The SHiP experiment and the MRPC technology

A. Blanco

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Fundação para a Ciência e Tecnologia, Portugal (CERN/FIS-INS/0006/2021, CERN/FIS-INS/0028/2021) and European Union's Horizon 2020 Research and Innovation programme under Grant Agreement AIDAinnova - No 101004761

Outlook

- SHiP experiment @ ECN3 @ CERN.

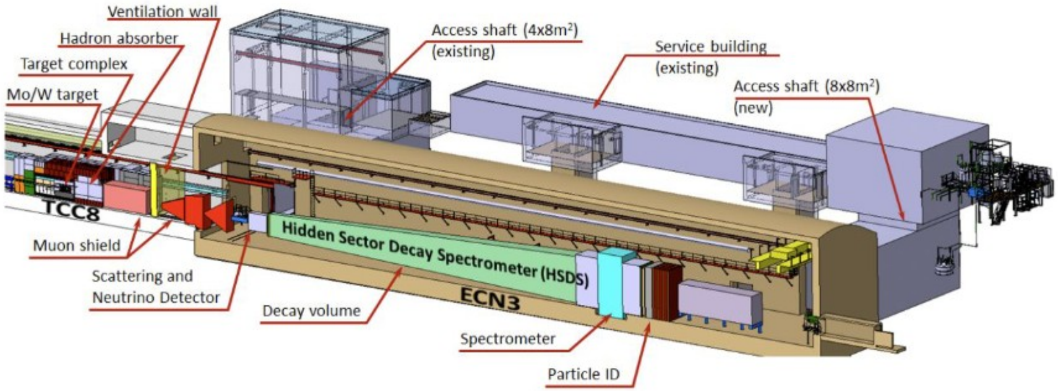
- Different sub-systems.

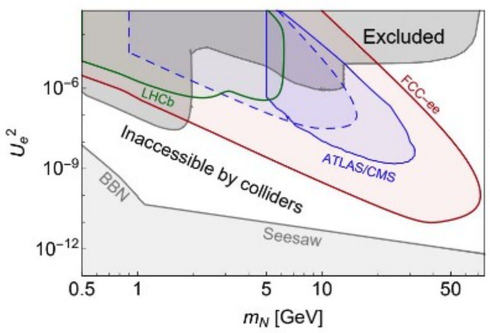
- Timing RPC technology for SHiP.

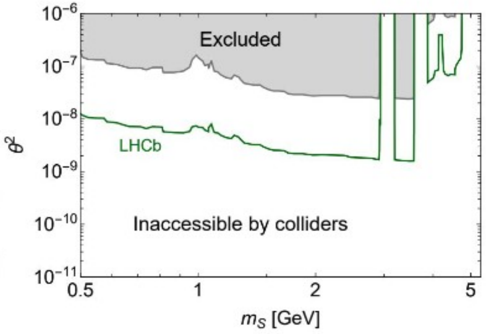
SHiP. Physics case

CERN Research Board approved SHiP/BDF to move forward to the Technical Design Report (TDR) Phase (to be ready in three years) in preparation for installation in ECN3.

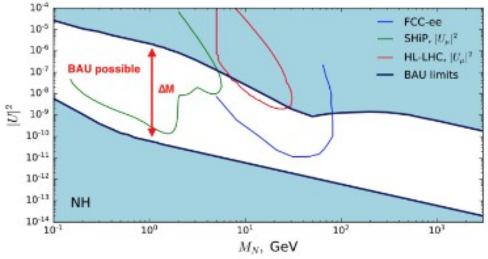
- The **main goal** of the experiment is to provide **sensitivity to Feebly Interacting Particle** (FIPs) models not accessible to colliders.







- General Purpose experiment for **Hidden Particles** in the forward region predicted by a large number of models of Hidden Sectors.



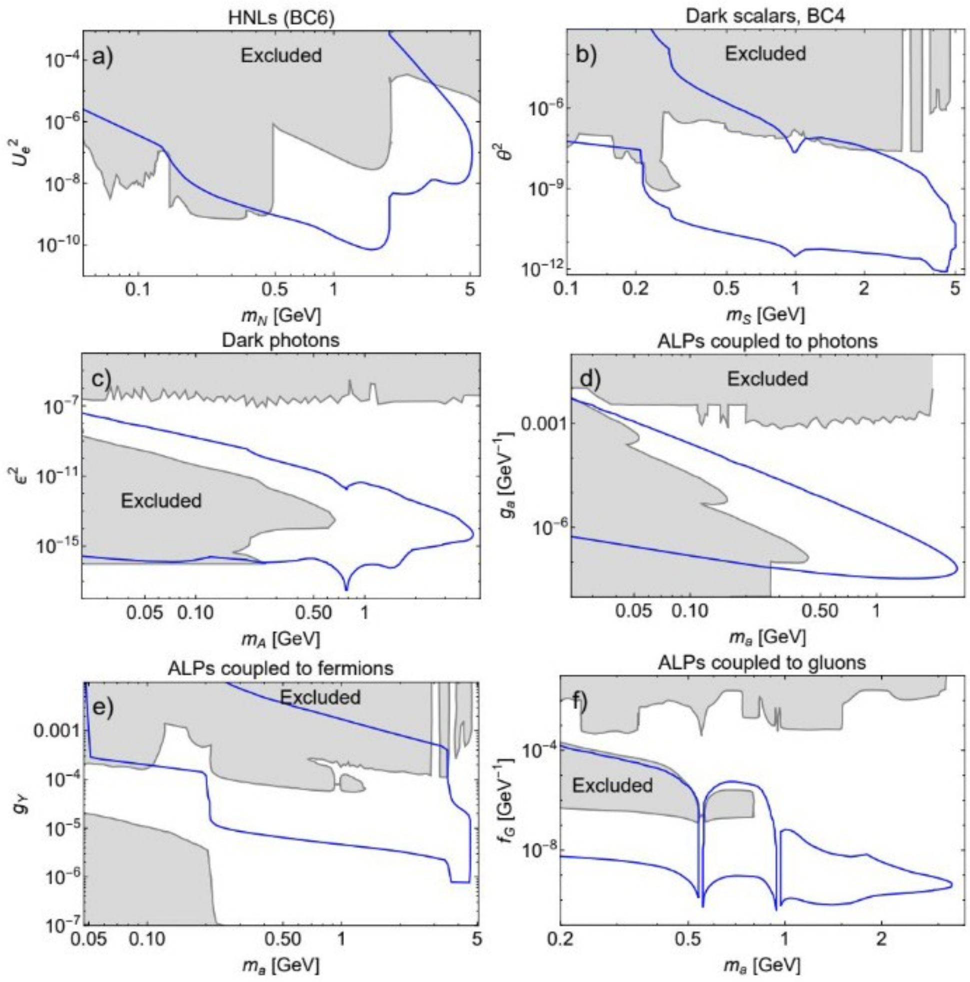
- The facility is ideally suited to study the interactions of **tau neutrinos.**

SHiP. Physics case

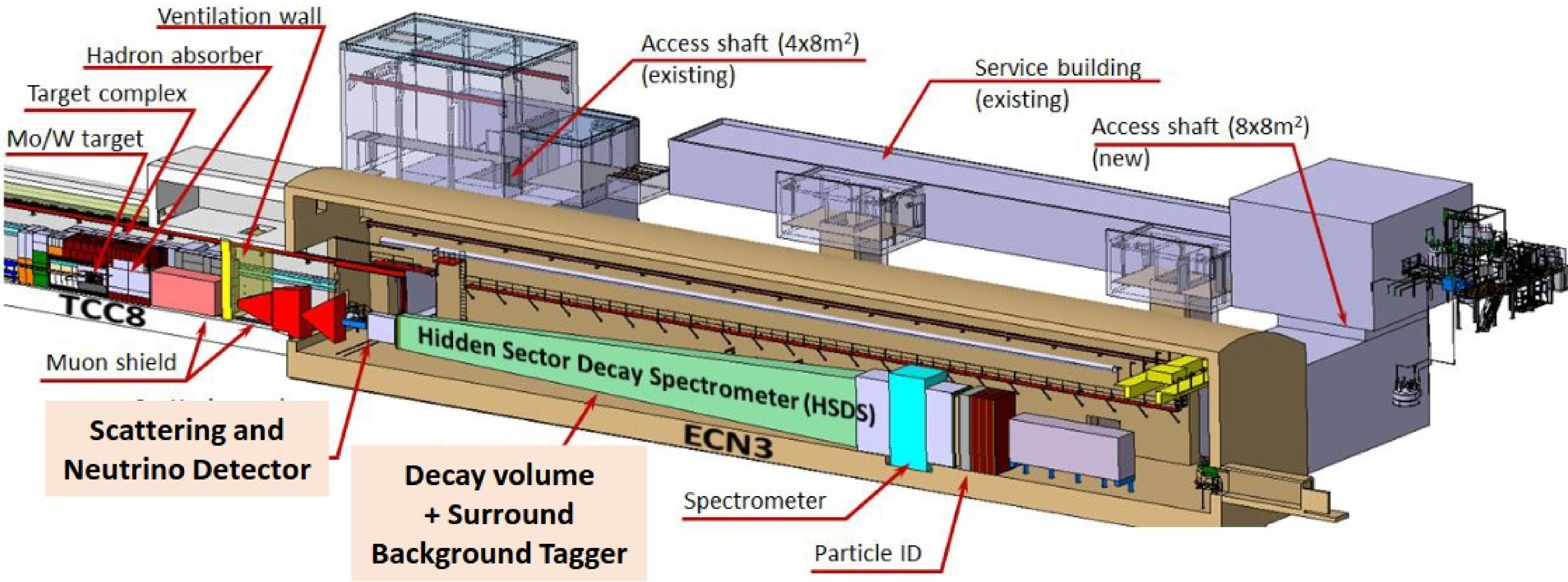
- Final states and models evaluated for sensitivity studies

	Physics model	Final state
HSDS	SUSY neutralino	$\ell^\pm\pi^\mp$, $\ell^\pm K^\mp$, $\ell^\pm\rho^\mp$, $\ell^+\ell^-\nu$
	Dark photons	$\ell^+\ell^-, 2\pi, 3\pi, 4\pi, KK, q\bar{q}, D\bar{D}$
	Dark scalars	$\ell\ell, \pi\pi, KK, q\bar{q}, D\bar{D}, GG$
	ALP (fermion coupling)	$\ell^+\ell^-, 3\pi, \eta\pi\pi, q\bar{q}$
	ALP (gluon coupling)	$\pi\pi\gamma, 3\pi, \eta\pi\pi, \gamma\gamma$
	HNL	$\ell^+\ell'^-\nu, \pi l, \rho l, \pi^0\nu, q\bar{q}'l$
	Axino	$\ell^+\ell^-\nu$
	ALP (photon coupling)	$\gamma\gamma$
	SUSY sgoldstino	$\gamma\gamma, \ell^+\ell^-, 2\pi, 2K$
SND	LDM	electron, proton, hadronic shower
	ν_τ, $\overline{\nu}_\tau$ measurements	$\tau^\pm$
	Neutrino-induced charm production (ν_e, ν_μ, ν_τ)	$D_s^\pm$, $D^\pm$, D^0, $\overline{D^0}$, Λ_c^+, $\overline{\Lambda_c}^-$

SHiP will provide an **unprecedented sensitivity** to hidden particle candidates

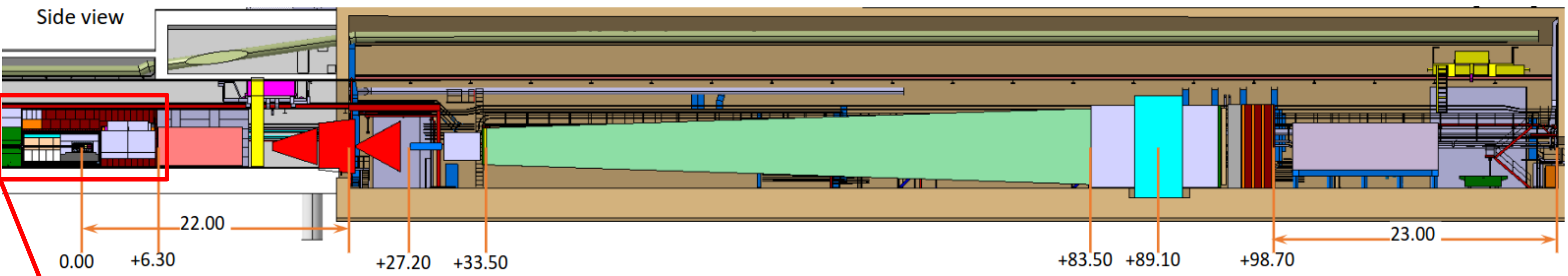


SHiP detector



A Review of the detector components is under way, in this documents the **current baseline options are described**

SHiP detector. Target



Complex target.

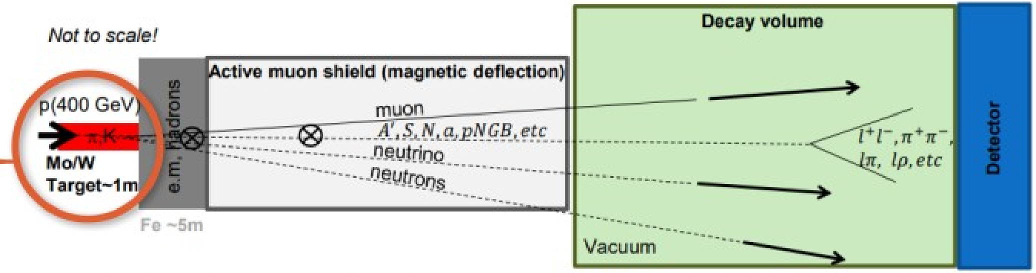
- **Beam Dump Target** / SHiP Target
  - ➢ Maximize production of charm and beauty hadrons & re-absorption of pions and kaons

High energy → production of charmed and beauty mesons

High ppp & POT → overcome small prod cross-section of extra rare events of hidden particles

High ρ, Z & A → Maximize p+ interaction

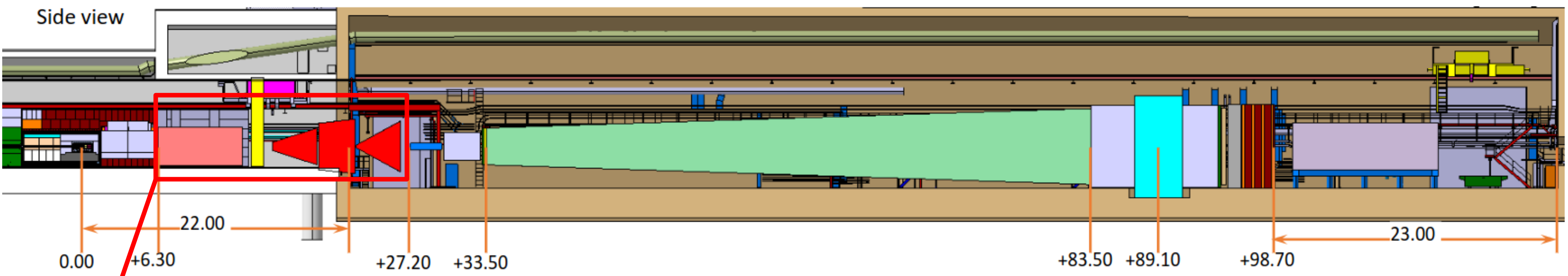
Shortest λ → Force absorption of K & π to reduce muon & neutrino background



R. Jacobsson

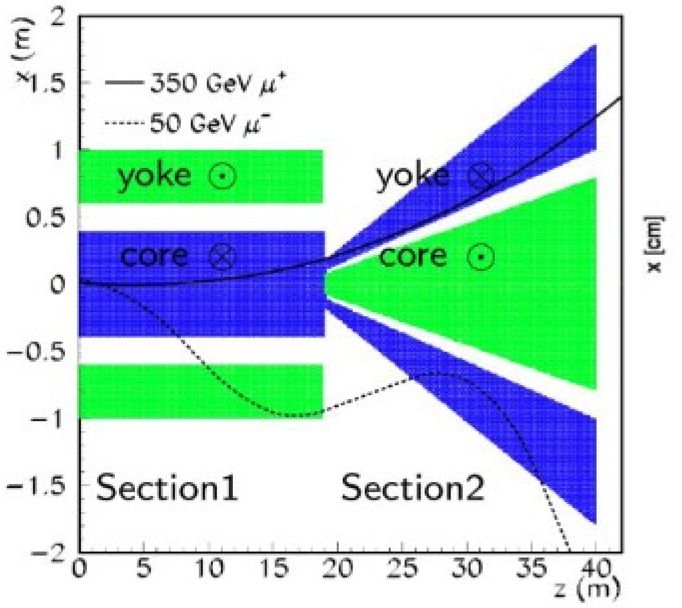
SPS Beam Dump Facility: Comprehensive Design Study, https://doi.org/10.23731/CYRM-2020-002
SHiP Experiment - Comprehensive Design Study report, https://cds.cern.ch/record/2704147

SHiP detector. Muon Shield

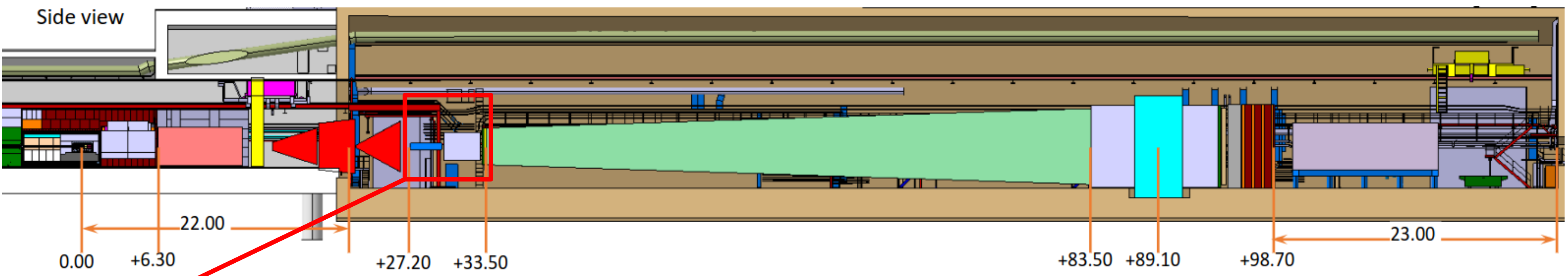


Muon Shield.
(CERN, UK)
Main Goal: Reduce muon rate upstream.

Super Conducting technology in the first part **& Conventional magnets** in the second part (with small inserts made of high quality iron to increase the field if needed)



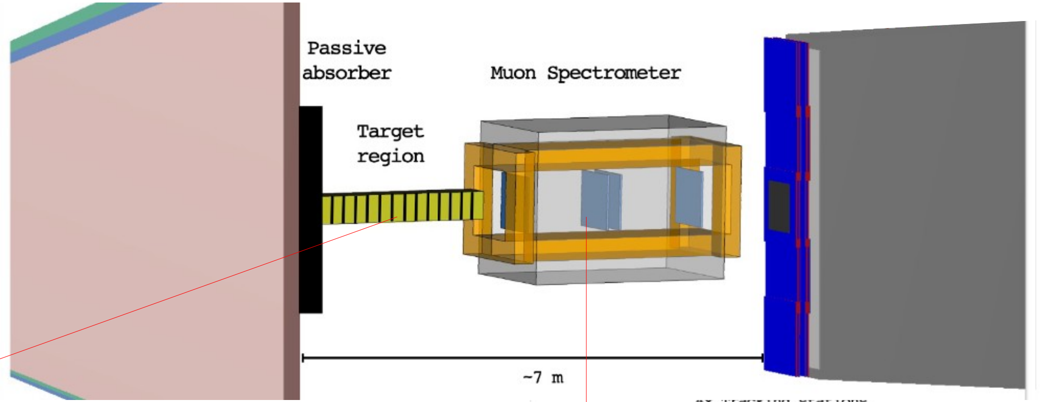
SHiP detector. Scatter Neutrino Detector (SND)

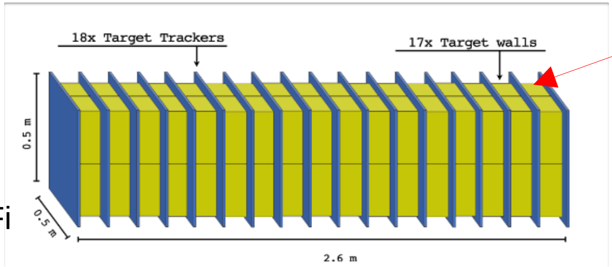


Huge synergy with
SND@LHC collaboration

Scatter Neutrino detector. (G. De Lellis, Naples)
(IT, CH, JP, KR, DE, TR).

Main Goal: Search for LDM and study neutrino physics, in particular tau neutrino physics

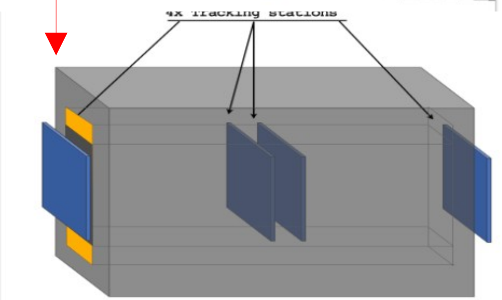




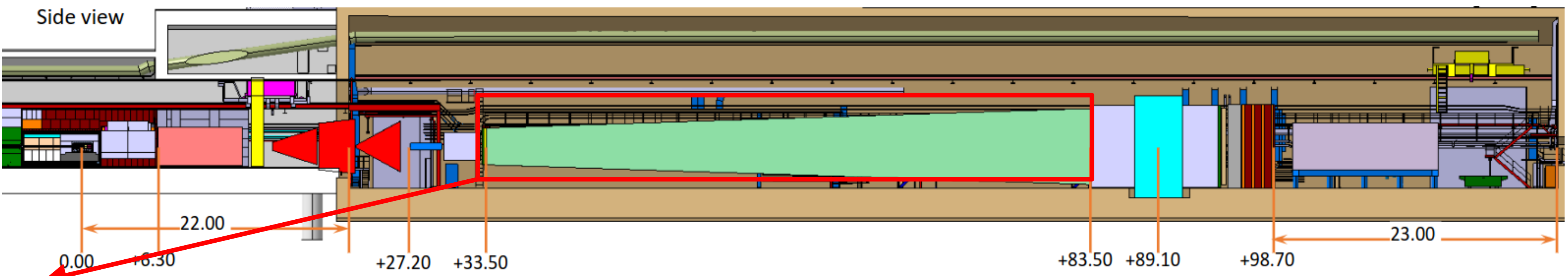
- Nuclear emulsion + SciFi

- Silicon detector, SciFi

- Position resolution of tracking stations 100 μm
- High efficiency (>99%) for angles up to 1 rad
- Drift tubes, SciFi

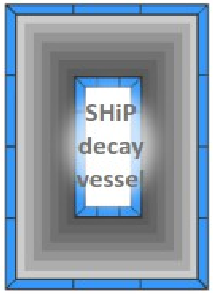


moving towards a primarily
electronically readout detector



Decay volume, Upstream and Surround Background Tagger, (UBT and SBT).
(Andrea Miano (Naples), H. Lacker (Berlin), A. Blanco (Coimbra)). (IT, CERN, DE, PT, CH, UA).
Main goal. Allow long-lived particles to decay and support Background Taggers.
=> Tag muons leaking through the muon shield and hadrons from muon and neutrino DIS interactions with material of the decay vessel and surrounding infrastructure

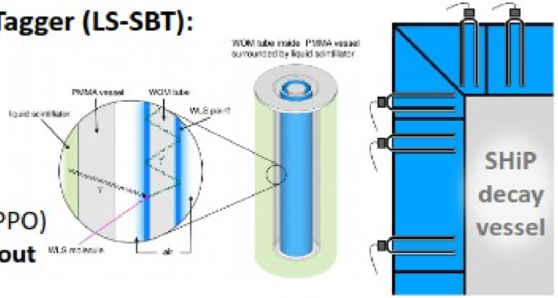
MRPC system (UBT) located in the entrance of the volume and **liquid scintillator readout by SiPM** fully surrounding the volume (SBT).



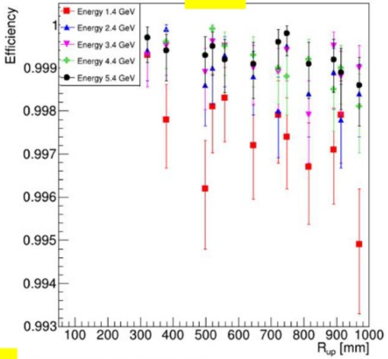
Liquid Scintillator-Surrounding Background Tagger (LS-SBT):
tagging of μ- and ν- induced BG

- **High efficiency:** > 99.0% for m.i.p.
- **Good time resolution:** $\mathcal{O}$(1 ns)

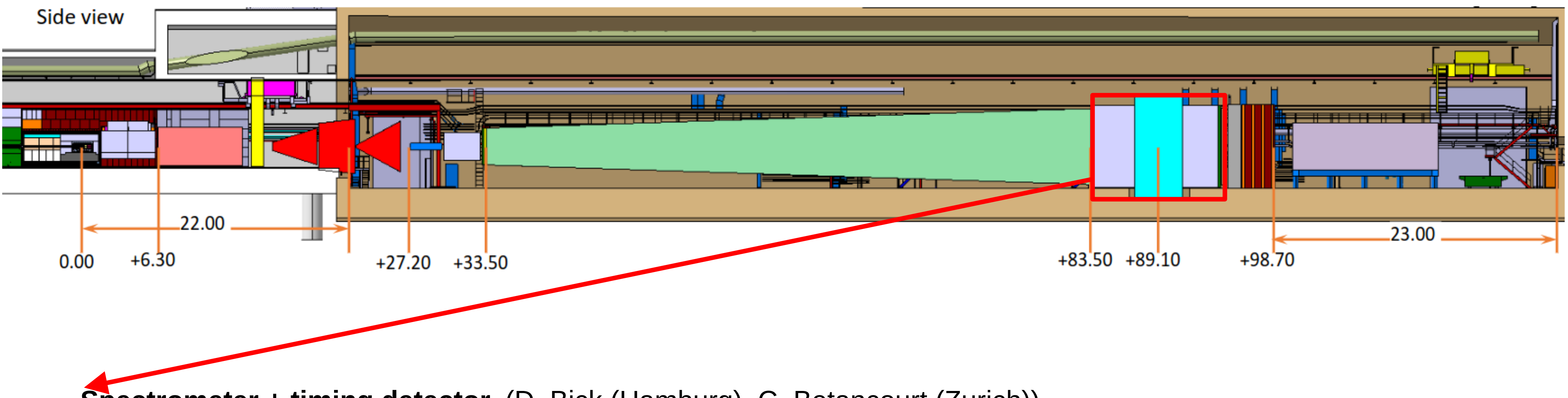
- **850 Segments:** Filled with **145 000l LS** (LAB + PPO)
- **Light Detectors:** 1 500 **WOMs with SiPM readout**



SBT



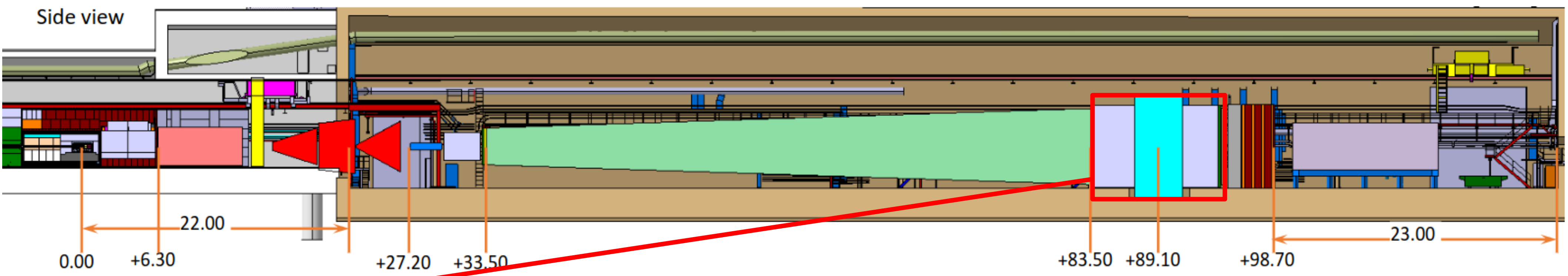
SHiP detector. Spectrometer and Timing Detector



Spectrometer + timing detector. (D. Bick (Hamburg), C. Betancourt (Zurich))
(DE, UA, CERN, CH)
Main goal. Accurately reconstruct, FIP decay vertex / invariant mass and IP at the proton target, reduce combinatorial background.

Ultra-light horizontal straws + platic scintillator.

SHiP detector. Spectrometer and Timing Detector



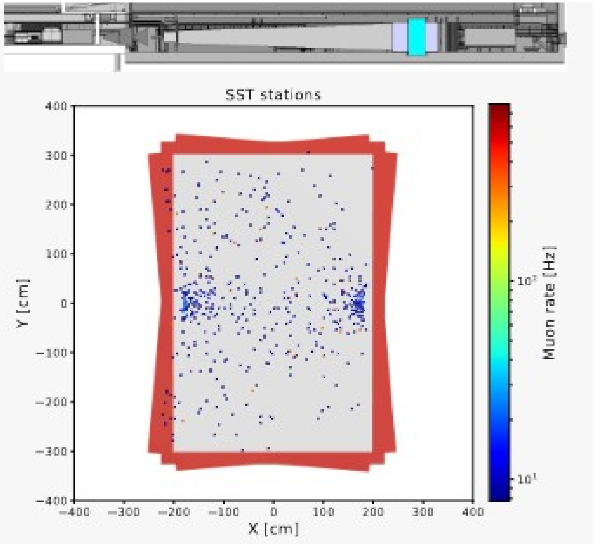
Ultra-light horizontal straws tubes (D. Bick (Hamburg))
(DE, UA, CERN)

Purpose, Requirements and Challenges

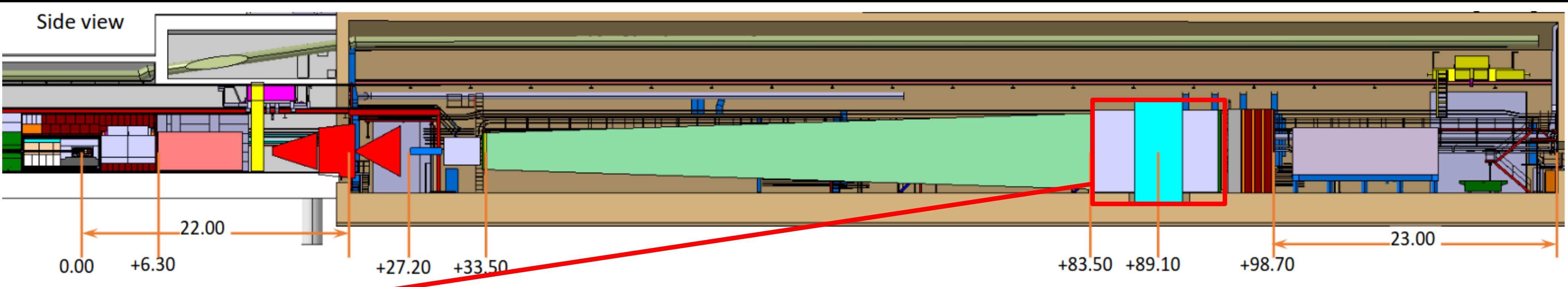
- Reconstruct tracks with high precision (better 120 µm)
- Operation in low pressure environment (**???**)
- Low material budget
- Large aperture 4 m × 6 m
- Moderate rate $\mathcal{O}(10\,\mathrm{kHz})$

Technical implementation

- Straw Tracker with ultra long tubes



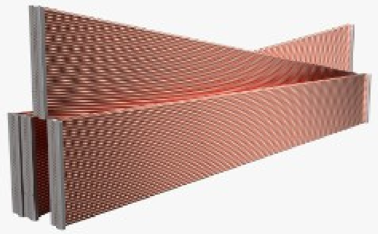
SHiP detector. Spectrometer and Timing Detector



Ultra-light horizontal straws tubes (D. Bick (Hamburg))
(DE, UA, CERN)

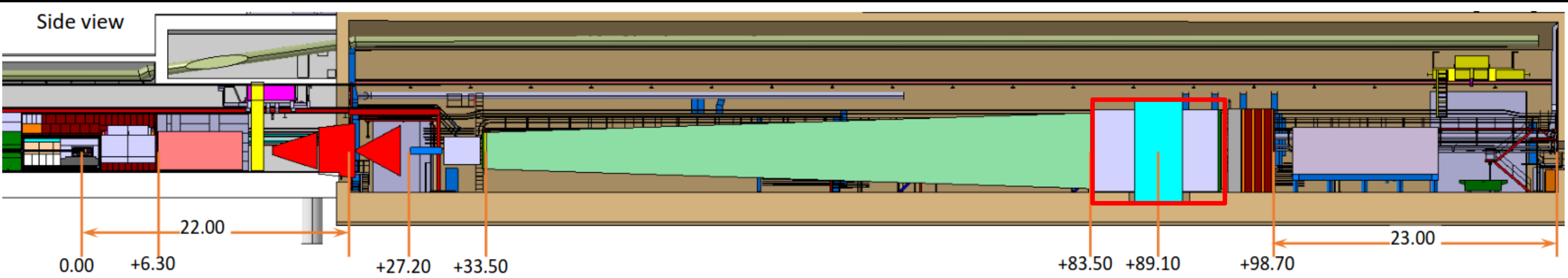
Straw Tubes

- Ultra-thin, ultra-long straws based on NA62 design.
- Longitudinally **ultrasonically welded**.
  - high strength (pressure tests with 3 bar)
  - no glued layers
  - small gas leakage
  - ▷ suitable for use in vacuum
- Successful operation in NA62.
- Intensive testing in the scope of DRD1.
- Wall thickness 36 μm Mylar
- Coating: Au (20 nm), Co (50 nm)
- Diameter: 2 cm, length: 4 m



- **4** stations next to magnet
- **4** views per station $y - u - v - y$
- stereo angle $\sim 10^\circ$
- **2** layers per view
- $6 \times 4\,\mathrm{m}^2$ aperture: **300** straws per layer
- Horizontal operation of straws
- ▷ 10000 channels

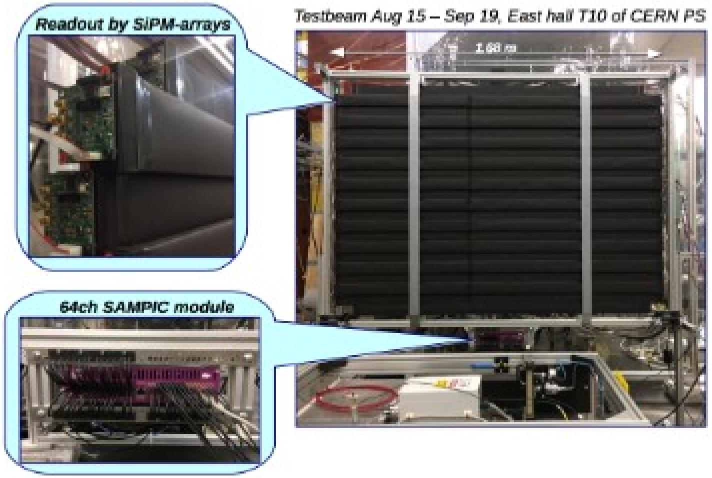
SHiP detector. Timing Detector

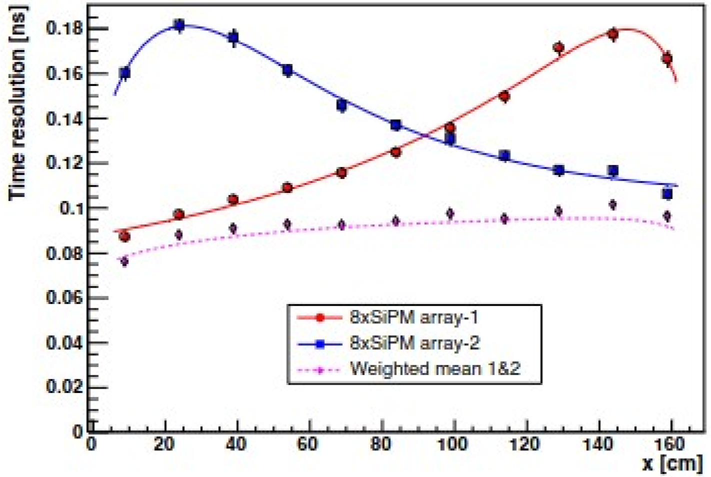


Timing detector (C. Betancourt (Zurich)) (CH)

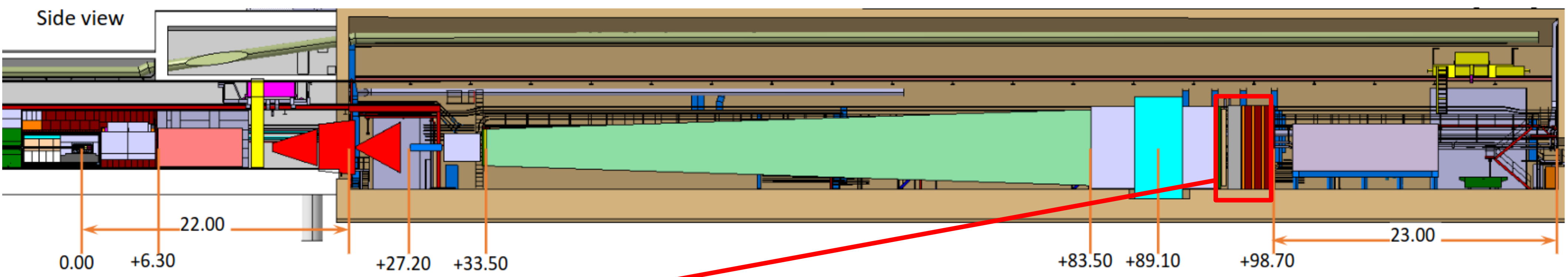
Main goal.
Reduce the combinatorial background.

=> < 100 ps.





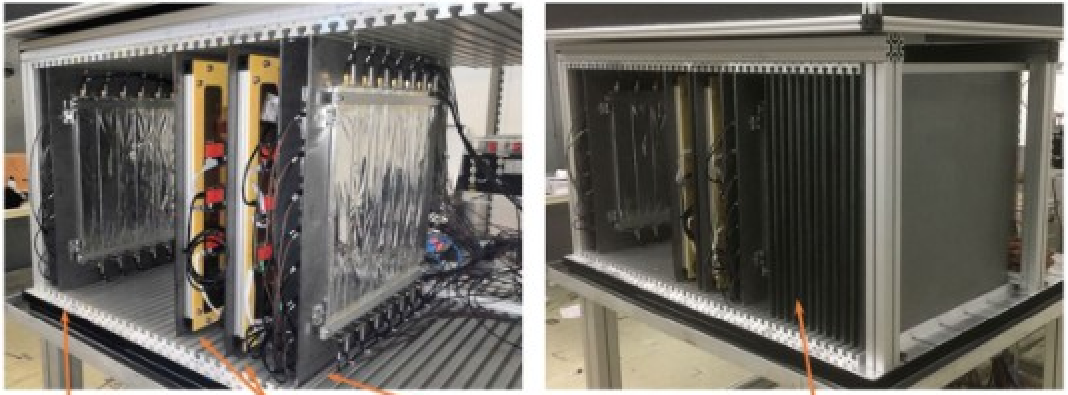
SHiP detector. Particle ID



Particle ID (W. Bonivento (Cagliari))
(DE, IT, UK)

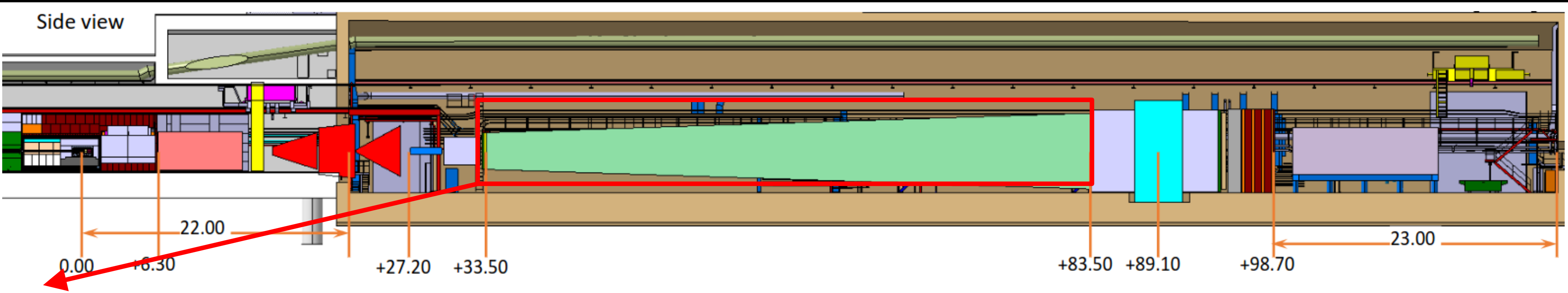
Main goal.
Identification of final states and used to reconstruct photons and pi0s.

Mixed technology
Scintillator bars for the regular Layers
MicroMegas as a baseline for High Precision layers used for shower directionality.



Extensive revision of the PID system underway

SHiP detector. Upstream Background Tagger



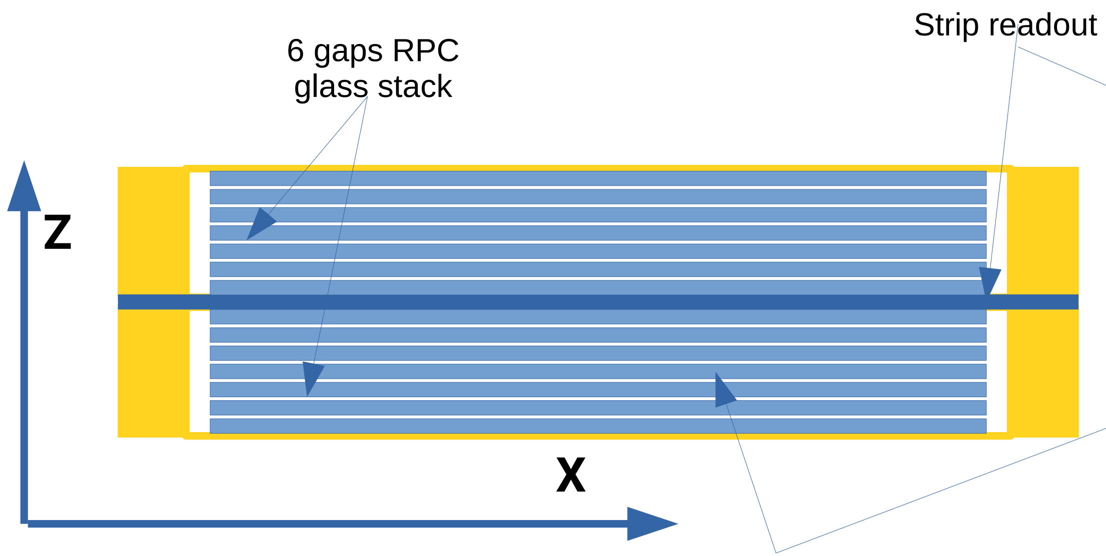
Upstream Background Tagger, (UBT).
A. Blanco (Coimbra)). (PT).

=> Tag muons leaking through the muon shield and hadrons from muon and neutrino DIS interactions with material of the decay vessel and surrounding infrastructure

MRPC system (UBT) located in the entrance of the decay volume should provide **~50 ps and > 99%.**

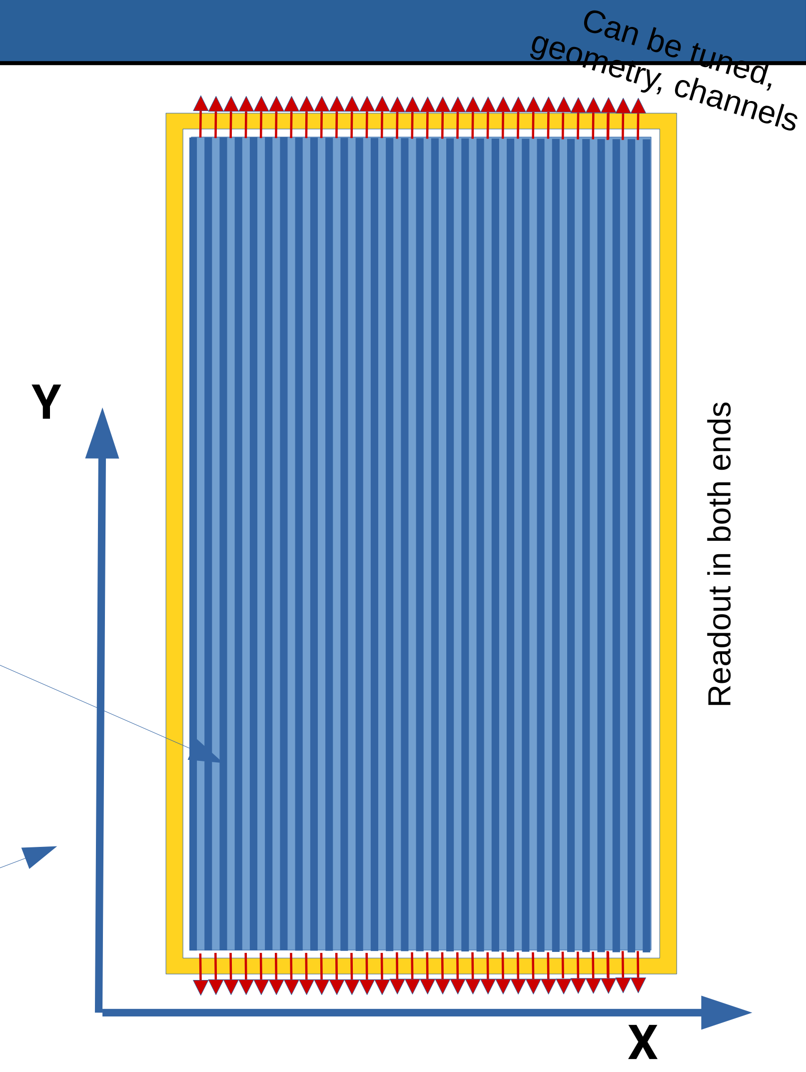
Timing RPC technology for SHiP, prototype

- **Modules composed of two 6 gaps RPCs** glass stack.
- **Strips 30 mm width** (placed in the middle of two stacks) readout in both sides.
- Active **area of 1500x1200 mm² = 1,8 m²**
- **Good time precision,** < 50 ps σ.
- **Good efficiency,** > 98 %
- Easy to build.
- **Low multiplicity**, few particles per module.



mRPC cross-section

Module



mRPC top View

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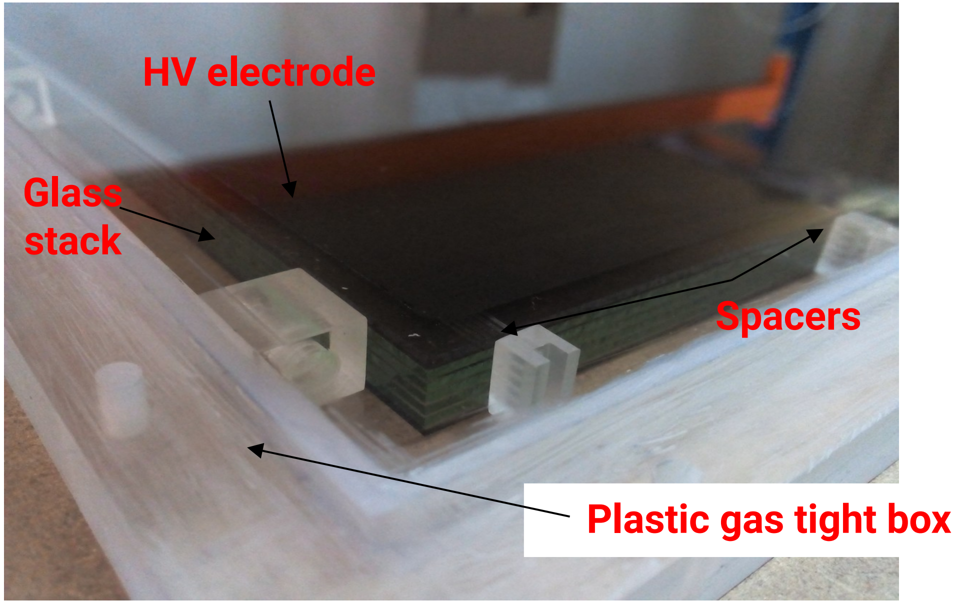
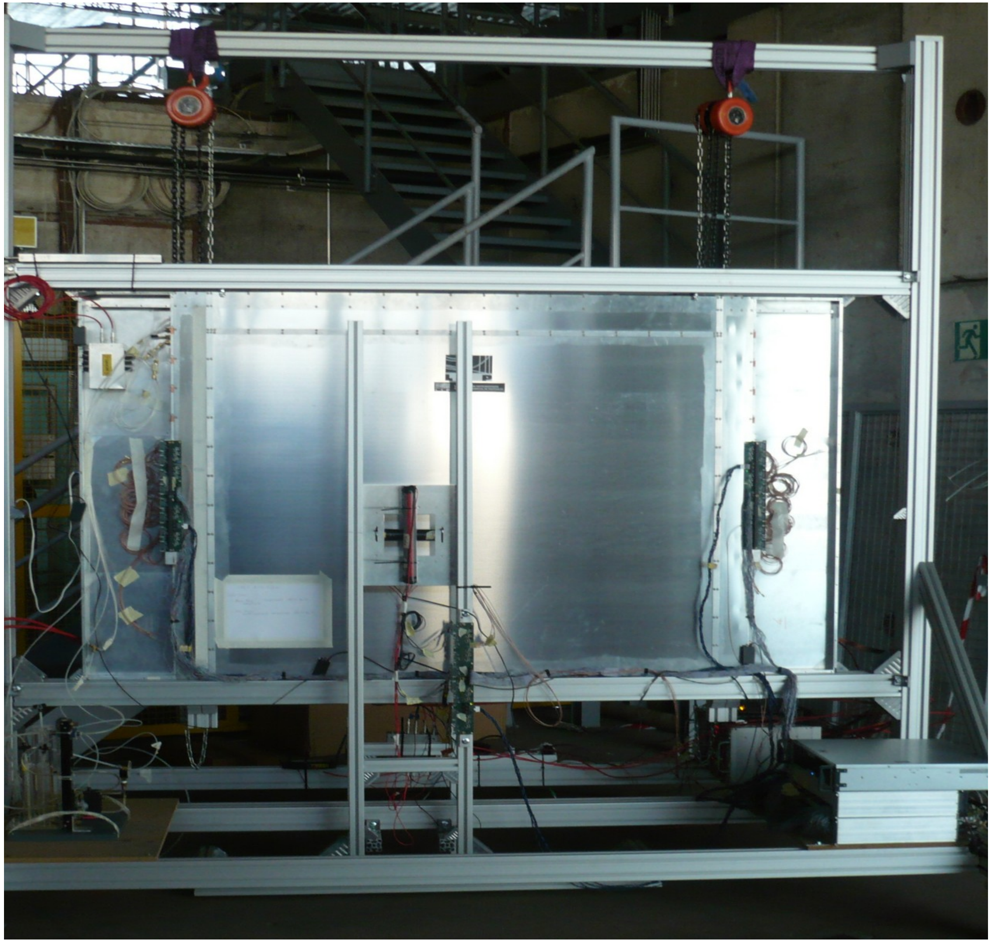


A **glass stack** contains the glass and HV electrodes enclosed in a plastic gas tight box with feed-throughs for gas and High Voltage.

Easy to build
completely gas tight,
no gas leaks, robust.

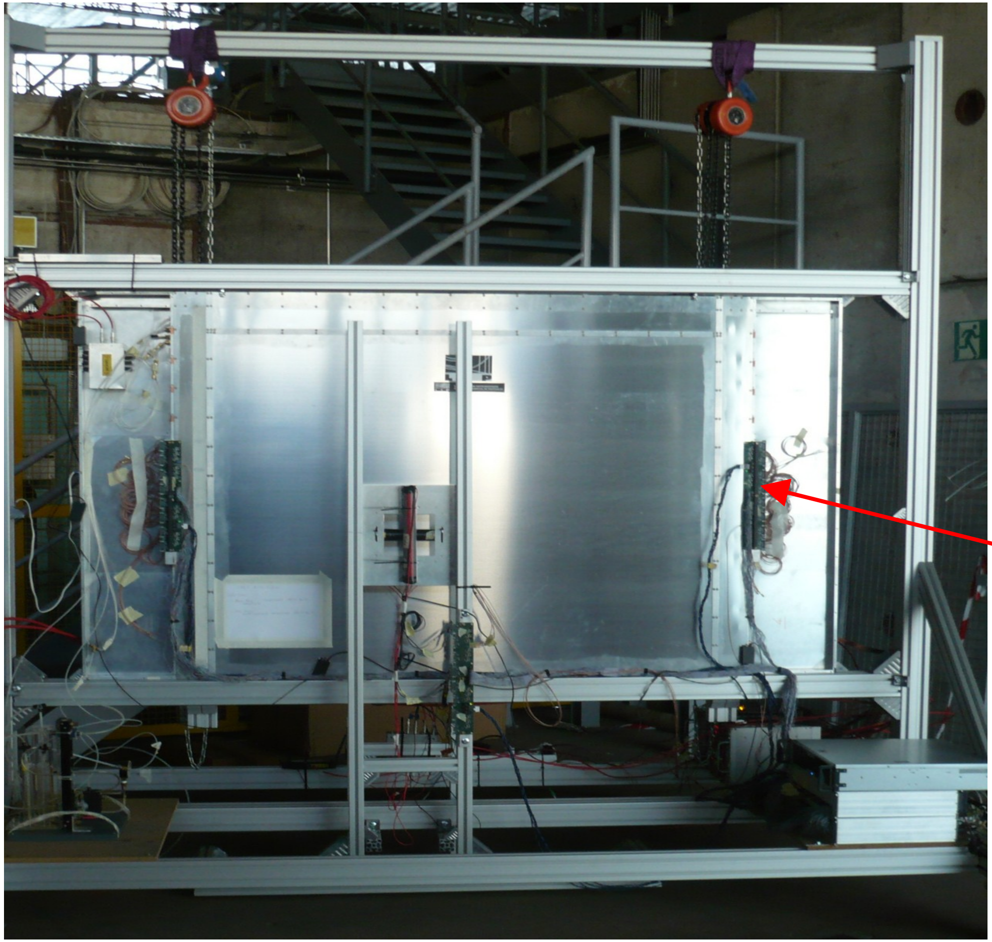
Decouples the gas and HV from the rest.

Timing RPC technology for SHiP, prototype



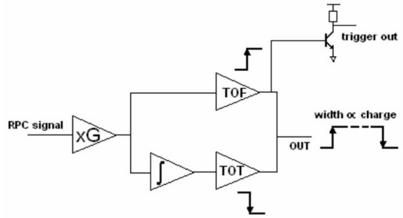
Gas system, 97.5% $C_2H_2F_4$ + 2,5% SF_6

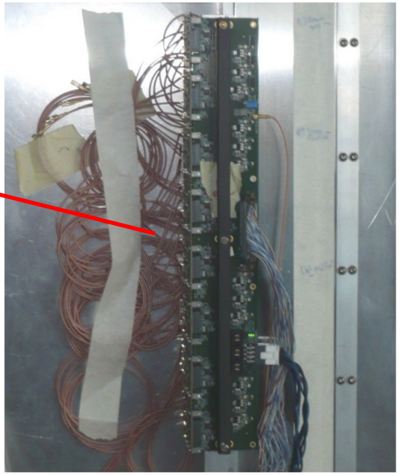
Timing RPC technology for SHiP, prototype



<u>FEE</u>, time (σ_t~35ps) and charge measurement in one single channel.

Strips are readout in both sides

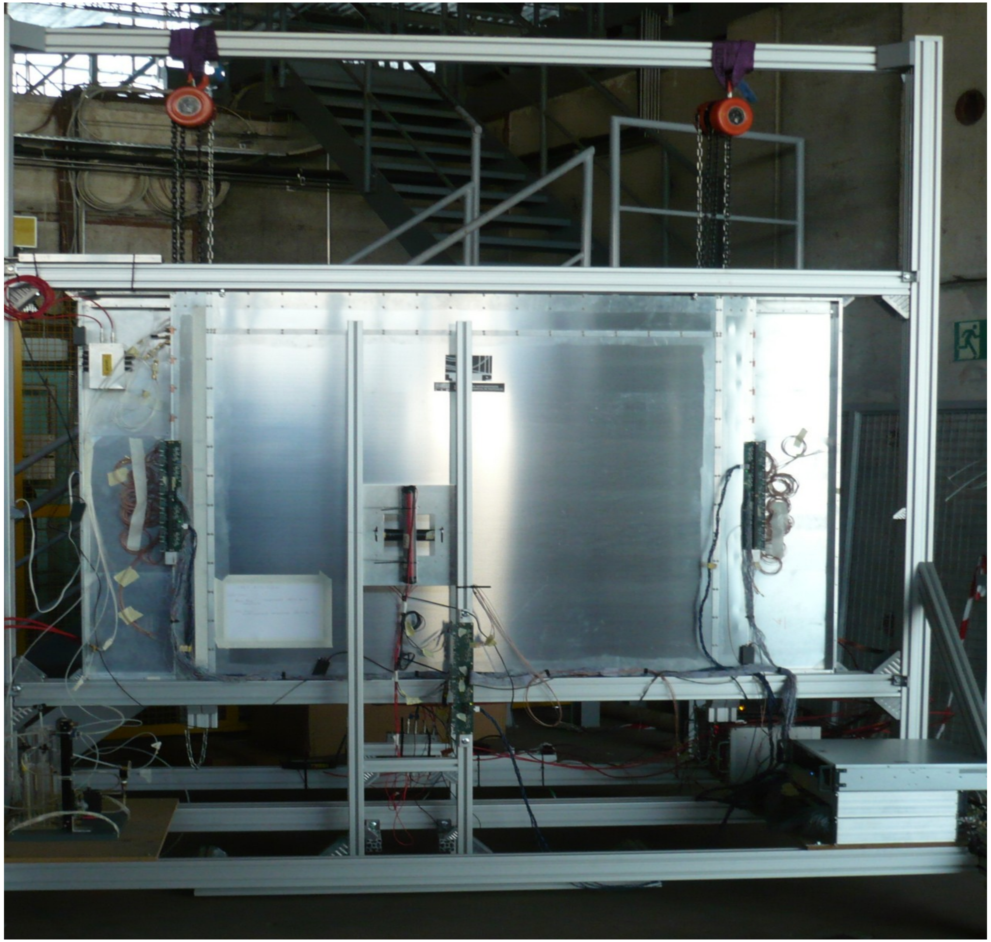


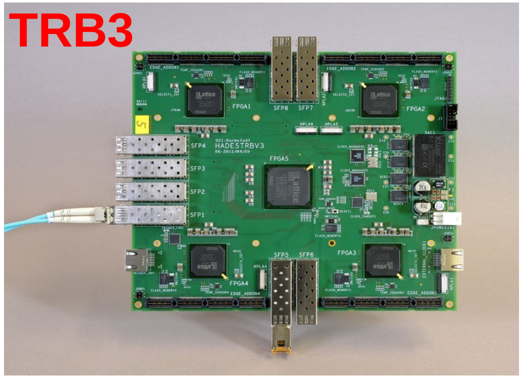


32 channels each side

[IEEE TNS 57, 2848 (2010)]

Timing RPC technology for SHiP, prototype





One central FPGA with trigger management capabilities plus 4 sockets with capability to operate.

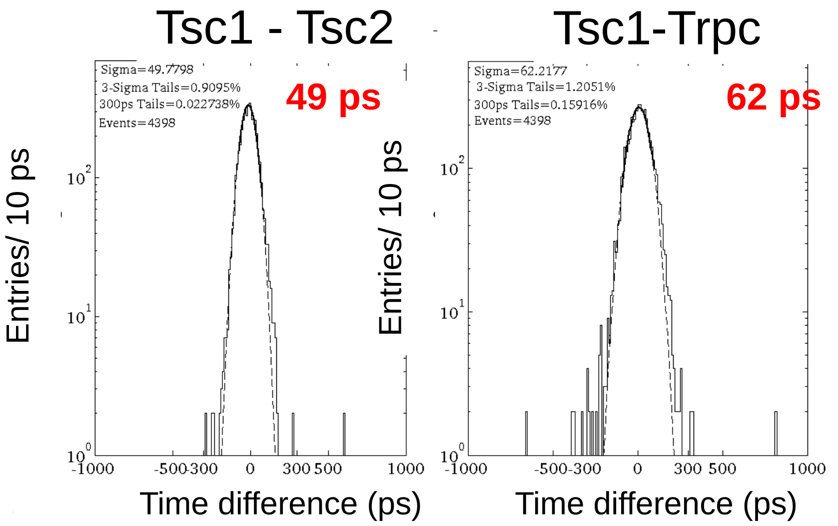
- **4 X 32 Multi-hit TDC**
  Time precision < 20 ps

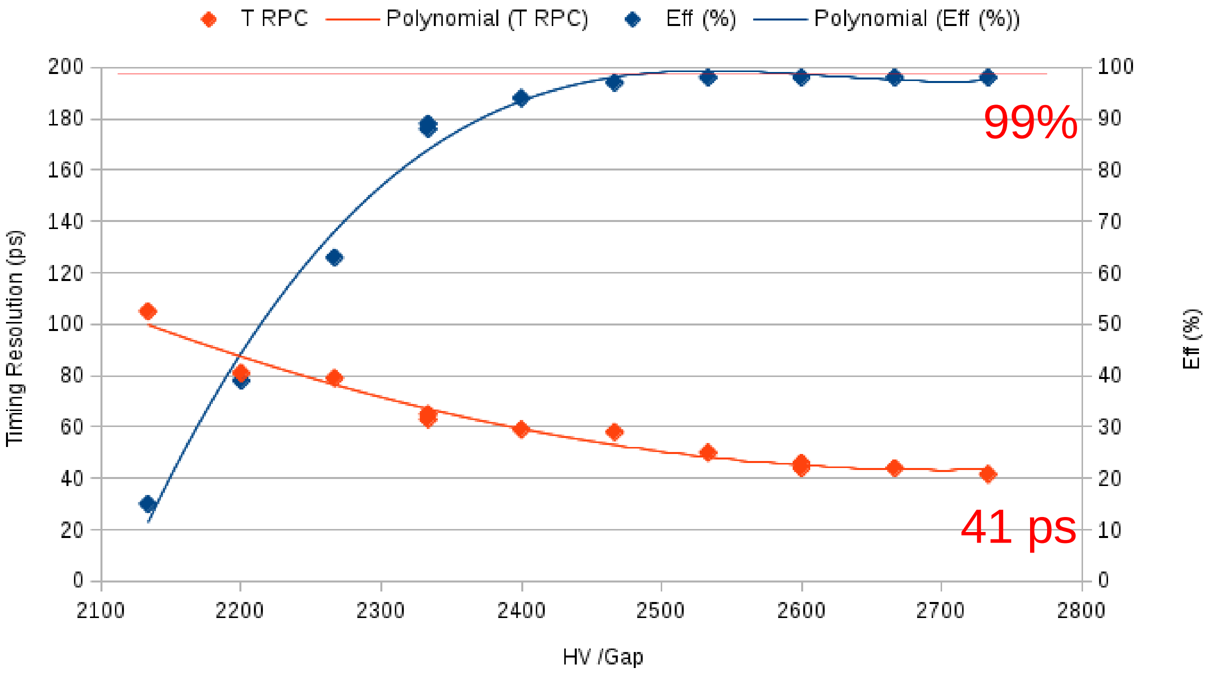
And much more

doi: 10.1088/1748-0221/8/12/C12043

Timing RPC technology for SHiP, prototype

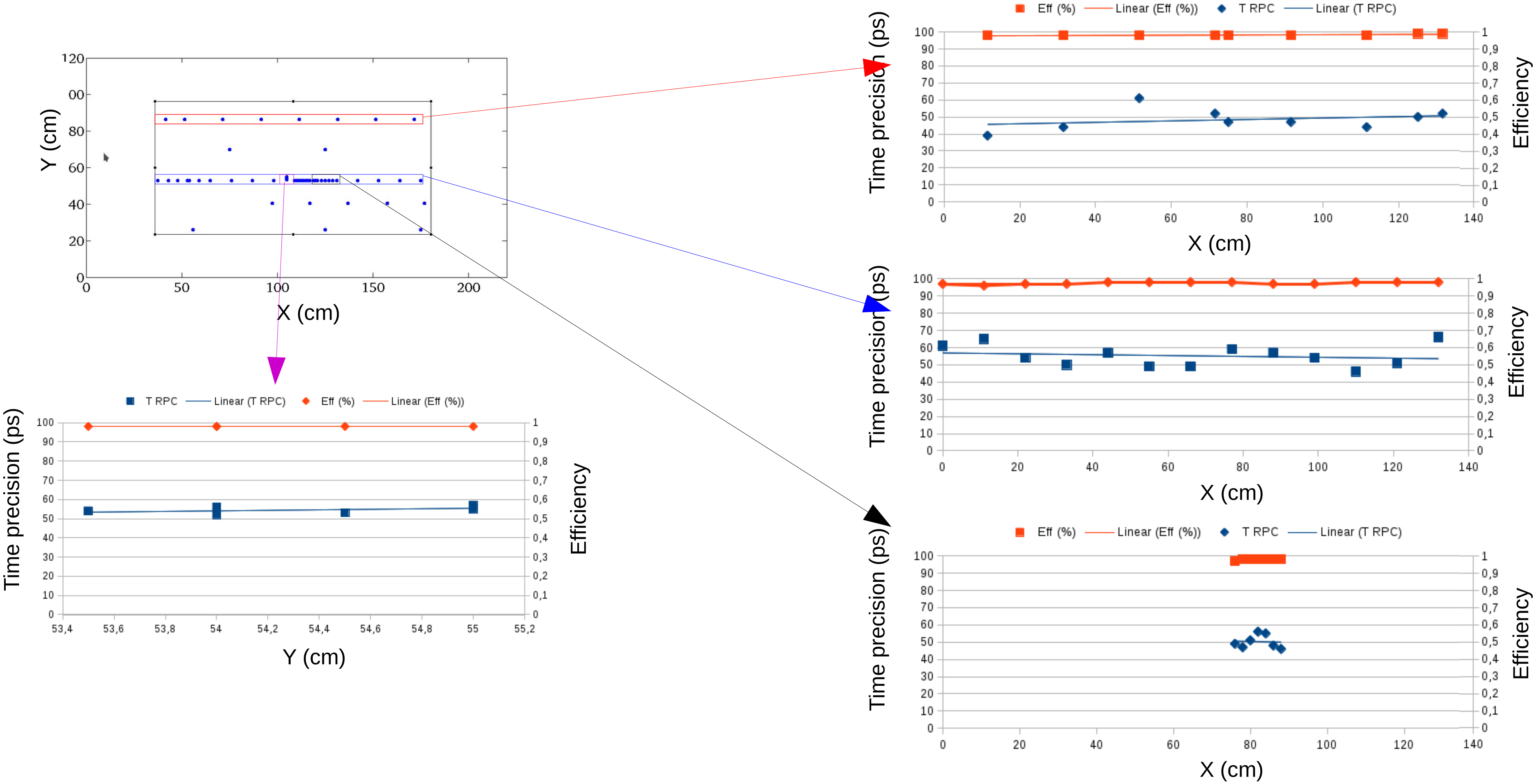
High voltage scan
Timing accuracy < **50 ps**
Efficiency > **98 %**





Timing RPC technology for SHiP, prototype

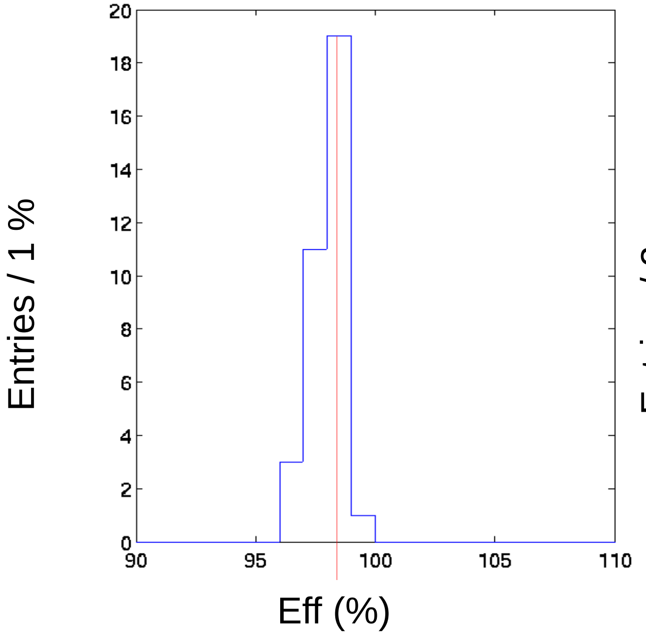
No noticeable dependence with position

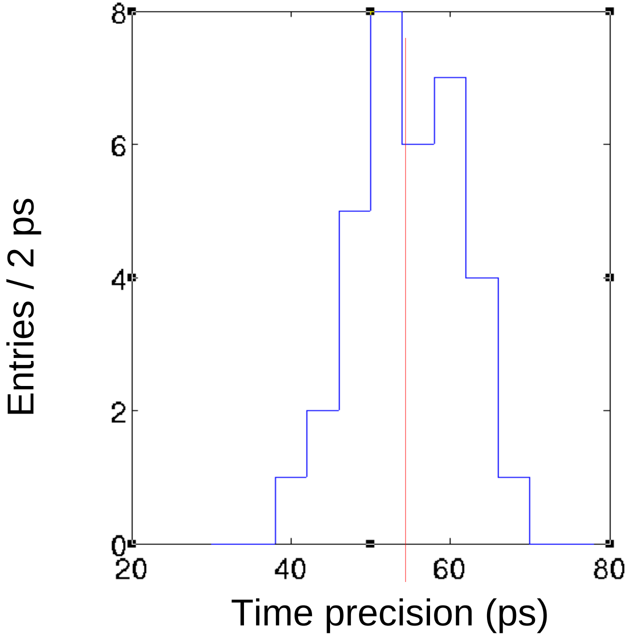


Timing RPC technology for SHiP, prototype

DOI 10.1088/1748-0221/15/10/C10017

All positions



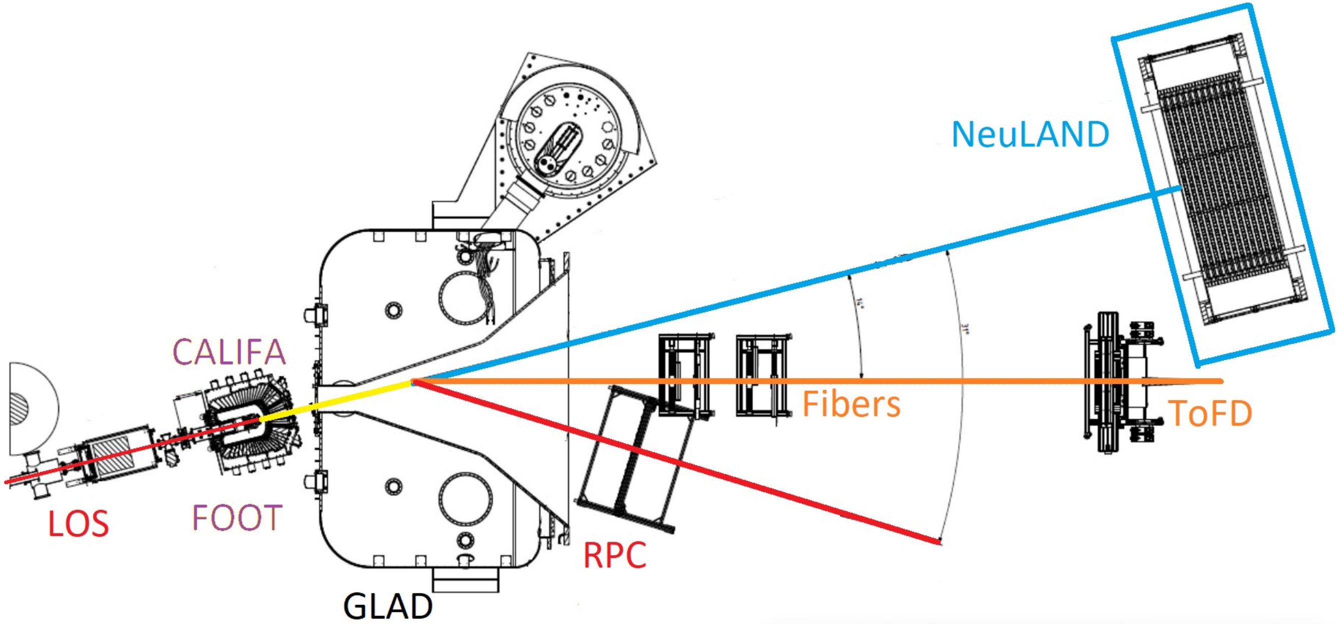


<98 %>

<54 ps>

The SHiP timing detector @ GSI

Reactions with Relativistic Radioactive Beams

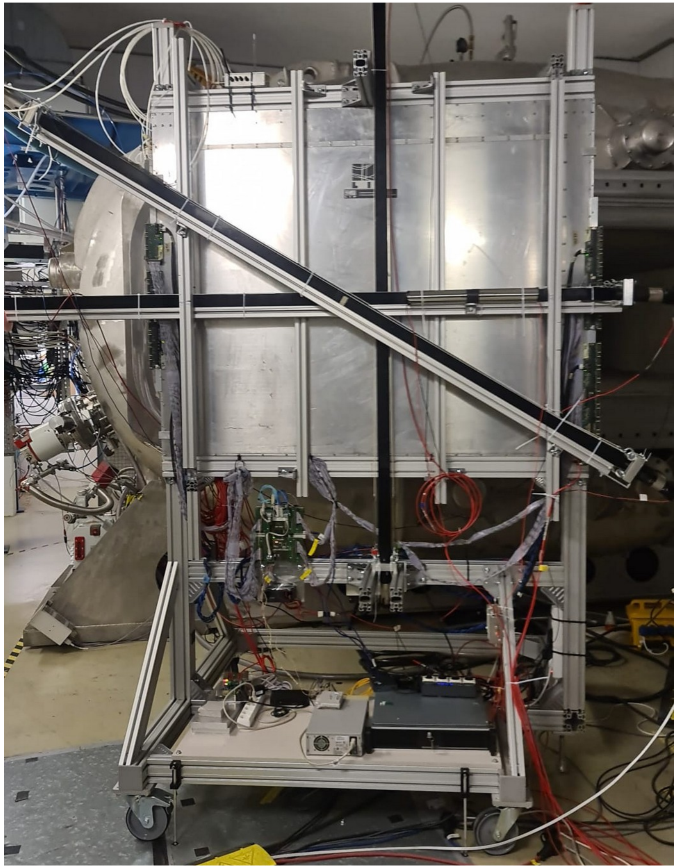


RPC was used as time of flight wall for the measurement of protons (~1-2 GeV/c) TOF in experiment s522 (2022), first characterization of Short-Range Correlations in exotic nuclei and recently (2024) in s118 and s091.

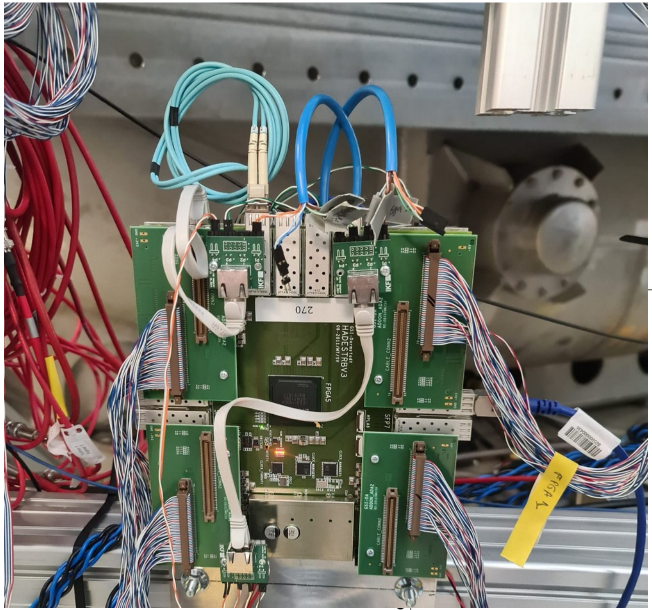
The SHiP timing detector @ GSI

DOI 10.1016/j.nima.2023.168445

DAQ integration (through white rabbit) with the existing R^3B DAQ successfully done

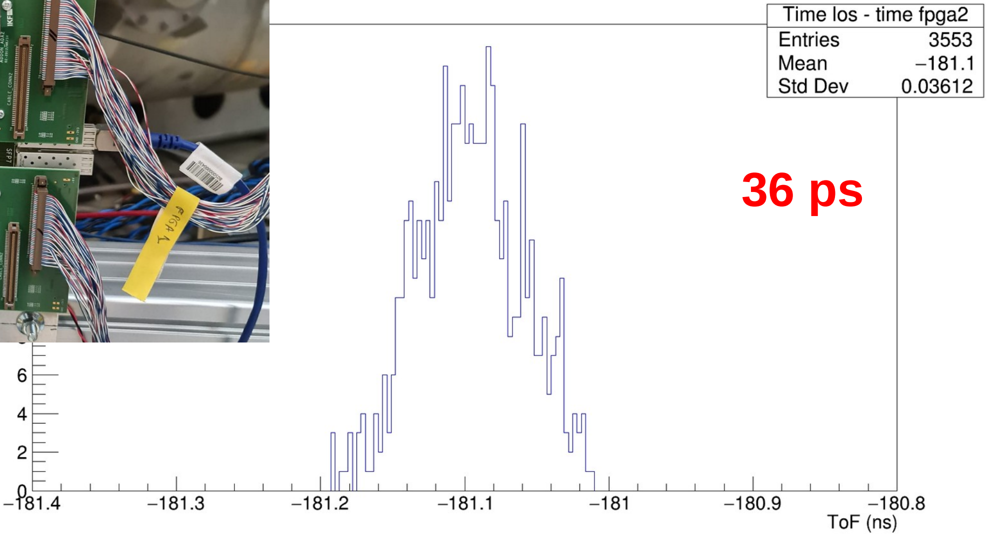


RPC @ GSI, the crossing bars are **scintillators** for **calibration** and **efficiency** measurement



RPC TRB DAQ

Start – RPC



36 ps

Electronic resolution between MRPC and start detector

The SHiP timing detector @ GSI

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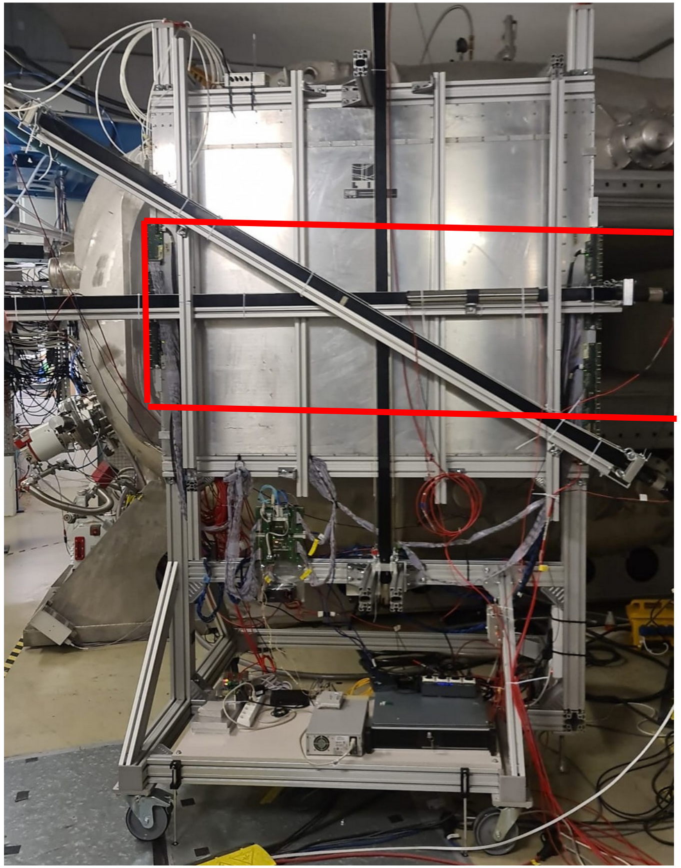

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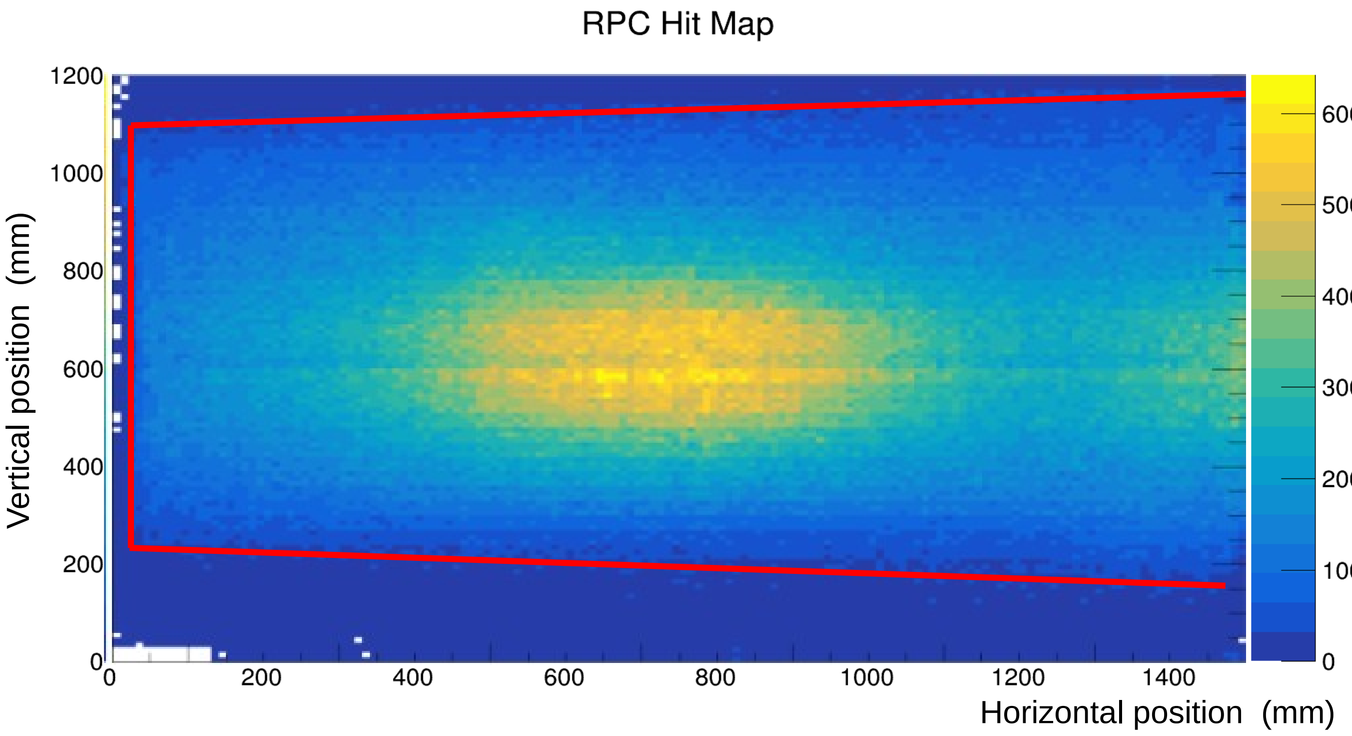
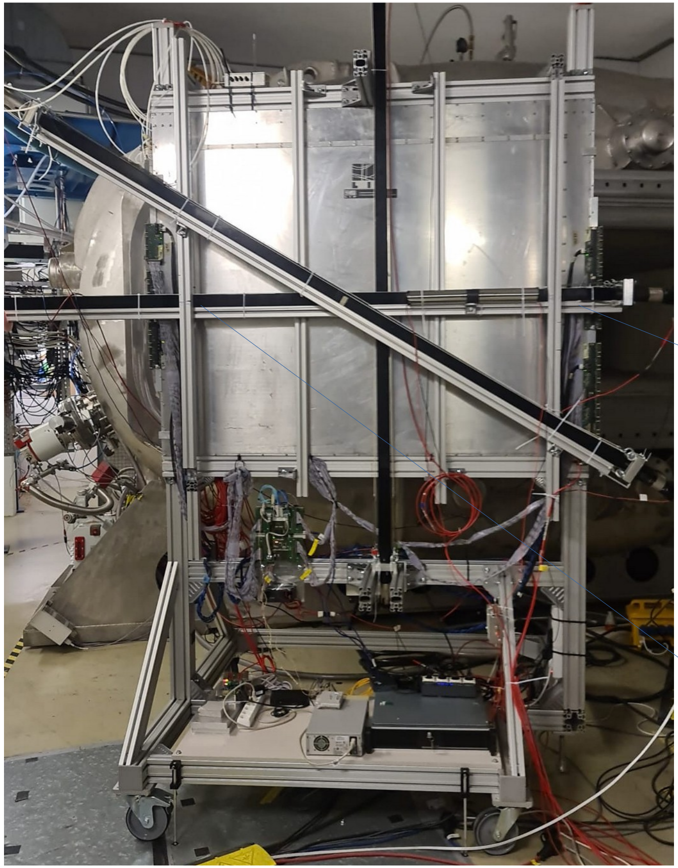


Shadow of the dipole magnet (GLAD)

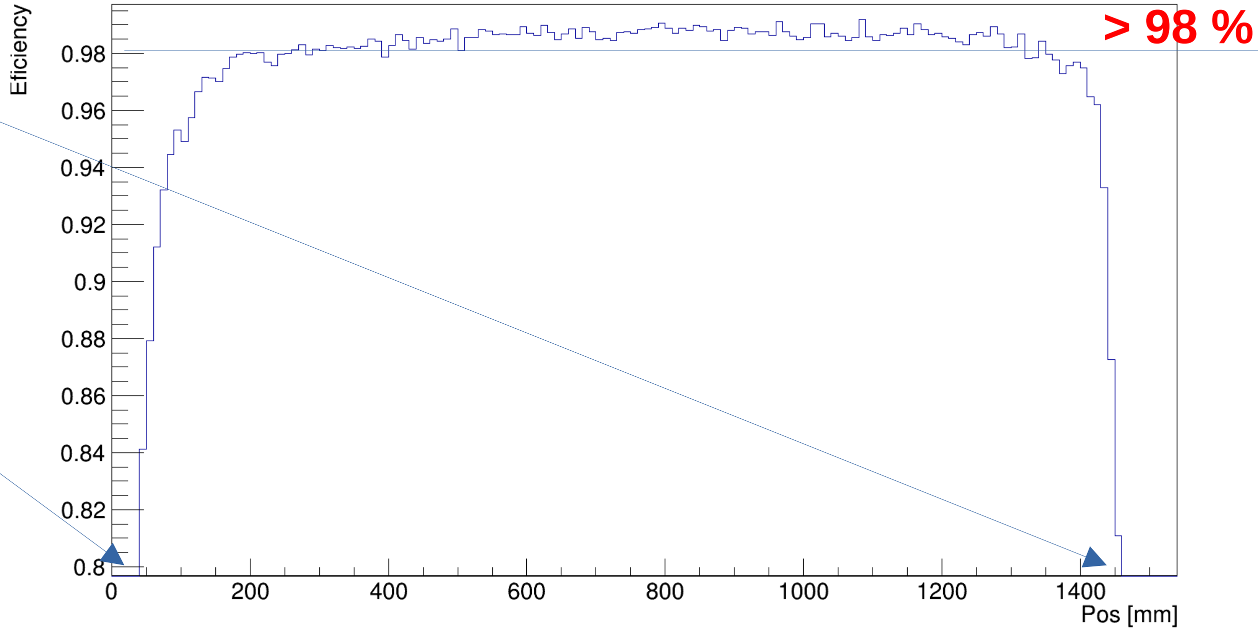
The SHiP timing detector @ GSI

DOI 10.1016/j.nima.2023.168445



RPC @ GSI, the crossing bars are **scintillators** for **calibration** and **efficiency** measurement

RPC efficiency using the R3B start Detector and horizontal sctintillator



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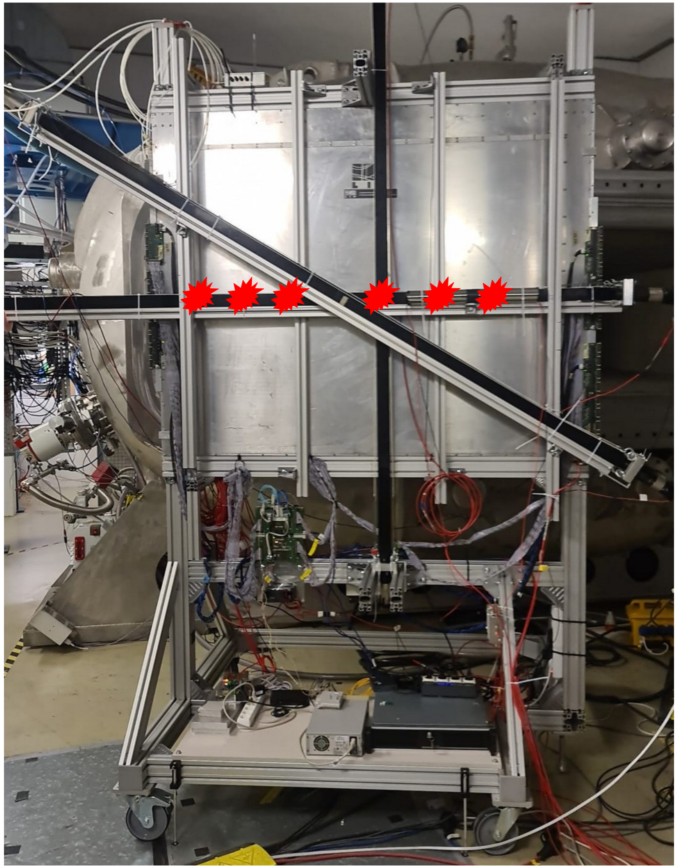
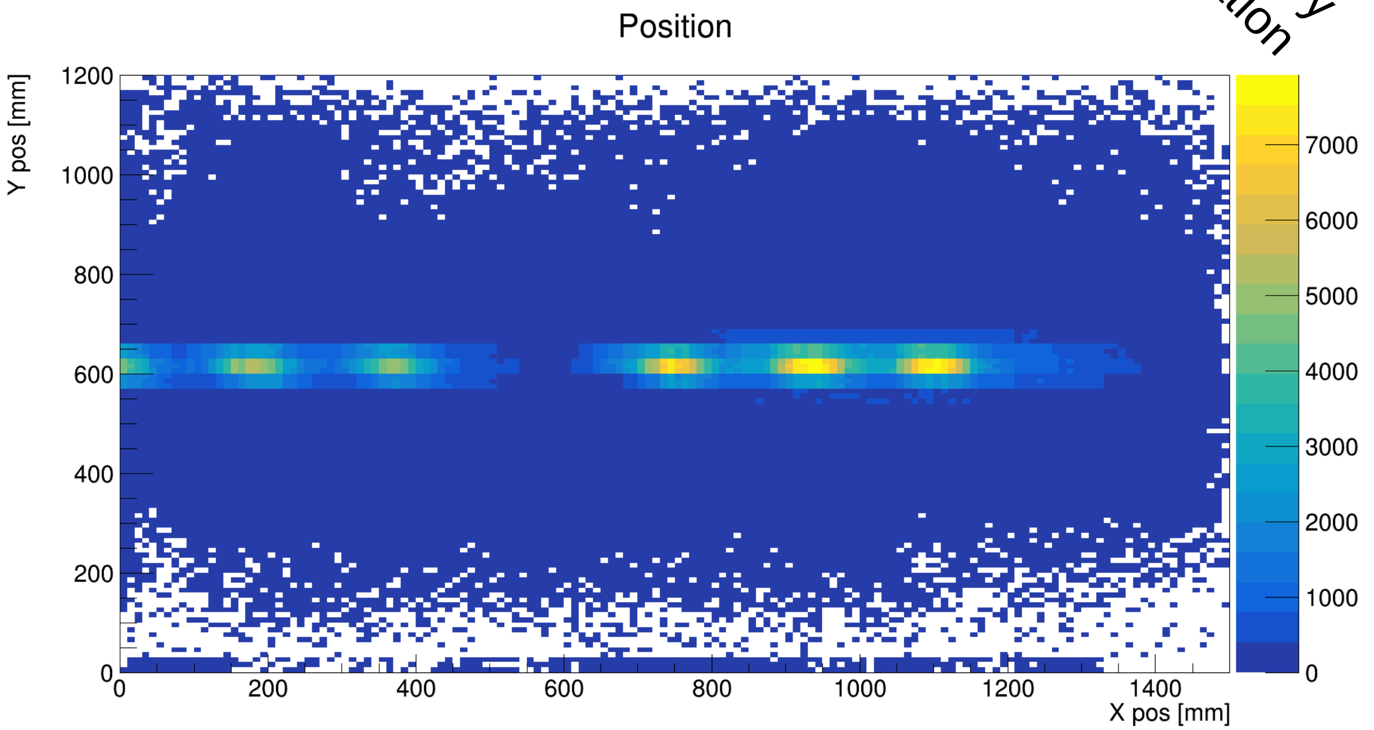


RPC @ GSI, the crossing bars are **scintillators** for **calibration** and **efficiency** measurement

Sweep run with ^{40}Ar. Shoot an ion beam directly , 6 positions, into the RPC for calibration proposes.

Preliminary calibration



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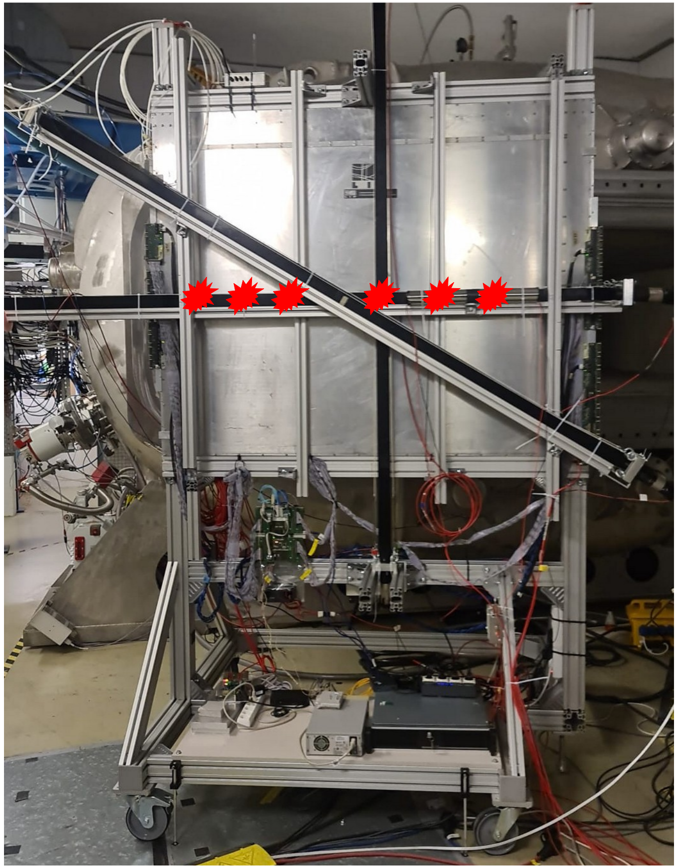

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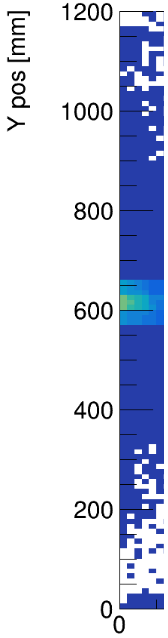
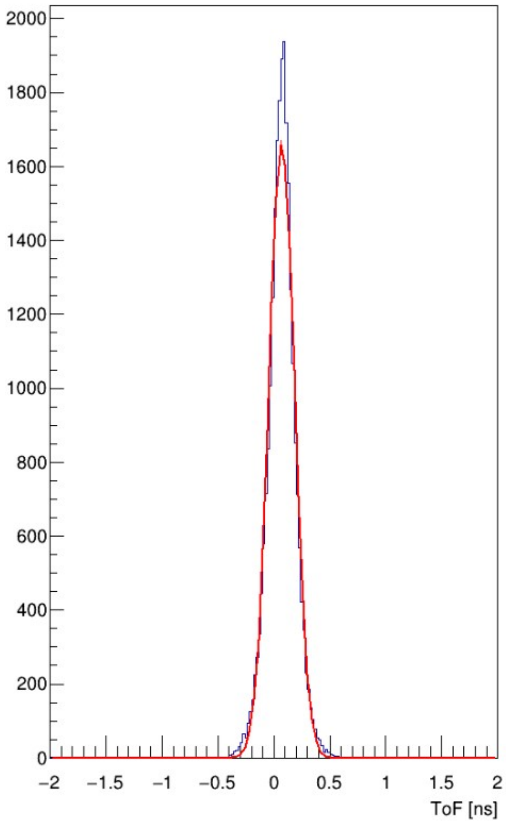
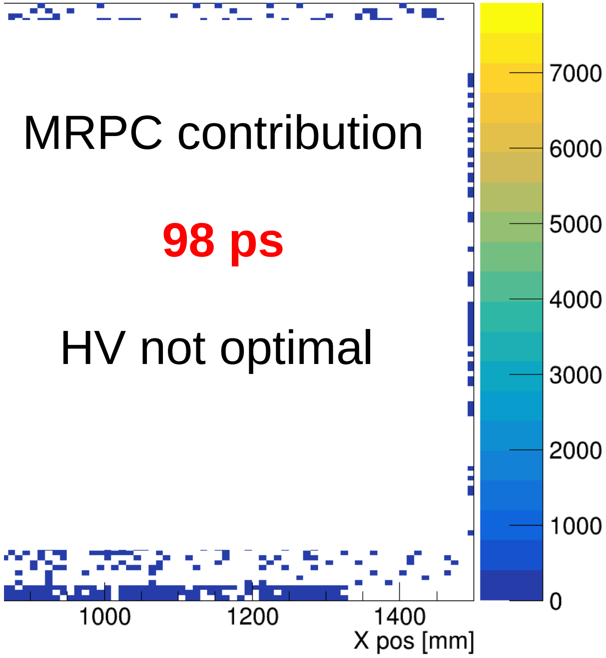




TOF (start - MRPC)

Preliminary calibration



MRPC contribution

98 ps

HV not optimal

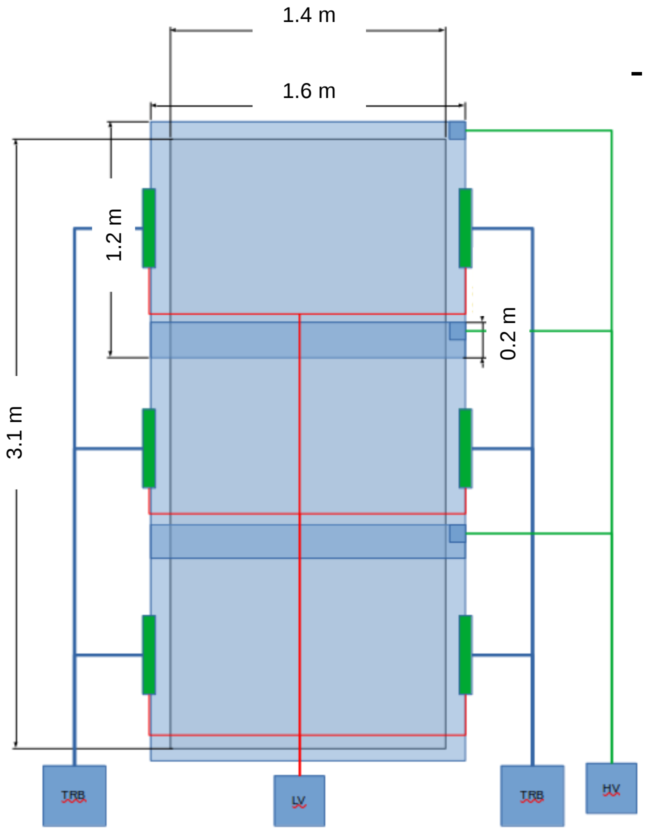
The SHiP timing detector @ GSI

SHiP experiment has been approved to move forward to the **Technical Design Report Phase**

Review of the detector components is under way

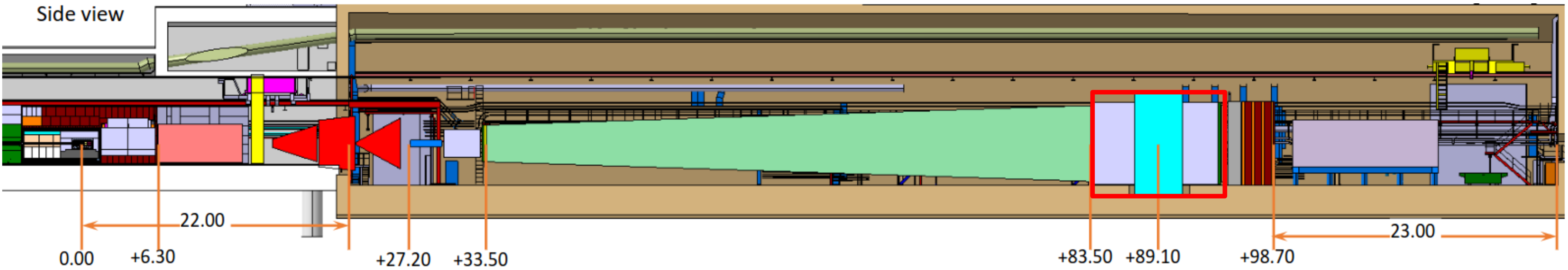
MRPC technology based on large modules to be used as background tagger
successfully tested in full size (~2 m^2) providing **~50 ps and ~98%** efficiency

Upstream Background Tagger @ ECN3



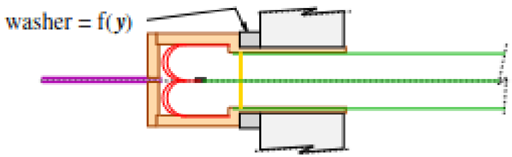
- All the sub-systems and cabling (HV, LV, data) match perfectly
  - 1x HV module/plane
  - 1x LV module/plane
  - 1.5 TRBs/plane

SHiP detector. Spectrometer



Three alternative designs

1 Constant force springs and adjusted pulling

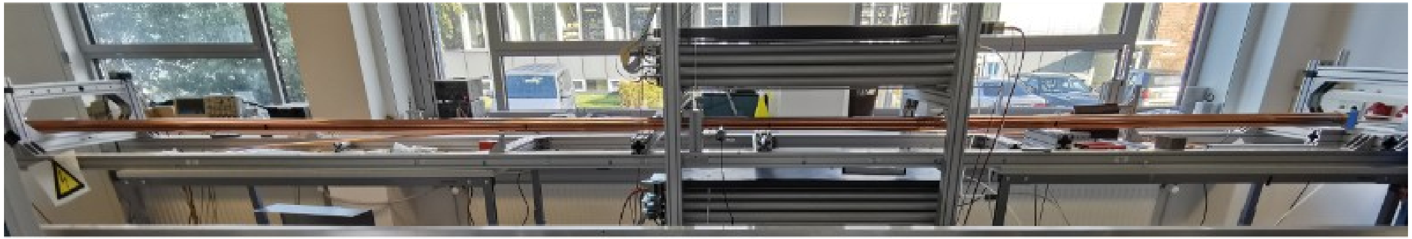


Increase pulling on the straws over time to compensate for relaxation

2 Cemented pack

Straws are glued together for stabilization
Based on PANDA idea.

3 Suspended bridge design



Straws supported by a carbon fiber, which defines sagging.

The RPC gas

Standard HFC solutions are no longer a possibility (due to high GWP).

- A green gas-based solution for timig RPC. Recent results (10.1016/j.nima.2024.169104) with HFO-1234ze ($C_3F_4H_2$) are quite promising but have to be verified, some concern still due to high streamer probability.


Operation of a low resistivity glass MRPC at high rate using ecological gas

G. Garillot [a b], Y.W. Baek [c d], D. Hatzifotiadou [d e], D.W. Kim [a b g], J.S. Kim [c d], B.G. Min [a b], S.W. Park [f], M.C.S. Williams [d g h], R. Zuyeuski [d g]

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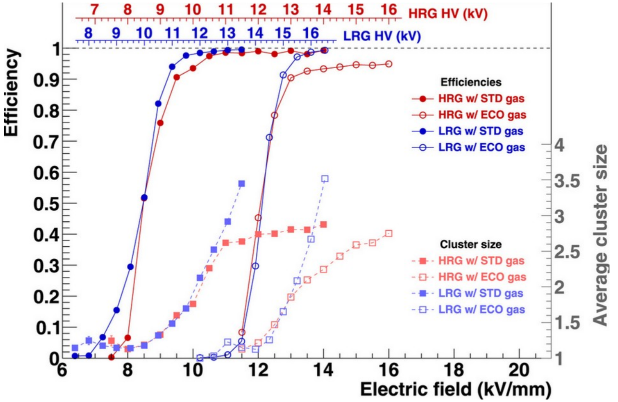
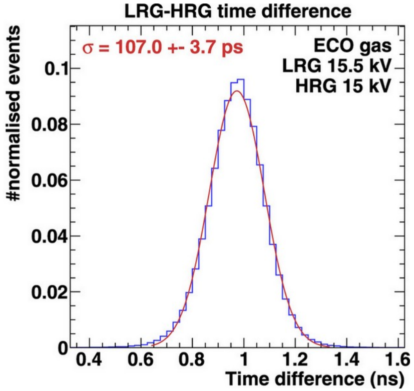
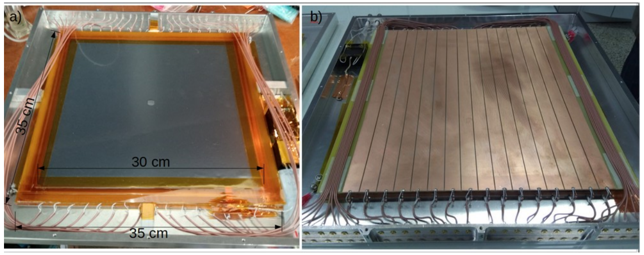
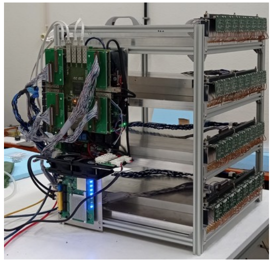




doi.org/10.1140/epjp/s13360-023-04647-1
arxiv.org/html/2402.18663v1

- Sealed (zero gas flow) RPC seems to be possible, e.g., sRPC@LHC, but not yet demonstrated with timing, ongoing work.





This should be addressed with high priority