Muon Target Simulations

Adriana Bungau
(Bob Cywinski)

University of Huddersfield

Motivation

....an FP6 NMI3 funded workshop at the Cockcroft Institute, Daresbury, in April 2008

Motivation

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Towards a dedicated high-intensity muon facility

R. Cywinski [a,*], A.E. Bungau [a], M.W. Poole [b], S. Smith [b], P. Dalmas de Reotier [c], R. Barlow [d], R. Edgecock [e], P.J.C. King [e], J.S. Lord [e], F.L. Pratt [e], K.N. Clausen [f], T. Shiroka [f]

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[b] ASTeC, STFC Daresbury Laboratory, Warrington, Cheshire WA4 4AD, UK
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Keywords:
Stand-alone muon sources
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ABSTRACT

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1. Introduction

The production of high-intensity, spin-polarised muon beams is intrinsically related to the availability of secondary pion beams, the generation of which, in turn, requires the use of high-intensity proton accelerators. The high costs related to accelerator construction and operation have resulted in the so-called multi-purpose facility model, where muon, neutron and particle physics experiments are carried out at the same facility, typically running a medium energy (~800 MeV) accelerator.

This co-existence, at best symbiotic and at worst parasitic, was understandable in the early days of μSR, when the technique was still in its infancy and the user community rather small. However, the resulting paradigm is a compromise in which many muon beam parameters are far from optimal, thereby limiting the potential of the μSR method and often precluding developments which could be realised at a dedicated source.

Today, when μSR has a wide user base and is a well established and powerful tool in condensed matter science which complements, and in some cases competes with neutron scattering [1,2], there are good reasons to investigate other models of muon beam delivery. Indeed there is a growing consensus that the concept of a stand-alone muon source is most certainly worth pursuing [3].

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Motivation

A stand-alone optimised muon facility could deliver x100 intensity gains in pulsed mode and comparable intensity to PSI in CW mode

A 1Gev, 0.5mA Fixed Field Alternating Gradient proton accelerator at KHz frequencies would be an appropriate and cost effective driver

	Cyclotron	FFAG	Synchrotron
Energy ~ 1 GeV	No	Yes	Yes
Current > 1 mA	Yes	Yes	No
Frequency	CW	0.1 – 2 kHz	30 – 60 Hz
Pulse length	Continuous (~ 1 ns)	10 ns – 1 μs	100ns to ~ 1 μs
Beam size ~mm^2	No	Yes	No
Extraction efficiency	Good	Good	Good
Operation	Easy	Easy	Not easy
Maintenance	Hard	Normal	Normal
Static fields	Yes	Yes	No
Size	Moderate	Compact	Very large
Mult. beam extraction	No	Yes	Difficult
Construction cost	High	Moderate	Very high
Existing technology	Yes	No!	Yes

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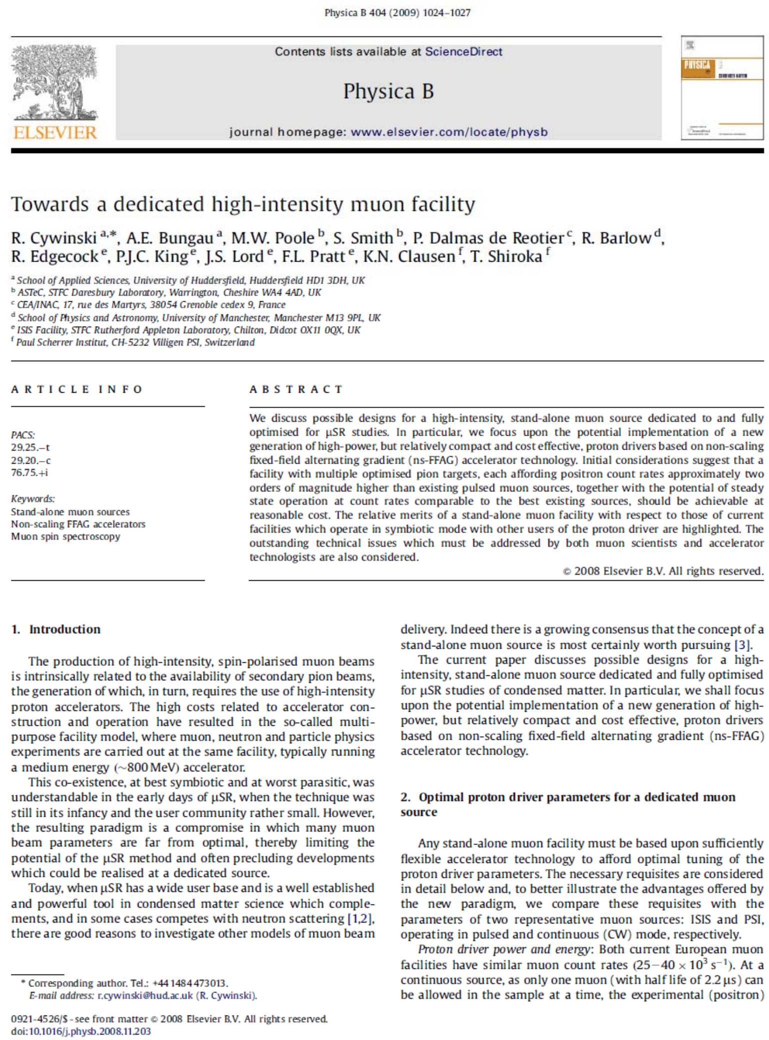
Simulations of (multiple) pion/muon production targets and accelerator/target/collection/beam optics combinations are necessary

......But first the codes have to be benchmarked
- *against the ISIS target*?

......could the ISIS target geometry/muon collection system be optimised as part of the same programme?

→ GEANT 4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GEANT4

Geant4 is a toolkit for the simulation of the passage of particles through matter

Developed and maintained at CERN

Originally intended for high energy physics experiments (eg LEP)

Now wide range of uses including medical, nuclear, and space science

Distributed as a set of C++ libraries

GEANT4 is already used in simulations of µSR experiments
eg, Prokscha, Shiroka, Lancaster, Sedlak ....

Can GEANT4 accurately simulate proton/target interactions ?

GEANT4 Simulation and Optimisation of the High-Field µSR Spectrometer

Kamil Sedlak[a,*], Robert Scheuermann[a], Alexey Stoykov[a,b] and Alex Amato[a]

Geant4 simulation of low energy µSR experiments at PSI

T.K. Paraïso, E. Morenzoni, T. Prokscha, A. Suter

GEANT4 as a simulation framework in µSR ★

T. Shiroka[a,b,*], T. Prokscha[a], E. Morenzoni[a], K. Sedlak[a]

[a]Laboratory for Muon Spin Spectroscopy, Paul Scherrer Institut, CH-5232 Villigen PSI, Switzerland
[b]Dipartimento di Fisica, Università di Parma & CNR-INFM, Viale G.P. Usberti 7/a, 43100 Parma, Italy

Abstract

GEANT4 is a Monte Carlo radiation transport toolkit which includes a complete range of functionalities required to build flexible simulation frameworks. Taking advantage of its open architecture and object-oriented design, we could develop a software suite, able to simulate µSR experiments and instrumentation. The versatility offered by this new tool has permitted us to model the existing instruments, thus allowing a fuller understanding of their operation. It has guided also the design and construction of new types of spectrometers, as those equipped for high-field µSR, where numerical simulations proved decisive in understanding the complex behaviour of the incoming muon beam and of the outgoing positrons in a high magnetic field environment. The developed µSR simulation framework, with its fully flexible and customizable design, will allow potential users not familiar with programming to focus exclusively on physics, by building and running their own applications without the need to modify the source code.

Key words: Computer modeling and simulation, GEANT4, Object-oriented design, Muon spin rotation
PACS: 07.05.Tp, 41.85.-p, 76.75.+i

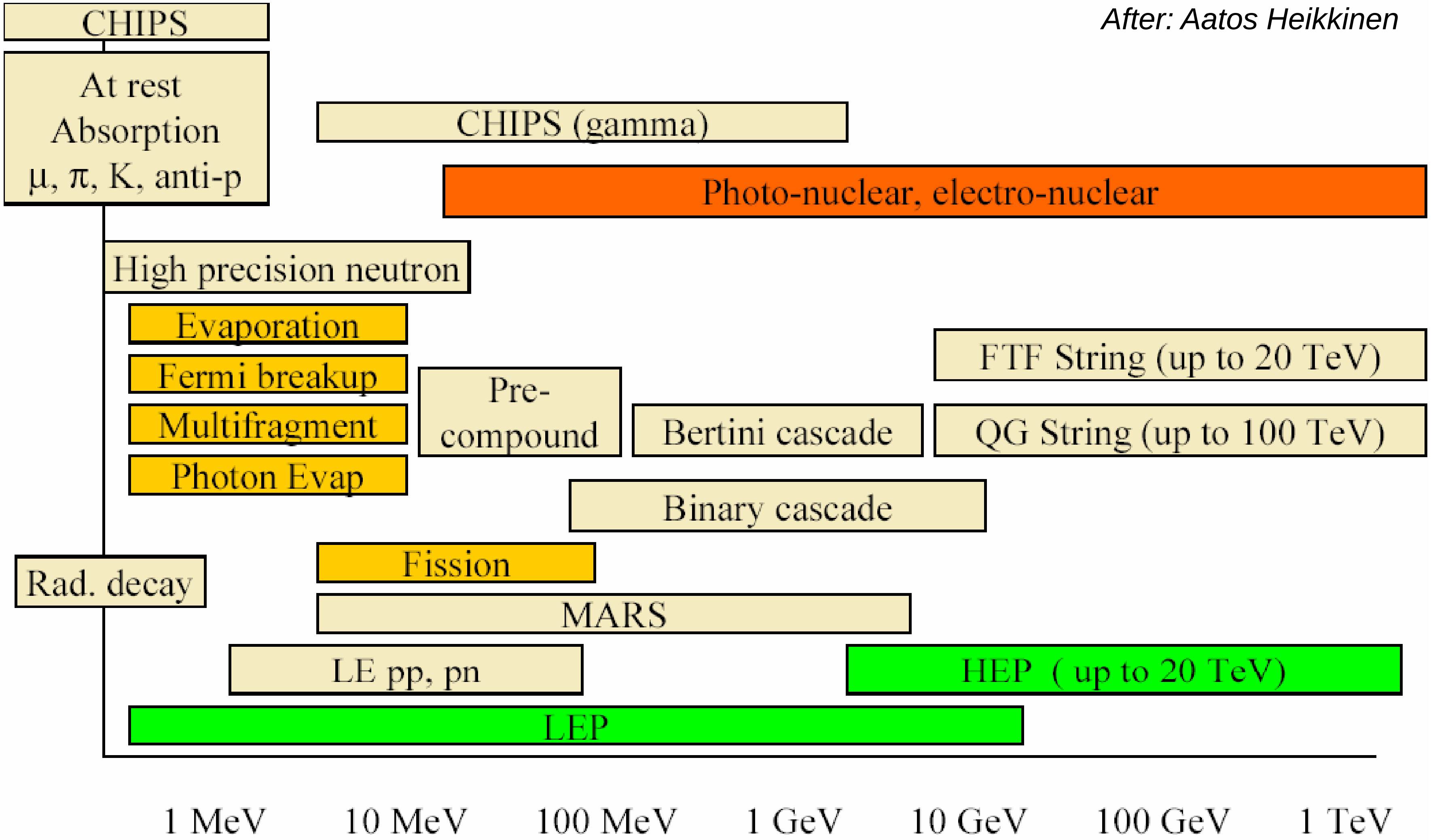
1. Introduction

The Monte Carlo method is a computer-based statistical sampling technique for solving complex, nonstandard problems. Due to its general-purpose, numerical approach the method has found a wide range of applications in many

which needs to accommodate more elaborate sample environments, the situation has changed. The growing demand to understand the detailed operation of muon spectrometers has been recognized by the FP6 JRA8 program, where the development of software code to enable full instrument simulation has a dedicated work package.

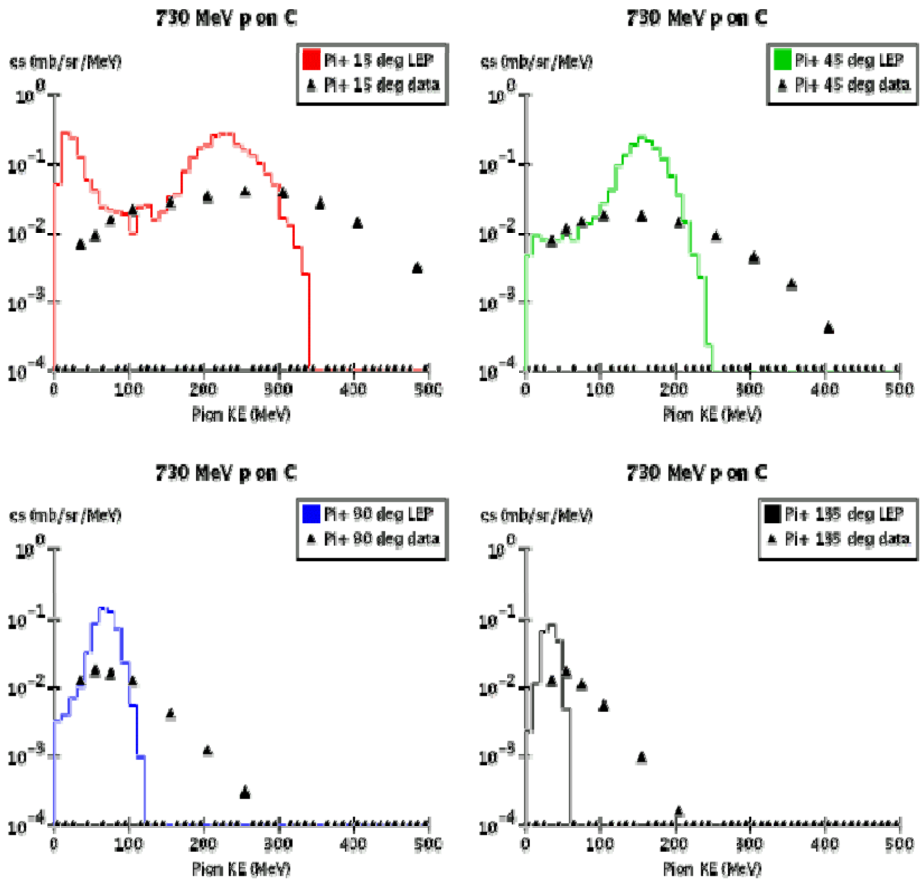
GEANT4: hadronic model inventory

After: Aatos Heikkinen

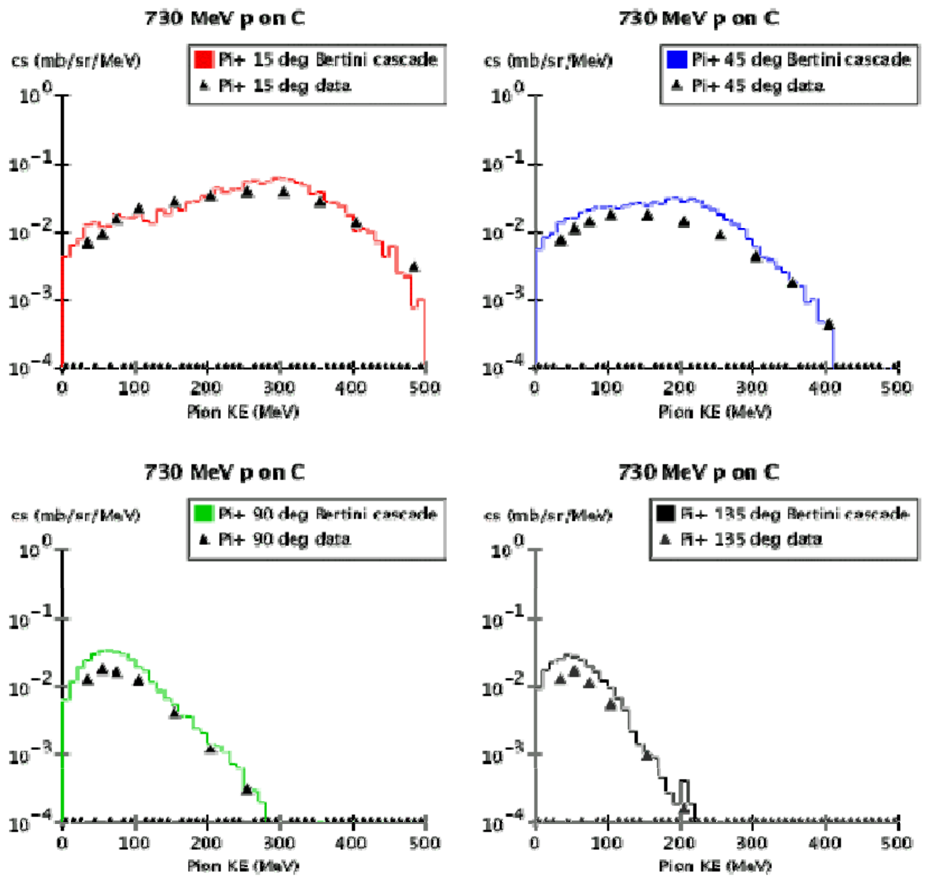


GEANT4: eg LEP *vs* Bertini

After: Aatos Heikkinen



Gean3.21 based Geant4 LEP model pion production from 730 MeV proton on Carbon.



Bertini cascade model pion production from 730 MeV proton on Carbon.

The ISIS muon target

Proton beam:

800MeV with ~1MeV energy spread

Focused to Gaussian “waist” at target with rms half width and rms half height of 5mm:

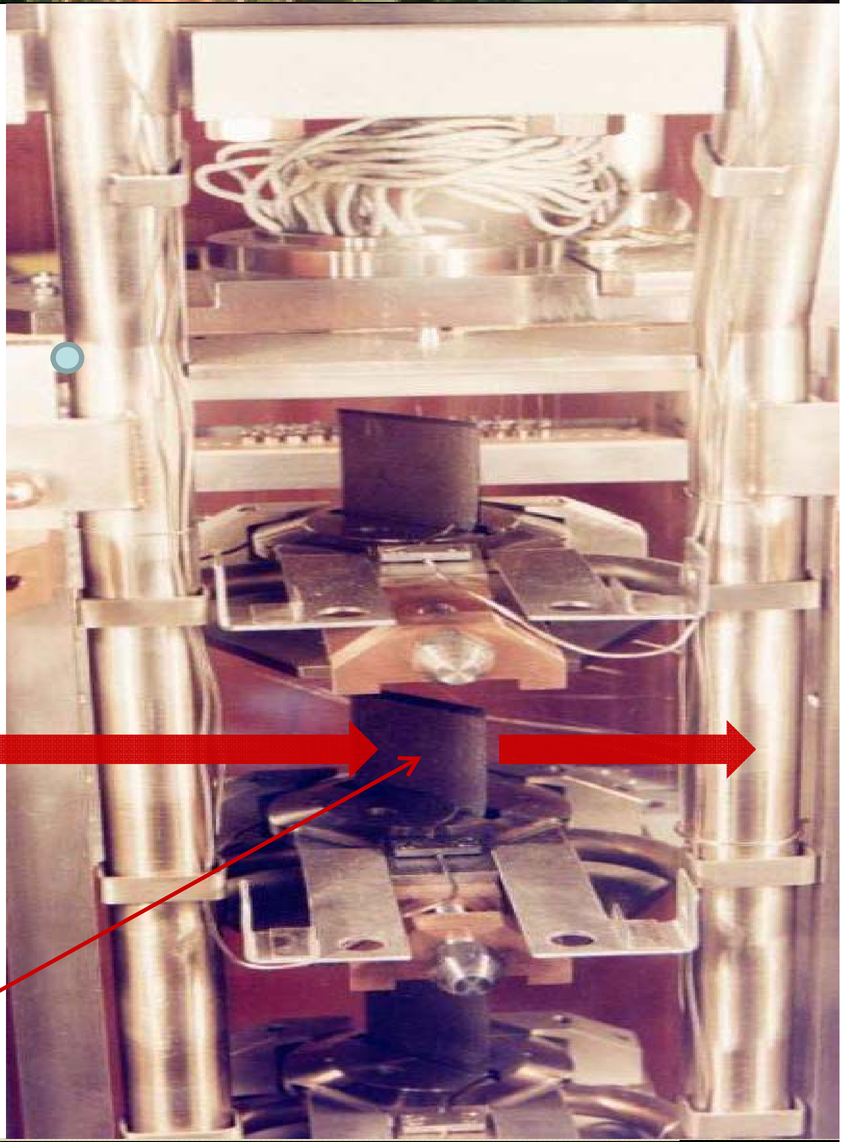
rms x’ = 6mrad   rms y’=5mrad

Target:

Graphite plate 50*50*7 mm^3

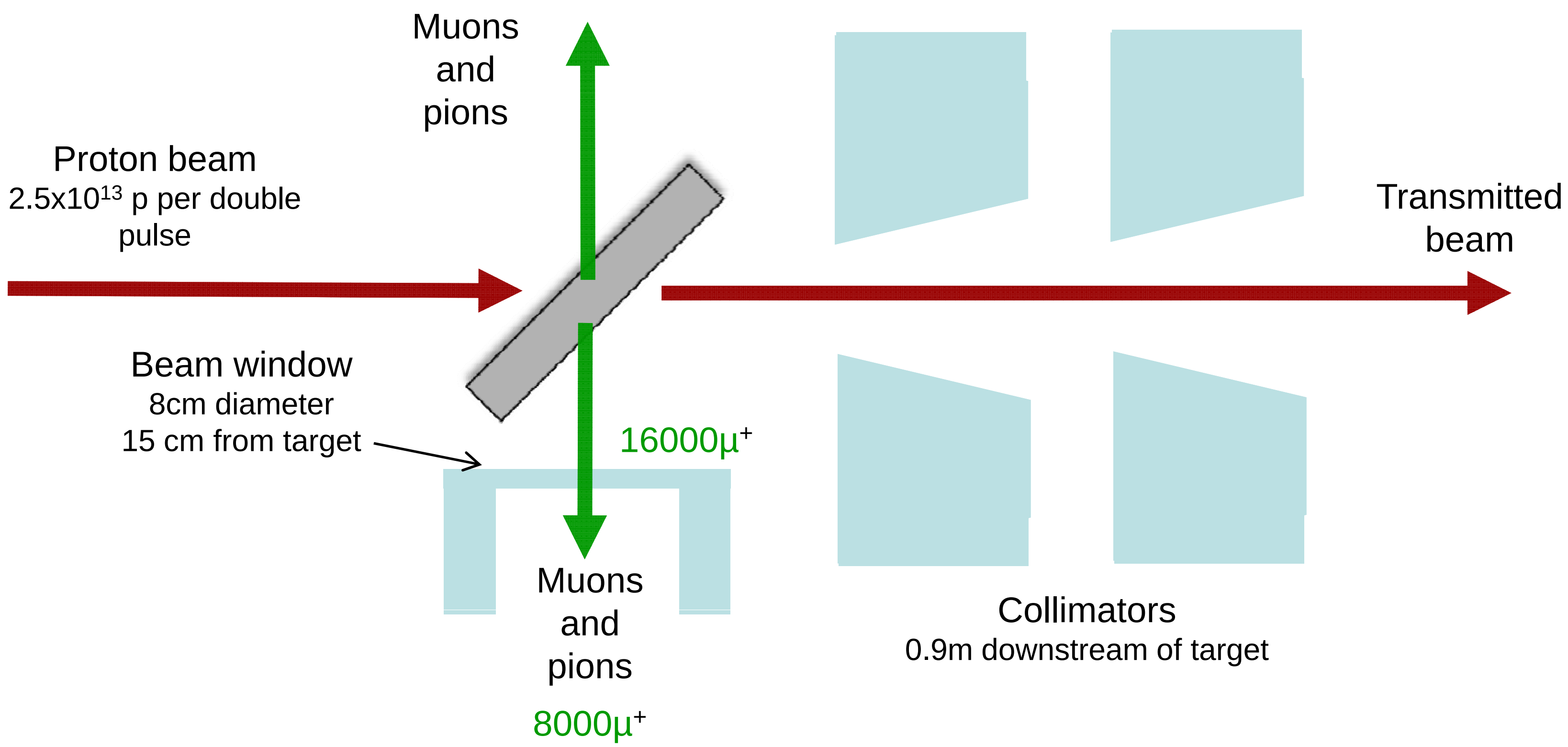
Oriented at 45^o to proton beam (rotated around vertical axis)

Effective path length through target ~10mm



Graphite muon production target

Simulation geometry



Spatial cut: (a) particles emerge from target within ±0.5cm vertically and ±3cm horizontally
(b) particles must be parallel to beamline axis with 180mrad in horizontal direction and 35 mrad in vertical direction

Momentum cut: momentum bite must be between 25.175 and 27.825 MeV/c (ie 10% around 26.5MeV/c)

GEANT4 simulations

GEANT4 and three physics models have been used:

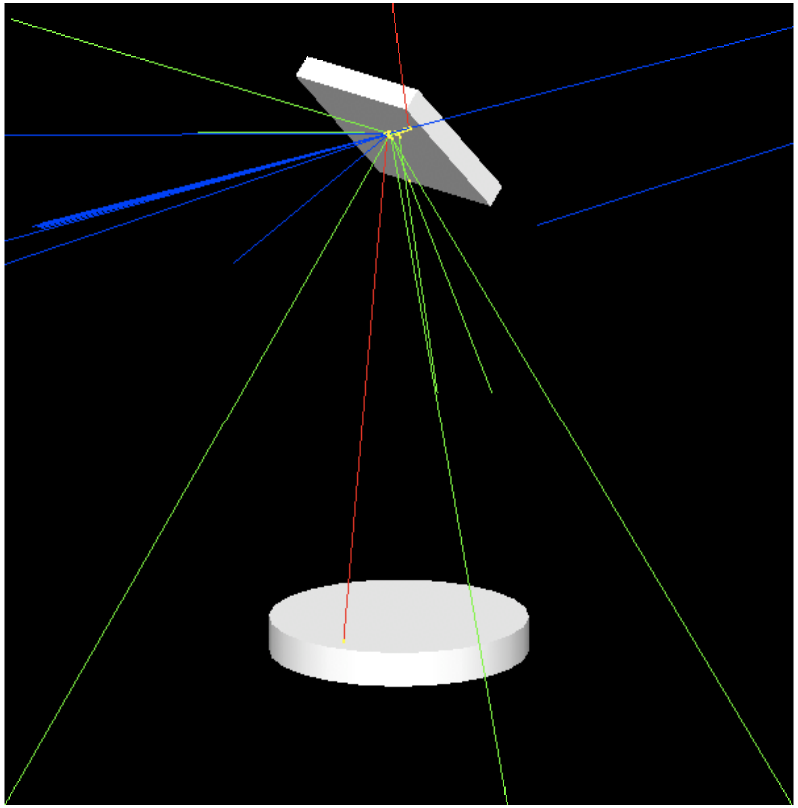
Bertini model

Binary Cascade Model

INCL-ABLA model.

Initial simulations of 2×10^{13} protons (corresponding to an ISIS double pulse) took a prohibitively long time to run

Shorter simulations of 4×10^{7} protons resulted in much poorer statistics, but in agreement with the longer runs and experiment, give the equivalent of 20000-40000 μ^{+} with the correct momentum and spatial cuts entering the beam window per ISIS double pulse.



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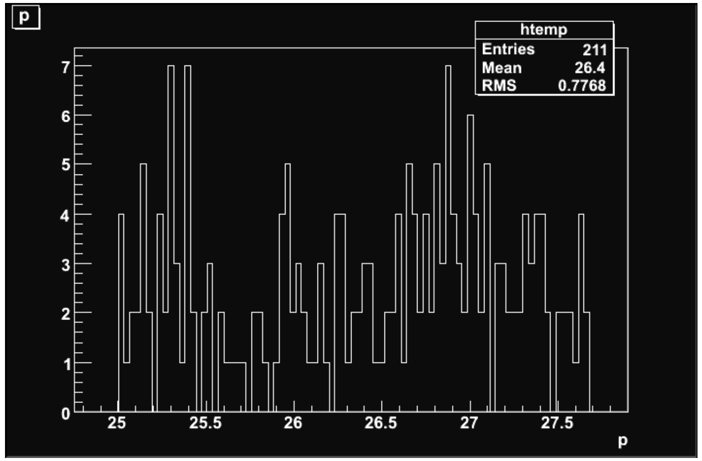
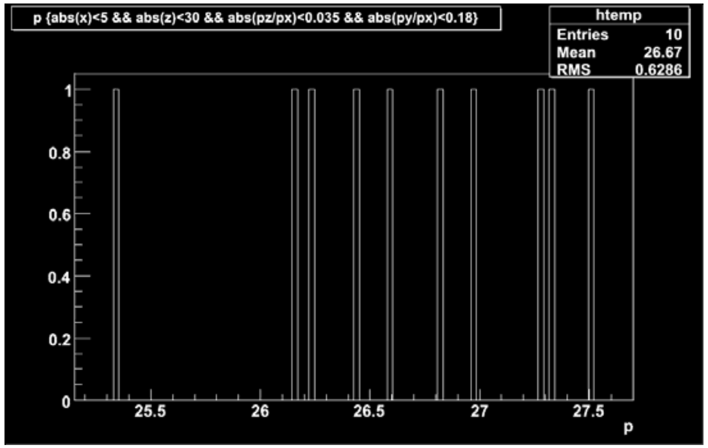


Momentum cut



Momentum, space and angle cut

The simulations showed a reasonably isotropic distribution of muons from the target – this was used to speed up the simulation procedures by separating pion production from muon transport

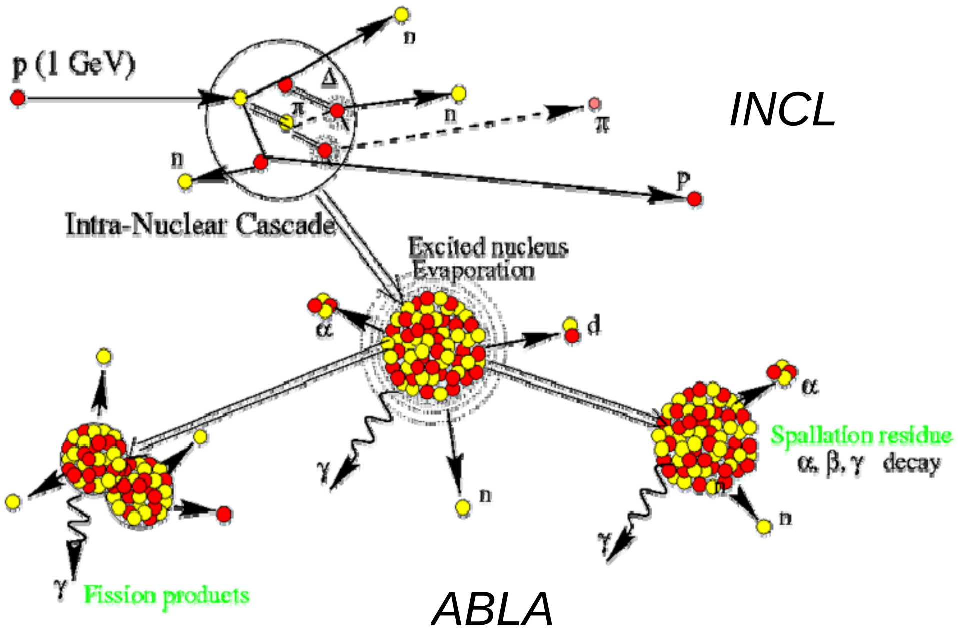
GEANT4 simulations

Each model generates the final state for hadron inelastic scattering by simulating the intra-nuclear cascade.

The Bertini model:
The target nucleus is treated as an average nuclear medium to which excitons (particle-hole states) are added after each collision.

The Binary Cascade model:
The target nucleus is modelled by a 3-D collection of nucleons, as opposed to a smooth nuclear medium.

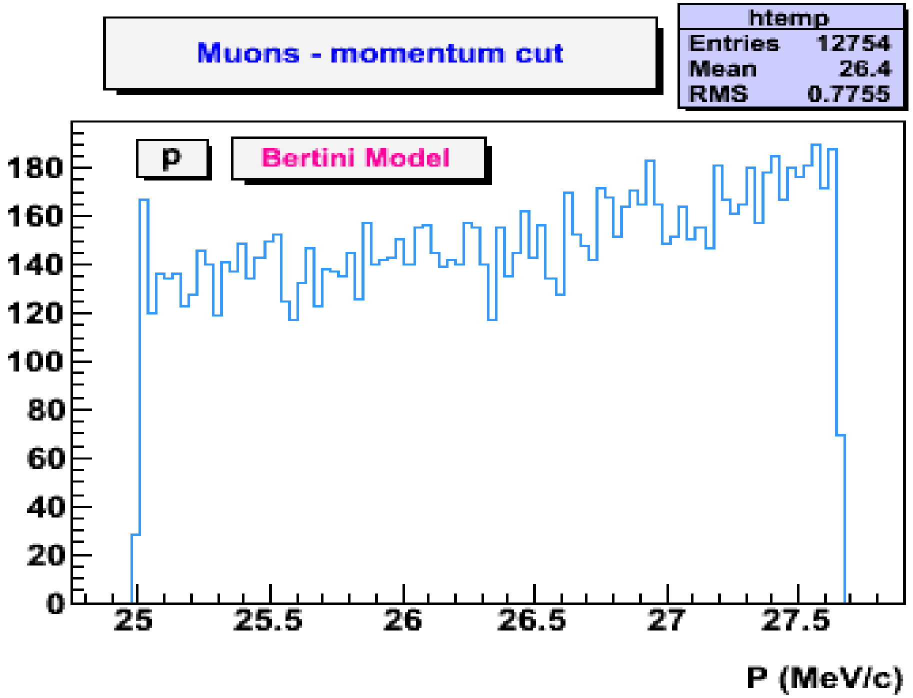
The INCL-ABLA model
The intra nuclear cascade is based upon the Liege cascade model (INCL) and the de-excitation is based on ABLA

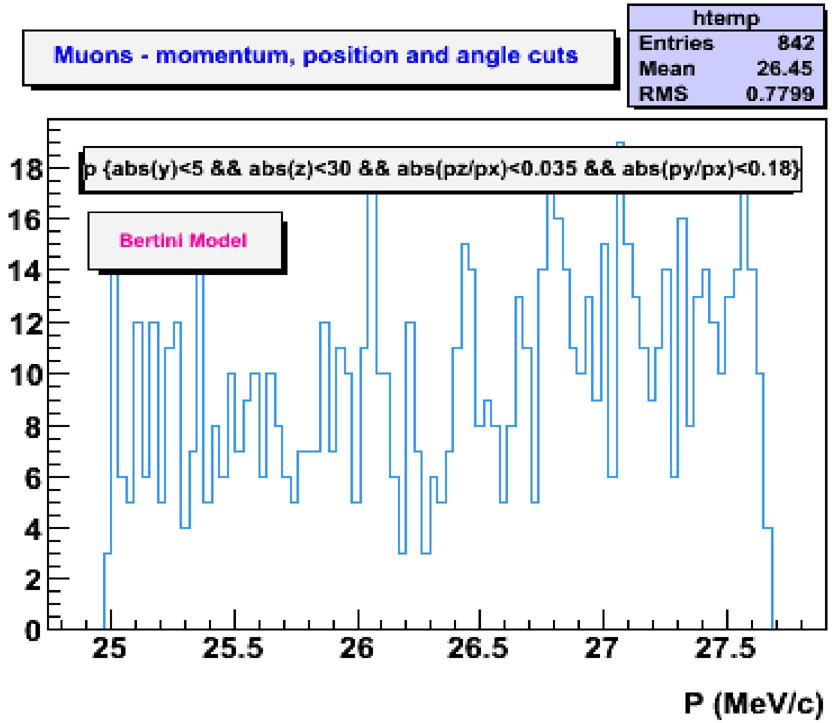


Bertini Cascade Model

- simulations are for 2.5 x 10^{11} protons on target

- for 2.5 x 10^{13} protons there are 84200 positive muons entering the beam window

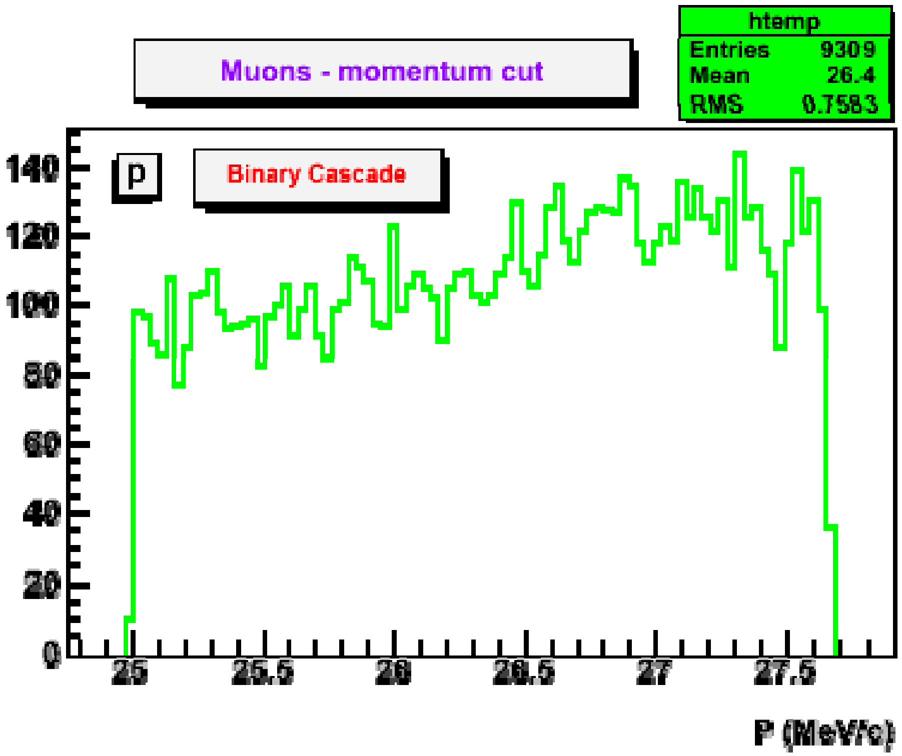


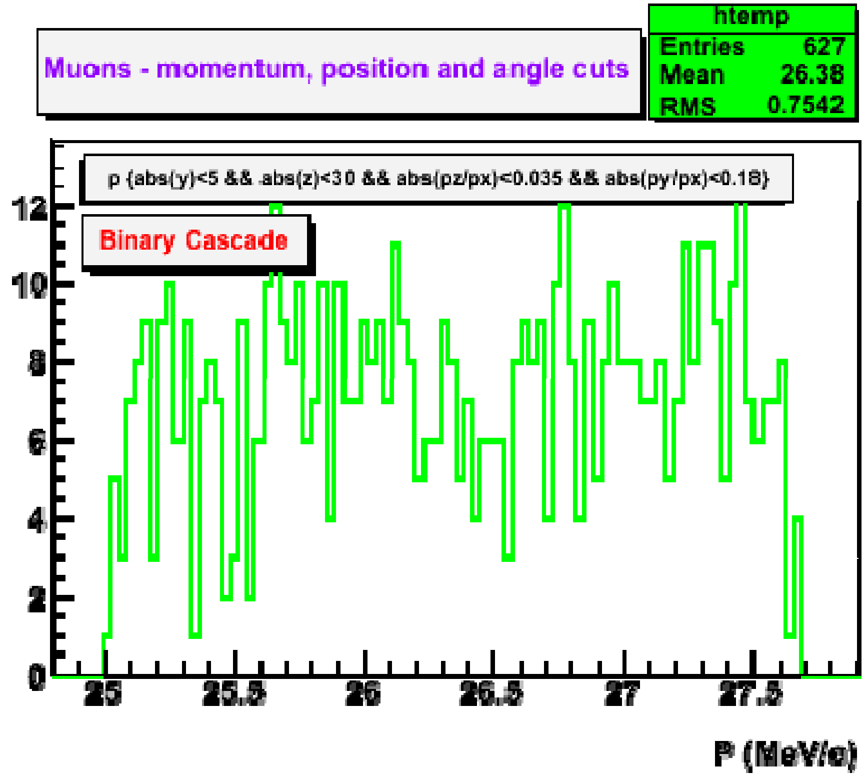


Binary Cascade Model

- simulations are for 2.5 x 10^{11} protons on target

- for 2.5 x 10^{13} protons there are 62700 positive muons entering the beam window

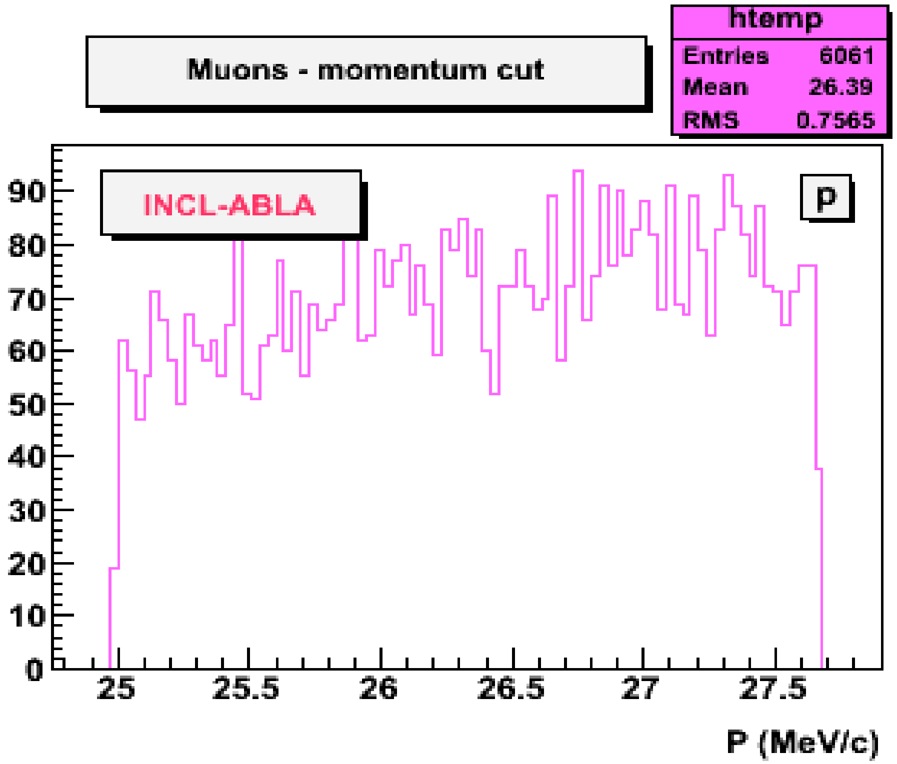


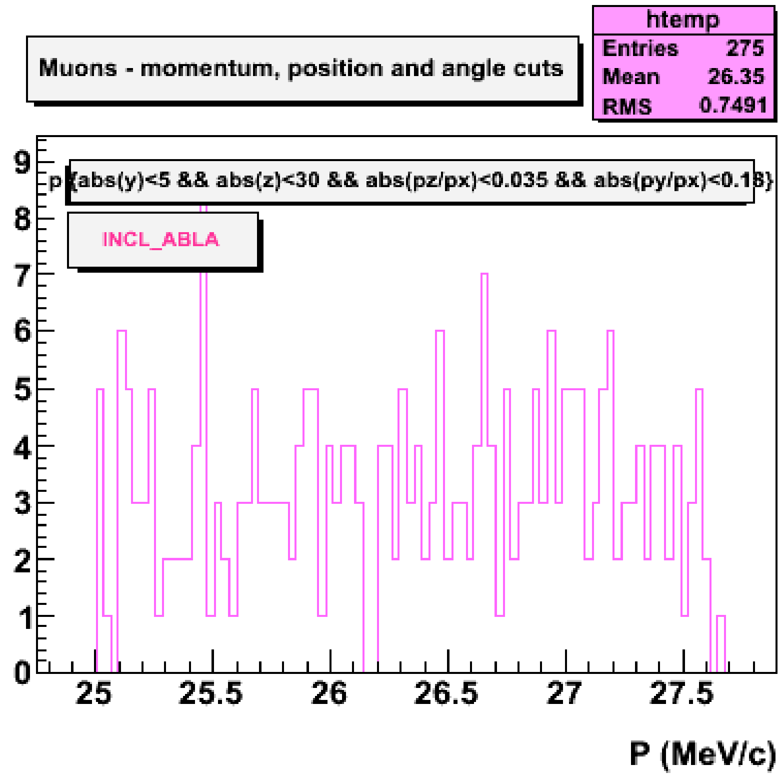


INCL-ABLA Model

- simulations are for 2.5×10^{11} protons on target

- for 2.5×10^{13} protons there are 27500 positive muons entering the beam window





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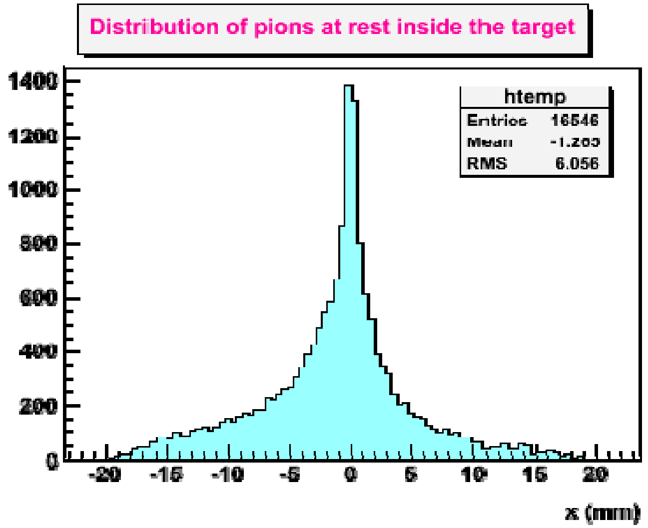
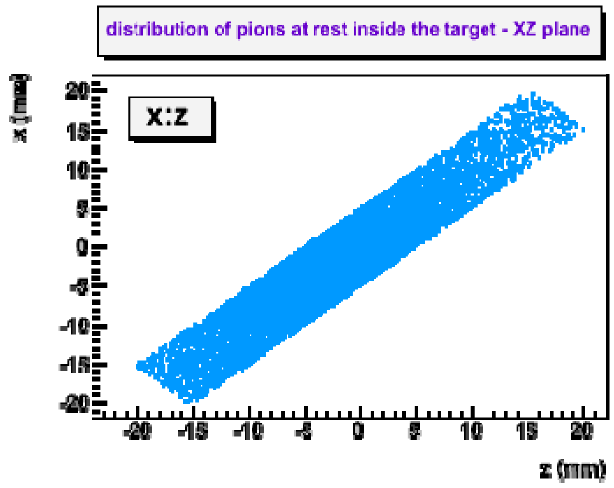
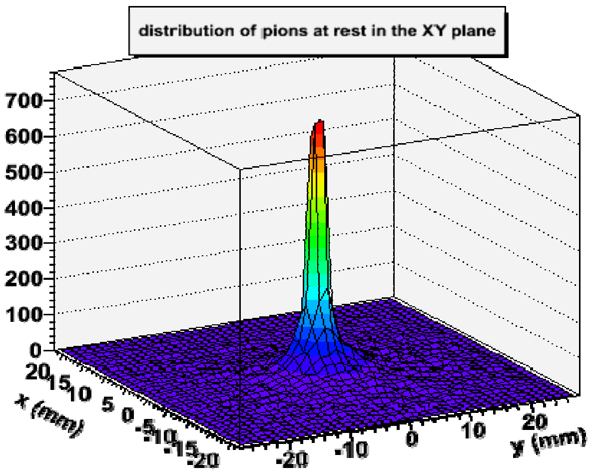
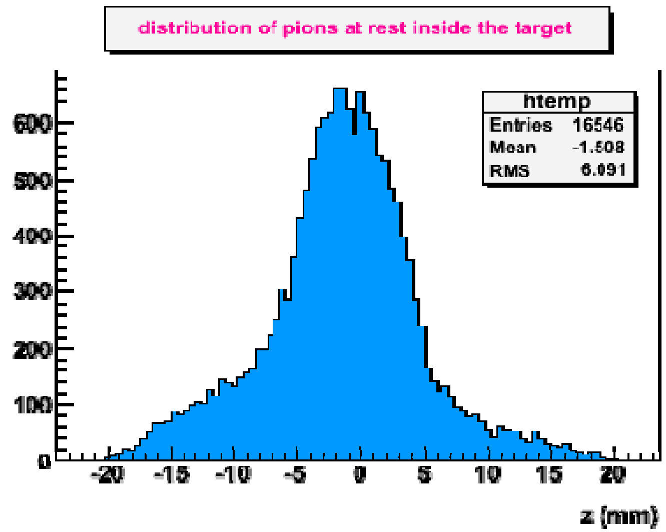
INCL-ABLA: pions at rest in target

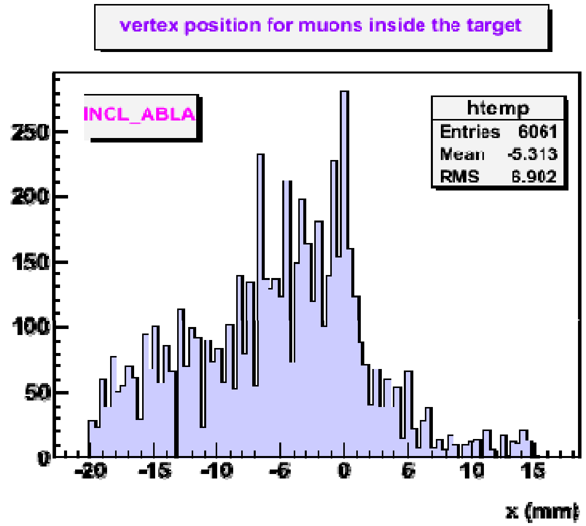


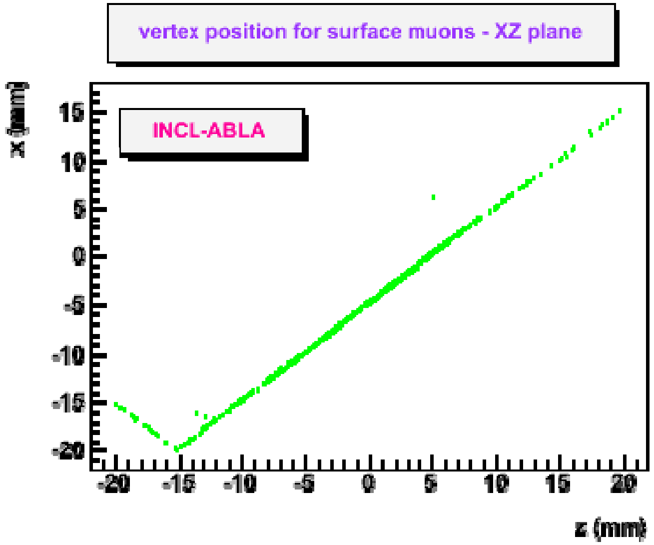


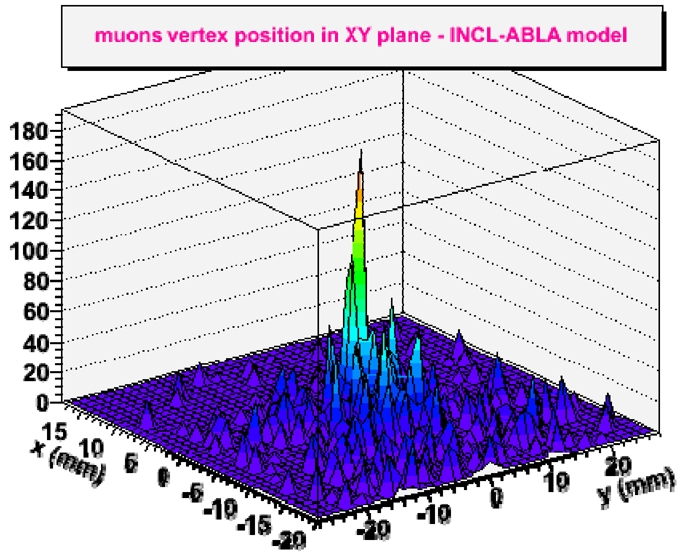


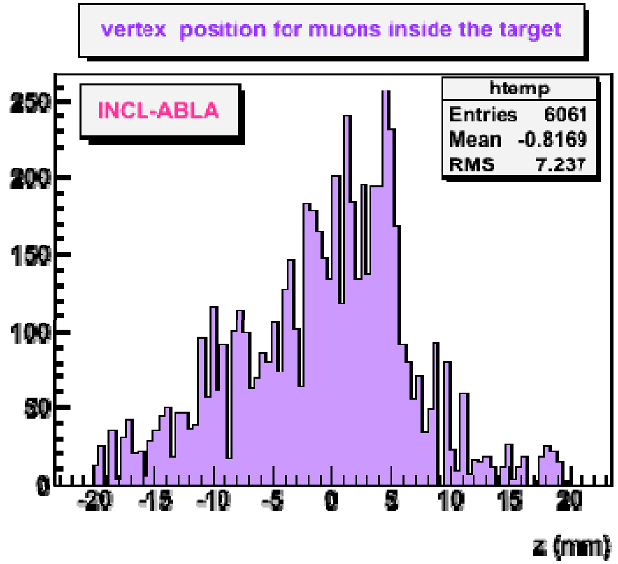


INCL-ABLA: muon production

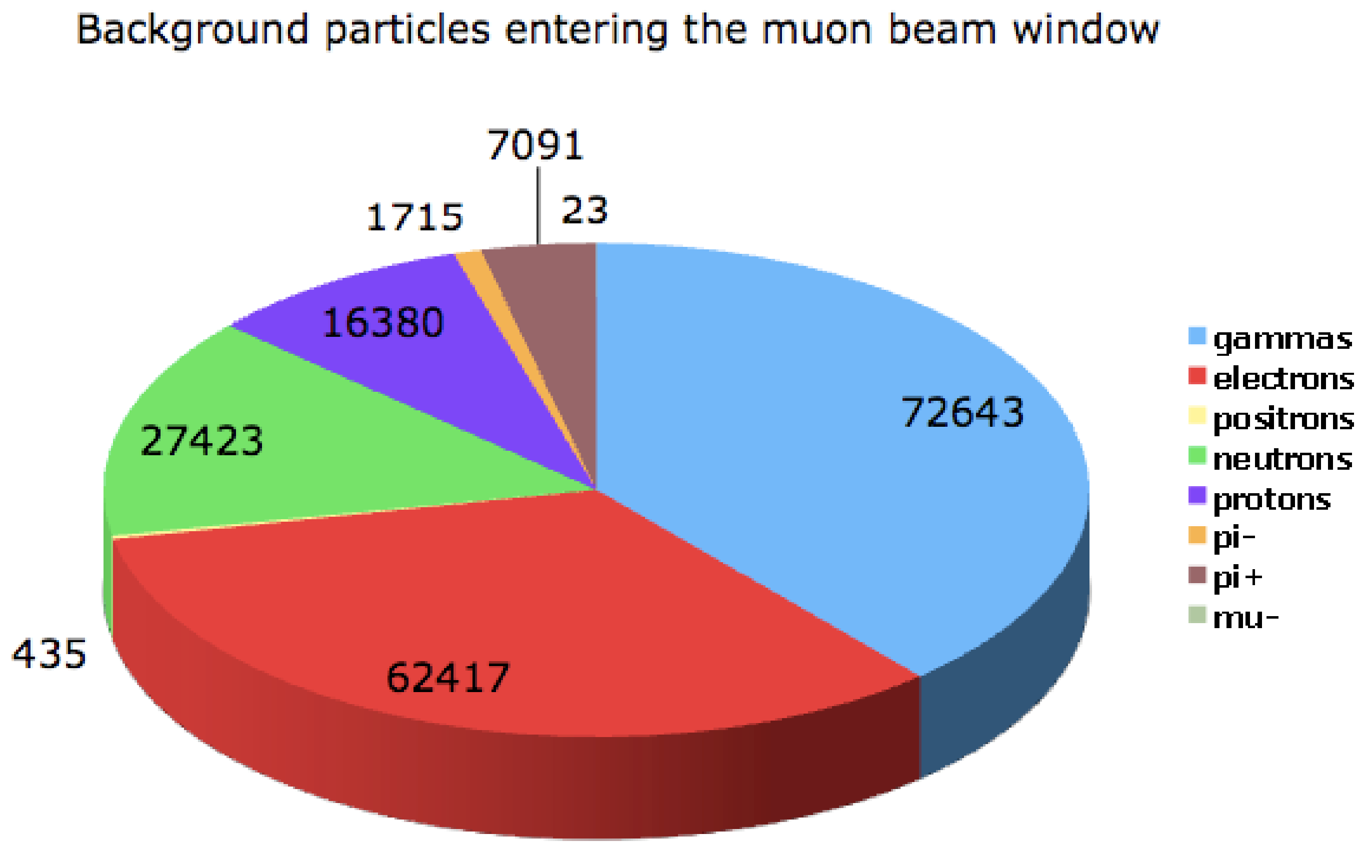




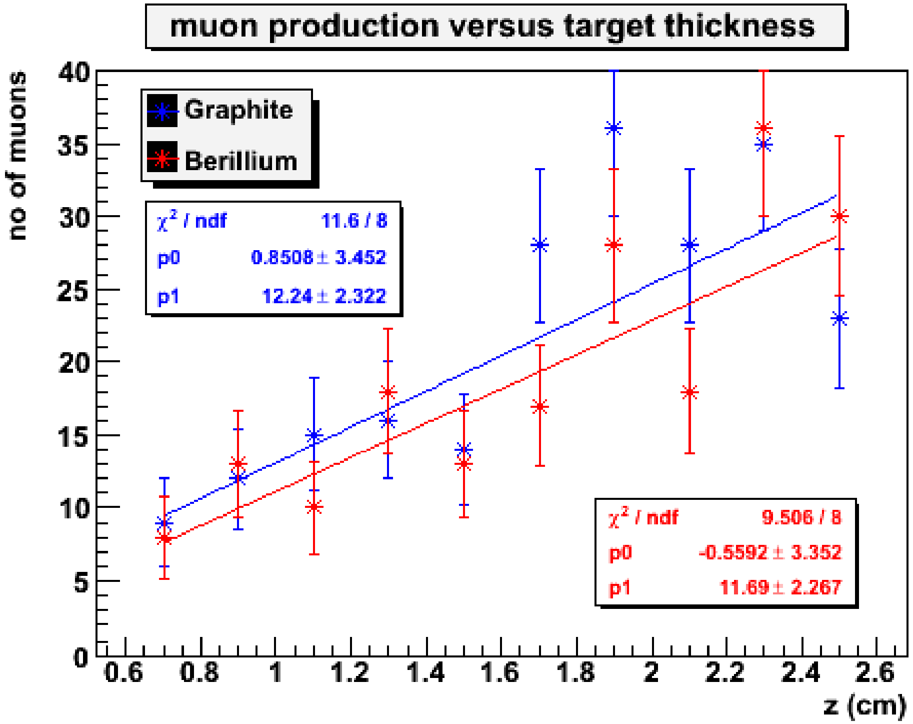


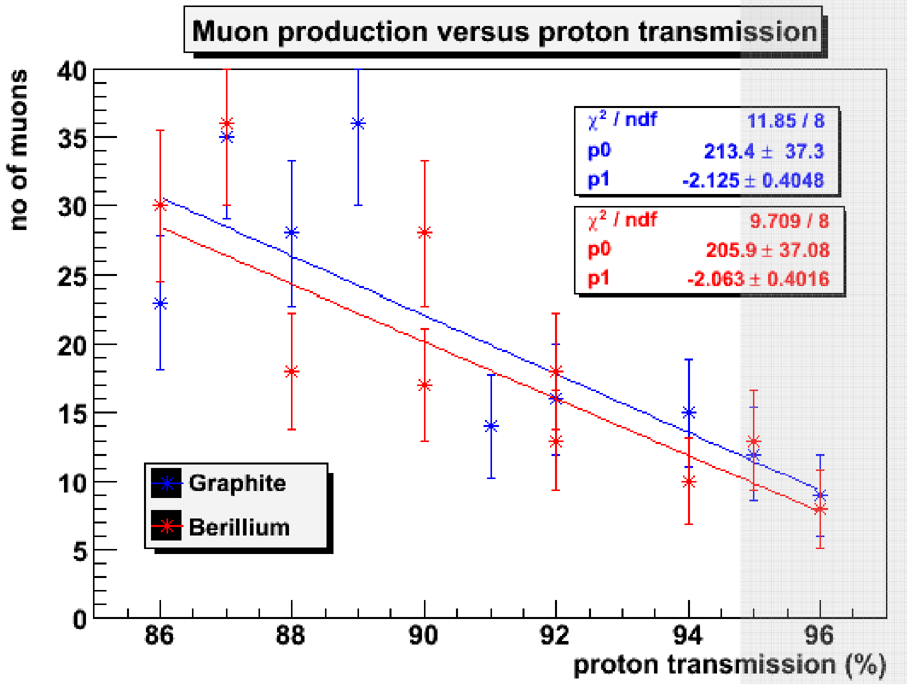


Unwanted particles



Target material





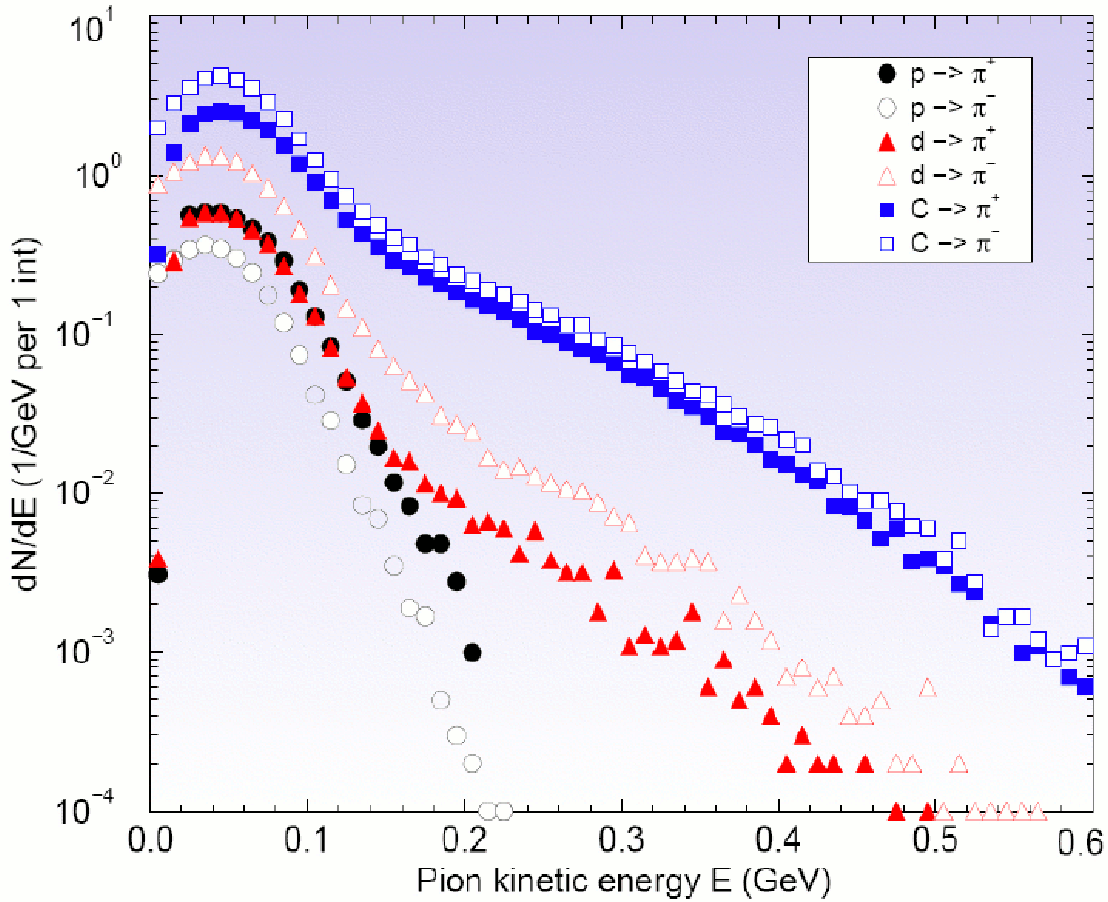
Next steps

- ❖ Composite targets (eg Ni coated Be)
- ❖ Complex geometries (eg small xsection pencil/conical target)
- ❖ Proton loss calculations
- ❖ Thermal load calculations
- ❖ Improvement of collimators and collection geometries

With implications for

- ❖ Neutrino factory
- ❖ Stand-alone dedicated muon facility (protons?)

Carbon ion beams



Pion spectra from 400 MeV/A projectiles on an Hg nucleus

Beam	π^+
p	0.0339
d	0.0337
C	0.190

Pion yield at

30 < E < 230 MeV

Carbon seems a promising projectile

Simulations by N. Mokhov (From Shiroka)