Fermilab U.S. DEPARTMENT OF ENERGY Office of Science

(Lepton) Collider Background Studies

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LCWS 2023 - SLAC
18 May 2023

Including information from: ilc clic C3 International MUON Collider Collaboration

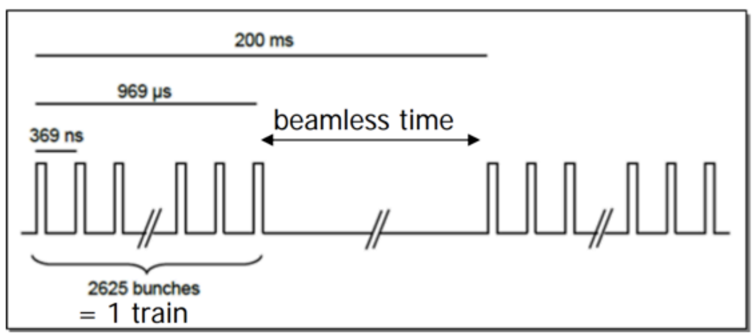
Overview

- Beam and machine induced backgrounds govern precision at lepton colliders
  - Less pristine detector environments result in low level and high-level mis-reconstructions
  - If background rate is too high, requires triggers, and may incur subtle biases
- There are three major types of these backgrounds
  - Incoherent pair production: e+ e- and mu+ mu-
  - Hadron photoproduction
  - Machine-beam interactions, e.g. collimation
- The importance of each backgrounds varies with beam configuration
  - Higher energies, larger or smaller emittance, bunch particle type all affect
- Most importantly, with new collider concepts we must repeat these studies!
  - C^3 is a popular and new accelerator concept with a different configuration
  - Different generators for each background, preservation of techniques important
- This talk will focus on linear Higgs factories, but higher energies mentioned

ILC - C^3 - CLIC

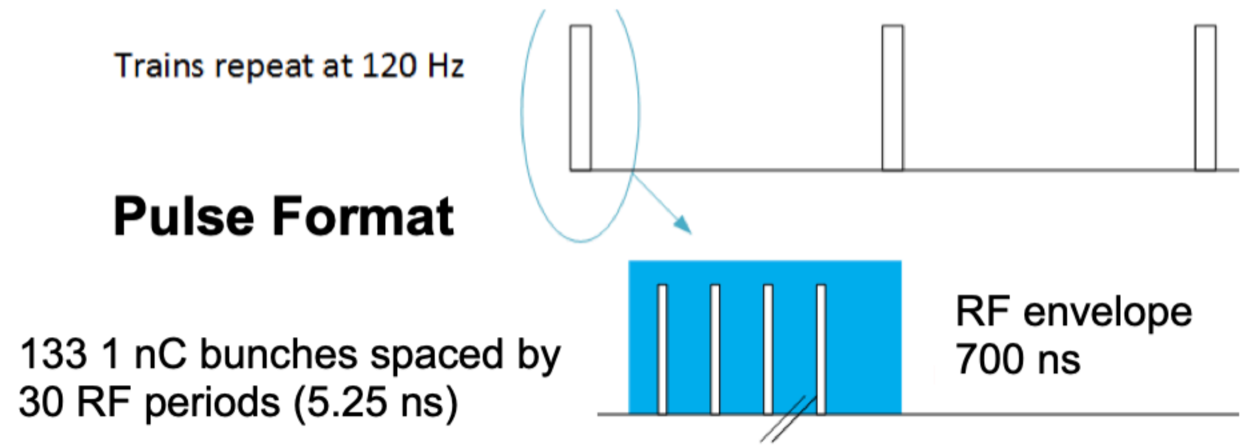
- There are extremely detailed performance calculations in the ILC TDR
  - However, C^3 has a radically different bunch structure from ILC, reminiscent of CLIC

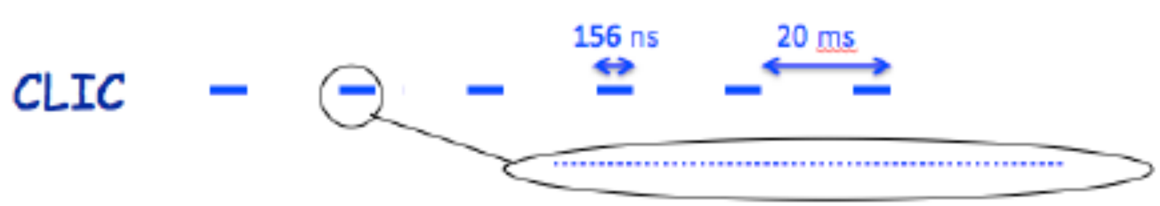
ILC timing structure



1 ms long bunch trains at 5 Hz
2820 bunches per train
308 ns spacing

C^3 timing structure



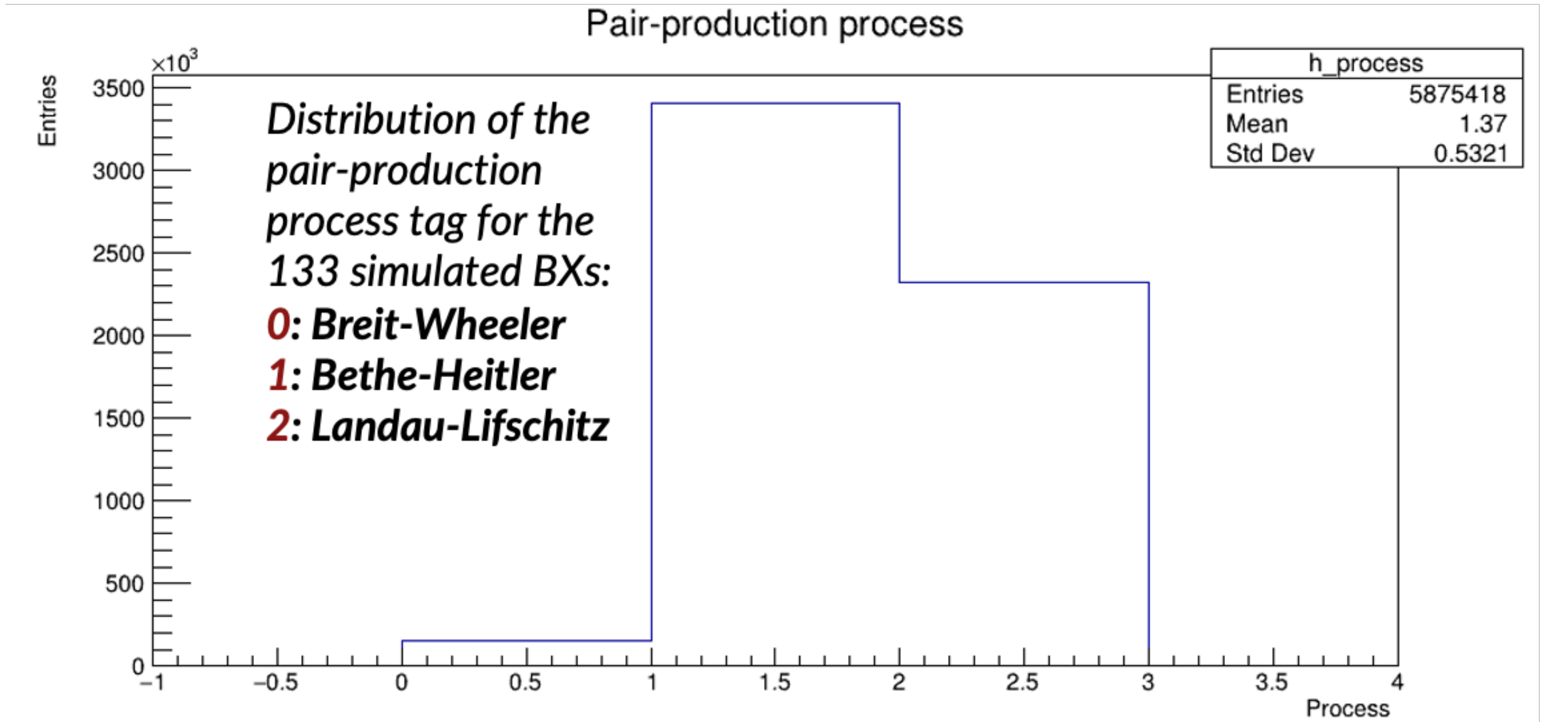


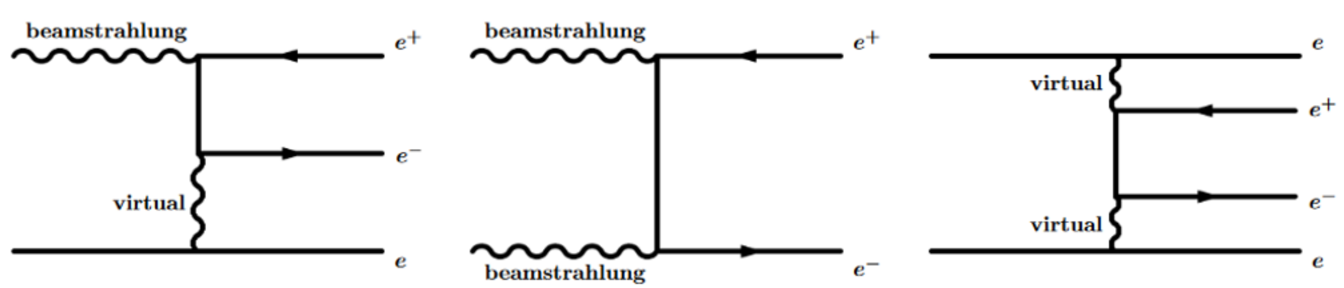
1 train = 312 bunches, 0.5 ns apart

- not to scale -

- C^3 Time structure and electronics needs at low level are different
  - But the overall concepts are similar, and technologies from LHC can deal with the 70x smaller bunch spacing (because of the 120 Hz repetition rate!)
  - Modern clocking and timing performance means that C3 background rates will be one-tenth of ILC due to the shorter bunch train and intrinsically better timing

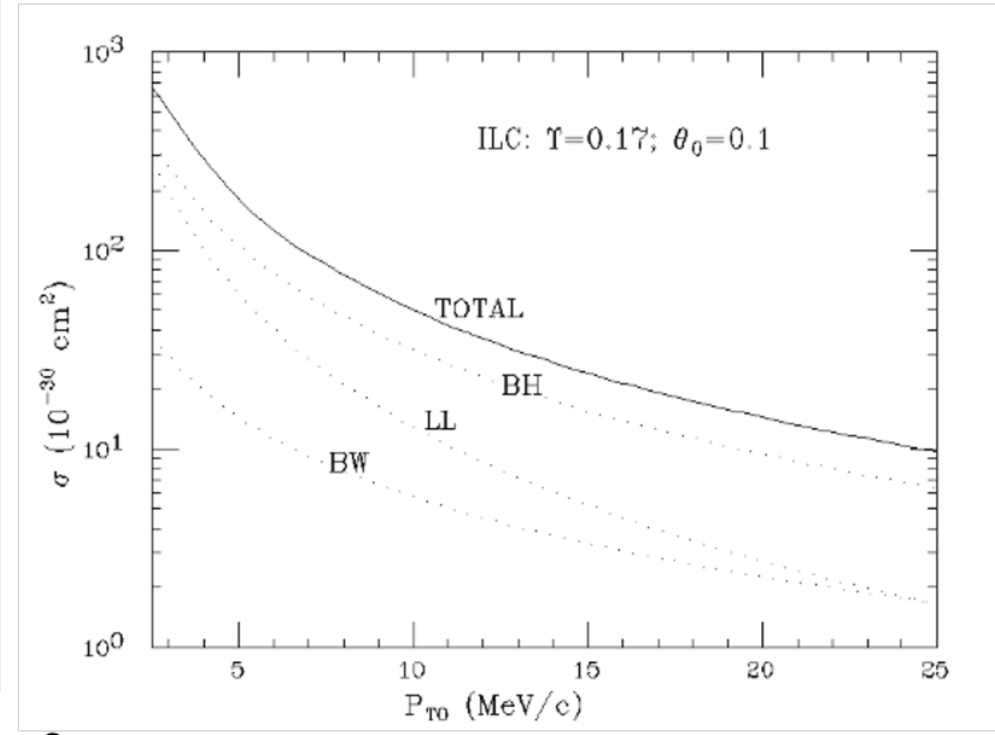
Incoherent electron/positron pair production





(a) *Bethe-Heitler* (b) *Breit-Wheeler* (c) *Landau-Lifschitz*

Source: https://bib-pubdb1.desy.de/record/405633/files/PhDThesis_ASchuetz_Publication.pdf



Source: https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.44.2209&rep=rep1&type=pdf

- This background comes from the generation of virtual or bremsstrahlung photons as bunches pass through each other
- To simulate the pair background we use the Guinea-Pig (GP) program
  - Use detailed input concerning expectations of beam focusing to predict bunch field and particle transport
  - There are additional handles for hadron photoproduction but GP's implementation is known to be inaccurate
  - Refined error analysis of predictions lacking in recent studies, need to develop some prescription

Results for previous ILC machine parameter update

- Most recent stable results are from 2017 machine parameter update
  - Simulation also with GuineaPIG
  - Detailed accounting of occupancy throughout detector
- Primary focus of this update was impact of muon backgrounds
  - Particular attention paid to investigating various shielding strategies
  - Muon background discussed later in this talk

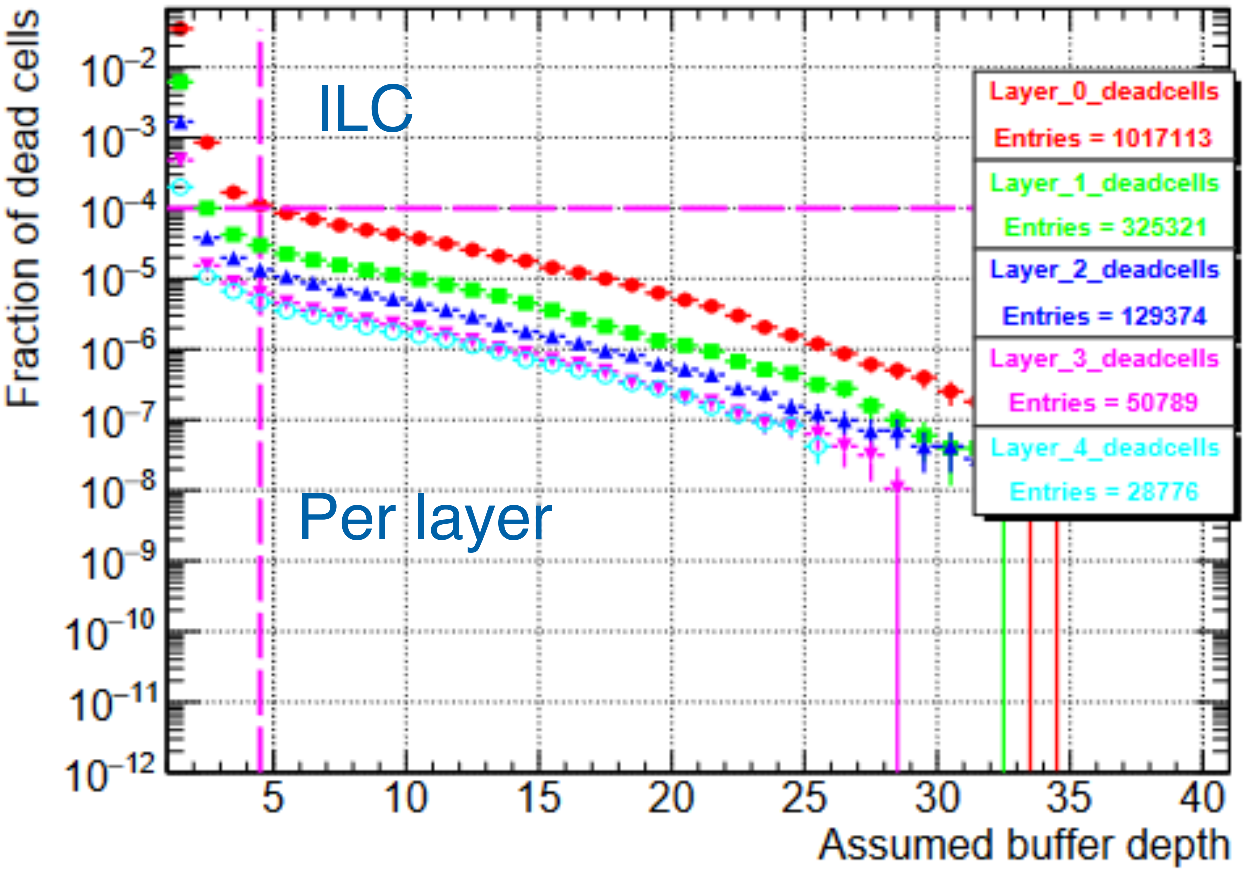
See D. Jeans Parallel

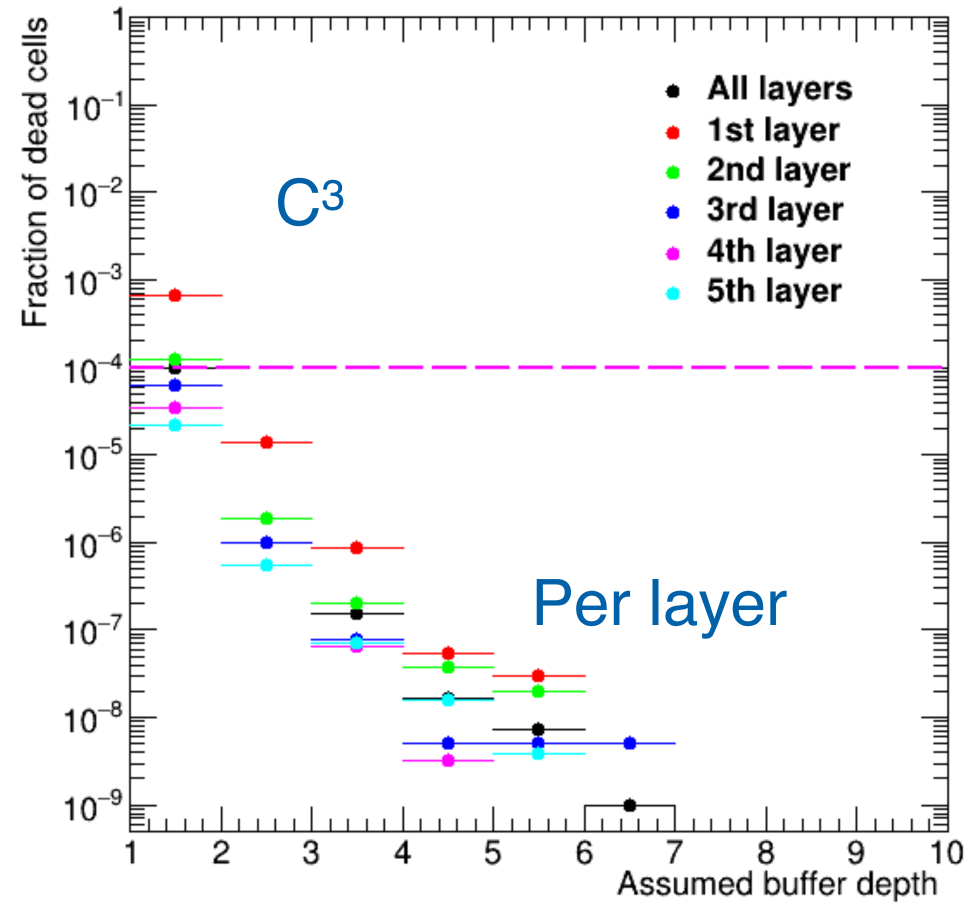
				VXD hits per BX					
	ECOM	aDID	nom. field	Layers 1, 2		Layer 3, 4		Layer 5, 6	
ILD model	[GeV]		[T]	Early	Late	Early	Late	Early	Late
ILD_l5_v03	250	no	3.5	1139	1234	213	48	64	19
ILD_l5_v05	250	yes	3.5	1125	334	222	14	69	6
ILD_l5_v06	500	yes	3.5	1321	691	258	29	70	13
ILD_s5_v03	250	no	4.0	909	1343	176	60	54	21
ILD_s5_v05	250	yes	4.0	910	453	177	22	52	7
ILD_s5_v06	500	yes	4.0	1057	963	206	38	63	18

Table 3: Estimated number of hits in the vertex detector induced by beamstrahlung pairs, split into early ($t < 15$ ns) and late ($t > 15$ ns) components. Hits induced by very low energy initial particles (less than 2 MeV) have a negligible contribution, and are ignored. Averaged over 100 BX.

Preliminary Results for C^3

See E. Mettner Parallel





- Checked many times to ensure fidelity of simulation and outcome of results
  - Concerns about magnetic field, exact versions of geometry, etc.
- Together with envelope confirmation indications that we could move the inner pixel layer closer
  - Closer hit: improved sagitta determination, HF tagging, triggering, electron reco.
- Confirms baseline expectation that C^3 ~ ILC/10

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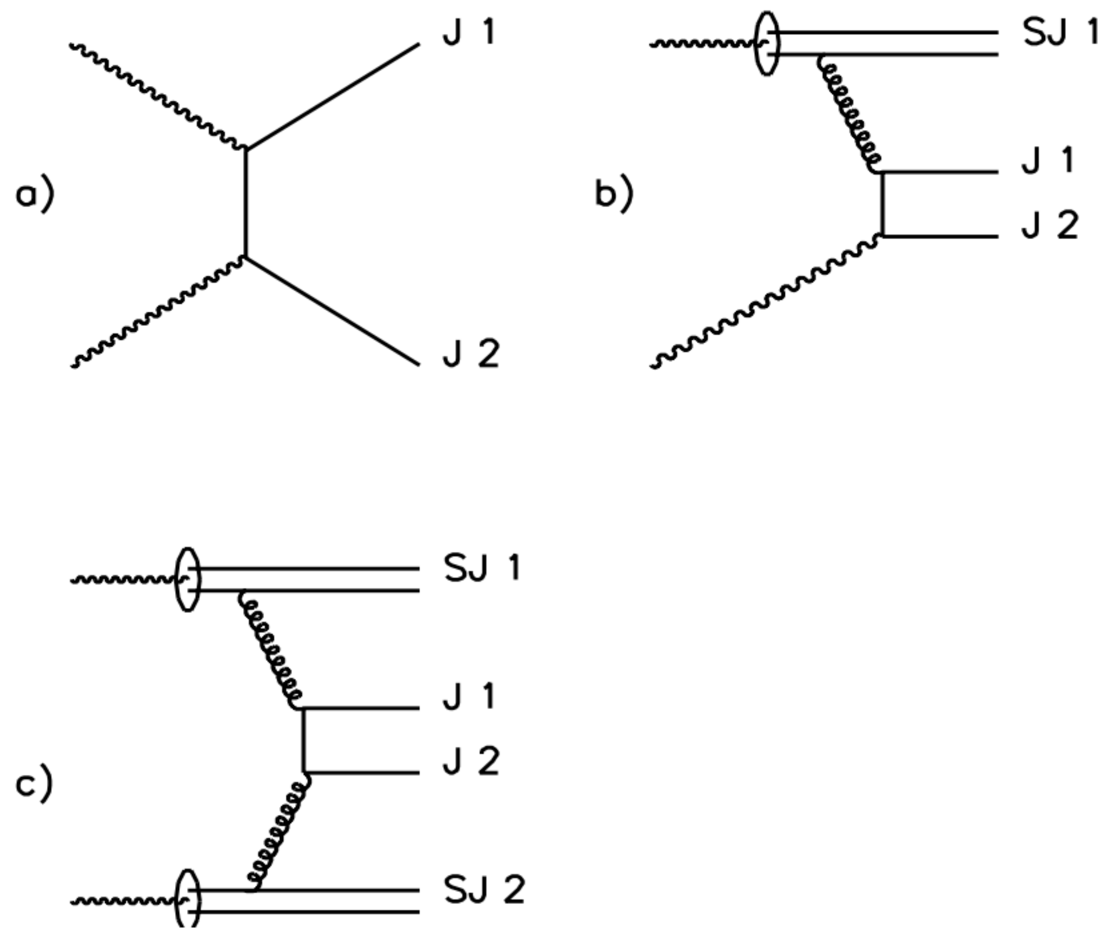
Hadron Photoproduction



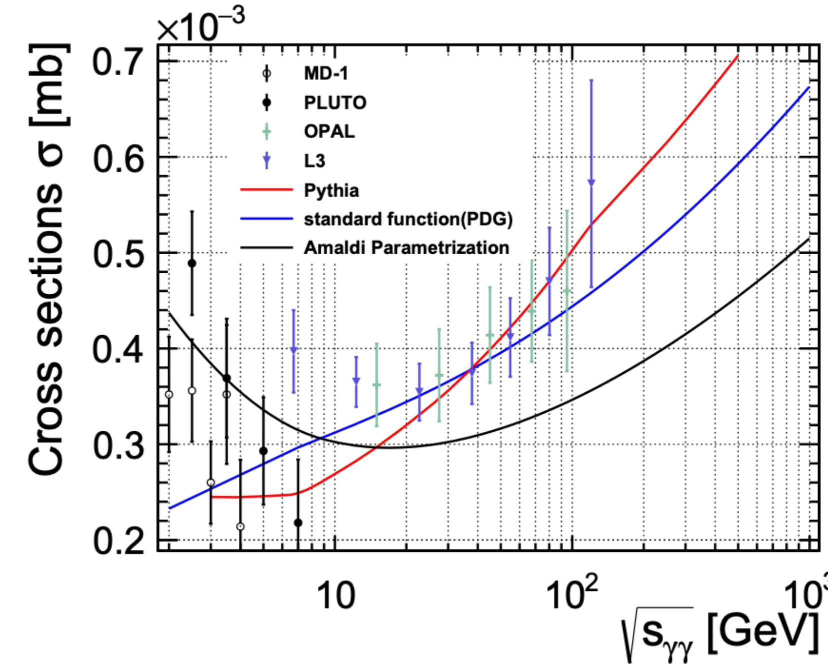
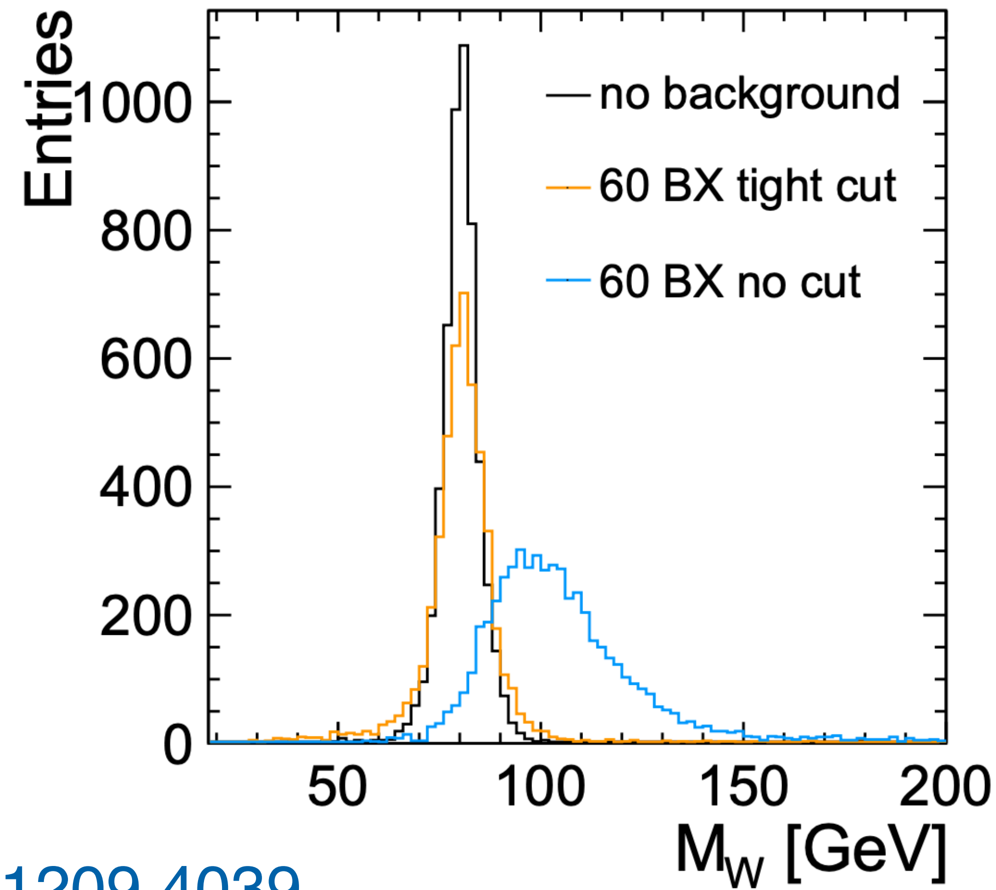


FIG. 2: Comparison of cross sections for $\gamma\gamma \rightarrow$ hadron processes as a function of centre of mass energy obtained from Amaldi parameterization [3], Standard paramerization [8] in PDG, Pythia and data from LEP [1], PETRA [6] and VEPP [5]

- Diagrams have similar topology to electron-positron background but include the possibility that the virtual photons pair-produce quarks
- Given smaller coupling to quarks and requirement for internal conversion this background is smaller
  - Measurements indicate ~10% of pair background at calorimeters, more central than e+ e-!
- Given the c.o.m. range over which we're producing events there are many details to consider

Hadron Photoproduction Results at ILC and CLIC



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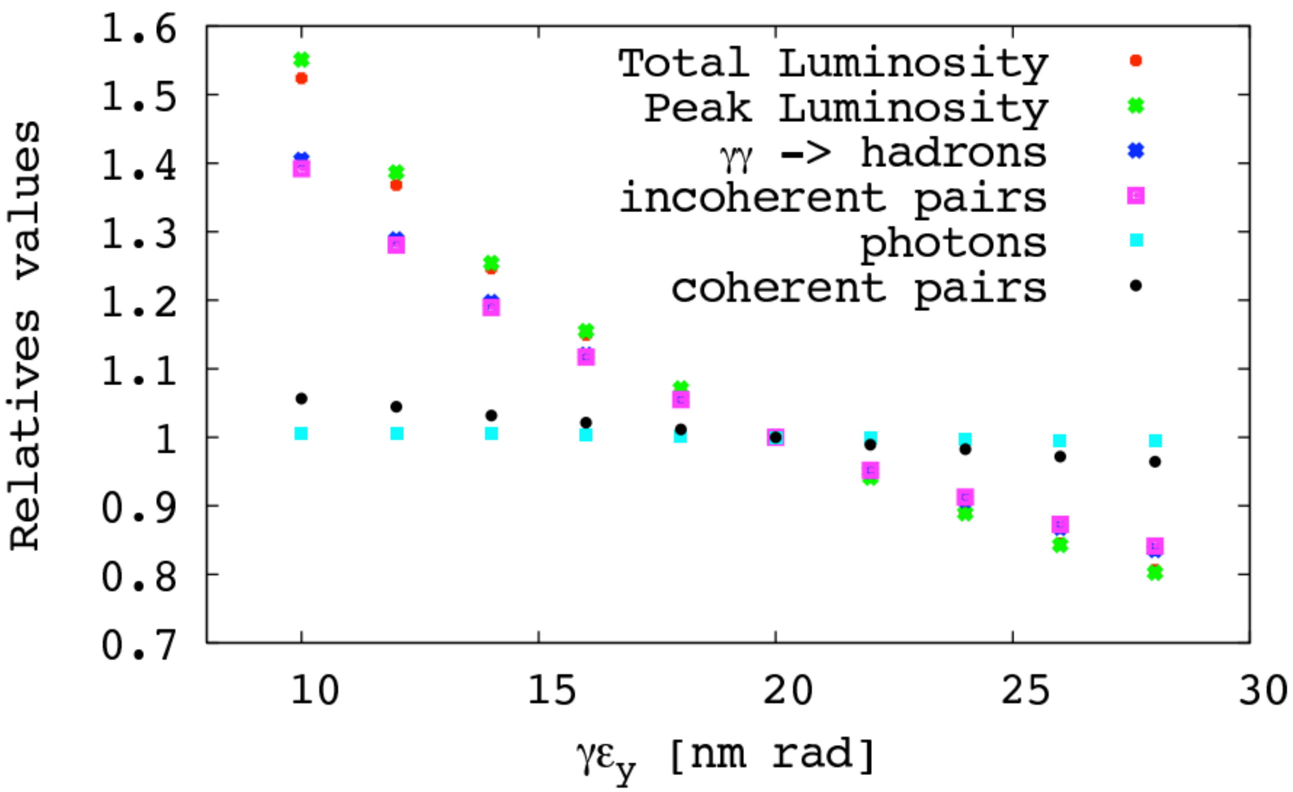
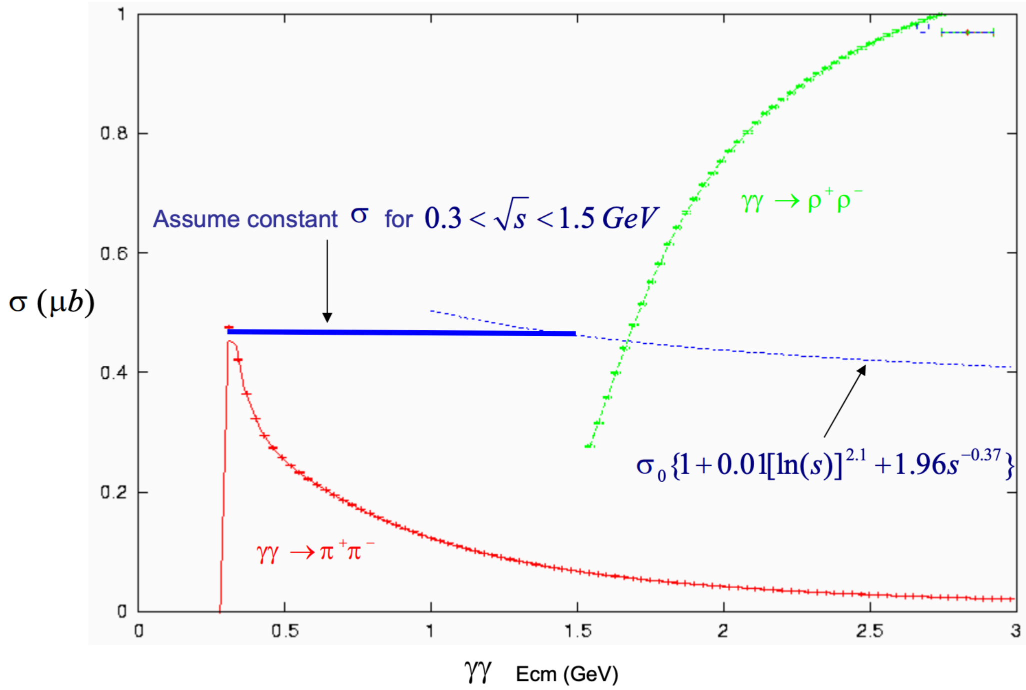


LCD-Note-2011-020

- Hadron photoproduction backgrounds particularly pernicious
  - Larger c.o.m. produces more central particles, including photons from pi0
  - Can affect jet reconstruction when rate is high enough
- As with pair production, hadron background scales with energy, emittance
  - Higher energy runs (WW, top) affected significantly more than Z-pole, Higgs-factory
  - cf. M. Swiatlowski Parallel on wakefield

Refinement of Simulation Strategy

T. Barklow, et al. (forthcoming)



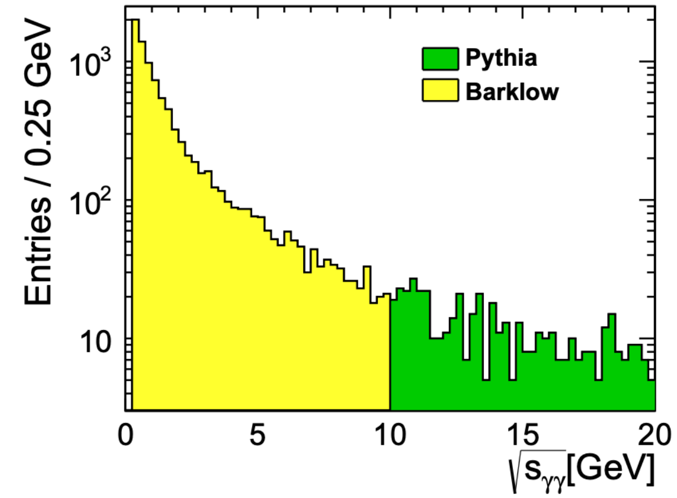


FIG. 1: Energy spectrum of $\gamma\gamma \to$ low p_T hadron events as a function of centre-of-mass energy. The figure shows the energy cutoff of 10 GeV below which the events are generated by the Barklow generator. Above 10 GeV the events are generated by Pythia.

- Previous hadron background studies combined multiple generators together
  - Various approximations for differential cross section
  - Hand-written generators in addition to Whizard and Pythia where their approximations hold
- Modern simulation significantly more streamlined
  - More direct integration of processes into Whizard and CIRCE programs
  - Best possible simulation of virtual photon flux throughout center-of-mass spectrum

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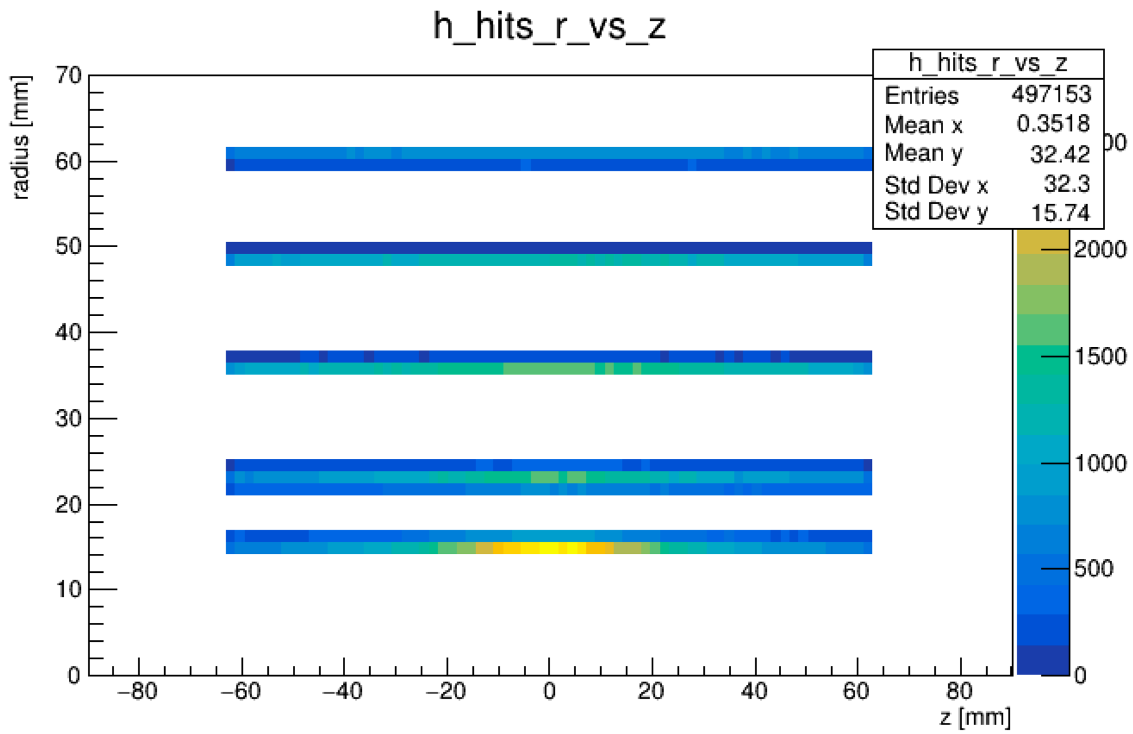
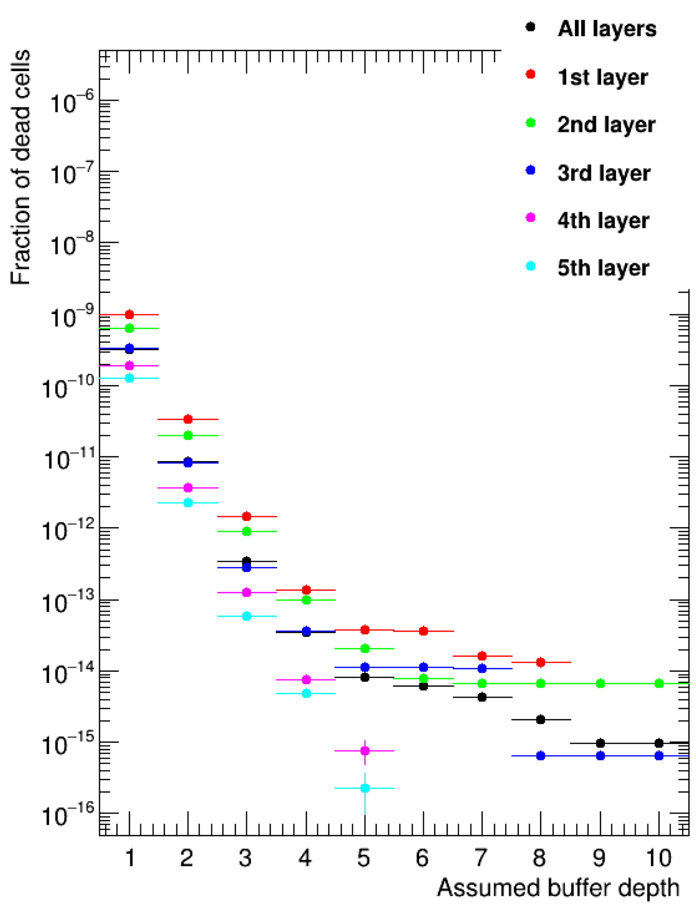
Status of Results for C³

See E. Mettner Parallel

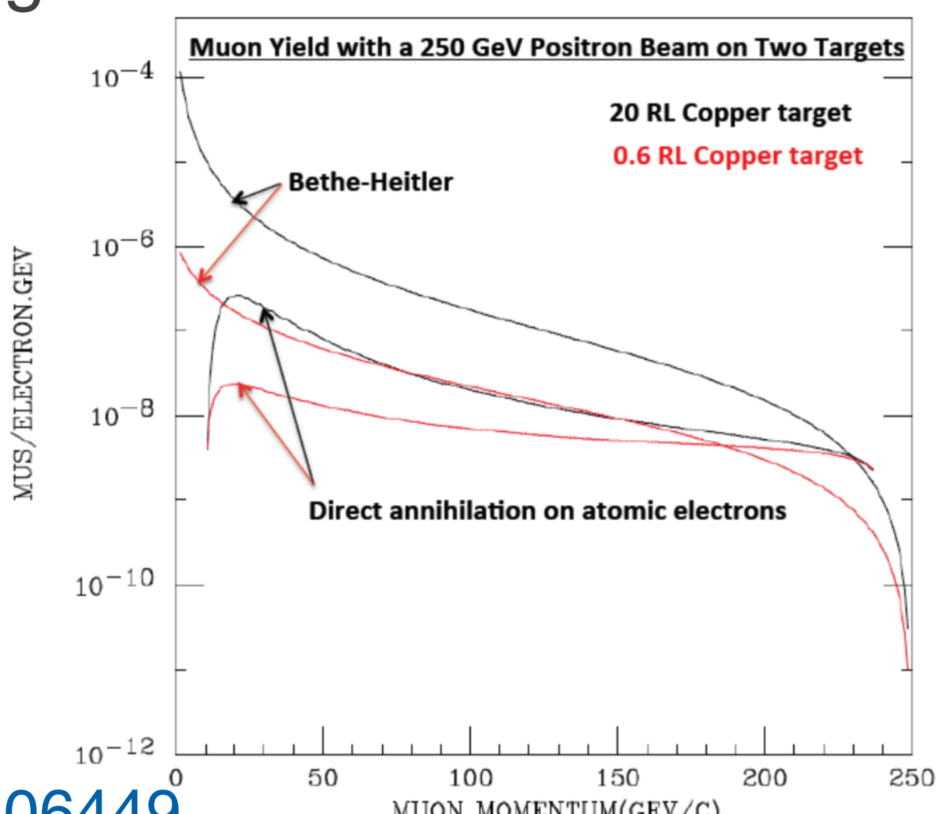
- While waiting for new generators, have completed Pythia 8 simulation
  - Find that hadron background in pixel detector (current focus) is 0.1% of pairs
  - Matches last ILC results for ratio to pair background, absolute yield is 10% of ILC
- Much more central occupancy distribution than electron pair production
  - As expected, backgrounds affect C³ detectors in the same way as ILC
  - Once we have T. Barklow generator in hand, proceed to overlay, physics studies!





Backgrounds from the Machine

- Incoherent muon production from beam interactions with collimator
- Mitigation strategies involve “spoiler” and “wall” magnets to deflect muons
  - Survivable rates achieved through a combination of both
- Simulation requires detailed transport treatment, material interactions in large volume



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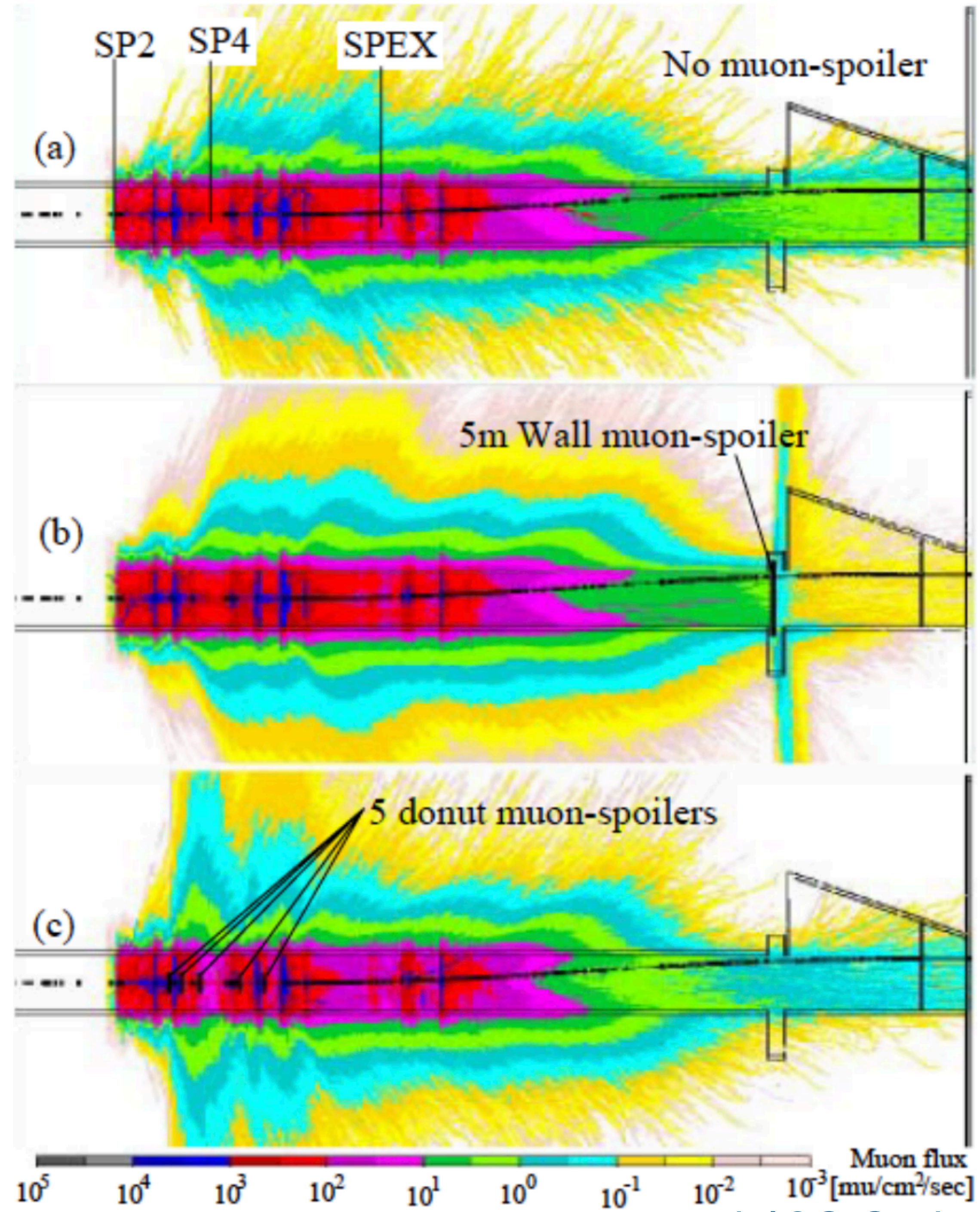

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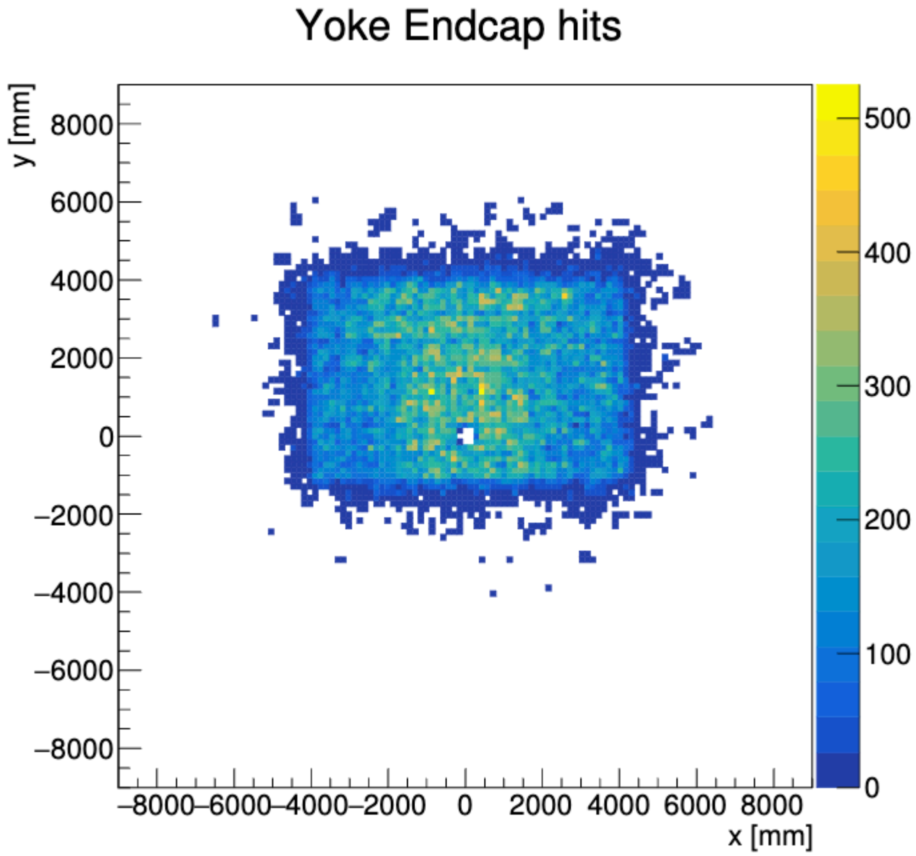
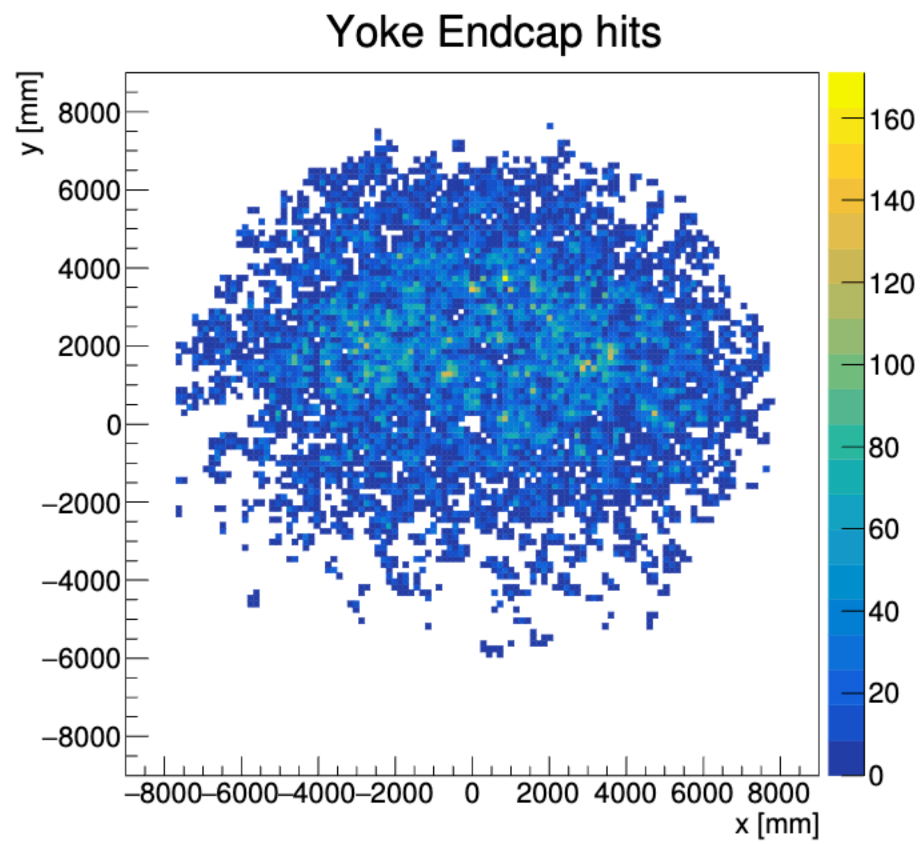
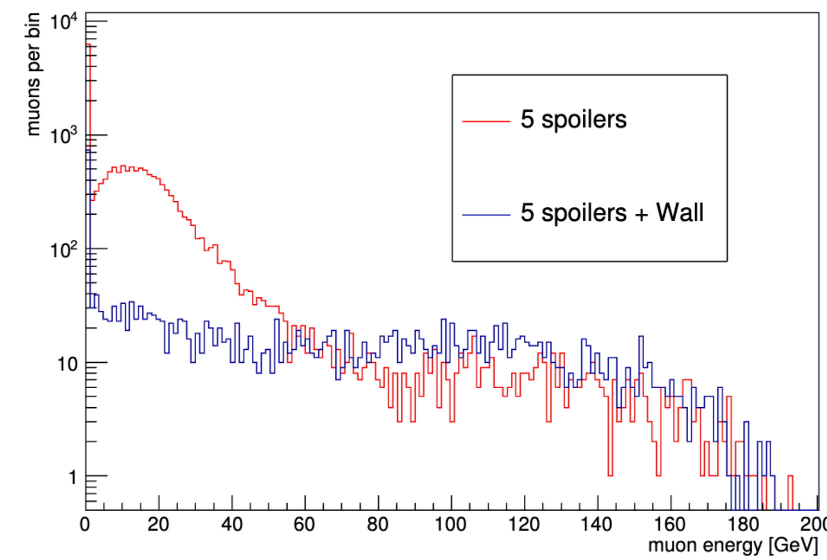
Results for ILC + ILD







- Muon simulations performed using MUCARLO (G. Feldman) simulation
  - Validated against older FLUKA implementations and measurements
  - Older results (ALCW2018) also show impact on TPC
- Variations of accelerator structure with and without magnetized wall
  - Wall reduces number of muons per bunch train by ~5x
  - Wall necessary for reasonable occupancy in ILD endcap detectors
  - Significant impact on detector design choices

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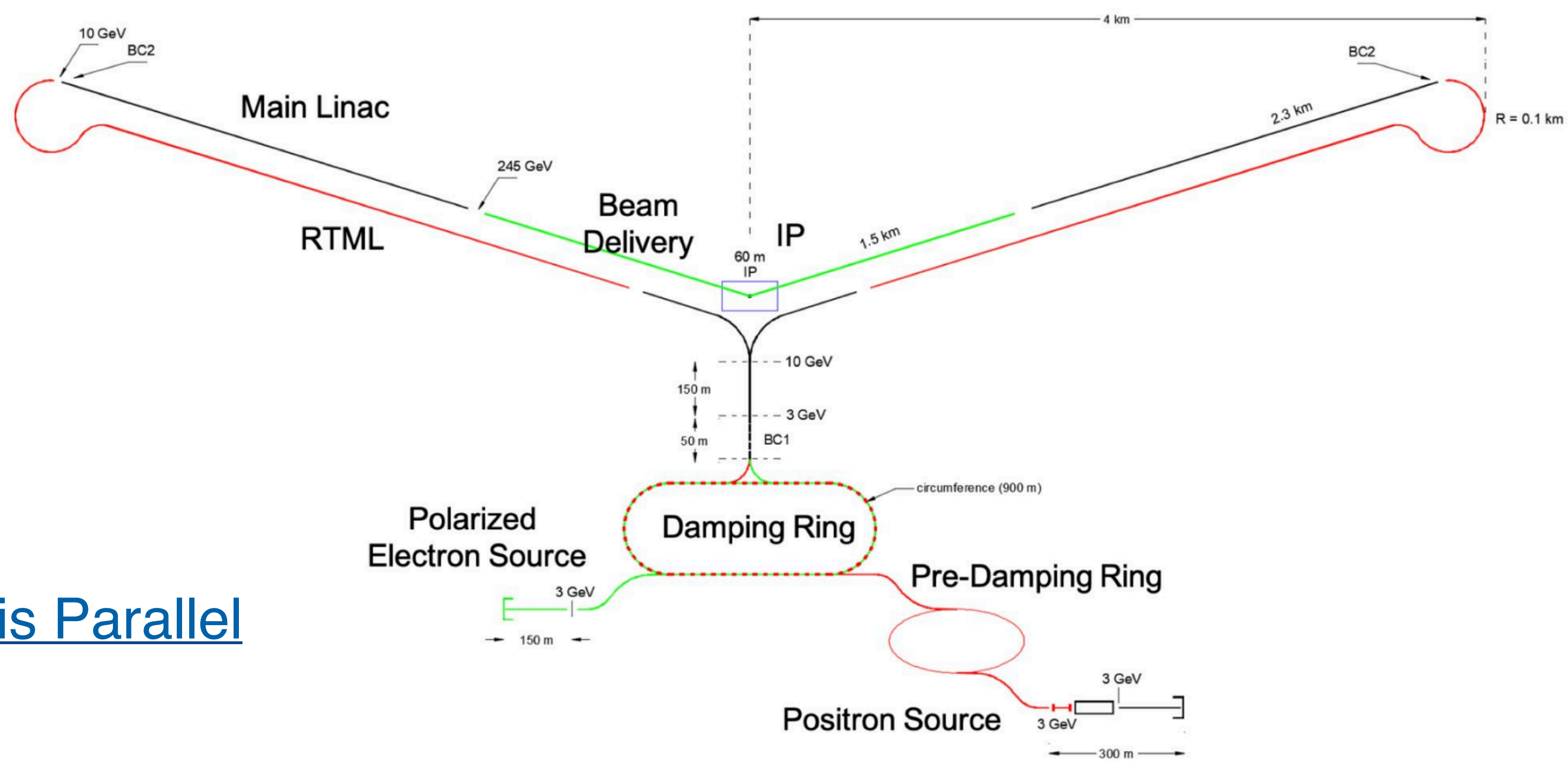
Towards achieving results at C3

C^3 - 8 km Footprint for 250/550 GeV



See D. Ntounis Parallel

- C3 will have a different BDS compared to ILC, and is significantly shorter
  - Need to provide detailed geometry and specialize our own version of MUCARLO
  - However - little possibility to get this code running again from scratch
  - Very little documentation, abandoned dialects of fortran, …
- Starting software project to produce these results for C3 over this summer
  - Aim to validate against ILC results
  - Show differences, finer considerations for significantly more compact machine

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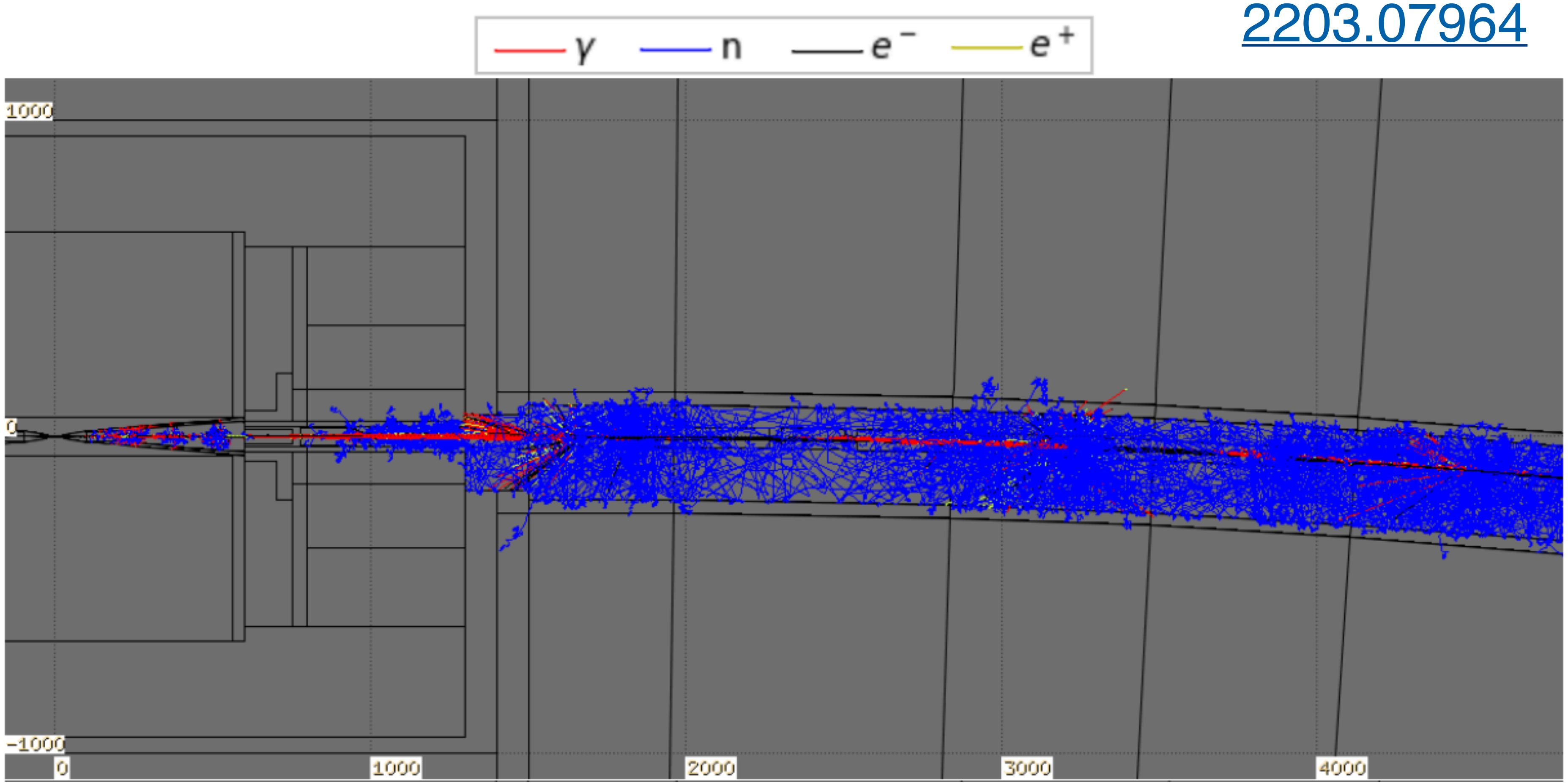
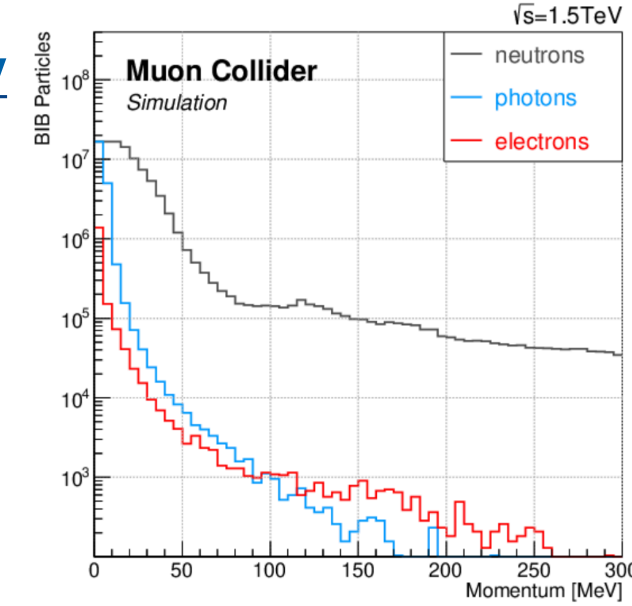
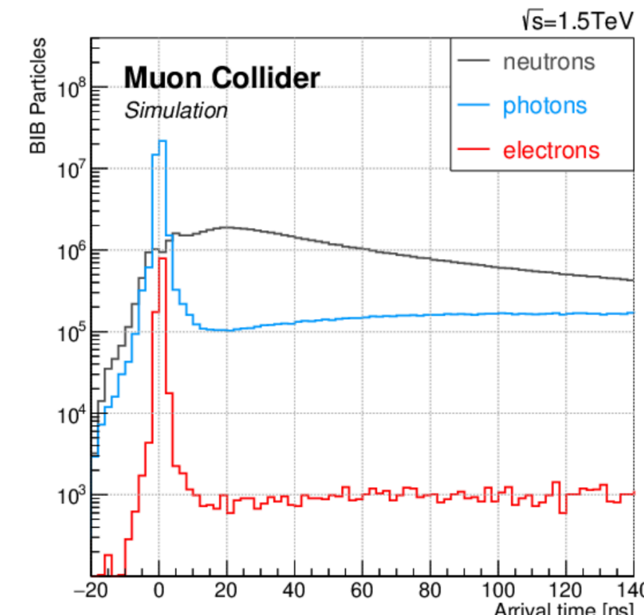
[See M. Swiatlowski Plenary]

A Note on the Muon Collider

[2203.07964]







- Enormous background from muon decay products interacting with the accelerator structure
  - Also a small rate of incoherent pair and hadron photo production (comoving electrons!)
- Muon collider machine background simulations are assembled using FLUKA
  - Particles that reach the experiment hall can be recorded and entered into GEANT for overlay with event
  - FLUKA comes with a package for describing geometries / beam lines (we should use it!)

Remarks and Conclusions

- Beam and machine induced backgrounds at lepton machines pose challenges to detector design and physics reach
  - Machine and beam design: flavor, energy, charge, optics can alter primary backgrounds
  - Particularly at high energies and small emittance, these backgrounds can easily overwhelm modern detector concepts without optimizations
    - Numerous promising future directions to open up design space

- C3 collider concept is making progress on its own background estimates
  - Major issue: 5ns bunch spacing requires accurate pileup overlay (CMS style)
    - This is a major software effort, but can/should be shared with MuC, FCC
  - However, assuming sufficient electronics: C3 = ILC / 10

- Updates to various collider concepts background studies at this workshop
  - Other plenaries, parallels - join in the discussion!
  - All lepton collider concepts use the same tools, we should work together
    - Not only to distribute expertise but to preserve knowledge about the tools we use to make these predictions