Higgs off-shell decay at ILC & new jet-clustering studies

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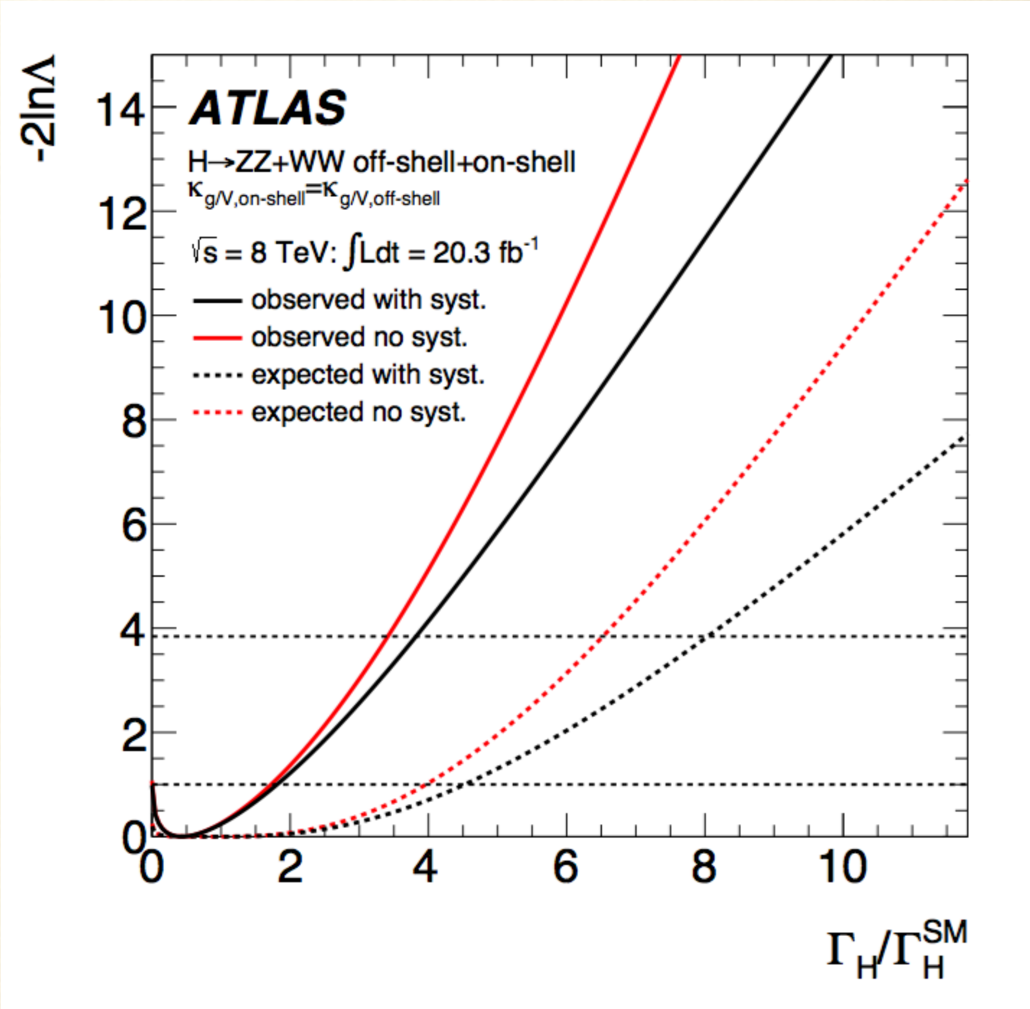
Higgs off-shell decay @ LHC: H*—>VV

$$\mu_{\text{off-shell}}(\hat{s}) \equiv \frac{\sigma^{gg\to H^*\to VV}_{\text{off-shell}}(\hat{s})}{\sigma^{gg\to H^*\to VV}_{\text{off-shell, SM}}(\hat{s})} = \kappa^2_{g,\text{off-shell}}(\hat{s}) \cdot \kappa^2_{V,\text{off-shell}}(\hat{s})$$

$$\mu_{\text{on-shell}} \equiv \frac{\sigma^{gg\to H\to VV}_{\text{on-shell}}}{\sigma^{gg\to H\to VV}_{\text{on-shell, SM}}} = \frac{\kappa^2_{g,\text{on-shell}} \cdot \kappa^2_{V,\text{on-shell}}}{\Gamma_H/\Gamma_H^{SM}}$$

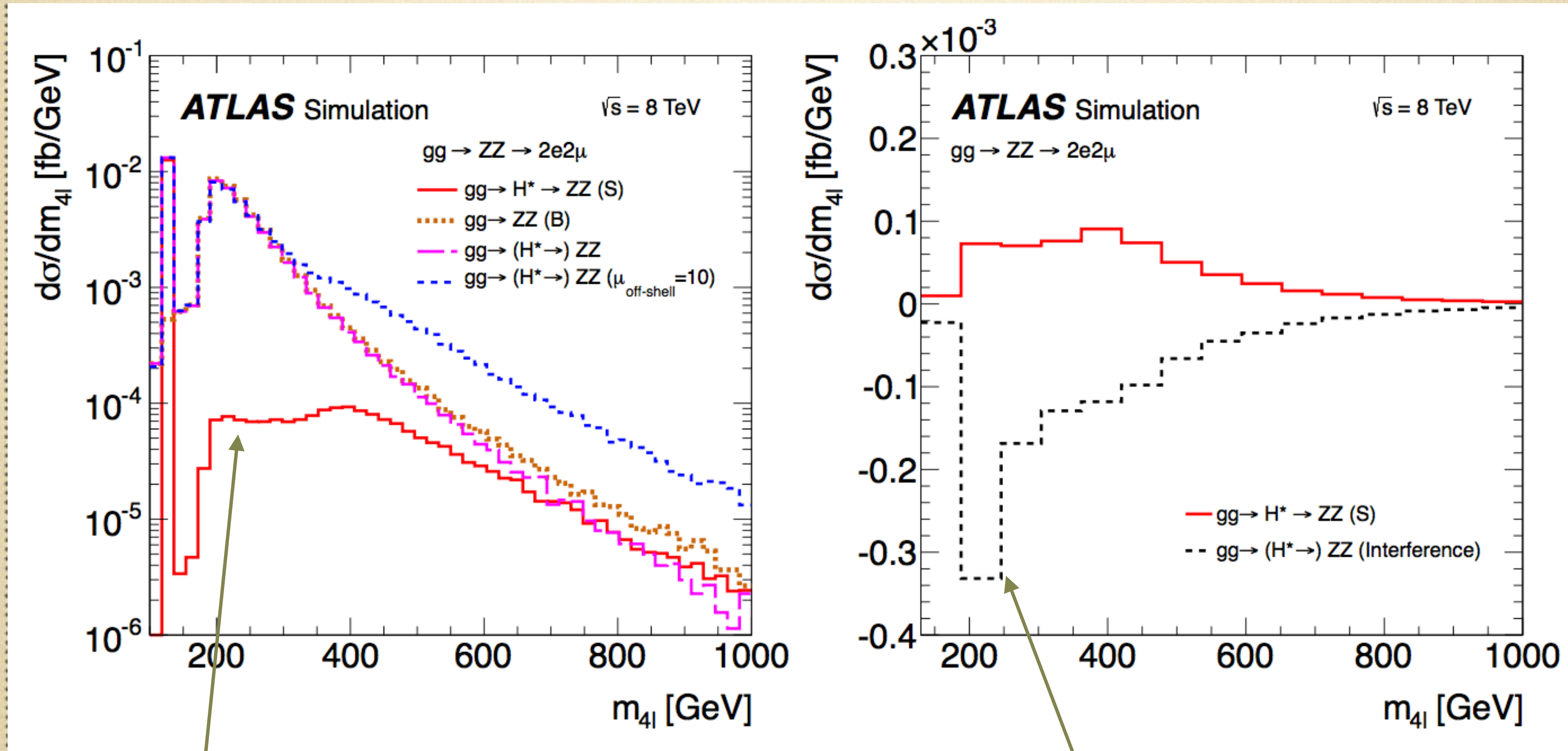
=



ATLAS, arxiv:1503.01060

but: κ is q^2 dependent —> model dependence

Higgs off-shell decay @ LHC: H*—>ZZ—>4l



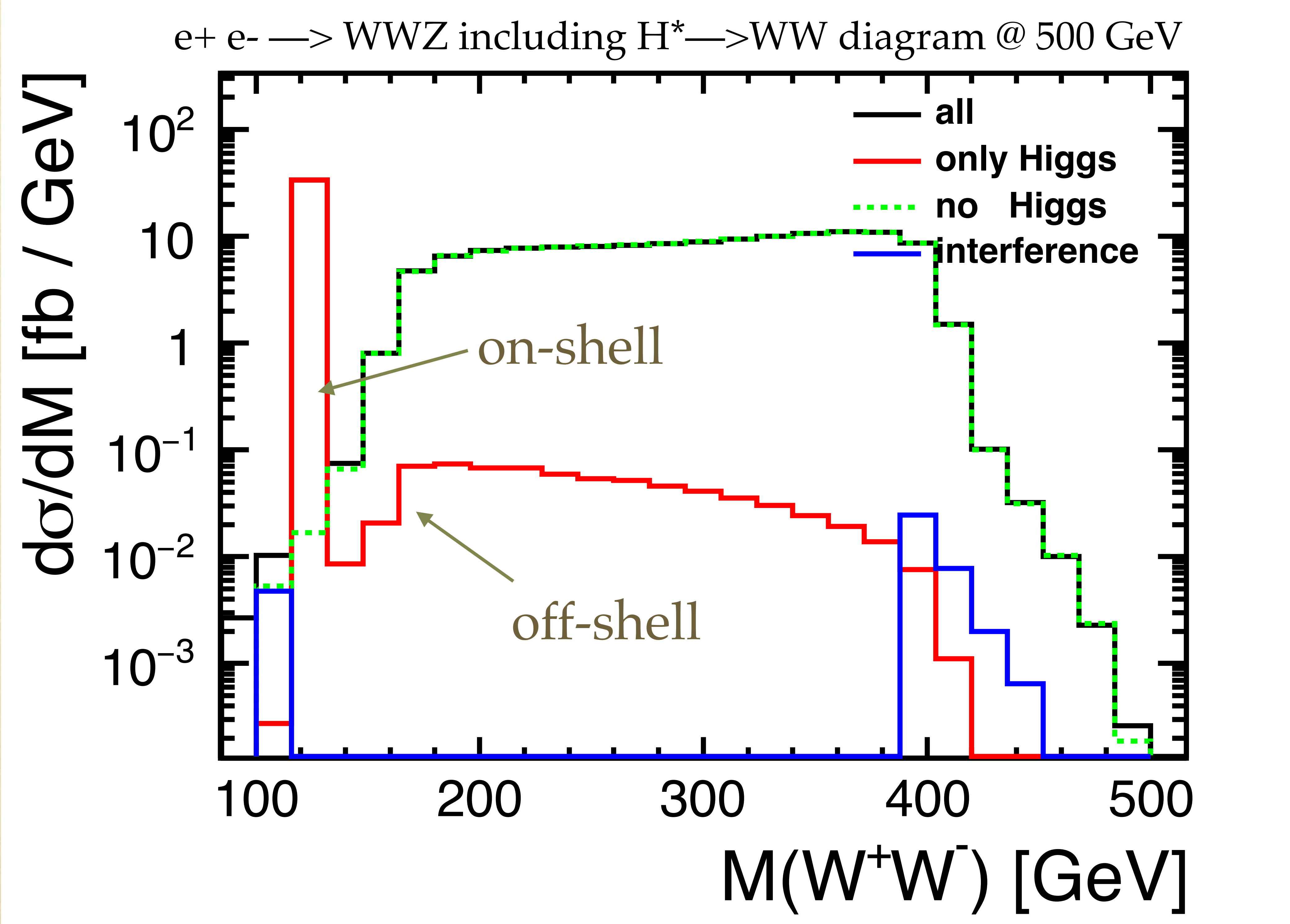
Higgs off-shell contribution

destructive interference, as well known in VV scattering to save unitarity

what would Higgs off-shell decay look like at ILC? Any impact/usage to other measurement?

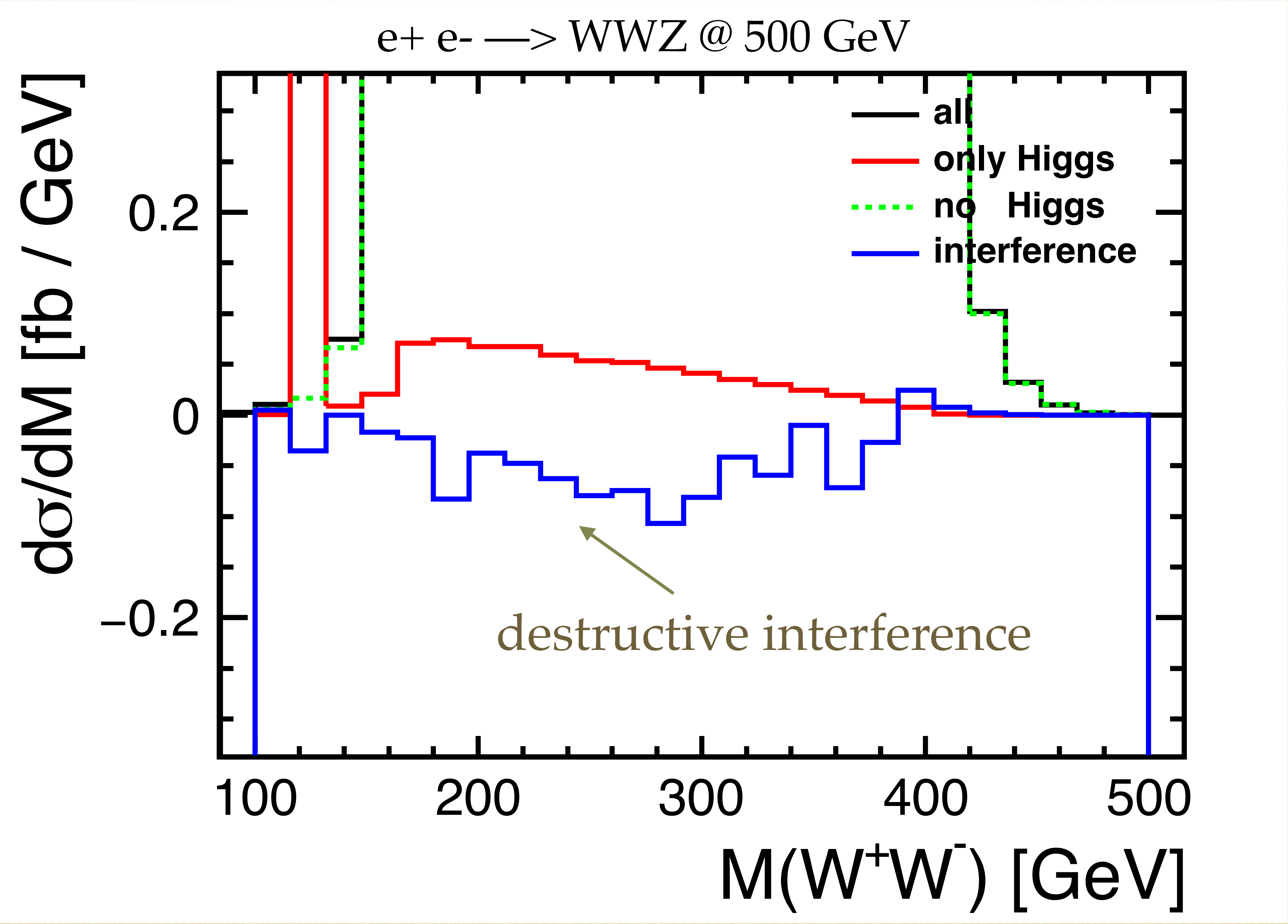
Higgs off-shell decay @ ILC: ZH*—>ZWW

generator by physsim (thanks to Fujii-san for solving some potential bugs)



off-shell contribution / on-shell ~ 3%

Higgs off-shell decay @ ILC: ZH*—>ZWW



Higgs off-shell decay @ ILC

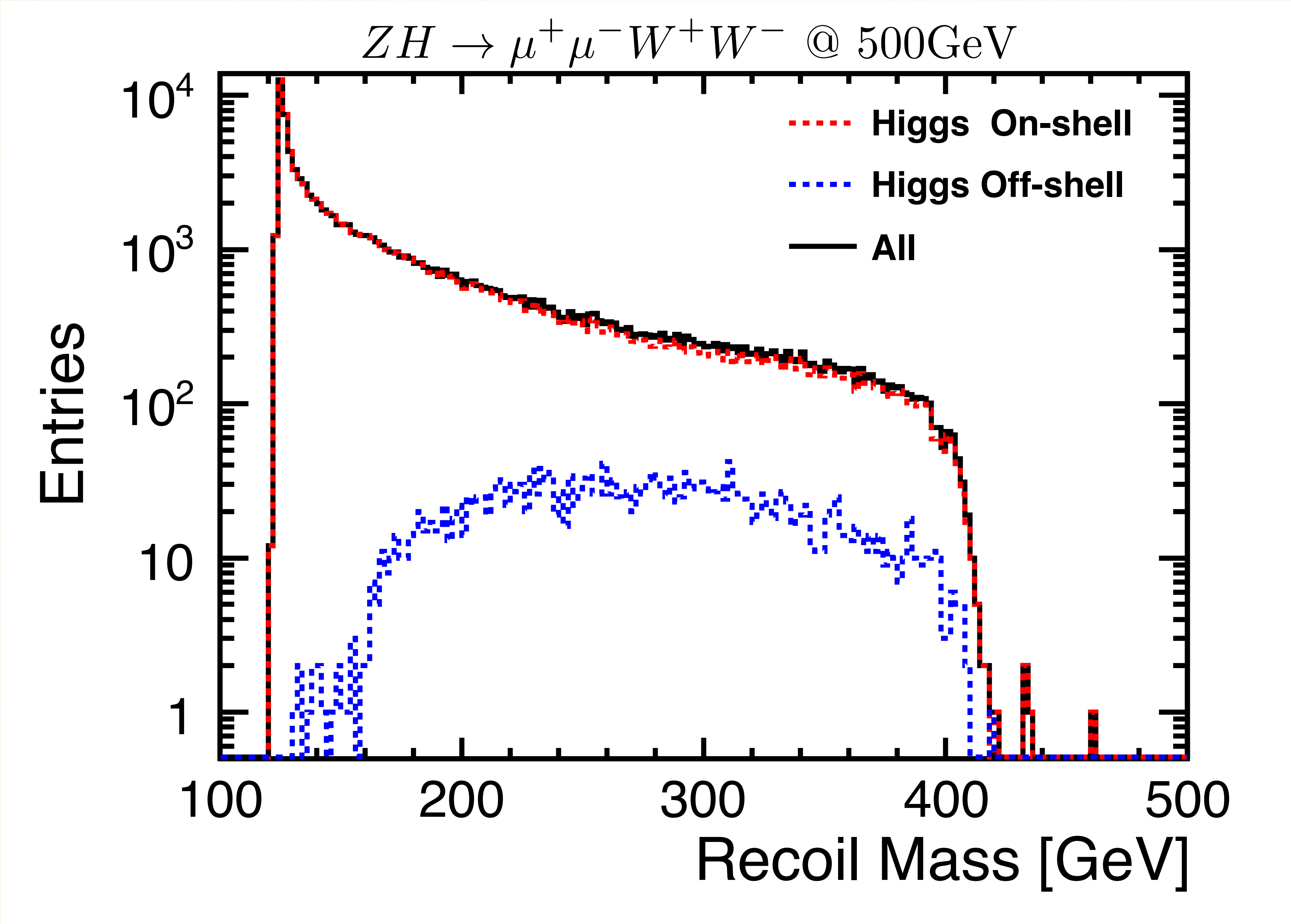
- contribution of Higgs off-shell decay seems rather small in ZH* process
- from the VV—>VV scattering study, Higgs diagram contribution is only large at high q^2 —> take a look at ννH (WW-fusion) process
- another question, would H*—>tt be accessible? If so, it might be another place to look at the top-Yukawa coupling?

x-section / fb	250 GeV	500 GeV	1000 GeV
ZH*—>ZWW	-	0.73	0.78
ννH*—>ννWW	0.0046	0.59	6.2
ννH*—>ννtt	-	0.0017	0.60

P(e-,e+) = (-1,+1); by whizard; assuming SM couplings.

to be done: need also give interference contribution in each process

what's the impact to recoil mass measurement?



in recoil mass, off-shell contribution is completely buried by the tail from beam-strahlung and ISR; but, what if non-SM coupling?

summary of Higgs off-shell decay @ ILC

- for SM coupling, Higgs off-shell decay only becomes important in WW-fusion channel at 1 TeV
- it's not surprising —> exactly part of the important study of VV —>VV scattering at 1 TeV
- would be interesting to take a look at possibility of measuring top-Yukawa coupling using H*—>tt at 1 TeV
- impact on recoil mass depends on model, possible strategy:
  - what to measure is separate σ_{ZH} (on-shell) and σ_{ZH^*} (off-shell)
  - to measure σ_{ZH} (on-shell), we need understand BG perfectly, which means we need measure/constrain H*—>WW anyhow because ZH* here is actually one of the background
  - use direct measurement H*—>WW, e.g. in $\nu\nu$H process

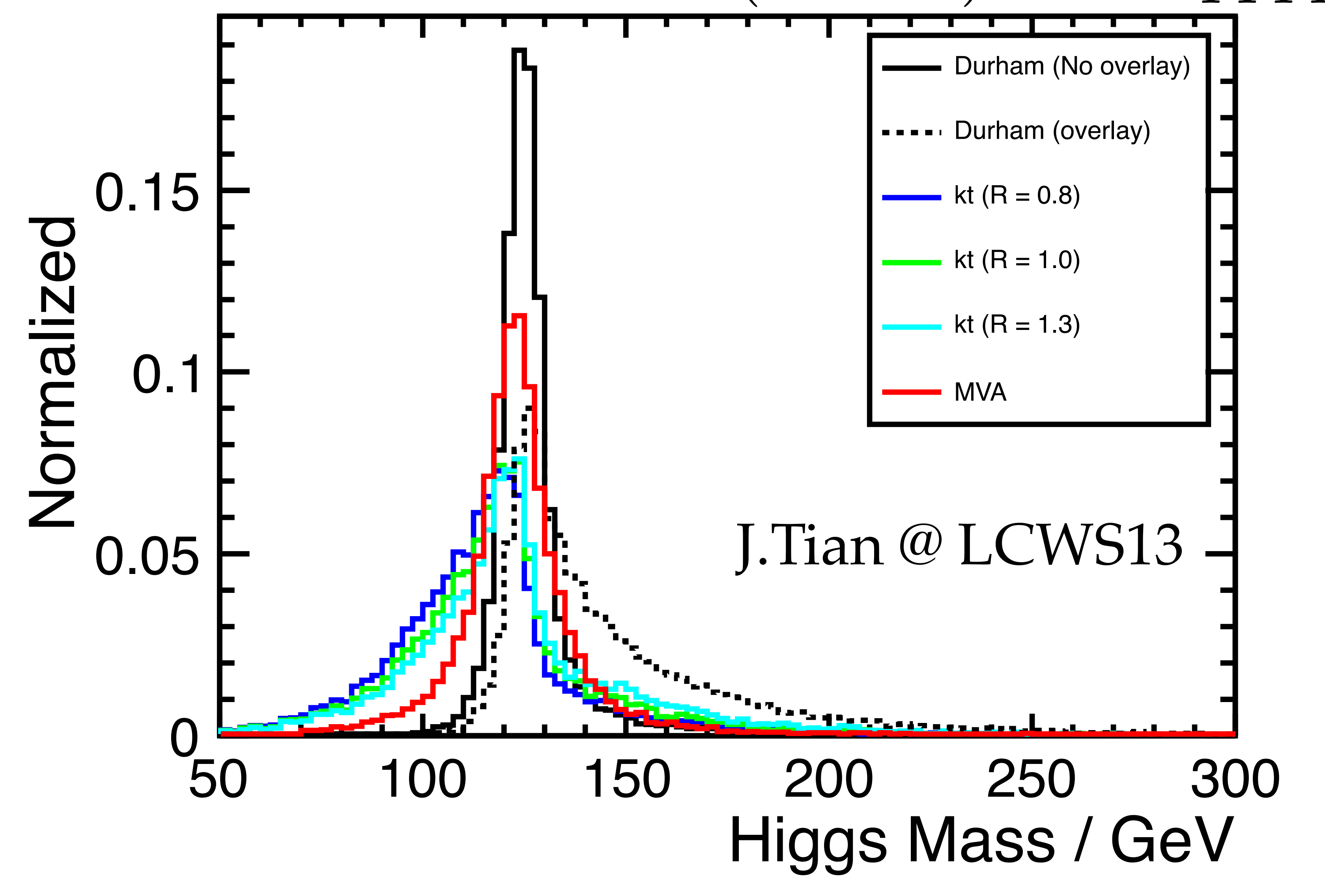
towards new jet-clustering algorithms

- learned from past studies, clearly two places we need better jet-clustering: overlay removal & Higgs self-coupling analysis
- for overlay removal, it's somewhat less challenging, seed particle-/vertex- based clustering seems a promising approach for this special purpose
- for general purpose jet-clustering, or namely color-singlet jet-clustering (e.g. in λHHH analysis), it's a real open challenge, definitely ambitious to do better than what experts have been doing for decades

seed particle-/vertex- based clustering for overlay removal

(there are also beam jets existing at ILC)

$$e^+ + e^- \to \nu\bar{\nu}H \to \nu\bar{\nu}(WW^*) \to \nu\bar{\nu}qqqq$$



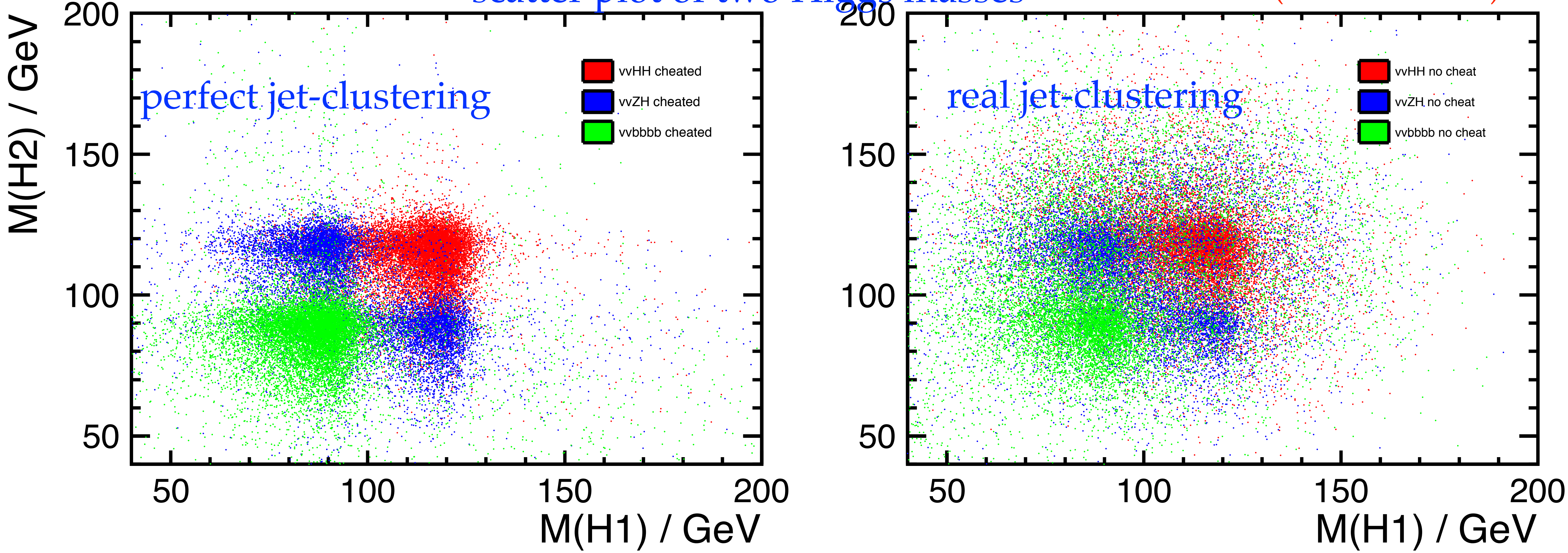
as a first step, MVA seed particle tagging already gives better performance in H—>WW* analysis; need generalize to clustering algorithm and add vertex seeds, and check whether it's better in other channels; ongoing

general purpose jet-clustering

what we know is really a little

color singlet jet clustering can improve λ_{HHH} measurement by 40%

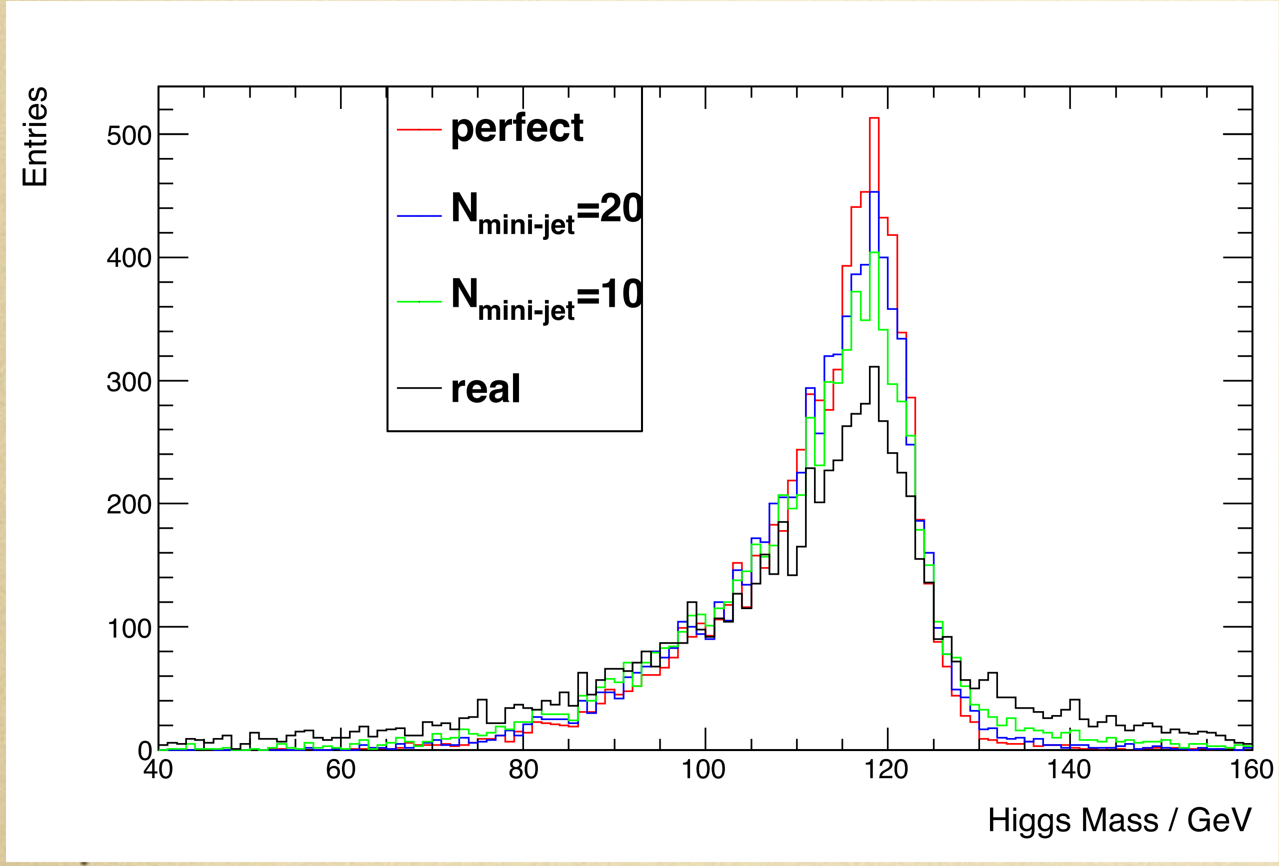
scatter plot of two Higgs masses vvHH mode: (ZZH and ZZZ)

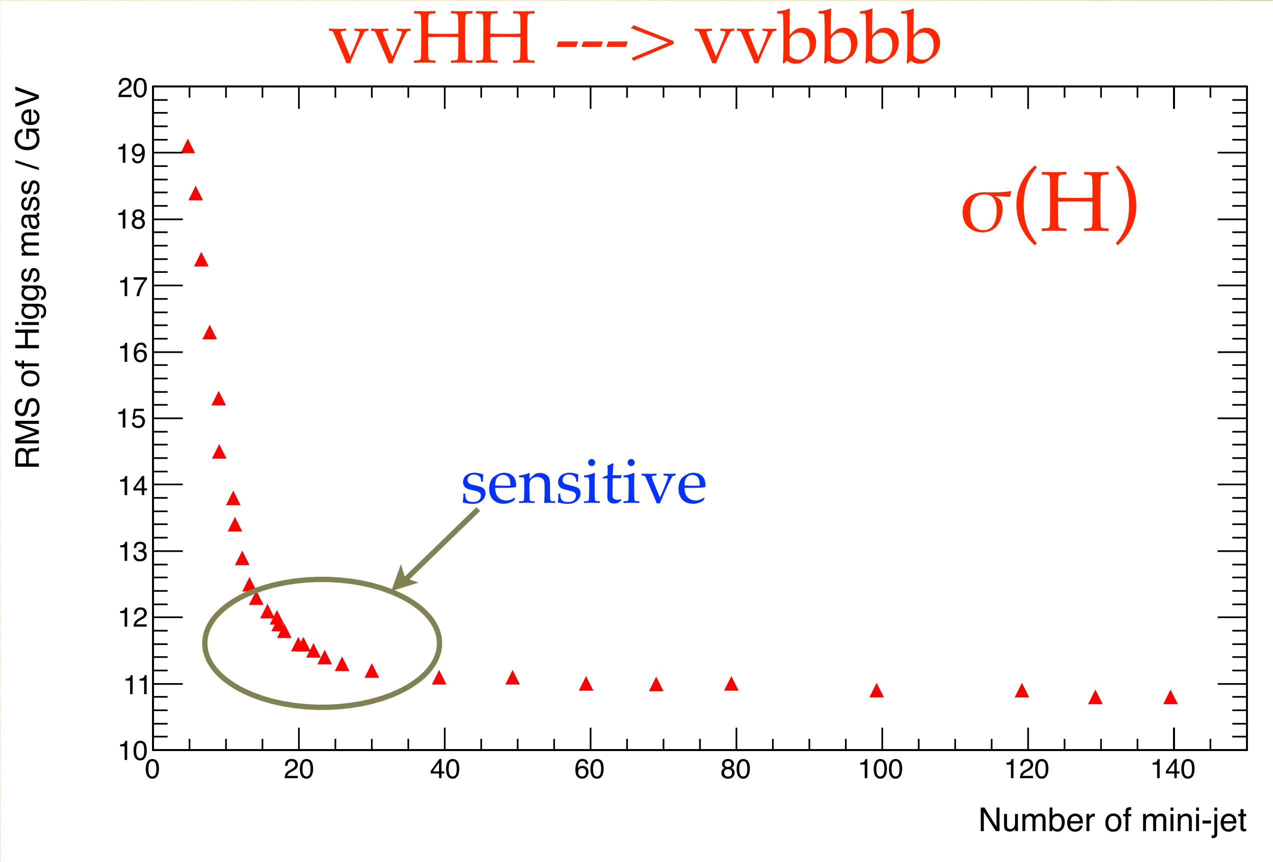


general purpose jet-clustering

what we know is really a little

Durham jet clustering starts to have major mis-clustering when remaining #mini-jet ~ 20





existing jet-clustering algorithms

Algorithm		resolution scale	comment
JADE	J	$2E_iE_j(1-\cos\theta_{ij})$	
DURHAM	D	$2\min(E_i^2, E_j^2)(1-\cos\theta_{ij})$	
DURHAM (LUCLUS $k_\perp$) (Also DURHAM/Lu)	DL	$\frac{2\lvert\mathbf{p}_i\rvert^2\lvert\mathbf{p}_j\rvert^2(1-\cos\theta_{ij})}{(\lvert\mathbf{p}_i\rvert+\lvert\mathbf{p}_j\rvert)^2}$	LUCLUS without reassignment and preclustering
LUCLUS	L	$\frac{2\lvert\mathbf{p}_i\rvert^2\lvert\mathbf{p}_j\rvert^2(1-\cos\theta_{ij})}{(\lvert\mathbf{p}_i\rvert+\lvert\mathbf{p}_j\rvert)^2}$	
GENEVA	G	$\frac{8}{9}E_{\text{vis}}^2\frac{E_iE_j(1-\cos\theta_{ij})}{(E_i+E_j)^2}$	
ANGULAR-ORDERED DURHAM	A	$2\min(E_i^2, E_j^2)(1-\cos\theta_{ij})$	CAMBRIDGE without soft-freezing
CAMBRIDGE	C	$2\min(E_i^2, E_j^2)(1-\cos\theta_{ij})$	
CAMBRIDGE (LUCLUS $k_\perp$)	CL	$\frac{2\lvert\mathbf{p}_i\rvert^2\lvert\mathbf{p}_j\rvert^2(1-\cos\theta_{ij})}{(\lvert\mathbf{p}_i\rvert+\lvert\mathbf{p}_j\rvert)^2}$	
DICLUS mode 0	Di0	$\frac{(s_{ji}-(m_i+m_j)^2)(s_{ik}-(m_i+m_k)^2)}{s_{ijk}}$	$3\to 2$ clustering
DICLUS mode 1	Di1	$\frac{(s_{ji}-(m_i+m_j)^2)(s_{ik}-(m_i+m_k)^2)}{s_{ijk}}$	largest initial cluster retains its direction
DICLUS mode 2	Di2	$\frac{s_{ji}s_{ik}}{s_{ijk}}$	largest initial cluster retains its direction

S. Morreti, et al., JHEP08 (1988) 001

algorithms evolve as new requirements appear

- when jet structure was first studied to establish the spin of quark, no clustering algorithm is actually need —> reconstruct the direction of jet axis by thrust already meets the requirement.
- then even when gluon jet was searched/discovered, only need generalize thrust to triplicity.
- for α_S study, we really need know the precise rate/angles of 2- or 3- jets events, JADE and LUCLUS clustering algorithm become necessary.
- mostly the later algorithms are proposed to cure some aspects of existing one
  - Durham algorithm is to cure the tendency in JADE that two soft jets joint has higher probability —> attach first soft jet to hard jet
  - Angular-Ordered Durham tries to help further reduce tendency of counter-intuitive soft jets

S. Morreti, et al., JHEP08 (1988) 001

algorithms evolve as new requirements appear

- Durham worked well at LEP/LEP2, where usually up to 4 jets are concerned
- it might be reasonable to have new standard to match the jets study at ILC, where 6-/8- jets events will be interested; and higher q^2 produces more complicated parton shower
- computing power is another factor that limited some new algorithms, most of existing ones are 2—>1 sequential, #combination ~ n^2; DICLUS is 3—>2, #combination ~ n^3; since computing power grows rather quickly, more ideas can be thought about, such as what we have tested, 20—>1, where #combination ~ milions, is certainly within current reach.

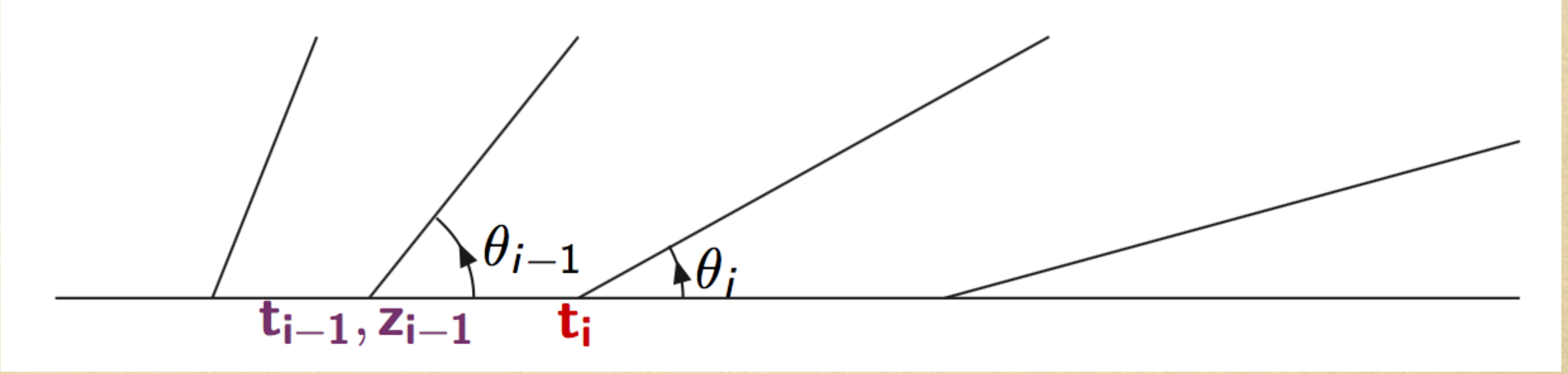
personal ideas about new jet clustering algorithm

- most of existing algorithms all work well at the beginning of clustering —> distances are small in any pre-clustering stage (i.e. mini-jets); but at later stage, the physical parton shower indeed can appear large distance, where we need more information then traditional two jets distance

- new idea is not very surprising, the most physical information at that mini-jets stage would be the likelihood of that parton shower

- possible algorithms: arrange the mini-jets to a tree based on angular ordering (earlier branching, larger angles) which is required by coherent QCD perturbative process; then assign each branching with a proper branching probability, and multiply them as the likelihood of that parton shower

$$
\begin{aligned}
P_{\mathrm{q}\to\mathrm{qg}}(z) &= C_F \frac{1+z^2}{1-z} \,, \\
P_{\mathrm{g}\to\mathrm{gg}}(z) &= N_C \frac{(1-z(1-z))^2}{z(1-z)} \,, \\
P_{\mathrm{g}\to\mathrm{q\bar{q}}}(z) &= T_R\,(z^2+(1-z)^2) \,, \\
P_{\mathrm{q}\to\mathrm{q}\gamma}(z) &= e_{\mathrm{q}}^2 \frac{1+z^2}{1-z} \,, \\
P_{\ell\to\ell\gamma}(z) &= e_{\ell}^2 \frac{1+z^2}{1-z} \,,
\end{aligned}
$$



$$
\mathrm{d}\mathcal{P}_a = \sum_{b,c} \frac{\alpha_{abc}}{2\pi} P_{a\to bc}(z)\,\mathrm{d}t\,\mathrm{d}z \;.
$$

backup

a new idea of Jet-Clustering: Georgi Algorithm

Jet function:

$$J_\beta(P_\alpha) \equiv E_\alpha - \beta \frac{P_\alpha^2}{E_\alpha} = E_\alpha \left[(1-\beta) + \beta v_\alpha^2\right] ,$$

- one interesting feature: jet-clustering can be done globally
- main procedure: find the set of particles with maximum jet function
- number of combinations = 2^N, where N is number of particles to be clustered
- in most jet processes, it almost impossible to start with this algorithm at the beginning, based on N= 100~150
- luckily, now we more or less know the real starting point, ~ 20 mini-jets, which means ~ 1 million combinations
- most interestingly, Jet function *= Likelihood of color-singlet system

implementation of Georgi Jet-Clustering

- a test version of GeorgiClustering has been implemented, with #mini-jet = 25. (kekcc:~tianjp/analysis/PostDBD/GeorgiClustering)
- number of combinations = 2^{25} ~ 32M, CPU time ~ 10s /event.
- several bugs in SatoruJetFinder have been found and fixed when we need more then 20 mini-jets. (kekcc:~tianjp/soft/MarlinReco/v01-10)
- surprisingly found that FastJetClustering(Processor) in current ilcsoft only supports kt type clustering; need a few efforts to support Durham (some one interested welcome to go ahead).

Jet function:

$$J_\beta(P_\alpha) \equiv E_\alpha - \beta \frac{P_\alpha^2}{E_\alpha} = E_\alpha \left[(1-\beta) + \beta v_\alpha^2\right] ,$$

a first look at new GeorgiClustering

original

$$J_\beta(P_\alpha) \equiv E_\alpha - \beta \frac{P_\alpha^2}{E_\alpha} = E_\alpha \left[(1-\beta) + \beta v_\alpha^2\right]$$

generalized

$$J_\beta^{(n)}(P_\alpha) \equiv E_\alpha^n \left[(1-\beta) + \beta v_\alpha^2\right]$$

- a practical issue is to decide value of β, which is essentially a degree of penalty to jet virtuality.
- I started with constant β from 1 to N…, found 1 may be too small, would be somewhere between 3~4, still working on that.
- I found most probably the β needs be tuned, to reflect different jet sub-structure; one variant is being investigated.
- I'm now looking at some benchmark, purity of jet, color singlet, etc…

see following slides