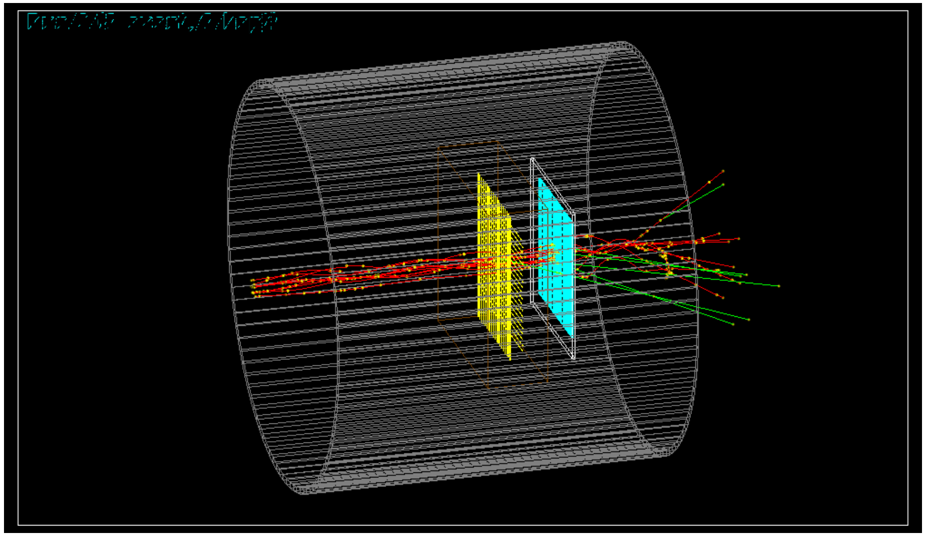
LAMPS simulation related activities

NPL-HIPex workshop, Feb. 25, 2021

Chong Kim

- **Outline**
  - PNU-NPL in LAMPS
  - 2020 KOMAC beam test
    a. Collimator MC
    b. Target MC
  - Recent activities



PNU-NPL in LAMPS What we can contribute

- **Working groups in current LAMPS**
  - CNU: BDC (Beam drift chamber, beam monitor and tracking)
  - Korea University:
    a. CeNum:
       a-1. TPC software development (Dr. Jang-yong Huh)
       a-2. Neutron detector (ZDC equivalent, mainly target forward neutrons)
    b. Prof. Ahn's group: BTOF/FTOF (2nd trigger and pID) design and building
  - IBS: TPC
  - Inha University: SC (start counter, 1st trigger detector) and VETO
  - Sejong University: AT-TPC (independent tracking in small acceptance w/ its own target)
  - No software dedicated group exists
    a. No progress regarding MC/Event building/Tracking software
    b. Are these items NOT needed? No. What's you going to do with your PC without OS?
    c. Do we have tons of time?
       No. Originally, LAMPS had to be in beam-ready condition within end of this year

KOMAC Beam Test   Necessity of simulation

- **Where, What, and Why**
  - KOMAC TR102 beam specifications
    a. Species: proton
    b. Energy: 100 MeV (± 10%)
    c. Irradiation area: [10 x 10] cm^2 (± 10% @ 3 cm - ϕ)
    d. Intensity (flux):
       d-1. $10^6 – 10^8$ /cm^2 · pulse (± 20%)
       d-2. 1 pulse/s, 1 μs bunch length

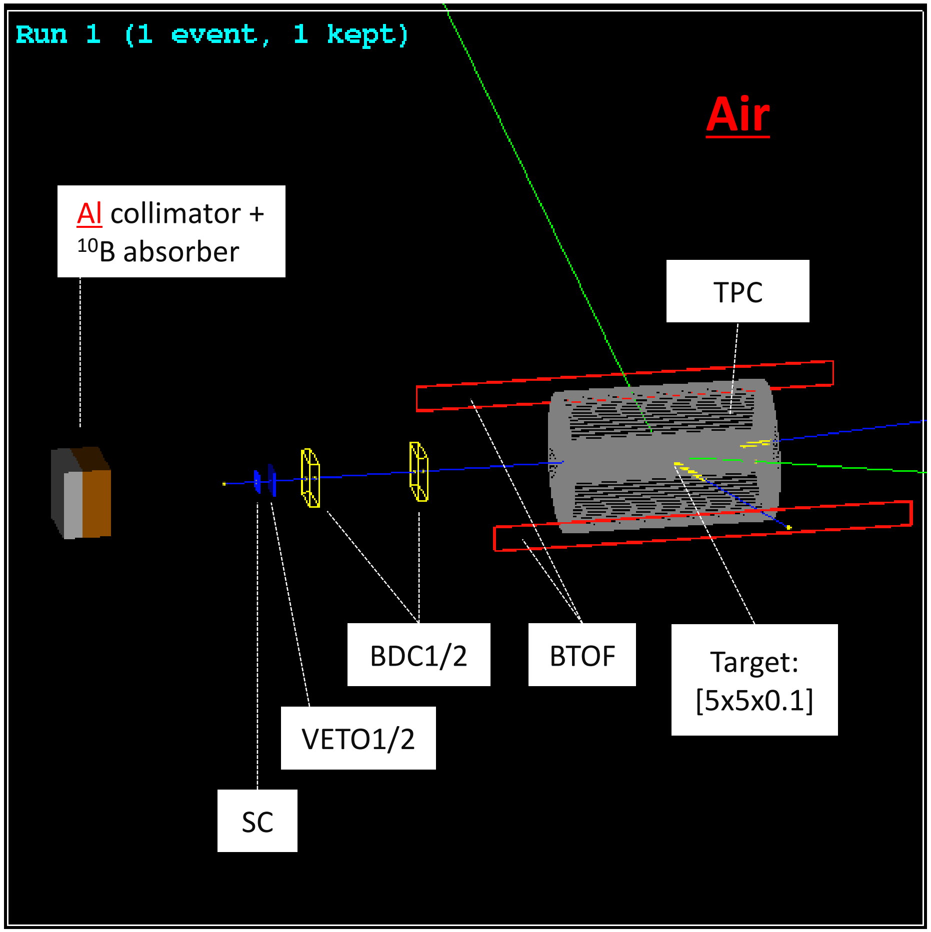
Official specification from webpage

Output energy	30 – 100 (MeV)
Avg. beam current	2 – 5 (mA)
Beam fluence	$10^6 – 10^8$ (#/cm^2 · pulse)
Beam uncertainty	- Fluence: ± 15 % - Beam uniformity: ± 10 % - Output energy: ± 10 %
Irradiation area	100 × 100 (mm)
Pulse width	0.05 – 1.33 (ms)

  - Necessity of optimization:
    a. Suppress the incident beam's intensity and BG → Collimator MC
       a-1. Assuming a proton makes an event, that's (↑) already GHz level rate -
       in reality, it'd be worse as an energetic proton likely induces 2^{nd} particles (n, γ, $e^{\pm}$, deuteron, etc)
       a-2. Not all detectors' recovery time is fast enough (ex. TPC):
       if such high, BG abundant rate pouring in, detectors' would lit up like Christmas tree
    b. Event rate control + Increase portion of "signal" among the acquired events → Target MC
       * We had to start with set the definition of signal

KOMAC Beam Test   Setup before test, before optimization

MC setup used until the end of the October



- **Early subsystems setup**

CAVEAT: this is NOT the final nor the actual setup!

- SC (Start counter):

  trigger, polyvinyl toluene scintillator

  (* $CH_2CH(C_6H_4CH_3)$)

- VETO (1 and 2):

  BG rejection, polyvinyl toluene scintillator

- BDC (1 and 2):

  tracker, p10 base wire chamber

  (* no tracking capability yet)

- pTPC:

  tracker, p10 base wire chamber

  (* no tracking capability yet)

- BTOF: trigger, polyvinyl toluene scintillator

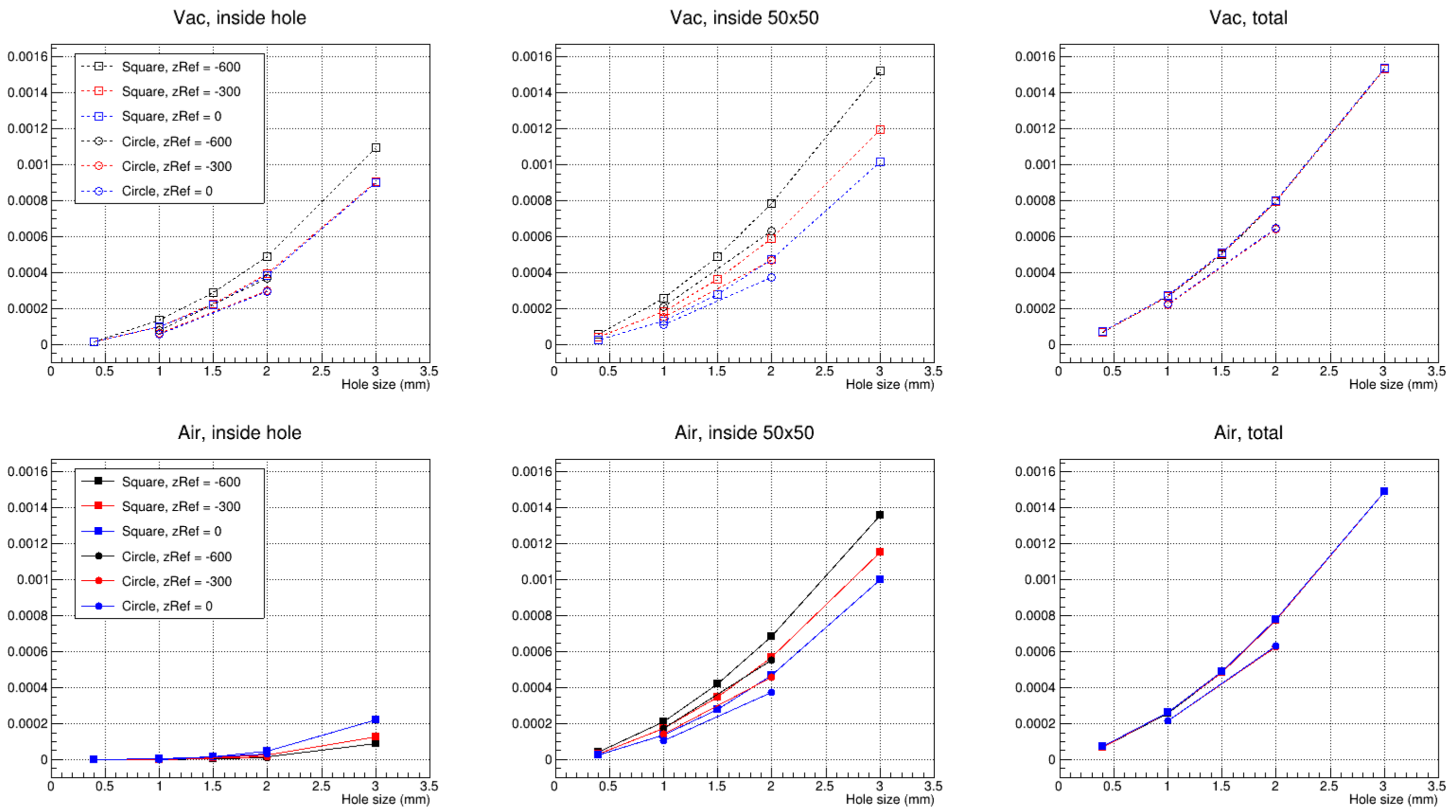
- Target: polyethylene (* C_2H_4)

KOMAC Beam Test - Collimator   Purpose

- **Collimator + Absorber MC**
  - Goals:
    a. Suppress incident beam intensity to controllable level
    b. Minimize 2nd particles production, especially the neutrons
  - Subjects of the study:
    a. Material
       a-1. Collimator: Aluminum (Al, Z = 13, 2.70 g/cm^3) or Acryl (Plexiglas, $C_5O_2H_8$, 1.18 g/cm^3)
       a-2. Absorber: Boron (^{10}B + ^{11}B, in 1:4) (during the test: borated (30%) polyethylene)
    b. Hole shape & size
       b-1. Circular: 1 and 2 (mm, diameter)
       b-2. Square: 0.4, 1.0, 1.5, 2.0, and 3.0 (mm, width)
       b-3. Slit: 0.4 (mm, width)
  - CAVEAT: this study deals only Collimator + Absorber, no other subsystems

KOMAC Beam Test - Collimator

Surviving flux by hole size/shape



– Effect of a collimator's hole shape and size

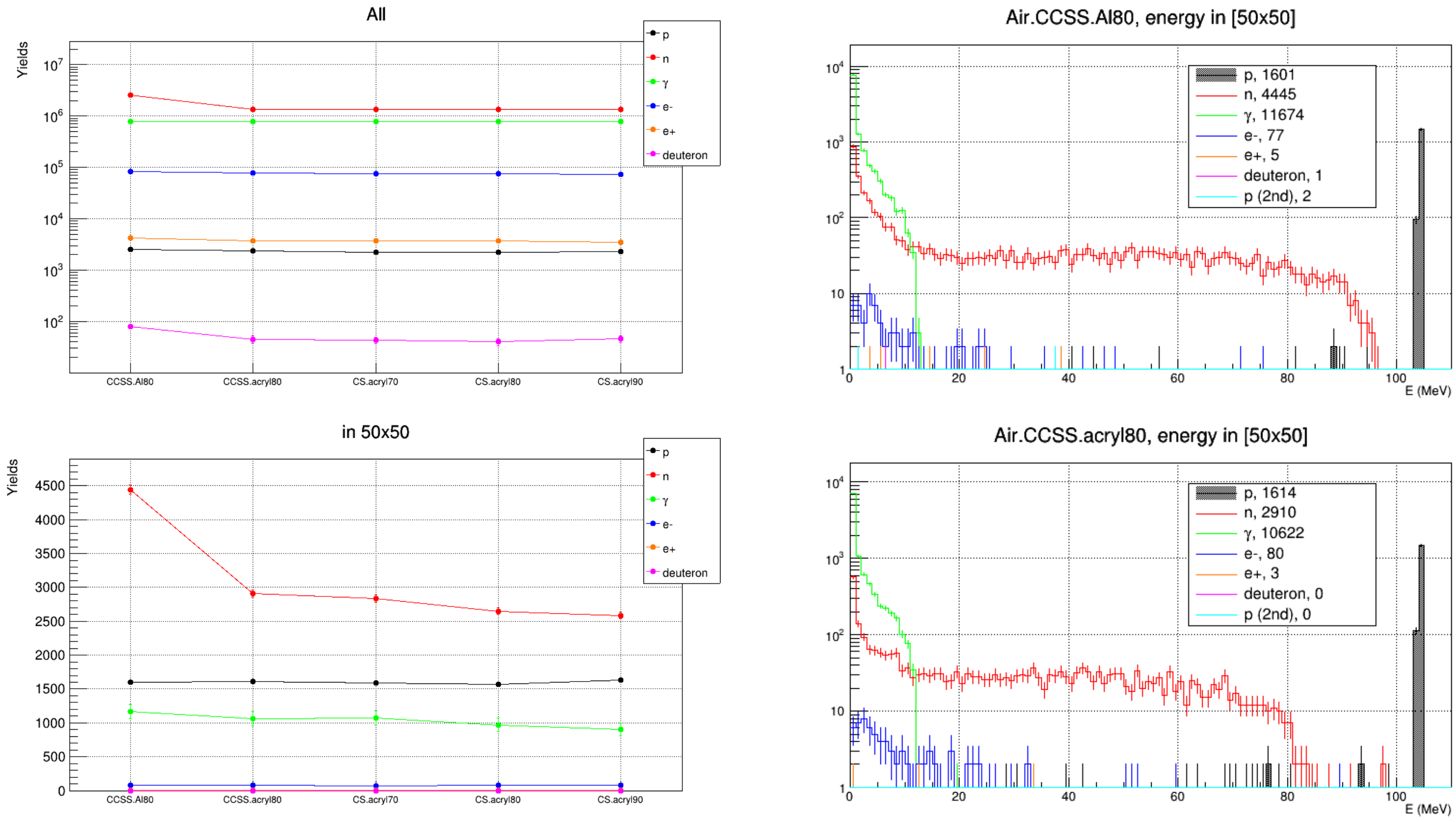
a. Surviving proton's yield (flux) estimation by projection from recording point

b. All conditions are same except hole size and shape (Al, [250 x 250] (mm^2) frame)

d. The only setup suppresses incoming flux below 10^{-4} is [0.4 x 0.4] square hole

e. Judging from 1^{st} column, the scattering in the air is NOT negligible

KOMAC Beam Test - Collimator Material and Thickness



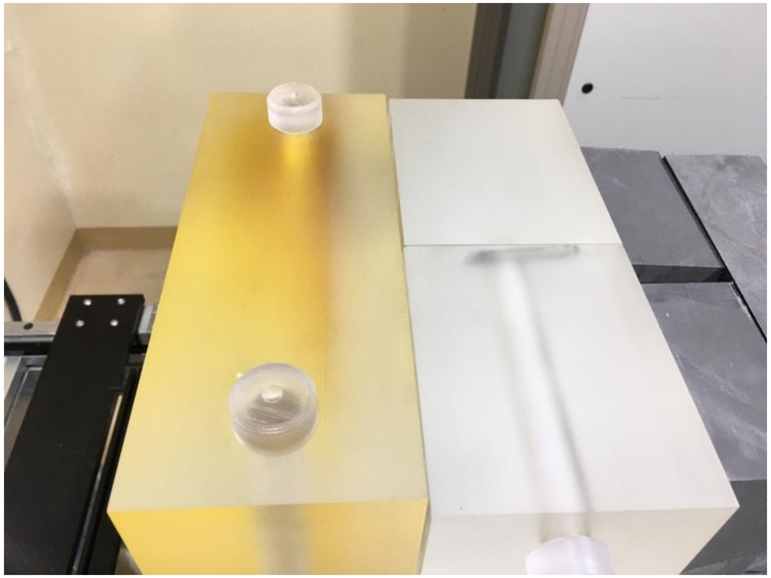
– Determine material and thickness for the collimator, by yields & pID at target position

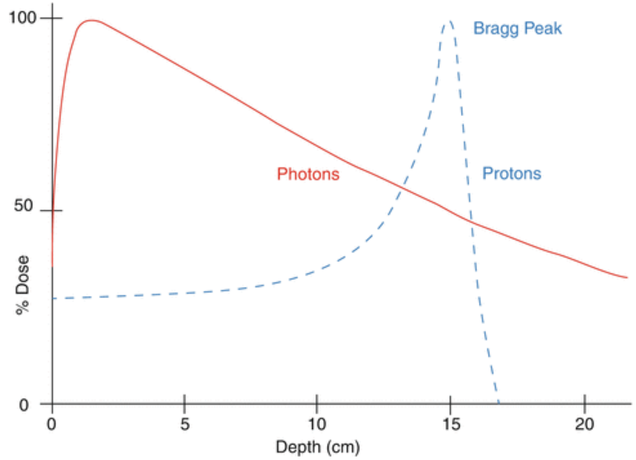
a. Two factors matter: proton suppression effectiveness and amount of BG generation

b. For same thickness, <u>Acryl has advantage over Al</u> in the manner of <u>less BG generation, especially for neutrons</u>

KOMAC Beam Test - Collimator

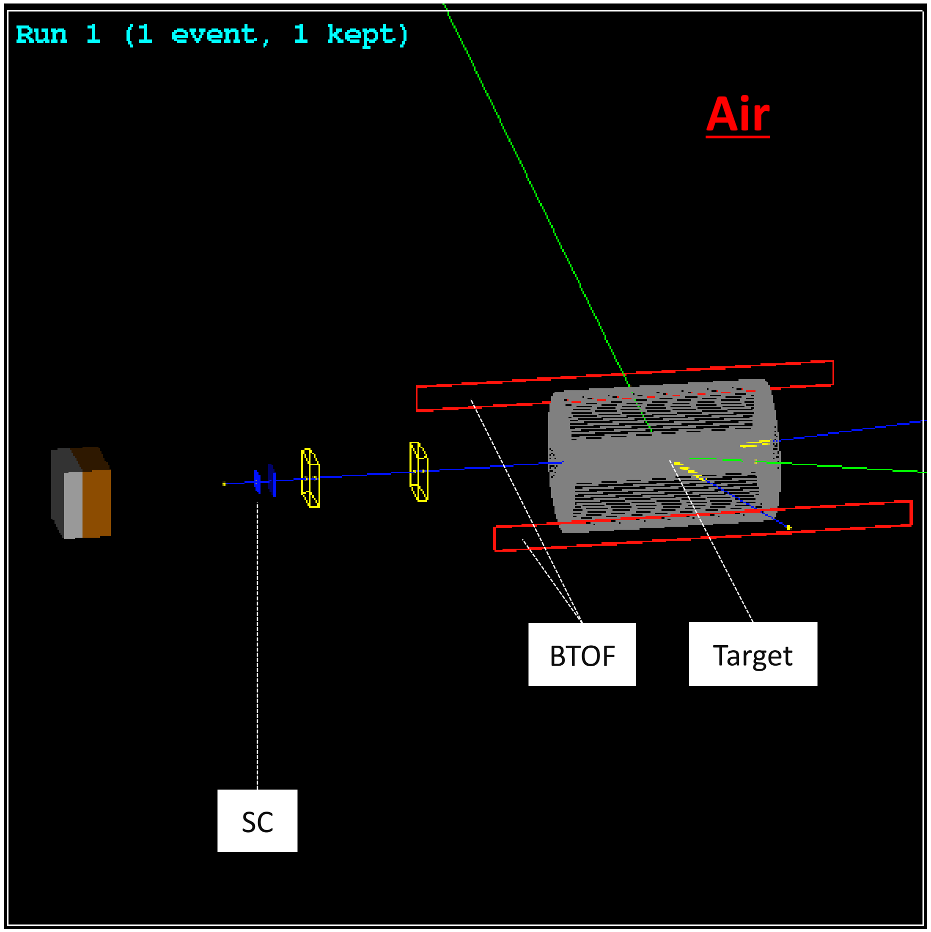
Material and Thickness





KOMAC Beam Test - Target   Define the signal

MC setup used until the end of the October



- **Signal and BG**
  - Signal:

    an event satisfy all following conditions

    a. Incident proton (~ 100 MeV) passes through collimator + ^{10}B absorber w/o scattering

    b. The proton deposits E > 2 MeV on SC, but keeps most of its energy intact until it reaches the target

    c. The proton interacts w/ the target, creates daughters

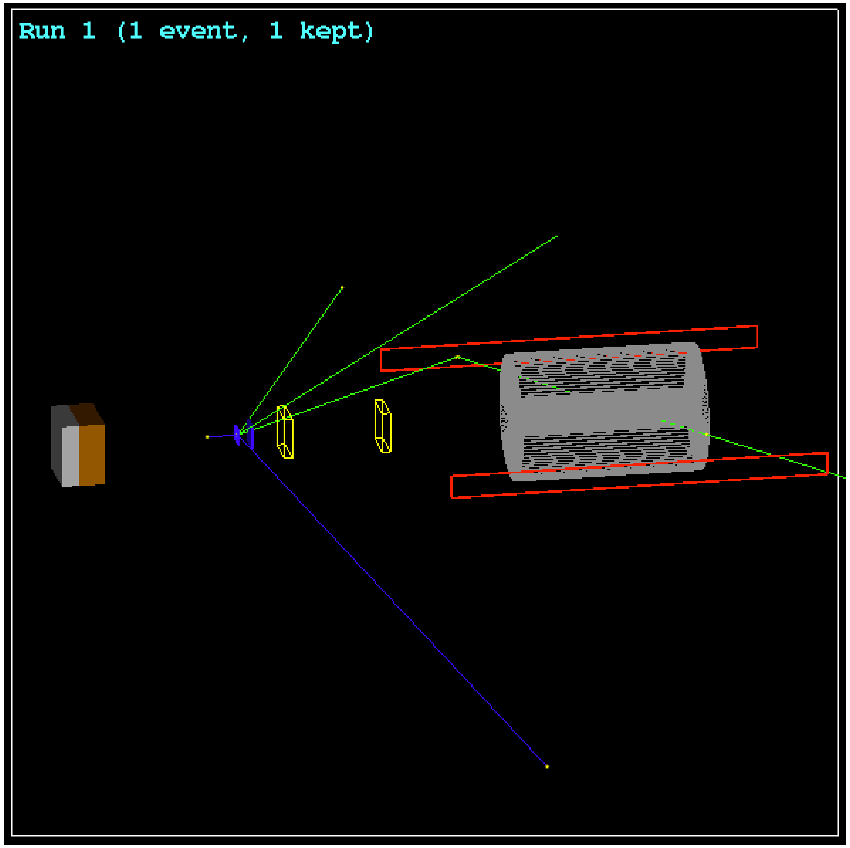
    d. Any daughter from the target (by the proton) reaches BTOF and deposits E > 0.1 MeV
  - BG:

    every event fails to satisfy any of above

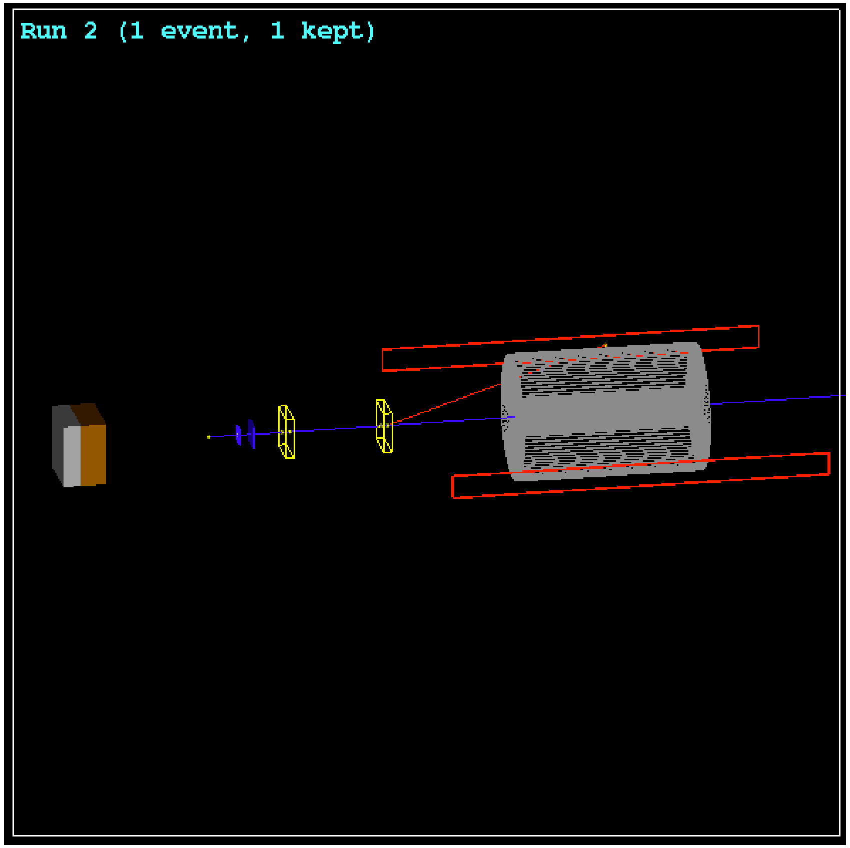
KOMAC Beam Test - Target

BG event display (1/2)

Proton inelastic at SC



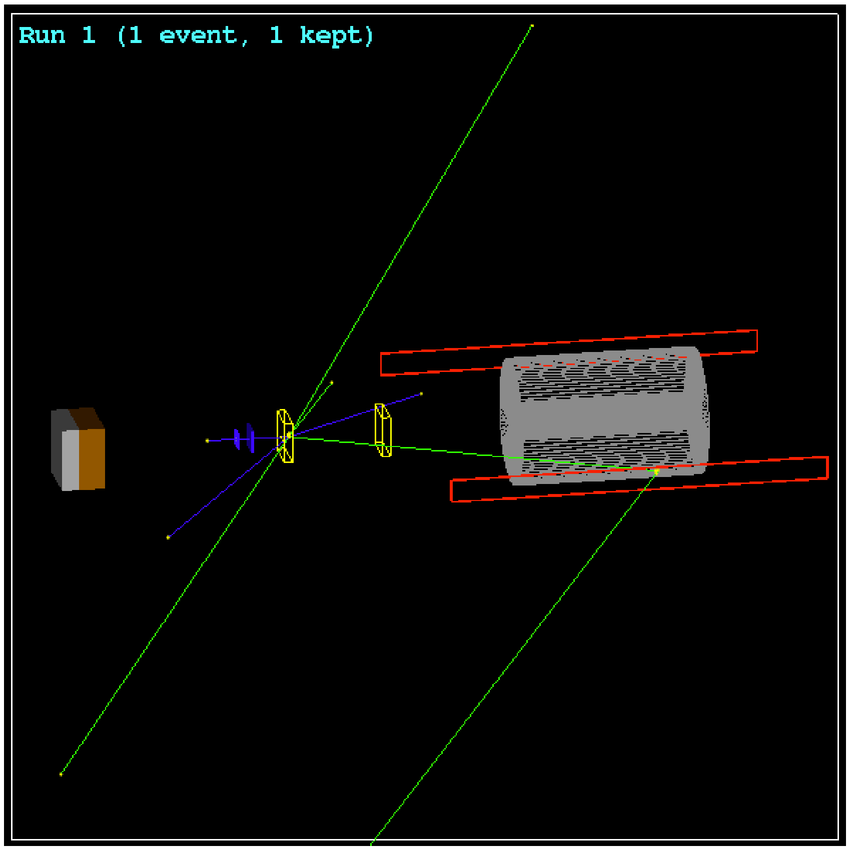
Proton ionization at BDC2



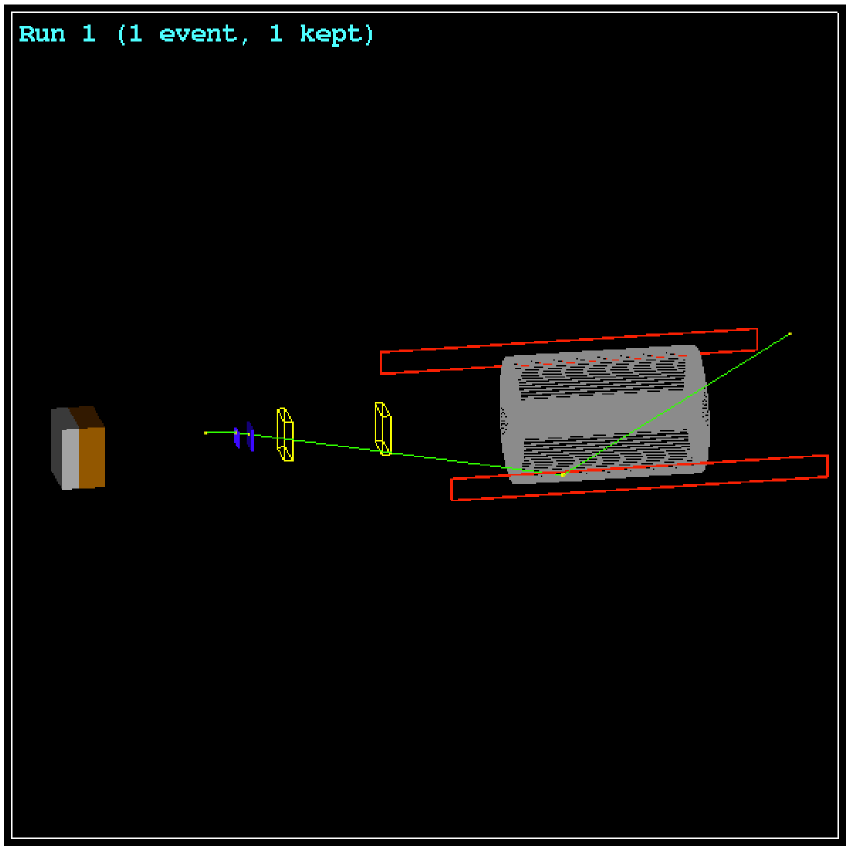
KOMAC Beam Test - Target

BG event display (2/2)

Proton inelastic at BDC1

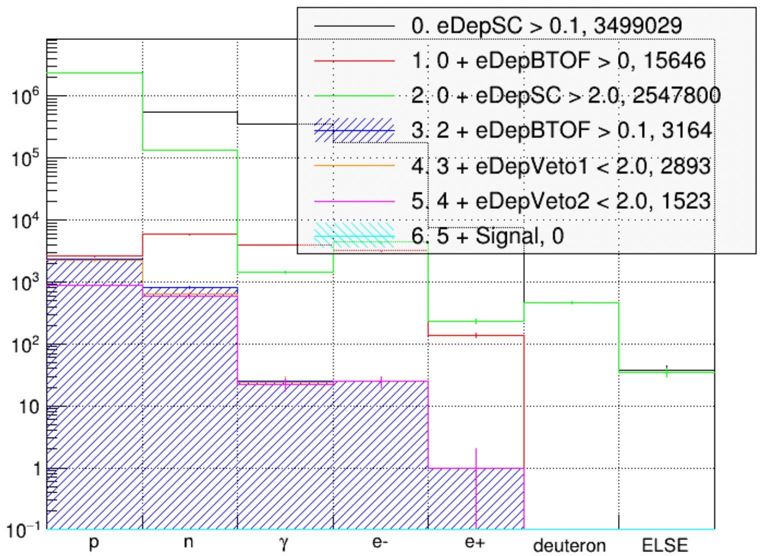


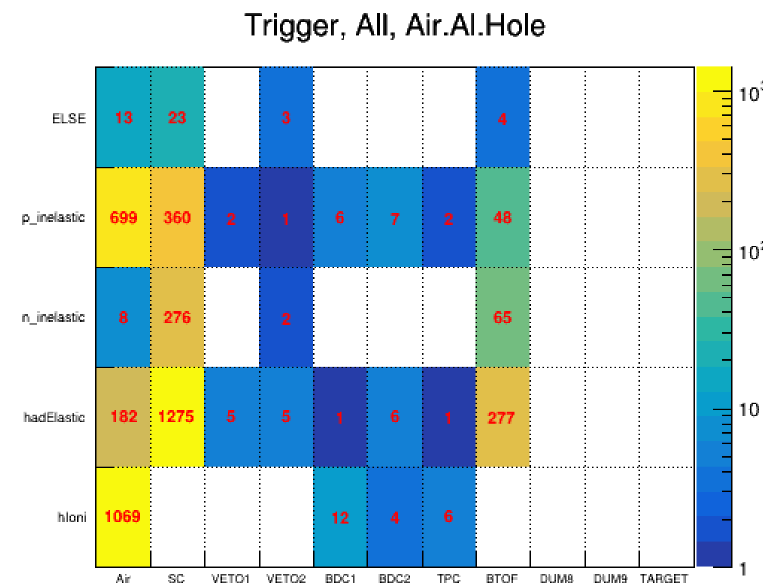
Neutron elastic at SC



KOMAC Beam Test - Target

Event rate and S/BG, before optimization





– Conditions at the end of October (before optimization)

a. Al + [0.4 x 0.4] square hole collimator, [5 x 5 x 0.1] target

b. S/BG = 0 (no signal at all) for 1.5 x 10^{11} input protons

c. High neutron contamination among the triggered events

d. Large amount of BG from air (a lot of incident protons scatter in the air)

– In short, the problems can be narrowed down into two

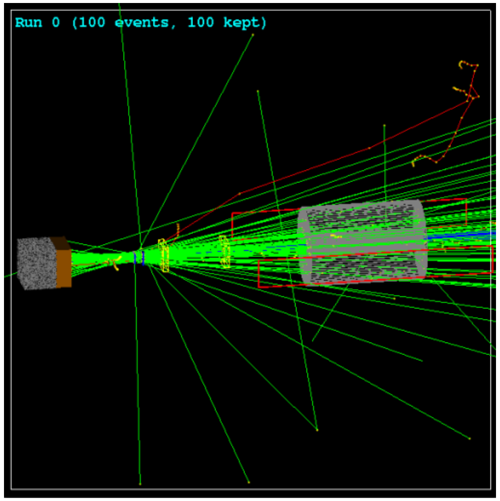
a. Almost no daughter particles are created at target → target optimization

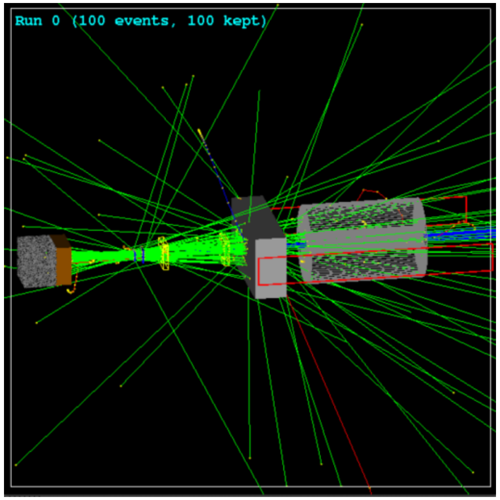
b. BG (especially from Air and SC) should be suppressed → collimator update + install 2nd absorber

KOMAC Beam Test - Target

After the updates, in early Nov.

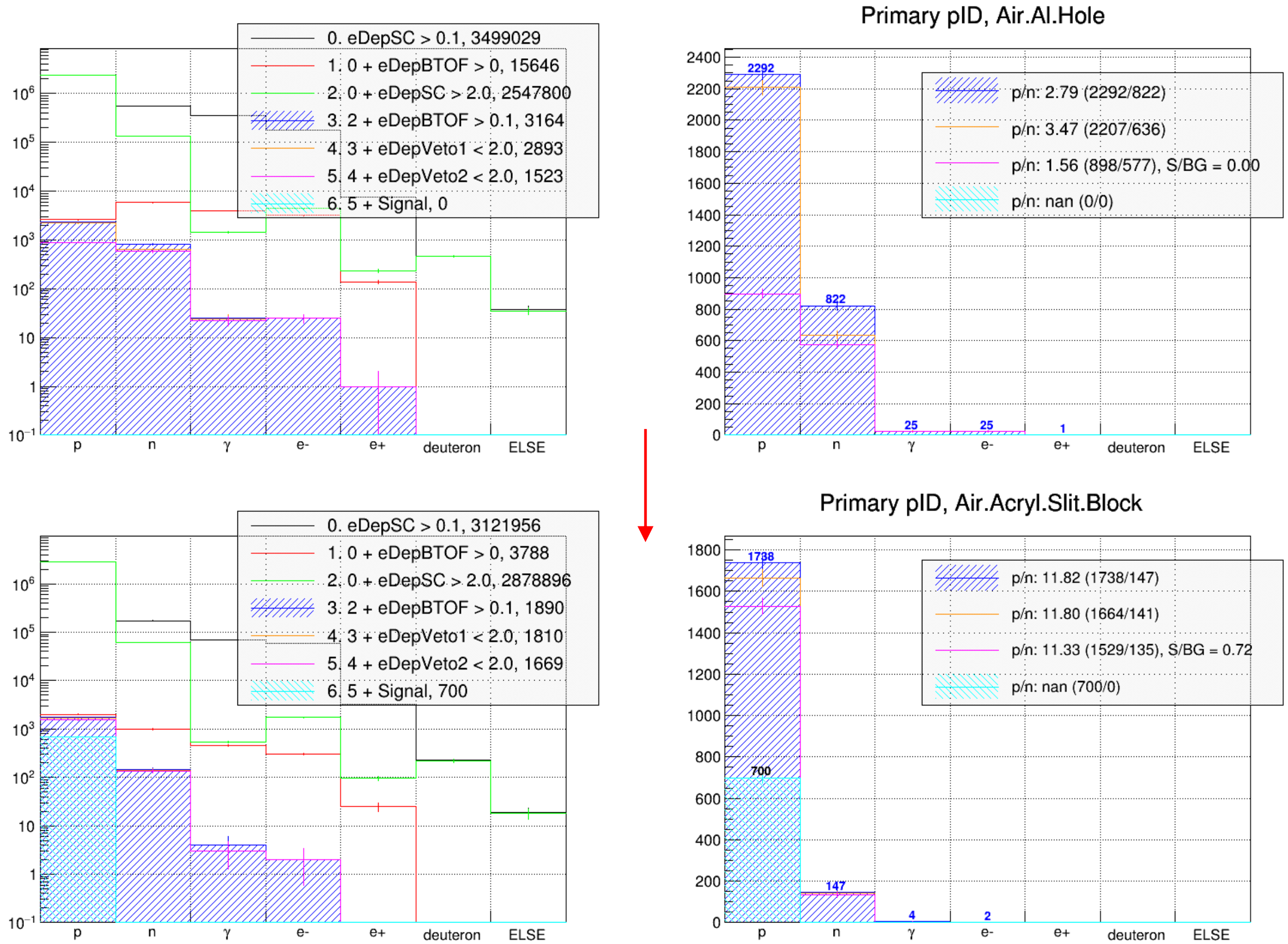
- Items updated in early November
  - Collimator changed:
    a. Al + hole (80 mm thick) → Acryl + slit (200 mm thick)
    b. Effect: BG reduction, especially neutrons
  - Target updated:
    a. [5 x 5 x 0.1] → [25 x 25 x 5] (mm^3)
    b. Effect: increased daughters creation at target → enhanced S/BG
  - 2^{nd} acryl absorber installed:
    a. Dimension: [800 x 400 x 200] (mm^3), w/ [50 x 50] square hole
    b. Location: between BDC2 and TPC, in front of BTOF
    c. Effect: block BG from scattering before target (mainly SC or air)
  - Samples to be compared:
    a. Subsys + target MC, by Al + hole collimator (conventional)
    b. Subsys + target MC, by Acryl + slit col. + 2^{nd} acryl absorber
  - Observables:
    a. Event rate
    b. 1^{st} daughters' creation process and location





KOMAC Beam Test - Target

After the updates, event rate



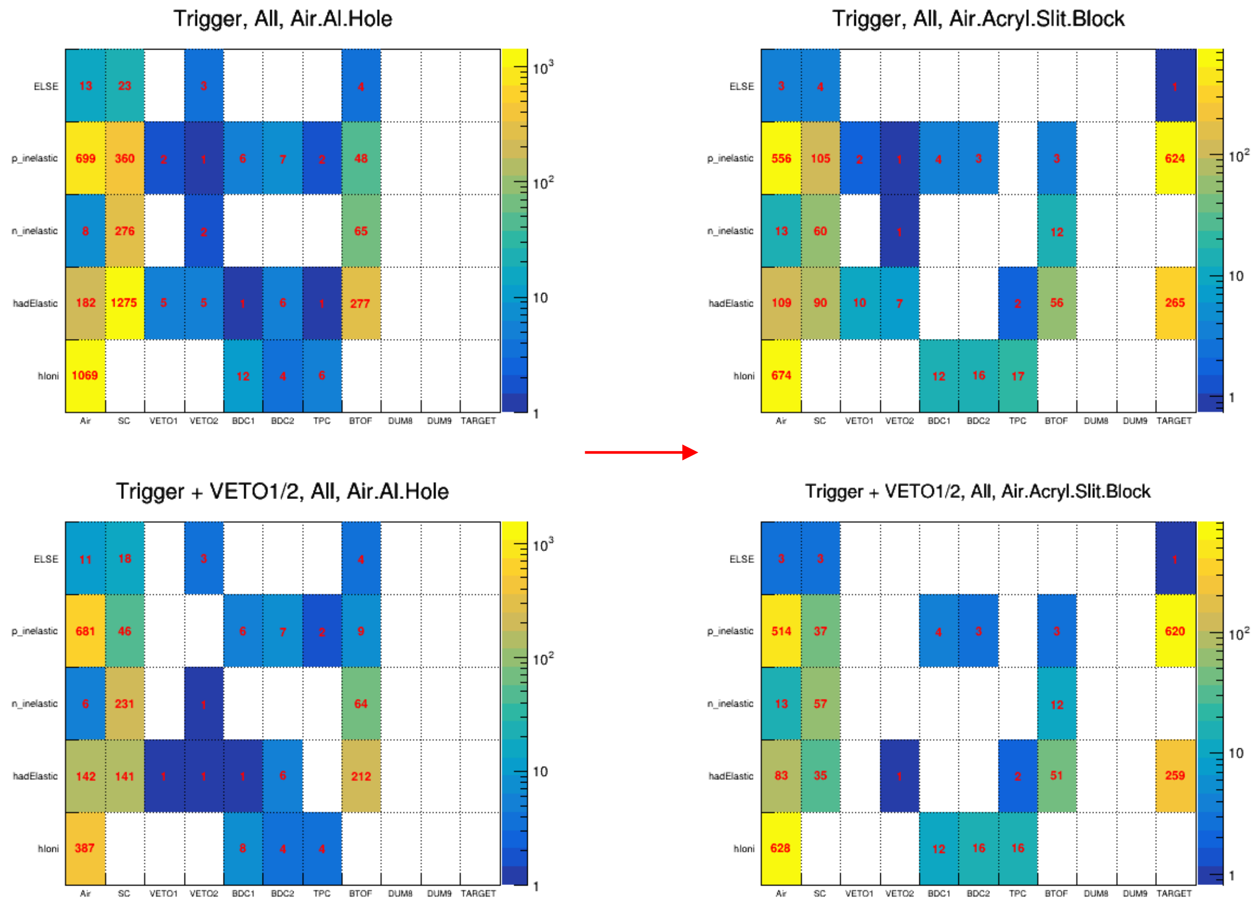
– Event rate before & after

a. The triggered rate reduced about half (3164 → 1890), but most of rejected events are BGs

b. Much enhanced S/BG ratio

KOMAC Beam Test - Target

After the updates, S/BG



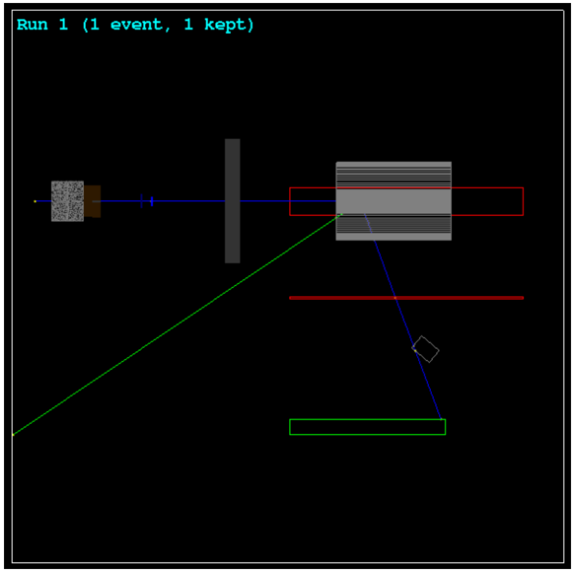
– Effect of 2nd acryl absorber

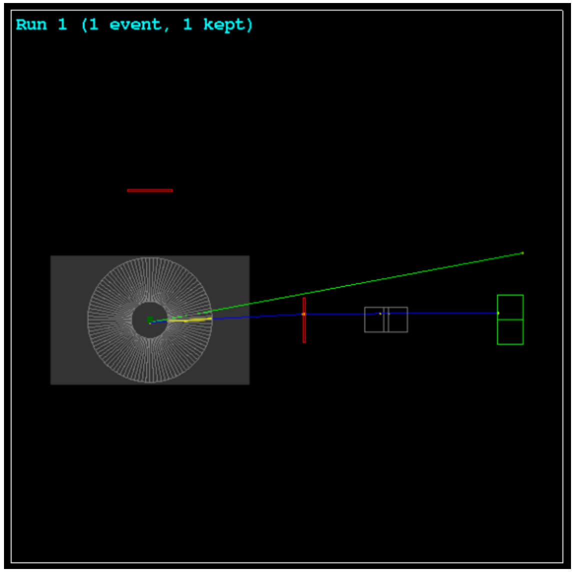
a. Large amount of “hIoni” at Air and “hadElastic” at SC are reduced

b. 2nd acryl absorber lifted burden of VETO counters judging from bottom row

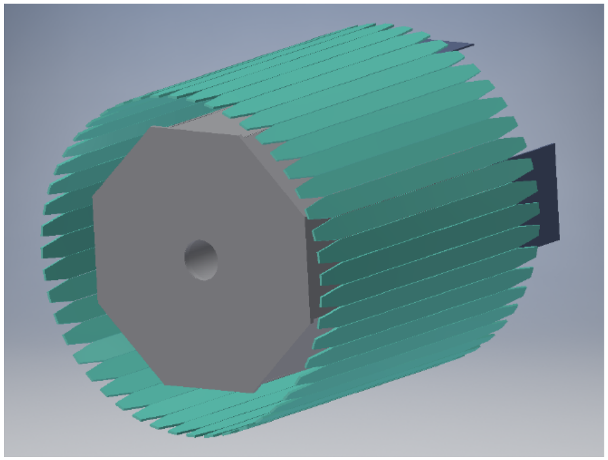
KOMAC Beam Test

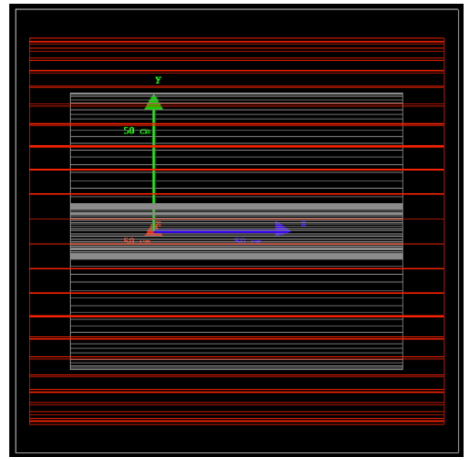
Setup at the test, after optimization

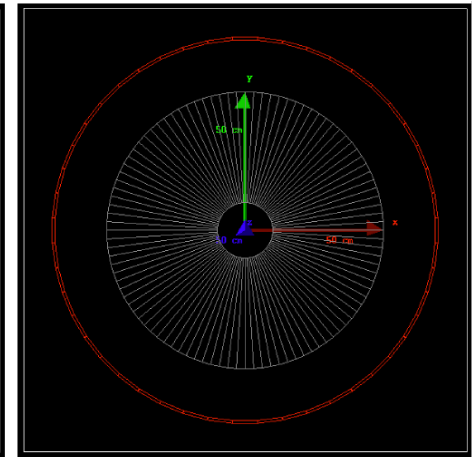


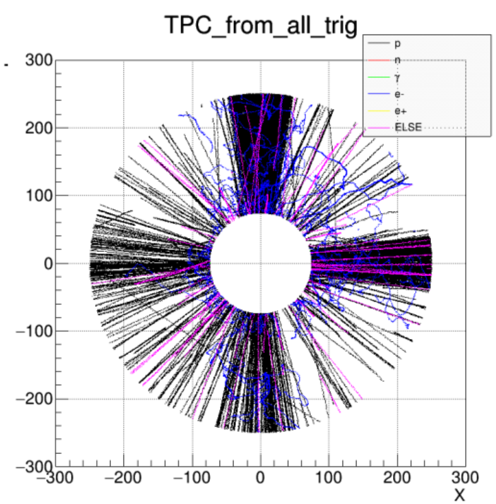


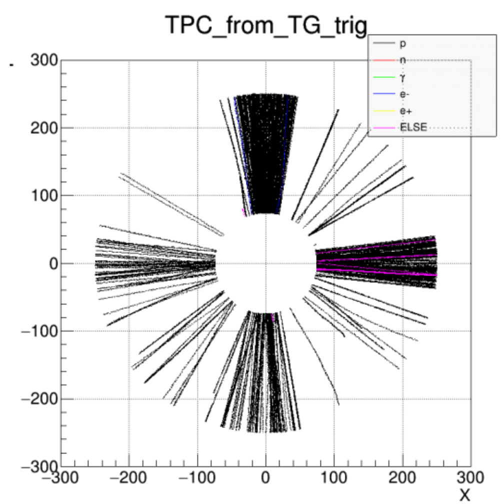
Recent Activities

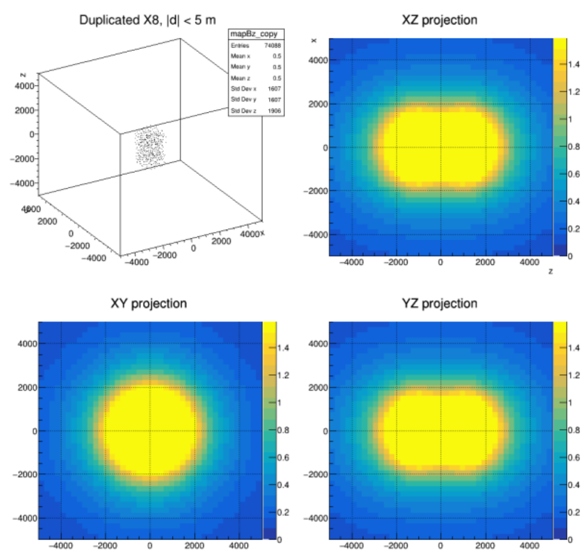








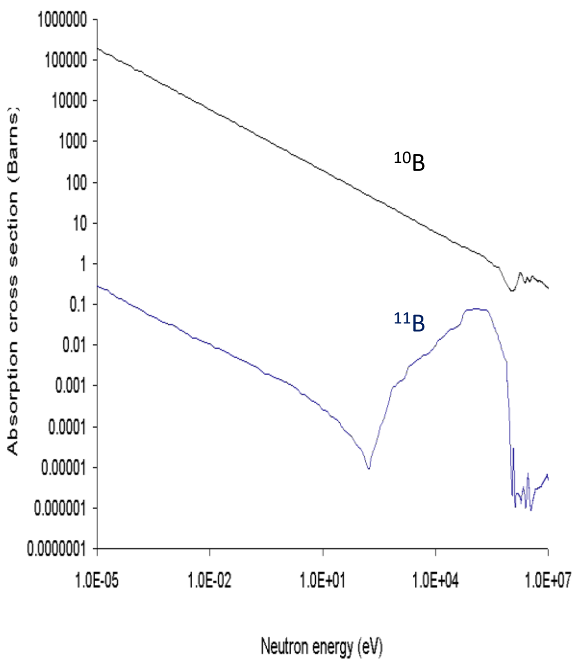


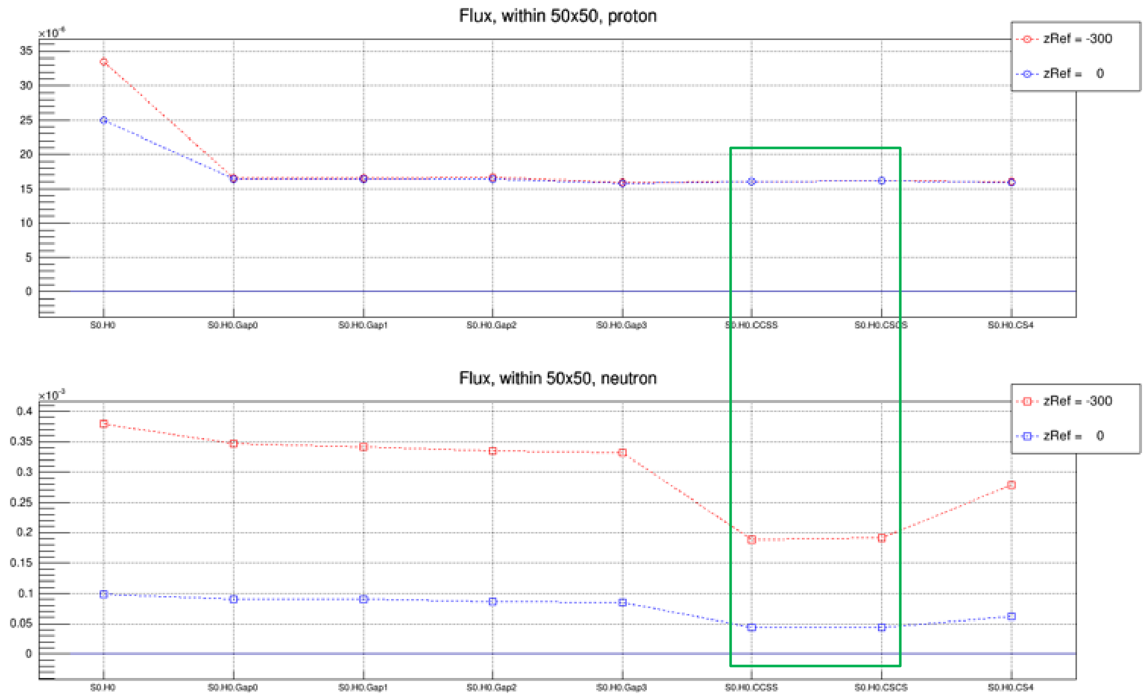


Summary

- **PNU-NPL in LAMPS**
  - No competing software group in current LAMPS
  - The necessity and effectiveness of simulation was shown in the KOMAC beam test
  - Various activities are underway, not only the simulation, but also software

Backup KOMAC – Boron absorber effect





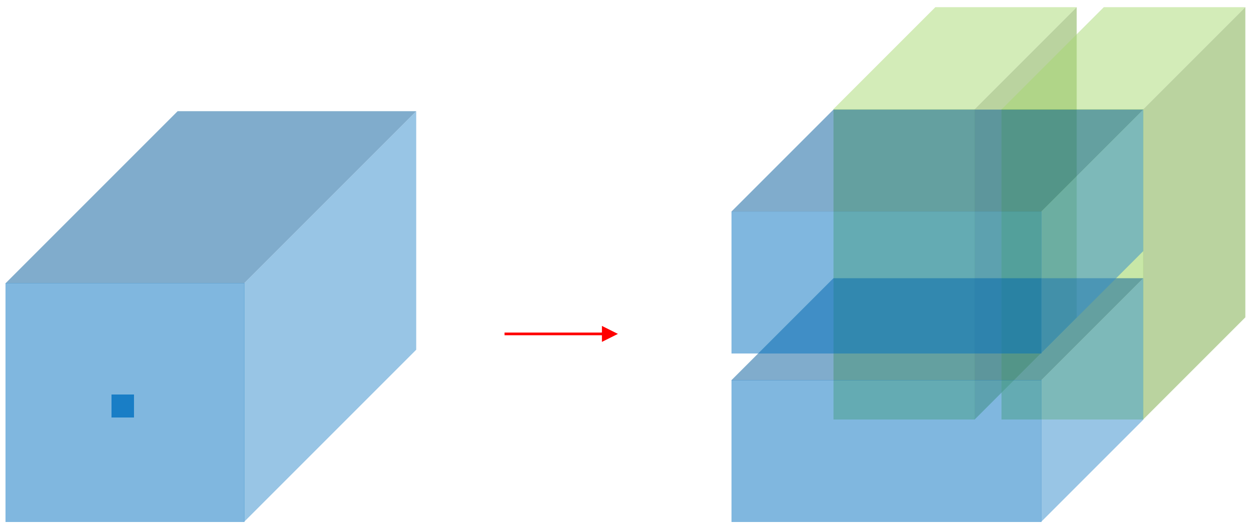
– Suppress neutrons by using Boron (or 1st absorber)

a. Protons can be suppressed by putting the collimator, but NOT all of them simply "gone" – they can knock out protons or neutrons inside the collimator

b. Borons "eats up" the neutrons by Boron-Neutron Capture Reaction – more effective for lower energy ones

c. Would put a boron block after collimator be beneficial? Yes, apparently

Backup KOMAC – Slit shape collimator



– Difficulty in shaping

a. Punching [0.4 x 0.4] square hole in thick (at least 8 cm) acryl was NOT available

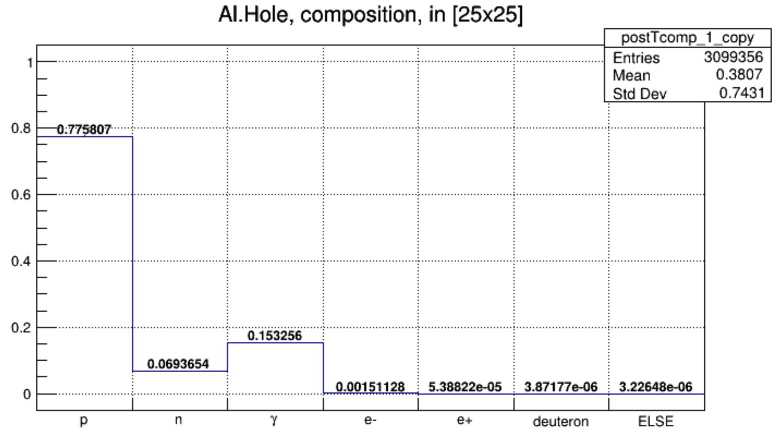
a-1. According to Dr. Huh, precision of laser cutting (the company he contacted) is few mm level

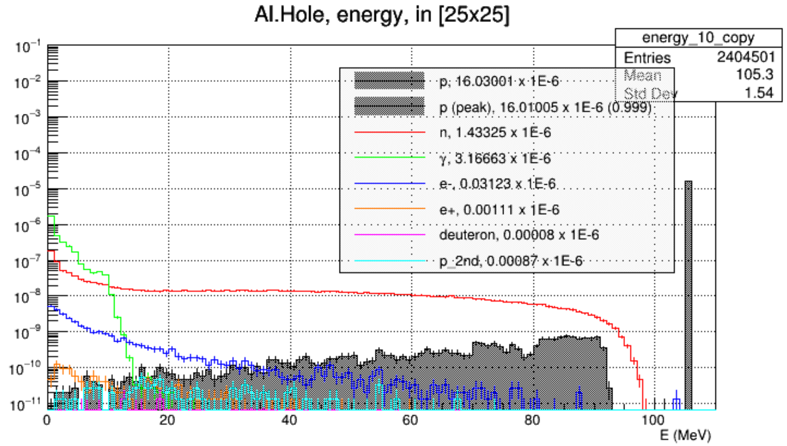
a-2. Laser cannot penetrate through such thickness

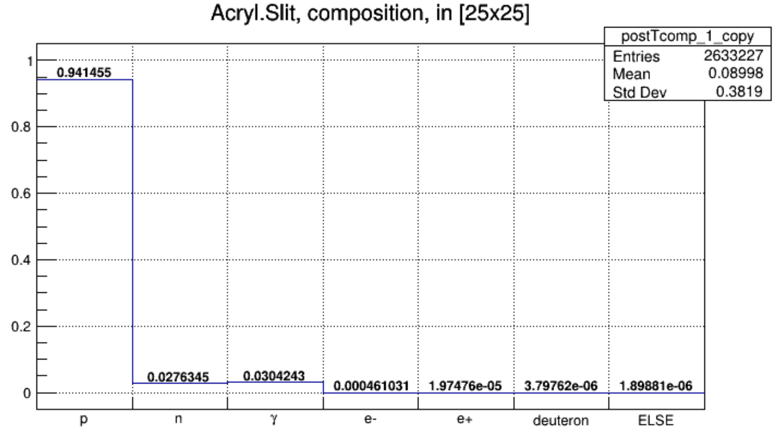
b. Design modified: 8 cm thick [0.4 x0.4] square hole → 10 cm thick 0.4 slit x 2

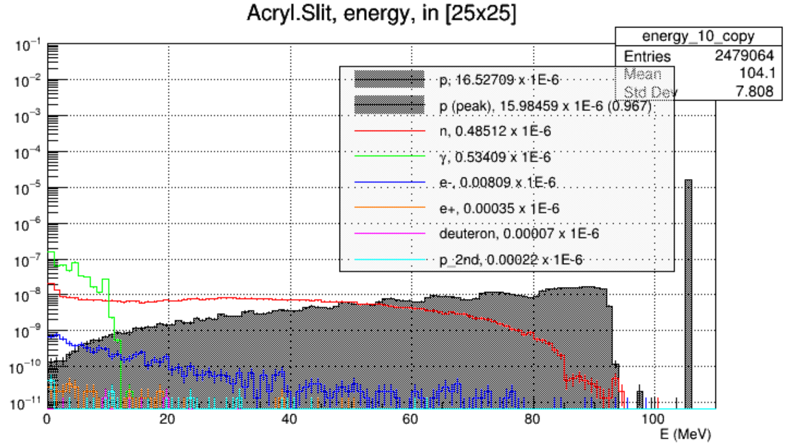
* Due to the slit, local (where the slit located) thickness reduced by half – thus total thickness increased twice

Backup KOMAC – Al + Square vs. Al + Slit







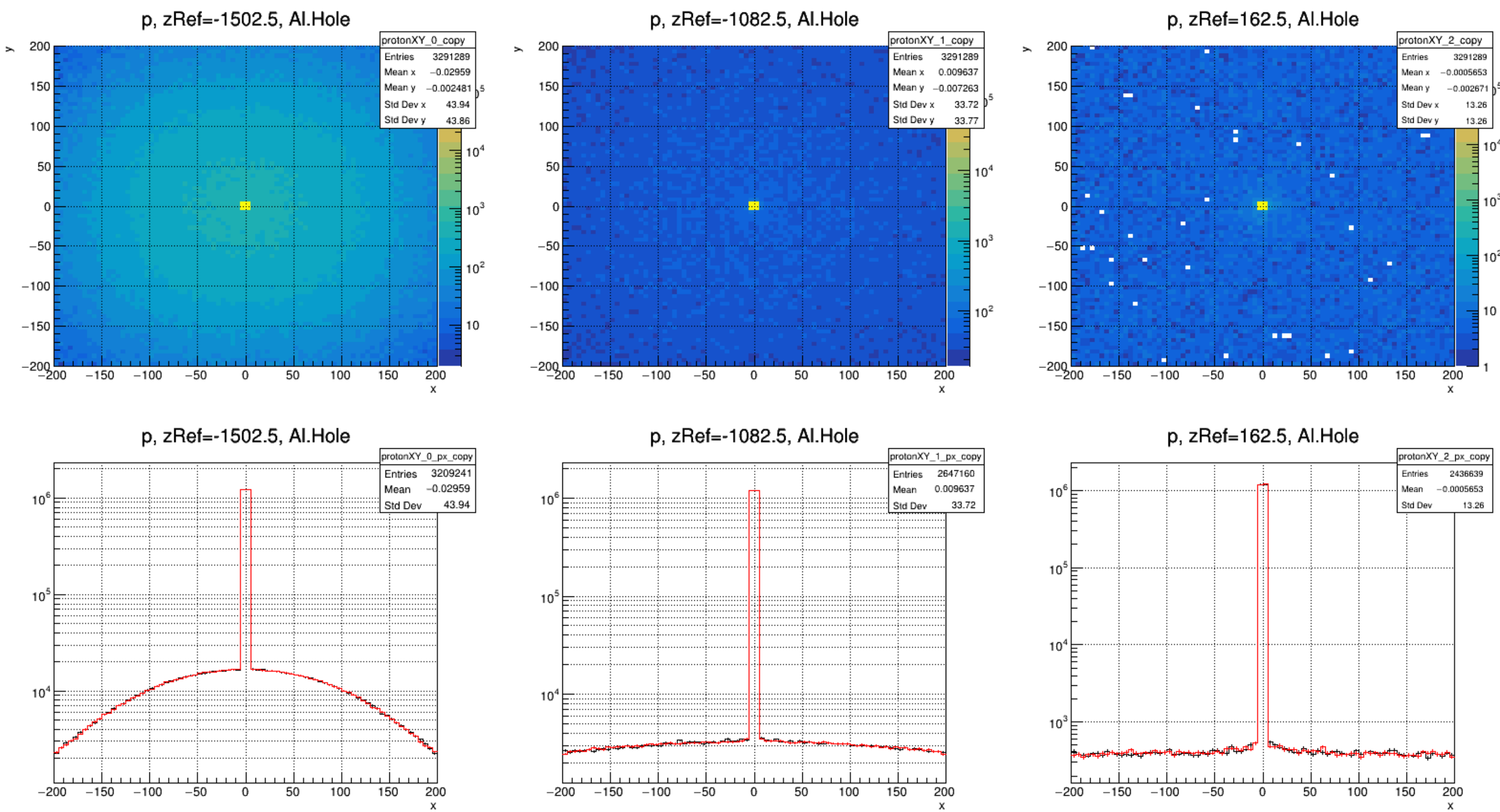


– After the change (square → slit)

a. Neutrons and γ are substantially reduced, while primary energetic protons are almost intact

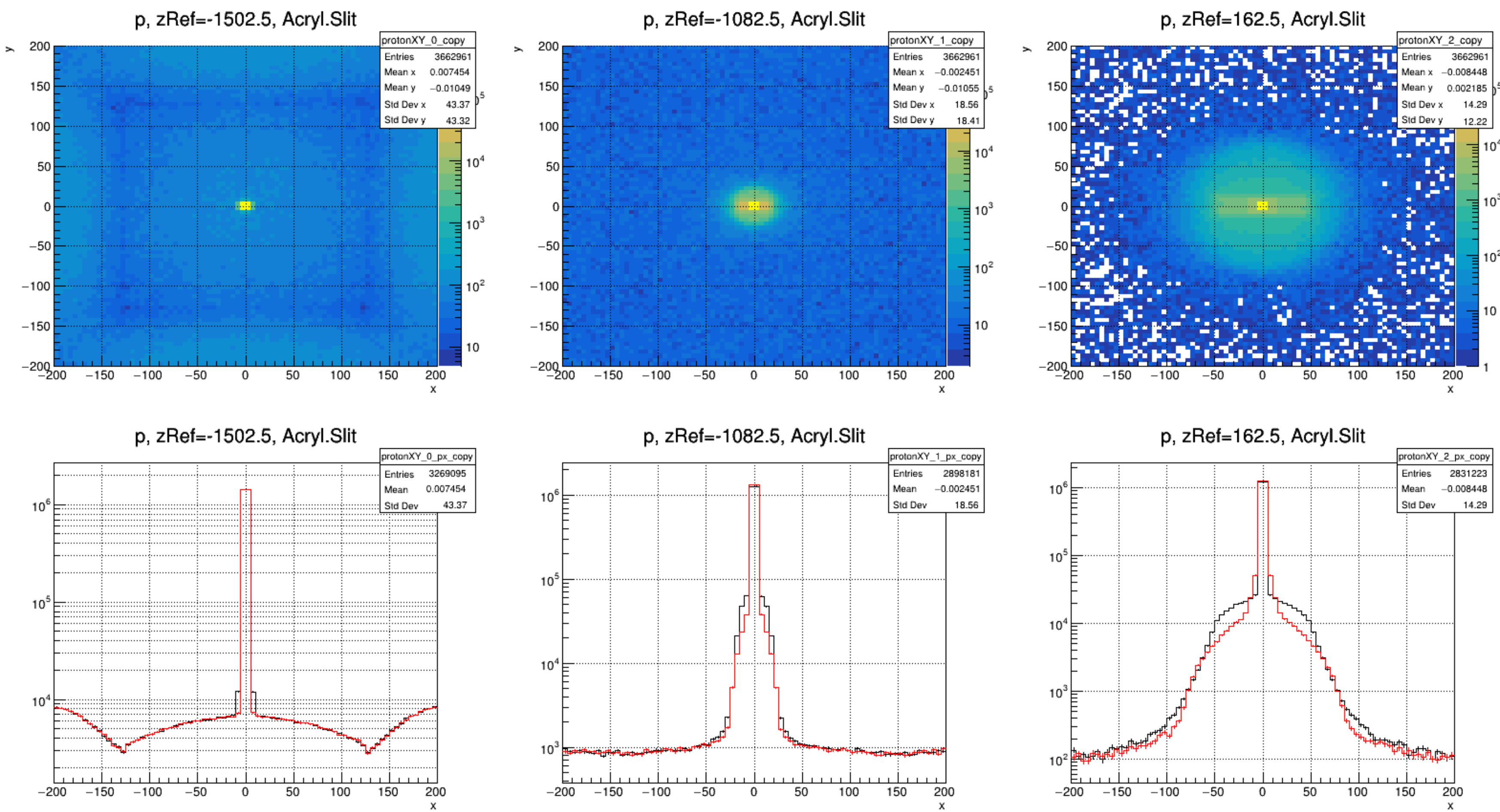
b. Less energetic protons (< 100 MeV) also increased, but not very problematic level

Backup KOMAC – Al + Square vs. Al + Slit, proton XY (square)



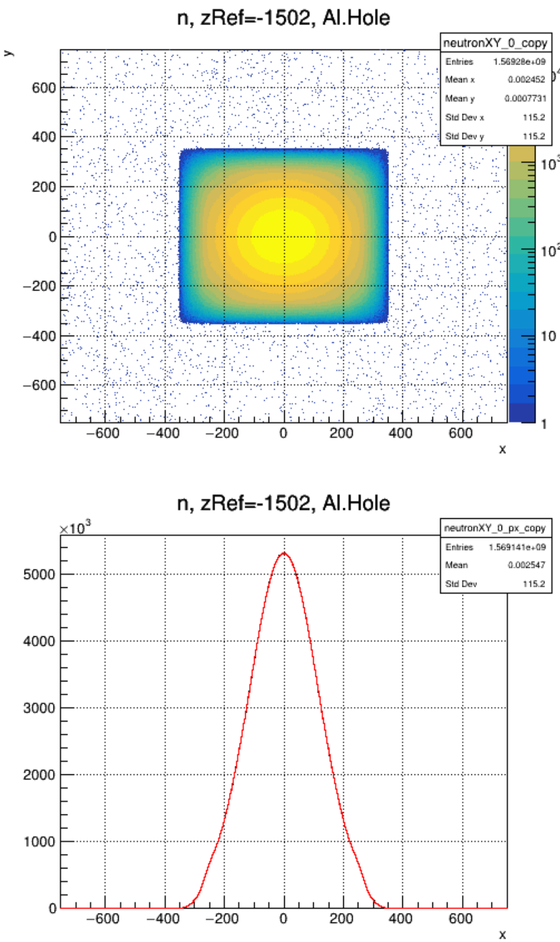
^{10}B downstream SC upstream Target center

Backup KOMAC – Al + Square vs. Al + Slit, proton XY (slit)

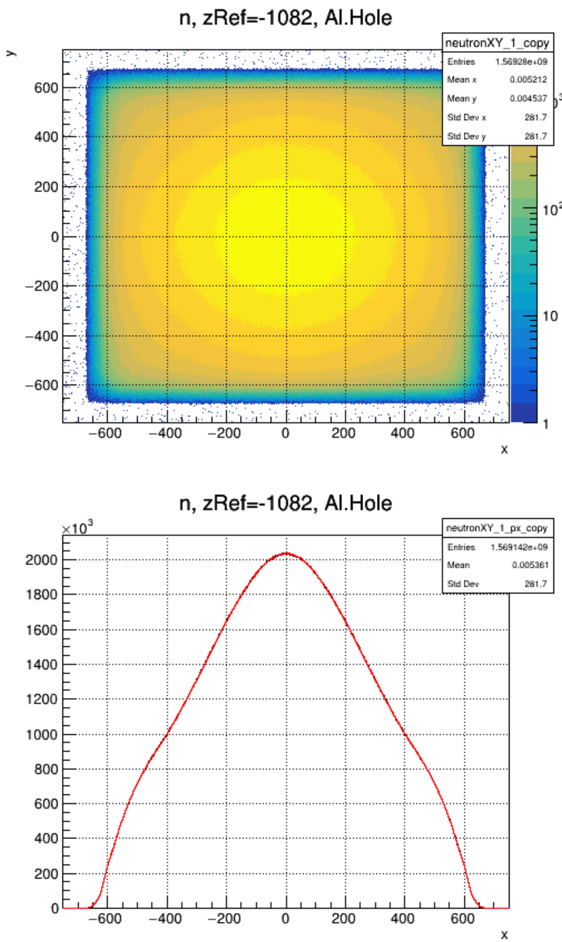


^{10}B downstream SC upstream Target center

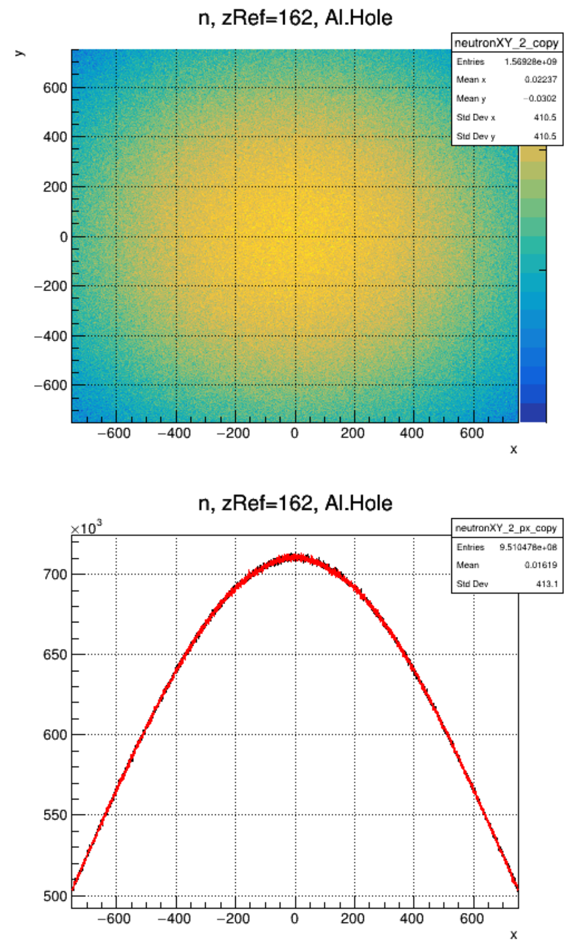
Backup KOMAC – Al + Square vs. Al + Slit, neutron XY (square)



^{10}B downstream

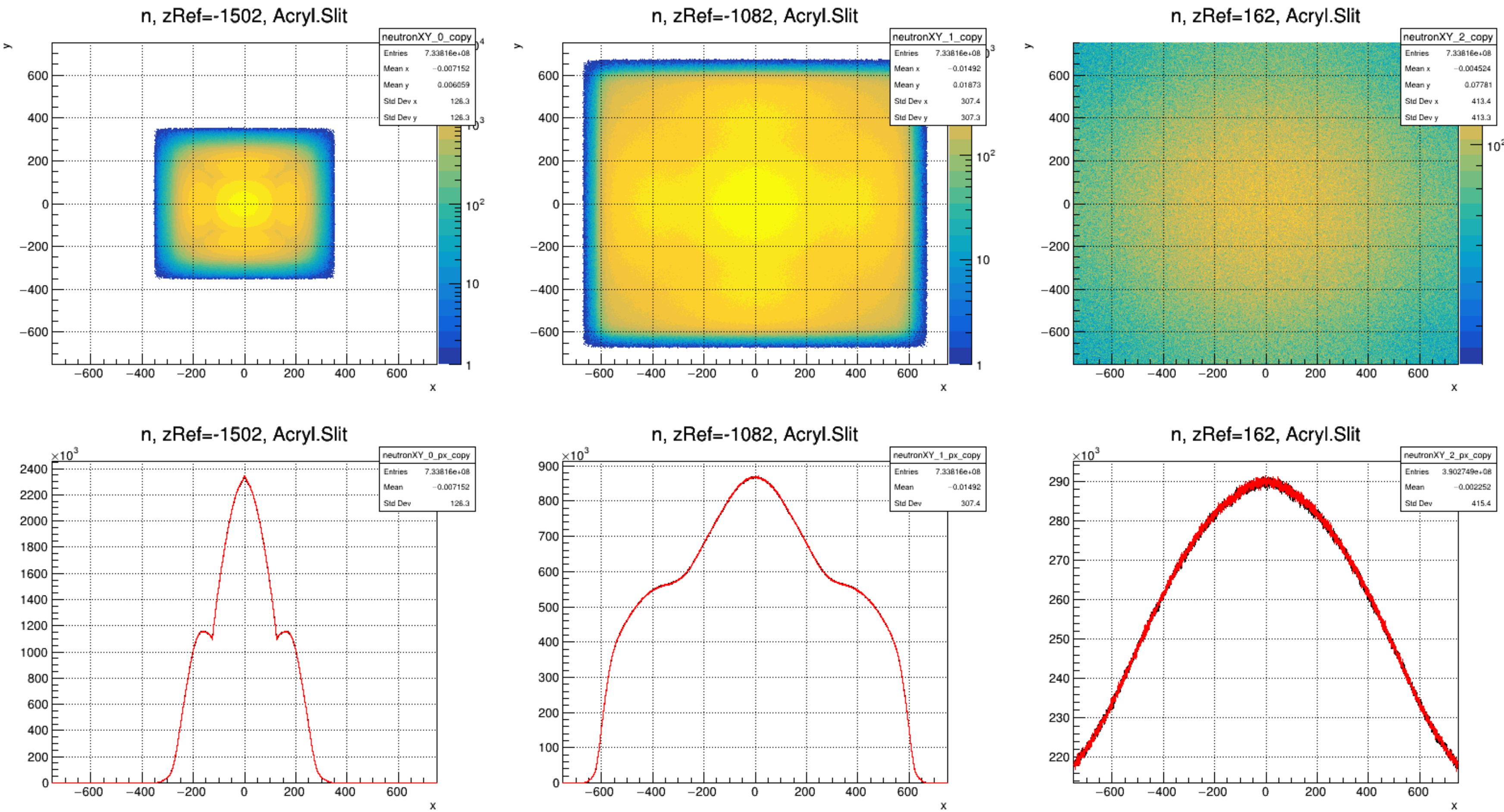


SC upstream



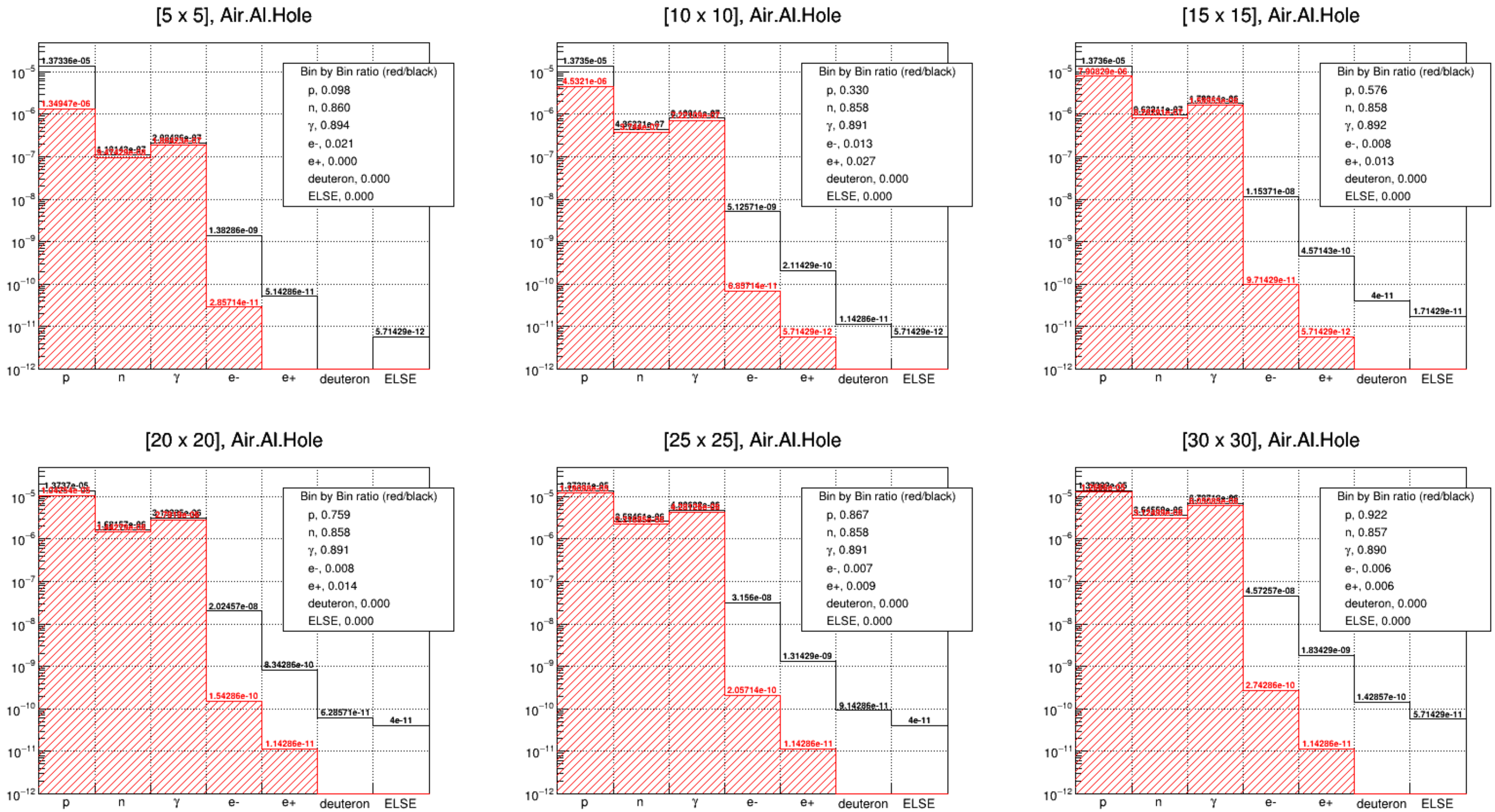
Target center

Backup KOMAC – Al + Square vs. Al + Slit, neutron XY (slit)



^{10}B downstream | SC upstream | Target center

Backup KOMAC – Target optimization (1/2)



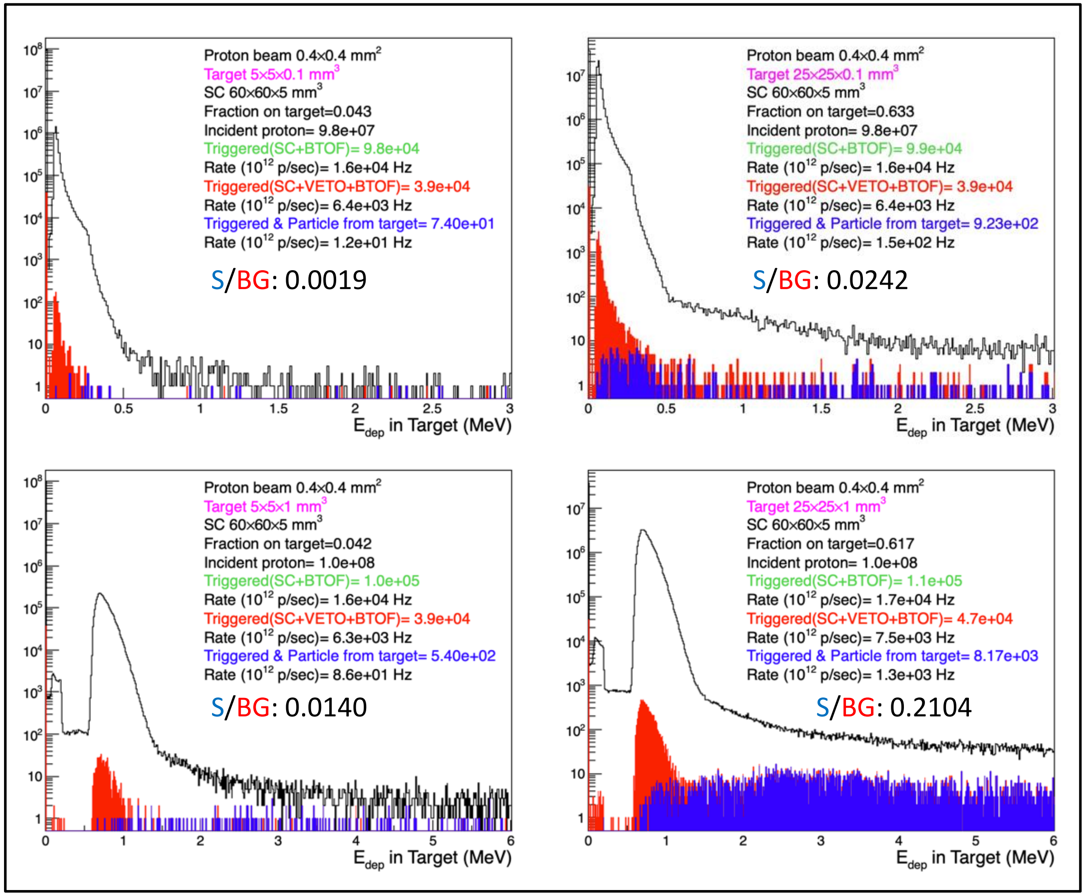
– To daughters be created at target,

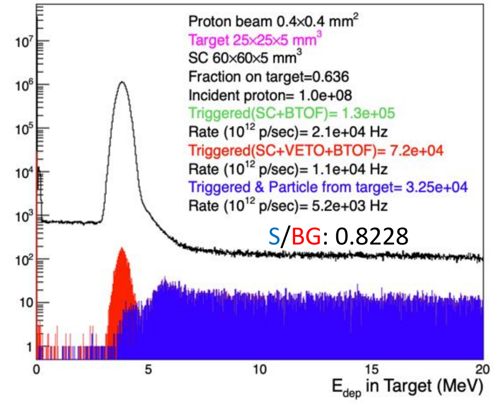
a. The primary proton's trajectory must be lie within the target XY

b. The target's thickness must be thick enough

Backup KOMAC – Target optimization (2/2)

Increasing target XY (→, [5x5] to [25x25]) or thickness (↓, 0.1 to 1)



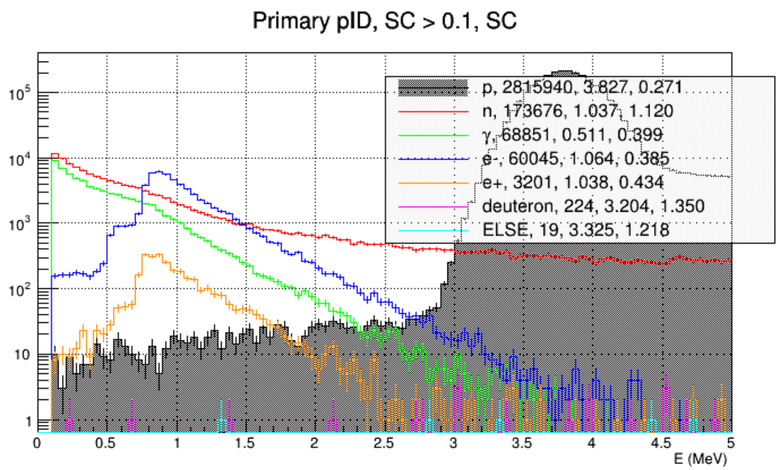


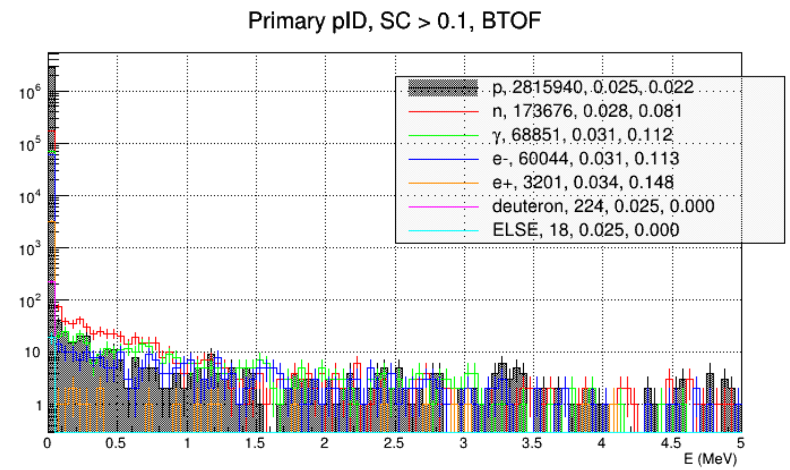
– Proton only MC to check the effect of target's XY and thickness

a. As target size ↑, the frequency of interaction (Fraction on target) increases

b. As target thickness ↑, more particles be created at target

Backup Deposited energy on SC / BTOF





- Total deposited energy on SC/BTOF, sorted out by incident primary pID
- Minimum energy threshold of triggers (SC and BTOF):
  a. SC > 2 MeV, determined based on the distribution
  b. BTOF > 0.1 MeV, determined based on Sr source
  (* adjusted to 1 MeV during actual beam test)

Backup Nuclear interaction length of the air and polyvinyl toluene

Atomic and nuclear properties of air (dry, 1 atm)

Quantity	Value	Units	Value	Units
<Z/A>	0.49919			
Specific gravity (20° C, 1 atm)	1.205E-03	g cm^{-3}		
Mean excitation energy	85.7	eV		
Minimum ionization	1.815	MeV g^{-1}cm^{2}	2.187E-03	MeV cm^{-1}
Nuclear collision length	61.3	g cm^{-2}	5.088E+04	cm
Nuclear interaction length	90.1	g cm^{-2}	7.477E+04	cm
Pion collision length	88.5	g cm^{-2}	7.348E+04	cm
Pion interaction length	122.0	g cm^{-2}	1.013E+05	cm
Radiation length	36.62	g cm^{-2}	3.039E+04	cm
Critical energy	87.92	MeV (for e^-)	85.96	MeV (for e^+)
Molière radius	8.83	g cm^{-2}	7330.	cm
Plasma energy $\hbar\omega_p$	0.71	eV		
Muon critical energy	1115.	GeV		
Boiling point @ 1 atm	78.80	K	-194.4	C
Index of refraction (0° C, 1 atm, Na D)	289.	$(n-1)\times10^6$		

Composition:

Elem	Z	Atomic frac*	Mass frac
C	6	0.00	0.000124
N	7	0.76	0.755267
O	8	0.23	0.231781
Ar	18	0.01	0.012827
* calculated from mass fraction data			

For muons, $dE/dx = a(E) + b(E)\,E$. Tables of $b(E)$: PDF TEXT
Table of muon dE/dx and Range: PDF TEXT
Explanation of some entries

Atomic and nuclear properties of polyvinyltoluene [$(2\text{-}CH_3C_6H_4CHCH_2)_n$]

Quantity	Value	Units	Value	Units
<Z/A>	0.54141			
Specific gravity	1.032	g cm^{-3}		
Mean excitation energy	64.7	eV		
Minimum ionization	1.956	MeV g^{-1}cm^{2}	2.019	MeV cm^{-1}
Nuclear collision length	57.3	g cm^{-2}	55.56	cm
Nuclear interaction length	81.3	g cm^{-2}	78.80	cm
Pion collision length	84.8	g cm^{-2}	82.19	cm
Pion interaction length	113.3	g cm^{-2}	109.8	cm
Radiation length	43.90	g cm^{-2}	42.54	cm
Critical energy	94.11	MeV (for e^-)	91.62	MeV (for e^+)
Molière radius	9.89	g cm^{-2}	9.586	cm
Plasma energy $\hbar\omega_p$	21.54	eV		
Muon critical energy	1195.	GeV		
Index of refraction (Na D)	1.580			

Composition:

Elem	Z	Atomic frac*	Mass frac
H	1	10.00	0.085000
C	6	9.03	0.915000
* calculated from mass fraction data			

For muons, $dE/dx = a(E) + b(E)\,E$. Tables of $b(E)$: PDF TEXT
Table of muon dE/dx and Range: PDF TEXT
Explanation of some entries

Backup SC/VETO setup during the beam test