Measurements of α and proposal for a_μ^{HLO} space-like

U. Marconi
INFN, Bologna

FCCP2017,

Capri, September 7, 2017

Work done in collaboration with:

G. Abbiendi, C. M. Carloni Calame, D. Galli,
F. V. Ignatov, M. Incagli, V. Ivantchenko,
U. Marconi, C. Matteuzzi, G. Montagna,
O. Nicrosini, M. Passera, C. Patrignani,
F. Piccinini, F. Pisani, L. Trentadue,
R. Tenchini, G. Venanzoni

Reference papers

A new approach to evaluate the leading hadronic corrections to the muon *g*-2 ☆

C. M. Carloni Calame[a], M. Passera[b], L. Trentadue[c], G. Venanzoni[d]

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Phys. Lett. B 746 (2015) 325

Measurement of the effective electromagnetic coupling in the space-like region with Bhabha scattering.

Measuring the leading hadronic contribution to the muon *g*-2 via μe scattering

G. Abbiendi[1], C. M. Carloni Calame[2], U. Marconi[1], C. Matteuzzi[3], G. Montagna[4,2], O. Nicrosini[2], M. Passera[5], F. Piccinini[2], R. Tenchini[6], L. Trentadue[7,3], and G. Venanzoni[8]

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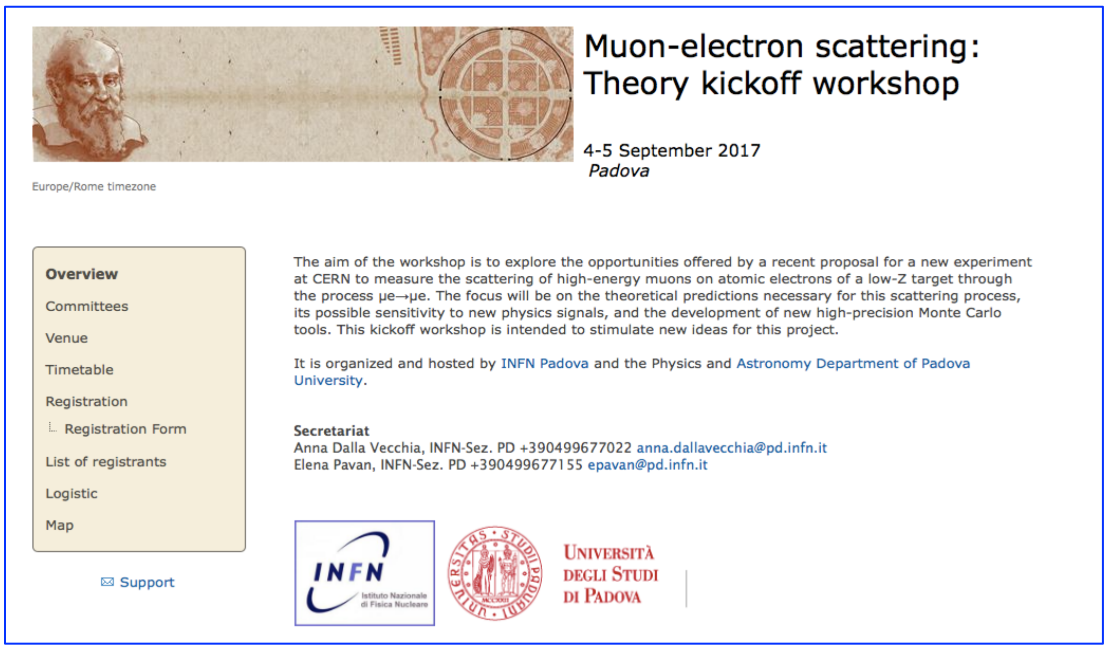
Università di Parma, Parma, Italy
[8] *INFN, Laboratori Nazionali di Frascati, Frascati, Italy*

Eur. Phys. J. C (2017) 77: 139.

Theory kickoff workshop

4-5 September 2017, Padova (Italy)

https://agenda.infn.it/internalPage.py?pageId=0&confId=13774



Muon-electron scattering: Theory kickoff workshop

4-5 September 2017
Padova

Europe/Rome timezone

Overview
Committees
Venue
Timetable
Registration
Registration Form
List of registrants
Logistic
Map

Support

The aim of the workshop is to explore the opportunities offered by a recent proposal for a new experiment at CERN to measure the scattering of high-energy muons on atomic electrons of a low-Z target through the process μe→μe. The focus will be on the theoretical predictions necessary for this scattering process, its possible sensitivity to new physics signals, and the development of new high-precision Monte Carlo tools. This kickoff workshop is intended to stimulate new ideas for this project.

It is organized and hosted by INFN Padova and the Physics and Astronomy Department of Padova University.

Secretariat
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INFN Istituto Nazionale di Fisica Nucleare
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Carlo Carloni Calame - INFN Pavia
Pierpaolo Mastrolia - U. Padova
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Paride Paradisi - U. Padova
Massimo Passera - INFN Padova (Chair)
Fulvio Piccinini - INFN Pavia
Luca Trentadue - U. Parma

Theory kickoff workshop (II)

Monday 04 September 2017

A spacelike determination of amuHLO via mu-e scattering data - aula Voci (14:30-15:00)

- Presenters: VENANZONI, G.

Muon-electron scattering detector: experimental challenges - aula Voci (15:00-15:30)

- Presenters: Dr. MARCONI, U.

Status of MCGPJ: e+e- -> e+e-, mu+mu-, ... generator with photon jets - aula Voci (15:30-16:00)

- Presenters: Mr. IGNATOV, F.

Muon decay at NNLO: plans and interim results - aula Voci (16:30-17:00)

- Presenters: SIGNER, A.; ULRICH, Y.

Towards mu-e scattering at NNLO: part-1 - aula Voci (17:00-17:30)

- Presenters: MASTROLIA, P.

Towards mu-e scattering at NNLO: part-2 - aula Voci (17:30-18:00)

- Presenters: PRIMO, A.; SCHUBERT, U.

Feynman integrals beyond multiple polylogarithms - aula Voci (18:00-18:30)

- Presenters: TANCREDI, L.

Tuesday 05 September 2017

Muon-electron scattering at NLO in QED - aula Voci (09:00-09:30)

- Presenters: CARLONI CALAME, C.

Preliminary considerations on hadronic contributions to mu-e scattering at NLO - aula Voci (09:30-10:00)

- Presenters: FAEL, Matteo

Preliminary considerations on the expansion by regions analysis for mu-e scattering - aula Voci (10:00-10:30)

- Presenters: BROGGIO, Alessandro

The amuHLO contribution from mu-e scattering and lattice QCD data [skype] - aula Voci (11:00-11:30)

- Presenters: Prof. KRSTIC MARINKOVIC, Marina

Relation between experimental and theoretical distributions in mu-e scattering - aula Voci (11:30-12:00)

- Presenters: VICINI, Alessandro

Effect of the atomic wave function in muon scattering off bound electrons - aula Voci (12:00-12:30)

- Presenters: DEL NOBILE, E.

Muon-electron scattering with GoSam - aula Voci (14:30-15:00)

- Presenters: OSSOLA, G.

QED contribution to the electron g-2 - aula Voci (15:00-15:30)

- Presenters: LAPORTA, S.

Preliminary considerations on the NP sensitivity of low-energy mu-e scattering data - aula Voci (15:30-16:00)

- Presenters: PARADISI, P.

Activities of the Physics Beyond Colliders study group at CERN [skype] - aula Voci (16:30-17:00)

- Presenters: DIEHL, M.

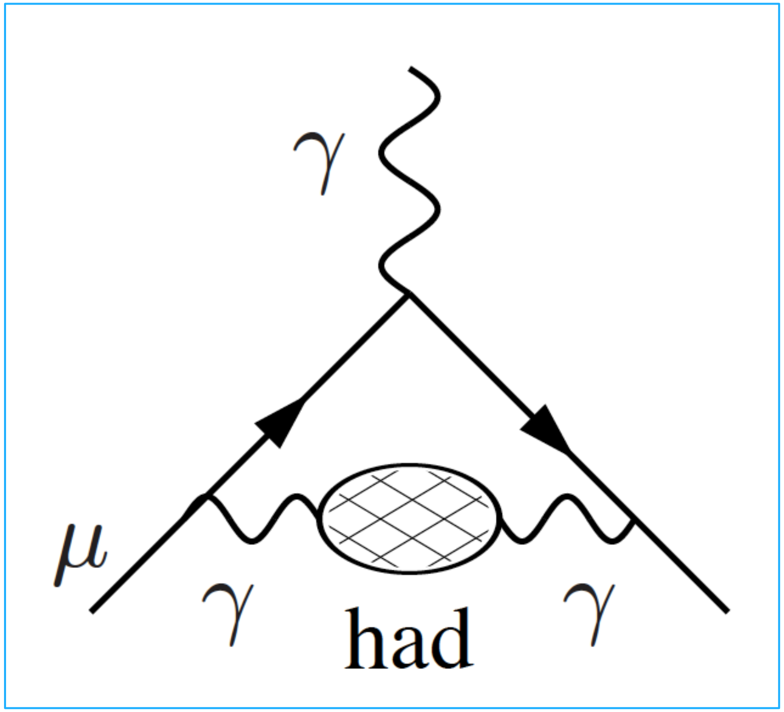
g-2 anomaly
Summary of the present status

- E821 experiment at BNL:
  $\mathbf{a_\mu^{E821} = (11659208.9 \pm 6.3)\times 10^{-10}}$ [0.54 ppm]
- The SM prediction:
  $\mathbf{a_\mu^{SM} = (11659180.2 \pm 4.9)\times 10^{-10}}$ [0.42 ppm]
- **3.5σ discrepancy**:

  $\mathbf{a_\mu^{E821} - a_\mu^{SM} = (28 \pm 8)\times 10^{-10}}$
- **Significance is limited by**:
  - Experimental uncertainty:
    New experiments planned at FNAL E989 and J-PARC, aiming to improve the precision x4.
  - **Theoretical uncertainty**:
    Theoretical precision is limited by low energy **hadronic effects**.

Hadronic Leading Order Contribution

Main contribution to the muon g-2 anomaly due to non perturbative hadronic effects



hadronic vacuum polarization

With time-like data

$a_\mu^{HLO} = (692.3 \pm 4.2) \times 10^{-10}$

$\delta a_\mu^{HLO} / a_\mu^{HLO} \sim 0.6\%$

We aim to
$\delta a_\mu^{HLO} / a_\mu^{HLO} \sim 0.3\%$
With the new approach

a_μ^{HLO} calculation with time-like data

- Optical theorem and analyticity:

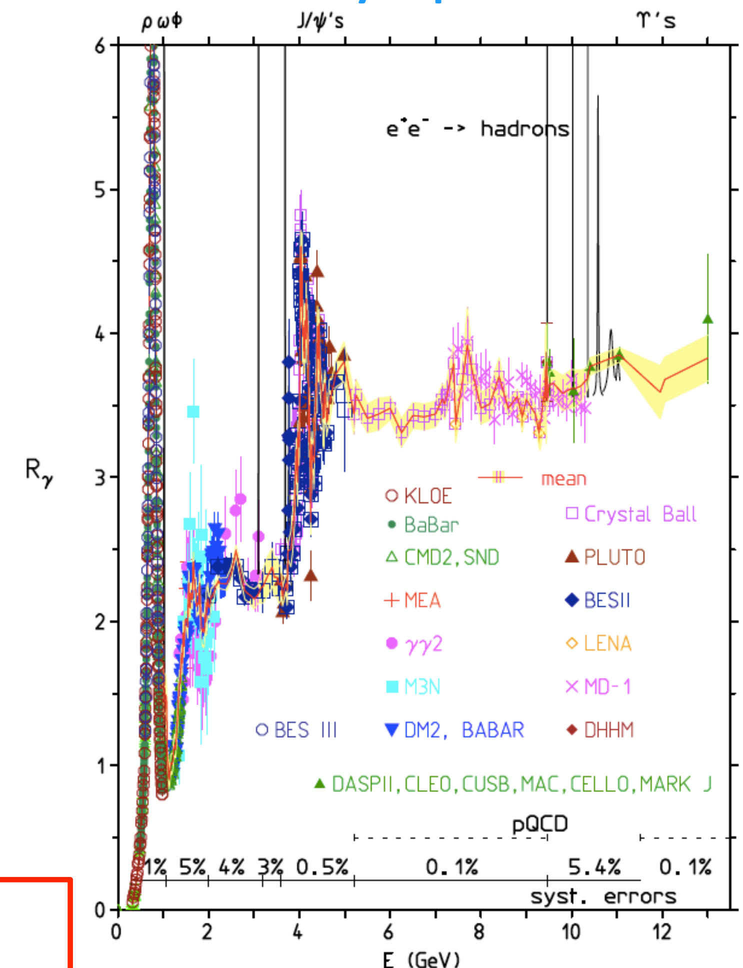
$$\sigma(s)_{(e^+e^-\to had)} = \frac{4\pi}{s}\,\mathrm{Im}\,\Pi_{hadron}(s)$$

$$a_\mu^{HLO} = \frac{1}{4\pi^3}\int_{4m_\pi^2}^{\infty} ds\, K(s)\cdot\sigma(s)_{(e^+e^-\to had)}$$

- The main contribution is in the highly fluctuating low energy region.

$$K(s) = \int_0^1 dx\,\frac{x^2(1-x)}{x^2+(1-x)(s/m^2)} \sim \frac{1}{s}$$

Collection of many experimental results

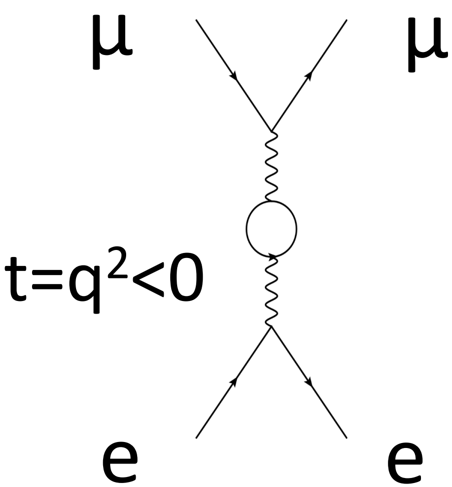


The high-energy tail of the integral is calculated using pQCD

The elastic scattering
$\mu + e(\text{rest}) \rightarrow \mu + e$

$\alpha(t)$ through:

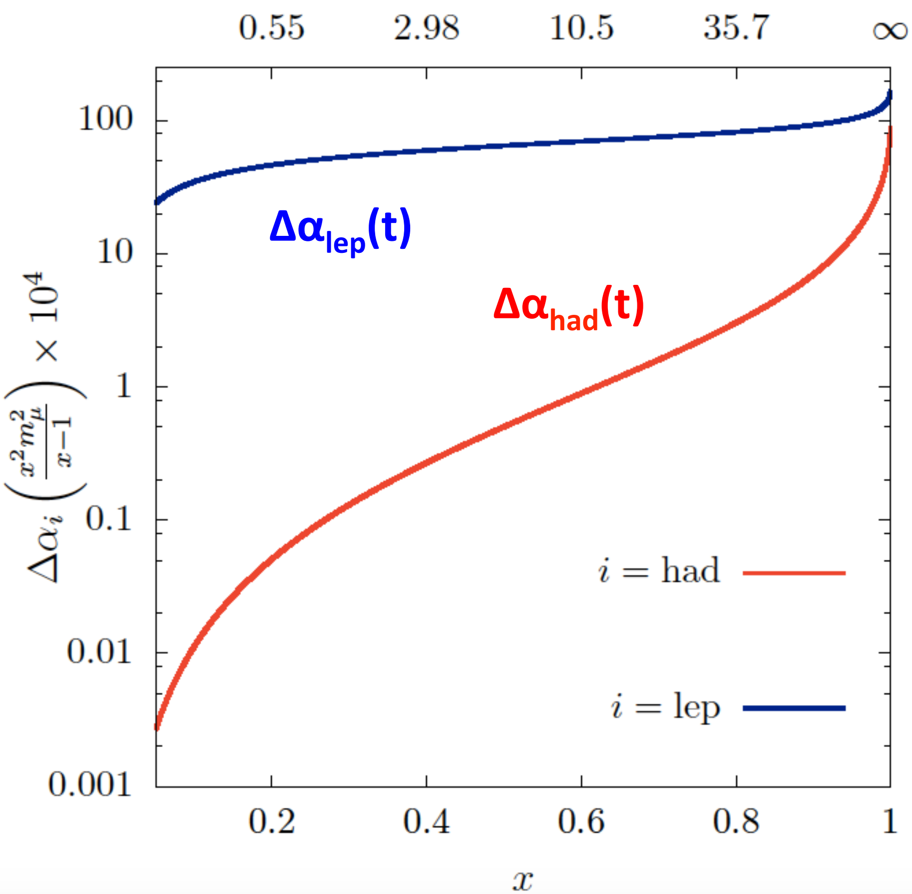
$$\frac{d\sigma}{dt} = \frac{d\sigma_0}{dt}\left|\frac{\alpha(t)}{\alpha(0)}\right|^2$$



$$\alpha(t) = \frac{\alpha(0)}{1-\Delta\alpha(t)}$$

$\Delta\alpha(t) = \Delta\alpha_{lep}(t) + \Delta\alpha_{had}(t)$

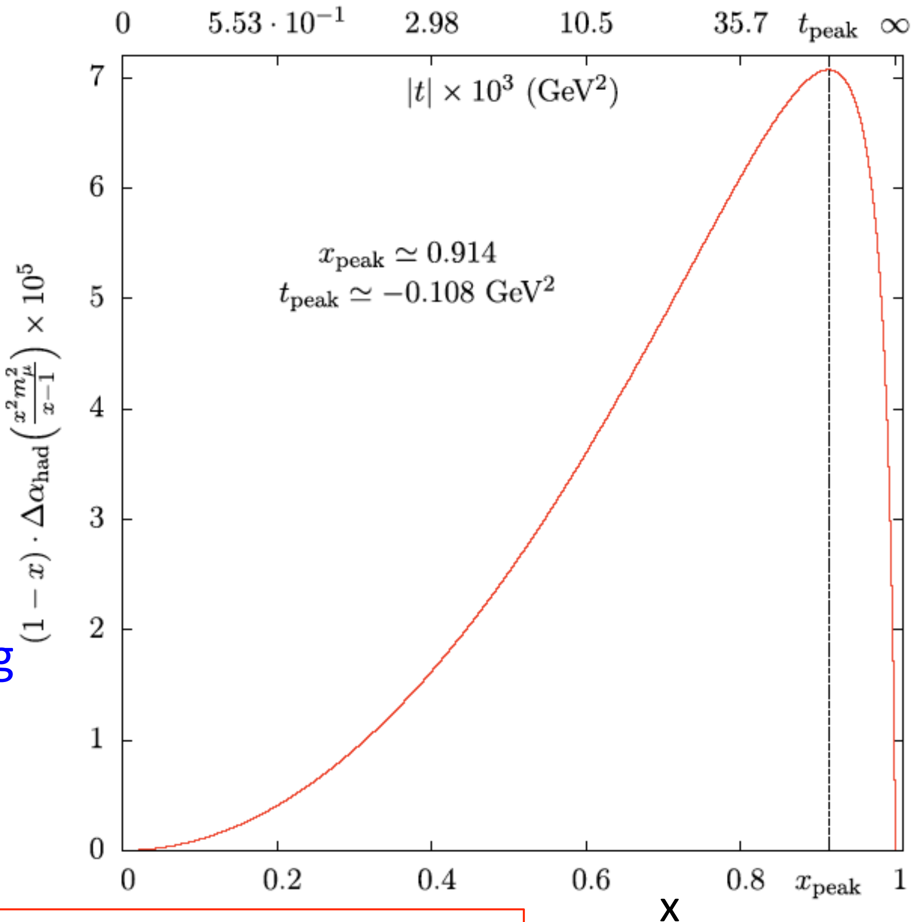
$$t = -m_\mu^2 \frac{x^2}{1-x} \left(10^{-3} GeV^2\right)$$



a_μ^{HLO} space-like approach

- **It requires just the single process**
  μ + e → μ + e elastic
  High intensity CERN muon beam of **E_μ ~ 150 GeV** colliding on atomic electrons at rest.
- **Highly boosted final state**:
  $0 < -t < 0.161$ GeV^2
  $0 < x < 0.93$ (peak is at $x = 0.914$)
  The range covers **87%** of the integral.
- Beyond the kinematics limit the integral (13%) can be determined using pQCD & time-like data, and/or lattice QCD results.

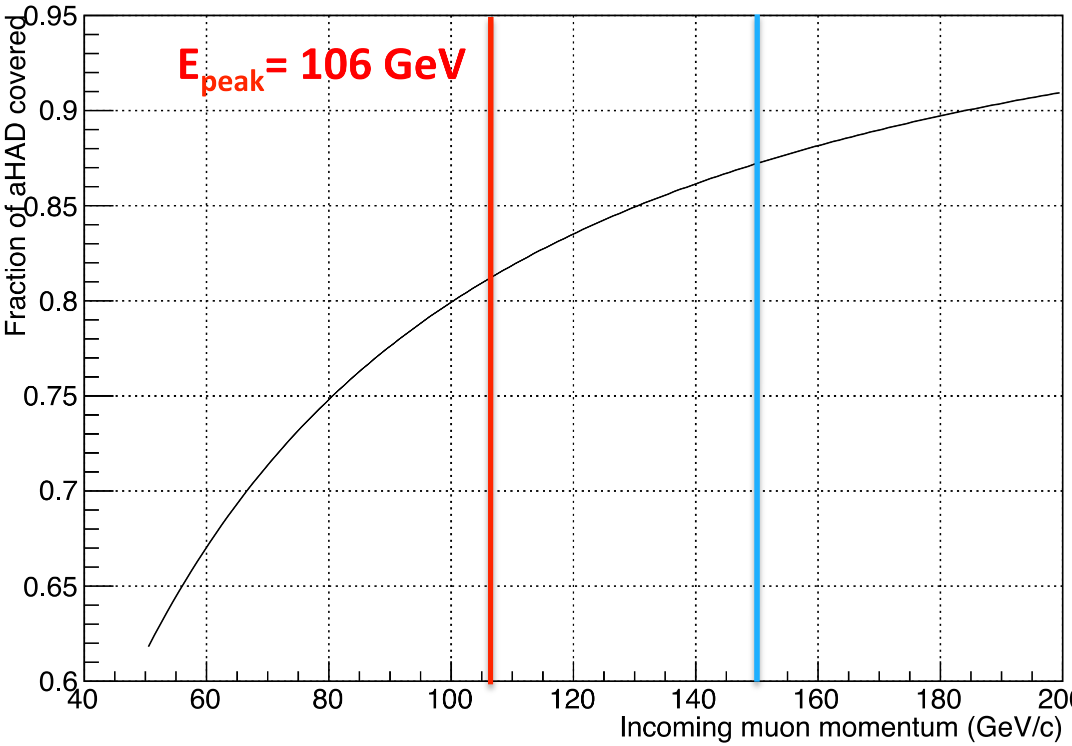
The expected shape of integral function

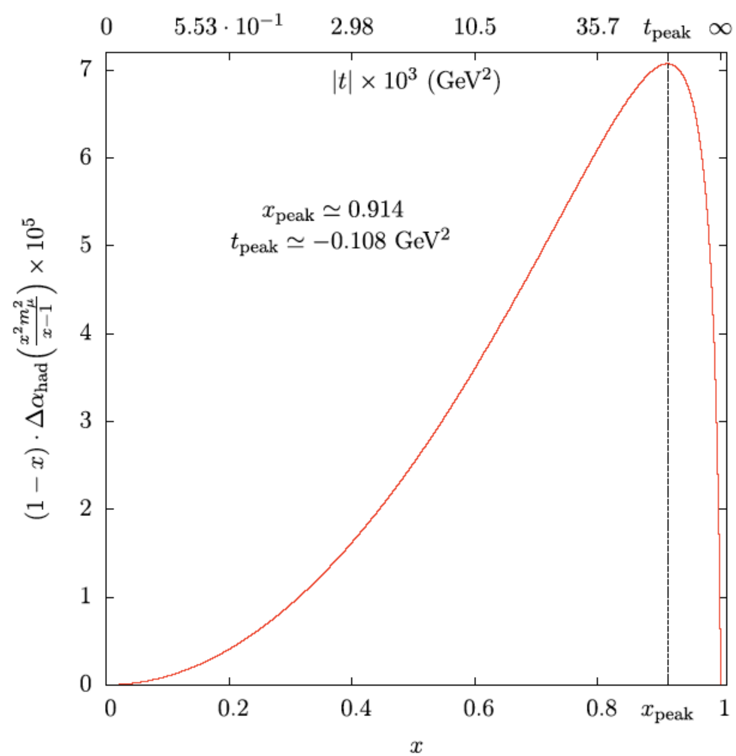


$$a_\mu^{HLO} = \frac{\alpha}{\pi} \int_0^1 dx\, (1-x) \cdot \Delta\alpha_{had}\left(-\frac{x^2 m_\mu^2}{1-x}\right)$$

Optimal Muon Beam Momentum

Fraction of the a_μ^{HLO} dispersive integral as a function of the muon beam momentum: p_μ = 150 GeV → 87% of the integral (0 < x < 93).





Beyond the kinematics limit the integral can be determined using pQCD & time-like data, and/or lattice QCD results.

Muon beam M2 at CERN

"Forty years ago, on 7 May 1977, CERN inaugurated the world's largest accelerator at the time – the Super Proton Synchrotron".

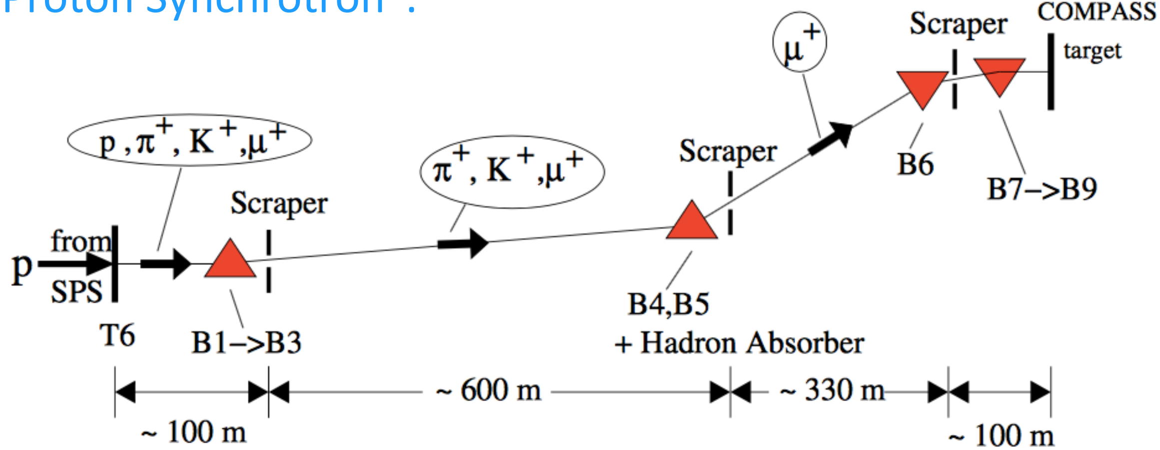


Table 3
Parameters and performance of the 160 GeV/c muon beam.

Beam parameters	Measured
Beam momentum $(p_\mu)/(p_\pi)$	(160 GeV/c)/(172 GeV/c)
Proton flux on T6 per SPS cycle	$1.2 \cdot 10^{13}$
Focussed muon flux per SPS cycle	$2 \cdot 10^8$
Beam polarisation	$(-80 \pm 4)\%$
Spot size at COMPASS target $(\sigma_x \times \sigma_y)$	$8 \times 8\,\mathrm{mm}^2$
Divergence at COMPASS target $(\sigma_x \times \sigma_y)$	0.4×0.8 mrad
Muon halo within 15 cm from beam axis	16%
Halo in experiment $(3.2 \times 2.5\,\mathrm{m}^2)$ at $\|x, y\| > 15$ cm	7%

I_{beam}> 10^7 muon/s, E_μ = 160 GeV

https://arxiv.org/pdf/hep-ex/0703049.pdf

Luminosity

The instantaneous luminosity can be calculated as:

$$\mathcal{L} = I_\mu \times \rho_e \times d = I_\mu \times \frac{N_A \cdot \rho \cdot Z}{W} \times d \qquad (1)$$

where I_μ is the intensity of the muon beam, ρ_e is the density of the electron scattering centers and d is the thickness of the target. ρ_e in turn can be expressed in terms of the material density ρ, the Avogadro's number N_A, the atomic number Z and the atomic weight W.

Assuming the intensity of the muon beam to be $I_\mu = 1.3 \times 10^7\ \mathrm{s}^{-1}$, the luminosity provided by Beryllium target, with $\rho_{Be} = 1.85\ \mathrm{gcm}^3$, $(Z/W)_{Be} = 0.44$, and a thickness $d = 60$ cm is:

$$\mathcal{L}_{Be} = 3.9 \times 10^{32}\ \mathrm{cm}^{-2}\mathrm{s}^{-1} = 0.39\ \mathrm{nb}^{-1}\mathrm{s}^{-1} \qquad (2)$$

The required luminosity that can be collected in two years of data taking, assuming 2×10^7 s/yr is:

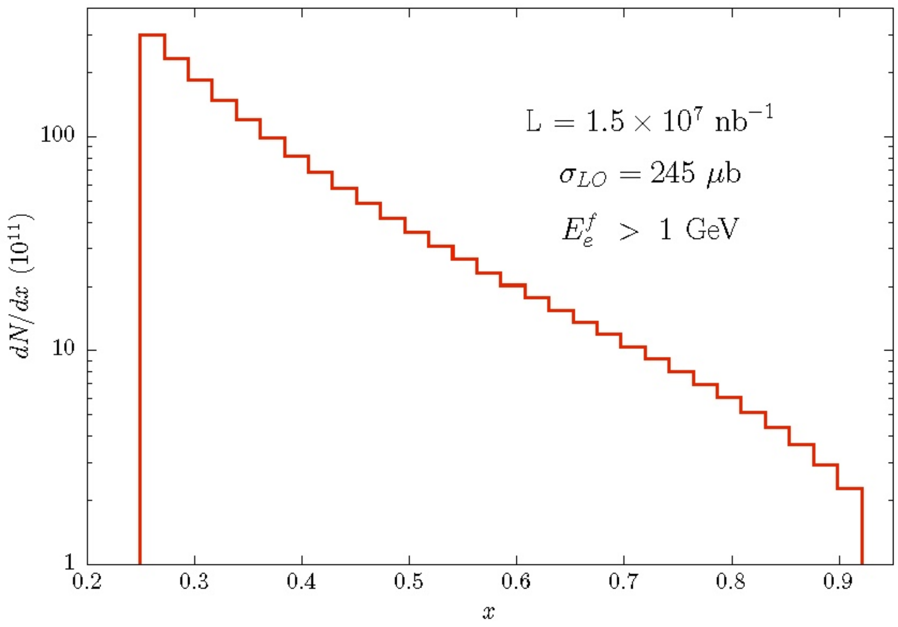
$$L_{Be} = 1.5 \times 10^7\ \mathrm{nb}^{-1} \qquad (3)$$

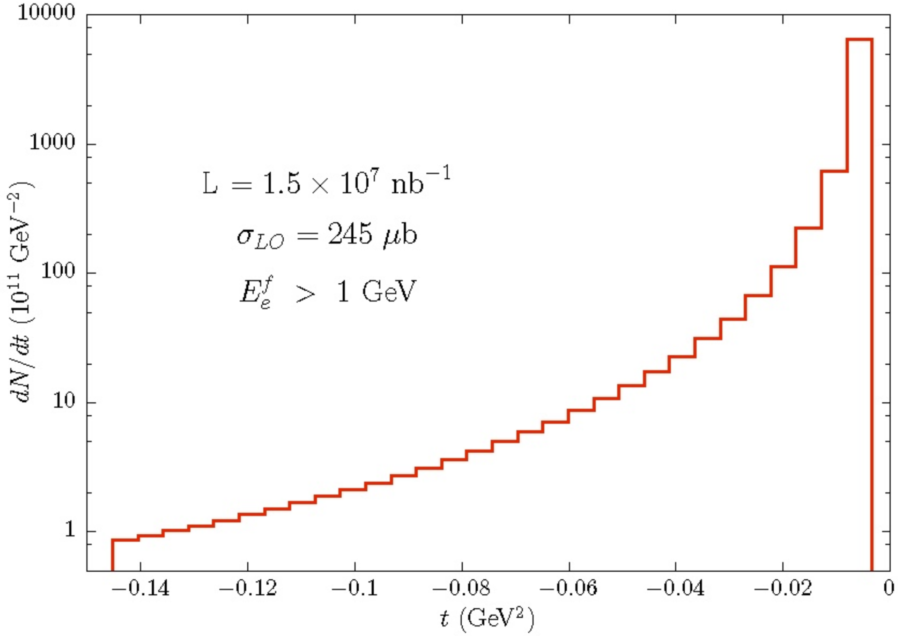
Assuming the muon electron elastic scattering cross-section, for scattered electrons of energy greater than 1 GeV is $\sigma_{\mu e} = 245\ \mu$b, then the expected event yield can be estimated to be:

$$N = L_{Be} \times \sigma_{\mu e} \sim 4 \times 10^{12} \qquad (4)$$

Luminosity (II)

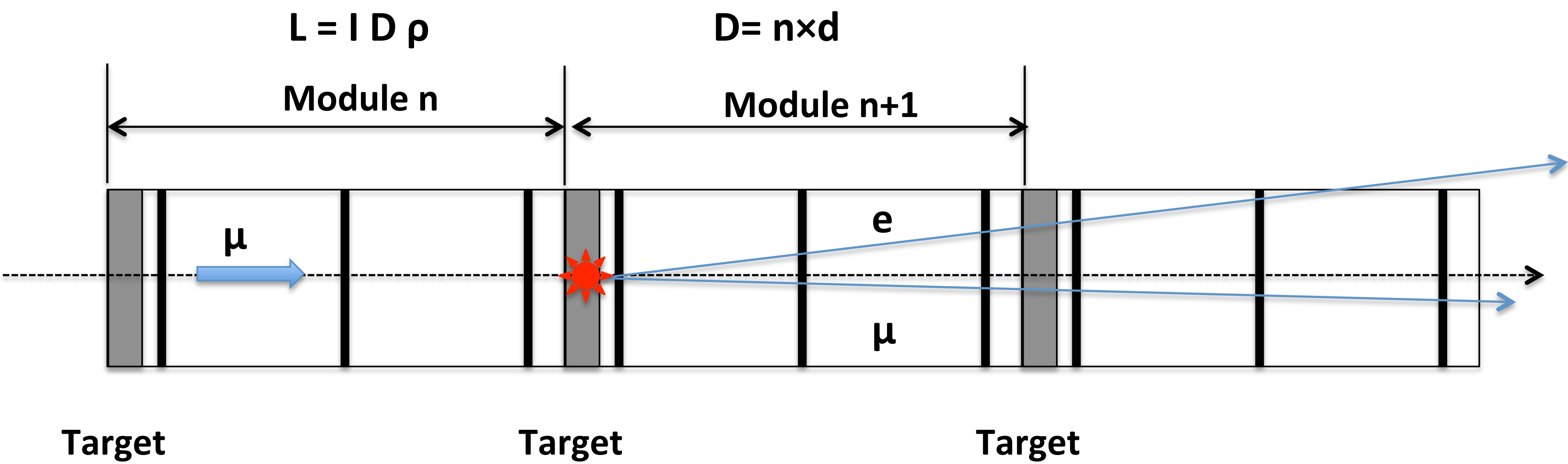
Monte Carlo generated events
LO elastic cross-section





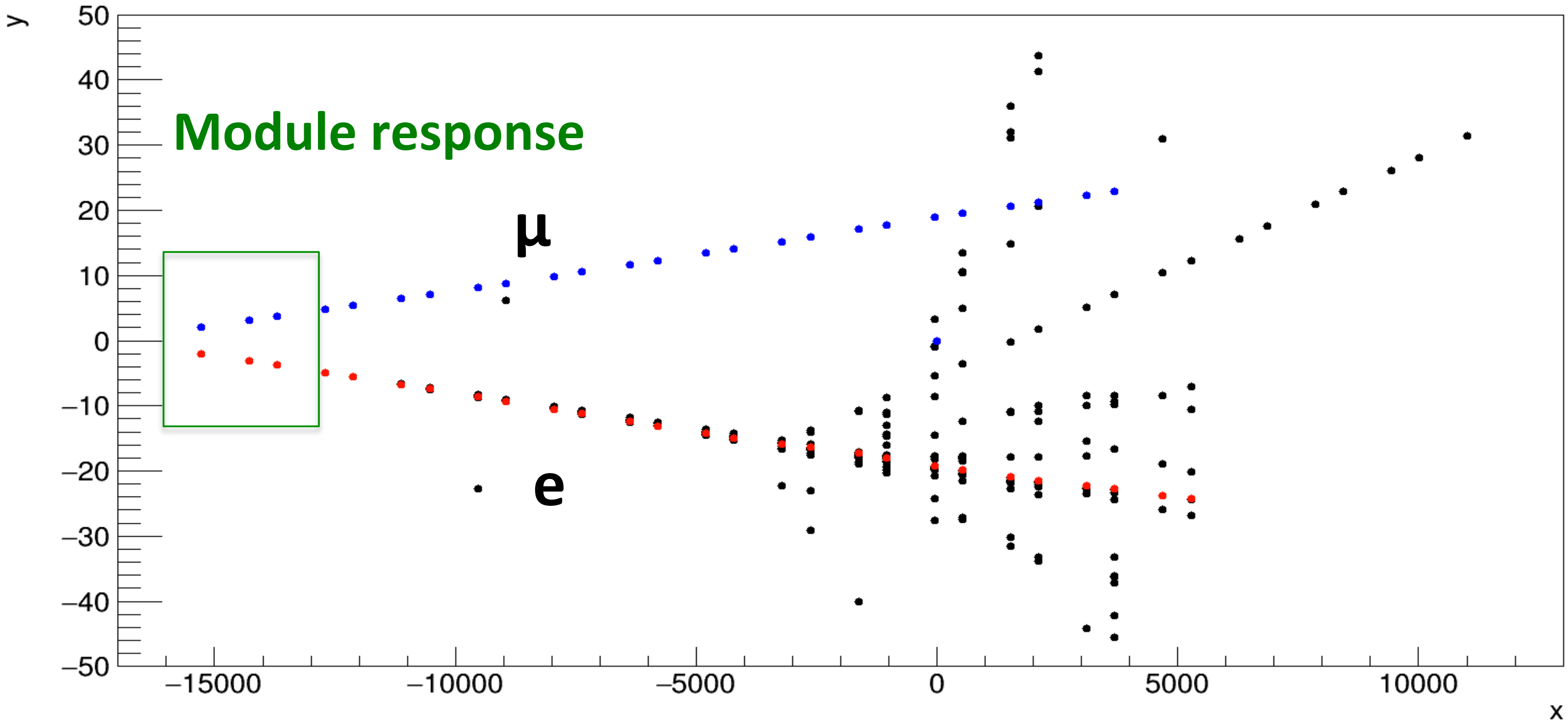
Detection principles

- We need to distribute the low Z target material in thin layers. Each layer has a thickness of the order of 10 mm.
- A detection module must be transparent to non interacting muons, but has to let us track muons while passing through, in order to measure the muon direction at any stage.
- The detection module where the interaction would take place must act as a standalone, independent detector.

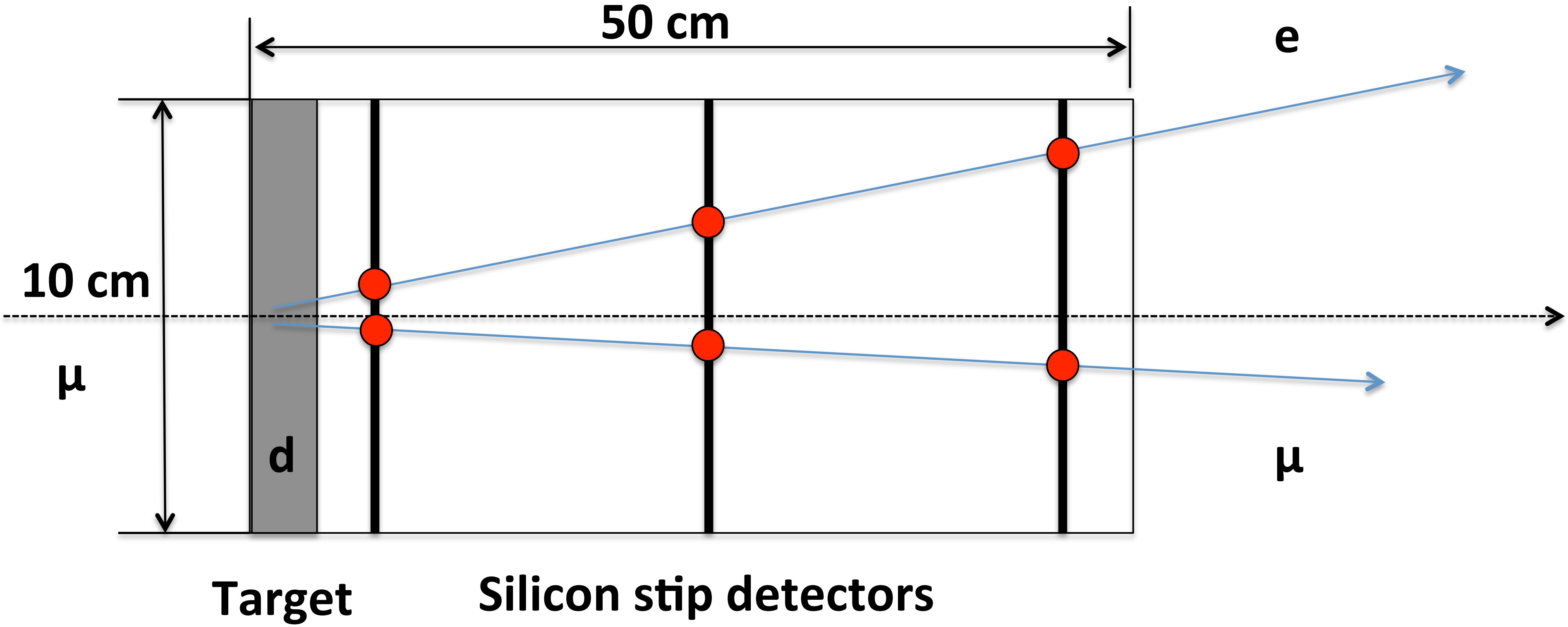


Detection principles (II)

PID capabilities



Measuring electron and muon angles

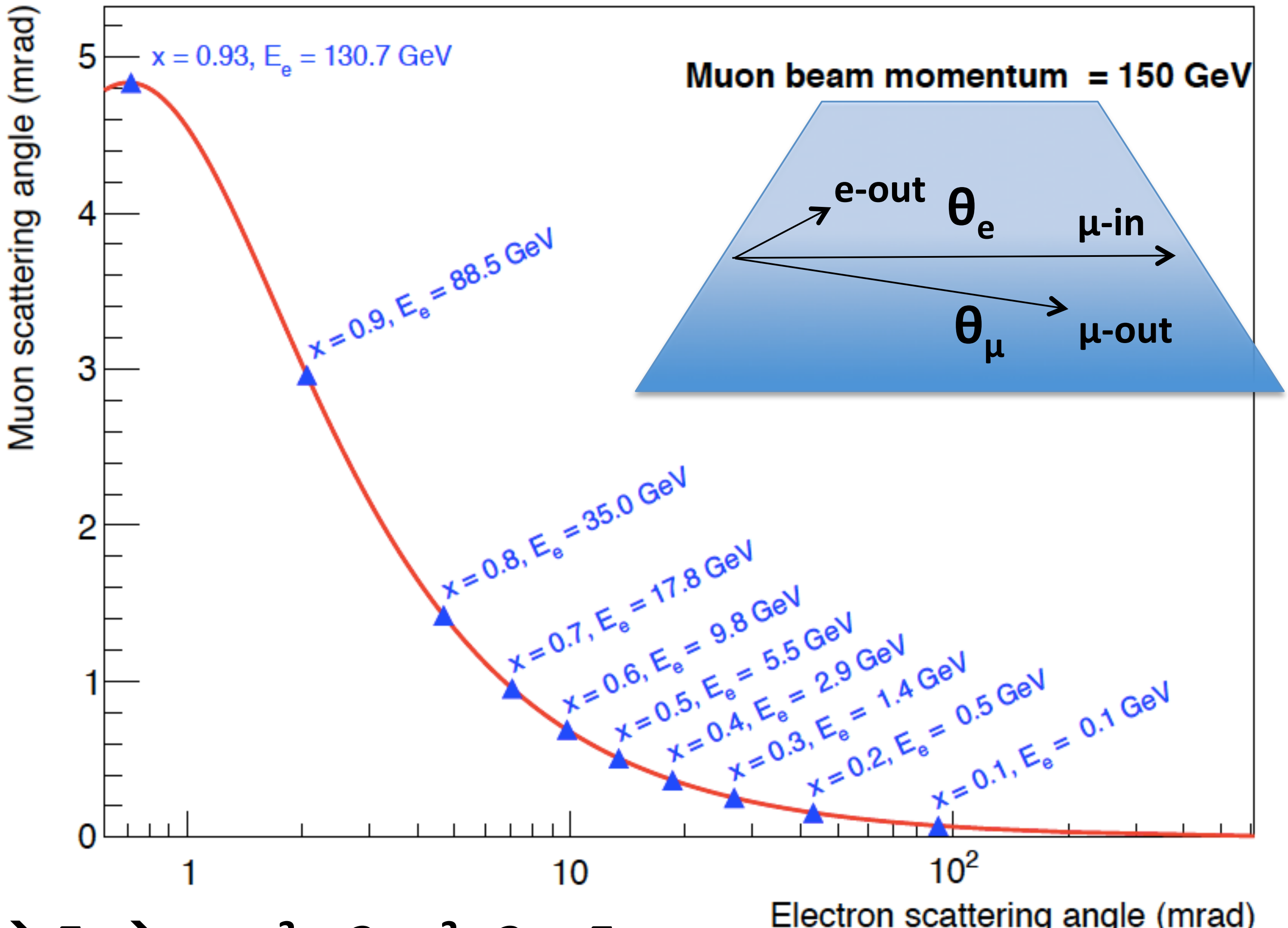


hit resolution ~10 μm

expected angular resolution ~ 10 μm / 0.5 m = 0.02 mrad

Elastic scattering in the (θ_e , θ_μ) plane

Coplanarity of the momentum vectors and angular kinematical constraint

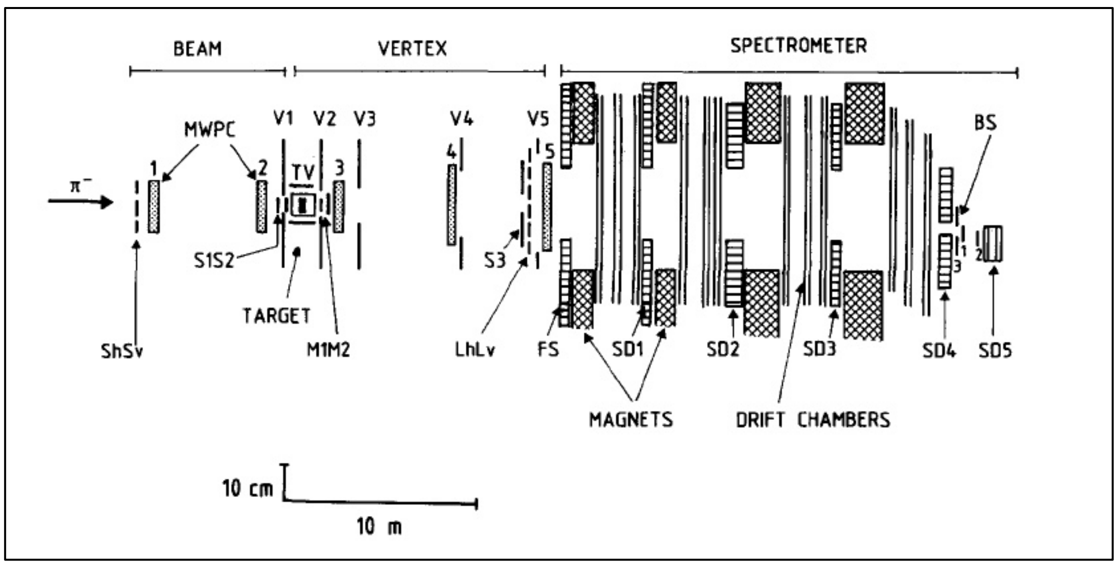


$\theta_e \rightarrow E_e \rightarrow t = q^2 = 2m_e^2 - 2m_eE_e$

NA7 experiment

A MEASUREMENT OF THE SPACE-LIKE PION ELECTROMAGNETIC FORM FACTOR,

"The pion form factor has been measured in the space-like q^2 region 0.014 to 0.26 $(GeV/c)^2$ by **scattering 300 GeV pions from the electrons of a liquid hydrogen target**".



Target: 28 cm liquid Hydrogen
X_0 (liquid H_2) = 890.5 cm

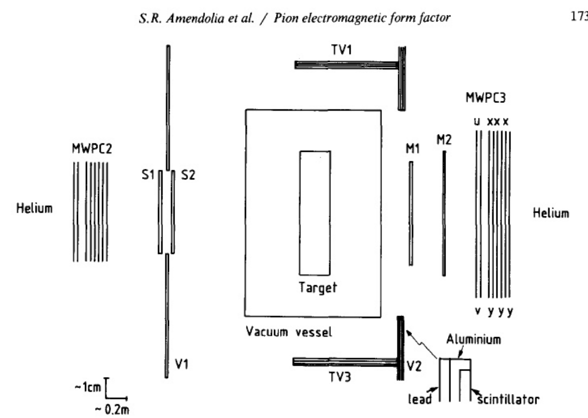


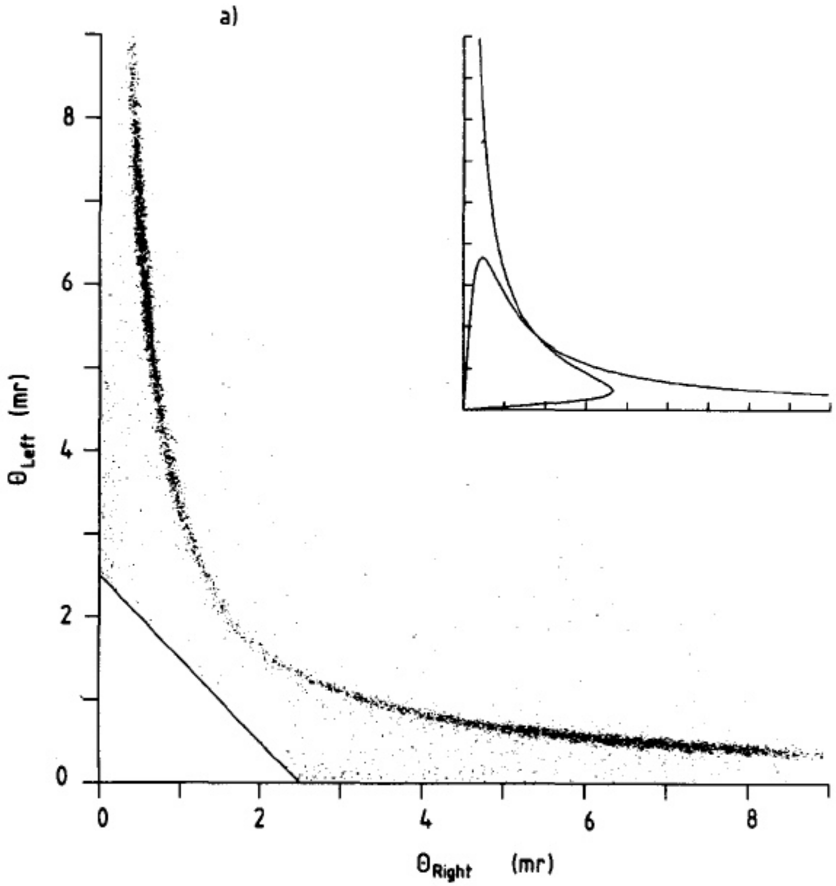
Fig. 4. Apparatus surrounding the target.

Nuclear Physics B277 (1986) 168-196

"**The q^2 variable for the final sample was determined from the angles alone**, up to the kinematic ambiguity which was resolved using the shower detectors. In this procedure the only rejection criterion involving the momenta was a cut against electrons of less than 1 GeV/c".

NA7 experiment

Elastic scattering in the (θ_R,θ_L) plane



“The scatter distribution of the measured polar angles of the right and left-going particles (θ_R,θ_L). Our estimate of q^2 was made from the point on the theoretical kinematic curve nearest to these angle coordinates”.

Coplanarity

180 *S.R. Amendolia et al. / Pion electromagnetic form factor*

EVFNTS

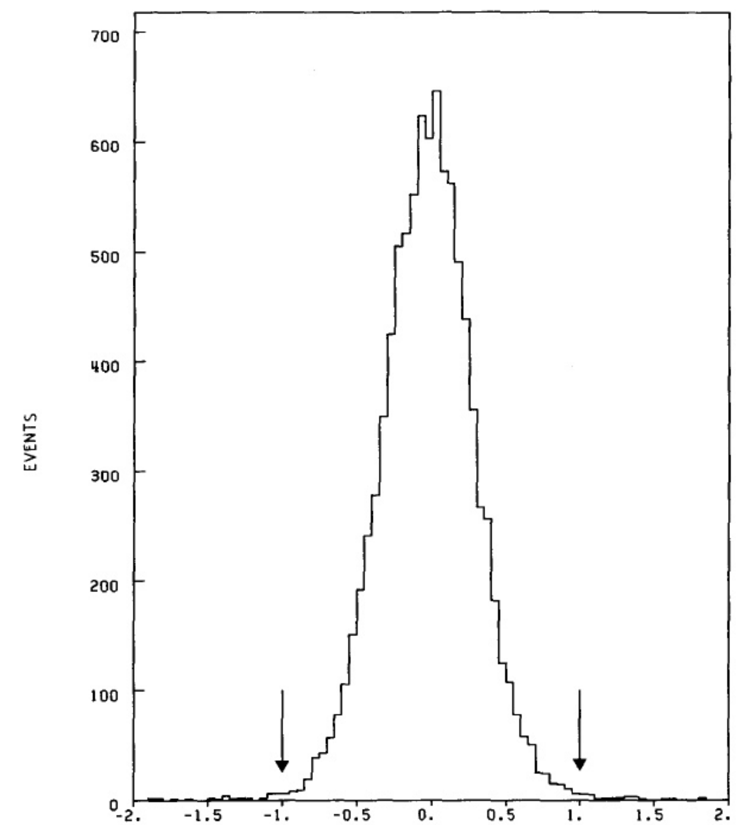
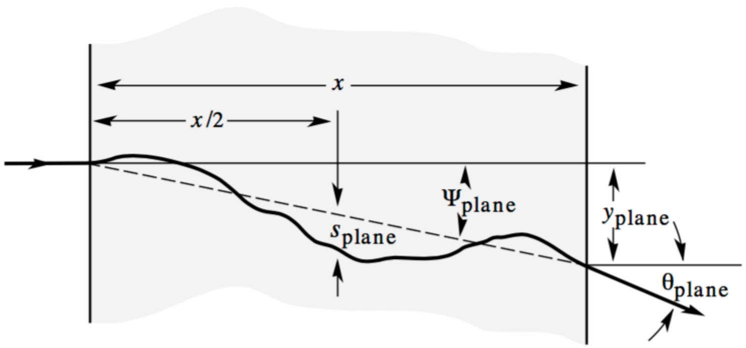


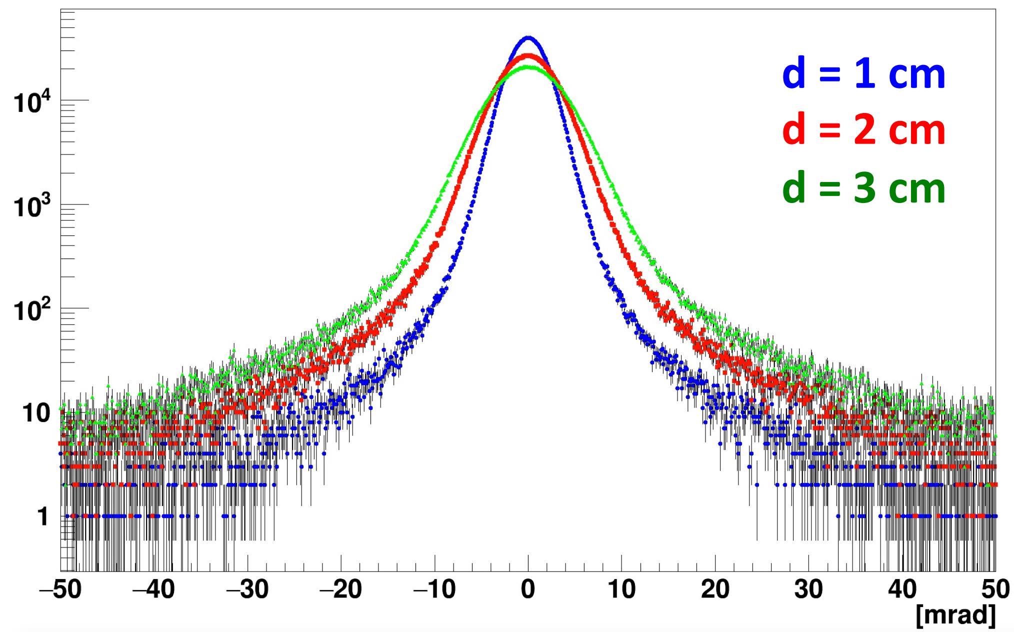
Fig. 8. The distribution of the triple scalar product of unit vectors along the incident and scattered tracks, in units of the applied cut. This varied smoothly with decreasing opening angle from 1.1×10^{-6} to 0.6×10^{-6}.

“A fraction of the hadronic background was rejected by requiring coplanarity of the incident and scattered tracks”

Effect of Multiple Scattering (MSC)

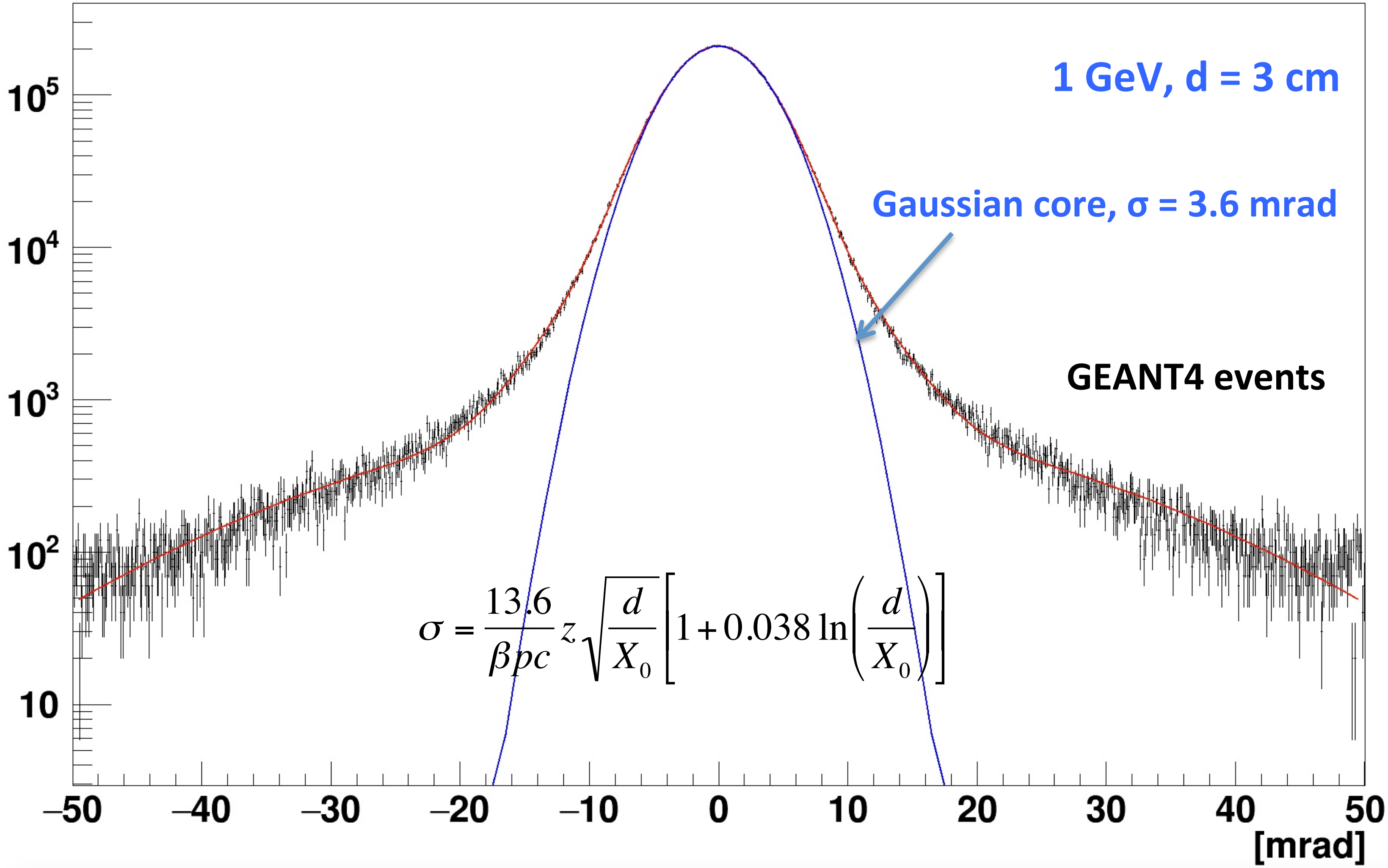


GEANT4, 1 GeV electrons, Be target



Vertices of the **μ + e → μ + e** collisions will be uniformly distributed inside the target along the direction of the beam axis.
The observable angles (electron and muon angles) depend therefore on the particles' path length inside the material and on their energies.
We need a MSC model to relate the observed angles to the scattering ones.

Modeling the MSC

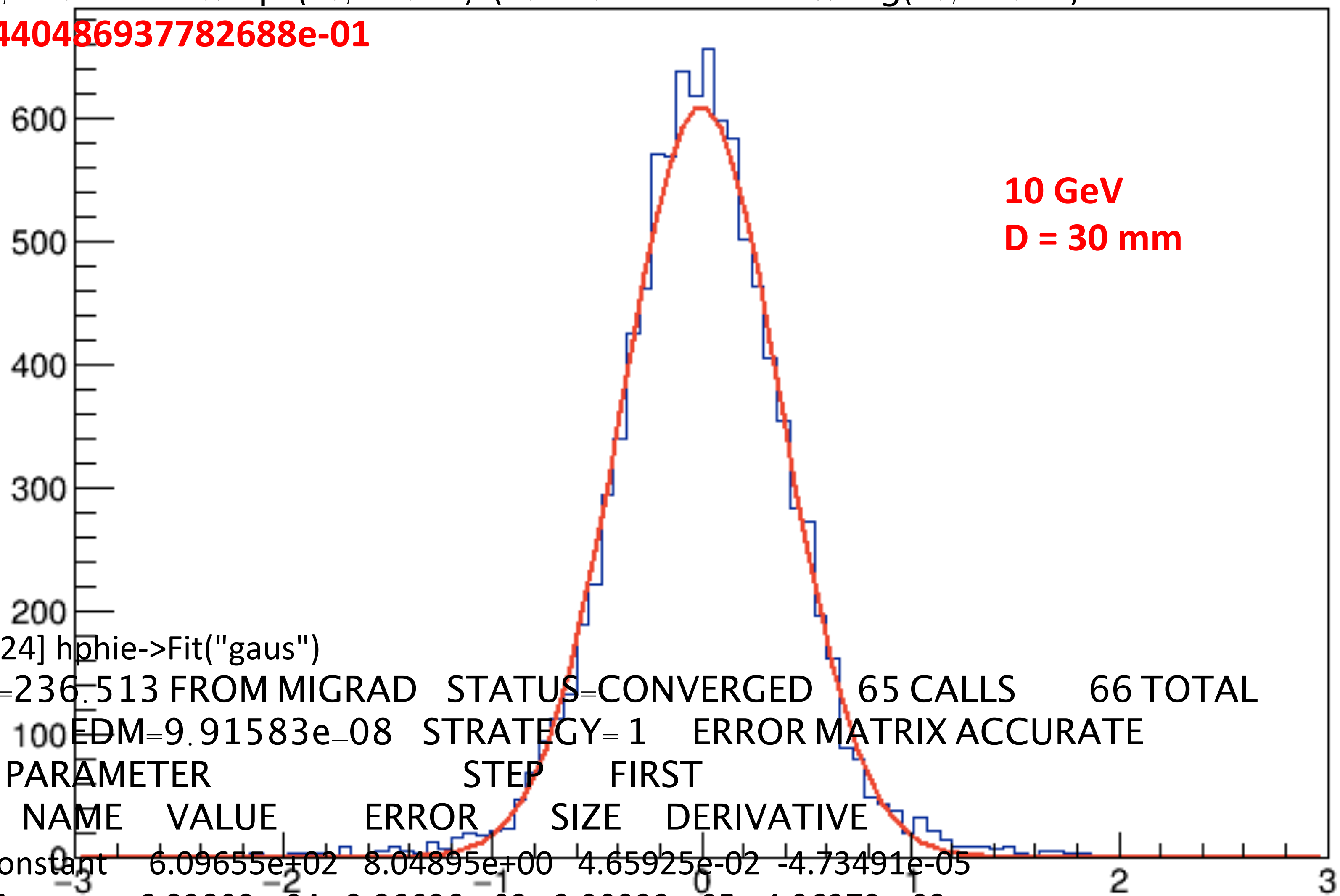


$$\sigma = \frac{13.6}{\beta pc} z \sqrt{\frac{d}{X_0}} \left[1 + 0.038 \ln\left(\frac{d}{X_0} \right) \right]$$

Highland formula (PDG) = 3.593 mrad

Modeling the MSC

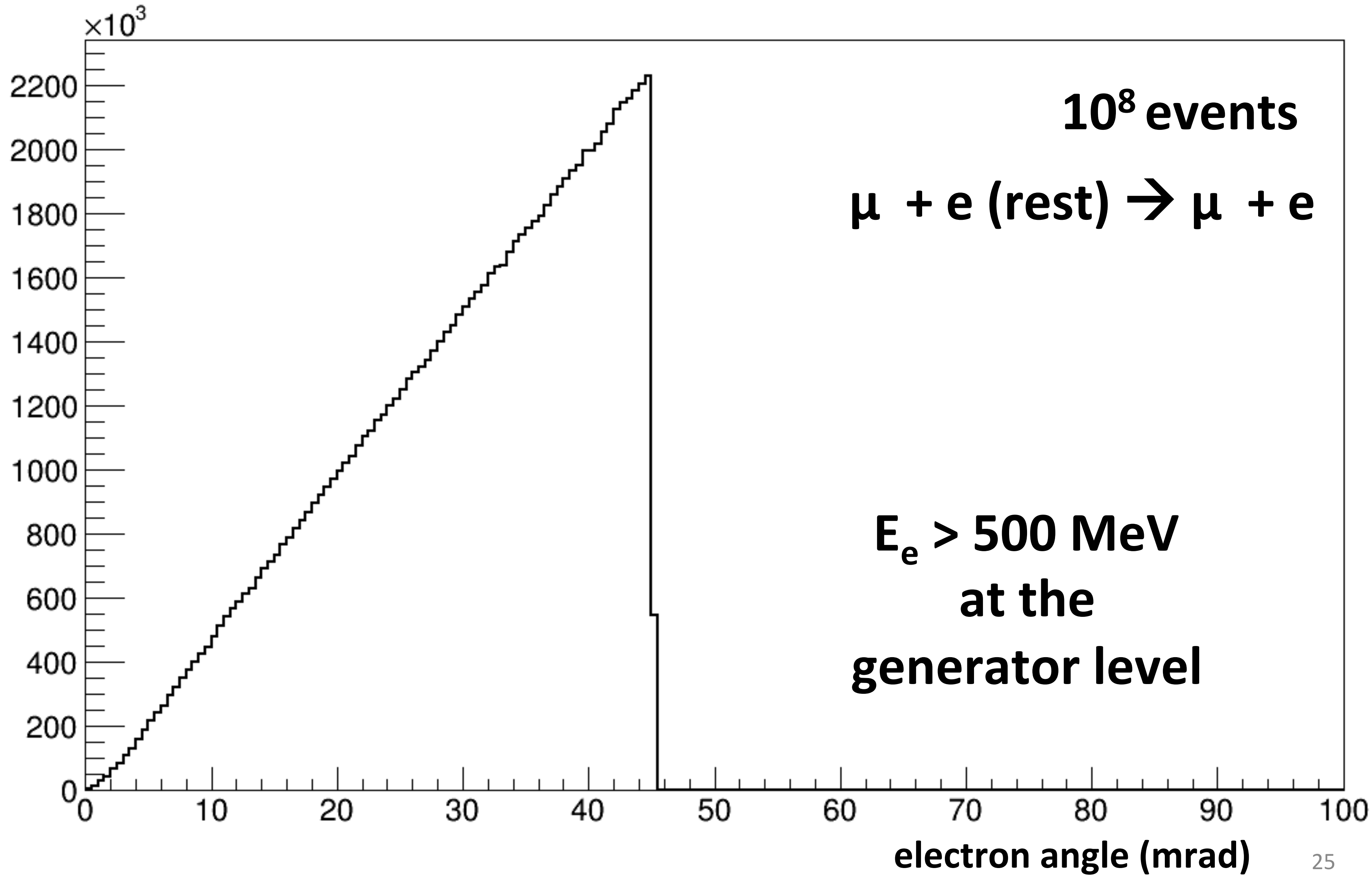
13.6/10.*TMath::Sqrt(3./35.28)*(1.+0.038*TMath::Log(3./35.28) =
3.59440486937782688e-01



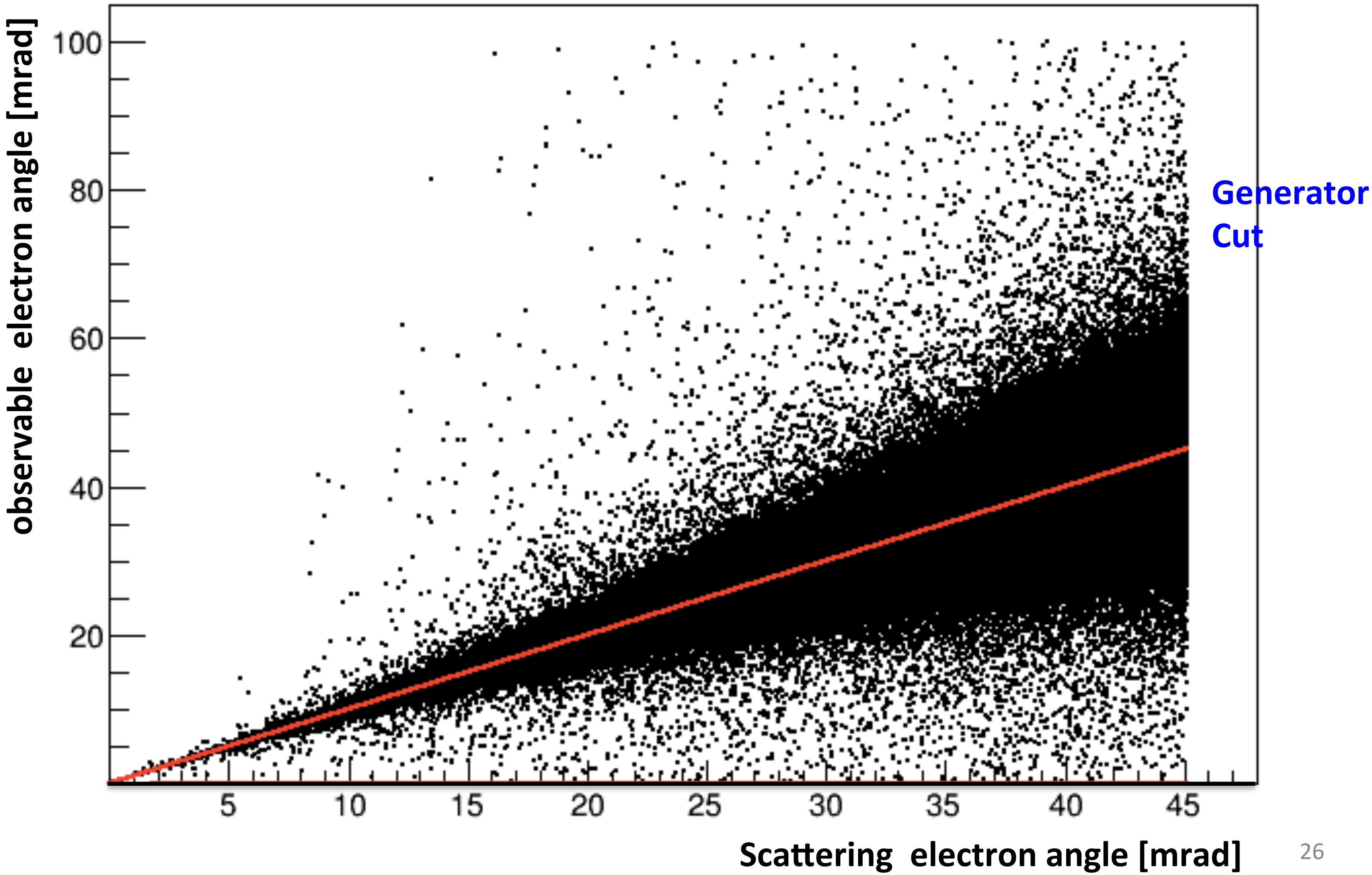

```
root [24] hphie->Fit("gaus")
 FCN=236.513 FROM MIGRAD    STATUS=CONVERGED      65 CALLS        66 TOTAL
                     EDM=9.91583e-08    STRATEGY= 1      ERROR MATRIX ACCURATE
  EXT PARAMETER                                   STEP         FIRST
  NO.   NAME      VALUE            ERROR          SIZE      DERIVATIVE
   1  Constant     6.09655e+02   8.04895e+00   4.65925e-02  -4.73491e-05
   2  Mean        -6.82802e-04   3.86606e-03   2.90922e-05  -4.96273e-02
   3  Sigma        3.80668e-01   3.21060e-03   1.49209e-05   1.26108e-02
```

20 detection modules
Beryllium target of d = 30 mm

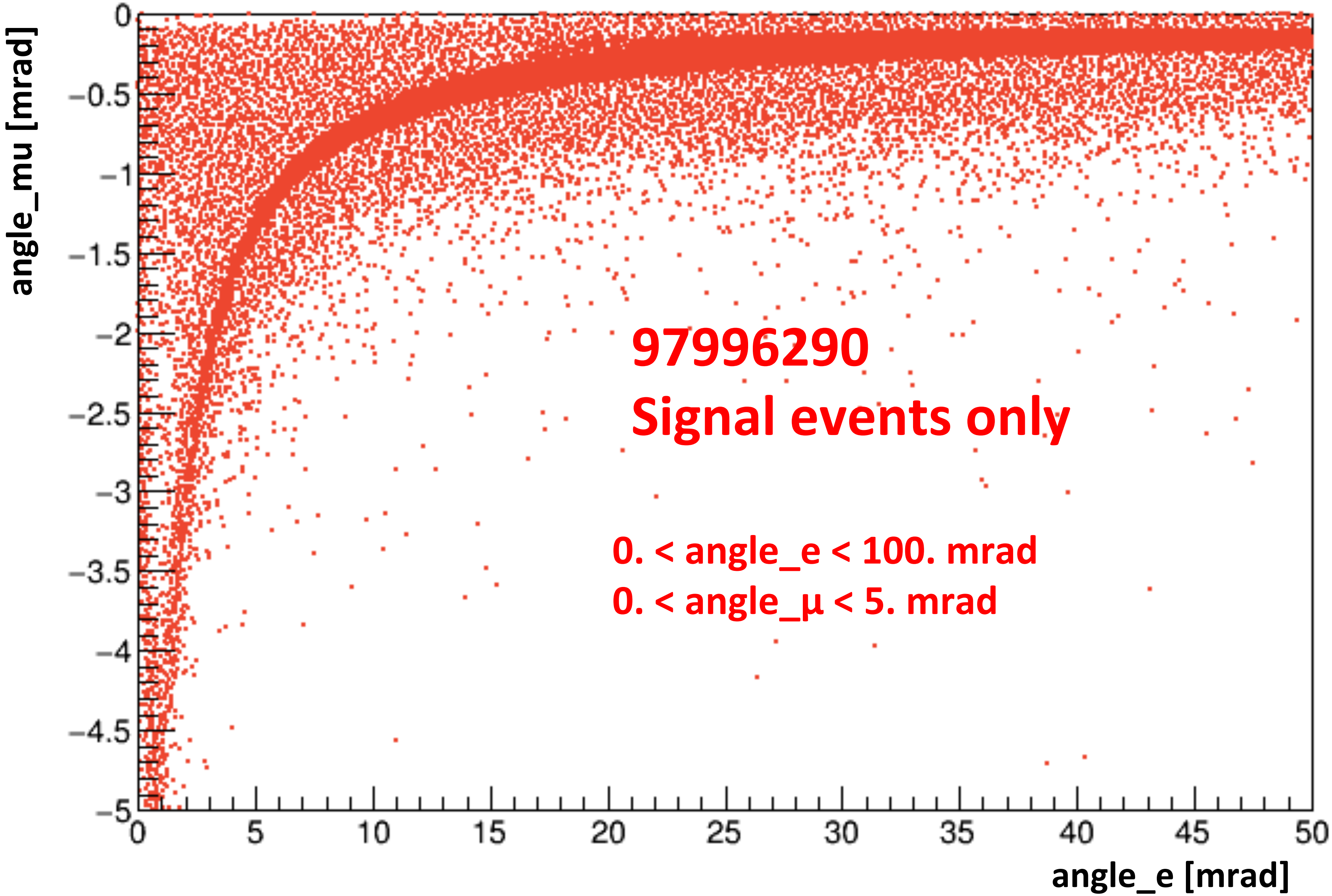
electrons angular distribution



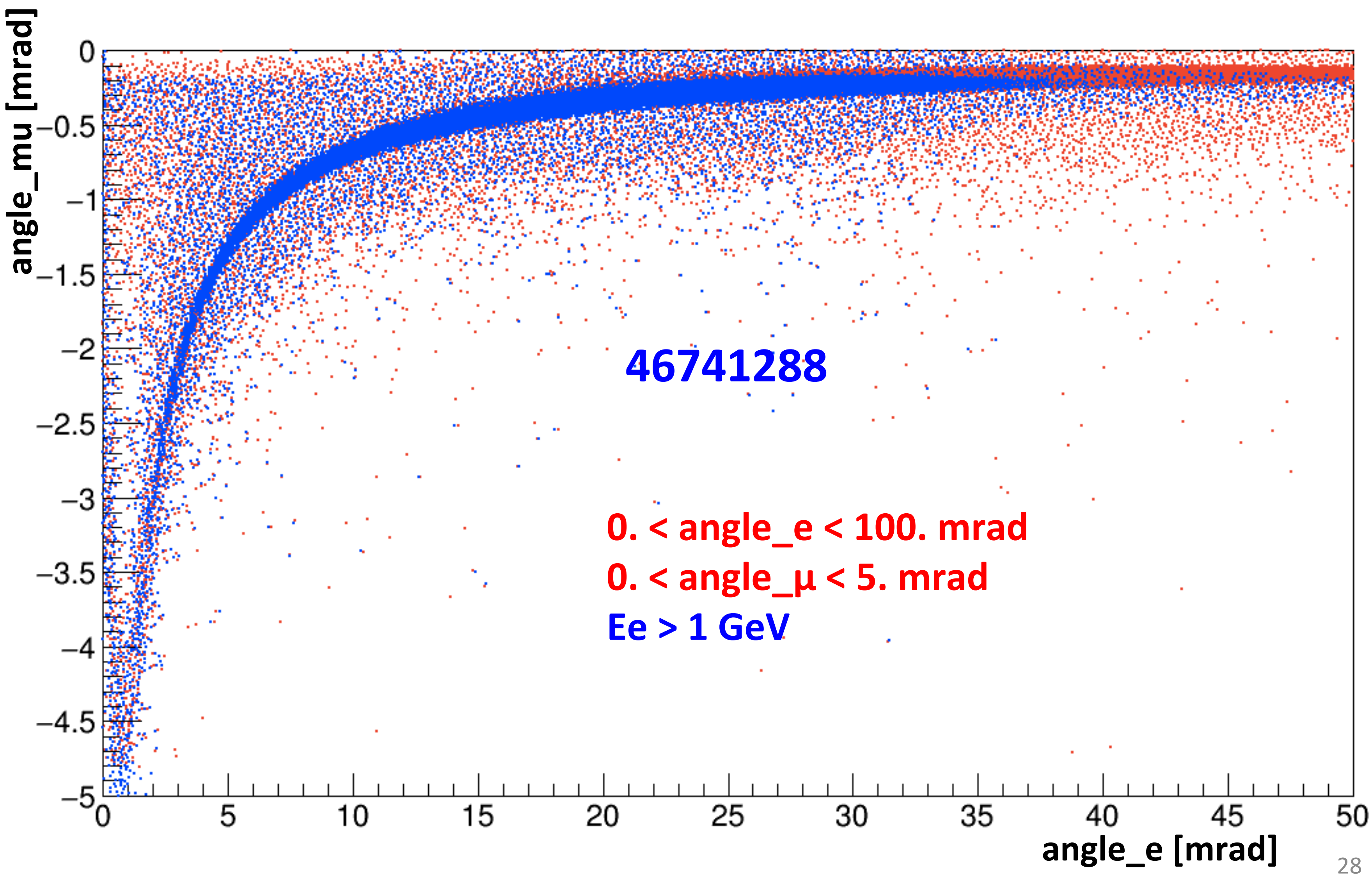
Observable electron angle



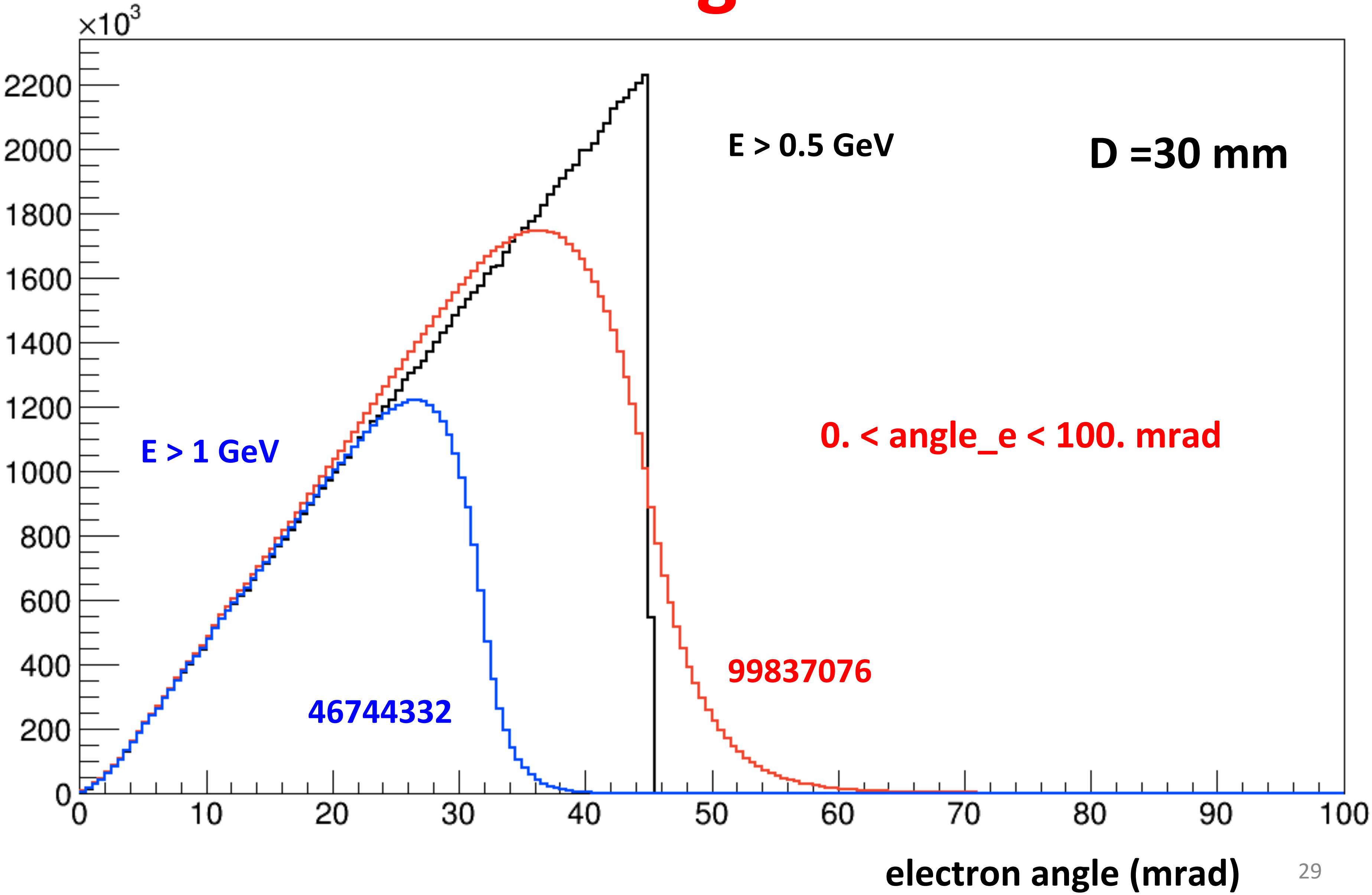
Observable 2D distribution



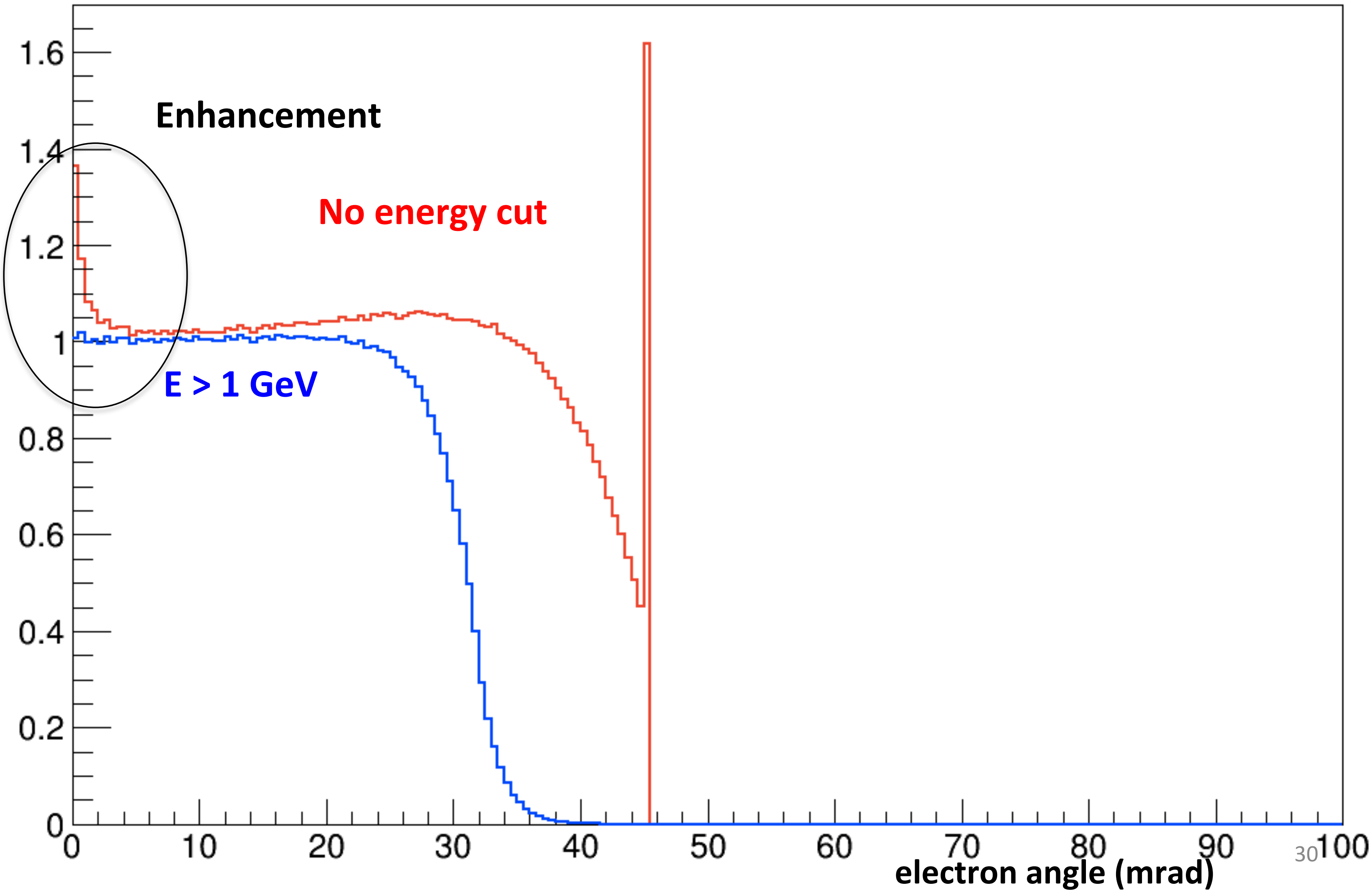
Observable 2D distribution



Observable angular distribution



Ratios Beryllium d= 30mm



Ratios

No energy cut

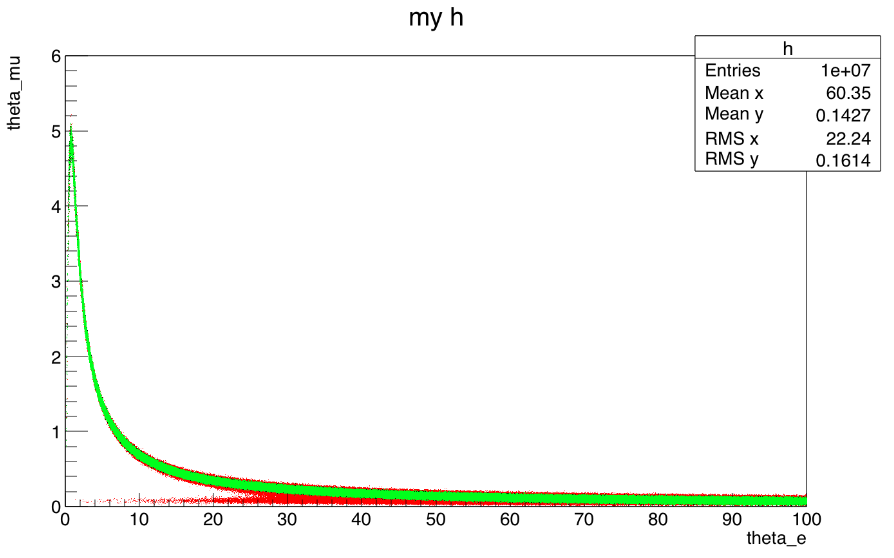
1	1.36456	21	1.01907
2	1.17188	22	1.02001
3	1.08106	23	1.01851
4	1.06502	24	1.01821
5	1.03915	25	1.0275
6	1.04478	26	1.02305
7	1.02638	27	1.0327
8	1.03087	28	1.02592
9	1.02947	29	1.01759
10	1.0136	30	1.02757
11	1.02227	31	1.03269
12	1.01763	32	1.0279
13	1.02187	33	1.0367
14	1.01443	34	1.03324
15	1.02077	35	1.03377
16	1.01715	36	1.03778
17	1.02284	37	1.03779
18	1.02102	38	1.0362
19	1.018	39	1.0372
20	1.02547	40	1.04158

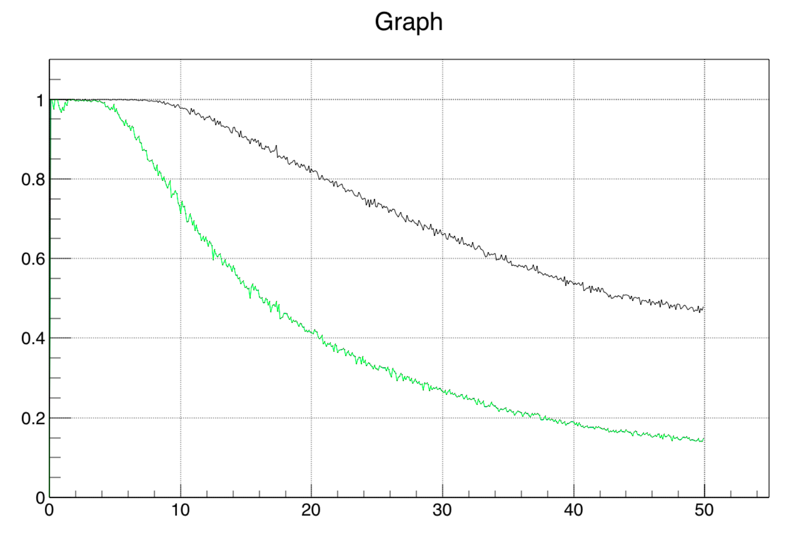
E > 1 GeV

1	1.00759	21	1.00321
2	1.01764	22	1.00402
3	0.999437	23	1.00218
4	1.00531	24	1.00136
5	0.996328	25	1.00983
6	1.01035	26	1.00531
7	0.998516	27	1.01385
8	1.00633	28	1.00673
9	1.00795	29	0.997822
10	0.994549	30	1.00677
11	1.00478	31	1.01088
12	1.00082	32	1.00544
13	1.0053	33	1.01321
14	0.998777	34	1.00858
15	1.00503	35	1.0079
16	1.00232	36	1.0104
17	1.00762	37	1.0089
18	1.00529	38	1.00614
19	1.00248	39	1.00501
20	1.00979	40	1.00742

Elasticity cut

Gaussian Model





$0.95\ s < (p\_e\ + p\_\mu)^2 < 1.05\ s$

$(p\_e\ + p\_\mu)^2 > 0.9\ s$

Remarks

- With the condition E_e > 1GeV the ratio:

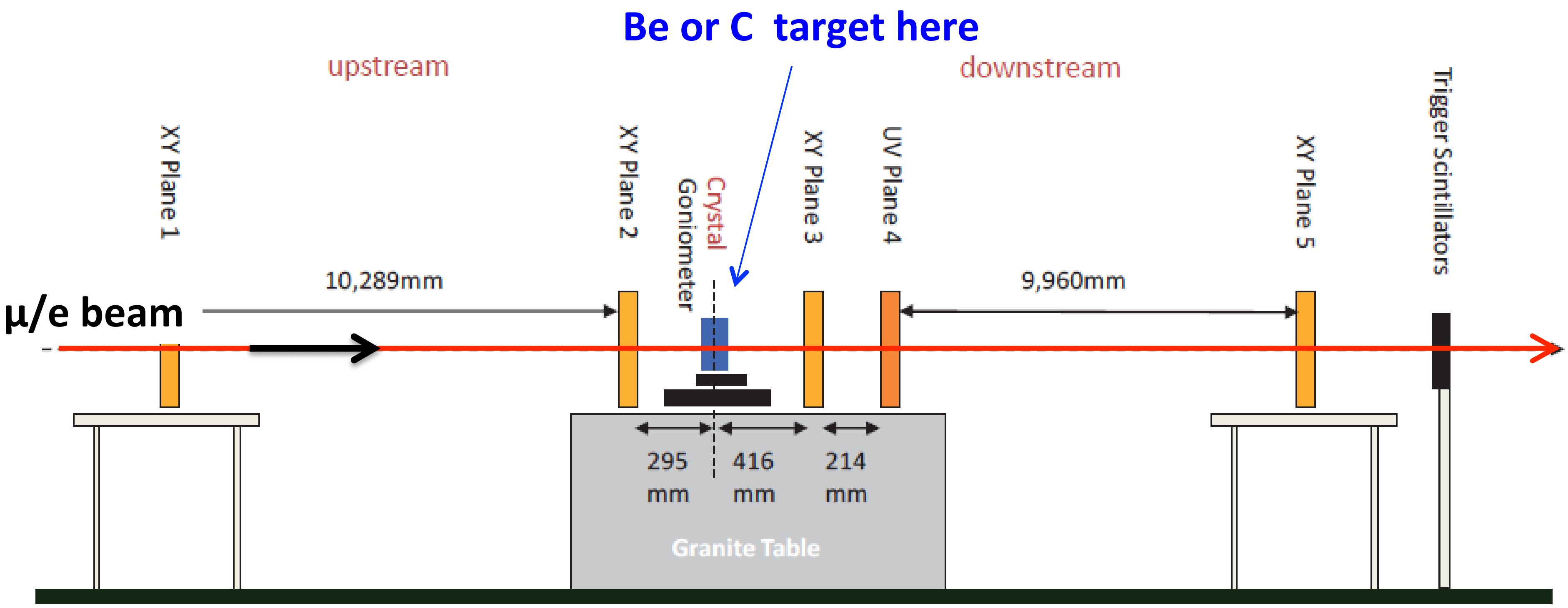
  r = obs_angle_e / true_angle_e

  turns out to be 1. within 1%.
- Aiming to r = 1.001: 1. within 0.1% we have to **decrease the targets thickness or found selection cuts to define the elastic events confidence region.**
- The ratio (efficency) must be evaluated bin per bin by means of GEANT. GEANT has to be cross checked against experimental data: to be precise at ~ 1%.
- The detector last module will provide the reference, calibration data.

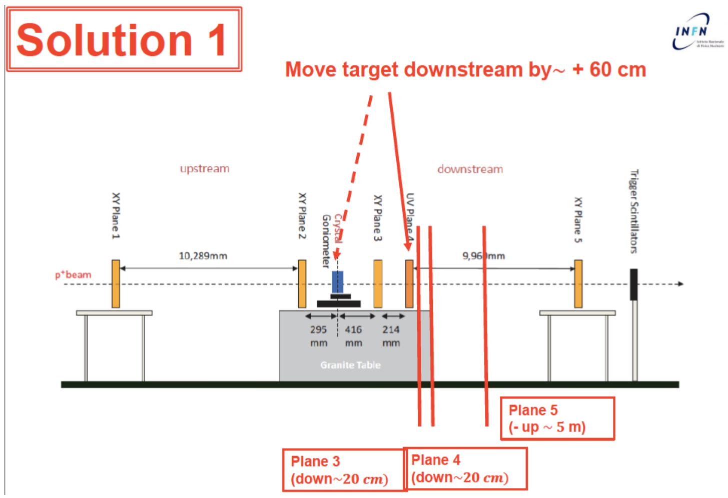
Test Beam

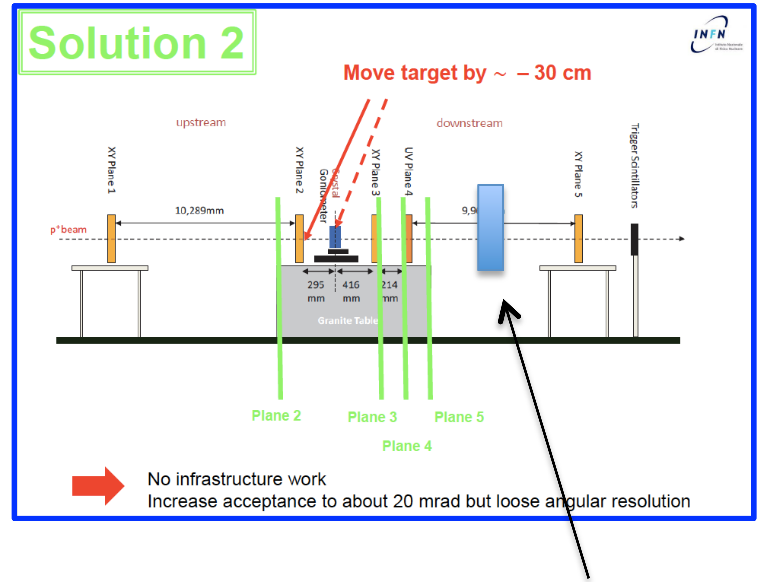
Check Geant4 MSC prediction and populate the 2D (θ_e , θ_μ) scattering plane

- 27 Sep-3 October 2017 allocated at CERN in "H8 Beam Line"
- 5 Si strips planes: 2 before (upstream) and 3 after the target
- Max rate 10 kHz
- Beam energy in the range 90 - 190 GeV



Test Beam (II)





Calorimeter

★ Solution 1 move upstream plane #5 (by ~ 5 m) and move downstream the target (by ~ 50 cm)

acceptance ~ 4.0 mrad

need infrastructure work

need recabling plane #5

(same comment for large angle electrons as solution 0)

★ Solution 2 change position of 4 planes (# 2,3,4,5) housing all of them on the existing table.

acceptance ~ 20 mrad

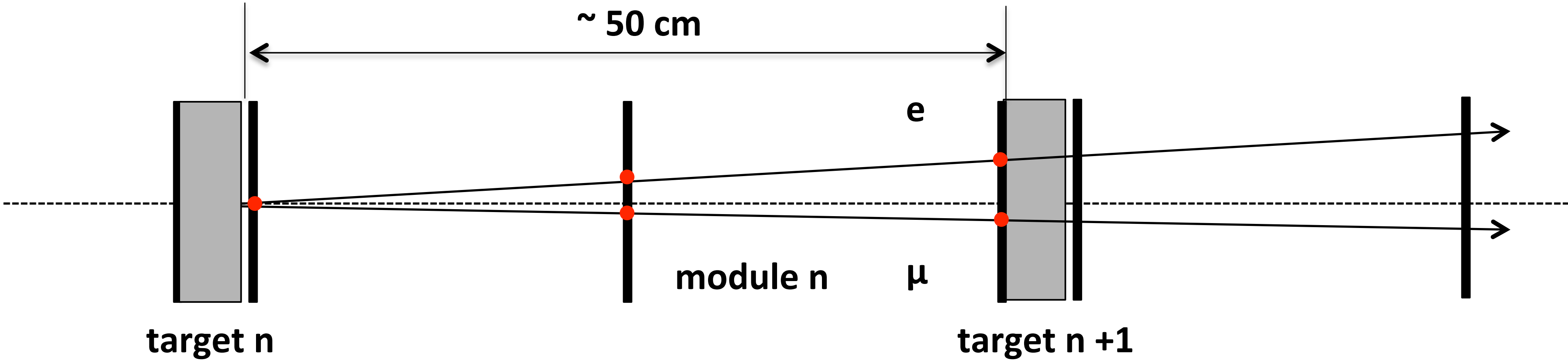
need recabling the optical fibers of pl 5

no *need of infrastructure work*

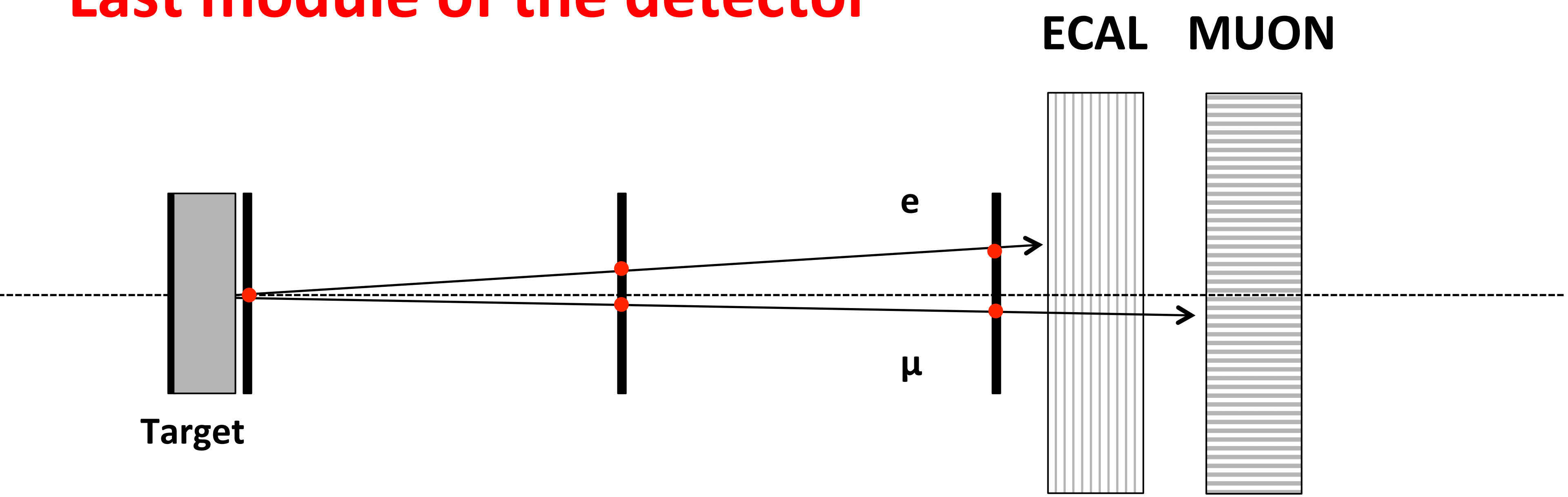
loose angular precision

(*) *acceptance defined at the last plane*

7



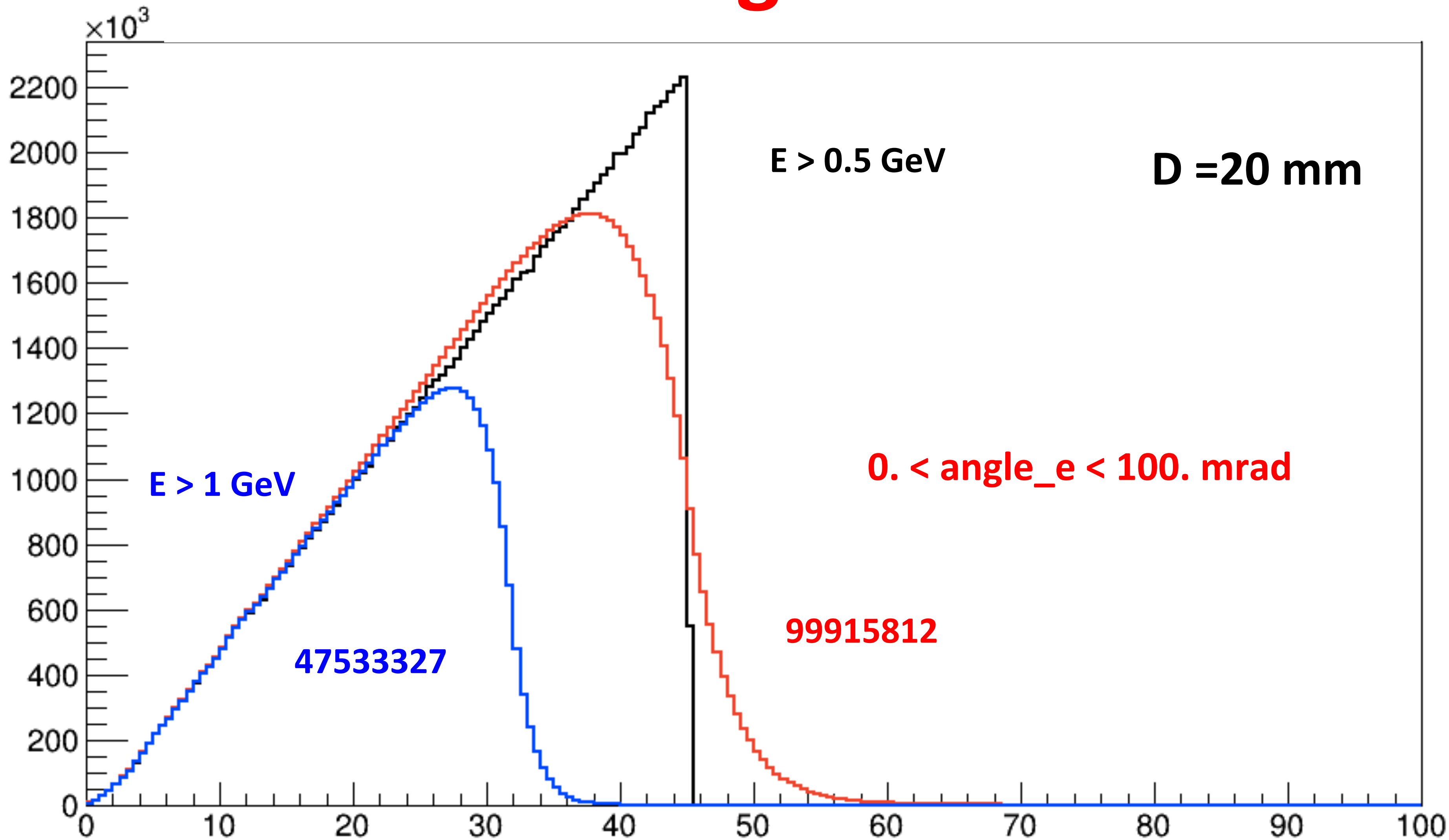
Last module of the detector



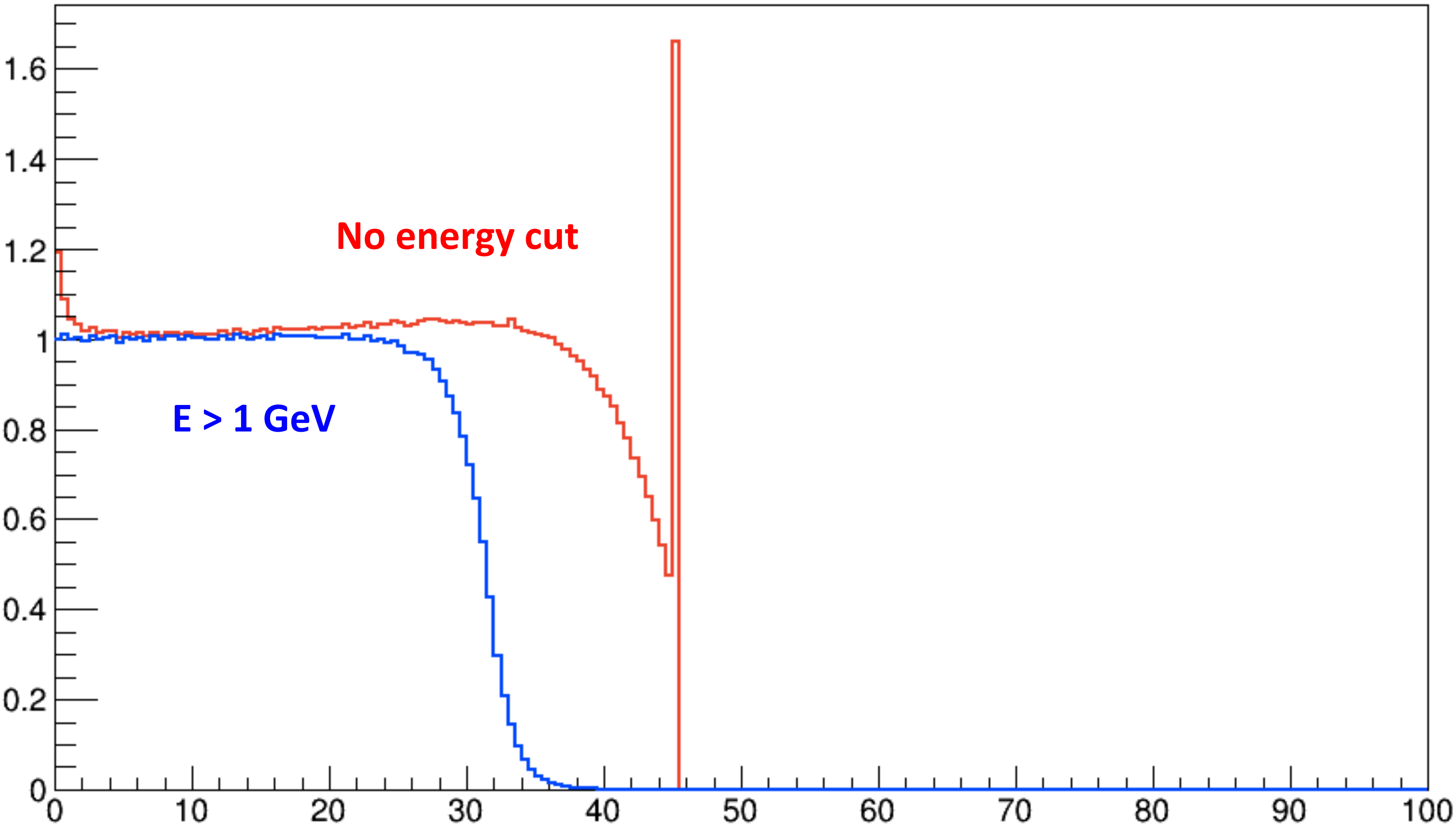
Measure both angle_e and E_e to define the reference, calibration curve. Detailed check of GEANT predictions.

D = 20 mm

Observable angular distribution

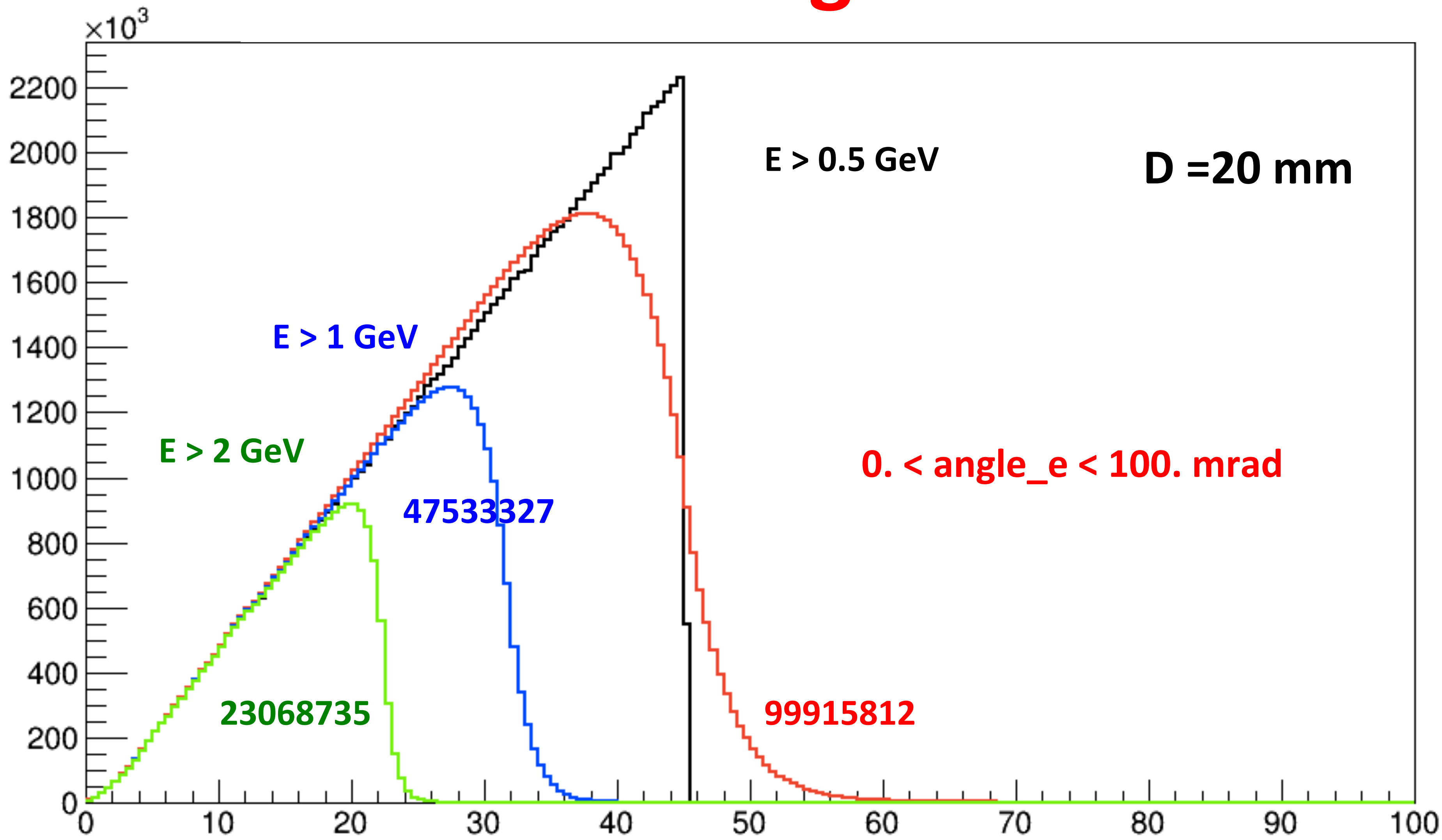


Ratios Beryllium d= 20mm



1 1.19309	1 1.00096	21 1.01225	21 1.00323	41 1.02574	41 1.00432
2 1.08886	2 1.00889	22 1.01173	22 1.00275	42 1.02706	42 1.00434
3 1.04524	3 1.0004	23 1.01013	23 1.0007	43 1.03396	43 1.00975
4 1.03398	4 1.00391	24 1.01071	24 1.0011	44 1.02646	44 1.00033
5 1.0173	5 0.996003	25 1.01855	25 1.00853	45 1.02733	45 0.999697
6 1.02618	6 1.00775	26 1.01135	26 1.00082	46 1.03529	46 1.00499
7 1.01393	7 0.998485	27 1.0224	27 1.01157	47 1.0271	47 0.994047
8 1.01658	8 1.00318	28 1.01534	28 1.00421	48 1.03381	48 0.997874
9 1.0194	9 1.00748	29 1.00949	29 0.997773	49 1.03274	49 0.993085
10 1.0044	10 0.993426	30 1.01689	30 1.00478	50 1.03892	50 0.994343
11 1.01432	11 1.00464	31 1.02039	31 1.00734	51 1.03623	51 0.986071
12 1.00881	12 0.999535	32 1.01412	32 1.00071	52 1.02796	52 0.971313
13 1.01282	13 1.00403	33 1.02374	33 1.00968	53 1.03448	53 0.96847
14 1.00564	14 0.99684	34 1.02165	34 1.00692	54 1.04138	54 0.964214
15 1.01356	15 1.00504	35 1.02047	35 1.00514	55 1.04564	55 0.952927
16 1.00786	16 0.999135	36 1.02246	36 1.00601	56 1.04313	56 0.932623
17 1.01358	17 1.00529	37 1.02272	37 1.00579	57 1.03974	57 0.905642
18 1.01372	18 1.00502	38 1.02401	38 1.0061	58 1.03706	58 0.8722
19 1.00975	19 1.00065	39 1.02129	39 1.00228	59 1.04133	59 0.837489
20 1.01411	20 1.00508	40 1.02346	40 1.00347	60 1.03571	60 0.783976

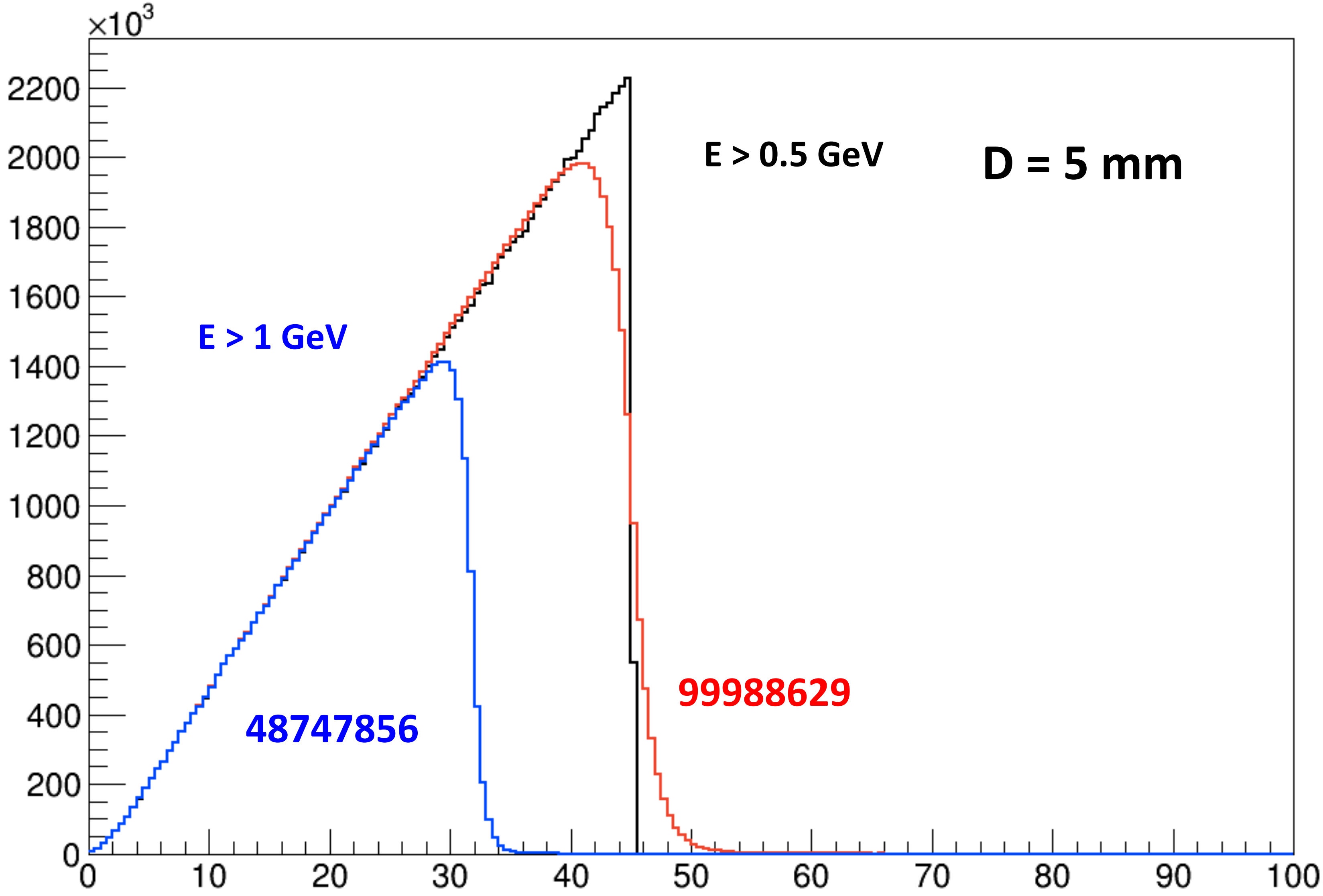
Observable angular distribution



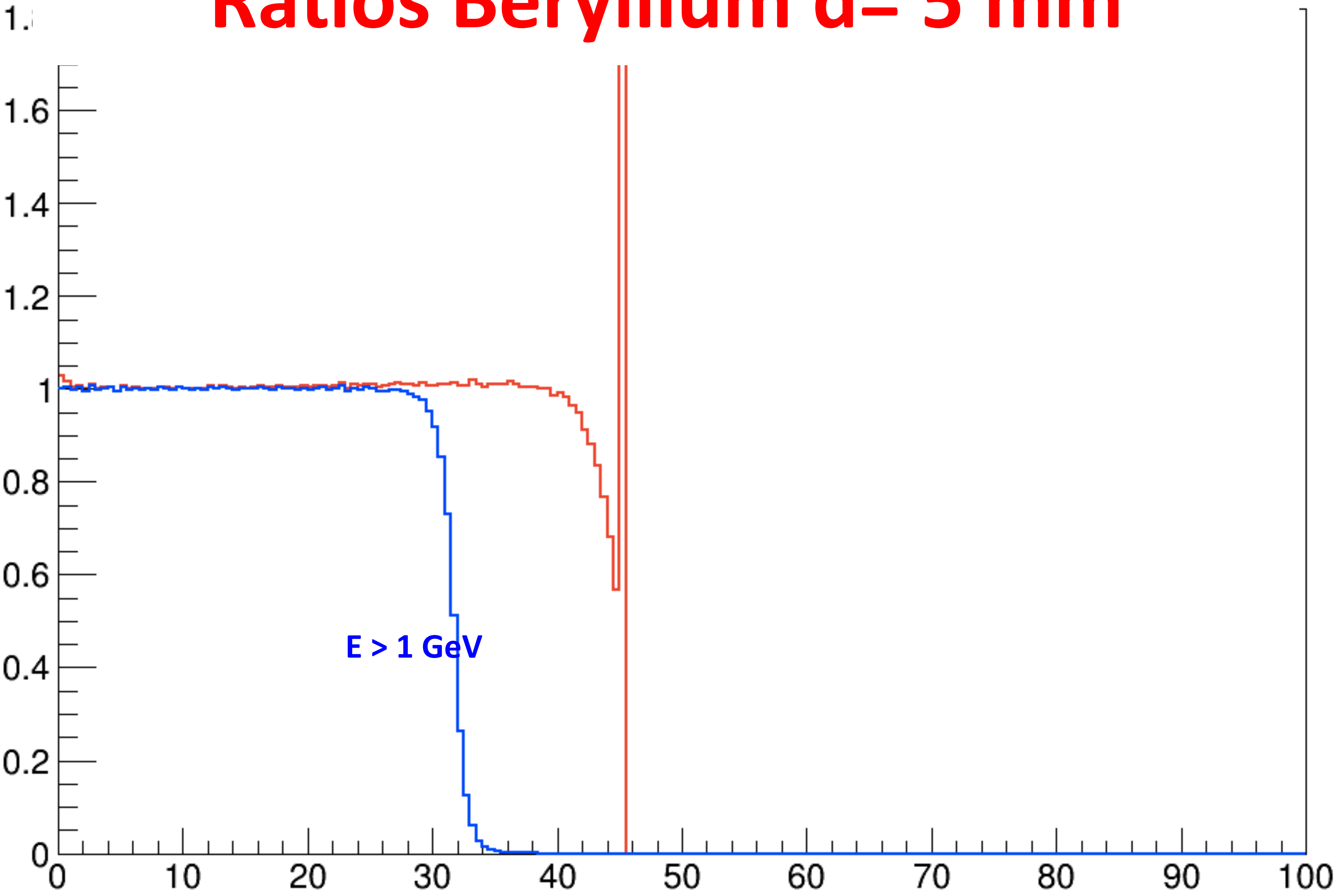
0 GeV	1 GeV	2 GeV
bin 1 ratio 1.19309	bin 1 ratio 1.00096	bin 1 ratio 0.996624
bin 2 ratio 1.08886	bin 2 ratio 1.00889	bin 2 ratio 1.0054
bin 3 ratio 1.04524	bin 3 ratio 1.0004	bin 3 ratio 0.998382
bin 4 ratio 1.03398	bin 4 ratio 1.00391	bin 4 ratio 1.00245
bin 5 ratio 1.0173	bin 5 ratio 0.996003	bin 5 ratio 0.994901
bin 6 ratio 1.02618	bin 6 ratio 1.00775	bin 6 ratio 1.00657
bin 7 ratio 1.01393	bin 7 ratio 0.998485	bin 7 ratio 0.997231
bin 8 ratio 1.01658	bin 8 ratio 1.00318	bin 8 ratio 1.00177
bin 9 ratio 1.0194	bin 9 ratio 1.00748	bin 9 ratio 1.00598
bin 10 ratio 1.0044	bin 10 ratio 0.993426	bin 10 ratio 0.99185
bin 11 ratio 1.01432	bin 11 ratio 1.00464	bin 11 ratio 1.00301
bin 12 ratio 1.00881	bin 12 ratio 0.999535	bin 12 ratio 0.997863
bin 13 ratio 1.01282	bin 13 ratio 1.00403	bin 13 ratio 1.00205
bin 14 ratio 1.00564	bin 14 ratio 0.99684	bin 14 ratio 0.994623
bin 15 ratio 1.01356	bin 15 ratio 1.00504	bin 15 ratio 1.00263
bin 16 ratio 1.00786	bin 16 ratio 0.999135	bin 16 ratio 0.996467
bin 17 ratio 1.01358	bin 17 ratio 1.00529	bin 17 ratio 1.00242
bin 18 ratio 1.01372	bin 18 ratio 1.00502	bin 18 ratio 1.00182
bin 19 ratio 1.00975	bin 19 ratio 1.00065	bin 19 ratio 0.997101
bin 20 ratio 1.01411	bin 20 ratio 1.00508	bin 20 ratio 1.00116
bin 21 ratio 1.01225	bin 21 ratio 1.00323	bin 21 ratio 0.998962
bin 22 ratio 1.01173	bin 22 ratio 1.00275	bin 22 ratio 0.997866
bin 23 ratio 1.01013	bin 23 ratio 1.0007	bin 23 ratio 0.995547
bin 24 ratio 1.01071	bin 24 ratio 1.0011	bin 24 ratio 0.995385
bin 25 ratio 1.01855	bin 25 ratio 1.00853	bin 25 ratio 1.00223
bin 26 ratio 1.01135	bin 26 ratio 1.00082	bin 26 ratio 0.993994
bin 27 ratio 1.0224	bin 27 ratio 1.01157	bin 27 ratio 1.00383
bin 28 ratio 1.01534	bin 28 ratio 1.00421	bin 28 ratio 0.995649
bin 29 ratio 1.00949	bin 29 ratio 0.997773	bin 29 ratio 0.988656
bin 30 ratio 1.01689	bin 30 ratio 1.00478	bin 30 ratio 0.994456

D = 5 mm

Observable angular distribution

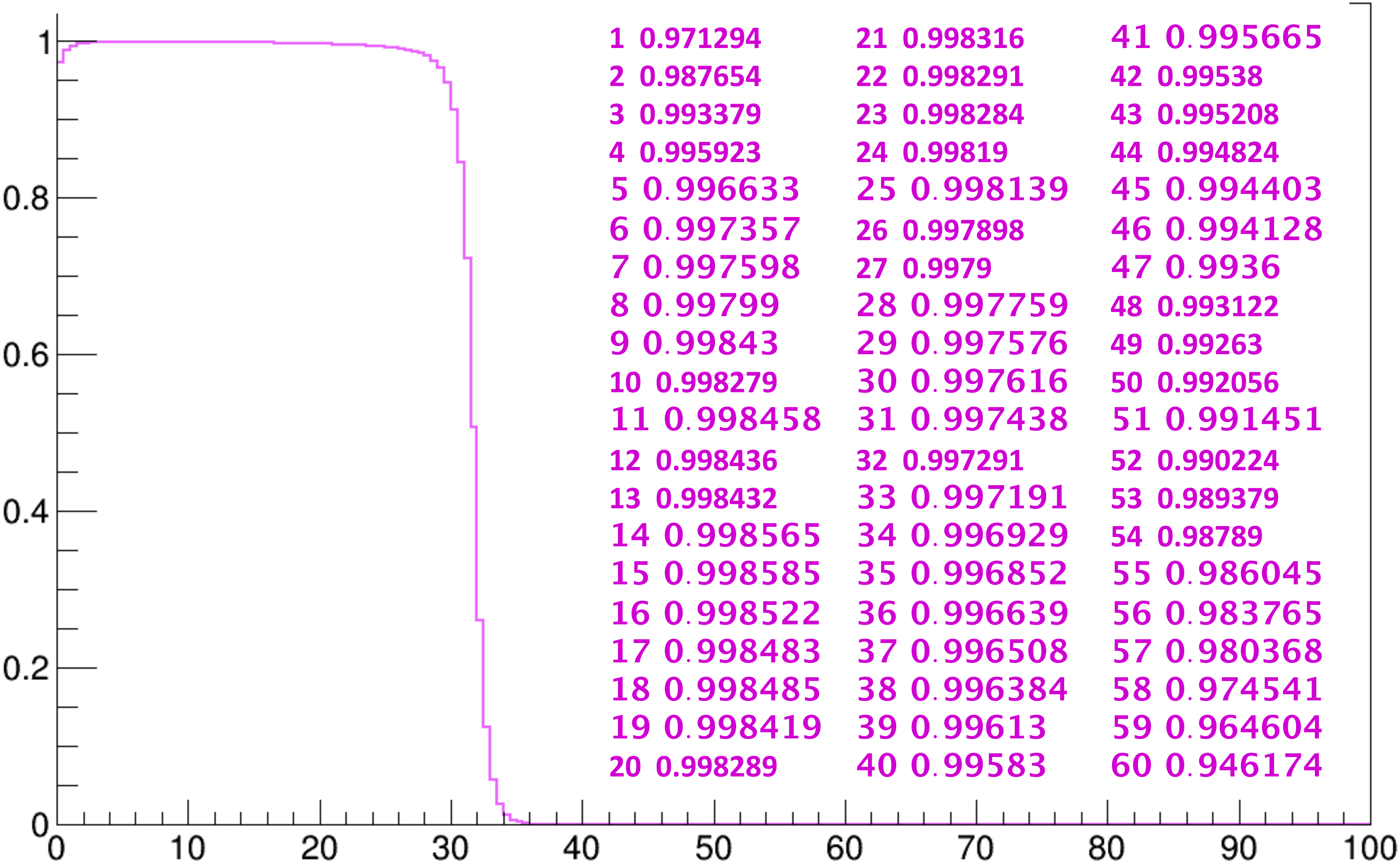


Ratios Beryllium d= 5 mm



1 1.02939	1 0.999839	21 1.00122	21 0.999531
2 1.01557	2 1.00304	22 1.00116	22 0.999446
3 1.0049	3 0.998245	23 1.00245	23 1.00073
4 1.00692	4 1.00281	24 1.00037	24 0.998558
5 0.999663	5 0.996298	25 1.00581	25 1.00394
6 1.00873	6 1.00606	26 1.00176	26 0.999656
7 0.99971	7 0.997309	27 1.0065	27 1.00438
8 1.00279	8 1.00078	28 1.00257	28 1.00033
9 1.0046	9 1.00302	29 0.999569	29 0.997146
10 0.995461	10 0.993748	30 1.00268	30 1.00029
11 1.00569	11 1.00414	31 1.00245	31 0.999884
12 1.00027	12 0.998707	32 1.0034	32 1.00068
13 1.0039	13 1.00233	33 1.00835	33 1.00552
14 1.00045	14 0.999013	34 1.00553	34 1.00244
15 1.00223	15 1.00081	35 1.00261	35 0.99945
16 0.999789	16 0.998311	36 1.00658	36 1.0032
17 1.00436	17 1.00284	37 1.00409	37 1.00058
18 1.00325	18 1.00173	38 1.00431	38 1.00068
19 1.0007	19 0.999116	39 1.0028	39 0.998918
20 1.00538	20 1.00366	40 1.00606	40 1.00186

Ratio of ratios Beryllium d= 5 mm



1	0.971294	21	0.998316	41	0.995665
2	0.987654	22	0.998291	42	0.99538
3	0.993379	23	0.998284	43	0.995208
4	0.995923	24	0.99819	44	0.994824
5	0.996633	25	0.998139	45	0.994403
6	0.997357	26	0.997898	46	0.994128
7	0.997598	27	0.9979	47	0.9936
8	0.99799	28	0.997759	48	0.993122
9	0.99843	29	0.997576	49	0.99263
10	0.998279	30	0.997616	50	0.992056
11	0.998458	31	0.997438	51	0.991451
12	0.998436	32	0.997291	52	0.990224
13	0.998432	33	0.997191	53	0.989379
14	0.998565	34	0.996929	54	0.98789
15	0.998585	35	0.996852	55	0.986045
16	0.998522	36	0.996639	56	0.983765
17	0.998483	37	0.996508	57	0.980368
18	0.998485	38	0.996384	58	0.974541
19	0.998419	39	0.99613	59	0.964604
20	0.998289	40	0.99583	60	0.946174

Conclusions

- Corrections to the observed electrons' angular distributions of the 0.1% level seems to be achievable by using thin ~10mm low Z targets.
- GEANT 4 predictions can be compared to the calibration module response (the last module). The CM will provide both the electron angle and energy measurements.
- We have to start the effect of elasticity selection cuts in terms of efficiency and rejection power.
- We are working to build a prototype of the calibration module to be tested next year.
- Tests of MSC description in Geant4 will come soon.