SuperBTF

Preliminary Studies for an extracted beam and neutron facility at the SuperB

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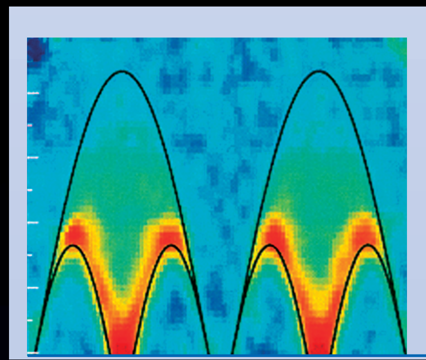
LNF-INFN

Outlook

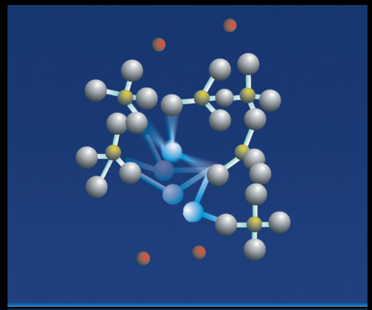
- Neutrons: scientific motivations
- Physics Overview
- Overview of Photonuclear Physics implementation (Fluka)
- Neutrons at DaΦne: measured photo-neutrons on W target (n@BTF: the feasibility test)
- Hadron Photo-production at SuperB: preliminar MC predictions
    - Optimized targets: choice of material and geometry
    - Monte Carlo predictions of hadron yield, spatial distribution and dynamic characterization

Scientific Motivation: research with neutrons



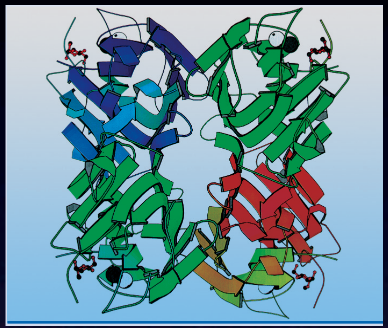
Solid State Physics:

Neutrons provide unique access to the magnetic structure and dynamics of solids.



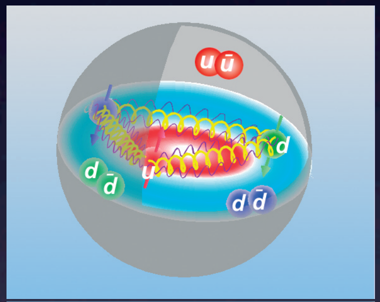
Neutron Scattering:

Neutron diffraction data is routinely used as the basis for structural models of crystals, glasses and liquids.



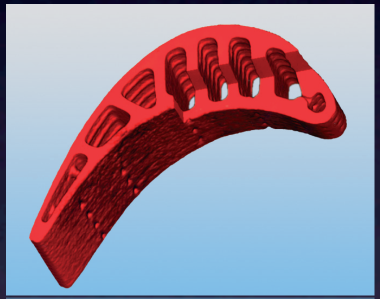
Biology and Biotecnology:

Neutrons are particularly sensitive to the dynamics of molecules and single atoms. .



Particle Physics

The neutron can be seen as a composite particle consisting of quarks, virtual pions and gluons. Its internal structure determines the decay process, the magnetic moment, and an anticipated electrical dipole moment that would indicate new physics beyond the Standard Model of particle physics. Related measurements can be performed using cold and ultra-cold neutrons. Essential contributions can be expected to the unification of fundamental forces in nature.



Material Science

Neutron sensitive imaging will add a dimension to real scale tomography radiography.

Drug Discovery:

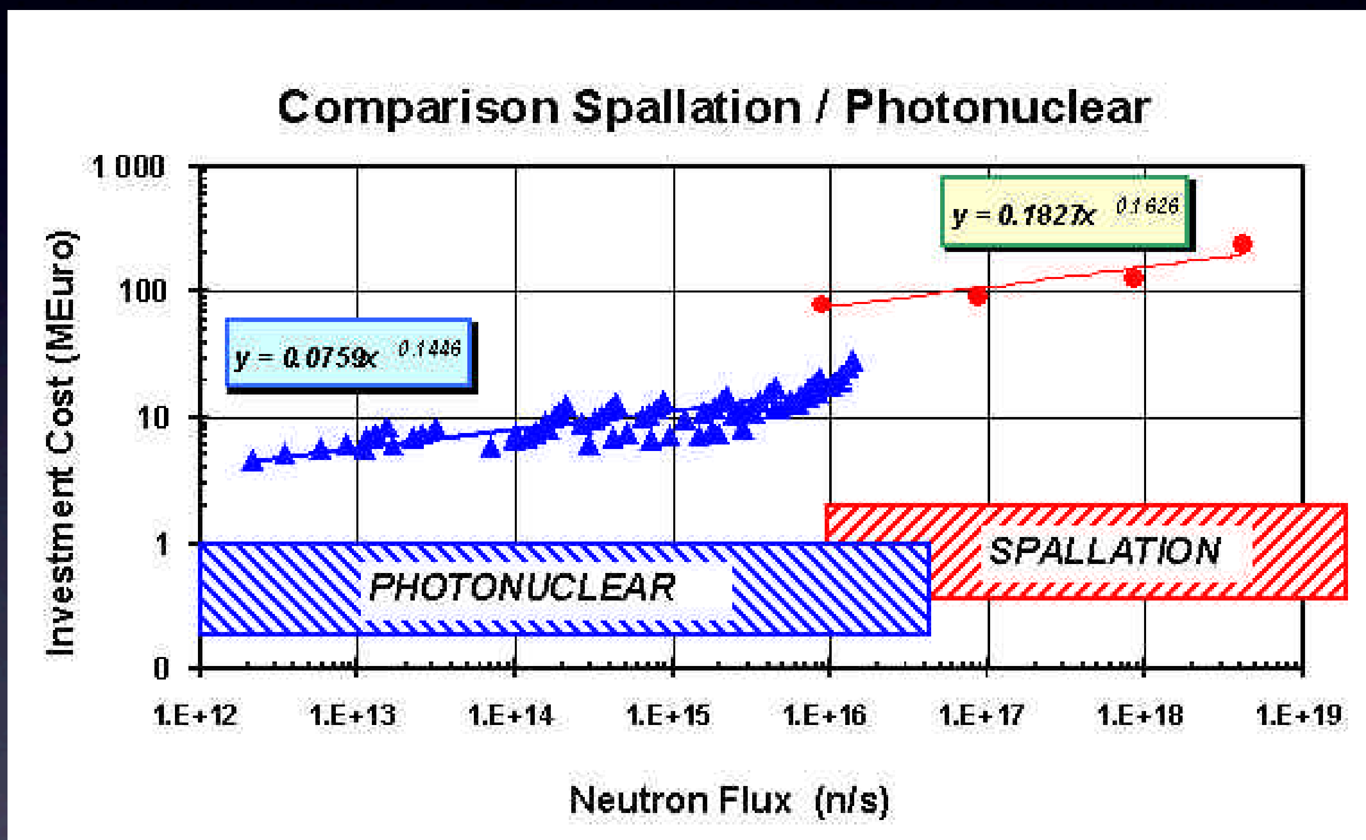
Knowledge of the three dimensional structures and dynamics of proteins and nucleic acids, as receptors for drug molecules, opens a structure based path to new drug discovery. For instance, major diseases in aging, such as Alzheimers, are caused by the formation of insoluble amyloid deposits of proteins in the brain and neurofibral tangles in the nerves. A combination of x-ray and neutron crystallographic studies, both of the enzymes that catalyse processing of the amyloid precursor proteins and of the proteins that associate with the plaques, could make an outstanding contribution to the design of therapeutic agents

Nuclear data Measurements:

Neutron Cross Section measurements (total, capture, fission, elastic, scattering gamma ray and neutron production) for supporting advanced Fuel cycle in New Generation Reactos

Spallation versus Photoneutron source

- Spallation source are very effective in producing neutrons, but are large and expensive
- Electron drivers although are much less effective in neutron production are rather cheap and compact machine that might also bring advantages in terms of reliability



Above a given neutron flux the spallation will be preferred while for the lower fluxes, the photonuclear process will tend to be more convenient

To obtain very high neutron fluxes by photo-production, much higher electron beam intensity will be necessary. This will increase the electron accelerator complexity, resulting in a less convenient solution from an engineering and economical point of view.

Plot reference:

Ref: D. Ridikas, H.Safa, M.L.Giacri – Conceptual Study of Neutron Irradiator Driven By Accelerator – *7th Information Exchange Meeting on Actinide and Fission Product P&T (NEA/OCDE), Jeju, Korea, 14-16 Oct. 2002*

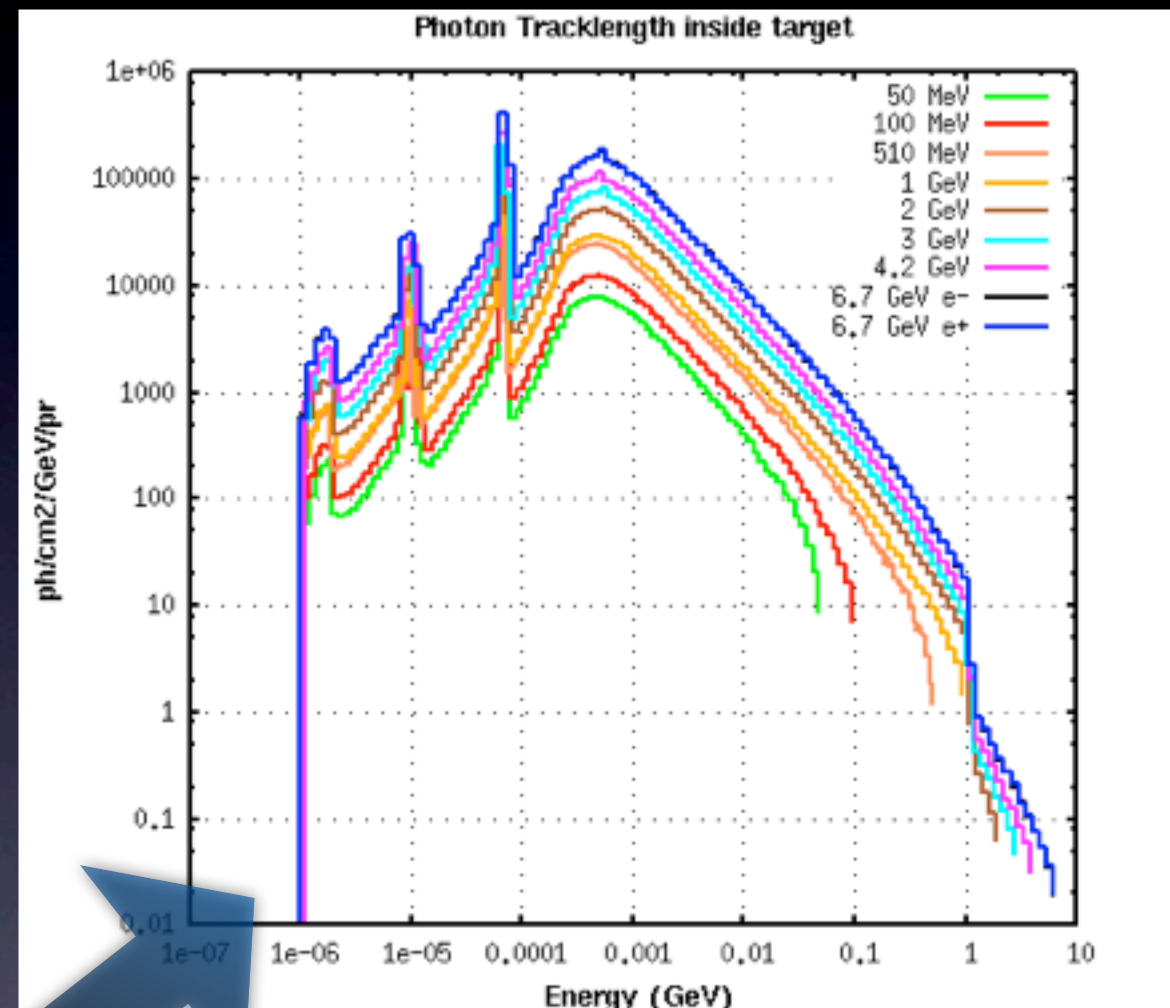
Physics Overview

Bremsstrahlung radiation:
High Energy Electrons on target

•More than 80% of electron interaction in the target produces Bremsstrahlung with continuos spectrum from 0 to E_e.

•The number of photons in a given energy interval is inversely proportional to the photon Energy

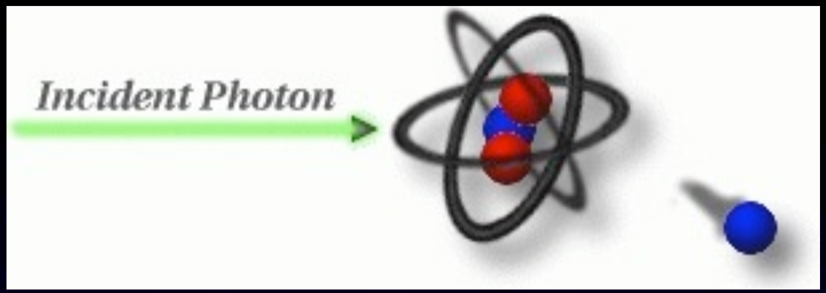
•These photons interact with the target nuclei, that are excited.These excited nuclei can emit neutron to come back to the fundamental status

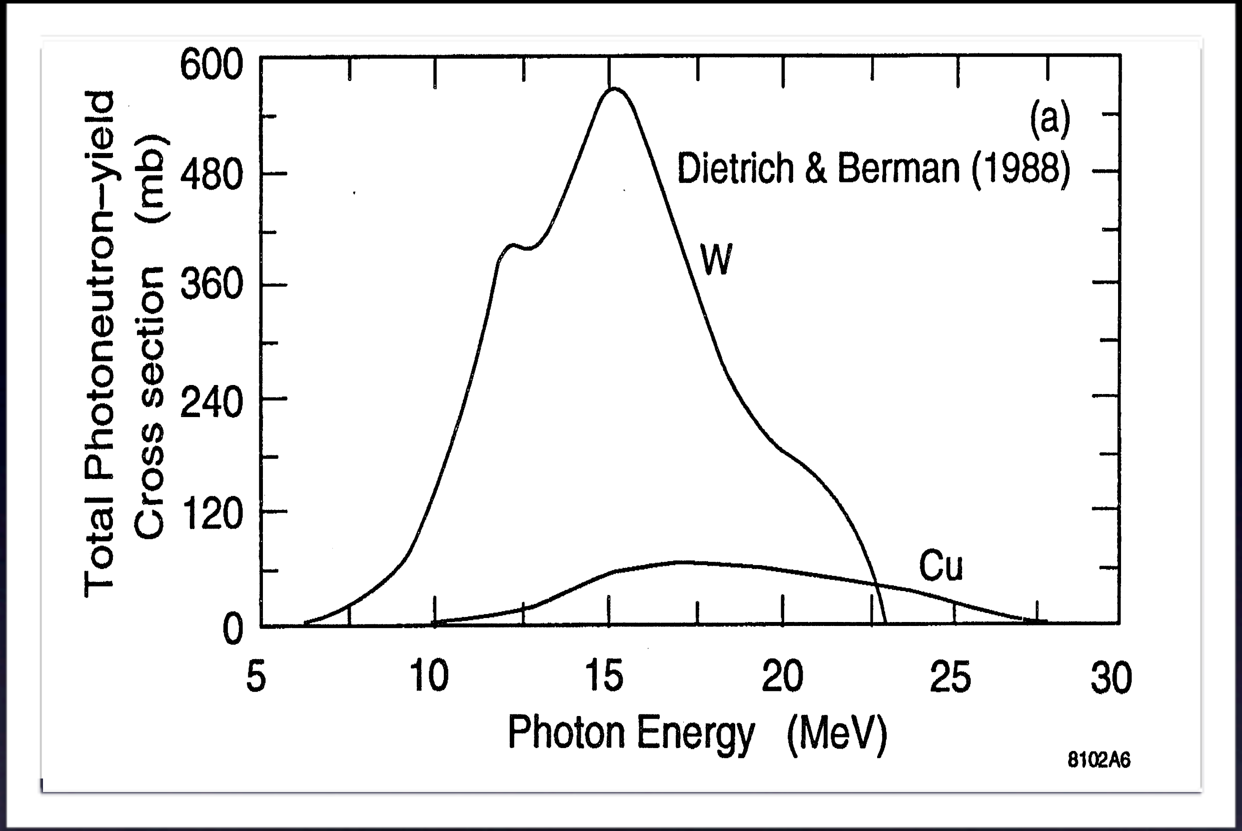


This cut is an artefact due to EMFCut card option for lower E of photon transport in order to save cpu Time

Bremsstrahlung Photon Spectrum in W Target

Photo-neutron and Proton Production



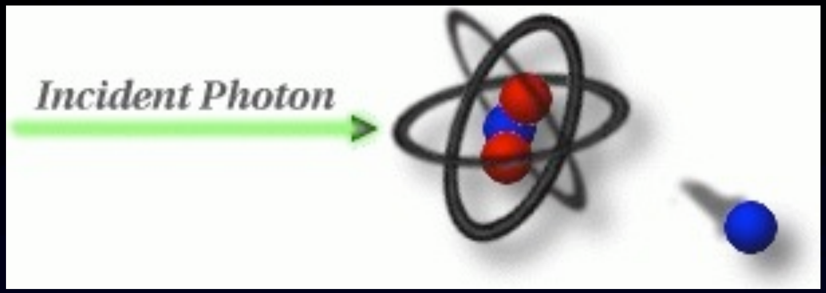


- It is a threshold reaction: energy greater than binding energy (5-15 MeV) is needed to release a neutron. Photoneutron physics is dominated by a giant resonance phenomena (GDR) in the energy range from few MeV up to few tens MeV
- Protons could be also emitted but the presence of large Coulomb barrier strongly represses this channel in heavy nuclei . Below Z=20 the proton yield is in general larger than the neutron yield, while the reverse is true in heavier elements

Three main mechanisms depending on E_γ

- Giant Dipole Resonance (E_γ <30 MeV)
- Quasi-Deuteron (E_γ >30 MeV)
- Intra-nuclear cascade: decays from produced photo-pions (E_γ >140 MeV)

Not only Neutrons.... what else ?:
Pions, Muons, Kaons,....



Pions are produced mainly by photo-production

$$\gamma p \rightarrow \pi^{+} n, \qquad \gamma n \rightarrow \pi^{-} n$$

Muons are produced by pion decays

$$\pi^{\pm} \rightarrow \mu^{\pm} + \nu_{\mu};\ m_{\pi} = 139.570 \text{ MeV}, \quad \tau = 2.6033 \times 10^{-8} \text{ s}, \ (99.99\ \%\ \text{branch}),$$
$$c\tau = 7.8045 \text{ m, and}$$

Muons are produced also by kaon decays

$$K^{\pm} \rightarrow \mu^{\pm} + \nu_{\mu};\ m_{K} = 493.677 \text{ MeV}, \quad \tau = 1.2384 \times 10^{-8} \text{ s}, \ (63.51\ \%\ \text{branch}),$$
$$c\tau = 3.713 \text{ m.}$$

Muons can also be produced by pair Bremsstrahlung if $E_{\gamma} > 211$ MeV

Fluka: Photonuclear implementation

Fluka is a single integrated code which can treat in a same run complete hadronics cascade (generation and transport of about 60 different particles) over an energy range spanning more than 14 orders of magnitude (up to 100 TeV). It is developed by INFN and CERN.

Photonuclear reactions have been implemented in 1994 opening the way toward a more accurate electron shielding design.

Fluka code deals with photonuclear reaction on the whole energy range.

Photon reactions with nuclei show features which are strongly changing with energy, in correspondence with very different interactions mechanism at the nuclear level. For modelling purpose 4 regions are distinguishable:

Giant Resonance
7<E<30 MeV

For medium and heavy nuclei, cross sections have been taken from the Atlas of Dietrich and Berman, Atomic Data and Nuclear Data Tables 38, 199 (1988), which provides cross section for neutron emission rather than total cross section: for heavy nuclei the two cross section are approximately equal

Quasi Deuteron Resonance
30<E<200MeV

Levinger absorption mechanism has been implemented

$$\sigma_{QD}(E_\gamma) = L\frac{NZ}{A}\sigma_D(E_\gamma)f(E_\gamma)$$

L is the Levinger constant given as function of A

Delta Resonance
E>140 MeV

Above the energy threshold per pion production, photonuclear interaction are characterized by excitation of Delta Resonance

High Energy Range
E>720 MeV

Above the delta resonance the Vector Meson Dominance model is used. The total cross section is obtained as :

$$\sigma_T = N\sigma_n + Z\sigma_p,$$

Photonuclear Cross Sections in Fluka

Taking advantage from:

- the new IAEA Photonuclear Data Library for 164 isotopes (2000)
- other evaluated data from various Laboratories (ORNL, LANL, CNDC, JAERI, KAERI, MSU)
- many experimental data make available via the EXFOR database

Un Important upgrade for the photonuclear physics was done in 2005: the Fluka Library was updated and completed:

At present a total cross section data for 190 nuclides have been inserted

190 nuclides data are tabulated :

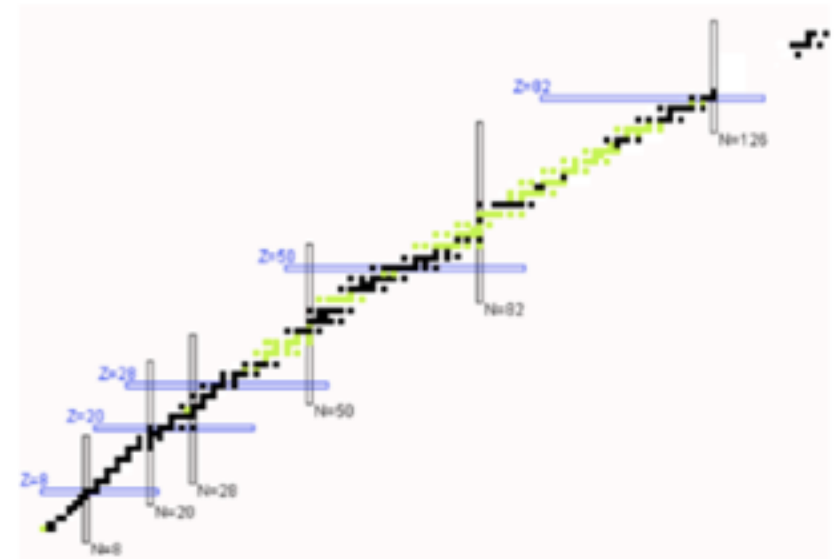


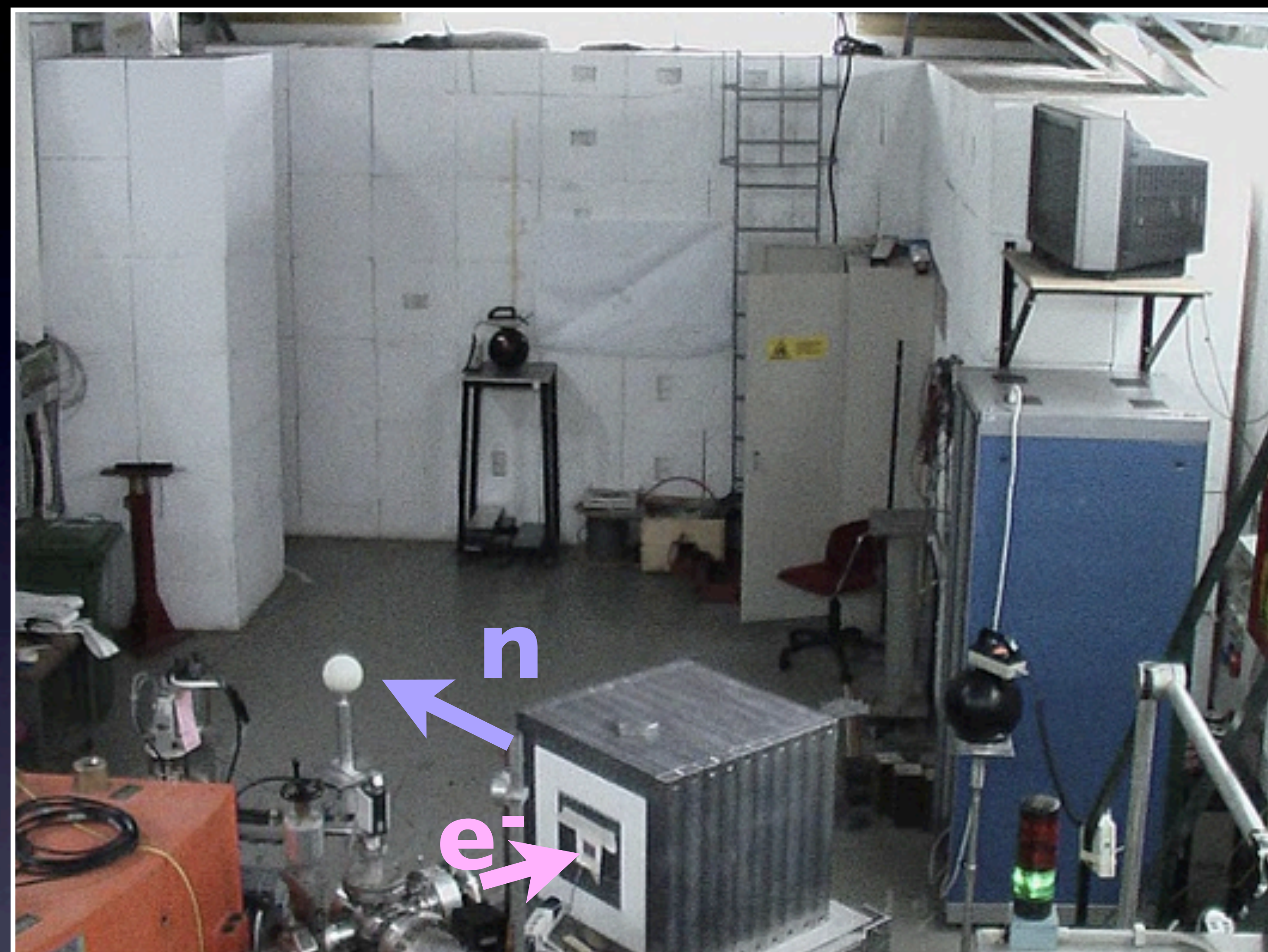
FIGURE 12. The 190 nuclides of the FLUKA GDR total cross section library (black squares). The grey squares indicate the stable nuclides not included in the library

If experimental cross sections are not available then Lorentz fits of the existing data are used:

- **If Z>29 then Lorentz parametrization is used (with published Lorentz parameters as peak energy, peak height, width) if they exist.** They are all those reported in the Atlas of Dietrich and Berman Atomic Data and Nuclear Data Tables 38, 199 (1988), except Pr, Au and Pb, for which we have used the parameters published in Berman et al., Phys. Rev. C36, 1286 (1987). otherwise
- **Lorentz parametrization with parametrized Lorentz parameters.** (it sounds funny, but Berman and Fultz (Rev. Mod. Phys. 47, 713 (1975) have published some general formulas giving the 3 Lorentz parameters as a function of A and Z.)

REFERENCE:

A. Fassò, A. Ferrari, P.R. Sala – Photonuclear Reactions in FLUKA: Cross Sections and Interaction Models – *AIP Conf. Proc. 769 (2005) pp.1303-1306*

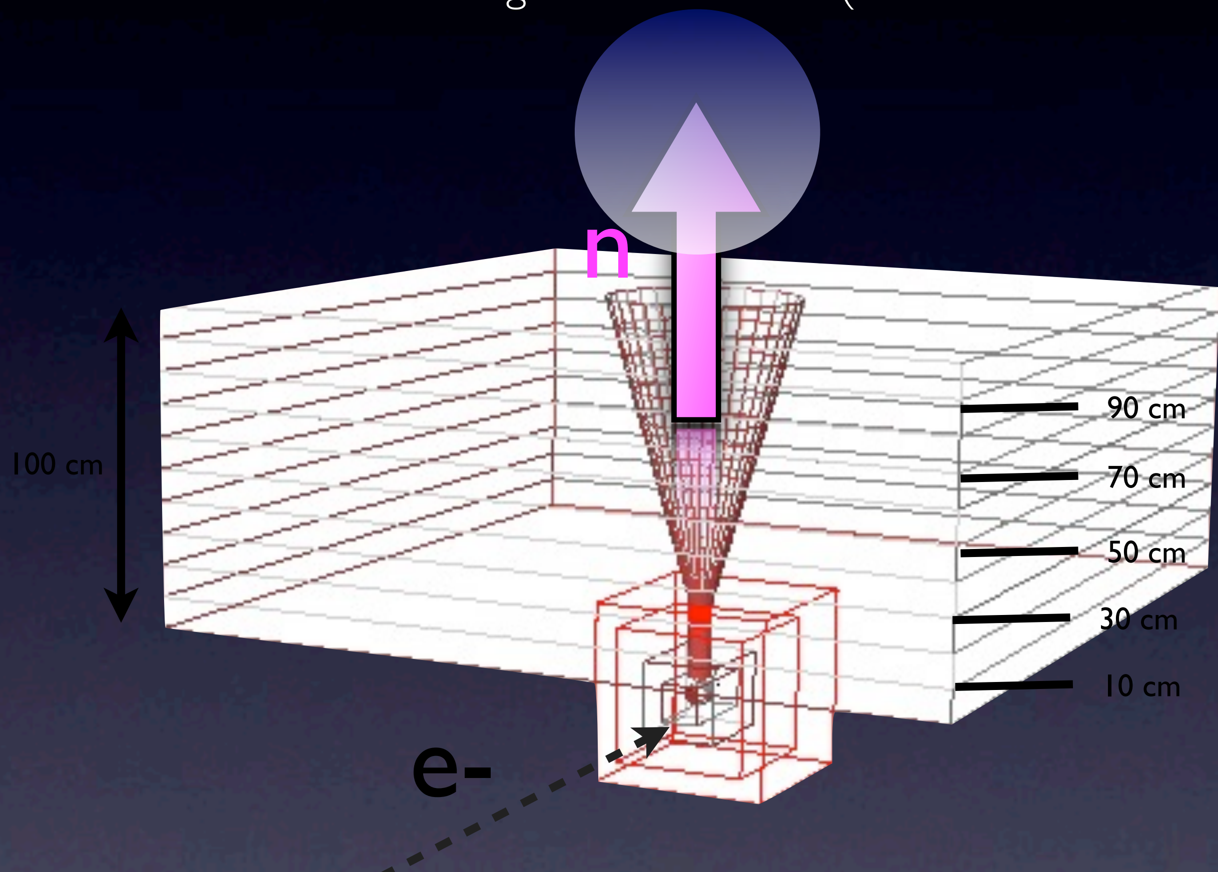


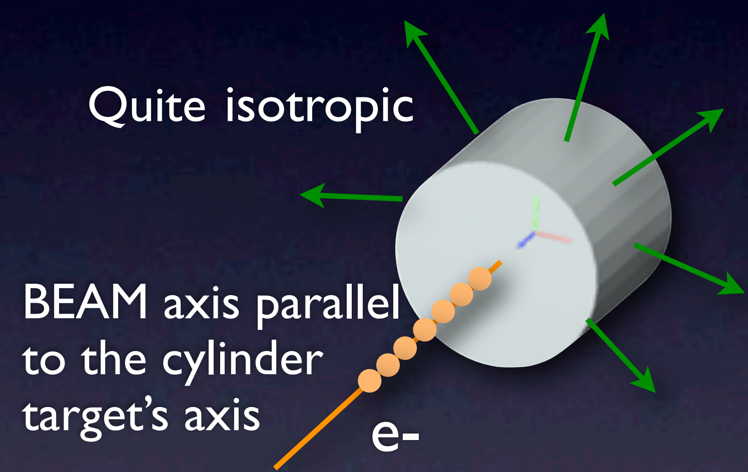
n@BTF:
Neutrons at DaΦne

Optimized DaΦne BTF target: neutron yield

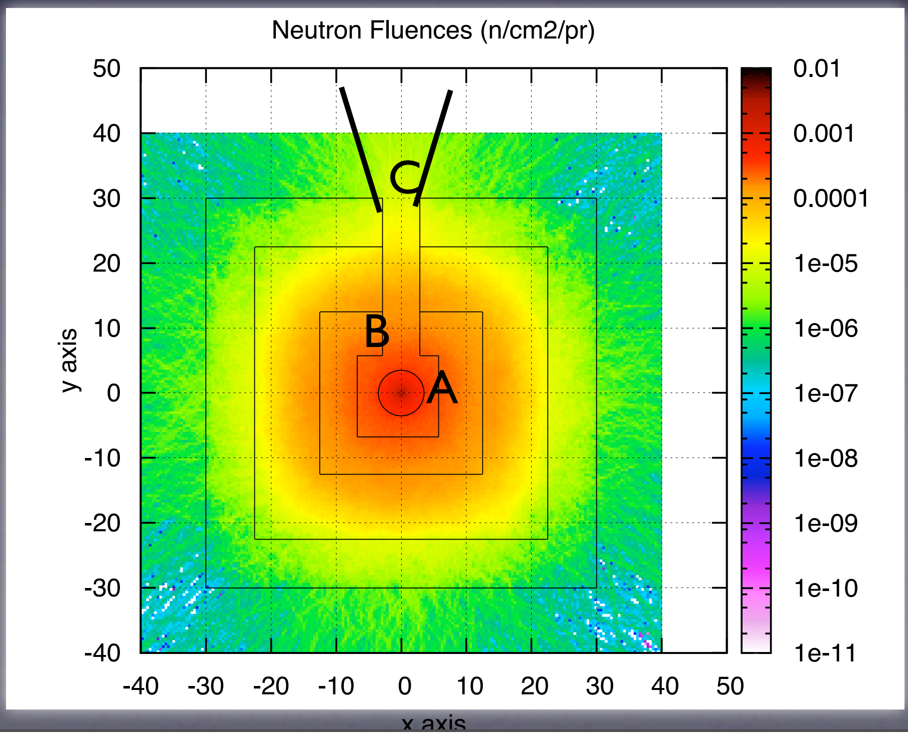
W cylinder R=35 mm L =60 mm(Z=74; ρ=19 g/cm3; X0=0.35 cm; MR=0.9 cm)

Optimization criterion: recursive process on calculating neutron fluence leaving the target, increasing linear dimensions (Rand L)
Best solution: the one for which, a new step would have affected only marginally the photoneutron yield (gain of only few %).
L from 15 to 20X0 gain less than 3% (so final choice 17X0 on the plateau); Same considerations: R final choice 10 X0.





n@BTF	Fluence [n/cm2/pr] (on all spectrum)	FLUX n/cm2/s (all spectrum)
exiting the target=ϕ1 (A)	1.0E-03 ±4%	5.00E+08
entering the shield=ϕ2 (B)	4.1E-04 ±4%	2.30E+08
leaving the shield=ϕ3 (C)	4.9E-05 ±4%	2.50E+07
1.5 m from shield=ϕ4 (D)	8.1E-07 ±4%	3.90E+05



Experimental setup and flux Measurement

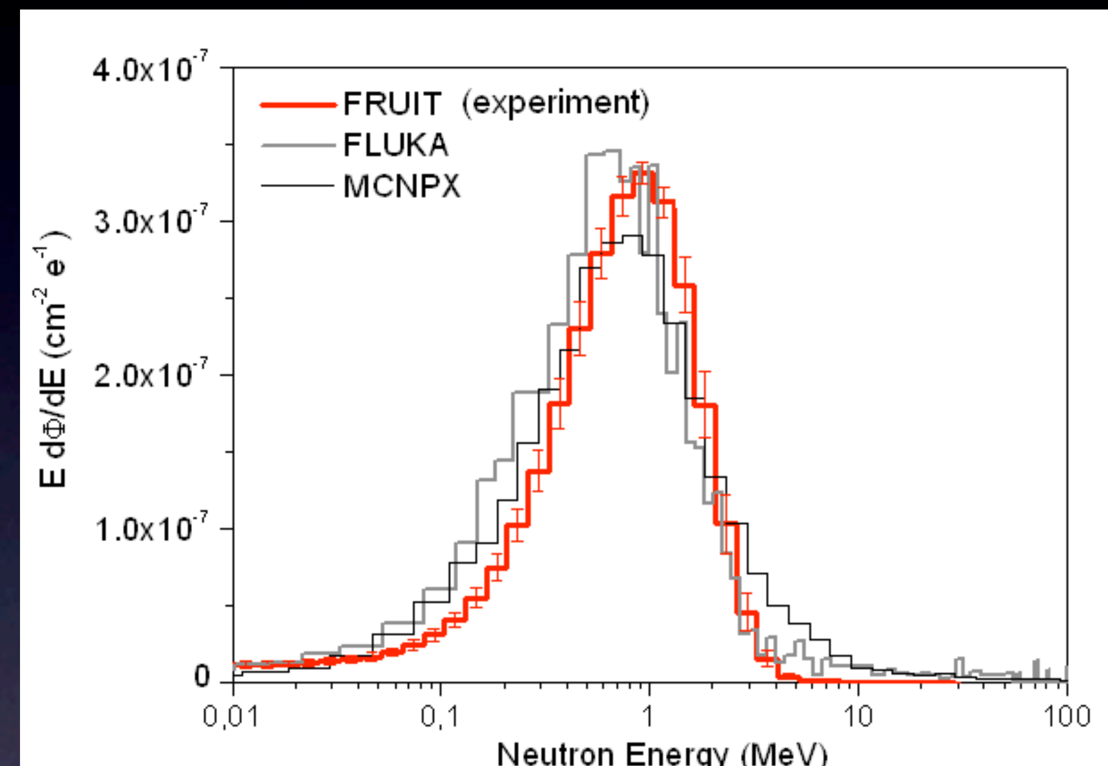
The flux above 10 keV is 6.53E-7 /cm2/pr

As expected, more than 80% is found around the Giant resonance (from 10 KeV up to 20 MeV)

Statistical uncertainty in the calculations less than 4%

Neutron Flux at 1.5m from shield = 4E+5 n/cm2/s corresponds to Equivalent Dose=45 mSv/h

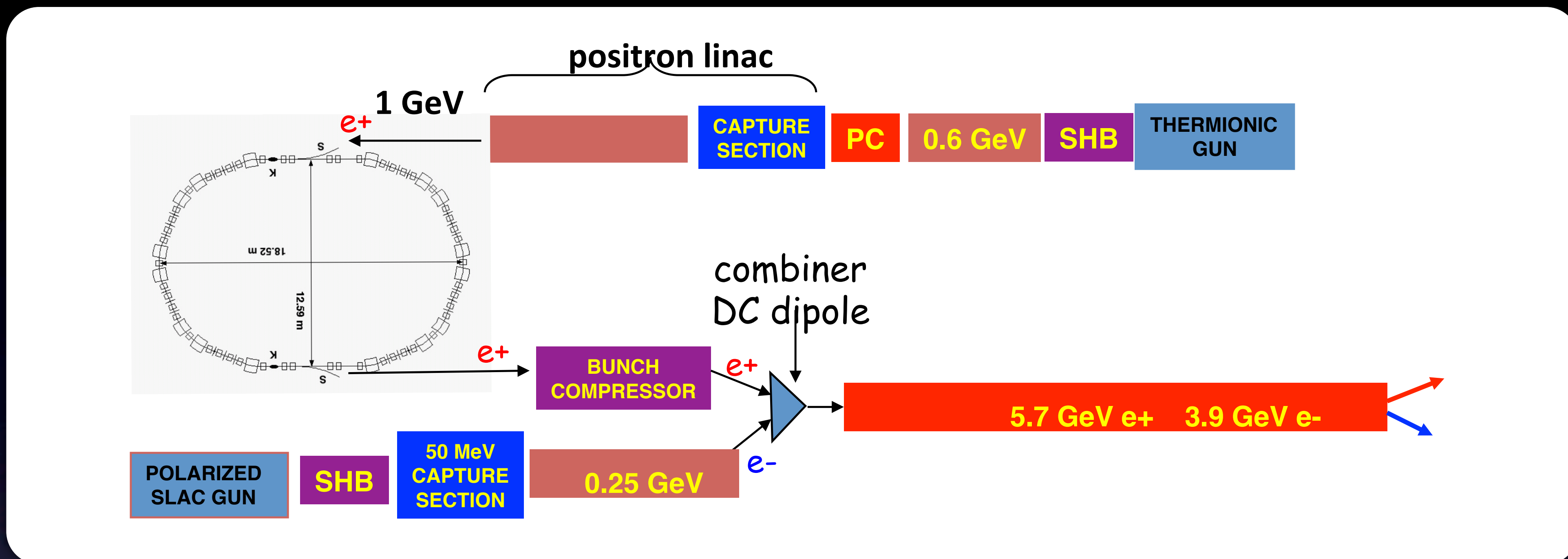
Lethargic (dϕ/dE)*E spectrum normalized to the total flux

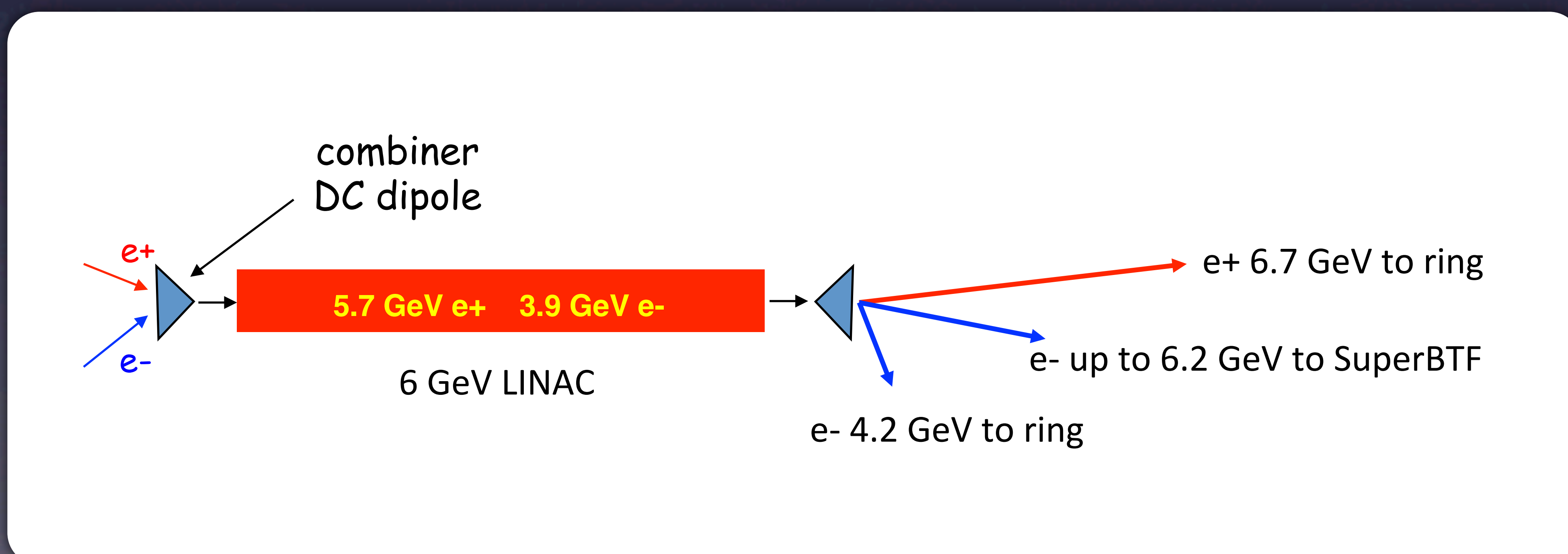


Total Neutron Flux per primary particle		
Experimental Measurement	FLUKA	MCNPX
8.04E-7 ±3%	**8.10E-7 ±4%**	**8.02E-07 ±0.2%**

From n@BTF toward more challenging and powerful tasks: the **SuperBTF**

SuperB layout

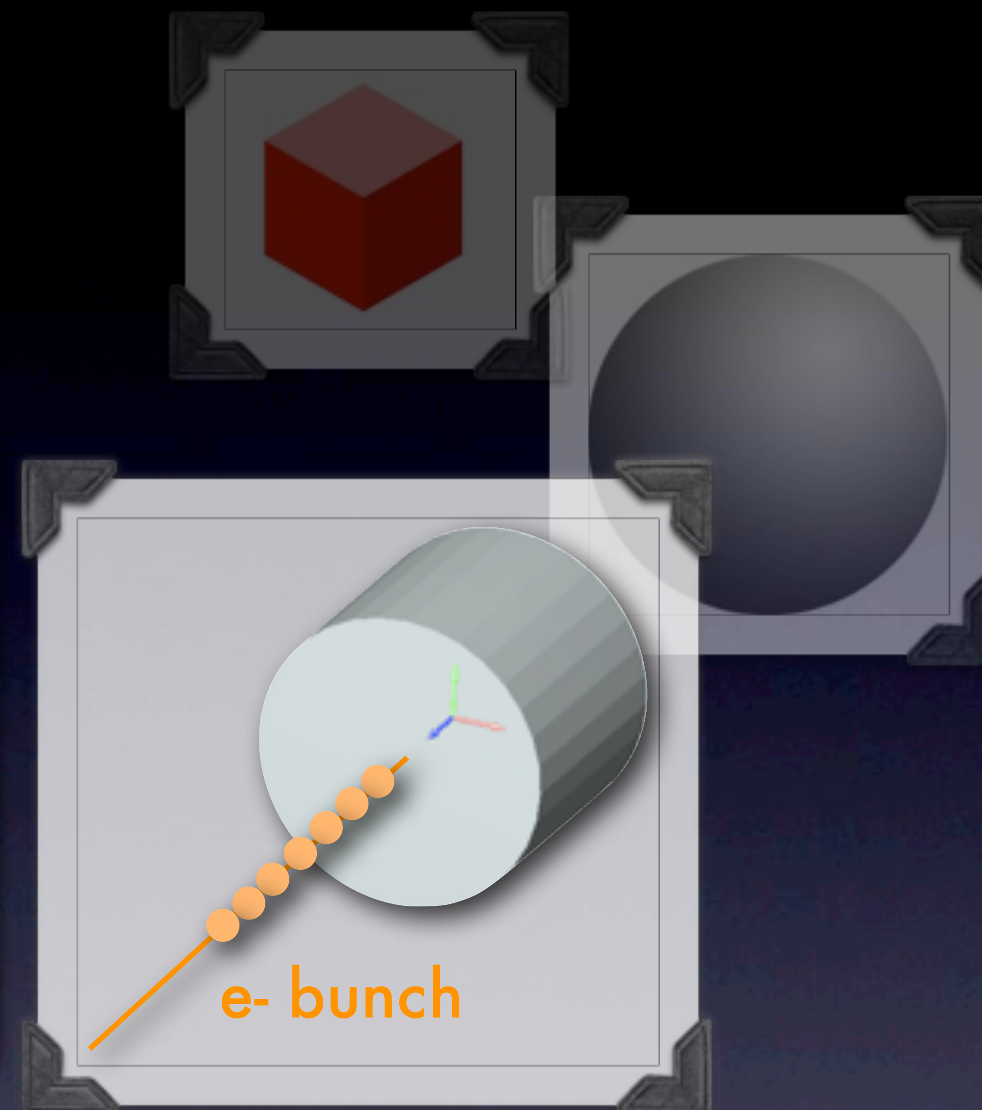




Target design strategy: performed activities

Relevant parameters of SuperB Main Rings for injection

	e^-	e^+
Energy (GeV) MC	4.18	6.70
Number of bunches	978	978
Particles/bunch Pred. Rate	6.6×10^{10}	5.1×10^{10}
Charge/bunch (nC)	10.6	8.2
Horizontal emittance (nm)	2.5	2.0
Vertical emittance (pm)	6.2	5.0
Relative energy spread	7.3×10^{-4}	6.4×10^{-4}
Lifetime (s)	269	254
Polarization	≈80%	0



- As starting point we used the DaΦne BTF optimized target. We identified these cases as BTF-like ones:
  - **W, Cu, U_238, Be , Al.**
- Thick target configurations for Al, Be, Cu have been simulated . Also Composed (W+Be+Au in progress)
- As primary beam we mainly used:
  - **4.18 GeV electron** for all the materials and target configuations
  - **6.2 GeV electrons and 6.7 GeV positrons in several cases (some of which are stil in progress)**

Hadron Yields from target (Ee=4.18 GeV)

	Material	Neutron	Proton	Pion+	Pion-	Muon+	Muon-	Kaon+	Kaon-
Thick Target	W(nat)	2.51	0.122	7.34E-03	0.013	3.80E-03	2.30E-04	3.75E-05	Negl
	U238	**3.7**	0.08	7.20E-03	**1.48E-02**	3.70E-03	2.40E-04	3.28E-05	Negl
	(TEST) Al	0.162	**0.156**	5.01E-03	5.39E-03	2.64E-03	1.01E-04	3.92E-06	Negl
	(Op)Cu	9.66E-01	**0.365**	**1.25E-02**	**1.48E-02**	**1.25E-02**	**6.68E-03**	**5.98E-05**	**9.80E-07**
Thin Target	Cu	0.21	0.08	3.20E-03	3.84E-03	8.60E-04	1.00E-04	2.80E-05	Negl
	Al	5.844-03	5.04E-03	5.16E-04	4.58E-04	1.01E-04	2.05E-05	Neg	Negl
	C	1.10E-03	1.20E-03	1.80E-04	1.97E-04	2.50E-05	1.00E-05	Negl	Negl
	Be	1.32E-03	5.51E-04	1.27E-04	1.39E-04	1.93E-05	1.04E-05	1.00E-05	Negl

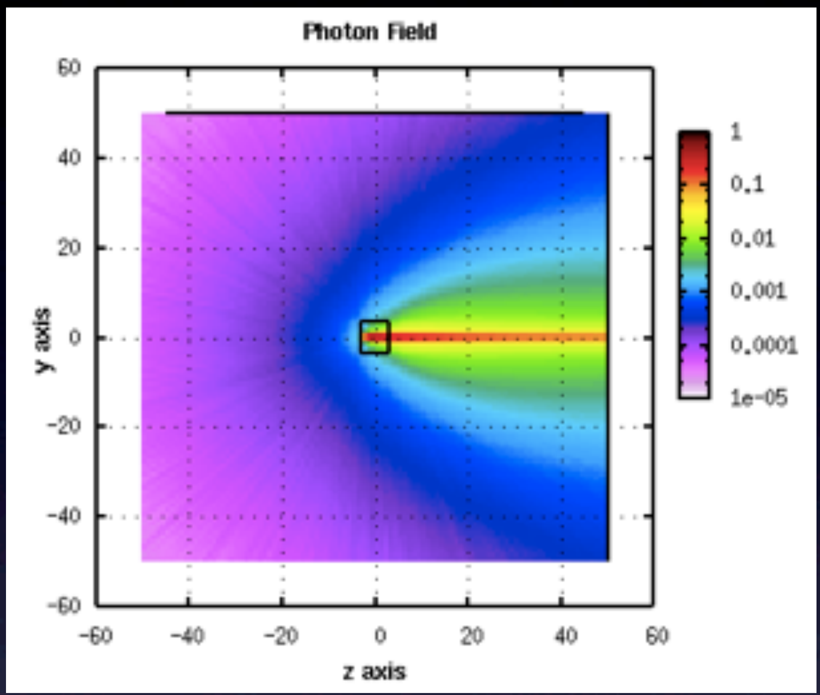
Legenda:
Blue cases have same geometry of W BTF target
Red ones have 10X0 radiation length depth (Thick target L> 10 X0)

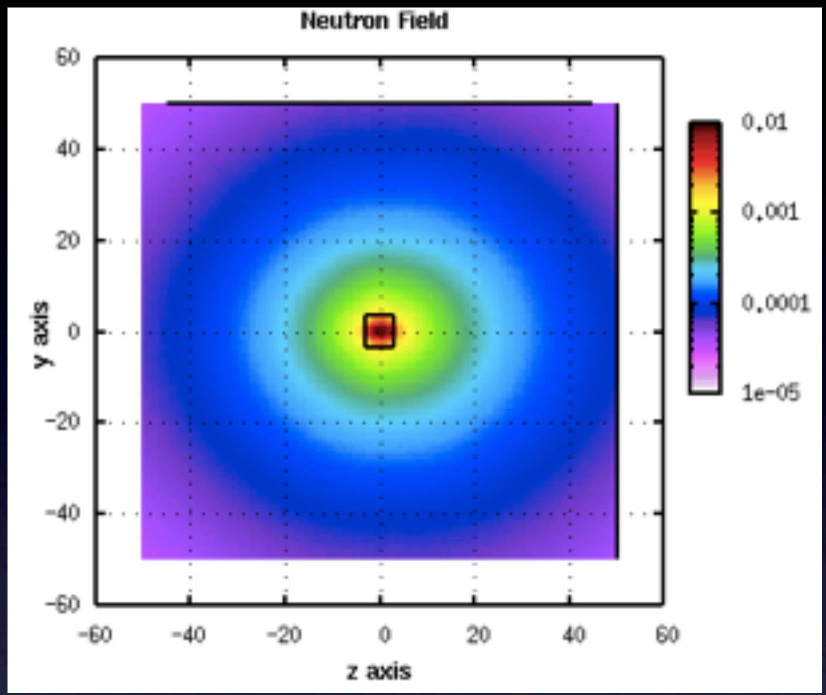
W-BTF: L=6cm, R=3.5 cm
Thick Al: L=70cm, R=12 cm
OpCu: L=14.30cm, R=7.15 cm

- These results have been obtained with a statistic of 5E+4 primary electrons and biasing techniques
- Values in columns are yield per primary
- Statistical error are < 5%
- We still need to have better statisctics and more severe simulations are running ...

Some considerations on neutron yield vs material and primary E

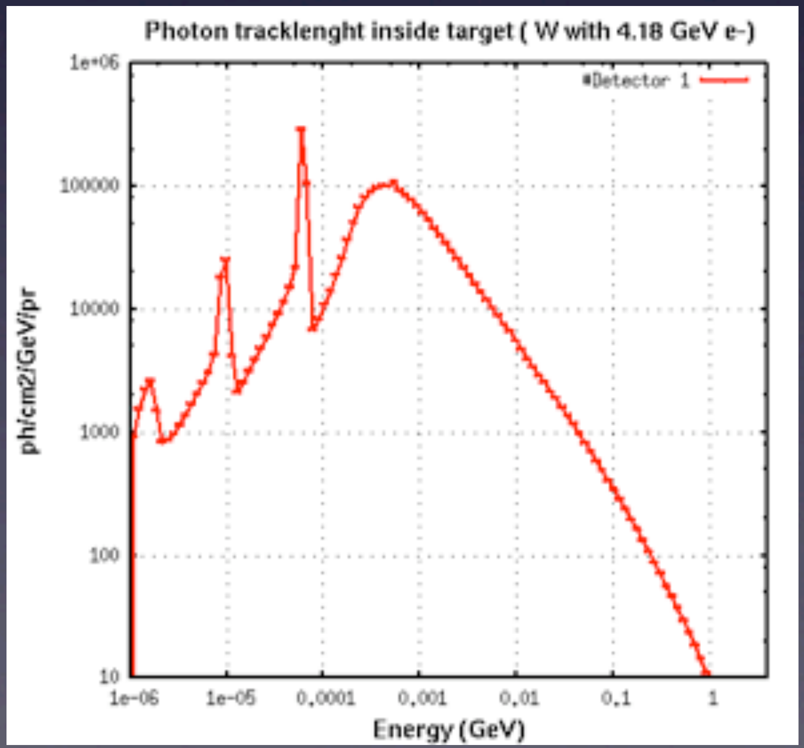
WBTF like(Ee = 4.18 GeV): Neutron

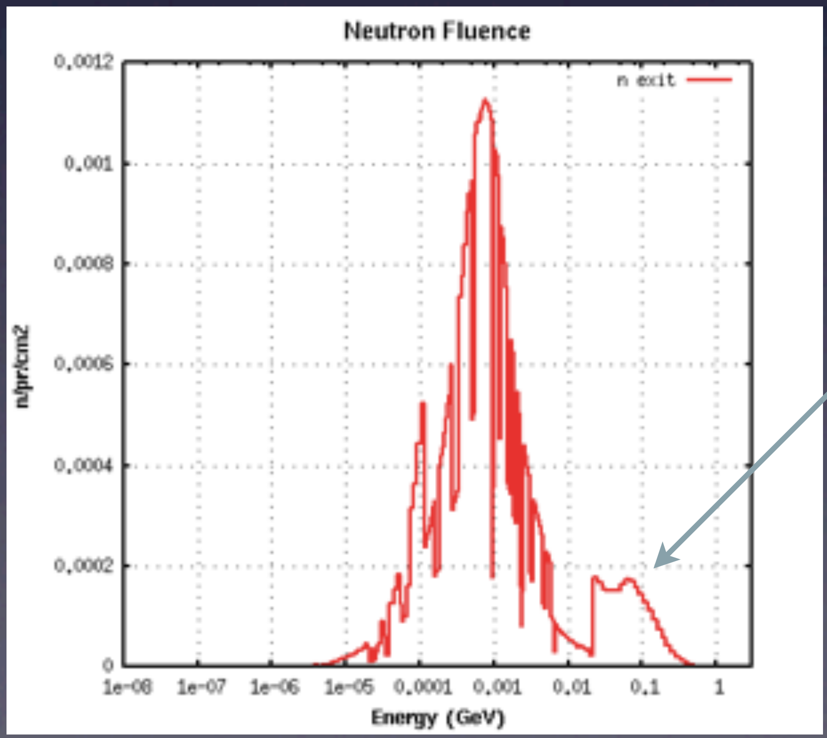




neutron balance per primary
(Ee=4.18 GeV)

neutron produced	neutron escaping	neutron absorbed
2.58	2.51	0.03



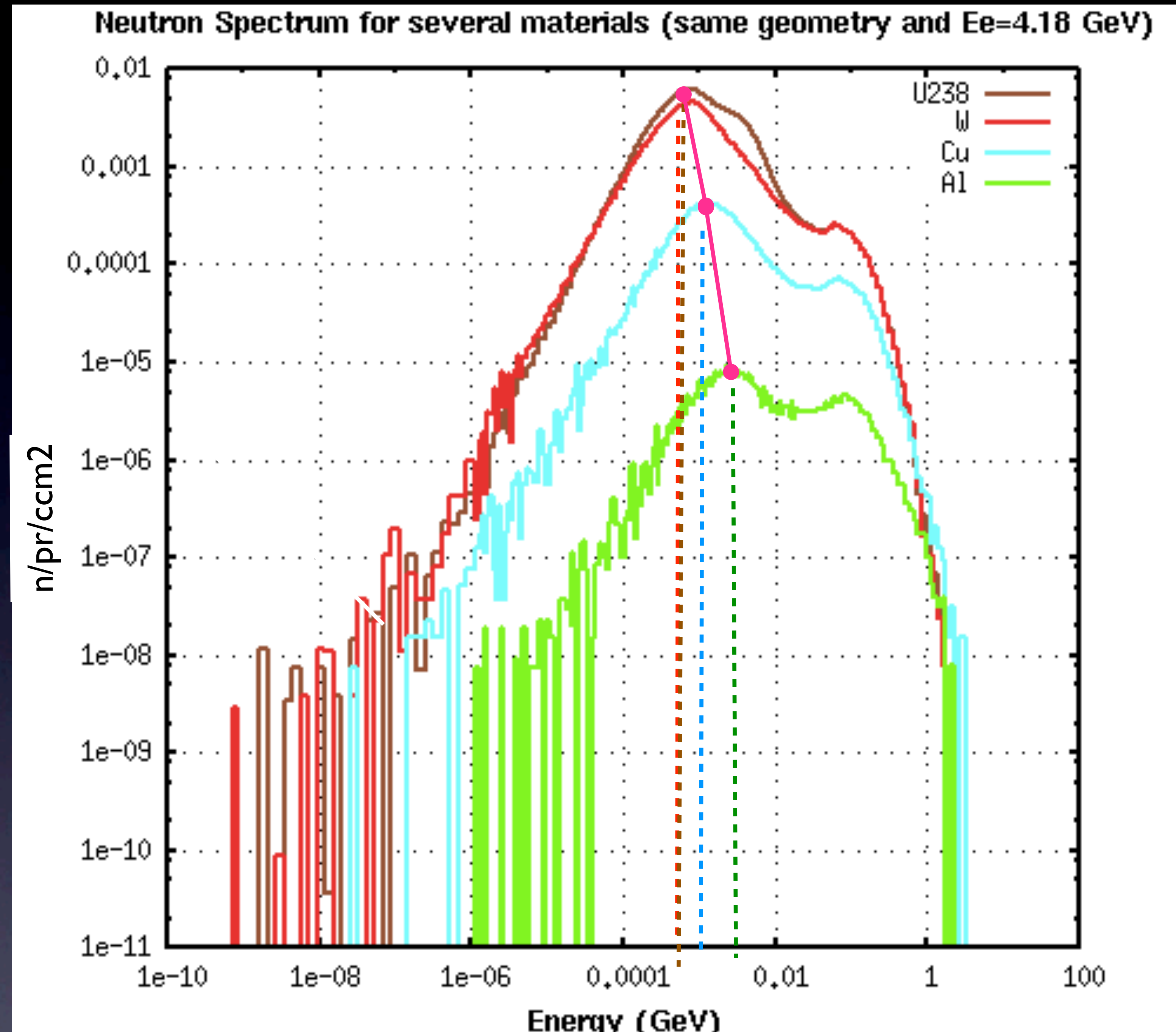


Important contribution at high energy (for E>100 MeV additional neutrons from bump pion reabsorption)

GDR Peak shift from U to Al

	Z	X0 (cm)	dens (g/cm3)
U238	92	0.32	18.95
W	74	0.35	19.3
Cu	29	1.43	8.96
Al	13	8.9	2.7

$R_M = 0.0265\, X_0\, (Z + 1.2)$

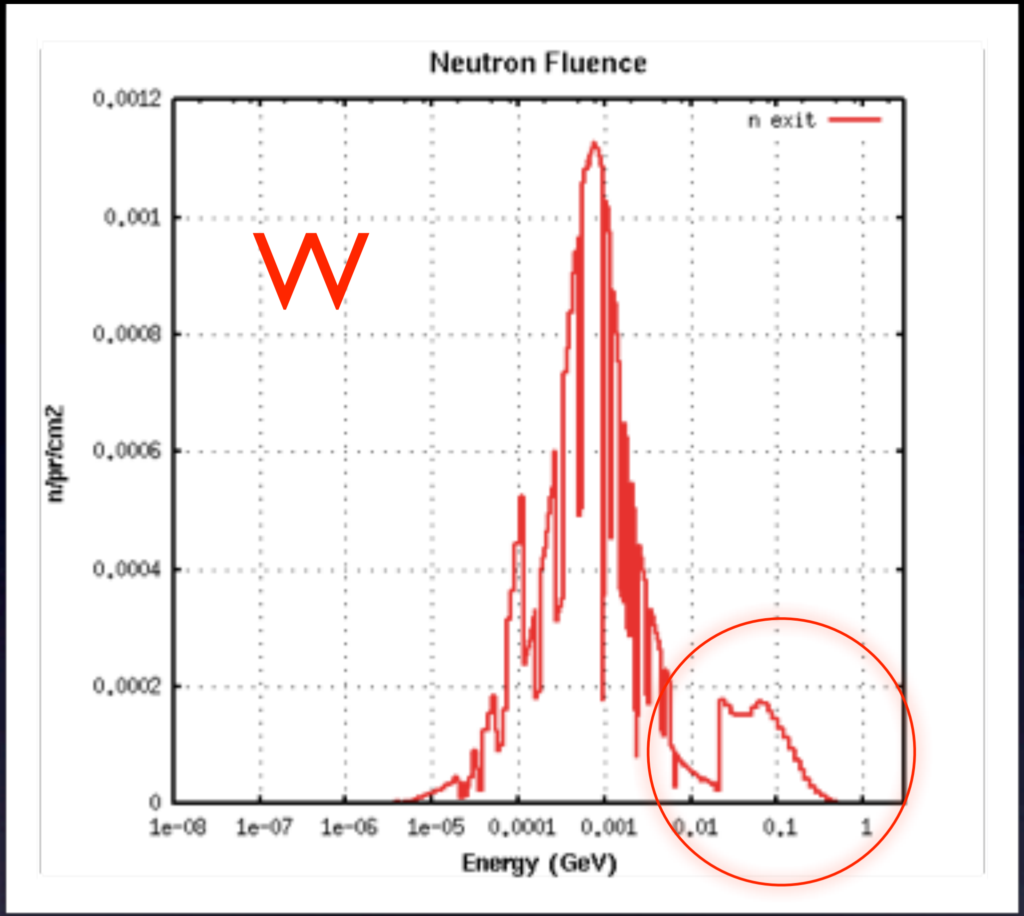


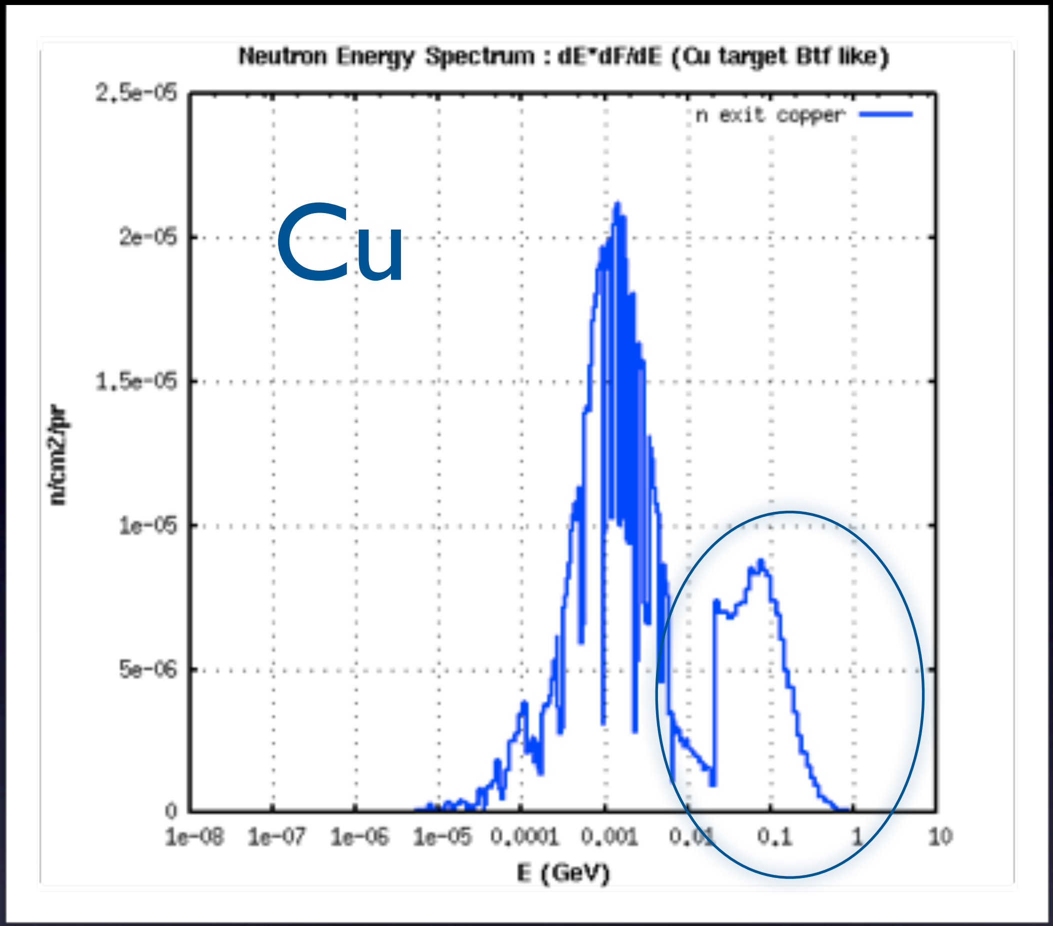
GDR peak shifts toward higher energies for lower atomic number material:

- ➡ U238 (peak)= 0.68 MeV
- ➡ W (peak)= 0.77 MeV
- ➡ Cu(peak)= 1.2 MeV
- ➡ AL (peak)= 2.3 MeV

The high energy neutron contribution is a more important fraction of the total yield for medium Z nuclei respect to high Z nuclei

Target BTF-like (4.18 GeV e-): neutron yield dependence on material (Cu vs W)





The high energy neutron contribution is a more important fraction of the total yield for medium Z nuclei respect to high Z nuclei

Neutron with E> 10 MeV are 6 % of total yield: 0.15 n/pr over 2.51 n/pr

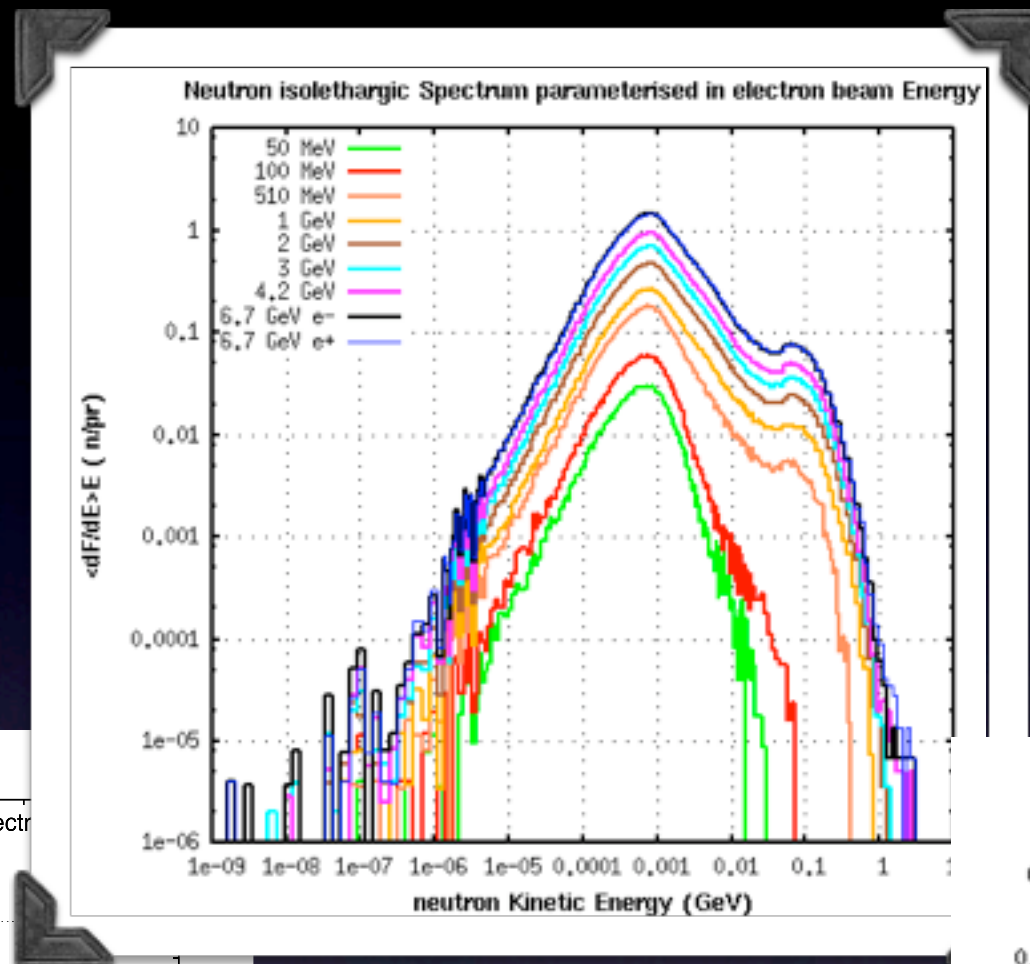
Neutron with E> 100 MeV are 0.84 % of total yield: 0.021 n/pr over 2.51 n/pr

Total Neutron fluence for Cu is 2 order of magnitude lower than W (fixed geometry and primary beam Energy)

Neutron with E> 10 MeV are 15 % of total yield 0.032 n/pr ove 0.21n/pr

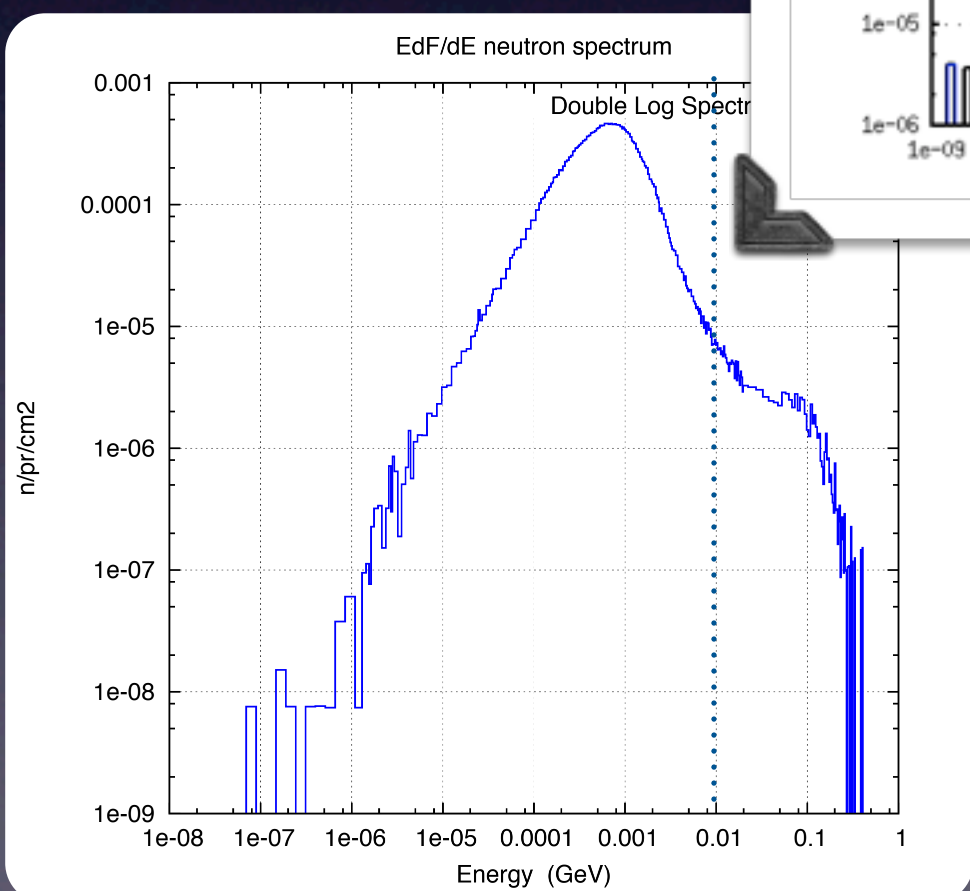
Neutron with E> 100MeV are 3 % of total yield 0.0063 n/pr ove 0.21n/pr

Neutron Spectrum dependence on primary energy beam



Neutrons with E > 10 MeV: less than 3 % of total yield

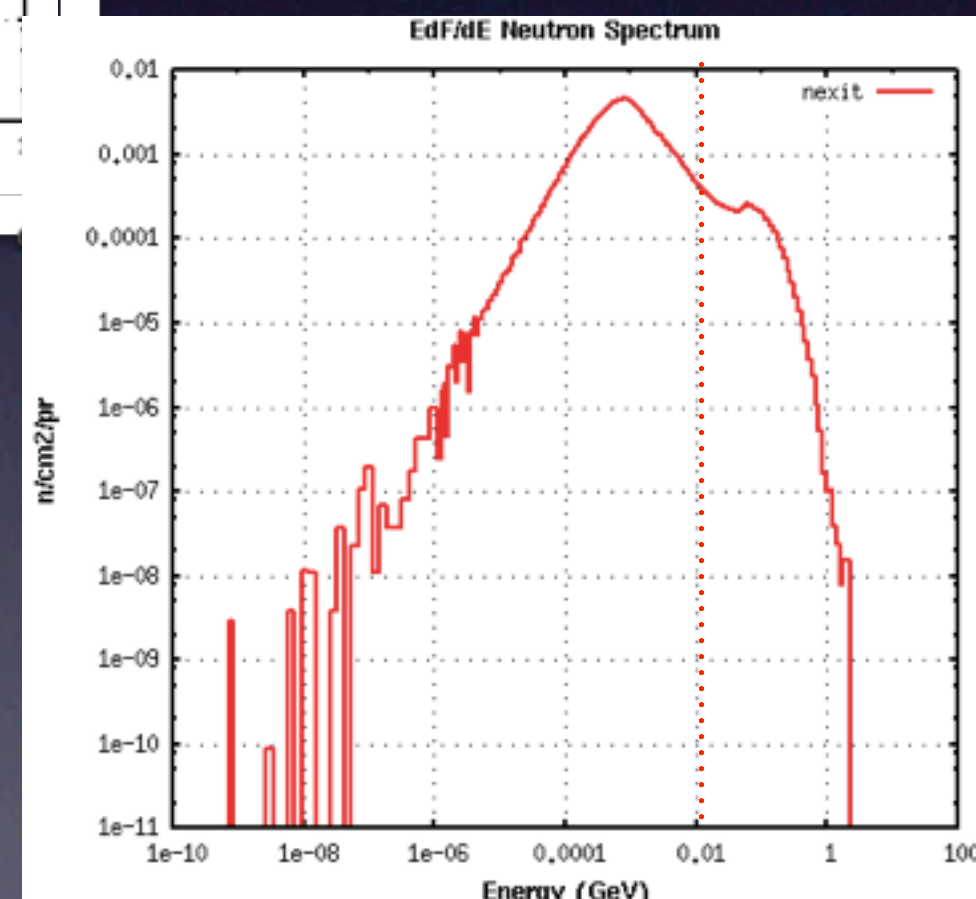
W-n@BTF : 510MeV e-



Neutrons produced in the target per primary electron: 0.2

Neutrons with E > 10 MeV: 6.5% of total yield

W-BTF like:4.18GeV e-



Neutrons produced in the target per primary electron: 2.23

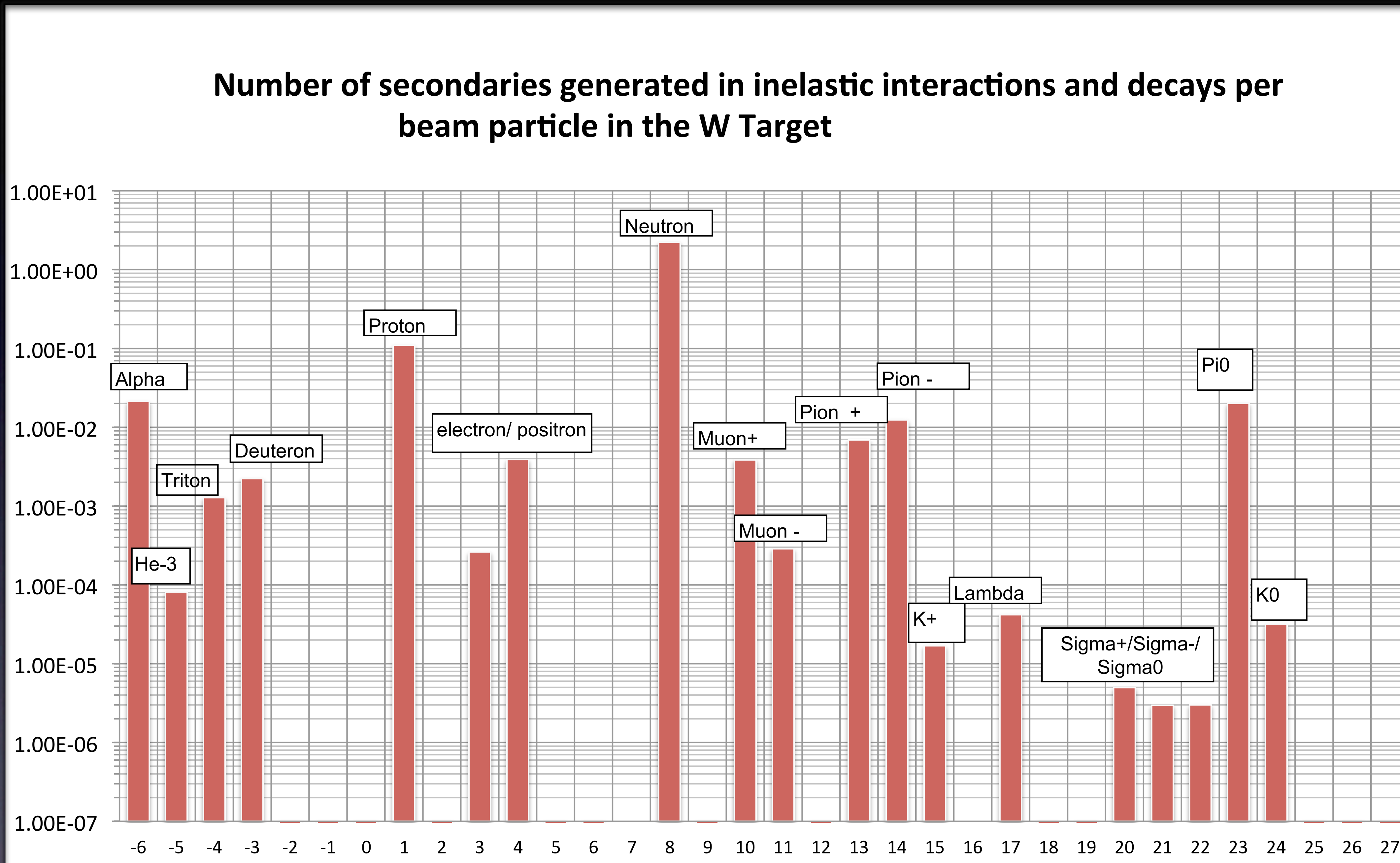
Measured Neutrons at DaΦNe BTF and Predicted for SuperBTF

Optimized W BTF Target	DaΦne (1E+10 e-/pulse & 50 Hz injection rate)		IF **SuperBTF Minimum rate (6.6E+10)*0.04 e-/pulse (5.1E+10)*0.04 e+/pulse Supposing 50 Hz injection**	
	Value per Primary @510 MeV	**Present Max Rate**	**Value per Primary @ 4.18 GeV**	**Minimum Expected Rate**
Neutron source (integrated on all the solid angle and all E spectrum)	0.21 [n]	1.E+11 [n/s]	2.51 [n]	3.28E+11 [n/s]
Flux around the target (integrated on all the solid angle and all E spectrum)	1. E-3 [n/cm2/pr]	5.E+8 [n/cm2/s]	1.2E-02 [n/cm2/pr]	1.6 E+9 [n/cm2/s]
Flux at 1.5 m along an extraction line	8.1 E-7 [n/cm2/pr]	3.9 E+5 [n/cm2/s]	----	---

n@BTF Measurements **

** Ref: Submitted NIM-A
"Experimental and numerical characterization of the neutron field produced in the n@BTF Frascati photo-neutron source"

What about other secondary hadrons: W target and OpCu cases



WBTF like (Ee-=4.18 GeV)

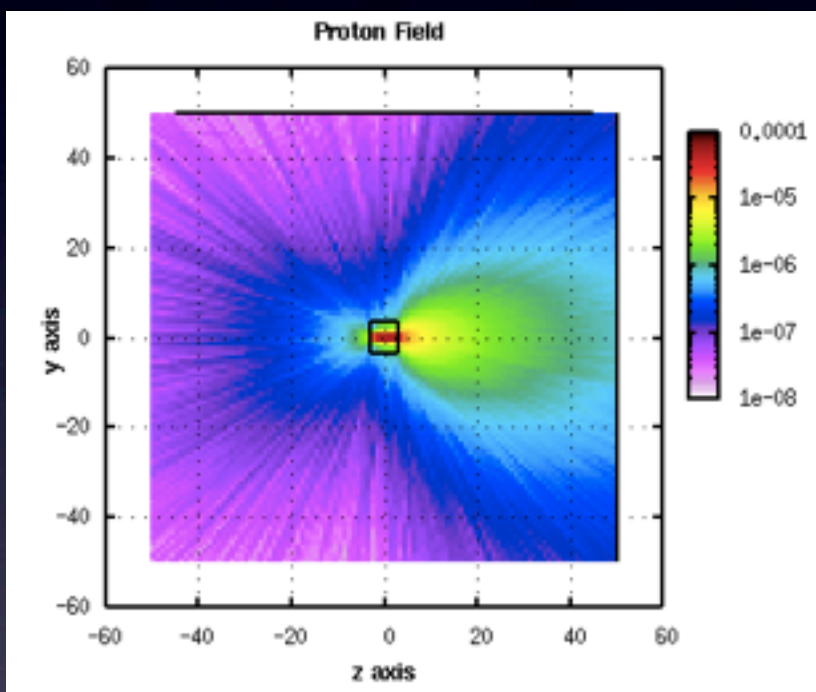
WBTF like (Ee = 4.18 GeV): proton spatial distribution

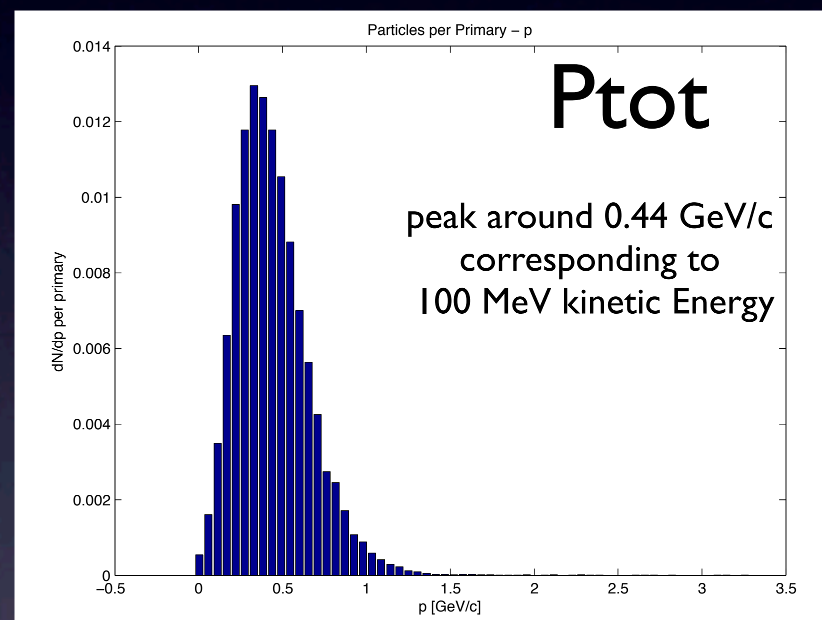
proton yield per primary e-

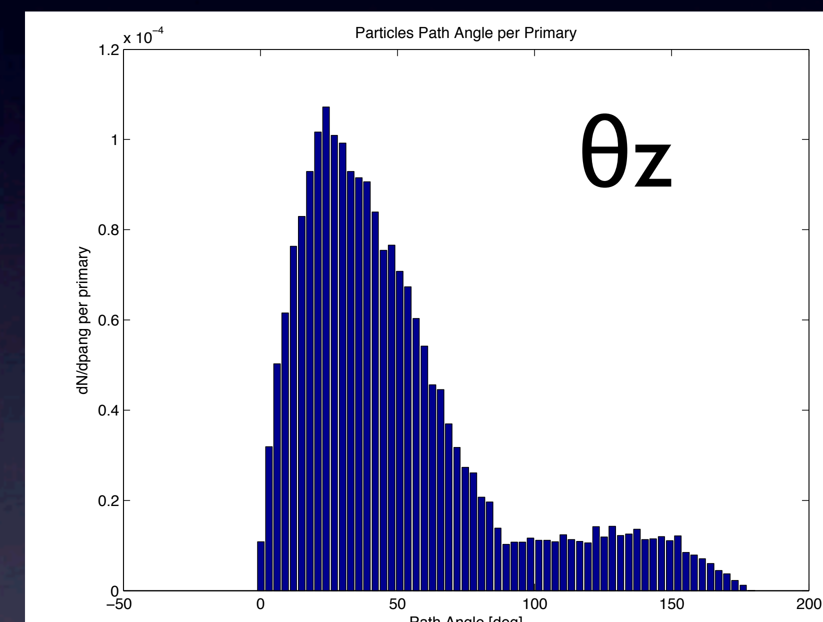
p	1.22E-01

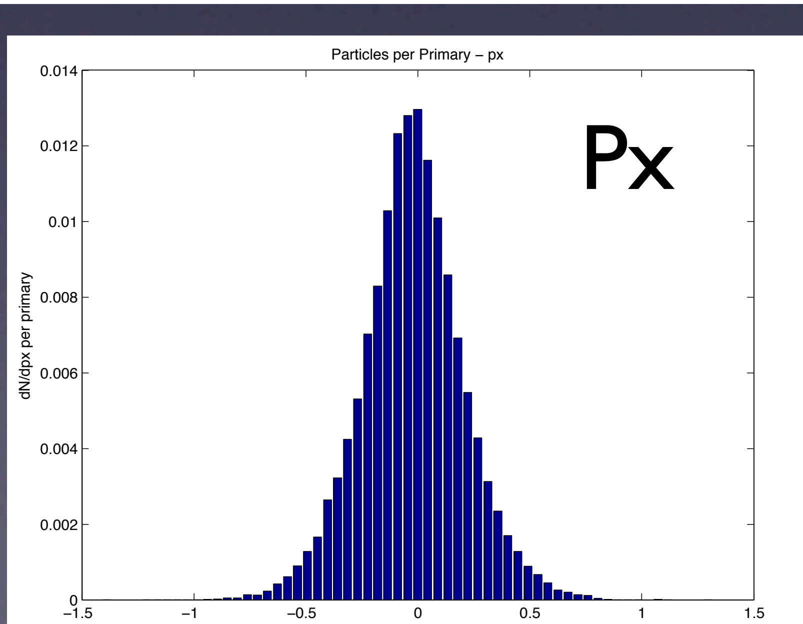
Protons are emitted mostly forward in a cone
less than 20 deg around Z
A n important contribution of backscattering is also present

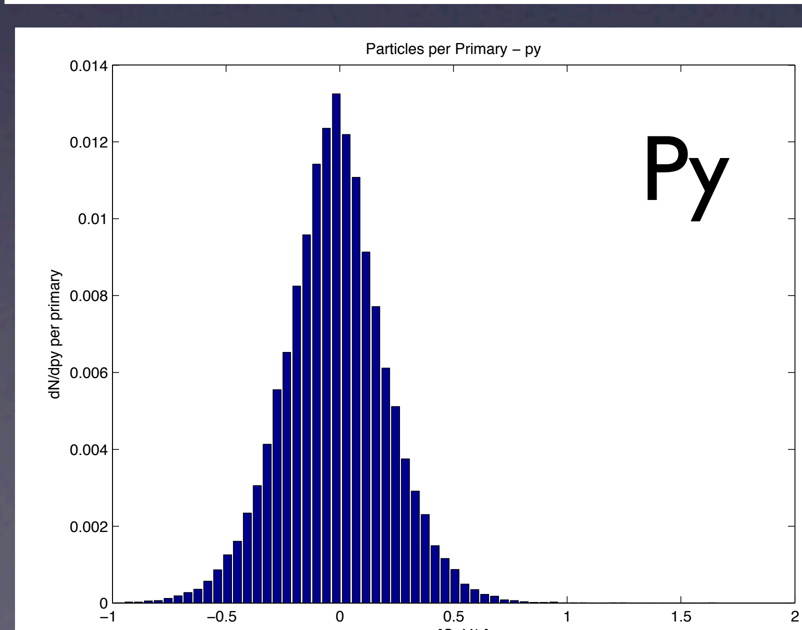
Angular Distribution respect to the incident beam direction

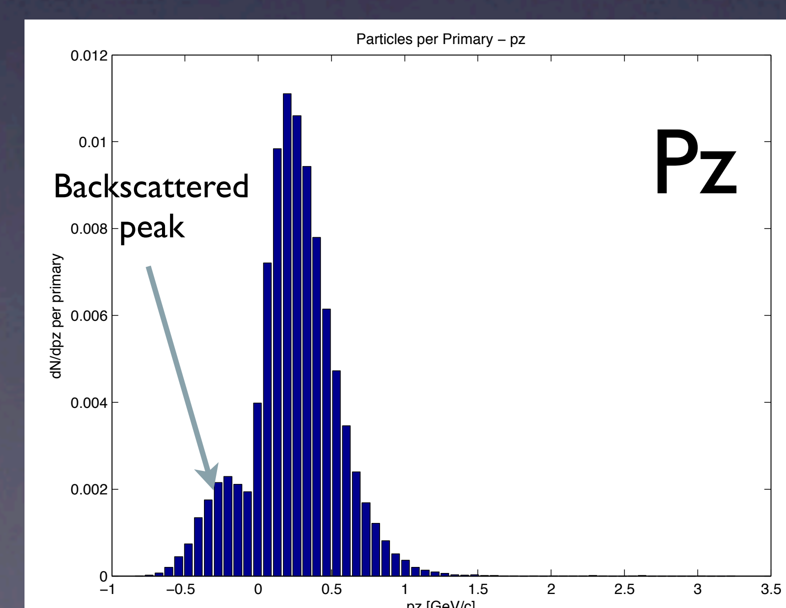




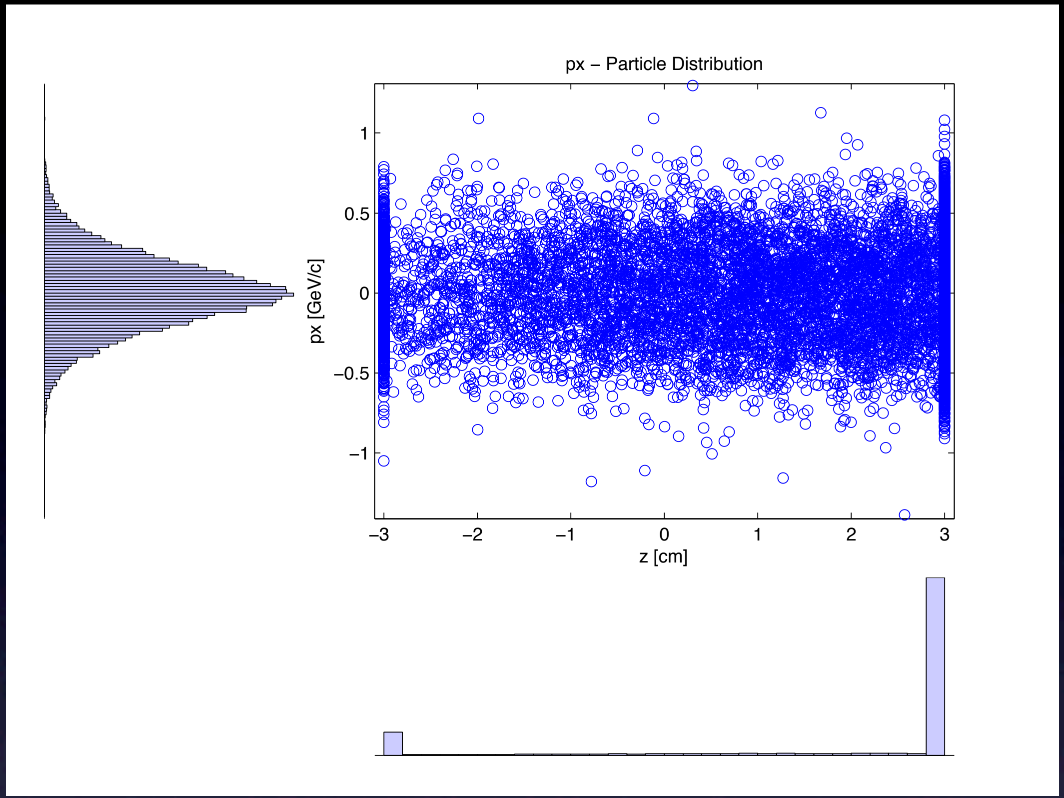


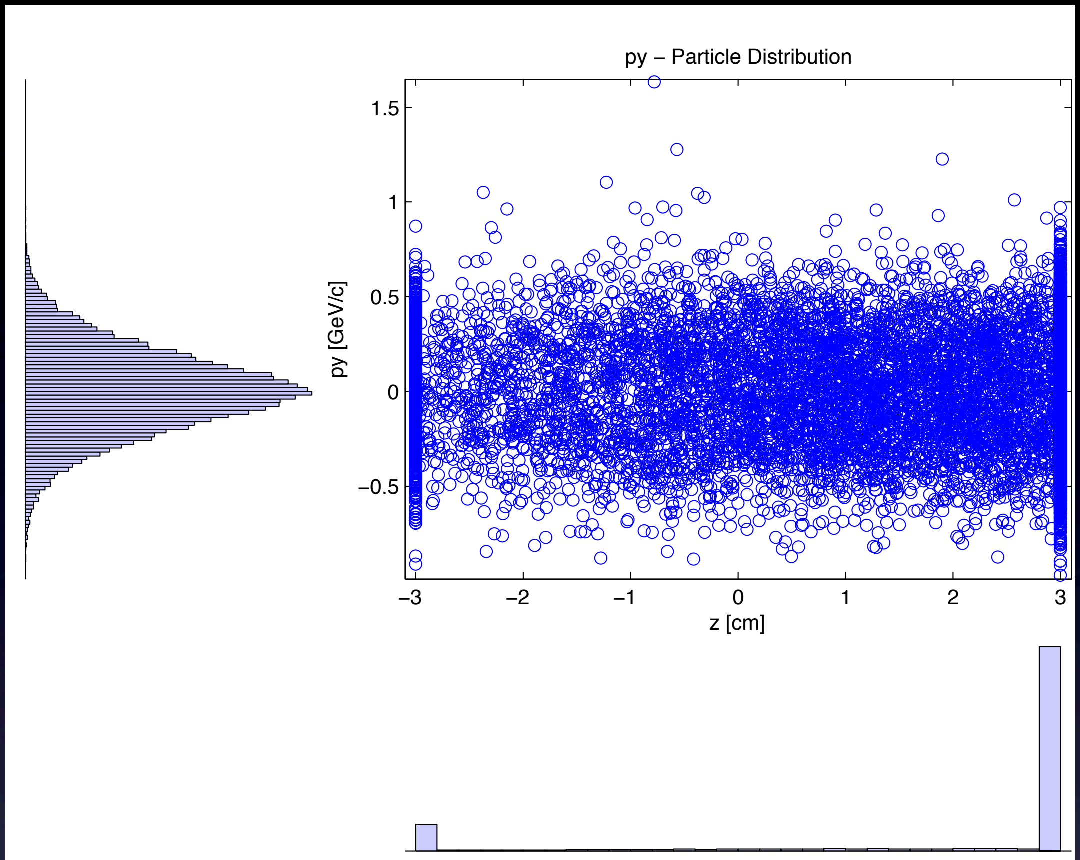


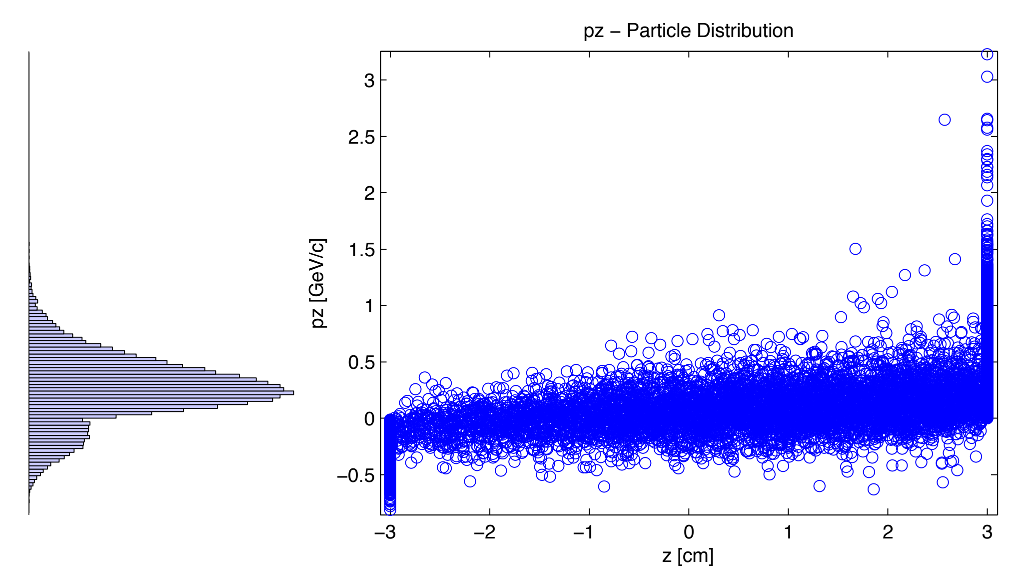




WBTF like (Ee = 4.18 GeV): proton

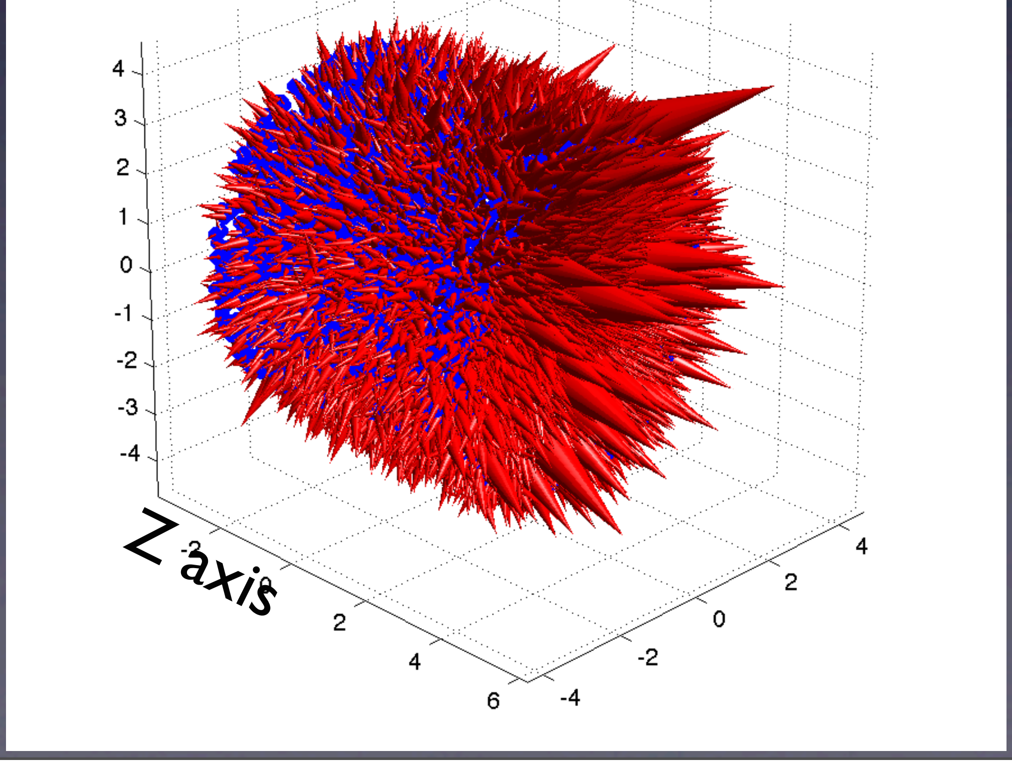




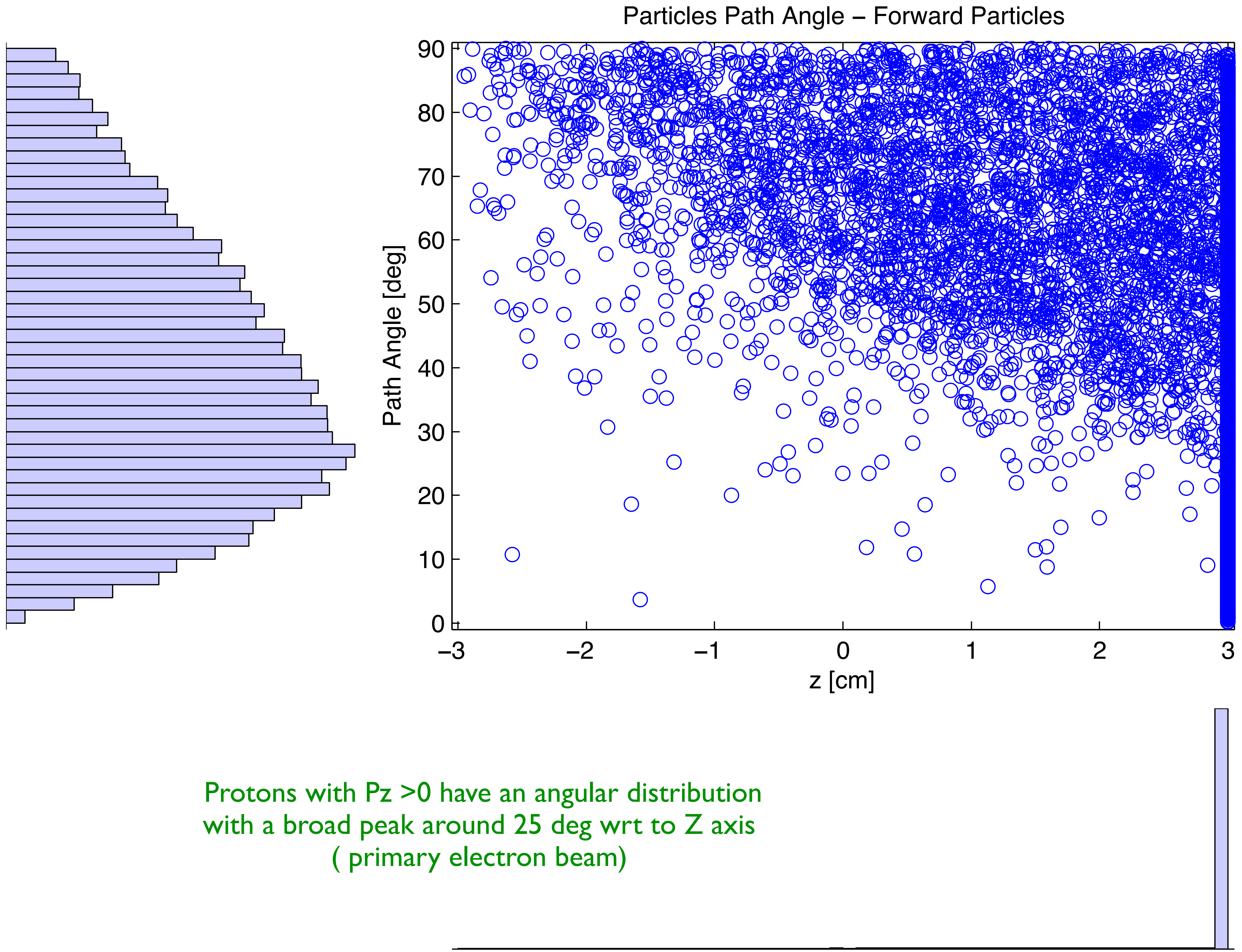


The higher momentum protons are escaping mainly from the forward flat surface

The lenght of the vector is proportional to the modulus of Momentum



WBTF like (Ee = 4.18 GeV): proton



Protons with Pz >0 have an angular distribution
with a broad peak around 25 deg wrt to Z axis
(primary electron beam)

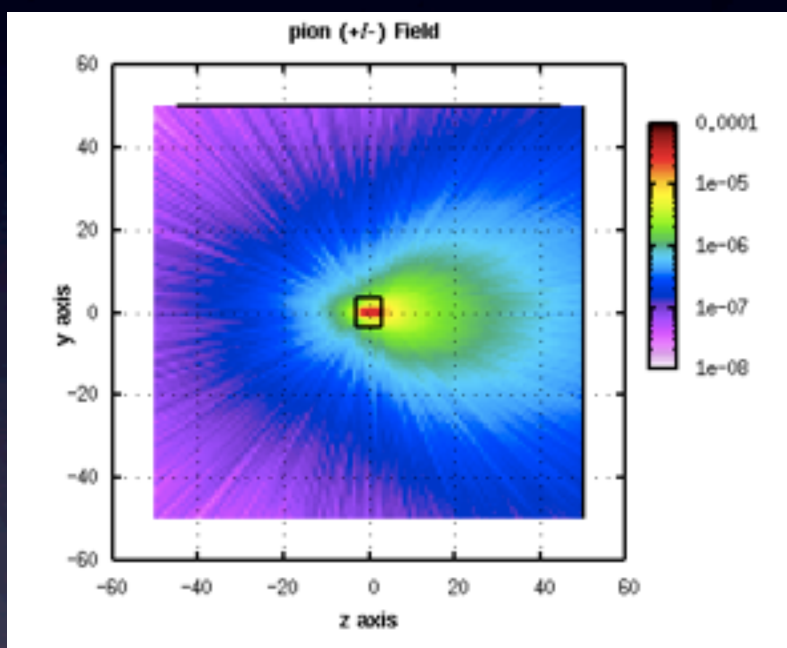
WBTF like (Ee = 4.18 GeV): pion+ spatial distribution

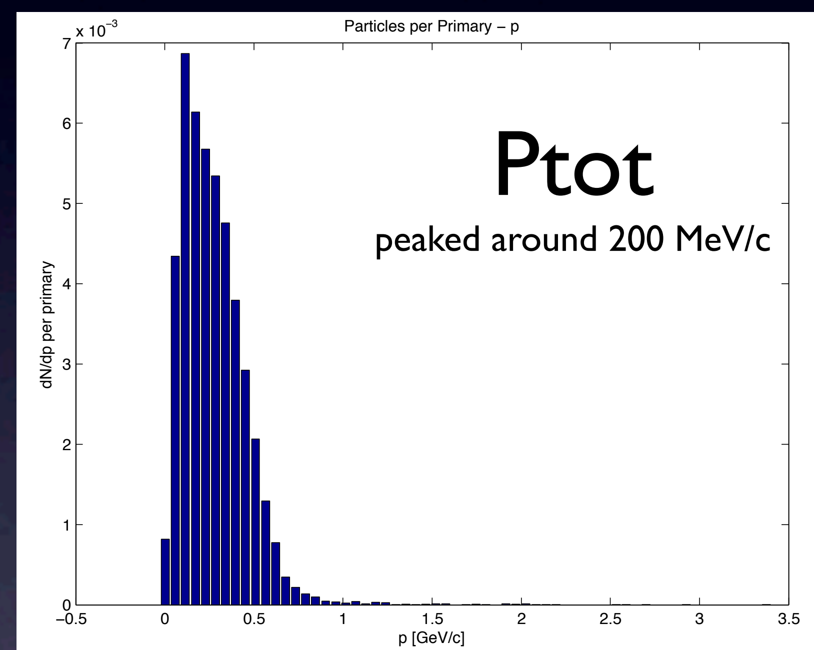
pion+ yield per primary e-

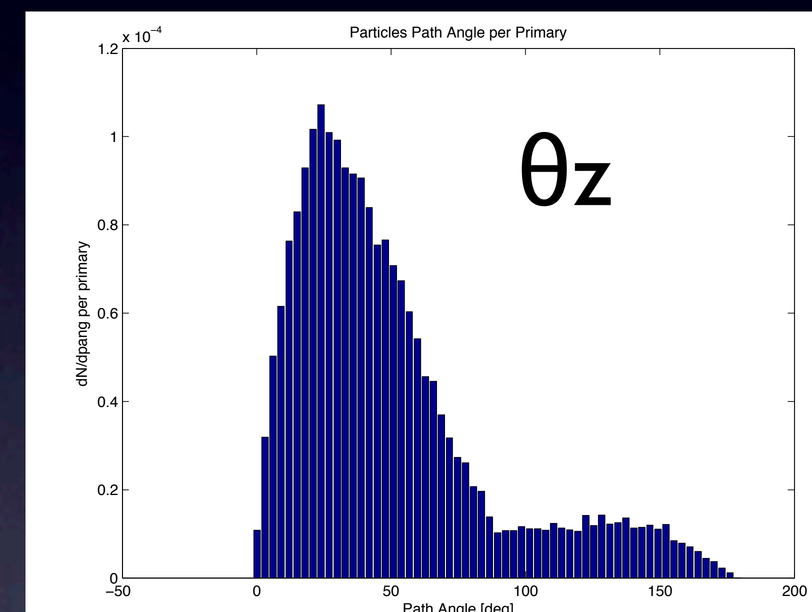
pion+	1.30E-02

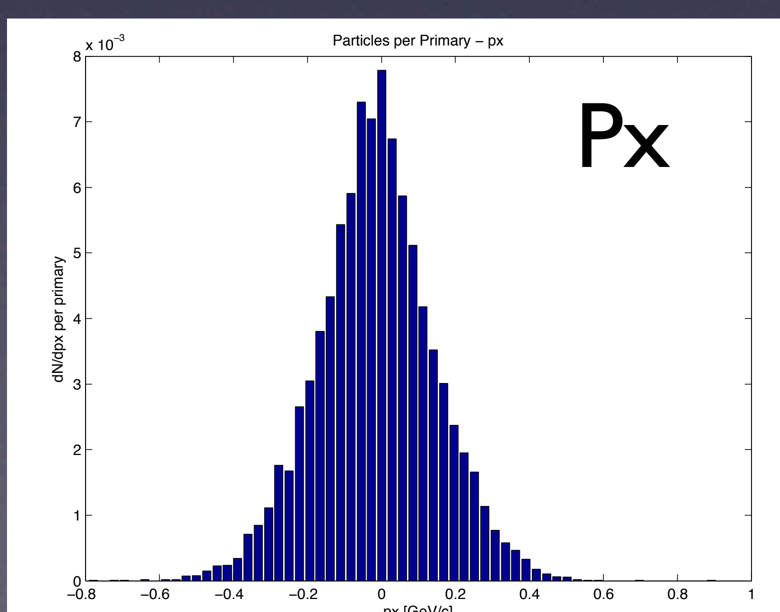
Pion+ are emitted mostly forward

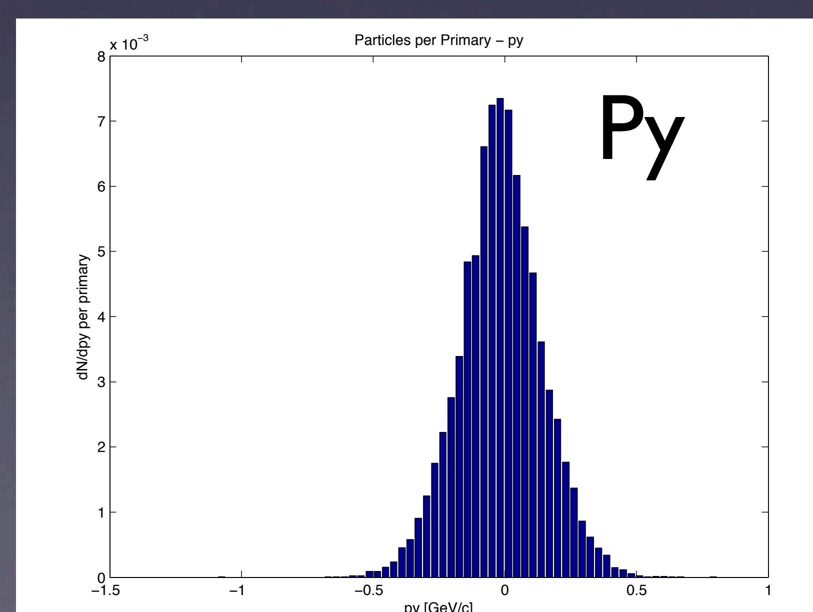
Angular Distribtution respect to the incident beam direction

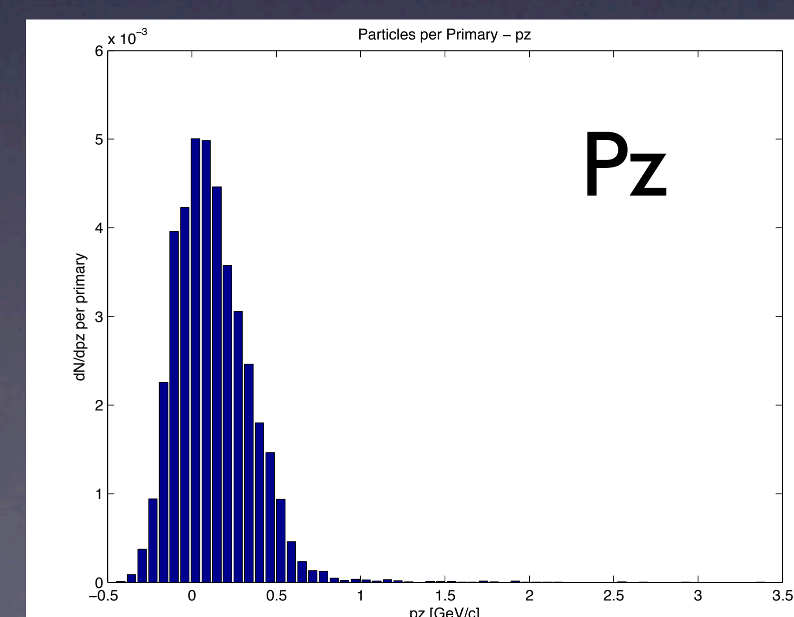




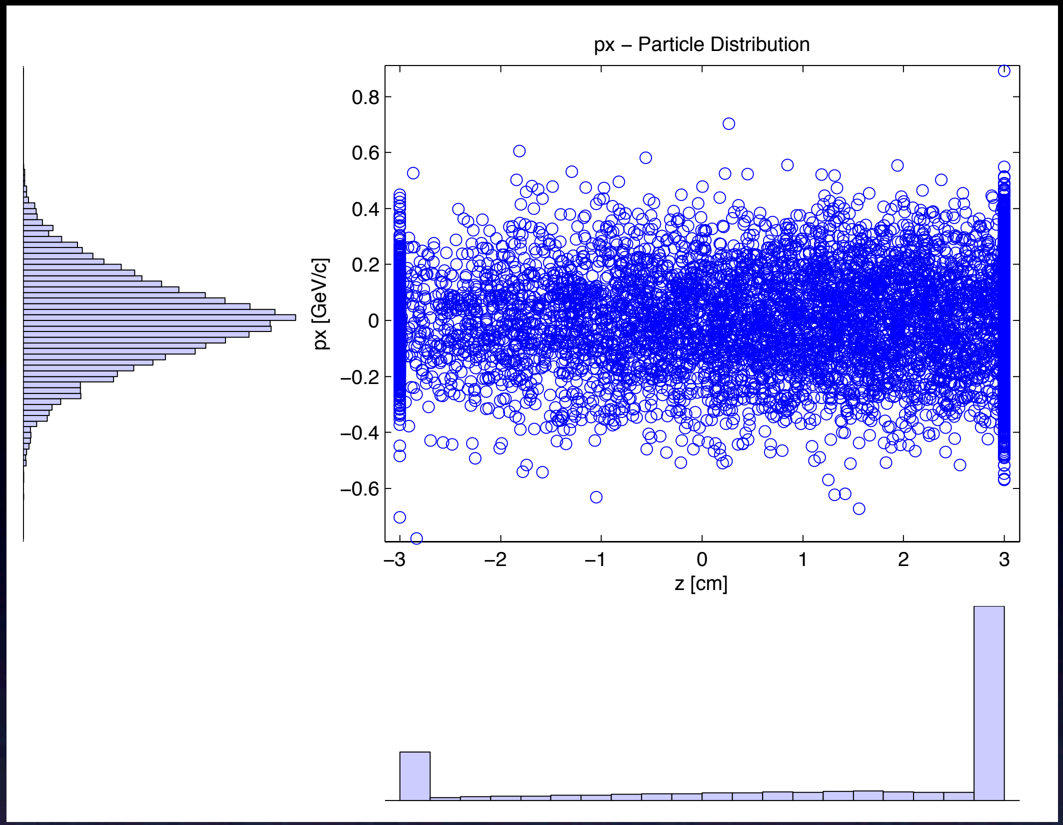


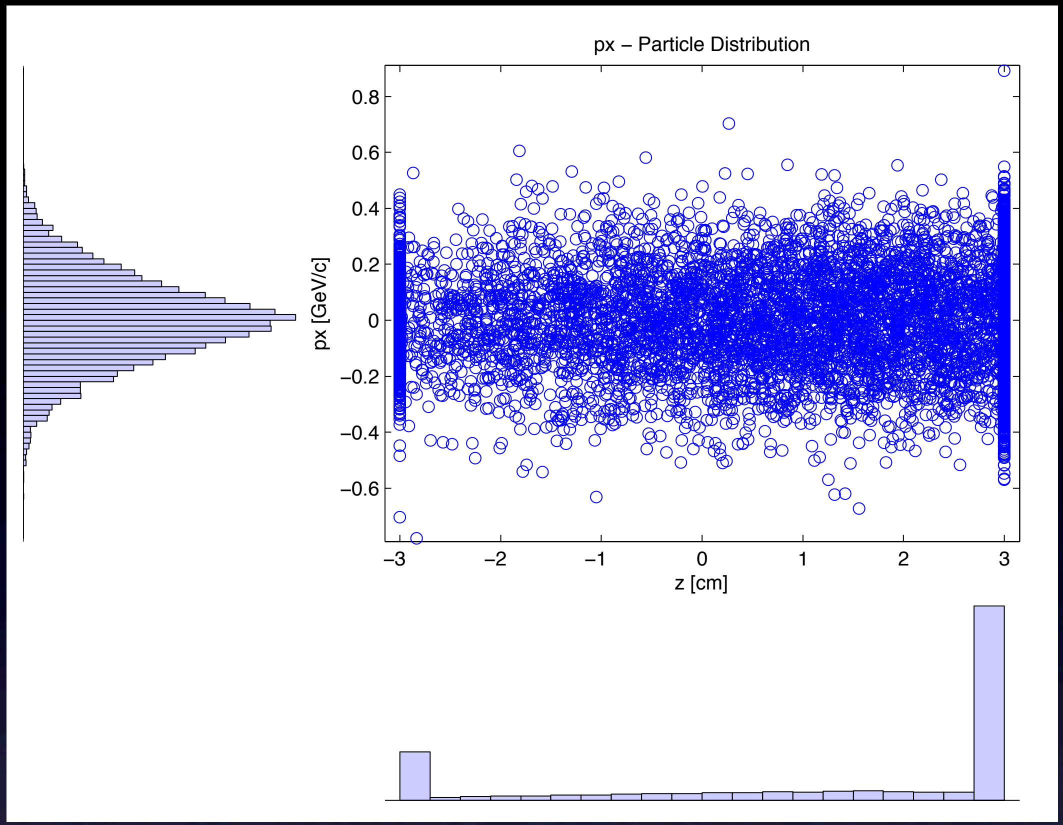


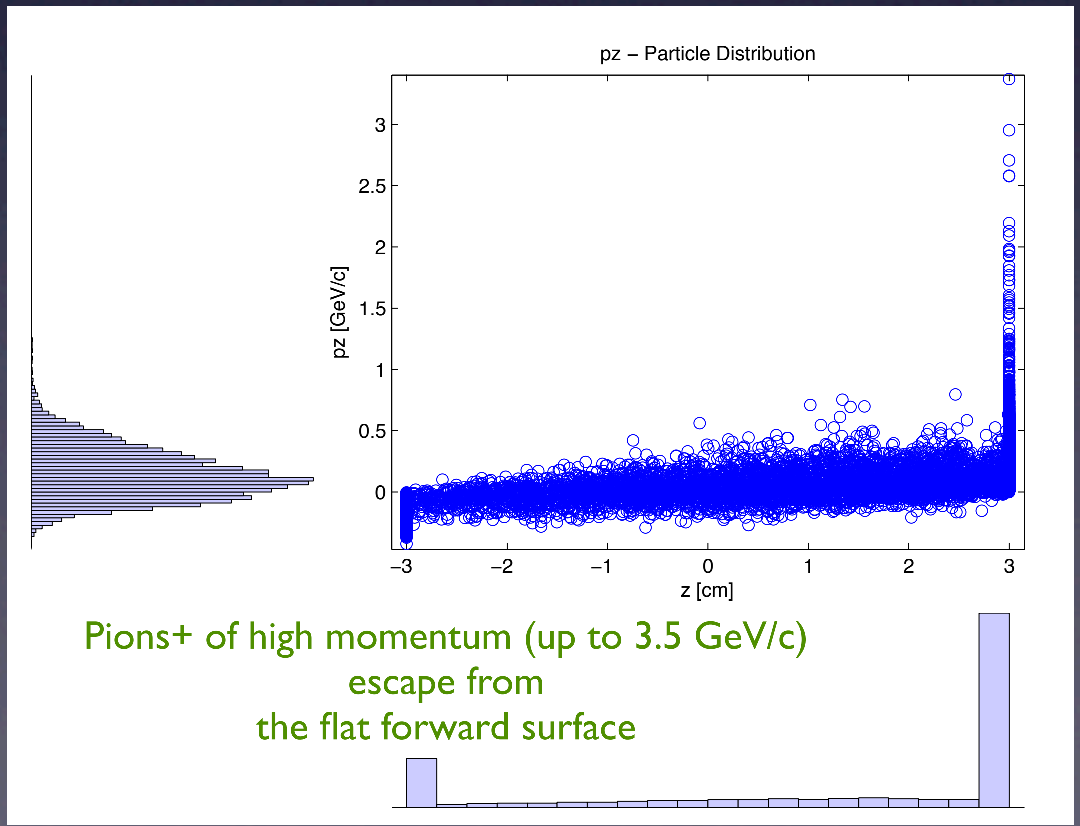




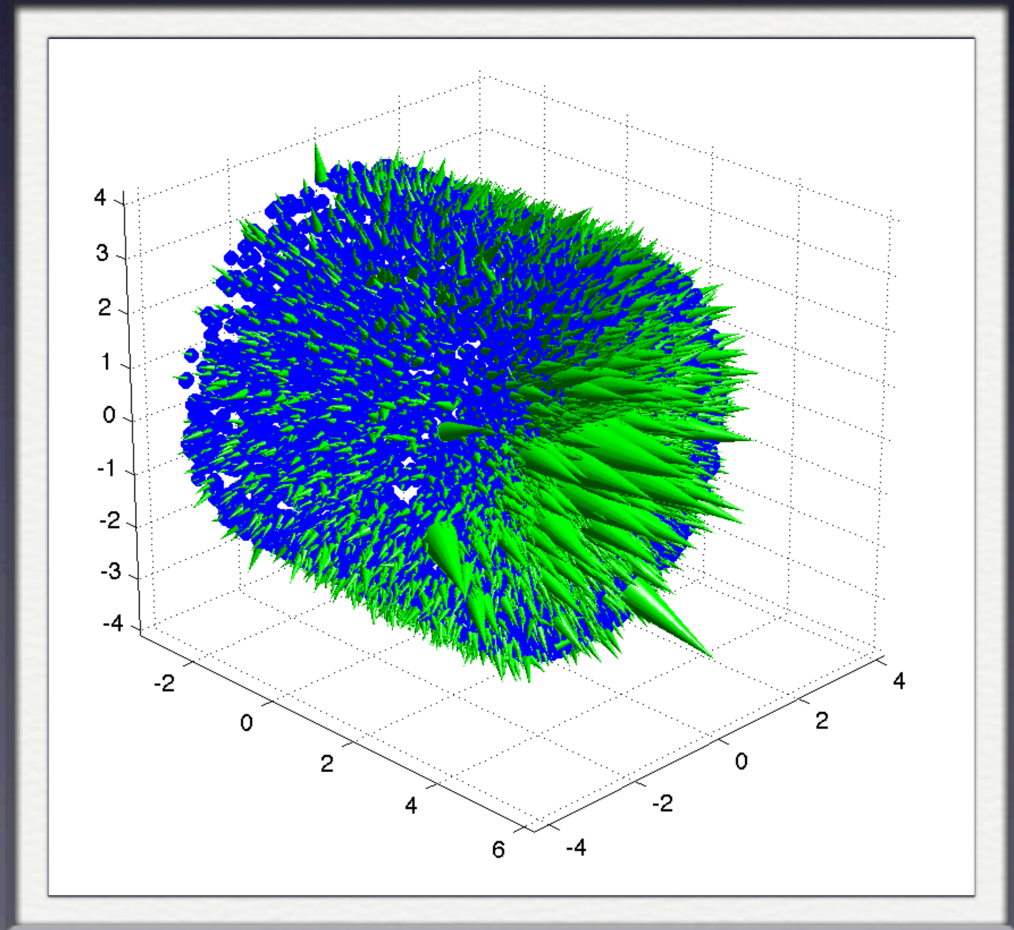
WBTF like (Ee = 4.18 GeV): Pion+



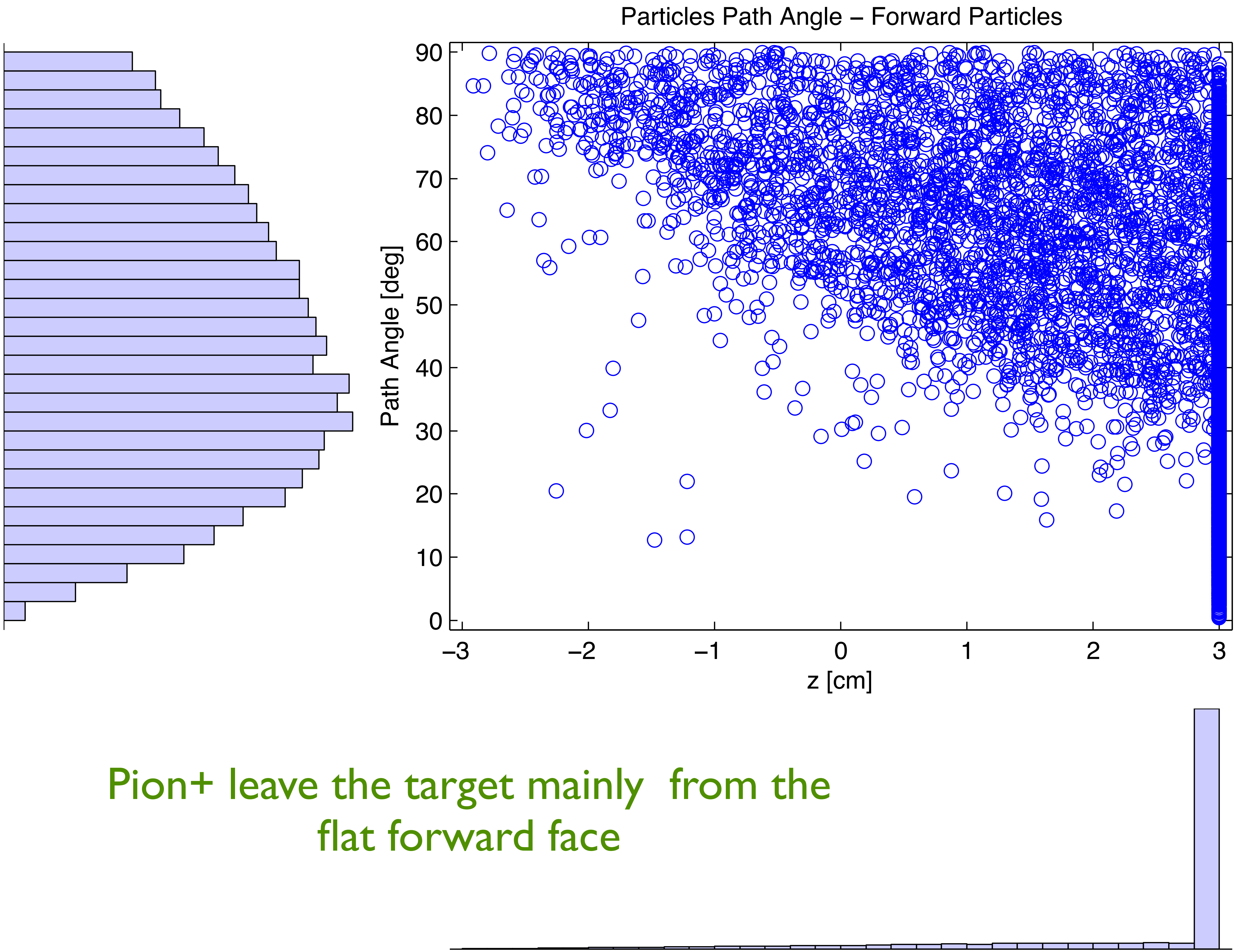




Pions+ of high momentum (up to 3.5 GeV/c)
escape from
the flat forward surface

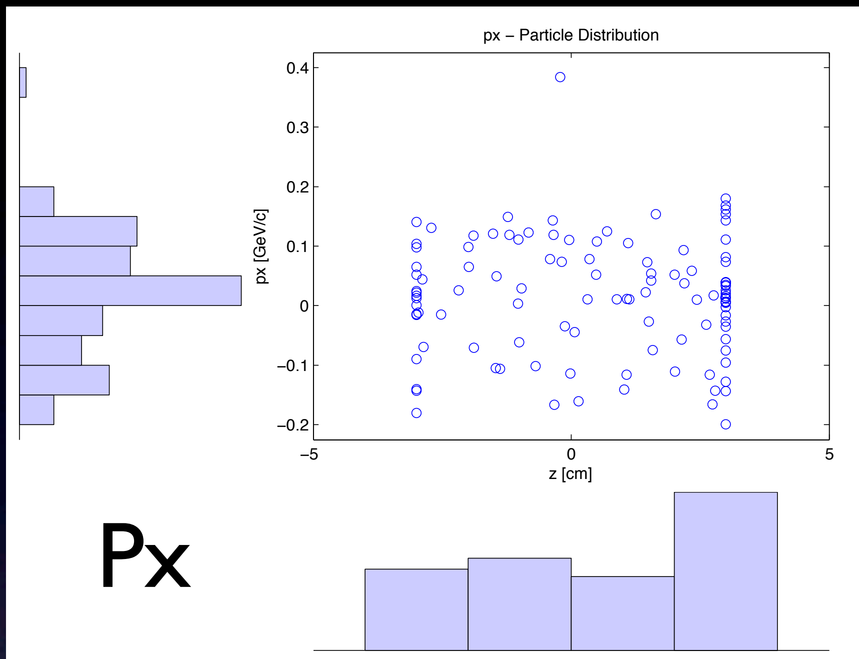


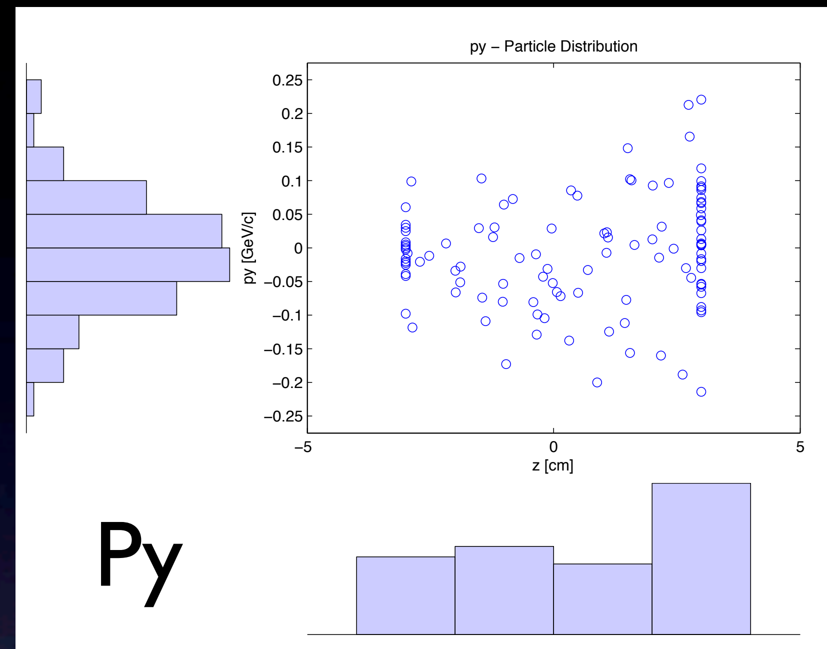
WBTF like (Ee = 4.18 GeV): Pion+

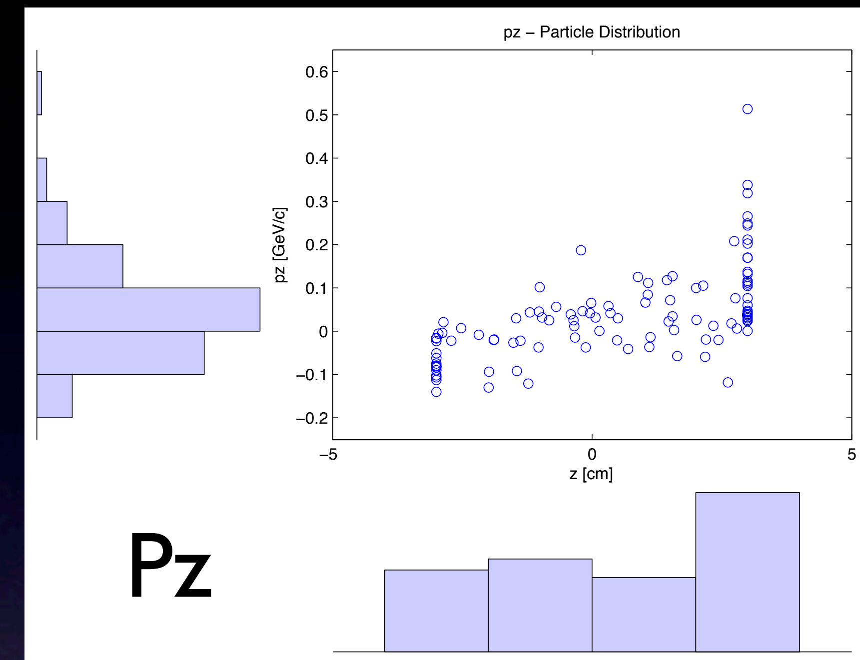


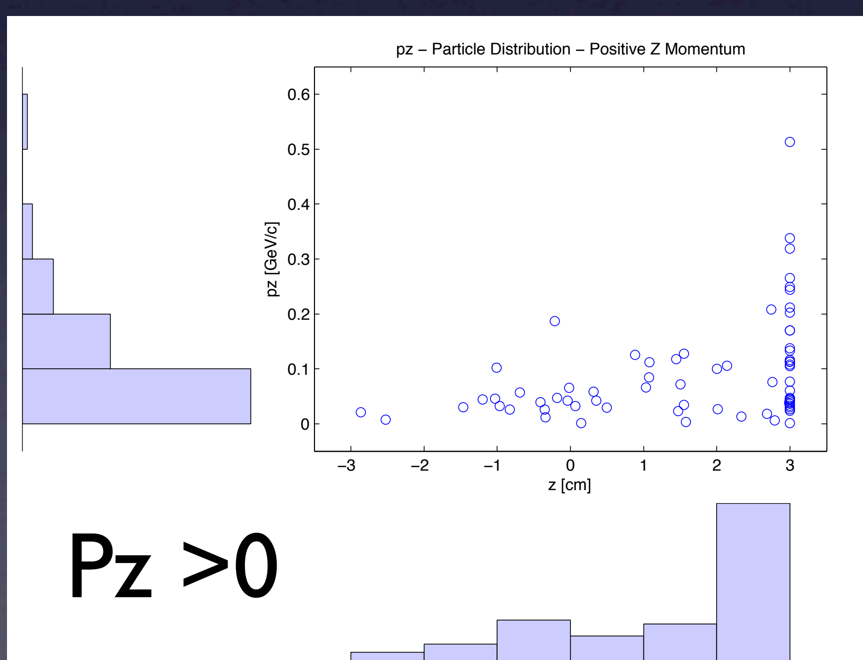
Pion+ leave the target mainly from the flat forward face

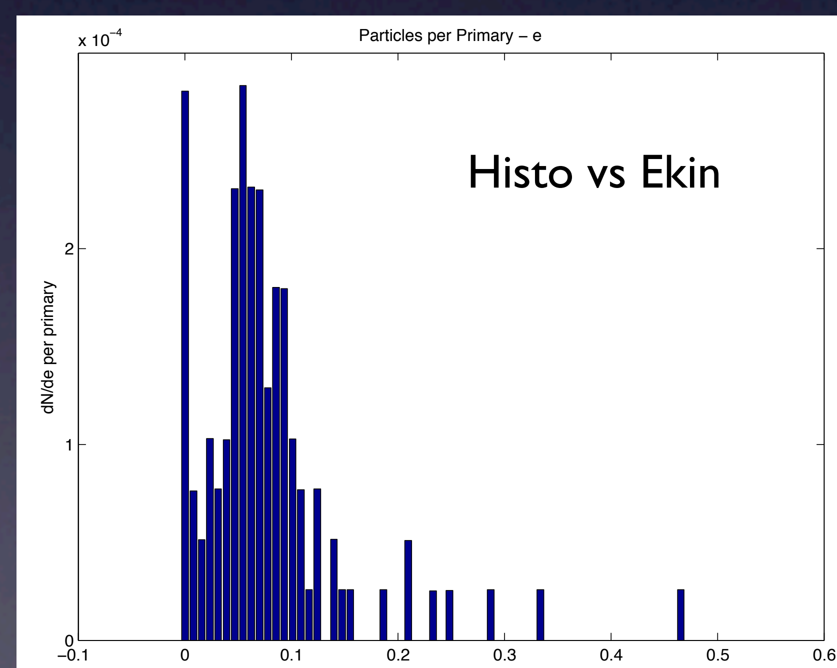
WBTF like(Ee = 4.18 GeV): Muon+

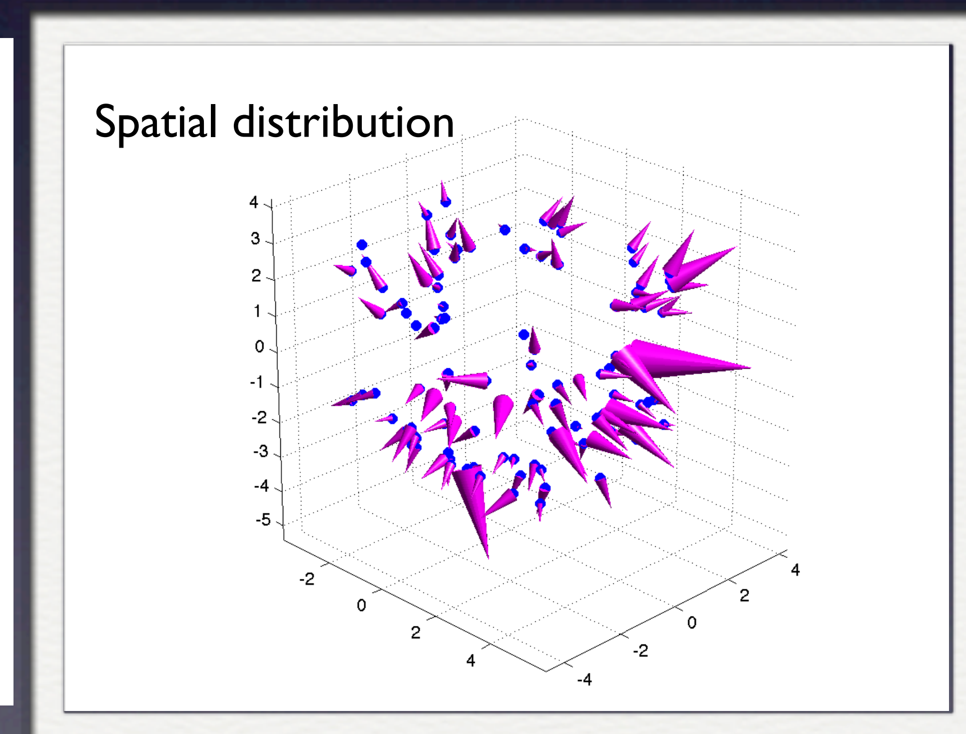






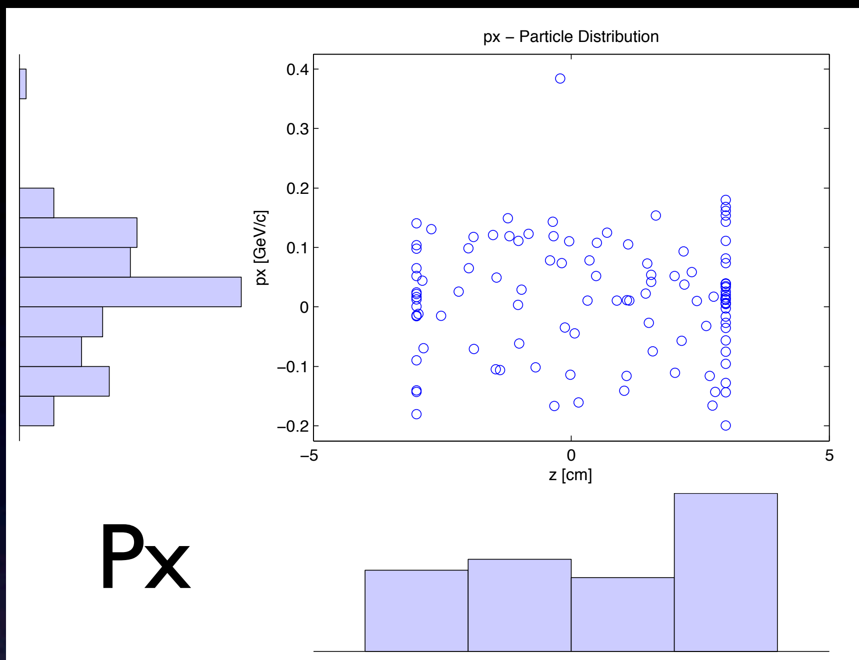


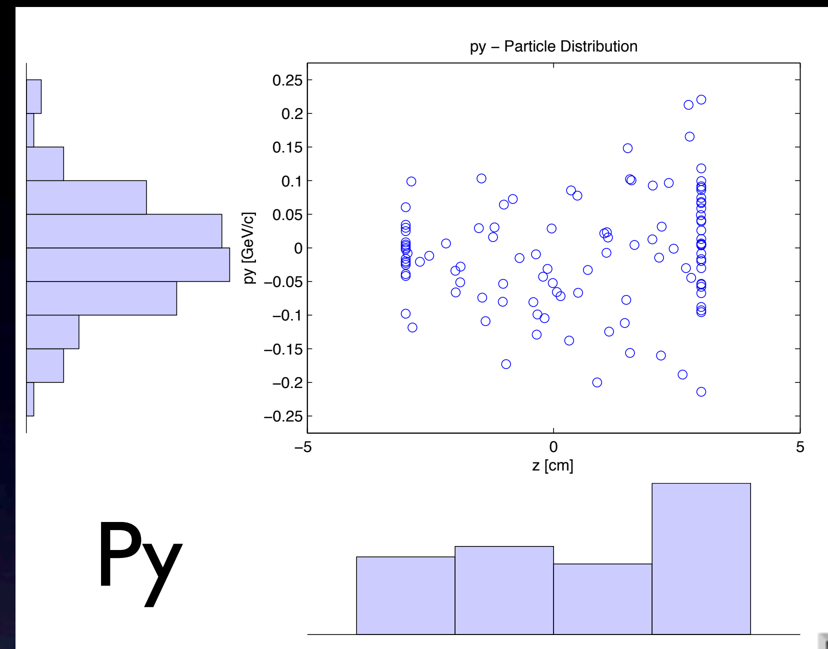


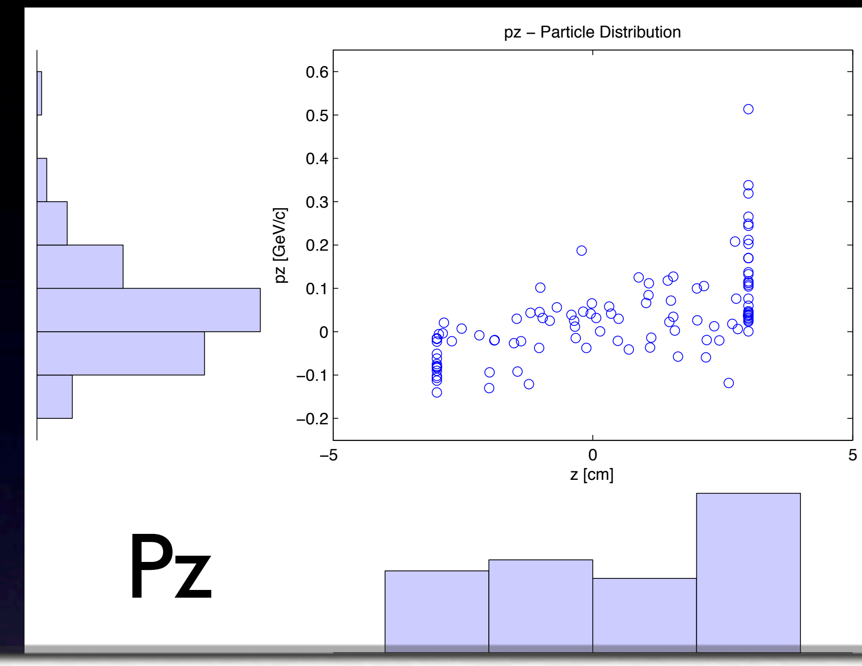


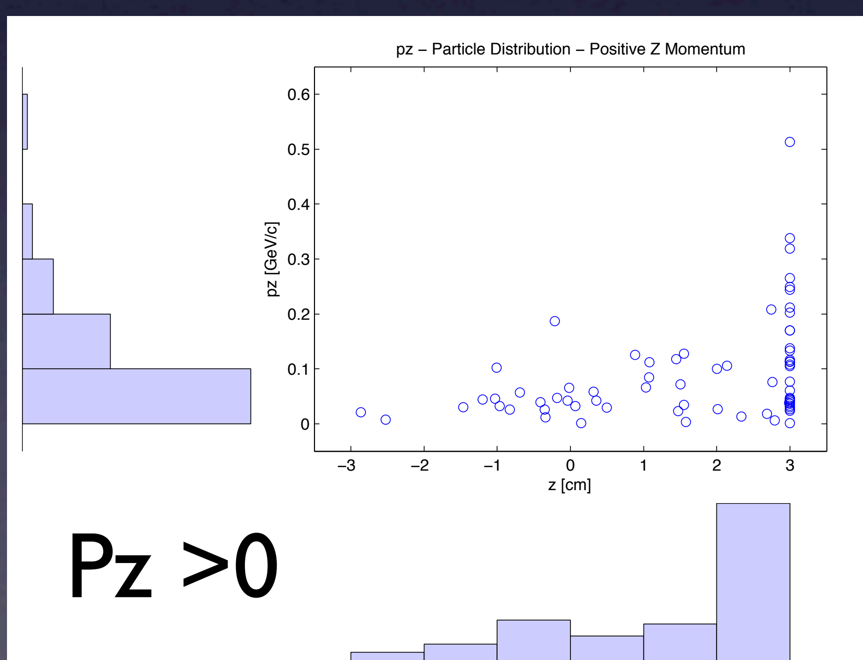
More statistics is needed to reconstruct more accurately the histograms
Higher energy Muons+ with (Pz>0) are escaping forwarding

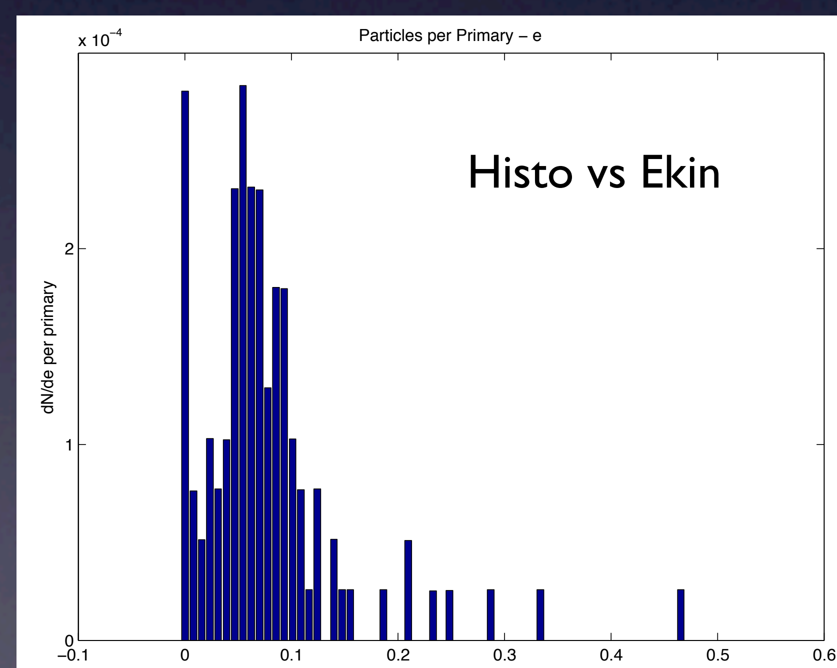
WBTF like(Ee = 4.18 GeV): Muon+

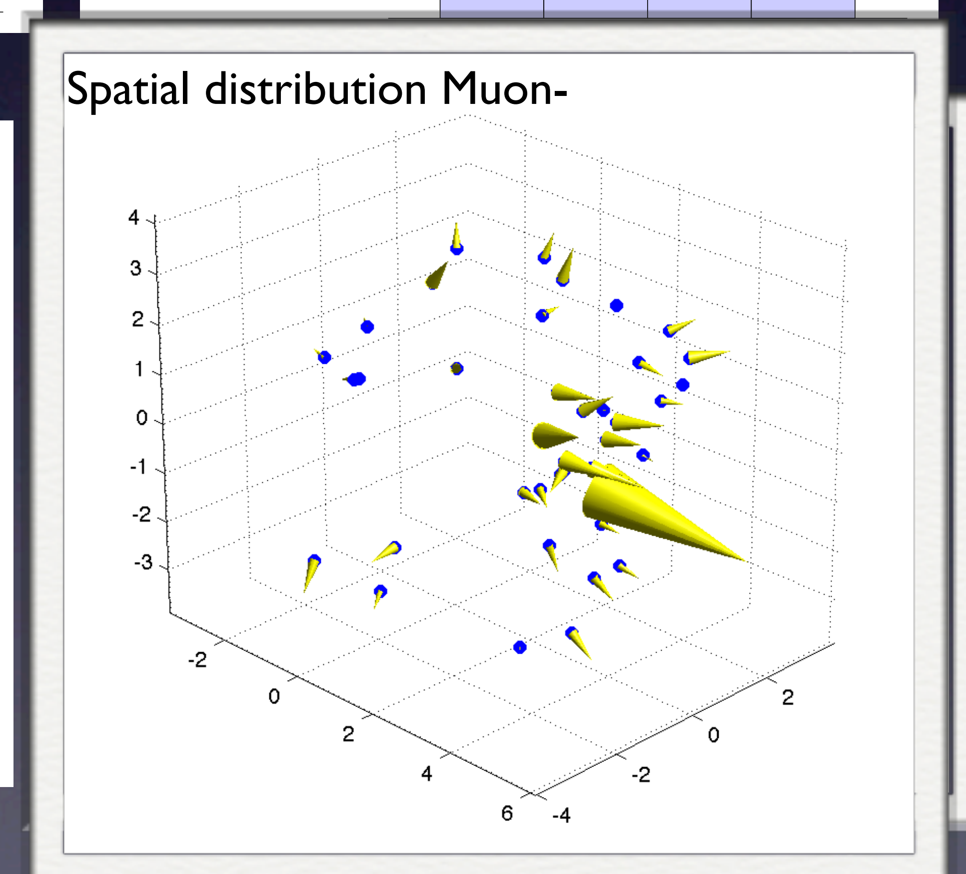






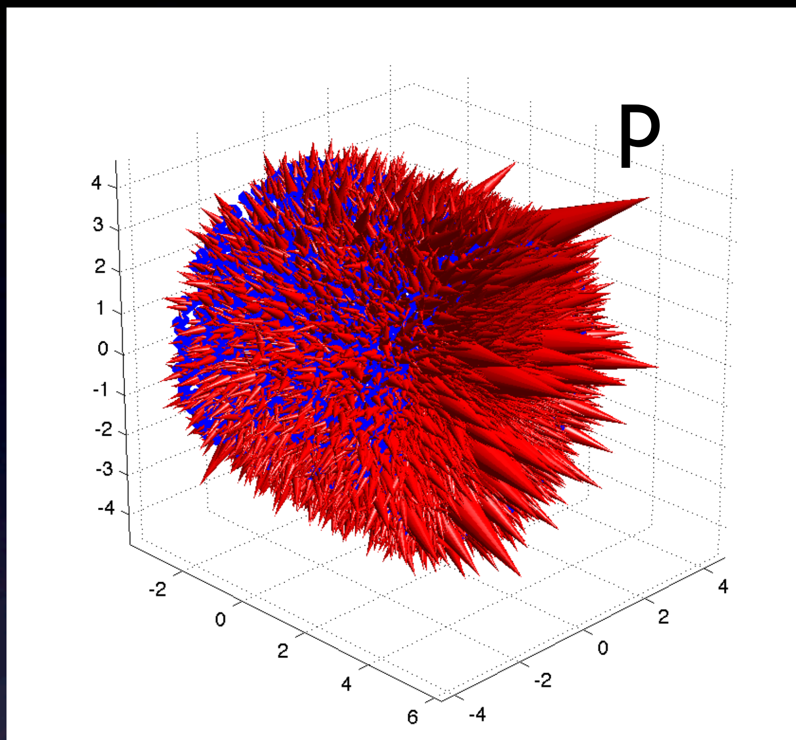


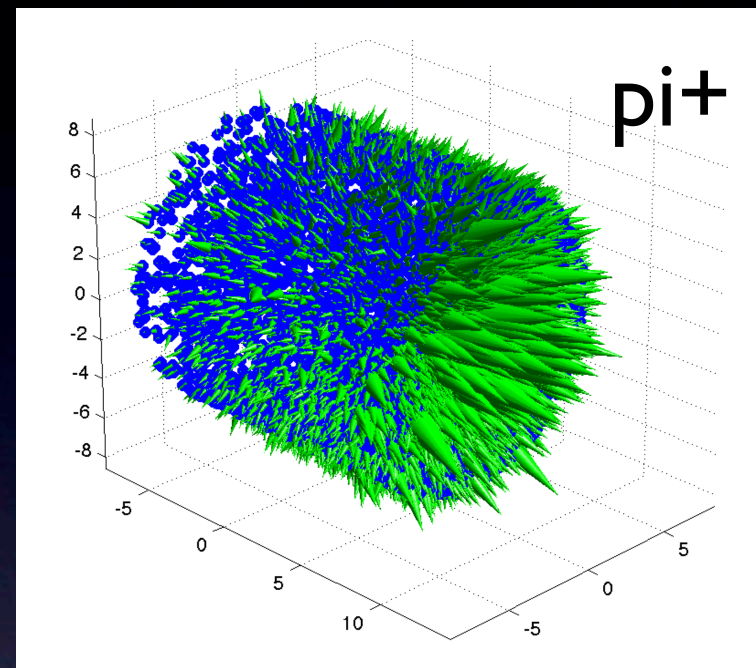


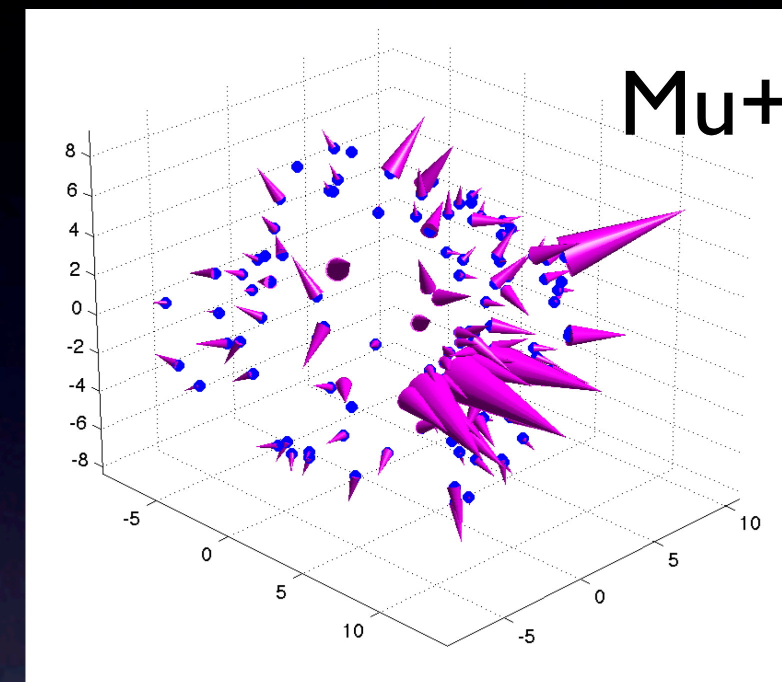


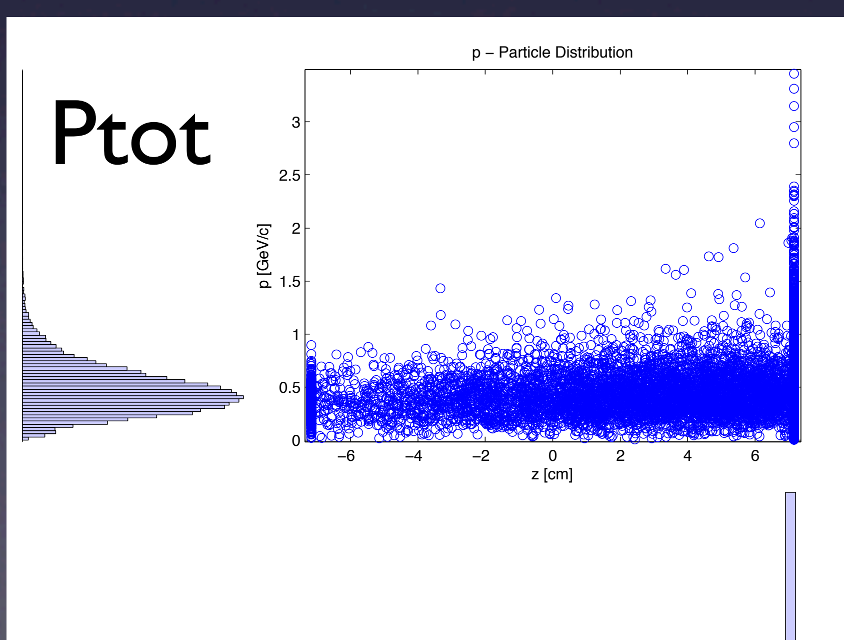
More statistics is needed to reconstruct more accurately the histograms
Higher energy Muons+ with (Pz>0) are escaping forwarding

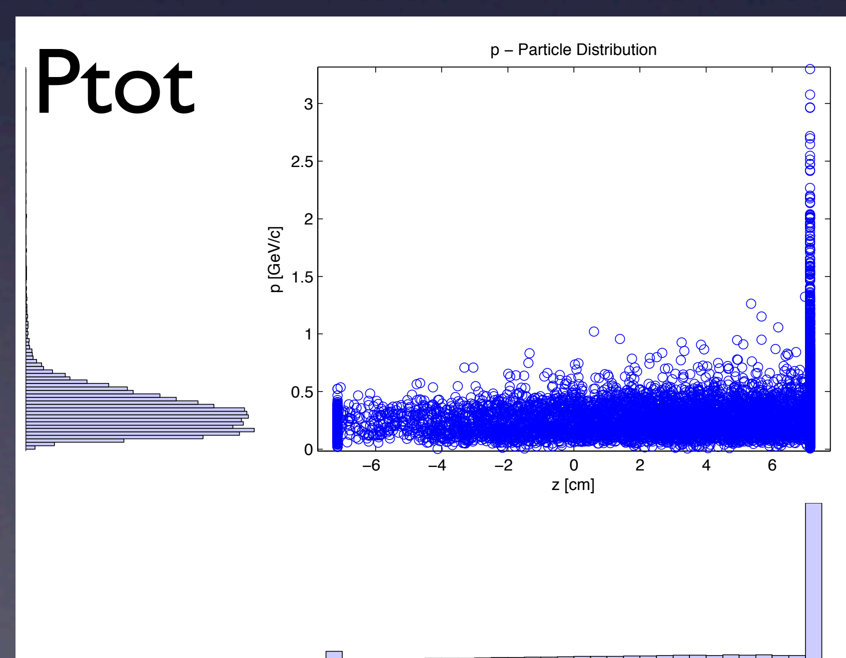
OpCu (Ee = 4.18 GeV): summary

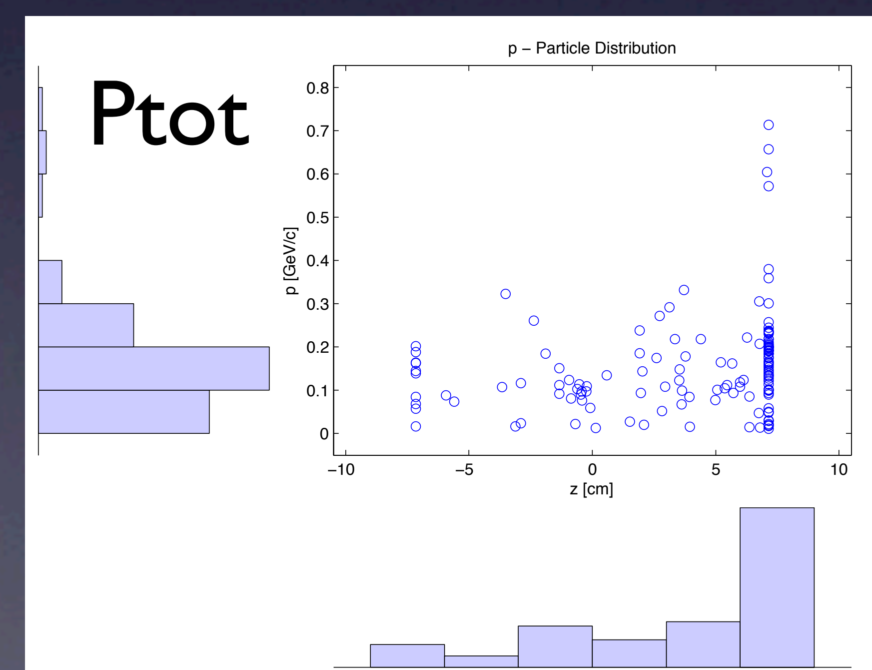




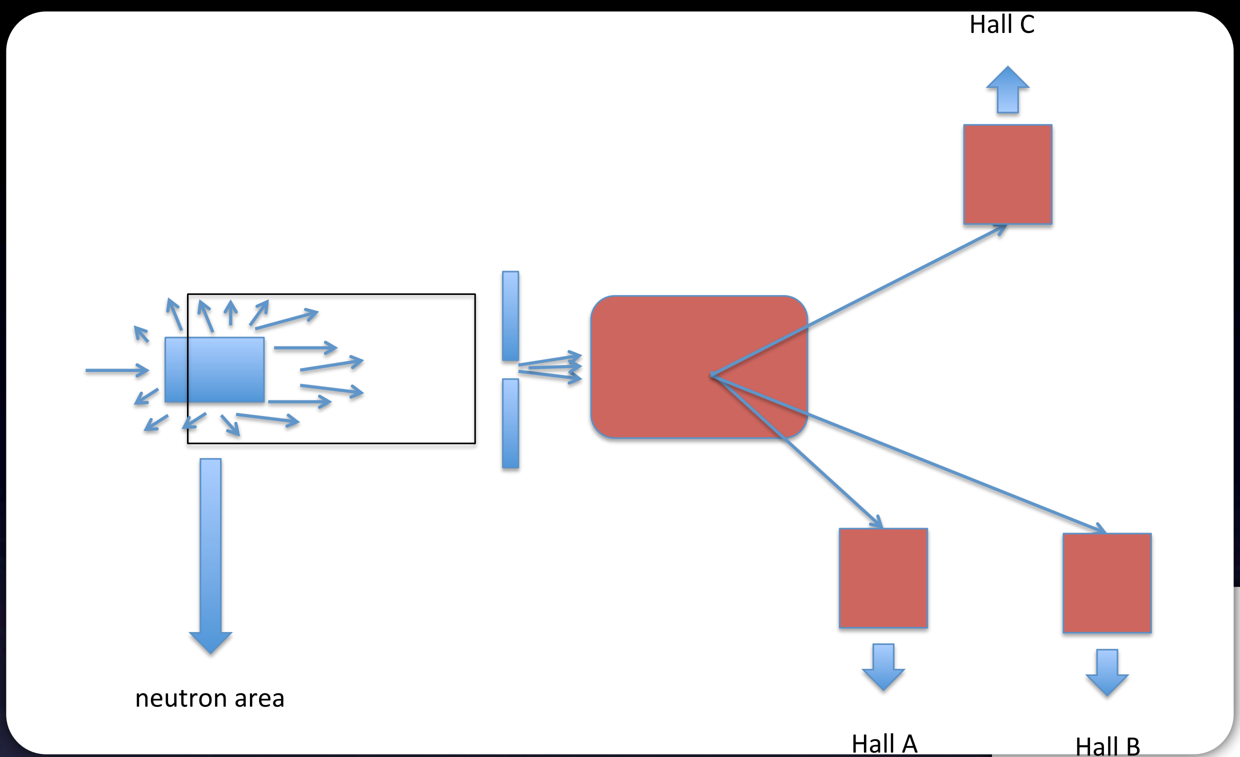


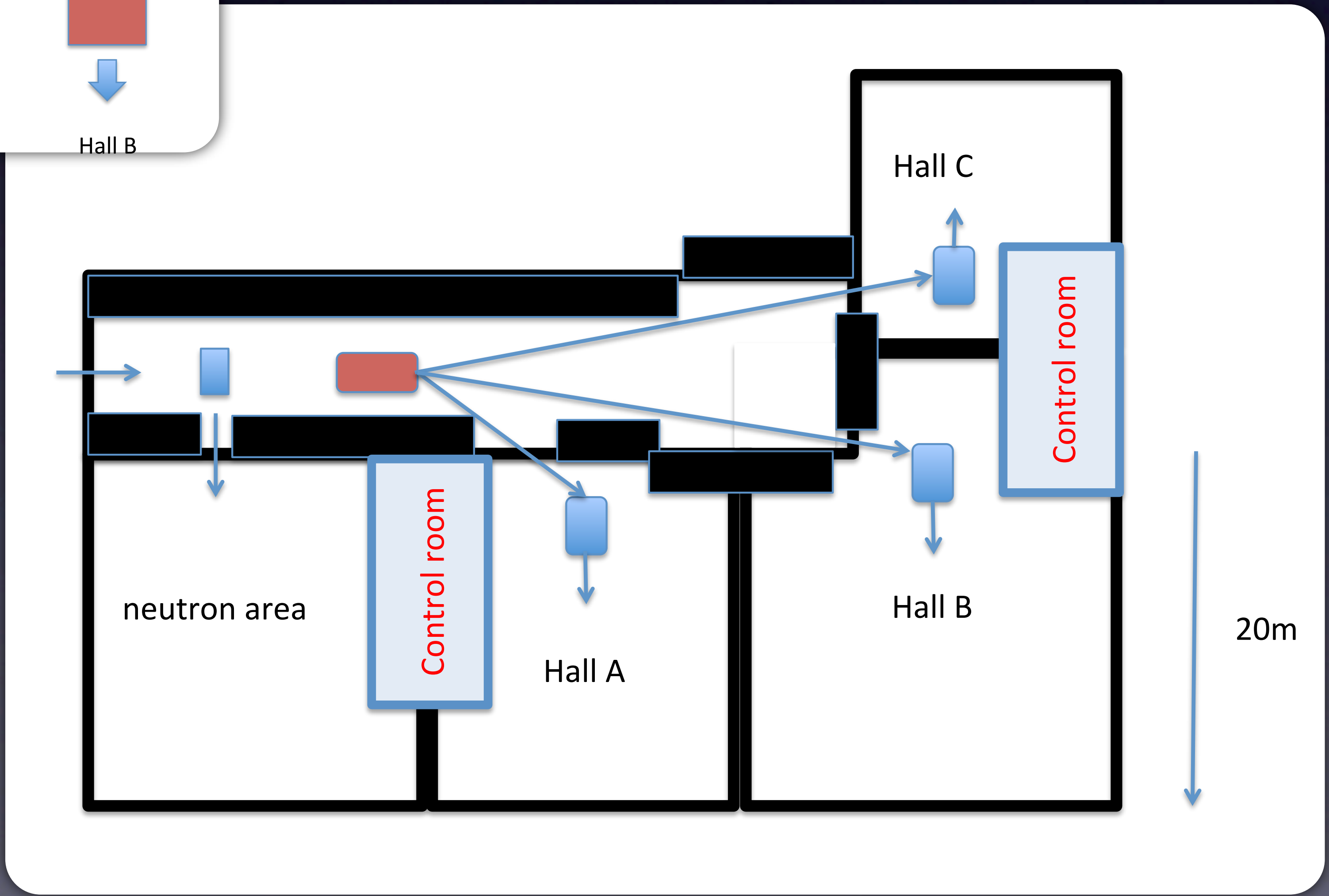






SuperBTF possible Layout





Conclusion and Future Plans

- Several Target Configurations have been studied and others are in progress
- Composed or Alloy Target configurations will be studied for optimization ...
- The best solution(s) will depend on the directive of the scientific community (more suitable and well designed targets)
- Future Tasks: Benchmarking with Geant4 and Ansys Simulation of thermal analysis

http://www.lnf.infn.it/acceleratori/btf/

THANK YOU FOR YOUR ATTENTION