**27.2.6.** ***Energy loss in mixtures and compounds***: A mixture or compound can be thought of as made up of thin layers of pure elements in the right proportion (Bragg additivity). In this case,

$$\frac{dE}{dx} = \sum w_j \left.\frac{dE}{dx}\right|_j , \tag{27.8}$$

where $dE/dx|_j$ is the mean rate of energy loss (in MeV g cm$^{-2}$) in the $j$th element. Eq. (27.1) can be inserted into Eq. (27.8) to find expressions for $\langle Z/A\rangle$, $\langle I\rangle$, and $\langle\delta\rangle$; for example, $\langle Z/A\rangle = \sum w_j Z_j/A_j = \sum n_j Z_j / \sum n_j A_j$. However, $\langle I\rangle$ as defined this way is an underestimate, because in a compound electrons are more tightly bound than in the free elements, and $\langle\delta\rangle$ as calculated this way has little relevance, because it is the electron density which matters. If possible, one uses the tables given in Refs. 24 and 31, which include effective excitation energies and interpolation coefficients for calculating the density effect correction for the chemical elements and nearly 200 mixtures and compounds. If a compound or mixture is not found, then one uses the recipe for $\delta$ given in Ref. 22 (repeated in Ref. 1), and calculates $\langle I\rangle$ according to the discussion in Ref. 11. (Note the "13%" rule!)

**27.2.7.** ***Ionization yields***: Physicists frequently relate total energy loss to the number of ion pairs produced near the particle's track. This relation becomes complicated for relativistic particles due to the wandering of energetic knock-on electrons whose ranges exceed the dimensions of the fiducial volume. For a qualitative appraisal of the nonlocality of energy deposition in various media by such modestly energetic knock-on electrons, see Ref. 32. The mean local energy dissipation per local ion pair produced, $W$, while essentially constant for relativistic particles, increases at slow particle speeds [33]. For gases, $W$ can be surprisingly sensitive to trace amounts of various contaminants [33]. Furthermore, ionization yields in practical cases may be greatly influenced by such factors as subsequent recombination [34].

## 27.3. Multiple scattering through small angles

A charged particle traversing a medium is deflected by many small-angle scatters. Most of this deflection is due to Coulomb scattering from nuclei, and hence the effect is called multiple Coulomb scattering. (However, for hadronic projectiles, the strong interactions also contribute to multiple scattering.) The Coulomb scattering distribution is well represented by the theory of Molière [35]. It is roughly Gaussian for small deflection angles, but at larger angles (greater than a few $\theta_0$, defined below) it behaves like Rutherford scattering, having larger tails than does a Gaussian distribution.

If we define

$$\theta_0 = \theta_{\rm plane}^{\rm rms} = \frac{1}{\sqrt{2}}\,\theta_{\rm space}^{\rm rms} . \tag{27.9}$$

then it is sufficient for many applications to use a Gaussian approximation for the central 98% of the projected angular distribution, with a width given by [36,37]

$$\theta_0 = \frac{13.6\ {\rm MeV}}{\beta c p}\, z\, \sqrt{x/X_0}\Big[1 + 0.038 \ln(x/X_0)\Big] . \tag{27.10}$$

Here $p$, $\beta c$, and $z$ are the momentum, velocity, and charge number of the incident particle, and $x/X_0$ is the thickness of the scattering medium in radiation lengths (defined below).



take p or se trouble! ($\beta = \frac{p}{E}$)

~~$\beta c p = E = \sqrt{938.27^2 + 500^2} = 1063.17$ MeV~~

$\theta_0 = \frac{13.6\ \text{MeV}}{1063.17\ \text{MeV}} \cdot 1 \cdot \sqrt{\frac{2.7}{303.73}} = 1.206 \cdot 10^{-3}$ rad.

$y \sim \theta_0 \cdot 2.7 = 3.26$ mm

$x = 2.7$ m

$X_0 = \frac{X_0}{\rho} = \frac{36.6\ \text{g}\ \text{dm}^3}{\text{cm}^2 \cdot 1.205\ \text{g}} = \frac{36.6\ \text{g} \cdot 1000\ \text{cm}^3}{\text{cm}^2 \cdot 1.205\ \text{g}} = 30373$ cm $= 303.73$ m

This value of $\theta_0$ is from a fit to Molière distribution [35] for singly charged particles with $\beta = 1$ for all $Z$, and is accurate to 11% or better for $10^{-3} < x/X_0 < 100$.

Eq. (27.10) describes scattering from a single material, while the usual problem involves the multiple scattering of a particle traversing many different layers and mixtures. Since it is from a fit to a Molière distribution, it is incorrect to add the individual $\theta_0$ contributions in quadrature; the result is systematically too small. It is much more accurate to apply Eq. (27.10) once, after finding $x$ and $X_0$ for the combined scatterer.

Lynch and Dahl have extended this phenomenological approach, fitting Gaussian distributions to a variable fraction of the Molière distribution for arbitrary scatterers [37], and achieve accuracies of 2% or better.

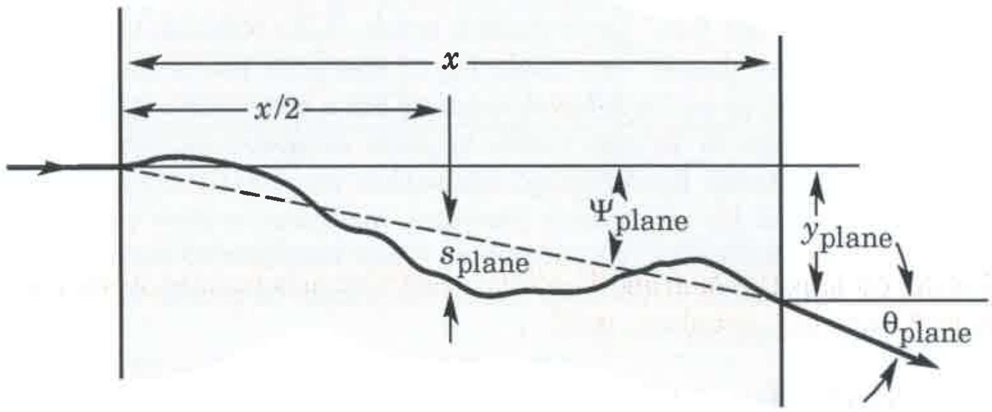



**Figure 27.8:** Quantities used to describe multiple Coulomb scattering. The particle is incident in the plane of the figure.

The nonprojected (space) and projected (plane) angular distributions are given approximately by [35]

$$\frac{1}{2\pi\,\theta_0^2}\exp\left(-\frac{\theta_{\rm space}^2}{2\theta_0^2}\right)d\Omega\ , \tag{27.11}$$

$$\frac{1}{\sqrt{2\pi}\,\theta_0}\exp\left(-\frac{\theta_{\rm plane}^2}{2\theta_0^2}\right)d\theta_{\rm plane}\ , \tag{27.12}$$

where $\theta$ is the deflection angle. In this approximation, $\theta^2_{\rm space} \approx (\theta^2_{{\rm plane},x} + \theta^2_{{\rm plane},y})$, where the $x$ and $y$ axes are orthogonal to the direction of motion, and $d\Omega \approx d\theta_{{\rm plane},x}\,d\theta_{{\rm plane},y}$. Deflections into $\theta_{{\rm plane},x}$ and $\theta_{{\rm plane},y}$ are independent and identically distributed.

Figure 27.8 shows these and other quantities sometimes used to describe multiple Coulomb scattering. They are

$$\psi^{\rm rms}_{\rm plane} = \frac{1}{\sqrt{3}}\,\theta^{\rm rms}_{\rm plane} = \frac{1}{\sqrt{3}}\,\theta_0\ , \qquad (27.13)$$

$$y^{\rm rms}_{\rm plane} = \frac{1}{\sqrt{3}}\,x\,\theta^{\rm rms}_{\rm plane} = \frac{1}{\sqrt{3}}\,x\,\theta_0\ , \qquad (27.14)$$

$$s^{\rm rms}_{\rm plane} = \frac{1}{4\sqrt{3}}\,x\,\theta^{\rm rms}_{\rm plane} = \frac{1}{4\sqrt{3}}\,x\,\theta_0\ . \qquad (27.15)$$

All the quantitative estimates in this section apply only in the limit of small $\theta^{\rm rms}_{\rm plane}$ and in the absence of large-angle scatters. The random variables $s$, $\psi$, $y$, and $\theta$ in a given plane are distributed in a correlated fashion (see Sec. 31.1 of this *Review* for the definition of the correlation coefficient). Obviously, $y \approx x\psi$. In addition, $y$ and $\theta$ have the correlation coefficient $\rho_{y\theta} = \sqrt{3}/2 \approx 0.87$. For Monte Carlo generation of a joint $(y_{\rm plane}, \theta_{\rm plane})$ distribution, or for other calculations, it may be most convenient to work with independent Gaussian random variables $(z_1, z_2)$ with mean zero and variance one, and then set

$$y_{\rm plane} = z_1\,x\,\theta_0(1-\rho^2_{y\theta})^{1/2}/\sqrt{3} + z_2\,\rho_{y\theta}x\,\theta_0/\sqrt{3}$$

$$= z_1\,x\,\theta_0/\sqrt{12} + z_2\,x\,\theta_0/2\ ; \qquad (27.16)$$

$$\theta_{\rm plane} = z_2\,\theta_0\ . \qquad (27.17)$$

Note that the second term for $y_{\rm plane}$ equals $x\,\theta_{\rm plane}/2$ and represents the displacement that would have occurred had the deflection $\theta_{\rm plane}$ all occurred at the single point $x/2$.

For heavy ions the multiple Coulomb scattering has been measured and compared with various theoretical distributions [38].

## 27.4. Photon and electron interactions in matter

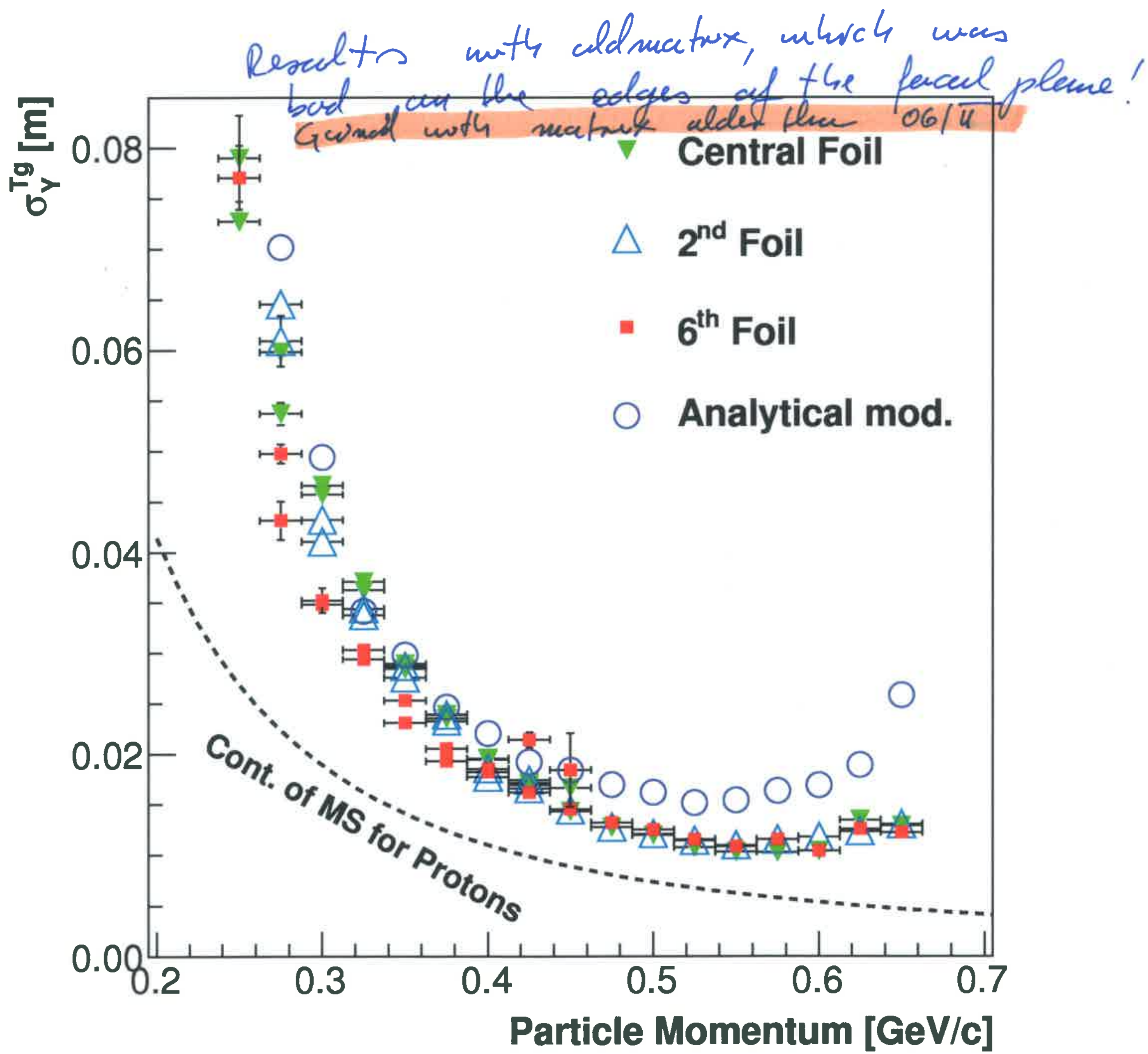
**27.4.1.** ***Radiation length***: High-energy electrons predominantly lose energy in matter by bremsstrahlung, and high-energy photons by $e^+e^-$ pair production. The characteristic amount of matter traversed for these related interactions is called the radiation length $X_0$, usually measured in g cm$^{-2}$. It is both (a) the mean distance over which a high-energy electron loses all but $1/e$ of its energy by bremsstrahlung, and (b) $\frac{7}{9}$ of the mean free path for pair production by a high-energy photon [39]. It is also the appropriate scale length for describing high-energy electromagnetic cascades. $X_0$ has been calculated and tabulated by Y.S. Tsai [40]:

$$\frac{1}{X_0} = 4\alpha r_e^2\frac{N_A}{A}\left\{Z^2\left[L_{\rm rad} - f(Z)\right] + Z\,L'_{\rm rad}\right\}\ . \qquad (27.18)$$

For $A = 1$ g mol$^{-1}$, $4\alpha r_e^2 N_A/A = (716.408$ g cm$^{-2})^{-1}$. $L_{\rm rad}$ and $L'_{\rm rad}$ are given in Table 27.2. The function $f(Z)$ is an infinite sum, but for elements up to uranium can be represented to 4-place accuracy by

$$f(Z) = a^2\left[(1+a^2)^{-1} + 0.20206\right.$$

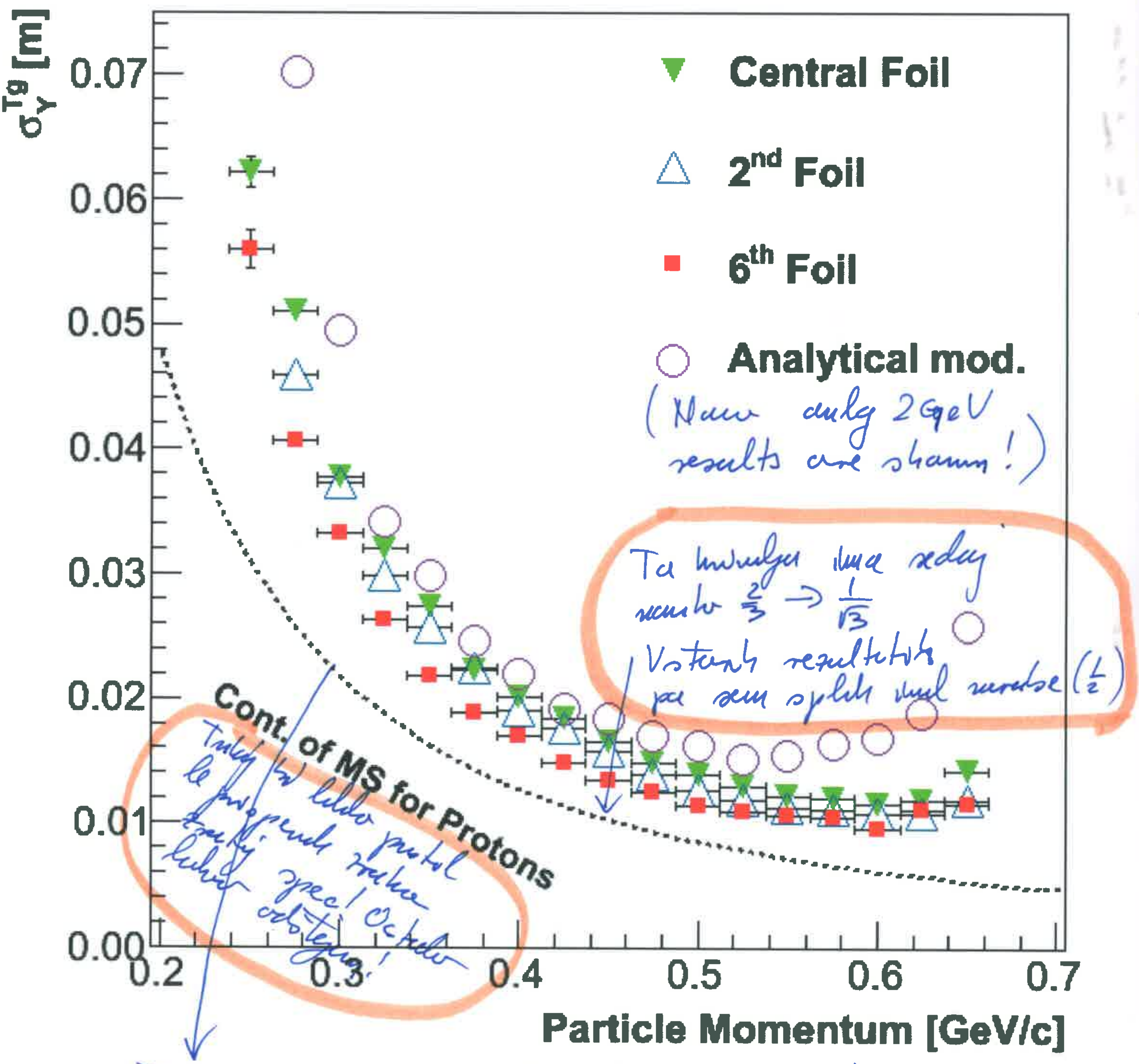
$$\left. -0.0369\,a^2 + 0.0083\,a^4 - 0.002\,a^6\right]\ , \qquad (27.19)$$


Results with old matrix, which was bad on the edges of the focal plane!
Generated with matrix older than '06/11
Central Foil
2nd Foil
6th Foil
Analytical mod.
Cont. of MS for Protons
0.00
0.02
0.04
0.06
0.08
σ_Y^Tg [m]
0.2
0.3
0.4
0.5
0.6
0.7
Particle Momentum [GeV/c]

08/06/11

# NEW RESULTS!

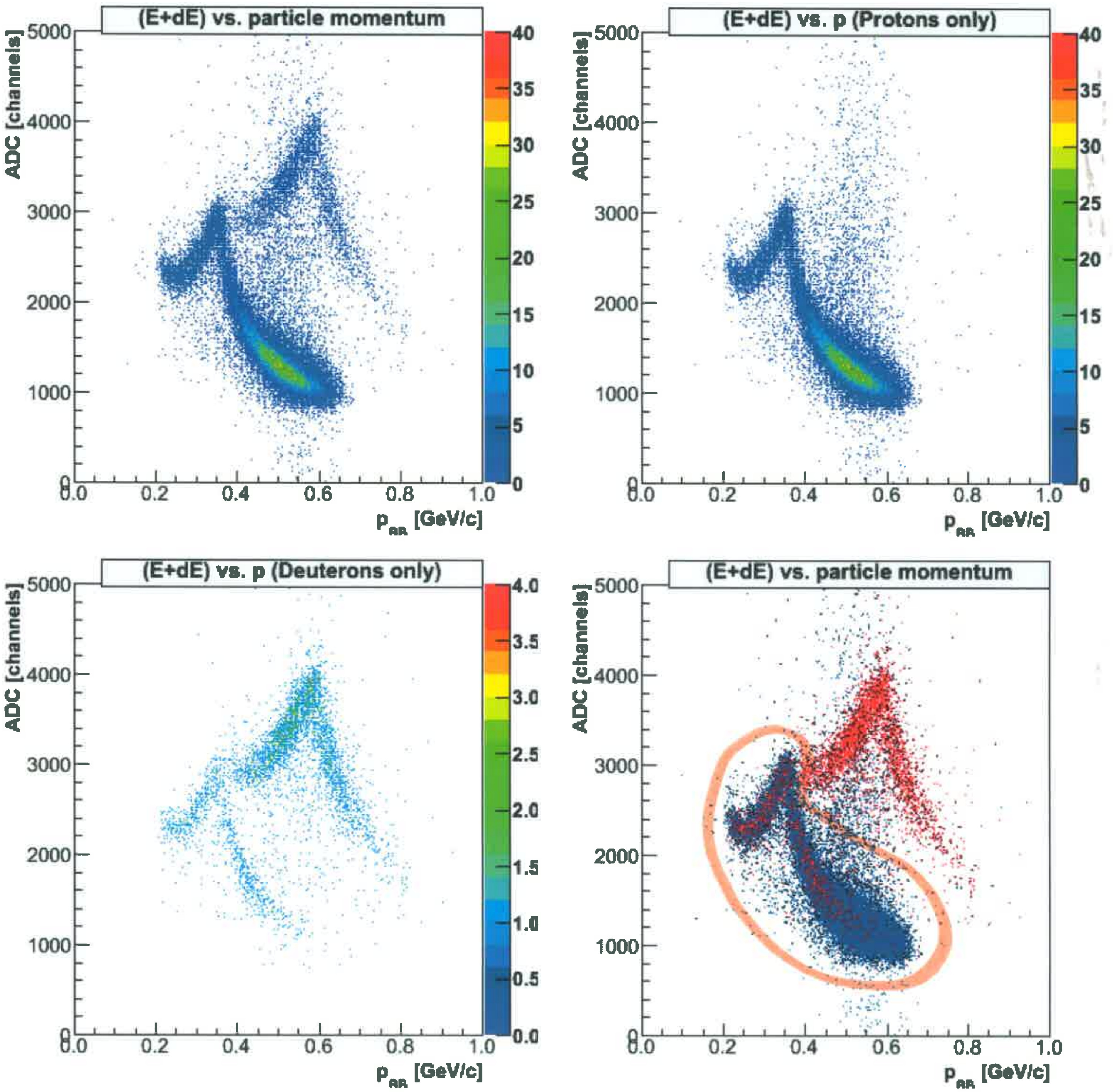
These are the results with the new matrix! Resolution is better on the edges, and slightly worse in the center!




Tega se ne da odšteti od zgornjih rezultatov, ker je to del spektrometra. Ta ne pride od tistega pred spektrometrom! Odšteti bi lahko le (-) tu zraka pred spektrometrom! To pa lahko naredim! Vprašaj Simona!?

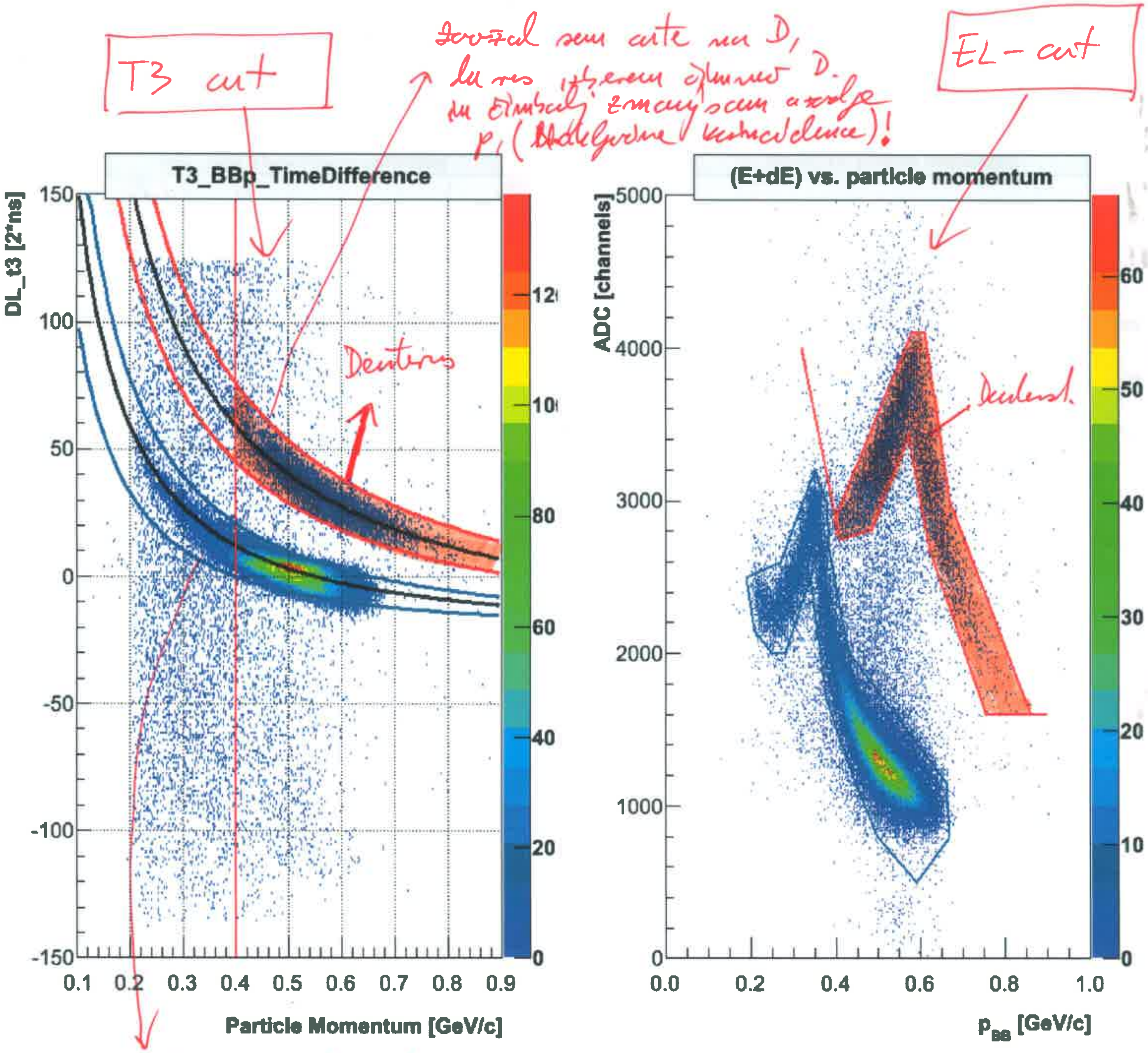
2.7 = 1.7 + 1

08/04/14



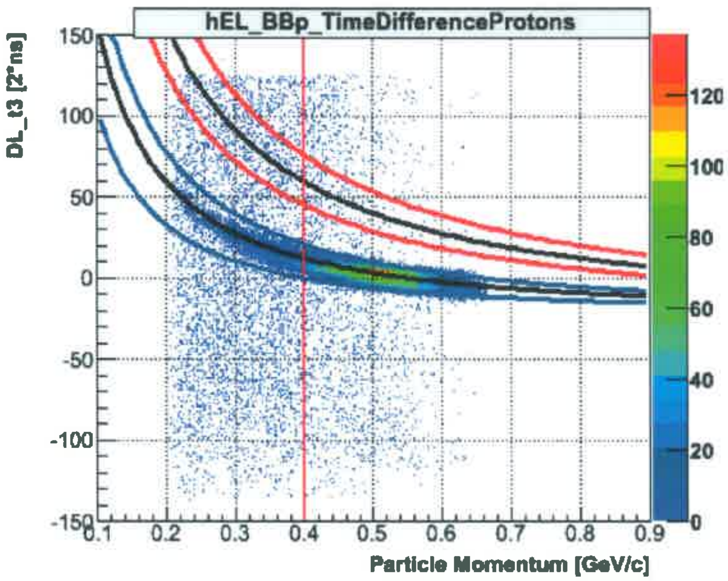

Ta so Pluto njegega PID, če namesto E-L plota za PID uporabim T3 cut!

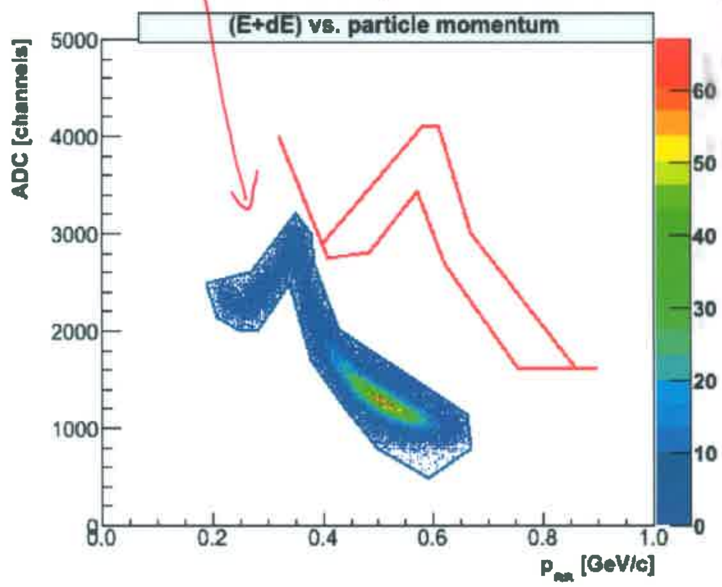
08/05/11

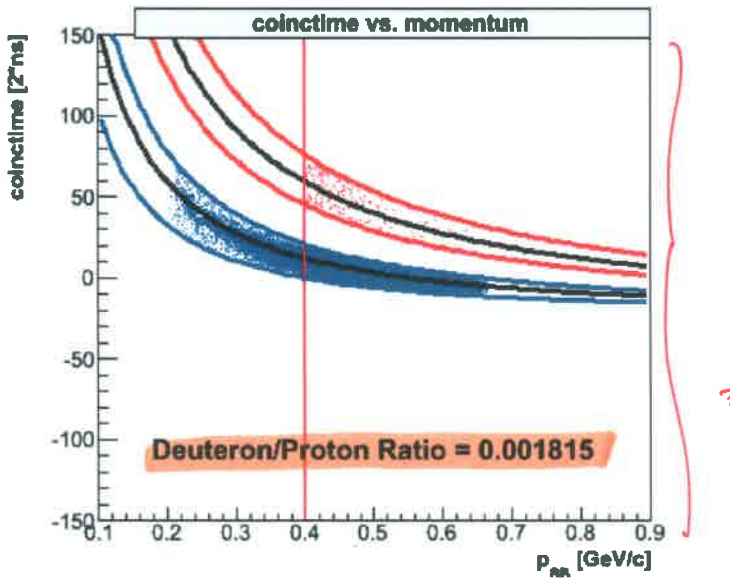



Dodal sem tudi ostre cute na dobre protone! Tako izpustim velik del naključnih koincidenc, ker jih tako kasneje odšteval z T3 histogramom.

E-L cut on Protons



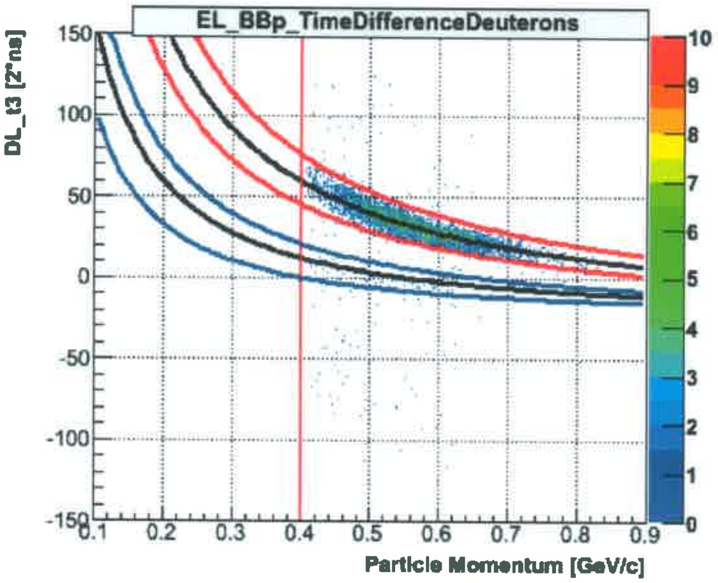



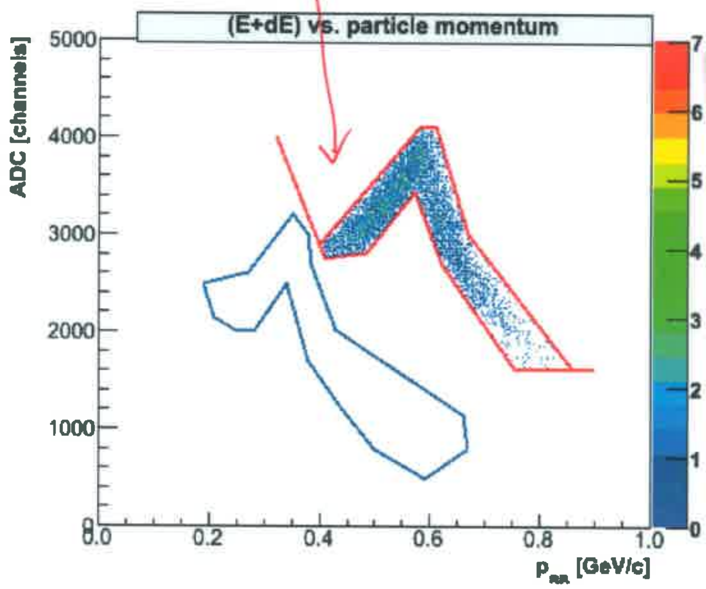



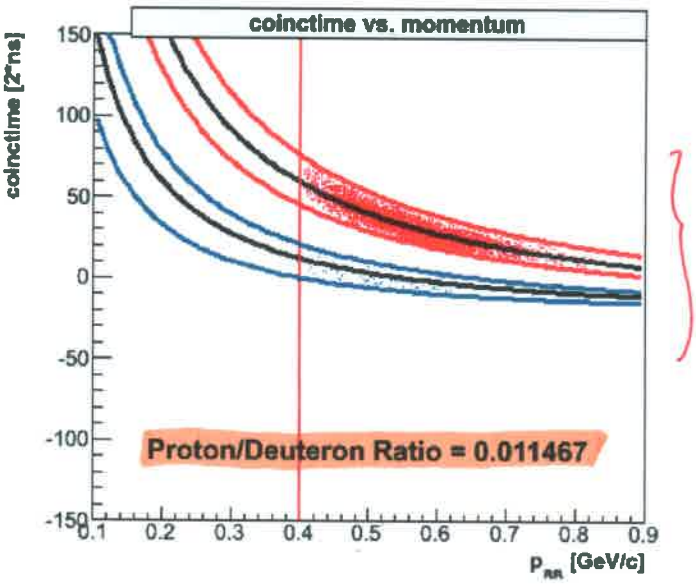

How many Protons are in fact Deuterons.
How many protons are ~~[illegible]~~ misidentified?
~~[illegible]~~ To check that, T3 cut is used!

0.2 %.

E-L cut on Deuterons



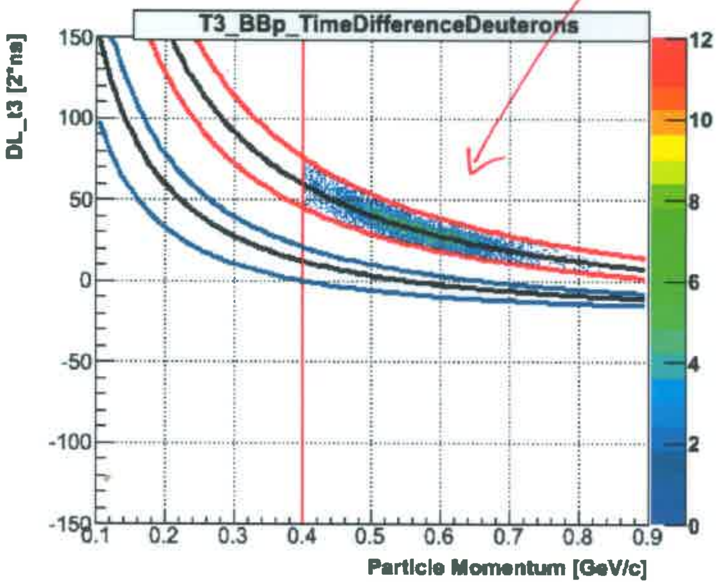

How many protons are identified as deuterons?

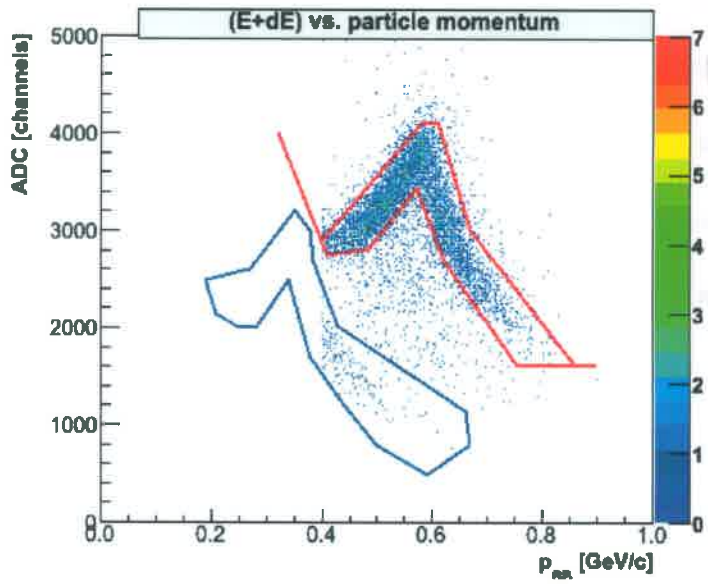
~ 1%

ZAKLJUČEK

Vsaj iz te analize se zdi, da E-L-PID dela bolje kot T3-PID. Poleg tega EL-PID omogoča, da v nadaljnji analizi konstantno odštejemo ozadje nelastičnih kanalov. !

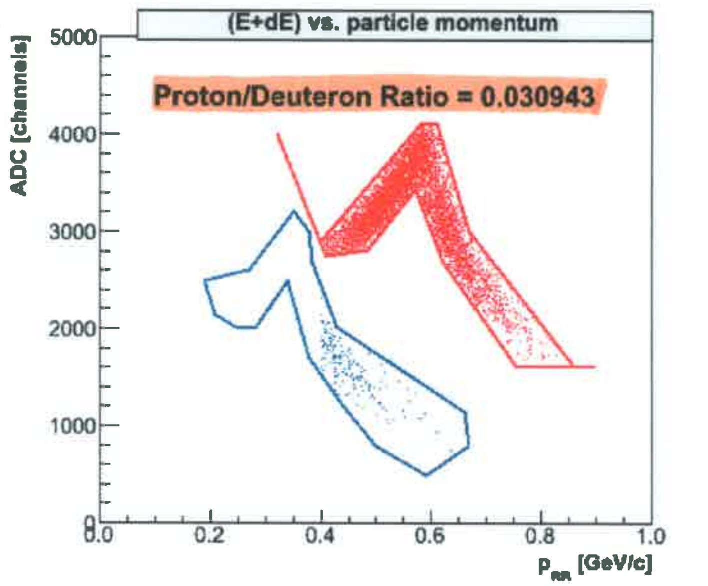
T3 – Cut on Deuterons



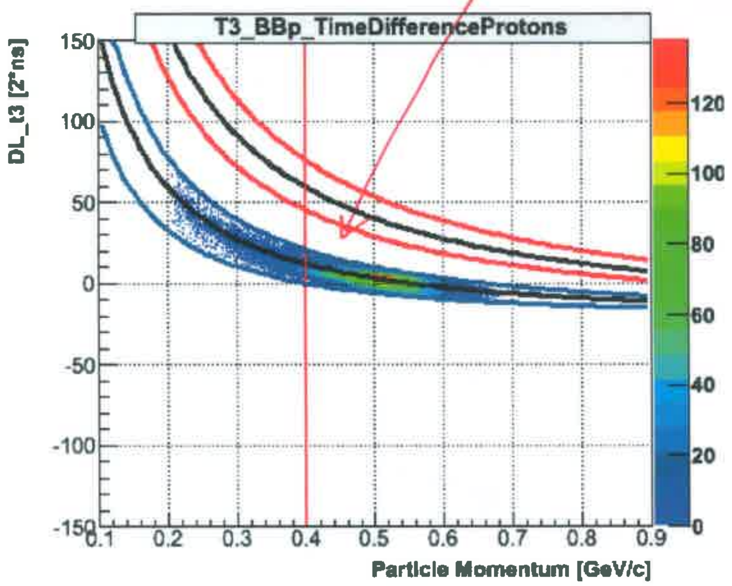



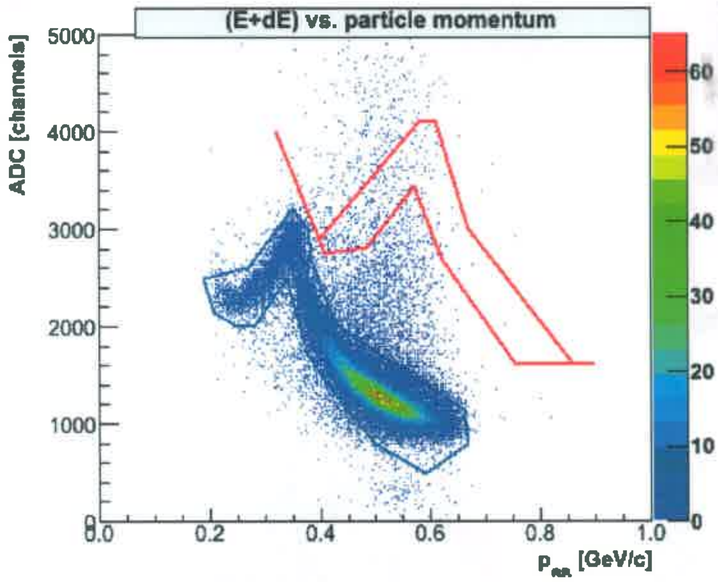

How many Protons are identified as Deuterons. To check this, EL-cut is used!

Contamination is ~ 3%.



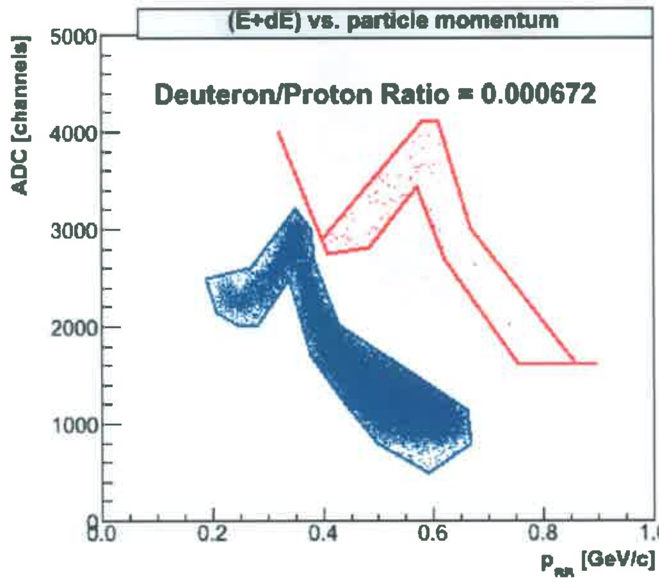
T3 - cut on Protons



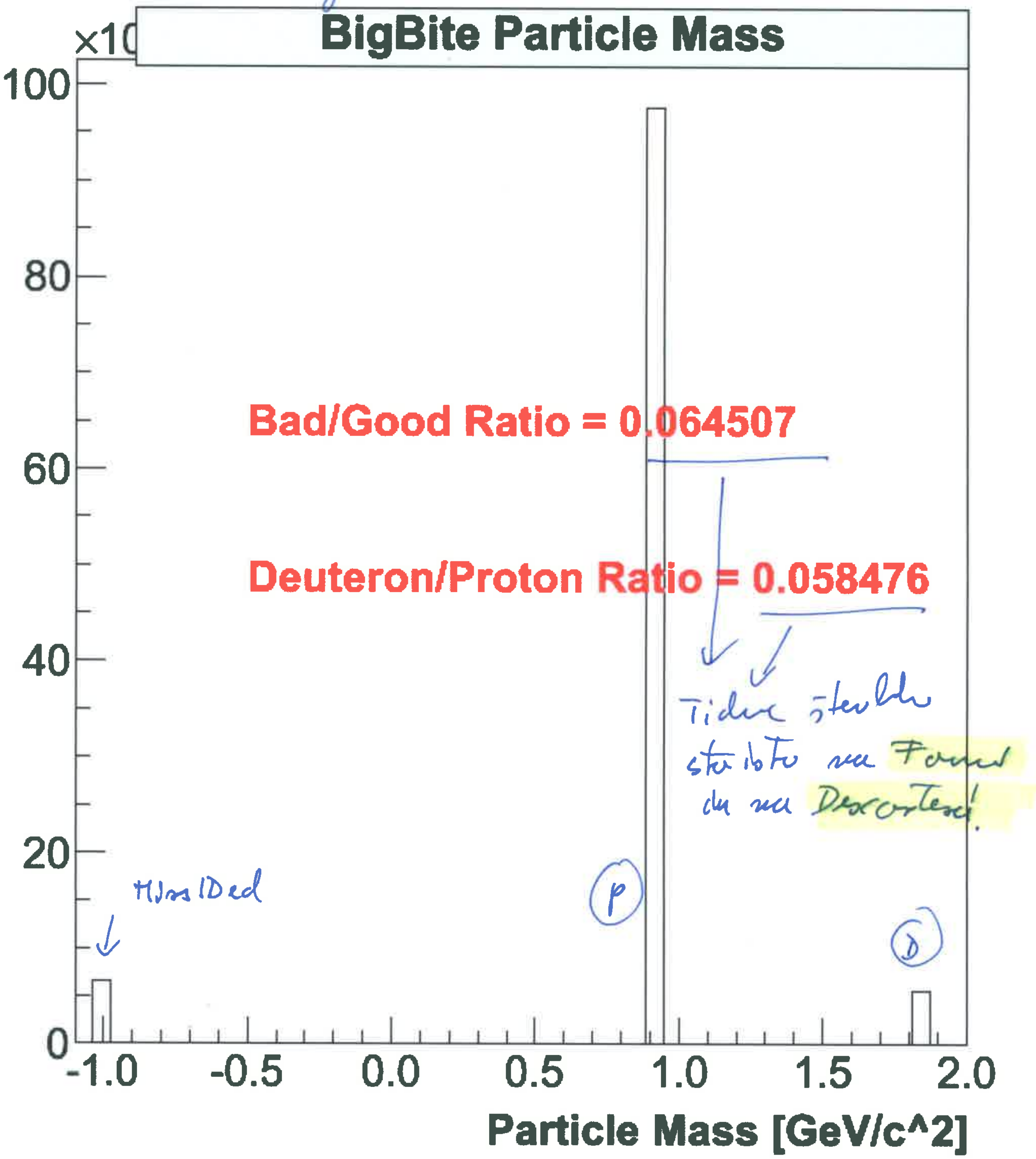

Contamination of Proton with deuteron, using T3 cut for PID, is

≲ 0.1%.



08/09/II

To je za run #2300




Pogledal sem, ali z Root fajli, ki jih analiziram na Forni dobim iste rezultate, kot jih dobim, ko naredim analizo na svojem računalniku! Zdi se, da da PID iste rezultate!

08/10/11

- With cleaned up Data set (Root file) Run #2300 needs ≲ 1 minute (58 sec) to ~~calculate~~ do the RunAsymmetry script!

- With old (uncleaned) Root file analysis took 7 minutes and 54 seconds! This is a lot more!

- There is also a large difference in the file size. Old root files are ~ 1.76 GB while the new file is only 0.36 GB. This means big difference, when transfering data from JLab to Ljubljana!

---

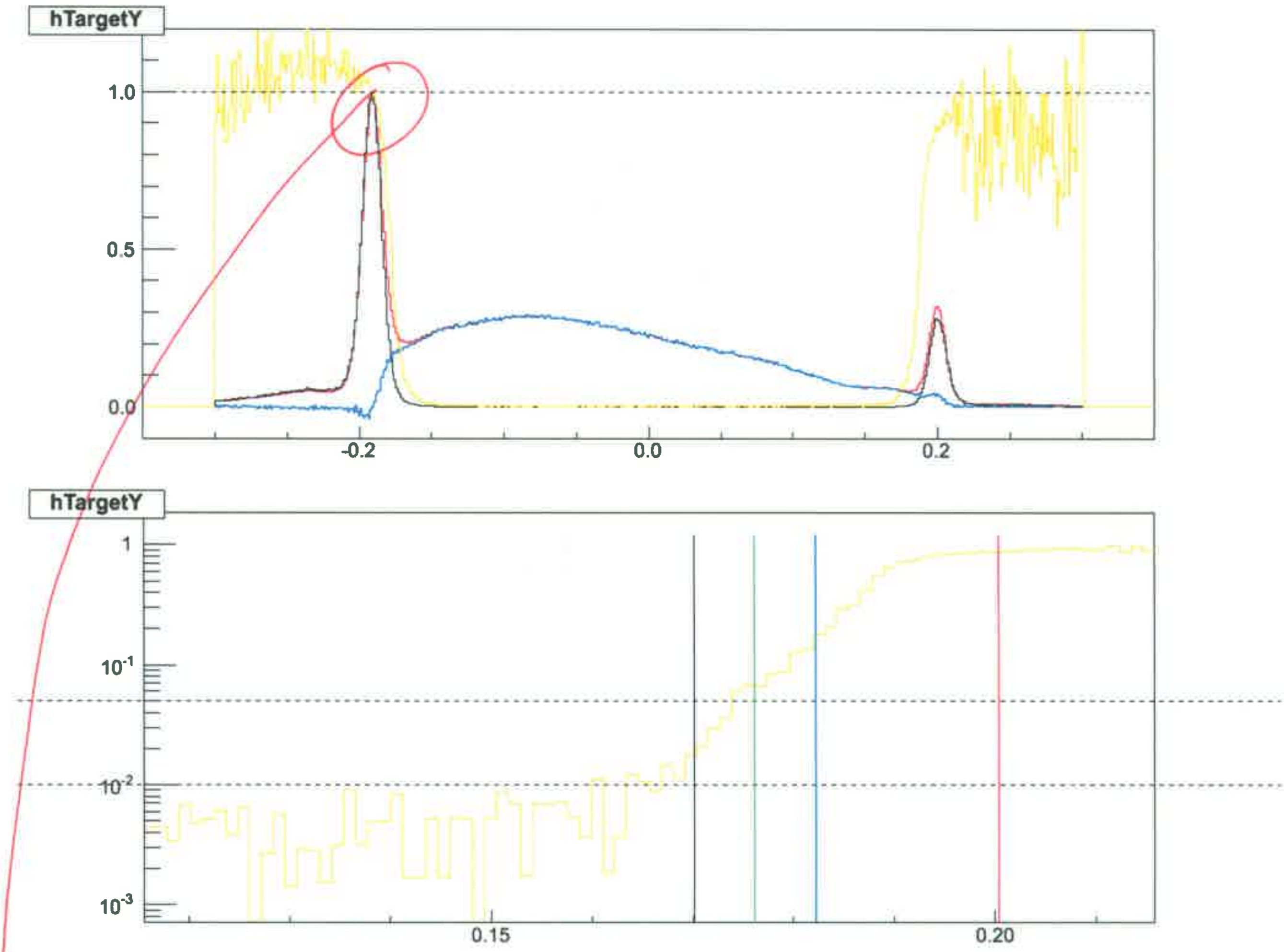
| | | | | | |
|---|---|---|---|---|---|
| #3156 | # = 826 k | DT = 15.44% | I = 10.3 μA | Q = 2.36 mC | t = 3.781 min |
| #3158 | # = 4M | DT = 6.78% | I = 7.74 μA | Q = 0.0159 C | t = 34.0 min |

| | | |
|---|---|---|
| #3156 | PS1 = 294, PS3 = 5, PS4 = 2 | PS2 = 254, PS5 = 1, PS6 = 1 |
| #3158 | PS1 = 294, PS3 = 10, PS4 = 2 | PS2 = 254, PS5 = 1, PS6 = 1 |

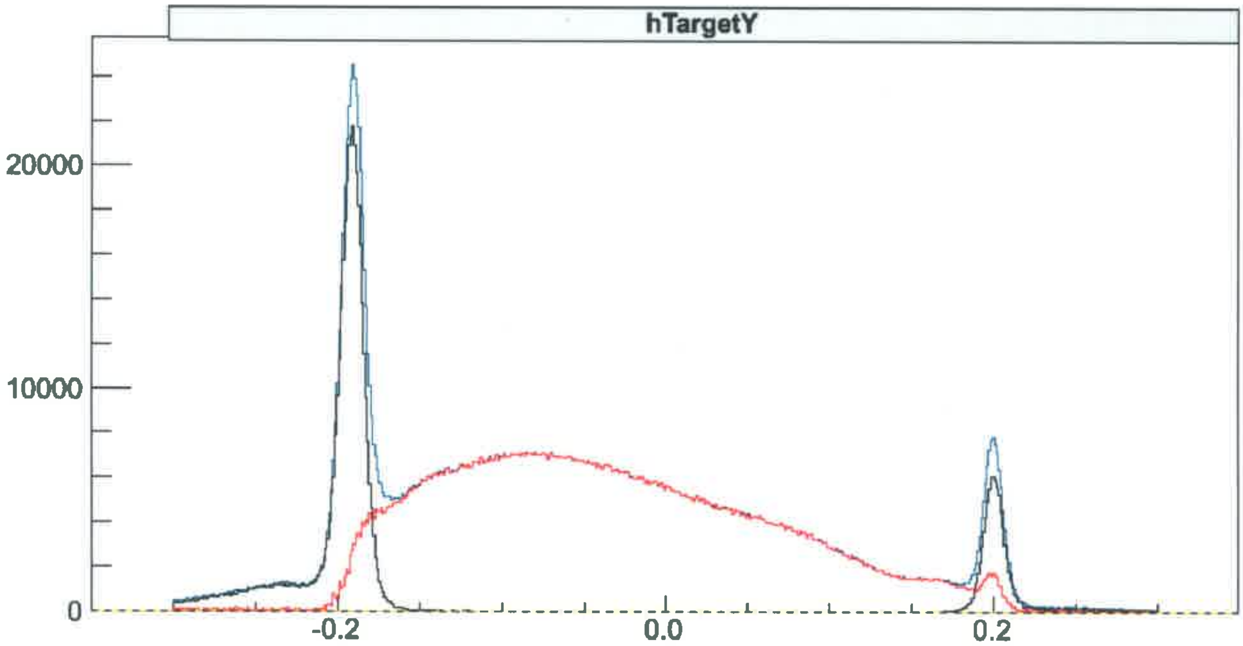
Do ~ 10% natančno ujemanje!

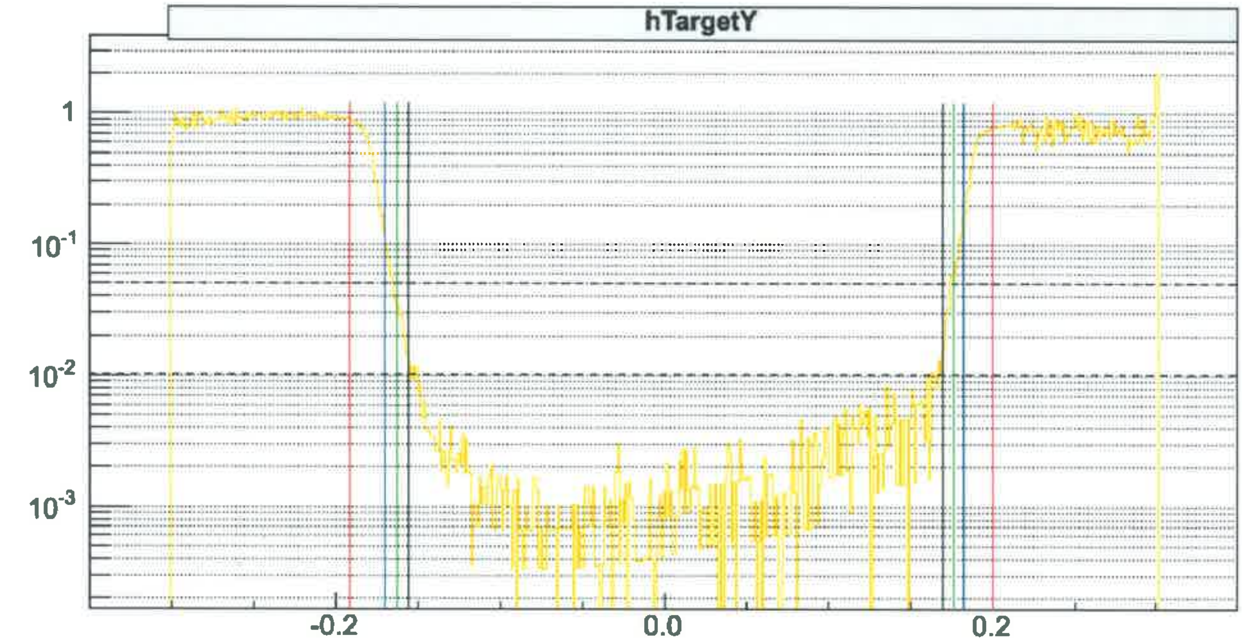
08/03/11



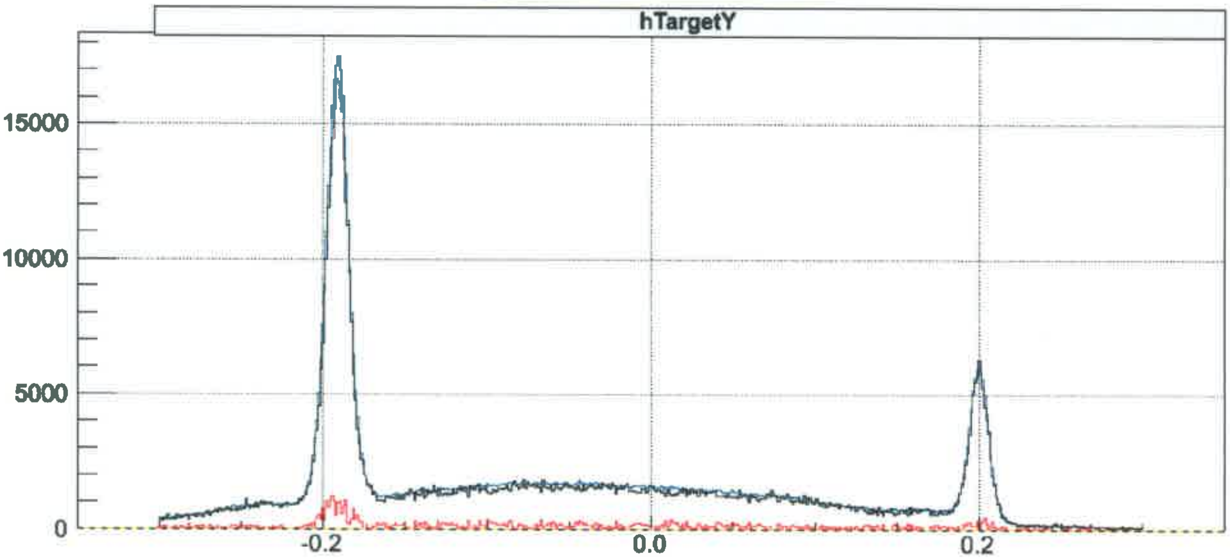


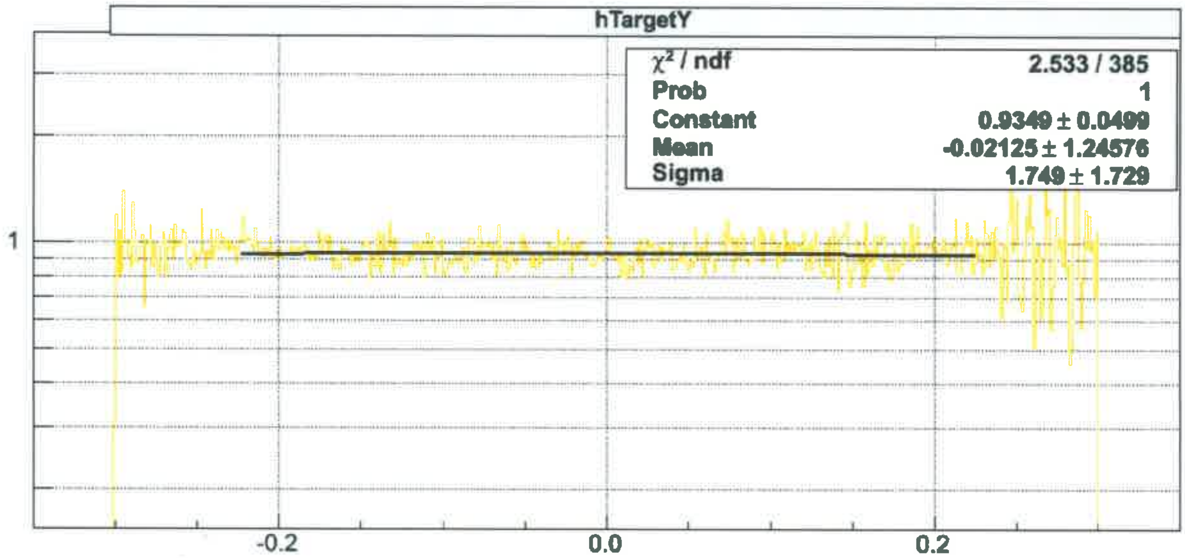

Normaliziraj tale na charge, ne na front peak! (Mislim pa, da ne bi smelo biti velike razlike!) Pazi na dead time!


hTargetY
20000
10000
0
-0.2
0.0
0.2


hTargetY
1
$10^{-1}$
$10^{-2}$
$10^{-3}$
-0.2
0.0
0.2

$PS3_1 = 5$ , $PS3_2 = 10$



PS$3_1$ = 10 ; PS$3_2$ = 200