The upgraded beam monitor system of the FAMU experiment at RIKEN-RAL

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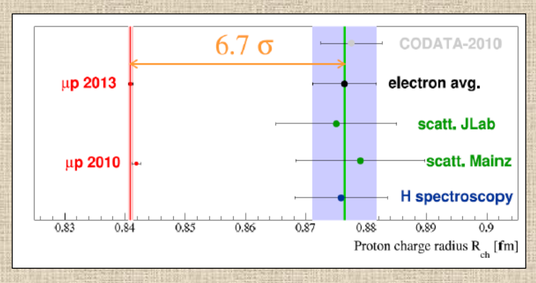
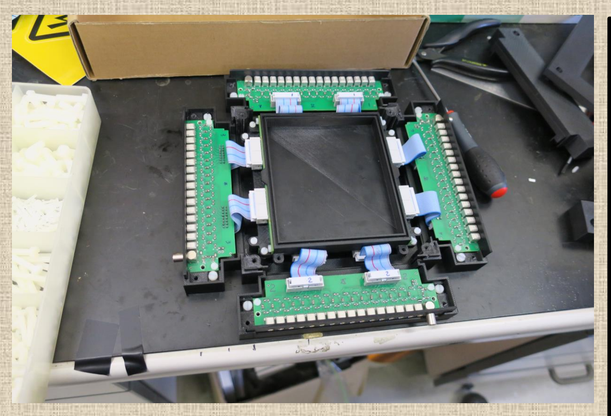
Introduction: the proton radius puzzle and the FAMU expt



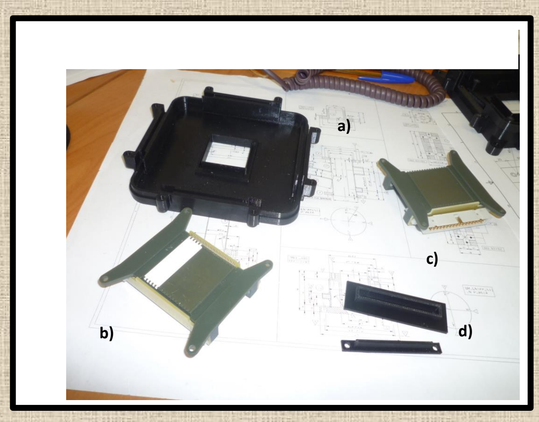
- 7σ discrepancy in the proton charge radius measurement from e and μ measurements
- Not so clear exp situation with Zemach radius

- Experimental method:
- μ^- stops in the hydrogen target and forms a muonic atom
- A laser pulse drives the hyperfine (HFS) transition
- The transition is detected via X-rays emitted after (μZ)* de-exicitation [μ^- transfer to high-Z atoms (added to hydrogen) in the target]
- Plot number of detected transitions vs the laser frequency → determine $\Delta E_{HFS} = h\nu_0$ (ν_o laser resonance frequency)
- determine the proton Zemach radius from ΔE_{HFS}

The FAMU hodoscope system



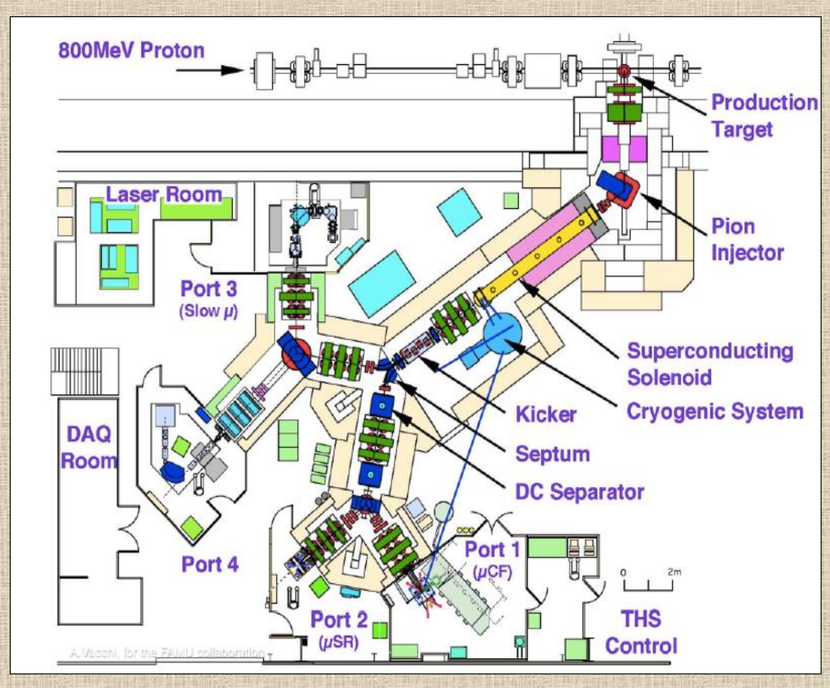
- Exploded view of the 3 mm pitch hodoscope

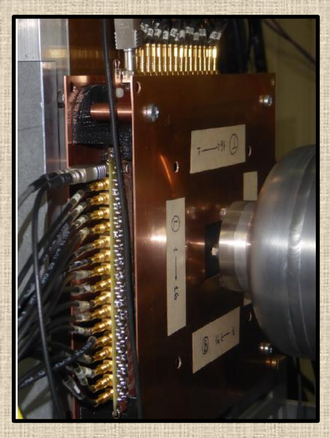


- Main mechanics components for 1 mm pitch hodo : (a) light-tight half detector box; (b), (c) fiber holders for X/Y planes

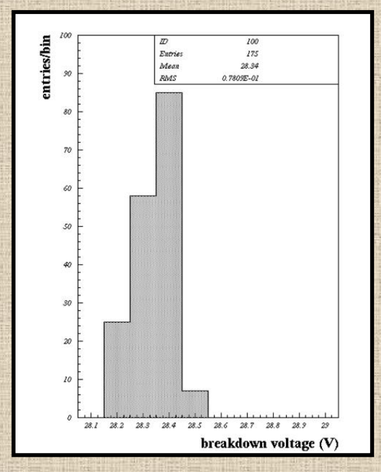
- The system is based on 3 different hodoscopes (1 with 1 mm and 2 with 3 mm pitch) with similar design
- 2 X/Y Bicron BCF12 square single clad scintillating fiber planes read by 3x3 mm² (or 1x1 mm2) Hamamatsu (Advansid) SiPM
- EMA coating (Al film wrapping) for 1 mm (3 mm) fibers to avoid light cross-talk
- As a first step: 32+32 channels readout by TPS readout boards (single SiPM powering/shaper/discr) + CAEN V792 QADC
- Improved electronics based on CAEN V1742 FADC (waveform → peak, area, time) and common HV for a fiber plane (V_{brk} in a large SiPM sample is very similar)
- Mechanics printed on a 3D printer
- Normally only the 1 mm pitch hodo is installed (in front of the target) for beam monitoring . Additional ones used for beam characterization

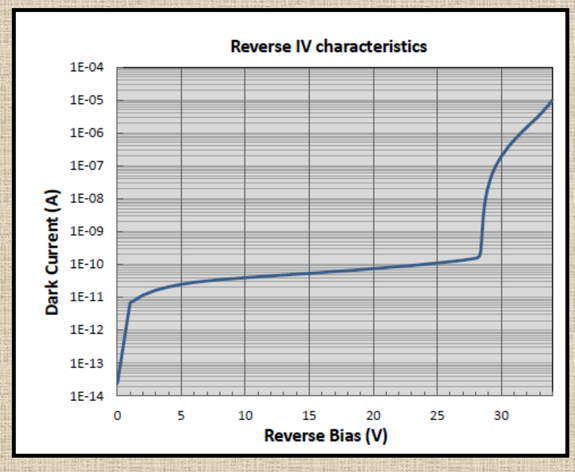
The RiKEN-RAL muon facility





- Installation of 1 mm hodo at RIKEN-RAL





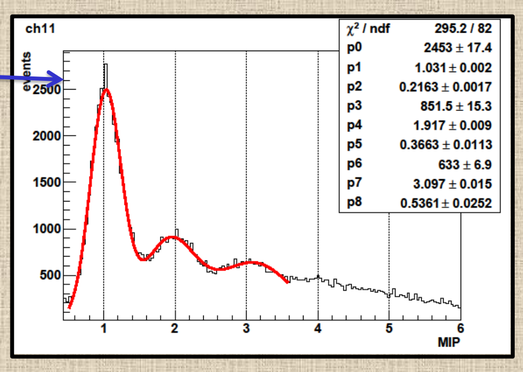
Advansid SiPM characteristics

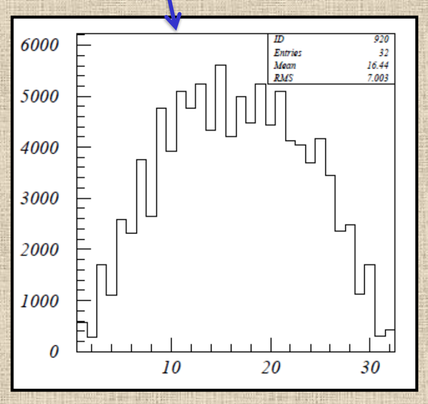
Beam properties: surface μ^+ (20-30 MeV/c), decay μ^+/μ^- (20-120 MeV/c)

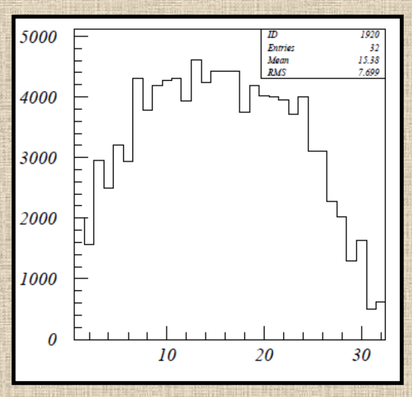
- Typical beam size ~10 cm² Δp/p FWHM 10% (decay muons), 5% (surface muons).
- Double pulse structure.
- An essential point is to study the steering of the beam into the target (need beam hodoscopes)

Performances at RIKEN-RAL

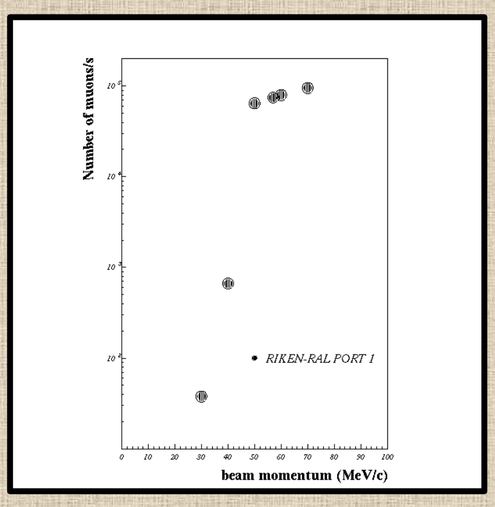
- 1/2 MIP separation at BTF (TPS readout)
- Measured beam intensity at RIKEN-RAL [normalized at previous meas. at 60 MeV/c]
- Measured beam profile at RIKEN-RAL







X/Ybeam profile at RiKEN-RAL



Beam hodoscope requirements:

- μ beams have very low intensity as compared to primary proton beams (pA instead of mA or mA) → conventional e.m. techniques (as current transformers, pickup, …) may not be used, as signal would be too small
- need to use destructive tecniques, based on particle interactions with a detector
- beam hodoscope must:
  - have minimal thickness along beam
  - sustain high beam rates
  - work in noisy environment

References:

- *A. Vacchi et al., SPIE Newsroom (2012) doi: 10.1117/2.1201207.004274*
- *A. Adamczack et al., JINST 11/05 P05007 (2016)*
- *R. Carbone et al, JINST 10/3 C08007 (2015)*
- *M. Bonesini et al., JINST 12 (2017) C03035;*
- *M.Bonesini, PoS(Nufact 2017) 159*