Monte Carlo Simulations of Nuclear Physics Experiments Using NPTool

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Outline

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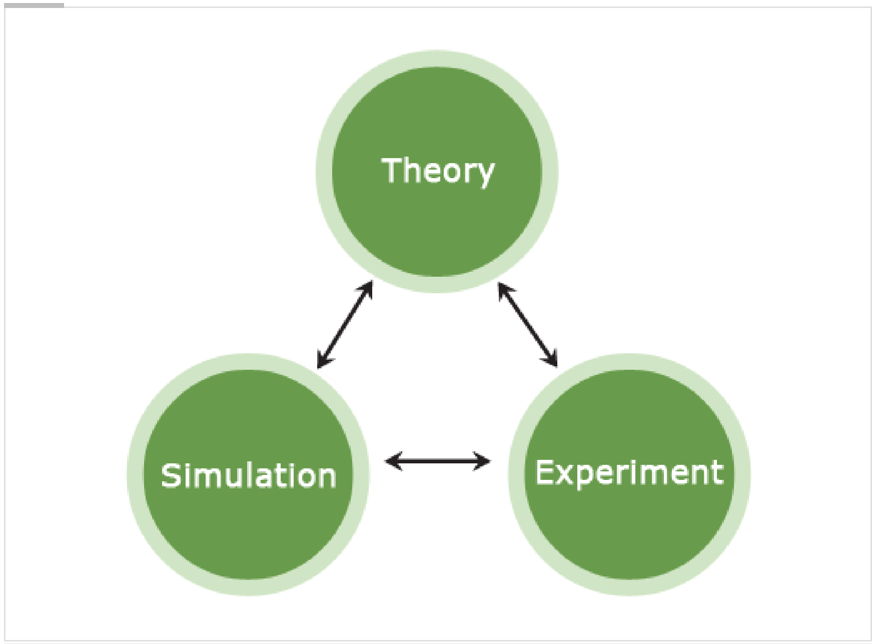
- Monte Carlo Simulations
- Simulations in Nuclear Physics Experiments
- The IS554 Experimental Setup
- Silicon as charge sensor detectors
- NPTool Simulations
- Geometrical efficiency of detector setup
- Nuclear Astrophysics at Bose Institute
- ^{7}Be + d reaction and higher excited states of ^{8}Be*
- Study of α - cluster transfer reaction of ^{7}Be
- Deuteron target breakup with ^{7}Be
- Outlook

Introduction to Simulations

Simulation is the imitation of the operation of a process or dynamical system.

- **Reduces chances of failure.**
- **Prevents over utilization of resources.**
- **Optimizes the performance.**



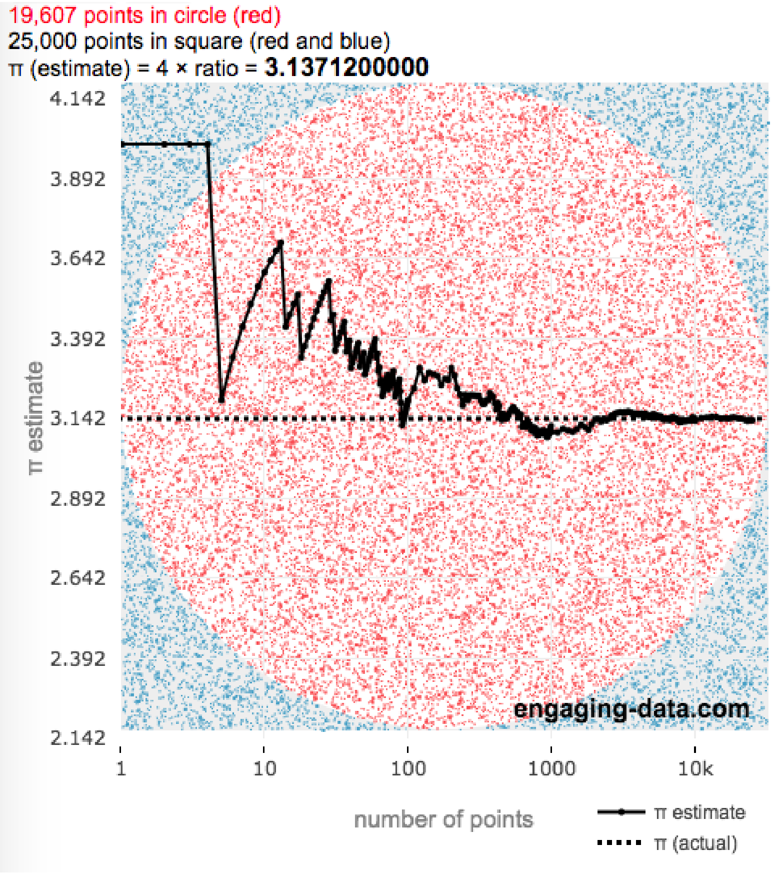
Monte Carlo Simulations

Monte Carlo Simulation is a model used to estimate possible outcomes of random events.

Probabilistic interpretation of an event through random number generators.

Its a mathematical model; but It has not any analytical solution.

It can reduce complex models to a set of basic instructions and events.



It was used initially in the developement of atom bombs in Los Alamos National Lab.

Simulations in Nuclear Physics Experiments

It is necessary to decide some preliminary things to carry out the simulations of nuclear experiments. Detailed Monte Carlo simulation is essential to determine these things.

- Possible emitting particles and its energy range
- Optimum thickness of target and detectors
- Detector geometry

The IS554 Experiment at ISOLDE

PI : Prof. Dhruba Gupta, Bose Institute

5 MeV/u ^{7}Be (Radioactive ion beam)

CD_2 (15 μm), CH_2 (15 μm) and ^{208}Pb targets (1 mg/cm^2)

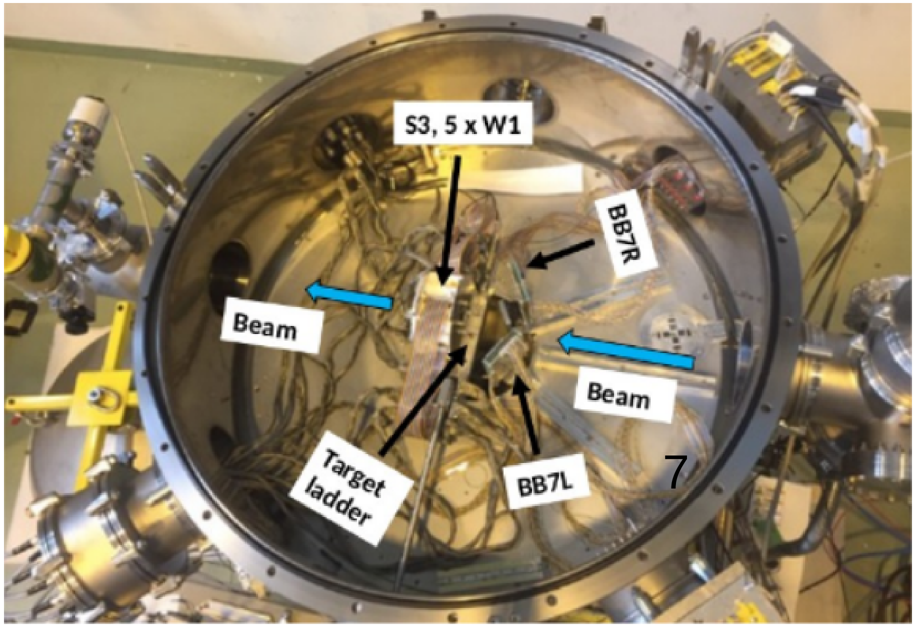
Beam intensity ~ 5 x 10^5 pps

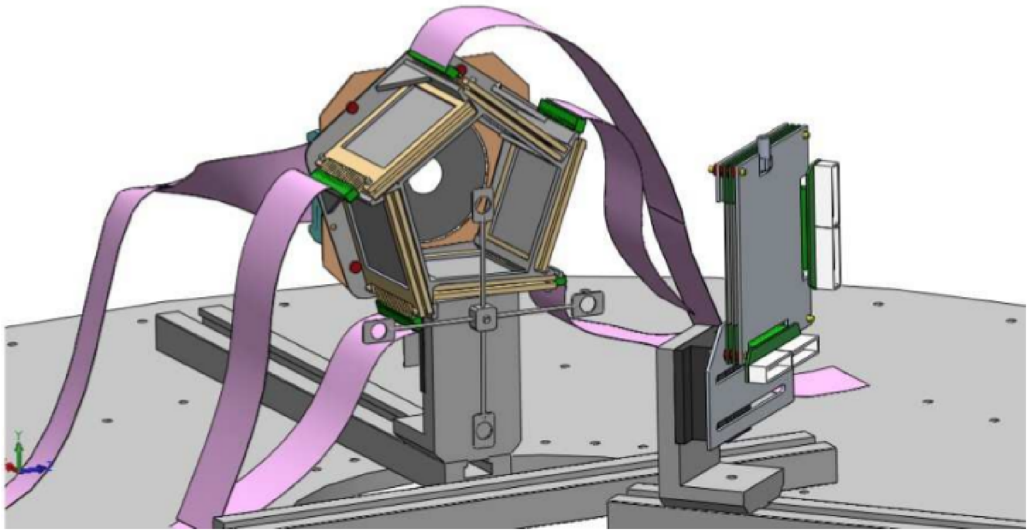
Wide angular coverage of detectors : 8^o – 165^o

IS554 collaboration

Bose Institute · CSIC · Lund University · Universidad de Huelva · University of Liverpool · University of Jyväskylä · ISOLDE · CERN

Experimental Setup

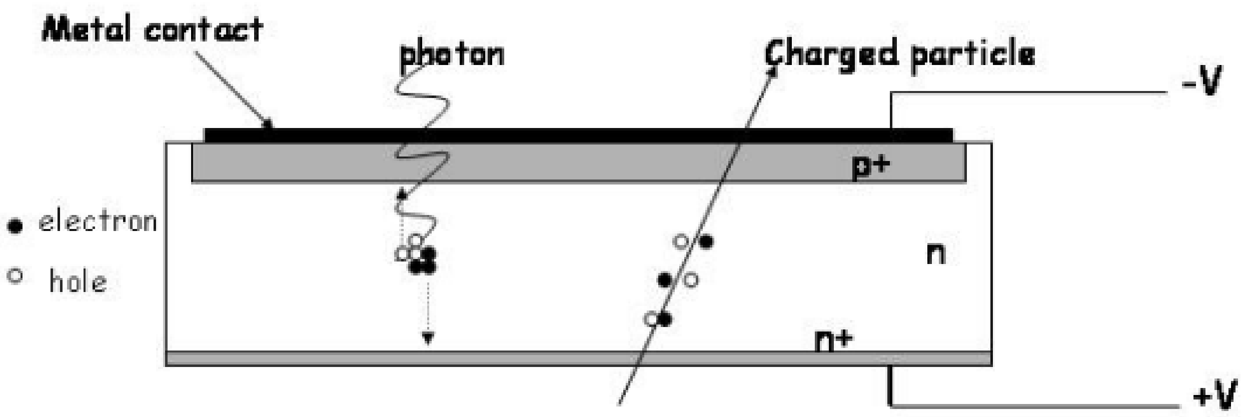


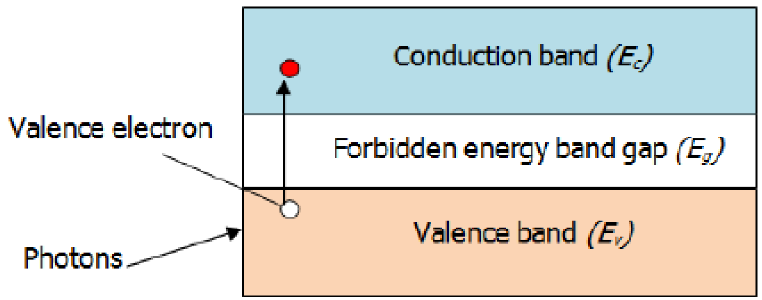


Charged particle detector setup

- **1 x S3 annular DSSD (24 x 32 strips, 1000 μm) covering front angles 8º – 25º**
- **5 x W1 DSSD (16 x 16 strips, 60 μm) in pentagon geometry covering angles 40º – 80º**
- **2 x BB7 DSSD (32 x 32 strips, 60 μm and 140 μm) covering back angles 127º – 165º**
- **The W1 and BB7 DSSDs are backed by 1500 μm thick unsegmented pads**
- **Total solid angle coverage of setup is about 31.9 % of 4π.**

Silicon as charge sensor detectors

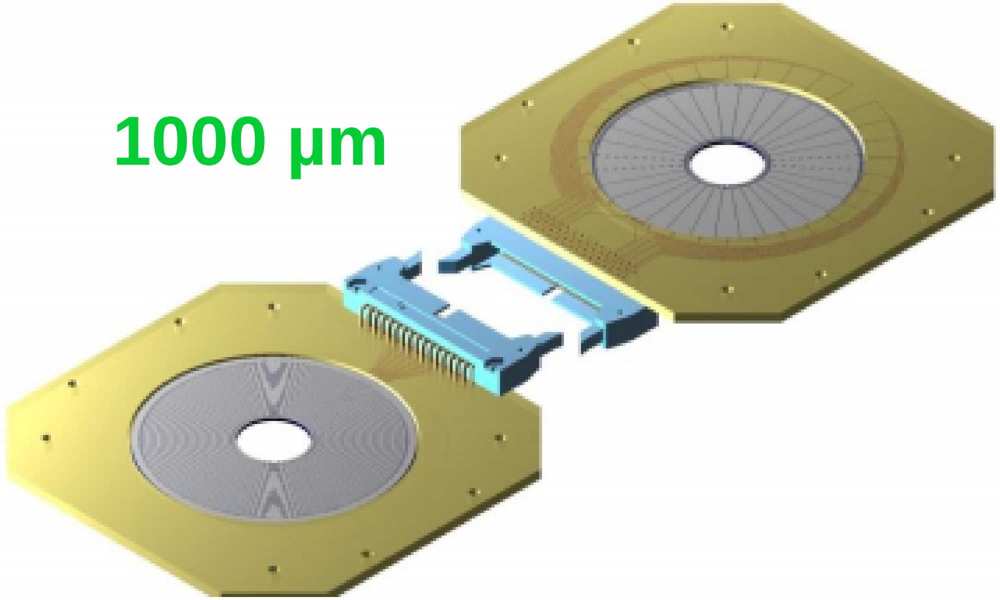




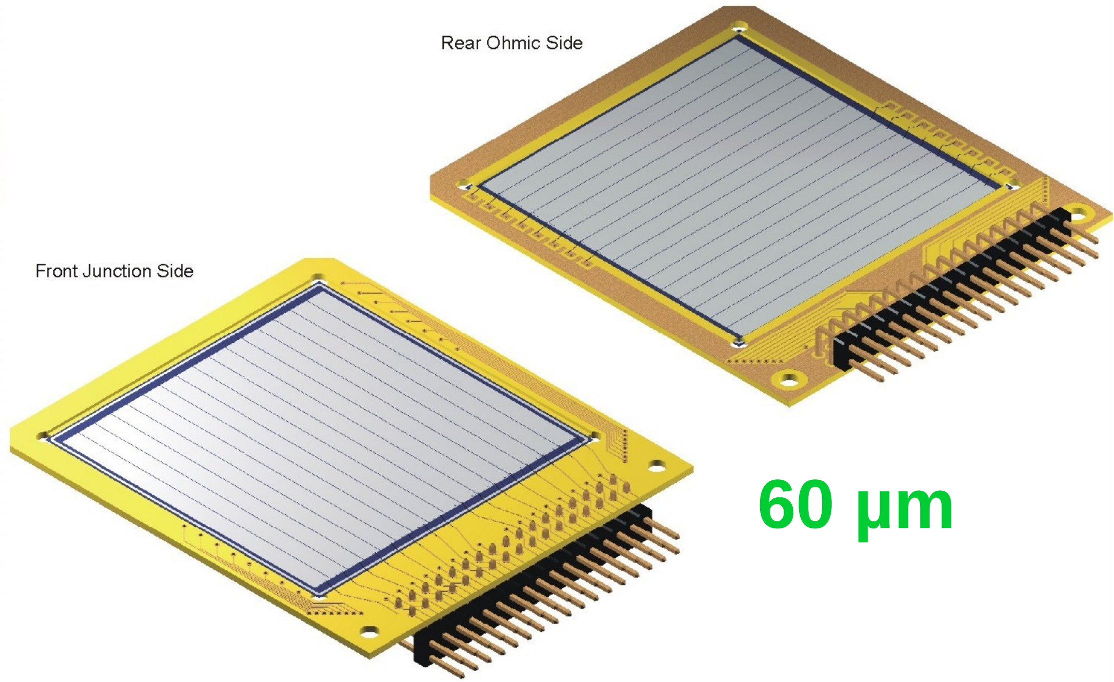
- **Depletion layer in the semiconductor behaves as a nuclear detector.**
- **Reverse biased connection creates large depletion region.**
- **Charged particles enter the depletion region and produce e-h pairs.**
- **Amount of energy neccessary to create e-h pair ~ 3 eV (very less).**
- **This moving electrons through circuit leads to the potential drop ~ current pulse.**

Detectors used in IS554

1000 µm



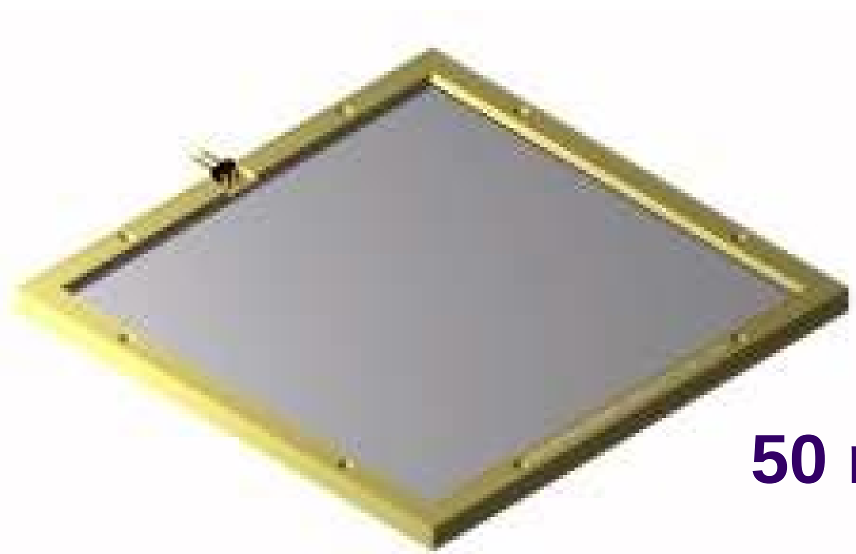
Annular S3 (24 x 32 strips)



60 µm

50 mm x 50 mm DSSDs

(16 x 16 strips)



1500 µm

50 mm x 50 mm Pad Detectors

Introduction to NPTool

- **Nuclear Physics Tool (NPTool) is an open source and Monte Carlo simulation framework.**

- **Used for data analysis and simulation of low energy nuclear physics.**

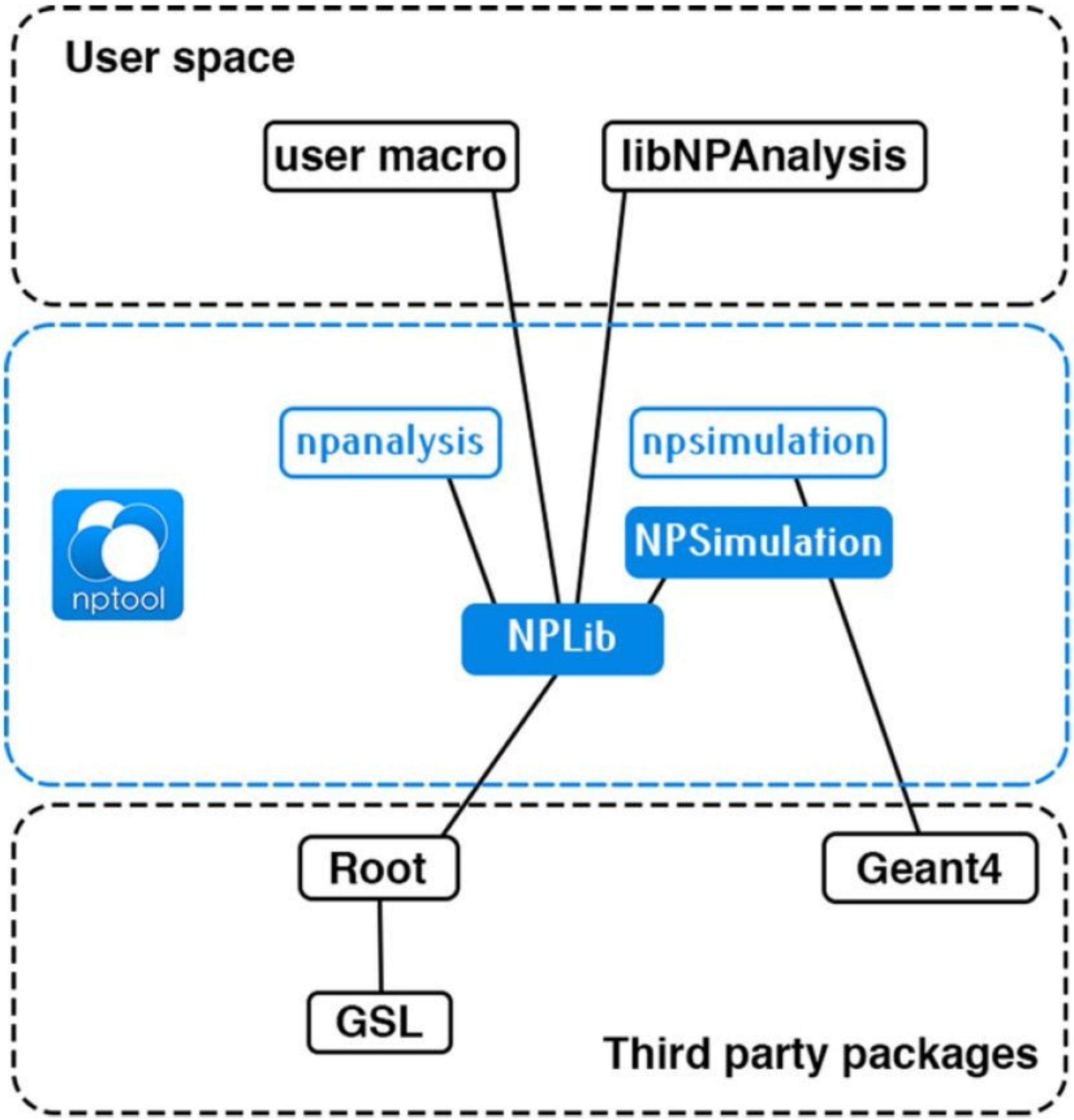
https://github.com/adrien-matta/nptool

- **It is based on Geant4 and ROOT CERN.**

- **NPTool offers unified framework for designing, preparing and analysing complex experiments employing multiple detectors.**

- **Successfully used in experimental facilities including GANIL, RIKEN, ALTO and TRIUMF.**

Structure of NPTool



A. Matta et al.,
J. Phys. G: Nucl. Part. Phys.
43, 045113 (2016)

NPTool Simulation

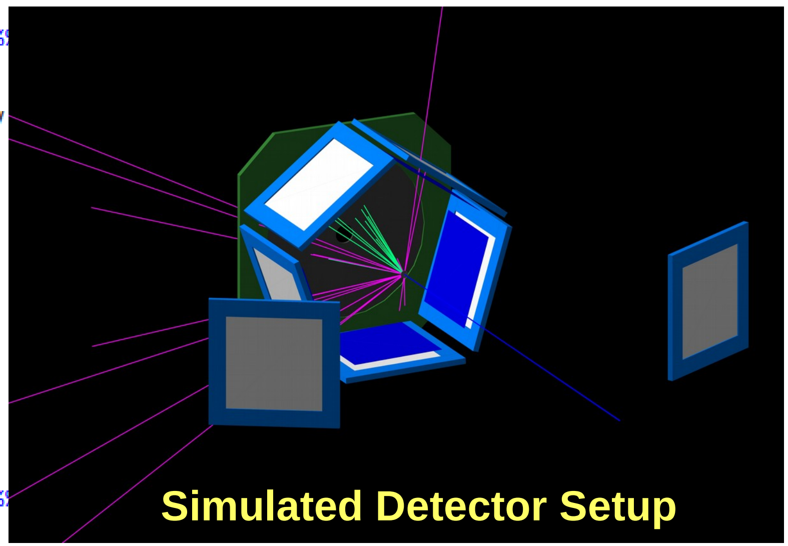
Detector Configuration

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
IS554 Detector Config
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
Target
 THICKNESS= 15 um
 RADIUS= 2 mm
 MATERIAL= CD2
 ANGLE= 0 deg
 X= 0 deg
 Y= 0 deg
 Z= 0 deg
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
AnnularS3
 Z=   74.1 mm
%%%%%%%% Detector 1 %%%%%%%%
W1
 X1_Y1= -47.951      24.898      9.13 mm
 X1_Y16=-47.951      24.898      59.63 mm
 X16_Y1= -6.421      53.616      9.13 mm
 X16_Y16=-6.421      53.616      59.63  mm
 VIS= all
%%%%%%%% Detector 2 %%%%%%%%
W1
 X1_Y1= -38.497      -37.91      9.13 mm
 X1_Y16=-38.497      -37.91      59.63 mm
 X16_Y1=-52.497      10.462      9.13 mm
 X16_Y16=-52.497     10.462      59.63 mm
 VIS= all
%%%%%%%% Detector 3 %%%%%%%%
W1
 X1_Y1= 24.16       -48.83      9.13 mm
 X1_Y16= 24.16      -48.83      59.63 mm
 X16_Y1= -26.32     -47.15      9.13 mm
 X16_Y16= -26.32    -47.15      59.63 mm
 VIS= all
%%%%%%%% Detector 4 %%%%%%%%
W1
 X1_Y1= 36.7092     -39.602     9.13 mm
 X1_Y16=36.7092     -39.602     59.63 mm
 X16_Y1=53.428      8.042       9.13 mm
 X16_Y16=53.428     8.042       59.63  mm
 VIS= all

%%%%%%%% Detector 5 %%%%%%%%
W1
 X1_Y1= 8.862       53.298      9.13 mm
 X1_Y16=8.862       53.298      59.63 mm
 X16_Y1= 49.008     22.675      9.13 mm
 X16_Y16=49.008     22.675      59.63  mm
 VIS= all
%%%%%%%% BB7R %%%%%%%%
W1
 X1_Y1= -150.33     32          -83.84 mm
 X1_Y32=-94.04      32          -116.35  mm
 X32_Y1= -150.33    -33         -83.84 mm
 X32_Y32= -94.0     -33         -116.35 mm
 VIS= all
%%%%%%%% BB7L %%%%%%%%
W1
 X1_Y1= 148.59      -32         -85.84 mm
 X1_Y32=92.3        -32         -118.34  mm
 X32_Y1= 148.59     33          -85.84 mm
 X32_Y32= 92.3      33          -118.34 mm
```

```
 VIS= all
%%%%%%%%%%%%%%%%%%%%%% PAD1 %%%%%%
SSSD

 A= -50.795         29.011      9.13 mm
 B= -50.795         29.011      59.63 mm
 C= -9.265          57.729      9.13 mm
 D=-9.265           57.729      59.63 mm
 VIS= all
%%%%%%%%%%%%%%%%%%%%%% PAD2 %%%%%%
SSSD

 A= -43.287         -39.344     9.13 mm
 B= -43.287         -39.344     59.63 mm
 C= -57.766         9.124       9.13 mm
 D=-57.766          9.124       59.63 mm
 VIS= all
%%%%%%%%%%%%%%%%%%%%%% PAD3 %%%%%%
SSSD

 A= 24.16           -53.33      9.13 mm
 B= 24.16           -53.33      59.63 mm
 C= -26.32          -52.15      9.13 mm
 D= -26.32          -52.15      59.63 mm
 VIS= all
%%%%%%%%%%%%%%%%%%%%%% PAD4 %%%%%%
SSSD

 A= 58.146          6.3864      9.13 mm
 B= 58.146          6.3864      59.63 mm
 C=41.4272          -41.2576    9.13 mm
 D=41.4272          -41.2576    59.63 mm
 VIS= all
%%%%%%%%%%%%%%%%%%%%%% PAD5 %%%%%%
SSSD

 A= 11.8944         57.2735     9.13 mm
 B= 11.8944         57.2735     59.63 mm
 C= 52.0404         26.651      9.13 mm
 D= 52.0404         26.651      59.63 mm
 VIS= all
%%%%%%%%%%%%%%%%%%%%%% PADL %%%%%%
SSSD

 A= 151.09          -32.0       -90.17 mm
 B= 94.8            -32.0       -122.67 mm
 C= 151.09          33.0        -90.17 mm
 D= 94.8            33.0        -122.67 mm
 VIS= all
%%%%%%%%%%%%%%%%%%%%%% PADR %%%%%%
SSSD

 A= -152.83         32.0        -88.17 mm
 B= -96.54          32.0        -120.68 mm
 C= -152.83         -33.0       -88.17 mm
 D= -96.54          -33.0       -120.68 mm
 VIS= all
```

Event Generator

```
7Be(d,p)2alpha reaction file
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
Beam
  Particle= 7Be
  ExcitationEnergy= 0.000 MeV
  Energy= 35.000 MeV
  SigmaEnergy= 0.0 MeV
  SigmaThetaX= 0.01 deg
  SigmaPhiY= 0.01 deg
  SigmaX= 0.0 mm
  SigmaY= 0.0 mm
  MeanThetaX= 0 deg
  MeanPhiY= 0 deg
  MeanX= 0 mm
  MeanY= 0 mm
  %EnergyProfilePath=
  %XThetaXProfilePath=
  %YPhiYProfilePath=
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
TwoBodyReaction
 Beam= 7Be
 Target= 2H
 Light= 1H
 Heavy= 8Be
 ExcitationEnergyLight= 0.00 MeV
 ExcitationEnergyHeavy= 0.00 MeV
 CrossSectionPath= flat.txt CS7Be
 ShootLight= 1
 ShootHeavy= 1
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
Decay 8Be
 Daughter= 4He 4He
 ExcitationEnergy= 0 0  MeV
 Threshold= 0.00 MeV
 BranchingRatio= 1.0
 LifeTime= 0 ns
 Shoot= 1 0
```



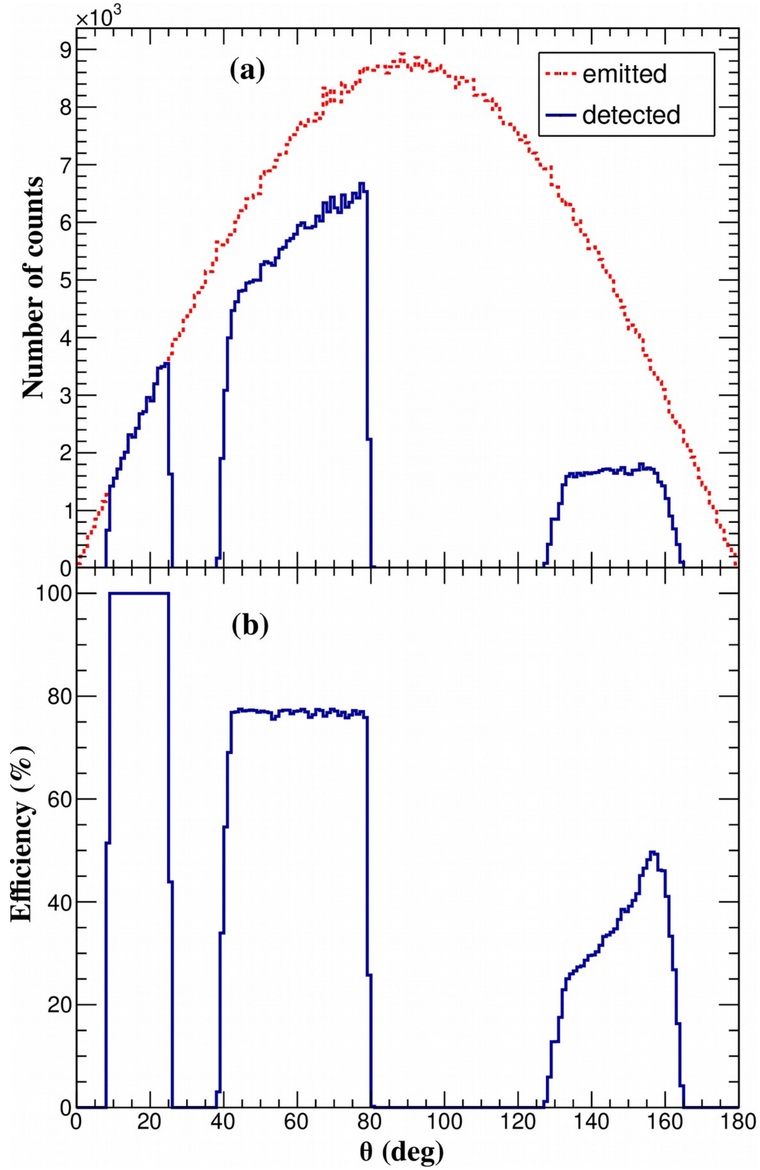
‘npsimulation’

Geometrical efficiency of detector setup

Isotropic source event generator

Geometrical Efficiency

$$= \frac{Detected\ Particles}{Emitted\ Particles} \times 100\,\%$$



Nuclear Astrophysics at Bose Institute

Study of $^{7}Be(d,p)^{8}Be^{*}$ transfer reaction to ascertain contribution of higher states of ^{8}Be in the context of the Cosmological Li Problem.

Resonance excitation in the $^{7}Be + d$ reaction
ISOLDE Newsletter 2020, Page 35

Resonance excitation in the $^{7}Be(d,p)^{8}Be^{*}$ reaction up to 20 MeV
ISOLDE Newsletter 2021, Page 45

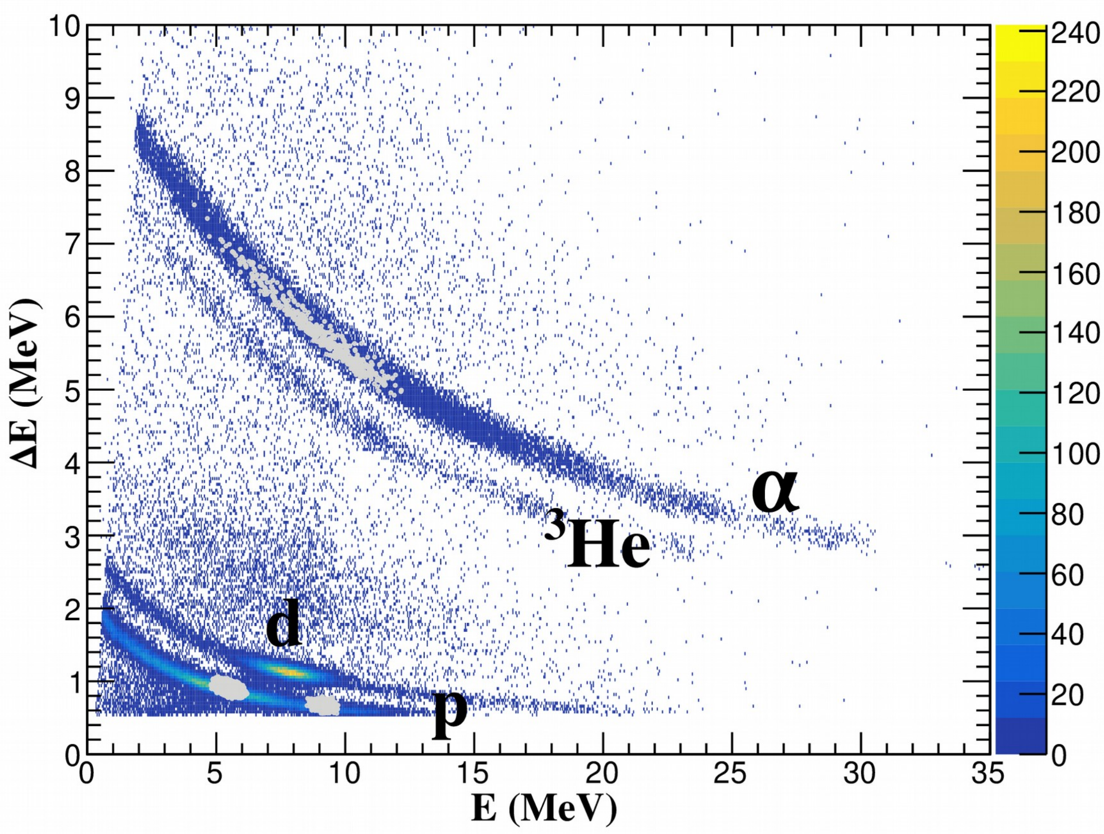
Study of α - cluster transfer reaction of ^{7}Be on ^{12}C to investigate the $^{12}C(\alpha,\gamma)^{16}O$ reaction in the CNO cycle which strongly influences the ratio of the abundances of ^{12}C to ^{16}O in the massive stars ($M > 0.55\ M_{solar}$)

Study of deuteron target breakup with ^{7}Be nuclei.

ΔE-E Spectrum for the reaction $^7Be + d$

$^7Be(d,p)^8Be^*$ → 2α reaction

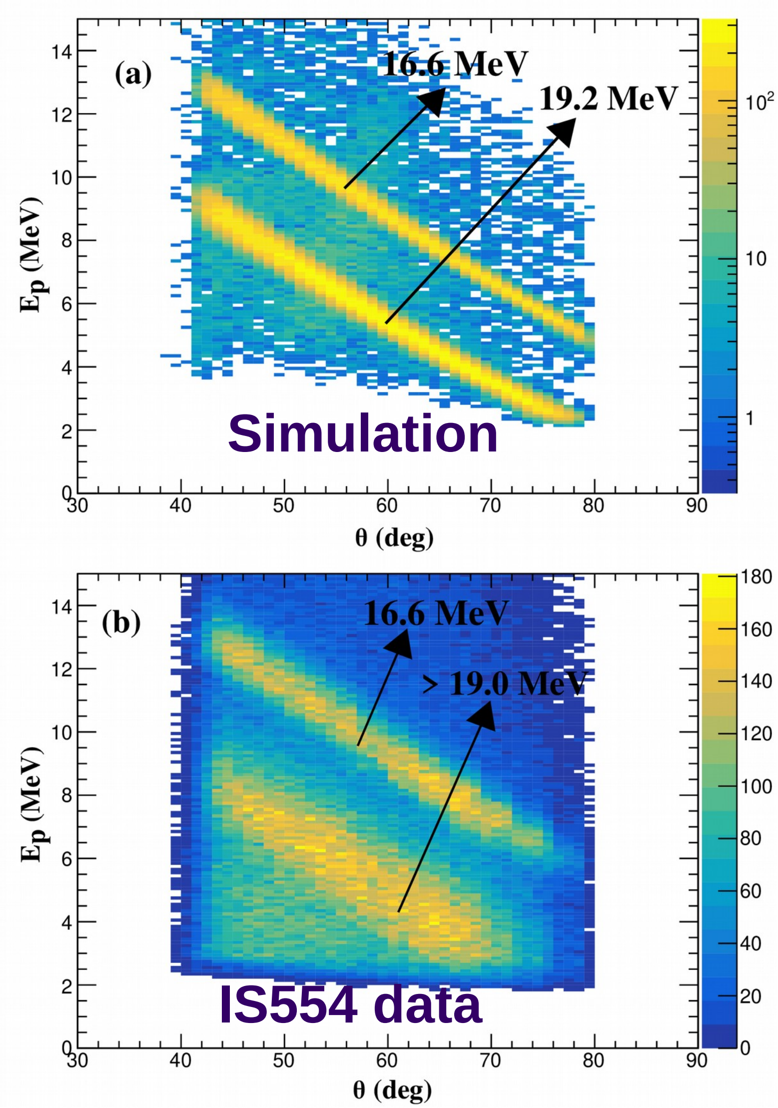
Blue dots ~ Experimental
Grey dots ~ Simulation
(for 16.6 and 19.2 MeV states of $^8Be^*$)

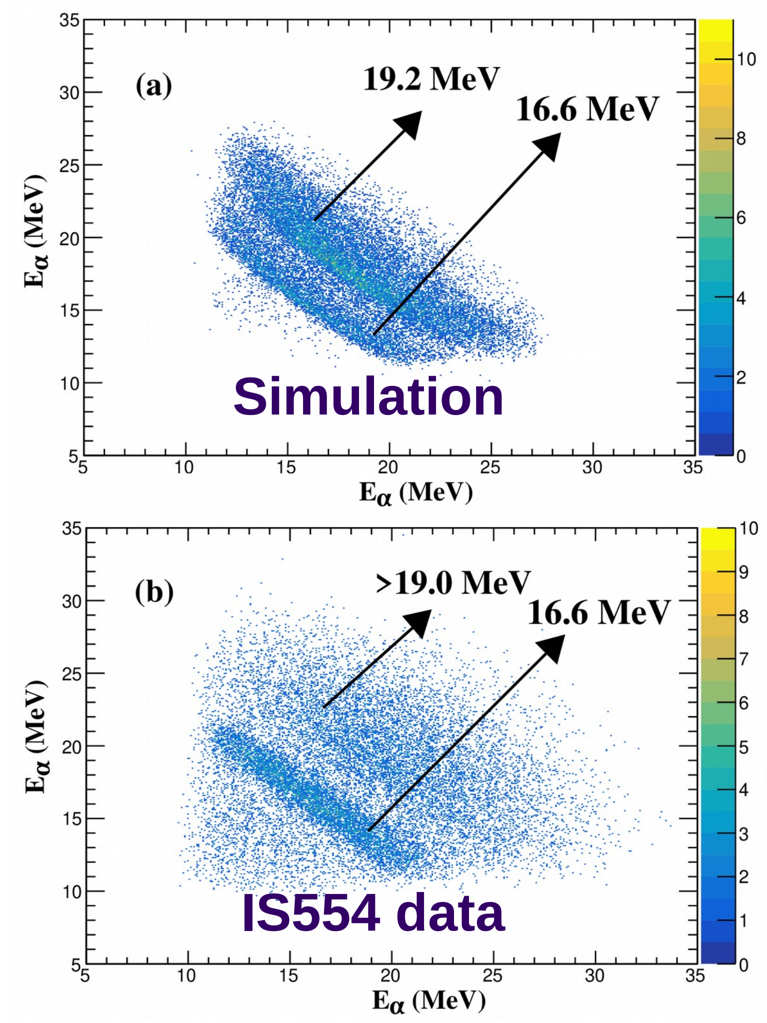


Bethe-Bloch formula of Energy Loss for charged particles in detectors (approximated)

$$-\frac{dE}{dx} \propto \frac{z^2 m}{E}$$

Higher excited states of $^{8}Be^{*}$

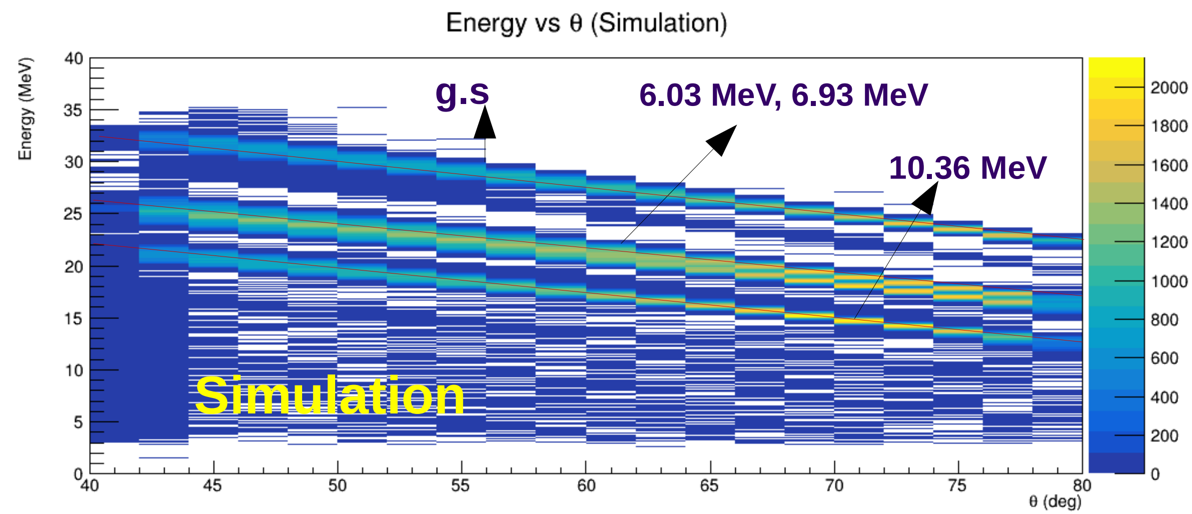


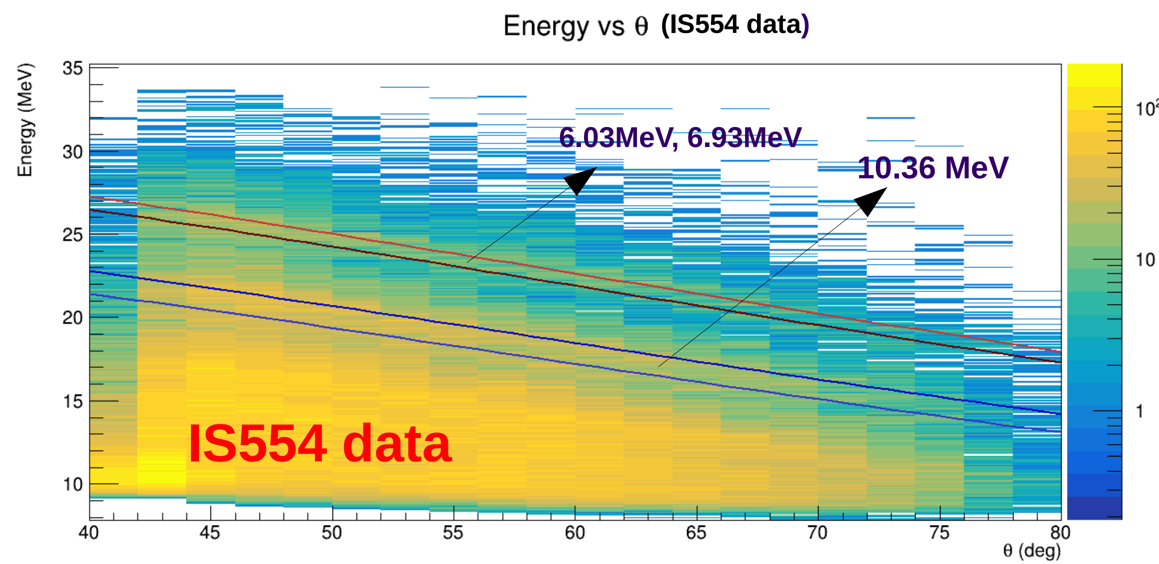


Study of α - cluster transfer reaction of ^{7}Be on ^{12}C

^{7}Be(^{12}C,^{3}He)^{16}O reaction channel.

Three excited states of ^{16}O shown in the kinematic plots are – 0.0 (g.s), 6.03, 6.93, 10.36 MeV states.

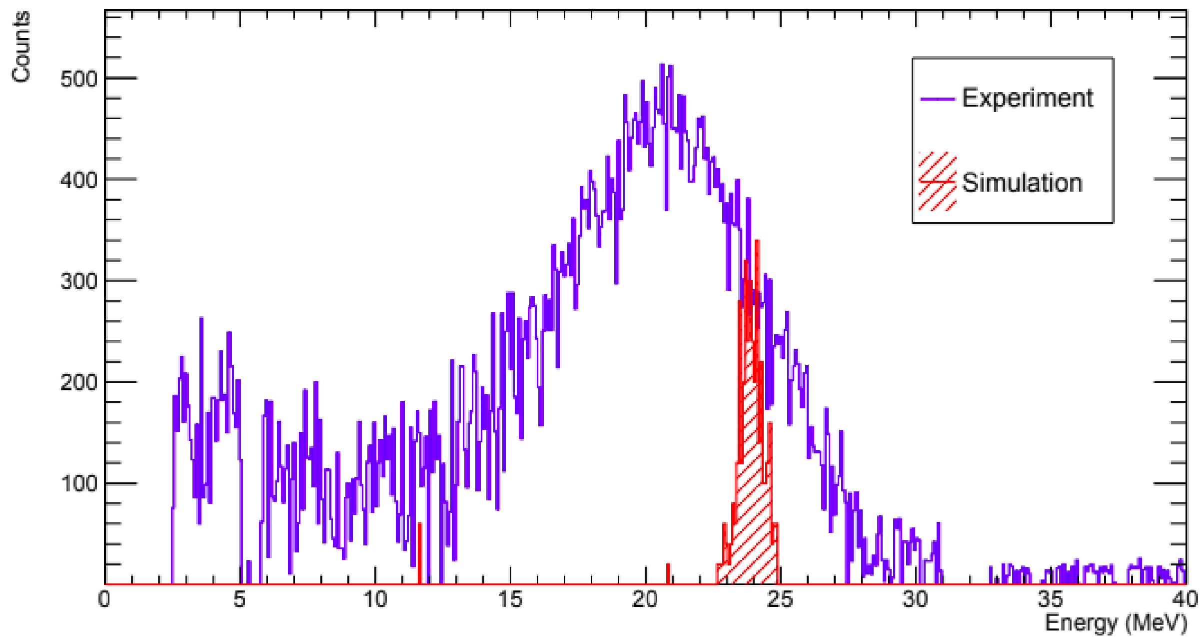




Deuteron target breakup with ^{7}Be nuclei

Deuteron is a very loosely bound nucleus of binding energy 2.23 MeV breaking into a proton and a neutron.

^{7}Be - p coincidence is needed to find the contribution of breakup.



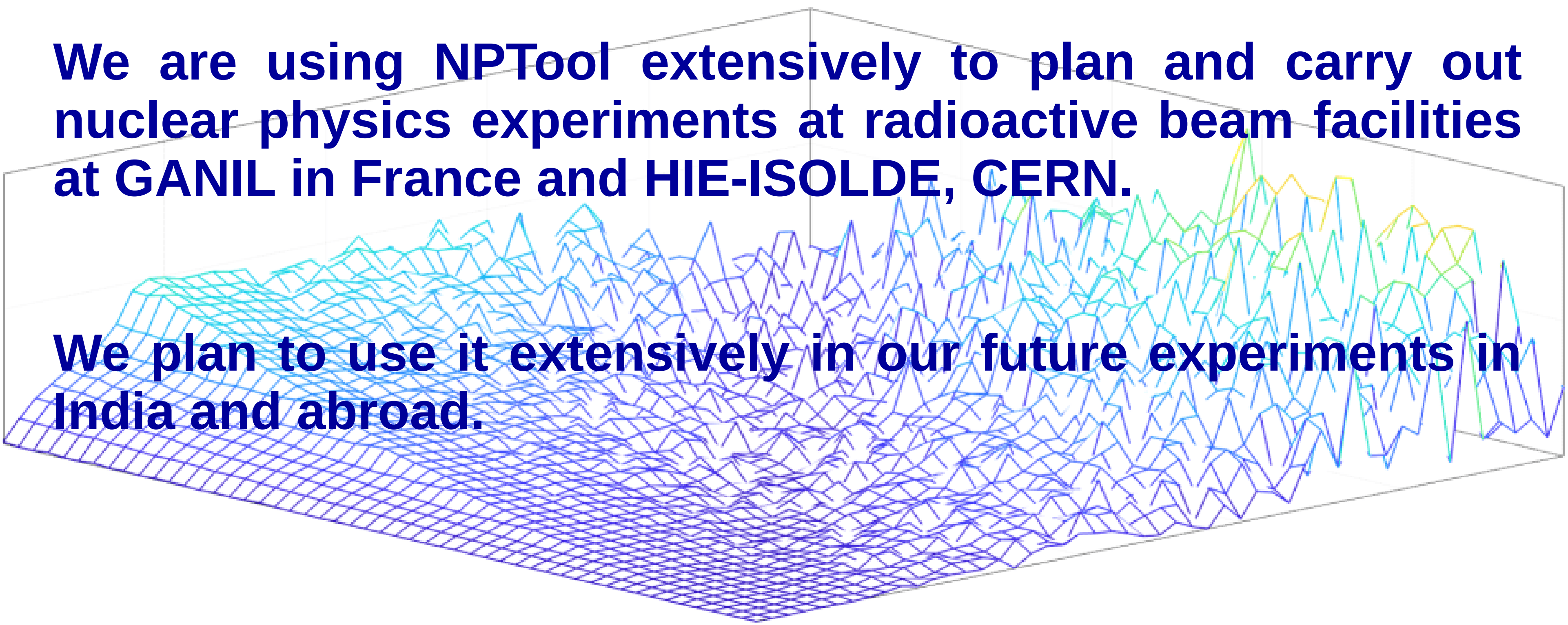
Energy vs Counts spectra in S3 by the ^{7}Be – p coincidence using Monte Carlo simulations

Outlook

Simulations are essential to nuclear physics experiments.

We are using NPTool extensively to plan and carry out nuclear physics experiments at radioactive beam facilities at GANIL in France and HIE-ISOLDE, CERN.

We plan to use it extensively in our future experiments in India and abroad.



Thank you for your attention

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Thank you for your attention