Generating low Q^2 events (aka $\gamma^*\gamma^*$ events with the matrix-element?)

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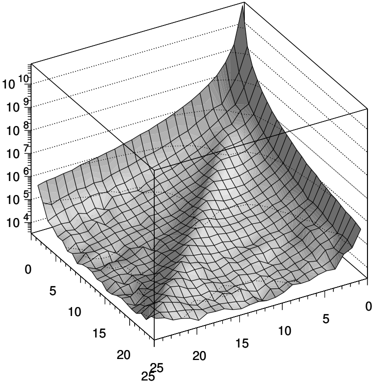
Outline

1. Introduction
2. Issues with the DBD $\gamma\gamma$ samples
3. Issues with `Whizard 2.8` $\gamma\gamma$ samples
4. Doing low Q^2 events with the matrix element
5. Proposal and TODO

Introduction

- The problem with low Q^2 is shown to the left: Number of events per bin with $\int \mathcal{L}$=10 ab^{-1}: Yes, that's $\sim$ 100 billion in one bin.
- So, efficient generation is needed.
- But not enough: Need to cut the phase-space.
- And do that in a consistent way that impacts physics as little as possible.



Introduction

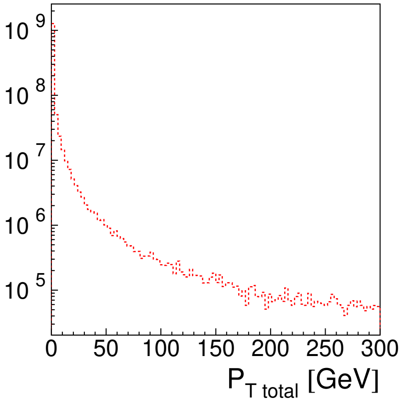
- A way to speed up is to use the *equivalent photon approximation* (EPA)
  - Approximate the flux of virtual photons.
  - Then simply generate $\gamma\gamma \to f\bar{f}$, a 2→2 process: Fast!
- Put restrictions on the Q^2 of the $e \to e$ scattering, and eg.on m_{ff}
- Also sub-divide in Q^2:
  - "$\gamma\gamma$": Both $Q^2 < 16$ GeV^2. EPA.
  - "$e\gamma$": $Q^2$of $e^{-(+)} < 16$ GeV^2, of $e^{+(-)} > 16$ GeV^2. EPA.
  - "SingleZee": Both $Q^2 > 16$ GeV^2. Matrix element.
  - ... and live with lower $\int \mathcal{L}$ (⇒ higher weights) for the first two.
- Done in the DBD samples, and can be done in a more consistent way with the latest `Whizard`
- However, there are issues ...

Issues with the DBD $\gamma\gamma$ samples

- A problem with EPA (in `Whizard` and in general) is to have *both* ISR (real photons) *and* EPA (virtual photons) off the same electron/positron.
- In `Whizard`, there is simply no ISR in the EPA samples.
- However, this means that the $f\bar{f}$ system can only get transverse momentum by recoiling against the out-going e^+e^- system, which means that it can be at most a few GeV, if a BCal veto is applied.
- In the DBD, an additional "$p_\perp$-kick" was applied.
- But this implied a number of issues...

Issues with the DBD $\gamma\gamma$ samples

- The Total $p_\perp$ of all stable particles in the DBD $\gamma\gamma$ samples:
- This utterly violates momentum conservation: The $p_\perp$ of the beams is $\equiv 0$!
- In addition this is the Total Energy of all stable particles ...in log-scale



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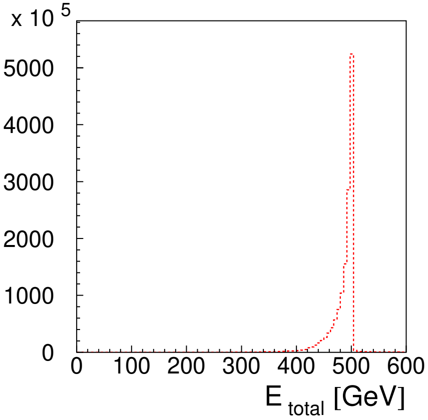

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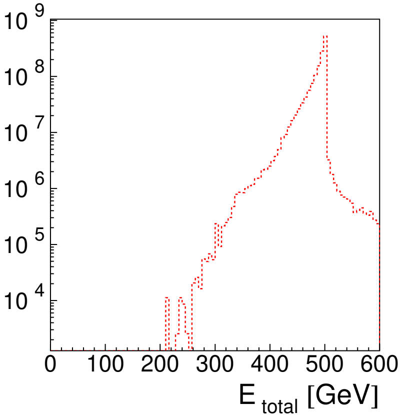
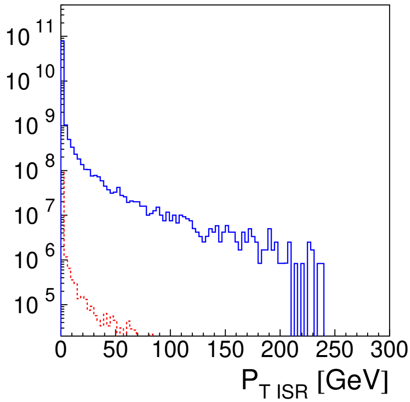


Issues with Whizard 2.8* $\gamma\gamma$ samples (*: = 2.8.3 rev 8385)

Compare Whizard EPA (red-dash) and Matrix element (blue-solid)

- In Whizard 2.8, the treatment of $p_\perp$ does not violate E and p conservation.
- However, there is still no ISR, so there is a juggling between the beam-remnants and the $f\bar{f}$ pair to achieve this.
- This influences other kinematic quantities in more-or-less haphazard ways:
  - Jumps in the q distribution between EPA and matrix element
  - or in the $p_{\perp f\bar{f}}$ one.



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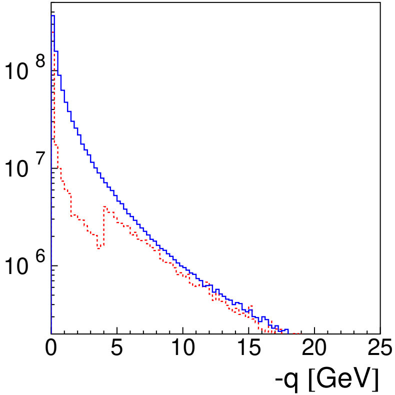

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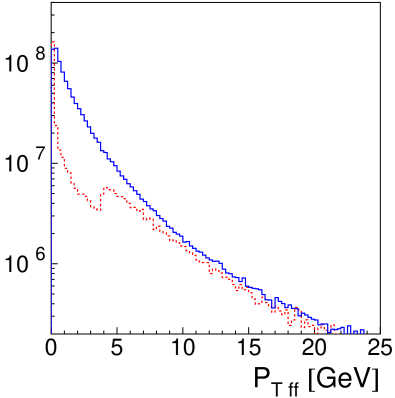

Doing low Q^2 events with the matrix element

- The "$\gamma^*\gamma^* \to f\bar{f}$" process is a sub-diagram of $\mathrm{e}^+\mathrm{e}^- \to e^+e^- f\bar{f}$ (AKA the "Single Zee" process), with low Q^2.
- Generating $\mathrm{e}^+\mathrm{e}^- \to e^+e^- f\bar{f}$ with the matrix-element prescription in Whizard avoids the "no ISR" problem, and also includes all diagrams eg. "bhabha+FSR*" (five pages of them...).
- But it is a 2→4 process. How bad is that? The dogma is that it is forbiddingly slow.
- Well, it is quite bad, in relative: takes 30-50 times longer than EPA.
- But in absolute, that is not such a big deal: One still generates $\sim$ 10 events / s.

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Doing low Q^2 events with the matrix element: Setup

- Still sub-divide in “high-high”, “high-low”, “low-high”, and “low-low” Q^2, to be able to balance the integrated luminosity.
- “low” to “high” still at Q^2=16 GeV^2.
- Need to cut at low Q^2 as well: go down as low as 2.5×10^{-3} GeV^2. Note that with EPA, no low limit is needed.
- Use standard “singleZee” setup otherwise (beam-spectrum, ISR).
- Cross-sections for $f\bar{f} = \mu^+\mu^-$ or $\tau^+\tau^-$ (worst case), compared to DBD:
  - “hh”: 5.65 pb (5.71 pb)
  - “lh/hl”: 70.9 pb (50.8 pb)
  - “ll”: 8483 pb (86 pb)
- Then explore other cuts, with minimal impact of physics, maximal impact on cross-section, to approach the DBD case.
- But note: the cross-sections for *real* photons are much larger!

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Doing low Q^2 events with the matrix element: Setup

Four different sets of generator cuts for “singleZee” explored:

1. $Q^2_{min} = 2.5 \times 10^{-3}$ GeV^2
   - Cross-section: 8483 pb
2. $Q^2_{min} = 0.49$ GeV^2
   - Cross-section: 126.2 pb
3. $Q^2_{min} = 2.5 \times 10^{-3}$ GeV^2, demand at least two leptons with $p_\perp >$ 300 MeV and with $\theta > 7^\circ$ (i.e. detectable as charged tracks)
   - Cross-section: 3319 pb
4. $Q^2_{min} = 0.04$ GeV^2, demand at least two leptons with $p_\perp > 300$ MeV and with $\theta > 7^\circ$
   - Cross-section: 1064 pb

Also do EPA with `Whizard 2.8`, with $\approx$ the same cuts as in DBD. Then compare.

Doing low Q^2 events with the matrix element

- Compare EPA (red-dash) and singleZee/setting 1 (blue-solid) for $e^+e^- \rightarrow \tau^+\tau^-$
  - Inv. mass of the $\tau^+\tau^-$-pair ...
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  - -q ...
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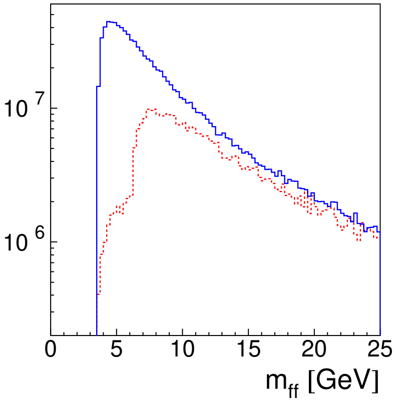

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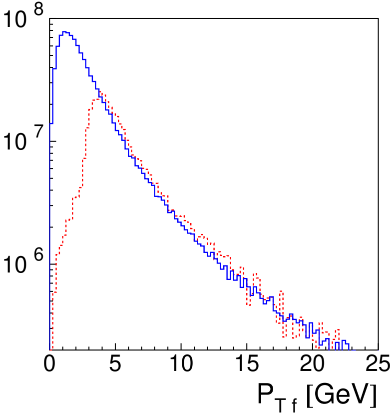

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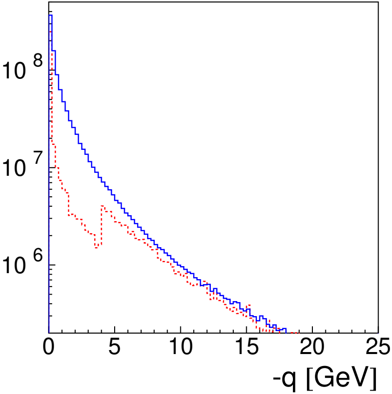

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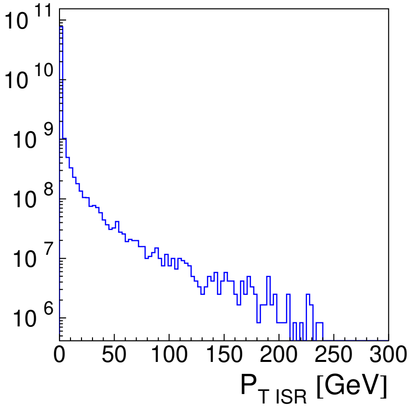

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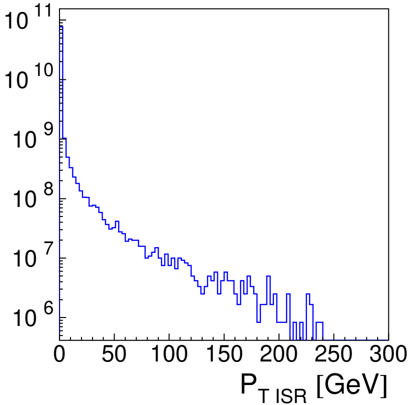

Conclusion: Missing events - jumps - no ISR - in EPA, but tails agree.

Doing low Q^2 events with the matrix element

Then: study the different generator cuts for the effect on physics events. Do a set of more and more restrictive cuts, and see what the difference is on detectable quantities. In particular, see if there is a difference wrt. the “no-cut” setup 1.

- The different case for physics events
  1. No cuts.
  2. Either four fermions seen, at least in BCal (=”Normal” 4-fermion events), OR both fermions in tracking, both beam-remnants in the beam-pipe (=Passing “low $\Delta(M)$ SUSY topology cuts”)
  3. All four fermions seen in the tracker OR passing “low $\Delta(M)$ SUSY topology cuts”
  4. All four fermions seen in the tracker OR both fermions in tracking, both beam-remnants in the beam-pipe, and missing $p_\perp > 2.5$ GeV (=Passing “low $\Delta(M)$ SUSY selection cuts”)
- No cut is made on the $M_{f\bar{f}}$, but rather on how visible the eevnt is. Cutting on $M_{f\bar{f}}$ is effective (in particular for muons), but is a cut on a observable highly relevant for physics.

Doing low Q^2 events with the matrix element

No-cut case, the lines correspond to setup 1 through 4

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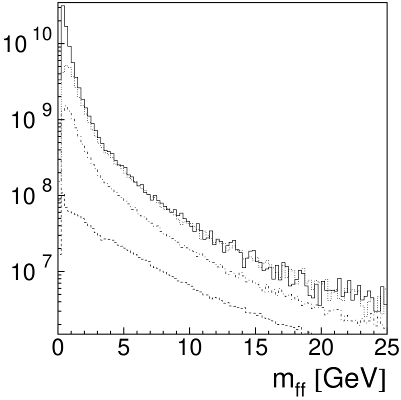

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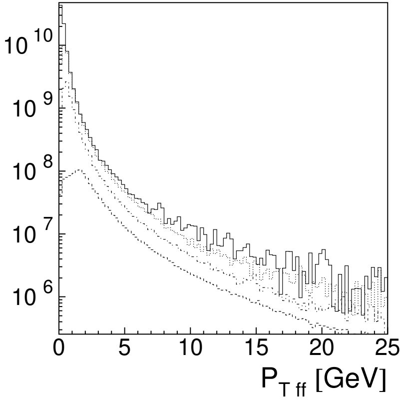

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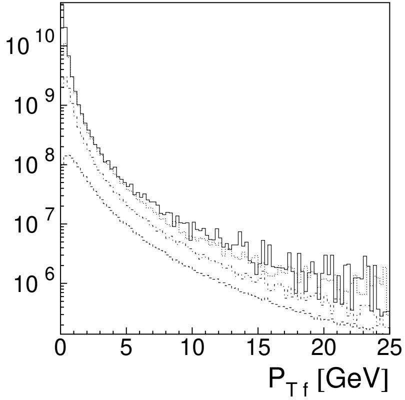

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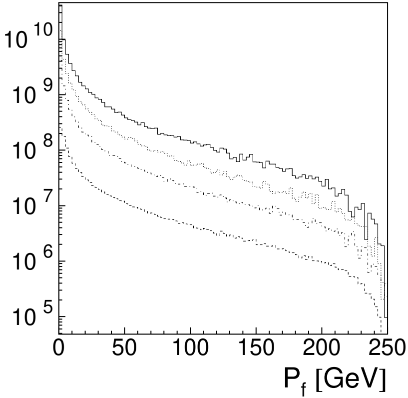

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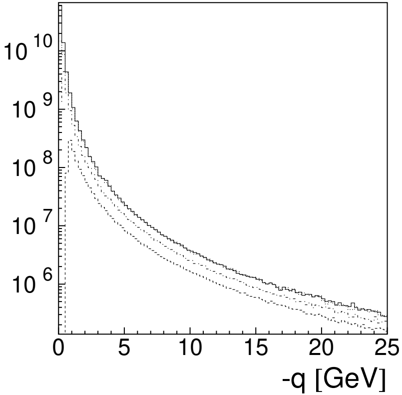

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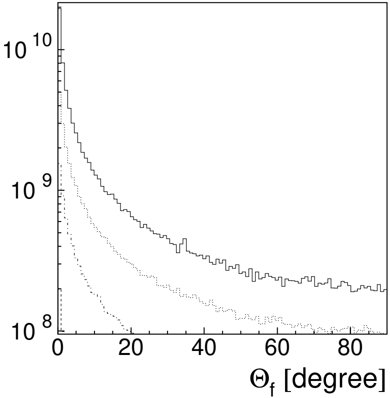

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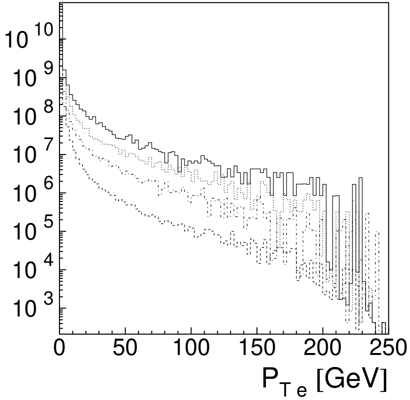

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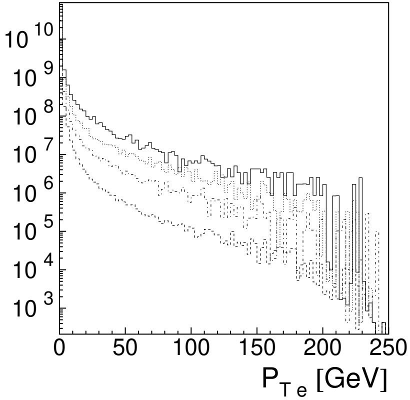

Conclusion: Shapes remain quite un-changed as the generator setup get more and more restrictive. Only the total changes.

Doing low Q^2 events with the matrix element

Cut case 4 (most restrictive), the lines correspond to setup 1 through 4. Warning: running out of stat (100000 events not enough...)

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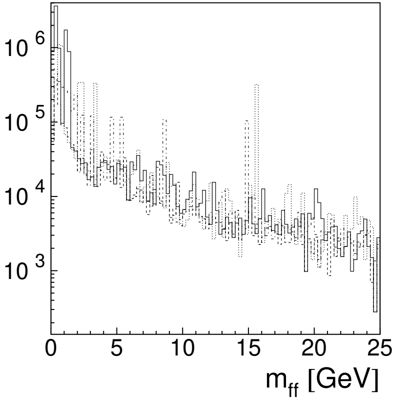

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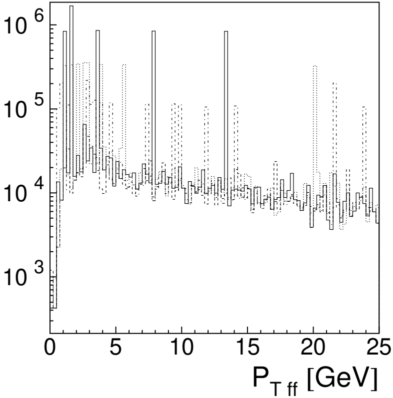

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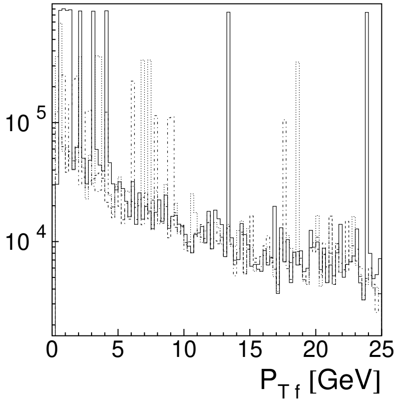

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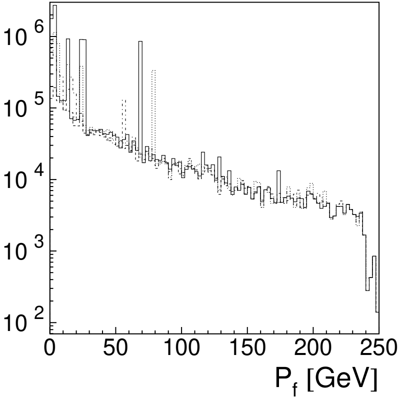

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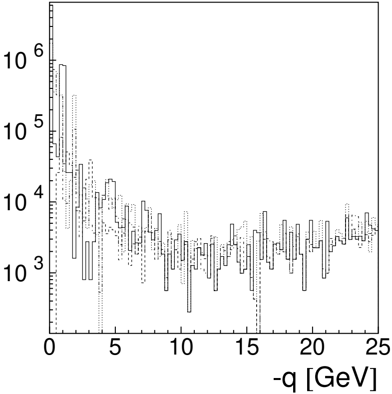
- $p_\perp$ of the beam-remnants



Doing low Q^2 events with the matrix element

Cut case 4 (most restrictive), the lines correspond to setup 1 through 4. Warning: running out of stat (100000 events not enough...)

- Inv. Mass of the $f\bar{f}$-pair
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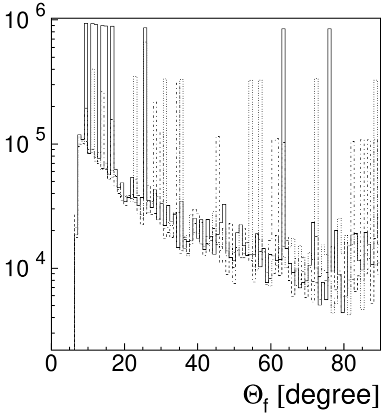

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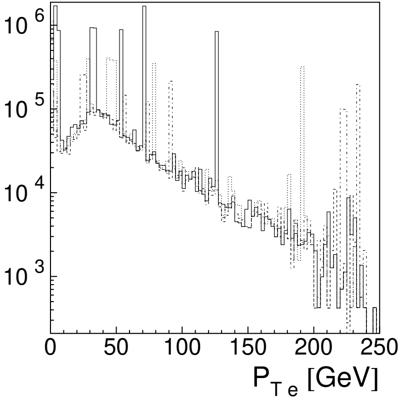

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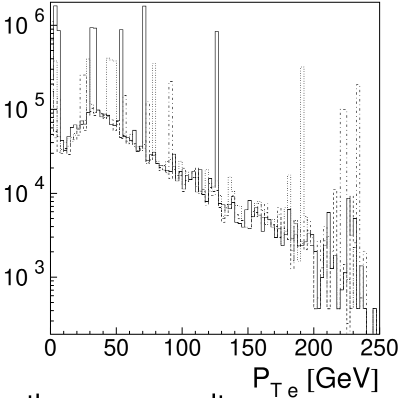

Conclusion: At this level, all setups give the same result.

Problems

- Q^2 is not such a good variable to cut on for acceptance. Think:
  - $Q^2 \approx 0$, but x (fraction of energy lost) small: Then the $f\bar{f}$ will have $P_{\perp\ f\bar{f}} \approx 0$, but $P_\perp$ of *each* f can go to $(1-x) \times E_{beam}$
- Try with no lower Q^2-cut for Zee: WORKS - but even slower and higher cross-section.
- Pure acceptance cuts can then be applied to remove events that won't be seen (or at least not be analysable), to get to an acceptable level with low impact on physics.
- But: the cuts macro in the `sindarin` applies to the frame *before* ISR, ie. not in the detector frame.
- The selection macro is applied on the final event, ie. after hadronisation and in the lab-frame, and could be used to reduce the output file-size (but not generation time).
- However, at this point I'm stuck, because I don't know how to select the hard subevent at this late stage ...

Proposal

- Replace all samples previously done with EPA by the corresponding Matrix element setup:
  - Solves all issues with EPA.
  - Cuts can be found that does not increase the total cross-section to generate.
  - Is not catastrophically more time consuming to generate
- Keep the four Q^2 regions separate,to allow for different $\int \mathcal{L} \Rightarrow$ same number of channels (but more polarisation cases).
- Classify the channels differently: `aa_2f` with `eW.pW` would become `Zee_ll` (with all four polarisation combinations), `ea_ff` with `eL.pW` or `eR.pW` would become `Zee_hl` (also four), etc.
- The real photon-induced processes remains as before.

TODO

Further channels:

- To date, I did not get $\mathrm{e^+e^-} \rightarrow e^+e^-e^+e^-$ to work, but didn't put much effort.
- Need to check that "virtual-on-real" photons work.
- What about *aa_4f*, *ae_5f*? Would be 6-fermion processes - the ones with only one e^+e^--pair is probably straight forward, but those with more?
- Also $\mathrm{e^+e^-} \rightarrow \nu_e \bar{\nu}_e f \bar{f}$ needs to be considered.

Definite cuts:

- Further optimisation to do.
- Right now, all channels (2- and 4-fermion as well as all $\gamma\gamma$ and $e\gamma$) can be done with a single `Whizard` steering file + a few command-line options. Is this still possible in the new setup?

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> **Question to the audience**
>
> Are there any topologies that might be visible and/or important that would not be generated by the setups described? In particular, any ones that would be there in the EPA case?

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Thank You !