FROM RESEARCH TO INDUSTRY

Irfu - CEA Saclay
Institut de recherche sur les lois fondamentales de l'Univers

VALIDATION OF THE PHYSICS MODELS IMPLEMENTED IN GEANT4 IN THE FRAMEWORK OF COMPACT NEUTRON SOURCES BASED ON LOW-ENERGY PROTON BEAMS

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www.cea.fr

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PURPOSE

Propose to develop the technologies necessary to build Compact Neutron Sources which could **replace the medium size research reactors,** especially involved in **fundamental physic studies** or **local sources for training** which can be:

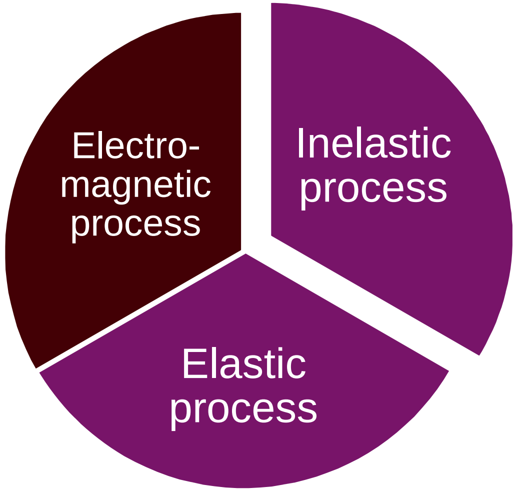
- Optimized the moderator (geometry, material, cold technology…).
- Optimized the shielding of the target due to gamma radiation.
- Optimized the cost of accelerator for particle beam.

Low energy reactions of protons and deuterons with Li or Be targets were more efficient at energy range below 20 MeV.

Need to qualify simulation tools at low-energy of protons (<20 MeV) and neutron physics via experiments

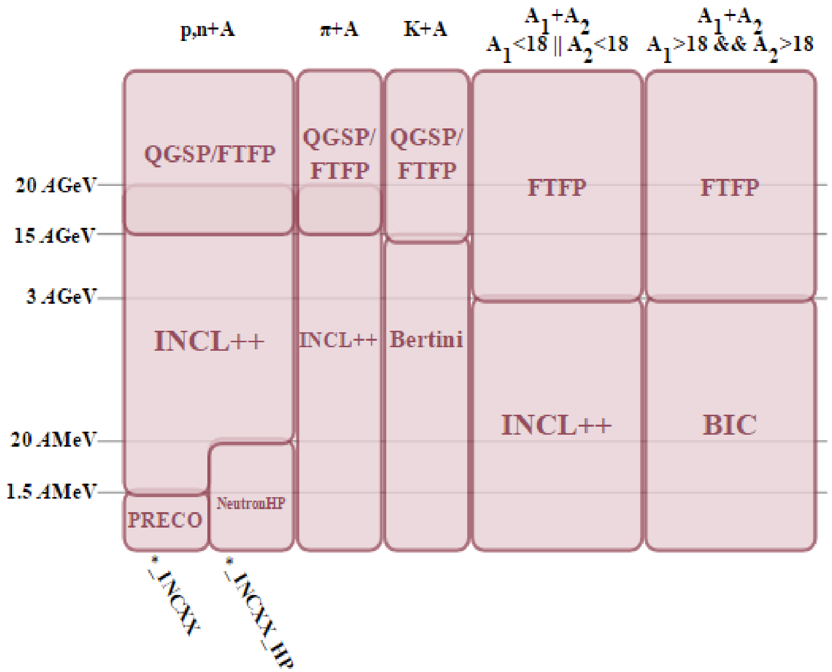
PHYSICS IN GEANT4 FOR BE(P,N) BELOW 20 MEV

- Option3 was provided (which designed for any applications required higher accuracy of electrons, hadrons and ion tracking without magnetic field).



- ChipsElasticModel (Chiral Invariant Phase Space)
- ChipsElastic cross section

- Barashenkov-Glauber cross section
- INCL++, BIC, BERT, AllHP models



Map of models for the INCLXX-based physics lists in Geant4 v10.1β.

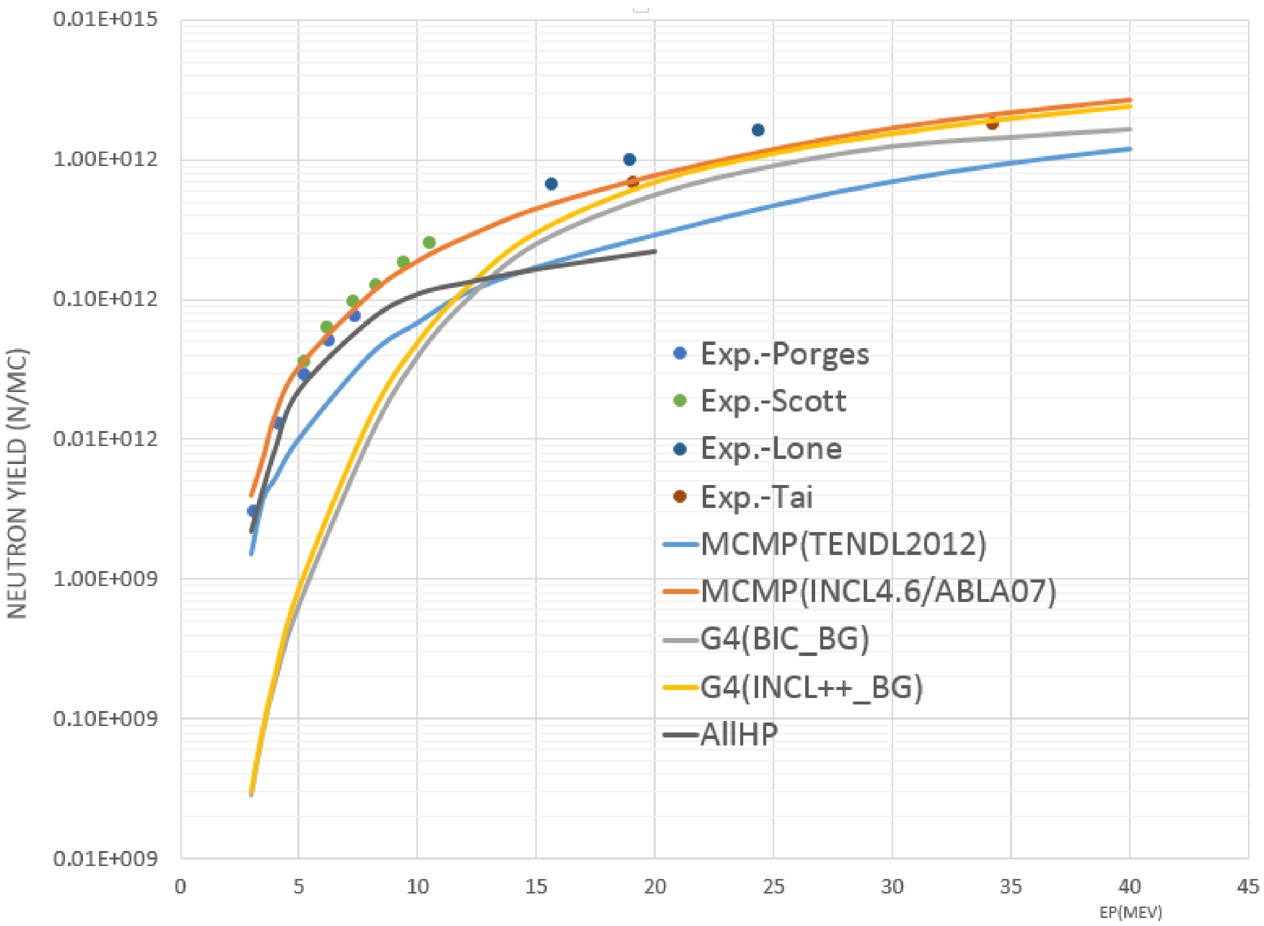
PHYSICS IN GEANT4 FOR BE(P,N) BELOW 20 MEV

Reference Physics Lists

- BIC_HP
- INCL++_HP
- AllHP (by default)

Using Glauber model with Gribov correction (Barashenkov-Glauber cross section)

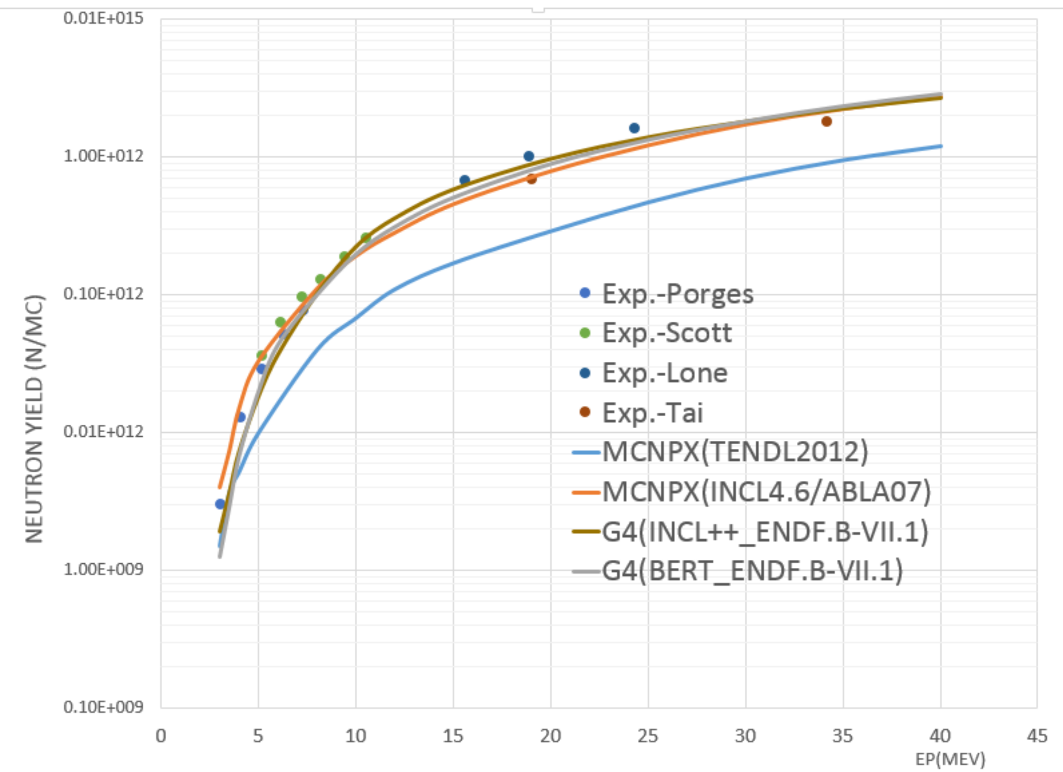
Geant4.10.02



=>The result shows an underestimation at low energy range (from 3 MeV to 20 MeV)

ENDF.B-VII.1 data cross section in Geant4

Beam energy (MeV)	G4(INCL++_ENDF.B-VII.1)	G4(BIC_ENDF.B-VII.1)	G4(BERT_ENDF.B-VII.1)
3	1.91E+11	1.91E+11	1.25E+11
3.5	3.68E+11	3.61E+11	2.91E+11
4.0	7.30E+11	6.67E+11	6.75E+11
5.0	1.84E+12	1.43E+12	1.99E+12
6.0	3.69E+12	2.45E+12	4.32E+12



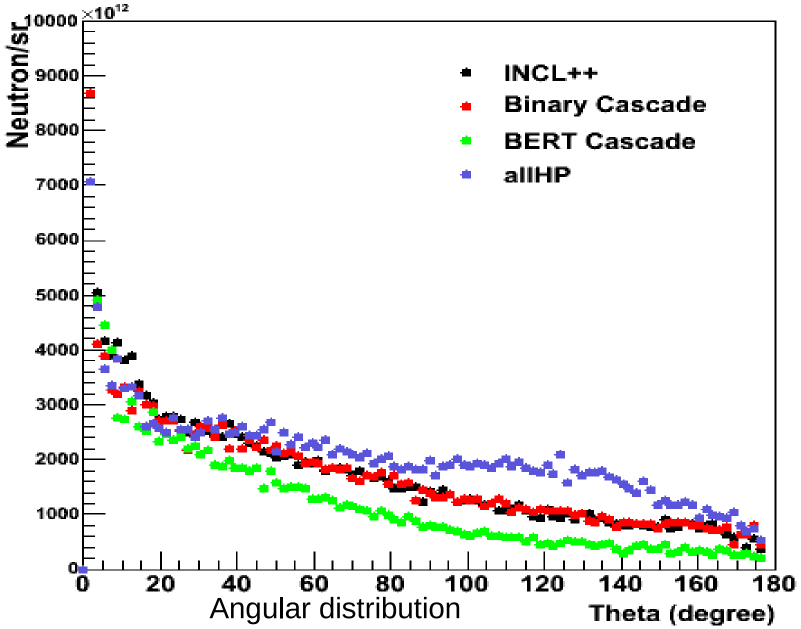
Experience

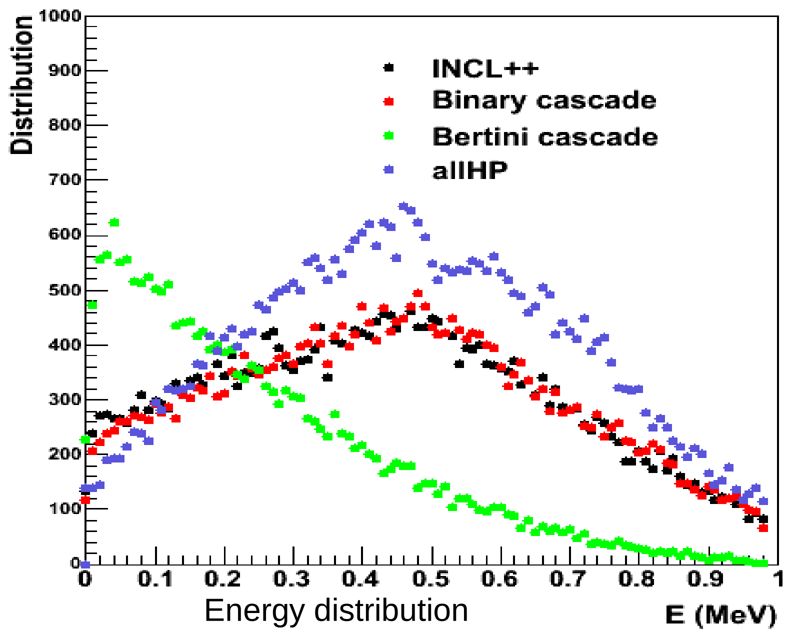
Proton (MeV)	Neutron Yield
3.05	3.04427E+11
4.09	1.30406E+12
5.17	2.91232E+12

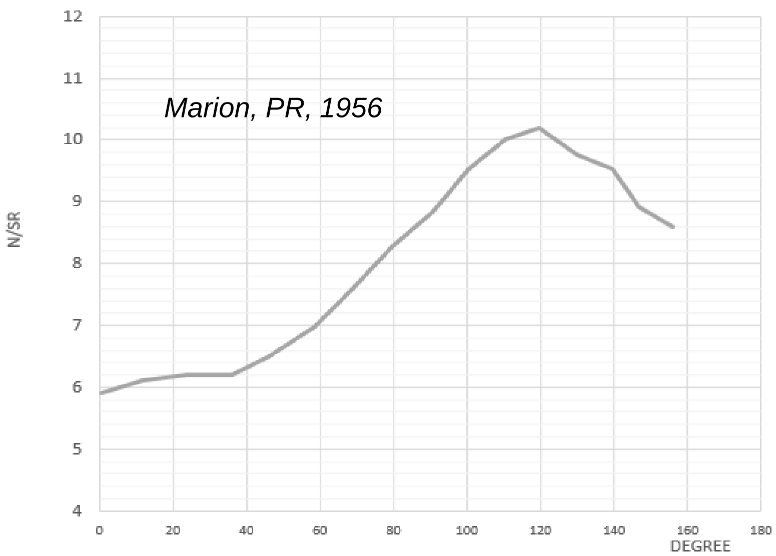
Lone, 1992, NDN

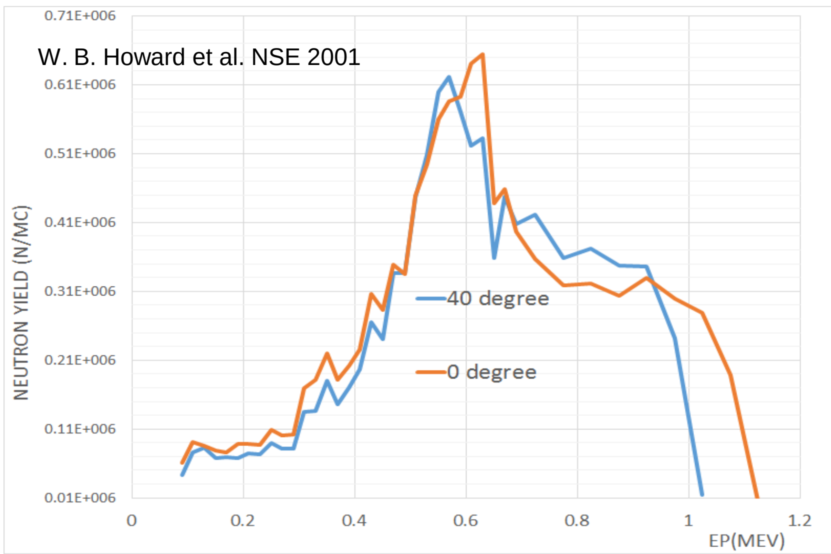
=> The simulations show **a factor 2 lower** than experimental data at low energy of proton (3 MeV – 6 MeV)

DISTRIBUTIONS OF REACTION BE(P,N) AT 3 MEV









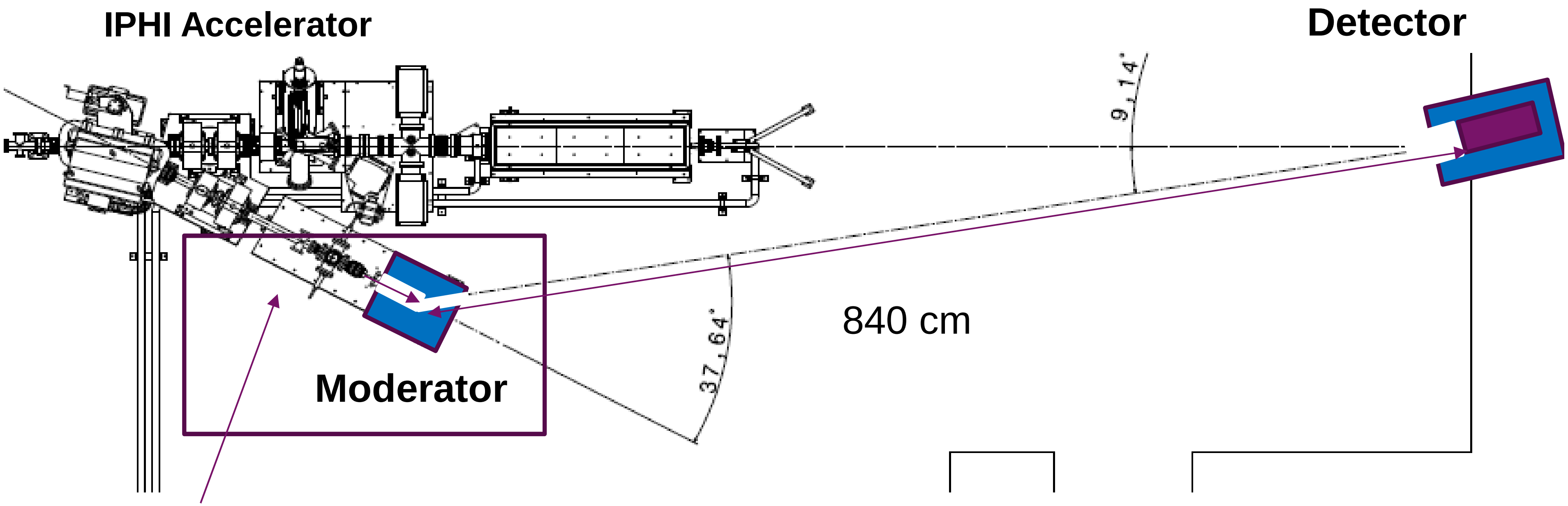
NEUTRON PHYSICS

1. Experiment
2. Comparison

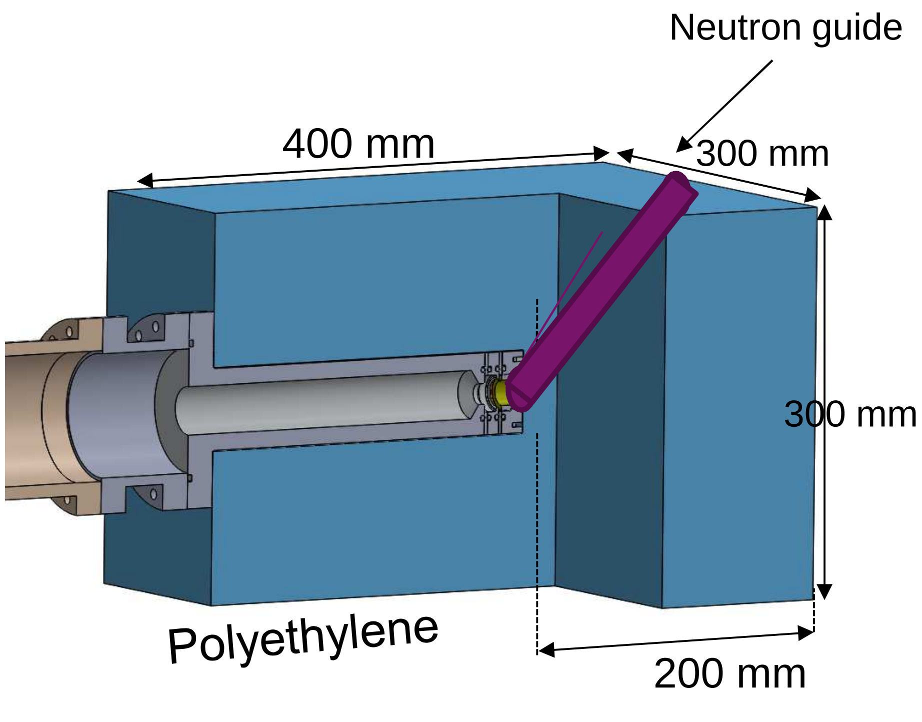
EXPERIMENT

To qualify simulation tools as Geant4, MCNP

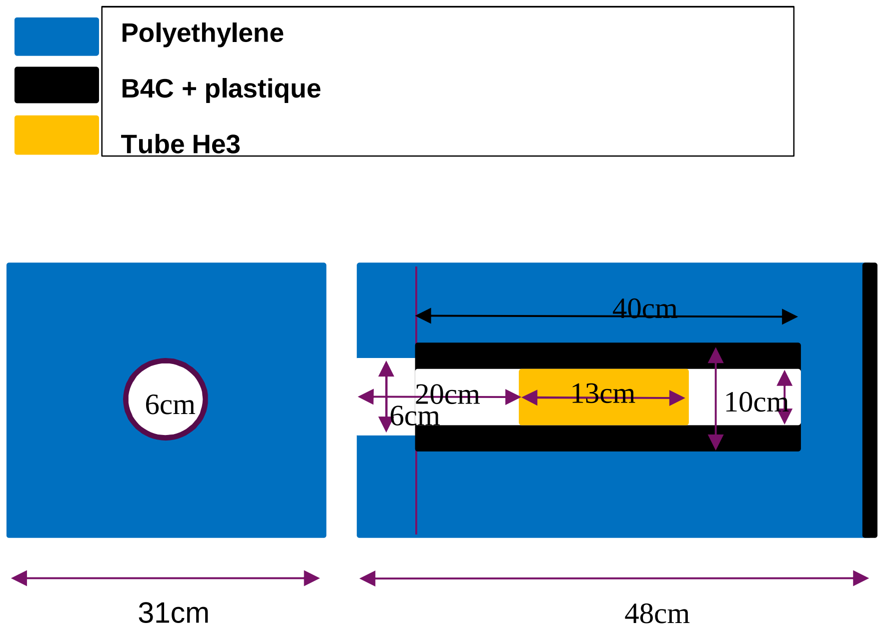
- Moderator in **polyethylene (blue)** : 30 x 40 cm,
- Proton beam 3 MeV and the current between 2.6 and 3.2 uA (~1.88E+13 proton/s),
- Angle of detector 38 degree,
- The distance from the beryllium target to **detector (violet)**: 840 cm.



- A neutron guide (cylinder hole and vacuum) at 38 degree,
- Diameter of neutron guide 2 cm,
- He3 detector was shielded by polyethylene and B4C to avoid reflected neutron from the walls



moderator



Detector case

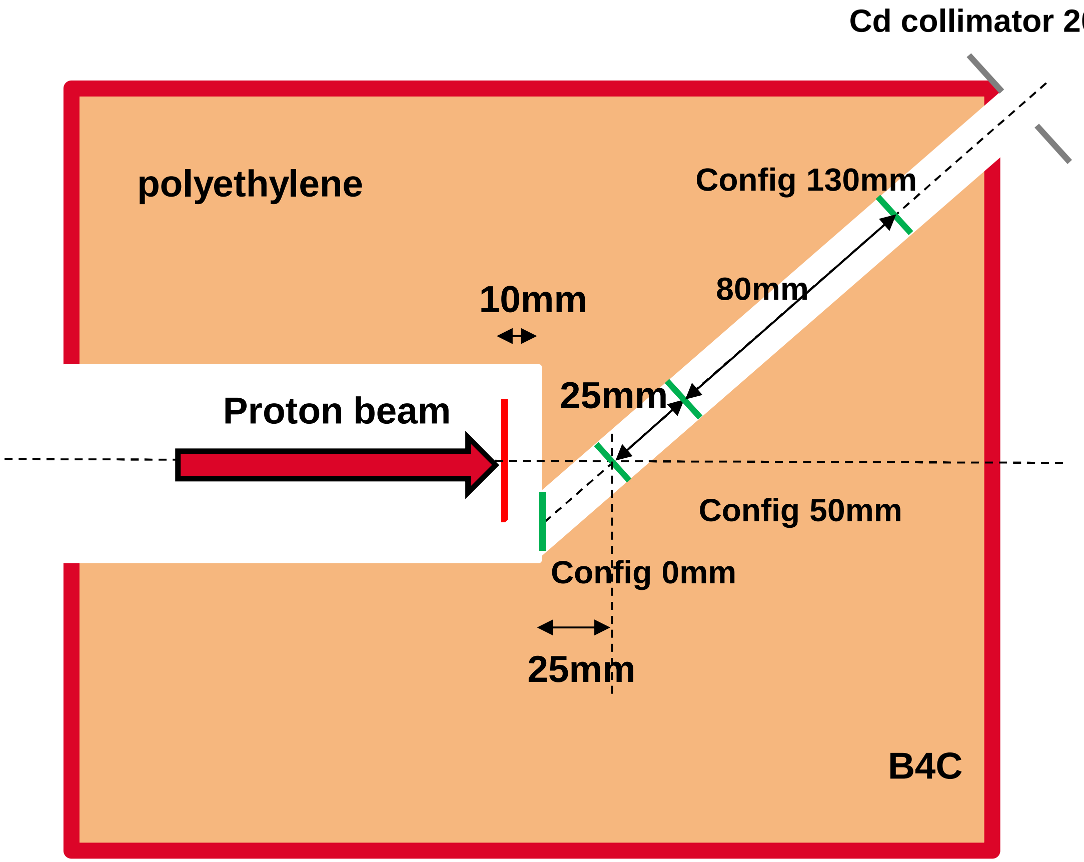
EXPERIMENT

Support tube

Moderator

Detector was shielded by polyethylene and B4C

CONFIGURATIONS OF MEASUREMENT



- **Config 0 mm** : No polyethylene inside the neutron guide.
- **Config 50 mm with B4C (**BORON_CARBIDE) : 50 mm polyethylene inside the neutron guide from support tube. There is a B4C layer around moderator.
- **Config 50 mm without B4C** : as config 50 mm but no a B4C layer.
- **Config 130 mm with B4C**: 130 mm polyethylene inside the neutron guide from support tube. There is a B4C layer around moderator.

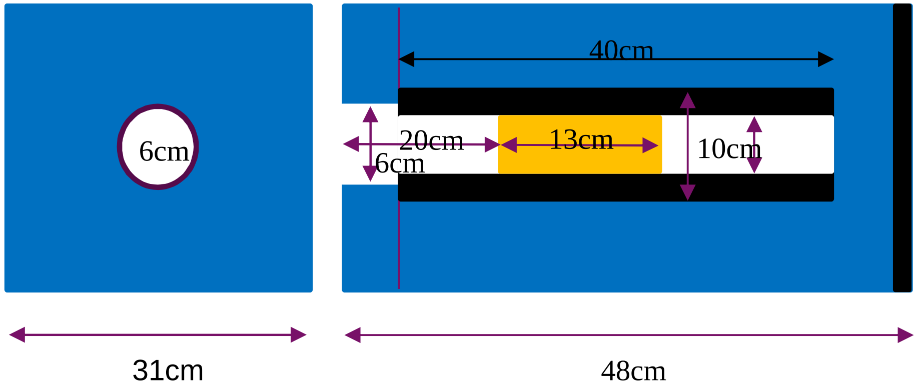
Neutron Time-of-Flight (TOF) mode:

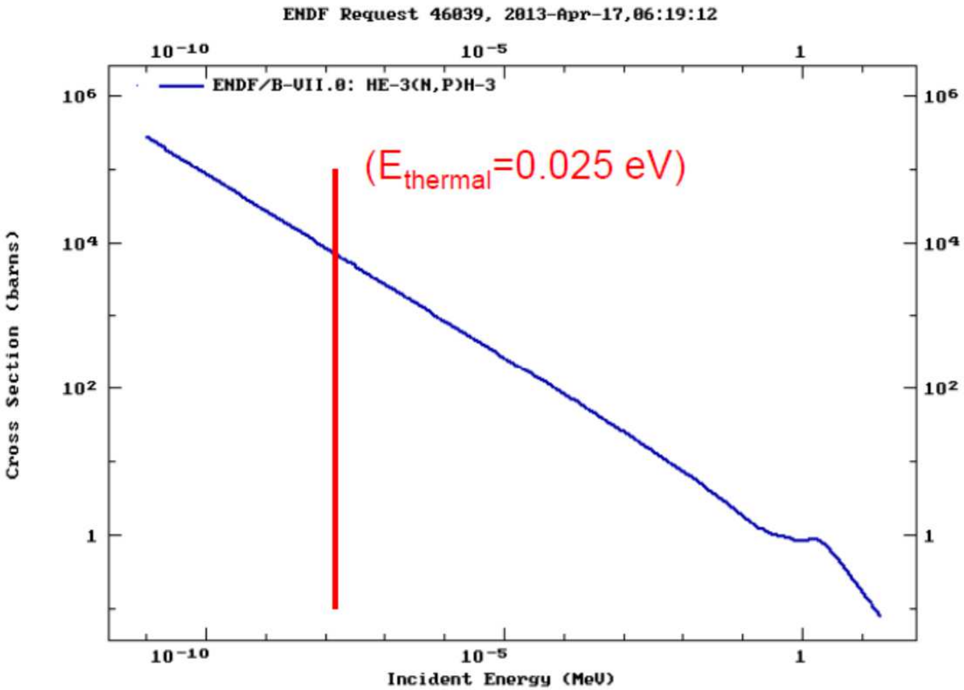
- step width: 20 µs,
- range: 10 ms,
- number of bin : 500 bins

He3 – Detector: 5 cm x 13 cm, 5 barns (0.86 kg/m3).

was synchronized with the clock signal of the accelerator radio-frequency

n + 3He -> proton + triton

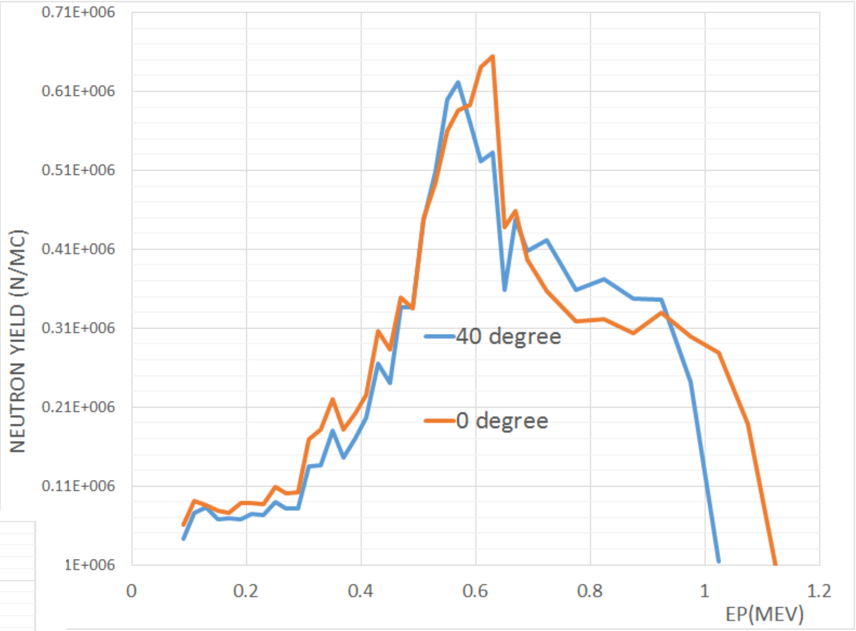




SIMULATION: NEUTRON SOURCE OF REACTION BE(P,N) AT 3 MEV

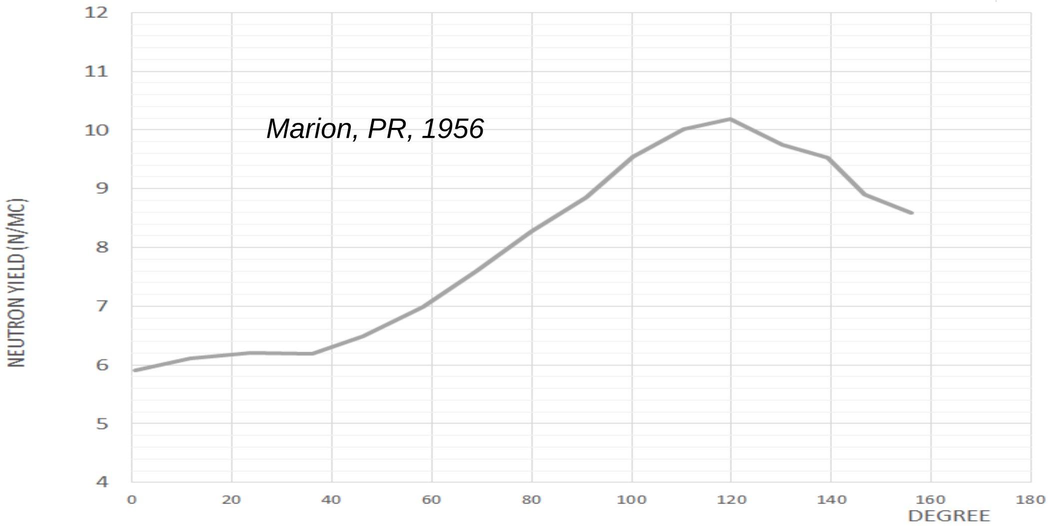
Proton	Neutron Yield
3.05E+00	3.04427E+11
4.09E+00	1.30406E+12
5.17E+00	2.91232E+12

Lone, 1992, NDN



Distribution of energy

Angular distribution



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Moderator

```
G4Element* C = new
G4Element("Carbon","C", 6,
12.00*g/mole);
G4Element* H_P = new
G4Element("TS_H_of_Polyethylene"
,"H_P", 1., 1.0079*g/mole);
G4Material* Polyethylene = new
G4Material("Polyethylene_ts",
0.94*g/cm3, ncomponents=2,
                        kStateLiquid,
293*kelvin, 1*atmosphere);
Polyethylene->AddElement(C,
natoms=1);
Polyethylene->AddElement(H_P,
natoms=2);
```

Detector

```
G4Isotope* he3 = new G4Isotope("he3",2,3);

G4Element* He3 = new
    G4Element("He3","He3", ncomponents=1);

He3->AddIsotope(he3,100.*perCent);

G4Material* He3Gas = new
    G4Material("He3Gas",0.86*kg/m3,
    ncomponents=1,kStateGas,293*kelvin,5*bar
    );

 He3Gas->AddElement(He3, natoms=1);
```

Physiclist

All neutron processes were activated:

```
// Create process: elastic
  G4HadronElasticProcess* process1 = new G4HadronElasticProcess();
  // Create process: inelastic
  G4NeutronInelasticProcess* process2 = new G4NeutronInelasticProcess();
  // Create process: nCapture
  G4HadronCaptureProcess* process3 = new G4HadronCaptureProcess();
  pManager->AddDiscreteProcess(process3);
```

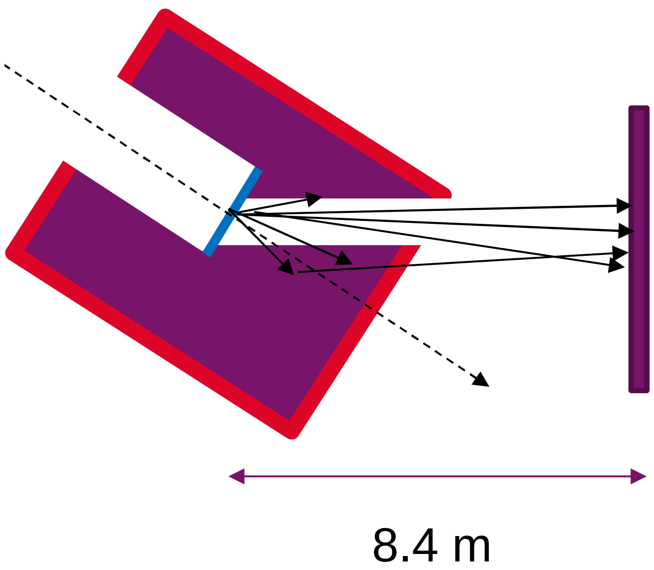
The thermal process was defined in the class **G4ParticleHPThermalScattering.**

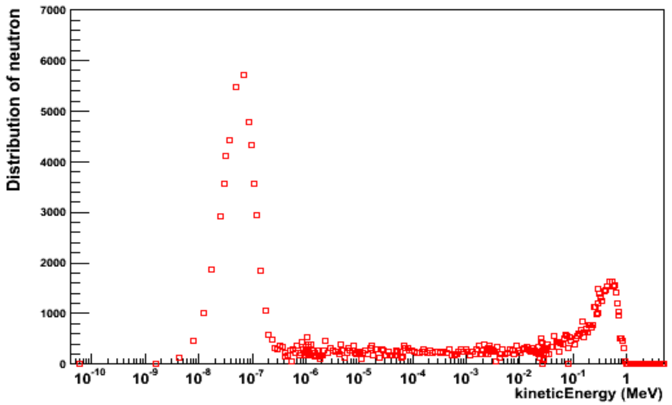
```
if (fThermal) {
    model1a->SetMinEnergy(4*eV);
    G4ParticleHPThermalScattering* model1b = new G4ParticleHPThermalScattering();
    process1->RegisterMe(model1b);
    process1->AddDataSet(new G4ParticleHPThermalScatteringData());
  }
```

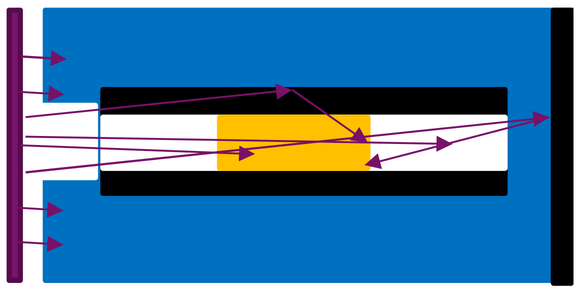
GEANT4 SIMULATION

To reduce calculation time, we separated the simulation into 2 steps:

- The first step: we simulated neutron from moderator and we registered the **distributions of energy and angle** of neutron and **position** of neutron on the face of detector case.
- The second step: we detected the reaction n + 3He -> proton + triton inside the detector He3 from the distributions of energy and angle.
- We recorded the energy distribution of neutron which reacted with 3He.

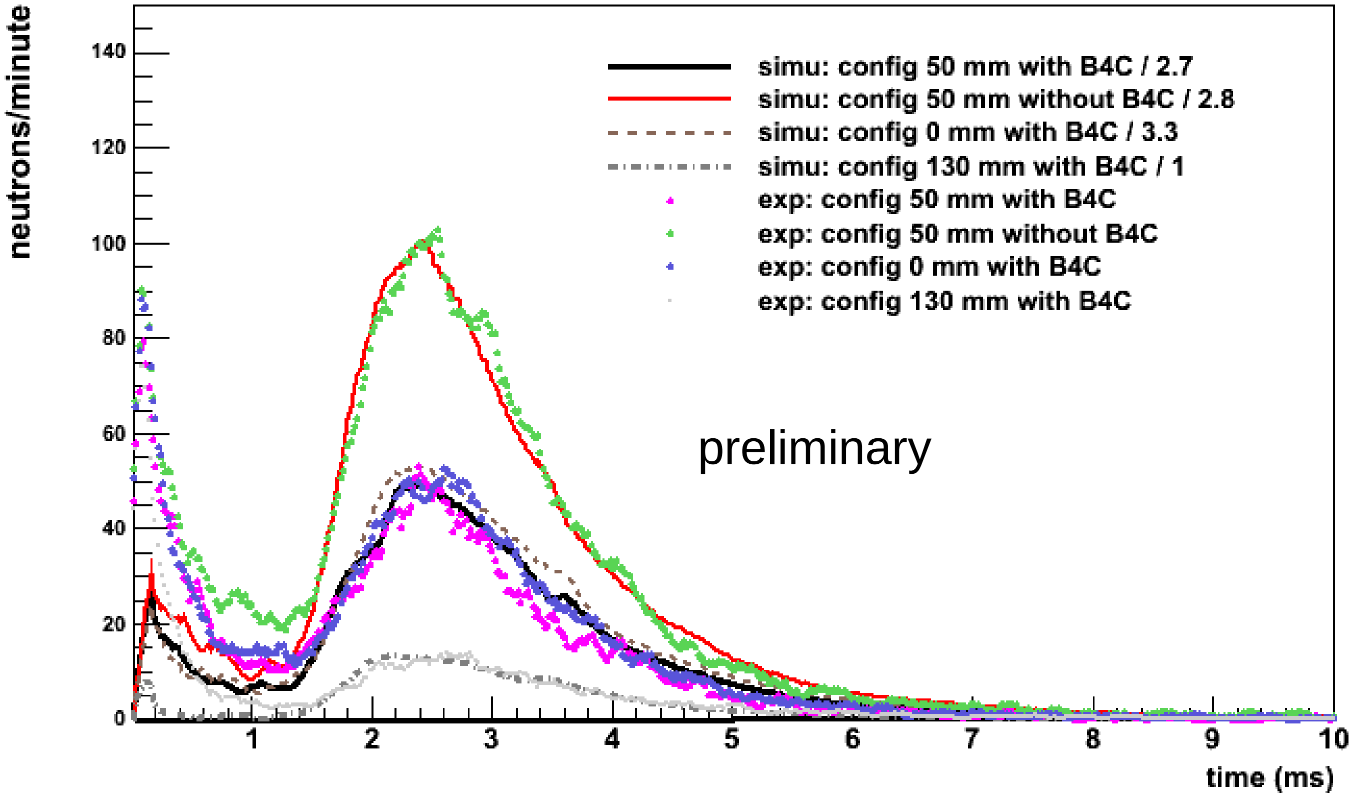






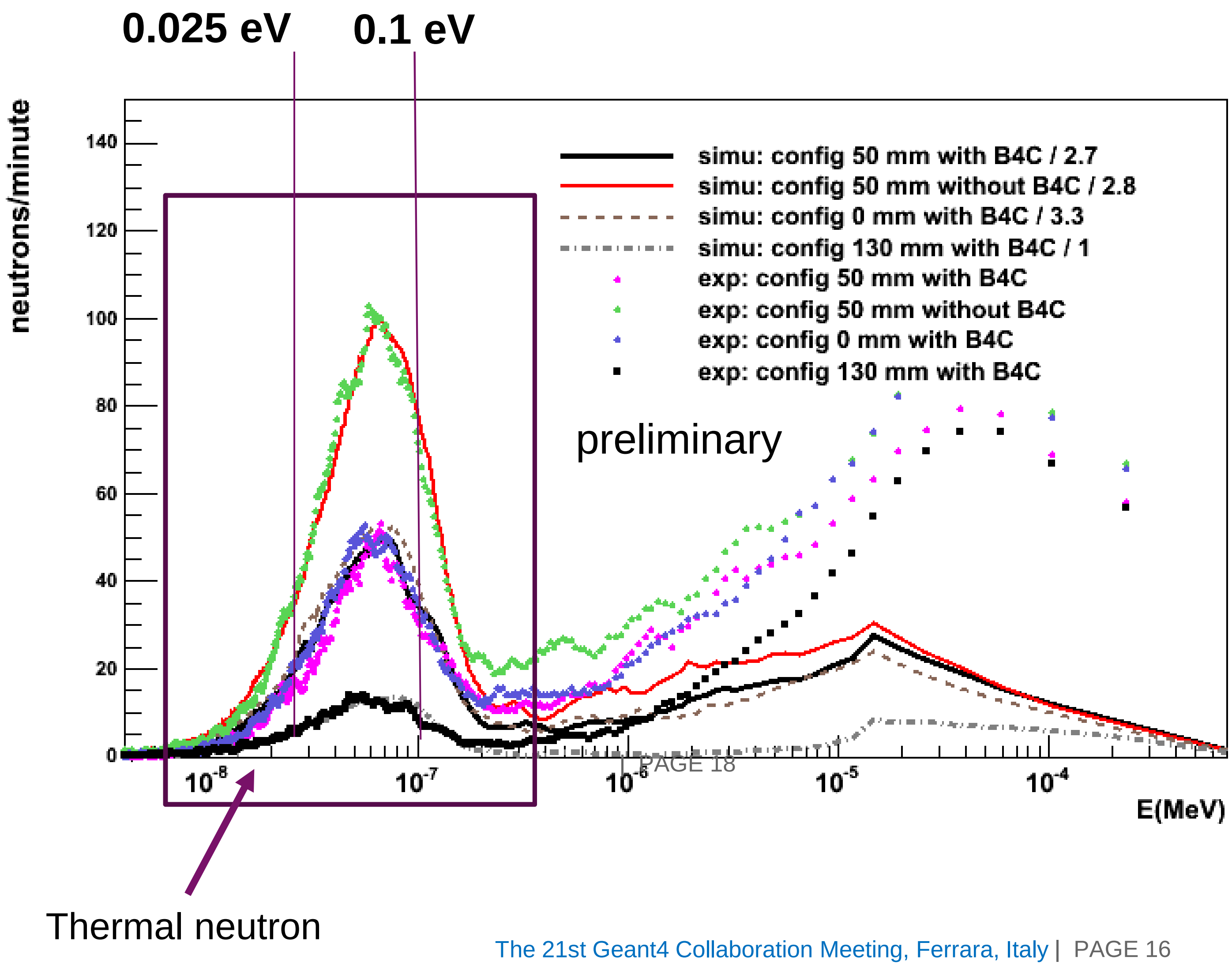
COMPARISON: TOF

1. From energy distribution of neutron on detector, we can deduce the time of flight by simulation.
2. The factors show the differences of neutron number between experimental data and simulation.
3. By adjusting the neutron production from the target, the results agree almost perfectly for exp. data and Geant4



COMPARISON: ENERGY DISTRIBUTION

1. A agreement in the form at the thermal region with the Maxwellian distribution calculated by Geant4 and experimental data.
2. The pics at Intermediate and fast regions come from the limit of response-time of detector.



CONCLUSION

1. In the reaction Be(p,n), the simulations show a factor 2 lower than experimental data at low energy of proton.
2. In the neutron physics, by adjusting the neutron number from the target, the results agree almost perfectly for experimental data and Geant4 in distribution of energy of neutron at thermal region.

Thank you for your attention

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NEUTRON SOURCE

Walker et al., PW 1965,

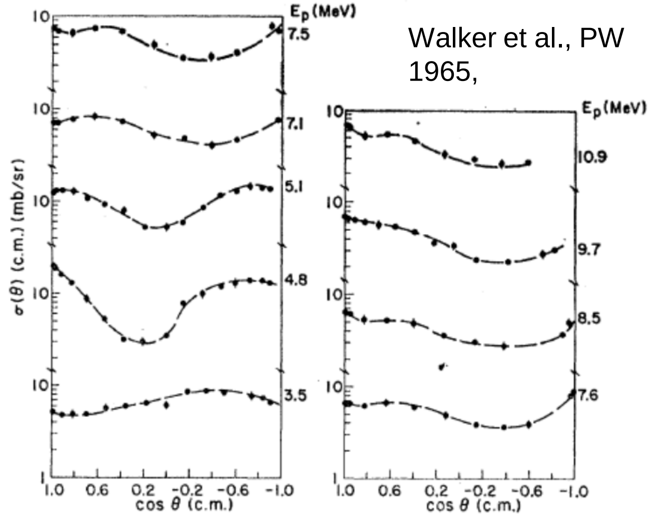
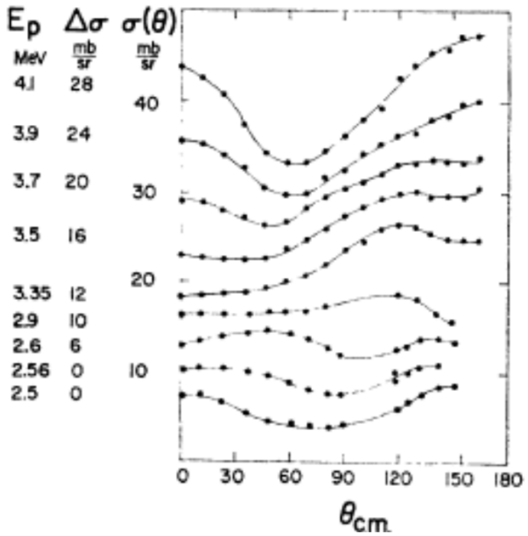


FIG. 2. Center-of-mass absolute differential cross sections for the $Be^9(p,n_0)B^9$ reaction versus laboratory bombarding energy.

Kelsey et al., PR, 1963



Marion, PR, 1956

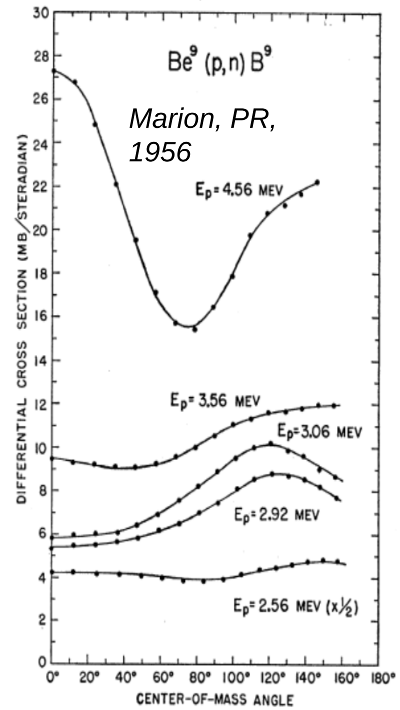


FIG. 2. Angular distributions of the neutrons from the $Be^9(p,n)B^9$ reaction at bombarding energies of 2.56, 2.92, 3.06, 3.56, and 4.56 Mev. The angular resolution was ±5°.

W. B. HOWARD ET AL, NUCLEAR SCIENCE AND ENGINEERING: **138**, 145–160 2001

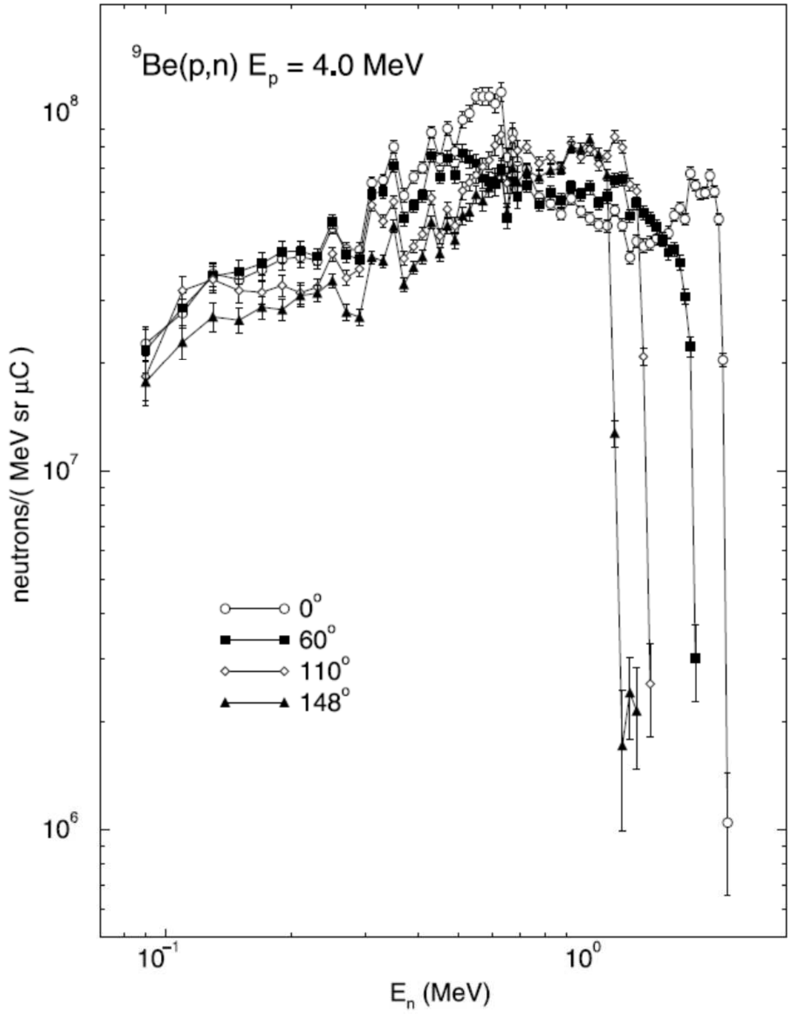


Fig. 10. The ^{9}Be(p,n) neutron spectra at three angles for $E_p = 4.0$ MeV.

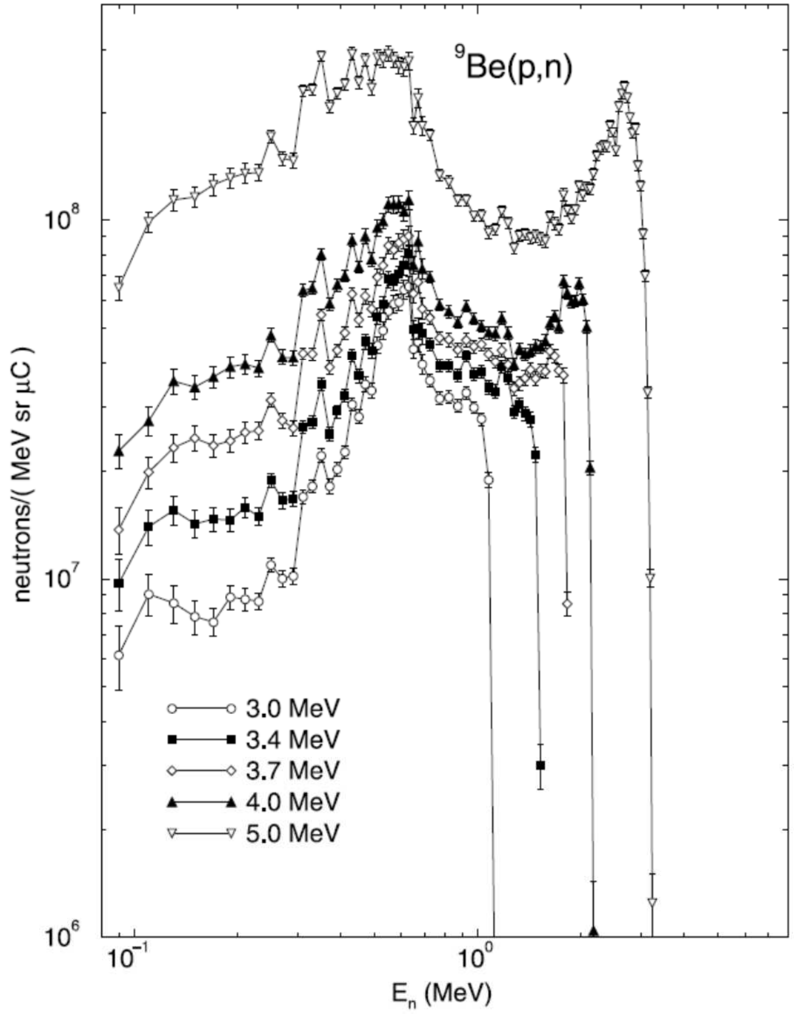


Fig. 11. The ^{9}Be(p,n) neutron spectra at 0 deg for four energies.