First measurements of non interceptive beam profile prototypes for mid-high intensity hadrons accelerators

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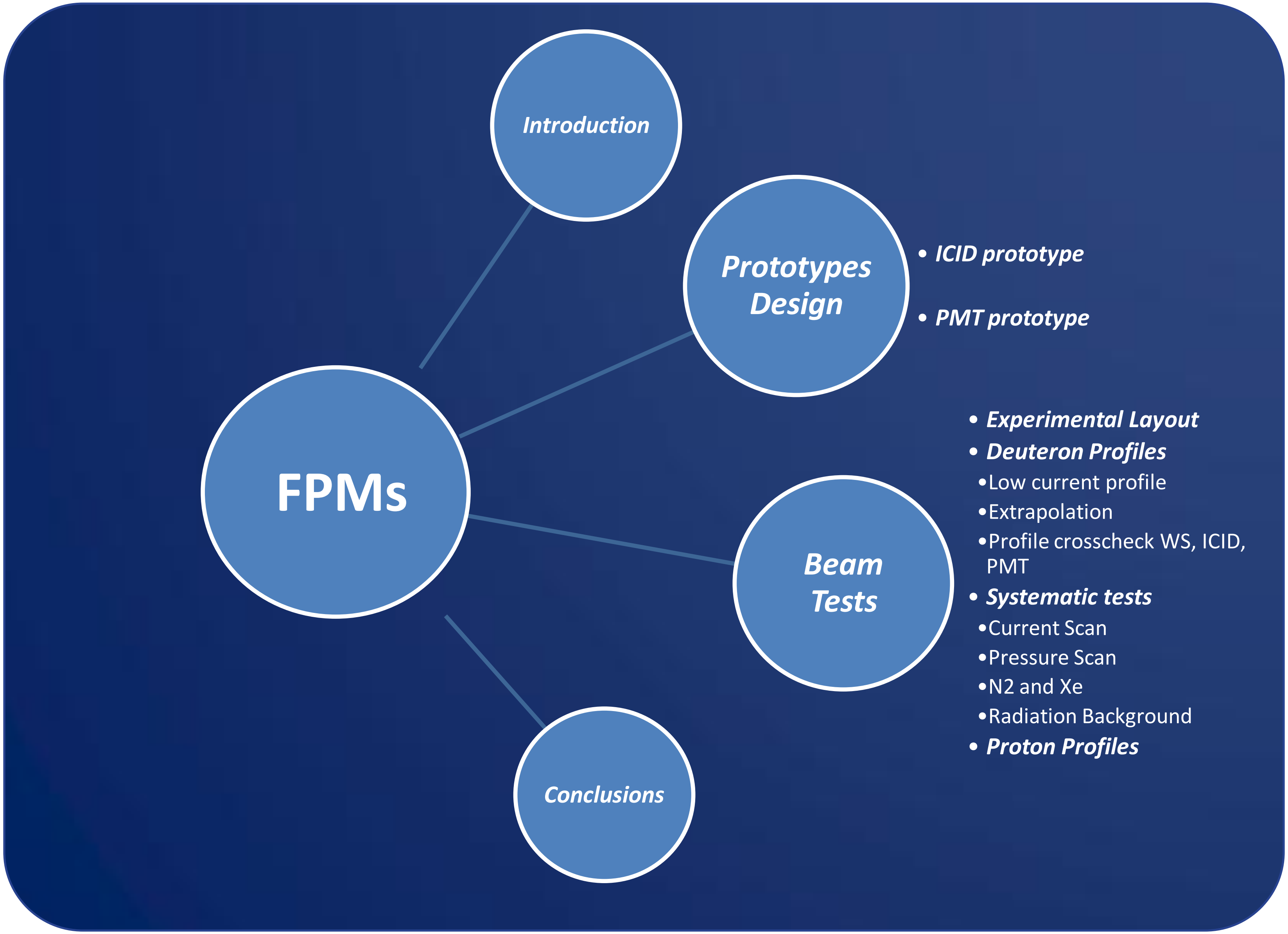

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• ICID prototype
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• Deuteron Profiles
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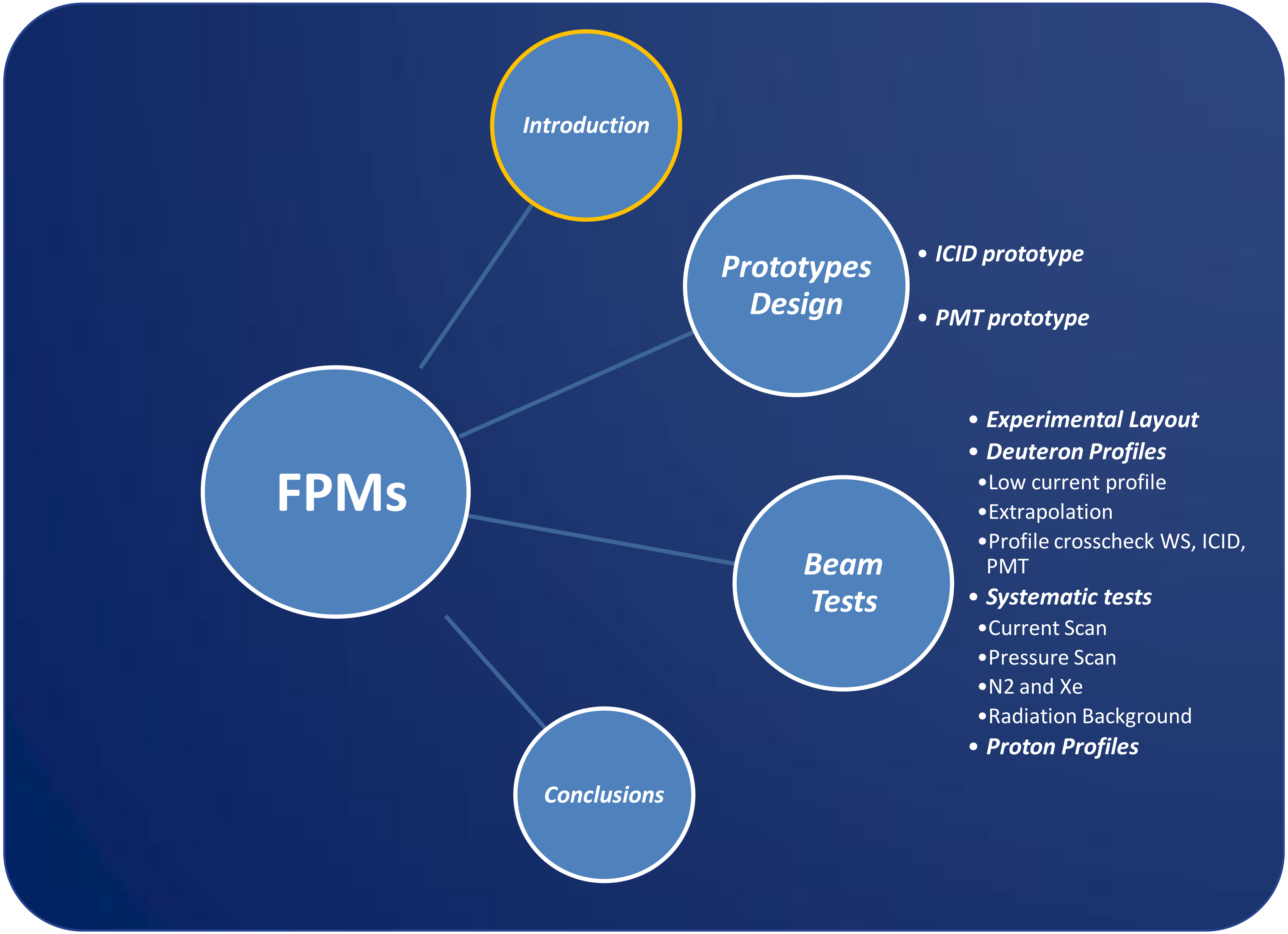

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IFMIF-EVEDA accelerator

EVEDA phase: *Engineering Validation and Engineering Design of the IFMIF project*

Main specifications

- Installation in Rokkasho-Japan
- manufacturing and tests of a prototype accelerator (1:1) with 9 MeV final energy.
- Deuterons, 125 mA (cw), 9 MeV (1.125 MW)
- Commissioning phase: 125 mA, pulsed mode down to >100 μs, 0.01% duty cycle.

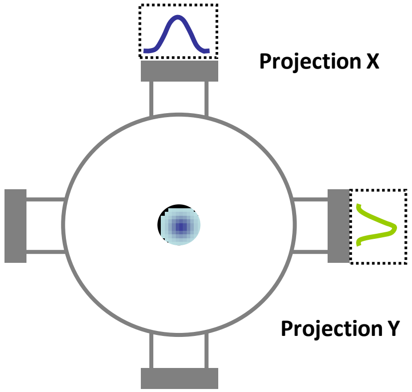
Introduction

Objective

to develop a non interceptive beam transverse profiler monitor

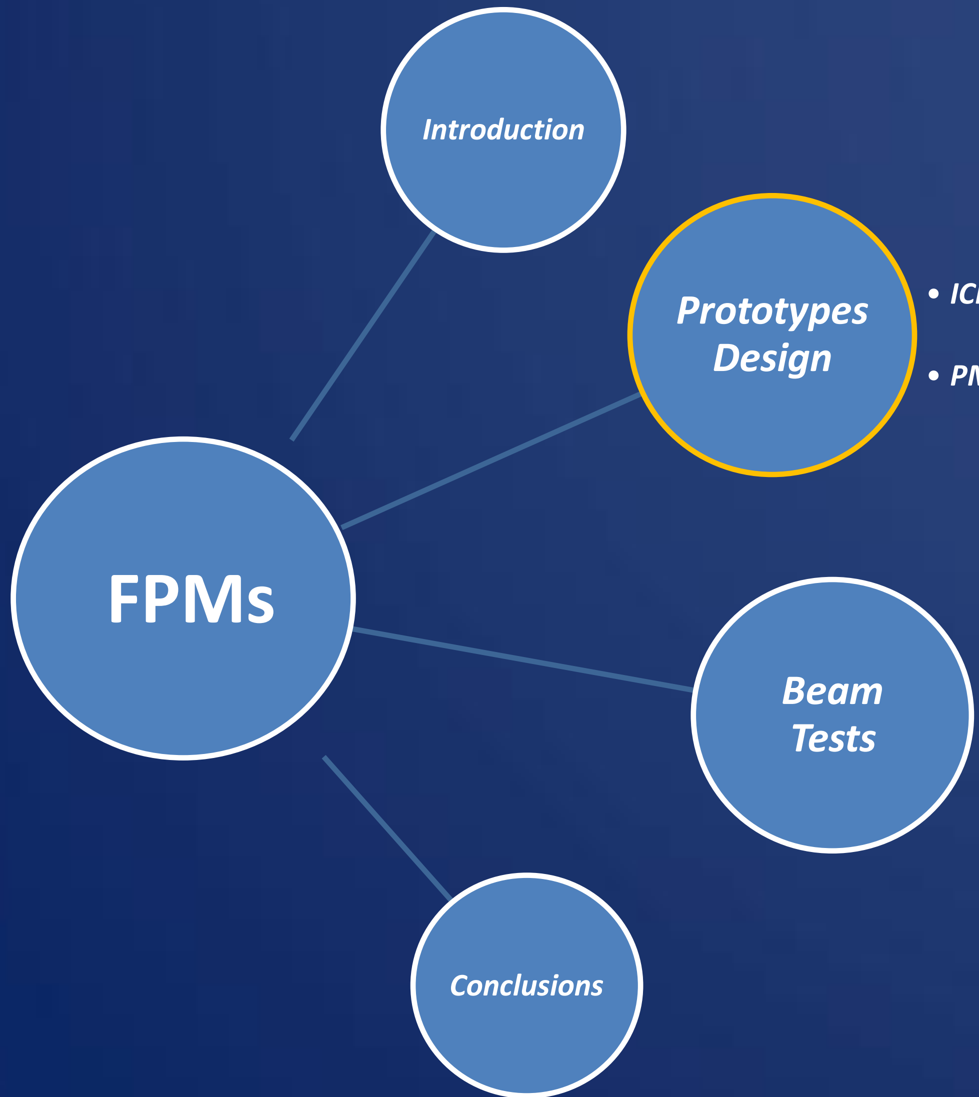
-Fluorescence of residual gas [1-2]

- Photons produced due to the excitation and de-excitation of the gas molecules or atoms of residual or injected gas
- The light emitted → collected → determination of the beam profiles.
- Vertical and horizontal beam profiles at same time/location
- Challenges: Big beam profiles, radiation background, high current
- Advantages: Flexibility, variable resolution, out of beam pipe, different transitions selectable if required



[1] M.A. Plum et al., Nucl. Instr. And Meth. A 492 (2002) 74-90
[2] P. Forck. Lecture notes on beam instrumentation and diagnostics. JUAS 2007

Summary



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FPMs: ICID Prototype

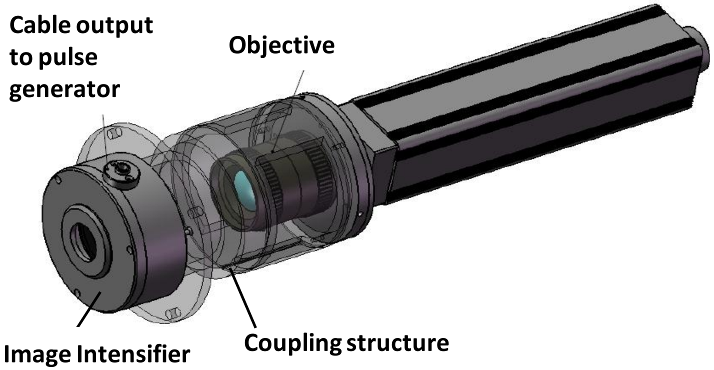
Two different prototypes for FPM have been developed:

- custom designed intensified camera
- linear multi-anode PMT array

- Designed to be used in low level light environments
- Highly flexible (resolution varied with a simple lens change, fast shuttering and integration times)

Protol

1. Lens system
2. Rad-hard CID camera
3. Custom Image intensifier & coupling



Key designs:

Single photo count
Fast shutter triggering the MCP voltages

Specifications:

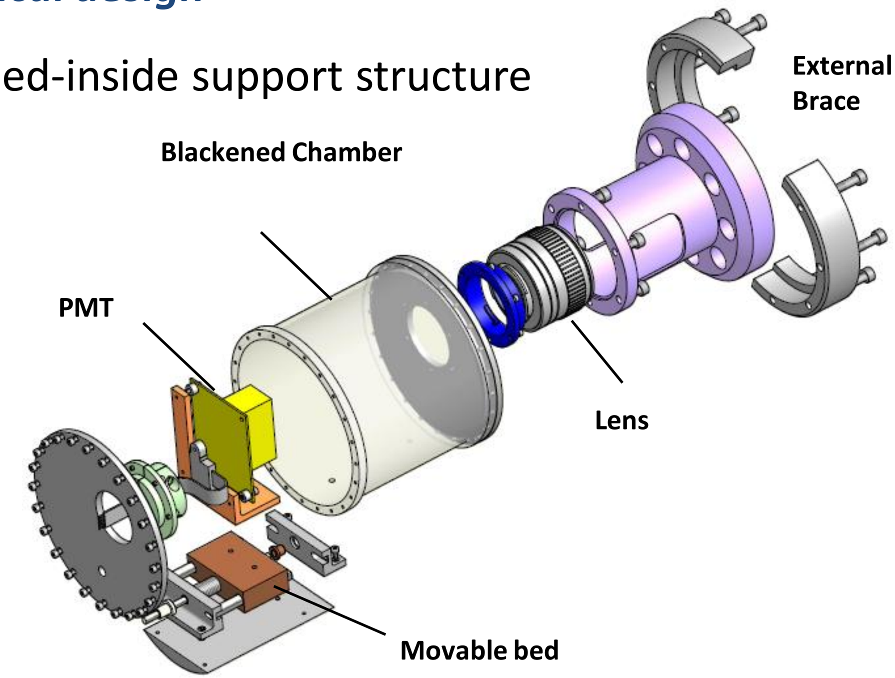
Intensifier: input clear glass, P46, Bialkali
Detector: 726x575 pixels, (pixel 13 μm)
Lens: Edmund optics f=25mm f/ 2.8

FPMs: PMT Prototype

Proto2

Mechanical design

•Blackened-inside support structure



1. Lens system
2. Linear multianode PMT array
3. Multichannel data acquisition system

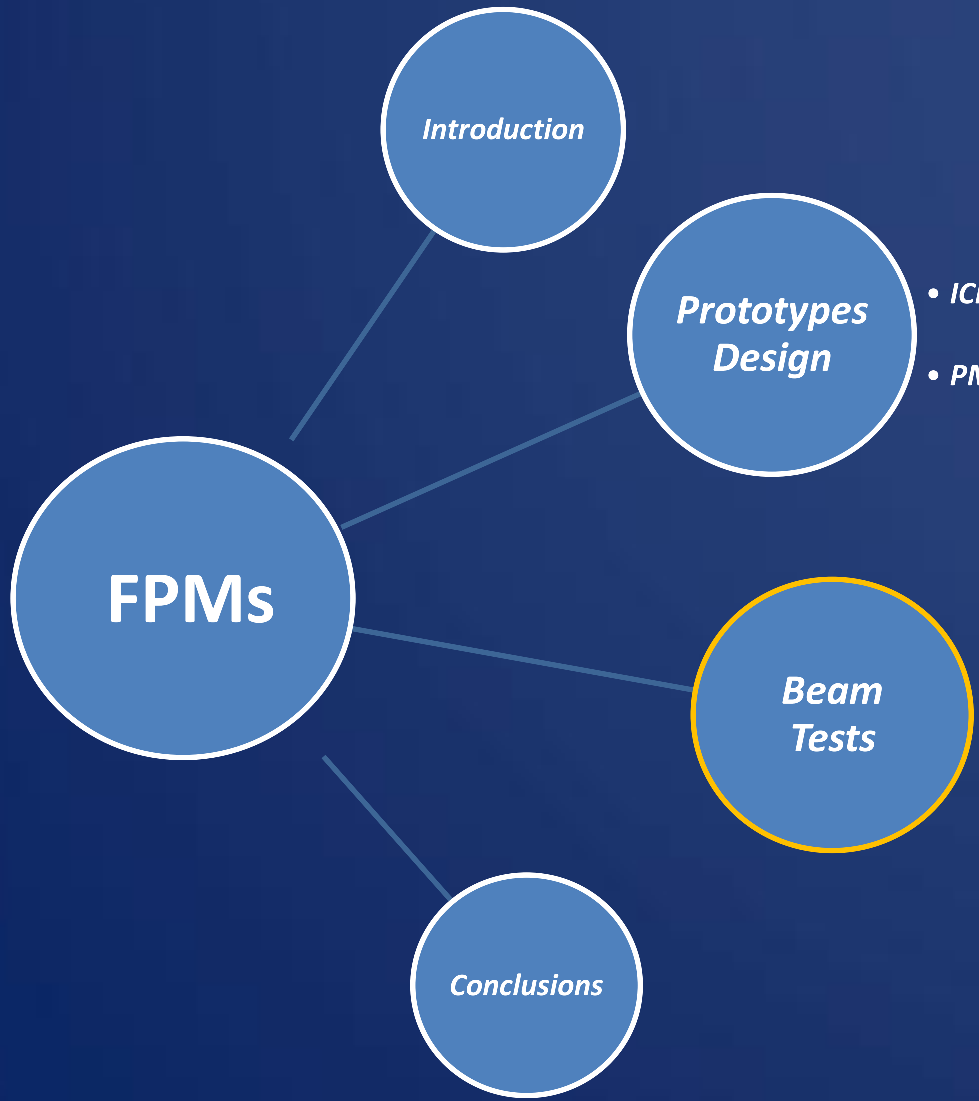
Design keys

•Movable bed improves the system optical properties

•Wall bypass system (green) for voltage and signal cables (avoid light contaminations)

•Vertical anchoring for the PMT board, space for signal and voltage cable installation

Summary



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Beam Tests

Introduction:

FPM prototypes tested at Centro Nacional de Aceleradores (CNA) at Sevilla.
Cyclotron for 9 MeV deuterons and 18 MeV protons. Beam current of tens of μA

Objective of the tests

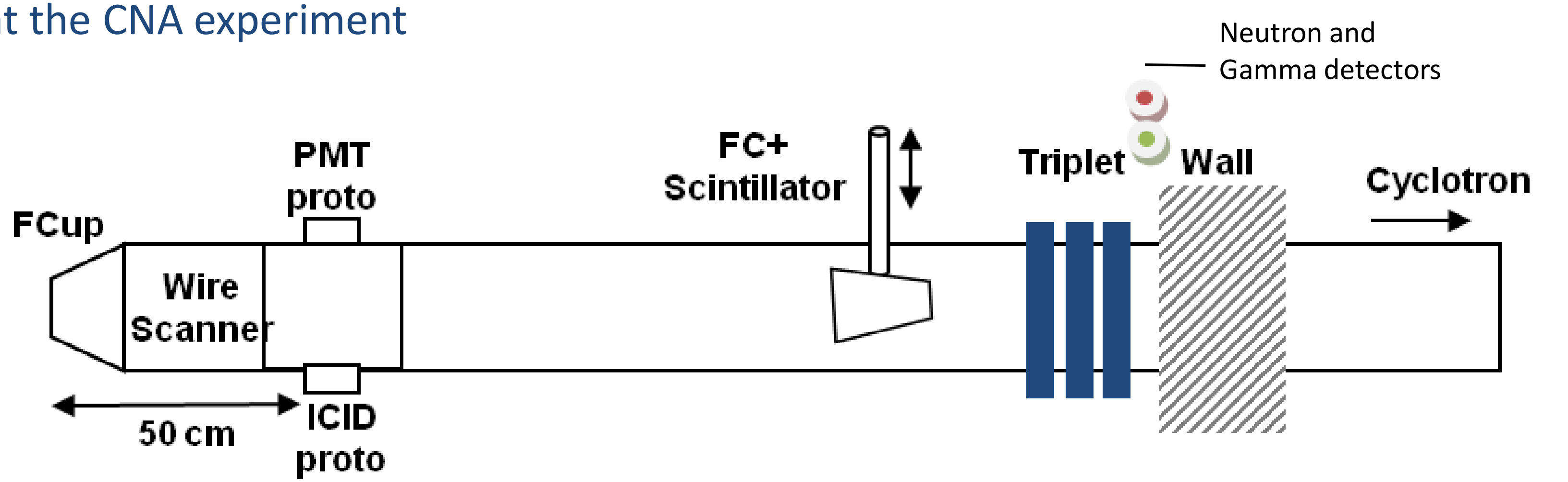
- To demonstrate the capability of measuring 9 MeV deuteron beam profiles (simulate IFMIF-EVEDA accelerator conditions).
- To validate profiles measured with the different prototypes with another profiler

Remarks

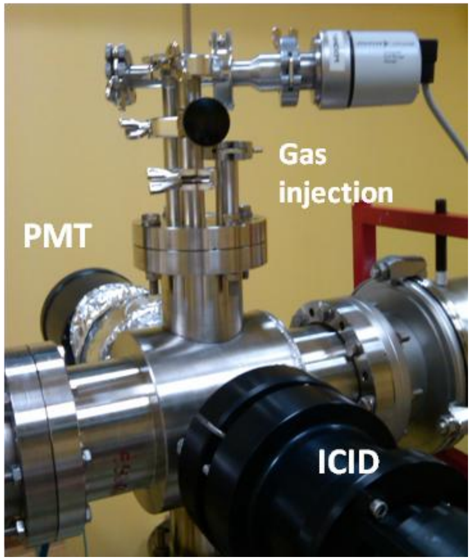
- The same ion and energy was used although beam current is far from 125 mA (low currents are worse conditions for FPMs)
- The rest of parameters involved i.e. cross sections, line transitions (BRs) and efficiencies among others will be the same. Less uncertainties

Beam Tests: Layout

Scheme at the CNA experiment
Top view



- Rotating Wire Scanner for cross-check
- FPM prototypes→ Y profile at the same location (in front)
- FCup/target close to FPMs
- Gas injection in the prototype vacuum chamber



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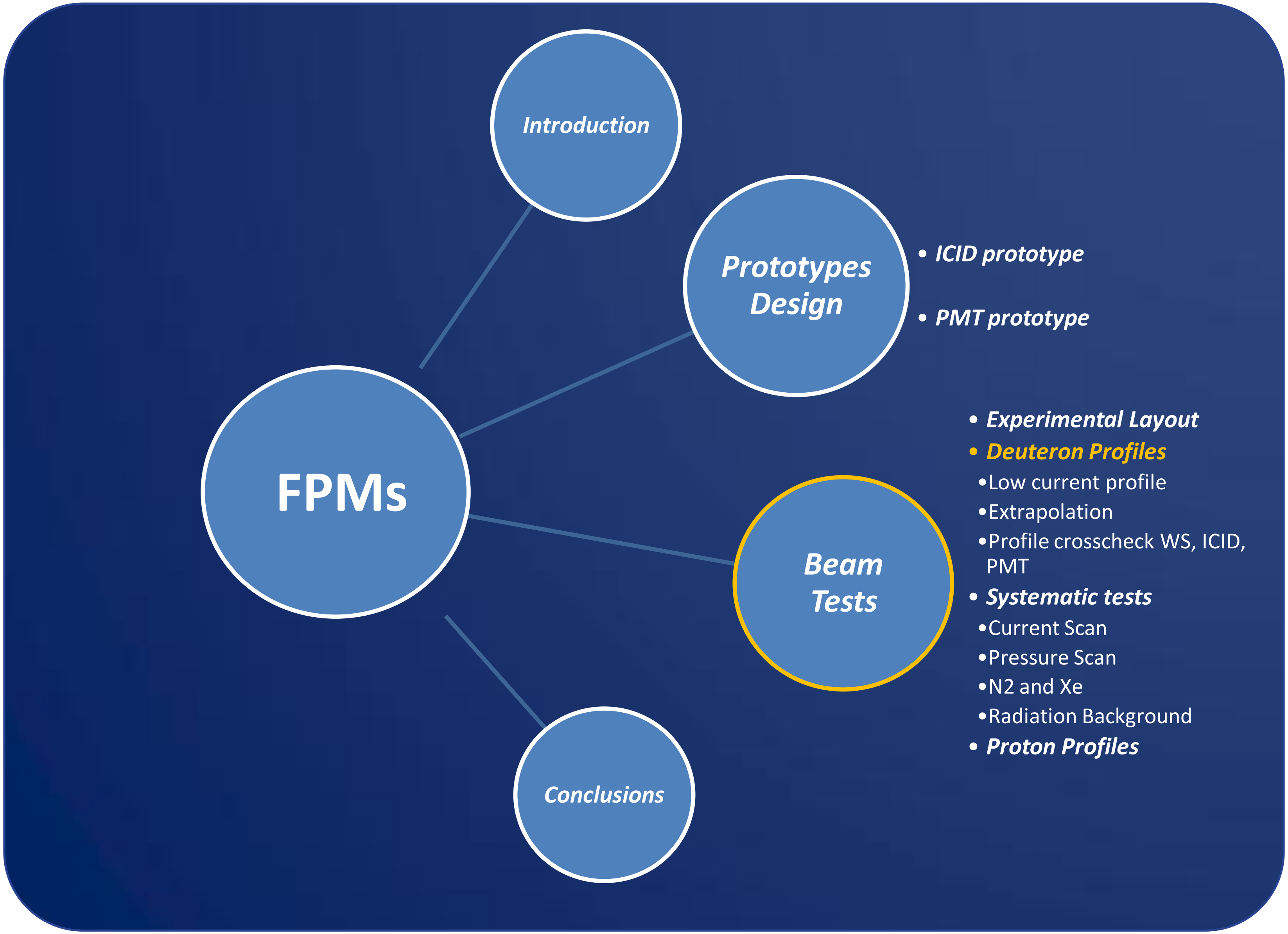
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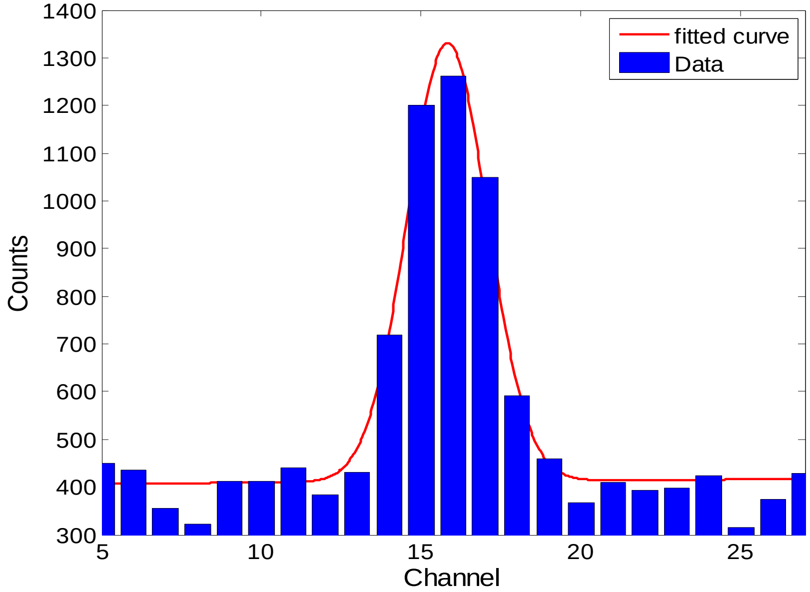
Deuteron Profiles (lowest beam current)

Deuteron profile recorded with lower beam current

Experimental conditions:

Beam Energy=9 MeV
Beam Intensity=400 nA
Pressure=3.6x10^{-4} mbar of N_2
Integration time=100 ms

Profile acquired only with PMT prototype



PMT voltage 900V

Gaussian fit:

FWHM (within RMSE) of 2.4±0.1 cm
Error within 95% of confidence interval FWHM=2.4±0.3 cm

Deuteron Profiles (extrapolations)

Extrapolation for IFMIF-EVEDA conditions (9 MeV, 125 mA, CW)

Fixed

Variable

$\mathcal{E}$=emissivity , number of photons emitted per second for a given length path d_{path}
I=beam current
P=pressure
σ^{eq}total cross section

$$\varepsilon \sim \sigma^{eq} \cdot P_{gas} \cdot I_{beam} \cdot d_{path}$$

Number of counts measured by a detector (N) depends on the emissivity, the solid angle (Ω), the integration of time (τ) and the total efficiency of the system (χ).

$$N \sim \varepsilon \cdot \Omega \cdot \tau \cdot \chi^{sist}$$

Deuteron Profiles (extrapolations)

Expected profiles for D^+ 9 MeV, 125 mA, CW

Using previous profile and experimental parameters → extrapolation
Requirement for 125 mA cw to measure profile with similar characteristics?

Product IxPxτ=constant → profile measurable

$$4e\text{-}4 \text{ mA} \times 3.6e\text{-}4 \text{ mbar} \times 100 \text{ ms} = 125 \text{ mA} \times 1e\text{-}6 \text{ mbar} \times t_{pulse}$$

→ *integration time of* **115 μs**

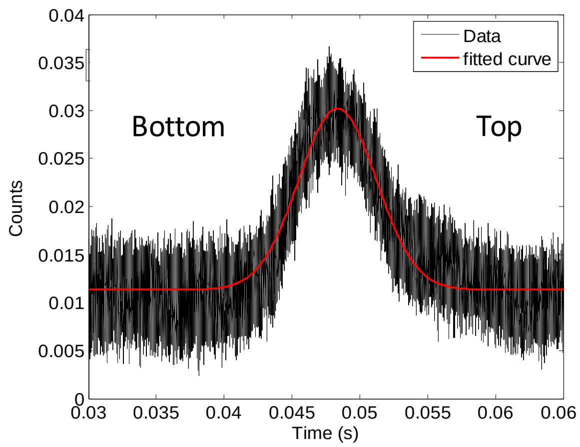
→ *minimum beam single pulse* → 0.01% duty cycle (115 μs)

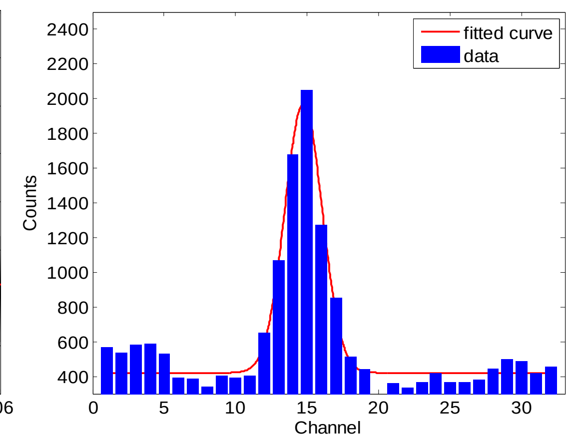
Deuteron Profiles (Profile Cross check)

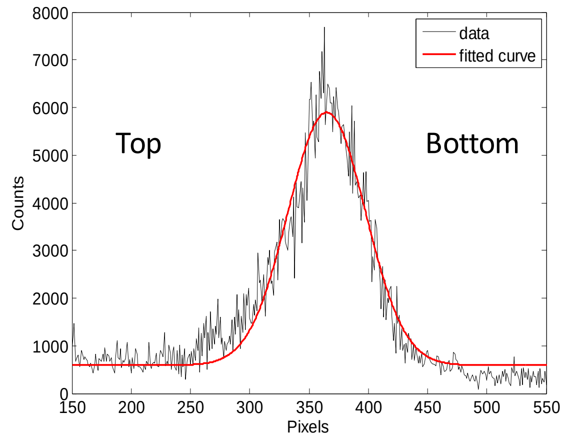
Crosscheck between ICID, PMT and Wire scanner (rotating).
Measurements were not possible until a 300V bias was applied to the FCup.

Experimental conditions:
Beam Energy=9 MeV
Beam Intensity=15 uA
Pressure=$7x10^{-4}$ mbar of N_2
ICID voltage=1580V, τ=20ms
PMT voltage=900V, τ=5ms

Note: radiation monitors measured **doses** of **~27.2mSv/h** for gammas and **~6.5 mSv/h** for neutrons

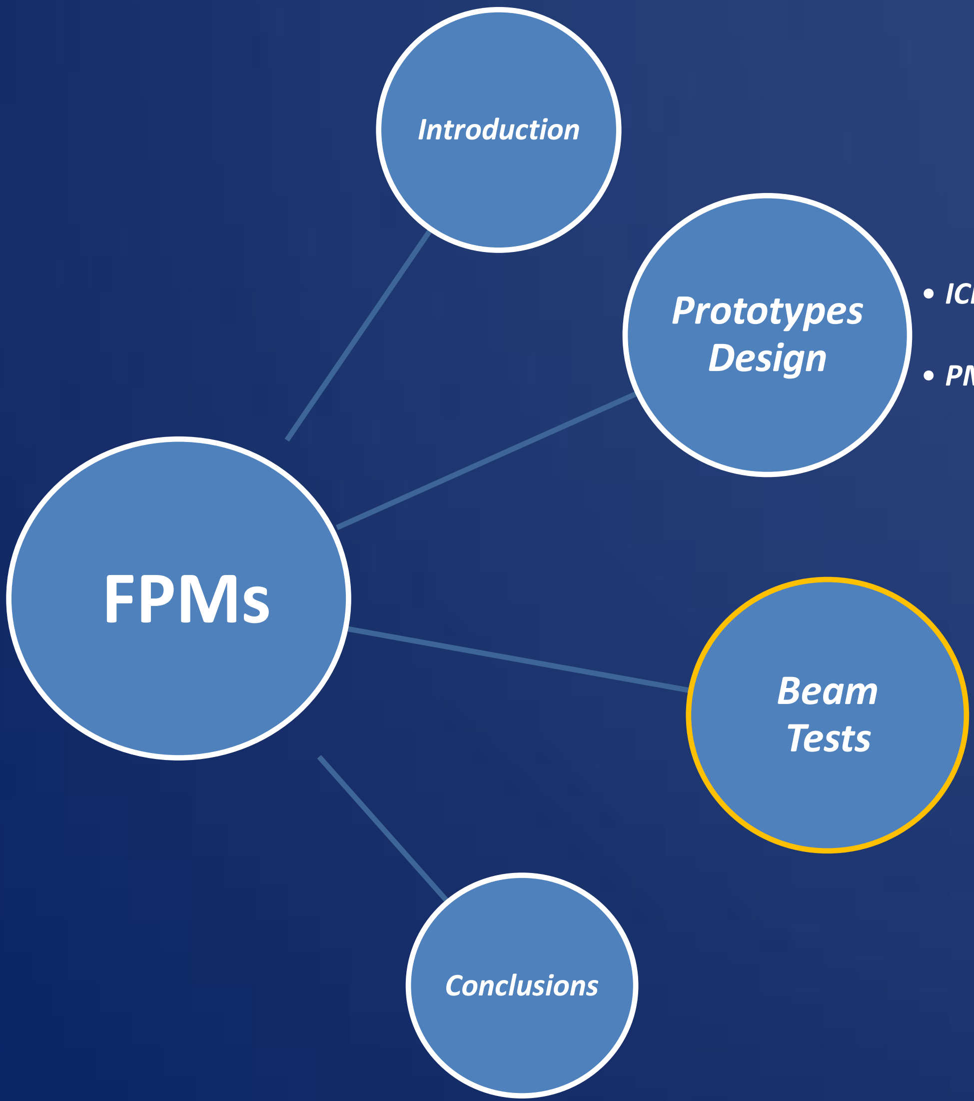






Profiler	FWHM (95% C.I.)
Wire Scanner	2.44±0.03 cm
PMT	2.4±0.3 cm
ICID	2.42±0.07 cm

Summary



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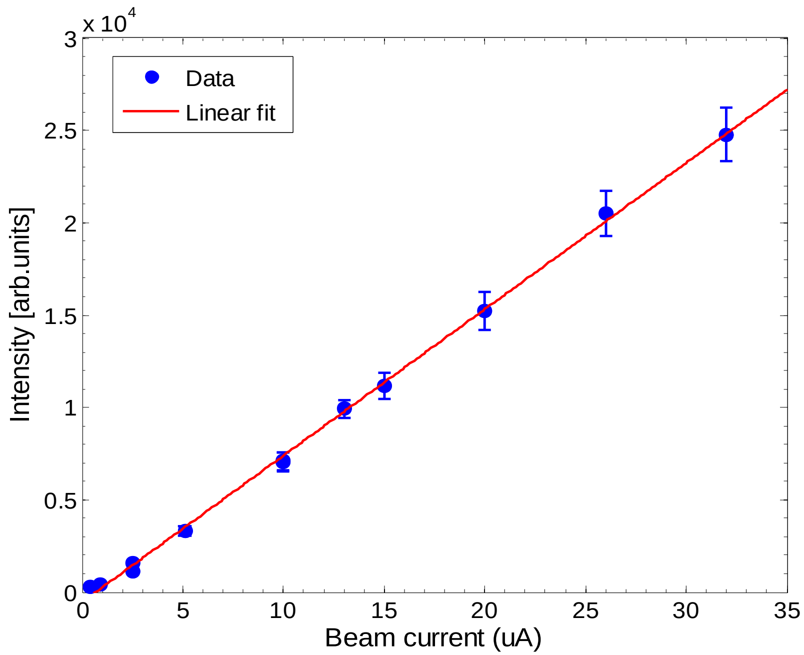
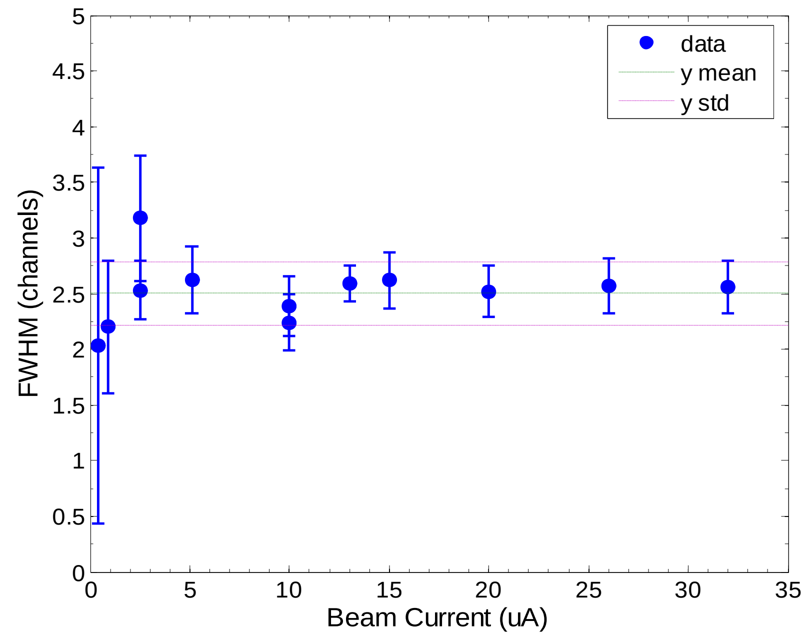
Current Scan

A current scan were performed to validate the premise that counts increase linearly with the beam current for deuterons





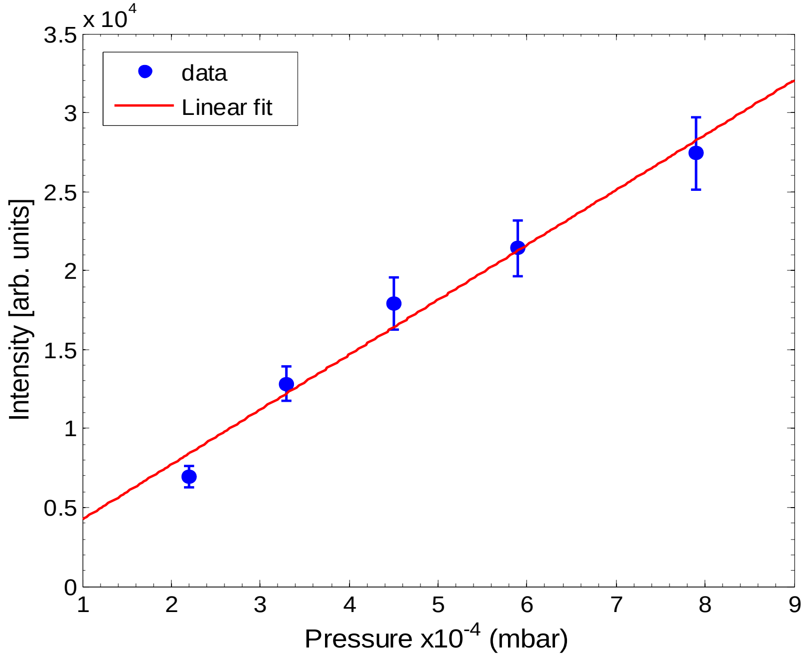
PMT voltage fixed at 900V, t=100ms for comparison, P=2e-4 mbar of Nitrogen

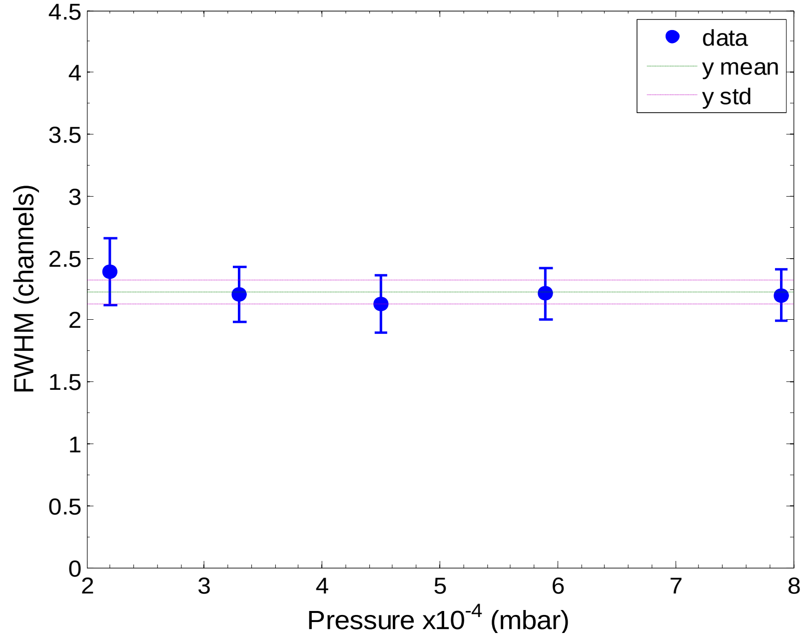
- Linear relation between intensity and beam current is found
- FWHM constant vs the beam current (within error bars) *

***No more than typical behavior of the cyclotron (more stable at high currents!)**

Pressure Scan

A pressure scan were performed to validate the premise that counts increase linearly with the vacuum pressure



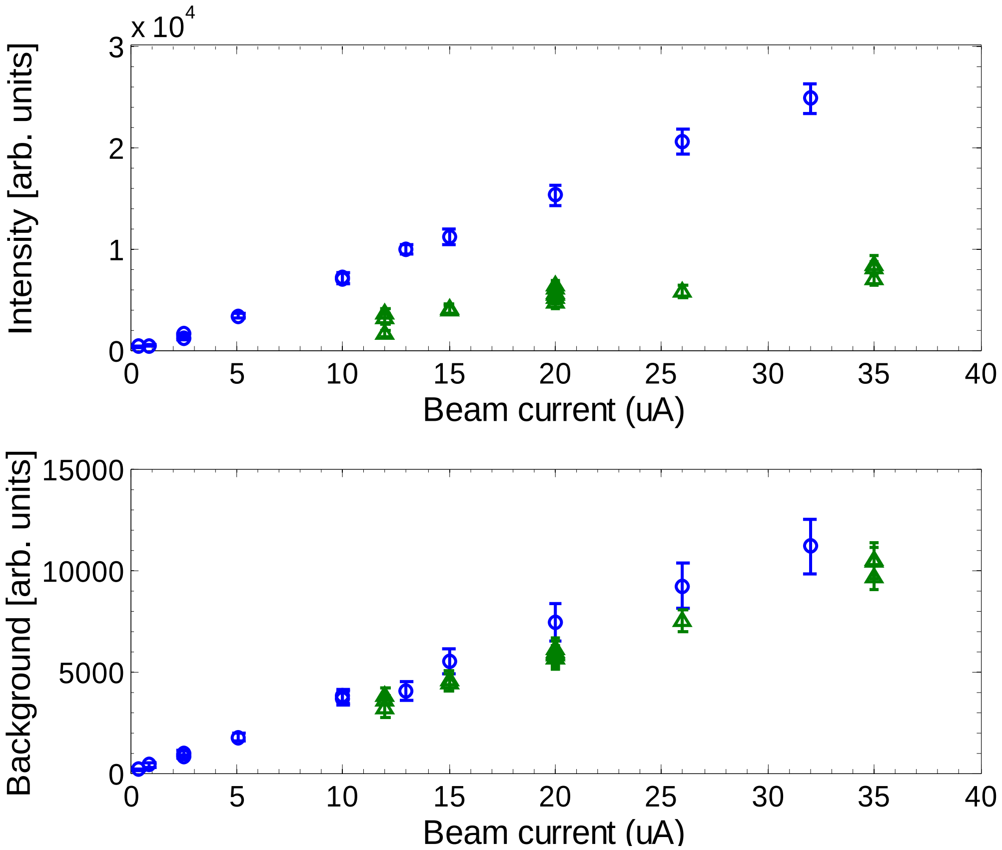


PMT voltage fixed at 900V, t=100ms for comparison, I=10uA

- Linear relation between intensity and pressure (with in error bars)
- FWHM does not change pressure (within error bars) Std~0.7mm

Nitrogen and Xenon

Profile intensities and background levels (qualitative comparisons)



Intensities N_2 vs Xe:

-Nitrogen 4 times higher than Xe
(even with higher pressure for Xe)

Background N_2 vs Xe:

-Constant within error bars
(Nitrogen 0.22 times higher without error bars)

Main contributor to background level
¿Scattered photons? ¿Radiation?

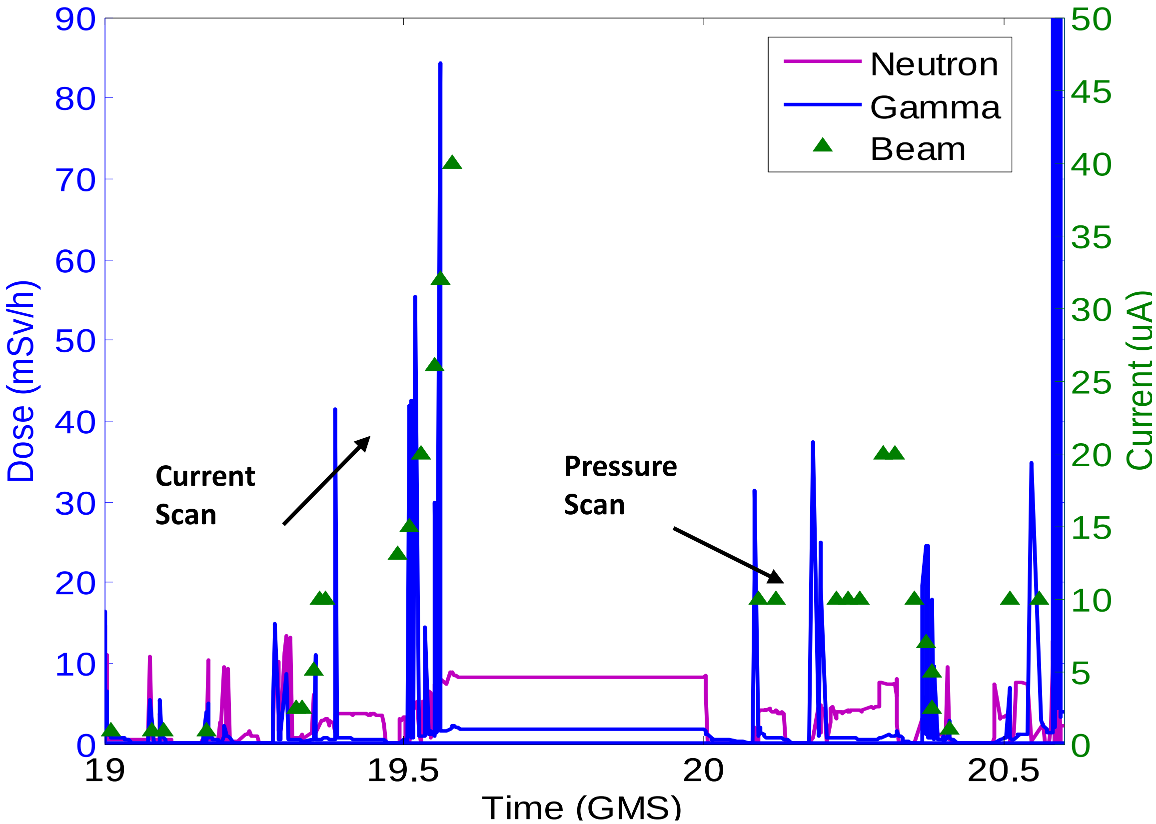
→**Radiation**
(Radiation is constant for a fixed beam current)

N_2 pressure $2x10^{-4}$ mbar, Xe pressure $8x10^{-6}$ mbar

Radiation Background

- No shielding between the beam profilers and target
- Profilers had to deal with an important gamma (and neutron) background
- Radiation useful to characterize profilers in hostile environments

Major contributor to measured background?



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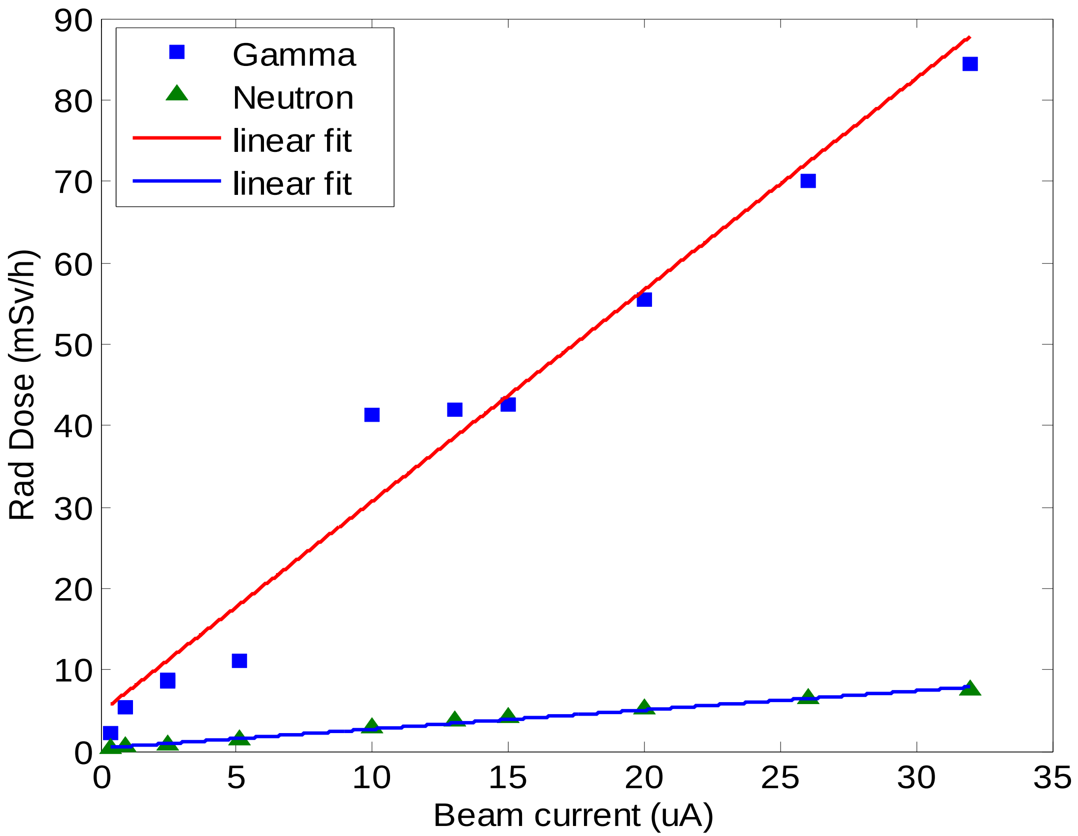


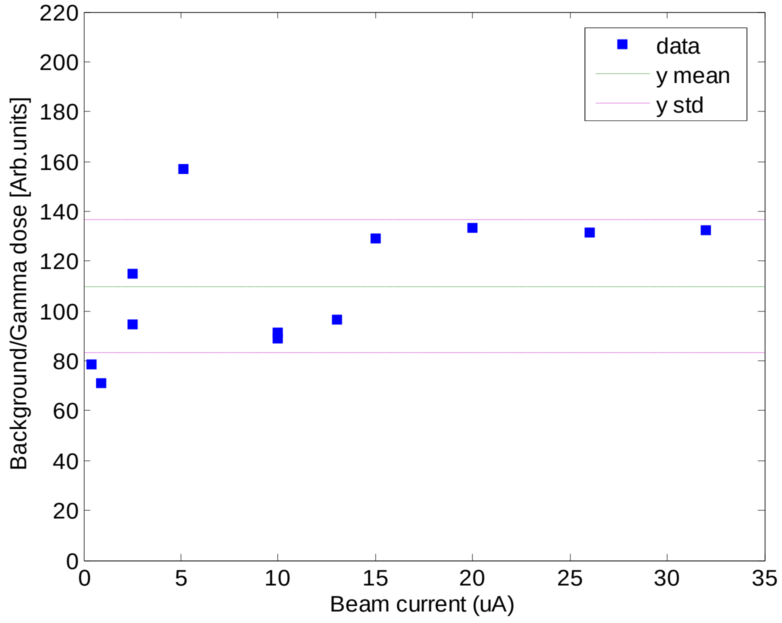
Radiation Background

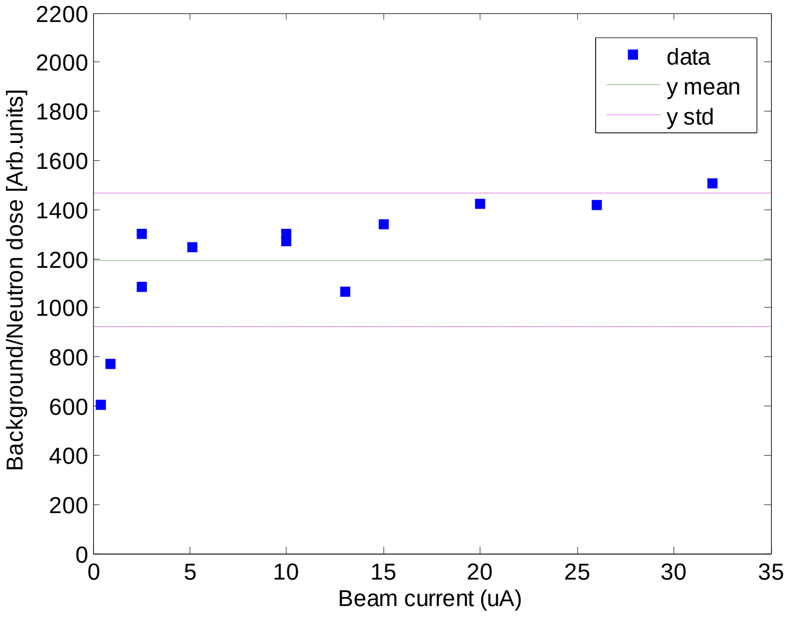
Radiation effects on detectors, two roles:

-Detector damage
(main responsible → neutrons)

-Contribution to radiation noise
(main responsible → gammas?)

Neutrons → neutrons + gammas
-High energy n → thermal n → gammas





Radiation Background

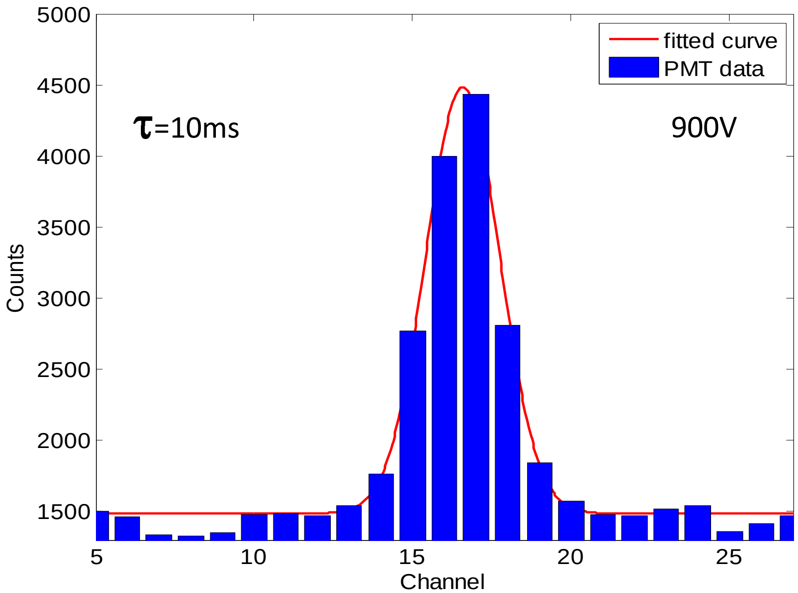
Beam profiles acquired with:

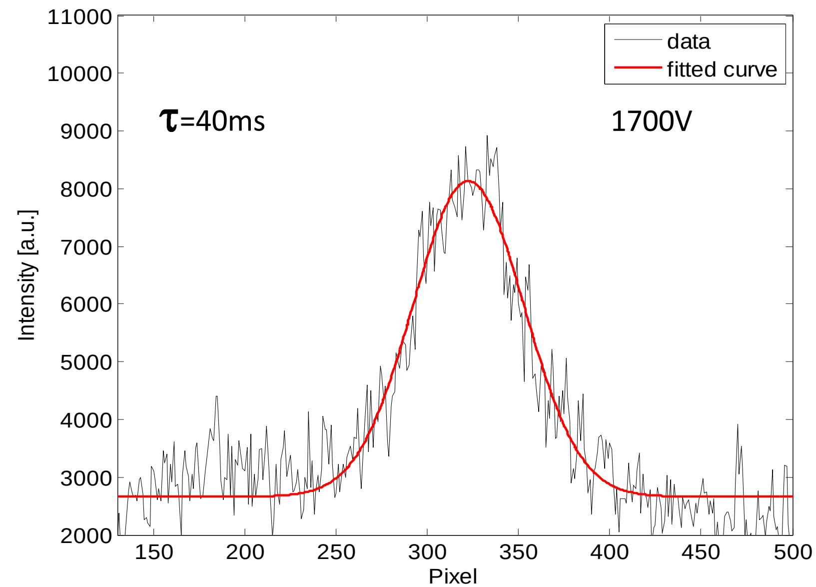
Pressure=2e-4 mbar, Beam Intensity=**40 uA**

Dose Rates:

Gammas: **84.3 mSv/h**

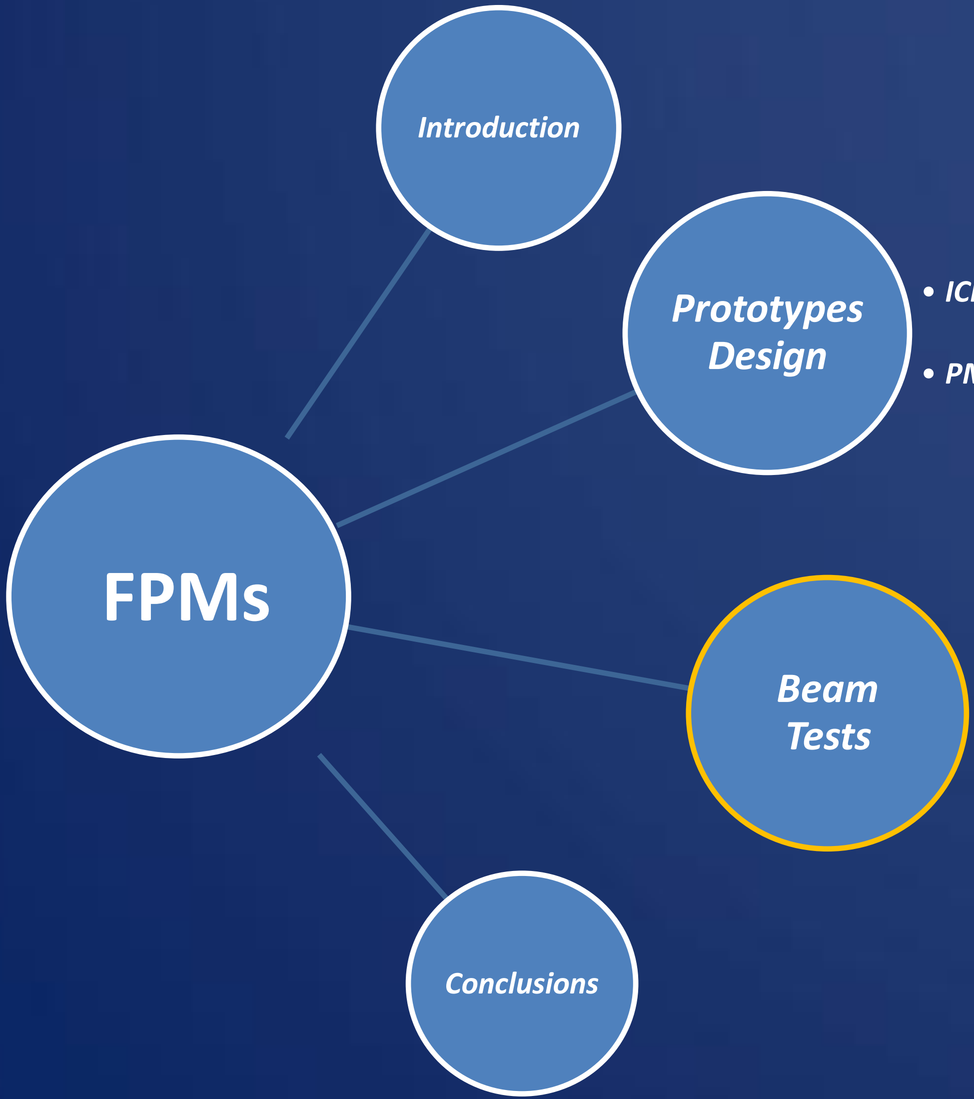
Neutrons: 8.8 mSv/h





Background reduction algorithm - ICID

Summary



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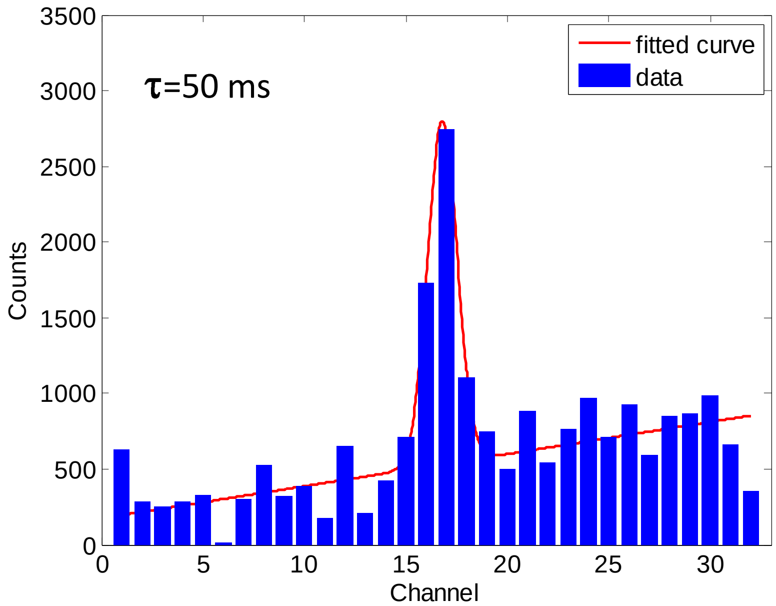
Proton Profiles

- 18 MeV proton profiles have been measured also with the FPM-PMT prototype in the cyclotron.
- Beam current of 10 uA, gas pressure of 3.2×10^{-4} mbar of N_2 gas
- 18 MeV proton beams equiv. to 36 MeV deuteron beams
- Should be close to the final IFMIF accelerator energy (40 MeV).



A factor of 3 is needed to match similar conditions for 9 MeV deuterons and 18 MeV protons (eq. 36 MeV deuterons)

(15 uA x 7e-4 mbar x 5 ms)/(10 uA x 3.2e-4 mbar x 50 ms)=1/3.

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- Two prototypes of non interceptive profilers based on residual gas fluorescence has been designed and build
- FPMs have been tested with 9 MeV deuteron and 18 MeV proton beams. Profile properties have been compared with an interceptive profiler
- Good agreement between profilers were found (no difference between profiles shapes, size or tails has been detected
- Measurements shows a good dynamic range
- Each prototype has its strong points, ICID more resolution, PMT less sensitive to radiation and little bit more efficient
- Design very flexible
- Profiler out of the beam pipe →easier maintenance, no impact on the accelerator operation, possibility of mirrors, telescopes, shielding
- Designs can accommodate to other acc. needs

Acknowledges

Authors would like to thank to

-all the people that helped us with comments, suggestions and fruitful discussions during the design phase (with special mention to D. Schneider from LANL and P. Forck's team from GSI).

-***all the CNA team*** for making possible these tests and for their kindly support during installation and measurements.

- CNA cyclotron's line responsible, *M. Carmen Jiménez (as a special recall),* because of her kindness, efforts and uncountable hours dedicated to conditioning the deuterons source and the experimental external line.

Thanks for your attention!