Tsinghua University

Luminosity Analysis

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Contents:

Collaboration meeting 05/06/2025

Overview

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Motivation for the luminosity scan

- The beam current range for our production runs: 3uA (KinC_x36_6) – 40uA (KinC_x60_3a/3b/4a/4b)
- Issues:
  - Low current: the potential BCM offset error could give the uncertainty about 0.2/3=6.7%;
  - High current: the boiling effect reduces about 2.5% yield at 25uA (about 4% at 40uA)
- We have in total 3 sets of luminosity scan runs:
  1. KinC_x50_2: Sep 30, 2023 – Oct 01,2023
  2. KinC_x50_0: May 13, 2024
  3. KinC_x60_3: May 19, 2024

	Lumi runs	k [GeV]	k' [GeV]	θ [degree]	Q^2 [GeV²]	x_B	W^2 [GeV²]
1st	1514-1530	10.539	6.667	12.49	3.326	0.458	4.820
2nd	6845-6849	6.370	2.638	21.05	2.243	0.320	5.641
	6850-6854	6.370	2.638	25.94	3.386	0.483	4.497
3rd	7003-7007	10.539	5.878	16.477	5.088	0.582	4.539

Overview

1st luminosity scan runs

Target	RunNo	ps4	Pre-scale	Current (μA)	Duration (min)	Events	h3/4 rate (kHz)
LH2	1514	0	1	5	10	1023966	2.429
	1515	2	3	10	10	912408	4.966
	1516	3	5	15	10	751598	7.137
	1517	4	9	25	15	811950	11.509
LD2	1518	7	65	40	15	521346	48.681
	1519	6	33	25	10	485796	30.510
	1520	6	33	18	10	289841	22.035
	1521	5	17	10	10	328346	12.158
	1522	4	9	5	10	345025	6.152
Carbon	1523	4	9	35	10	180135	4.044
	1524	3	5	35	10	156607	3.893
	1525	3	5	40	10	187356	4.563
	1526	3	5	25	10	144809	2.831
	1528	2	3	15	10	153366	1.513
	1530	0	1	5	15	190627	0.560

- KinC_x50_2
- HMS 12.493°
- SHMS 36.88°
- NPS 20.58°
- Calo HV off
- Sweep magnet off
- EDTM 100Hz

Overview

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2nd luminosity scan runs

Target	RunNo	ps4	Pre-scale	Current (μA)	Duration (min)	Events
Carbon	6845	0	1	5	10	130446
	6846	0	1	20	10	484576
	6847	0	1	15	10	323955
	6848	0	1	10	10	210257
	6849	0	1	3	14	83328
LH2	6850	0	1	5	10	170876
	6851	0	1	20	11	558105
	6852	0	1	15	10	440747
	6853	0	1	10	10	315654
	6854	0	1	3	10	118057

- KinC_x50_0
- EDTM 40Hz
- SHMS 36.88°

Carbon runs:

- HMS 21.05°

LH2 runs:

- HMS 25.94°

Overview

3rd luminosity scan runs

Target	RunNo	ps4	Pre-scale	Current (μA)	Duration (min)	Events
Carbon	7003	0	1	40	6	212049
	7004	0	1	30	8	207087
	7005	0	1	20	12	208227
	7006	0	1	10	22	217021
	7007	0	1	5	32	203780

- KinC_x60_3
- EDTM 40Hz
- SHMS 36.443°
- HMS 16.477°

Yield Analysis

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Analysis procedure

- Use 2 μA cut to calculate the charge for each run
- Apply the same 2 μA cut when selecting El-REAL events
- Calculate the average beam current with the 2 μA cut

Scaler Yield

$$\frac{\text{scaler\_htrig4} - \text{scaler\_edtm}}{\text{charge}}$$

Cuts for scaler counting:

- Beam current cut

Non-tracking Yield

$$\frac{\#\text{ of events} \times \text{ps-factor}}{\text{charge} \times \text{LT}}$$

Cuts for event selection:

- Beam current cut
- Non-edtm
- npeSum>6
- 0.6<etotnorm<1.5

Tracking Yield

$$\frac{\#\text{ of events} \times \text{ps-factor}}{\text{charge} \times \text{LT} \times \text{track\_eff}}$$

Cuts for event selection:

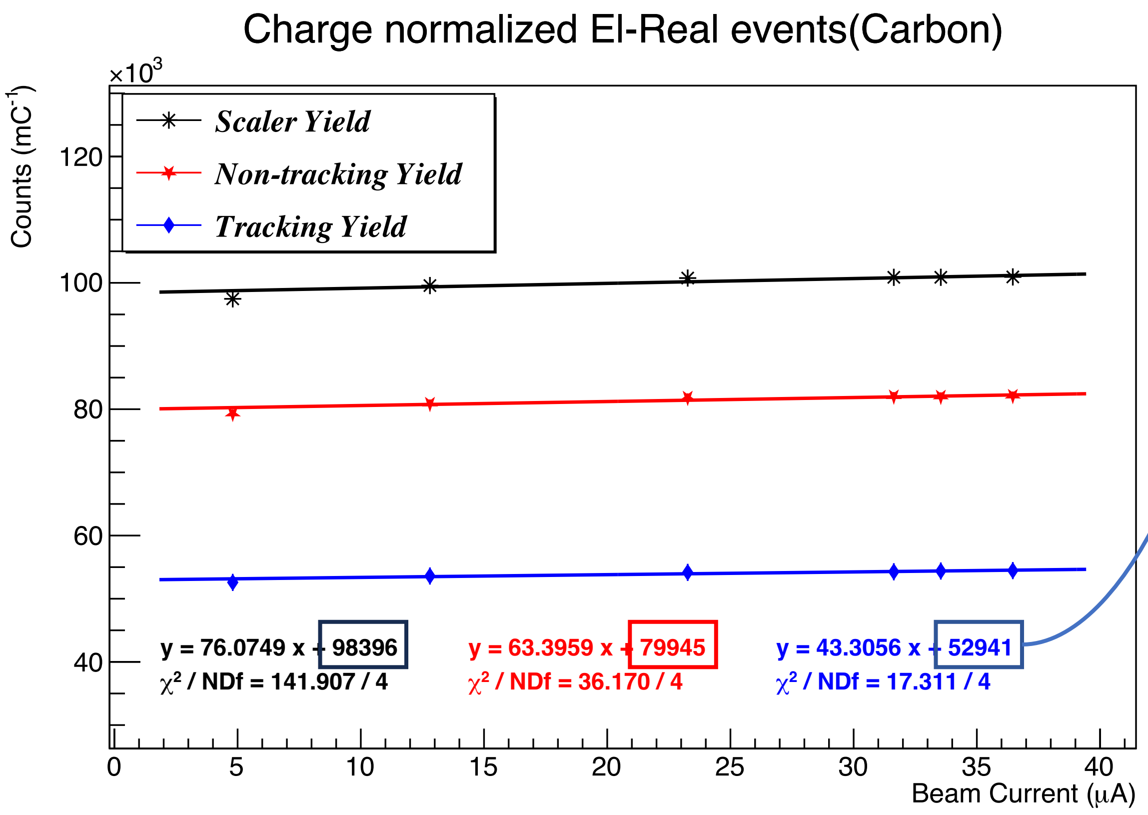
- Beam current cut
- Non-edtm
- npeSum>6
- 0.6<etottracknorm<1.5
- $|\text{gtr\_dp}| \leq 8$
- $|\text{vtx\_z}| \leq 4$
- vtx_ok and gtr_ok

$$\text{LT} = \frac{\#\text{ of events } (no\ EDTM)}{\text{scaler\_htrig4} - \text{scaler\_edtm}} \times \text{ps factor}$$

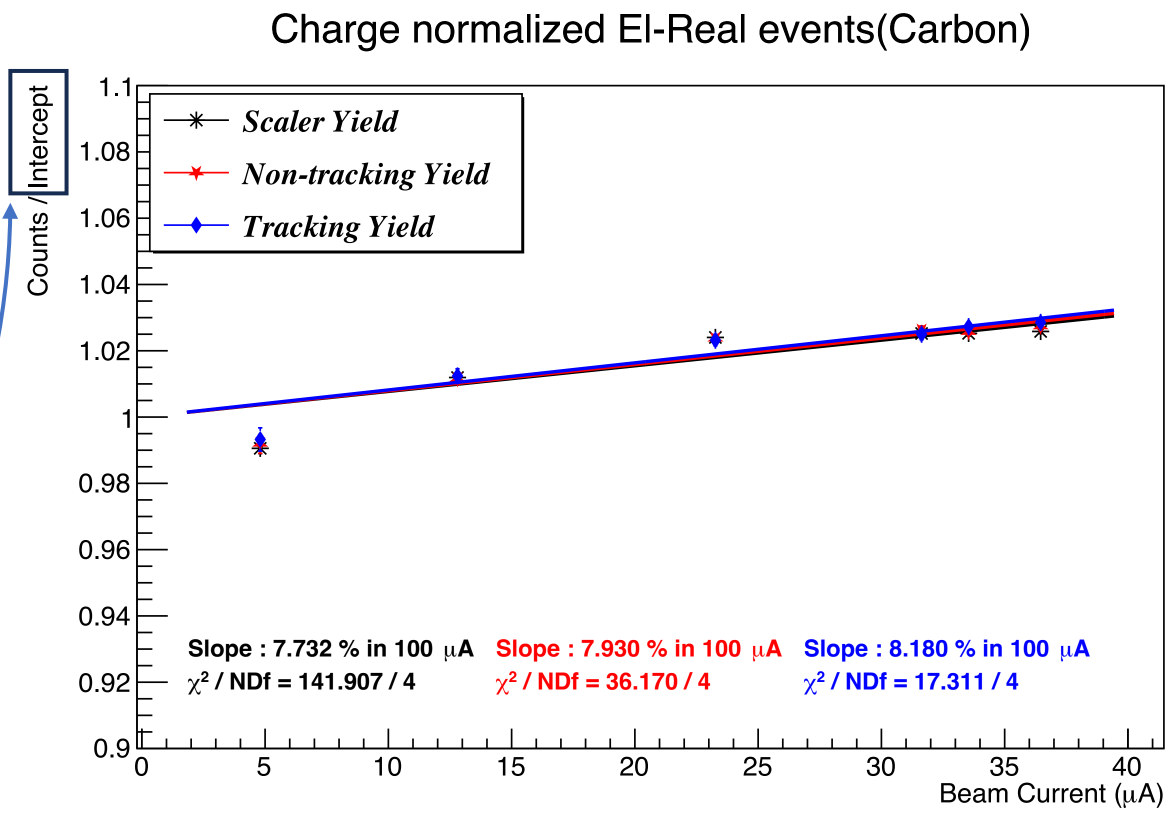
Yield Analysis

Analysis procedure

- Linear fitting



First Fitting



Second Fitting

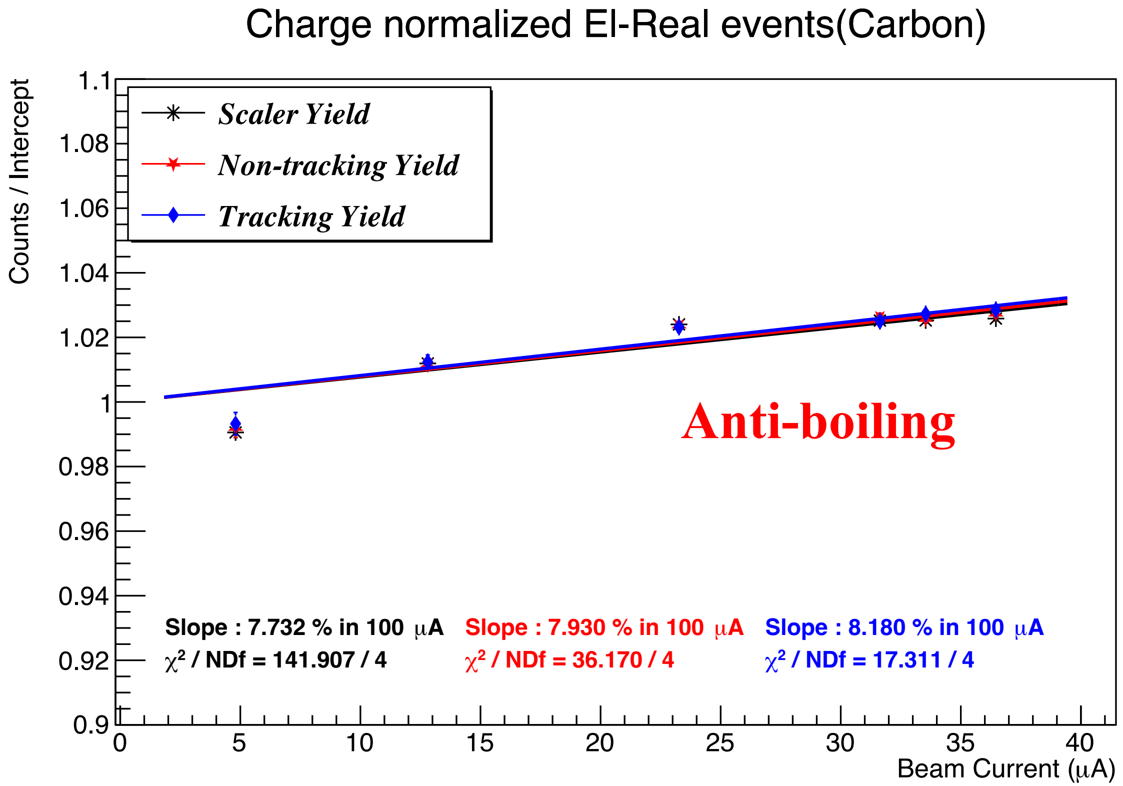
Yield Analysis

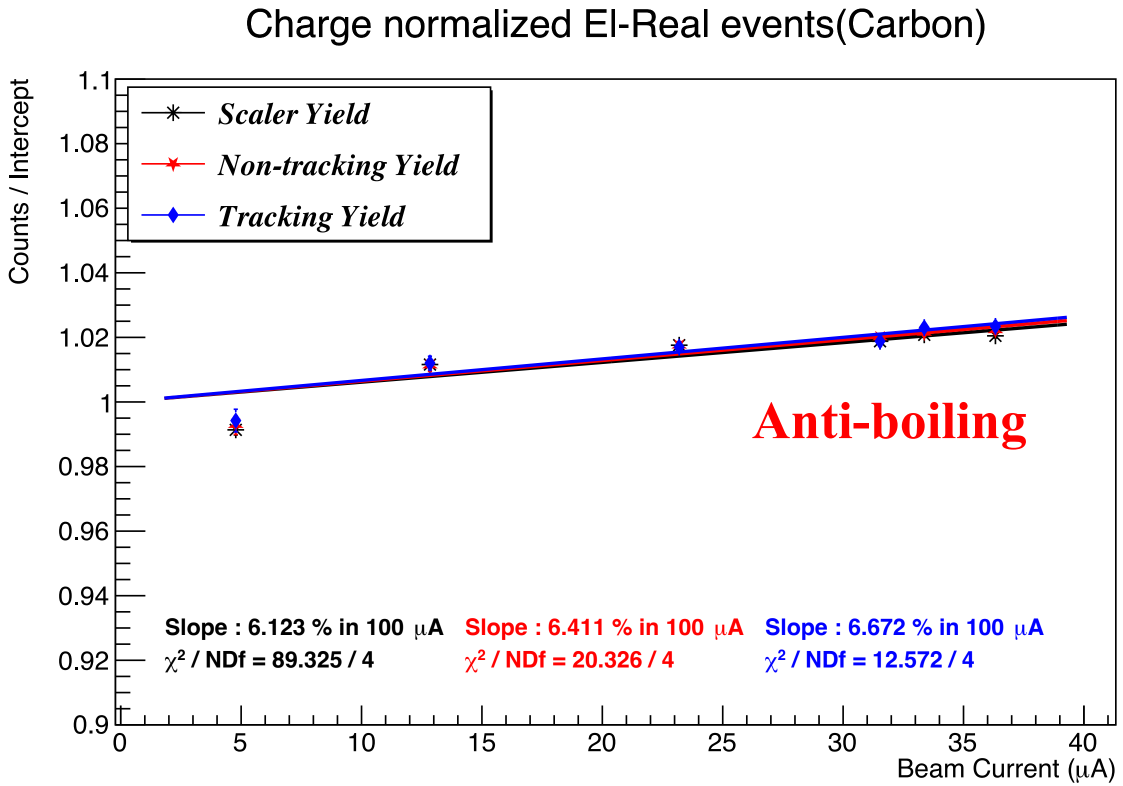
■ Carbon Yield vs beam current

❑ KinC_x50_2

- 1st luminosity scan runs
- BCM4A used for charge and current calculation
- BCM4A gain = 9597
- BCM4A offset = −1839

- BCM2 used for charge and current calculation
- BCM2 gain = 5707
- BCM2 offset = 249300



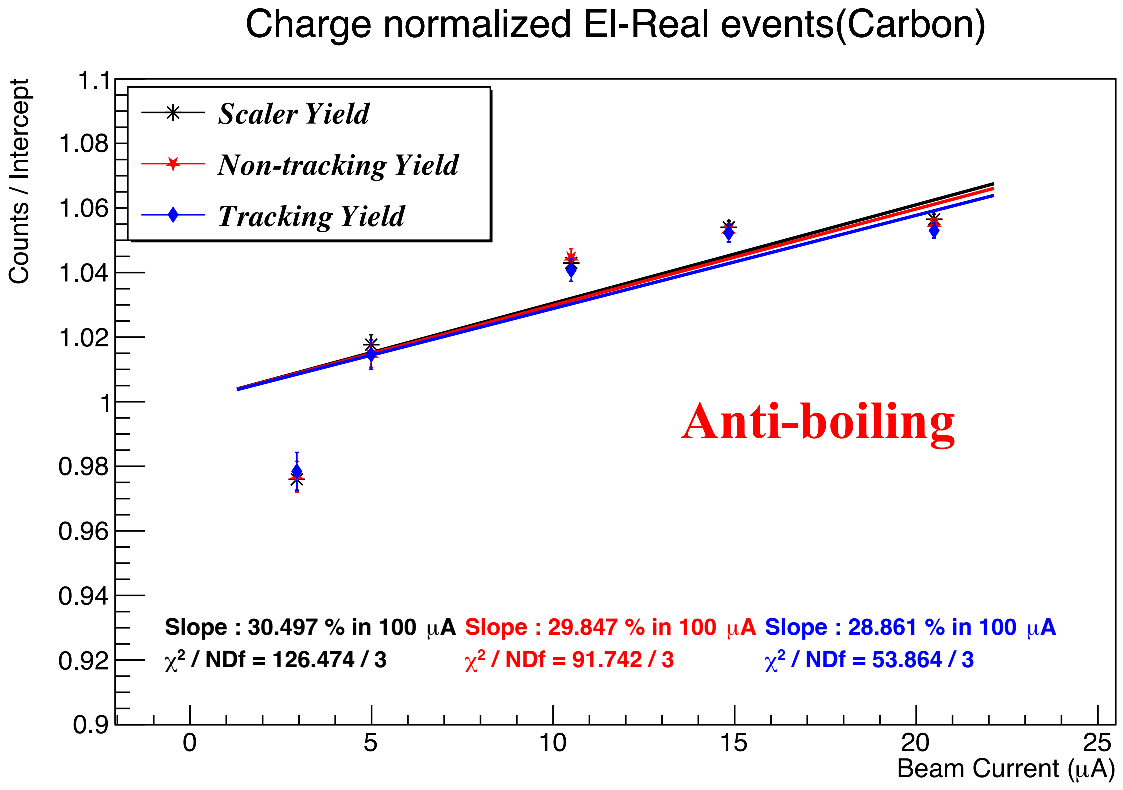


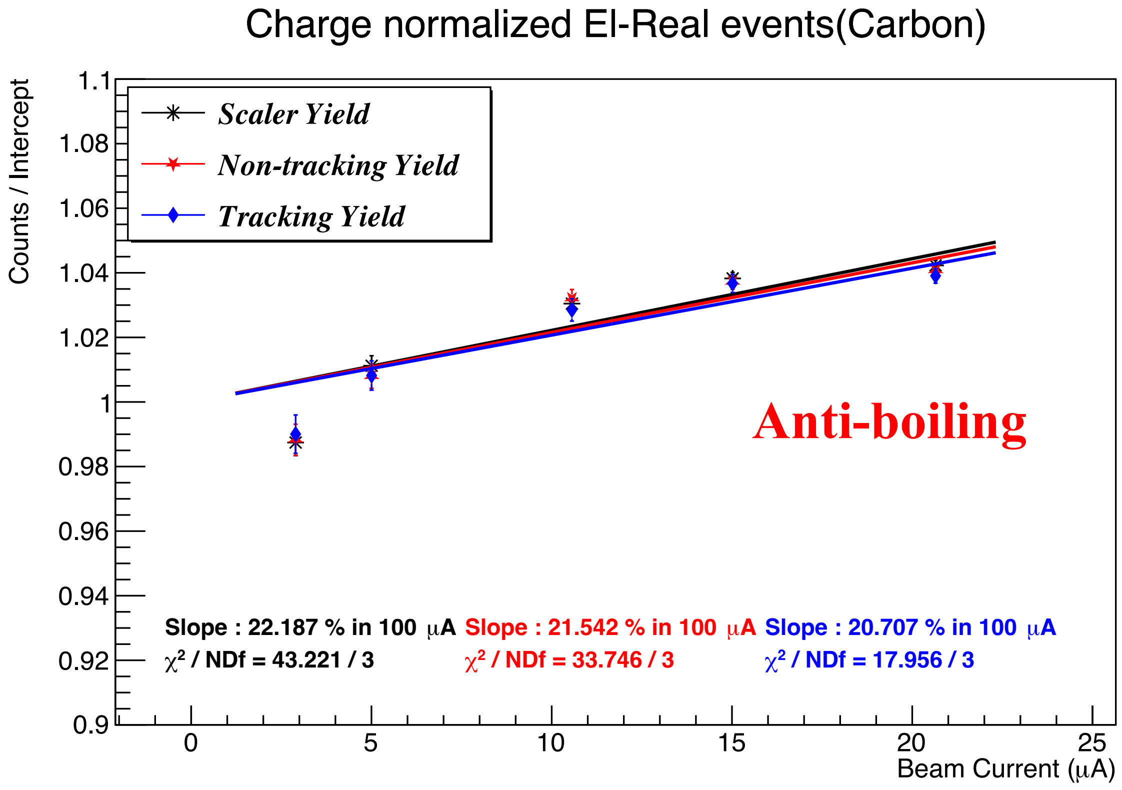
Yield Analysis

Carbon Yield vs beam current

KinC_x50_0

- 2nd luminosity scan runs
- BCM4A used for charge and current calculation
- BCM4A gain = 9597
- BCM4A offset = −1839
- BCM2 used for charge and current calculation
- BCM2 gain = 5707
- BCM2 offset = 249300
- The anti-boiling effect is much larger for the 2nd luminosity scan runs





Yield Analysis

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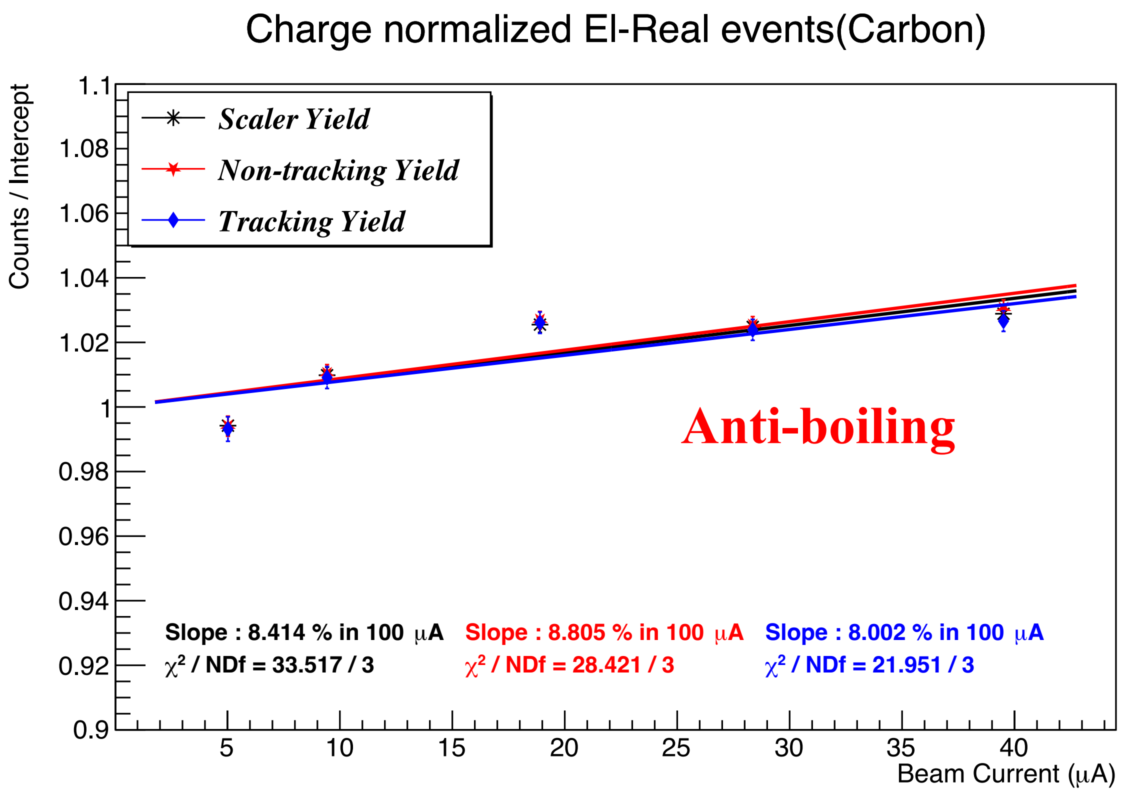
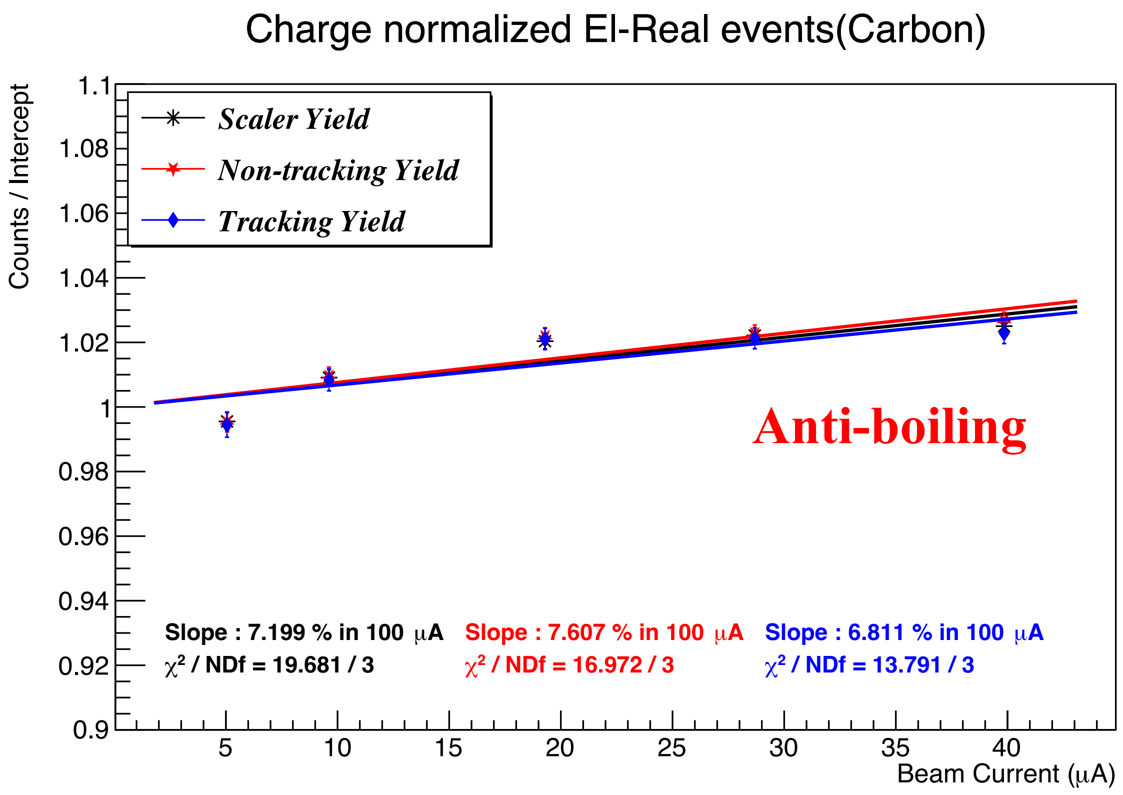
Carbon Yield vs beam current

❑ KinC_x60_3

- 3rd luminosity scan runs
- BCM4A used for charge and current calculation
- BCM4A gain = 9597
- BCM4A offset = −1839

- BCM2 used for charge and current calculation
- BCM2 gain = 5707
- BCM2 offset = 249300





BCM Offset Issue

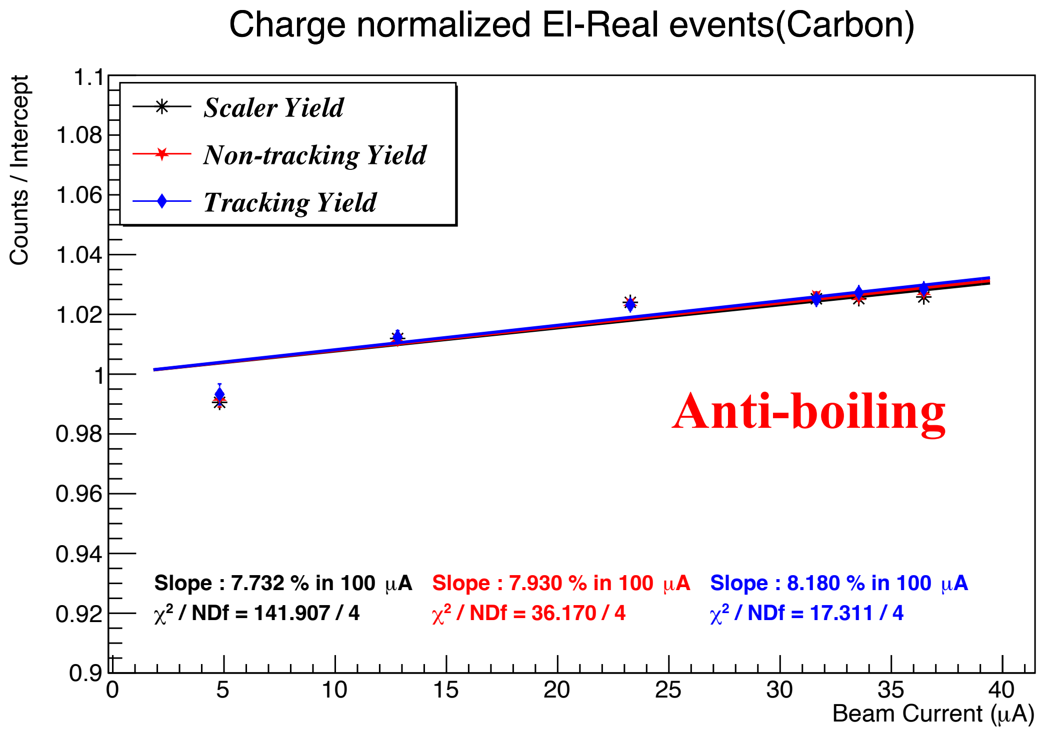
Possible impact from BCM offset error

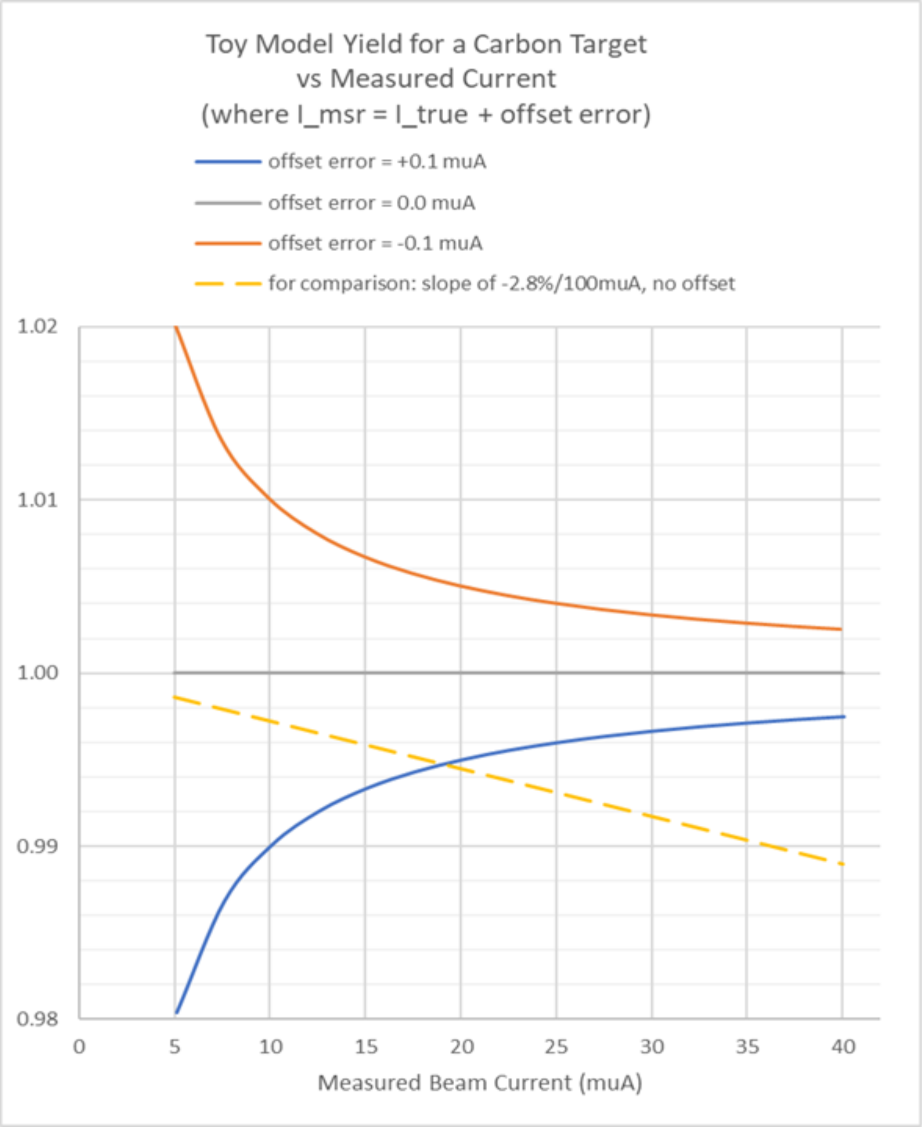
- The formula to calculate the BCM4A current:

$$I_{BCM4A} = \frac{(scaler_{diff} \div Time_{diff}) - \boxed{(-1839)}}{\boxed{9597}}$$

OFFSET

GAIN



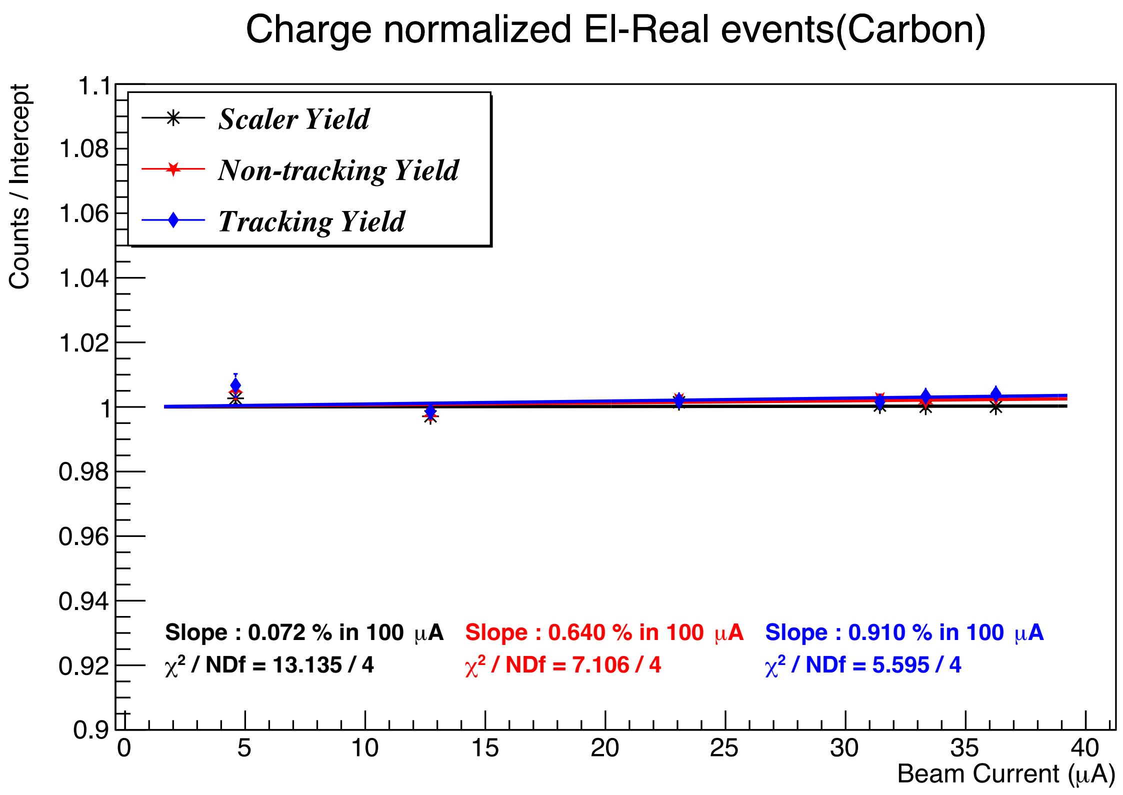


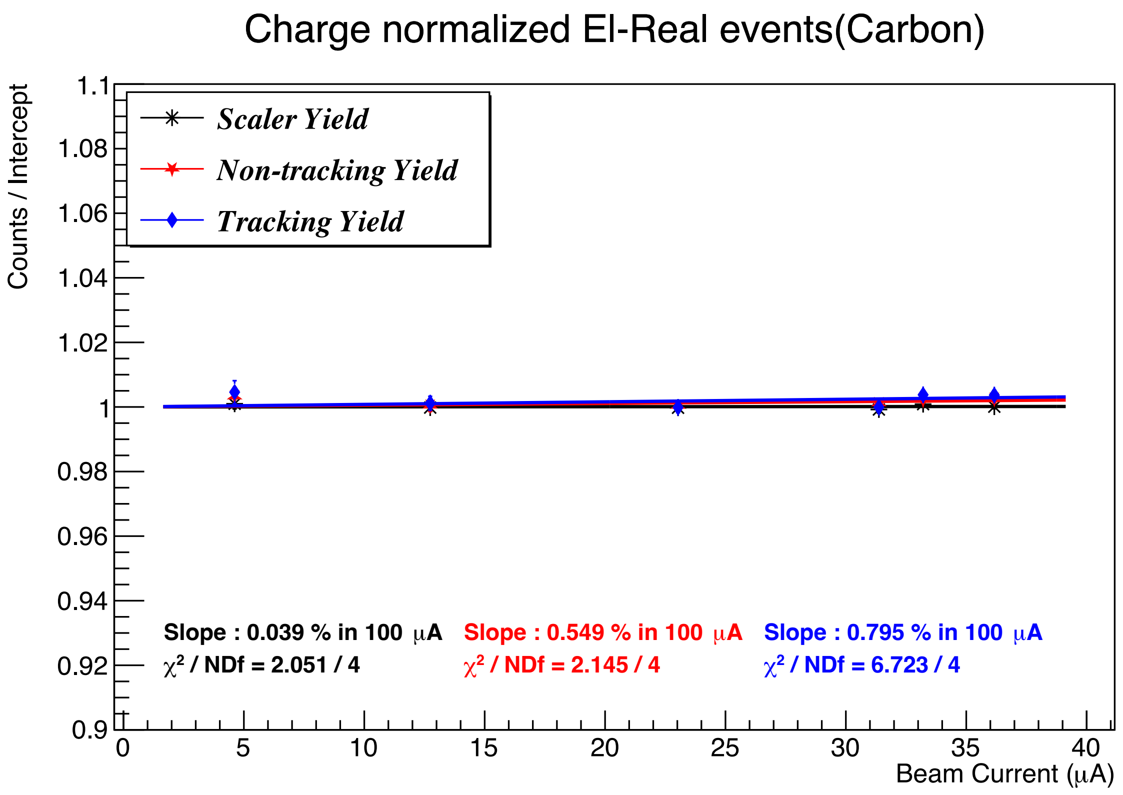
BCM Offset Issue

Offset that cancels the anti-boiling

- 1st luminosity scan runs
- BCM4A used for charge and current calculation
- BCM4A gain = 9597
- BCM4A offset = 103 (BCM calib: −1839)

- BCM2 used for charge and current calculation
- BCM2 gain = 5707
- BCM2 offset = 250219 (BCM calib: 249300)





BCM Offset Issue

Offset that cancels the anti-boiling

BCM calibration: BCM2: gain = 5707, offset = 249300
BCM4A: gain = 9597, offset = −1839

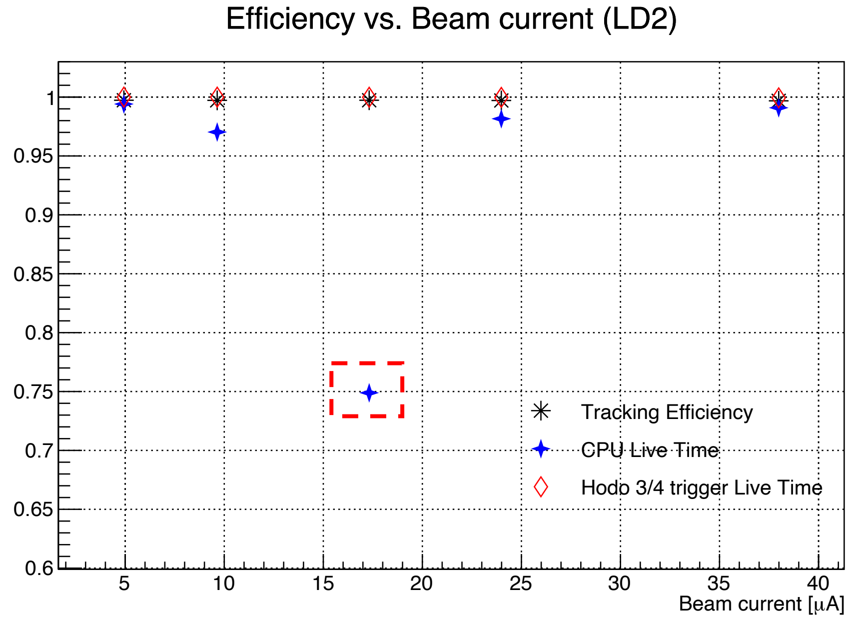
- Summary for all the 3 sets of luminosity runs:
  - Equivalent current offset: offset_diff = (offset_new − offset_calib) / gain_calib
- The new BCM offsets go beyond the error bar in Christine's BCM calibration results (about twice of the error bar)
- The offset_diff for KaonLT is only about 33nA (0.033 μA)

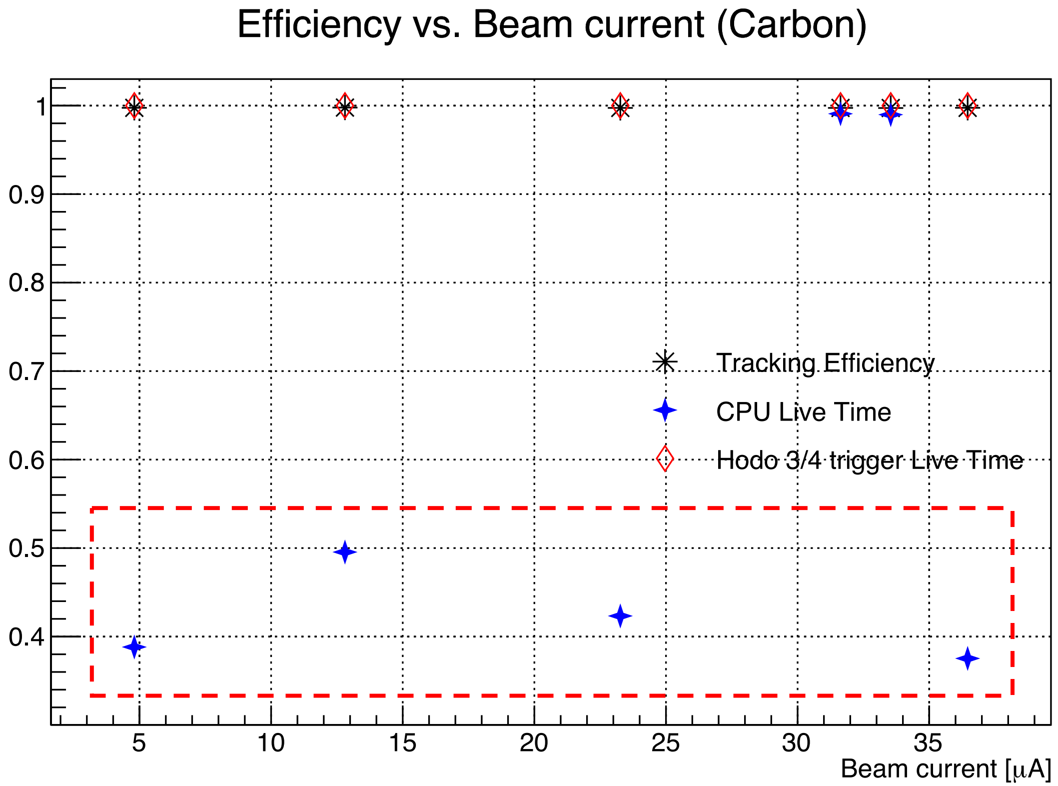
	Carbon runs	Current(μA)	BCM4A		BCM2	
			offset	offset_diff	offset	offset_diff
Fall 2023	1523-1530	5-40	103	0.20 μA	250219	0.16 μA
May 13, 2024	6845-6849	3-20	588	0.25 μA	250390	0.19 μA
May 19, 2024	7003-7007	5-40	47	0.20 μA	250281	0.17 μA

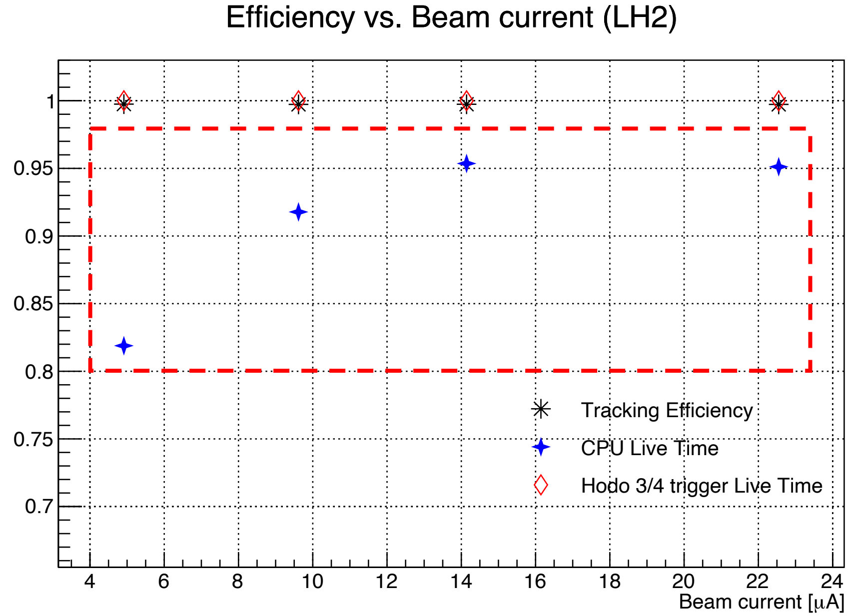
Live Time Issue

1st luminosity scan runs

- The tracking efficiency is very high
- The h3/4 trigger efficiency is also very high
- The CPU LT is suspiciously low



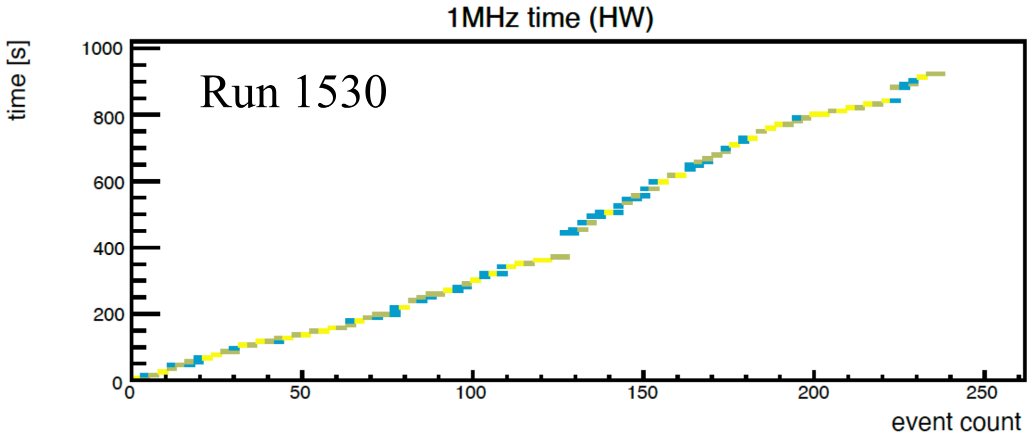


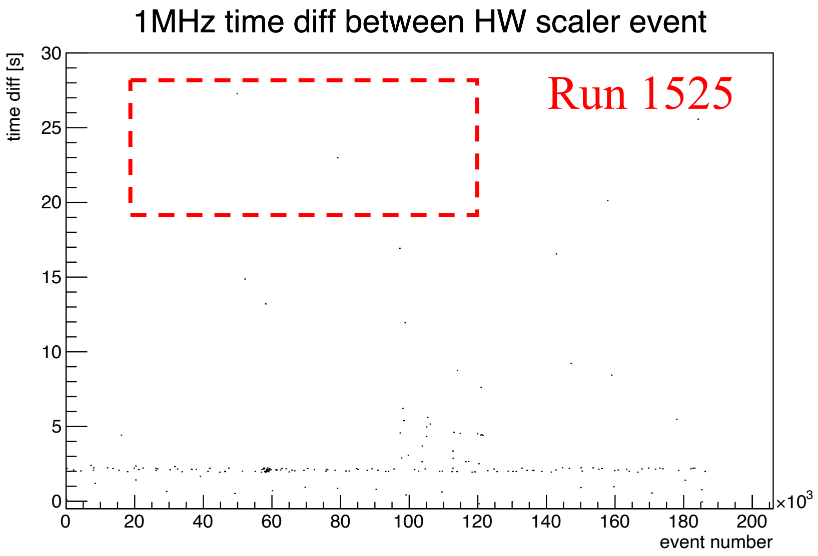


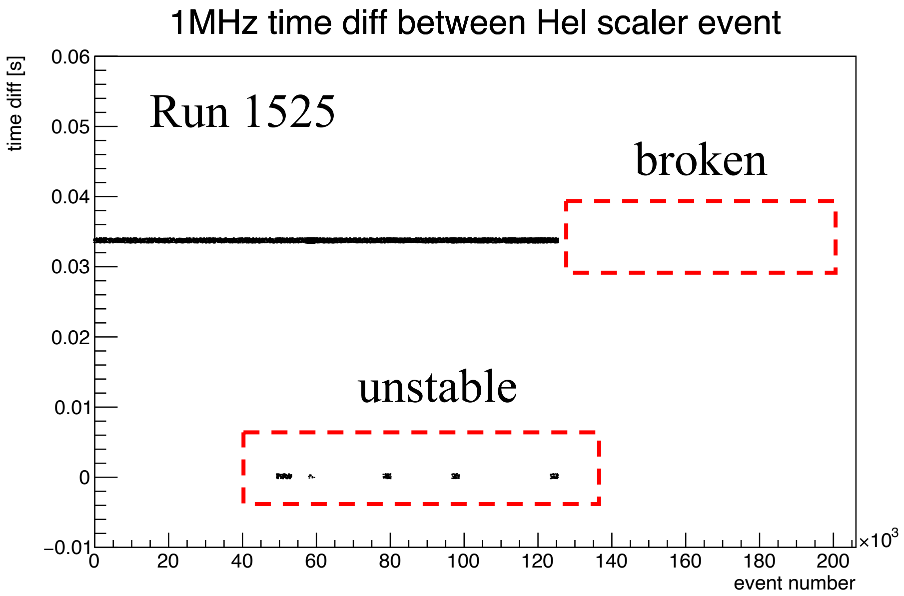
Live Time Issue

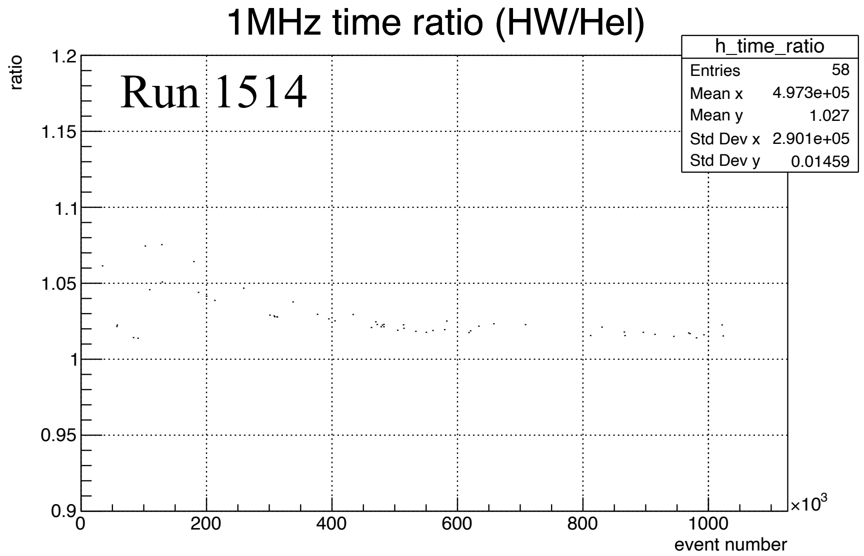
1st luminosity scan runs

- Bad HW scaler and unstable/broken Hel scaler









Live Time Issue

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1st luminosity scan runs

Target	RunNo	ps4	Pre-scale	Current (μA)
LH2	1514	0	1	5
	1515	2	3	10
	1516	3	5	15
	1517	4	9	25
LD2	1518	7	65	40
	1519	6	33	25
	1520	6	33	18
	1521	5	17	10
	1522	4	9	5
Carbon	1523	4	9	35
	1524	3	5	35
	1525	3	5	40
	1526	3	5	25
	1528	2	3	15
	1530	0	1	5

Among 15 runs, only 5 runs have good scalers:

	runs
good time sync	1518, 1519, 1522, 1523, 1524
unstable Hel scaler	1520, 1525, 1526, 1528, 1530
broken Hel scaler	1525, 1526, 1530

Live Time Issue

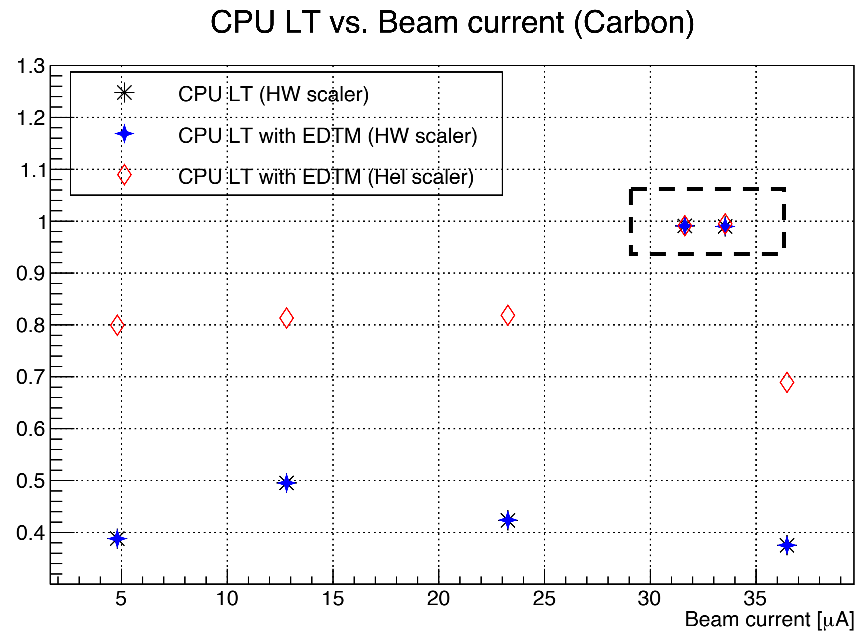
1st luminosity scan runs

Target	RunNo	ps4	Pre-scale	Current (μA)
LH2	1514	0	1	5
	1515	2	3	10
	1516	3	5	15
	1517	4	9	25
LD2	1518	7	65	40
	1519	6	33	25
	1520	6	33	18
	1521	5	17	10
	1522	4	9	5
Carbon	1523	4	9	35
	1524	3	5	35
	1525	3	5	40
	1526	3	5	25
	1528	2	3	15
	1530	0	1	5

Among 15 runs, only 5 runs have good scalers:

	runs
good time sync	1518, 1519, 1522, 1523, 1524
unstable Hel scaler	1520, 1525, 1526, 1528, 1530
broken Hel scaler	1525, 1526, 1530

The good runs have high cpu LT:



Live Time Issue

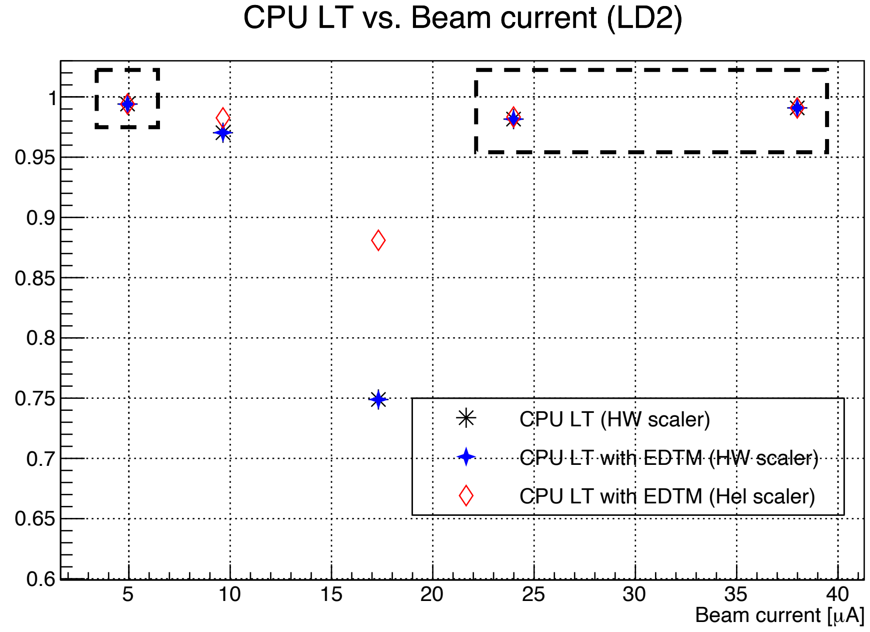
1st luminosity scan runs

Target	RunNo	ps4	Pre-scale	Current (μA)
LH2	1514	0	1	5
	1515	2	3	10
	1516	3	5	15
	1517	4	9	25
LD2	1518	7	65	40
	1519	6	33	25
	1520	6	33	18
	1521	5	17	10
	1522	4	9	5
Carbon	1523	4	9	35
	1524	3	5	35
	1525	3	5	40
	1526	3	5	25
	1528	2	3	15
	1530	0	1	5

Among 15 runs, only 5 runs have good scalers:

	runs
good time sync	1518, 1519, 1522, 1523, 1524
unstable Hel scaler	1520, 1525, 1526, 1528, 1530
broken Hel scaler	1525, 1526, 1530

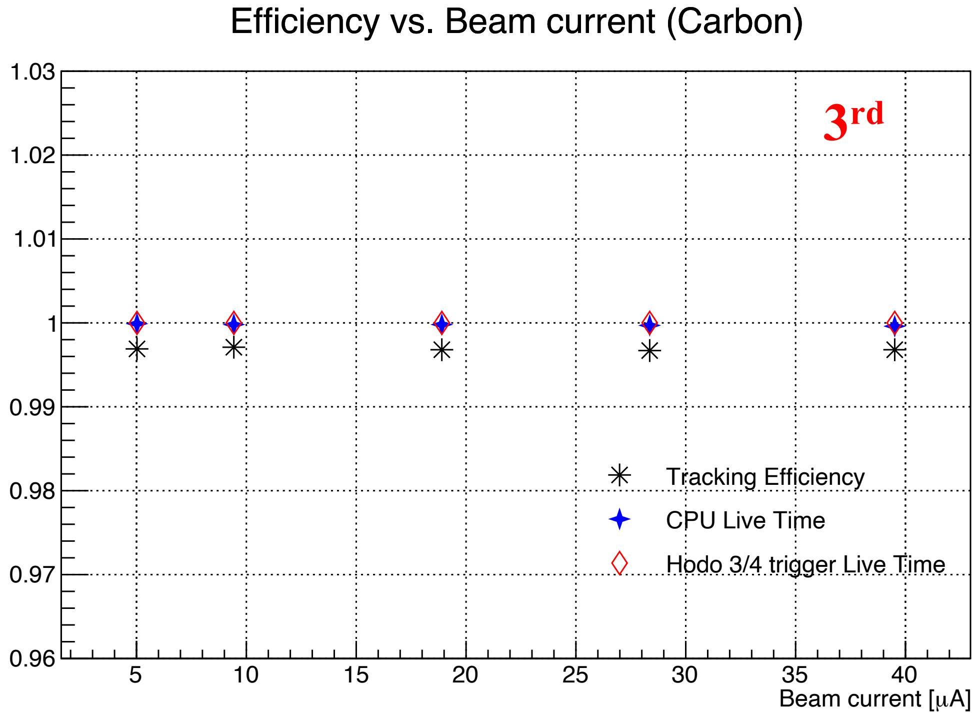
The good runs have high cpu LT:

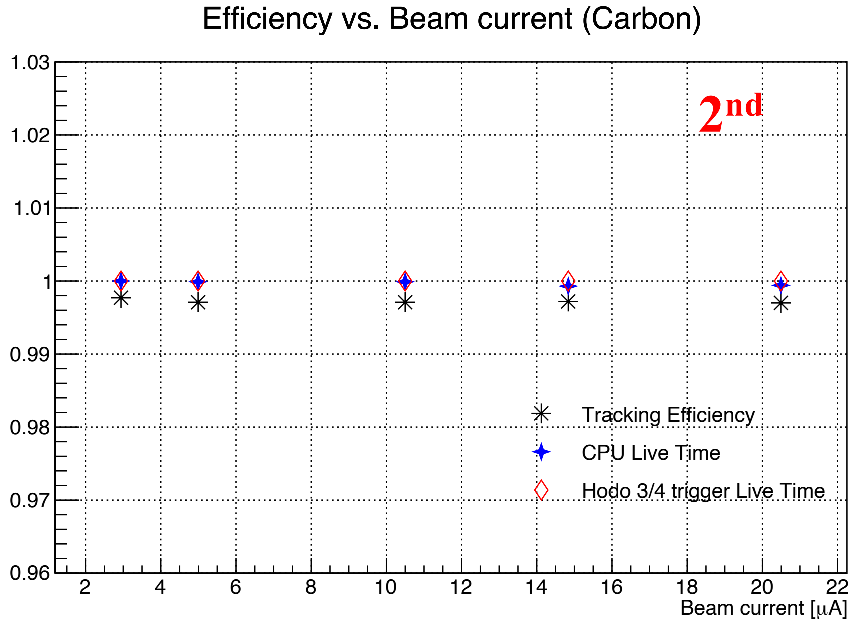


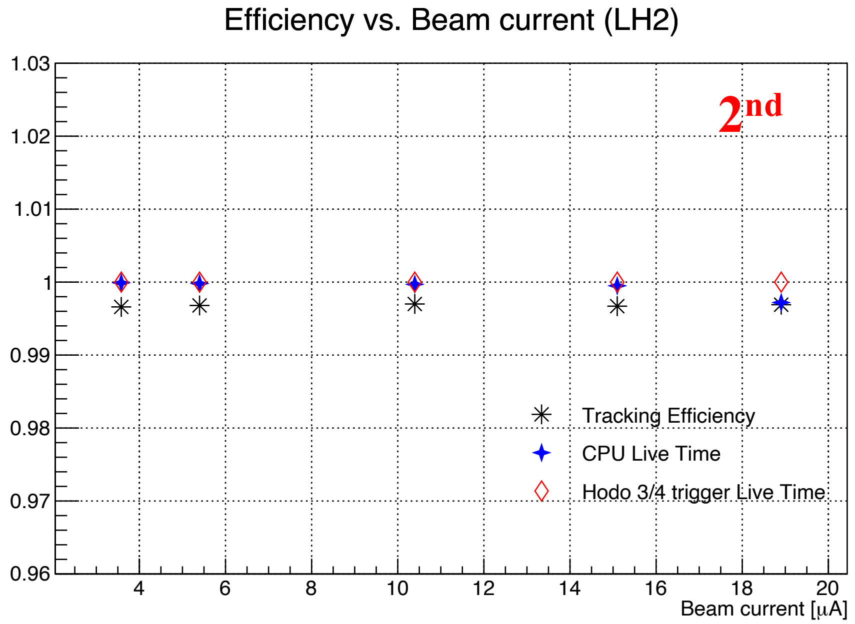
Live Time Issue

2nd and 3rd luminosity scan runs

- The tracking efficiency is relatively lower than the 1st runs
- The h3/4 trigger efficiency is also very high
- The CPU LT also very high
- The HW and Hel scalers are also good







BCM Offset Issue

Offset that cancels the anti-boiling

BCM calibration: BCM2: gain = 5707, offset = 249300
BCM4A: gain = 9597, offset = −1839

- Summary for all the 3 sets of luminosity runs:
  - Equivalent current offset: offset_diff = (offset_new − offset_calib) / gain_calib
- The new BCM offsets go beyond the error bar in Christine's BCM calibration results (about twice of the error bar)
- The offset_diff for KaonLT is only about 33nA (0.033 μA)
- Considering the LT issue in the 1^{st} runs:
  1. Although the scaler maybe not stable, the tracking and non-tracking yield are still showing the anti-boiling effect
  2. If we just ignore the 1^{st} runs, the 2^{nd} and 3^{rd} runs also show the anti-boiling effect

	Carbon runs	Current(μA)	BCM4A		BCM2	
			offset	offset_diff	offset	offset_diff
Fall 2023	1523-1530	5-40	103	0.20 μA	250219	0.16 μA
May 13, 2024	6845-6849	3-20	588	0.25 μA	250390	0.19 μA
May 19, 2024	7003-7007	5-40	47	0.20 μA	250281	0.17 μA

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LH2 Boiling effect based on different BCM offsets

Unit of slope: % in 100 μA

- If we just assume the new BCM offsets are correct and see the impact on the LH2 boiling slope (tracking yield):

BCM4A offset	LH2 tracking yield vs. current slope	
	Fall 2023 runs	May 13, 2024 runs
103	−7.576	−8.764
588	−10.653	−14.384
47	−7.220	−8.106

The boiling correction for LH2 at 100 μA: 10.8 ± 3.6 %
The boiling correction for LH2 at 25 μA: 2.7 ± 0.9 %

BCM2 offset	LH2 tracking yield vs. current slope	
	Fall 2023 runs	May 13, 2024 runs
250219	−7.822	−9.130
250390	−9.647	−12.407
250281	−8.481	−10.309

The boiling correction for LH2 at 100 μA: 10.1 ± 2.3 %
The boiling correction for LH2 at 25 μA: 2.525 ± 0.575 %

- The anti-boiling effect is much larger for the 2nd luminosity scan runs (May 13, 2024)
- The existence of 2nd luminosity scan runs could bring at most 1% uncertainty to the LH2 boiling correction (at 25 μA)

Boiling Effect

■ LD2 Boiling effect based on different BCM offsets

Unit of slope: % in 100 μA

➢ If we just assume the new BCM offsets are correct and see the impact on the LD2 boiling slope (tracking yield):

BCM4A offset	LD2 tracking yield vs. current slope
	Fall 2023 runs
103	−5.817
588	−7.322
47	−5.644

The boiling correction for LD2 at 100 μA: 6.5 ± 0.84 %
The boiling correction for LD2 at 25 μA: 1.625 ± 0.21 %

BCM2 offset	LD2 tracking yield vs. current slope
	Fall 2023 runs
250219	−5.229
250390	−6.126
250281	−5.556

The boiling correction for LD2 at 100 μA: 5.678 ± 0.45 %
The boiling correction for LD2 at 25 μA: 1.420 ± 0.112 %

Summary

Summary

1. There are 3 sets of luminosity scan runs
   - Many of the 1st set of luminosity scan runs have unhealthy scalers (highly related with the low efficiency runs)
   - The unbroken Hel scaler improves the CPU LT but it's still not close to 100%
   - The 2nd and 3rd sets of runs have healthy scalers and high CPU LT
2. All carbon runs show anti-boiling with the BCM calibration results
   - The 2nd set of luminosity scan runs show a much larger anti-boiling effect
   - The existence of 2nd luminosity scan runs could bring at most 1% uncertainty to the LH2 boiling correction (at 25 μA)
   - The LD2 boiling effect is smaller than the LH2
3. The beam current offset should be about 200nA to make the carbon yield flat
   - It goes beyond the error bar in Christine's BCM calibration results (about twice of the error bar)
   - The value for KaonLT is only about 33nA

THANKS!

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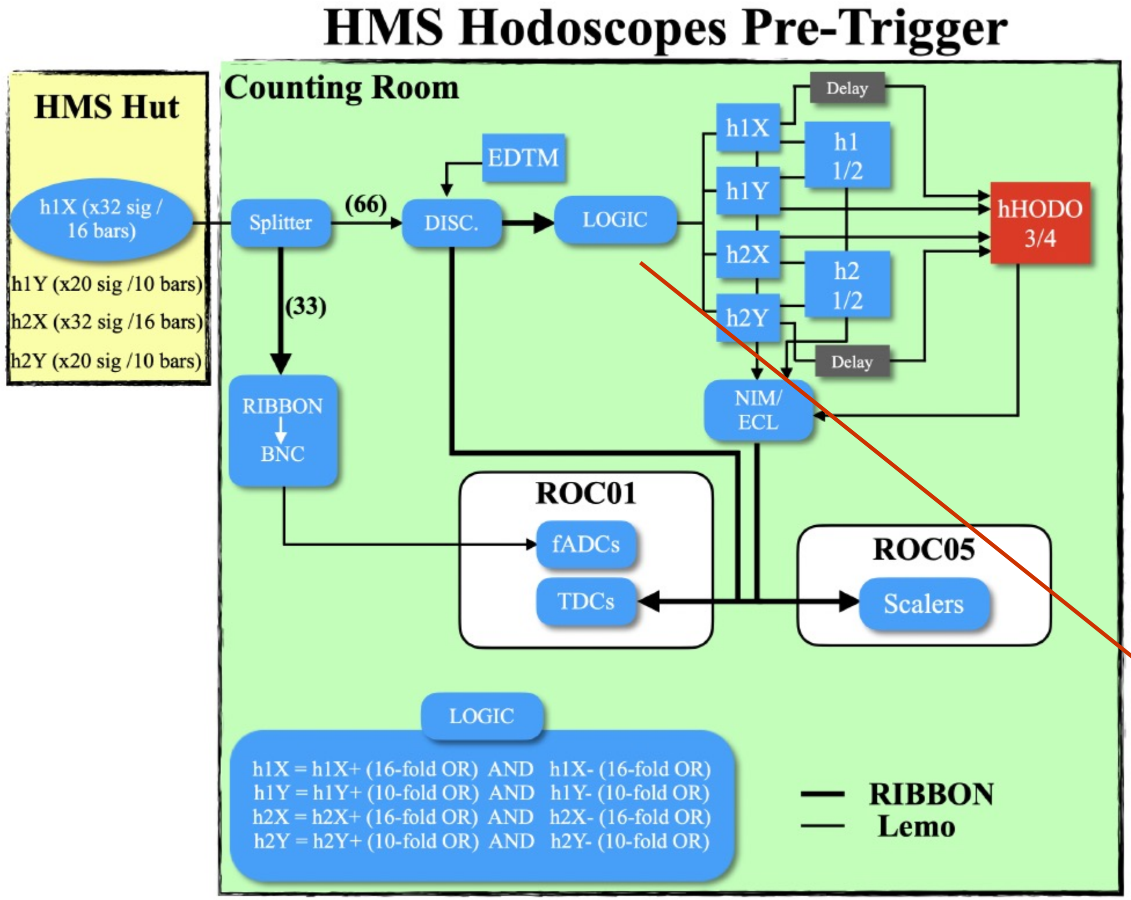
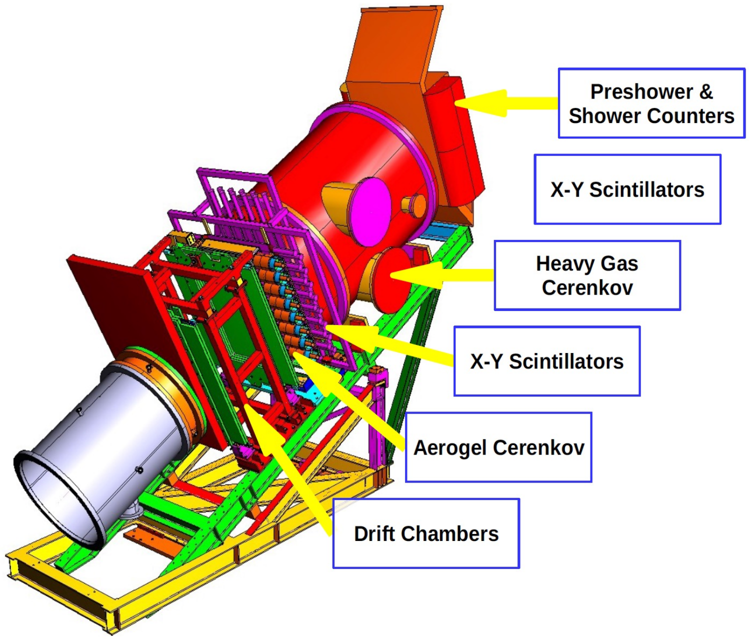
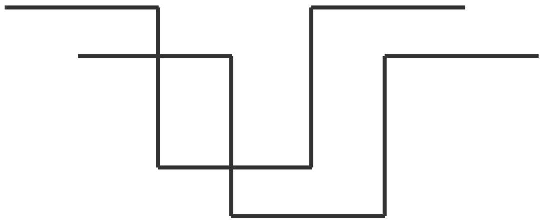
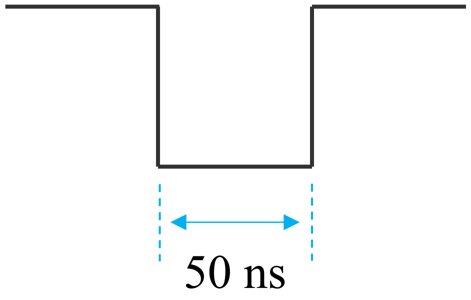
h3/4 trigger efficiency





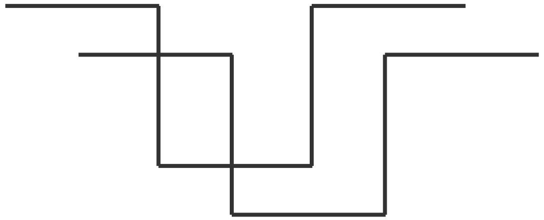




The double pulse resolution (DPR) = 50 ns

Backup

h3/4 trigger efficiency



Assume for plane i , that Li is the probability of being unblocked or “Live”, and Di is the probability of being ”Dead”. Of course, Li + Di = 1, for i = 1,4 . We can generate a list of all combos by multiplying out

(L1+D1)*(L2+D2)*(L3+D3)*(L4+D4)

and here they are (the multiplication signs are implicit):

L1L2L3L4	L1L2L3D4	L1L2D3L4	L1L2D3D4
L1D2L3L4	L1D2L3D4	L1D2D3L4	L1D2D3D4
D1L2L3L4	D1L2L3D4	D1L2D3L4	D1L2D3D4
D1D2L3L4	D1D2L3D4	D1D2D3L4	D1D2D3D4

The double pulse resolution (DPR) = 50 ns

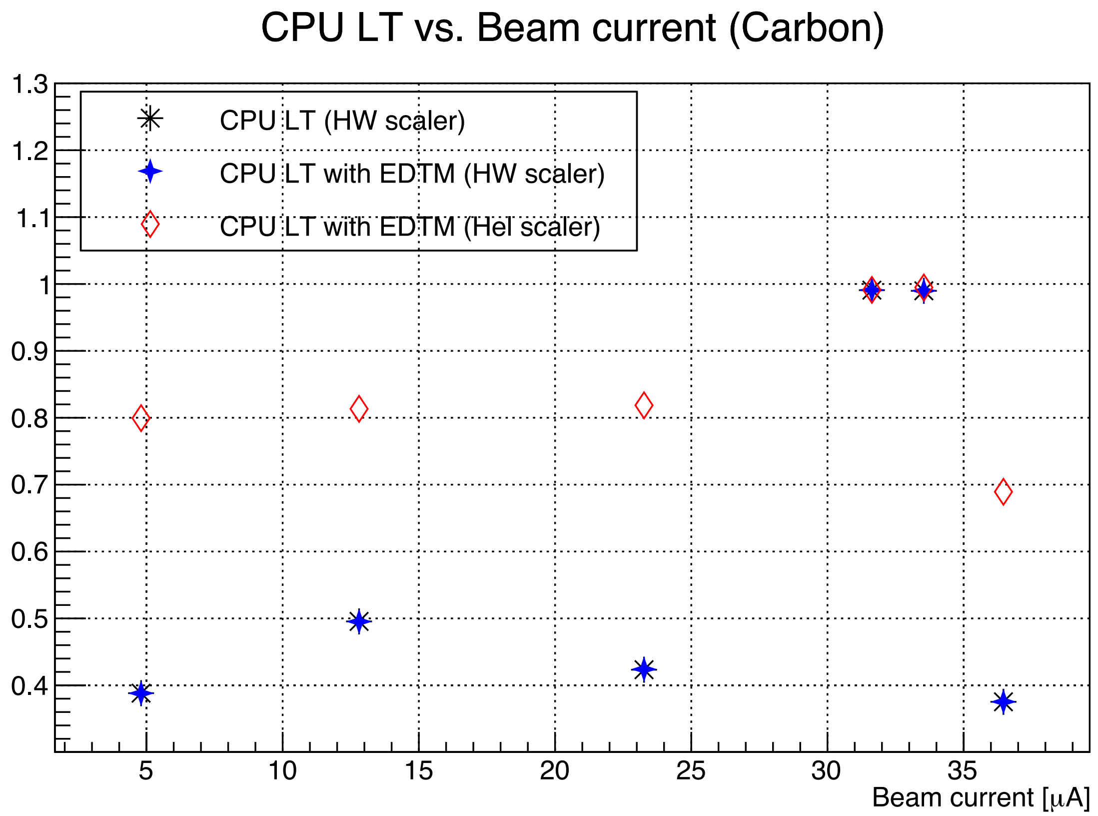
The deadtime for the 1^{st} plane is
D1 = Rate1*DPR
L1=1-D1
and similarly for the other 3 planes.

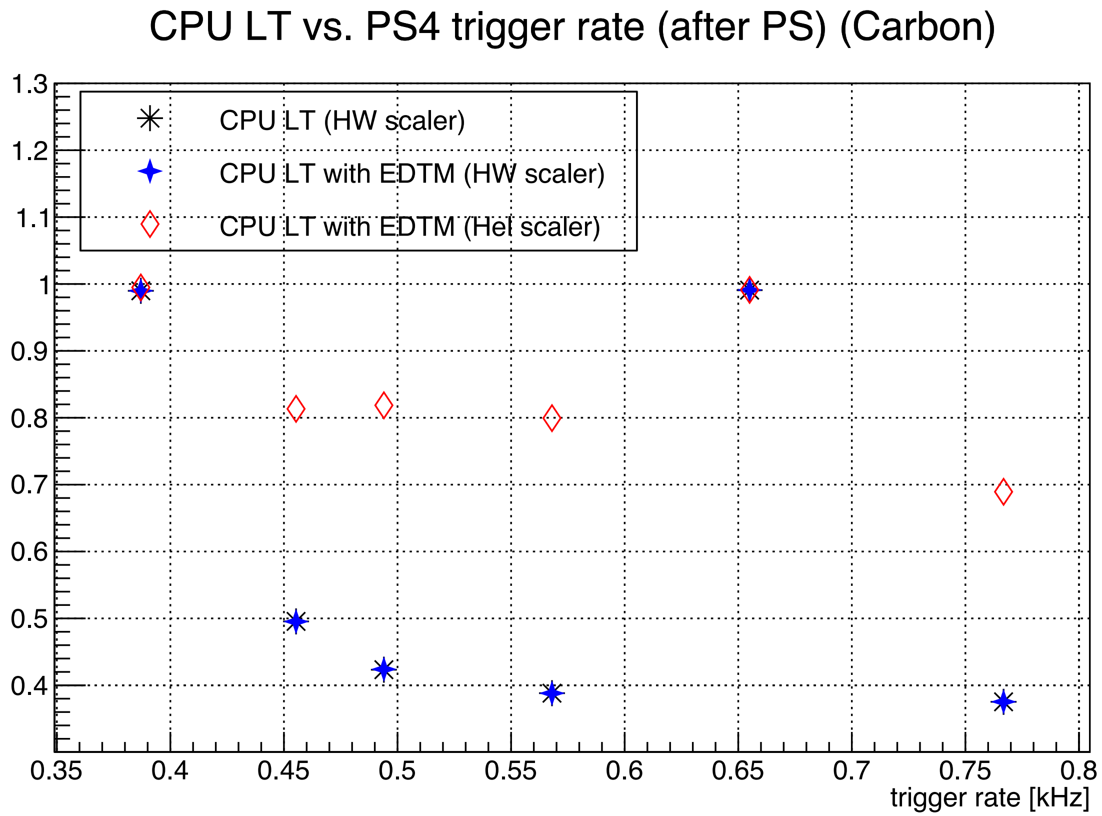
If your eyes are glazing over, these are readily interpretable. Eg, the combo label “L1D2L3D4” means
“(Prob the 1^{st} plane is Live) x (Prob the 2^{nd} plane is Dead) x (Prob the 3^{rd} plane is Live) x (Prob the 4^{th} plane is Dead)”

CPU Live Time

CPU LT: 1st set of luminosity scan runs (Fall 2023)

When HW scalers are bad, if Hel scaler gives better result?



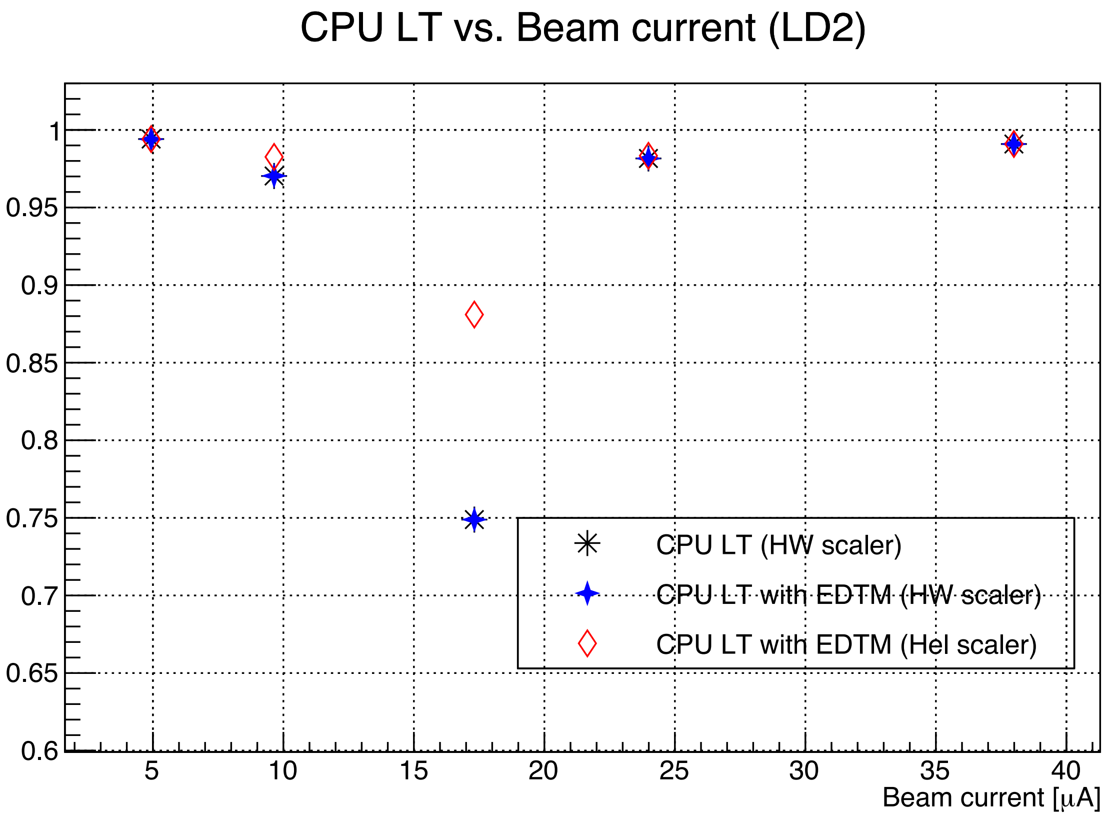


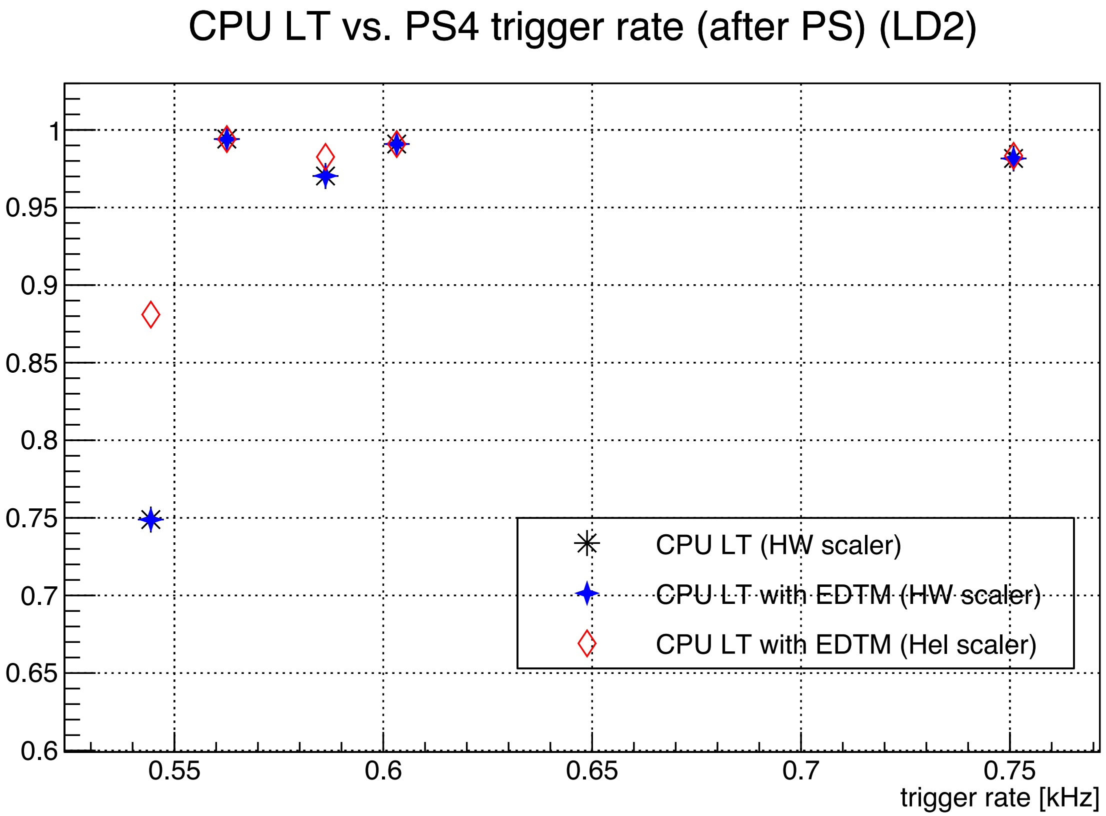
$$LT = \frac{\text{\# of events (no EDTM)}}{\text{scaler\_htrig4} - \text{scaler\_edtm}} \times \text{ps factor}$$

CPU Live Time

CPU LT: 1st set of luminosity scan runs (Fall 2023)

When HW scalers are bad, if Hel scaler gives better result?

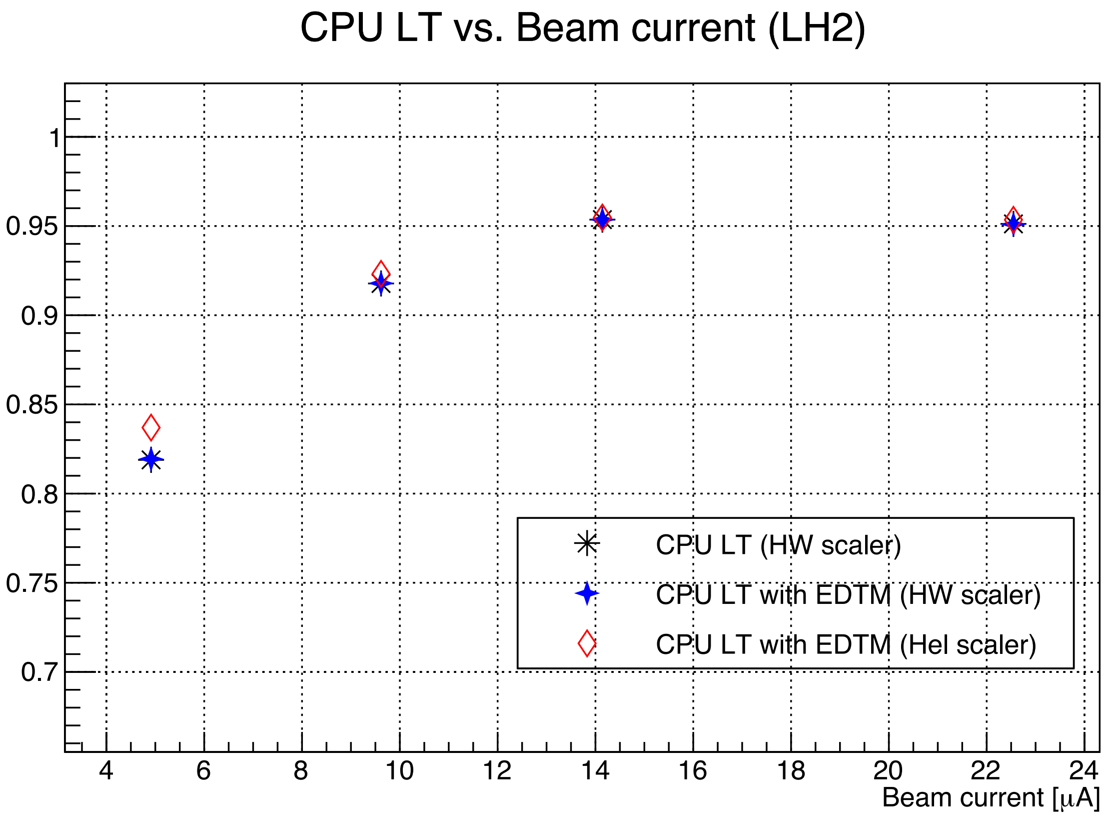


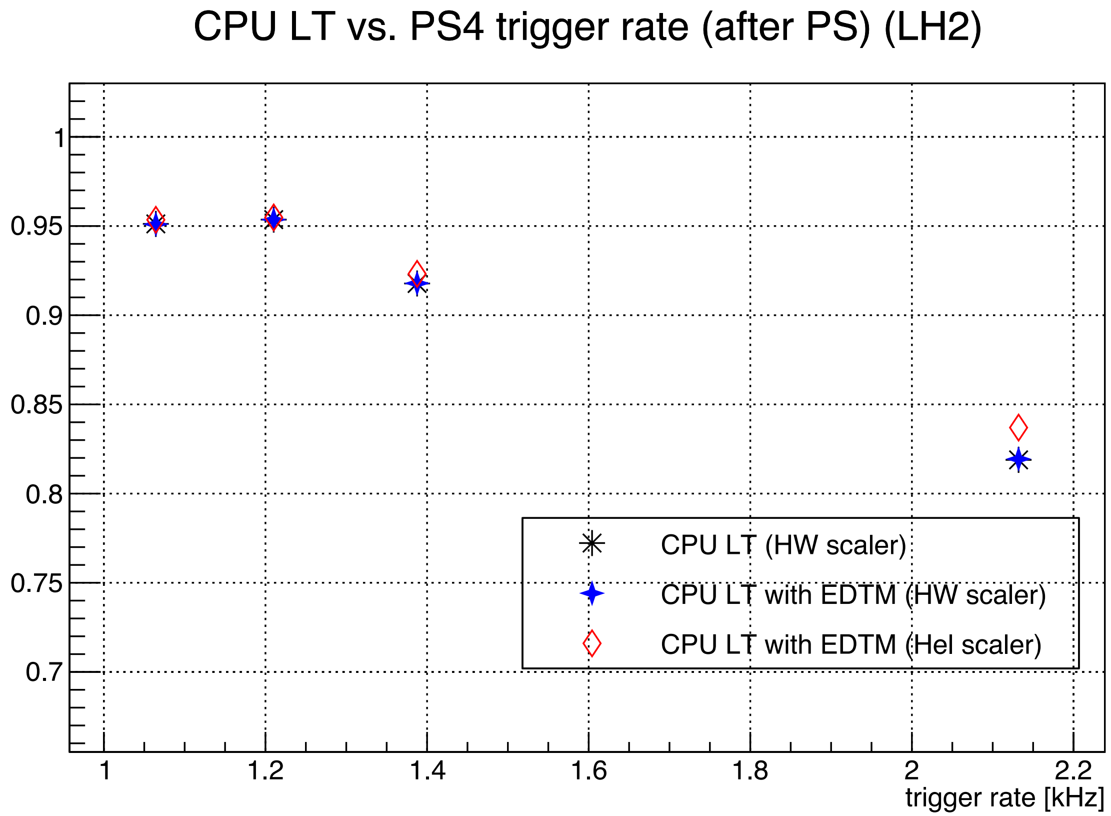


CPU Live Time

CPU LT: 1st set of luminosity scan runs (Fall 2023)

When HW scalers are bad, if Hel scaler gives better result?

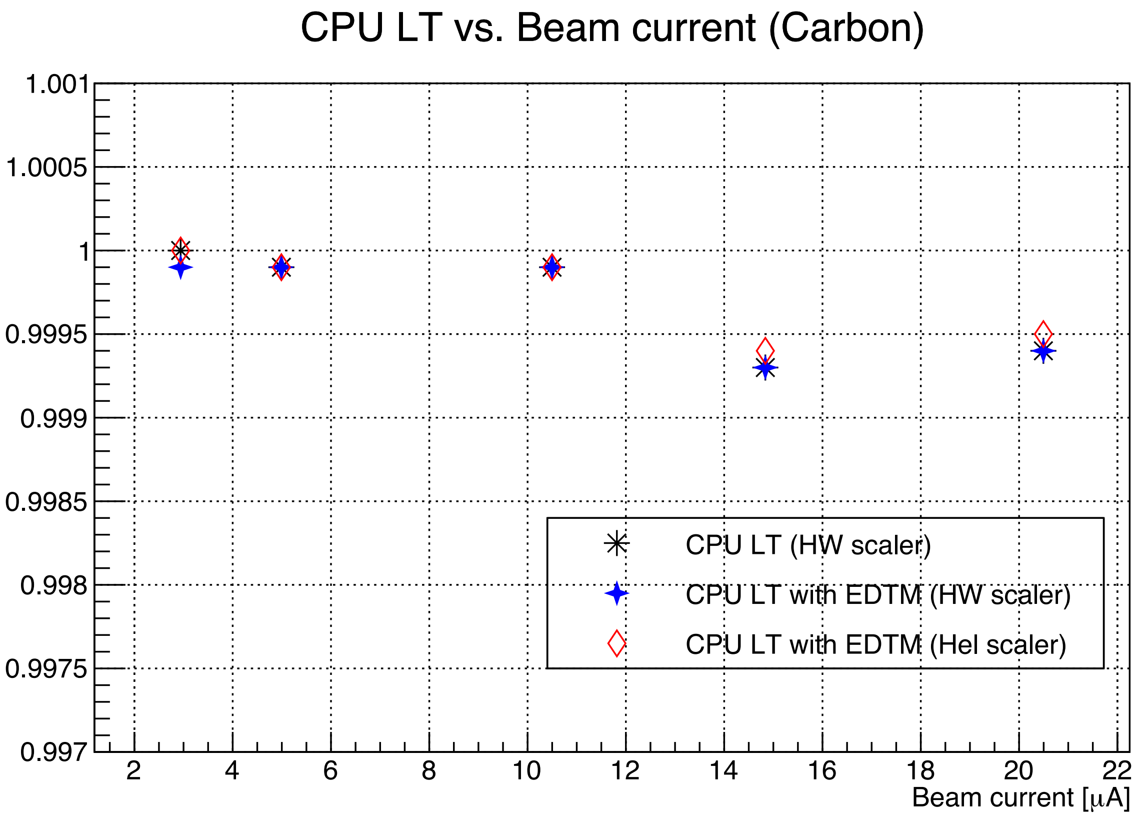


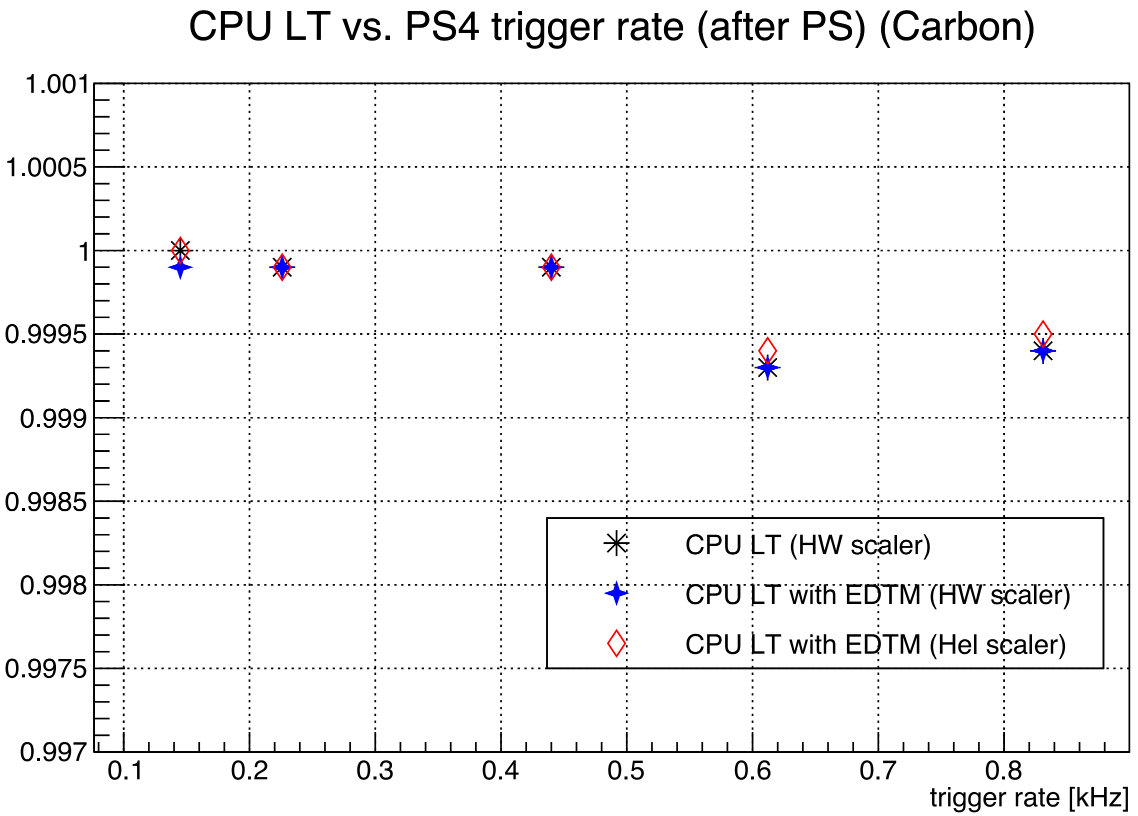


CPU Live Time

Tsinghua University

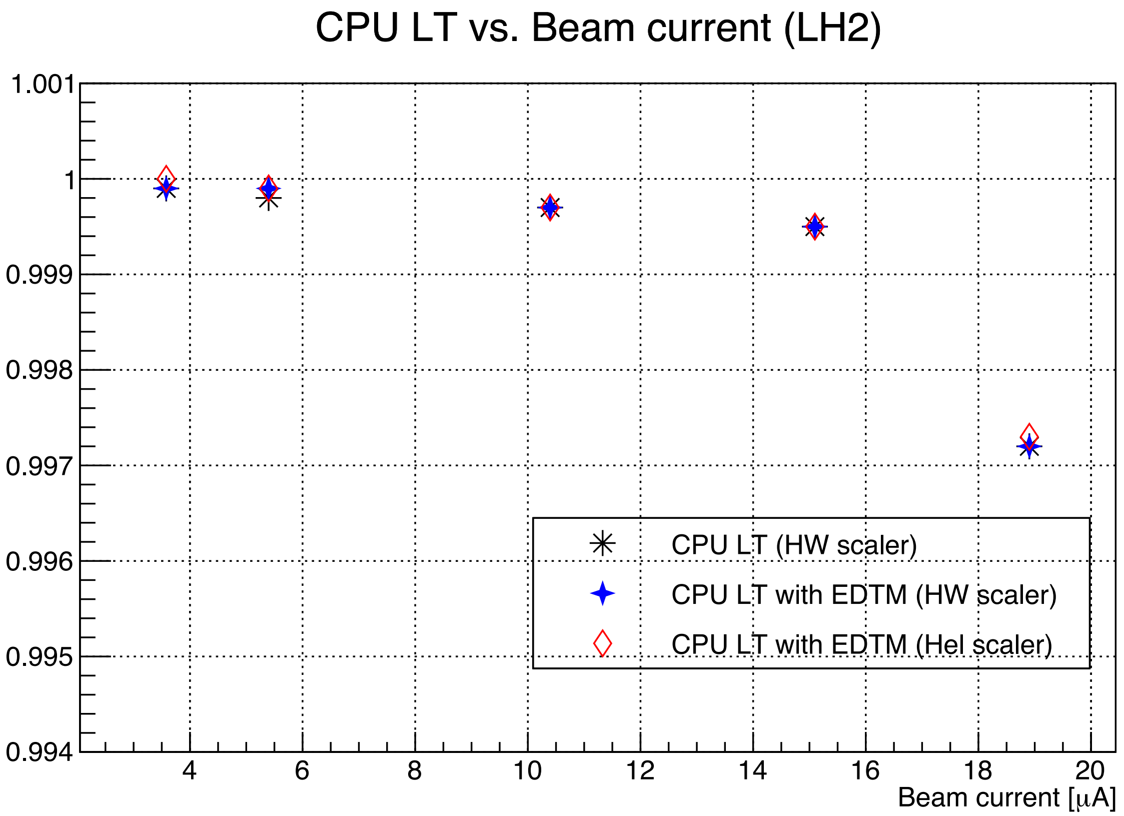
CPU LT: 2nd set of luminosity scan runs (Fall 2023)

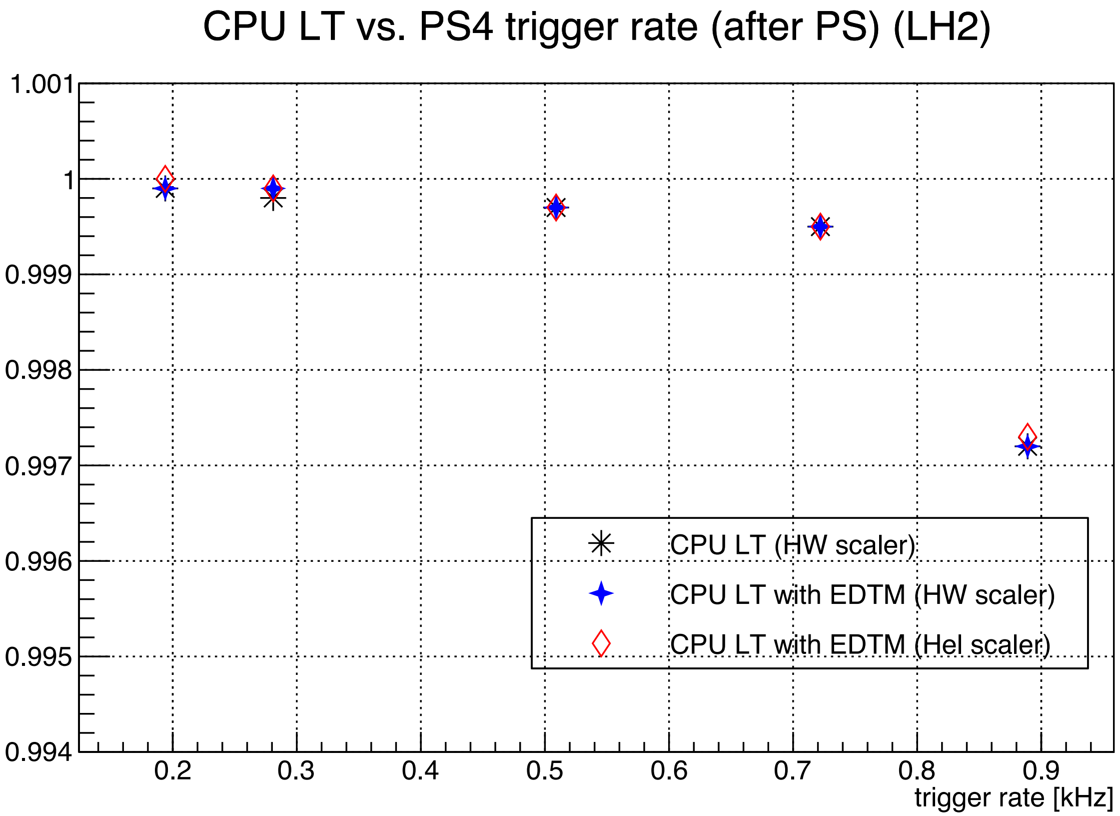




CPU Live Time

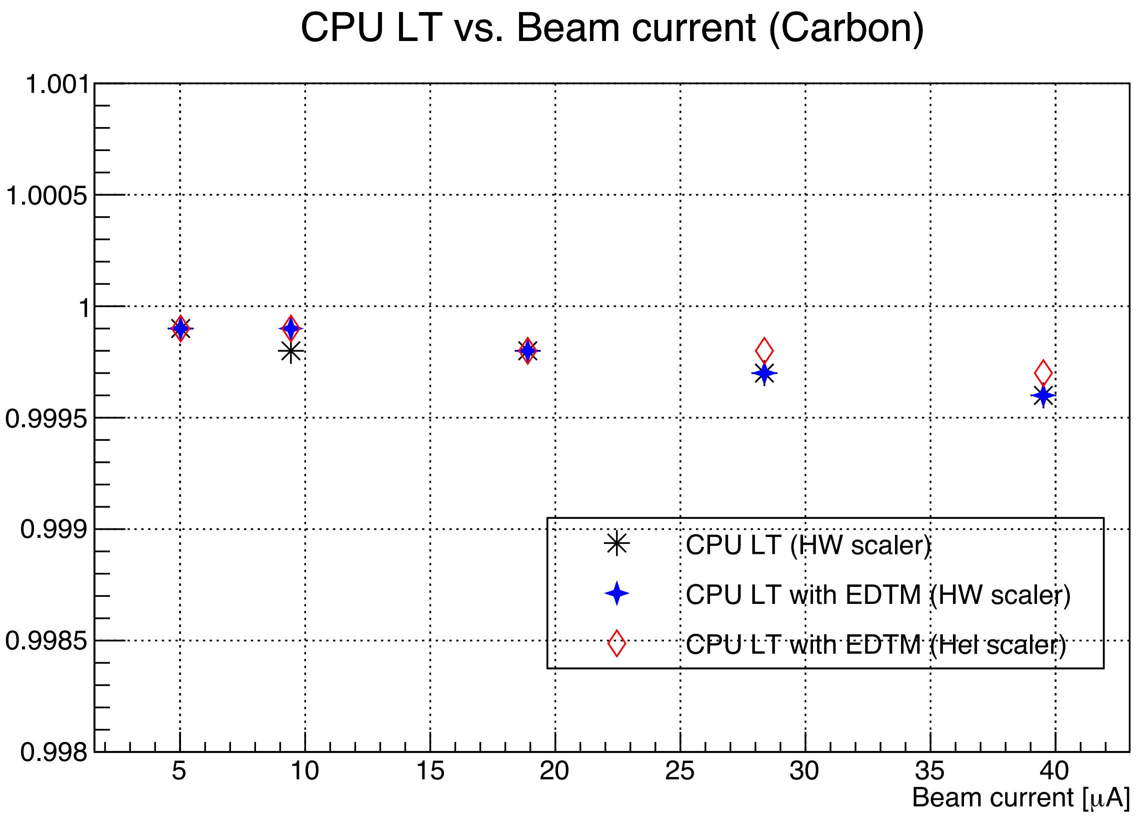
CPU LT: 2nd set of luminosity scan runs (Fall 2023)

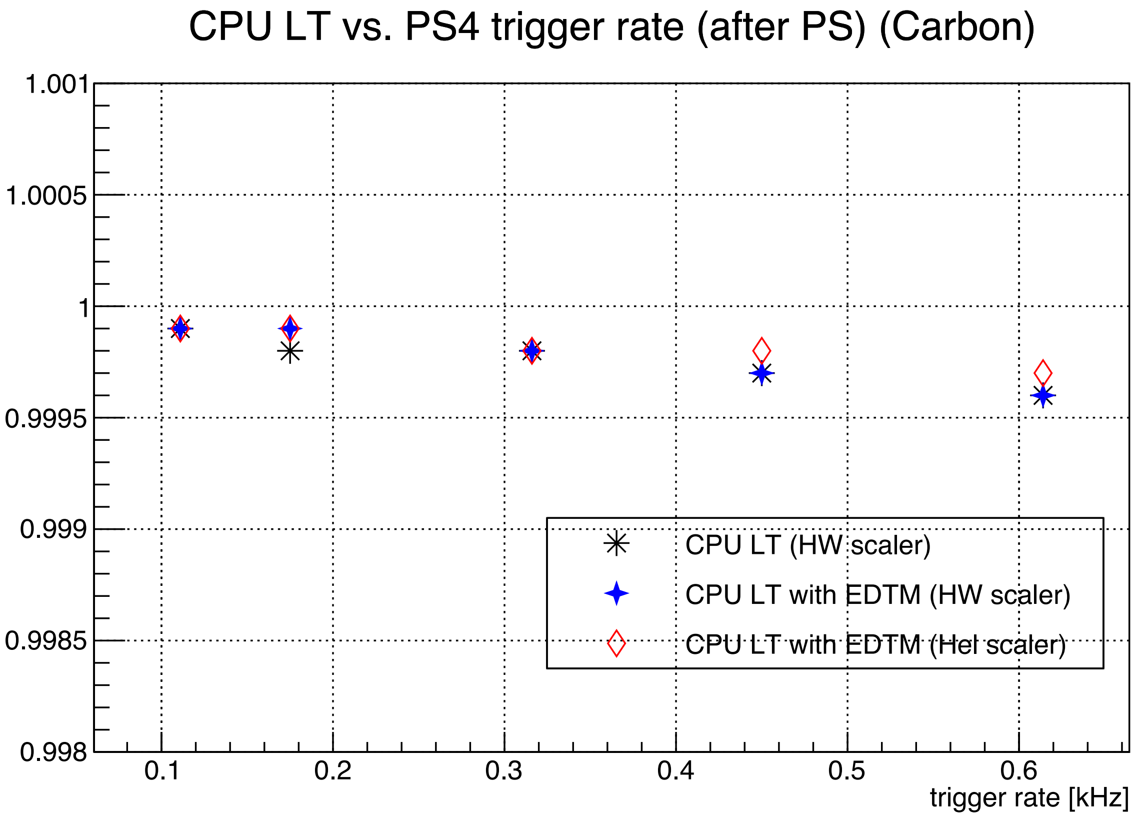




CPU Live Time

CPU LT: 3rd set of luminosity scan runs (Fall 2023)

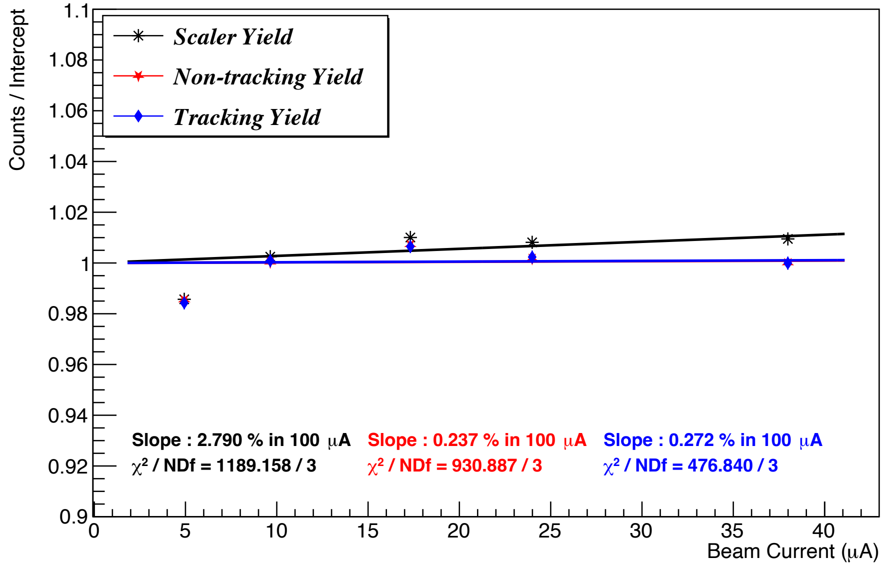




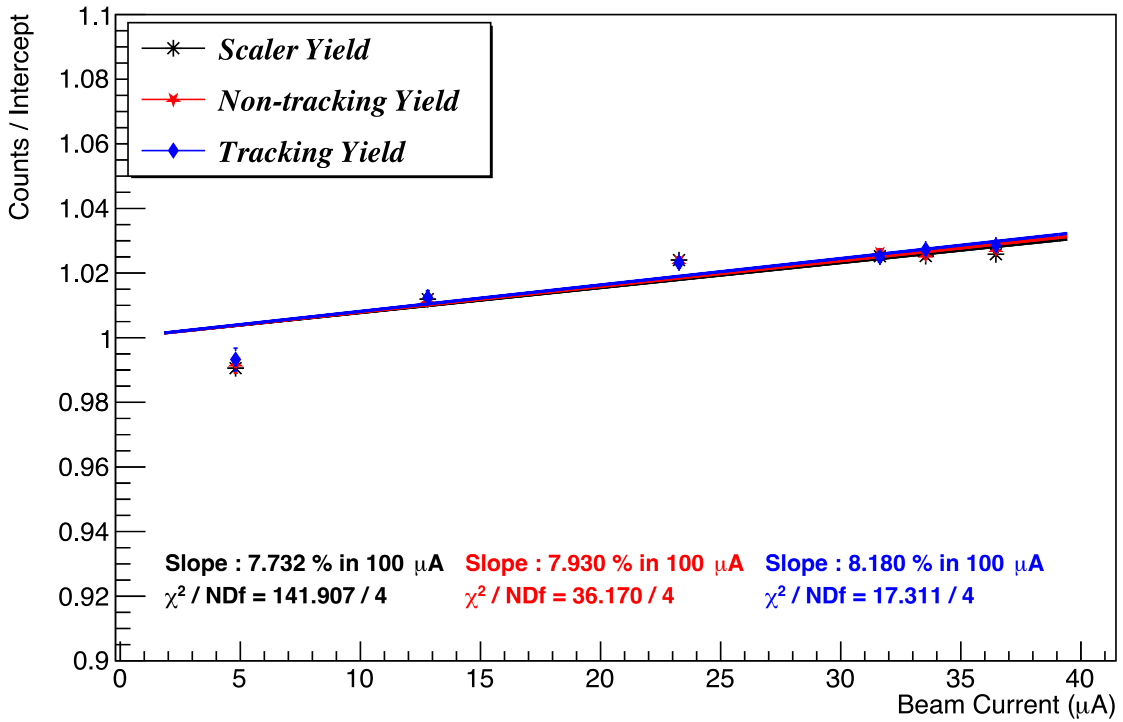
Yield vs beam current

- 1^{st} luminosity scan runs
- BCM4A used for charge and current calculation
- BCM4A gain = 9597
- BCM4A offset = −1839

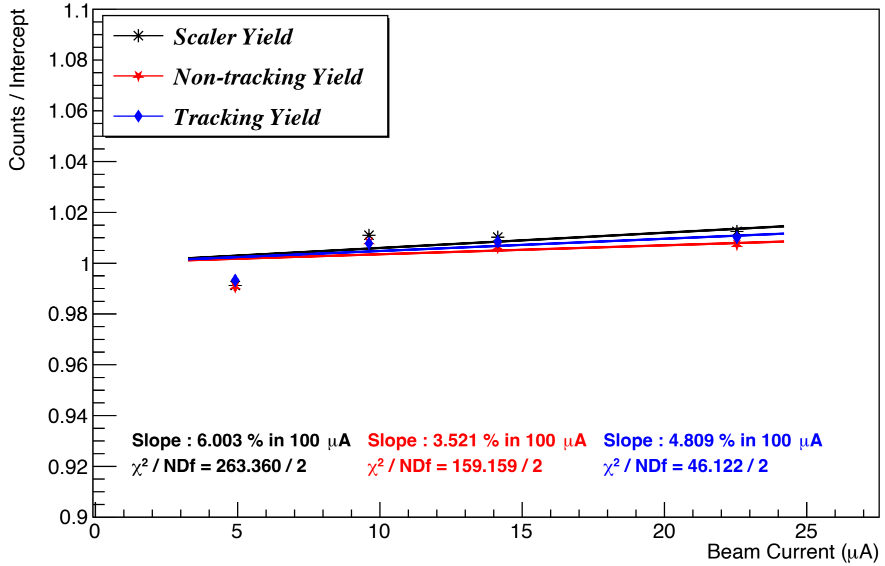
Charge normalized El-Real events(LD2)



Charge normalized El-Real events(Carbon)



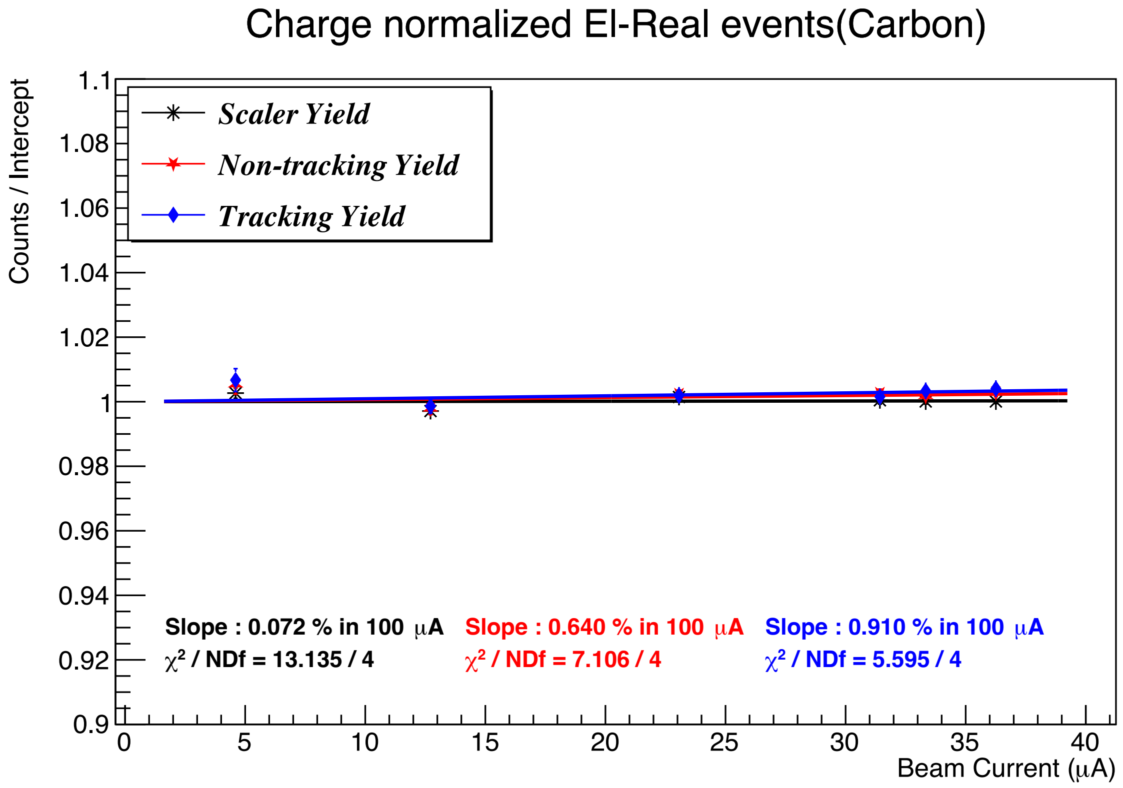
Charge normalized El-Real events(LH2)

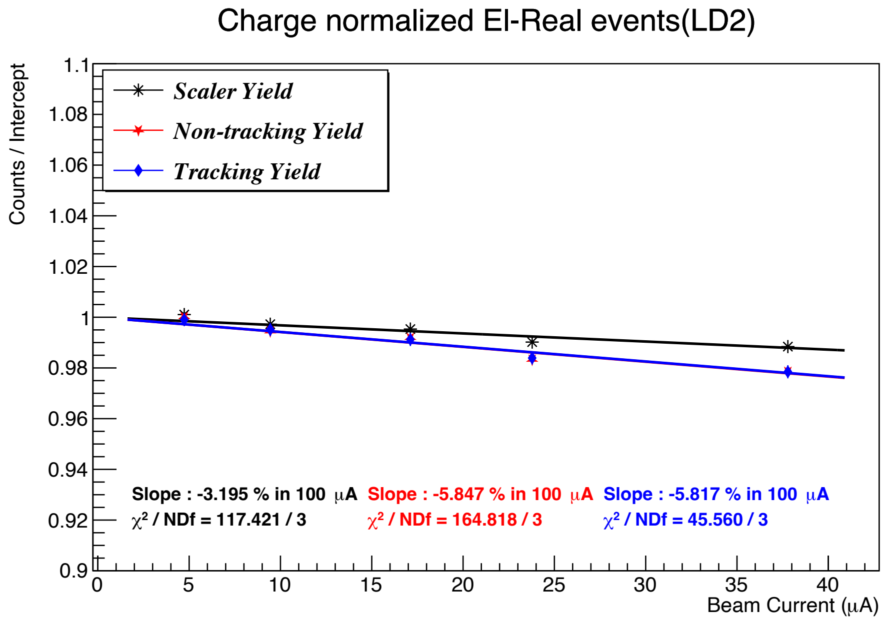


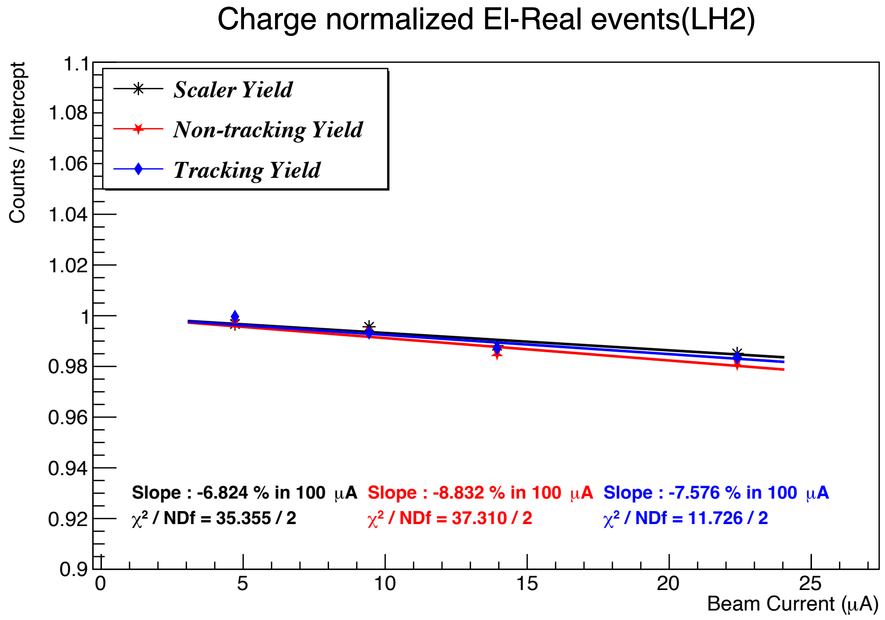
BCM Offset Issue

Offset that cancels the anti-boiling

- 1st luminosity scan runs
- BCM4A used for charge and current calculation
- BCM4A gain = 9597
- BCM4A offset = 103



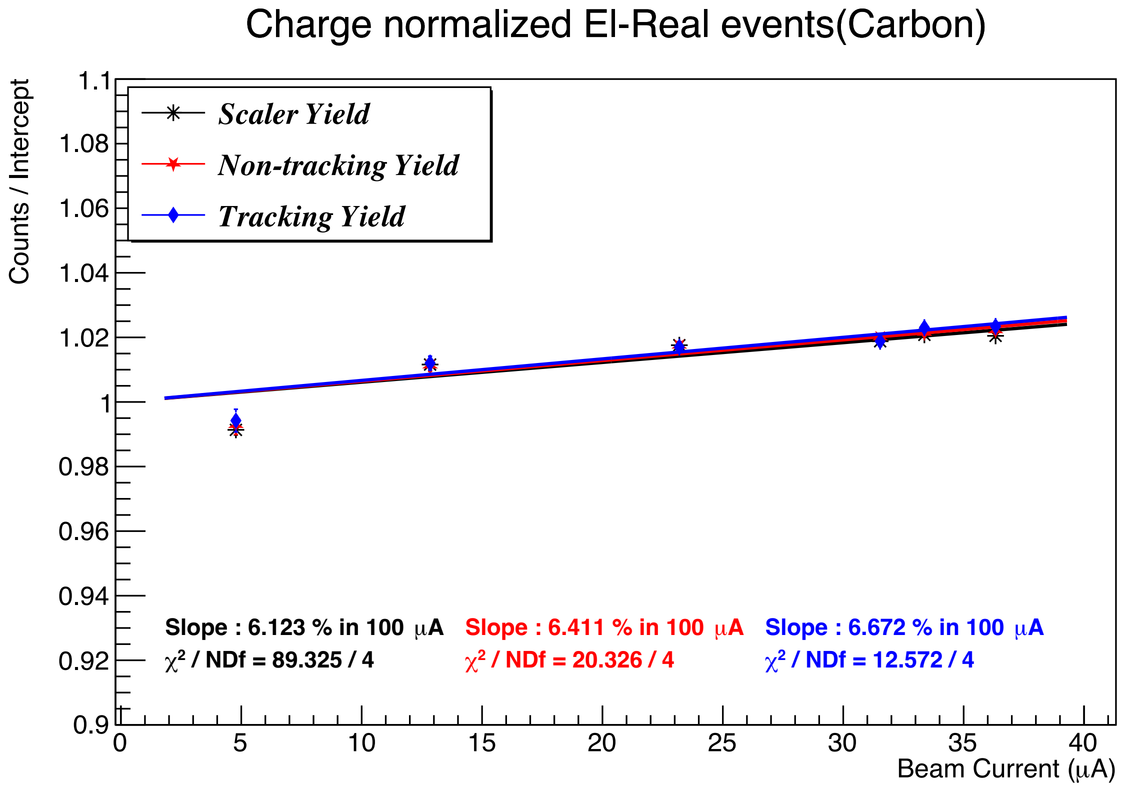


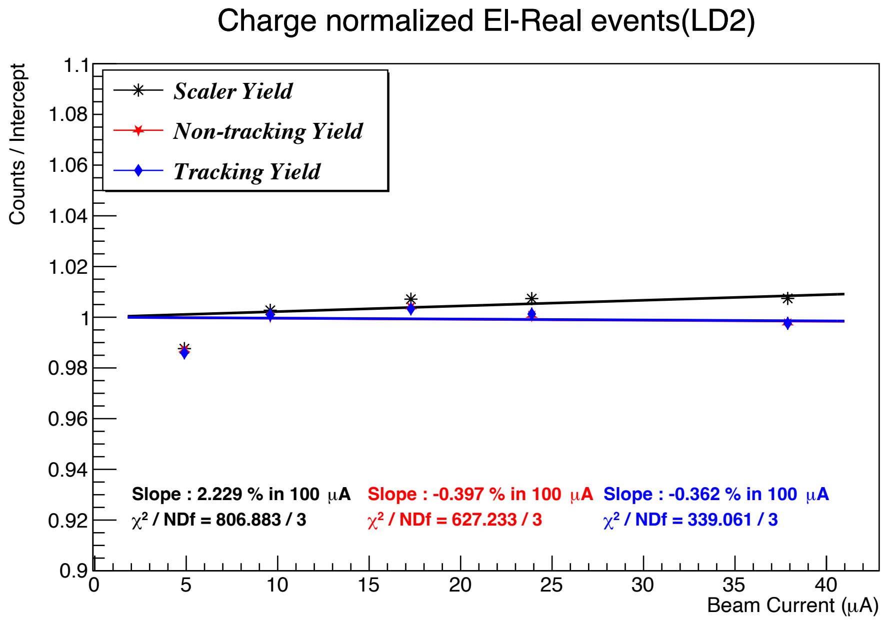


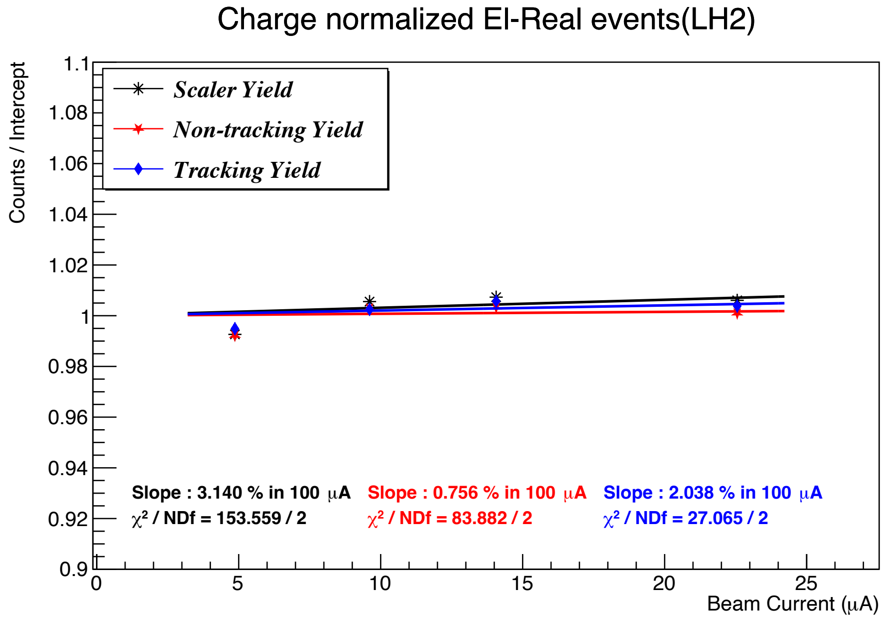
Yield Analysis

Yield vs beam current

- 1st luminosity scan runs
- BCM2 used for charge and current calculation
- BCM2 gain = 5707
- BCM2 offset = 249300





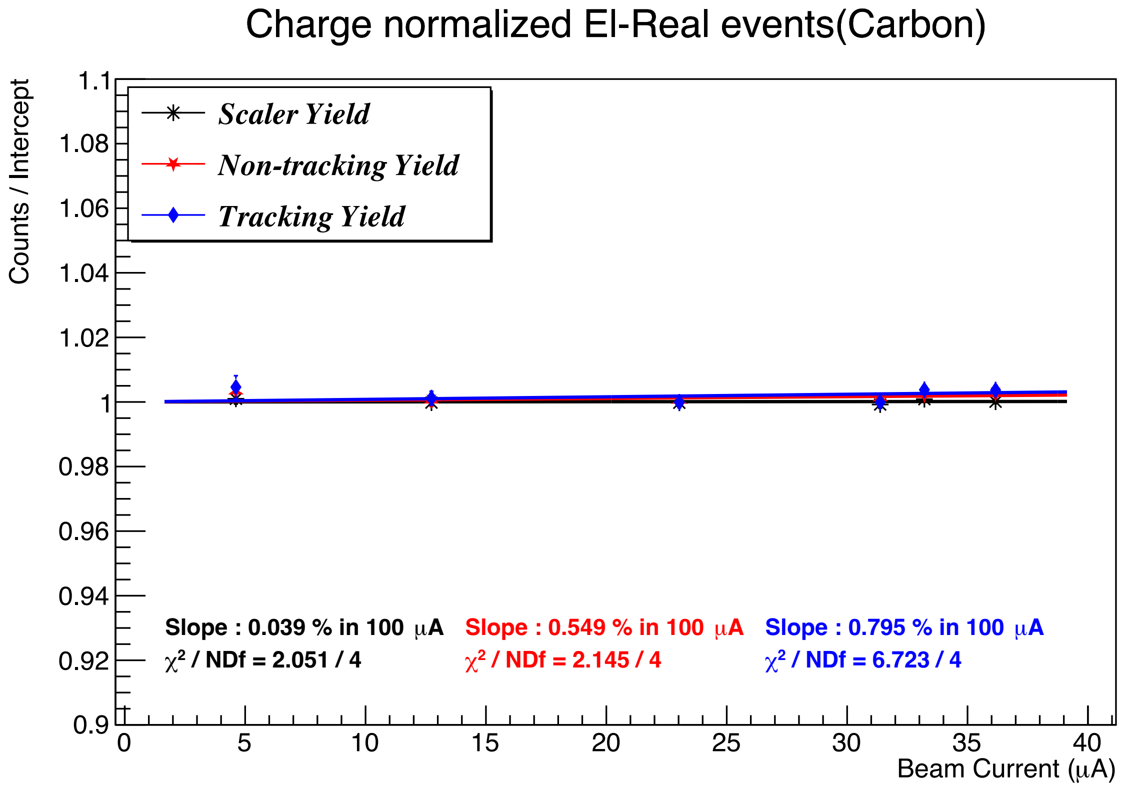


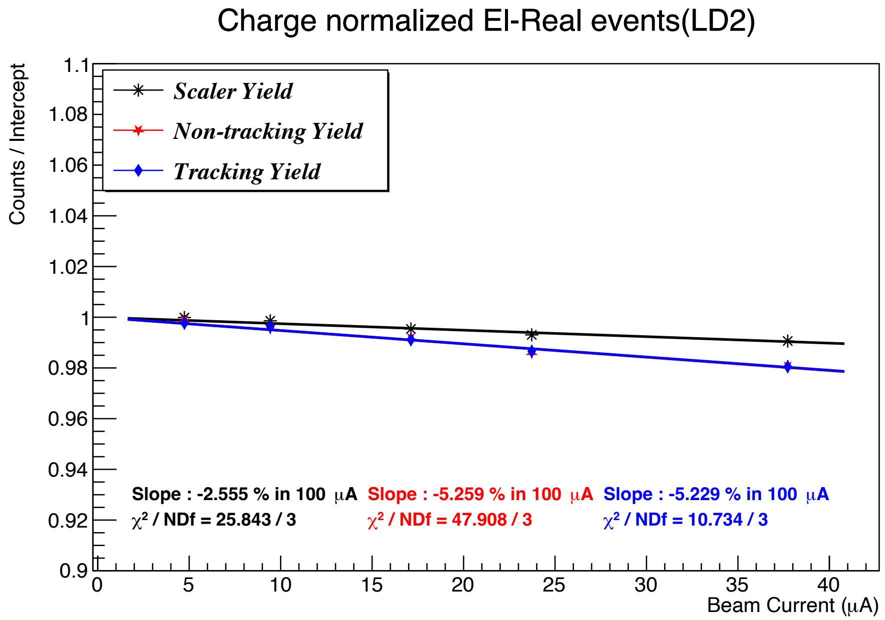
BCM Offset Issue

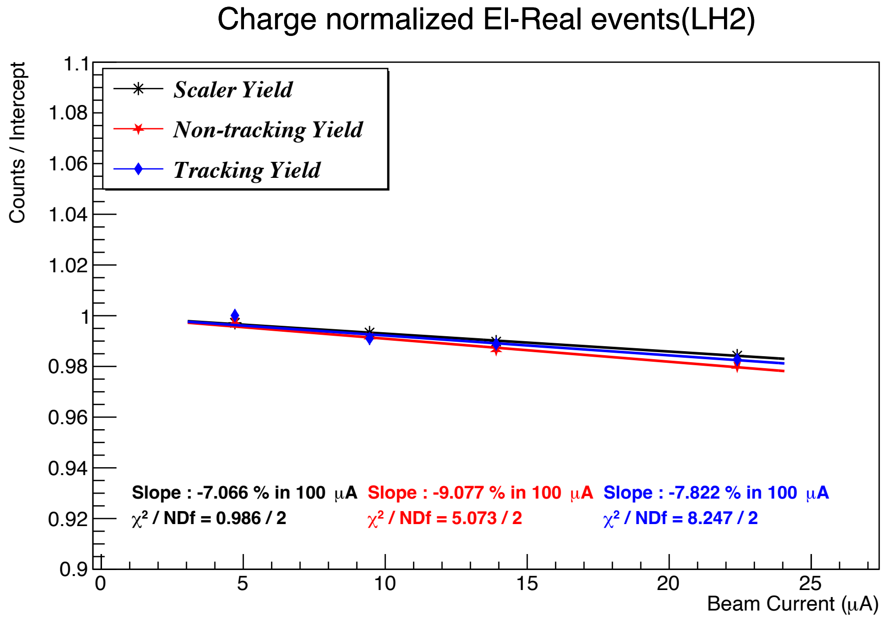
Tsinghua University

Offset that cancels the anti-boiling

- 1st luminosity scan runs
- BCM2 used for charge and current calculation
- BCM2 gain = 5707
- BCM2 offset = 250219





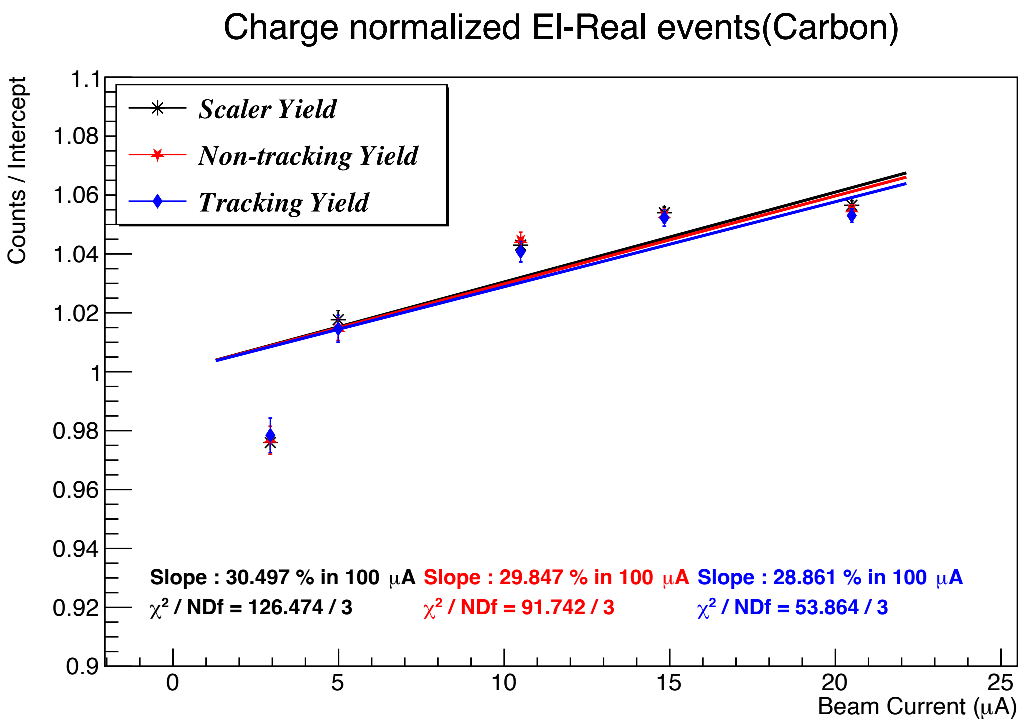


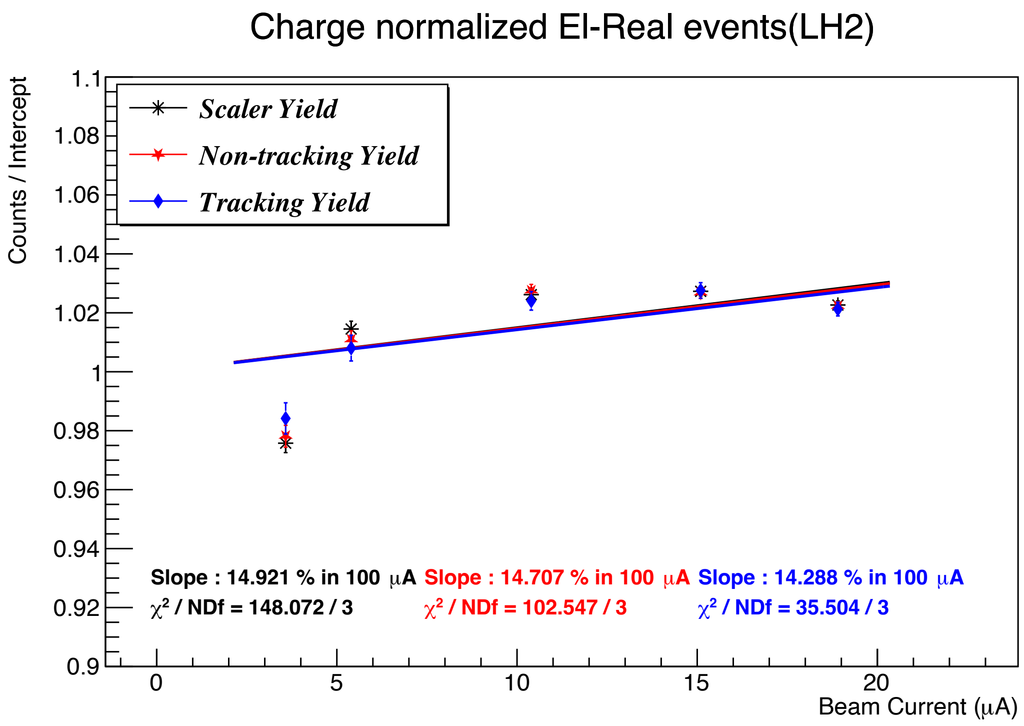
Yield Analysis

Tsinghua University

Yield vs beam current

- 2^{nd} luminosity scan runs
- BCM4A used for charge and current calculation
- BCM4A gain = 9597
- BCM4A offset = −1839
- The anti-boiling effect is much larger for the 2^{nd} luminosity scan runs

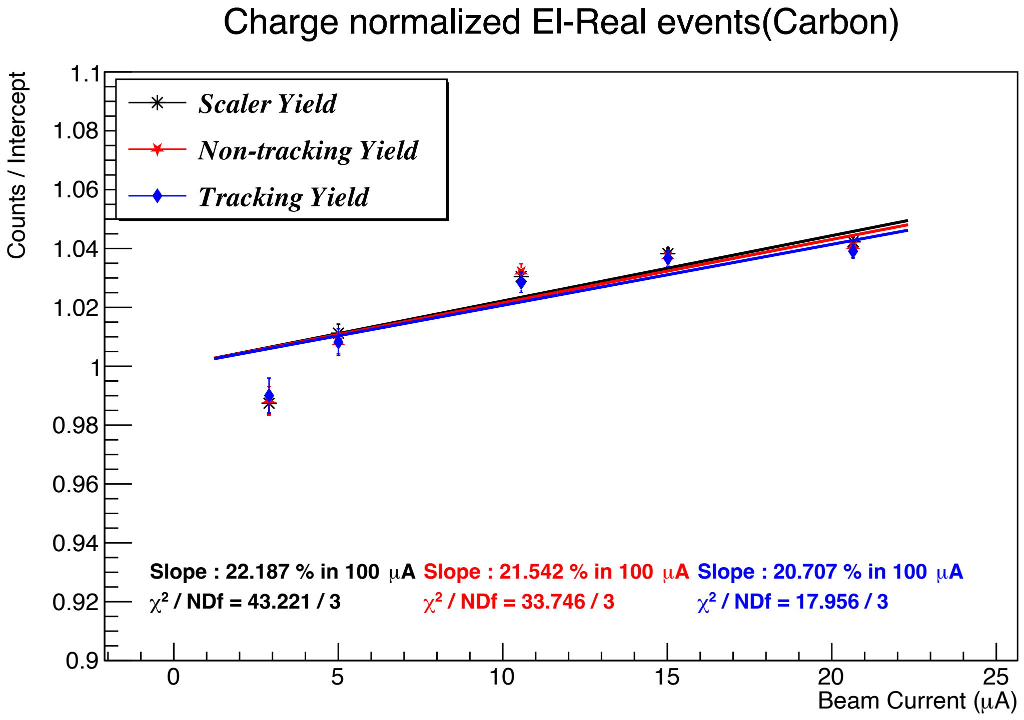


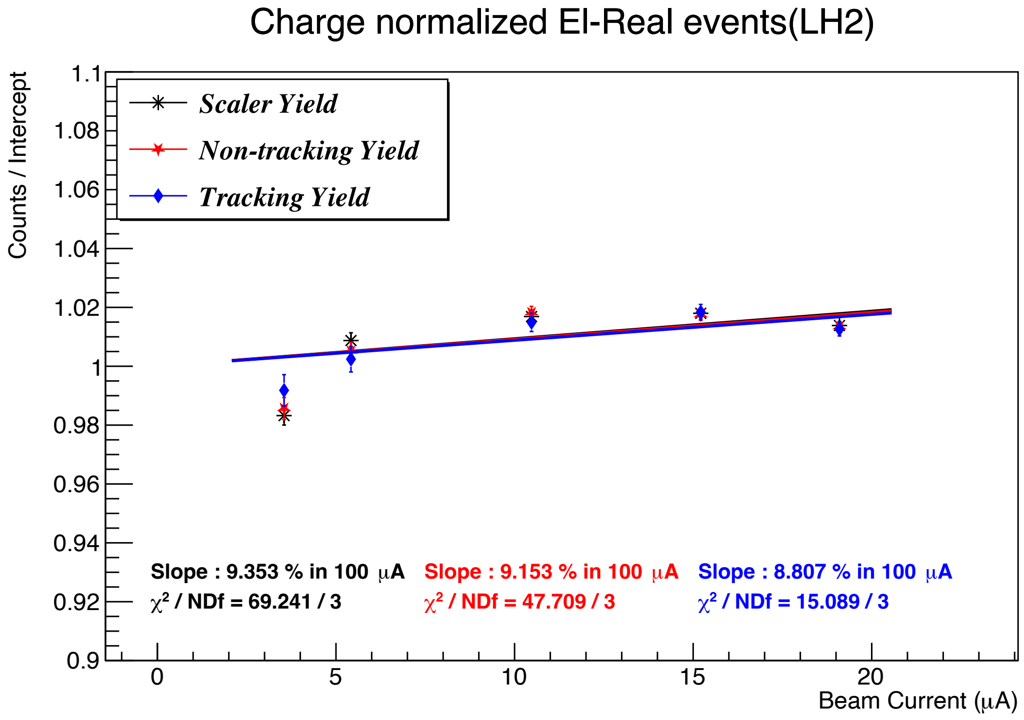


Yield Analysis

Yield vs beam current

- 2nd luminosity scan runs
- BCM2 used for charge and current calculation
- BCM2 gain = 5707
- BCM2 offset = 249300
- The anti-boiling effect is much larger for the 2nd luminosity scan runs



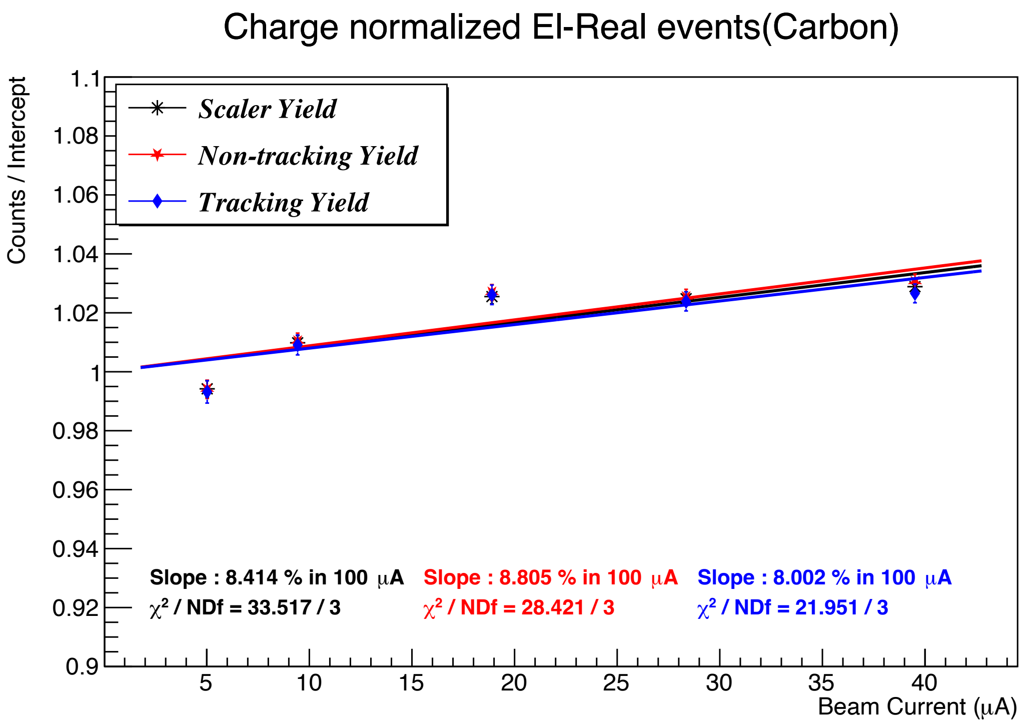


Yield Analysis

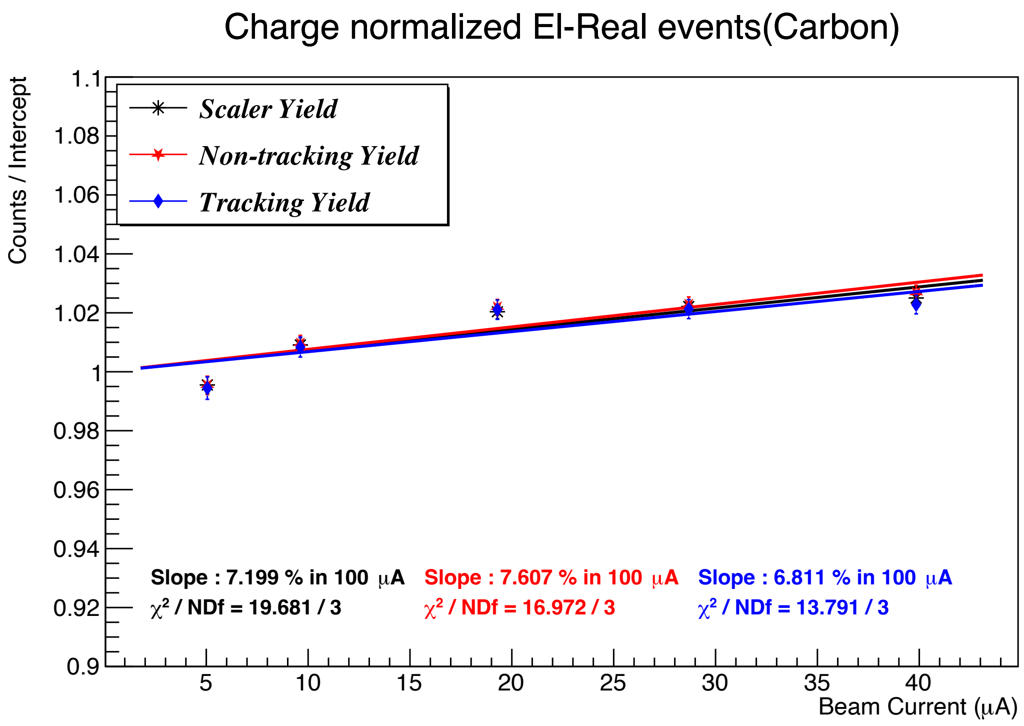
Tsinghua University

Yield vs beam current

- 3^{rd} luminosity scan runs
- BCM4A used for charge and current calculation
- BCM4A gain = 9597
- BCM4A offset = −1839



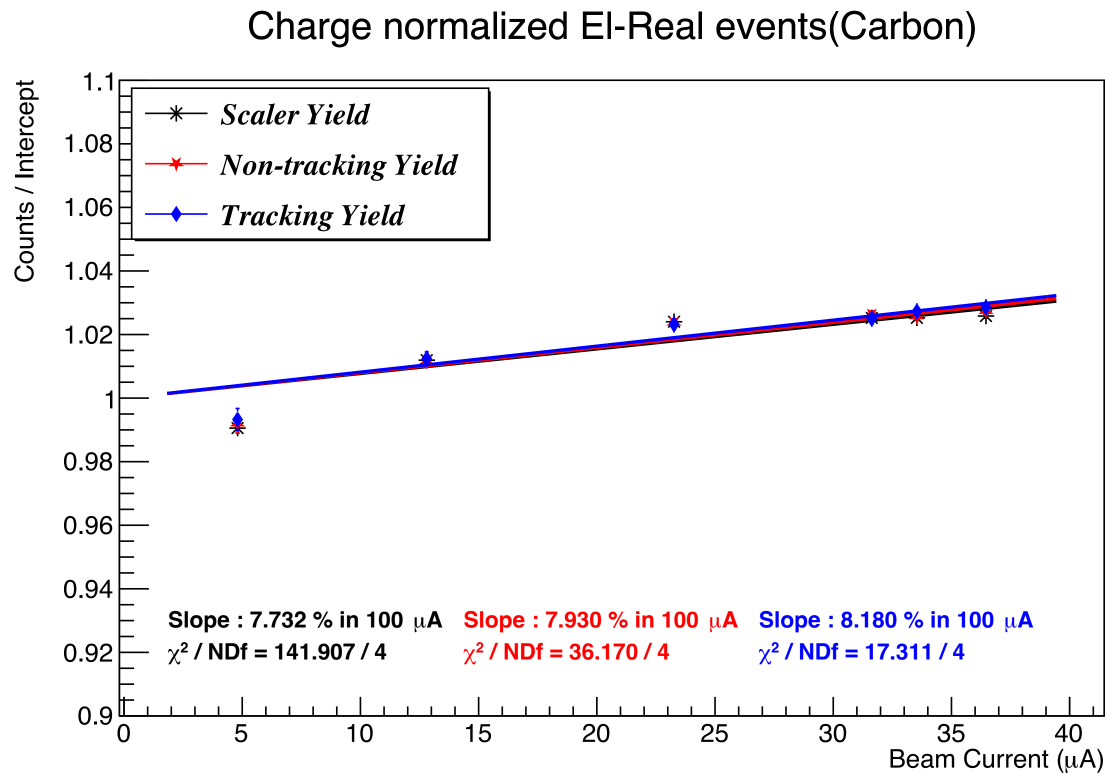
- 3^{rd} luminosity scan runs
- BCM2 used for charge and current calculation
- BCM2 gain = 5707
- BCM2 offset = 249300



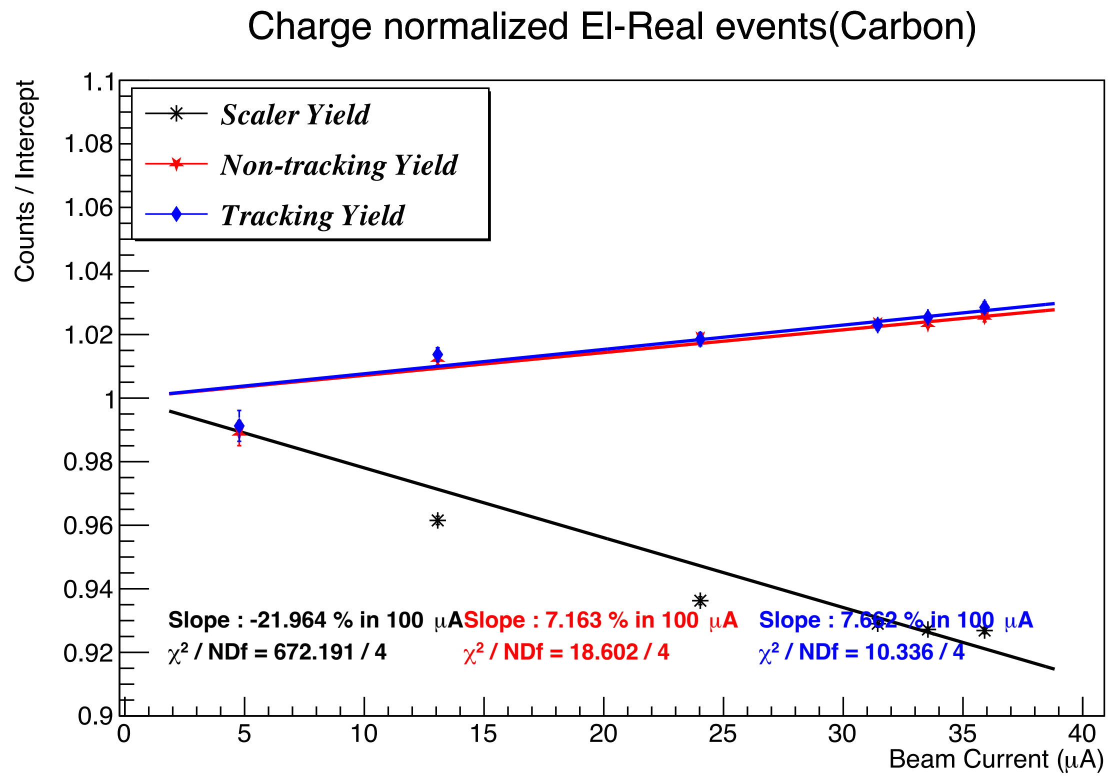
Yield Plots

Yield plots: 1st set of luminosity scan runs (Fall 2023)

HW scaler



Hel scaler

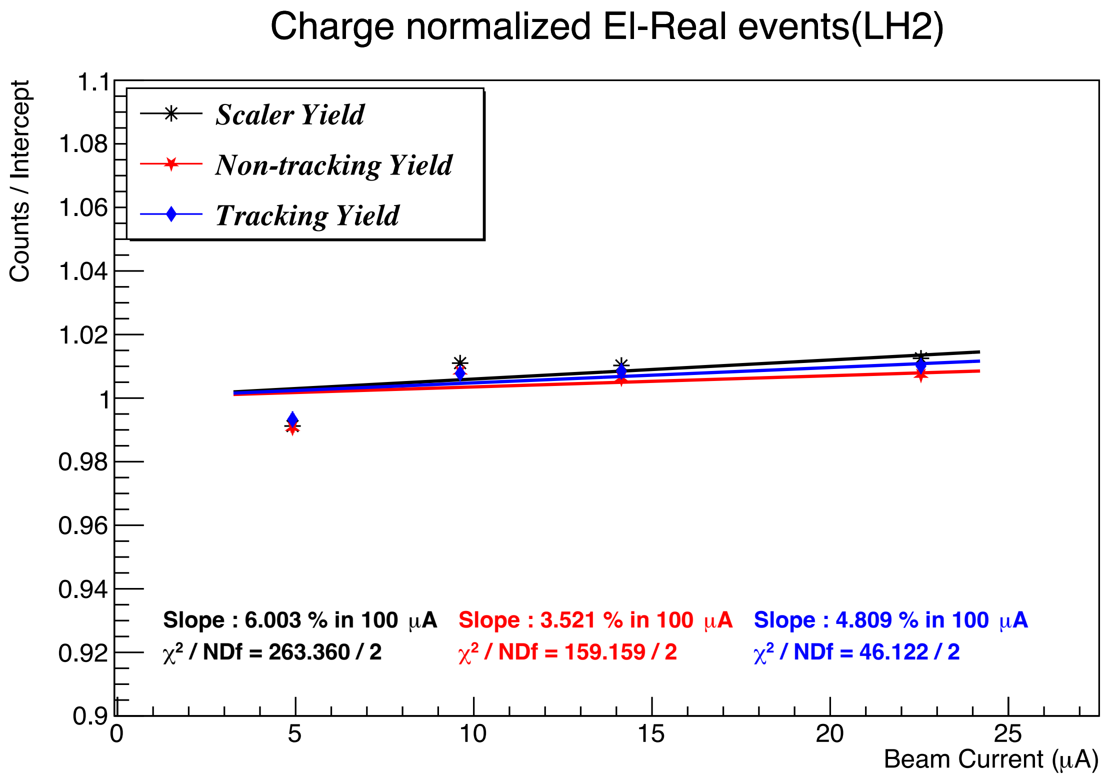


The scaler yield from Hel scaler also contains the EDTM events (there's no EDTM scaler in TSHelH tree)

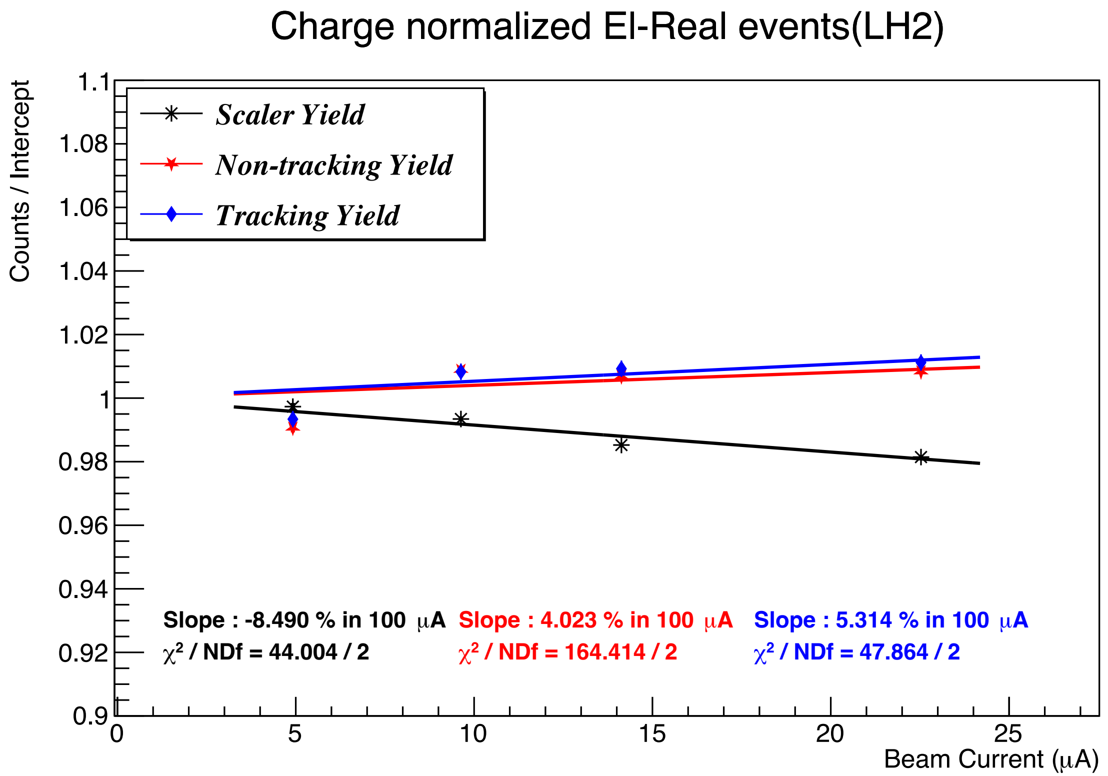
Yield Plots

Yield plots: 1st set of luminosity scan runs (Fall 2023)

HW scaler



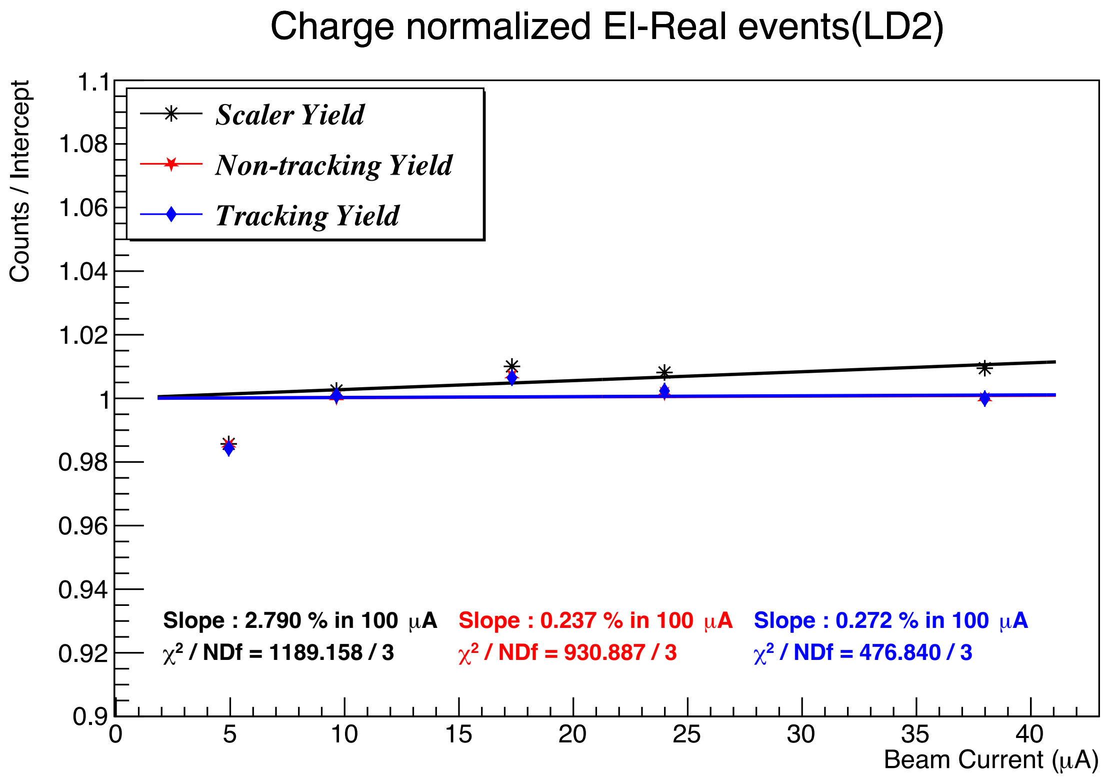
Hel scaler



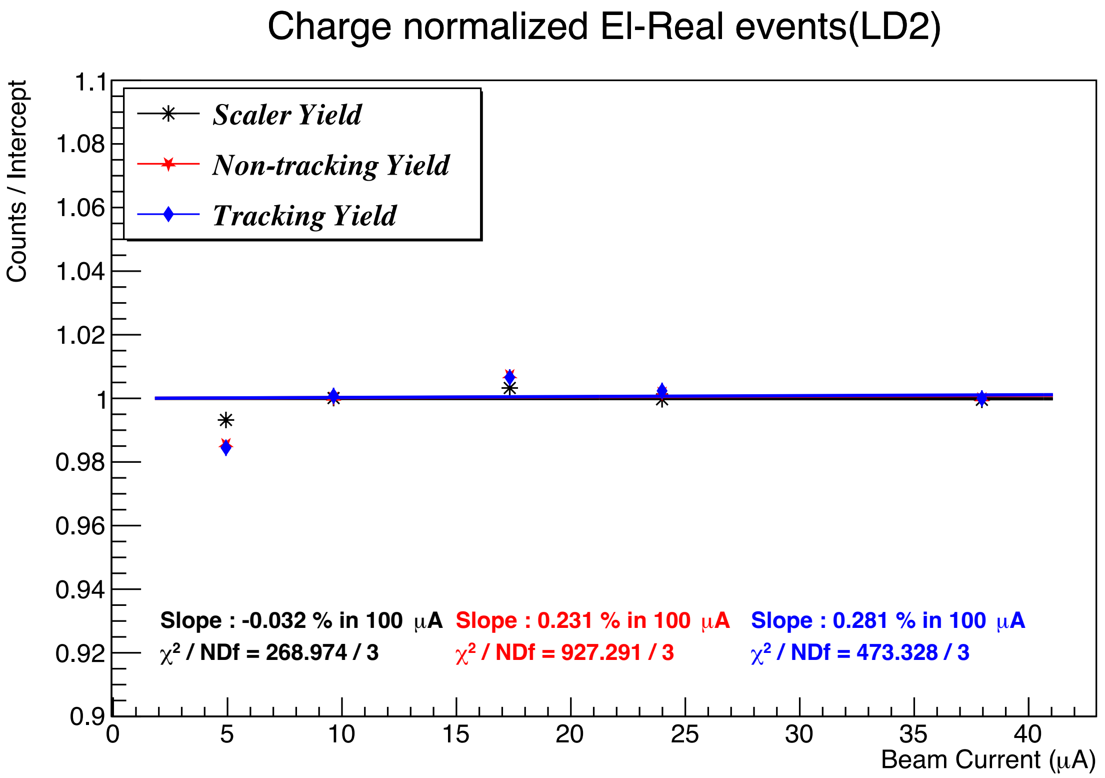
Yield Plots

Yield plots: 1st set of luminosity scan runs (Fall 2023)

HW scaler

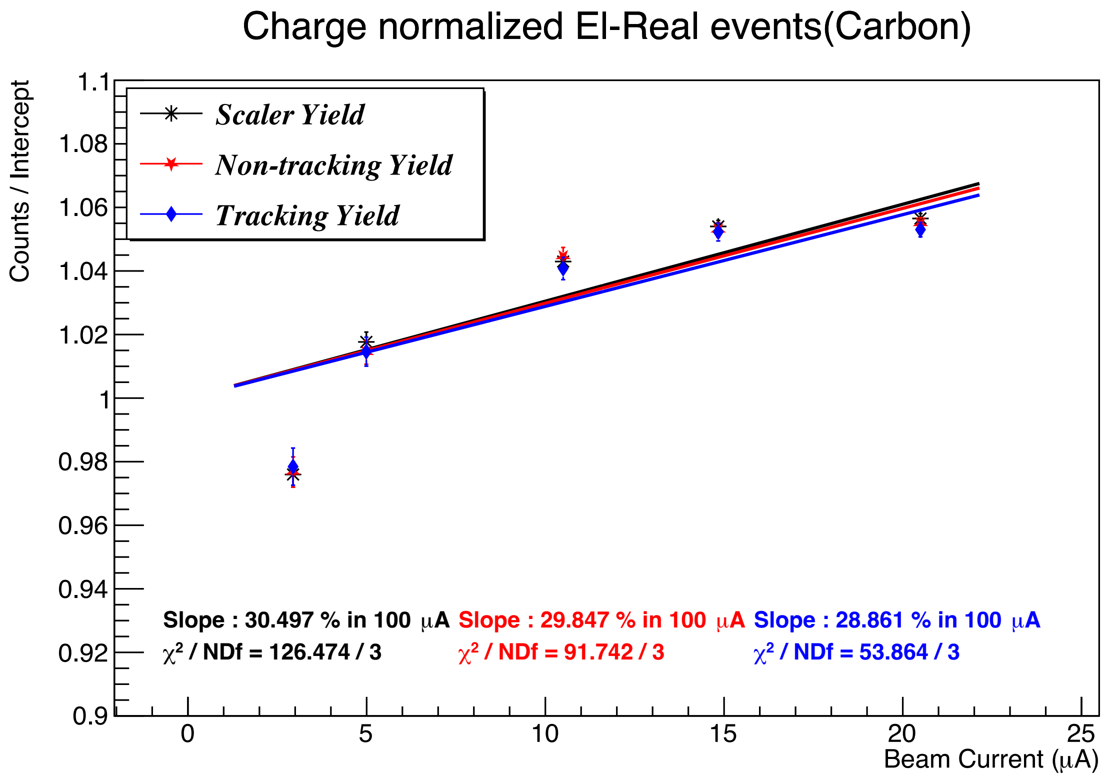


Hel scaler

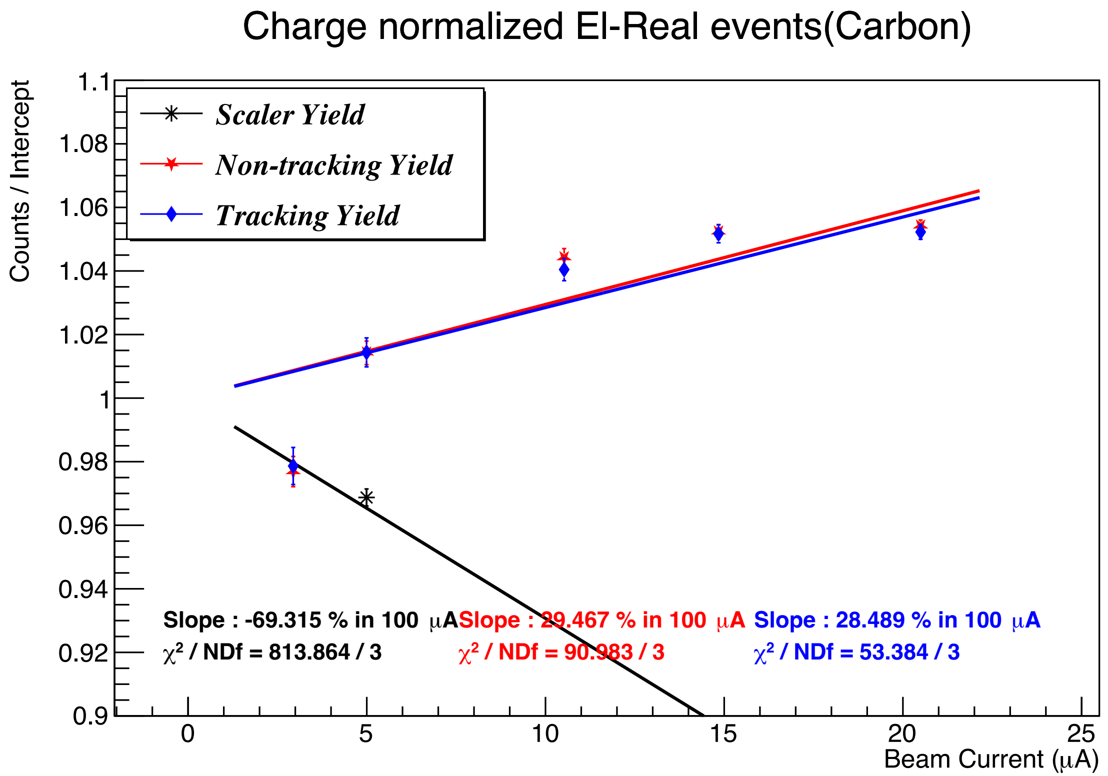


Yield plots: 2nd set of luminosity scan runs (Spring 2024)

HW scaler



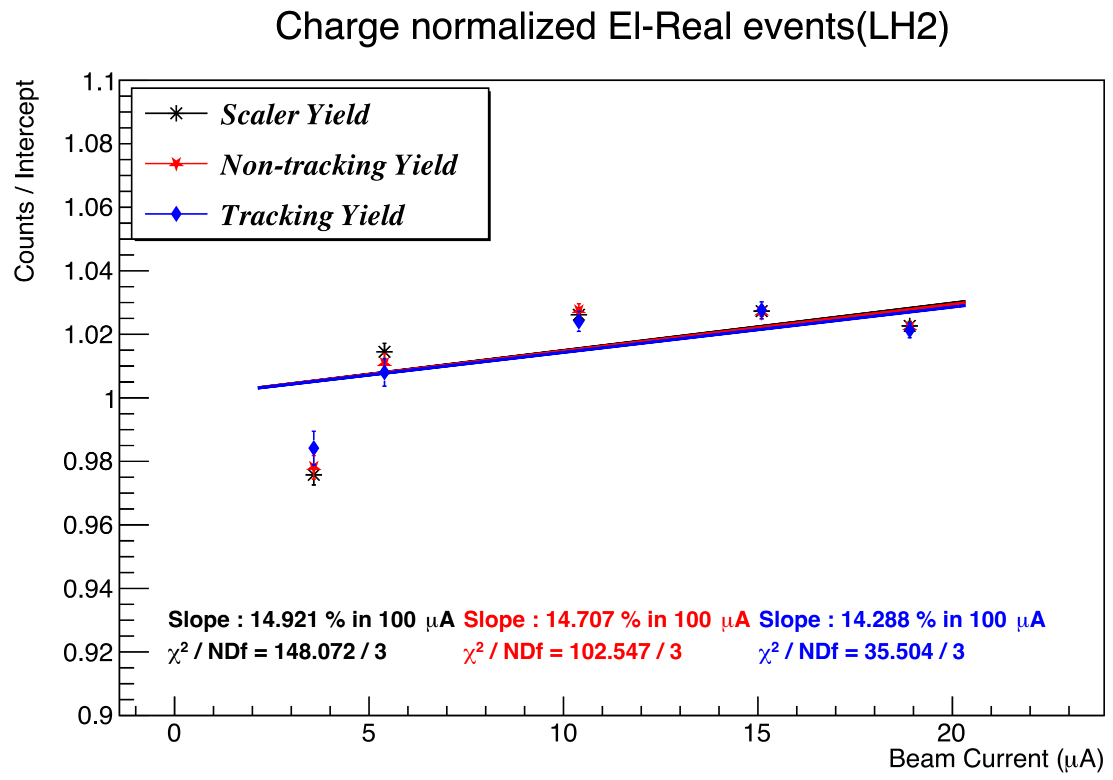
Hel scaler



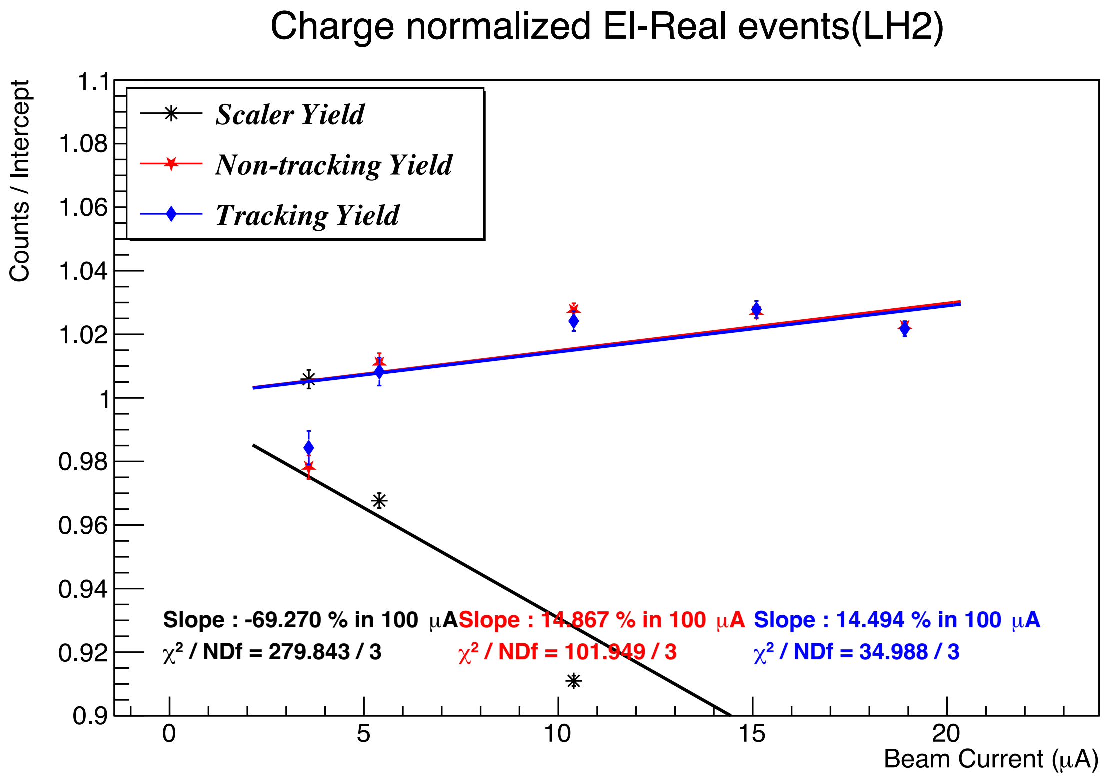
Yield Plots

Yield plots: 2nd set of luminosity scan runs (Spring 2024)

HW scaler



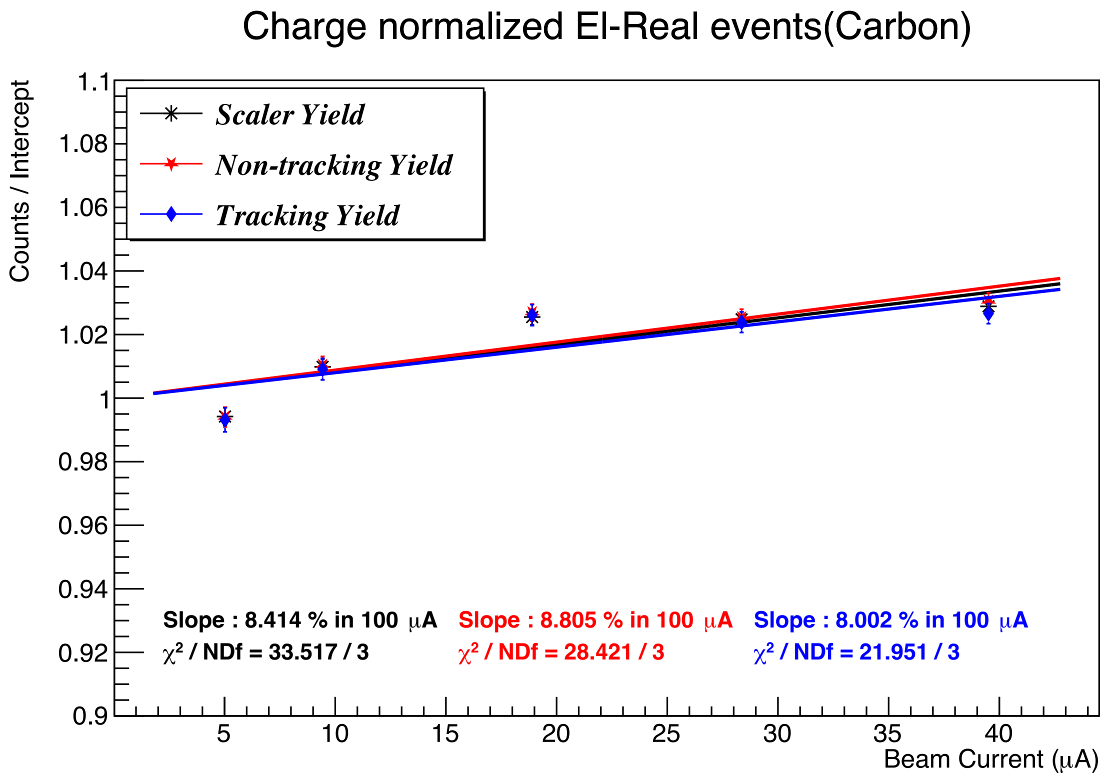
Hel scaler



Yield Plots

Yield plots: 3rd set of luminosity scan runs (Spring 2024)

HW scaler



Hel scaler