Simulation of Radiation on the FEE
Summary

A. Sandoval

TPC meeting CERN 8.10.03

Fluka calculations for radiation at the FEE

- Georgios Tsiledakis presented at the last TPC meeting
- Blahoslav Pastircak presented at the Technical Forum 18 June 03 revised
- Andreas Morsch done last week
- Georgios Tsiledakis new calculations using a Si scoring region and on both sides of TPC

Discrepancies

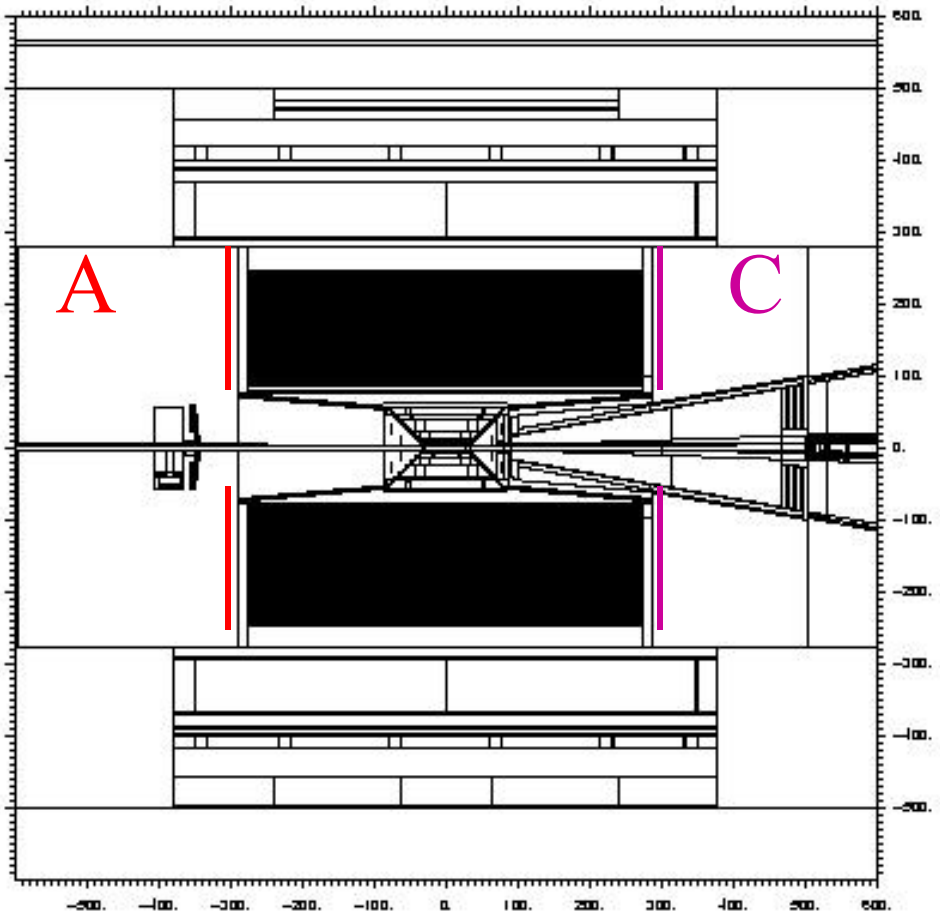
- Luciano and Dieter found several discrepancies between **G**eorgios and **B**lahoslav calculations
  - **G:** 1 and 10 cm Al before scoring region placed on the A side, **B:** scoring on the B side (μ absorber side)
  - They used different assumptions for 10y Alice
    - **G**: 2.5 10^7 s of PbPb
    - **B**: pp, ArAr and PbPb
  - **B:** mislabeled the p and π spectra
  - **B:** had a mistake on the fluences for the TPC, TRD and TOF

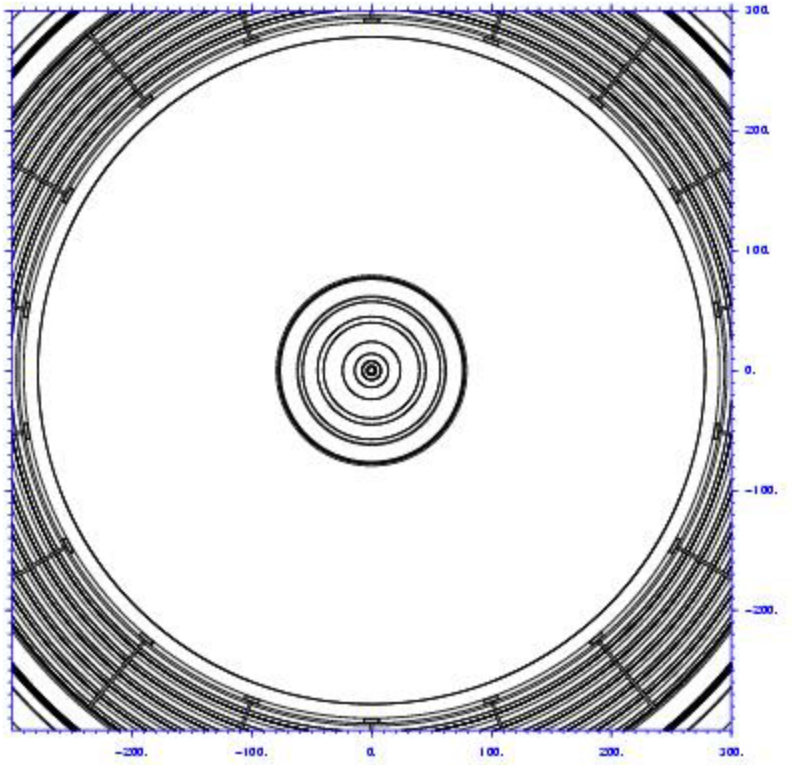
Andreas run a simulation last week and confirms Georgios results, still factor 2 discrepancy with latest Blahoslav

New calculation of Georgios

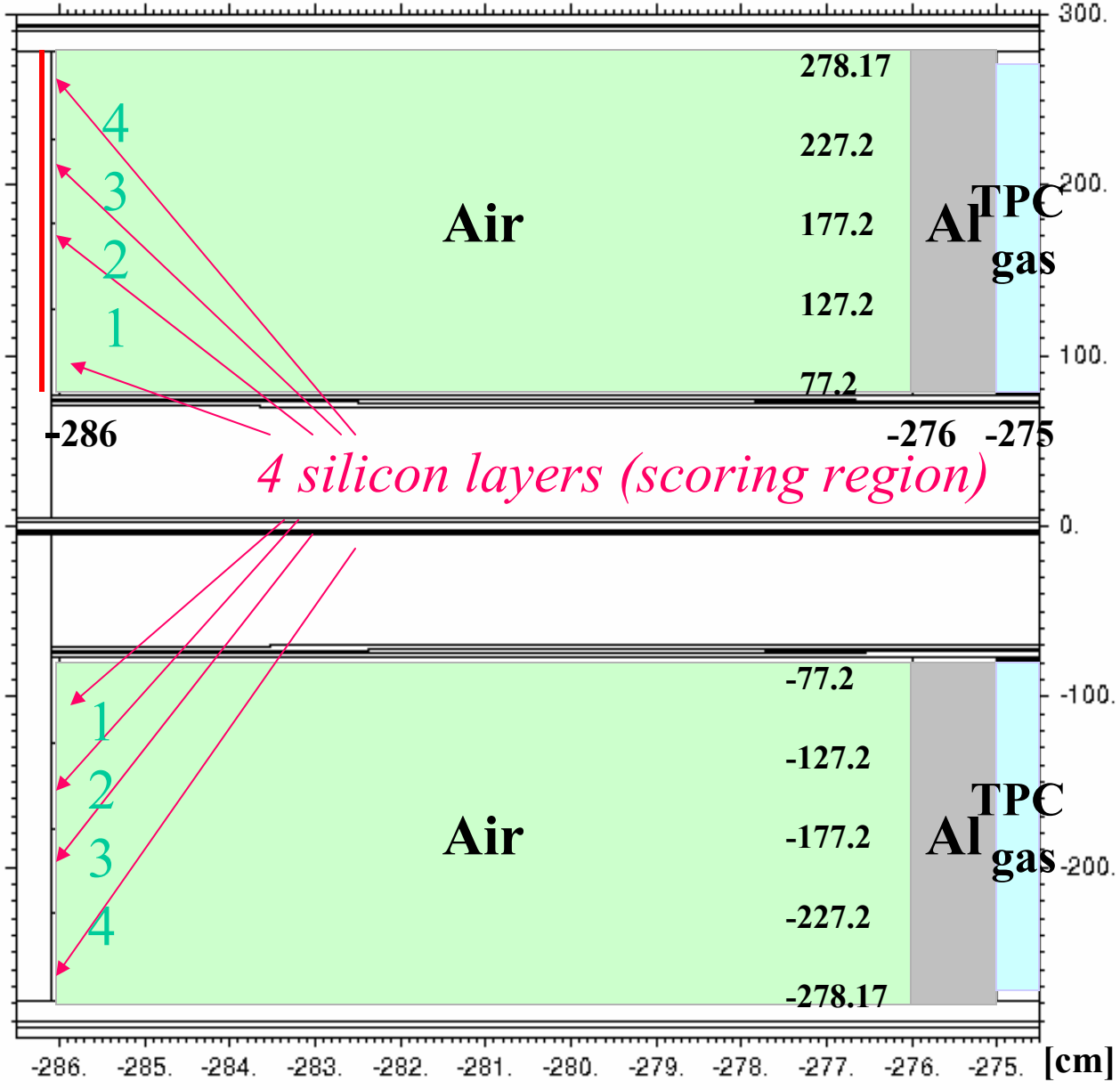
- Run on both the absorber and non absorber side
- Used a 1mm Si scoring region after 1 1cm of Al
- I will extract the main result relevant for the FEE
- his presentation included here for completements

Geometry





Left side of TPC (1 mm of Silicon)



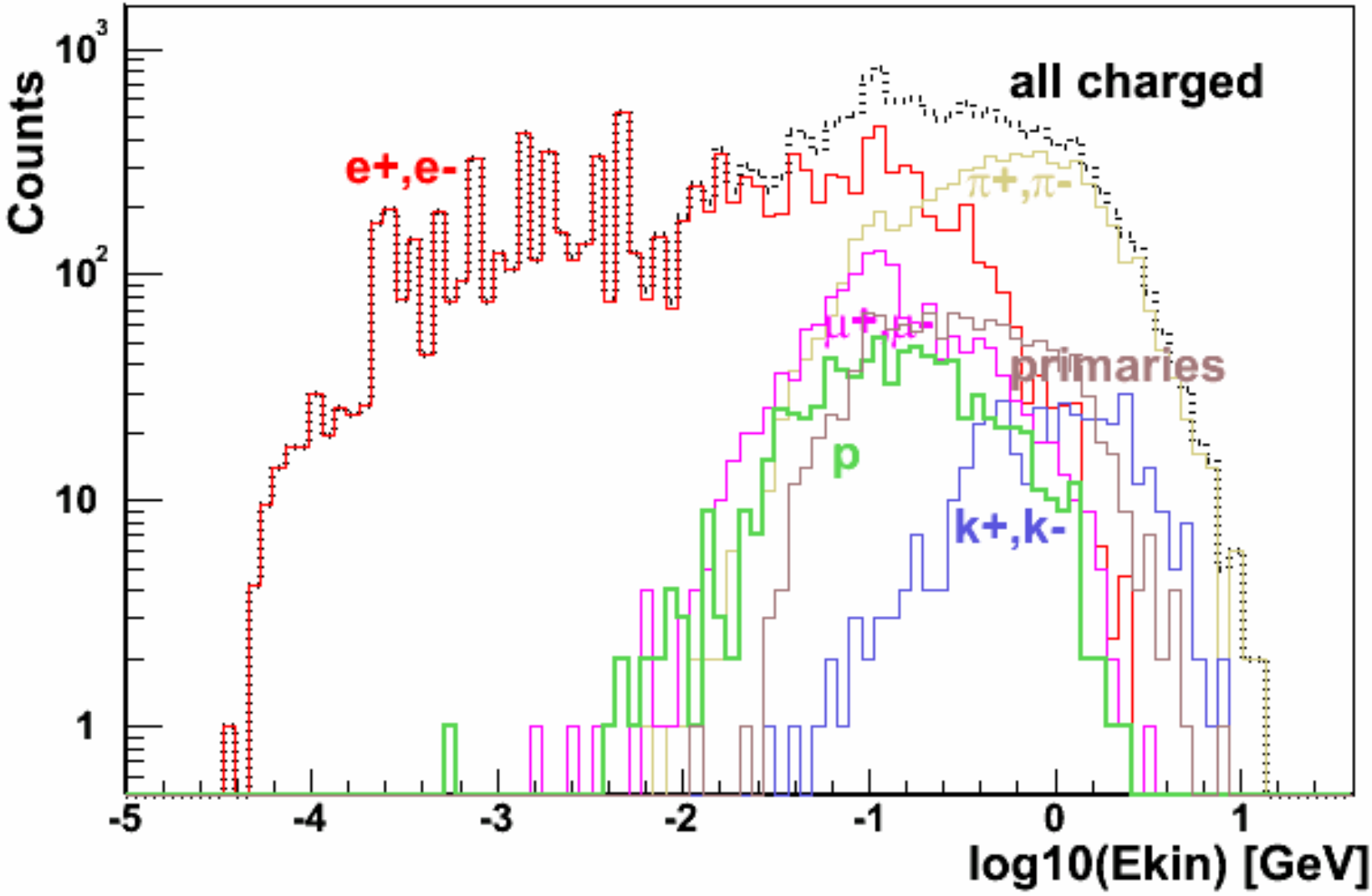
4 silicon radial segments of 1mm width for scoring ($-286.1 < z < -286$), 10cm far from the left end-cup of the TPC (1cm of Al thick)

layers	Volume (cm^3)	Area (cm^2)
1	3210.7	32107
2	4781.5	47815
3	6352.3	63523
4	8092.3	80923

Left side of TPC

Energy spectra (1mm of Si)

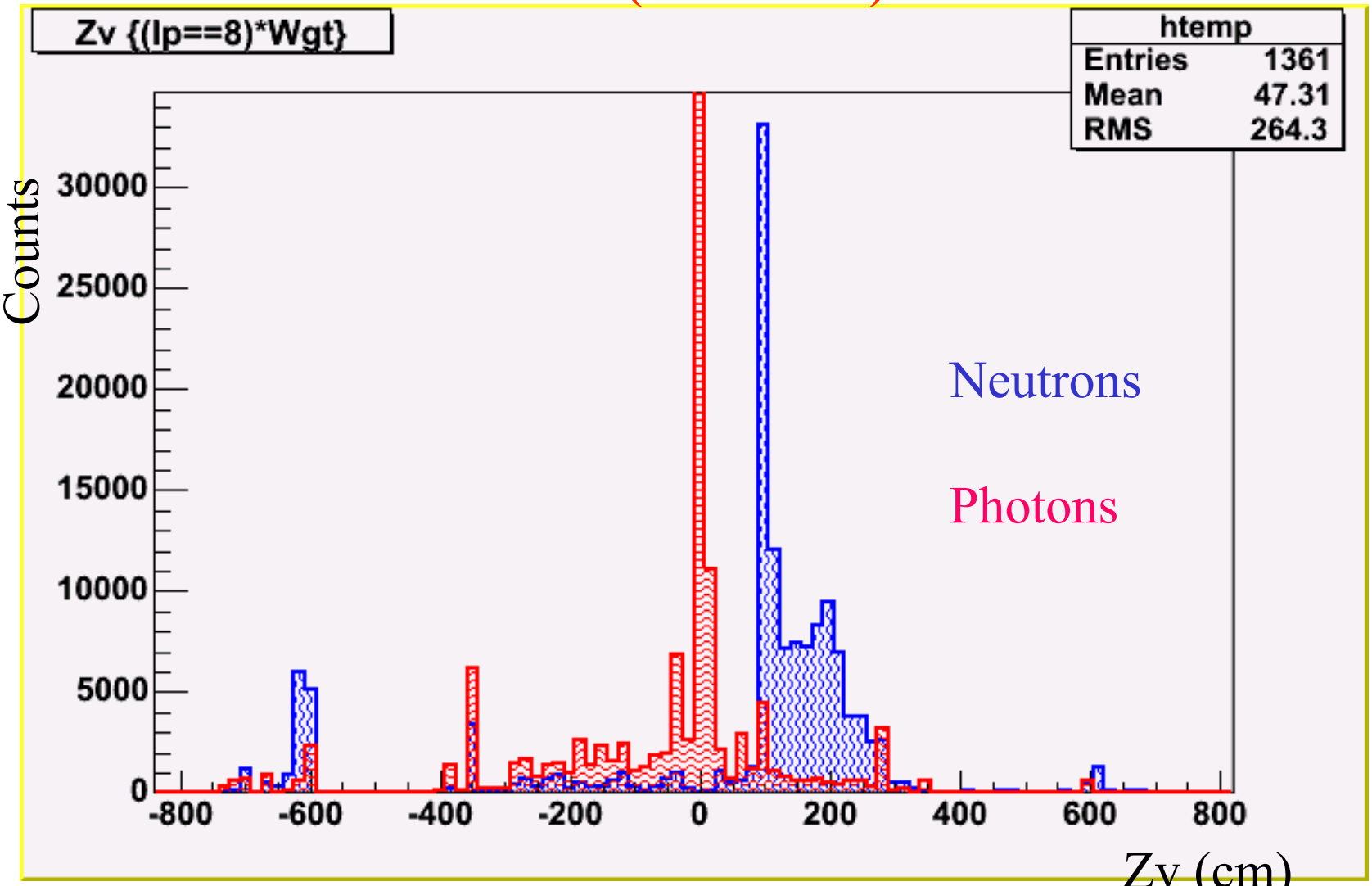
98.3 % p, 99.9 % π+/-, k+/-, 99.1 % μ+/-, 59 % e+/-, 4.9 % n, have **E > 10 MeV**



1 central event

Z distribution of neutrons and photons origin in the scoring region

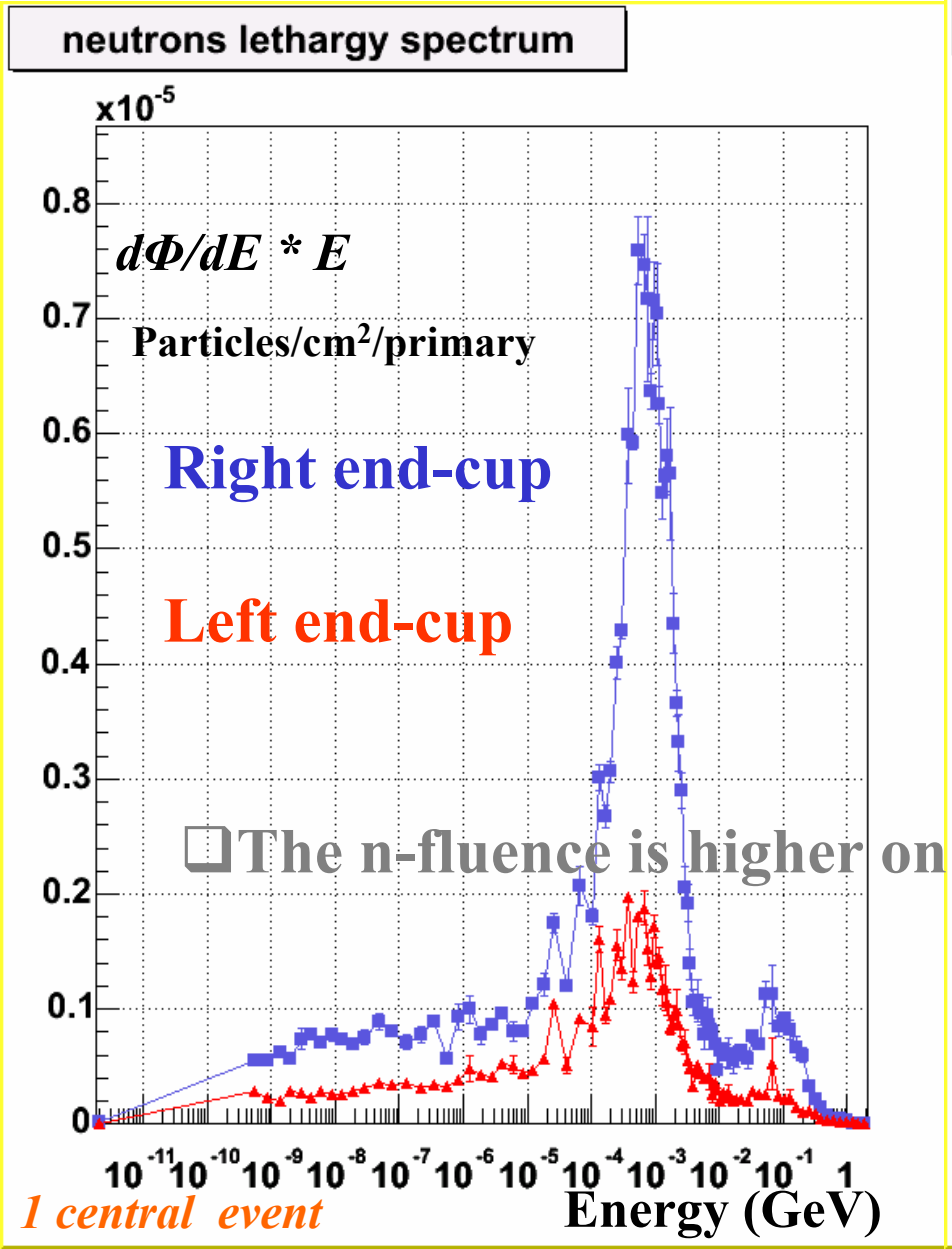
(1mm of Si)

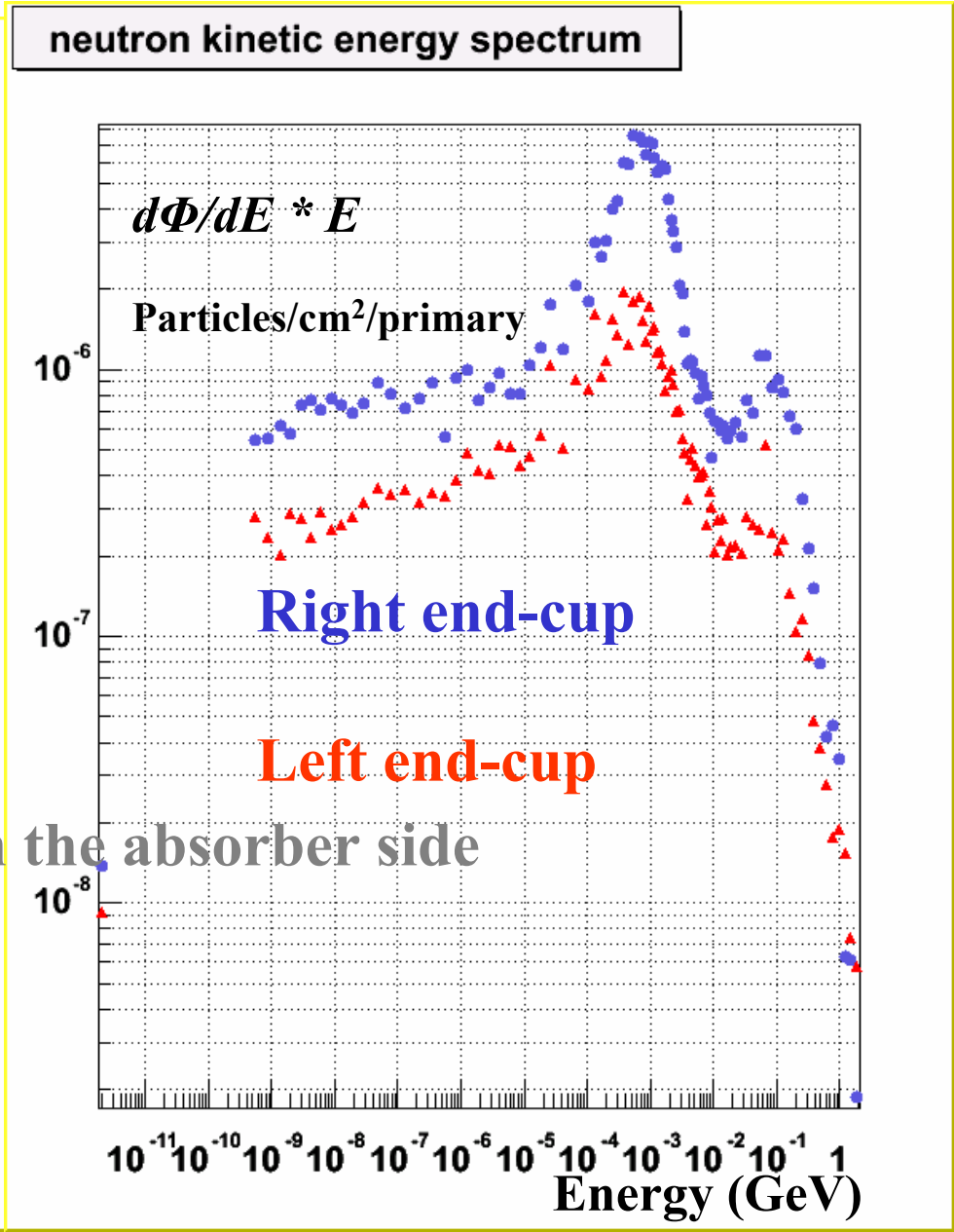


1 central event

Neutron spectra layer 1 (1mm of Si)

Right side of TPC

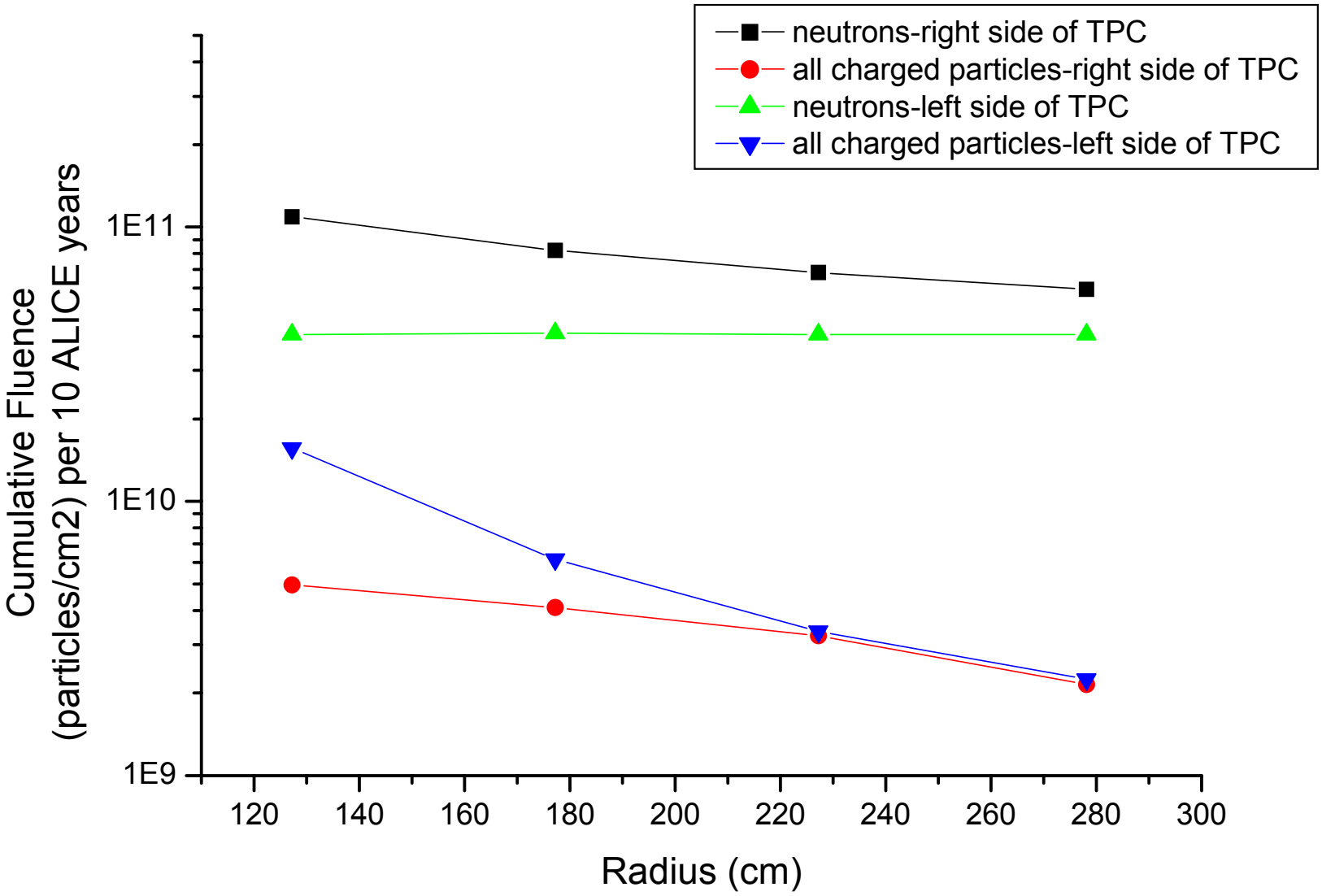




- The n-fluence is higher on the absorber side

1 central event

Cumul. Fluences (Particles/cm^2) per 10 ALICE years



- **At the inner radius on the absorber side, the n-fluence is higher (factor 3) and the charged fluence smaller (factor 3) compared with the left side of the TPC.**

Cumul. Fluences (Particles/cm^2/primary) per central event *Left side of TPC*

1cm Al **(1mm of Si)**

layers	1	2	3	4
protons	1.52E-7 +/- 9.6 %	7.22E-8 +/- 11.5 %	6.34E-8 +/- 19.3 %	3.61E-8 +/- 8.5 %
electrons/positrons	3.5E-6 +/- 23 %	1.1E-6 +/- 25.1 %	4.61E-7 +/- 15.5 %	3.08E-7 +/- 7.3 %
neutrons	1.27E-5 +/-1.3 %	1.28E-5 +/- 2.1%	1.27E-5 +/- 1.2%	1.27E-5 +/- 1.3 %
thermal neutrons	1.87E-6	1.75E-6	1.77E-6	1.86E-6
muons+/-	2.81E-7 +/-12.4 %	2.14E-7 +/- 2.2 %	1.45E-7 +/- 8.6 %	1.06E-8 +/- 7.1 %
pions+/-	8.94E-7 +/- 1 %	5.13E-7 +/- 2.5 %	3.65E-7 +/- 4%	2.42E-7 +/- 3 %
kaons+/-	6.03E-8 +/- 3.5 %	2.8E-8 +/-13.3 %	1.83E-8 +/- 9.3 %	1.02E-8 +/- 6.9 %
charged	4.89E-6 +/- 17 %	1.92E-6 +/- 14.3 %	1.05E-6 +/- 7.3 %	7.03E-7 +/- 2.2 %

Multiply with **$3.2*10^{15}$** to get the cumulative fluences for each layer in 10 ALICE years of Pb+Pb. [(80000 primaries) *($4*10^{10}$)=$3.2*10^{15}$]

Cumul. Fluences (Particles/cm^2/primary) per central event *Right side of TPC*

1cm Al (1mm of Si)

layers	1	2	3	4
protons	1.03E-7 +/- 26.7 %	6.04E-8 +/- 6.9 %	3.93E-8 +/- 10.6 %	4.01E-8 +/- 11.7 %
electrons/positrons	1.0E-6 +/- 26.4 %	6.1E-7 +/- 6.8 %	4.5E-7 +/- 26 %	3.16E-7 +/- 9.7 %
neutrons	3.42E-5 +/-1.6 %	2.57E-5 +/- 0.3 %	2.13E-5 +/- 0.9 %	1.85E-5 +/- 0.5 %
thermal neutrons	2.82E-6	2.58E-6	2.44E-6	2.54E-6
muons+/-	1.47E-7 +/- 9 %	1.51E-7 +/- 7.3 %	1.31E-7 +/- 13.7 %	8.22E-8 +/- 5 %
pions+/-	2.92E-7 +/-5.7 %	4.37E-7 +/- 3.1 %	3.71E-7 +/- 2. 4%	2.23E-7 +/- 2.8 %
kaons+/-	7.54E-9 +/- 14 %	2.37E-8 +/-15.1 %	1.59E-8 +/- 12.5 %	9.85E-9 +/-27.9 %
charged	1.55E-6 +/- 17.3 %	1.28E-6 +/- 3.6 %	1.01E-6 +/- 12.5 %	6.72E-7 +/- 5.3 %

Multiply with **$3.2*10^{15}$** to get the cumulative fluences for each layer in 10 ALICE years of Pb+Pb. [(80000 primaries) *($4*10^{10}$)=$3.2*10^{15}$]

Particles > 10 MeV/cm^2/s in PbPb

- Cum fluences (particles/cm2/primary) * 80,000/5 *8000 Hz

particle	A side(z>0)	C side (z<0)
n	1700	4200
n > 10 MeV	83	206
p	20	13
π	116	38

Radiation study of the TPC electronics

Georgios Tsiledakis, GSI

Topics

- Radiation transport code (FLUKA)
- Geometry description
- Definition of the suitable scoring region
- Calculation of the number of the particles and their energy distributions for both sides of the TPC
- Estimation of the particle fluences & Edep & dose
- Summary

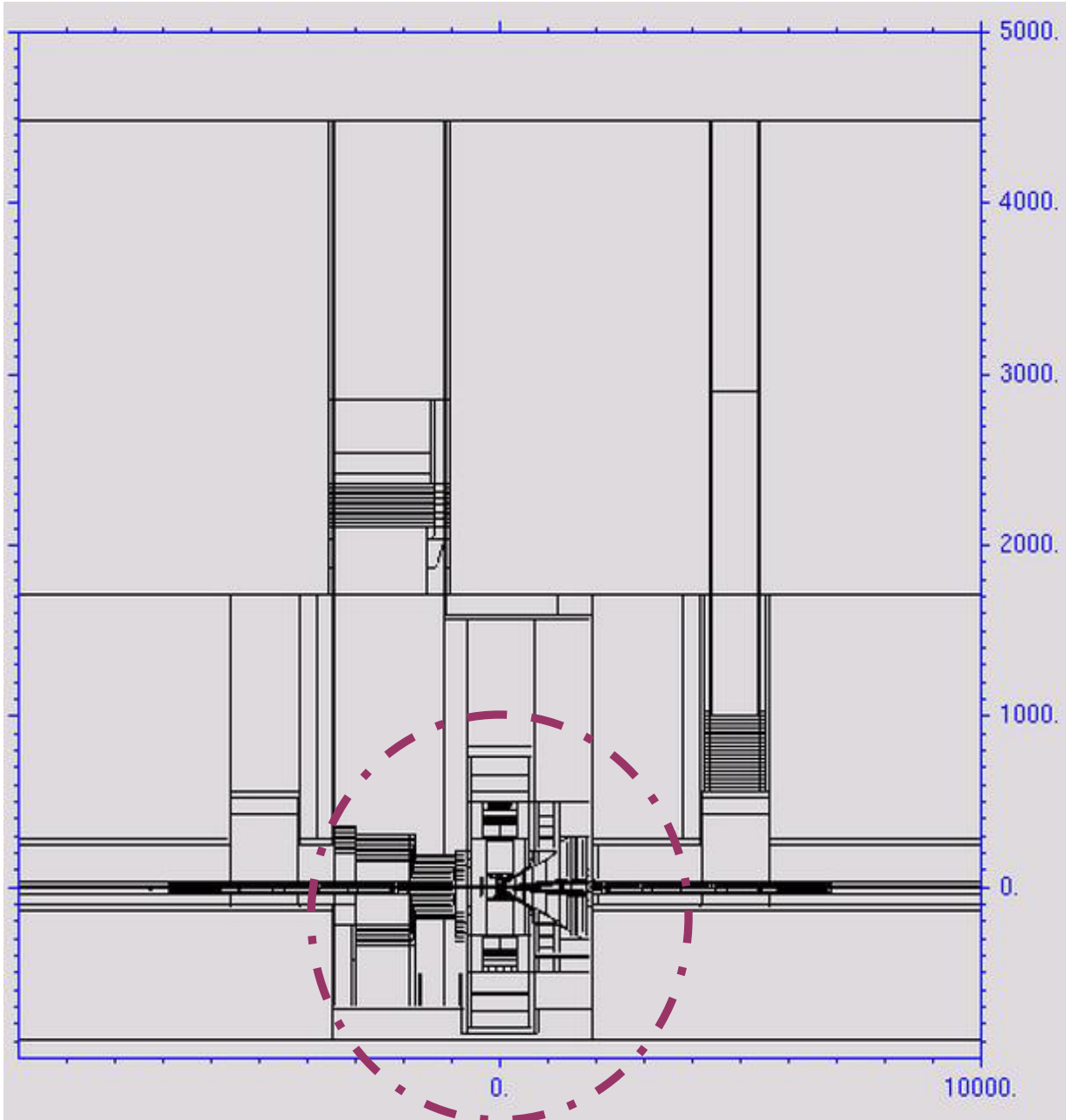
Simulation code (FLUKA)

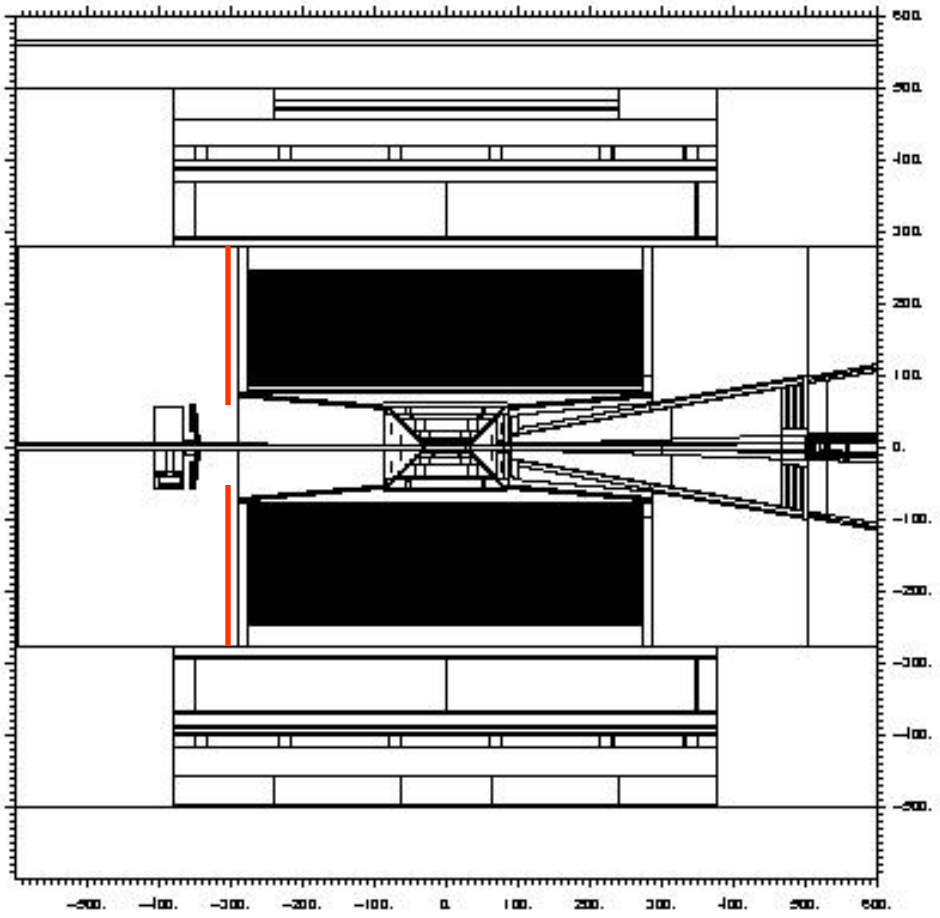
- Hadron-hadron and hadron-nucleus elastic and inelastic interactions 0-20 TeV
- Electromagnetic and muon interactions 0-100 TeV (pair production and bremsstrahlung, multiple coulomb scattering and magnetic field transport, delta ray production)
- Particle transport: all stable hadrons, electrons, positrons, muons, photons
- Neutron multigroup transport and interactions 0-20 MeV
- Neutron capture reactions with explicit photon emission
- Accurate and detailed ionization energy loss
- Efficient model for multiple scattering for all charged particles

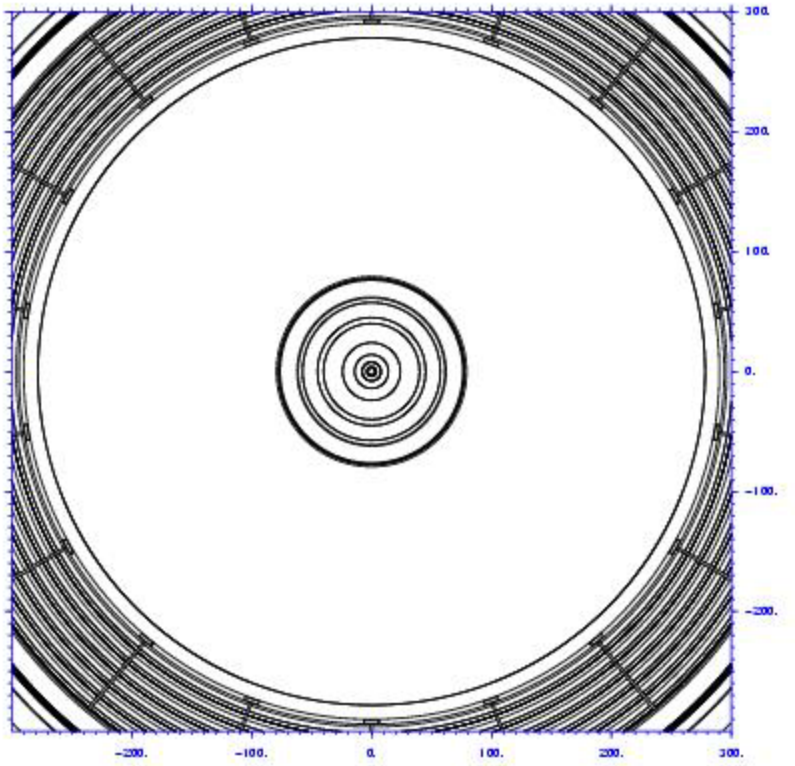
For this study, the transport cut for charged hadrons is set to 10 keV.
The energy thresholds for electrons and photons that are used in central detectors are 50 keV and 30 keV respectively.

Geometry description

FLUKA uses the Combinatorial Geometry. About 3200 volumes and 1500 regions are needed to describe the full ALICE experimental area, including the cavern, tunnels, vertical shafts, rooms, shielding, inner triplet and separation dipoles, the surrounding hall, beam elements, detectors and racks. Particle backscattering from concrete walls of caverns and shafts is taken into account by approximating the walls by a 30 cm layer of concrete. Regions behind this layer are treated as black-holes.







TPC gas volume: 79.25<r<278 cm and |z|<275 cm

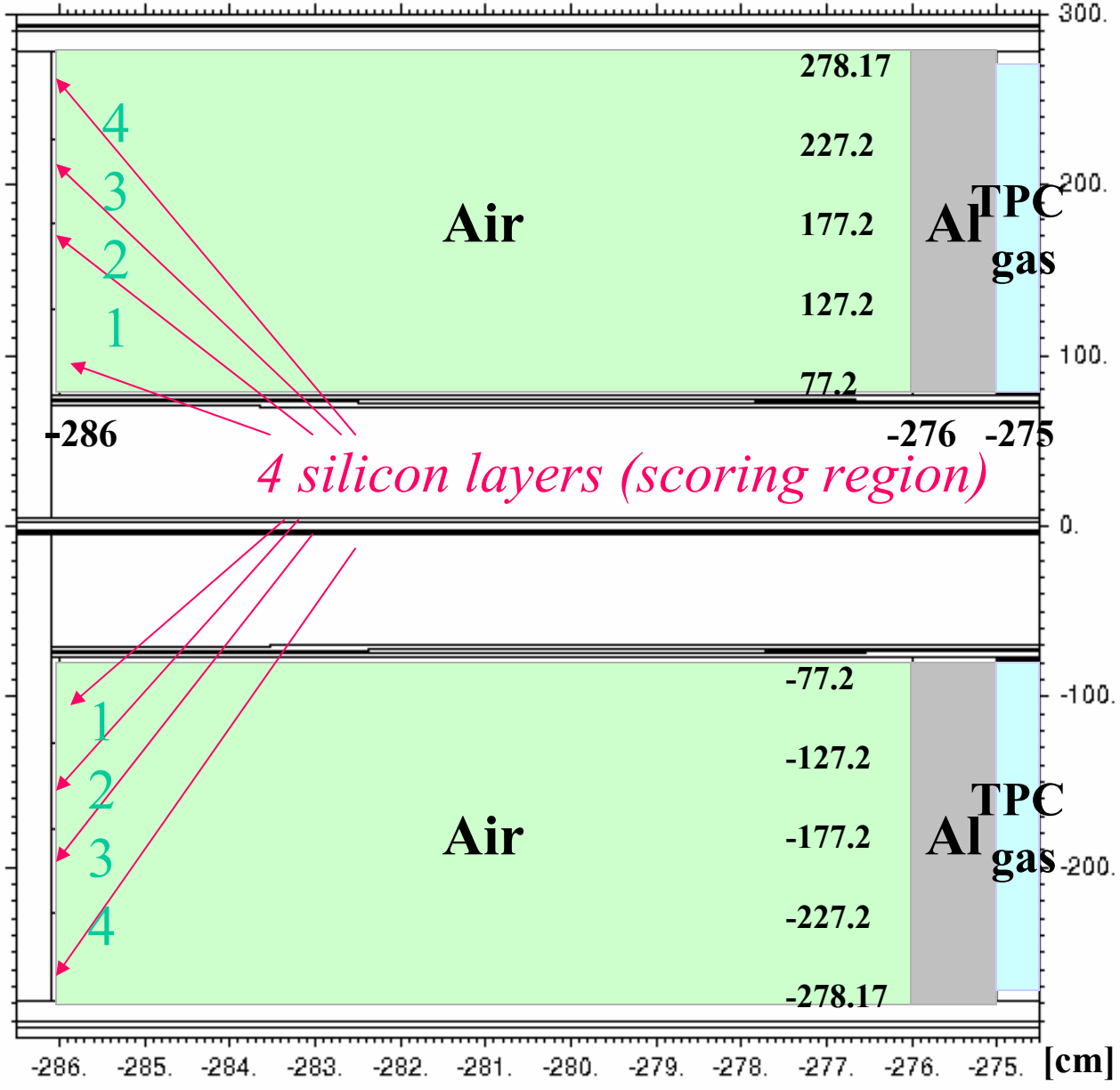
TPC gas: (90% Ne + 10% CO_2) $Wgt_{tot}=0.9M_{Ne}+0.1*(M_C+2M_O)$

There is a correspondence between FLUKA materials and low-energy neutron cross-sections.

FLUKA low-energy neutron library doesn't include Neon.

Therefore, Fluorine has been chosen instead.

Left side of TPC (1 mm of Silicon)



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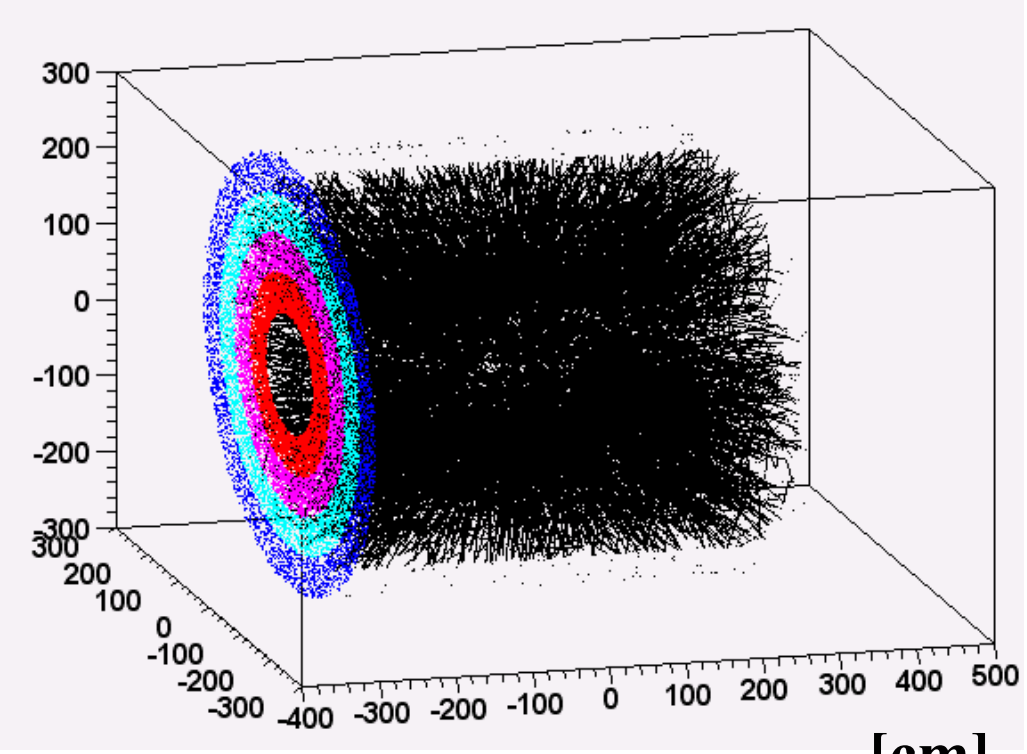


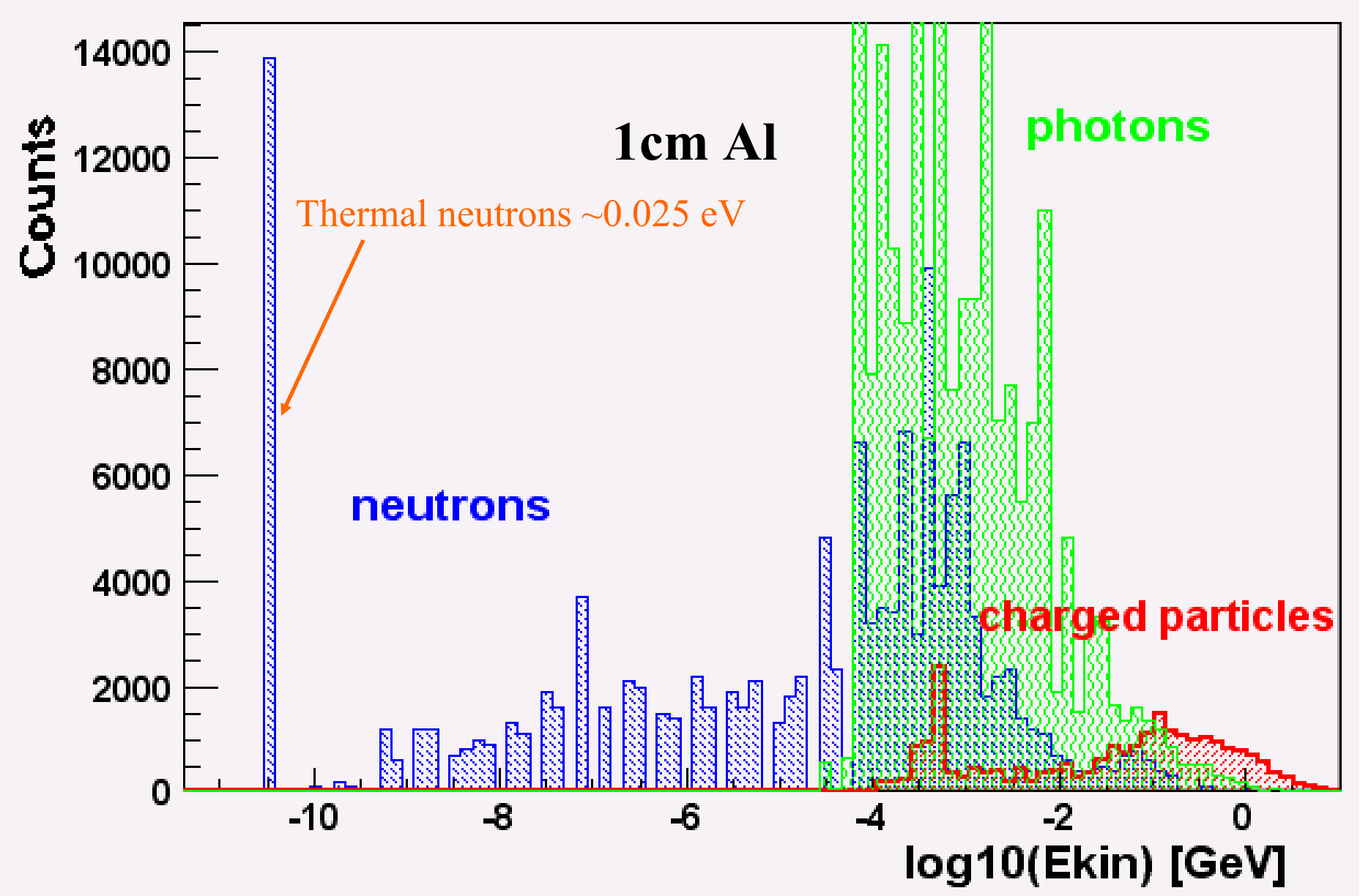
1 FLUKA event: 80000 pions and kaons (HIJING) are propagated in the ALICE geometry at $|\eta|<5$

In this study 5 fluka runs have taken place for 16000 primaries each run and after merging we had **one central event** in total.

Estimation of particle numbers

- The radiation is strongly correlated to the total number of produced particles.
- Use of a "current" estimator for counting particles from a boundary crossing scoring on each of the 4 layers apart that form the scoring region.

Energy spectra



Number of particles per central event

Left side of TPC

1cm Al (1mm of Si)

layers	1	2	3	4	sum
protons	292	200	155	156	803
electrons	4476	1551	1070	584	7681
positrons	1897	906	339	309	3451
photons	58286	60649	29010	67192	215137
neutrons	17796	35758	34999	49756	138349
muons+/-	390	457	368	325	1540
pions+/-	2140	1664	1452	1109	6365
kaons+/-	164	106	84	53	407
primaries	85	171	519	474	1249
charged	9359	4884	3468	2536	20247

Multiply with **$4*10^{10}$** to get the number of particles traversing a layer in 10 ALICE years of Pb+Pb.

[(8000 Hz)*(10 years)*(2.5 *10^6 sec/year)/(5 :to get from central to min bias multiplicity)]

Number of particles per 10 ALICE years 1cm Al (1mm of Si)

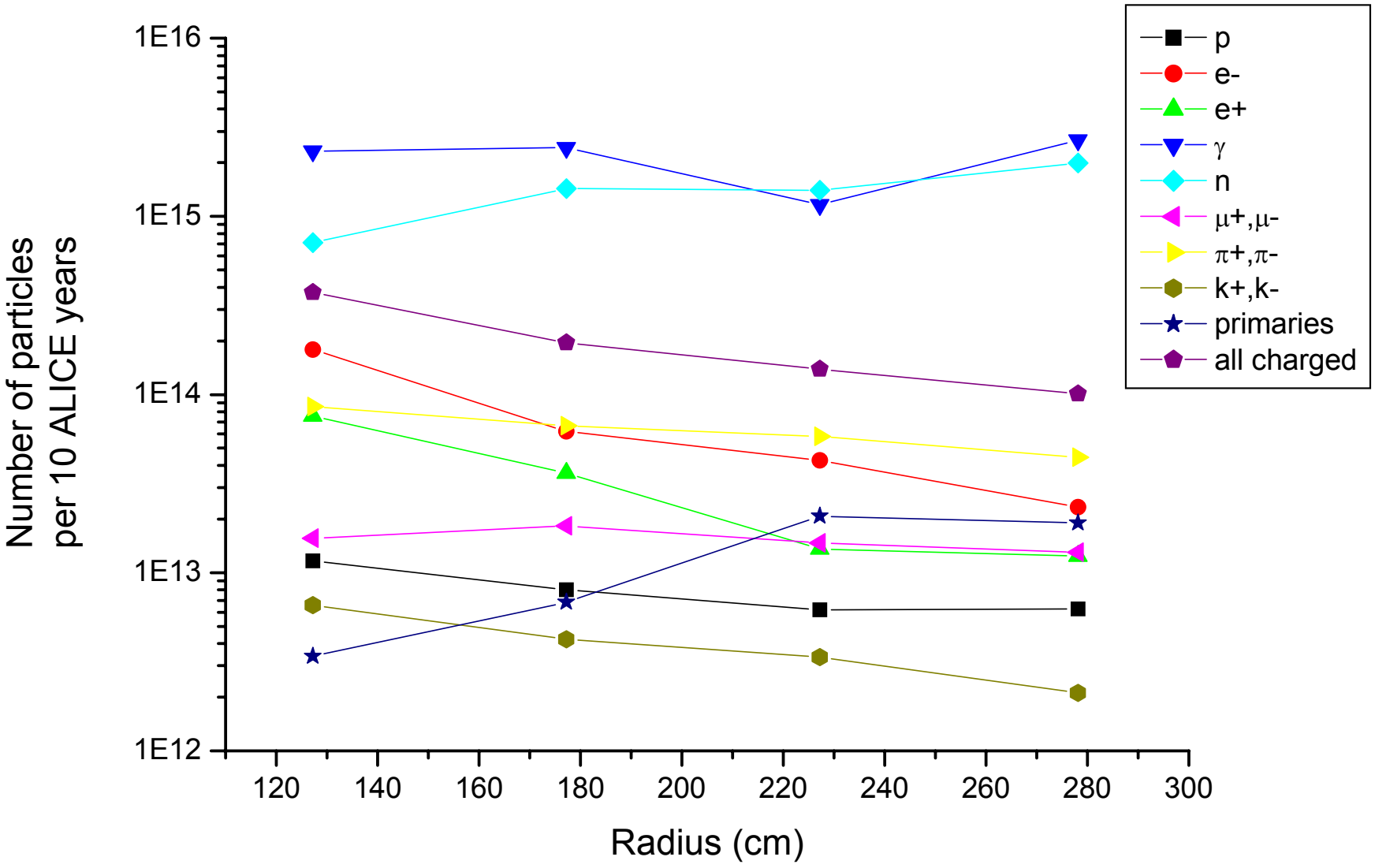
Left side of TPC

layers	1	2	3	4	sum
protons	1.168E+13	8E+12	6.2E+12	6.24E+12	3.21E+13
electrons	1.79E+14	6.2E+13	4.28E+13	2.34E+13	3.07E+14
positrons	7.588E+13	3.62E+13	1.36E+13	1.24E+13	1.38E+14
photons	2.331E+15	2.43E+15	1.16E+15	2.69E+15	8.61E+15
neutrons	7.118E+14	1.43E+15	1.4E+15	1.99E+15	5.53E+15
muons+/-	1.56E+13	1.83E+13	1.47E+13	1.3E+13	6.16E+13
pions+/-	8.56E+13	6.66E+13	5.81E+13	4.44E+13	2.55E+14
kaons+/-	6.56E+12	4.24E+12	3.36E+12	2.12E+12	1.63E+13
primaries	3.4E+12	6.84E+12	2.08E+13	1.9E+13	5E+13
charged	3.744E+14	1.95E+14	1.39E+14	1.01E+14	8.1E+14

Number of particles per 10 ALICE years

Left side of TPC

(1mm of Si)



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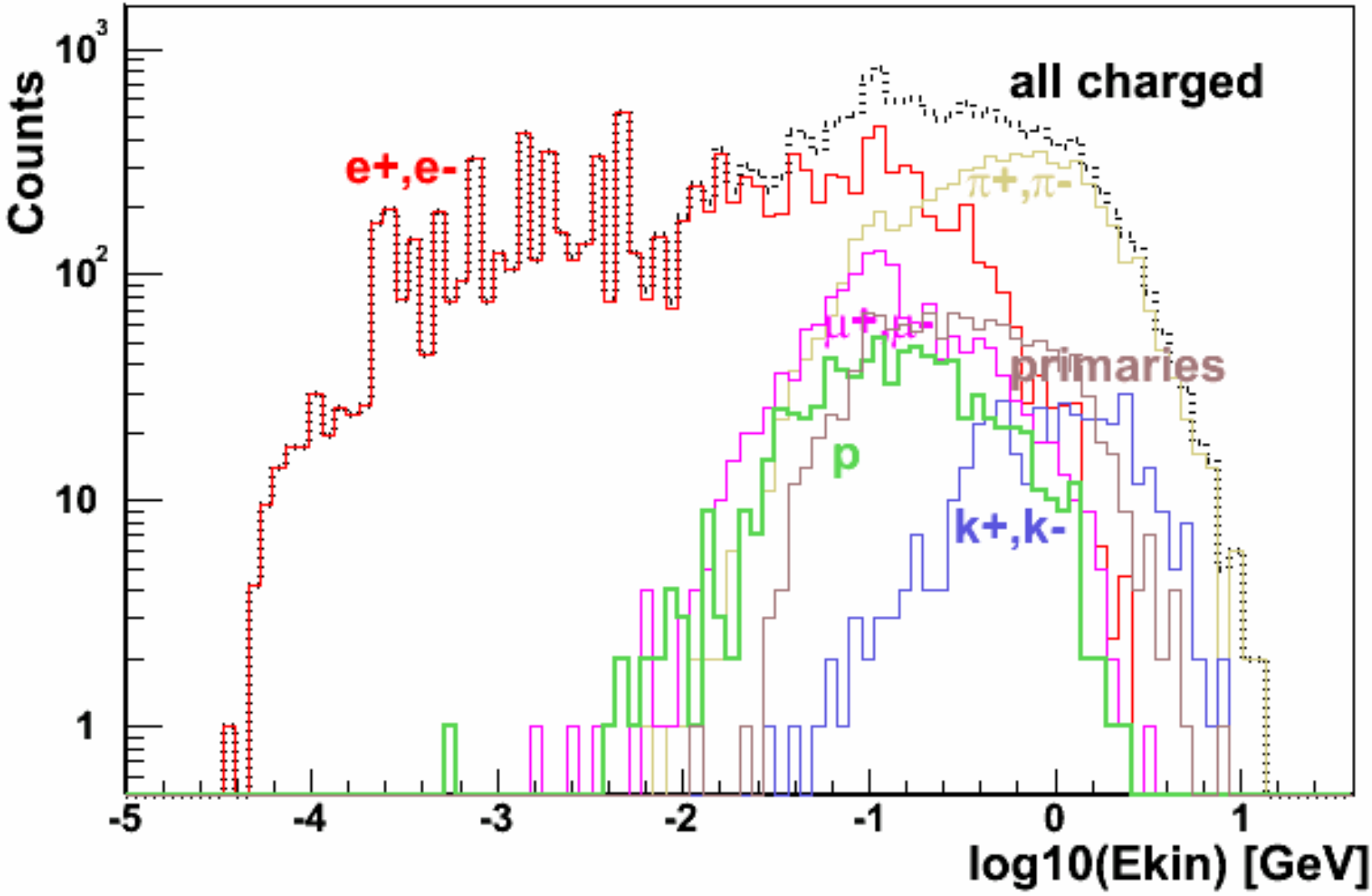
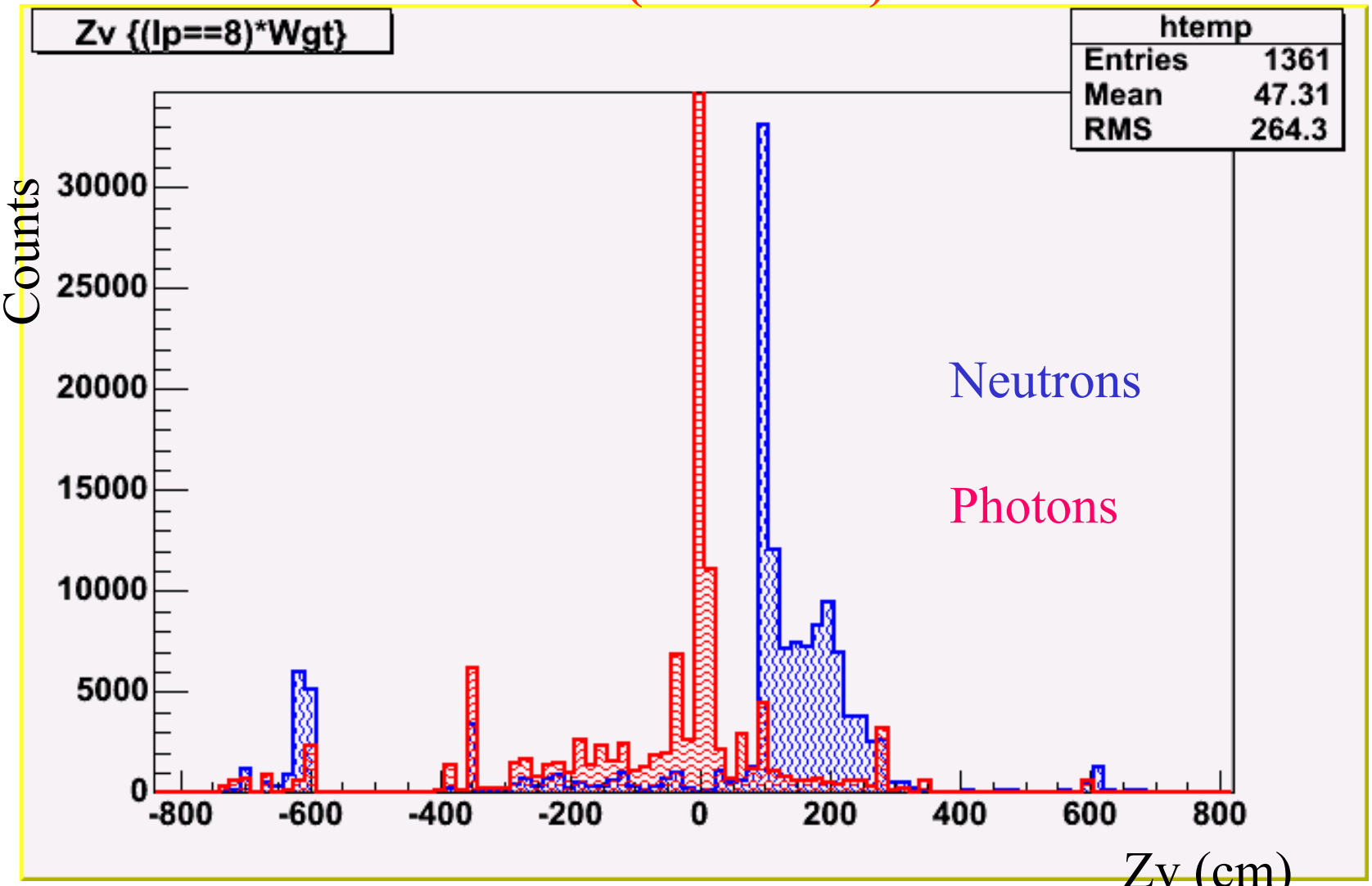


1 central event

Z distribution of neutrons and photons origin in the scoring region

(1mm of Si)

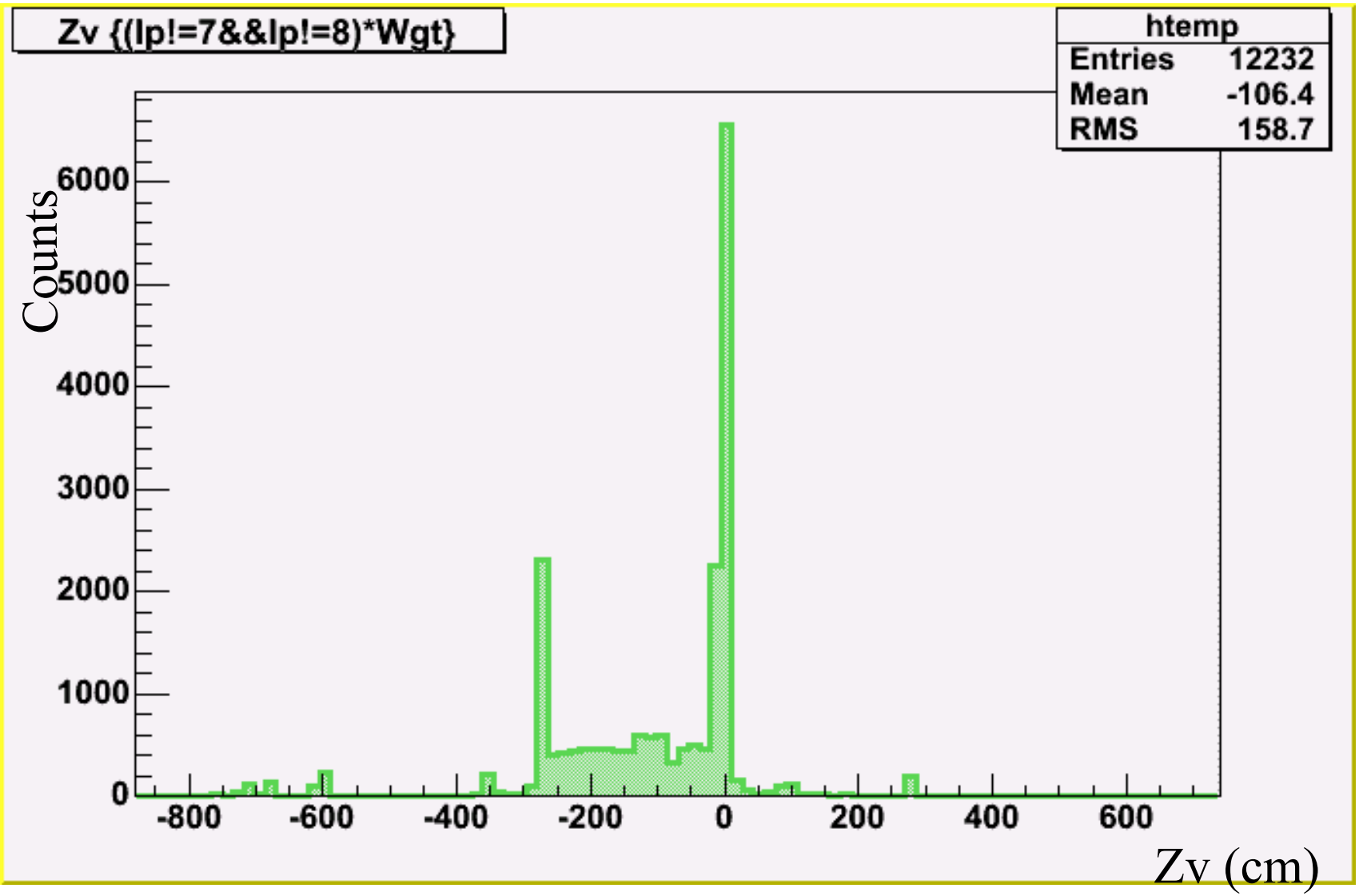


1 central event

Left side of TPC

Z distribution of all charged particles origin in the scoring region

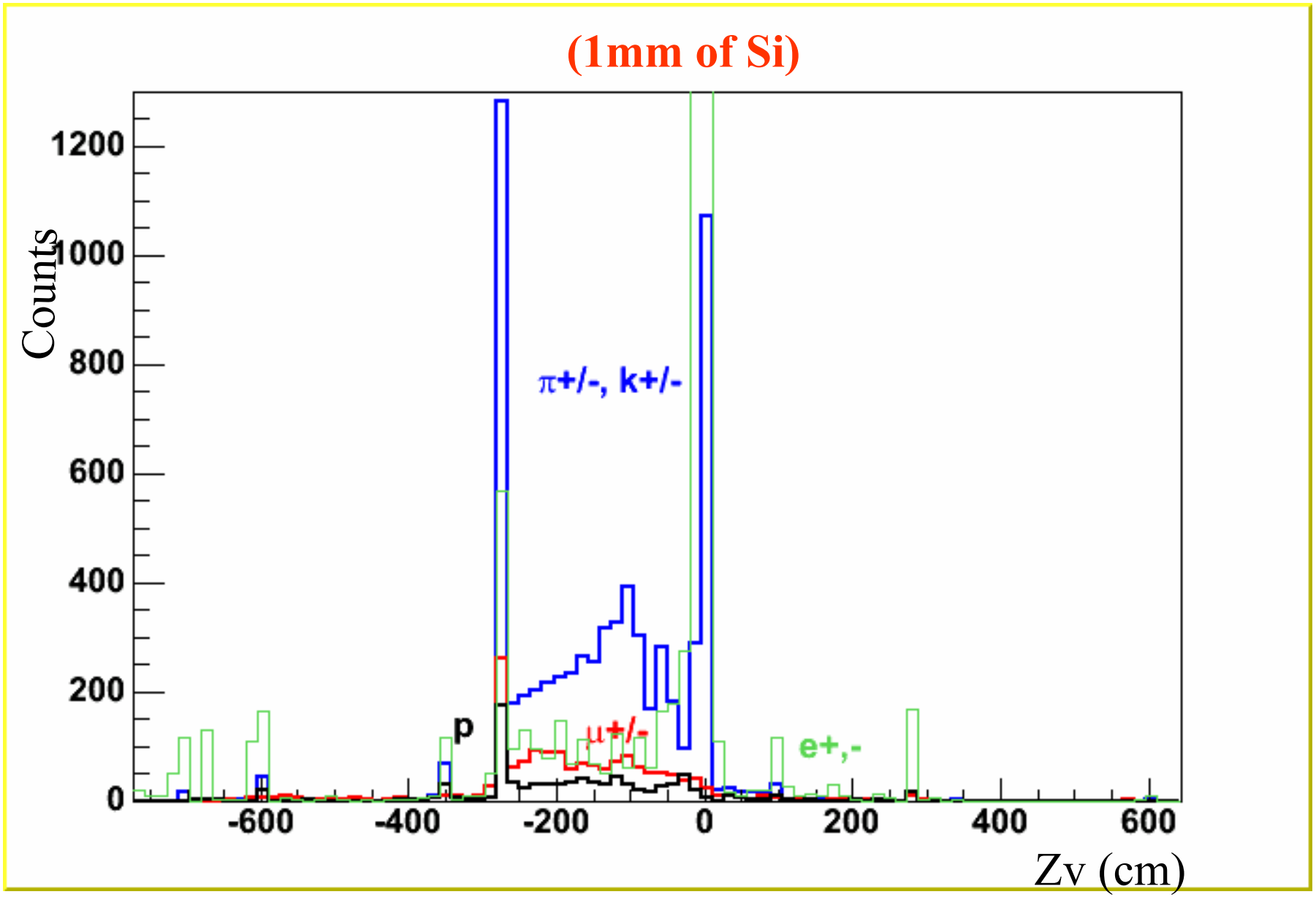
(1mm of Si)



1 central event

Left side of TPC

Z distribution of charged particles origin in the scoring region



1 central event

Particle fluxes and fluences

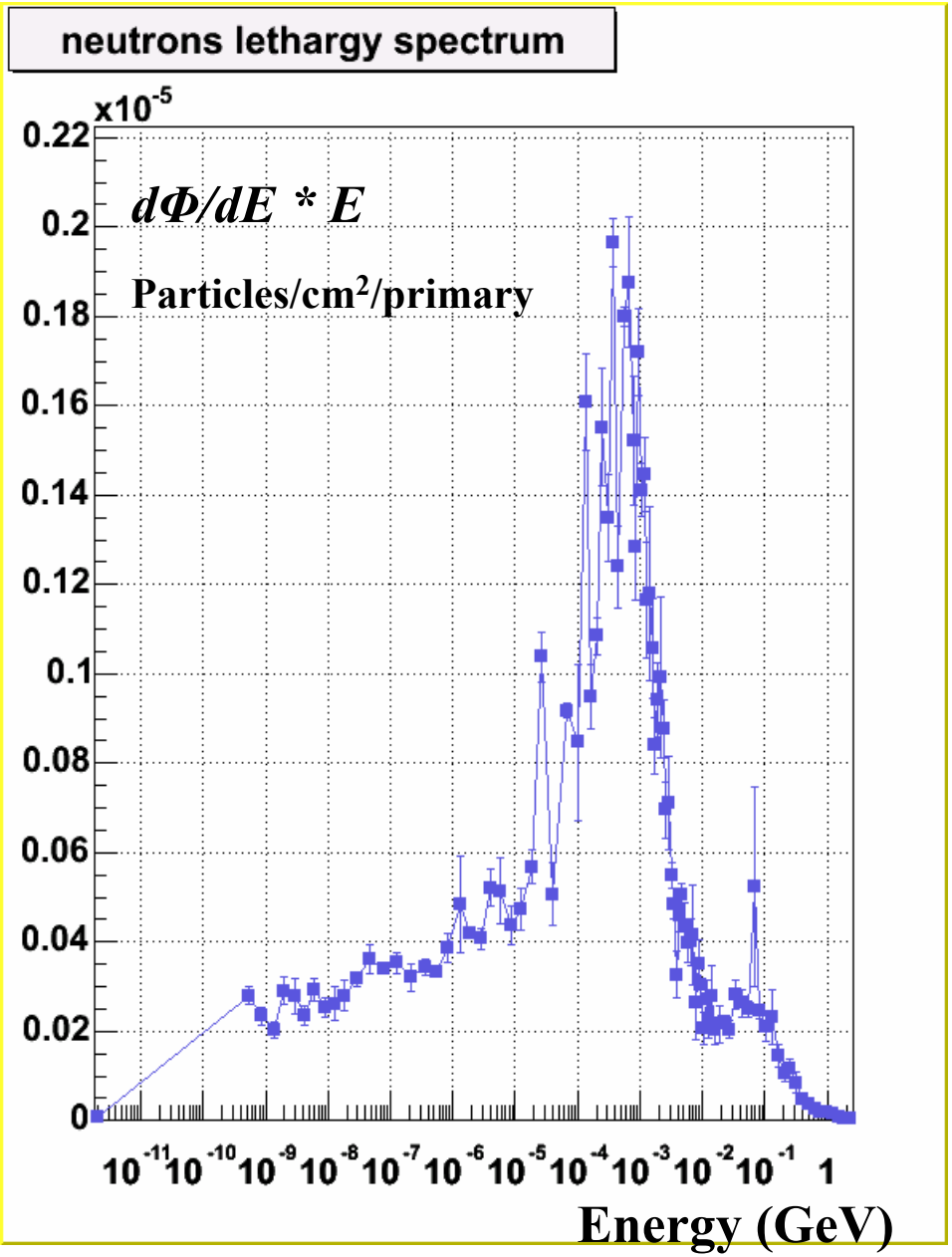
"Flux" counts the rate of arrivals per unit area indepedent of particle direction and its real physical meaning is that of path density, whereas "current" counts the rate crossing through a given plane, referred to area elements in the surface of the plane.

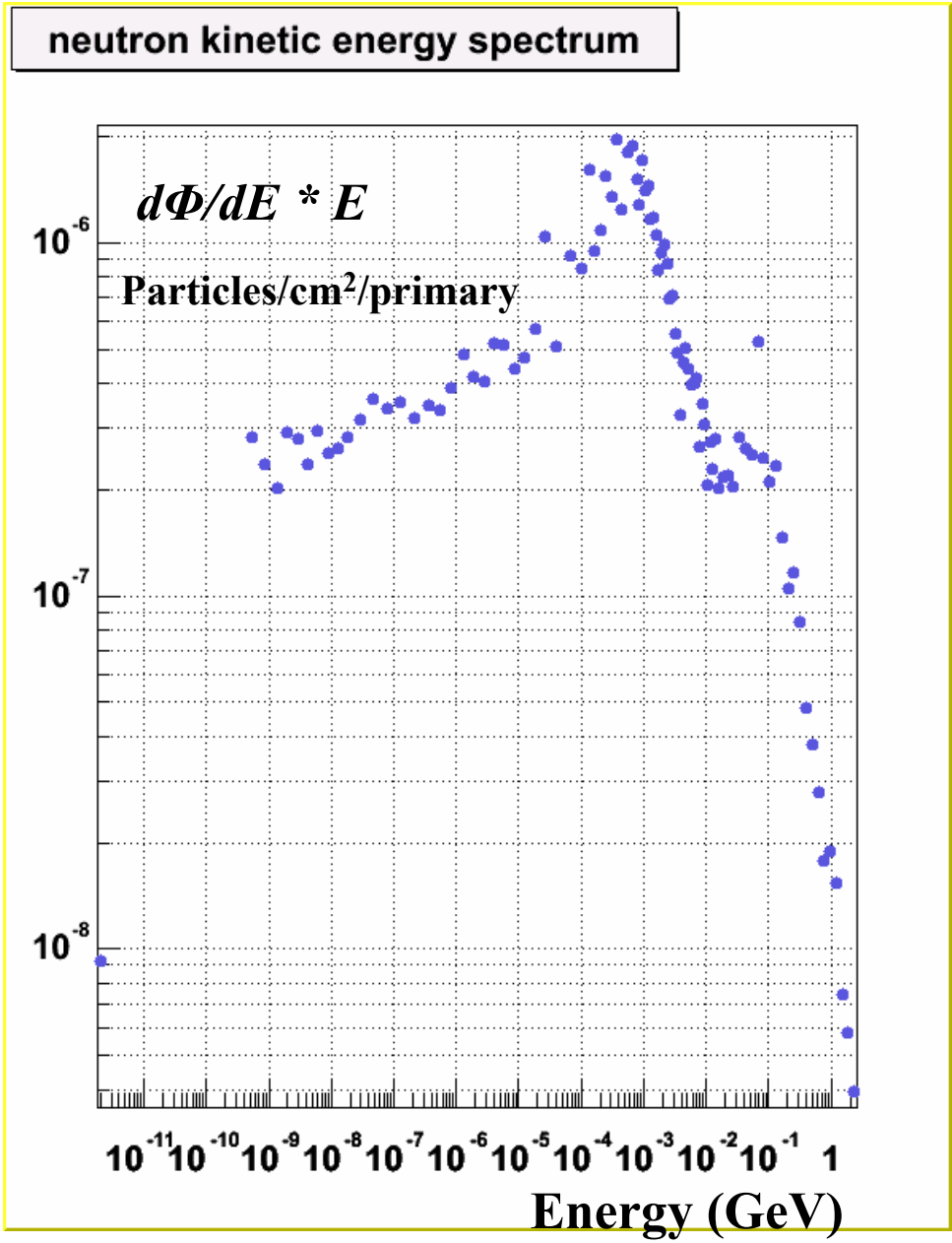
In FLUKA, ***flux*** is defined as the track-length of a particle per unit of volume and its unit can be expressed as ($cm^{-2}\ s^{-1}$) and ***fluence*** is the time integral of flux expressed in units of (cm^{-2}).

The results of the FLUKA tracklength estimator are always given as differential distributions of fluence in energy ($cm^{-2}\ GeV^{-1}$) per primary.

The following plots are designed to allow visual integration of fluence having the areas under the curves proportional to the fluence (lethargy spectrums).

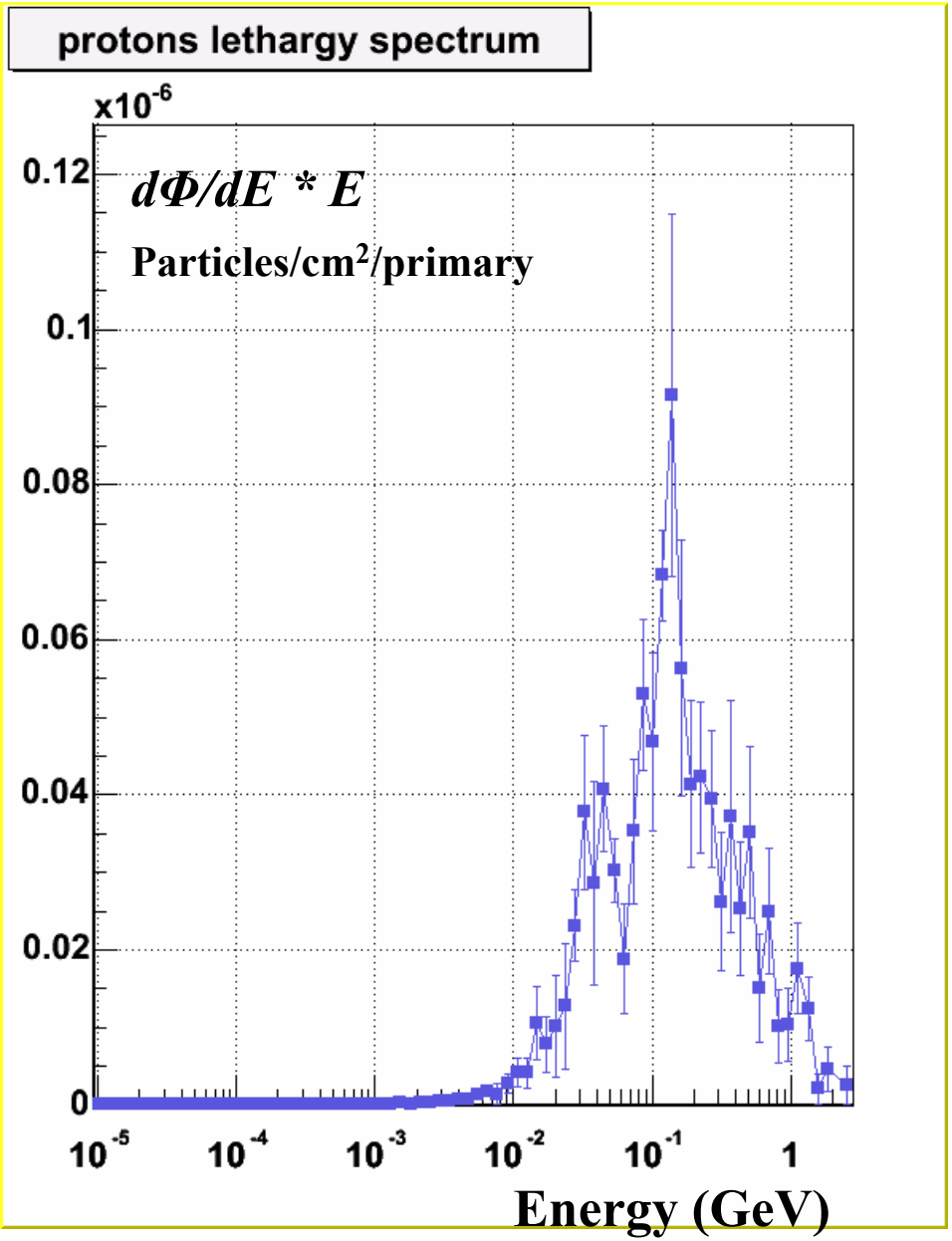
Neutron spectra layer 1 (1mm of Si) *Left side of TPC*

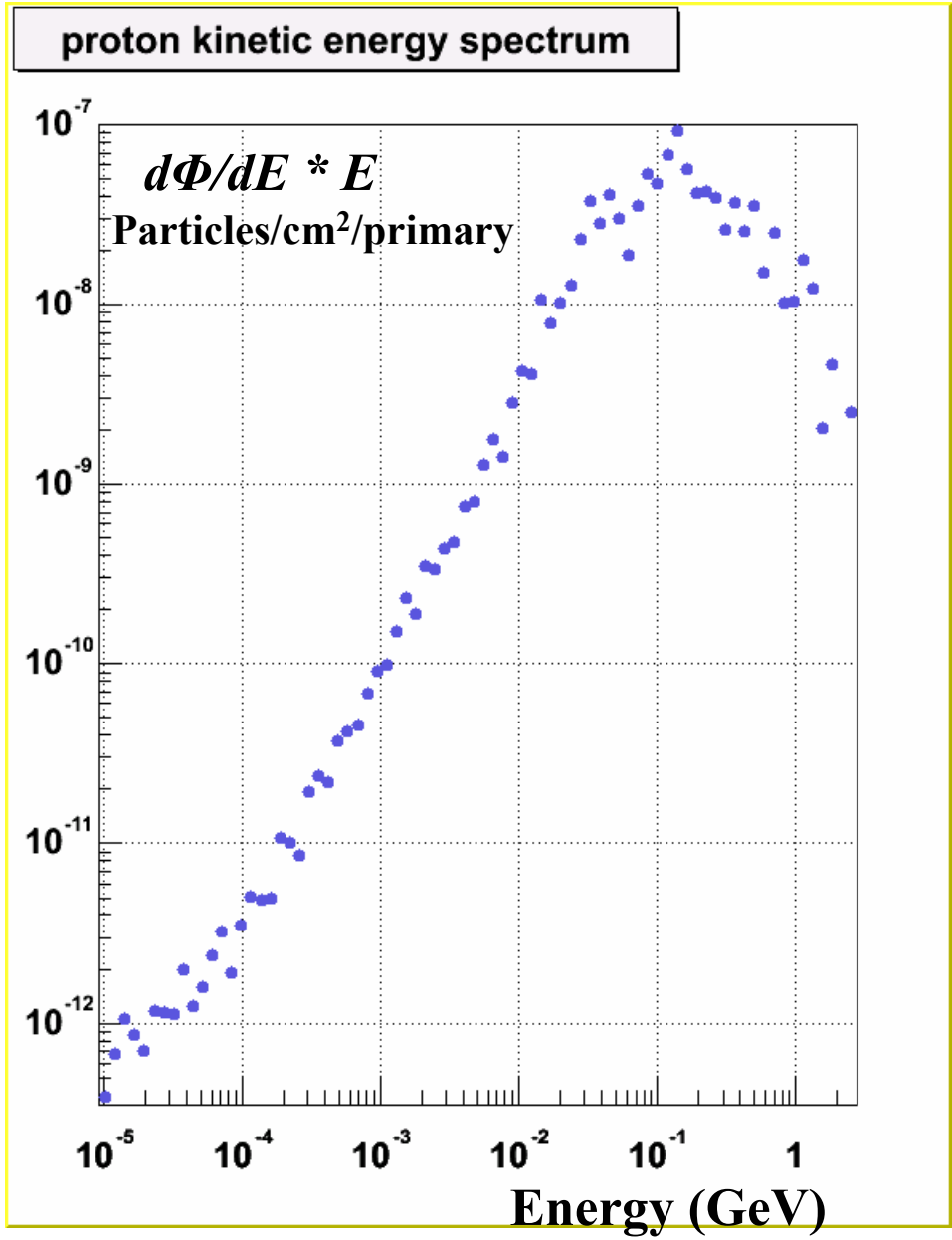




1 central event

Proton spectra layer 1 (1mm of Si) *Left side of TPC*

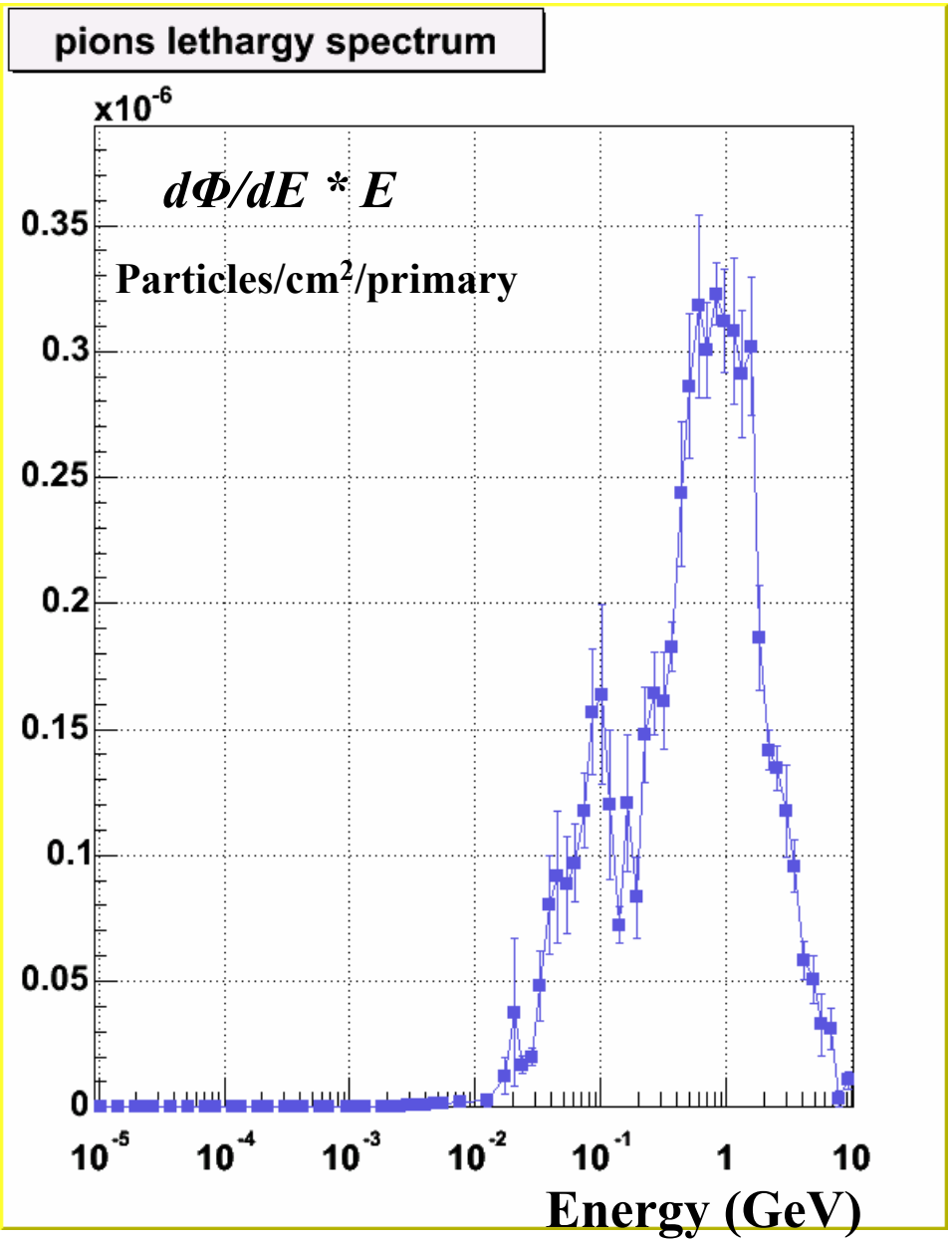


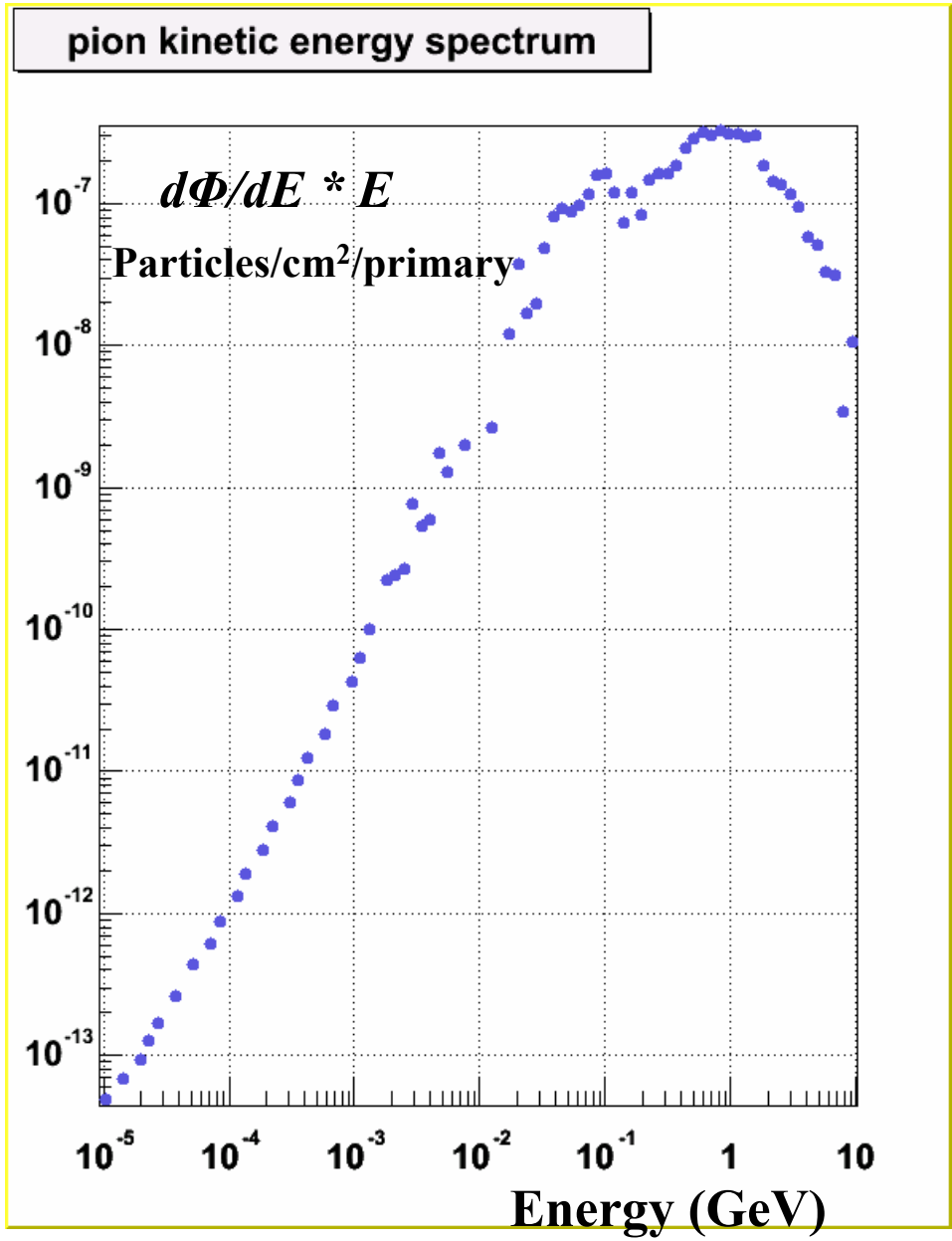


1 central event

Pion spectra layer 1 (1mm of Si)

Left side of TPC

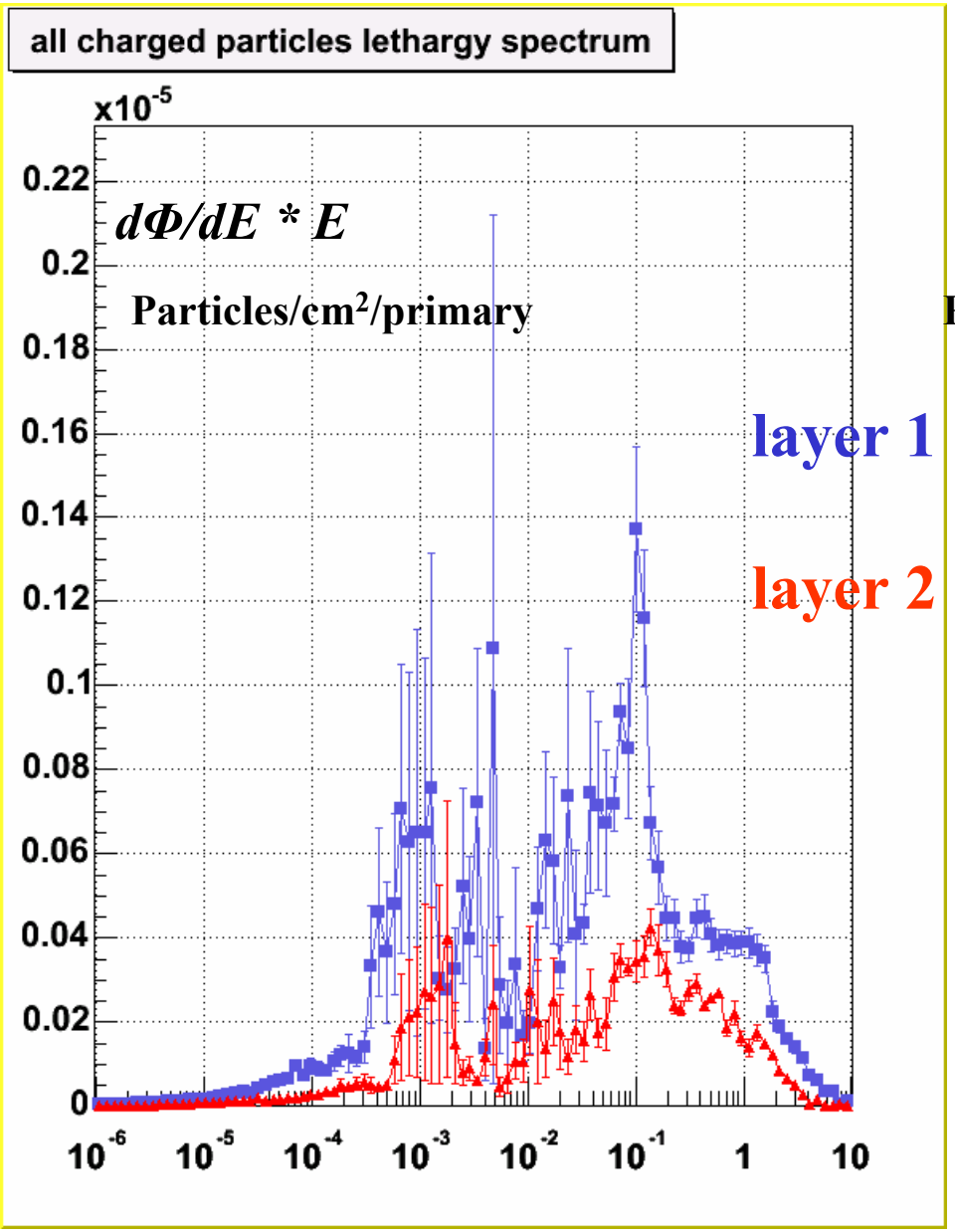


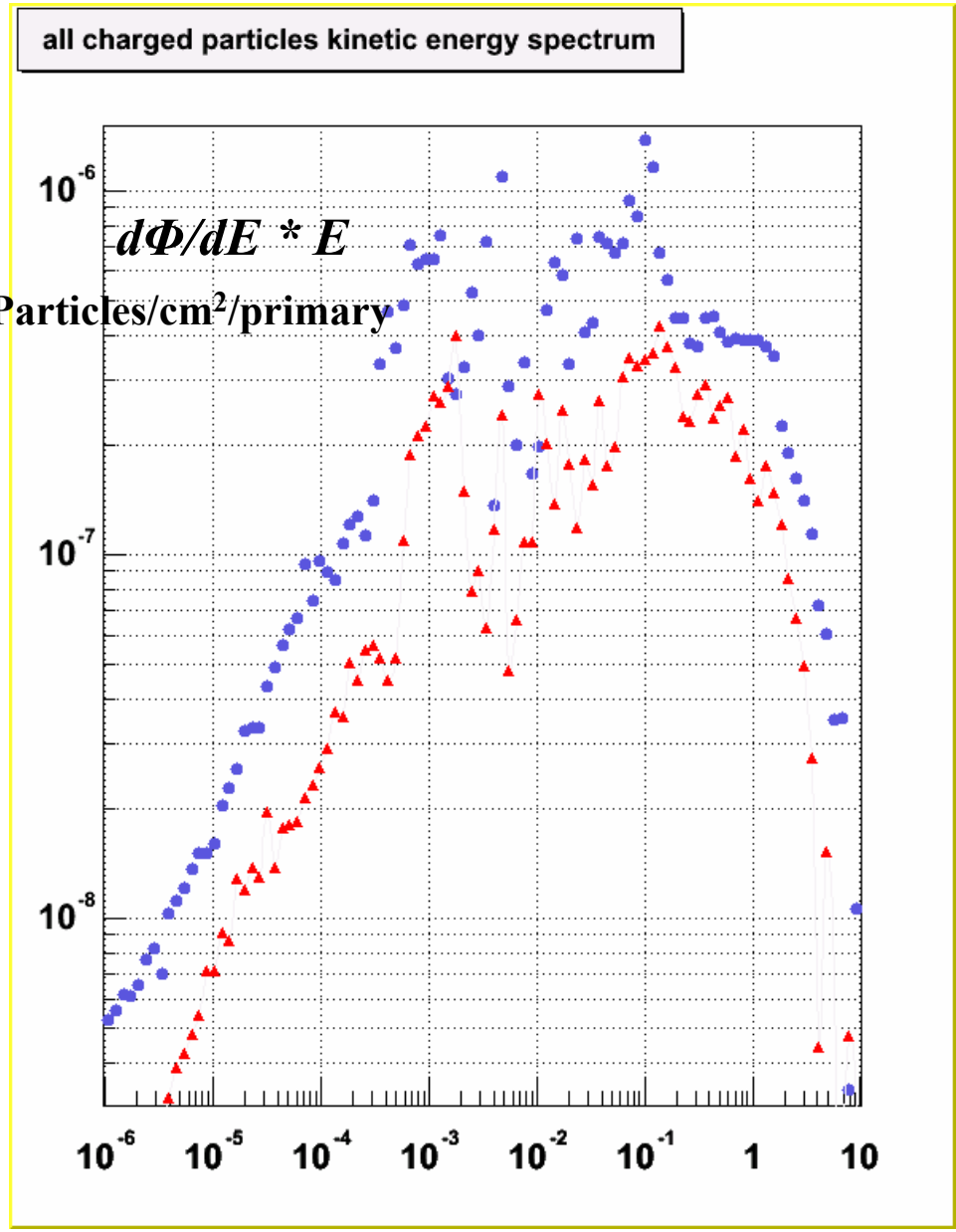


1 central event

All charged spectra (1mm of Si)

Left side of TPC





1 central event

Energy (GeV)

Energy (GeV)

Cumul. Fluences (Particles/cm^2/primary) per central event *Left side of TPC*

1cm Al **(1mm of Si)**

layers	1	2	3	4
protons	1.52E-7 +/- 9.6 %	7.22E-8 +/- 11.5 %	6.34E-8 +/- 19.3 %	3.61E-8 +/- 8.5 %
electrons/positrons	3.5E-6 +/- 23 %	1.1E-6 +/- 25.1 %	4.61E-7 +/- 15.5 %	3.08E-7 +/- 7.3 %
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pions+/-	8.94E-7 +/- 1 %	5.13E-7 +/- 2.5 %	3.65E-7 +/- 4%	2.42E-7 +/- 3 %
kaons+/-	6.03E-8 +/- 3.5 %	2.8E-8 +/-13.3 %	1.83E-8 +/- 9.3 %	1.02E-8 +/- 6.9 %
charged	4.89E-6 +/- 17 %	1.92E-6 +/- 14.3 %	1.05E-6 +/- 7.3 %	7.03E-7 +/- 2.2 %

Multiply with **$3.2*10^{15}$** to get the cumulative fluences for each layer in 10 ALICE years of Pb+Pb. [(80000 primaries) *($4*10^{10}$)=$3.2*10^{15}$]

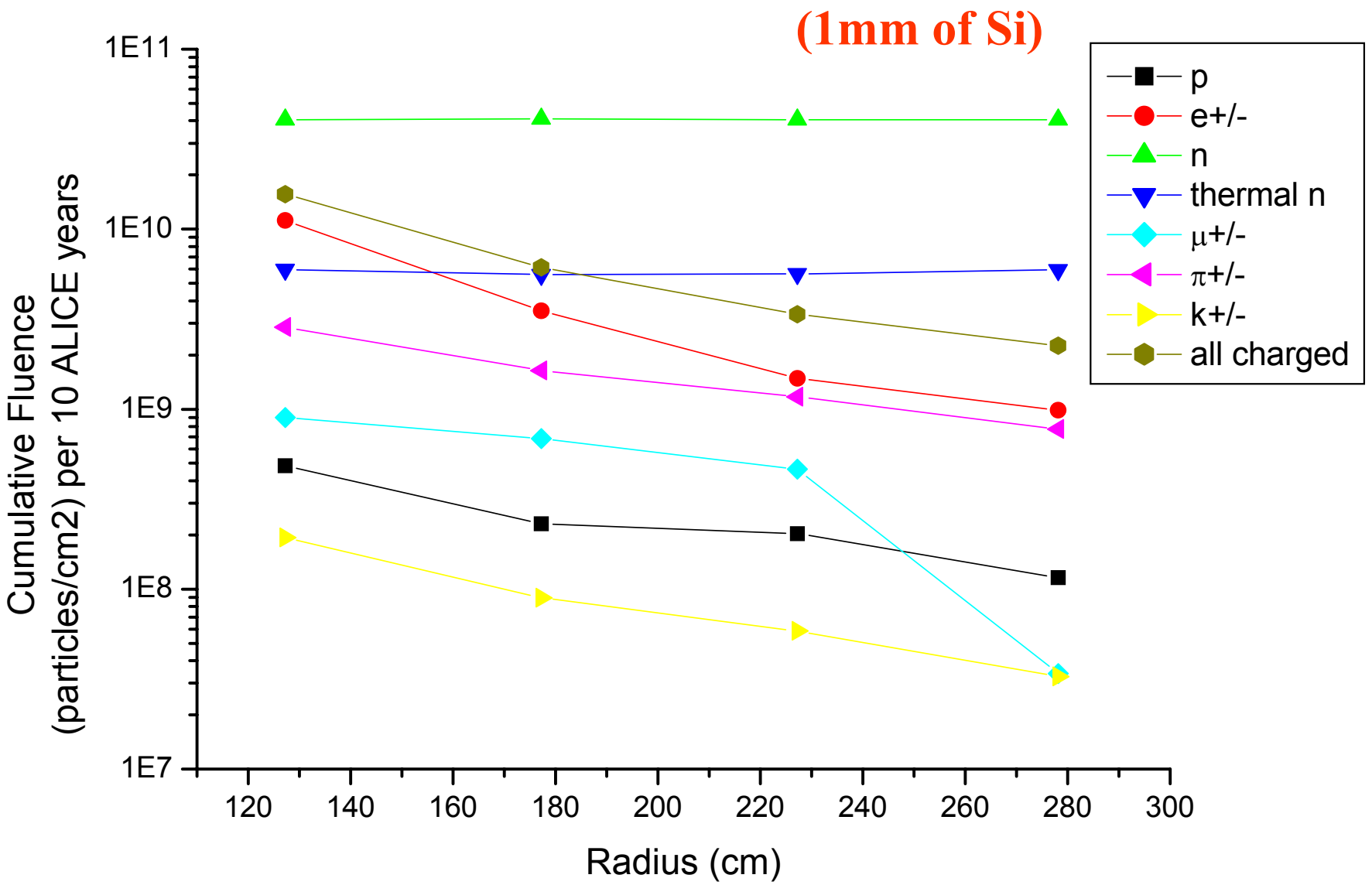
Cumul. Fluences (Particles/cm^2) per 10 ALICE years

Left side of TPC

1cm Al (1mm of Si)

layers	1	2	3	4
protons	4.86E+08+/-9.6%	2.31E+08+/-11.5%	2.03E+08+/-19.3%	1.16E+08+/-8.5%
electrons/positrons	1.12E+10+/-23%	3.52E+09+/-25.1%	1.48E+09+/-15.5%	9.86E+08+/-7.3%
neutrons	4.06E+10+/-1.3%	4.10E+10+/-2.1%	4.06E+10+/-1.2%	4.06E+10+/-1.3%
thermal neutrons	5.98E+09	5.60E+09	5.66E+09	5.95E+09
muons+/-	8.99E+08+/-12.4%	6.85E+08+/-2.2%	4.64E+08+/-8.6%	3.39E+07+/-7.1%
pions+/-	2.86E+09+/-1%	1.64E+09+/-2.5%	1.17E+09+/-4%	7.74E+08+/-3%
kaons+/-	1.93E+08+/-3.5%	8.96E+07+/-13.3%	5.86E+07+/-9.3%	3.26E+07+/-6.9%
charged	1.56E+10+/-17%	6.14E+09+/-14.3%	3.36E+09+/-7.3%	2.25E+09+/-2.2%

Cumul. Fluences (Particles/cm^2) per 10 ALICE years *Left side of TPC*



Left side of TPC

5 runs of 16000 primaries~1event

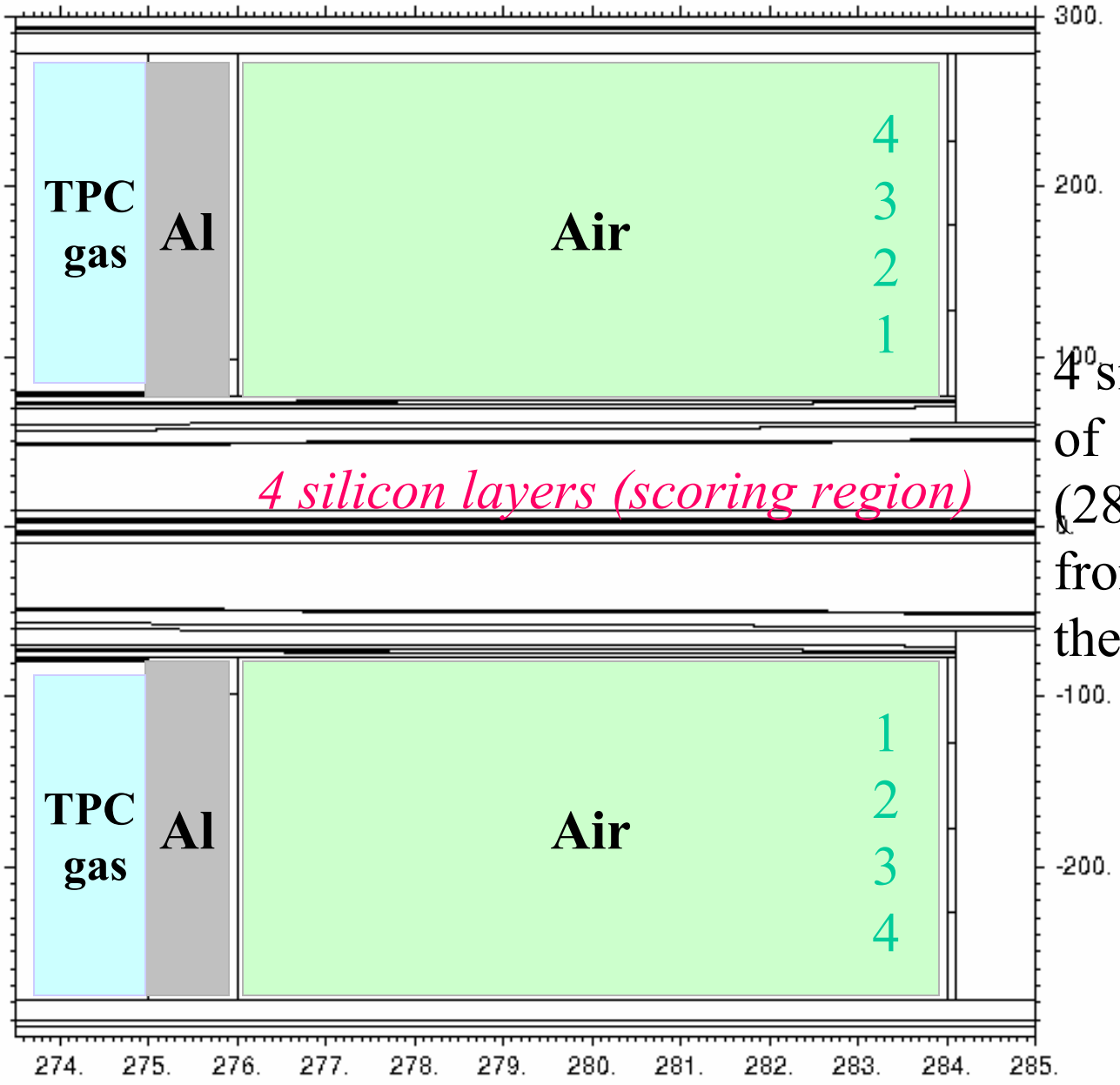
1Region number	Region volume in cubic cm	ENERGY Density GEV/cm**3 /one beam particle	EM-ENRGY Density GEV/cm**3 /one beam particle	PROTON STAR Density STARS/cm**3 /one beam particle	NEUTRON STAR Density STARS/cm**3 /one beam particle
1056	1.000000000E+00	5.228842926E-05	2.868397255E-05	0.000000000E+00	0.000000000E+00
1057	1.000000000E+00	3.529706367E-05	1.348630710E-05	0.000000000E+00	0.000000000E+00
1058	1.000000000E+00	3.117645649E-05	7.654761995E-06	0.000000000E+00	1.875000000E-04
1059	1.000000000E+00	3.255433553E-05	1.420496019E-05	0.000000000E+00	0.000000000E+00
1056	1.000000000E+00	6.351411173E-05	3.416408680E-05	0.000000000E+00	0.000000000E+00
1057	1.000000000E+00	5.506546700E-05	3.434473228E-05	0.000000000E+00	6.250000000E-05
1058	1.000000000E+00	3.758578125E-05	1.012275596E-05	0.000000000E+00	1.875000000E-04
1059	1.000000000E+00	2.920703726E-05	8.598977349E-06	0.000000000E+00	6.250000000E-05
1056	1.000000000E+00	6.388757880E-05	4.007919299E-05	0.000000000E+00	0.000000000E+00
1057	1.000000000E+00	3.687861249E-05	1.375218141E-05	0.000000000E+00	0.000000000E+00
1058	1.000000000E+00	2.971775008E-05	9.817833827E-06	0.000000000E+00	0.000000000E+00
1059	1.000000000E+00	3.103435475E-05	1.138261350E-05	0.000000000E+00	0.000000000E+00
1056	1.000000000E+00	4.995045059E-05	2.154595575E-05	0.000000000E+00	0.000000000E+00
1057	1.000000000E+00	4.715594685E-05	1.755726195E-05	6.250000000E-05	1.250000000E-04
1058	1.000000000E+00	4.116514216E-05	1.814900004E-05	0.000000000E+00	1.875000000E-04
1059	1.000000000E+00	2.898567663E-05	1.118720117E-05	0.000000000E+00	6.250000000E-05
1056	1.000000000E+00	9.578925940E-05	6.807516556E-05	0.000000000E+00	6.250000000E-05
1057	1.000000000E+00	3.556810181E-05	1.250580045E-05	0.000000000E+00	6.250000000E-05
1058	1.000000000E+00	3.372518153E-05	8.518603611E-06	0.000000000E+00	1.250000000E-04
1059	1.000000000E+00	2.847068540E-05	7.412758915E-06	0.000000000E+00	6.250000000E-05

To obtain ***doses*** (in **Gy**) the Edep (in **GeV**) must be multiplied by (10^9***e*/*rho***Volume***), where ***rho*** is the material density in g/cm^3 and ***e*** the electron charge in Cb (rho_{Si}=2.329)

Total and EM absorbed dose in these 1mm thick layers of Si per 10 ALICE years

Layer 1cm Al	1	2	3	4
Total Dose (Gy)	4.46 +/- 1.23	1.93 +/- 0.41	1.00 +/- 0.52	0.65 +/- 0.33
Dose from e+/-,γ (Gy)	2.67 +/- 1.23	0.83 +/- 040	0.38+/-0.14	0.29 +/- 0.08

Right side of TPC (1 mm of Silicon)



4 silicon radial segments of 1mm width for scoring ($284 < z < 284.1$), 8cm far from the right end-cup of the TPC (1cm of Al thick)

Number of particles per central event

Right side of TPC

1cm Al (1mm of Si)

layers	1	2	3	4	sum
protons	113	147	134	147	541
electrons	1097	971	854	954	3876
positrons	464	586	334	281	1665
photons	16530	34581	22930	28187	102228
neutrons	41502	49600	50853	57780	199735
muons+/-	234	348	368	300	1250
pions+/-	492	1449	1495	1030	4466
kaons+/-	19	91	72	51	233
primaries	103	197	567	435	1302
charged	2419	3592	3257	2763	12031

Multiply with **$4*10^{10}$** to get the number of particles traversing a layer in 10 ALICE years of Pb+Pb.

[(8000 Hz)*(10 years)*(2.5 *10^6 sec/year)/(5 :to get from central to min bias multiplicity)]

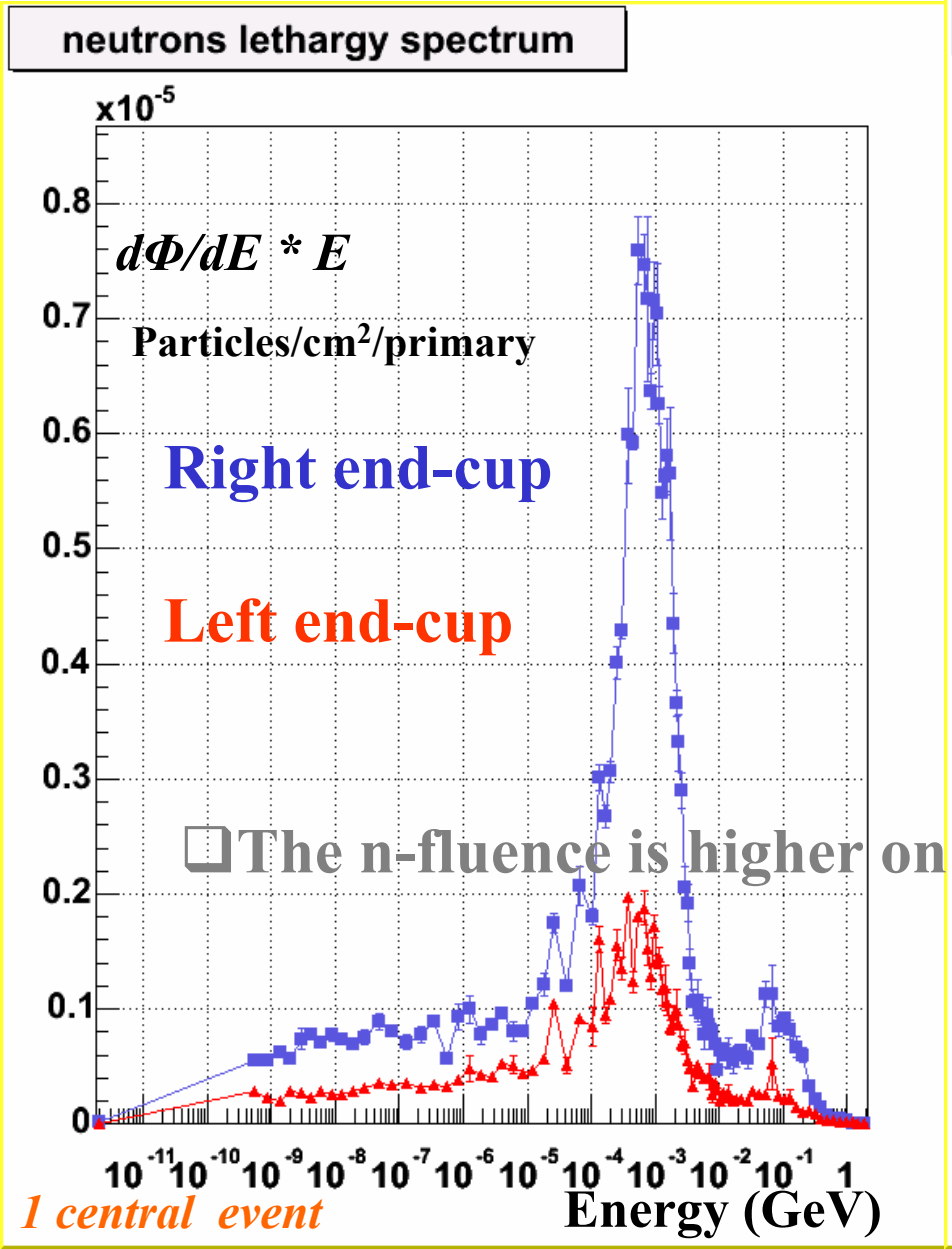
Number of particles per 10 ALICE years 1cm Al (1mm of Si)

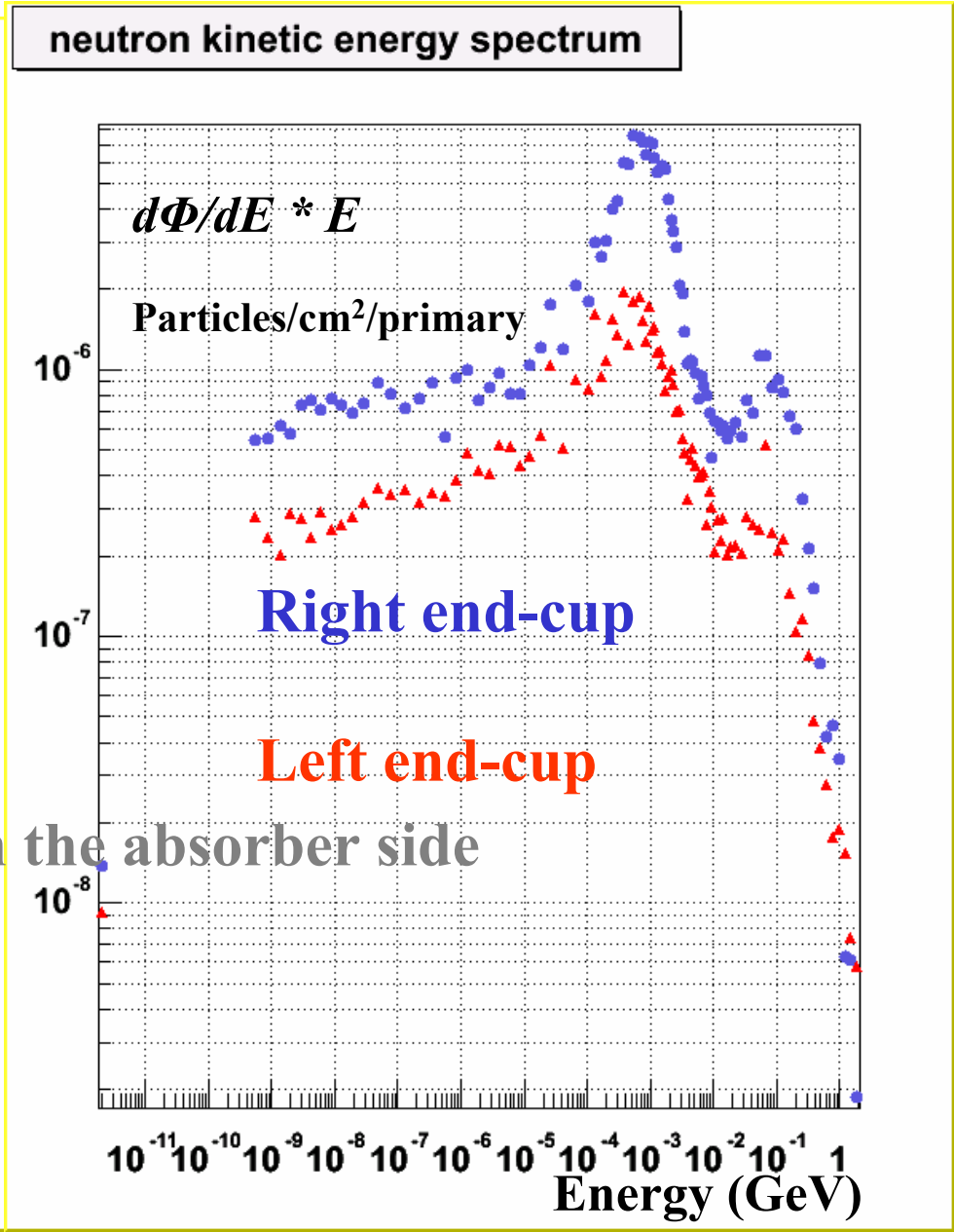
Right side of TPC

layers	1	2	3	4	sum
protons	4.52E+12	5.88E+12	5.36E+12	5.88E+12	2.164E+13
electrons	4.39E+13	3.88E+13	3.42E+13	3.82E+13	1.55E+14
positrons	1.86E+13	2.34E+13	1.34E+13	1.12E+13	6.66E+13
photons	6.61E+14	1.38E+15	9.17E+14	1.13E+15	4.089E+15
neutrons	1.66E+15	1.98E+15	2.03E+15	2.31E+15	7.989E+15
muons+/-	9.36E+12	1.39E+13	1.47E+13	1.2E+13	5E+13
pions+/-	1.97E+13	5.8E+13	5.98E+13	4.12E+13	1.786E+14
kaons+/-	7.6E+11	3.64E+12	2.88E+12	2.04E+12	9.32E+12
primaries	4.12E+12	7.88E+12	2.27E+13	1.74E+13	5.208E+13
charged	9.68E+13	1.44E+14	1.3E+14	1.11E+14	4.812E+14

Neutron spectra layer 1 (1mm of Si)

Right side of TPC





- The n-fluence is higher on the absorber side

1 central event

Cumul. Fluences (Particles/cm^2/primary) per central event *Right side of TPC*

1cm Al (1mm of Si)

layers	1	2	3	4
protons	1.03E-7 +/- 26.7 %	6.04E-8 +/- 6.9 %	3.93E-8 +/- 10.6 %	4.01E-8 +/- 11.7 %
electrons/positrons	1.0E-6 +/- 26.4 %	6.1E-7 +/- 6.8 %	4.5E-7 +/- 26 %	3.16E-7 +/- 9.7 %
neutrons	3.42E-5 +/-1.6 %	2.57E-5 +/- 0.3 %	2.13E-5 +/- 0.9 %	1.85E-5 +/- 0.5 %
thermal neutrons	2.82E-6	2.58E-6	2.44E-6	2.54E-6
muons+/-	1.47E-7 +/- 9 %	1.51E-7 +/- 7.3 %	1.31E-7 +/- 13.7 %	8.22E-8 +/- 5 %
pions+/-	2.92E-7 +/-5.7 %	4.37E-7 +/- 3.1 %	3.71E-7 +/- 2. 4%	2.23E-7 +/- 2.8 %
kaons+/-	7.54E-9 +/- 14 %	2.37E-8 +/-15.1 %	1.59E-8 +/- 12.5 %	9.85E-9 +/-27.9 %
charged	1.55E-6 +/- 17.3 %	1.28E-6 +/- 3.6 %	1.01E-6 +/- 12.5 %	6.72E-7 +/- 5.3 %

Multiply with **$3.2*10^{15}$** to get the cumulative fluences for each layer in 10 ALICE years of Pb+Pb. [(80000 primaries) *($4*10^{10}$)=$3.2*10^{15}$]

Cumul. Fluences (Particles/cm^2) per 10 ALICE years

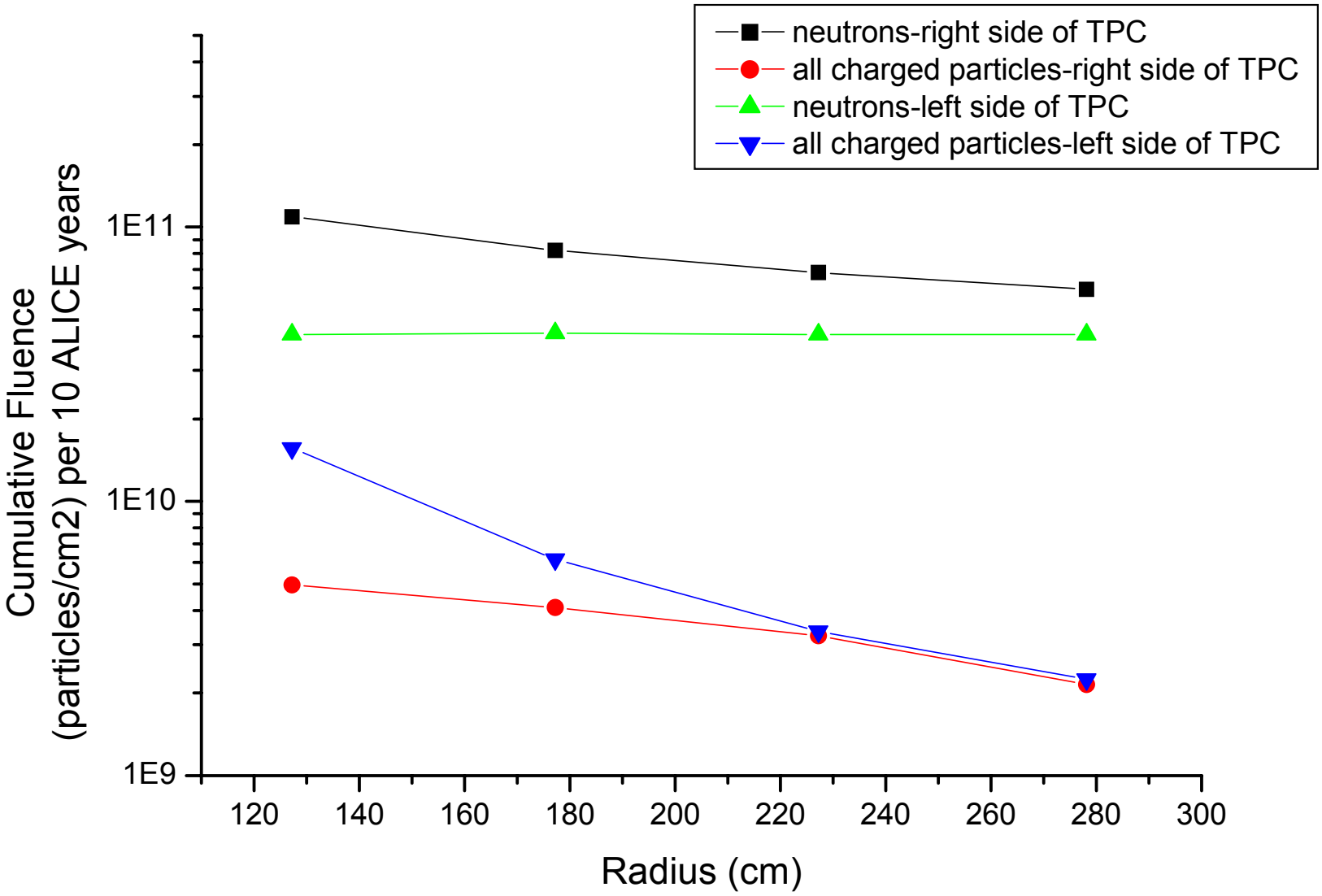
Right side of TPC

1cm Al (1mm of Si)

layers	1	2	3	4
protons	3.30E+08	1.93E+08	1.26E+08	1.28E+08
electrons/positrons	3.20E+09	1.95E+09	1.44E+09	1.01E+09
neutrons	1.09E+11	8.22E+10	6.82E+10	5.92E+10
thermal neutrons	9.02E+09	8.26E+09	7.81E+09	8.13E+09
muons+/-	4.70E+08	4.83E+08	4.19E+08	2.63E+08
pions+/-	9.34E+08	1.40E+09	1.19E+09	7.14E+08
kaons+/-	2.41E+07	7.58E+07	5.09E+07	3.15E+07
charged	4.96E+09	4.10E+09	3.23E+09	2.15E+09

✓Same errors (%) as the previous table

Cumul. Fluences (Particles/cm^2) per 10 ALICE years



- **At the inner radius on the absorber side, the n-fluence is higher (factor 3) and the charged fluence smaller (factor 3) compared with the left side of the TPC.**

Fluences and doses for 10 ALICE years

Regions	**Neutron fluence [Particles/cm^3]**	**Proton fluence [Particles/cm^3]**	**Dose [Gy]**
Inner TPC gas	1.7E+11		5.73
TPC gas-total	9.9E+10	2.6E+8	2.1
TRD gas-total	8.6E+10		0.7
TPC elec(right)	(0.6-1.1)E+11	(1.3-3.3)E+8	0.4-4
TPC elec(left)	4.1E+10	(1.2-4.9)E+8	0.5-6

These results were obtained by multiplying fluences and energy depositions from 1 central event/primary with a factor : **$3.2*10^{15}$** ((80000 primaries) *($4*10^{10}$))

Summary

The cumulative fluence of neutrons as well as of charged particles is expected to be of the order of 10^{11} particles/cm^2 per 10 ALICE years and the absorbed dose less than 10 Gy.

The results of this simulation concerning the particle rates, fluences and energy distributions should be taken into account for checking the radiation tolerance of the electronics.