Charged particle reconstruction efficiency

S. Stepanyan (JLAB)

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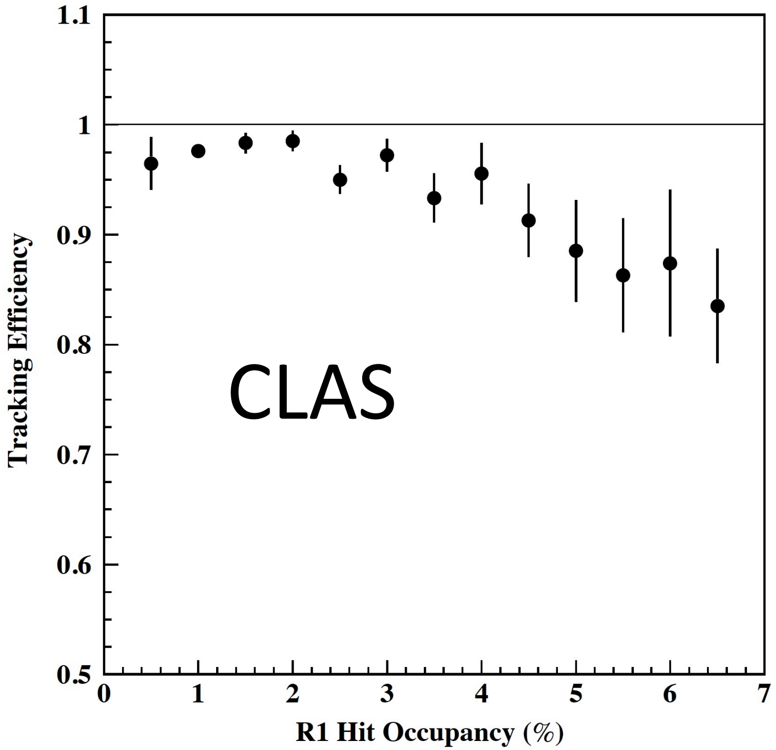
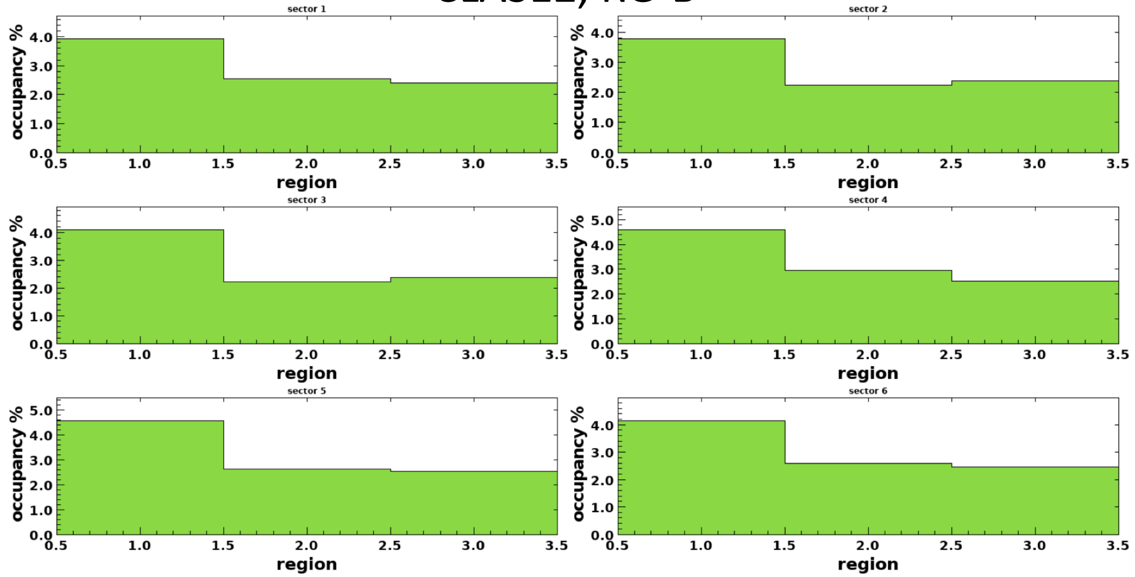
The issue – from CLAS to CLAS12

- In order to have sufficiently high track reconstruction efficiency, CLAS experiments kept DC occupancies below 3%
- CLAS tracking efficiency was >90% for occupancies <4%. ”The tracking efficiency decreases at high luminosity by ~1% per 1% increase in chamber occupancy”.



- CLAS12 uses the same approach, keeps occupancies <4%
- However, it is evident from multiple studies that the tracking efficiency drops with ~0.5%/nA rate, or about 70%-75% of reconstruction for DC occupancies of ~4%
- This could be simply misinterpretations of the occupancies in CLAS and CLAS12 (*hypothetically, maybe 4% in CLAS12 == 10% in CLAS*)
- **Or, it could be due to algorithmic changes in the tracking and event reconstruction**

CLAS12, RG-B



Scope and goals of a small group of experts and enthusiasts

- Understand larger than expected increase of track/charged-particles reconstruction inefficiency as a function of luminosity
- Aid reconstruction code improvements, tracking algorithms (both CD and FD) and event builder
- Develop method(s) for efficiency correction in the analysis

Approaches

- Study of positively and negatively charged particle multiplicities as a function of luminosity, for FD (Stepan, Nathan, Joseph, FX)
- The rate of tracks reconstructed by both, CD and FD trackers, for CD (Stepan)
- A normalized yield of physics reactions, for FD so far, (Nick, Joseph, FX, Stepan)
- Study of DC 5 SL track candidate efficiency (Mikhail)
- Reconstruction of simulated data with and without overlaid beam background, for FD (Josh, Volker)
- Low luminosity beam data overlaid with high luminosity beam background, for FD (Veronique, Stepan)

Luminosity scan runs

- Spring RG-A inbending – 4301, 4302, 4303, 4304 and 4307 with 2 nA, 10 nA, 30 nA, 50 nA and 75 nA, respectively
- Fall RG-A inbending – 4893, 4895, 4887, 4888 and 4900 with 2 nA, 4 nA, 10 nA, 25 nA, and 60 nA, respectively
- Fall RG-A outbanding – 5443, 5444, 5453, and 5543 with 5 nA, 20 nA, 40 nA, and 50 nA, respectively
- Engineering FT-OFF inbending - 2285, 2341, and 2327 with 25 nA, 75 nA, and 60 nA, respectively
- RG-K FT-ON outbanding – 5681, 5682, 5683, and 5684 with 10 nA, 20 nA, 30 nA, and 50 nA, respectively
- RG-k FT-OFF outbanding – 5877, 5879, 5886, and 5885 with 10 nA, 30 nA, 60 nA and 75 nA, respectively
- RG-B inbending – 6226, 6227, 6224(5), and 6299 with 5 nA, 15 nA, 35 nA and 50 nA, respectively

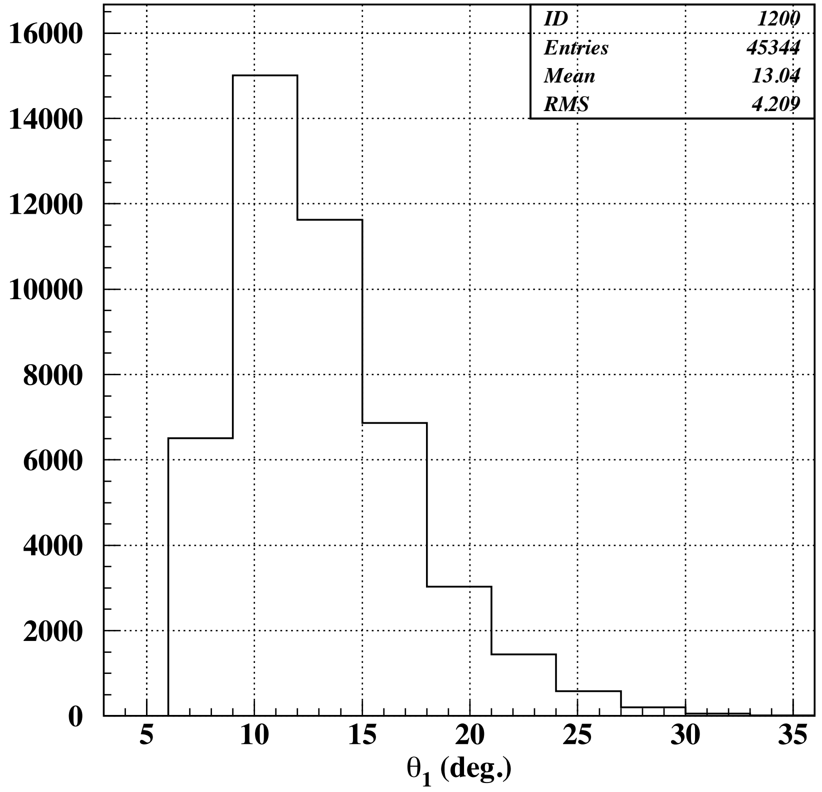
(%/nA)	RG-B, Winter-Spring 2019	Spring e- inbending	Fall e- inbending	Fall e- outbending	Eng. Run FToff e- inb.	RG-K FT-ON, outbending	RG-K FToff, 6.5 GeV, outbending
α −positives	0.4	0.46	0.49	0.27	0.49	0.33	0.325
α −negatives	0.41	0.38	0.48	0.34	0.46	0.44	0.151
α −positives, PID	0.48	0.6	0.63	0.37	0.55	1 (prot)	1.05 (prot.)
α −negatives, PID	0.51	0.59	0.66	0.45	0.55	0.7 (e-)	0.93 (e-)

Multiplicity studies

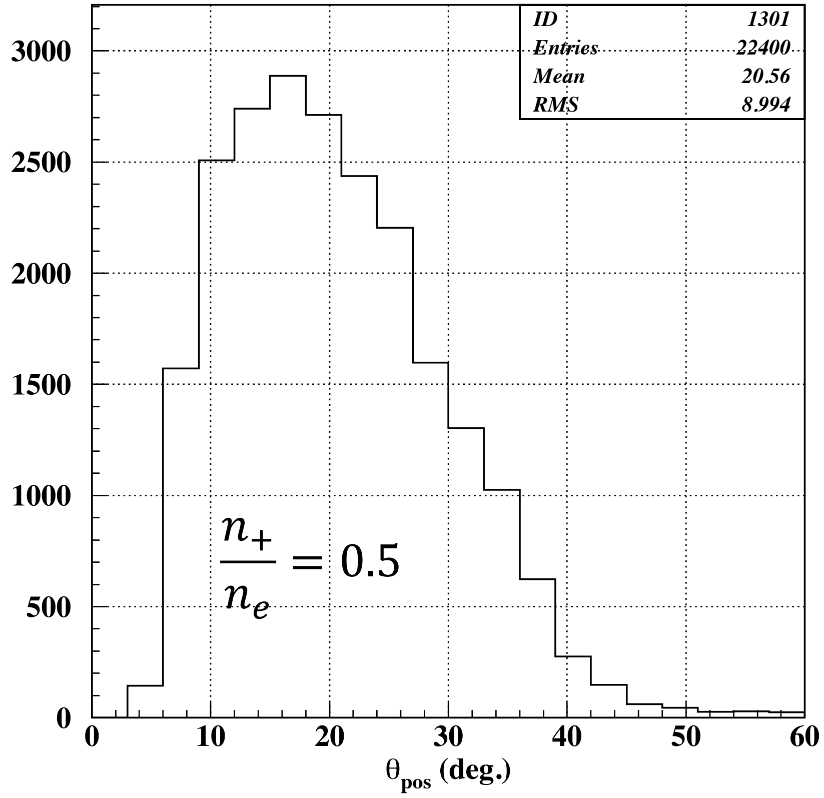
- Electrons – event builder PID=11 and p > 2 GeV
- Positively and negatively charged tracks with p>0.4 GeV, PID $|\chi^2| < 20$, $Sector_h \neq Sector_e$

Beam current 2nA

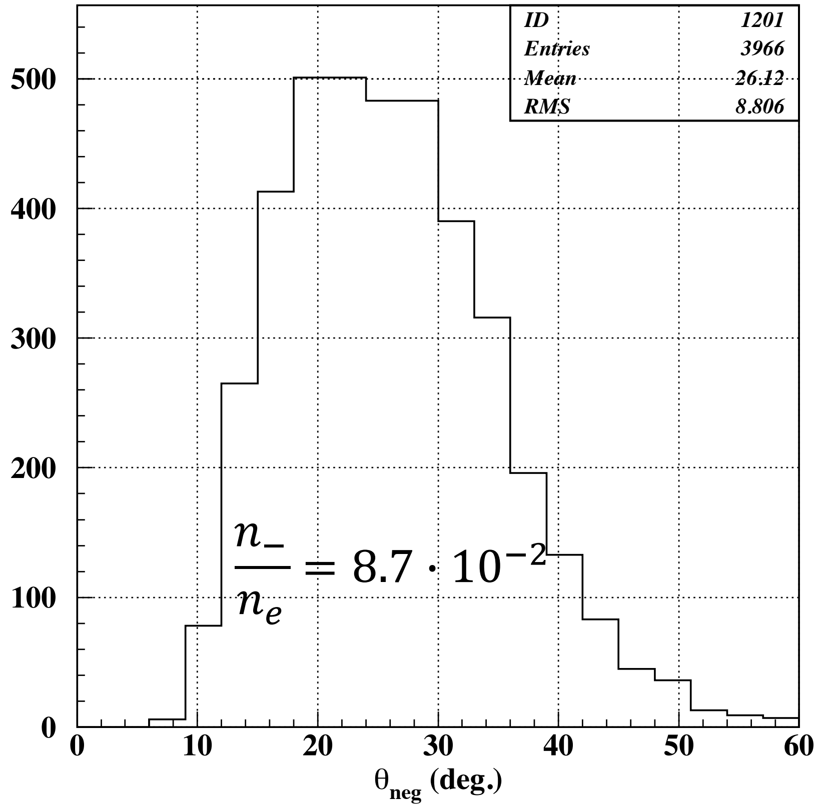
Electrons, PID=11, p>2 GeV



e- & Positively charged tracks

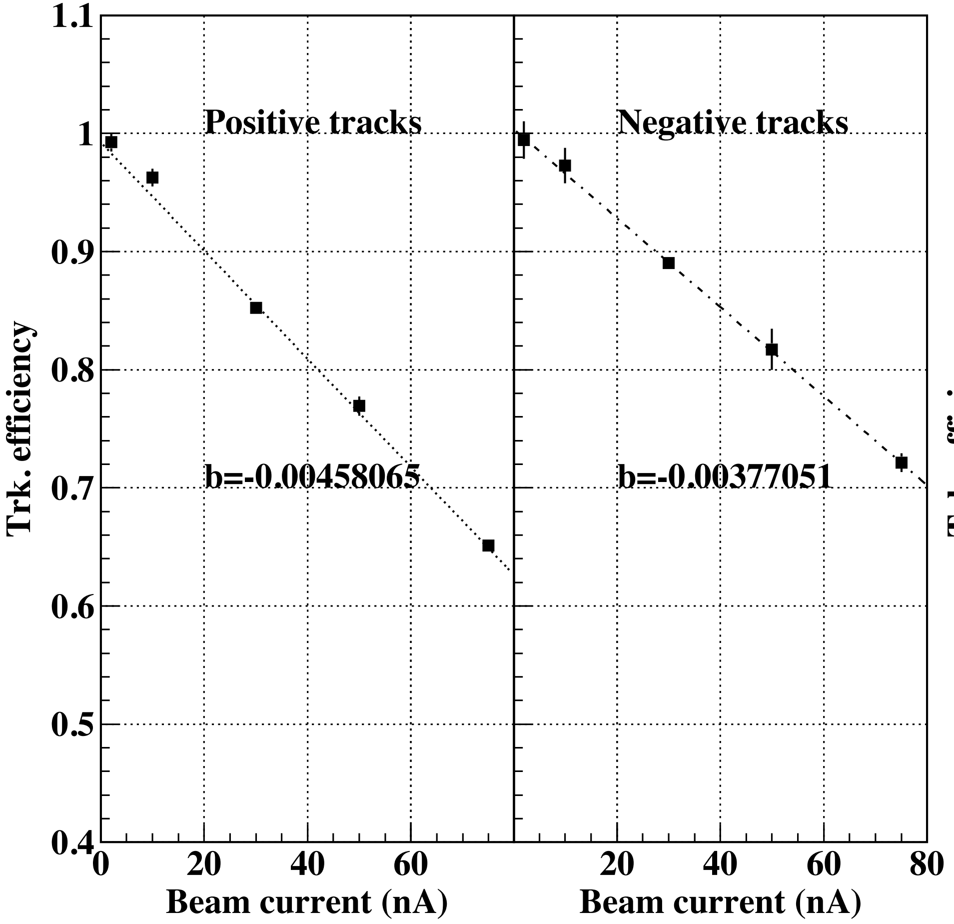


e- & Negatively charged tracks

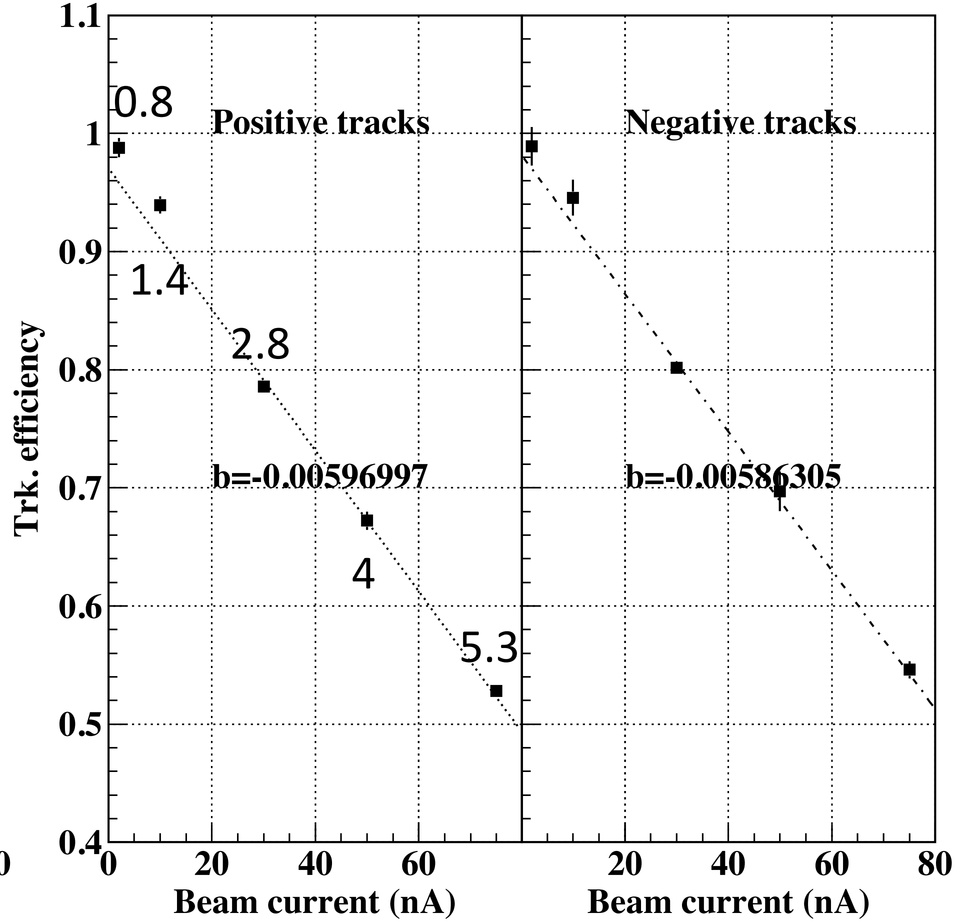


Normalized multiplicity of positively and negatively charged tracks

All TBT tracks



PID $|\chi^2| < 20$

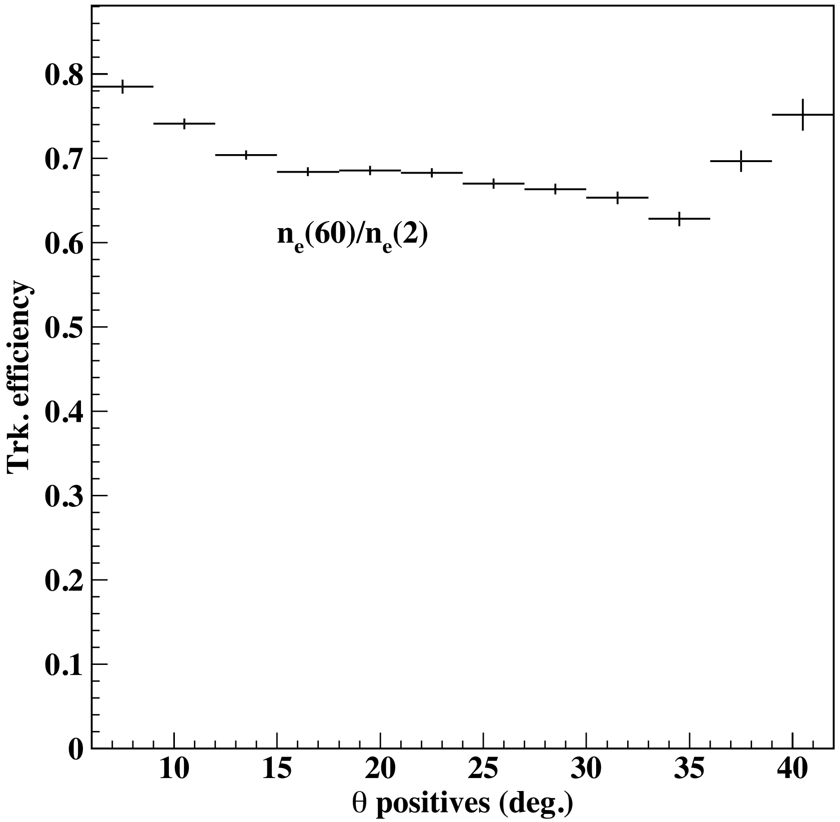


$$n_i = \frac{N_i}{N_e};$$
$$n_i(I) = a + b \times I;$$
$$Trk.efficiency = \frac{n_i}{a};$$

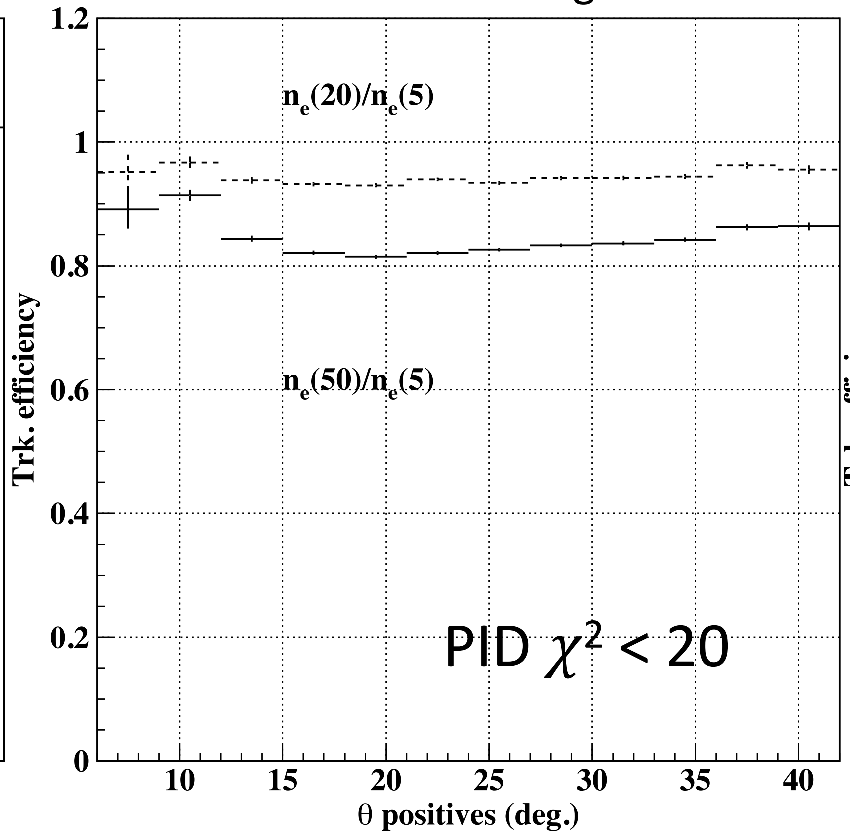
At I=0 nA rates are normalized to 1.

Angular dependence

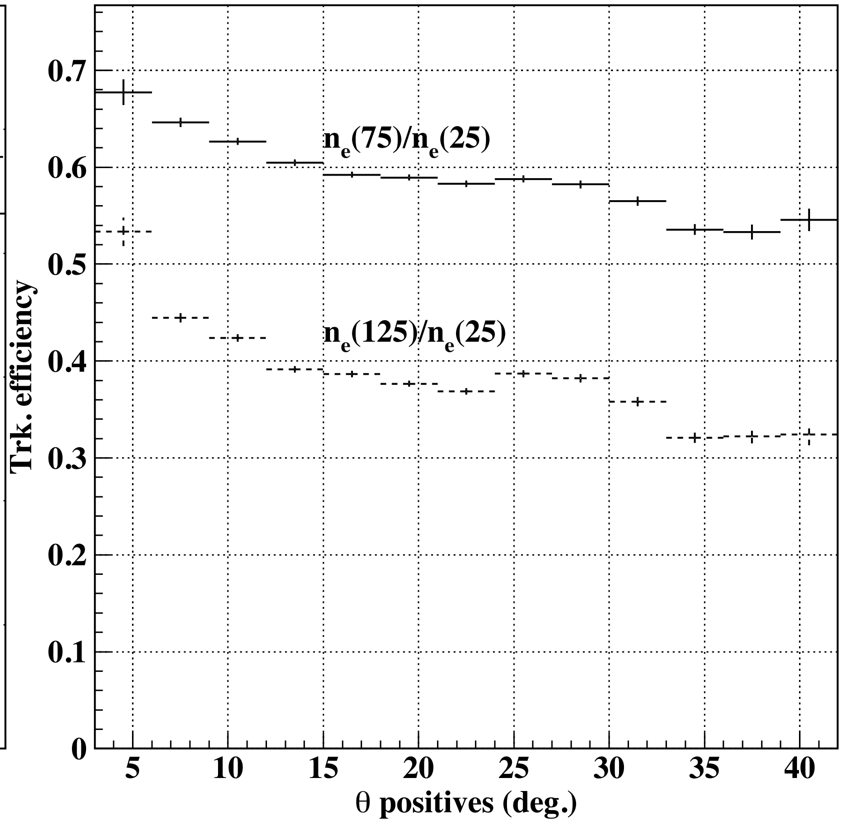
Inbending



Outbending

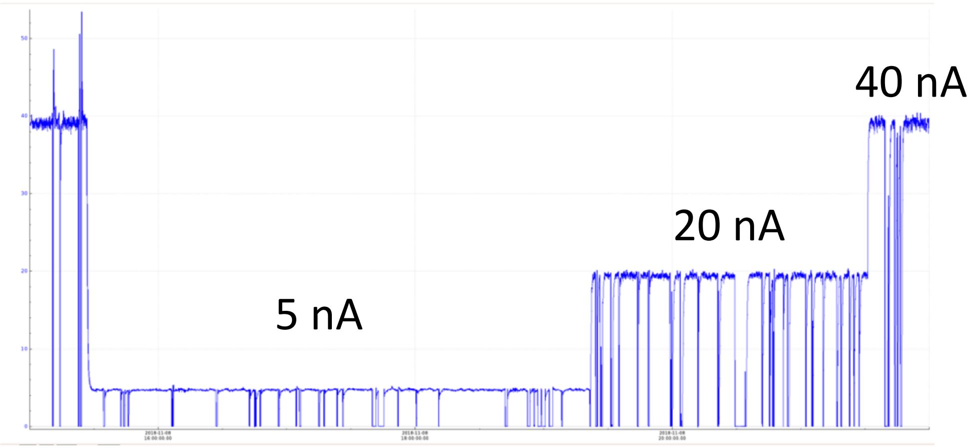


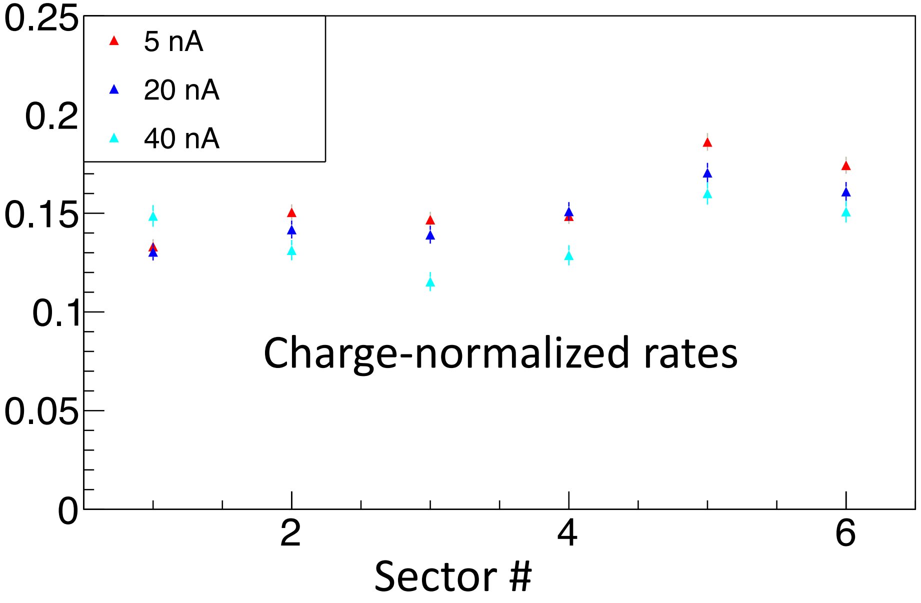
Engineering run, FT-OFF



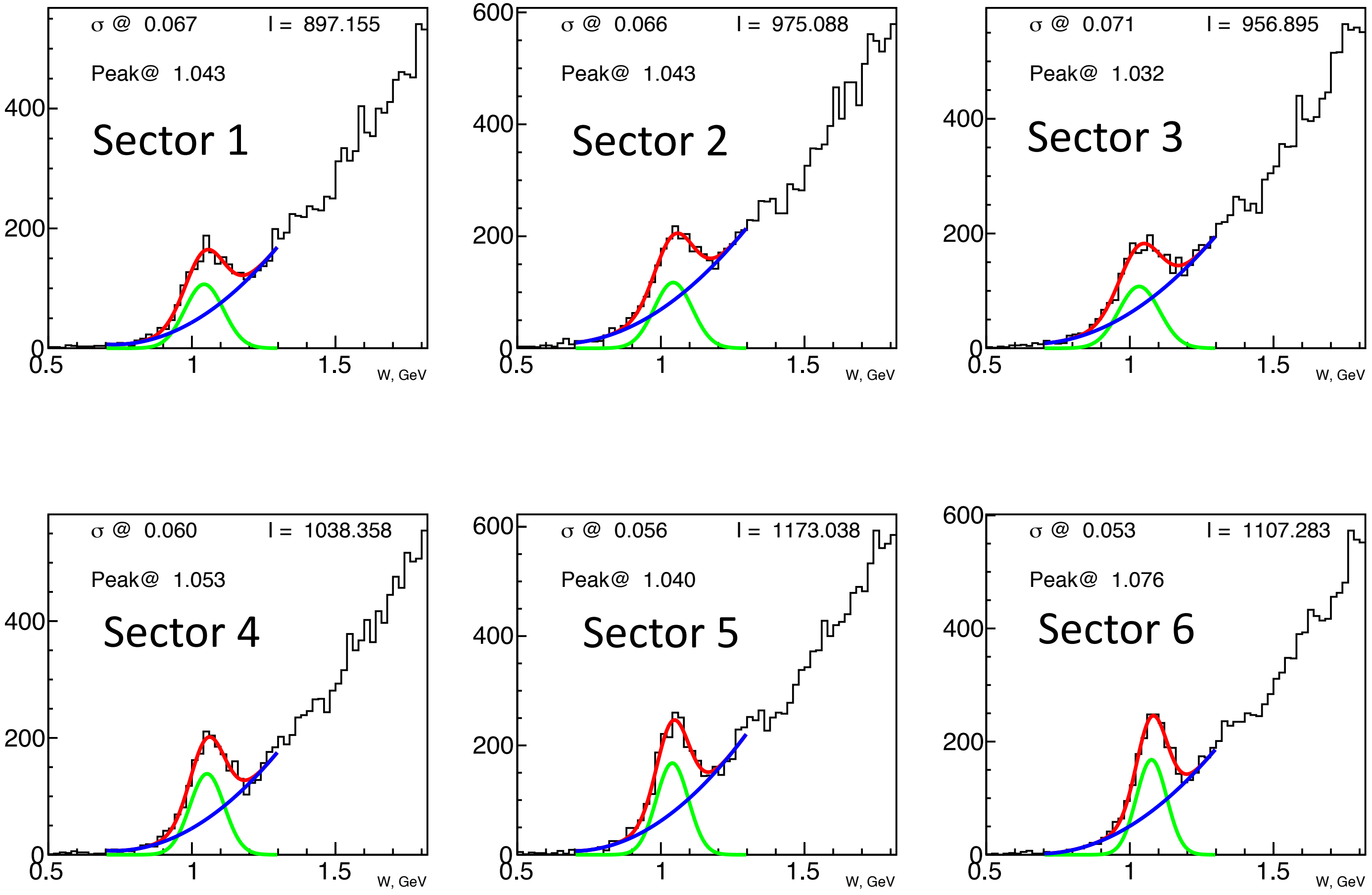
There is angular dependence of the efficiency, perhaps there is also momentum dependence – not yet studies

Elastic electrons, RG-A fall outbending – 5 nA, 20 nA, 40 nA





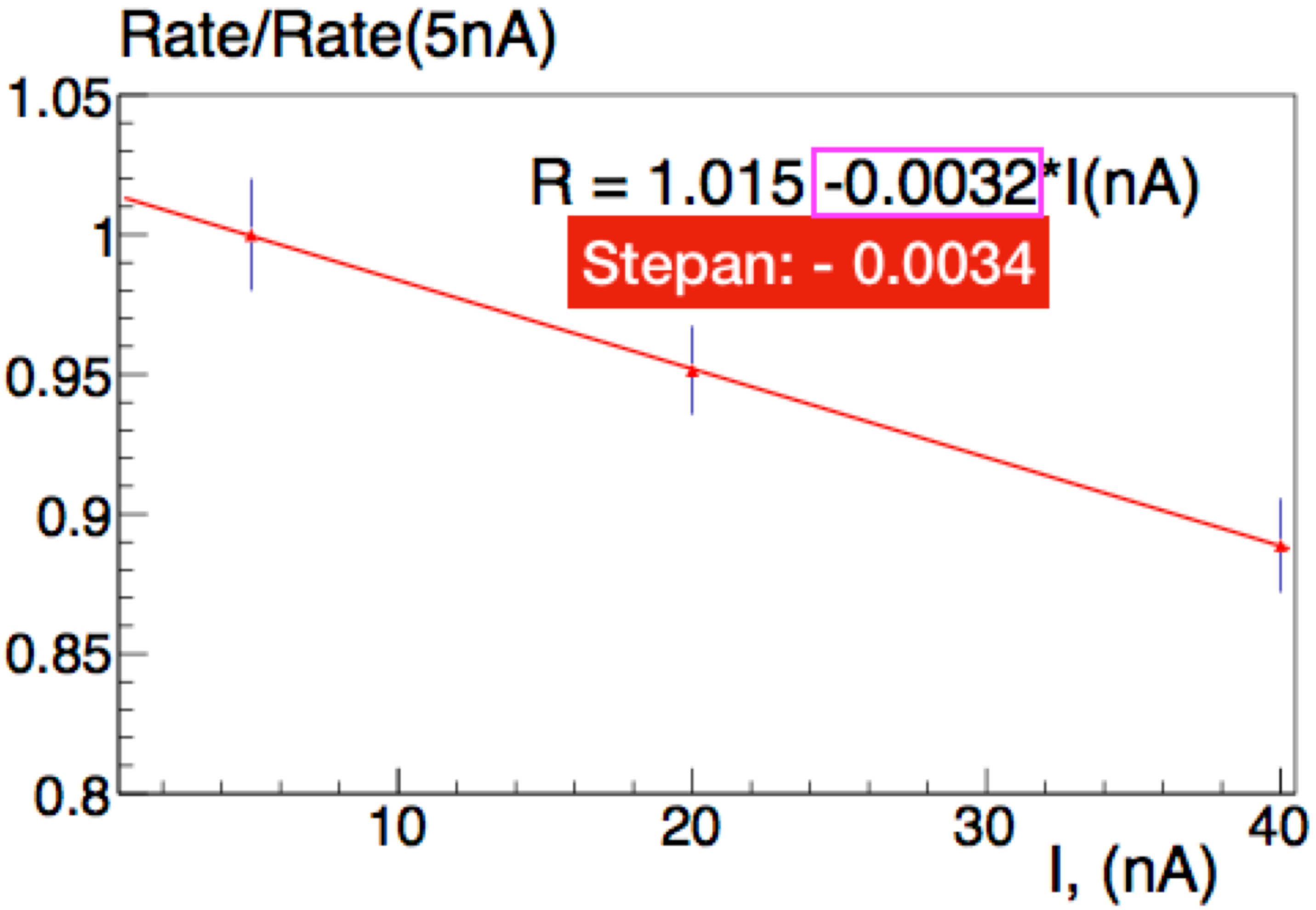
Run 5444, 20 nA



Fit with Gaussian+2nd order polynomial finction

From N. Markov

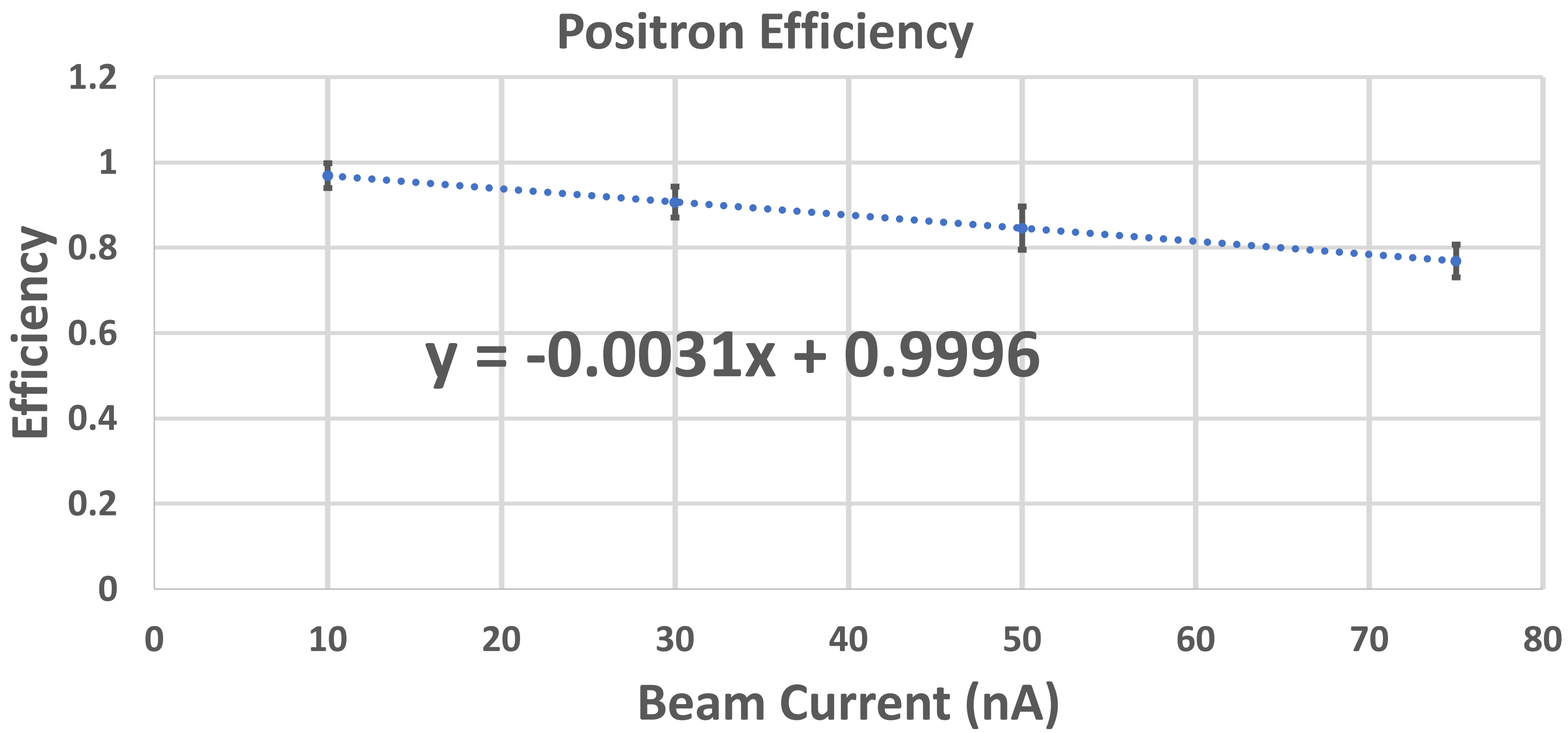
Normalized elastic electron rates as function of beam current



Positron multiplicity (Joseph)

- Electron/Positron Vertex Time Difference < 0.9 ns
- Electron/Positron Vertex Position Difference < 5 cm
- Electron Sector ≠ Positron Sector
- p > 1.5 GeV for both electron and positron
- Efficiency calculated from the ratio:

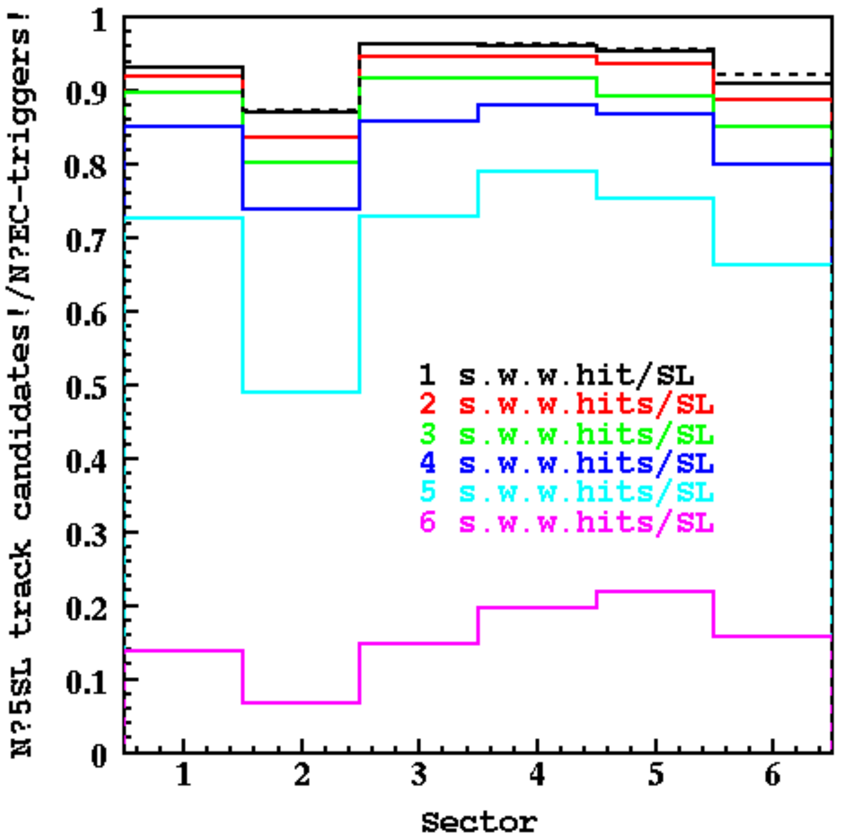
$$\frac{N_{e+e-}}{N_{e-}}$$

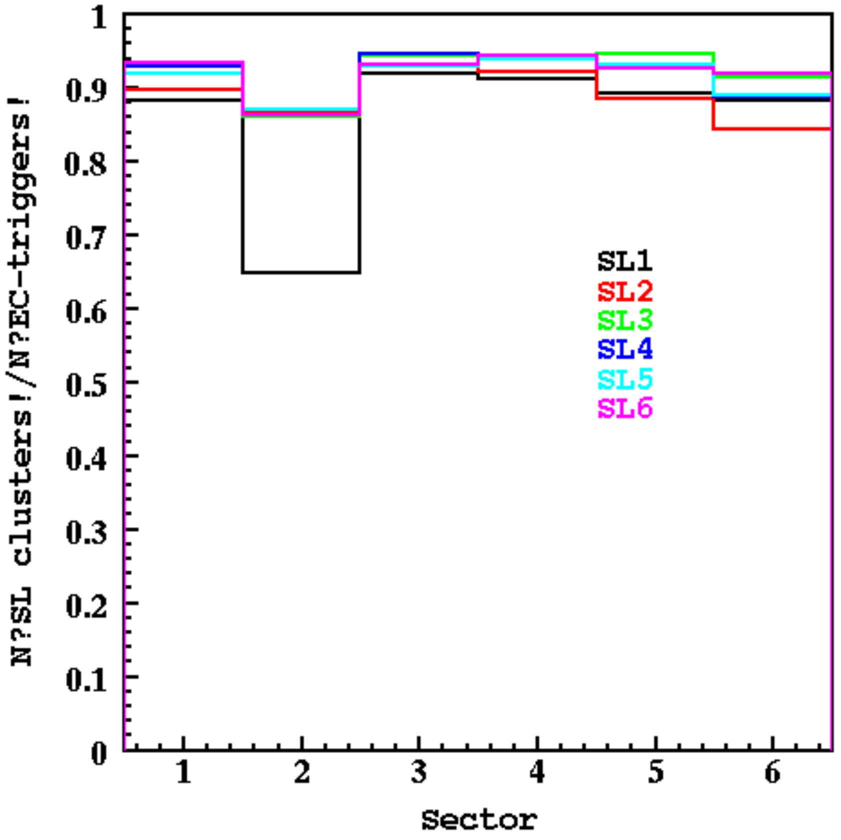


Spring RG-A, inbending

DC track segment efficiency (Mikhail)

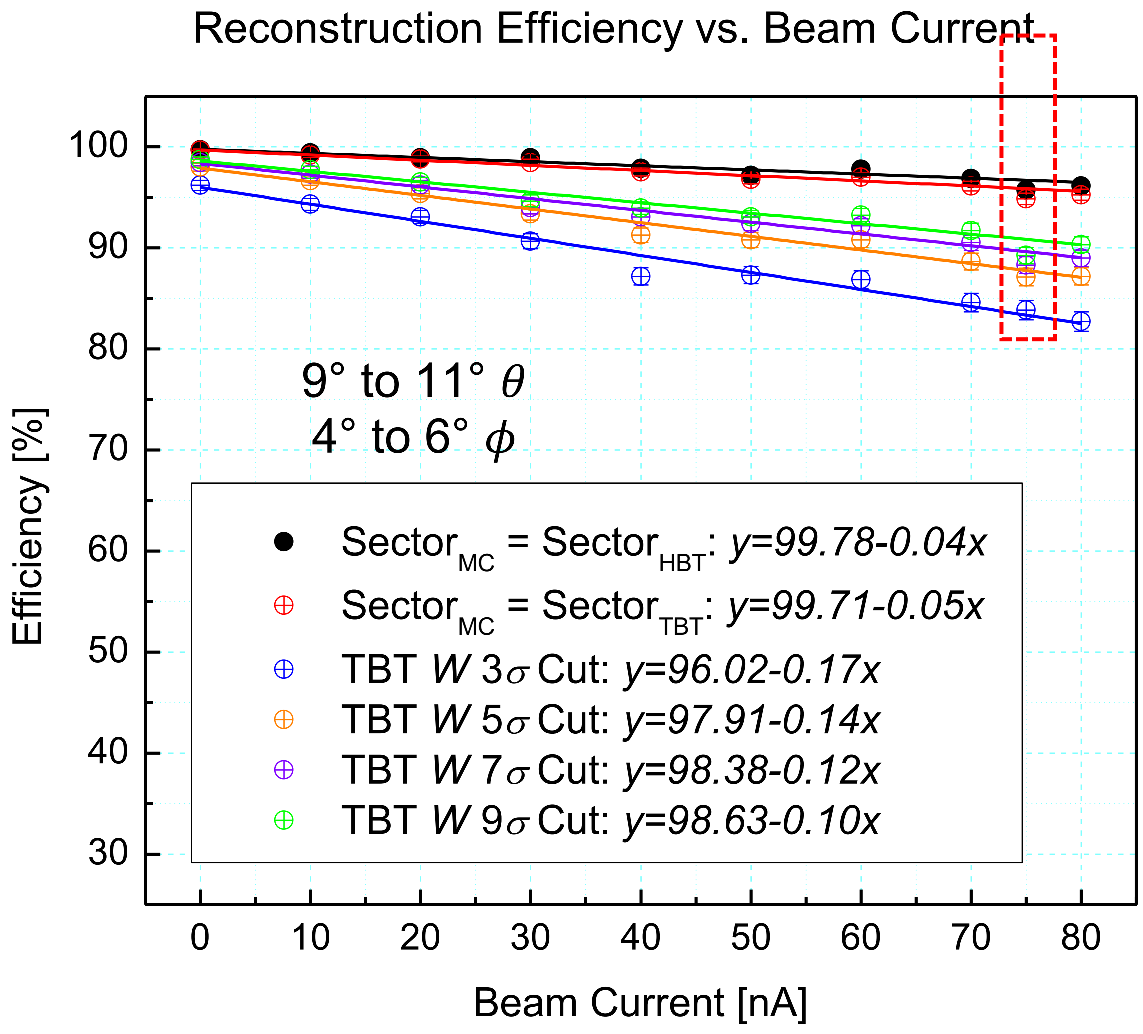
- Data from run 2467, alignment run at 2.2 GeV. A simple exercise to compare the number of very basic track candidates (actually clusters in at least 4 Super Layers) to the number of EC-hits satisfying trigger conditions with 1 degree of the "track" projection
- DC efficiency is defined as the ratio of events with 4 SL () track candidates matched to EC hit divided by number of EC hits above the thresholds, 0.6 GeV. 0.954 GeV, and 2 GeV.
- Efficiency with energy cut >2 GeV is about 95%. Note R1 occupancy is ~1.5%, as for 10 nA prod. runs

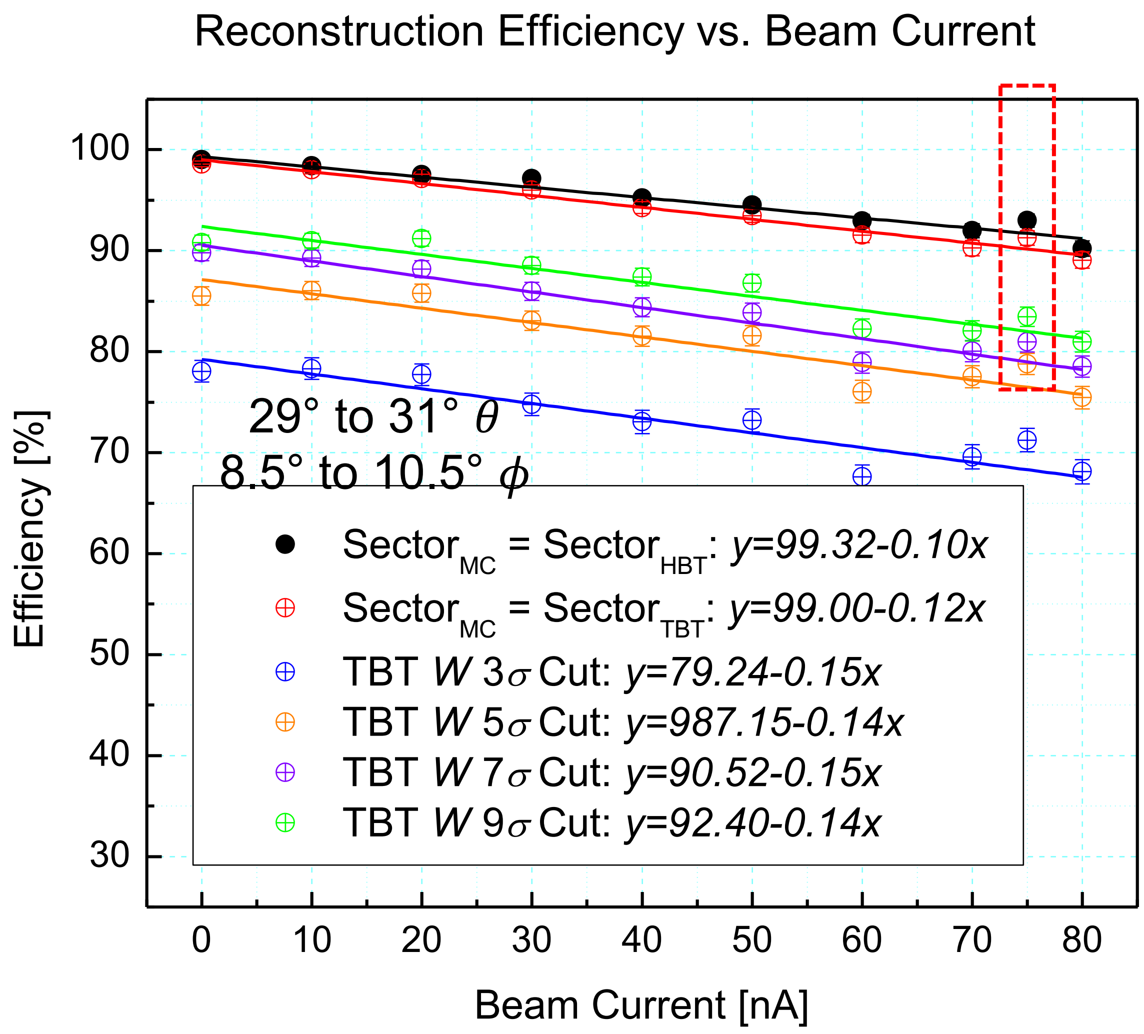




Efficiency studies with simulation, muons (Josh)

Beam background of various currents have been added to the simulated events before the reconstruction

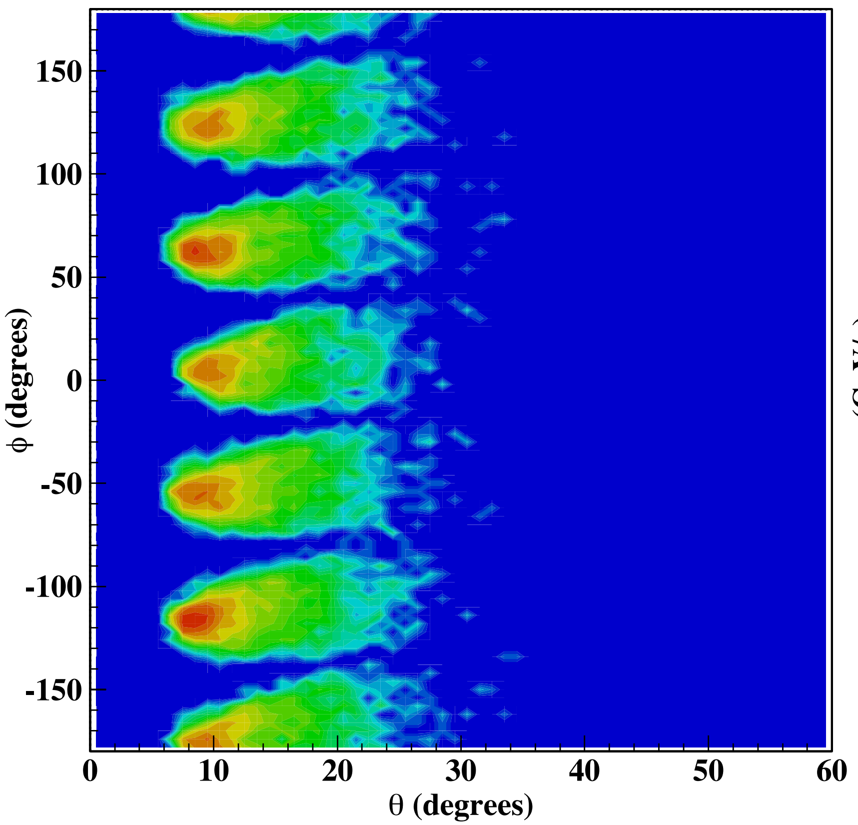


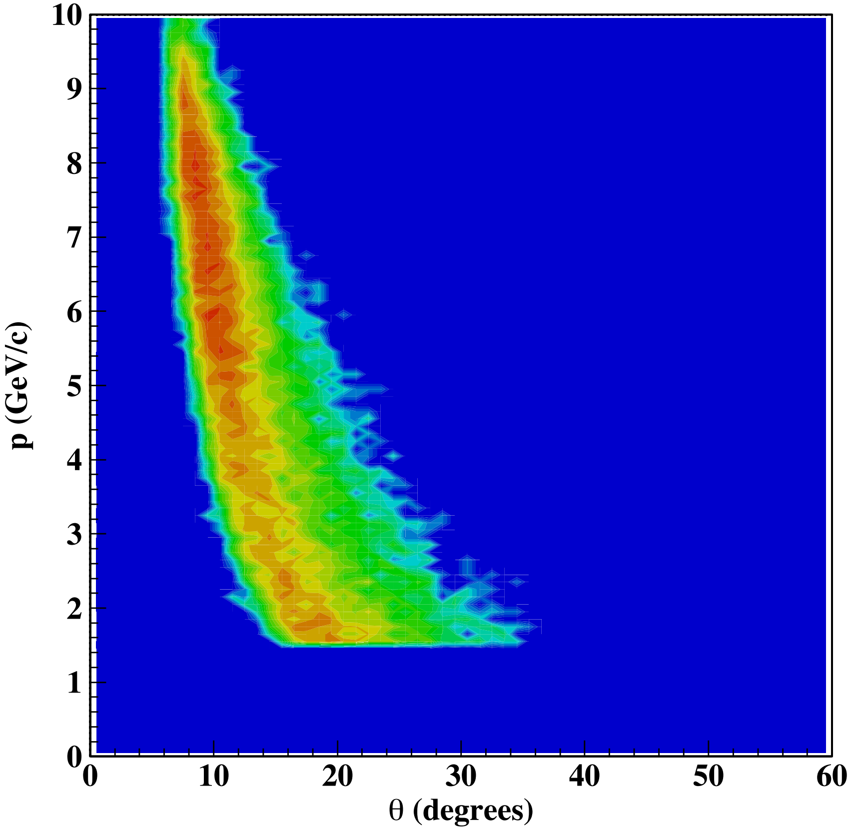


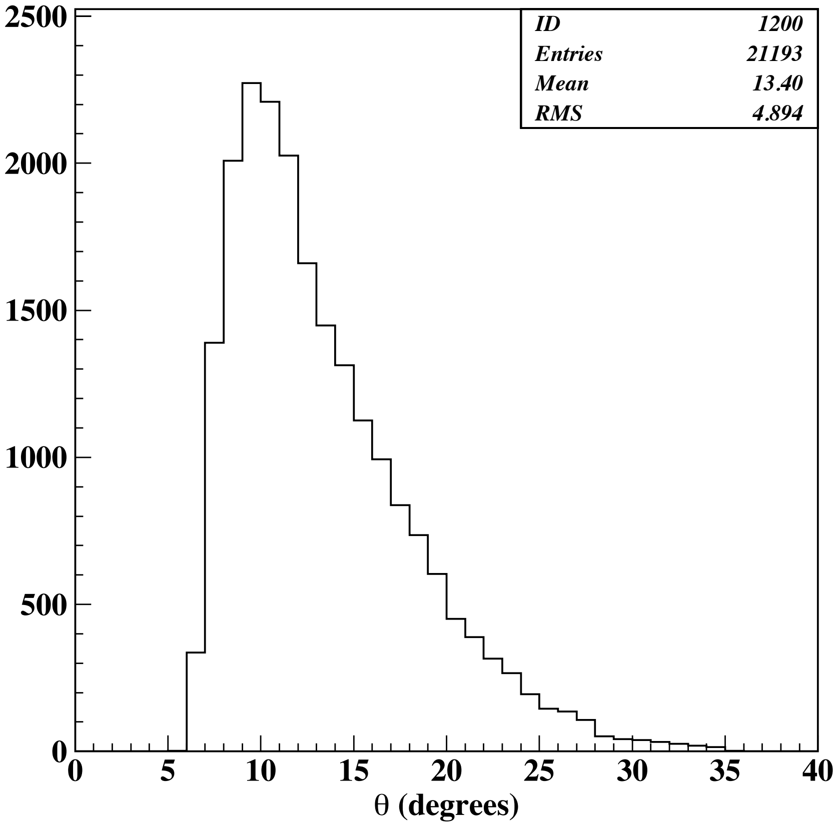
Validation of the beam background merging with simulated event is needed.

Merged beam data (Veronique)

Run 4150, 2nA, original sample 21193 electrons, p>1.5 GeV





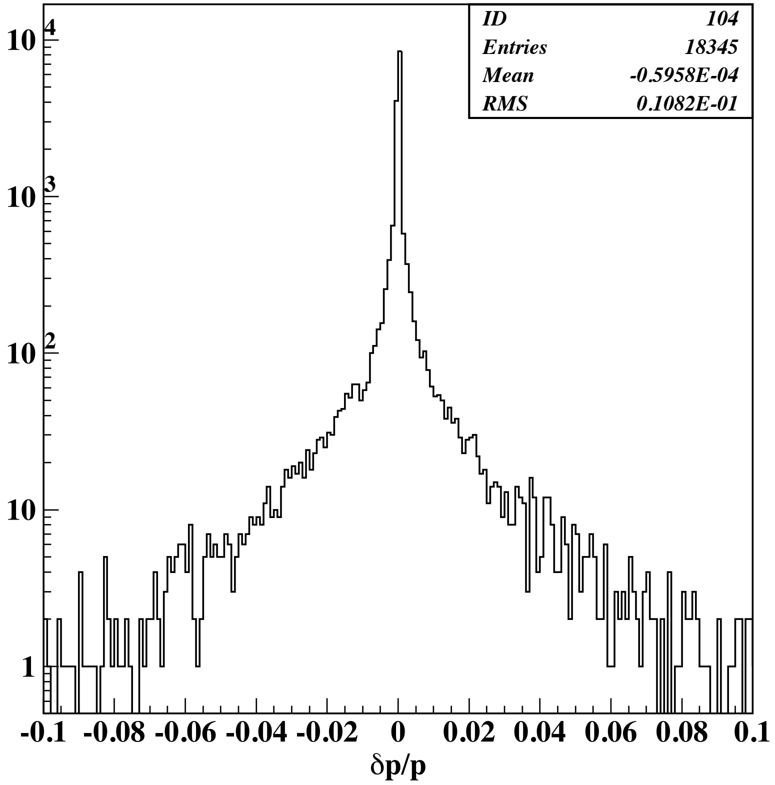


The event sample, with merged background corresponding to 50 nA beam current has been analyzed with the same software

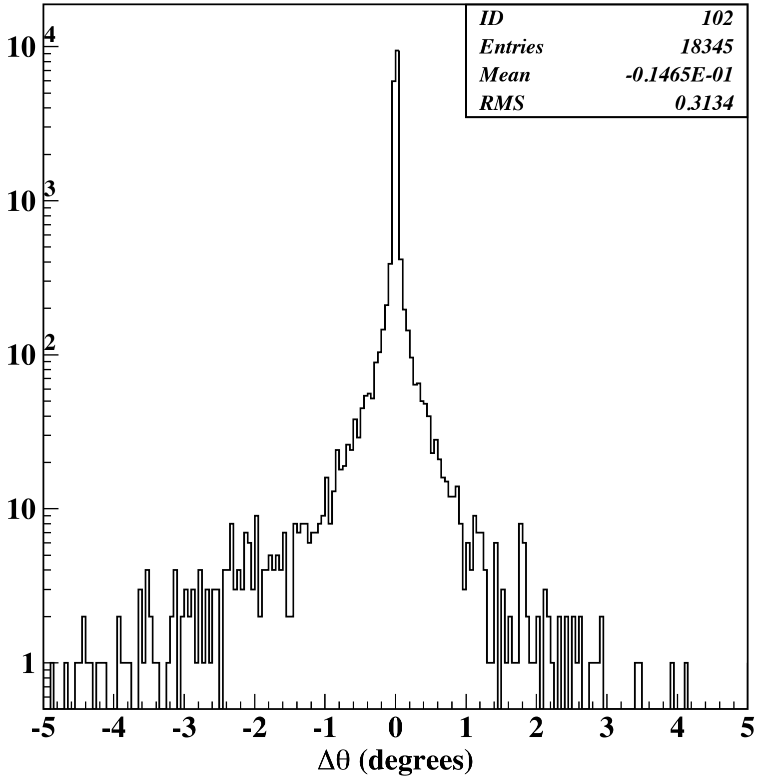
2 nA electrons reconstructed in the 50 nA bckg. merged sample

18345 electrons are identified in the 50 nA merged sample in the same event and in the same sector where the electron in the original 2 nA sample was reconstructed:

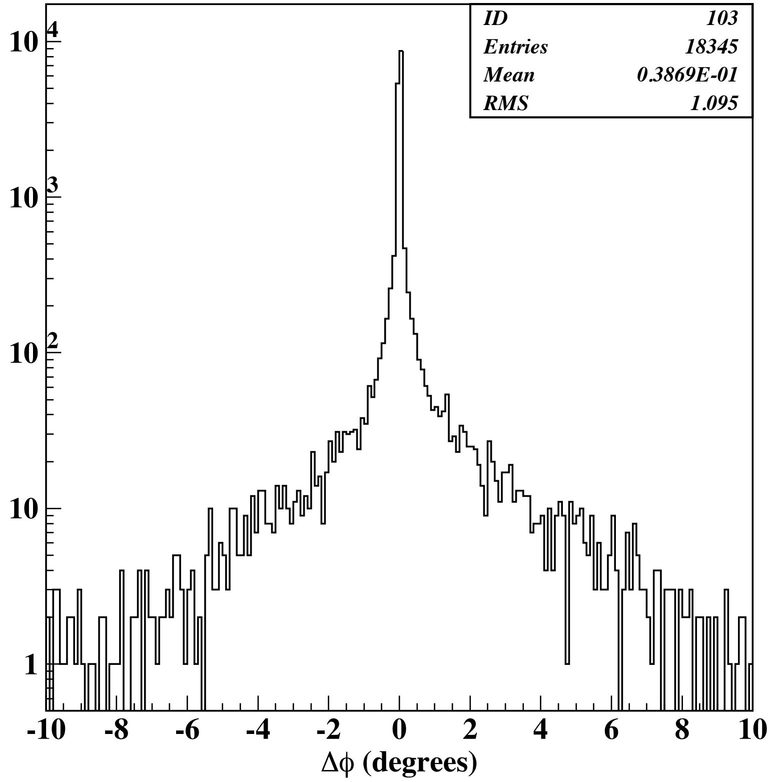
$$\frac{\delta p}{p} = \frac{p_2^{el} - p_{50}^{el}}{p_2^{el}}$$



$$\Delta\theta = \theta_2^{el} - \theta_{50}^{el}$$



$$\Delta\varphi = \varphi_2^{el} - \varphi_{50}^{el}$$



Non-Gaussian tails that will not be able to accommodate with any kinematic fit or momentum/angle corrections.

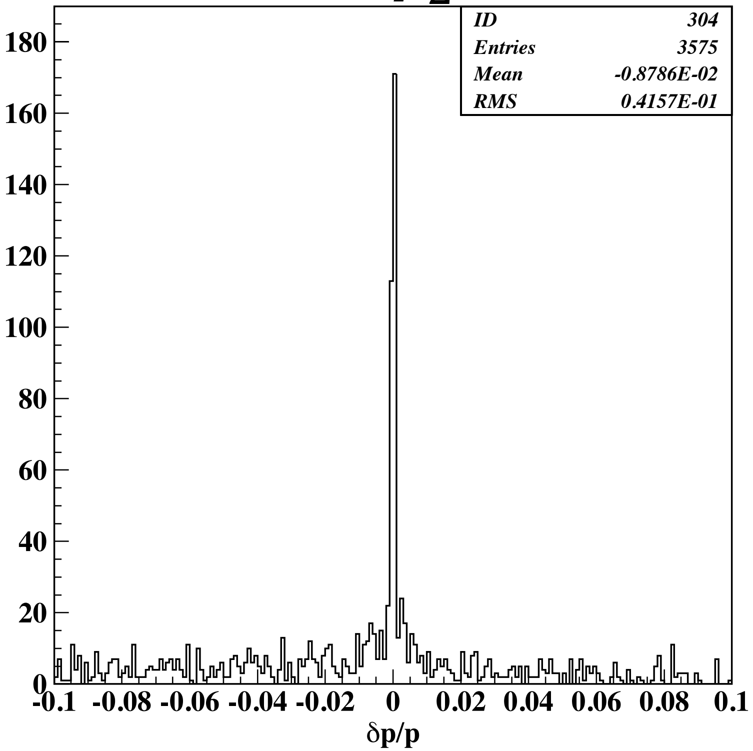
2 nA electron events as negative tracks in the merged sample

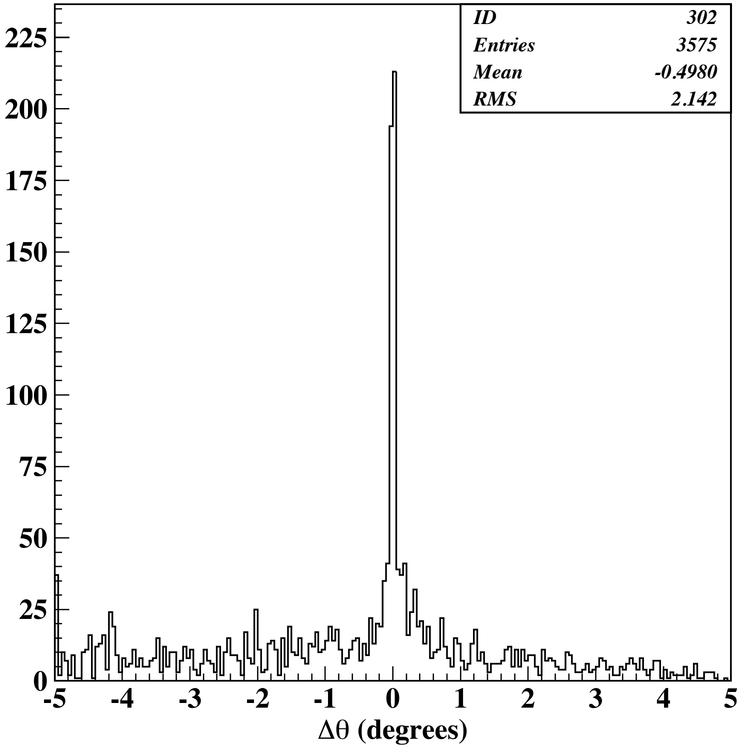
3575 negative tracks are found in the same event and in the same sector where the electron in the original 2 nA sample was reconstructed:

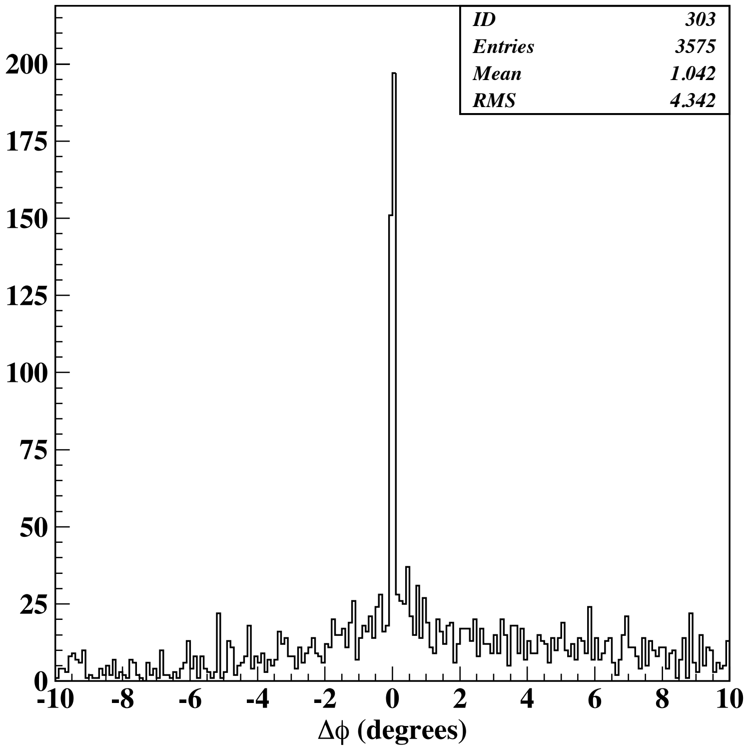
$$\frac{\delta p}{p} = \frac{p_2^{el} - p_{50}^{h-}}{p_2^{el}}$$

$$\Delta\theta = \theta_2^{el} - \theta_{50}^{h-}$$

$$\Delta\varphi = \varphi_2^{el} - \varphi_{50}^{h-}$$





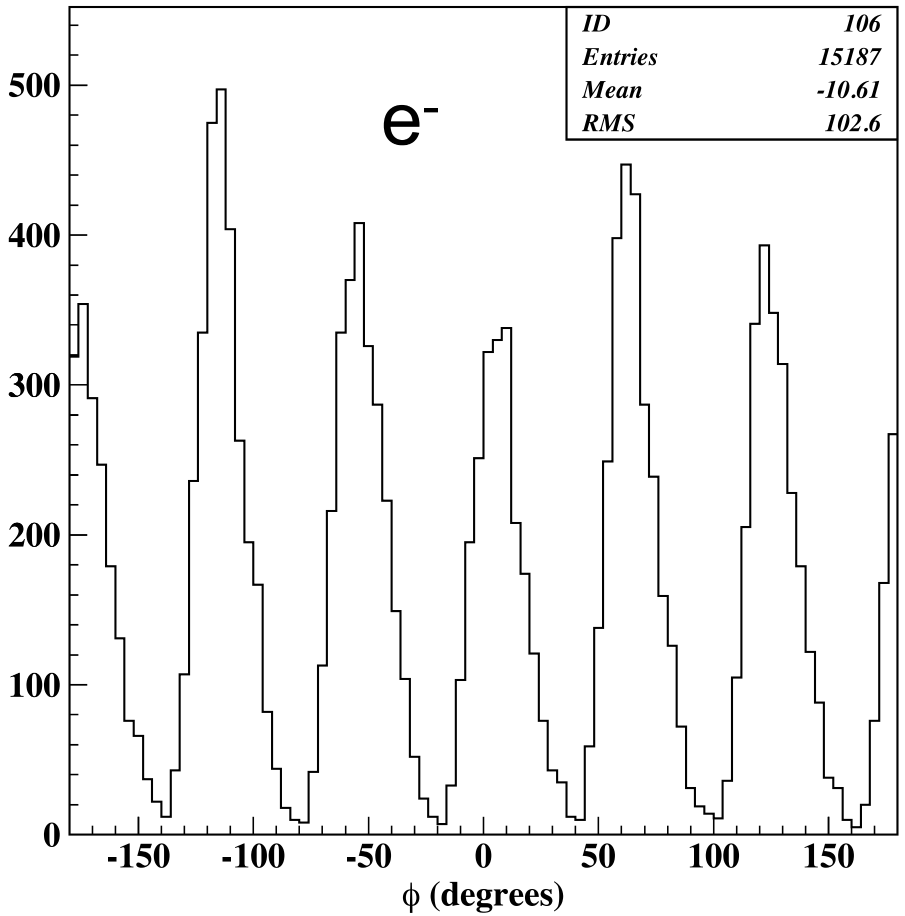


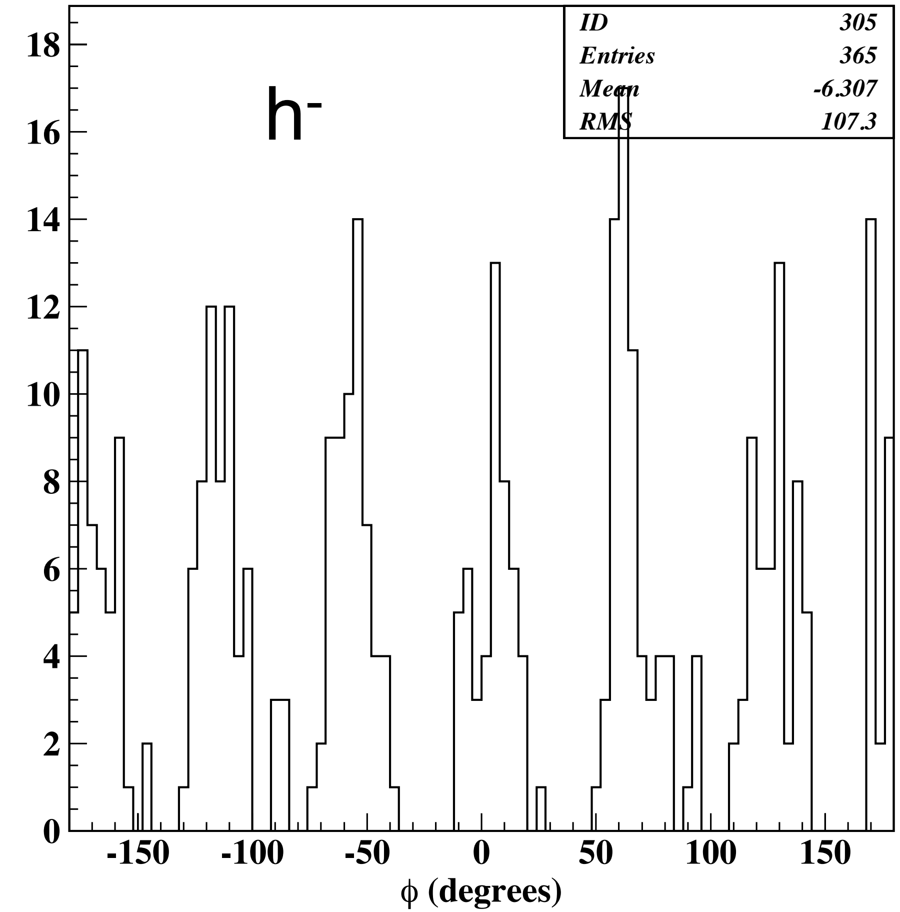
15% of the original 2nA electrons, and only 10% of these negative tracks have close to the original track parameters

e-'s form the 2 nA sample as a h- or e- in the merged sample

Total of 15523 electrons + negative tracks, or 73% of the original electrons were reconstructed within (before the last changes this number was 69%):

$$|\Delta p/p| < 0.5\%,\ |\Delta\vartheta| < 0.5^o \text{ and } |\Delta\varphi| < 1^o$$

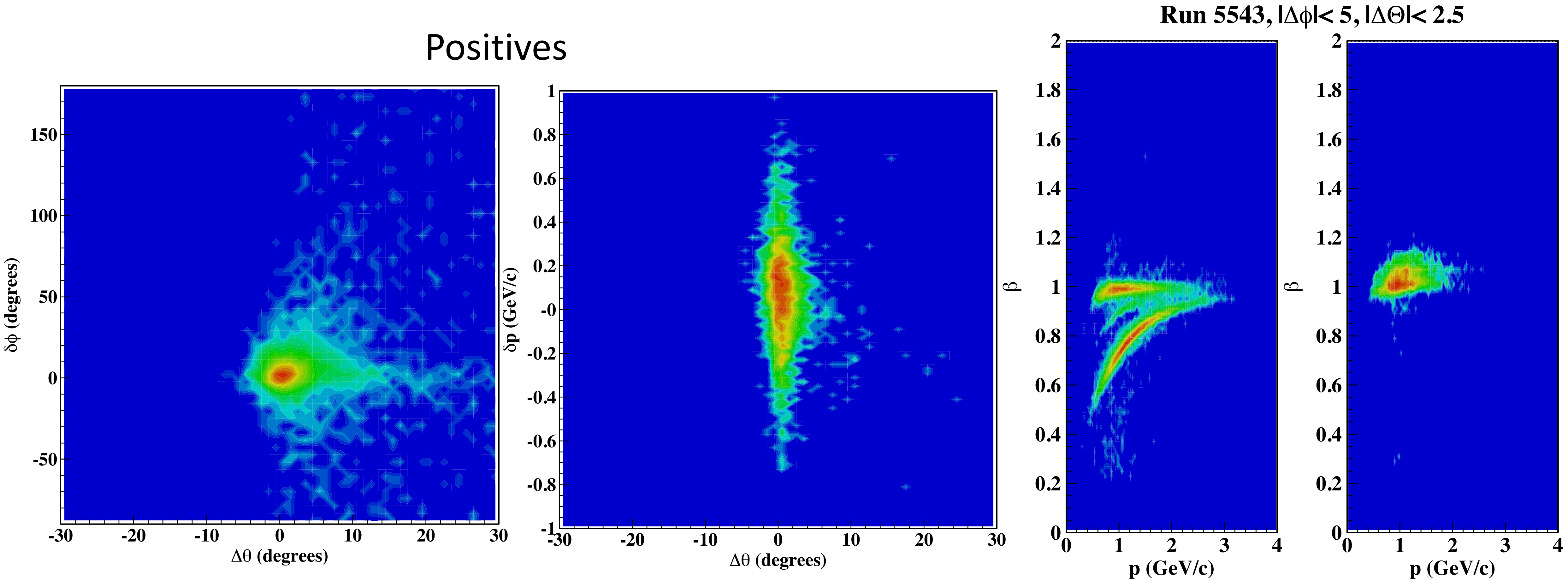




Tracks reconstructed in FD and CD

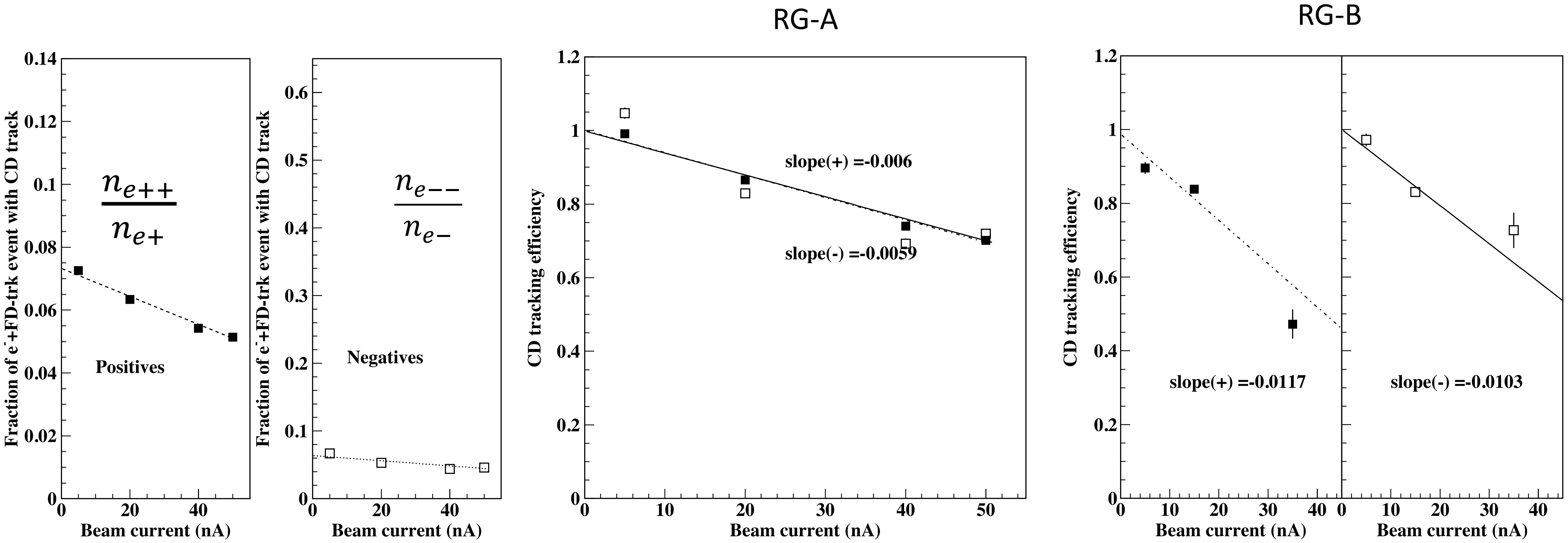
- Electrons with p > 2 GeV and one FD track
- FD tracks: P_+>0.8 GeV/P_->0.6 GeV, $35^o < \vartheta < 40^o$

Positives



CD tracking efficiency

- Loop over CD tracks and select events with $|\varphi_{CD} - \varphi_{FD}| < 5^o$ and $|\vartheta_{CD} - \vartheta_{FD}| < 2.5^o$, n_{e++} or n_{e--}
- Calculate fraction of e with -/+ FD track events with CD track as $\frac{n_{e++}}{n_{e+}}$ or $\frac{n_{e--}}{n_{e-}}$,
- Fit with $f = a + bi$, where i is the beam current



Summary and general remarks

(%/nA)	RG-B, Winter-Spring 2019	Spring e- inbending	Fall e- inbending	Fall e- outbending	Eng. Run FToff e- inb.	RG-K FT-ON, outbending	RG-K FToff, 6.5 GeV, outbending
α −positives	0.4	0.46	0.49	0.27	0.49	0.33	0.325
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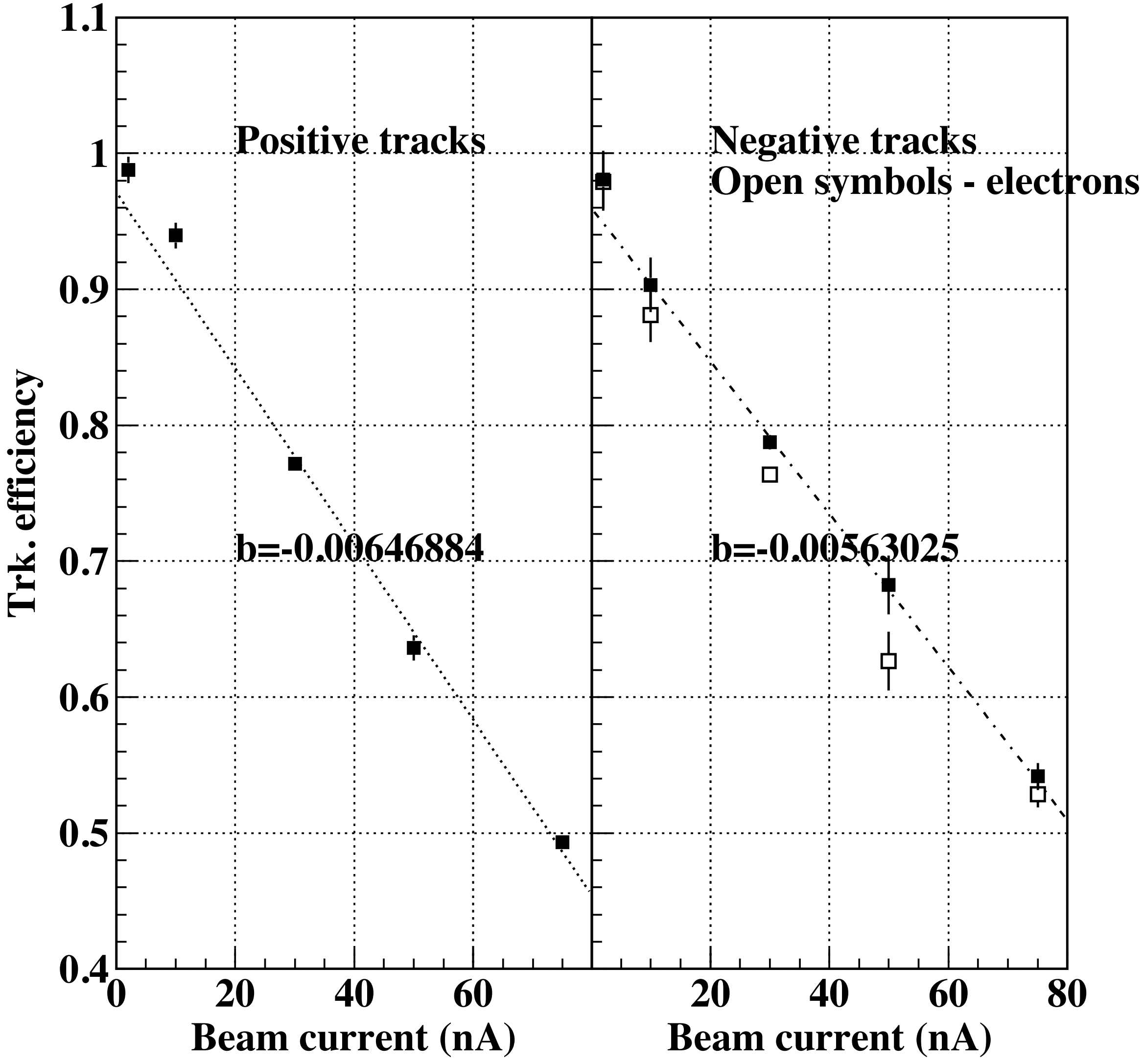
- A comparable rate of reconstruction efficiency decrease with the increase of beam current from all studies, much larger than what was expected from CLAS experience
- Significant difference in inefficiency slopes with and without PID cuts
- “Outbending” setting has a smaller rate of efficiency drop
- FT-OFF configuration is no different from FT-ON in terms of the inefficiency rate
- Simulations with the background merging (limited to muons) has some peculiarities that must be understood
- Slopes of reconstruction efficiency decrease for FD and CD tracking are very close.

Path forward

- Efforts to improve the reconstruction efficiency must continue using 2 nA beam date merged with beam background (Veronique, Nathan, Stepan …)
- Regardless of the success with the software developments, we still will be left with significant losses of event reconstruction efficiency that must be properly corrected for each physics reaction
- The efficiency losses are physics reaction (kinematics, topology …), and individual track angle and momentum dependent. More studies with final calibrations and reconstruction algorithms will be needed to determine all dependences.

Note: background effects 3-momentum reconstruction and produces long tails outside of the expected Gaussian distribution of the momentum resolutions. This cannot be corrected with traditional momentum corrections or taking into account in kinematic fits.

- The simulation is the main method to correct for inefficiency for physics analysis. The beam background merging with simulated events using data from random trigger samples has to be fully validated
- The validation of the background merging method should be done first with low luminosity data merged with the beam background by comparing the yields of high rate physics reactions. Then, reproduce that results using simulations (perhaps using topology and kinematics of events form data merging studies)



Note: background effects 3-momentum reconstruction and produces long tails outside of the expected Gaussian distribution of the momentum resolutions. This cannot be corrected with traditional momentum corrections or taking into account in kinematic fits, exclusive reaction will cut out these tails, losing events. The inclusive analysis must worry about bin migration …