The use of Geant4 simulations for training a DNN to perform the NeuLAND data analysis

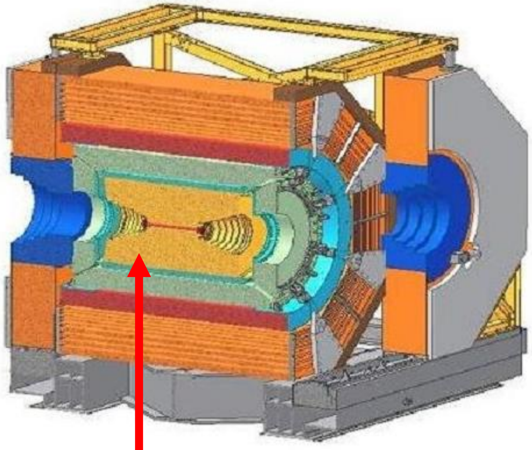
C. A. Douma

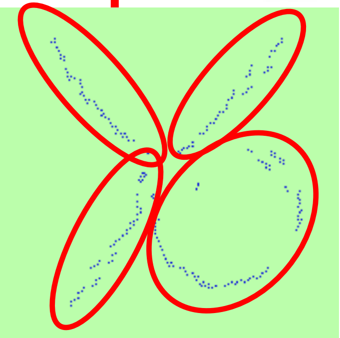
24 April 2019

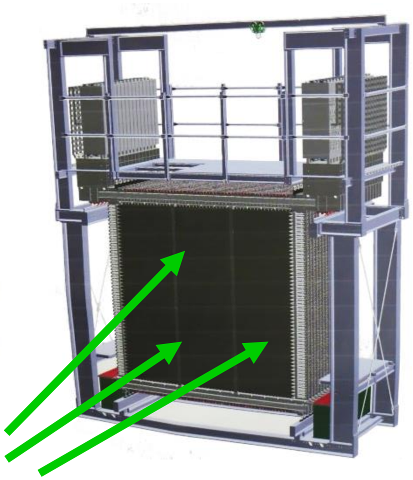
Machine Learning & DNNs

Deep artifical Neural Network (DNN) ➔ Can learn any math. function/alogoritm
if network is complex enough
➔ Ideal for complex data analysis

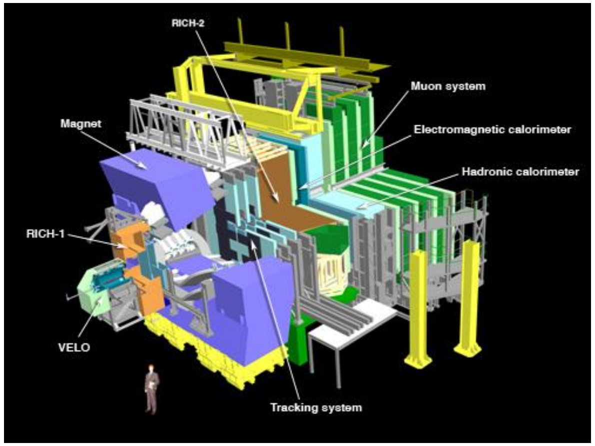
BES-III detector







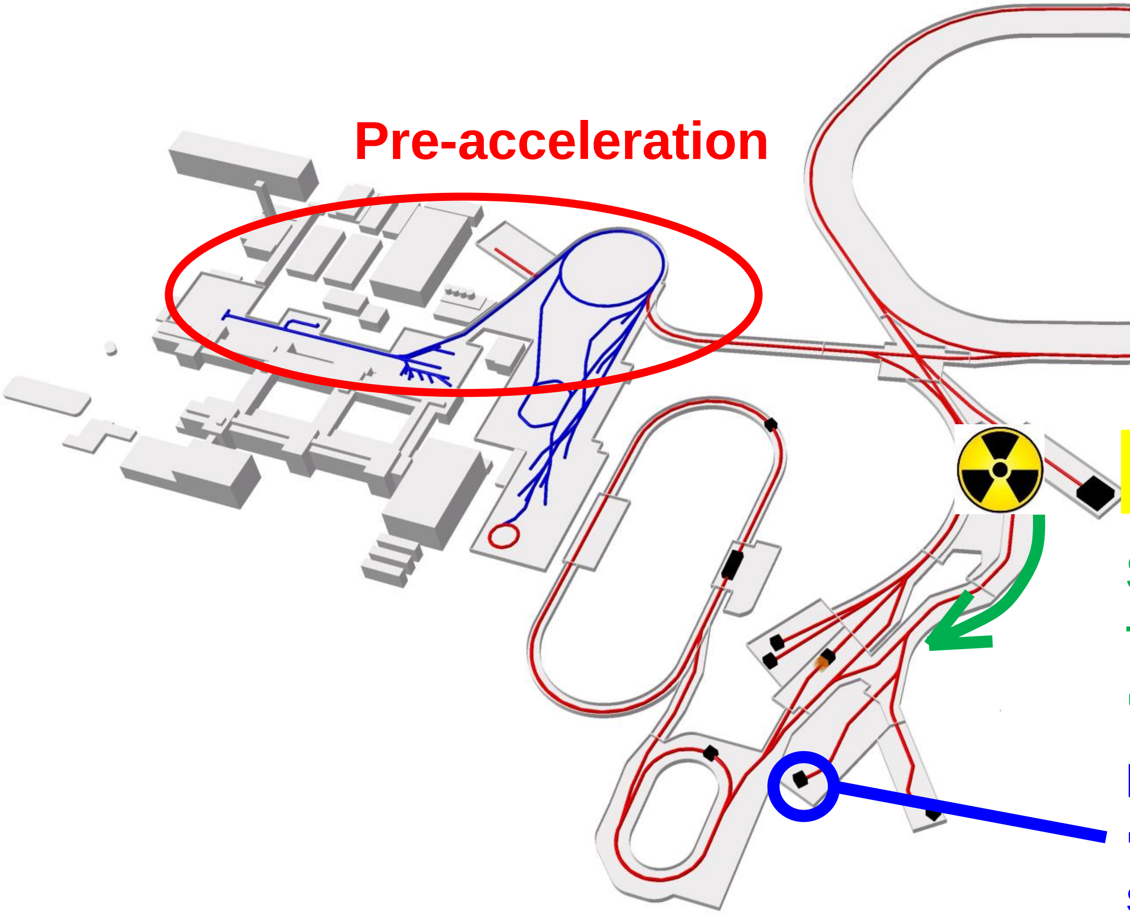
NeuLAND detector:
ID incoming neutrons
➔ **Our case!**



Other applications…?

Resolve individual tracks in drift chamber in magnetic field.
H. de Vries, MSc thesis, RUG (upcoming).

R3B Experiment in a nutshell



Pre-acceleration

Primary accelerator

Fixed primary target

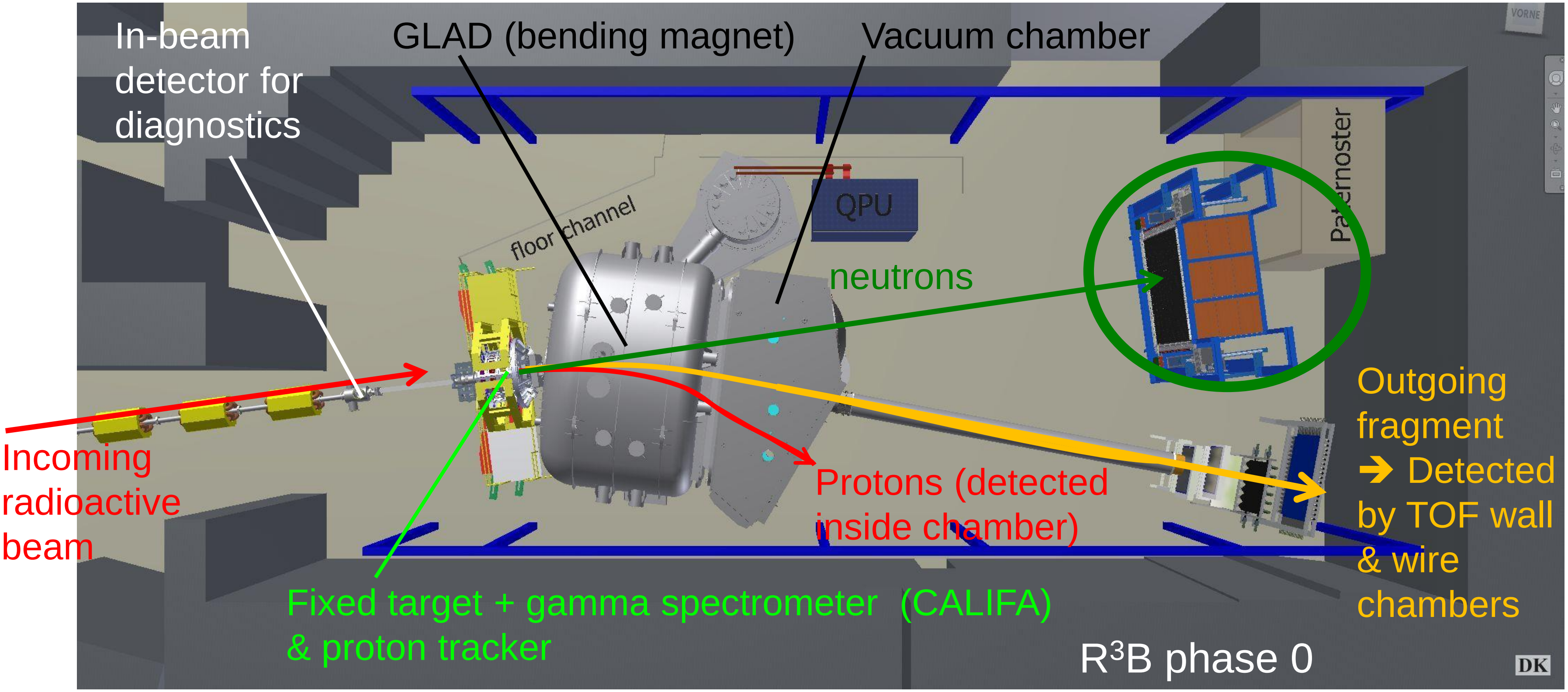
Selection of exotic fragments
➔ Radioactive Beam

R3B experiment
➔ Measure nuclear structure of the beam

R3B Experiment in a nutshell

Full kinematic reconstruction of nuclear **R**eactions with **R**adioactive **R**elativistic **B**eams

Neutrons are detected by NeuLAND ➔ **Neu**(=new) **L**arge **A**rea **N**eutron **D**etector)



In-beam detector for diagnostics

GLAD (bending magnet)

Vacuum chamber

neutrons

Incoming radioactive beam

Protons (detected inside chamber)

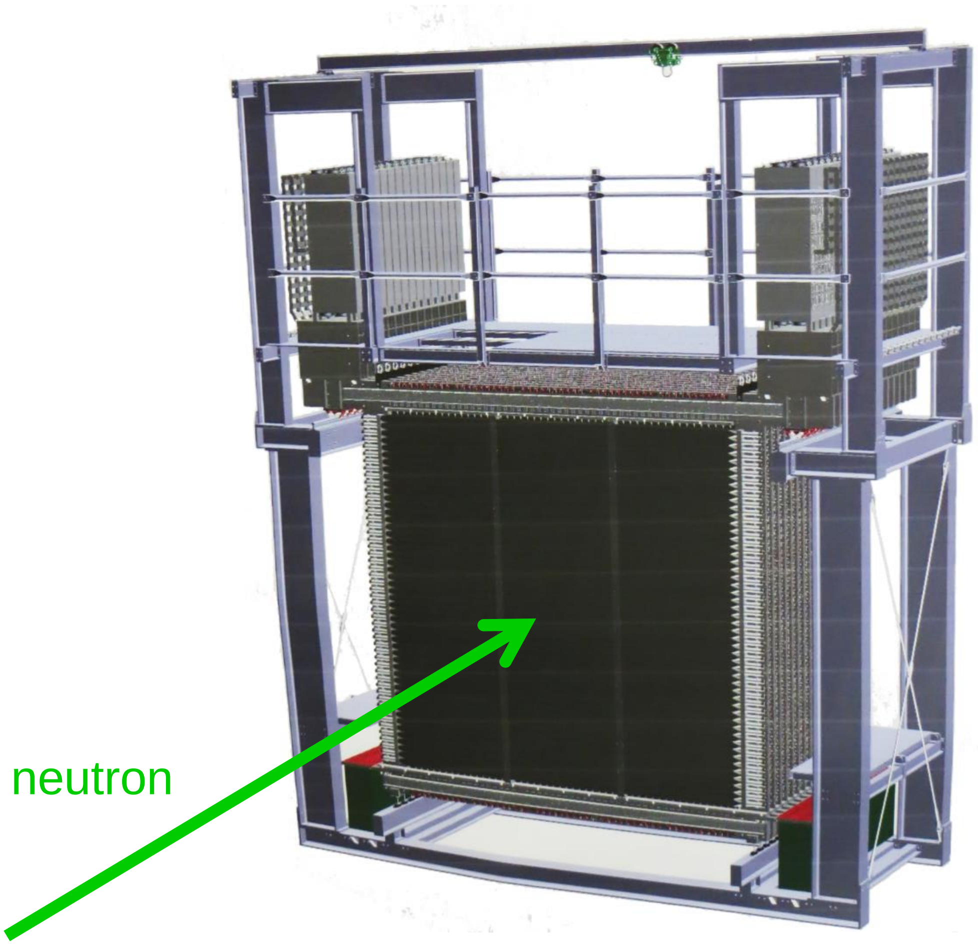
Outgoing fragment ➔ Detected by TOF wall & wire chambers

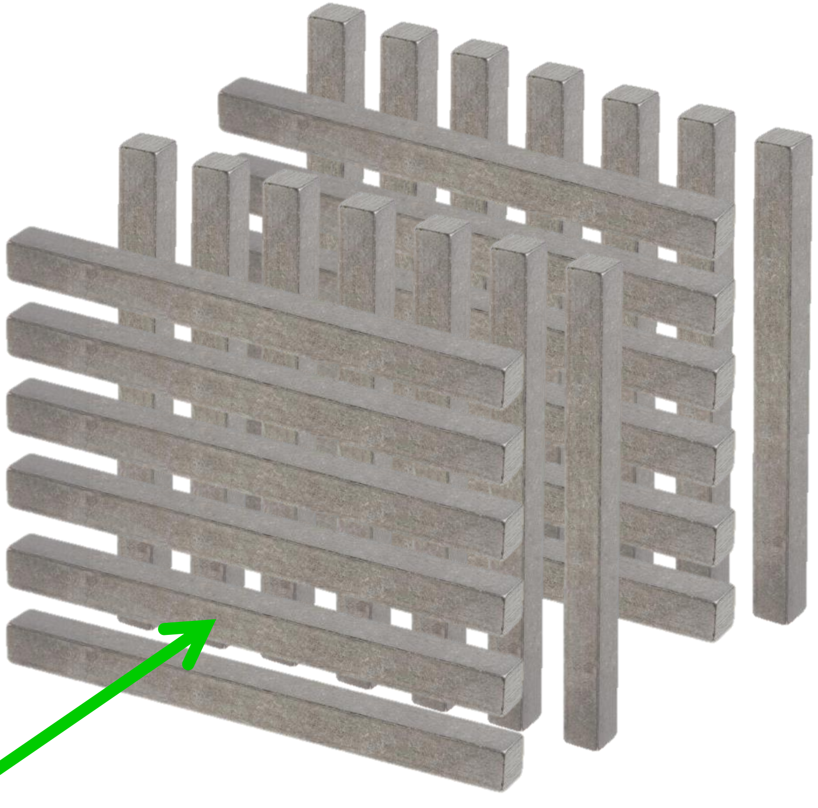
Fixed target + gamma spectrometer (CALIFA) & proton tracker

R^{3}B phase 0

NeuLAND neutron detection

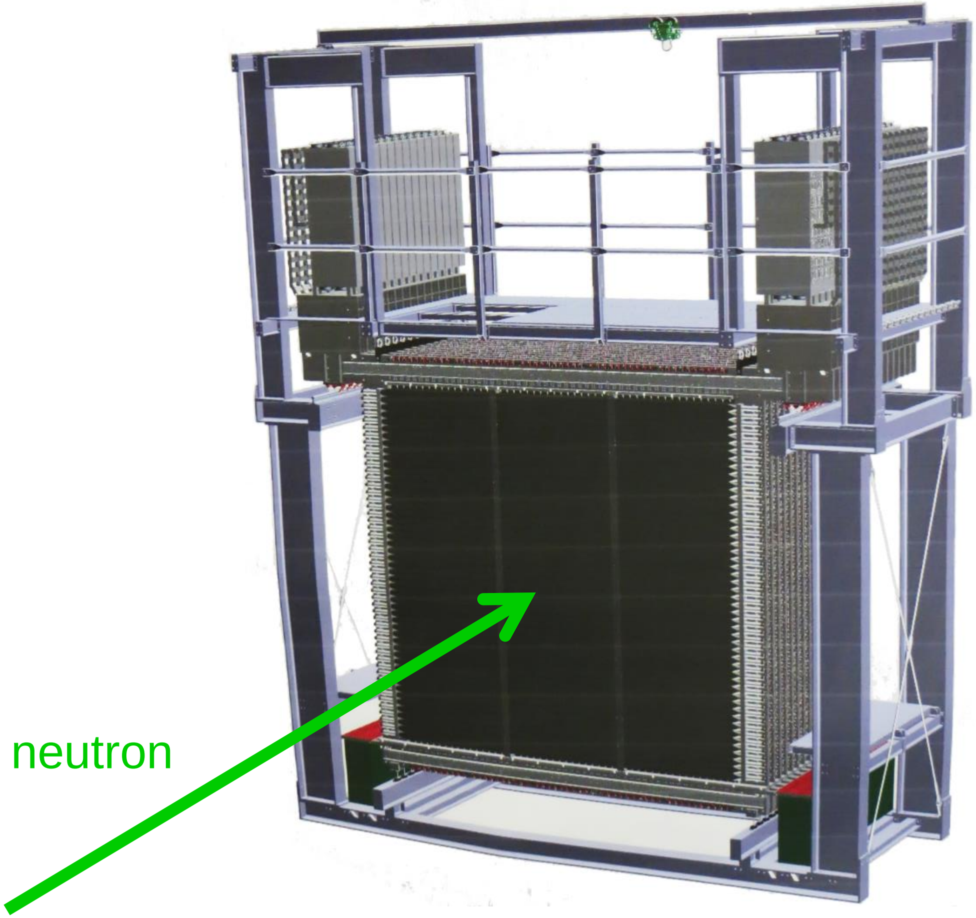
Scintillator bars: 50 bars per plane,
30 hor. planes & 30 vert. planes;
PMT on both ends of the bar

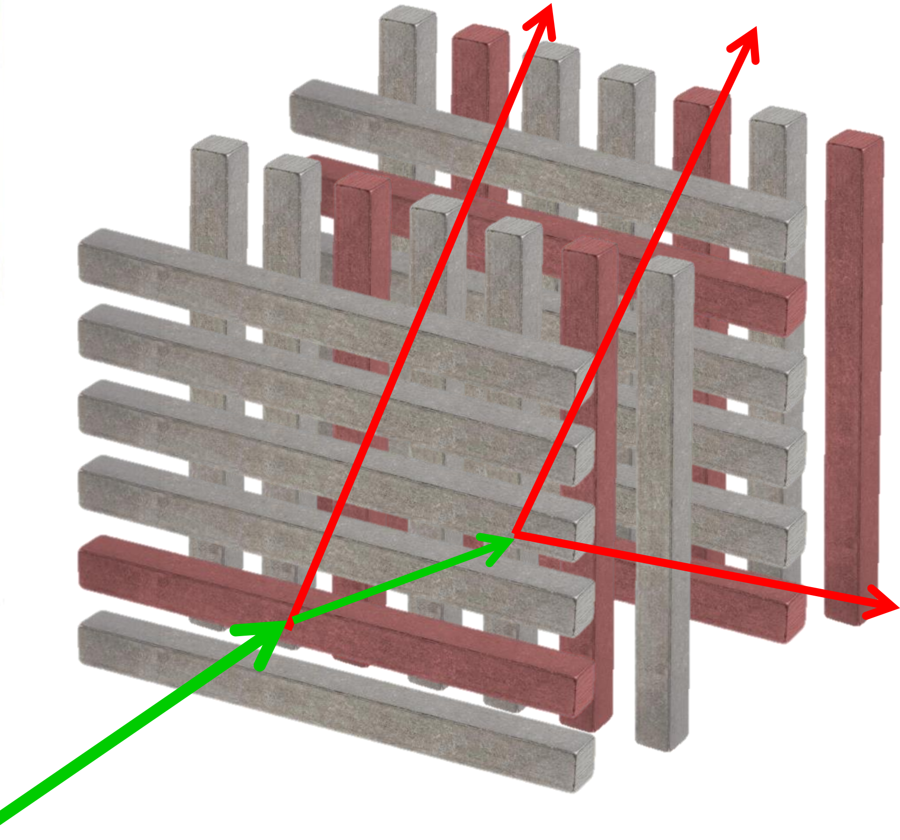




NeuLAND neutron detection

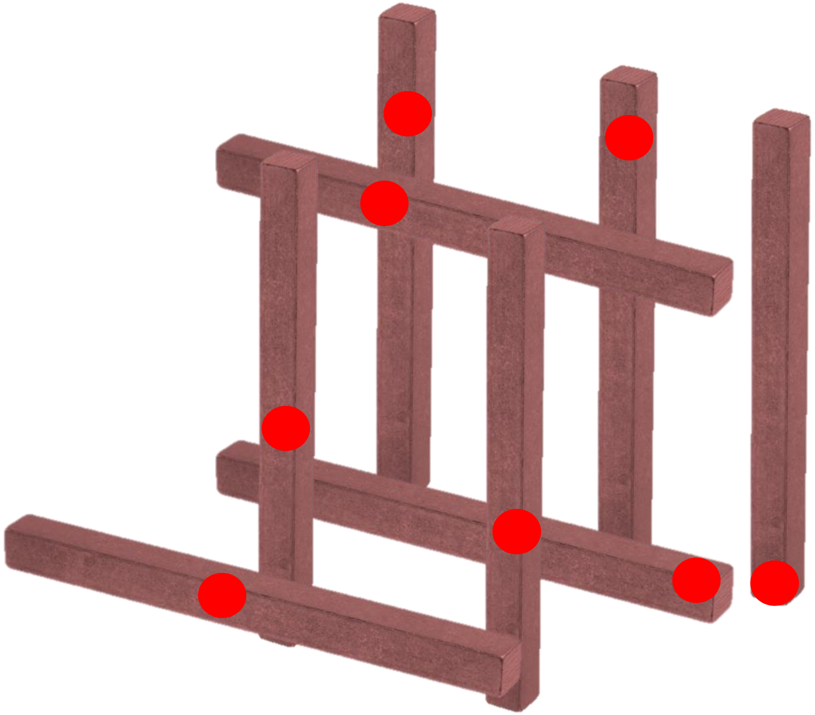
Scintillator bars: 50 bars per plane, 30 hor. planes & 30 vert. planes; PMT on both ends of the bar





NeuLAND neutron detection

Measured PMT signals

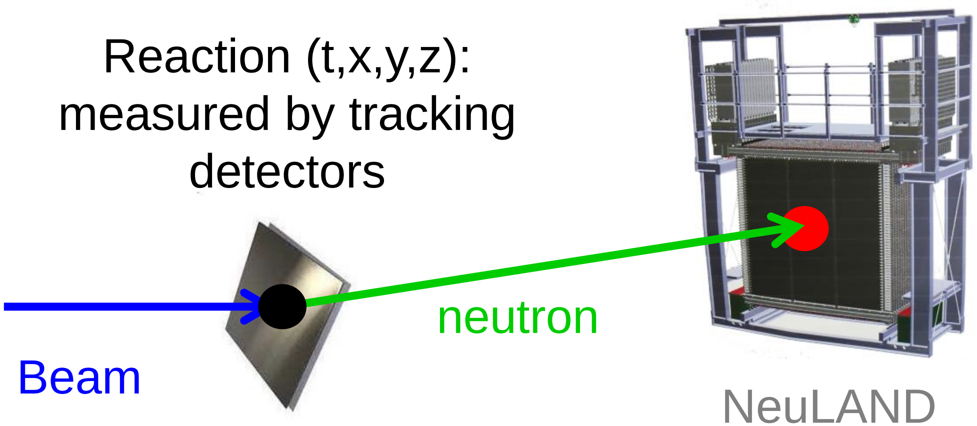


Reconstruct (t,x,y,z,E) from TDC & QDC

NeuLAND neutron detection

What we need:

Reaction (t,x,y,z):
measured by tracking detectors



neutron

Beam

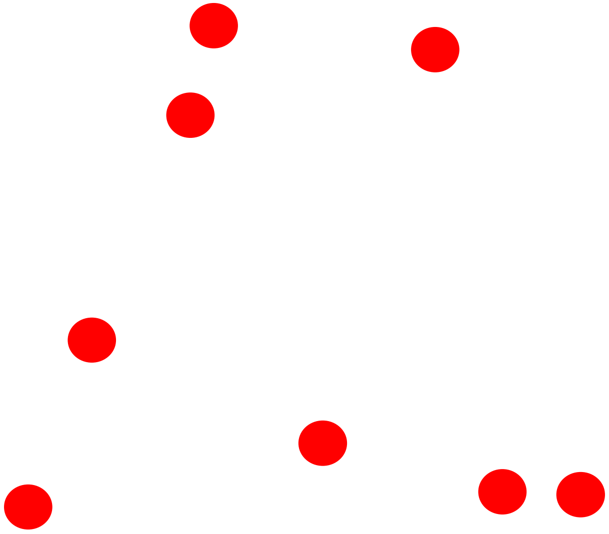
Target

NeuLAND

First hit (t,x,y,z)
of neutron

Reconstruct neutron momentum vector
From Reaction & First Hit.

Our data: NeuLAND digis:
(t,x,y,z,E) signals



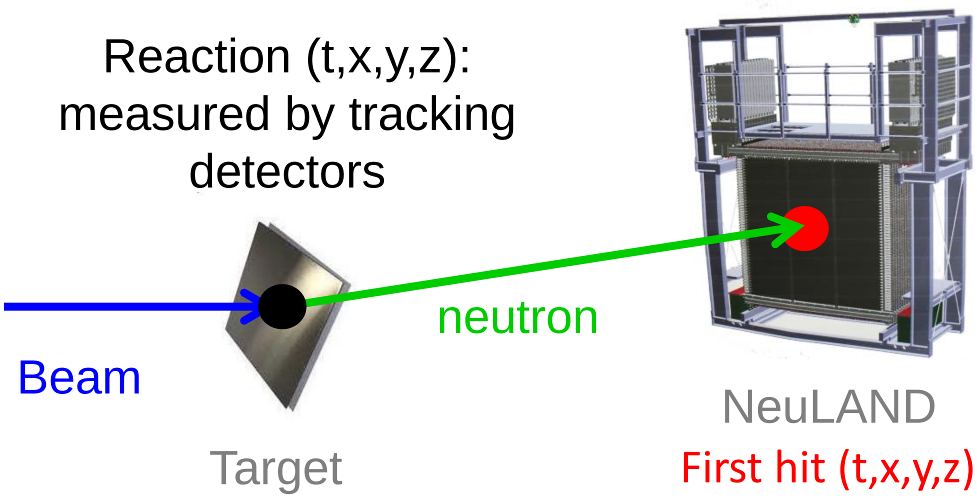
Which one is the First hit?

NeuLAND neutron detection

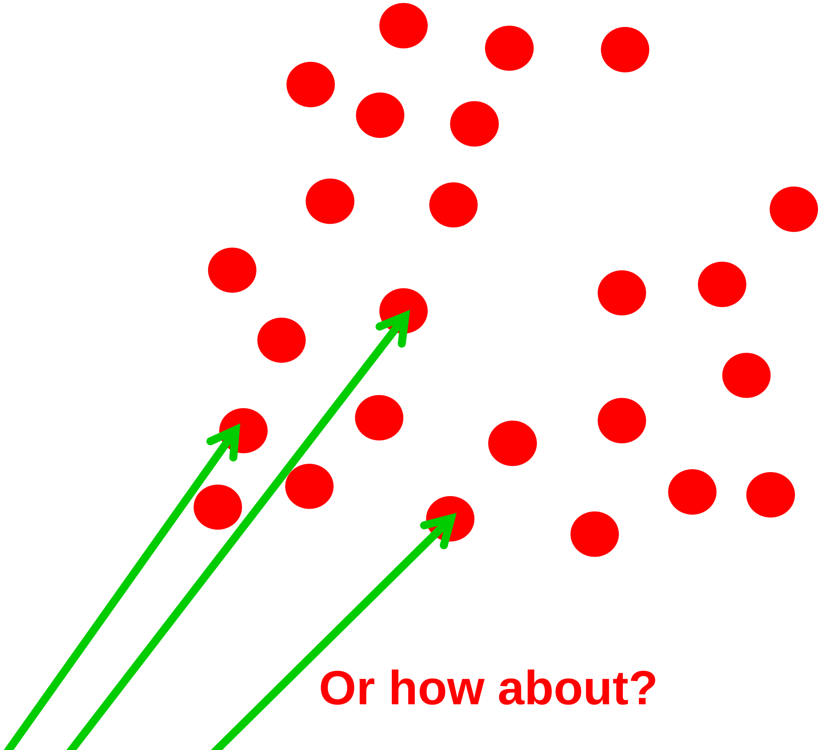
What we need:

Our data: NeuLAND digis: (t,x,y,z,E) signals

Reaction (t,x,y,z): measured by tracking detectors



First hit (t,x,y,z) of neutron



Or how about?

Reconstruct neutron momentum vector From Reaction & First Hit.

Use of Machine Learning

Given a set of (t,x,y,z,E)-signals:

1. How many first hits do they contain? (What is the multiplicity?)
2. Which of those signals are the first hits? (Which are the neutrons?)

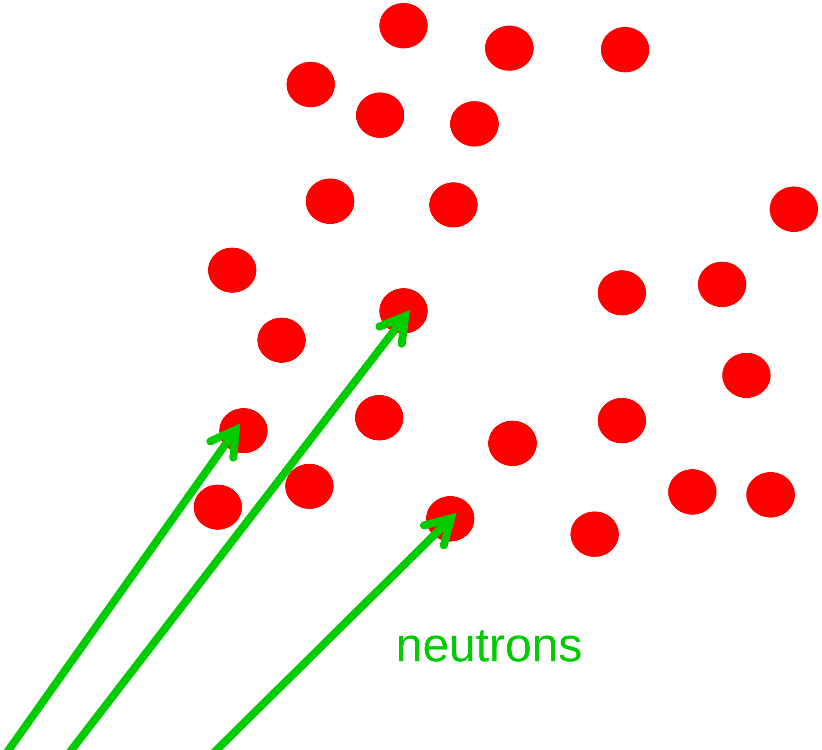
➔ Use Geant4 Monte Carlo simulations to generate data.

➔ Feed it to a DNN for training.

➔ But what if simulations do not represent reality?

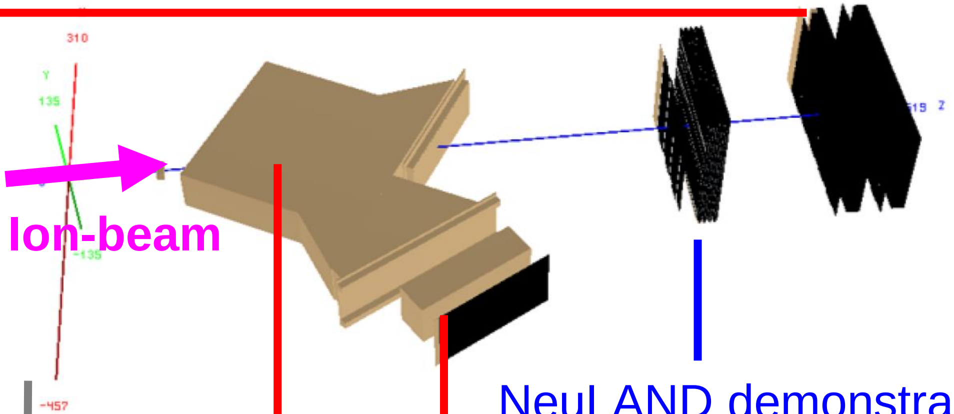
➔ We need accurate Geant4 physics lists!

Our data: NeuLAND digis: (t,x,y,z,E) signals



Benchmarking of Physics Lists

NEBULA detector



NeuLAND demonstrator (8x50 bars, 4 double planes): K. Boretzky et al., MU-NUSTAR-NR-12, GSI report 2014

SAMURAI dipole magnet

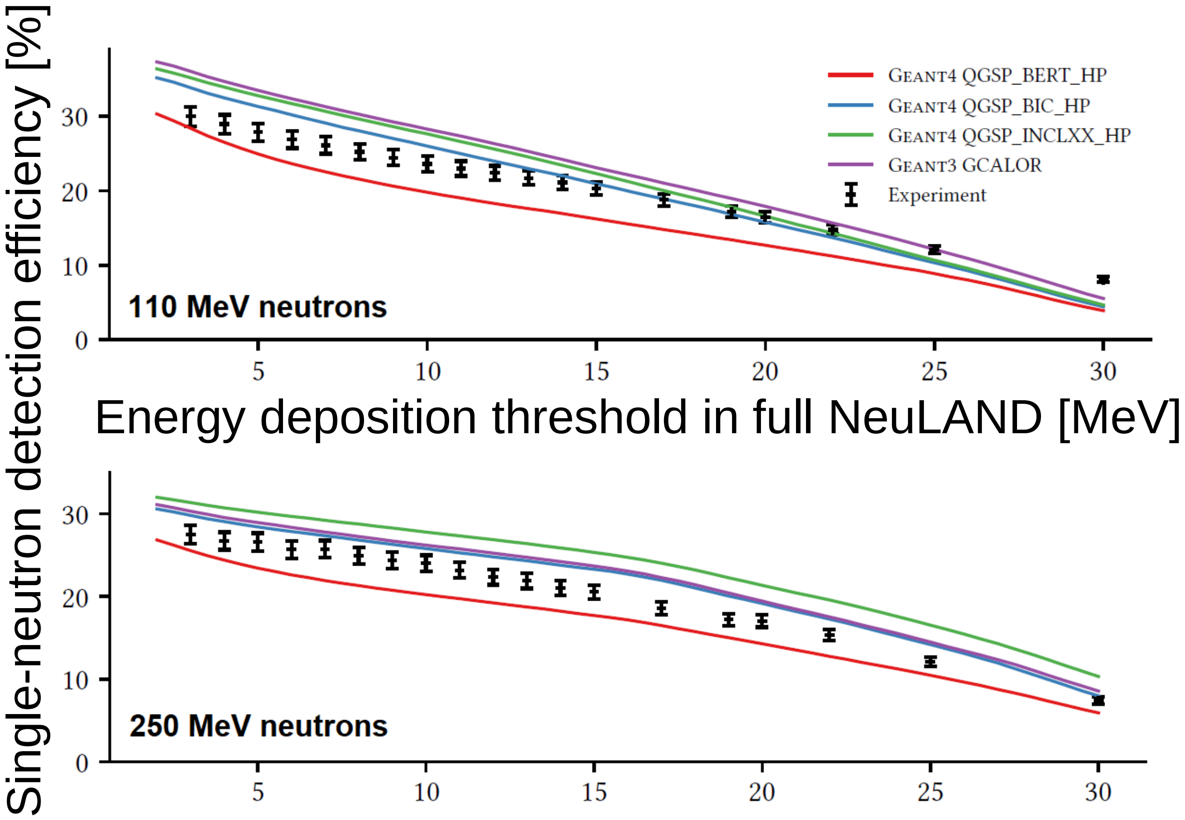
Ion TOF hodoscope

SAMURAI setup: T. Kobayashi *et al.*, NIMB 317, 294 (2013)

Simulation done by: J. Mayer, Ph.D. thesis, Universität zu Köln (2018)

➔ **Benchmark single-neutron detection efficiency**

Benchmarking of Physics Lists



BERT: Bertini cascade model & quark-gluon string model with low E neutron physics

BIC: same, but uses Binary Cascade model

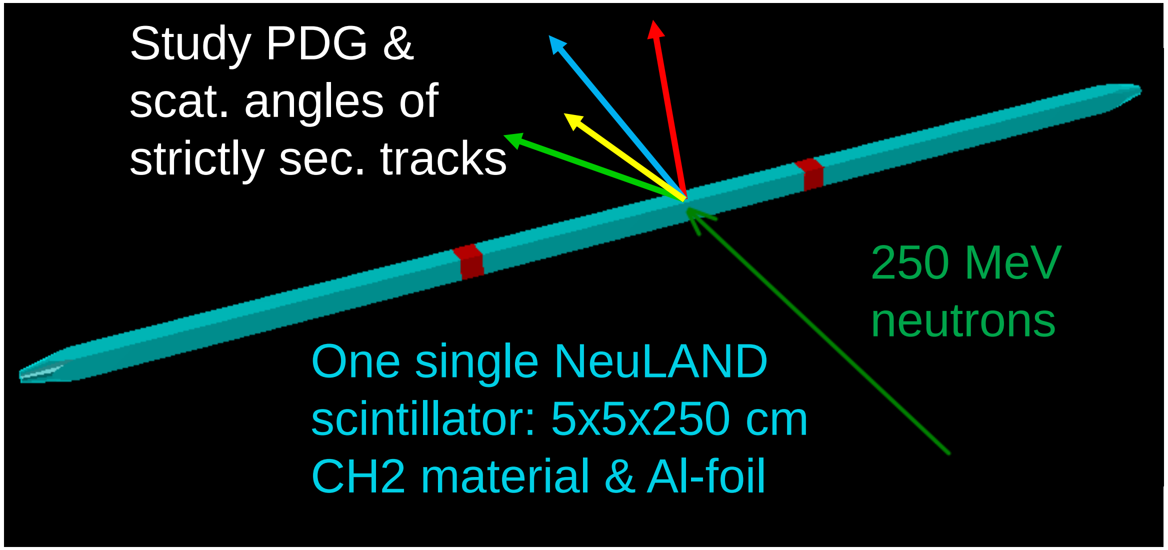
INCL++: same, but uses Liege Intranuclear Cascade model & N-reactions A≤18

Our observation:
Exp ≈ ½ (BERT+INCL++)

- ➔ **What causes the diff. between phys. lists?**
- ➔ **Consequences for DNN?**

Shower developement

➔ Study in the simplest configuration

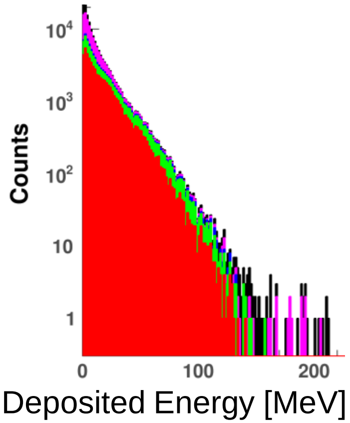


Phys. List	Interactions:
QGSP_INCLXX_HP	MC: 7.15% Det: 4.75%
QGSP_INCLXX	MC: 7.22% Det: 4.81%
FTFP_INCLXX_HP	MC: 7.20% Det: 4.79%
QGSP_BERT_HP	MC: 7.21% Det: 3.88%
QGSP_BIC_HP	MC: 7.21% Det: 4.48%
QBBC	MC: 7.15% Det: 4.45%
ShieldingM	MC: 7.17% Det: 3.89%

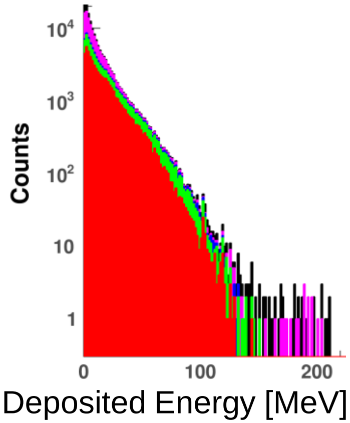
10^6 events simulated ➔ ≈0.1% stat. inaccuracy.
MC: #events where sec. tracks were created.
Det: #events where both PMTs fired.
➔ Interaction rate is ≈ same.
➔ Diff. in detection rate due to what?

Energy deposition

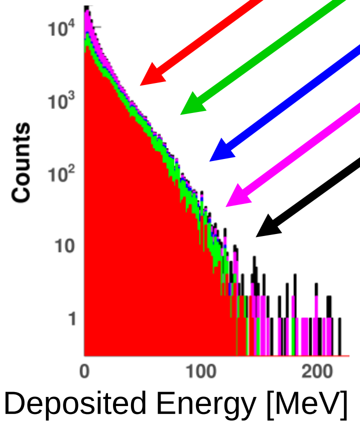
QSGP_INCLXX_HP

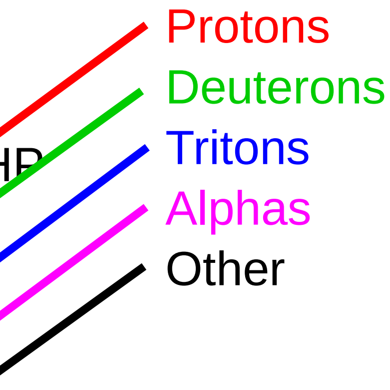


QSGP_INCLXX



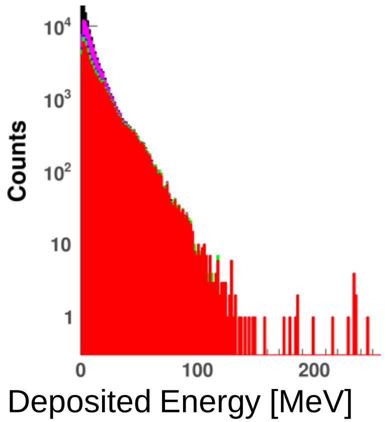
FTFP_INCLXX_HP



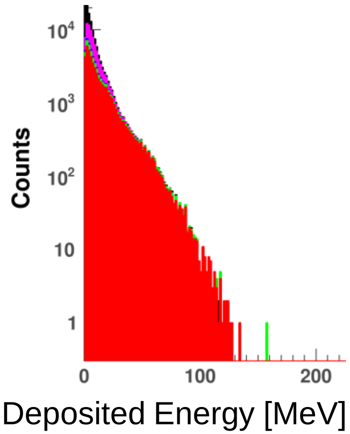


Protons
Deuterons
Tritons
Alphas
Other

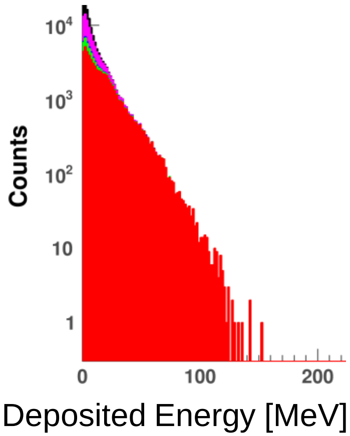
ShieldingM



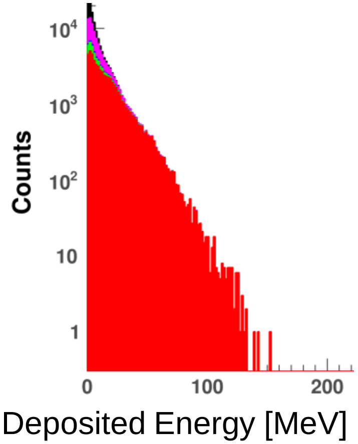
QSGP_BERT_HP



QSGP_BIC_HP



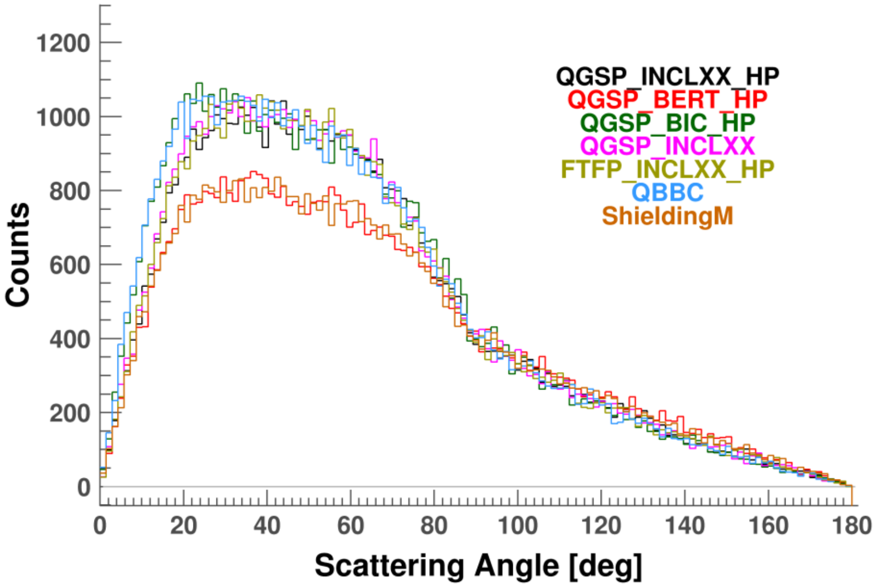
QBBC

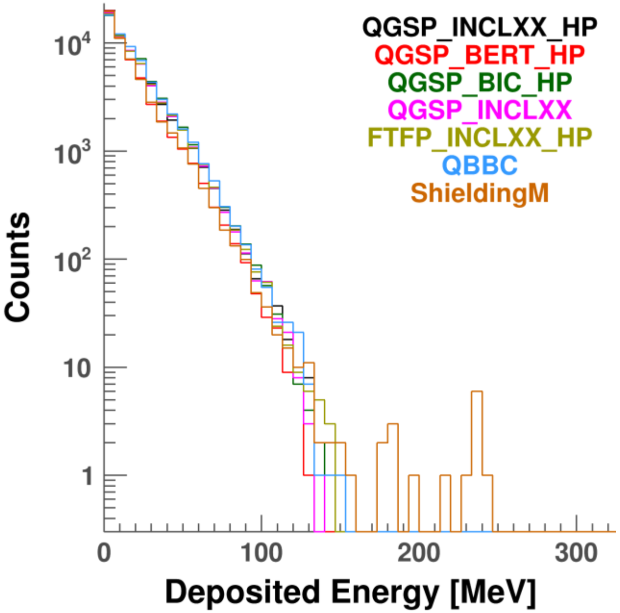


Only INCL++ has significant (d,t,α) contributions

Particle tracks

Protons





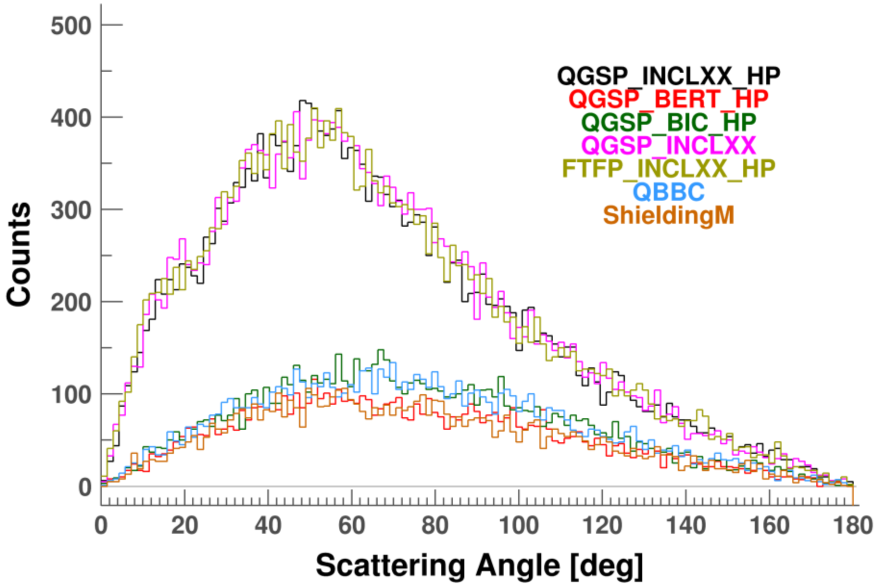
➔ ShieldingM & BERT produce less protons than the others
➔ Scattering behaviour is ≈ same

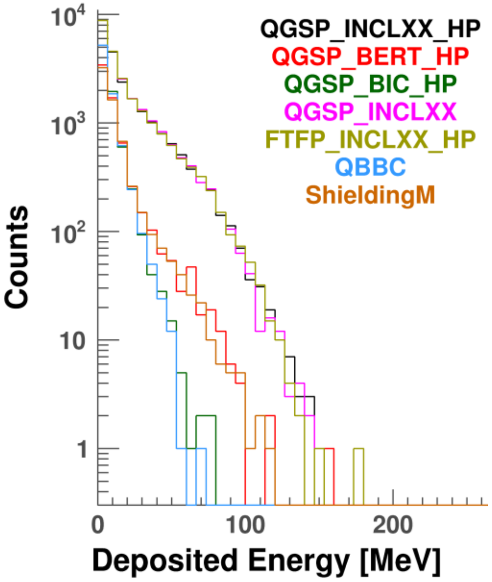
➔ Behaviour is ≈ same for all physics lists
➔ Height is slightly different due to number of protons

➔ Differences are: nr. of produced protons & presence of (*d*,*t*,α) tracks.

Particle tracks

Deuterons



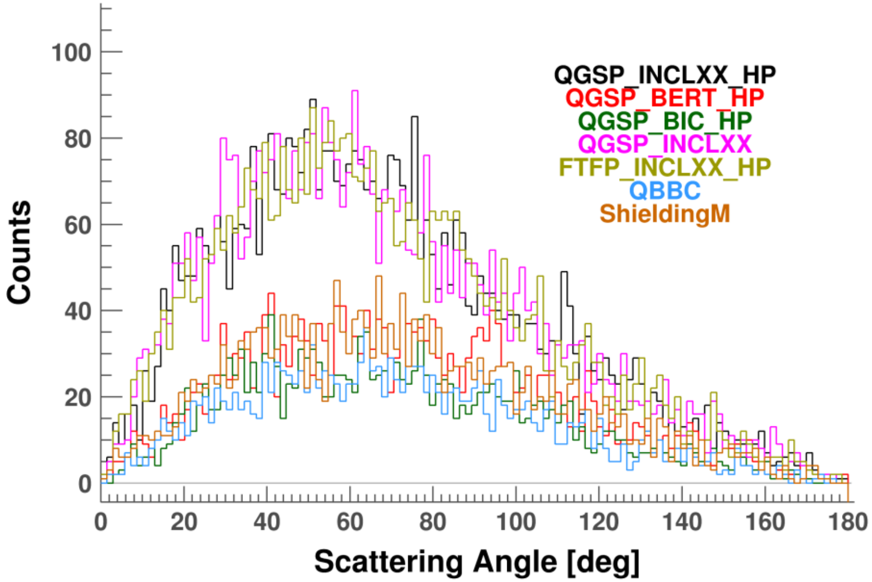


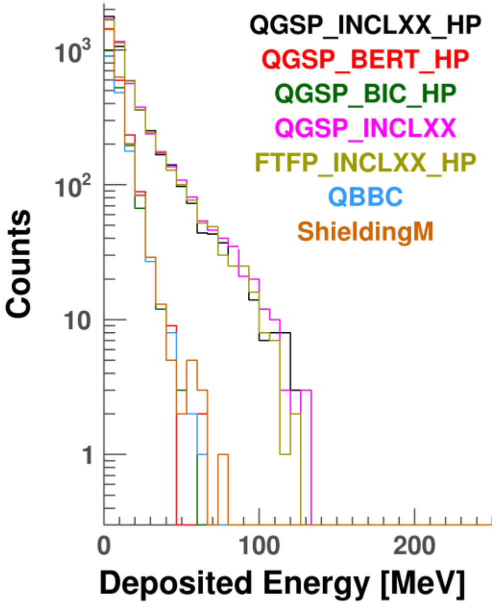
➔ INCL++ has more deuterons & they are slightly more forward boosted.

➔ The produced deuterons also deposite (a lot) more energy for INCL++.

Particle tracks

Tritons



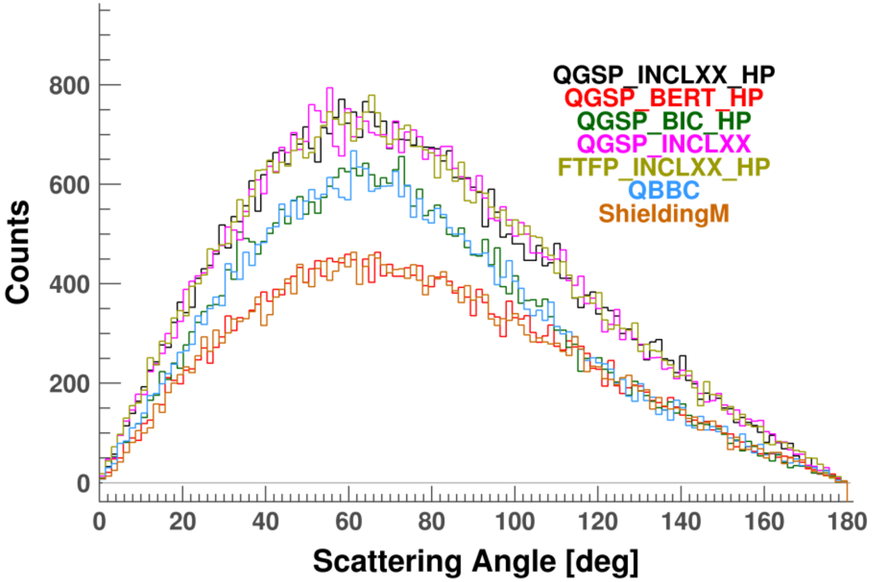


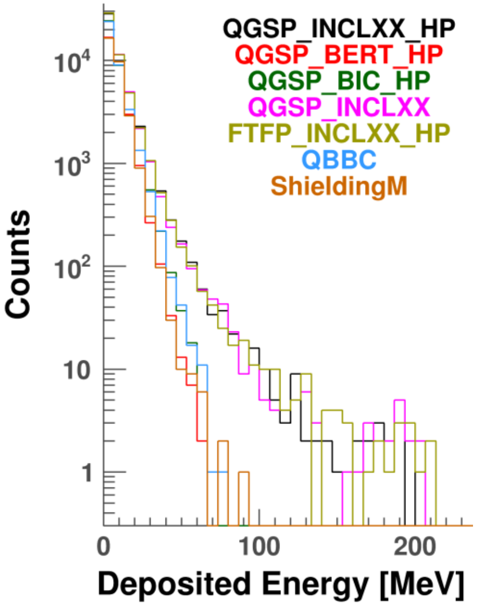
➔ Scattering behaviour is ≈ same as for deuterons (just less particles).

➔ E_{dep} is also ≈ same for non-INCL++ models

Particle tracks

Alphas

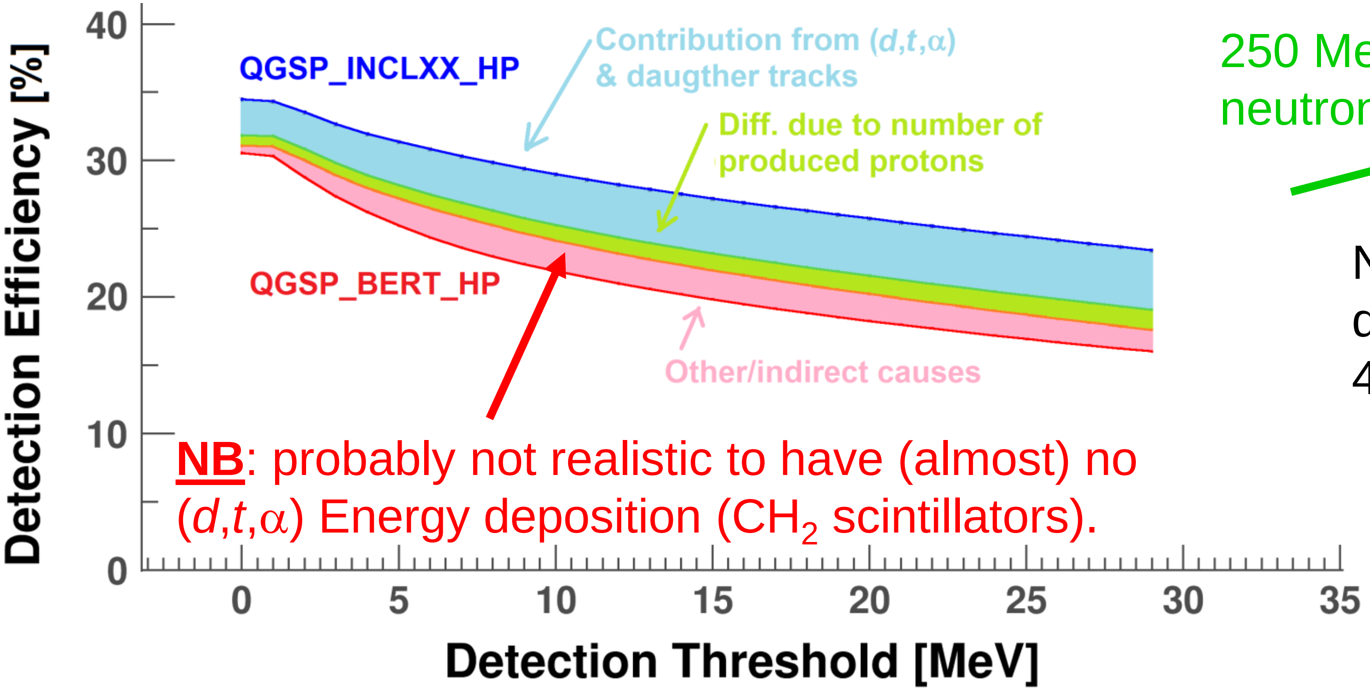




➔ Number of α-particles differs.
➔ Scattering behaviour is ≈ same.

➔ Low energy deposition is ≈ same.
➔ Few α-particles at higher energies, except for INCL++.

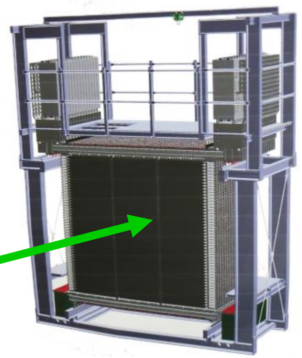
Comparing the contributions



NB: probably not realistic to have (almost) no (*d*,*t*,α) Energy deposition (CH_2 scintillators).

➔ We need: exp ≈ ½ (BERT + INCL++)
➔ We see: |BERT – INCL++| = 50% due to (*d*,*t*,α) tracks
= 25% due to nr. of prod. protons
= 25% other/indirect causes

250 MeV neutrons:



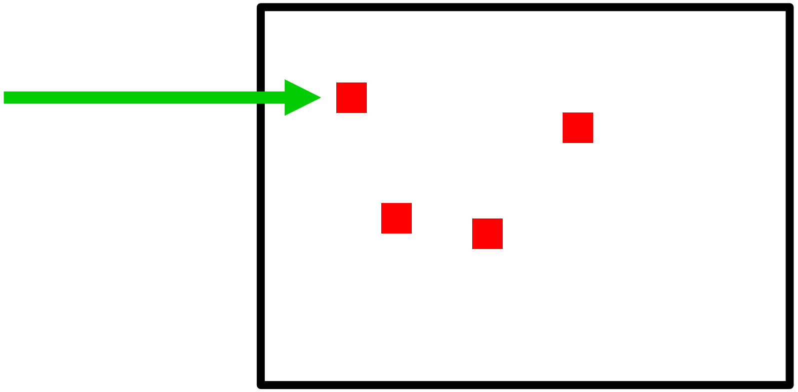
NeuLAND demonstrator
4 double planes @ 11m

Geometry & event generator are slightly different from J. Mayer, Ph.D. Thesis
➔ So no benchmarking to exp. data (still working…)

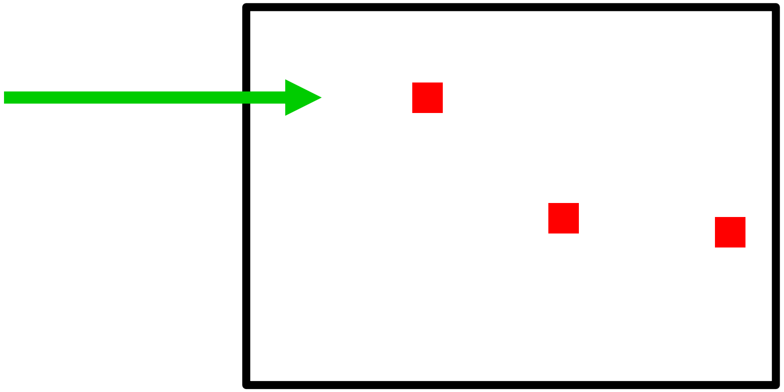
Physics list effects on DNN

Single neutron detection efficiency @ 250 MeV & 4 double planes:
20% – 32% (dep. on E_{thres}) & |BERT – INCL++| ≈ 8%

High neutron detection efficiency



Low neutron detection efficiency



➔ DNN uses neighbouring relations to find primaries
M. Polleryd, M.Sc. thesis, Chalmers University (2017)

➔ Physics list effects could be significant.

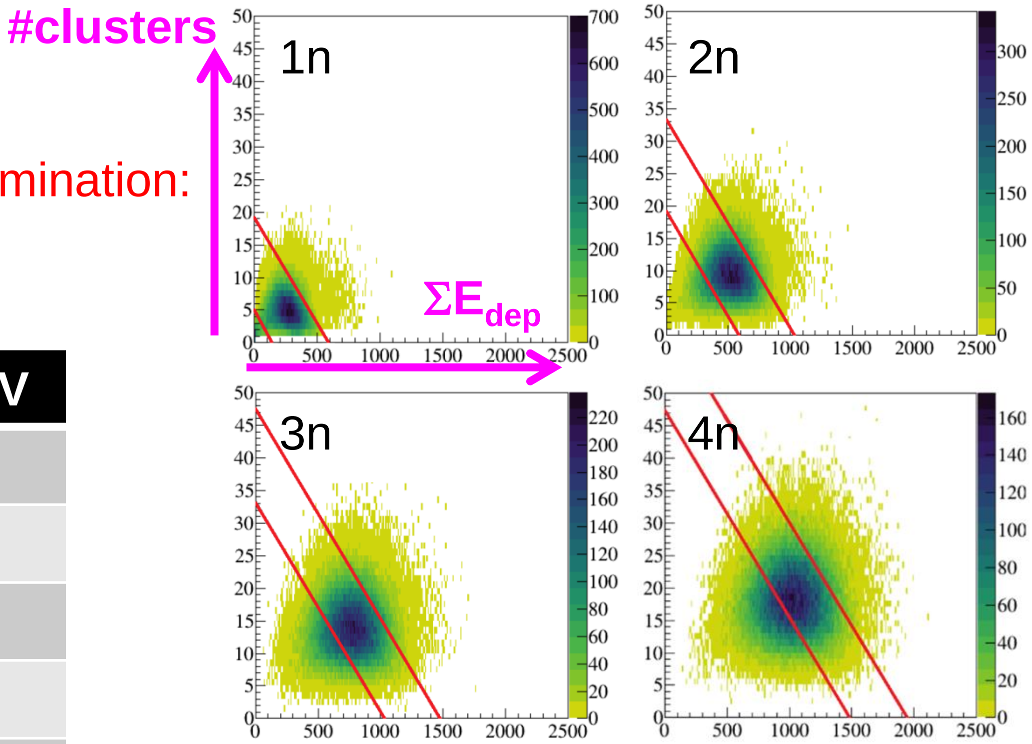
➔ DNN is still under development

➔ Use classical methods to estimate effects

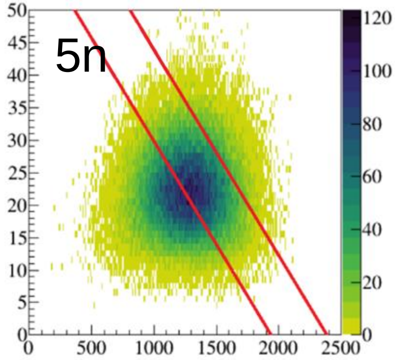
Physics list effects

Traditional Method for multiplicity determination:
➔ Simulate INCL++ & BERT
➔ exp ≈ ½ (BERT + INCL++)

	200 MeV	600 MeV	1000 MeV
0n	77±4%	74±1%	74±1%
1n	73±8%	79±2%	80±1%
2n	62±11%	65±1%	71±1%
3n	58±10%	56±1%	61±1%
4n	46±8%	52±3%	54±3%
5n	57±8%	61±2%	62±4%



30 double planes for NeuLAND @ 14 m distance



➔ Physics lists errors are larger at lower energies
➔ Relative errors: larger at higher multiplicities
➔ NeuLAND is designed to detect high multiplicities

Physics list effects

Full NeuLAND detector:
30 double planes

Traditional Method for multiplicity determination:

➔ Simulate INCL++ & BERT

➔ exp ≈ ½ (BERT + INCL++)

	200 MeV	600 MeV	1000 MeV
0n	77±4%	74±1%	74±1%
1n	73±8%	79±2%	80±1%
2n	62±11%	65±1%	71±1%
3n	58±10%	56±1%	61±1%
4n	46±8%	52±3%	54±3%
5n	57±8%	61±2%	62±4%

Partial NeuLAND detector:
12 double planes

200 MeV	600 MeV	1000 MeV
82±2%	82±1%	83±1%
43±32%	63±3%	63±1%
57±5%	51±1%	52±1%
43±15%	42±1%	44±1%
49±12%	41±2%	37±1%
35±15%	48±5%	50±1%

➔ Physics lists errors are larger at lower energies

➔ Relative errors: larger at higher multiplicities

➔ NeuLAND is designed to detect high multiplicities

➔ Physics list errors grow when detector gets smaller.

Conclusion

- NeuLAND detects fast neutrons: 100 MeV – 1000 MeV.
- Benchmarking revealed: exp ≈ ½ (QGSP_BERT_HP + QGSP_INCLXX_HP) for single-neutron detection efficiency.
- Diff. = 50% due to (d,t,α) tracks, 25% due to nr. of prod. protons & 25% other.
- Effects are <2% at higher energies, but very significant at lower energies.
- These differences prevent us from properly training our DNN.

➔ A new physics list is needed with:

- E_{dep} from (d,t,α) tracks & nr. of prod. protons between BERT & INCL++.
- neutron detection eff. (E_{dep} in CH_2 scintillators): ½ (BERT + INCL++).
- implement with special attention at lower neutron energies.

Thank you!