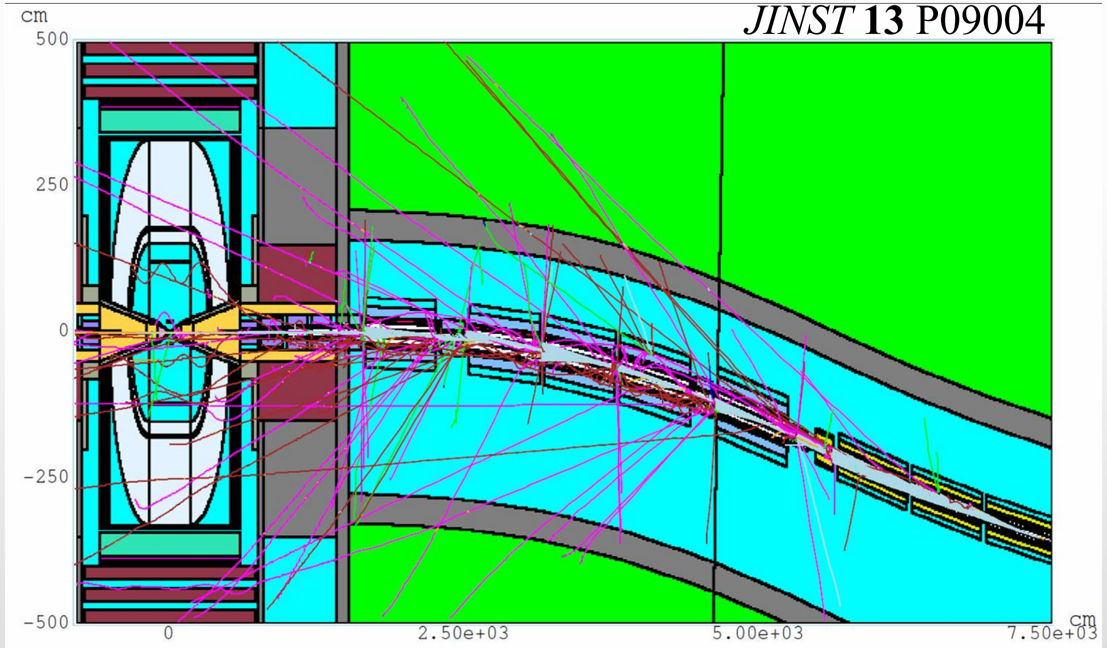
Muon Collider – Full simulation

August 26, 2020

The Challenge: beam-induced background

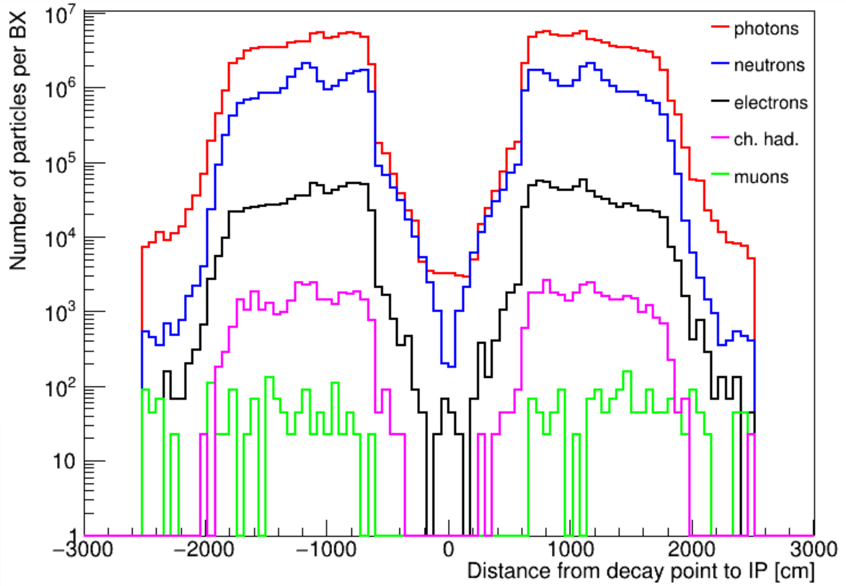
Muon induced background is critical for:

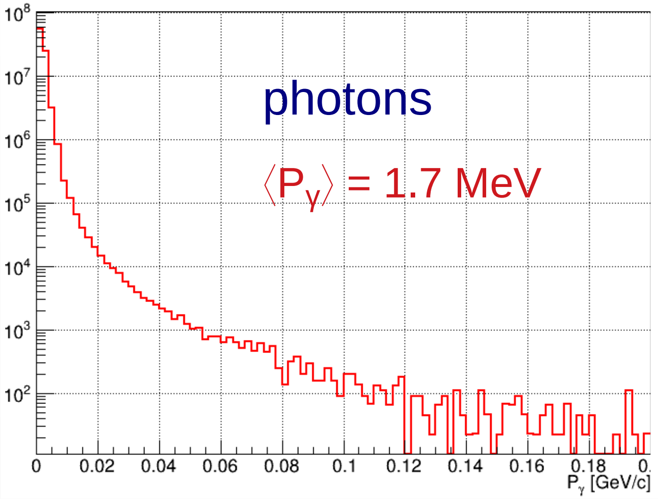
- Magnets, they need to be protected
- Detector, the performance depends on the rate of background particles arriving to each subdetector and the number and the distribution of particles at the detector depends on the lattice

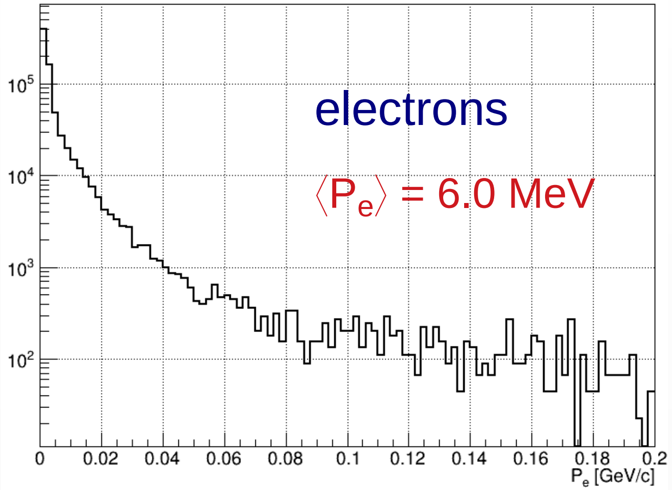


- MAP developed a realistic simulation of beam-induced backgrounds in the detector by implementing a model of the tunnel and the accelerator ±200 m from the interaction point.
- Secondary and tertiary particles from muon decays are simulated with MARS15 then transported to the detector.
- Two tungsten nozzles play a crucial role in background mitigation inside the detector.

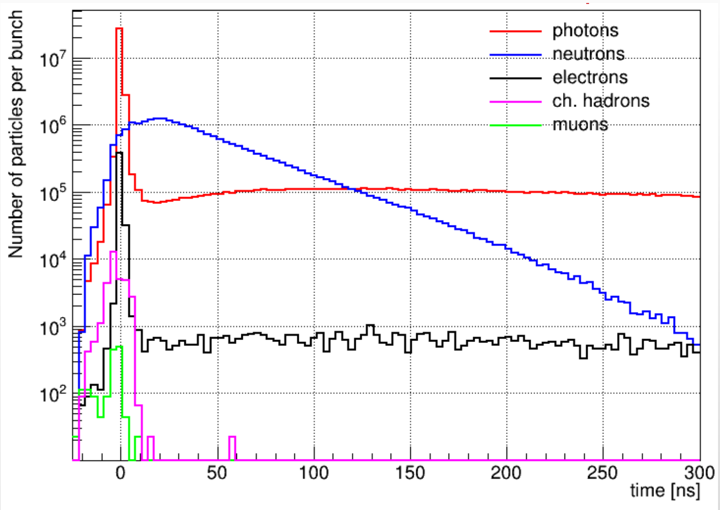
Beam-induced background properties for 750 GeV $\mu^{\pm}$ beams







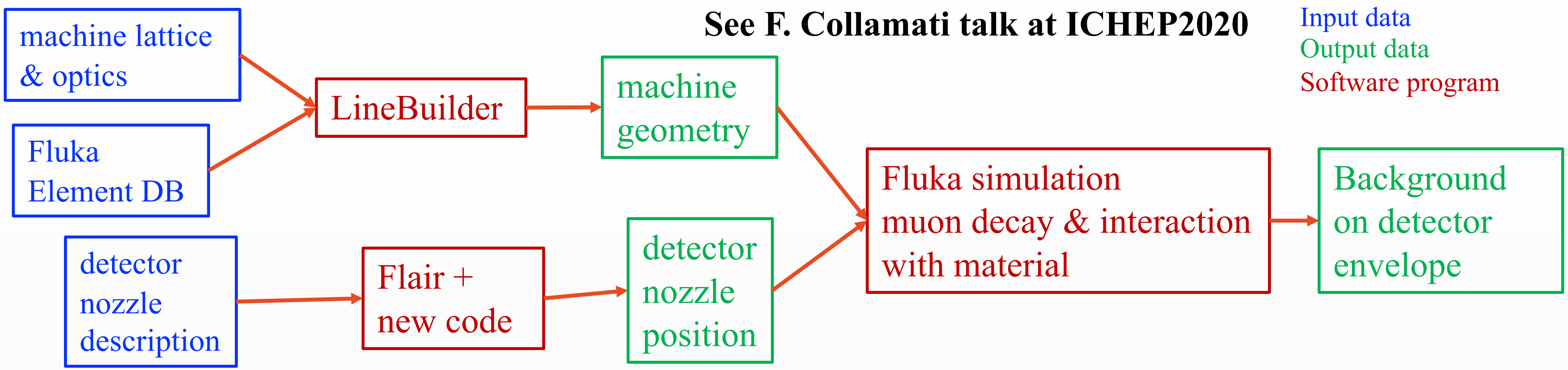
Contributions form μ decays |z| > 25 m become negligible for all background species but Bethe-Heitler muons

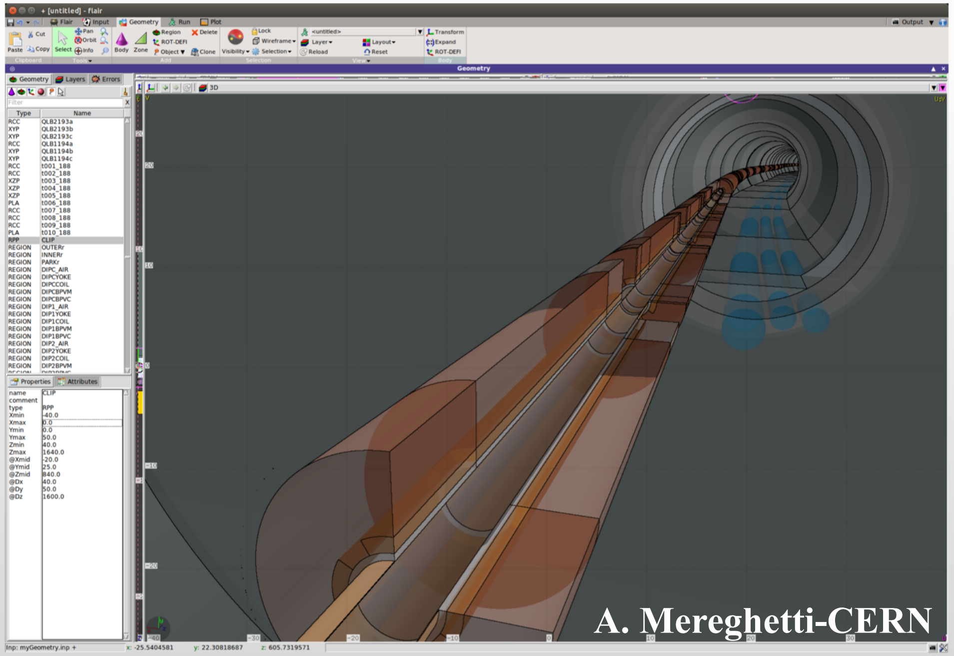


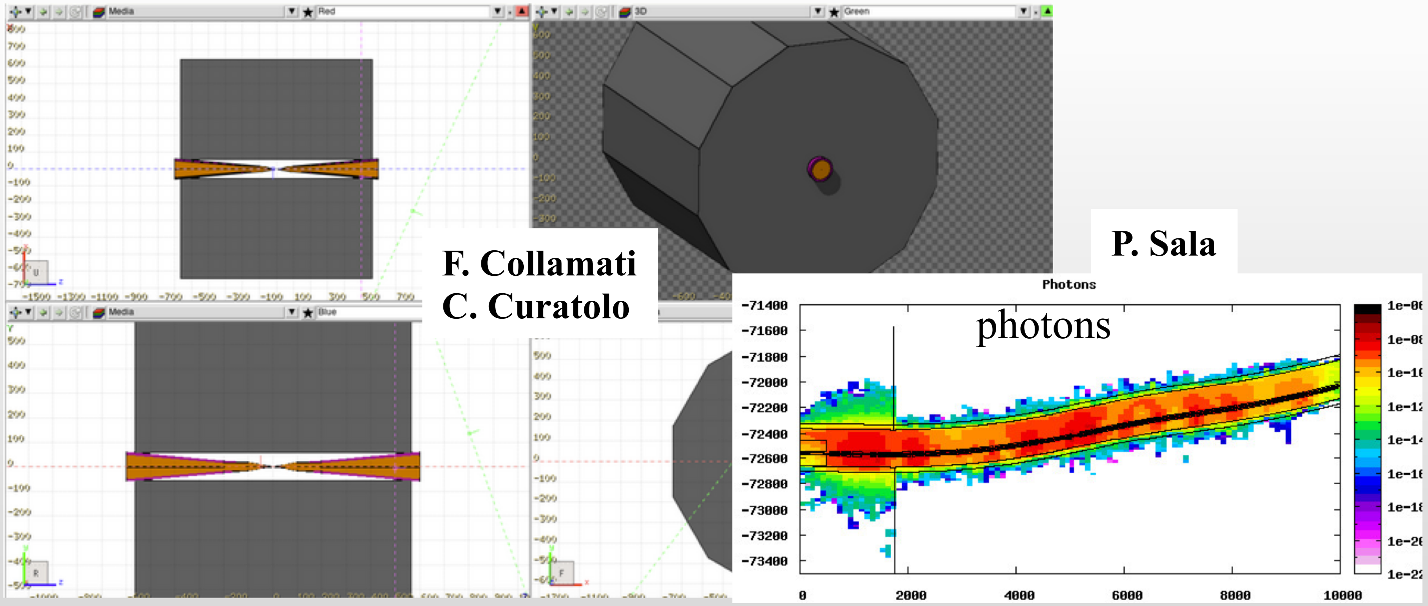
Secondary and tertiary particles have low momentum and different arrival time in the IP.

The beam-induced background simulation

See F. Collamati talk at ICHEP2020







Beam Induced Background Studies

Work plan and collaboration:

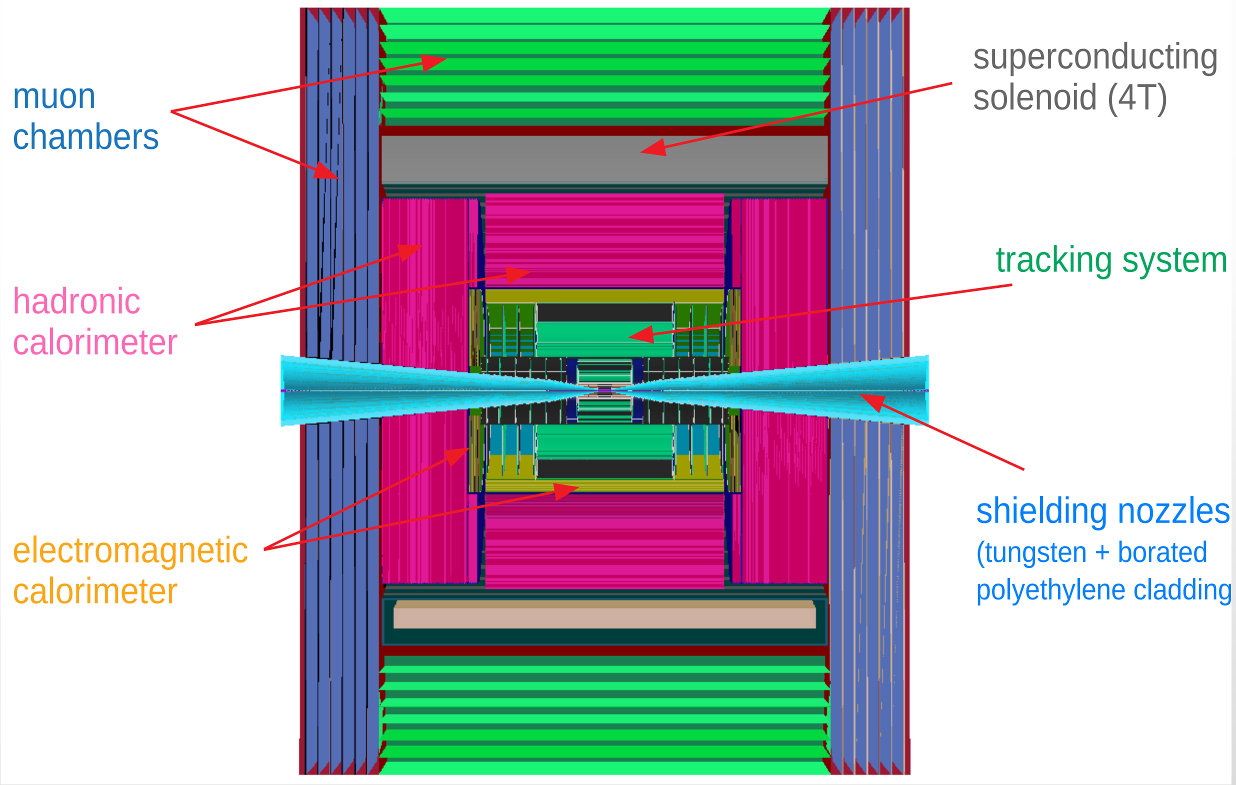
- The software necessary to perform beam-induce-background (BIB) studies is ready.

- The BIB can be studied and characterized at different center-of-mass energies:
  - $\sqrt{s} = 1.5$ TeV is what was available from MAP, used to test the full software chain, thanks to MAP collaboration for providing the machine lattice and optics.

  - $\sqrt{s} = 3$ TeV is the next step, machine lattice and optics are needed, it should be available from previous MAP activities. Some work may be needed. The “nozzle” shape and material has to be optimized or other mitigation strategies have to be studied.

Study of Detector Response at $\sqrt{s}$ =1.5 TeV

The simulation/reconstruction tools supports signal + beam-induced background merging.
ILCSoft, which will be part of the Future Collider Framework, Key4hep, is used.



The current detector will be optimize in the future.

Vertex Detector (VXD)
- 4 double-sensor barrel layers 25x25μm^2
- 4+4 double-sensor disks ”

Inner Tracker (IT)
- 3 barrel layers 50x50μm^2
- 7+7 disks ”

Outer Tracker(OT)
- 3 barrel layers 50x50μm^2
- 4+4 disks ”

Electromagnetic Calorimeter (ECAL)
- 40 layers W absorber and silicon pad sensors, 5x5 mm^2

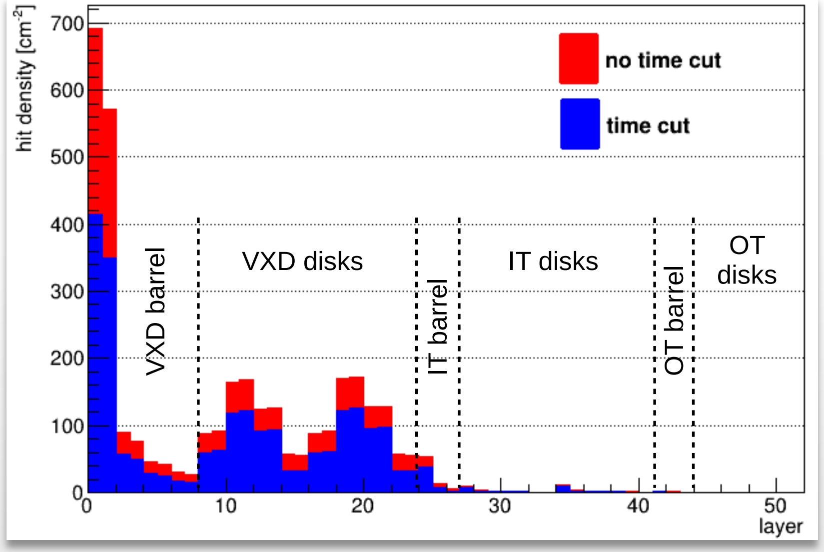
Hadron Calorimeter (HCAL)
- 60 layers steel absorber & plastic scintillating tiles, 30x30 mm^2

Tracking performance at $\sqrt{s}$ =1.5 TeV

See M. Casarsa talk at ICHEP2020

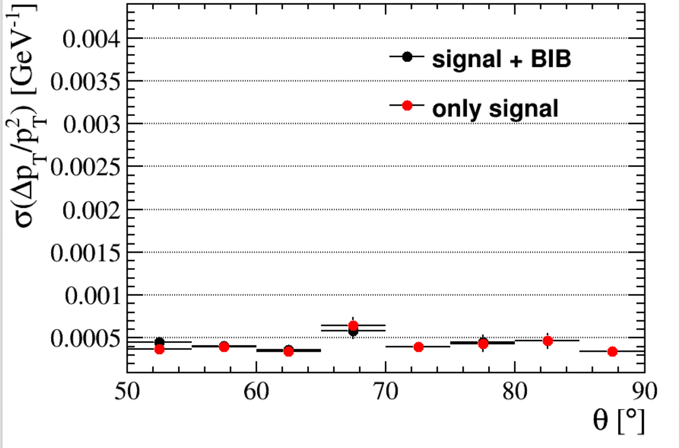
L.Sestini M. Casarsa N. Bartosik L. Buonincontri

Effects of beam-induce background can be mitigated by exploiting “5D” detectors, i.e. including timing.

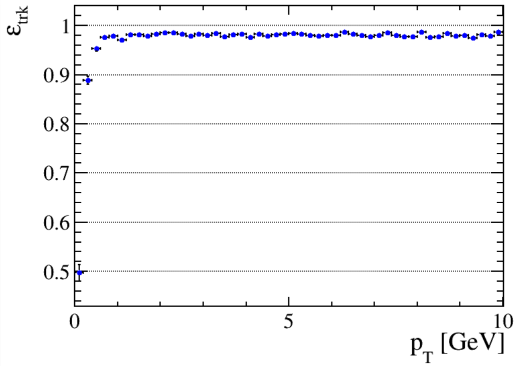


- Simplified digitization: position + time smearing. Realistic digitization in progress.
- Double-layer based BIB rejection in progress.

Track momentum resolution

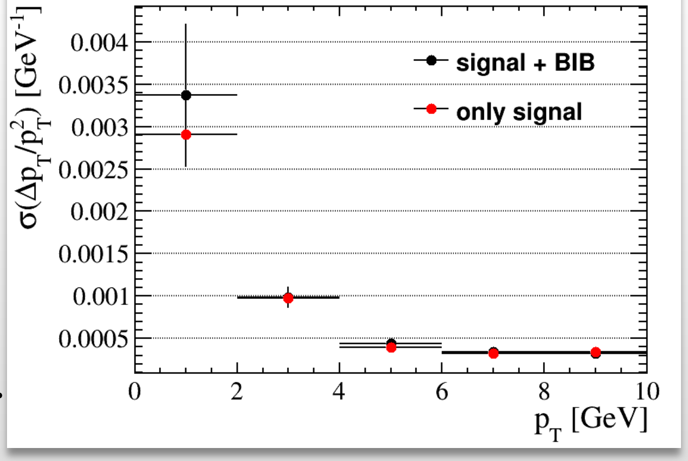


Track momentum efficiency

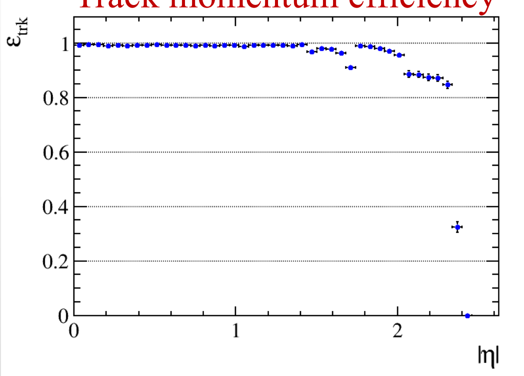


Signal=muon gun

Track momentum resolution



Track momentum efficiency



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

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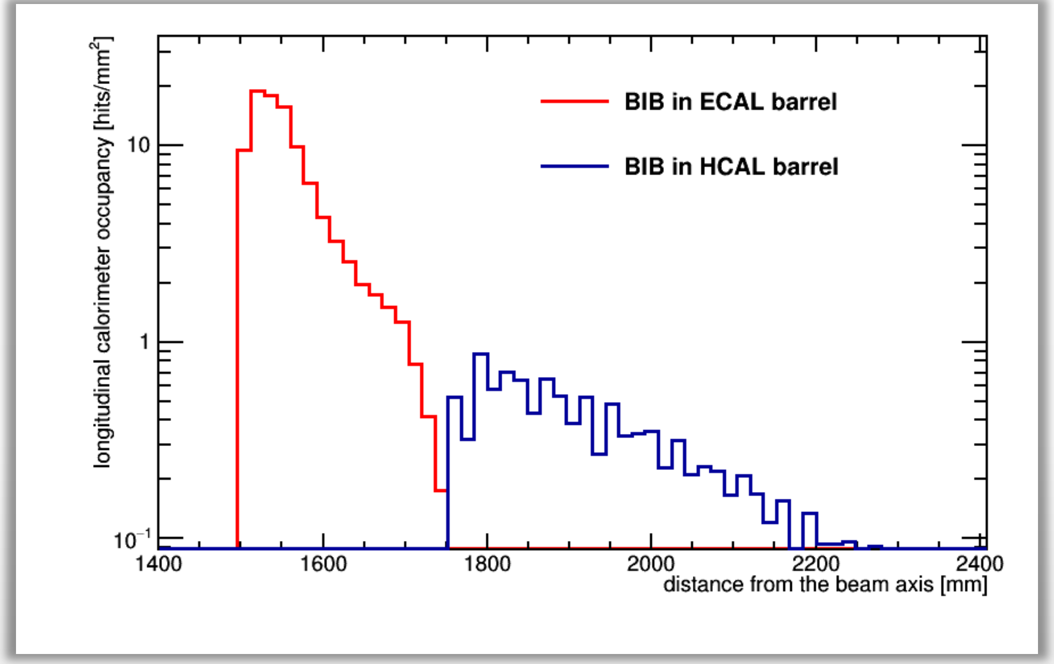
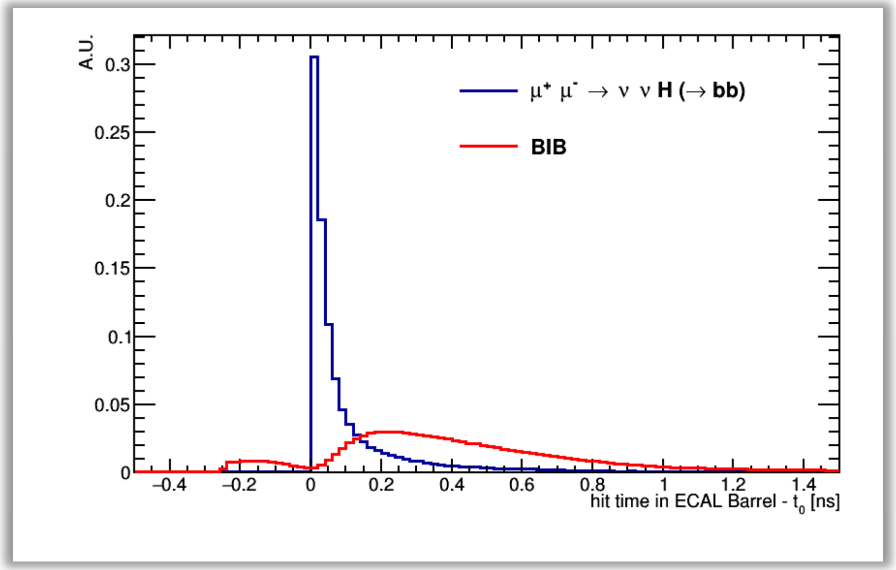
Calorimeter Occupancy



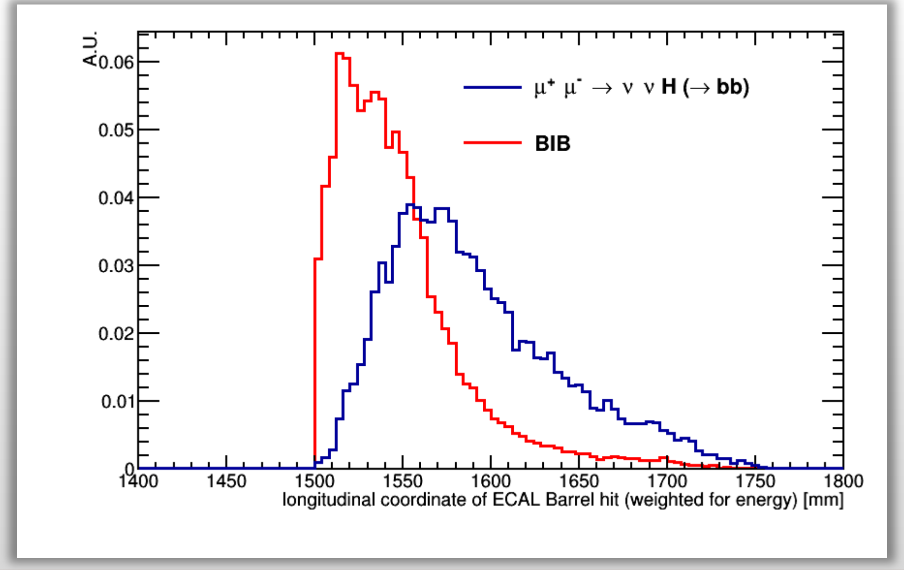
- New jet reconstruction algorithm based on particle flow is in progress.
- New jet b-tag algorithm based on machine learning methods under development.

See M. Casarsa talk at ICHEP2020

ECAL barrel hit arrival time – t_0



ECAL barrel longitudinal coordinate



Jet Reconstruction and b-tag performance at $\sqrt{s}$ =1.5 TeV

Using the MAP detector and framework, performance have been determined using **simple and rough methods** for the reconstruction

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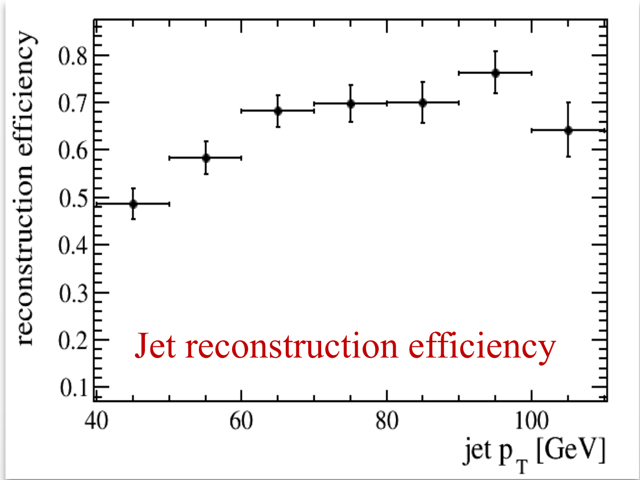
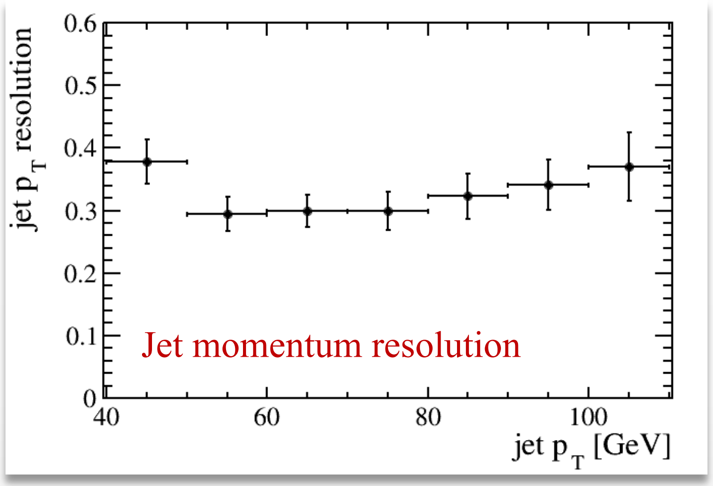
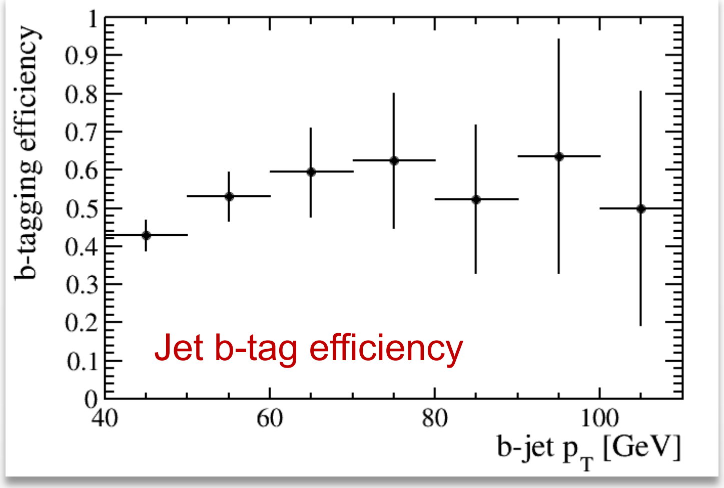






Background tagging:

- fake rate: 1 ÷ 3 %
- Tests show fake rate is manageable

Higgs $b\bar{b}$ Couplings Results

See L. Sestini talk at ICHEP2020

- The instantaneous luminosity, $\mathcal{L}$, at different $\sqrt{s}$ is taken from MAP.
- The acceptance, A, the number of signal events, N, and background, B, are determined with simulation.
- One detector and 4 Snowmass years are assumed.

$\sqrt{s}$ [TeV]	A [%]	ϵ [%]	$\mathcal{L}$ [$cm^{-2}s^{-1}$]	$\mathcal{L}_{int}$ [ab^{-1}]	σ [fb]	N	B	$\frac{\Delta\sigma}{\sigma}$ [%]	$\frac{\Delta g_{Hbb}}{g_{Hbb}}$ [%]
1.5	35	15	$1.25 \cdot 10^{34}$	0.5	203	5500	6700	2.0	1.9
3.0	37	15	$4.4 \cdot 10^{34}$	1.3	324	33000	7700	0.60	1.0
10	39	16	$2 \cdot 10^{35}$	8.0	549	270000	4400	0.20	0.91

	$\sqrt{s}$ [TeV]	$\mathcal{L}_{int}$ [ab^{-1}]	$\frac{\Delta g_{Hbb}}{g_{Hbb}}$ [%]
Muon Collider	1.5	0.5	1.9
	3.0	1.3	1.0
	10	8.0	0.91
CLIC	0.35	0.5	3.0
	1.4	+1.5	1.0
	3.0	+2.0	0.9

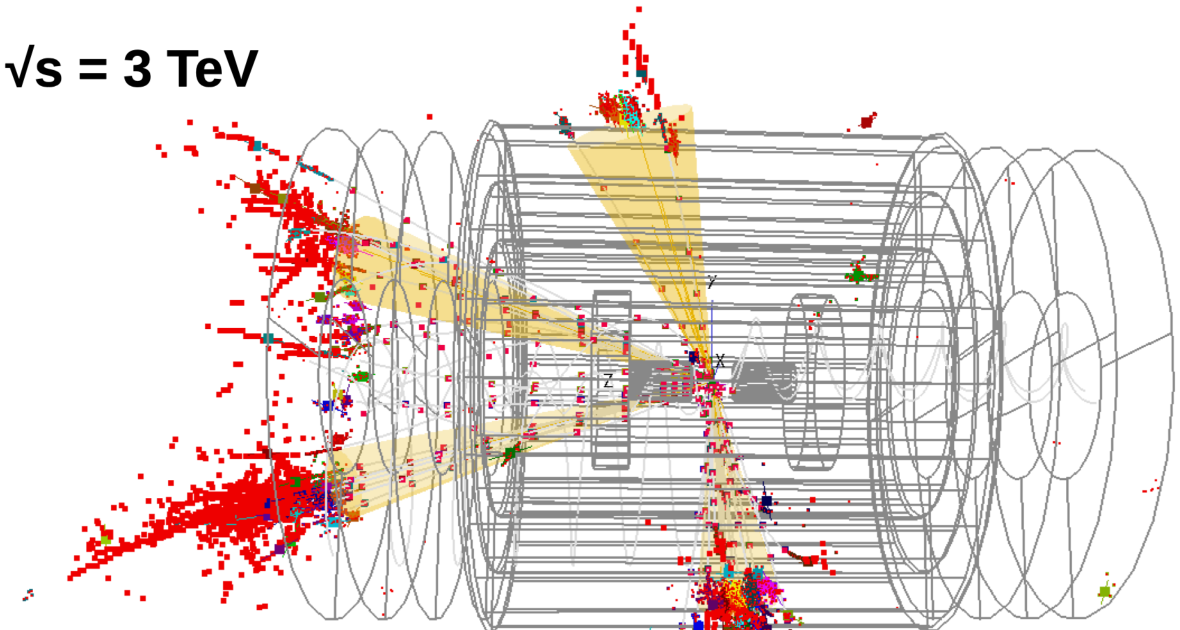
CLIC numbers are obtained with a model-independent multi-parameter fit performed in three stages, taking into account data obtained at the three different energies.

Results published on JINTST as Detector and Physics Performance at a Muon Collider

$\mu^+\mu^- \to \nu\bar{\nu}\ H(\to b\bar{b})\ H(\to b\bar{b})$

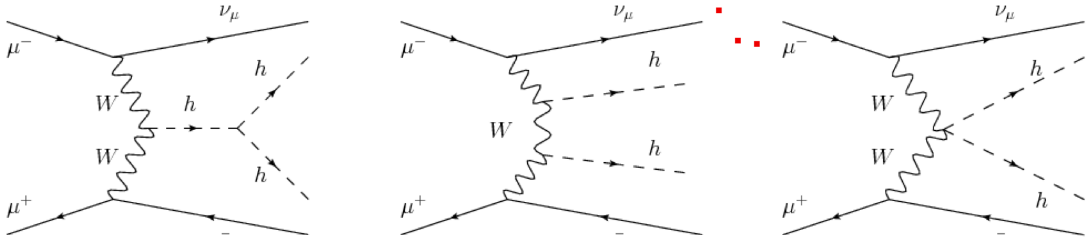
PRELIMINARY

$\sqrt{s}$ = 3 TeV

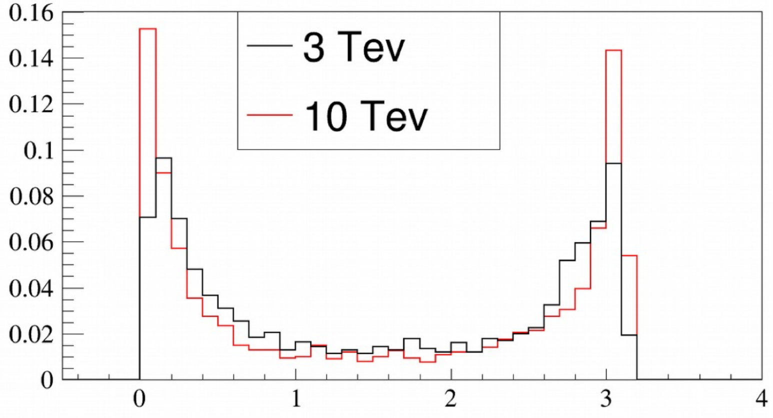


Talk by Massimo Casarsa on Detector
→ July 29 Future Detectors session
More info on detector in backup

See L. Sestini talk at ICHEP2020



- Next step: **study of the HH production.**
- We are now using a **modified version of the CLIC detector**, with nozzles and a different vertex detector, using the ILCSoft framework for the full simulation and reconstruction.
- Signal and backgrounds are generated with WHIZARD.
- Higgs is likely to be emitted in the forward region.



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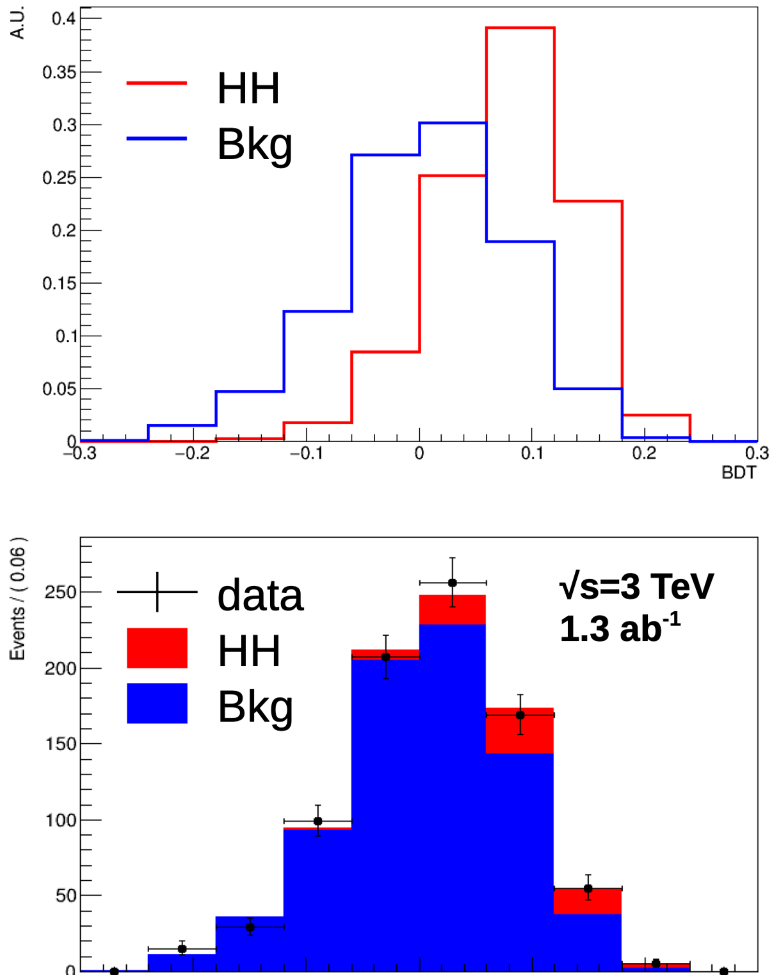
HH cross section measurement

PRELIMINARY



- As a first attempt to estimate the HH cross section uncertainty at 3 TeV, we applied the tagging efficiencies obtained in the 1.5 TeV case → **Again this is very conservative!**
- A 5-observable Boosted Decision Tree has been trained to separate signal from background.
- **With 1.3 ab^{-1} (4 years of data taking) at 3 TeV we expect to select 67 HH events and 745 background events.**
- With a simple fit to the BDT → **An uncertainty of 33% on the cross section has been obtained**.

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