Exploration of New Physics – Muon to Positron Transition at COMET experiment

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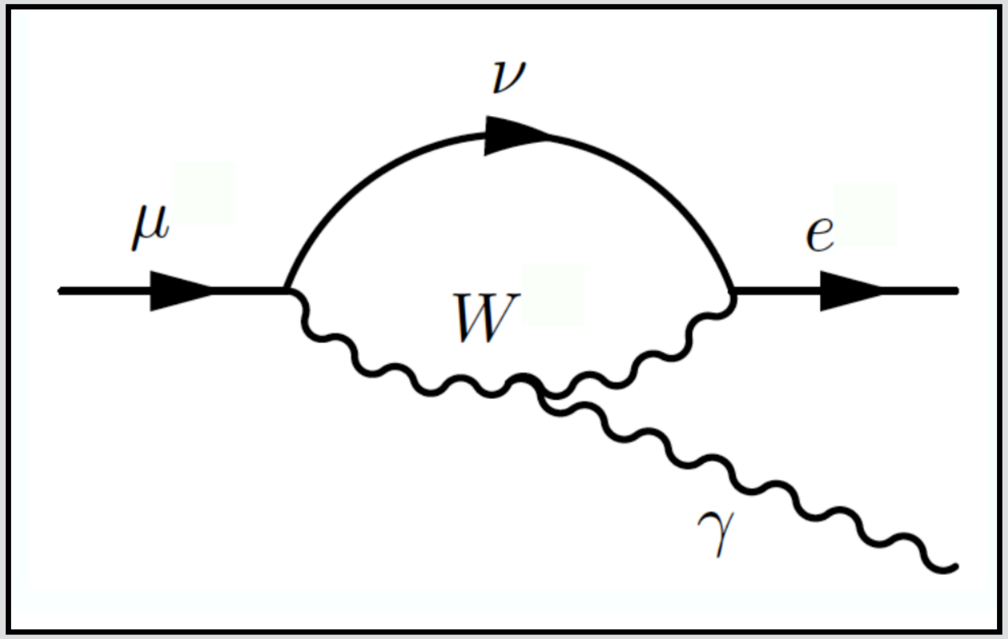
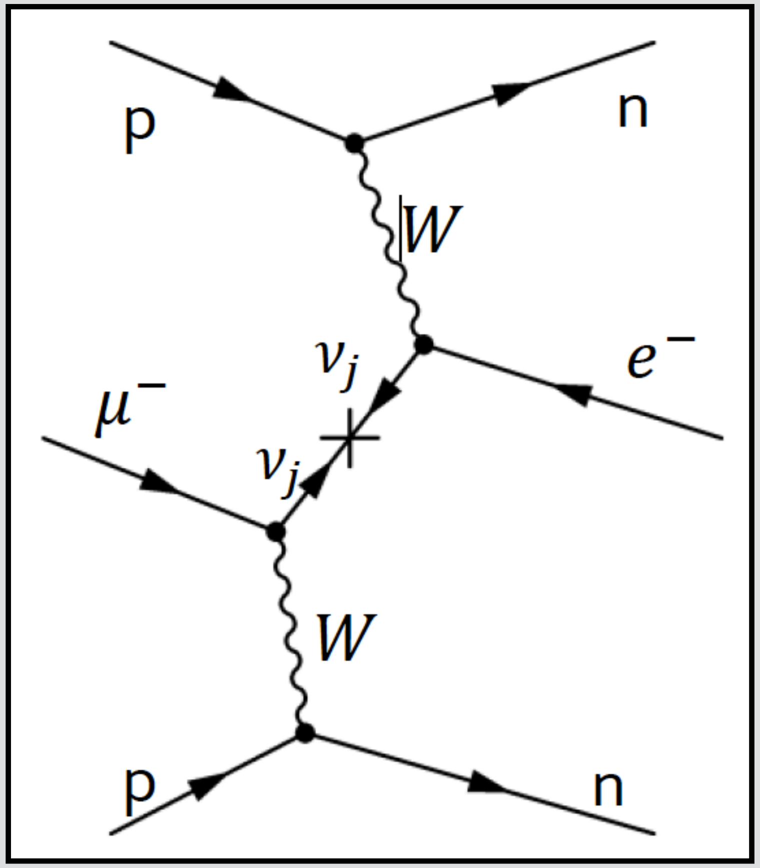
CLFV and LNV



- In minimal extension of the standard model considering neutrinos as **<u>Dirac particles and lepton number symmetry</u>**
- E.g. of CLFV μ-e conversion: Neutrino Oscillation + Stand model

$$\mathrm{BR}(\mu \to e\gamma) = \frac{3\alpha}{32\pi} \left| \sum_{k=1,3} U_{ej} U^*_{\mu j} \frac{m^2_{\nu_j}}{M^2_W} \right|^2 \simeq \mathscr{O}(10^{-55}\text{–}10^{-54}),$$

- Leads to the search of CLFV for experiments like , DeMee, COMET, Mu2e



- Apart from $\mu^- e^-$ conversion ,

$$\mu^- + N(A,Z) \to e^+ + N(A,Z-2)$$

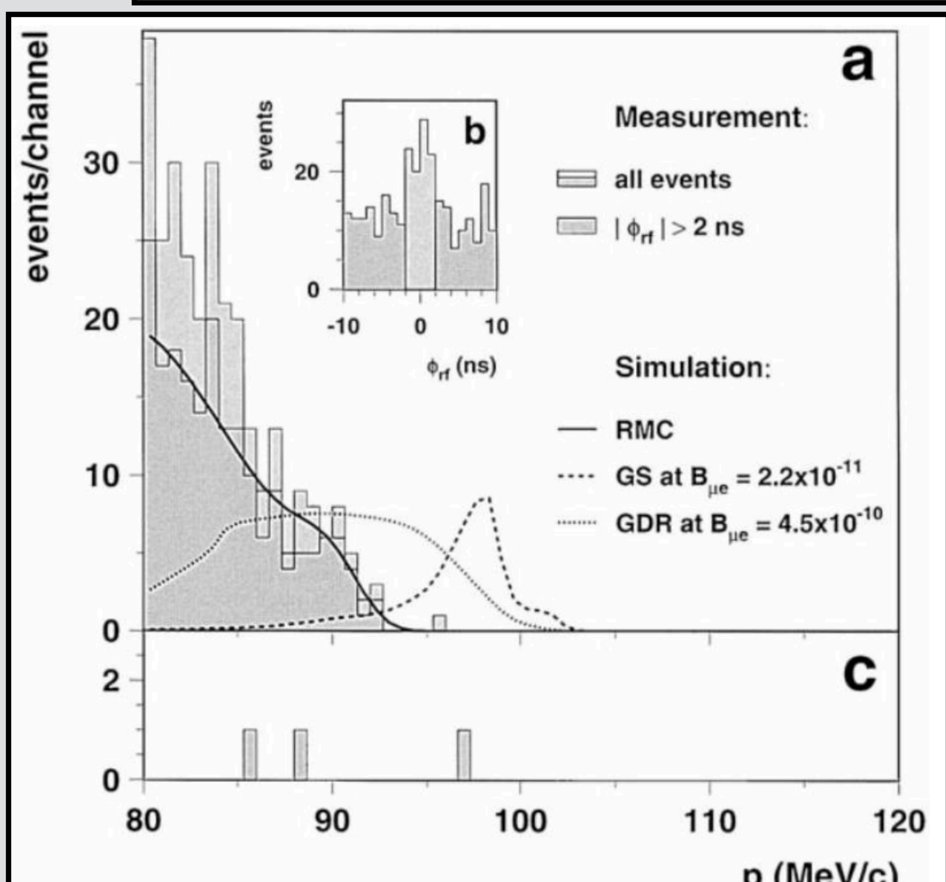
- A process violating both **flavour** and **lepton number** (L_e-L_μ = ΔL=-2)
- Extended SM : Majorana neutrinos, we can calculate the branching ratio ~ O(10^{-24}) [1]→ New Physics !

[1] :P.Domin, et al.

History of Search of Muon Positron conversion

Table 1: Past experiment on $\mu^- \to e^+$ conversion

Year	Location	Process	Upper limit	Reference
1982	SIN	$\mu + S \to e^+ + Si^*$	$< 9 \times 10^{-10}$	[1]
1988	TRIUMF	$\mu + Ti \to e^+ + Ca^*$	$< 1.7 \times 10^{-10}$	[2]
1993	PSI	$\mu + Ti \to e^+ + Ca$	$< 4.3 \times 10^{-12}$	[3]
		$\mu + Ti \to e^+ + Ca^*$	$< 8.9 \times 10^{-11}$	
1998	PSI	$\mu + Ti \to e^+ + Ca$	$< 1.7 \times 10^{-12}$	[4]
		$\mu + Ti \to e^+ + Ca^*$	$< 3.6 \times 10^{-11}$	



- Best one Titanium by SINDRUM experiment,
- Branching ratio ~ 1.7×10^{-12}

COMET Phase-I experiment

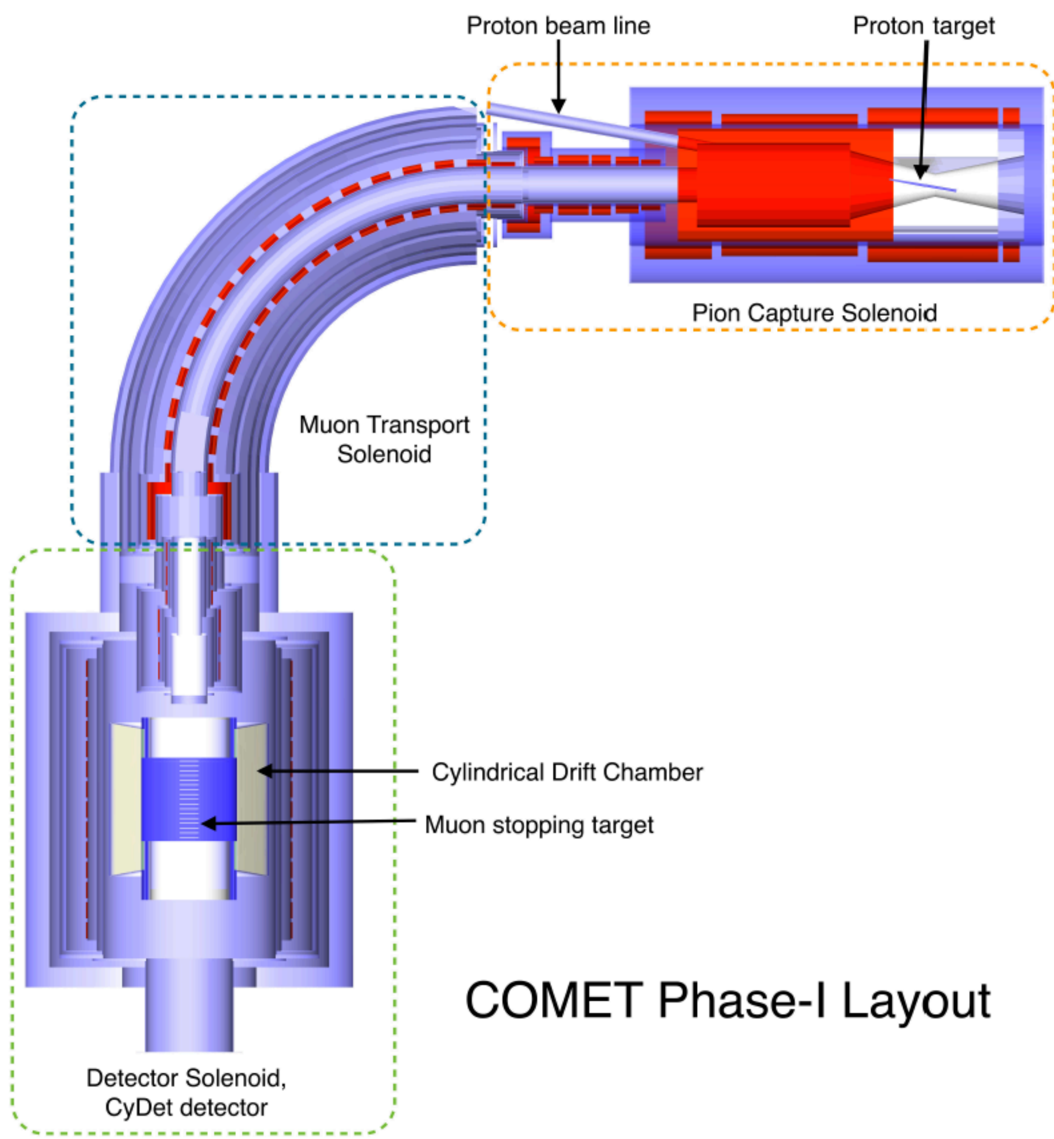


FIGURE 3.2: *Schematic layout of the COMET Phase-I experiment*

$$\boxed{\mu^- + Al \to e^+ + Na} \tag{3.1}$$

$$\mu^- + Al \to e^- + Al \tag{3.2}$$

$$\mu^- + N(Z) \to \mu^+ + N(Z-2) \tag{3.3}$$

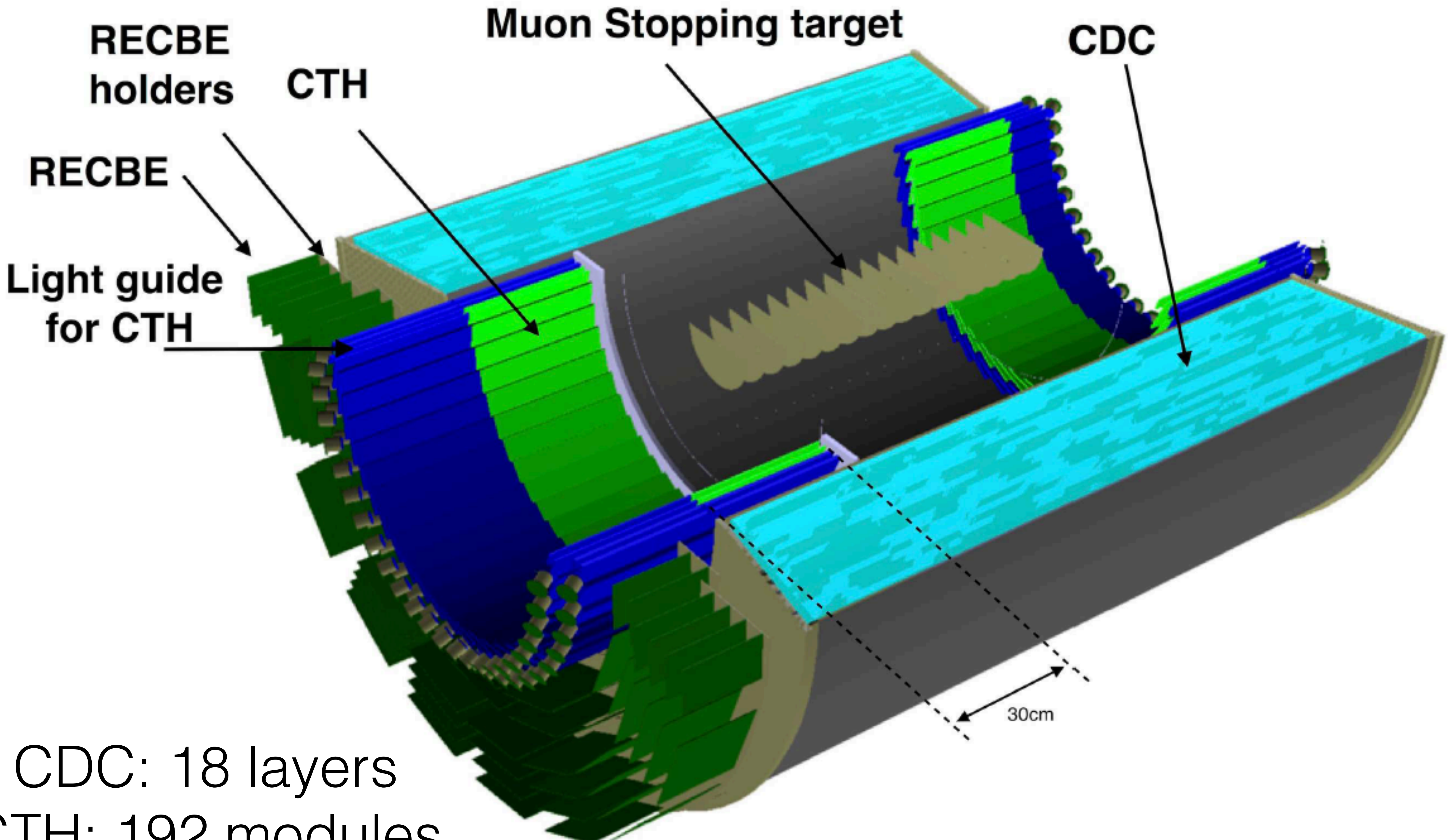
$$\mu^- \to e^- + X \tag{3.4}$$

$$\mu^- + e^- \to e^- + e^- \tag{3.5}$$

$$\boxed{m_\mu + M_{Al} + B_\mu = E_{\mu^- e^+} + M_{Na} + E_{recoil}}$$

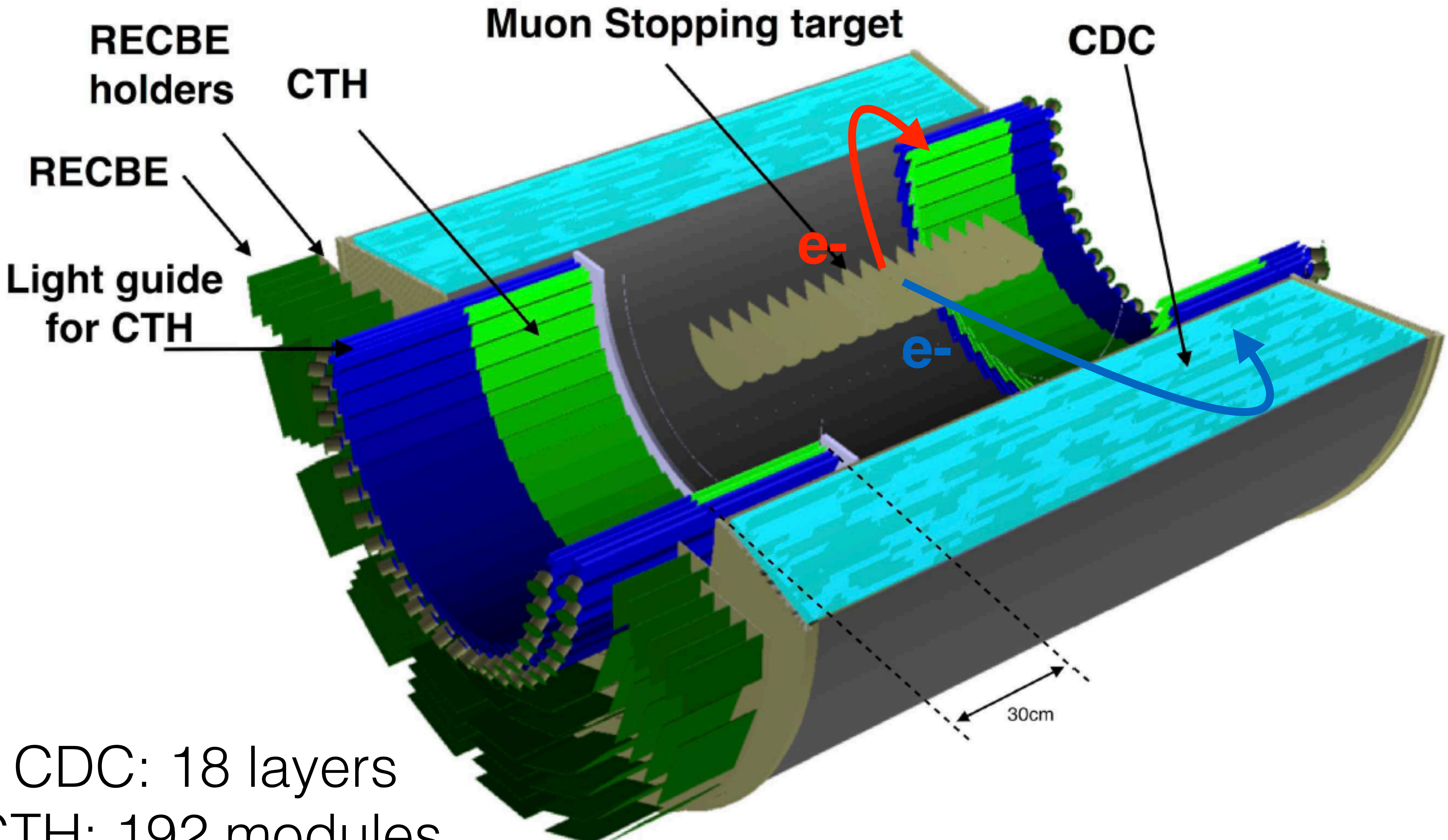
- Nucleus:
  - Ground state : 92.32 MeV
  - Excited state : [73.58 MeV - 92.32 MeV]
- Bonus for COMET: Technically the same process for compare to μ-e conversion

Cylindrical Detector Section



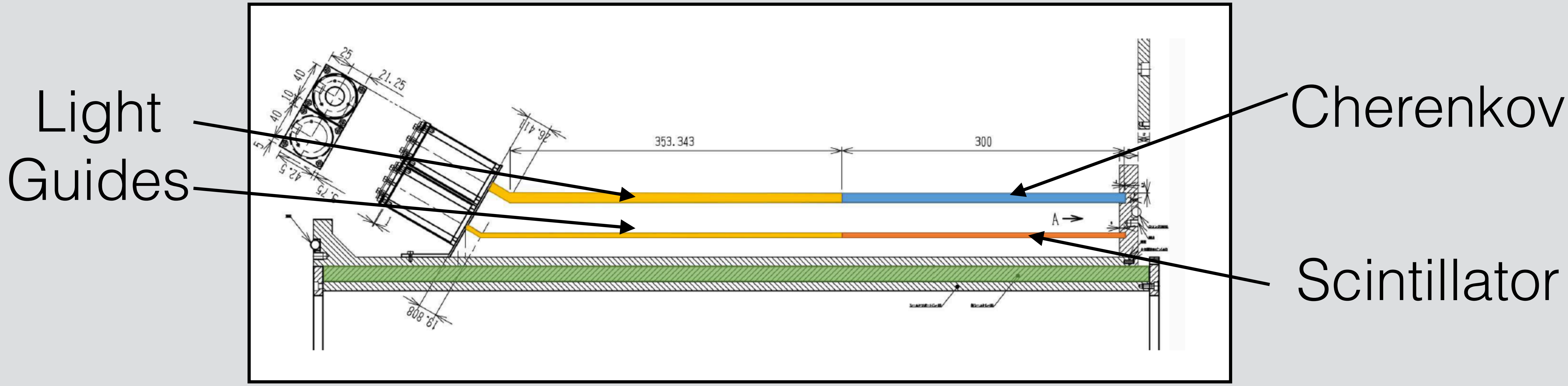
CDC: 18 layers
CTH: 192 modules

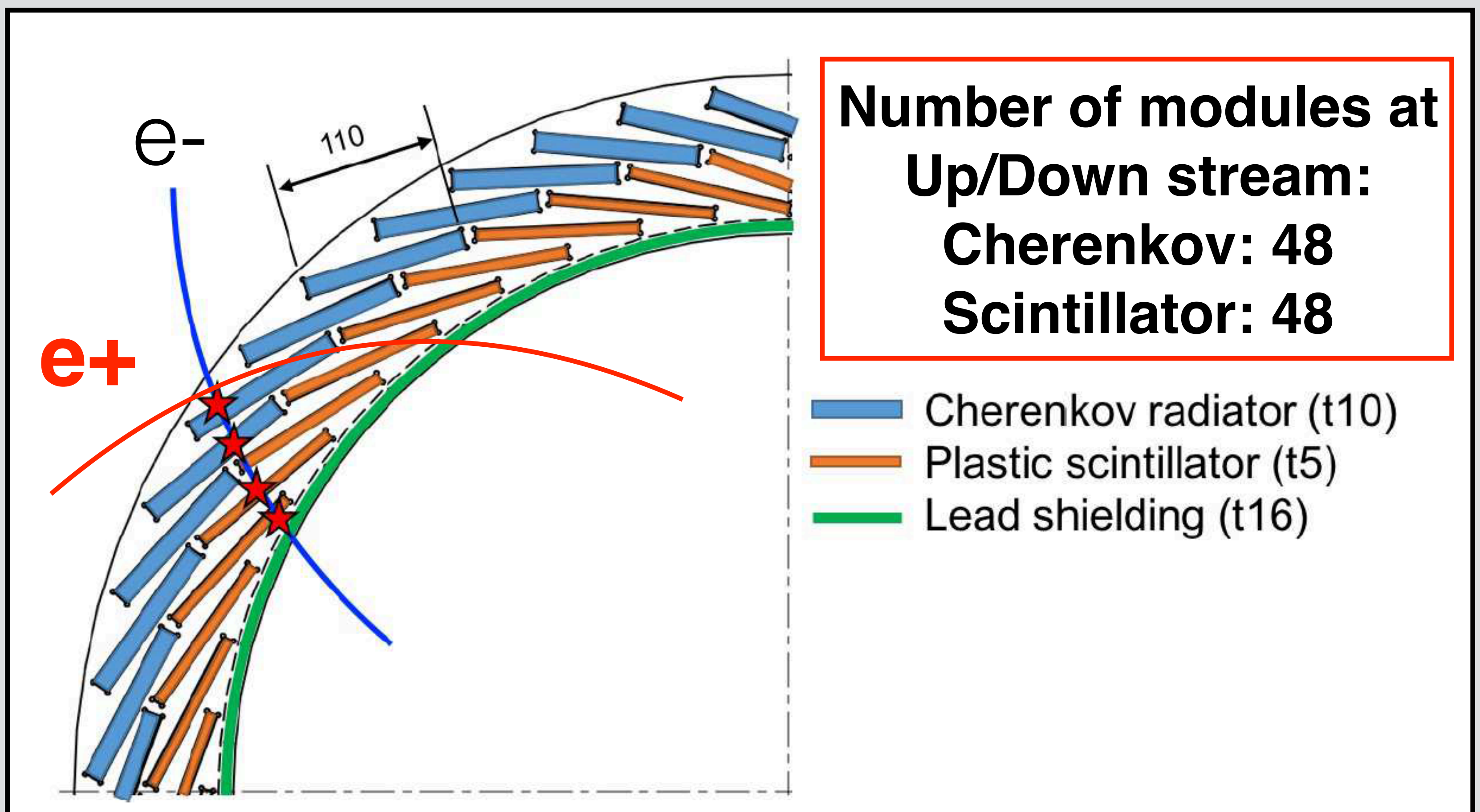
How e-/e+ becomes a USEFUL signal?



CDC: 18 layers
CTH: 192 modules

Design of trigger hodoscope





<u>Defintion</u>

N-fold coincidence : Number of modules electron/positron pass through and produce a coincidence

Signal Sensitivity calculation

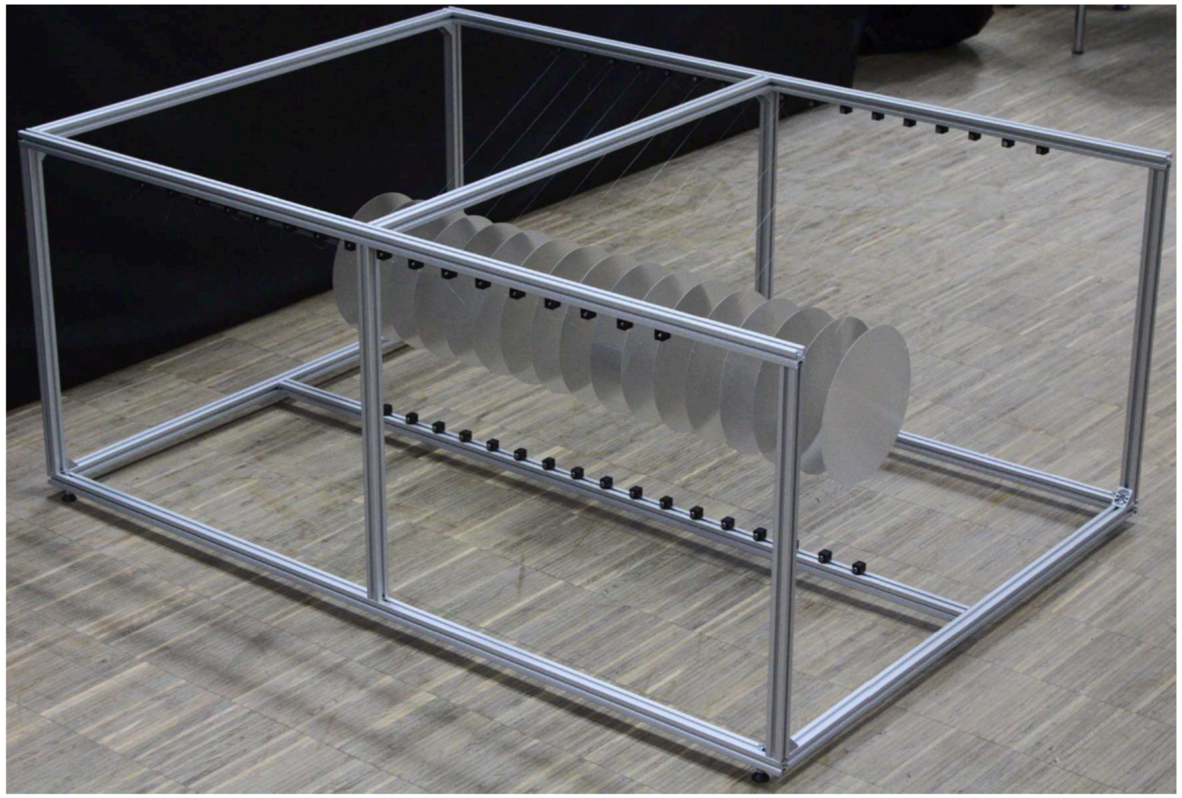
$$B(\mu^- + N(Z) \rightarrow e^+ + N(Z-2)) = \frac{1}{N_\mu(Z) \cdot f_{\text{cap}}(Z) \cdot f_{\text{gnd}}(Z) \cdot A_{\mu\text{-}e}(Z)} \quad (4.2)$$

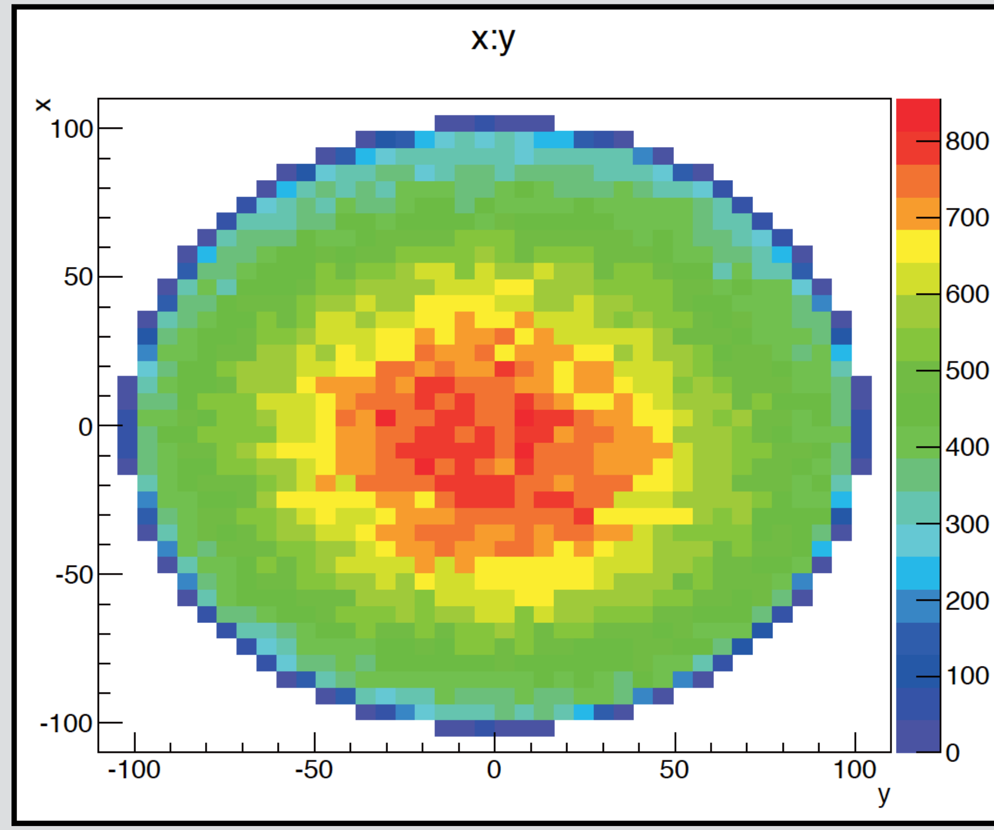
- **Dependence of the branching ratio:**
  - Number of stopped muons
  - Fraction of muons captured by nucleus
  - Fraction of nucleus with ground state at the final state
  - Acceptance of signals

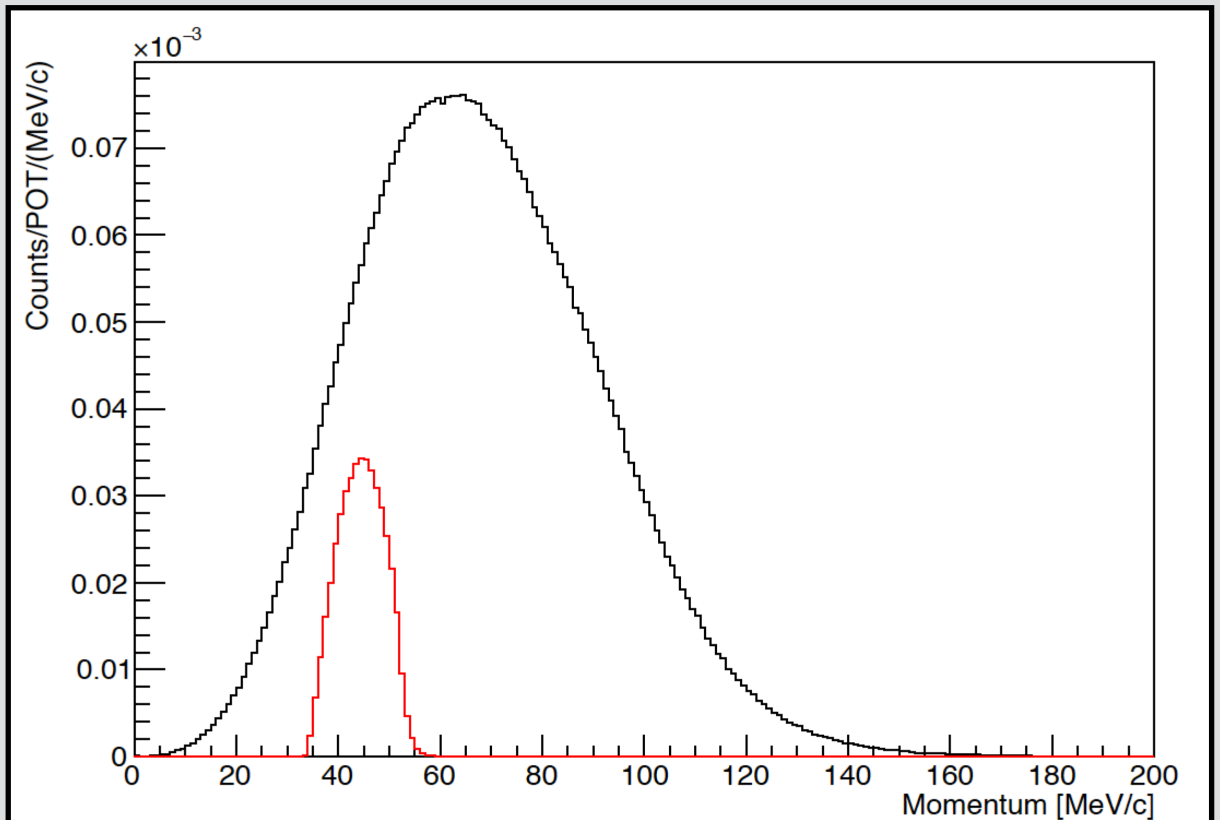
	Signal Electron	Signal Positron
Muon Capture rate (f_{cap})	0.61 (Al)	0.61 (Al)
Fraction of ground state (f_{gnd})	0.9	0.4

- **Acceptance of signals**
  - Online trigger efficiency
  - DAQ efficiency
  - Track finding efficiency
  - Track Fitting efficiency
  - Momentum && Time Cut efficiency
  - Geometrical Acceptance

Stopped muons for Aluminum





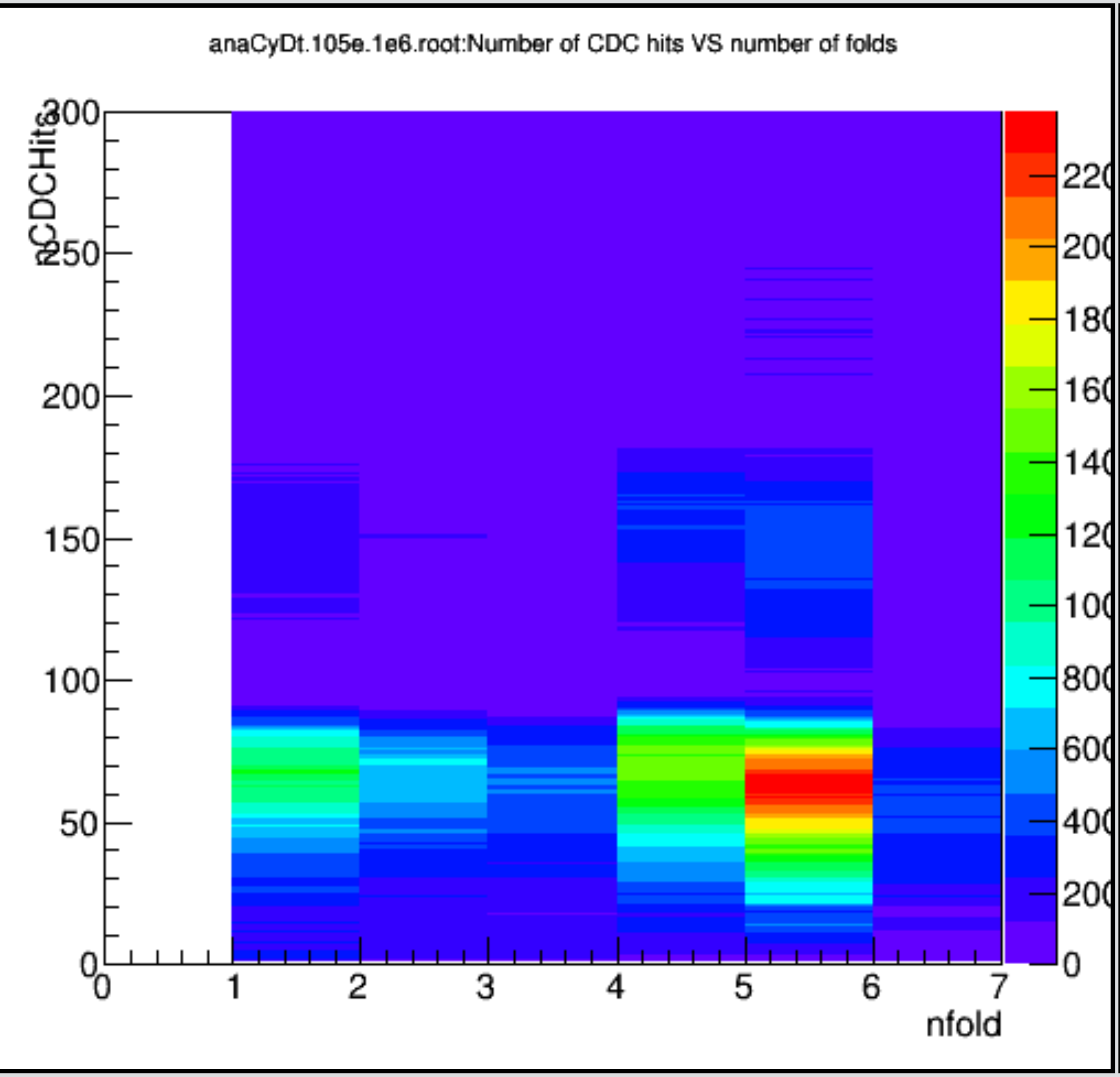


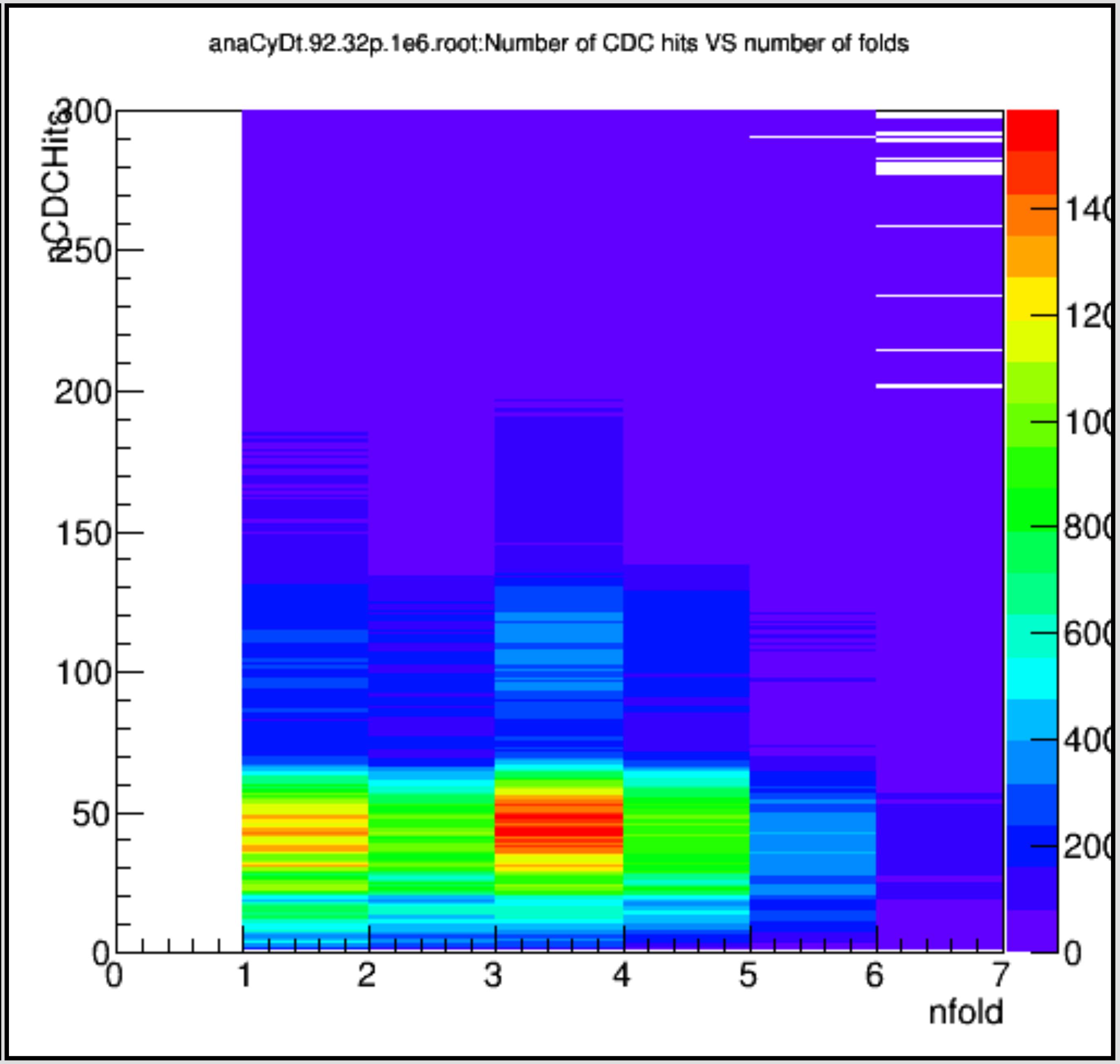
Yield (per proton):	After muon-transport section	Stopped in muon target
Muons	5.0×10^{-3}	4.7×10^{-4}
Pions	3.5×10^{-4}	3.0×10^{-6}

Models	Simulator	$N(\pi^- + \mu^-)/p$ at 3 m
CEM	MARS	0.061 ± 0.001
CEM/LAQGSM	MARS	0.138 ± 0.001
LAQGSM	MARS	0.144 ± 0.001
LAQGSM	GEANT	0.1322 ± 0.0007
QGSP_BERT	GEANT	0.0511 ± 0.0002
QGSP_BIC	GEANT	0.1278 ± 0.0005
FTFP_BERT	GEANT	0.0440 ± 0.0002

TABLE 3.2: *Comparison of the π^- and μ^- yields three meters backwards from the proton target for different hadron production codes from TDR of COMET [3]*

Positrons/Electrons acceptance studies

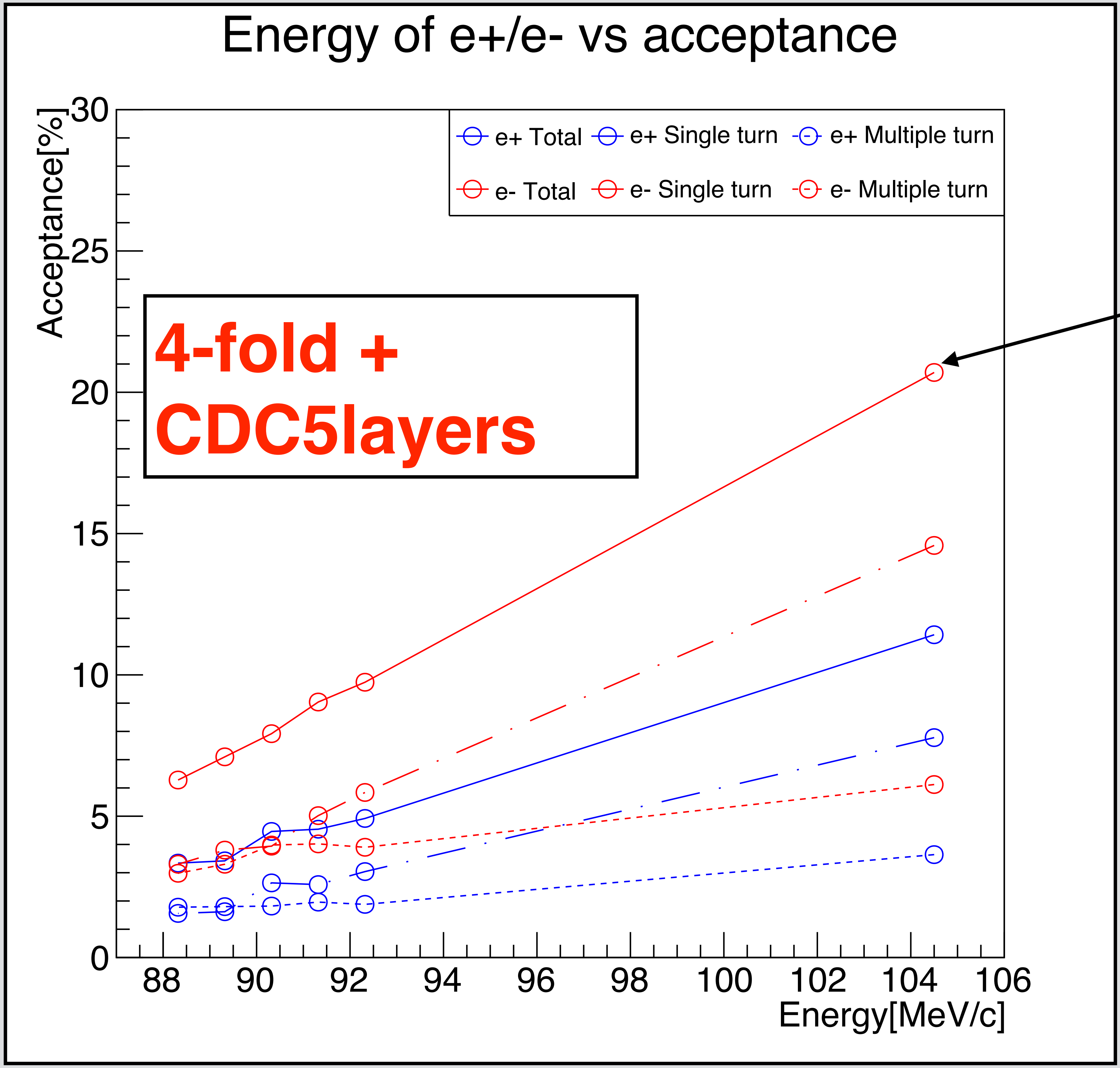




105 MeV Electron
Mainly 4-5 folds

92.3 MeV Positron

Simulation of signal e+e- Acceptance (A)



COMET
μe conversion
signal

Basically, with the current design of CTH,

$\boldsymbol{A_{e-}/A_{e+} \sim 2}$

Signal Sensitivity calculation

$$SES = Br(\mu^- + Al \to e^- + Al) = \frac{1}{N_\mu \cdot f_{cap} \cdot f_{gnd} \cdot A_{\mu-e}}$$

Aμe	105MeV e-	92.32 e+	Commets
Online event selection	0.9	0.9	
DAQ efficiency	0.9	0.9	
Track finding efficiency	0.99	0.99	
Geometrical acceptance + track quality cuts	0.21	0.042	
Momentum window	0.91	0.62	e-: 103.6 MeV < Pe < 106.0 MeV e+:91.5 MeV < Pe < 92.5 MeV
Time window	0.50/0.31	0.78/0.48	500 ns or 700 ns cut
Total	**0.077/0.048**	**0.016/0.010**	

Aimed Single Event Sensitivity (SES)	3 x 10^{-15}	3 x 10^{-14}	2 orders than the current limit
N muons needed	1.3 x 10^{16} (7.9 x 10^{15})	9.1 x 10^{15} (5.7 x 10^{15})	
N protons needed	2.7 x 10^{19} (1.7 x 10^{19})	1.9 x 10^{19} (1.2 x 10^{19})	($R_{\mu\text{-stop}}$) Stopping ratio 4.7 x 10^{-4}
Time for Physics run	**122 days** (76 days)	**88 days** (55 days)	3.2kw 8GeV proton 0.4μA

Potential Backgrounds that can fake a signal

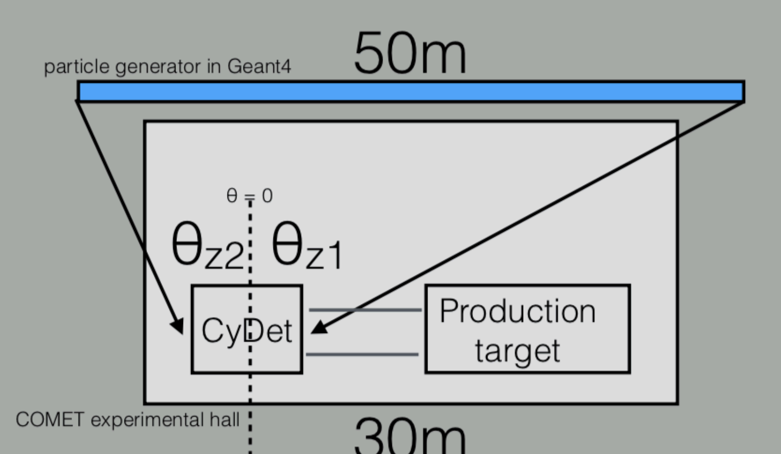
- **<u>Backgrounds</u>**
  - Decay In orbit
  - Internal/external Radioactive Muon Captured
  - Internal/external Radioactive Pion Captured
  - Cosmic ray background
  - Beam background (Not mentioned here, very small)
  - Anti proton (Not mentioned here)

Cosmic ray background

Cosmic ray calculation:

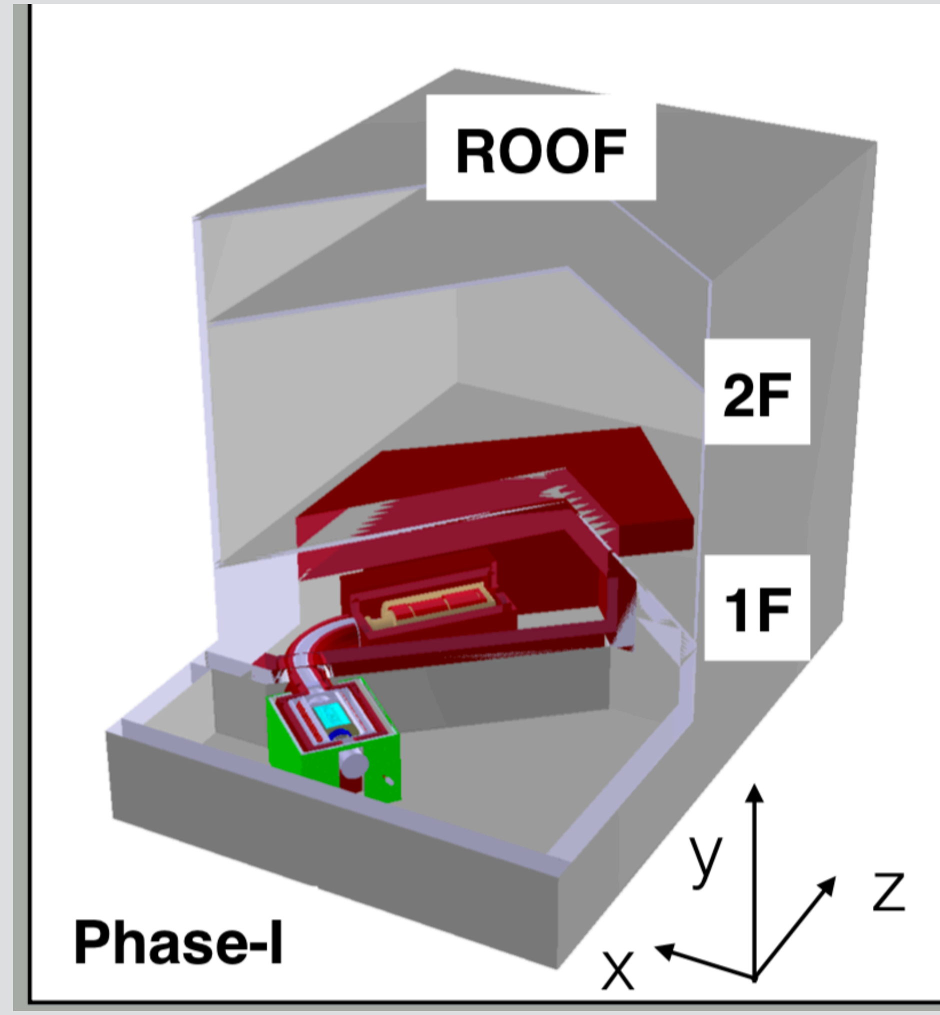
Assume Muon Flux : 1 [cm^{-2}/min]
Experimental hall size : (50 x 50) m^2 = (5000 x 5000) cm^2
Physics measurement : 100 days = 144000 mins
Veto Efficiency (ε_{CRV}) : 99.99% ~ 1e-4 (for now)
Duty factor w/ time gate : 0.25
(144000 mins)*(5000*5000cm^2)*(1/cm^2/mins/μ)*(ε_{CRV})*0.25 ~ 9e11*ε_{CRV}

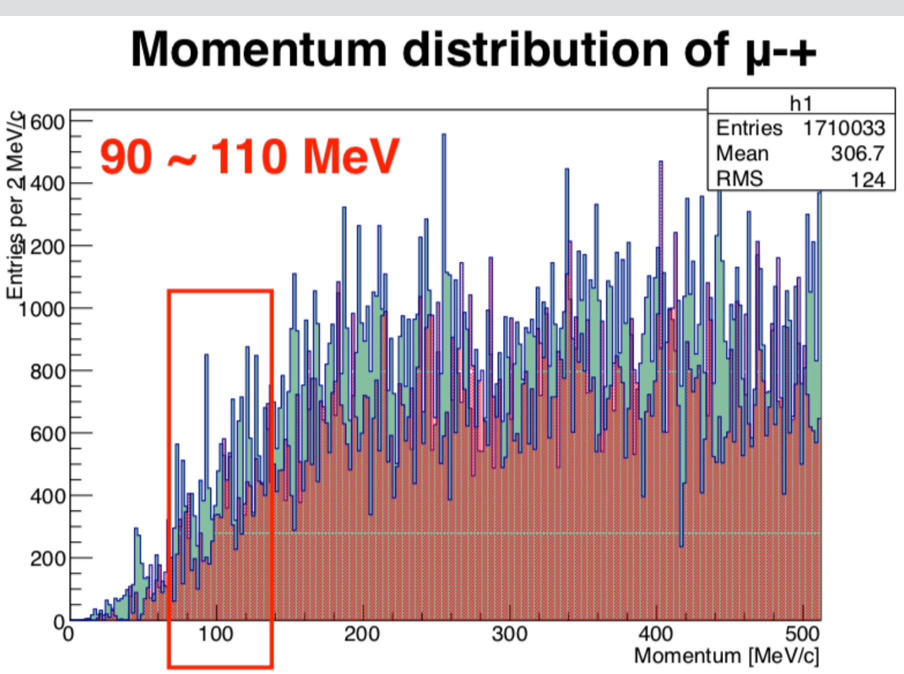
Number of cosmic muons needed ~ $10^{12}\varepsilon_{CRV}$,
where ε_{CRV} is the CRV veto efficiency

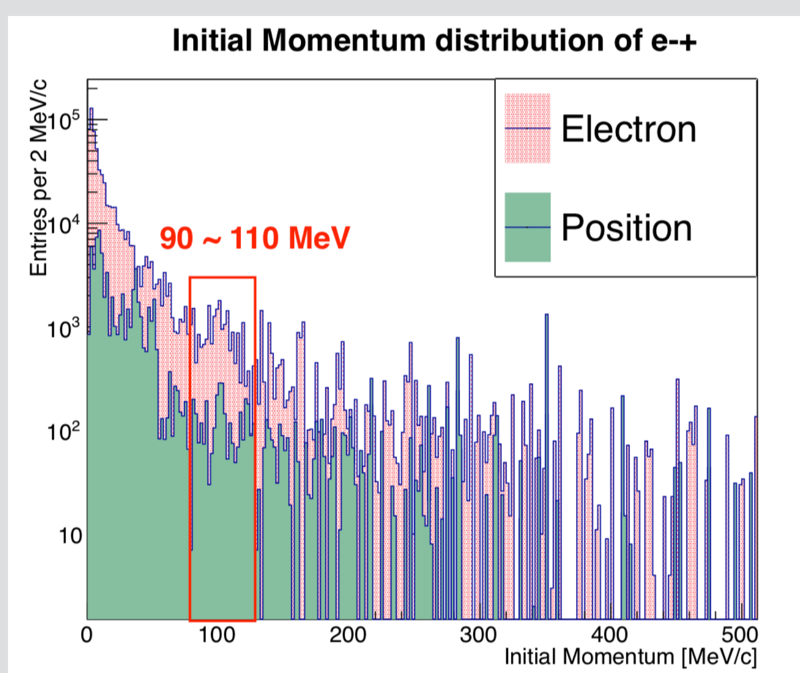


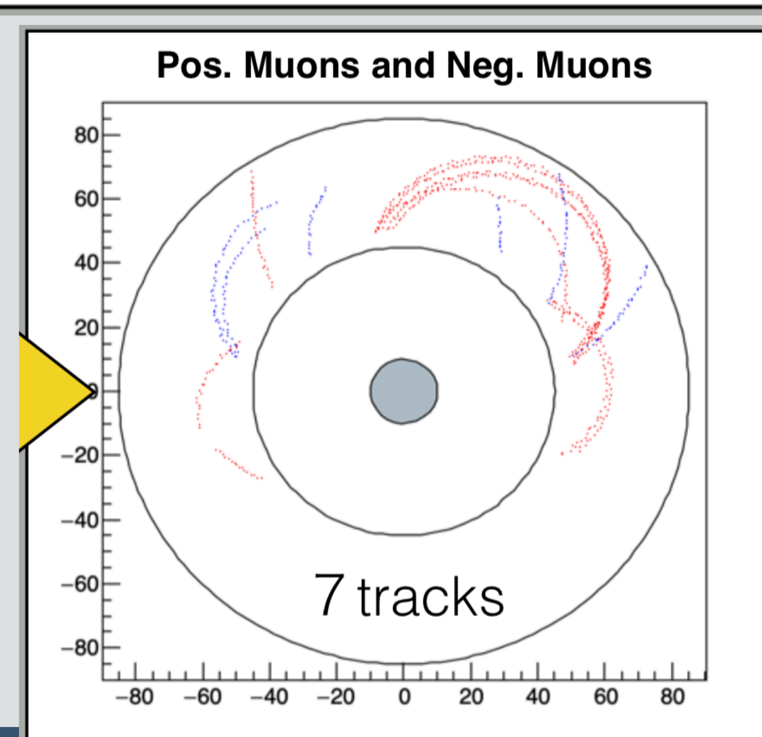
Max θ_{z2} ~ 0.964 rad
Max θ_{z1} ~ 0.653 rad

Range of cosmic ray that can arrive at CyDet ~ (-37 ~ 55) degrees
**** No horizontal muons ****

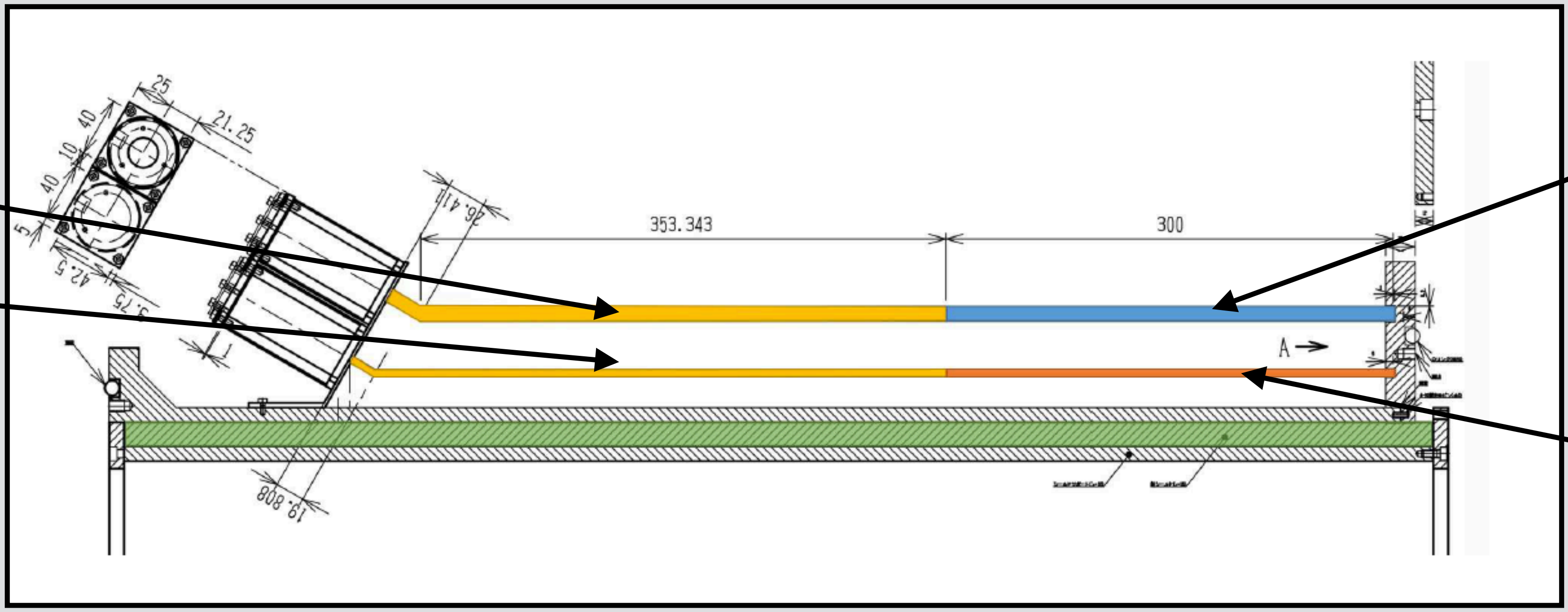




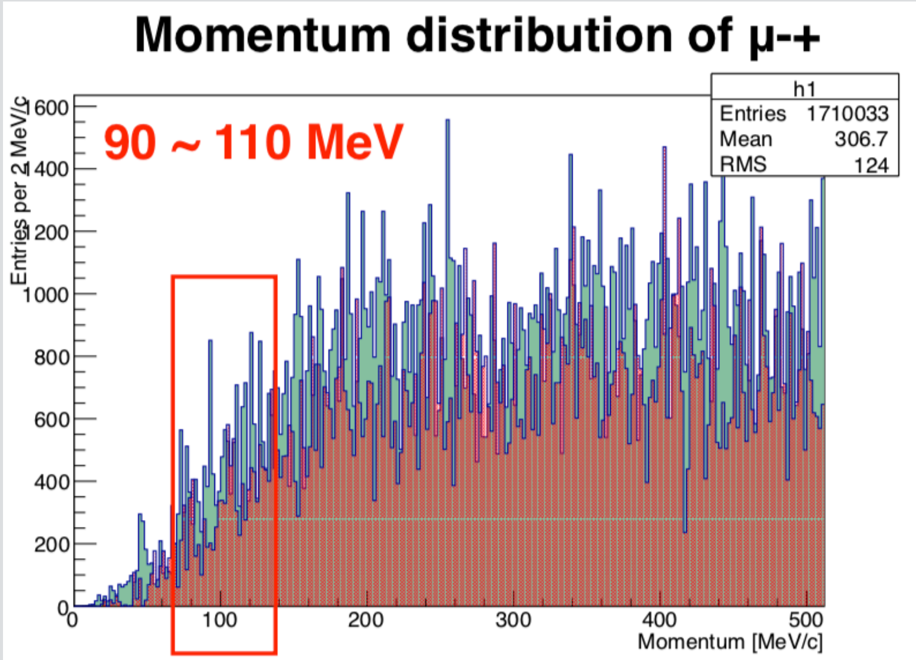


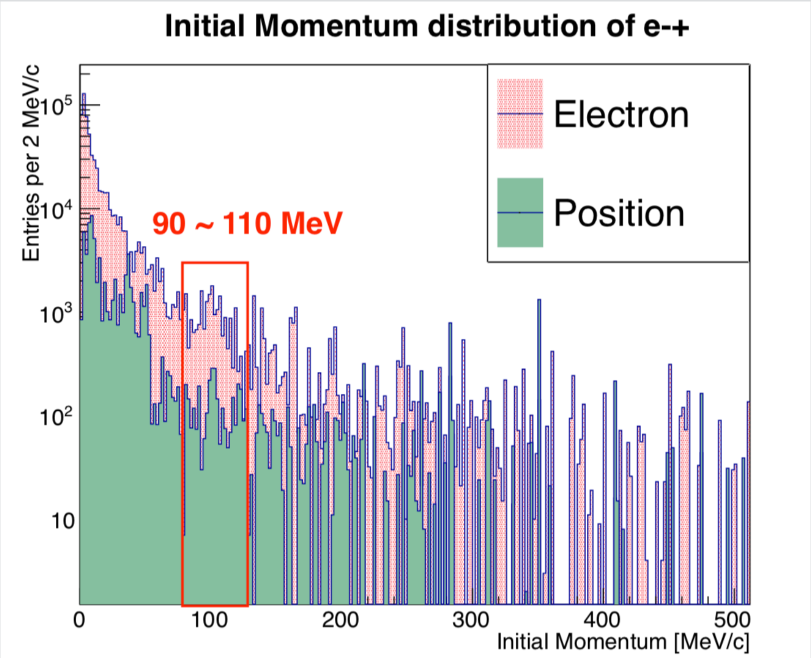


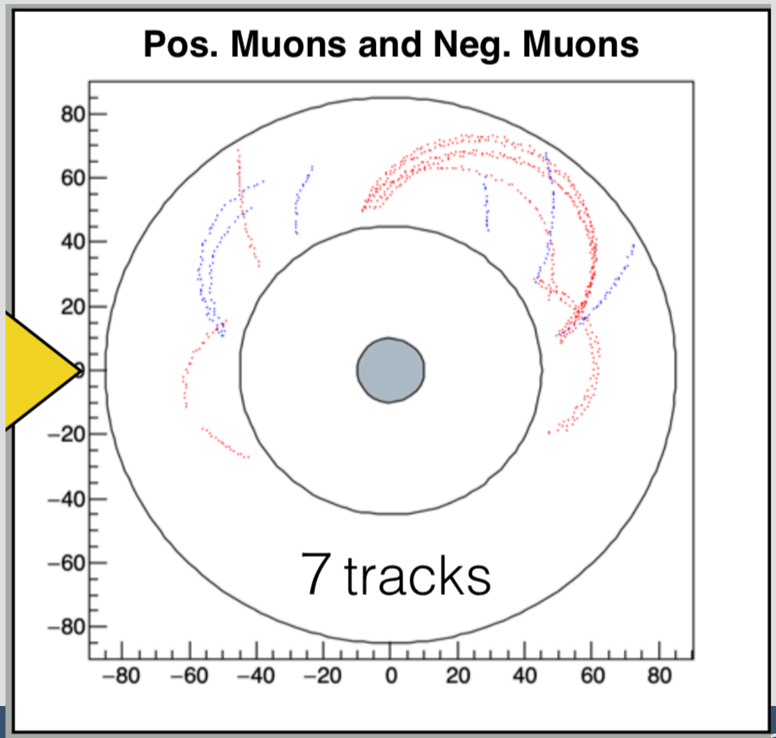
Cosmic ray background



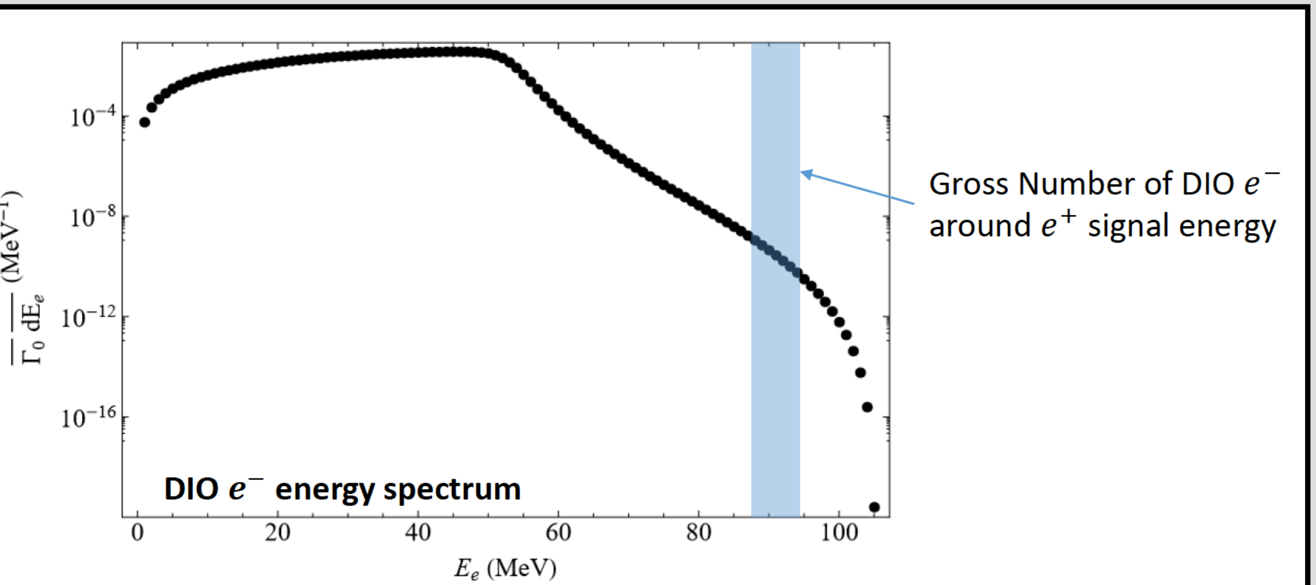
- Cherenkov can do PID, it can identify muons



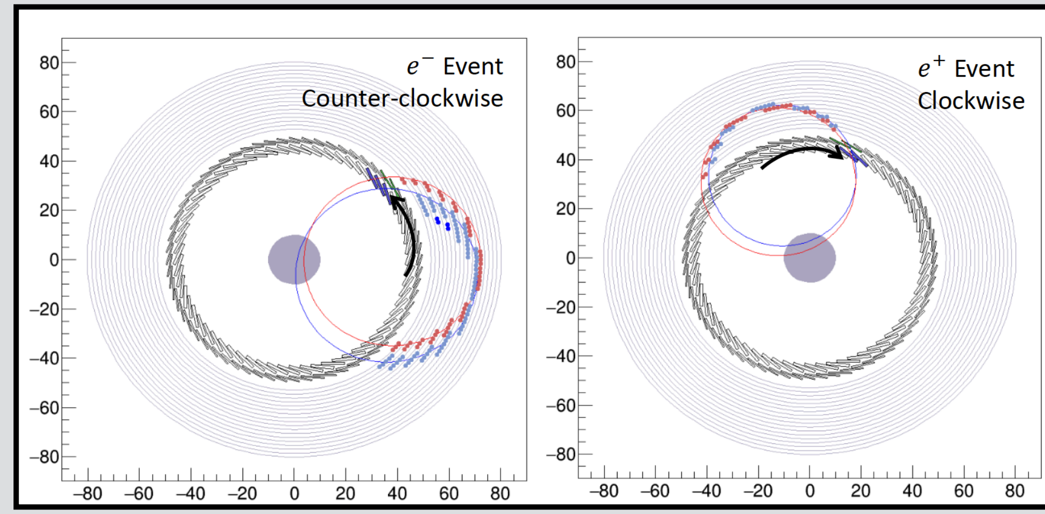




DIO Charge IDentification (CID)



$P(e^- \to e^+)$: Charge Misidentification Rate of e^- as $e^+ \to 0.2$ %
$P(e^+ \to e^-)$: Charge Misidentification Rate of e^+ as $e^- \to 8.5$ %



$$N_{MICp} = N_p \cdot R_{\mu\text{-stop/p}} \cdot (1-f_{cap}) \cdot Br(DIO) \cdot A_{DIO} \cdot P_{e-\to e+}$$

Parameters	Value	Description
N_p	1.9×10^{19} (1.2×10^{19})	Number of needed protons
$R_{\mu\text{-stop/p}}$	4.7×10^{-4}	Muon stopping rate
f_{cap}	0.61	Nuclear capture rate
Br(DIO)	6.77×10^{-10}	90 - 105MeV/c
$P_{e-\to e+}$	0.002	MIC rate
A_{DIO}	100%	DIO acceptance

- Even 100 % -> you only have 7.3e-4 event

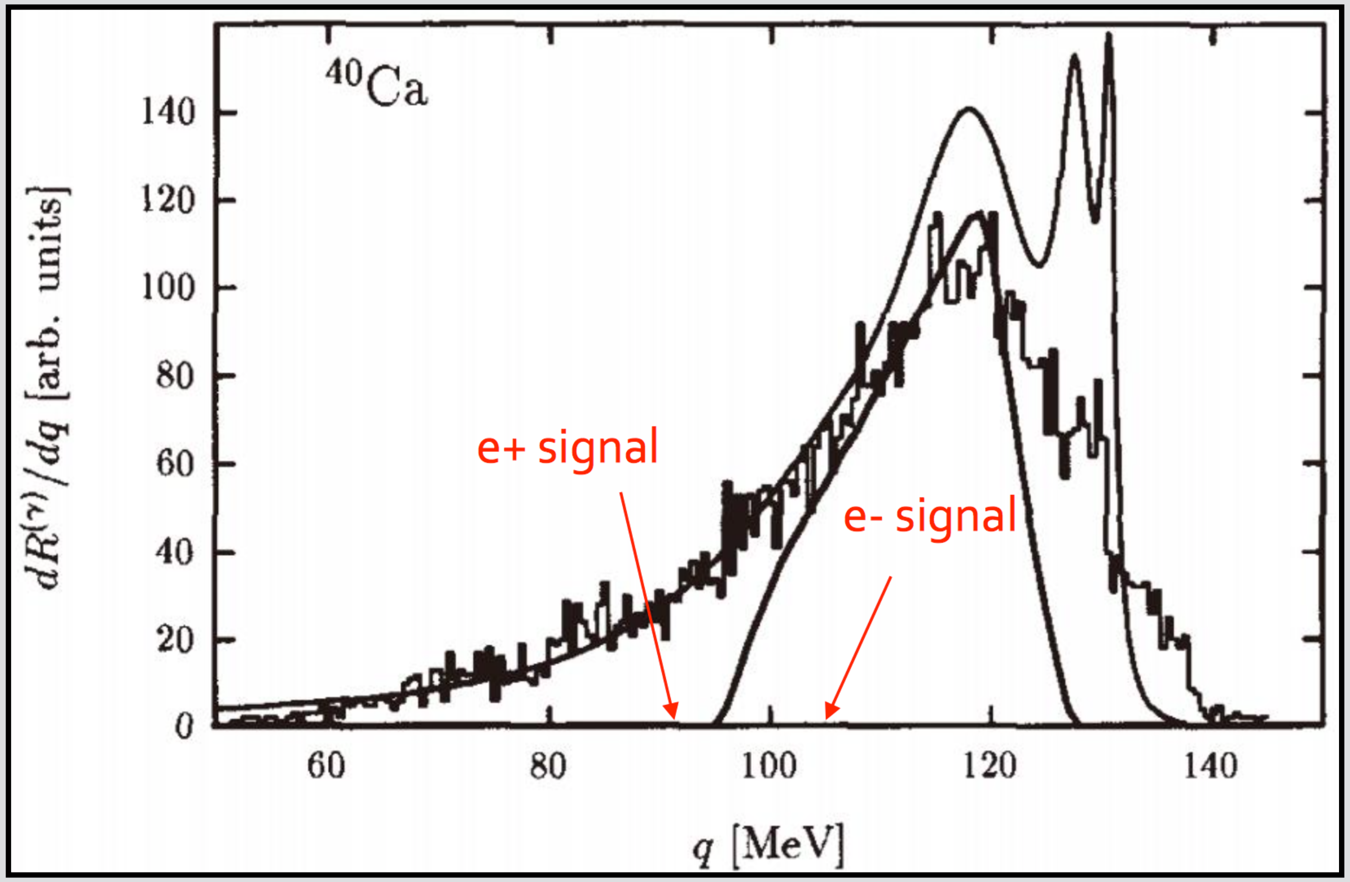
Radiative pion capture (RPC)

1. **Two types of RPC**

External : $\pi^- + Al \rightarrow \gamma + Na$ followed by $\gamma \rightarrow e^- + e^+$

Internal : $\pi^- + Al \rightarrow e^- + e^+ + Na$

2. **RPC depends highly on the Extinction factor**
3. **From 8GeV/c experiment extinction factor (<1e-10) is guarantee**



1. **Simulated 1e7 gamma for xRPC studies according to the experimental data**
2. **Mainly to check if the RPC is negligible or not**

Radiative pion capture (RPC)

Event selection	Value	Remark
Online event selection efficiency	0.9	TDR
DAQ efficiency	0.9	TDR
A_{xRPC}	8.7e-6 (1.4e-5)	
Total (A_{RPC_e})	7.0e-6 (1.1e-5)	700 ns (500 ns) cut
Expected xRPC in physics run	**8.2e-4 (1.3e-3)**	

$$\boxed{N_{xRPCe} = N_p \cdot R_{ext} \cdot R_{\pi\text{-stop/p}} \cdot Br(E\gamma) \cdot A_{xRMC\_e}}$$

Parameters	Value	Description
N_p	1.9×10^{19} (1.2×10^{19})	Number of needed protons
R_{ext}	< 1e-10	Extinction rate
$R_{\pi\text{-stop/p}}$	3.1×10^{-6}	Pion stopping rate
$Br(E\gamma)$	0.02	Branching ratio of γ_{RpC}
A_{xRMC_e}	7.0e-6 (1.1e-6)	xRPC acceptance

RPC rate is at negligible level

Radiative muon capture (RMC)

1. **Two types of RMC**

External : $\mu^- + Al \rightarrow \nu_\mu + Mg + \gamma$ Followed by $\gamma \rightarrow e^- + e^+$

Internal : $\mu^- + Al \rightarrow \nu_\mu + Mg + e^- + e^+$ (Virtual Photon)

2. **Endpoint energy of photon ~ 101.85 MeV → 101.34 MeV for e+**

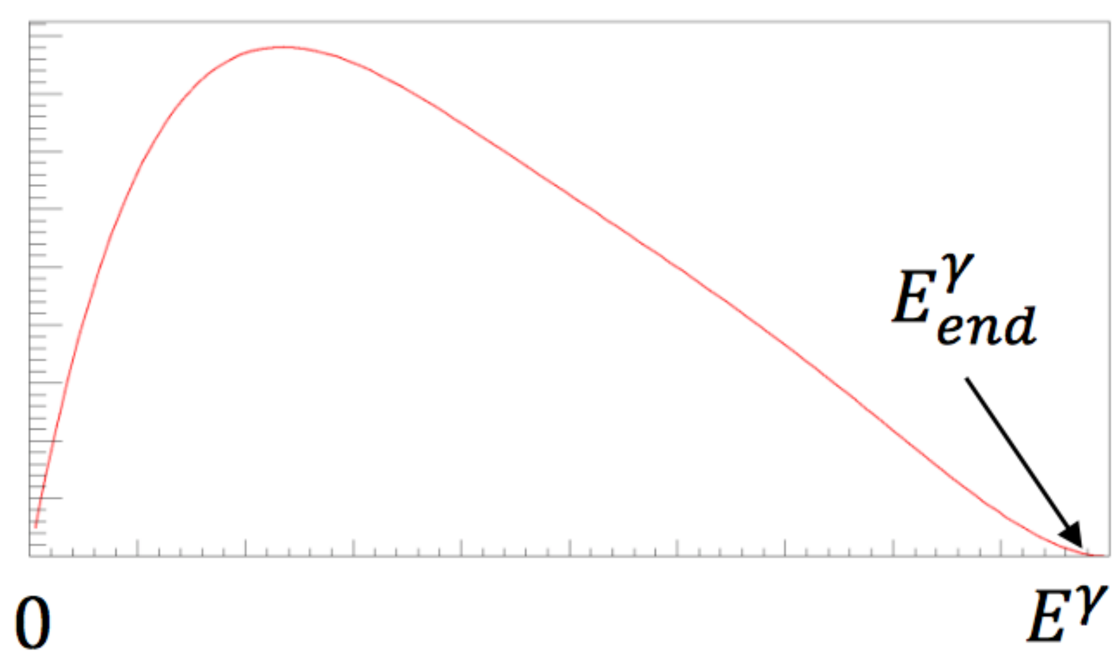
1. **Experimentally Br(Eγ > 57 MeV) ~ 1.9 x 10^{-5}**
2. **Spectrum is calculated in "Phy Rev C, Volume 32,Number5, Nov 1985"**

   ➡ Spectrum of gamma can be described as:

$$P(x) = C(1 - 2x + 2x^2)x(1-x)^2, \qquad x = \frac{E_\gamma}{E^\gamma_{end}}$$

Br(Eγ > 88.32 MeV) ~ 1 x 10^{-8}

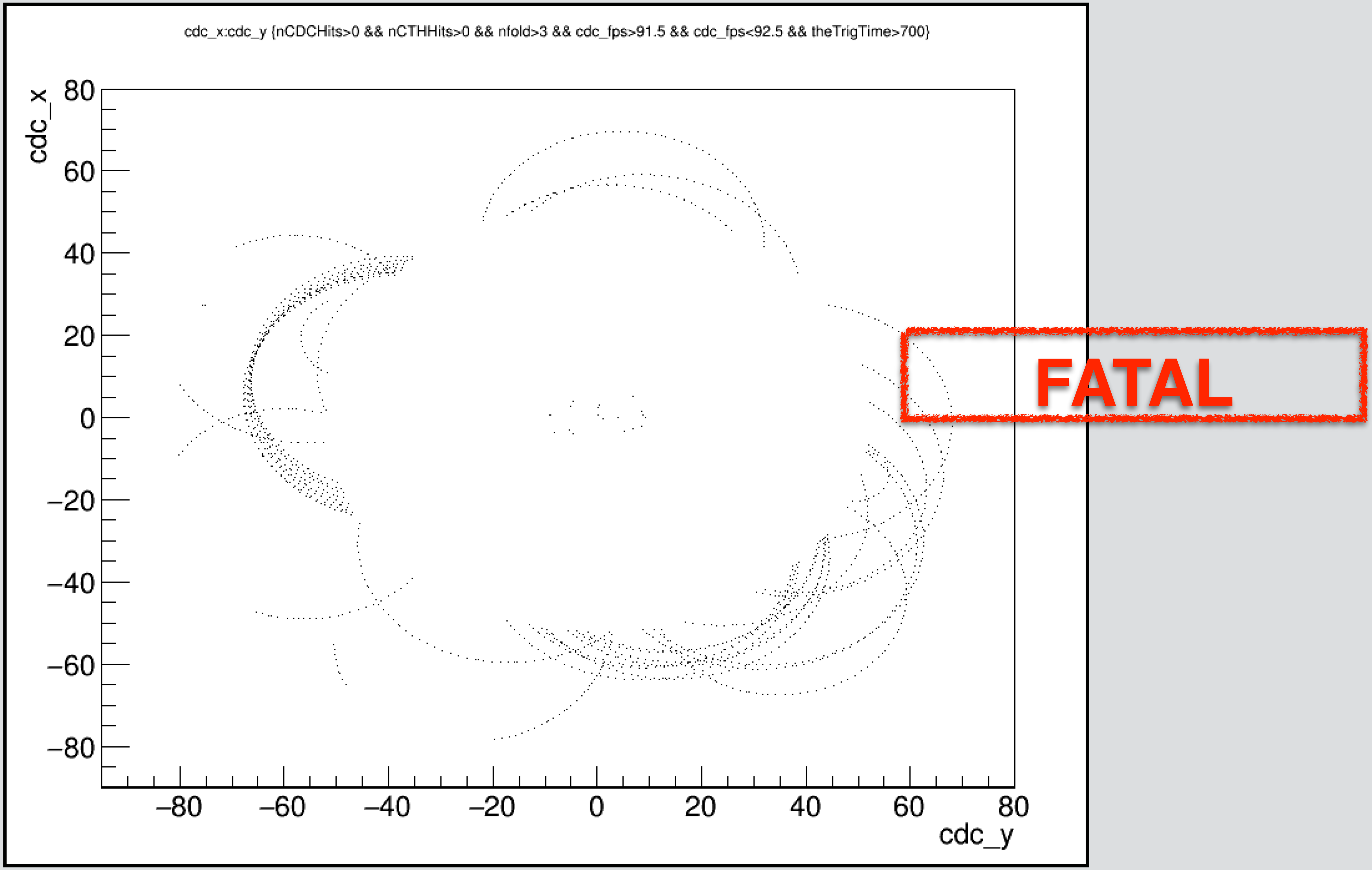
O(1e7) of RMC gamma are generated



RMC photon energy (E_γ) spectrum

How to avoid x/iRMC background?

CDC cross section



We cannot avoid it actually…they are all from the disk….

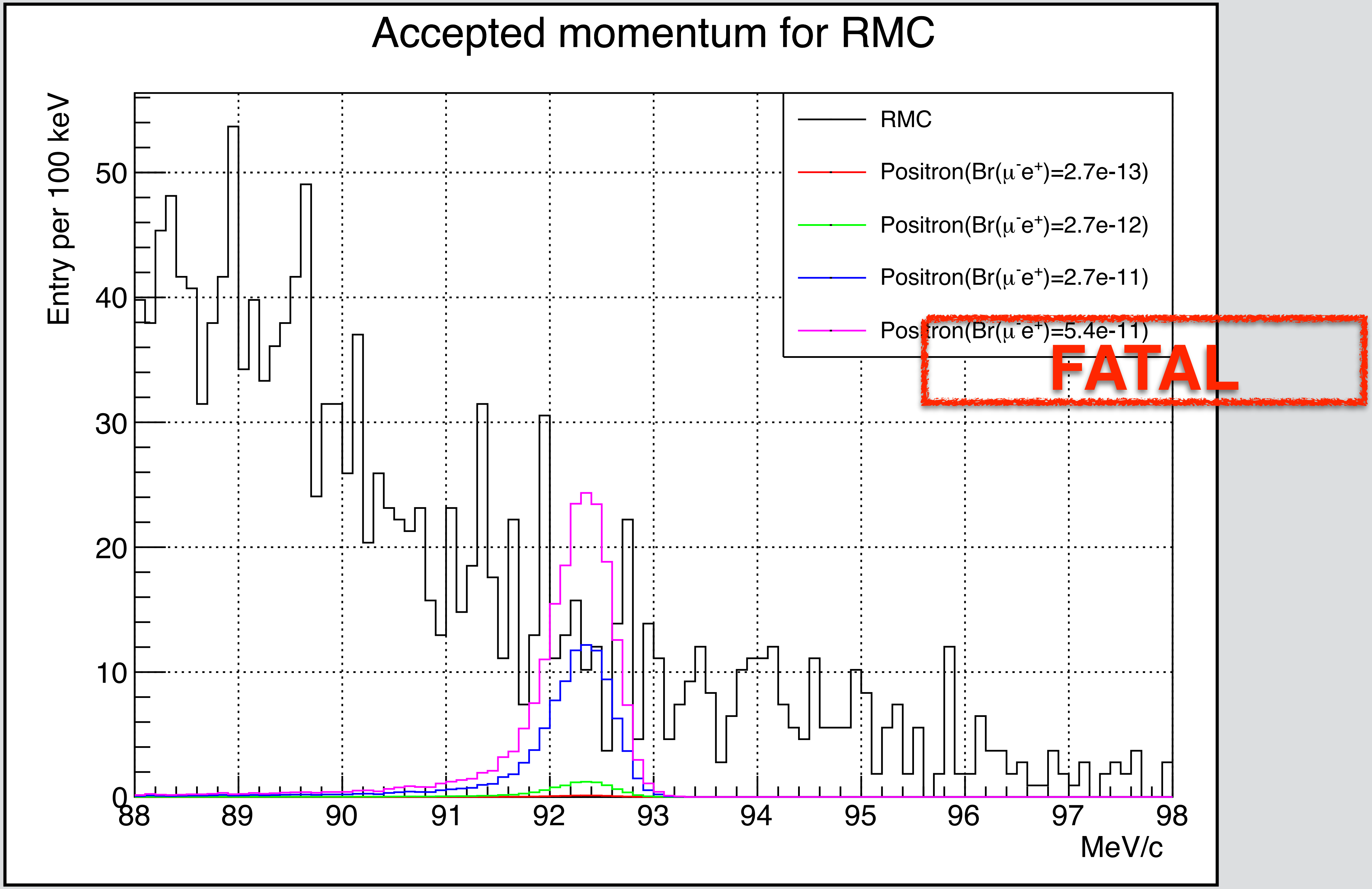
External Radiative muon capture (xRMC)

Event selection	Value		Remark
Online event selection efficiency	0.9		TDR
DAQ efficiency	0.9		TDR
Geometrical acceptance (coincidence)	0.006		
+ Momentum window	0.002		
+Time window	0.17	(0.42)	700 ns (500 ns) cut
Total (A_{RMC_e})	1.4e-6	(3.6e-6)	
Expected xRMC in physics run	**120**	**(310)**	**FATAL**

$$N_{xRMCe} = N_p \cdot R_{\mu\text{-stop}/p} \cdot f_{cap} \cdot Br(E\gamma) \cdot A_{xRMC\_e}$$

Parameters	Value	Description
N_p	1.9×10^{19} (1.2×10^{19})	Number of needed protons
$R_{\mu\text{-stop}/p}$	4.7×10^{-4}	Muon stopping rate
f_{cap}	0.61	Nuclear capture rate
$Br(E\gamma > 88.32 MeV)$	1×10^{-8}	Branching ratio of γ_{RMC}
A_{xRMC_e}	1.4e-6 (3.6e-6)	xRMC acceptance

Momentum of RMC



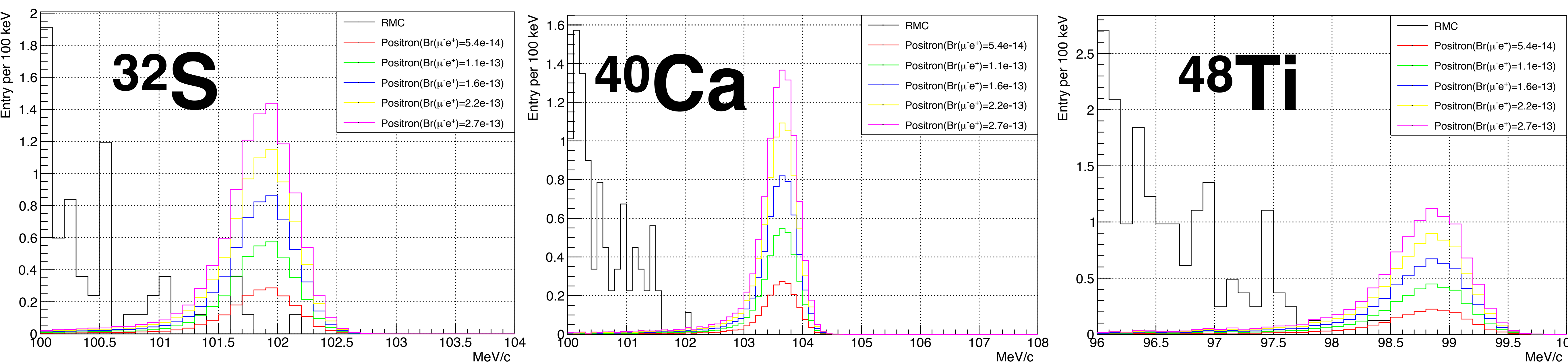
- Too many e- for 92.32 MeV electrons

Prospective : Change of targets?

Atom	$E_{\mu^- e^+}$ (MeV)	$E_{\mu^- e^-}$ (MeV)	E_{RMC}^{end} (MeV)	N.A. (%)	f_{cap} (%)	τ_{μ^-} (ns)
^{27}Al	92.30	104.97	101.34	100	61.0	864
^{32}S	101.80	104.76	102.03	95.0	75.0	555
^{40}Ca	103.55	104.39	102.06	96.9	85.1	333
^{48}Ti	98.89	104.18	99.17	73.7	85.3	329
^{50}Cr	104.06	103.92	101.86	4.4	89.4	234
^{54}Fe	103.30	103.65	101.93	5.9	90.9	206
^{58}Ni	104.25	103.36	101.95	68.1	93.1	152
^{64}Zn	103.10	103.04	101.43	48.3	93.0	159
^{70}Ge	100.67	102.70	100.02	20.8	92.7	167

Prospective : Change of targets?

Atom	$E_{\mu^- e^+}$ (MeV)	$E_{\mu^- e^-}$ (MeV)	E_{RMC}^{end} (MeV)	N.A. (%)	f_{cap} (%)	τ_{μ^-} (ns)
^{27}Al	92.30	104.97	101.34	100	61.0	864
^{32}S	101.80	104.76	102.03	95.0	75.0	555
^{40}Ca	103.55	104.39	102.06	96.9	85.1	333
^{48}Ti	98.89	104.18	99.17	73.7	85.3	329



Summary

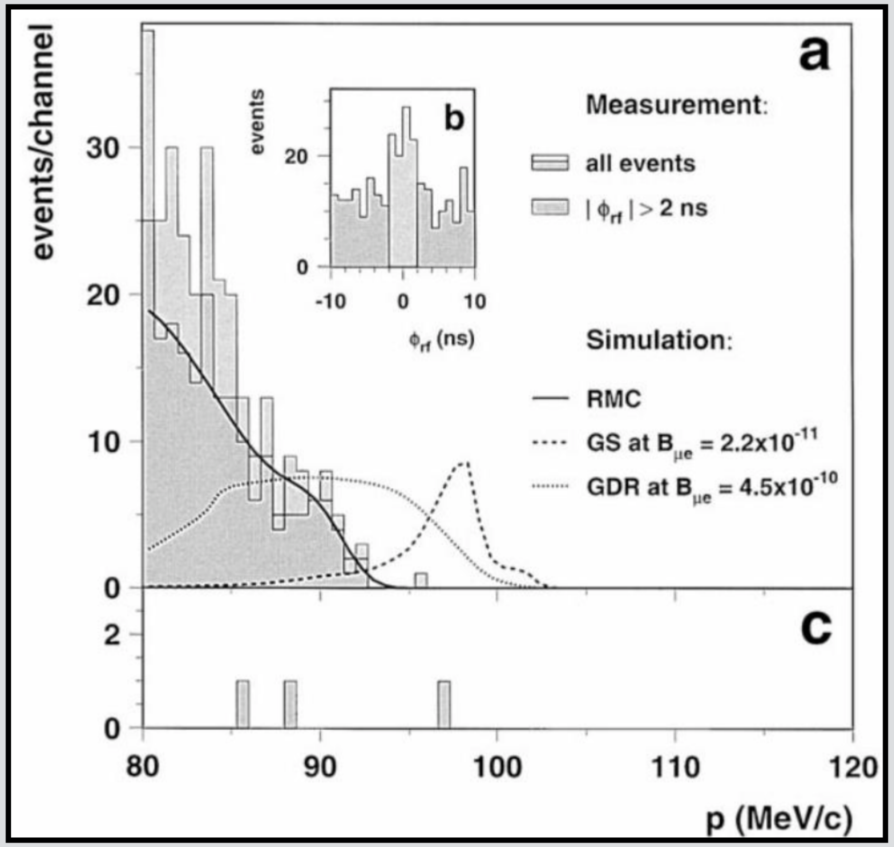
- Aluminium target is not a good target for Muon-Positron conversion search
- RMC shows bad results, we have to find a target material that has a energy peak further away from it
- Potential targets shows promising result in terms of RMC background with a branching ratio

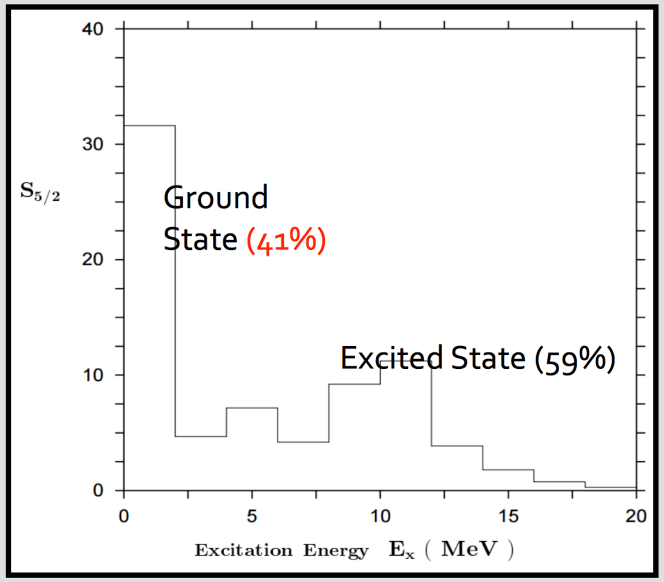
Backup

COMET: Muon to positron process

$$\mu^- + N(A,Z) \rightarrow e^+ + N(A,Z-2)$$

- A process violating both **flavour** and **lepton number** ($\Delta L=2$)
- Analogous to neutrinoless double beta decay
- Signal is monenergetic 92.3 MeV/c positron (ground state)
- Current limit : SINDRUM II: 1.7 x 10^{-12} (90% CL) on Ti
- Intrinsic background
  - Radiative Muon Capture (RMC)
  - Radiative Pion Capture (RPC)
  - Comsic Ray Background (CRB)
  - Muon Decay-in-orbit (DIO)

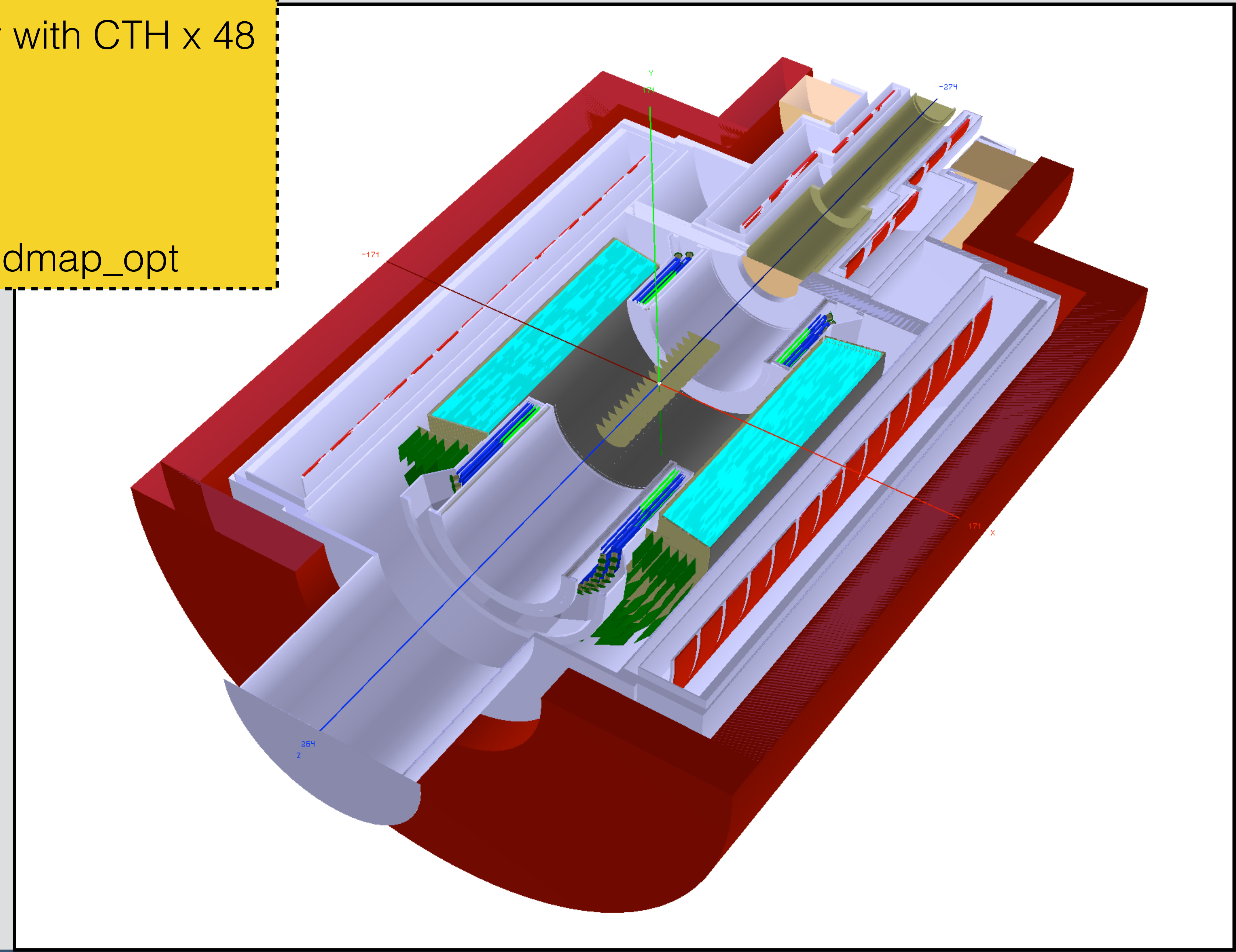




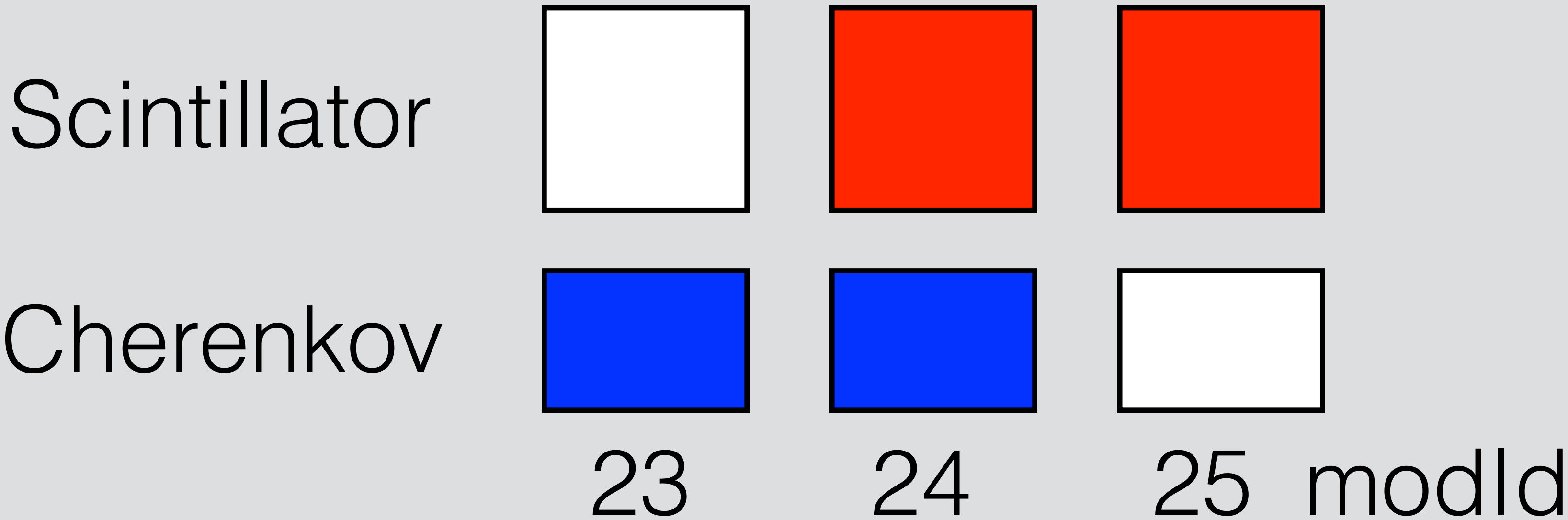
Positron/Electron signal studies

Simulation setup

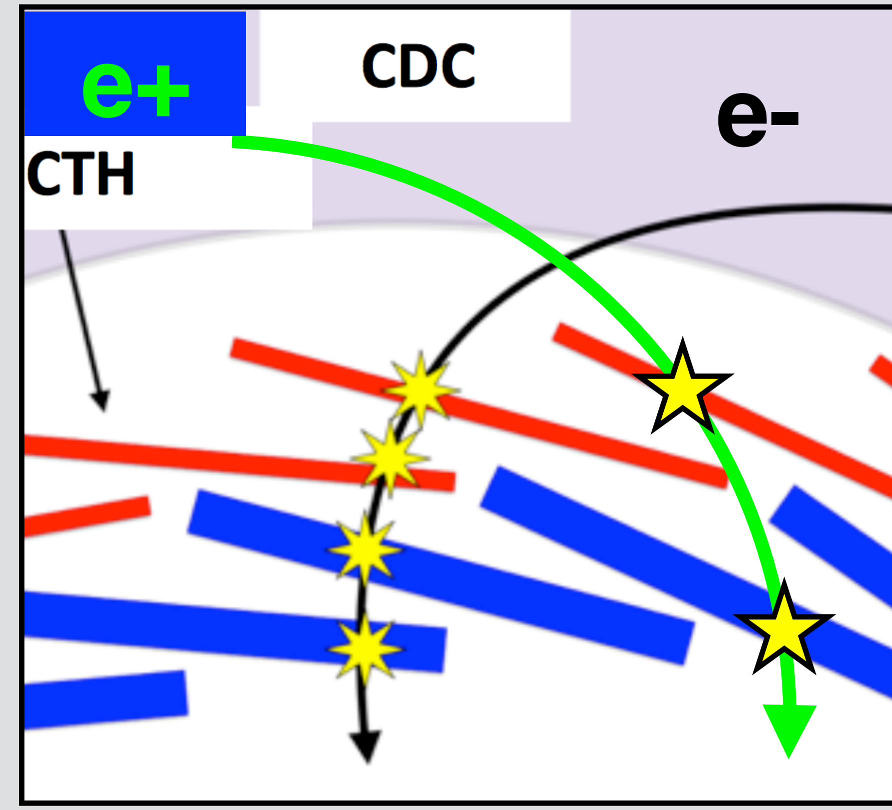
1. Not official ICEDUST (will be soon after merge request OK)
2. Updated geometry with CTH x 48
3. Shielding
4. RECBE
5. Magnetic field: 150630_defaultFieldmap_opt



Trigger Algorithm on CTH

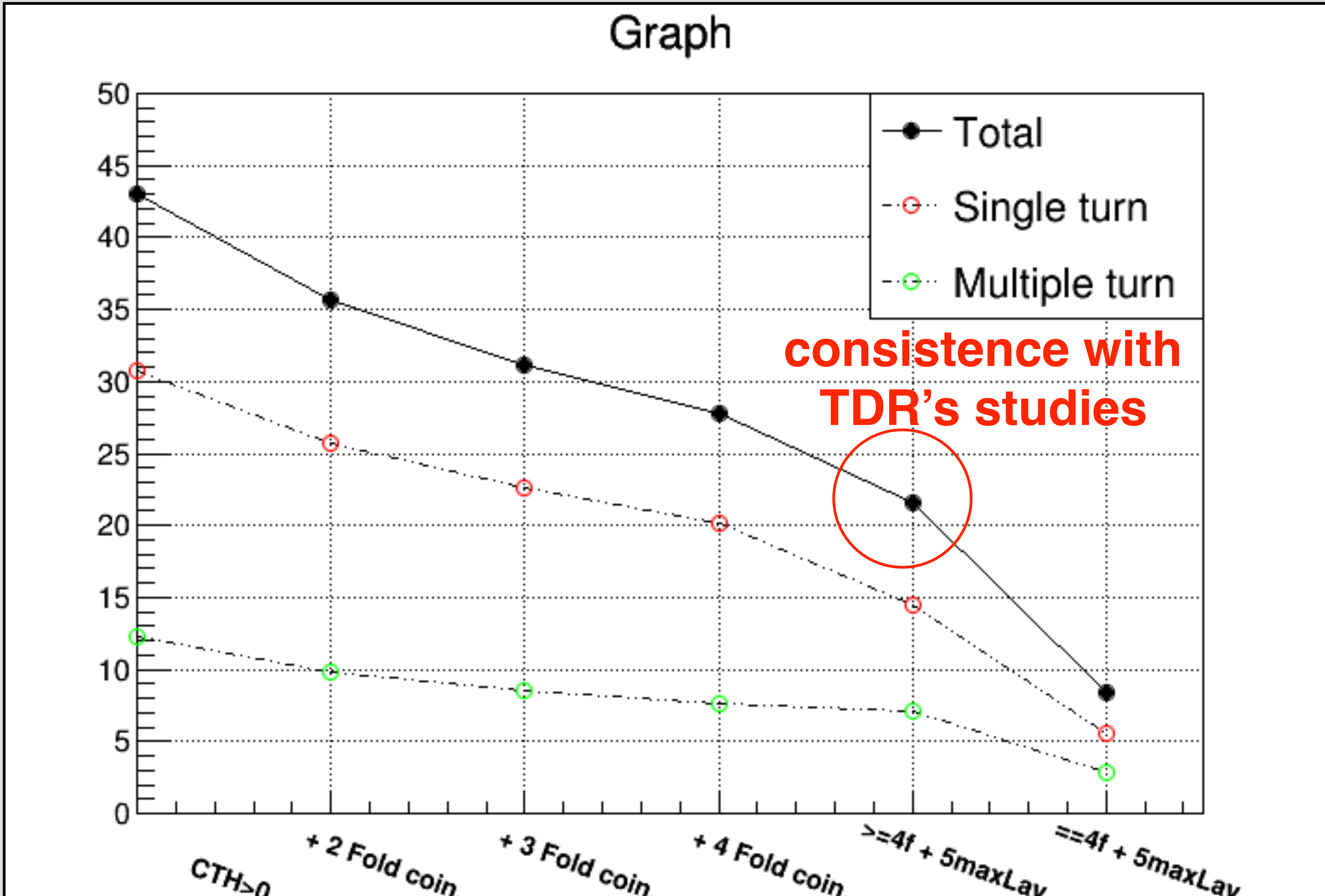


Combination : 2^3

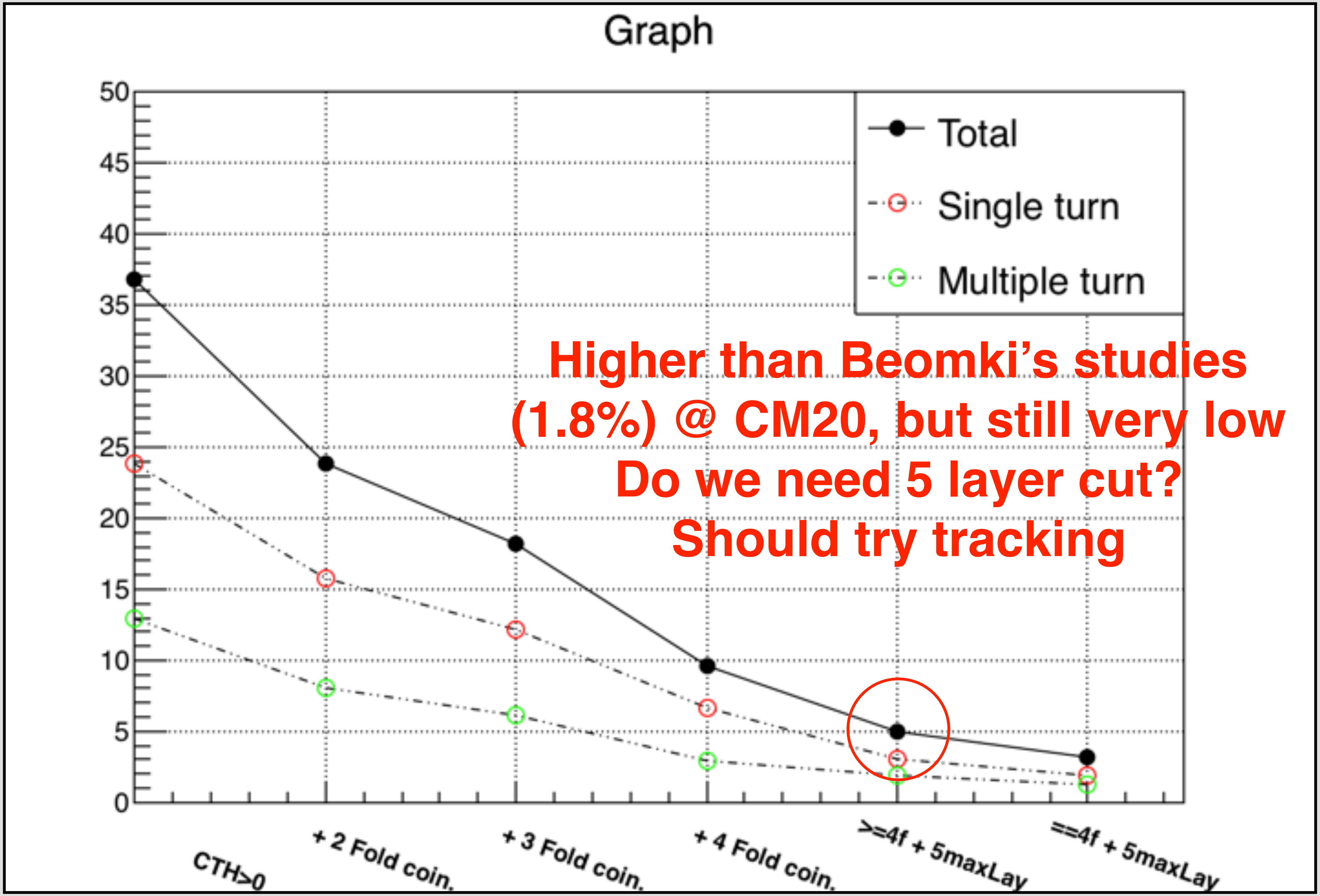


1. **Remove hits**
   - ➡ cherenkov : beta < 1/1.5
   - ➡ scintillator : energy deposition < 63 keV
2. **Loop over each module from scintillator/cherenkov**
3. **Count if there are hits in clockwise direction**
   - ➡ in the case I show there are 4 combinations picked up
4. **Pick up the best type**
   - ➡ type = countSci + (countChe+1)*2^3 , where type=(0,71)

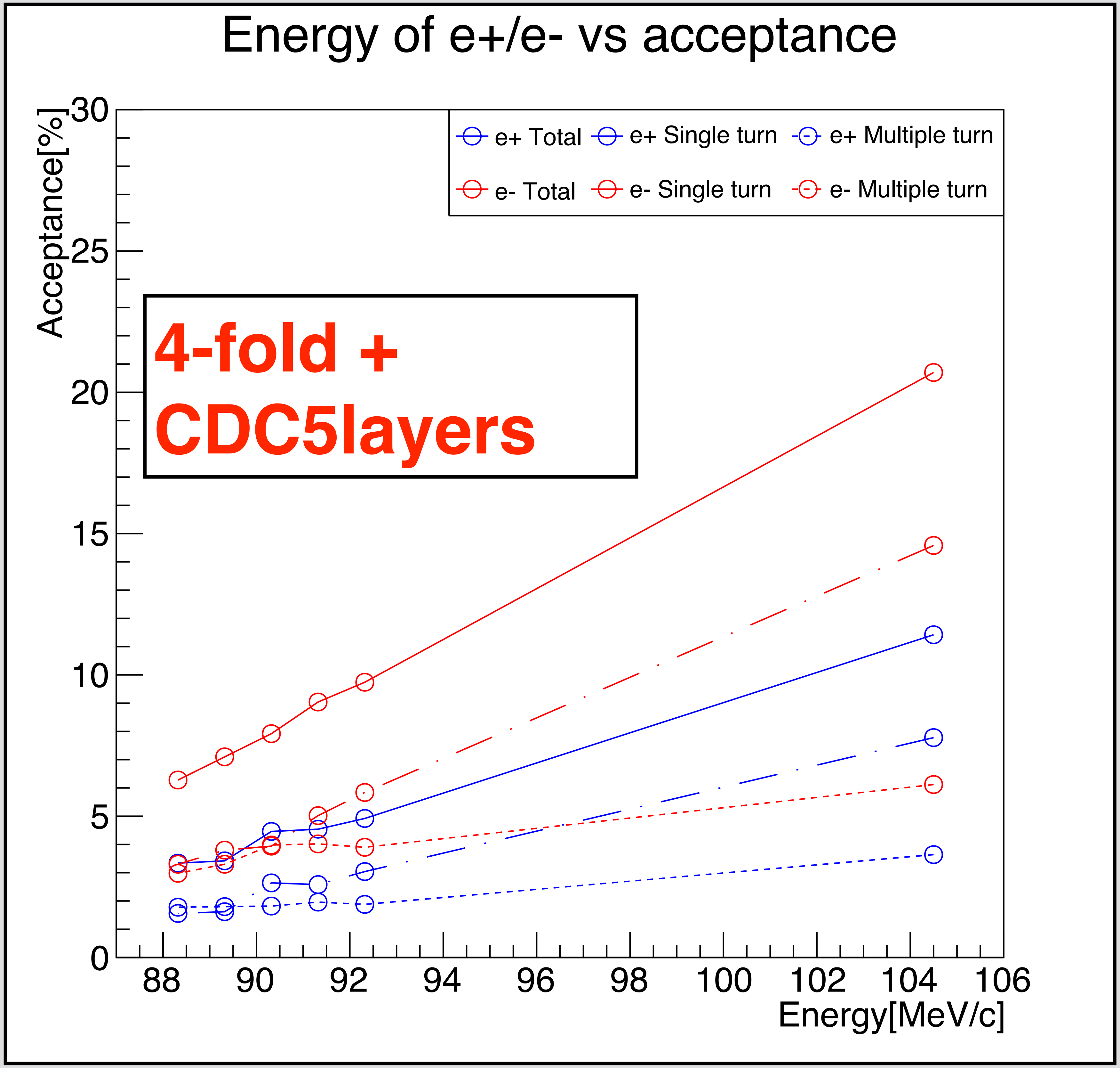
Acceptance of e- (104.5MeV)



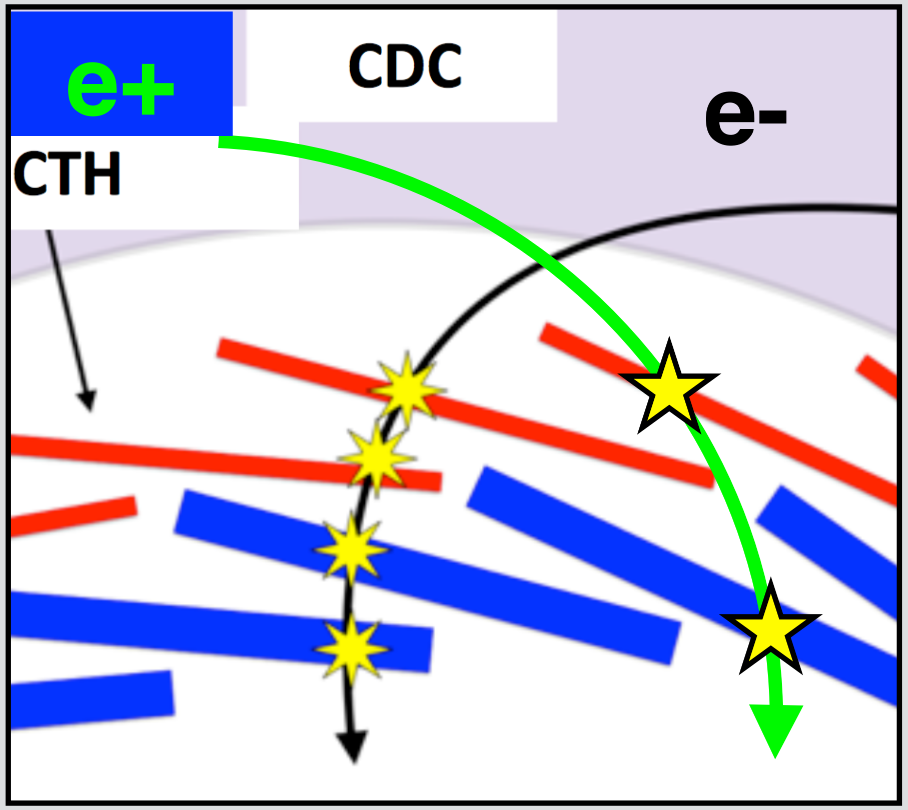
Acceptance of e+ (92.32MeV)



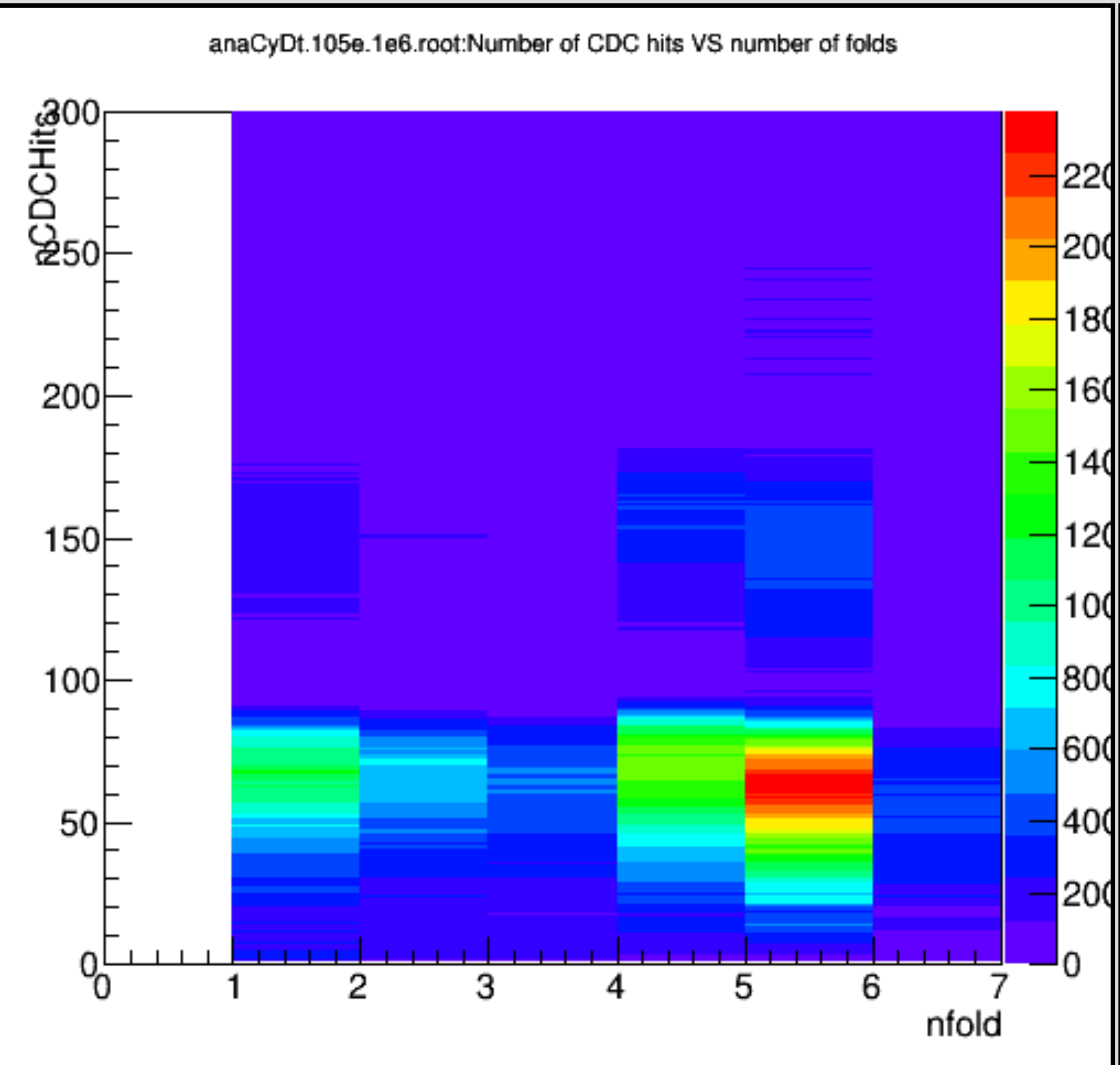
Summary for electron and positron with cut

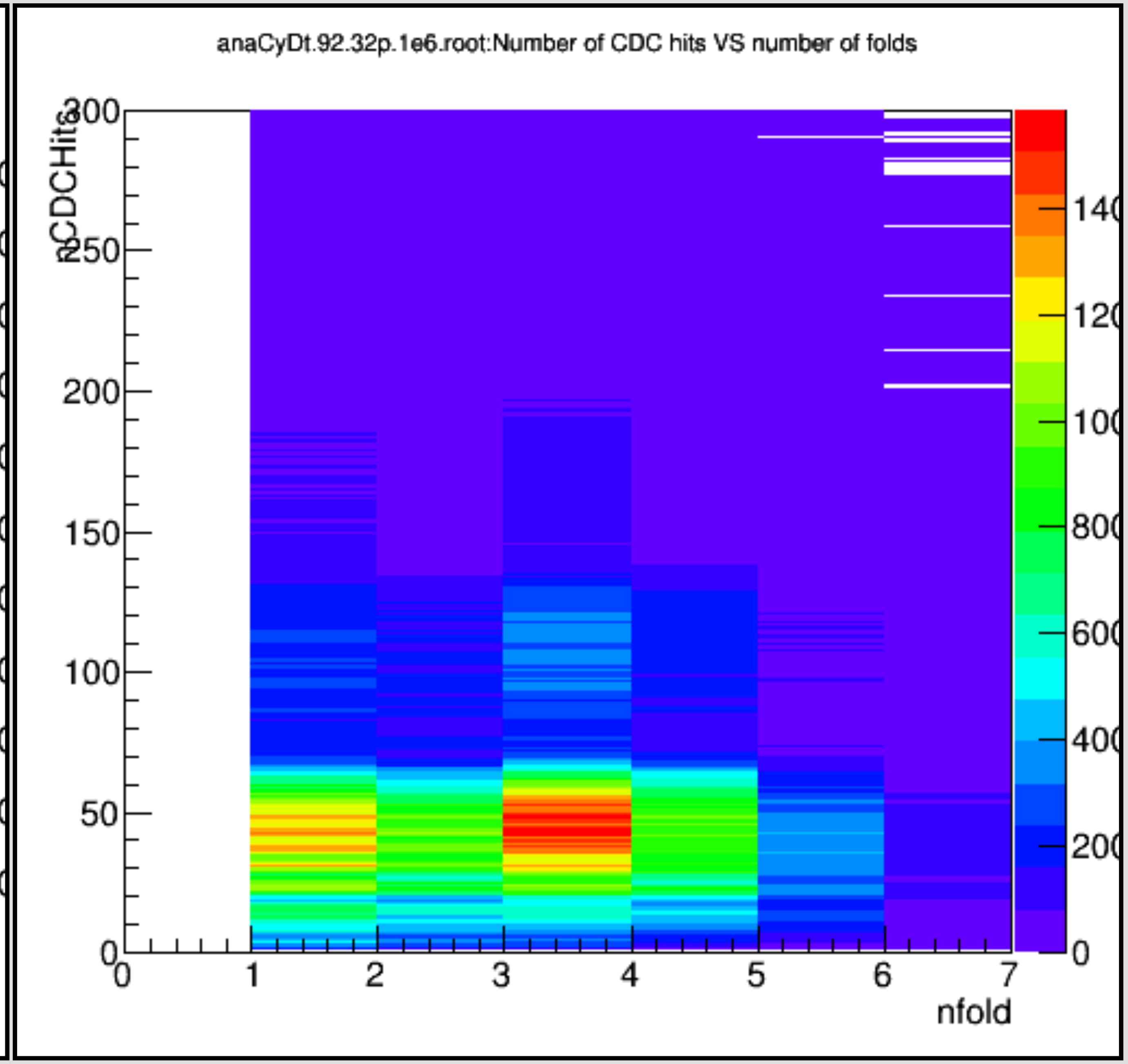


1. e-(104.5) total:
   ➡ **21.6%**
2. e-(92.32) total:
   ➡ **9.74%**
3. e+(92.32) total:
   ➡ **4.21%**



Electrons acceptance studies





105 MeV Electron

92.3 MeV Positron

TDR comparison

Event selection	Value	Comments
Online event selection efficiency	0.9	Secti[illegible]
DAQ efficiency	0.9	
Track finding efficiency	0.99	
Geometrical acceptance + Track quality cuts	0.18	
Momentum window ($\varepsilon_{\mathrm{mom}}$)	0.93	103.6 MeV/c < P_e <106.0 MeV/c
Timing window ($\varepsilon_{\mathrm{time}}$)	0.3	700 ns < t < 1170 ns
Total	0.041	

TDR Should be updated!!

	105MeV e-	92.32 e+	Commets
Online event selection	0.9	0.9 ?	
DAQ efficiency	0.9	0.9	
Track finding efficiency	0.99	0.99 ?	
Geometrical acceptance + track quality cuts	0.21	0.042	
Momentum window	0.91	0.62	e-: 103.6 MeV < Pe < 106.0 MeV e+:91.5 MeV < Pe < 92.5 MeV
Time window	0.50/0.31	0.78/0.48	500 ns or 700 ns cut
Total	0.077/0.048	0.016/0.010	
TDR value	0.041		700ns cut

Sensitivity estimation

$$SES = Br(\mu^- + Al \rightarrow e^- + Al) = \frac{1}{N_\mu \cdot f_{cap} \cdot f_{gnd} \cdot A_{\mu-e}}$$

	e-	e+
Muon Capture rate (f_{cap})	0.61 (Al)	0.61 (Al)
Fraction of ground state (f_{gnd})	0.9	0.4
Conversion rate (Aμ-e)	0.048(0.077)	0.010(0.016)

	e-	e+	Commets
Aimed Single Event Sensitivity (SES)	3 x 10^{-15}	3 x 10^{-14}	2 orders than the current limit
N muons needed	1.3 x 10^{16} (7.9 x 10^{15})	9.1 x 10^{15} (5.7 x 10^{15})	
N protons needed	2.7 x 10^{19} (1.7 x 10^{19})	1.9 x 10^{19} (1.2 x 10^{19})	Sam@CM23 ($R_{\mu\text{-stop}}$) Stopping ratio 4.7 x 10^{-4}
Time for Physics run	**122 days** (76 days)	**88 days** (55 days)	3.2kw 8GeV proton 0.4μA

Only positron's Background studies

Radiative muon capture (RMC)

1. **Two types of RMC**

External : $\mu^- + Al \rightarrow \nu_\mu + Mg + \gamma$ Followed by $\gamma \rightarrow e^- + e^+$

Internal : $\mu^- + Al \rightarrow \nu_\mu + Mg + e^- + e^+$ (Virtual Photon)

2. **Endpoint energy of photon ~ 101.85 MeV → 101.34 MeV for e+**

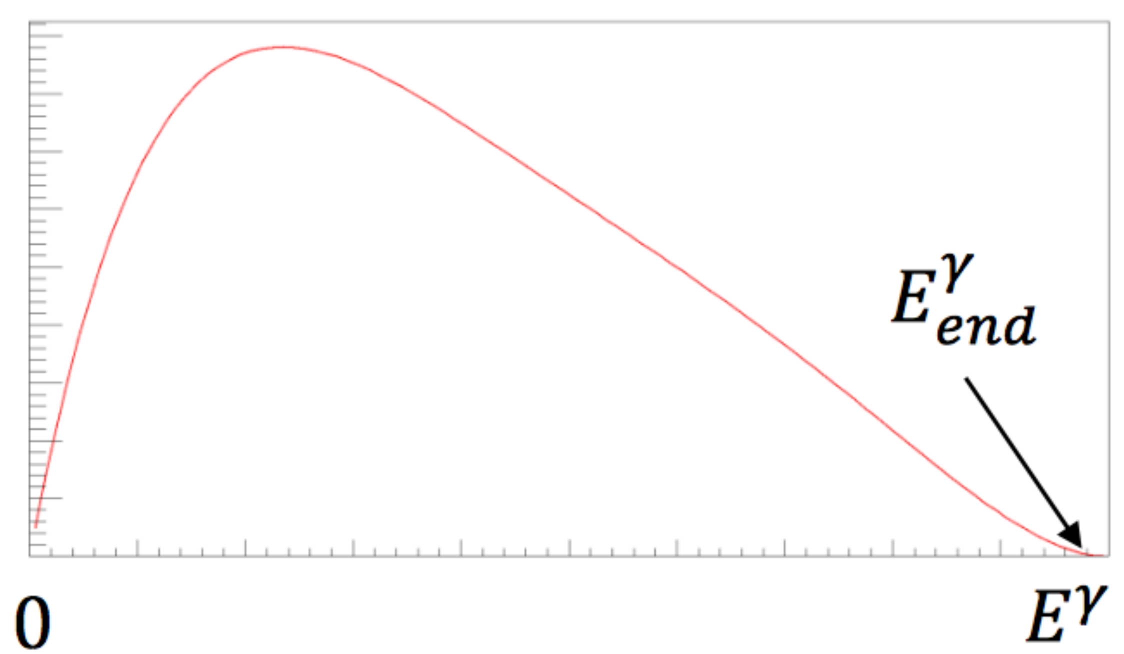
1. **Experimentally Br(Eγ > 57 MeV) ~ 1.9 x 10^{-5}**
2. **Spectrum is calculated in "Phy Rev C, Volume 32,Number5, Nov 1985"**

➡ Spectrum of gamma can be described as:

$$P(x) = C(1 - 2x + 2x^2)x(1-x)^2, \qquad x = \frac{E_\gamma}{E^\gamma_{end}}$$

Br(Eγ > 88.32 MeV) ~ 1 x 10^{-8}

O(1e7) of RMC gamma are generated



RMC photon energy (E_γ) spectrum

External Radiative muon capture (xRMC)

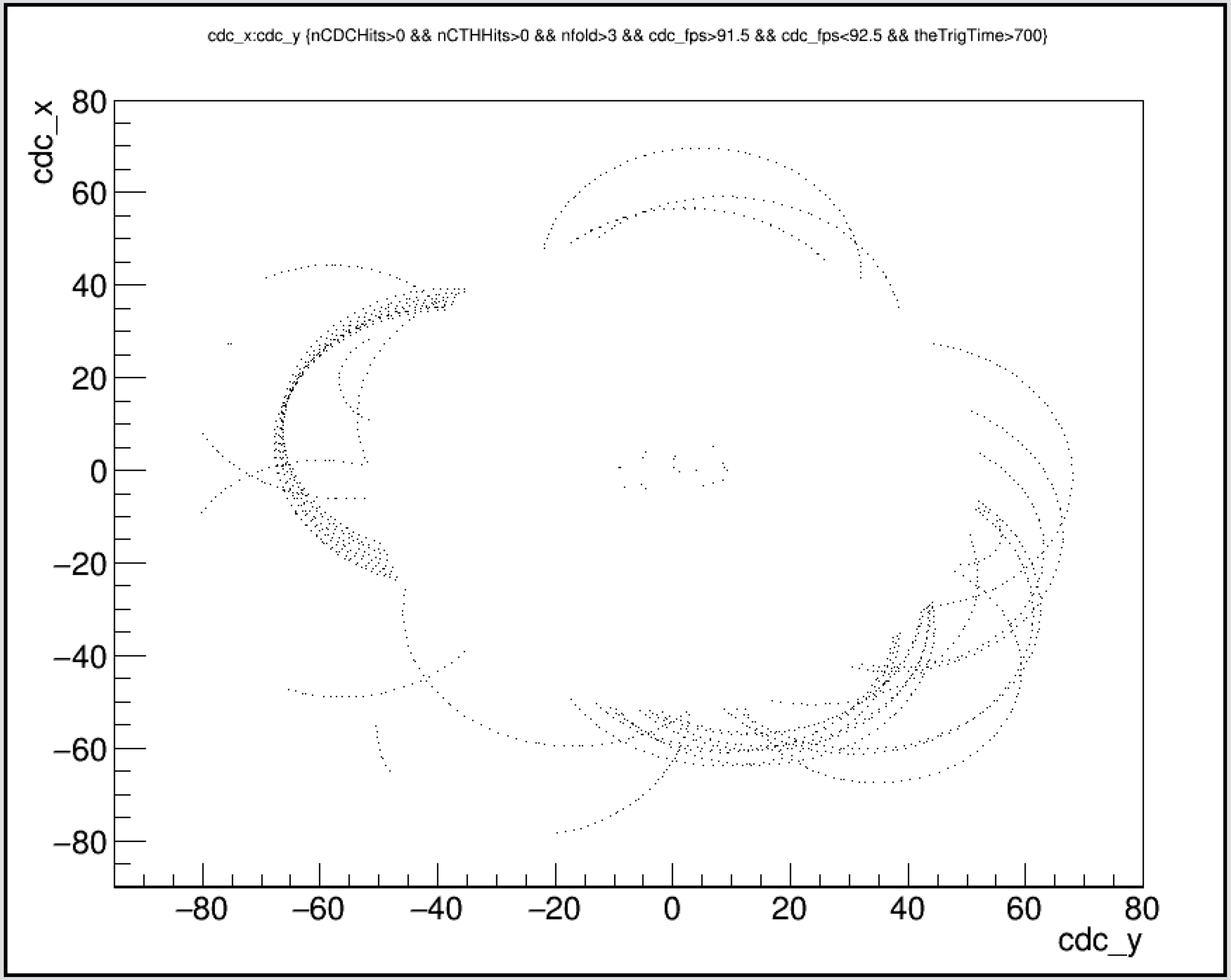
Event selection	Value		Remark
Online event selection efficiency	0.9		TDR
DAQ efficiency	0.9		TDR
Geometrical acceptance (coincidence)	0.006		
+ Momentum window	0.002		
+Time window	0.17	(0.42)	700 ns (500 ns) cut
Total (A_{RMC_e})	1.4e-6	(3.6e-6)	
Expected xRMC in physics run	**120**	**(310)**	

$$N_{xRMCe} = N_p \cdot R_{\mu\text{-stop/p}} \cdot f_{cap} \cdot Br(E\gamma) \cdot A_{xRMC\_e}$$

Parameters	Value	Description
N_p	1.9×10^{19} (1.2×10^{19})	Number of needed protons
$R_{\mu\text{-stop/p}}$	4.7×10^{-4}	Muon stopping rate
f_{cap}	0.61	Nuclear capture rate
$Br(E\gamma > 88.32 MeV)$	1×10^{-8}	Branching ratio of γ_{RMC}
A_{xRMC_e}	1.4e-6 (3.6e-6)	xRMC acceptance

How to avoid x/iRMC background?

CDC cross section



We cannot avoid it actually…they are all from the disk….

Internal Radiative muon capture (iRMC)

Internal : $\mu^- + Al \to \nu_\mu + Mg + e^- + e^+$ (Virtual Photon)

1. iRMC is very dangerous
2. Energy can go up to 101.34 MeV
3. Can happen in the disk

➡ We cant know if the event is from RMC or μ-e+

The paper by Norman M. Kroll [6] gave an estimation of Internal Radiative Pion Capture (RPC) Branching ratio compared to External RPC. (Material independently)

$$\rho = \frac{Br_{Int-RPC}}{Br_{Ext-RPC}} \approx 0.007(\approx \alpha ?)$$

1. If this is true, we can have 0.7 or 0.4 events of Internal RMC

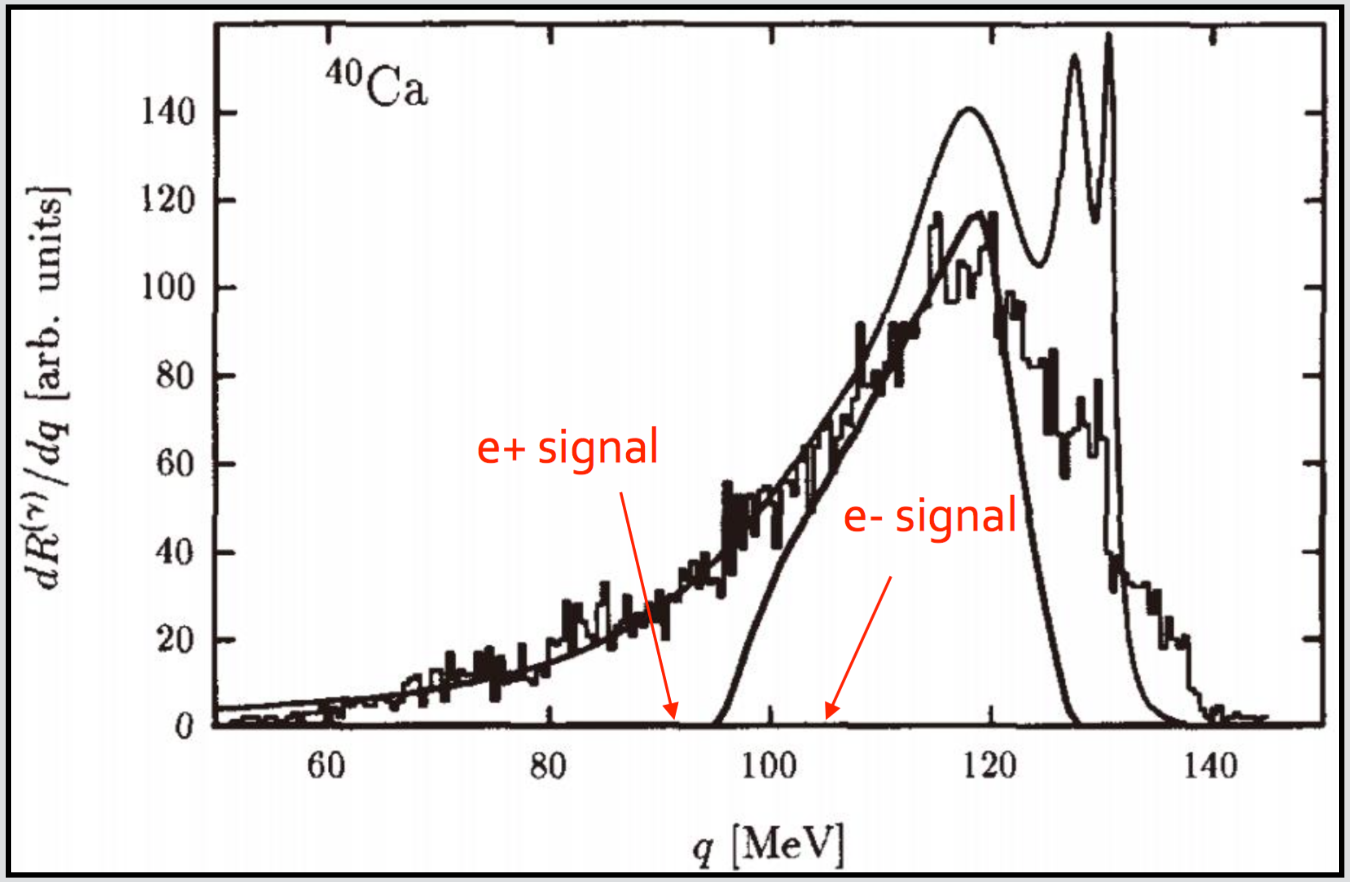
Radiative pion capture (RPC)

1. **Same as RMC, two types of RPC**

External : $\pi^- + Al \rightarrow \gamma + Na$ followed by $\gamma \rightarrow e^- + e^+$

Internal : $\pi^- + Al \rightarrow e^- + e^+ + Na$

2. **RPC depends highly on the Extinction factor**
3. **From 8GeV/c experiment extinction factor (<1e-10) is guaranteed @CM25**



1. **Simulated 1e7 gamma for xRPC studies according to the experimental data**
2. **Mainly to check if the RPC is negligible or not**

Radiative pion capture (RPC)

Event selection	Value	Remark
Online event selection efficiency	0.9	TDR
DAQ efficiency	0.9	TDR
A_{xRPC}	8.7e-6 (1.4e-5)	
Total (A_{RPC_e})	7.0e-6 (1.1e-5)	700 ns (500 ns) cut
Expected xRMC in physics run	**8.2e-4 (1.3e-3)**	

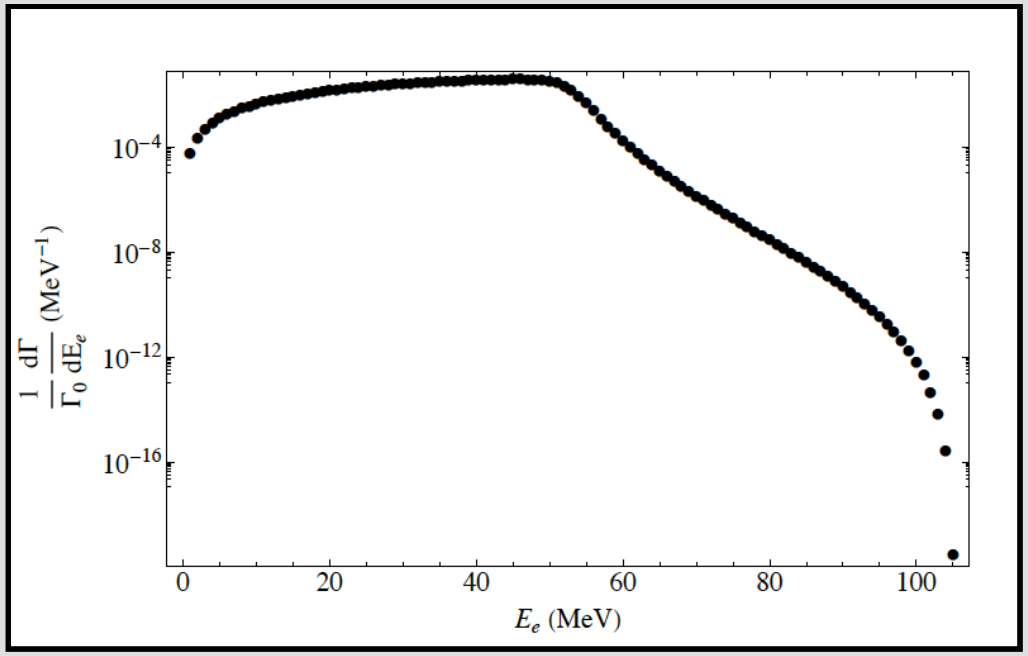
$$N_{xRPCe} = N_p \cdot R_{ext} \cdot R_{\pi\text{-stop/p}} \cdot Br(E\gamma) \cdot A_{xRMC\_e}$$

Parameters	Value	Description
N_p	1.9×10^{19} (1.2×10^{19})	Number of needed protons
R_{ext}	< 1e-10	Extinction rate
$R_{\pi\text{-stop/p}}$	3.1×10^{-6}	Pion stopping rate
Br(Eγ)	0.02	Branching ratio of γ_{RpC}
A_{xRMC_e}	7.0e-6 (1.1e-6)	xRMC acceptance

RPC rate is at negligible level

Mis-Identification of Charge (MIC)

1. Mis-identification of charge can be dangerous
2. In SINDRUM-II, $P_{e^- \to e^+}$~0.2%



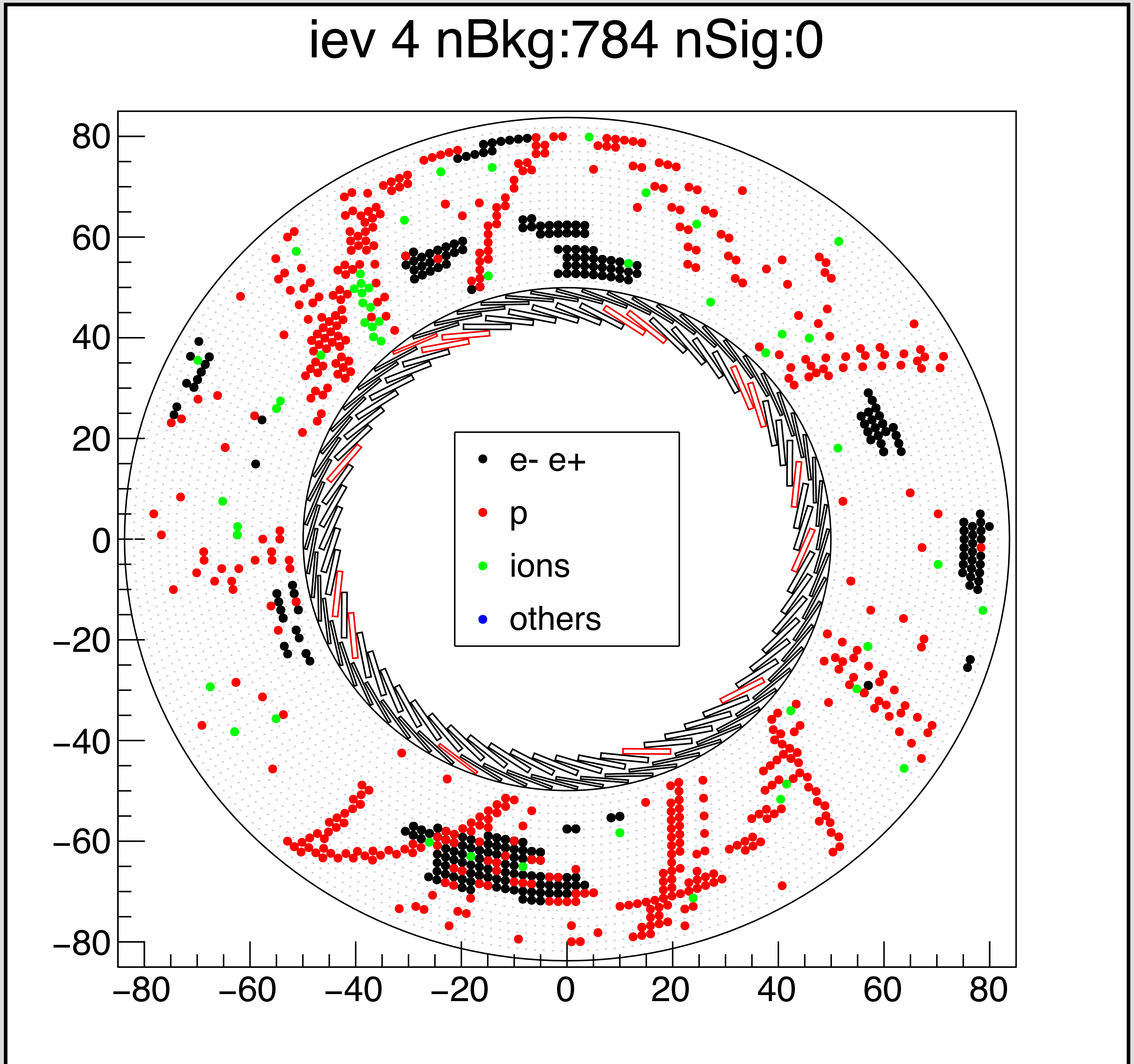
1. $N_{e90} / N_{e105} \sim 10^5$
2. Further studied needed

$$N_{MICp} = N_p \cdot R_{\mu\text{-stop}/p} \cdot (1-f_{cap}) \cdot Br(DIO) \cdot A_{DIO} \cdot P_{e^- \to e^+}$$

Parameters	Value	Description
N_p	1.9×10^{19} (1.2×10^{19})	Number of needed protons
$R_{\mu\text{-stop}/p}$	4.7×10^{-4}	Muon stopping rate
f_{cap}	0.61	Nuclear capture rate
Br(DIO)	6.77×10^{-10}	90 - 105MeV/c
$P_{e^- \to e^+}$	0.002	MIC rate
A_{DIO}	???	DIO acceptance

Beam related background

Beam related background



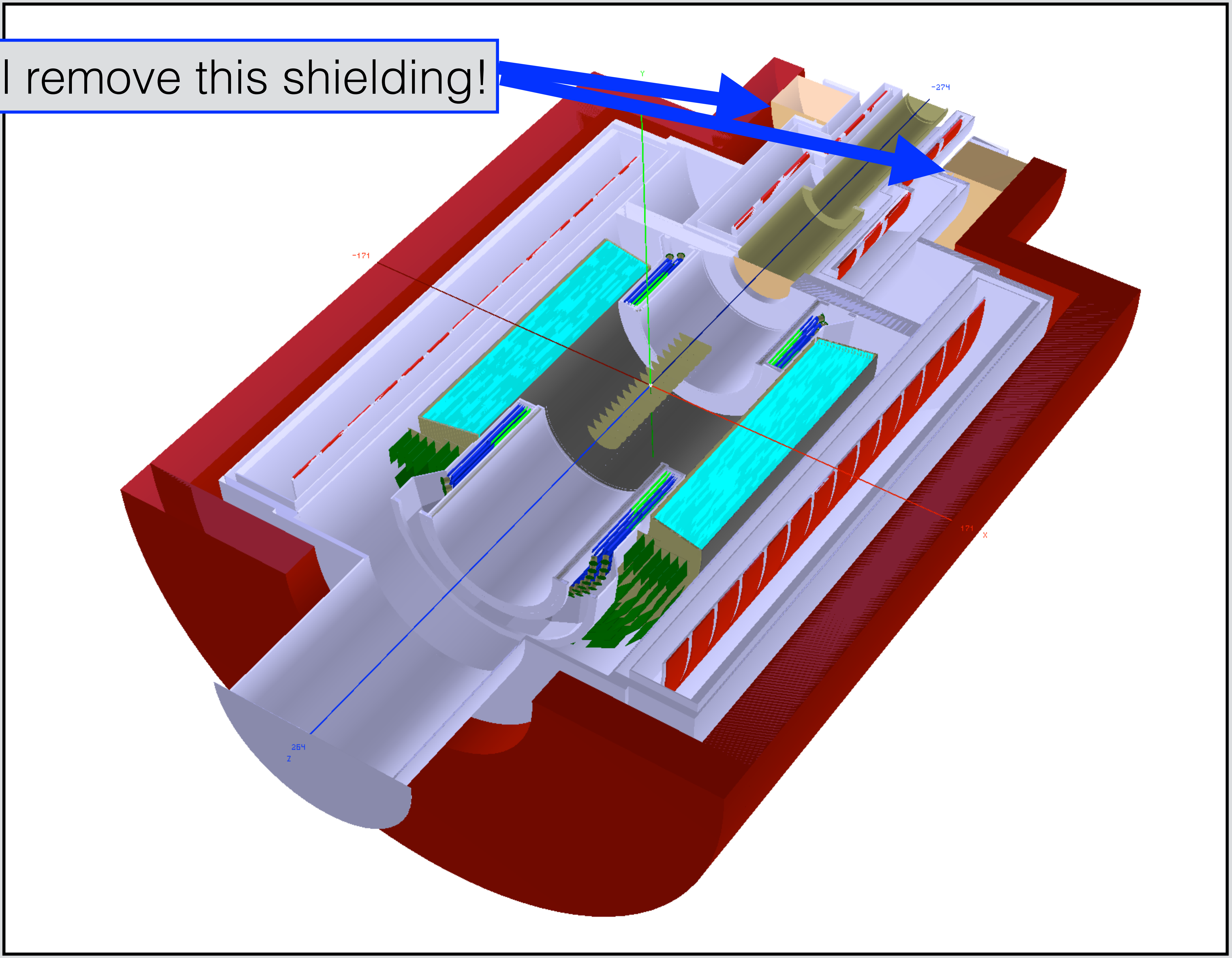
Previous studies: MC3b analysis by Beomki @ CM20
→ No e+ even with out momentum cut

However, I will do mass production of MC4 or 5 data for later purpose soon!

Occupancy of CDC ~ 784/4482 = 17.5%

Updated geometry

We will remove this shielding!



Anti proton background

Cosmic ray background

Background summary

Type	Background	Estimated events (TDR)	e+
Physics	Muon decay in orbit	0.01	0.01
	Radiative muon capture	0.0019	**120 (310)**
	Neutron emission after muon capture	< 0.001	< 0.001
	Charged particle emission after muon capture	< 0.001	< 0.001
Prompt Beam	* Beam electrons		
	* Muon decay in flight		
	* Pion decay in flight		
	* Other beam particles		
	All (*) Combined	≤ 0.0038	< ?
	Radiative pion capture	0.0028	**< 8.2e-4 (1.3e-3)**
	Neutrons	$\sim 10^{-9}$	$\sim 10^{-9}$
Delayed Beam	Beam electrons (positron)	~ 0	~ 0
	Muon decay in flight	~ 0	~ 0
	Pion decay in flight	~ 0	~ 0
	Radiative pion capture	~ 0	~ 0
	Anti-proton induced backgrounds	0.0012	~ 0.0012
Others	Cosmic rays†	< 0.01	<0.01
Total		0.032	**~ 120 (310)**

† This estimate is currently limited by computing resources.

Other possibilities

Endpoint energies for $\mu^- \to e^+$ conversion and radiative muon capture for the various titanium isotopes

A	abundance (%)	$E^{max}_{\mu^- e^+}$ (MeV)	E^{max}_{RMC} (MeV)
46	7.94	102.26	91.4 ± 2.0
47	7.44	100.66	93.2 ± 2.0
48	73.78	98.99	89.7 ± 2.0
49	5.51	95.98	91.8 ± 2.0
50	5.34	91.39	86.9 ± 2.0

If we go higher in Z, we may find lower endpoint of energy of RMC, some works have been carried out by our collaborators already! But still many room to improve!
Ofcos not only the RMC, but RPC and DIO, which are important for muon positron studies

PHYSICAL REVIEW D **96,** 075027 (2017)

Future experimental improvement for the search of lepton-number-violating processes in the $e\mu$ sector

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(Received 20 August 2017; published 18 October 2017)

The conservation of lepton flavor and total lepton number are no longer guaranteed in the Standard Model after the discovery of neutrino oscillations. The $\mu^- + N(A, Z) \to e^+ + N(A, Z-2)$ conversion in a muonic atom is one of the most promising channels to investigate the lepton number violation processes, and measurement of the $\mu^- - e^+$ conversion is planned in future $\mu^- - e^-$ conversion experiments with a muonic atom in a muon-stopping target. This article discusses experimental strategies to maximize the sensitivity of the $\mu^- - e^+$ conversion experiment by introducing the new requirement of the mass relation of $M(A, Z-2) < M(A, Z-1)$, where $M(A, Z)$ is the mass of the muon-stopping target nucleus, to eliminate the backgrounds from radiative muon capture. The sensitivity of the $\mu^- - e^+$ conversion is expected to be improved by 4 orders of magnitude in forthcoming experiments using a proper target nucleus that satisfies the mass relation. The most promising isotopes found are ^{40}Ca and ^{32}S.

DOI: 10.1103/PhysRevD.96.075027

Summary

Signal acceptance studies for e+e- shown

e+ : ~ 0.010(0.016)

e- : ~ 0.048(0.077)

Days of physics run for e+e- predicted (aiming at 2 orders higher than current limit)

e+ : 88 days (55 days)

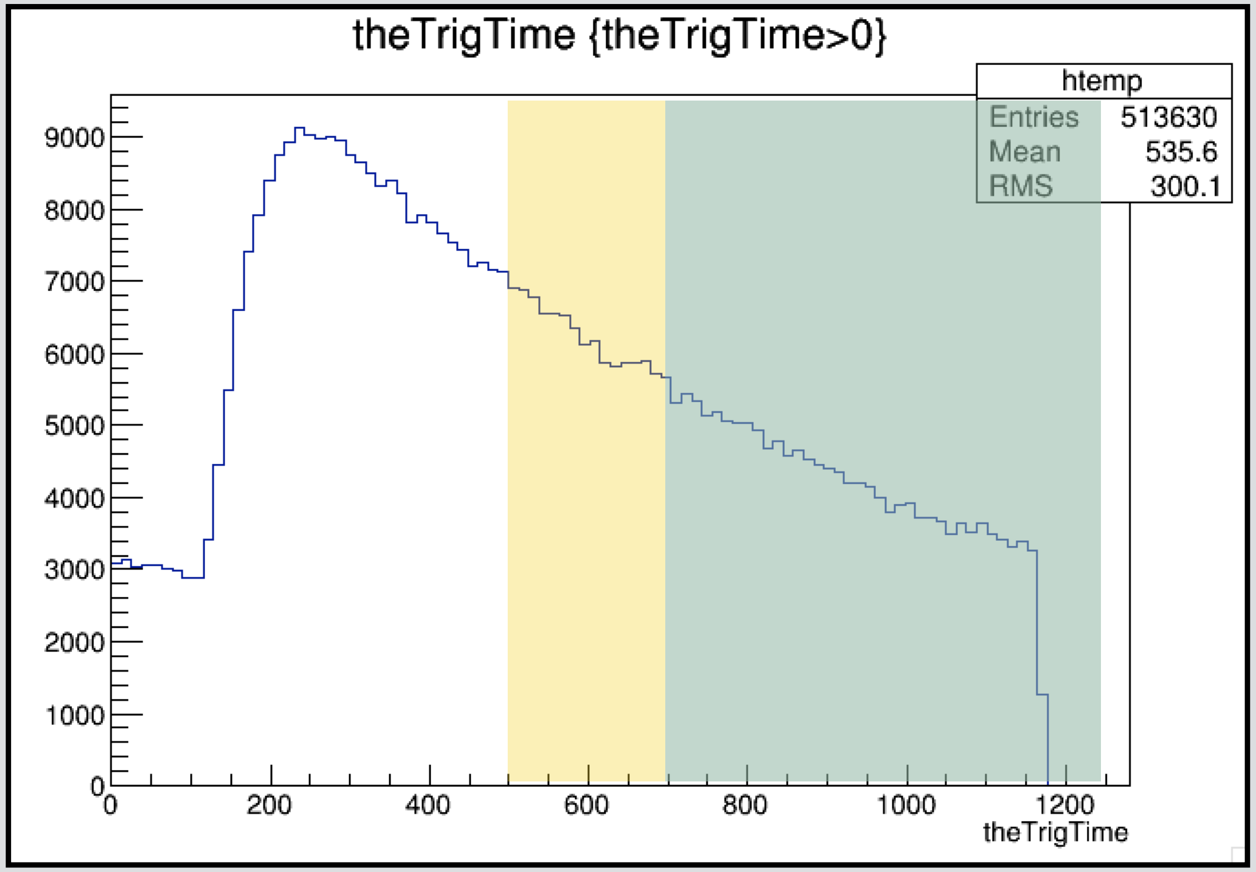
e- : 122 days (76 days)

Background

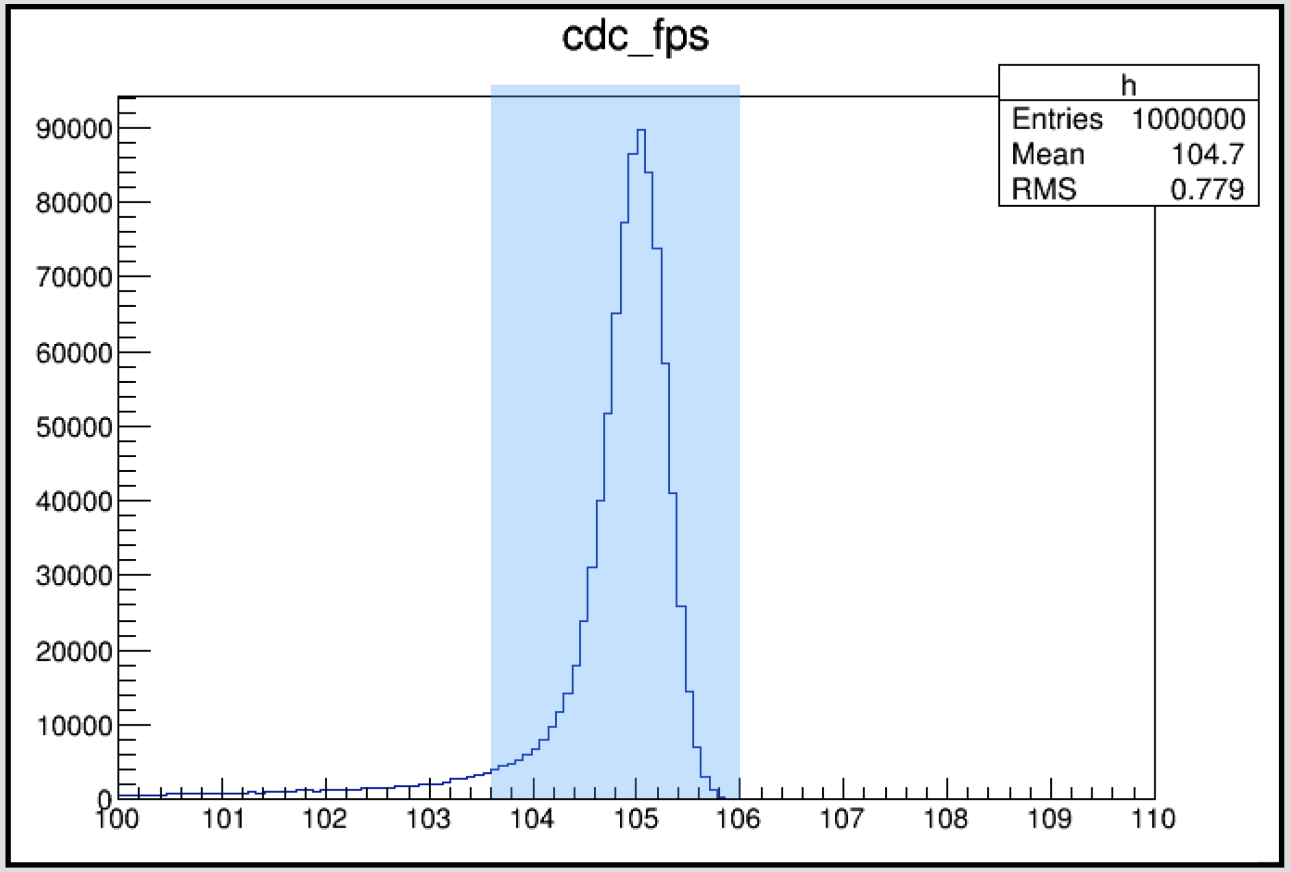
RMC and RPC revisited

RMC is the dominant part of the background ~ 120 (310) events

Timing and Momentum window cut of e-



500 ns or 700 ns cut

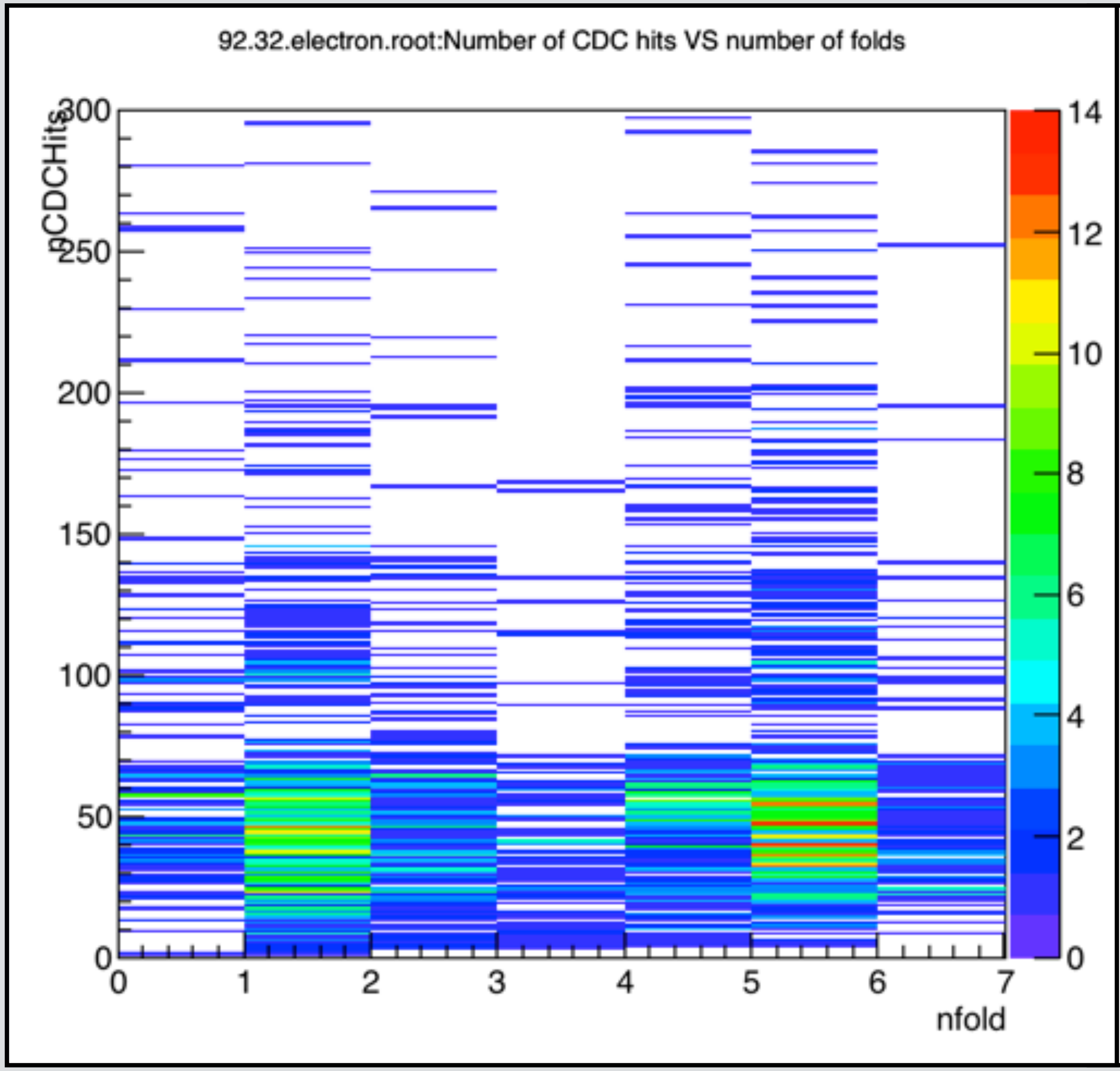


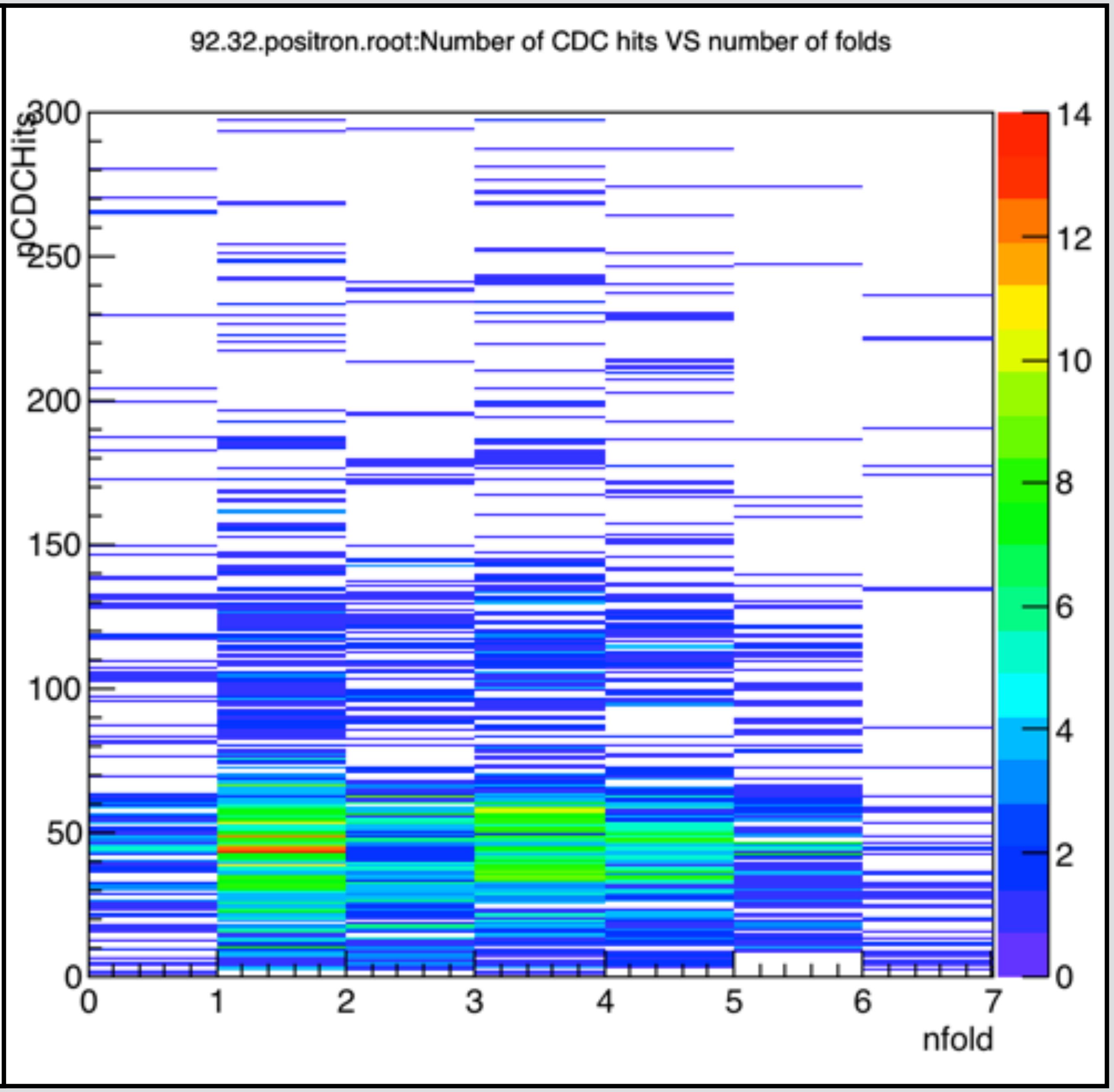
103.6 MeV/c < Pe < 106.0MeV

Reasons for low acceptance

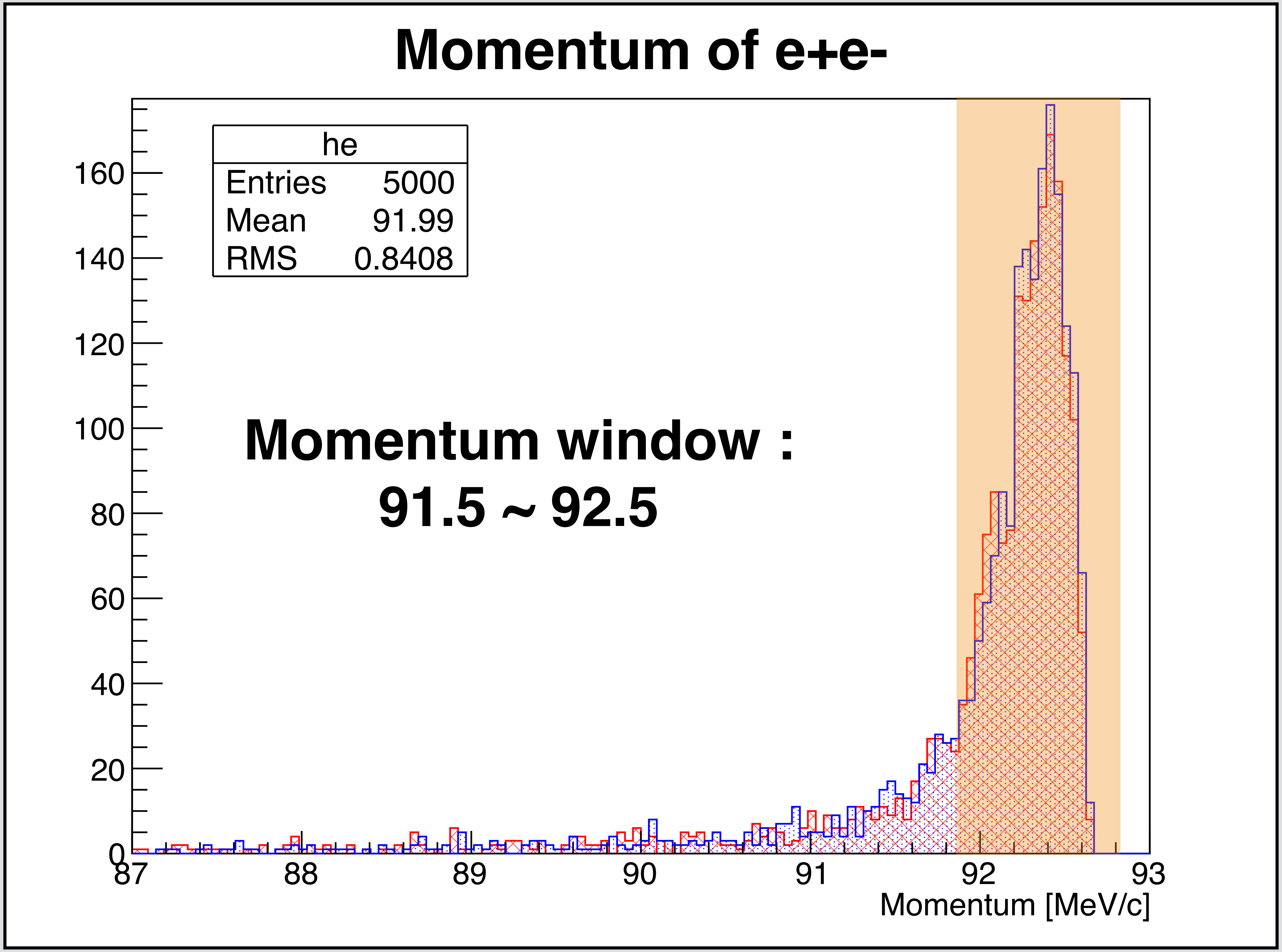
Electron 92.32

Positron 92.32

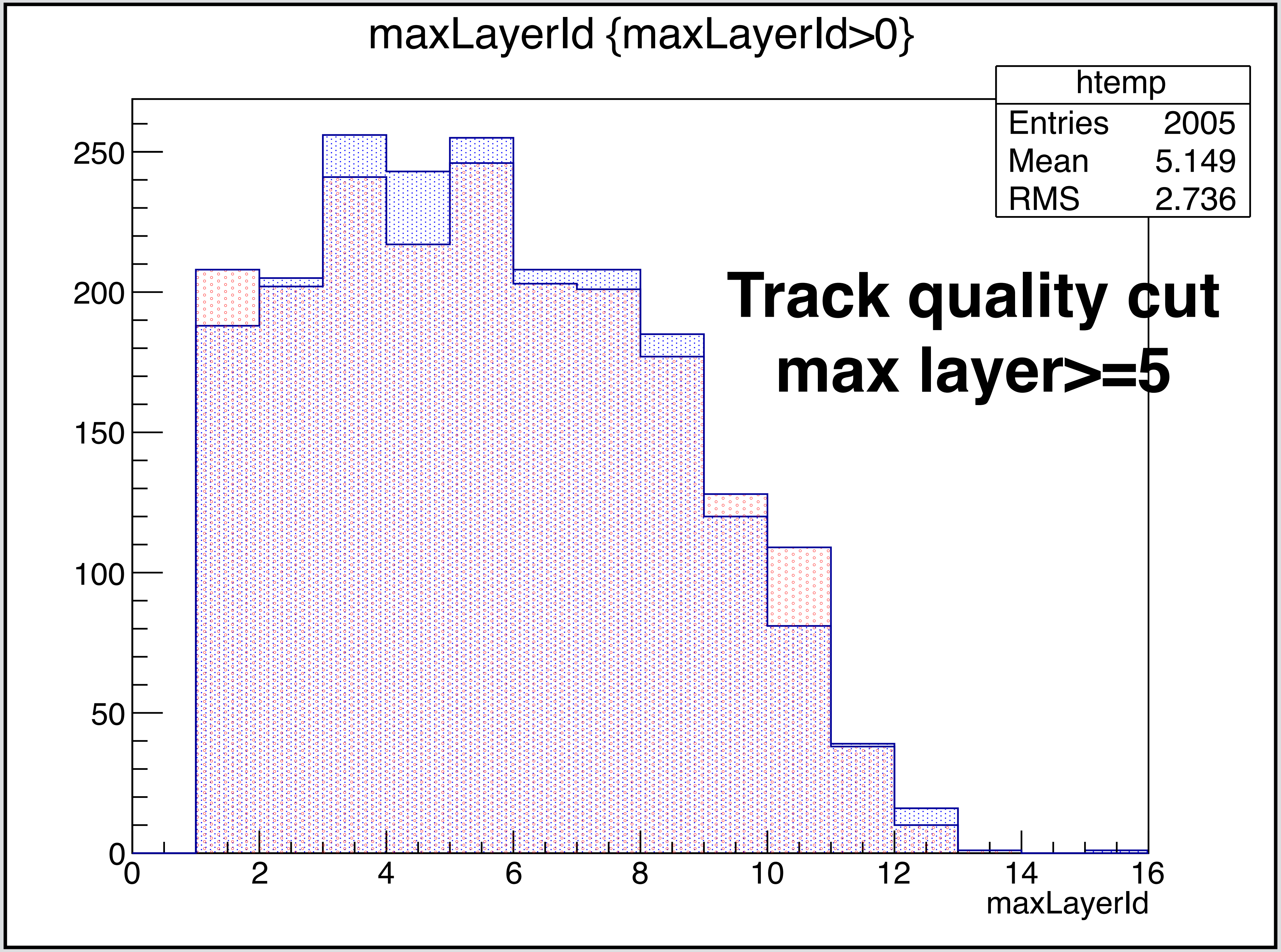




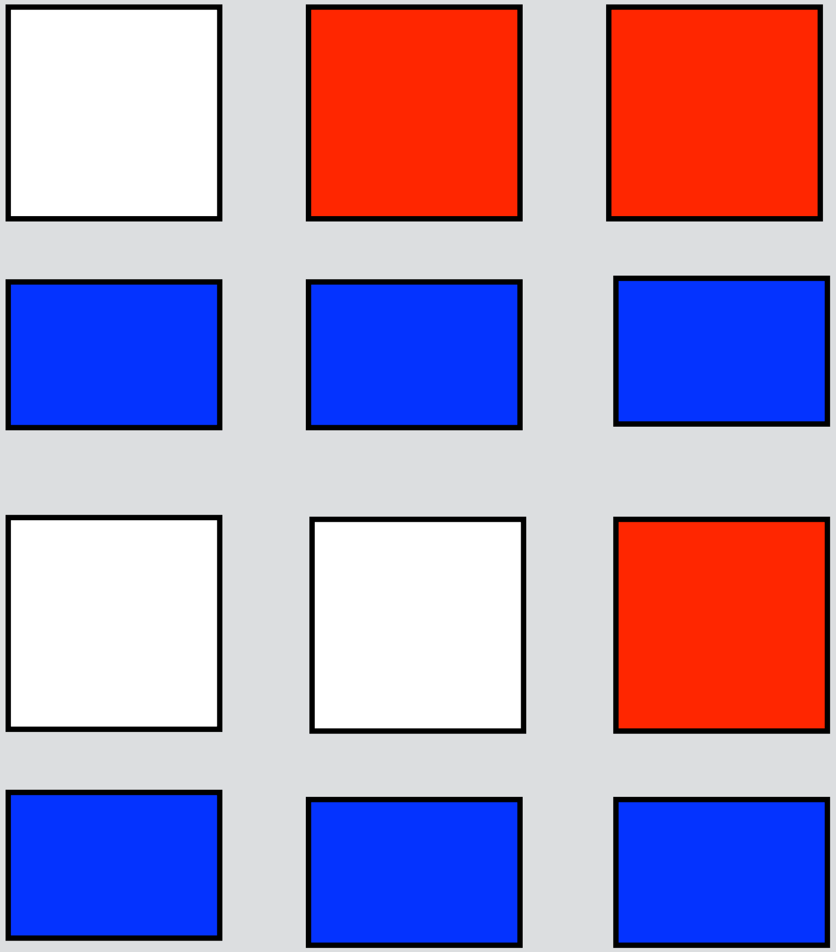
e+ e- measured at first layer of CDC



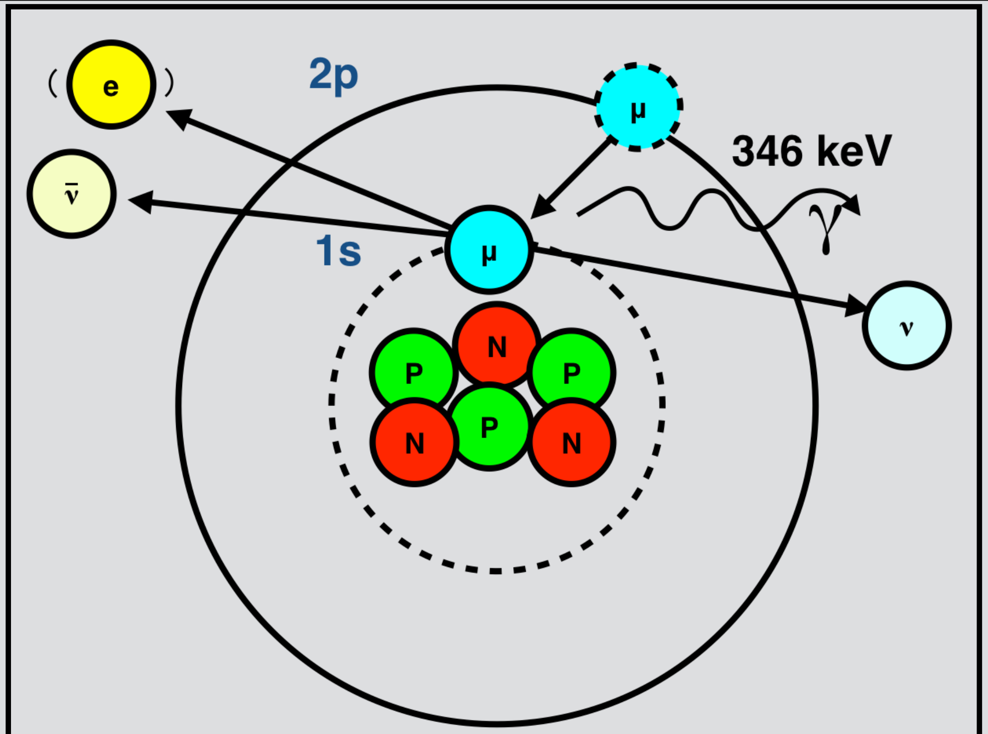
e+ e- layer distribution at 92.32 MeV/c



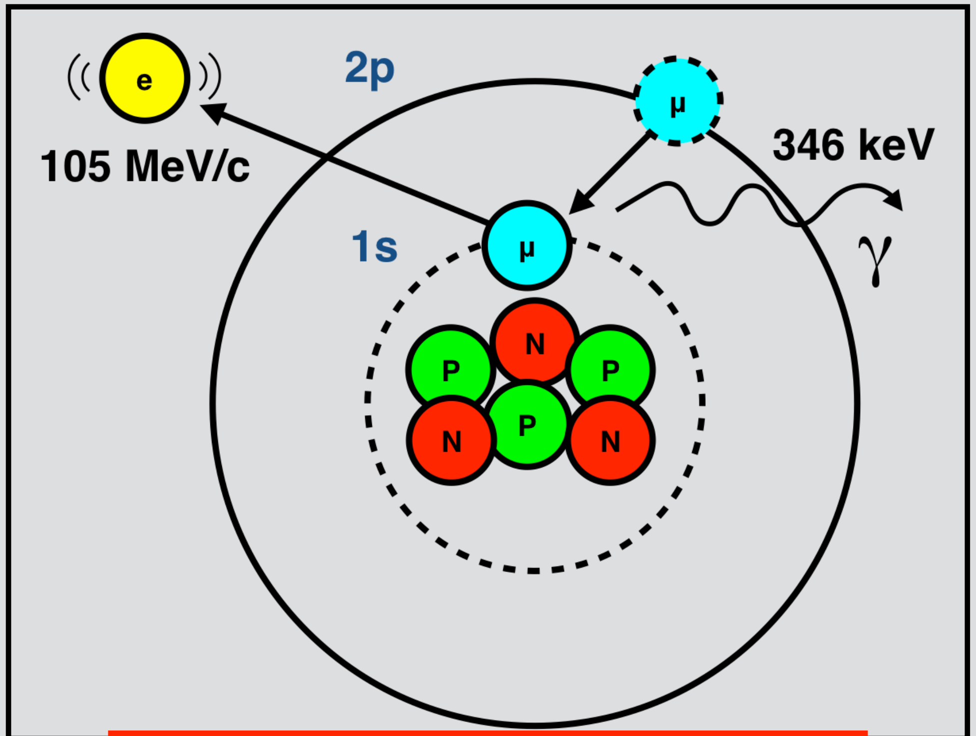
Trigger Algorithm on CTH



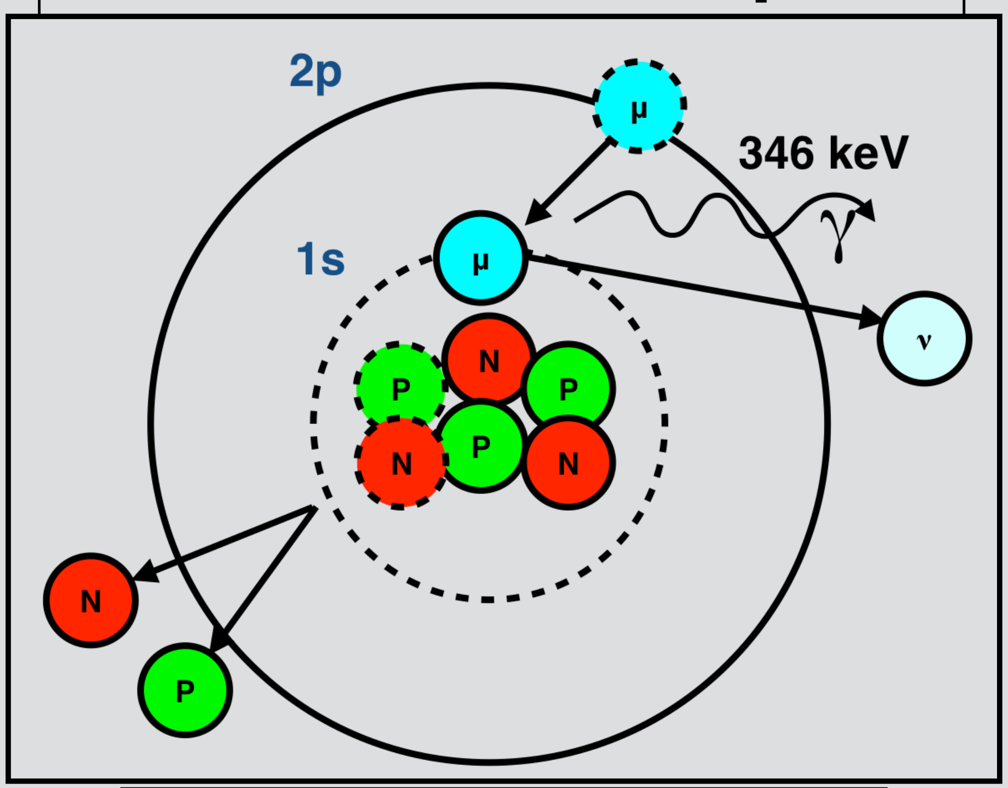
Muonic atom process



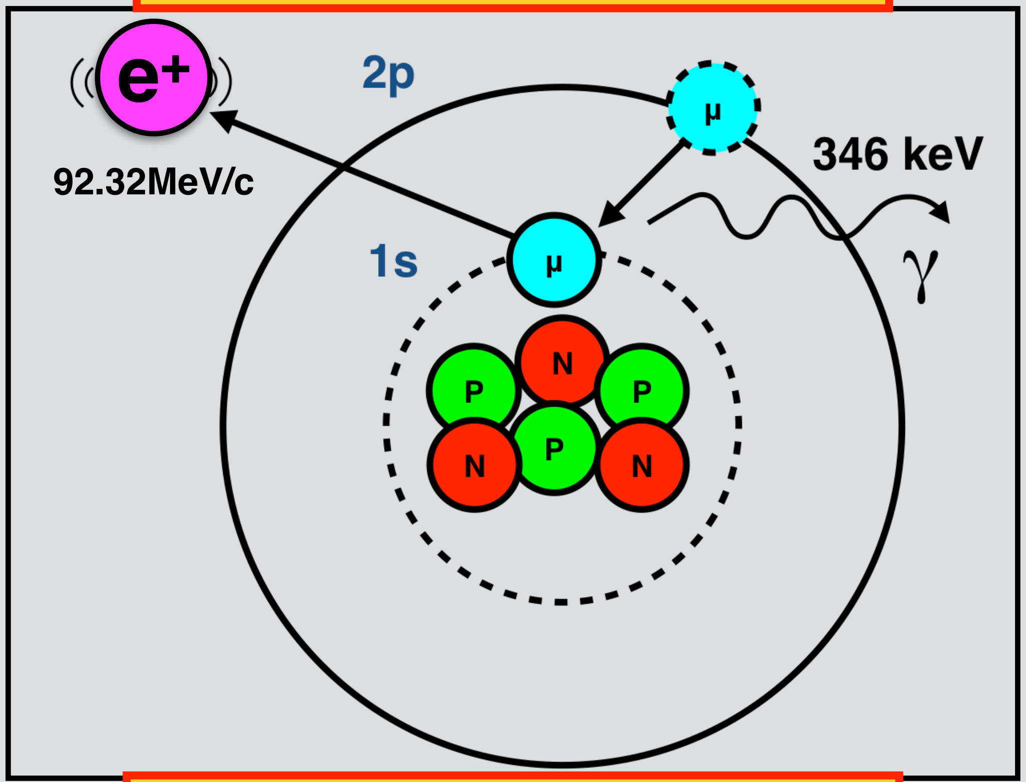
Muonic nuclear capture



μ-e- Conversion



Bound Muon decay

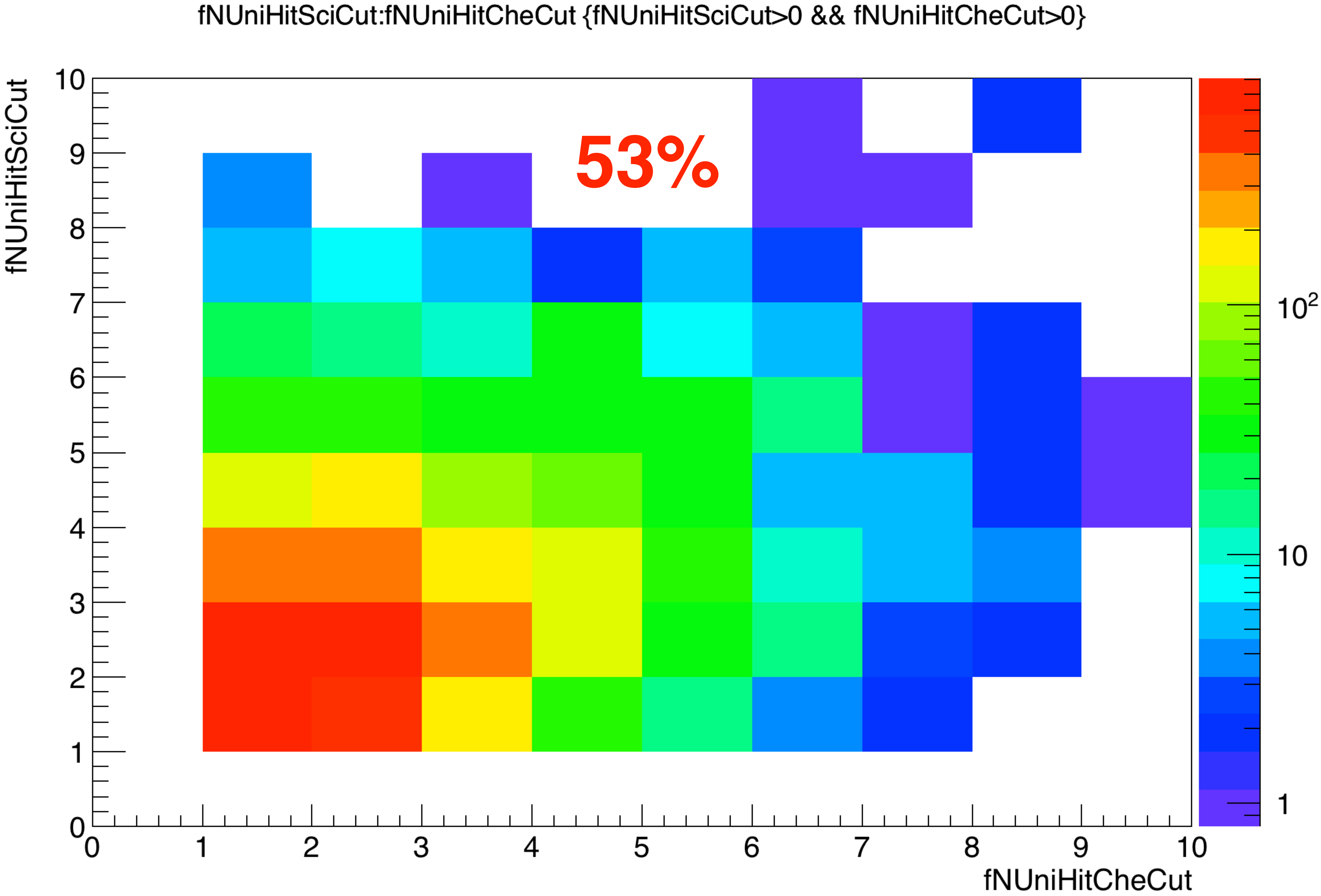


μ-e+ Conversion

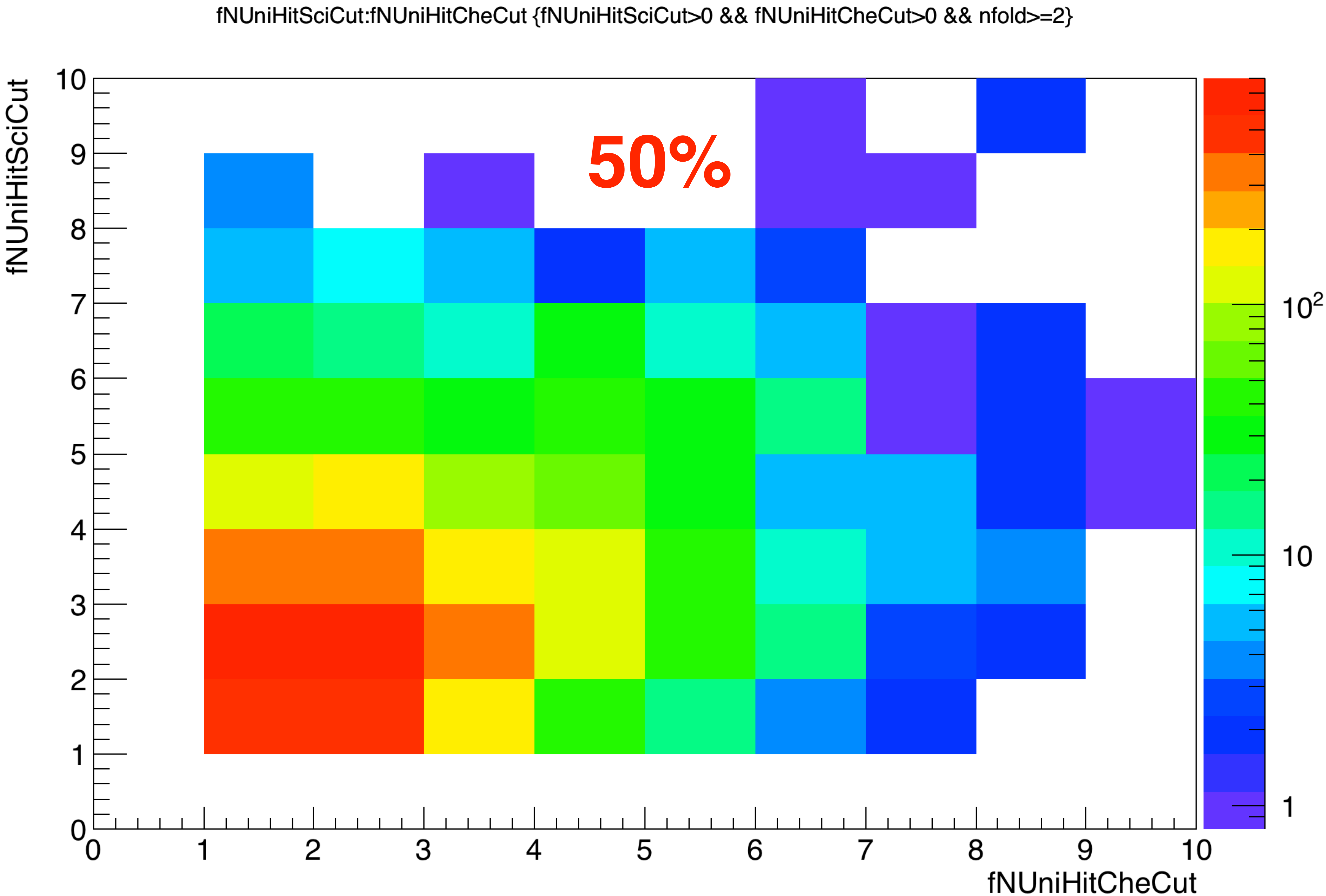
Why occupancy is low compare to TDR value?

Overlapping problem in SimG4

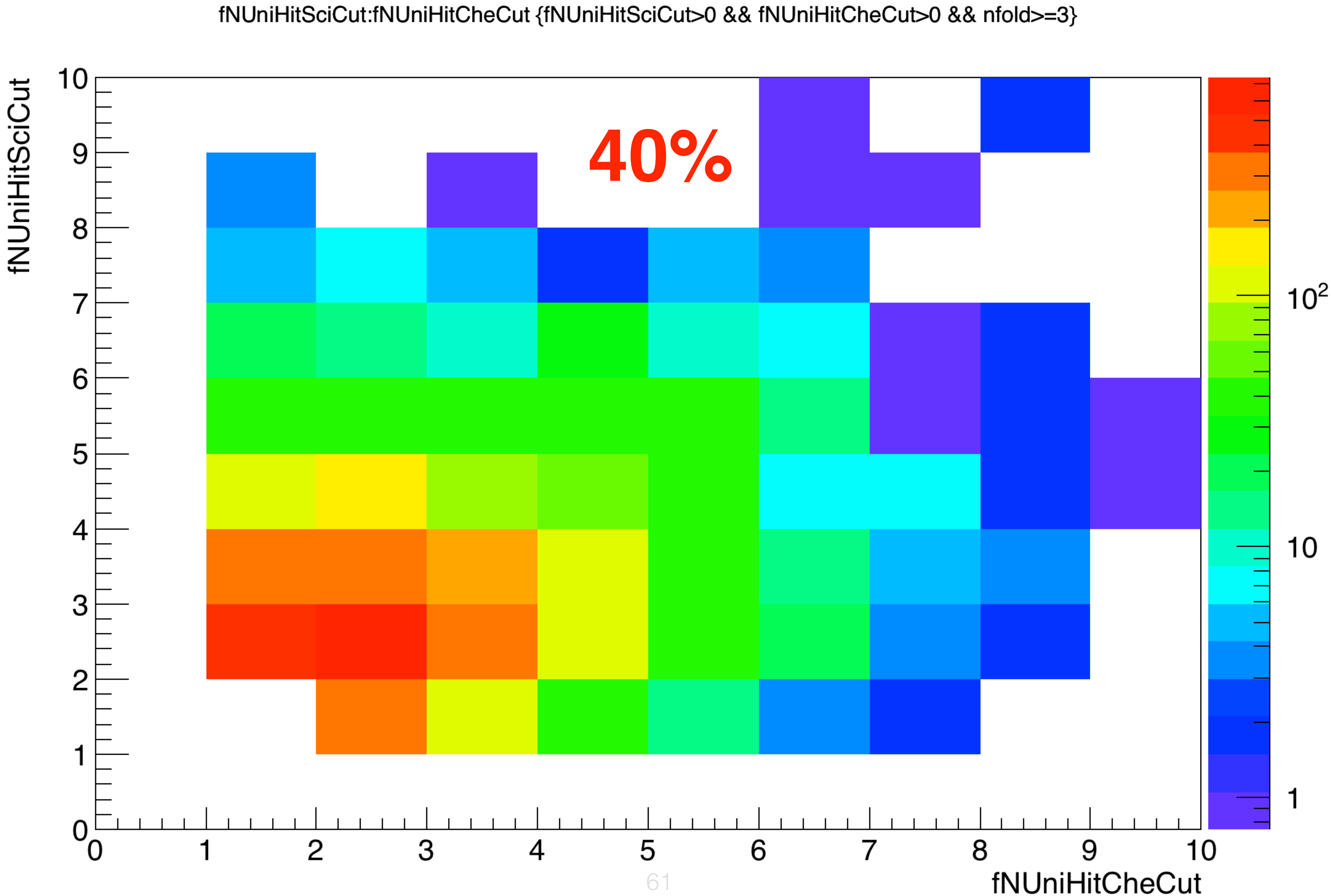
105MeV CTH has hits



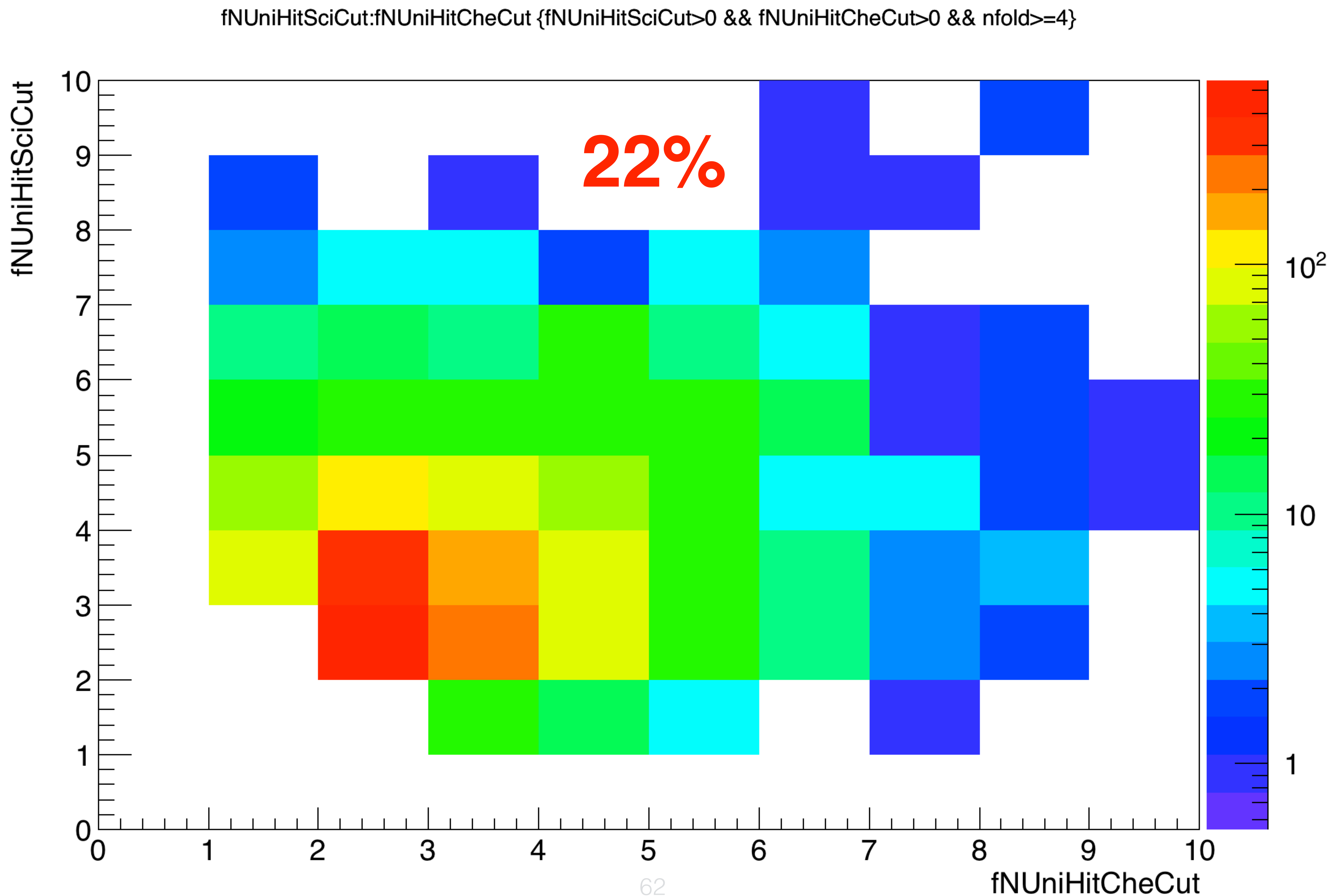
105MeV 2fold coincidence



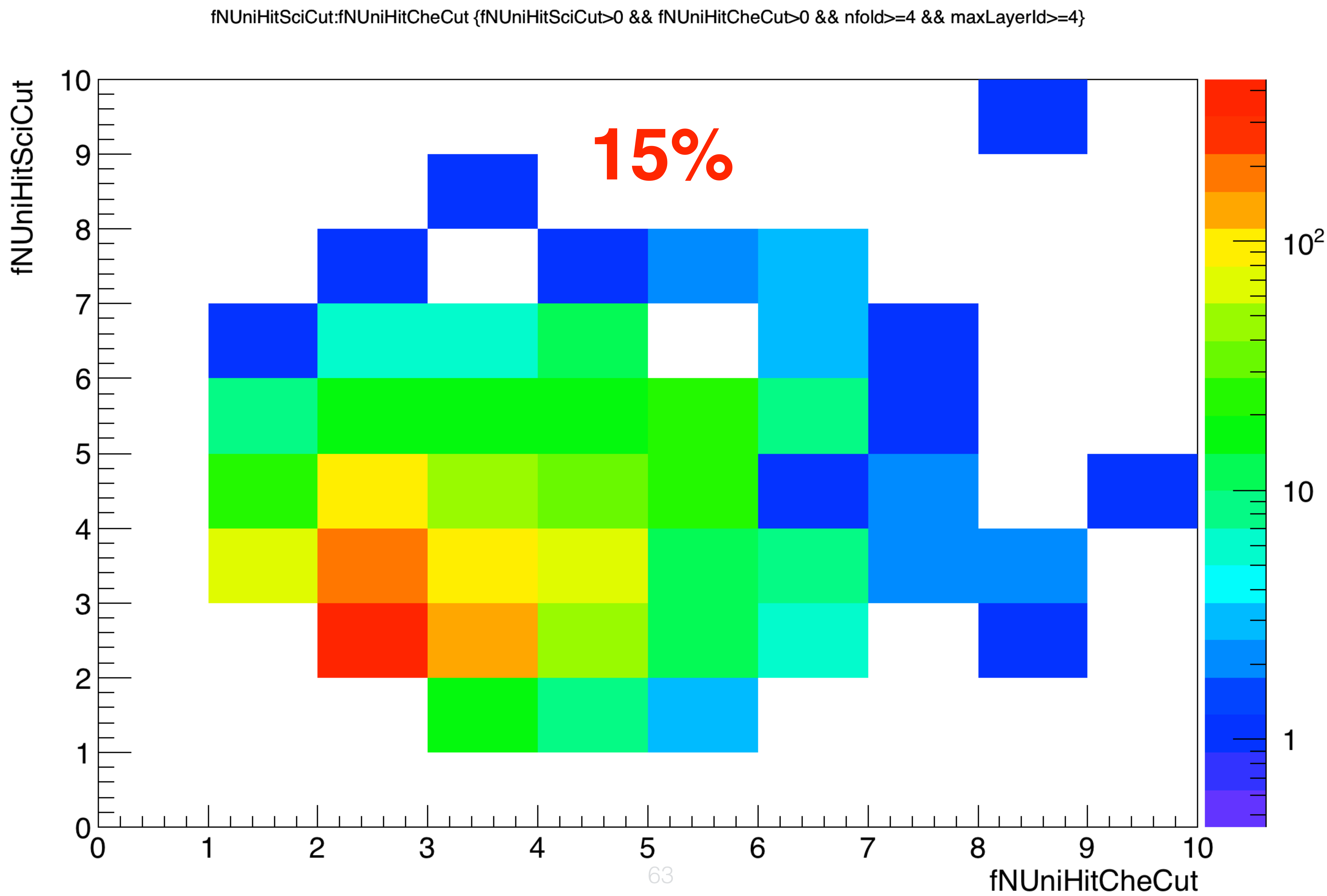
105MeV 3fold coincidence



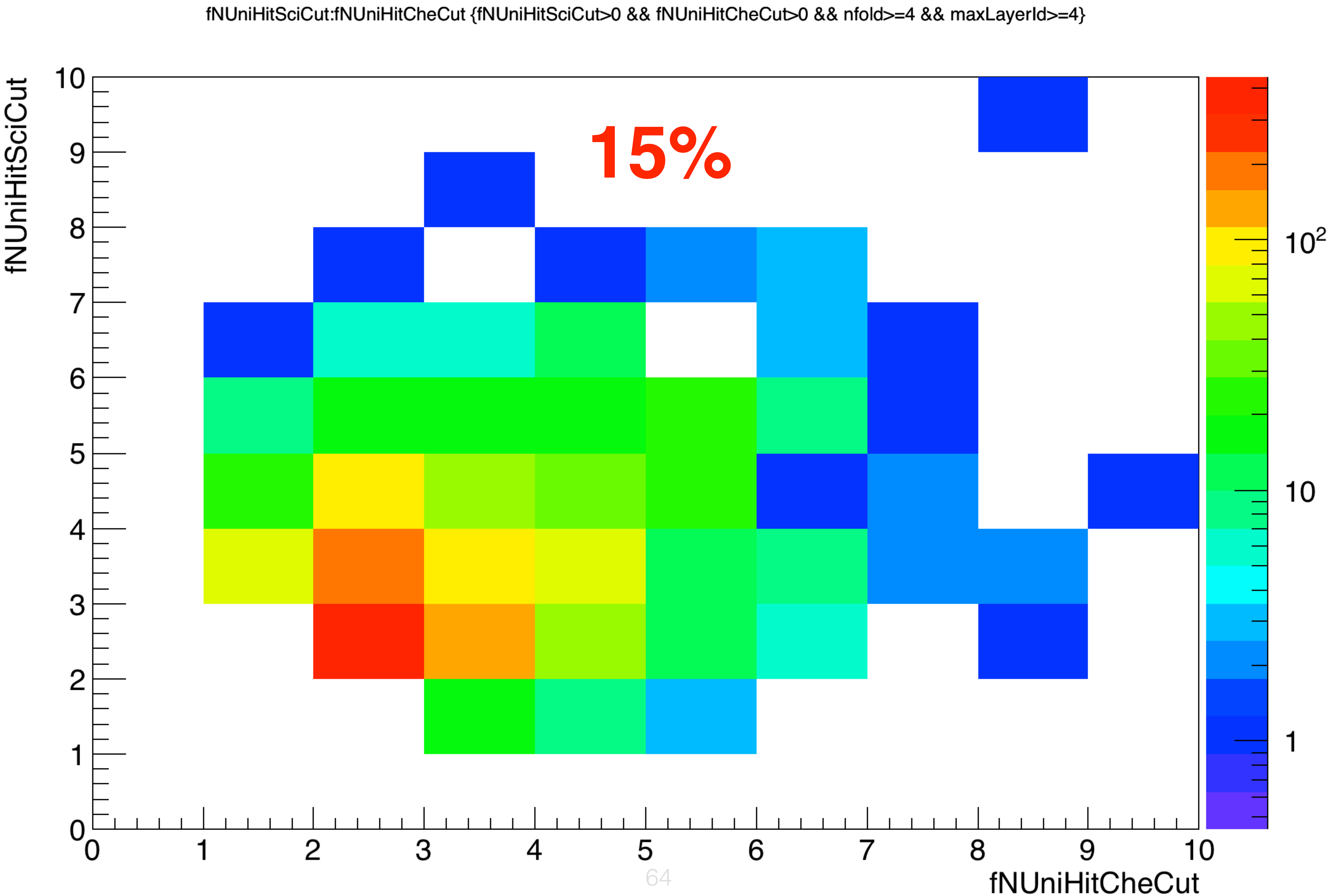
105MeV 4fold coincidence



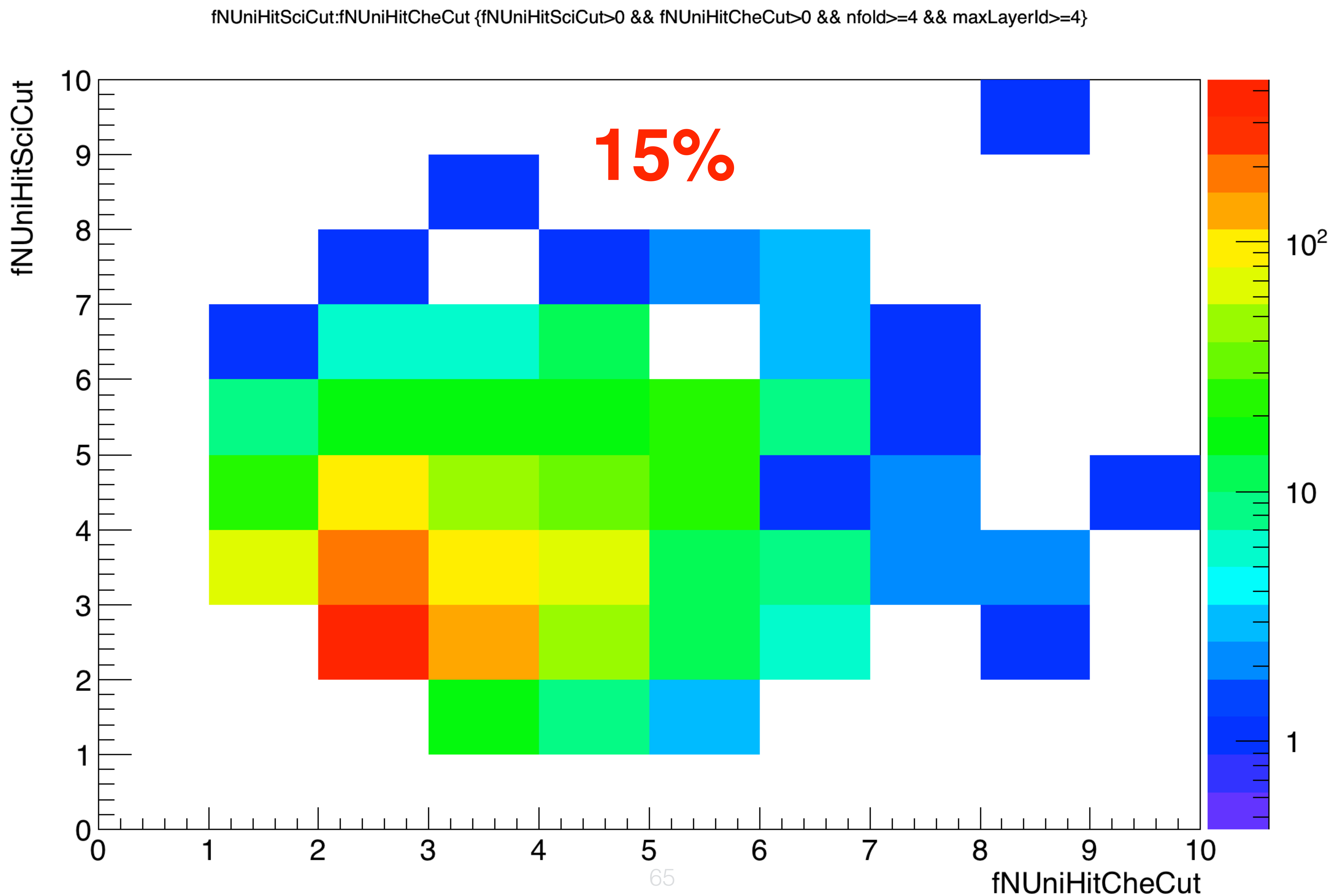
105MeV 4fold coincidence



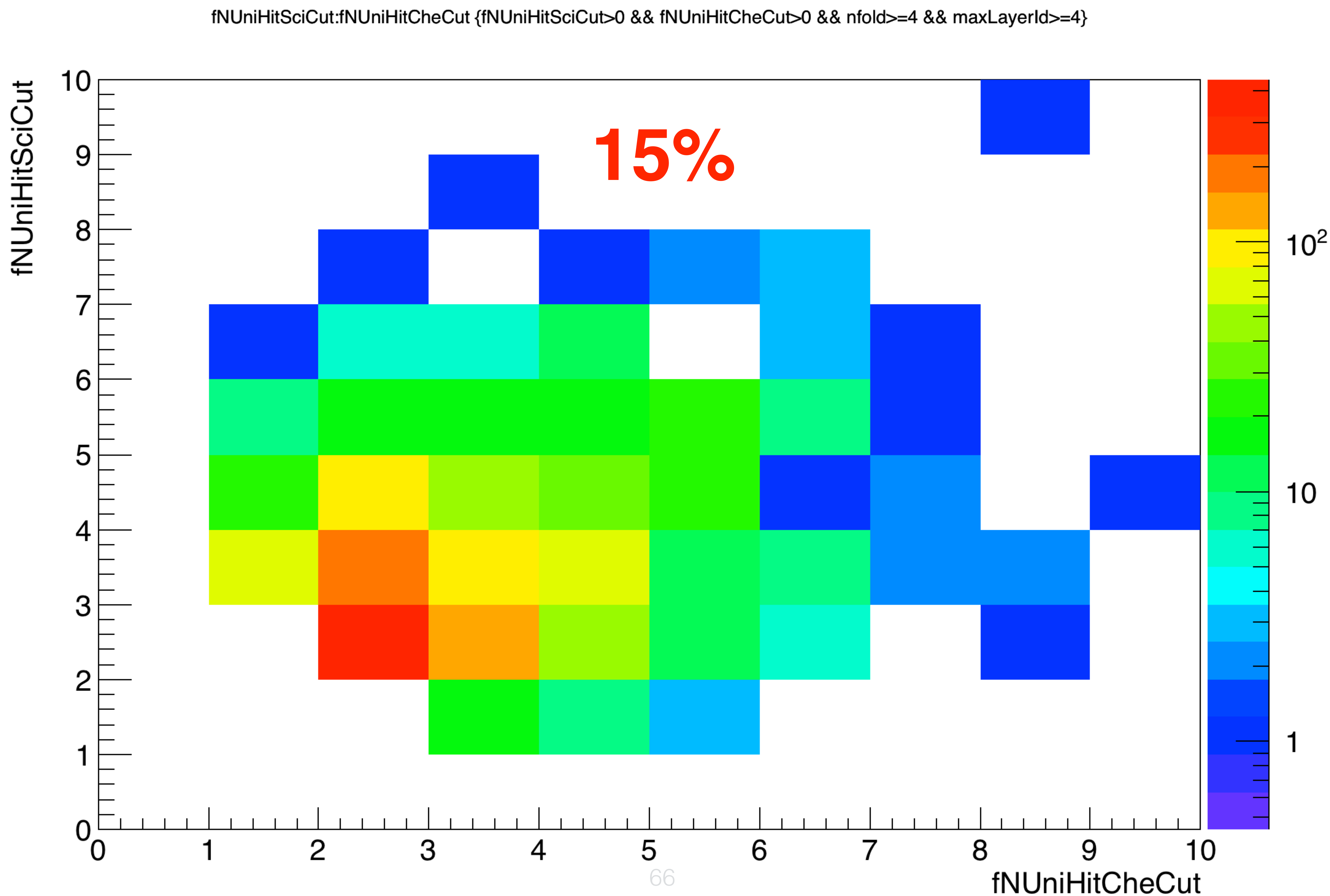
105MeV 4fold coincidence + >= 5 CDC layer



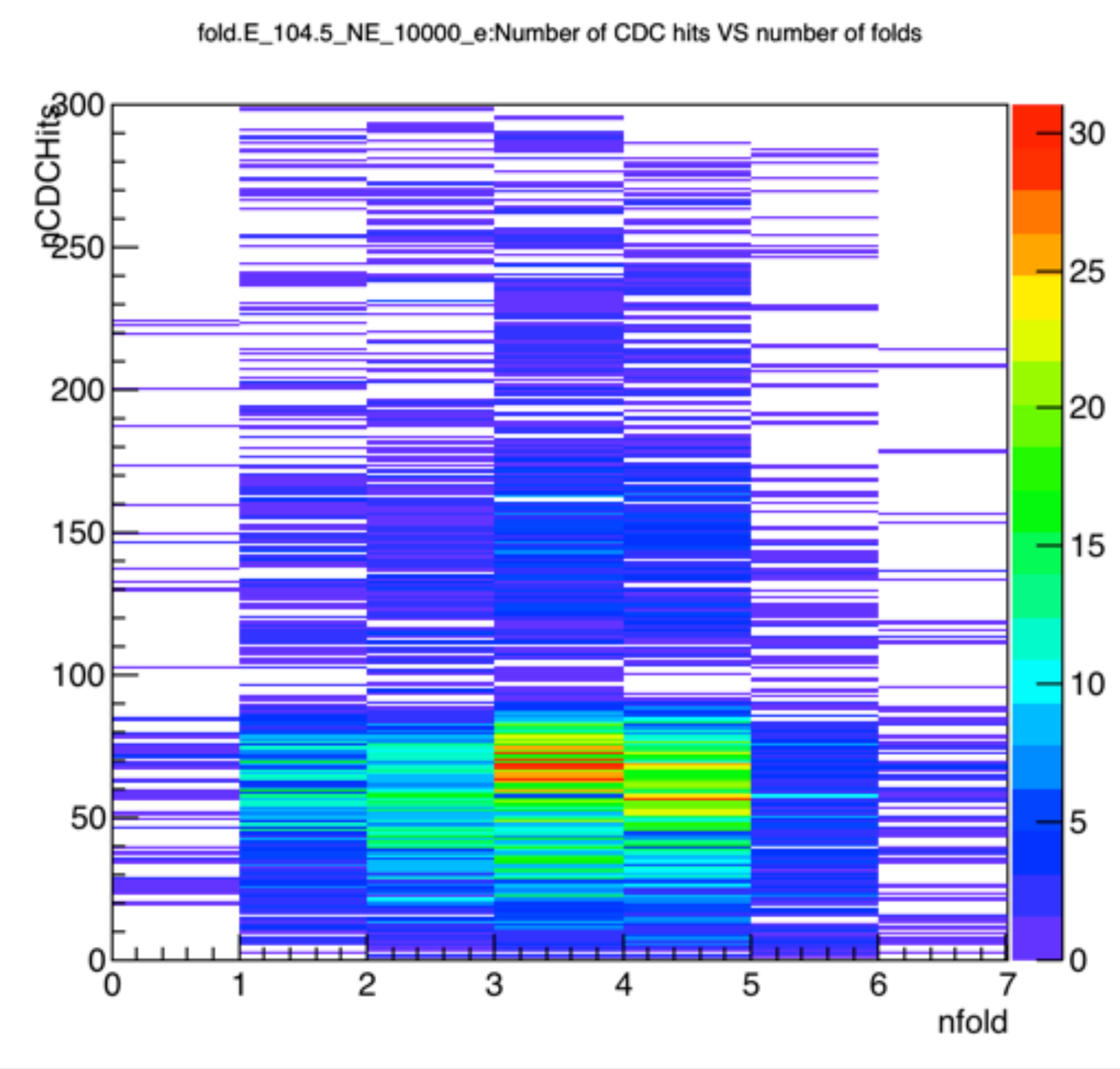
105MeV 4fold coincidence + >= 5 CDC layer



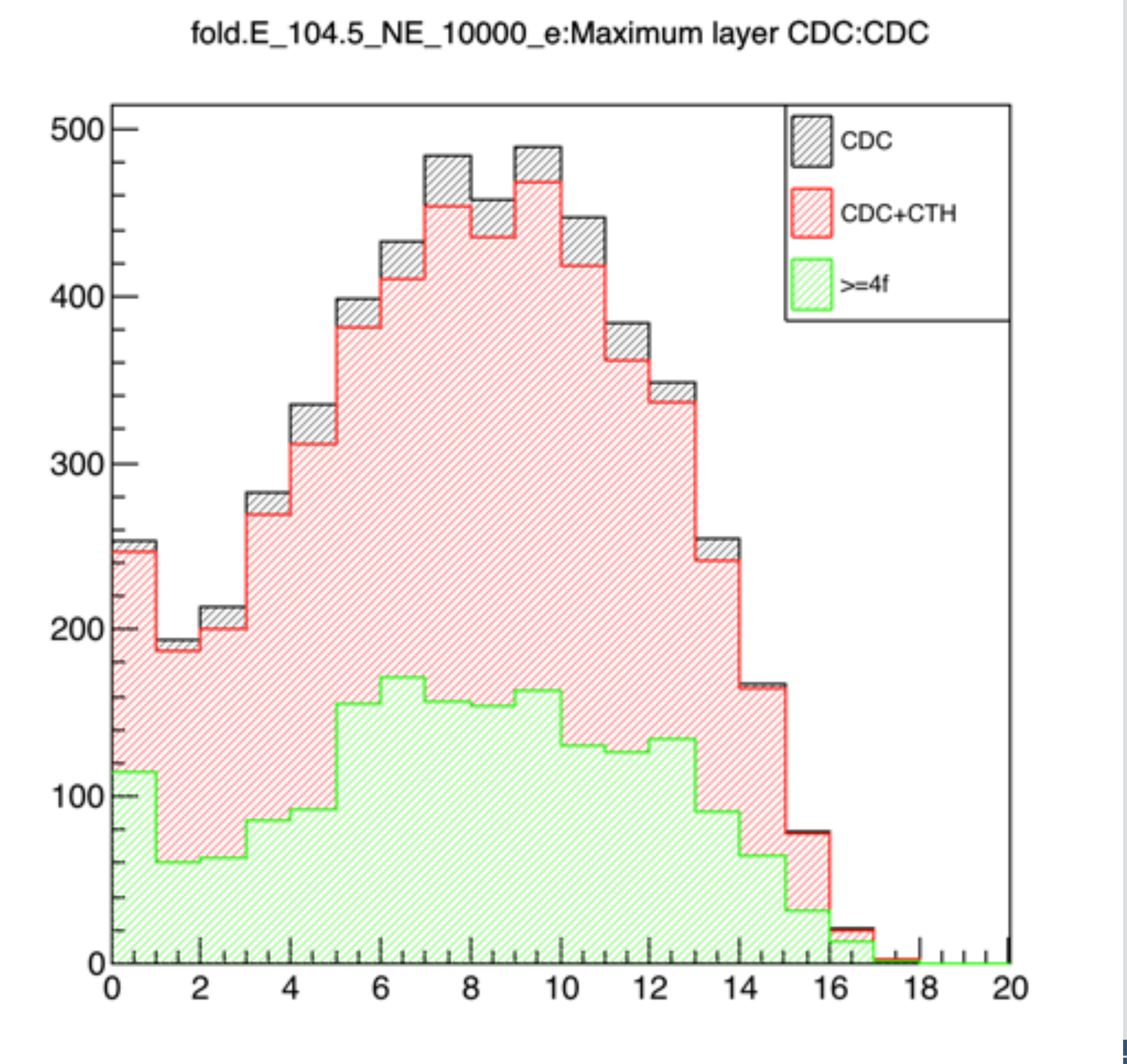
105MeV 4fold coincidence + >= 5 CDC layer && >=30 CDC hits



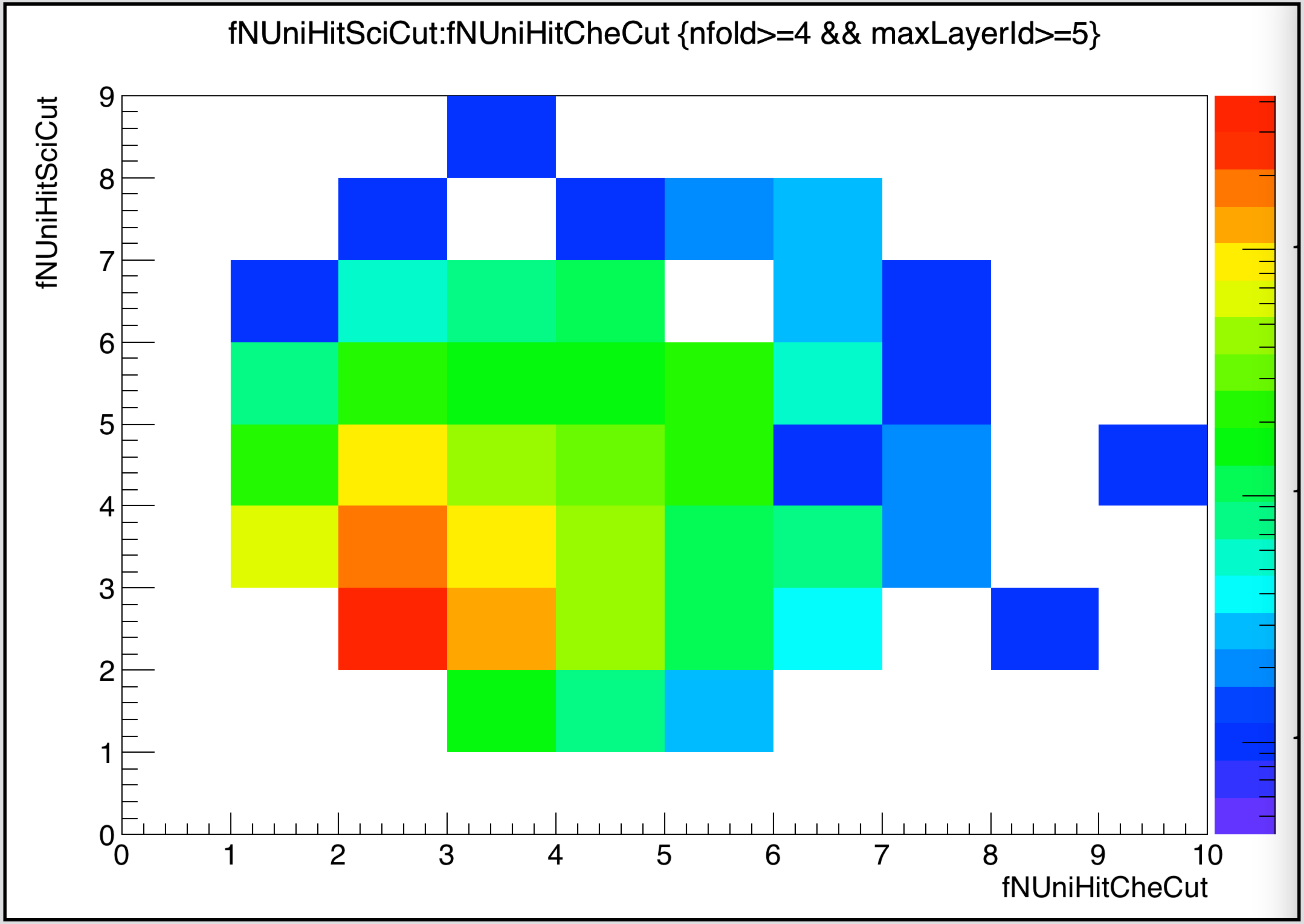
105MeV Electrons just signal



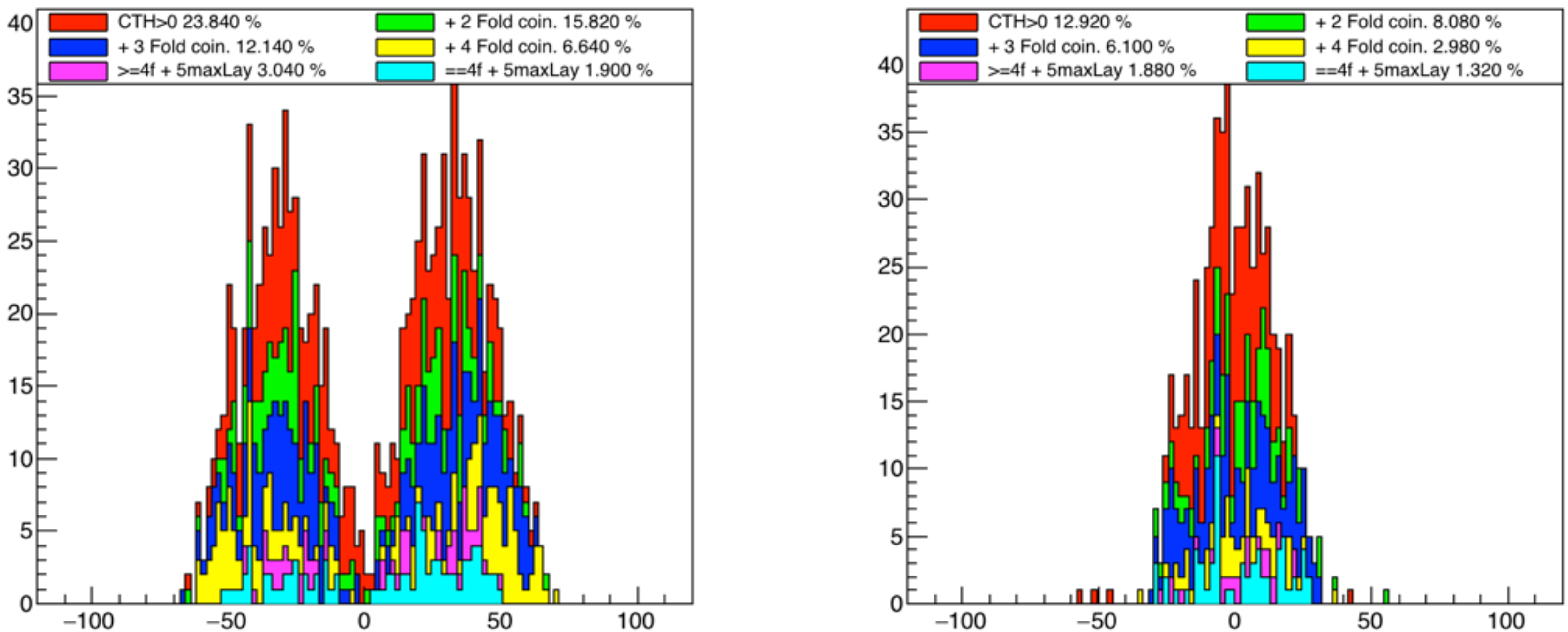
105MeV Electrons just signal



105MeV Electrons just signal



Momentum distribution e+ 92.32



Yohei's slide

Chen's updated results

single

CDC hit	35.4%
CTH 4-fold	16.6%
CDC 5layer	12.7%

multi

CDC hit	13.7%
CTH 4-fold	7.4%
CDC 5layer	7.3%

my result & TDR

single

	case1	case2	case3	TDR
CDC hit	0.3706	0.3764	0.34656	0.3456
CTH 2-fold	0.1911	0.1949	0.18119	0.2125
CTH indirect	0.1911	0.1888	0.18031	0.1871
CTH 4-fold	0.1353	0.134	0.12457	0.1628
CDC 5layer	0.1073	0.1039	0.09873	0.1270

multi

	case1	case2	case3	TDR
CDC hit	0.1316	0.1405	0.13647	0.1773
CTH 2-fold	0.086	0.0916	0.0823	0.1283
CTH indirect	0.086	0.0916	0.08228	0.1208
CTH 4-fold	0.0614	0.0653	0.05819	0.0999
CDC 5layer	0.0611	0.0646	0.05742	0.0972