Status of e/p separation studies

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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		

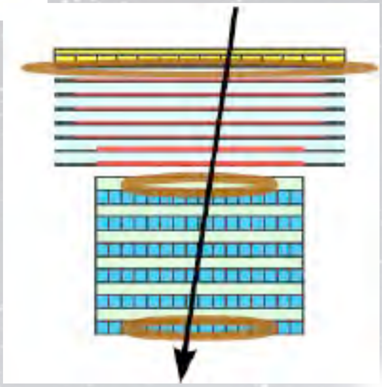
Event Selection

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:

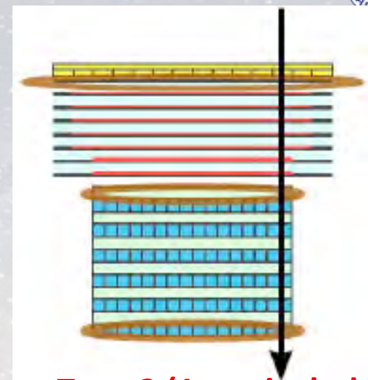
1. Event types 1-4, using MC tracking for now.
2. HE trigger: TASC1 ≥ 55 MIP & IMC8xy ≥ 15 MIP
3. Selection based upon Fraction of Energy in last hit TASC layer (f_E) vs Energy Weighted Spread in TASC (R_E).
4. Fraction of energy deposited in the last IMC layer within 1 Moliere radius (E1MR / EIMC).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

CALET Event Type Definitions

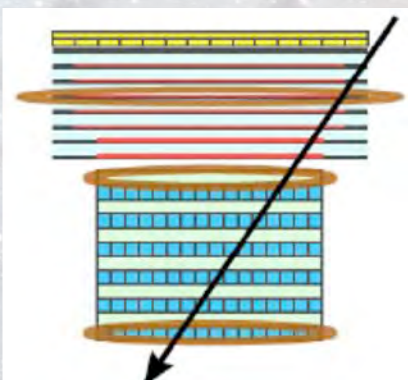


Acc. Type 1:
IMC Lay 1 Top && TASC Top (1 PWO log inside) && TASC Bottom (1 PWO log Inside)

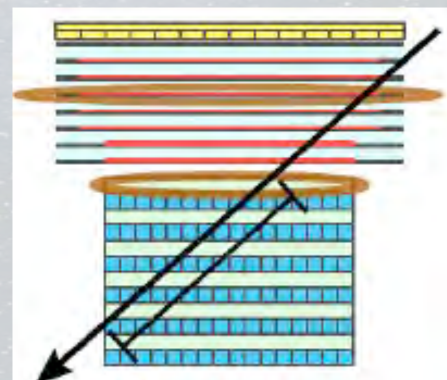
CALET CAD Model Rev 15		
Acc Type	GF (Epics) cm^2 sr	GF (Wefel) cm^2 sr
1	466.1±6.1	464.0±2.4
2	175.8±3.8	181.2±3.7
3	123.8±3.2	124.0±4.1
4	172.9±3.7	-
Total	938.6±8.7	-



Acc. Type 2 (1 not included):
IMC Lay 1 Top && TASC Top (outside PWO logs only) && TASC Bottom (outside PWO logs only)



Acc. Type 3:
NOT (Type 1 or Type 2)
IMC Lay 4 Top && TASC Top && TASC Bottom

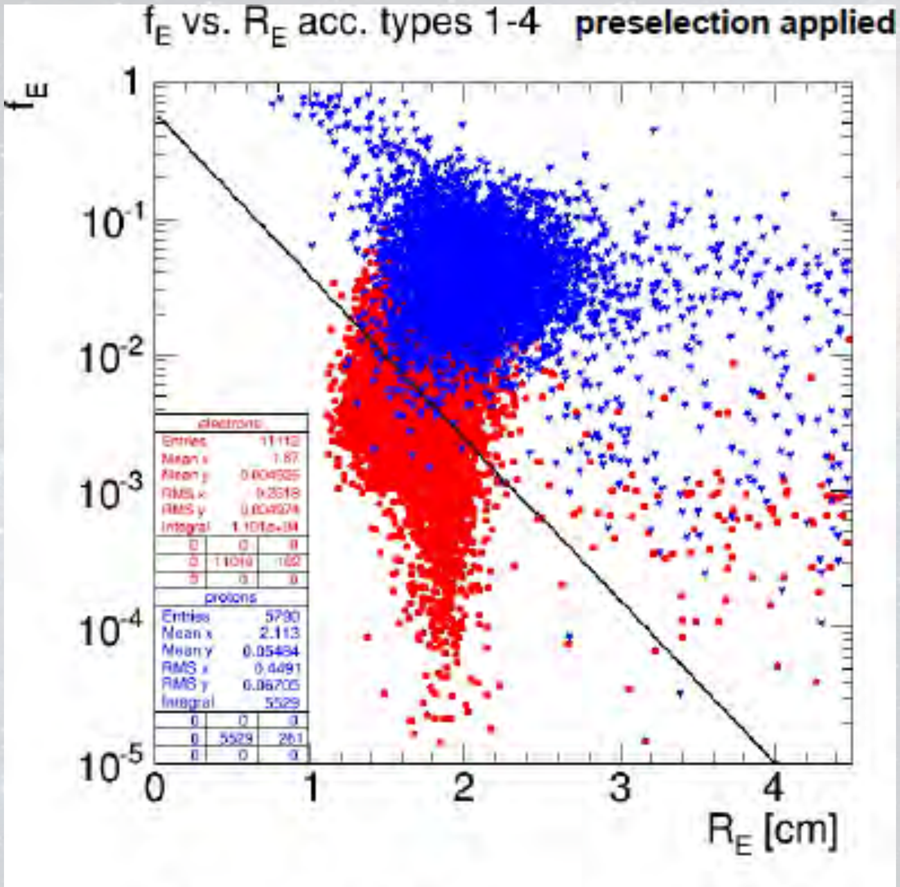


Acc. Type 4:
NOT (Type 1 or 2 or 3)
IMC Lay 4 Top && TASC Top && NOT (TASC Bottom) && TASC Length > 27 X_0

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

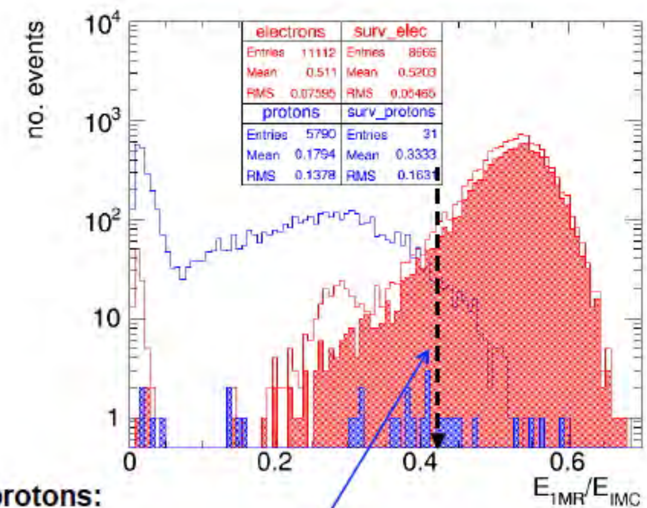
xi,j coordinate of log j in layer i

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

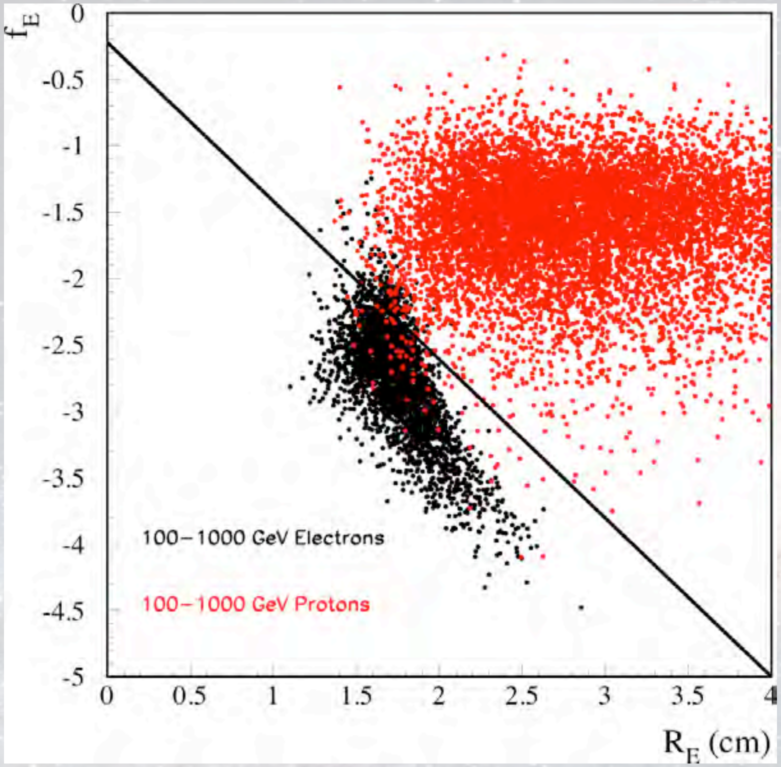
$\varepsilon_p = 7.2\times10^{-6}$ $\varepsilon_{ele} = 0.705$

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

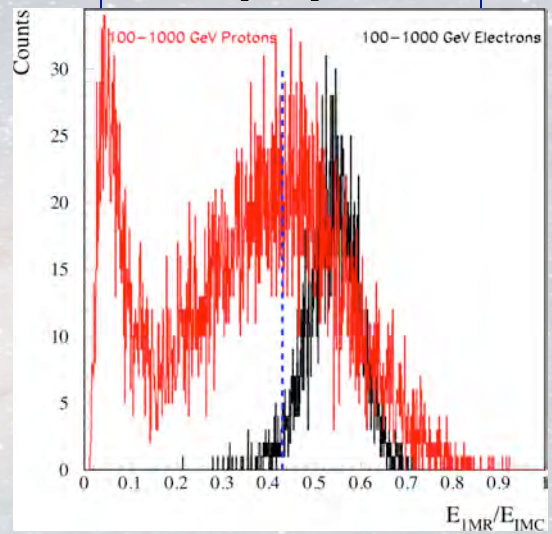
ε_P = 1.1e-5 ε_e = 0.706

Epics-based Results

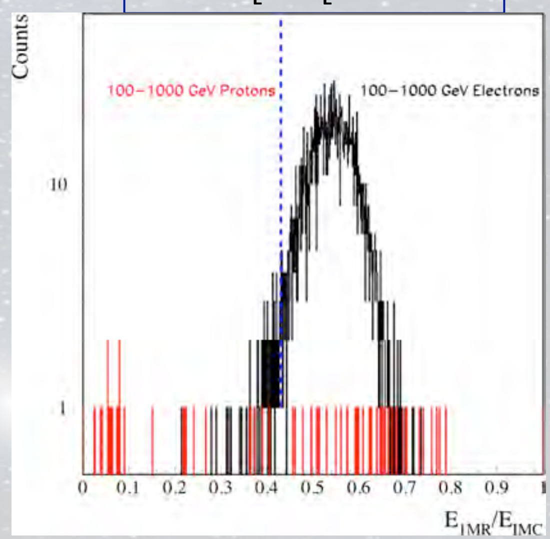
100 – 1000 GeV Protons
100 – 1000 GeV Electrons



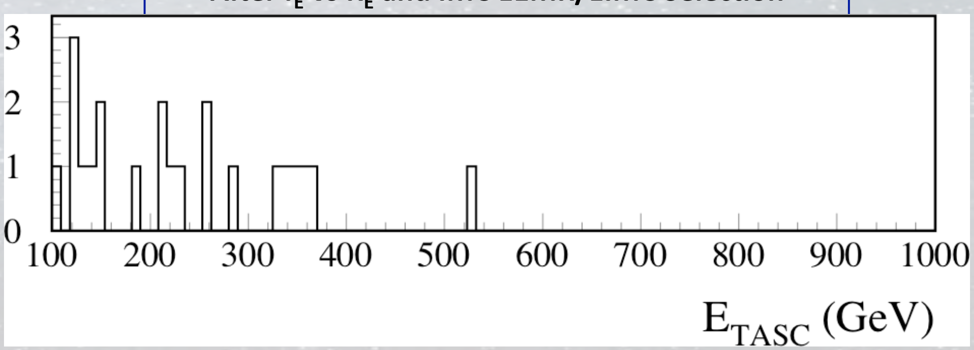
Before f_E vs R_E Selection



After f_E vs R_E Selection



After f_E vs R_E and IMC E1MR/EIMC Selection



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	

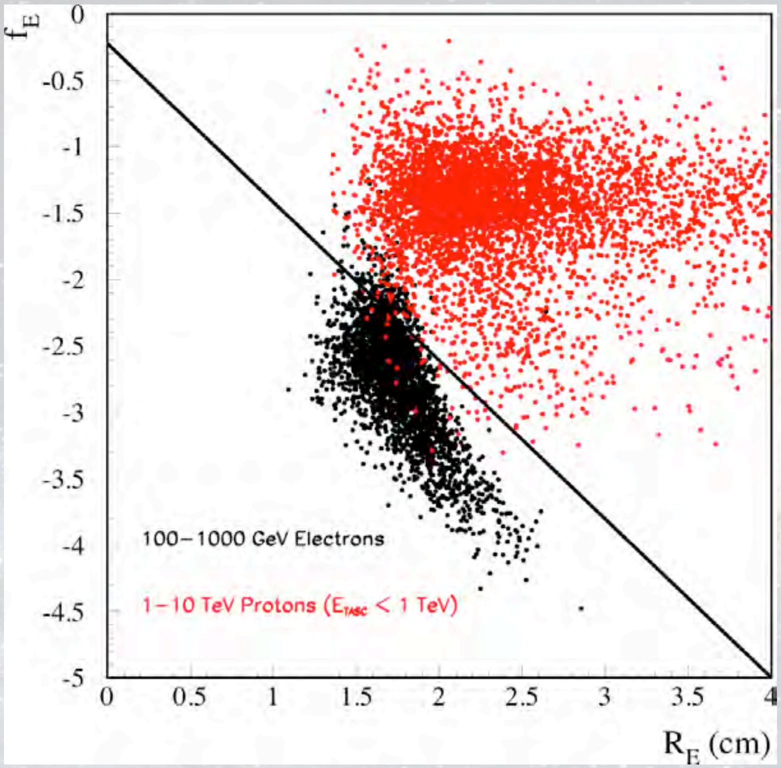
In 100 – 1000 GeV electron band:
- Proton rejection factor: $\varepsilon_e/\varepsilon_P$ = 1.1e3
- Mizuno Flux Ratio: $\Phi_P/\Phi_{e\pm}$ = 362 ➔ 33% proton contamination in 100 – 1000 GeV electron range from 100 – 1000 GeV protons

Mizuno Reference: ApJ 614, 2004

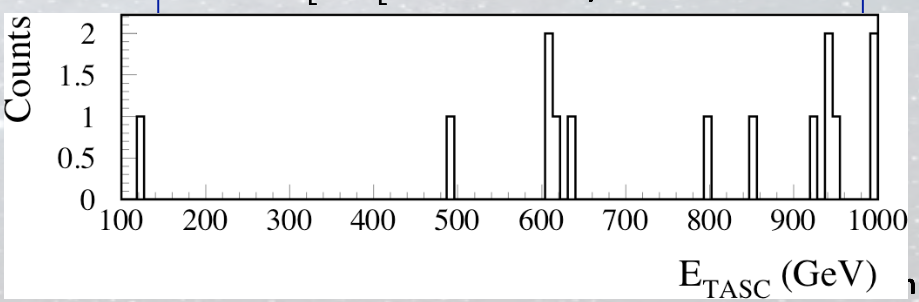
Proton Flux: $\phi_p(E) \sim E^{-2.83}$ e± Flux: $\phi_{e\pm}(E) \sim E^{-3.3}$

Epics-based Results

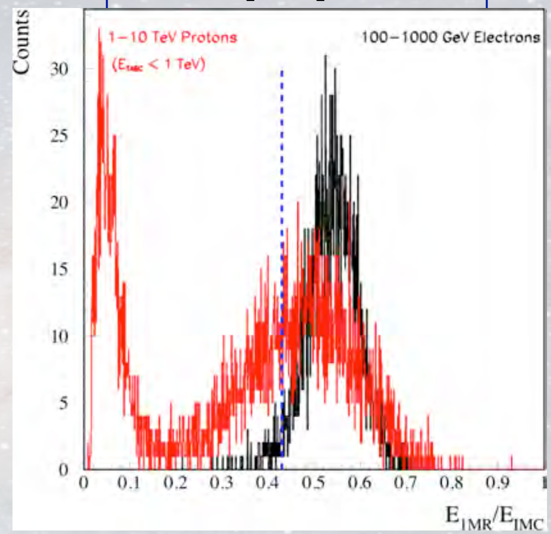
1 – 10 TeV Protons
100 – 1000 GeV Electrons



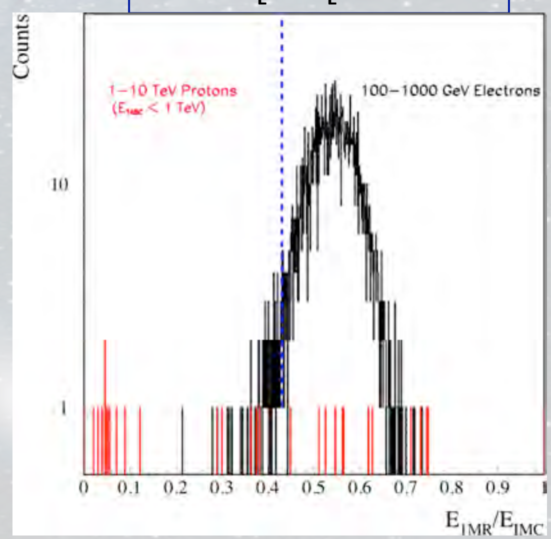
After f_E vs R_E and IMC E1MR/EIMC Selection



Before f_E vs R_E Selection



After f_E vs R_E Selection



Selection Flow

1 – 10 TeV Protons
100 – 1000 GeV Electrons

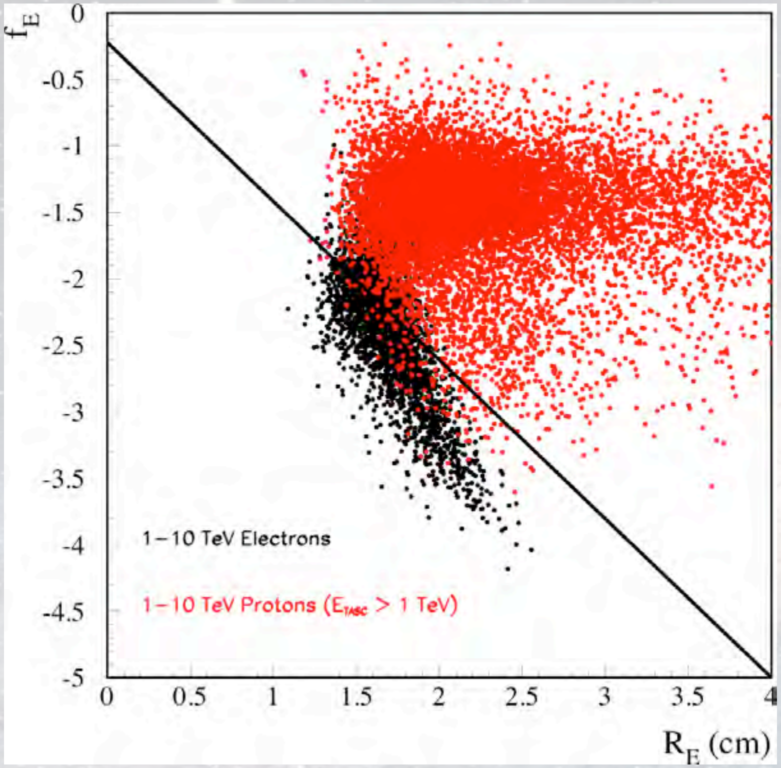
Selection Cut	Protons 1 – 10 TeV	Electrons 100 – 1000 GeV
Thrown Events	6,002,688	500,224
Type 1 - 4	34,886	2839
+ HET	11,403 (ε_P= 0.337)	2839 (ε_e= 1.0)
+ E_{TASC} < 1 TeV	5,216	2839
+ f_E vs R_E selection	32 (ε_P= 9.2e-4)	2629 (ε_e= 0.93)
+ E1MR / EIMC selection	14 (ε_P= 4.0E-4)	2532 (ε_e= 0.89)
+ 912 ≤ E_{TASC} < 1 TeV	**6 (ε_P= 1.7e-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:

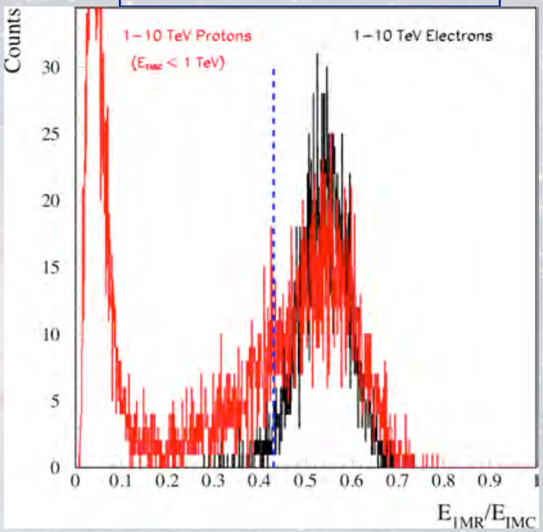
- Proton rejection factor: $\varepsilon_e/\varepsilon_P$ = 2.2e3
- Mizuno Flux Ratio: $\Phi_P/\Phi_{e\pm}$ = 6 ➔ 0.3% proton contamination in 100 – 1000 GeV electron range from 1 – 10 TeV protons.

Epics-based Results

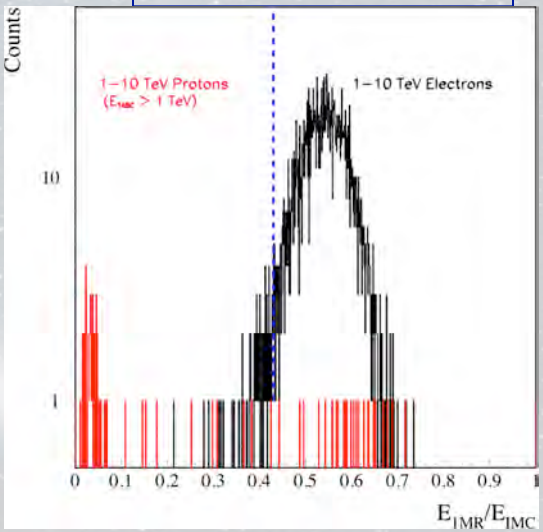
1 – 10 TeV Protons
1 – 10 TeV Electrons



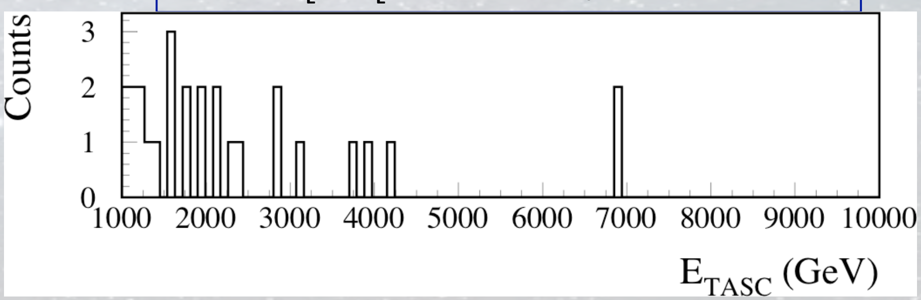
Before f_E vs R_E Selection



After f_E vs R_E Selection



After f_E vs R_E and IMC E1MR/EIMC Selection



Selection Flow

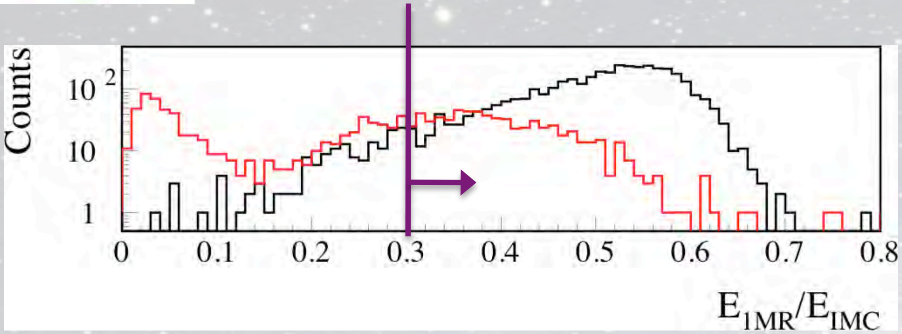
1 – 10 TeV Protons
1 – 10 TeV Electrons

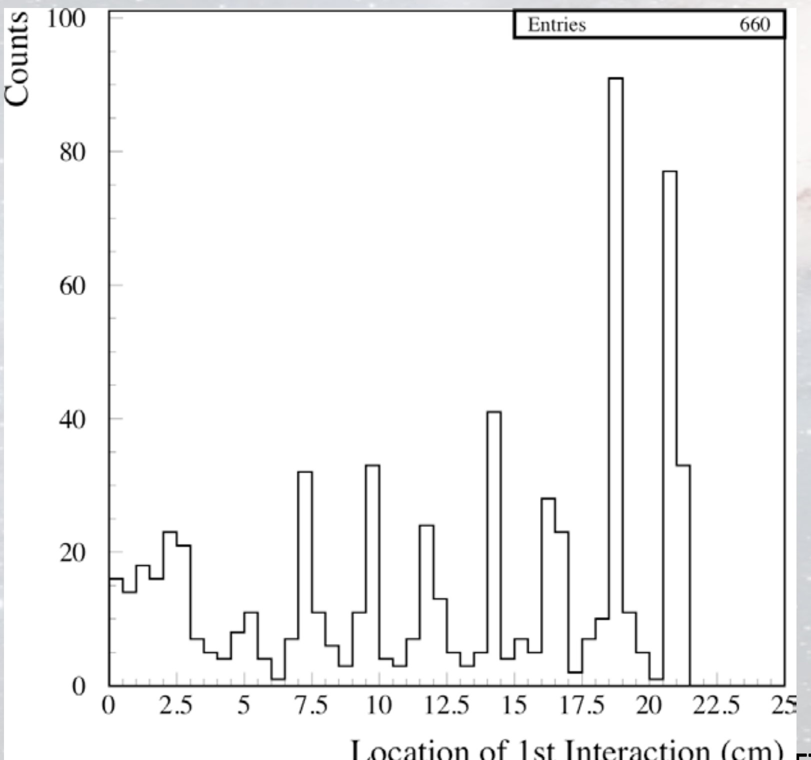
Selection Cut	Protons 1 – 10 TeV	Electrons 1 – 10 TeV
Thrown Events	6,002,688	500,224
Type 1 - 4	34,886	2959
+ HET	11,403 (ε_P= 0.337)	2959 (ε_e= 1.0)
+ $E_{TASC} \geq$ 1 TeV	6,087 (ε_P= 0.174)	2959
+ f_E vs R_E selection	97 (ε_P= 2.8E-3)	1882(ε_e= 0.636)
+ E1MR / EIMC selection	27 (ε_P= 7.7E-4)	1683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

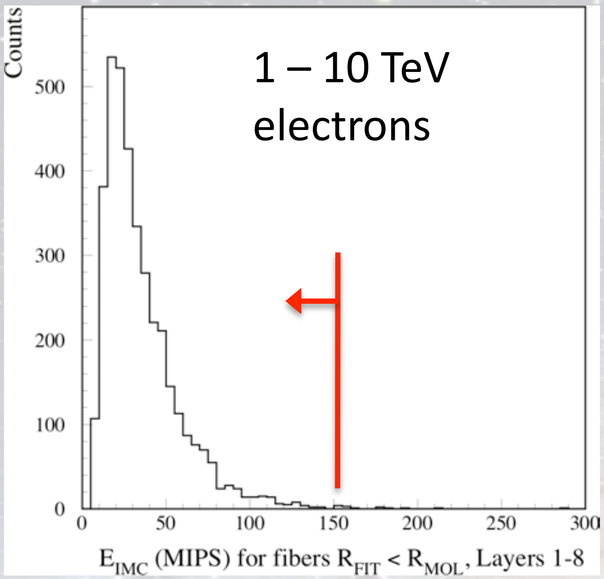
- Type 1 – 4 events
- HET trigger
- **E1MR / EIMC > 0.3**

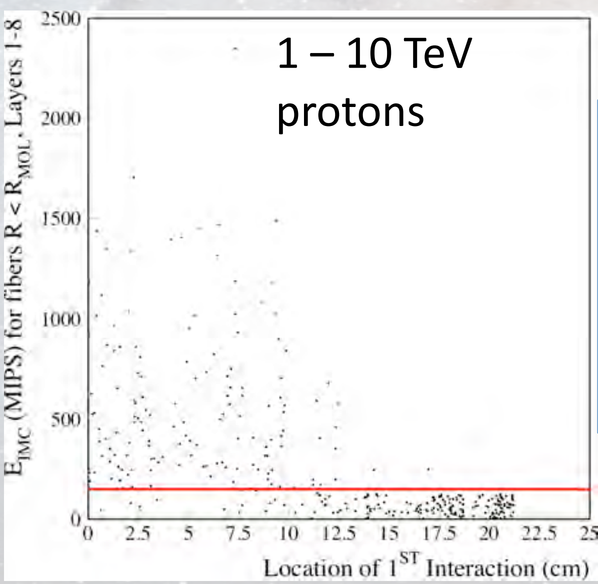
All events have a 1st interaction in the IMC

- IMC depth: 3 X_o ; λ_I ~ 0.1
- In the IMC, Electromagnetic 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?

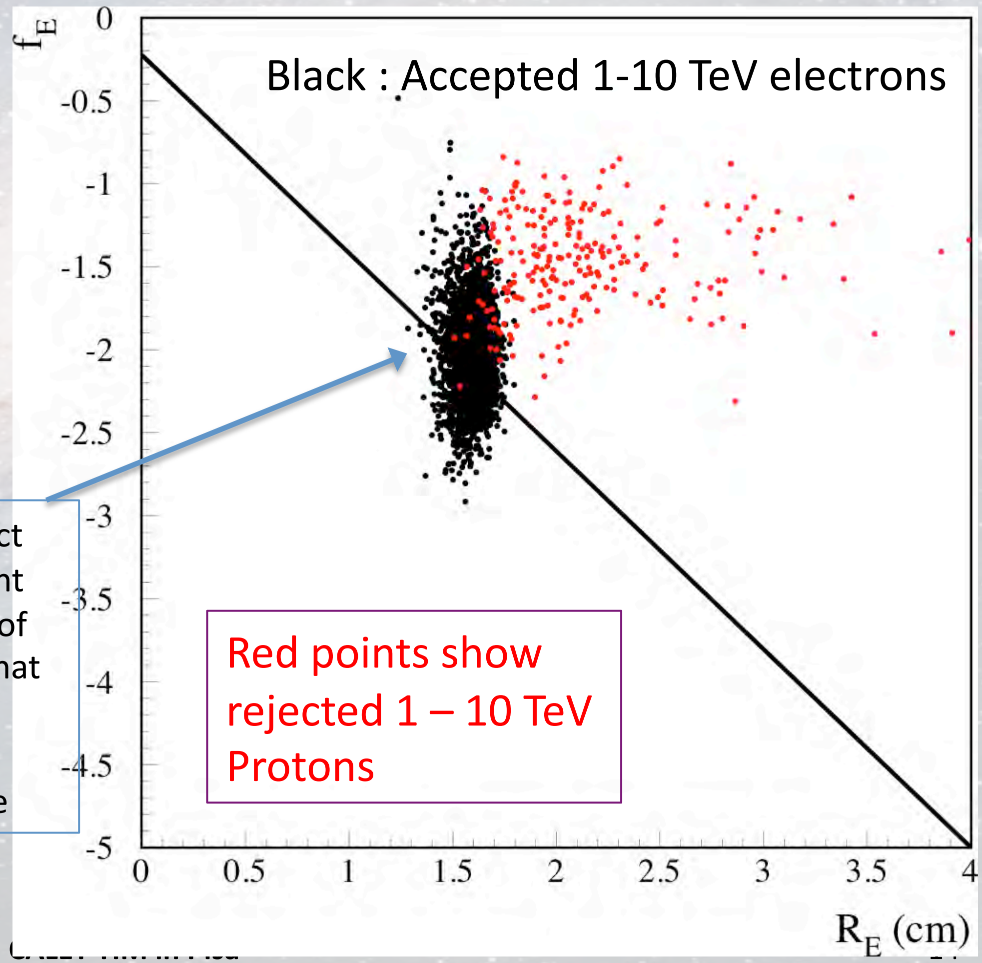
E_{IMC} for fibers with $R_{FIT} < R_{MOL}$

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



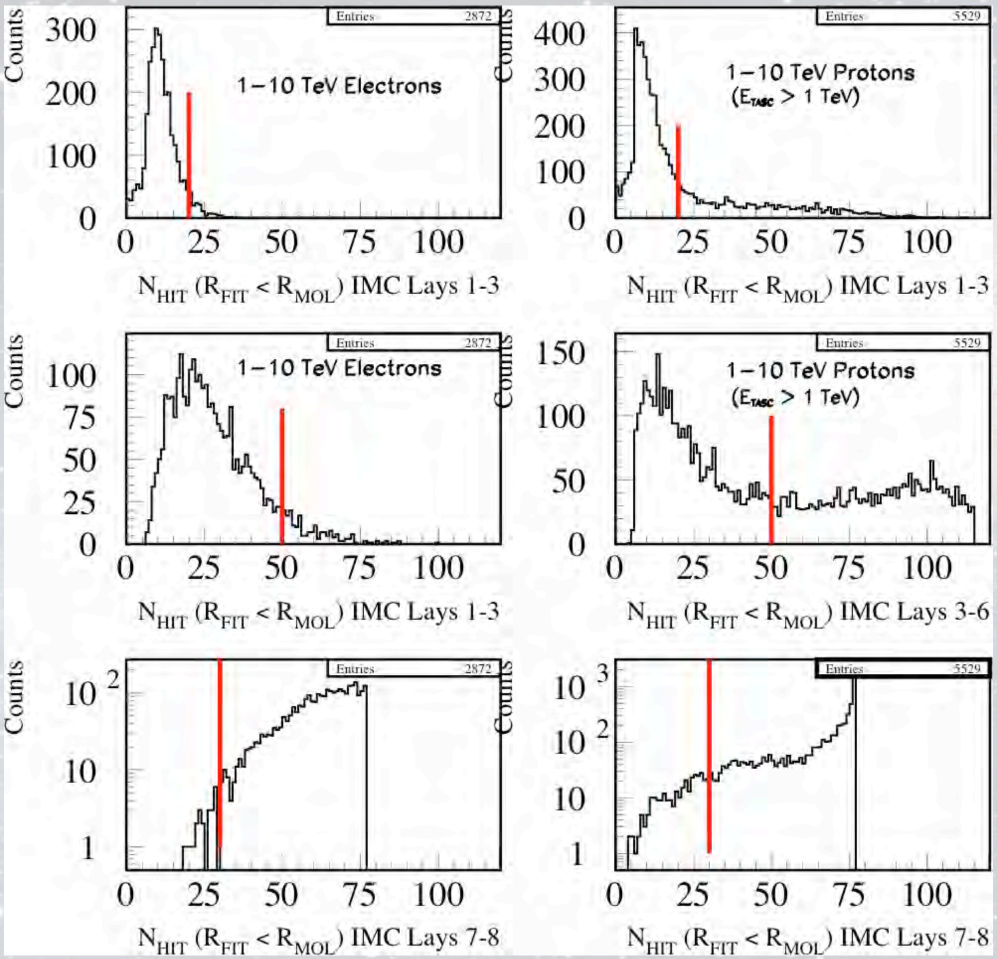


Can reject significant fraction of events that mimic electron response



IMC Hit Distributions

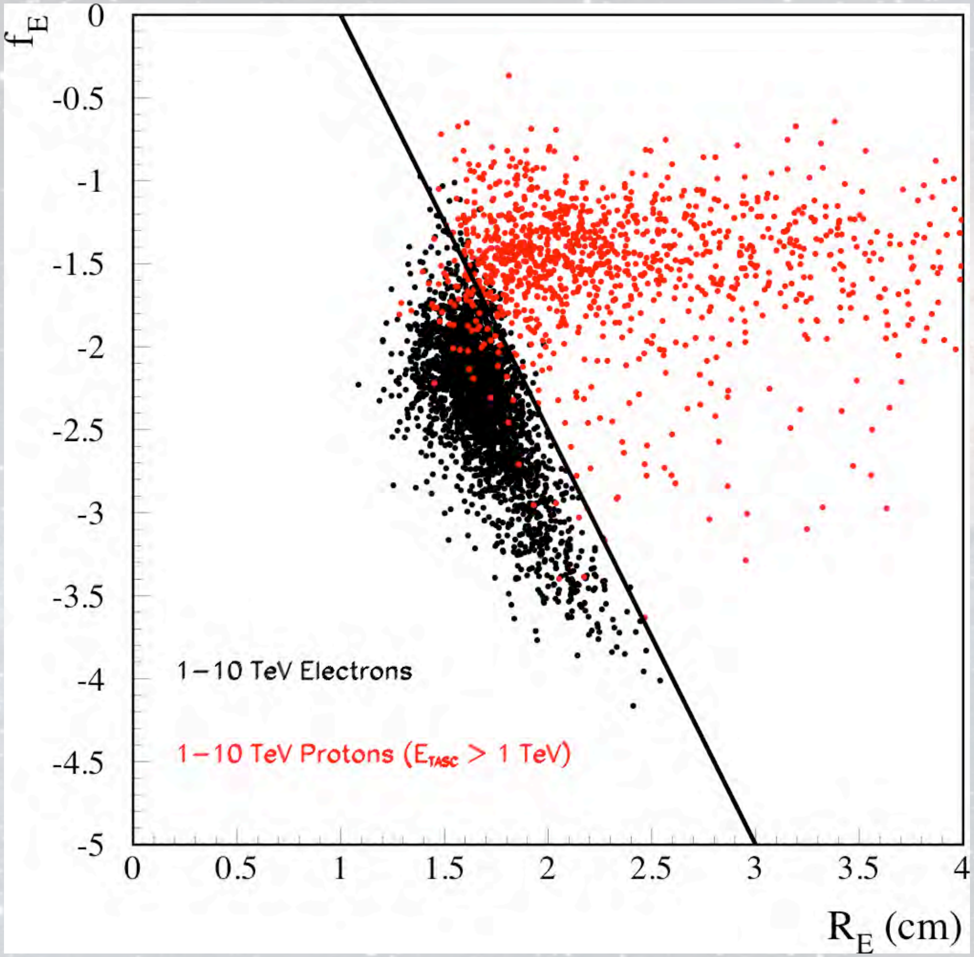
1 – 10 TeV Protons
1 – 10 TeV Electrons



- Sum energy and number of hit fibers within 1 R_{MOL} from track.
- Compare distributions of 1-10 TeV protons to 1-10 TeV electrons (HPC run data).
- Define selection criteria:
    - Σ IMC Layers 1 – 3 : $N_{HIT} < 20$
    - Σ IMC Layers 1 – 3 : $N_{HIT} < 50$
    - Σ IMC Layers 1 – 3 : $N_{HIT} > 30$

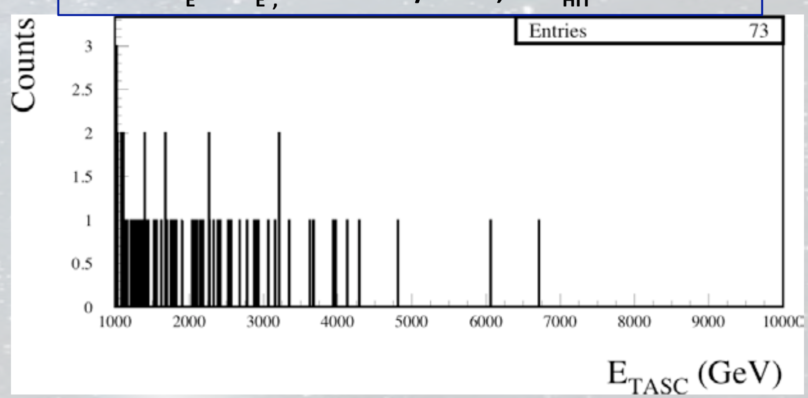
f_E vs R_E Selection

1 – 10 TeV Protons
1 – 10 TeV Electrons



- $E_{1MR}/E_{IMC} > 0.3$ & IMC hit cuts applied first
- $E_{TASC} \geq$ 1 TeV
- New definition of f_E vs R_E Selection

After f_E vs R_E , IMC E1MR/EIMC, & N_{HIT} Selection



Selection Flow

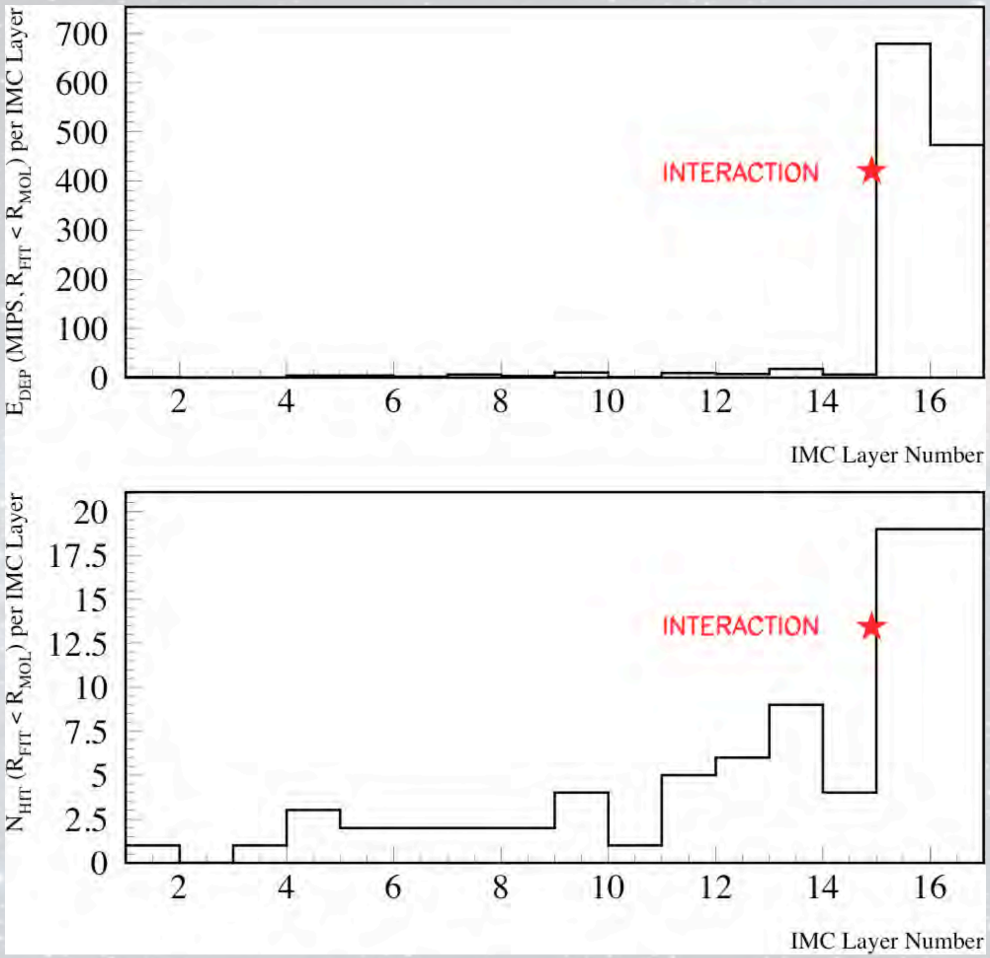
1 – 10 TeV Protons
1 – 10 TeV Electrons

Selection Cut	Protons 1 – 10 TeV	Electrons 1 – 10 TeV
Thrown Events	6,002,688	500,224
Type 1 - 4	34,886	2959
+ HET	11,403 (ε_P= 0.337)	2959 (ε_e= 1.00)
+ $E_{TASC} \geq 1$ TeV	6,085 (ε_P= 0.174)	2894 2959 (ε_e= 0.98)
+ E1MR / EIMC selection	3082 (ε_P= 8.83e-2)	2872(ε_e= 0.97)
+ IMC hit dist selection	1314 (ε_P= 3.77e-2)	2539(ε_e= 0.86)
+ f_E vs R_E selection	73 (ε_P= 2.1e-3)	2411 (ε_e= 0.81)
Comments	1 evt < 100 GeV	

In 100 – 1000 GeV electron band:

- Proton rejection factor: $\varepsilon_e/\varepsilon_P$ = 386
- Mizuno Flux Ratio: $\Phi_P/\Phi_{e\pm}$ = 1083 ➔ 281% proton contamination in 1 – 10 TeV electron range from 1 – 10 TeV protons.

IMC Profile for an accepted proton Event



- 1 – 10 TeV Proton Sample
- $E_{TASC} \geq 1$ TeV
- Top Plot: Energy per layer for fibers within 1 R_{MOL}
- Bottom Plot: Number of hit fibers per layer within 1 R_{MOL}
- **Can this be exploited to reject protons based upon this 'impulsive' response in IMC.**