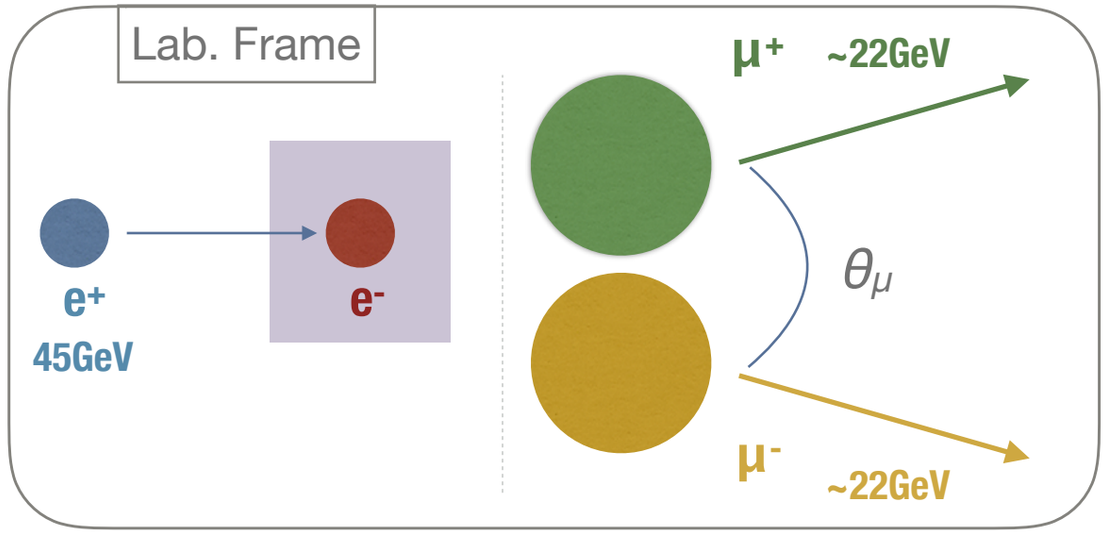
MUON PRODUCTION TARGETS

***Francesco Collamati** - INFN Rome*
LEMMA working group

THE MUON PRODUCTION ISSUE

✦ **LEMMA** idea is to exploit direct muon production via $e^+e^- \rightarrow \mu^+\mu^-$

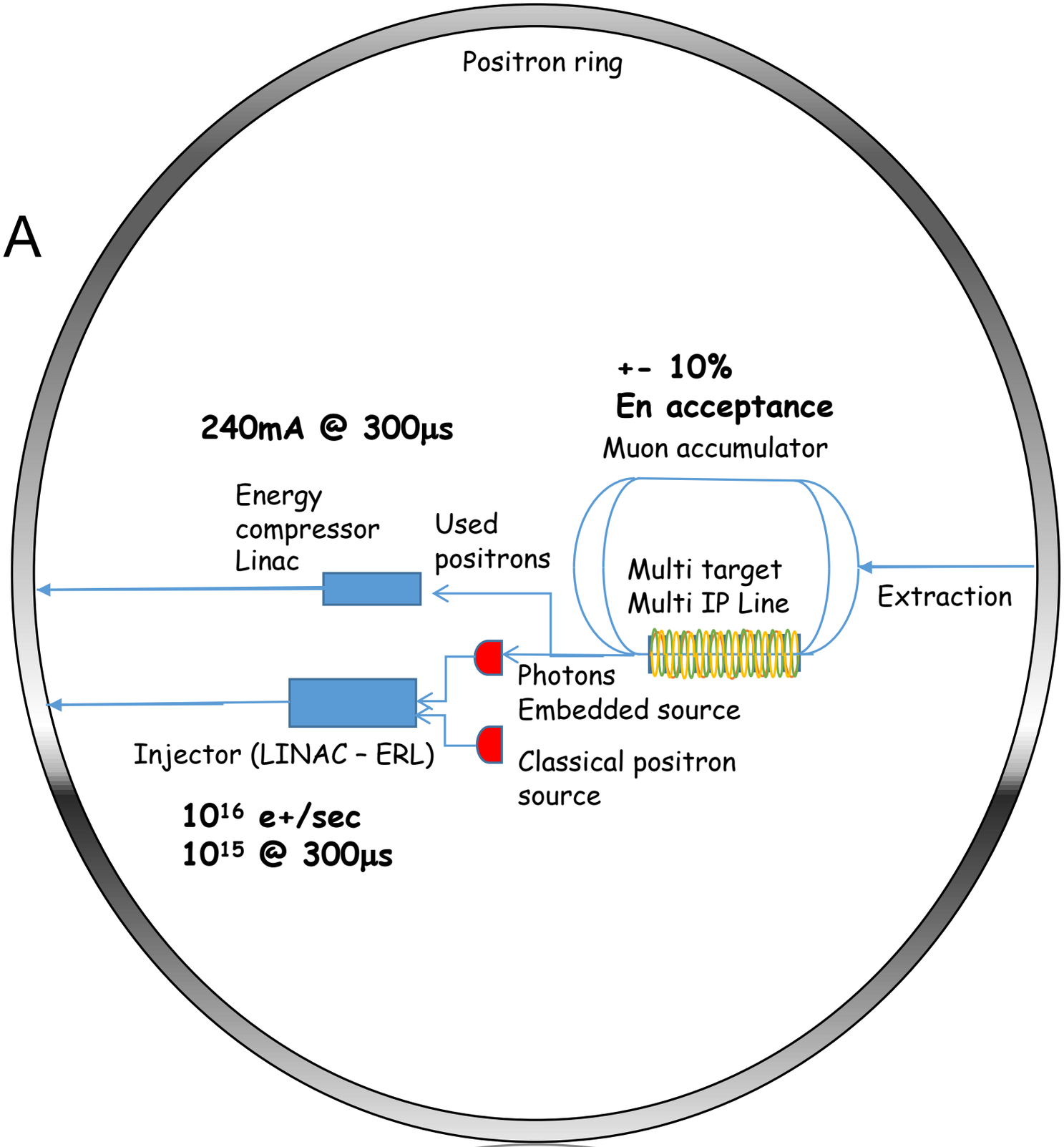
- ✓ Low emittance
- ✓ Small energy spread
- ✓ Low background
- ✓ Reduced losses from decay



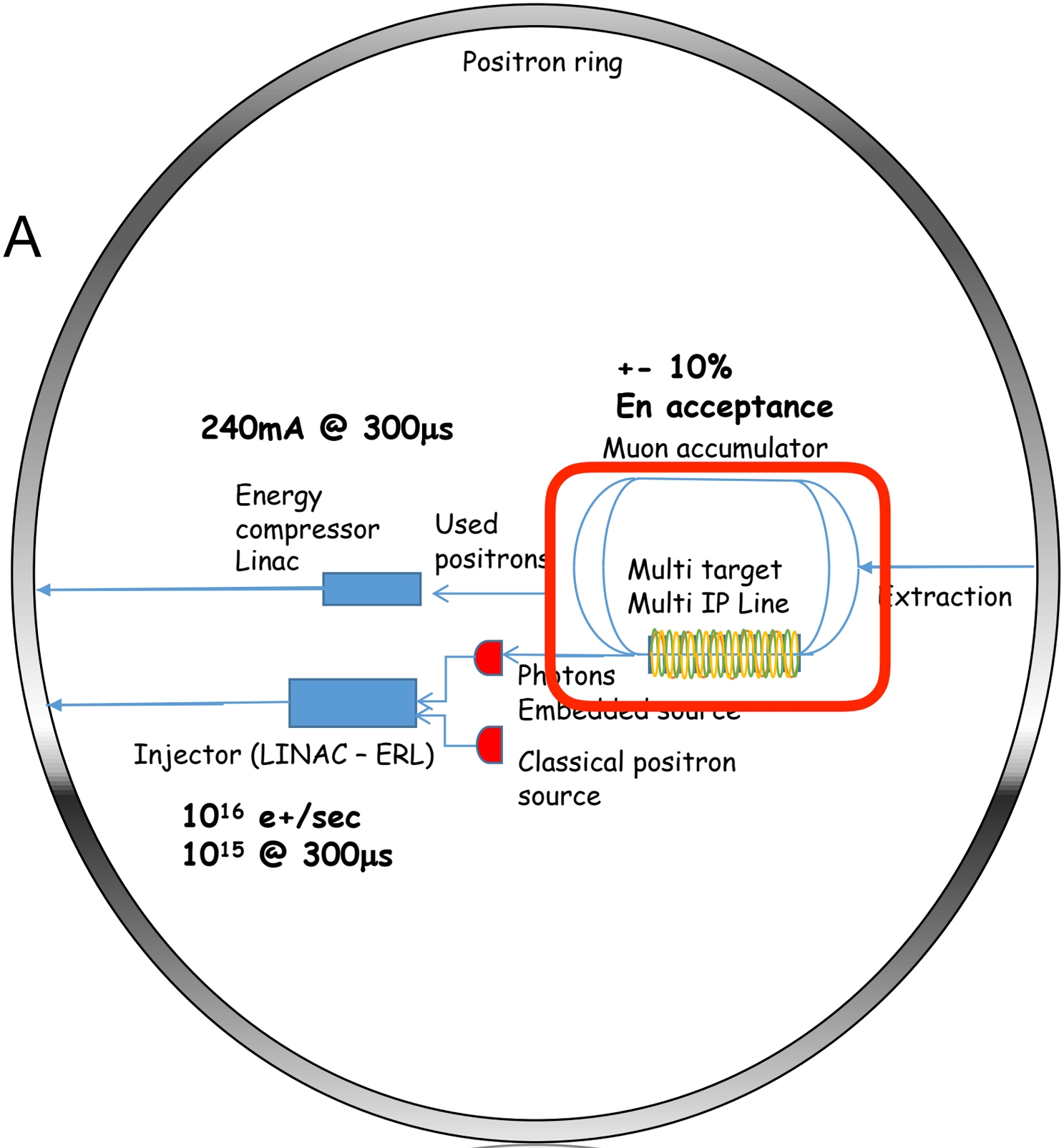
✦ Due to the very **small cross section** of the positron annihilation process, an elevated amount of positrons must be used

- ➡ Positron source intensity
- ➡ Power load on target

THE LEMMA SCHEME



THE LEMMA SCHEME

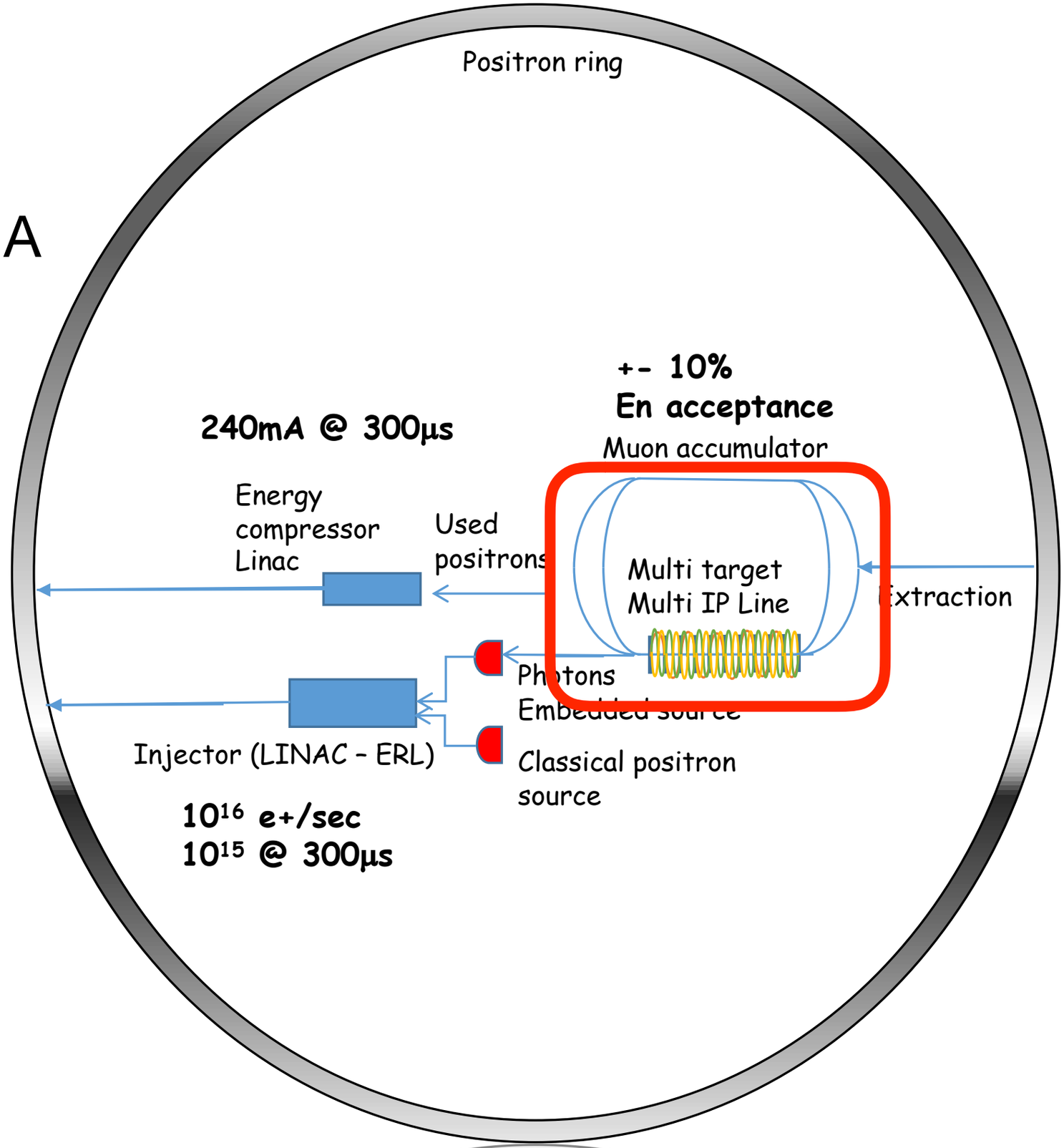


THE LEMMA SCHEME

A tool is needed to study/ optimize muon production in a variety of possible configurations

number/size/position of targets, beam energy/size.....

line optics



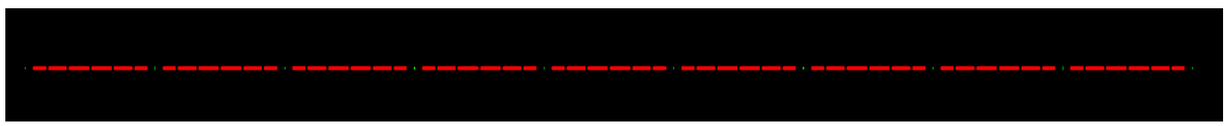
THE TOOL USED

✦ The natural tool would seem Geant4, but to effectively use it with the possibility to vary all parameters some form of automatisation (from machine optics to G4) is needed

✦ For this study, **MDISim** was used, which is a tool developed by H. Burkhardt @CERN for LHC/FCC studies, that enables to:

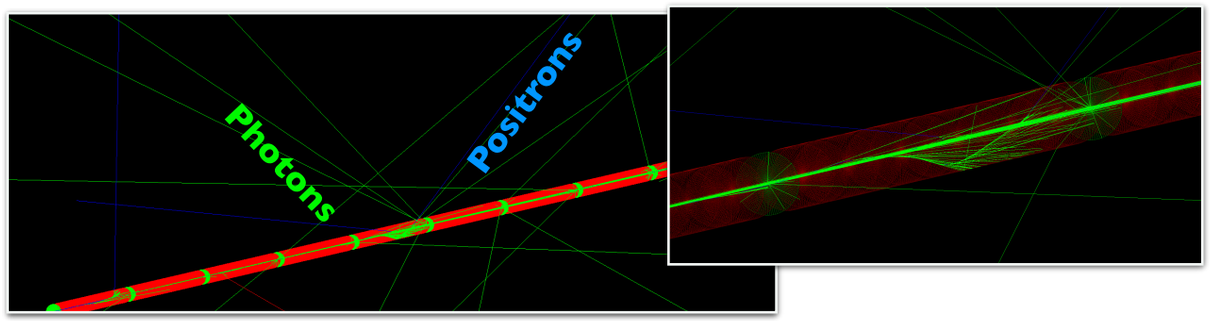
REF

- ✓ Read the machine optics
- ✓ Import it (geometry + magnetic fields) in Geant4 (via gdml)



example of a multi target positron line

✦ Once in Geant4, a whole lot of studies can be performed!



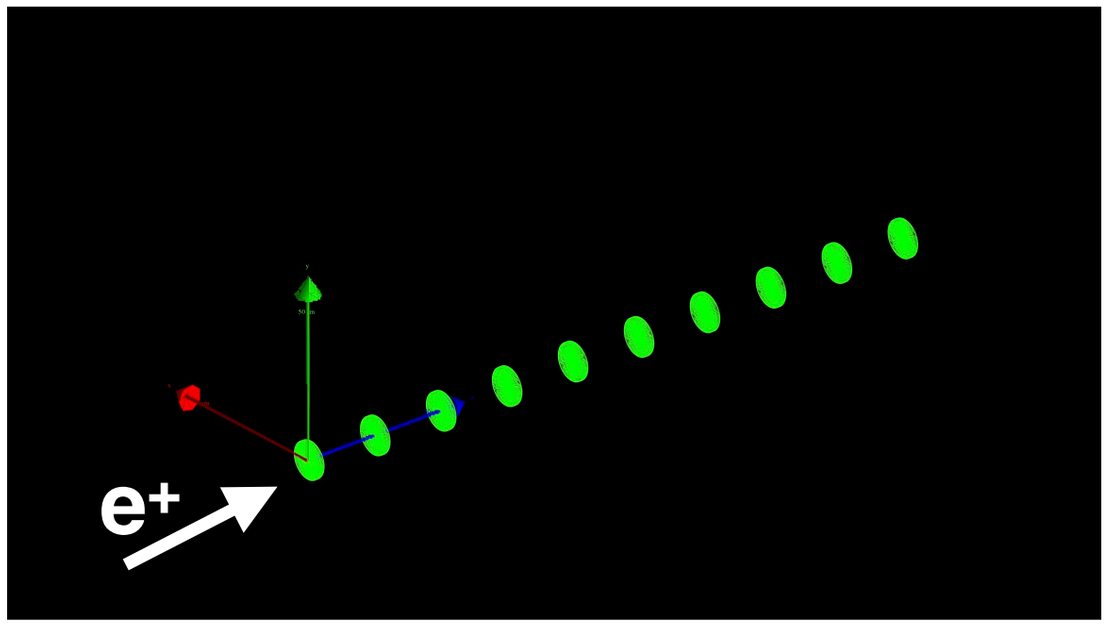
THE MUON PRODUCTION ISSUE

✦ As a first approach, a “Single IP - Multi Target Line” was used

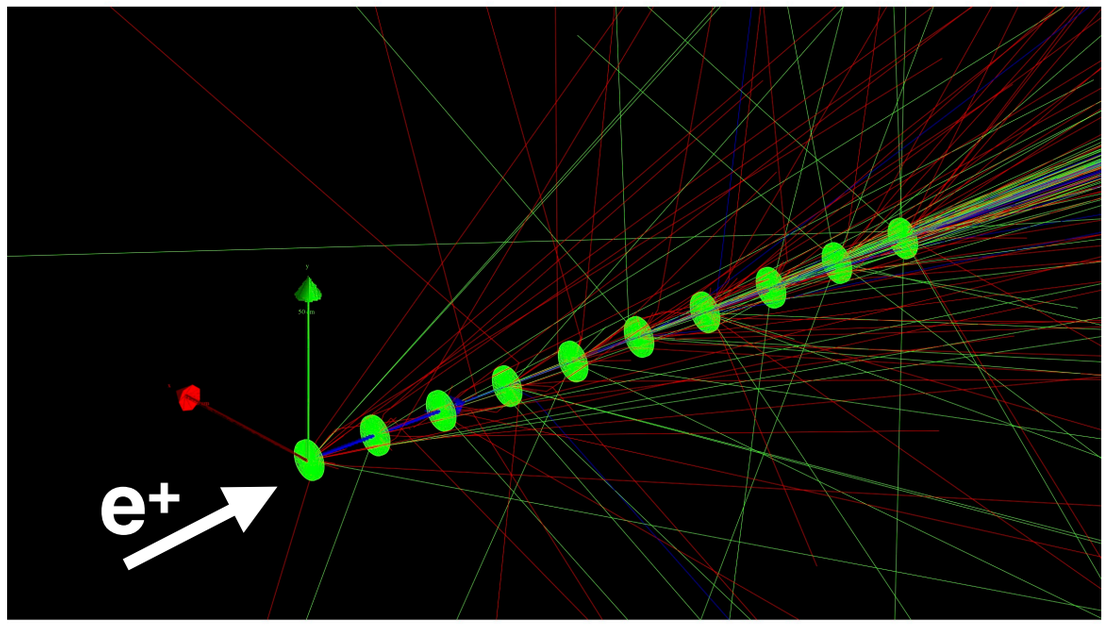
➡ 10 Berillium targets

➡ 1 cm thick each

➡ 2 m total z length



THE MUON PRODUCTION ISSUE



✦ As a first approach, a “Single IP - Multi Target Line” was used

➡ 10 Berillium targets

➡ 1 cm thick each

➡ 2 m total z length

✦ A primary beam of positrons is fired, E=45GeV by default

✦ Particles are tracked along the line, taking into account all relevant processes

- ✓ Bremsstrahlung
- ✓ Ionisation
- ✓ Multiple scattering
- ✓ Secondaries creation
- ✓ (…)

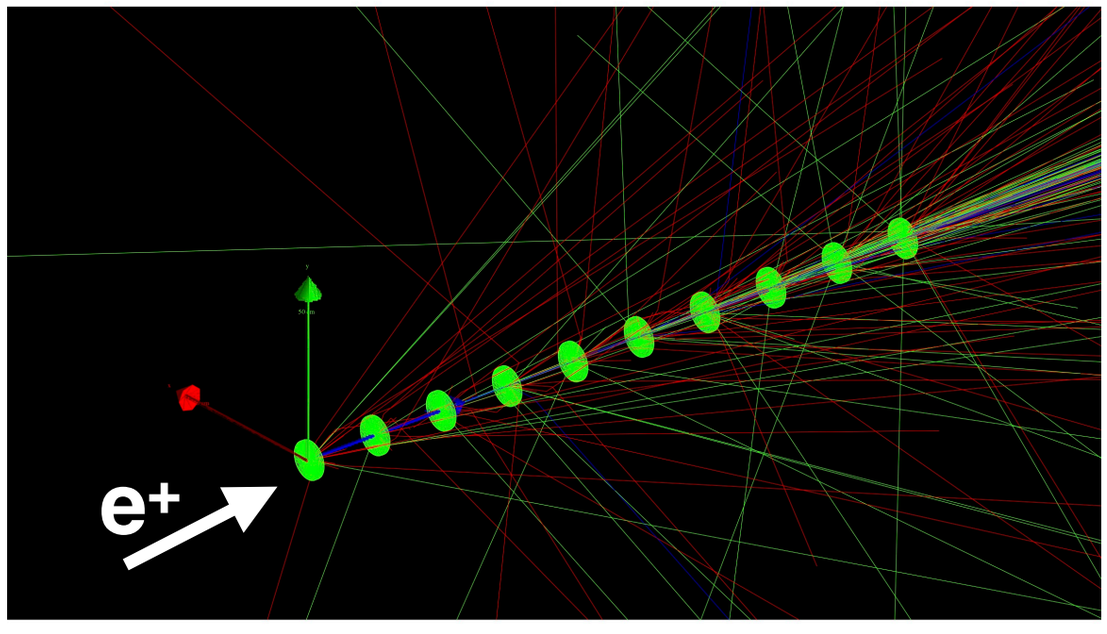
THE MUON PRODUCTION ISSUE

✦ As a first approach, a “Single IP - Multi Target Line” was used

➡ 10 Berillium targets

➡ 1 cm thick each

➡ 2 m total z length



✦ A primary beam of positrons is fired, E=45GeV by default

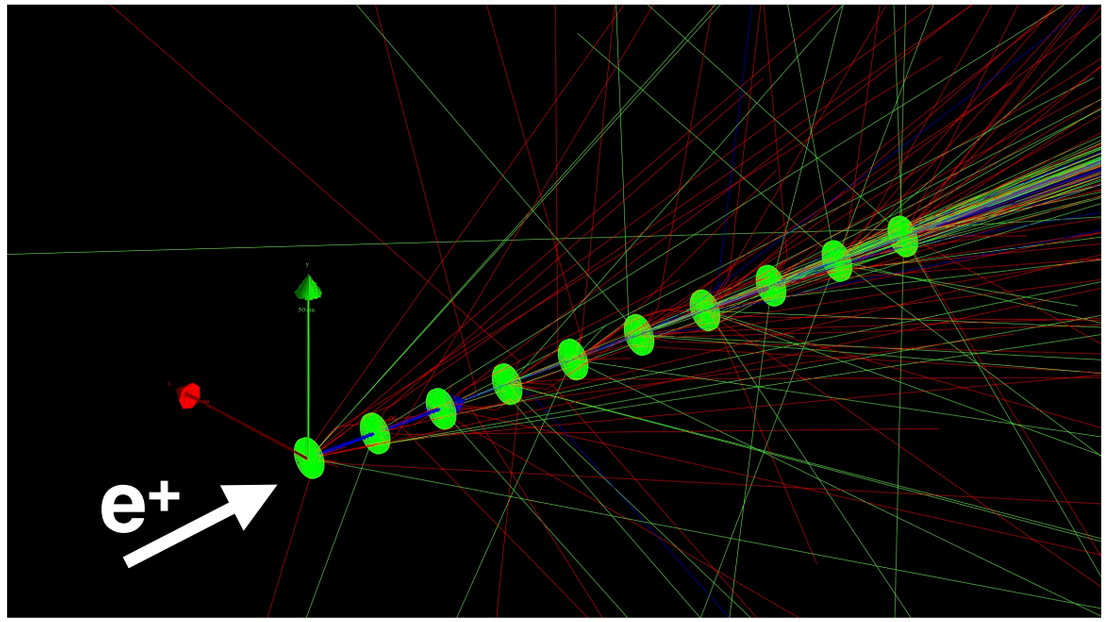
✦ Particles are tracked along the line, taking into account all relevant processes

- ✓ Bremsstrahlung
- ✓ Ionisation
- ✓ Multiple scattering
- ✓ Secondaries creation
- ✓ (…)

Aim of the study:
How **many muons** are produced?
Which **quality** of the beam?
How about the **positron degradation**?

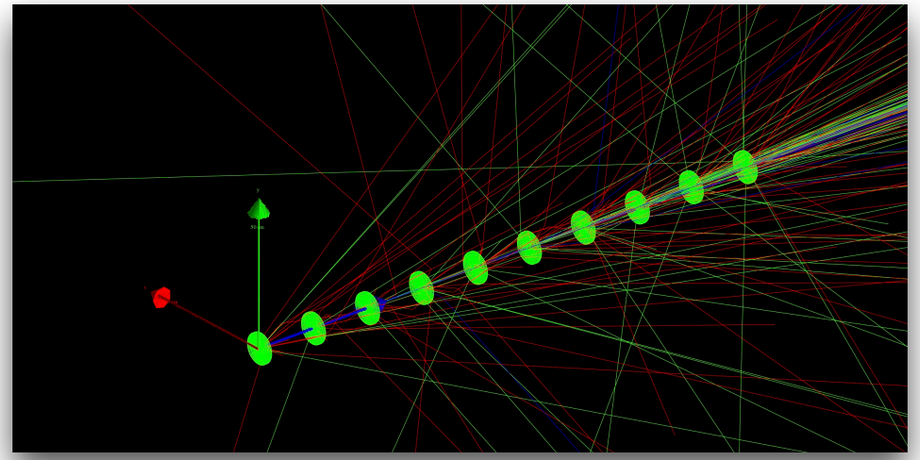
THE MUON PRODUCTION ISSUE

- **CAVEAT**: the muon production **cross section** has been artificially **biased**

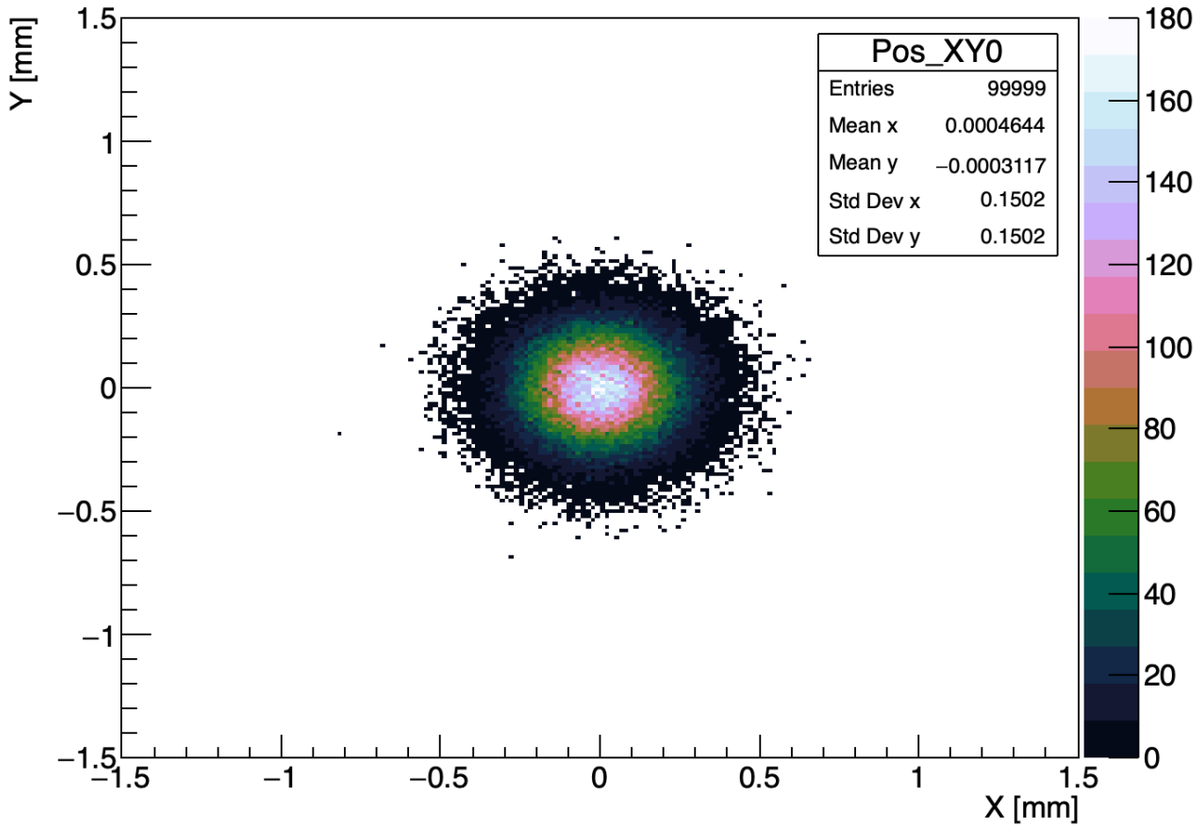


- To see enough muons in a reasonable amount of CPU time
- ~x10^3 factor, then properly taken into account in following plots
- Small (~%) effect on positrons survival

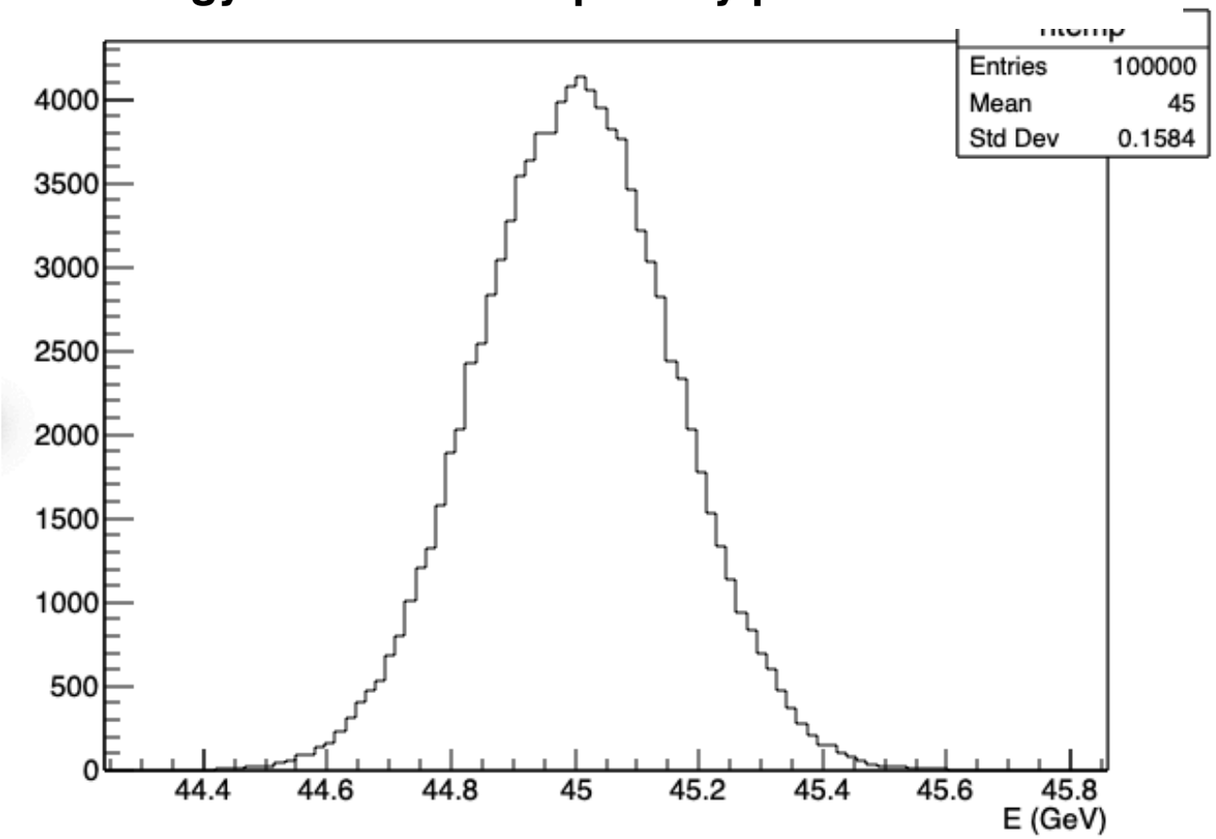
SIMULATION RESULTS



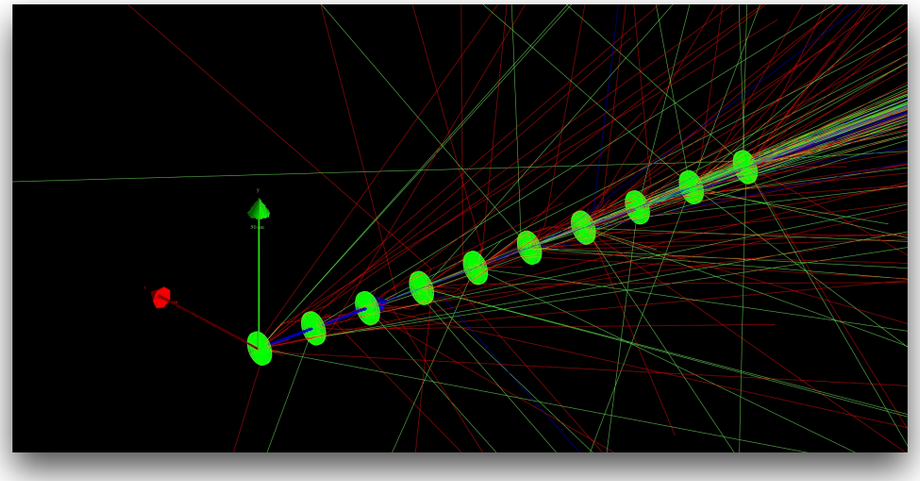
Spot size of primary positron beam



Energy distribution of primary positron beam

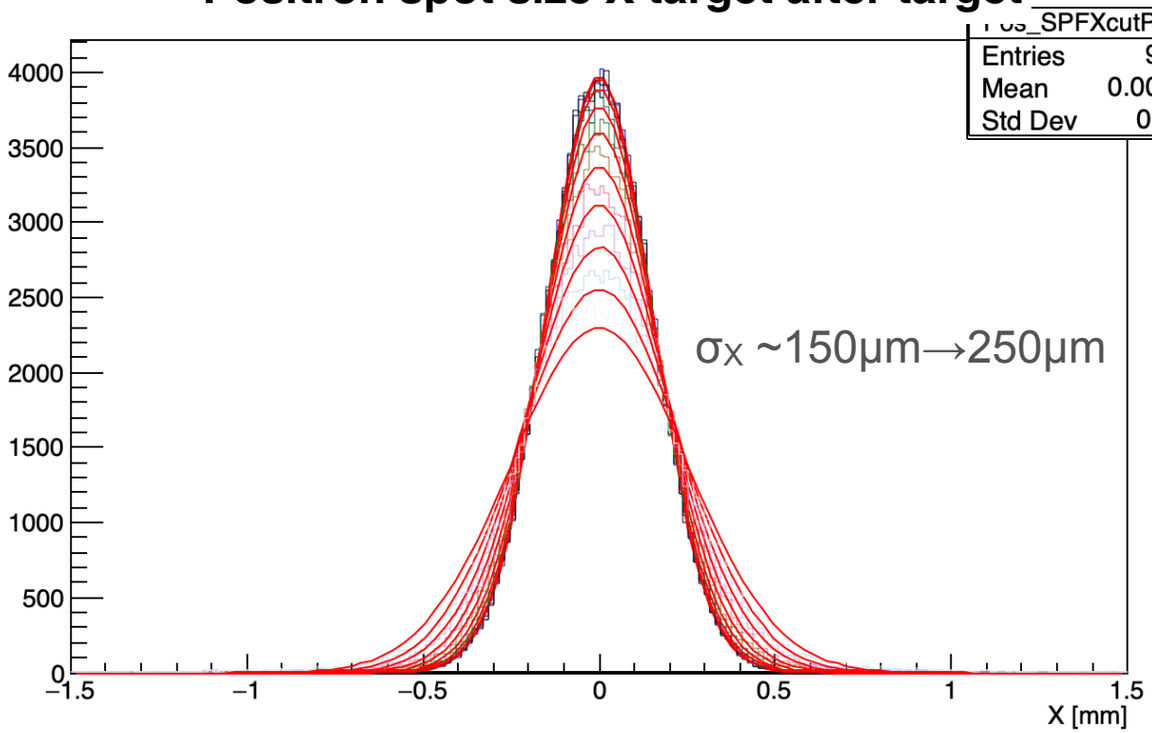


SIMULATION RESULTS

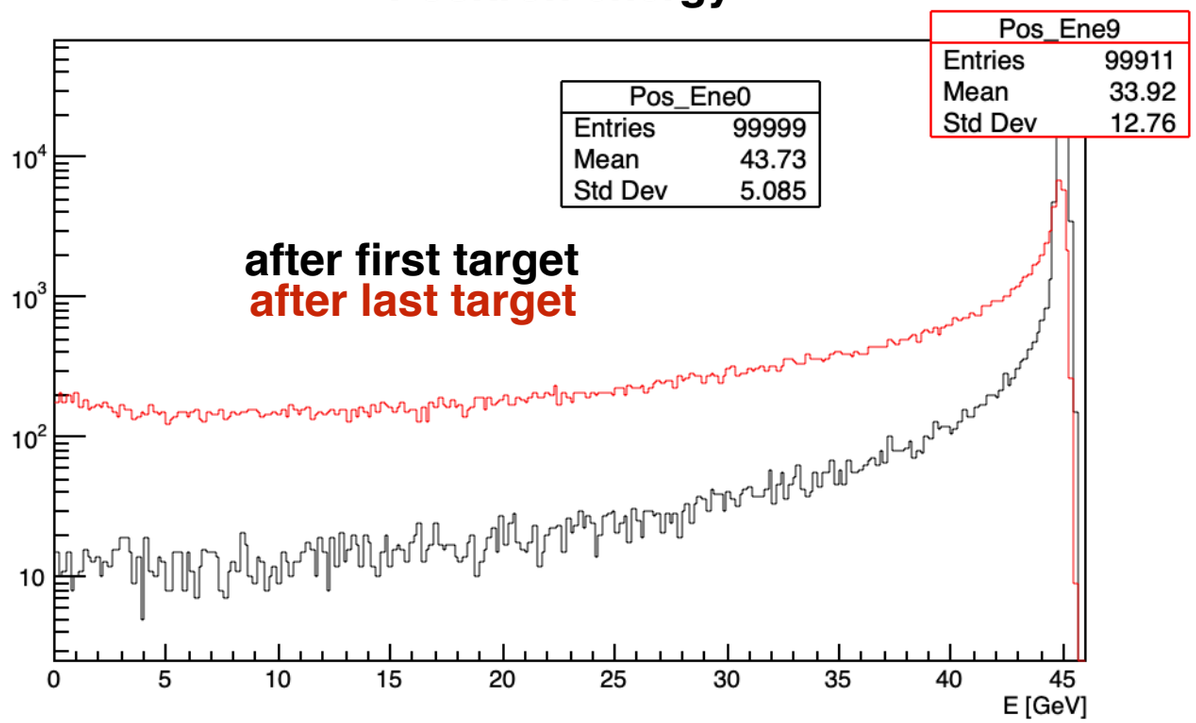


- 45 GeV positrons
- 10x1cm Be targets

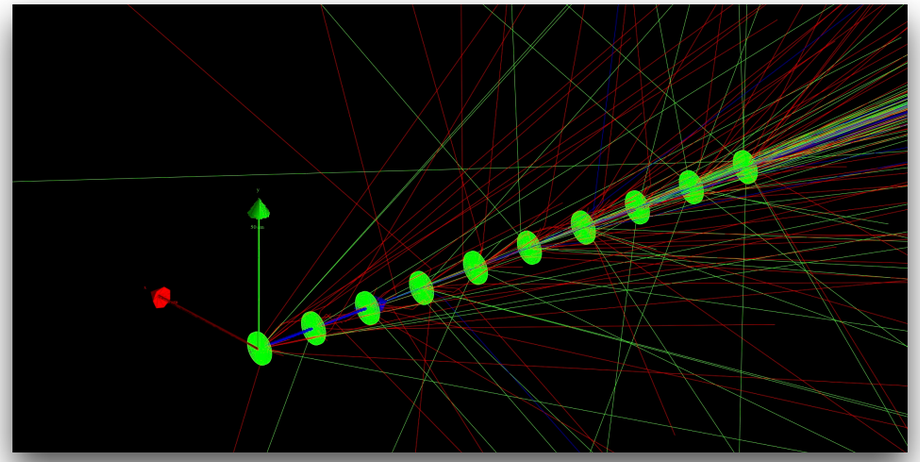
Positron spot size X target after target



Positron energy

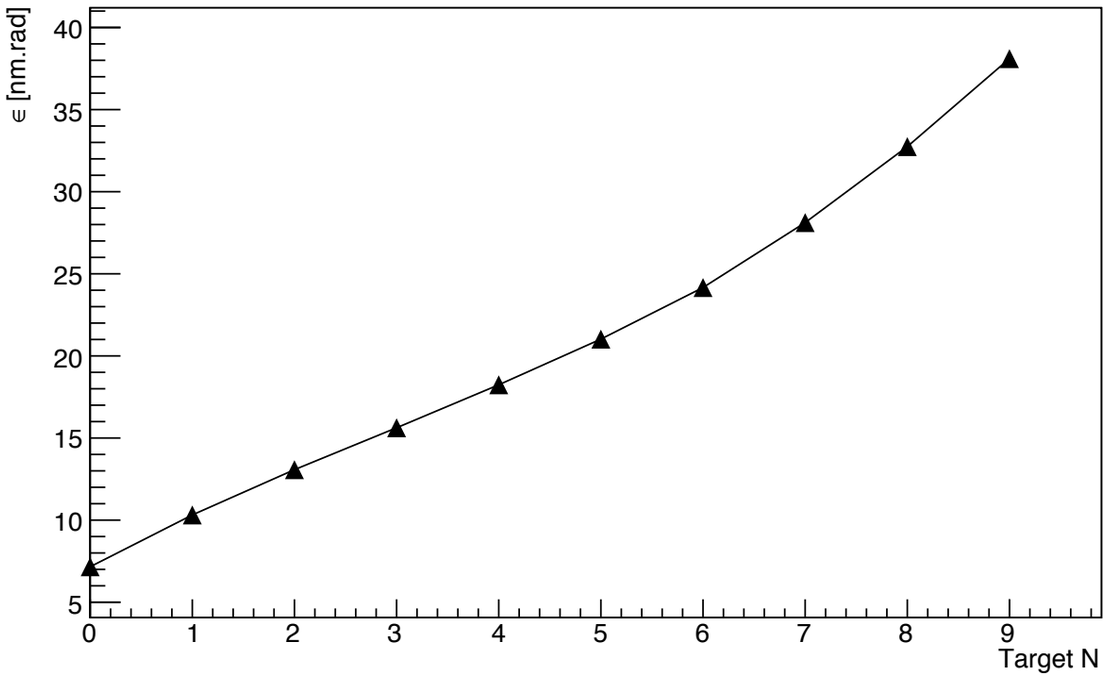


SIMULATION RESULTS

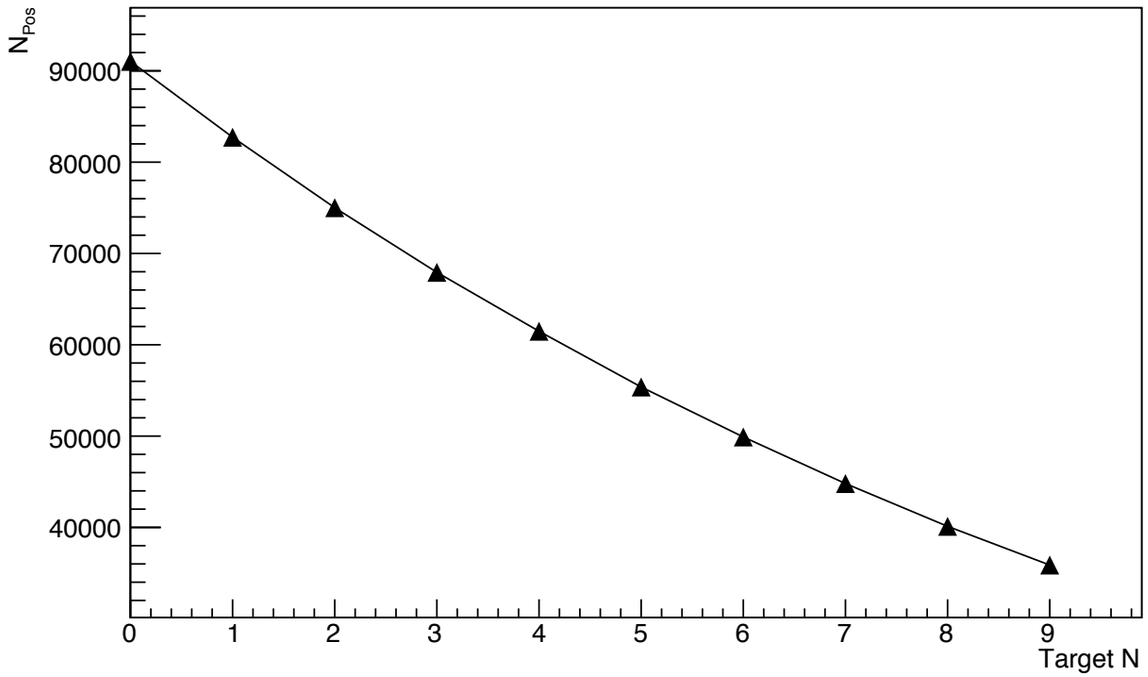


- 45 GeV positrons
- 10x1cm Be targets

Positron horizontal emittance

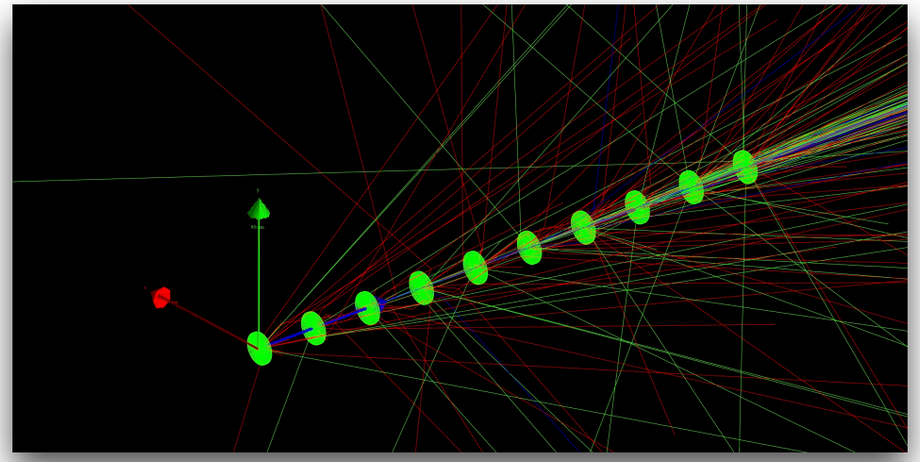


Positron survival (+-5% en. acc.)

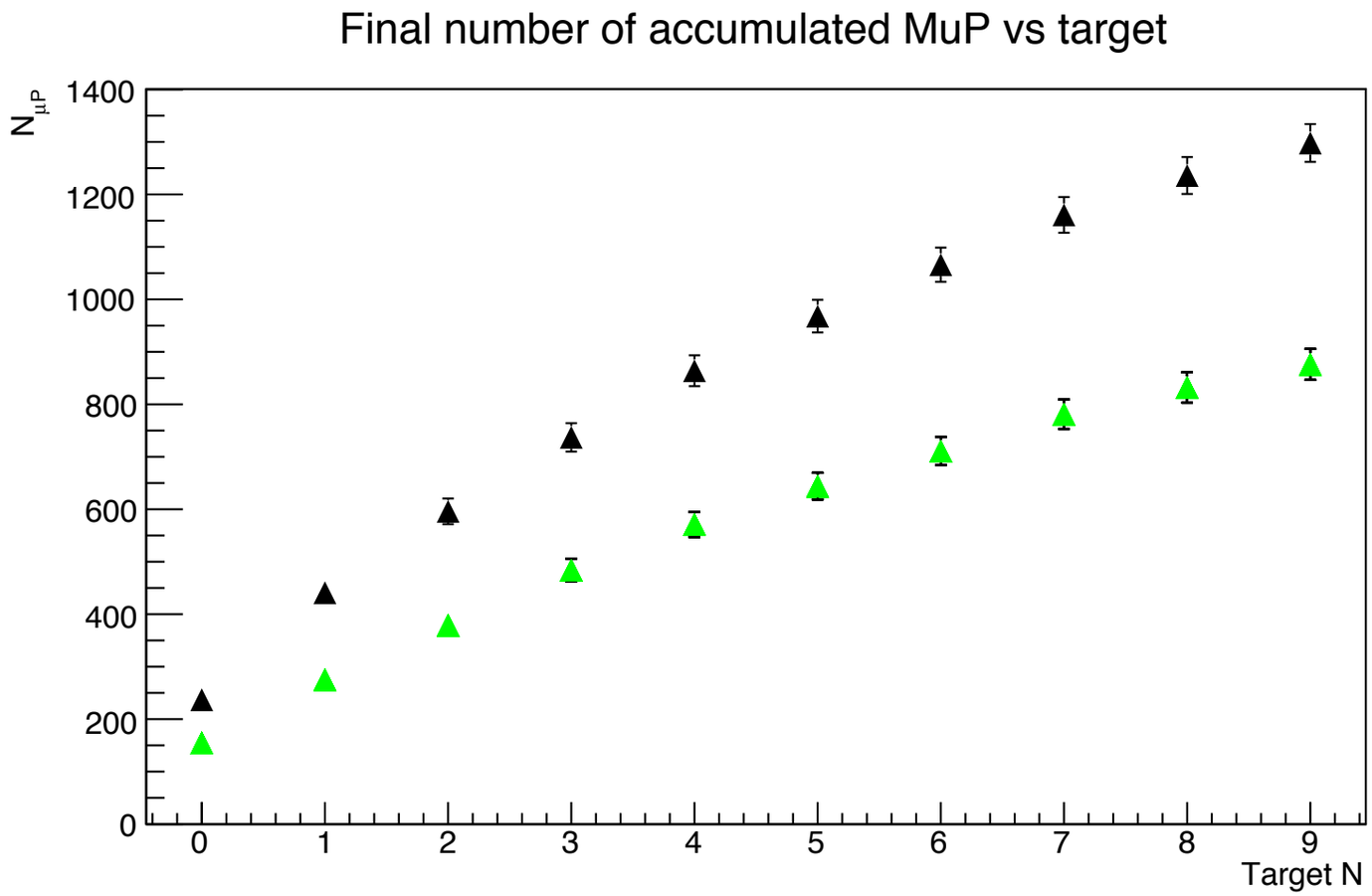


More than the 60% of the primary positron beam is lost after 10 targets

SIMULATION RESULTS

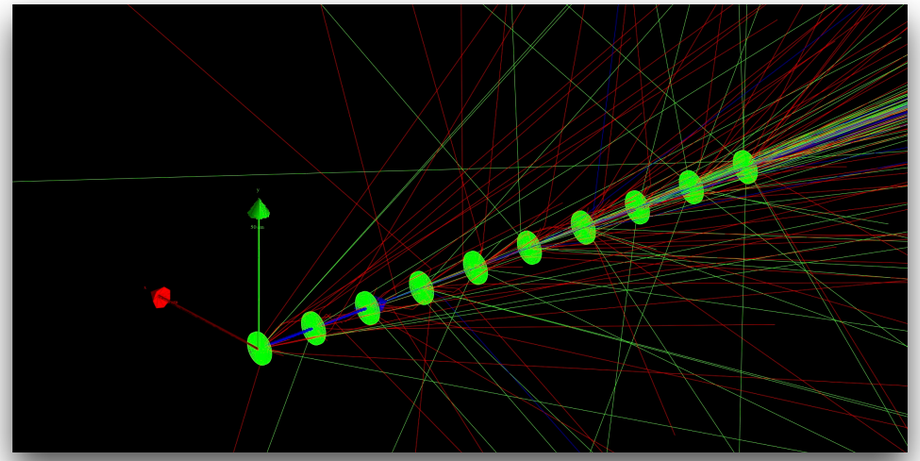


- 45 GeV positrons
- 10x1cm Be targets

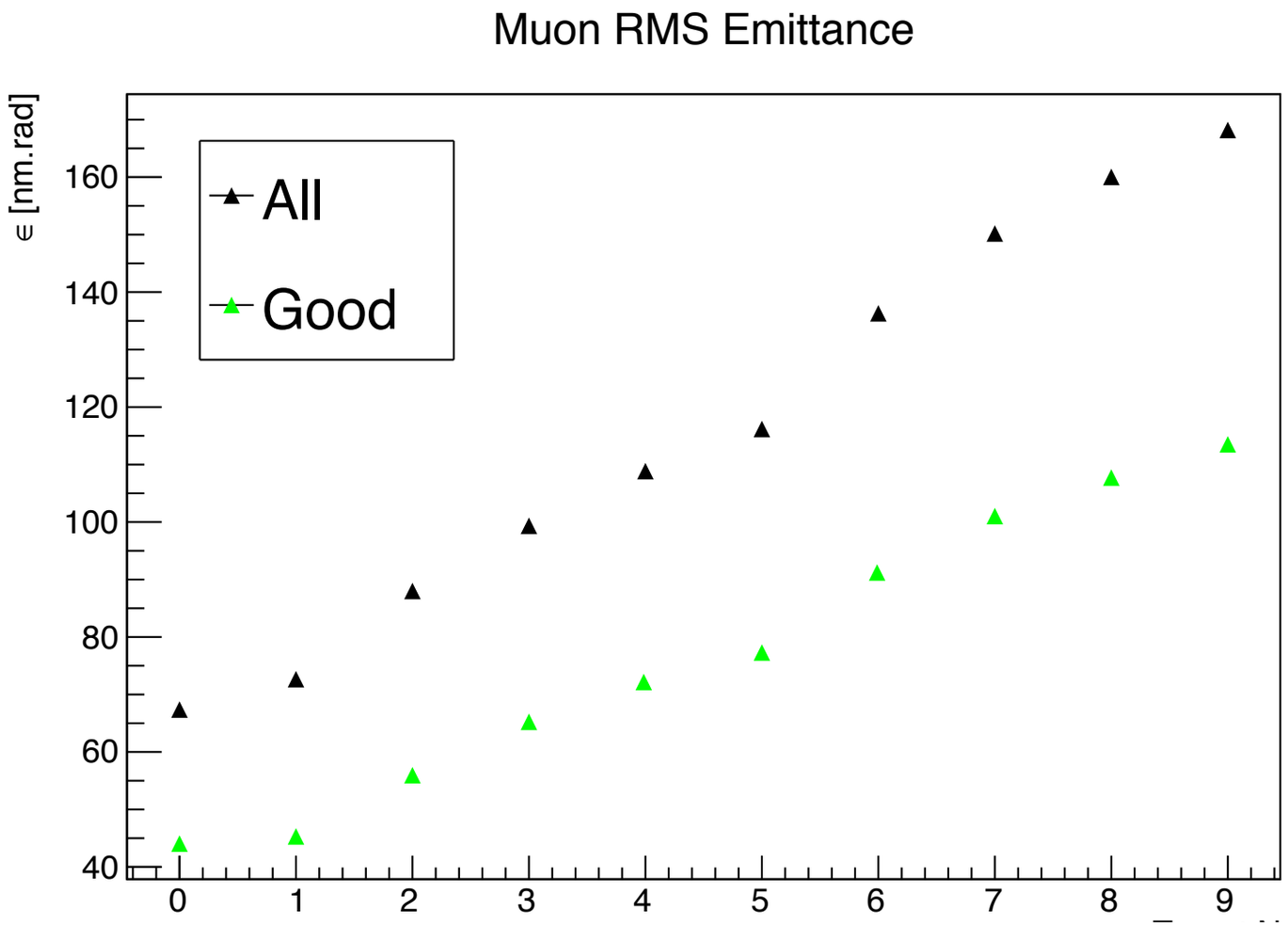


Mu energy acceptance +8-12%
(see Blanco's talk)

SIMULATION RESULTS



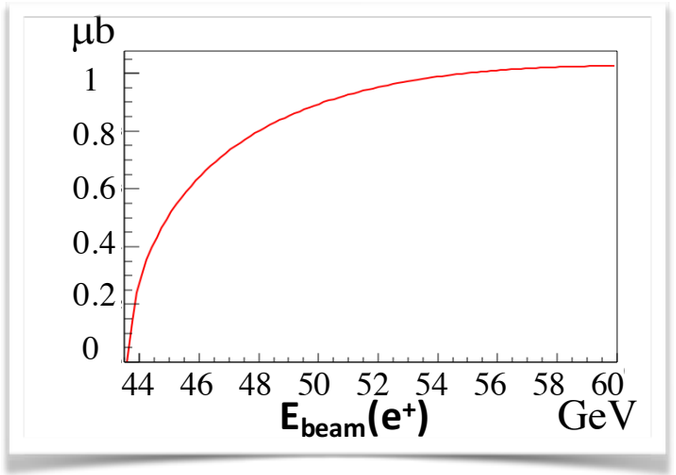
- 45 GeV positrons
- 10x1cm Be targets



Mu energy acceptance +8-12%
(see Blanco's talk)

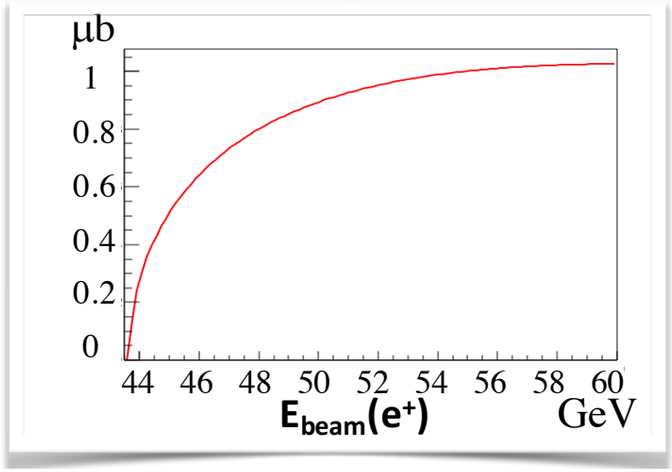
SIMULATION RESULTS

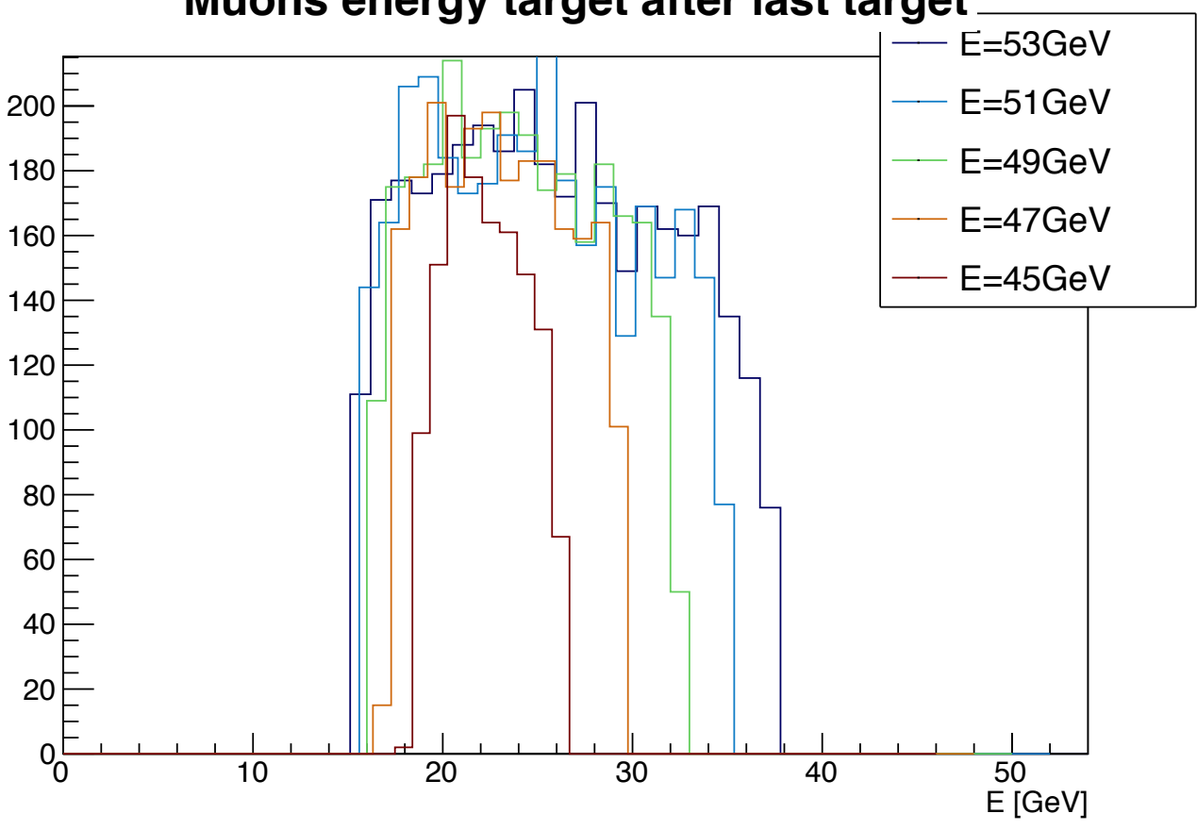
What happens if we rise the beam energy?

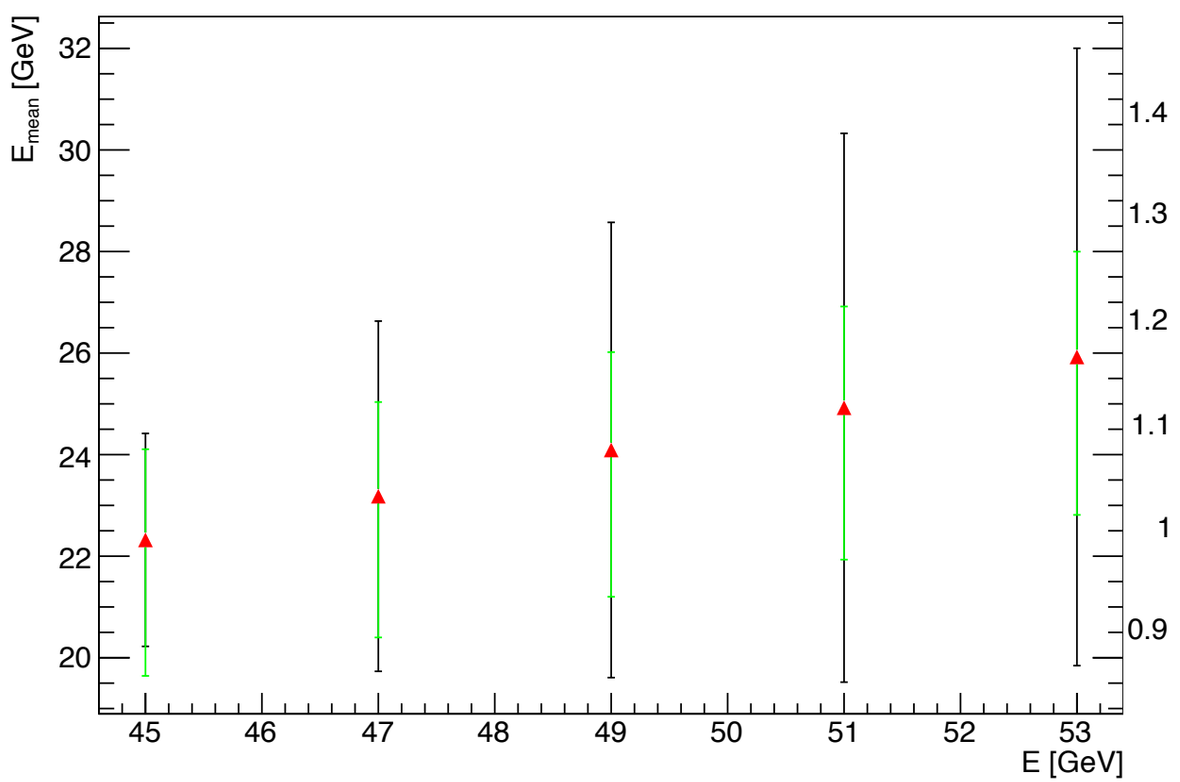


SIMULATION RESULTS

What happens if we rise the beam energy?



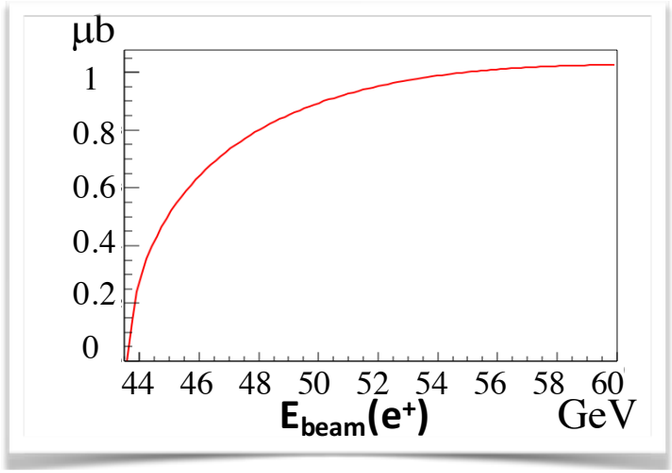




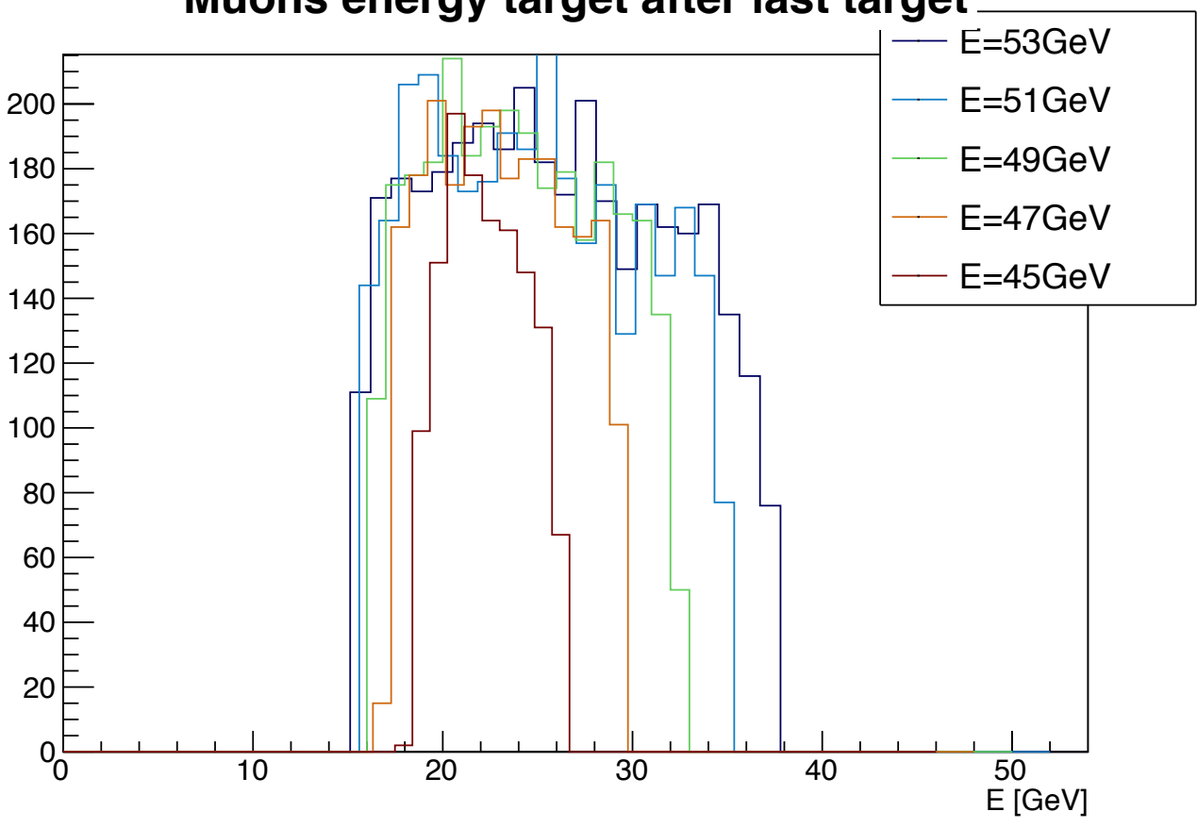
Mu energy acceptance +8-12%
(see Blanco's talk)

SIMULATION RESULTS

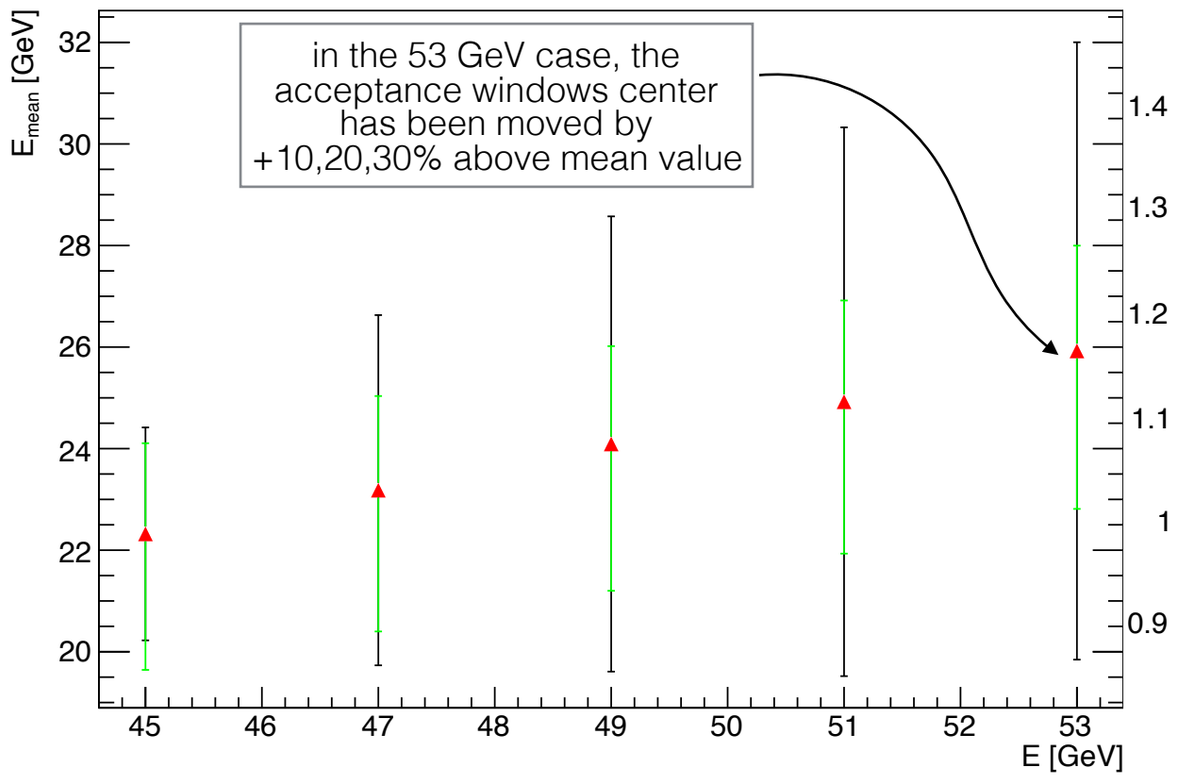
What happens if we rise the beam energy?



Muons energy target after last target



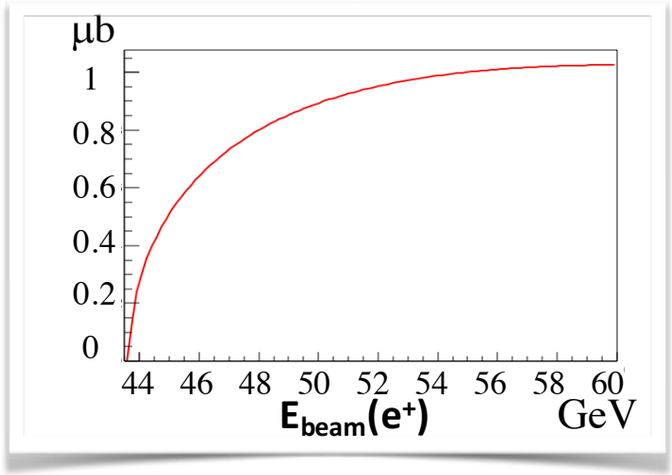
Mean energy (+- RMS) of muons after last target

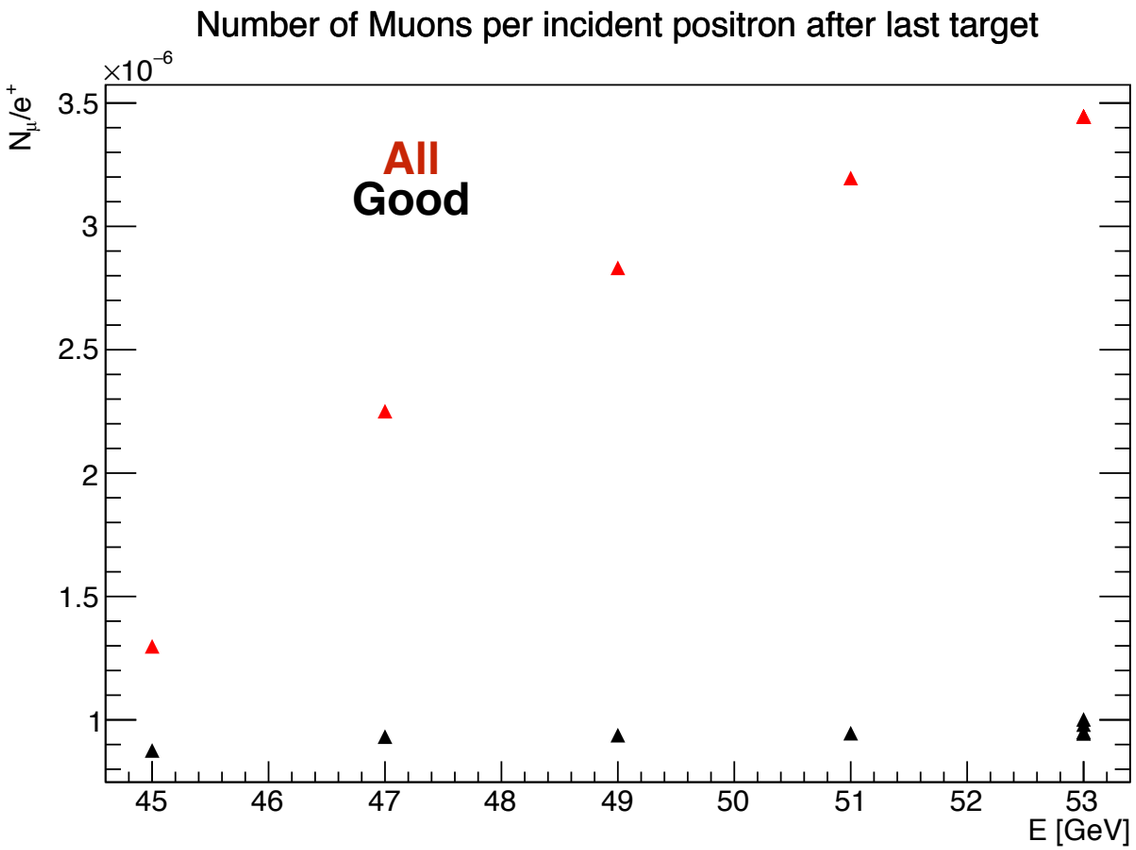


Mu energy acceptance +8-12%
(see Blanco's talk)

SIMULATION RESULTS

What happens if we rise the beam energy?



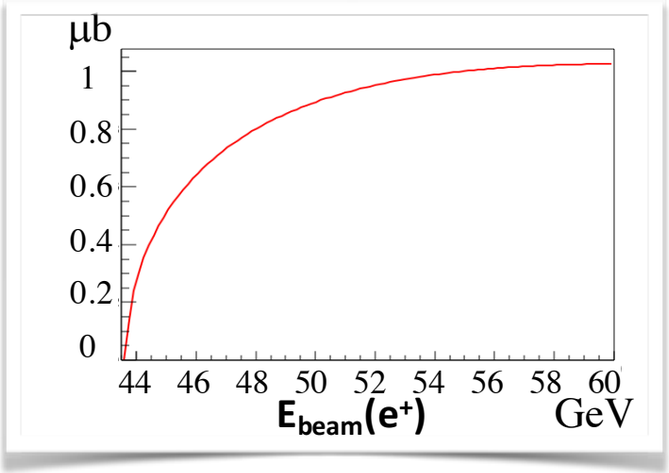


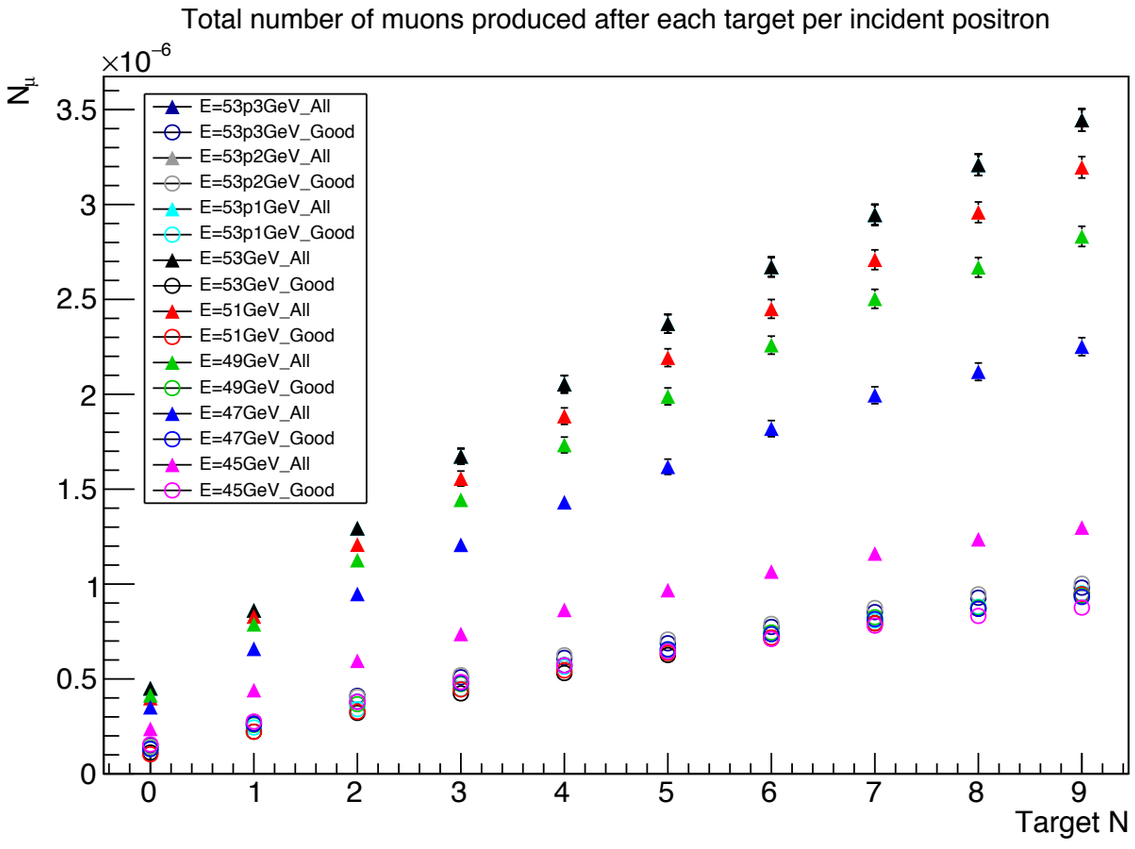
- ✦ 45 GeV positrons
- ✦ 10x1cm Be targets

- ➡ Rising the energy, there is a significant **increase** in the total **number** of **produced muons**
- ➡ The increase is much less evident if we select “good” muons

SIMULATION RESULTS

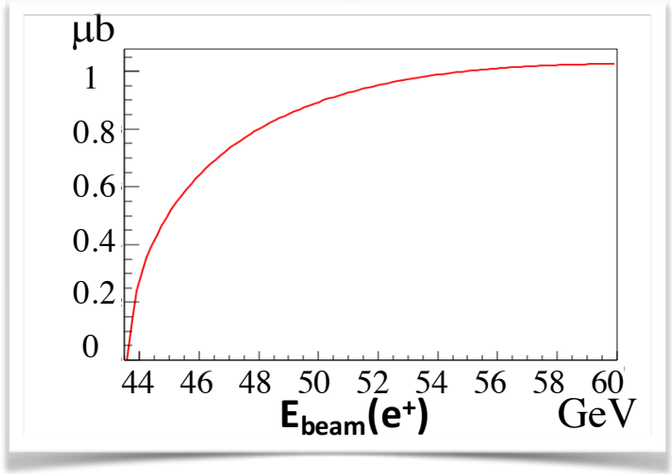
What happens if we rise the beam energy?

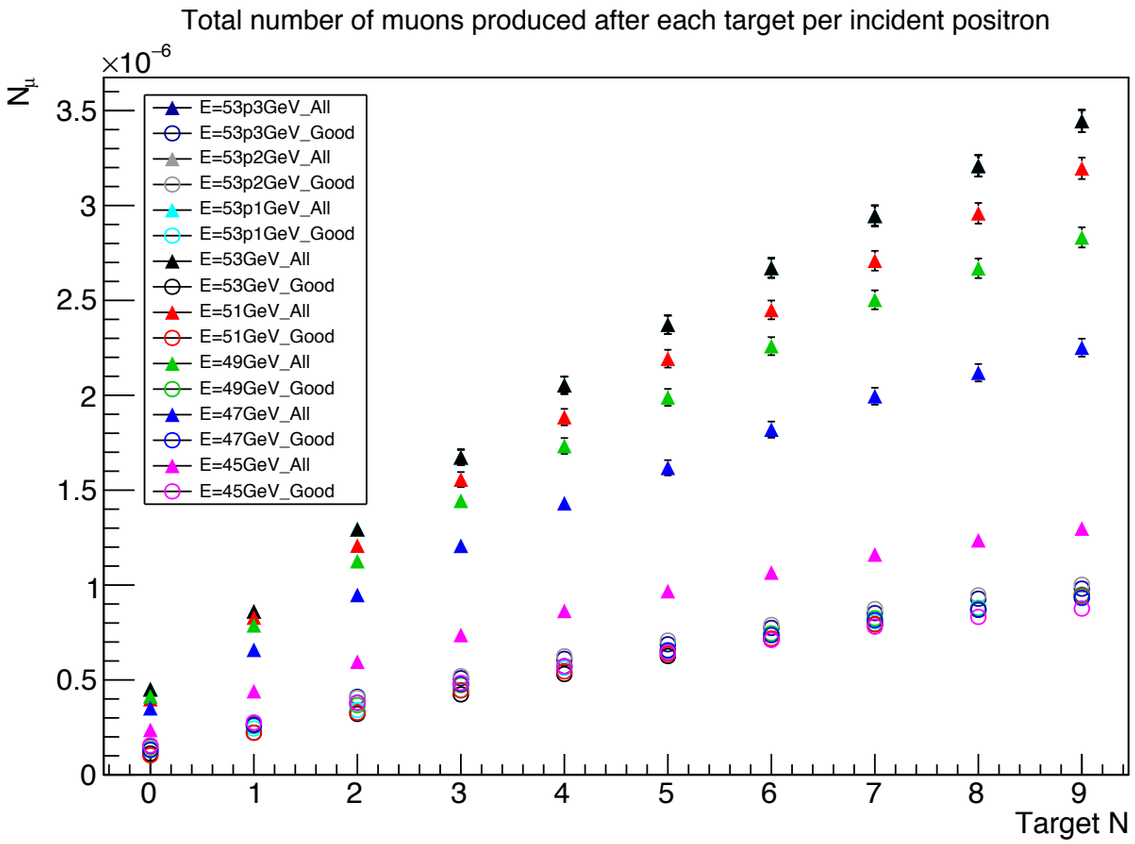


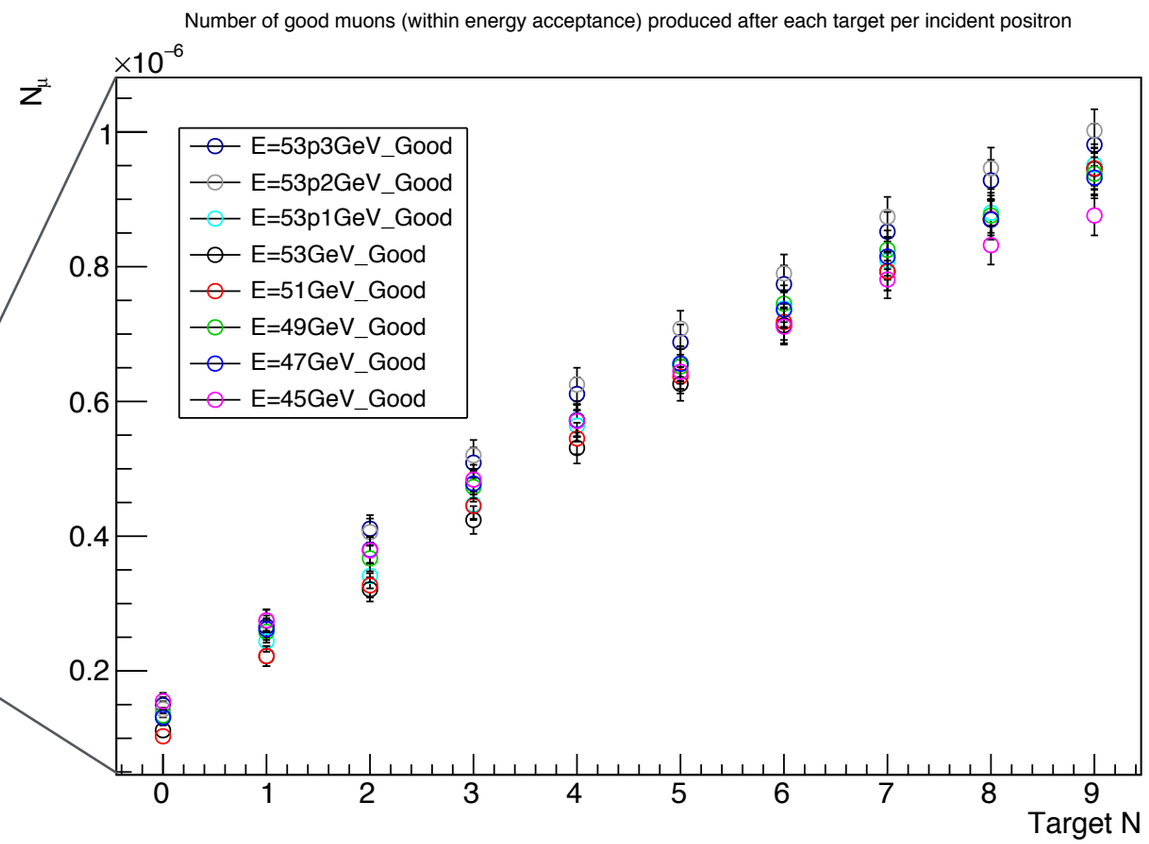


SIMULATION RESULTS

What happens if we rise the beam energy?

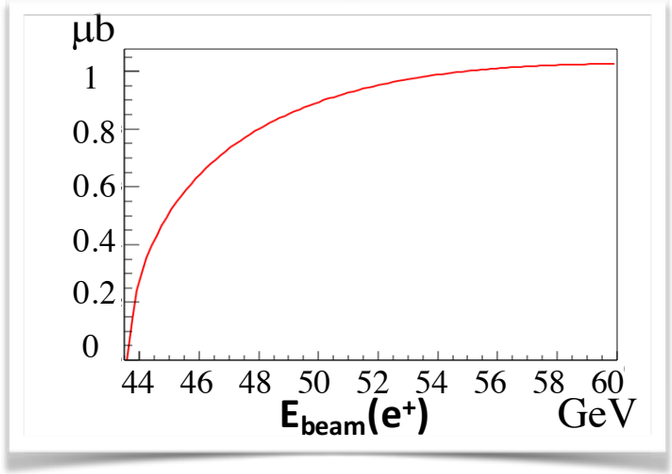


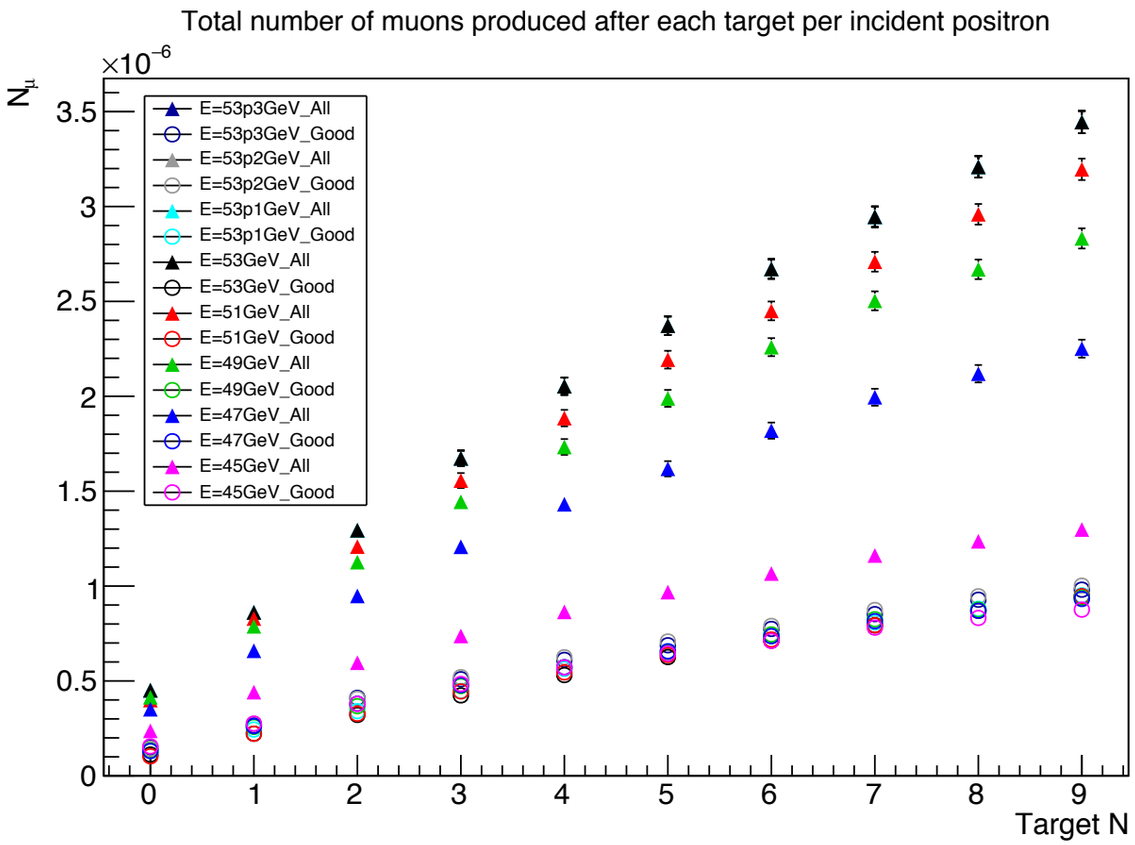


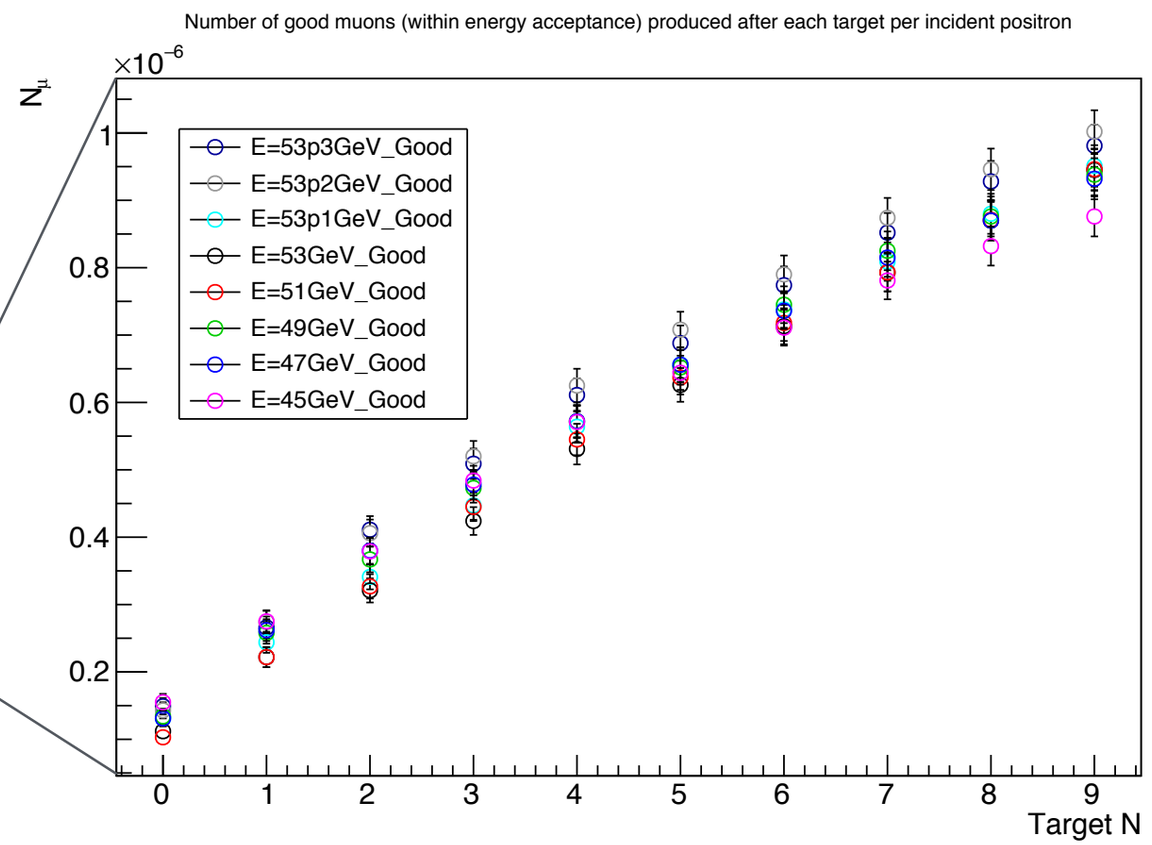


SIMULATION RESULTS

What happens if we rise the beam energy?



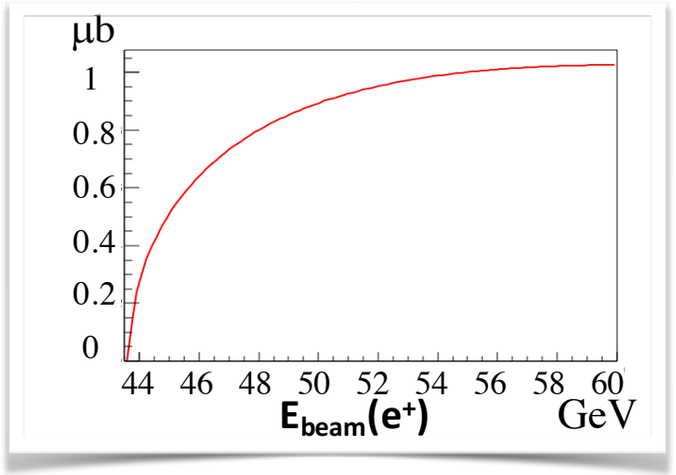


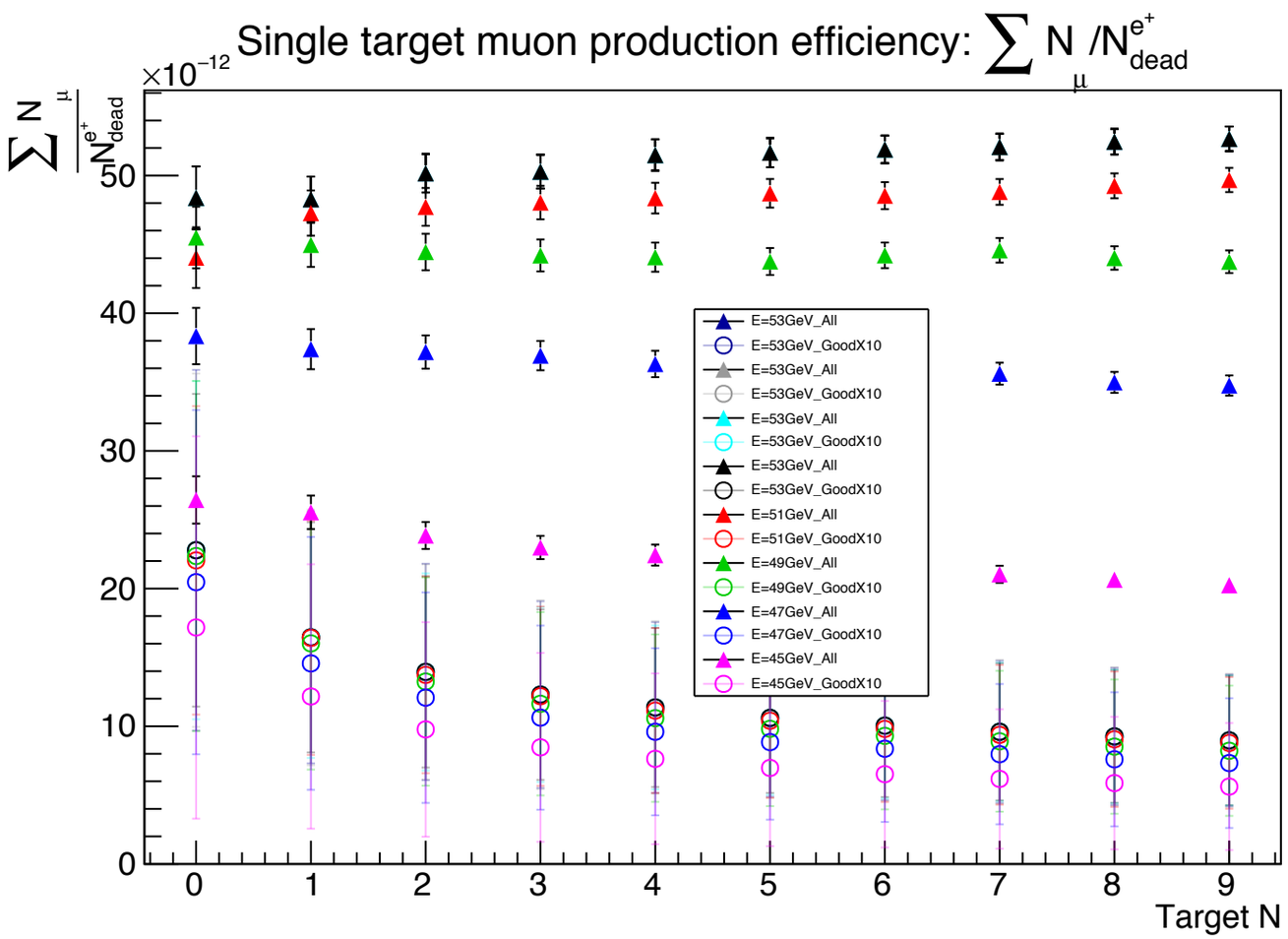


- ➡ Best configuration @last target:
  - E=53GeV
  - Collection window centred at 26.3 GeV (23.2-28-.4)
- ➡ ~10% increase

SIMULATION RESULTS

What happens if we rise the beam energy?





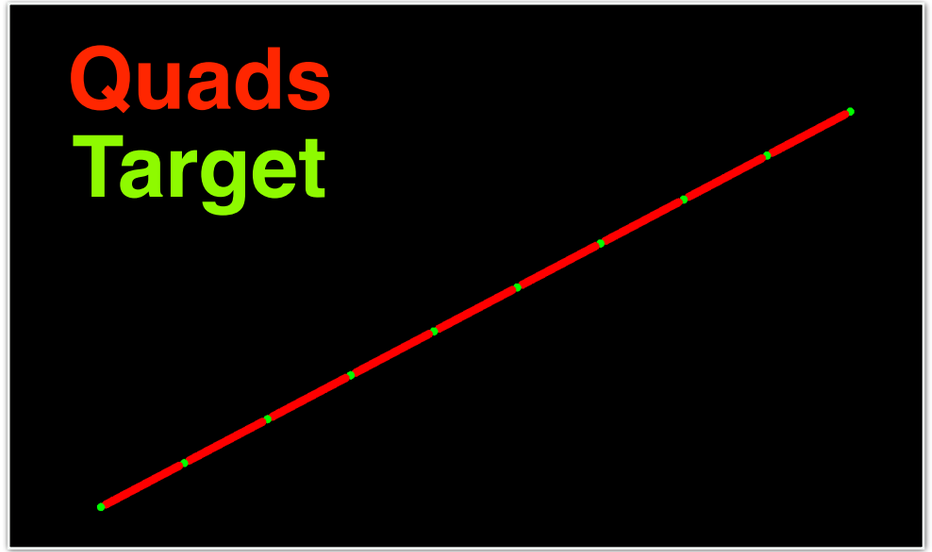
Number of muons alive/good after the N-target vs number of positrons put outside energy acceptance by the N-target

➡ **Tradeoff** between amount of muons produced ad positron beam degradation

MULTI IP MULTI TARGET LINE

MULTI IP
MULTI TARGET
LINE

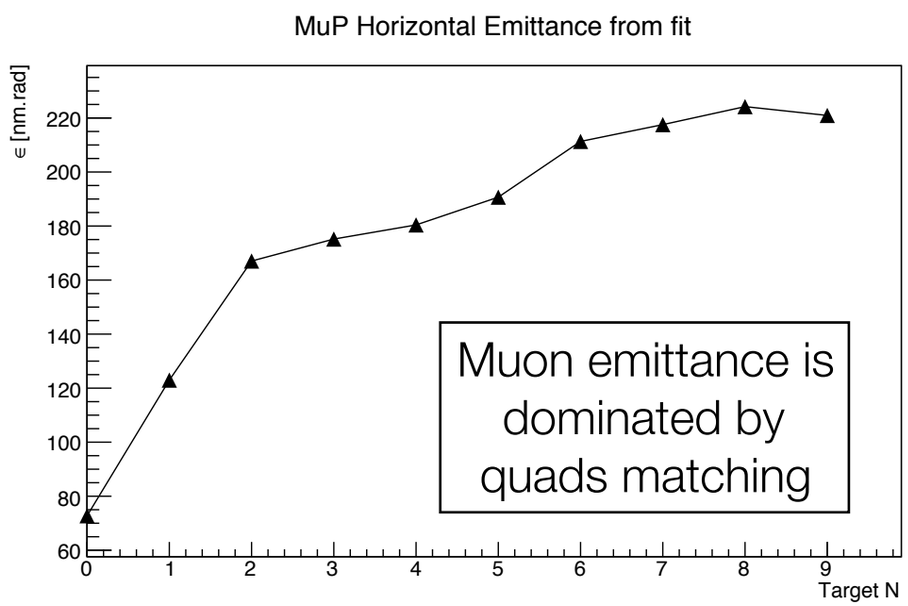
✦ The software tool allows to import any optics line in Geant4 to perform the same study



✦ **Powerful**.. but **complicated**!

✦ The optics contribution becomes crucial

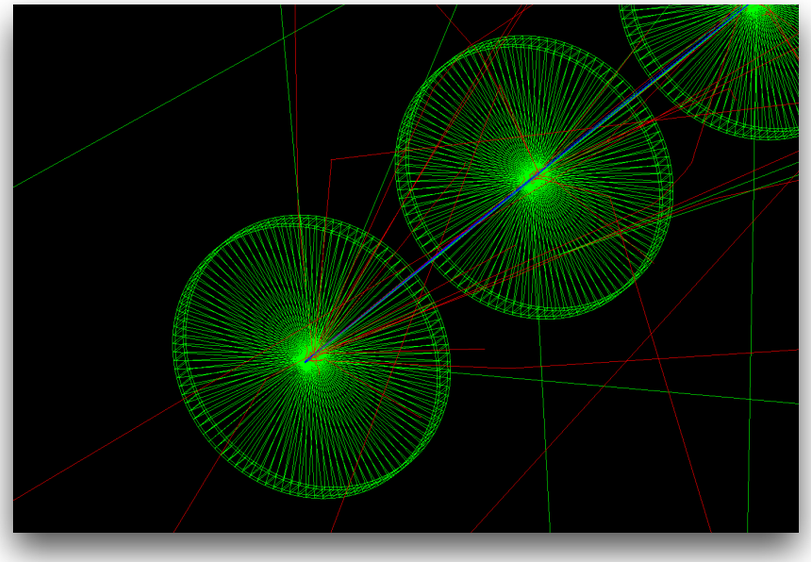
➡ 10 Beryllium targets
➡ 3 mm thick each
➡ 45 m total z length



POWER LOAD CONSIDERATIONS

POWER LOAD CONSIDERATIONS

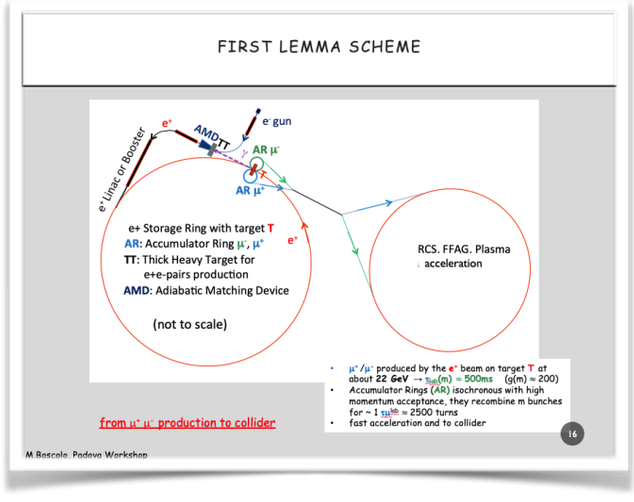
✦ To compensate for the low cross section, a huge amount of ~45 GeV positrons must collide with the target



➜ **power deposition** and **target temperature** must be kept under control

✦ The detailed study of power deposition had been developed in the “LEMMA-0 scheme”

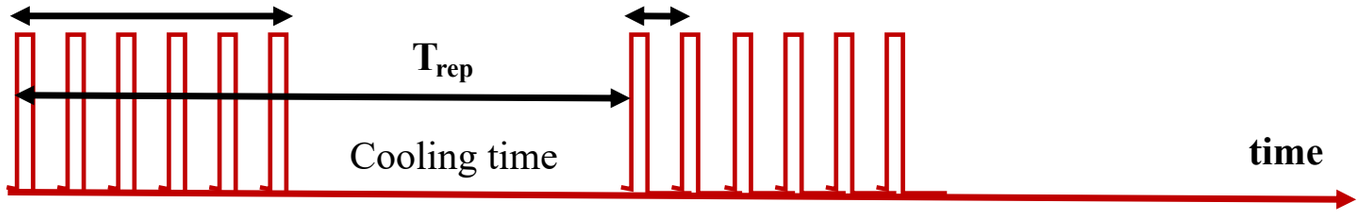
✦ Energy deposition is simulated with FLUKA, and dedicated codes are used to simulate heat propagation, dissipation, steady state temperature…



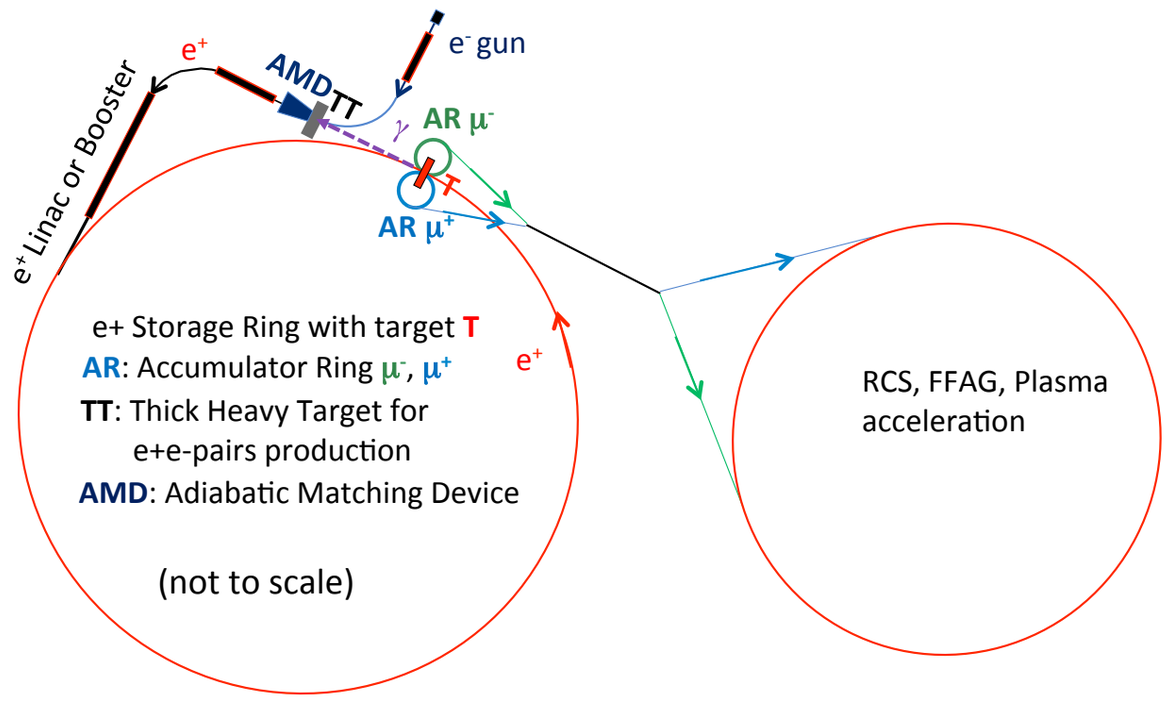
Ref: “Theoretical modeling for the thermal stability of solid targets in LEMMA muon collider” - G. Cesarini, HiRadMat 2019

POWER LOAD CONSIDERATIONS

Symbol	Description	Reference Value
a	Gaussian beam spot size	300 μm
τ	bunch duration	10 ps
Npart	positron number	$3 \cdot 10^{11}$
Npulses	number of consecutive bunches	100
Tpulse	time between two bunches	400 ns
Theating	total time of N_{pulses}	40 μs
Trep	repetition time of the N_{pulses} sequence	0.1 s

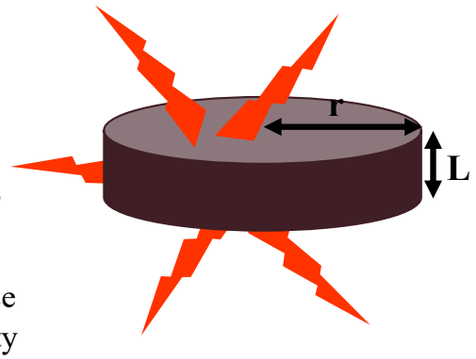


- ✦ “LEMMA0” Scheme
- ✦ 45 GeV positrons
- ✦ 1x3mm targets
- ✦ Beryllium/Carbon



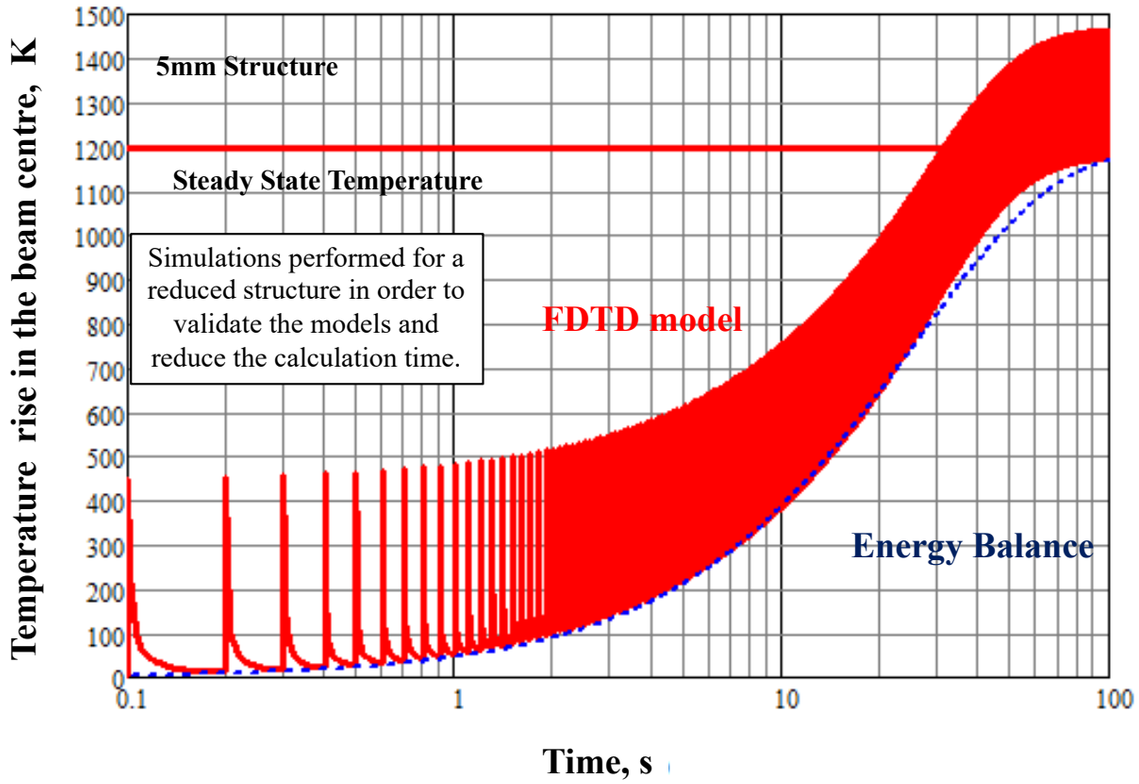
STEADY STATE TEMPERATURE

$$\Delta T = \sqrt{T_{amb}^4 + \left(\frac{a^2 \cdot L}{r^2 + r \cdot L}\right)\frac{C_{\max,a} \cdot N_{part} \cdot N_{pulses}}{\varepsilon \cdot \sigma_B \cdot T_{rep}}} - T_{amb}$$

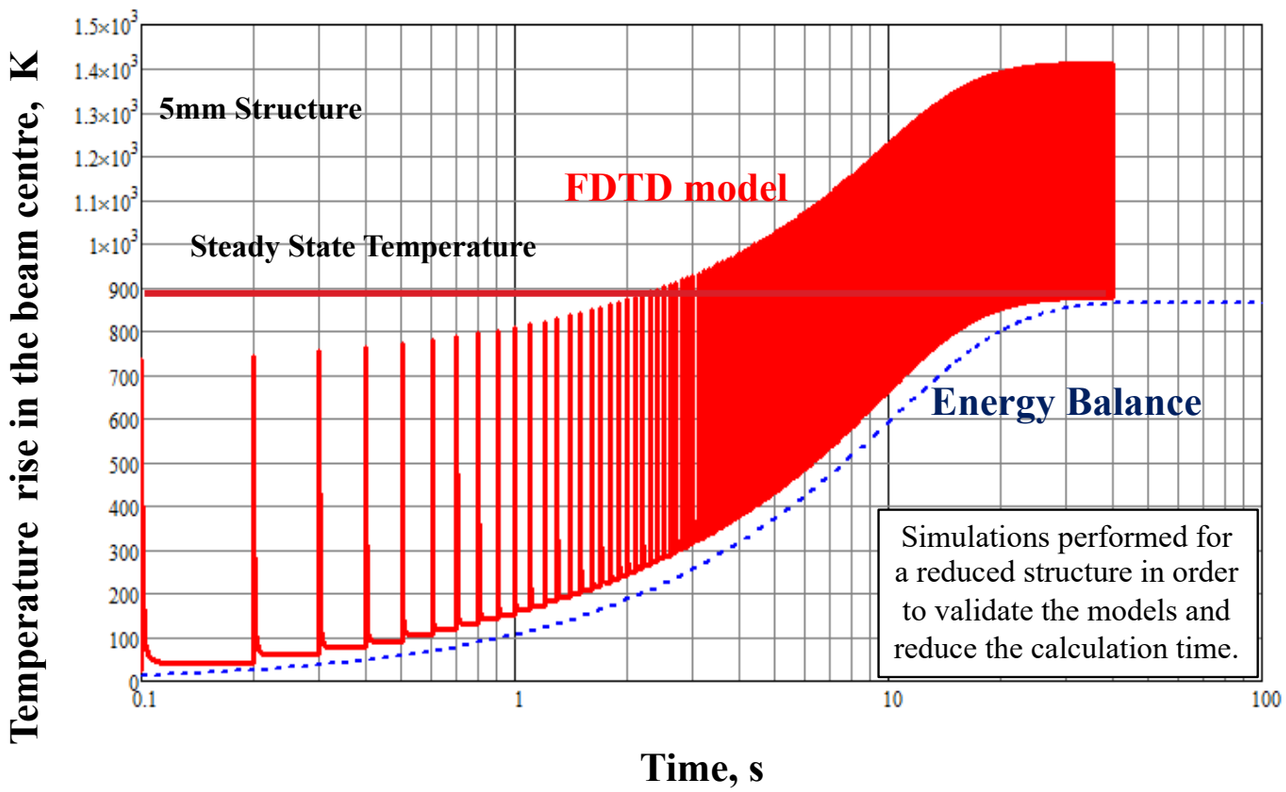


ε emissivity, $\boldsymbol{\sigma_B}$ Stefan-Boltzmann constant, $\mathbf{T_{rep}}$ pulse train repetition period, $\mathbf{C_{max,a}}$ deposited energy density peak by the Fluka data

Beryllium



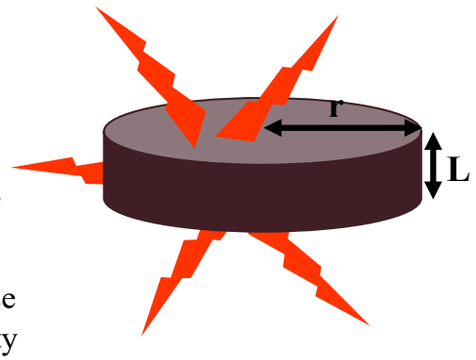
Carbon

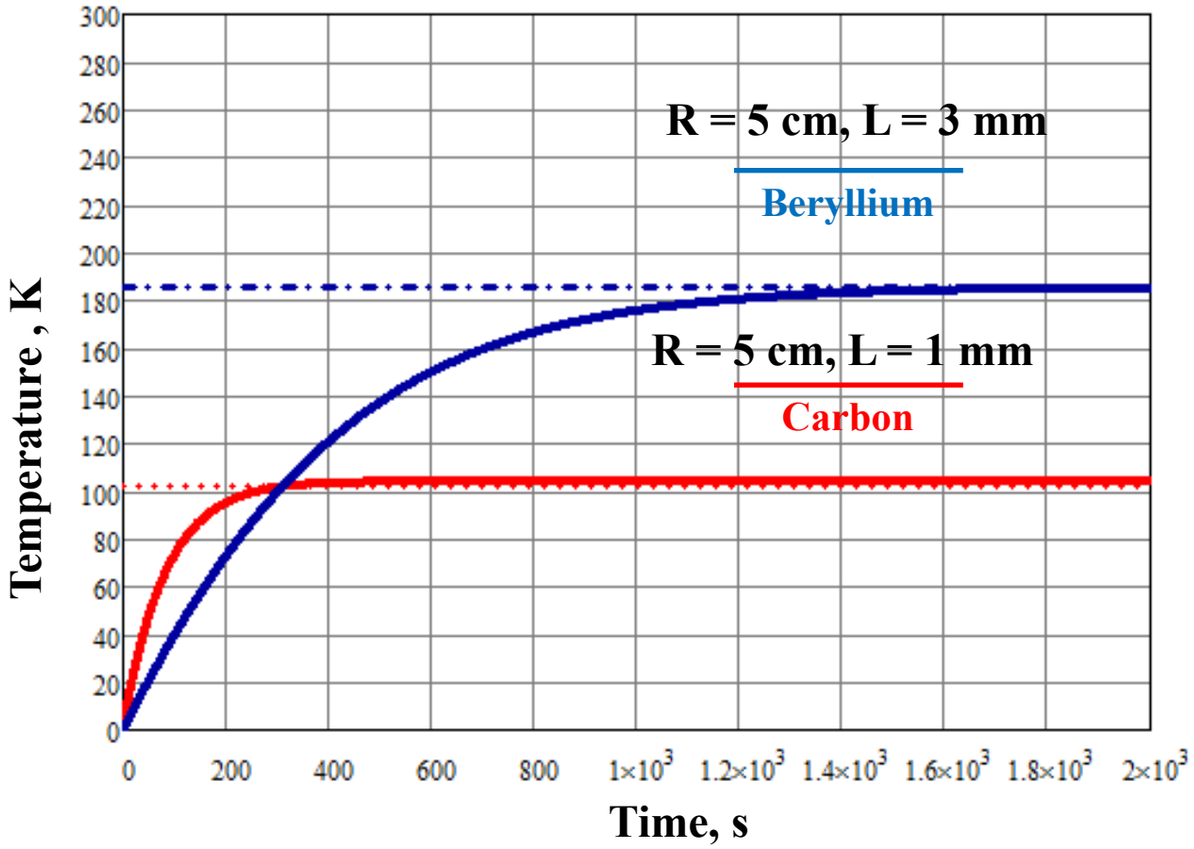


STEADY STATE TEMPERATURE

$$\Delta T = \sqrt{T_{amb}^4 + \left(\frac{a^2 \cdot L}{r^2 + r \cdot L}\right)\frac{C_{\max,a} \cdot N_{part} \cdot N_{pulses}}{\varepsilon \cdot \sigma_B \cdot T_{rep}}} - T_{amb}$$

ε emissivity, $\boldsymbol{\sigma_B}$ Stefan-Boltzmann constant, $\mathbf{T_{rep}}$ pulse train repetition period, $\mathbf{C_{max,a}}$ deposited energy density peak by the Fluka data





Beryllium target

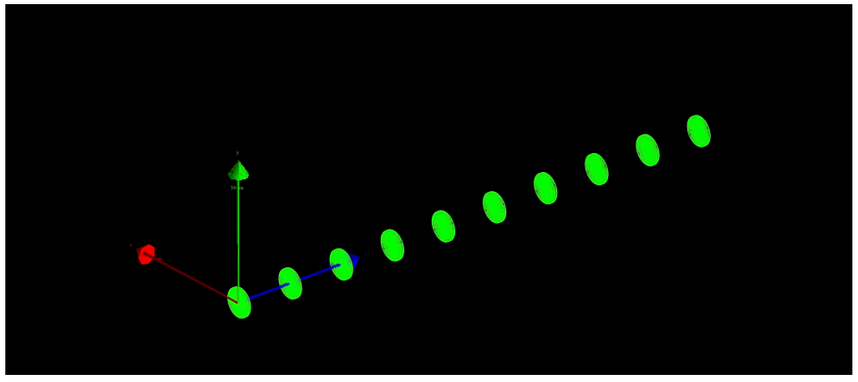
radius r = 5 cm, thickness L = 3 mm;
Steady state temperature increase: ΔT_{SS}=185.5 K
Melting point: 1551 K

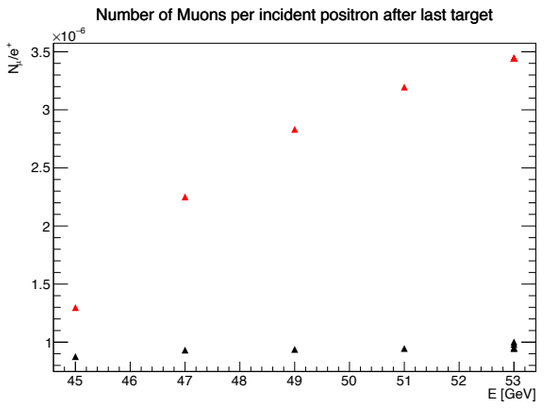
Carbon target

radius r = 5 cm, thickness L = 1 mm;
Steady state temperature increase: ΔT_{SS}=102.5 K
Melting point: 3923 K

MUON PRODUCTION TARGET: **SUMMARY**

- ✦ A powerful Monte Carlo simulation has been developed
- ✦ As a first approach, a “Single IP - Multi Target Line” has been simulated
  - ➡ 10 Berillium targets
  - ➡ 1 cm thick each
  - ➡ 2 m total z length

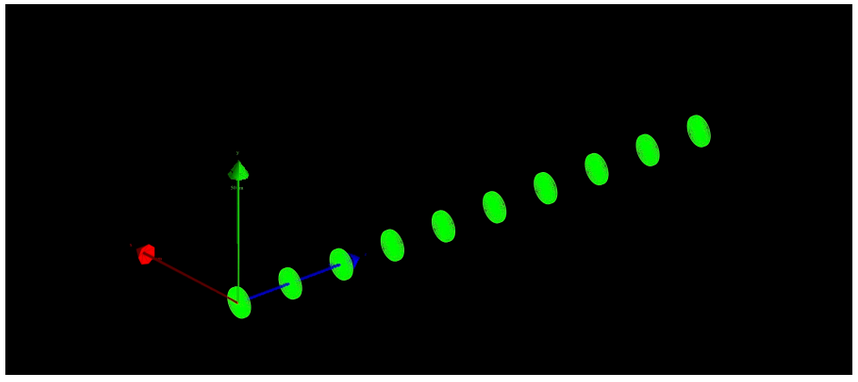


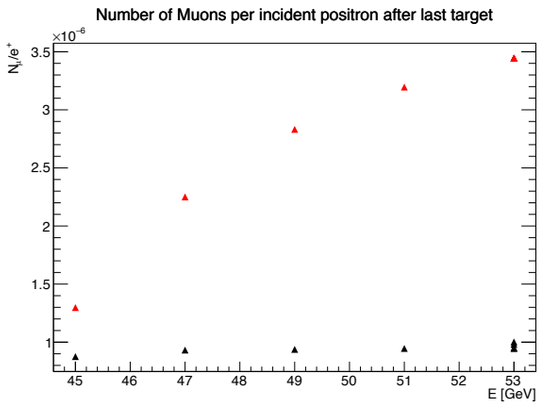


- ✦ **Rising** the positron beam **energy** leads to a greater number of muons (x3), but the **advantage** is strongly **reduced** (+10%) after muon collection **cuts**
- ✦ An **optimal working point** must be identified as the best **tradeoff** between muon production, positron degradation and power load on the target
- ✦ A software algorithm to analyse power deposition has been developed in the LEMMA0 scheme, and is going to be applied also in the actual LEMMA scheme
- ✦ *+ new target options…*

MUON PRODUCTION TARGET: **SUMMARY**

- ✦ A powerful Monte Carlo simulation has been developed
- ✦ As a first approach, a “Single IP - Multi Target Line” has been simulated
  - ➡ 10 Berillium targets
  - ➡ 1 cm thick each
  - ➡ 2 m total z length



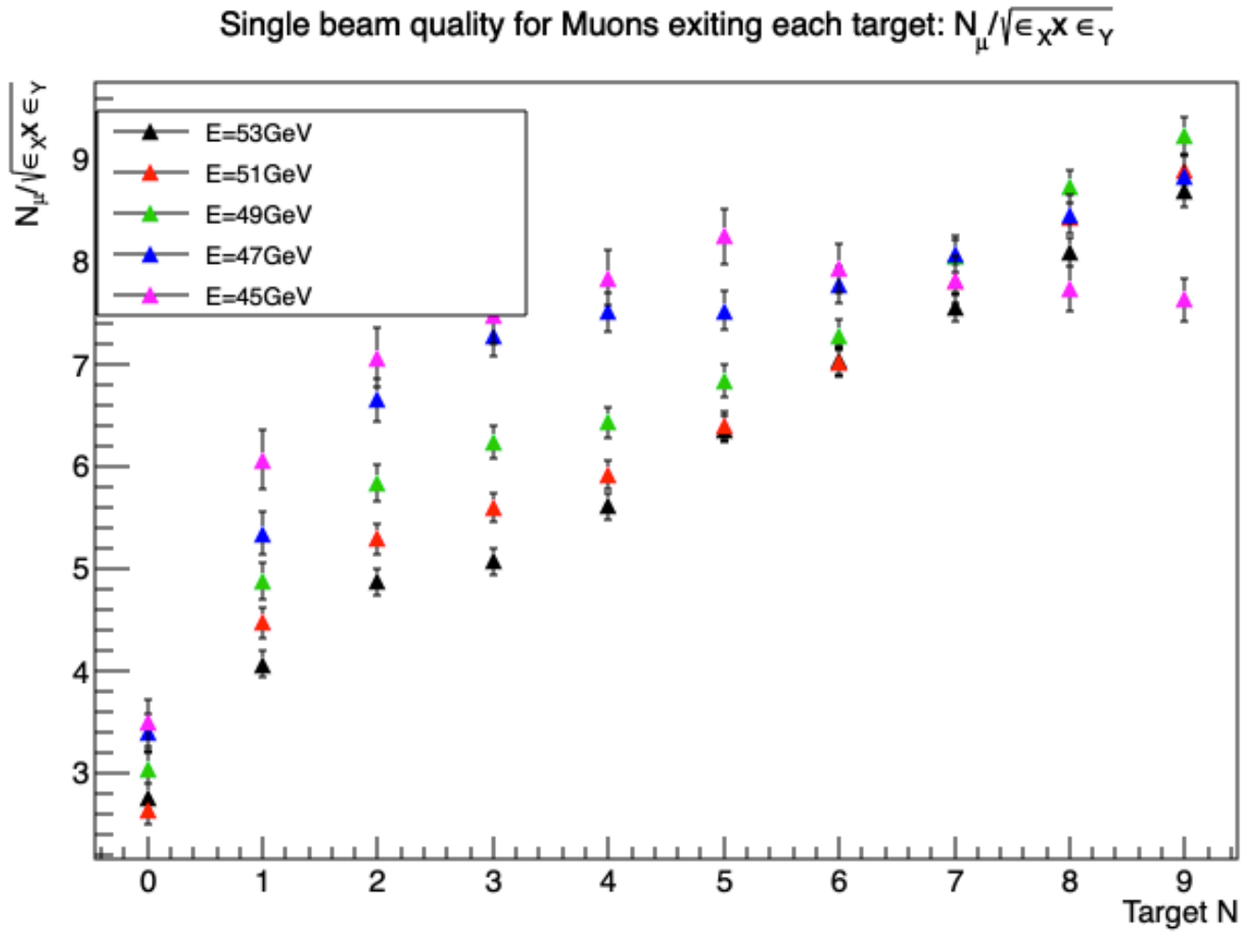


- ✦ **Rising** the positron beam **energy** leads to a greater number of muons (x3), but the **advantage** is strongly **reduced** (+10%) after muon collection **cuts**
- ✦ An **optimal working point** must be identified as the best **tradeoff** between muon production, positron degradation and power load on the target
- ✦ A software algorithm to analyse power deposition has been developed in the LEMMA0 scheme, and is going to be applied also in the actual LEMMA scheme
- ✦ *+ new target options…*

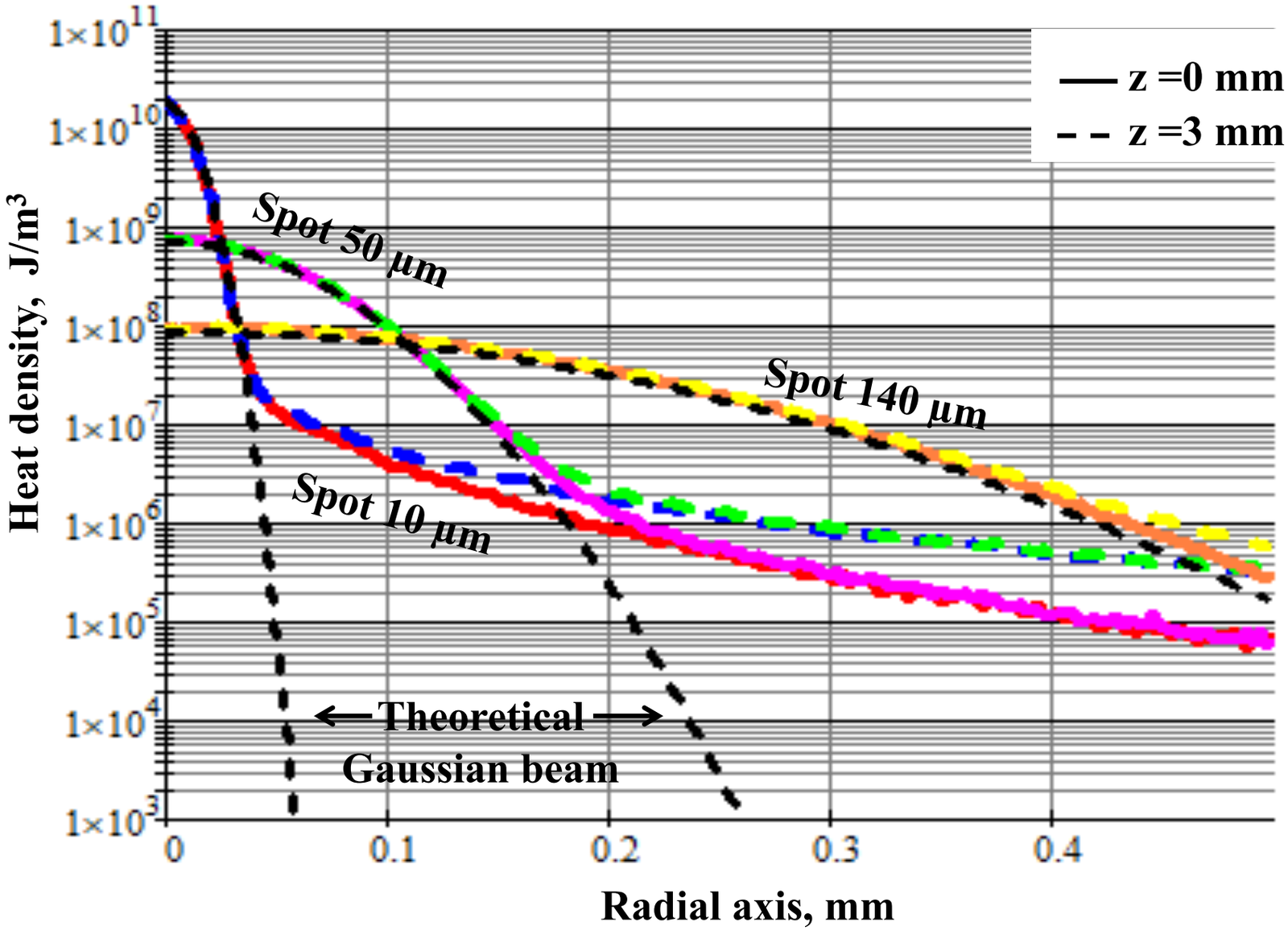
Thank you for your attention!

BACKUP

SIMULATION RESULTS



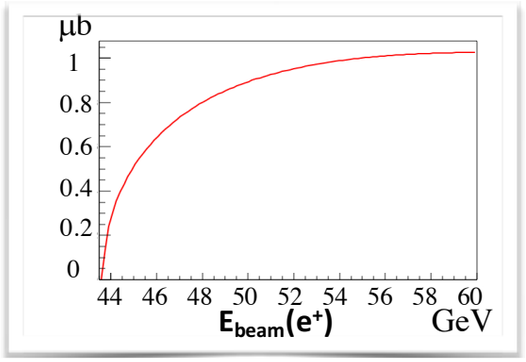
SIMULATION RESULTS



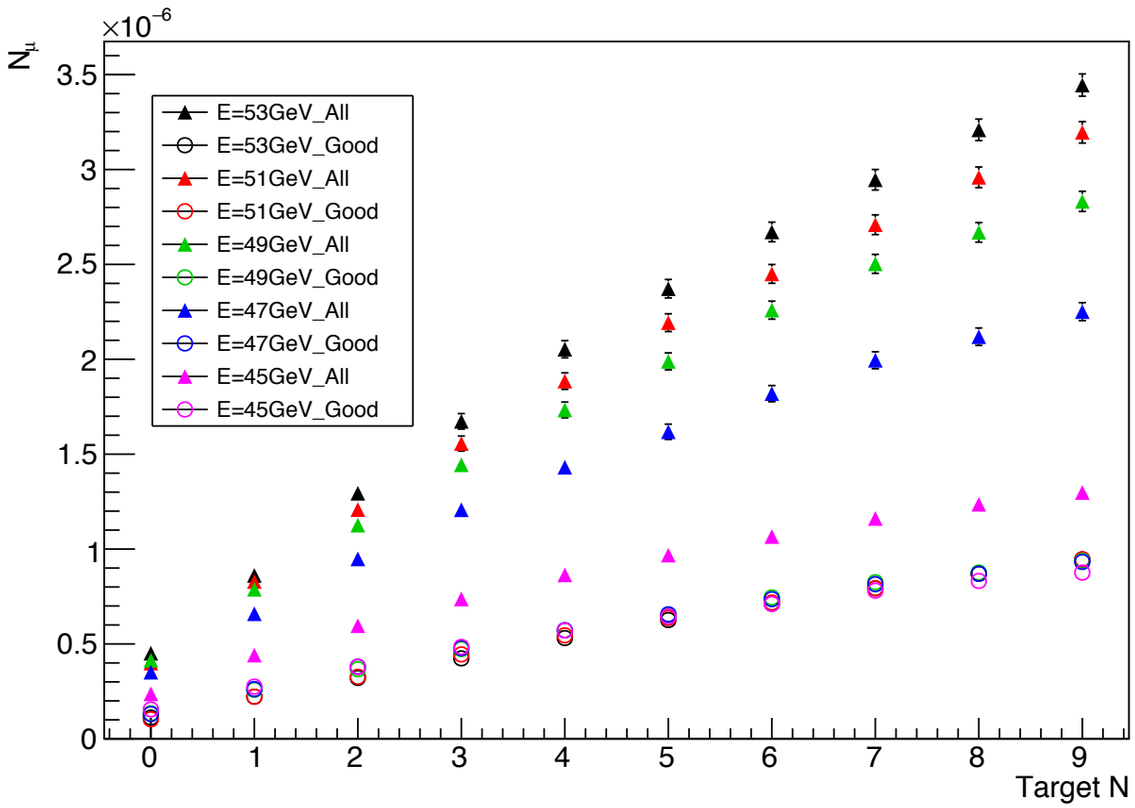
Muons energy target after target

SIMULATIO N RESULTS

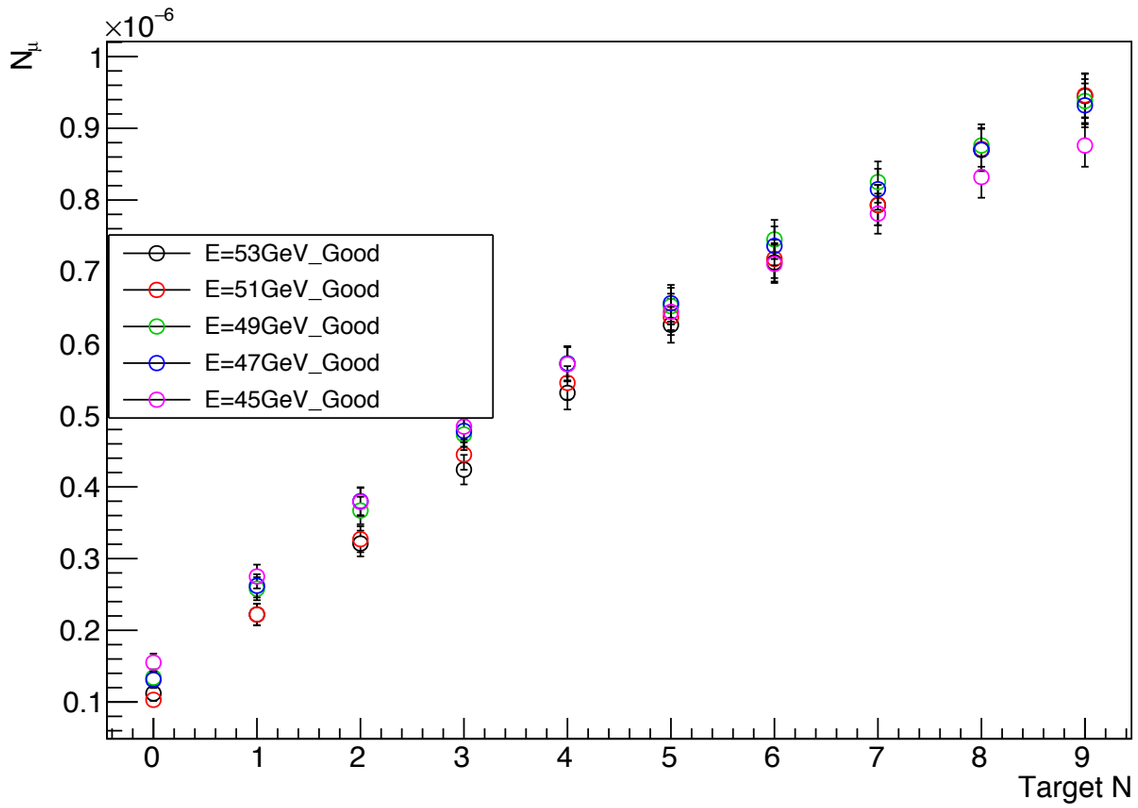
What happens if we rise the beam energy?



Total number of muons produced after each target per incident positron



Number of good muons (within energy acceptance) produced after each target per incident positron



THE MUON PRODUCTION ISSUE

- **CAVEAT**: the muon production **cross section** has been artificially **biased**
  - To see enough muons in a reasonable amount of CPU time
  - ~x10^3 factor, then properly taken into account in following plots
  - What effect on positrons' survival?