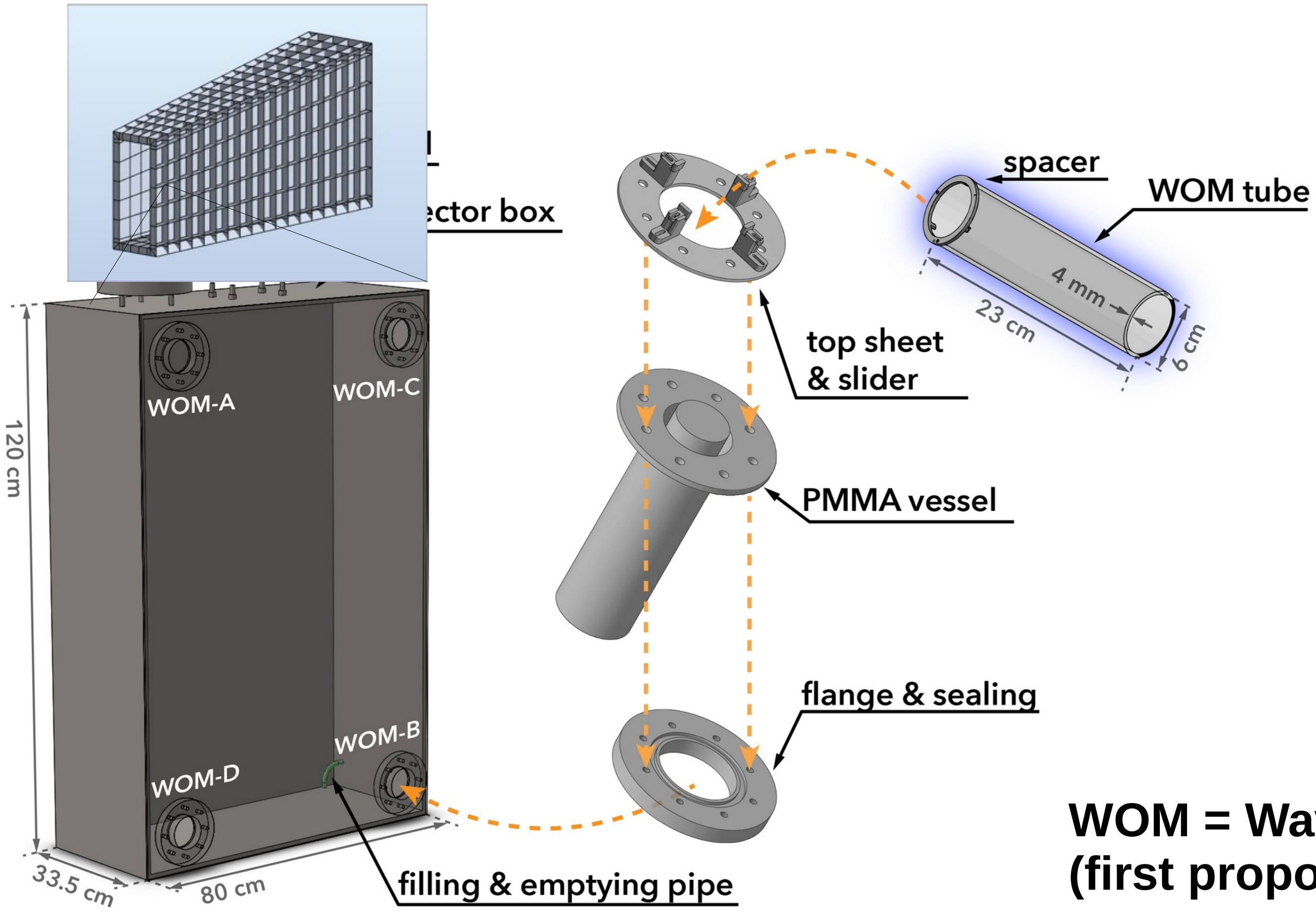
→ O(2000) cells of variable size (30 x 80 x O(50-150) cm³)
→ O(300 m³)

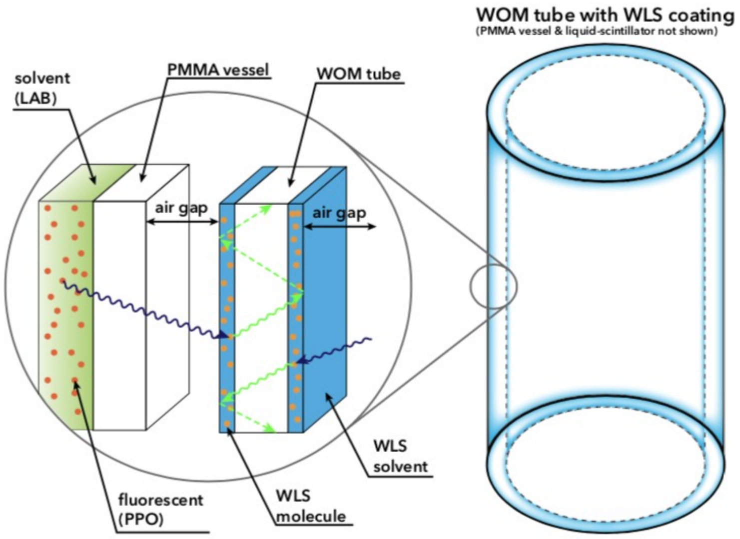


Cells completely filled with liquid scintillator
→ Excellent Coverage

Outer wall: Soft steel (O(2 cm) thickness)

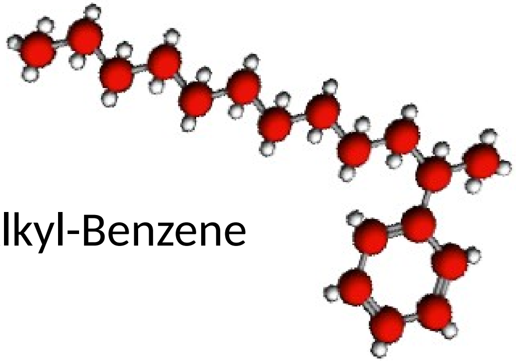
Detection principle (here for a test detector)





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

SBT: Liquid Scintillator

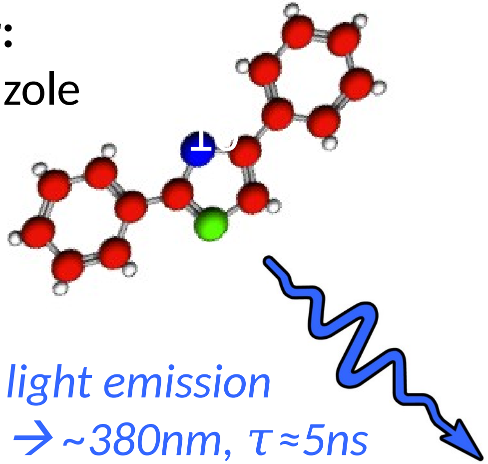


solvent:
Linear Alkyl-Benzene (LAB)

+

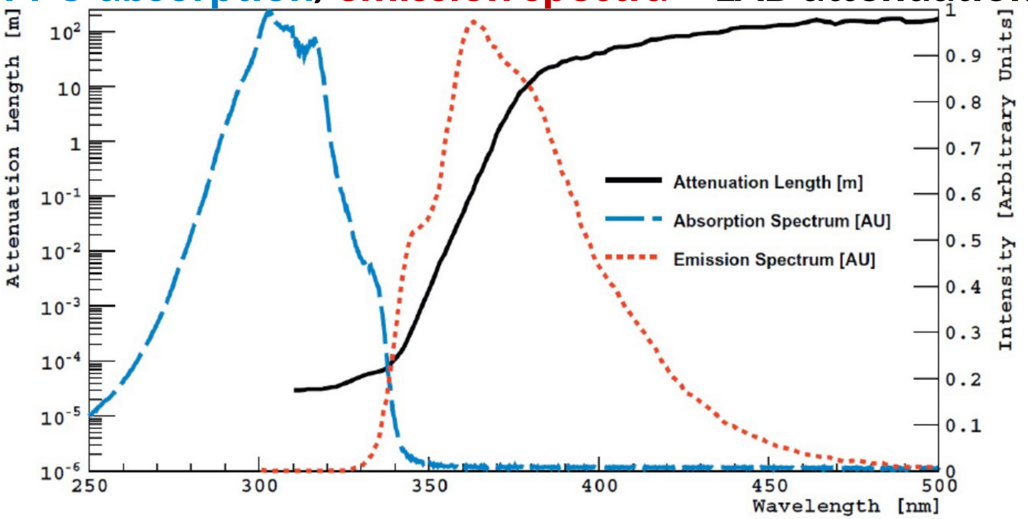
non-radiative
→ 280nm

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



light emission
→ ~380nm, τ≈5ns

PPO absorption/emission spectra + LAB attenuation



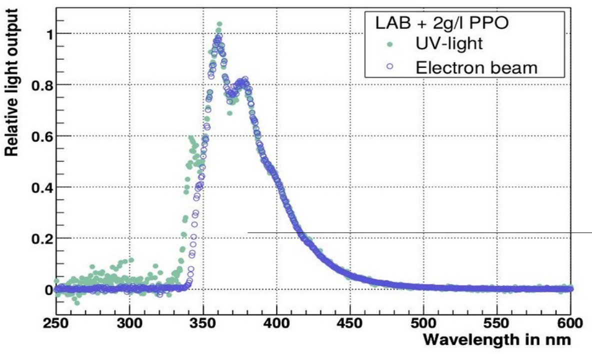
Light yield: ~10^4 photons/MeV

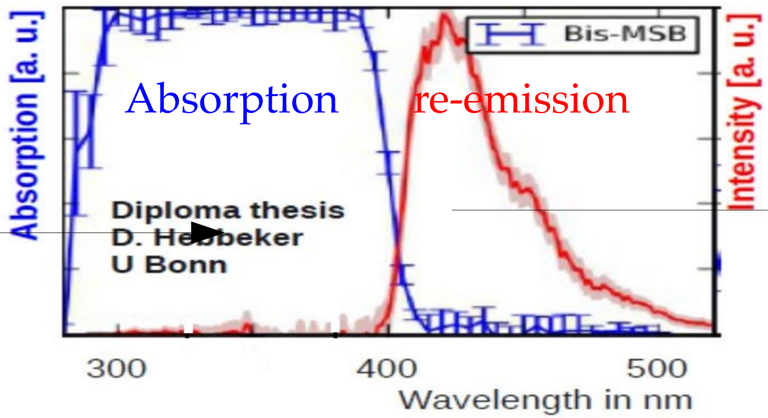
Composition:

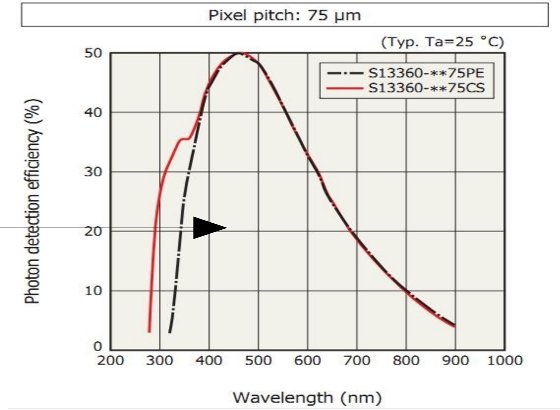
→ **Solvent: LAB**
- high transparency: λ_{scat}~20m @ 400nm

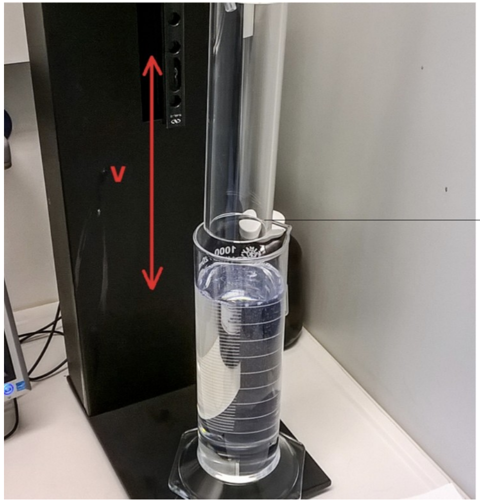
→ **Fluor: PPO**
- fast timing: O(ns)
- high efficiency: ε_{PPO} > 90-95%
- high solubility: ~100g/l okay

Wavelength-Shifting Optical Modules (WOMs)

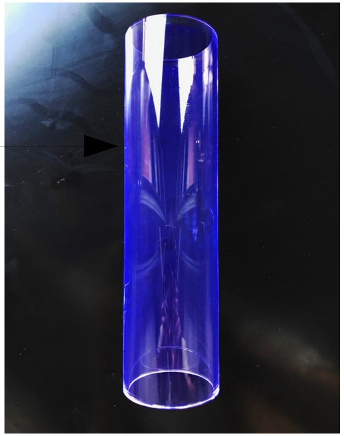




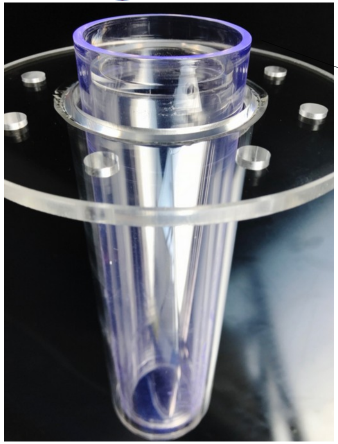




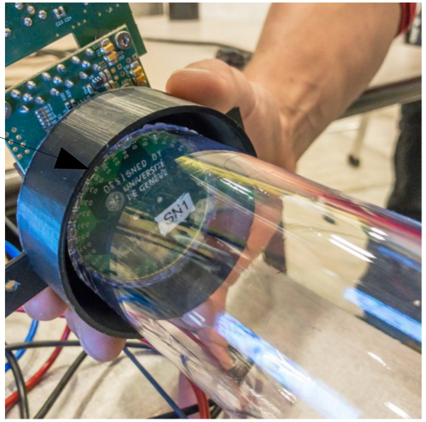
WOM dip-coating with WLS dye



Dip-coated WOM tube



Vessel separating WOM from LS



Optical coupling to 40-SiPM ring array

Performance Goals and Achievements

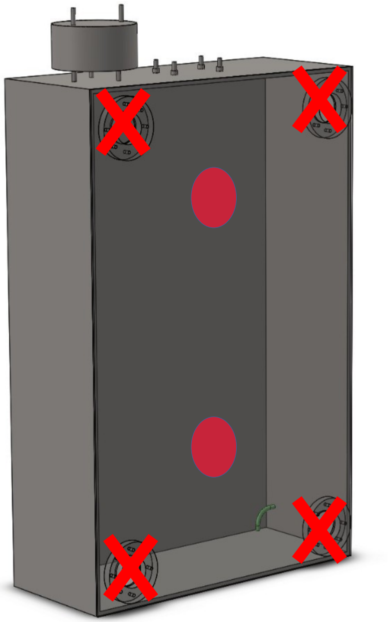
- **SHiP BG rejection performance assumes for LS-SBT:**
  1. E_{dep} > 45 MeV (in at least one cell) → ΔE of cosmics μ trasversing a (30 cm thick) cell
  2. ε=99.9%

- **Good homogeneity**

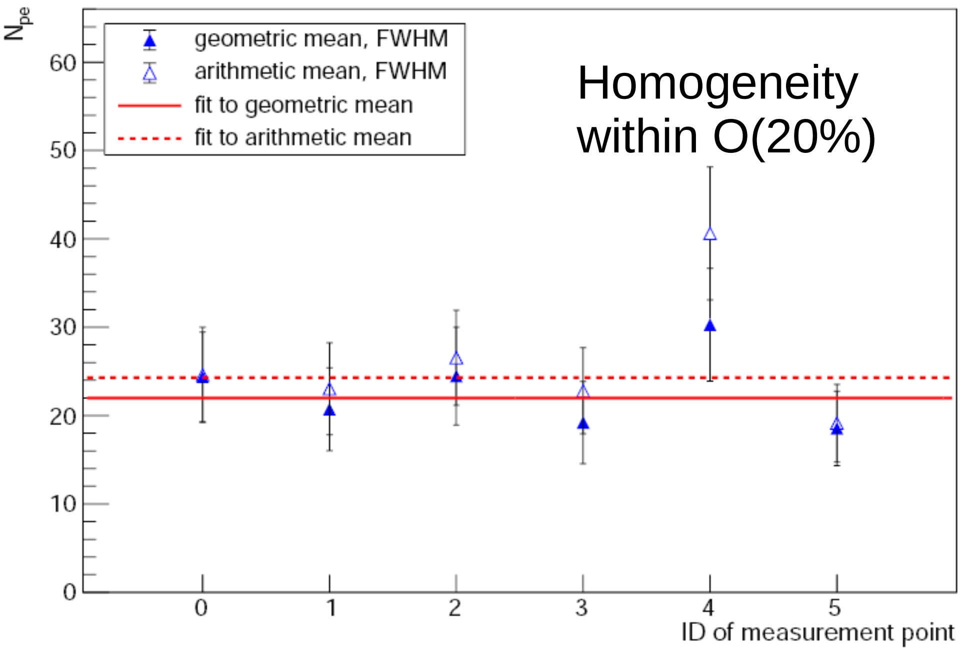
- **Good time resolution and small deadtime**

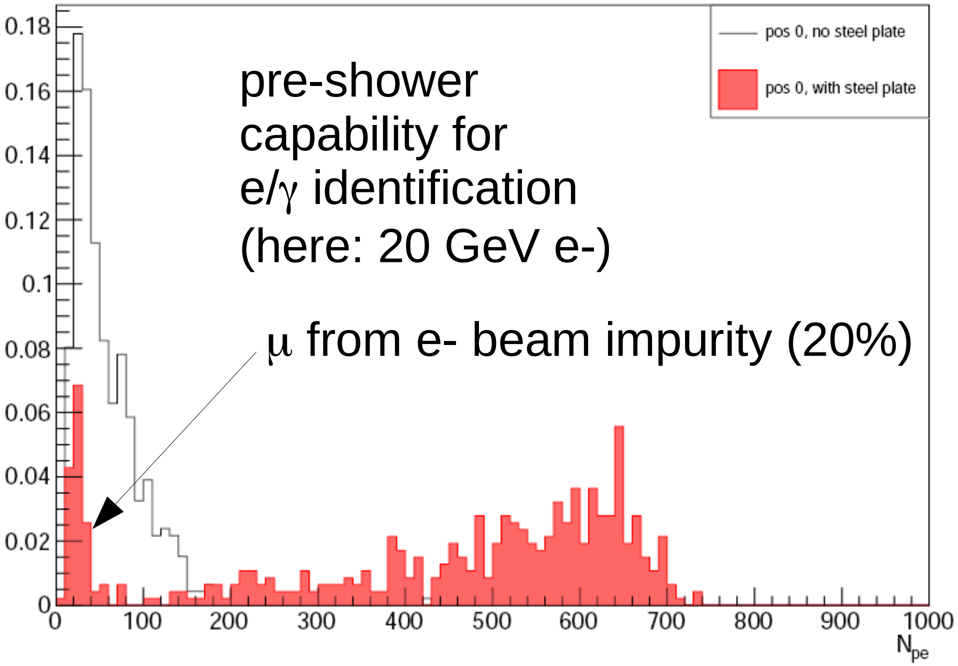
- **Good spatial resolution**

→ 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]

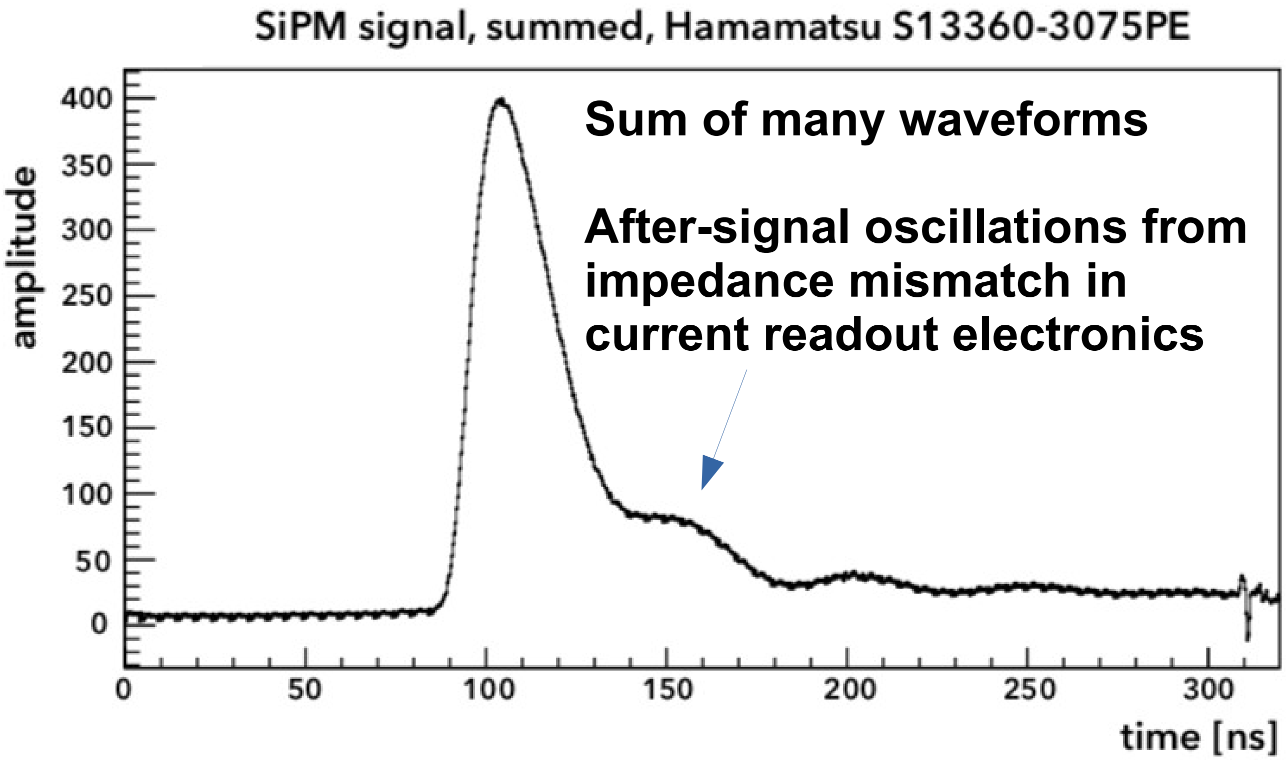
Proof-of-principle measurements with a liquid-scintillator detector using wavelength-shifting optical modules

CERN SPS Testbeam 2017

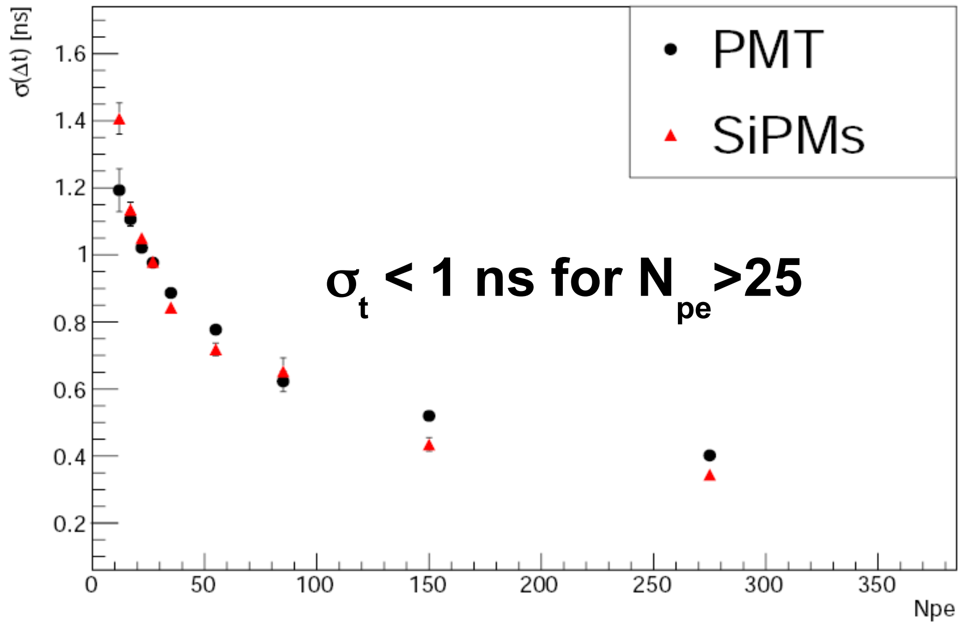
Performance Goals and Achievements

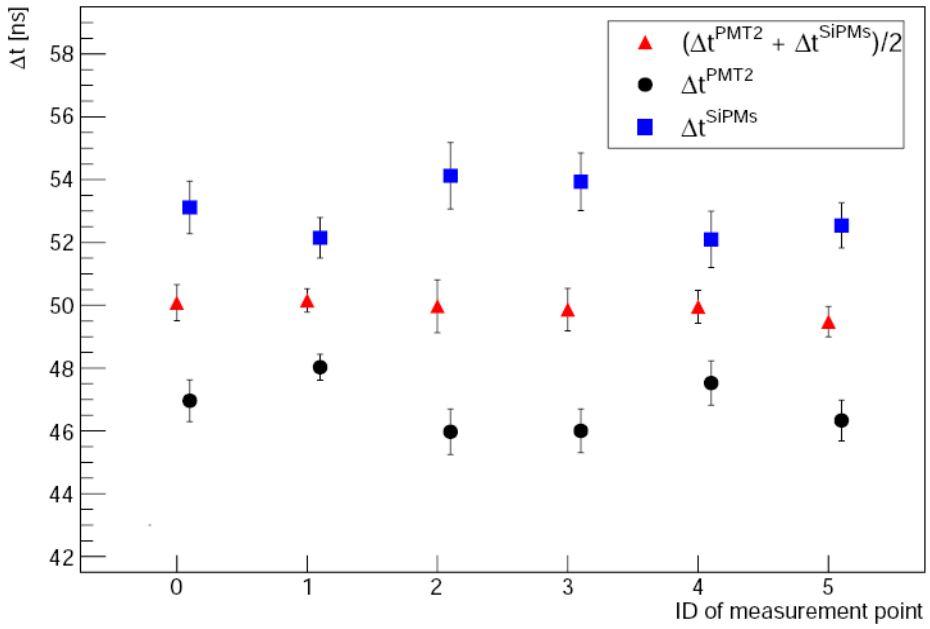
- **Fast rising edge**
  → good time resolution

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



Performance Goals and Achievements

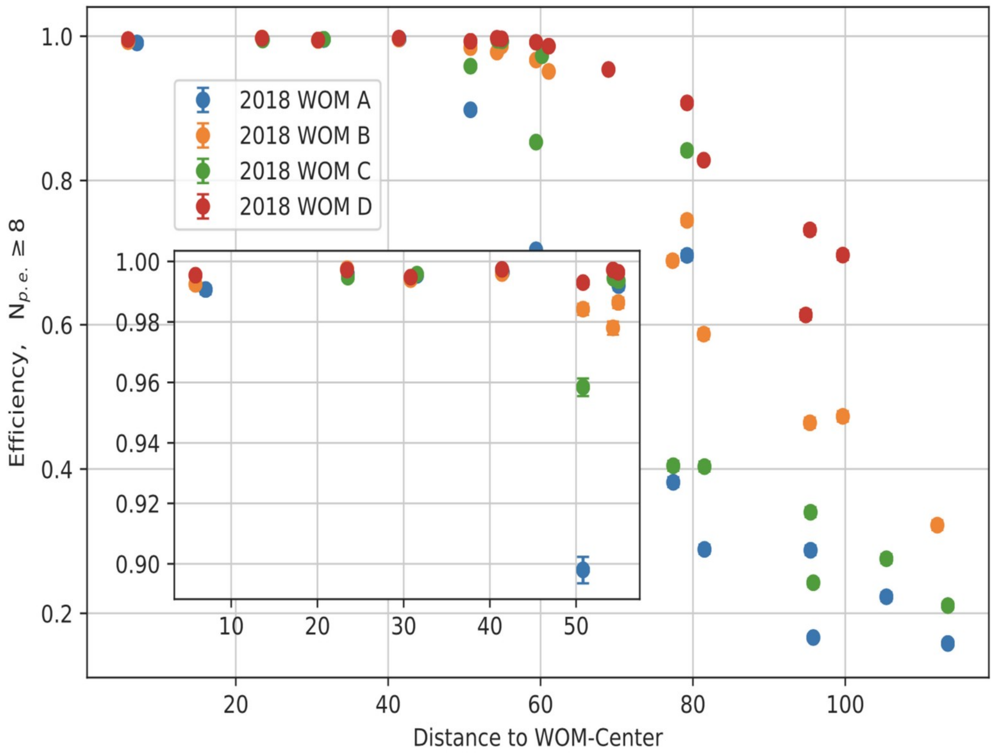




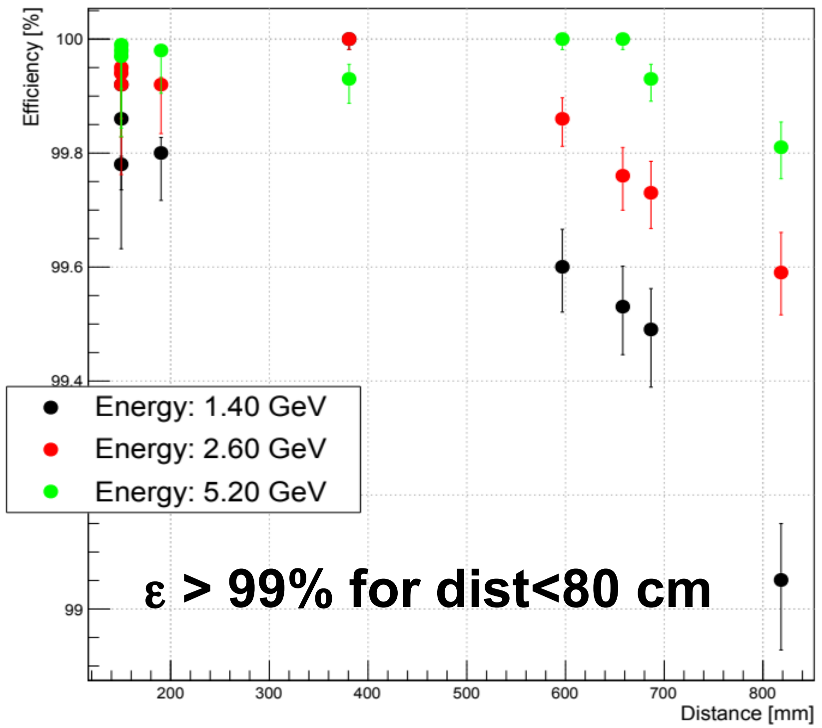
CERN SPS Testbeam 2017

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)**



Main areas for LS-SBT R&D:

- **Design of the decay vessel wrt integration of the LS-SBT (Structural aspects, filling/emptying, chemical compatibility btw soft steel & LS, reflectivity coating, access to inner part of vacuum vessel; holes, flanges, ...)**
- **Increase of photon yield (SiPMs, liquid scintillator, reflectivity coating)**
- **WOM(-vessel) design**
- **Photon transport simulations**
- **FairSHiP simulations (→ BG studies, electromagnetic debris)**
- **Electronics (SiPMs (incl. Powering), FE, concentrator)**
- **Prototypes**
- **Testbeams**
- **Cost reductions**