The virtual γ saga, part II and end

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ILD SW&ANA phone meeting

The virtual γ saga: Intro

- The process $e^+e^- \to e^+e^- + f\bar{f}$ is difficult to generate: If the 4-momentum transfer between incoming and outgoing $e^{+(-)}$ (= $q \approx$ the scattering angle) becomes small, the process is dominated by scattering of virtual γ:s radiated off the $e^{+(-)}$
- It becomes very hard to evaluate the phase-space integral from the full M.E. treatment, and event-generation becomes very slow.
- At some lowest q, we switch from the M.E. treatment to the *equivalent photon approximation* (EPA), where the flux of virtual (or better "quasi-real") photons is evaluated, and the process becomes $\gamma\gamma \to f\bar{f}$, i.e. a $2 \to 2$ process.
- NB: In both cases, there is a minimum $M_{f\bar{f}}$ (4 GeV for e:s, $2\times M_\tau$ for τ:s, 10 GeV for quarks. For μ:s either 4 GeV or $2\times M_\mu$)

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HOWEVER ....

- The regions didn't match !
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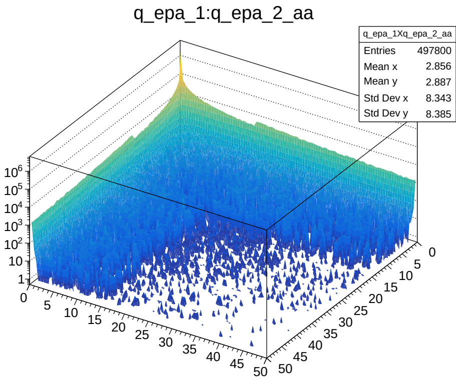

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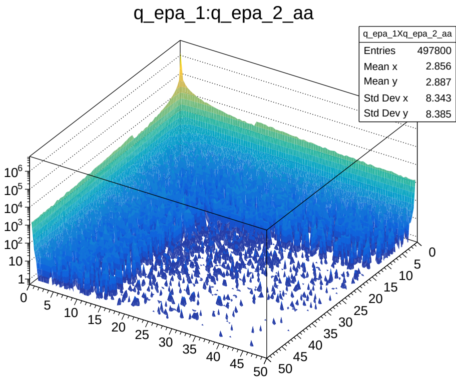

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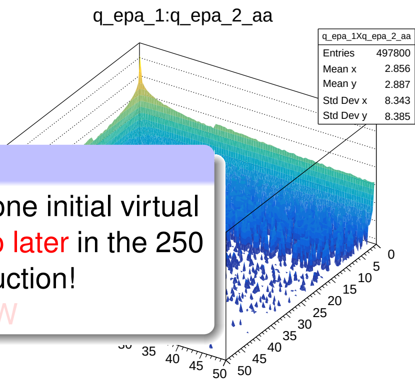

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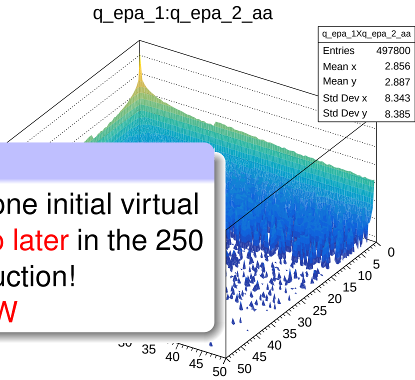

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The virtual γ saga: Problem solved!

- Wolfgang Kilian (WHIZARD author) confirmed:
  - There *was* indeed a factor $\equiv 2$ missing per virtual photon if beam-polarisation is on in WHIZARD V2.X.
  - Fixed in WHIZARD V3.X
- It is clear that the cut in Q^2 between the M.E. and the EPA generation of $e^+e^- \to e^+e^- + X$ was too high wrt the cut on m_X.
- This I've studied, and found that $\sqrt{|Q^2|} = 0.05$ is a good separation, even for a cut m_X at 4. The cut in $\sqrt{|Q^2|}$ in the existing M.E. samples is at 4, so there is a missing part for $\sqrt{|Q^2|} \in [0.05, 4]$ (NB: A year ago, I found that 0.2 would work, but further scrutiny showed that it still was to high :( )
- Tip from Filip:
  - There *is* a way to emulate an *OR* in the cuts-definition in the sindarin ($a \vee b \Leftrightarrow \neg(\neg a \wedge \neg b)$ ...) $\Rightarrow$ The "L-shaped" missing phase-space in the M.E. part of $e^+e^- \to e^+e^- + X$ can be generated in a single step.

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Final cuts

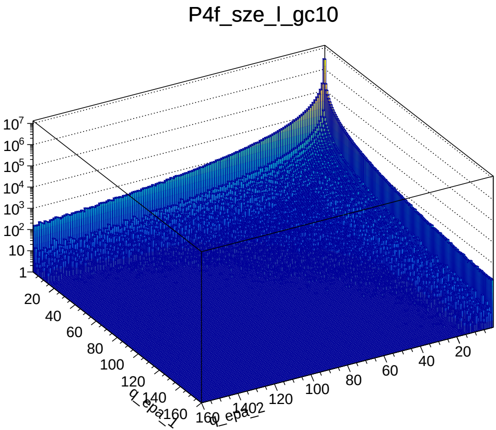
- For both $\sqrt{|Q^2|} > 2$, M.E. : No cuts, except default $m_{f\bar{f}}$. No cut on $m_{\mu^+\mu^-}$
- For both $\sqrt{|Q^2|} > 0.05$ and at least one $\sqrt{|Q^2|} < 2$, M.E.: As above, except $m_{\mu^+\mu^-} > 4$
- For one $\sqrt{|Q^2|} > 0.05$ and one $\sqrt{|Q^2|} > 0.05$, γ^*e : As above, and $\Delta(\eta_{f\bar{f}}) < 6.2626$.
    - The pseudo-rapidity distance cut corresponds to $\theta > 7^\circ$ if the $f\bar{f}$-system would be at rest in the lab. Guarantees that at least one of them is in the tracker after boosting the *ff*-system to the lab.
- For both $\sqrt{|Q^2|} > 0.05$, $\gamma^*\gamma^*$: As above.

Additional cuts for the plots

- "Leptonic" means μ:s or τ:s, not electrons: In $\mathrm{e^+e^-} \to e^+e^-e^+e^-$, between which electrons or positrons should the Q^2 be calculated ?
- For the same reason, there is no $\Delta(\eta_{f\bar{f}})$ in the M.E. cases: which e^+e^- pair is the "$f\bar{f}$"-pair in $\mathrm{e^+e^-} \to e^+e^-e^+e^-$?
- So, we demand that one (or two) of the final fermions are above 7° to the beam to be able to compare the M.E. regions with γ^* ones.
- Sometimes $-Q^2$ comes out negative in the γ^* cases (never in the M.E. ones) - probably because m_e was neglected in my math :(. Therefore it was demanded that $-Q^2 > 0$, and the γ^* samples were weighted up by the corresponding loss of events.

Q^2 vs. Q^2

- Full range ($\gamma\gamma$, $e^+/e^-\gamma$ and M.E. high and low Q^2)
- Transition M.E. high and low Q^2 (=16)
- Transition M.E. to EPA ($= 2.5 \cdot 10^{-3}$)



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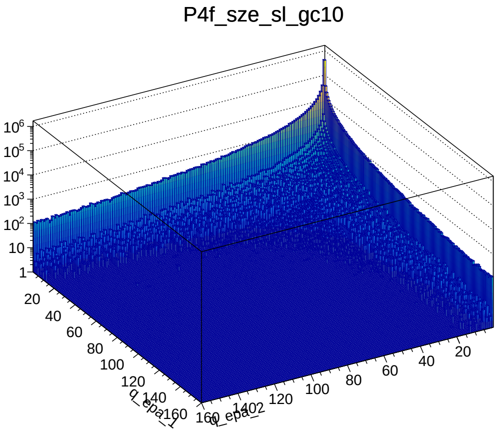

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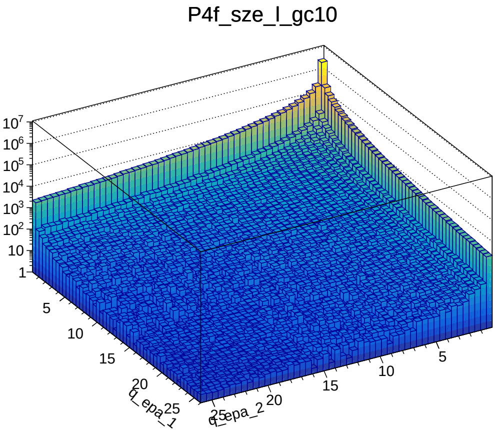

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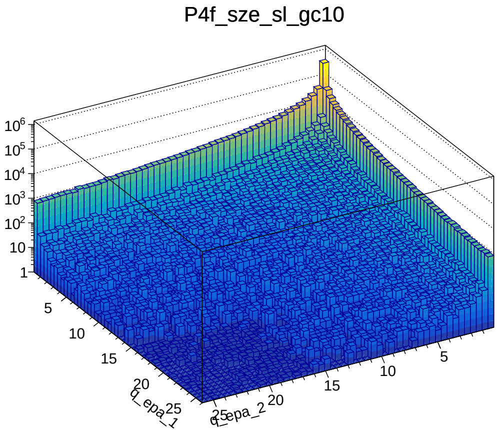

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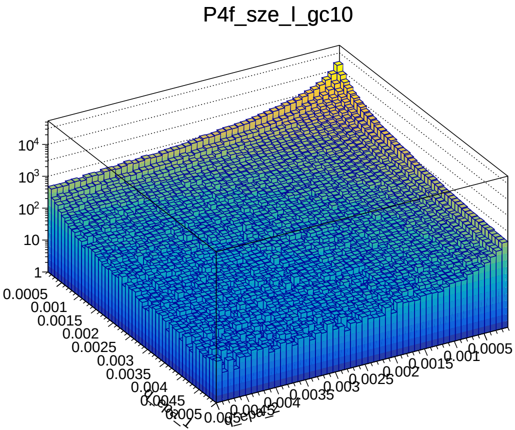

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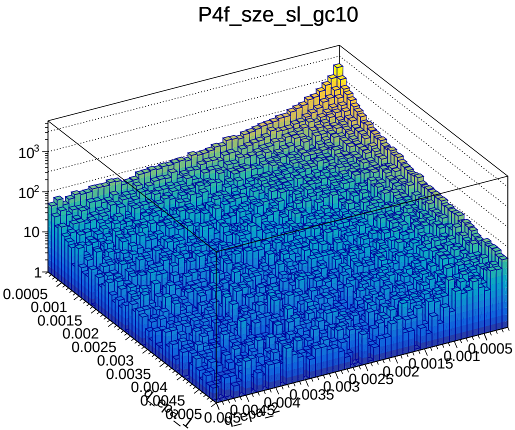

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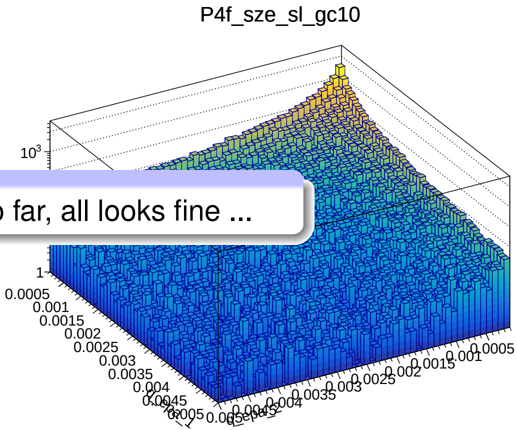
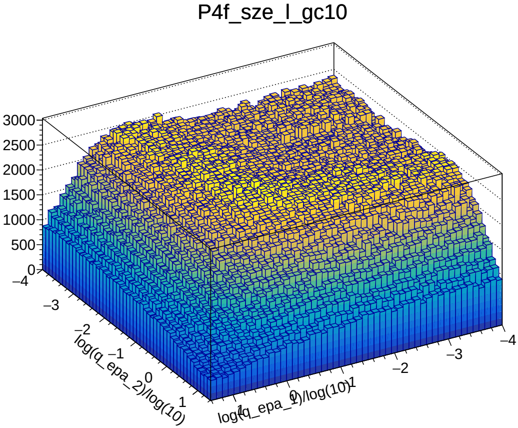


So far, all looks fine ...

$\lg|Q^2|$ vs. $\lg|Q^2|$

Blow up the lower transition region, by plotting against the logarithm of $|Q^2|$ ($\lg(0.05^2) = -2.60$)

- Leptonic...
- Demand that both fermions are above 7°.
- Hadronic...
- Demand that both fermions are above 7°.



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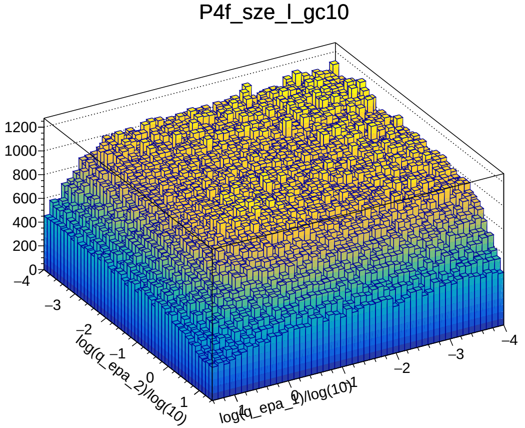

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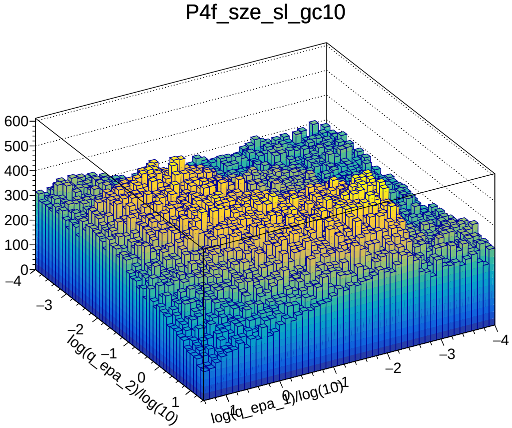

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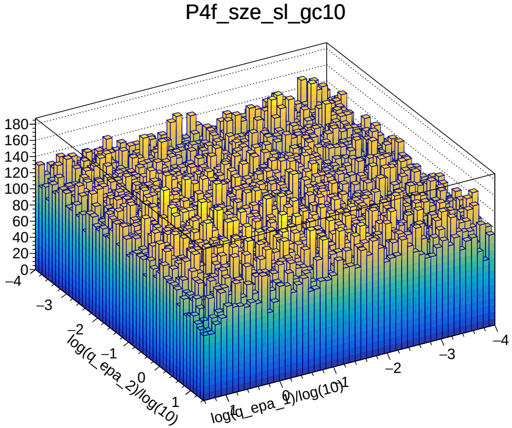

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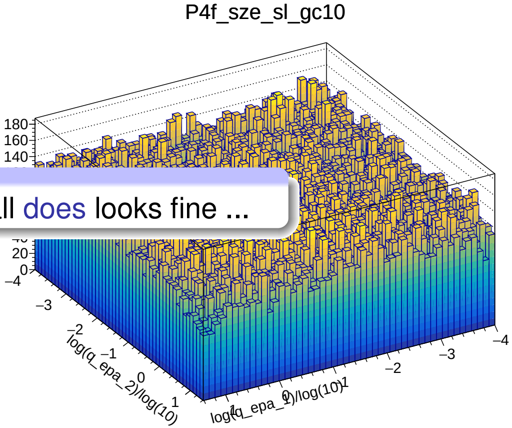
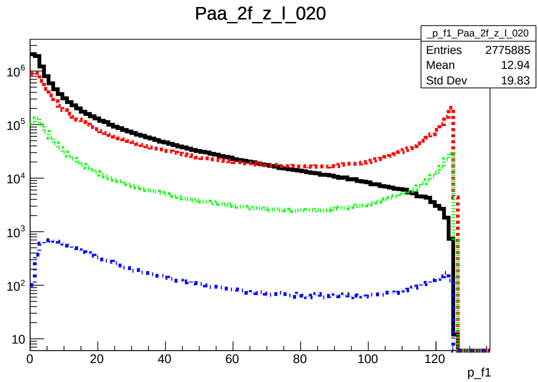


So all does looks fine ...

Properties of new events (for $\int \mathcal{L} = 5\ \mathrm{fb}^{-1}$)

In all plots: black = aa, red = ae, green = M.E., low Q^2, and blue = M.E., high Q^2.

- Muon p
- Muon p_T
- Di-muon mass
- Di-muon mass, both μ:s in tracking.
- Recoil-mass
- Recoil-mass, $m_{\mu\mu}$ close to $m_Z \Rightarrow$ Higgs to invisible, anyone ?



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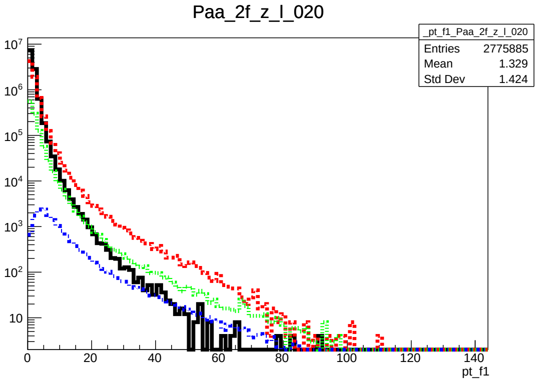

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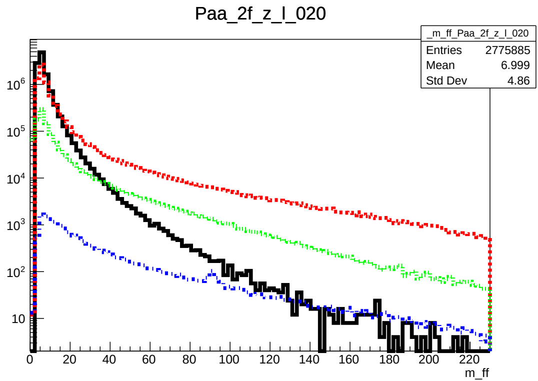

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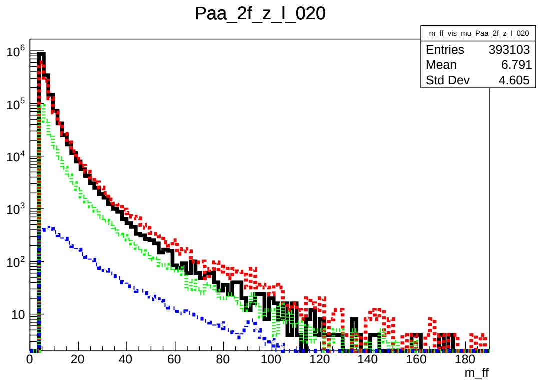

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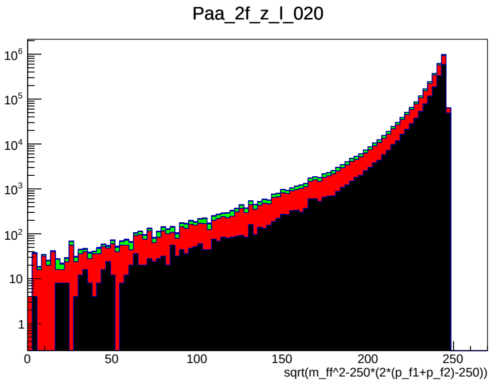

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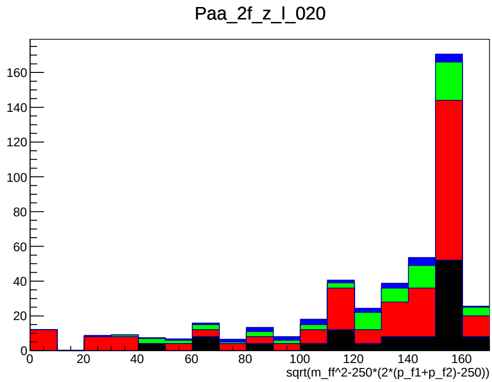


Cross-sections of new samples

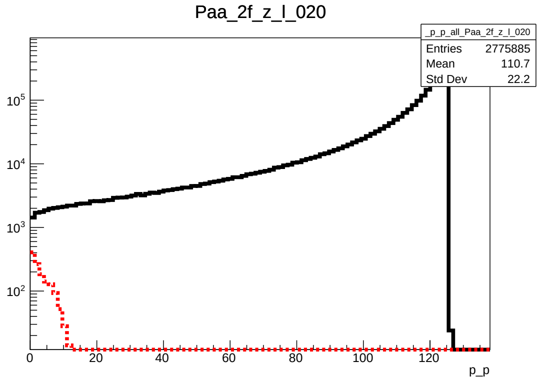
sample	leptonic pb	hadronic pb	# Mevents generated ($\sim$ 1 ILC year)
aa_2f	9234	414	1259
ae_3f	1426	136	142
ea_3f	1427	137	142
4f_szeloq (LL and RR)	1117	172	54
4f_szeloq (LR and RL)	1123	175	276
Total			1873

The generated events are on the grid.
Note that the standard assumptions is *a lot*. The 5/1/1/5 ab^{-1} for the "normal" samples is $\sim$ 10 times the full H20 statistics, and the reduced 1/0.2/0.2/1 is still more than the 11 years of H20 running, except for aa_2f, where it is about 1/2 of H20 .

Small events ....

For aa_2f:

- Just 0.04 % of the events will have a beam-remnant seen in the BeamCal, and then it only deposits a few GeV.
- The energy of the $f\bar{f}$ system, for events where both f:s are above 7 deg.
- So, typically there is only a few GeV that hits *anything* in these events.



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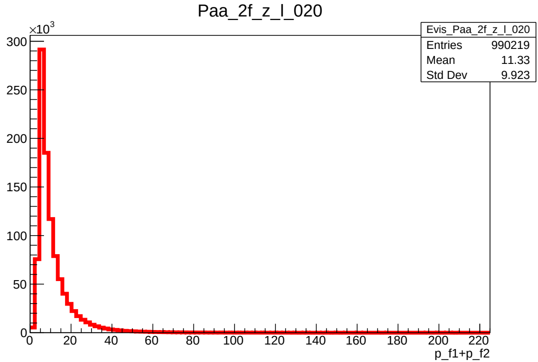

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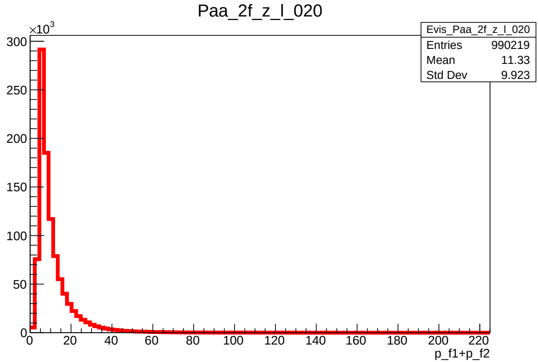

Small events ....

- So, the average seen energy for the aa_2f class is only 11 GeV = 4 % of 250 GeV.
- Also the ae/ea_3f events are smaller than “typical” events: One beam-remnant is down the beam-pipe, but also the other, high Q^2, one is in 25 % of the events.
- The average seen energy is $\sim$ 94 GeV in this case = 37 % of 250 GeV.
- Both aa_2f and ae/ea_3f are mainly leptonic: 94 % and 91 %, respectively.
- All this indicates that simulation ($\propto E_{vis}$), and reconstruction ($\propto E_{vis}$ and multiplicity) should be much faster than for the “typical” events.
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Simulation and Reconstruction estimates (fresh off the press from Ryo Yonamine)

250 GeV samples

group	nbjobs	total_nb_inputs	totev_submit		CPUday sim+rec	SIM (TB)	REC (TB)	DST (TB)
aa_2f_leptonic_eW_pW	133,800	446	267,600,000		9,450	40.8	180.9	6.17
aa_2f_leptonic_eW_pB	123,433	529	370,300,000		10,383	40.4	177.2	8.45
aa_2f_leptonic_eB_pW	123,400	617	370,200,000		10,839	44.6	160.9	7.41
aa_2f_hadronic_eW_pW	71,600	358	71,600,000		6,042	38	83.7	2.9
aa_2f_hadronic_eW_pB	60,133	451	90,200,000		6,613	43.9	82.4	3.39
aa_2f_hadronic_eB_pW	60,267	452	90,400,000		6,672	40.6	87.4	3.47
aa_4f	229	40	929000		14	0.03	0.08	0
5f	946	52	620000		87	0.8	1.09	0.03
3f	617008	1504	712440000		71949	460.3	752.78	18.76
Total	**1,190,816**	**4,449**	**1,974,289,000**		**122,049**	**709**	**1,526**	**51**

-> ~ 40days for 3000 CPUs

Conclusion and Gotchas

- The problem with virtual γ:s is solved, and events are generated, and available on the grid.
- With a production corresponding to $\sim$ 1 ILC year, all can be processed on the grid in 2-3 months (< 1 year ....)
- Note that there are a lot of channels to consider to completely cover $eetoe^+e^-f\bar{f}$: 38 in total!
- In addition there are lots of small cross-section channels $eetoe^+e^-f\bar{f}f'\bar{f}'$ also to be considered.

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- Different channels have different kinematic cuts. Pay attention to the $m_{f\bar{f}}$ cuts in particular!
- Note that there is no ISR emitted before the virtual photon is, so depending on the channel, there might be 0,1, or 2 ISRs present.
- The γ^* samples are not very sophisticated. Good enough for background studies, but not for dedicated studies of $\gamma\gamma$ physics ! Use dedicated generators for that.
- This also goes for $\mathrm{e^+e^-} \rightarrow e^+e^-e^+e^-$ where interference effects will be lost in the factorising approach of the EPA.
- Further consolidation is needed for the $\mathrm{e^+e^-} \rightarrow e^+e^-f\bar{f}f'\bar{f}'$, in particular if the kinematic cuts do match those of M.E. 6-fermions with electrons.

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