THE LOW ENERGY NEUTRON BEAM

A QA_QC TOOL FOR THE PARTICLE DETECTORS

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OUTLINE

1. Why we study the neutrons
2. LHC/ATLAS background
3. Neutron beams at “Demokritos” Lab
4. Neutron detection efficiency measurements
5. GEANT4 calculations & final results
6. Conclusions
7. Epilogue

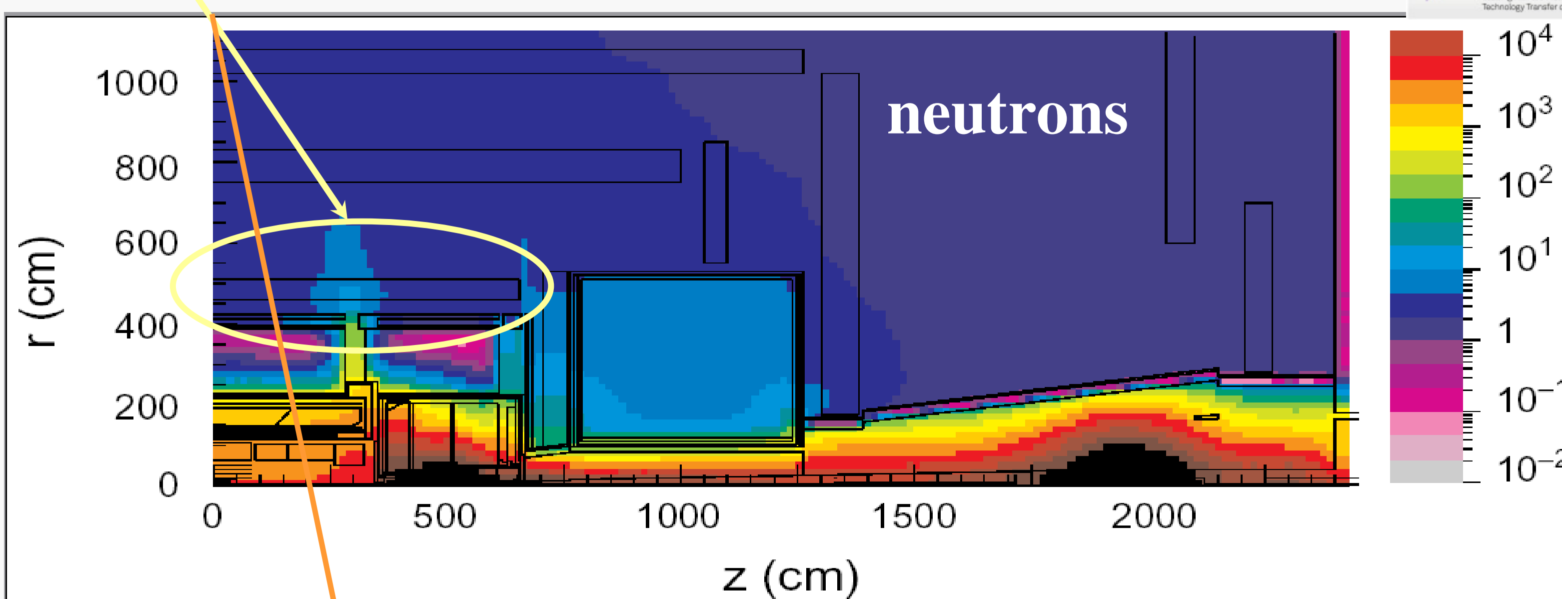
Low-Energy Neutron Beam Study

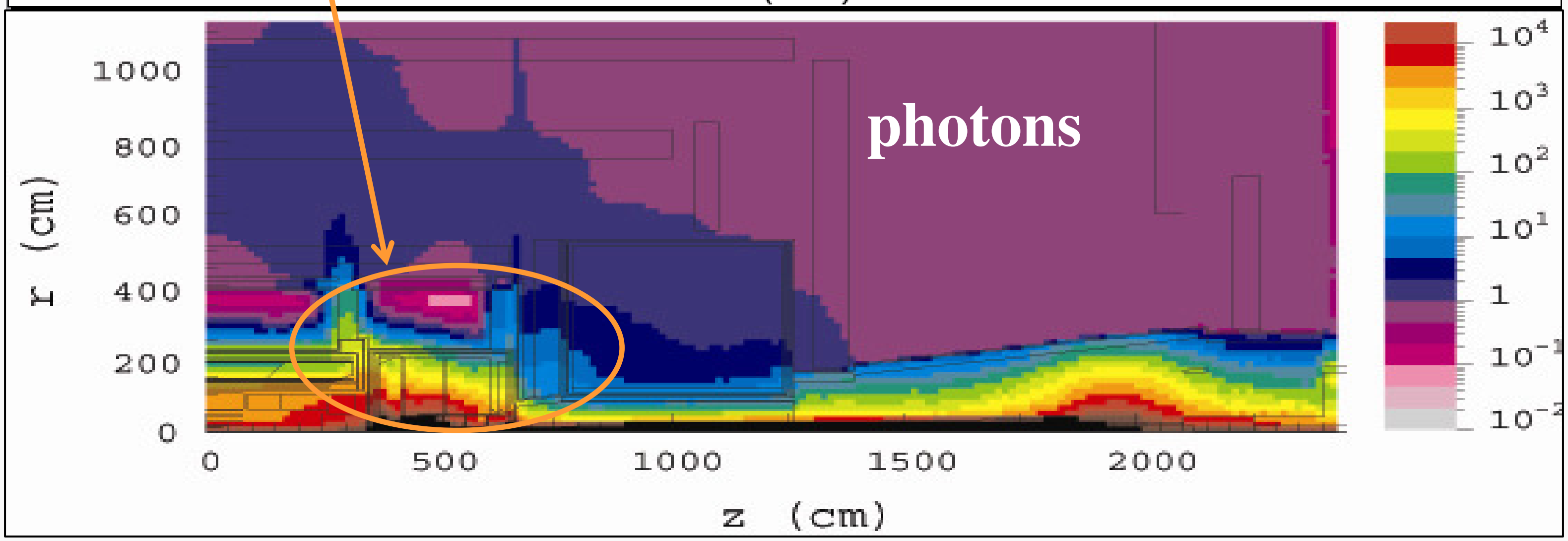
Do we need to study the neutron sensitivity of the Particle Detectors?

Low-Energy Neutron Beam Study

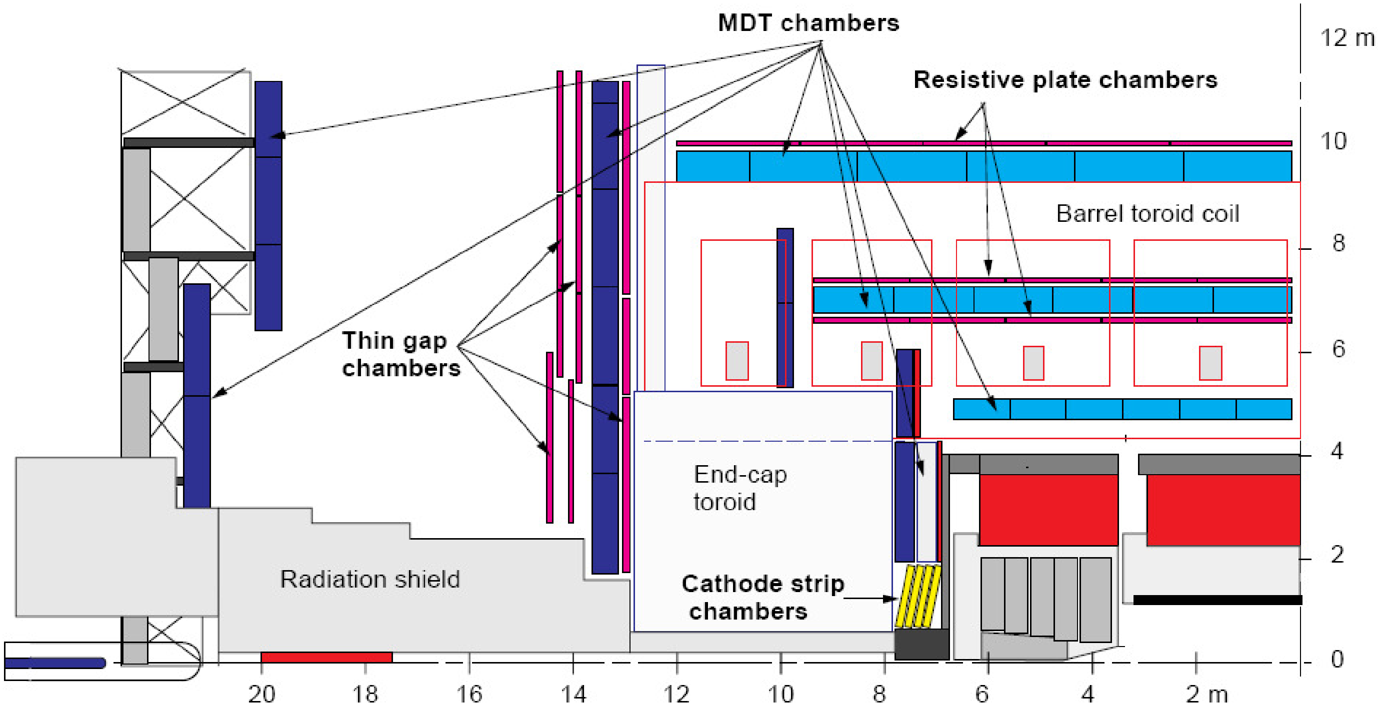
- LHC/ANY other accelerator for PP experiments produces large and comparable fluxes of photons and neutrons, i.e. in the ATLAS muon spectrometer area
- Neutron ionization charge deposition @ the Monitored Drift Tubes (MDTs) can be hundreds of times larger than the charge deposition of a single muon!
- The increased charge per unit length of anode could cause aging to the detector and to its electronics

BIS MDT



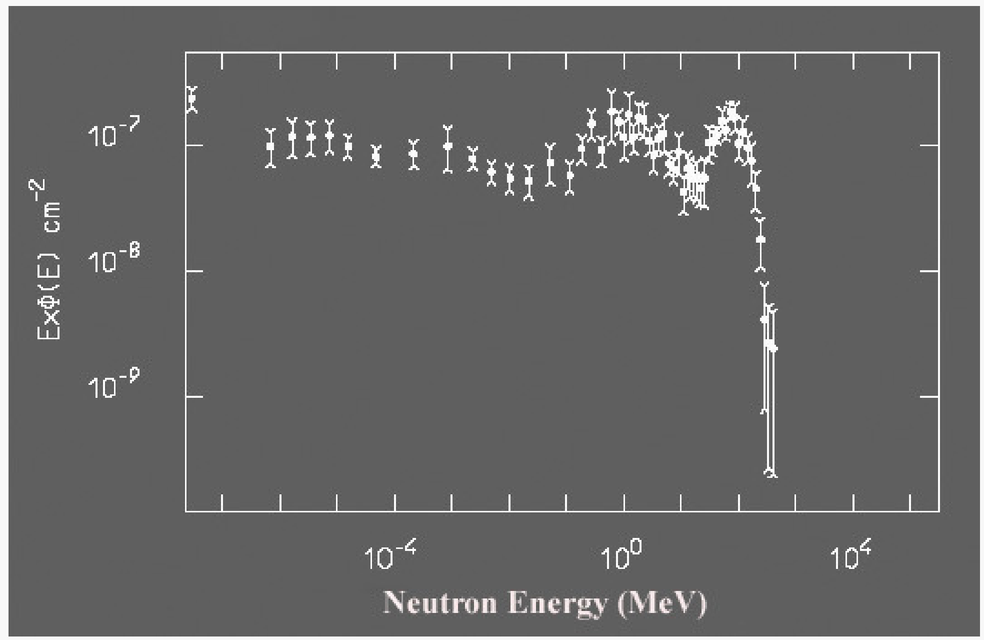


The expected neutron fluence (kHz/cm^2) in the ATLAS cavern, (ATLAS muon-TDR)



ATLAS Muon Spectrometer

The energy spectrum of the expected neutron background radiation in the ATLAS cavern (ATLAS muon TDR)



Low-Energy Neutron Beam Study

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Neutron Beams:

5.5 MV Tandem Van der Graff accelerator of NCSR "Demokritos"

- 0.3 - 6.3 MeV, via $^{7}Li(p, n)^{7}Be$
- 4.0 -12.0 MeV, via $d(d, n)^{3}He$
- 15.0 -21.0 MeV, via $t(d, n)^{4}He$

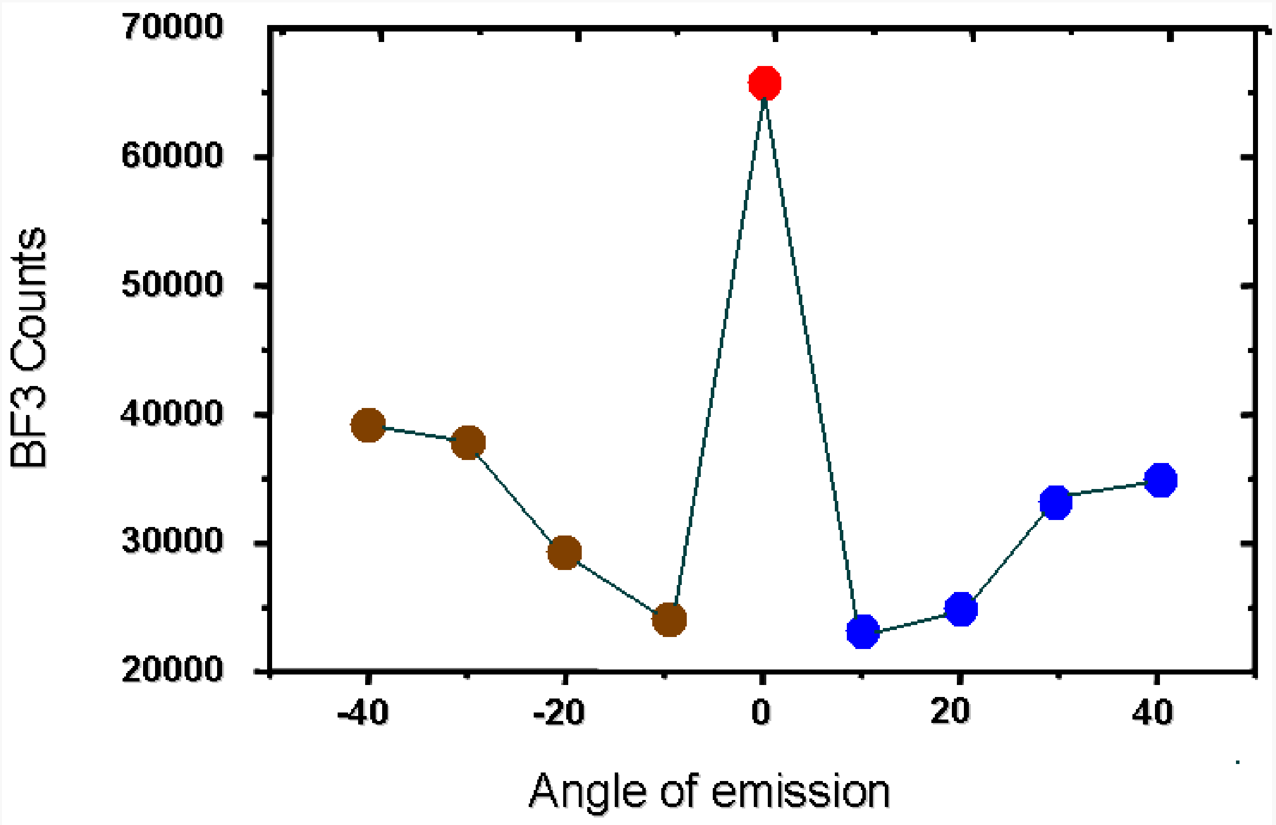
Beam Properties:

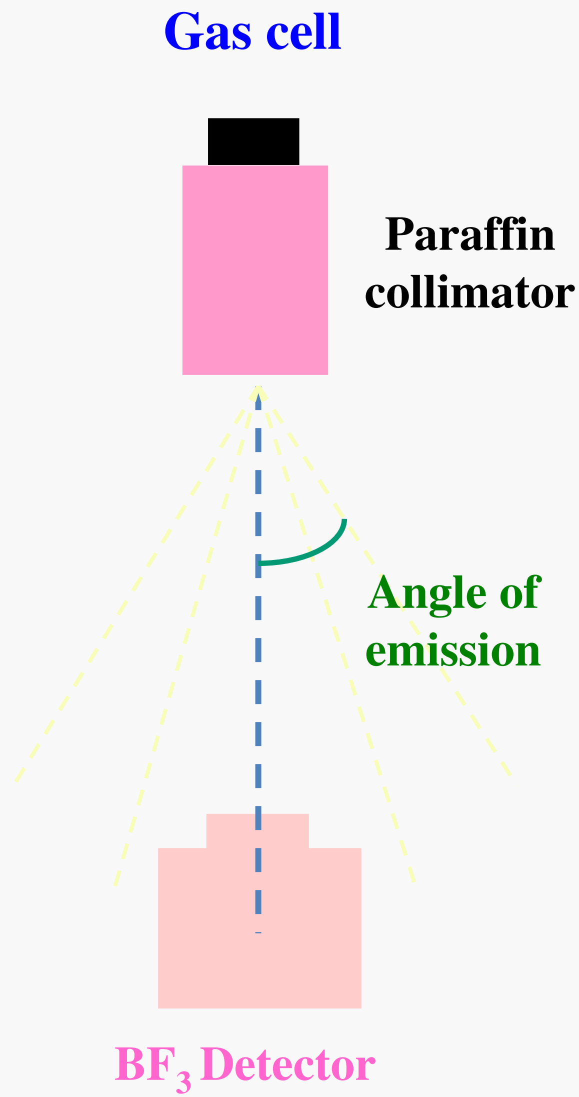
- Monochromatic source of neutrons
- Neutron fluence highly peaked in the forward direction up to 103 kHz/cm^2

Low-Energy Neutron Beam Study

The neutron flux versus the angle of emission has been studied by a BF_3 neutron detector

The measured neutron flux vs the angle of emission





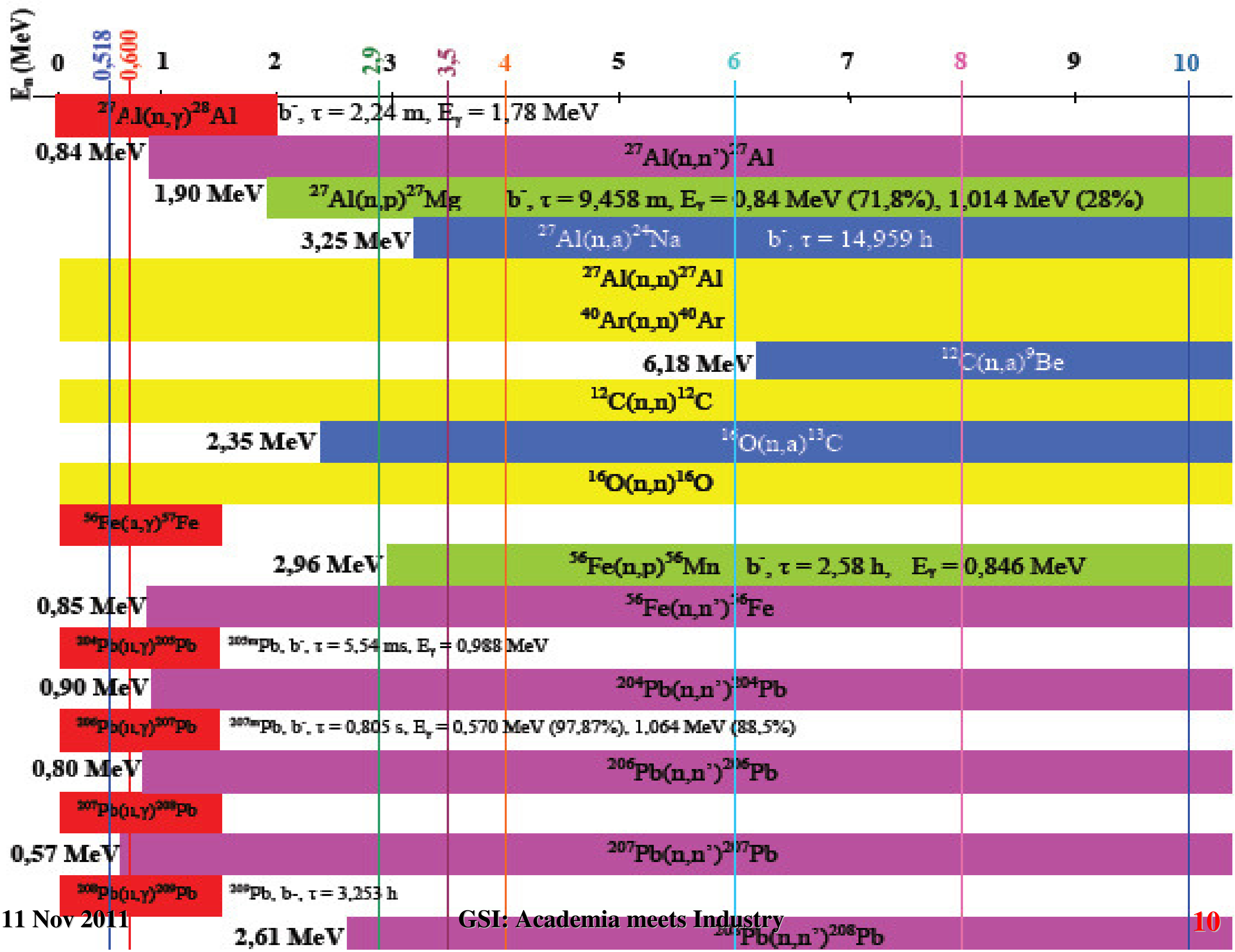
Low-Energy Neutron Beam Study

The materials of the Monitored Drift Tube - MDT

Aluminum walls

Ar:CO_2 (93:7) Gas mixture

W:Re (97:3) Anode Wire (HT:3080V)



E_n (MeV)
0
0,518
0,600
1
2
2,9
3
3,5
4
5
6
7
8
9
10
$^{27}Al(n,\gamma)^{28}Al$
b^-, τ = 2,24 m, E_γ = 1,78 MeV
0,84 MeV
$^{27}Al(n,n')^{27}Al$
1,90 MeV
$^{27}Al(n,p)^{27}Mg$
b^-, τ = 9,458 m, E_γ = 0,84 MeV (71,8%), 1,014 MeV (28%)
3,25 MeV
$^{27}Al(n,a)^{24}Na$
b^-, τ = 14,959 h
$^{27}Al(n,n)^{27}Al$
$^{40}Ar(n,n)^{40}Ar$
6,18 MeV
$^{12}C(n,a)^{9}Be$
$^{12}C(n,n)^{12}C$
2,35 MeV
$^{16}O(n,a)^{13}C$
$^{16}O(n,n)^{16}O$
$^{56}Fe(n,\gamma)^{57}Fe$
2,96 MeV
$^{56}Fe(n,p)^{56}Mn$
b^-, τ = 2,58 h, E_γ = 0,846 MeV
0,85 MeV
$^{56}Fe(n,n')^{56}Fe$
$^{204}Pb(n,\gamma)^{205}Pb$
^{205m}Pb, b^-, τ = 5,54 ms, E_γ = 0,988 MeV
0,90 MeV
$^{204}Pb(n,n')^{204}Pb$
$^{206}Pb(n,\gamma)^{207}Pb$
^{207m}Pb, b^-, τ = 0,805 s, E_γ = 0,570 MeV (97,87%), 1,064 MeV (88,5%)
0,80 MeV
$^{206}Pb(n,n')^{206}Pb$
$^{207}Pb(n,\gamma)^{208}Pb$
0,57 MeV
$^{207}Pb(n,n')^{207}Pb$
$^{208}Pb(n,\gamma)^{209}Pb$
^{209}Pb, b-, τ = 3,253 h
2,61 MeV
$^{208}Pb(n,n')^{208}Pb$

Low-Energy Neutron Beam Study

- **The background radiation in the experimental area and measurements for its limitation**

- Neutrons coming from neutron elastic and inelastic scatterings with the surrounding materials

- Prompt photons coming from neutron inelastic scatterings with the surrounding materials in the hall

a BF_3 counter, sensitive to neutrons, was used to monitor the neutron flux

Low-Energy Neutron Beam Study

In order to prevent scattered neutrons from reaching the BF_3 detector, three conditions have been studied :

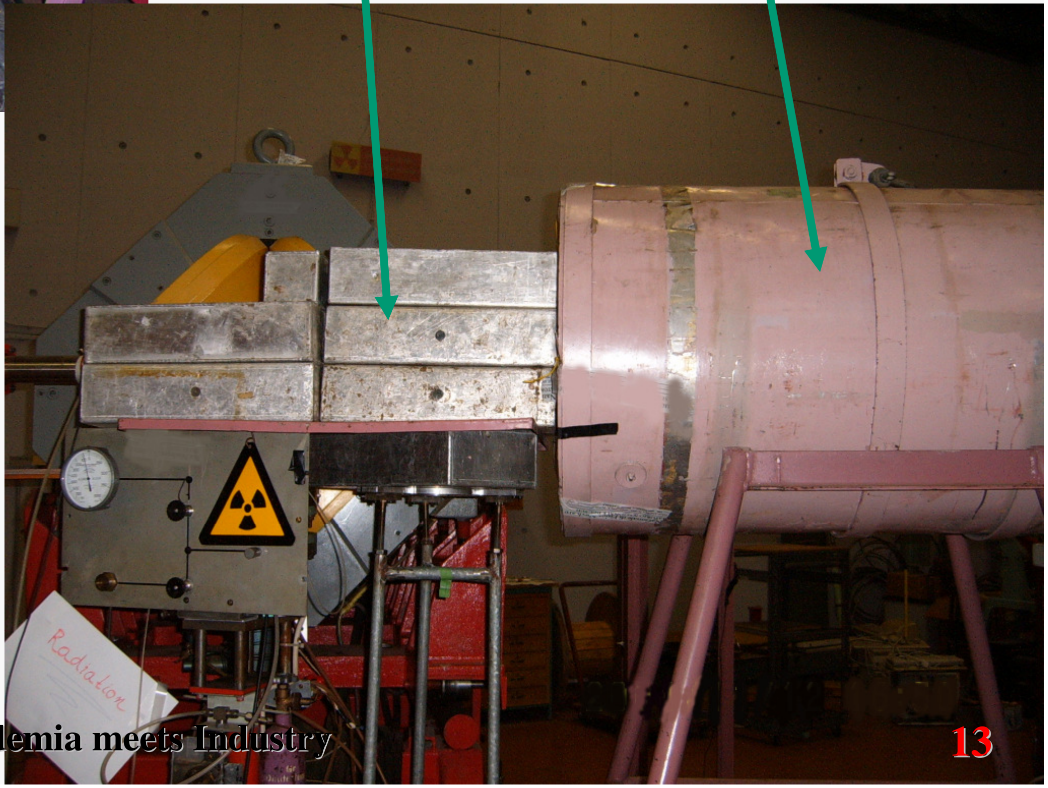
1. Neutron beam hitting directly the BF_3 detector
2. A paraffin collimator was placed in frond of the Gas Cell
3. Paraffin blocks were placed on the floor

A combination of the paraffin collimator and the paraffin blocks on the floor minimizes the scattered neutrons going to the BF3 detector

Gas Cell built in paraffin blocks

Paraffin Collimator

Paraffin Blocks on the floor



Low-Energy Neutron Beam Study

Prompt photons

Study of two conditions:

- collimator's exit open
- collimator's exit closed

	collimator's exit open	collimator's exit closed
BF_3 counts	610537	139821
MDT counts	3557123	3103159

→ collimator's exit closed

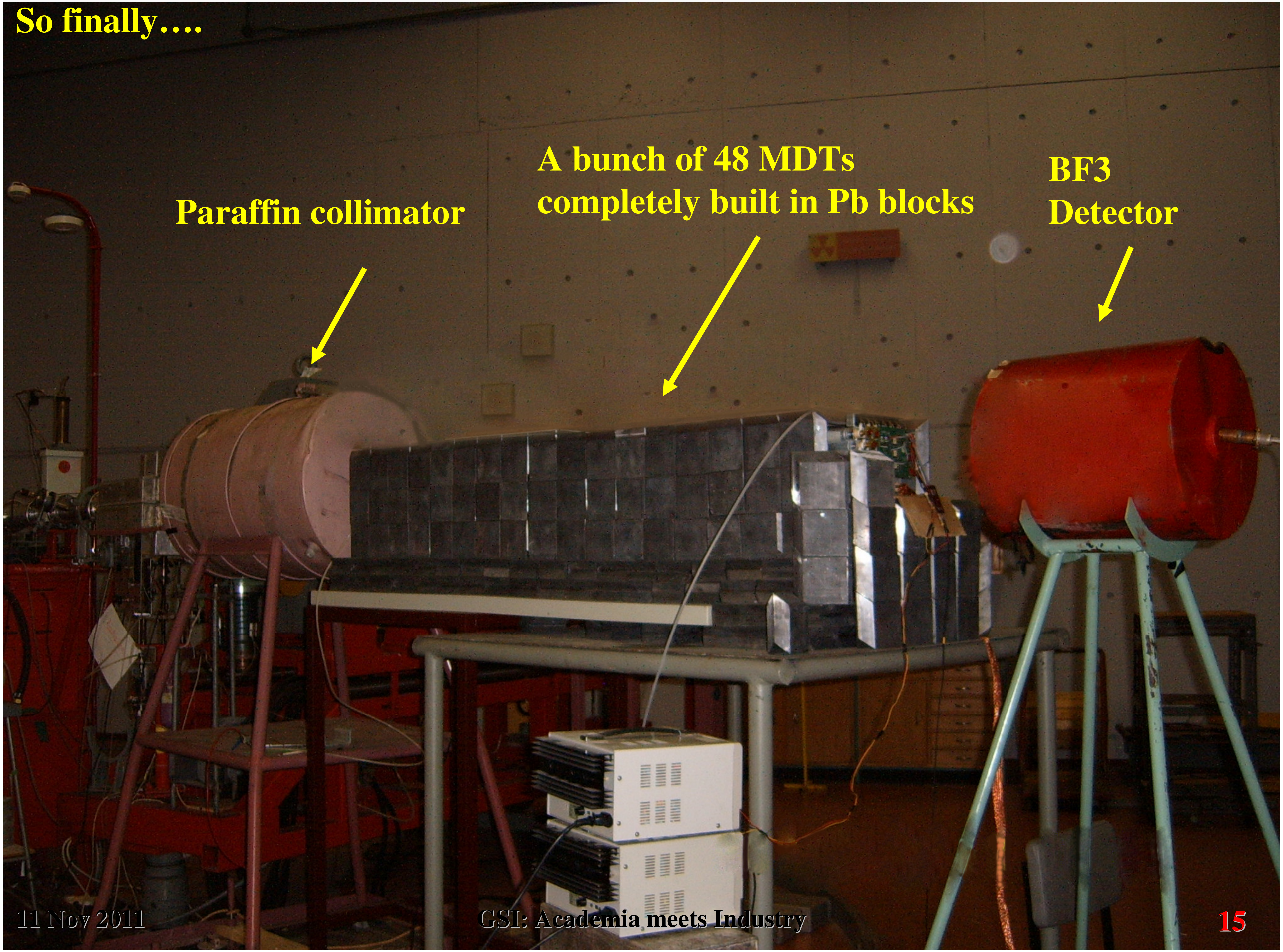
Limitation of emitted neutrons to 22,90%

Limitation of MDT counts only to 87,2%

Many MDT counts are due to

Prompt Photons

So finally….


Paraffin collimator
A bunch of 48 MDTs
completely built in Pb blocks
BF3
Detector

Low-Energy Neutron Beam Study

Neutron beam studies

with the reaction:

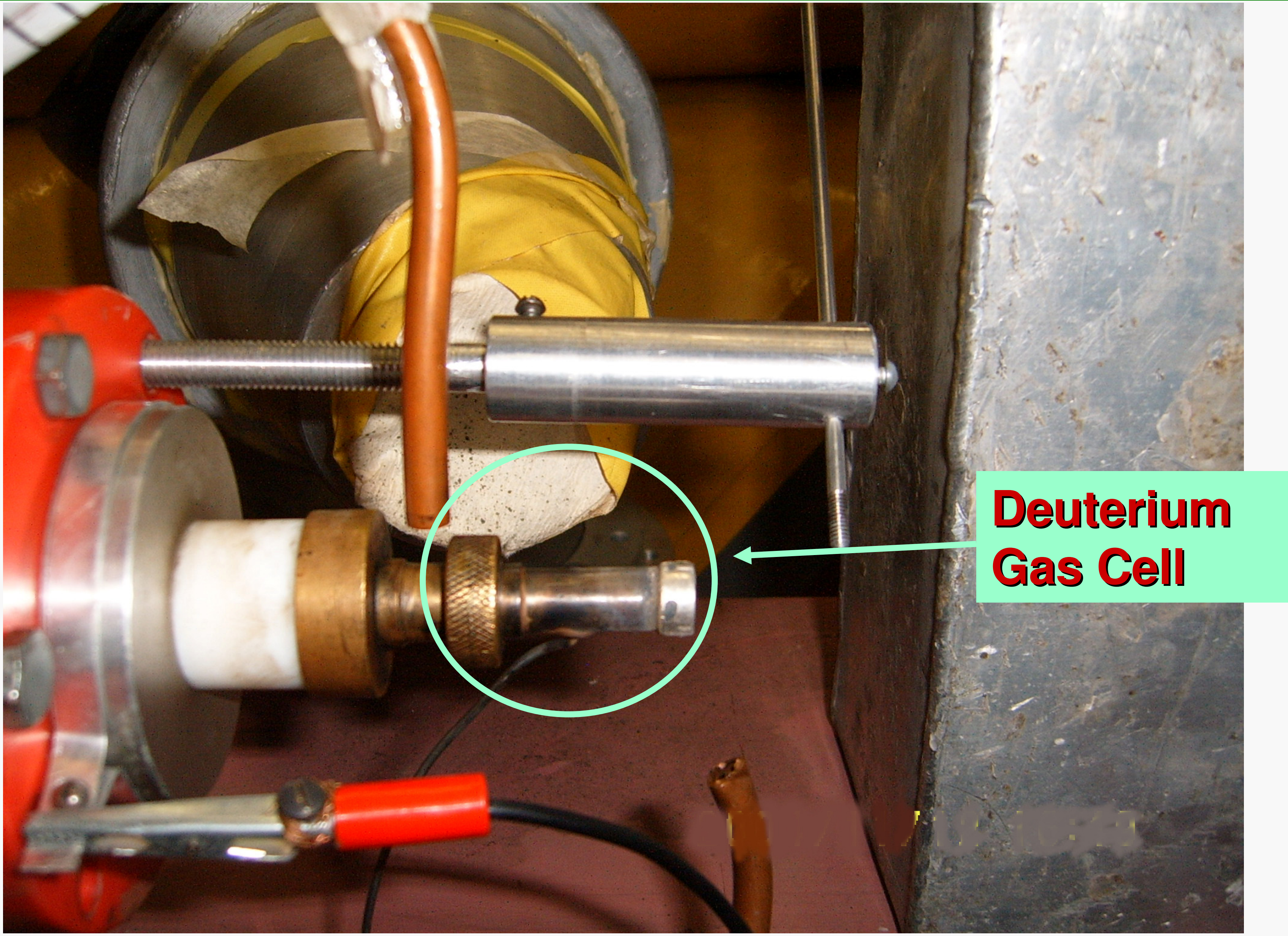
$$d + d \rightarrow {}^{3}He + n$$

4.0 -12.0 MeV

The Experimental Setup

- A deuteron beam hits a stainless steel gas cell target of 3.7 cm long, filled with deuterium gas under a few bars pressure
- The entrance window is a 5 μm Mo foil and the beam stops on a 1 mm Pt foil
- The deuterium gas pressure can be monitored and refilled electronically when the cell pressure falls below a preset level

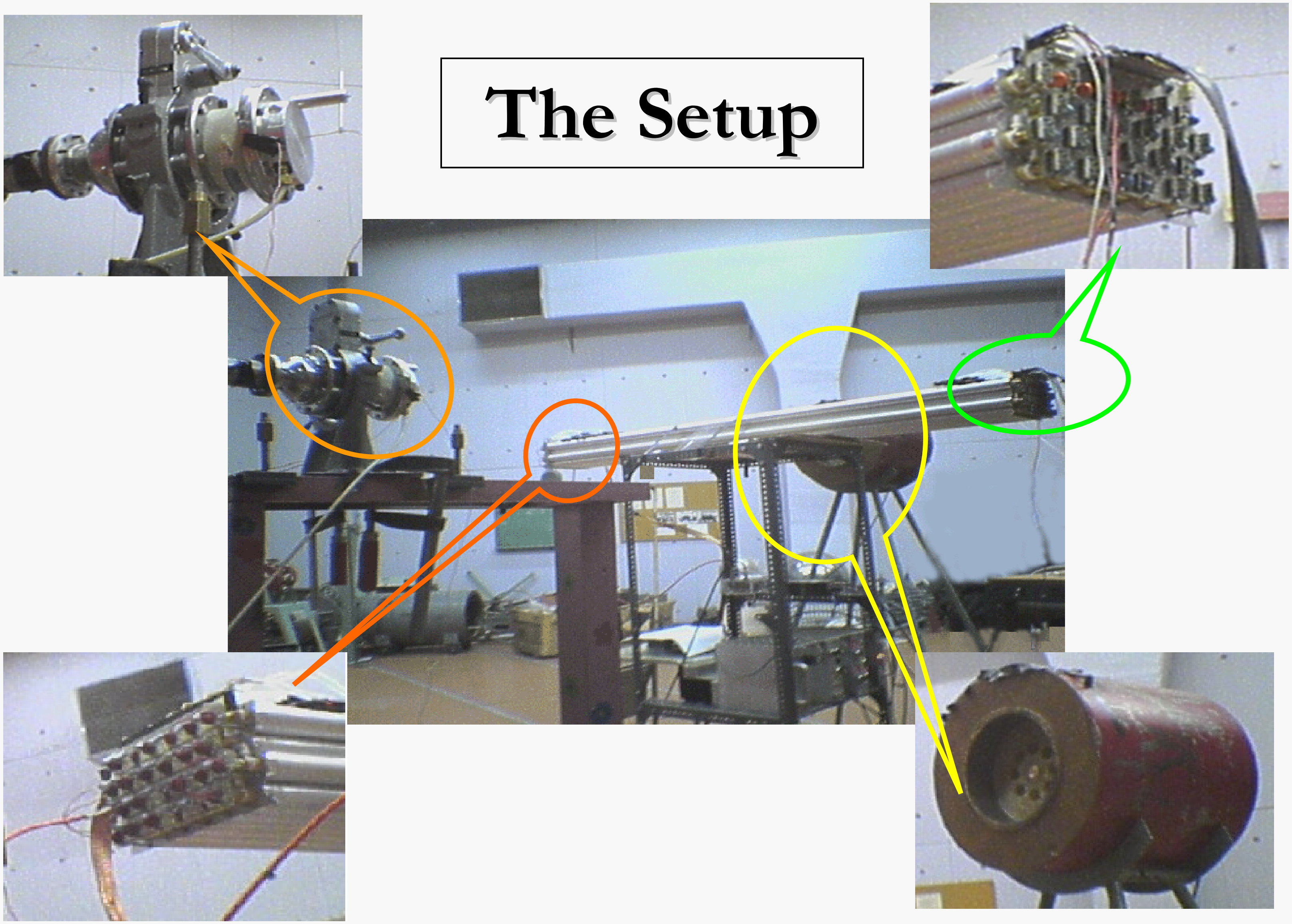
Low-Energy Neutron Beam Study



Tritium Target

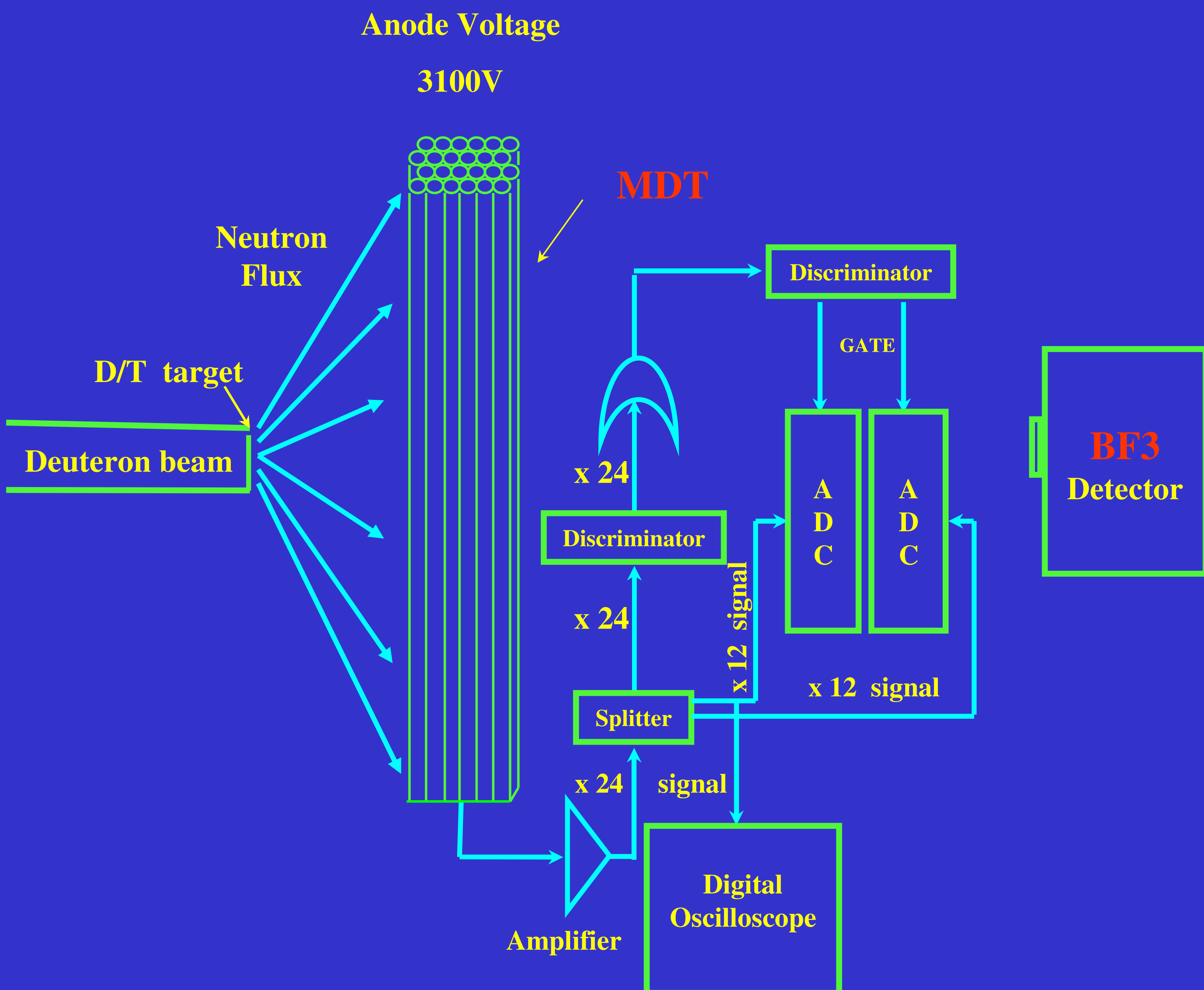
Read Out card

The Setup



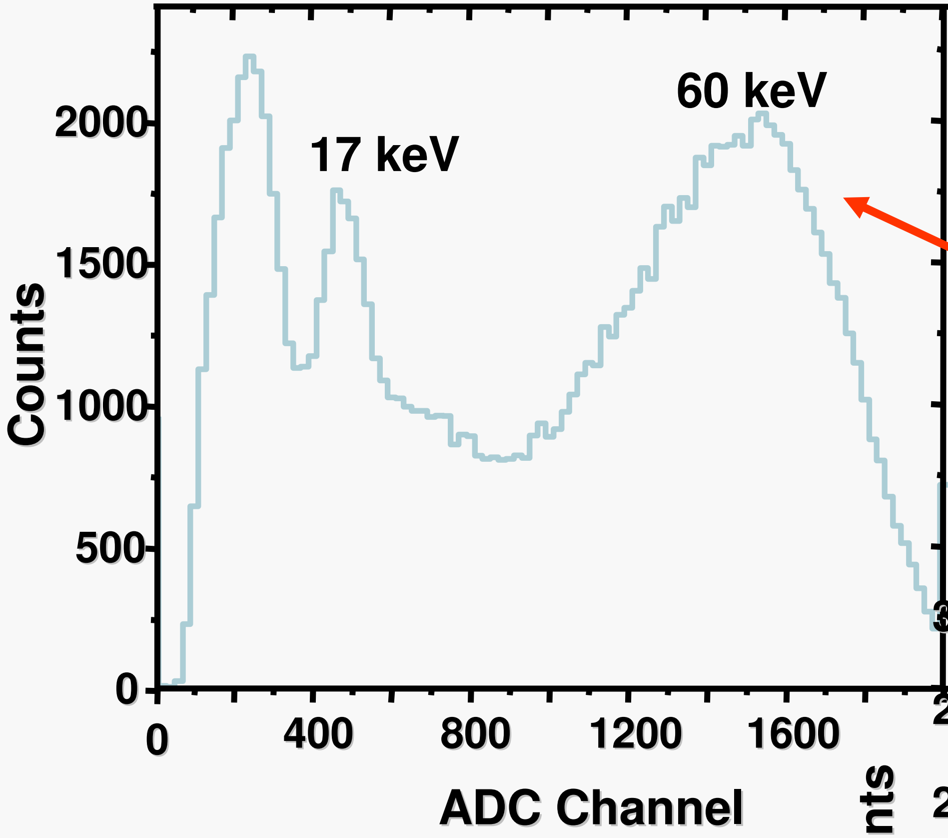
Anode Voltage card

BF_3 Detector

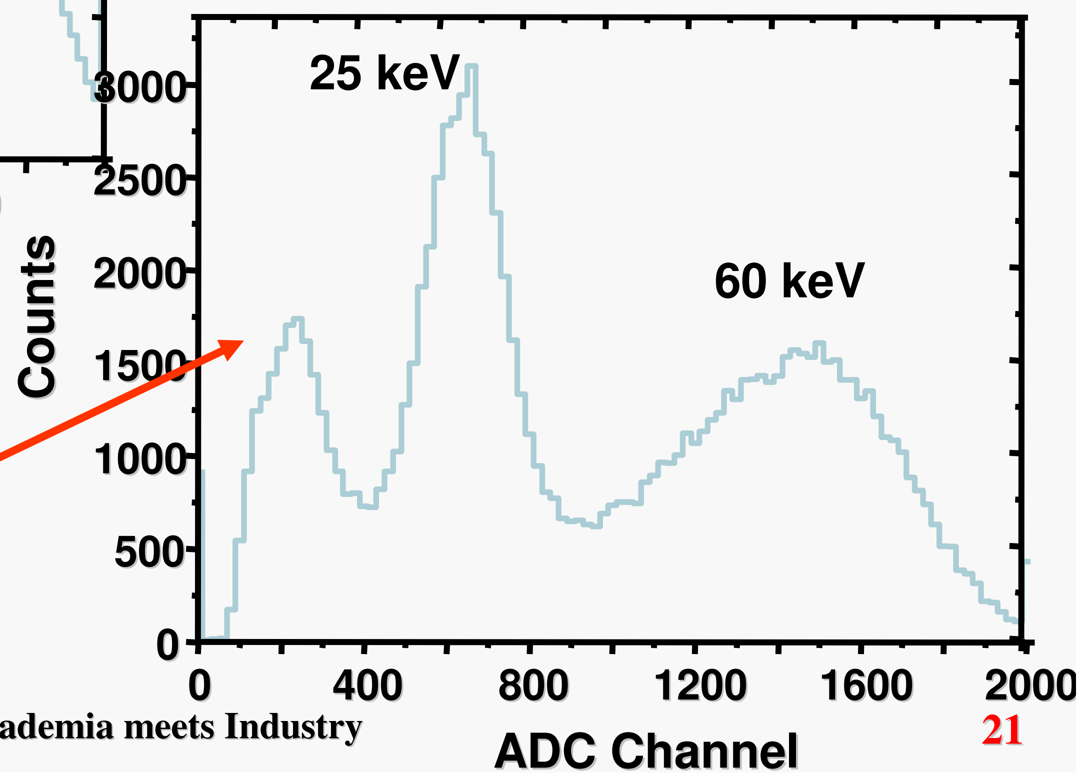

Anode Voltage
3100V
MDT
Neutron Flux
D/T target
Deuteron beam
Discriminator
GATE
A D C
A D C
BF3 Detector
x 24
Discriminator
x 24
x 12 signal
x 12 signal
Splitter
x 24
signal
Amplifier
Digital Oscilloscope

Low-Energy Neutron Beam Study

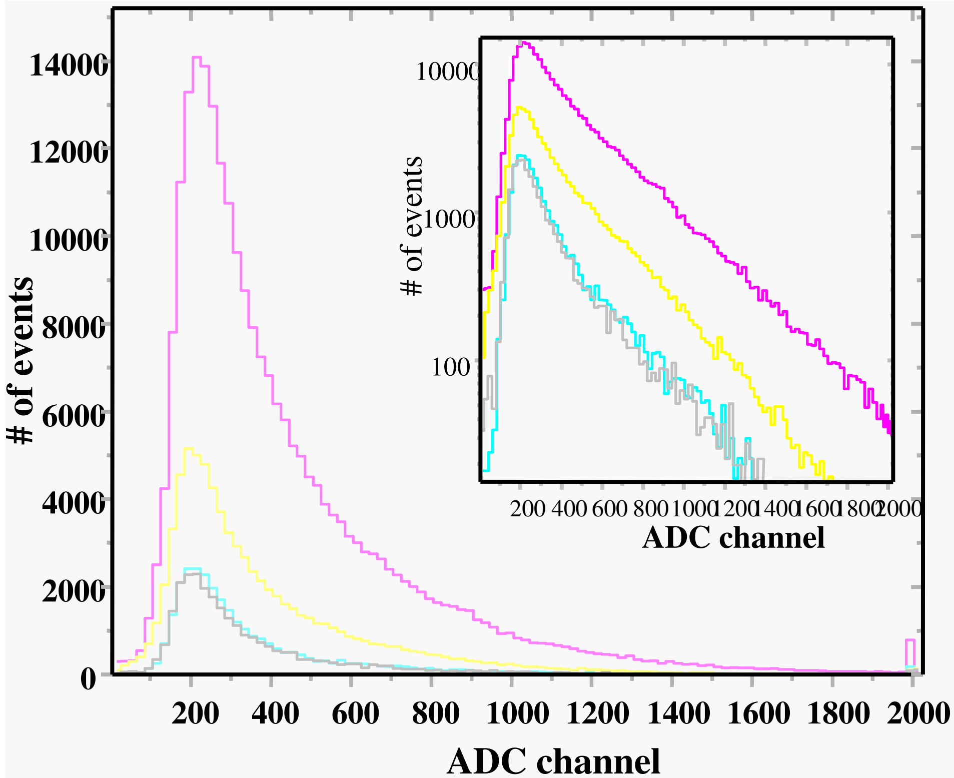
MDT CALIBRATION



ADC calibration spectrum from a ^{241}Am + Mo foil source



ADC calibration spectrum from a ^{241}Am + Sn foil source



E_n = 3,5 MeV

Neutron beam

Activation

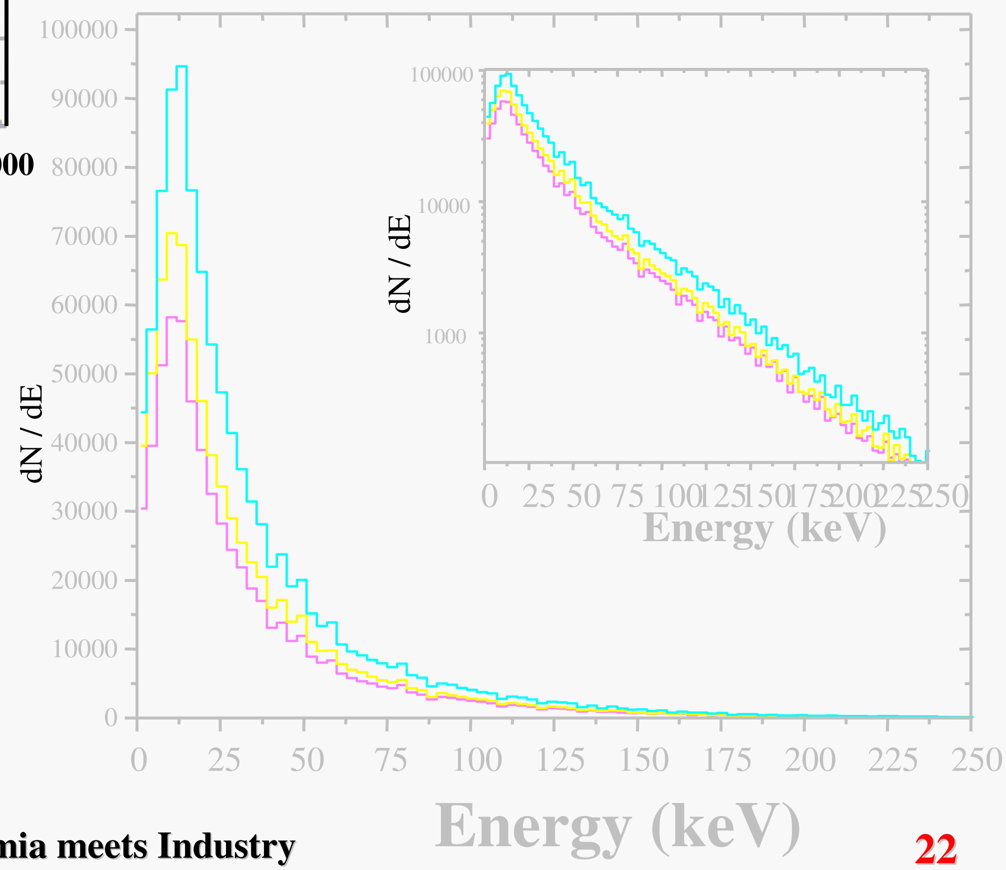
Neutron Beam, Pb

Activation, Pb

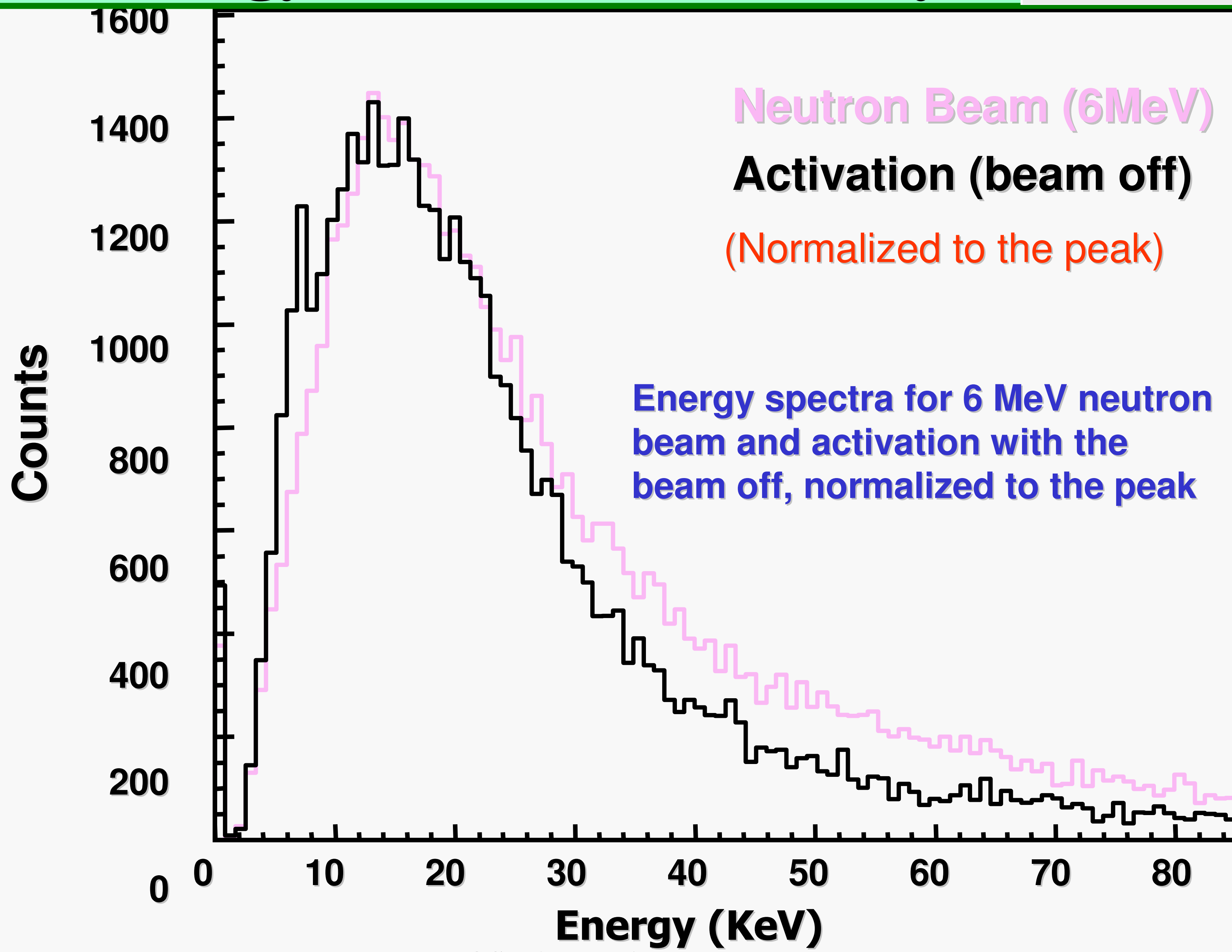
E_n = 6 MeV

E_n = 8 MeV

E_n = 10 MeV



Low-Energy Neutron Beam Study



Low-Energy Neutron Beam Study

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Special Care: The Neutron flux measurement and normalisation

Method: An **Fe** foil irradiated in front of the neutron beam. It's activation is measured offline. The neutron flux is then calculated by :

$$\Phi = \frac{N' e^{\lambda t_w}}{\left(1 - e^{-\lambda t_{act}}\right) \sigma \, eff \, I_\gamma \, F_B \, N_0} \quad \left(cm^{-2}\right)$$

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Where,

N’ : counts measured offline (dead time corrected)

t_w : time between the end of the irradiation and the beginning of the offline measurement

λ : decay constant of Fe

t_{act} : time of the activation measurement

σ : cross section of the 56Fe(n,p)56Mn reaction

eff : the efficiency of the detector for the offline measurement

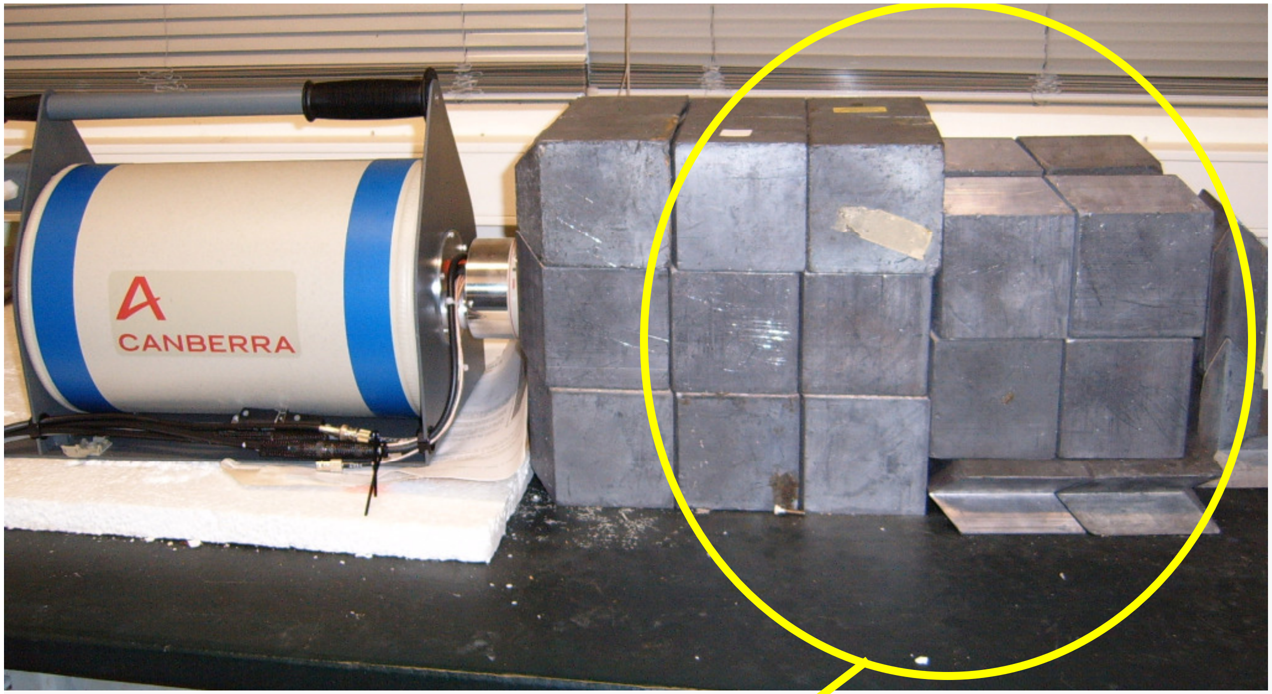
F_B : correction factor due to the activation of the Fe foil during the irradiation

I_γ : branching ratio of the $^{56}Fe(n,p)^{56}Mn$ reaction

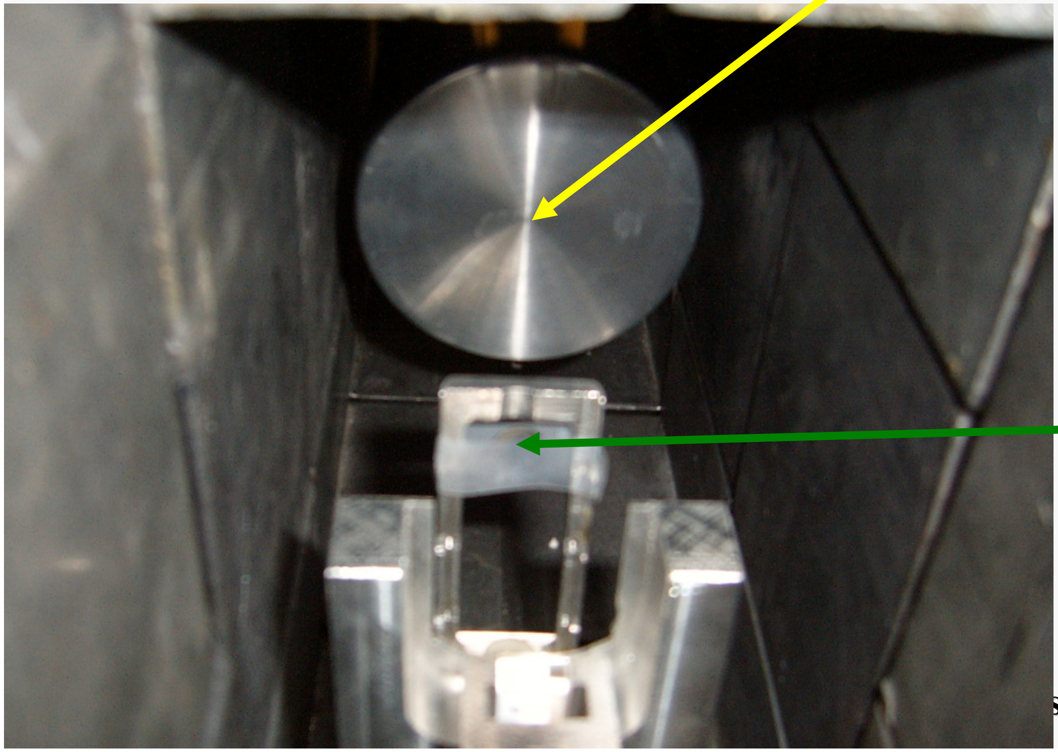
t_{irr} : the irradiation time of the Fe foil

N_0 : initial number of nuclei in the Fe foil

$$F_B = \frac{1 - e^{-\lambda t_{irr}}}{\lambda t_{irr}}$$



The Germanium detector during the off-line measurement of the Fe foil activation for normalizing the runs and measuring the accumulated neutron beam



The activated Fe foil

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The measured neutron fluxes*, corresponding to the MDT's solid angle, are :

Neutron Energy (MeV)	6	8	10
Neutron Flux Φ (neutrons/cm^2) X 10^8	(0.75 ± 5.22)	(2.18 ± 1.06)	(3.42 ± 1.67)
Neutron Fluence F (neutrons/cm^{2}s) X 10^4	(0.50 ± 3.50)	(1.45 ± 1.01)	(2.29 ± 1.53)

*Preliminary results

MDT efficiency to 6, 8 and 10 MeV neutrons

Neutron Energy (MeV)	6	8	10
F_n (neutrons/cm^2 s) x10^4	(0.50 ± 3.50)	(1.45 ± 1.01)	(2.29 ± 1.53)
R_{MDT} (neutrons/cm^2 s)	97.09 ± 0.35	224.88 ± 0.06	261.18 ± 0.09
$\varepsilon = R_{MDT}/F_n$ x10^{-2}	(1.94 ± 1.36)	(1.54 ± 1.07)	(1.14 ± 0.76)

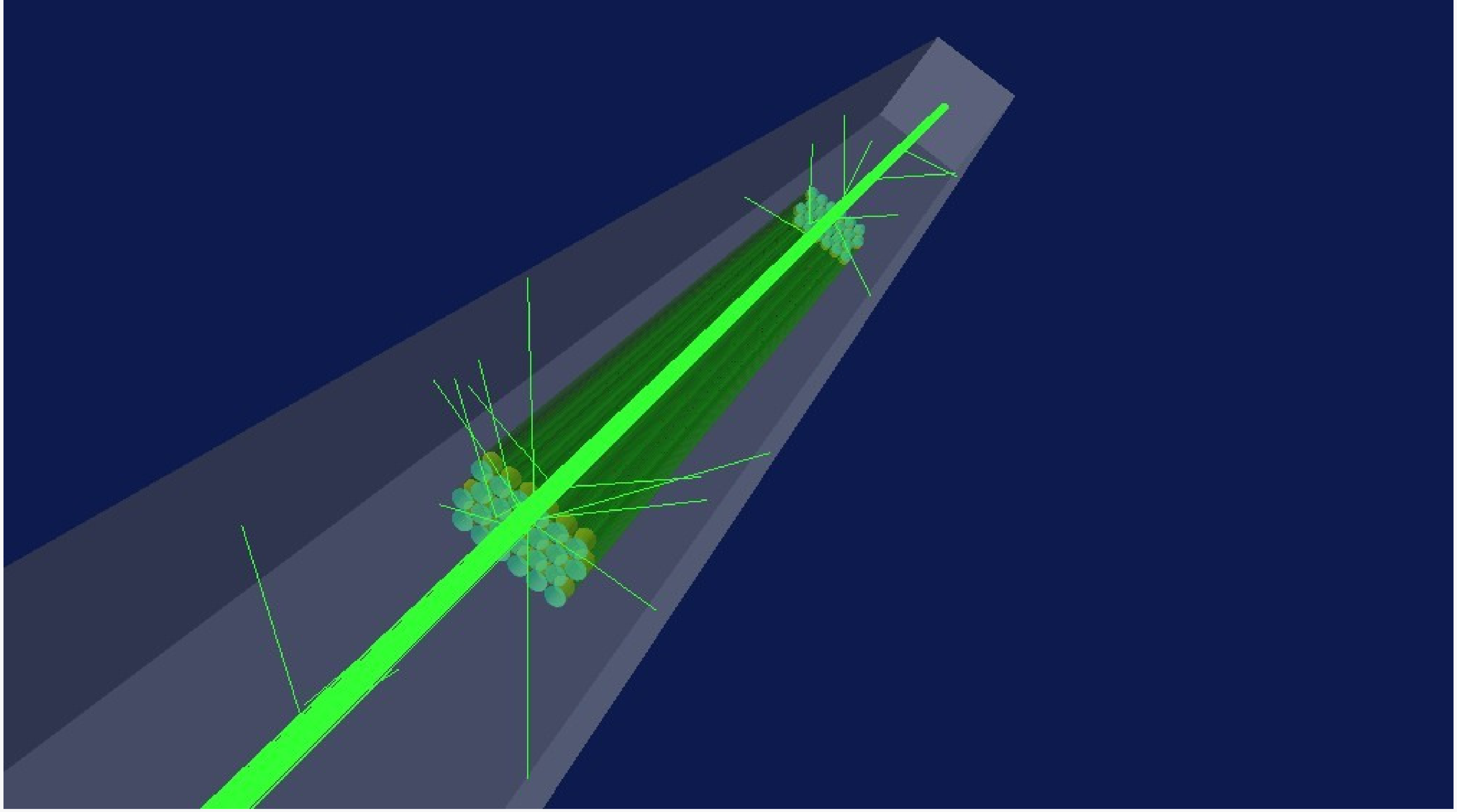
Development of a simulation model

Low-Energy Neutron Beam Study

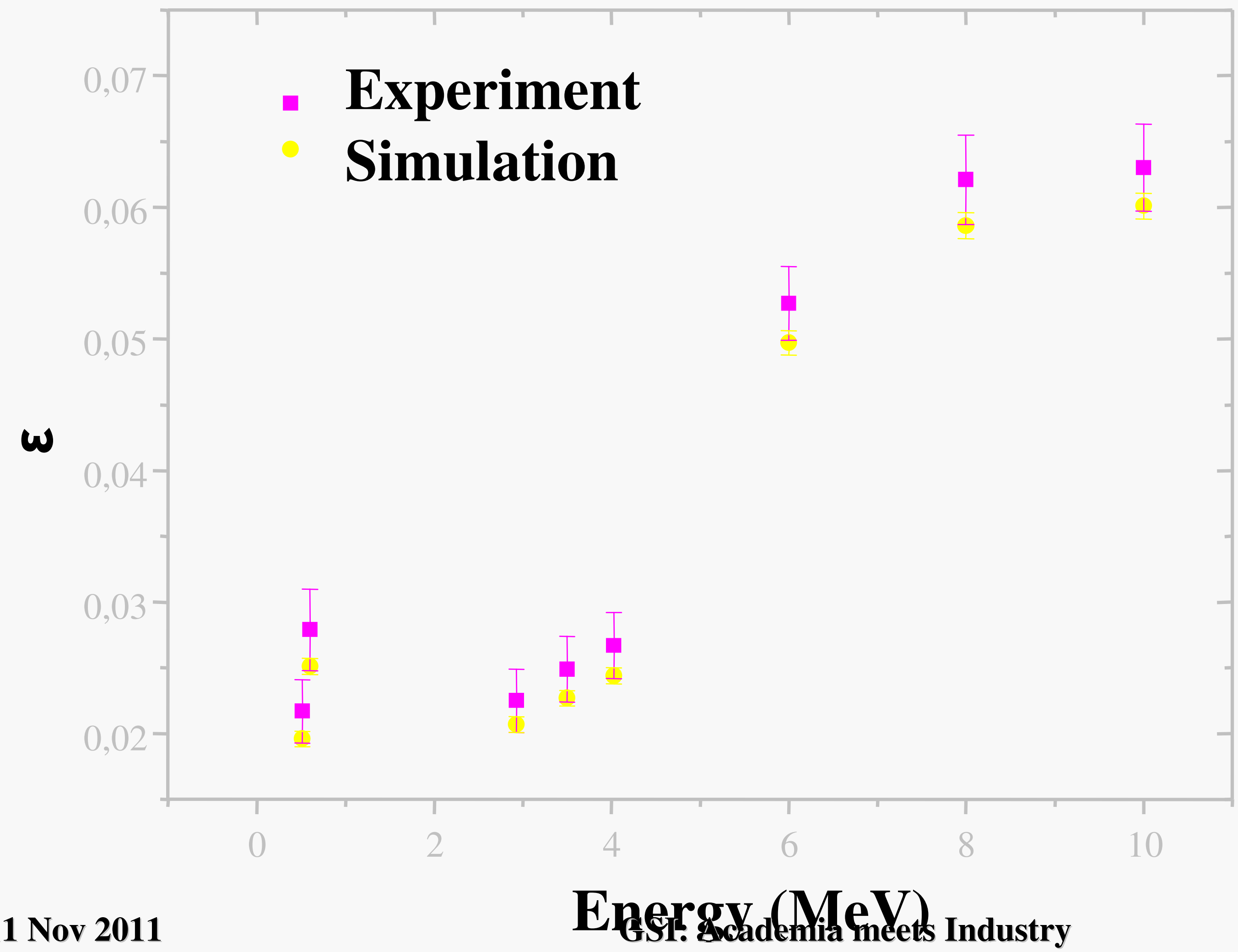
- Use of the GEANT-4 simulation toolkit
- Good description of the geometry
- Good description of neutron physics

Low-Energy Neutron Beam Study

The geometry used for the simulation model and the neutron beam hitting the MDTs

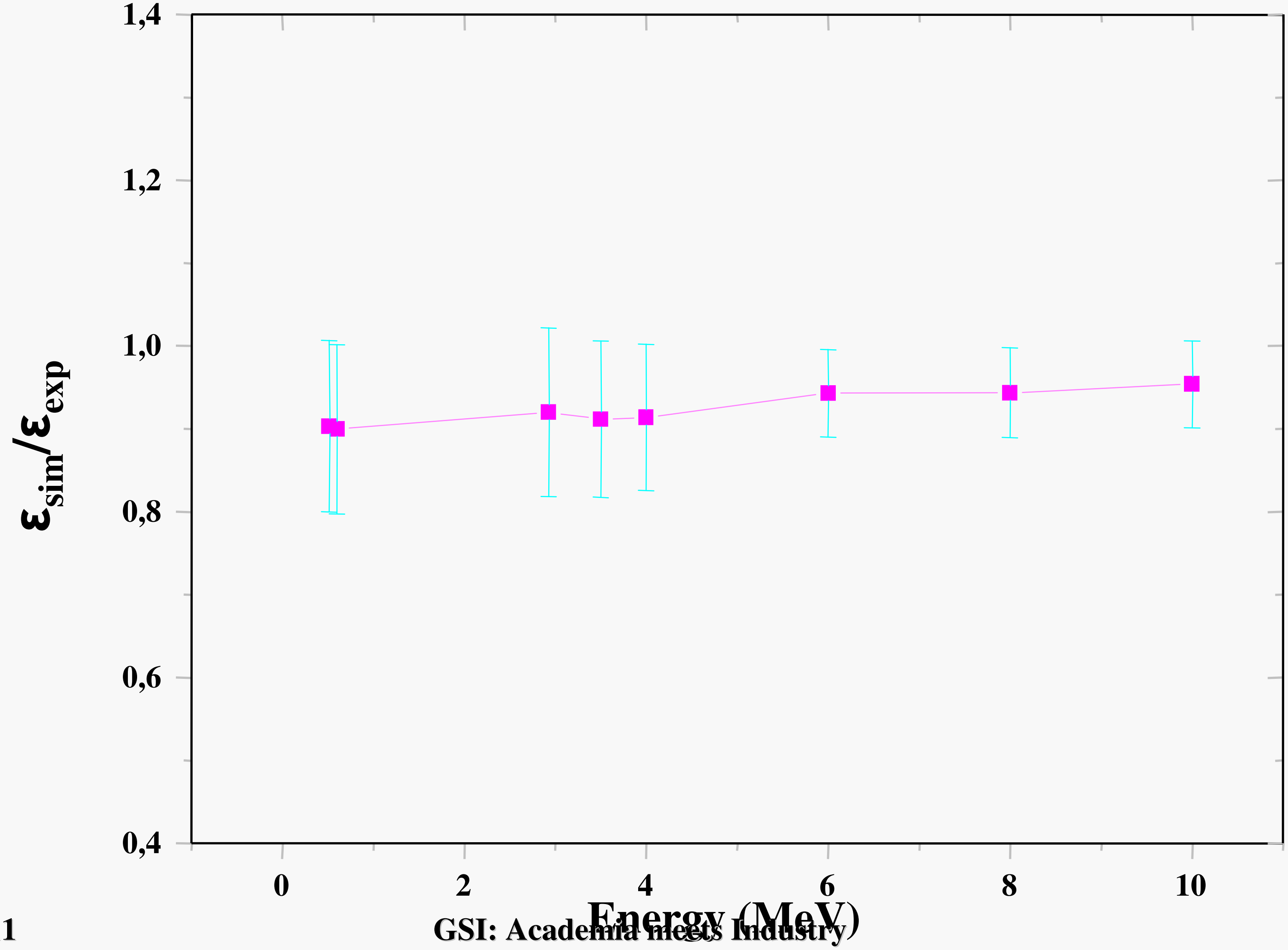


The experimental and the simulated results for the MDT efficiency response to 0.518 – 10 MeV neutrons



Relatively good agreement between the experiment and the simulation

The ratio of the simulated over the experimental MDT detection efficiency response to 0.5 - 10 MeV neutrons



Conclusions

➢ We have studied the response of an array of the ATLAS muon detectors exposed to neutron beams of energies (0.52 – 10.00) MeV:

- ✓ Monitored Drift Tubes (MDT)
- ✓ Cathode Strip Chambers (CSC)
- ✓ Thin Gap Chambers (TGC) (ATLAS-upgrade)
- ✓ Micro-Megas (ATLAS-upgrade)

➢ We have developed a simulation model of the experiment, using the Geant4 toolkit

New simulations under preparation with MCNP, etc.

1.Study of a micro-megas chamber in a neutron beam, **2010 *JINST* 5 (2005)**
2.Determination of the ATLAS MDT chambers response to 0.5–10 MeV neutrons and development of a simulation model, **NIM A575, 402 (2007)**

Conclusions

- We are participating to the ATLAS Cavern background studies with experimental and simulation results, under the Super-LHC beams energy and luminosity conditions

- The Athens neutron beam facility and developed methodology can be provided for ANY particle detector QA_QC test or any other high-tech material tests

Epilogue

" … 'Ων έστιν γάρ ημίν τοίσί τε των φυσίων τοίσί τε των τεχνέων οργάνοις επικρατέειν, τουτέων εστίν ημίν δημιουργοίς είναι, άλλων δέ ούκ έστιν. "

Ιπποκράτης 460-370 π.Χ.

"… there, we can prevail with the help of the physical or the scientific instruments; there we, only, have the possibility to become creators. "

Hippocrates 460-370 BC

Hippocrates *was born around* ***460 BC*** *on the island of* ***Kos***, ***Greec****e.*
He became known as the ***founder of medicine*** *and was regarded as the* ***greatest physician*** *of his time.*
He based his medical practice on ***observations*** *and on the* ***study*** *of the* ***human body****.*
He ***rejected*** *the views of his time that considered* ***illness*** *to be caused by superstitions and by possession of evil spirits and disfavor of the gods.*