A better way of generating low Q^2 events (aka $\gamma^*\gamma^*$ events)

Mikael Berggren[1]

[1]DESY, Hamburg

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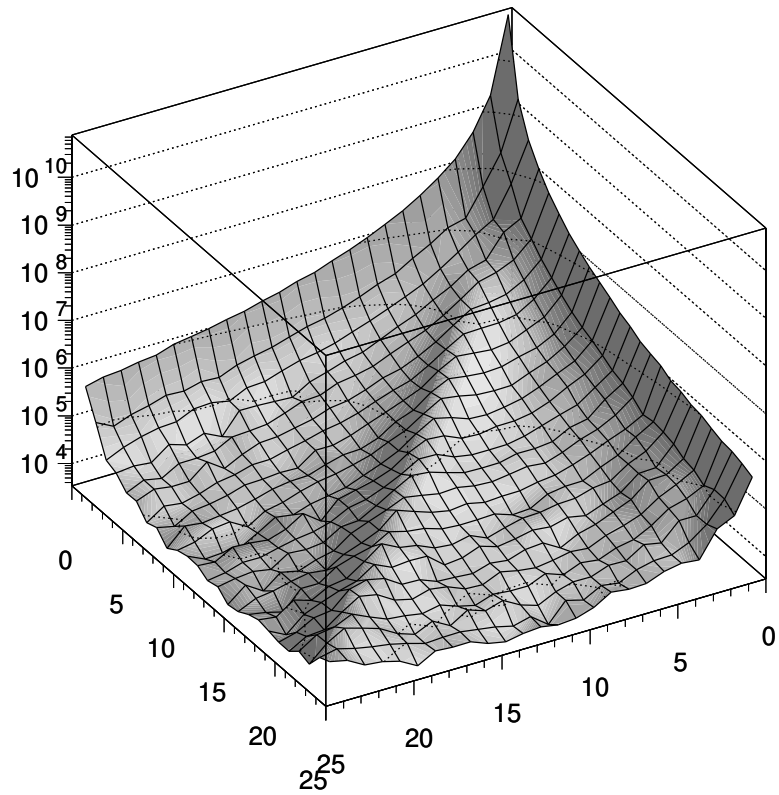
Outline

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

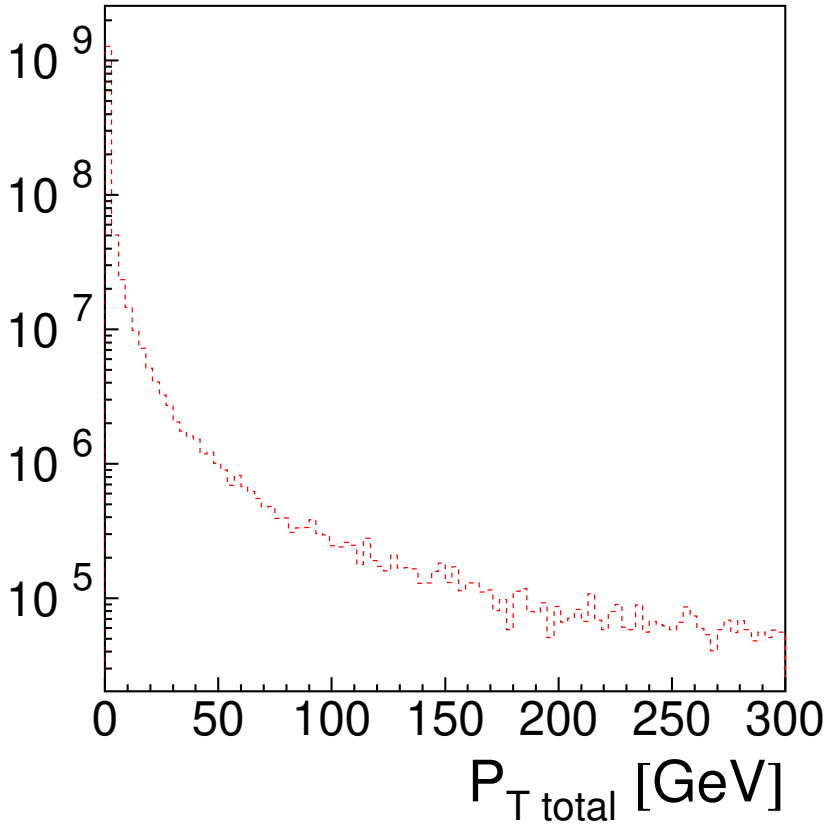
- A way to speed up is to use the *equivalent photon approximation* (EPA)
  - Approximate the flux of virtual photons.
  - Then simply generate $\gamma\gamma \to f\bar{f}$, a 2→2 process: Fast!
- Put restrictions on the Q^2 of the $e \to e$ scattering, and eg.on m_{ff}
- Also sub-divide in Q^2:
  - "$\gamma\gamma$": 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 $\int \mathcal{L}$ ($\Rightarrow$ 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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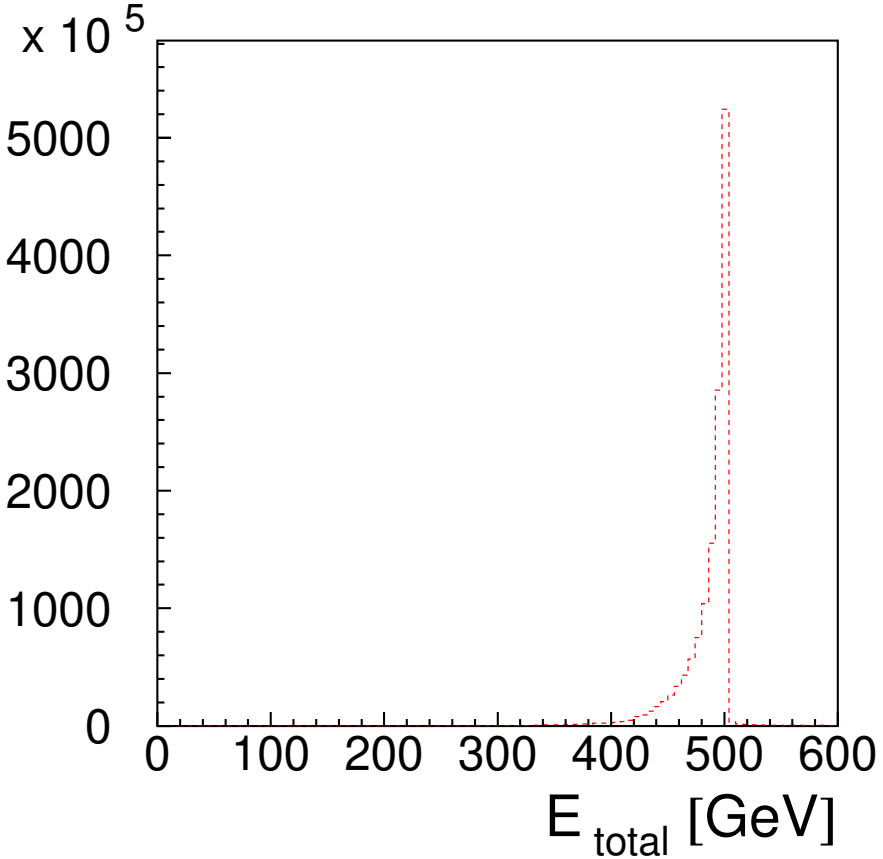

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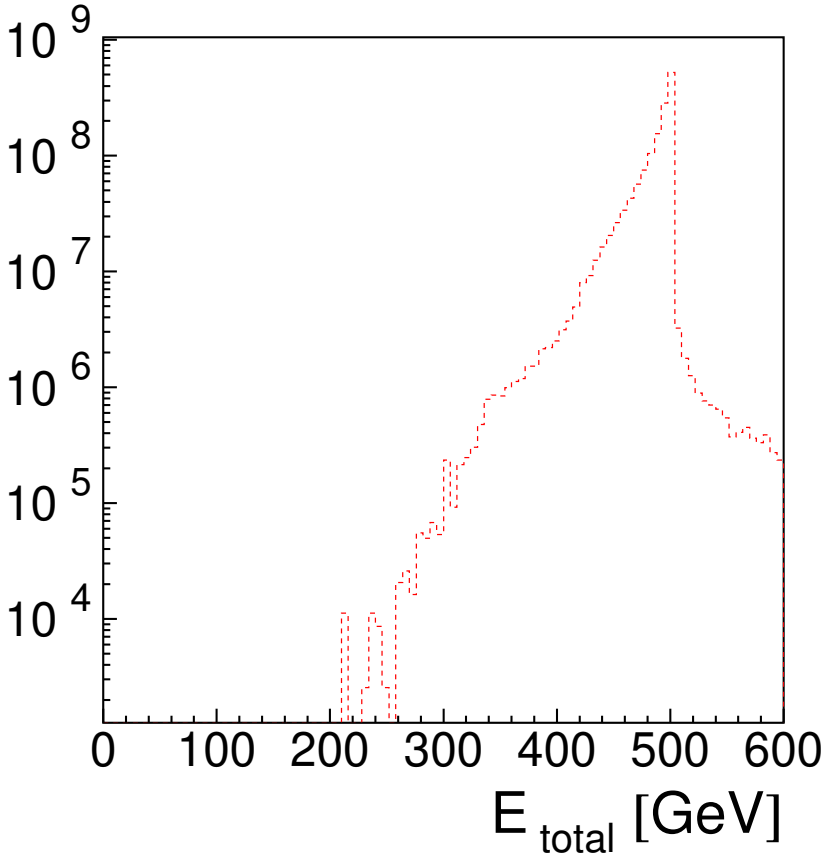
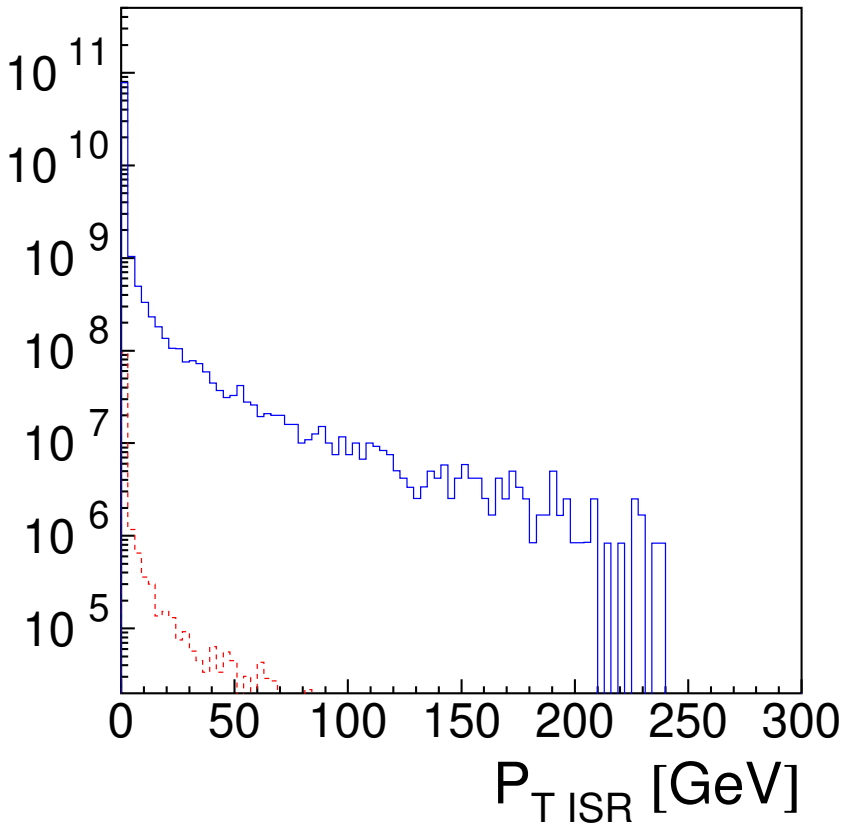


Issues with Whizard 2.8 $\gamma\gamma$ samples

- 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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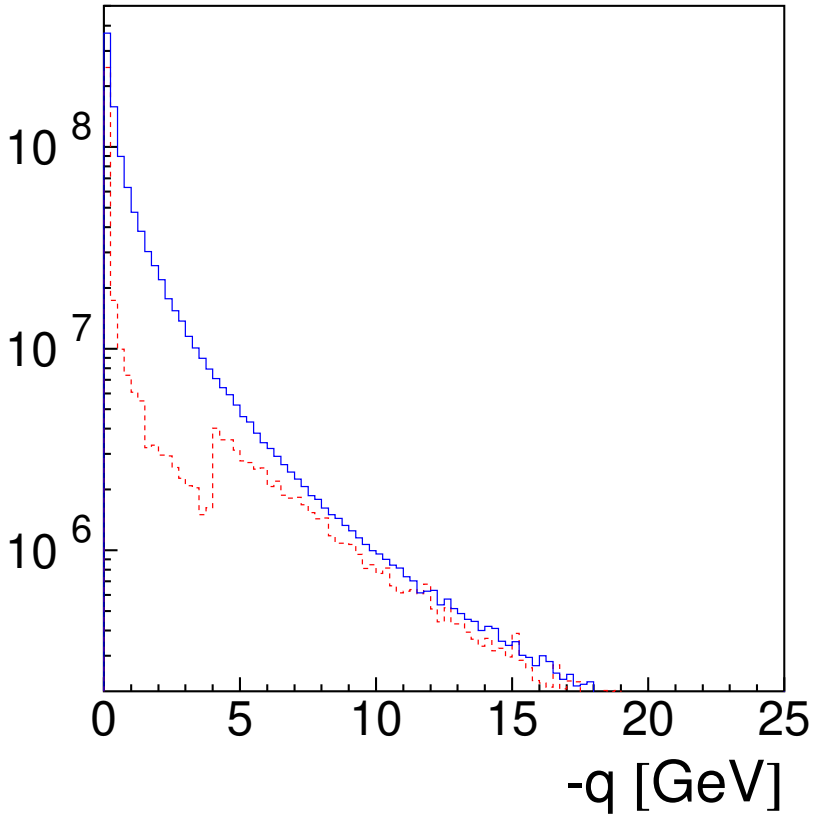

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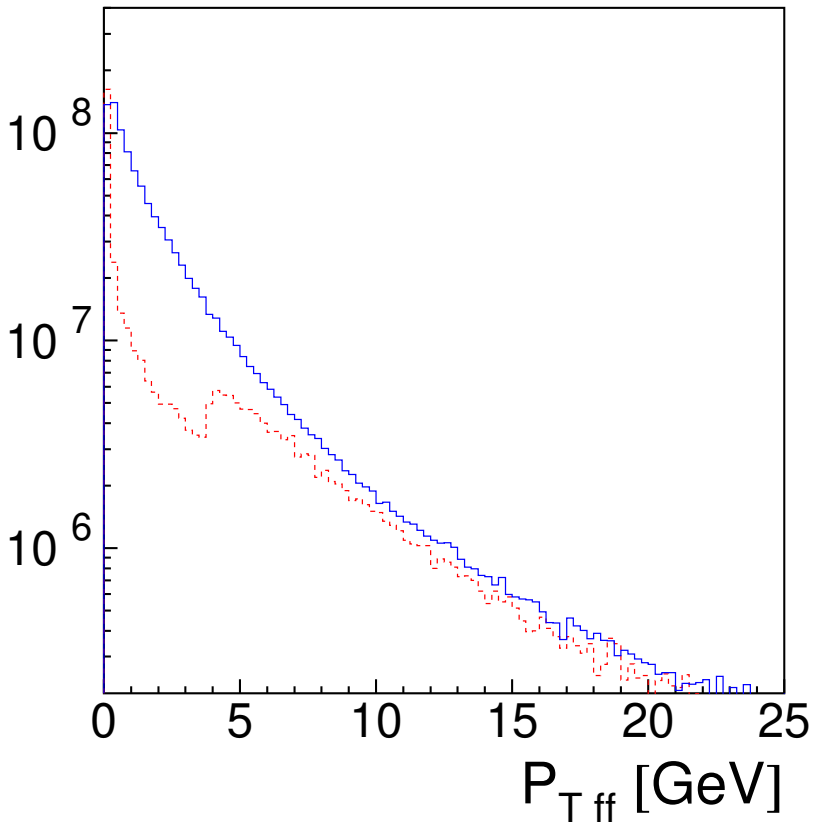

Doing low Q^2 events with the matrix element

- The "$\gamma^*\gamma^* \to f\bar{f}$" process is a sub-diagram of $e^+e^- \to e^+e^-f\bar{f}$ (AKA the "Single Zee" process), with low Q^2.
- Generating $e^+e^- \to e^+e^-f\bar{f}$ 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 ∼ 10 events / s.

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~~Dogma~~

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 $\theta > 7°$ (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 $\theta > 7°$
   - 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 and singleZee/setting 1 for $e^+e^- \to \tau^+\tau^-$
  - Inv. mass of the $\tau^+\tau^-$-pair ...
  - $P_\perp$ of the τ^+:s ...
  - -q ...
  - ... and $p_\perp$ for the ISR in the "ll" case.

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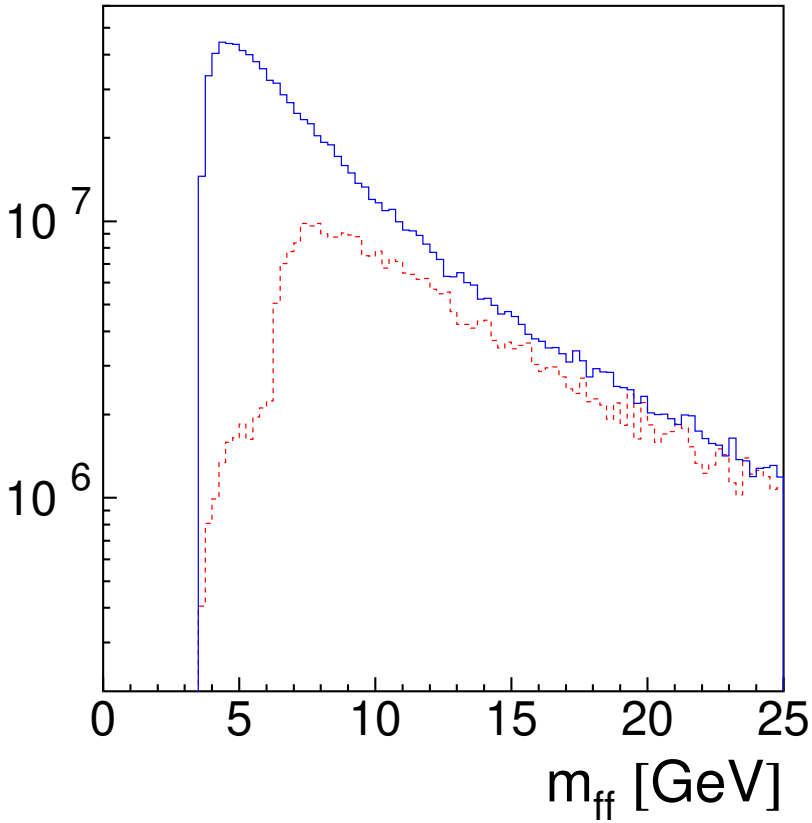

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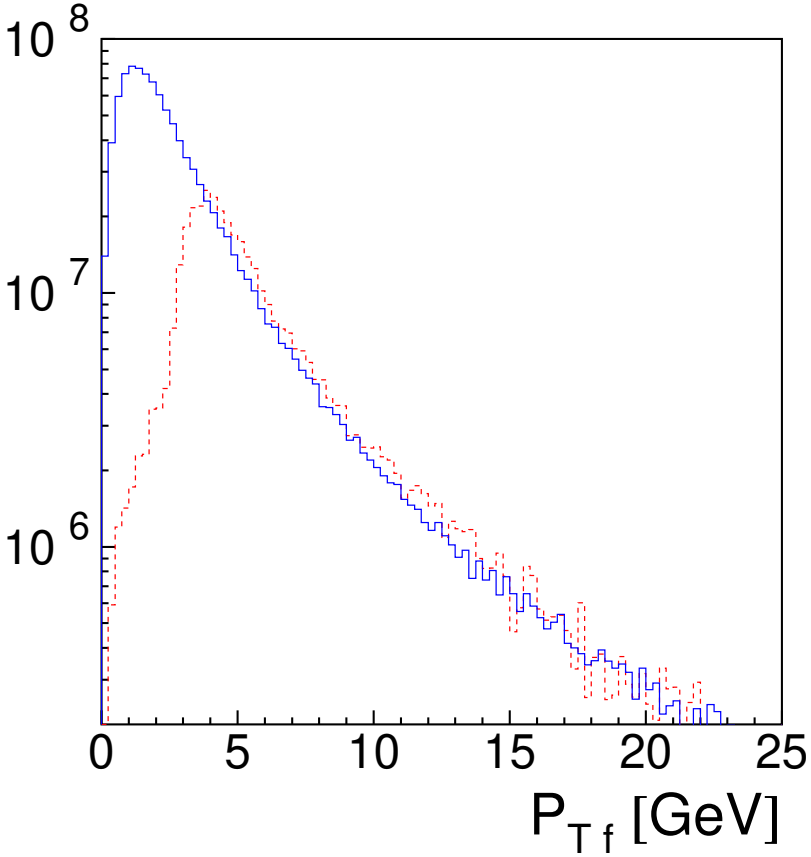

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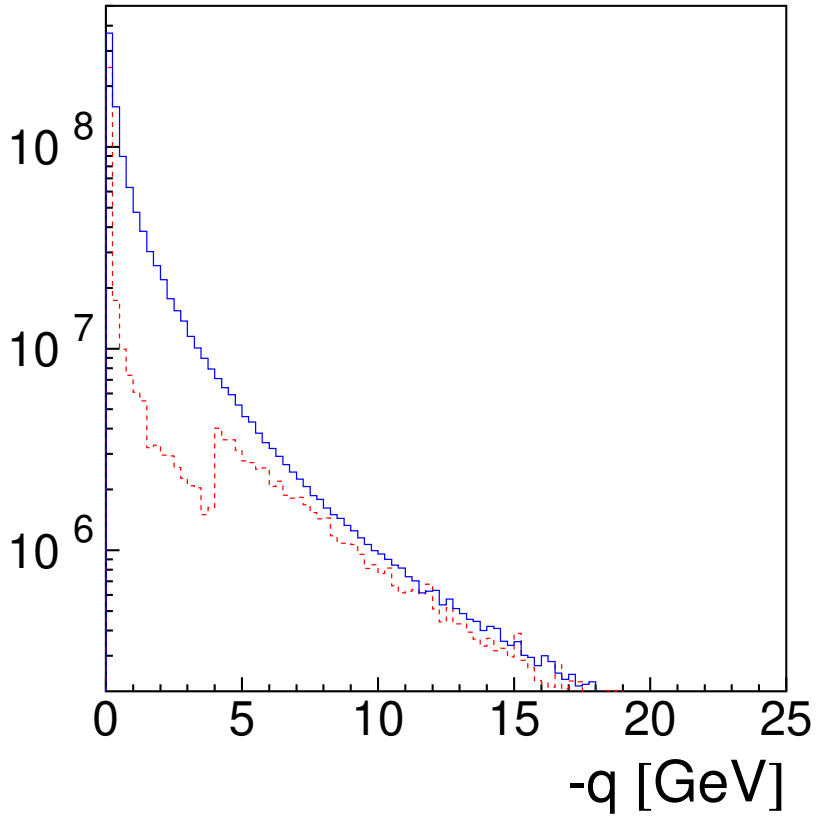

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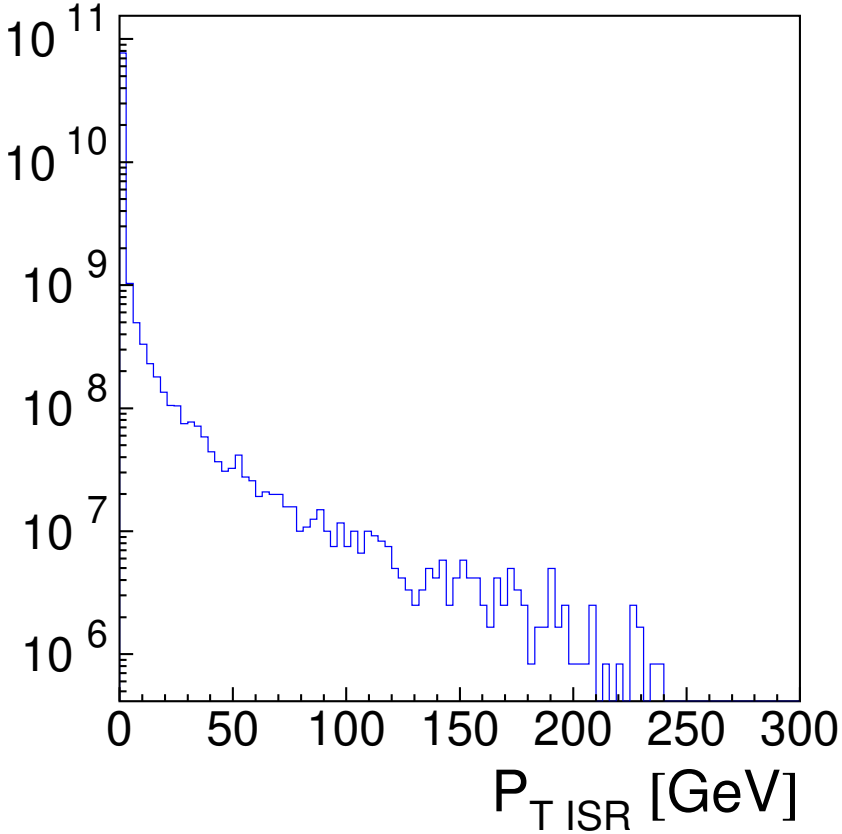

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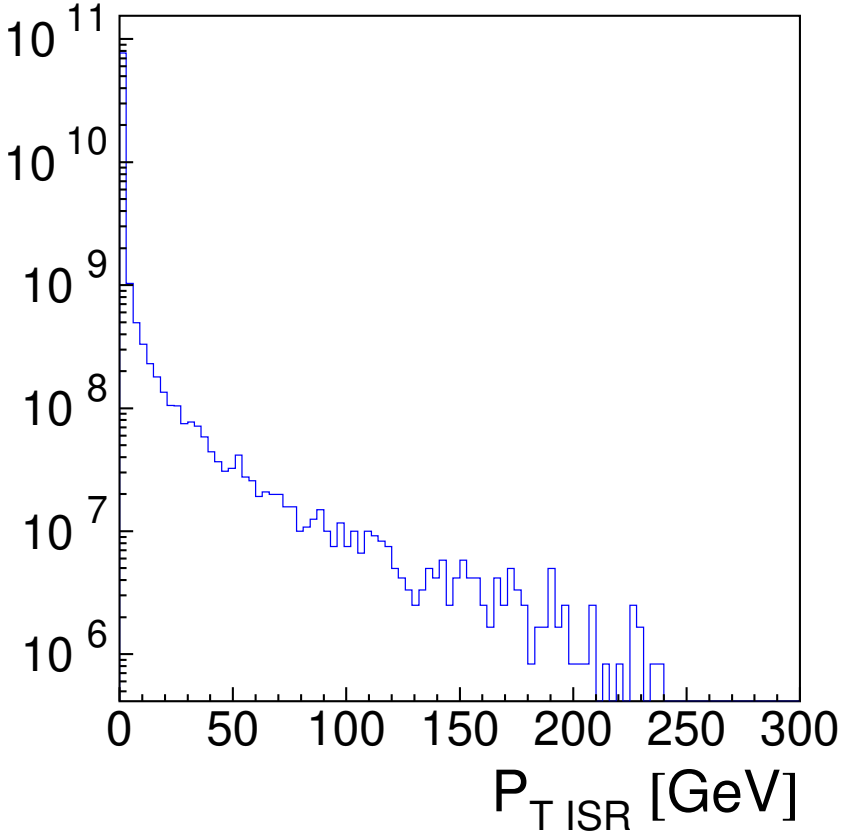

Conclusion: Missing events - jumps - no ISR - in EPA, but tails agree.

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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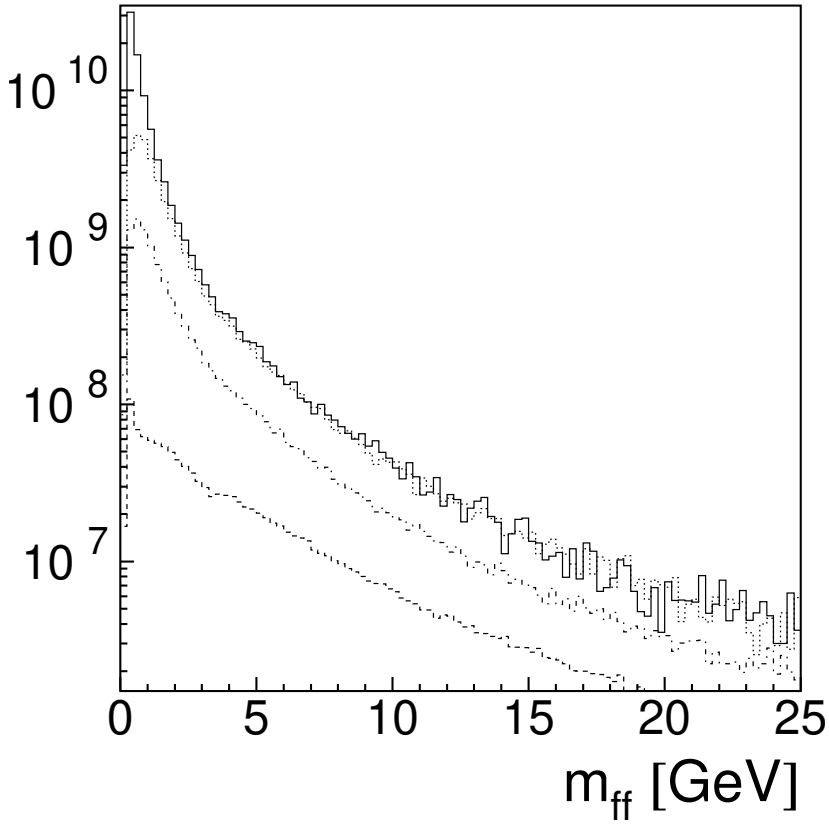

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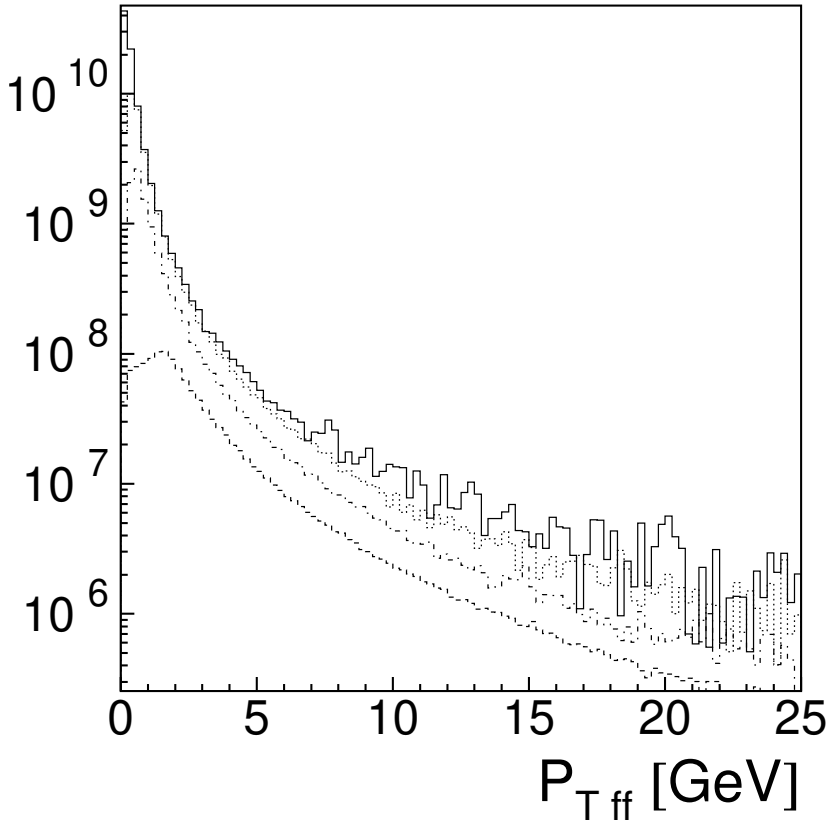

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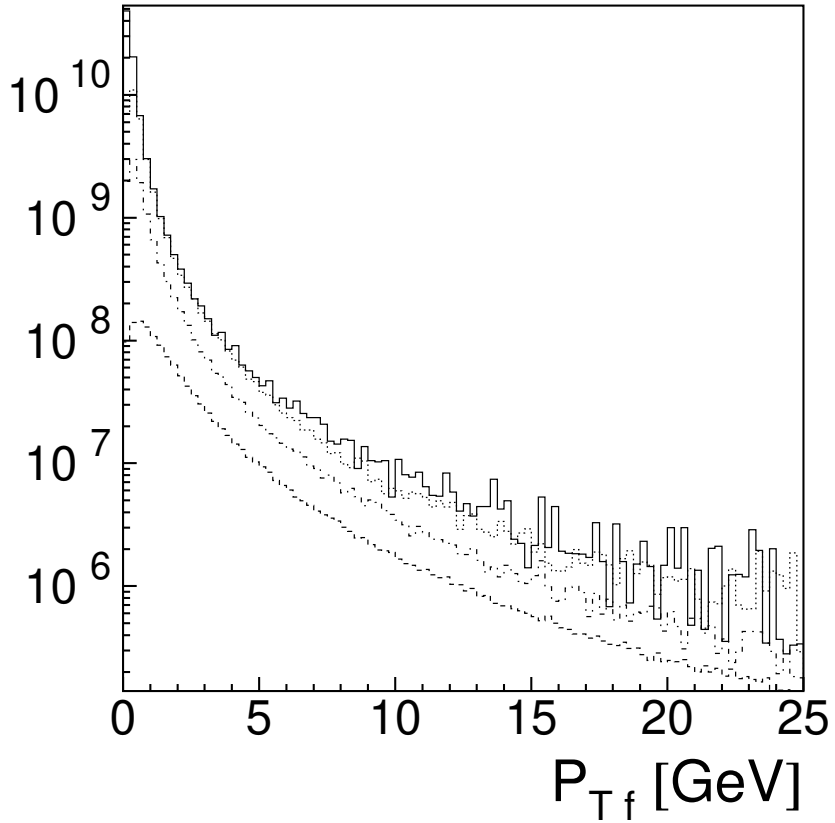

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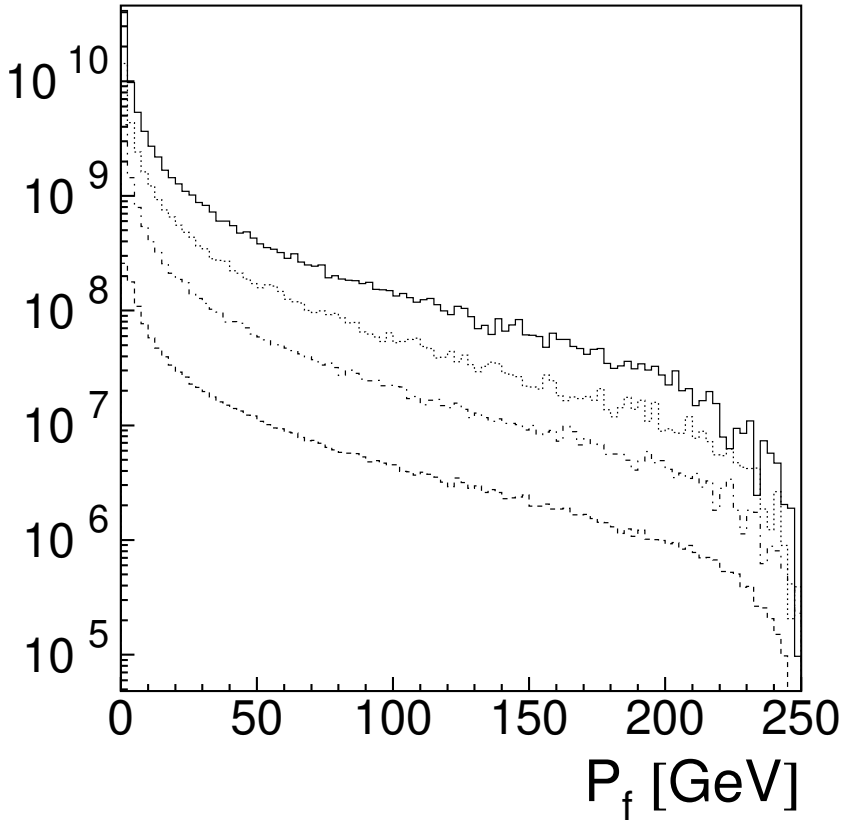

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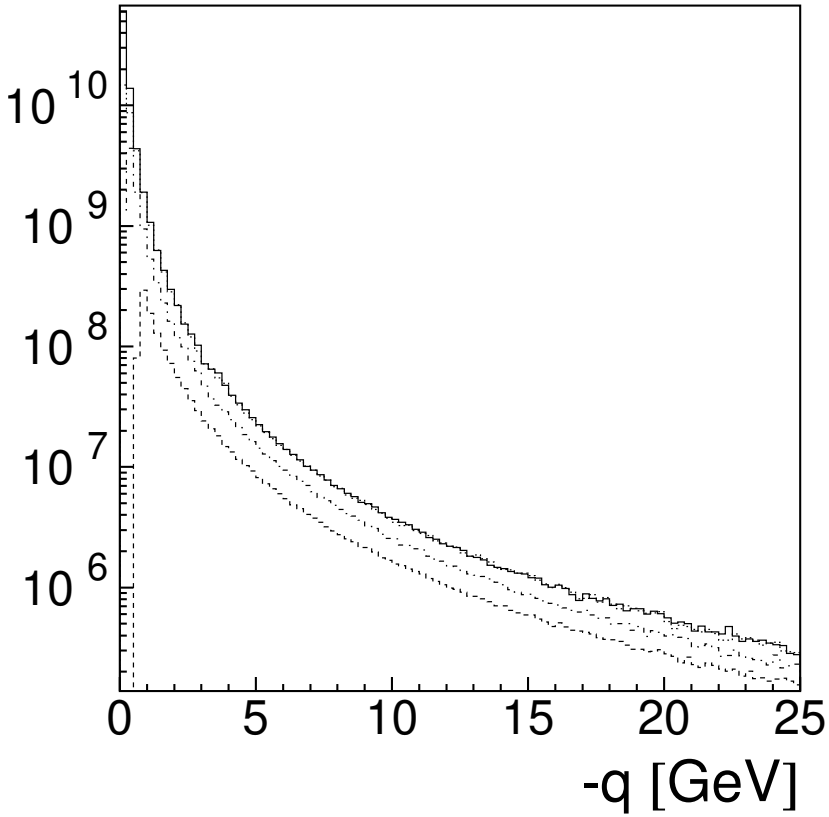

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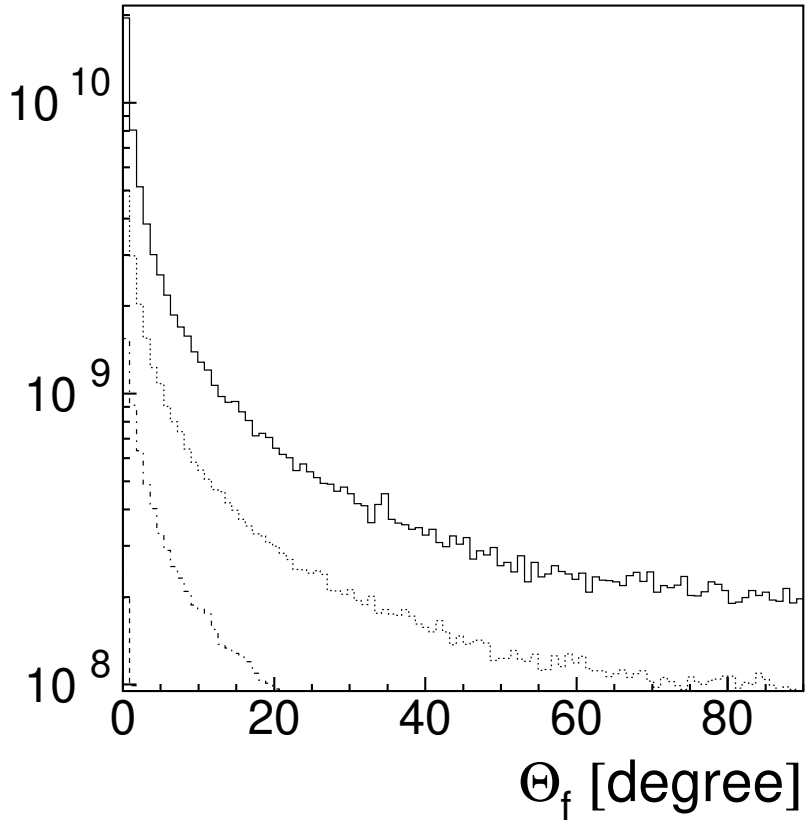

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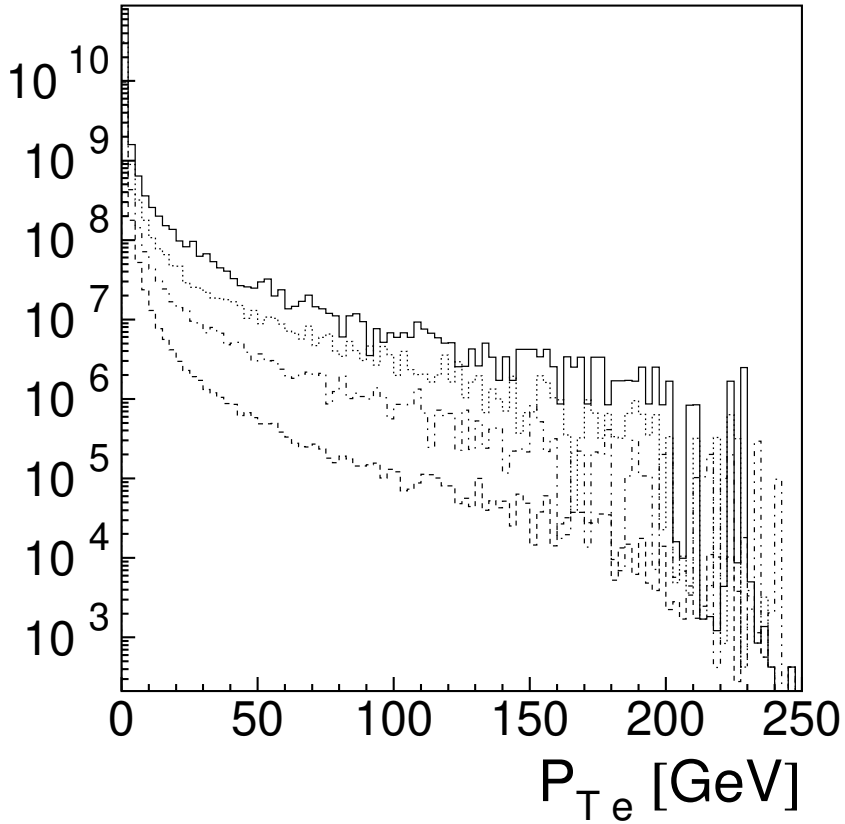

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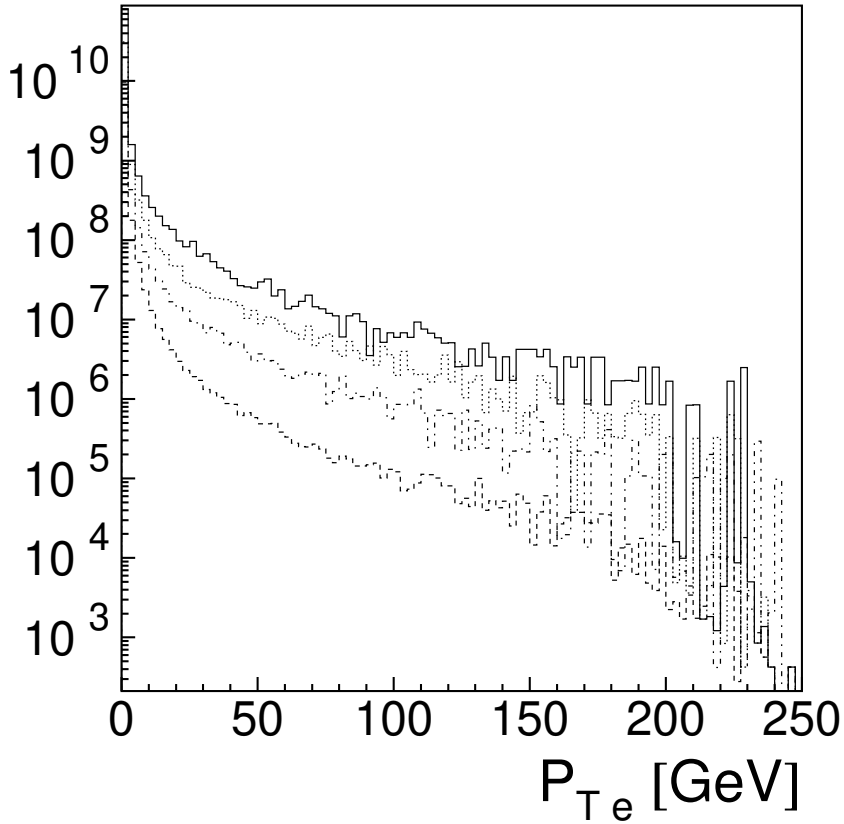

Conclusion: Shapes remain quite un-changed as the generator setup get more and more restrictive. Only the total changes.

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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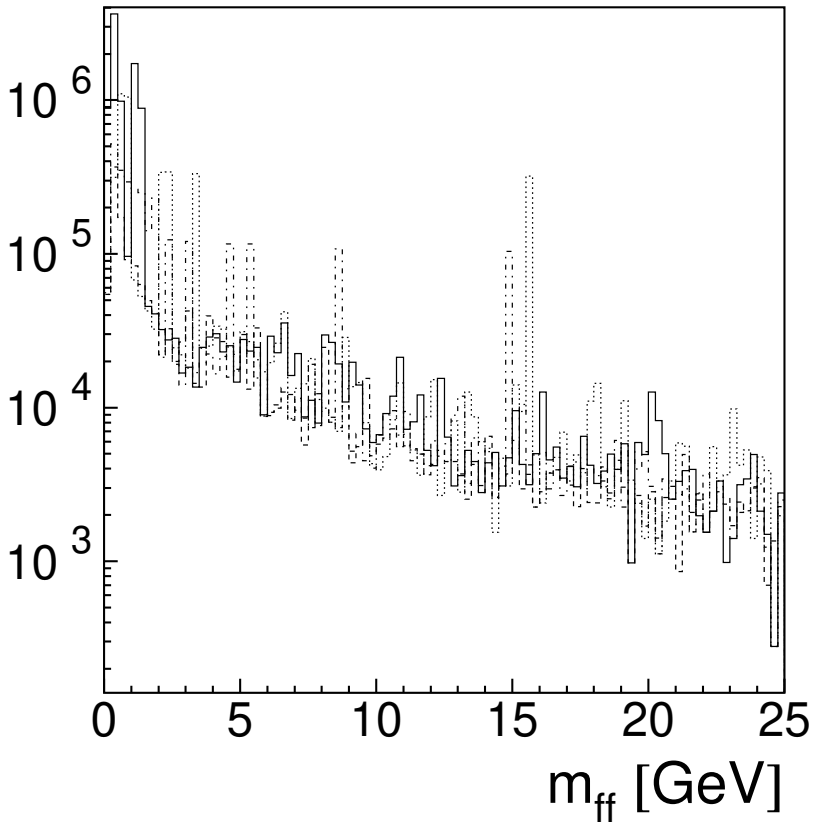

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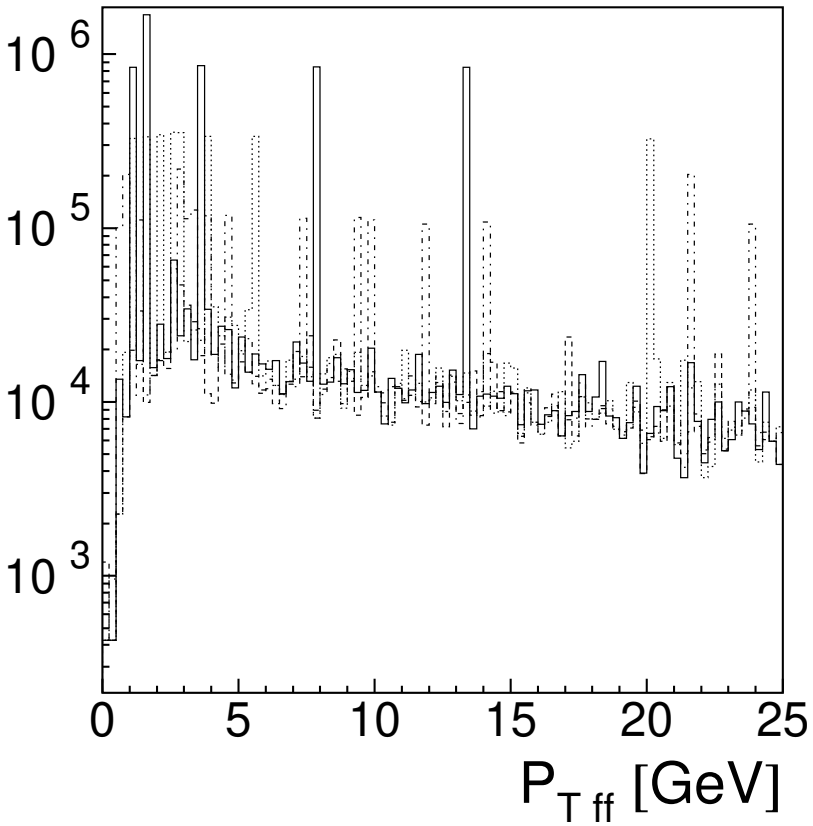

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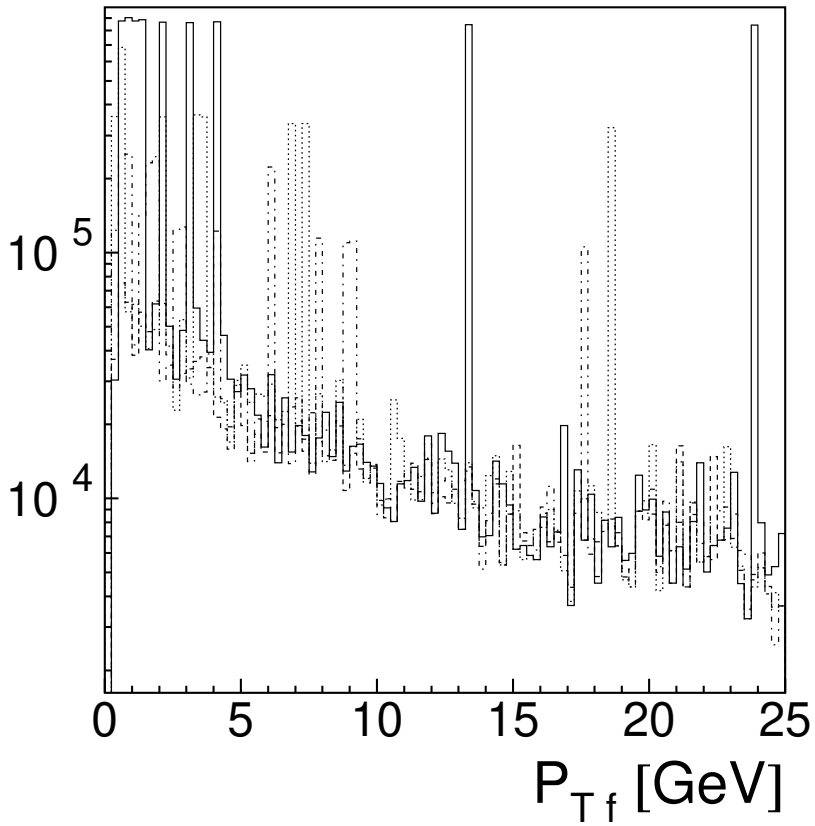

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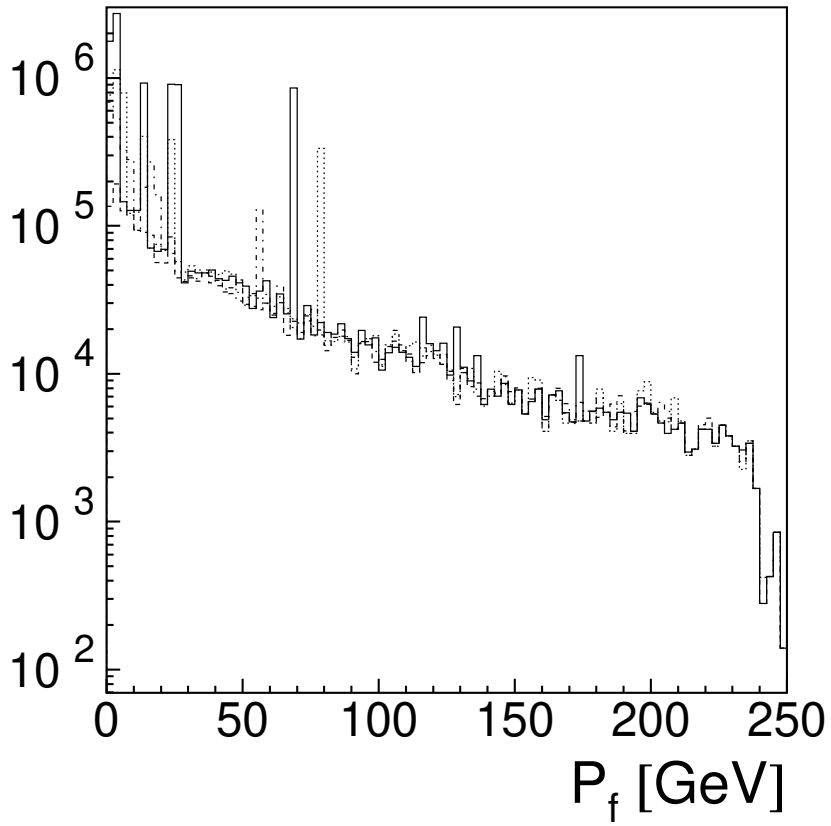
Cut case 4 (most restrictive), the lines correspond to setup 1 through 4. Warning: running out of stat (100000 events not enough...)

- Inv. Mass of the $f\bar{f}$-pair
- $p_\perp$ of the $f\bar{f}$-pair
- $p_\perp$ of the f:s
- p of the f:s
- -q
- Angle to beam of the f:s
- $p_\perp$ of the beam-remnants



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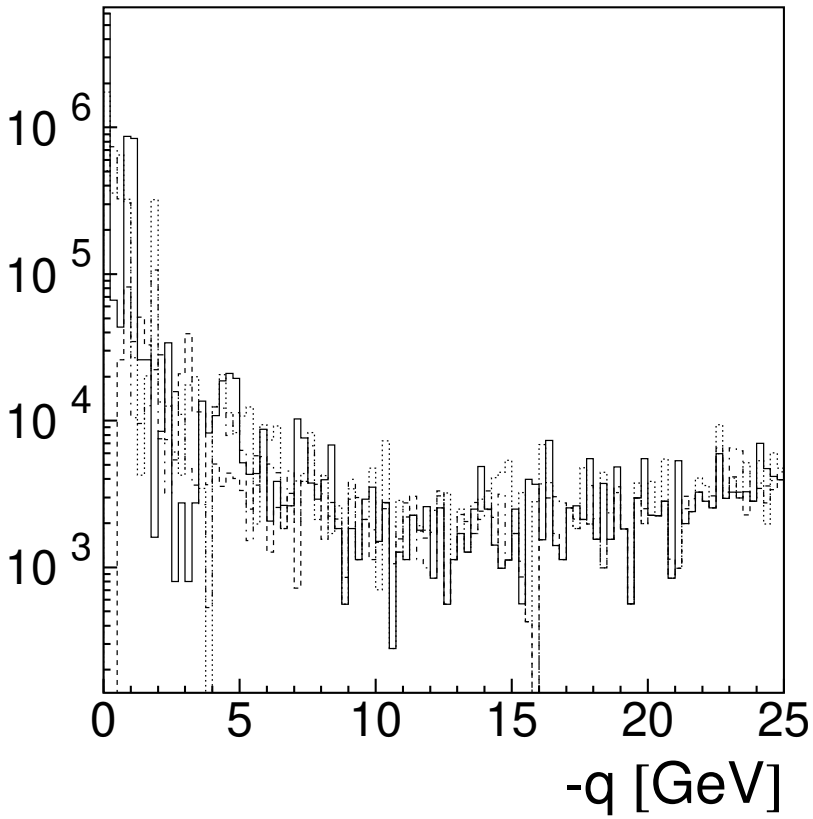

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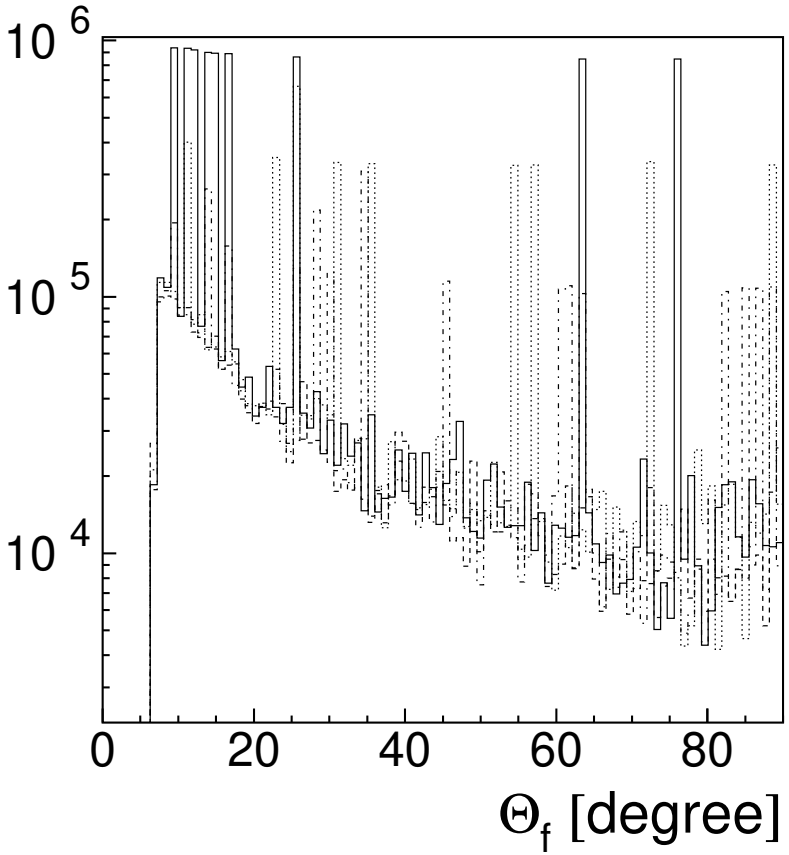

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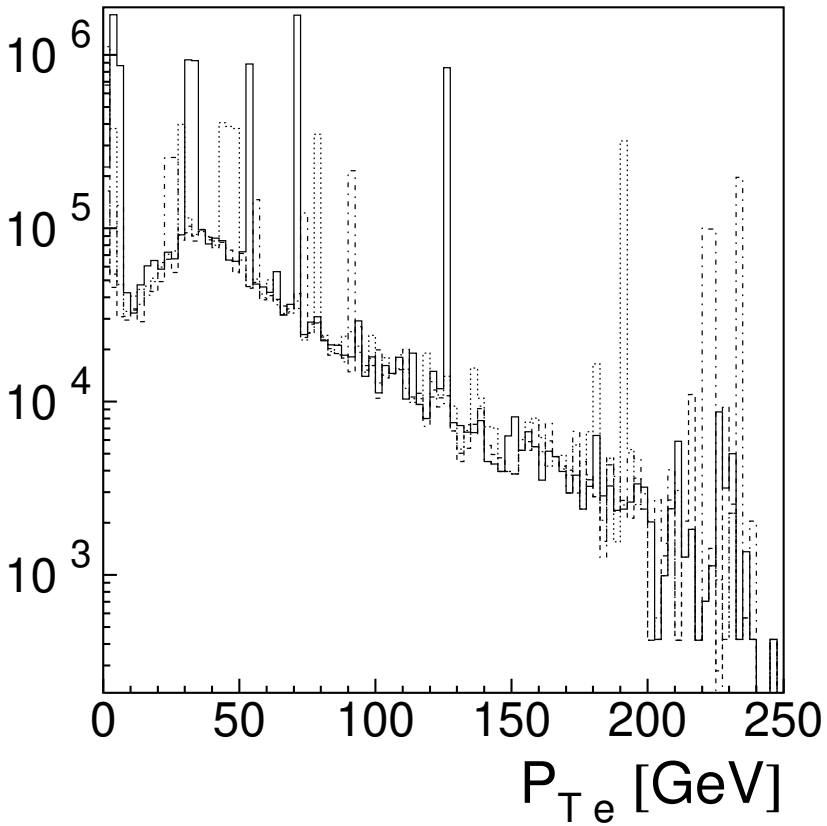

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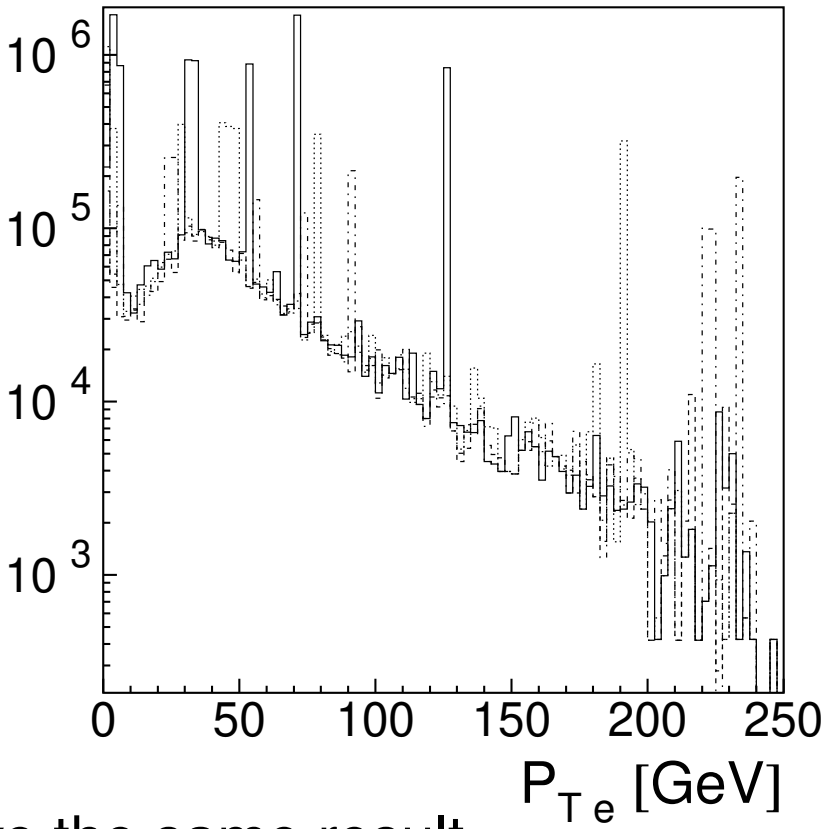

Conclusion: At this level, all setups give the same result.

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 $e^+e^- \to e^+e^-e^+e^-$ 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 $e^+e^- \to \nu_e\bar{\nu}_e f\bar{f}$ 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 !