

NARROW BAND NEUTRON SOURCES PRODUCED BY ULTRA INTENSE LASER



2013

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SAPIENZA
UNIVERSITÀ DI ROMA



OUTLINE

Introduction to the laser driven neutron sources

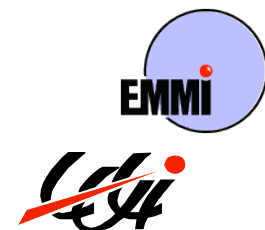
Neutron features and applications

How we want generate a narrow energy band neutron source

First experiment carry out at the ELFIE laser facility (LULI, Ecole Polytechnique, France)

Preliminary analysis and results

Conclusions and prospective



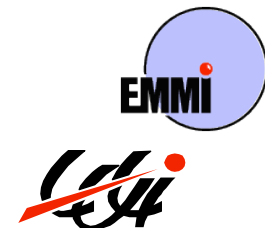
LASER-DRIVEN NEUTRON SOURCES

Neutrons production is an interesting applications for protons ad ions accelerated due to the laser-plama interaction

The high intensity ($>10^8$ W/cm²), short (<ps) laser pulses give the possibility to generate **picosecond, collimated neutrons**

Alternative to conventional neutron sources

- **SNS** (Spallation Neutron Source)
- **HFIR** (High Flux Isotope Reactor)



LASER-DRIVEN NEUTRON SOURCES

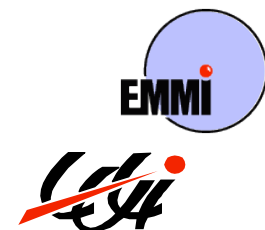
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✓ Costs



LASER-DRIVEN NEUTRON SOURCES

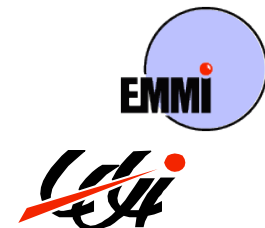
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Alternative to conventional neutron sources

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- ✓ Costs
- ✓ Dimension



LASER-DRIVEN NEUTRON SOURCES

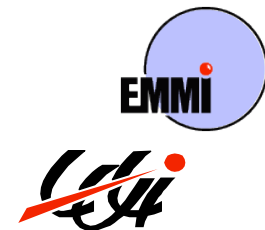
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Alternative to conventional neutron sources

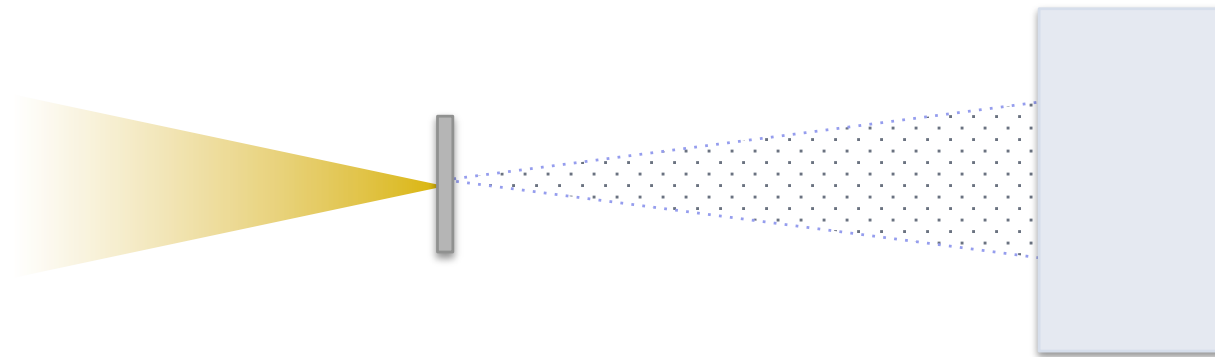
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- **HFIR** (High Flux Isotope Reactor)

- ✓ Costs
- ✓ Dimension
- ✓ Duration



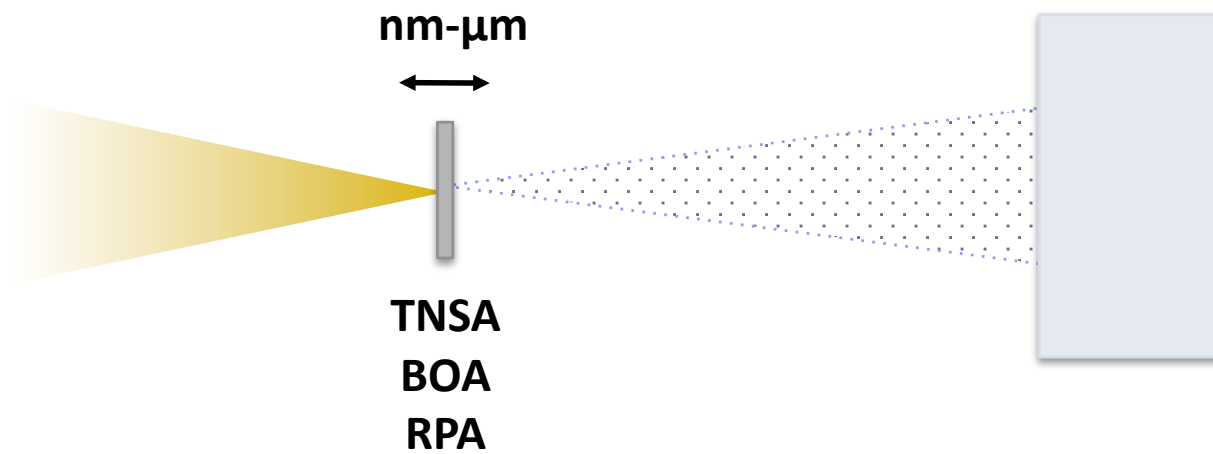
LASER-DRIVEN NEUTRON SOURCES

The laser-plasma community is exploring several schemes for producing neutron source



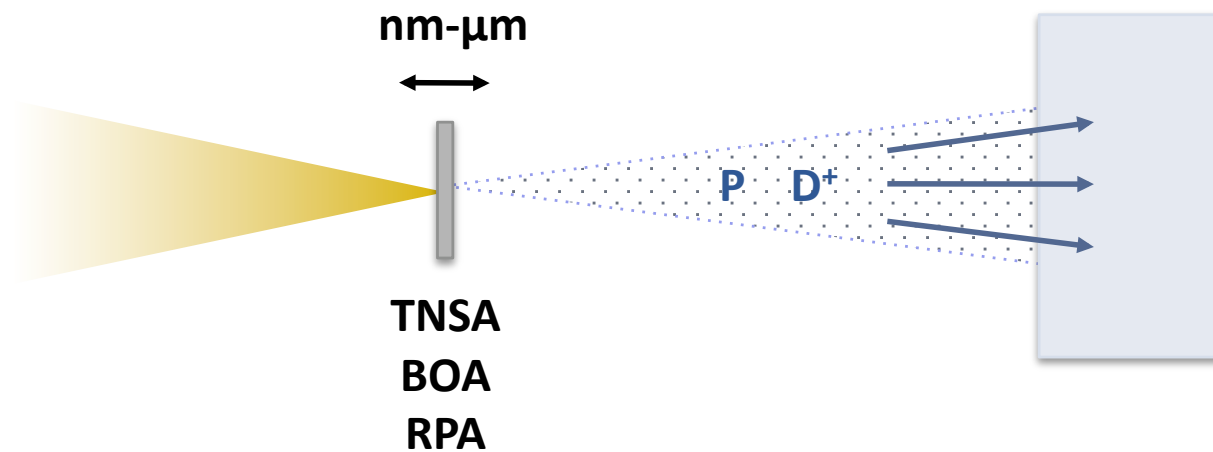
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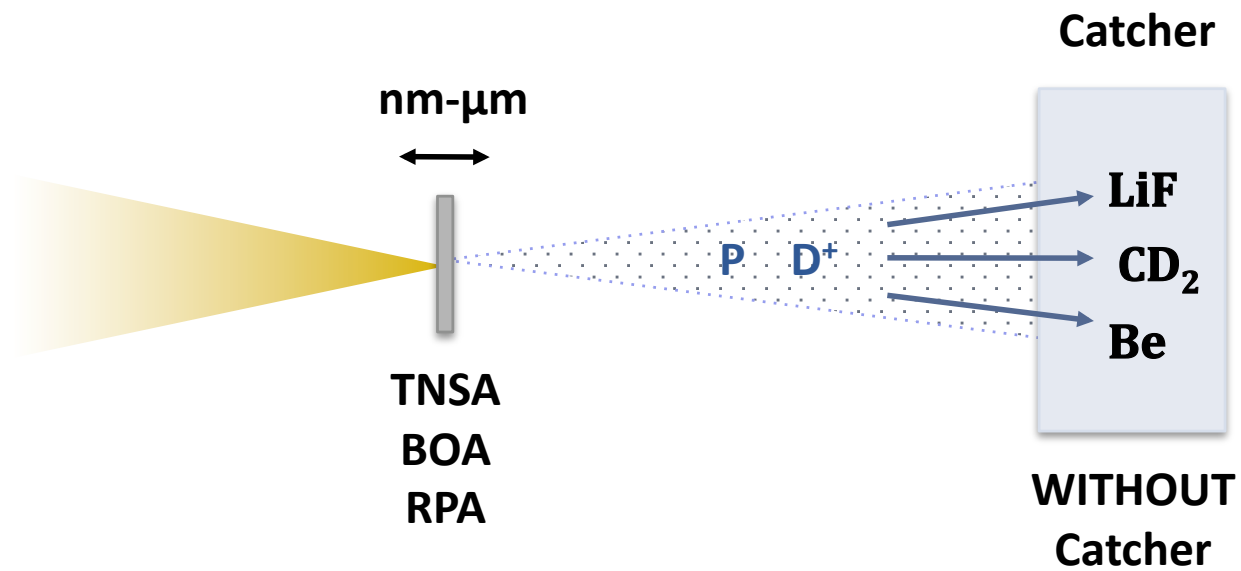
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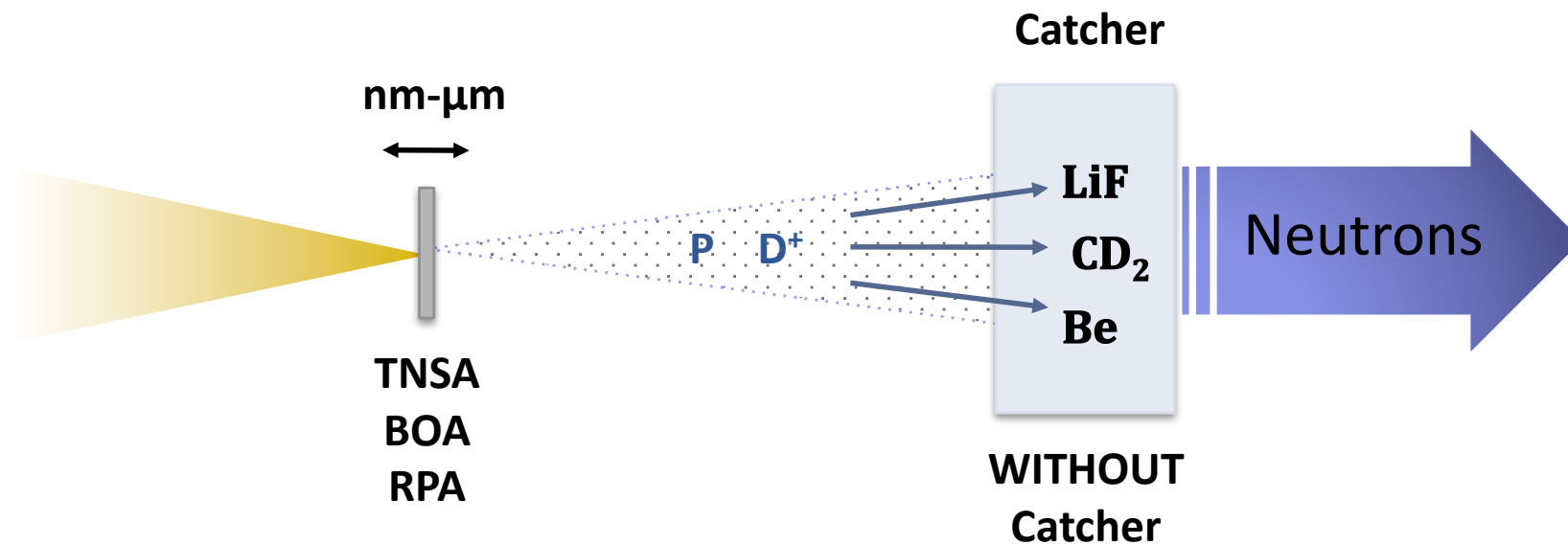
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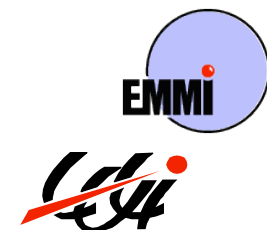


NEUTRONS FEATURES AND APPLICATIONS

As neutral particles, neutrons are **highly penetrating** and they can be used as **non-destructive** probe

- Neutron radiography
- Time resolved spectroscopy
- Testing of semi-conductor devices and materials used for shielding of spacecraft or aircraft
- Development of resistant materials for fusion/fission reactors
- Diagnosis of containers used for storage of radioactive nuclear waste
- Biological investigation (neutron's ability to discriminate between hydrogen and deuterium)

The most attractive feature of this neutron source is its **short pulse duration that opens possibility of material studies on a ps time scale**



NEUTRONS FEATURES AND APPLICATIONS

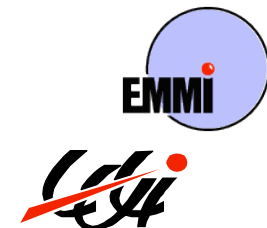
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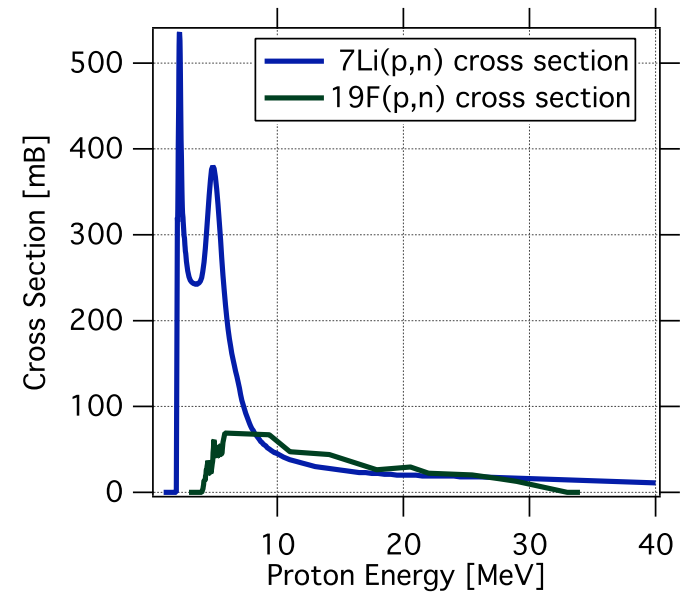
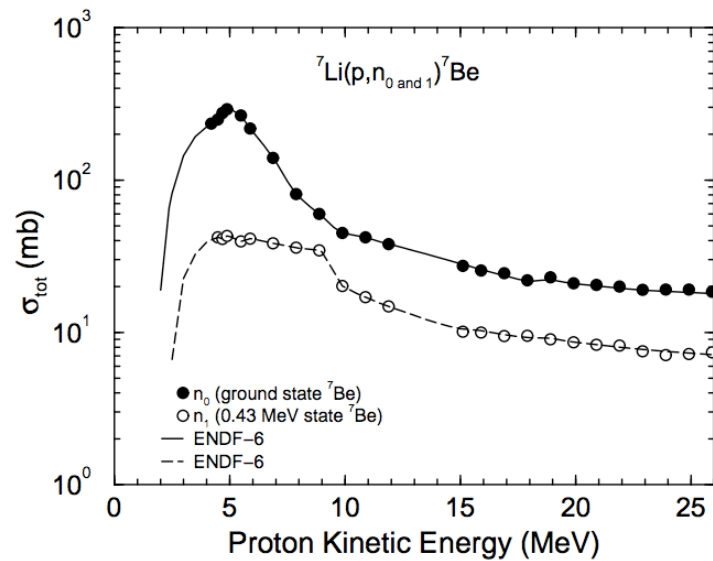
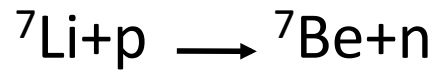
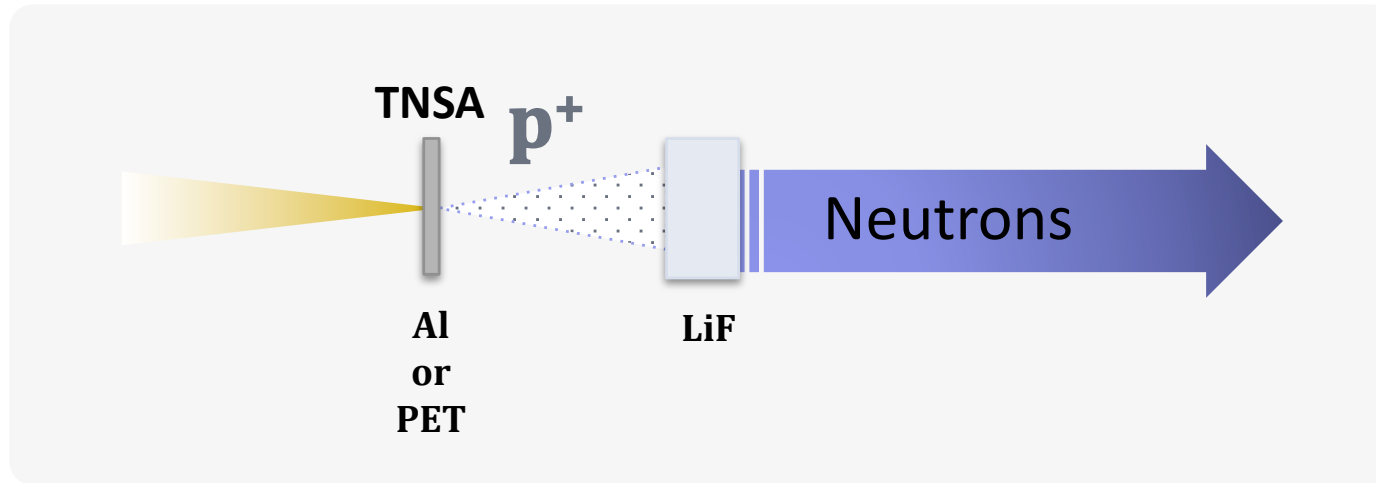
The most attractive feature of this neutron source is its **short pulse duration that opens possibility of material studies on a ps time scale**

performing **high time resolution measurements**

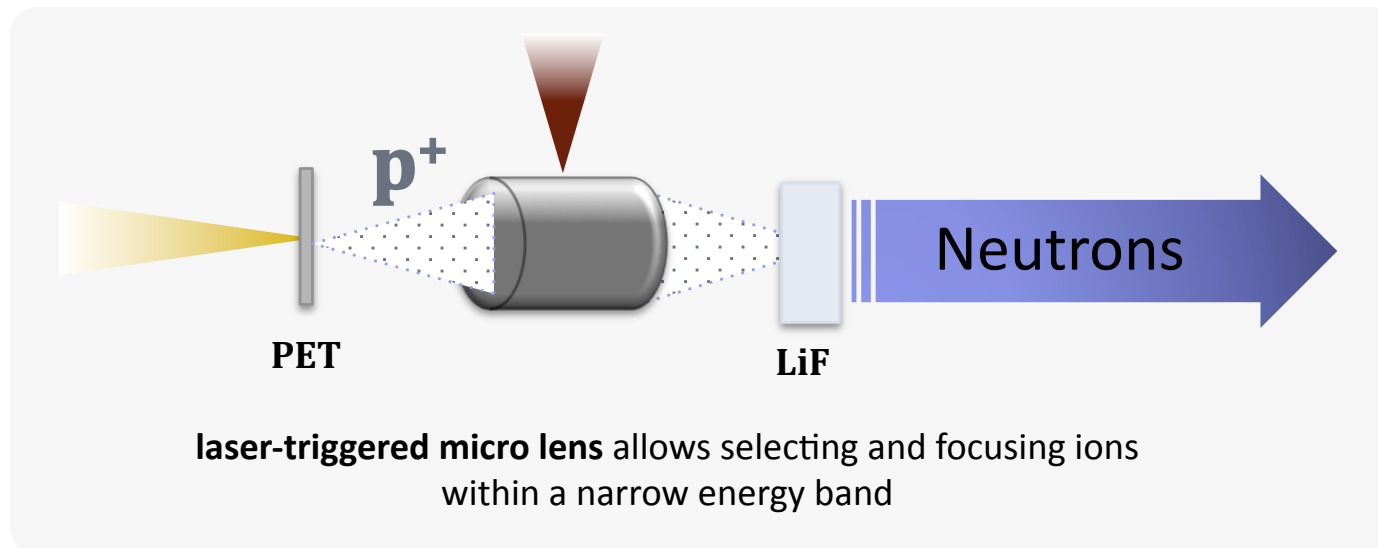
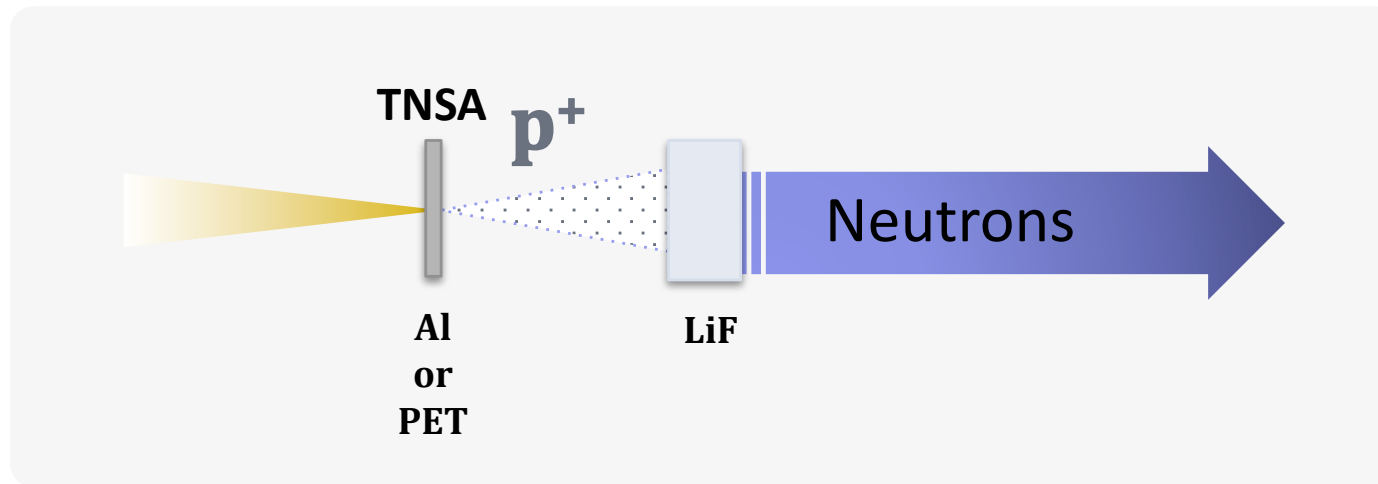
**Narrow Energy Bandwidth
Neutron Source**



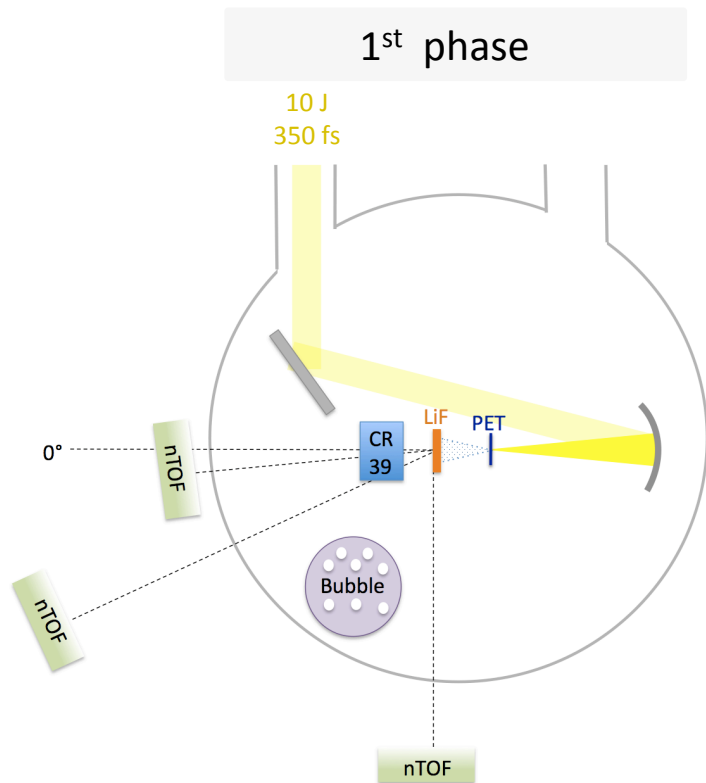
NARROW BAND NEUTRON SOURCE – BASIC SCHEME



NARROW BAND NEUTRON SOURCE



PHASES OF EXPERIMENT AND SET UP



Study of the neutron source
generate using

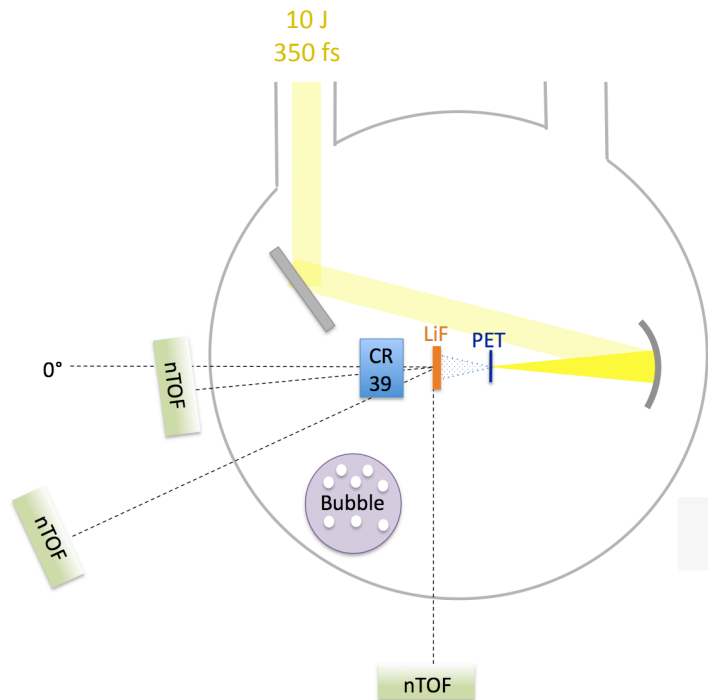
Al 25 μm or PET 50 μm
ELFIE C1 laser beam(10 J, 350 fs)

PHASES OF EXPERIMENT AND SET UP

1st

2nd

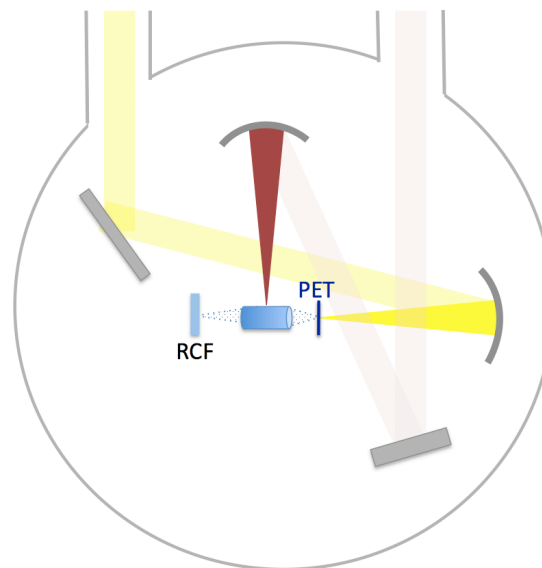
1st phase



Study of the focusing effect
obtained using

- PET 50 μm
- ELFIE C1 laser beam (10 J, 350 fs)
- 3mm Al Cylinder
- ELFIE C2 laser beam (10 J, 350 fs)

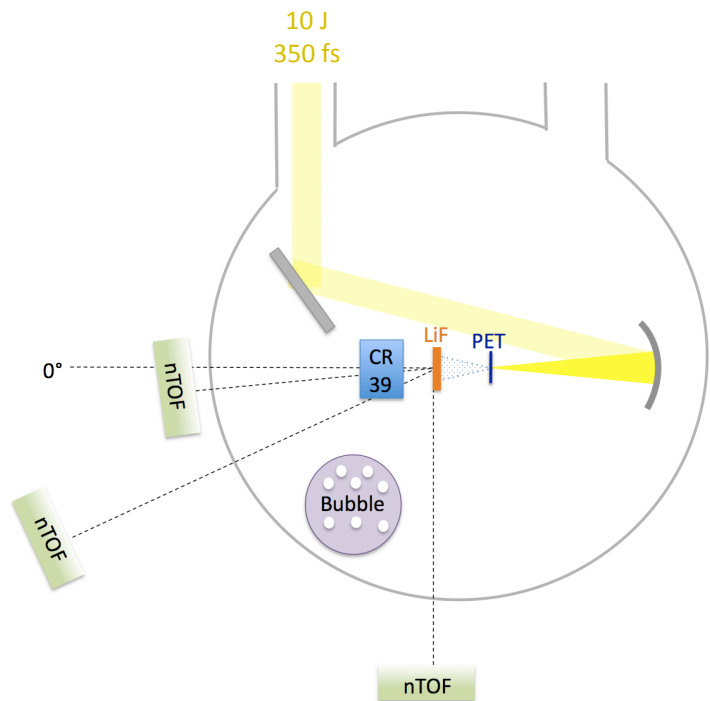
2nd phase



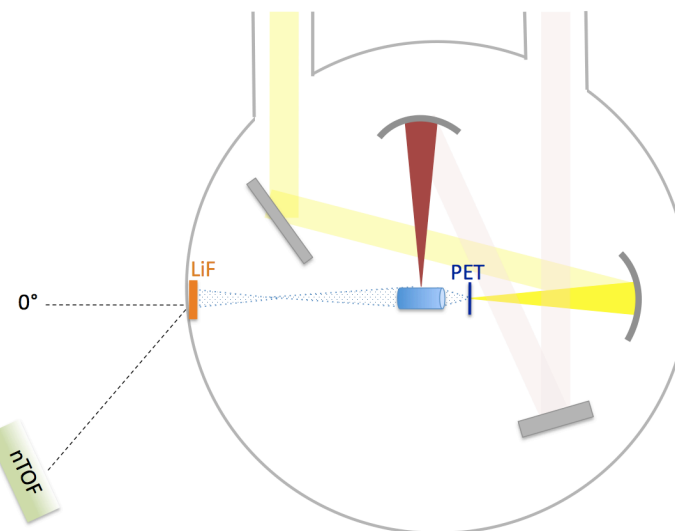
PHASES OF EXPERIMENT AND SET UP

1st
2nd
3rd

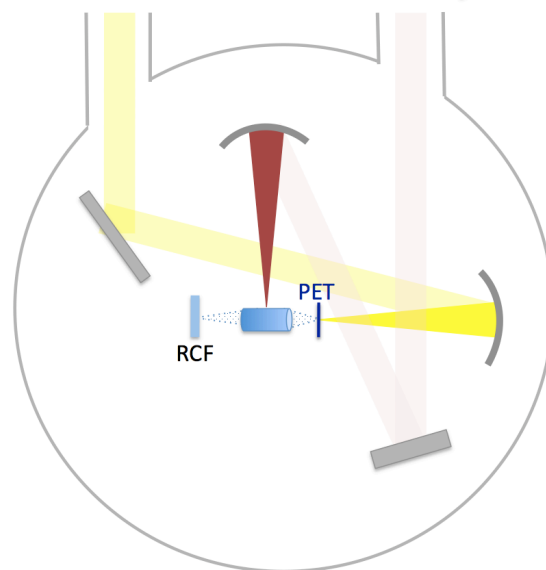
1st phase



3rd phase



2nd phase



study of neutron source
generate using

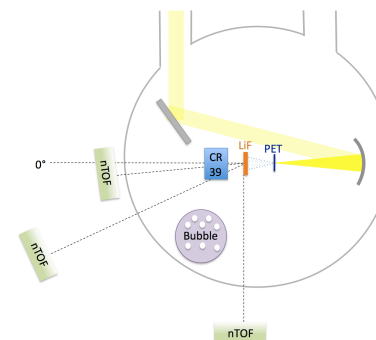
- PET 50 μm
- ELFIE C1 laser beam (10 J, 350 fs)
- 3mm Al Cylinder
- ELFIE C2 laser beam (10 J, 350 fs)

EMMI

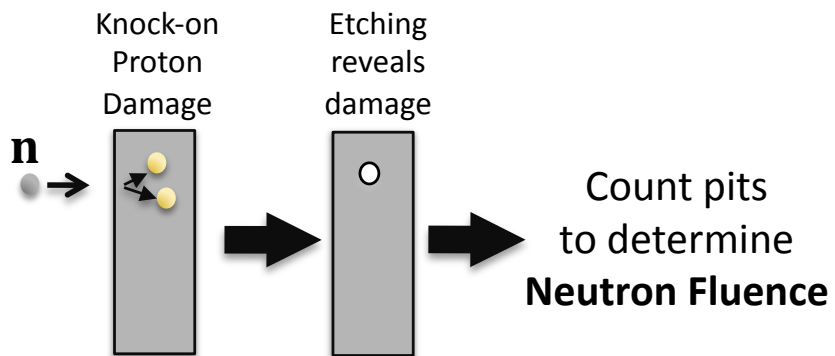


NEUTRON FLUX RESULTS

1st
2nd
3rd

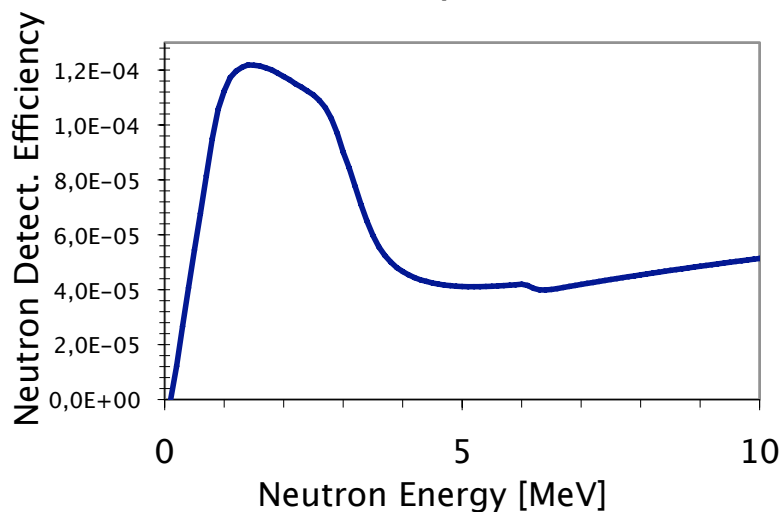


CR-39 Neutron Detector

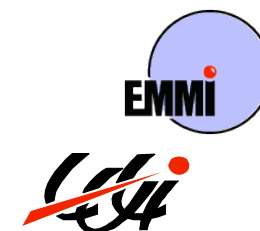


- ✓ Insensitive to X-ray and electron
- ✓ Highly sensitive to ions (we shielded with 2 mm of Pb)

CR39 Neutron Detection Efficiency 6hr Etch



	Energy Range [MeV]	Measurement [n/sr/shot]
CR-39	0.5 to 6	3.7E+06



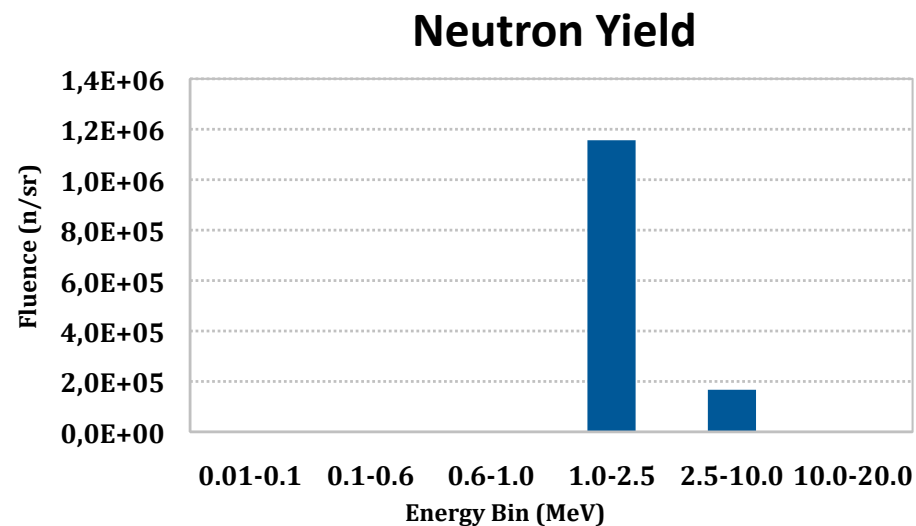
NEUTRON FLUX RESULTS

1st
2nd
3rd

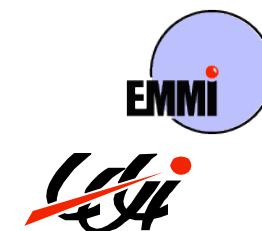
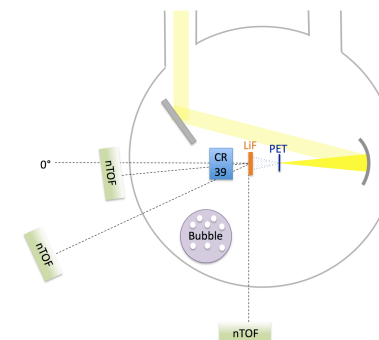
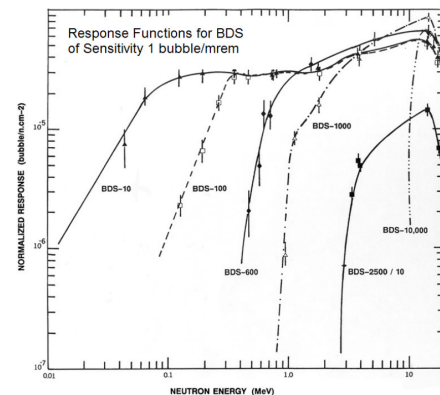
Bubble Detector

- Neutrons interact with small droplets of superheated liquid causing bubble formation in the detectors.
- By using an array of detectors with different cross-sections the neutron yield can be inferred without spectra assumptions.

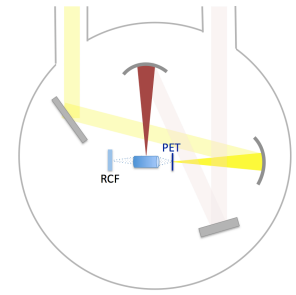
Due to the low fluence of neutrons, multiple shots were required to recover the



	Energy Range [MeV]	Measurement [n/sr/shot]
CR-39	0.5 to 6	3.7E+06
Bubble	1.0 to 2.5	1.2E+06
Bubble	2.5 to 10	1.7E+05



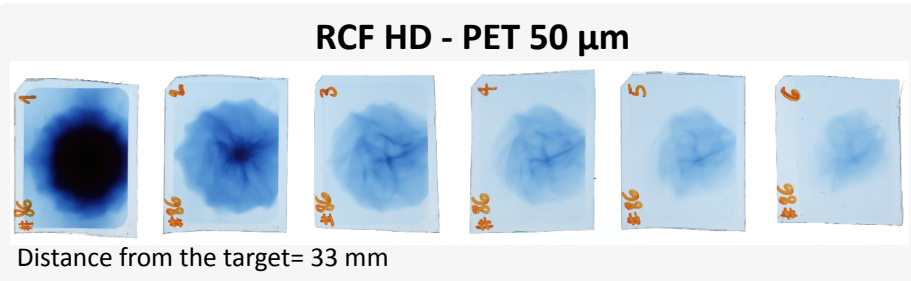
PROTON BEAM WITH AND WITHOUT LENS



1st
2nd
3rd

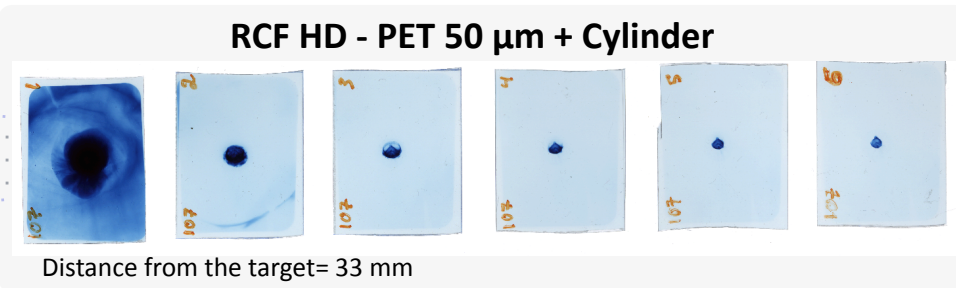
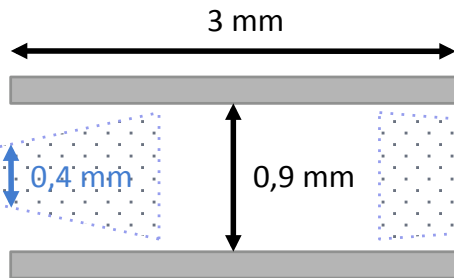
PET

p^+

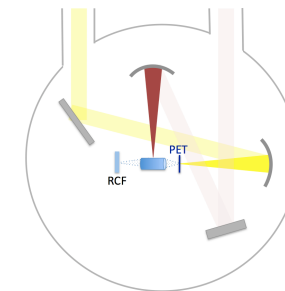


PET

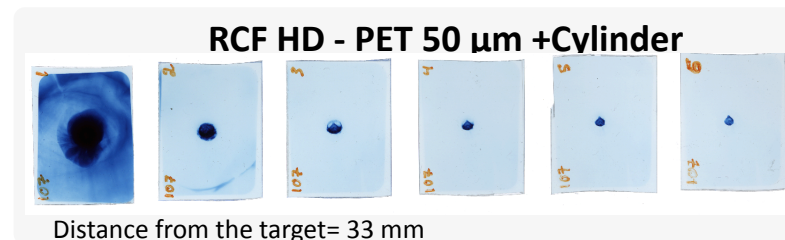
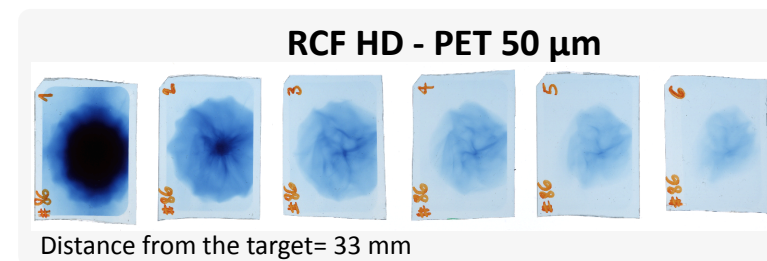
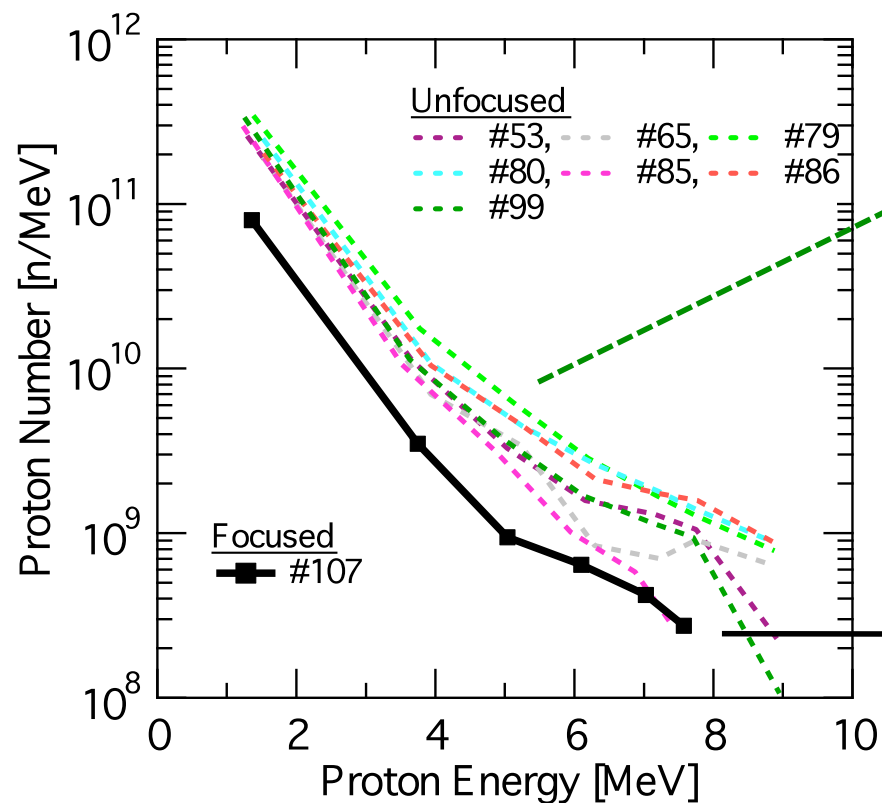
p^+



PROTON BEAM WITH AND WITHOUT LENS

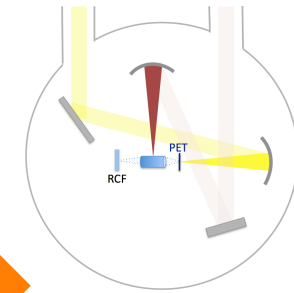


1st
2nd
3rd

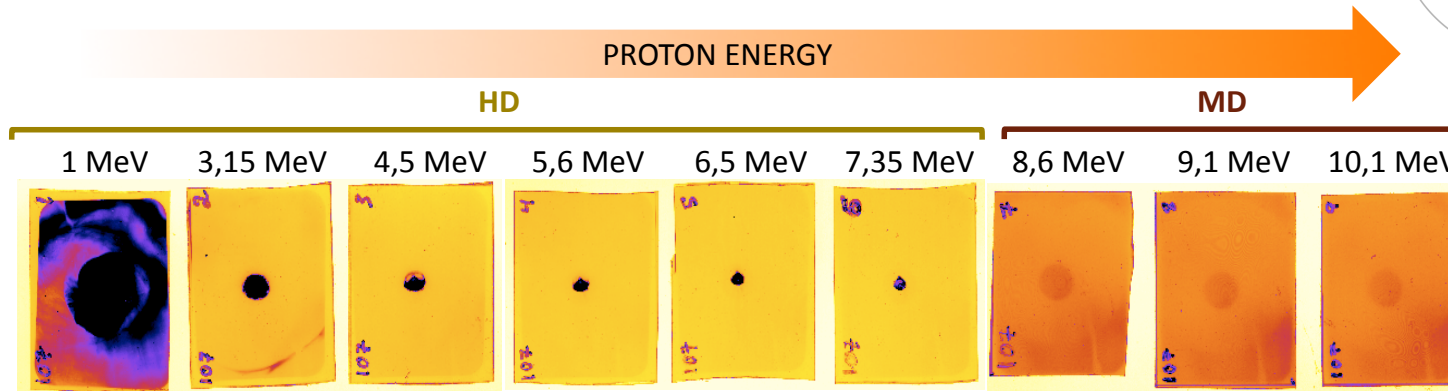


The focused beam contained 30% of the number of protons as the original beam and retained a similar exponential profile.

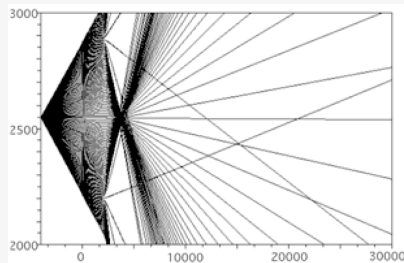
FOCALIZED PROTON BEAM



1st
2nd
3rd



PIC SIMULATION [2]

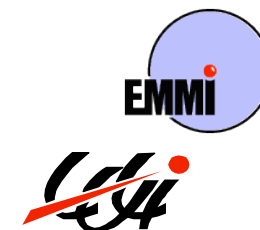


[2] E. d'Humières
(2012) *Ion Acceleration by High Intensity Short Pulse Lasers, Laser Pulses*

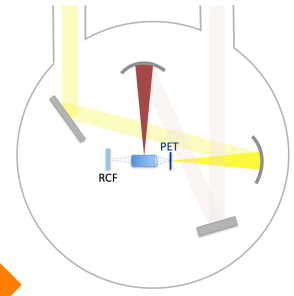
LOW ENERGY PROTONS

They are **before the middle** of the cylinder when it is irradiated

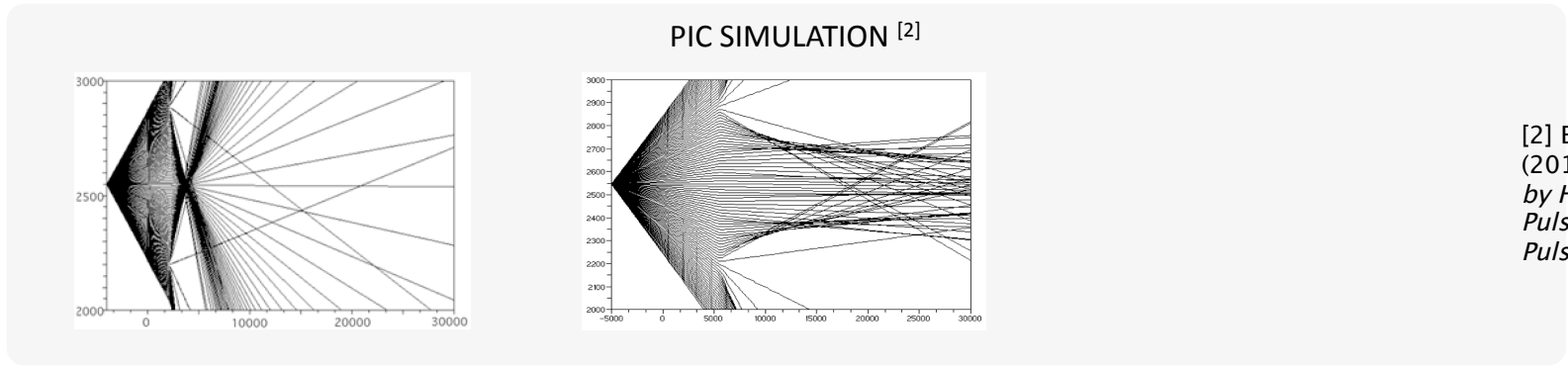
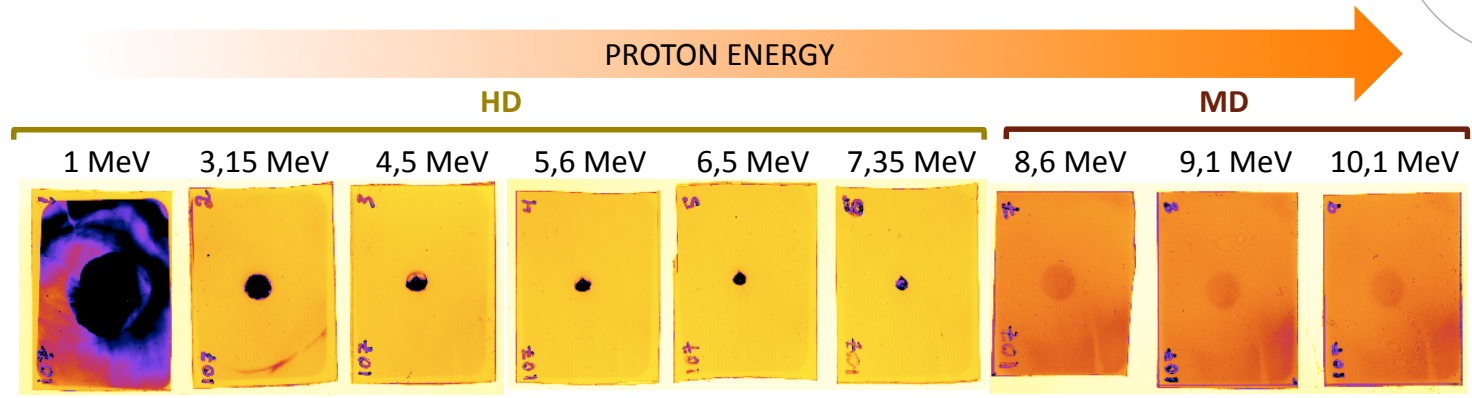
FOCALIZED AT SHORT DISTANCE



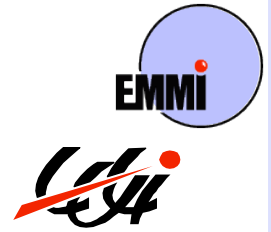
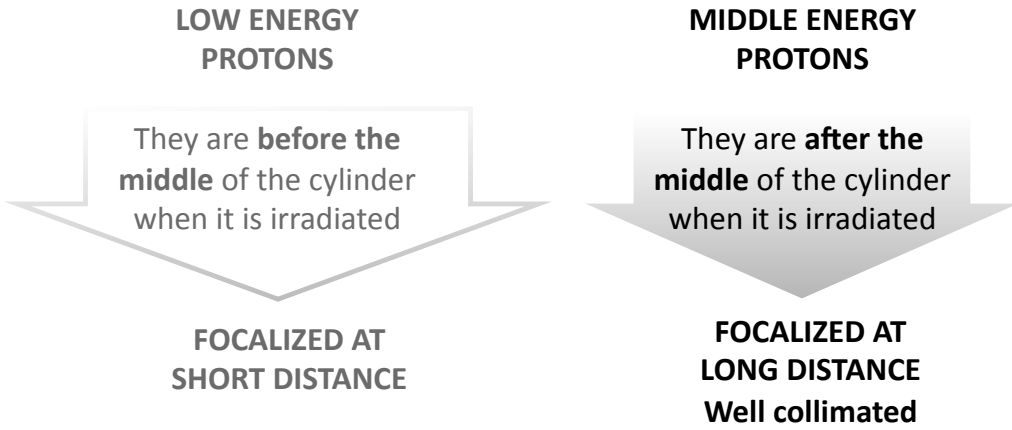
FOCALIZED PROTON BEAM



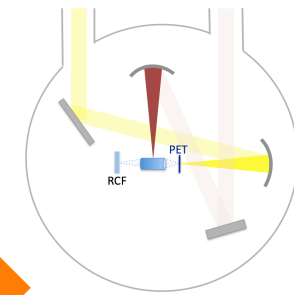
1st
2nd
3rd



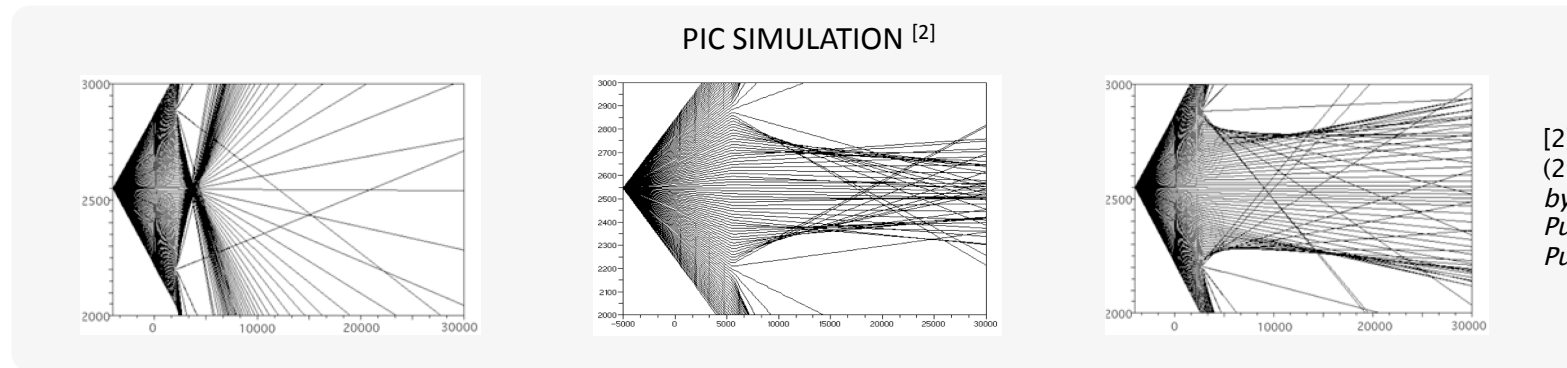
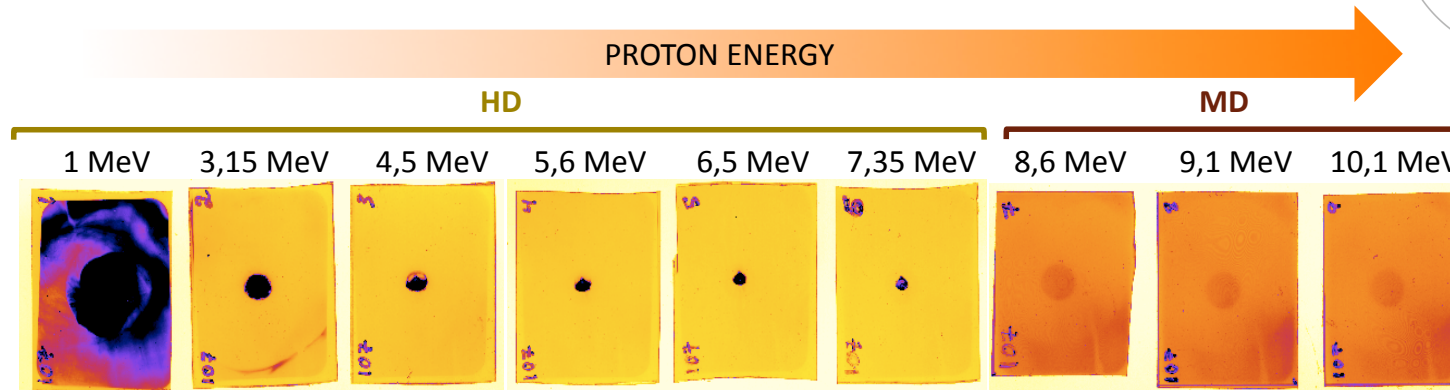
[2] E. d'Humières (2012) *Ion Acceleration by High Intensity Short Pulse Lasers, Laser Pulses*



FOCALIZED PROTON BEAM



1st
2nd
3rd



[2] E. d'Humières (2012) *Ion Acceleration by High Intensity Short Pulse Lasers, Laser Pulses*

LOW ENERGY PROTONS

They are **before the middle** of the cylinder when it is irradiated

FOCALIZED AT SHORT DISTANCE

MIDDLE ENERGY PROTONS

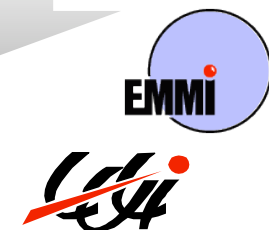
They are **after the middle** of the cylinder when it is irradiated

FOCALIZED AT LONG DISTANCE
Well collimated

HIGH ENERGY PROTONS

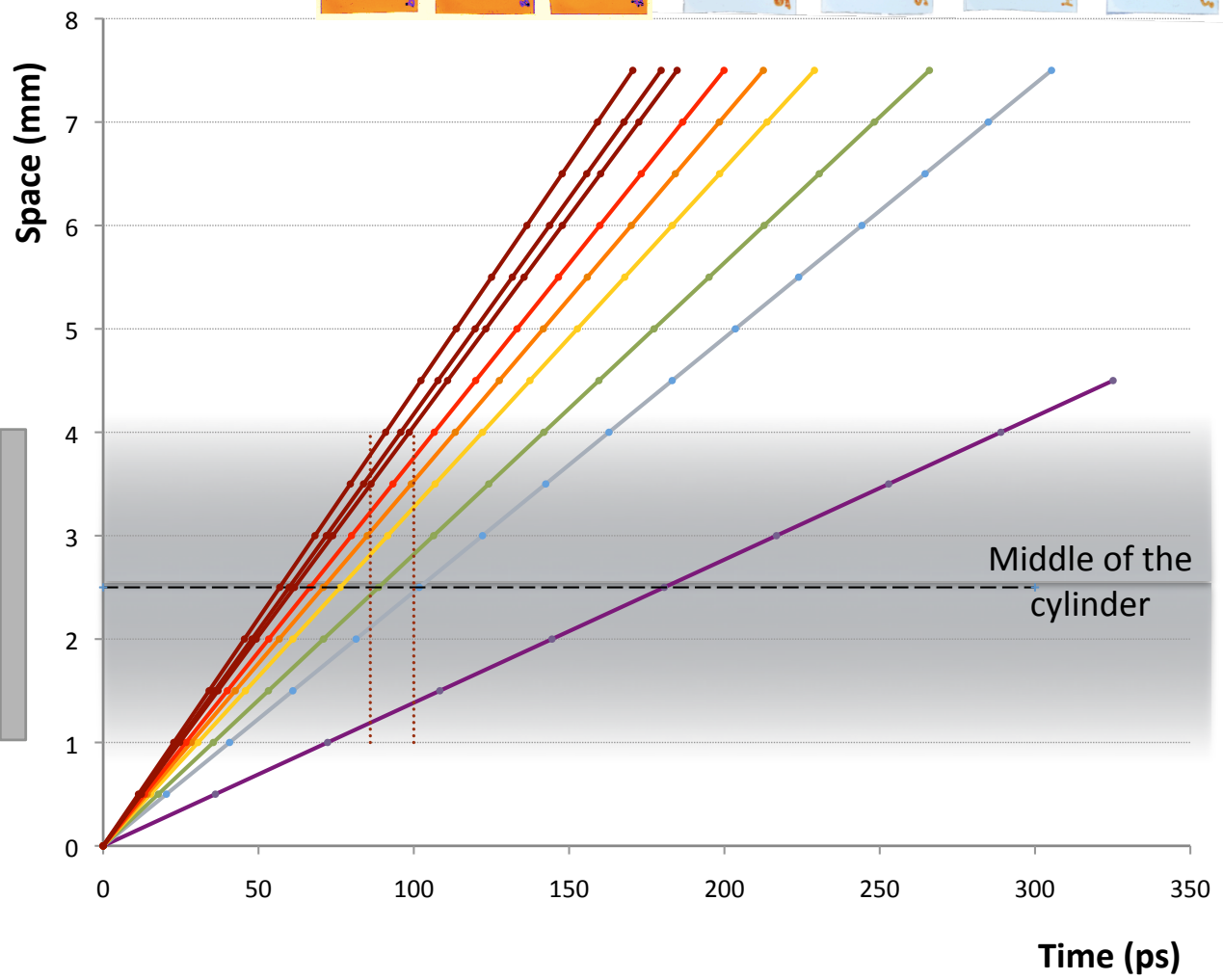
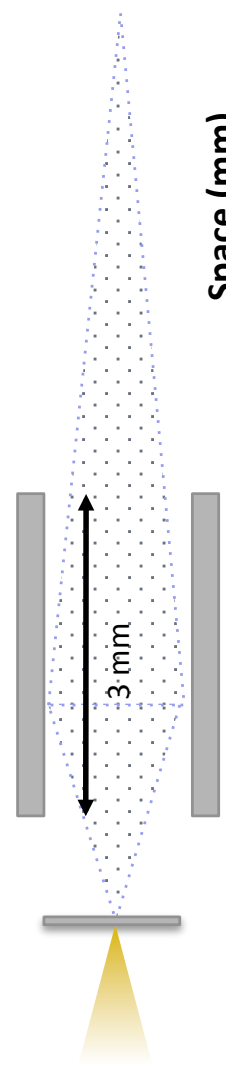
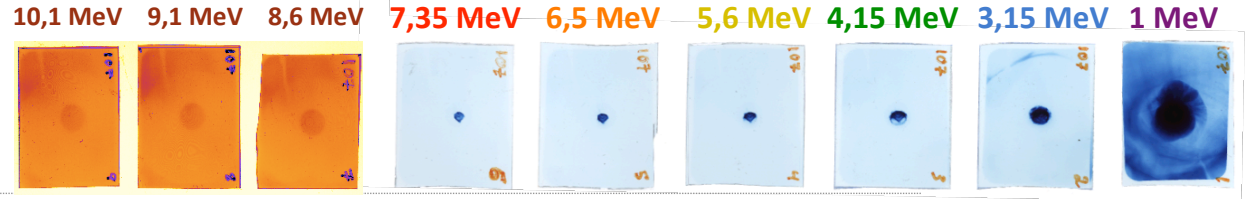
They are already **outside** the cylinder when it is irradiated

NOT FOCALIZED



TUNABLE PLASMA MICROLENS

1st
2nd
3rd



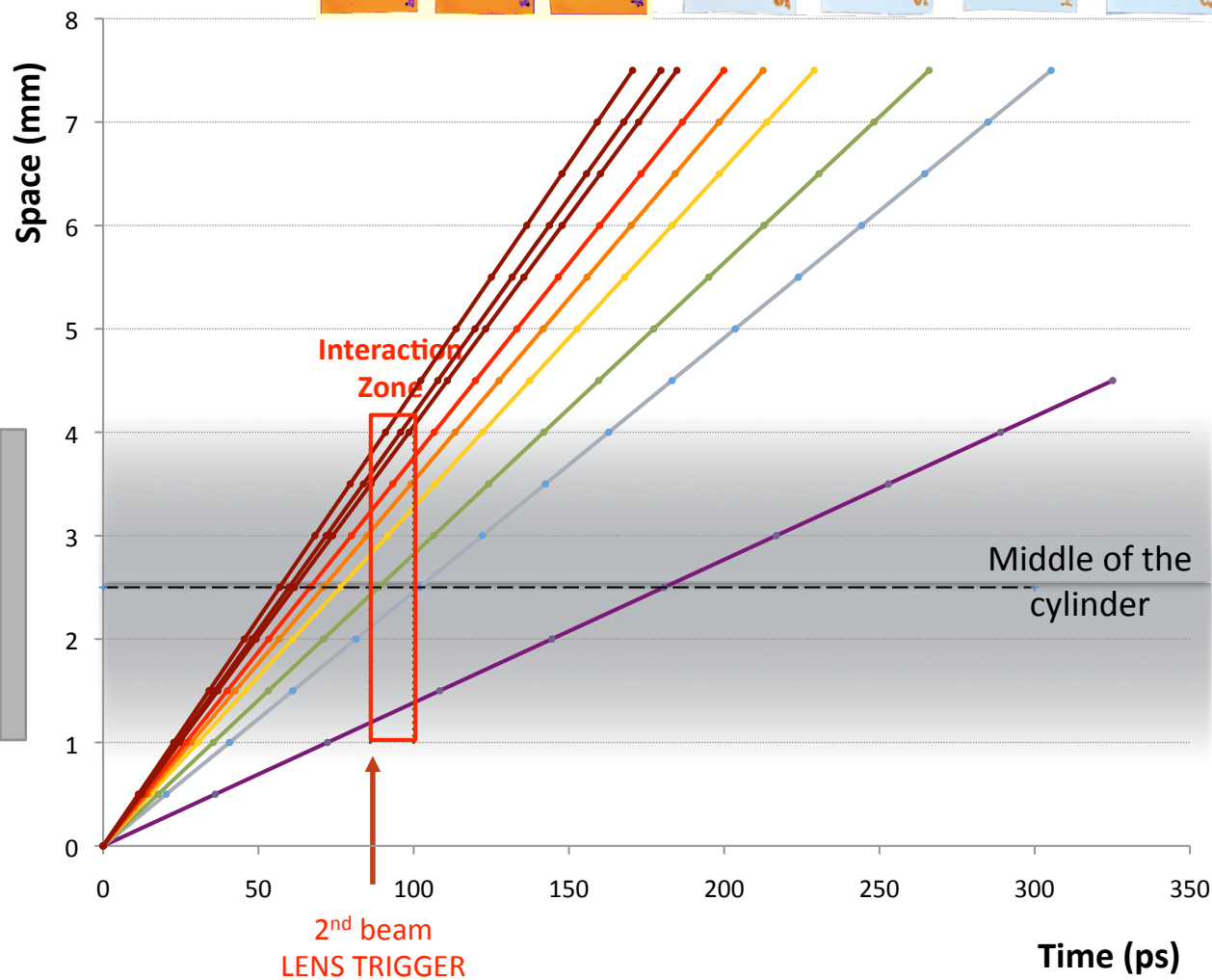
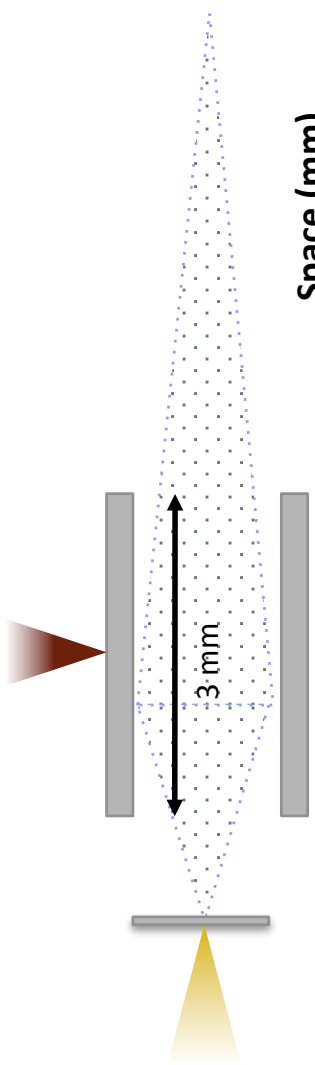
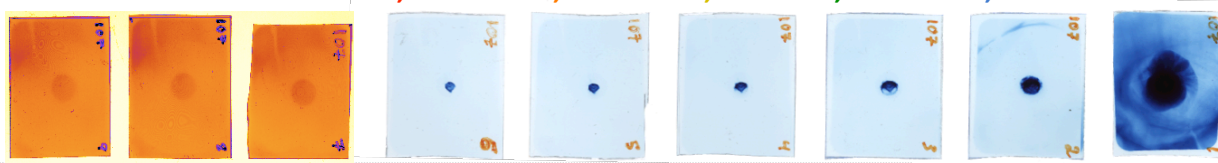
- Proton Energy**
- 1 Mev
 - 3,15 MeV
 - 4,15 MeV
 - 5,6 MeV
 - 6,5 MeV
 - 7,35 MeV
 - 8,6 MeV
 - 9,1 MeV
 - 10,1 MeV



TUNABLE PLASMA MICROLENS

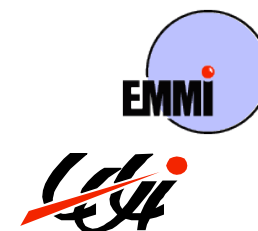
1st
2nd
3rd

10,1 MeV 9,1 MeV 8,6 MeV 7,35 MeV 6,5 MeV 5,6 MeV 4,15 MeV 3,15 MeV 1 MeV



Proton Energy

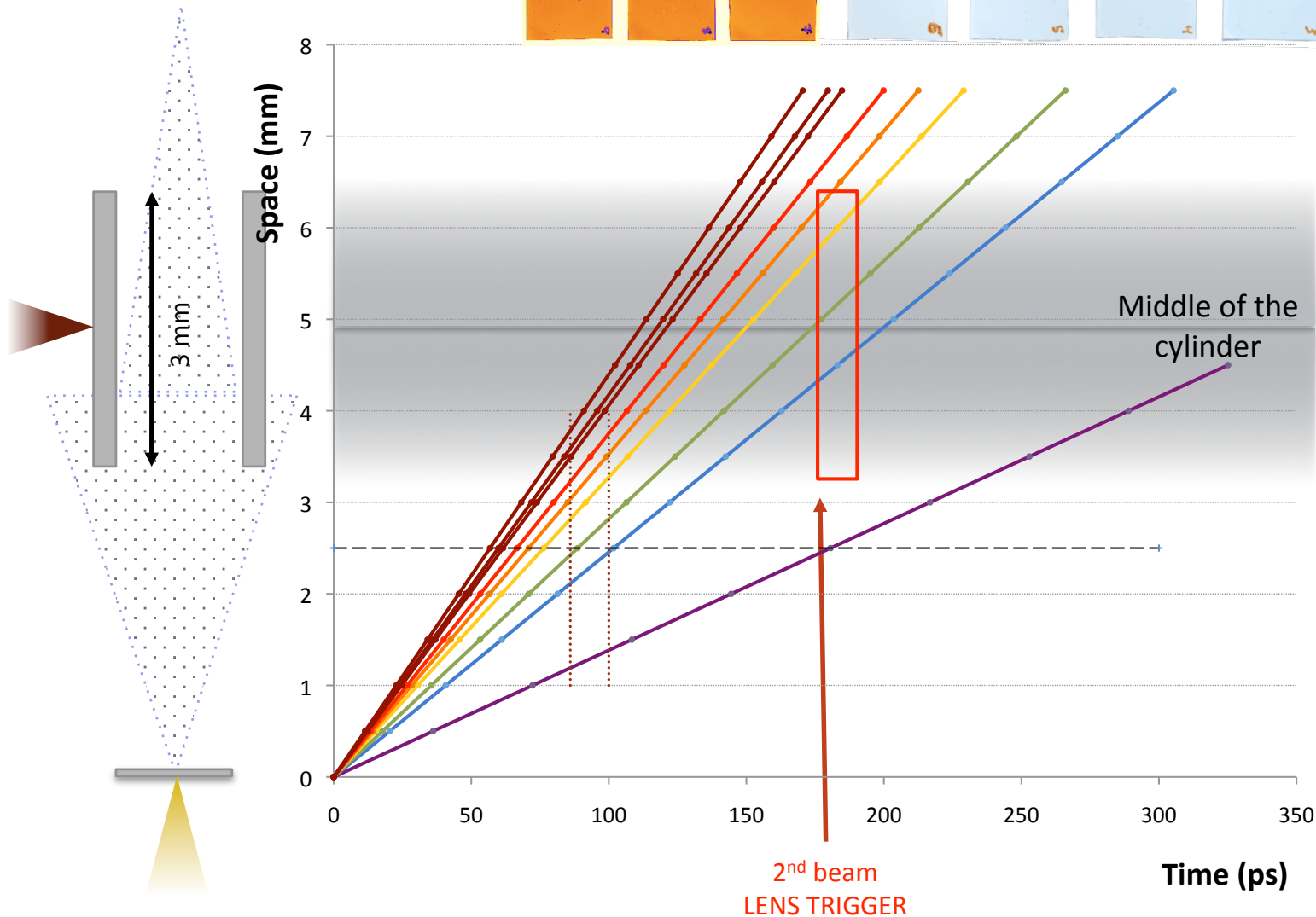
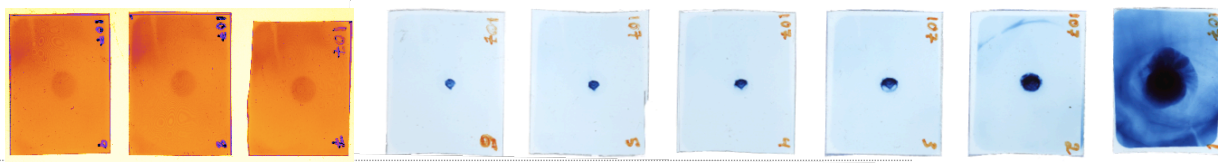
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- 9,1 MeV
- 10,1 MeV



TUNABLE PLASMA MICROLENS

1st
2nd
3rd

10,1 MeV 9,1 MeV 8,6 MeV 7,35 MeV 6,5 MeV 5,6 MeV 4,15 MeV 3,15 MeV 1 MeV

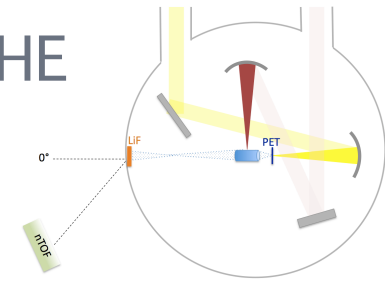


Proton Energy

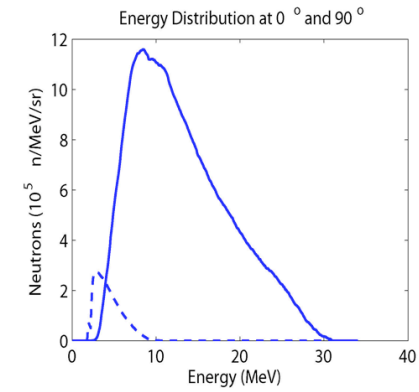
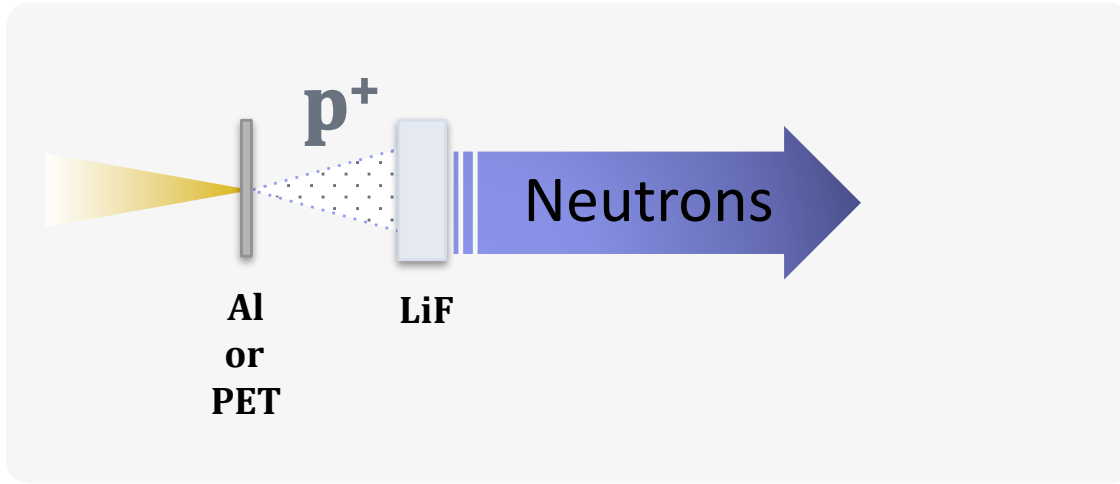
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- 5,6 MeV
- 6,5 MeV
- 7,35 MeV
- 8,6 MeV
- 9,1 MeV
- 10,1 MeV



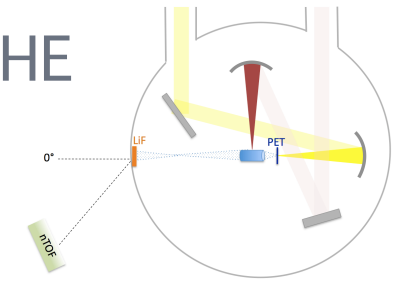
WE EXPECT TO SELECT A DESIRED PART OF THE SPECTRUM



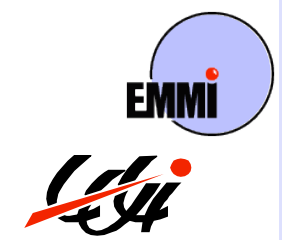
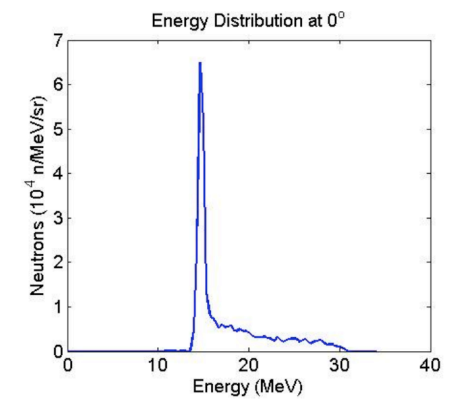
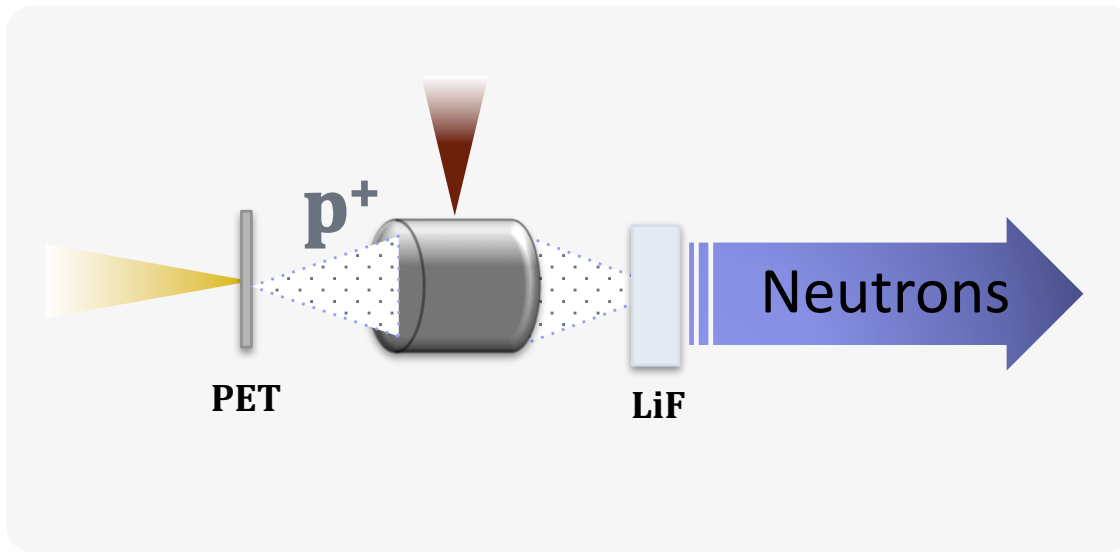
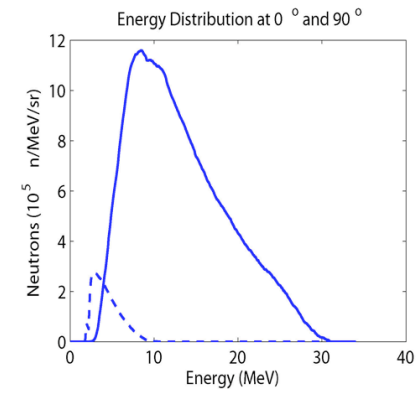
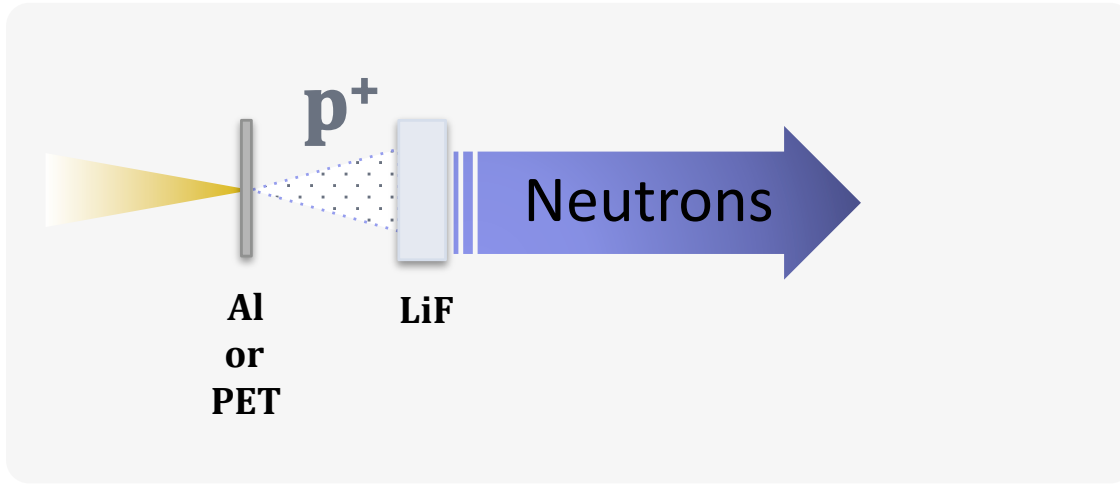
1st
2nd
3rd



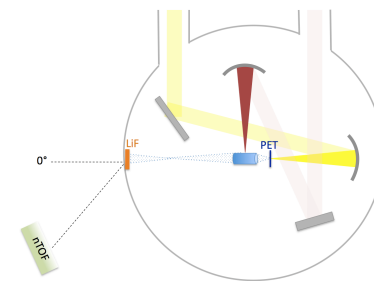
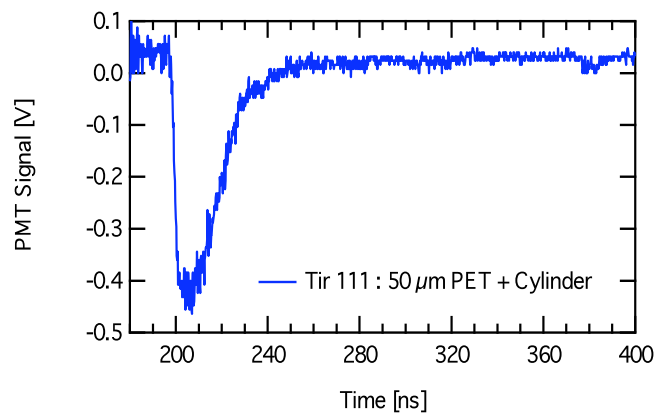
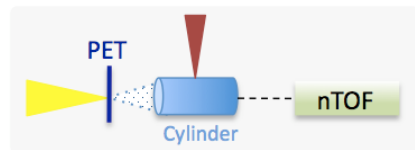
WE EXPECT TO SELECT A DESIRED PART OF THE SPECTRUM



1st
2nd
3rd



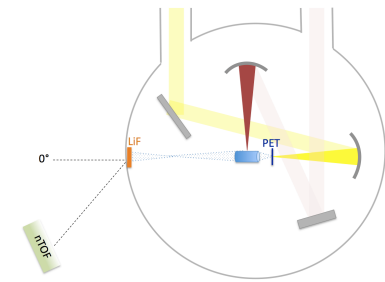
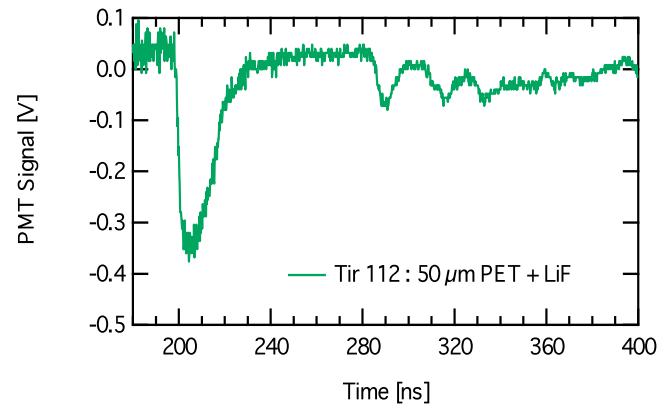
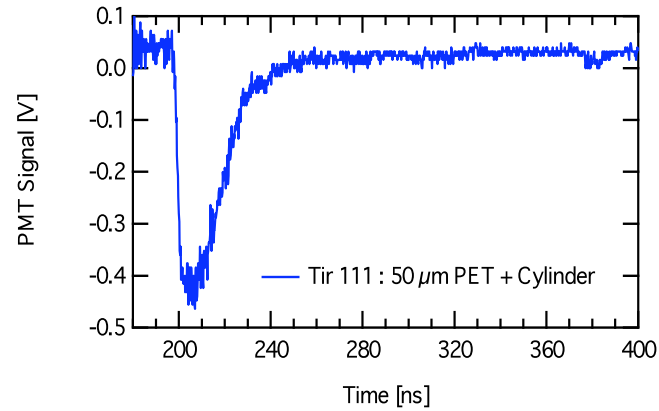
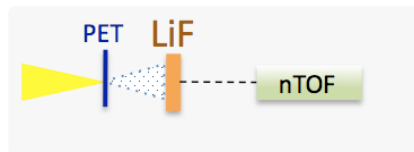
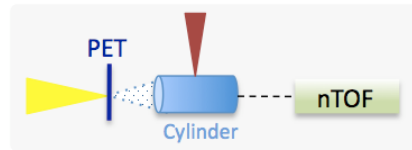
SOME nTOF RESULTS



Gamma and X-ray signal

1st
2nd
3rd

SOME nTOF RESULTS

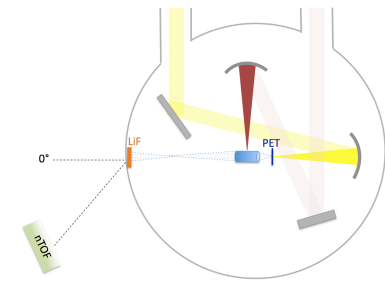
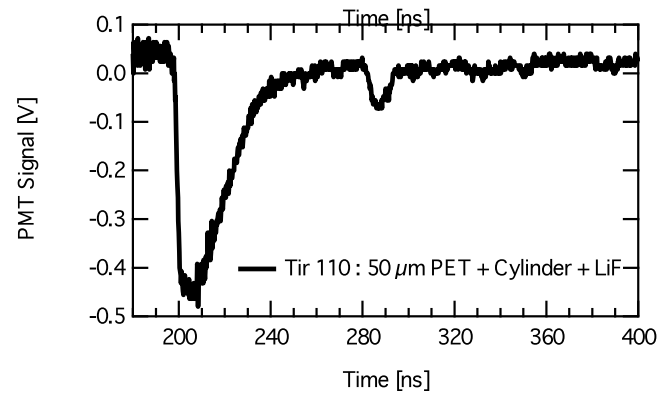
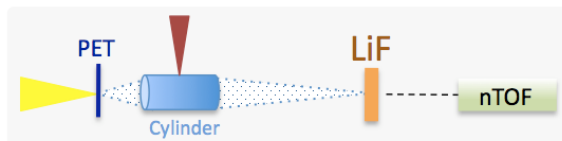
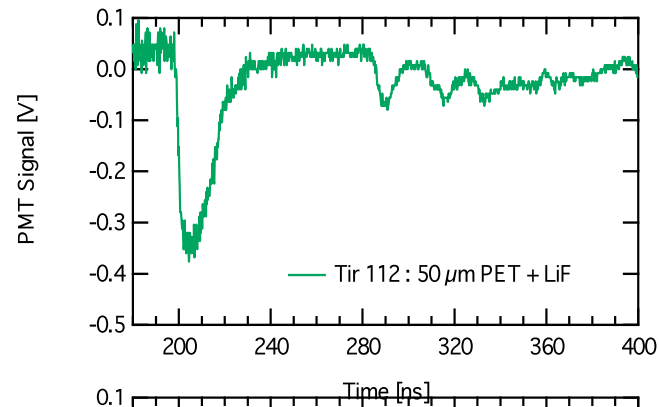
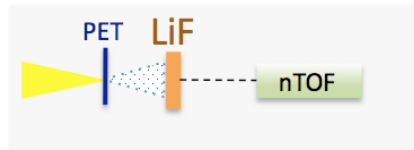
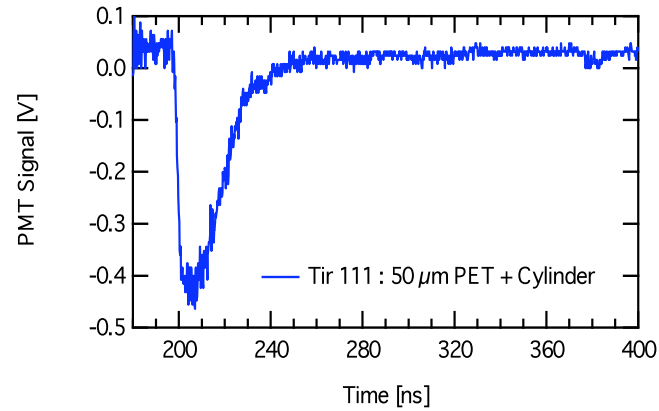
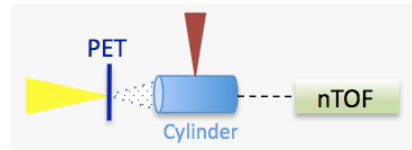


Gamma and X-ray signal

Gamma and X-ray signal
+ **NEUTRONS**

1st
2nd
3rd

SOME nTOF RESULTS



1st
2nd
3rd

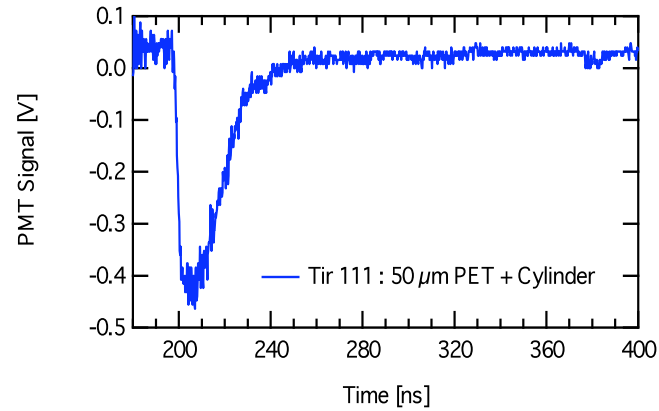
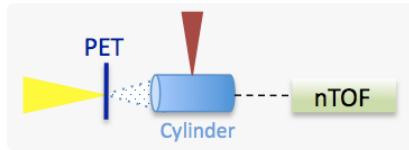
Gamma and X-ray signal

Gamma and X-ray signal
+ **NEUTRONS**

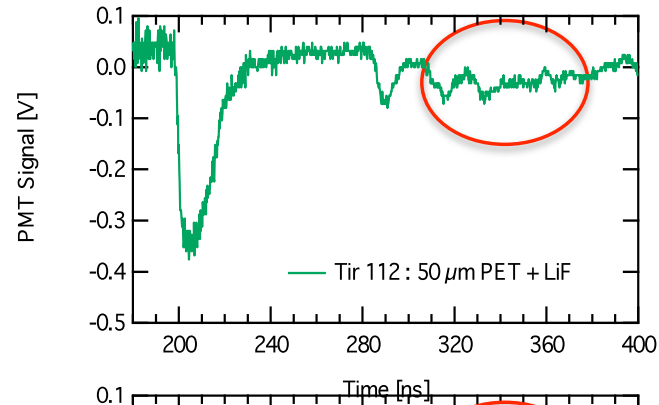
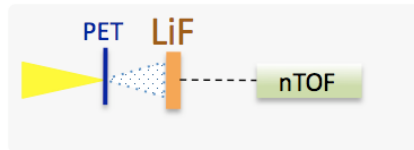
Gamma and X-ray signal
+ **NEUTRONS**



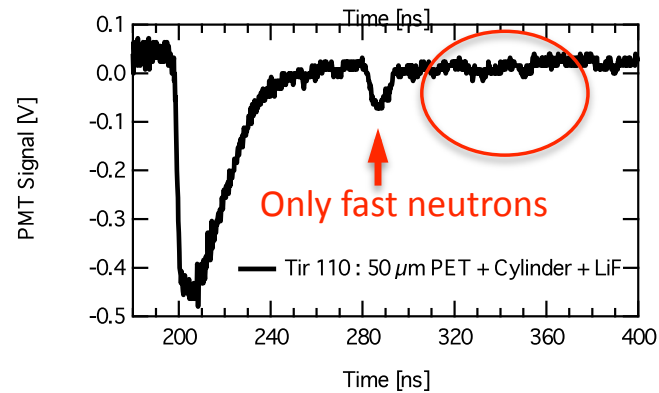
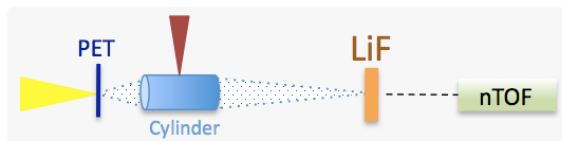
SOME nTOF RESULTS



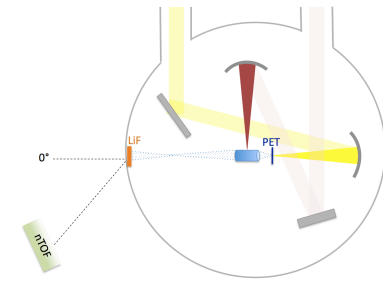
Gamma and X-ray signal



Gamma and X-ray signal
+ **NEUTRONS**



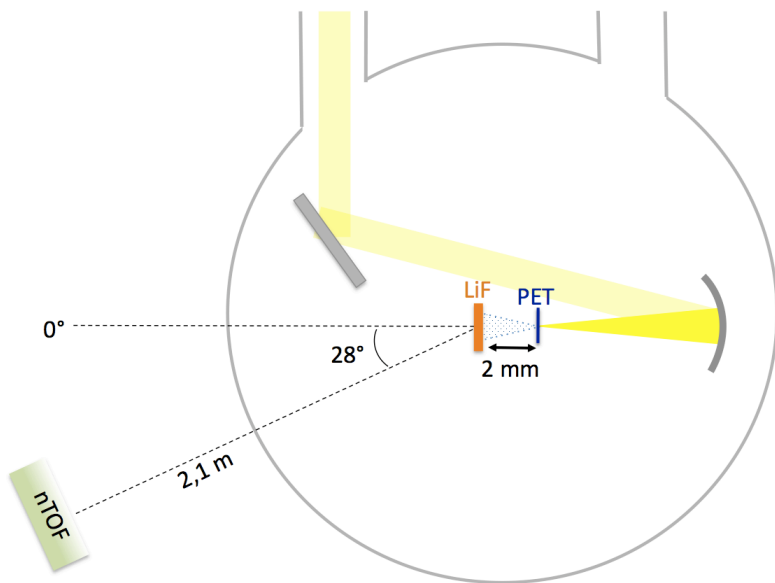
Gamma and X-ray signal
+ **NEUTRONS**



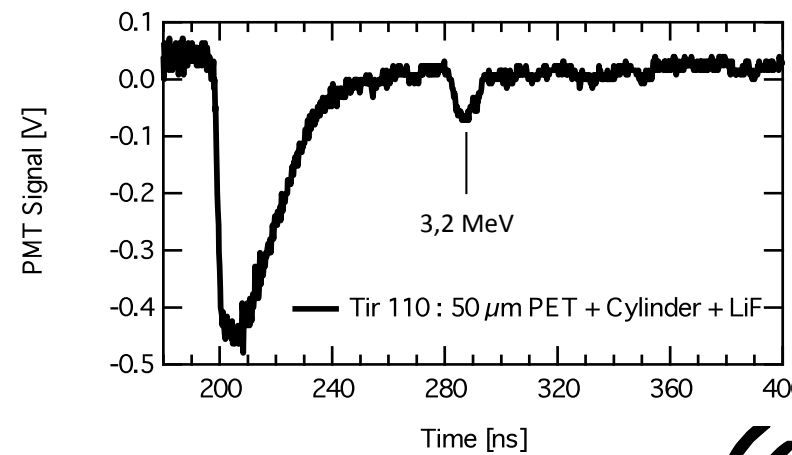
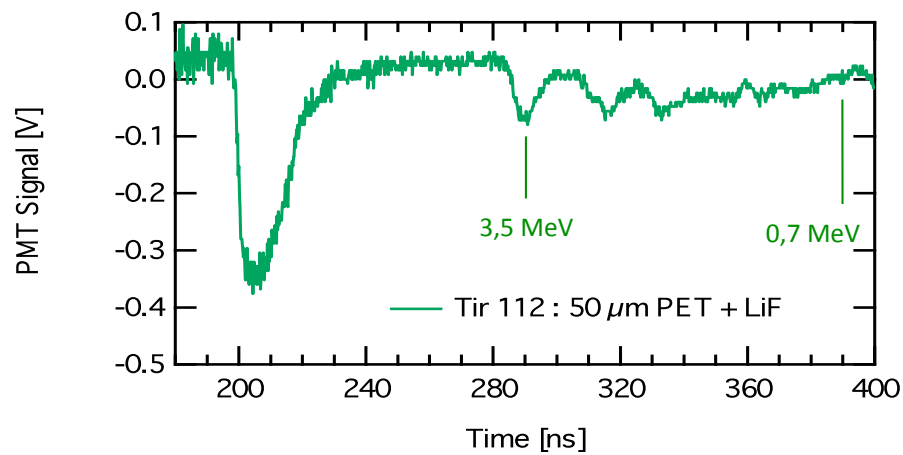
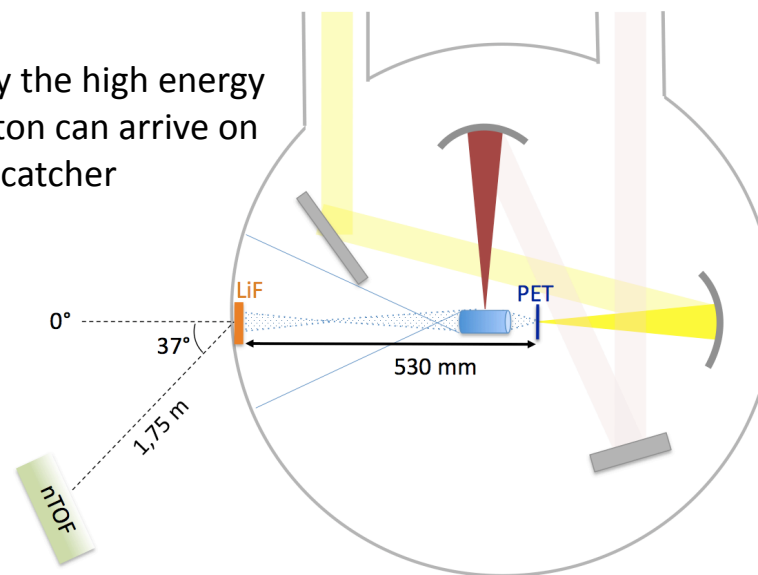
1st
2nd
3rd



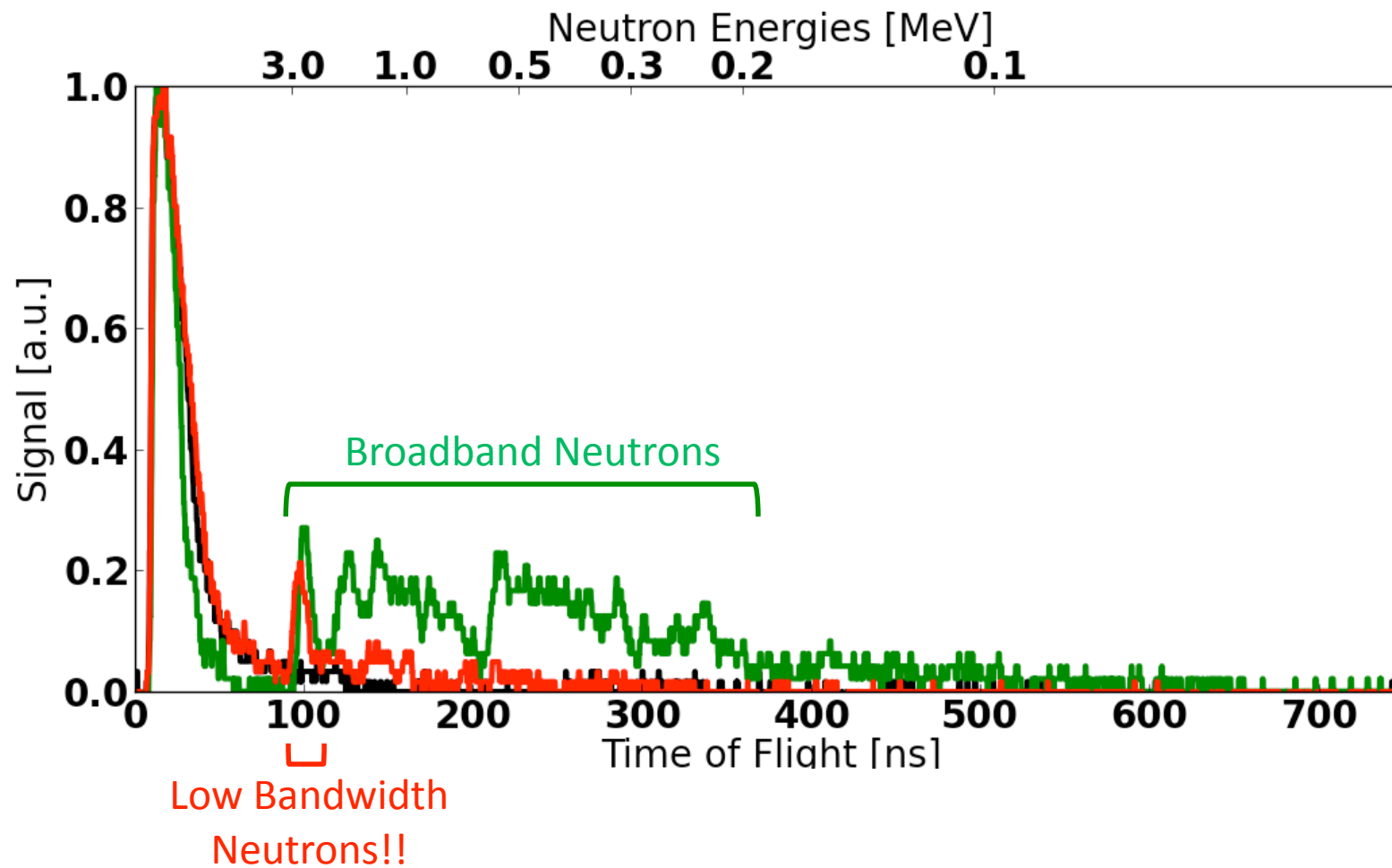
COMPARISON OF RESULTS



Only the high energy proton can arrive on the catcher



THANKS TO THE CYLINDER WE HAD OBTAINED A LOW BANDWIDTH NEUTRONS



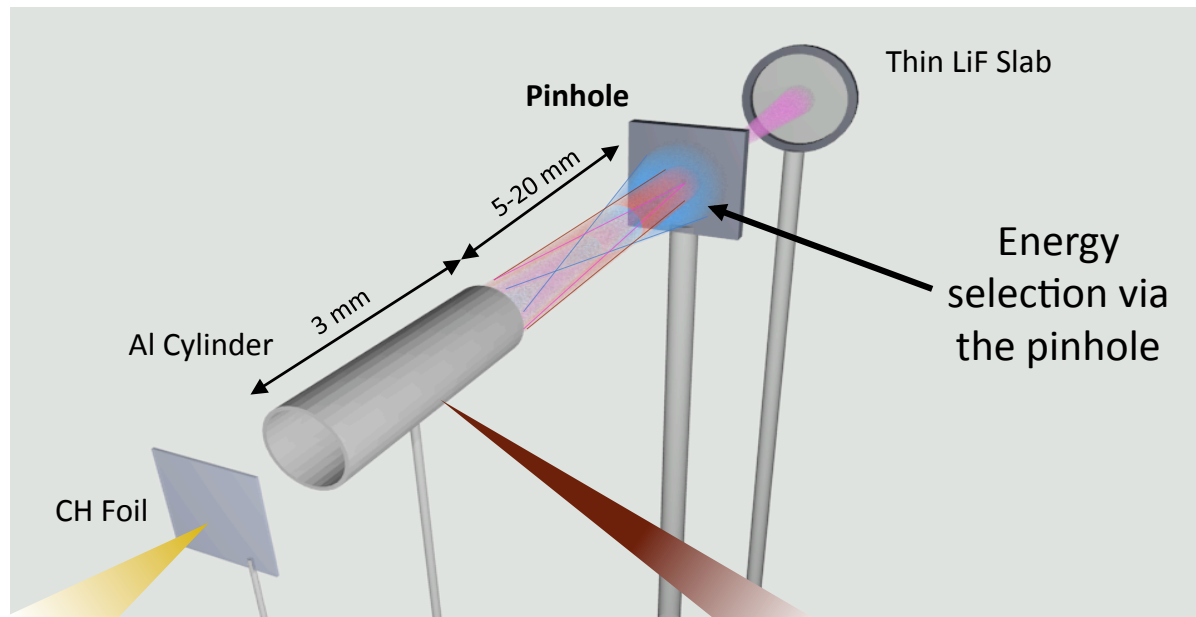
1st
2nd
3rd

CONCLUSIONS AND PERSPECTIVES

A neutron source with a flux of the order of 10^6 n/sr has been generated in the ELFIE facility

Proton focusing achieved experimentally with $\sim 30\%$ efficiency

A low bandwidth neutron source has been observed



CONCLUSIONS AND PERSPECTIVES

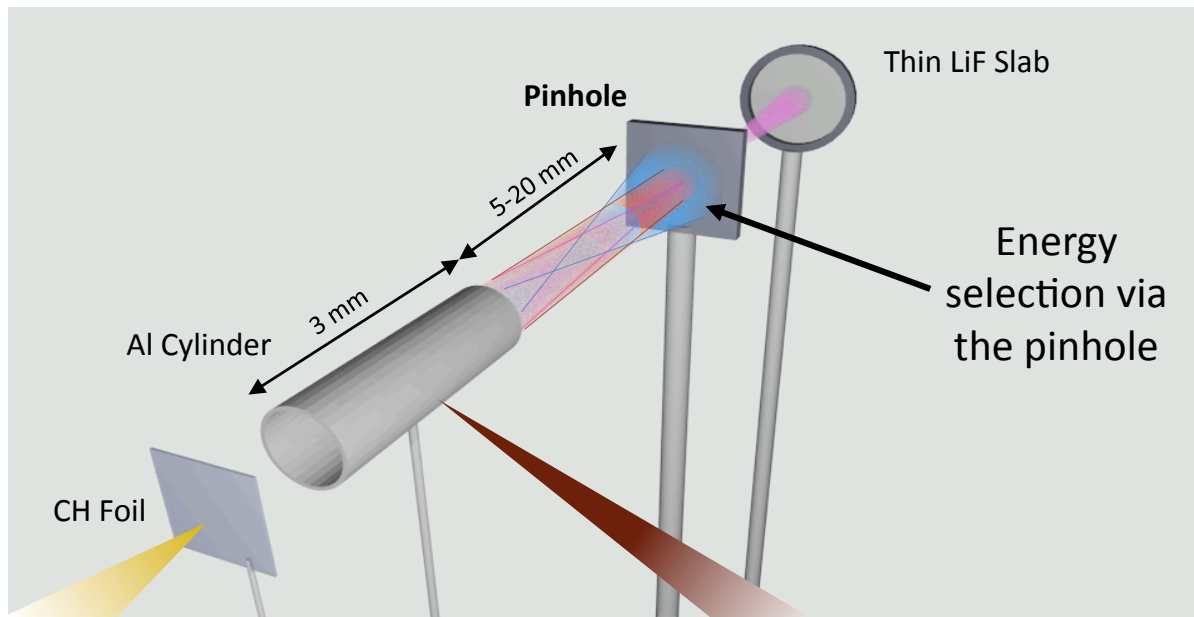
A neutron source with a flux of the order of 10^6 n/sr has been generated in the ELFIE facility

Proton focusing achieved experimentally with $\sim 30\%$ efficiency

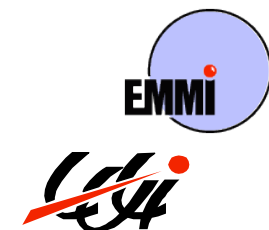
A low bandwidth neutron source has been observed

UPCOMING Experiment

**TITAN LASER FACILITY
LLNL**

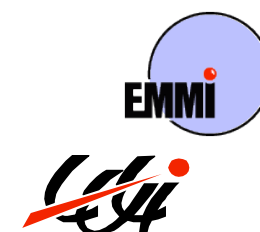


- ✓ Higher proton energy
- ✓ Higher proton flux
- ✓ Characterization of the low bandwidth neutron source



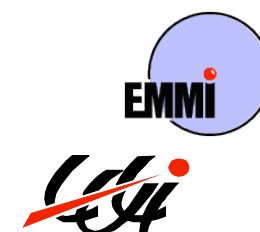


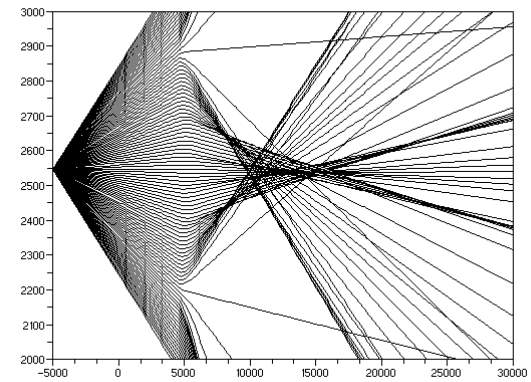
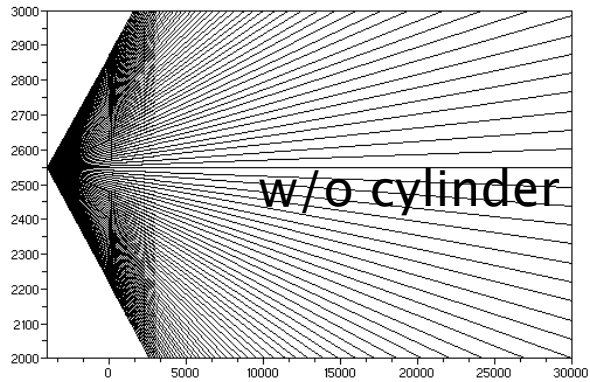
Thank you



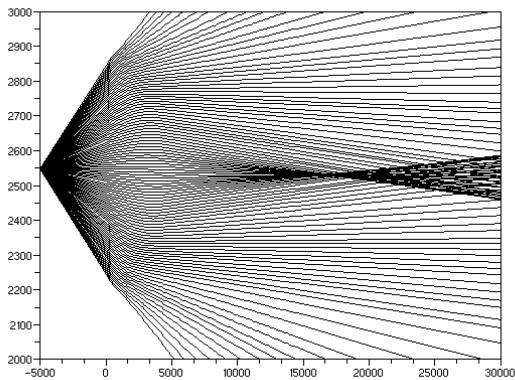


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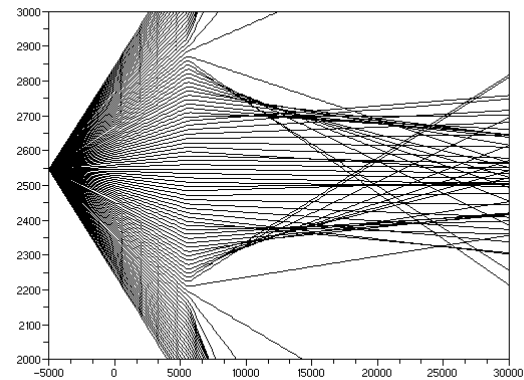




EARLY Triggered with 10^{20} W.cm⁻²



Triggered with 10^{19} W.cm⁻²



LATE Triggered with 10^{19} W.cm⁻²