New Physics Searches at a Muon Collider

Hannsjörg Weber (Fermilab)

LoI #228

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Also close collaboration with Italian/ European colleagues who are working on the muon collider.

Executive Summary

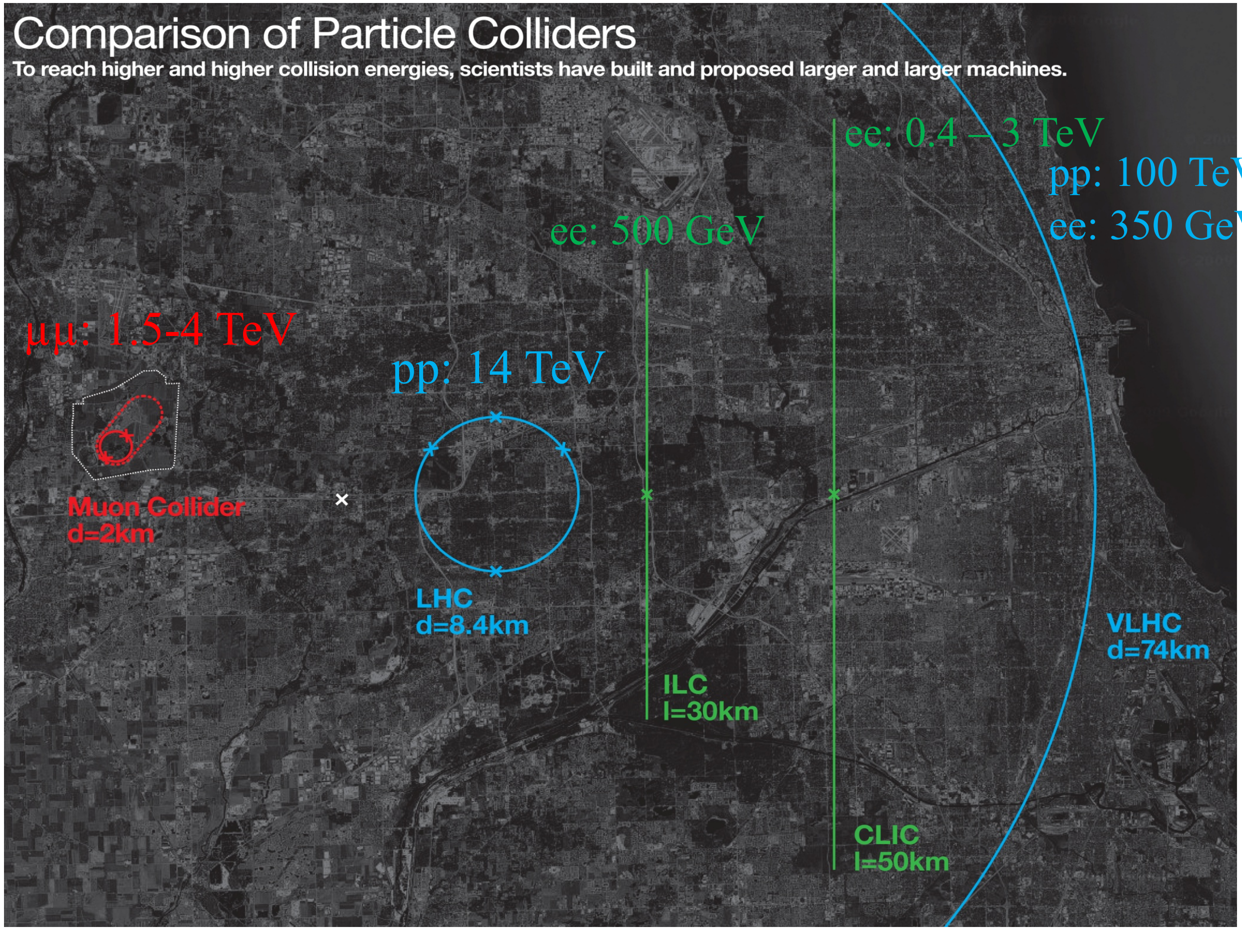
- In LoI #226 we propose to study the new physics sensitivity **at a muon collider**.
  - First, identify and overcome the challenges in the reconstruction (see also LoI #234).
  - Use these result to study new physics signatures. We made 4 concrete proposals:

1. Dark matter and resonances: model-independent with ISR, model-dependent with mediator (such has a heavy boson). E.g. if coupling happens through vector bosons, muon colliders might yield highest sensitivity.
2. Electroweakinos: At high $\sqrt{s}$, the EWKino cross section rises strongly compared to the SM background → possibly high sensitivity. One question: can we tag soft tracks when there is beam-induced backgrounds (BIBs).
2. Another avenue could be looking for RPV. Similar argument as above: Cross section not that much smaller as those of background, unlike for a pp machine.
3. Long-lived particles: This might be very challenging in the presence of the BIB.

- Also check out LoI #177, utilizing the muon collider for standard model physics.
  - The authors of these three LoIs work together. We also work with our European colleagues.

Why muon collider?

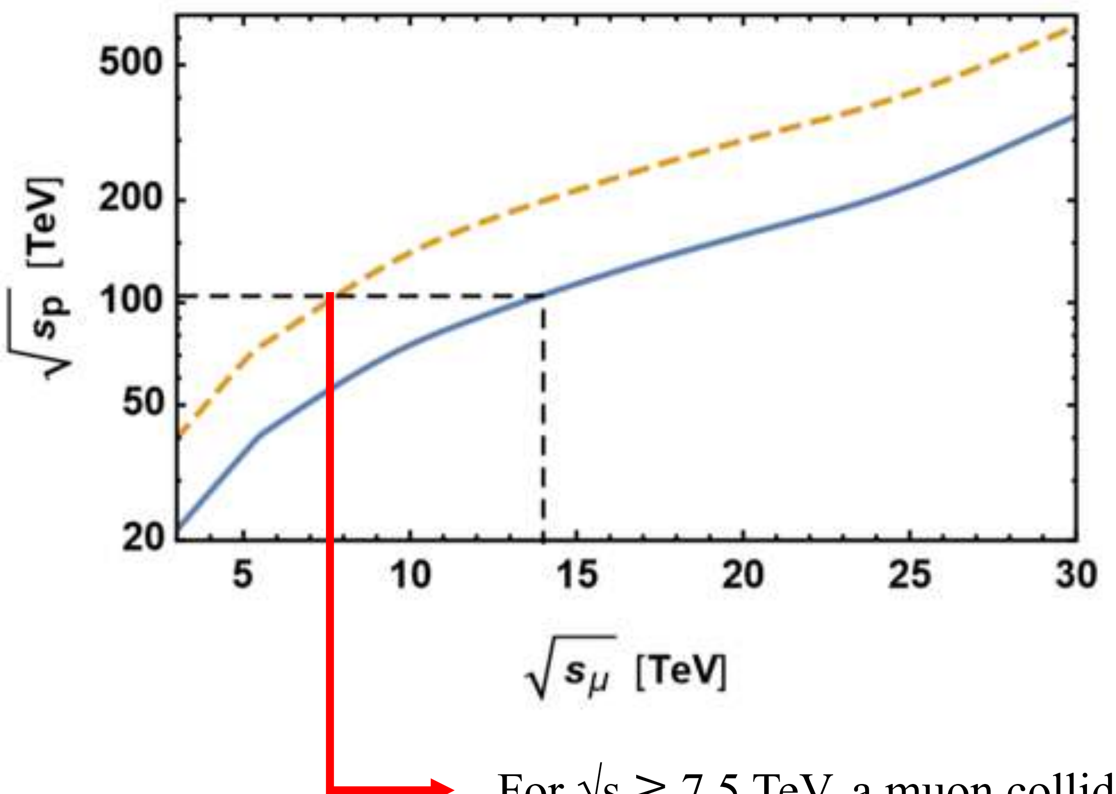
- Muons are heavy: Can build small footprint collider for multi-TeV collisions.



- With further advances could build a 6 TeV muon collider of the size of the Tevatron.

Why muon collider?

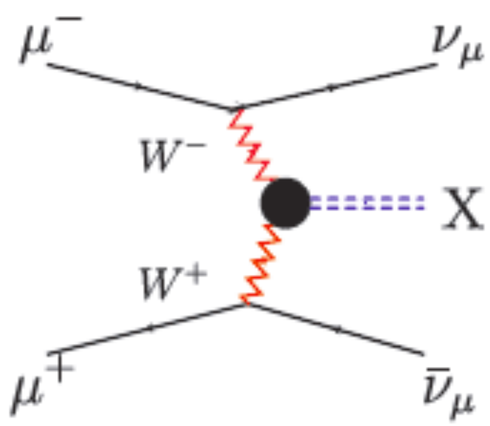
- Muons are heavy: Can build small footprint collider for multi-TeV collisions.
- Muons are fundamental particles – i.e. collisions take advantage of full c.o.m. energy of the beam.

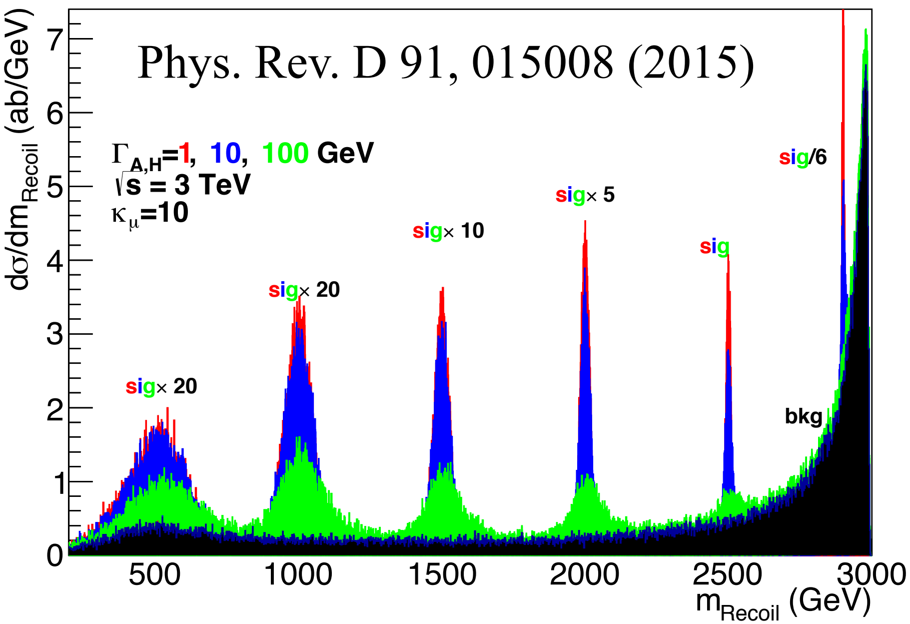


For $\sqrt{s} \gtrsim 7.5$ TeV, a muon collider will surpass a 100 TeV pp machine for electroweak physics.

Our proposal for studies

- Our LoI calls for generic exploration of the new physics parameter space, but we named three topics that are of interest to the signees:
  - Resonances and Dark matter: e.g. H/Z' → invisible + ISR (photon) or H/Z' → XX (X = ℓ, V, or h).
    - Resonance search can be done with a √s scan.





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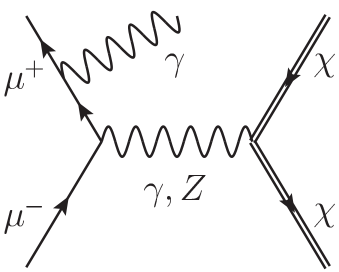
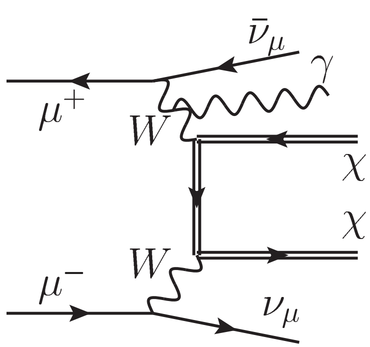
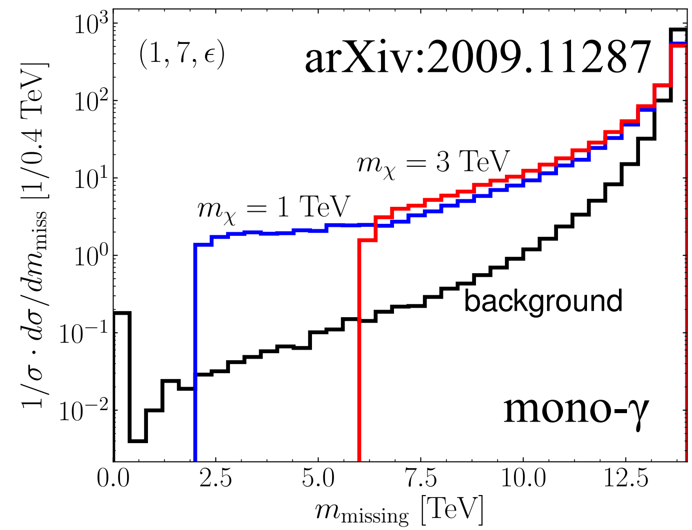
  - Resonances and Dark matter: e.g. H/Z' → invisible + ISR (photon) or H/Z' → XX (X = ℓ, V, or h).
    - Model-independent search by selecting on an ISR object, e.g. a photon.



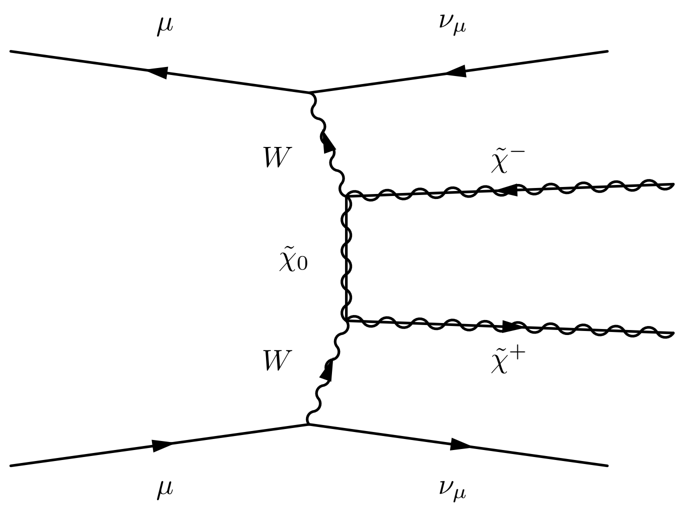




$$m^2_{\rm missing} = (p^{\rm in}_{\mu^+} + p^{\rm in}_{\mu^-} - p^{\rm out}_{\gamma})^2$$

Our proposal for studies

- Our LoI calls for generic exploration of the new physics parameter space, but we named three topics that are of interest to the signees:
  - Electroweak Supersymmetry.
    - Particular strong at high energy due to large VBF cross section.
    - Due to low (hard scatter) background should be able to select soft decay products (careful of BIB, see later).



(e)

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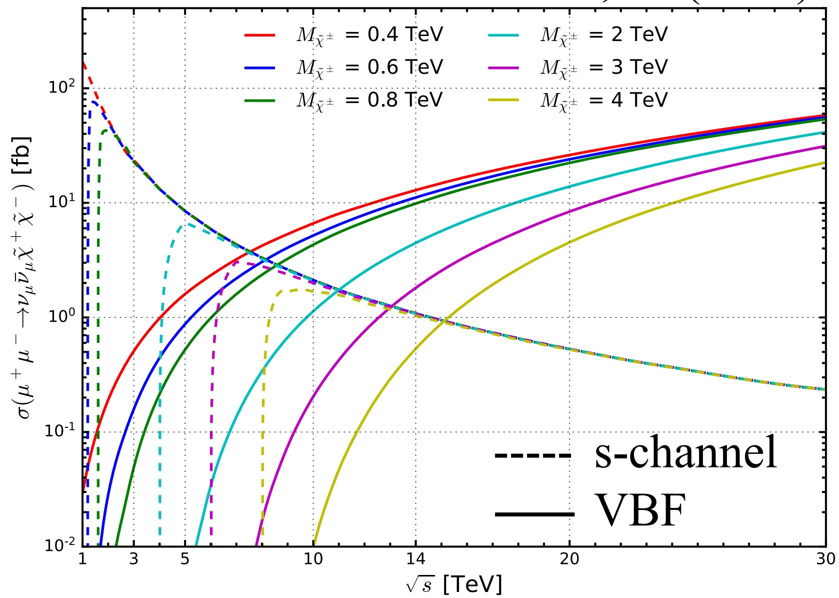
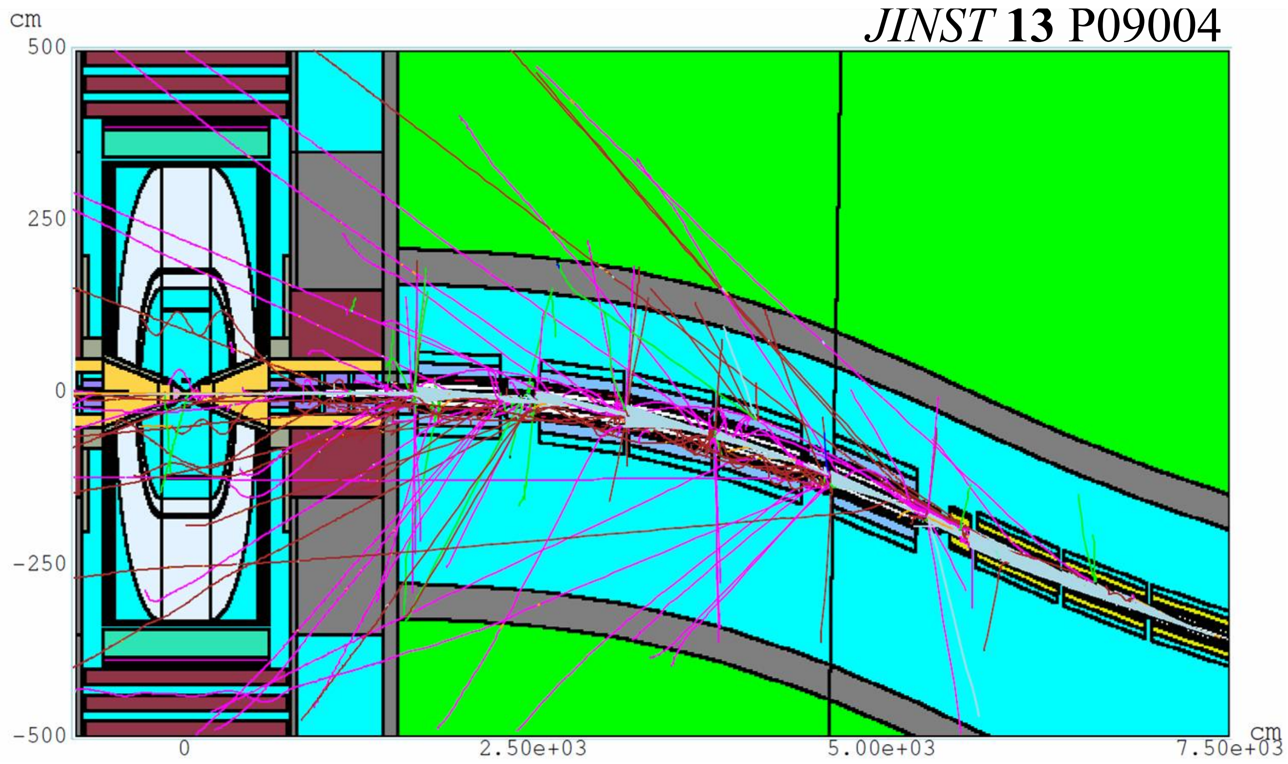


Our proposal for studies

- Our LoI calls for generic exploration of the new physics parameter space, but we named three topics that are of interest to the signees:
  - Long-lived particle searches.
    - Except for HSCP, extremely difficult as LLP searches rely on displacements, different timing, or other non-conventional signatures.
    - But those, also appear for the BIB (see later) – so need to see how we can discriminate BIB vs. LLPs.

Challenges of physics at a muon collider

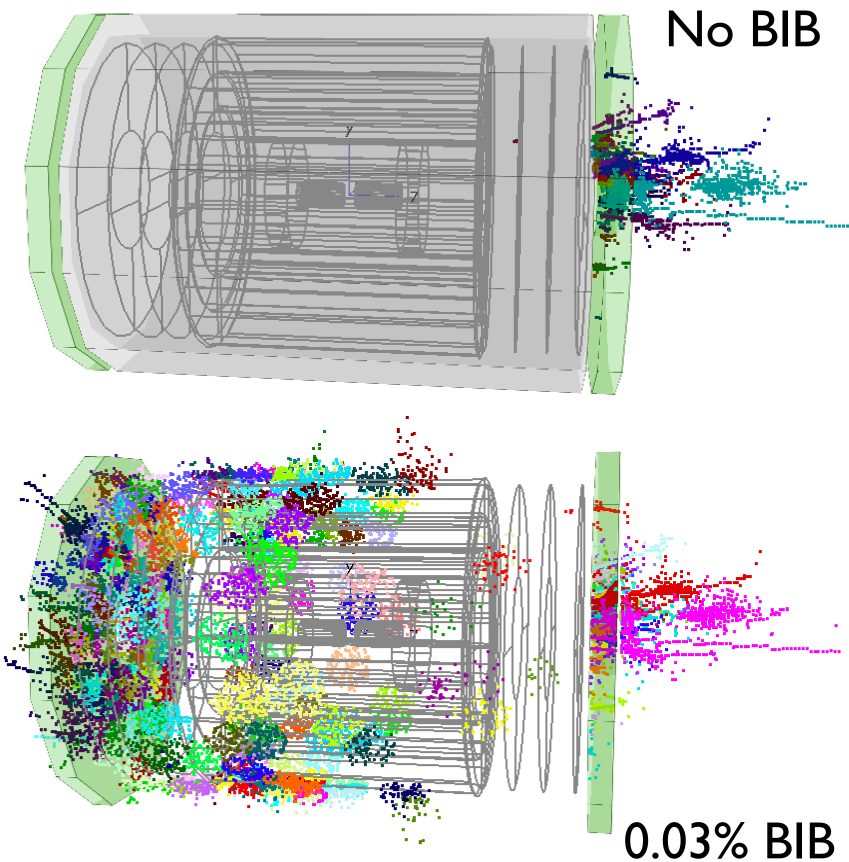
- Muons are unstable, and decay in-flight.
  - This plot is done with MARS simulation at $\sqrt{s}$ = 1.5 TeV.



Challenges of physics at a muon collider

- Muons are unstable, and decay in-flight.
  - The detector is bombarded by particles.

M. Swiatlowski



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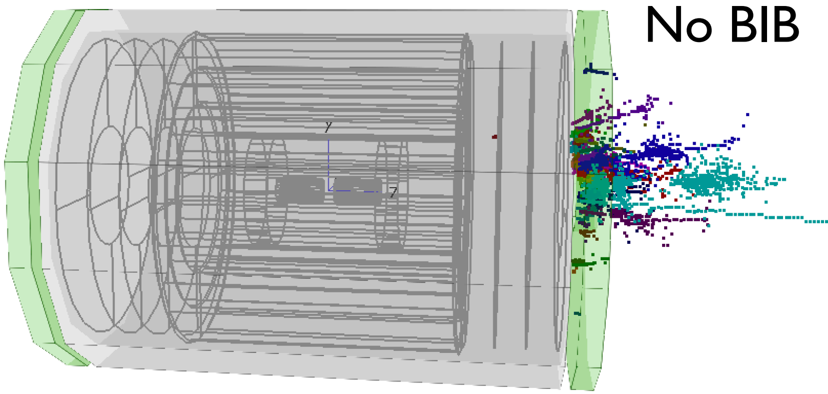
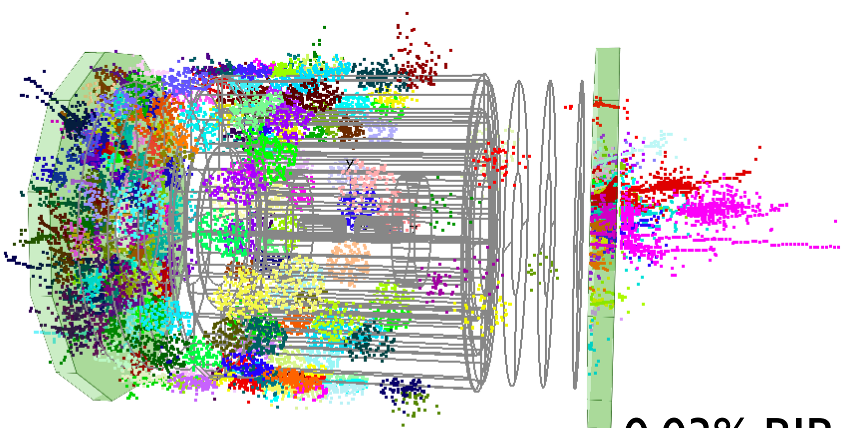
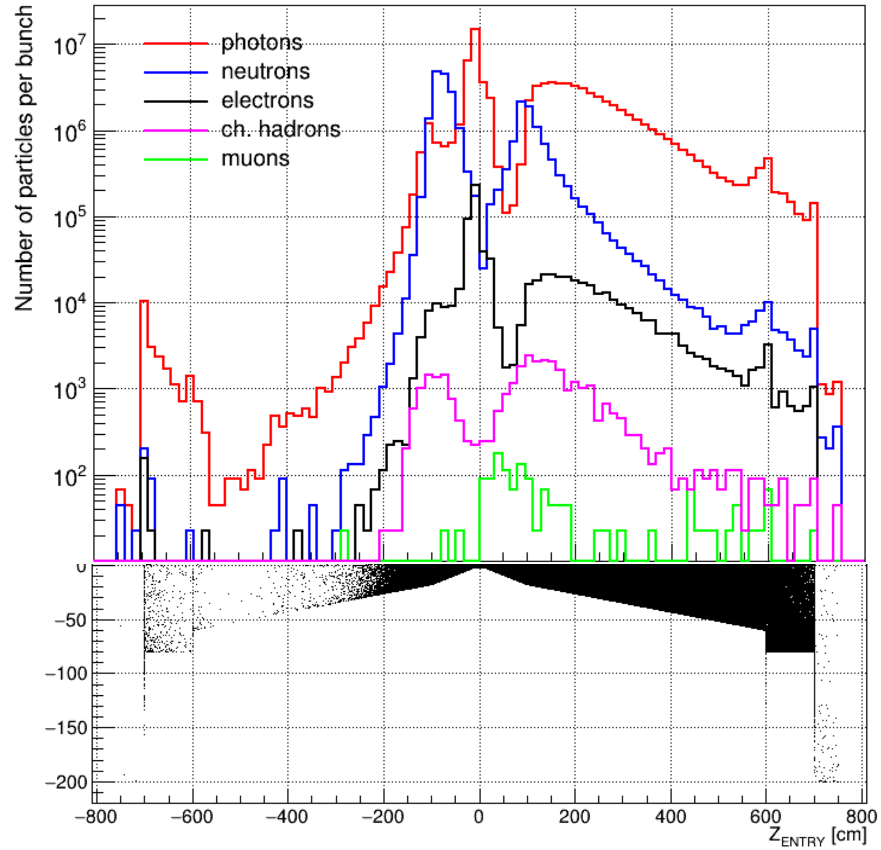


No BIB



0.03% BIB

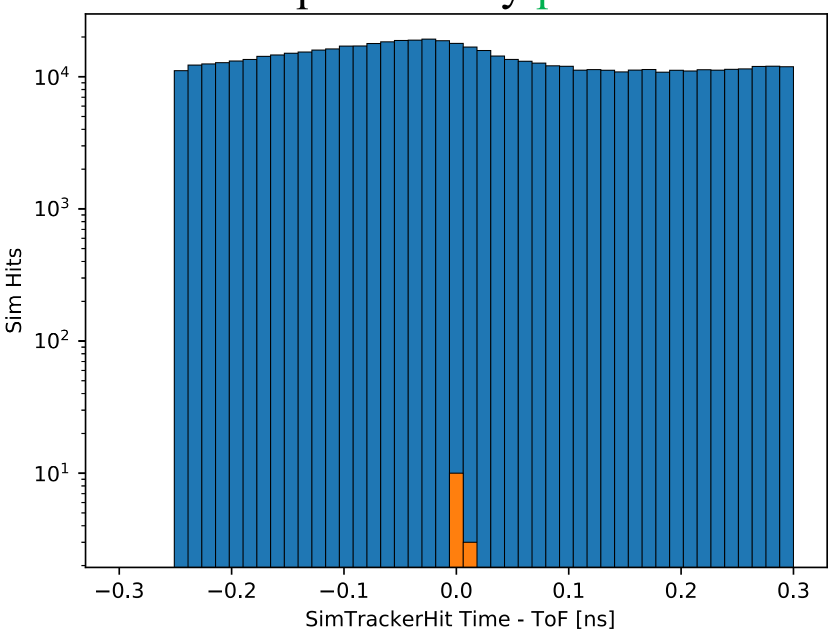
M. Casarsa

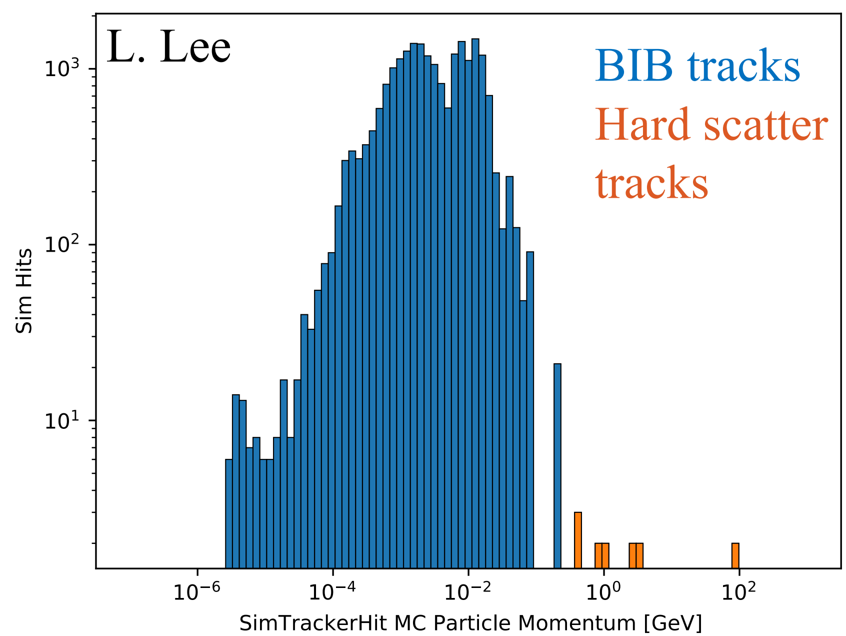


750-GeV μ^- beam

Challenges of physics at a muon collider

- Muons are unstable, and decay in-flight.
  - The detector is bombarded by particles.
  - Need all experimental handles available to us:
    - Detector with in-built absorber against the beam-induced background (BIB).
    - BIB are not in-time.
    - BIB is extremely soft.
    - BIB particles fly parallel to the beam.





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    - BIB are not in-time.
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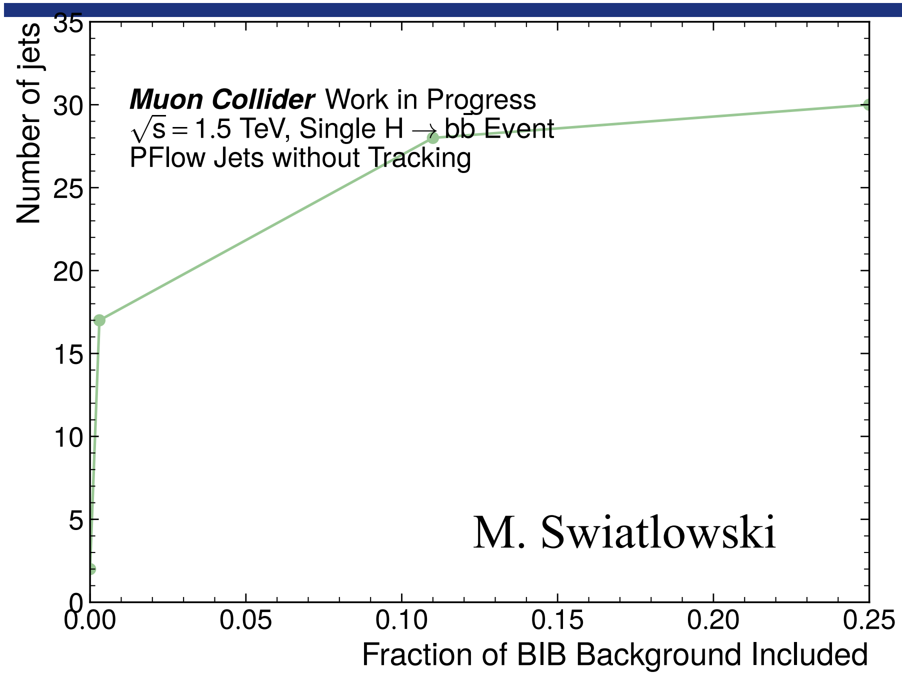
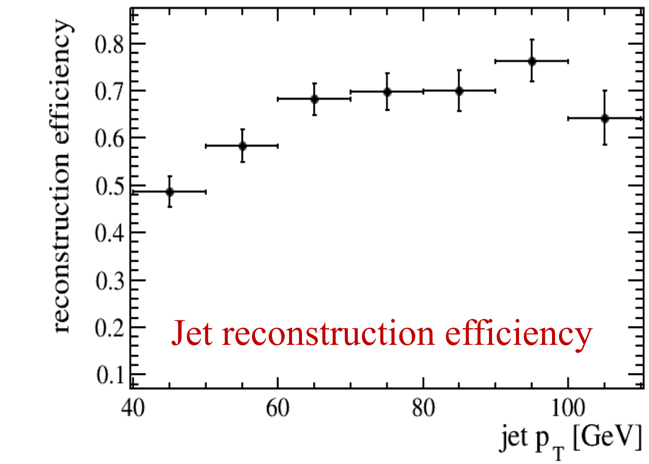
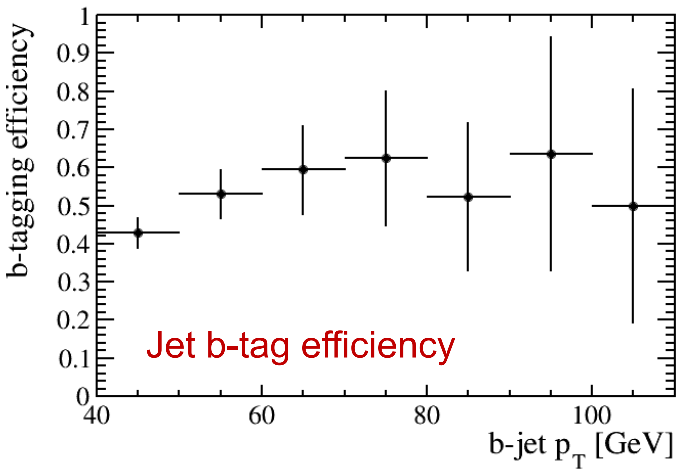
    - BIB particles fly parallel to the beam.
  - But still, some work ahead of us!



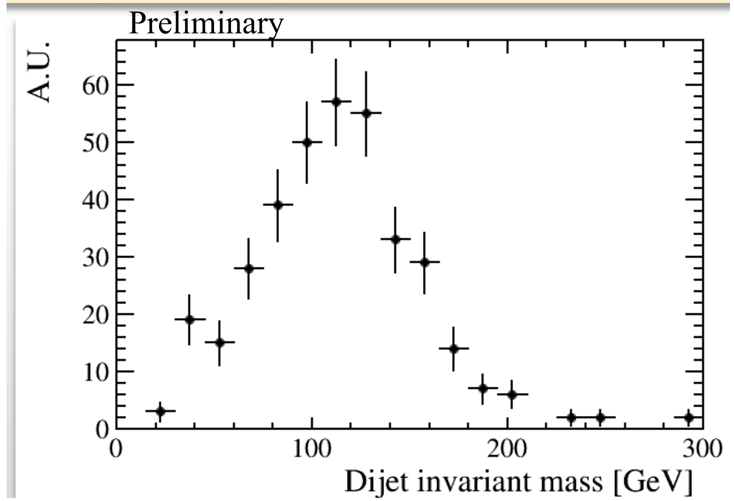
Challenges can be overcome

- Our European colleagues used the full simulation to do a H(bb) measurement at √s = 1.5 TeV.





$\mu^+\mu^- \rightarrow H\nu\bar{\nu} \rightarrow b\bar{b}\nu\bar{\nu}$ + beam-induced background fully simulated



	$\sqrt{s}$ [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

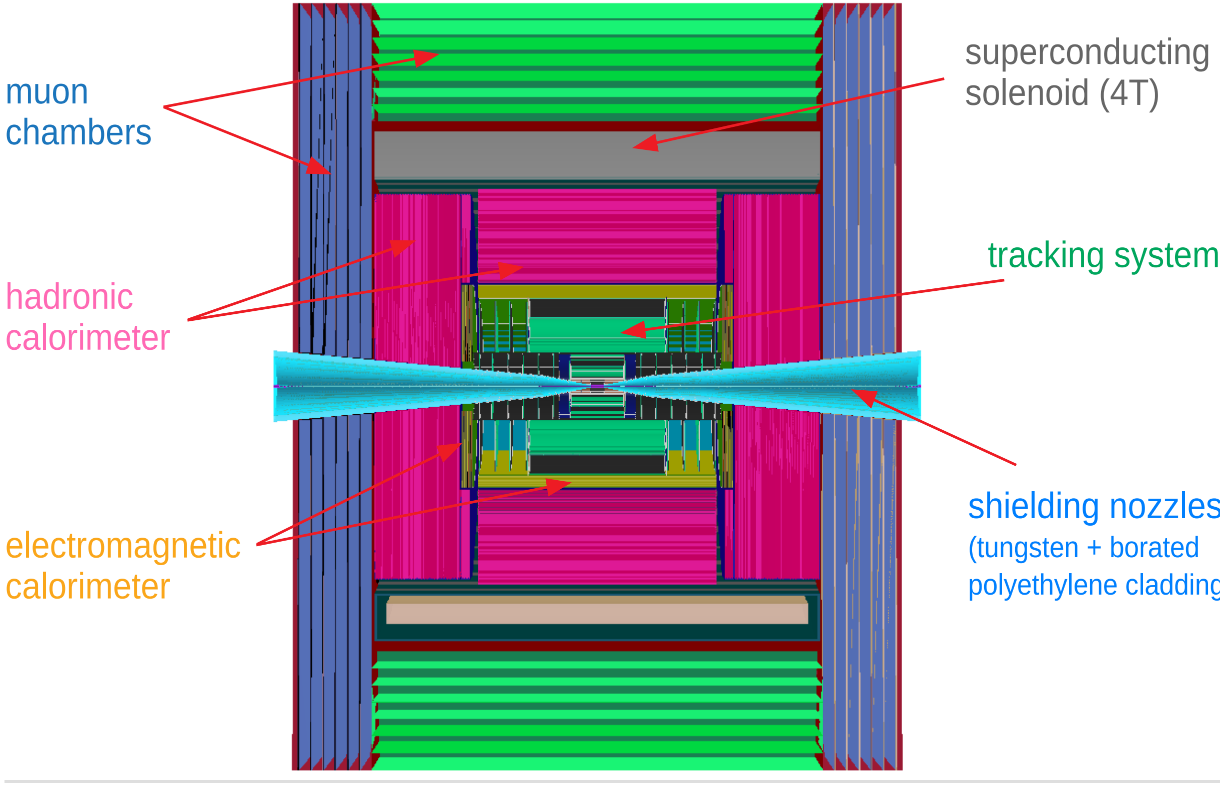
Looking ahead

- The first delphes card has been created:
  - https://github.com/delphes/delphes/blob/master/cards/delphes_card_MuonColliderDet.tcl
- But we are working on studies to improve the reconstruction – and validate and improve that detector card with full simulation.

- As Delphes card was finalized only last week, we have no physics studies to show (yet), but we are starting organizing these studies now.
  - As we are starting physics studies now, if you are interested: it is a great time to join! – Just contact me.

Backup

Muon collider experiment



Machine parameter

Center of mass energy $\sqrt{s}$ (TeV)	.126	3	14
Circumference (km)	.3	4.5 (26.7*)	14 (26.7*)
Interaction regions	1	2	2
Peak luminosity (10^{34} cm^{-2} s^{-1})	0.008	4.4	40
Int. lum. per exp. (ab^{-1}/year)	0.001	0.5	3
Time between coll. (μs)	1	0.025	90
Cycle rep. rate (Hz)	1	6(35*)	4(7*)
Energy spread (rms, %)	0.004	0.1	0.1
Bunch length (rms, mm)	63	5	1
IP beam size (μm)	75	3.0	0.6
β^*, amplitude function at IP (mm)	17	5	1
Avg. magnetic field (T)	10(?)	8(5.5*)	10.5(5.5*)
Max. magnetic field (T)	10(?)	12	16
Proton driver beam power (MW)	4	4	1
Total facility AC power (MW)	200	230	290