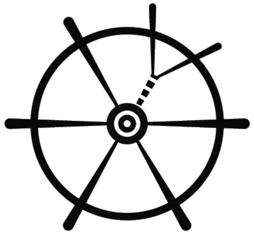
THE SHiP EXPERIMENT AND THE RPC TECHNOLOGY

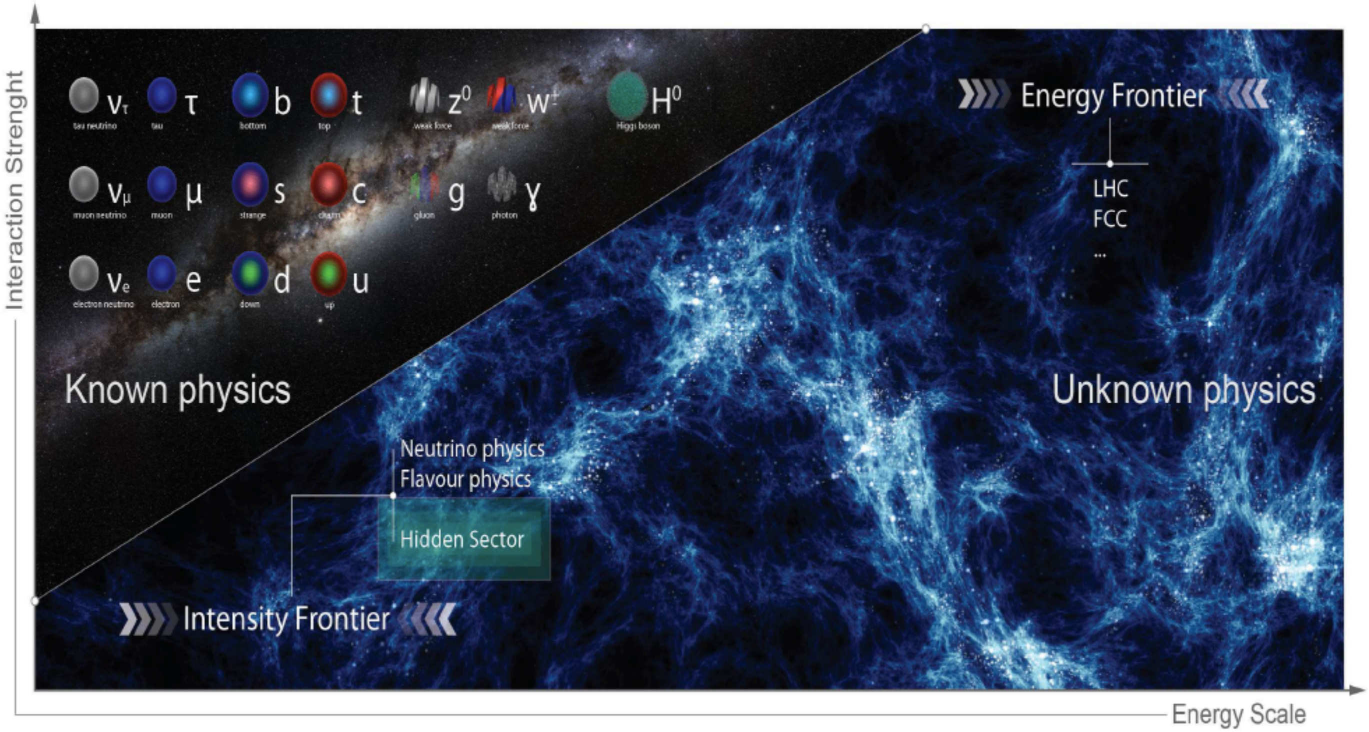
Giovanni De Lellis

Università Federico II and INFN, Naples, Italy
On behalf of the SHiP Collaboration

MOTIVATION



- The **Standard Model** provides an explanation for most of subatomic processes



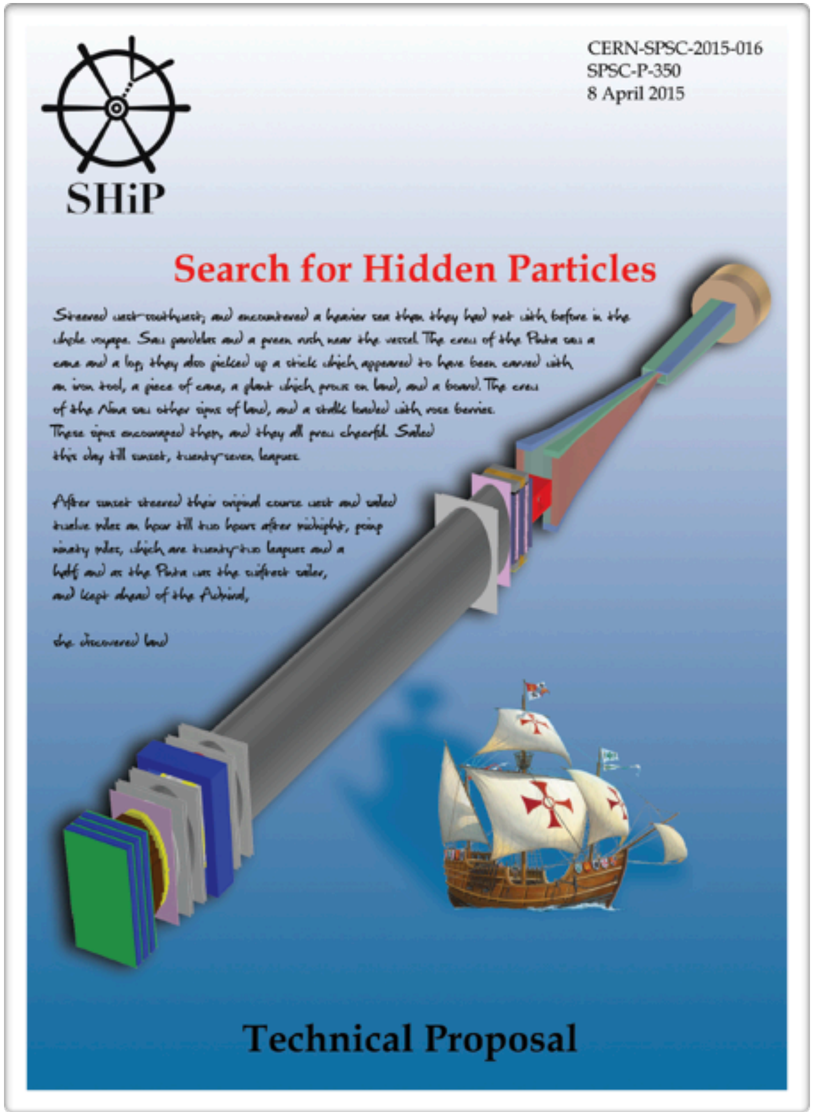
- Although very successful, it fails to explain many observed phenomena
  - **Dark Matter**
  - **Neutrino Oscillation and masses**
  - **Matter/antimatter asymmetry in the Universe**

- A **Hidden Sector (HS)** of weakly-interacting BSM particles as an explanation

Energy Frontier:
Heavy particles → high energy collisions

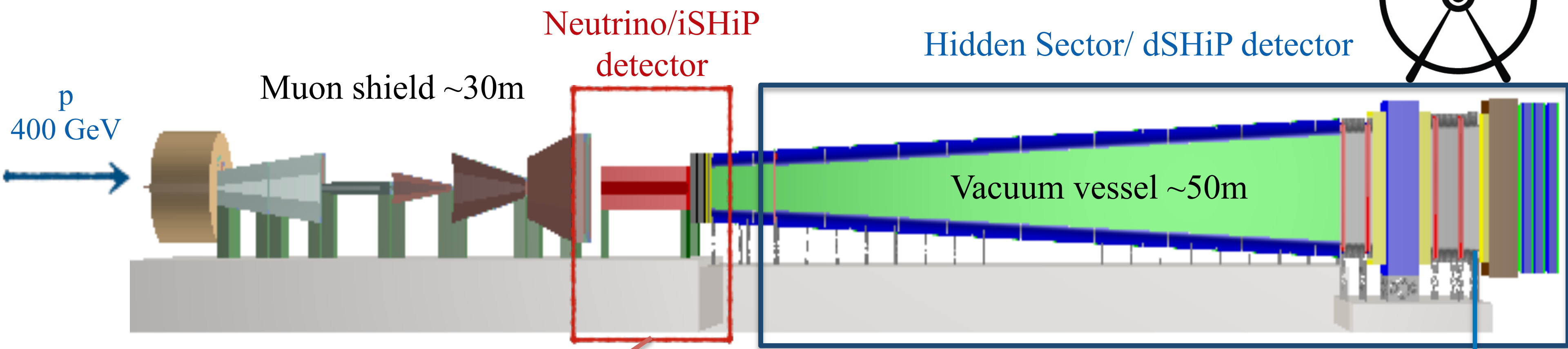
Intensity Frontier:
Very weakly interacting particles → high intensity beam

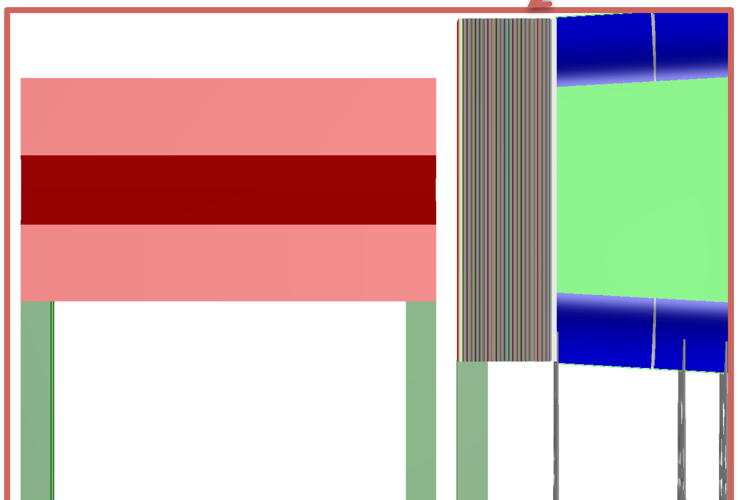
THE SHiP PROJECT



- SHiP (Search for Hidden Particles) in a proposed fixed target experiment at CERN SPS
- Collaboration of 250 members from 49 institutes, 17 countries
- Technical Proposal
  arXiv:1504.04956 (2015)
- Physics case prepared by 80 theorists
  Rep. Prog. Phys. 79 (2016)
  arXiv:1504.04855
- Positive SPSC recommendation
- Comprehensive Design Study by 2019
  → decision about approval in 2020
- Important actor in the CERN Physics Beyond Colliders study group

SHiP Detector Layout





Multigap Resistive Plate Chambers

- possible option for dSHiP Timing Detector
- Required time resolution: <100 ps
- Transverse size: 5x10 m^2

24 RPC planes 214 x 490 cm^2

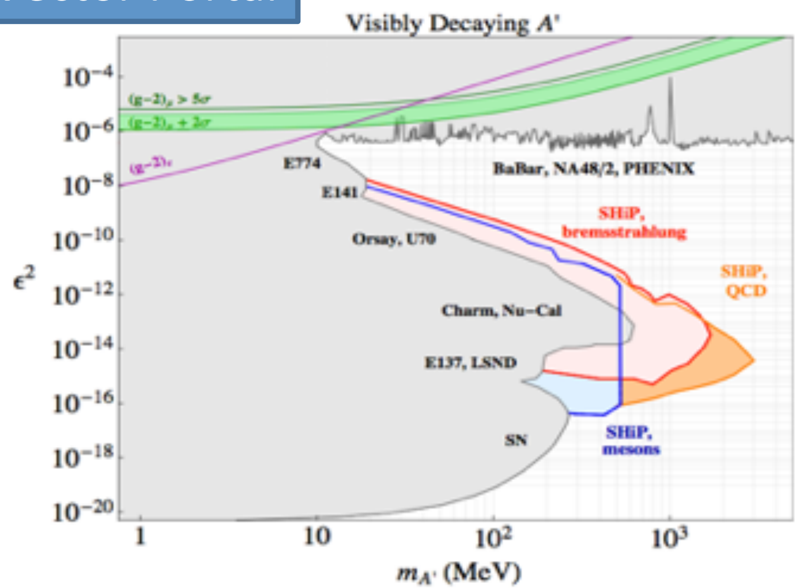
Acting as:

- Muon Tagger for iSHiP detector
- Upsteam Veto System for dSHiP detector

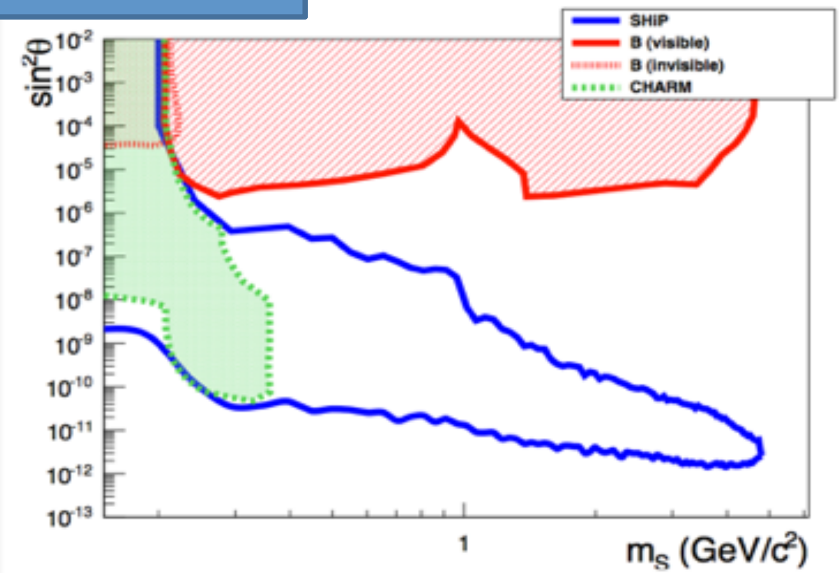
SHiP sensitivity to Hidden Sector

Based on 2x10^{20} pot
@400 GeV in 5 years

Vector Portal

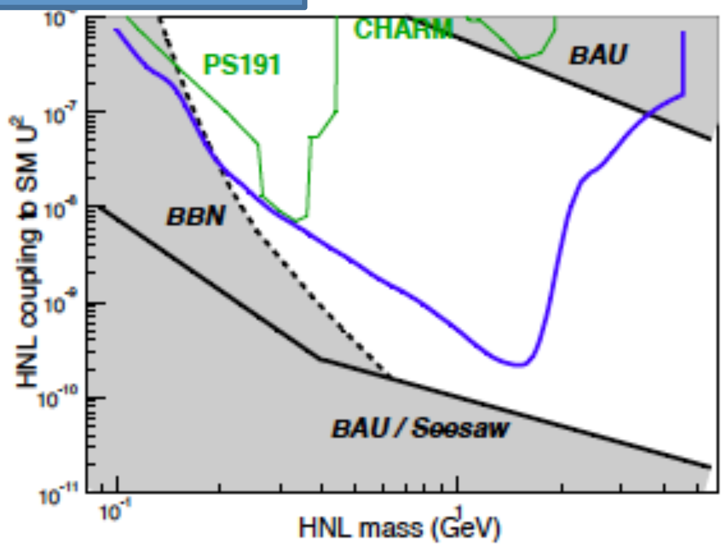


Scalar Portal

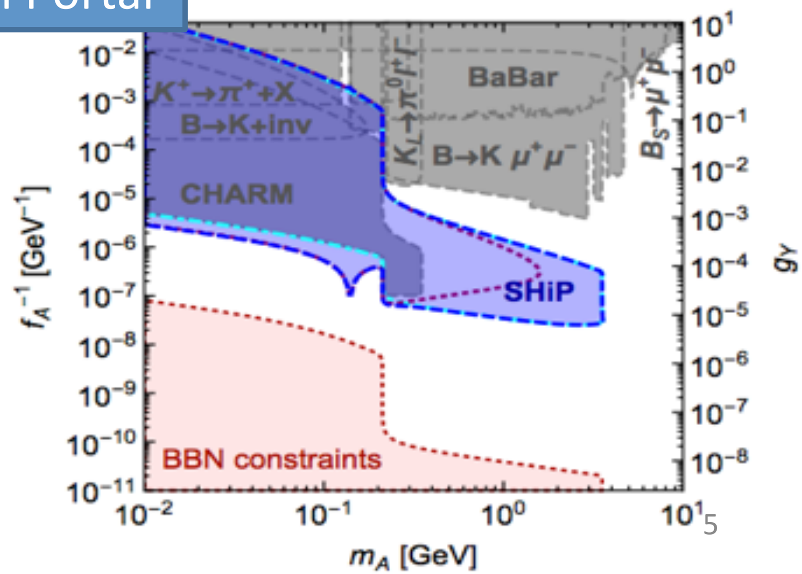


Neutrino Portal

sensitivity to HNLs



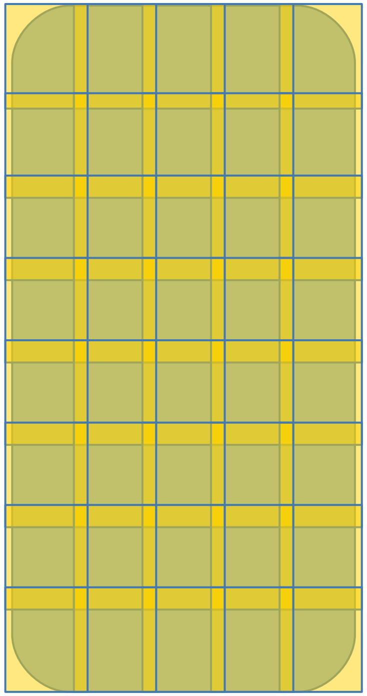
Axion Portal



The Timing Detector implementation based on MRPCs.

Schematic drawing (Alberto Blanco and Paulo Fonte)

- **Modules composed of two 6 gaps RPCs** sensitive volumes.
- Strip (placed in the middle of two sensitive volumes) readout on both sides
- Active **area of 1500x1200 mm^2 = 1,8 m^2**
- **Good time resolution,** < 100 ps σ.
- **Good efficiency,** > 95 %
- Easy to build.
- **Low multiplicity**, few particles per module.



Area to be covered 10x5 m^2
⇒ 40 MRPC modules with overlap
Ongoing optimization on the size

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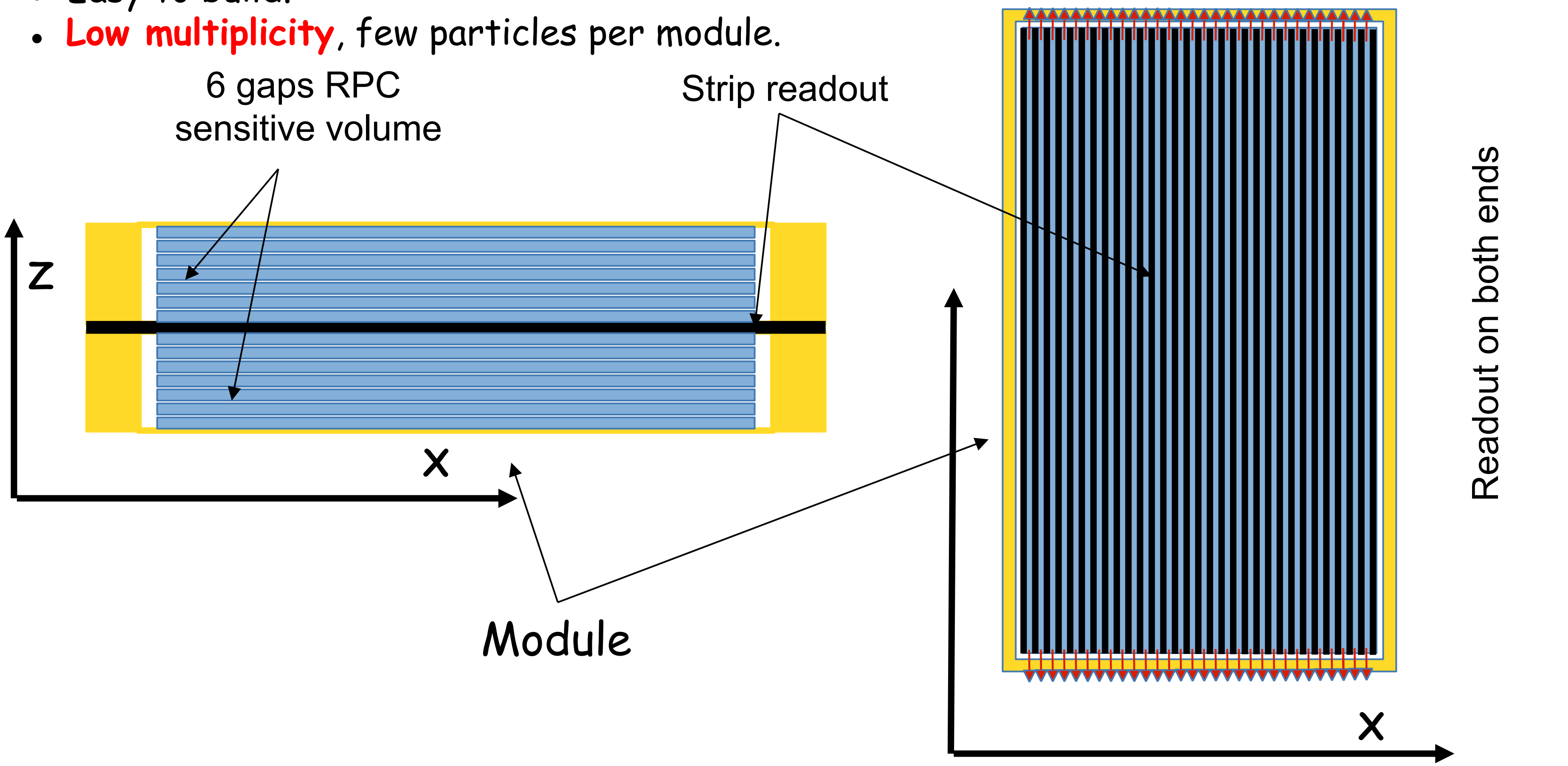

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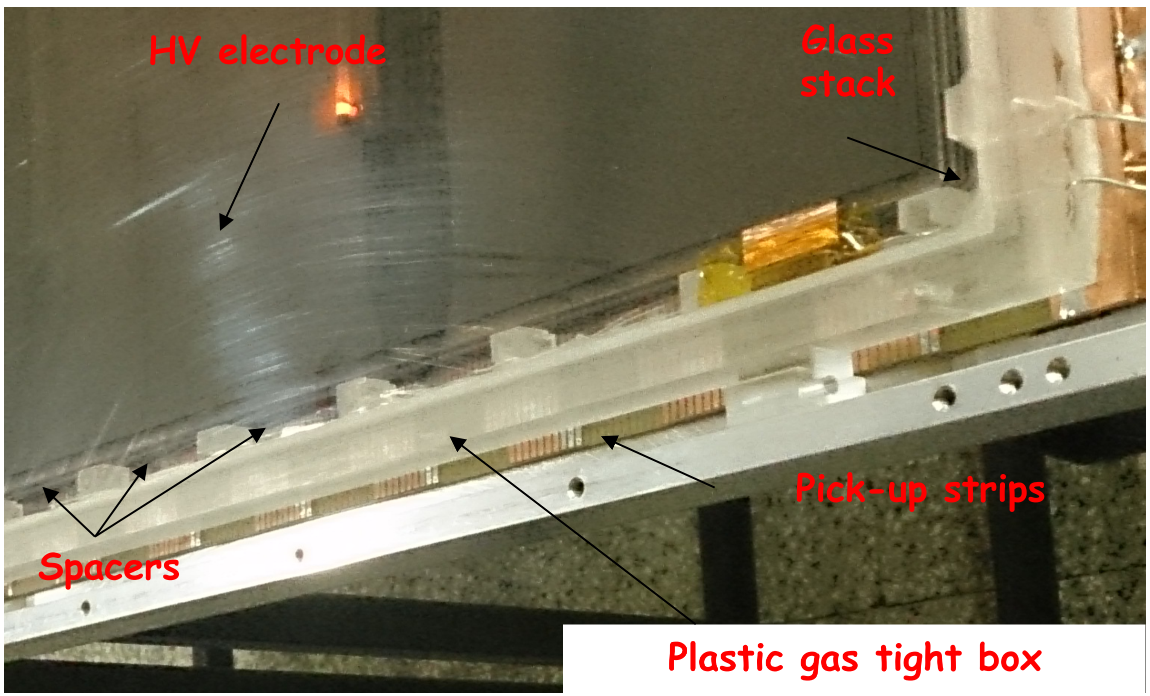


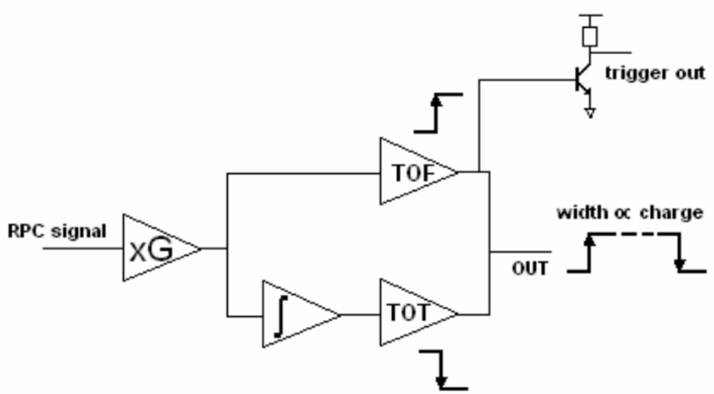
A **sensitive volume** contains the glass and HV electrodes enclosed in a plastic gas tight box with feed-throughs for gas and High Voltage.

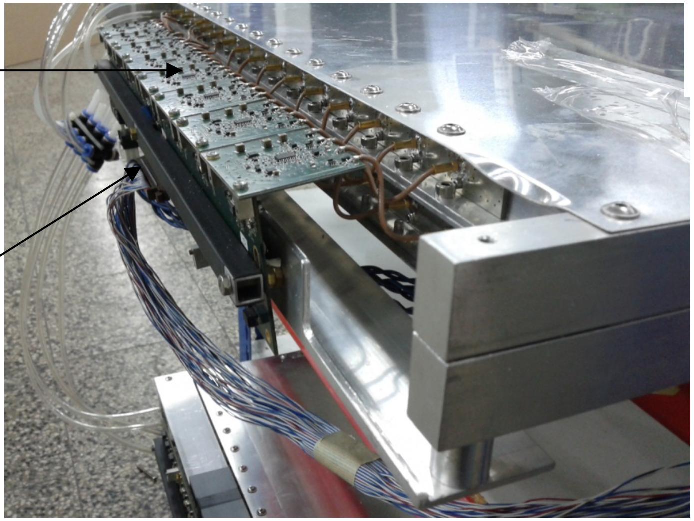
Easy to build
completely gas tight,
no gas leaks

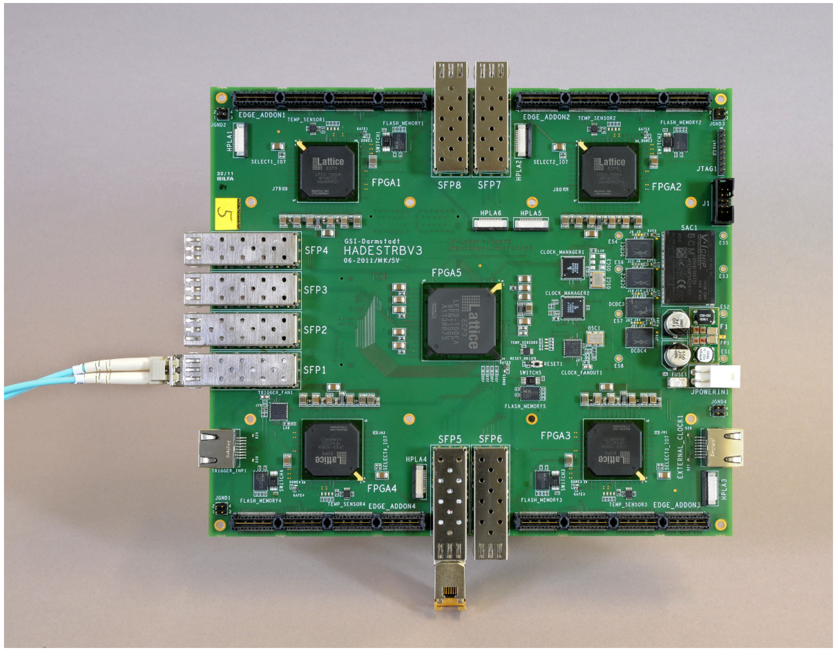
Testing MRPCs (Alberto Blanco and Paulo Fonte)

All systems borrowed from the HADES-TOF

- **FEE, time (σ_t~40ps) and charge measurement in one single channel.**
- Strips are readout in both sides







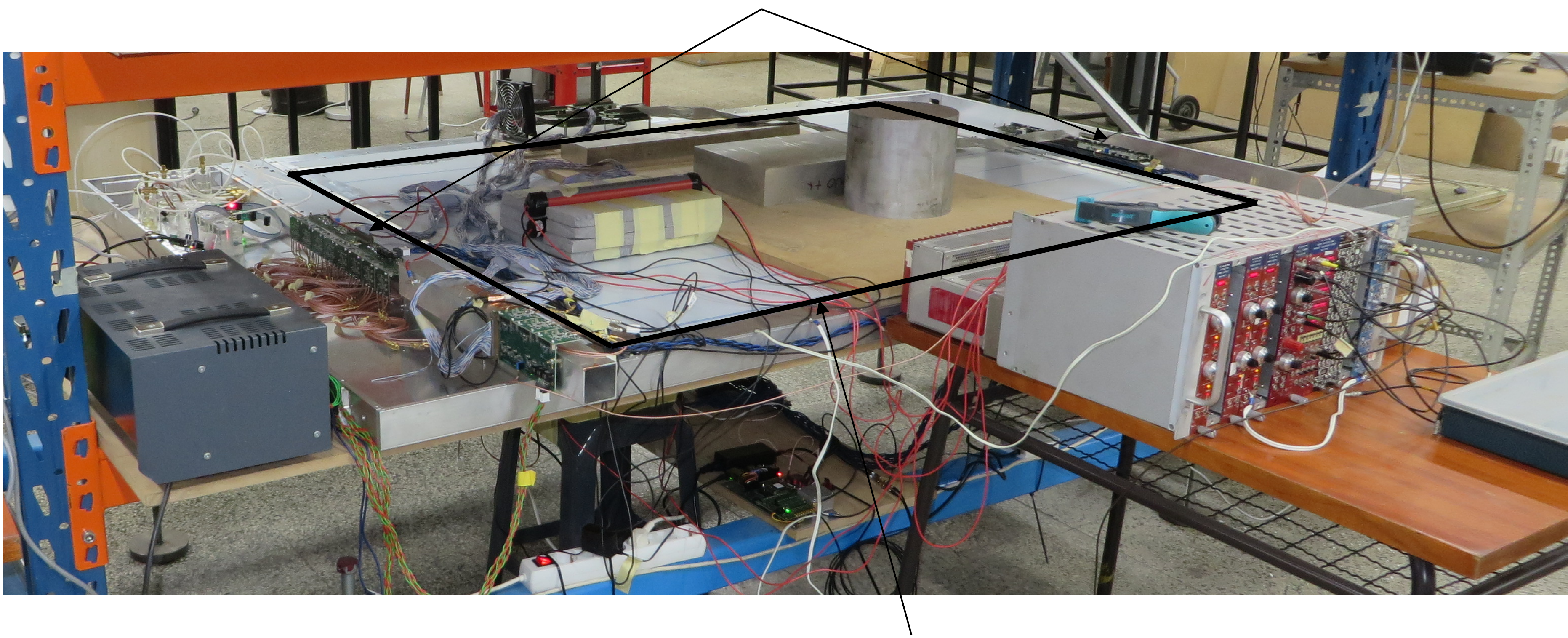
One central FPGA with trigger management capabilities plus 4 sockets with capability to operate.

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

And much more

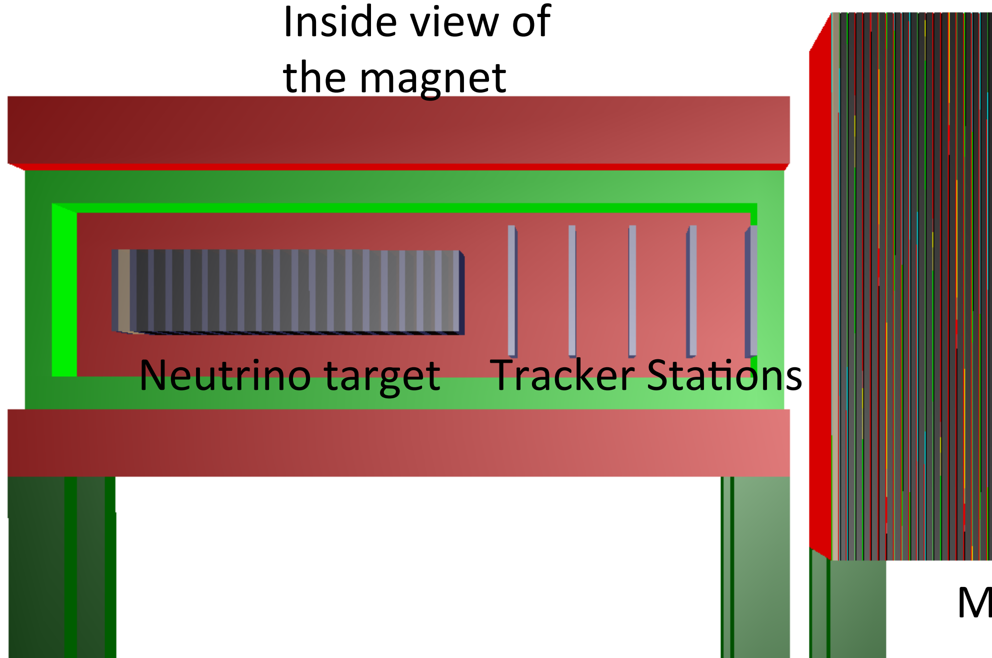
[IEEE TNS 57, 2848 (2010)]
A Neiser et al 2013 JINST 8 C12043
doi: 10.1088/1748-0221/8/12/C12043

Testing MRPCs
(Alberto Blanco and Paulo Fonte)



- First prototype just assembled and instrumented few days ago
- Time resolution and efficiency under evaluation.

Neutrino detector layout



In the magnetized region:

- ECC walls and target trackers, followed by tracker stations.

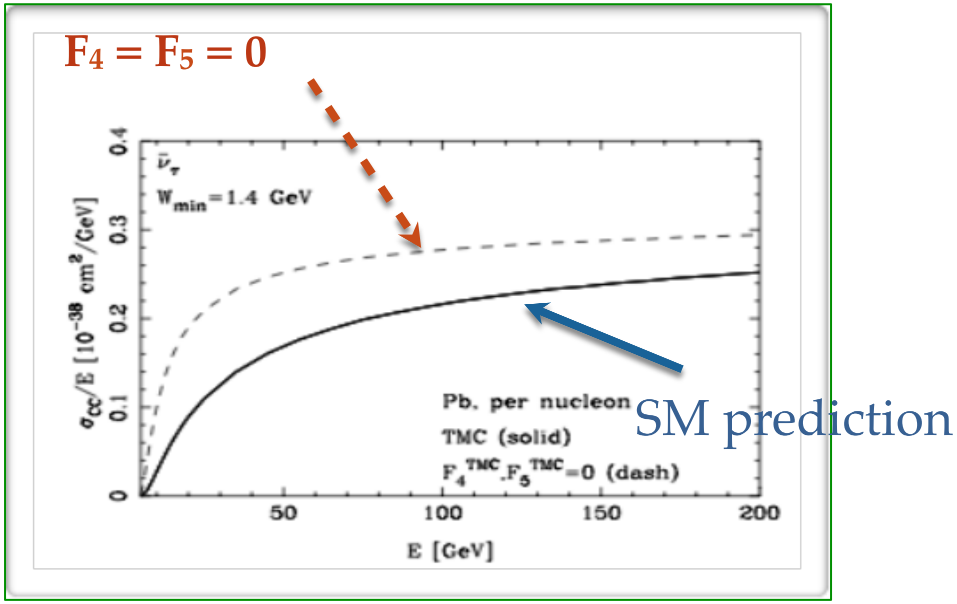
Outside the magnet:

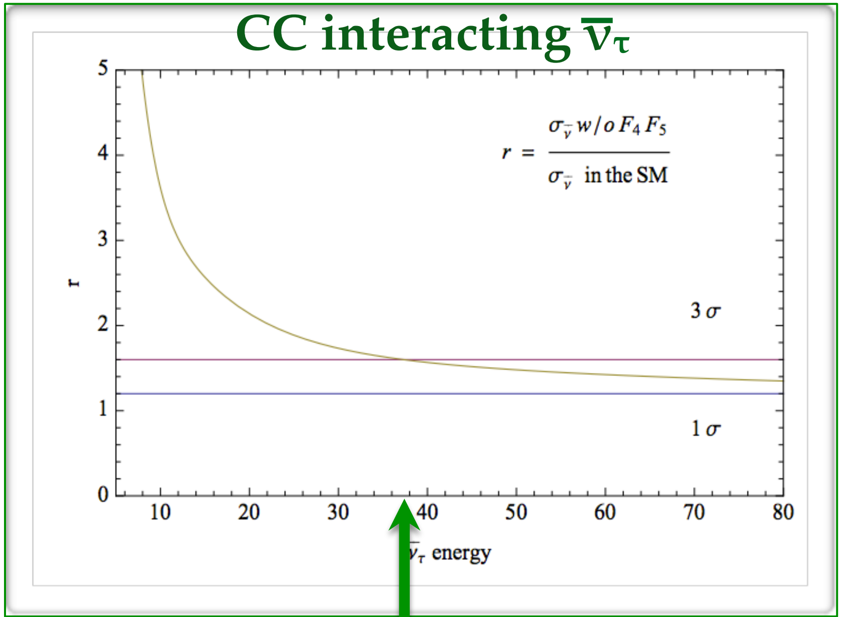
- Muon detector

F_4 AND F_5 STRUCTURE FUNCTIONS

First evaluation of F_4 and F_5, not accessible with other neutrinos

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





$E(\overline{\nu}_\tau) < 38$ GeV

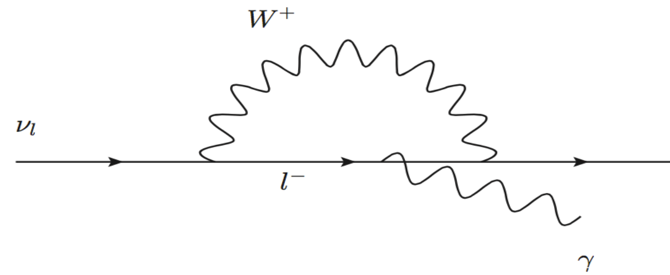
- At LO $F_4 = 0$, $2xF_5 = F_2$
- At NLO $F_4 \sim 1\%$ at 10 GeV

TAU NEUTRINO MAGNETIC MOMENT

A massive neutrino may interact e.m.

→ magnetic moment proportional to its mass

$$\boxed{\mu_\nu = \frac{3\,e\,G_F\,m_\nu}{8\,\pi^2\,\sqrt{2}} \simeq (3.2 \times 10^{-19}) \left(\frac{m_\nu}{1\,\mathrm{eV}}\right) \mu_B}$$



Current limits
$$\begin{cases} (\nu_e) & \mu_\nu < 2.9 \cdot 10^{-11} \mu_B \\ (\nu_\mu) & \mu_\nu < 6.9 \cdot 10^{-10} \mu_B \end{cases}$$

$$\left.\frac{\sigma_{(\nu e, \bar{\nu} e)}}{dT}\right|_{\mu_\nu} = \frac{\pi \alpha_{em}^2 \mu_\nu^2}{m_e^2} \left(\frac{1}{T} - \frac{1}{E_\nu}\right)$$

No interference as it involves a spin flip of the neutrino

$$\theta^2_{\nu-e} < 2m_e/E_e$$

IN SHiP

SIGNAL SELECTION

$$\begin{cases} \theta_{\nu-e} < 30\,mrad \\ E_e > 1\ \mathrm{GeV} \end{cases}$$

$$n_{evt} = \frac{\mu_\nu^2}{\mu_B^2} \int \Phi_{\nu_\tau} \sigma^\mu N_{nucl} dE = 4.3 \times 10^{15} \frac{\mu_\nu^2}{\mu_B^2}$$

BACKGROUND PROCESSES

$\nu_x(\bar{\nu}_x) + e^- \to \nu_x(\bar{\nu}_x) + e^-$	NC	750
$\nu_e + e^- \to e^- + \nu_e$	CC	
$\nu_e + n \to e^- + p$	QE	11700
$\bar{\nu}_e + p \to n + e^+$	QE	
$\nu_e(\bar{\nu}_e) + N \to e^-(e^+) + X$	DIS	1700

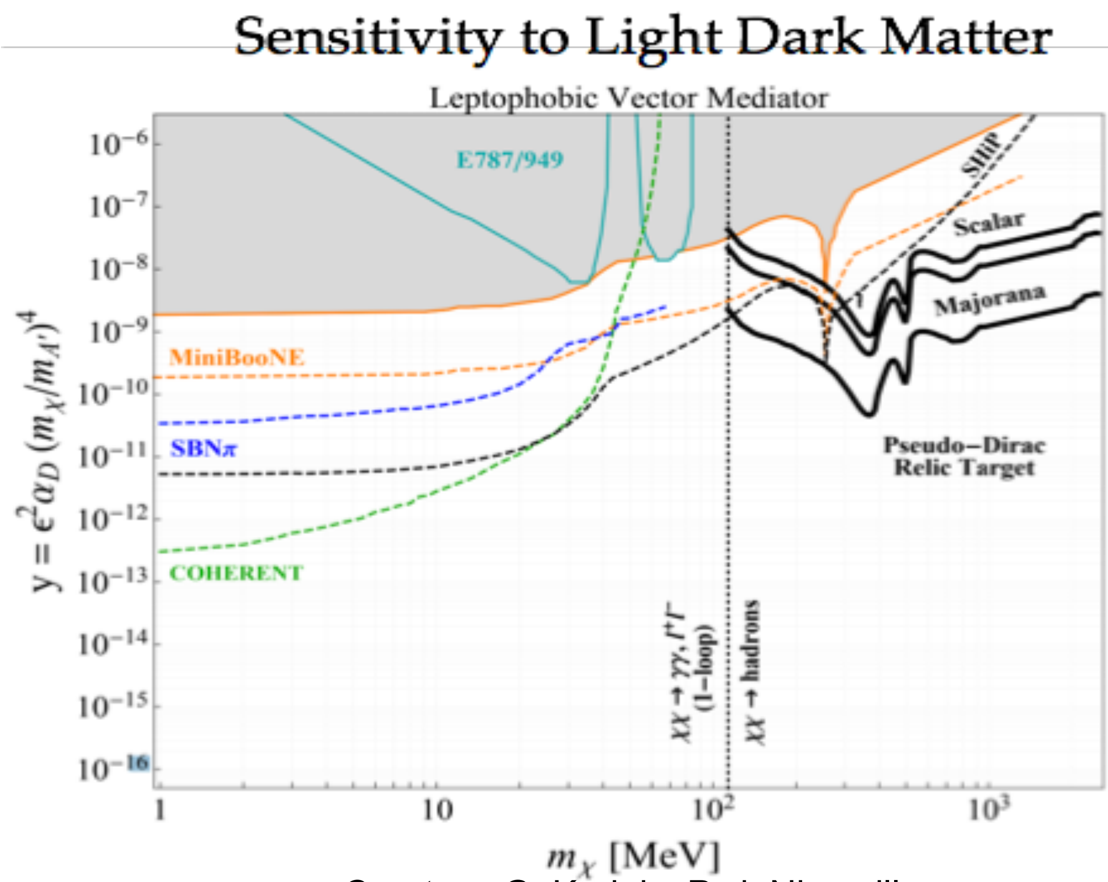
Assuming 5% systematics from DIS measurements

SHiP can explore a region down to

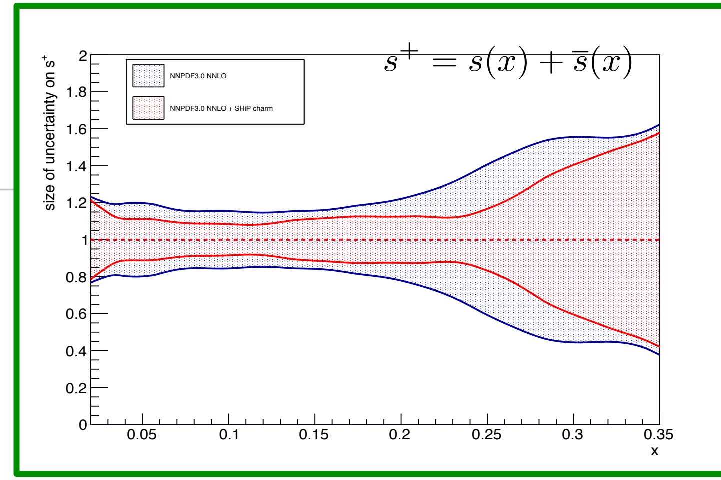
$$\boxed{\mu_\nu = 1.3 \times 10^{-7} \mu_B}$$

SHiP Physics Program for Neutrino/iSHiP

- Strange quark content of the nucleon
- Light Dark Matter search



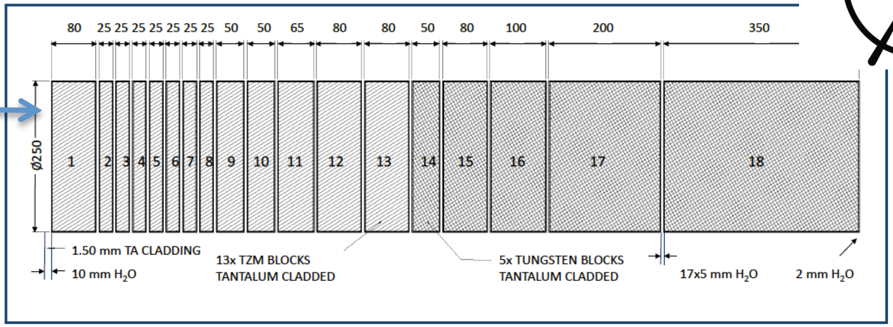
Courtesy G. Krnjaic, P. deNiverville
arXiv:1707.04591v1

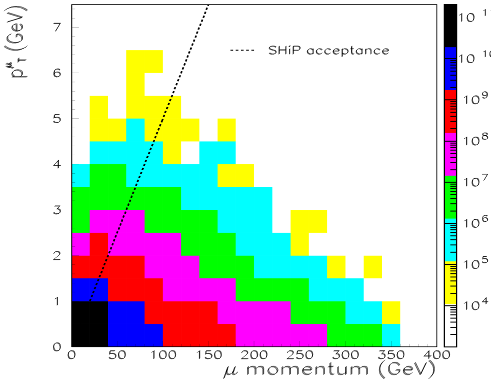


Strange quark content

Measurement of Muon Flux In July 2018

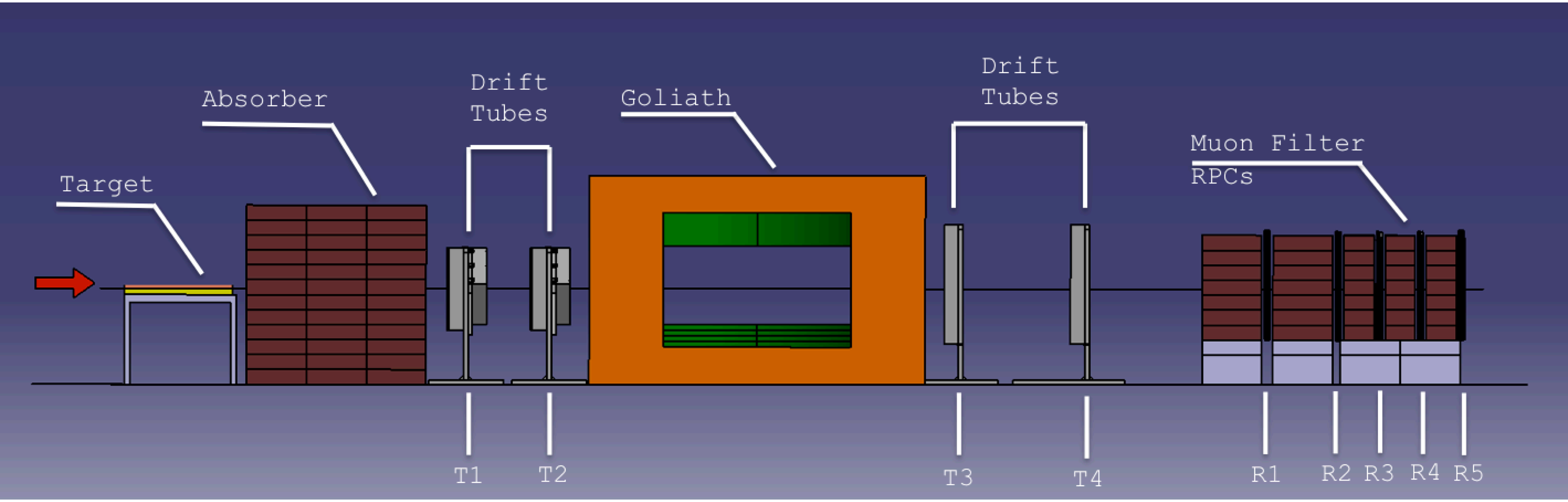
- **SHIP target replica** , TZM 58 cm-thick + Tungsten 58 cm-thick
- **Spectrometer** to measure momentum and charge of the muons
- **Muon tagger** to identify muons





SPSC-EOI-016

10^{11} pot → 100 events in the dangerous corner
Validate simulation

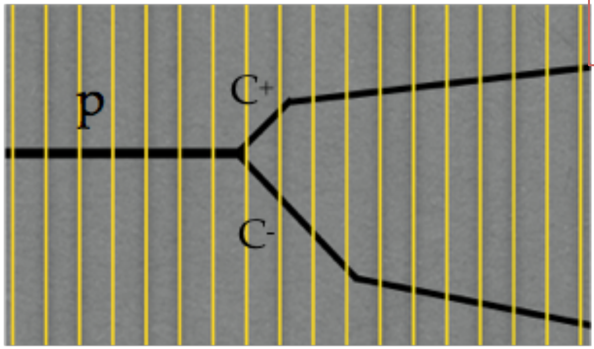


CHARM MEASUREMENTS IN JULY 2018

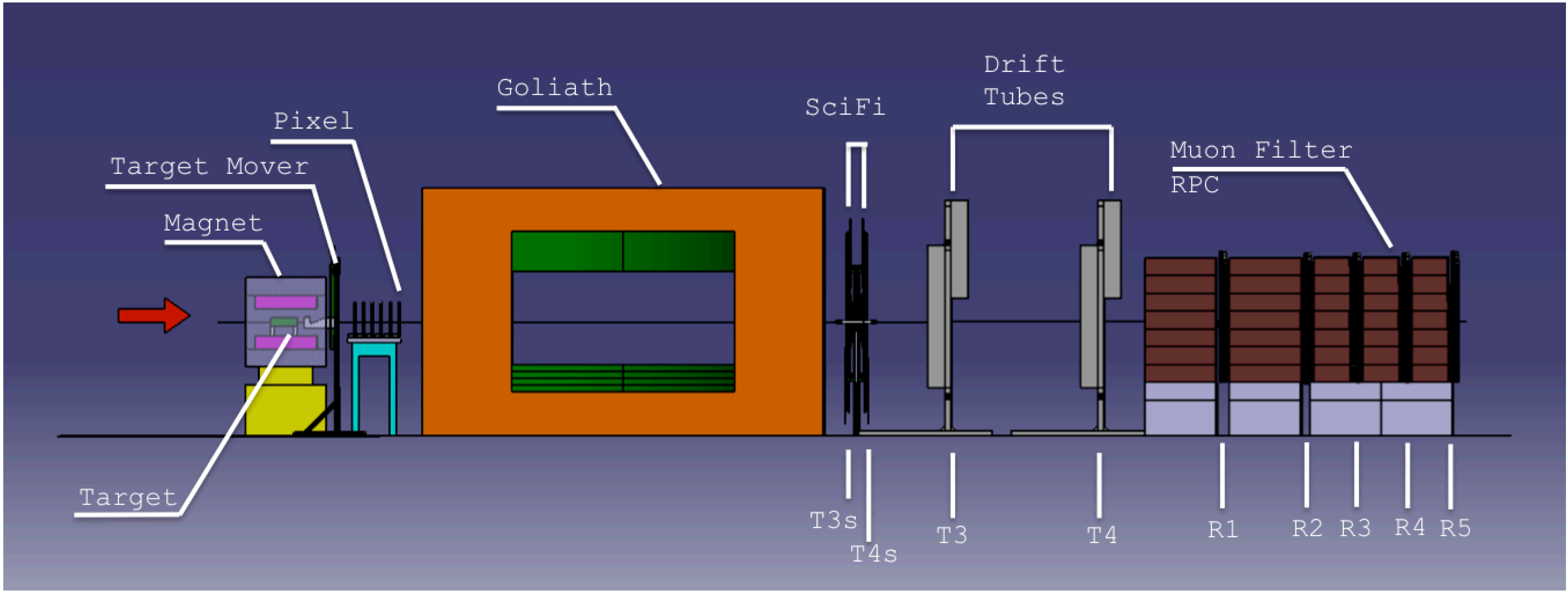
- Measurement of inclusive $d^2\sigma/dEd\theta$ charm cross section in thick target
- Validation of cascade production in the target (factor ~3)

SPSC-EOI-017

- **Lead target**, 12.5×10 cm^2 Pb plates interleaved with emulsion to identify charmed hadrons
- **Spectrometer** to measure momentum and charge of charm daughters
- **Muon tagger** to identify muons



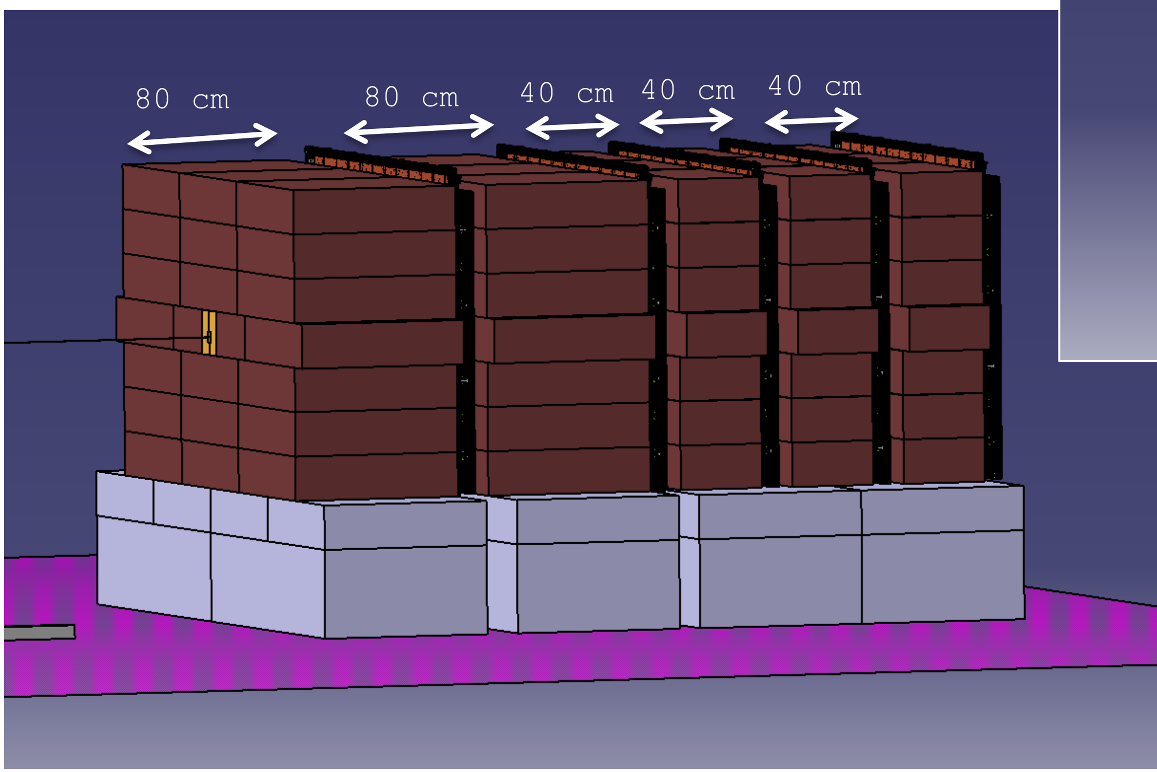
5 x 10^7 pot → ~ 10000 charmed hadron pairs

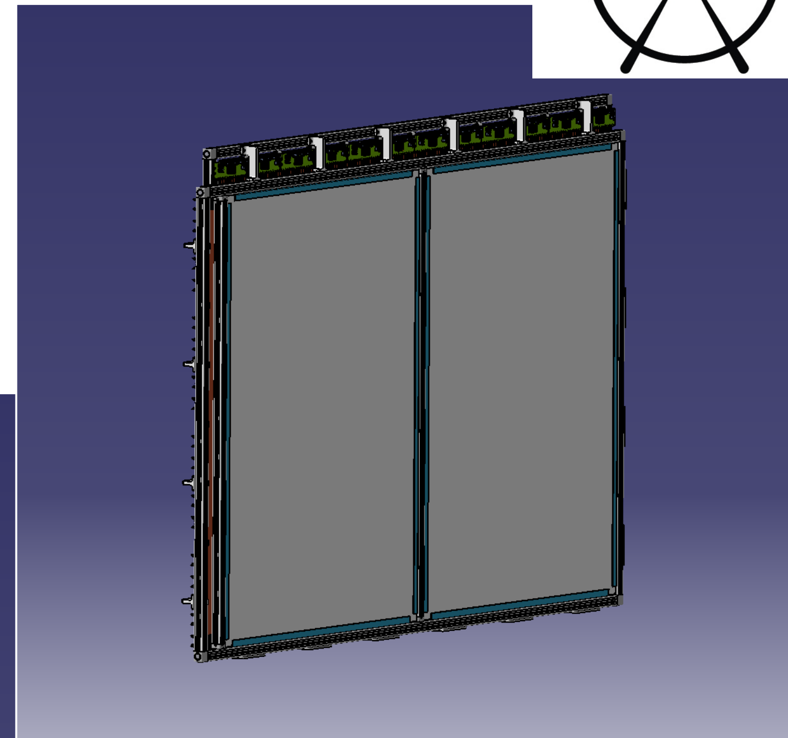


Muon Tagger

5 Iron walls
5 RPC planes

- Iron blocks assembled in order to have a 5x5cm^2 hole along beam direction

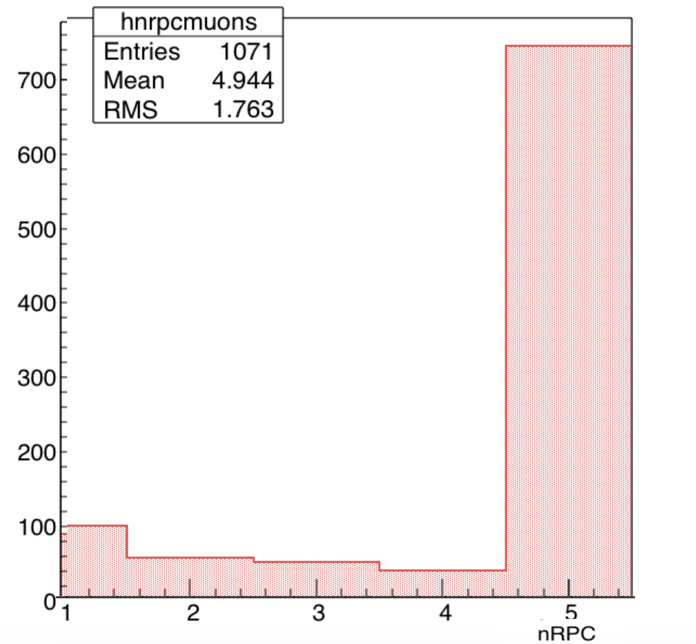




MUON TAGGER

Muon identification

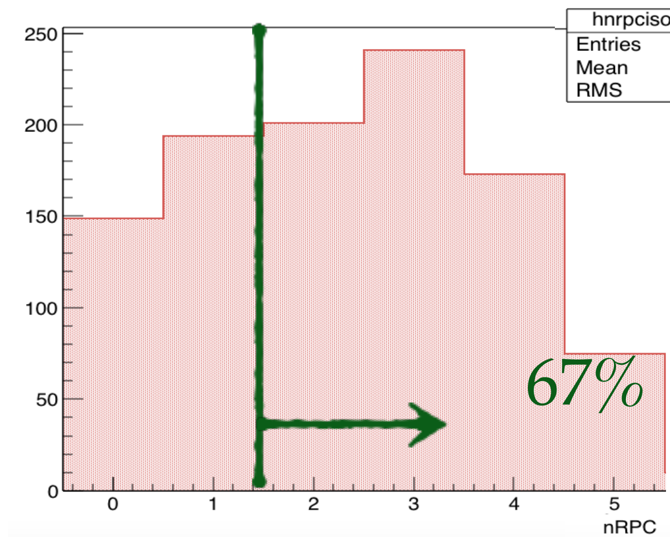
- Number of RPC planes crossed by muons produced in charm decays
- Normalization: muons entering the Muon Tagger



RPC planes crossed	Fraction of muons
≥ 2	0.82
≥ 3	0.77
≥ 4	0.72
≥ 5	0.69

Muon isolation

- Muon isolation in > 2 RPC planes for muon tracking and for the measurement of its slope
- Muon isolation criteria: at least 1 cm distance (strip width) both in x and y coordinates with respect to the closest hit in the same RPC plane



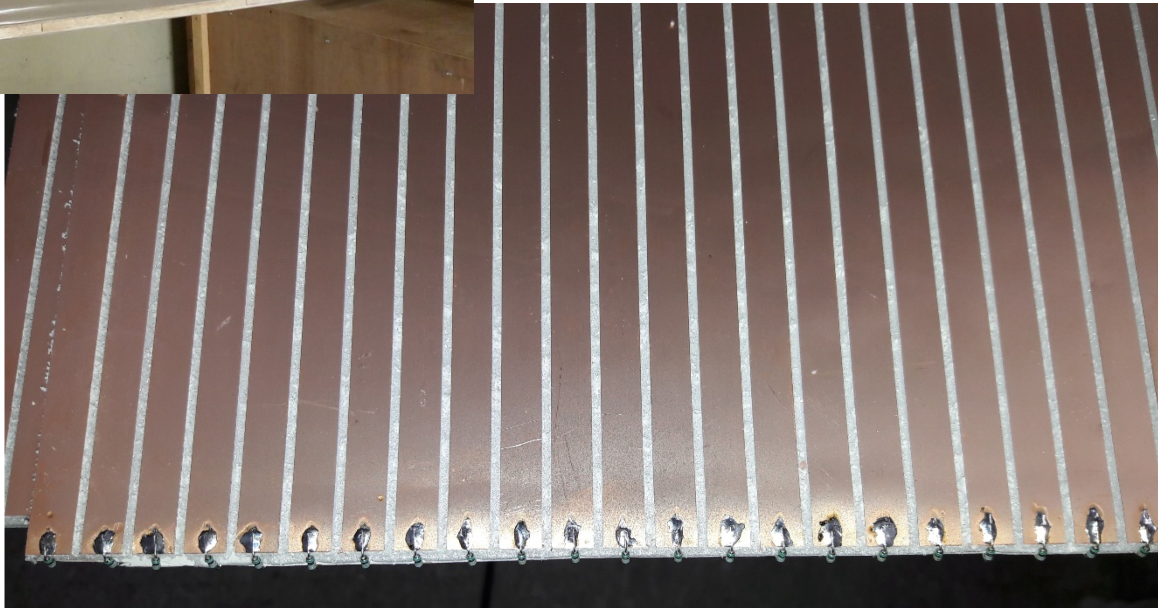
- Requirement to build a muon track: at least two RPC planes where muon is isolated

Status of RPC production (KODEL)

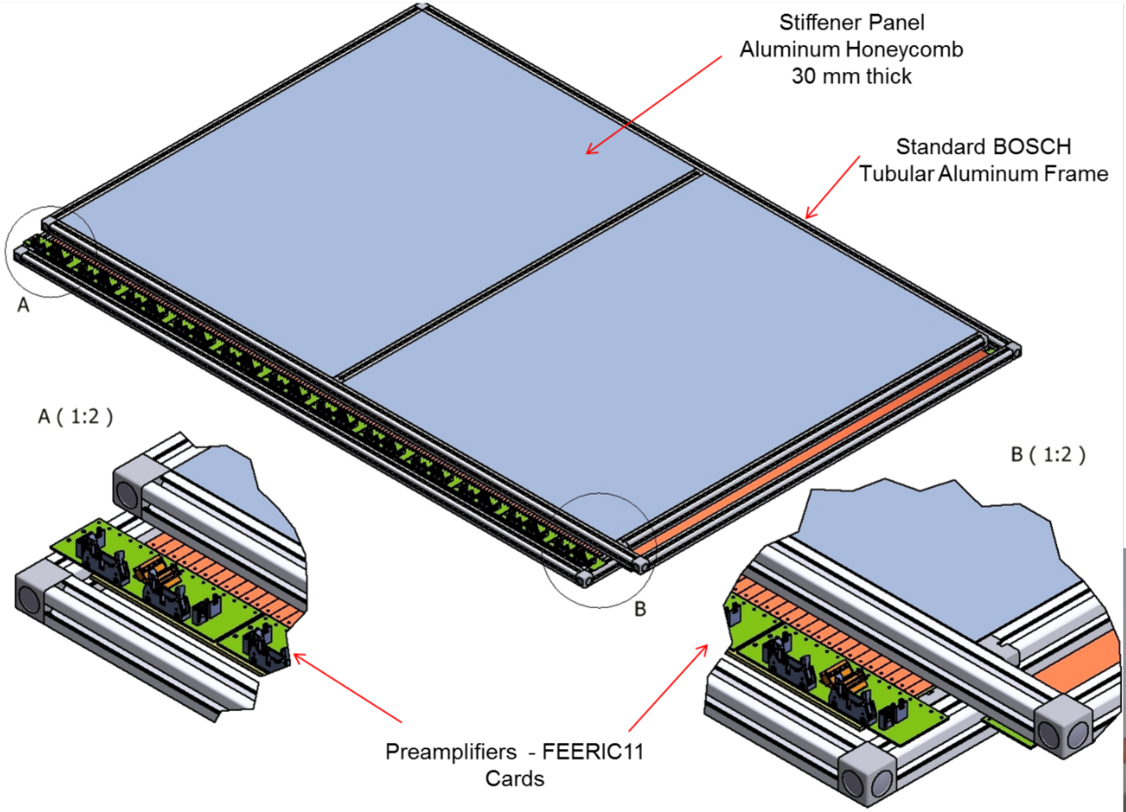
Sung Park
Kyong Sei Lee

Gaps at CERN

Strip panel

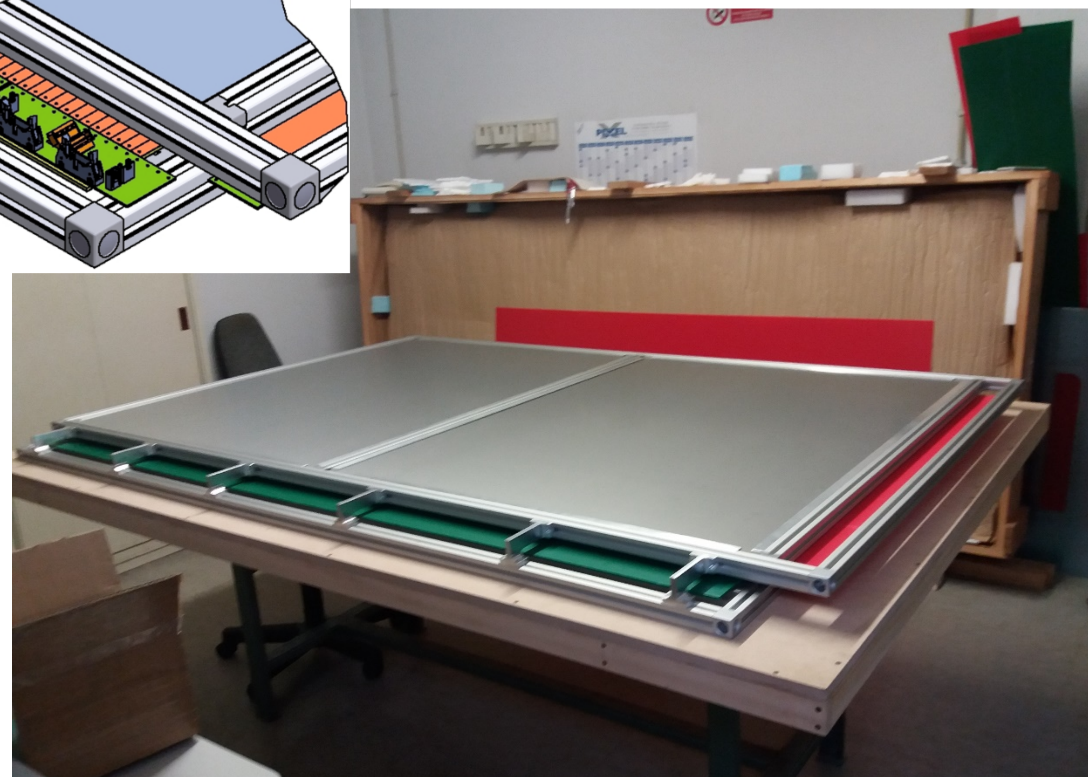


RPC mechanical structure



Mechanics Service INFN - Bari

Prototype



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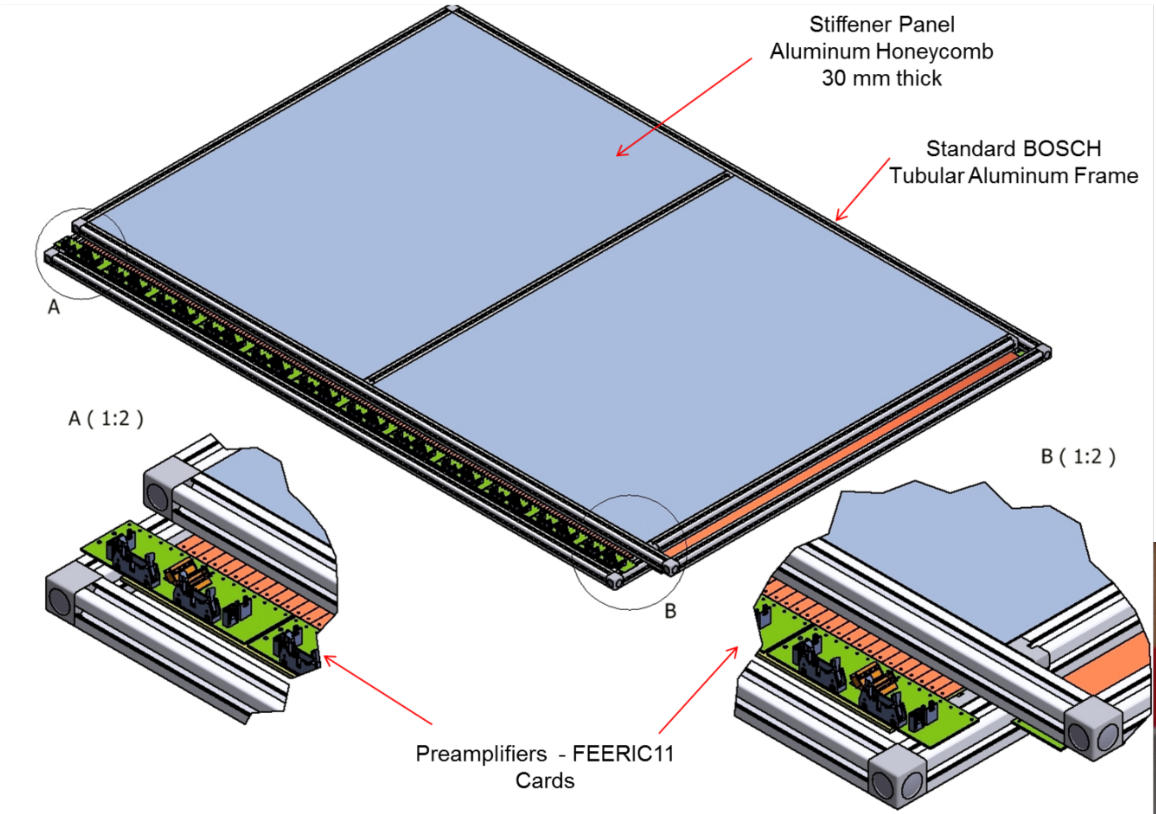

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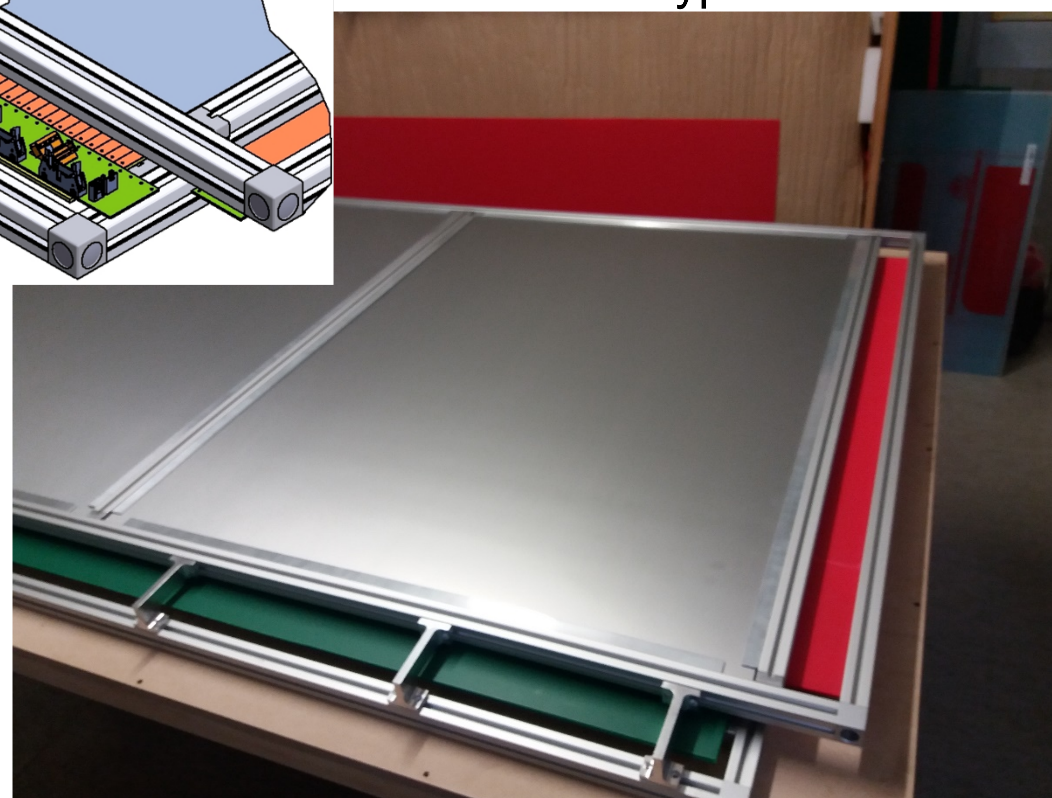
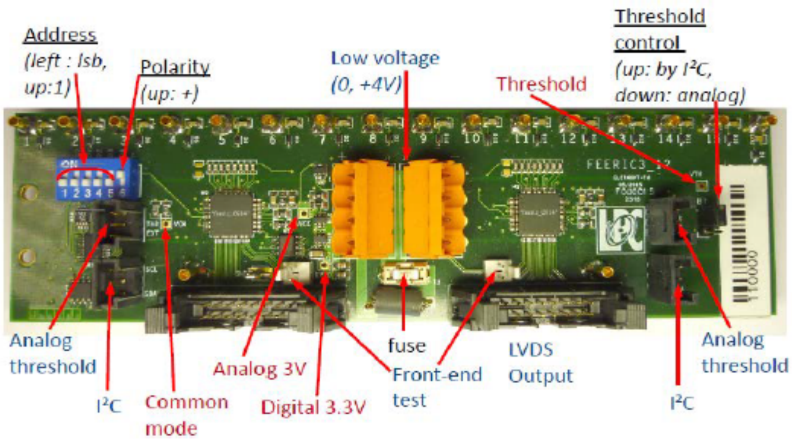


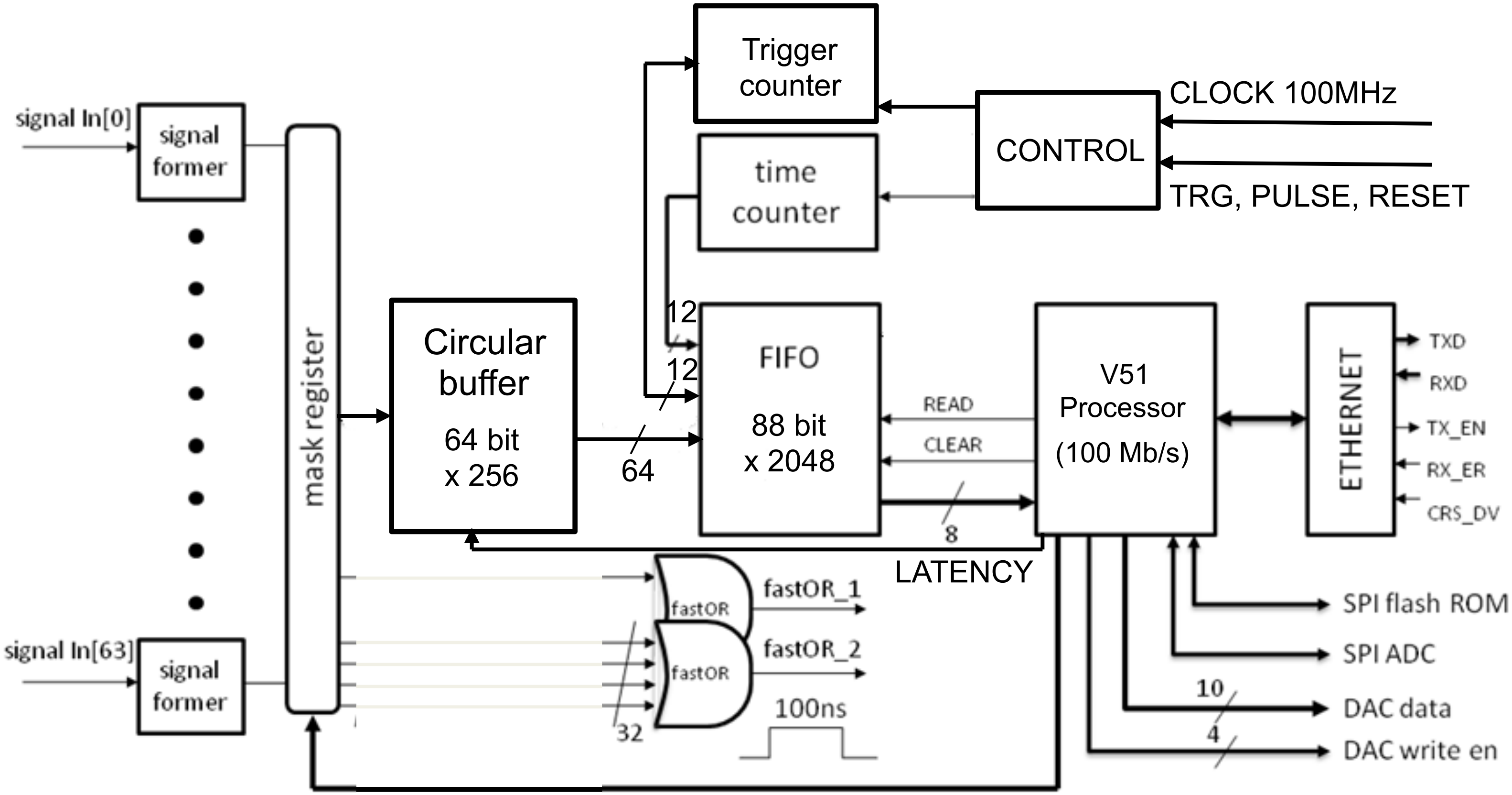
RPCs Frontend Electronics

R. De Asmundis, INFN - Napoli

- Frontend electronics: 112 cards (16 channels each), FEERIC 11 – ALICE
- Cards were delivered in Naples in December
- Preparation of FE card test (including slow control) in progress in Naples



Readout boards: new firmware block scheme (Saverio Simone, Bari)



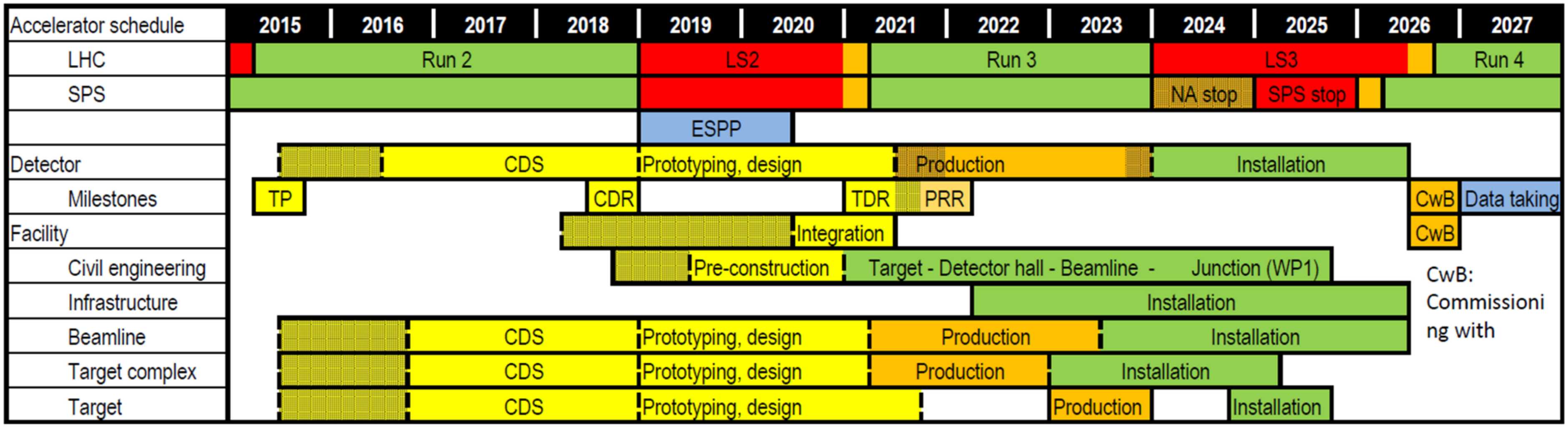
- Input signals (after masking) are stored in a circular buffer (pipeline) at 100MHz (all boards are synchronised at 100MHz).

- The 100MHz internal clock can be *synchronised* with an external signal through the Trigger Supervisor board

- Upon arrival of a trigger signal, the 64-bit hit map corresponding to a pre-determined latency + trigger number (12bit) + time stamp (12bit) are written to a FIFO.

SHiP

Project schedule and next steps



- ✓ *Schedule optimized to avoid interference with operation of North Area*
  - ➔ *Four separate work packages (junction cavern, beam line, target complex and detector hall)*
  - ➔ *Use LS3 for junction cavern and first short section of SHiP beam line*
- ✓ *Positive recommendation by the SPSC in January 2016 to prepare a Comprehensive Design Study 2016-2018*
- ✓ *CERN DG launched the "Physics Beyond Colliders" Working Group*
- ✓ *Outcome of the WG at the European HEP strategy in 2020*
- ✓ *Construction/production 2021-*
  - ✓ ***Data taking 2026***
- ✓ *RPCs may play an important role (your contribution is very welcome!)*