



Muon Target Simulations

Adriana Bungau (Bob Cywinski)







workshop at the Cockcroft Institute, Daresbury, in April 2008

Towards a Next Generation **European Muon Source**



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1. Introduction

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ARTICLE INFO

responding autors 7nc. +44 1484 472012. mail address r.sywinski@hud.ac.uk (& sywinski). 0921-4526/5-see four matter © 2006 Elsevier B.V. All rights relevue doi: 10.1010/6/ physio.2008.11.203

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nai homepage: www.

R. Cywinski 4. R. Cywinski 4. R. Edgecock 4. P.J.C. King 4. J.S. Lord 4. S. Smith 5. P. Dalmas de Reotier 4. R. Barlow 4. School 9 Applied Sciences University of Huddersheld Hild Gradel Hild Sciences University of Huddersheld Hudd

Towards a dedicated high-intensity muon facility

ABSTRACT

A. SUBERION, S. FJAN, MING, J. S. LUNG, S. L. ITAL, "FALL TALK," School of Applied Statements (Journaus) of Historistical Holderschole Hold 2000 (J. Application of Applied Statements), Warriston, October Wal, et al. 2000 (J. CASHING, T., And et al. Advances, J. Machine Management, School and Machine Management (Astronomy Barlines, Statements), Machine Management, Management (Astronomy Barlines, School and Machines, Machines Mills Barl, Like (Astronomy Barlines, Caster Statements), Caster Statement, Mills Barl, Like (Astronomy Barlines, Caster Statements), Caster Statement, Mills Barl, Like (Astronomy Barlines, Caster Statements), Caster Statements, Mills Barl, Like (Astronomy Barlines, Caster Statements), Caster Statements, Mills Barl, Like (Astronomy Barlines, Caster Statements), Caster Statements, Mills Barl, Like (Machines, Machines, Mills, Barlines, Mills, M

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2. Optimal proton driver parameters for a dedicated muon Any stand-alone muon facility must be based upon sufficiently how day, arouting the forest on afford onlinear training of the Any stand-slone muon facility must be based upon sufficiently flexible accelerator technology to afford optimal tuning of the in detail below and to better illustrate the advantages are considered the new paradigm, we compare these requisites with the

the new paradigm, we compare these requisites with the parameters of two representative mon sources. ISS and PSD objects in pluse power and cinegy. Both curves, ISS and PSD and arrive power and cinegy. Both curves, ISS and PSD for the source as only one muon (with half life of 2.2 µS) can detail below and, to better illustrate the advantages offered by e-new_paradigm, we compare these requisites with the reameters of two reomsonitative much courses (second the This have similar muon count rates $(25-d0 \times 10^{+} \text{s}^{-1})$. At a since source, as only one muon (with half life of $2.2 \, \mu\text{s}^{-1}$). At a blowed in the sample at a time, the remembrand (restricted) continuous source, as only one muon (with half life of <...(is) on be allowed in the sample at a time, the experimental (position)

University of HUDDERSFIELD

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 ~mm²	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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Towards a dedicated high-intensity muon facility

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⁴ School of Applied Sciences, University of Huddersfield, Huddersfield, HDI 3DH, UK ASTC, STK Densbury, Iaboutory, Wurnigton, Cheinlen Wei 44D, UK ⁶ CEA/INKC, Tr. nue des Martyrs, 38054 Grenoble cedex 9, Pance ⁶ School of Physica and Astronomy, University of Manchester, Manchester M13 9FL, UK ⁸ ISS Facility, STK? Rutherford Appleton Laboratory, Chilton, Ddot OX11 0QX, UK ⁷ Mau Scherrer Institut, CH-522 Willen PLS, Switzerland

	We discuss possible designs for a high-intensity, stand-alone muon source dedicated to and full optimised for uSR studies. In particular, we focus upon the potential implementation of a new		
PACS:			
29.25t	generation of high-power, but relatively compact and cost effective, proton drivers based on non-scalin		
29.20c	fixed-field alternating gradient (ns-FFAG) accelerator technology. Initial considerations suggest that		
76.75.+i	facility with multiple optimised pion targets, each affording positron count rates approximately tw		
	orders of magnitude higher than existing pulsed muon sources, together with the potential of stead		
Keywords:	state operation at count rates comparable to the best existing sources, should be achievable a		
Stand-alone muon sources	reasonable cost. The relative merits of a stand-alone muon facility with respect to those of curren		
Non-scaling FFAG accelerators			
Muon spin spectroscopy	facilities which operate in symbiotic mode with other users of the proton driver are highlighted. Th		
widon spin speciroscopy	outstanding technical issues which must be addressed by both muon scientists and accelerate		
	technologists are also considered.		
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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-caled multipurpose facility model, where muon, neutron and particle physics experiments are carried out at the same facility, typically running a medium energy (~800MeV) 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

0921-4526/\$ - see front matter © 2008 Elsevier B.V. All rights reserved, doi:10.1016/j.physb.2008.11.203 delivery. Indeed there is a growing consensus that the concept of a stand-alone muon source is most certainly worth pursuing [3].

The current paper discusses possible designs for a highintensity, stand-alone muon source dedicated and fully optimised for μ SR studies of condensed matter. In particular, we shall focus upon the potential implementation of a new generation of highpower, but relatively compact and cost effective, proton drivers based on non-scaling fixed-field alternating gradient (ns-FFAG) accelerator technology.

2. Optimal proton driver parameters for a dedicated muon source

Any stand-alone muon facility must be based upon sufficiently flexible accelerator technology to afford optimal tuning of the porton driver parameters. The necessary requisites are considered in detail below and, to better illustrate the advantages offered by the new paradigm, we compare these requisites with the parameters of two representative muon sources: ISS and PSI, operating in pulsed and continuous (CW) mode, respectively.

Proton driver power and energy: Both current European muon facilities have similar muon count rates $(25 - 40 \times 10^3 \text{ s}^{-1})$. At a continuous source, as only one muon (with half life of 2.2 µs) can be allowed in the sample at a time, the experimental (positron)

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

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?



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Towards a dedicated high-intensity muon facility

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0921-4526/\$-see front matter © 2008 Elsevier B.V. All rights reserved, doi:10.1016/j.physb.2008.11.203 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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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 as a simulation framework in μ SR *

T. Shiroka ^{a,b,*}, T. Prokscha ^a, E. Morenzoni ^a, K. Sedlak ^a ^aLaboratory for Muon Spin Spectroscopy, Paul Scherrer Institut, CH-5232 Villigen PSI, Switzerland ^bDipartimento di Fisica, Università di Parana & CNR-INFM, Viale C.P. Useberti 77, 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 μ SR 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 μ SR, 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 μ SR 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 ocde.

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



NMI3, Zurich, 30 March '09



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 mm³

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

Effective path length through target ~10mm

Graphite muon production target



HUDDERSF

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 2x10¹³ protons (corresponding to an ISIS double pulse) took a prohibitively long time to run

Shorter simulations of $4x10^7$ 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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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 10¹¹ protons on target
- for 2.5 x 10¹³ protons there are 84200 positive muons entering the beam window





Binary Cascade Model

- simulations are for 2.5 x 10¹¹ protons on target

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



NMI3, Zurich, 30 March '09

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INCL-ABLA Model

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

- for 2.5 x 10¹³ protons there are 27500 positive muons entering the beam window



INCL-ABLA: pions at rest in target



NMI3, Zurich, 30 March '09



INCL-ABLA: muon production











Unwanted particles

Background particles entering the muon beam window





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



Beam	π^+	
р	0.0339	
d	0.0337	
С	0.190	

Pion yield at 30 < E < 230 MeV

Carbon seems a promising projectile

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

Simulations by N. Mokhov (From Shiroka)

