Status of e/p separation studies using LSU HPC data

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- **Goal:** To demonstrate that CALET can measure electrons and reject protons with high efficiency using Epics-based simulation of CALET CAD model.
- **Compare:** Epics-based results to FLUKA-based results reported by Paolo Maestro at the 2014 TIM in Tokyo.
- **Procedure (with input from Alex Moiseev):** Develop further selection criteria, eventually determining the probability that a proton of energy E will be recorded as an electron with energy E'. Need to have the the probability of accepting a proton event in the electron sample to be small, eg $< 10^{-5}$.
- **Presenting current status of the analysis at GSFC.**

LSU HPC Data Set

CALET Epics Configuration:

- Epics9.161, Cosmos7.644, CALET CAD Model Rev 15.
- Dpmjet3 hadronic interation model.
- Events thrown over partial sphere up to 110° zenith angle.
- All thrown events recorded, no pre-selection. Allows for complete data set.
- Events generated in decades of energy, E^{-1} spectra.

Energy Bin	Protons Thrown	Electrons Thrown	Analyzed here
10 – 100 GeV	6.1e6	4e6	
100 – 1000 GeV	43.0e6	4e6	p 7e6; e 0.5e6
1 – 10 TeV	43.0e6	4e6	p 6e6; e 0.5e6
10 – 30 TeV		1e6	
10 – 100 TeV	27.9e6		
100 – 1000 TeV	0.6e6		

Event Selection

As a starting point, use Paolo's selection criteria he used for the FLUKA-based analysis he presented at the last CALET TIM (see Slides--maestro-ep_discrimination_fluka.pdf).

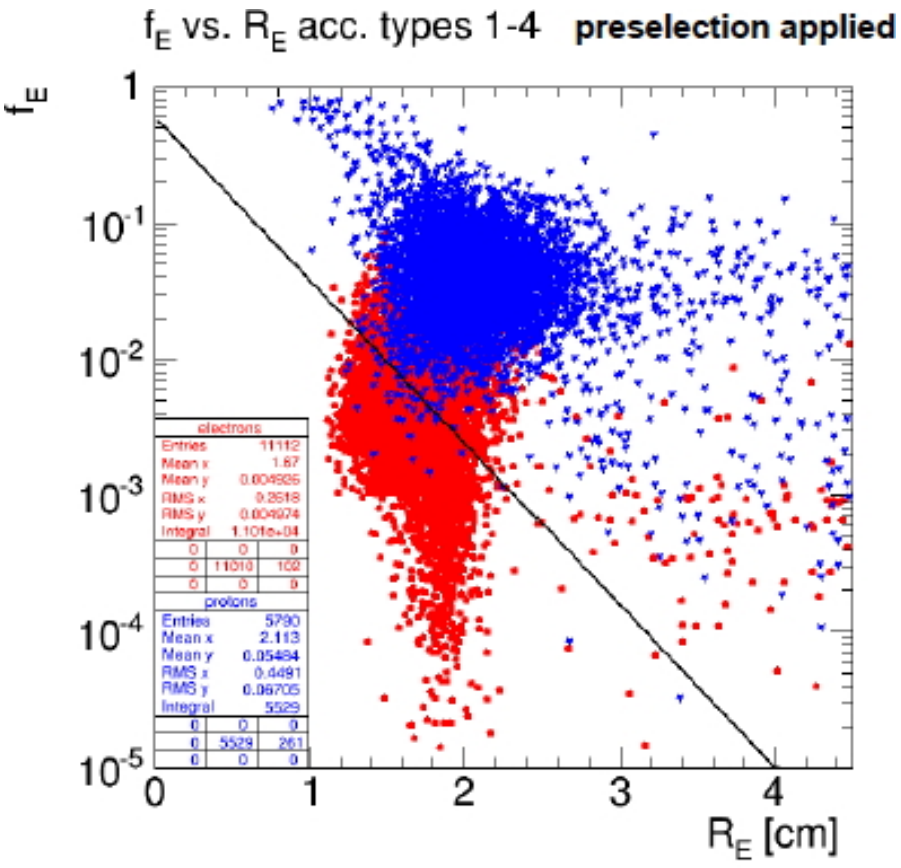
Selection Cuts:

1. Event types 1-4, using MC tracking for now.
2. HE trigger: TASC1 ≥ 55 MIP & IMC8xy ≥ 15 MIP
3. Selection based upon Fraction of Energy in last hit TASC layer (f_E) vs Energy Weighted Spread in TASC (R_E).
4. Fraction of energy deposited in the last IMC layer within 1 Moliere radius (E1MR / EIMC).
5. Fit of the longitudinal profile in IMC (*not implemented yet at GSFC*).

Summary of Paolo's FLUKA Results I

Particle	Energy range (GeV)	No. events
Electrons	20-2000	5.8×10^5
Protons	10^3-10^5	8.3×10^5

912 GeV ≤ E_{TASC} ≤ 1000 GeV



After this cut, 31 protons survive

$f_E = E_{exit}/E_{TASC}$

$$R_E = \sqrt{\frac{\sum_i (\sum_j \Delta E_{i,j} \times R_i^2)}{\sum_i \sum_j \Delta E_{i,j}}}$$

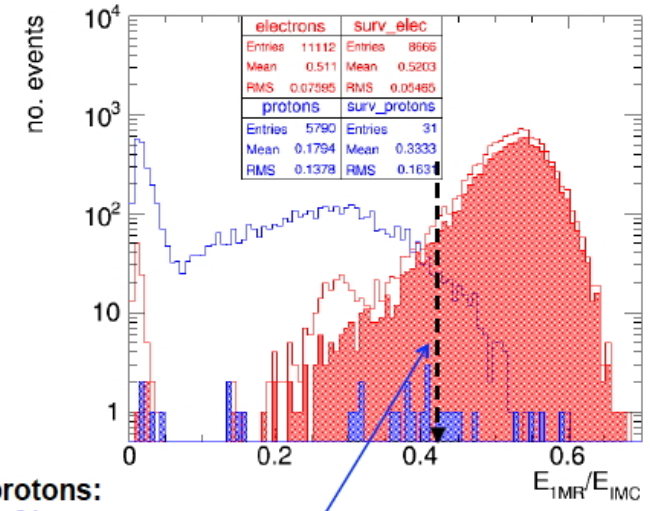
$$R_i = \sqrt{\frac{\sum_j (\Delta E_{i,j} \times (x_{i,j} - x_{i,c})^2)}{\sum_j \Delta E_{i,j}}}$$

i layer # 0,…,11 j log # 0,…,15
ΔEij energy deposit in log j layer i
xi,j coordinate of log j in layer i
xi,c intercept of shower axis with layer i

Summary of Paolo's FLUKA Results II

912 GeV ≤ E_{TASC} ≤ 1000 GeV

Fraction of energy in IMC



surviving protons:
f_E vs. R_E cut 31
&& IMC cut 9

Fraction of energy deposited in the last IMC layer within 1 Moliere radius (~9 fibers)
$E_{1MR} / E_{IMC} > 0.43$

Selection cut	Protons	Electrons
In MC acceptance	829561	11588
In TASC E bin	12956	11588
HET	6092	11588
IMC tracking	5790	11112
f_E vs R_E	31	8666
IMC 1RM cut	9	8177
IMC profile fit	6	8174

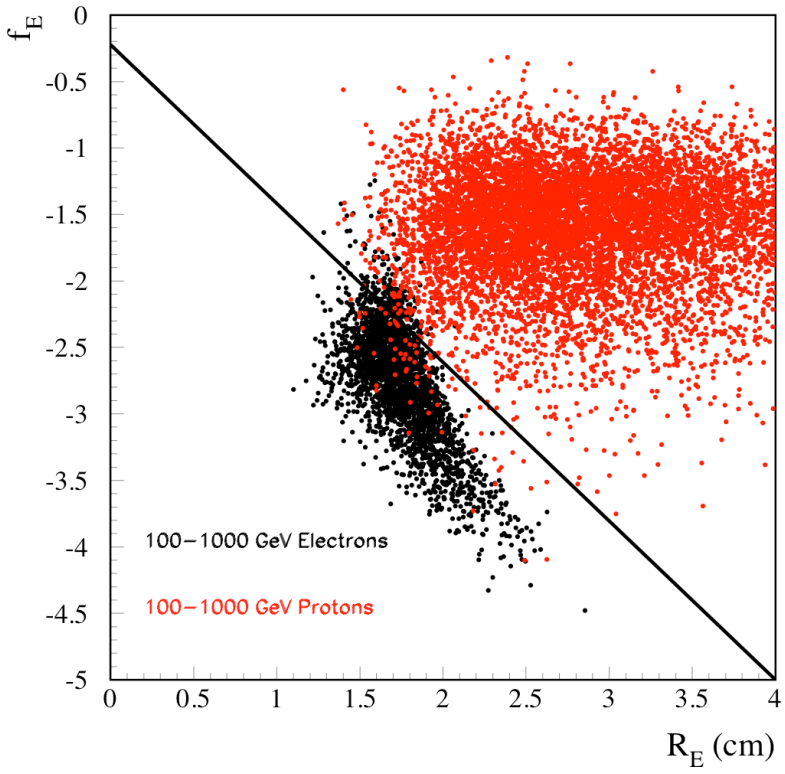
$\varepsilon_p = 7.2\times10^{-6}$ $\varepsilon_{ele} = 0.705$

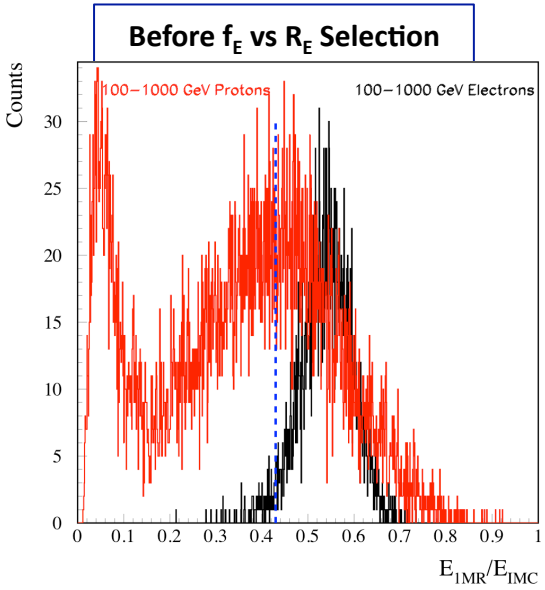
$R = \varepsilon_{ele}/\varepsilon_p \sim 9.75\times10^4$

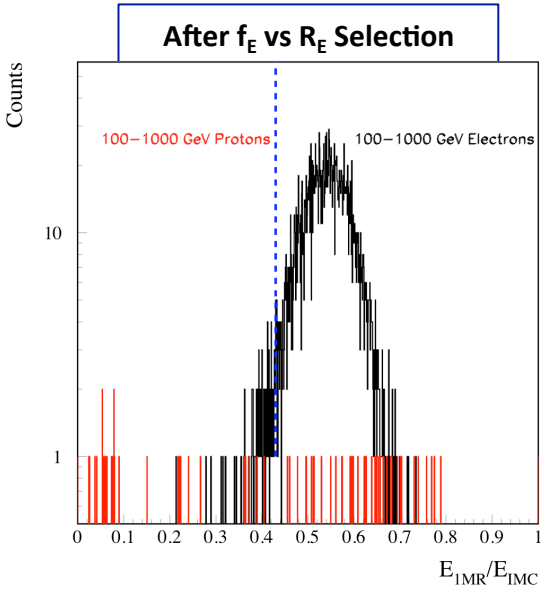
ε_P = 1.1e-5 ε_e = 0.706

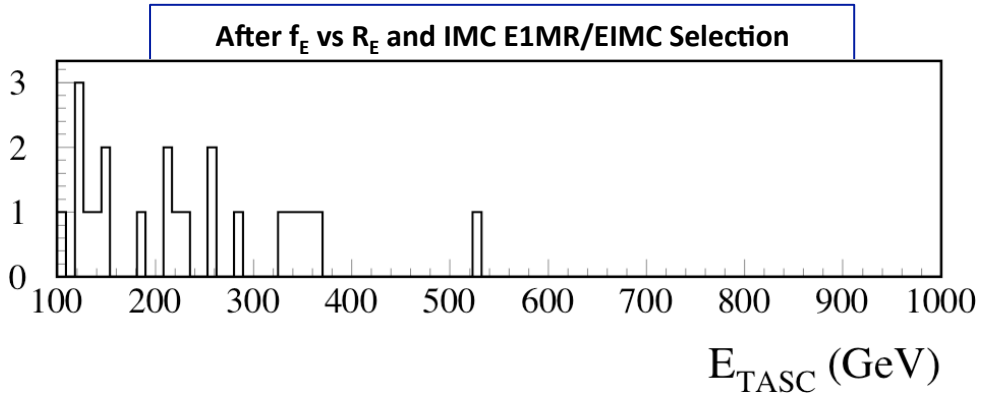
Epics-based Results

100 – 1000 GeV Protons
100 – 1000 GeV Electrons









Selection Flow

100 – 1000 GeV Protons
100 – 1000 GeV Electrons

Selection Cut	Protons 100 – 1000 GeV	Electrons 100 – 1000 GeV
Thrown Events	7,001,600	500,224
Type 1 - 4	40,602	2839
+ HET	10,148 (ε_P= 0.250)	2839 (ε_e= 1.0)
+ f_E vs R_E selection	67 (ε_P= 1.7E-3)	2629 (ε_e= 0.93)
+ E1MR / EIMC selection	32 (ε_P= 7.9E-4)	2532 (ε_e= 0.89)
Comments	18 events < 100 GeV not considered in this table	

In 100 – 1000 GeV electron band:

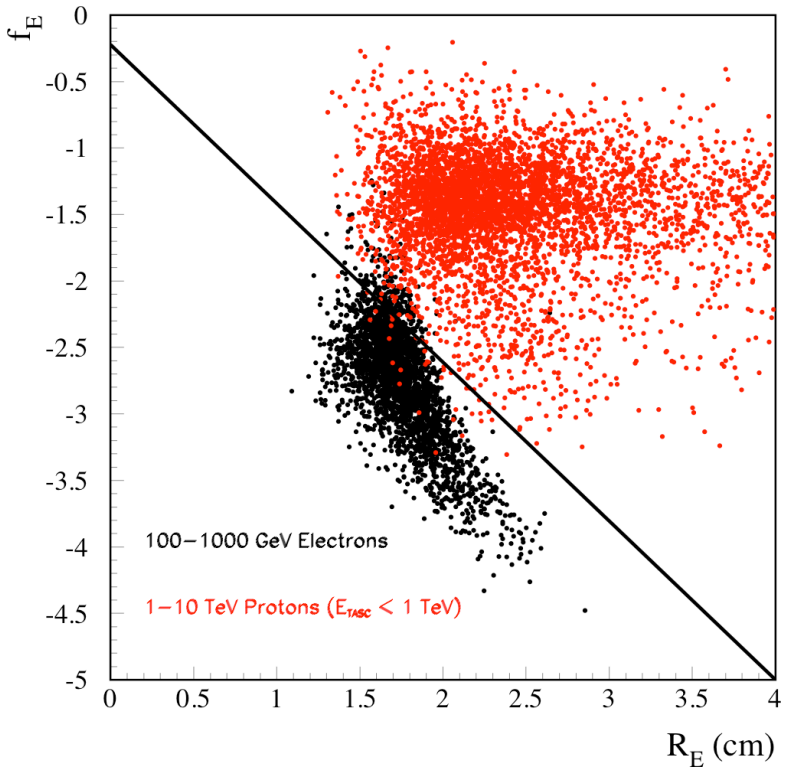
- Proton rejection factor: $\varepsilon_e/\varepsilon_P$ = 1.1e3
- Mizuno Flux Ratio: $\Phi_P/\Phi_{e\pm}$ = 362 ➔ 33% proton contamination in 100 – 1000 GeV electron range from 100 – 1000 GeV protons

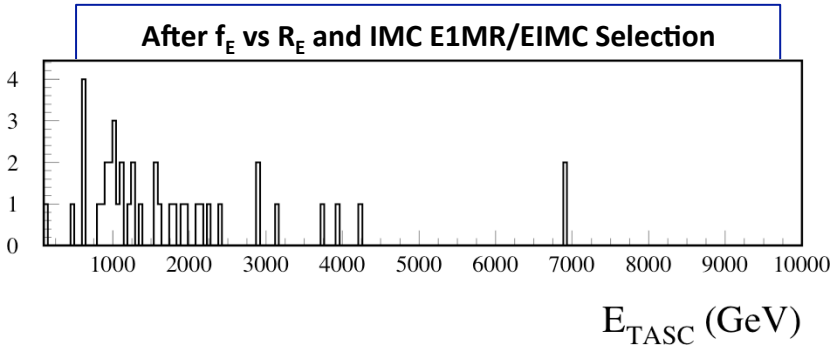
Mizuno Reference: ApJ 614, 2004

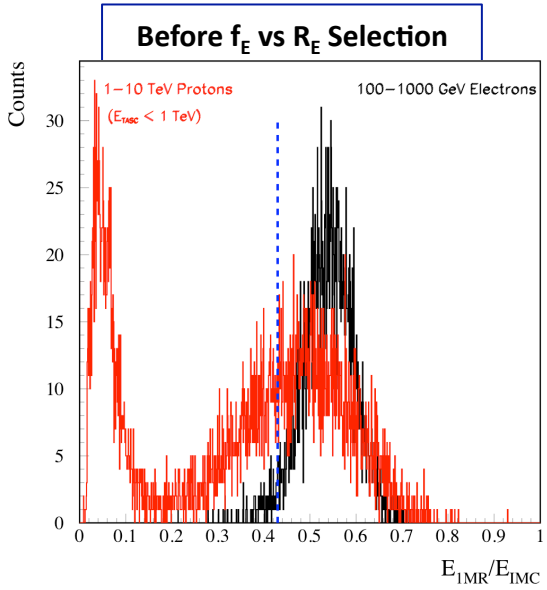
Proton Flux: $\phi_p(E) \sim E^{-2.83}$ $e^{\pm}$ Flux: $\phi_{e\pm}(E) \sim E^{-3.3}$

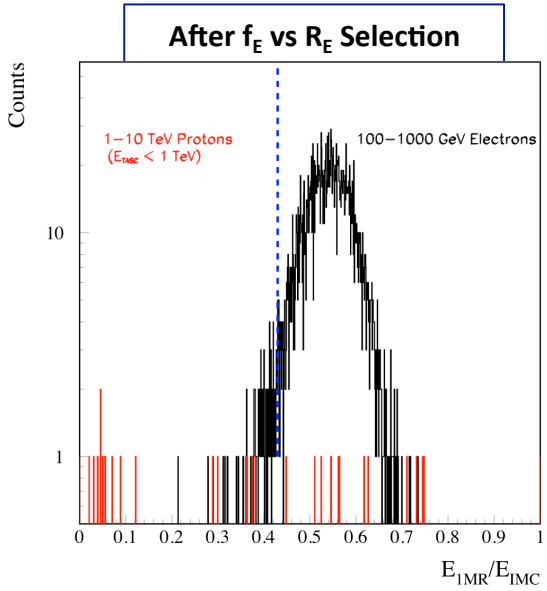
Epics-based Results

1 – 10 TeV Protons
100 – 1000 GeV Electrons









Selection Flow

1 – 10 TeV Protons
100 – 1000 GeV Electrons

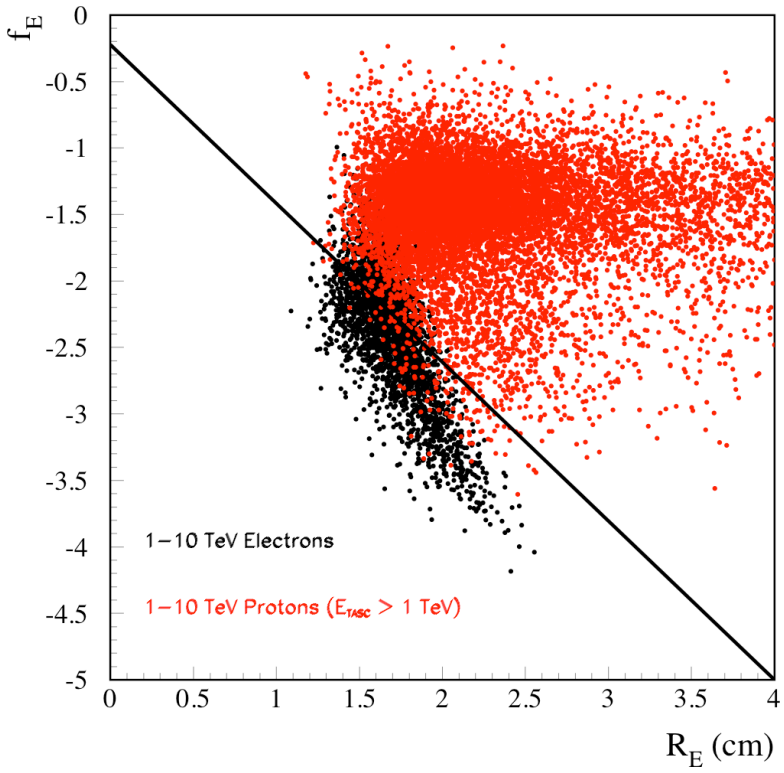
Selection Cut	Protons 1 – 10 TeV	Electrons 100 – 1000 GeV
Thrown Events	6,002,688	500,224
Type 1 - 4	34,886	2839
+ HET	11,403 (ε_P= 0.337)	2839 (ε_e= 1.0)
+ E_{TASC} < 1 TeV	5,216	2839
+ f_E vs R_E selection	32 (ε_P= 9.2e-4)	2629 (ε_e= 0.93)
+ E1MR / EIMC selection	14 (ε_P= 4.0E-4)	2532 (ε_e= 0.89)
+ 900 ≤ E_{TASC} < 1 TeV	**4 (ε_P= 1.1e-4)** (FLUKA 1.1e-5)	ε_e= 0.80 (FLUKA 0.71)
Comments	1 evt < 100 GeV not considered in this table	

In 100 – 1000 GeV electron band:

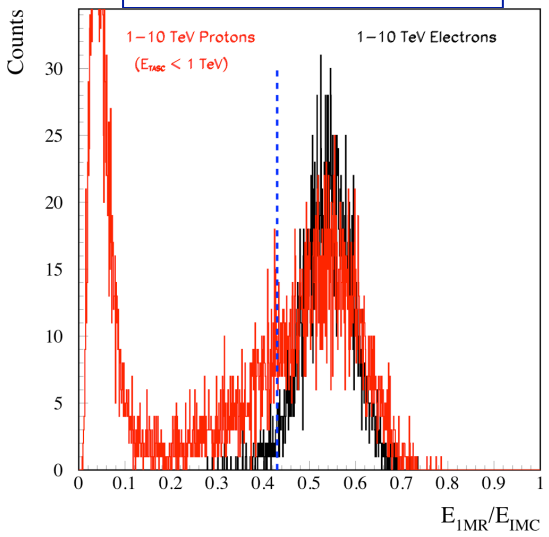
- Proton rejection factor: $\varepsilon_e/\varepsilon_P$ = 2.2e3
- Mizuno Flux Ratio: $\Phi_P/\Phi_{e\pm}$ = 6 ➔ 0.3% proton contamination in 100 – 1000 GeV electron range from 1 – 10 TeV protons.

Epics-based Results

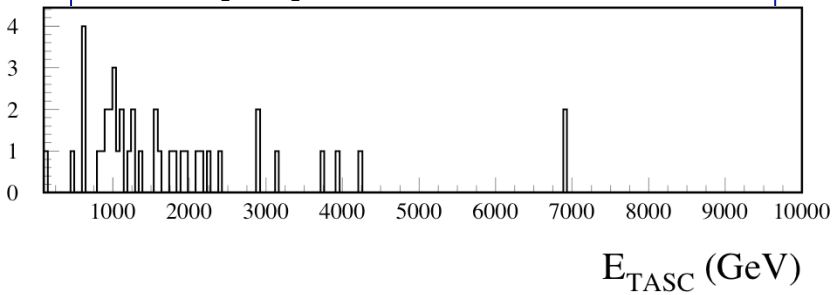
1 – 10 TeV Protons
1 – 10 TeV Electrons



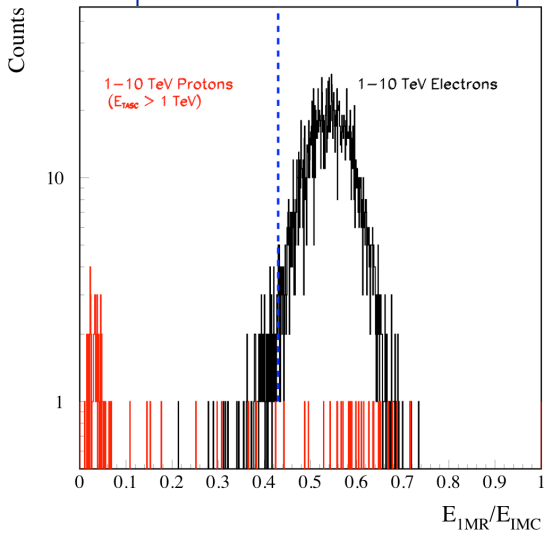
Before f_E vs R_E Selection



After f_E vs R_E and IMC E1MR/EIMC Selection



After f_E vs R_E Selection



Selection Flow

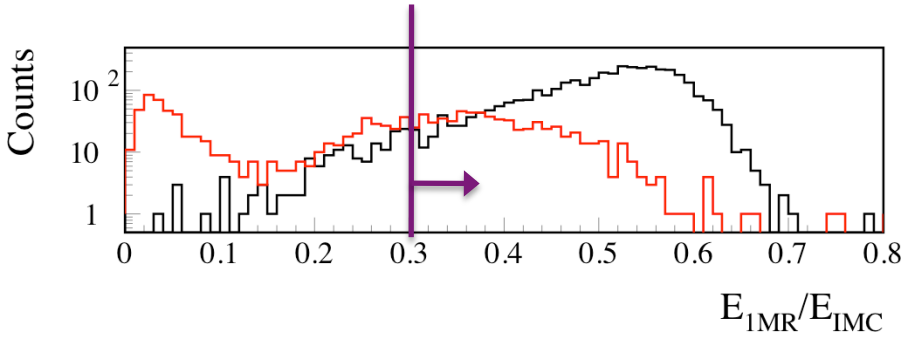
1 – 10 TeV Protons
1 – 10 TeV Electrons

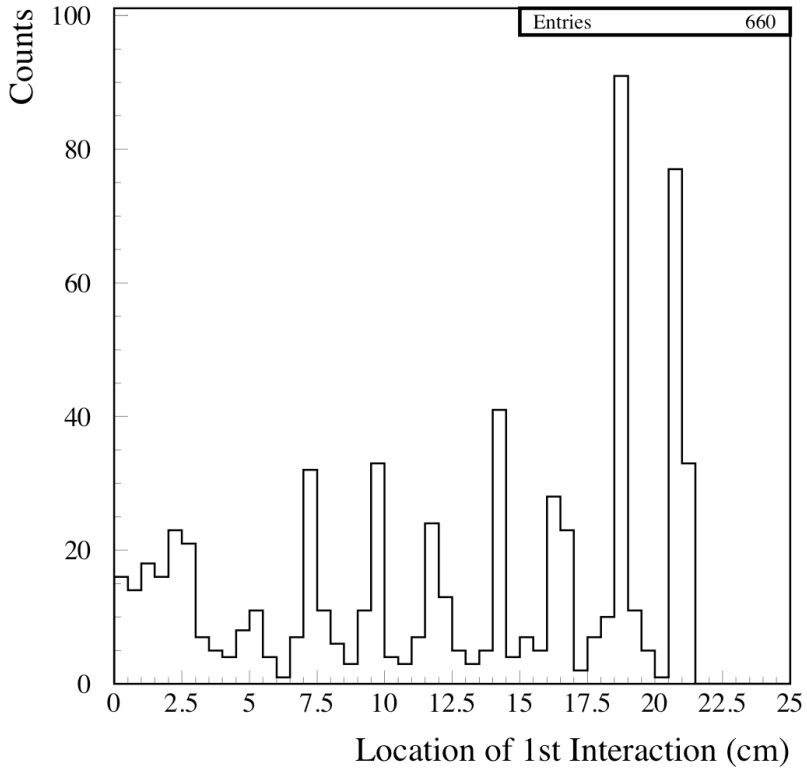
Selection Cut	Protons 1 – 10 TeV	Electrons 100 – 1000 GeV
Thrown Events	6,002,688	500,224
Type 1 - 4	34,886	2959
+ HET	11,403 (ε_P= 0.337)	2959 (ε_e= 1.0)
+ $E_{TASC} \geq 1$ TeV	6,087 (ε_P= 0.174)	2959
+ f_E vs R_E selection	97 (ε_P= 2.8E-3)	1882(ε_e= 0.636)
+ E1MR / EIMC selection	27 (ε_P= 7.7E-4)	1683 (ε_e= 0.569)
Comments	1 evt < 100 GeV	

In 100 – 1000 GeV electron band:

- Proton rejection factor: $\varepsilon_e/\varepsilon_P$ = 739
- Mizuno Flux Ratio: $\Phi_P/\Phi_{e\pm}$ = 1083 ➔ 147% proton contamination in 1 – 10 TeV electron range from 1 – 10 TeV protons.

What is causing the proton background?





1-10 TeV Biased event samples:

- Center on top of CALET (4 cm × 4 cm)
- Isotropic distribution
- E^{-1} spectra
- 10,000 events

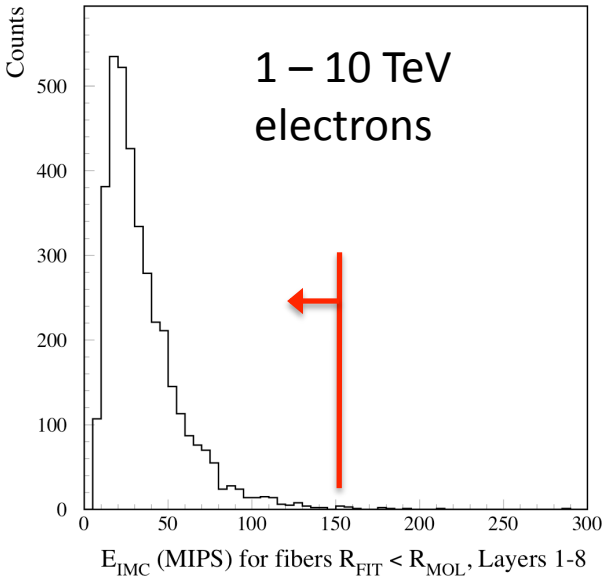
Selection:

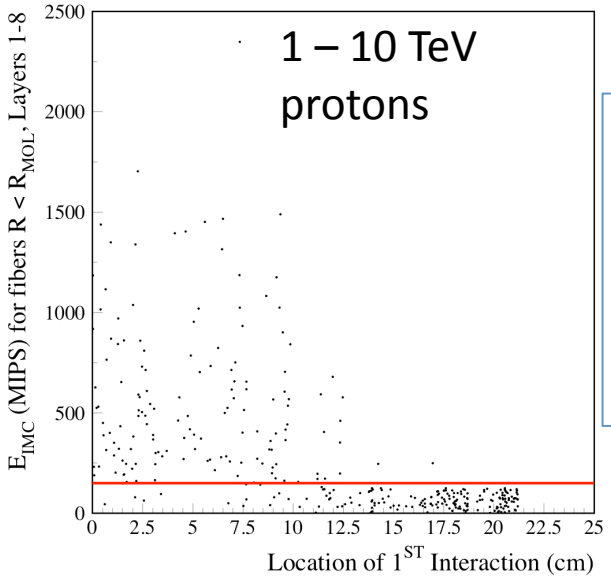
- Type 1 – 4 events
- HET trigger
- **E1MR / EIMC > 0.3**

All events have a 1st interaction in the IMC

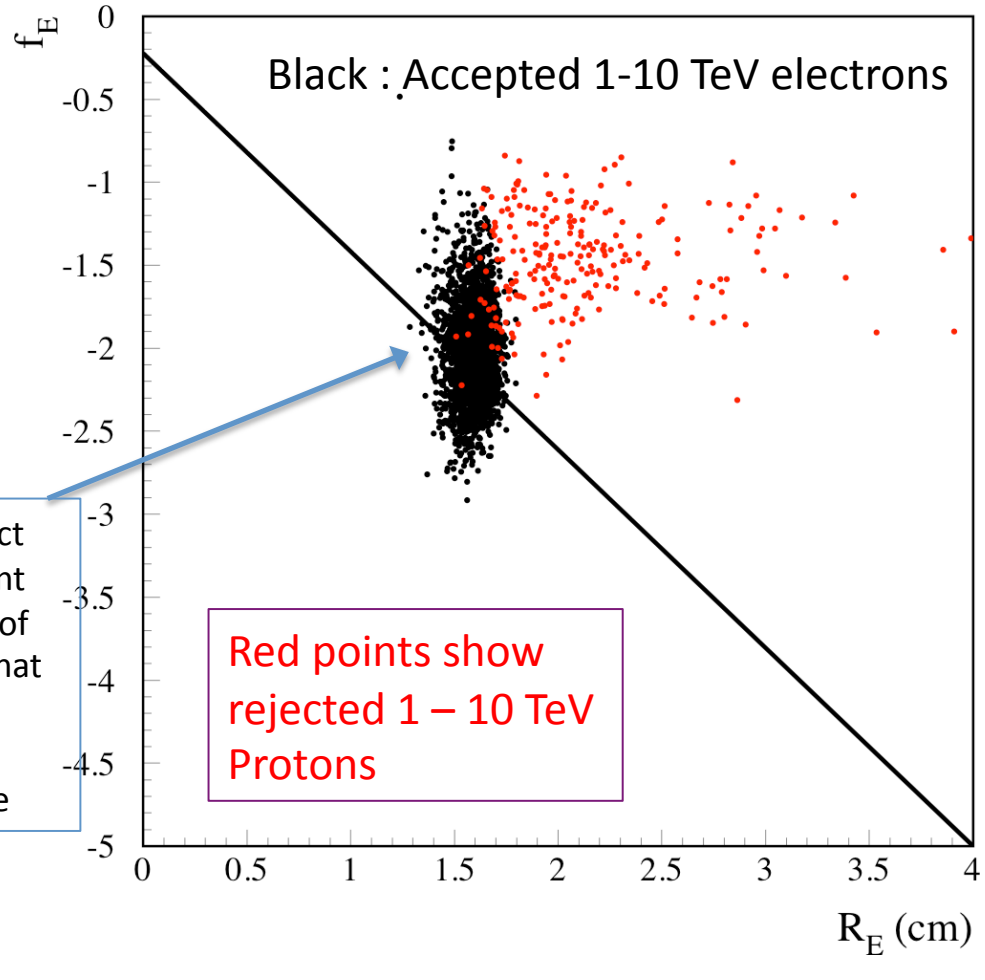
- IMC depth: 3 X_o ; $\lambda_I << 1$
- In the IMC, Electomagnetic showers are fairly well sampled… but for hadronic showers the IMC is a 'thin target'.
- can we indentify the first interaction of these events in the IMC?

E_{IMC} for fibers with $R_{FIT} < R_{MOL}$





- Assume 0.5 MIP E_{THR} for each fiber
- Sum x,y fibers in layers 1 – 8 if $R_{FIT} < R_{MOL}$ (± 9 fibers)



Can reject significant fraction of events that mimic electron response

Work in Progress

Implement IMC longitudinal profile fit cut

Evaluate other IMC variables to improve proton rejection while maintaining electron acceptance, evaluate energy dependence of selection variables.

Run on entire HPC data set

Evaluate acceptance of upward-moving events