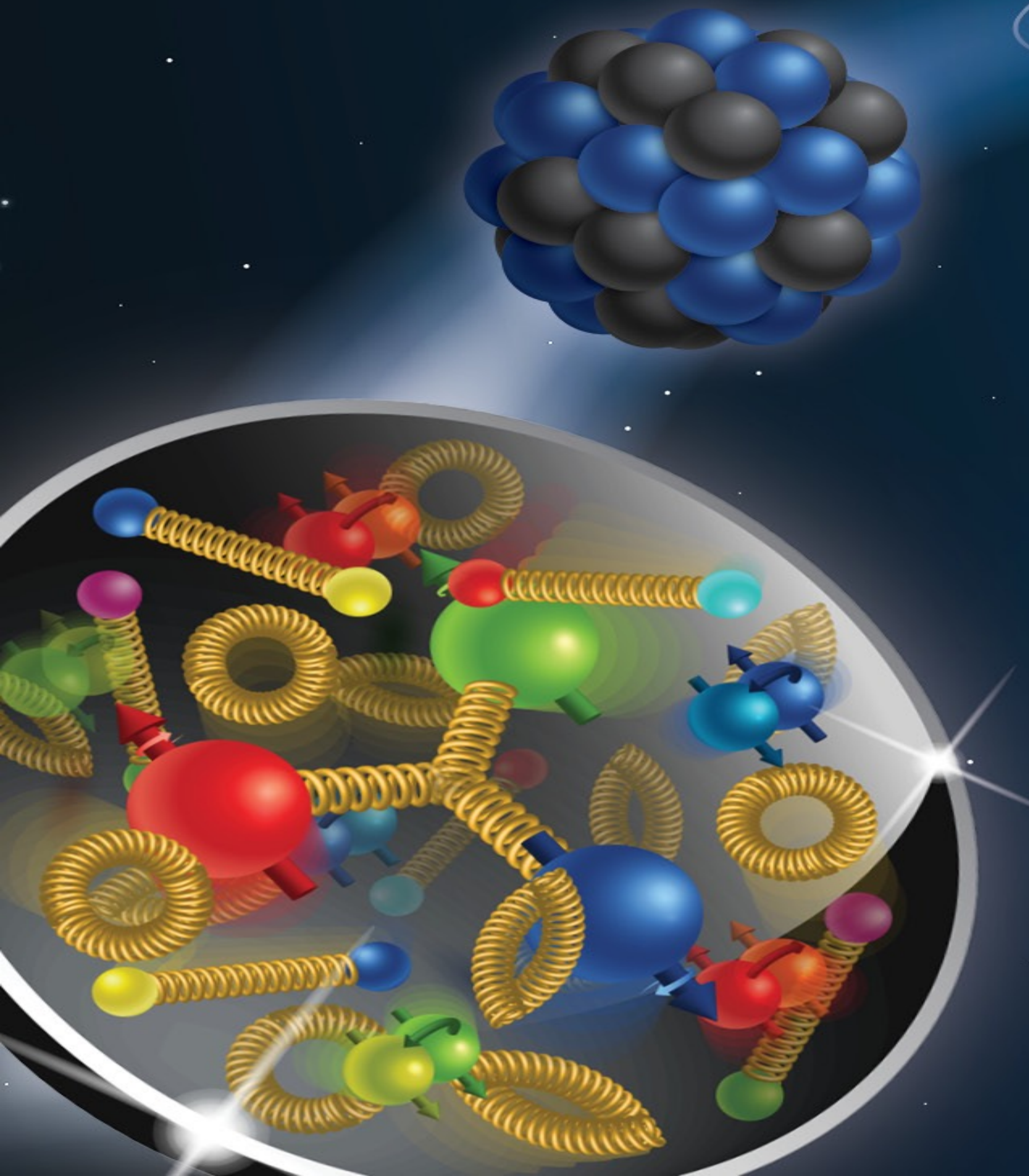

Far-Forward Detectors and Acceptances in IP8

Cross-Collaboration Far-Forward Meeting

June 7th, 2021

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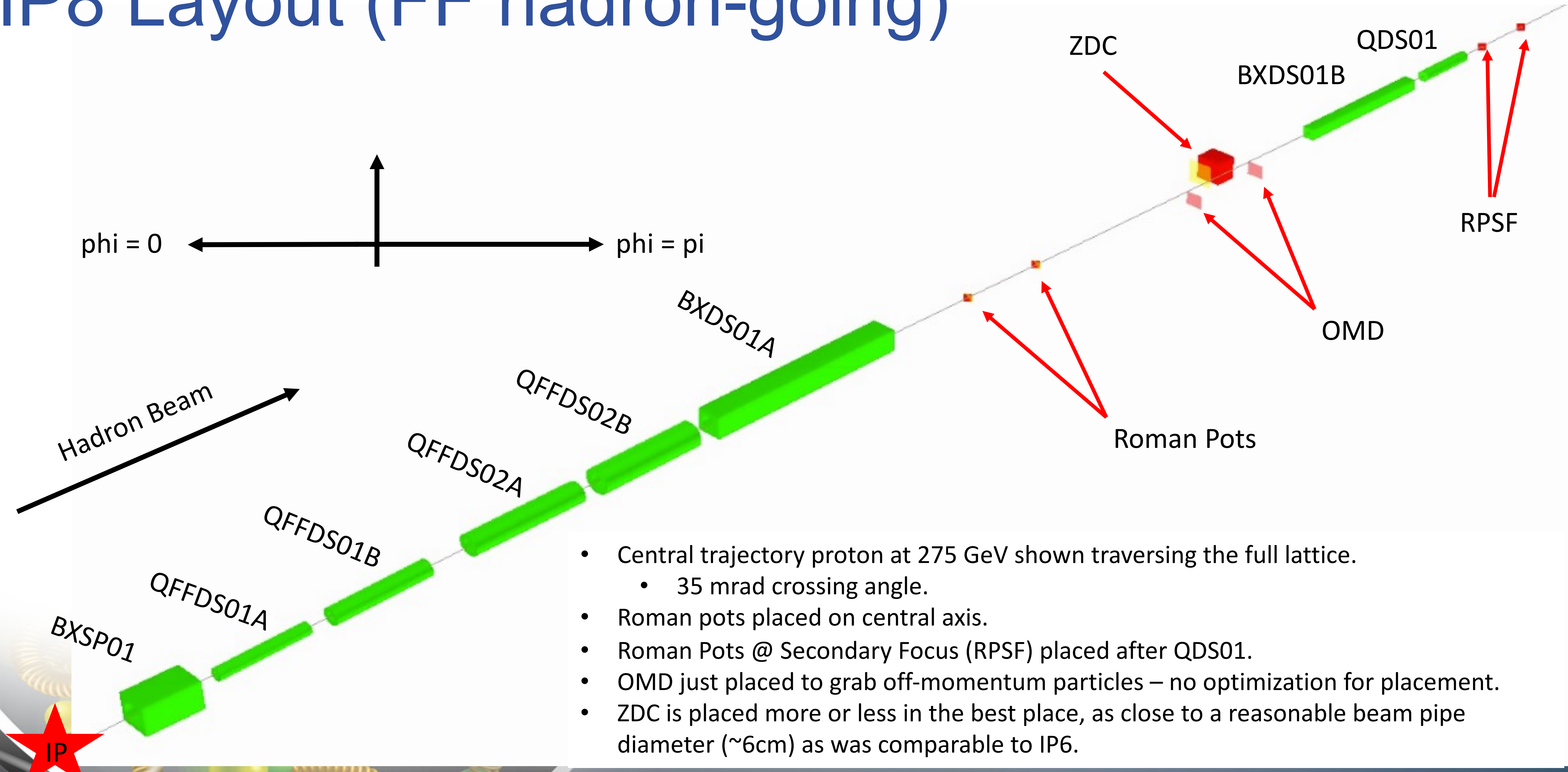
Electron Ion Collider

BROOKHAVEN NATIONAL LABORATORY
U.S. DEPARTMENT OF ENERGY | Office of Science

Preliminaries

- Imported everything in EicRoot/GEANT.
  - Placed a few detectors mirroring the placement in IP6 (RP, ZDC, Off-Momentum Det.).
  - Roman Pots positioned on central beam axis.
  - Also added a detector at the secondary focus (see later slides) – Roman Pots @ Secondary Focus (RPSF).
- All studies done using particle gun for now, with momentum ranges selected to coincide with relevant physics channels.
- Some preliminary plots with optics numbers from IP6.
  - IP6 beta functions at the Roman Pots.
  - IP6 $\boldsymbol{\beta}^*$ numbers for the Roman Pots @ Secondary Focus (RPSF).

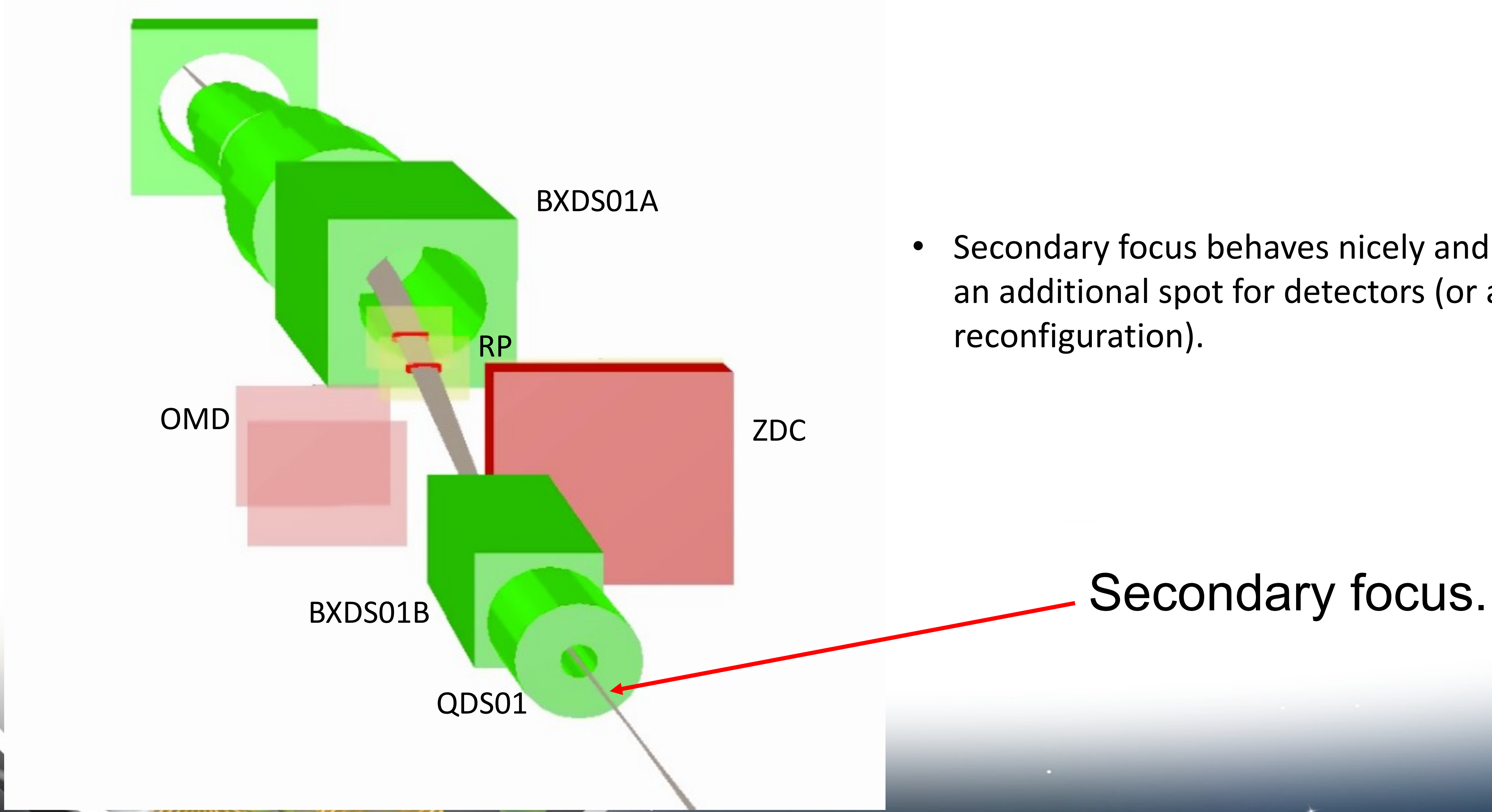
IP8 Layout (FF hadron-going)



- Central trajectory proton at 275 GeV shown traversing the full lattice.
    - 35 mrad crossing angle.
- Roman pots placed on central axis.
- Roman Pots @ Secondary Focus (RPSF) placed after QDS01.
- OMD just placed to grab off-momentum particles – no optimization for placement.
- ZDC is placed more or less in the best place, as close to a reasonable beam pipe diameter (~6cm) as was comparable to IP6.

Secondary Focus

- p = 275 GeV protons
- 0 < theta < 2 mrad



- Secondary focus behaves nicely and allows for an additional spot for detectors (or a complete reconfiguration).

Proton Acceptance

Quick Digression – proton "xL" range vs. physics

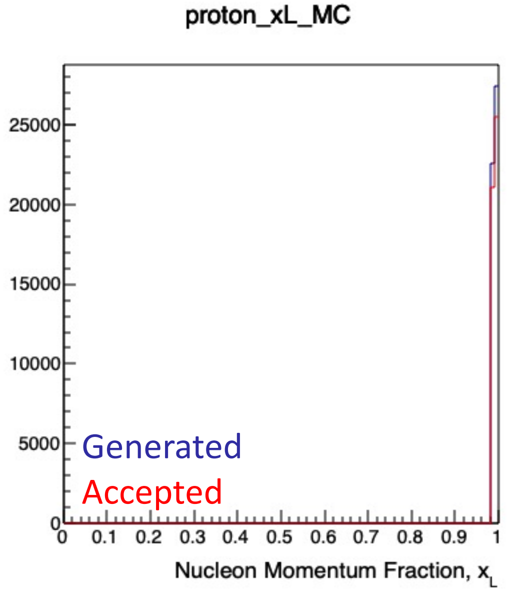
- Different physics channels produce particles with different momentum w.r.t. the beam and with different scattering angles.

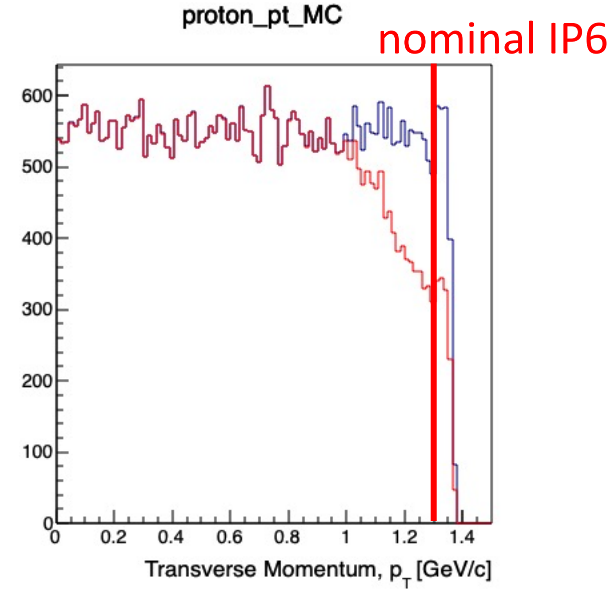
Process	Theta range (at top energy)	xL range	Detector (in IP6)
e+p DVCS	$0 < \theta < 5$ mrad	0.9 – 1.0	Roman Pots
e+d diffractive (spectator proton)	$0 < \theta < 5$ mrad (mostly up to 2 mrad)	0.45– 0.55	Roman Pots; OMD
e+d diffractive (struck proton)	$0 < \theta < 10$ mrad (up to 15 for the tails)	0.2 – 0.6 (sometimes higher)	OMD; B0 det.
e+He3 (spectator protons)	$0 < \theta < 10$ mrad	0.6 – 0.7	Roman Pots
e+Au	$0 < \theta < 10$ mrad	0.35 - 0.55	All three

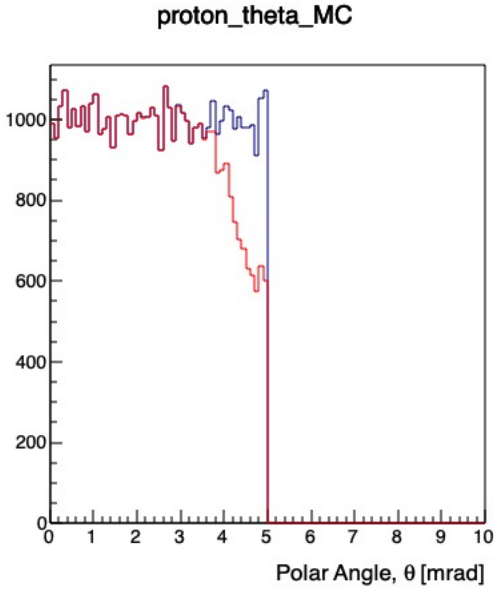
- The above true for the IP6 configuration – of course with the secondary focus and different setup, a different detector configuration may be optimal for IP8.

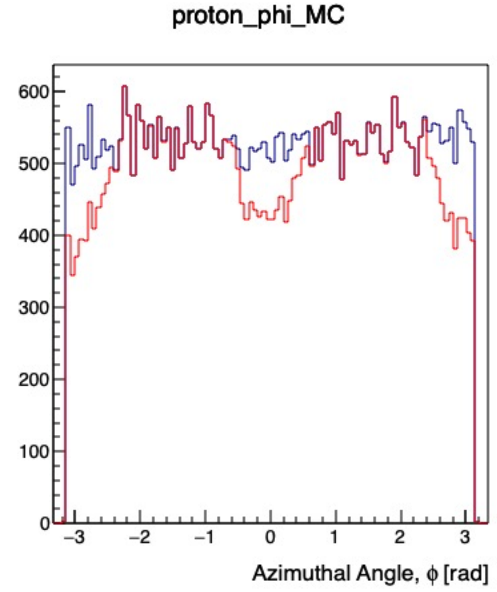
Protons with 0.98 < x_L < 1.0

- 270 < p < 275 GeV protons
- 0 < theta < 5 mrad









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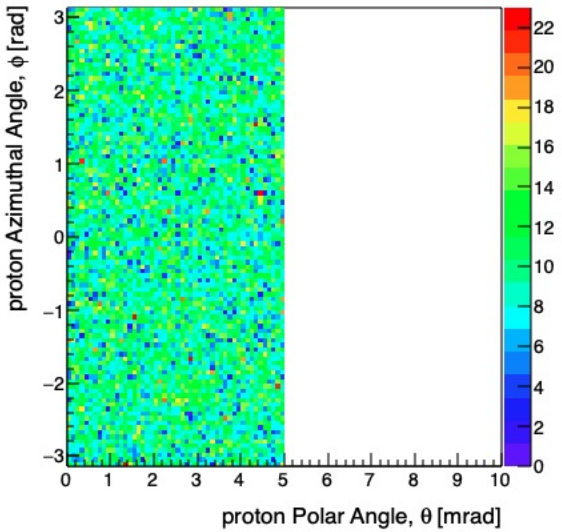

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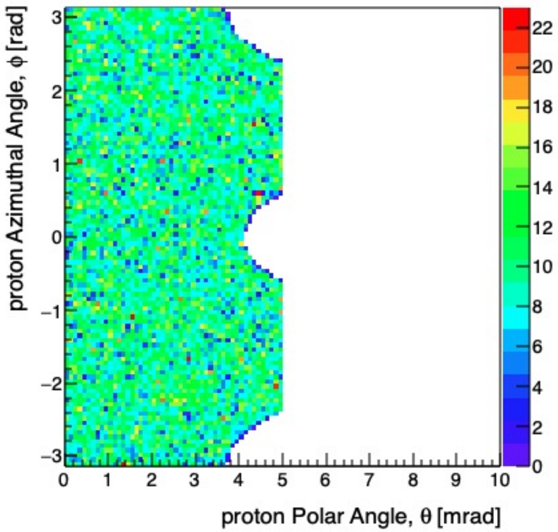
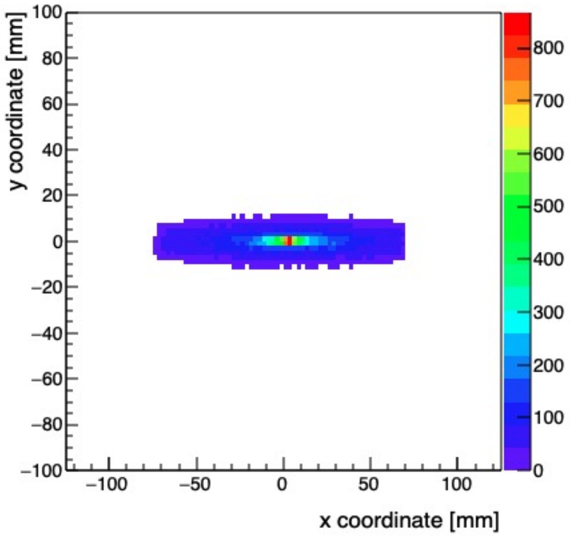
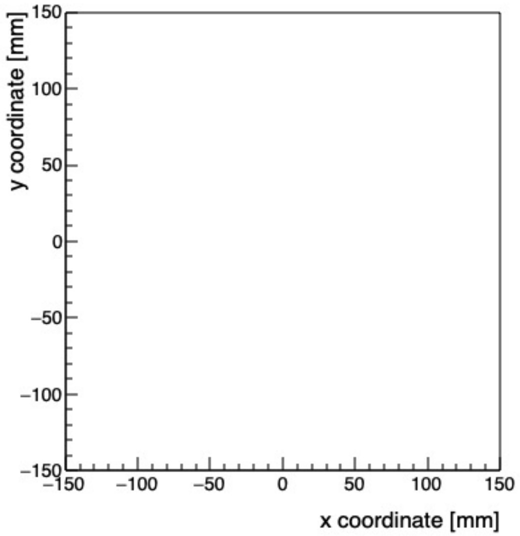


Roman Pots

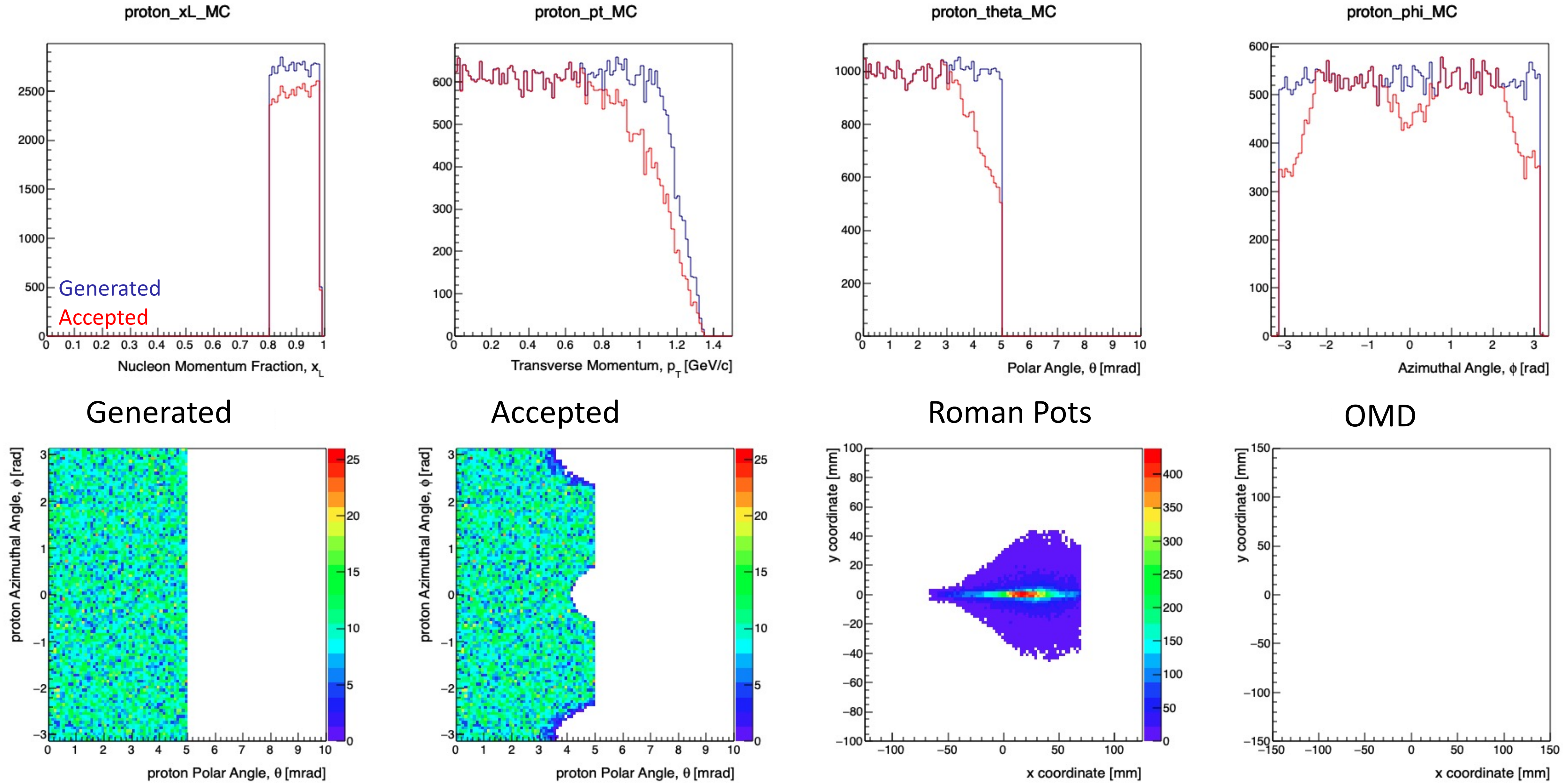


OMD



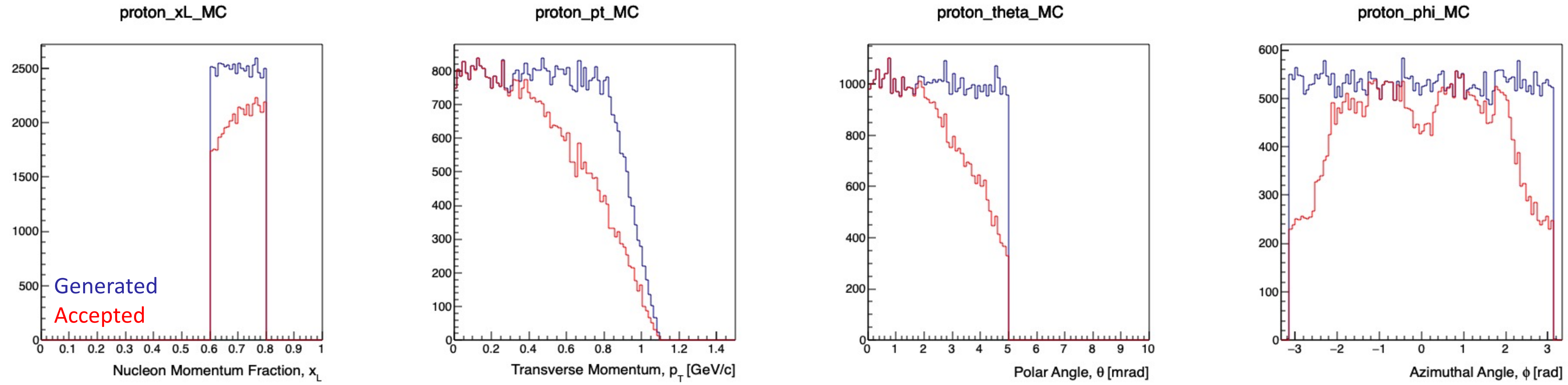
Protons with $0.8 < x\_L < 0.98$

- 220 < p < 270 GeV protons
- 0 < theta < 5 mrad



Protons with 0.6 < xL < 0.8

- 165 < p < 220 GeV protons
- 0 < theta < 5 mrad



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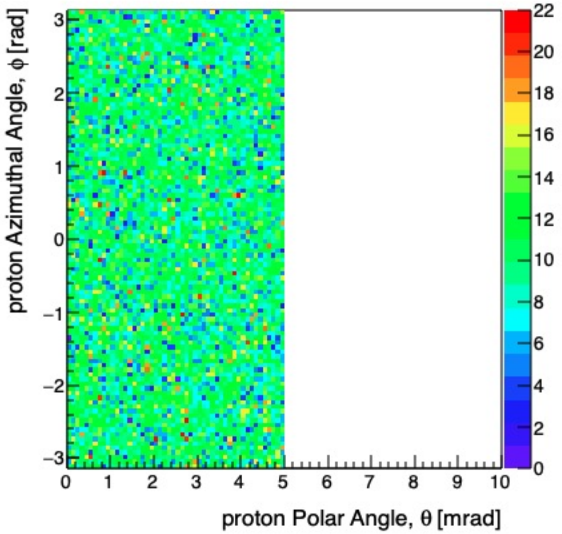

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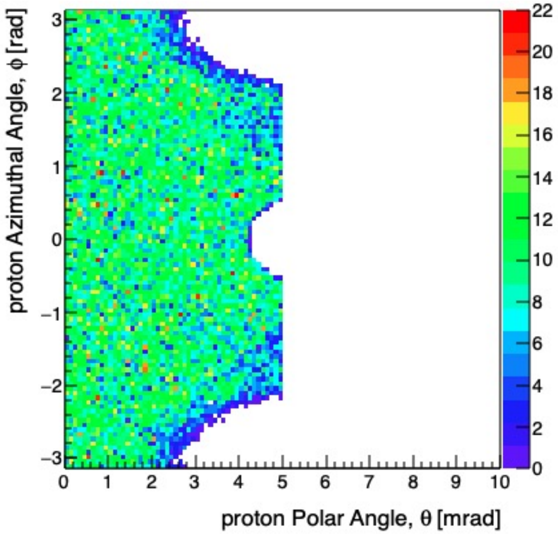
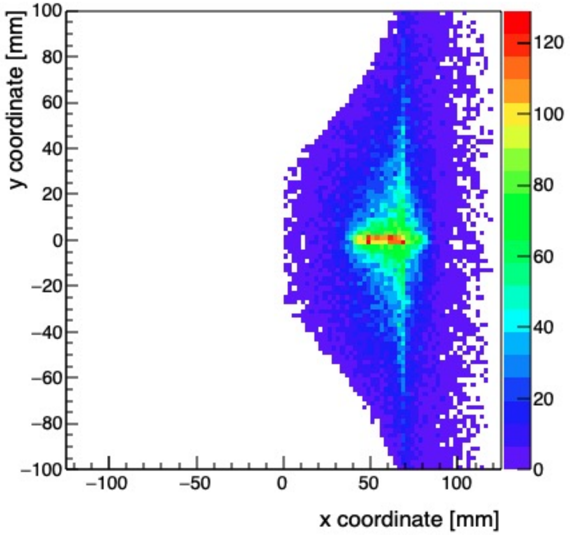
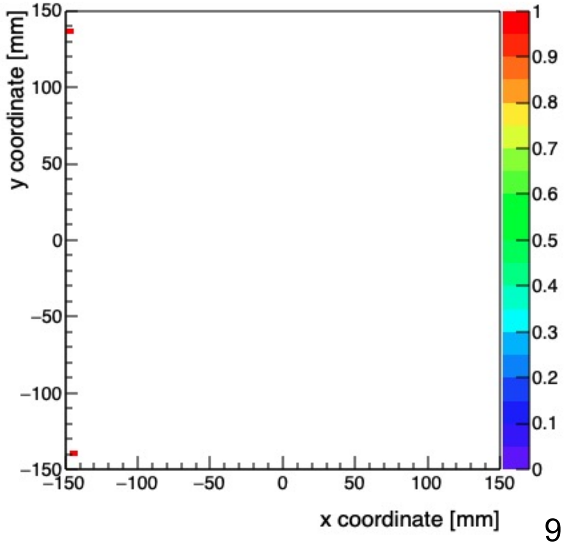


Roman Pots

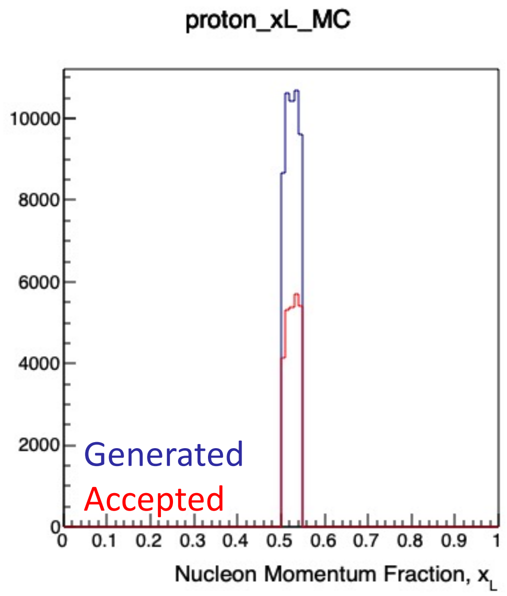


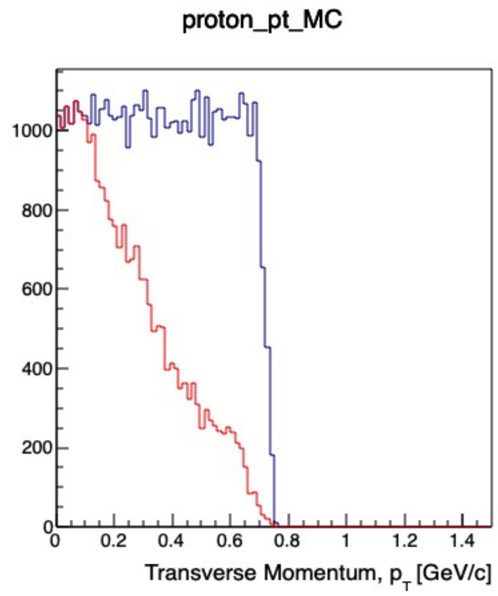
OMD

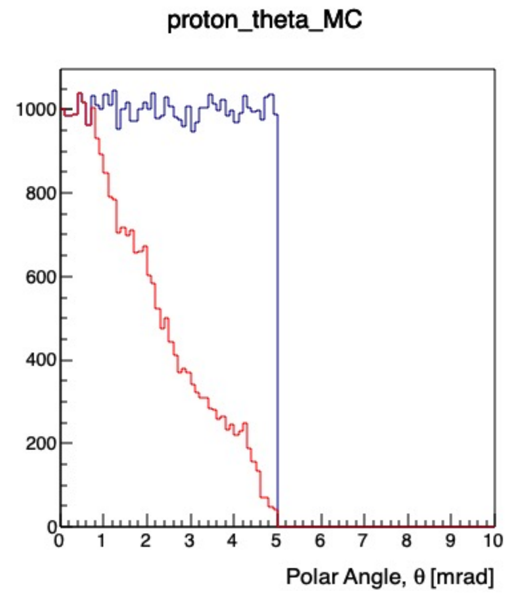


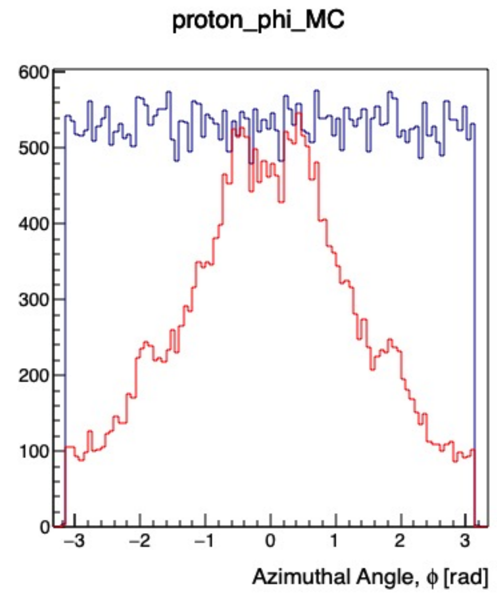
Protons with 0.45 < xL < 0.55

- 138 < p < 151 GeV protons
- 0 < theta < 5 mrad









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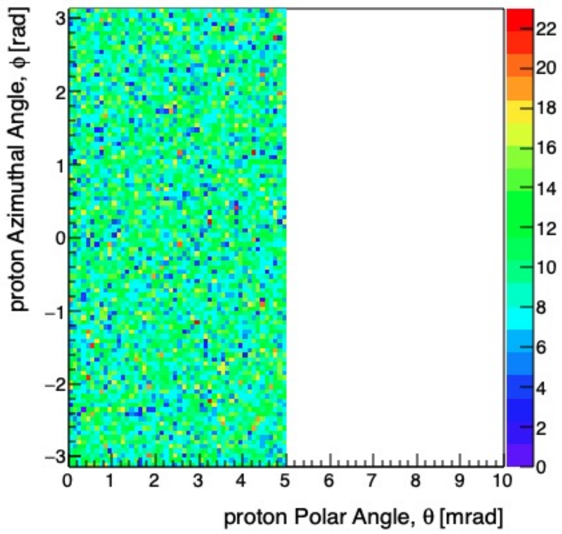

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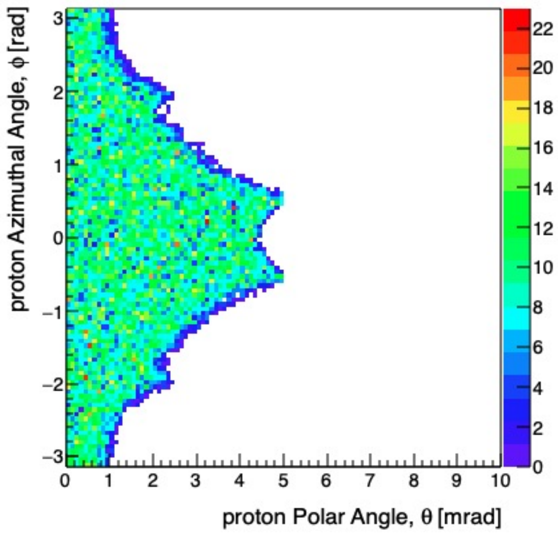
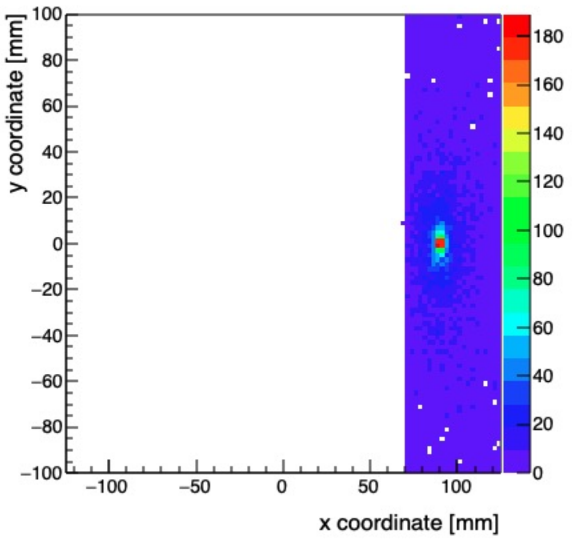
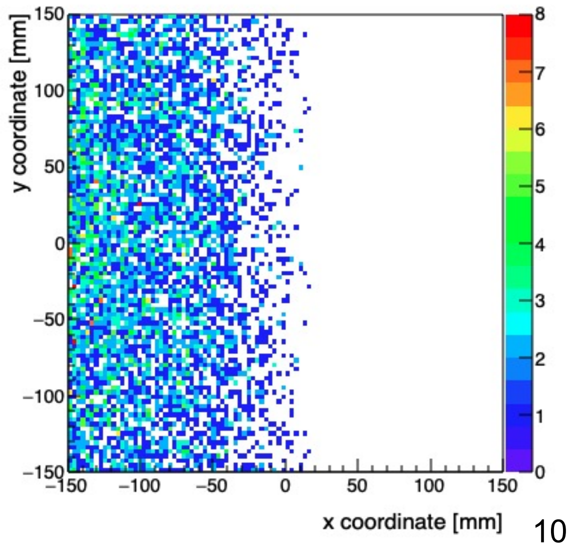


Roman Pots



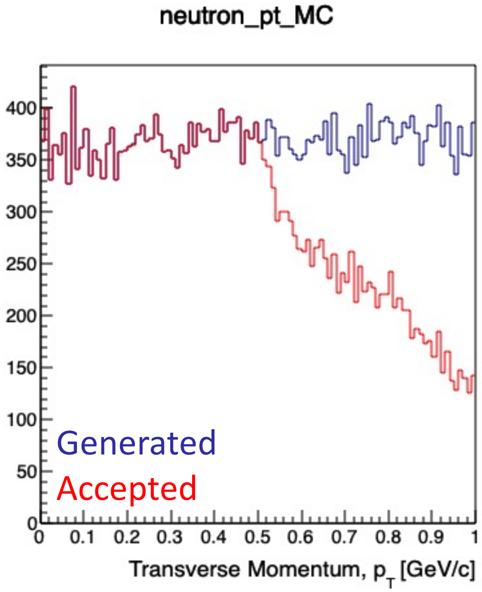
OMD

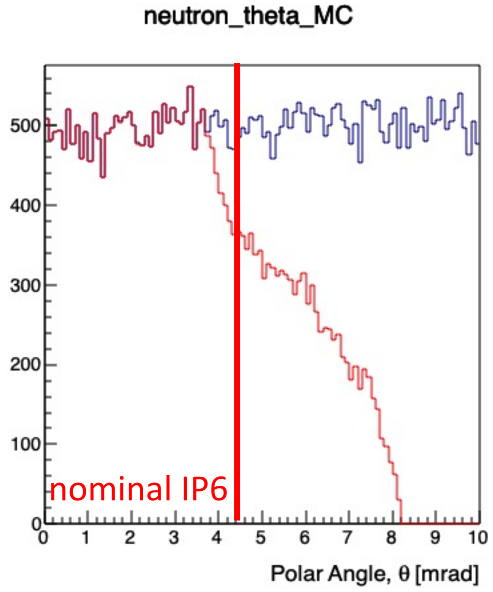


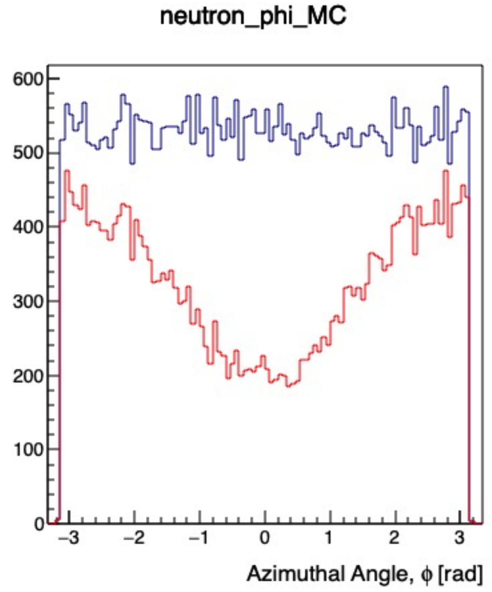
Neutron Acceptance

Neutrons

- p = 135 GeV protons
- 0 < theta < 10 mrad







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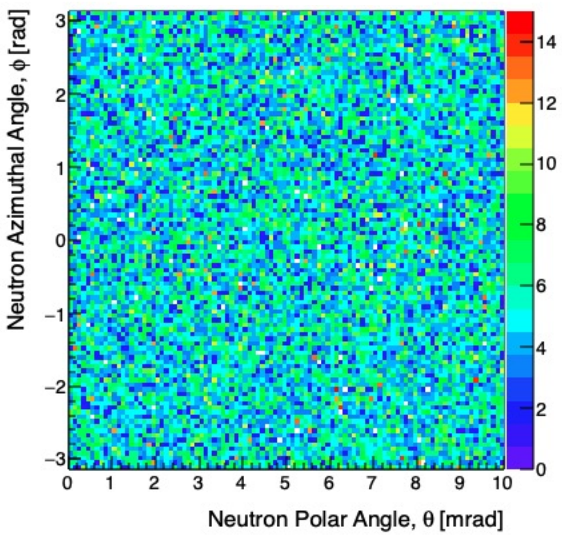

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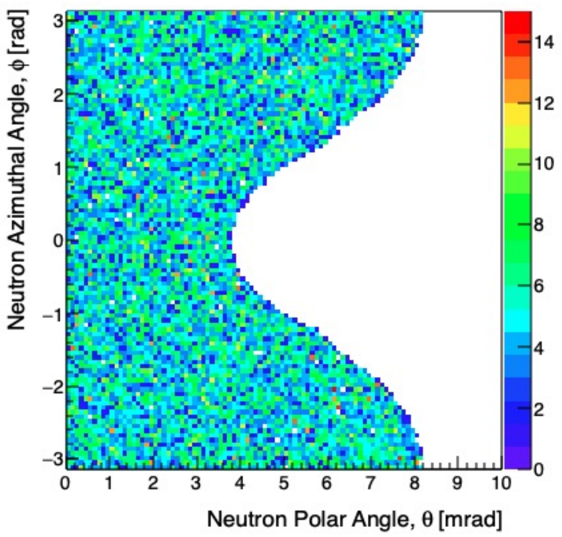
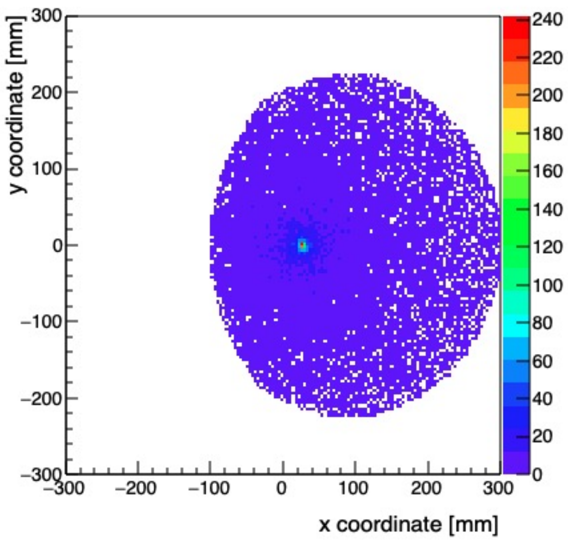
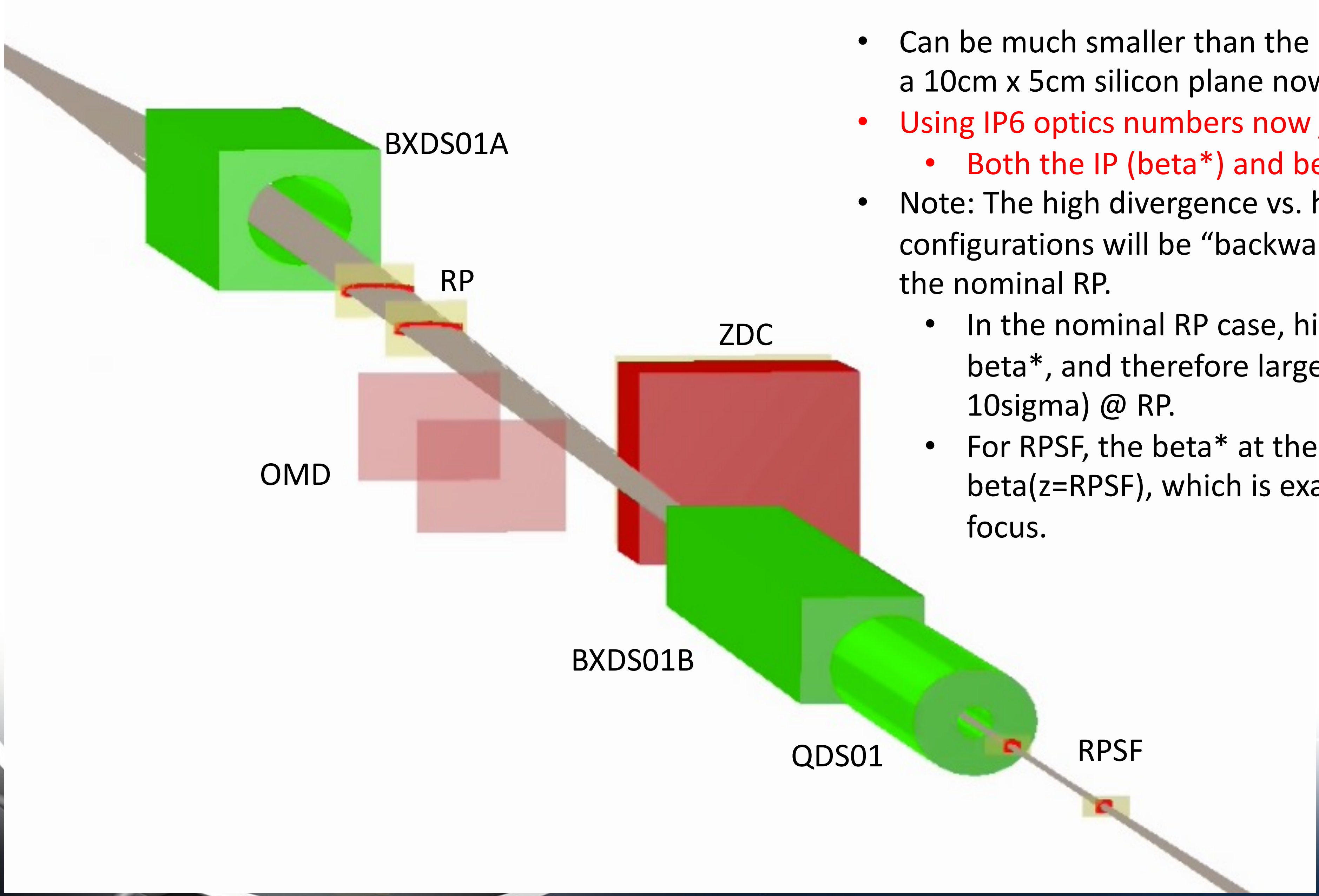


ZDC



Secondary Focus + Optics

Roman Pots @ Secondary Focus (RPSF)



- Can be much smaller than the nominal Roman Pots (I am using a 10cm x 5cm silicon plane now – similar to STAR RP size).
- Using IP6 optics numbers now just to illustrate the basics.
  - Both the IP (beta*) and beta functions at RP in IP6.
- Note: The high divergence vs. high acceptance optics configurations will be “backwards” for the RPSF compared to the nominal RP.
  - In the nominal RP case, high divergence means small beta*, and therefore larger beta functions (and larger 10sigma) @ RP.
  - For RPSF, the beta* at the IP is directly proportional to the beta(z=RPSF), which is exactly the point of the secondary focus.

Table 3.4: EIC beam parameters for different center-of-mass energies $\sqrt{s}$, with strong hadron cooling. High acceptance configuration.

high acceptance

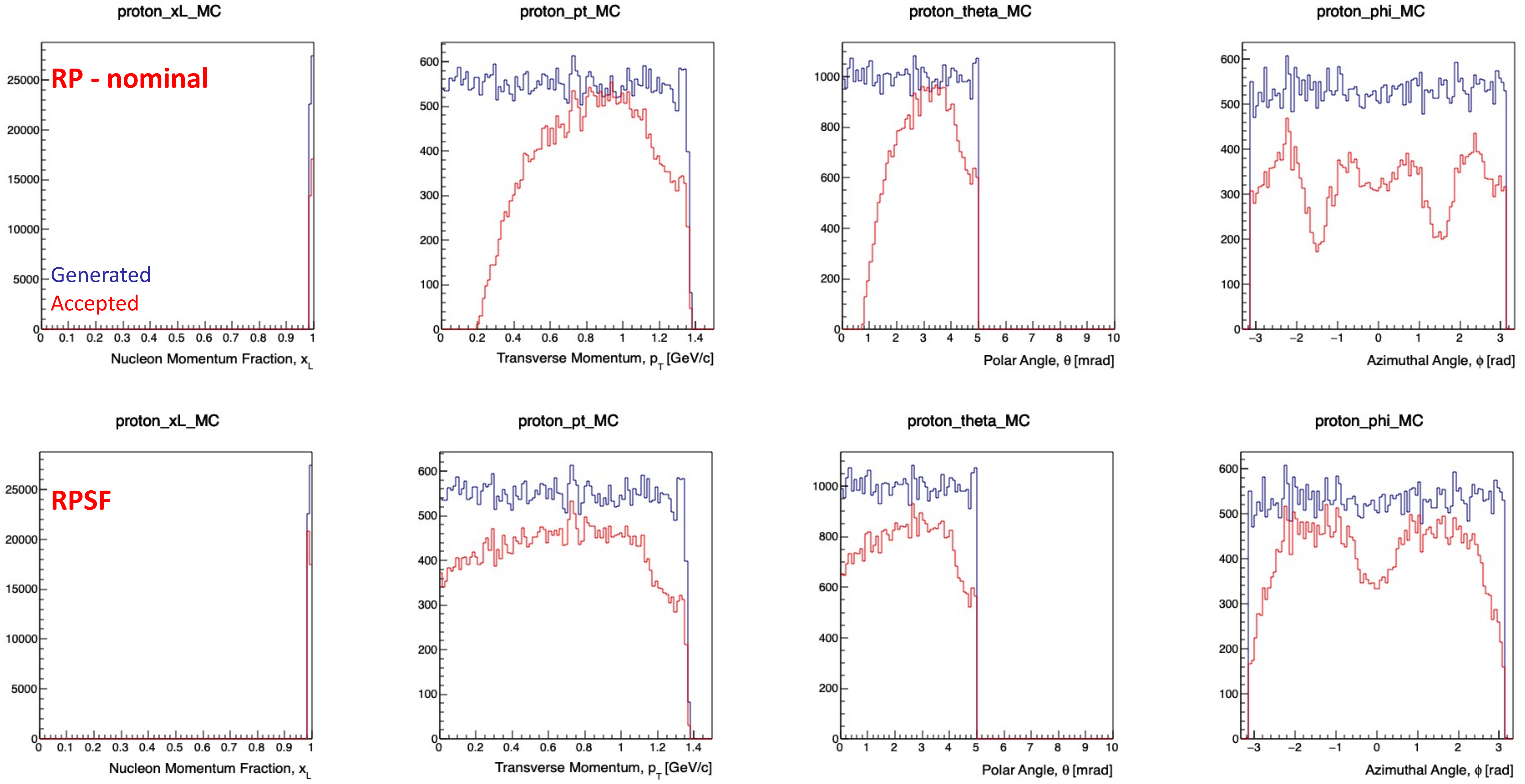
Species	proton	electron
Energy [GeV]	275	18
CM energy [GeV]	140.7	
Bunch intensity [10^{10}]	18.9	6.2
No. of bunches	290	
Beam current [A]	0.69	0.227
RMS norm. emit., h/v [μm]	5.2/0.46	845/70
RMS emittance, h/v [nm]	17.6/1.6	24.0/2.0
β^*, h/v [cm]]	417/38	306/30
IP RMS beam size, h/v [μm]	271/24	
K_x	11.1	
RMS $\Delta\theta$, h/v [μrad]	65/65	89/82
BB parameter, h/v [10^{-3}]	3/3	92/100
RMS long. emittance [10^{-3}, eV·s]	36	
RMS bunch length [cm]	6	0.9
RMS $\Delta p/p$ [10^{-4}]	6.8	10.9
Max. space charge	0.007	neglig.
Piwinski angle [rad]	2.8	0.9
Long. IBS time [h]	2.0	
Transv. IBS time [h]	2.0	
Hourglass factor H	0.99	
Luminosity [10^{33}cm^{-2}s^{-1}]	0.32	

high divergence

Species	proton	electron
Energy [GeV]	275	18
CM energy [GeV]	140.7	
Bunch intensity [10^{10}]	19.1	6.2
No. of bunches	290	
Beam current [A]	0.69	0.227
RMS norm. emit., h/v [μm]	5.2/0.47	845/71
RMS emittance, h/v [nm]	18/1.6	24/2.0
β^*, h/v [cm]]	80/7.1	59/5.7
IP RMS beam size, h/v [μm]	119/11	
K_x	11.1	
RMS $\Delta\theta$, h/v [μrad]	150/150	202/187
BB parameter, h/v [10^{-3}]	3/3	93/100
RMS long. emittance [10^{-3}, eV·s]	36	
RMS bunch length [cm]	6	0.9
RMS $\Delta p/p$ [10^{-4}]	6.8	10.9
Max. space charge	0.007	neglig.
Piwinski angle [rad]	6.3	2.1
Long. IBS time [h]	2.0	
Transv. IBS time [h]	2.0	
Hourglass factor H	0.91	
Luminosity [10^{33}cm^{-2}s^{-1}]	1.54	

Table 3.3: EIC beam parameters for different center-of-mass energies $\sqrt{s}$, with strong hadron cooling. High divergence configuration.

RPSF vs. Roman Pots (IP6 optics – High Acceptance)



RPSF vs. Roman Pots (IP6 optics – High Acceptance)

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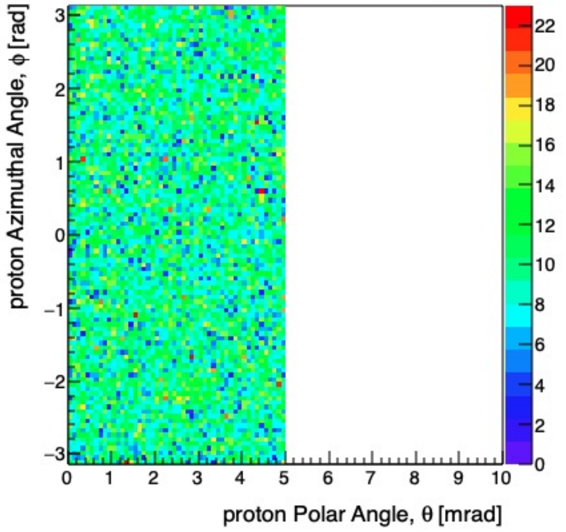

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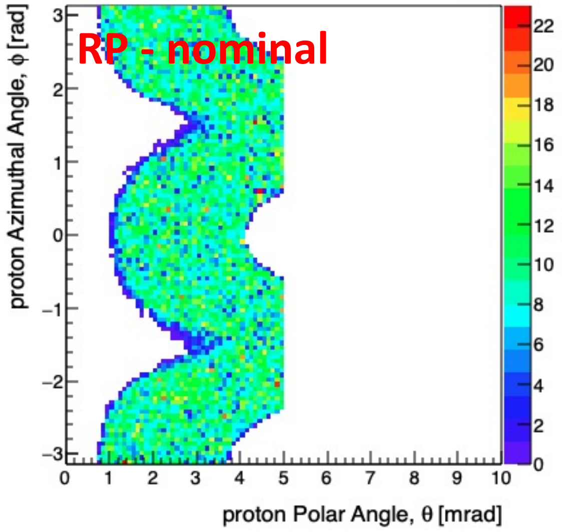
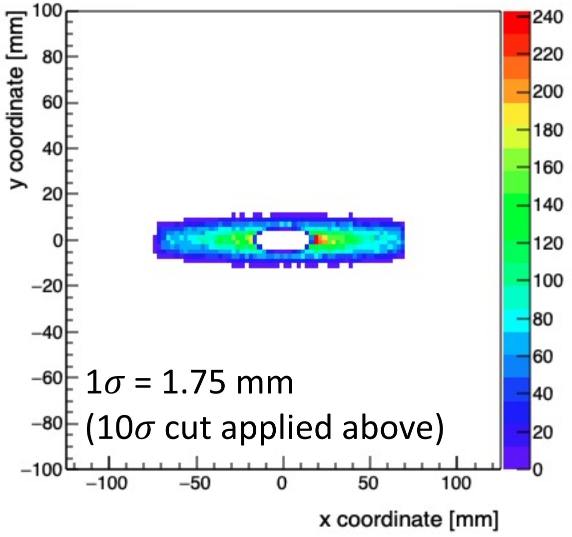
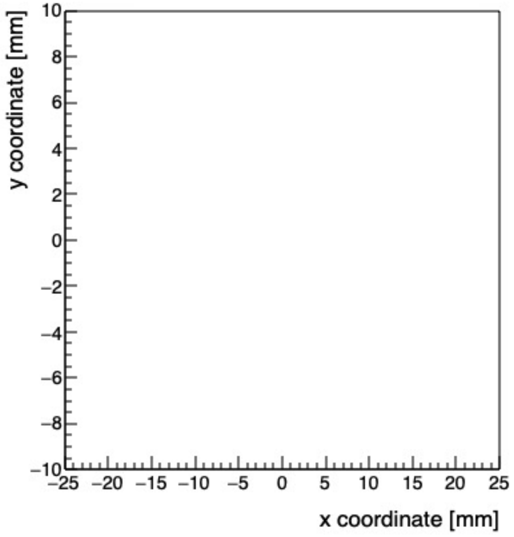


RP hits



RPSF hits



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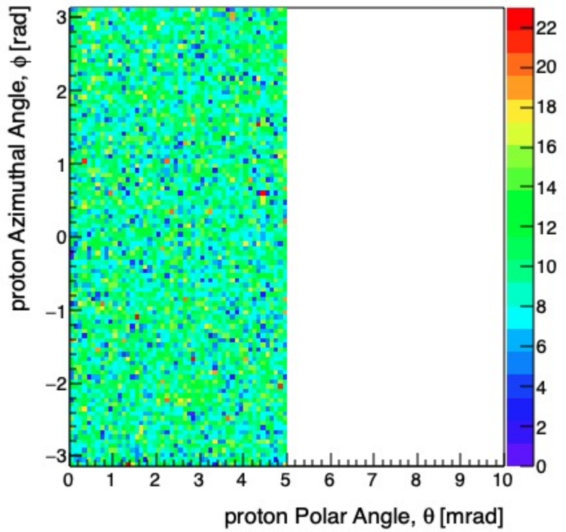

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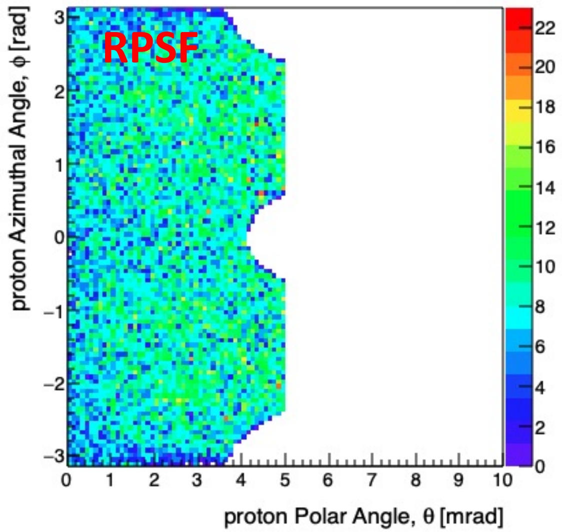
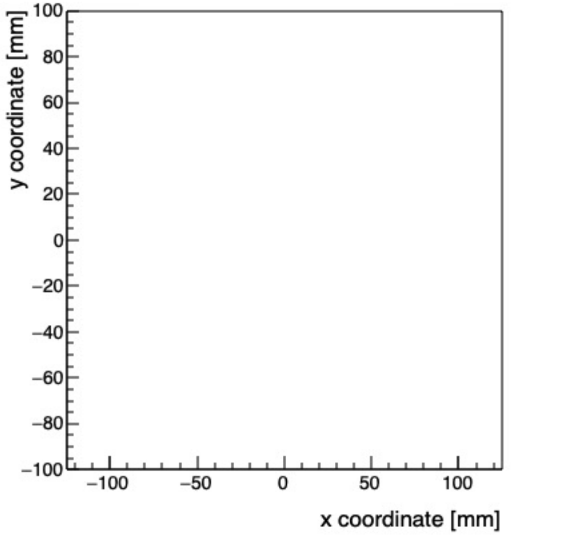
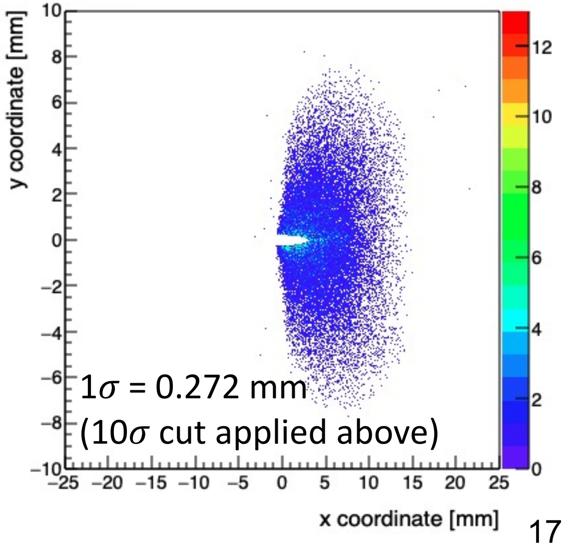


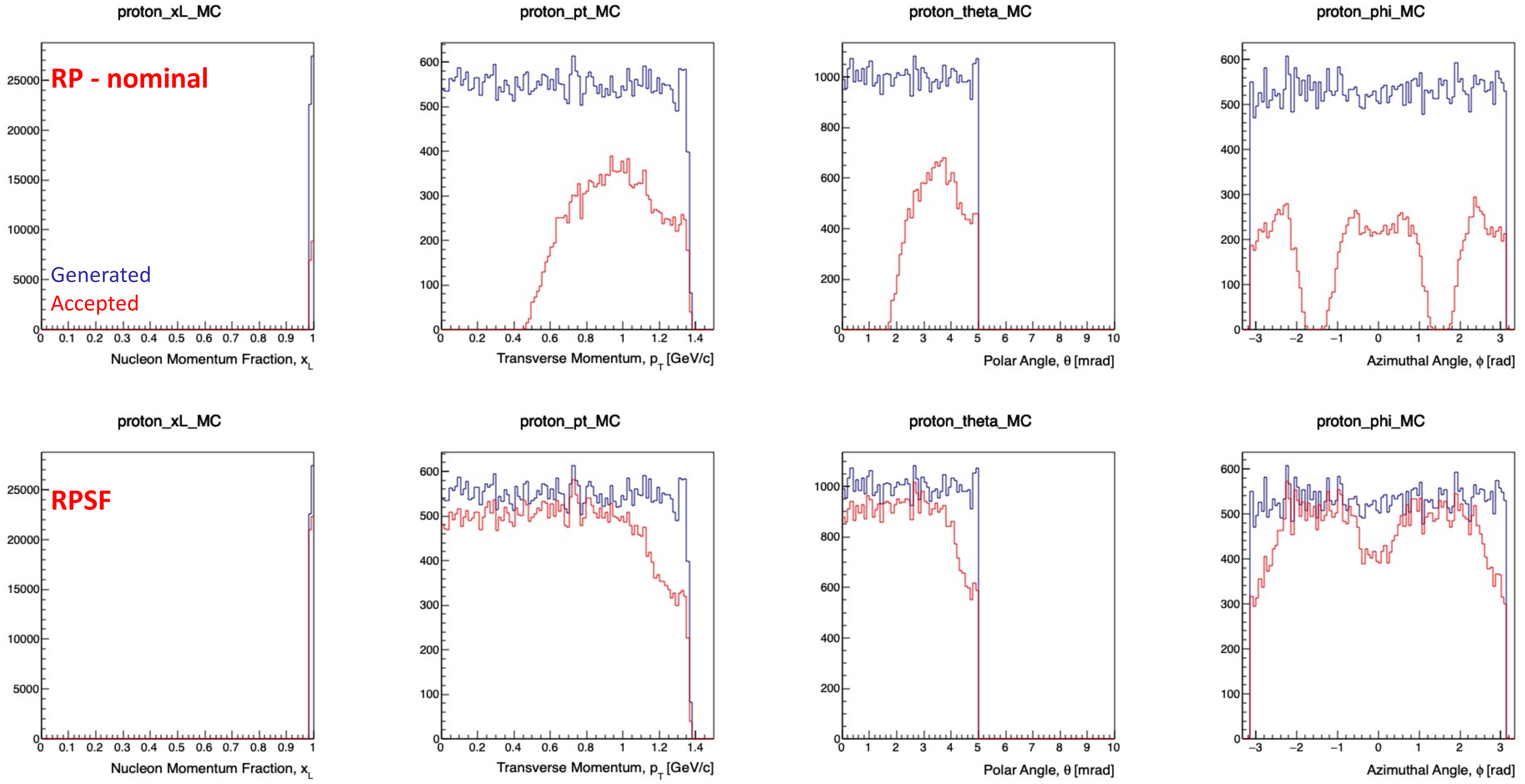
RP hits



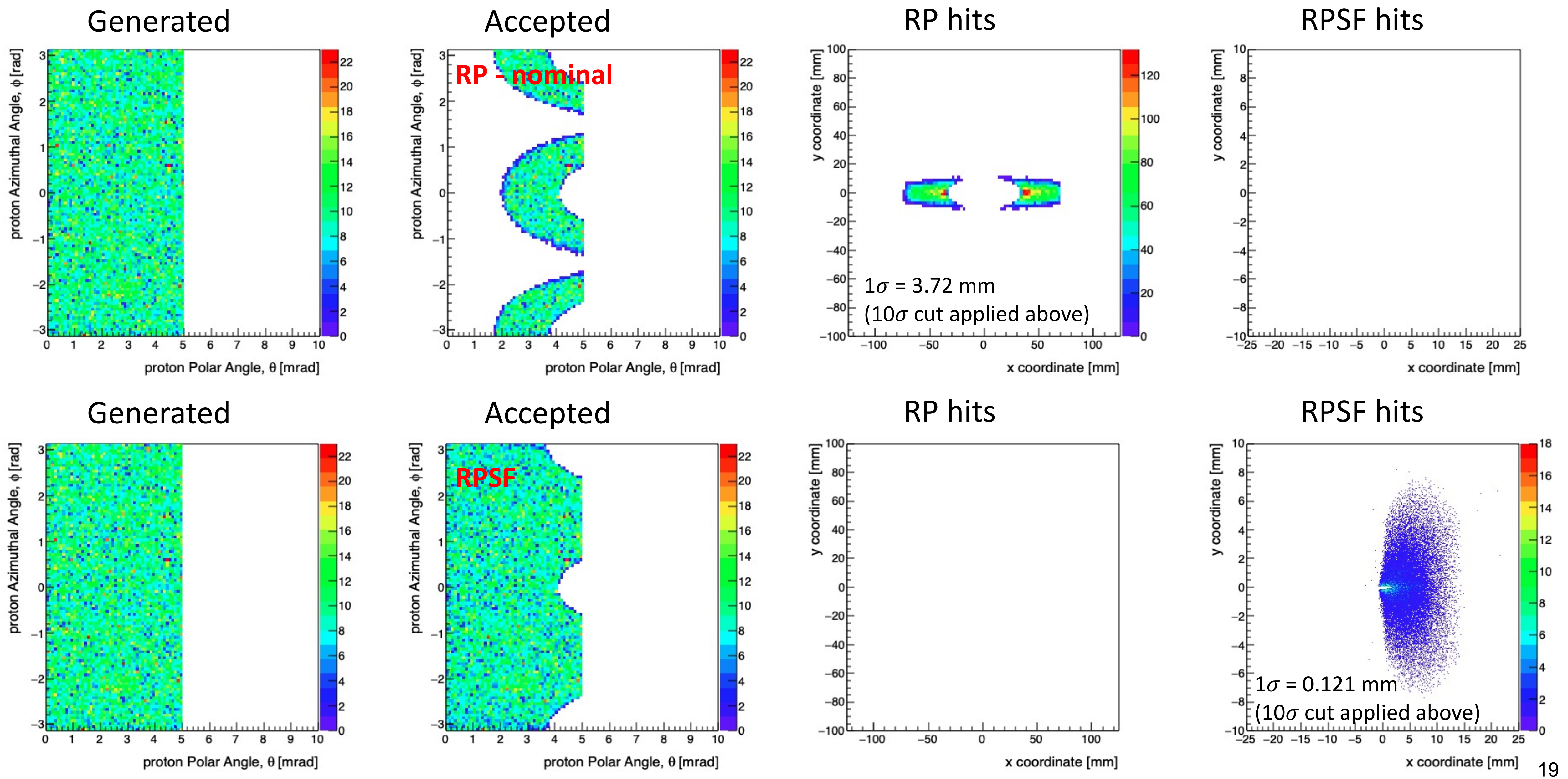
RPSF hits



RPSF vs. Roman Pots (IP6 optics – High Divergence)



RPSF vs. Roman Pots (IP6 optics – High Divergence)



Summary

- First IP8 layout provides good acceptance to both protons and neutrons.
  - Almost the same coverage for RP protons as IP6 (theta ~ 4 mrad full coverage).
  - About the same azimuthally symmetric coverage for neutrons (~4 mrad), but more acceptance for neutrons at phi = 0.
- Secondary focus is observable in GEANT.
  - Have some preliminary sanity checks on the behavior and benefits w.r.t. acceptance.
  - Will need optics information (beta functions, emittance, etc.) to do a more careful look.
- Off-momentum protons have a different overall behavior than in IP6 - will impact detector placement/usage.
- In general, may want to re-think the basic layout of detectors w.r.t. Roman Pots vs. Roman Pots @ secondary focus, and the OMD.
- Space for B0 detector equivalent needs to be understood.

IP6 and IP8 have many acceptance overlaps, and places where they enhance each other. The two IPs together will provide an incredibly strong, complementary physics program for the EIC!

Comparison of magnets in IP6/IP8

IP6

name	center_x [m]	center_y [m]	center_z [m]	rin(z-in) [m]	rin(z-out) [m]	dout [m]	length [m]	angle [mrad]	B [T]	gradient [T/m]
B0PF	0.132497	0.0	5.89913	0.2000	0.2000	0.5000	1.200	0.00	-1.300	0.000
B0APF	0.197995	0.0	7.69866	0.0430	0.0430	0.1860	0.600	25.0	-3.474	0.000
Q1APF	0.244734	0.0	9.22834	0.0560	0.0560	0.2120	1.460	19.5	0.000	-72.608
Q1BPF	0.300512	0.0	11.0629	0.0780	0.0780	0.2560	1.610	15.0	0.000	-66.180
Q2PF	0.39495	0.0	14.1673	0.1315	0.1315	0.3620	3.800	14.8	0.000	40.737
B1PF	0.490747	0.0	18.0667	0.1350	0.1350	0.3700	3.000	34.0	-3.400	0.000
B1APF	0.600444	0.0	20.8159	0.1680	0.1680	0.4360	1.500	25.0	-2.700	0.000
B2APF	1.522232	0.0	41.9092	0.2	0.2	0.5	5.76	25.0	5.94	0.000

IP8

name	center_x [m]	center_y [m]	center_z [m]	rin(z-in) [m]	rin(z-out) [m]	dout [m]	length [m]	angle [mrad]	B [T]	gradient [T/m]
BXSP01	0.212097365	0.0	6.096002106	0.245	0.245	0.690	1.2	0.0	4.586506375	0.000
QFFDS01A	0.260495441	0.0	8.195691084	0.061387	0.061387	0.29	2.0	42.817	0.0000	-63.50670778
QFFDS01B	0.347191048	0.0	10.79426544	0.0859775	0.0859775	0.40	2.2	42.426	0.0000	-45.37532028
QFFDS02A	0.482534997	0.0	14.19184893	0.1119875	0.1119875	0.51	2.6	23.373	0.0000	34.17940681
QFFDS02B	0.573577467	0.0	17.19045056	0.12512	0.12512	0.62	2.4	37.155	0.0000	31.13999517
BXDS01A	0.737879152	0.0	21.28801935	0.19	0.19	0.56	4.8	30.75	4.443442343	0.0000
BXDS01B	0.905112089	0.0	38.48809706	0.055	0.055	0.29	3.6	21.5	-4.59686275	0.0000
QDS01	0.983427868	0.0	41.53706604	0.04	0.04	0.28	1.500	29.0	0.0000	2.526510576

Central Proton Orbit Coordinates

Proton orbit @ exit of magnet [meters] BXSP01 (x_global, y_global, z_global) = (0.2308459, 0.0000000, 6.6960089)
Proton orbit @ exit of magnet [meters] QFFDS01A (x_global, y_global, z_global) = (0.3059584, -0.0000026, 9.1946698)
Proton orbit @ exit of magnet [meters] QFFDS01B (x_global, y_global, z_global) = (0.3913427, -0.0000122, 11.8933887)
Proton orbit @ exit of magnet [meters] QFFDS02A (x_global, y_global, z_global) = (0.5092839, -0.0000293, 15.4915869)
Proton orbit @ exit of magnet [meters] QFFDS02B (x_global, y_global, z_global) = (0.6073845, -0.0000542, 18.3900232)
Proton orbit @ exit of magnet [meters] BXDS01A (x_global, y_global, z_global) = (0.7329013, -0.0001179, 23.6893164)