*International Conference on Technology and Instrumentation in Particle Physics*

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# RPCs for the SND Muon System of the SHiP experiment

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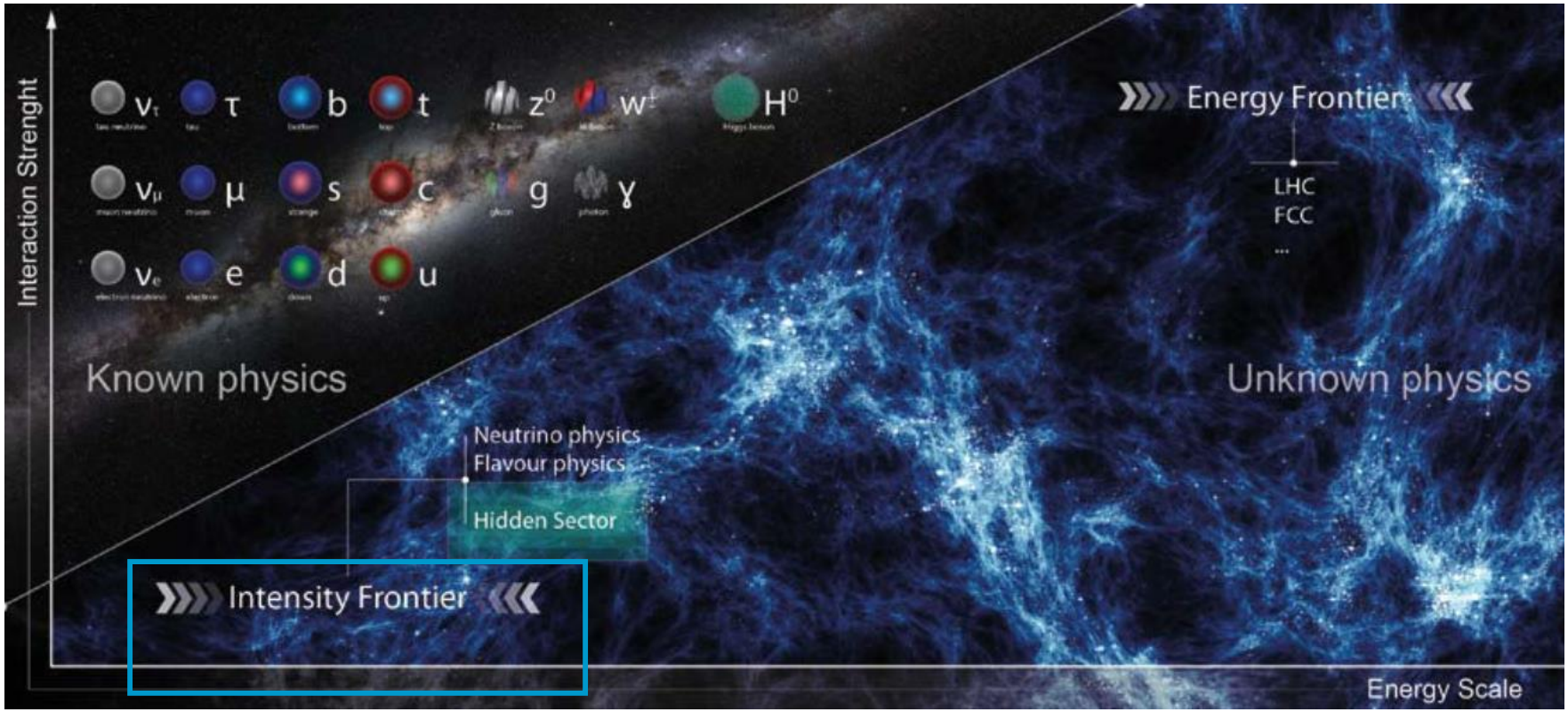
# Content

- The SHiP experiment;
- The SHiP Scattering and Neutrino Detector (SND);
- RPCs for the SND Muon System;
- Prototypes of the SHiP RPCs;
- Test results of RPC prototypes;
- R&D for SHiP RPCs.

# Physics beyond the Standard Model

Hints of New Physics: dark matter, neutrino oscillations, matter/antimatter asymmetry



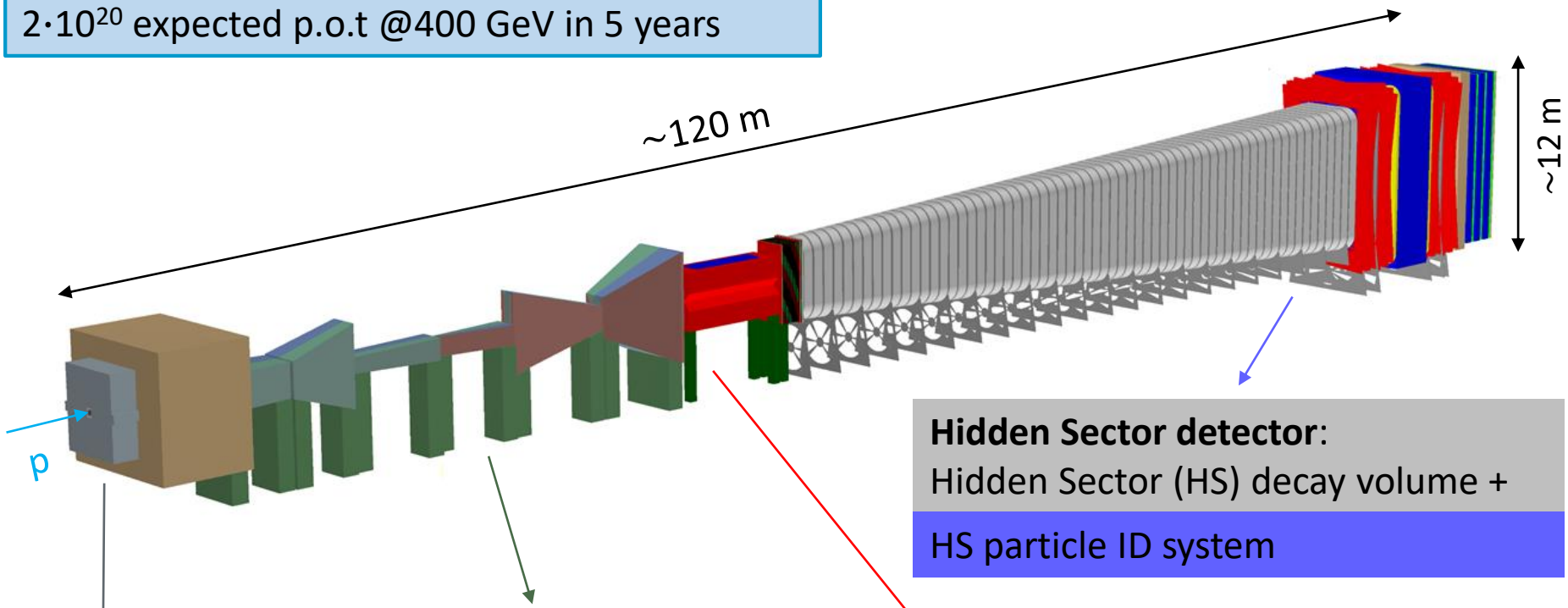

Several theories suggest the existence of "hidden" neutral fleebly interacting particles with low masses (around the GeV scale)

need to probe the intensity frontier *[e.g. Search for Hidden Particles (**SHiP**) experiment]*

# The SHiP experiment

Proposed beam dump experiment at CERN SPS
$2 \cdot 10^{20}$ expected p.o.t @400 GeV in 5 years

*Technical Proposal: arXiv:1504.04956, 2015*



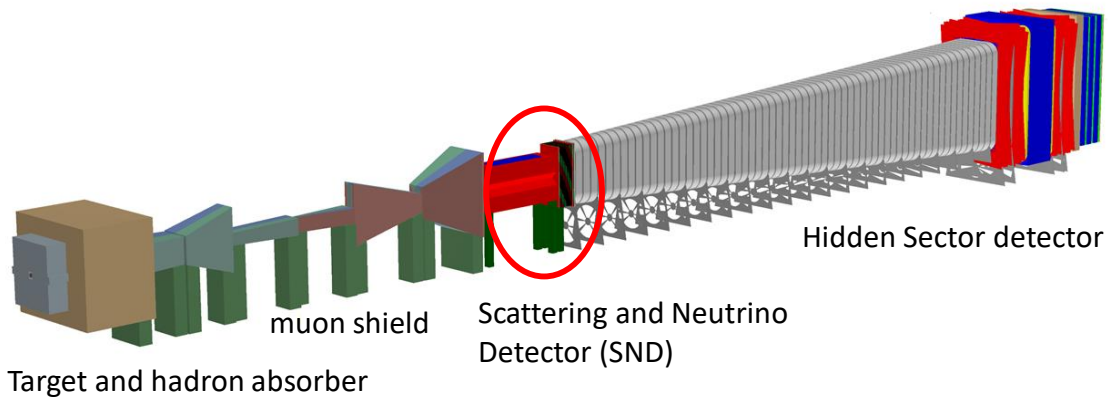

**Hidden Sector detector**:
Hidden Sector (HS) decay volume +
HS particle ID system

**High density target**
optimised
for heavy meson
production
+ **hadron absorber**

**Magnetised muon shield**:
- $\sim 10^{11}$ μ in 1 spill reduced to < $10^5$
- muon spectrum validated in a dedicated experiment

**Scattering and Neutrino detector**
designed in order to study the large neutrino flux produced at the beam dump

# Scattering and Neutrino Detector




*Expected neutrino flux @ beam dump*

| | <E>[ GeV ] | Beam dump |
|---|---|---|
| $N_{\nu_e}$ | 4.1 | $2.8 \times 10^{17}$ |
| $N_{\nu_\mu}$ | 1.5 | $4.2 \times 10^{18}$ |
| $N_{\nu_\tau}$ | 7.4 | $1.4 \times 10^{16}$ |
| $N_{\overline{\nu}_e}$ | 4.7 | $2.3 \times 10^{17}$ |
| $N_{\overline{\nu}_\mu}$ | 1.6 | $2.7 \times 10^{18}$ |
| $N_{\overline{\nu}_\tau}$ | 8.1 | $1.4 \times 10^{16}$ |

Neutrino physics goals @SND:

- cross section measurements of all ν flavours;
- ν-induced charm production studies;
- $\nu_\tau$ and $\overline{\nu_\tau}$ physics with high statistics;
- evaluation of F4 and F5 not accessible with $\nu_{e,\mu}$ .

$$\frac{d^2\sigma^{\nu(\overline{\nu})}}{dxdy} = \frac{G_F^2 M E_\nu}{\pi(1+Q^2/M_W^2)^2}\left((y^2x + \frac{m_\tau^2 y}{2E_\nu M})F_1 + \left[(1-\frac{m_\tau^2}{4E_\nu^2}) - (1+\frac{Mx}{2E_\nu})\right]F_2 \pm \left[xy(1-\frac{y}{2}) - \frac{m_\tau^2 y}{4E_\nu M}\right]F_3 + \frac{m_\tau^2(m_\tau^2+Q^2)}{4E_\nu^2 M^2 x}F_4 - \frac{m_\tau^2}{E_\nu M}F_5\right),$$

So far:

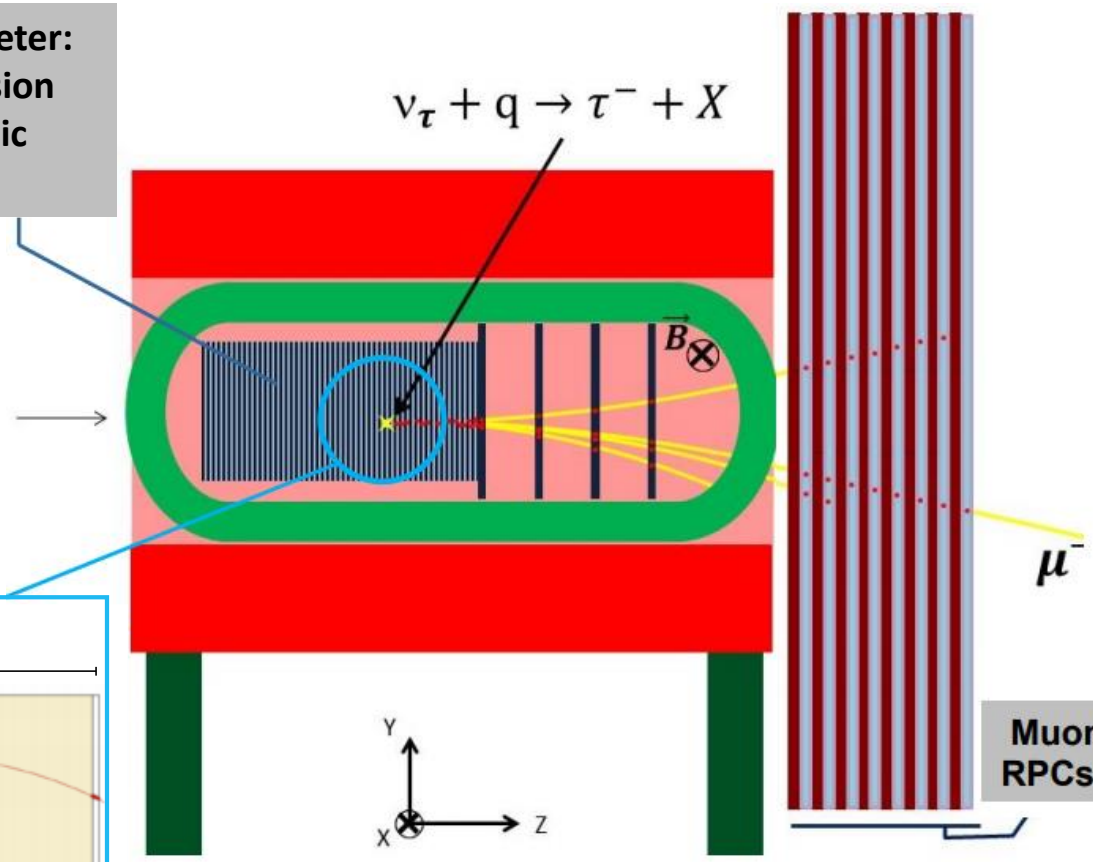
- 9 $\nu_\tau$ events by DONUT + 10 $\nu_\mu$->$\nu_\tau$ oscillations by OPERA
- $\overline{\nu_\tau}$ never been observed

| Decay channel | $\nu_\tau$ | $\overline{\nu}_\tau$ |
|---|---|---|
| $\tau \to \mu$ | 1200 | 1000 |
| $\tau \to h$ | 4000 | 3000 |
| $\tau \to 3h$ | 1000 | 700 |
| total | 6200 | 4700 |

Total number of expected $\nu_\tau$ and $\overline{\nu_\tau}$ events to be observed @SND

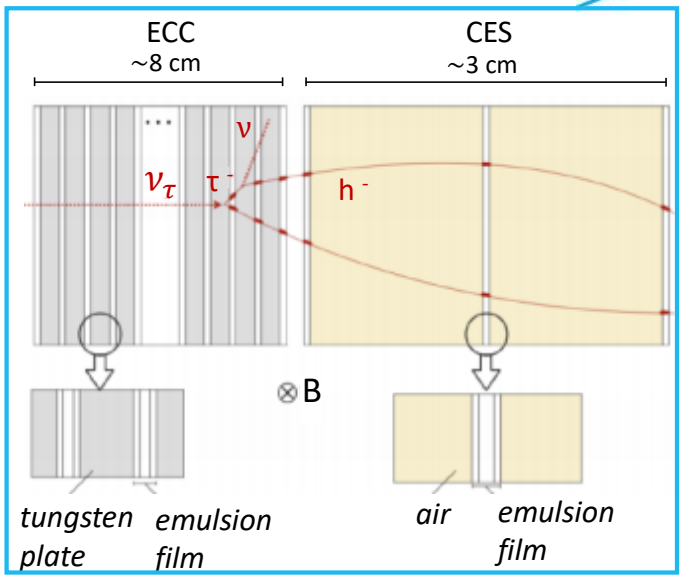
# Scattering and Neutrino Detector

**Precision spectrometer: Magnetised emulsion target + electronic trackers**



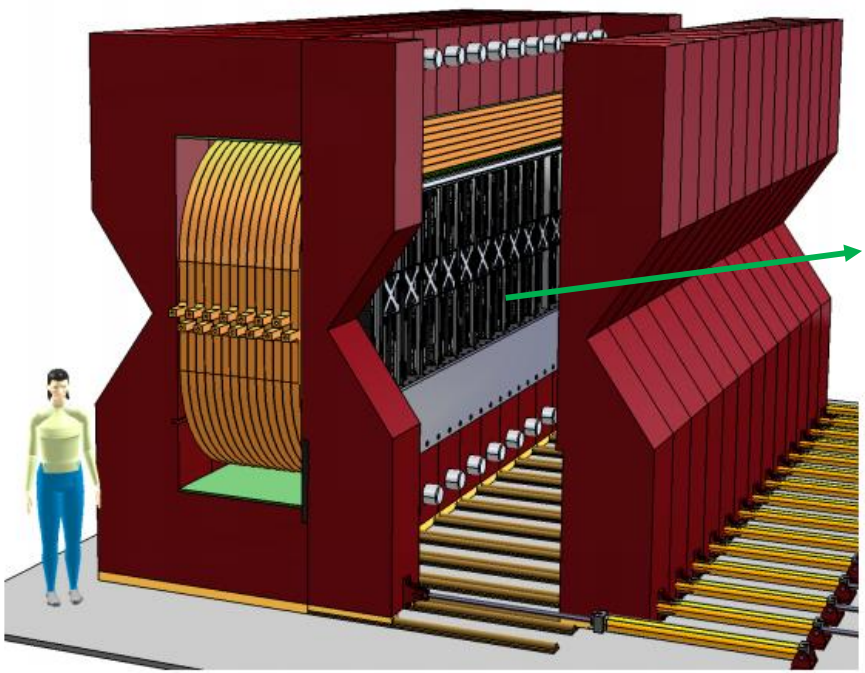

**Muon ID system: RPCs + iron filters**

ECC bricks à la OPERA

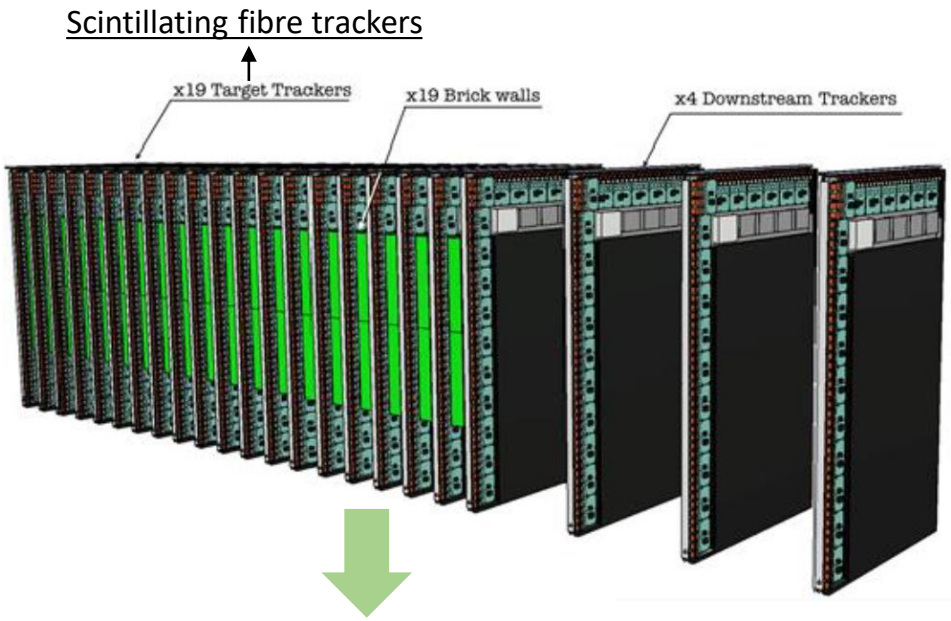


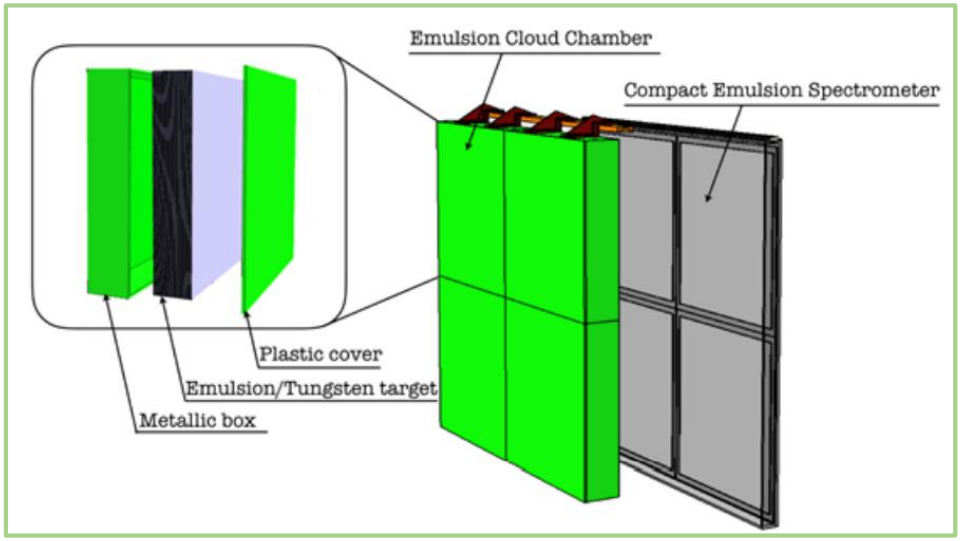

- τ decay vertex reconstructed thanks to the sub-micrometric resolution of the emulsion target;
- target magnetisation allows to distinguish between $\nu_\tau$ and $\overline{\nu_\tau}$.

# SND precision spectrometer



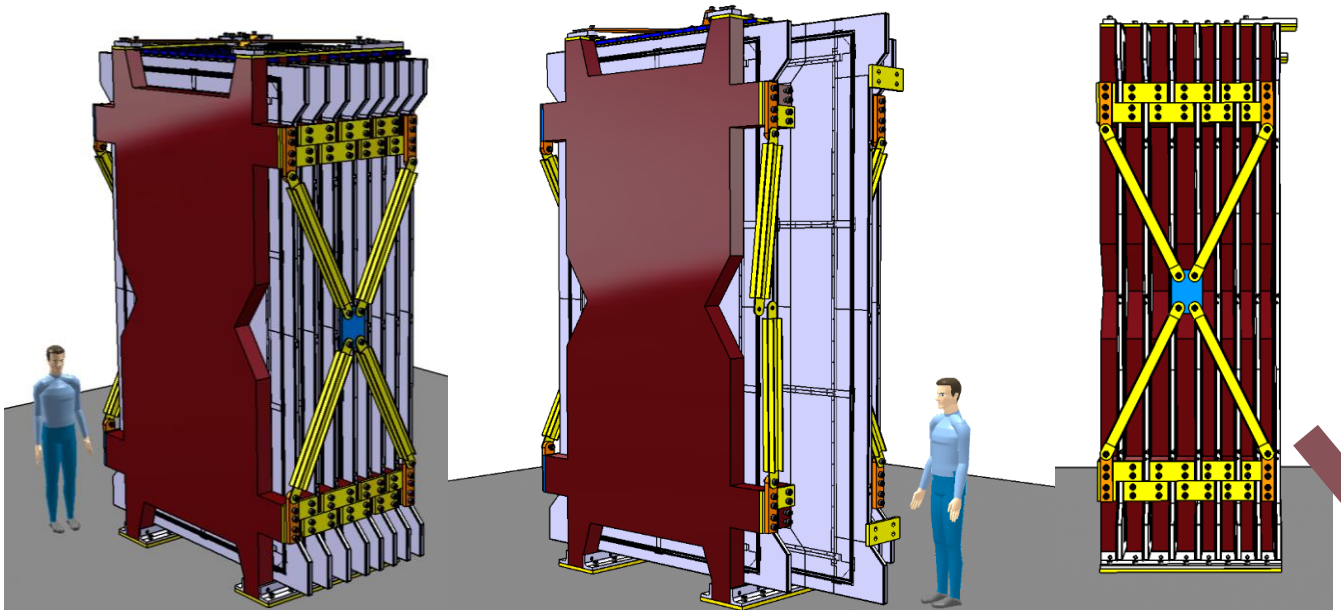
*JINST 15(2020) P01027*



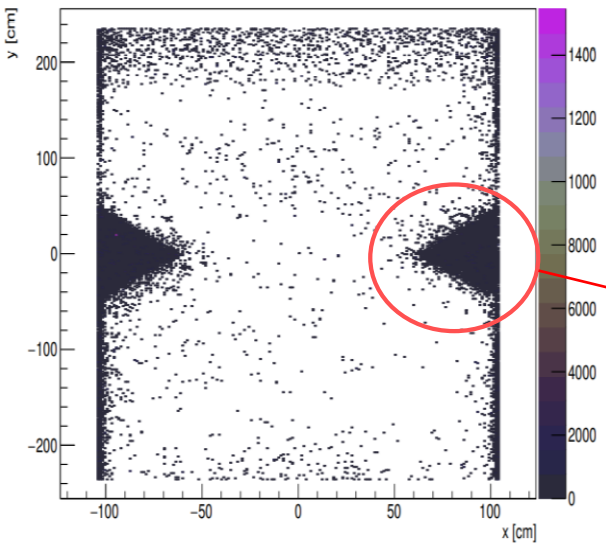




- Magnetised volume of ~10 $m^3$;
- B~1.2 T, spatial field omogenity ~1%;
- maximum external stray field ~10 mT;
- opening / closing mechanism to allow for emulsion film replacement during run.

# SND Muon Identification system

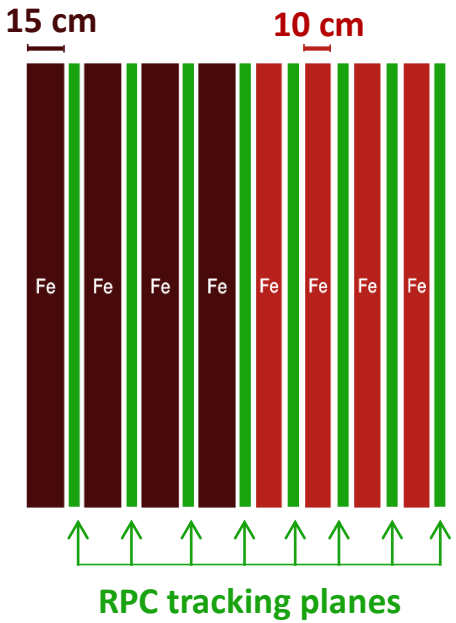


**8 tracking planes based on RPCs** identifying muons with high efficiency **interleaved with iron walls**, acting as hadron filters




Detector planes are hanging from the top of a support structure and extracted through upper trails

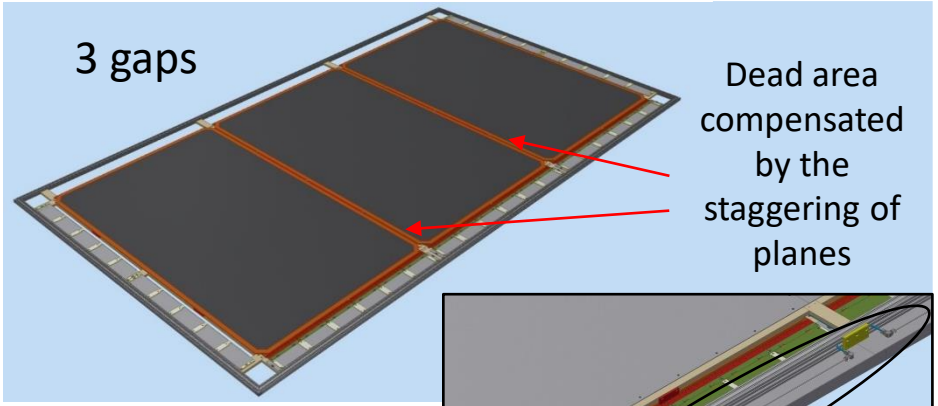
Maximum expected charged particle rate ~400 Hz/cm$^2$: RPCs operated in avalanche mode

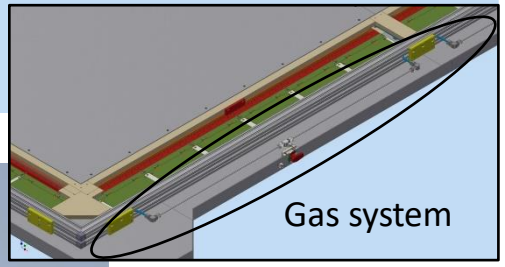


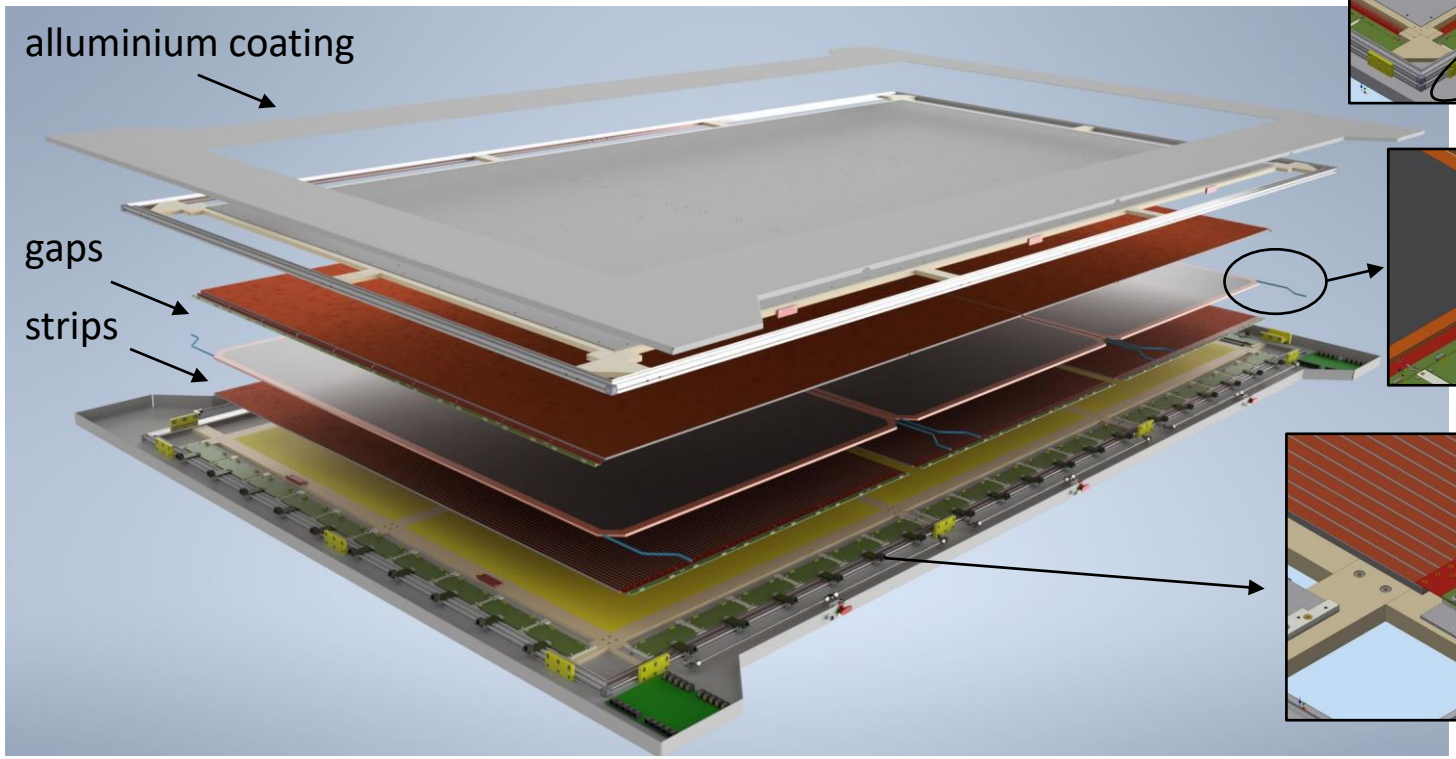
# RPCs for SND muon system

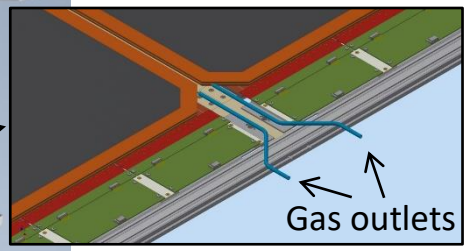
RPC tracking plane (~2 x 4 $m^2$ ):

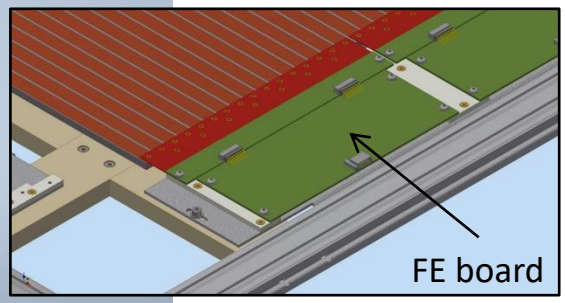
- 3 gaps (~1.9 x 1.2 $m^2$ each), operated in avalanche mode;
- readout by 2 panels of perpendicular strips (pitch ~1cm, lenght ~2m);
- mechanical structure including all services (HV, gas distribution, front-end boards).



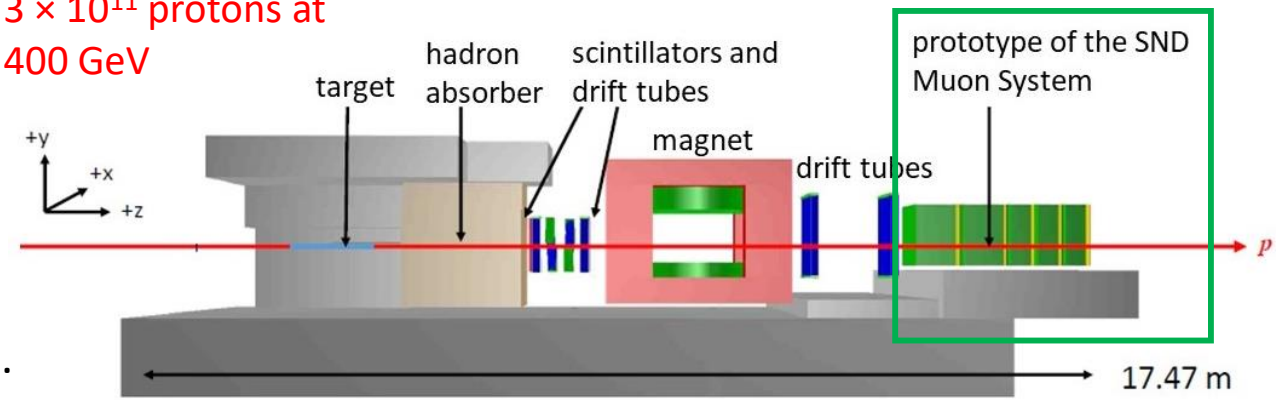



# Prototypes for SHiP RPCs

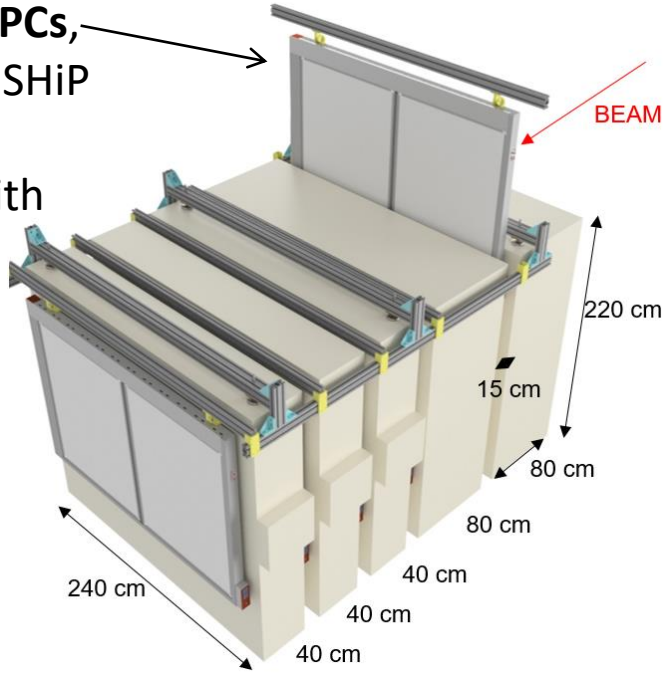
*Eur. Phys. J. C 80 (2020) 284*

In 2018 the SHiP Collaboration installed a small-scale replica of the experiment target in the H4 beam line in order to measure the muon flux generated by the SHiP target.

$3 \times 10^{11}$ protons at 400 GeV

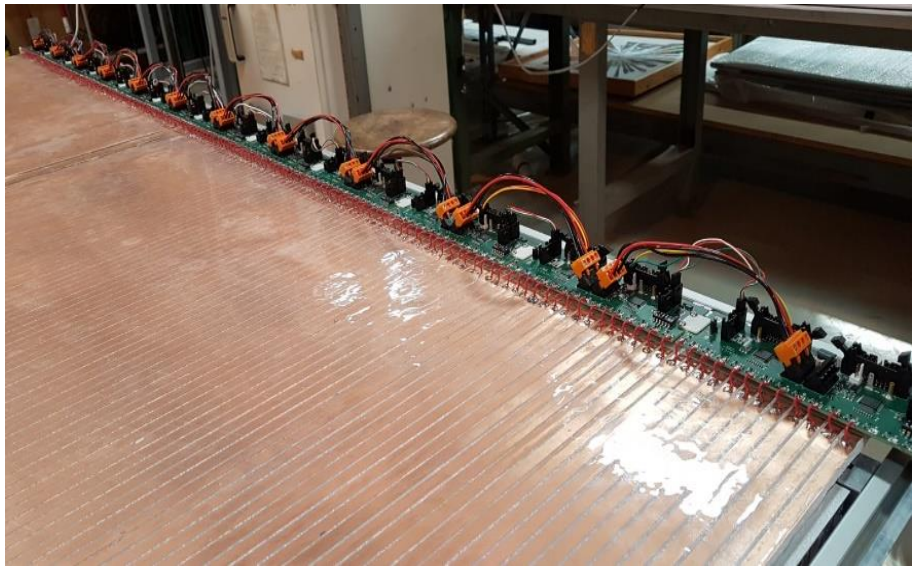



5 **single gap RPCs**, prototypes of SHiP muon planes, interleaved with iron slabs

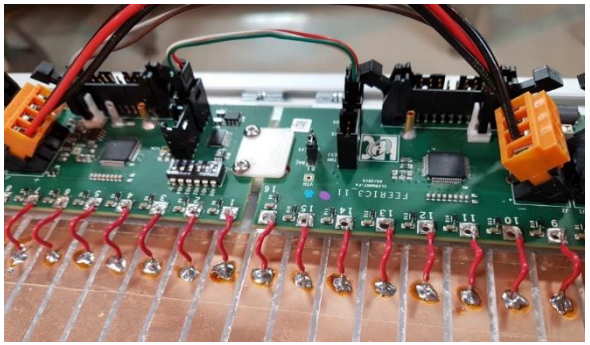


# Prototypes for SHiP RPCs

A pilot production of five RPCs, prototypes of the SHiP tracking planes, was made for the muon-flux measurement by the Bari, Napoli and KODEL SHiP groups.

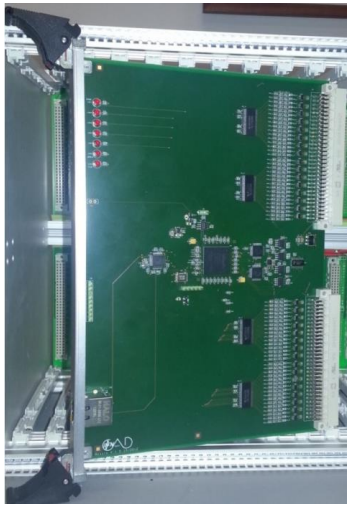


- Dimension: ~(1.9 × 1.2) $m^2$ ;
- Gap width: 2 mm;
- Readout by 2 panels of perpendicular strips with pitch of ~1 cm;
- Bakelite electrodes thickness: 2 mm;
- Operated in avalanche mode.



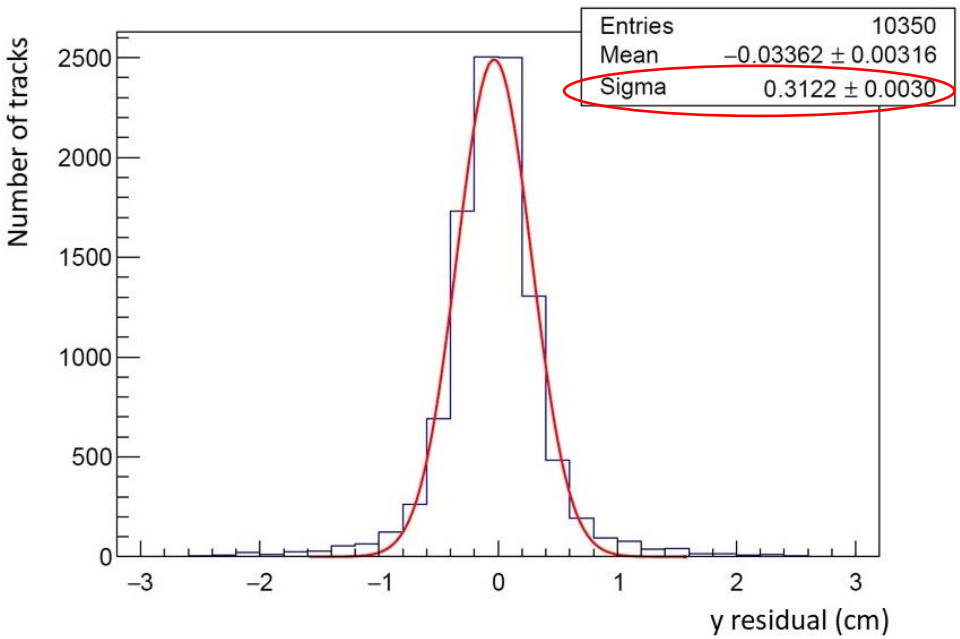
FE board with 2 FEERIC ASICs by ALICE *[JINST 9 (2014) C09013]*

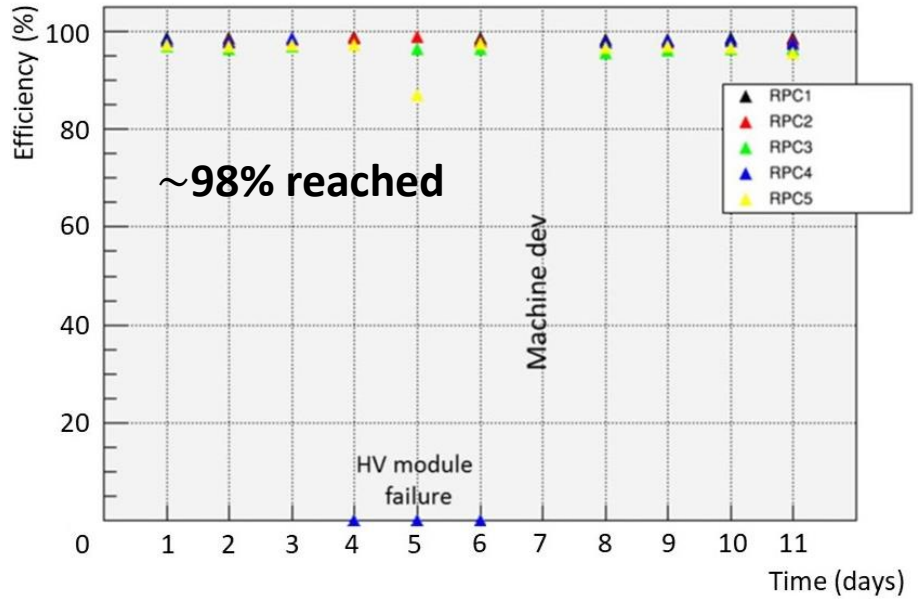
Parallel signal transmission



Data processed and transmitted via Ethernet to the DAQ by custom readout boards [INFN-Bari]

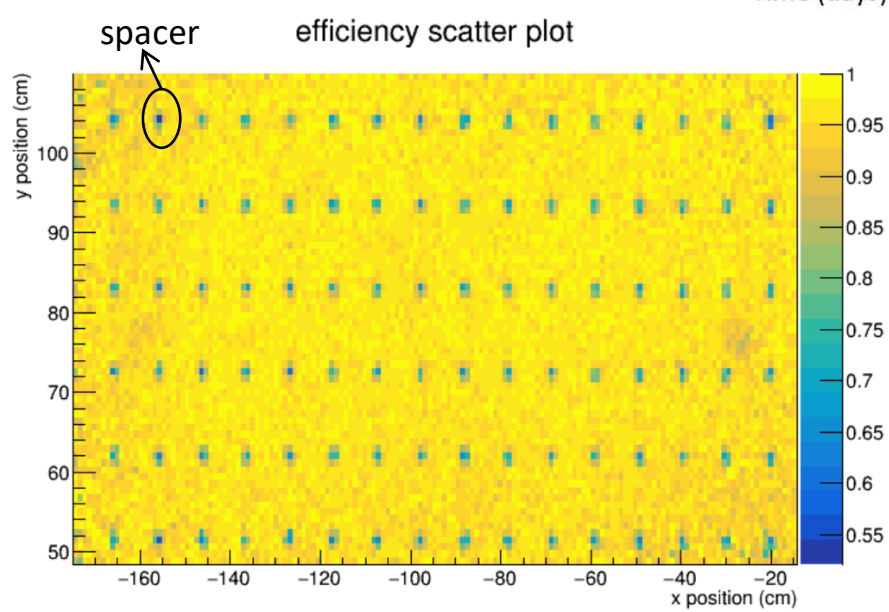
# Performance of SHiP RPCs with standard gas mixture




Standard gas mixture:
95.2% R134a - 4.5% $iC_4H_{10}$ - 0.3% $SF_6$

- Efficiency reached by all chambers: ~98%;
- Spatial resolution: about 3 mm;
- Uniform spatial response provided.



# R&D activities: eco-friendly gas mixtures

- Fluorinated greenhouse gases (GHGs) with high **Global Warming Potential (GWP)** have been recently limited in EU [EU regulation 517/2014].

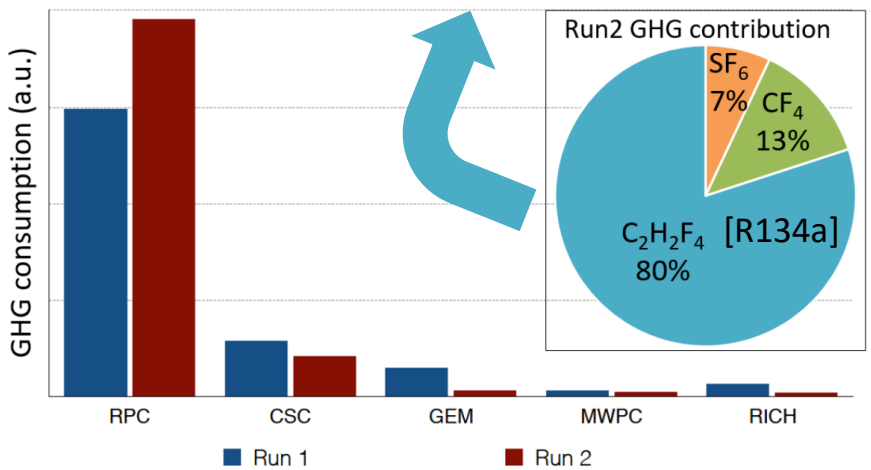
*quantifies the contribution of a gas to the greenhouse effect, normalized to the effect of $CO_2$*

- CERN is committed to reducing its direct greenhouse gas emissions [CERN Env. Report].

**Alternative eco-friendly gas mixtures for RPCs** under study. Requirements:
- low toxicity;
- not flammable;
- detector performance comparable with standard gas mixture.

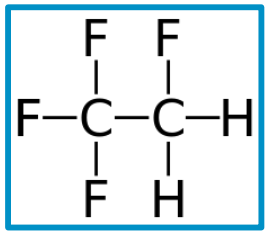
*JINST 15 (2020) C10028*

R134a: standard gas mixture main component, GWP=1430

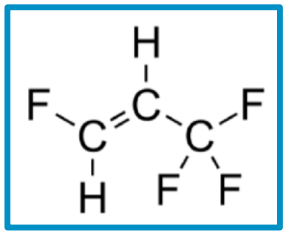



- R134a is being replaced in industrial applications with HydroFluoro-Olefins (HFOs). Initial strategy:

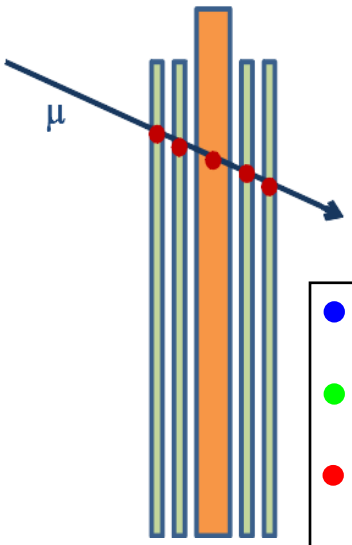
**R134a, GWP=1430**



**HFO-1234ze, GWP=6**

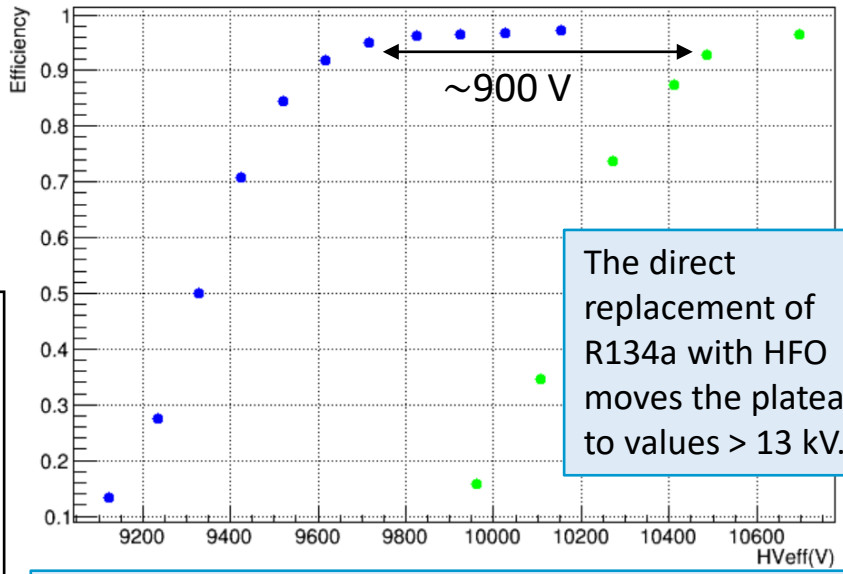


# R&D activities: eco-friendly gas mixtures



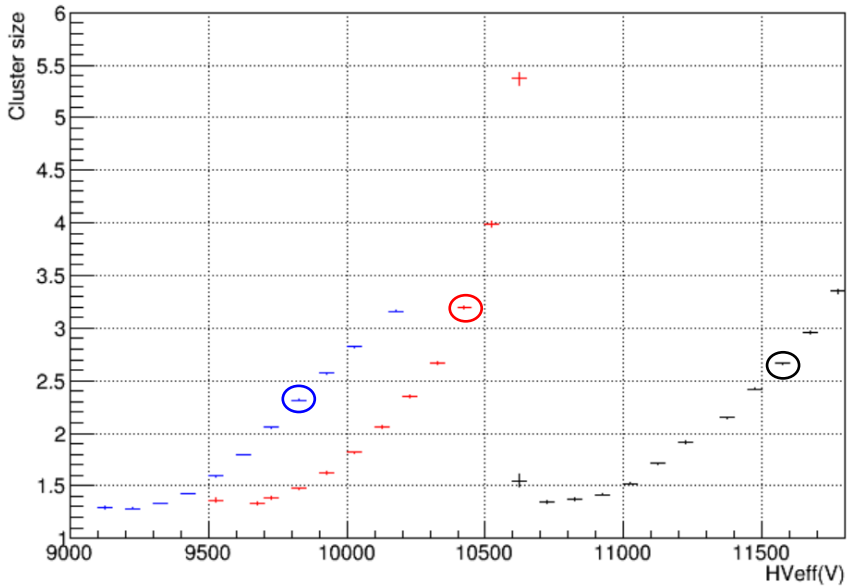

RPC under test
RPCs for trigger and tracking
muon track

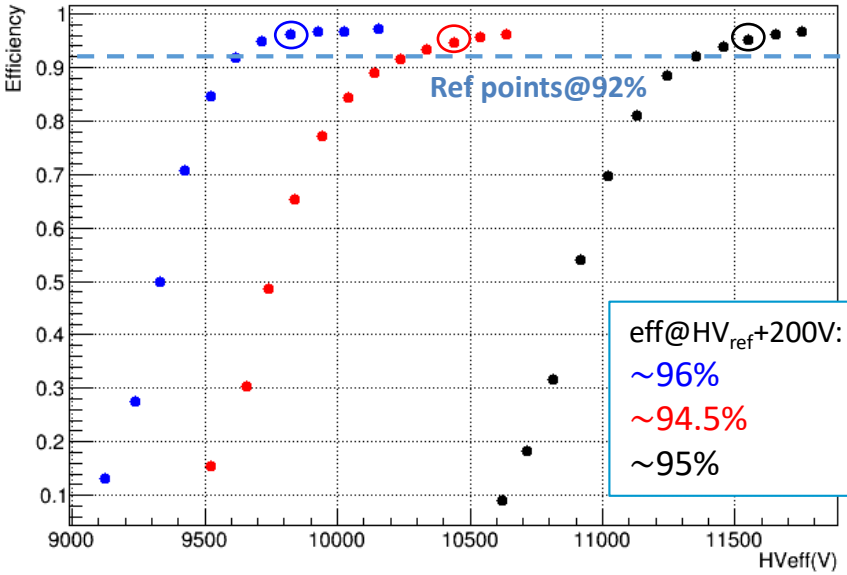
- Standard gas mixture: GWP~1470
  **94.5% R134a-0% HFO**-5%$iC_4H_{10}$ -0.5% $SF_6$
- **84.5% R134a-10% HFO**-5% $iC_4H_{10}$-0.5% $SF_6$ [GWP~1330]
- **25% HFO-69.5% $CO_2$**-5% $iC_4H_{10}$-0.5% $SF_6$ [GWP~120]
- **35% HFO-60%$CO_2$**-4.5% $iC_4H_{10}$-0.5% $SF_6$ [GWP~120]




The direct replacement of R134a with HFO moves the plateau to values > 13 kV.

$CO_2$ addition : eff. plateau decreased to values < 12 kV.

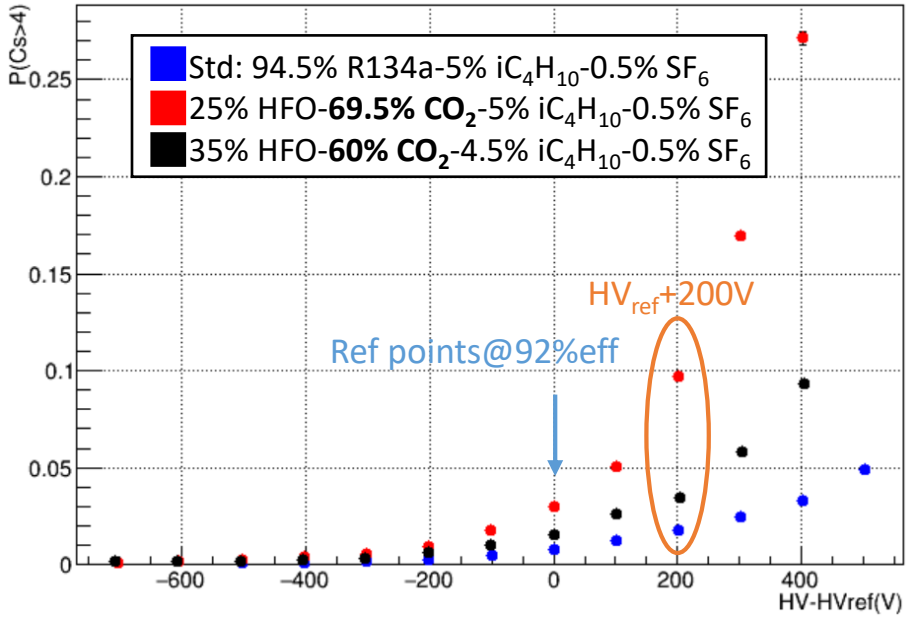



eff@$HV_{ref}$+200V:
~96%
~94.5%
~95%

# R&D activities: eco-friendly gas mixtures

*Probability of observing events with cluster size > 4*




*Performance of HFO/$CO_2$ based mixtures wrt standard case*

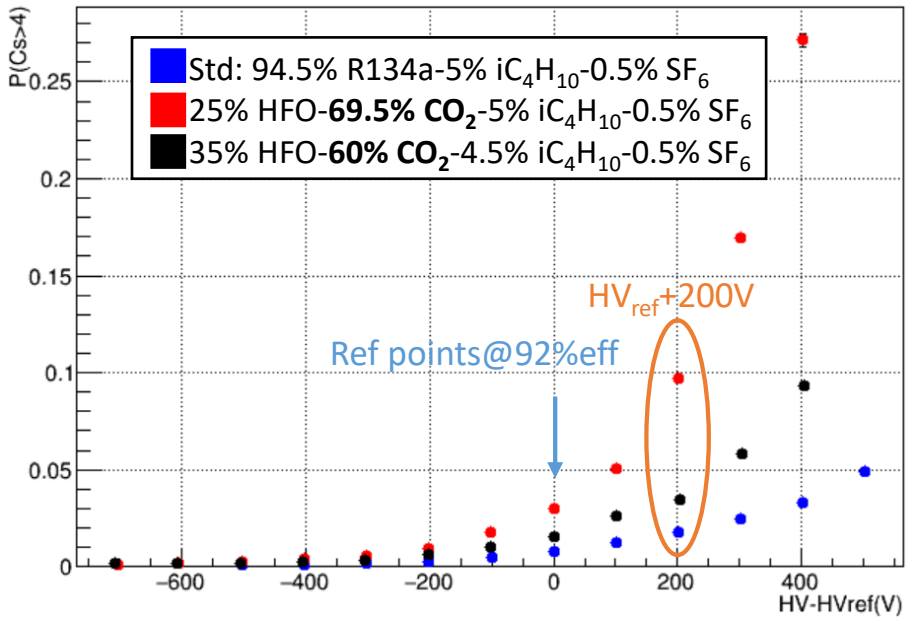
Increasing $CO_2$ %

| mix | GWP | HVref+200V | eff | Av. cluster size | P(Cs>4) |
|---|---|---|---|---|---|
| | ~1470 | ~9800 V | ~96% | ~2.3 | ~2% |
| | ~120 | ~11550 V | ~95% | ~2.7 | ~3.5% |
| | ~120 | ~10450 V | ~94.5% | ~3.2 | ~10% |

- The probability of observing large cluster size events increases with the $CO_2$ amount;
- For the eco-gas mixture with 60% $CO_2$ @$HV_{ref}$+200V:
  P(Cs>4) is ~1.7 higher than standard case;
  the efficiency is ~1% less wrt std case.

# R&D activities: eco-friendly gas mixtures

*Probability of observing events with cluster size > 4*

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  P(Cs>4) is ~1.7 higher than standard case;
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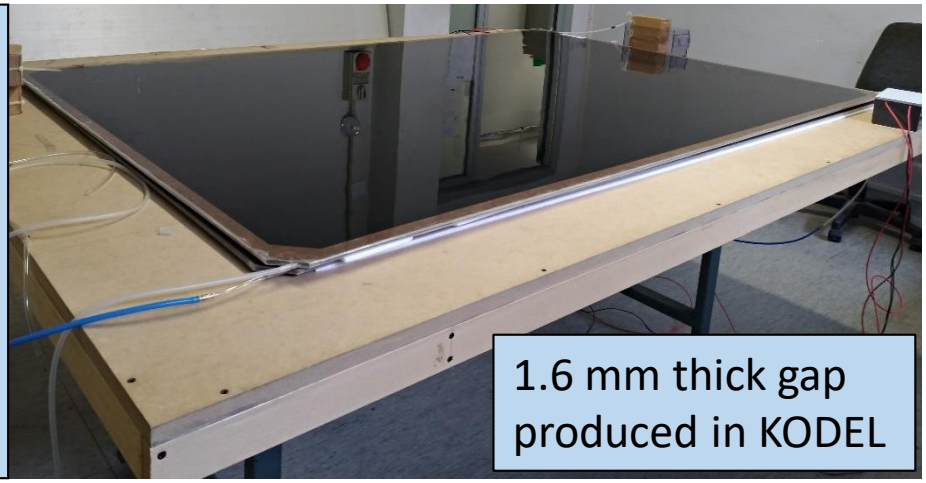
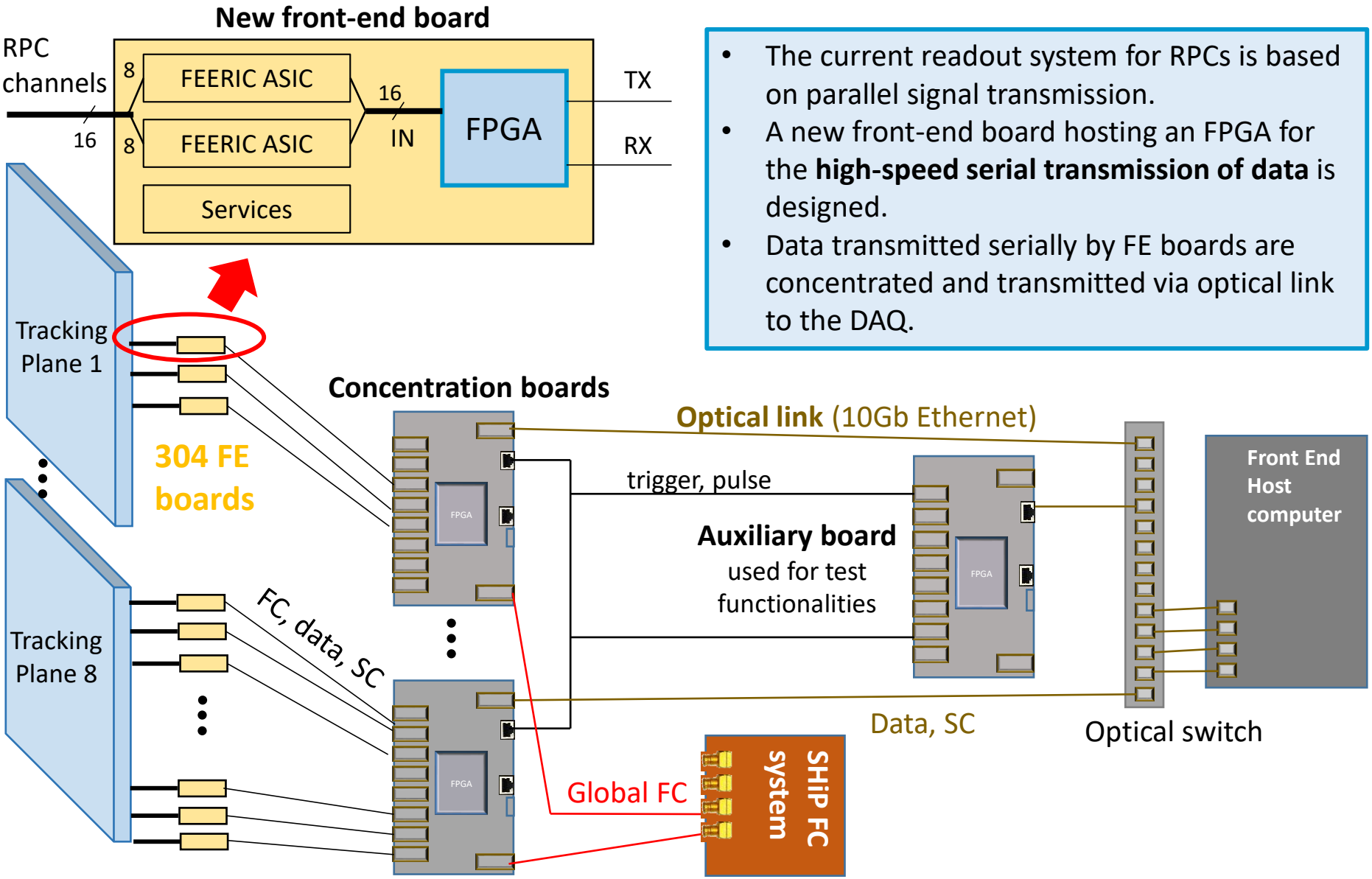
New gaps with reduced thickness are under study:

- Decreased average charge delivered;
- Improvement of RPC performance with eco-gas;
- Higher rate capability;
- Improved detector longevity.



1.6 mm thick gap produced in KODEL

# R&D activities: readout system for SHiP RPC




- The current readout system for RPCs is based on parallel signal transmission.
- A new front-end board hosting an FPGA for the **high-speed serial transmission of data** is designed.
- Data transmitted serially by FE boards are concentrated and transmitted via optical link to the DAQ.

# Conclusion

**The SHiP SND Muon System**

- The SHiP experiment could study neutrino physics with unprecedented statistics. A dedicated Scattering and Neutrino Detector (SND) is thus being designed.
- The SND is equipped with a Muon Identification System based on RPC technology.

**Prototypes of SHiP RPCs**

- Five 2 mm-gap prototypes of SHiP RPCs have been produced, tested with cosmic rays and exposed at H4 beam line with standard gas mixture.
- RPCs showed uniform spatial response, efficiency of ~98% and resolution of ~3 mm.

**R&D for SHiP RPCs**

- Eco-friendly gas mixtures based on HFO and $CO_2$ for SHiP RPCs are currently under study.
- In order to improve RPC performance with eco-gas, gaps with reduced thickness are being tested.
- The readout system for SHiP RPCs including a new FE board for the high-speed serial transmission of data from detector planes to the DAQ is being designed.

# Thank you!