The Compact Muon Solenoid Experiment

CMS Draft Note

Searches for Heavy Stable Charged Particles

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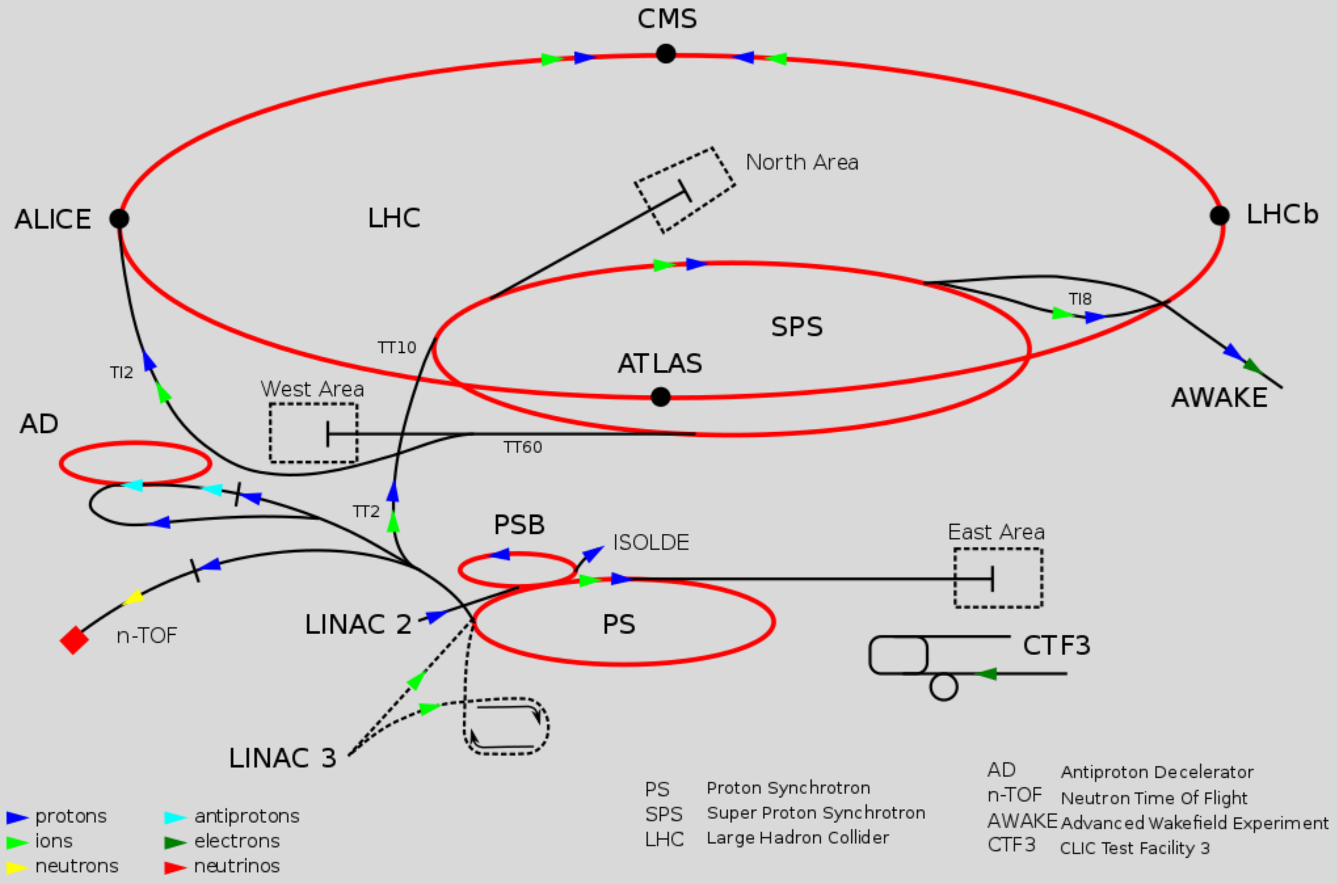
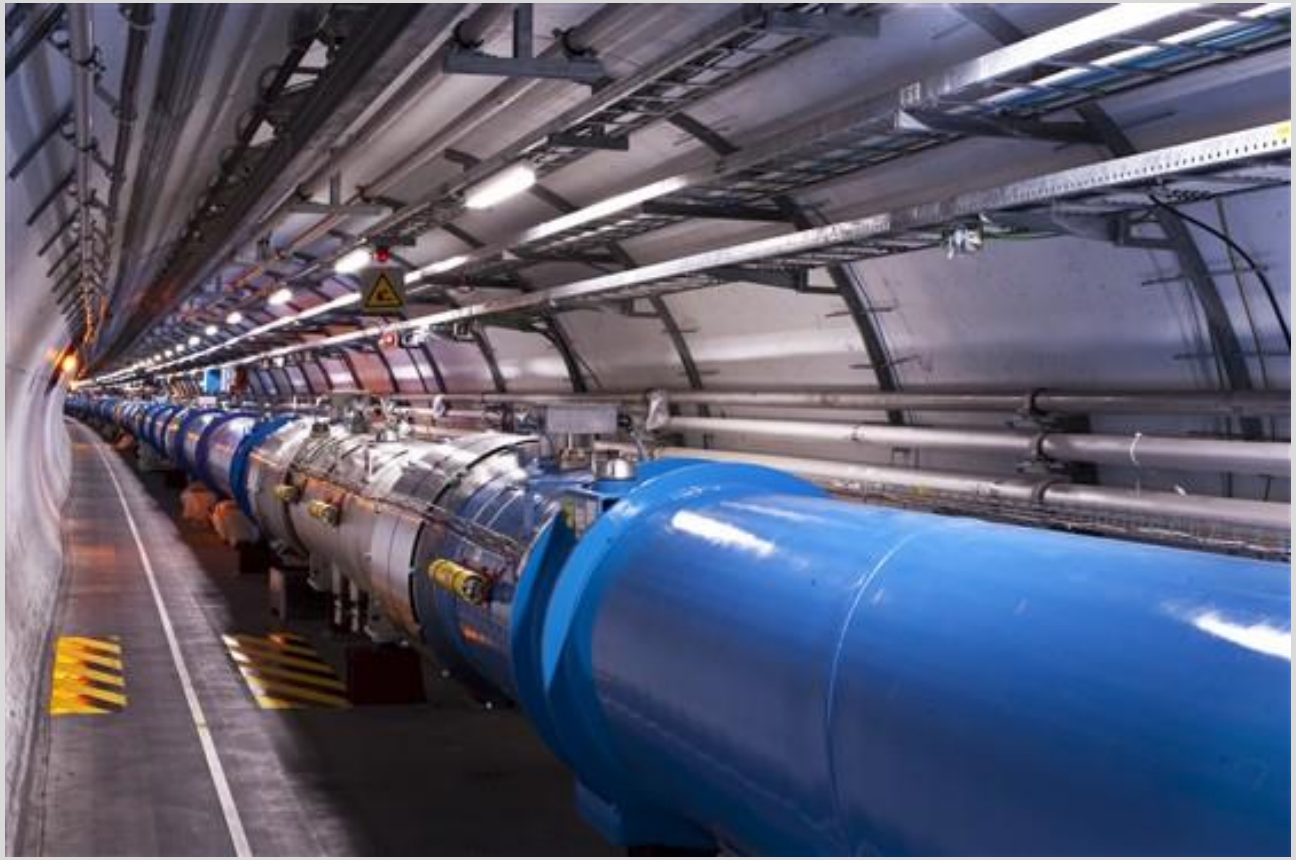
Large Hadron Collider



World largest and highest energy particle collider
27km in circumference, as deep as 175m
Up to 13 TeV total collision energy

- Higgs mechanism
- Supersymmetry
- Nature of dark matter

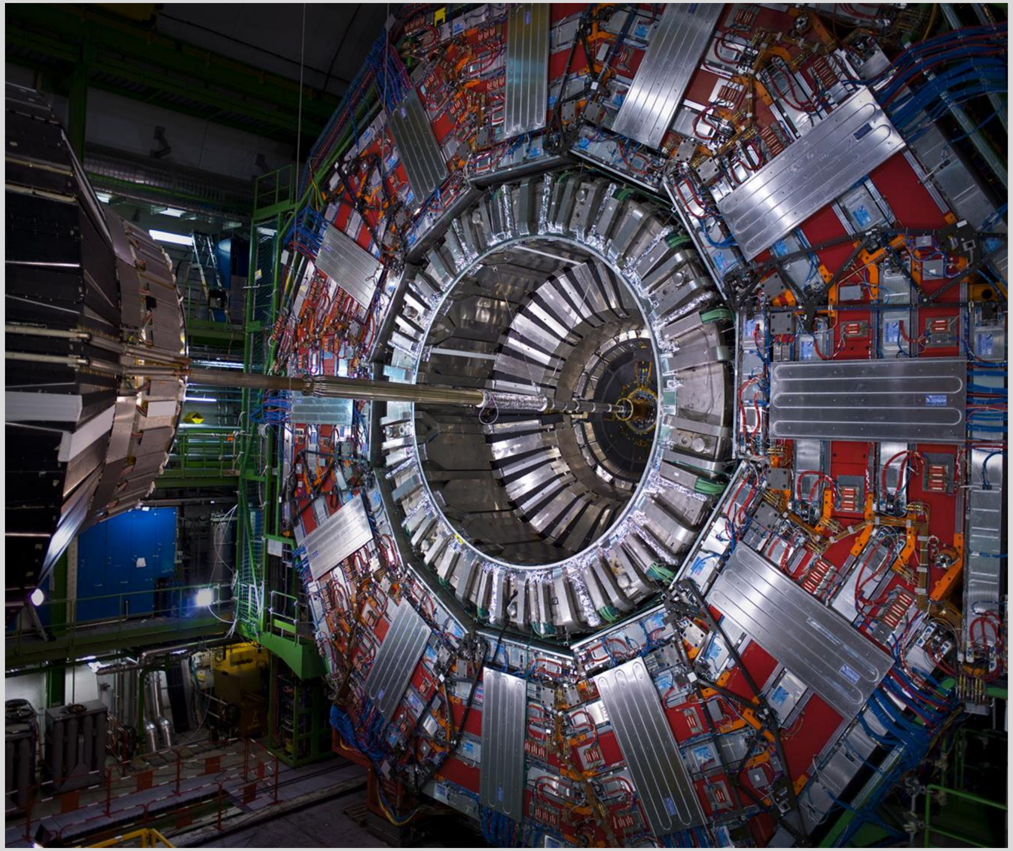
Large Hadron Collider



The LHC and its main detectors :

- ATLAS : ATLAS studies the Higgs boson and looks for signs of new physics, including the origins of mass and extra dimensions
- ALICE : ALICE is studying a fluid form of matter called Quark-gluon plasma that existed shortly after the Big Bang
- LHCb : LHCb investigates what happened to the missing antimatter in the count of the matter created by the Bing Bang

Compact Muon Solenoid



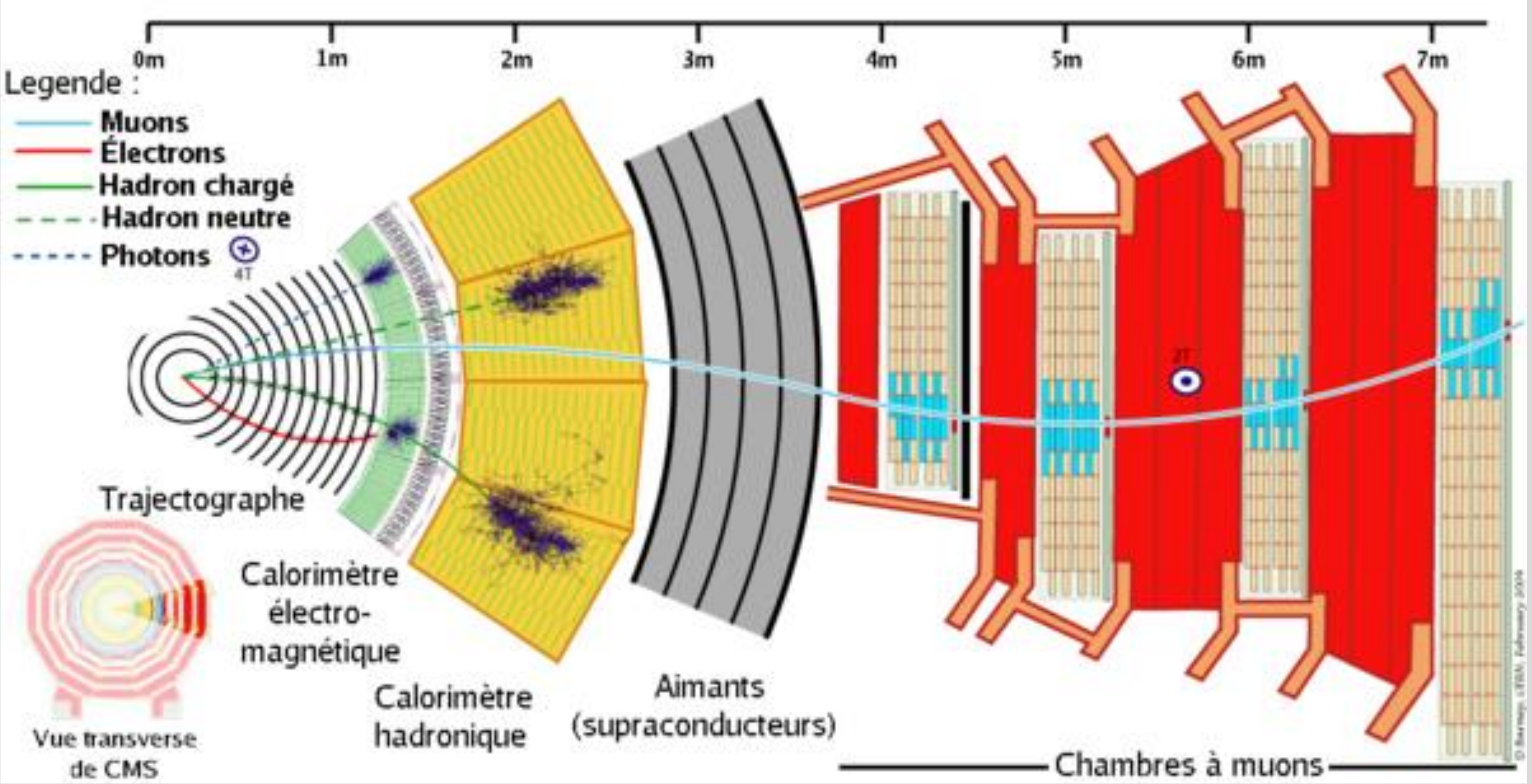
Characteristics :

- 21m long x 15m wide
- 14 000 Tonnes
- Magnetic field intensity of 4T

Major goals :

- Confirm and improve measurements concerning the Standard Model (SM)
- Discovery of the Higgs Boson (2012)
- Explore physics at TeV energy
- Search for Physics beyond the standard model (BSM)
- Study of the Quark-Gluons plasma in heavy ion collisions

CMS Detector

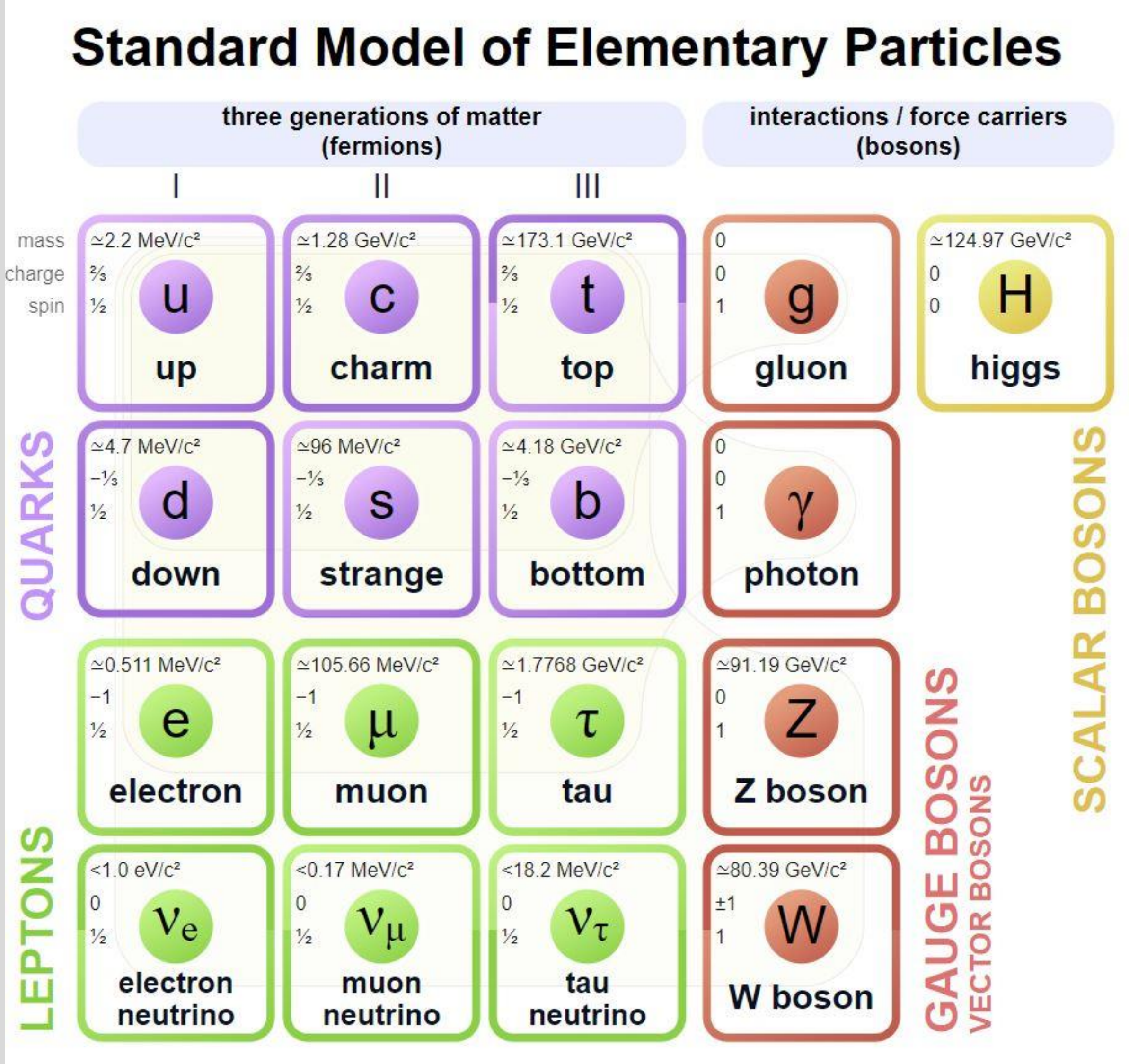


The CMS detector is composed of sub-systems detectors:

- The Tracker (Pixel silicon detector)
- The Electromagnetic Calorimeter ECAL
- The Hadronic calorimeter HCAL
- The Magnet
- The Muon detector

Muons ~ electrons and positron but ~ 200x massive

HSCP (Heavy Stable Charged Particle)

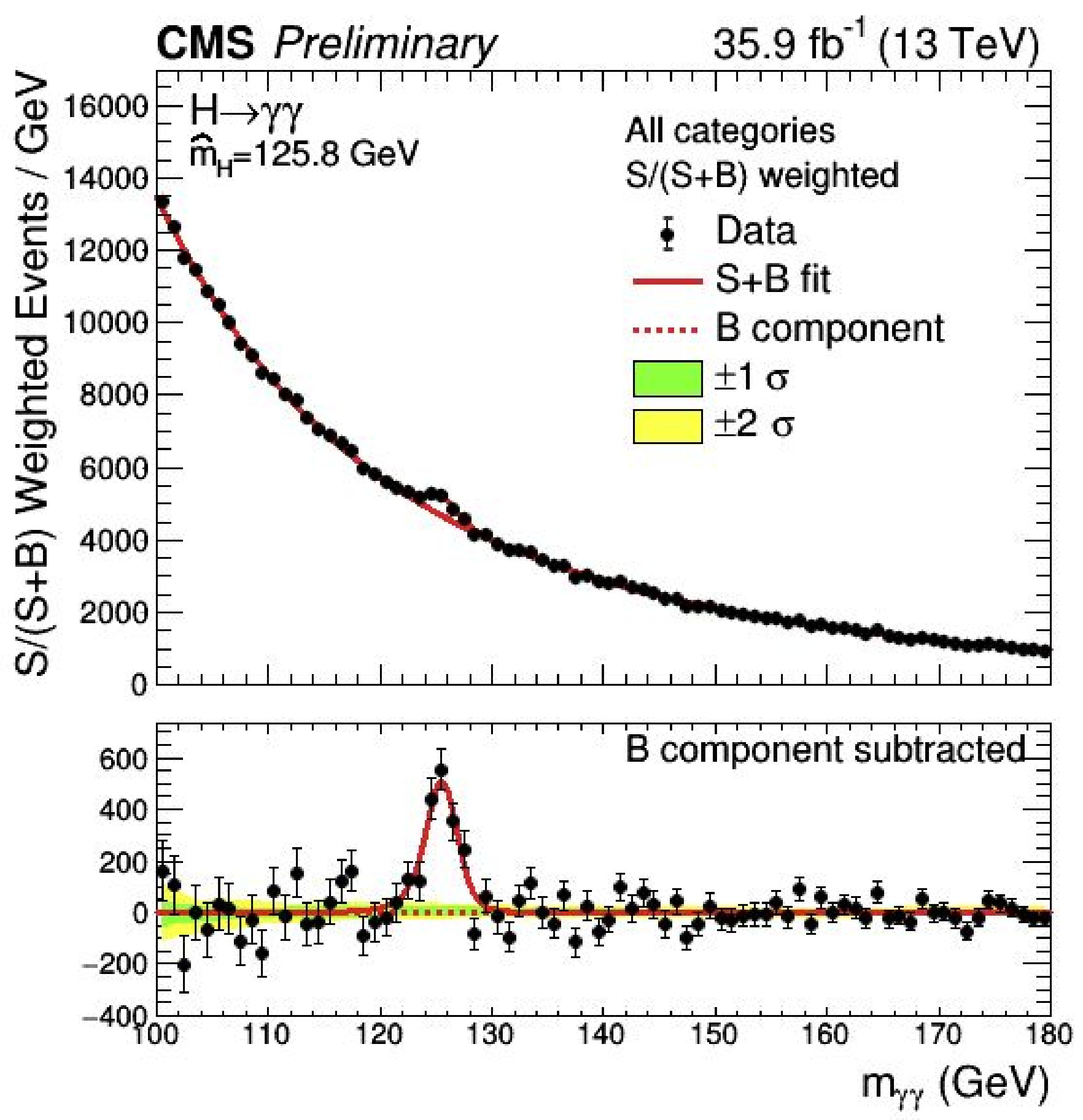


Many extensions of the standard model include heavy, long-lived, charged particles that might have speed significantly less than the speed of light

- Heavy: HSCP rate of energy loss
- Long-lived: Long lifetime means if goes further in the detector
- Charged: HSCP particles might have a charge Q not equal to + or - 1e

Particle detection method

- Prediction of the number of events expected at a certain energy point (background)
- Prediction for the mass distribution and the masses of HSCPs
- Subtraction of the background and analysis of the remaining signal



Variables used to predict masses

- Equation used to determine masses :

$$I_h = K * \frac{m^2}{p^2} + \mathrm{C}$$

- Ih = Harmonical estimator for dE/dx
- K and C empirical constant extracted from data
- m = mass of a particle
- p = impulsion of a particle
- We will also use another estimator I_{as} that is the probability of deviation from the MIP

Two different analysis

Trk-only

Trk+TOF

Table 1: Preselection criteria for the various analyses

	Trk-only | Trk+TOF
Track Type	Inner Track | Global Muon
|η|	< 2.1
P_T (GeV)	> 55
# of dE/dx Measurements	> 5
#TOF Measurements	/ | >7
1 / β	/ | >1

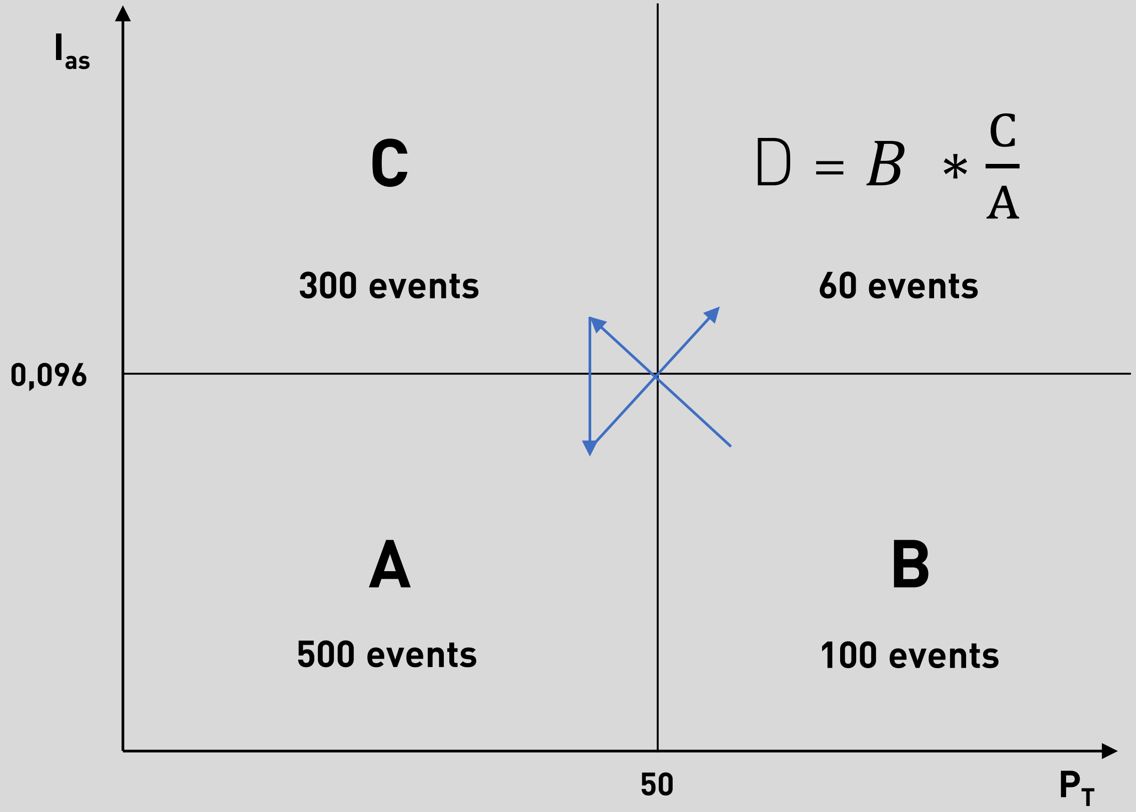
- This table shows all the preselective cuts that were applied before applying the ABCD method

- Less preselective criteria for the Trk-only

Background Prediction

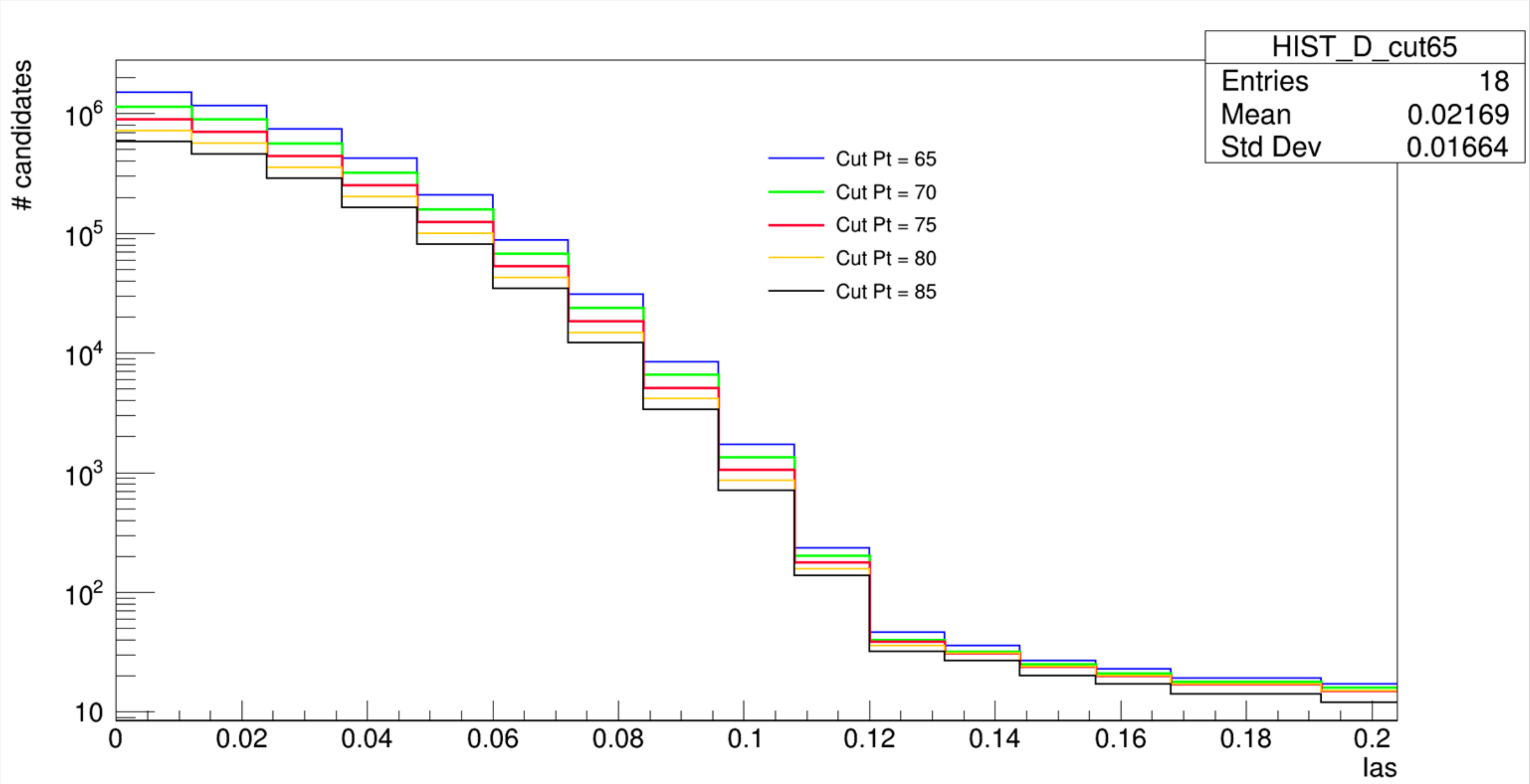
NAME	P_T cut	I_{as} cut
A	Fail	Fail
B	Fail	Pass
C	Pass	Fail
D	Pass	Pass

ABCD Method

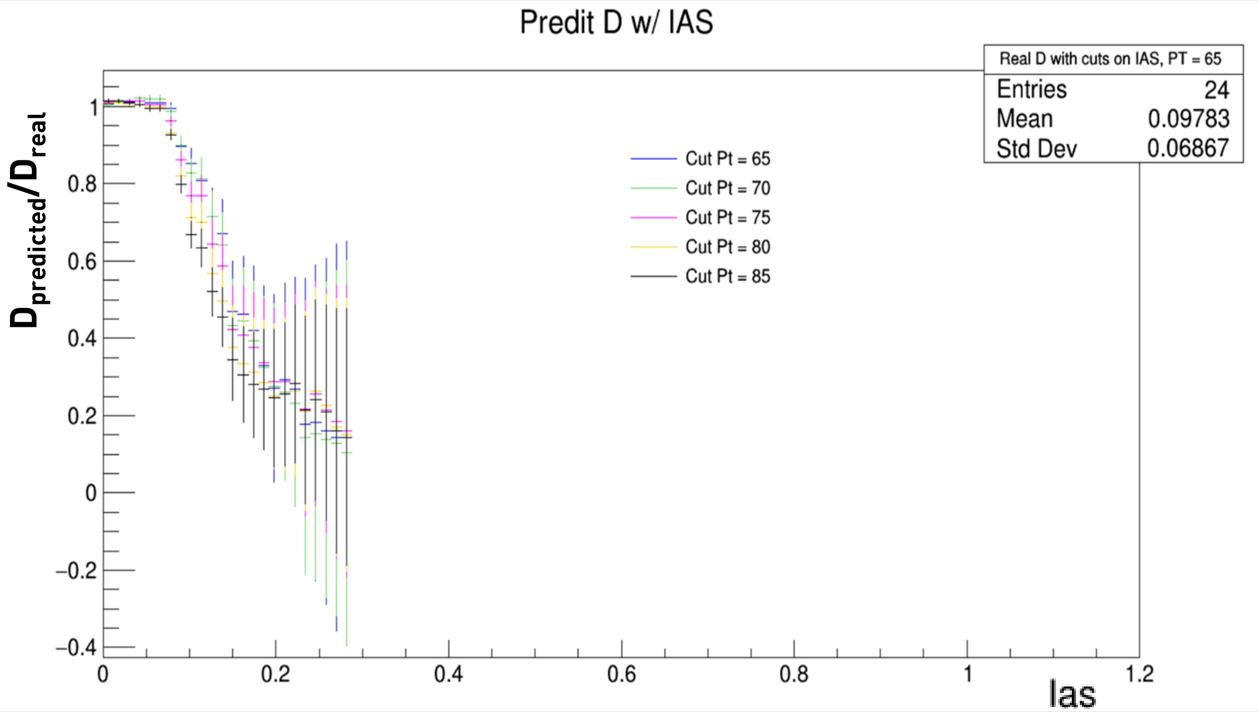


- ABCD method to theoretically presume the number of background tracks

candidates in D depending on PTs/Ias thresholds

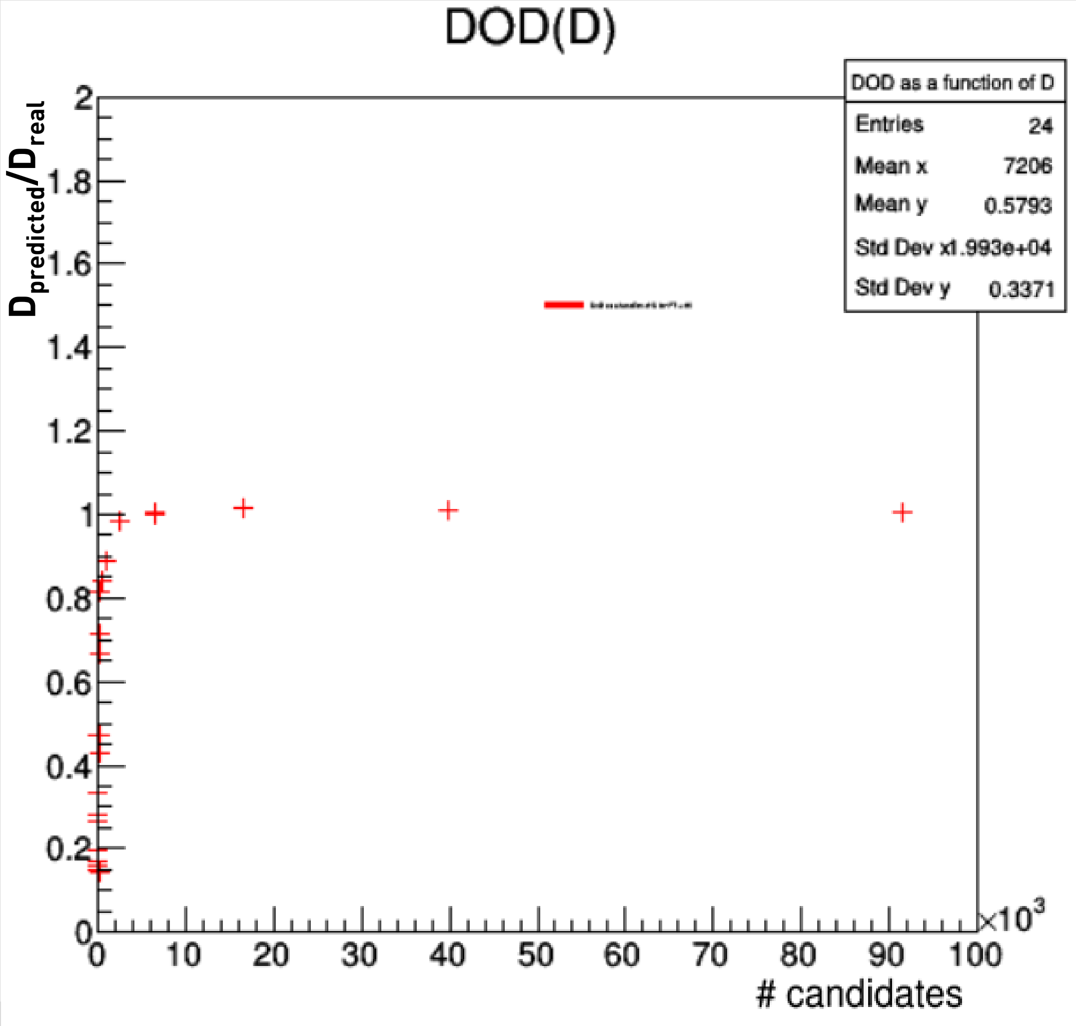


$\#D_{predicted}$ / $\#D_{real}$ when we vary the IAS cut



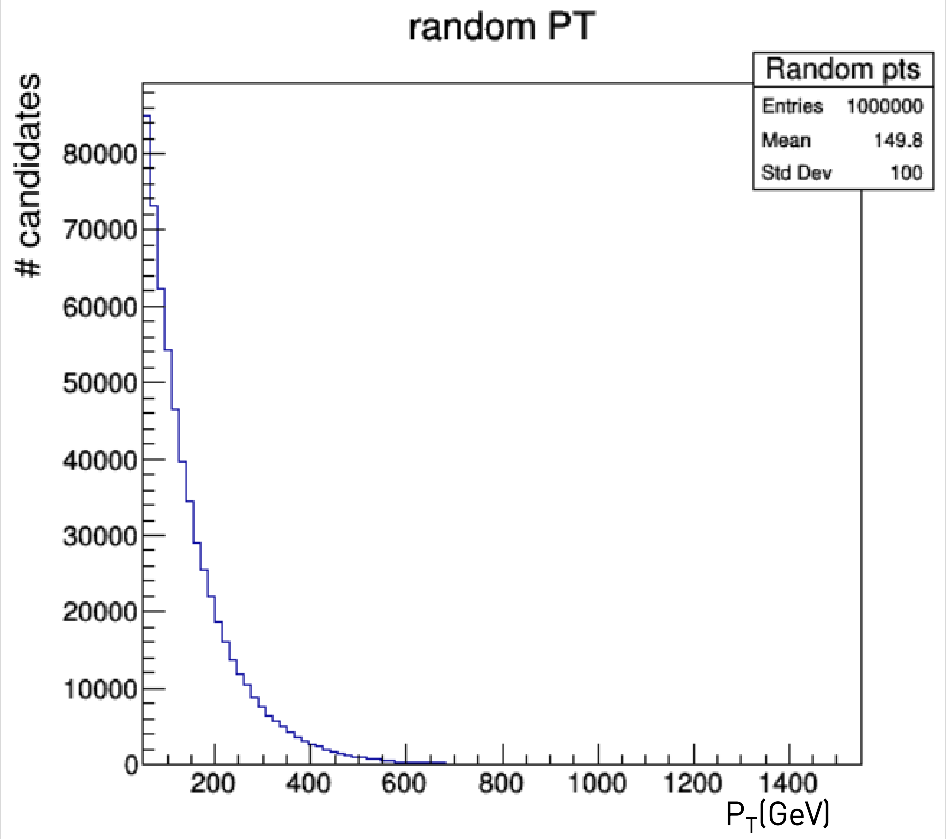
- Stability of the ratio beyond a certain point

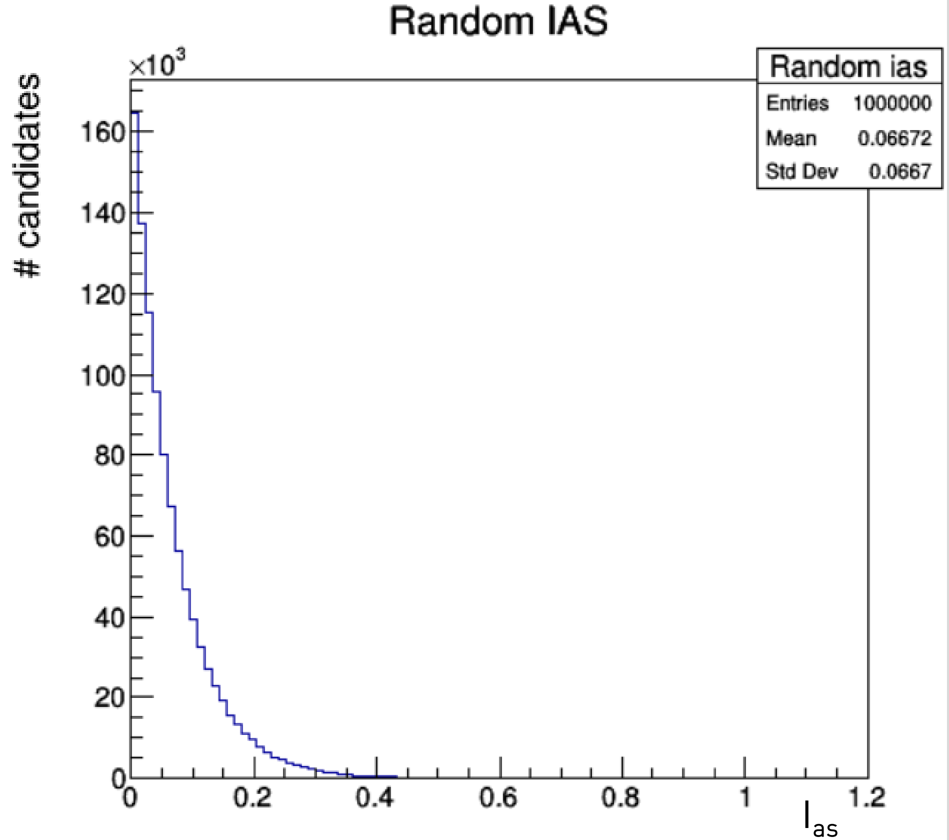
$\#D_{predicted}$ / $\#D_{real}$ for a large number of candidates



Generating random PT and IAS

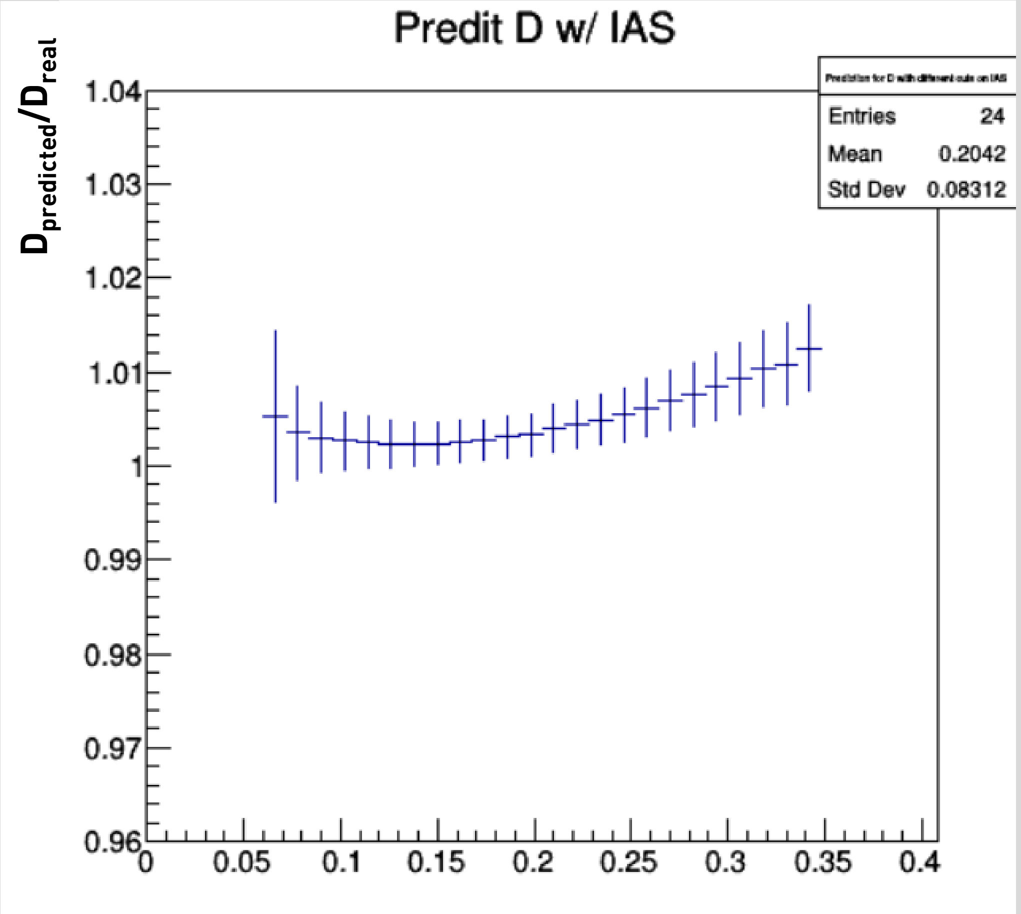
- Generation of a random set of P_T and I_{as} following an exponential distribution



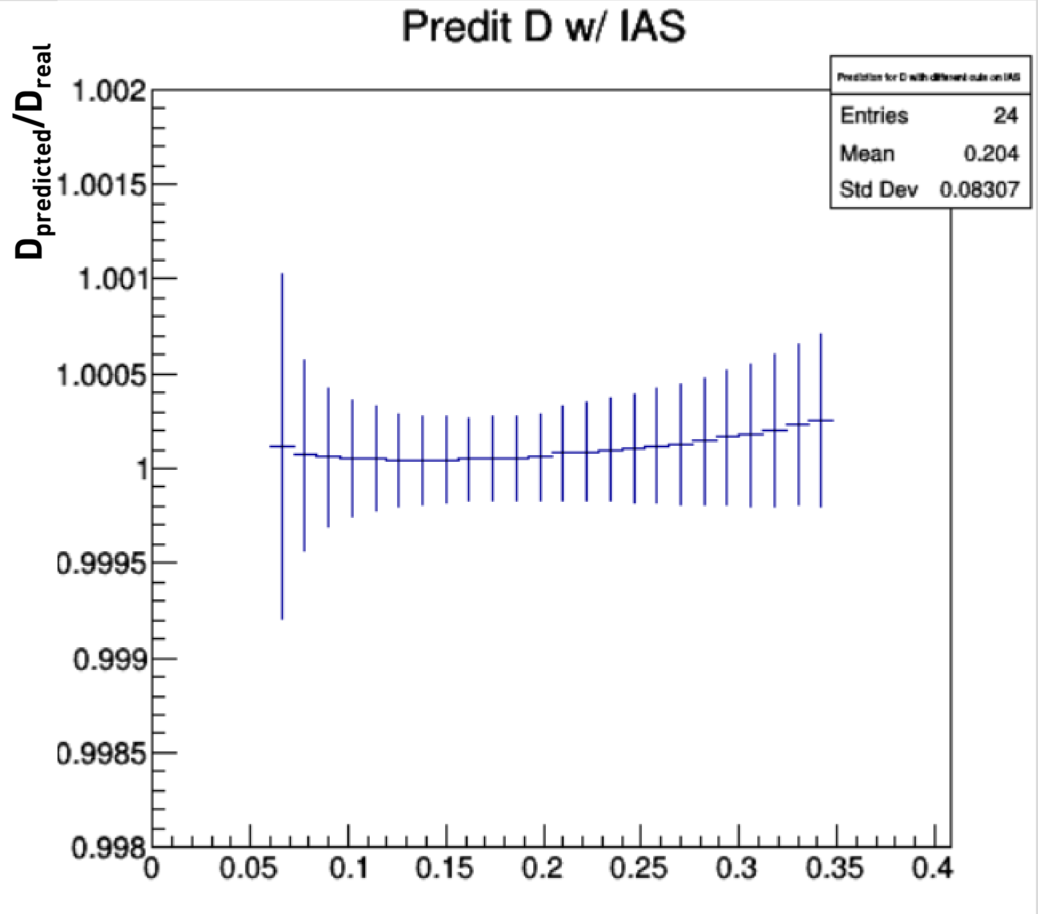


$\#D_{predicted}$ / $\#D_{real}$ for a random generation

100.000 candidates

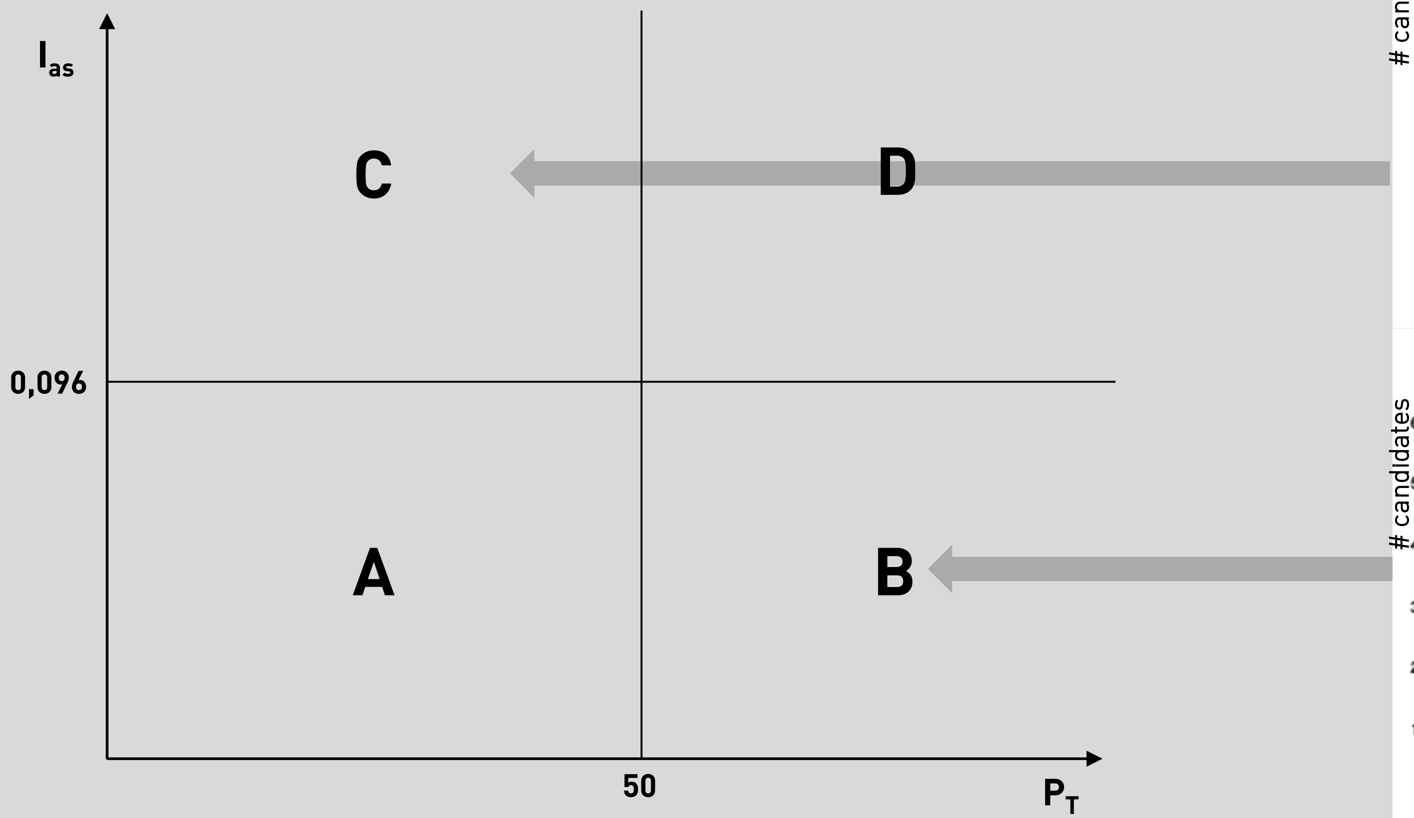


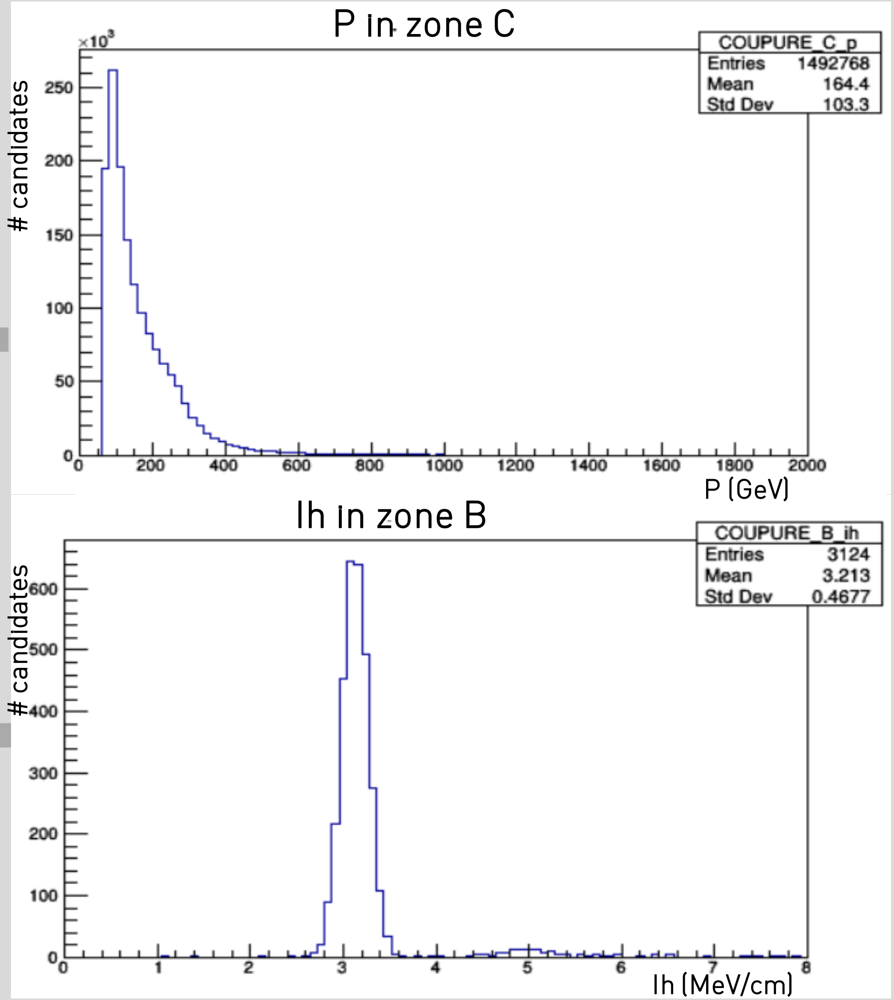
1.000.000 candidates



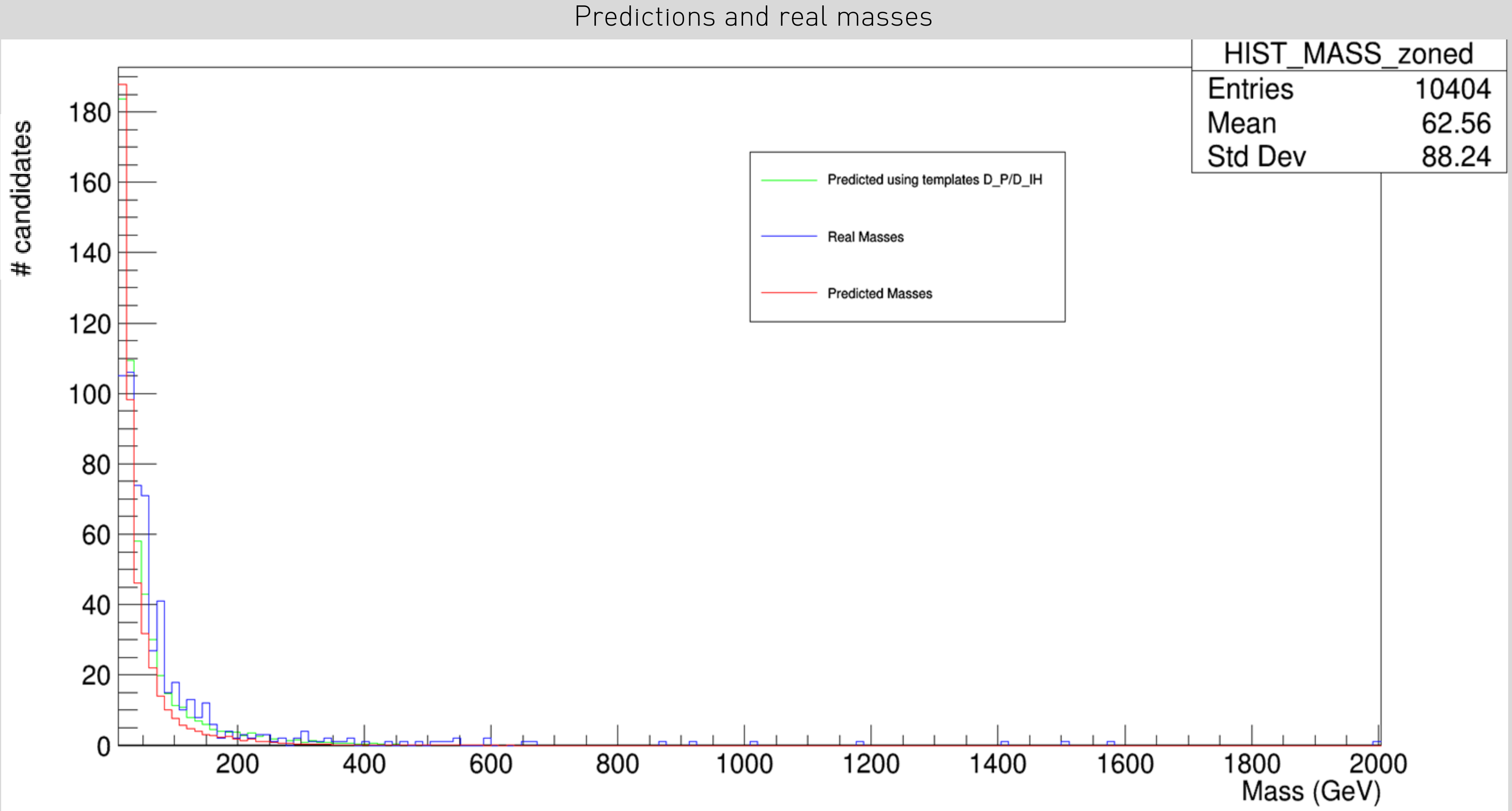
Prediction of mass distribution

- Shape of the mass distribution using P and Ih from regions B and C

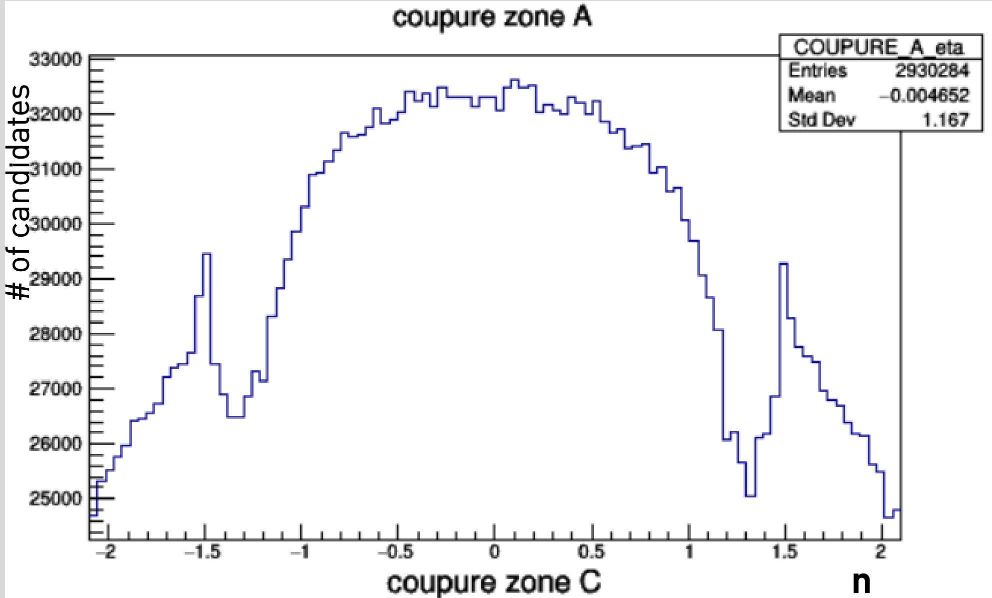


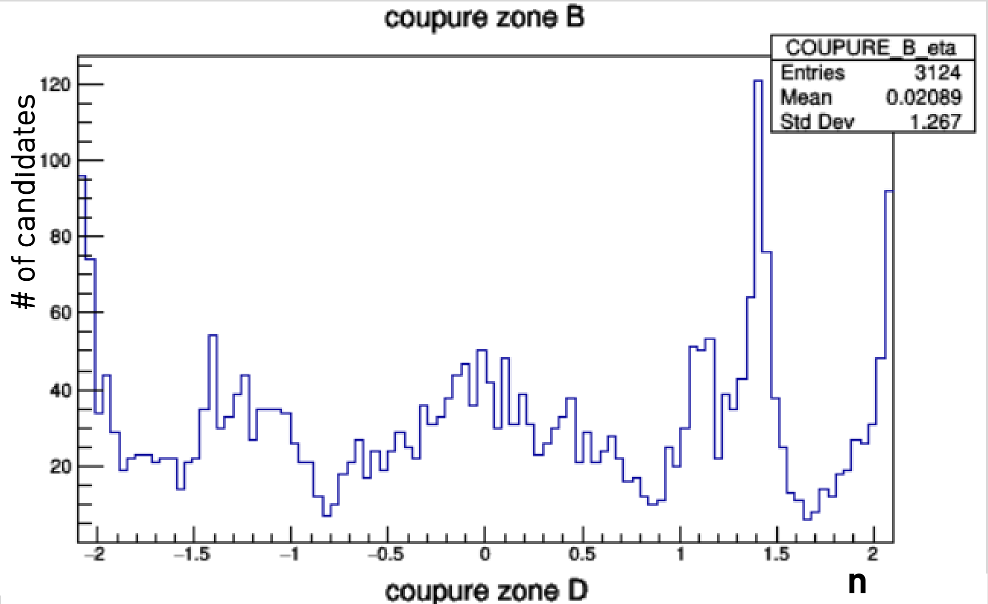


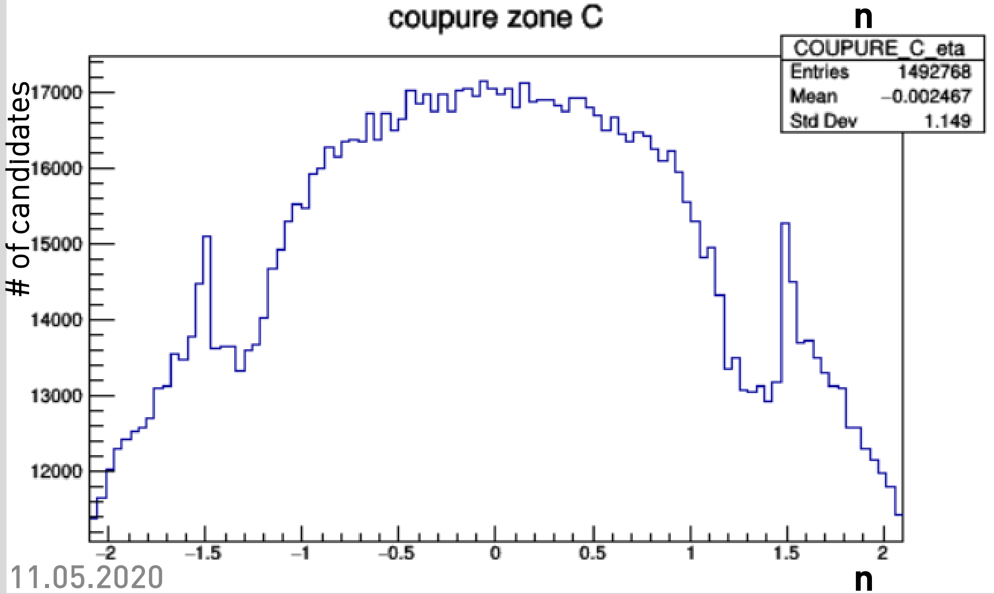
Predicted masses

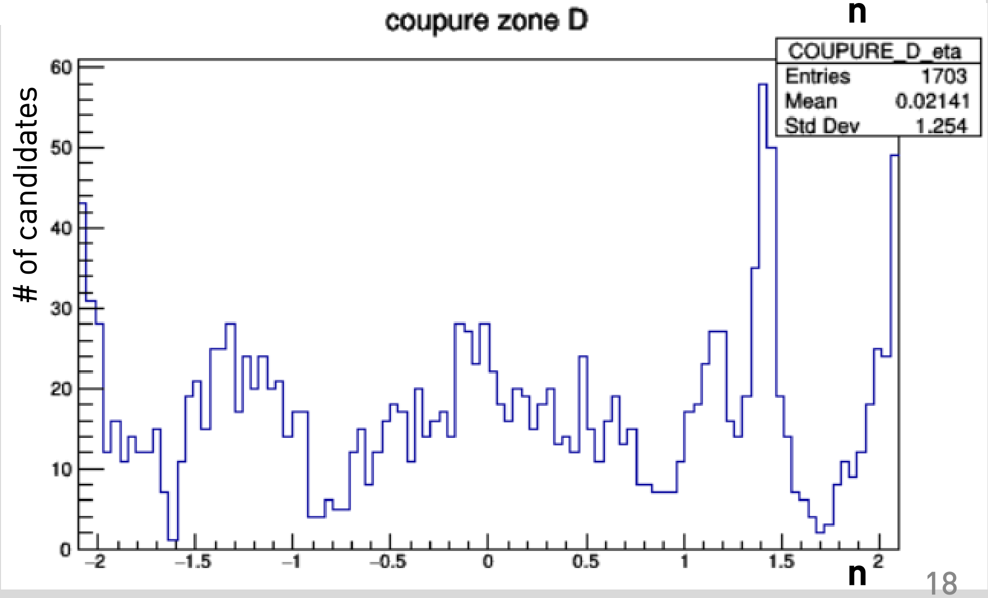


Eta in zones A,B,C,D for DY

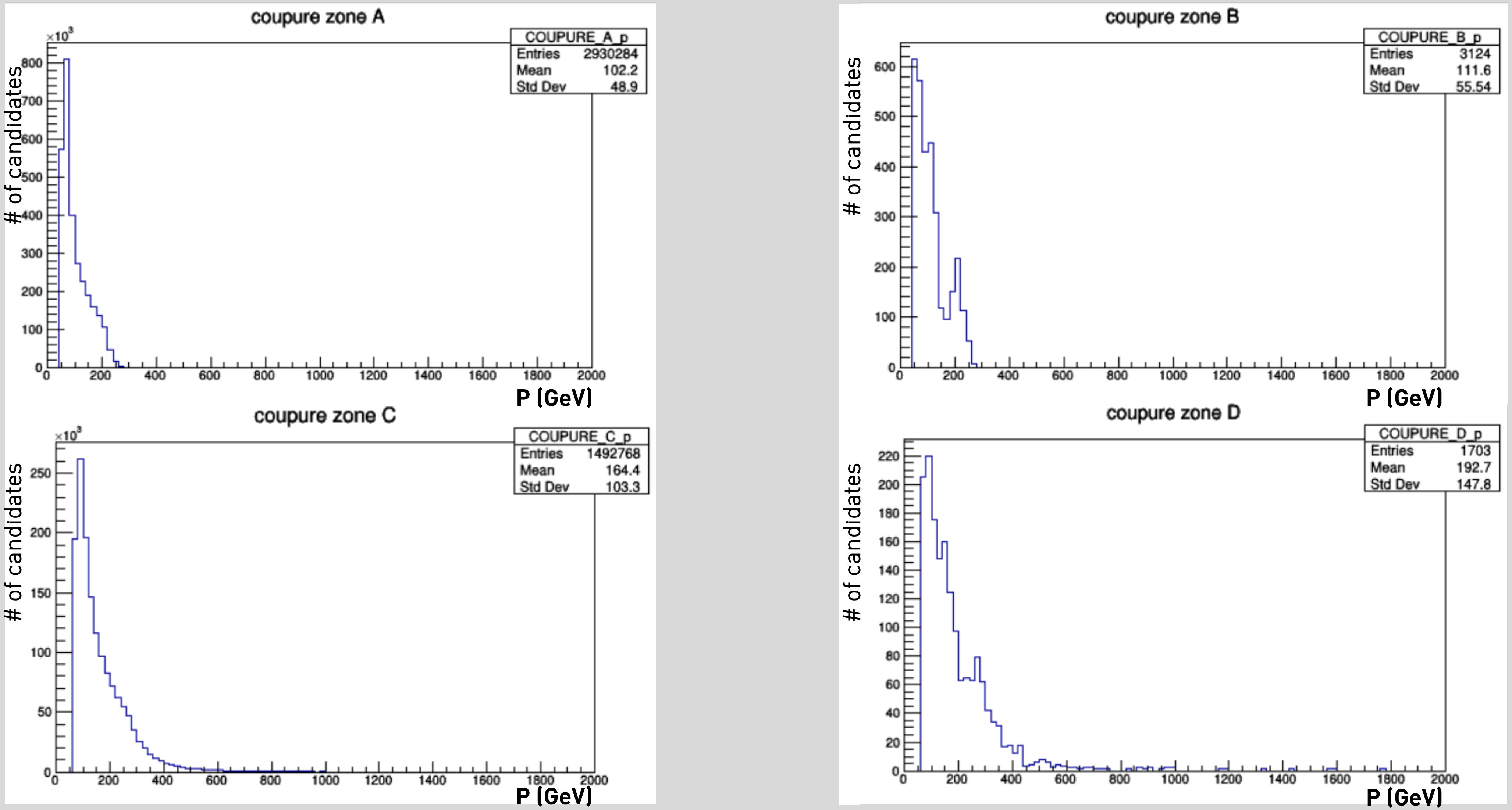




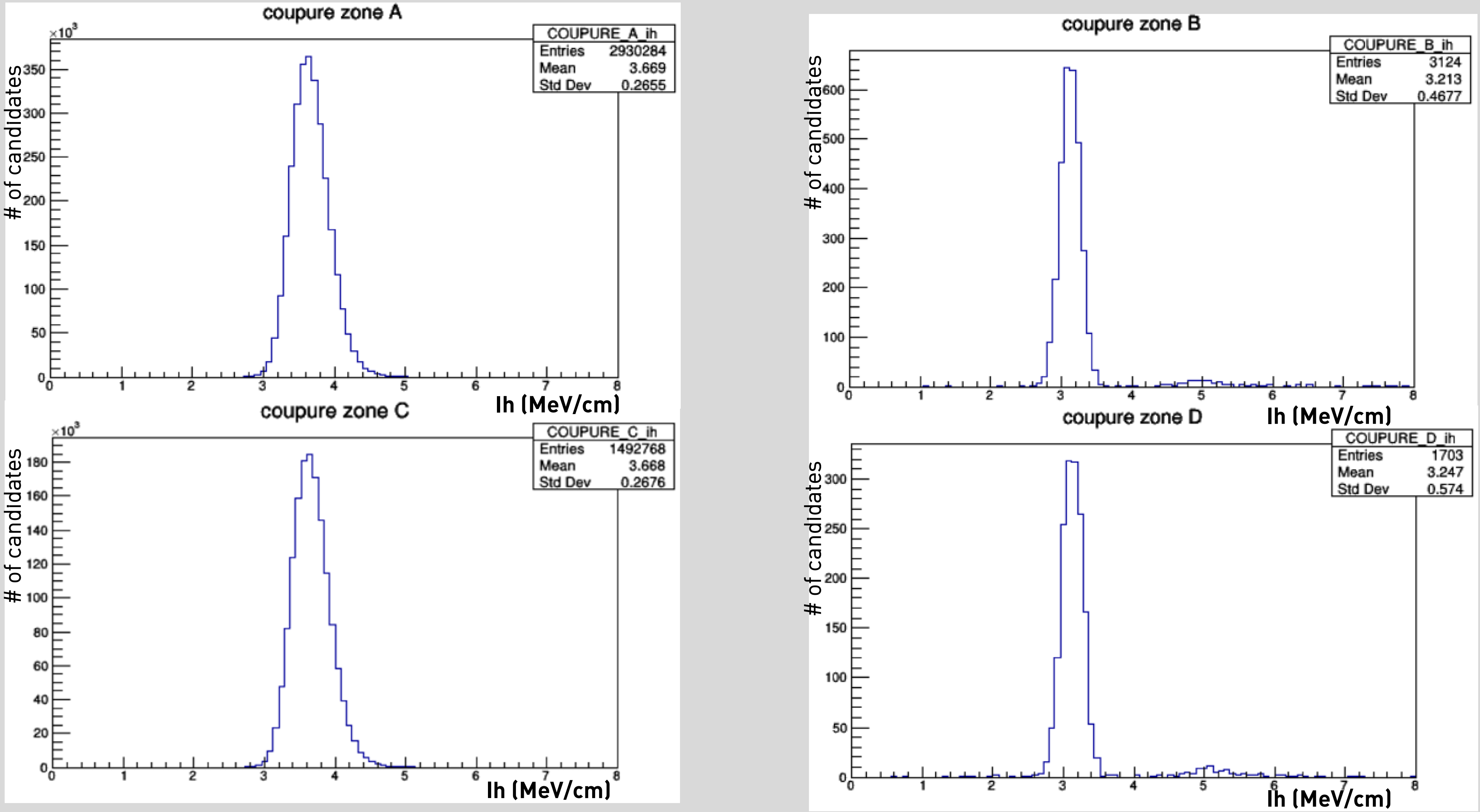




P in zones A,B,C,D



Ih in zones A,B,C,D



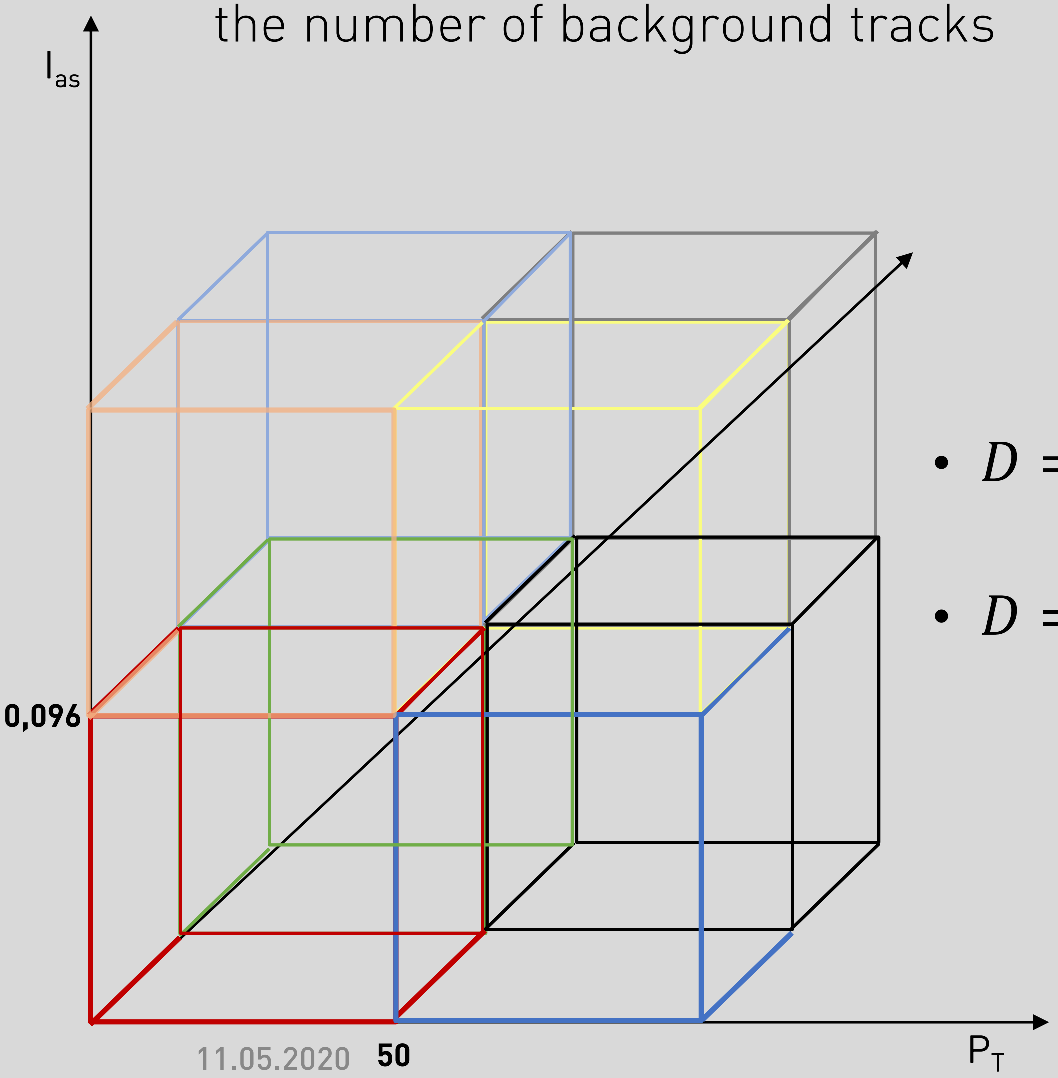
Background Prediction

- $\frac{1}{\beta} = 1 + c * \frac{t}{d}$
- $D = B * \frac{C}{A}$
- $D = A * \frac{G}{E} * \frac{F}{E}$

NAME	P_T cut	dE/dx Cut	1/ß Cut
A	Fail	Fail	Pass
B	Fail	Pass	Pass
C	Pass	Fail	Pass
D	Pass	Pass	Pass
E	Fail	Fail	Fail
F	Fail	Pass	Fail
G	Pass	Fail	Fail
H	Pass	Pass	Fail

Background Prediction

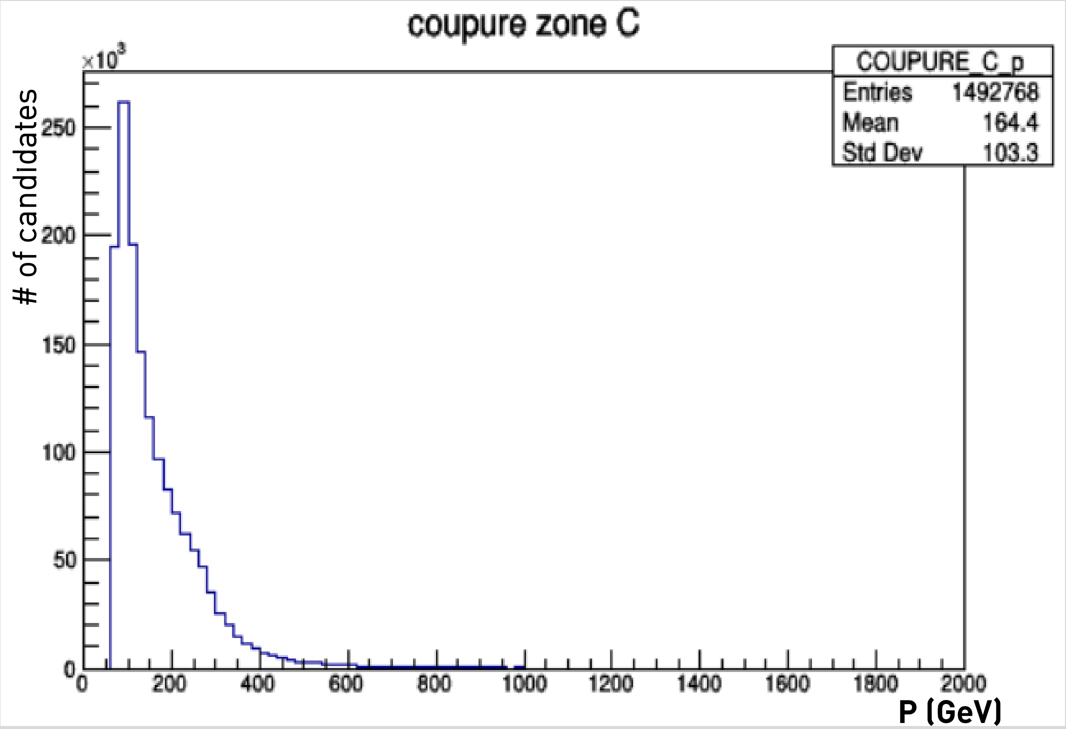
- ABCD-EFGH contains 1/ß cuts as well as the Time Of Flight to theoretically presume the number of background tracks

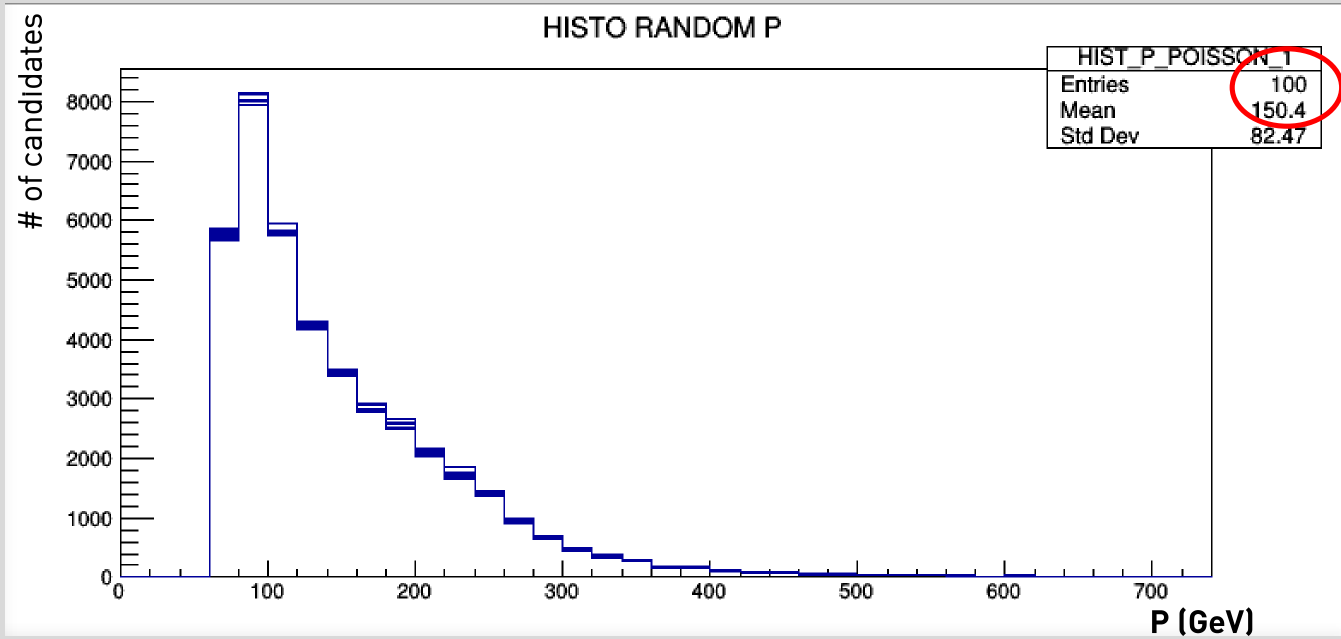


- $D = B * \frac{C}{A}$
- $D = A * \frac{G}{E} * \frac{F}{E}$

NAME	P_T cut	dE/dx Cut	1/ß Cut
A	Fail	Fail	Pass
B	Fail	Pass	Pass
C	Pass	Fail	Pass
D	Pass	Pass	Pass
E	Fail	Fail	Fail
F	Fail	Pass	Fail
G	Pass	Fail	Fail
H	Pass	Pass	Fail

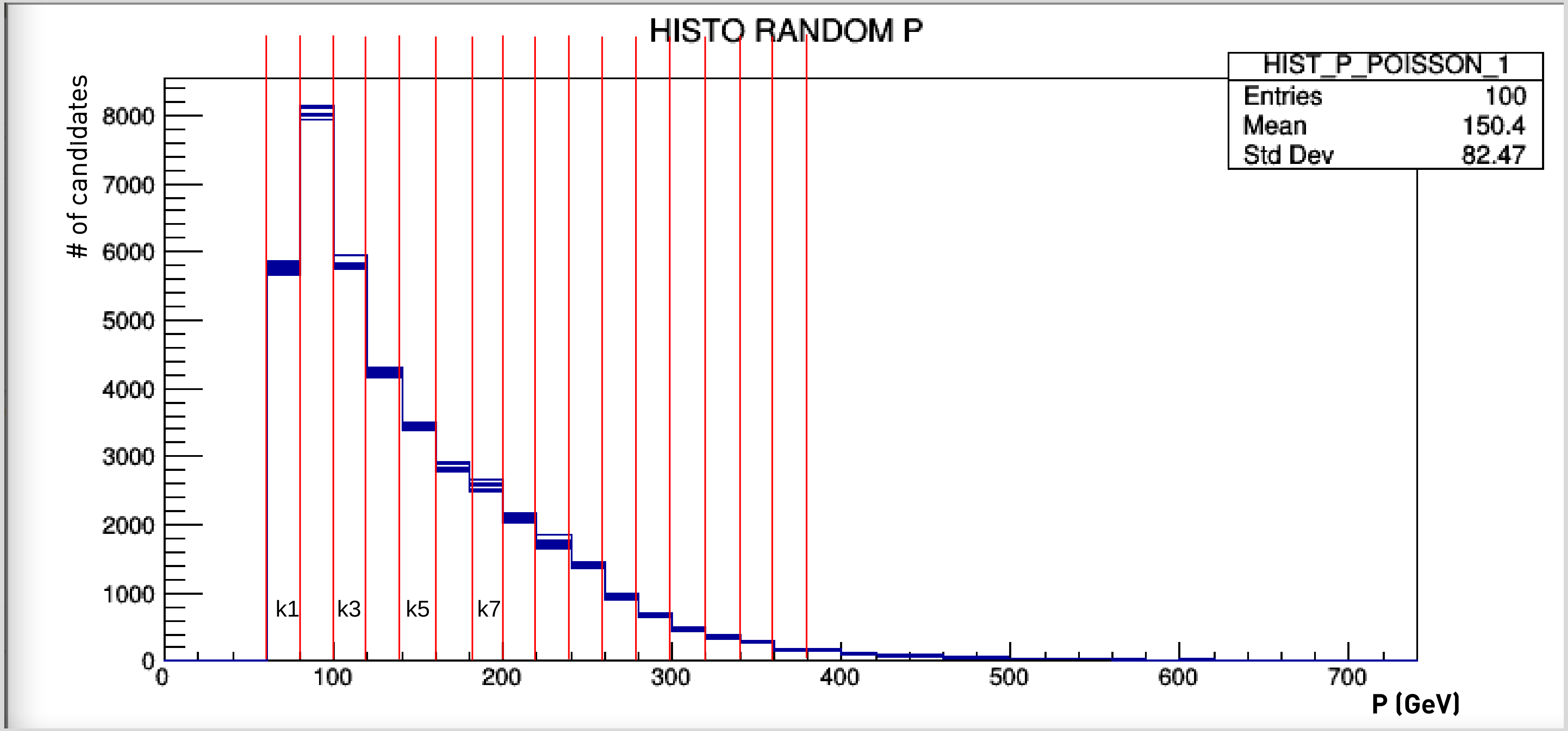
Generating pseudo-experiment





- Make the number of event per bins vary ~ poisson distribution
- Variables P and Ih

Generating pseudo-experiment



- Generation of 100 pseudo-experiments

Generating pseudo-experiment

- Combine all the pseudo experiment :

$$D = A * \frac{G}{E} * \frac{F}{E}$$

$$A_i \frac{F_i G_i}{E_i * E_i} * \left(\frac{k_{il}}{F_i}\right) * \left(\frac{n_{ij}}{G_i}\right) = \left(\frac{k_{il} * n_{ij}}{E_i E_i}\right) * A_i$$

Total number of event in each zone

Number of events in each bin

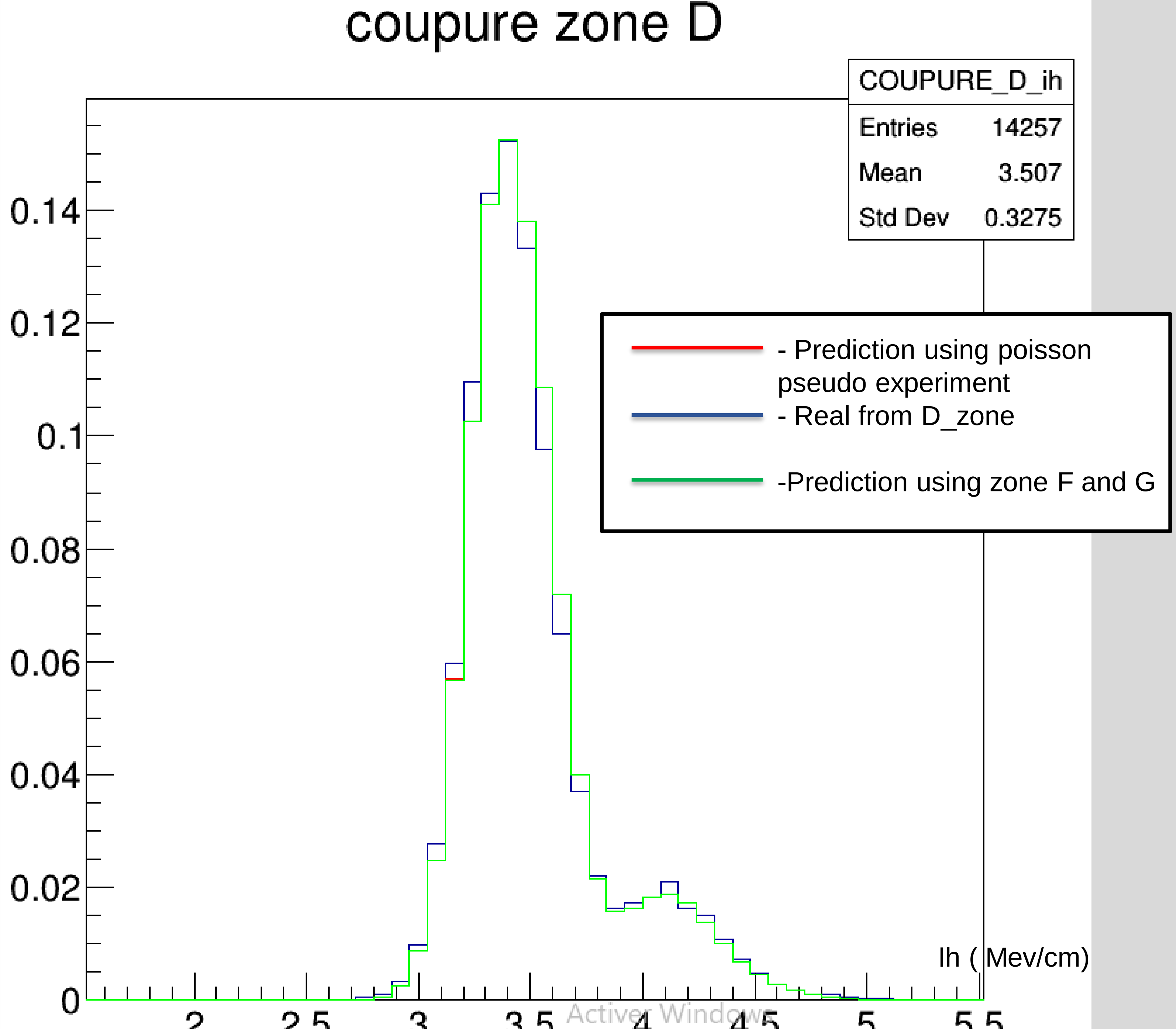
Generating pseudo-experiment

- Combine all the pseudo experiment :

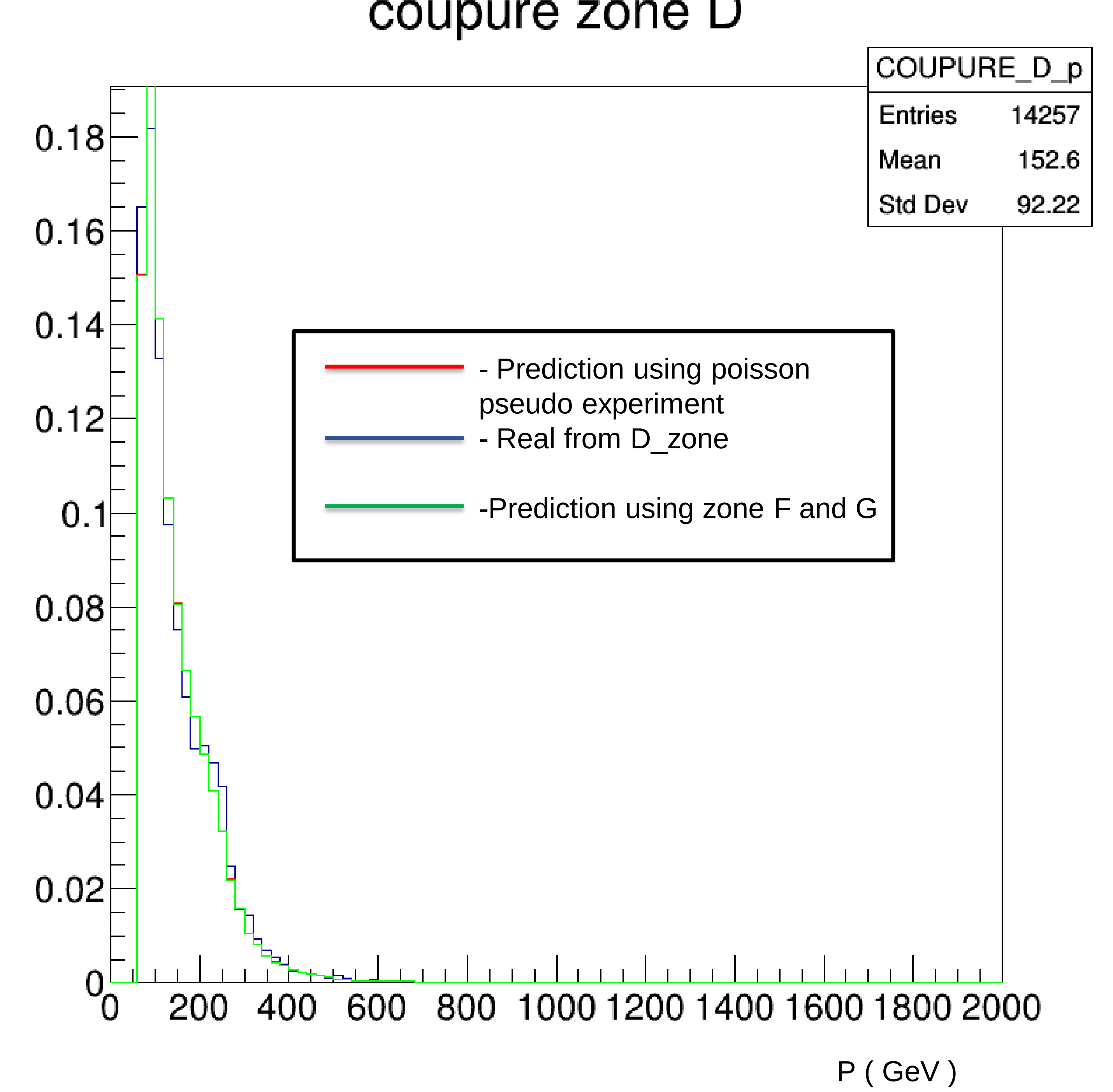
$$D = A * \frac{F}{E} * \frac{G}{E}$$

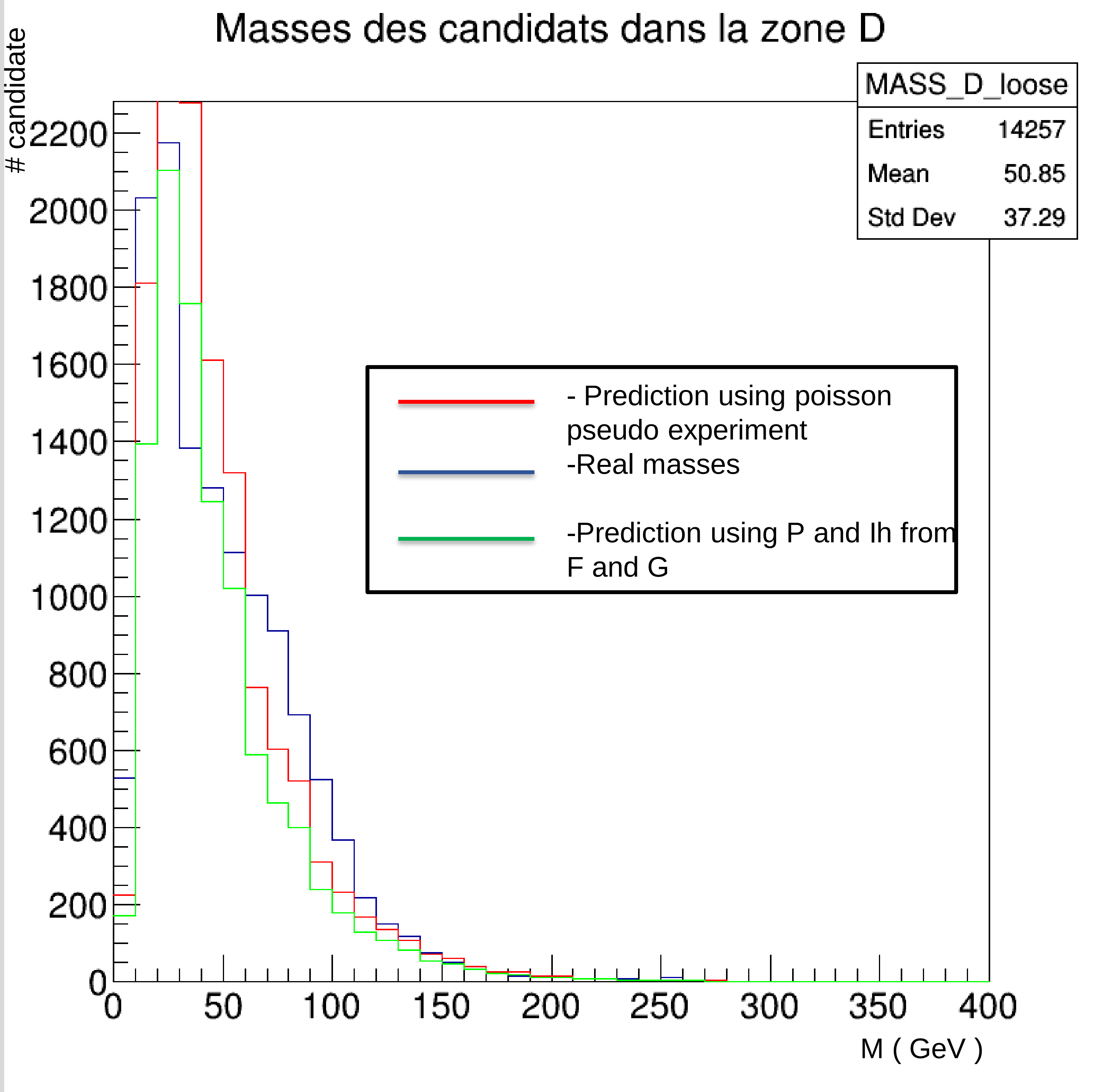
$$A_i \frac{F_i G_i}{E_i * E_i} * \left(\frac{k_{il}}{F_i}\right) * \left(\frac{n_{ij}}{G_i}\right) = \left(\frac{k_{il} * n_{ij}}{E_i E_i}\right) * A_i$$

$$k_{il} = bin\ content\ from\ F\ i^{th}\ experiment$$
$$n_{ij} = bin\ content\ from\ G\ i^{th}\ experiment$$



coupure zone D
COUPURE_D_ih
Entries 14257
Mean 3.507
Std Dev 0.3275
- Prediction using poisson pseudo experiment
- Real from D_zone
-Prediction using zone F and G
Ih (Mev/cm)
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
2
2.5
3
3.5
4
4.5
5
5.5


coupure zone D
COUPURE_D_p
Entries 14257
Mean 152.6
Std Dev 92.22
- Prediction using poisson pseudo experiment
- Real from D_zone
-Prediction using zone F and G
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0 200 400 600 800 1000 1200 1400 1600 1800 2000
P (GeV)


Masses des candidats dans la zone D
MASS_D_loose
Entries 14257
Mean 50.85
Std Dev 37.29
candidate
- Prediction using poisson pseudo experiment
-Real masses
-Prediction using P and Ih from F and G
M (GeV)
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
0
50
100
150
200
250
300
350
400

To go further

- All theses prediction are based on the assumption that P, IH , 1/Beta , have no correlation, but we see a correlation in the distribution of Pt(eta). We would need to correct this correlation
- Make a prediction from 1/ß < 1 to get a " signal free " zone of prediction
- Use our program on real data and not Monte-Carlo simulations
- Change our cut values to see if we can get better prediction

Summary

A number of searches for heavy stable charged particles produced in proton-proton collisions at $\sqrt{s}$ = 13TeV using the CMS detector are presented. Two complementary analyses were performed: a search using only the tracker and a search using both the tracker and the muon system. Estimated events are found to be compatible with reality, but the mass spectra could be improved with little more time and better conditions (remote access, very high lags)

APPENDIX

1) Codes

   https://github.com/DenkMybu/CMS

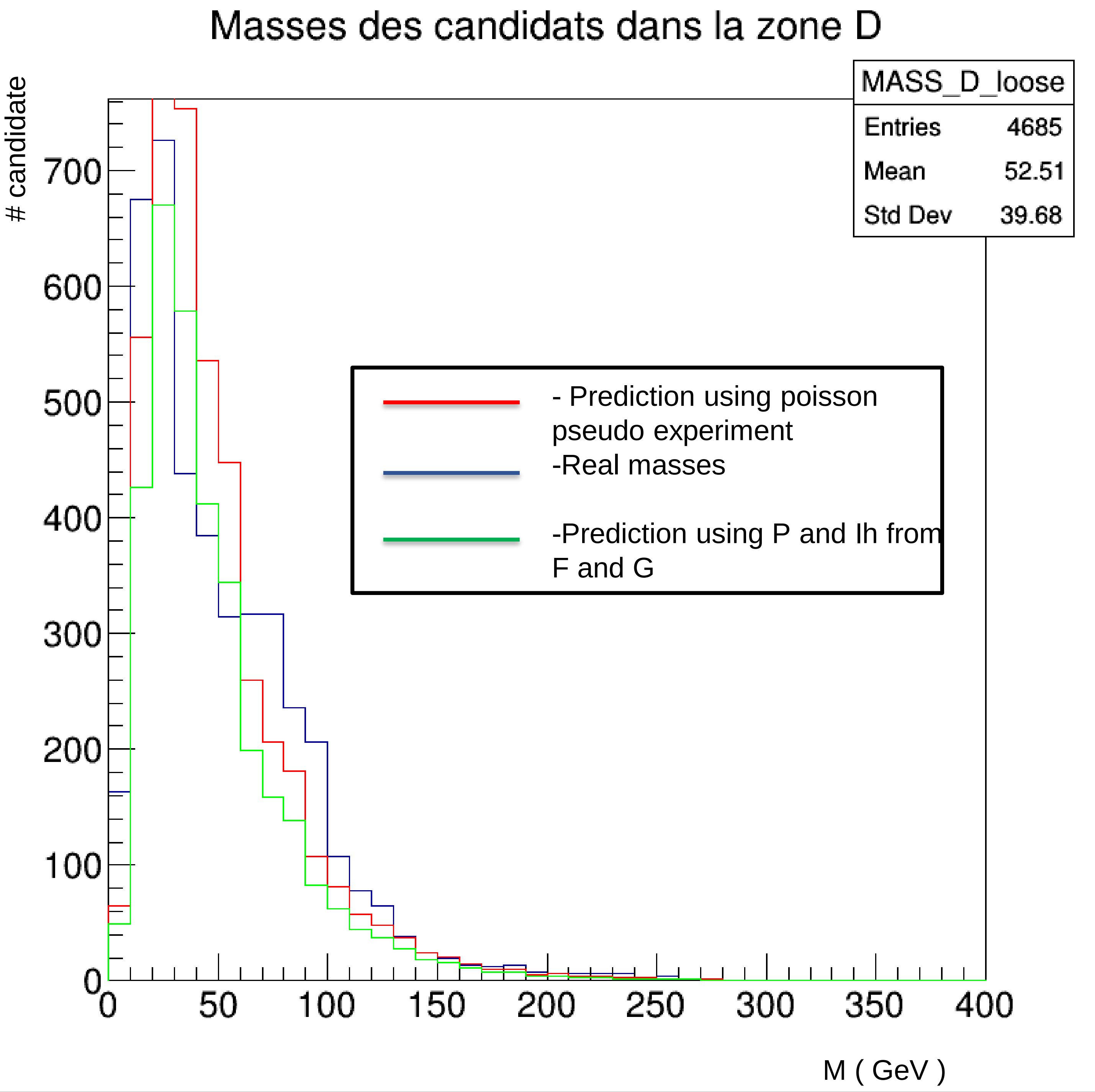
1) Graphs
   a) Antoines graphs
   b) Raphael graphs

```
   c_pt c_ias c_beta
E = 0     0     0
G = 1     0     0
F = 0     1     0
H = 1     1     0
A = 0     0     1
C = 1     0     1
B = 0     1     1
D = 1     1     1
D_1=  C*B / A
D_2=  H*B / F
D_5=  H*C / G
D_3=  A*G*F / E*E
D_4=  E*C*B / G*A
Nombre candidats = 7115968
 E = 3.85473e+06 // 54.1701%
 G = 128502 // 1.80583%
 F = 1.2098e+06 // 17.0013%
 H = 40754 // 0.572712%
 A = 1.38807e+06 // 19.5064%
 C = 46382 // 0.651802%
 B = 433469 // 6.0915%
 D = 14257 // 0.200352%
```

```
E_strict = 5.51906e+06 // 77.5588%
G_strict = 183661 // 2.58097%
F_strict = 219025 // 3.07794%
H_strict = 7701 // 0.108221%
A_strict = 1.10464e+06 // 15.5233%
C_strict = 37048 // 0.520632%
B_strict = 43353 // 0.609235%
D_strict = 1485 // 0.0208686%

Estimateur de D
D_1 = 14484.2 +- 71.8212
D_2 = 14675.3 +- 74.132
D_5 = 14602 +- 465.635
D_3 = 14522.8 +- 69.2736
D_4 = 14557 +- 76.8114

D_1_strict = 1454 +- 10.38
D_2_strict = 1541.35 +- 17.6375
D_5_strict = 1524.31 +- 42.8366
D_3_strict = 1458.81 +- 8.28303
D_4_strict = 1470.26 +- 18.9006
```

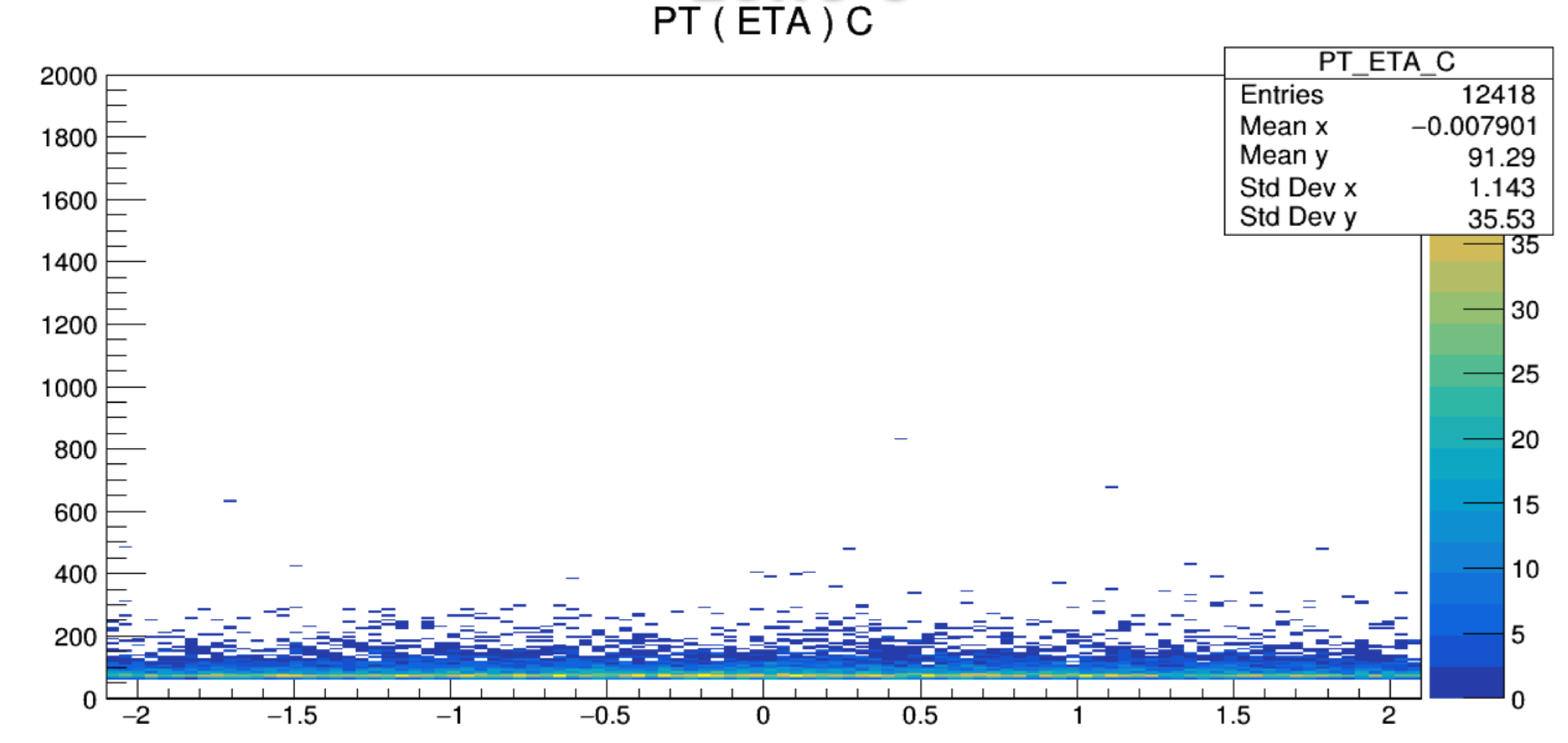

Masses des candidats dans la zone D
MASS_D_loose
Entries 4685
Mean 52.51
Std Dev 39.68
candidate
0
100
200
300
400
500
600
700
- Prediction using poisson pseudo experiment
-Real masses
-Prediction using P and Ih from F and G
0
50
100
150
200
250
300
350
400
M (GeV)

$$I_h = \left(\frac{1}{N_{85\%}} \sum_{i}^{N_{85\%}} c_i^2\right)^{-1/2}$$

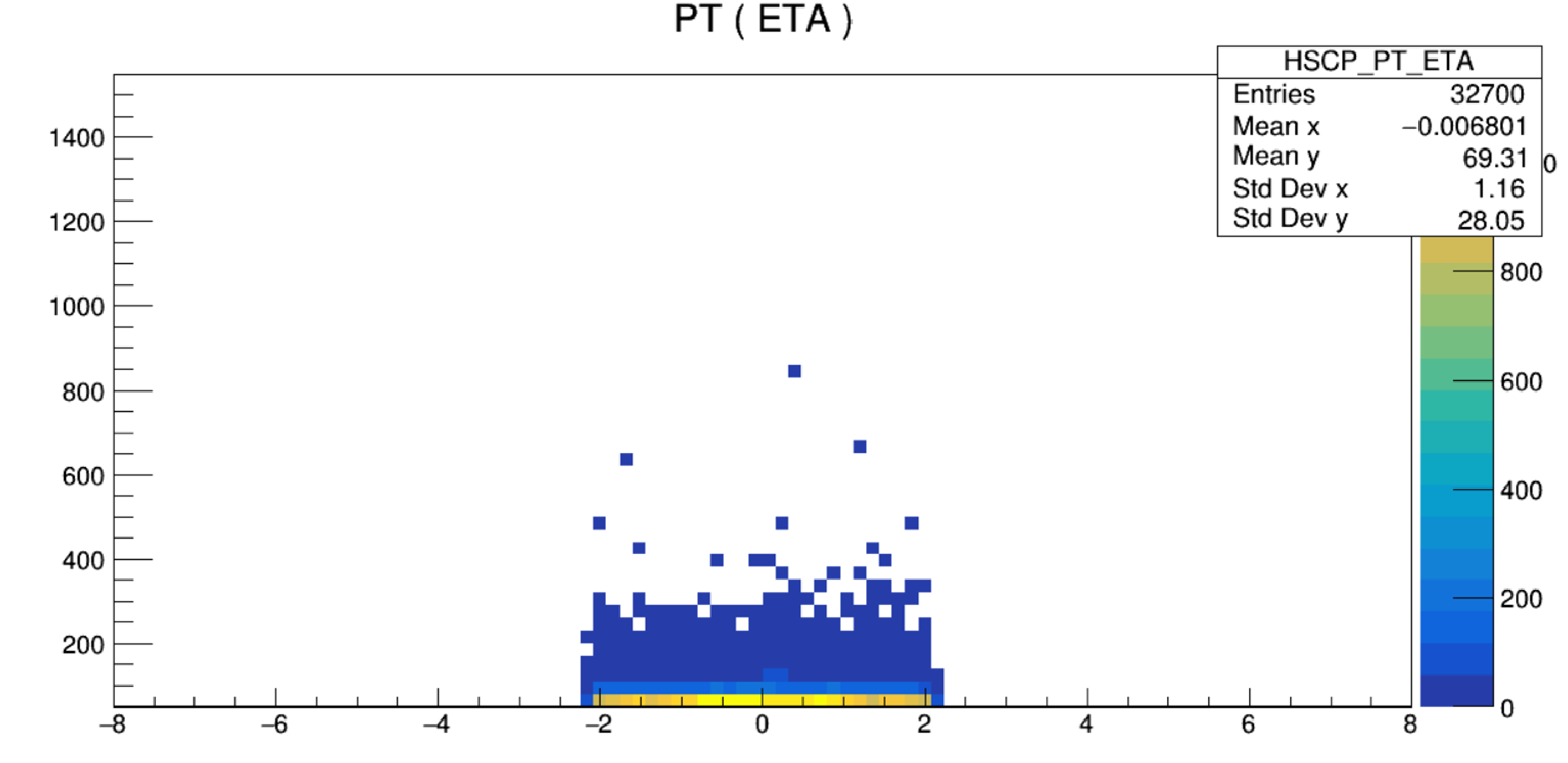
$$I_{as} = \frac{3}{N} * \left(\frac{1}{12N} + \sum_{i=1}^{N} [P_i * (P_i - \frac{2i-1}{2N})\hat{}2]\right)$$

$\boldsymbol{c_i}$ is the charge per unit path length in the detector of the I measurement for a given track
N is the number of charge measurements in the tracker
Pi Is the probability for a minimum ionizing particle (MIP) to produce a charge smaller or equal to the I charge measurement for the observed path length in the detector

2D histogram PT/Eta in zone C

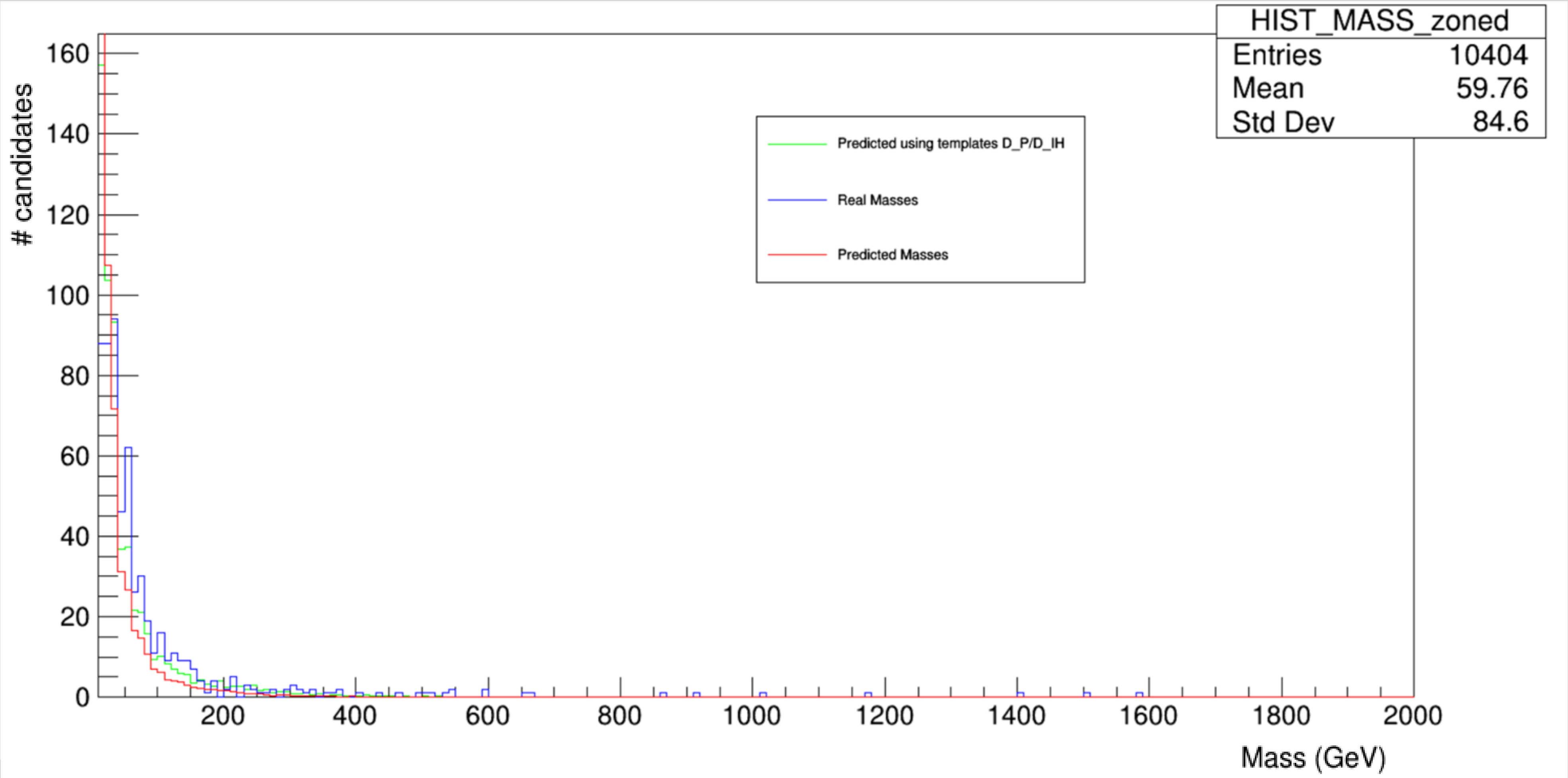


2D histogram PT/Eta in total



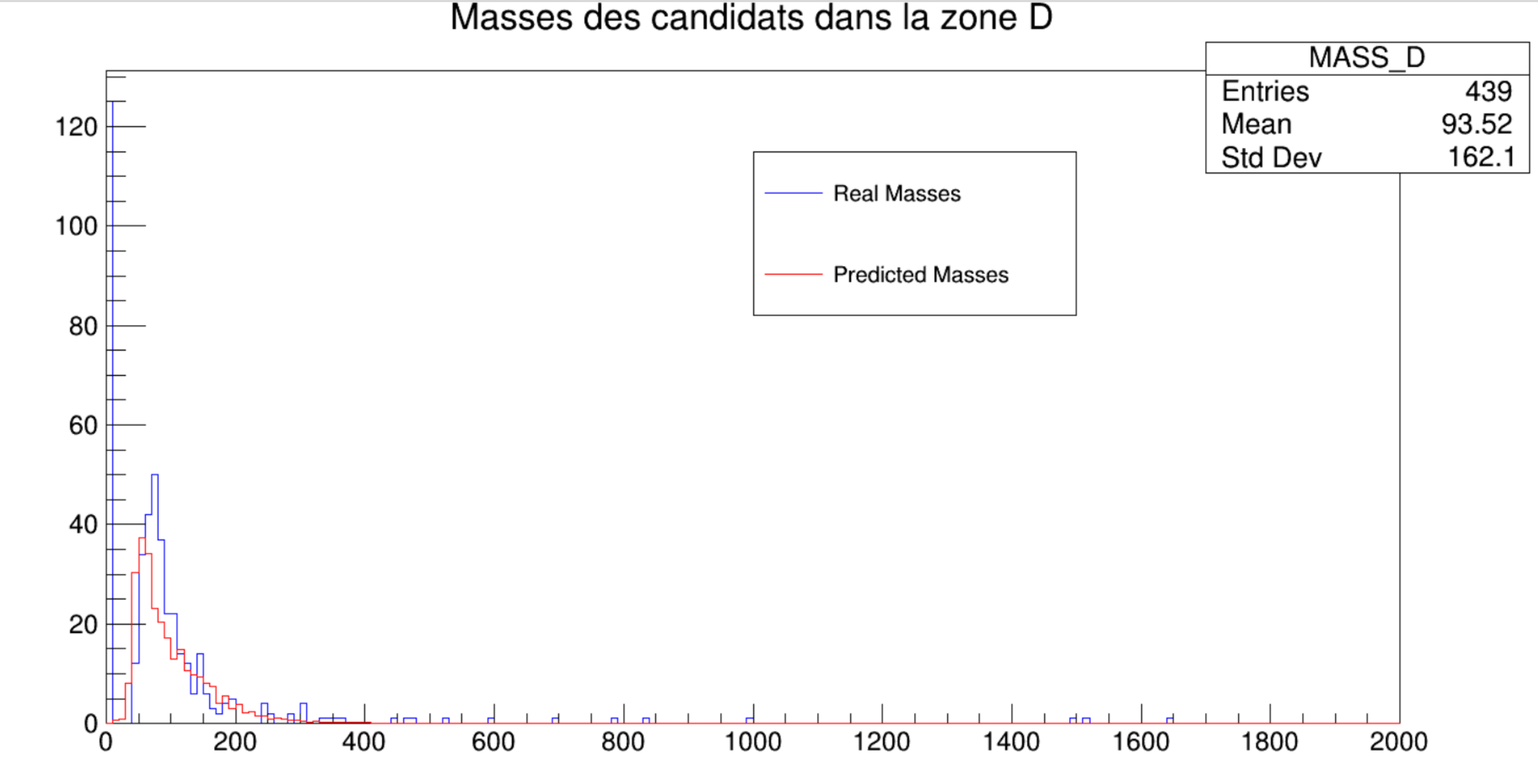
Predicted masses

Predictions and real masses on Drell-Yan set



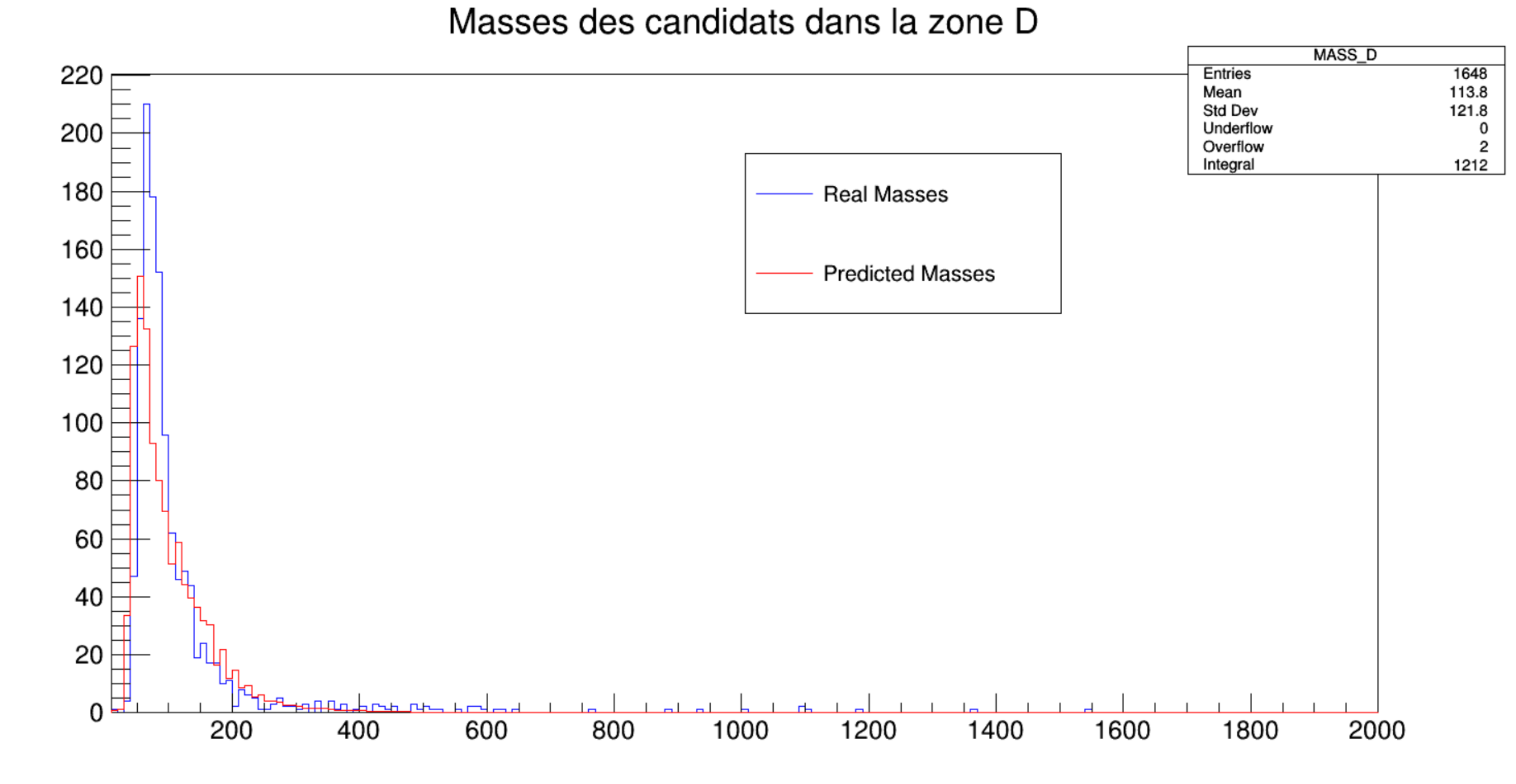
Predicted masses

Predicted masses for W process



Predicted masses

Predicted masses for DY process



Correlations

```
Number that made it : 67768

 Correlation PTT vs PTM : 0.0652517

 Correlation PT vs MUONINVERSEBETA : 0.00127551

 Correlation PT vs ETA : -0.0202177

 Correlation PT vs IAS : -0.00322041

 Correlation PT vs IH : 0.00670748
```

```
Number that made it : 24191

 Correlation PTT vs PTM : 0.713074

 Correlation PT vs MUONINVERSEBETA : -0.0661556

 Correlation PT vs ETA : -0.0344832

 Correlation PT vs IAS : 0.0111363

 Correlation PT vs IH : -0.0338677
```