t tbar + isolated photon production at NLO accuracy matched with PS

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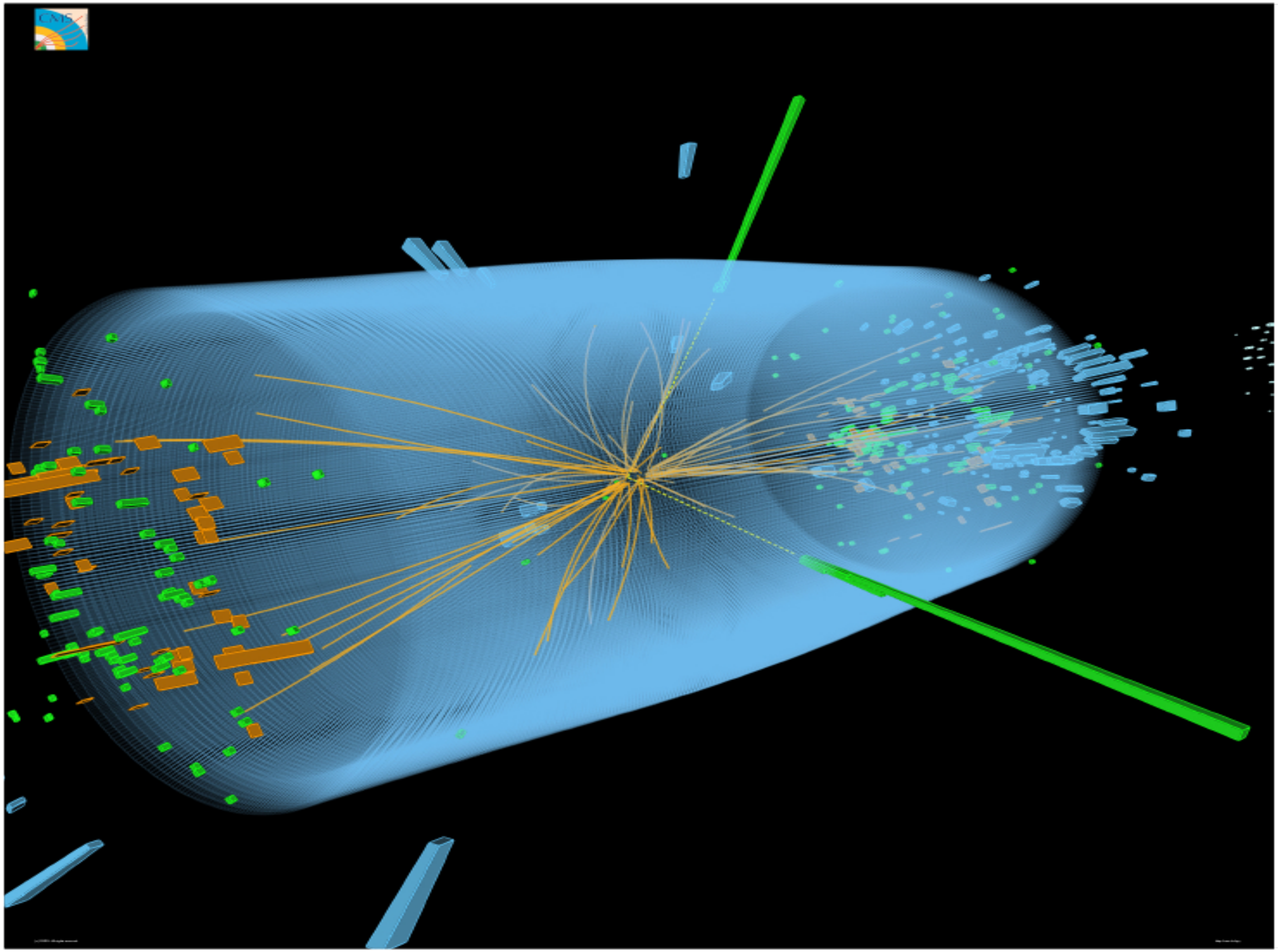
in collaboration with
Adam Kardos

Higgs boson has been discovered



Higgs boson has been discovered

- m_H [GeV]=125.5±0.2_{stat}±0.6_{syst} (ATLAS 2013)
  125.7±0.3_{stat}±0.3_{syst} (CMS 2013)

- All measured properties are consistent with SM expectations within experimental uncertainties
  - spin zero
  - parity +
  - couples to masses of W and Z (with c_V=1 within experimental uncertainty)
- Prime task at LHC: to measure its couplings

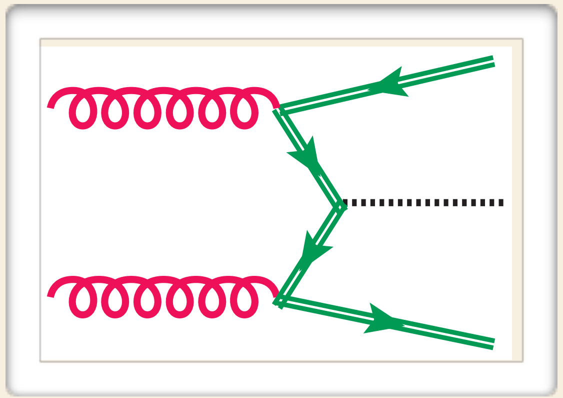
t-quark: potential tool for discovery

- The t-quark is heavy, Yukawa coupling ~1
  m_t [GeV]=173.34±0.64 (LHC+TeVatron, 2014)
  ($\Rightarrow y_t$=0.997±0.003)

  $\Rightarrow$ plays important role in Higgs physics
  (more tantalizing: $m_t\, m_Z = (125.7 \pm 0.3)^2\ \mathrm{GeV}^2$)
- y_t cannot be measured in $H \to t\bar{t}$ decay ($m_t > m_H$)

tTH hadroproduction

- y_t can be measured in pp $\rightarrow$ tTH through many decay channels (all very difficult):



  - hadrons with single lepton: $\mathrm{t} \rightarrow \mathrm{b}\ell\nu,\ \bar{\mathrm{t}} \rightarrow \bar{\mathrm{b}}jj,\ \mathrm{H} \rightarrow \mathrm{b}\bar{\mathrm{b}}$
  - hadrons with dilepton: $\mathrm{t} \rightarrow \mathrm{b}\ell\nu,\ \bar{\mathrm{t}} \rightarrow \bar{\mathrm{b}}\ell\nu,\ \mathrm{H} \rightarrow \mathrm{b}\bar{\mathrm{b}}$
  - hadrons with hadronic tau: $\mathrm{t} \rightarrow \mathrm{b}\ell\nu,\ \bar{\mathrm{t}} \rightarrow \bar{\mathrm{b}}jj,\ \mathrm{H} \rightarrow \tau_h^+\tau_h^-$
  - diphoton with lepton: $\mathrm{t} \rightarrow \mathrm{b}\ell\nu,\ \bar{\mathrm{t}} \rightarrow \bar{\mathrm{b}}jj,\ \mathrm{H} \rightarrow \gamma\gamma$
  - diphoton with hadrons: $\mathrm{t} \rightarrow \mathrm{b}\ jj,\ \bar{\mathrm{t}} \rightarrow \bar{\mathrm{b}}jj,\ \mathrm{H} \rightarrow \gamma\gamma$
  - same sign dilepton: $\mathrm{t} \rightarrow \mathrm{b}\ jj,\ \bar{\mathrm{t}} \rightarrow \bar{\mathrm{b}}jj,\ \mathrm{H} \rightarrow \ell\nu\ell[\nu]$
  - 3 leptons with di, trilepton: $\mathrm{t} \rightarrow \mathrm{b}\ell\nu,\ \bar{\mathrm{t}} \rightarrow \bar{\mathrm{b}}jj,\ \mathrm{H} \rightarrow \ell[\nu]\ell[\nu]$
  - 4 lepton with di, trilepton: $\mathrm{t} \rightarrow \mathrm{b}\ell\nu,\ \bar{\mathrm{t}} \rightarrow \bar{\mathrm{b}}\ell[\nu],\ \mathrm{H} \rightarrow \ell[\nu]\ell[\nu]$

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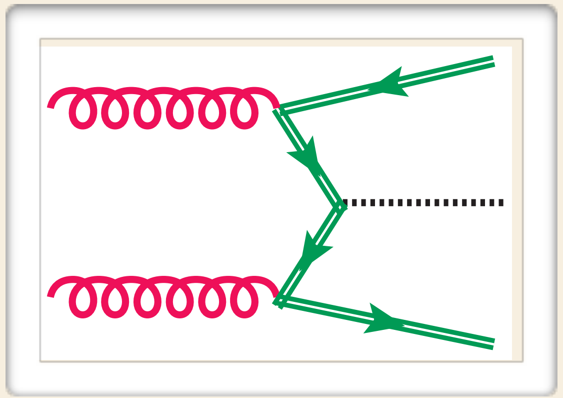

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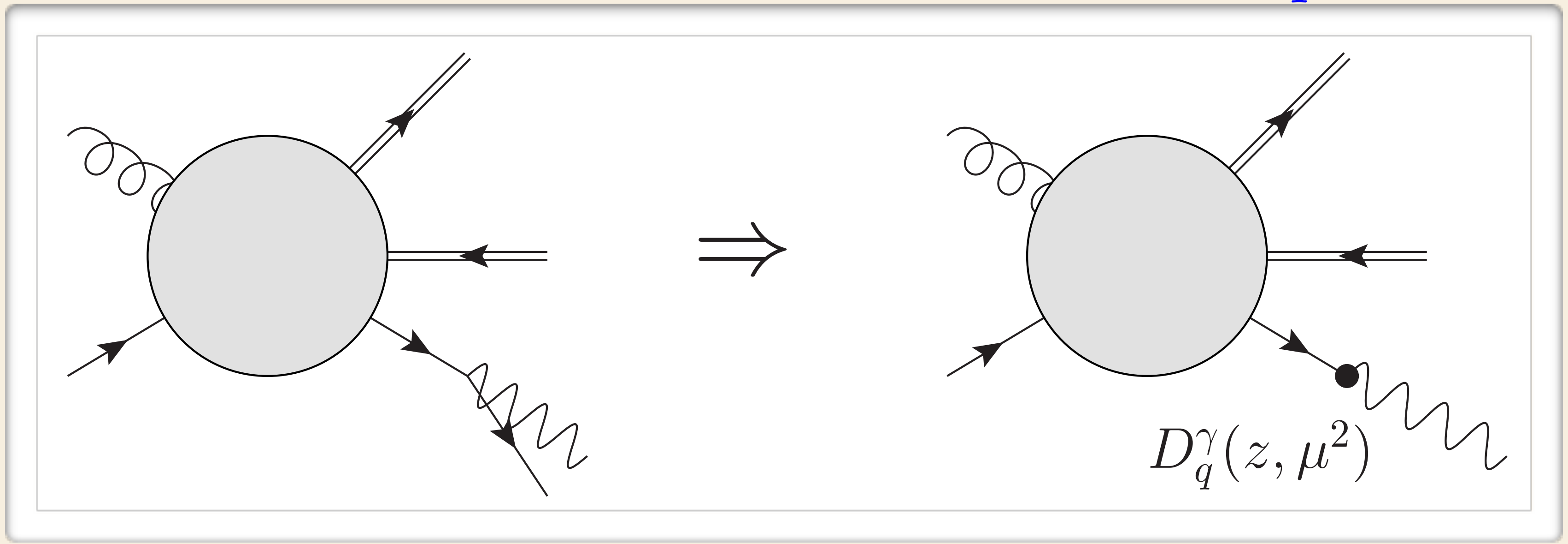
Isolated photons in the final state

... are cumbersome theoretically

two contributions: direct fragmentation

$$\sigma = \sigma_d + \sigma_f$$

Origin of the fragmentation contribution is a light quark - photon singularity absorbed into the fragmentation function $D_q^\gamma(z, \mu^2)$



photon fragmentation is not known well

Fragmentation function

Fragmentation function

- cannot be computed in perturbation theory, only its evolution
- suppressed by isolation, hard to measure

Can we avoid it?

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- yes: isolate photon from partons with cone radius decreasing as parton energy inside the cone decreases (smooth isolation of Frixione):

$$E_{\perp,\mathrm{had}} = \sum_{i \in \mathrm{tracks}} E_{\perp,i}\Theta\left(\delta - R(p_\gamma, p_i)\right) < E_{\perp,\gamma}\left(\frac{1-\cos\delta}{1-\cos\delta_0}\right)$$

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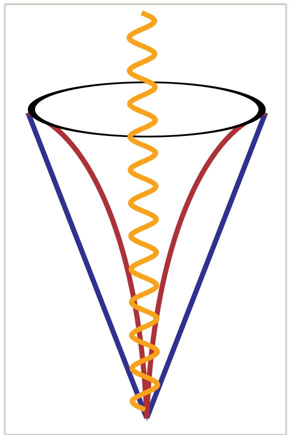

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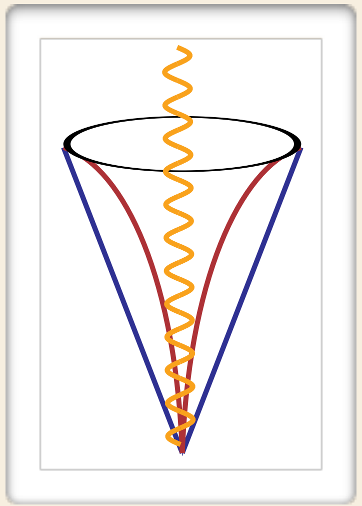

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- but experimenters prefer cone of fixed radius with reduced hadronic activity inside the cone:

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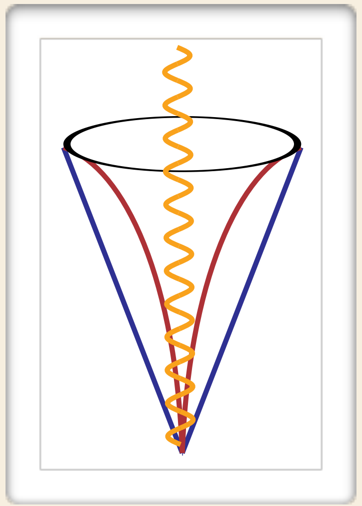

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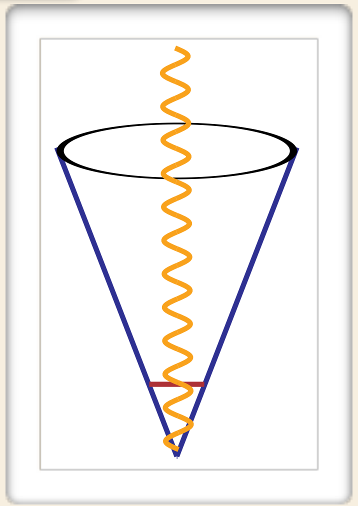

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Resolution:

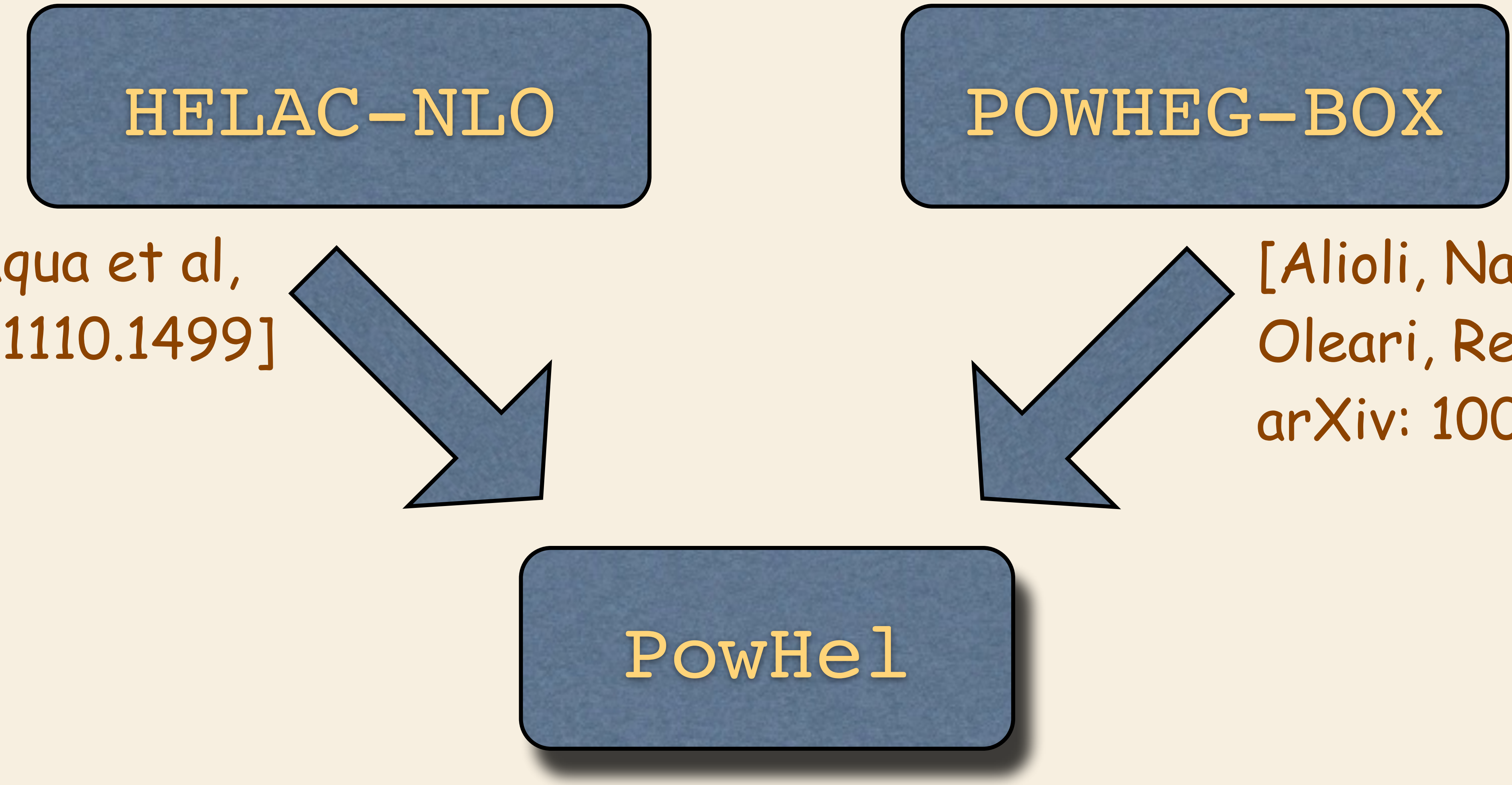
Generate events with loose photon generation isolation

(i.e. small δ_0^{gen})

using the POWHEG method

[Kardos and Trócsányi, arXiv: 1406.2324]

PowHel framework



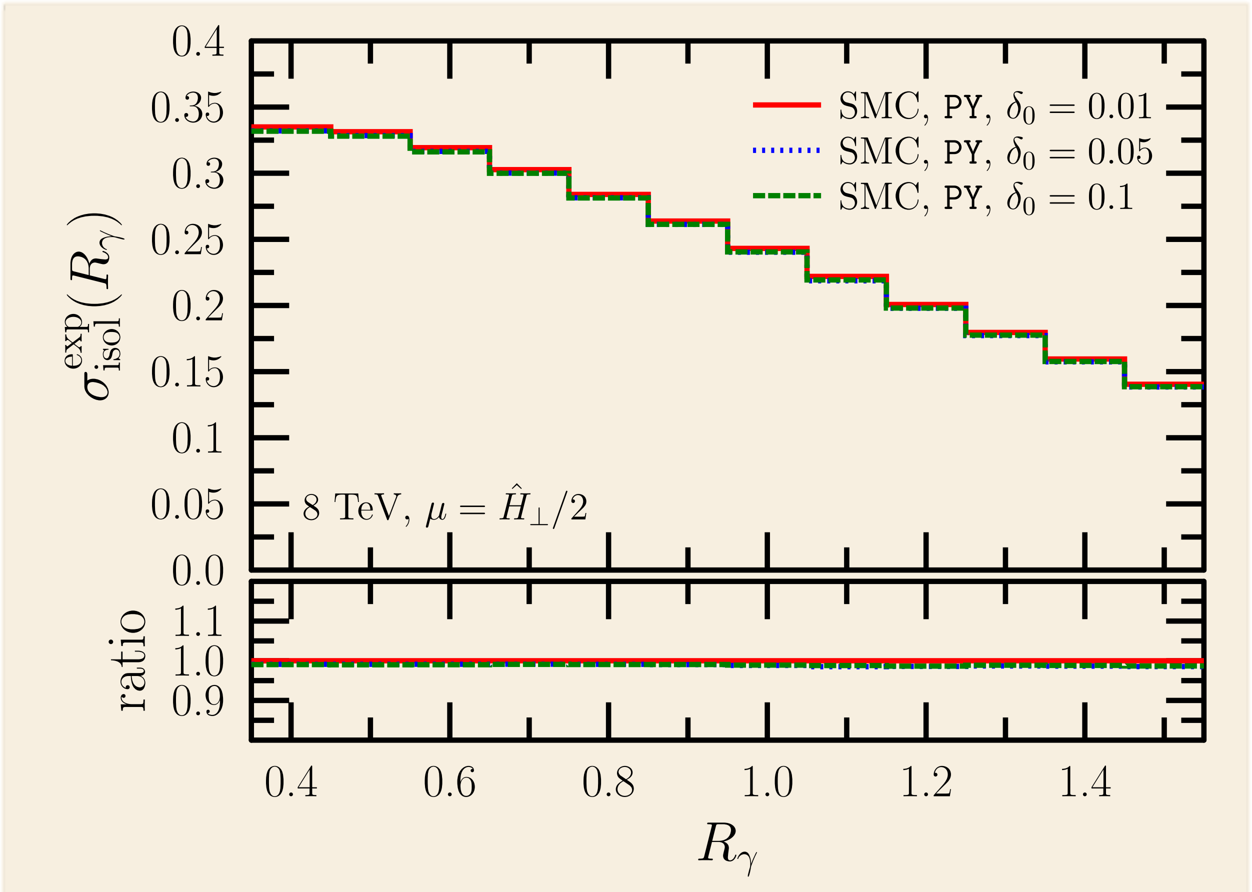
[Bevilaqua et al, arXiv: 1110.1499]

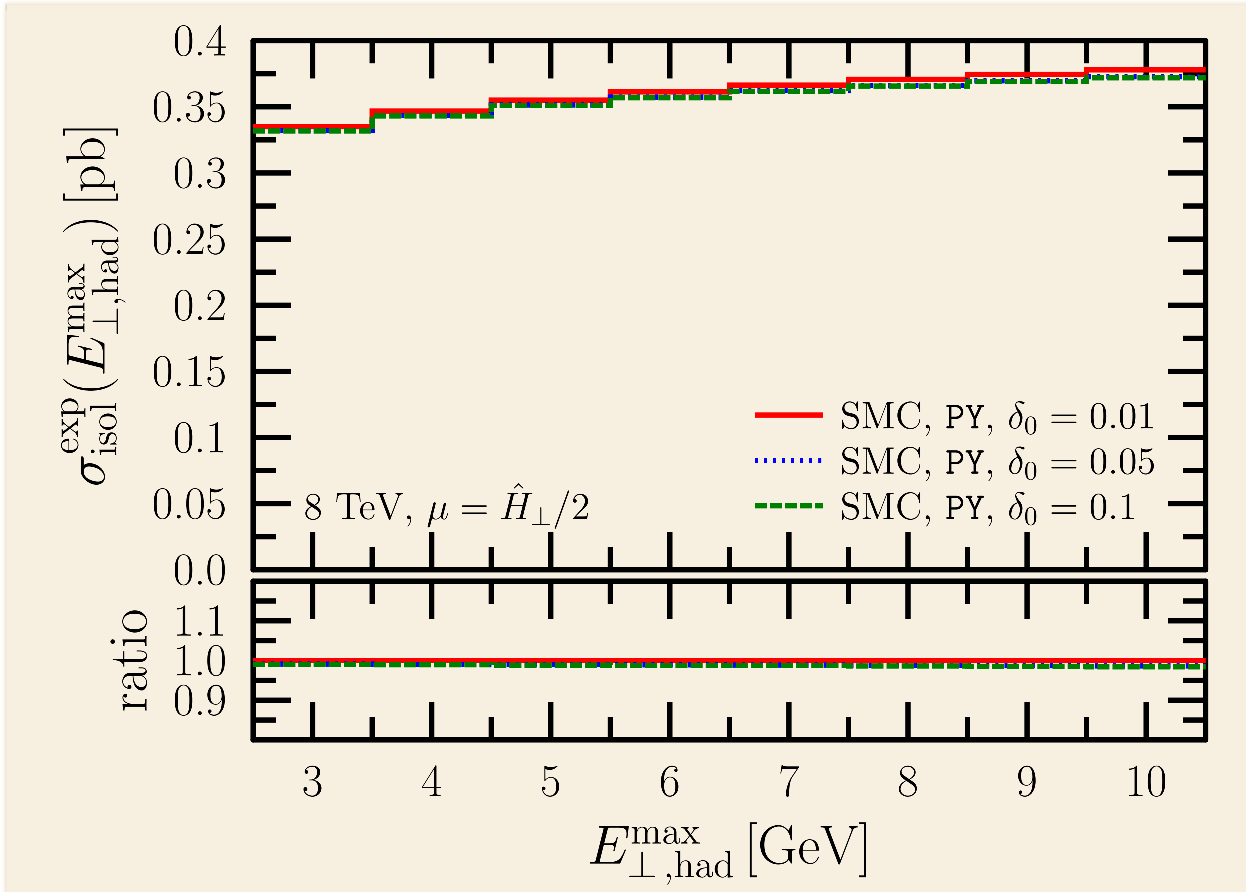
[Alioli, Nason, Oleari, Re, arXiv: 1002.2581]

RESULT of PowHel:

Les Houches file of Born and Born+1st radiation events (LHE) ready for processing with SMC followed by almost arbitrary experimental analysis

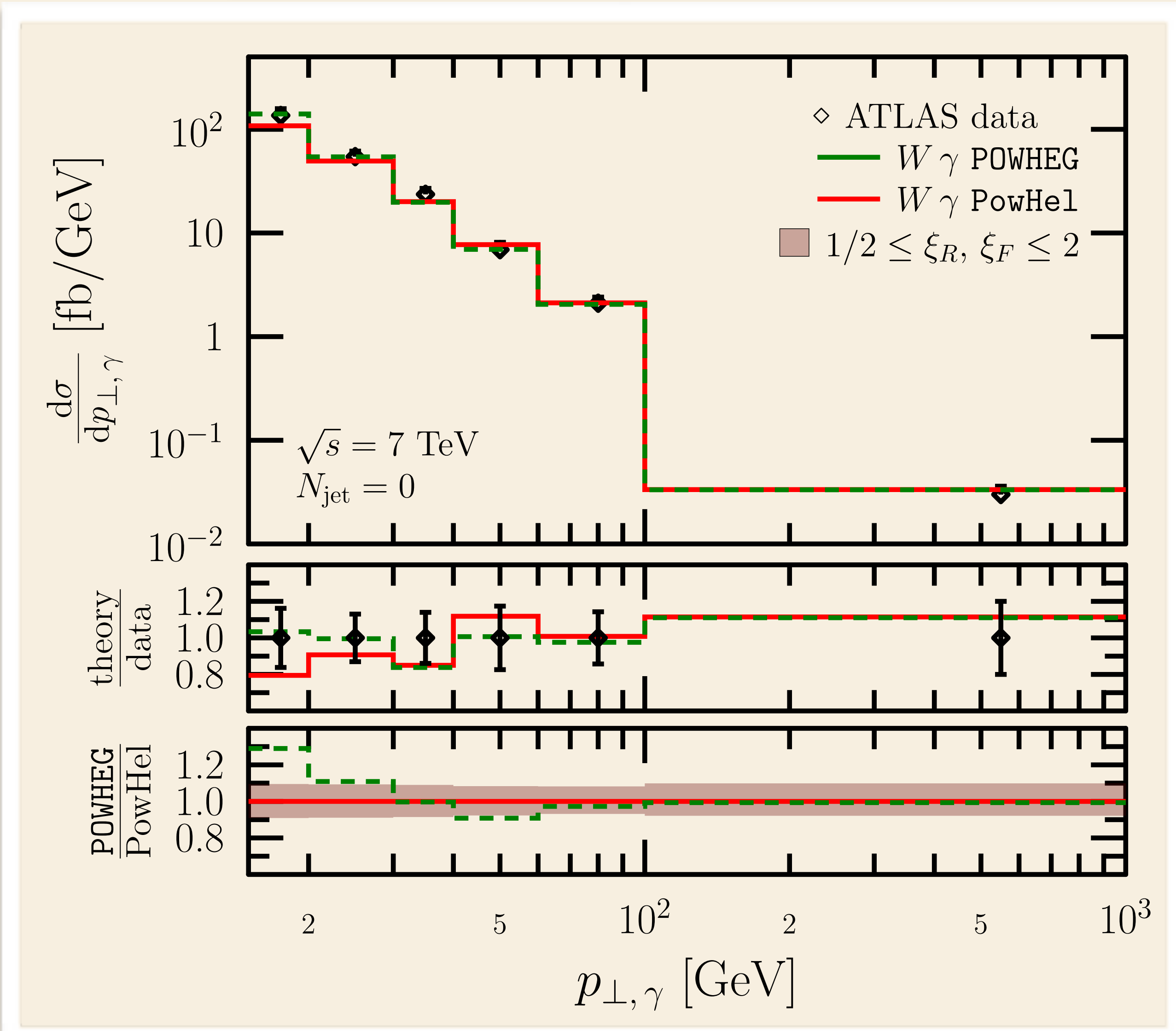
Physical predictions do not depend on the generation isolation…

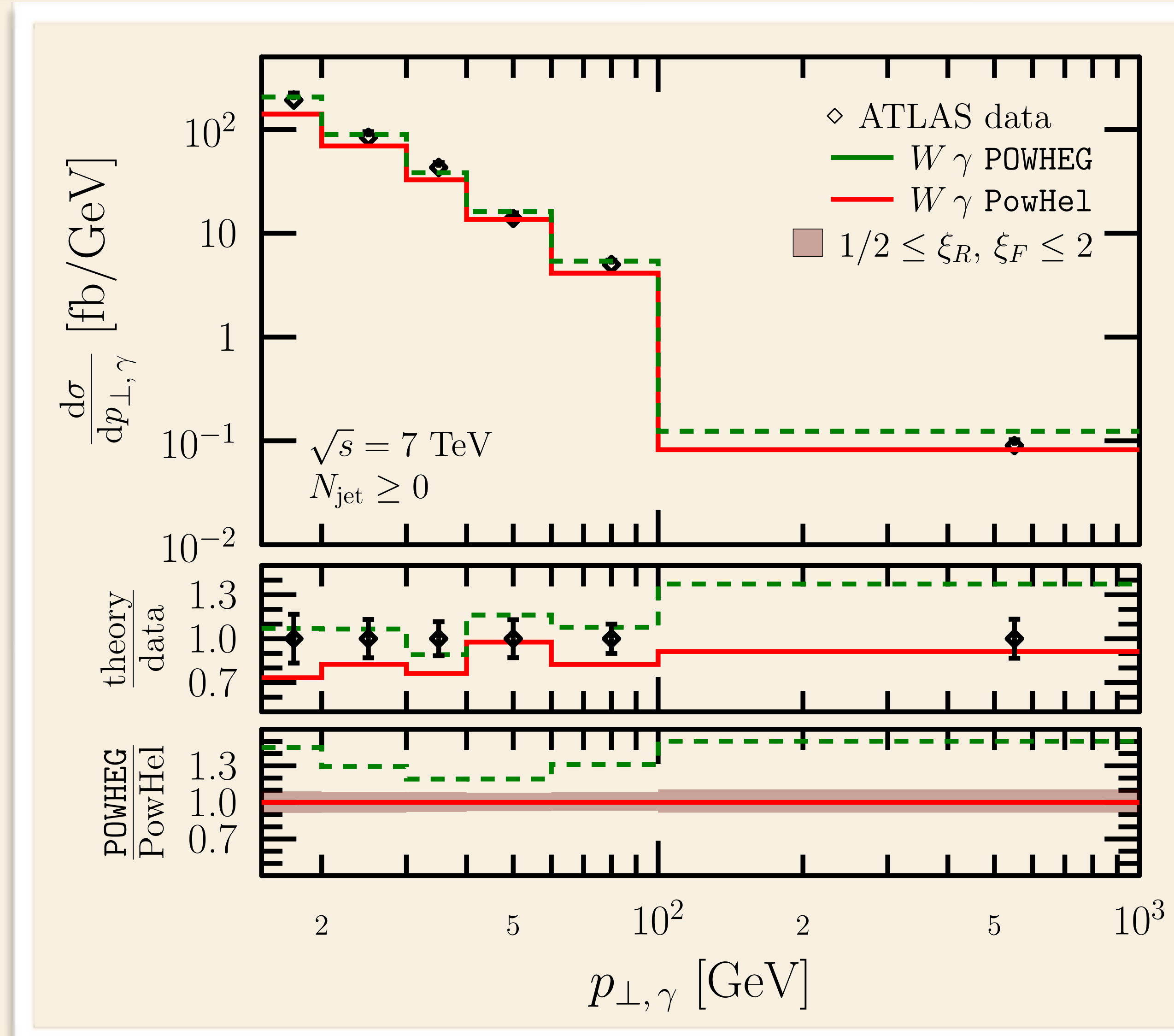




… if it is small enough

Check method with Wγ production





good description of ATLAS data if radiated photon is harder than accompanying jets

POWHEG (+MiNLO): [Barze et al: 1408.5766]

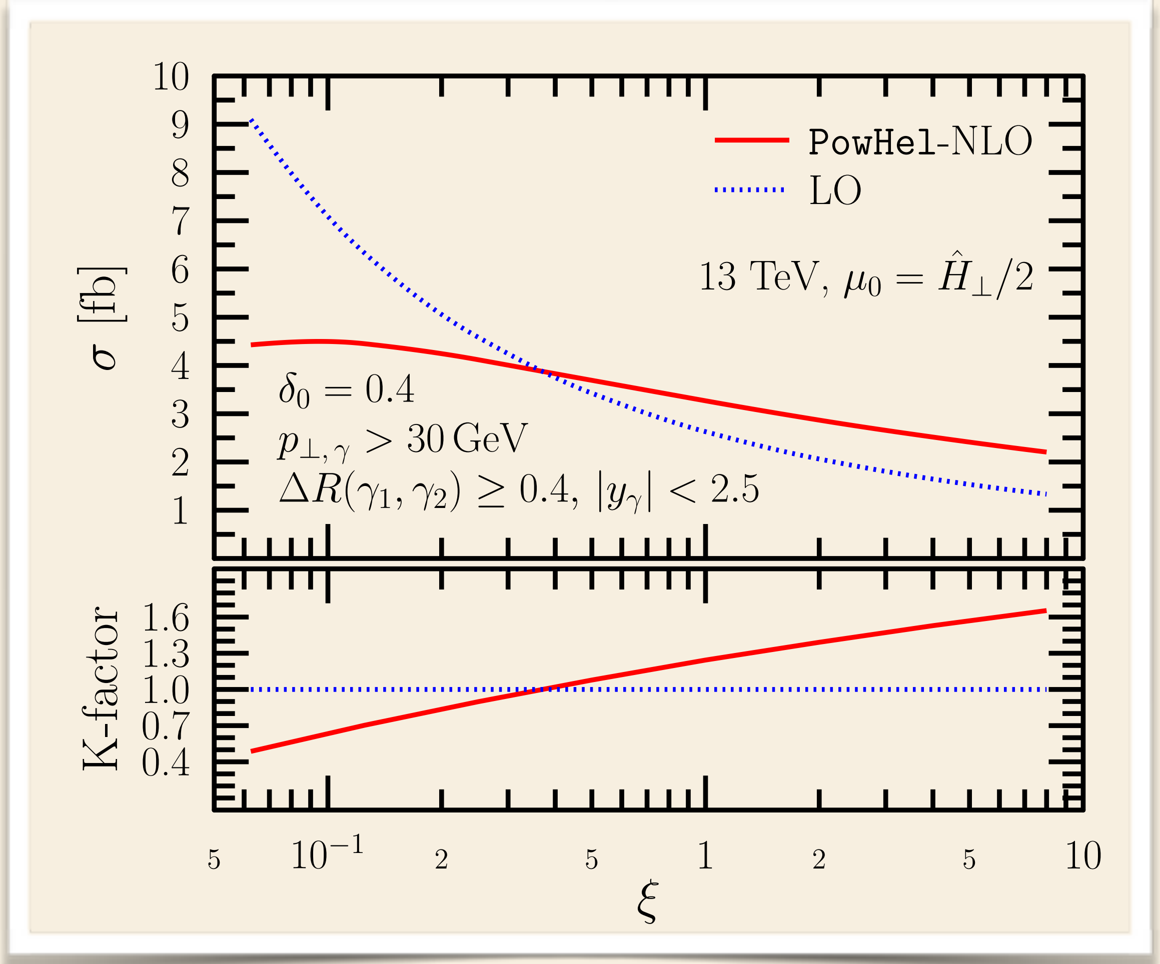
fragmentation is modeled by interleaved QCD+QED shower

$t\bar{t}\gamma\gamma$ hadroproduction at NLO and matched to PS

[Kardos and Trócsányi, arXiv: 1408.0278]

Choice of scales

We use the dynamical scale $\mu_{dyn} = H_T/2$, where H_T is the scalar sum of transverse masses of final-state particles present in the underlying Born event



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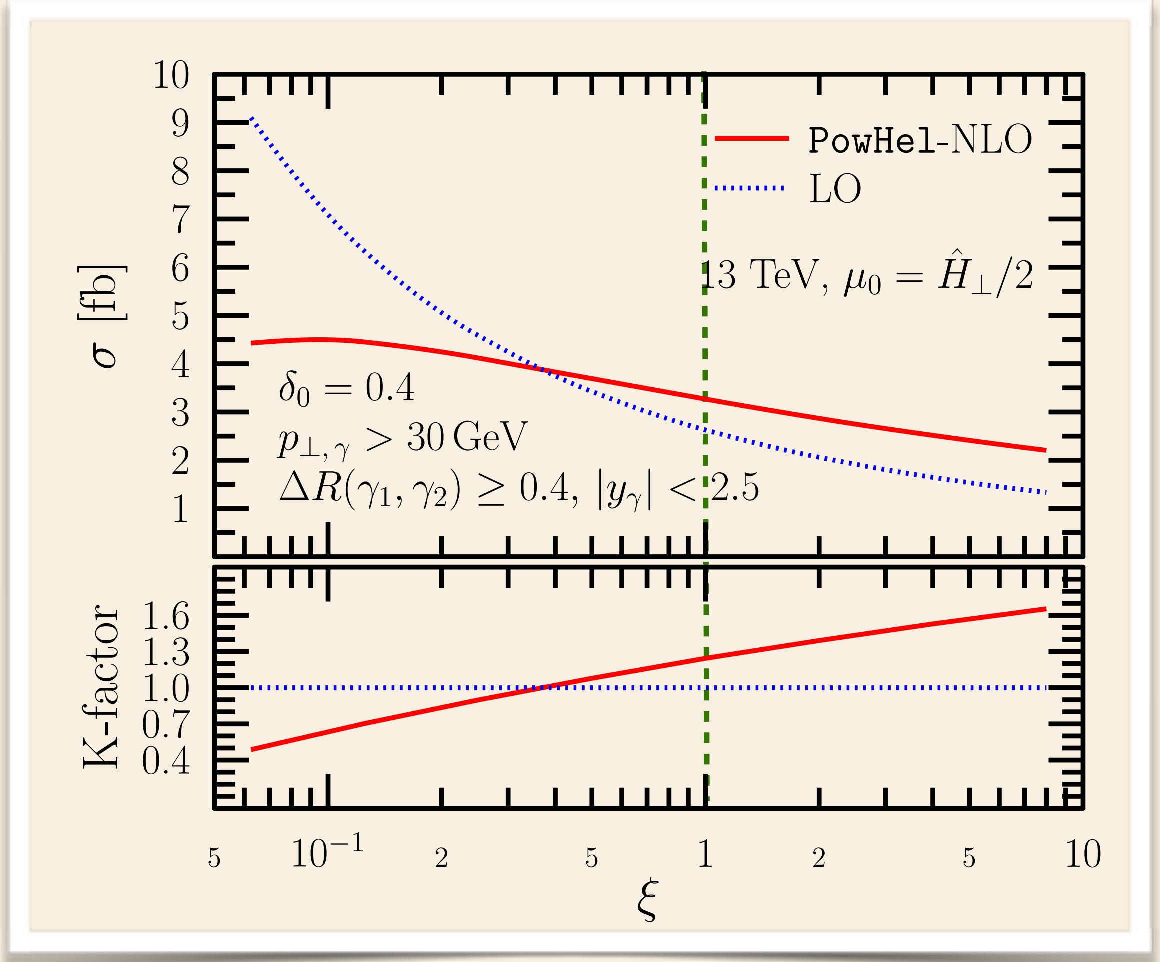
With this scale

✓ the K factor is moderate, implying good convergence

✓ σ_{LO} = 2.6 fb, σ_{NLO} = 3.3 fb
K = 1.24 (@ 13 TeV with cuts)



scale dependence:

LO: $^{+30\%}_{-27\%}$, NLO: $^{+14\%}_{-13\%}$, largest if $\mu_R = \mu_F = \mu_{dyn}$

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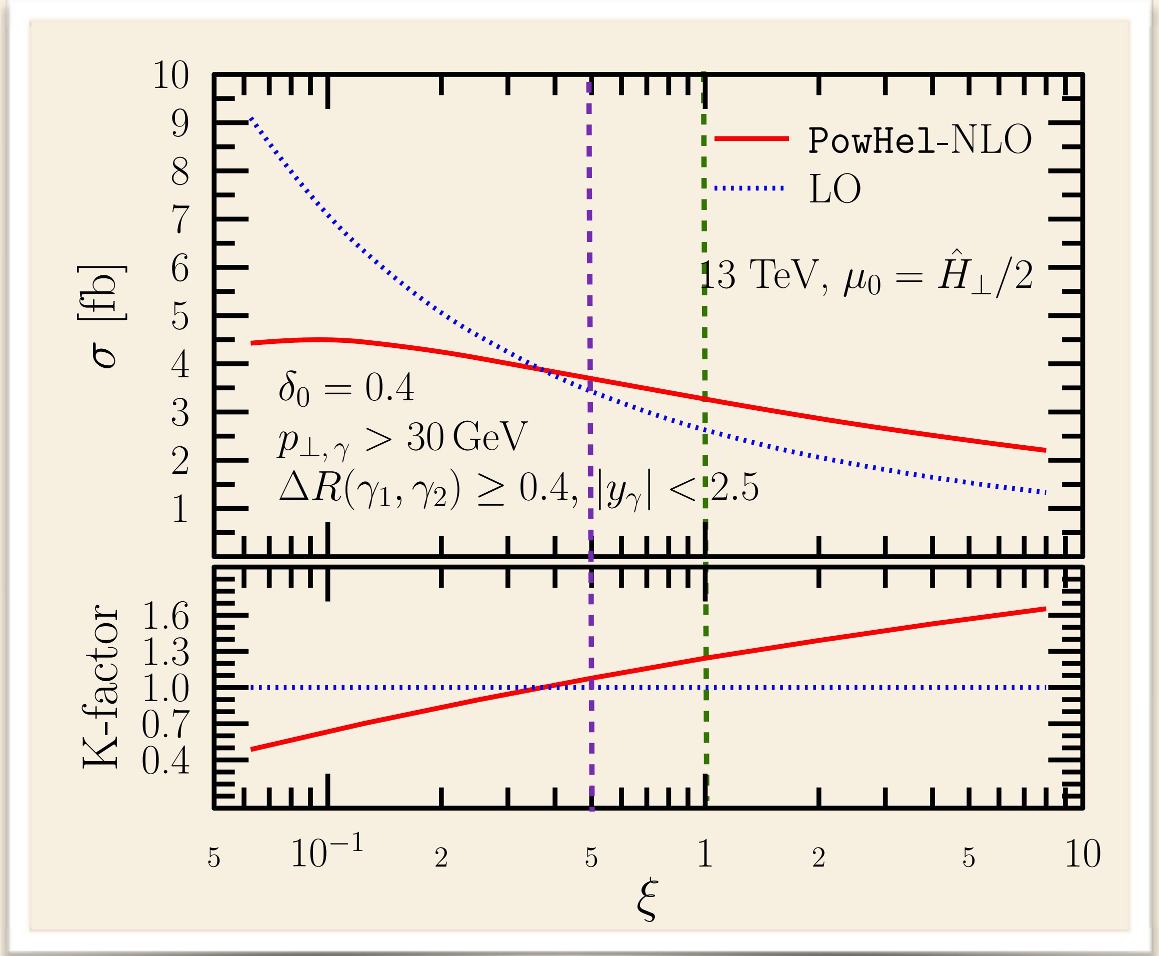

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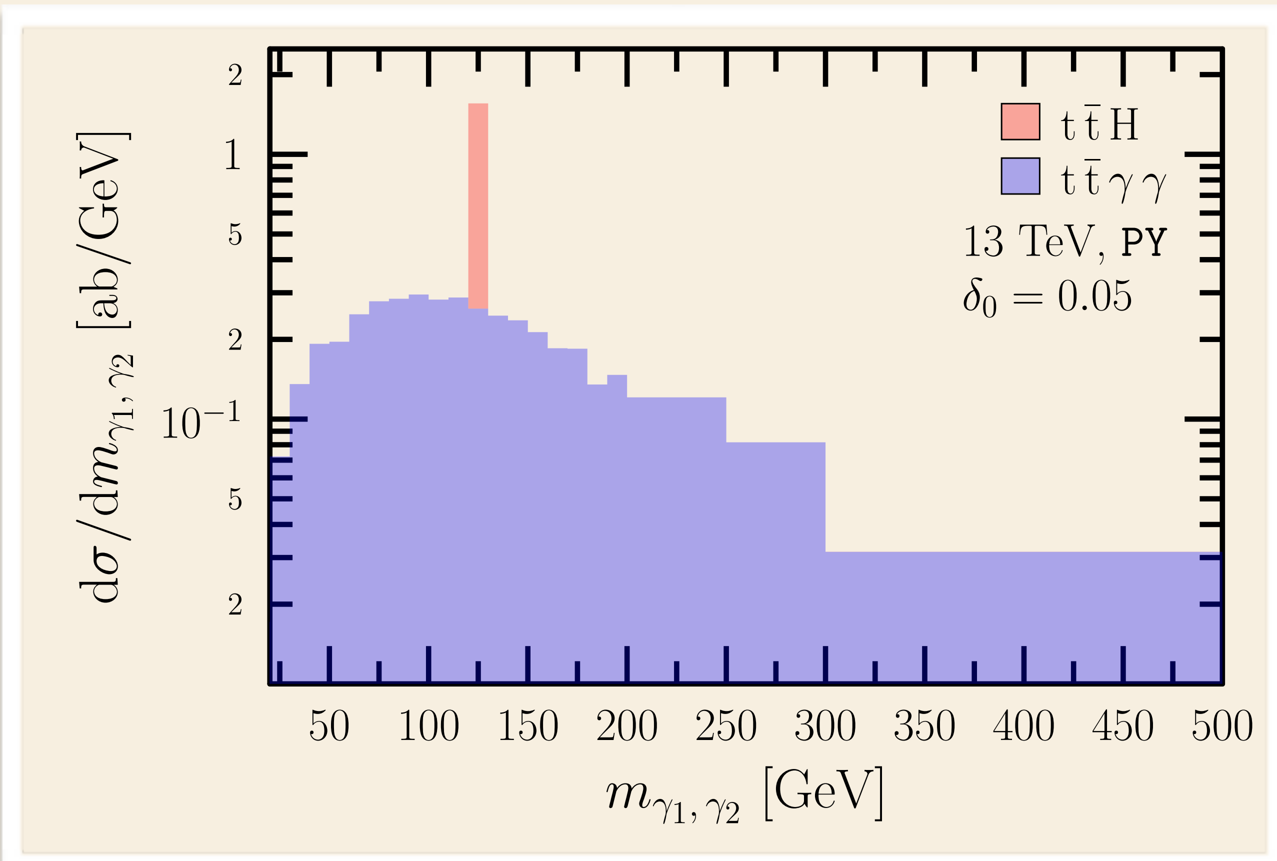
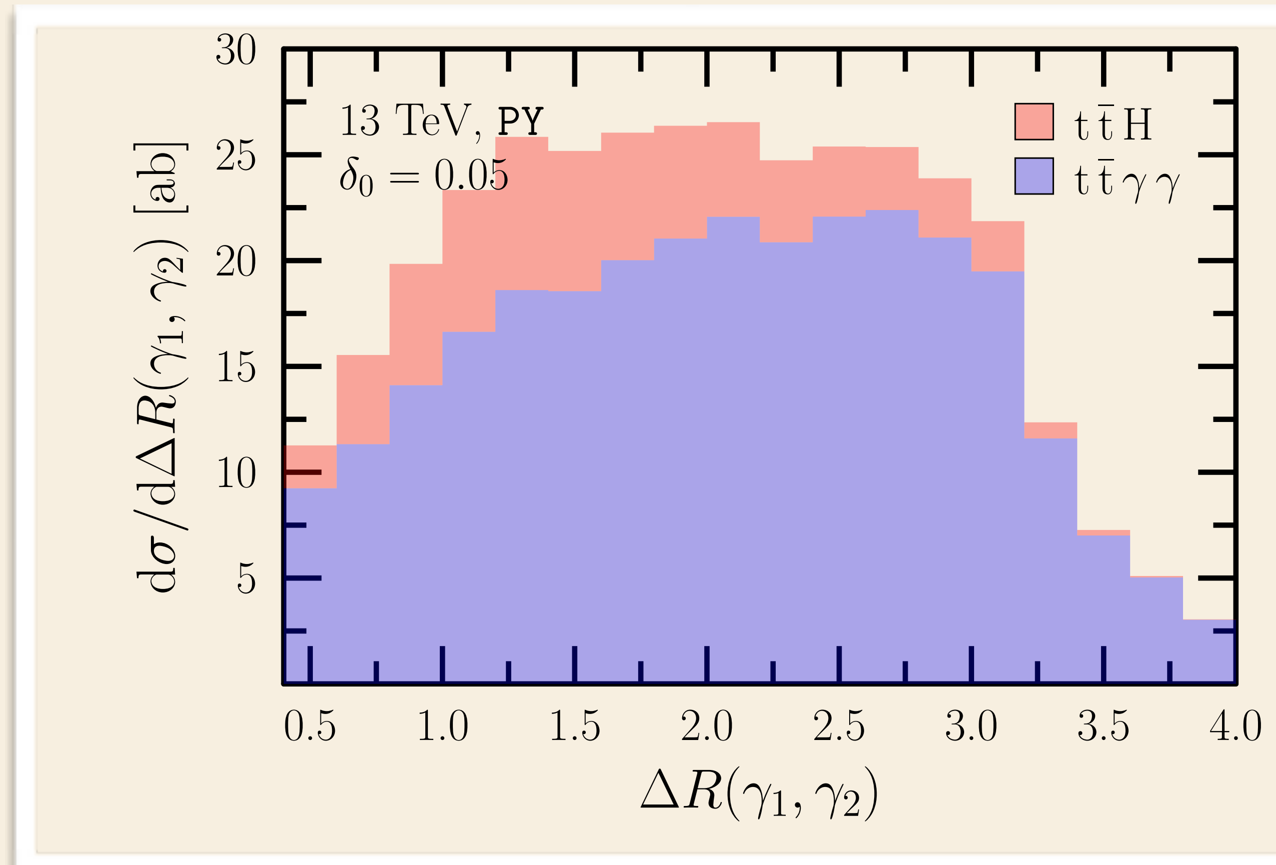
Combine with:

tTH hadroproduction at NLO
and matched to PS

[Garzelli, Kardos, Papadopoulos and Trócsányi, arXiv: 1108.0387]

$pp \to t\bar{T}\ (H \to \gamma\gamma)$ signal over $pp \to t\bar{T}\ \gamma\gamma$ background





obtained with HEPTopTagger, CT10NLO, PYTHIA-6.4.25

signal: $\mu_R = \mu_F = m_t + m_H/2 = (172.5 + 62.5)$ GeV

background: $\mu_R = \mu_F = H_T/2$

Conclusions

- POWHEG method offers a simple way for generating almost inclusive sample of pre-showered events with (loosely isolated) photons
- Predictions for hadroproduction of Wγ final states agree with ATLAS data if the photon is harder than the accompanying jet(s)
- Predictions presented for hadroproduction of tTγ and tTγγ final states at NLO accuracy (and matched with PS)
- Effects of PS are small
- Events are available on request or at http://grid.kfki.hu/twiki/bin/view/DbTheory/

Processes available in PowHel

✓ tT	[Kardos et al, arXiv:
✓ tT + Z	1111.0610,1111.1444,
✓ tT + W	1208.2665,
✓ tT + H/A	1108.0387,
✓ tT + j	1101.2672,
✓ WWbB	1405.5659, Friday 9:54
✓ tT + bB	1303.6291, 1408.0266
✓ tT, W + γ	1406.2324
✓ tT + γ γ	1408.0278]

The end

Extra slides

HEPTopTagger

- Jet reconstruction using all the hadronic tracks with the C/A algorithm with $R = 1.5$ using FastJet
- Only those jets were considered for which $p_\perp > 200$ GeV and $|y| < 5$
- The t-quark candidate subjets were looked for in the jet-mass range of 150–200GeV
- We selected that particular subjet as a t-quark jet for which the jet mass was the closest to m_t

Selection cuts for tTH signal

- Two hard photons in central region with $p_{\perp,\gamma} > 30$ GeV and $|y_\gamma| < 2.5$.
- The photons are isolated from each other: $\Delta R(\gamma_1, \gamma_2) > 0.4$.
- Jet clustering on all the hadronic tracks with the anti-$k_\perp$ algorithm as implemented in FastJet with $R = 0.4$ and $p_{\perp,j} > 30$ GeV. Photons are isolated from these jets by $\Delta R(\gamma, j) > 0.4$ measured in the rapidity-azimuthal angle plane.
- Both of the hard photons are isolated from the top jet obtained by top tagging and from the three subjets of the top jet by $\Delta R(\gamma,j) > 0.4$ measured on the rapidity-azimuthal angle plane.
- One hard lepton in the central region with $p_\perp > 30$ GeV and $|y_l| < 2.5$, without distinction between leptons and antileptons.
- The lepton is isolated from both the jets and the photons with $\Delta R(l, i) > 0.4$, $i \in \{\gamma, j\}$ measured on the rapidity-azimuthal angle plane.
- Around photons the minimal hadronic activity in a cone of $R = 0.4$ is $E_{max} = 3$ GeV.