Machine Detector Interface WG: Beam–Induced Background simulations

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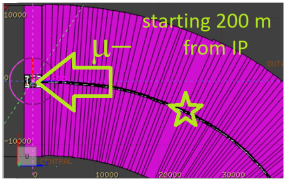
Machine Detector Interface WG of International Muon Collider Collaboration:

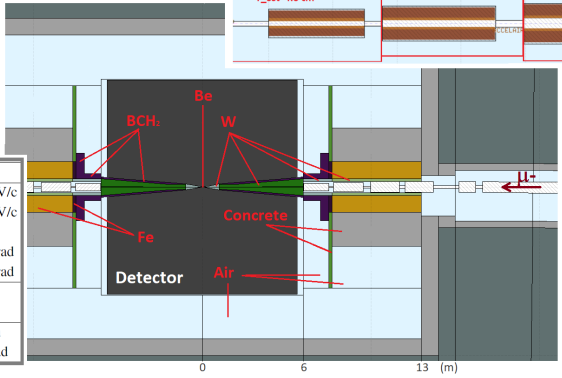
- INFN: BIB @ 1.5 TeV using MAP machine design and optics files OK
  BIB @ 3 TeV using MAP machine design and optics files to be optimized
- BIB simulation tool setup: LineBuilder + FLUKA + Python script for analysis
- Machine Detector Interface (MDI) layout description for 1.5 TeV CM energy
- MARS15 vs FLUKA results @ 1.5 TeV CM energy
- Preliminary FLUKA results @ 3 TeV CM energy

- CERN: original machine design @ 10 TeV and BIB studies

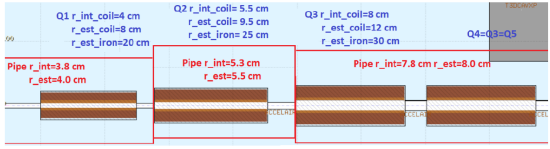
Simulation tool: **LineBuilder + FLUKA**
Data analysis: **Python**



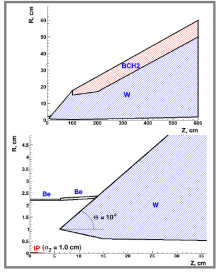
IR



IR Quadrupoles



Nozzle

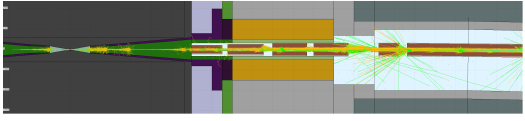


Parameter	Value	
Beam momentum	750	GeV/c
Beam momentum spread	0	GeV/c
Bunch intensity	2×10^{12}	
$\epsilon^n_{x,y}$ normalised RMS emittance	$25\ \pi\ 10^{-6}$	m rad
$\epsilon^g_{x,y}$ geometric RMS emittance	$3.5\ \pi\ 10^{-9}$	m rad
$\beta_{x,y}$	1	cm
$\alpha_{x,y}$	0	
$\sigma_{x,y}$ RMS beam size	5.96	μm
$\sigma_{x',y'}$ RMS beam divergence	596	μrad

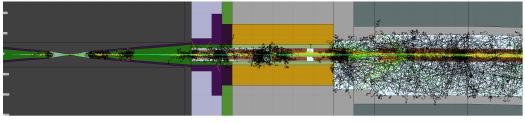
- "Muon collider interaction region design" Y. I. Alexahin (2011)
- "A study of muon collider background rejection criteria in silicon vertex and tracker detectors" V. Di Benedetto (2018)

- Realistic μ^- beam simulated 200 m from IP
- Lattice, optics and MARS15 simulated files provided by MAP
- MDI passive elements retrieved by MAP publications
- Energy threshold cuts: γ & e^+/e^- & charged hadron & μ^+/μ^- 100 keV, neutron 1 meV
- Only muon decays within 25 m from IP considered for the comparison
- Secondary muons simulated via decays within 200 m from IP (backup slide)
- Implicit symmetry for counterpropagating μ^+ beam

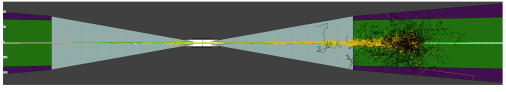
FLUKA tracking without neutrons, some events



FLUKA tracking with neutrons, some events



zoom on one selected decay

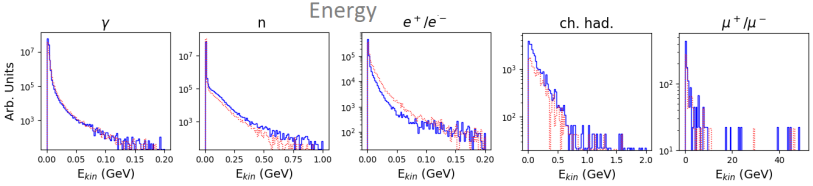


Very good agreement between MARS15 and FLUKA, reason for remaining discrepancies possible layout differences, missing infos about passive elements and absorbers

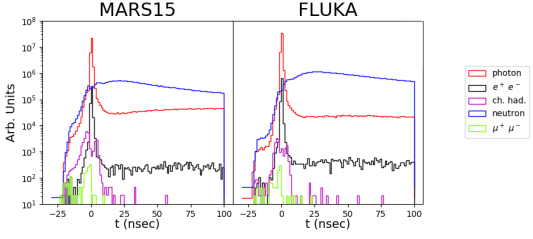
Number

Particle (E_{th})	MARS15	FLUKA
Photon (100 keV)	$8.6\,10^7$	$5\,10^7$
Neutron (1 meV)	$7.6\,10^7$	$1.1\,10^8$
Electron/pos (100 keV)	$7.5\,10^5$	$8.5\,10^5$
Ch. Hadron (100 keV)	$3.1\,10^4$	$1.7\,10^4$
Muon (100 keV)	$1.5\,10^3$	$1\,10^3$

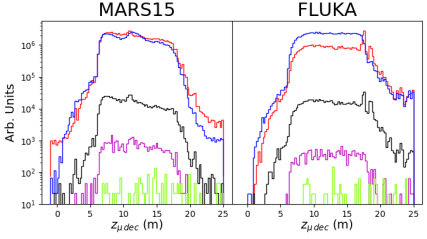
Energy



Time



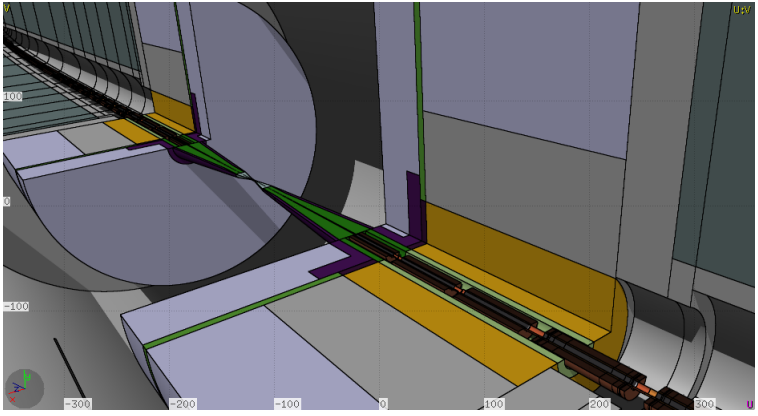
z decay primary muon



"Detector Backgrounds at the Higgs Factory Muon Collider: MARS vs FLUKA" N. V. Mokhov (2018)

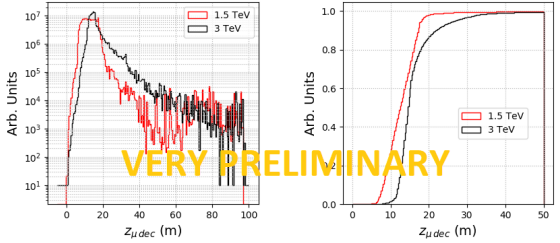
FLUKA simulations @ 3 TeV

- LineBuilder + FLUKA simulation setup ready for 3 TeV
- Lattice and optics provided by MAP not fully optimized
- Same IR used for 1.5 TeV: it has to be optimized

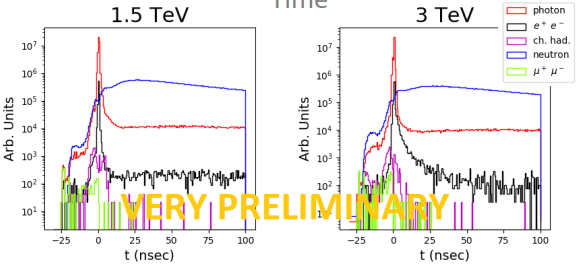


Many latest improvments to 1.5 TeV simulation still to be applied to 3 TeV: very preliminary results for 3 TeV

z primay muon decay & cumulative



Time



Work done

- New simulation setup LineBuilder + FLUKA:
  flexible tool to simulate BIB at any desired CM energy and optimize machine lattice and MDI
- Reproduction of MAP configuration at 1.5 TeV:
  high sensitivity of BIB at MDI design, nozzles filter higher energy γ and e^+/e^- (backup slide)
- FLUKA benchmarked against MARS15 results at 1.5 TeV:
  very good agreement, small discrepancies probably given by residual differences in MDI layout
- All results at 1.5 TeV and comparison with MARS15 submitted to JINST:
  "Advanced assessment of Beam Induced Background at a Muon Collider"

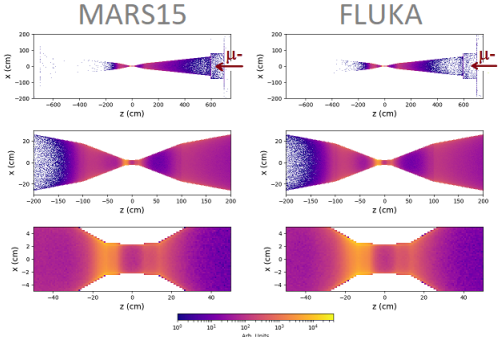
- computational needs @1.5 TeV:
good statistics decays within 100 m run takes $\approx$ 500 CPU hours and $\approx$ 2.5 GB

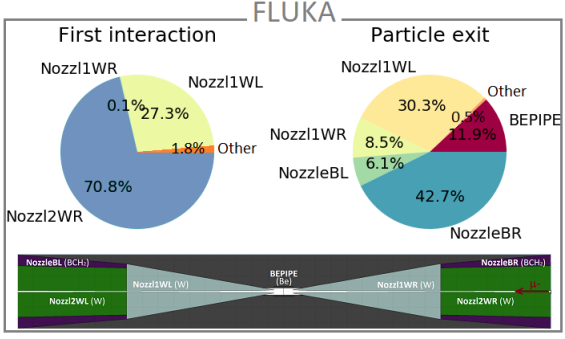
Work in progress

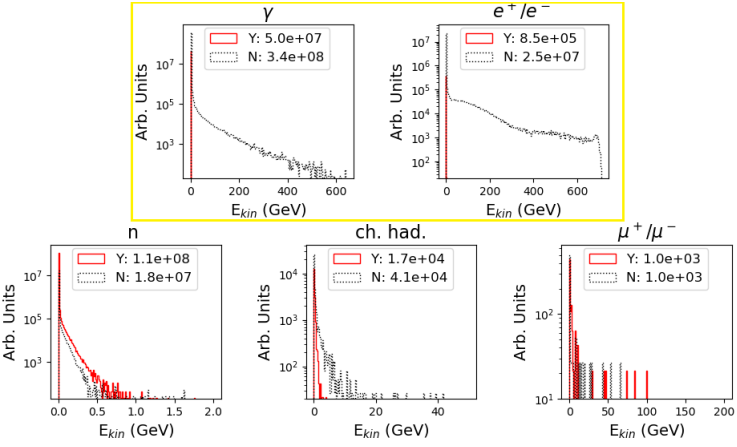
- Study of FLUKA-based BIB in the detector
- Simulation of 3 TeV configuration based on MAP lattice: lattice, nozzle and IR optimization needed

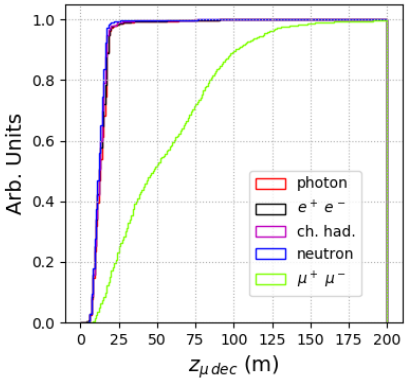
- computational needs @3 TeV:
low statistics $\approx$ 100 configurations takes $\approx$ 100000 CPU hours and $\approx$ 100 GB

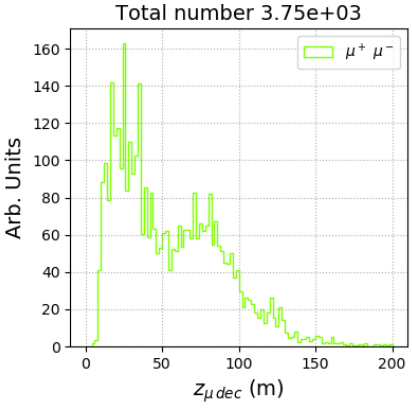
Backup slides


MARS15
FLUKA
μ-
μ-
x (cm)
z (cm)

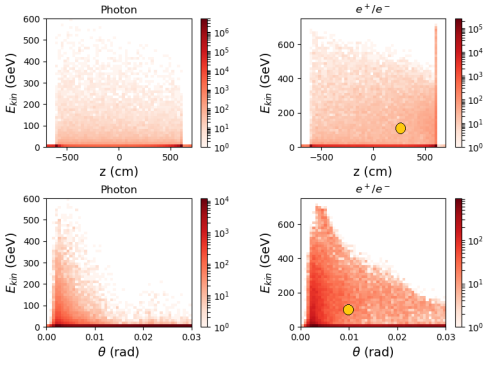

FLUKA
First interaction
Nozzl1WR
Nozzl1WL
0.1%
27.3%
1.8%
Other
70.8%
Nozzl2WR
Particle exit
Nozzl1WL
Other
30.3%
0.5%
BEPIPE
11.9%
Nozzl1WR
8.5%
6.1%
NozzleBL
42.7%
NozzleBR
NozzleBL (BCH₂)
NozzleBR (BCH₂)
Nozzl1WL (W)
BEPIPE (Be)
Nozzl1WR (W)
Nozzl2WL (W)
Nozzl2WR (W)
μ+


γ
Y: 5.0e+07
N: 3.4e+08
Arb. Units
E_kin (GeV)
e⁺/e⁻
Y: 8.5e+05
N: 2.5e+07
Arb. Units
E_kin (GeV)
n
Y: 1.1e+08
N: 1.8e+07
Arb. Units
E_kin (GeV)
ch. had.
Y: 1.7e+04
N: 4.1e+04
Arb. Units
E_kin (GeV)
μ⁺/μ⁻
Y: 1.0e+03
N: 1.0e+03
Arb. Units
E_kin (GeV)

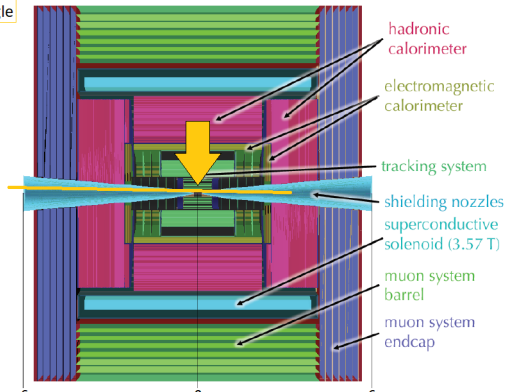

Arb. Units
1.0
0.8
0.6
0.4
0.2
0.0
0
25
50
75
100
125
150
175
200
$z_{\mu\,dec}$ (m)
photon
$e^+\,e^-$
ch. had.
neutron
$\mu^+\,\mu^-$


Total number 3.75e+03
Arb. Units
160
140
120
100
80
60
40
20
0
0
50
100
150
200
$z_{\mu\,dec}$ (m)
$\mu^+\,\mu^-$

Ex: 100 GeV electron exit at 3 m with 0.01 rad angle



reaches the inner layers of the tracking system



For bunch crossing, 2×10^{12} muons/bunch, 200 days/year operation, 100 kHz bunch crossing rate