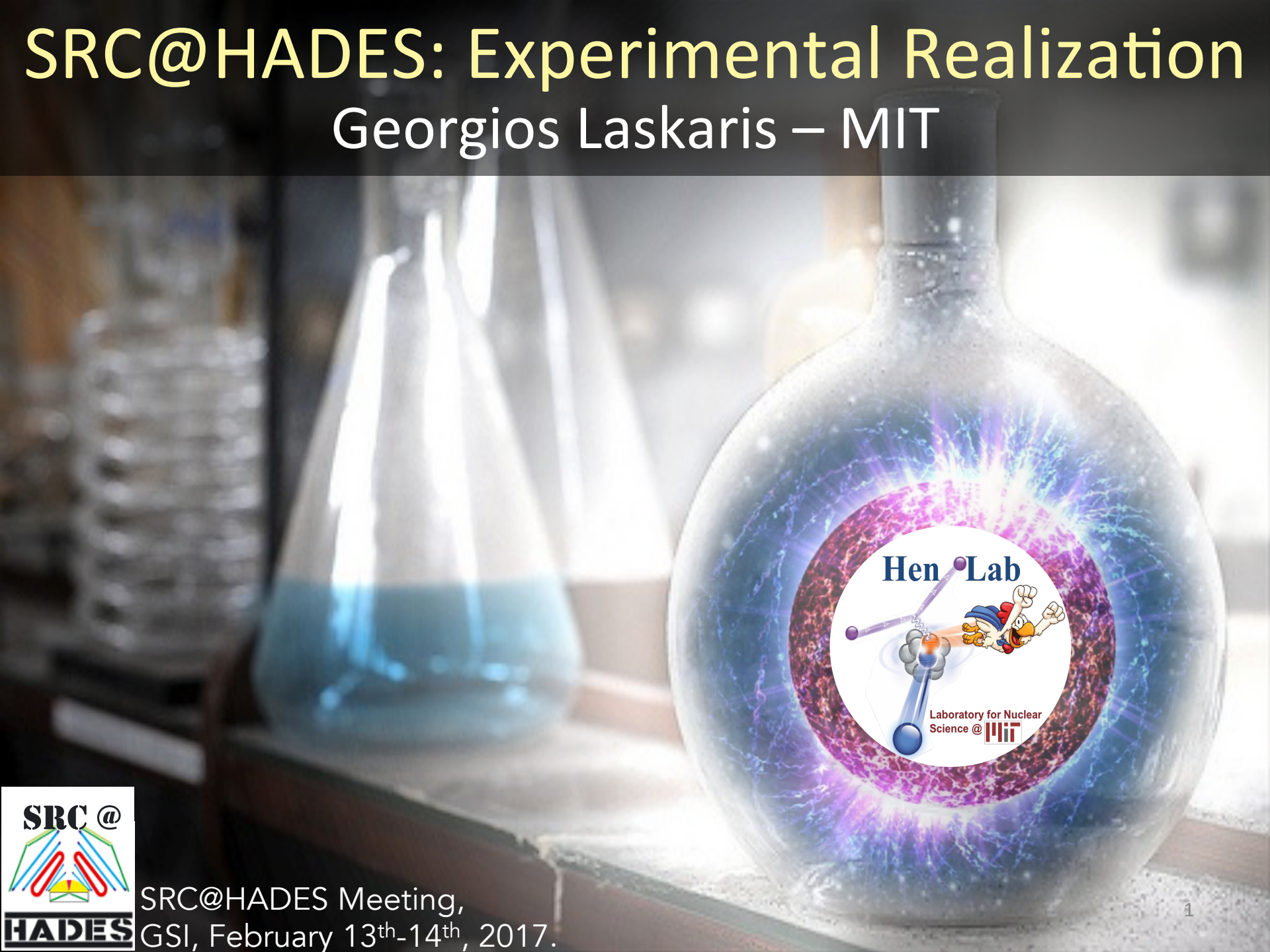
SRC@HADES: Experimental Realization

Georgios Laskaris – MIT



SRC@HADES Meeting,
GSI, February 13th-14th, 2017.

Outline

- SRC Kinematics 101
- Proposed experimental setup
- Resolutions and observables
- Expected Rates for Phase I and II
- Conclusions

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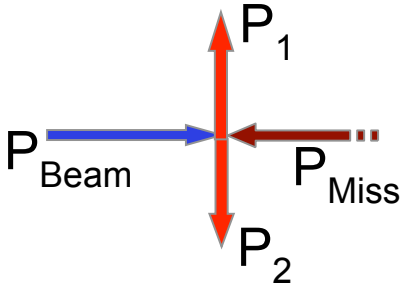
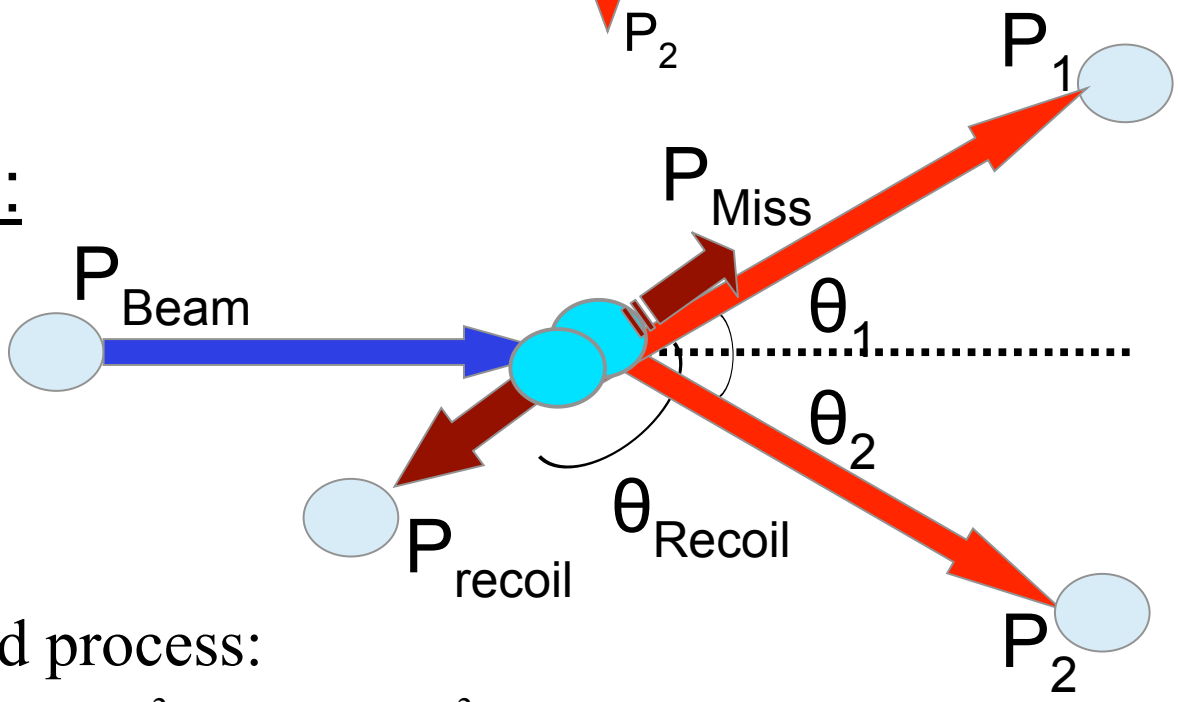
SRC Kinematics: 2N-SRC

C.M. Frame ($90^o \pm 10^o$ scattering):



Lab Frame:



- SRC dominance:

$$|p_{recoil}| \geq 250 MeV/c$$

- Hard process:

$$-t = -(pb - p1)^2 > 2(GeV/c)^2$$

$$-u = -(pb - p2)^2 > 2(GeV/c)^2$$

$$s = (p1 + p2)^2 > 2(GeV/c)^2$$

SRC Kinematics: 3N-SRC

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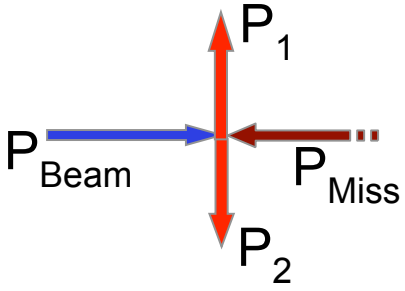

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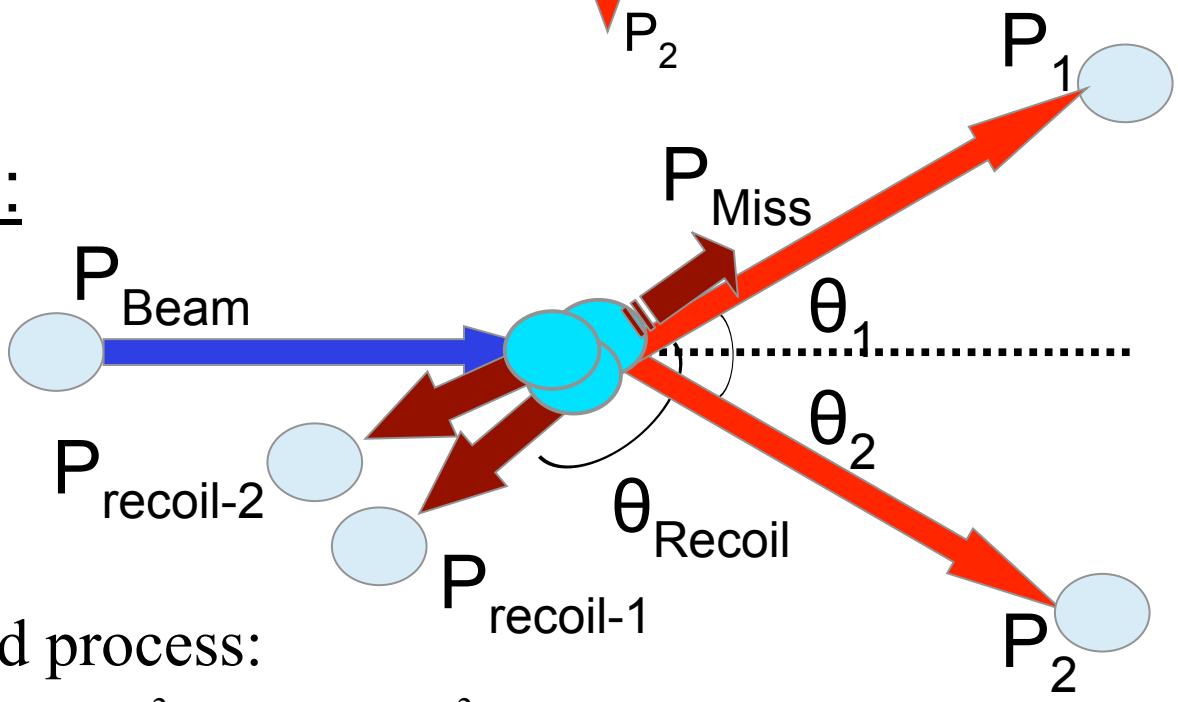

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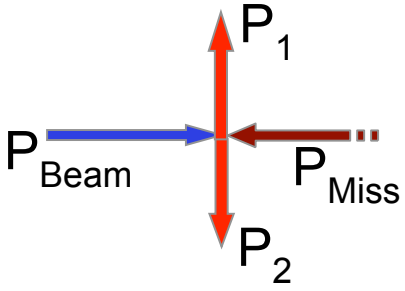

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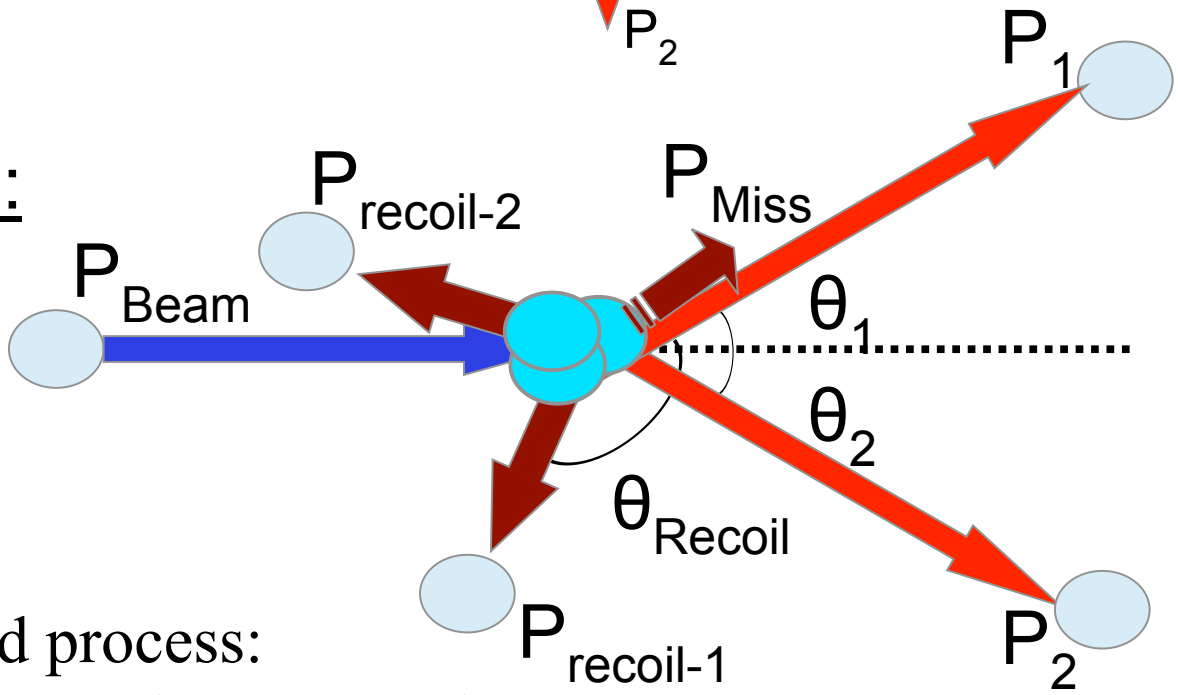

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Experimental requirements

1. Detection of two, high-momentum, leading protons in the beam direction. (HADES)

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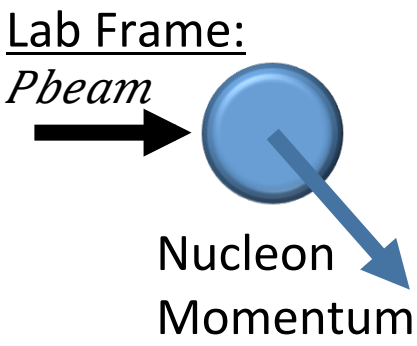
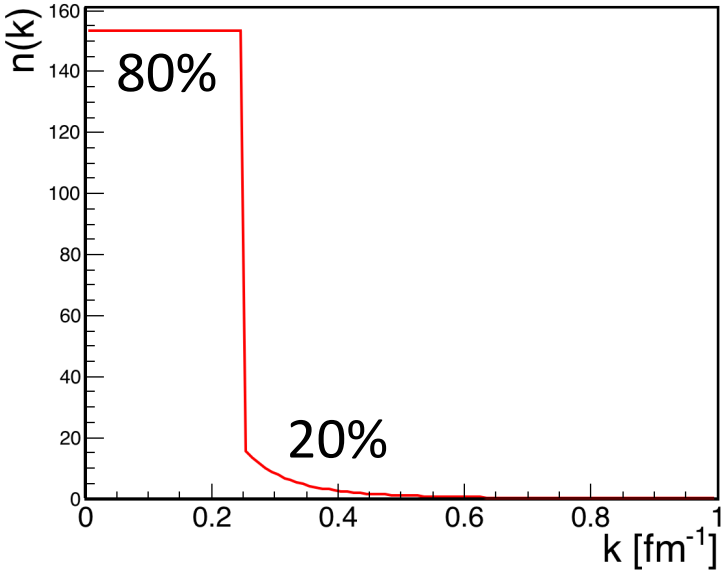
Kinematical Simulation

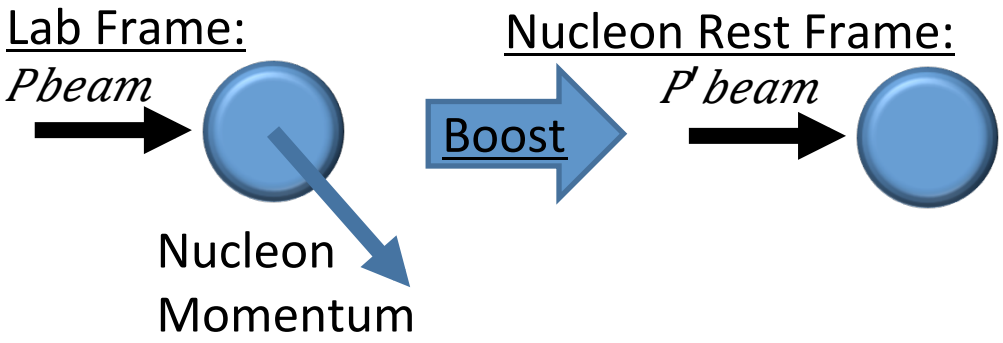
1. Raffle a nucleon from a correlated Fermi-Gas model.





Kinematical Simulation

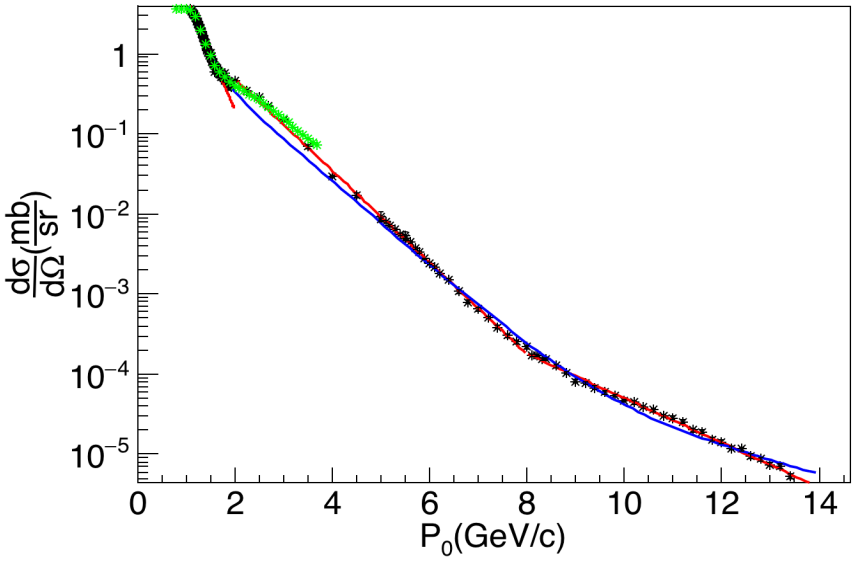
1. Raffle a nucleon from a correlated Fermi-Gas model.
2. Boost to the nucleon rest frame and get the cross-section for (p,2p) elastic scattering in this frame.



Fit of quasi-elastic pp differential cross sections data @ 90° c.m.

C.W Akerlof *et al.,* Phys. Rev. **159**, 1138(1967).
R.C Kammerud *et al.,* Phys. Rev. D **4**,1309(1971).
D.Sivers *et al.,* Physics Reports **1**, 1-121(1976).
M.Garcon *et al.,* Nuclear Physics A **445**, 669(1985).

SAID Model



Kinematical Simulation

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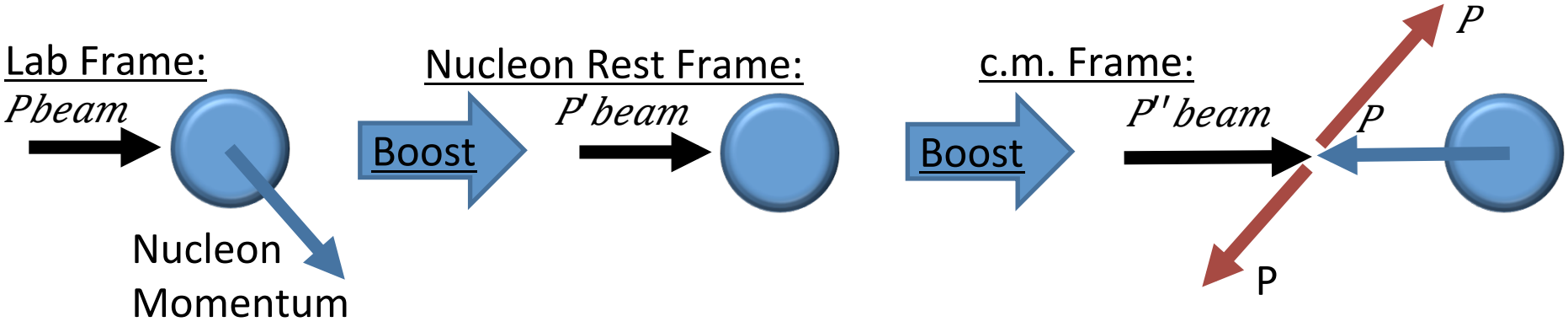
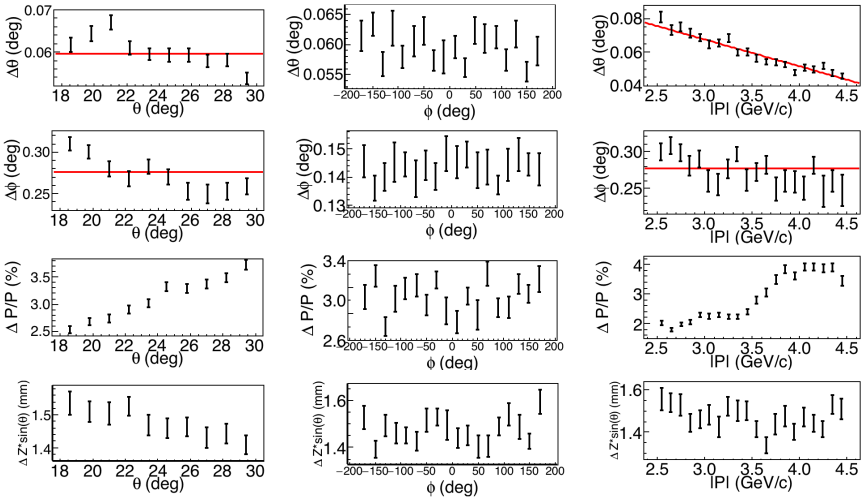
3. Boost to the c.m. and do the scattering for angles of 60^o – 120^o. Keep only events with $|s|,|t|,|u| \geq 2$ $(GeV/c)^2$.

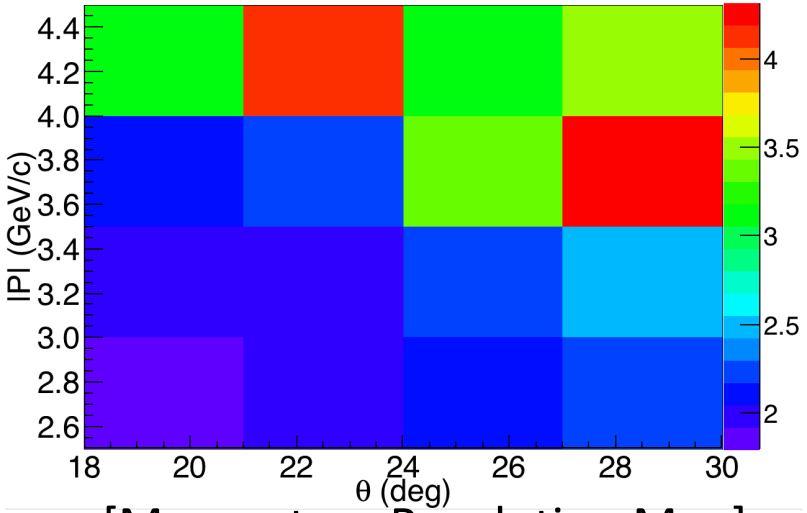


Kinematical Simulation

1. Raffle a nucleon from a correlated Fermi-Gas model.
2. Boost to the nucleon rest frame and get the cross-section for (p,2p) elastic scattering in this frame.
3. Boost to the c.m. and do the scattering for angles of 60^o – 120^o. Keep only events with $|s|,|t|,|u| \geq 2$ $(GeV/c)^2$.
4. Boost back to the lab frame and "smear" the protons according to the HADES resolution (extracted from the HADES GEANT3 simulation)



[Angular resolutions and correlations]



[Momentum Resolution Map]

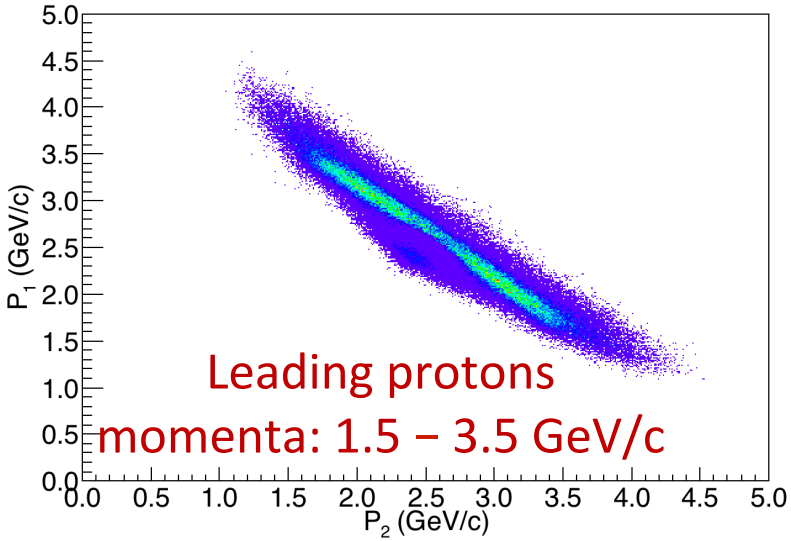
Kinematics for 3.5 GeV beam

Simulated Scattering off a SRC pair

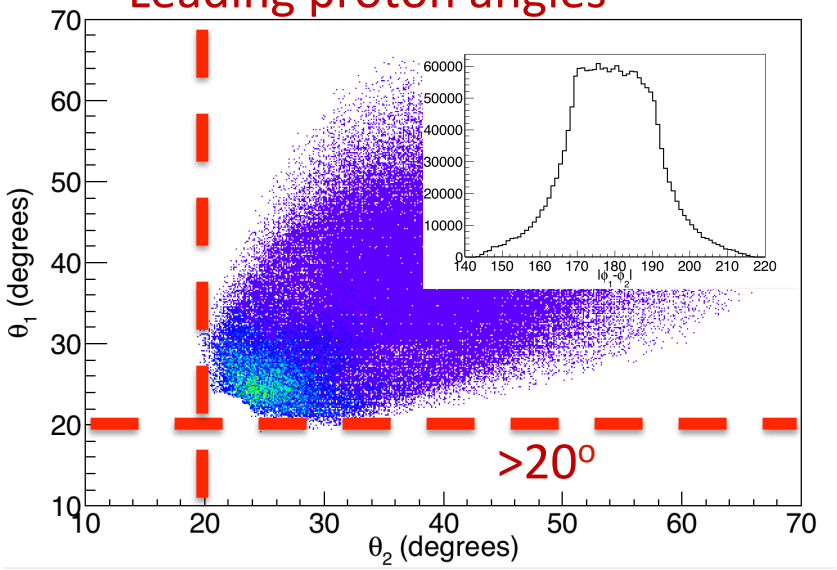
$$\theta_{c.m.}^{pp} = 90^\circ \pm 10^\circ$$

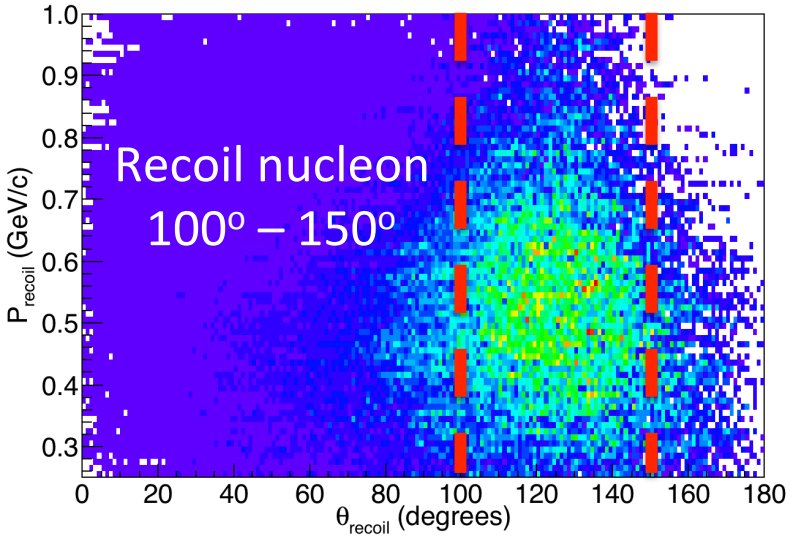
$$\sigma_{c.m.}^{SRC} = 140 MeV/c$$

$$n(k)_{k>k_F} = 1/k^4$$



Leading proton angles





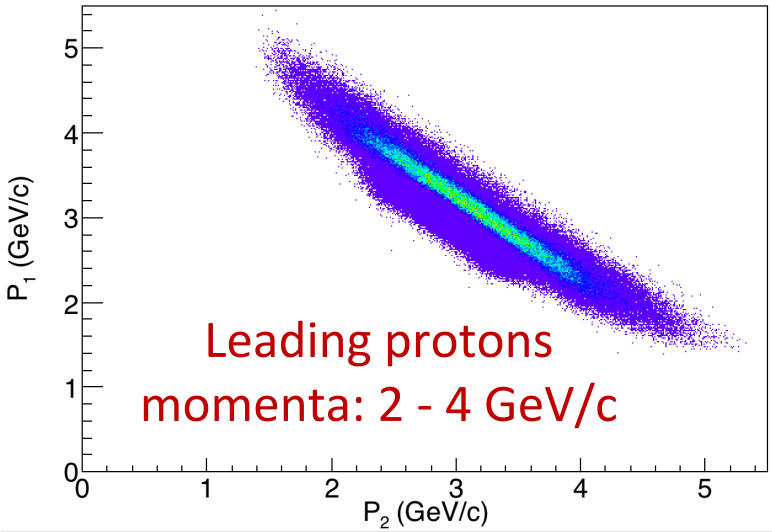
Kinematics for 4.5 GeV beam

Simulated Scattering off a SRC pair

$$\theta_{c.m.}^{pp} = 90^\circ \pm 10^\circ$$

$$\sigma_{c.m.}^{SRC} = 140 MeV/c$$

$$n(k)_{k>k_F} = 1/k^4$$



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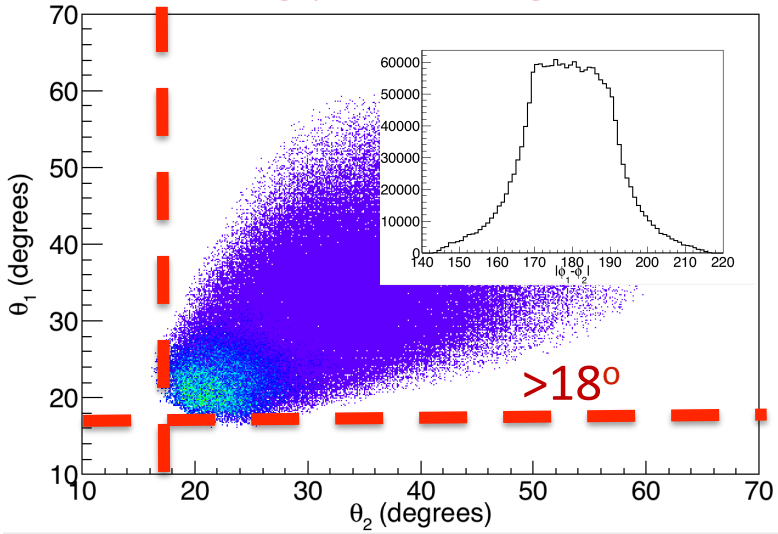

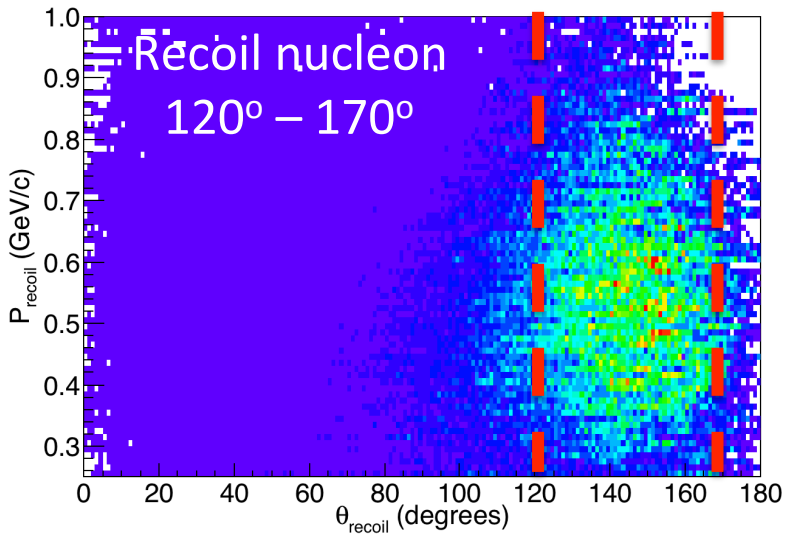

Experimental requirements

1. Detection of two, high-momentum, leading protons in the beam direction. (HADES)
   - 2 protons have similar momenta. (~ 1.5 – 4.0 GeV/c)
   - 2 protons go into opposite sectors.
   - Angular range: 18^{o} – 45^{o}.

2. Detection of one (two), low-momentum, recoil nucleon in the backwards direction. (New Recoil detector)
   - Recoil nucleon momentum ranges from 200 – 800 MeV/c.
   - No significant angular correlation with the 'leading' protons
   - Angular range: 100^{o} – 170^{o}.

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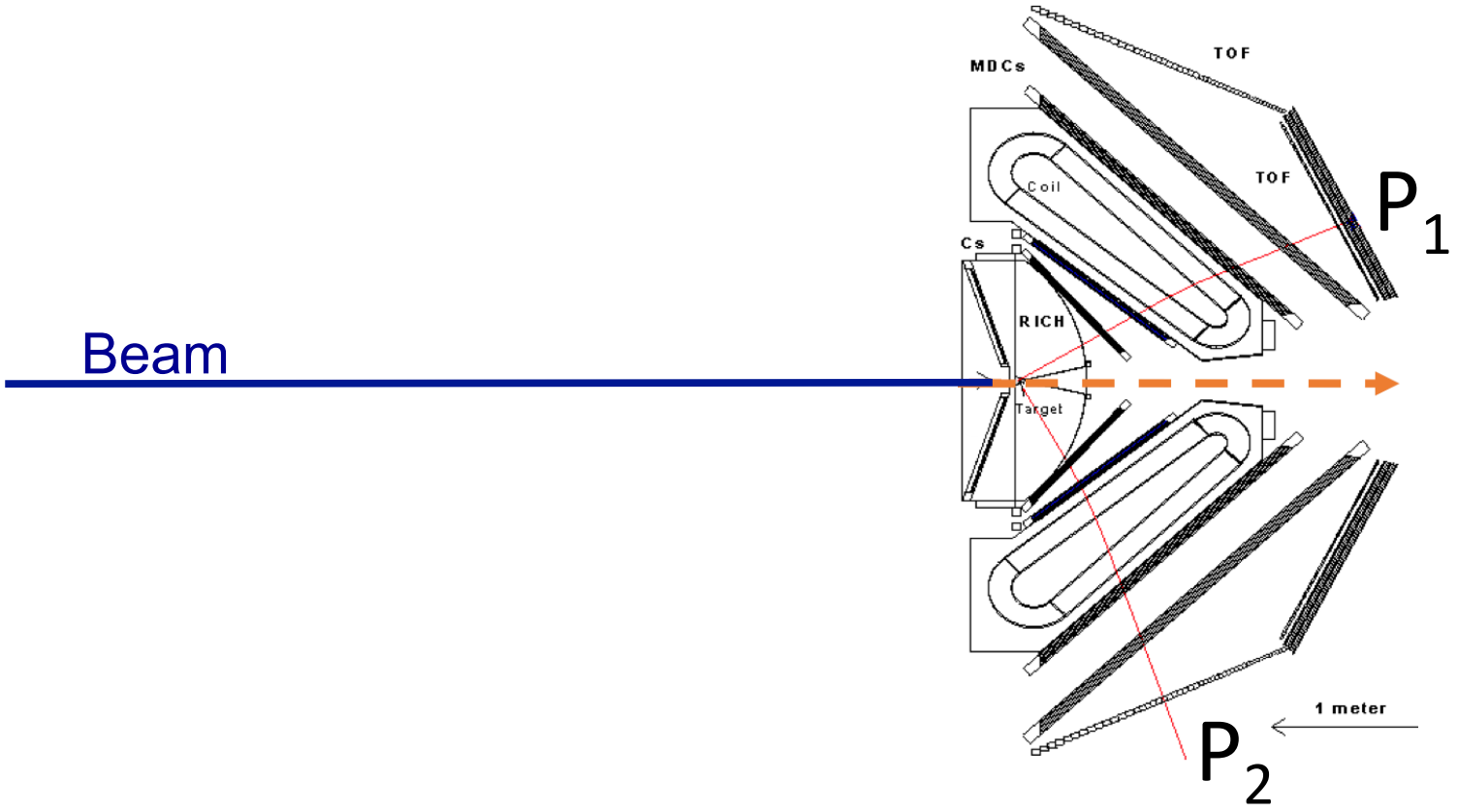
Experimental Setup: HADES

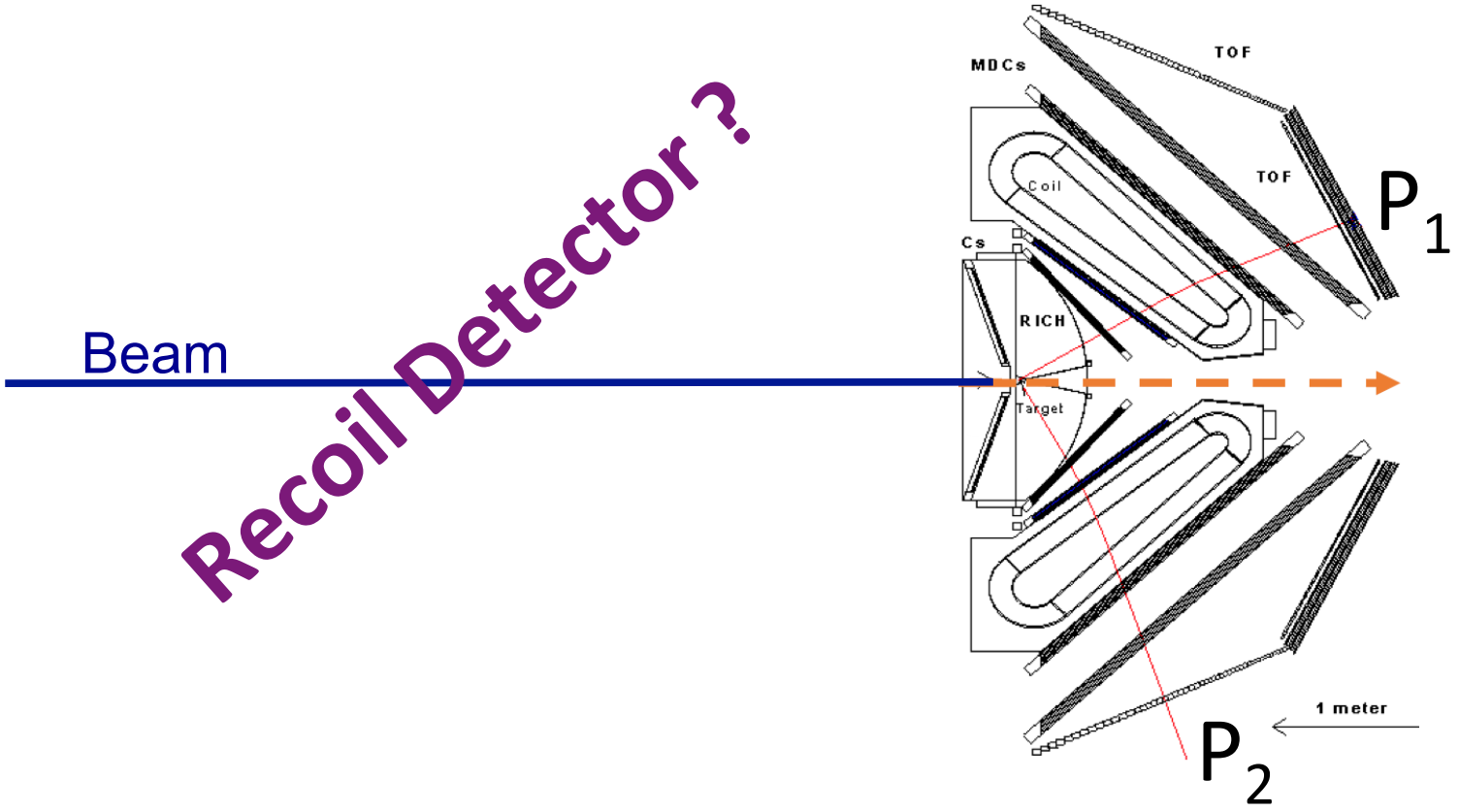


$\Delta\Omega \approx 50\%$

Proton PID > 95%

$18^{o} \leq \theta_{1,2} \leq 45^{o}$

Experimental Setup: Recoil Det.



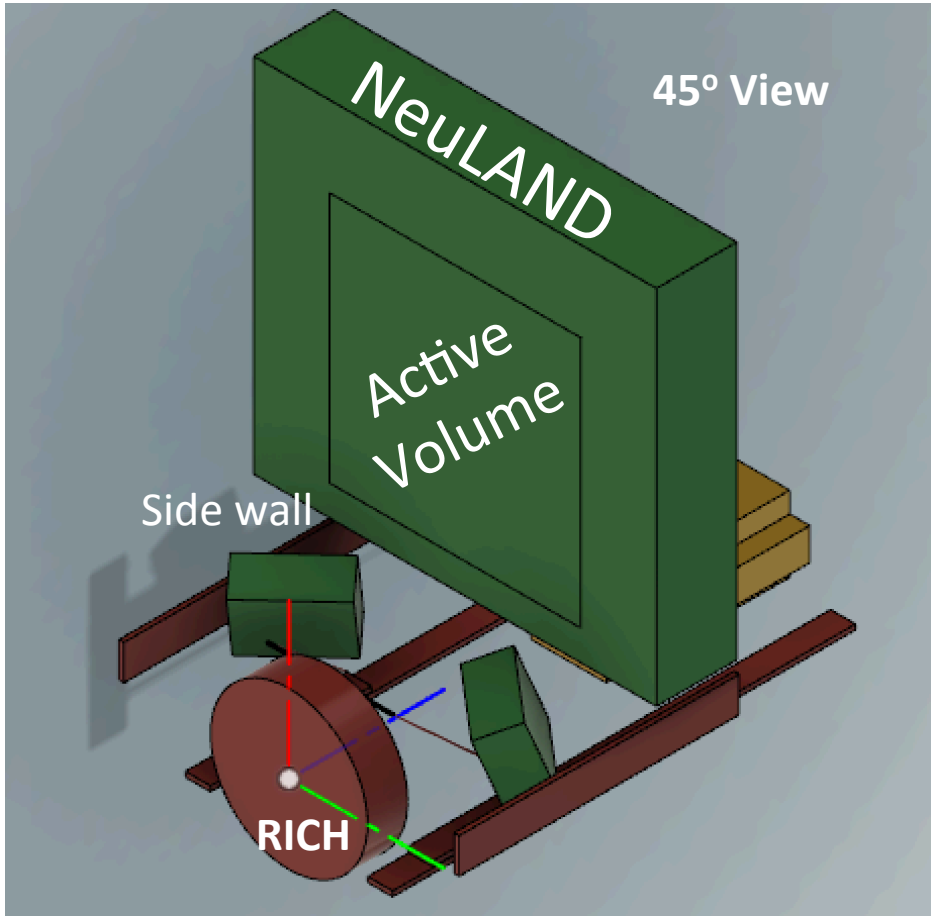
Recoil Detector:

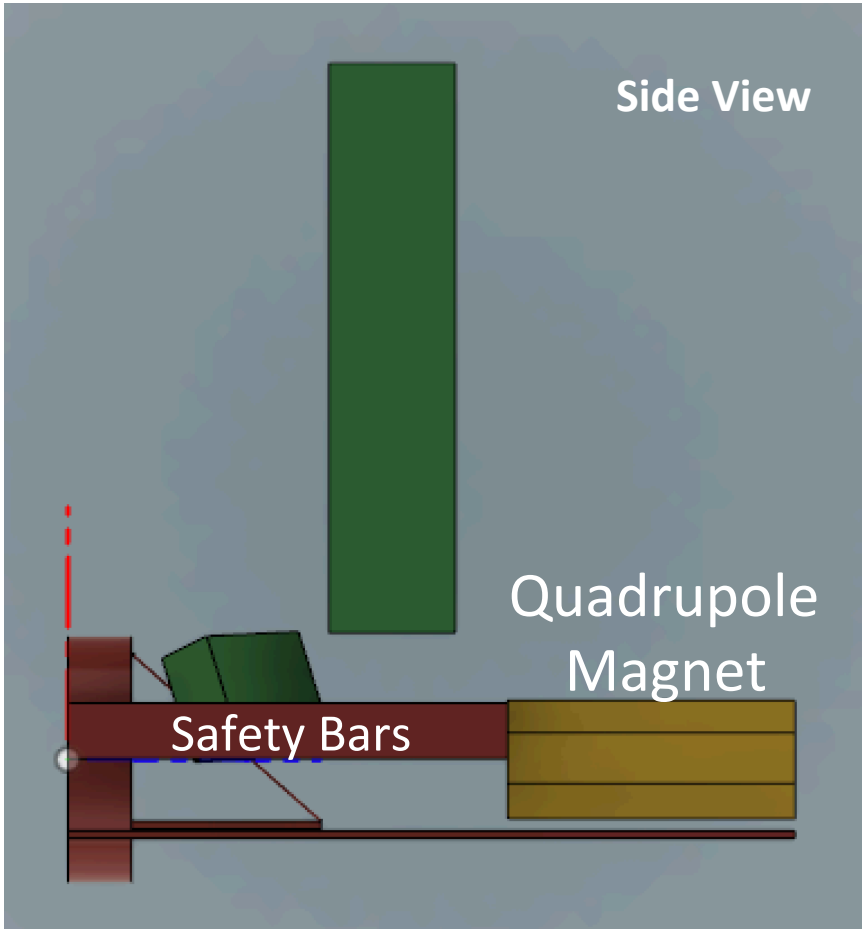
$\Delta\Omega \approx 20\%$ | $\sigma_{TOF} \sim 400$ ps

$E \approx 30 - 50\%$ (neutrons) | $\Delta P/P(500\ MeV/c) < 4\%$

$110^o \leq \theta_{recoil} \leq 160^o$ | $\Delta P(500\ MeV/c) \approx 10 - 20\ MeV/c$

Experimental Setup: Recoil Det.





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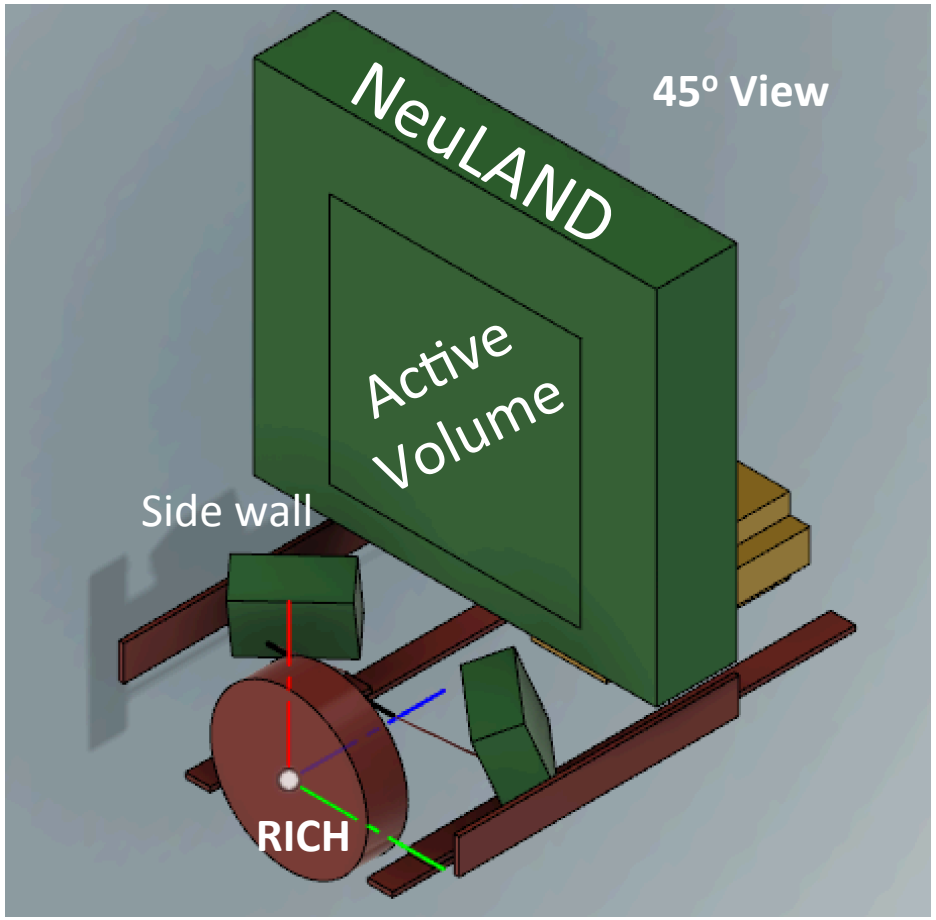


Central wall:

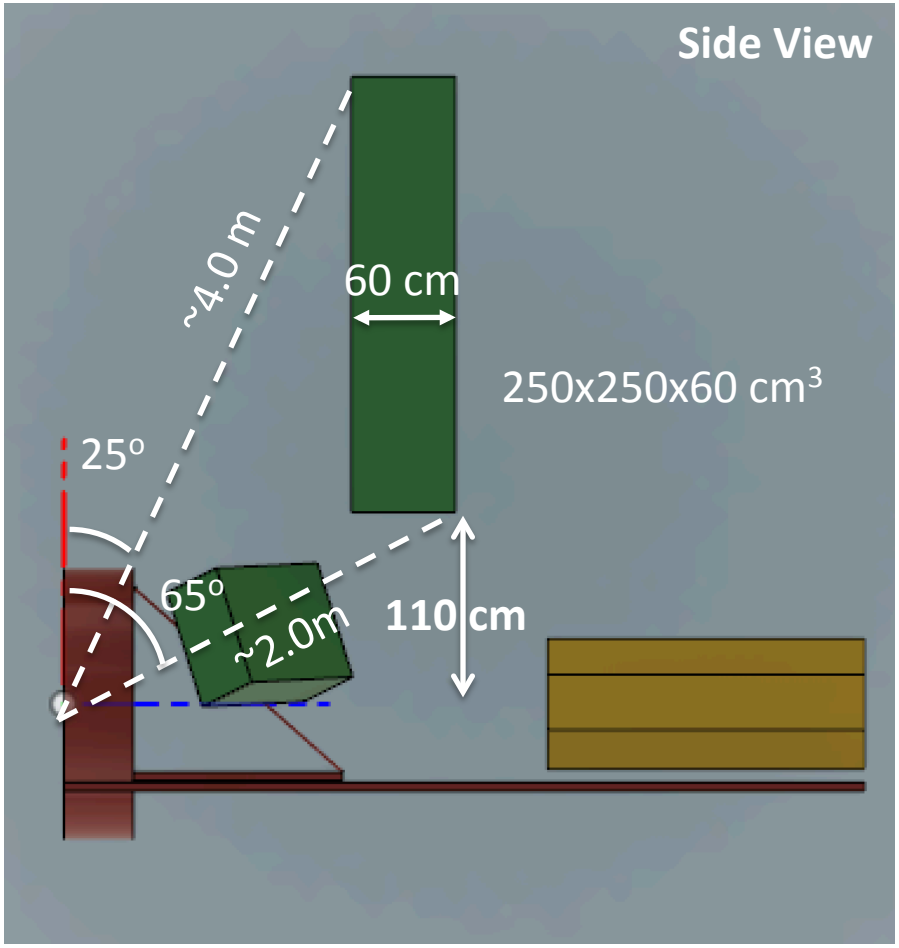
- 6 NeuLAND modules.
- Active volume: 250x250x60 cm^3
- Composed of 250x5x5 cm^3 bars readout using two 1'' PMTs.

Two small side walls (for 3N-SRC search)

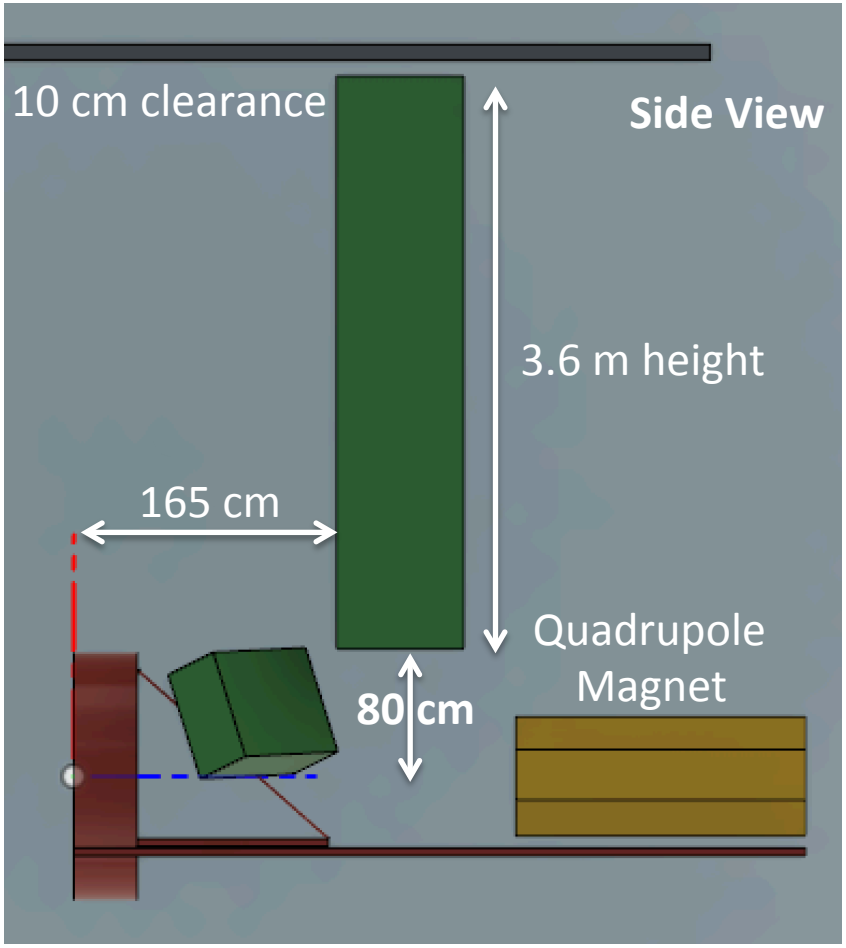
- 8 planes each.
- Active volume: 90x70x40 cm^3
- Composed of 70x5x5 cm^3 bars readout using two 2'' PMTs.

Experimental Setup: Recoil Det.

Active Area

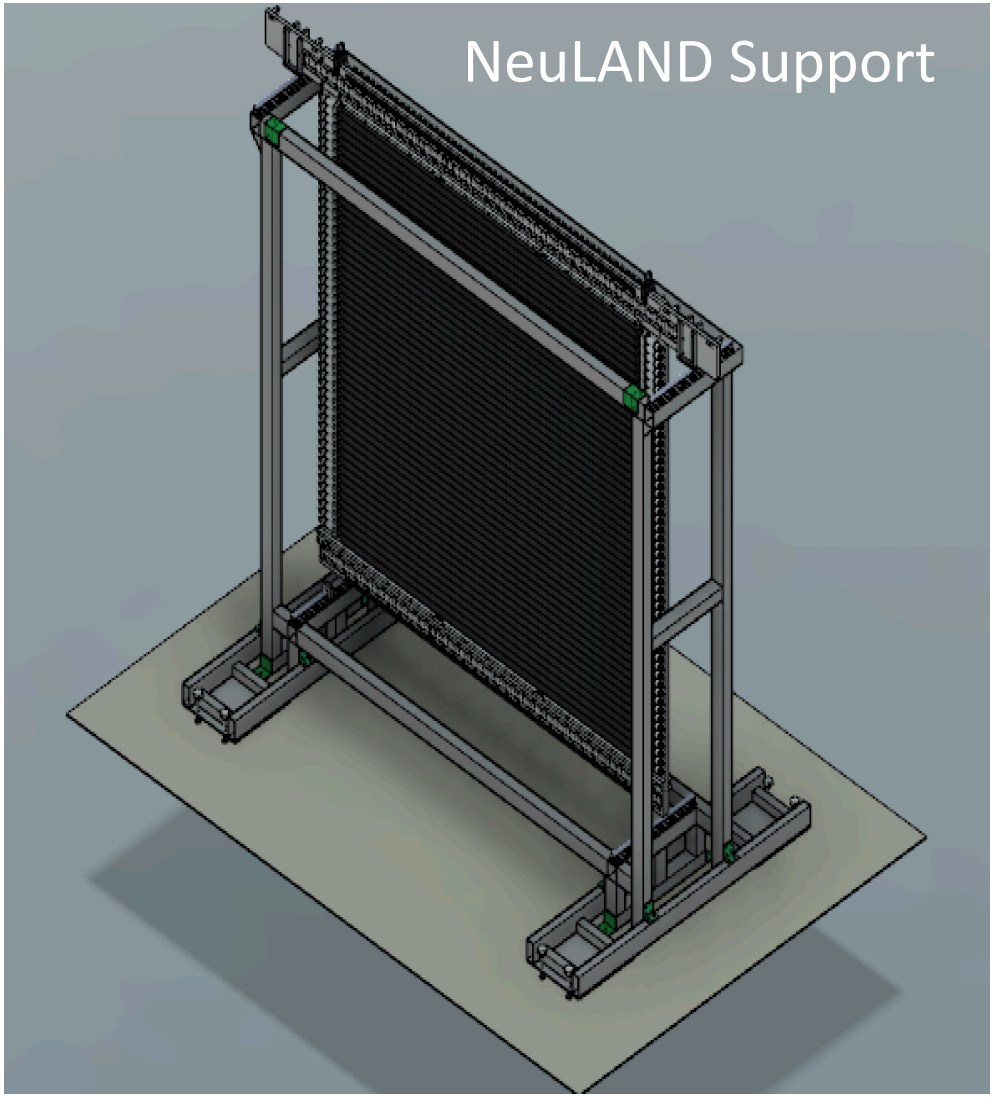


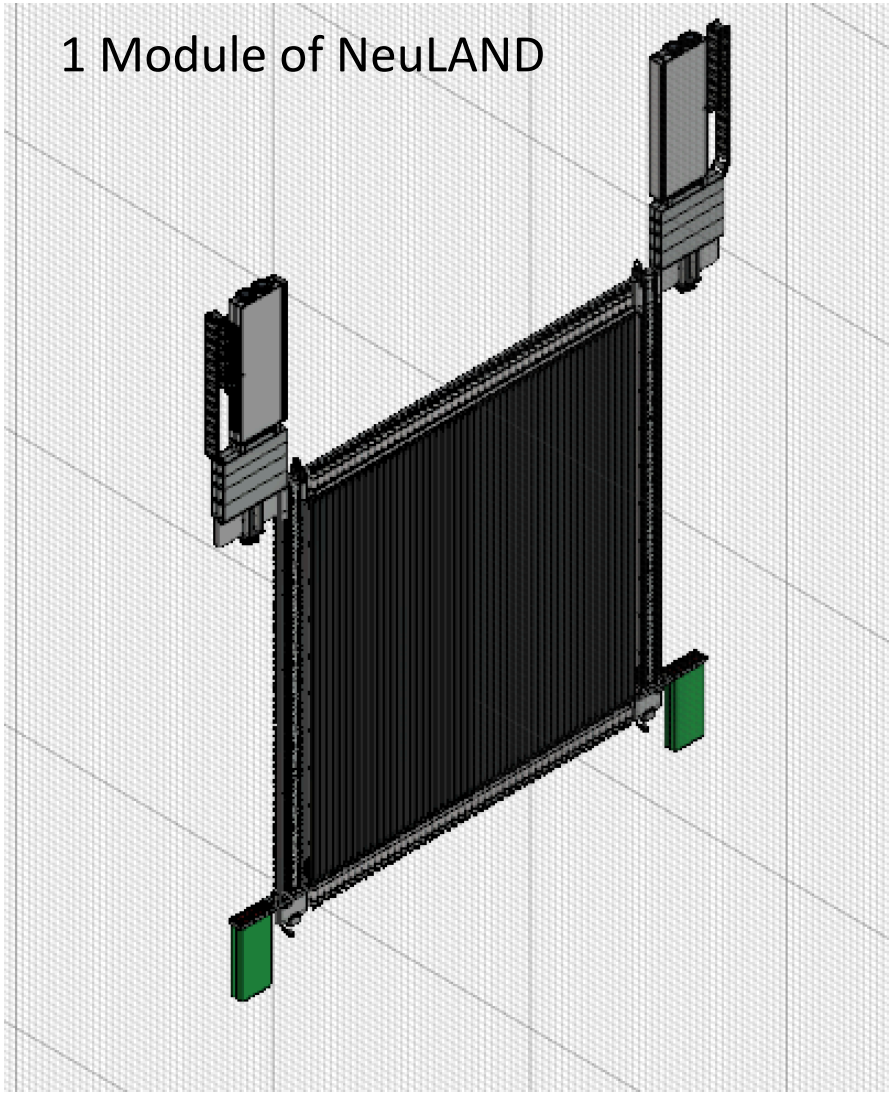
+ support structure



NeuLAND Angular Coverage: 115° – 155°

Experimental Setup: Recoil Det.





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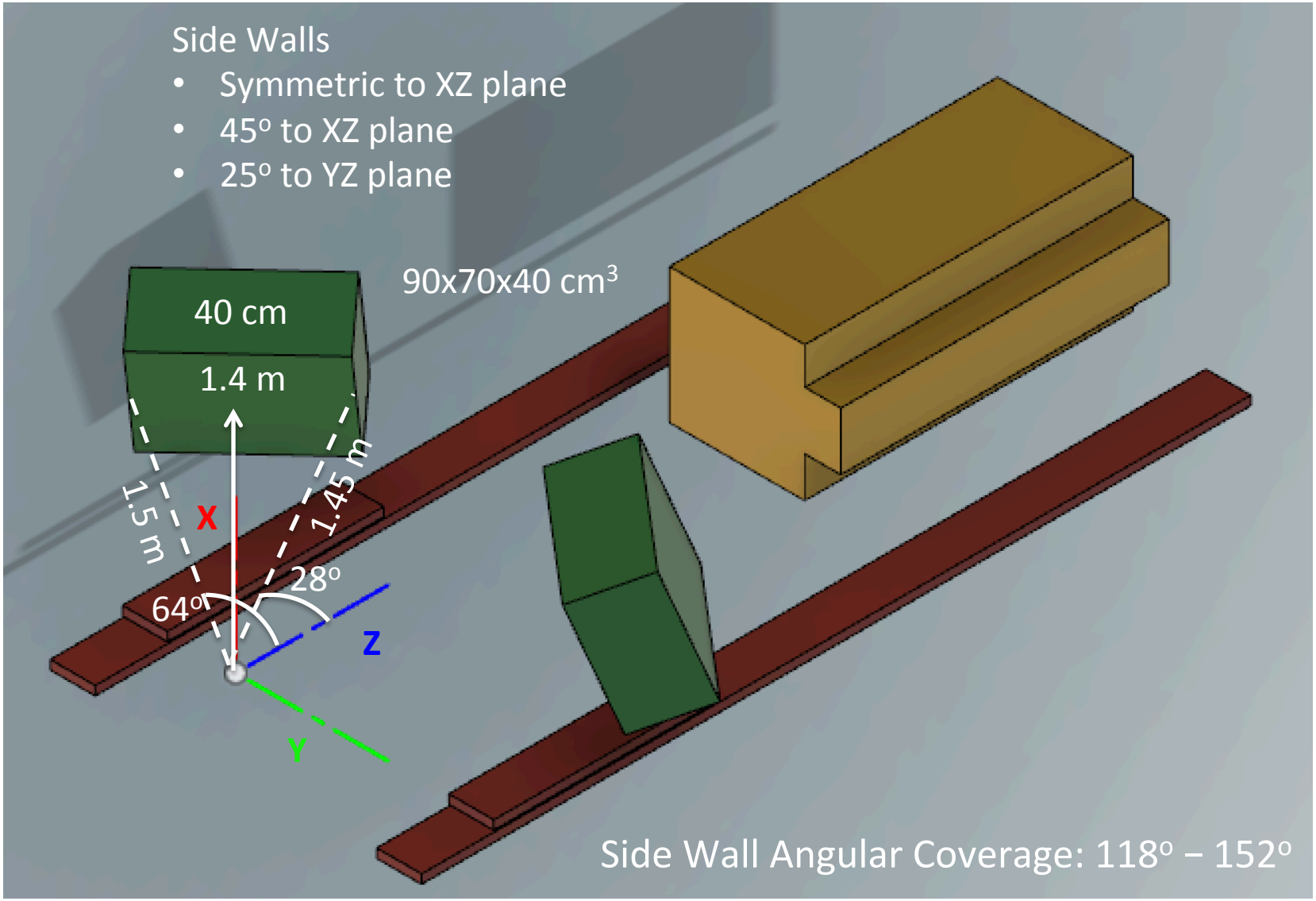

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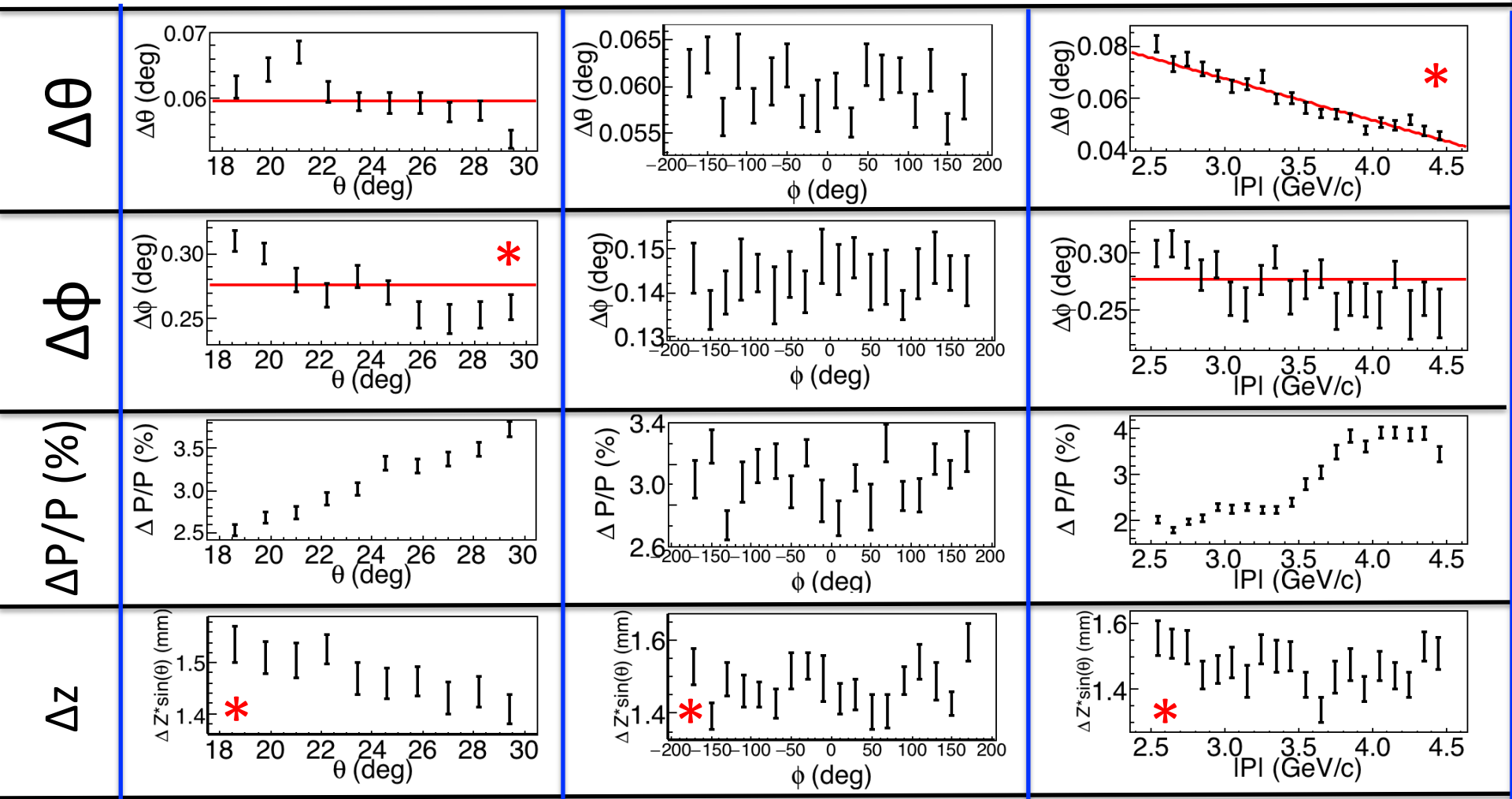
HADES Resolutions

Proton Reconstruction Resolutions as extracted from full HADES GEANT3



θ (deg) ϕ (deg) P (GeV/c)

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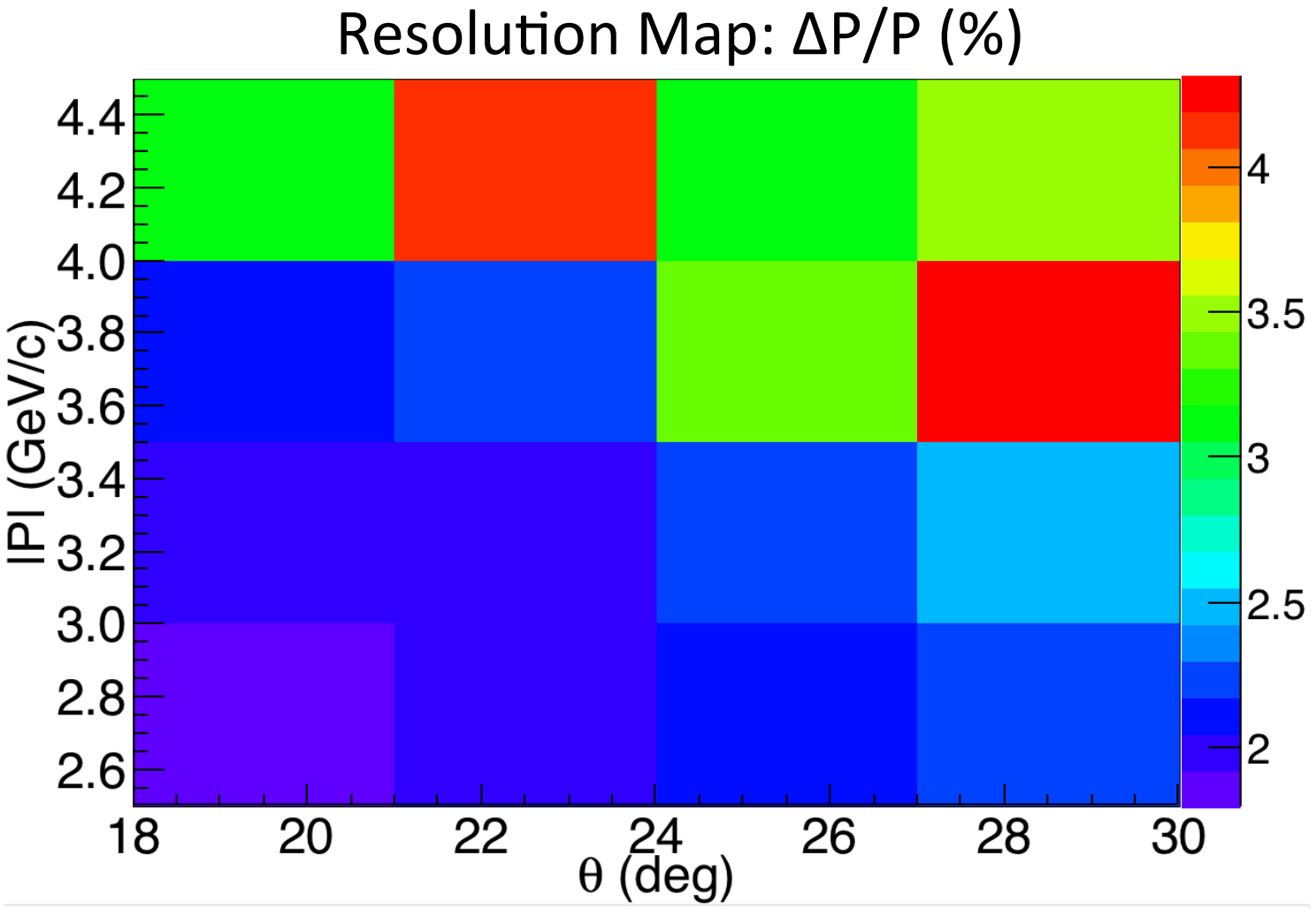
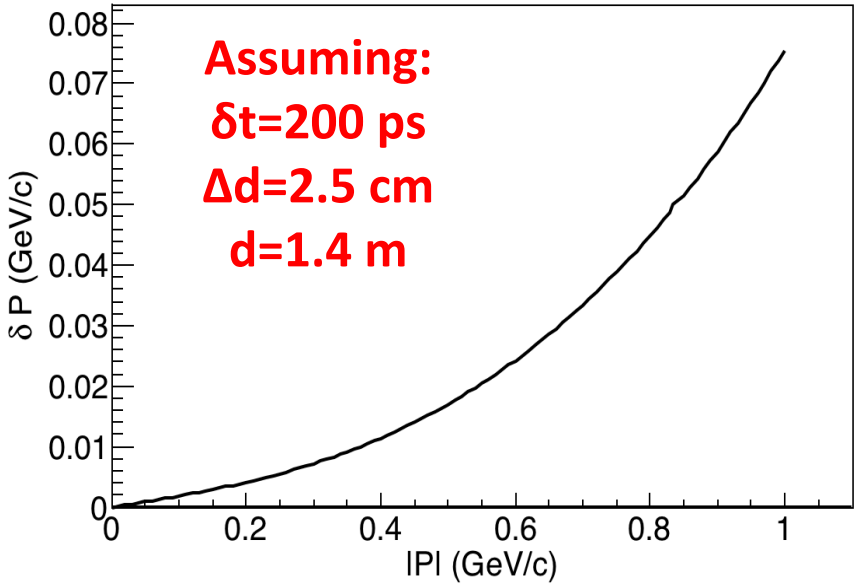
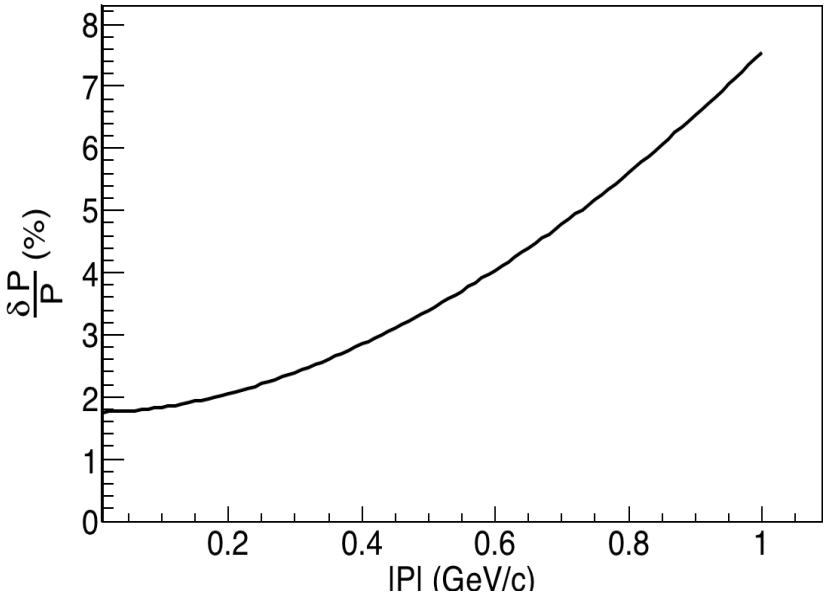
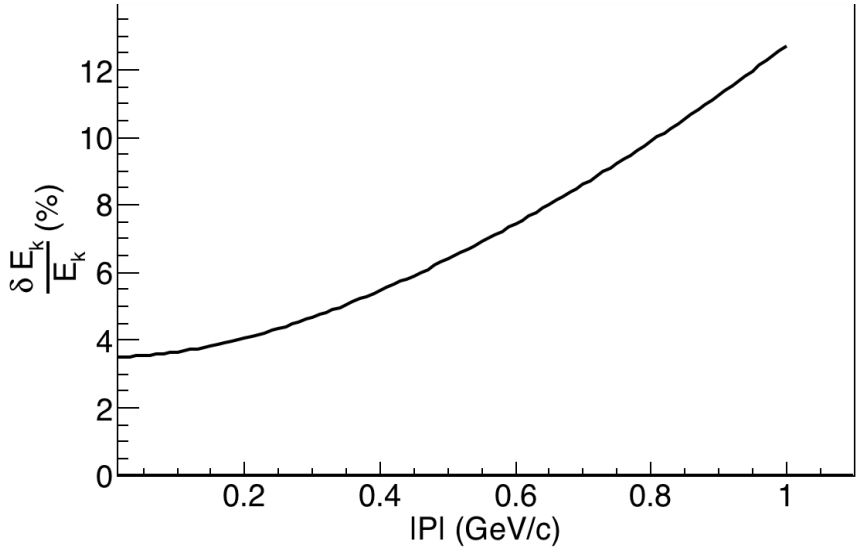
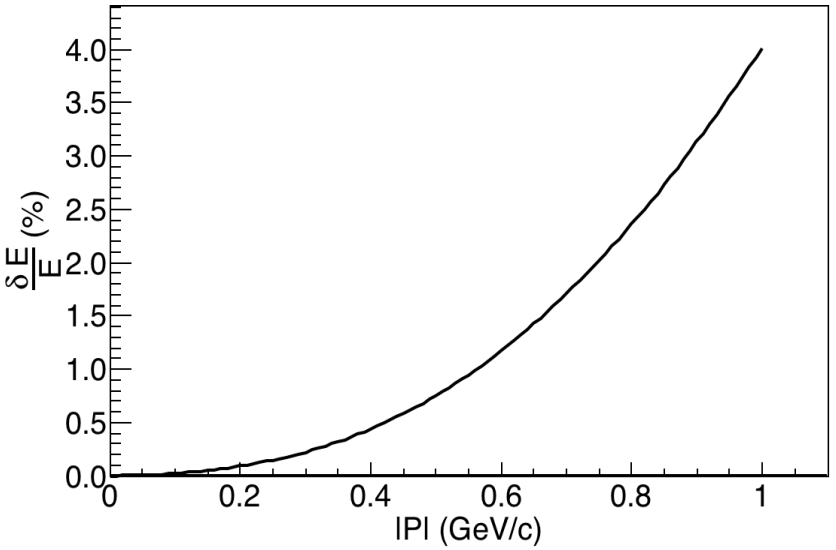


Recoil Detector Resolutions



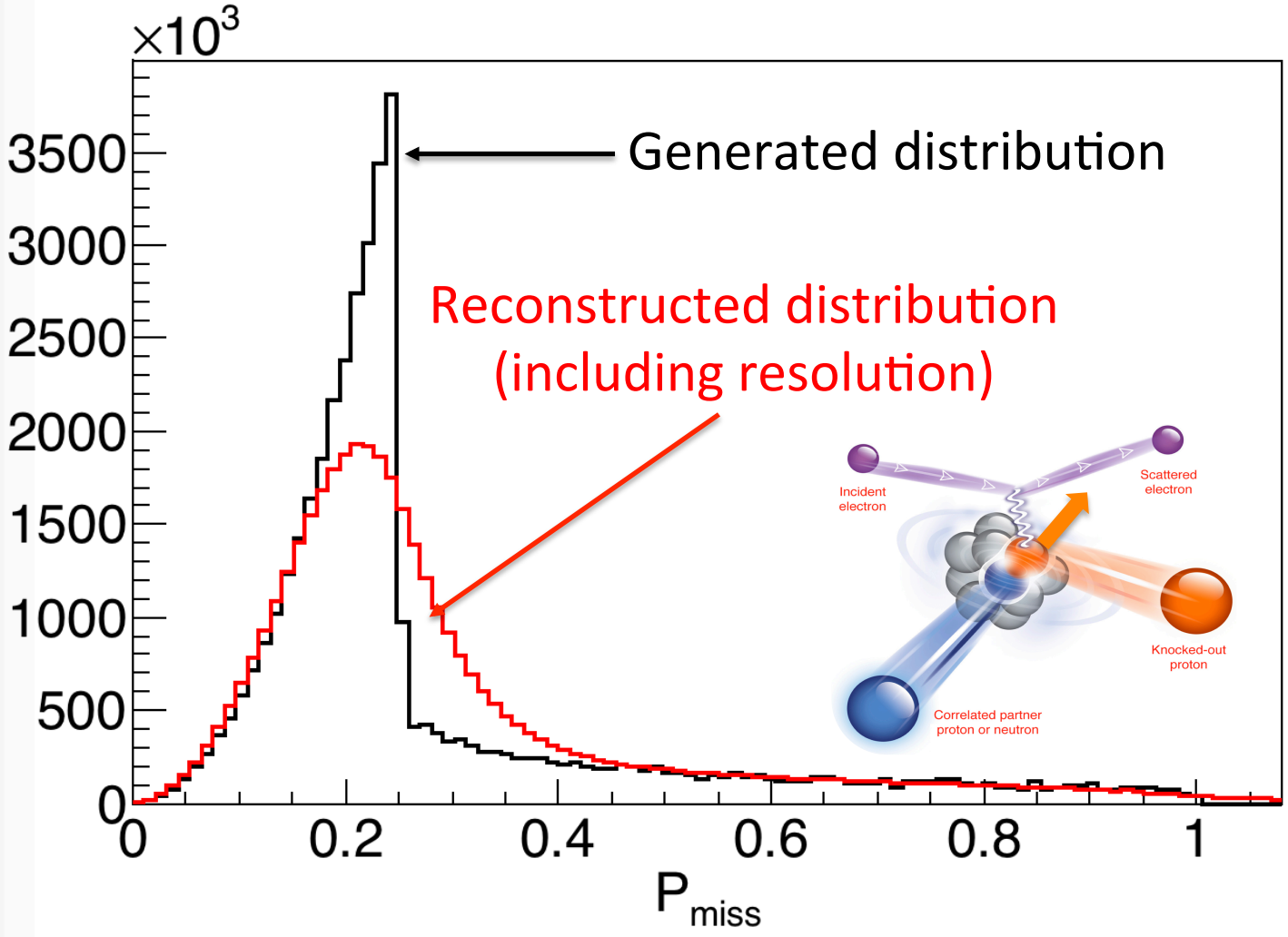






Observables: Missing Momentum

Reconstructed missing momentum distribution



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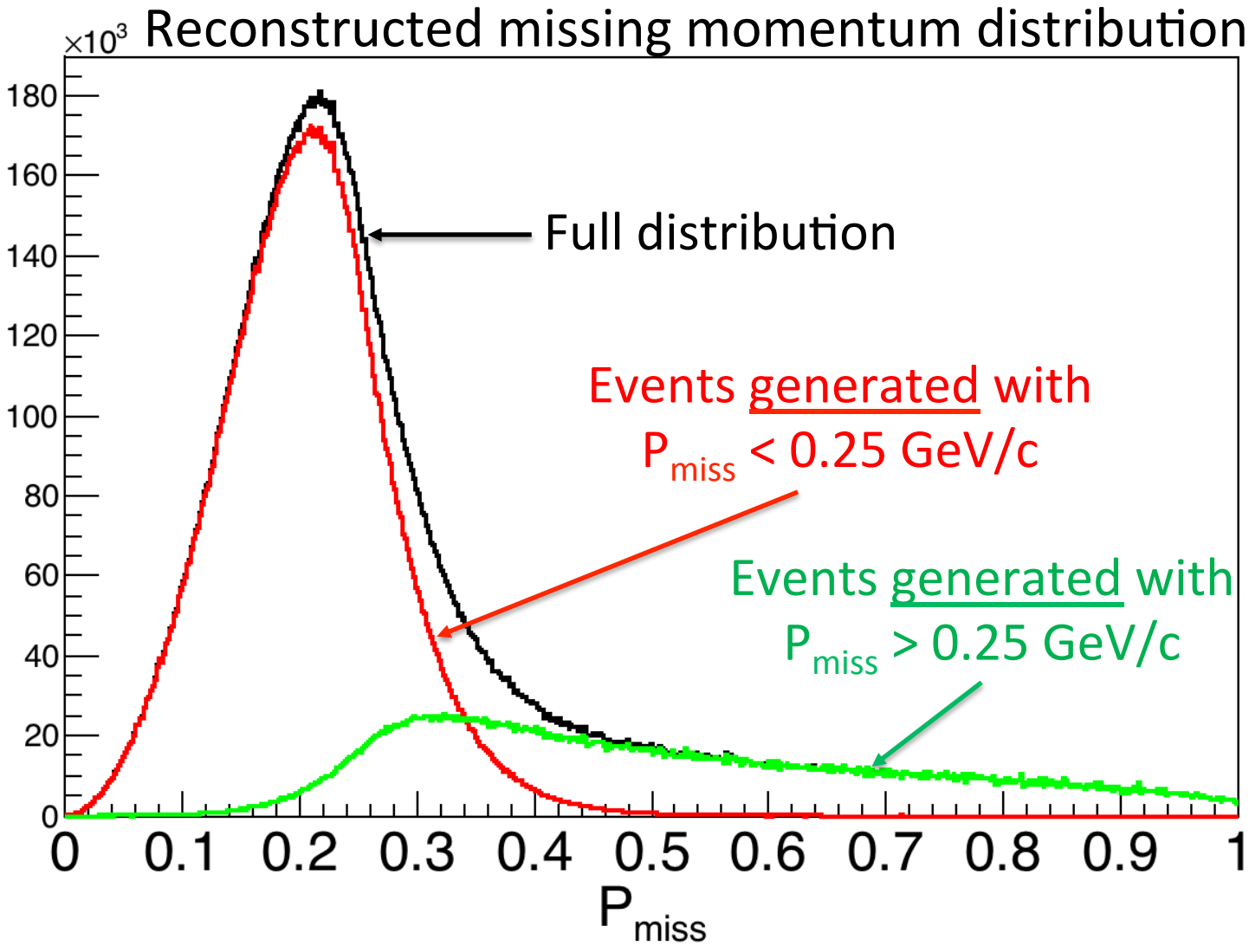

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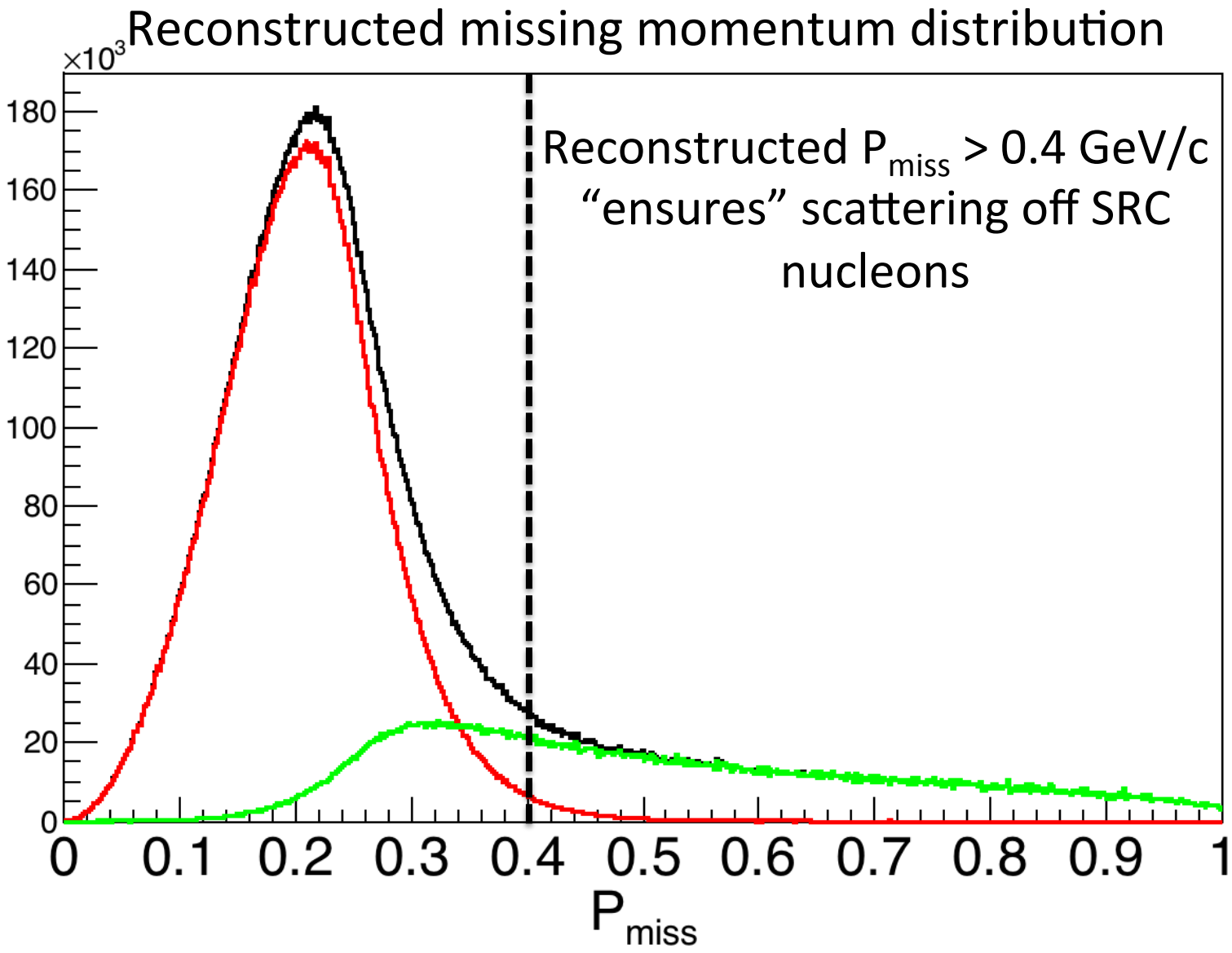
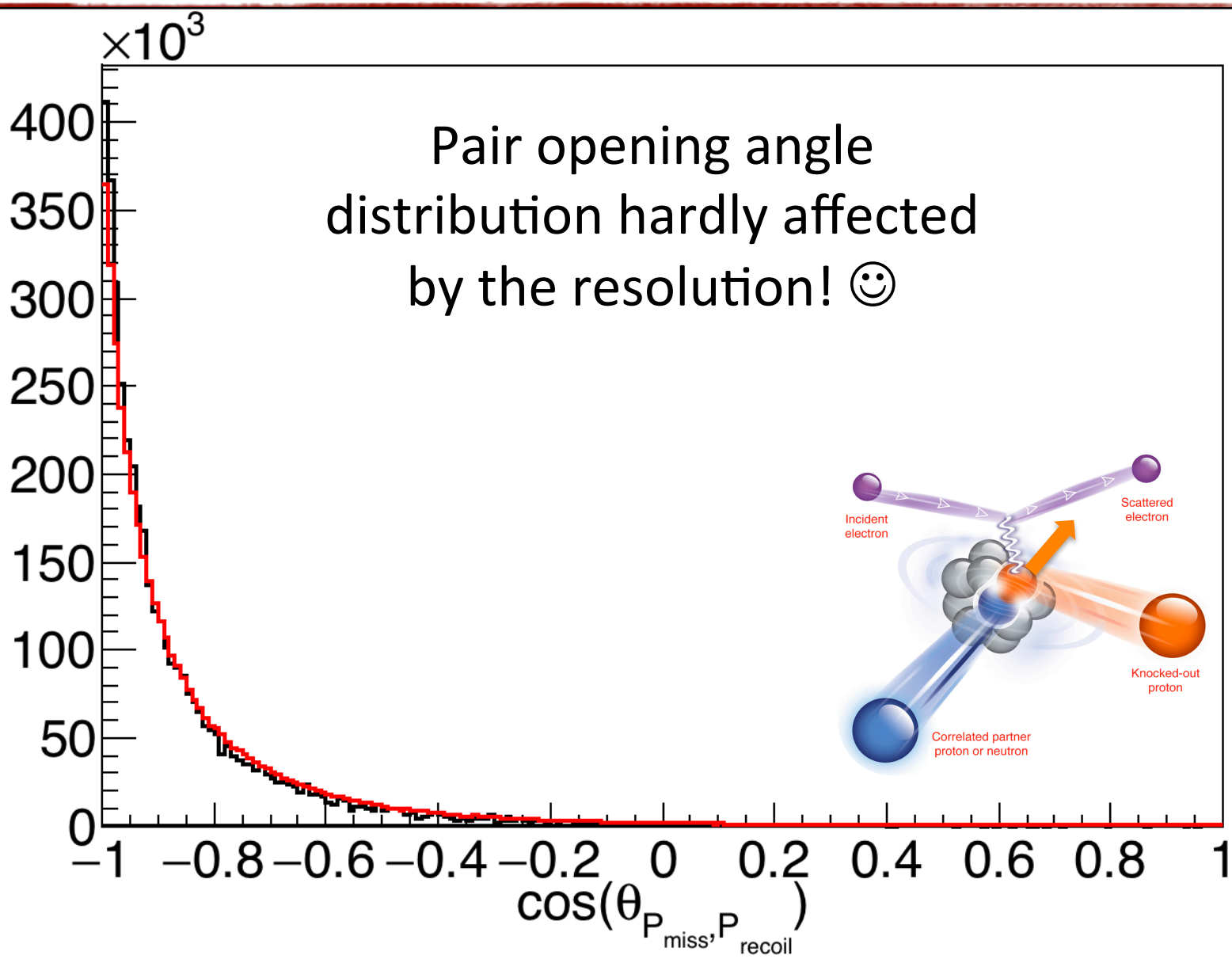


Observables: Pair Opening Angle



Pair opening angle distribution hardly affected by the resolution! ☺

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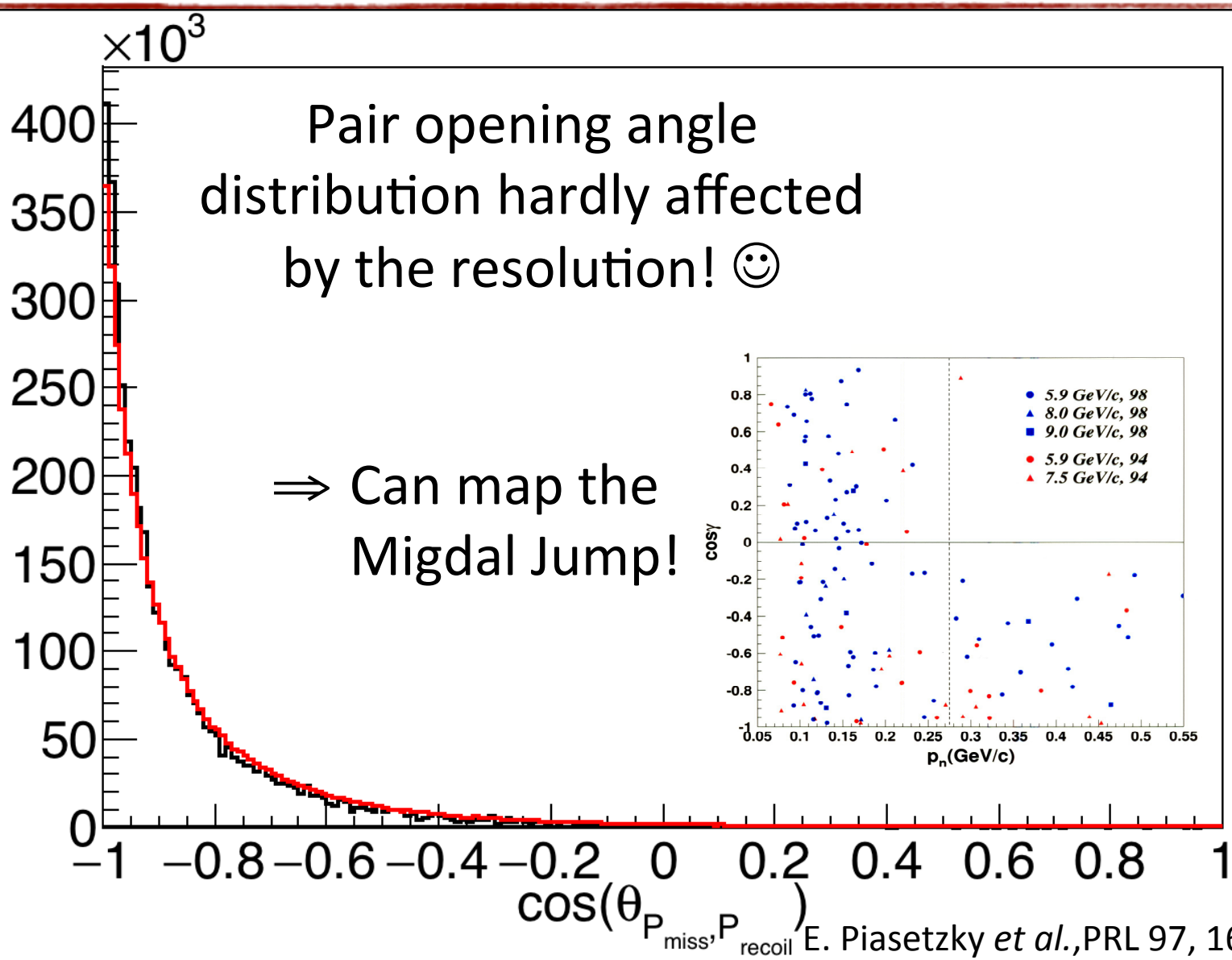
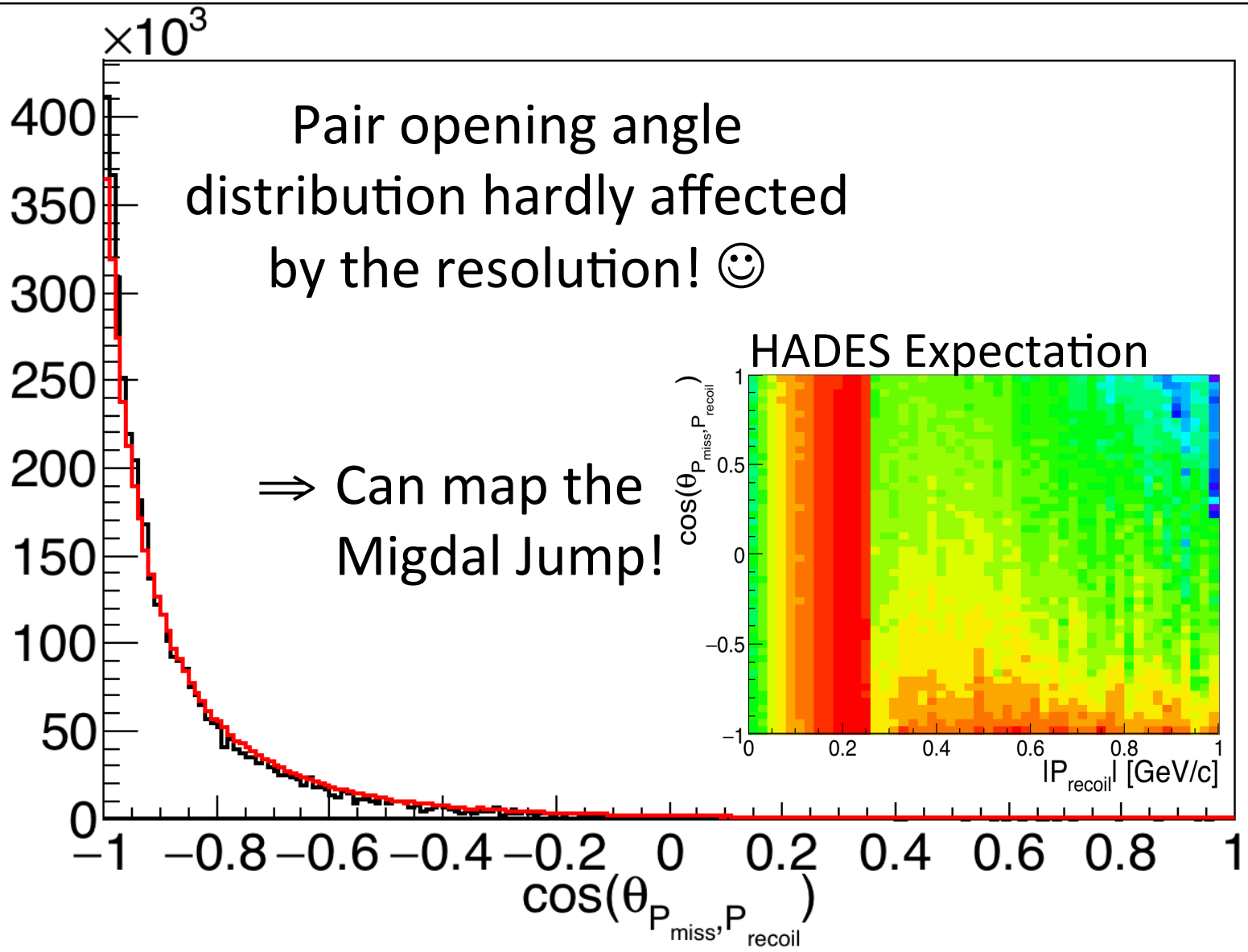


Pair opening angle distribution hardly affected by the resolution! ☺

⇒ Can map the Migdal Jump!

E. Piasetzky *et al.*,PRL 97, 162504 (2006).

Observables: Pair Opening Angle



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SRC@HADES: Two Phases Approach

- **Phase I @ 3.5 GeV:**
  - **Run in parallel to Di-lepton experiment using dedicated trigger**
  - **Recoil detector: NeuLAND only**
  - **Targets: ^{93}Nb, ^{12}C, ^{40}Ca**
  - **RICH in place**
  - **Measure only A(p,2pn) and 3N-SRC: A(2pnn)**
- **Phase II @ 4.5 GeV:**
  - **Run a dedicated SRC experiment**
  - **Recoil detector: NeuLAND + side walls**
  - **Possible Targets: ^{12}C, ^{28}Si, ^{40}Ca, ^{48}Ca, ^{56}Fe, ^{93}Nb, ^{112}Sn, ^{124}Sn, ^{208}Pb**
  - **Remove RICH**
  - **Measure A(p,2pN) and A(p,2p2N)**

Phase I @ 3.5 GeV: Run Plan

- Run in parallel to Di-lepton (p+^{93}Nb) experiment @ 3.5 GeV
- Required trigger condition for Di-lepton experiment at HADES acceptance is multiplicity M ≥ 2
- At 1x10^7 p/s and 2% interaction probability➔

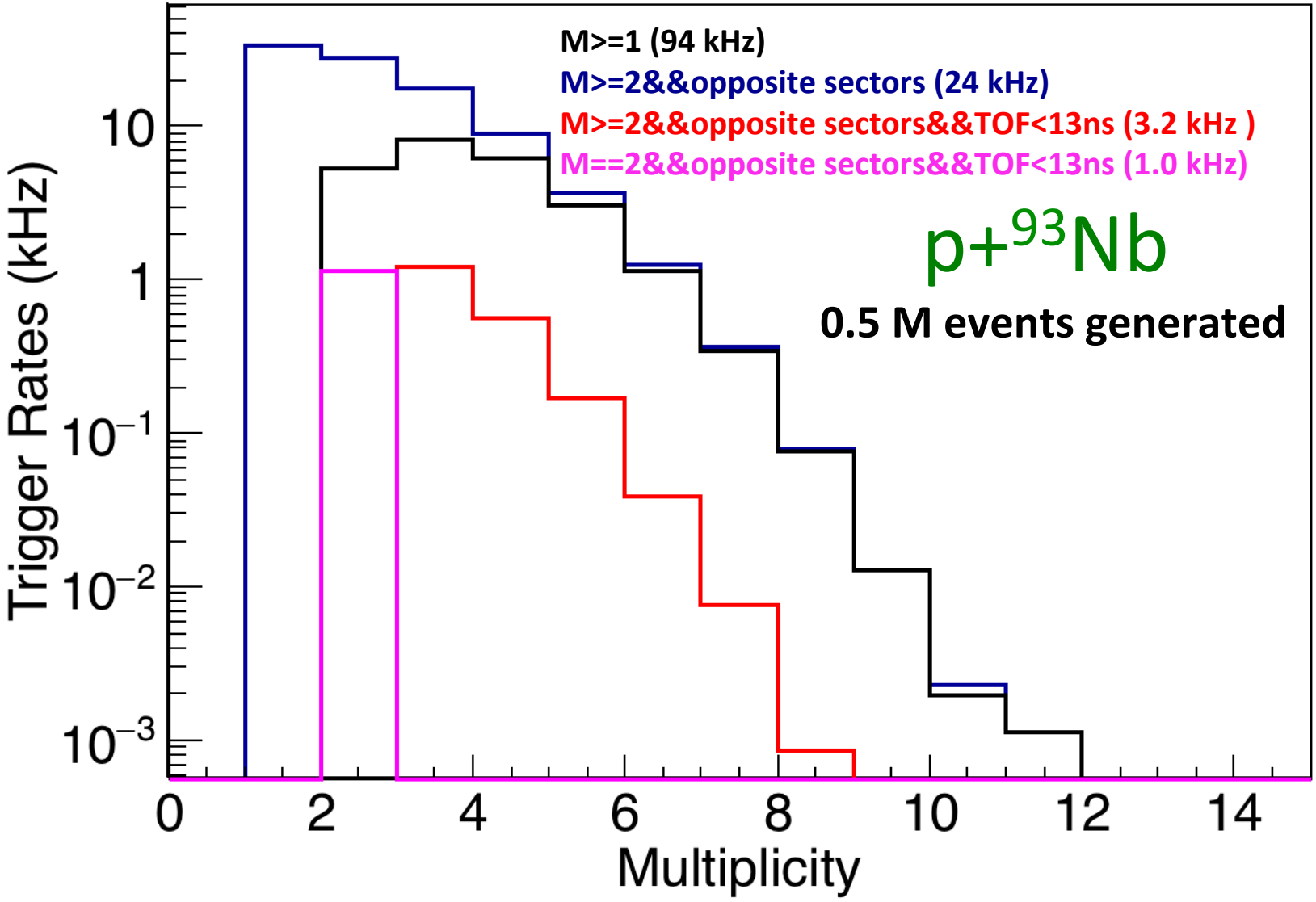
  M ≥ 2 trigger rate is 140 kHz (based on UrQMD)

Phase I @ 3.5 GeV: Run Plan

- A x3 reduction in flux necessary to be within 50 kHz (maximum trigger rate of HADES)

- We propose:
  - keeping $7*10^6$ - $1x10^7$ p/s with a x2 – 3 prescale on the M ≥ 2 trigger.
  - Add dedicated SRC trigger. No prescale. Up to 5 kHz.

Dedicated Trigger for SRC@ 3.5 GeV



Targets

Two options to have some 'A-dependence' study:

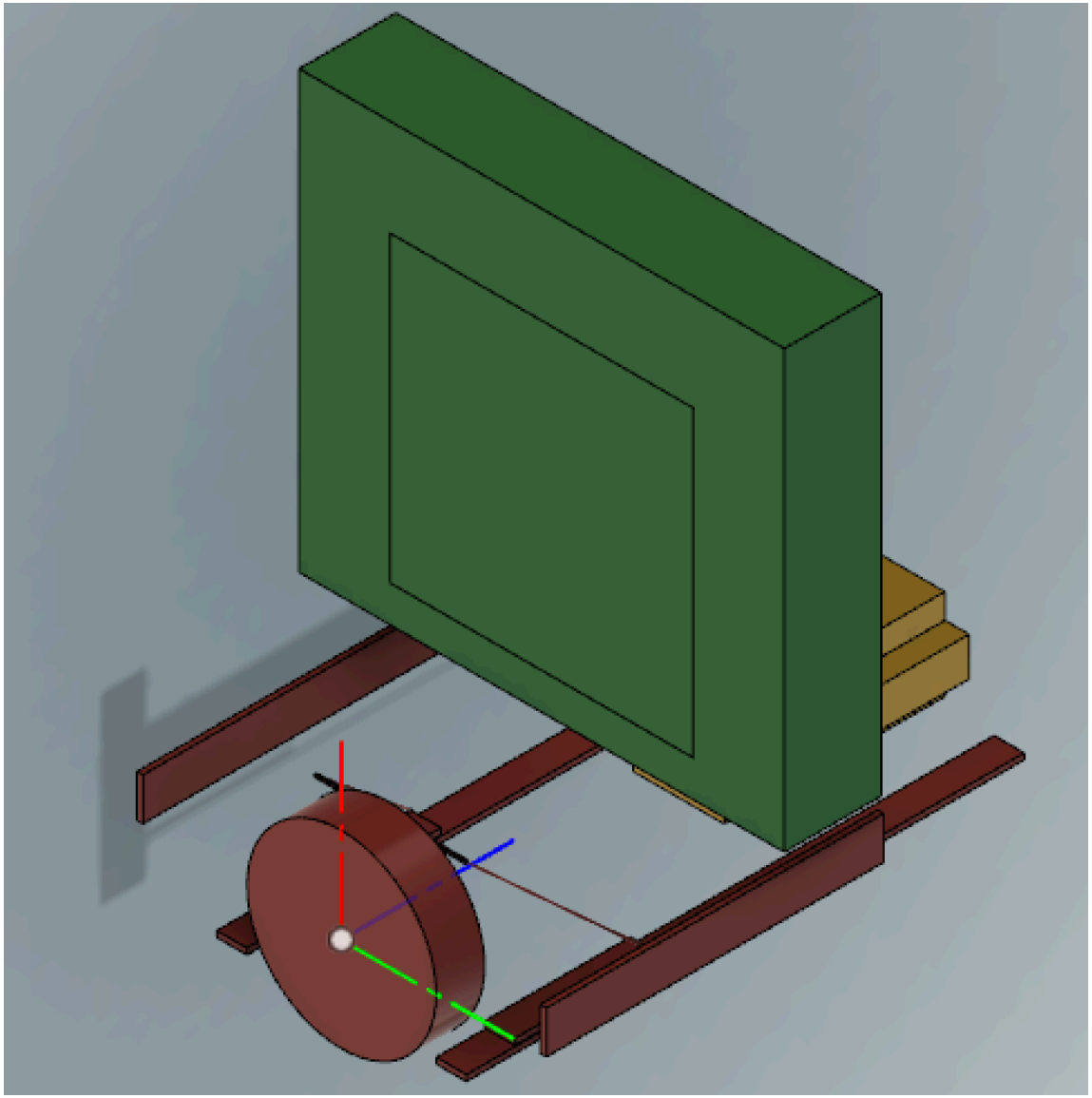
- Instead of 10 ^{93}Nb foils, use 8 ^{93}Nb foils, 1 ^{12}C foil and 1 ^{40}Ca
- Change target array towards the end of the run to ^{12}C + ^{40}Ca foils

Targets	Target Thickness (gr/cm^2)	Interaction Probability (%)
^{12}C	0.17	0.2
^{40}Ca	0.25	0.2
^{93}Nb	2.7	1.6

Experimental Setup: Recoil Det.

For Phase I:

- RICH in place
- use NeuLAND only

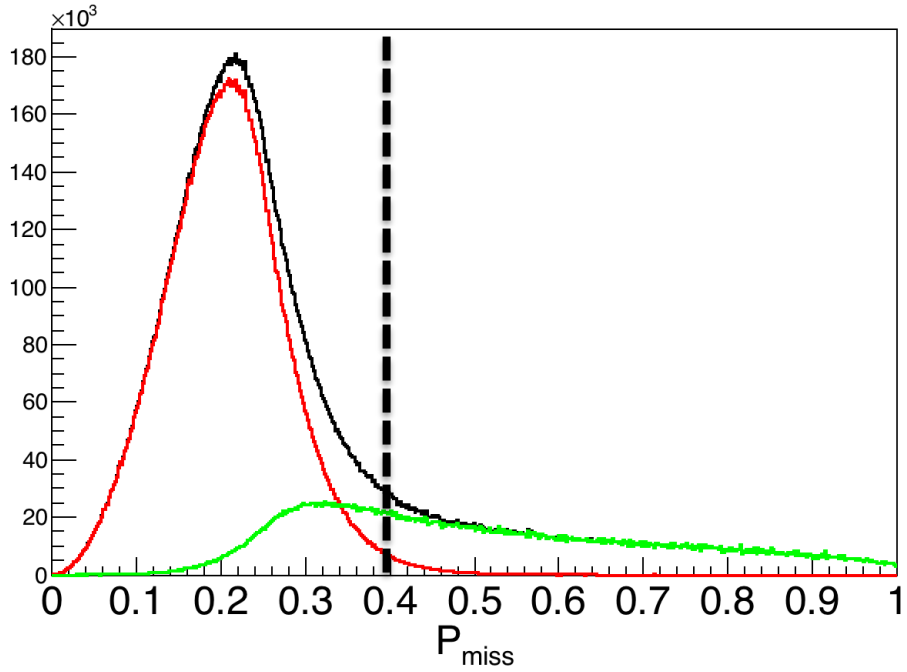


Rate Estimate: Parameters

Parameters	Values
Target Thickness	10^{24} protons/cm^2
Beam flux	7x10^6 p/sec
Time	4 weeks
Duty cycle	100%
Target Transparency	0.35*0.35
Neutron Efficiency	0.4
Acceptance	0.3(2p) x 0.15(n)
Other things	0.1

Cuts and Rates @ 3.5 GeV

Quantities	Cuts
θ_{cm}	$80^o<\theta_{cm}<100^o$
θ_{lab} for P_1 and P_2	$18^o<\theta_{lab}<30^o$
$\Delta\varphi_{lab}=\lvert\varphi 1-\varphi 2\rvert$ of P_1,P_2	$170^o<\Delta\phi_{lab}<190^o$
s,t,u	>2 GeV^2
P_{miss}	P_{miss}>0.40 GeV/c



For Phase I, the expected total number of events is:

- **np-SRC via ^{93}Nb(p,2pn): 8,000 events.**
- **np-SRC via ^{12}C (p,2pn) and ^{40}Ca(p,2pn): 1,000 events**.

SRC@HADES: Two Phases Approach

- Phase I @ 3.5 GeV:
  - Run in parallel to Di-lepton experiment using dedicated trigger
  - Recoil detector: NeuLAND
  - Targets: ^{93}Nb, ^{12}C, ^{40}Ca
  - RICH in place
  - Measure only A(p,2pn) and 3N-SRC: A(2pnn)
- **Phase II @ 4.5 GeV:**
  - **Run a dedicated SRC experiment**
  - **Recoil detector: NeuLAND + side walls**
  - **Possible Targets:** ^{12}C, ^{28}Si, ^{40}Ca, ^{48}Ca, ^{56}Fe, ^{93}Nb, ^{112}Sn, ^{124}Sn, ^{208}Pb
  - **Remove RICH**
  - **Measure A(p,2pN) and A(p,2p2N)**

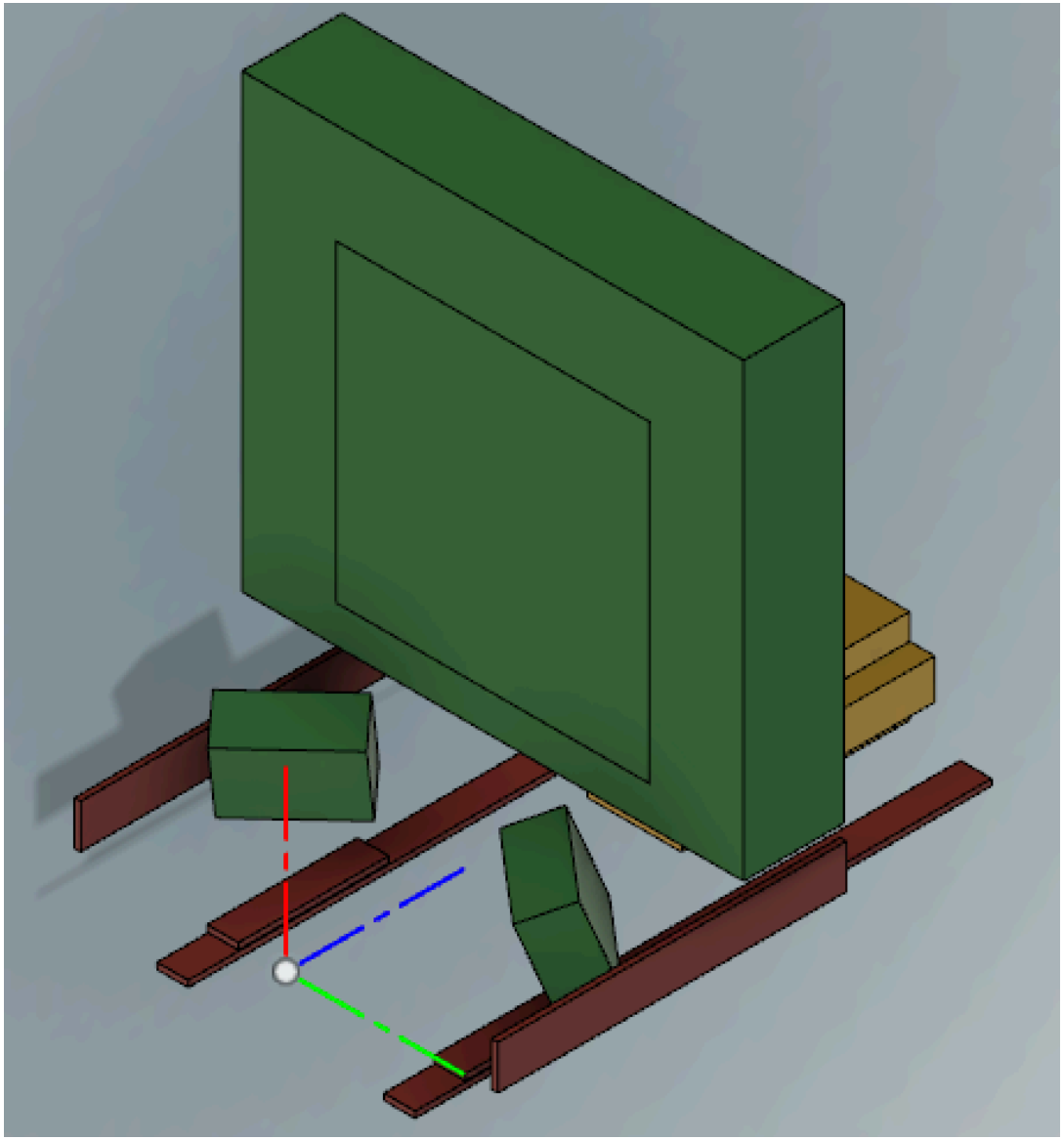
Phase II: Run Plan

- SRC run with dedicated trigger: M ≥ 2 && opp. sect. && $TOF_{1,2}$ <13 ns
- Recoil detector: NeuLAND and small side walls
- For the measurement of recoil protons, RICH detector has to be removed
- Up to five different targets will be used including symmetric and asymmetric nuclei

Experimental Setup: Recoil Det.

For Phase II:

- Remove RICH
- NeuLAND+side walls

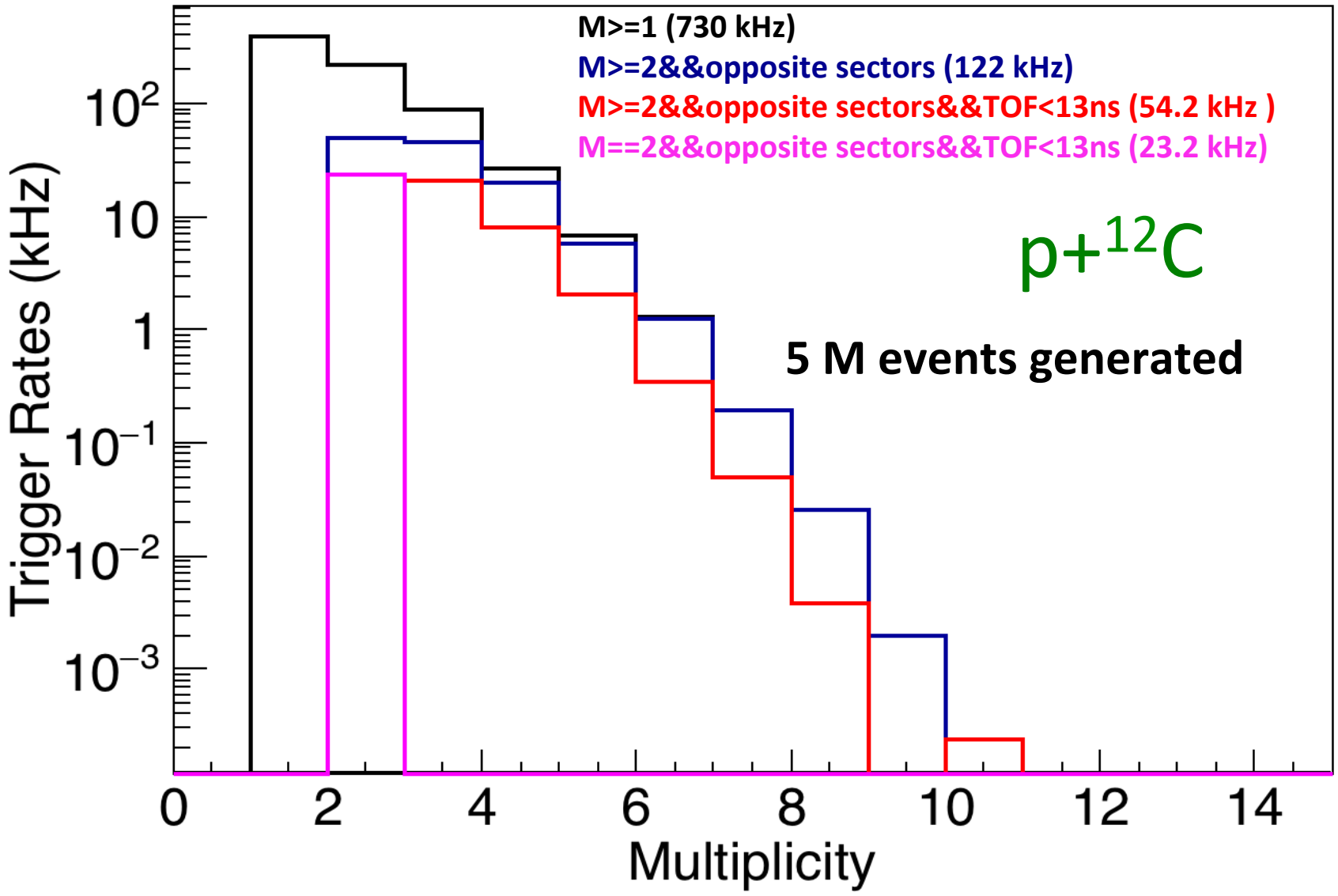


Possible Targets

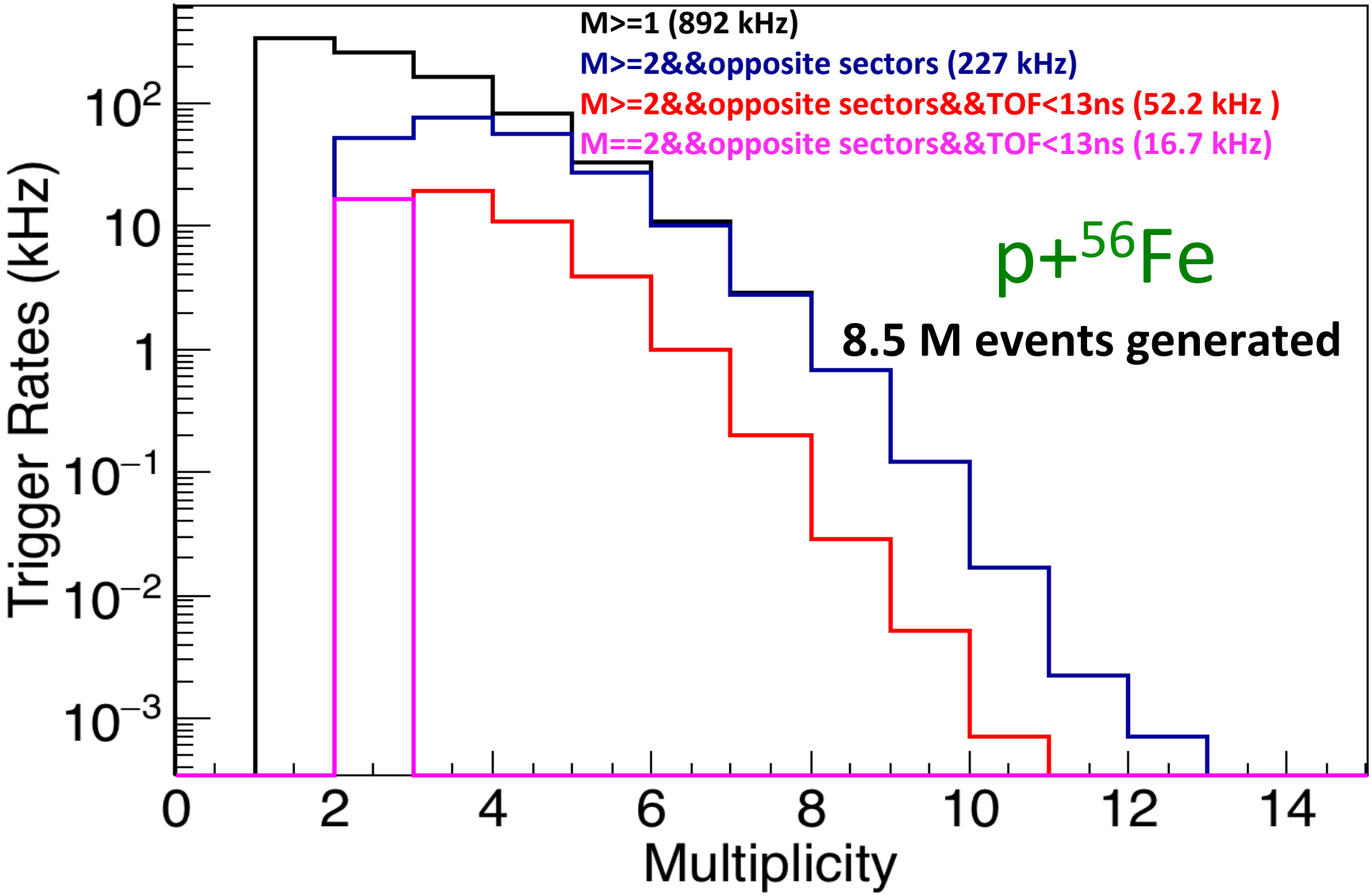
Possible Targets	Target Thickness (gr/cm^2)
^{12}C	1.7
^{28}Si	2.2
^{40}Ca	2.5
^{48}Ca	2.7
^{56}Fe	2.8
^{93}Nb	3.3
^{112}Sn	3.5
^{124}Sn	3.7
^{208}Pb	4.4

Interaction probability 2%

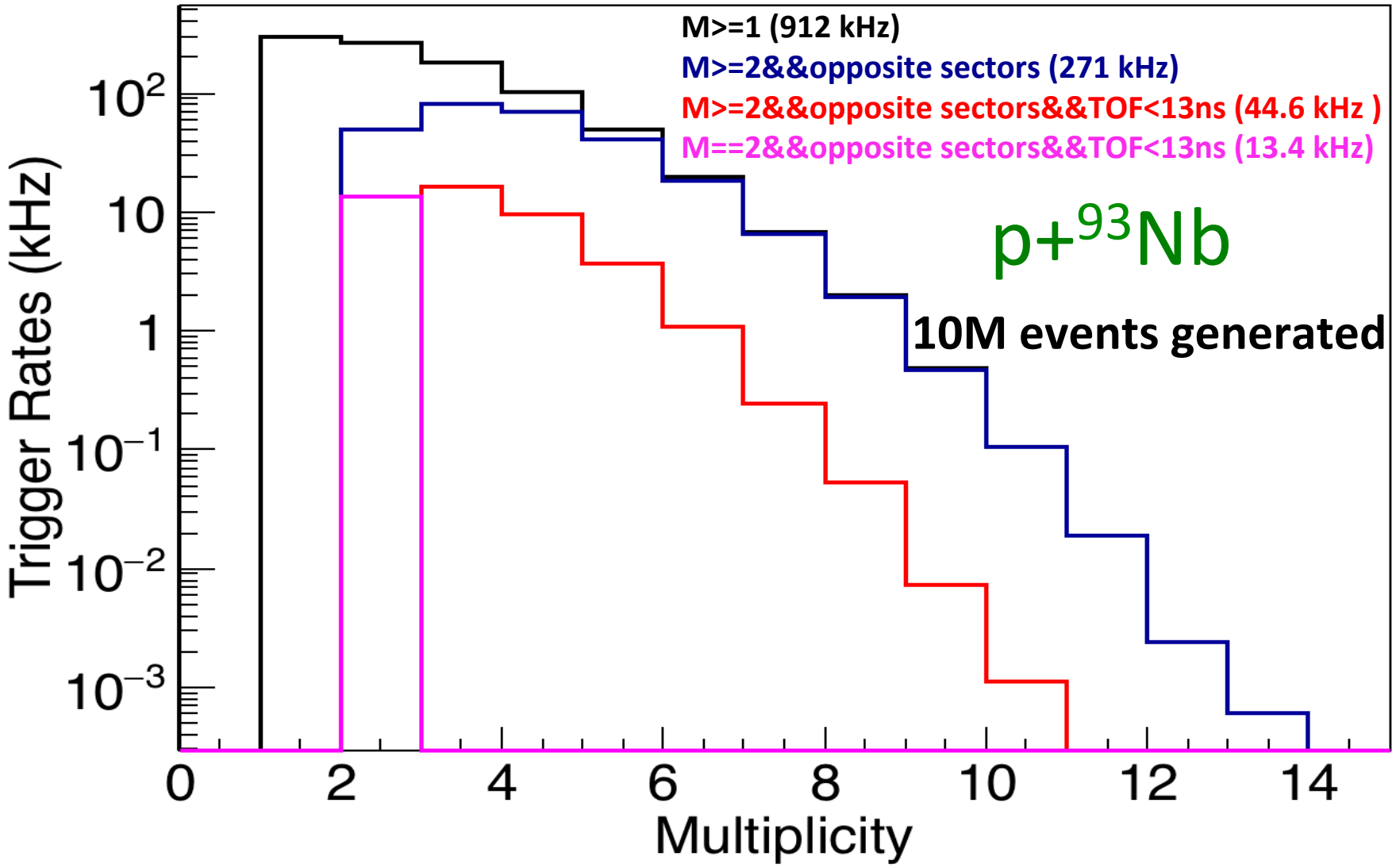
Trigger Rates for ^{12}C @ 4.5 GeV



Trigger Rates for ^{56}Fe @ 4.5 GeV



Trigger Rates for ^{93}Nb @ 4.5 GeV

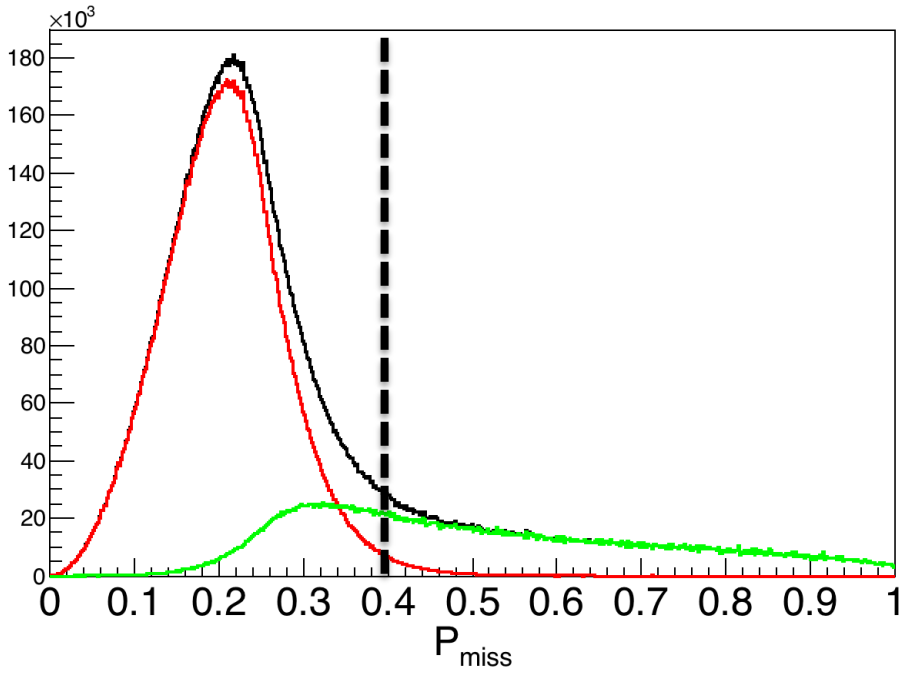


Rate Estimate: Parameters

Parameters	Values
Target Thickness	10^{24} protons/cm^2
Beam flux	6x10^7 p/sec
Time	4 weeks
Duty cycle	50%
Target Transparency	0.35*0.35
Neutron Efficiency	0.4
Acceptance	0.75(2p) x 0.3(n)
Other things	0.1

Cuts and Rates @ 4.5 GeV

Quantities	Cuts
θ_{cm}	$80^o<\theta_{cm}<100^o$
θ_{lab} for P_1 and P_2	$18^o<\theta_{lab}<30^o$
$\Delta\varphi_{lab}=\lvert\varphi 1-\varphi 2\rvert$ of P_1,P_2	$170^o<\Delta\phi_{lab}<190^o$
s,t,u	>2 GeV^2
P_{miss}	P_{miss}>0.40 GeV/c



For Phase II, the expected total number of events per target (5 targets) is:

- **np-SRC via. A(p,2pn): 10,000 events.**
- **pp-SRC via. A(p,2pp): 4,000 events.**

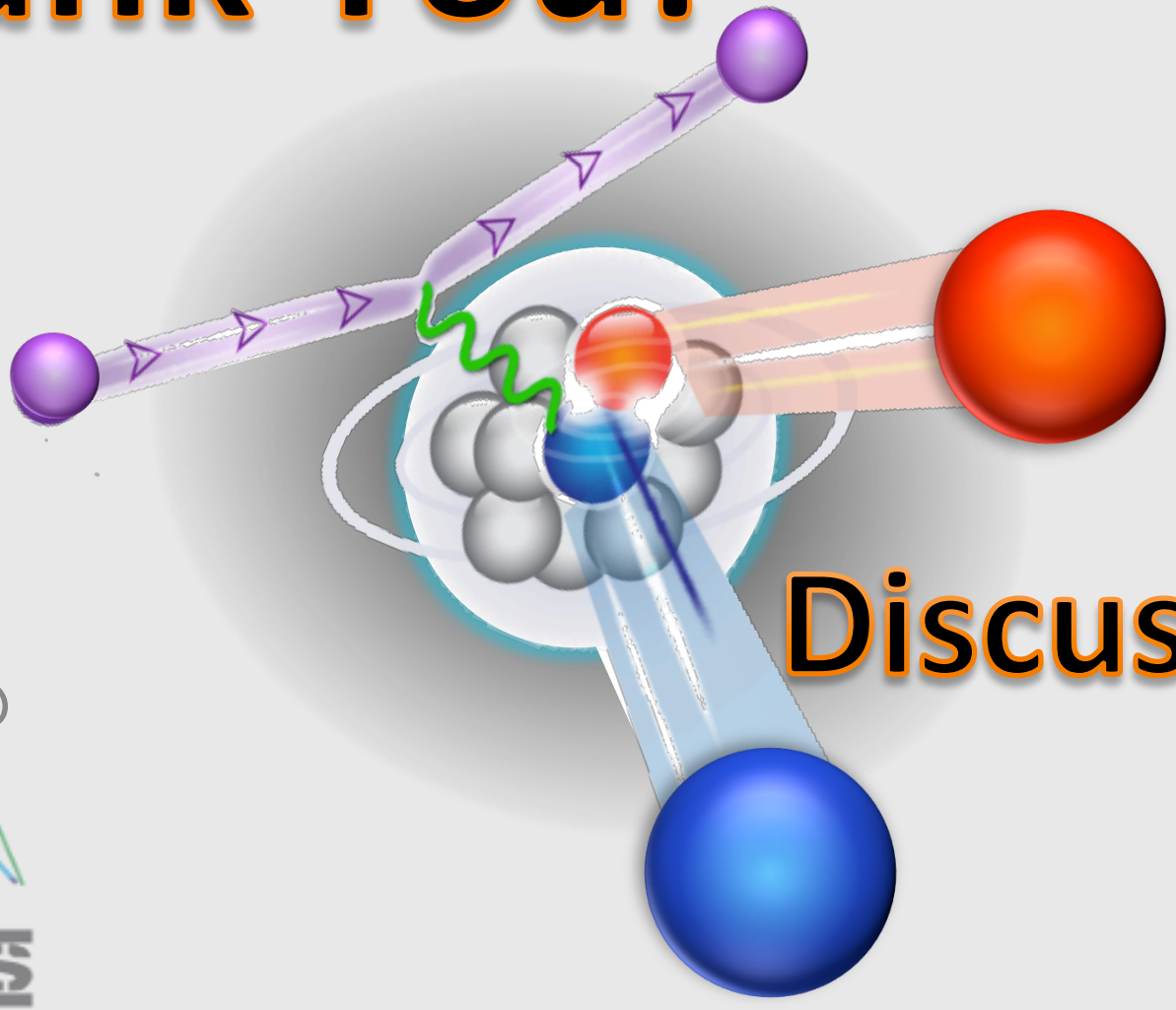
Outline

- ✓ SRC Kinematics 101
- ✓ Proposed experimental setup
- ✓ Resolutions and observables
- ✓ Expected Rates for Phase I and II
- **Conclusions**

Conclusions

- HADES combined with a new recoil detector can measure for first time thousands of 2N and 3N-SRC pairs
- NeuLAND ideal for being the main part of the new recoil detector
- Essential to execute the experiment in two phases:
  - Phase I: SRC experiment in parallel to Di-lepton program acquiring few thousands of events on 3 different targets measuring only neutrons
  - Phase II: Dedicated SRC experiment acquiring events on several targets measuring both recoil neutrons and protons

Thank You!



Discussion…

SRC @ HADES

Benchmark with 3.5 GeV (p,2p) **DATA**

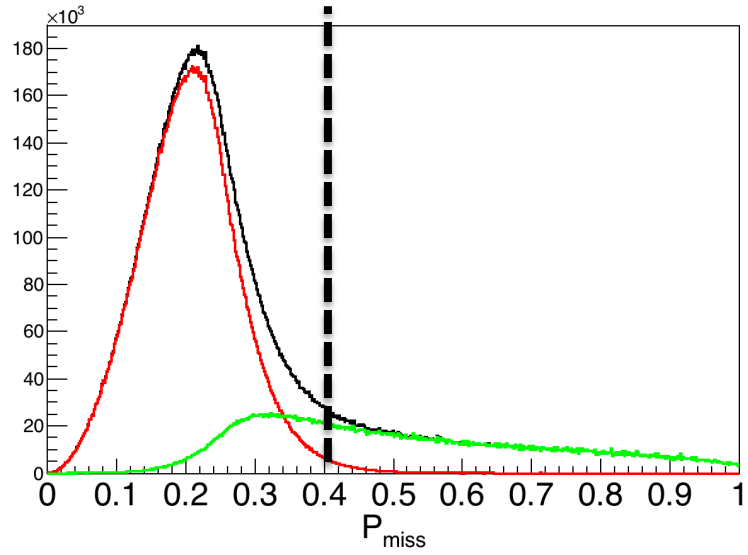
Our Goal: Identify quasi-elastic Nb(p,2p) events in the data and compare their rate to our simulation

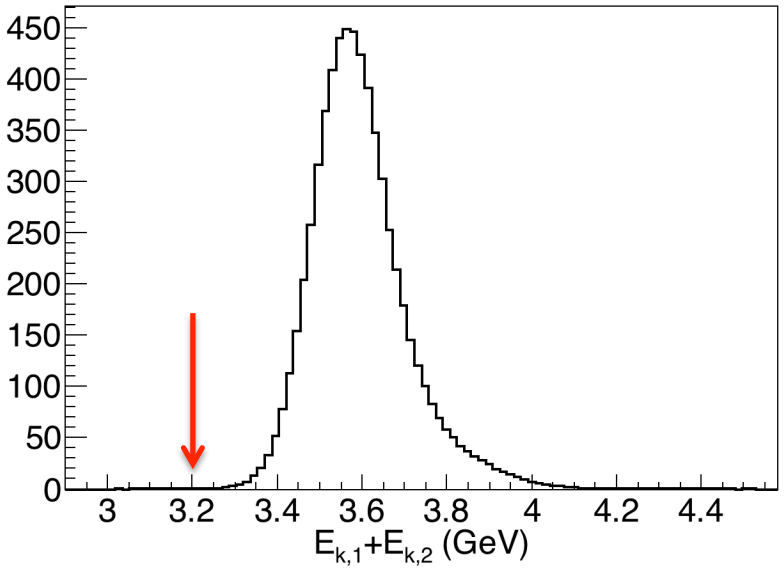
Parameters	Values
Target Thickness	10^{24} protons/cm^2
Beam flux	$2x10^6$ p/sec
Time	4.66 hr
Duty cycle	0.83
DAQ Efficiency	0.7
Downscaling Factor	3
Target Transparency	0.35*0.35
Acceptance	0.5
Other things	0.5

Event Selection Cuts

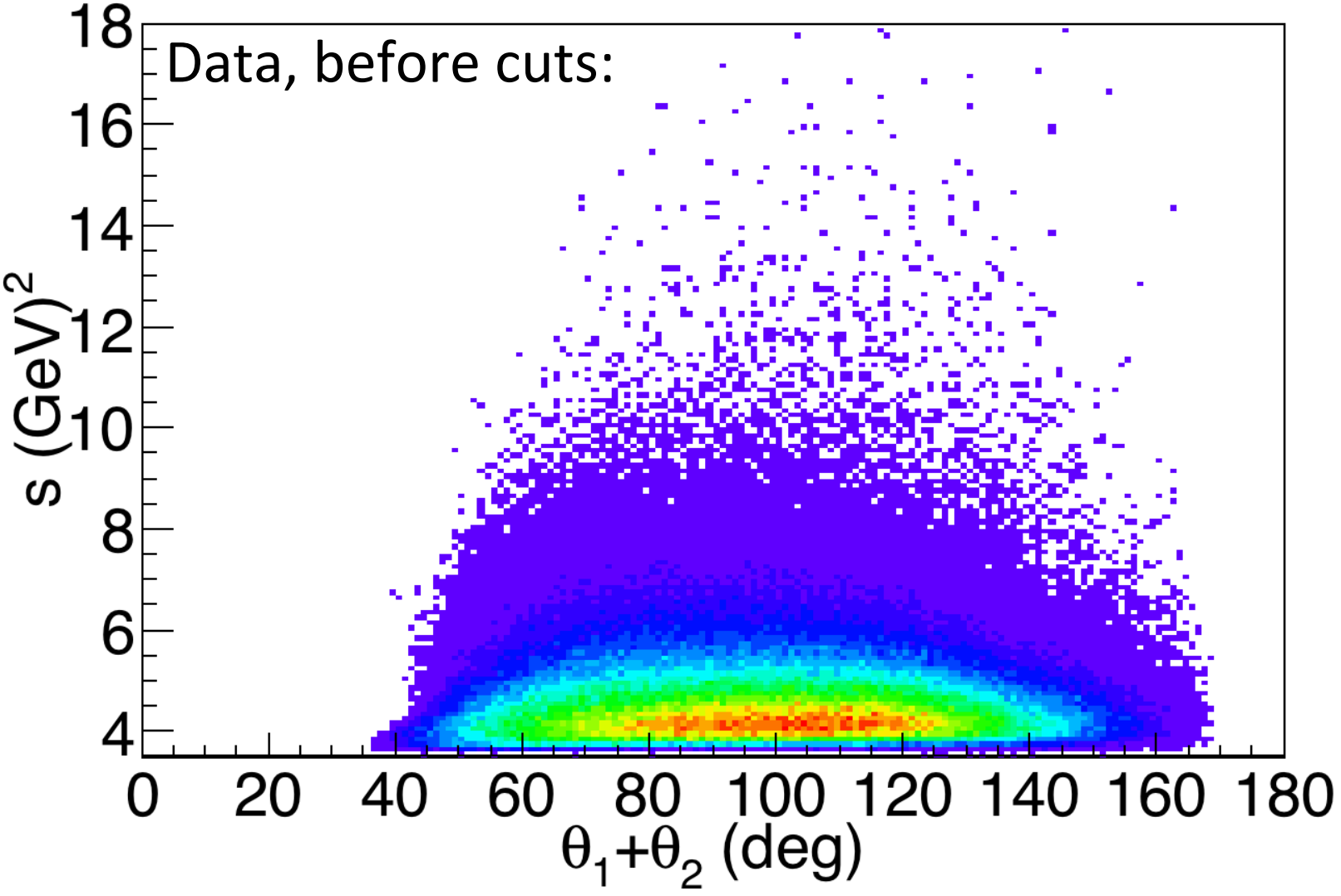
Quantities	Cuts
θ_{cm}	$60^o<\theta_{cm}<120^o$
θ_{lab} for P_1 and P_2	$18^o<\theta_{lab}<85^o$
s,t,u	>2 GeV^2
ϕ_{lab} for P_1 and P_2	$170^o<\Delta\phi_{lab}<190^o$
Multiplicity	2 tracks required
Additional cuts	P_{miss}>0.50 GeV/c P_{miss}<1.0 GeV/c (E_1+E_2)>3.2 GeV/c

(applied to both simulation and data)



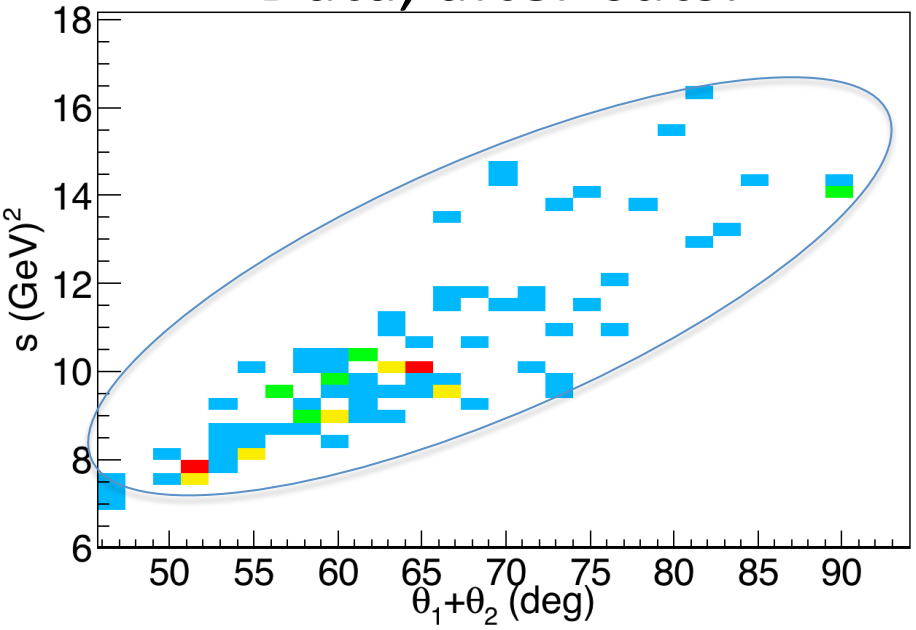


Verification of QE Correlations

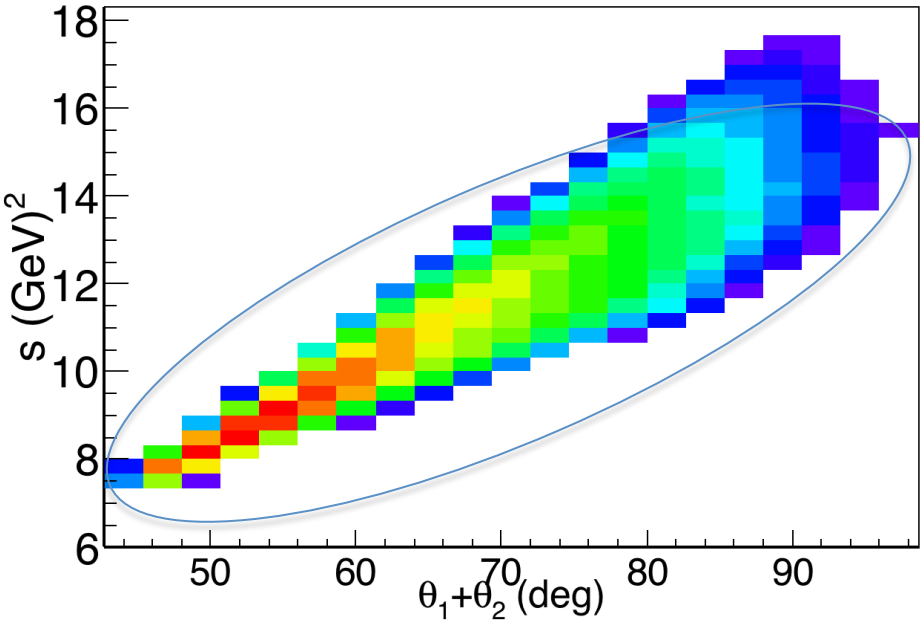


Verification of QE Correlations

Data, after cuts:



Simulation, after cuts:



Events:

Simulation/Data ~ 4

(depending on the exact value of the cuts used)

GEANT3 simulation for p+^{93}Nb