T_0 determination of LGAD-TOF at EIC

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In collaboration with
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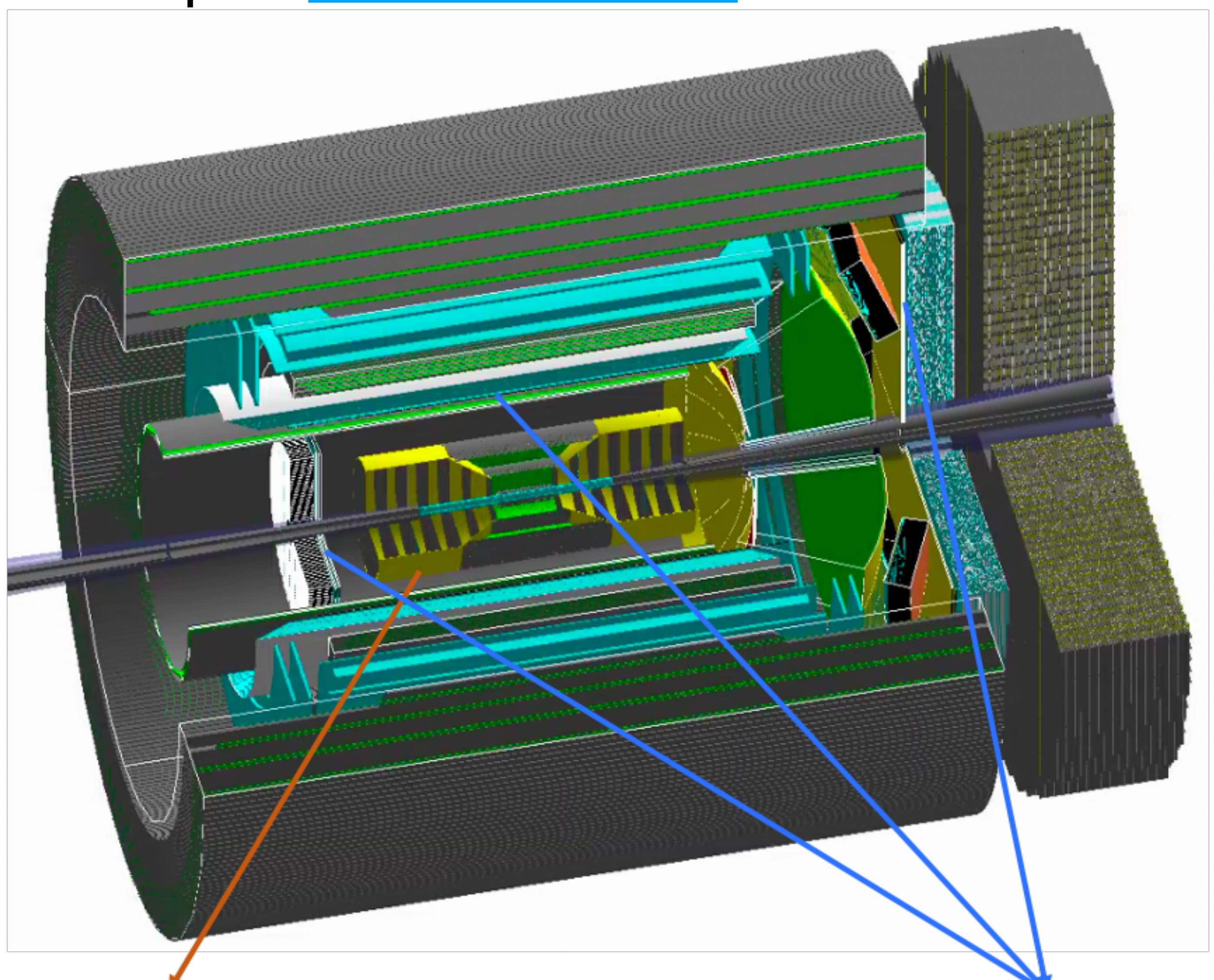
Proposal eRD29
Mid-term report

* This work was done in Rice

Detector setup in full simulation

- Base on Fun4All adopted by the ECCE collaboration
  - See detailed setup in G4_TTL_EIC.C



All silicon tracker
(LBL group: arXiv:2102.08337)

LGAD-TOF layers
(This work)

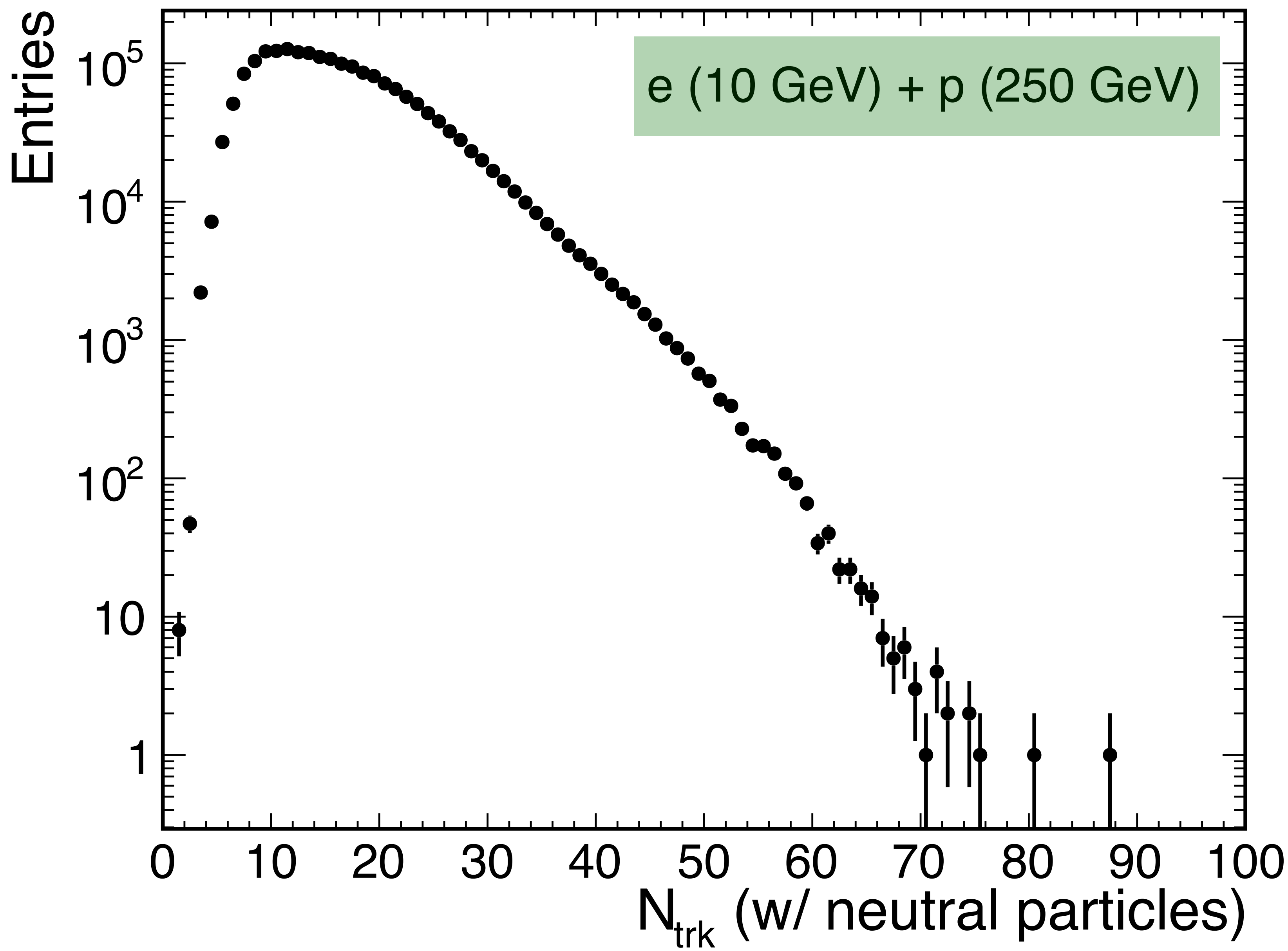
Detector setup in full simulation

	TOF layers	R^{barrel}	Length	Z location	R^{endcap}_{in}	R^{endcap}_{out}	η coverage	Area (m^2)
Backward	$ETTL_0$			-1.555	0.077	0.655	[-3.7, -1.6]	1.33
	$ETTL_1$			-1.585	0.078	0.667	[-3.7, -1.6]	1.38
Barrel	$CTTL_0$	0.92	3.6				[-1.4, 1.4]	**20.8**
Forward	$FTTL_0$			2.87	0.116	1.690	[1.3, 3.9]	8.93
	$FTTL_1$			2.89	0.117	1.702	[1.3, 3.9]	9.05
Total Area (m^2)								41.49

- LGAD performance *[arXiv:2003.04838]*
  - **Timing resolution: 20ps - 60 ps / layer**
  - Spatial resolution: 30-375 μm [No discussion of the tracking impact here]
- LGAD-TOF Materials
  - **Only silicon layer was turned on in this simulation**
  - Place holder for other materials

```
ttl->get_geometry().AddLayer("SiliconSensor", "G4_Si", tSilicon, true, 100);
ttl->get_geometry().AddLayer("Metalconnection", "G4_Al", 100 * um, false, 100);
ttl->get_geometry().AddLayer("HDI", "G4_KAPTON", 20 * um, false, 100);
ttl->get_geometry().AddLayer("Cooling", "G4_WATER", 100 * um, false, 100);
ttl->get_geometry().AddLayer("Support", "G4_GRAPHITE", 50 * um, false, 100);
ttl->get_geometry().AddLayer("Support_Gap", "G4_AIR", 1 * cm, false, 100);
ttl->get_geometry().AddLayer("Support2", "G4_GRAPHITE", 50 * um, false, 100);
```

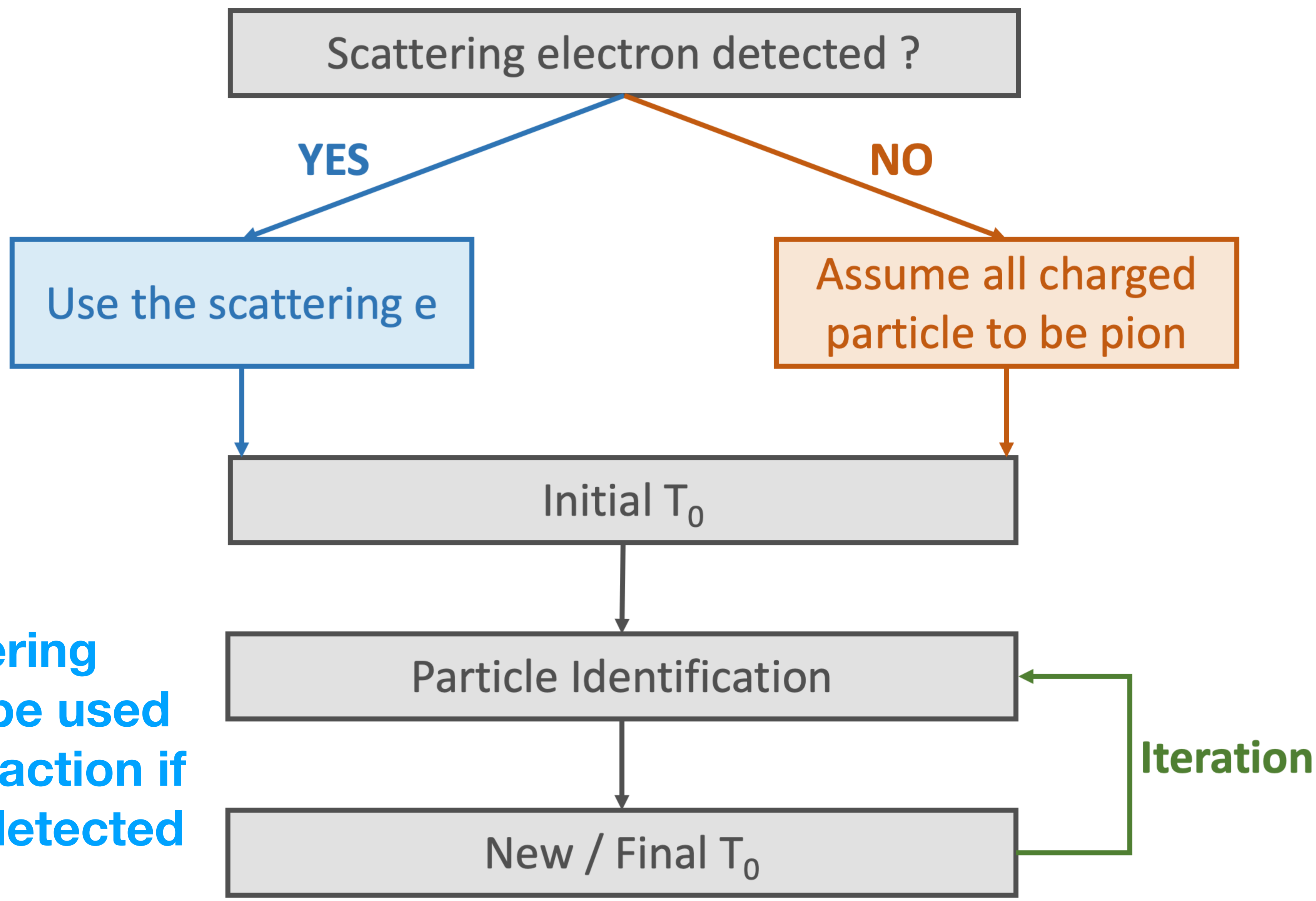
Event generator



- Pythia 6 generator embedded in fun4All
  - N_{trk} includes neutral particles, e.g., photon
  - N_{trk} in full kinematic space

Strategy of T_0 determination

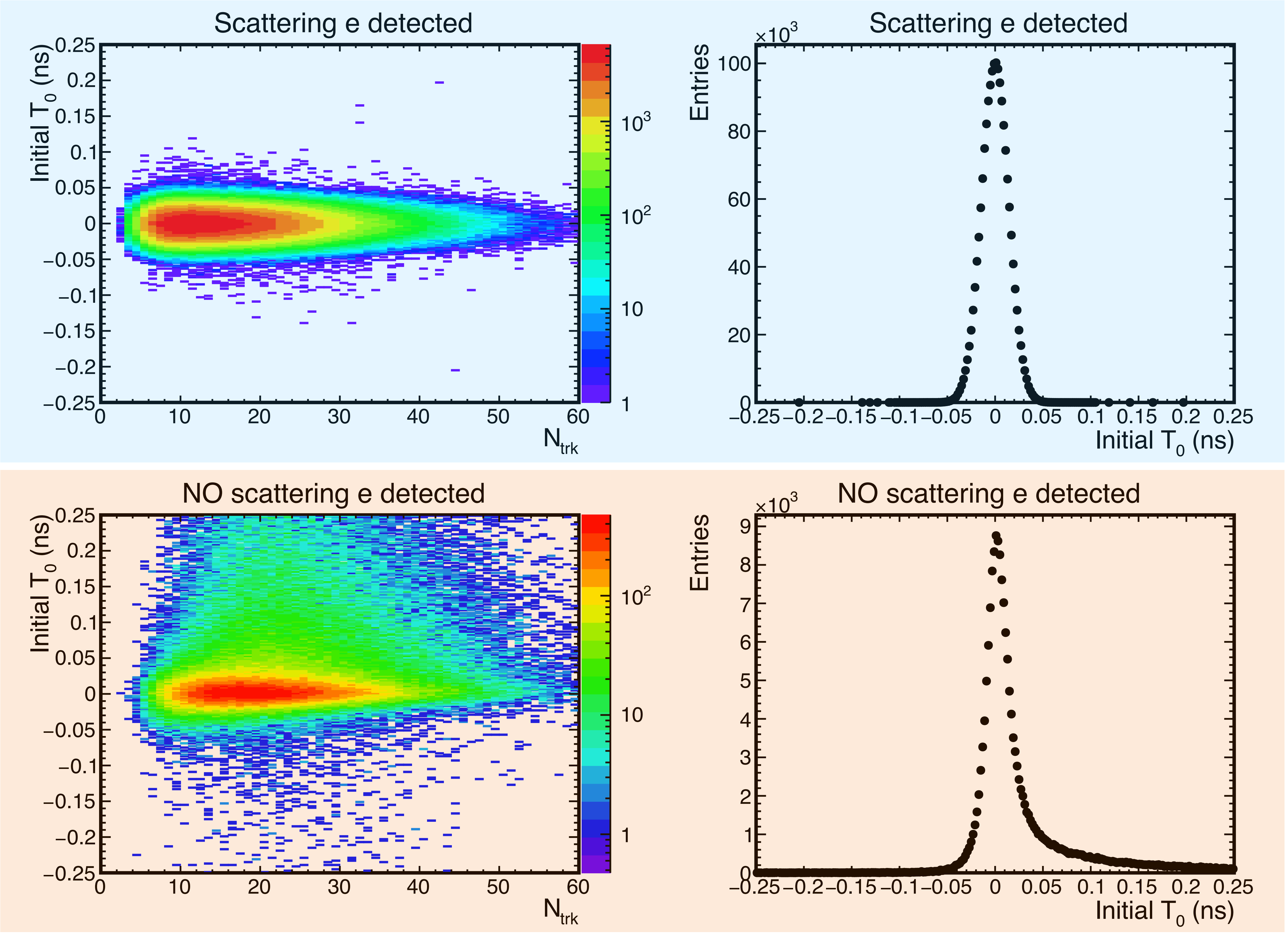
- Almost impossible to build a T_0 detector in EIC
  - Low charged particle yield
  - Excellent intrinsic timing resolution of TOF



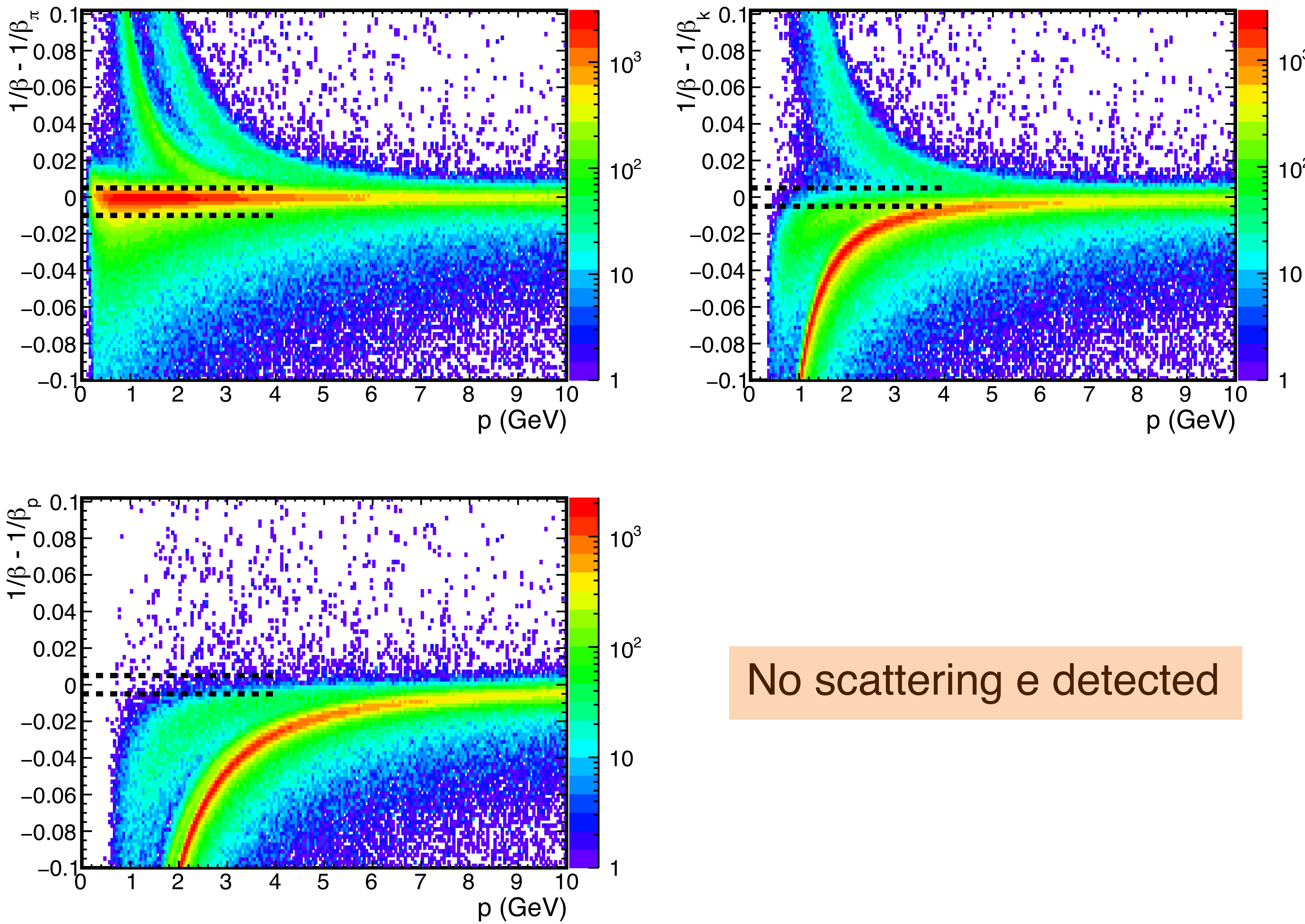
The scattering electron will be used for every interaction if successfully detected

The following detailed studies use 20 ps / layer as an example

Initial T_0 determination

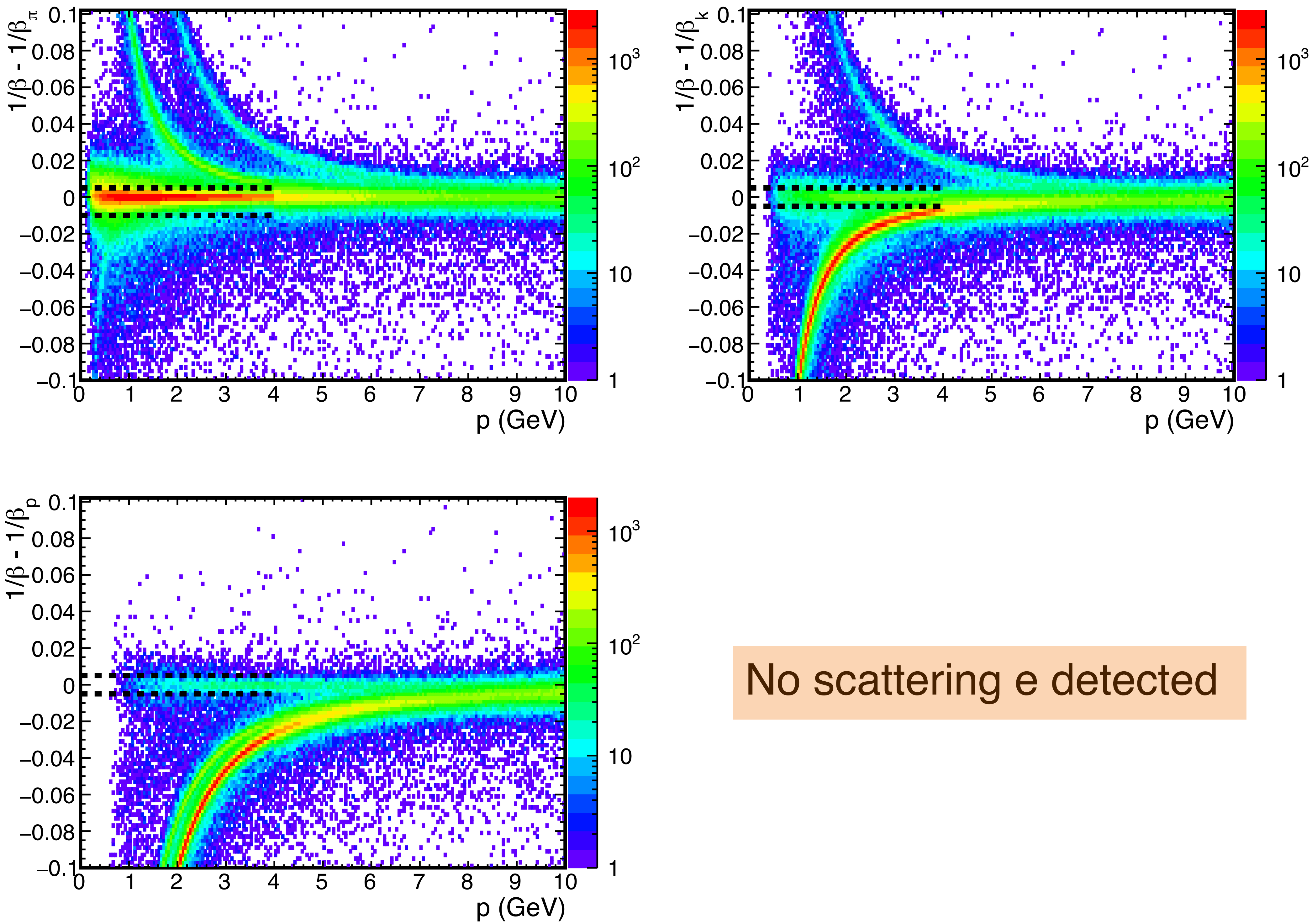


First iteration to improve T_0



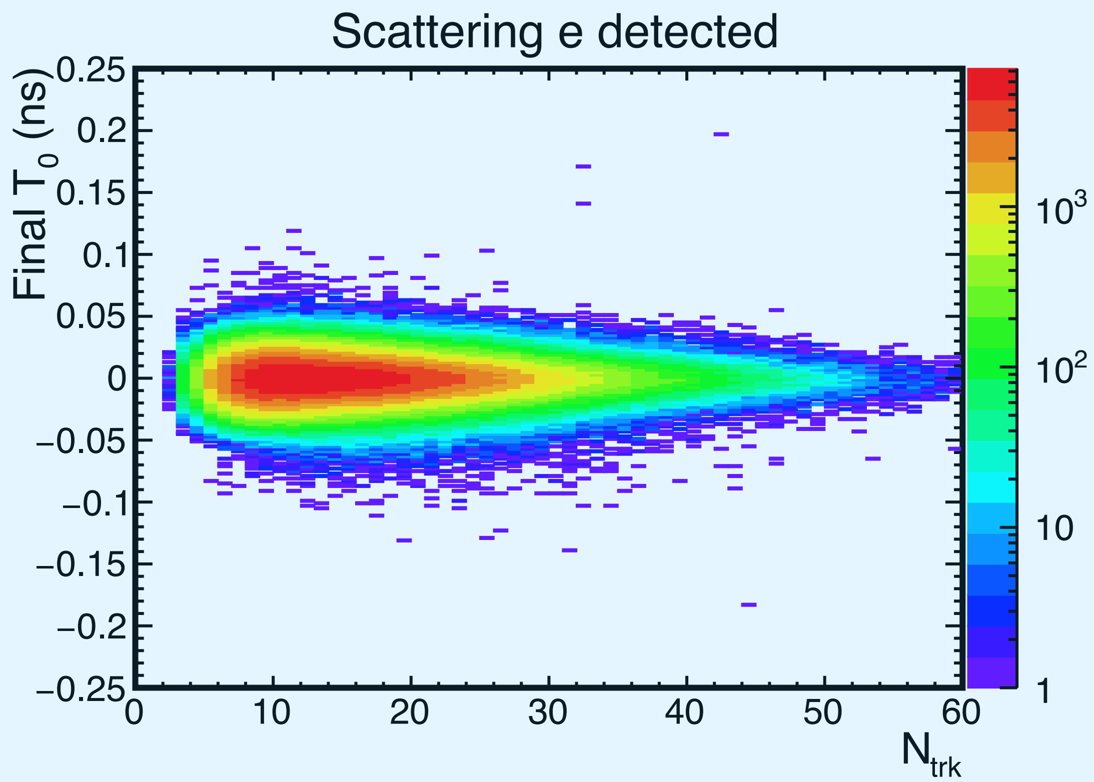
No scattering e detected

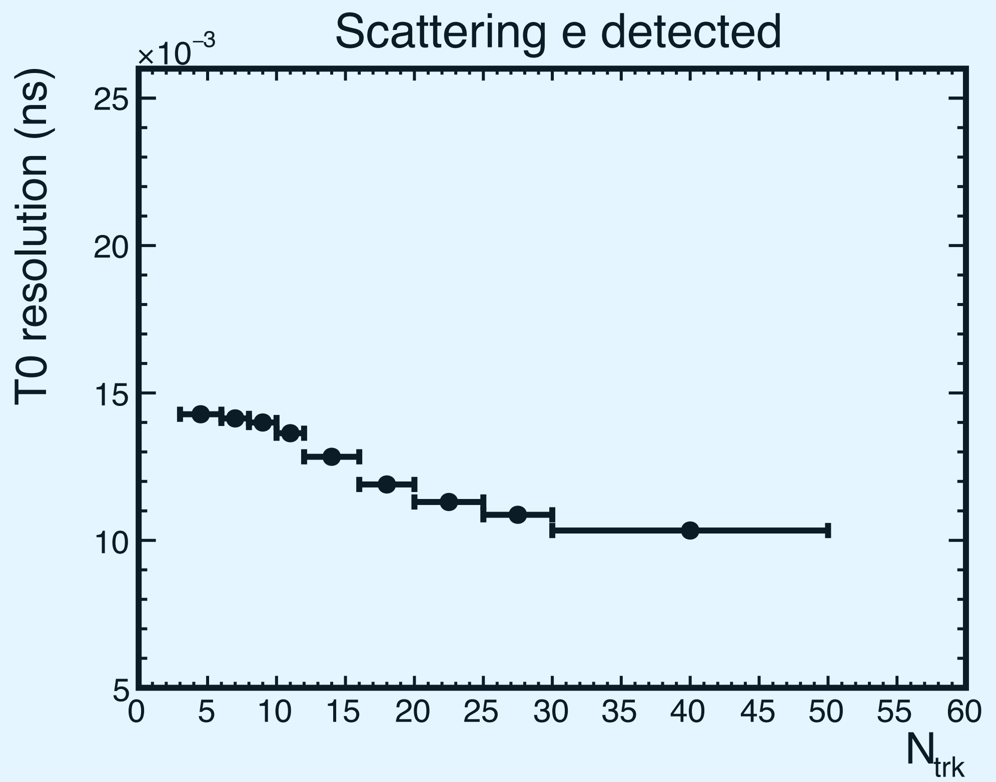
Last iteration to improve T_0

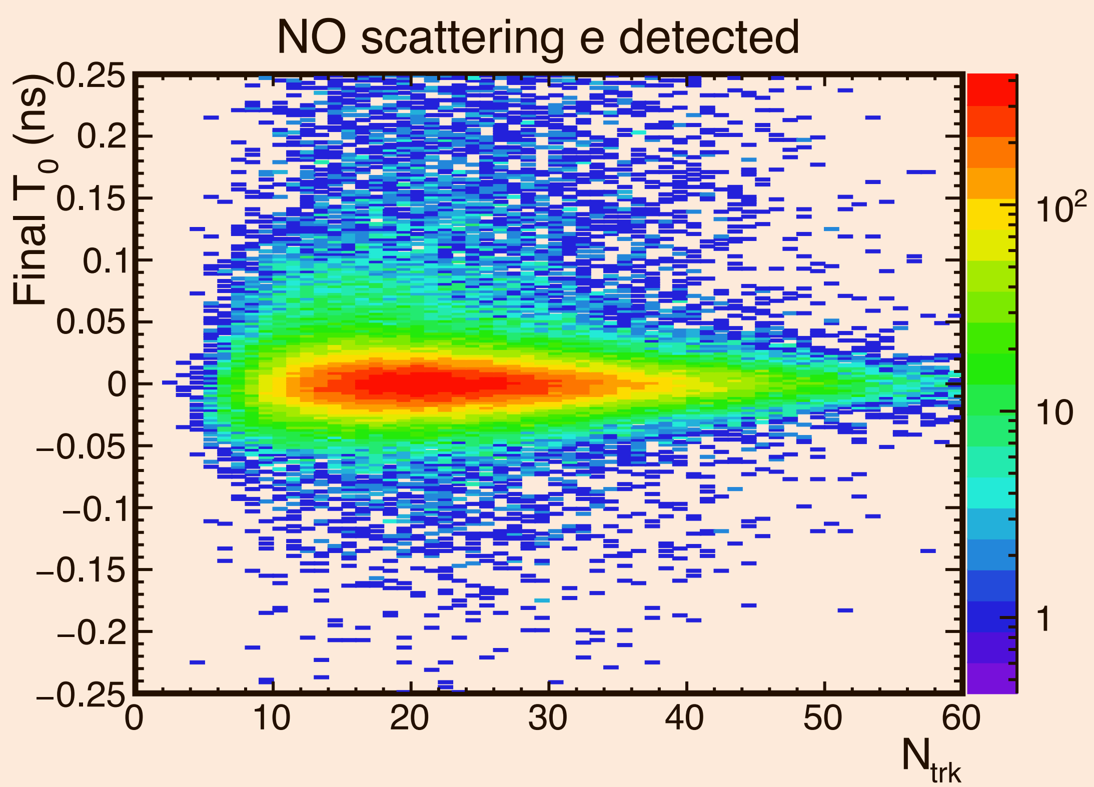


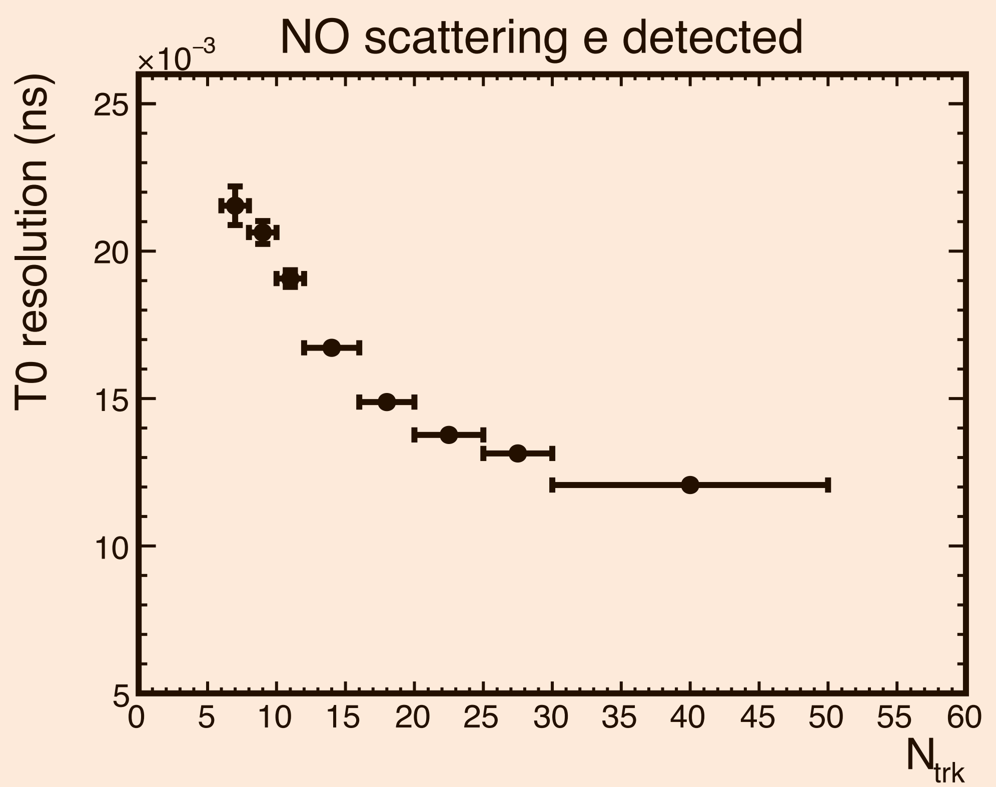
No scattering e detected

Final T_0 after iteration

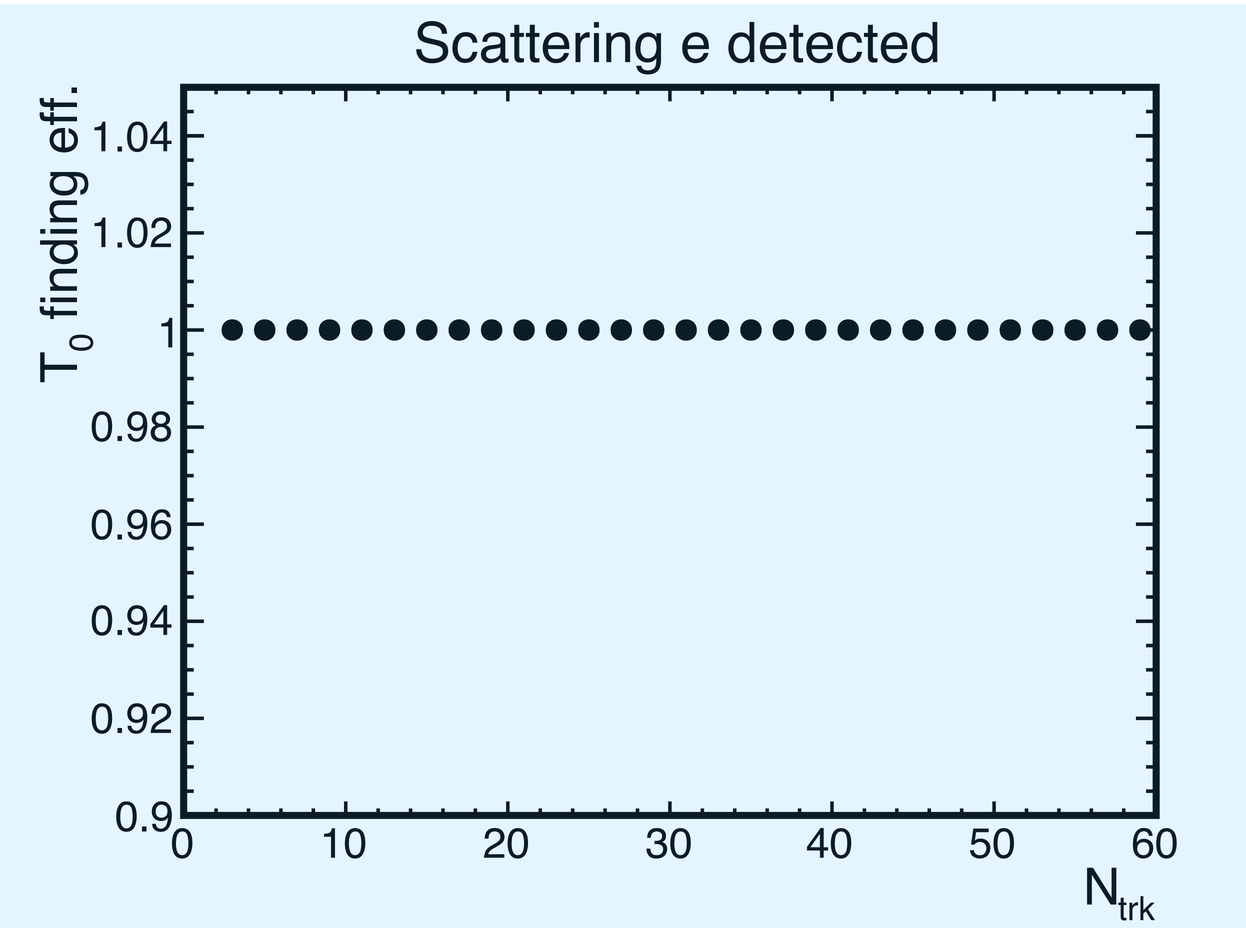


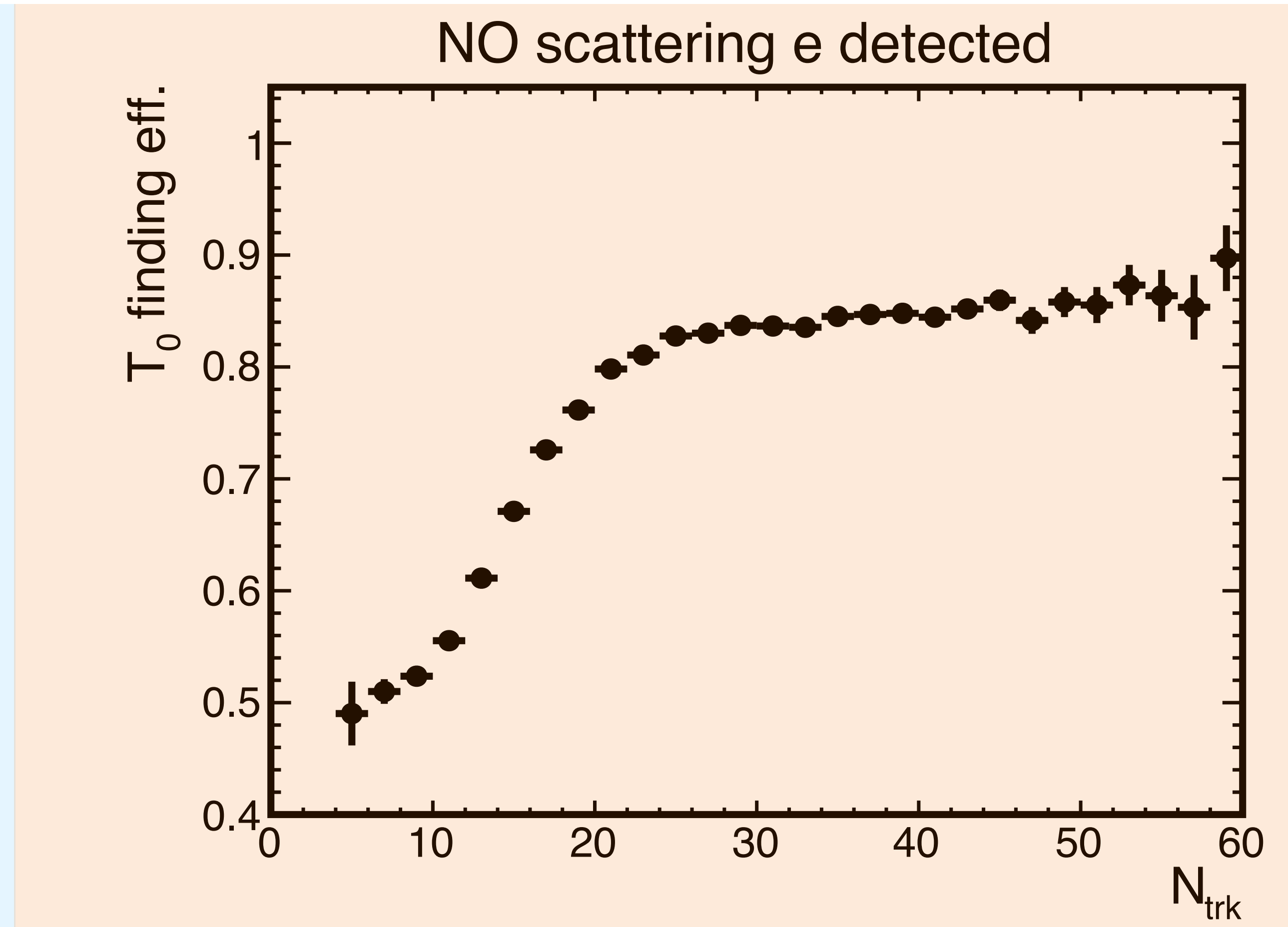






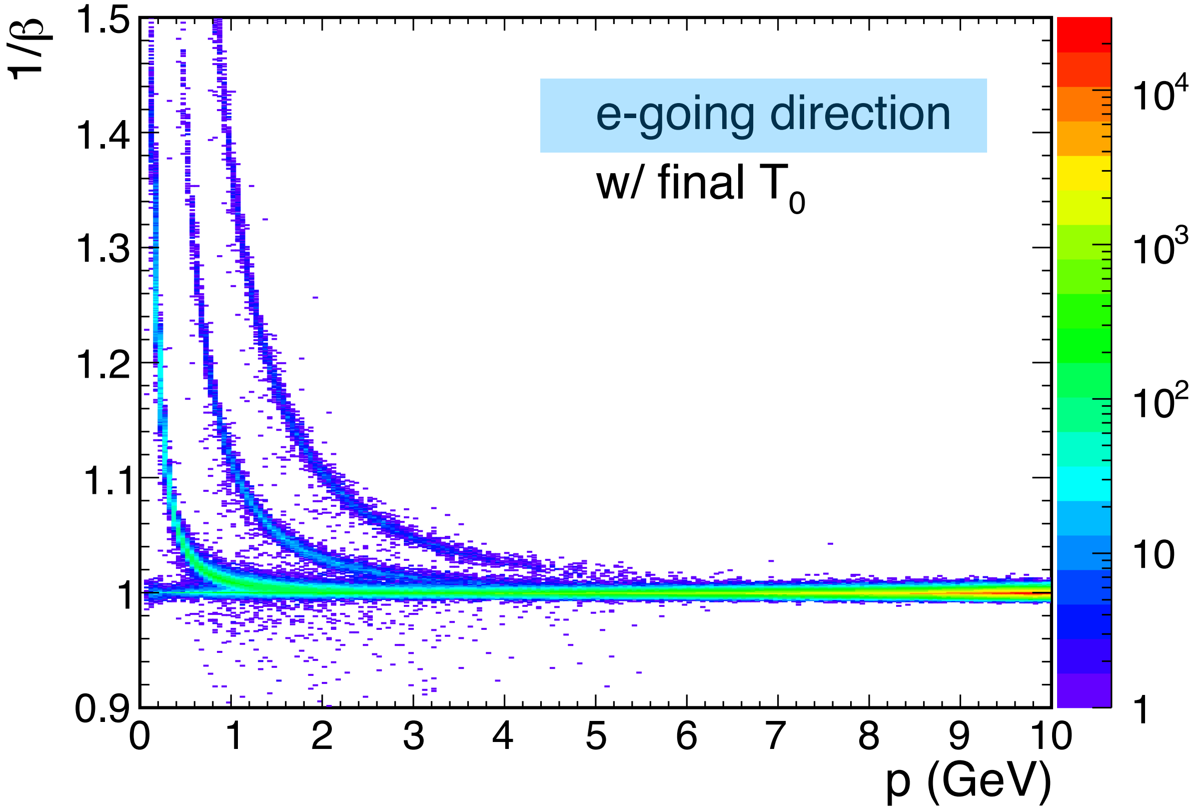
T_0 finding efficiency

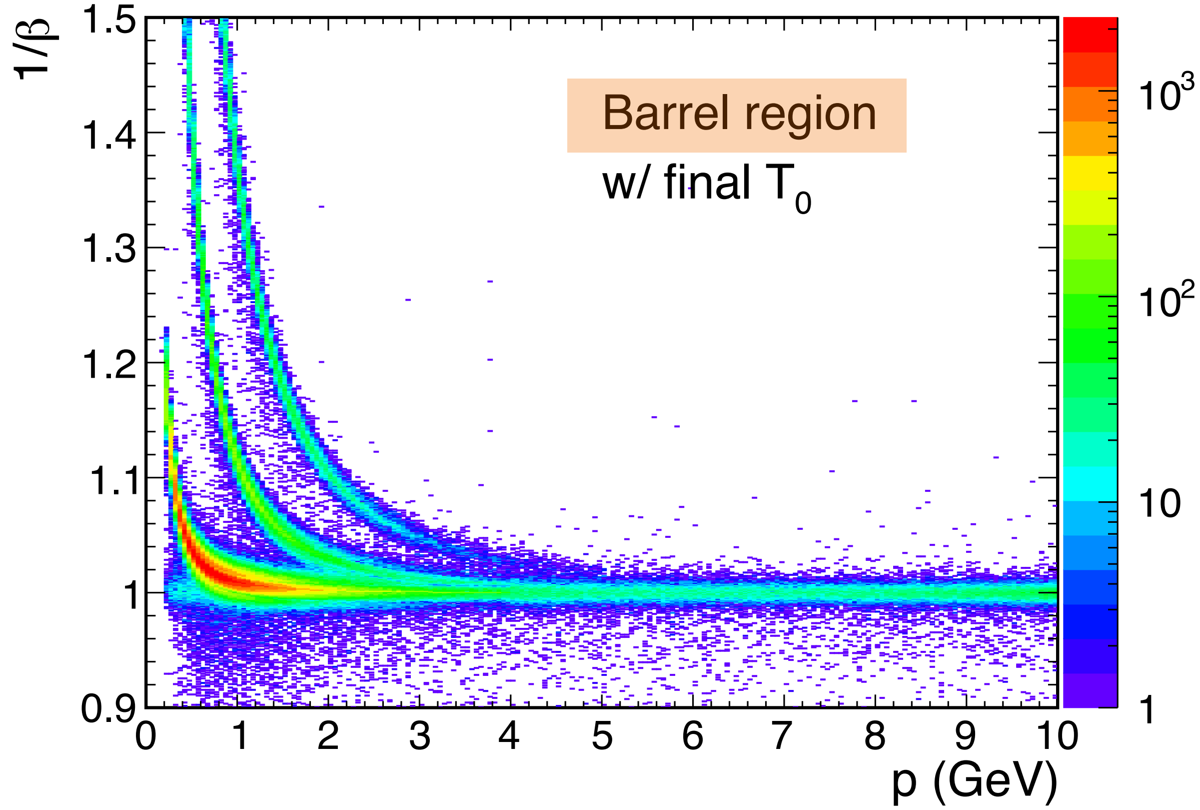


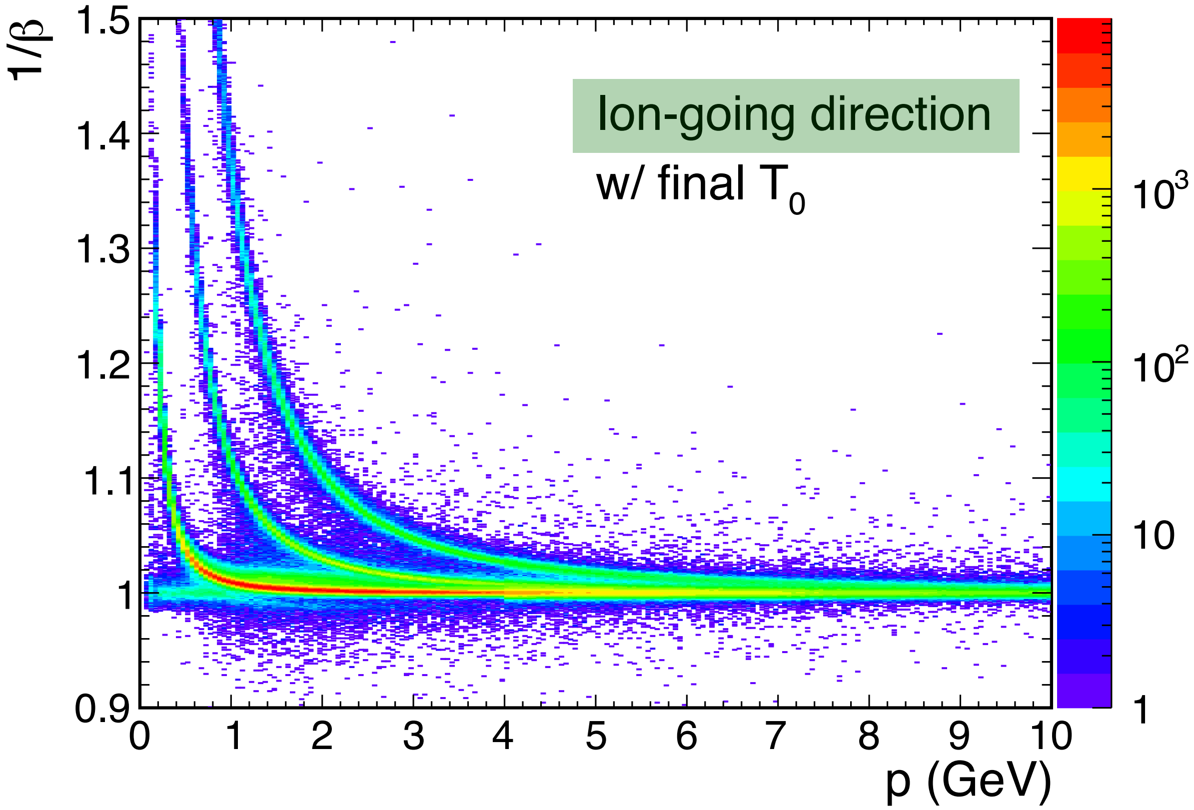


No detecter efficiency loss considered

$1/\beta$ vs. p

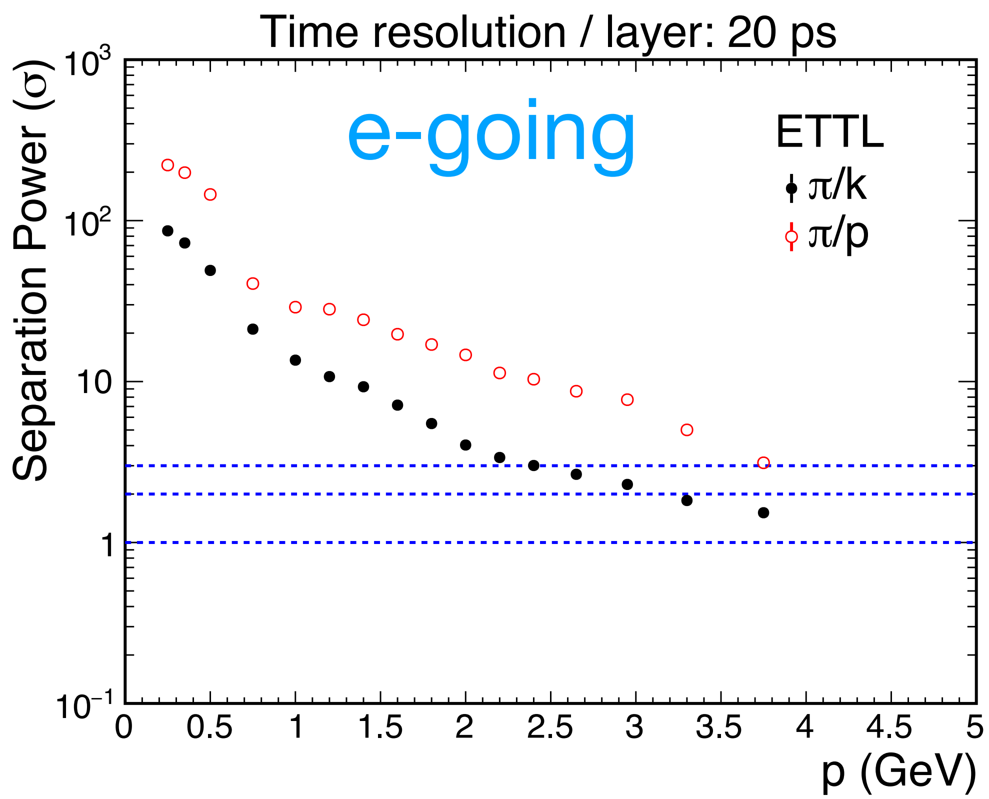


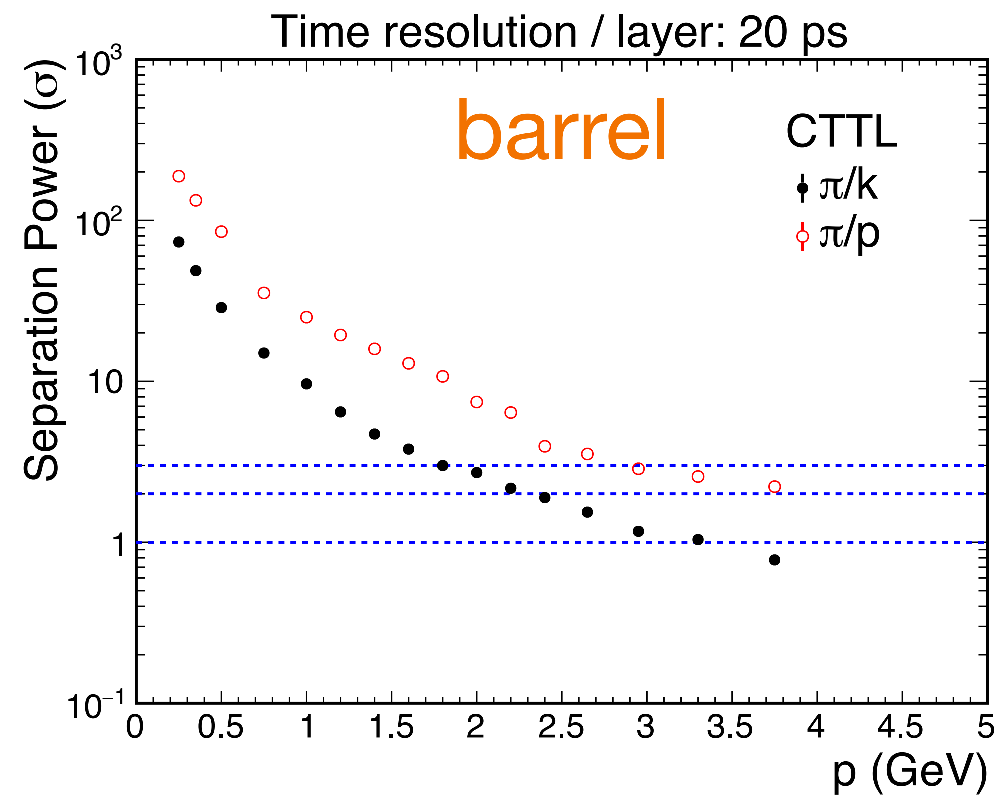


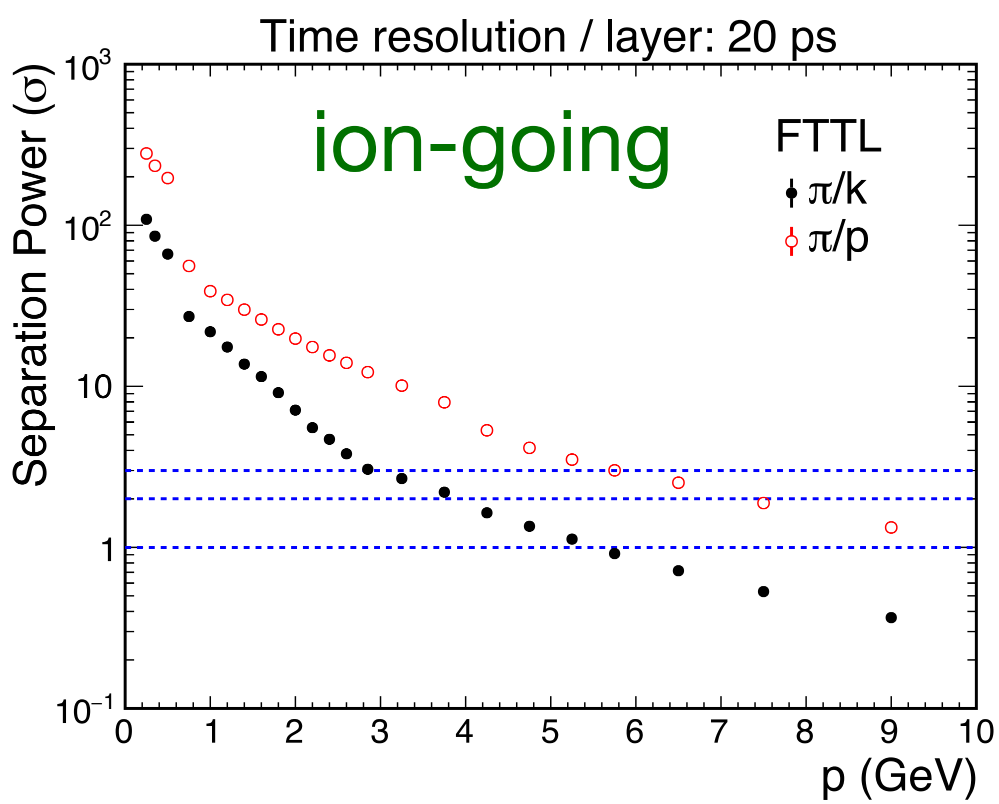


- Uncertainty sources
  - Intrinsic timing resolution
  - T_0 resolution
  - Path length uncertainty

TOF PID capability

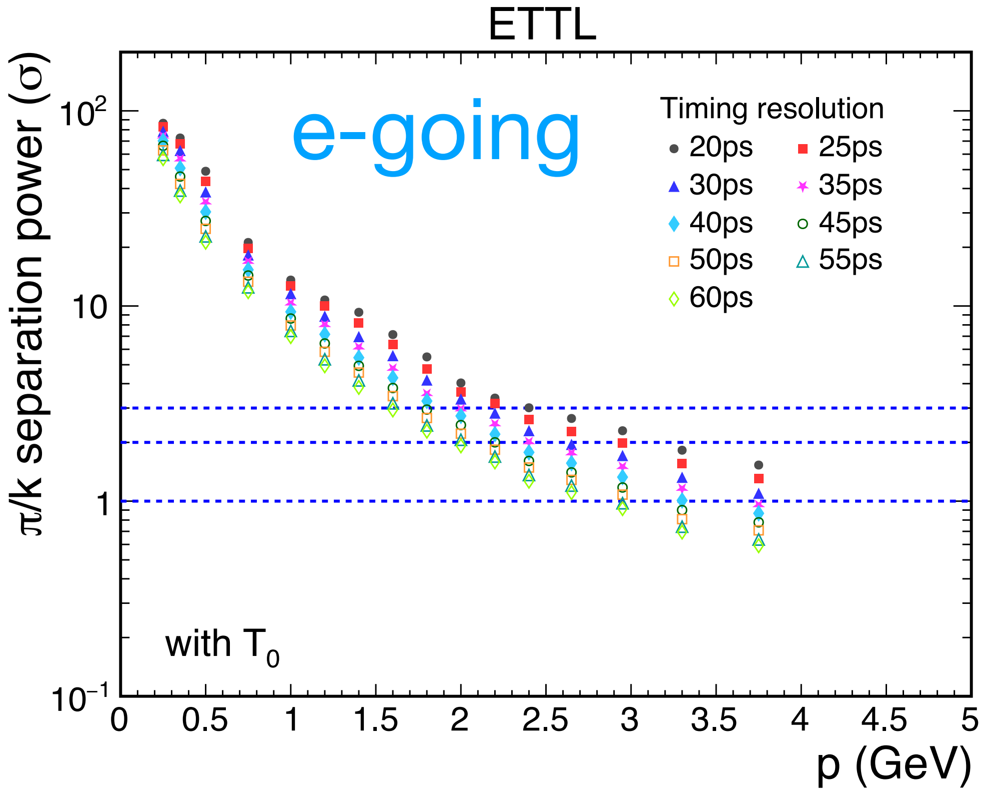


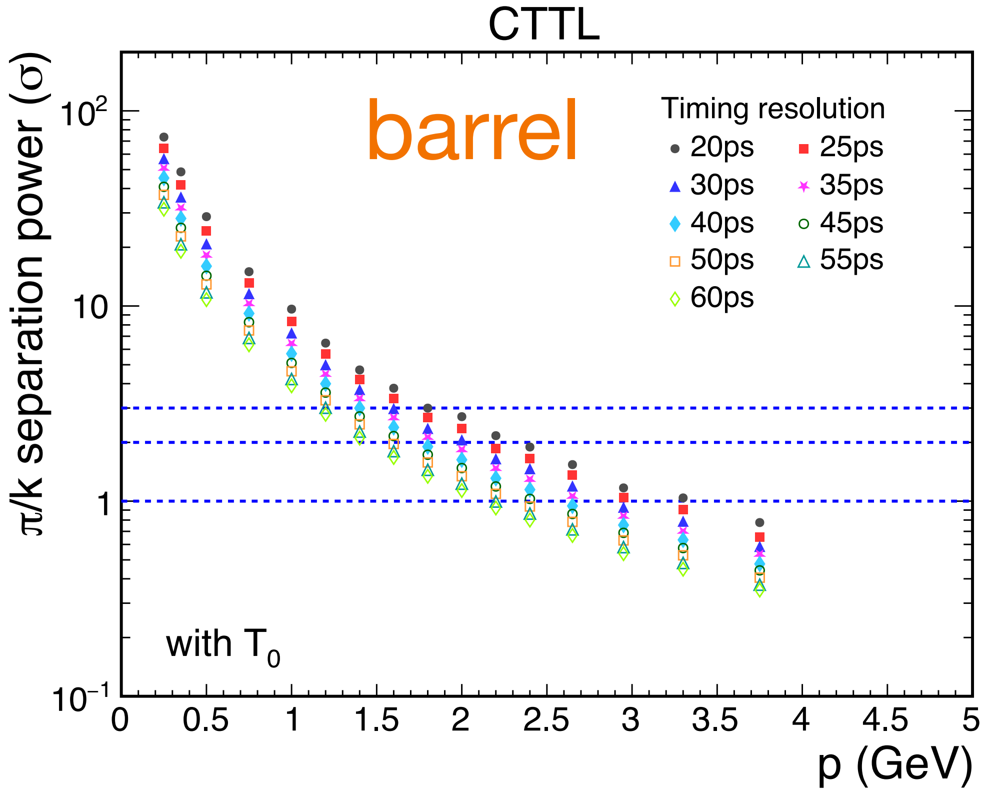


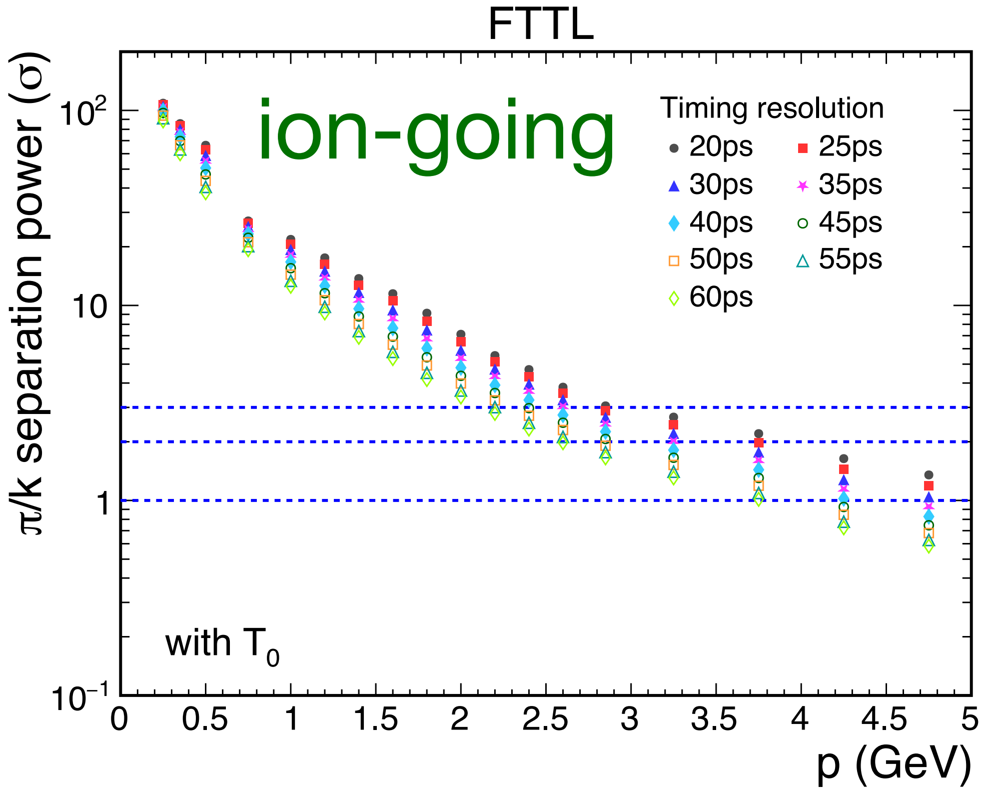


- Combining (m)dRICH, PID over full p covered

TOF PID capability (π/K separation)







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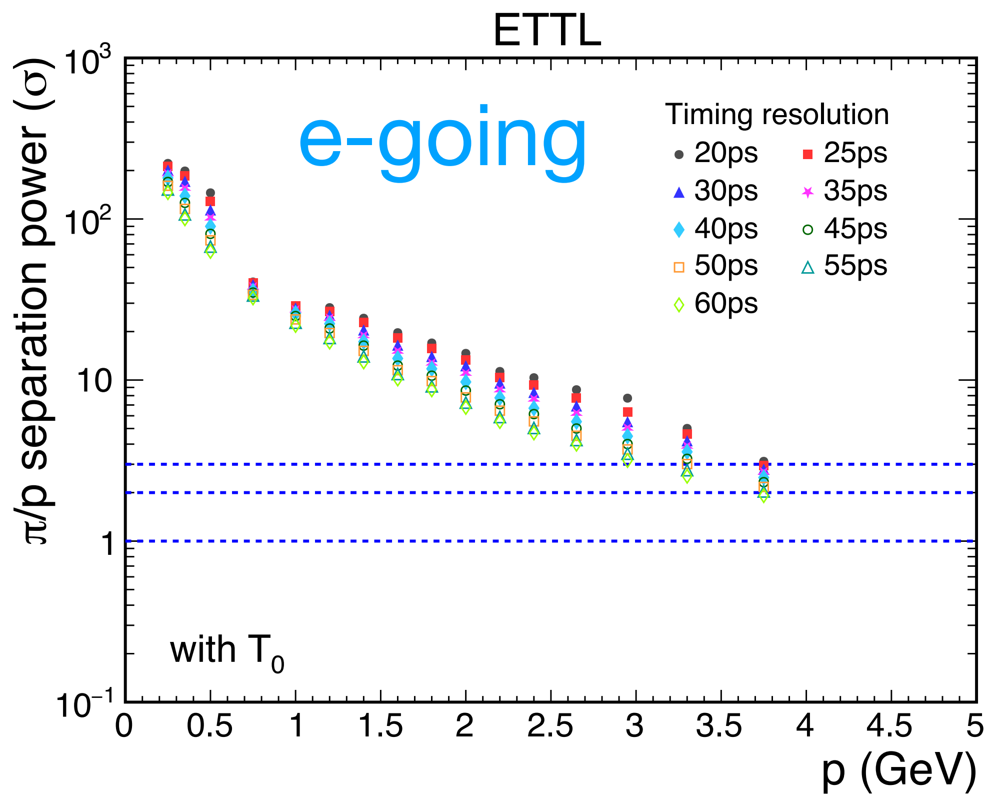
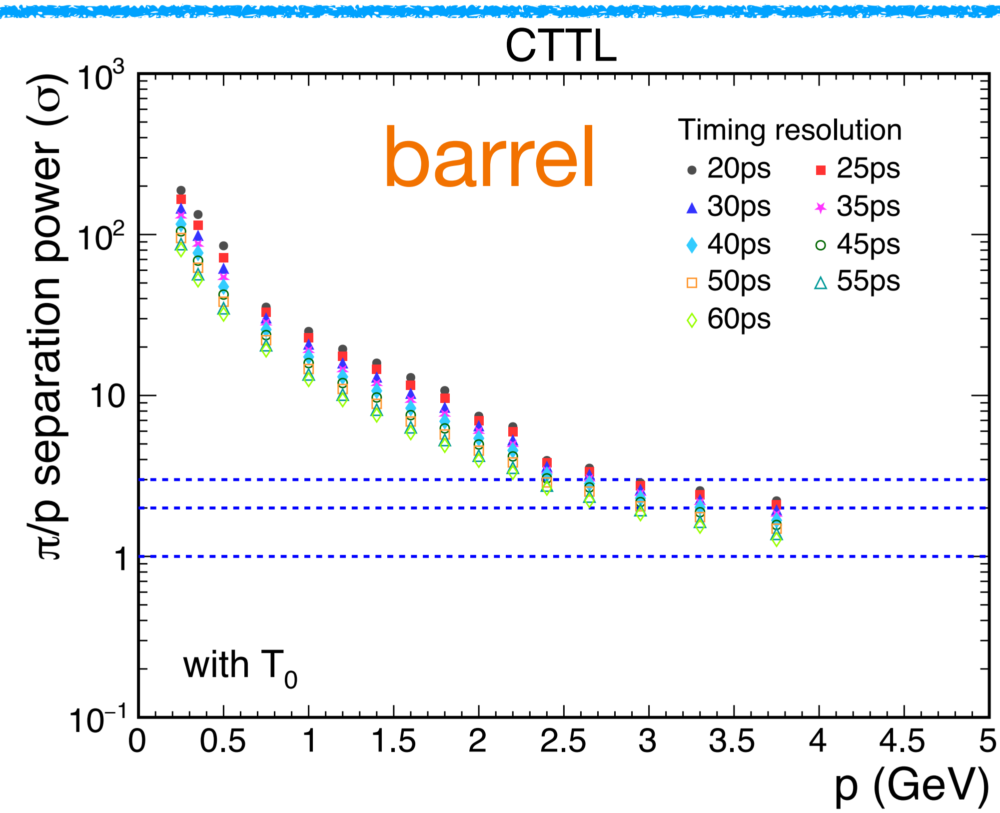
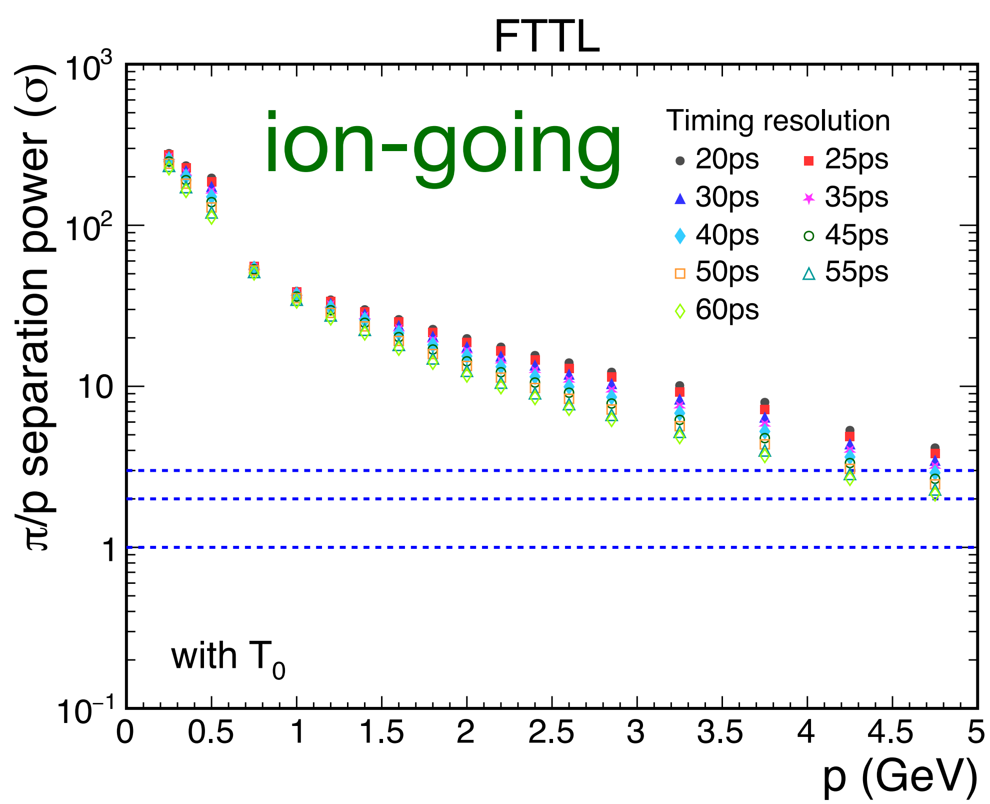
TOF PID capability (π/p separation)



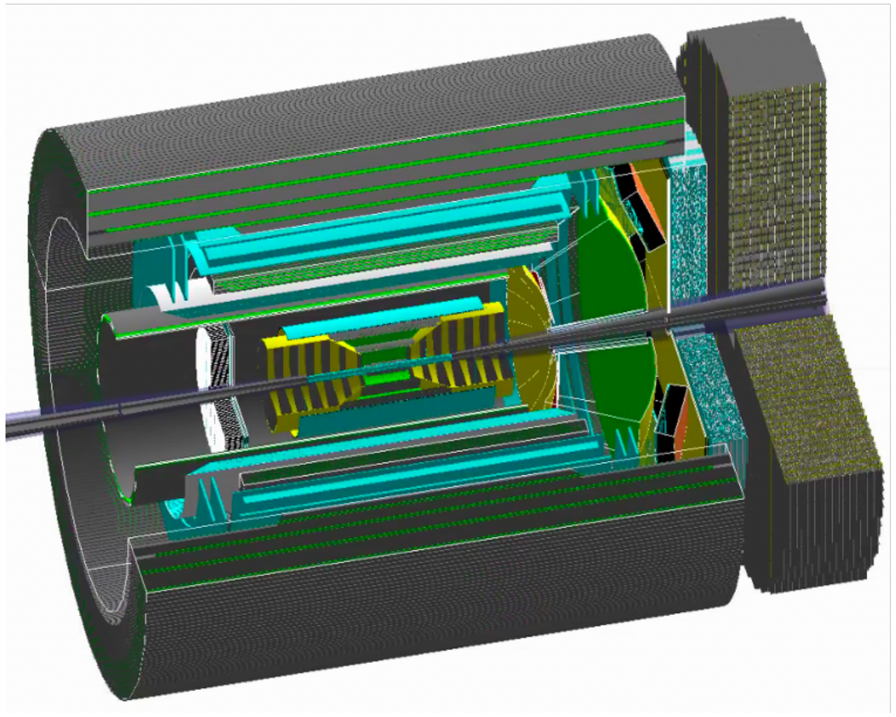




- Combining (m)dRICH, PID over full p covered

Summary and outlook

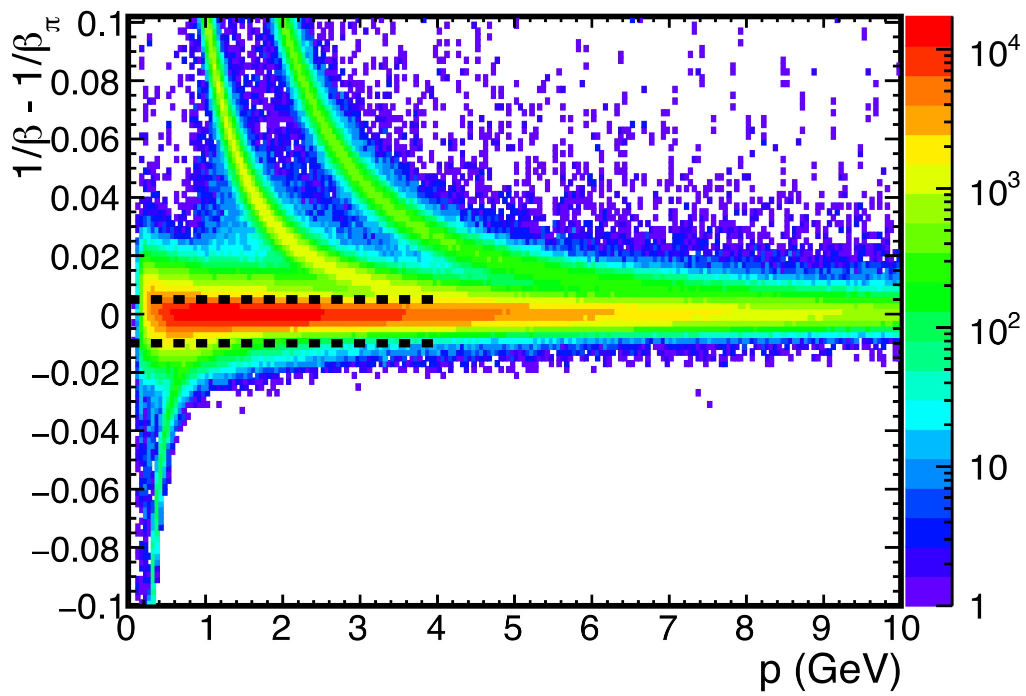
- Implemented a LGAD-TOF in Fun4All
- Through full simulation
  - Studied start-less T_0
  - Estimated PID capability

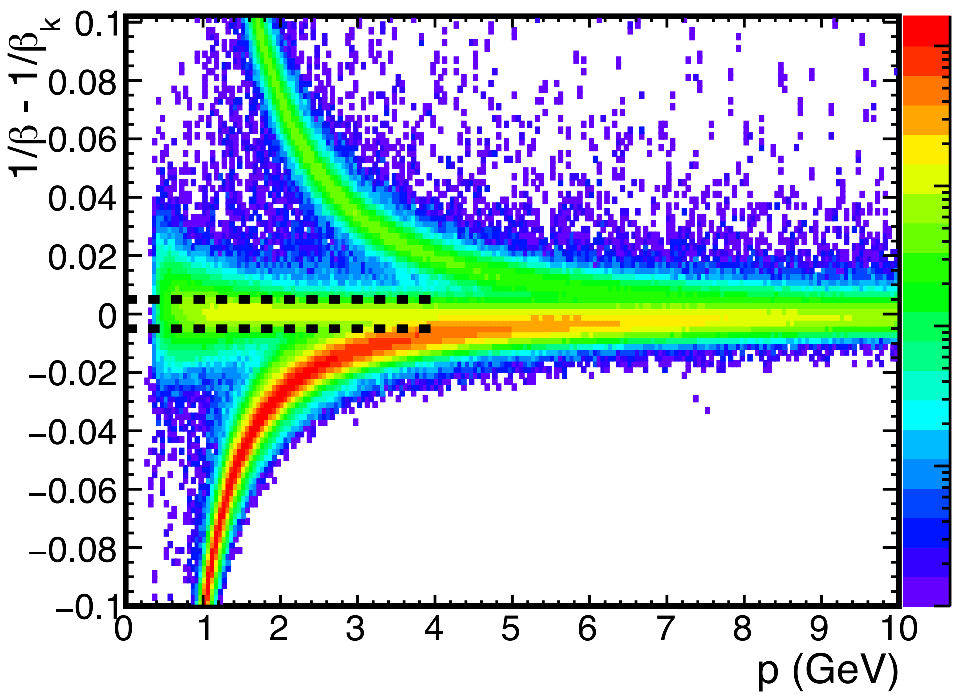


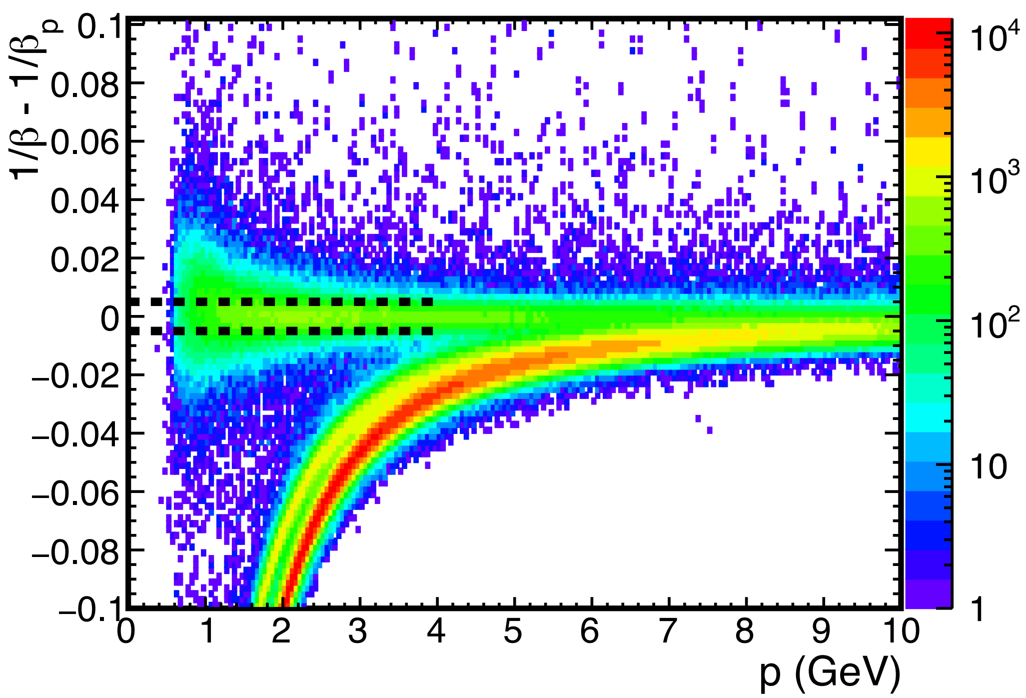
- Improve T_0 determination
- Reduce barrel radius and check the PID capability ⟶ Only focus on low p track
  - Radius: 0.92 m ⟶ 0.5 m
  - Length: 3.6m ⟶ 2.0 m
  - Area: 20.8 m^2 ⟶ 6.28 m^2

Backup

First iteration to improve T_0

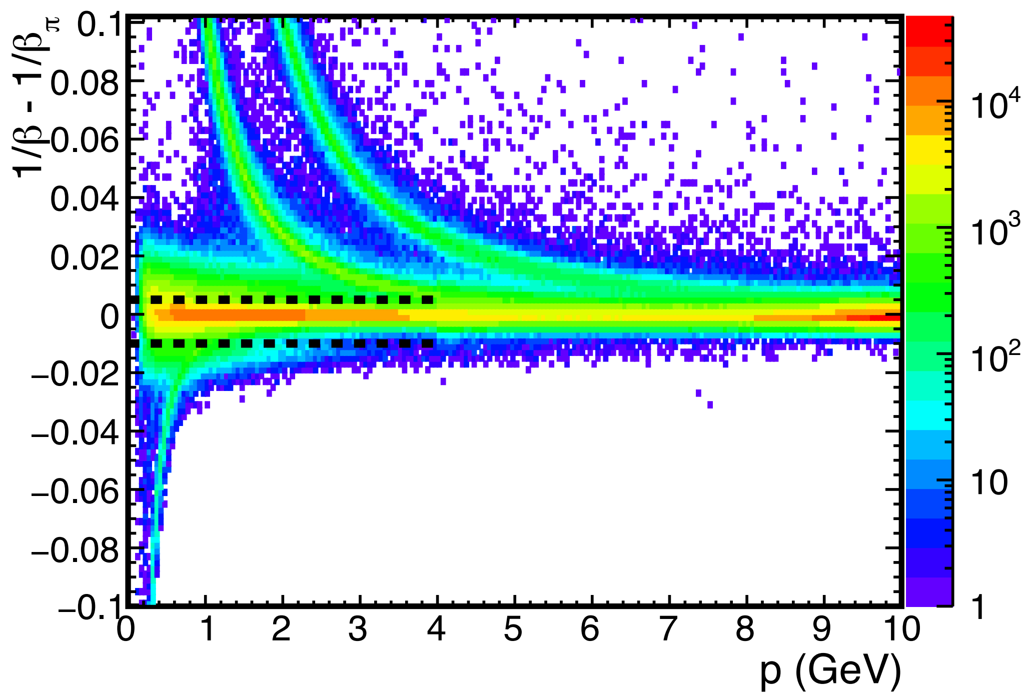


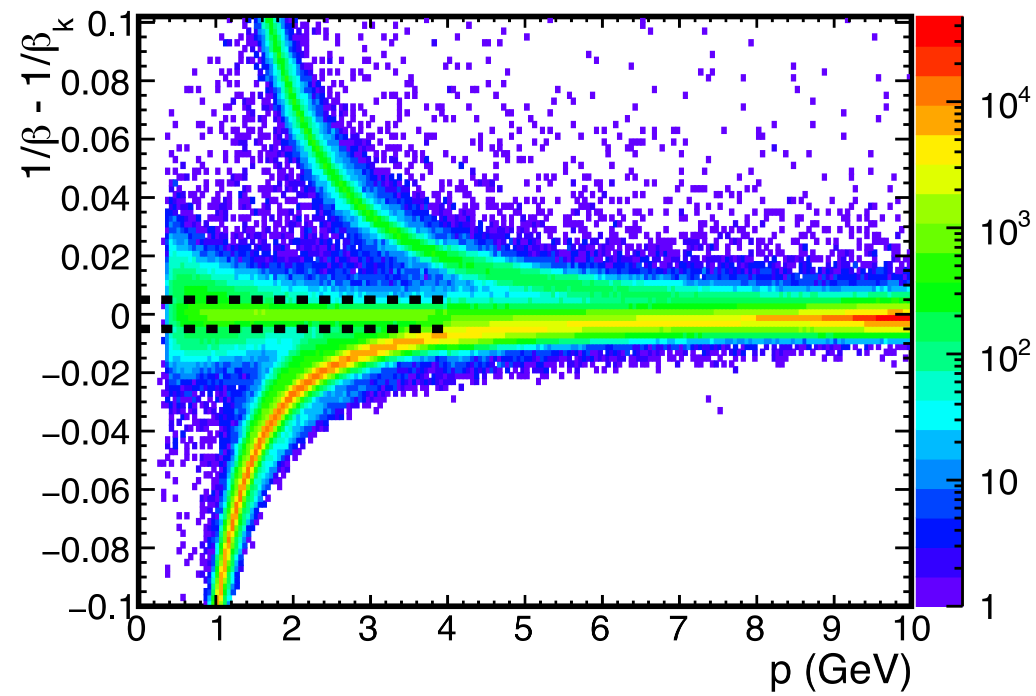


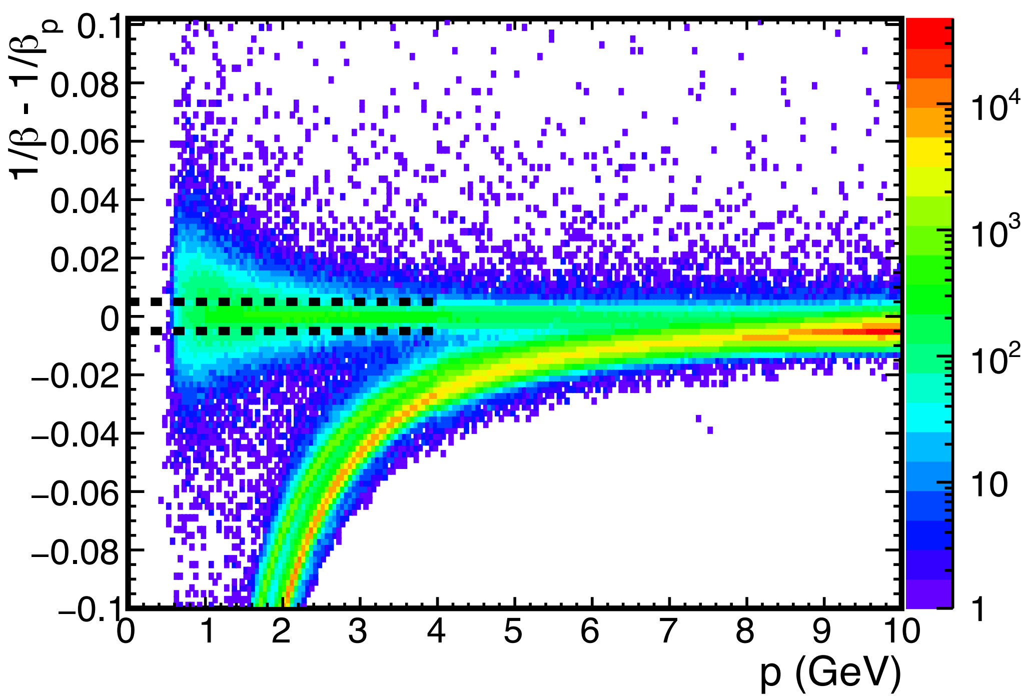


Detected scattering e

Last iteration to improve T_0







Detected scattering e

Iteration to improve T_0

EIC Detector Requirements

η	Nomenclature			Tracking			Electrons		π/K/p PID		HCAL	Muons
				Resolution	Allowed X/X_0	Si-Vertex	Resolution σ_E/E	PID	p-Range (GeV/c)	Separation	Resolution σ_E/E	
-6.9 — -5.8	↓ p/A	Auxiliary Detectors	low-Q^2 tagger	$\delta\theta/\theta < 1.5\%$; $10^{-6} < Q^2 < 10^{-2}$ GeV^2								
…												
-4.5 — -4.0			Instrumentation to separate charged particles from photons				2%/√E					
-4.0 — -3.5												
-3.5 — -3.0		Central Detector	Backwards Detectors	$\sigma_p/p \sim 0.1\% \times p + 2.0\%$	~5% or less	TBD		π suppression up to 1:10⁴	≤ 7 GeV/c	≥ 3σ	~50%/√E	
-3.0 — -2.5												
-2.5 — -2.0				$\sigma_p/p \sim 0.05\% \times p + 1.0\%$								
-2.0 — -1.5							7%/√E					
-1.5 — -1.0												
-1.0 — -0.5			Barrel	$\sigma_p/p \sim 0.05\% \times p + 0.5\%$		$\sigma_{xyz} \sim 20$ μm, $d_0(z) \sim d_0(r\phi) \sim 20/p_T$ GeV μm + 5 μm	(10-12)%/√E		≤ 5 GeV/c		TBD	TBD
-0.5 — 0.0												
0.0 — 0.5												
0.5 — 1.0												
1.0 — 1.5			Forward Detectors	$\sigma_p/p \sim 0.05\% \times p + 1.0\%$		TBD			≤ 8 GeV/c		~50%/√E	
1.5 — 2.0												
2.0 — 2.5									≤ 20 GeV/c			
2.5 — 3.0				$\sigma_p/p \sim 0.1\% \times p + 2.0\%$								
3.0 — 3.5									≤ 45 GeV/c			
3.5 — 4.0	↑e	Auxiliary Detectors	Instrumentation to separate charged particles from photons									
4.0 — 4.5												
…												
> 6.2			Proton Spectrometer	$\sigma_{intrinsic}(\|t\|)/\|t\| < 1\%$; Acceptance: $0.2 < p_T < 1.2$ GeV/c								

Table 2: Physics requirements for a an EIC detector

EIC Detector Requirements and R&D Handbook