The SHiP timing detector based on MRPC

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FCT Fundação para a Ciência e a Tecnologia
MINISTÉRIO DA CIÊNCIA, TECNOLOGIA E ENSINO SUPERIOR

REPÚBLICA PORTUGUESA

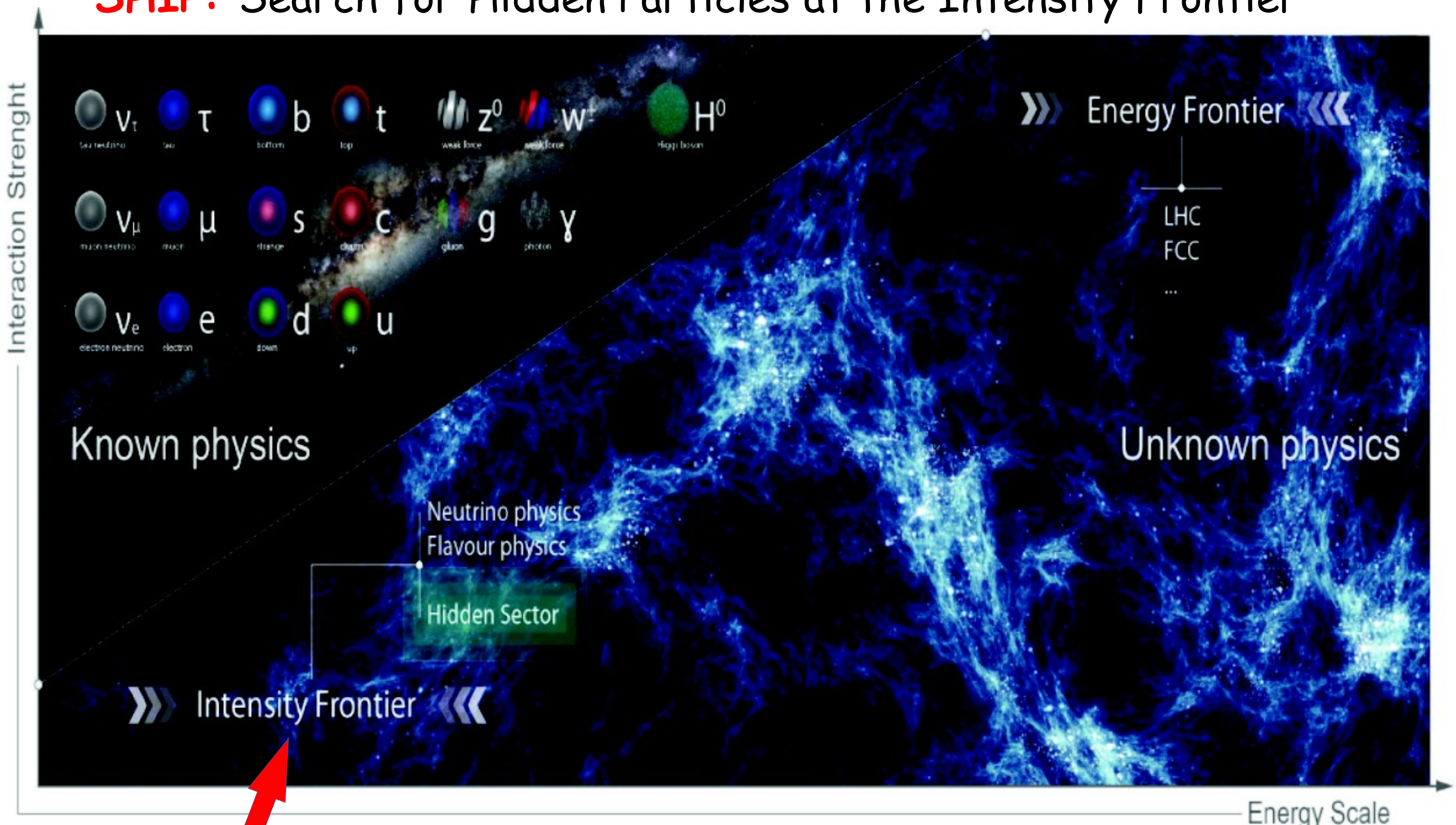
Outlook

- The SHiP experiment.
- Timing detector for SHiP based on MRPCs.
- Test beam result at CERN.
- Conclusions.

SHiP Experiment at CERN

https://ship.web.cern.ch/ship/

SHIP: Search for Hidden Particles at the Intensity Frontier

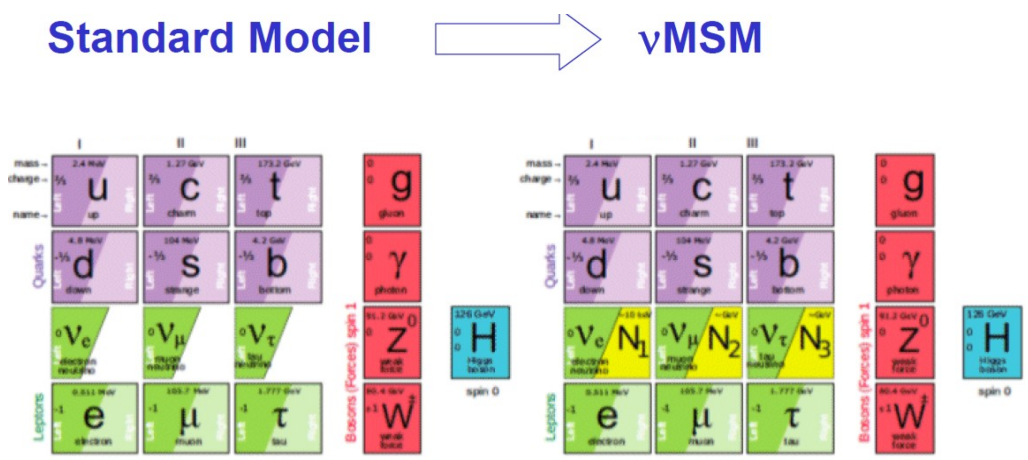


SHIP

Hidden-Sector Physics:

Models	*Final states*
HNL, SUSY neutralino	$l^+\pi^-$, l^+K^-, $l^+\rho^-$ $\rho^+\rightarrow\pi^+\pi^0$
Vector, scalar, axion portals, SUSY sgoldstino	l^+l^-
HNL, SUSY neutralino, axino	$l^+l^-\nu$
Axion portal, SUSY sgoldstino	$\gamma\gamma$
SUSY sgoldstino	$\pi^0\pi^0$

Search for Heavy Neutral Leptons *(HNLs)*



N = Heavy Neutral Lepton

- Role of $\mathbf{N_1}$ with mass of few KeV: dark matter
- Role of $\mathbf{N_2}$, $\mathbf{N_3}$ with mass in 100 MeV to 2 GeV region: "give" masses to neutrinos and produce baryon asymmetry of the Universe

Tau neutrino (τ_ν) physics

ν interaction rates for 5 years of nominal operation *(2 x 10^{20} p.o.t)*

	Φ	<E> (GeV)
ν_μ	1.7×10^6	29
ν_e	2.5×10^5	46
ν_τ	7.6×10^3	59
Anti-ν_μ	6.7×10^5	28
Anti-ν_e	9.0×10^4	46
Anti-ν_τ	3.9×10^3	58

First experimental measurement of anti-ν_τ interactions!

Neutrino DIS: structure functions and strange quark nucleon content

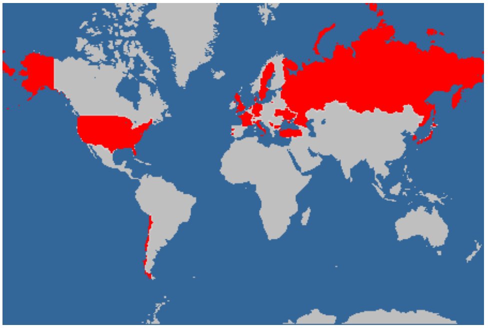
$$\frac{d^2\sigma^{\nu(\overline{\nu})}}{dxdy} = \frac{G_F^2 M E_\nu}{\pi(1+Q^2/M_W^2)^2}\Bigg((y^2x + \frac{m_\tau^2 y}{2E_\nu M})F_1 + \left[(1-\frac{m_\tau^2}{4E_\nu^2}) - (1+\frac{Mx}{2E_\nu})\right]F_2 \pm \left[xy(1-\frac{y}{2}) - \frac{m_\tau^2 y}{4E_\nu M}\right]F_3 + \frac{m_\tau^2(m_\tau^2+Q^2)}{4E_\nu^2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

First evaluation of F_4 and F_5 *(not accessible with ν_e and ν_μ)*

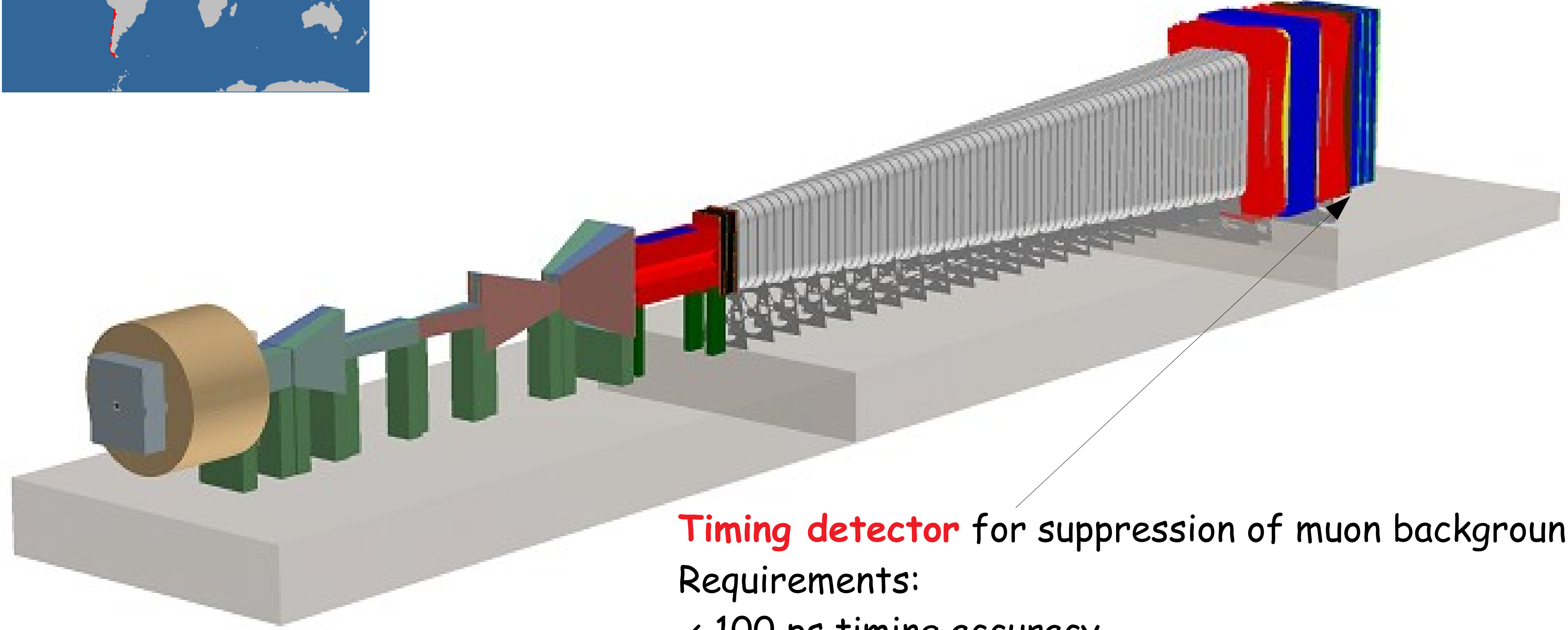
Light Dark Matter (LDM) searches

SHiP Experiment at CERN

https://ship.web.cern.ch/ship/



SHiP is currently a collaboration of 54 institutes from 18 countries.



Timing detector for suppression of muon background

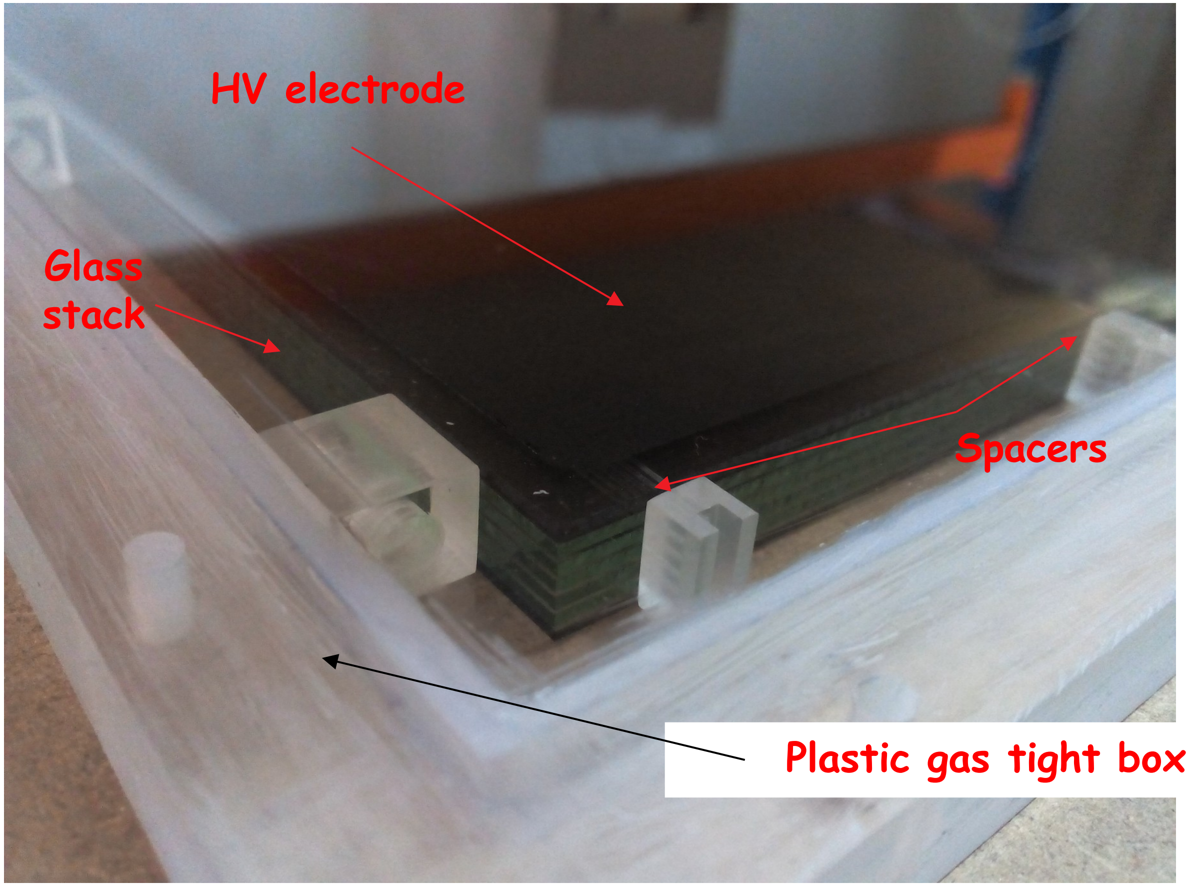
Requirements:

- < 100 ps timing accuracy
- High efficiency
- Coverage of 50 m^2

SHiP implementation in FairSHiP

The TD implementation. MRPC Sealed glass stack

- **Modules composed of two 6 (0.3 mm) gaps** sealed glass stacks (SGS).



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

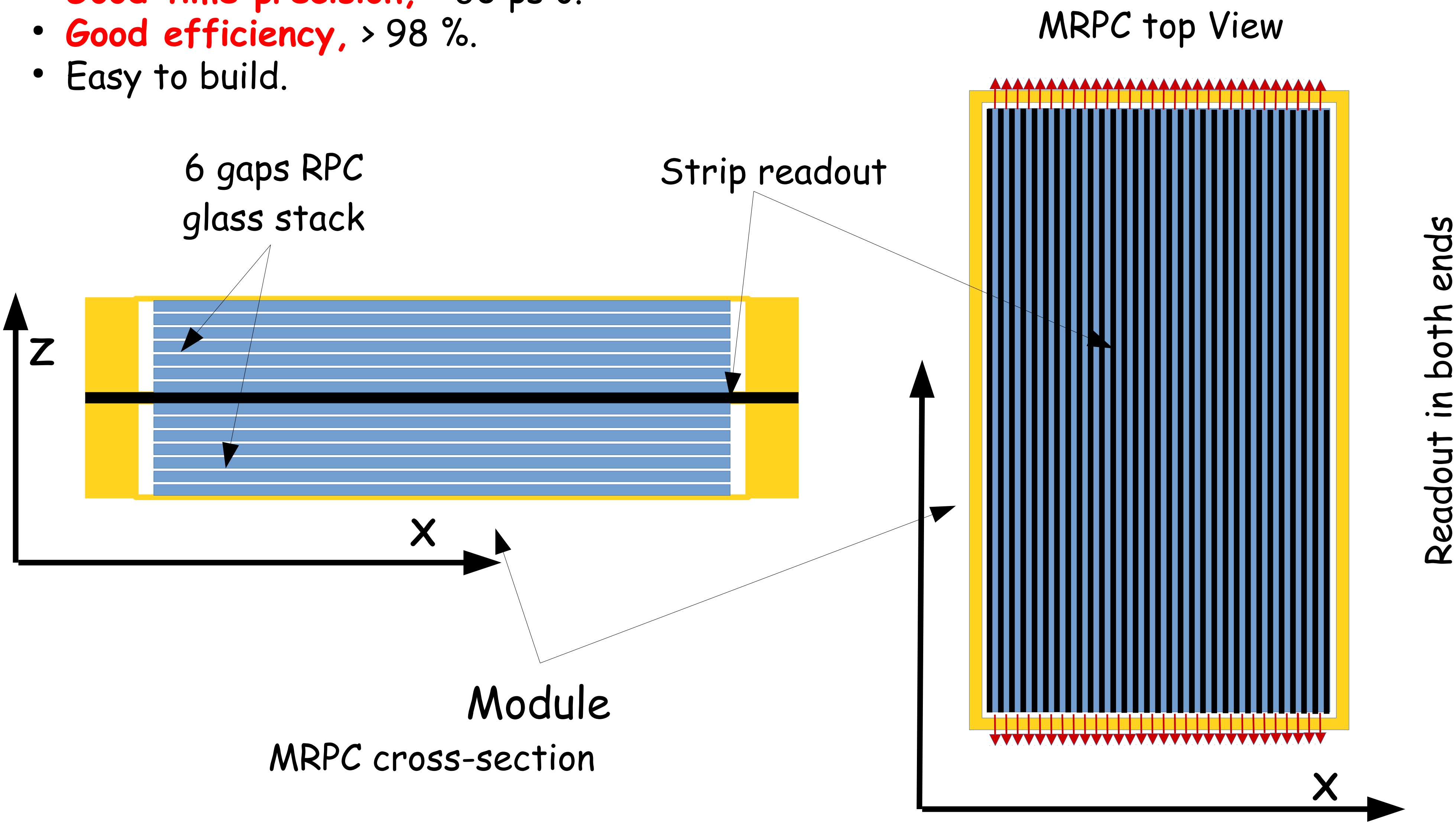
Easy to build completely gas tight, no gas leaks, robust. Low gas consumption

Decouples the gas and HV from the rest, specifically readout electrodes

In competition with a scintillator based approach

The TD implementation. Schematic drawing.

- **Modules composed of two 6 (0.3 mm) gaps** sealed glass stacks (SGS).
- **Strips 37 mm width** (placed in the middle of two SGS) readout in both sides.
- Active **area of 1600x1200 mm² = 1,9 m².**
- **Good time precision,** < 60 ps σ.
- **Good efficiency,** > 98 %.
- Easy to build.



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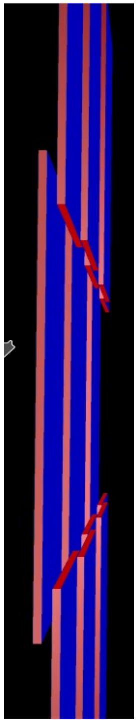
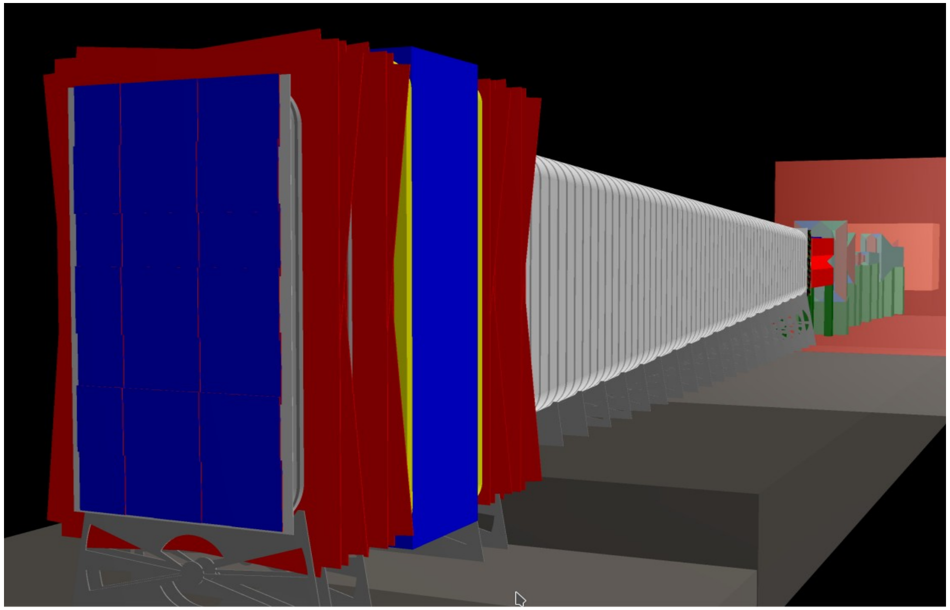
Side view



Rear view

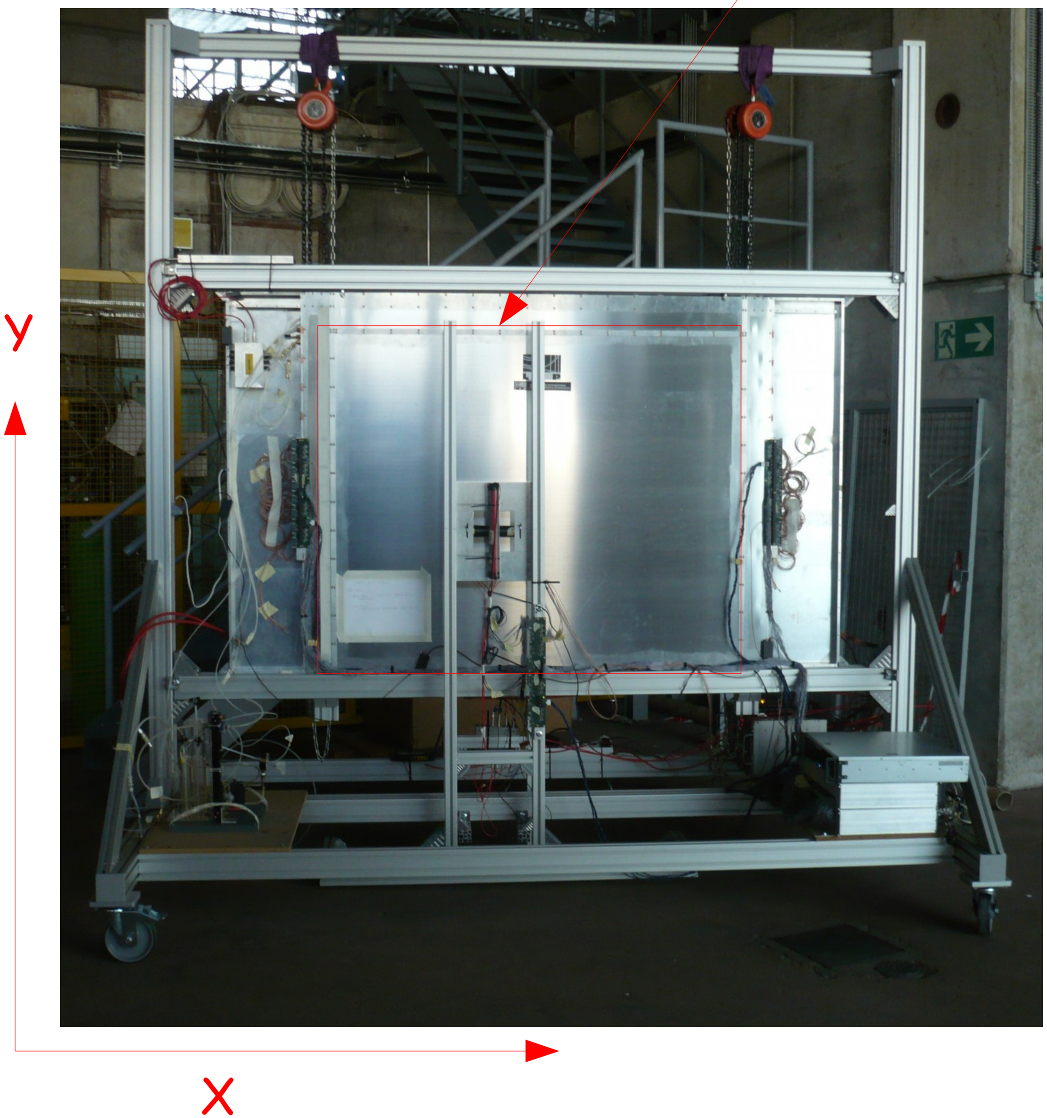


MRPC timing detector implementation
in Fair SHiP (SHiP experiment software).

Area to be covered 10x5 m^2
=> 35 MRPC modules with overlap
=> 35 modules x 64 channels/module
= **2240 channels.**

Test beam. Setup.

RPC prototype almost **full size**
1500x1200 mm^2 = 1,8 m^2



Test beam. Setup.

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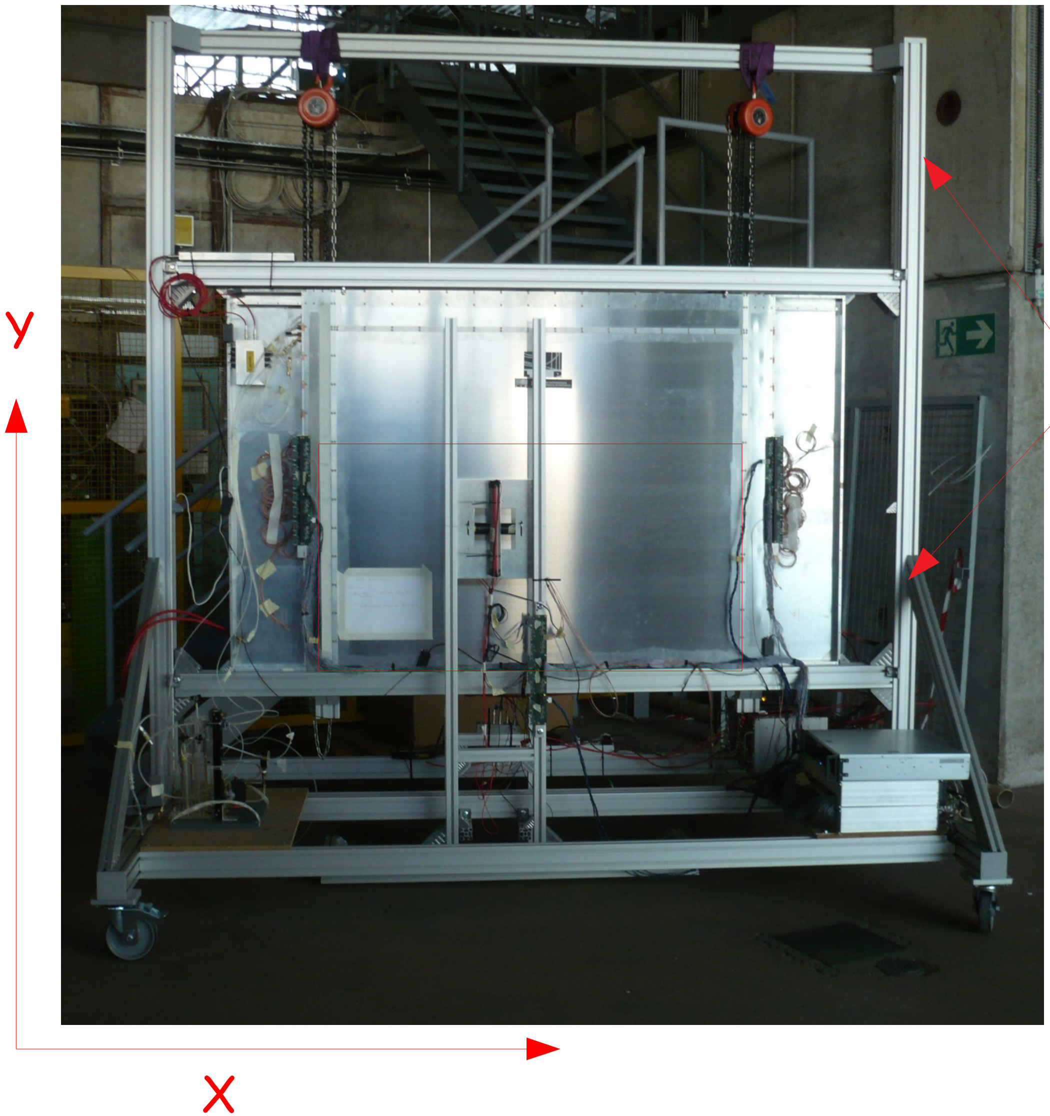
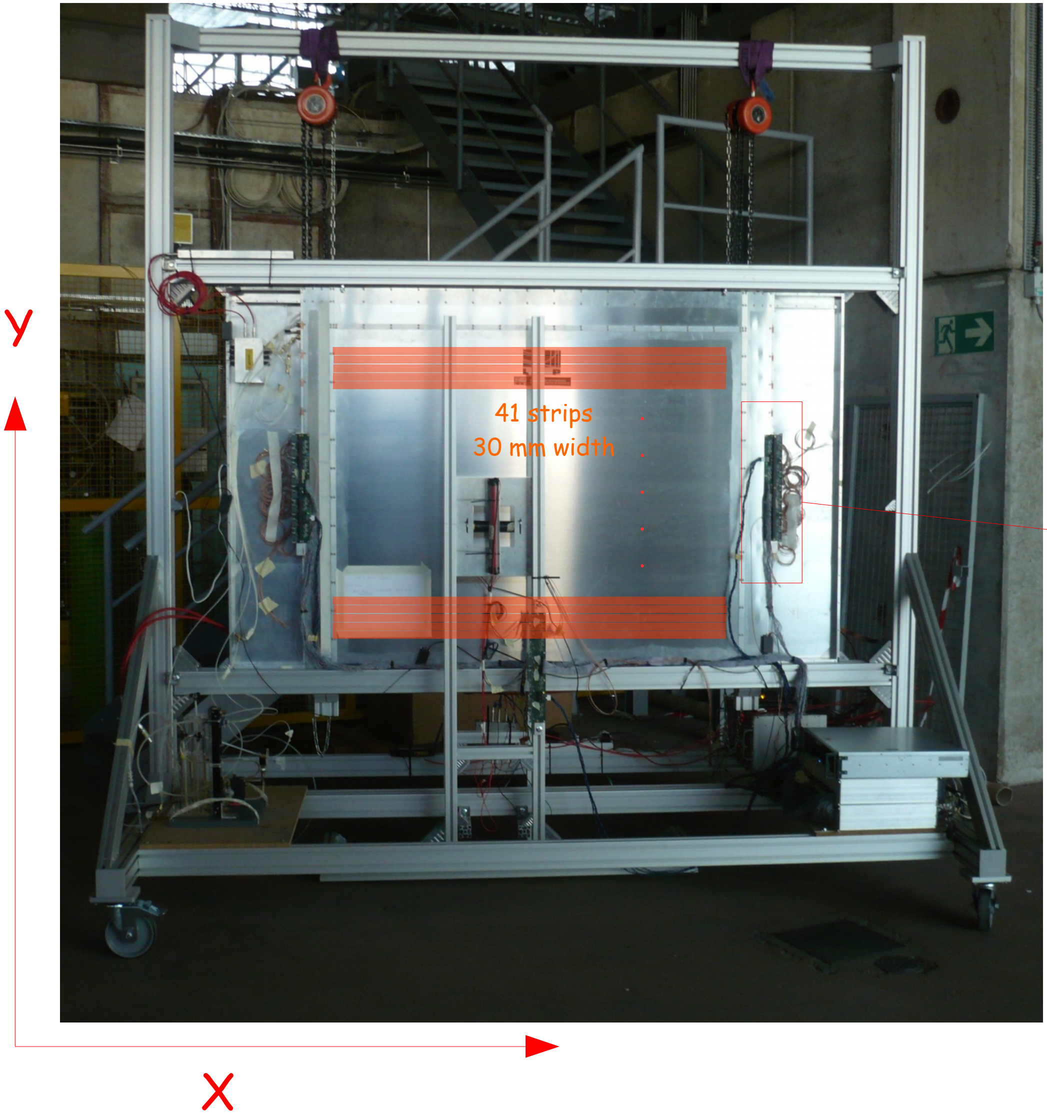


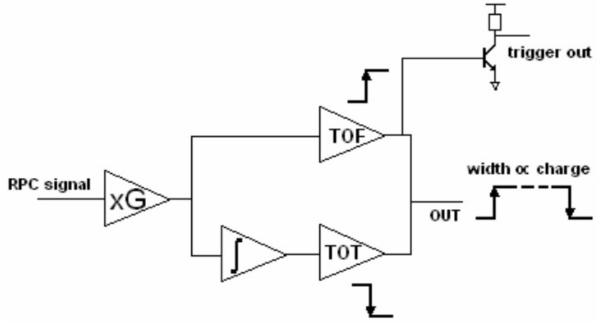
Due to limitations on the mechanical structure that holds the RPC only 2/3 of the active area can be scanned

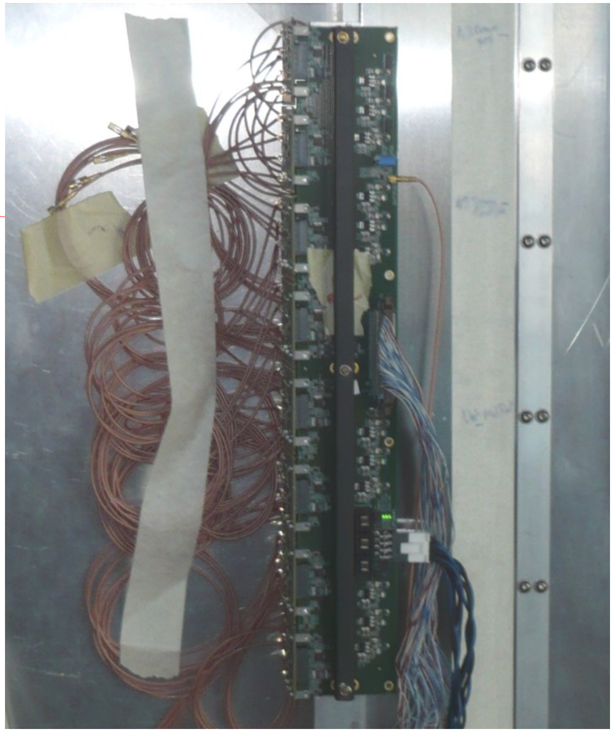
FEE borrowed from HADES-RPC TOF

FEE, time (σ_t~30 ps) and charge measurement in one single channel.

Strips are readout in both sides







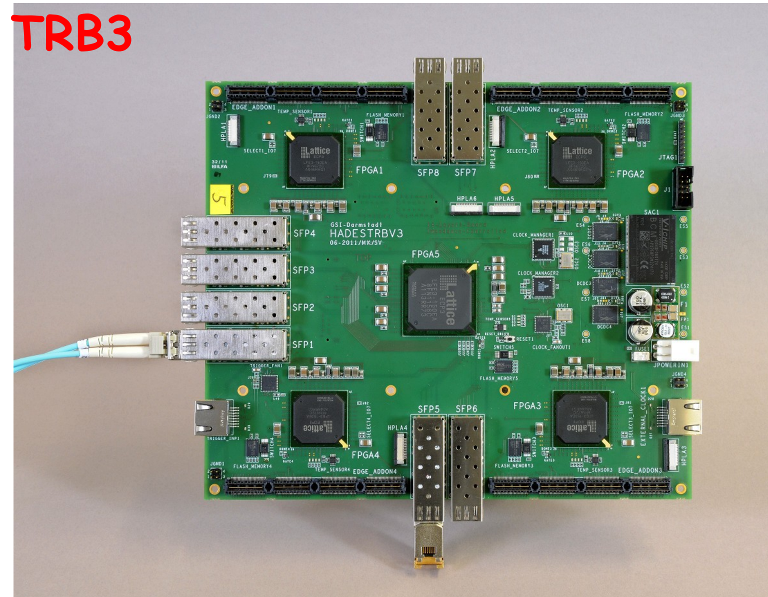
32 channels each side

[IEEE TNS 57, 2848 (2010)]
10.1109/TNS.2010.2056928

DAQ borrowed from HADES DAQ.

Y

X



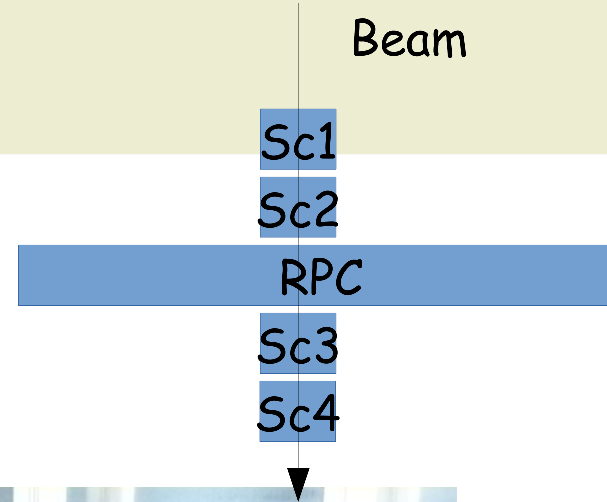
One central FPGA with trigger management capabilities plus

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

  And much more, ADCs ....

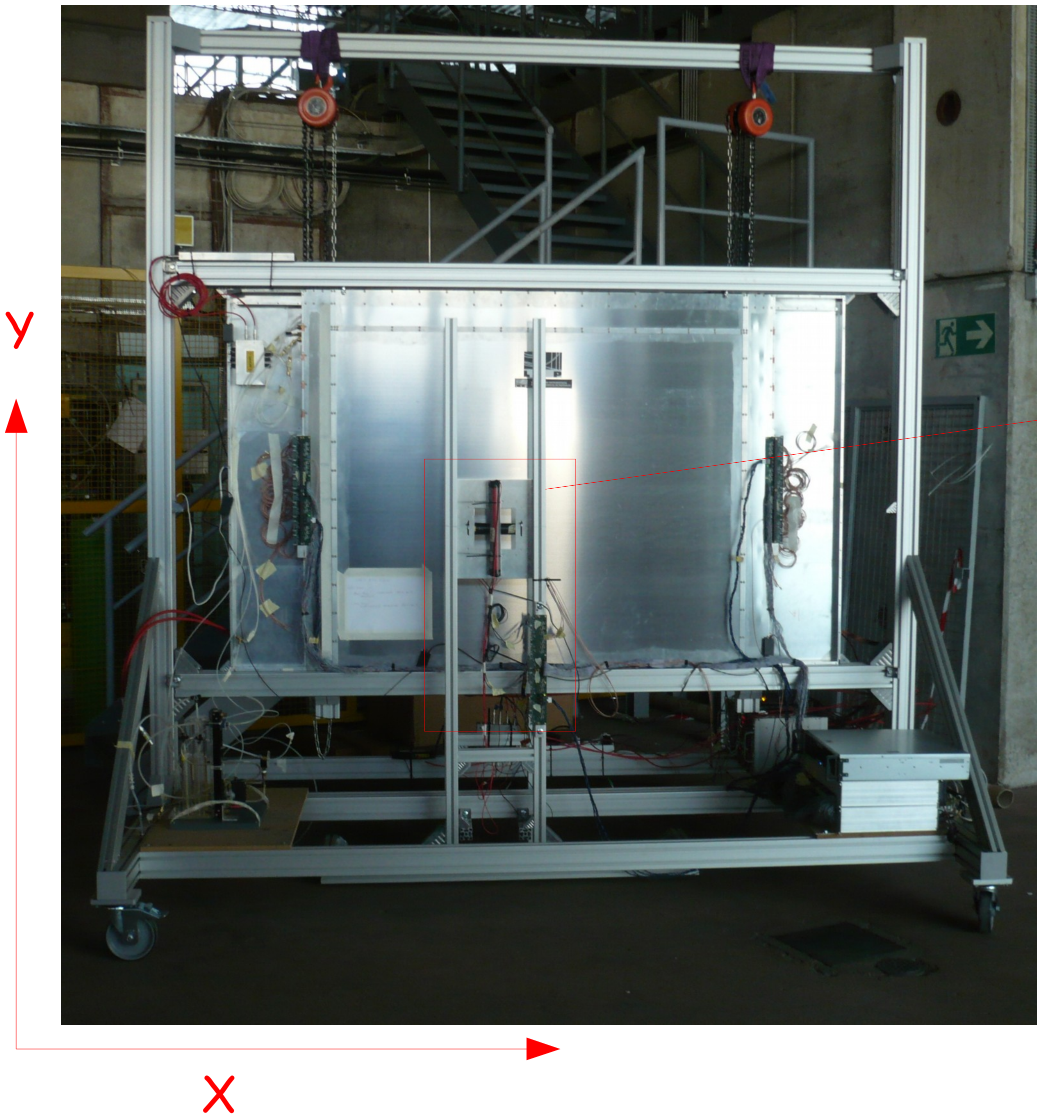
A Neiser et al 2013 JINST 8 C12043

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



Fast timing scintillators telescope 2 in front and 2 in the rear. **30-40 ps σ in beam.**

Used as a reference



Ancillary systems

HV power supply

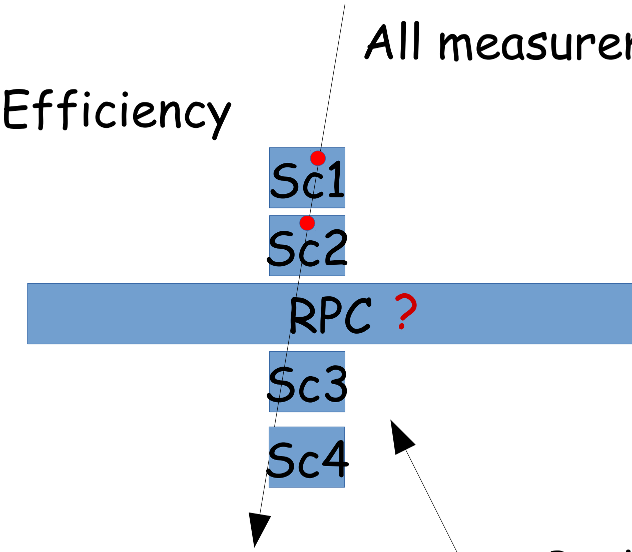
LV power supply

Gas system, 97.5% $C_2H_2F_4$ + 2,5% SF_6 @ 50 cc/min

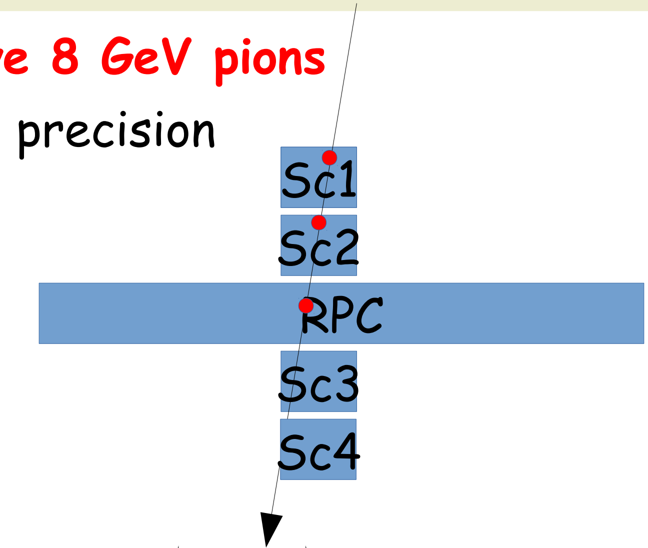
Test beam. Efficiency and time precision

All measurements made with **negative 8 GeV pions**

Efficiency



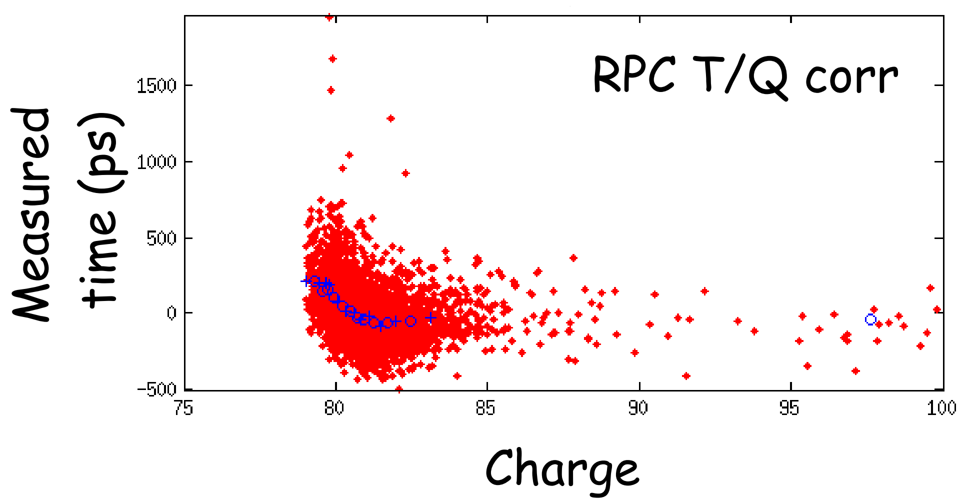
Timing precision

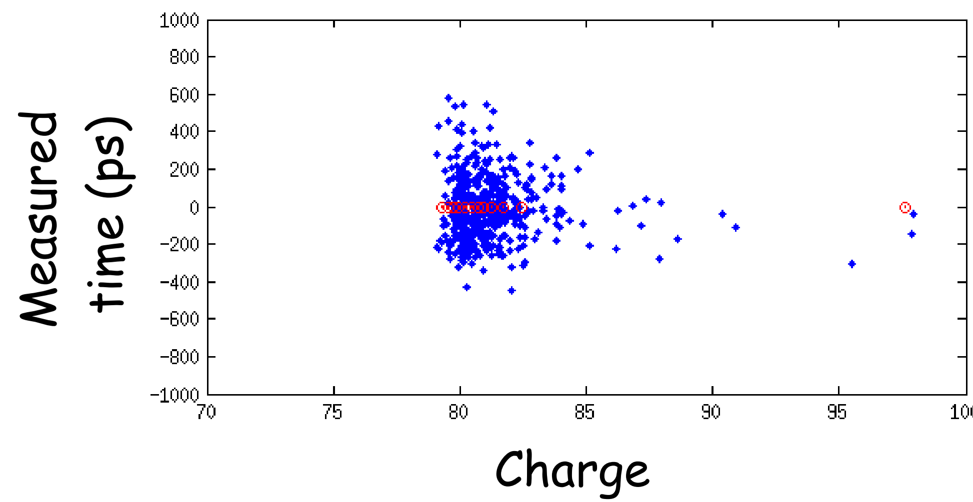


Preliminary analysis
only include two scintillators

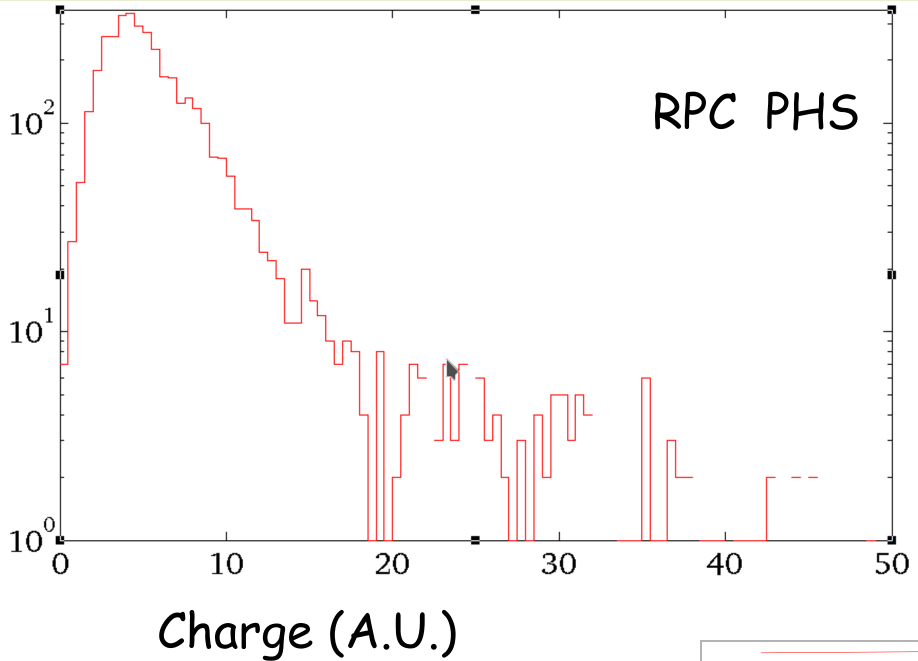
$$\begin{pmatrix}1 & 1 & 0\\ 1 & 0 & 1\\ 0 & 1 & 1\end{pmatrix}\begin{pmatrix}\sigma(RPC)^2\\ \sigma(SC1)^2\\ \sigma(SC2)^2\end{pmatrix}=\begin{pmatrix}\sigma(\Delta(RPCSC1))^2\\ \sigma(\Delta(RPCSC2))^2\\ \sigma(\Delta(SC1SC2))^2\end{pmatrix}$$

Time from RPC and scintillators are corrected by charge. Walk correction.

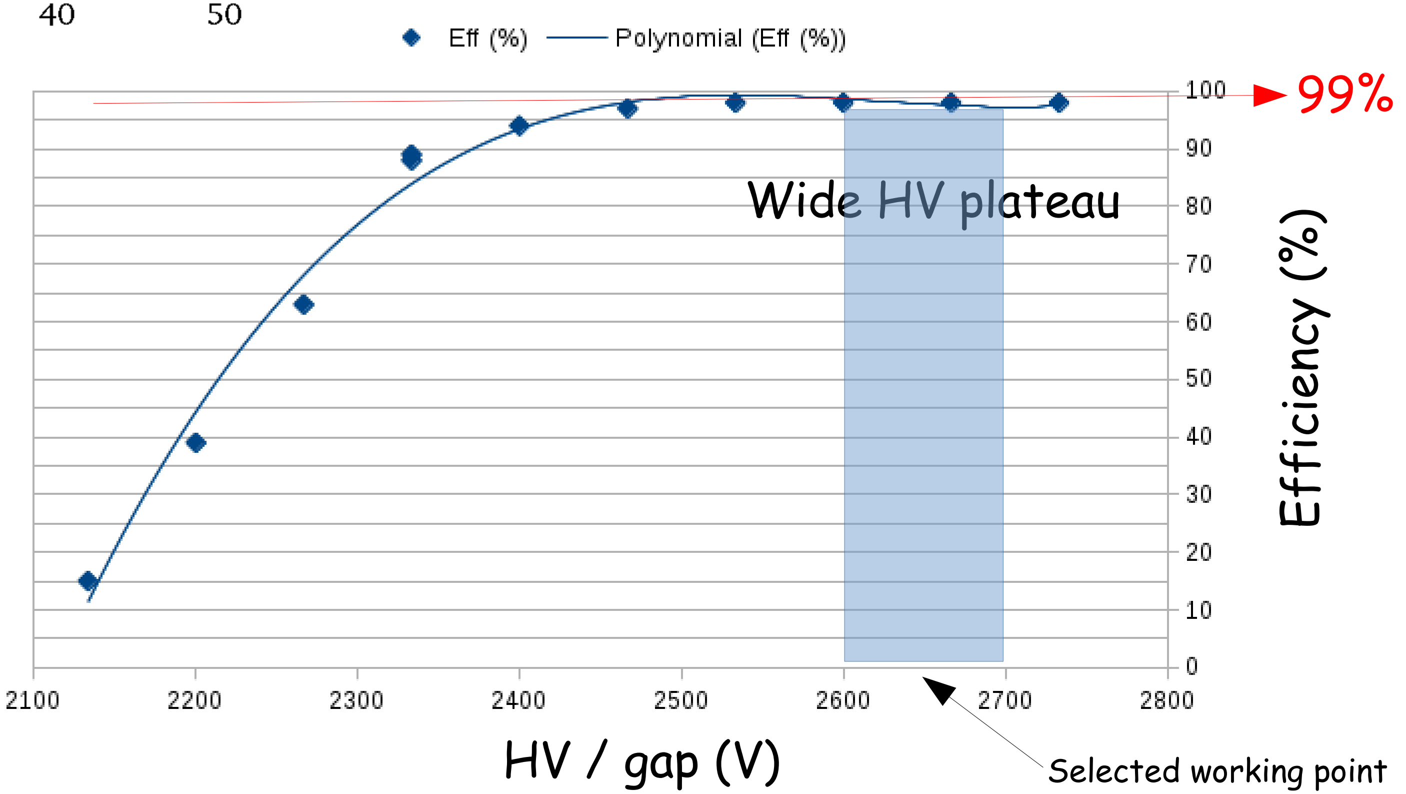




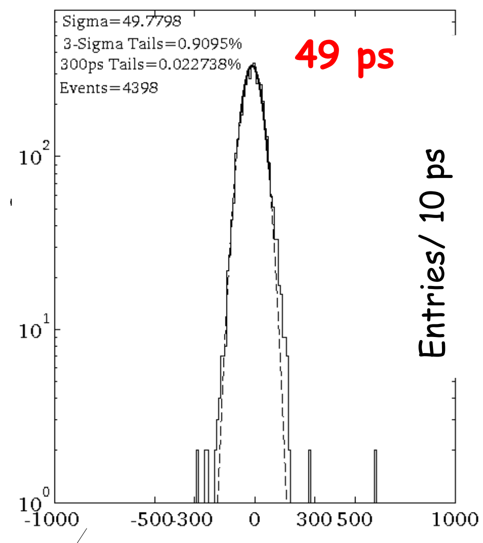
Test beam. Efficiency and timing vs HV.

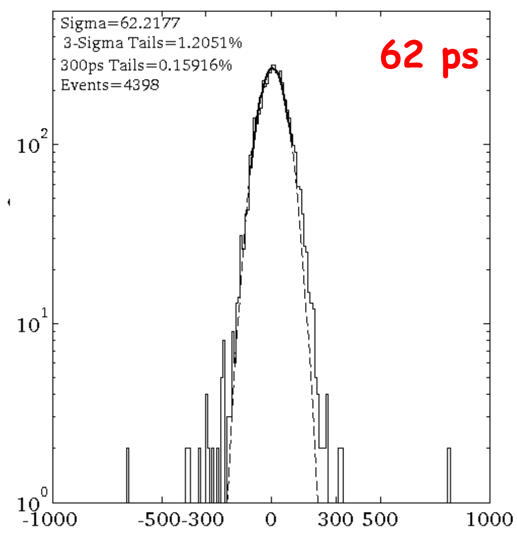


Arbitrary point,
but quite homogeneous on the entire area



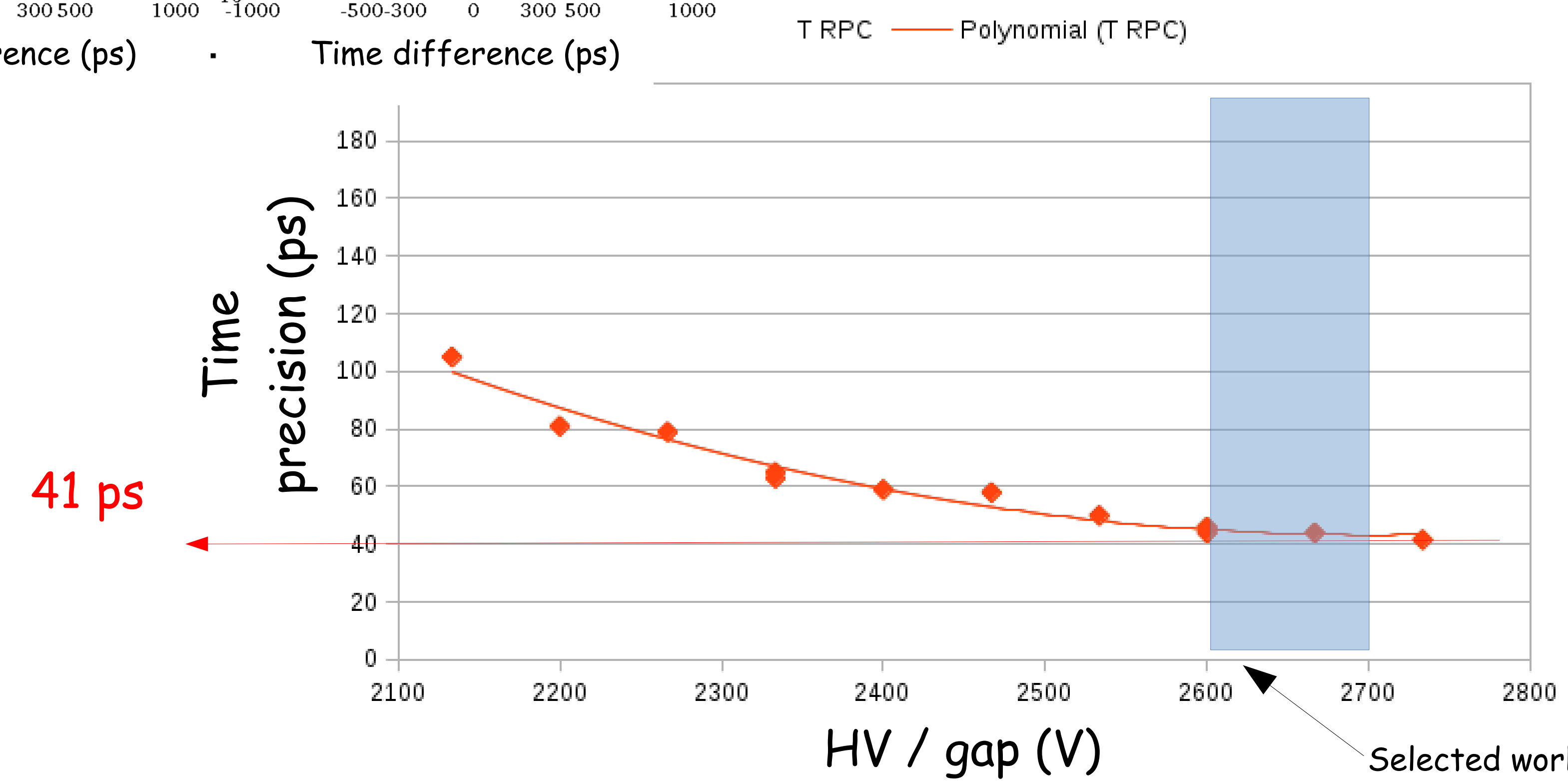
Test beam. Efficiency and timing vs HV.



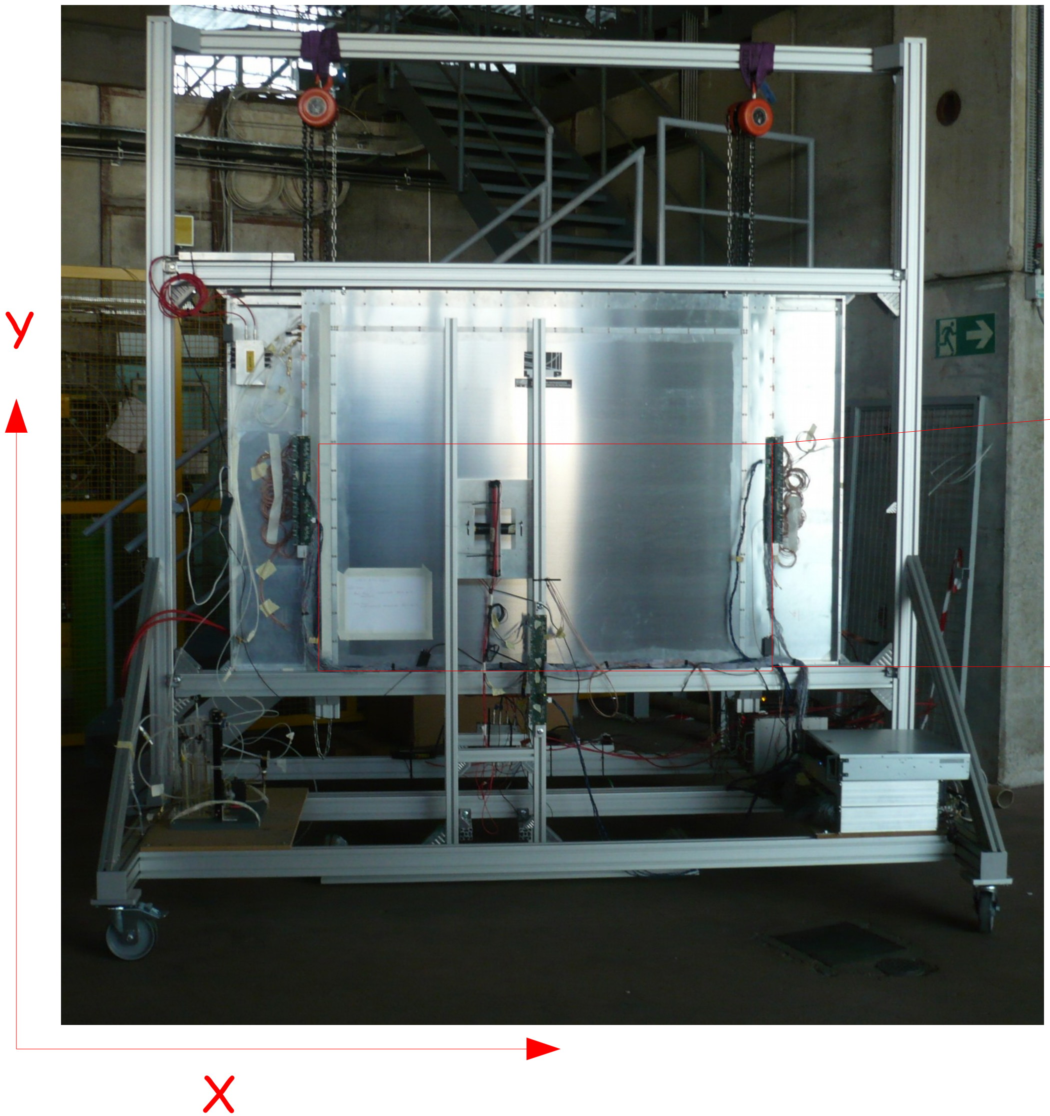


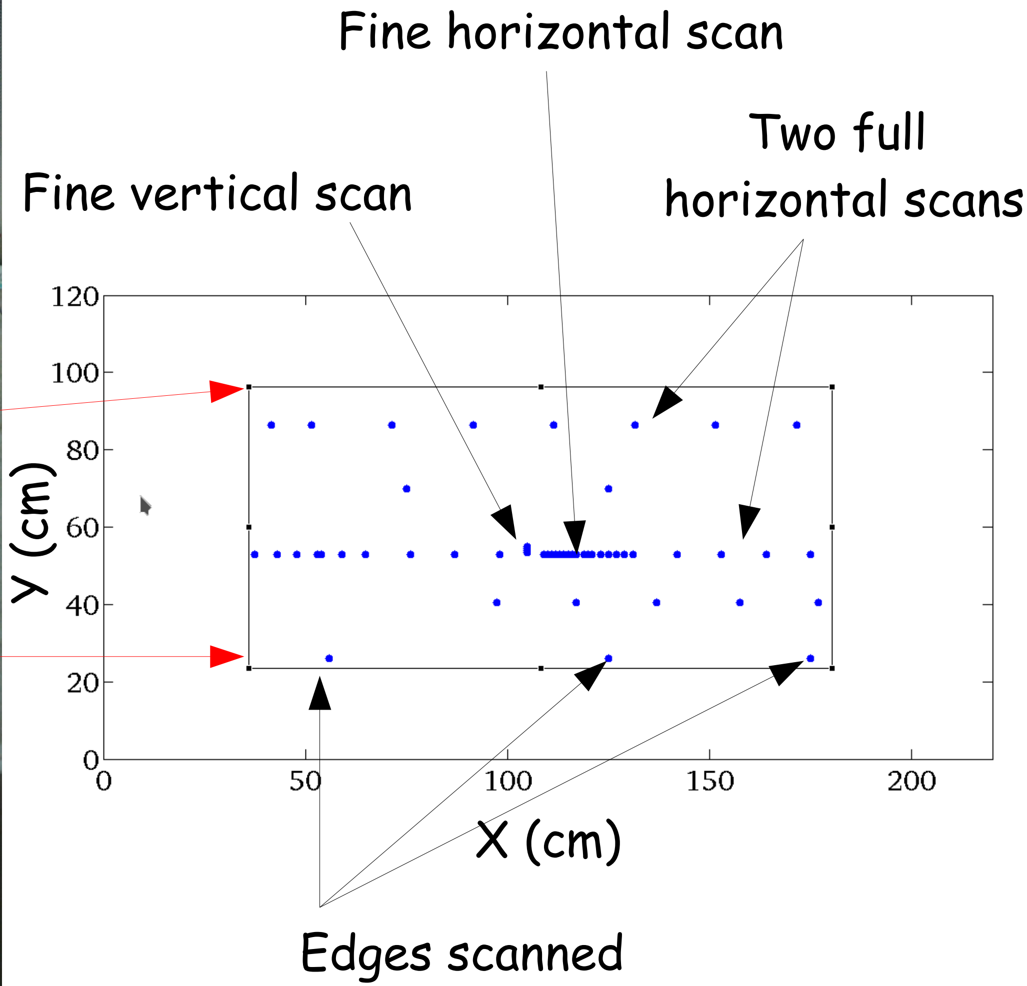
FEE and DAQ start to have impact

Arbitrary location in the active area, but quite homogeneous on the entire area



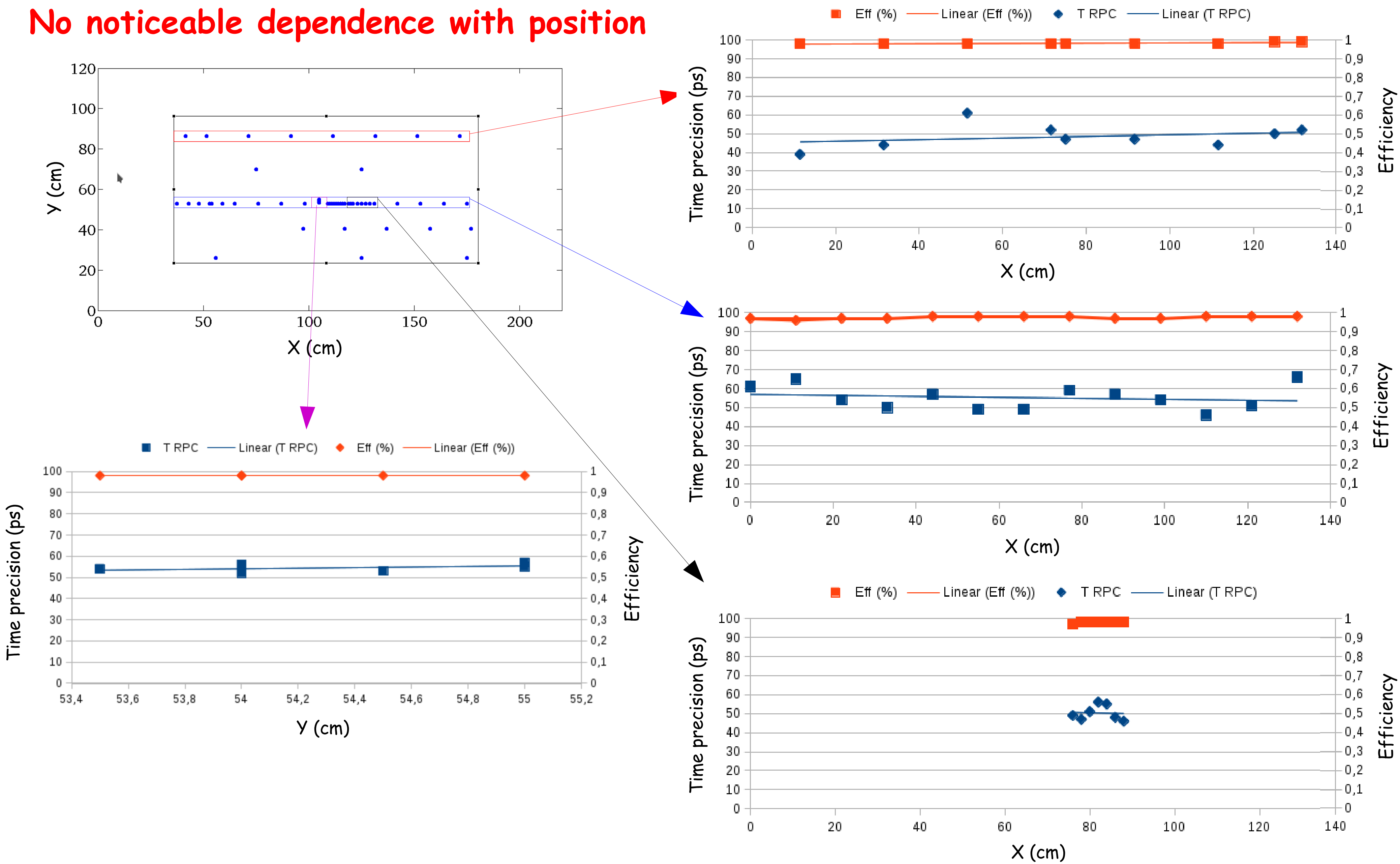
Test beam. Efficiency and timing vs X, Y.





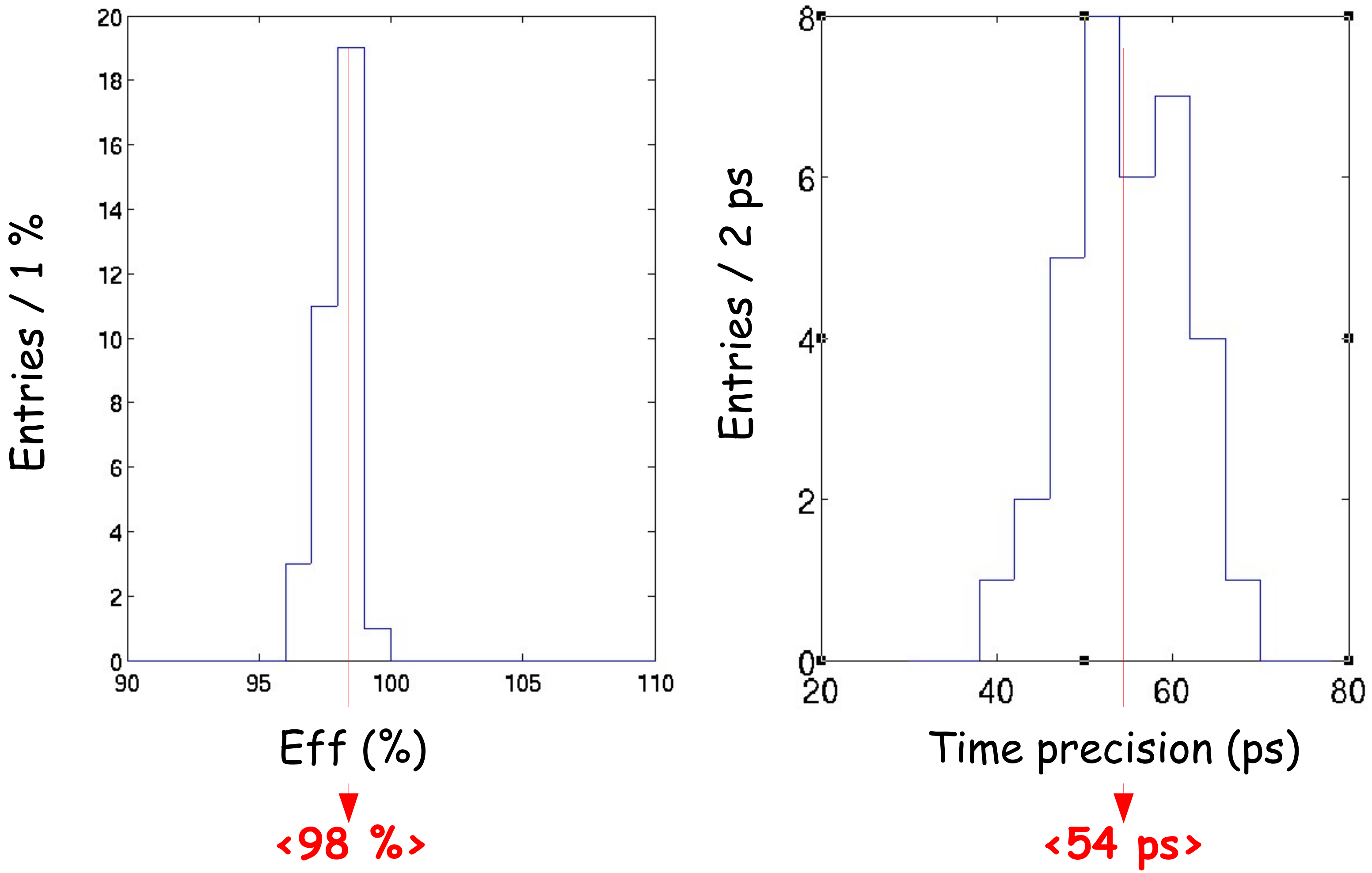
Test beam. Efficiency and timing vs X, Y.

No noticeable dependence with position

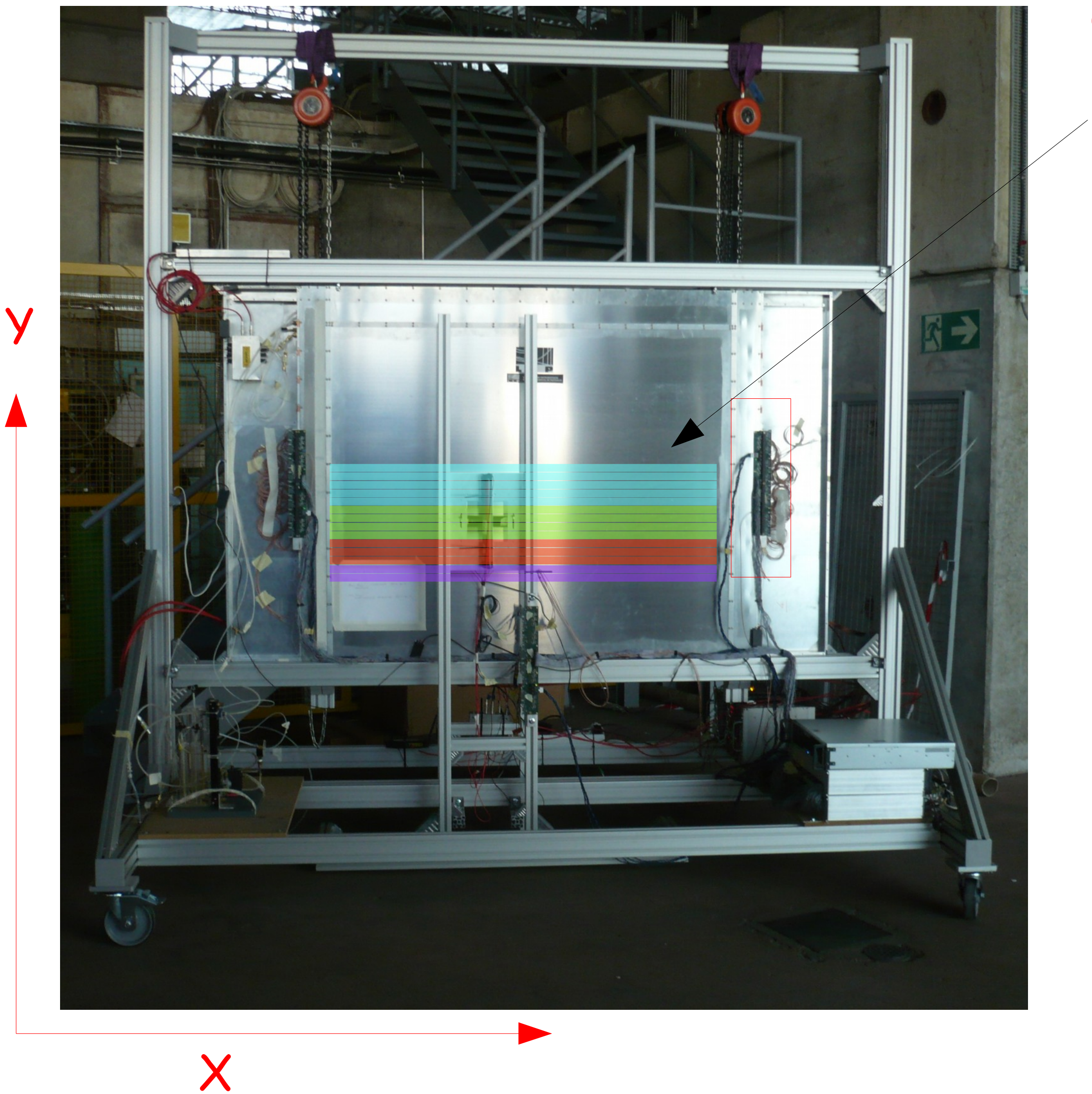


Test beam. Efficiency and timing vs X, Y.

All positions



Detector completely rewired during beam time



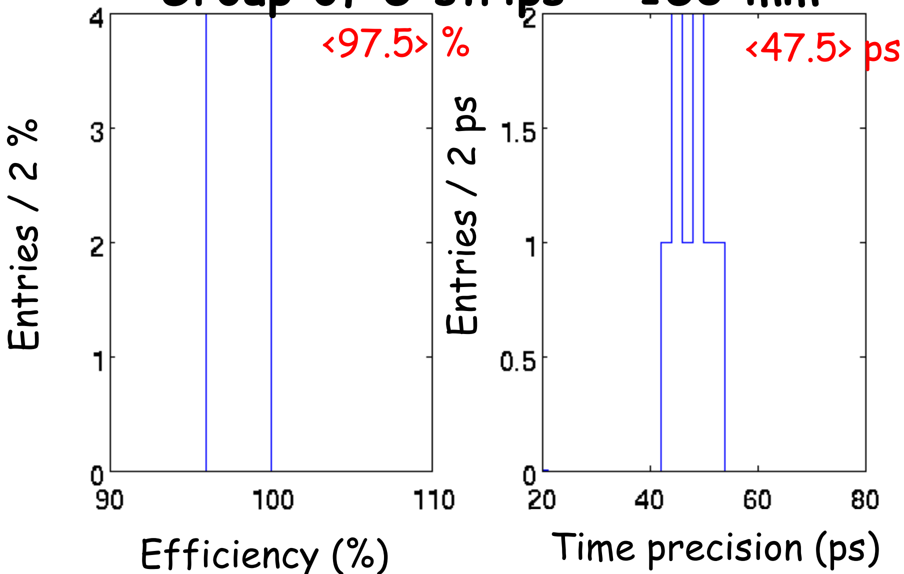
Group several strips in one single channel
2 (60 mm), 3 (90 mm),
4 (120 mm) , 5 (150 mm)
strips together

Motivation => simplify the detector, if possible, to make it cheaper but keeping performance unaltered.

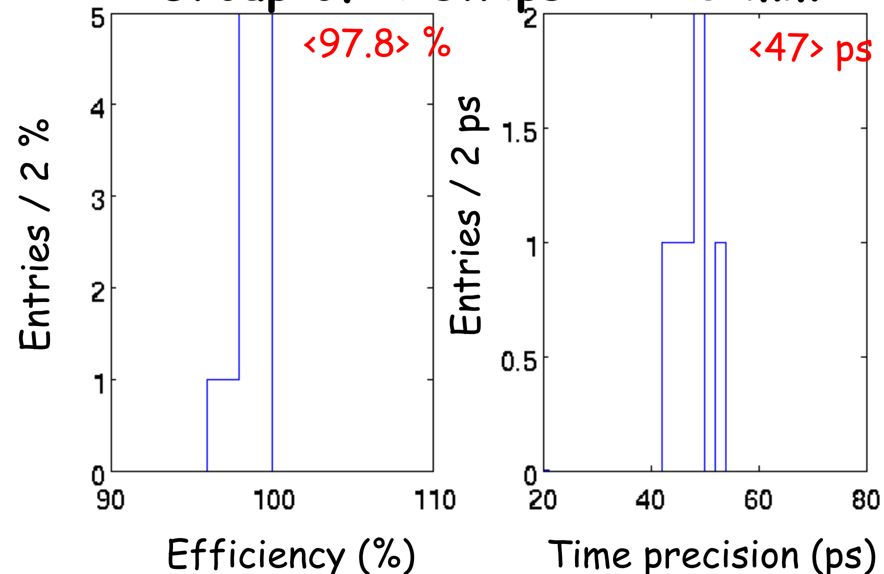
Test beam. Modifications to baseline design. Grouping strips.

Tested in the **center** and in one of the **sides** of the **strips group**

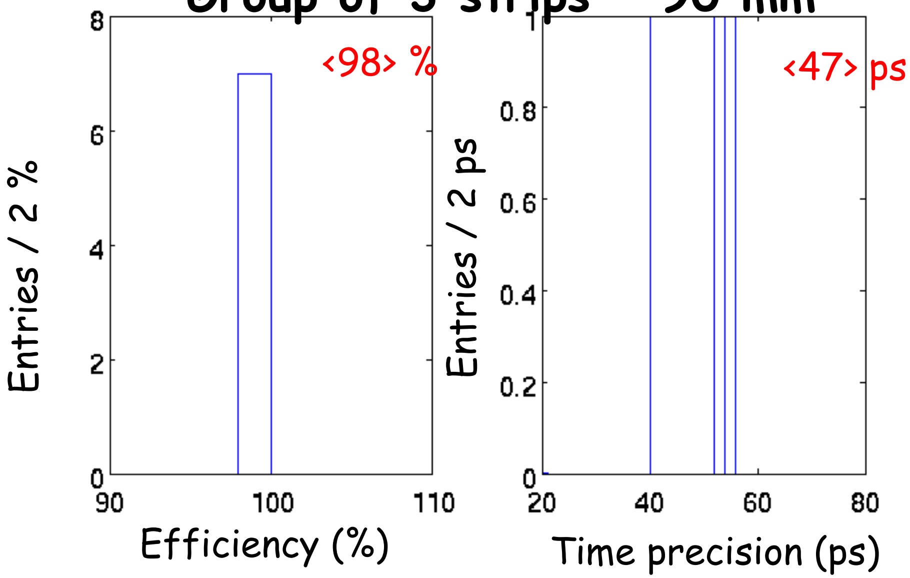
Group of 5 strips ~ 150 mm



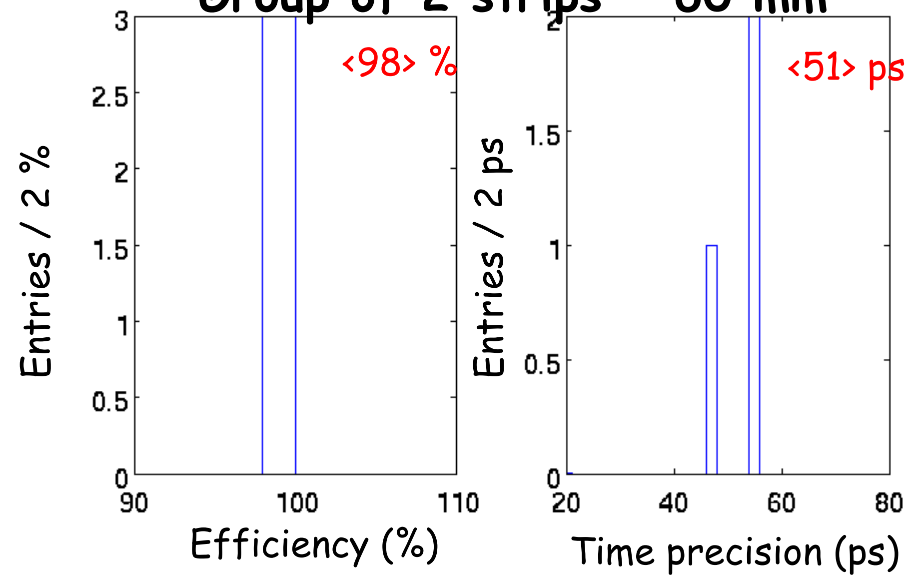
Group of 4 strips ~ 120 mm



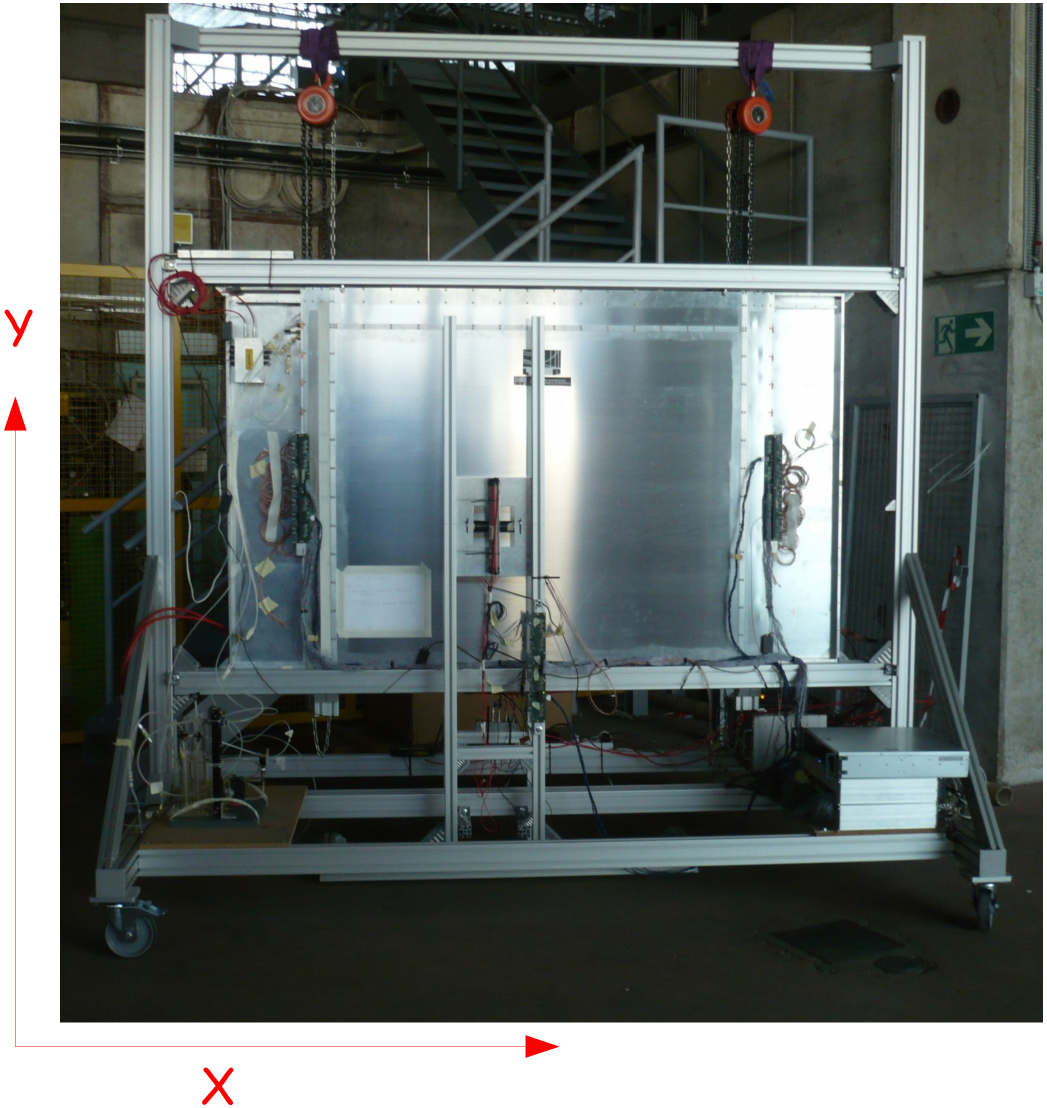
Group of 3 strips ~ 90 mm



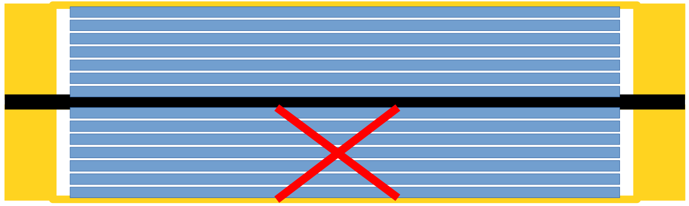
Group of 2 strips ~ 60 mm



Test beam. Modifications to baseline design. One SGS.



Only one glass stack connected



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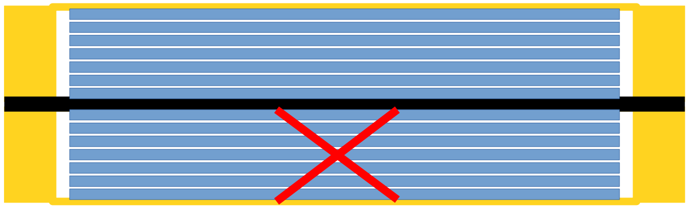
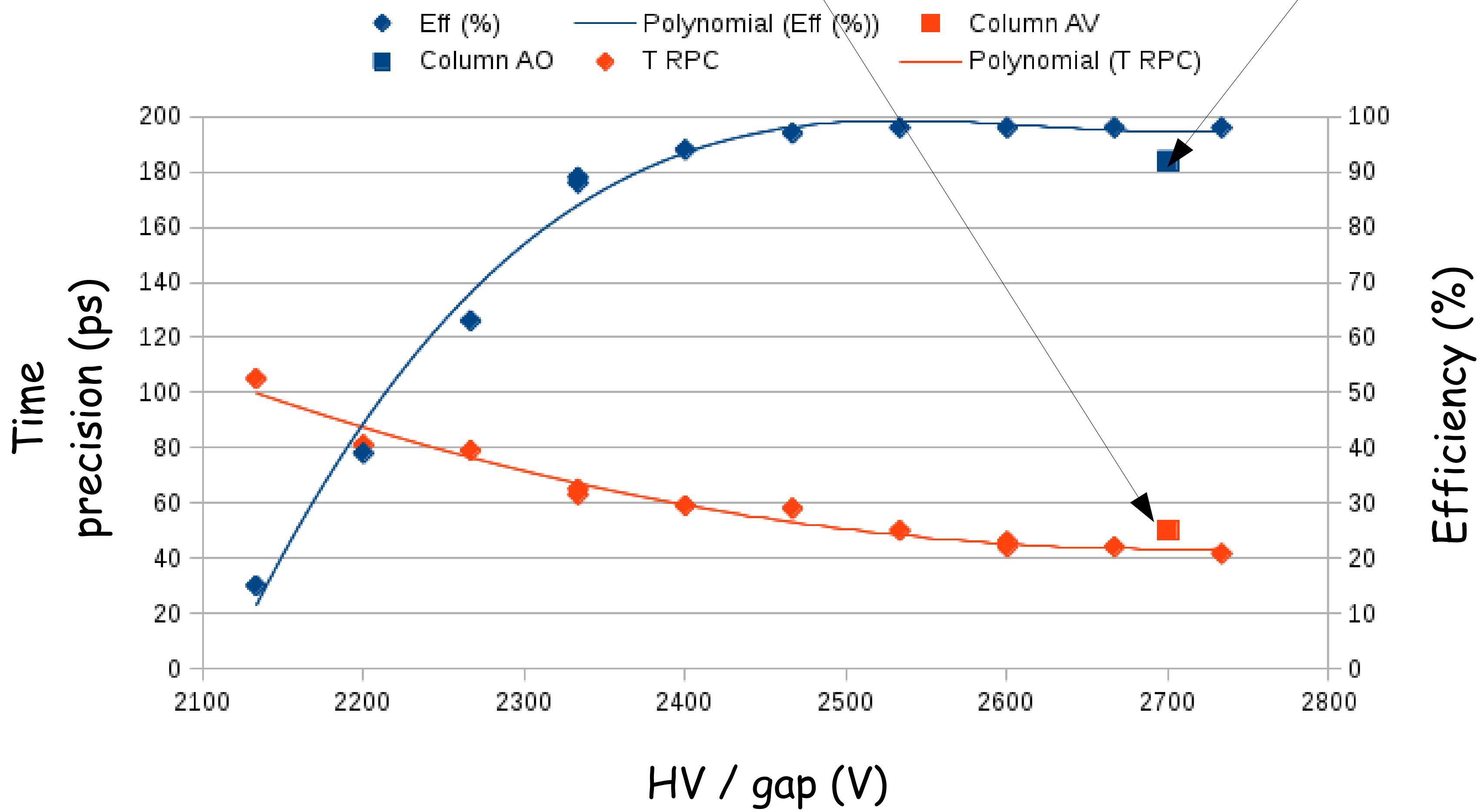
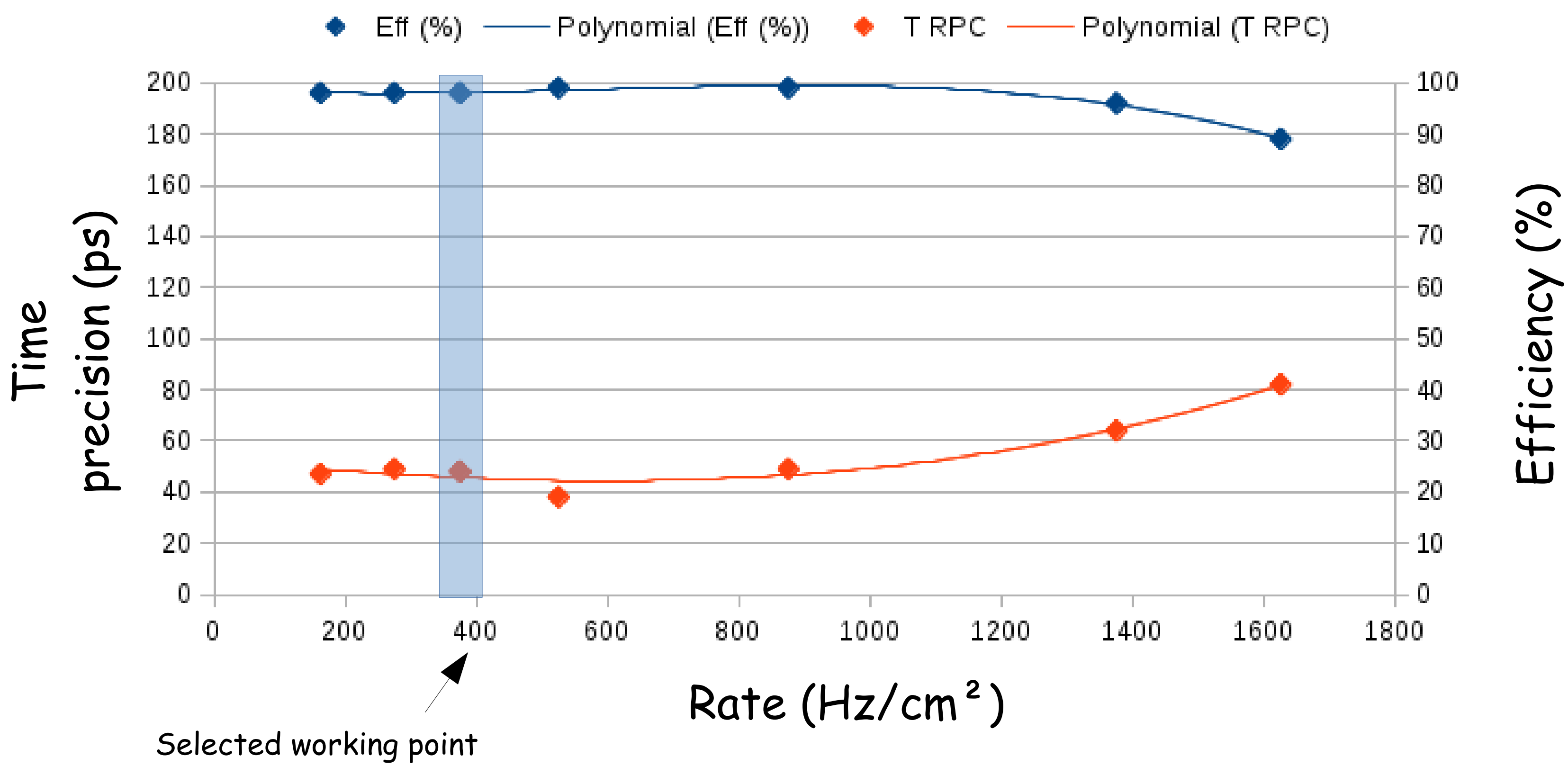


Timing precision slightly degrades but efficiency drops down to 92 %



Test beam. Rate capability.



But the short spill at CERN (0.4 sec) is quite favorable for RPC =>
in continuous irradiation or spill > 1-2 sec results will get worse

Conclusions.

Requirements of the **ShiP timing detector** are **fulfilled** by the proposed technology based on MRPC.

Timing accuracy **~ 54 ps** together with an efficiency of **98 %** without noticeable dependence with position over **~ 2 m^2 active area.**

Strips up to **150 mm width** are possible **without degradation.**

New concept in the construction of timing RPCs that allows the construction of large area (1-2 m^2) chambers in a easy way decreasing the production cost.