# K Factors in H->ZZ*->4l

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### Thanks to a lot of people:

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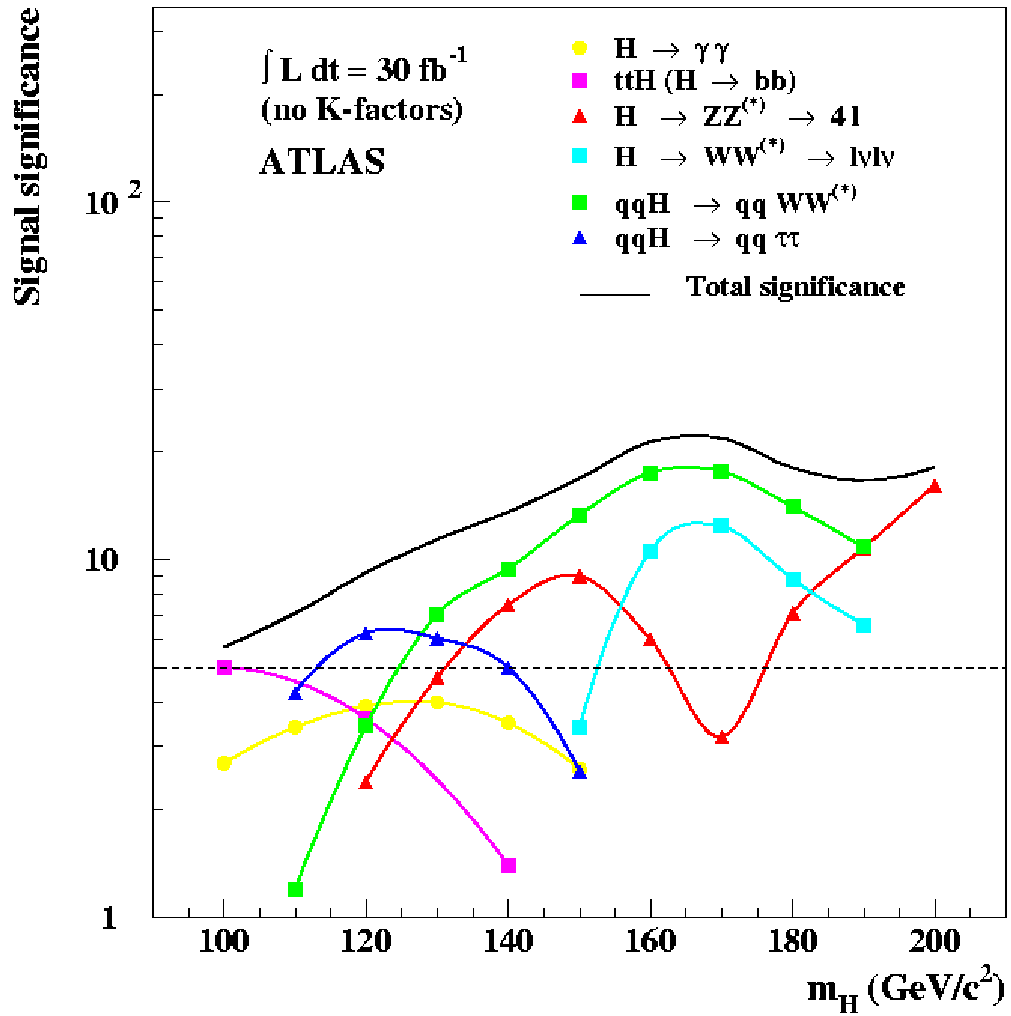
# Outline

- Revisiting the H->4l channels
  - Move towards NLO MC description
- K factor evaluation with MCFM
  - Effect of cuts and IFSR
- Significance and luminosity plots
- Further improvements
  - Higgs transverse momentum
  - NLO event generators
- Conclusions

# Revisiting the H->4l channels (1)

- VBF has changed the picture at low mass
- H->4l still powerful at low mass
  - Clean signature
  - Room for improvement
    - Large K factor
    - Exploit lepton angular correlations
- Heavy Higgs
  - Needs to be revisited



# Revisiting the H->4l channels (2)

- **After isolation cuts, ZZ main background**
  - LO MC used, need to move towards NLO MC's

## Expected number of events for 30 fb$^{-1}$ (TDR 1999)

| Higgs mass (GeV) | 120 | 130 | 150 | 170 | 180 |
|---|---|---|---|---|---|
| Signal | 4.1 | 11.4 | 26.8 | 7.6 | 19.7 |
| $t\bar{t}$ | 0.01 | 0.02 | 0.03 | 0.02 | 0.02 |
| $Zb\bar{b}$ | 0.08 | 0.12 | 0.19 | 0.17 | 0.19 |
| $ZZ^*$ | 1.23 | 2.27 | 2.51 | 2.83 | 2.87 |
| $ZZ \rightarrow \tau\tau ll$ | 0.13 | 0.20 | 0.25 | 0.08 | 0.02 |
| Significance ($S/\sqrt{B}$) | 3.4 | 7.0 | 15.5 | 4.3 | 11.2 |
| Significance (Poisson) | 2.4 | 4.8 | 15.5 | 3.2 | 11.2 |

## A couple of definitions

- **$K(NLO) = \sigma^{NLO} / \sigma^{LO}$ where $\sigma^{LO}$ is evaluated for $\mu_R$ (renormalization scale) and $\mu_F$ (factorization scale) such that $\mu_R = \mu_F = M_H$ ($M_Z$)**
- **$K(NNLO) = \sigma^{NNLO} / \sigma^{LO}$**

## For the sake of clarity

- **Distinguish between MC for <u>cross-section calculation</u> and MC for <u>event generation</u>**
- **NLO program used here is a MC for cross-section calculation**

# K factors with MCFM

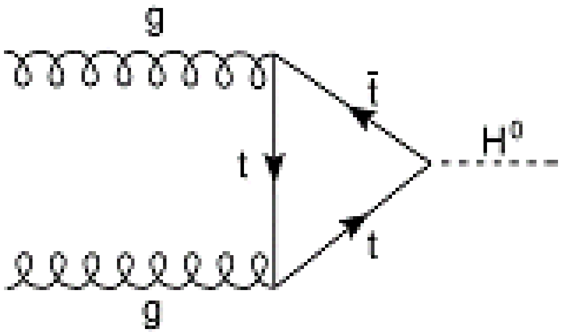
- MCFM (J.Campbell and K.Ellis) is used for K factors evaluation
  - Complete NLO ME based calculation
  - http://mcfm.fnal.gov/
  - Signal:
    - Contains ME for SM Higgs with major decays
    - Agrees with Spira's program for total Higgs NLO cross-section
  - Background:
    - Full ZZ ME treatment (with decays)
    - In agreement with previous NLO calculations

# Effect of cuts on K factors (1)

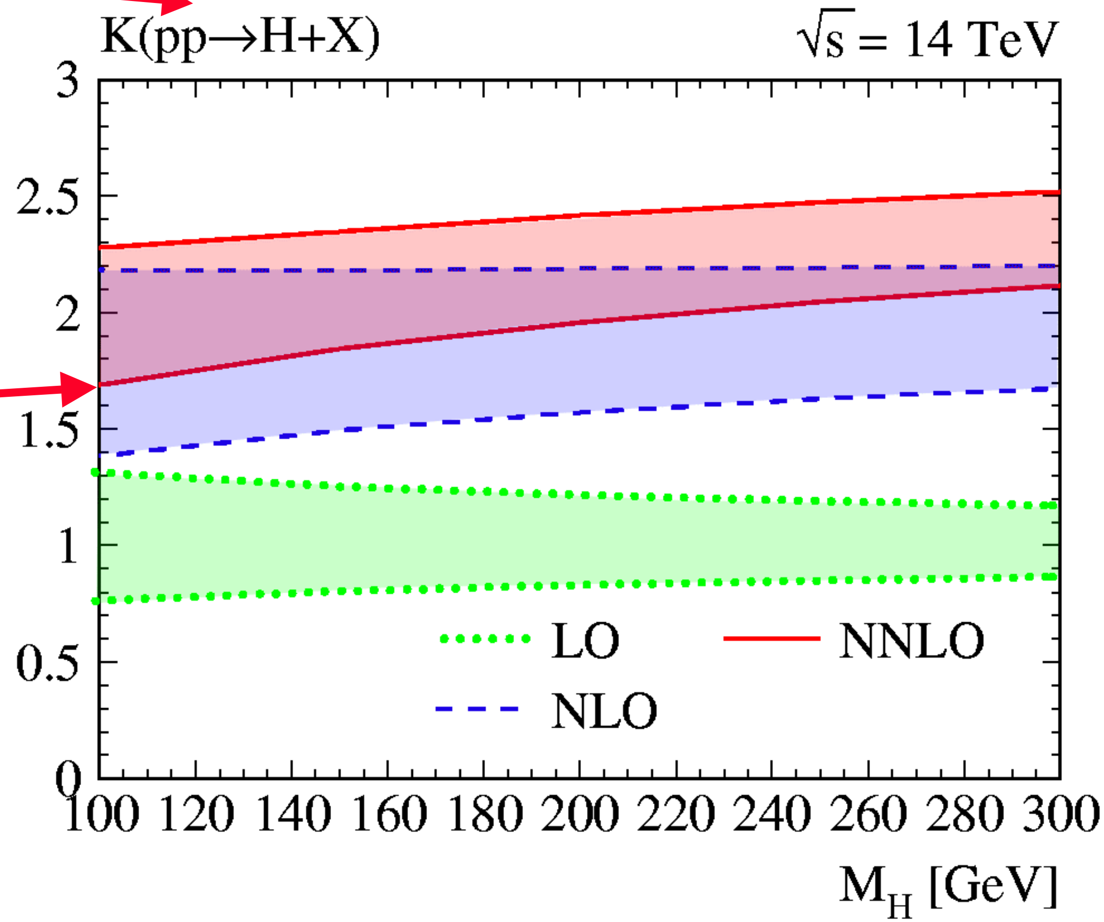
- K factors, K(NLO), usually refer to the ratio of NLO to LO total cross-sections after integrating over transverse momentum and angles of incoming and outgoing particles
  - Experiments apply cuts on transverse momentum and angles of decay particles in final state
  - K(NLO) should not be applied on MC's
  - $K_{CUTS}$(NLO) needs to be implemented:

$$K_{CUTS}(NLO) = \frac{\int_{CUTS} \sigma(NLO)}{\int_{CUTS} \sigma(LO)}$$

# Effect of cuts on K factors (2)



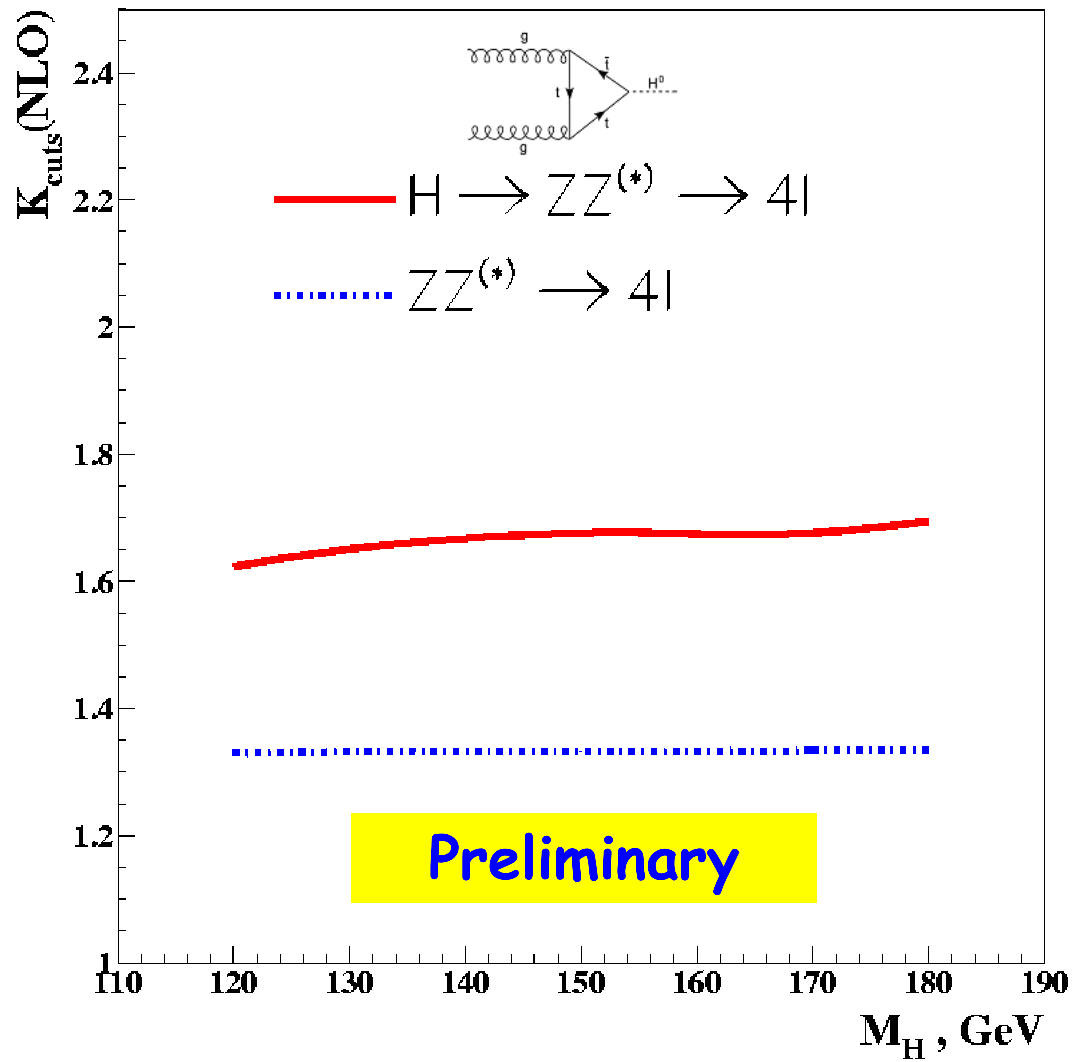

**After R.Harlander**




- "Theoretical" K(NLO) normalized to lowest possible value for NNLO calculation
  - K(NLO)=1.7 for $M_H$=120 GeV
  - Conservative estimate

# Effect of cuts on K factors (3)

- Applied selection cuts presented in TDR for <u>low mass Higgs:</u>
  - Lepton $P_T$ thresholds
  - Lepton invariant masses
  - Lepton isolation
- Effect of cuts:
  - Signal:
    - $K_{CUTS}/K \approx 0.95$
  - ZZ:
    - $K_{CUTS}/K \approx 1$
- Small cut effect for low mass Higgs



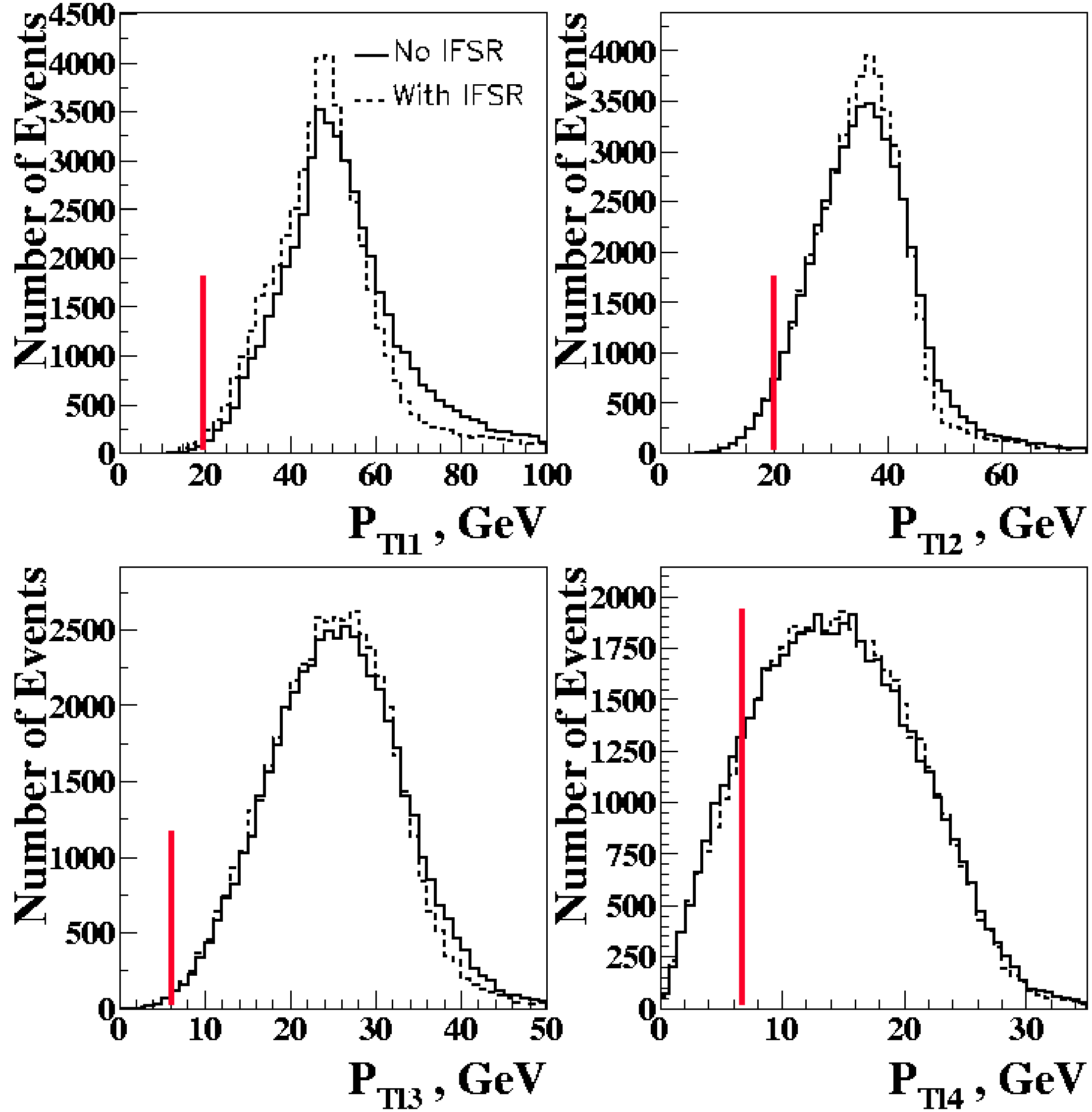
# Effect of IFSR (1)

- LO ME + IFSR strictly speaking <u>is no more LO:</u>
  - IFSR used not only to cure infrared and collinear divergences:
    - IFSR used for hard parton emission
    - IFSR hard emission changed transverse momentum of final state particles
- Before blindly applying K factors on MC's one should check kinematical effect of hard IFSR:
  - Define $\varepsilon_{CUTS}(PS)$ at parton level:

$$\varepsilon_{CUTS}(PS) = \frac{\int_{CUTS} \sigma_{IFSR}(LO)}{\int_{CUTS} \sigma_{NOIFSR}(LO)}$$

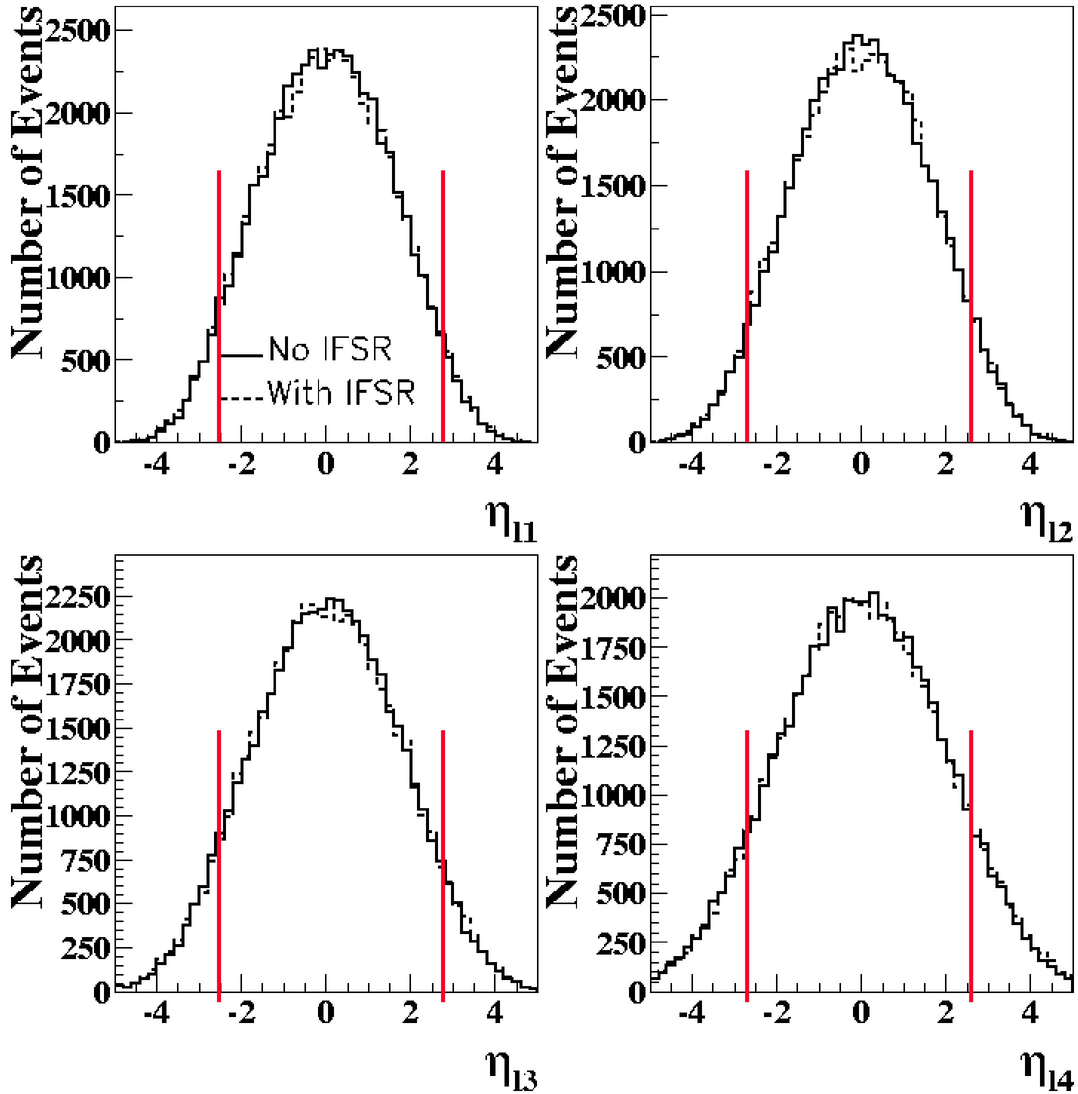
# Effect of IFSR (2)

- H->ZZ*->4l with and without IFSR
  - Leptons ordered in transverse momentum
- Hard IFSR parton radiation changes the transverse momentum in high $P_T$ region
  - Expect little effect on low mass analysis



# Effect of IFSR (3)

- H->ZZ*->4l with and without IFSR
  - Leptons ordered in transverse momentum
- IFSR has little effect on pseudorapidity distributions of leptons



# Effect of IFSR (4)

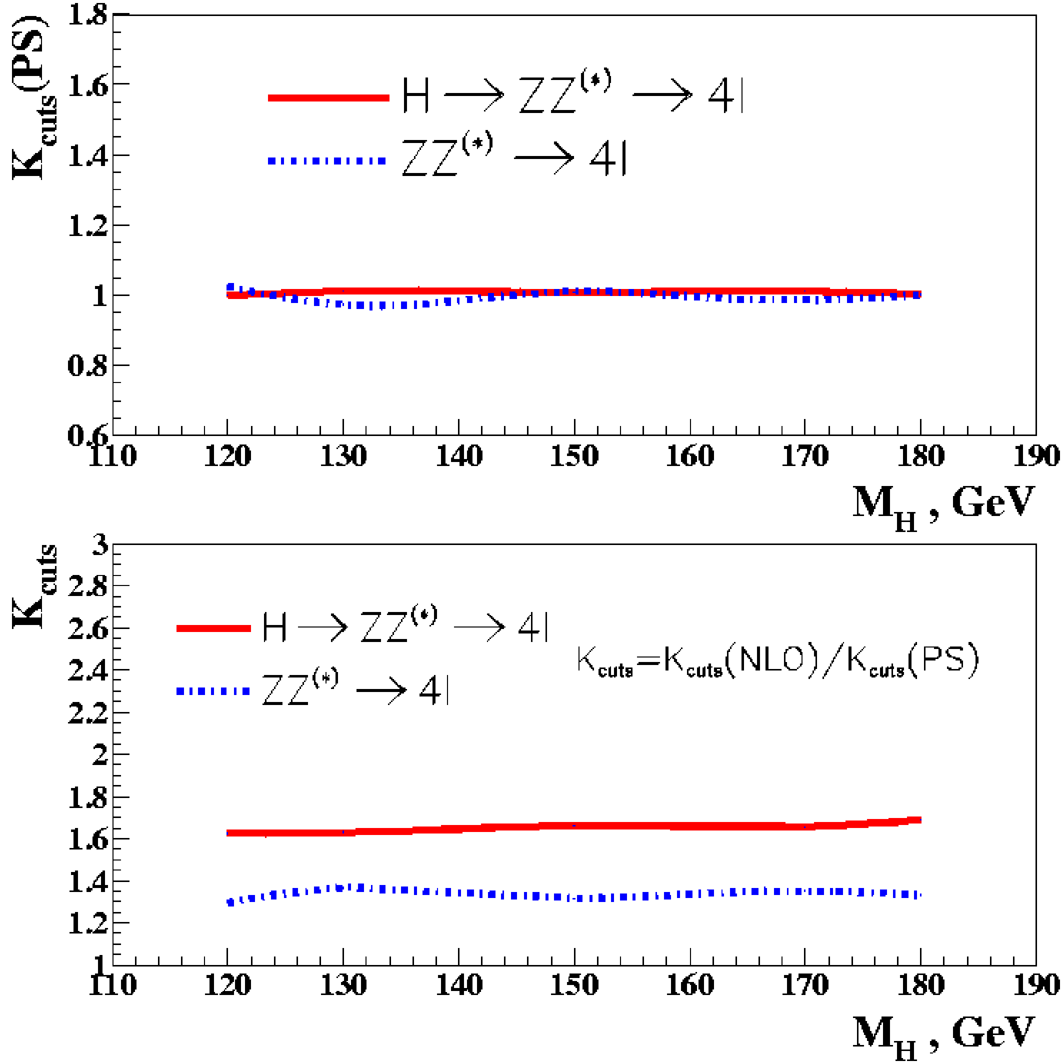
**Preliminary**

- Strictly speaking one should correct for IFSR effects:

$$K_{CUTS} \approx K_{CUTS}(NLO) / \varepsilon_{CUTS}(PS)$$

- Because in <u>low mass</u> analysis thresholds are low effect of IFSR is small:

$$K_{CUTS}^{LowMass} \approx K_{CUTS}(NLO)$$



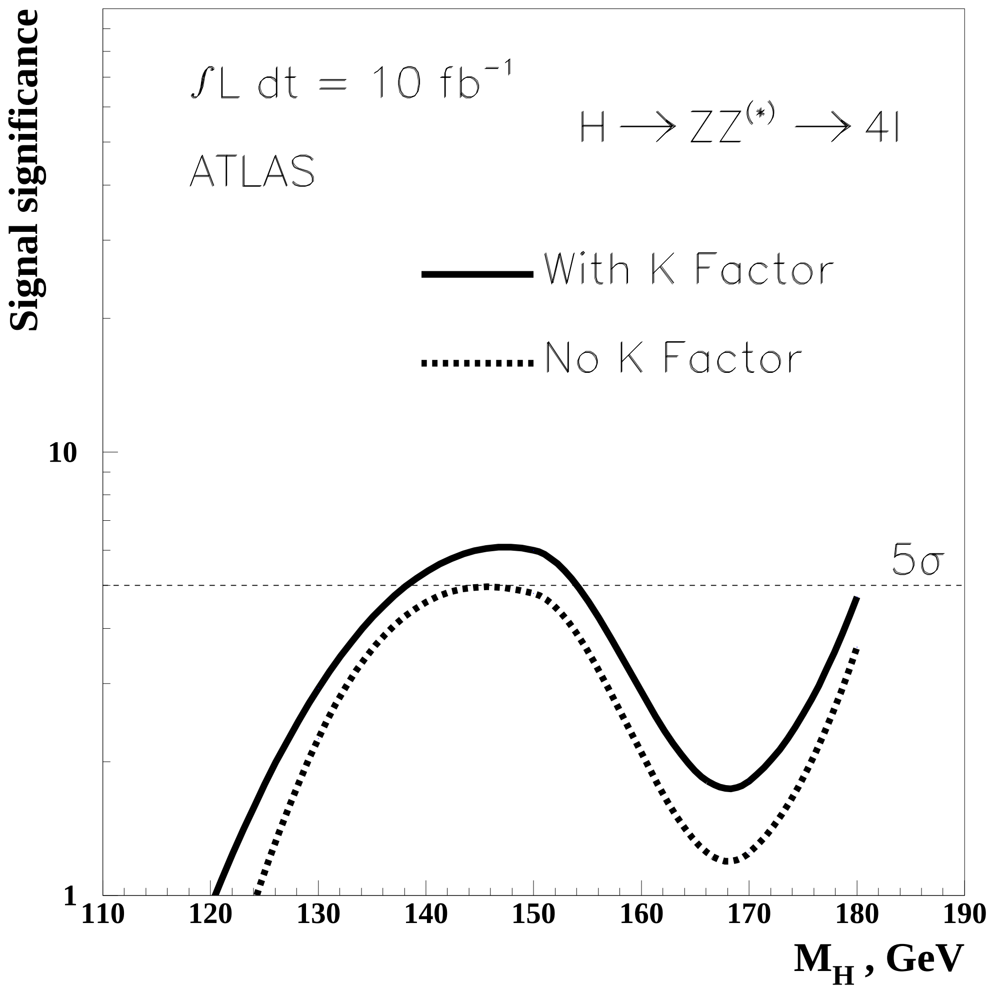
# "Effective" K factor

- gg-fusion does not saturate the LO cross-section
  - Conforms about 70% of the total LO cross-section
    - Apply $K_{VBF}$(NLO)=1.1. "Effective" K factor≈1.5

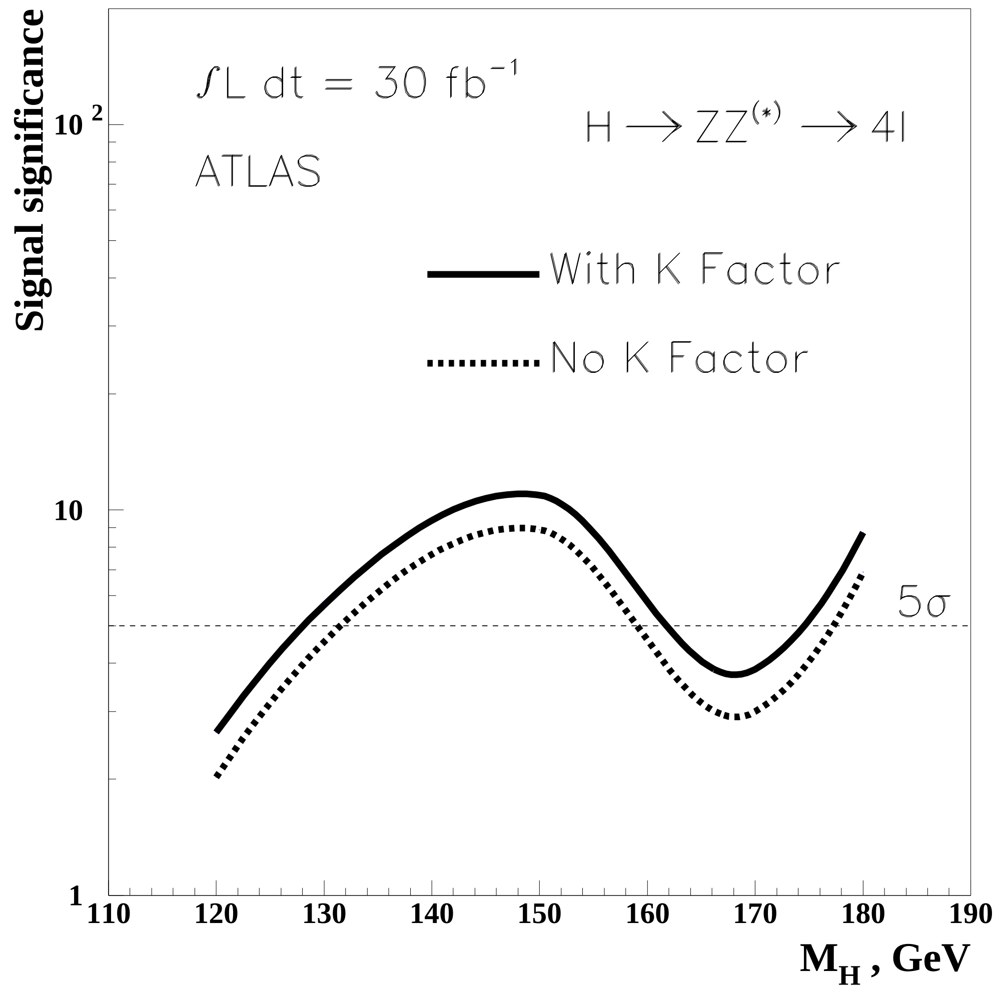
| $M_H$(GeV) | $\sigma_{VBF}$ | $\sigma_{gg}$ | $\sigma_{tot}$ | $\sigma_{VBF}/\sigma_{tot}$ | $\sigma_{gg}/\sigma_{tot}$ |
|---|---|---|---|---|---|
| 120 | 4.20 | 17.21 | 23.96 | 0.18 | 0.72 |
| 130 | 3.94 | 14.80 | 20.75 | 0.19 | 0.72 |
| 140 | 3.61 | 13.13 | 18.28 | 0.20 | 0.72 |
| 150 | 3.44 | 11.65 | 16.35 | 0.21 | 0.71 |
| 160 | 3.19 | 10.46 | 14.67 | 0.22 | 0.71 |
| 170 | 2.95 | 9.39 | 13.21 | 0.22 | 0.71 |
| 180 | 2.80 | 8.42 | 12.04 | 0.23 | 0.71 |

# Signal Significance

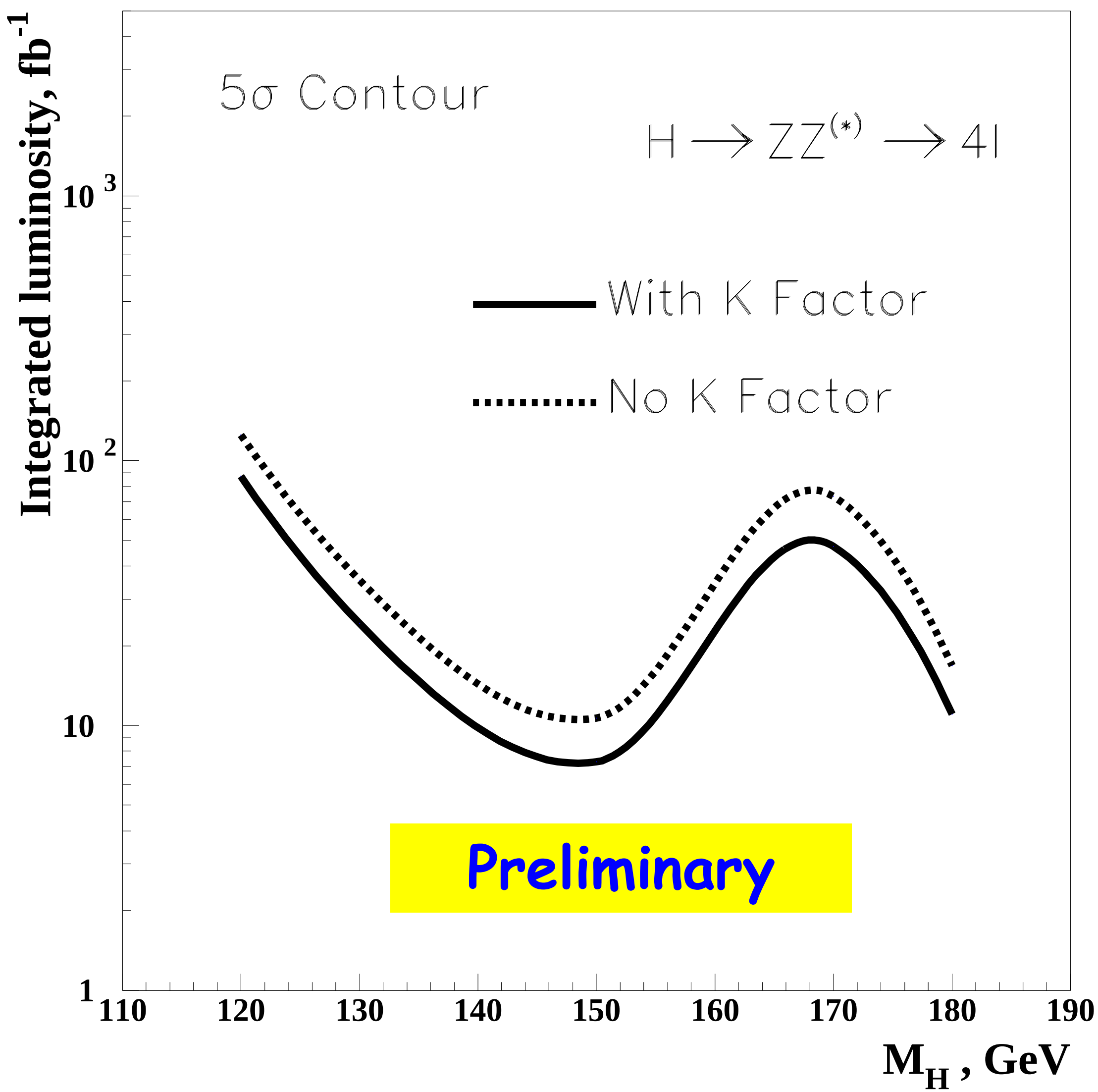
Preliminary




Preliminary



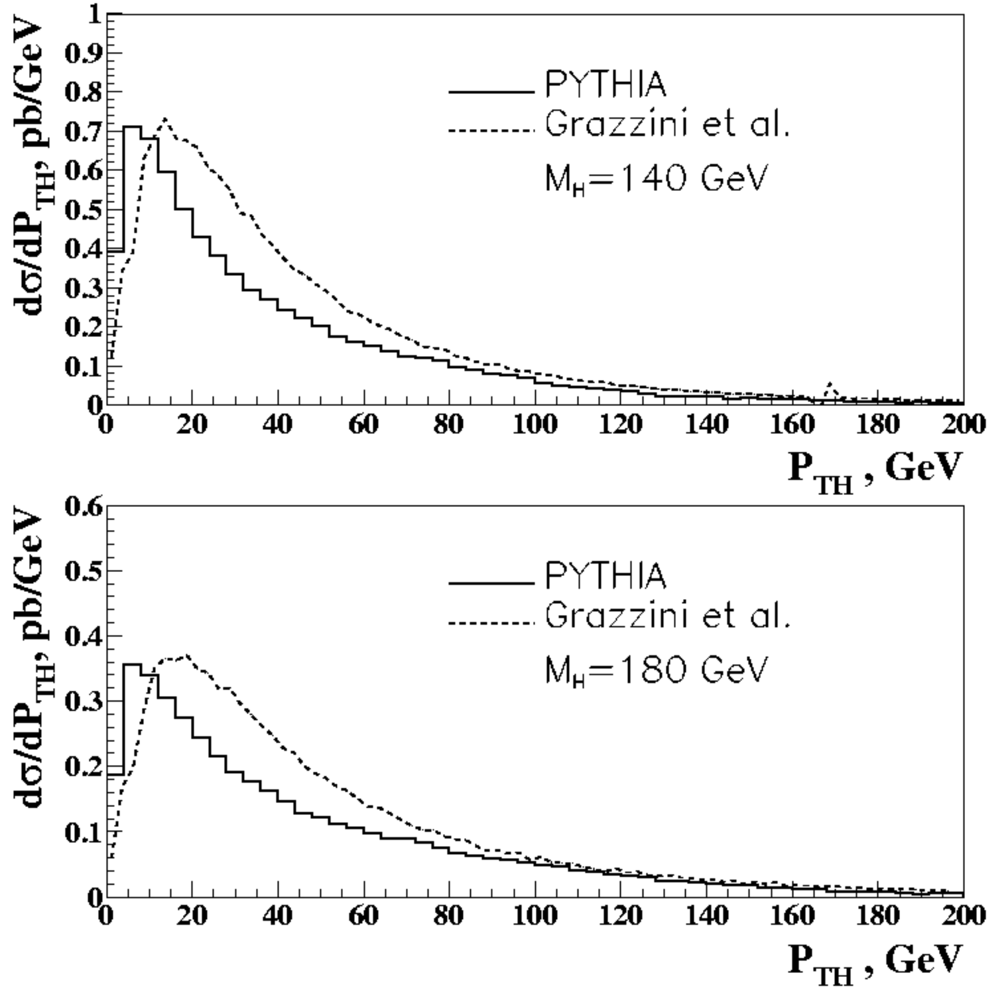
# Luminosity Plot



# Higgs $P_T$ (1)

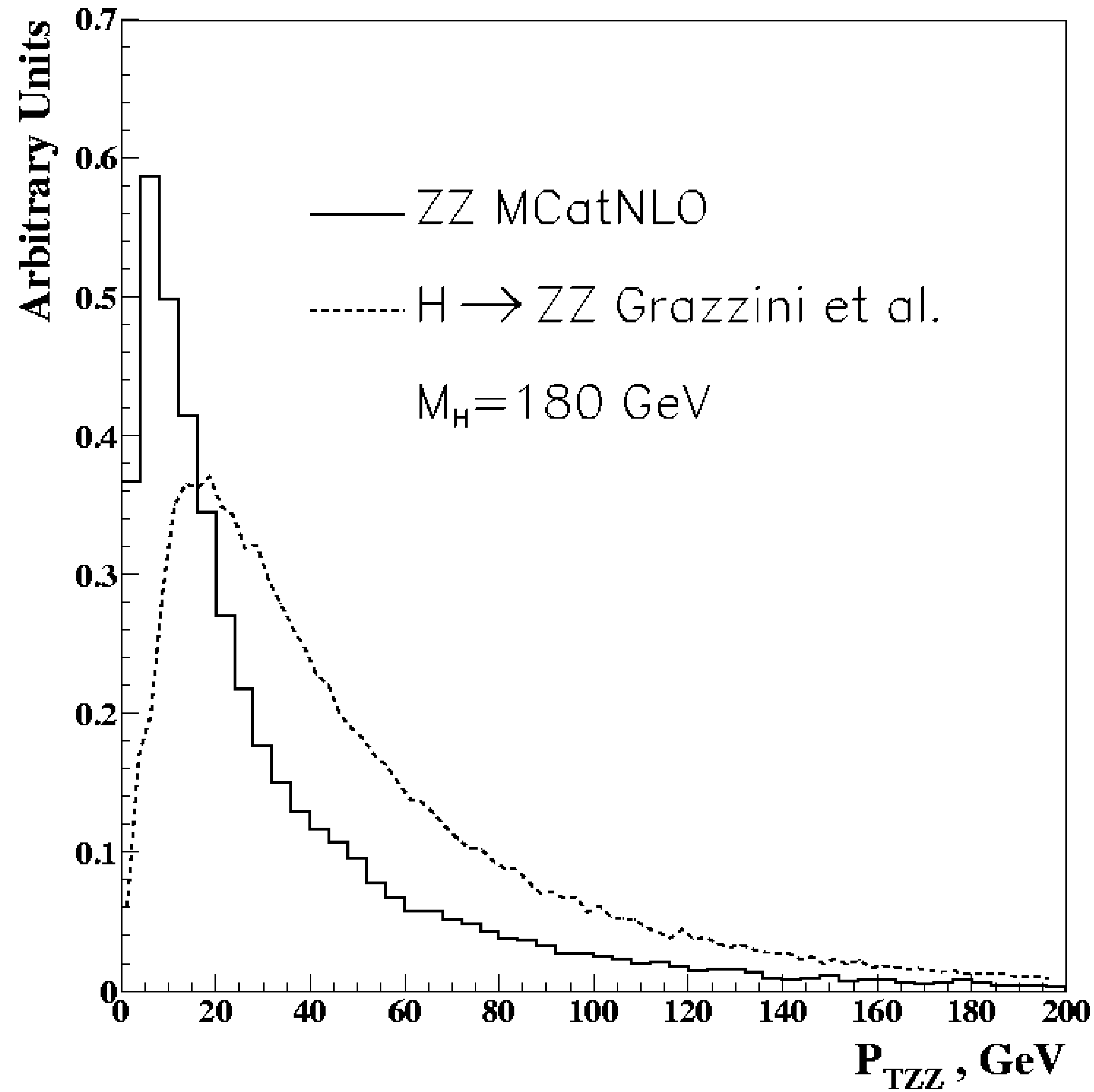
hep-ph/0302104

- Higgs $P_T$, a very important discriminating variable
- A lot of progress in theory:
  - Within $M_{TOP}$->∞ limit
  - NNLO accuracy in perturbation theory
  - All order re-summation
    - NNLL accuracy
- Much harder spectrum compared to parton shower prediction



# Higgs $P_T$ (2)

- May help suppress background in low mass analysis
- Very important for high mass analysis

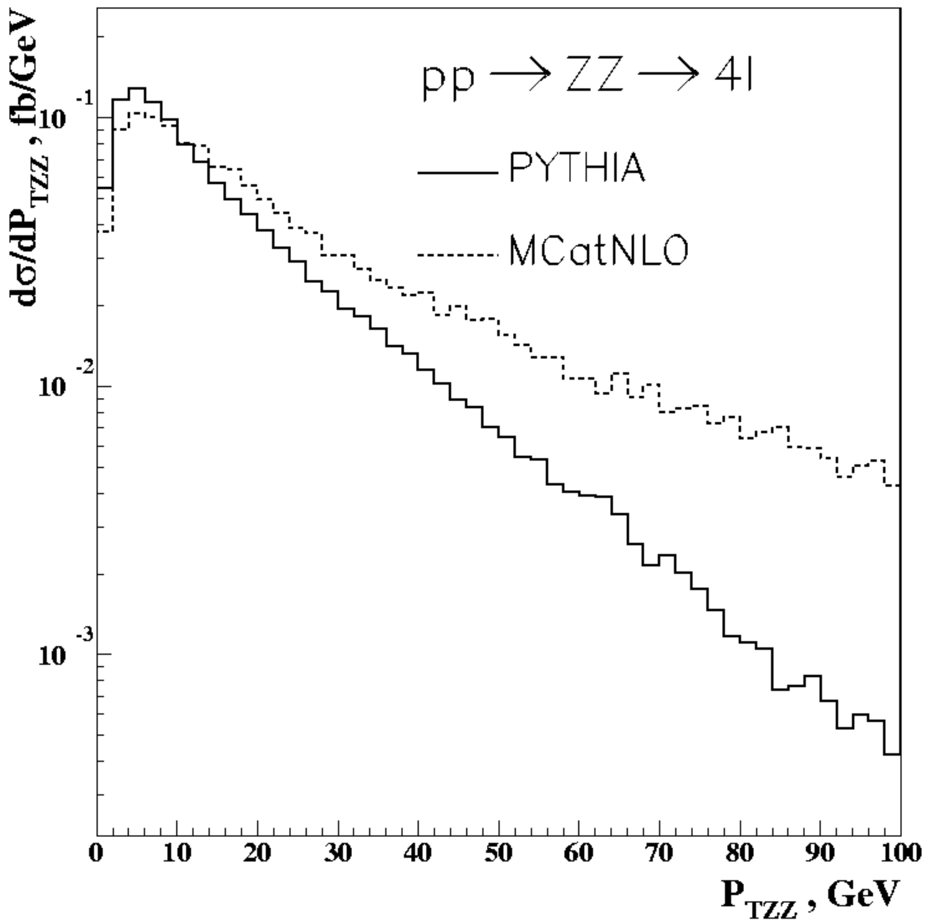


# Event Generators (1)

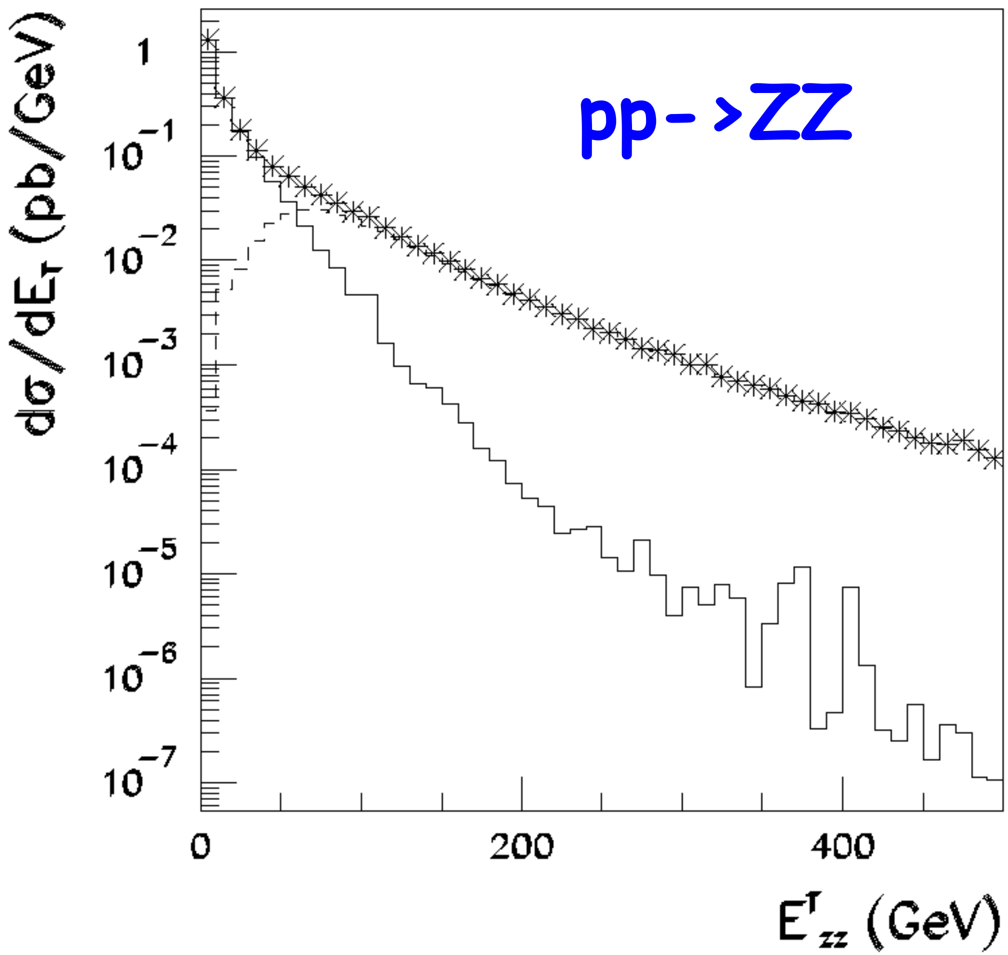
- MCFM does not provide event generation
  - Fine for cut analyses
    - May profit from more realistic Higgs $P_T$ prediction
  - Need a NLO event generator for multivariate analyses
- New recent developments in ZZ production:
  - Matrix element and parton shower matching
    - MC@NLO, S.Frixione, B.Webber, hep-ph/0204244
      - Total rates good to NLO
    - Y.Kurihara et al., Nucl. Phys. B654 (2003) 301-319
      - Total rates good to LO

# Event Generators (2)

**MC@NLO**




**Kurihara et al.**



# Conclusions

- Signal and main background K factors in H->ZZ*->4l analysis evaluated with MCFM
  - Effect of cuts and IFSR small
- Reduction of 30-35% in luminosity for discovery with conservative K factor!
- Envision further improvements:
  - Use Higgs $P_T$ as discriminating variable
  - Move to multivariate analysis
    - Use NLO event generators
  - Revisit lepton isolation full simulation study
- Will move to high masses
  - Role of Higgs's $P_T$ is more important