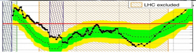
Karlsruhe Institute of Technology

NLO-QCD Corrections to (WZ)/Wγ-Production at LHC

Karlsruhe Institute of Technology (KIT)
Johannes Bellm | December 15, 2011

INSTITUTE FOR THEORETICAL PHYSICS



14	Alemannia Aachen	-9	14
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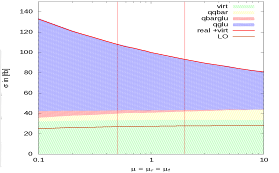
18	Hansa Rostock (N)	-17	11



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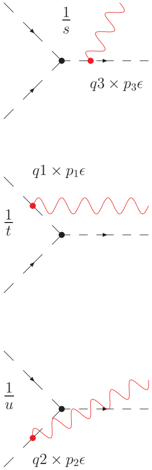
Motivation

- missing process in VBFNLO
- large K-factor (3.5) (radiation zero,gluon-pdf)
- sensitive to anomalous couplings
- comparison to MCFM

Radiation Zero



Amplitude: $M = \sum_i \frac{q_i \times p_i \epsilon}{p_i p_\gamma} = \sum_i \frac{A_i \times B_i}{C_i}$

- A: charge conservation: $\sum_i q_i = 0$
- B: transverse polarization: $\sum_i p_i \epsilon = p_\gamma \epsilon = 0$
- C: $m_\gamma = 0 : \sum_i p_i p_\gamma = p_\gamma p_\gamma = 0$

$$\rightarrow M = \sum_i \frac{A_i \times B_i}{C_i} = \frac{1}{C_3}(A_1 C_2 - A_2 C_1)\left(\frac{B_2}{C_2} - \frac{B_1}{C_1}\right)$$

So the amplitude gets zero when:

$$\frac{Q_1}{Q_2} = \frac{t}{u}$$

Radiation Zero

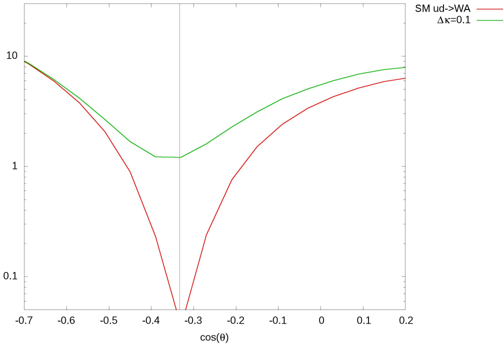
In the standard model there is a triple vertex $q\bar{q}W$. From every leg a photon can be radiated.

- A: generalized Jacobi identity (group-theory)
- B: spatial gen. Jacobi identity (see gen. Bianchi identity in GR)
- C: $s - M_W^2 + t + u = 0$

we get:

$$\frac{d\sigma(d\bar{u} \to W^- \gamma)}{dcos\theta_{W-d}} = \left(\frac{q_{\bar{u}}}{q_d} - \frac{t}{u}\right)^2$$

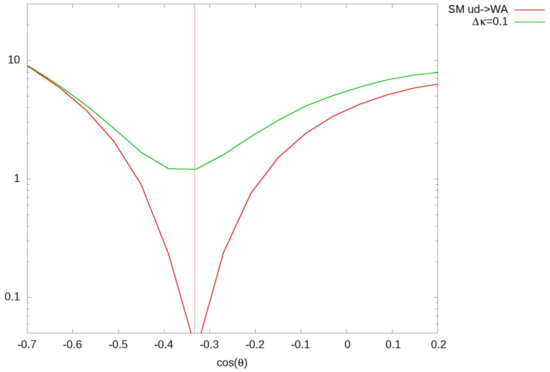
the amplitude vanishes
for $cos\theta = -1/3$



Radiation Zero

with anomalous vertex for $WW\gamma$,
(no local gauge theory, no covariant derivative):

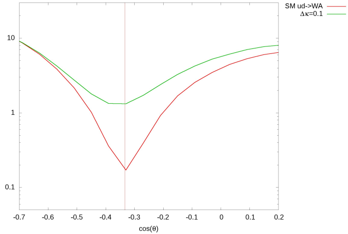
$$\frac{\sigma(d\bar{u} \to W^-\gamma)}{d\cos\theta_{W-d}} = \left(\frac{q_{\bar{u}}}{q_d} - \frac{t}{u}\right)^2 \Gamma_1 + (\kappa - 1)\left(\frac{q_{\bar{u}}}{q_d} - \frac{t}{u}\right)\Gamma_2 + (\kappa - 1)^2\Gamma_3$$



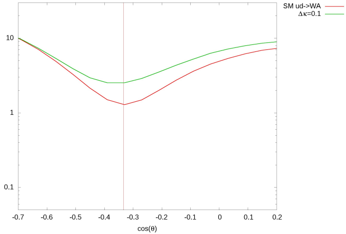
zero-conditions:

- final W on shell
- no final state radiation
- $q\bar{q}$ collider
- only QCD-LO

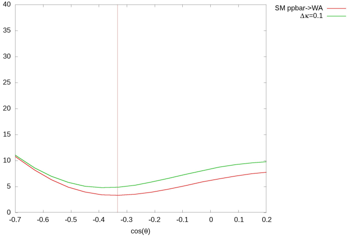
Radiation Zero



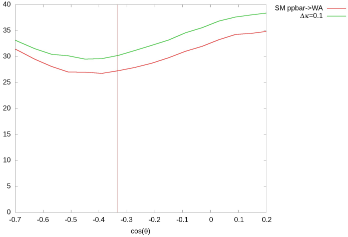
LO



LO



LO



NLO

Radiation Zero

K-factors for diboson production and the effect of radiation zero:

W^+W^-	1.5
$W^\pm Z$	1.9
$W^\pm\gamma$	3.5

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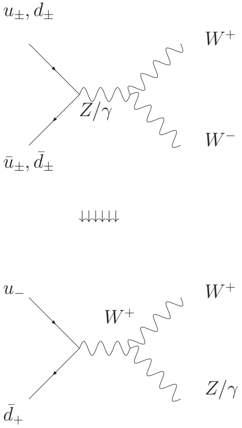
Implementation



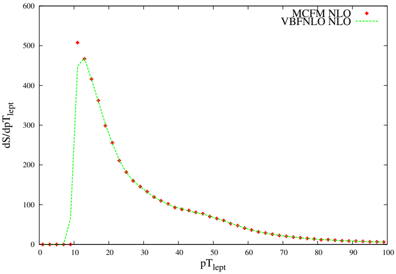
Differences to W^+W^-(V.Hankele):

- $WZ/W\gamma$ has always left(right)handed incoming (anti)fermions [W attachment]
- outgoing fermions from $Z/\gamma*$ or γ itself can have $\pm$-helicities
- new combination of PDFs (as in WZZ or $W\gamma\gamma$)
- additional anomalous couplings have been added (B.Feigl)
- new phase space generator needed
- the NLO-QCD part is basically the same!

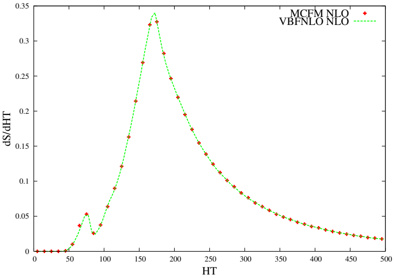
Checks

- In the code: $|M|^2$ comparison with automatic generated MADGRAPH-code ($\mathcal{O}(10^-7)$)
- LO: comparison with SHERPA ($\mathcal{O}(10^-3)$)
- NLO: comparison with MCFM ($\mathcal{O}(10^-3)$)

$W^+\gamma$



W^-Z



Checks

- VBFNLO has $W^{\pm}\gamma j$ and $W^{\pm}Zj$ @ NLO with anomalous couplings (Englert)
- different implementations of the triboson vertices (Feigl,Englert)
- differences appear $\rightarrow$ could be solved:

$(f_{WWW}; f_W; f_b)$,FORM	W^+Z LO +j (310)	W^+ZJ LO (640)	ratio
(0;0;0), off (SM)	36.109	36.122	0.99966
$(1; 0; 0) \cdot 10^{-4}$, off	348.377	348.408	0.99991
$(0; 6; 0) \cdot 10^{-4}$, off	4272.325	4271.854	1.00011
$(0; 0; 1) \cdot 10^{-3}$, off	66.825	66.821	1.00006
$(0.5; 2; 6) \cdot 10^{-4}$,off	573.984	573.568	1.00073
$(0.5; 2; 6) \cdot 10^{-4}$,on	342.127	342.300	0.99950

Catani-Seymour Subtraction Formalism

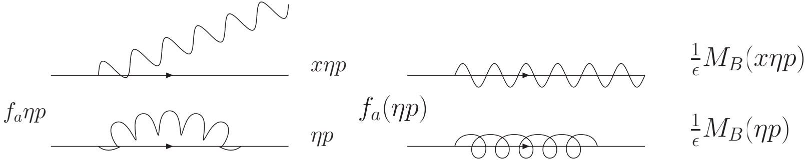
- dipole formalism (Martin's talk)
- no jets @ LO
- LHC $\rightarrow$ two initial state hadrons
- new collinear term $\rightarrow$ PDF-renormalization (Karol's talk)

Catani-Seymour Subtraction Formalism

DIS:

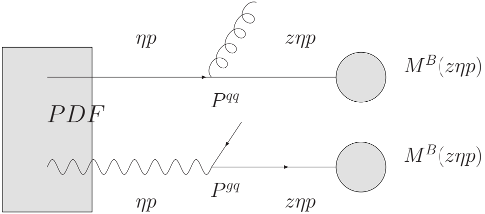
$$\sigma^{NLO}(p) = \sum_a \int_0^1 d\eta \underbrace{f_a(\eta)}_{PDF} \left[\int_m d\sigma_a^V(\eta p) + \int_{m+1} d\sigma_a^R(\eta p) + \underbrace{\int_m d\sigma_a^C(\eta p)}_{coll.CT} \right]$$

- Why do we need the collinear counterterm?



Collinear Remainder

$$d\sigma_a^C(\eta p) = -\frac{\alpha_s}{2\pi}\frac{1}{\Gamma(1-\epsilon)}\sum_b \int_0^1 dx \left[-\frac{1}{\epsilon}\left(\frac{4\pi\mu^2}{\mu_F^2}\right)^{\epsilon} P^{ab}(x) + ..\right] d\sigma_b^B(x\eta p)$$



next step:

- construct local counter term with dipoles $D^{ai,b}$ (Martins talk)
- integrate out the additional jet in d-Dimensions

We get:

$$\int_{m+1} d\sigma_a^A(p) + \int_m d\sigma_a^C(p) =$$

$$\int_m [\underbrace{d\sigma_a^B(p)\boldsymbol{I(\epsilon)}}_{cancels\ d\sigma^V} + \underbrace{\sum_b \int_0^1 dx(\boldsymbol{K}^{a,b}(x) + \boldsymbol{P}^{a,b}(xp))d\sigma_b(xp)]}_{remormalisation\ of\ PDF}$$

Different approach:

$$\sigma(p) = \sum_a \int_0^1 d\eta f_a(\eta)\sigma_a(\eta p) =$$

$$= \sum_{a,b} \int_0^1 d\eta dz\ f_a(\eta)(\delta_{ab}\delta(1-z) + \alpha_s \tilde{P}_{ab}(z))(\sigma_b^{LO}(\eta z p) + \sigma_b^{NLO}(\eta z p)) + ...$$

$$\sigma^{NLO}(p) = \sum_a \int_0^1 d\eta f_a(\eta)\sigma_a^{NLO}(\eta p)$$

$$+ \sum_{a,b} \int_0^1 d\eta'\ JF dz'\ \alpha_s\ f_a(z',\eta')\tilde{P}_{ab}(z',\eta')\sigma_b^{LO}(\eta' p)$$

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Anomalous Couplings

$W W \gamma$ terms in an effective Lagrangian (CP-conserving):

$$\mathcal{L}_{WW\gamma} = -ie\left[W^{\dagger}_{\mu\nu}W^{\mu}A^{\nu} - W^{\dagger}_{\mu}A_{\nu}W^{\mu\nu} + \kappa_{\gamma}W^{\dagger}_{\mu}W_{\nu}F^{\mu\nu} + \frac{\lambda_{\gamma}}{m_W^2}W^{\dagger}_{\sigma\mu}W^{\mu}_{\nu}F^{\nu\sigma}\right]$$

- κ_{γ}=1,$\lambda_{\gamma} = 0 \rightarrow$ SM
- Sep11(Fermilab): $0.6 < \kappa_{\gamma} < 1.4$, $-0.08 < \lambda_{\gamma} < 0.07$
- unitary problems for high energy behavior: $\hat{s} + u + t$-channel (see WW-scattering without a higgs)
- formfactor needed:

$$\frac{1}{(1 + \frac{s}{\Lambda^2})^n}$$

Unitary and Formfactors

For the high energy ($m_W/\sqrt{s} \to 0$) behavior we take a look at the $\Delta M_{\sigma_\gamma \sigma_W}(\Delta\kappa, \lambda)$:

$$\Delta M_{\pm 0} = \frac{e^2}{sin(\theta_W)} \frac{\sqrt{s}}{2m_W} [\Delta\kappa + \lambda] \frac{1}{2} (1 \mp cos\Theta) \quad (1)$$

$$\Delta M_{\pm\pm} = \frac{e^2}{sin(\theta_W)} \frac{s}{2m_W^2} [\lambda] \frac{1}{\sqrt{2}} (sin\Theta) \quad (2)$$

$$\Delta M_{\pm\mp} = 0 \quad (3)$$

The third amplitude is not possible because of s-channel exchange.($\pm, \mp$) needs $J \geq 2$

Cuts

- Wj-production with misidentified jet is serious $\rightarrow p_{T\gamma} > 100 GeV$
- $M_T(l\gamma,\nu)$[1] $> 90 GeV$, $R(l,\gamma)$[2] > 0.7 together with high $p_{T\gamma}$ suppresses final state bremsstrahlung
- For $O = p_{T\gamma}$ a p_{Tj}-veto = 50GeV

[1] $M_T(l\gamma,\nu) = [(m(l\gamma)^2 + |pT(l\gamma)|^2)^{1/2} + |\not{p}_T|]^2 - |p_T(l\gamma) + \not{p}_T|^2$
[2] $R = \sqrt{\Delta\eta^2 + \Delta\phi^2}$

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Inclusive vs. Exclusive

$$\sigma^{N^n LO} \rightarrow \sigma^{N^{n+1} LO}$$

With this step one get an new real emission, a new jet.

What is an inclusive X-section?

Define:

$$\sigma_{incl}(W\gamma) = \sigma_{excl}(W\gamma) + \sigma_{excl}(W\gamma j) + \sigma_{excl}(W\gamma jj) + .. \quad (4)$$

$$= \sum_n \sigma_{excl}(W\gamma(n \times j)) \quad (5)$$

Inclusive vs. Exclusive

How to define a exclusive X-section?

$$\sigma_{incl}(W\gamma) = \sigma_{excl}(W\gamma) + \sum_n \sigma_{excl}(W\gamma j(n \times j)) \quad (6)$$

$$= \sigma_{excl}(W\gamma) + \sigma_{incl}(W\gamma j) \quad (7)$$

so:

$$\sigma_{excl}(W\gamma) = \sigma_{incl}(W\gamma) - \sigma_{incl}(W\gamma j) \quad (8)$$

Inclusive vs. Exclusive

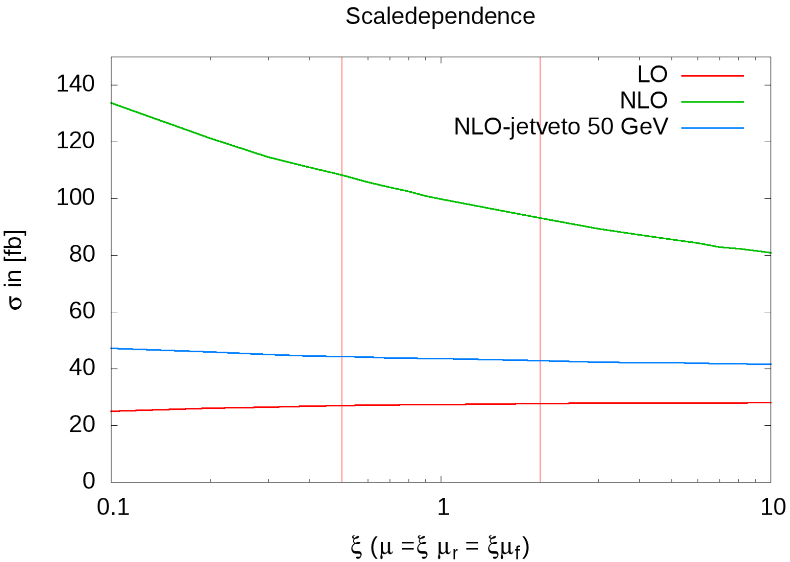
$\mathcal{O}(\alpha_s)$:

$$\sigma^{NLO}_{excl}(W\gamma) = \sigma^{NLO}_{incl}(W\gamma) - \sigma^{LO}_{incl}(W\gamma j) = \sigma^{NLO}_{veto}(W\gamma) \qquad (9)$$

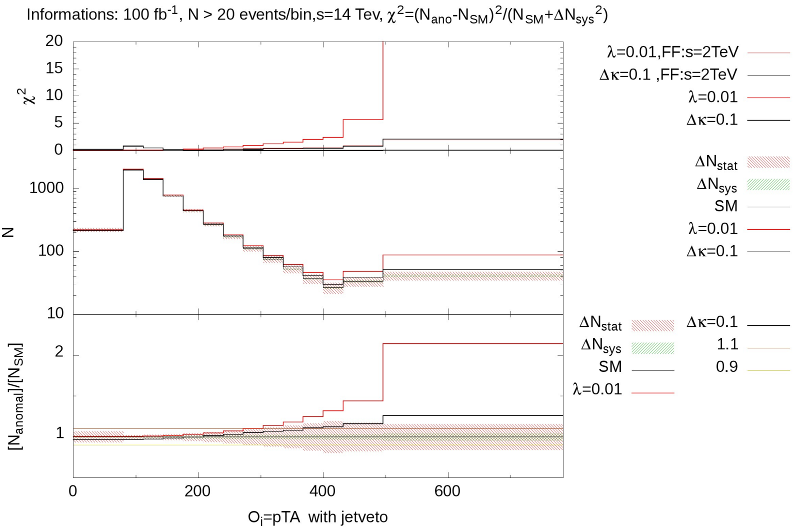
Next question: Whats the theoretical uncertainty for σ^{NLO}_{veto}?

- scale variation of the difference?
- say $\sigma^{NLO}_{incl}(W\gamma)$ and $\sigma^{LO}_{incl}(W\gamma j)$ are independent? Scale estimated uncertanties have to sum up?
- a new way?

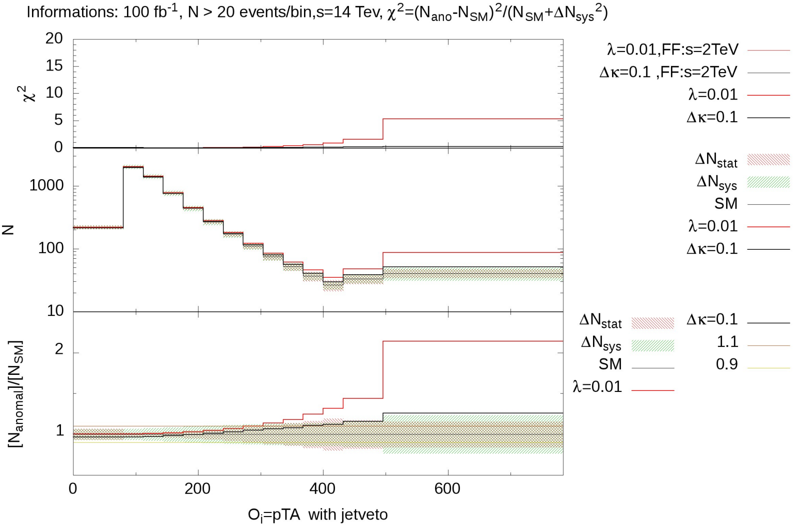
Inclusive vs. Exclusive



Scale Variation of the Difference



Independent Scale Variation



New Way

$$\Delta\sigma^{NLO}_{excl}(W\gamma) = \Delta\sigma^{NLO}_{incl}(W\gamma) + \Delta\sigma^{LO}_{incl}(W\gamma j)$$

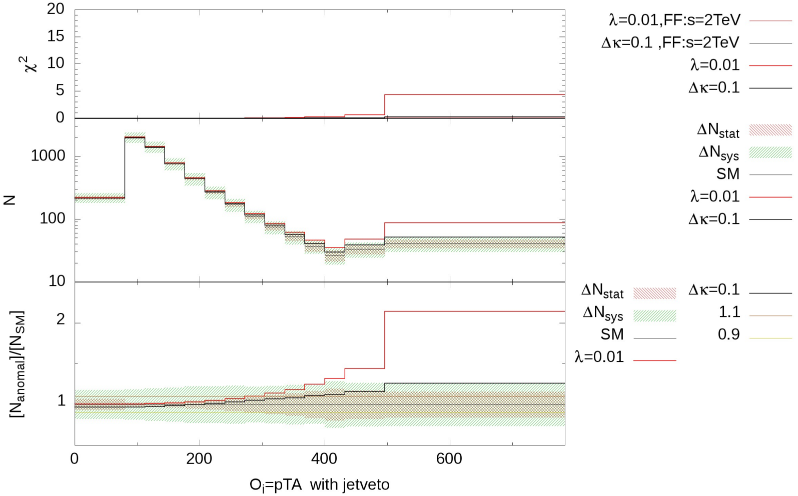
$$with:$$

$$\Delta\sigma^{NLO}_{incl}(W\gamma) = \frac{1}{2}(|\sigma^{NLO}_{incl}(W\gamma)_{\xi=2} - \sigma^{NLO}_{incl}(W\gamma)_{\xi=0.5}|$$

$$\Delta\sigma^{LO}_{incl}(W\gamma j) = |\sigma^{NLO}_{incl}(W\gamma j) - \sigma^{LO}_{incl}(W\gamma j)|$$

New Way

Informations: 100 fb^{-1}, N > 20 events/bin,s=14 Tev, $\chi^2=(N_{ano}-N_{SM})^2/(N_{SM}+\Delta N_{sys}{}^2)$



New Way and Independent Scale Variation

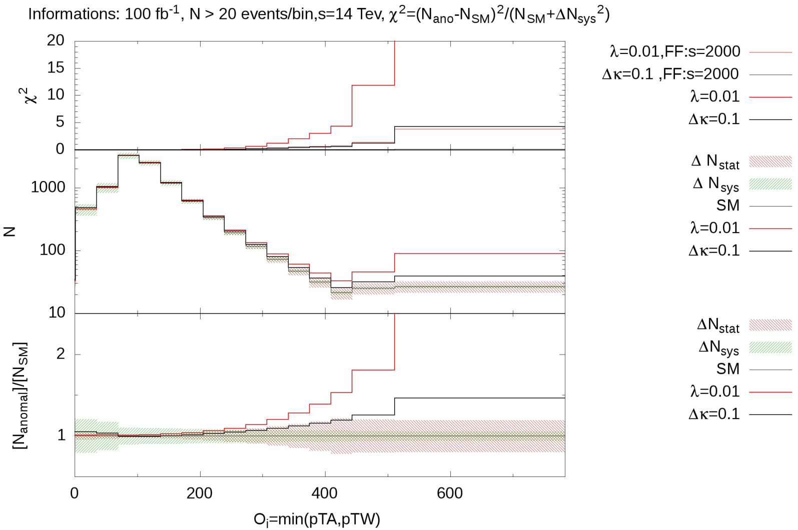
Pro:

- The vetoed σ is less inclusive $\rightarrow$ large logarithms can appear. @ every order of perturbation theory.
- Fine tuning of the uncertainty cannot be done.
- For $W\gamma j$ @ LO we have the best estimation for the error with the NLO-calculation.

Contra:

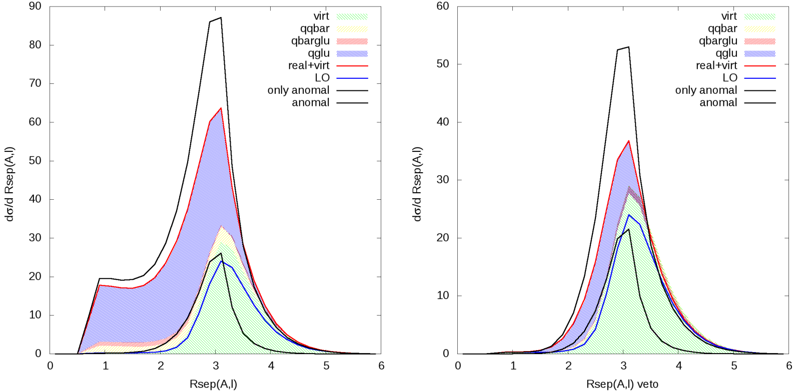
- In $\mathcal{O}(\alpha_s^2)$ more jets appear $\rightarrow$ a cut on E_{had} suppresses higher order contributions
- Overestimation? doublecounting of the uncertainty coming from $W\gamma j$ @ LO

Inclusive



Informations: 100 fb^{-1}, N > 20 events/bin,s=14 Tev, $\chi^2=(N_{ano}-N_{SM})^2/(N_{SM}+\Delta N_{sys}{}^2)$
χ^2
N
$[N_{anomal}]/[N_{SM}]$
O_i=min(pTA,pTW)
λ=0.01,FF:s=2000
$\Delta\kappa$=0.1 ,FF:s=2000
λ=0.01
$\Delta\kappa$=0.1
ΔN_{stat}
ΔN_{sys}
SM
λ=0.01
$\Delta\kappa$=0.1
ΔN_{stat}
ΔN_{sys}
SM
λ=0.01
$\Delta\kappa$=0.1

New Cuts



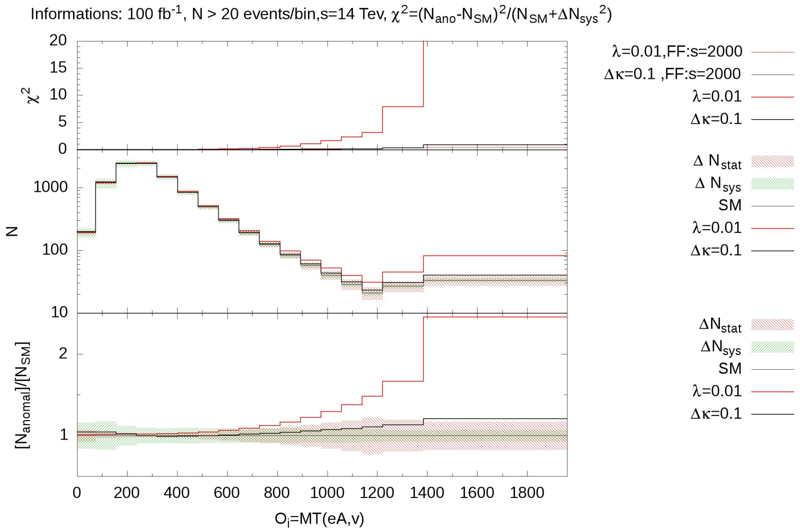
Is this infrared safe?

Outlook

- what influence has $gg \to W\gamma jj$? ($W\gamma j@NLO$)
- New cuts for inclusive searches.
- *Wj* Process not yet available, but 'easy' to get from WVVj or WVj (different structure)
- make the analysis for WZ production

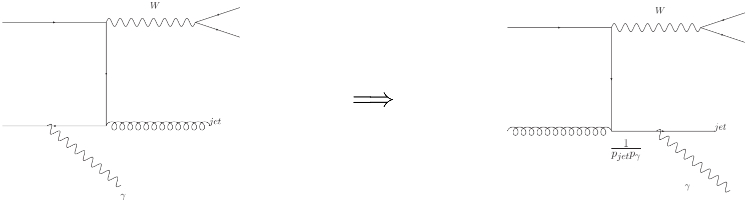
Thank you for your attention!

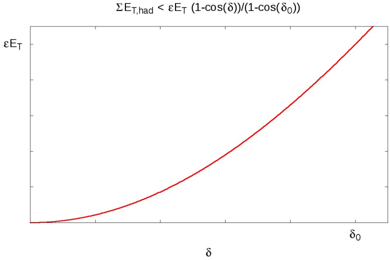
Inclusive



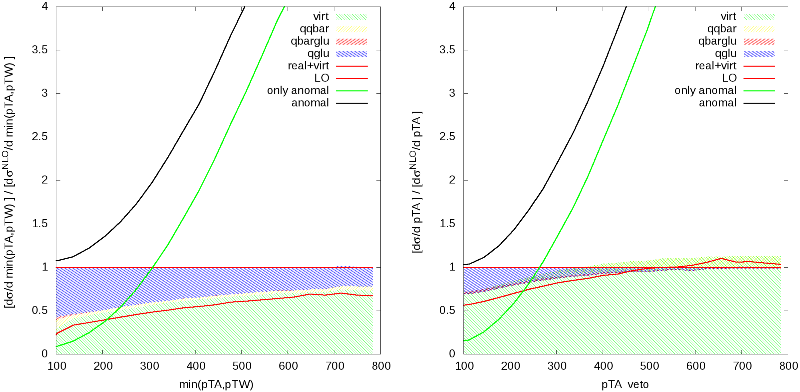
Informations: 100 fb-1, N > 20 events/bin,s=14 Tev, χ2=(Nano-NSM)2/(NSM+ΔNsys2)
20
15
10
5
0
χ2
1000
100
10
N
2
1
[Nanomal]/[NSM]
0
200
400
600
800
1000
1200
1400
1600
1800
Oi=MT(eA,v)
λ=0.01,FF:s=2000
Δκ=0.1 ,FF:s=2000
λ=0.01
Δκ=0.1
Δ Nstat
Δ Nsys
SM
λ=0.01
Δκ=0.1
ΔNstat
ΔNsys
SM
λ=0.01
Δκ=0.1

Photon isolation à la Frixione





pT_γ vs. $min(pT_\gamma, pT_W)$



Inclusive vs. Exclusive