e/p discrimination with EPICS simulated data

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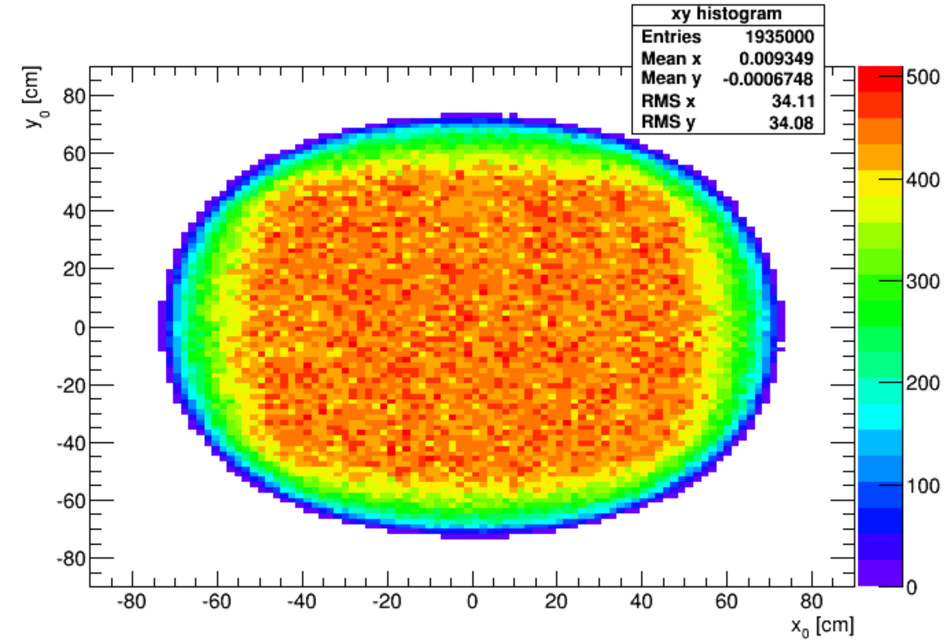
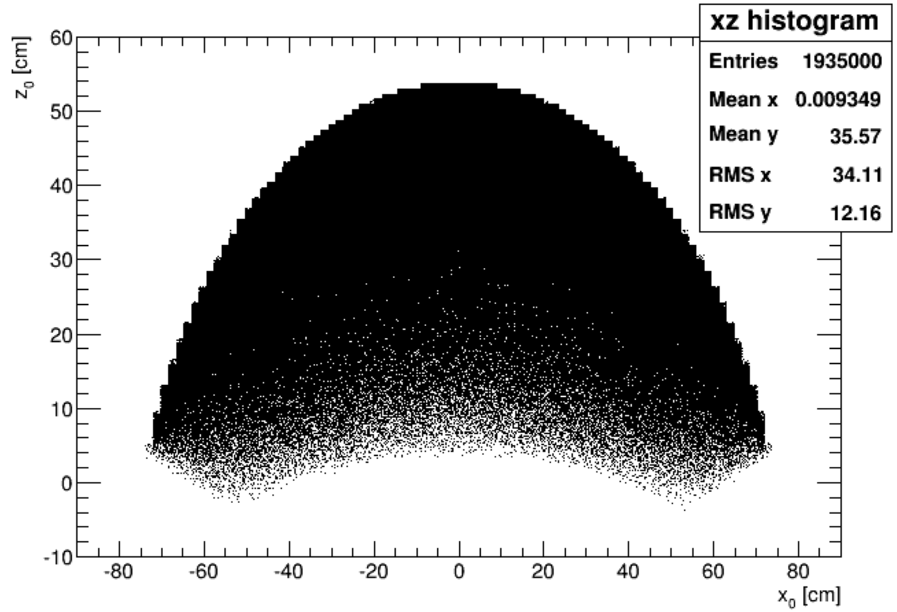
Simulation details

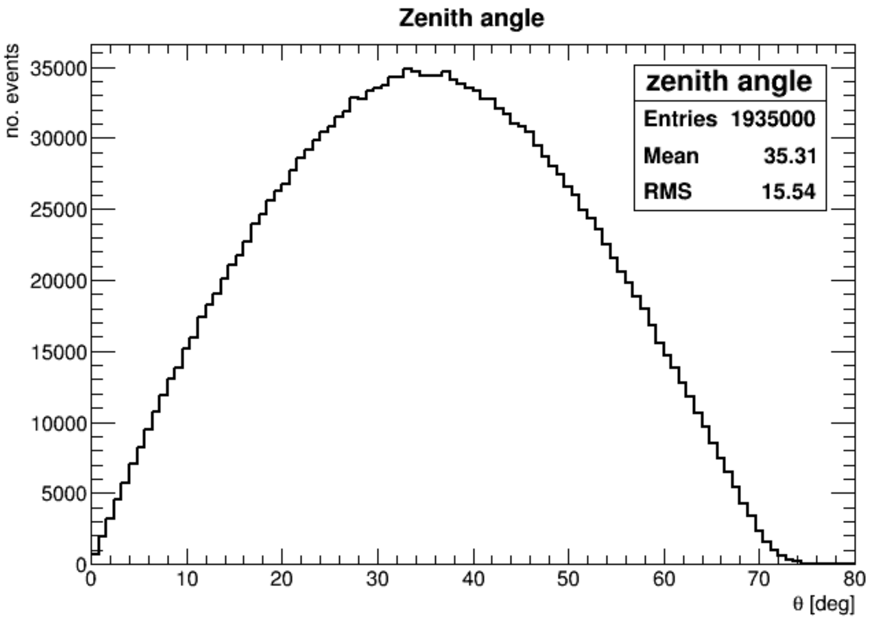
- EPICS simulation run on the Florence farm;
- **EPICS** version **9.165** (July 5, 2014), **COSMOS 7.645** (April 3, 2014);
- **CALET CAD geometry implemented (Rev. 21)**;
- **Isotropic event generation on a hemisphere (R = 78 cm)**;
- **E^{-1} power-law for electrons and protons** (to have enough population in high-energy bins);
- **Dpmjet3** hadronic interaction model adopted.

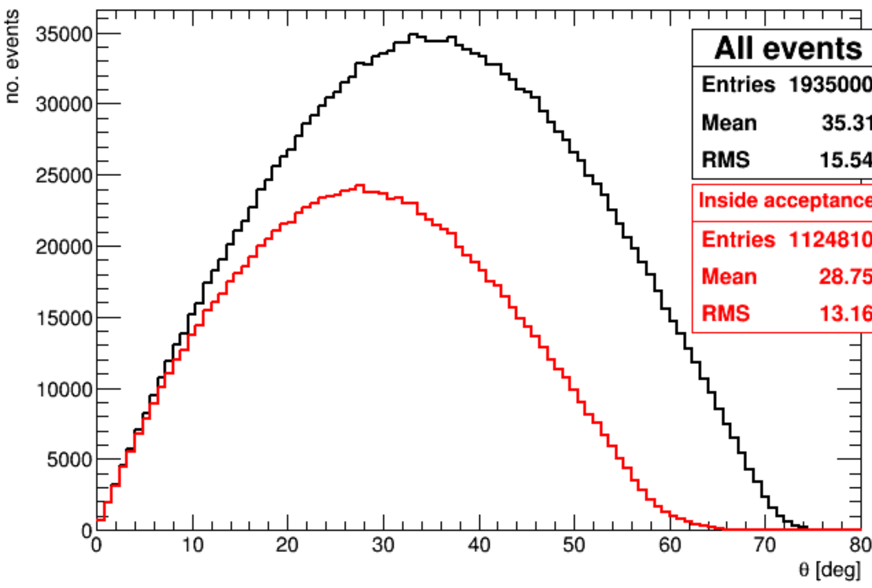
Particle	Energy range (GeV)	Spectral index	No. events EPICS	Hemisphere radius (cm)
Electrons	20-2000	1.0	**3.0×10^5**	78
Protons	10^3-10^5	1.0	**1.935×10^6**	78

Generated protons

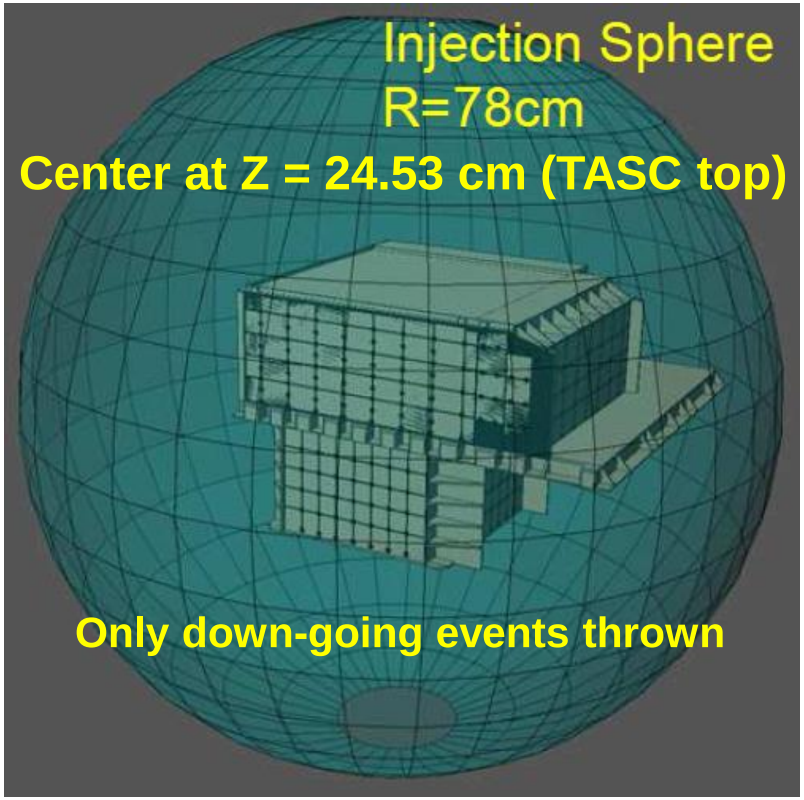








CALET Geometrical Factor



All thrown events

- **cross the 4th IMC W layer;**
- **cross TASC top;**
- **their pathlength in TASC > 9 cm (10 X_0).**

Geometrical factor

$$S\Omega = \frac{N_{sel}}{N_0} \cdot S_0\Omega_0$$ **~ 0.096 m^2sr**

N_{sel}: number of events satisfying the above conditions (**1.935 x 10^6**)

N_0: number of generated events (**~ 2.42 x 10^8**);

$S_0\,\Omega_0$: geometrical factor of the generation surface (**= $2\pi^2R^2$ = 12.009 m^2sr**)

S_0: incident area (**= $2\pi R^2$ = 3.823 m^2**)

Ω_0: solid angle $= \int_0^{2\pi} d\phi \int_0^1 cos\theta d(cos\theta)$ **= π**

Selection criteria

Preselection

- Particle incident MC direction inside acceptance (types 1- 4);

- TASC energy deposit (E_{TASC}) inside energy bin;
  we used realistic energy bin with width chosen according to the expected electron statistics: (912 - 1000) GeV.

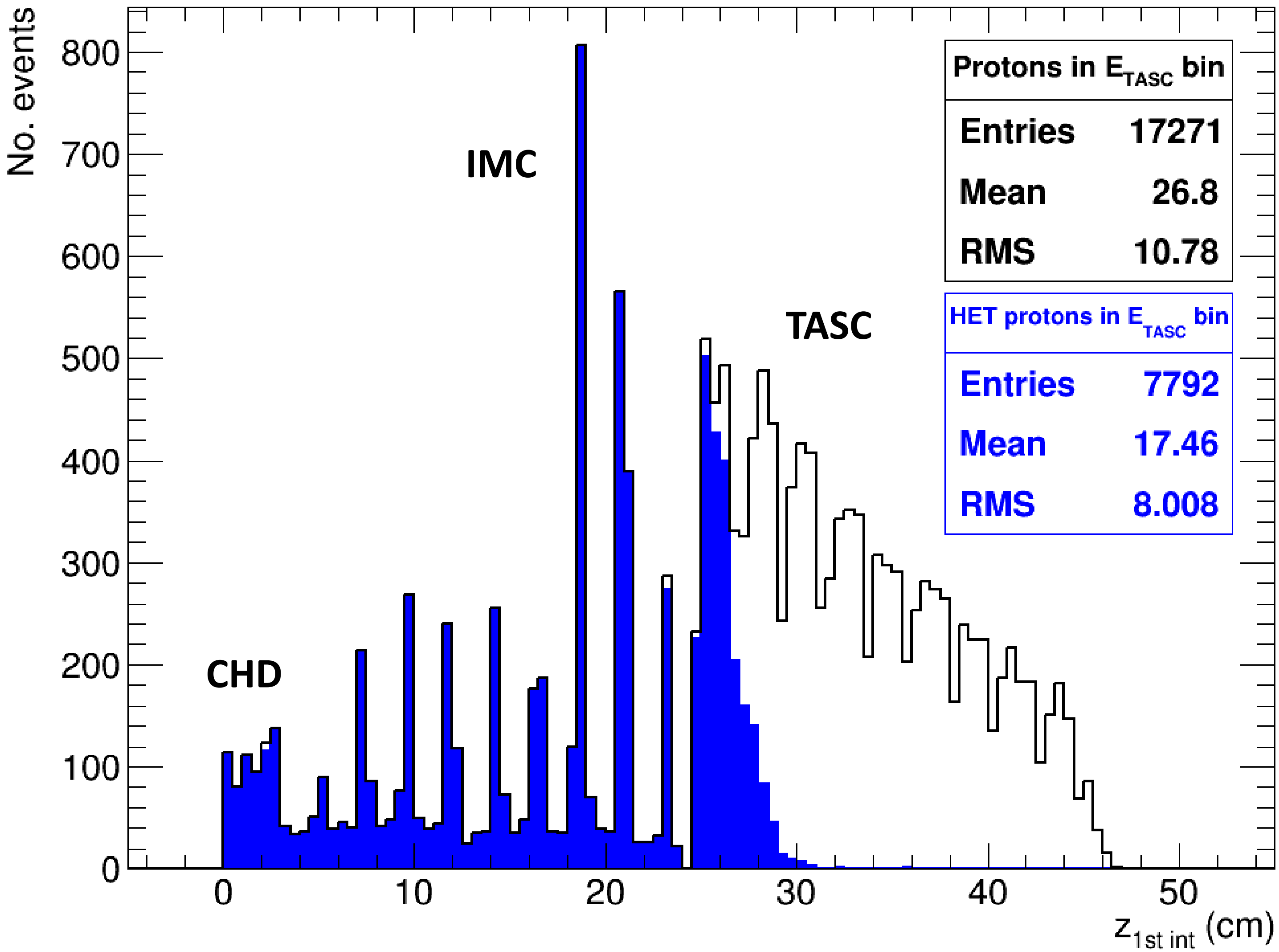
- High Energy Trigger (HET): ① TASC1 > 55 MIP (1 MIP ~ 22 MeV in a PWO log, normal incidence)
  ② IMC layer 7x+8x > 7.5 MIP
  IMC layer 7y+8y > 7.5 MIP (1 MIP ~ 310 keV in 2 (X,Y) fibers)

Selection cuts

- Fraction of energy in the last hit TASC layer (f_E) vs. Energy Weighted Spread (R_E):
  $f_E = \frac{E_{exit\ layer}}{E_{TASC}}$, $E_{exit\ layer}$ is the layer where the incident particle direction gets out of the TASC;
- Fraction of energy deposited in the last IMC layer within 1 Molière radius (E_{1MR} / E_{IMC});

- Total energy deposited in the CHD paddles (E_{CHD}).

High Energy Triggered protons

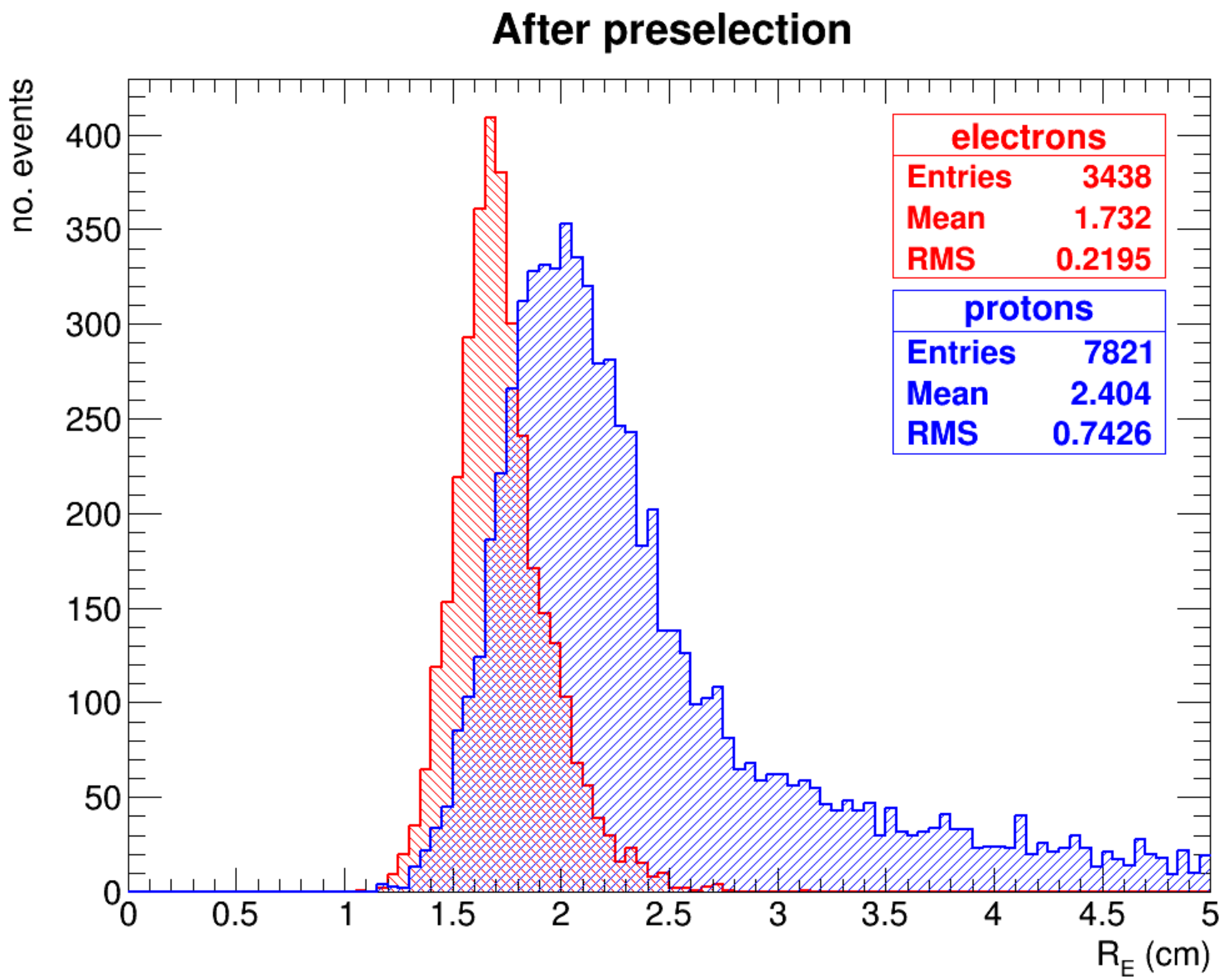


~ 80.3% out of the about 1.1 x 10^6 protons inside acceptance are interacting;
~ 45.1% (FLUKA: ~ 47%) of protons in the chosen TASC energy bin are triggered.

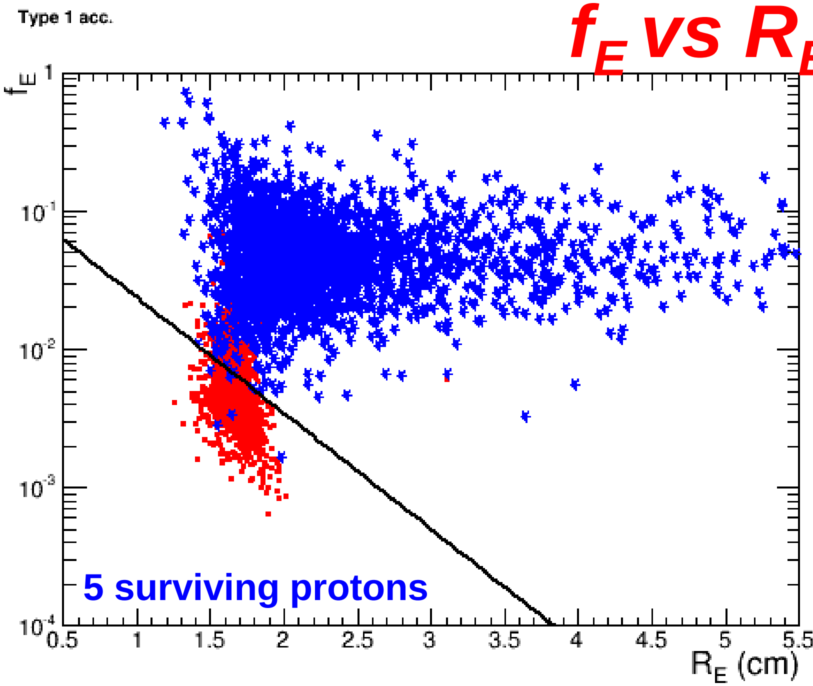
Energy Weighted Spread

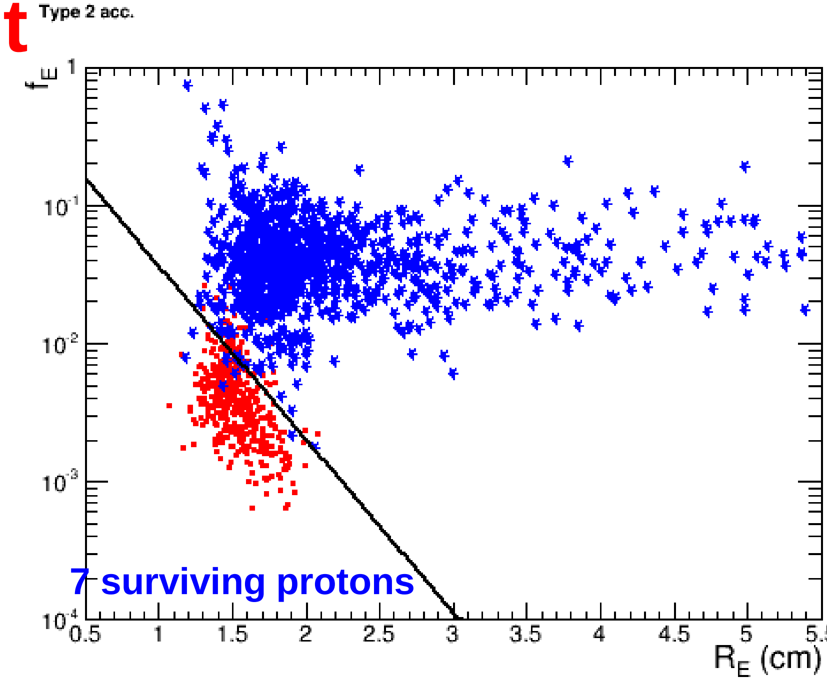
$$R_i = \sqrt{\frac{\sum_j (\Delta E_{i,j} \times (x_{i,j} - x_{i,c})^2)}{\sum_j \Delta E_{i,j}}} \qquad R_E = \sqrt{\frac{\sum_i (\sum_j \Delta E_{i,j} \times R_i^2)}{\sum_i \sum_j \Delta E_{i,j}}}$$

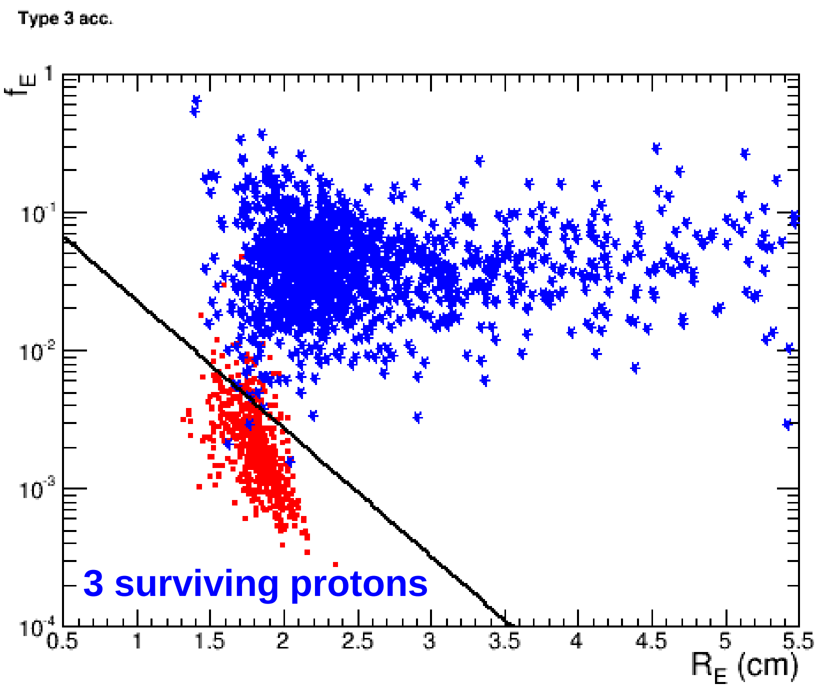
i layer # 0,…,11 j log # 0,…,15
$\Delta E_{i,j}$ energy deposit in log j layer i
$x_{i,j}$ coordinate of log j in layer i
$x_{i,c}$ intercept of primary particle direction with layer i

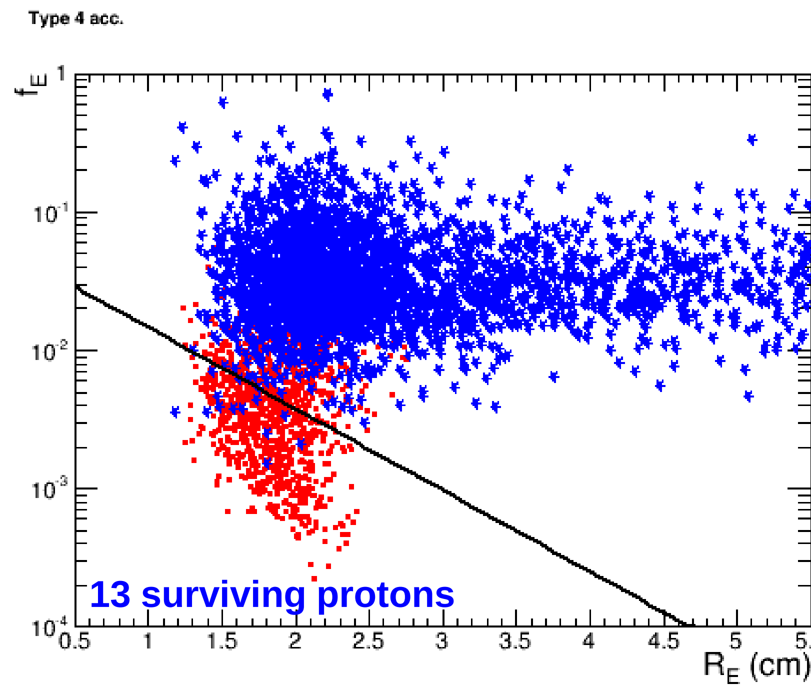


f_E vs R_E cut

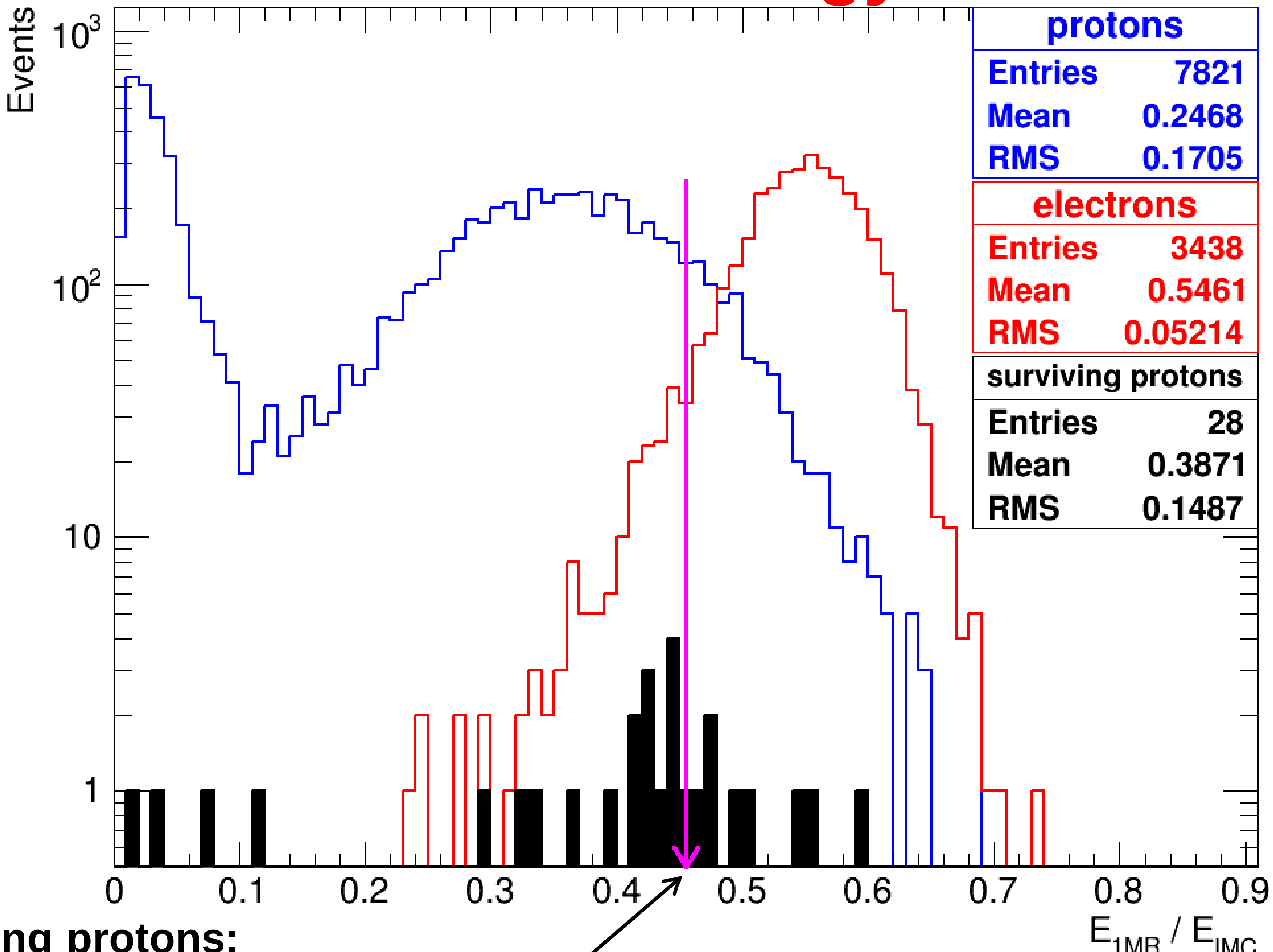

Type 1 acc.
f_E
R_E (cm)
5 surviving protons


Type 2 acc.
f_E
R_E (cm)
7 surviving protons


Type 3 acc.
f_E
R_E (cm)
3 surviving protons


Type 4 acc.
f_E
R_E (cm)
13 surviving protons

Fraction of energy in IMC



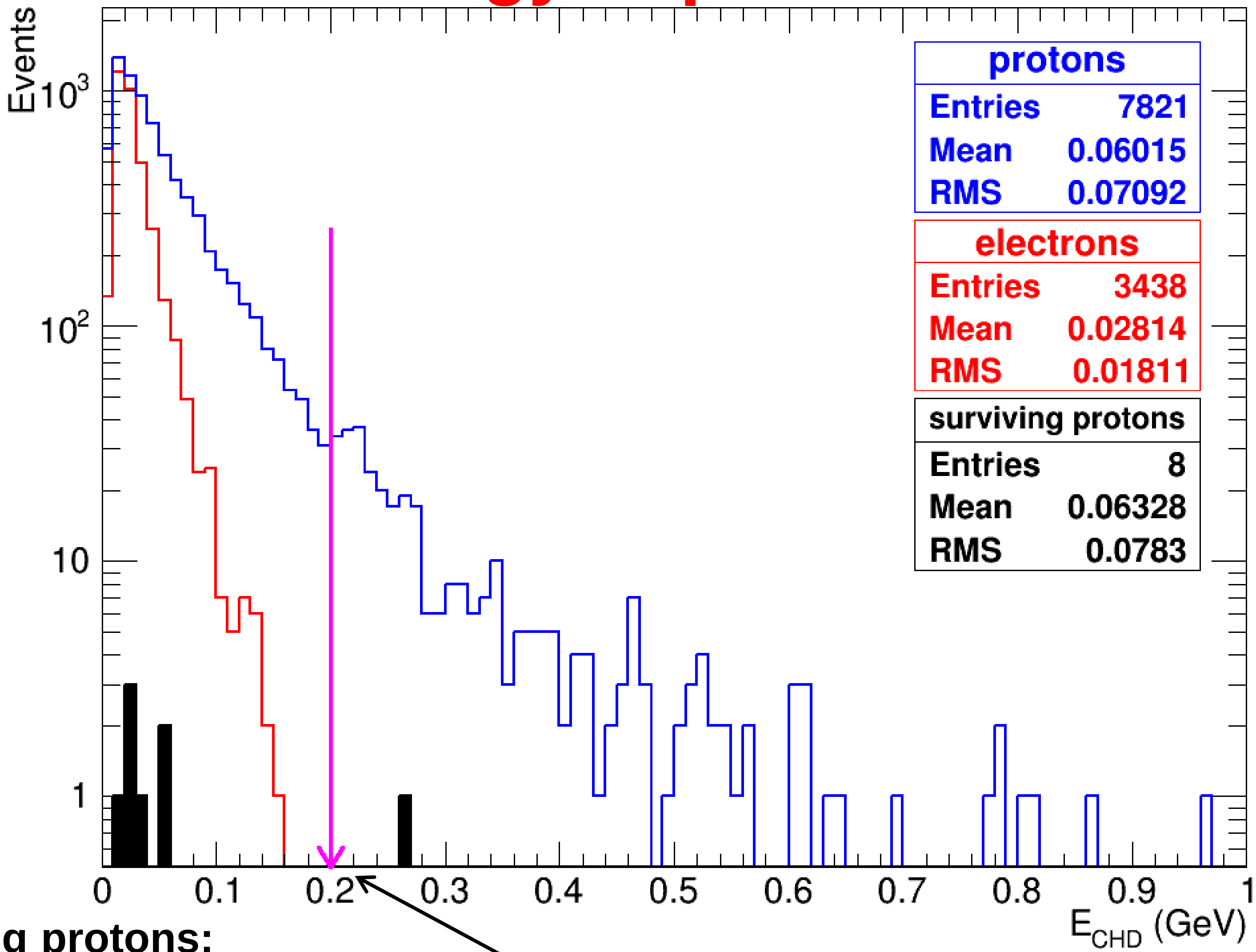
surviving protons:

***f_E vs. R_E* cut**	**28**
&& IMC cut	**8**

Fraction of energy deposited in the last IMC layer within 1 Molière radius (~ 9 fibers)

E_{1MR} / E_{IMC} > 0.455

Total energy deposited in CHD



surviving protons:

IMC cut **8**

IMC && CHD cut **7**

Integrated CHD paddle signal

***E_{CHD}* < 0.2 GeV**

e⁻, p efficiencies and p rejection power

E^{-1} protons	Cut	Type 1 Acc.	Type 2 Acc.	Type 3 Acc.	Type 4 Acc.	Total
	In MC acc.	422168	155212	194355	353075	1124810
	In E_{TASC} bin	6333	2394	3151	5422	17300
	HET	2600	1019	1319	2883	7821
	f_E vs R_E	5	7	3	13	28
	IMC 1RM cut (> 0.455)	3	2	0	3	8
	CHD cut (< 0.2)	3	1	0	3	7

~ 0.9% (FLUKA: ~ 1.6%) out of the initial 1.935 x 10^6 protons have an energy deposit in the chosen bin i.e. 912 < E_{TASC} < 1000 GeV.

E^{-1} electrons	Cut	Type 1 Acc.	Type 2 Acc.	Type 3 Acc.	Type 4 Acc.	Total
	In MC acc.	65525	24239	30319	54345	174428
	In E_{TASC} bin	1321	467	569	1081	3438
	HET	1321	467	569	1081	3438
	f_E vs R_E	966	418	502	622	2508
	IMC 1RM cut (> 0.455)	937	400	476	594	2407
	CHD cut (< 0.2)	937	400	476	594	2407

Electron efficiency

$$\varepsilon_{c,e} = (70.0 \pm 0.8) \times 10^{-2}$$

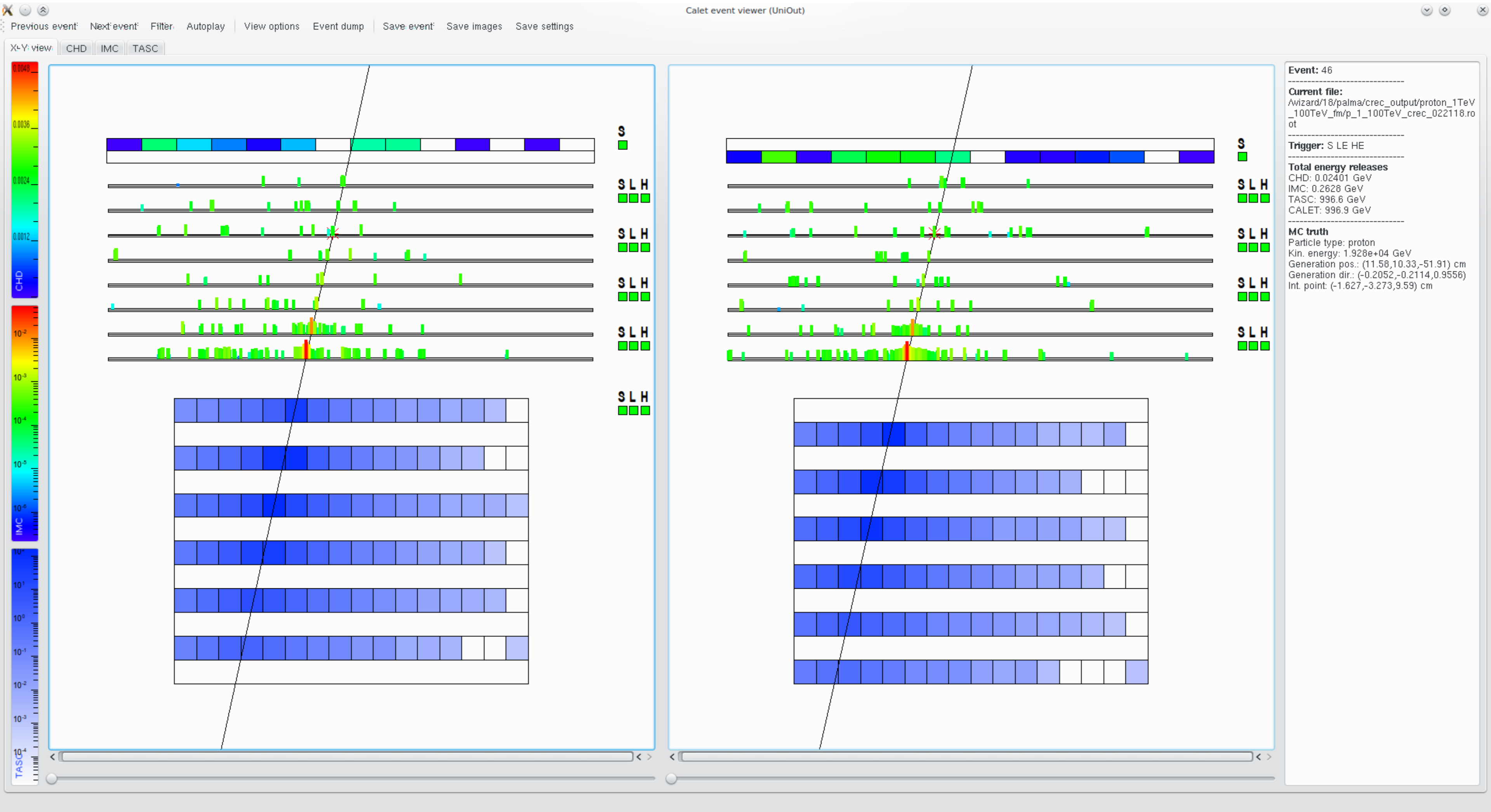
Proton efficiency

$$\varepsilon_{c,p} = (6.2^{+3.4}_{-2.3}) \times 10^{-6}$$

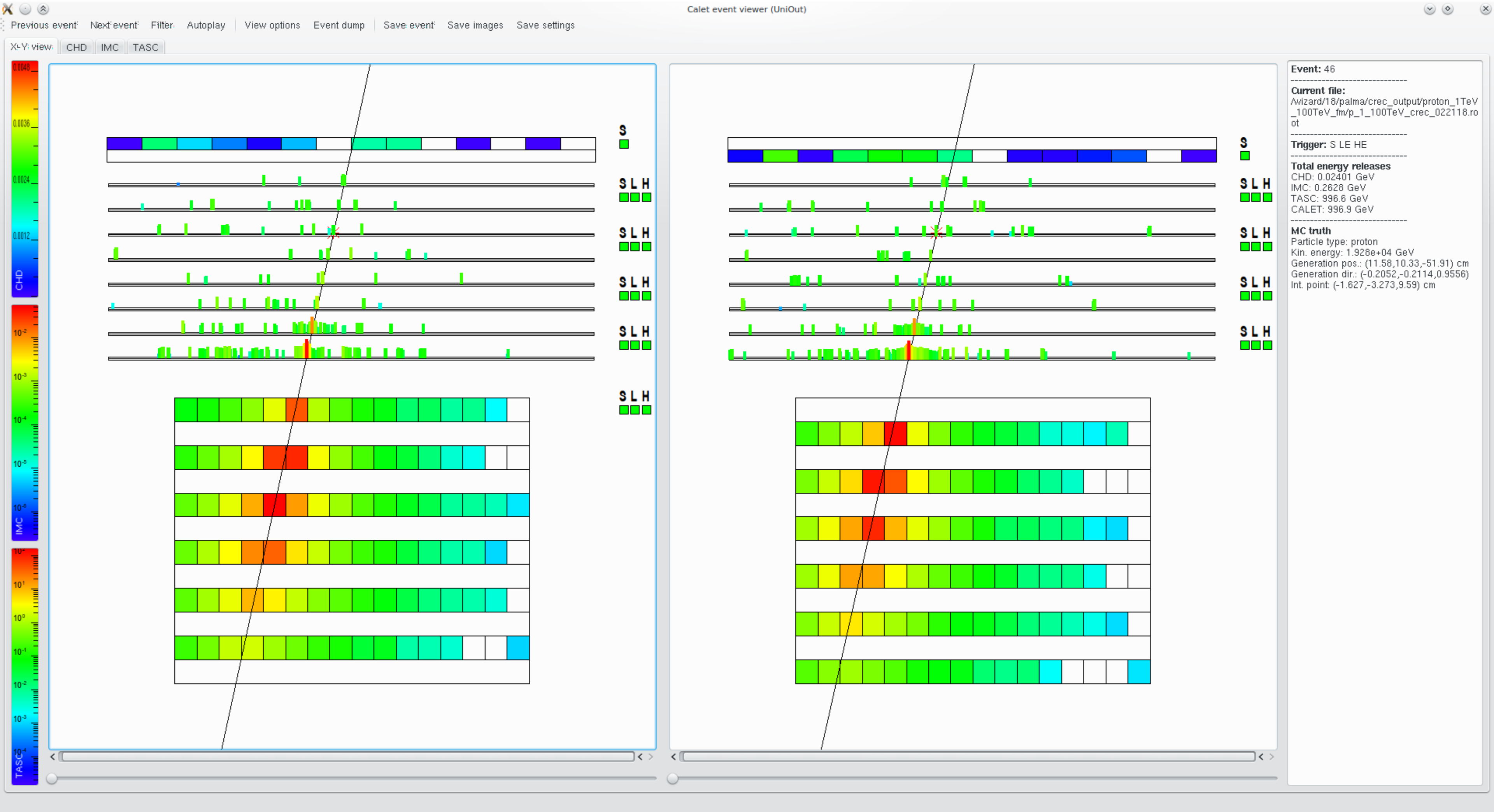
Proton rejection power

$$\varepsilon_{c,e}/\varepsilon_{c,p} = (1.1^{+0.6}_{-0.4}) \times 10^{5}$$

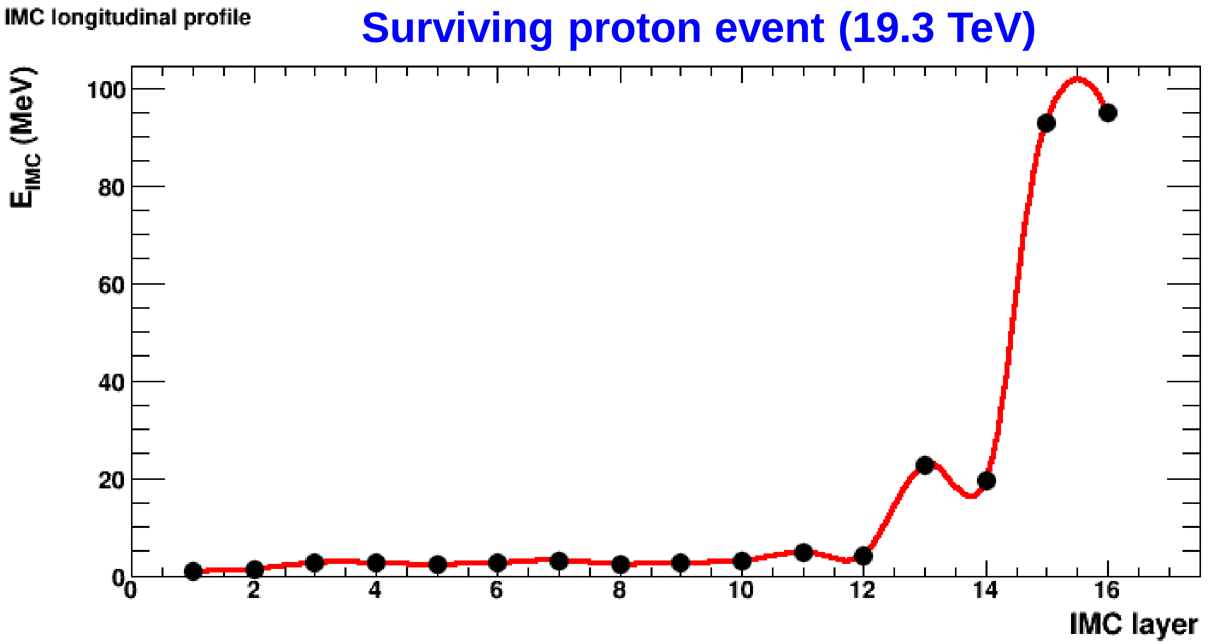
Surviving proton event (19.3 TeV)

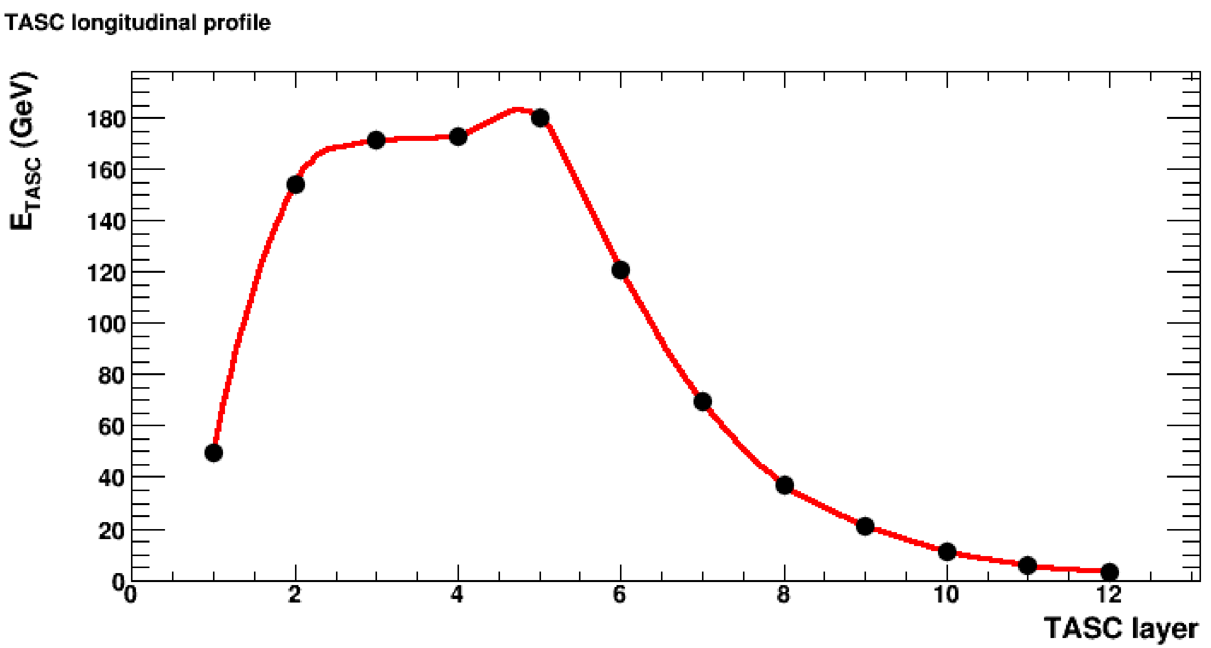


Surviving proton event (19.3 TeV)



IMC and TASC longitudinal profiles





Multivariate analysis (MVA)

- Multivariate methods are widely used for the **classification of events** of different types;

- We used MVA as an alternative method to evaluate CALET capability to **discriminate electrons from protons** and compared with analysis based on consecutive selection cuts;

- We used TMVA 4 (http://tmva.sourceforge.net) that is a Toolkit for Multivariate Data Analysis with ROOT;
  TMVA provides different classifier methods, both linear and non-linear, to select signal from background events.

- Different multivariate methods have been trained with the same electron and proton samples used in the previous analysis and **Boosted Decision Trees (BDT) turned out to be the most performing for the present classification problem**;

- **The trained BDT** are then applied to the test data set and **provide scalar outputs according to which an event can be classified as either signal or background**.

Boosted Decision Trees

- Same preselection as used in the analysis based on consecutive selection cuts;

- **11 input variables**
  - Energy Weighted Spread ($\boldsymbol{R_E}$);
  - Fraction of energy in the last hit TASC layer ($\boldsymbol{f_E}$);
  - Fraction of energy deposited in the last IMC layer within 1 Molière radius ($\boldsymbol{E_{1MR} / E_{IMC}}$);
  - Total energy deposited in CHD ($\boldsymbol{E_{CHD}}$);
  - variables from Γ-fit to longitudinal shower profile in TASC: $\boldsymbol{t_{max} = \alpha / b}$, $\boldsymbol{b}$, $\boldsymbol{\chi^2/ndf}$, **the starting point of the shower**

$$\frac{dE}{dt} = E_0 \frac{b^{(\alpha+1)}}{\Gamma(\alpha+1)} t^{\alpha} e^{-bt} \qquad t = x/X_0$$

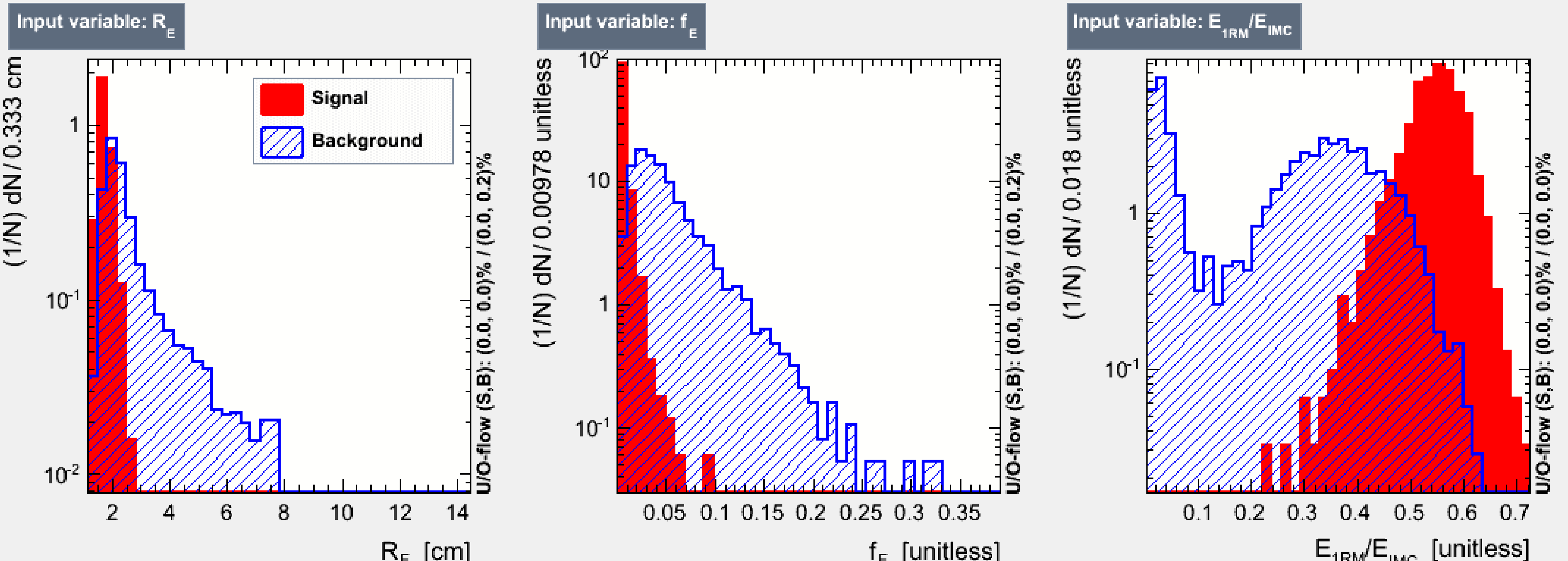
  - variables from IMC profile parabola-fit: $\boldsymbol{p_0}$, $\boldsymbol{p_1}$, $\boldsymbol{\chi^2/ndf}$

$$\frac{dE}{dt} = p_0 t^2 + p_1$$

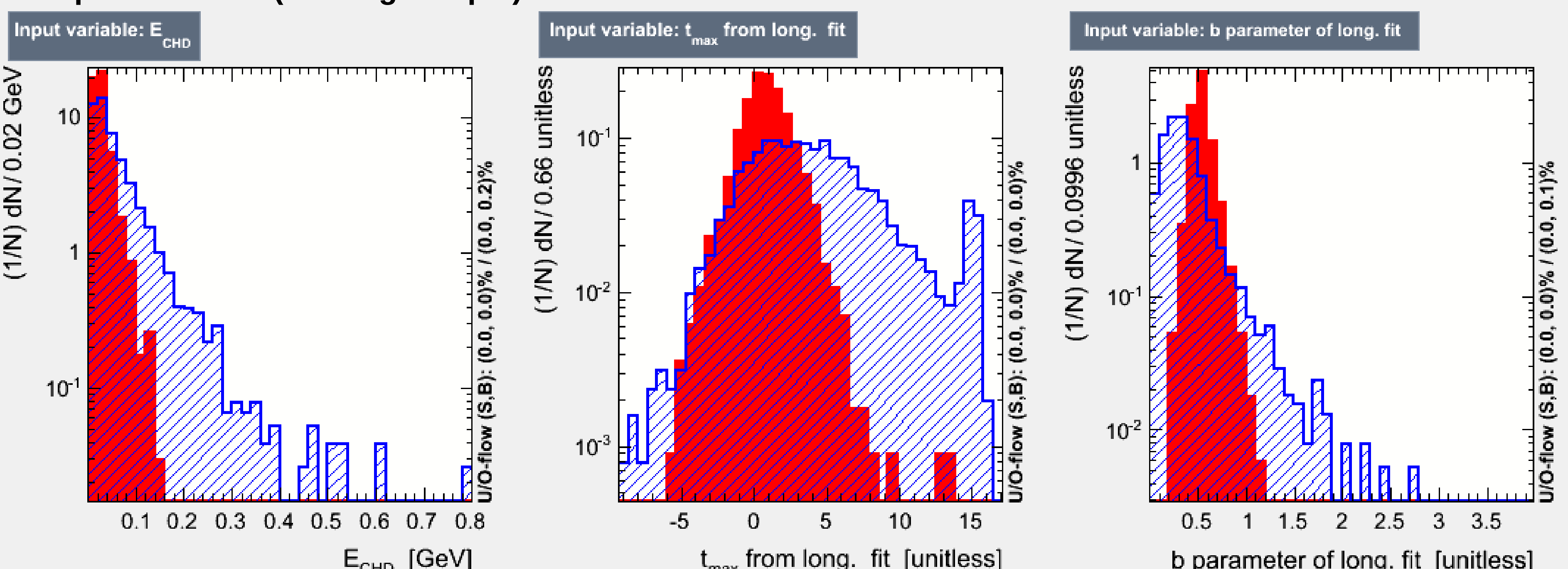
- Preselected samples of **electrons (3438)** and **protons (7821)** are used for training and test

  Training sample: 1719 electrons 3875 protons

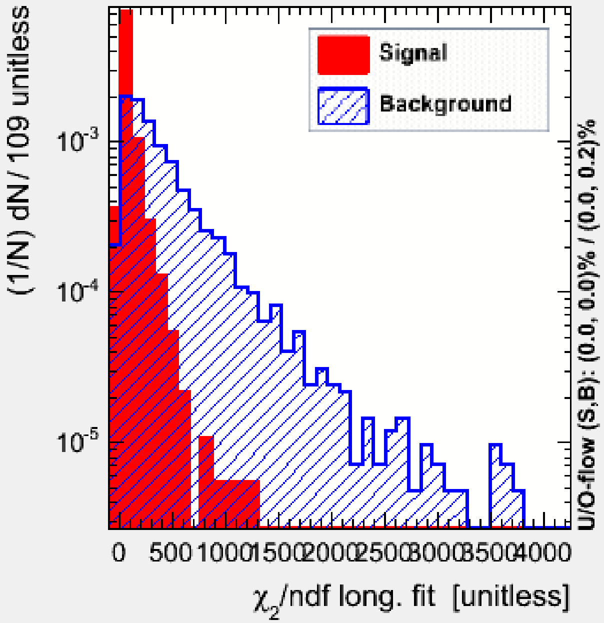
  Test sample: 1719 electrons 3874 protons



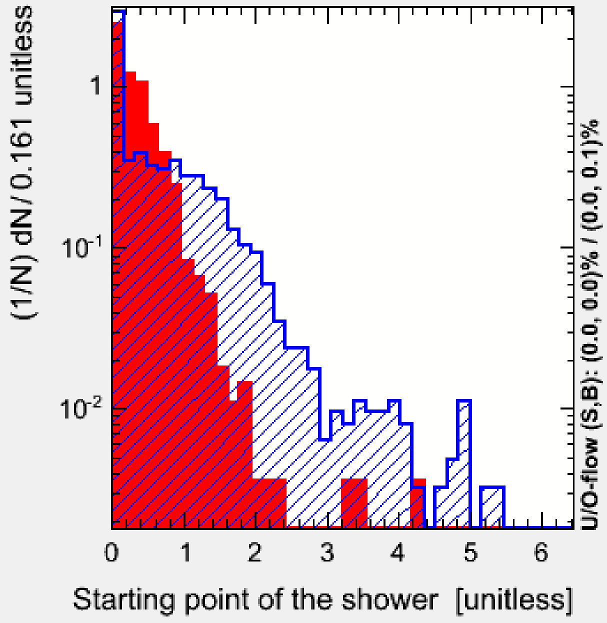
11 input variables (training sample)



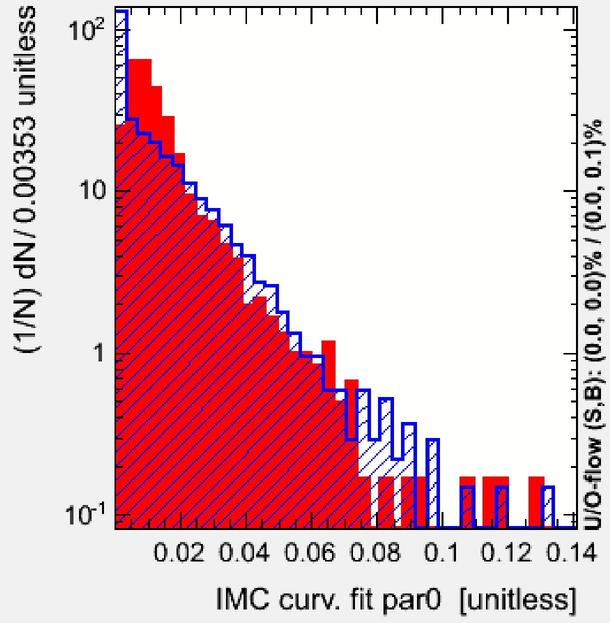
Input variable: χ_2/ndf long. fit



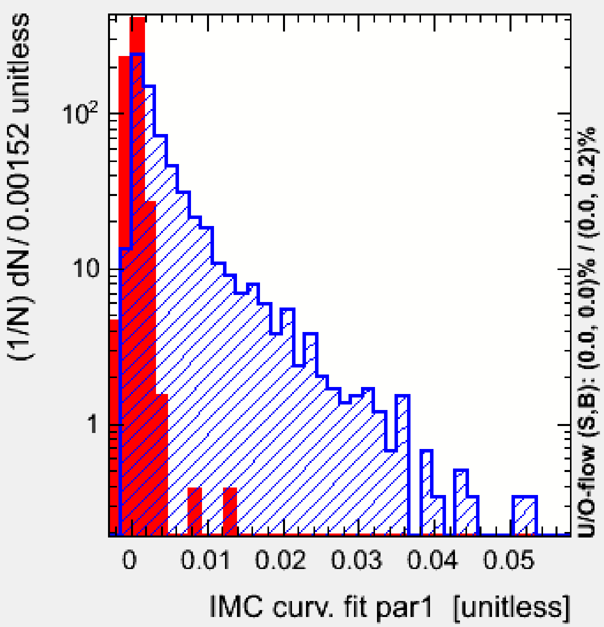
Input variable: Starting point of the shower



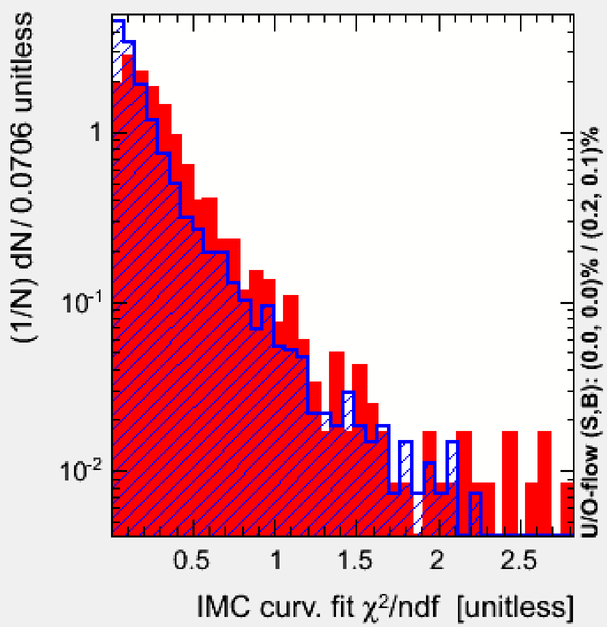
Input variable: IMC curv. fit par0



Input variable: IMC curv. fit par1

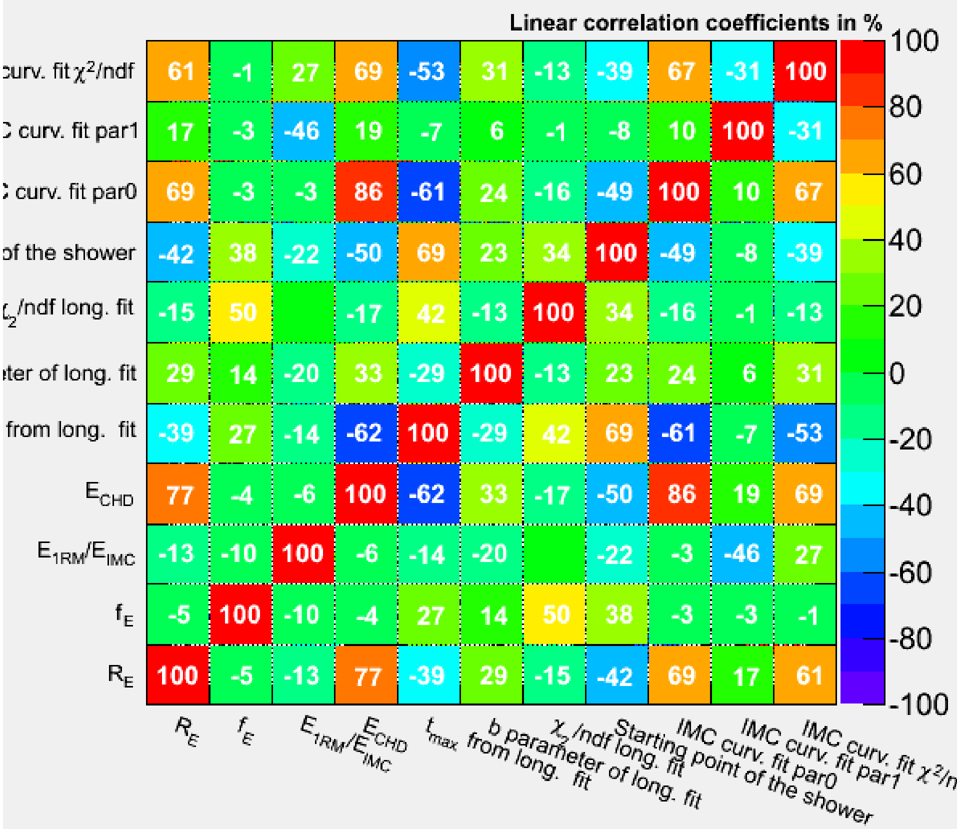


Input variable: IMC curv. fit χ^2/ndf

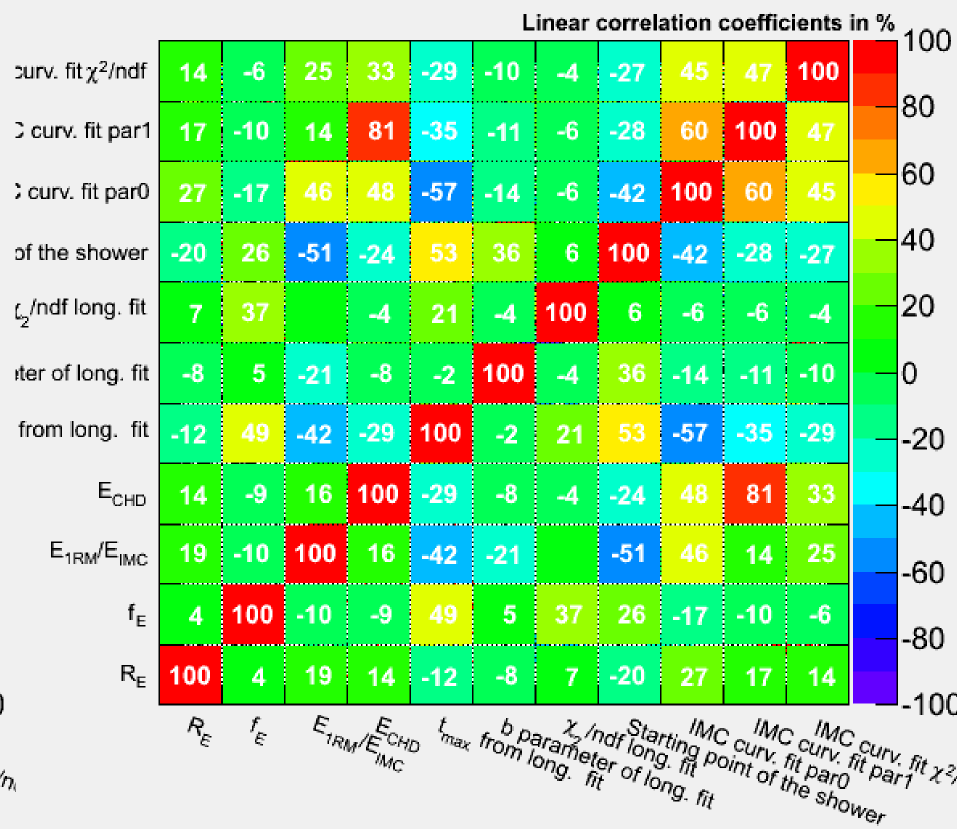


Input variable linear correlation coefficients

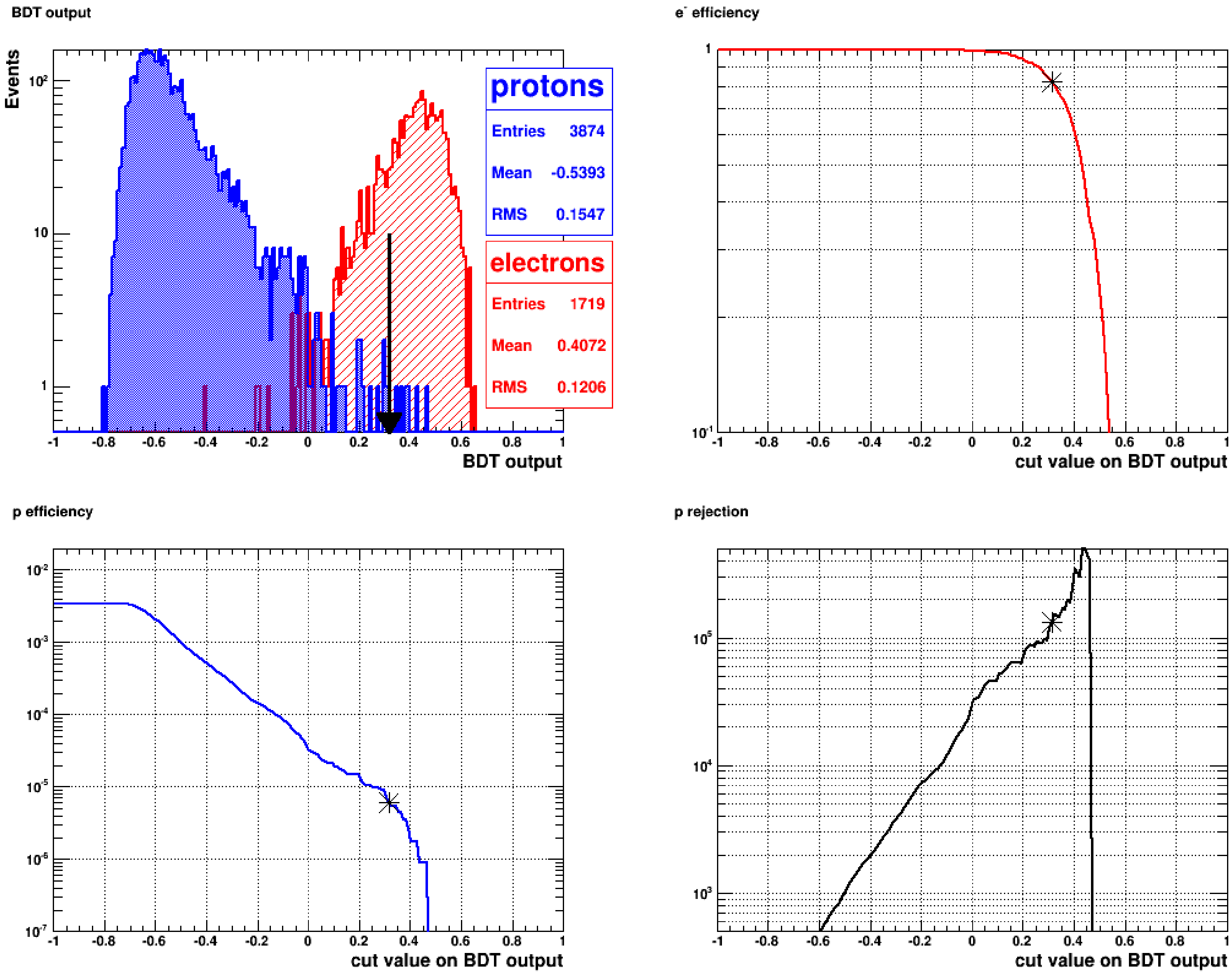
Correlation Matrix (signal)



Correlation Matrix (background)



BDT test sample: efficiencies and p rejection



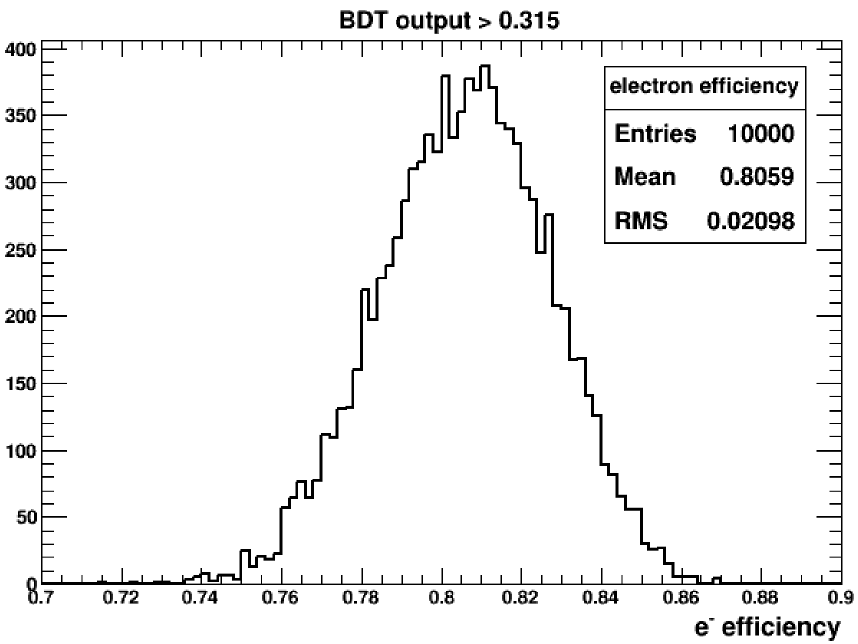
BDT output > 0.315

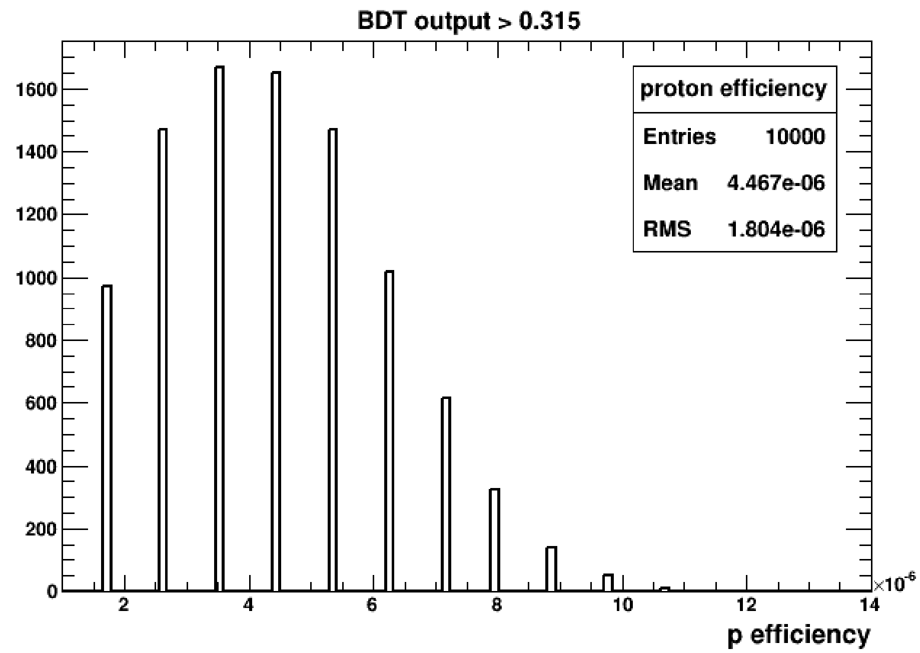
ε_{ele} ~ 82%

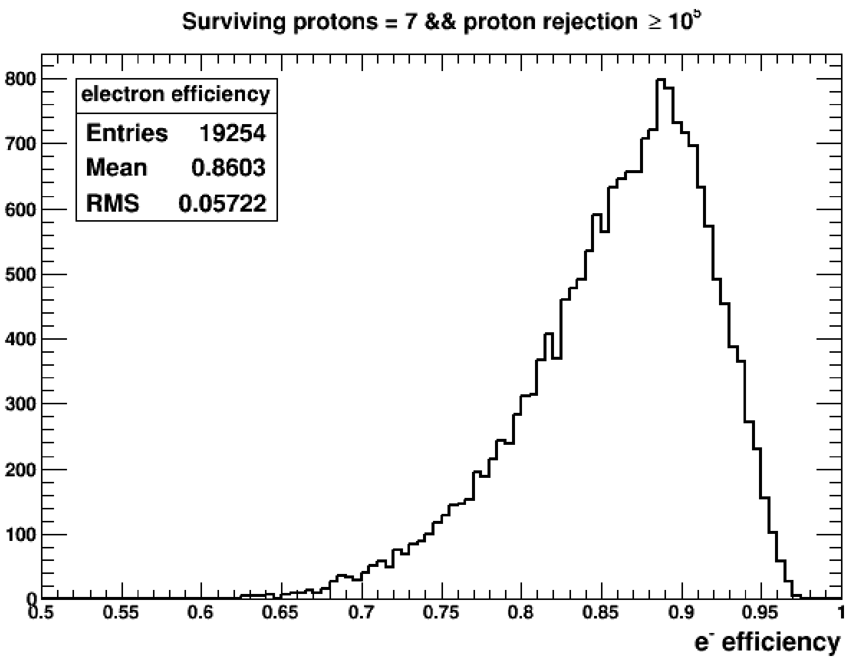
ε_p ~ 6.22×10^{-6}

$R = \varepsilon_{ele} / \varepsilon_p$ ~ 1.32×10^5

BDT stability test







MVA analysis with BDT has been repeated 10000 times and the **training and test samples have been selected randomly** from the preselected electron and proton samples (one half of the input sample for training and the other half for testing).

We estimated **electron efficiency** by applying a fixed BDT cut, *BDT output > 0.315* (upper plot) and by requesting *surv. protons = 7 && proton rejection* ≥ *10^5* (lower plot).

Conclusions

- We estimated e/p separation at 1 TeV with EPICS-based simulation of CALET CAD Model (Rev. 21).
  We used two different approaches: **standard consecutive selection cuts** and **Boosted Decision Trees**.

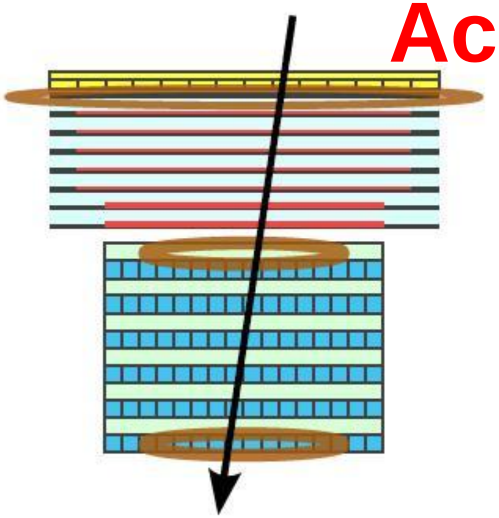
- The first analysis allows to achieve an **electron efficiency ~ 70%** and **a proton efficiency ~ 6.2 x 10^{-6}**, corresponding to a **proton rejection power ~ 1.1 x 10^{5}**. These results are completely in agreement with those obtained from EPICS-based simulation of Pisa-distributed CALET model (see presentation at 2013 CERN TIM).

- These results have also been compared to those from multivariate analysis with BDT. With equal values for **proton efficiency ~ 6.22 x 10^{-6}** and **proton rejection power ~ 1.32 x 10^{5}**, the analysis with BDT shows **an increased electron efficiency ~ 82%**. These results are consistent with the latest FLUKA-based results (see presentation by Paolo at 2014 Waseda TIM).

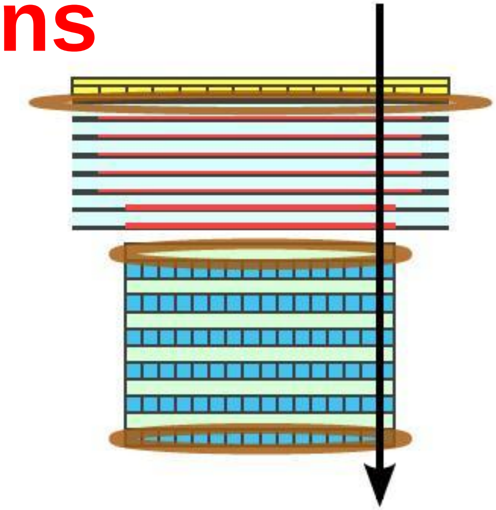
- To be done: use digitized hits and estimate e/p separation in different energy bins.

Backup slides

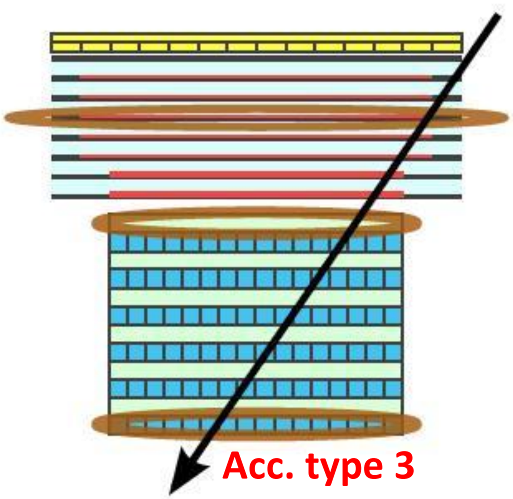
Acceptance configurations



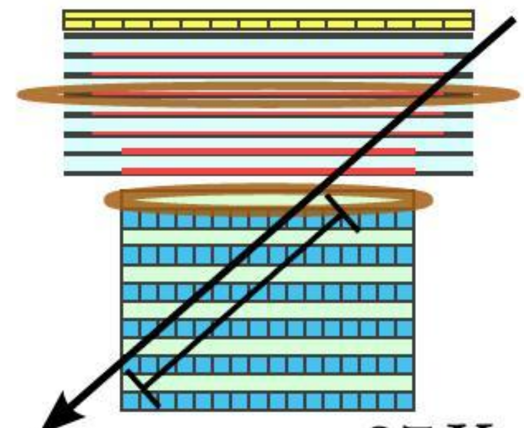
Acc. type 1:
CHD Top && TASC Top
(1 PWO log inside)
&& TASC Bottom
(1 PWO log inside)



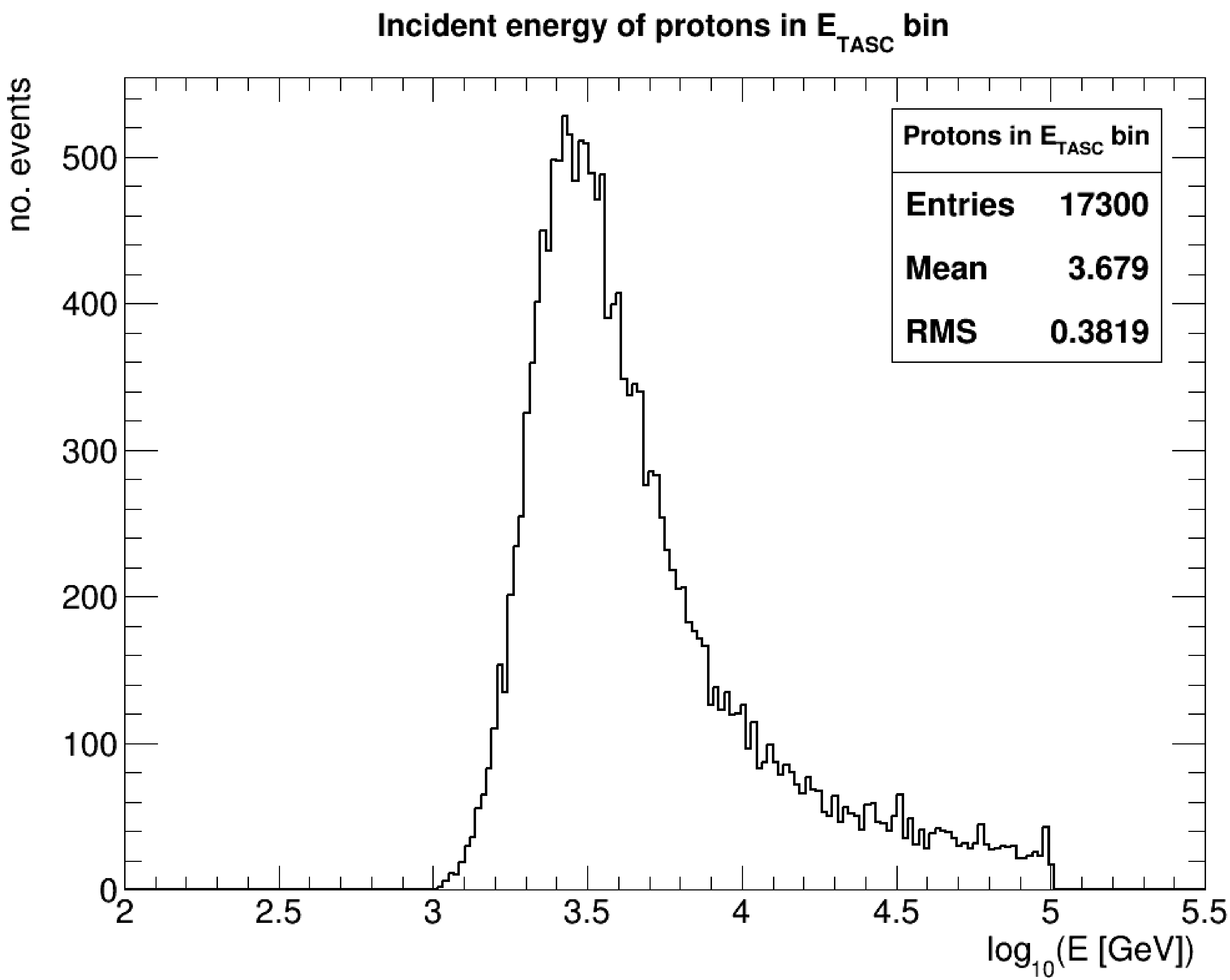
Acc. type 2 (1 not included):
CHD Top && TASC Top
(lateral PWO log)
&& TASC Bottom
(lateral PWO log)



Acc. type 3
(1 & 2 not included):
NOT IMC Top && 4th IMC layer
&& TASC Top && TASC Bottom

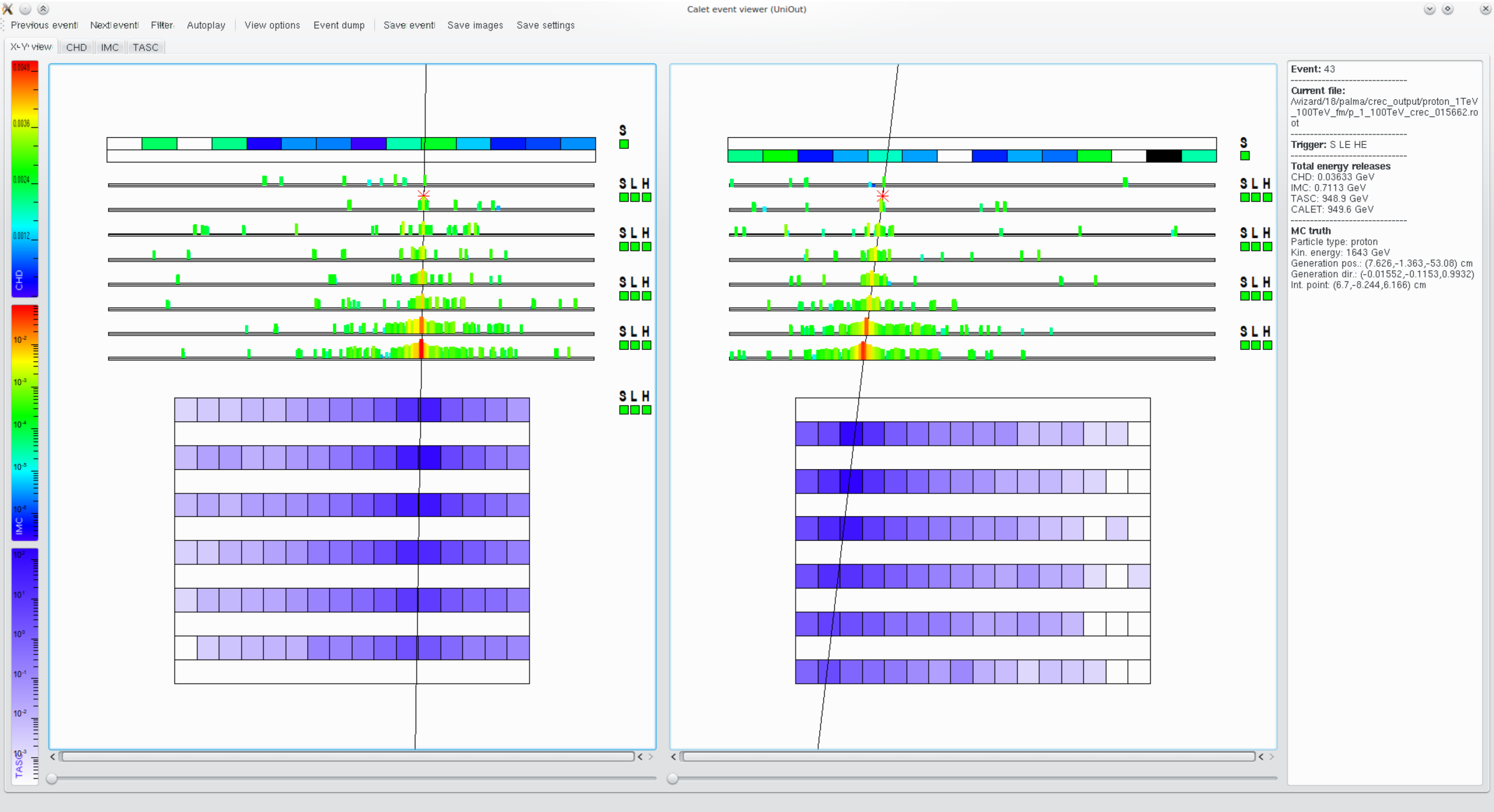


Acc. type 4 (1 & 2 & 3 not included): $> 27X_0$
i) NOT IMC Top && 4th IMC layer
&& TASC Top && NOT TASC Bottom
ii) IMC Top && NOT TASC Bottom



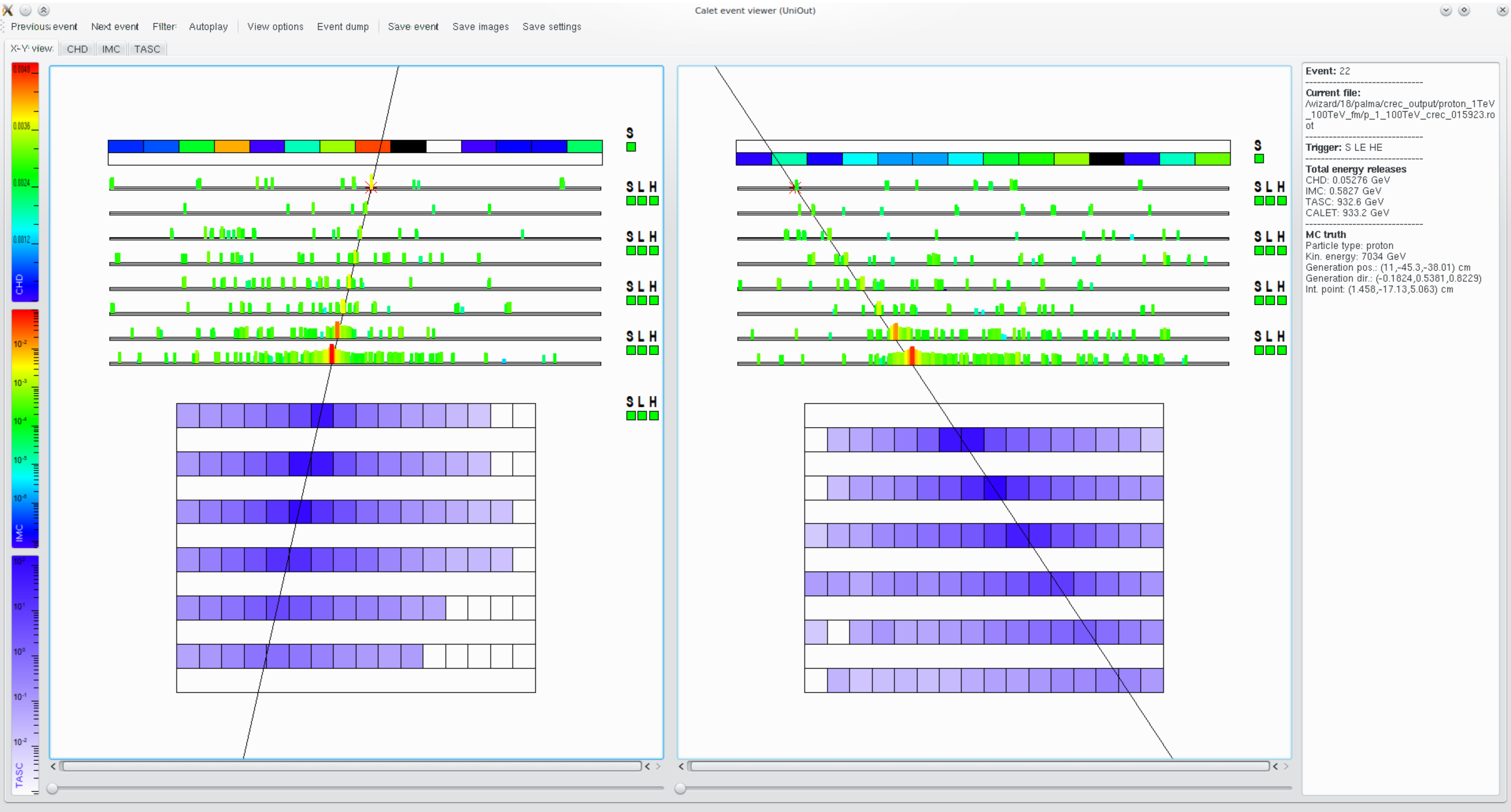
Incident energy of protons in E_{TASC} bin
no. events
Protons in E_{TASC} bin
Entries 17300
Mean 3.679
RMS 0.3819
0
100
200
300
400
500
2
2.5
3
3.5
4
4.5
5
5.5
$\log_{10}$(E [GeV])

Surviving proton event (1643 GeV)

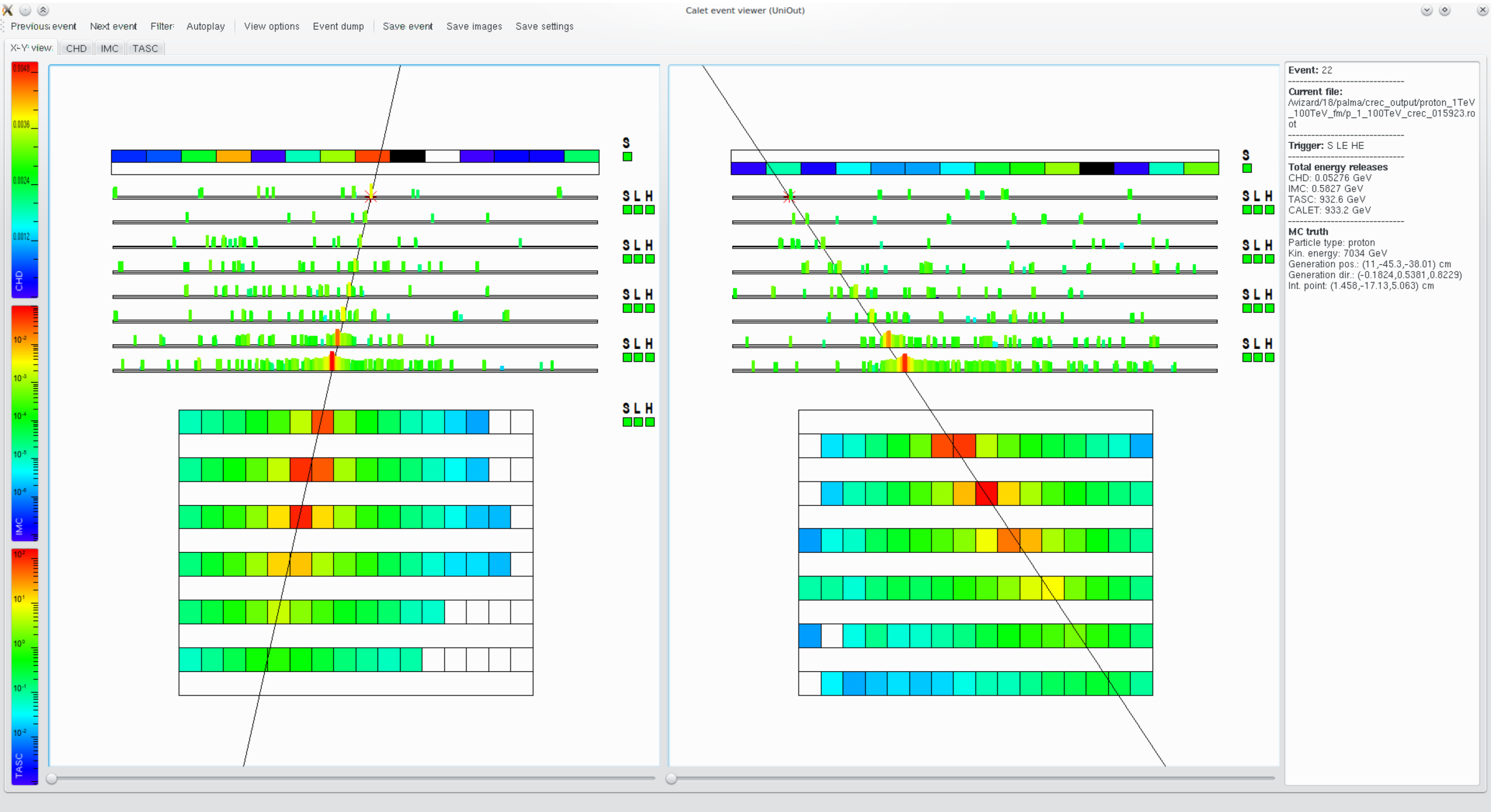


Surviving proton event (1643 GeV)

Surviving proton event (7034 GeV)



Surviving proton event (7034 GeV)



Type Acc.: 2
x0: 25.2296 cm
y0: 29.4779 cm
z0: -43.1348 cm
costheta: 0.840468
theta: 32.8104 deg
E0: 1696.7 GeV
TASC length: 35.3201 X0
TASC exit layer: 11
Zint: 2.0384 cm (CHD)
fe: 0.00214068
re: 1.90781 cm
CHDetot: 0.0592724 GeV
TASC ly: 0 TASCedep: 97.0739 GeV
TASC ly: 1 TASCedep: 147.687 GeV
TASC ly: 2 TASCedep: 206.878 GeV
TASC ly: 3 TASCedep: 169.448 GeV
TASC ly: 4 TASCedep: 147.278 GeV
TASC ly: 5 TASCedep: 91.4931 GeV
TASC ly: 6 TASCedep: 57.2516 GeV
TASC ly: 7 TASCedep: 30.6308 GeV
TASC ly: 8 TASCedep: 15.5481 GeV
TASC ly: 9 TASCedep: 8.10186 GeV
TASC ly: 10 TASCedep: 4.50906 GeV
TASC ly: 11 TASCedep: 2.09357 GeV
TASC ly: 12 TASCedep: 977.994 GeV
TASCelast: 2.09357 GeV
IMC ly: 0 IMCedep: 2.98738 MeV
IMC ly: 1 IMCedep: 3.53452 MeV
IMC ly: 2 IMCedep: 40.1871 MeV
IMC ly: 3 IMCedep: 9.22027 MeV
IMC ly: 4 IMCedep: 20.2659 MeV
IMC ly: 5 IMCedep: 18.2385 MeV
IMC ly: 6 IMCedep: 20.096 MeV
IMC ly: 7 IMCedep: 22.4651 MeV
IMC ly: 8 IMCedep: 23.0273 MeV
IMC ly: 9 IMCedep: 22.5444 MeV
IMC ly: 10 IMCedep: 34.3153 MeV
IMC ly: 11 IMCedep: 30.6505 MeV
IMC ly: 12 IMCedep: 123.815 MeV
IMC ly: 13 IMCedep: 116.95 MeV
IMC ly: 14 IMCedep: 345.881 MeV
IMC ly: 15 IMCedep: 330.291 MeV
IMC ly: 16 IMCedep: 1164.47 MeV
e1rm: 0.478218 GeV

Type Acc.: 4
x0: -20.9084 cm
y0: -9.371 cm
z0: -50.0289 cm
costheta: 0.936334
theta: 20.5553 deg
E0: 4568.9 GeV
TASC length: 29.1886 X0
TASC exit layer: 11
Zint: 18.6349 cm (IMC)
fe: 0.0035957
re: 1.40264 cm
CHDetot: 0.0157603 GeV
TASC ly: 0 TASCedep: 24.1476 GeV
TASC ly: 1 TASCedep: 97.7348 GeV
TASC ly: 2 TASCedep: 169.83 GeV
TASC ly: 3 TASCedep: 190.5 GeV
TASC ly: 4 TASCedep: 159.291 GeV
TASC ly: 5 TASCedep: 130.962 GeV
TASC ly: 6 TASCedep: 83.0663 GeV
TASC ly: 7 TASCedep: 54.7249 GeV
TASC ly: 8 TASCedep: 29.8073 GeV
TASC ly: 9 TASCedep: 18.3083 GeV
TASC ly: 10 TASCedep: 7.84911 GeV
TASC ly: 11 TASCedep: 3.48678 GeV
TASC ly: 12 TASCedep: 969.708 GeV
TASCelast: 3.48678 GeV
IMC ly: 0 IMCedep: 0.8834 MeV
IMC ly: 1 IMCedep: 0.61388 MeV
IMC ly: 2 IMCedep: 1.09186 MeV
IMC ly: 3 IMCedep: 1.97468 MeV
IMC ly: 4 IMCedep: 1.74865 MeV
IMC ly: 5 IMCedep: 1.6383 MeV
IMC ly: 6 IMCedep: 1.24951 MeV
IMC ly: 7 IMCedep: 0.92566 MeV
IMC ly: 8 IMCedep: 3.67096 MeV
IMC ly: 9 IMCedep: 1.8583 MeV
IMC ly: 10 IMCedep: 1.86918 MeV
IMC ly: 11 IMCedep: 2.34987 MeV
IMC ly: 12 IMCedep: 11.7178 MeV
IMC ly: 13 IMCedep: 14.2416 MeV
IMC ly: 14 IMCedep: 45.5184 MeV
IMC ly: 15 IMCedep: 40.3115 MeV
IMC ly: 16 IMCedep: 131.664 MeV
e1rm: 0.479568 GeV

Type Acc.: 4
x0: 7.2323 cm
y0: -30.1269 cm
z0: -47.0526 cm
costheta: 0.881292
theta: 28.2014 deg
E0: 1294.8 GeV
TASC length: 28.781 X0
TASC exit layer: 10
Zint: 4.6136 cm
fe: 0.00437328
re: 1.74233 cm
CHDetot: 0.0279114 GeV
TASC ly: 0 TASCedep: 85.74 GeV
TASC ly: 1 TASCedep: 174.442 GeV
TASC ly: 2 TASCedep: 191.216 GeV
TASC ly: 3 TASCedep: 178.722 GeV
TASC ly: 4 TASCedep: 147.002 GeV
TASC ly: 5 TASCedep: 92.9011 GeV
TASC ly: 6 TASCedep: 54.0585 GeV
TASC ly: 7 TASCedep: 32.599 GeV
TASC ly: 8 TASCedep: 18.9103 GeV
TASC ly: 9 TASCedep: 9.95746 GeV
TASC ly: 10 TASCedep: 4.33893 GeV
TASC ly: 11 TASCedep: 2.25746 GeV
TASC ly: 12 TASCedep: 992.145 GeV
TASCelast: 4.33893 GeV
IMC ly: 0 IMCedep: 3.86494 MeV
IMC ly: 1 IMCedep: 3.73714 MeV
IMC ly: 2 IMCedep: 7.78123 MeV
IMC ly: 3 IMCedep: 7.2775 MeV
IMC ly: 4 IMCedep: 12.8685 MeV
IMC ly: 5 IMCedep: 10.4208 MeV
IMC ly: 6 IMCedep: 29.6789 MeV
IMC ly: 7 IMCedep: 17.7283 MeV
IMC ly: 8 IMCedep: 19.2914 MeV
IMC ly: 9 IMCedep: 17.6273 MeV
IMC ly: 10 IMCedep: 29.0739 MeV
IMC ly: 11 IMCedep: 25.1737 MeV
IMC ly: 12 IMCedep: 82.6925 MeV
IMC ly: 13 IMCedep: 83.2068 MeV
IMC ly: 14 IMCedep: 244.389 MeV
IMC ly: 15 IMCedep: 244.117 MeV
IMC ly: 16 IMCedep: 838.929 MeV
e1rm: 0.490054 GeV

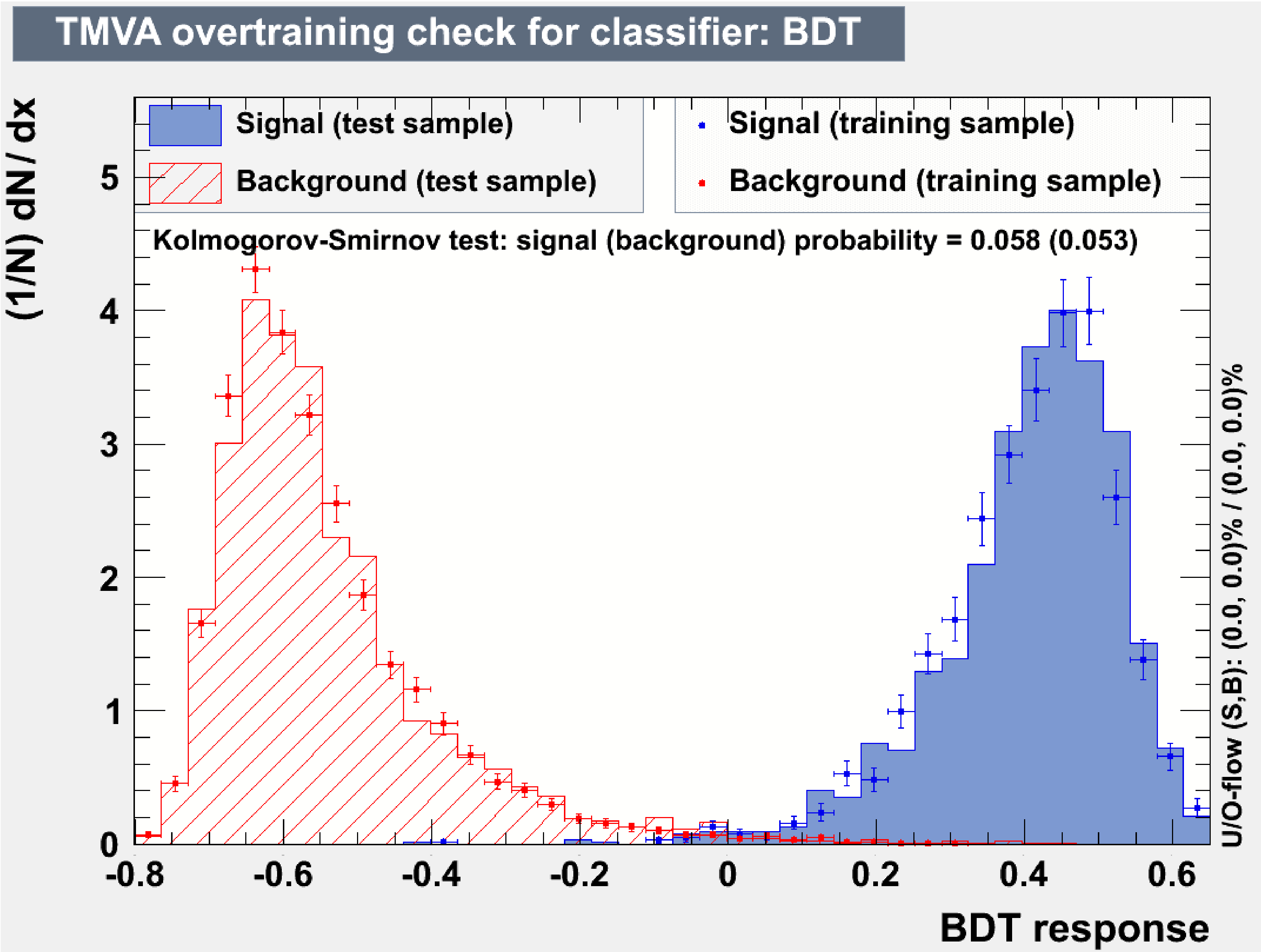
Type Acc.: 1
x0: 7.6258 cm
y0: -1.3629 cm
z0: -53.0844 cm
costheta: 0.993204
theta: 6.6836 deg
E0: 1643.4 GeV
TASC length: 29.8885 X0
TASC exit layer: 11
Zint: 6.1662 cm (IMC)
fe: 0.00616549
re: 1.64474 cm
CHDetot: 0.036333 GeV
TASC ly: 0 TASCedep: 58.4134 GeV
TASC ly: 1 TASCedep: 147.729 GeV
TASC ly: 2 TASCedep: 183.195 GeV
TASC ly: 3 TASCedep: 200.86 GeV
TASC ly: 4 TASCedep: 127.472 GeV
TASC ly: 5 TASCedep: 95.6551 GeV
TASC ly: 6 TASCedep: 55.7891 GeV
TASC ly: 7 TASCedep: 34.8669 GeV
TASC ly: 8 TASCedep: 20.8069 GeV
TASC ly: 9 TASCedep: 11.7855 GeV
TASC ly: 10 TASCedep: 6.40382 GeV
TASC ly: 11 TASCedep: 5.84998 GeV
TASC ly: 12 TASCedep: 948.827 GeV
TASCelast: 5.84998 GeV
IMC ly: 0 IMCedep: 1.45702 MeV
IMC ly: 1 IMCedep: 1.06052 MeV
IMC ly: 2 IMCedep: 3.5085 MeV
IMC ly: 3 IMCedep: 3.22548 MeV
IMC ly: 4 IMCedep: 10.5168 MeV
IMC ly: 5 IMCedep: 9.49334 MeV
IMC ly: 6 IMCedep: 11.5596 MeV
IMC ly: 7 IMCedep: 13.8441 MeV
IMC ly: 8 IMCedep: 18.1591 MeV
IMC ly: 9 IMCedep: 17.0607 MeV
IMC ly: 10 IMCedep: 24.8274 MeV
IMC ly: 11 IMCedep: 23.1218 MeV
IMC ly: 12 IMCedep: 91.923 MeV
IMC ly: 13 IMCedep: 86.1917 MeV
IMC ly: 14 IMCedep: 200.829 MeV
IMC ly: 15 IMCedep: 193.69 MeV
IMC ly: 16 IMCedep: 710.468 MeV
e1rm: 0.46659 GeV

Type Acc.: 1
x0: 11.0044 cm
y0: -45.2996 cm
z0: -38.0068 cm
costheta: 0.822891
theta: 34.6248 deg
E0: 7033.5 GeV
TASC length: 36.0745 X0
TASC exit layer: 11
Zint: 5.063 cm (IMC)
fe: 0.00165429
re: 1.9915 cm
CHDetot: 0.0527571 GeV
TASC ly: 0 TASCedep: 78.6379 GeV
TASC ly: 1 TASCedep: 163.147 GeV
TASC ly: 2 TASCedep: 167.353 GeV
TASC ly: 3 TASCedep: 195.723 GeV
TASC ly: 4 TASCedep: 149.162 GeV
TASC ly: 5 TASCedep: 84.3053 GeV
TASC ly: 6 TASCedep: 45.2509 GeV
TASC ly: 7 TASCedep: 24.7367 GeV
TASC ly: 8 TASCedep: 12.9126 GeV
TASC ly: 9 TASCedep: 6.64056 GeV
TASC ly: 10 TASCedep: 3.17202 GeV
TASC ly: 11 TASCedep: 1.54276 GeV
TASC ly: 12 TASCedep: 932.584 GeV
TASCelast: 1.54276 GeV
IMC ly: 0 IMCedep: 5.19974 MeV
IMC ly: 1 IMCedep: 1.74335 MeV
IMC ly: 2 IMCedep: 1.73164 MeV
IMC ly: 3 IMCedep: 2.19666 MeV
IMC ly: 4 IMCedep: 4.39772 MeV
IMC ly: 5 IMCedep: 2.88398 MeV
IMC ly: 6 IMCedep: 7.82834 MeV
IMC ly: 7 IMCedep: 8.32547 MeV
IMC ly: 8 IMCedep: 10.3252 MeV
IMC ly: 9 IMCedep: 9.63443 MeV
IMC ly: 10 IMCedep: 12.6146 MeV
IMC ly: 11 IMCedep: 11.1585 MeV
IMC ly: 12 IMCedep: 55.2882 MeV
IMC ly: 13 IMCedep: 59.4015 MeV
IMC ly: 14 IMCedep: 196.769 MeV
IMC ly: 15 IMCedep: 192.079 MeV
IMC ly: 16 IMCedep: 581.577 MeV
e1rm: 0.5518 GeV

Type Acc.: 1
x0: 11.5764 cm
y0: 10.3325 cm
z0: -51.911 cm
costheta: 0.955624
theta: 17.1329 deg
E0: 19275 GeV
TASC length: 31.0639 X0
TASC exit layer: 11
Zint: 9.5901 cm (IMC)
fe: 0.00283607
re: 1.55907 cm
CHDetot: 0.0240129 GeV
TASC ly: 0 TASCedep: 49.7342 GeV
TASC ly: 1 TASCedep: 154.33 GeV
TASC ly: 2 TASCedep: 171.436 GeV
TASC ly: 3 TASCedep: 172.876 GeV
TASC ly: 4 TASCedep: 180.009 GeV
TASC ly: 5 TASCedep: 120.955 GeV
TASC ly: 6 TASCedep: 69.5863 GeV
TASC ly: 7 TASCedep: 37.3201 GeV
TASC ly: 8 TASCedep: 21.0991 GeV
TASC ly: 9 TASCedep: 10.7492 GeV
TASC ly: 10 TASCedep: 5.62359 GeV
TASC ly: 11 TASCedep: 2.82627 GeV
TASC ly: 12 TASCedep: 996.545 GeV
TASCelast: 2.82627 GeV
IMC ly: 0 IMCedep: 0.9101 MeV
IMC ly: 1 IMCedep: 1.1436 MeV
IMC ly: 2 IMCedep: 2.58005 MeV
IMC ly: 3 IMCedep: 2.571 MeV
IMC ly: 4 IMCedep: 2.39681 MeV
IMC ly: 5 IMCedep: 2.76977 MeV
IMC ly: 6 IMCedep: 3.13636 MeV
IMC ly: 7 IMCedep: 2.21965 MeV
IMC ly: 8 IMCedep: 2.71035 MeV
IMC ly: 9 IMCedep: 3.09863 MeV
IMC ly: 10 IMCedep: 4.63158 MeV
IMC ly: 11 IMCedep: 4.2408 MeV
IMC ly: 12 IMCedep: 22.5457 MeV
IMC ly: 13 IMCedep: 19.4614 MeV
IMC ly: 14 IMCedep: 92.858 MeV
IMC ly: 15 IMCedep: 94.8756 MeV
IMC ly: 16 IMCedep: 262.149 MeV
e1rm: 0.59696 GeV

Type Acc.: 4
x0: -2.9467 cm
y0: 19.2467 cm
z0: -51.0007 cm
costheta: 0.938133
theta: 20.2597 deg
E0: 31106 GeV
TASC length: 26.5609 X0
TASC exit layer: 10
Zint: 2.2971 cm (CHD)
fe: 0.00385066
re: 1.48678 cm
CHDetot: 0.0231406 GeV
TASC ly: 0 TASCedep: 77.0627 GeV
TASC ly: 1 TASCedep: 162.587 GeV
TASC ly: 2 TASCedep: 191.503 GeV
TASC ly: 3 TASCedep: 176.389 GeV
TASC ly: 4 TASCedep: 142.665 GeV
TASC ly: 5 TASCedep: 90.8264 GeV
TASC ly: 6 TASCedep: 60.2873 GeV
TASC ly: 7 TASCedep: 31.3705 GeV
TASC ly: 8 TASCedep: 17.0618 GeV
TASC ly: 9 TASCedep: 8.90311 GeV
TASC ly: 10 TASCedep: 3.71194 GeV
TASC ly: 11 TASCedep: 1.60691 GeV
TASC ly: 12 TASCedep: 963.975 GeV
TASCelast: 3.71194 GeV
IMC ly: 0 IMCedep: 2.36178 MeV
IMC ly: 1 IMCedep: 2.38977 MeV
IMC ly: 2 IMCedep: 4.66735 MeV
IMC ly: 3 IMCedep: 5.27486 MeV
IMC ly: 4 IMCedep: 6.69366 MeV
IMC ly: 5 IMCedep: 4.68672 MeV
IMC ly: 6 IMCedep: 10.0094 MeV
IMC ly: 7 IMCedep: 8.5979 MeV
IMC ly: 8 IMCedep: 11.5984 MeV
IMC ly: 9 IMCedep: 12.4694 MeV
IMC ly: 10 IMCedep: 21.4032 MeV
IMC ly: 11 IMCedep: 18.6789 MeV
IMC ly: 12 IMCedep: 77.4512 MeV
IMC ly: 13 IMCedep: 89.7133 MeV
IMC ly: 14 IMCedep: 249.096 MeV
IMC ly: 15 IMCedep: 235.485 MeV
IMC ly: 16 IMCedep: 760.577 MeV
e1rm: 0.549182 GeV

BDT classifier output distributions



Surviving proton events (BDT > 0.315)

BDT: 0.424996
fe: 0.00283607
Re: 1.55907 cm
E1rm: 0.59696
Echd: 0.0240129 GeV
E0: 19275 GeV

BDT: 0.389421
fe: 0.00385066
Re: 1.48678 cm
E1rm: 0.549182
Echd: 0.0231406 GeV
E0: 31106 GeV

BDT: 0.393849
fe: 0.00358725
Re: 1.19459 cm
E1rm: 0.452568
Echd: 0.0125488 GeV

BDT: 0.363908
fe: 0.0064671
Re: 2.51337 cm
E1rm: 0.527967
Echd: 0.136543 GeV

BDT: 0.465012
fe: 0.00883249
Re: 1.66805 cm
E1rm: 0.609894
Echd: 0.0156853 GeV

BDT: 0.316043
fe: 0.00692779
Re: 1.60211 cm
E1rm: 0.51566
Echd: 0.0104418 GeV

BDT: 0.344883
fe: 0.00210835
Re: 1.62321 cm
E1rm: 0.443486
Echd: 0.0243508 GeV
