MDI and Detector

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Interaction Region and MDI Design

The high luminosity requires:

- Low beta-function at the IP (few cm)
- High number of muons per bunch ($N_\mu \sim 2 \cdot 10^{12}$)

Muons decay particles…back of the envelope evaluation:

beam 1.5 TeV $\lambda = 9.3\times10^6$m, with $2\times10^{12}\,\mu$/bunch $\Rightarrow 2\times10^5$decay per meter of lattice.

Beam induced background, if not properly treated, could be critical for:

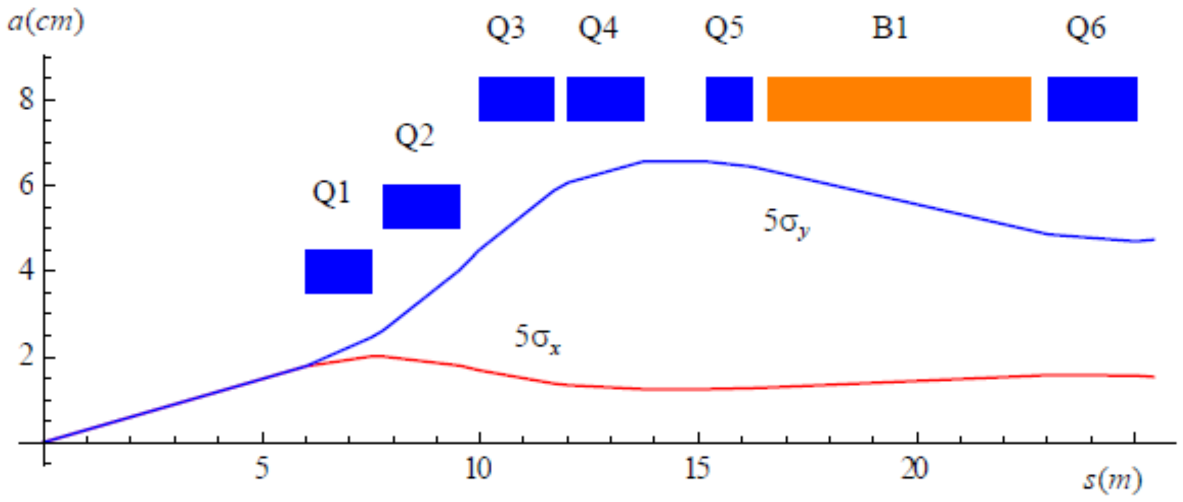
- Magnets, they need to be protected.
- People, due to neutrino induced radiation.
- Detector, the performance depends on the rate of background particles arriving to each subdetector.

A holistic approach is needed, tight together the development of the IR optics, the magnets and the shielding strategies (magnets and detector).

Optimization of Interaction Region at $\sqrt{s} = 1.5$ TeV

Y.I. Alexahin et al. *Muon Collider Interaction Region Design* FERMILAB-11-370-APC
N.V. Mokhov et al. *Muon collider interaction region and machine-detector interface design* Fermilab-Conf-11-094-APC-TD

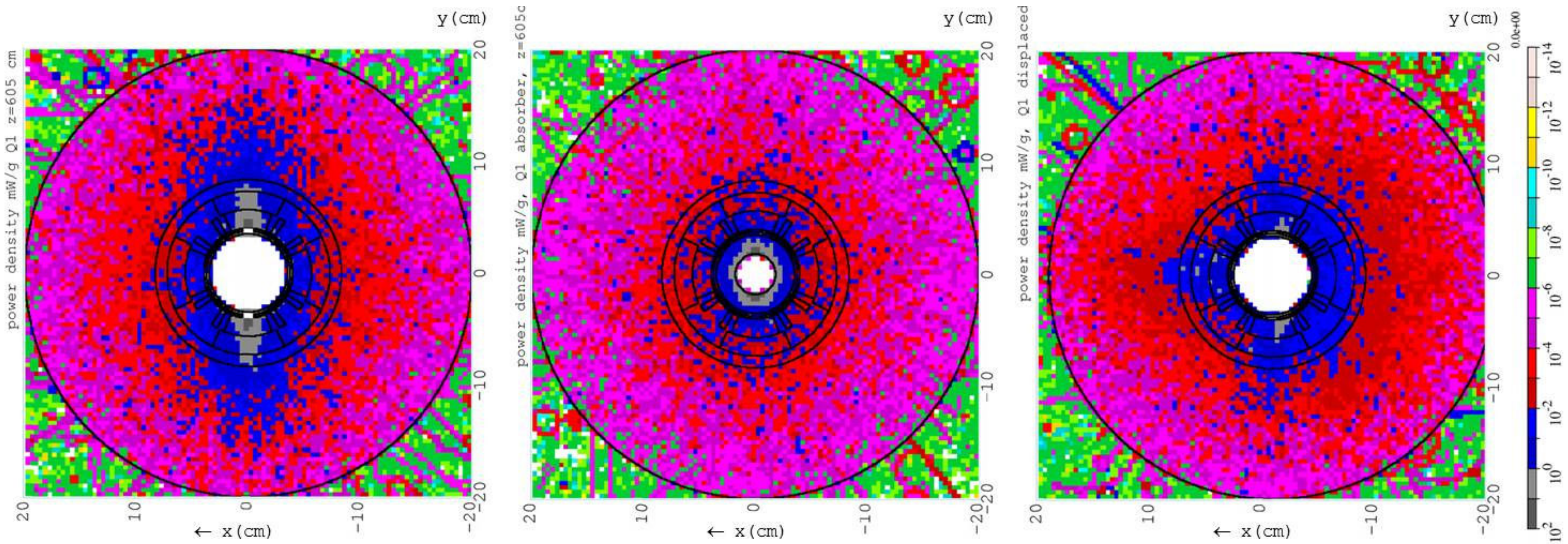
Parameter	**Unit**	**Value**
Beam energy	TeV	0.75
Repetition rate	Hz	15
Average luminosity / IP	10^{34}/cm^2/s	1.1
Number of IPs, N_{IP}	-	2
Circumference, C	km	2.73
β^*	cm	1 (0.5-2)
Momentum compaction, α_p	10^{-5}	-1.3
Normalized r.m.s. emittance, $\varepsilon_{\perp N}$	π·mm·mrad	25
Momentum spread, σ_p/p	%	0.1
Bunch length, σ_s	cm	1
Number of muons / bunch	10^{12}	2
Beam-beam parameter / IP, ξ	-	0.09
RF voltage at 800 MHz	MV	16



Quadrupoles in Nb_3Sn characteristics in the papers.
Dedicated dipoles to minimize the number of decay electrons in the coils and in the inner part of the detector.

Optimization of Interaction Region at $\sqrt{s} = 1.5$ TeV with absorbers

Important role is played by the absorber materials



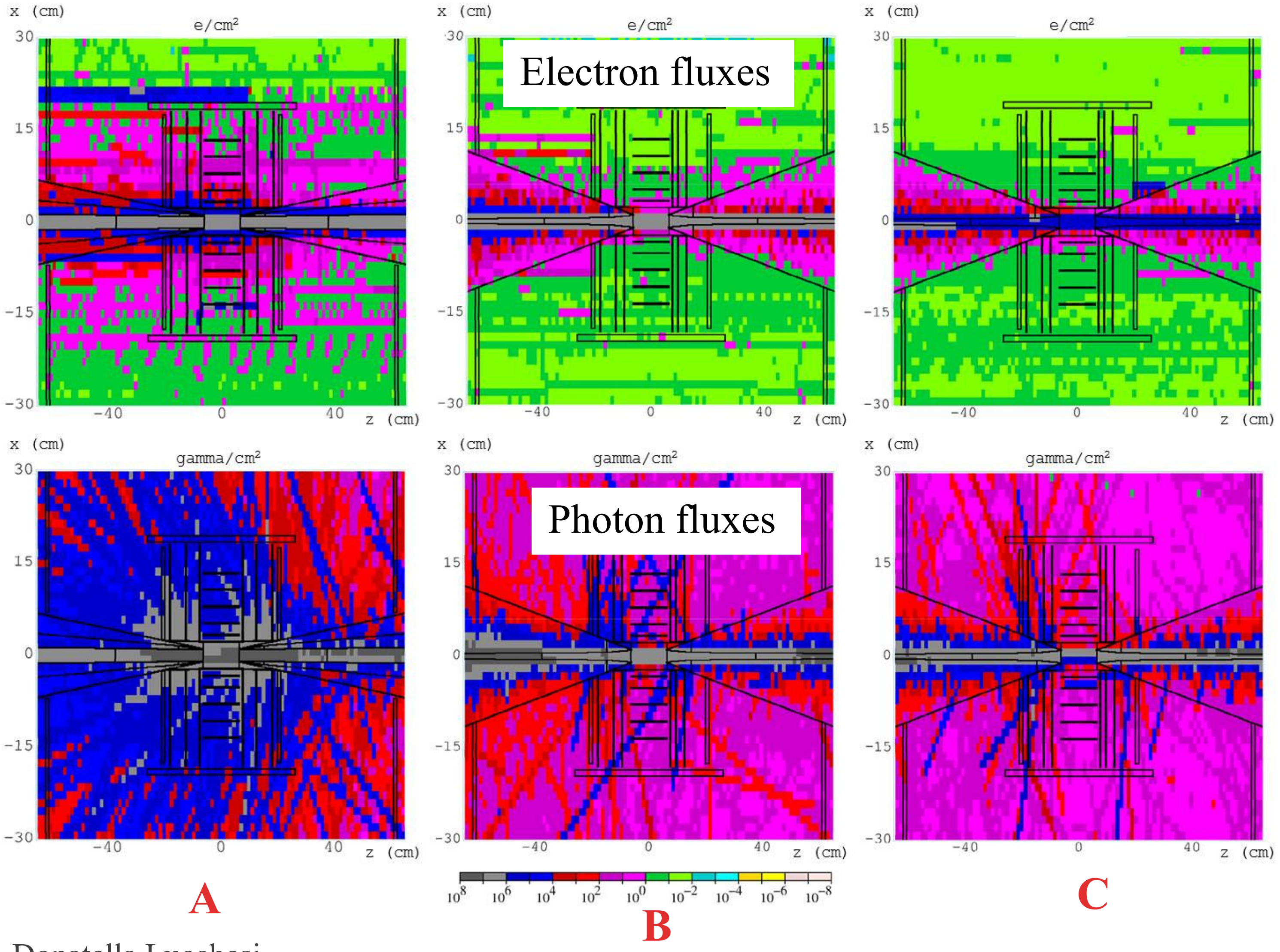
Standard, tungsten nozzle

+ tungsten liners inside quadrupoles

+ horizontal displacement of 0.1 of their aperture

Deposited power density in Q1 (mW/g)

IR and Detector background



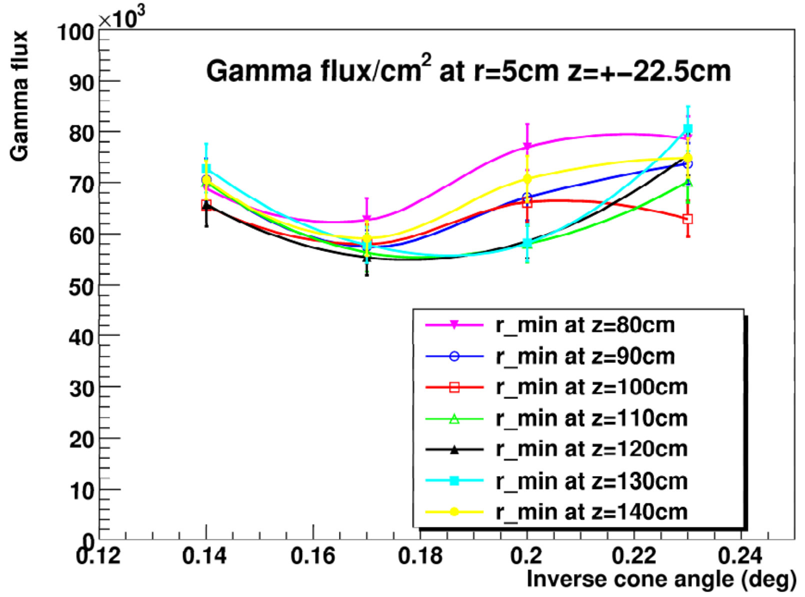
A: no masks between magnets, 6° cone with a 5σ radius liner up to 2 m from IP;
B: 5σ masks inserted between FF quads, cone angle 10°, 5σ liner up to 1 m from IP;
C: same as above plus FF quad displacement.

Results:

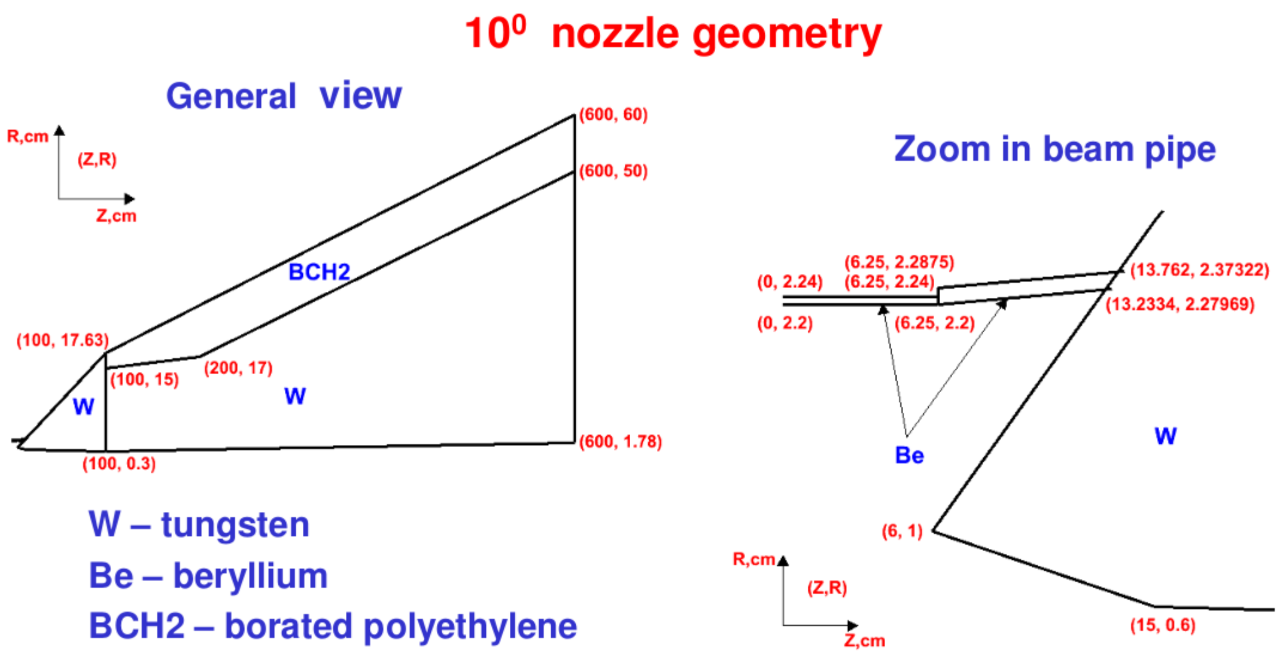
- Masks and increased cone angle reduce $e^{\pm}$ and γ fluxes by factors 300 and 20.
- Displacing FF quads increases $e^{\pm}$ flux by up to 50% decreases γ flux by factor 15

Further Detector Nozzle Optimization

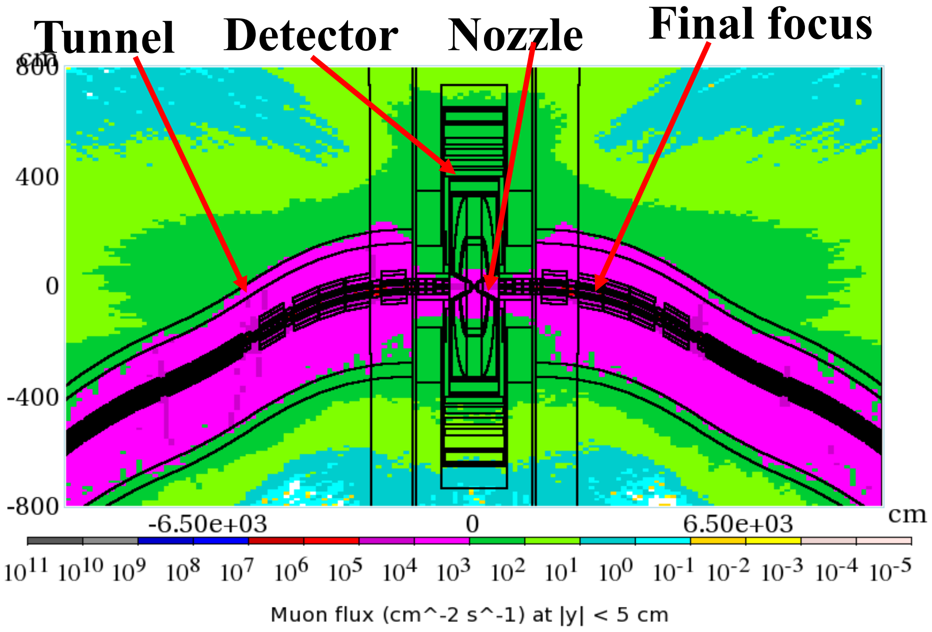
For example, gamma flux as a function of the angle of inner cone opening towards IP at the outer cone angle of 10°

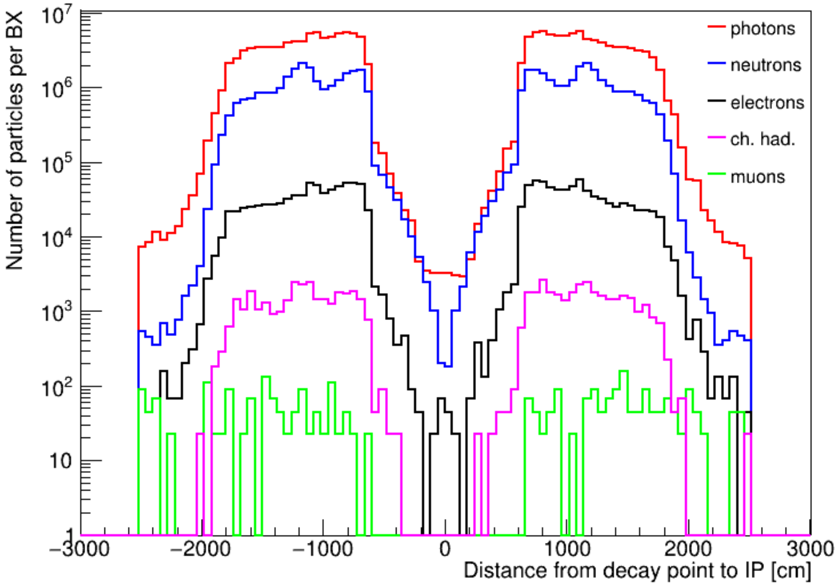


These studies have brought to the final nozzle configuration



Beam-Induced Background study

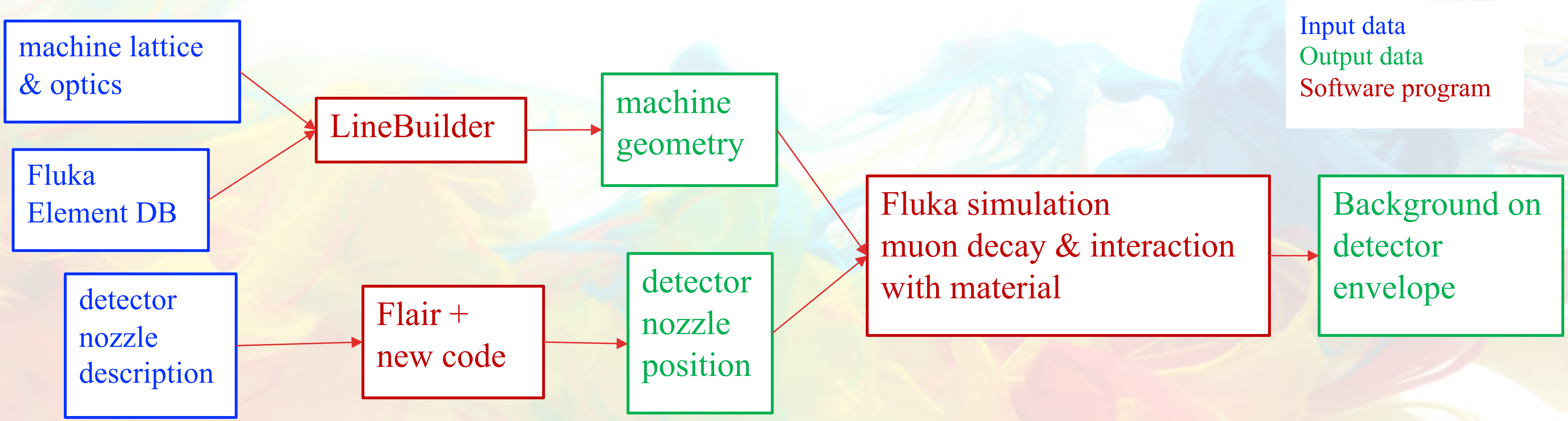




Muon flux: E~ 10-100 GeV in the detector. Produced as Bethe-Heitler pairs.

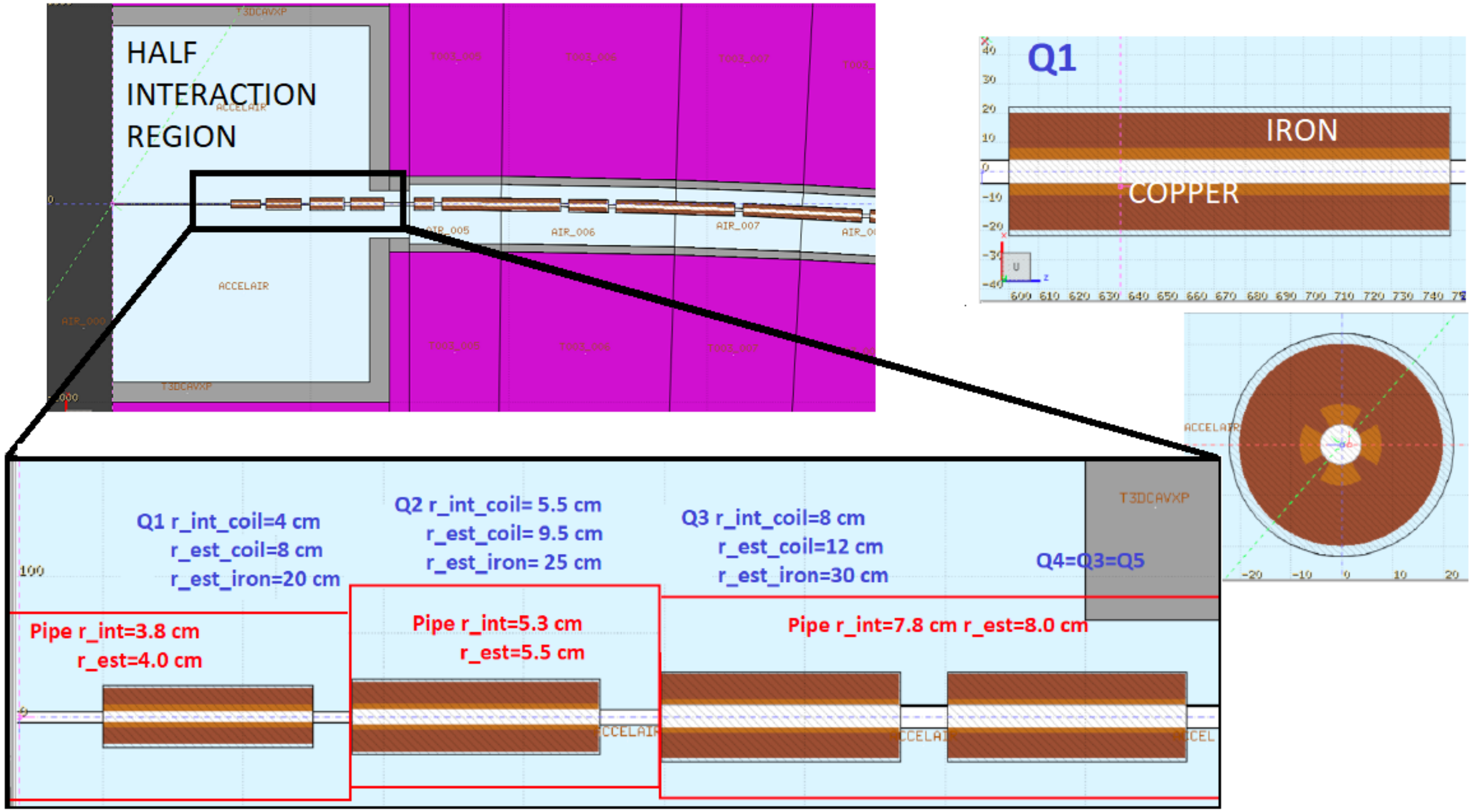
Produced with MARS15: particles arriving to the detector.

Further Detector Nozzle Optimization



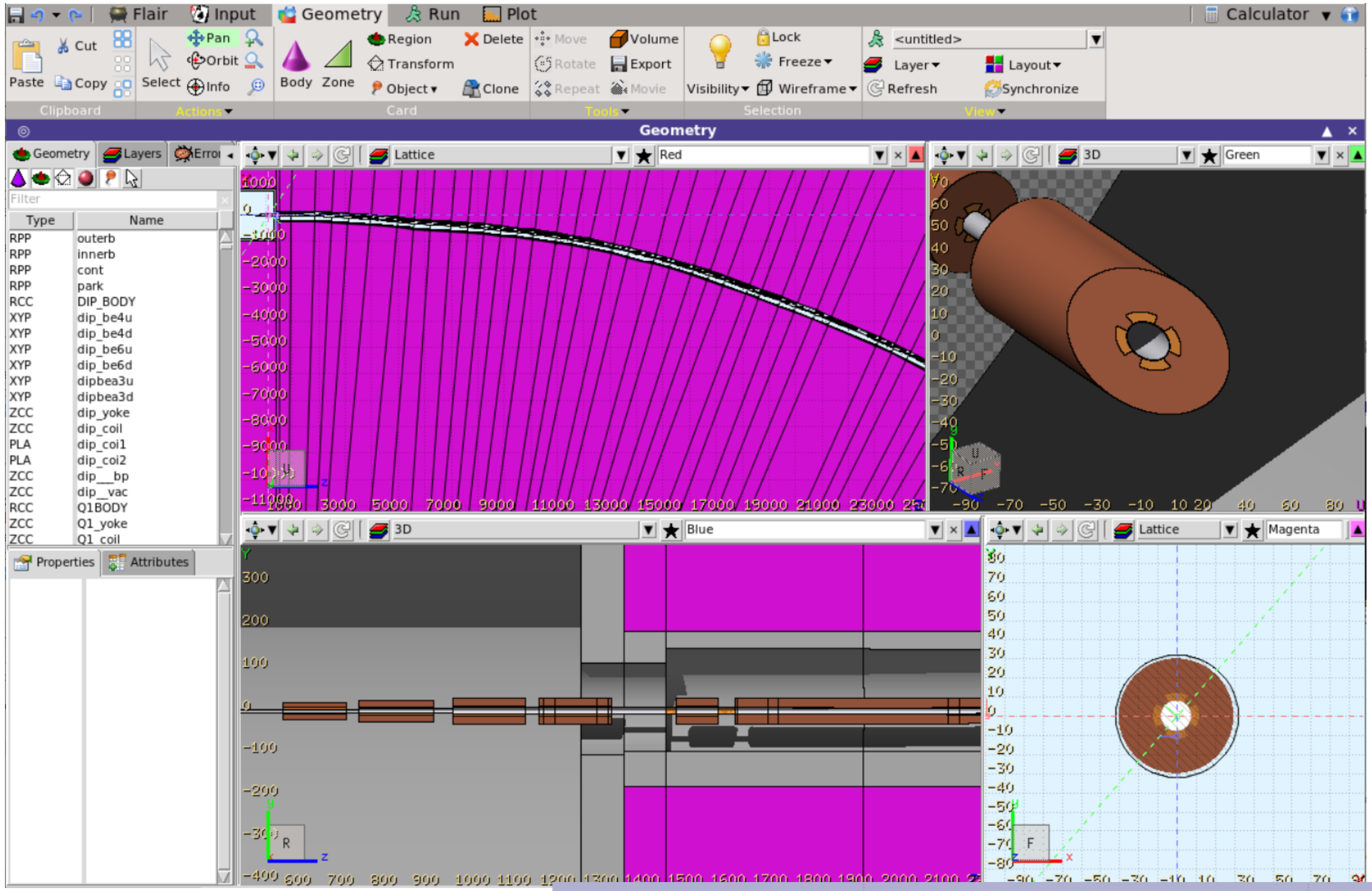
IR elements and geometry produced by LineBuilder visualized by FLAIR

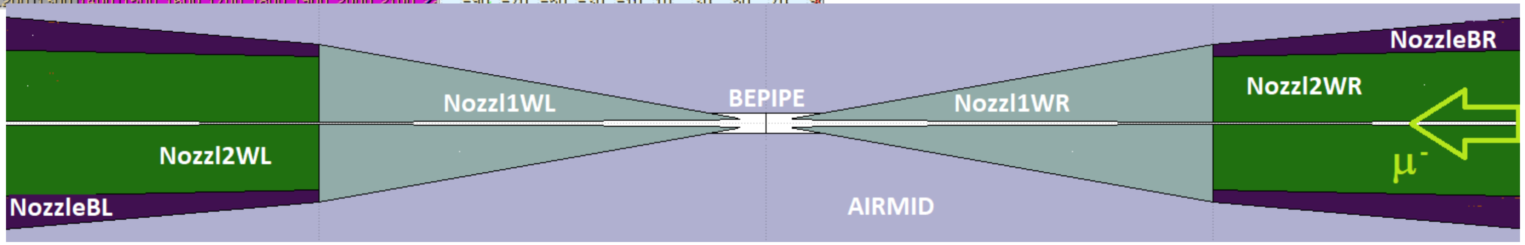
➡ Beam Pipe aperture, coil transverse dimensions, materials…



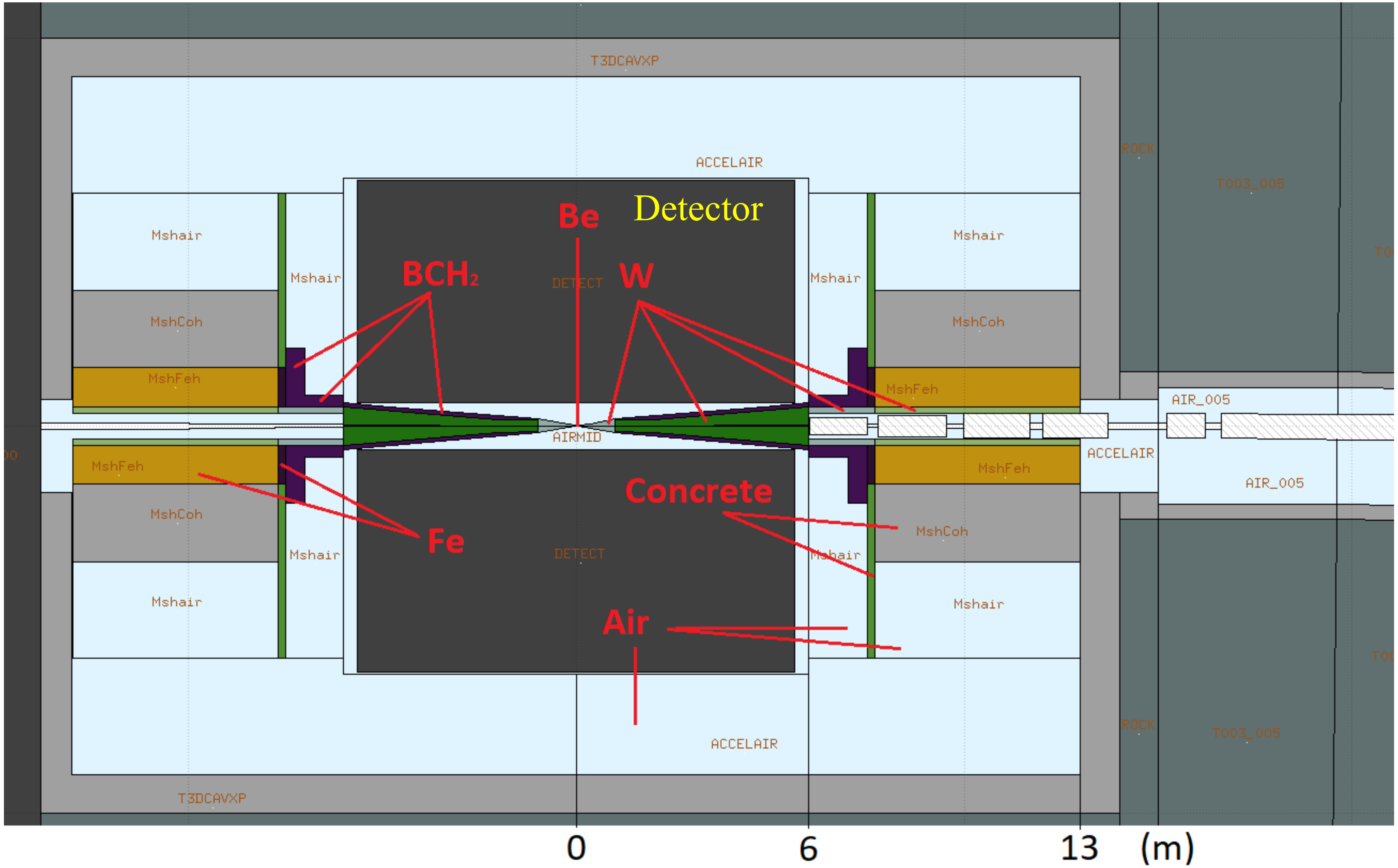
- MAP optic files.
- Details on magnets material and passive elements are also needed

Visualization of all the elements of the IR

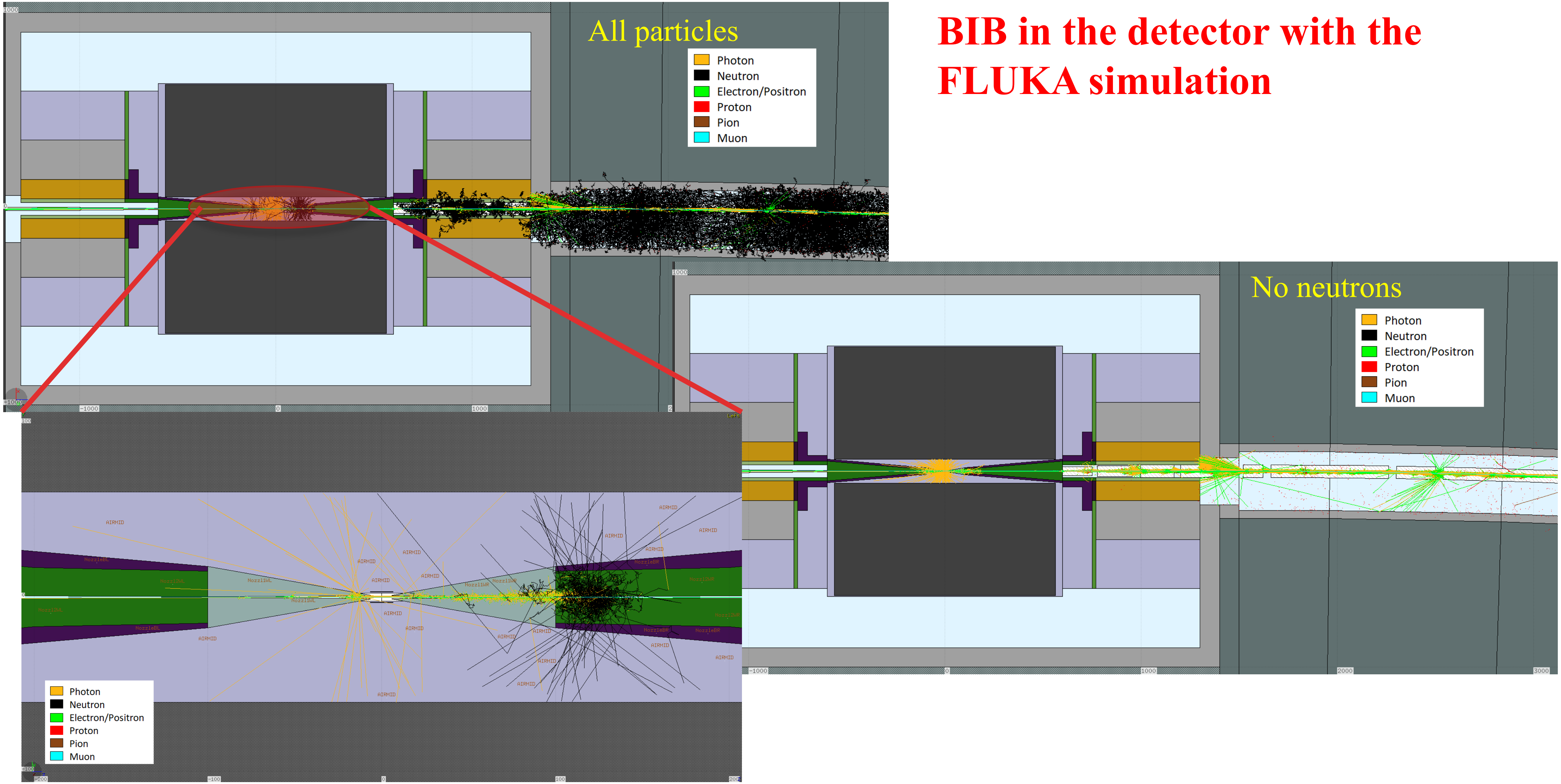




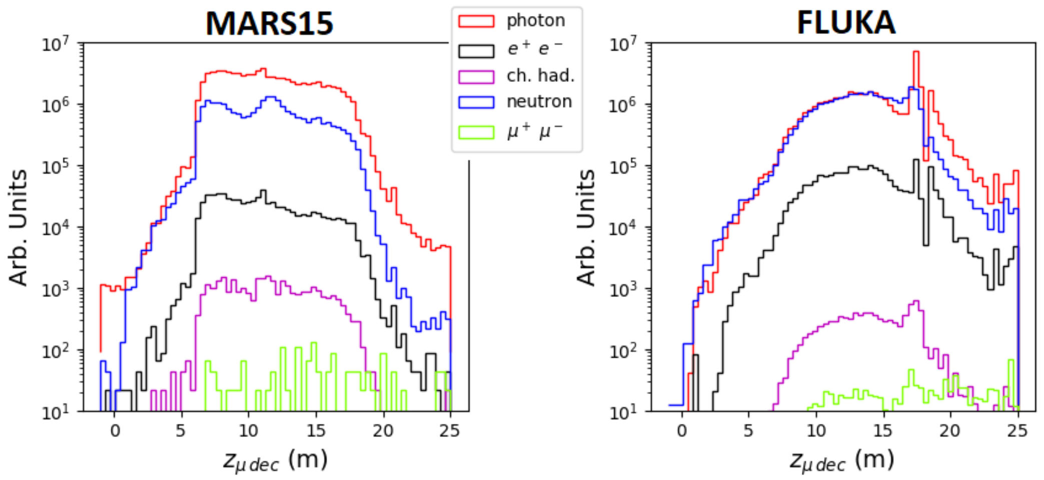
Complete IR Design



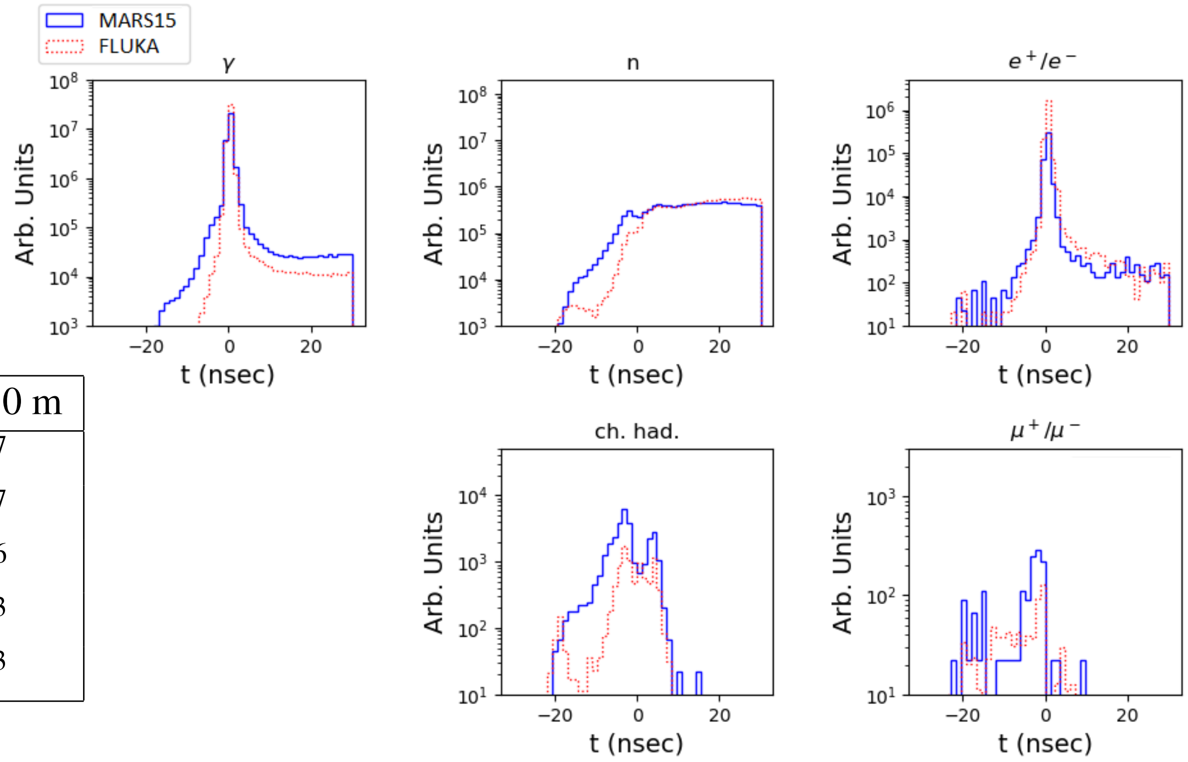
BIB in the detector with the FLUKA simulation



Comparison MARS15 - FLUKA



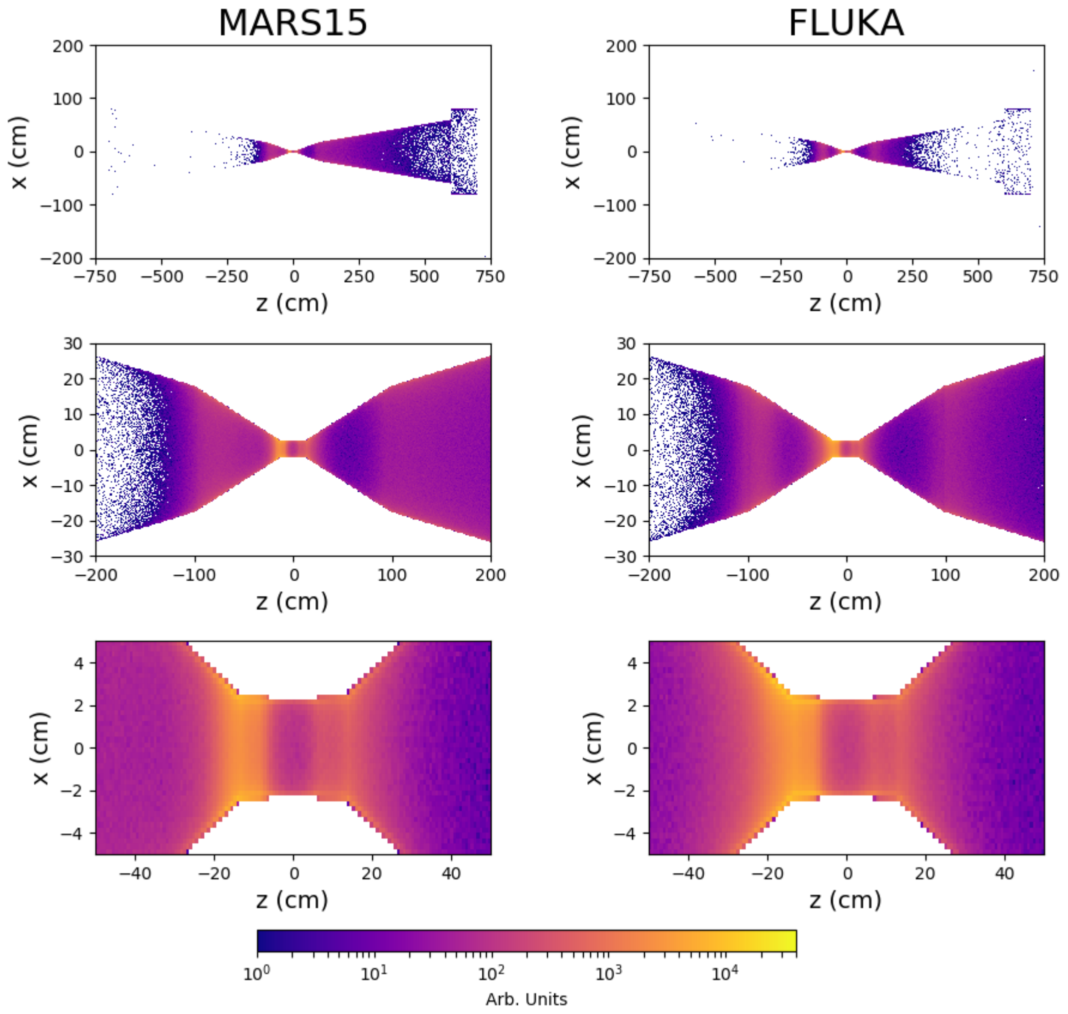
One beam, μ^- of 750 GeV with $2 \cdot 10^{12}$ particles/bunch



Particle (E_{th}, MeV)	MARS15	FLUKA 25 m	FLUKA 250 m
Photon (0.2)	8.3 10^7	4.24 10^7	4.34 10^7
Neutron (0.1)	2.44 10^7	3.33 10^7	3.36 10^7
Electron/positron (0.2)	7.23 10^5	2.06 10^6	2.11 10^6
Ch. Hadron (1)	3.07 10^4	8.94 10^3	9.20 10^3
Muon (1)	1.47 10^3	8.73 10^2	3.75 10^3

Discussion of the discrepancies later

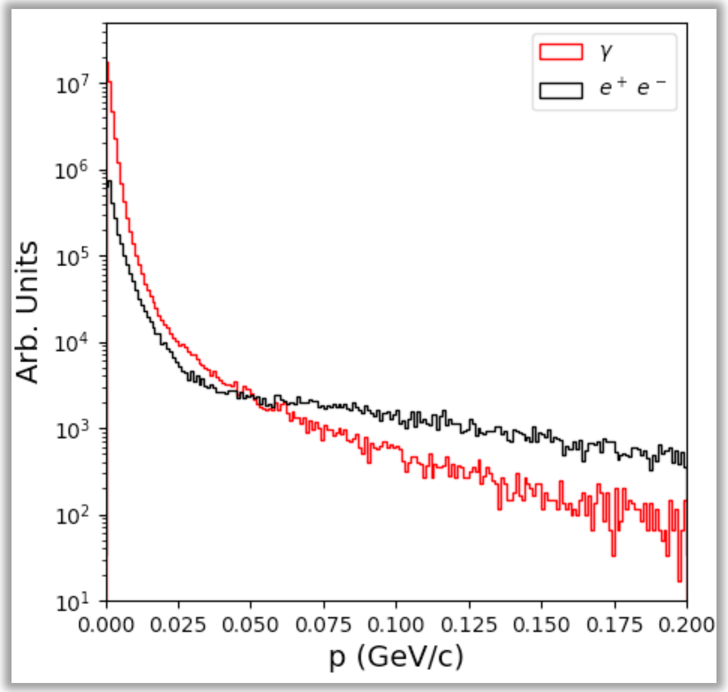
Comparison MARS15 - FLUKA

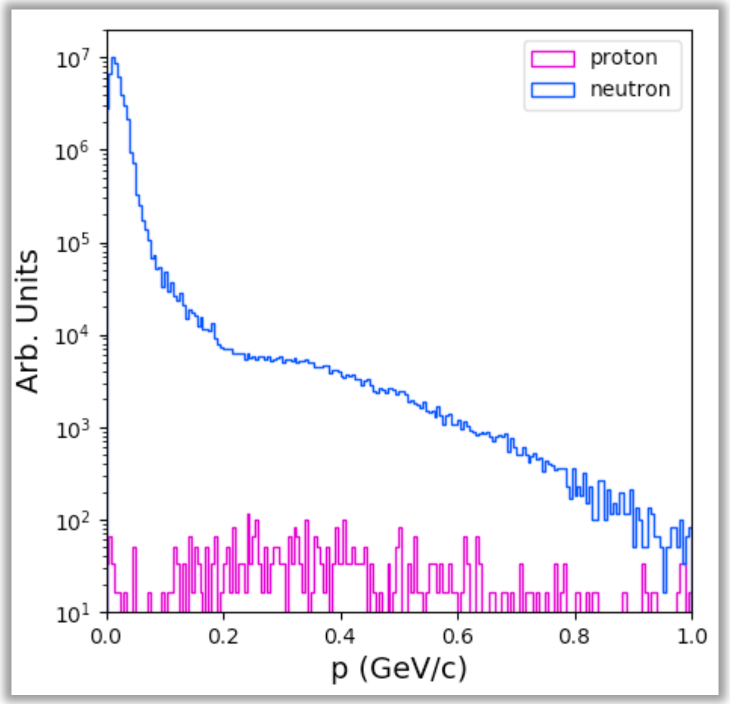


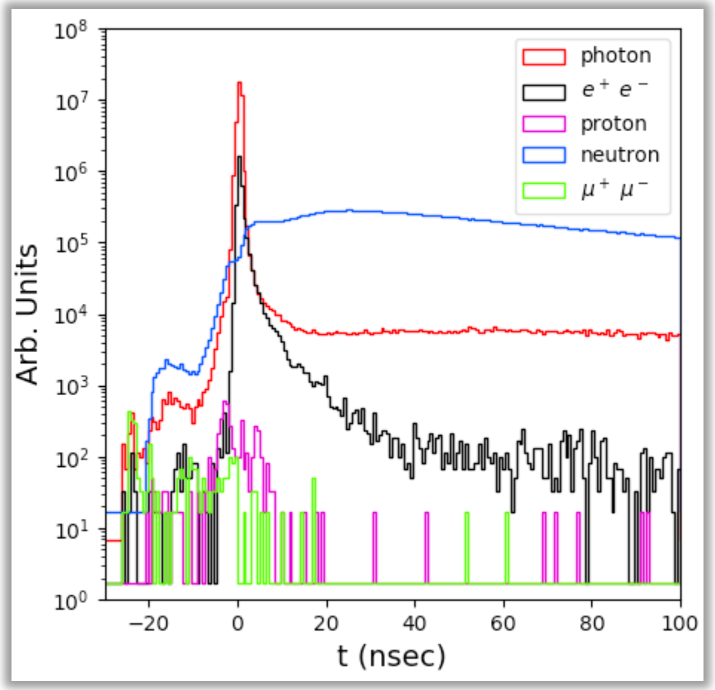
One beam, μ^- of 750 GeV with $2 \cdot 10^{12}$ particles/bunch

Results in details

One beam, μ^- of 750 GeV with $2 \cdot 10^{12}$ particles/bunch

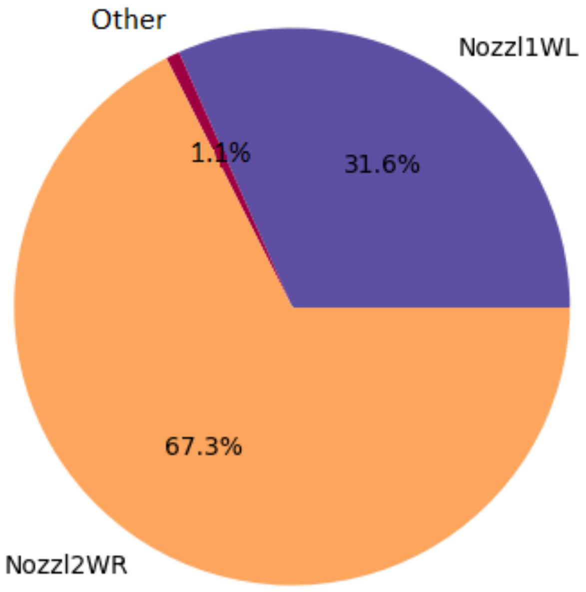






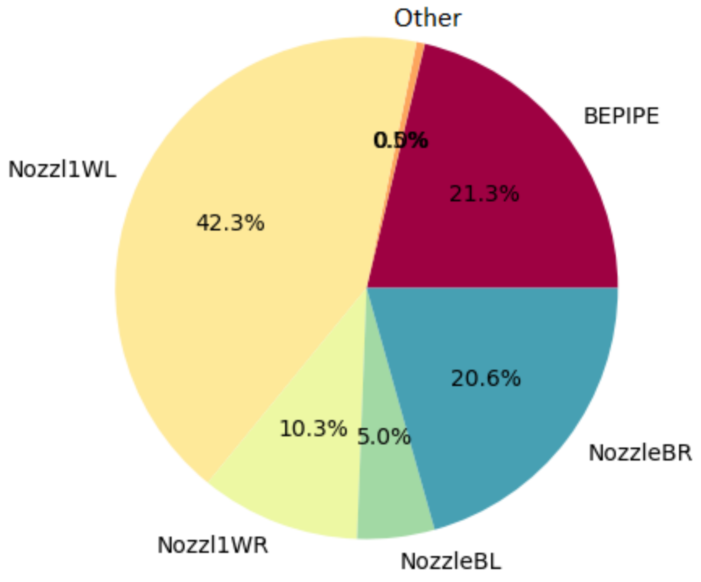
Beam-Induced Background Origin

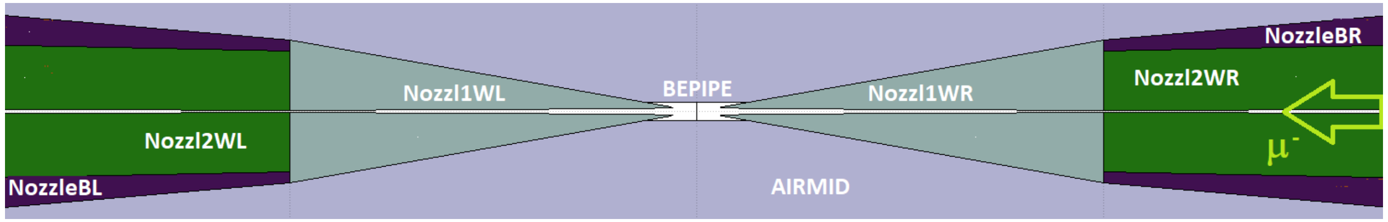
One beam, μ^- of 750 GeV with $2 \cdot 10^{12}$ particles/bunch



Elements of the IR where the first interaction of the first muon decay product occurs

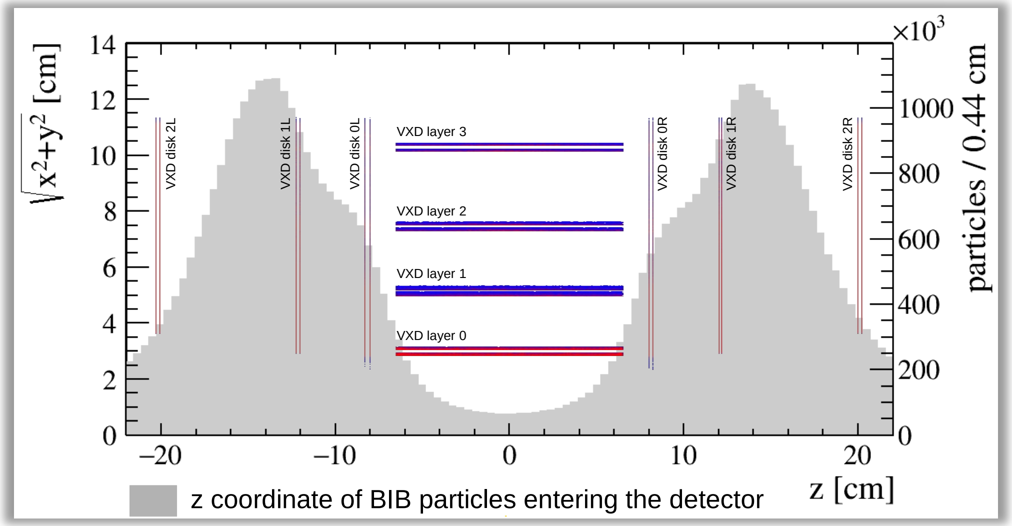
Elements of the IR where BIB particles exit and enter the detector



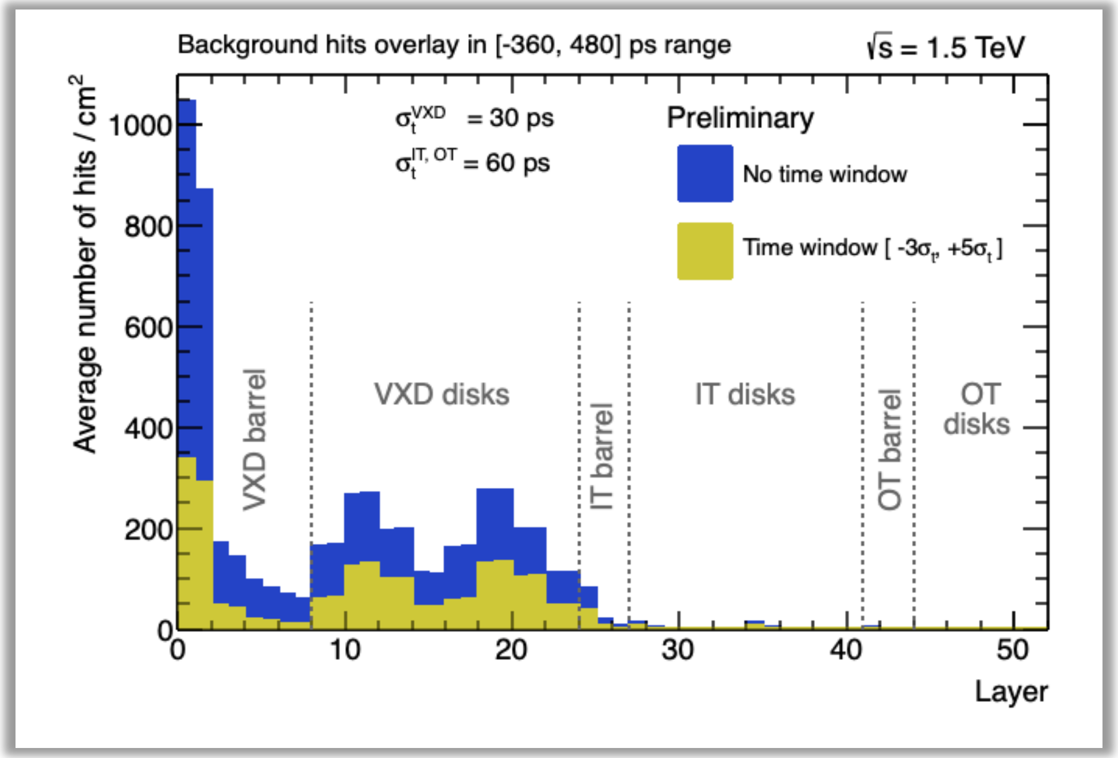


Given the BIB, how do we design the detector?

Tracker at $\sqrt{s}$ =1.5 TeV

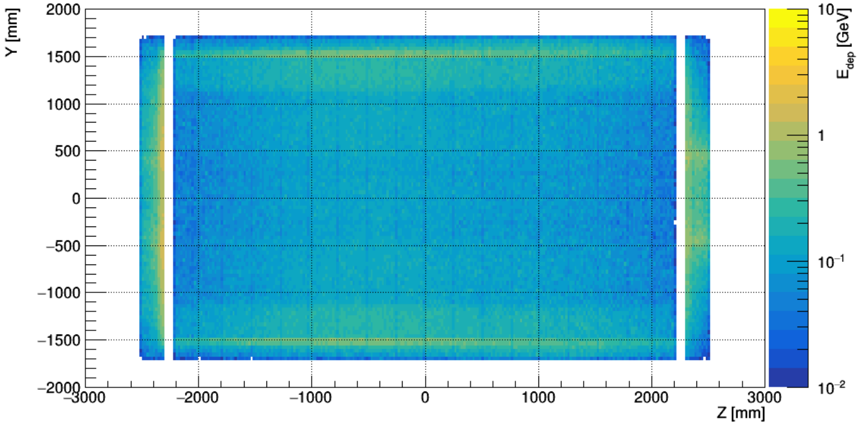


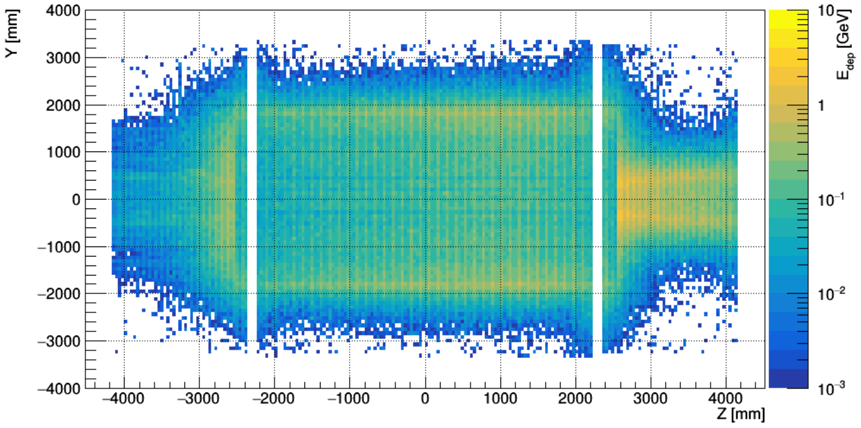
Vertex detector properly designed to not overlap with the BIB hottest spots around the interaction region.



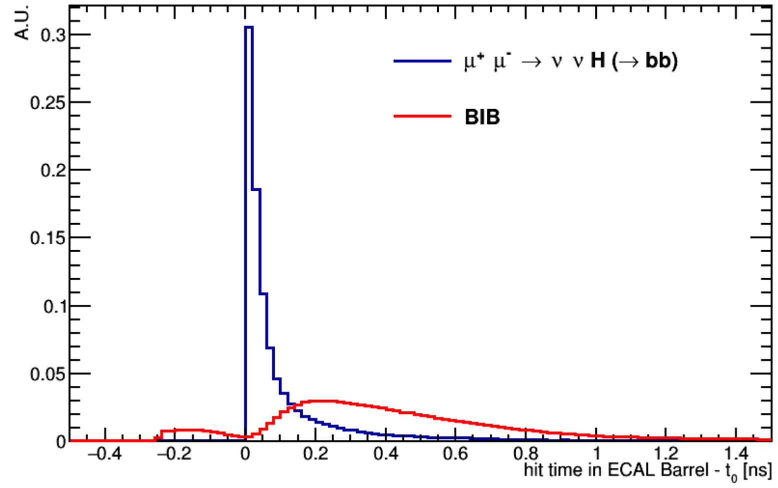
Tracking performance have been studied applying timing and energy cuts on clusters reconstruction compatible with IP time spread.

Calorimeter at $\sqrt{s}$ =1.5 TeV

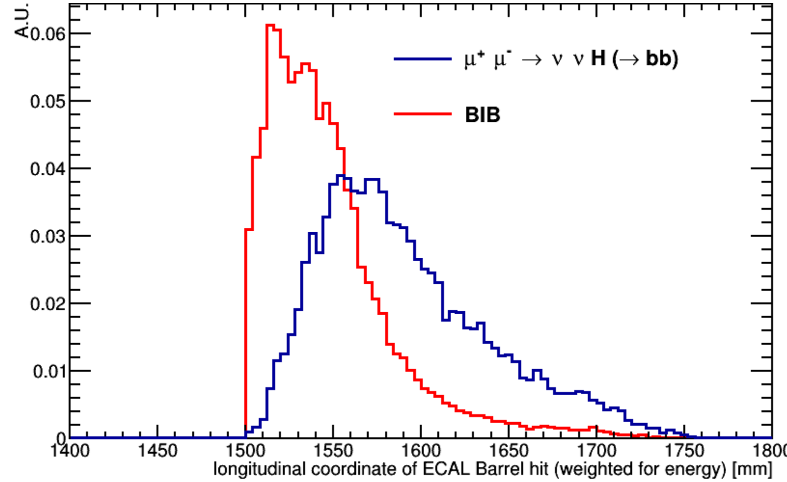




ECAL barrel hit arrival time – t_0



ECAL barrel longitudinal coordinate



BIB deposits large amount of energy in both ECAL and HCAL

Is this the end of the story?

Improvements

Particle (E_{th}, MeV)	MARS15	FLUKA 25 m	FLUKA 250 m
Photon (0.2)	$8.3\ 10^7$	$4.24\ 10^7$	$4.34\ 10^7$
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Muon (1)	$1.47\ 10^3$	$8.73\ 10^2$	$3.75\ 10^3$

Previous Studies

Detector Backgrounds at the Higgs Factory Muon Collider: MARS vs FLUKA show differences of factor ~2 Here differences go up and down …

Sources of differences:

- Different materials between MARS and FLUKA?
- Passive materials, do we have all the absorbers?

→ Database with the full IR description

- Intrinsic differences MARS15 vs FLUKA? → Generate BIB with both codes using exactly same IR

Lattice improvements

- Add collimators to remove secondary muons coming from very far?
- Further optimization of absorbers and nozzle?
- Further optimization of magnets aperture and liner?

Is there a way to benchmark simulation? Is it possible to have high energy muon beams?

To conclude

- Simulation and analysis tools to optimize MDI are ready and well tested.
- Benchmark Monte Carlo? Test with data?
- Nest step is nozzle optimization at $\sqrt{s} = 3$ TeV where the IR lattice is well tuned. Work is already in progress.

Strong collaboration between accelerator and detector physicists is mandatory for the proper MDI design.

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