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U.S. DEPARTMENT of ENERGY

LDRD-C 25-043 project conclusion

Tunable Neutron Beam through Deuteron Disassociation

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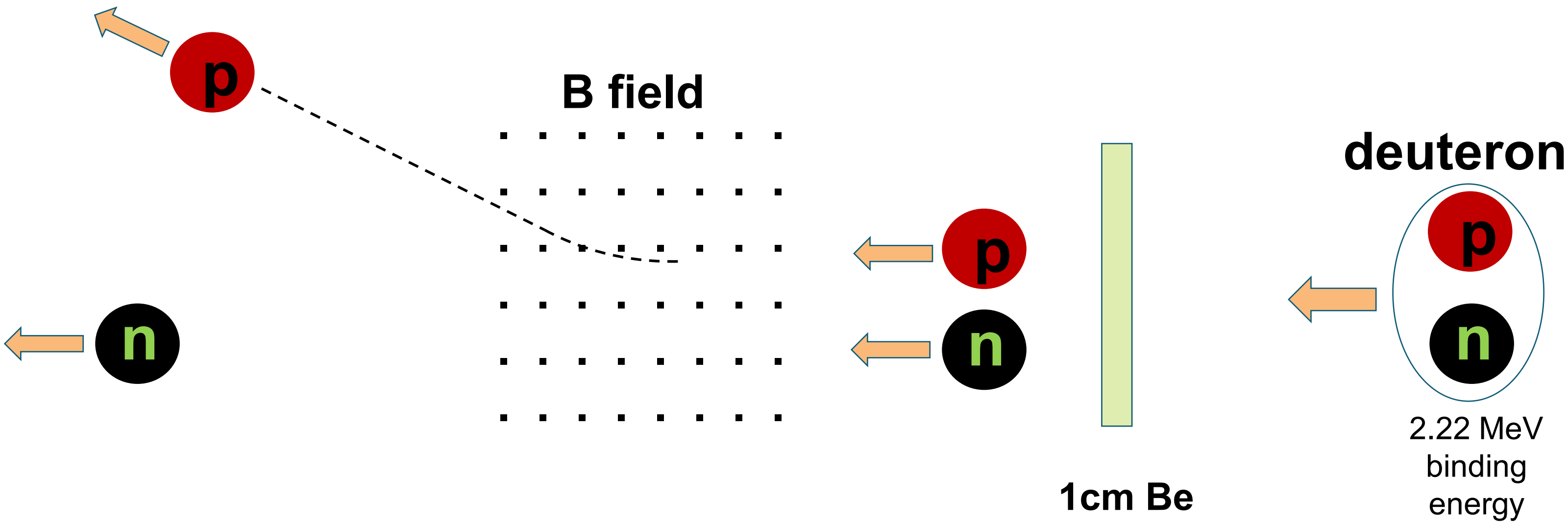
December 18th, 2025

Tunable Neutron Beam through Deuteron Disassociation



Method: (1947) disassociation reaction strips the loosely-bounded deuteron into (p + n) pair with similar energies, ~2% possibility for 100 MeV/n deuteron on a 1 cm Be.

This work focused on deuteron 100 MeV/u.

Goal: once "mono-energetic" neutron is demonstrated, a tunable neutron beam (15-200MeV) is achievable with existing technology, reaching 10^{10} neutrons/cm^2/sec.

Approved for FY2025 (LDRD-C $75k, covers 8hr beam time at NSRL, engineer time, etc.).

- Results of a **beam test** (Sept. 3rd, 2025), with deuteron and proton beams 100 MeV/u
- Conclusion and next steps.

Why Fast Neutron (E_{kin} = 15MeV - 200MeV) ?

Applications of neutron technology are limited by the available neutron sources:

- Reactors neutrons (thermal): $E_{kin} << 1$ MeV.
- Fusion neutrons (Deuteron-Deuteron, Deuteron-Tritium): E_{kin} =2.5 MeV, 14.1 MeV.
- Accelerator based proton-spallation neutrons: wide energy not easily selectable.

Fast neutron beam (E_{kin} = 15MeV-200MeV) with selectable energy is not currently available to satisfy the needs of:

- Isotope production.
- Aviation Industry: neutron induced radiation damages in electronics.
- National Security:
  - fast-neutron cross-sections for weapons design and simulation.
  - imaging of subcritical nuclear material in high-energy and high-density states.

It's well-known since 1940s that deuteron disassociation on a light nuclear target produces mono-energetic neutrons, **a practical fast-neutron beam with tunable energies has never been demonstrated.**

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R. Serber, *Phys. Rev.* 72, 1008 (1947)

PHYSICAL REVIEW VOLUME 72, NUMBER 11 DECEMBER 1, 1947

The Production of High Energy Neutrons by Stripping*

R. SERBER
Radiation Laboratory, Department of Physics, University of California, Berkeley, California

(Received August 28, 1947)

"…The **yield of neutrons from a 1/2-inch Be** target (in which the energy loss for 190-Mev deuterons is 20 Mev) **is nearly 2 percent**."

This work focused on deuteron@100 MeV/u, on 1 cm Be target

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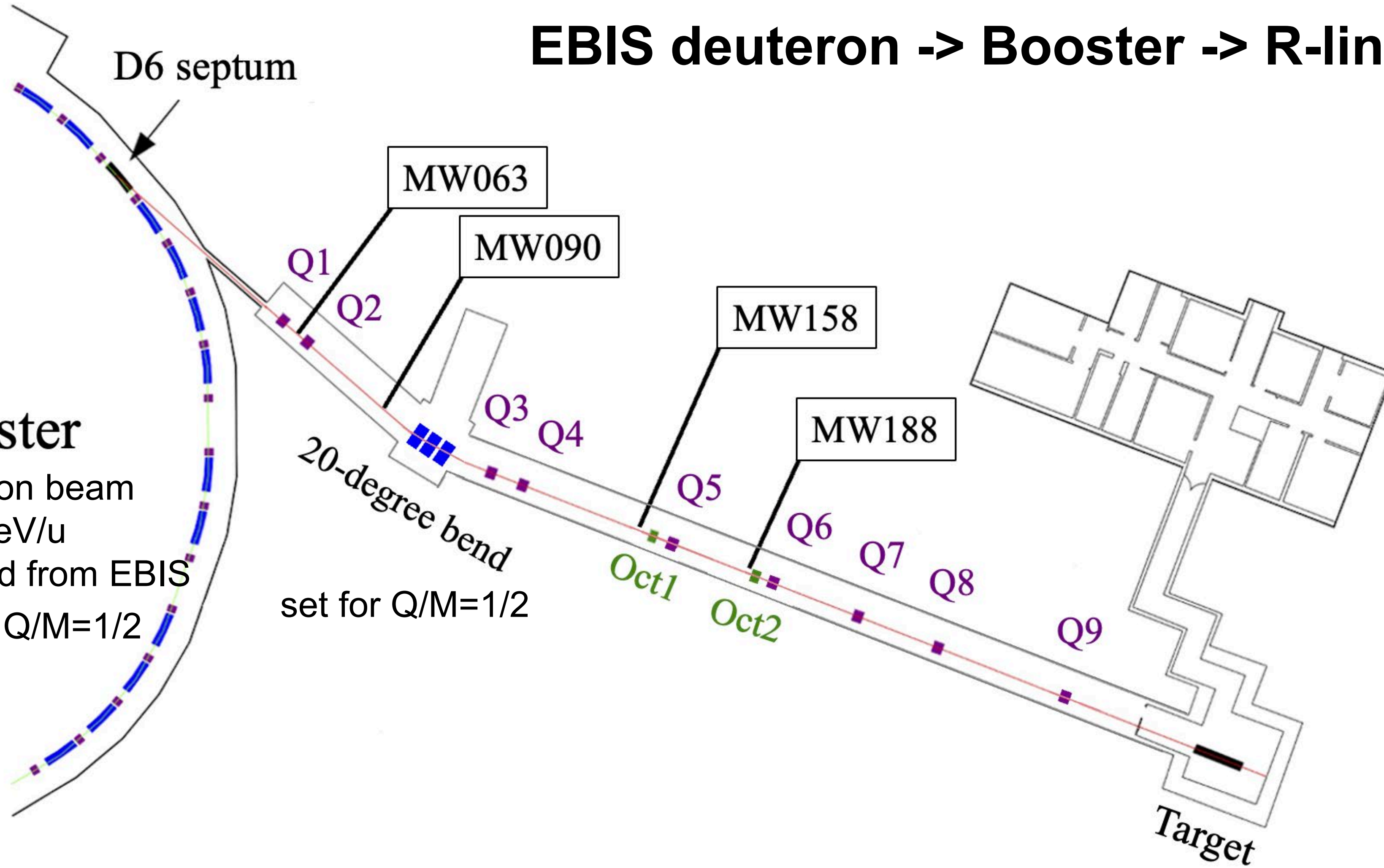
Deuteron Beam in the NSRL beam line (Booster R-line)

EBIS deuteron -> Booster -> R-line



Booster

deuteron beam
100 MeV/u
injected from EBIS

set for Q/M=1/2

set for Q/M=1/2

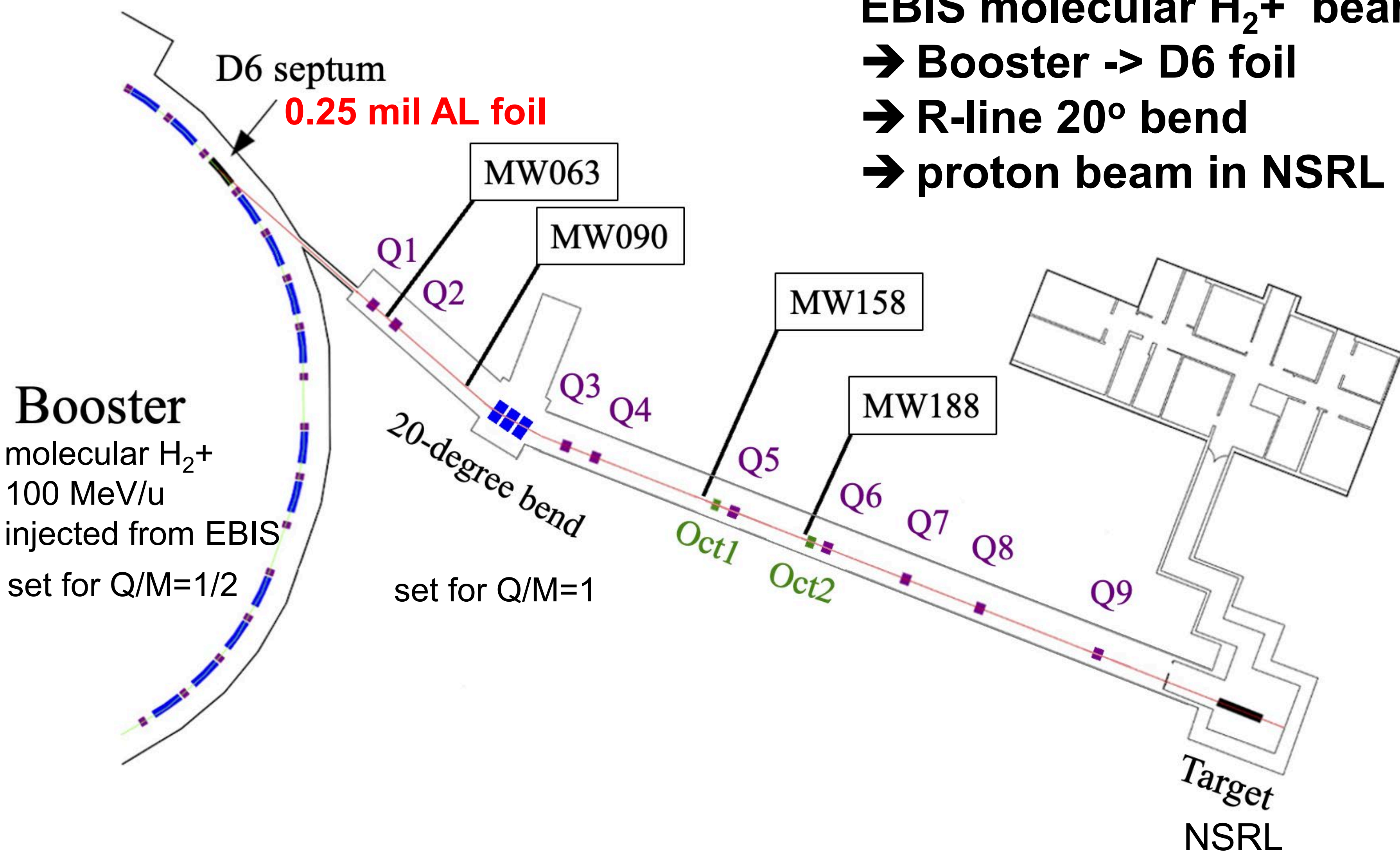
This work focused on deuteron@100 MeV/u

NSRL

The first time EBIS deuterons delivered to the Booster R-line.

Proton beam in the NSRL beam line (Booster R-line)

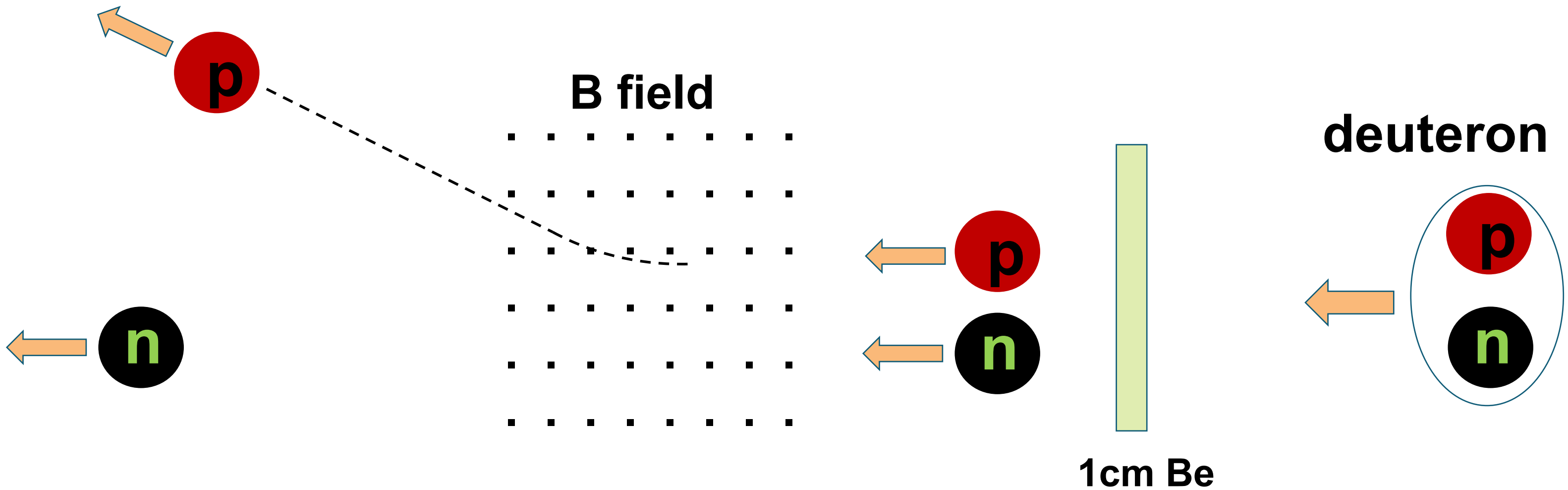
EBIS molecular H_2+ beam
➔ Booster -> D6 foil
➔ R-line 20° bend
➔ proton beam in NSRL



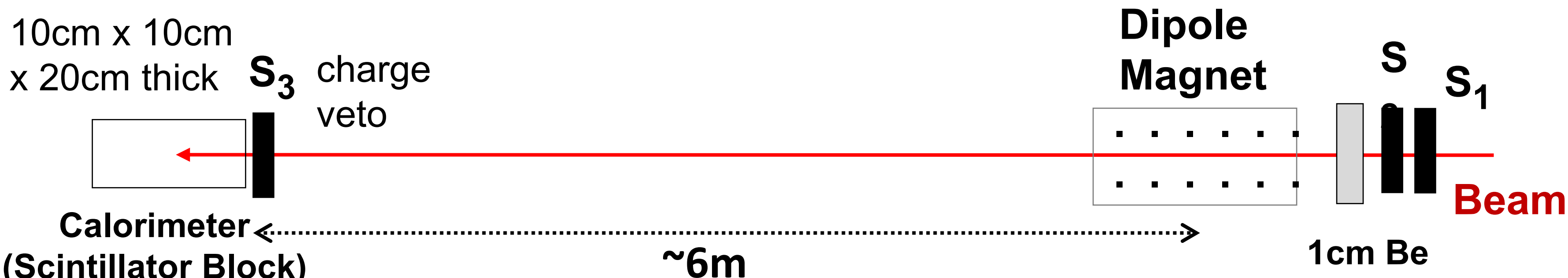
The first time EBIS protons (from H2+) delivered to the Booster R-line.


Beam
CAUTION
THIS DEVICE MAY OPERATE REMOTELY
NSRL Target Room

Test Setup



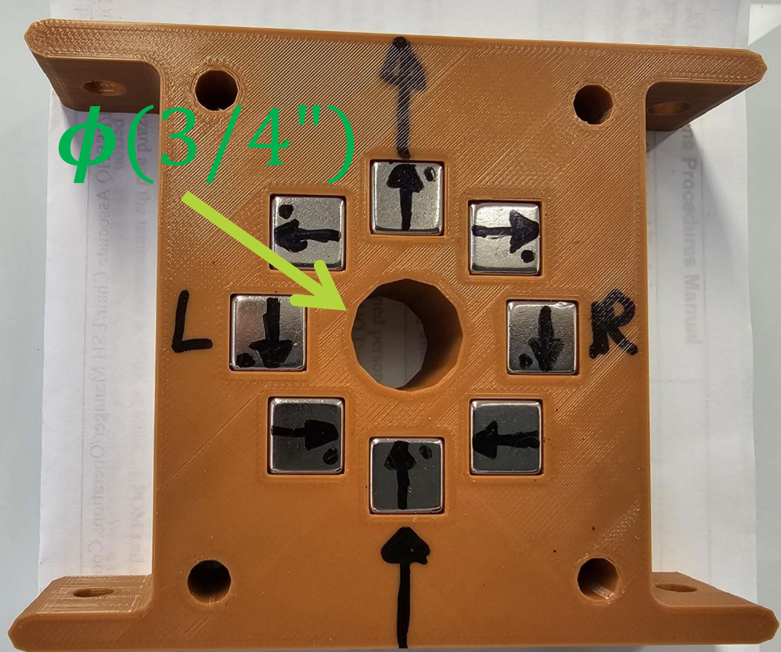
(1947) disassociation reaction strips the loosely bounded deuteron into p + n with similar energies, with a ~2% possibility for 100 MeV/n deuteron on a 1 cm Be target.

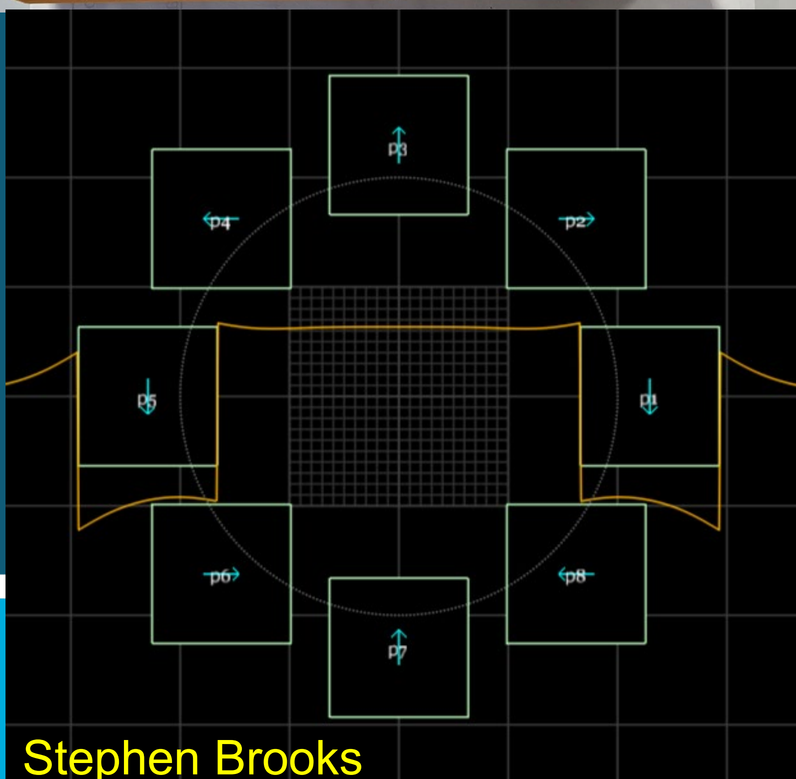


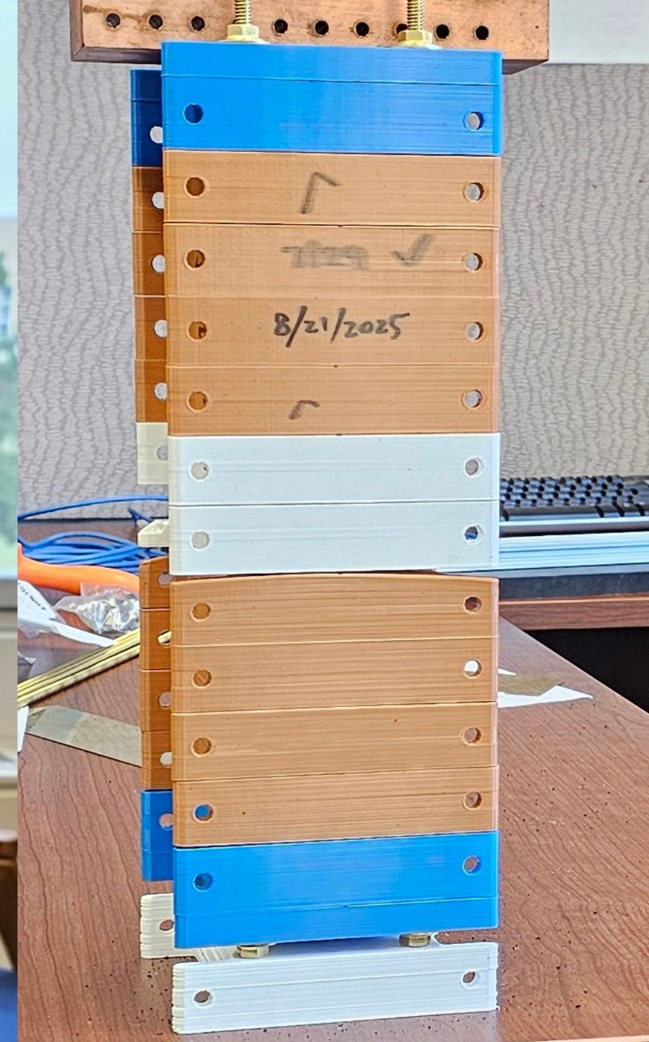
neutron detection through (n,p) interactions.

Trigger:
(S_1+S_2)+Calorimeter

scintillator S1, S2, S3: 5”x5”x1/4”







Dipole Magnet

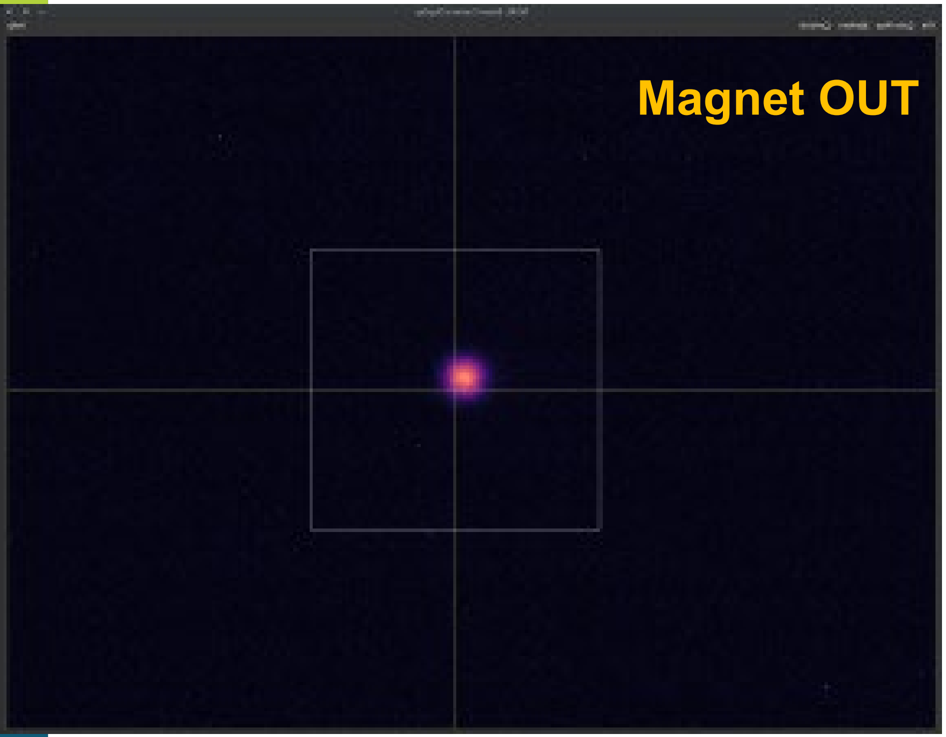
B=0.475 tesla, L=12"

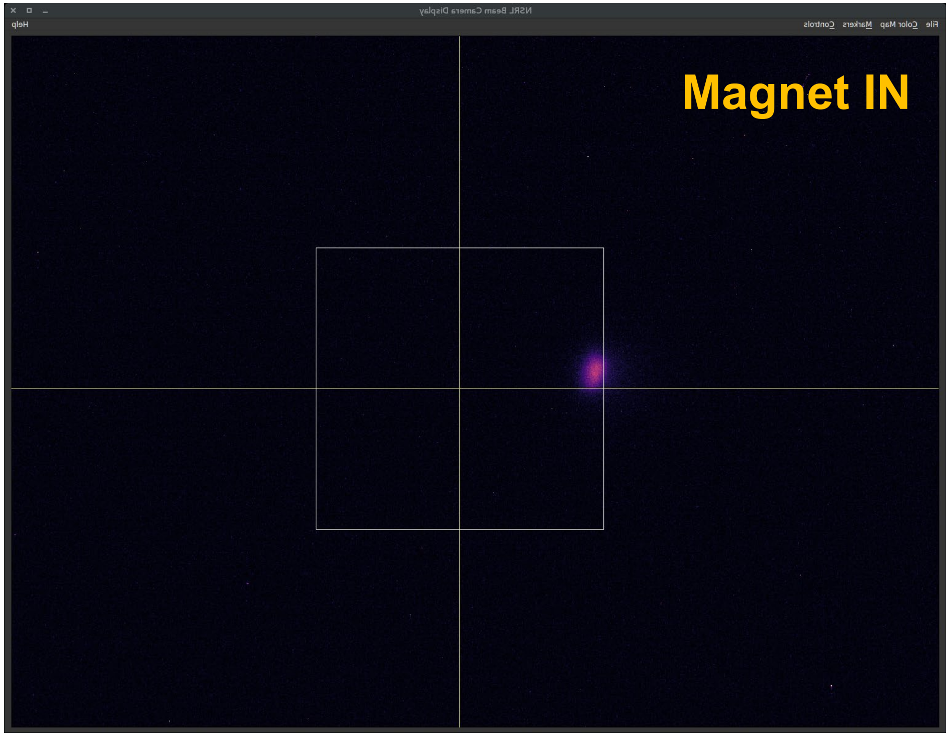
BdL ~ 0.145 Tesla.meter

center clearance:0.75"

100 MeV/u deuterium beam, a 10x10cm square shown as a reference

Beam camera screen: ~ 130cm from center of magnet





primary beam displacement: ~5 cm

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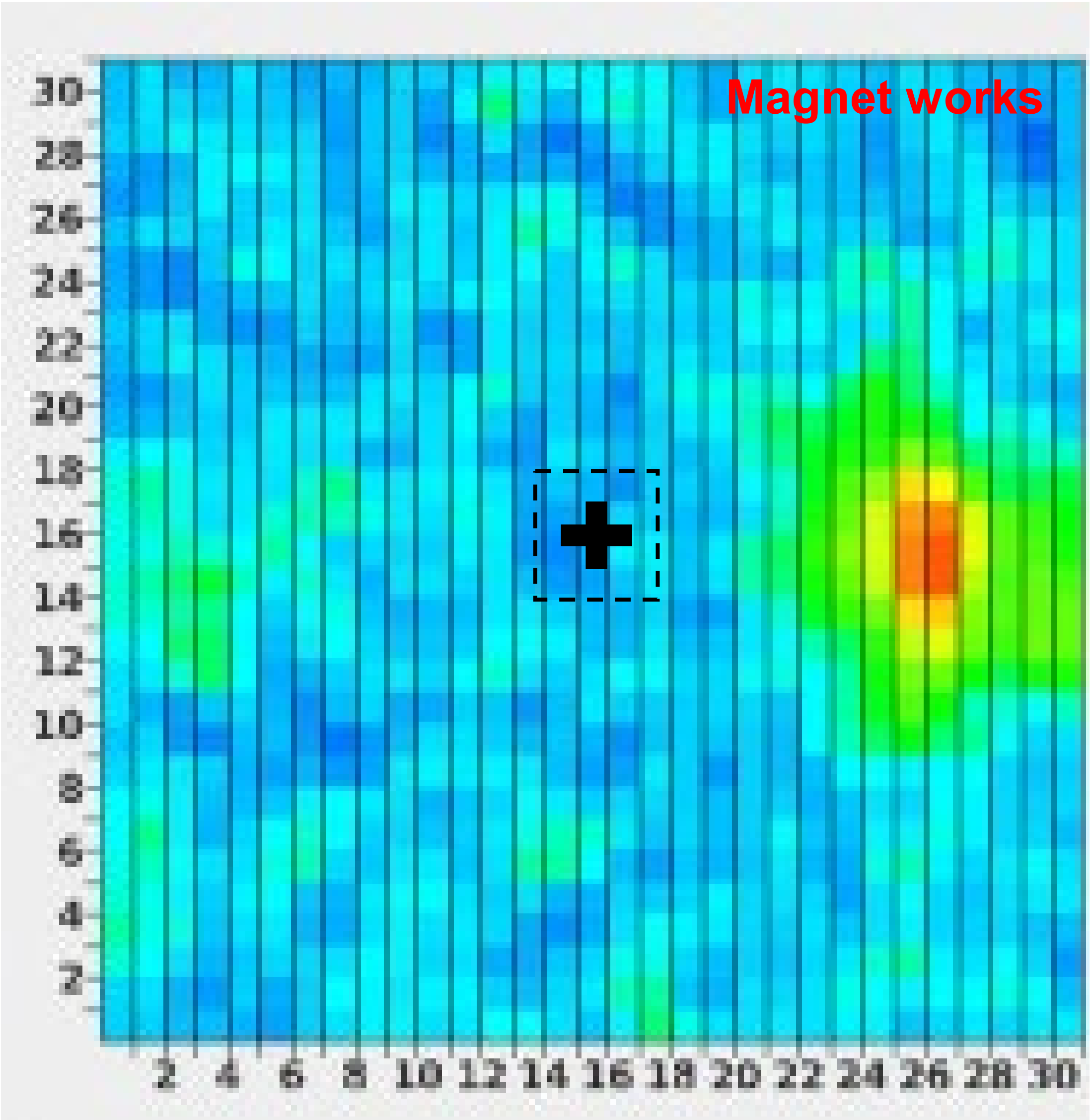
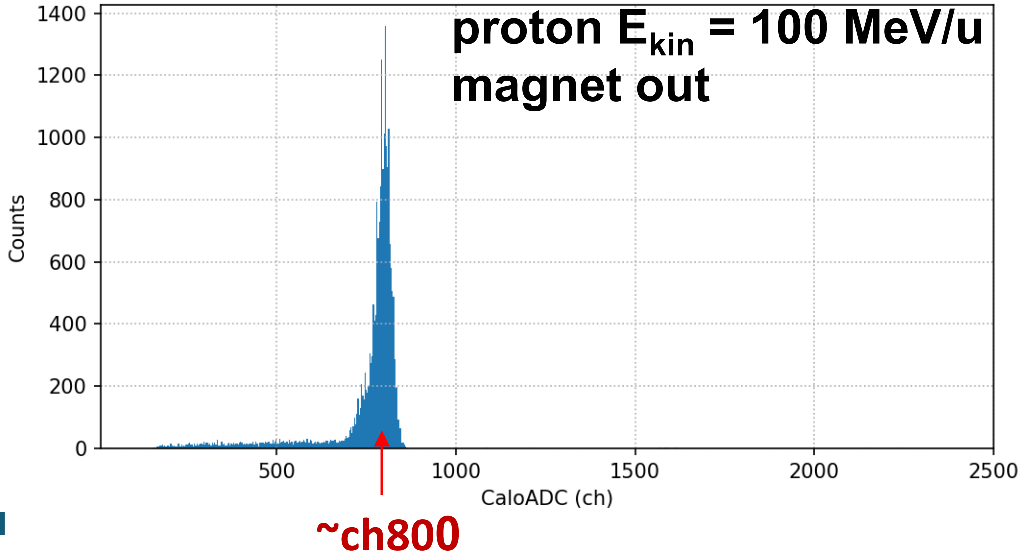
100 MeV/u deuteron beam through the magnet.
At the Strip-Chamber (1” pitch) behind the Calorimeter (~650cm from magnet-center),
Primary deuteron beam displacement: ~10” (25.4cm)

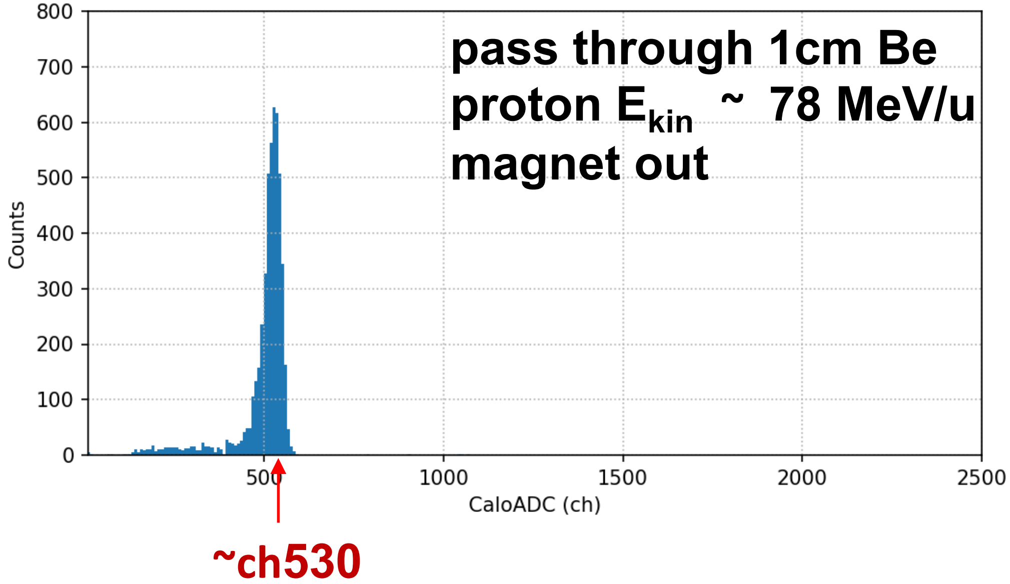


Calorimeter size:
scintillator block
(10cm x 10cm) x 20cm thick

At downstream:
the primary deuteron beam is kicked far away from the calorimeter

Calorimeter ADC





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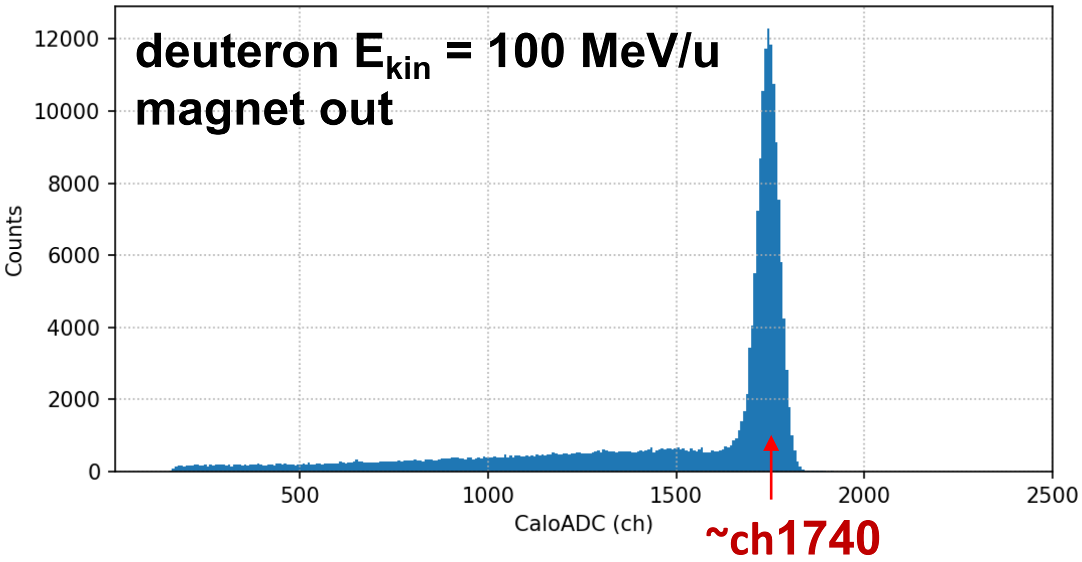
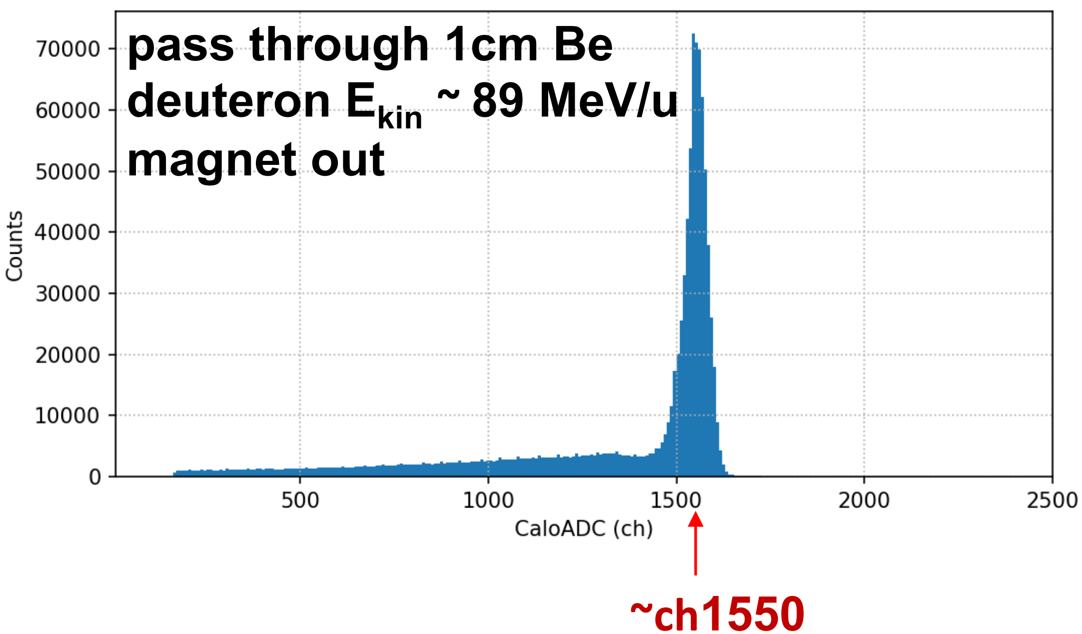
Calorimeter ADC





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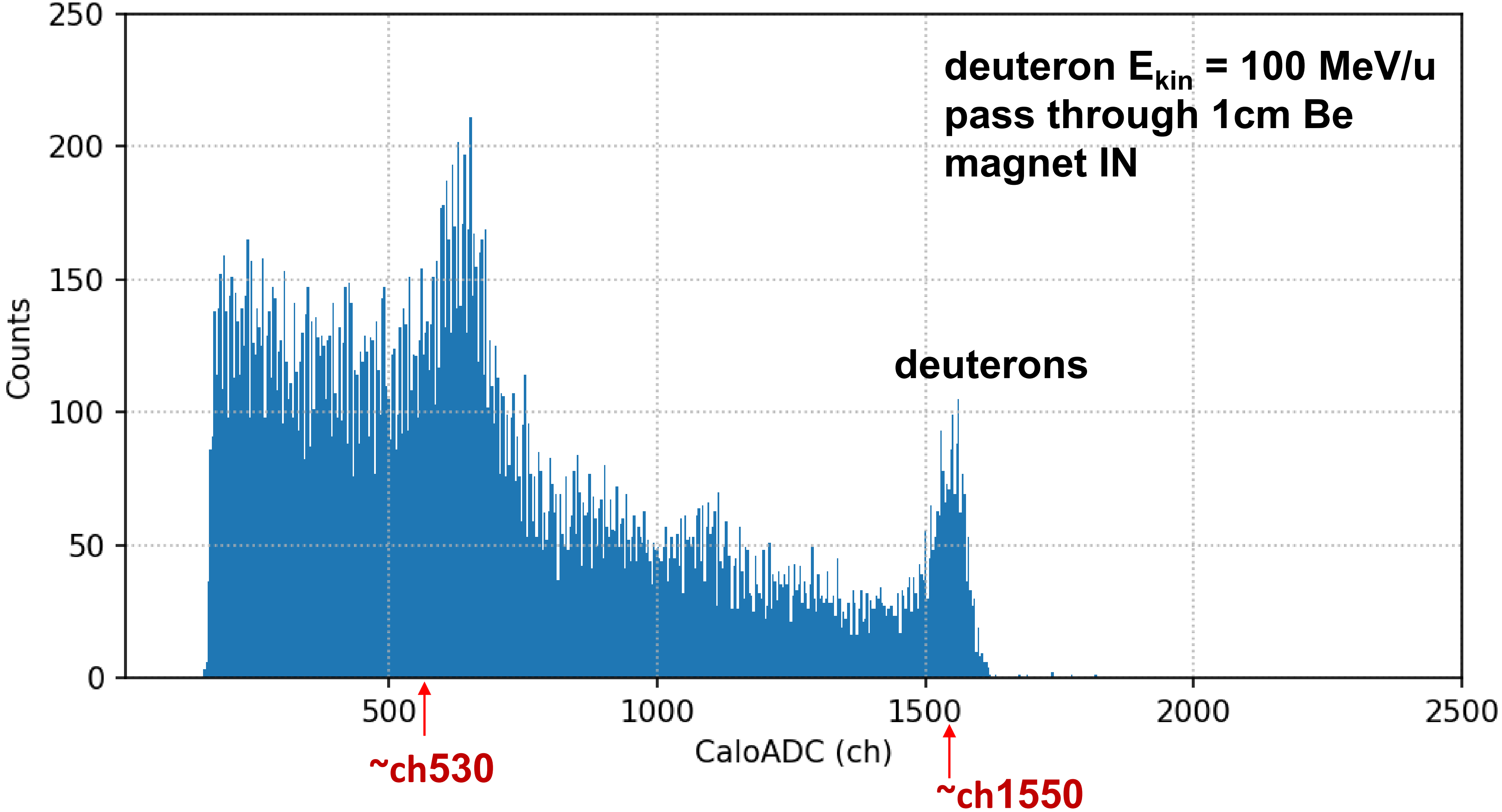
Calorimeter ADC



Scaler Rates (4.8 sec per spill):
(S_1+S_2): 200k/spill
S_3 : 1200/spill
Calorimeter: 270/spill
Trigger (S_1+S_2)+Calorimeter: 90/spill

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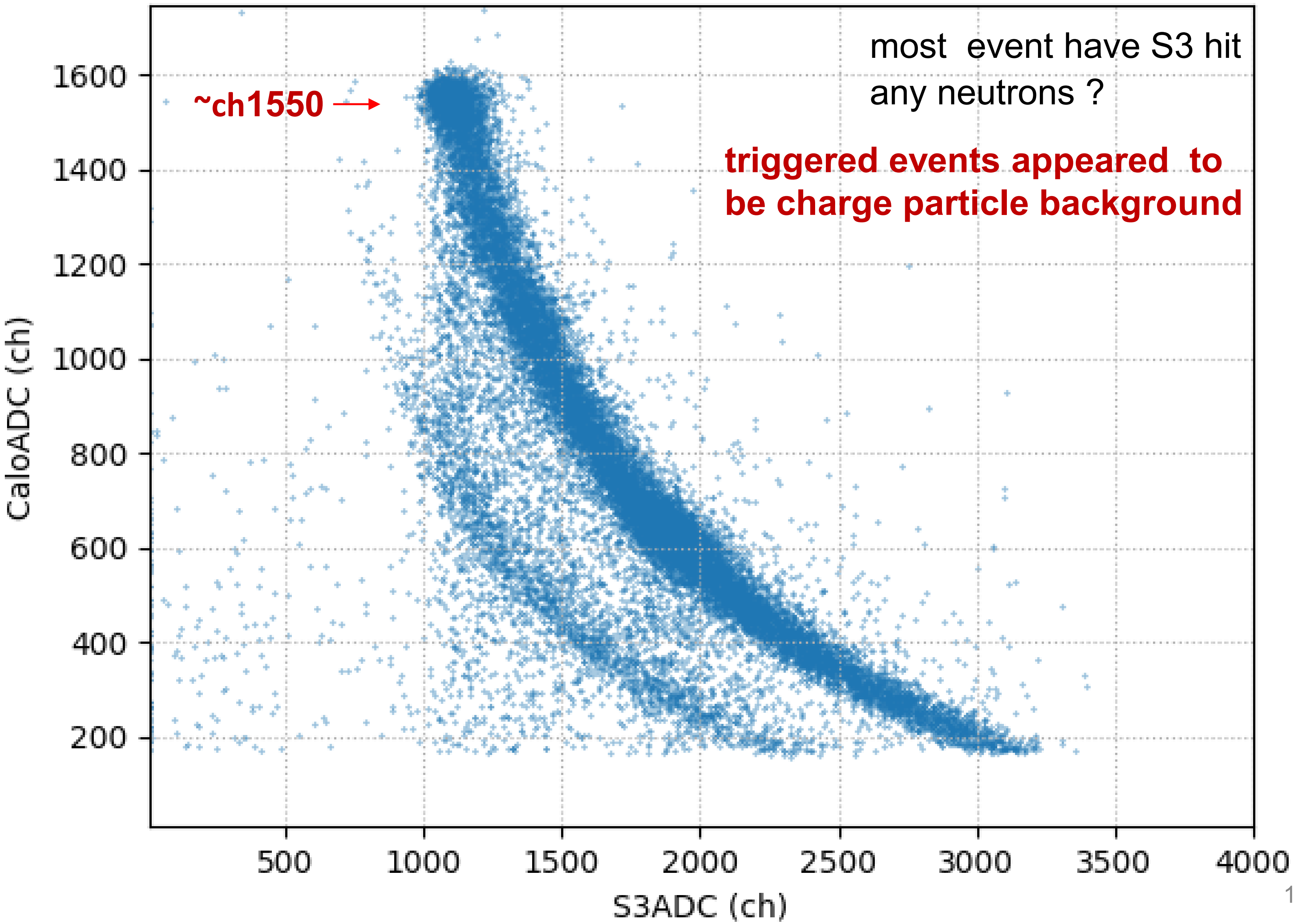
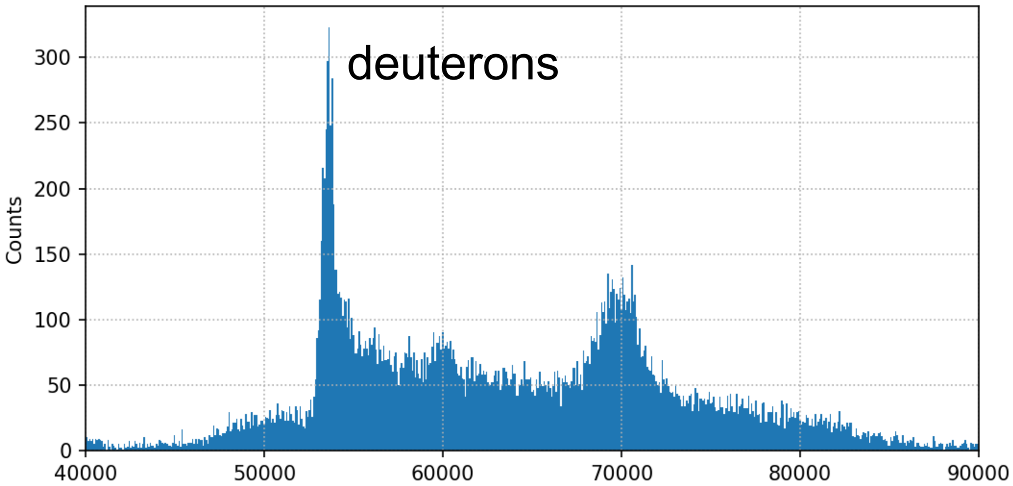
Calorimeter_ADC vs S3_ADC all events

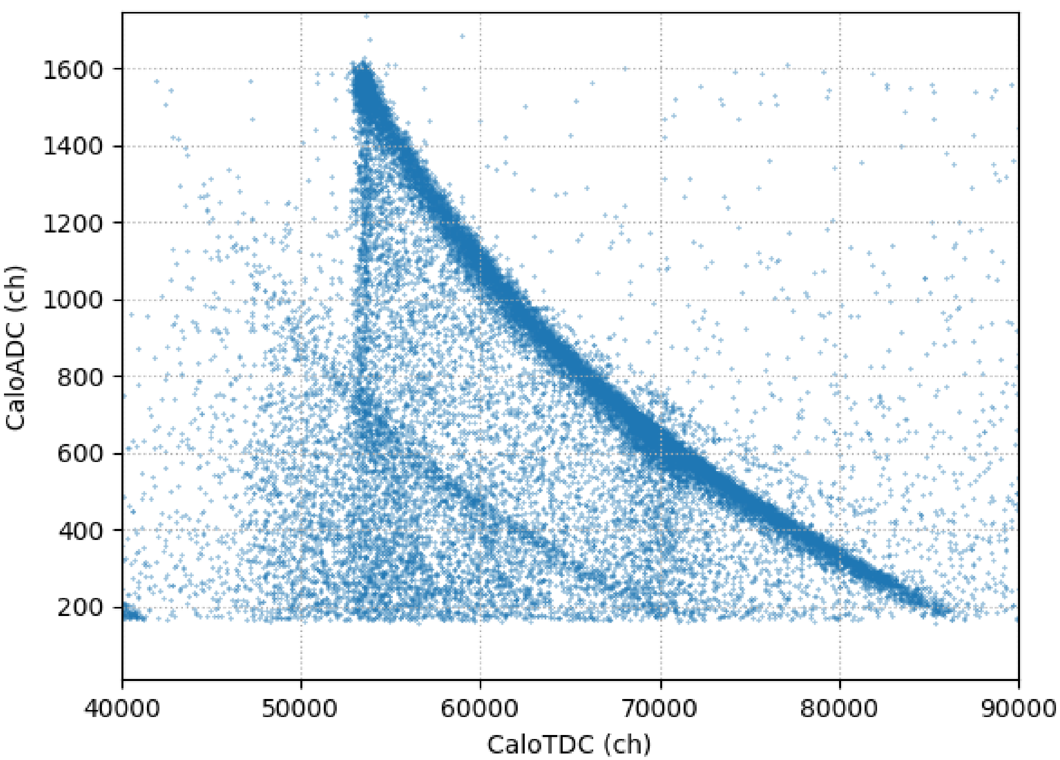


Calorimeter Flight-Time

any neutrons ?

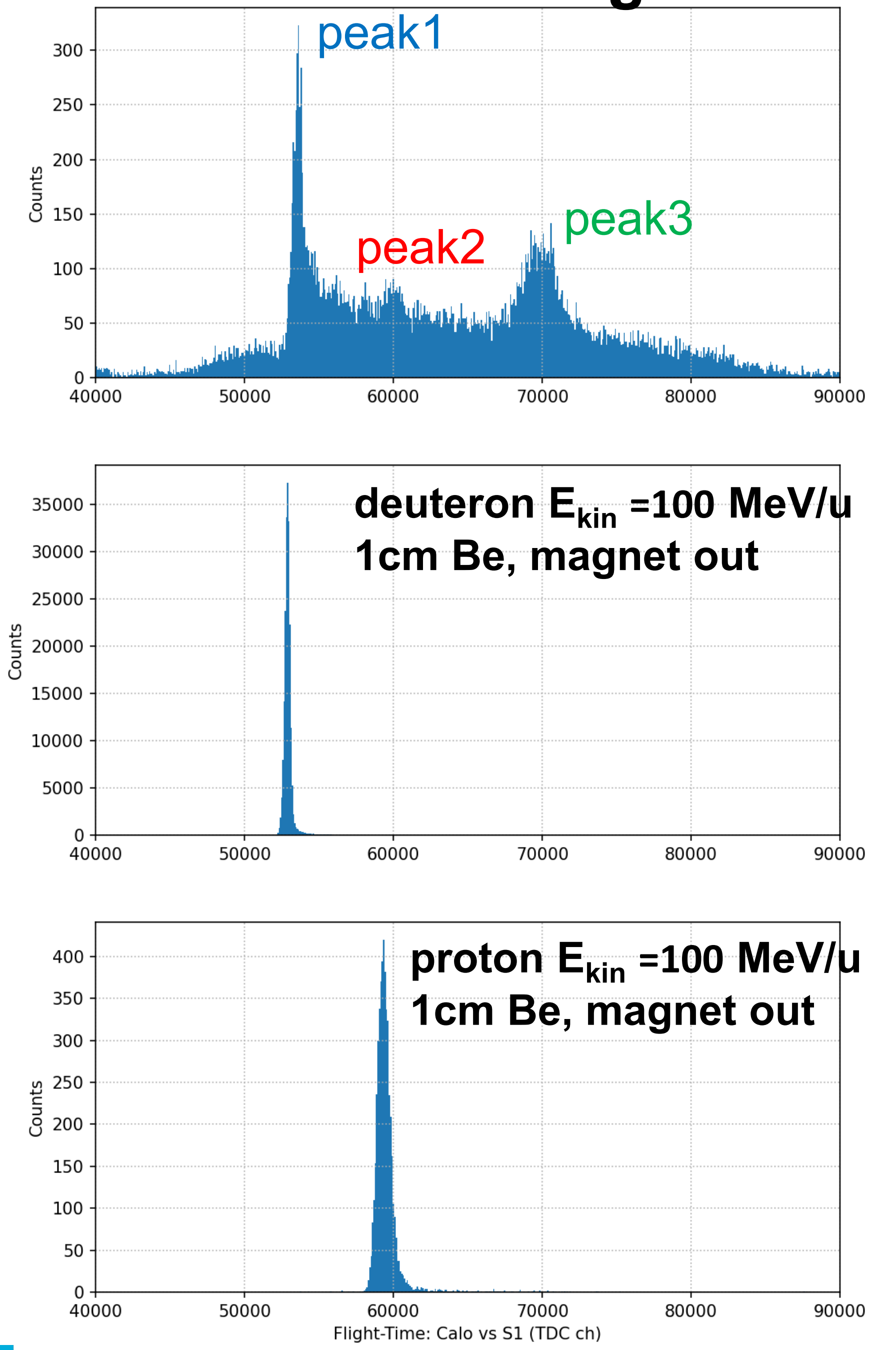


Calorimeter Flight-Time vs ADC

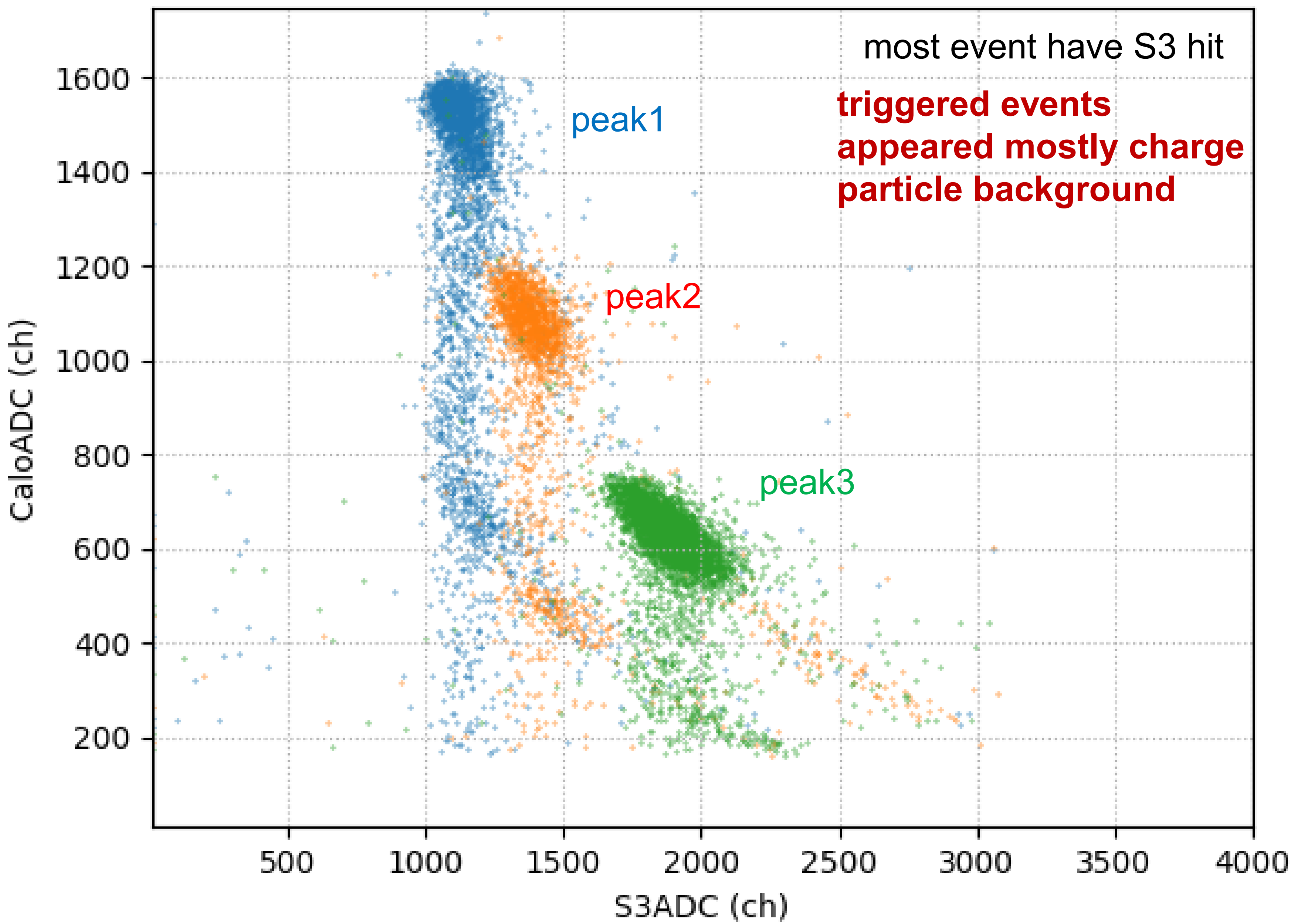


Calorimeter Flight-Time

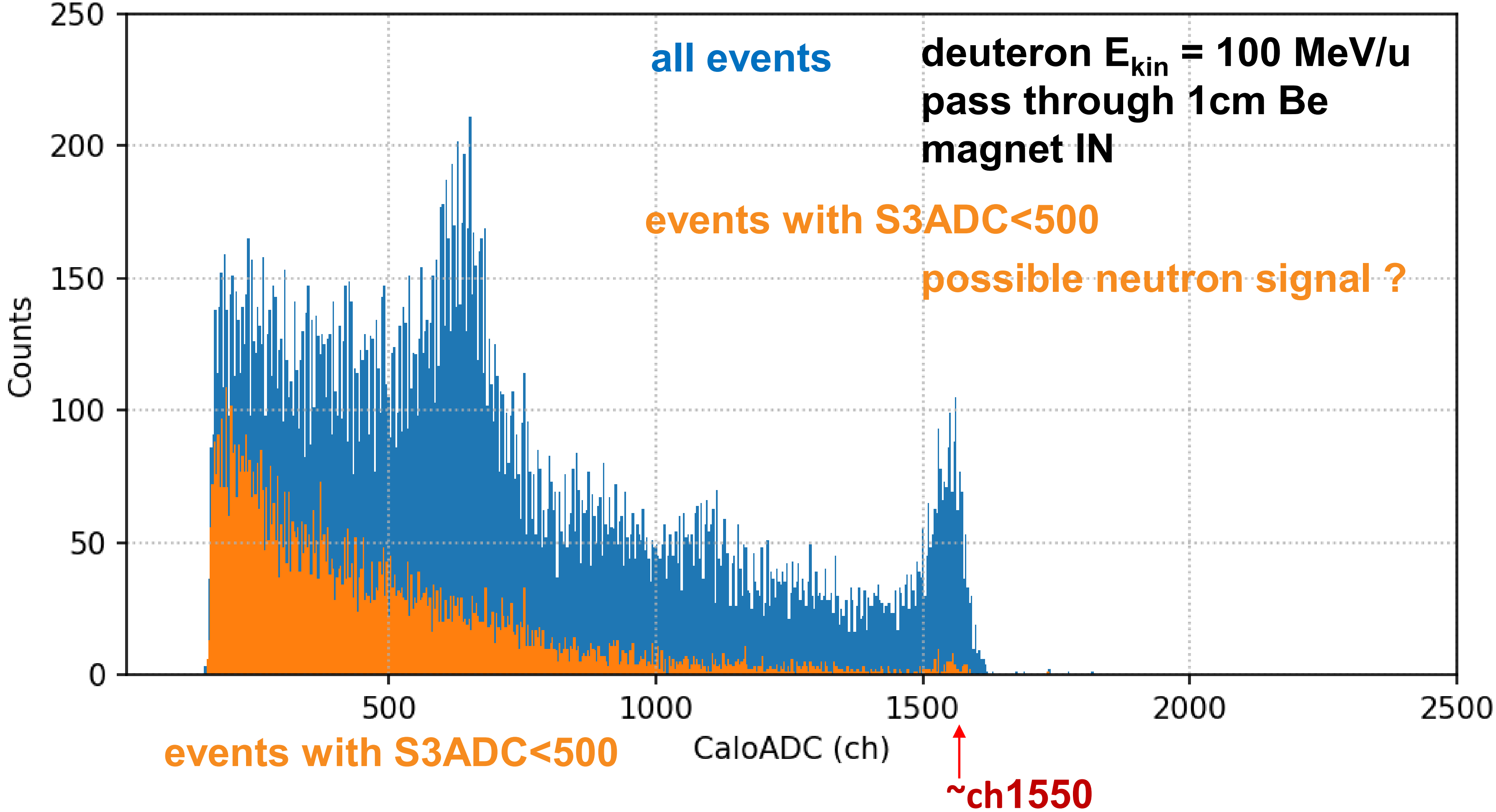
any neutrons ?



Calorimeter_ADC vs S3_ADC with Flight-Time Cuts



Calorimeter ADC



Not expecting neutron conversion (n,p) reaction
lead to protons with well-defined energy

Conclusions

It's well-known since 1940s that deuteron disassociation on a light nuclear target produces mono-energetic neutrons, **a practical fast-neutron beam with tunable energies has never been demonstrated.**

BNL has all the facilities/technologies to make such a tunable neutron beam possible:

- **EBIS provides deuteron beam (and proton through H_2+).**
- Booster and slow extracted beam, for deuteron up to 1000 MeV/u.
- NSRL beam line and the Target Room.

We conducted a beam test: did not pinpoint neutron signal, triggered events appeared mostly from background.

Improvements Planned (LDRD-C proposal submitted for FY2026):

- **An open-slot dipole magnet**: to clearly sweep away all primary beam deuterons and the breakup protons.
- **Tag the breakup proton** with scintillator strip detectors.
- **A neutron telescope detector**: multi-layer segmented scintillators. (charge-veto + flight-time, combined with a range-telescope)

Next Step:

Event-by-event tagged neutrons as a clear demonstration.

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Next Step: event-by-event tagged neutron