

Muon Collider Detector

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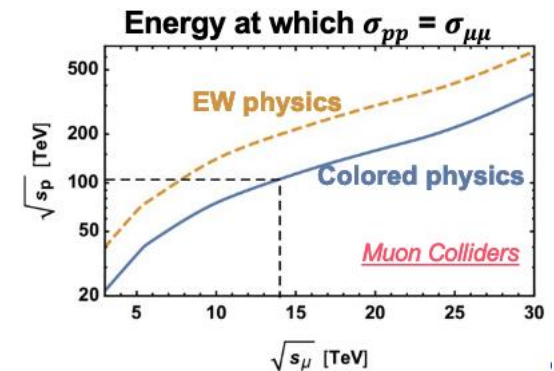


Physics Motivation

HE Muon collider described as “simply a dream machine”:

- Direct searches (pair production, VBF, resonances, DM, ...)
- High-rate measurements (single H, self coupling, rare H decays, top,)
- High energy probes (di- and tri-boson, di-fermion, EFT, compositeness...)
- Muon physics (LFU, $b \rightarrow s\mu\mu$, $g-2$, ...)

Exciting new perspective in the collider physics
interest from the theory community!



307.04743	2005.10289	2008.12204	2012.11555	2102.11292	2104.05720
301.06150	2006.16277	2009.11287	2101.10334	2103.01617	etc ...
303.13628	2007.14300	2012.02769	2102.08386	2103.14043	

It's Competitive:

κ -0 fit	HL-LHC	LHeC	HE-LHC		ILC			CLIC			CEPC	FCC-ee		FCC-ee/ eh/hh	$\mu^+\mu^-$ 10000
			S2	S2'	250	500	1000	380	1500	3000		240	365		
κ_W [%]	1.7	0.75	1.4	0.98	1.8	0.29	0.24	0.86	0.16	0.11	1.3	1.3	0.43	0.14	0.06
κ_Z [%]	1.5	1.2	1.3	0.9	0.29	0.23	0.22	0.5	0.26	0.23	0.14	0.20	0.17	0.12	0.23
κ_g [%]	2.3	3.6	1.9	1.2	2.3	0.97	0.66	2.5	1.3	0.9	1.5	1.7	1.0	0.49	0.15
κ_γ [%]	1.9	7.6	1.6	1.2	6.7	3.4	1.9	98*	5.0	2.2	3.7	4.7	3.9	0.29	0.64
$\kappa_{Z\gamma}$ [%]	10.	—	5.7	3.8	99*	86*	85*	120*	15	6.9	8.2	81*	75*	0.69	1.0
κ_c [%]	—	4.1	—	—	2.5	1.3	0.9	4.3	1.8	1.4	2.2	1.8	1.3	0.95	0.89
κ_t [%]	3.3	—	2.8	1.7	—	6.9	1.6	—	—	2.7	—	—	—	1.0	6.0
κ_b [%]	3.6	2.1	3.2	2.3	1.8	0.58	0.48	1.9	0.46	0.37	1.2	1.3	0.67	0.43	0.16
κ_μ [%]	4.6	—	2.5	1.7	15	9.4	6.2	320*	13	5.8	8.9	10	8.9	0.41	2.0
κ_τ [%]	1.9	3.3	1.5	1.1	1.9	0.70	0.57	3.0	1.3	0.88	1.3	1.4	0.73	0.44	0.31

arXiv 2103.14043

...and complementary!

Abstract

We lay out a comprehensive physics case for a future high-energy muon collider, exploring a range of collision energies (from 1 to 100 TeV) and luminosities. We highlight the advantages of such a collider over proposed alternatives. We show how one can leverage both the point-like nature of the muons themselves as well as the cloud of electroweak radiation that surrounds the beam to blur the dichotomy between energy and precision in the search for new physics. The physics case is buttressed by a range of studies with applications to electroweak symmetry breaking, dark matter, and the naturalness of the weak scale. Furthermore, we make sharp connections with complementary experiments that are probing new physics effects using electric dipole moments, flavor violation, and gravitational waves. An extensive appendix provides cross section predictions as a function of the center-of-mass energy for many canonical simplified models.

5	Complementarity	58
5.1	EDMs	58
5.2	Flavor	60
5.3	Gravitational waves	67

Muon collider as potential direct probe of indirect signals from EDM, Flavour, Gravitational Waves...

\sqrt{s} (TeV)	$N_{\text{post-cuts}}$		
	$\mu^+\mu^- \rightarrow \mu\tau$	$\mu^+\mu^- \rightarrow \mu\tau\nu_\mu\nu_\tau$	$\mu^+\mu^- \rightarrow \tau^+\tau^-$
.125	0.0948	30.8	3.42×10^4
3	53.3	6.32×10^3	40.4
6	212	3.26×10^3	9.52
14	1.14×10^3	1.14×10^3	0.138
100	5.73×10^4	60.9	0.0312

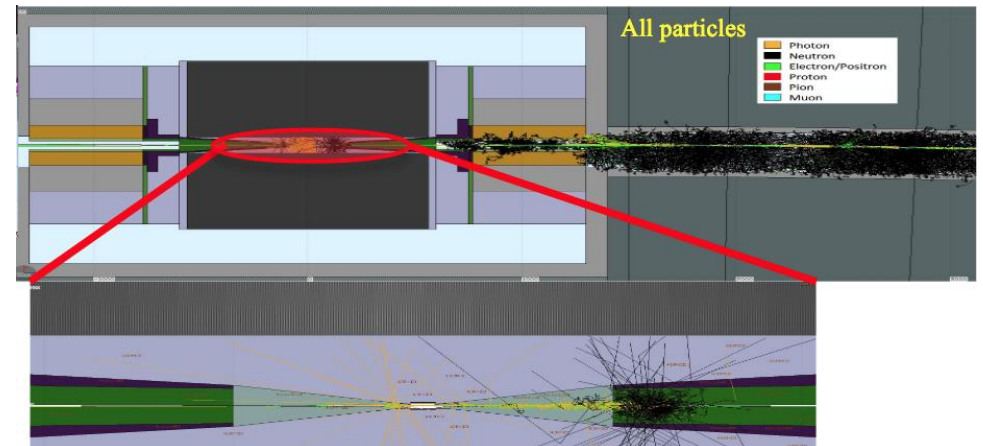
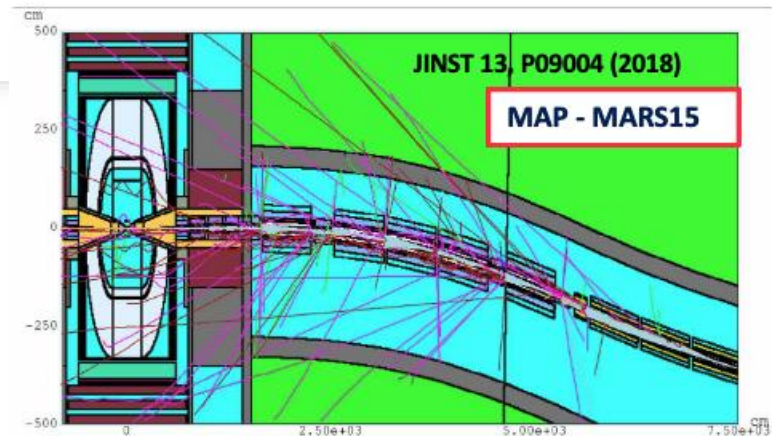
arXiv 2103.14043

Table 5: Number of signal and background events after kinematic cuts and estimating the loss of signal efficiency due to initial state radiation for 1 ab^{-1} of data and $c^{\tau 3\mu}/\Lambda^2 = 1/(50 \text{ TeV})^2$.

Challenges for a Muon Collider Detector

Prototypical machine design to deliver:

- 1 bunch/beam
- Collision spacing: 10 / 15 μs @ 1.5 / 3 TeV
- $\sigma_z \sim 10 / 5$ mm @ 1.5 / 3 TeV
- Beam Induced Background:
 - Muon decays $4E5$ decays/m/crossing at 3 TeV
 - Tertiary muons produced far from collision points
 - Showers from final triplets



Baseline Detector Model

optimization @ 1.5 [3] TeV

hadronic calorimeter

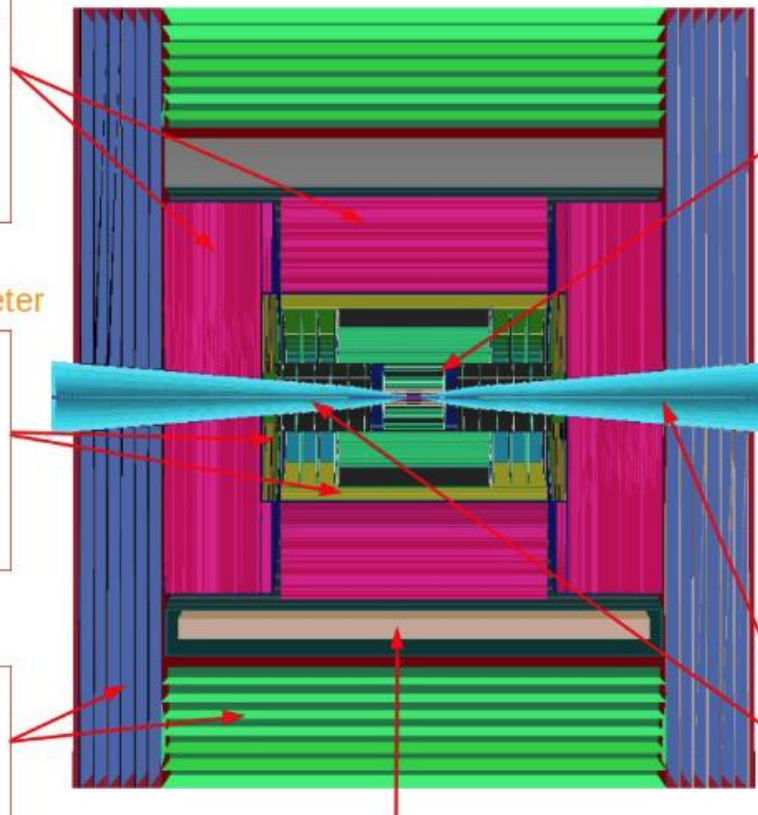
- ◆ 60 layers of 19-mm steel absorber + plastic scintillating tiles;
- ◆ 30x30 mm² cell size;
- ◆ 7.5 λ_I .

electromagnetic calorimeter

- ◆ 40 layers of 1.9-mm W absorber + silicon pad sensors;
- ◆ 5x5 mm² cell granularity;
- ◆ 22 $X_0 + 1 \lambda_I$.

muon detectors

- ◆ 7-barrel, 6-endcap RPC layers interleaved in the magnet's iron yoke;
- ◆ 30x30 mm² cell size.



superconducting solenoid (3.57T)

tracking system

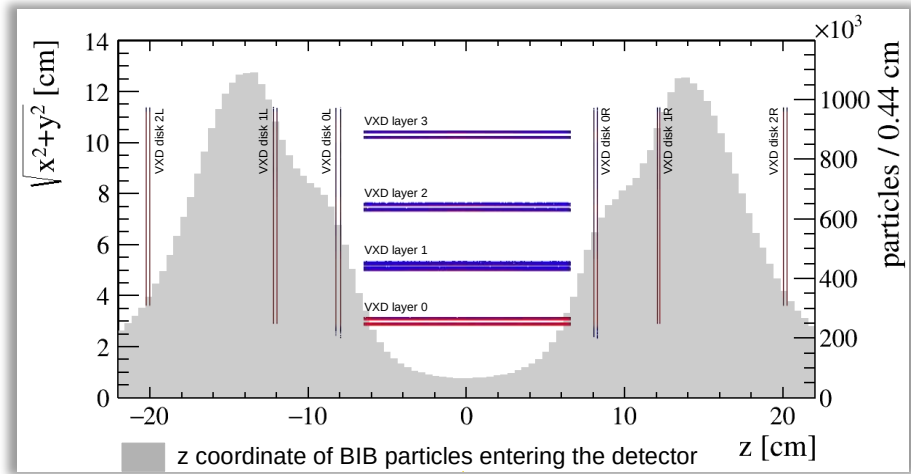
- ◆ **Vertex Detector:**
 - double-sensor layers (4 barrel cylinders and 4+4 endcap disks);
 - 25x25 μm^2 pixel Si sensors.
- ◆ **Inner Tracker:**
 - 3 barrel layers and 7+7 endcap disks;
 - 50 μm x 1 mm macro-pixel Si sensors.
- ◆ **Outer Tracker:**
 - 3 barrel layers and 4+4 endcap disks;
 - 50 μm x 10 mm micro-strip Si sensors.

shielding nozzles

- ◆ Tungsten cones + borated polyethylene cladding.

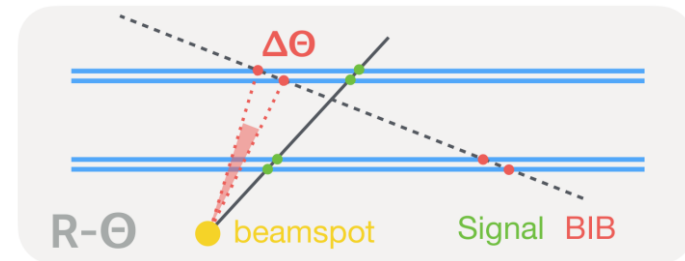
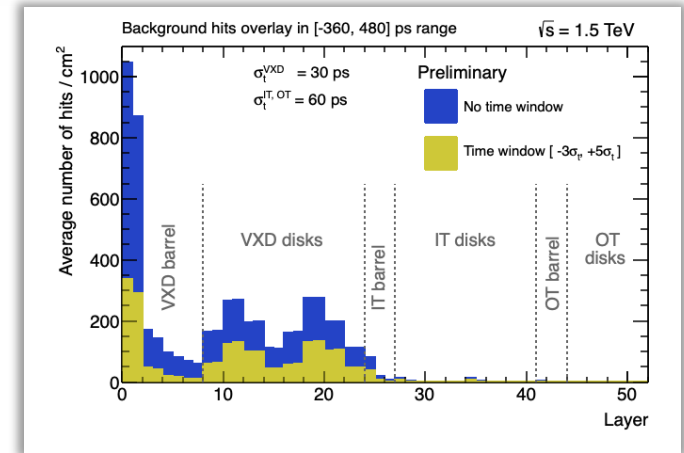
- CLIC baseline detector model model
- MAP-designed MDI and vertex detector

Tracker [1.5 TeV]



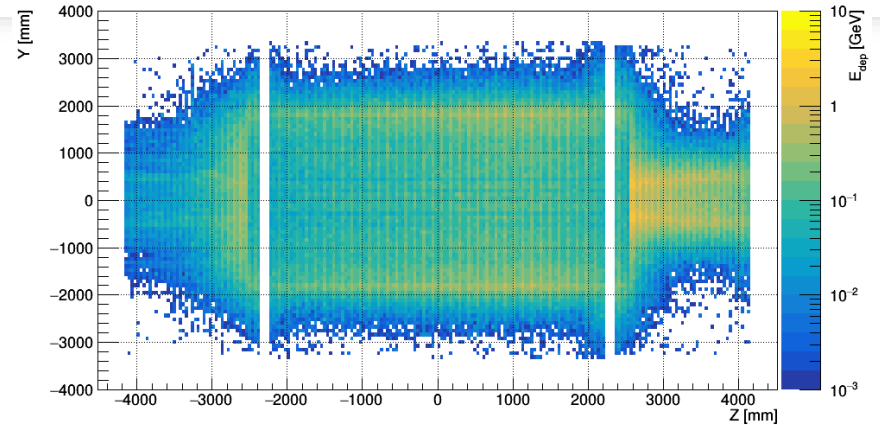
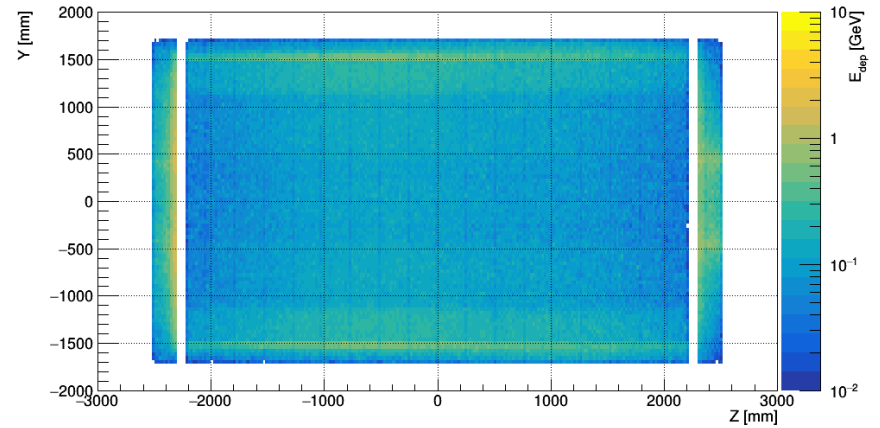
Main focus on BIB effects:

- Design avoids “hottest” BIB regions
- Readout timing window tuned to exclude out of time BIB
- Granularity tuned to $\lesssim 1\%$ occupancy
- Additional expedients under study against BIB:
 - Cluster shape
 - Use of PV for angular matching of doublets
- What about secondary vertices and LLP?

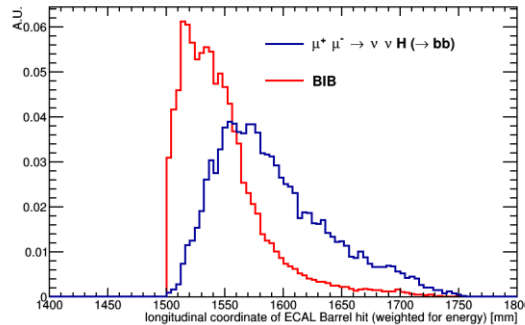
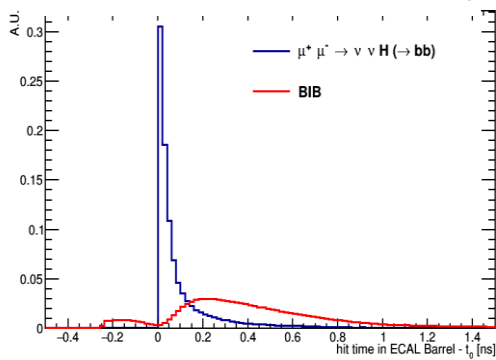


Calorimeters

- BIB deposits large amounts of energy both in EM and Hadr. Calorimeters
- Timing and shower profile allow in principle to distinguish:



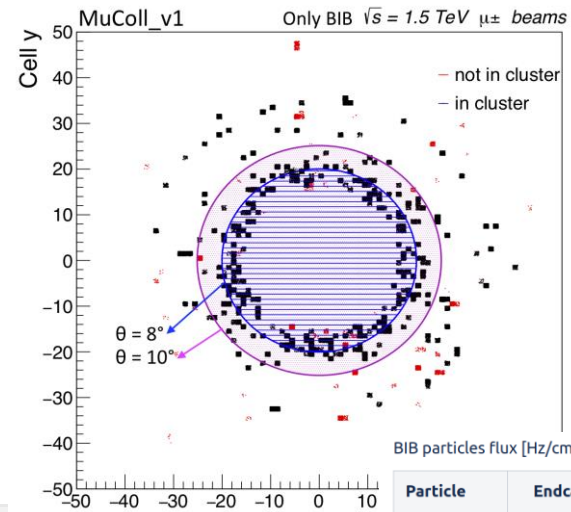
ECAL barrel hit arrival time - t_0



Computational (& DAQ?)
challenge in efficient
separation from BIB
background!

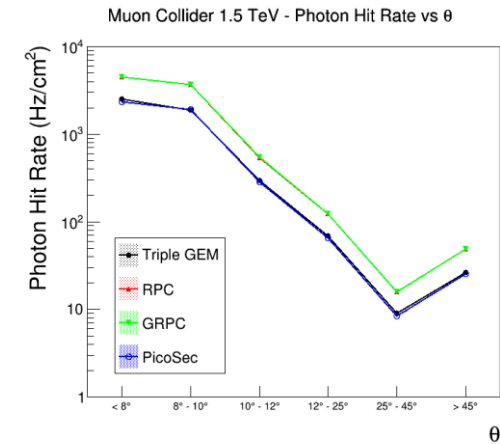
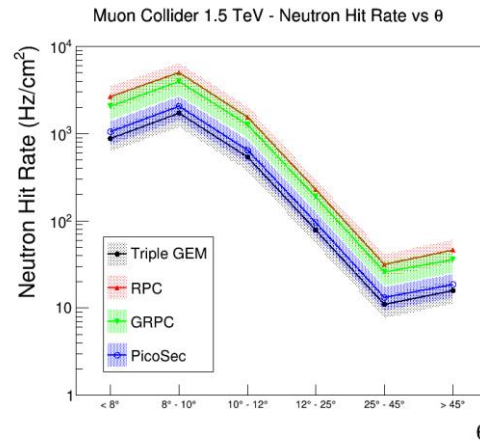
Muon Detectors

- Several detector technologies explored
- BIB not a performance issue of properly handled

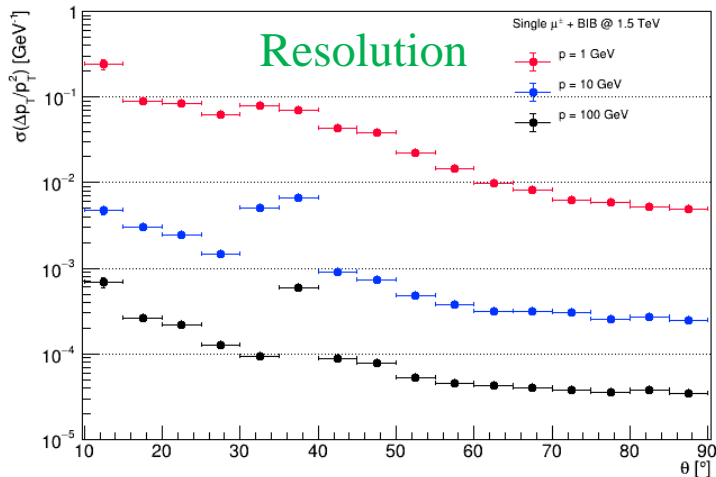
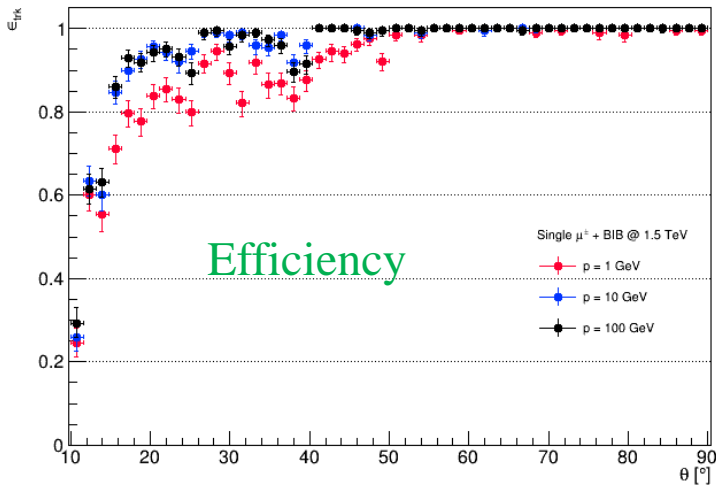


BIB particles flux [Hz/cm²] in different regions (bunch crossing time 10 μs):

Particle	Endcap (θ > 12°)	Endcap (8° < θ < 12°)	Endcap (θ < 8°)	Barrel
neutrons	1.2 · 10 ³	5 · 10 ⁴	1.2 · 10 ⁶	1.4 · 10 ²
photons	6.2 · 10 ²	1 · 10 ⁴	7.2 · 10 ⁵	5
protons	16	3 · 10 ²	2.4 · 10 ⁴	---
μ+ μ-	3	3.7 · 10 ²	1.2 · 10 ⁴	---
pions, kaons	< 1	70	1 · 10 ³	---
e+ e-	3	3.3 · 10 ²	5 · 10 ³	< 1
Total	≈ 2 kHz/cm ²	≈ 60 kHz/cm ²	≈ 2 MHz/cm ²	≈ 200 Hz/cm ²

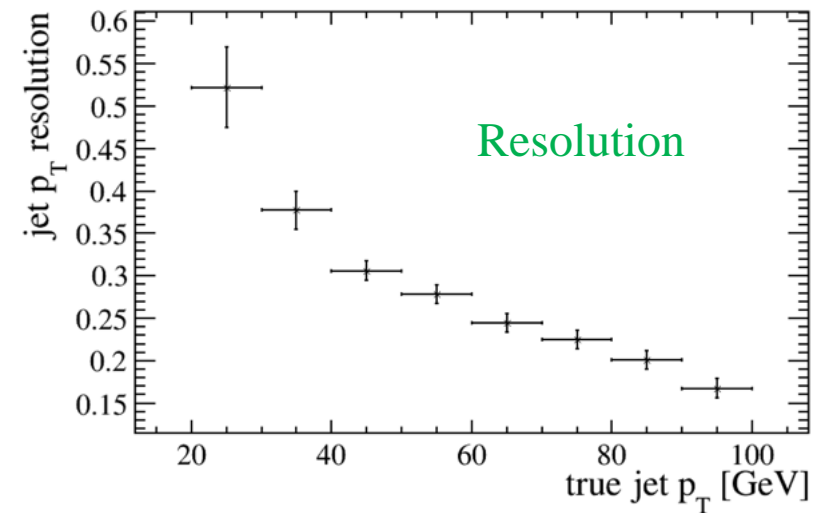
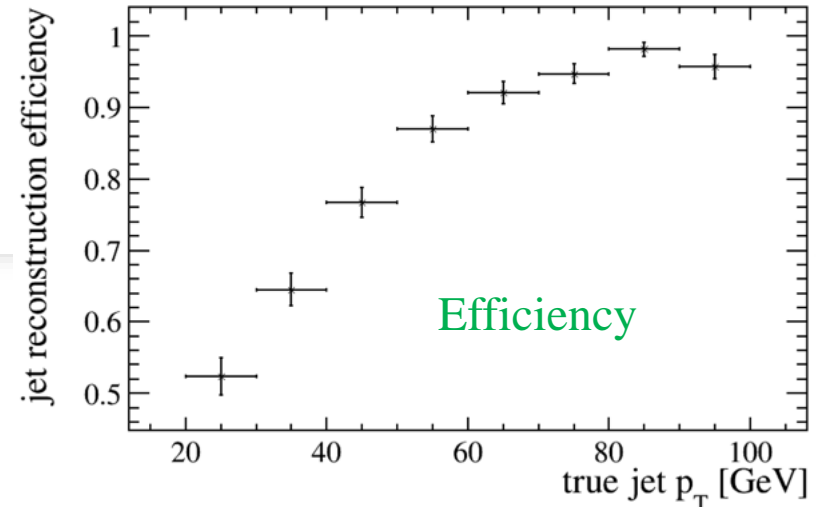


Tracking and Jet reconstruction performance

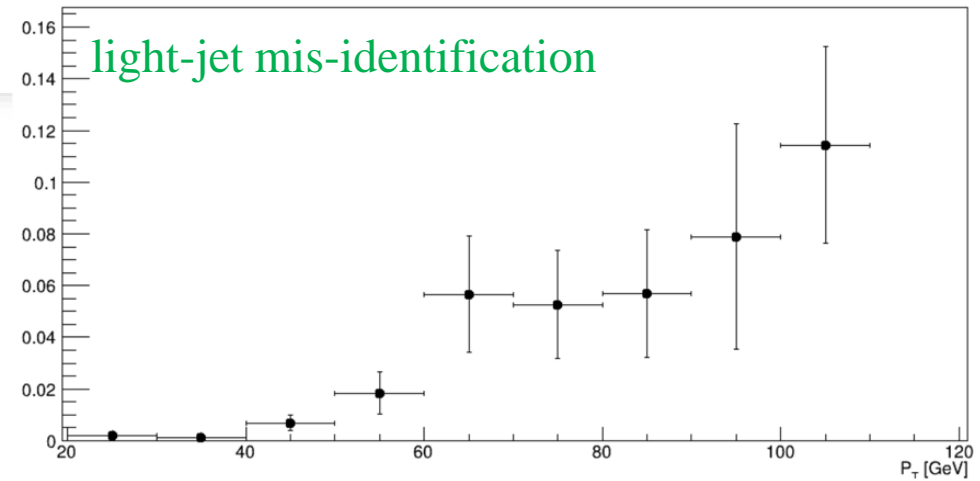
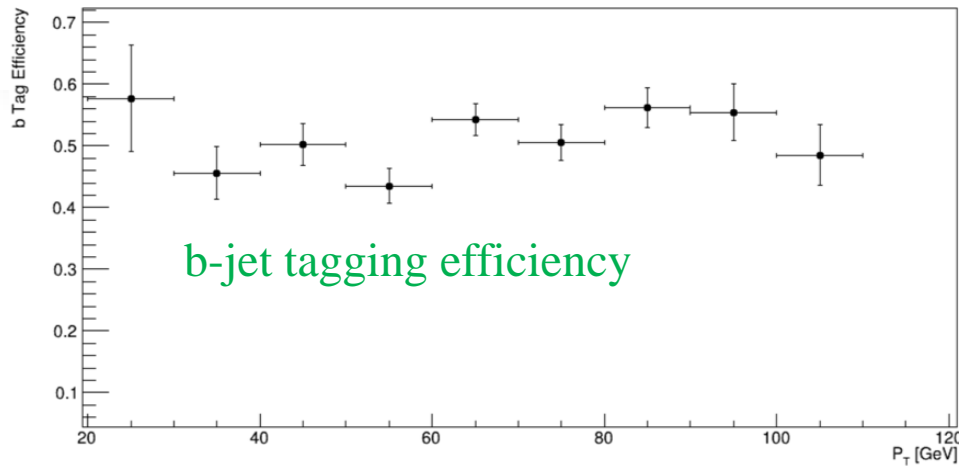


- Efficiency drops in nozzle region
- Resolution degrades too

Need further optimization of detectors and algorithms!



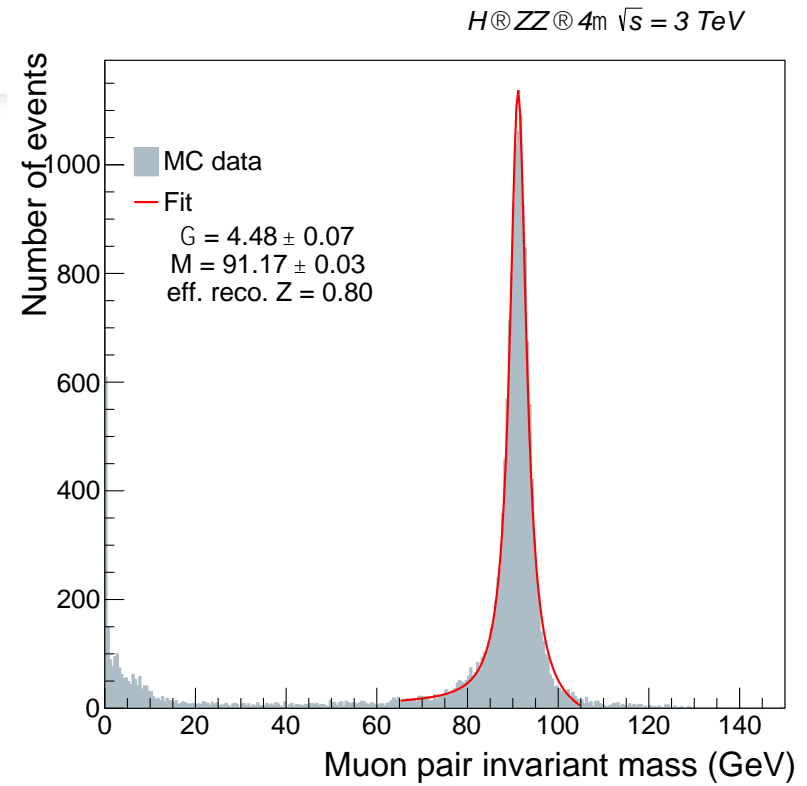
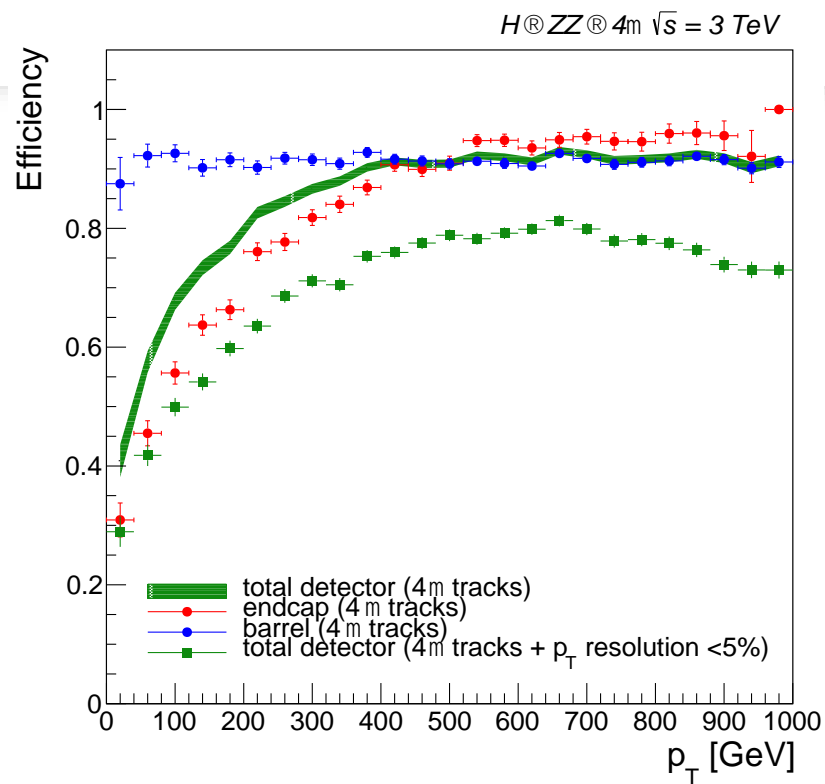
B-jets and Secondary Vertex Reconstruction



B-jet ID

- Regional-tracking selected tracks
- Early steps towards b-tagging *work*in*progress*
 - ML approach under study

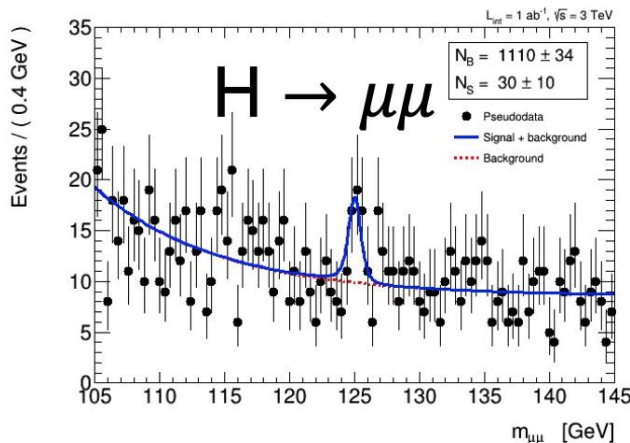
Muon Reconstruction



Beyond “detector performance”

As detector design and simulation mature, detailed physics studies become possible

- Growing engagement within the Snowmass process



27 Sept. 2021

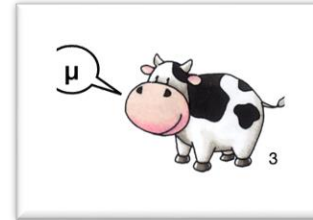
🔍

EPS2021 Posters and Talks

📅 Tuesday 13 Jul 2021, 09:00 → 19:00 Europe/Zurich

09:00	→ 09:20 Dark-SUSY channels to study muon reconstruction performance at the Muon	🕒 20m 🔍
Speaker: Chiara Aime' (Pavia University and INFN (IT))		
📎 Poster_EPS.pdf		
09:20	→ 09:40 Design a calorimeter system for the Muon Collider experiment	🕒 20m 🔍
Speaker: Lorenzo Sestini (Universita e INFN, Padova (IT))		
📎 poster_muocol_calo...		
09:40	→ 10:00 Prospects for the measurement of $\sigma H \rightarrow \mu\mu$ at a 3-TeV muon collider	🕒 20m 🔍
Speaker: Alessandro Montella (University of Trieste and INFN-Trieste)		
📎 hmumu_muocol_eps...		
10:00	→ 10:20 Study of Beam Induced background at muon collider	🕒 20m 🔍
Speaker: Francesco Collamati (INFN Roma I (IT))		
10:20	→ 10:40 Tracking and track reconstruction at a muon collider in the presence of beam-induced background	🕒 20m 🔍
Speaker: Hannsjorg Weber (Humboldt University of Berlin (DE))		
📎 haweber_EPS2021...		
10:40	→ 11:00 Tracking with ACTS for a Muon Collider detector	🕒 20m 🔍
Speaker: Karol Krizka (Lawrence Berkeley National Lab. (US))		
📎 tracking.pdf		
11:00	→ 11:20 Using cluster shape for beam-background suppression in a future muon collider experiment	🕒 20m 🔍
Speaker: Elodie Deborah Resseguie (Lawrence Berkeley National Lab. (US))		
📎 MuCo_EPS2021_er...		
11:20	→ 11:40 Higgs boson couplings at muon collider (talk)	🕒 20m 🔍
Speaker: Laura Buonincontri (Universita e INFN, Padova (IT))		
11:40	→ 12:00 Muon reconstruction performance and detector-design considerations for a Muon Collider (Talk)	🕒 20m 🔍
Speaker: Ilaria Vai (Pavia University and INFN (IT))		
📎 EPSHEP2021_ilaria...		

Summary



The Muon Collider appeal:

- Exciting physics potential
- Novelty of approach
- Complementarity to other future technologies

...but also an exciting detector and DAQ R&D challenge!

Early detector design under study:

- CLIC inspired
- BIB driven
- Exciting challenge:
 - Detector technology
 - DAQ and data handling
 - Computing