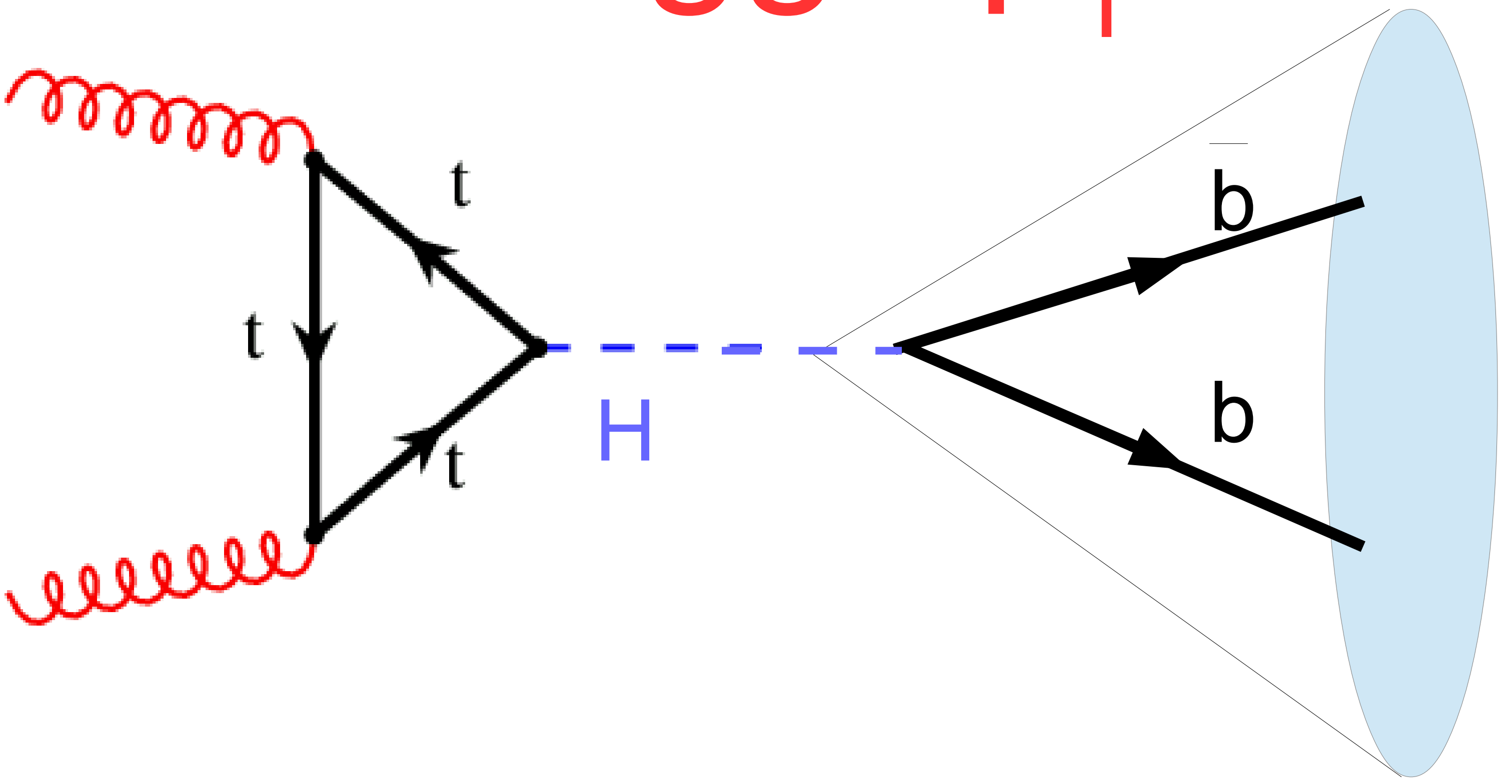
Higgs p_T



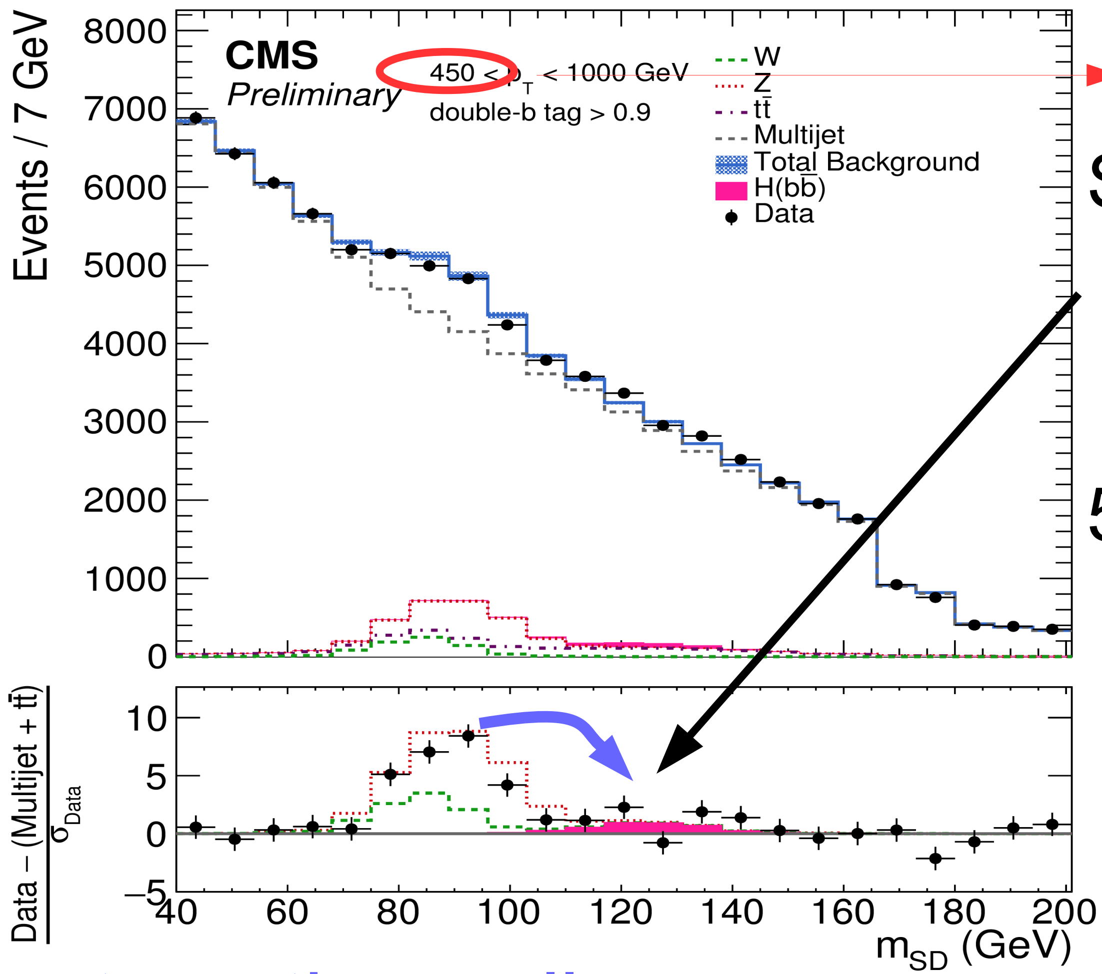
Phil Harris
for CMS (MIT)

A new analysis

μ(Powheg)=3.1

$\mu_Z = 0.776\ -0.142/+0.142\ \text{(stat.)}\ -0.126/+0.187\ \text{(syst.)}$

$\mu = 2.321\ -1.505/+1.511\ \text{(stat.)}\ -0.433/+0.982\ \text{(syst.)}$



Really high p_T

Sensitivity is 1σ @35fb-

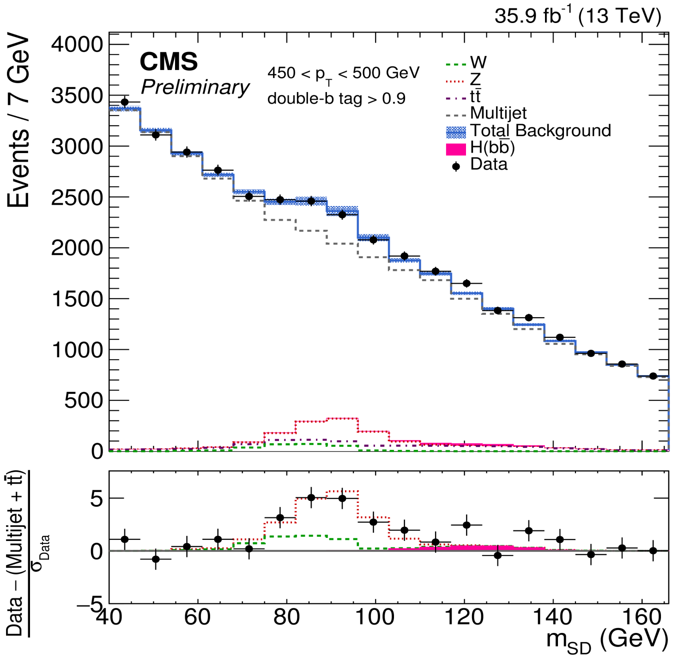
5σ sensitivity for Higgs production

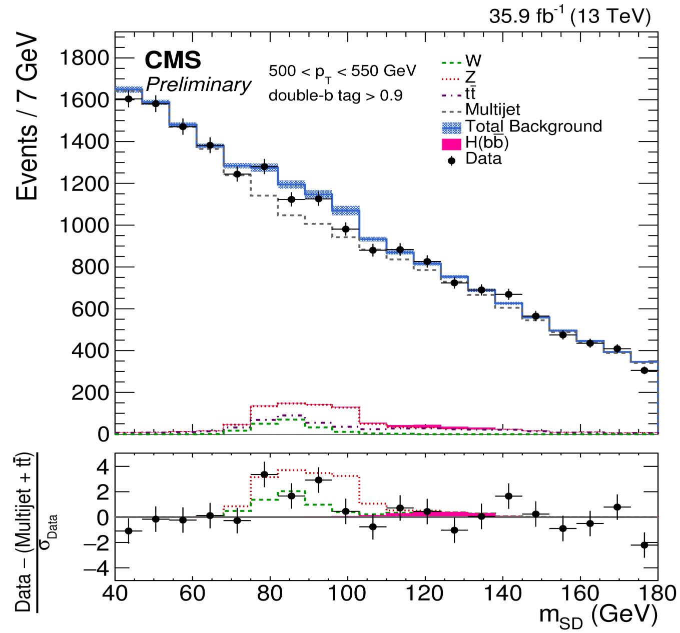
No systematics wall.

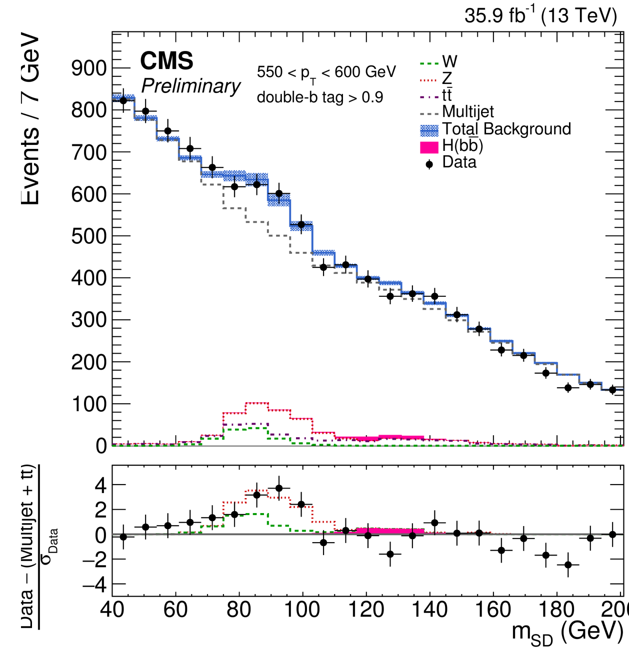
Everything determined by its neighbour (Z) except p_T

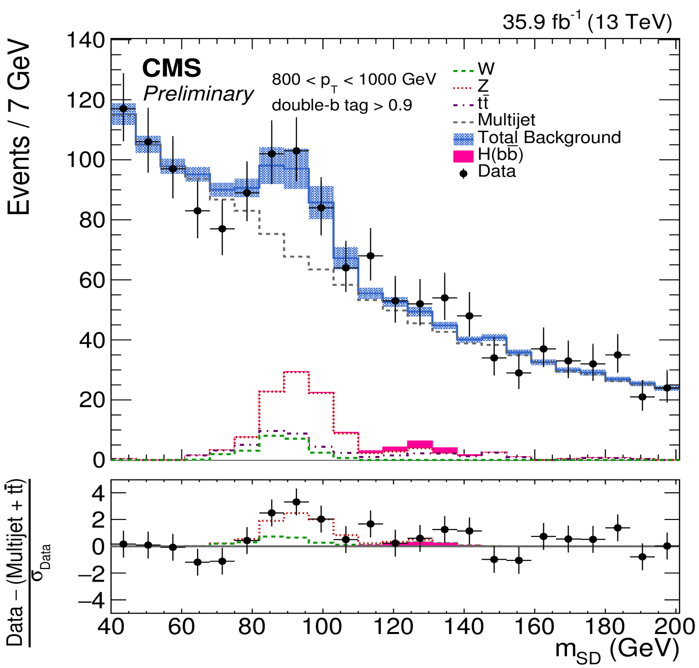
For Higgs we use 6 bins 450-1000 GeV

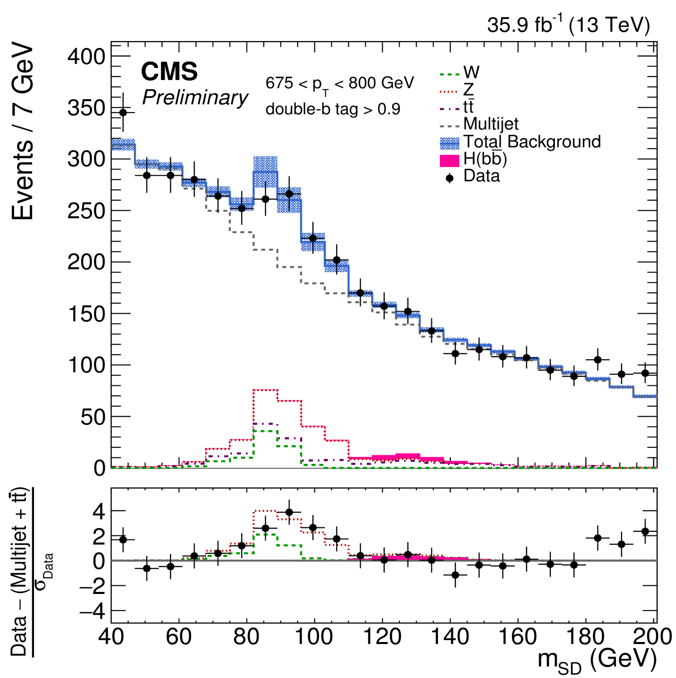
The Full p_T range

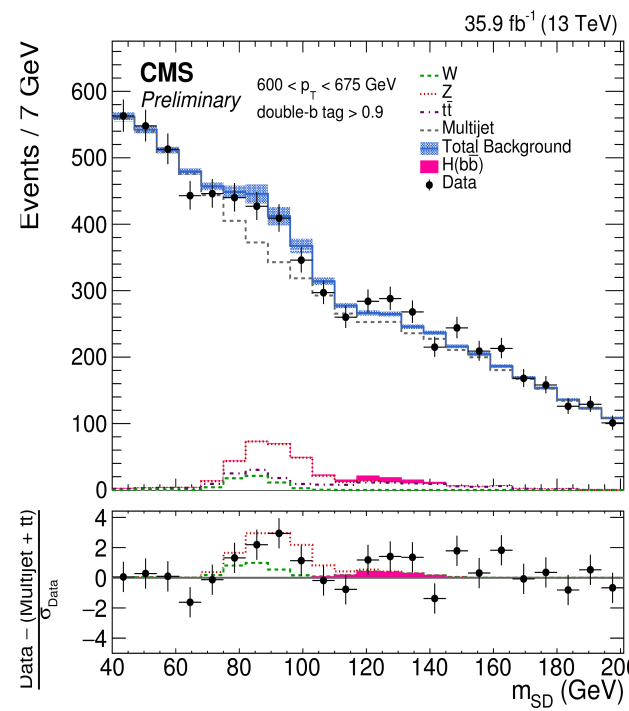












Overview Slide

- Some cause for concern:
  - Quoted cross section seems very large
  - When comparing cross section with other resutls
    - Appears larger than previous estimates
    - We will get back to this concern

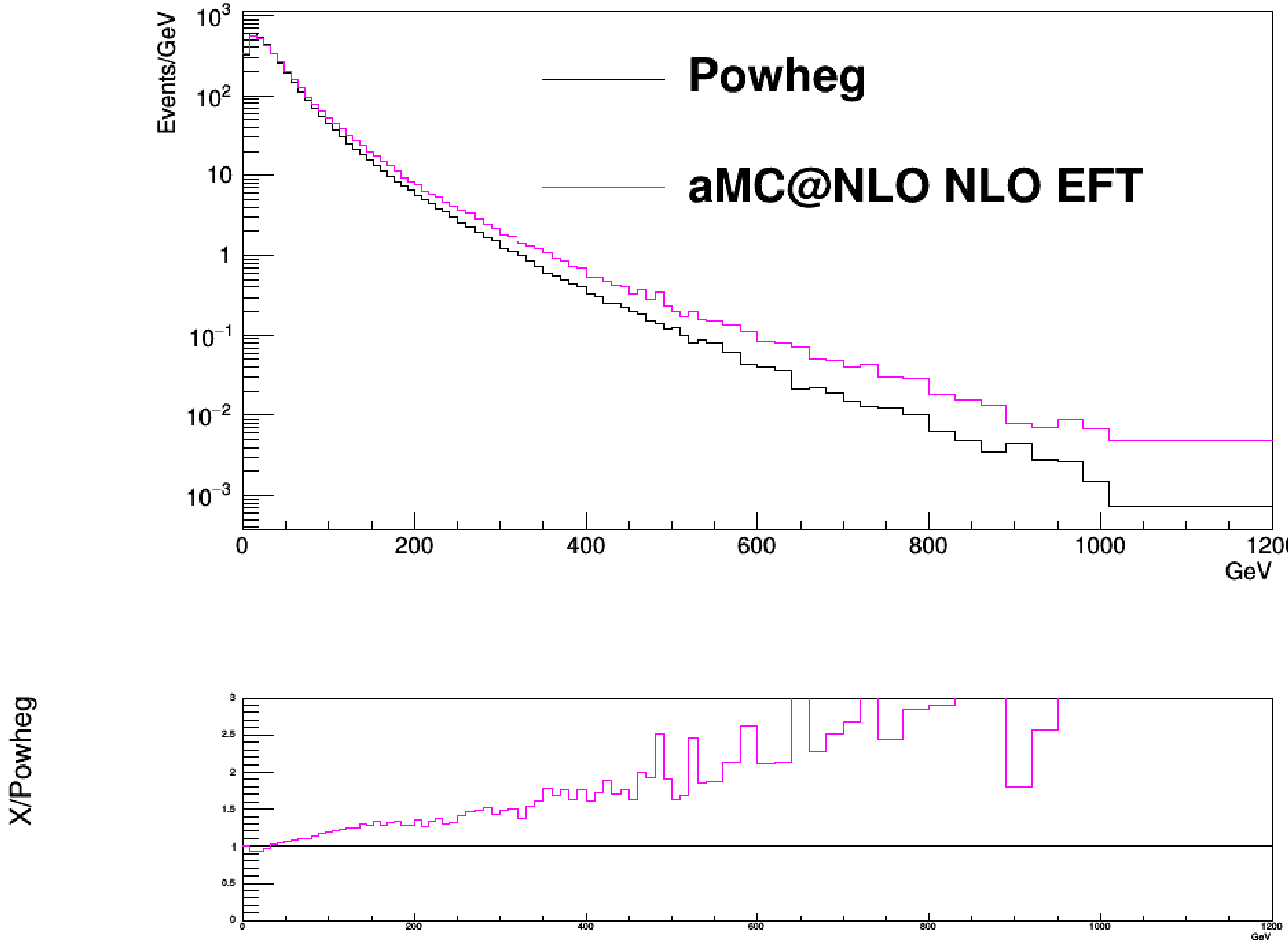
- First of all : a recap of high p_T Higgs computation
  - There are a number of different effect thats go in
  - Lets go through each of the effects
    - Try to understand how we can achiever the state of the art

What is the best Higgs p_T :Options

- The key is to identify two different effects
  - Finite top mass effect
  - NNLO differential corrections
- What are the known orders :
  - Differential EFT : NNLO H+1jet production
  - Finite top mass : almost NLO
  - At MC level EFT : NLO H+0/1/2jet
  - At MC level finite top mass : LO 0/1/2
- As a baseline: CMS default Powheg (2012)
  - 1 Jet @ NLO with LO finite top mass correction

Going to EFT from our baseline

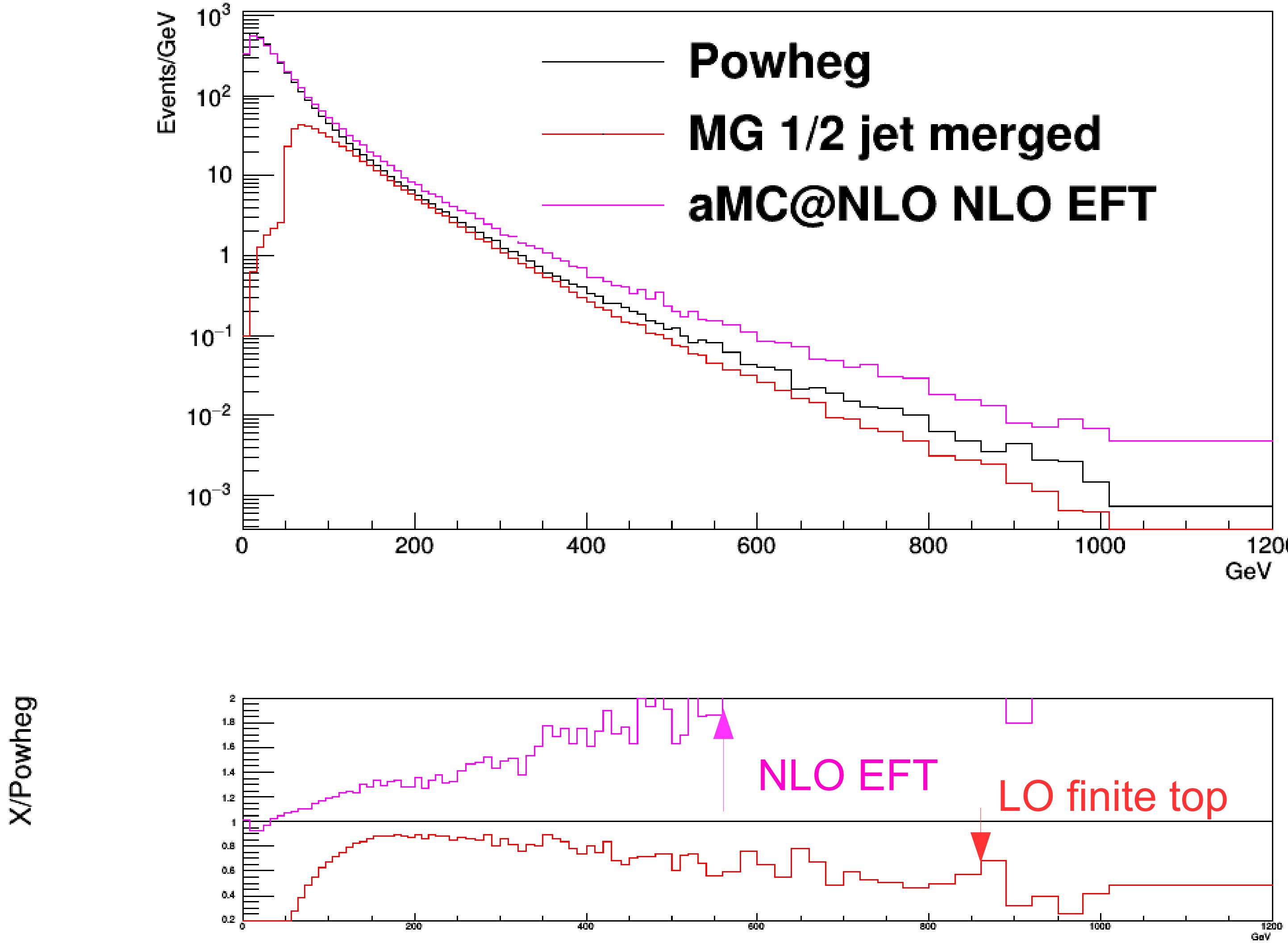
- When going to EFT large gain



Gives a feel of the yield increase on top of Powheg baseline

Going to LO w/finite top from baseline

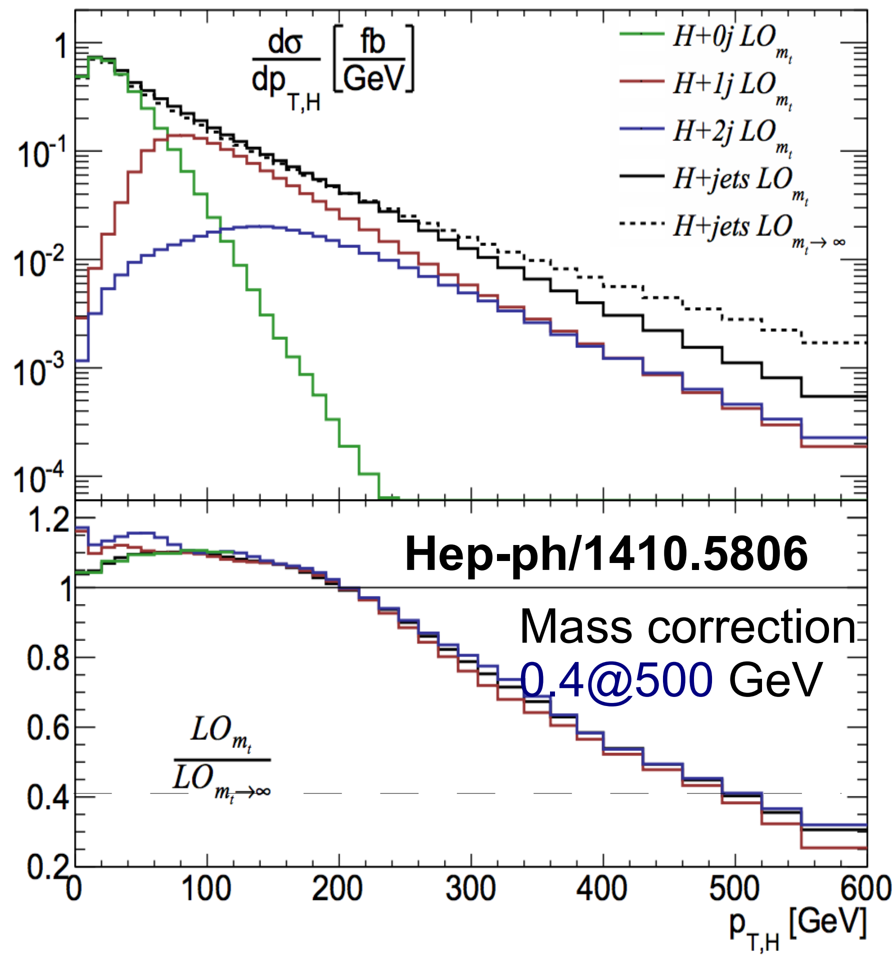
- Adding the finite top mass merged LO its lower

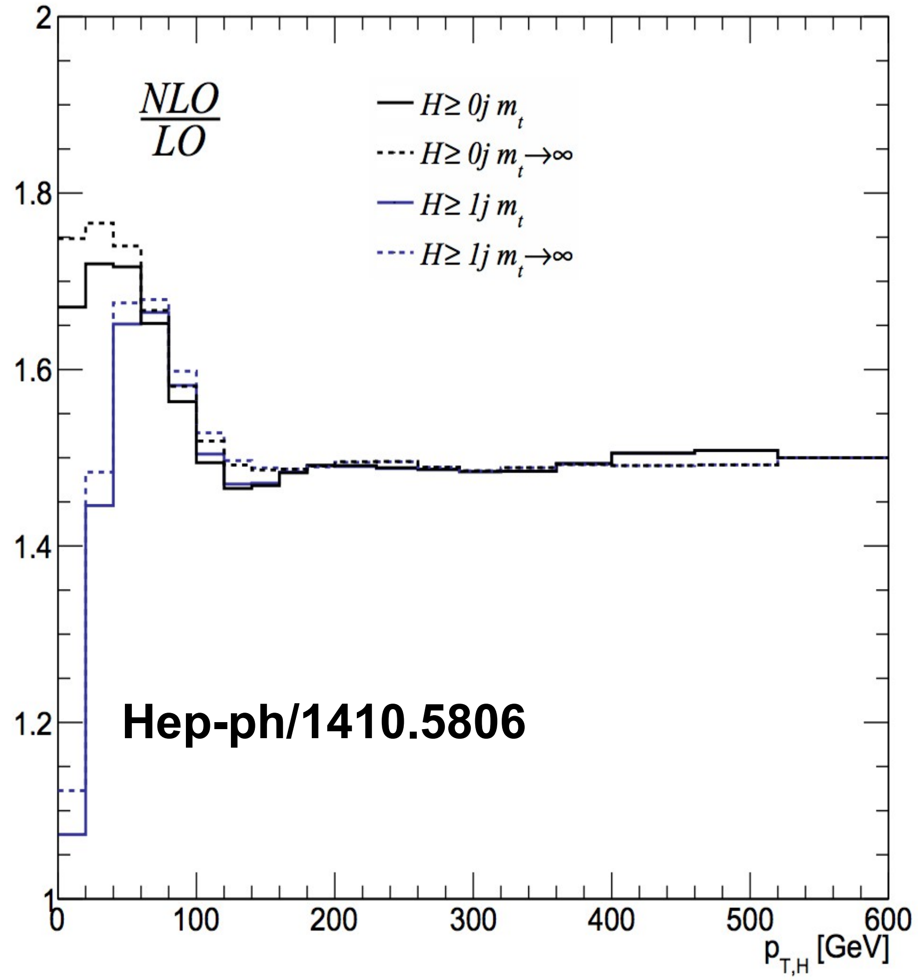


Gives a feel of the lower bound of conventional approaches

Proposal for Adding higher order

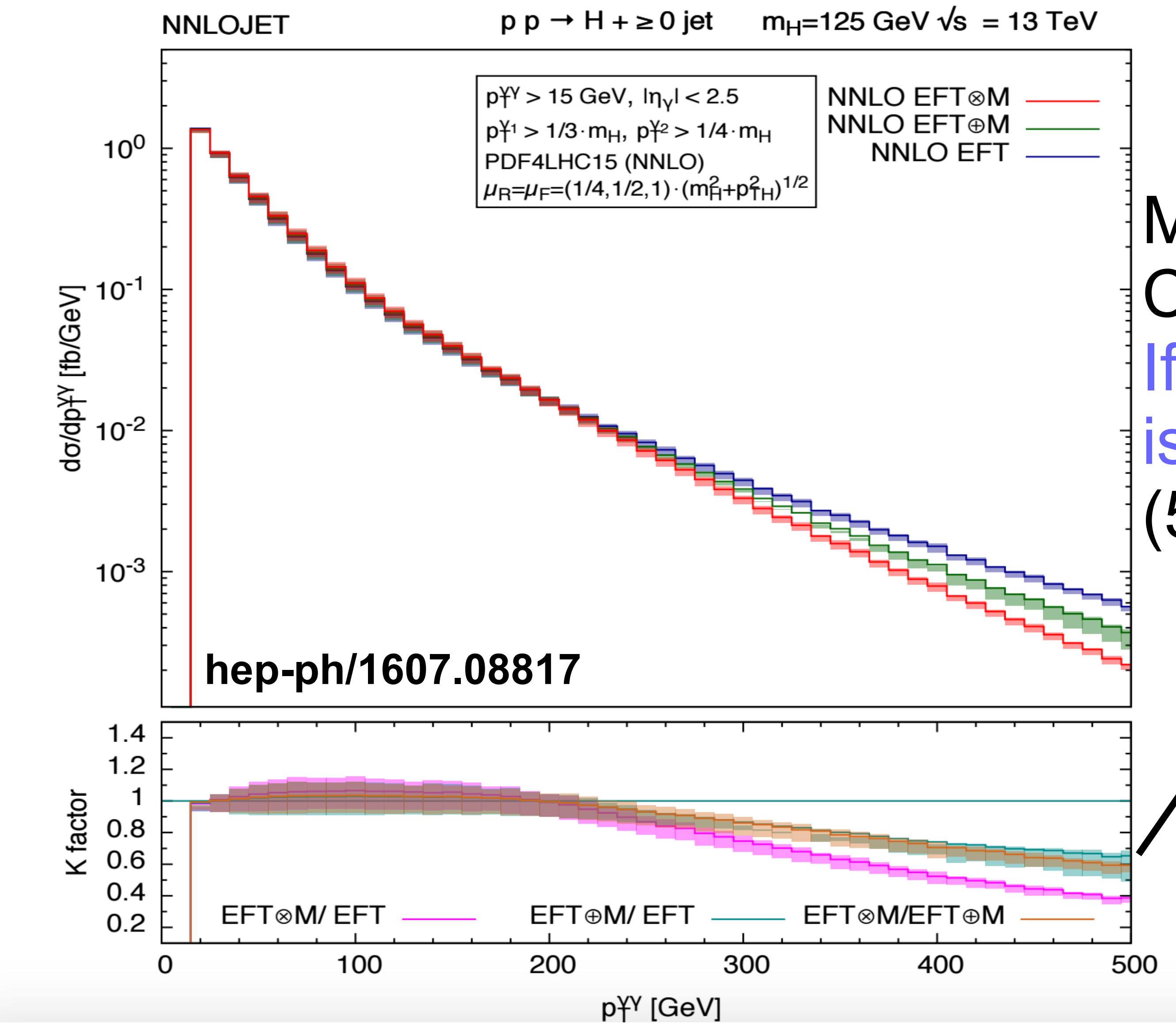
- Older paper proposals : (now conventional)
  - Merge finite top mass samples 0-2 jets with CKKW
    - Use NLO factor of 1.5 for each jet based on EFT calculation





The mass corrections

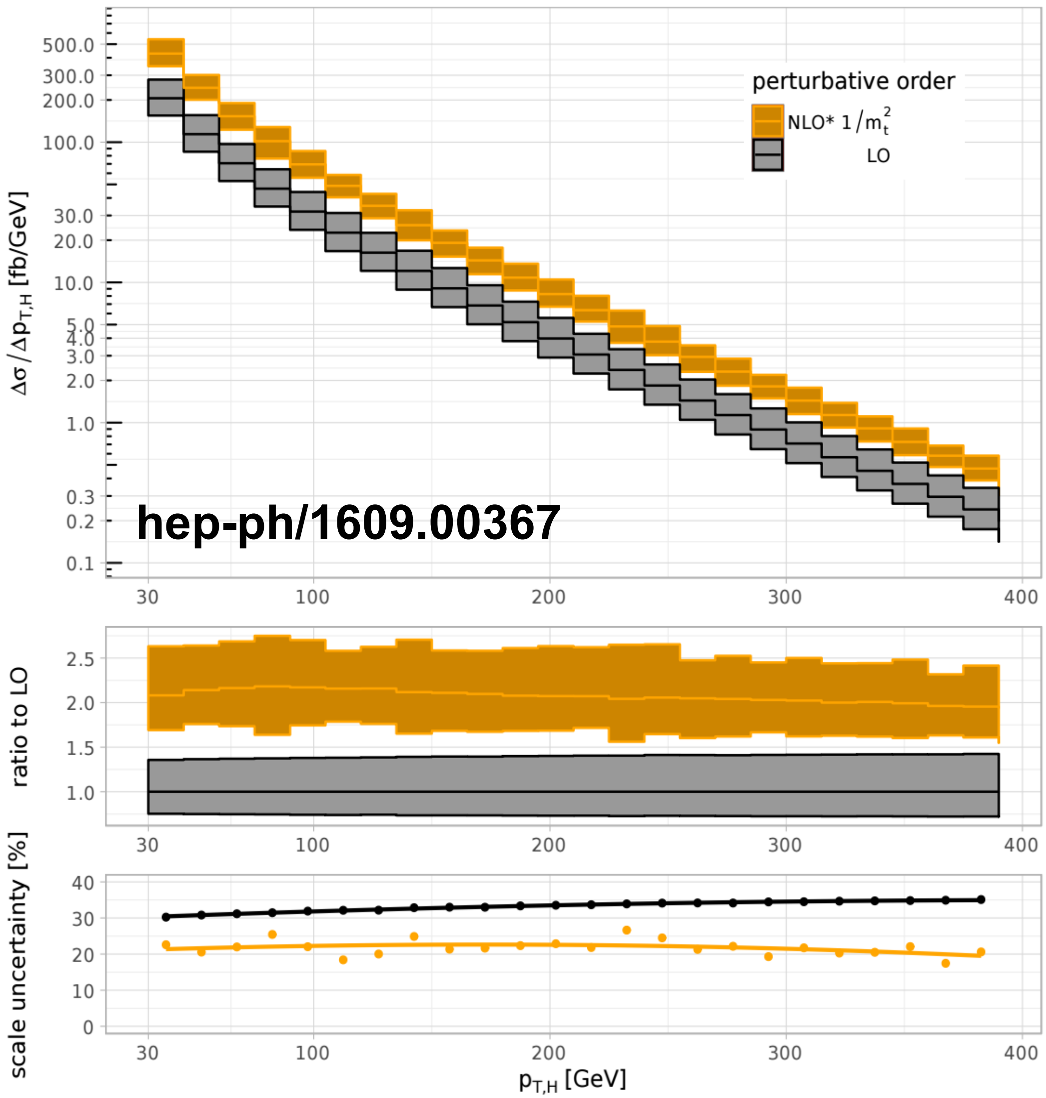
- Whats the right variation in mass corrections



Mass corrections
Can vary from 0.4 to 0.6
If a conservative choice is taken
(50% uncertainty)

Correcting LO to Full Correction

- Multiply by a factor of 2 to get NLO?



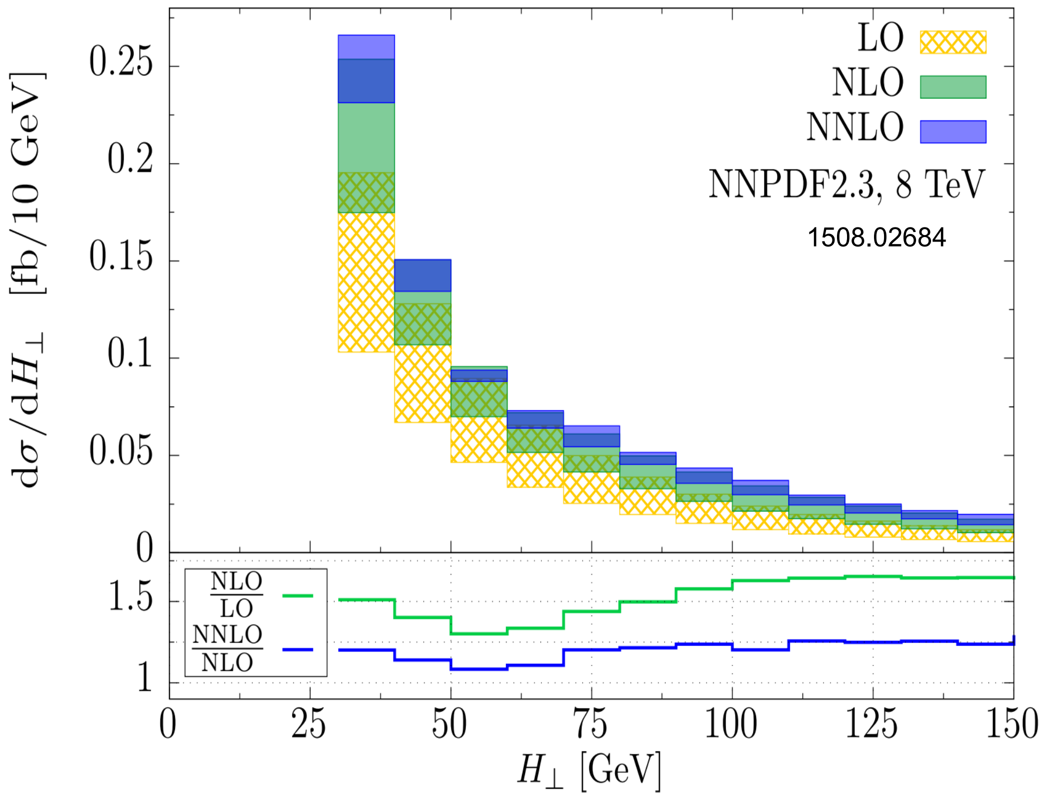
Using the finite top mass to go to high pT we need to correct

After this NNLO correction should be applied on top

This is what we settled on

Going to the Highest EFT order

- When adding NNLO we gain another 1.25



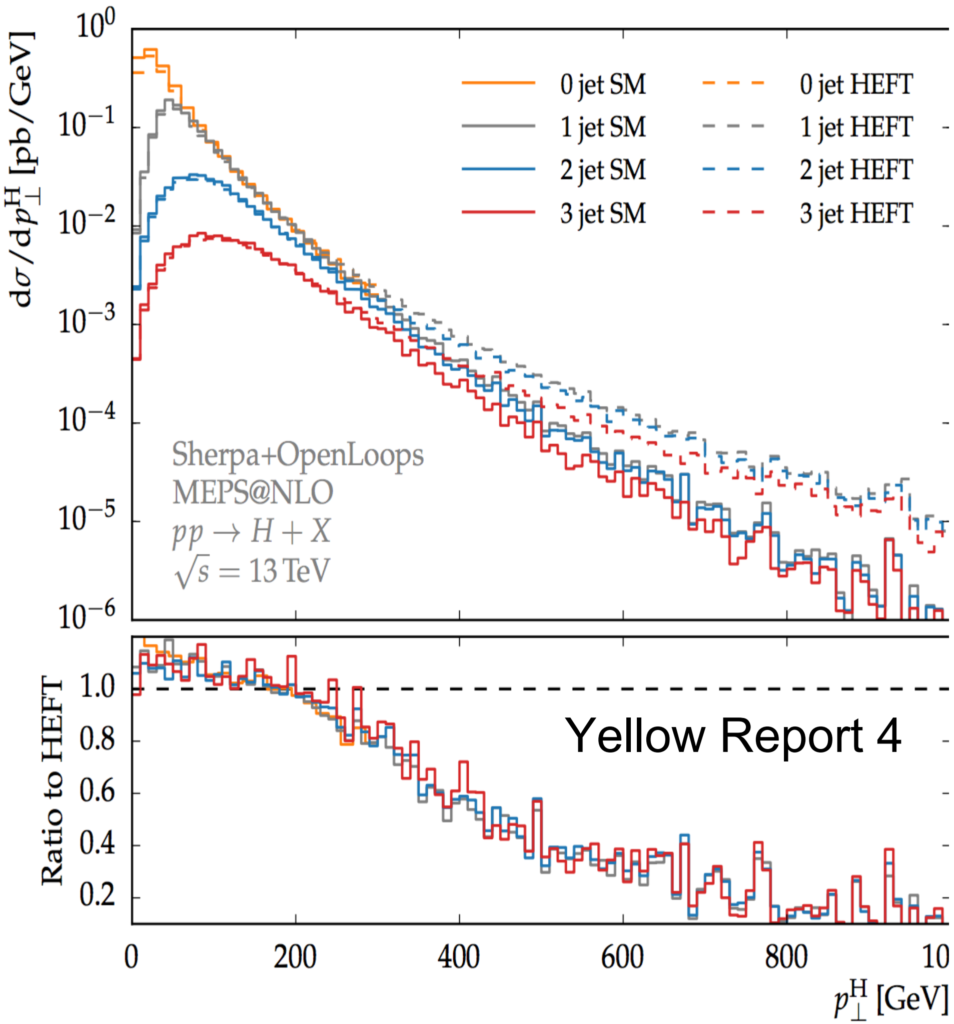
We couldn't find anything going to high p_T

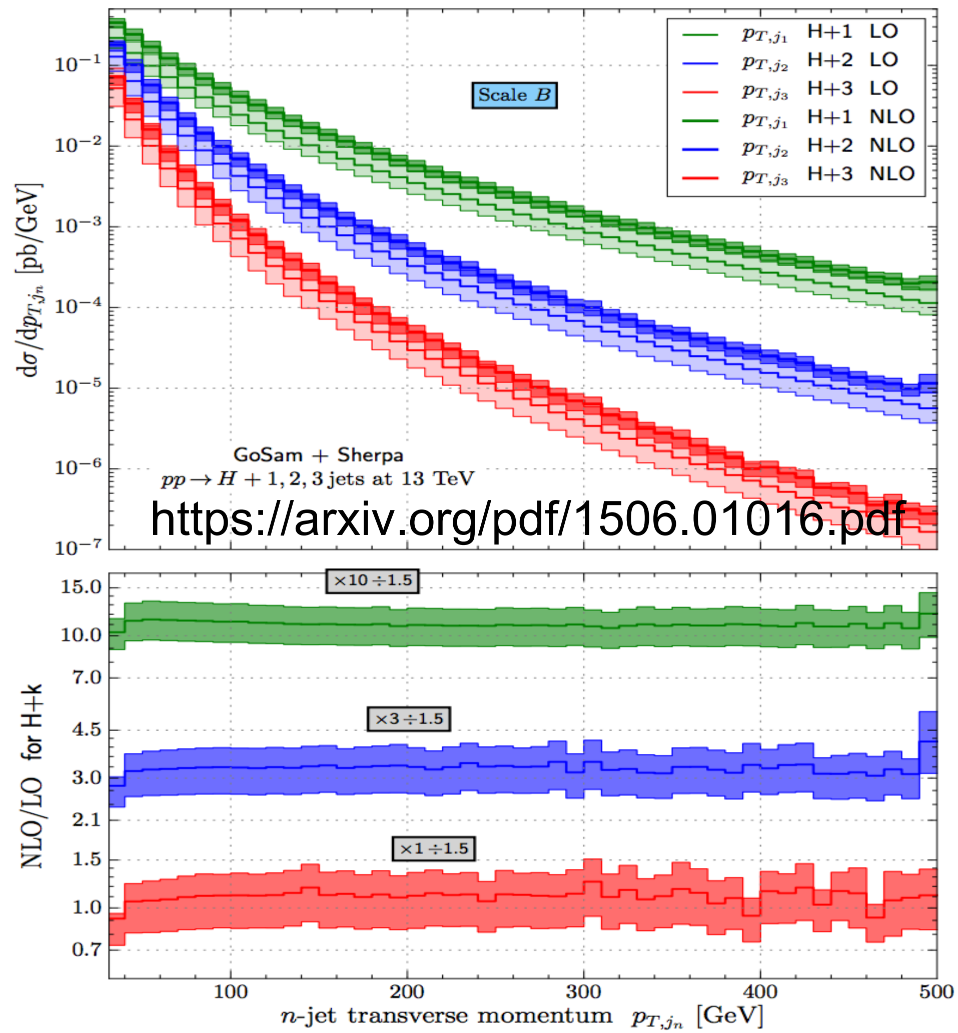
No plots beyond 150 GeV

We add this too

NLO Corrections & mass per jet

- Following yellow & Go SAM report
  - Claim NLO corrections are same over jet multiplicity

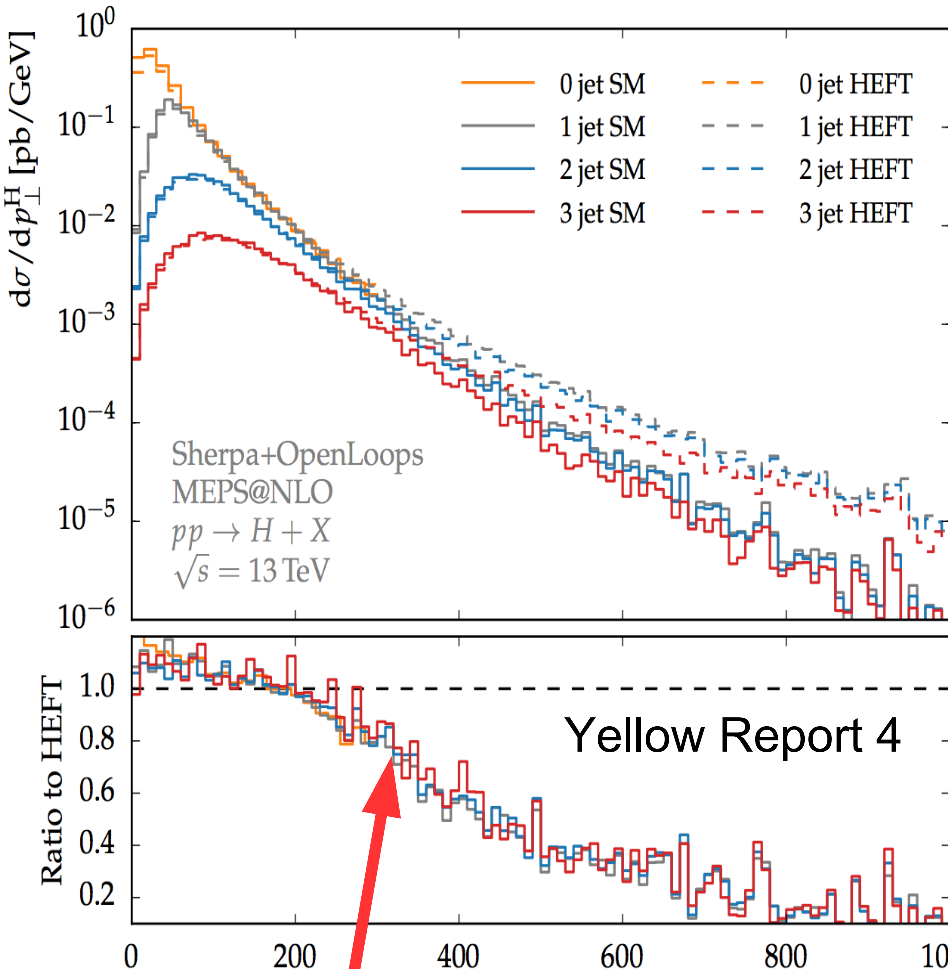


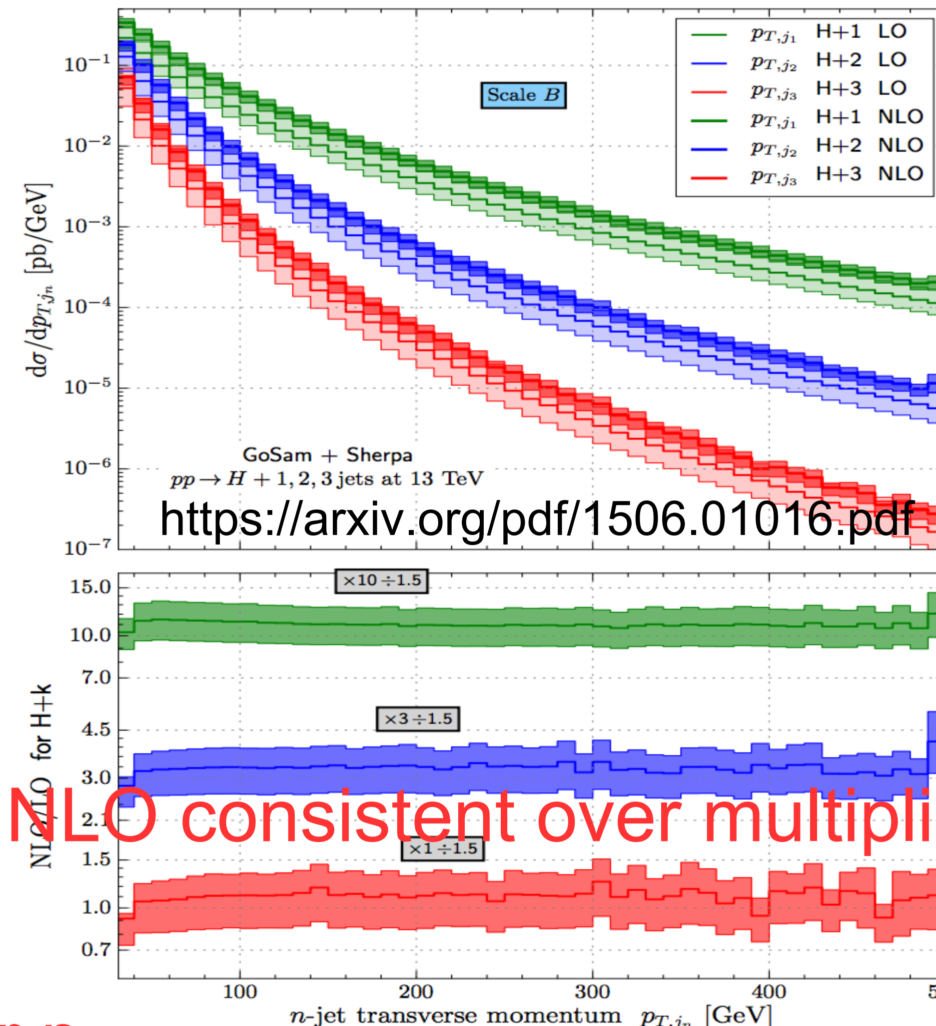


https://arxiv.org/pdf/1506.01016.pdf

NLO Corrections & mass per jet

- Following yellow & Go SAM report
  - Claim NLO corrections are same over jet multiplicity





Mass Corrections consistent over p_T

Adopted Scheme

- We do not claim this is correct
  - It was a choice
  - We also showed the Powheg result

$$\text{ggF H(NNLO}+\text{m}_t) = \text{Powheg}(1\text{ jet } m_t) \times \frac{\text{MG LO } 0-2\text{ jet } m_t}{\text{Powheg}(1\text{ jet } m_t)} \times \frac{\text{NLO } 1\text{ jet } m_t}{\text{LO } 1\text{ jet } m_t} \times \frac{\text{NNLO } 1\text{ jet } m_t \to \infty}{\text{NLO } 1\text{ jet } m_t \to \infty}$$

Reco

CKKW Merged Sample

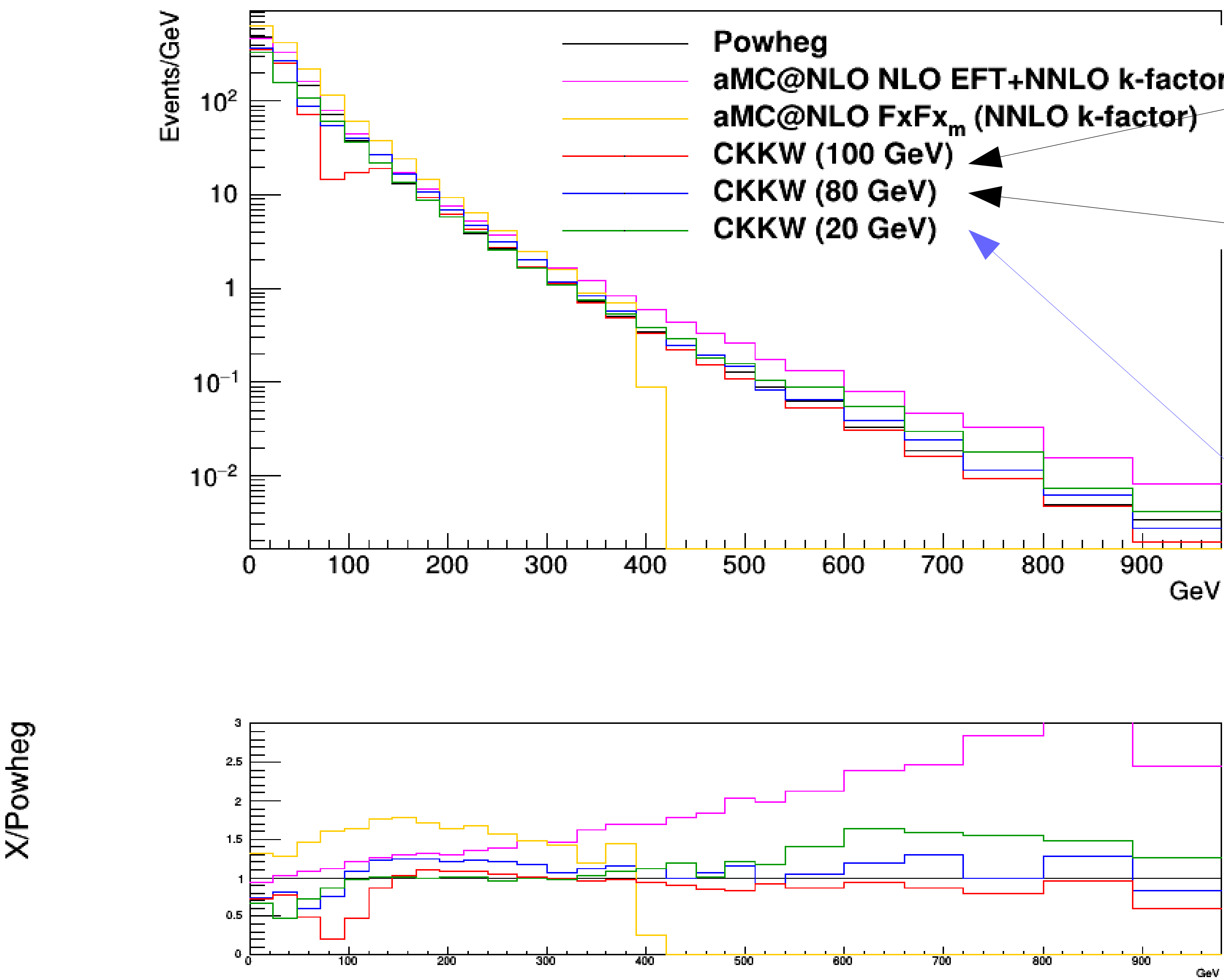
NLO FT*
Factor of 2

NNLO EFT
Factor of 1.25

Applying 1jet k-factors to both 1 and 2 jet (slide 12)

Result Comparison

- Run Bare Pythia using default CKKW
  - Using ME from Madgraph $Q^2 = m^2 + p_T^2$



Merging at 200 GeV Or more

Higher than generation

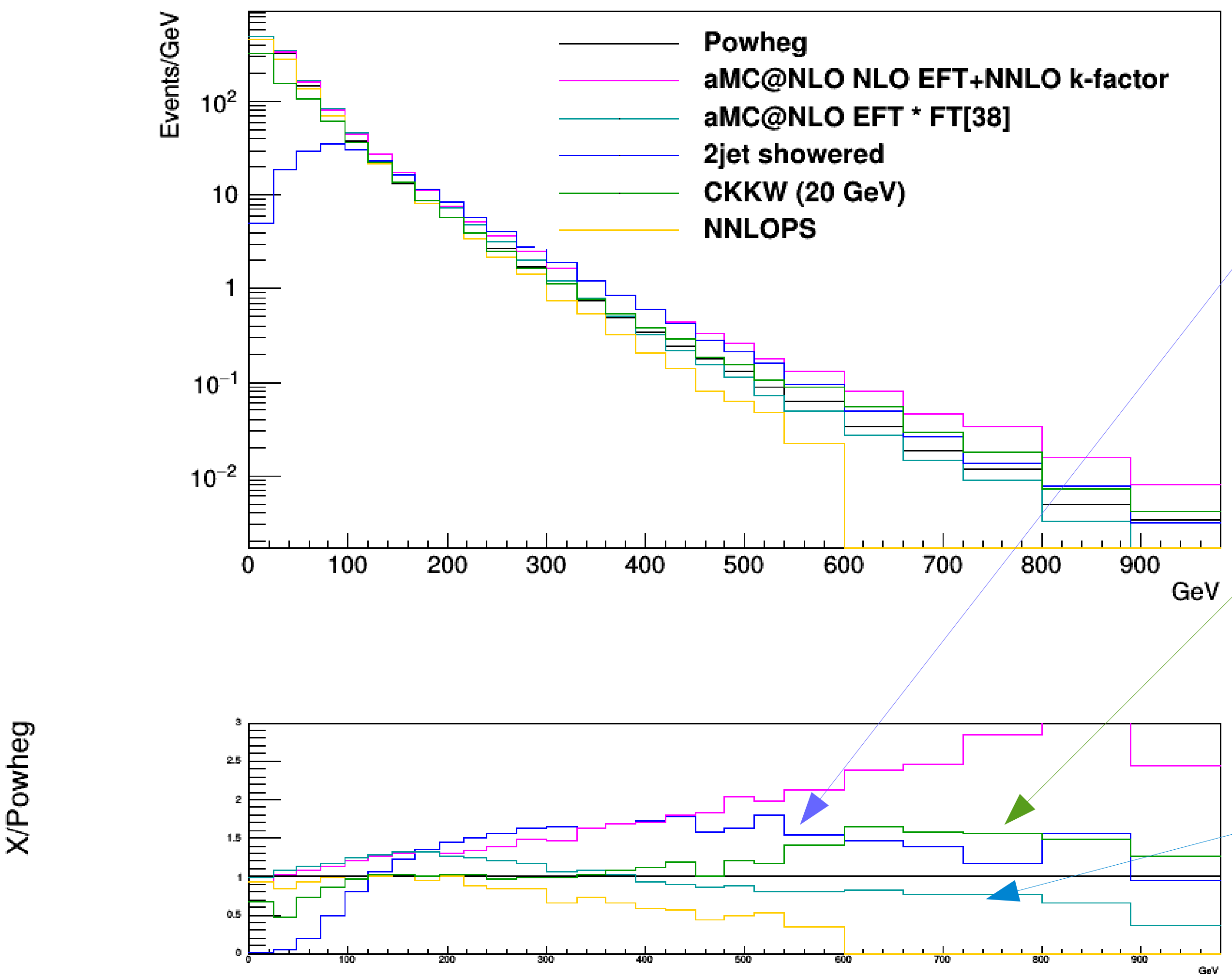
Merging scale at generation

20 GeV gives same scale factor in tail as 2jet

Comparison

Variation over high p_T is roughly 30% → Consequently

We took green gives roughly 1.3±0.4 wrt to Powheg



2jet inclusive shower

CKKW-L Merged
With k-factors

NLO EFT w/finite top mass correction normalized to N^3LO

References for calculation

- Powheg:
  - σ yellow report 4 : https://arxiv.org/abs/1610.07922
  - Differential : http://xxx.lanl.gov/abs/1111.2854
- MG CKKW + kfactors:
  - LO 0/1/2j : https://arxiv.org/abs/1507.00020
  - NLO*(1j) : https://arxiv.org/abs/1609.00367
  - M corr per jet : (YR4) https://arxiv.org/abs/1610.07922
  - NLO per jet : https://arxiv.org/pdf/1506.01016
  - NNLO (picking 1 of 3):https://arxiv.org/abs/1504.07922
  - M corr with NNLO : https://arxiv.org/abs/1607.08817

Concern about quoted Cross section

- Michelangelo *et al* kindly provided us with this

	pt>400	pt>450	pt>500
MCFM (parton, fixed order)			
LO(EFT) [mu=m_H]	72.8	50.8	36.2
LO(EFT) [mu=m_{T,H}]	32.0	20.9	14.0
LO(mtop) [mu=m_{T,H}]	11.8	6.4	3.6
NLO(EFT) [mu=m_{T,H}]	59.8	39.2	26.3
K_NLO = NLO(eft)/LO(eft)	1.87	1.88	1.88
NLO(mtop) = LO(mtop) x K_NLO	22.05	12.00	6.76
NLO(mtop)*BR(H->bb)	12.79	6.96	3.92
1.25 * NLO(mtop)*BR(H->bb)	**15.99**	**8.70**	**4.90**
POWHEG no-shower			
HJ-MiNLO (mtop)	28.0	15.4	8.8
HJ-MiNLO (mtop) * BR(H->bb)	16.2	8.93	5.10
POWHEG shower			
HJ-MiNLO (mtop) + PYTHIA	30.4	16.9	9.5
[HJ-MiNLO (mtop) + PYTHIA] * BR(H->bb)	17.6	9.8	5.5

We quote:
σ=31.7
With
BR(H→bb)
In fiducial
region

Additional Note : Scheme in PAS

- Typo: wrote infinite top when meant finite top for Powheg

CKKW merged

$$\mathrm{GF\,H(NNLO + m_t)} = \mathrm{Powheg}(1\,\mathrm{jet}\ m_t \to \infty) \times \frac{\mathrm{MG\ LO\ 0-2\,jet}\ m_t}{\mathrm{Powheg}(1\,\mathrm{jet}\ m_t \to \infty)} \times$$

$$\times \frac{\mathrm{NLO\ 1\,jet}\ m_t}{\mathrm{LO\ 1\,jet}\ m_t} \times \frac{\mathrm{NNLO\ 1\,jet}\ m_t \to \infty}{\mathrm{NLO\ 1\,jet}\ m_t \to \infty}.$$

Factor of 2 Factor of 1.25

Corrected Text Scheme

- Error in our text
  - Powheg is using finite top mass approximation

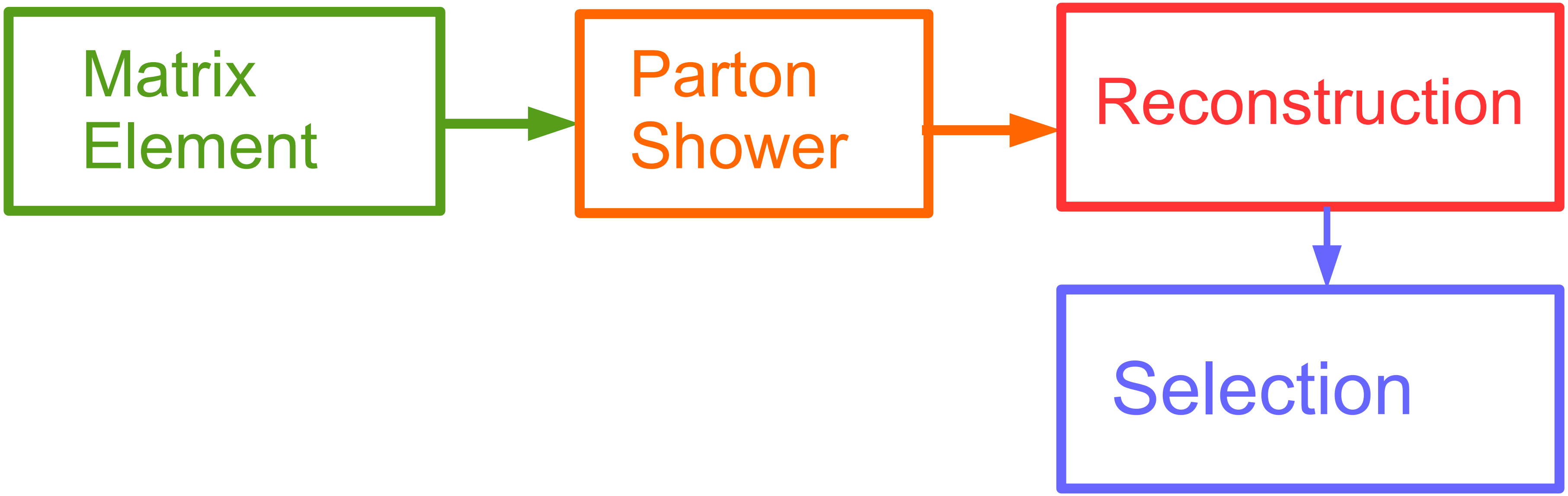
$$\mathrm{ggF\ H(NNLO+m_t)} = \mathrm{Powheg}(1\ \mathrm{jet}\ m_t) \times \frac{\mathrm{MG\ LO\ 0-2\ jet}\ m_t}{\mathrm{Powheg}(1\ \mathrm{jet}\ m_t)} \times \frac{\mathrm{NLO\ 1\ jet}\ m_t}{\mathrm{LO\ 1\ jet}\ m_t} \times \frac{\mathrm{NNLO\ 1\ jet}\ m_t \to \infty}{\mathrm{NLO\ 1\ jet}\ m_t \to \infty}$$

Powheg includes LO finite top mass correction to NLO EFT

Previous formula was just a typo in the document

What are differences in our numbers?

- Chain from ME to Reconstruction

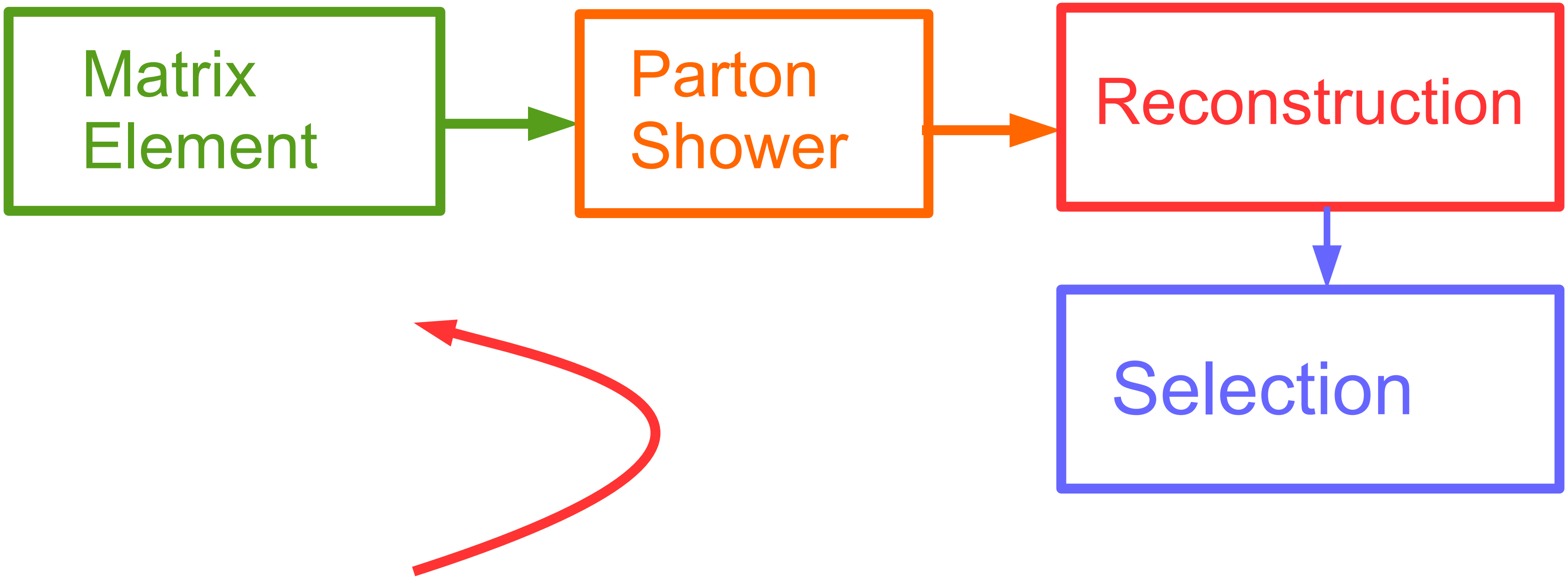


In the paper quote a number on :

Selected Higgs Jets with p_T > 450 GeV

What are differences in our numbers?

- Chain from ME to Reconstruction



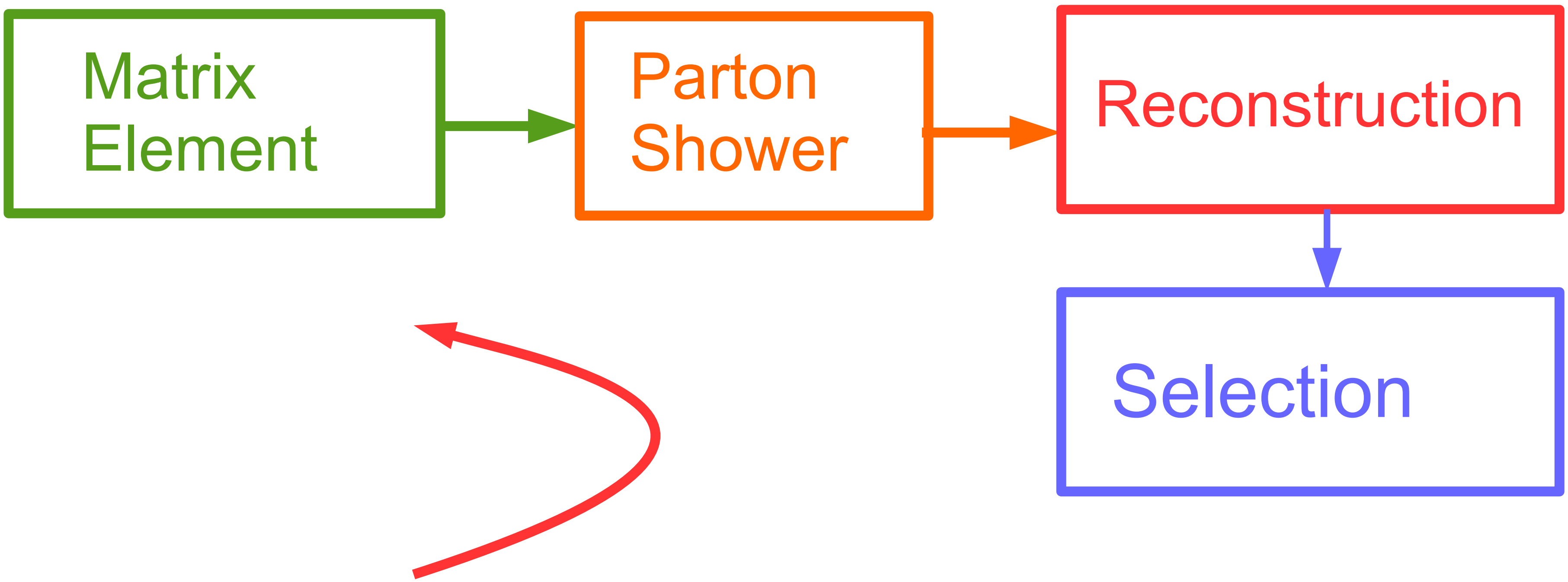
In the paper quote a number on :

Selected Higgs Jets with p_T > 450 GeV

Back to the matrix element so we can compare requires backpeddaling through a few effects

What are differences in our numbers?

- Chain from ME to Reconstruction



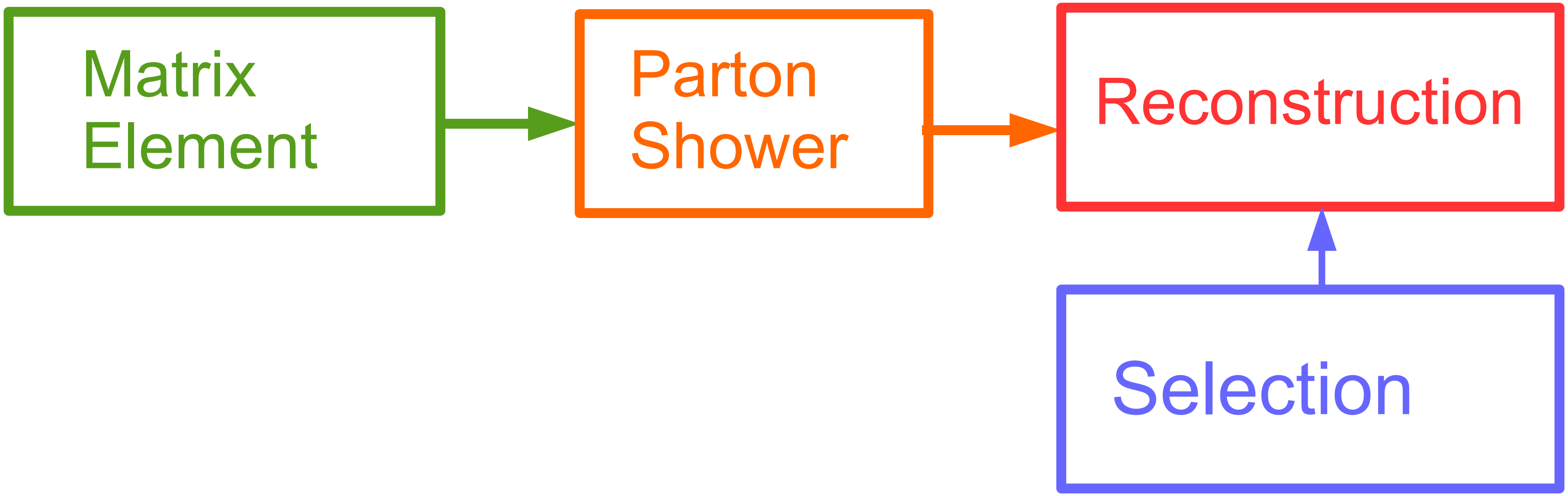
In the paper quote a number on :

Selected Higgs Jets with p_T > 450 GeV

Back to the matrix element so we can compare requires backpeddaling through a few effects

Back tracking

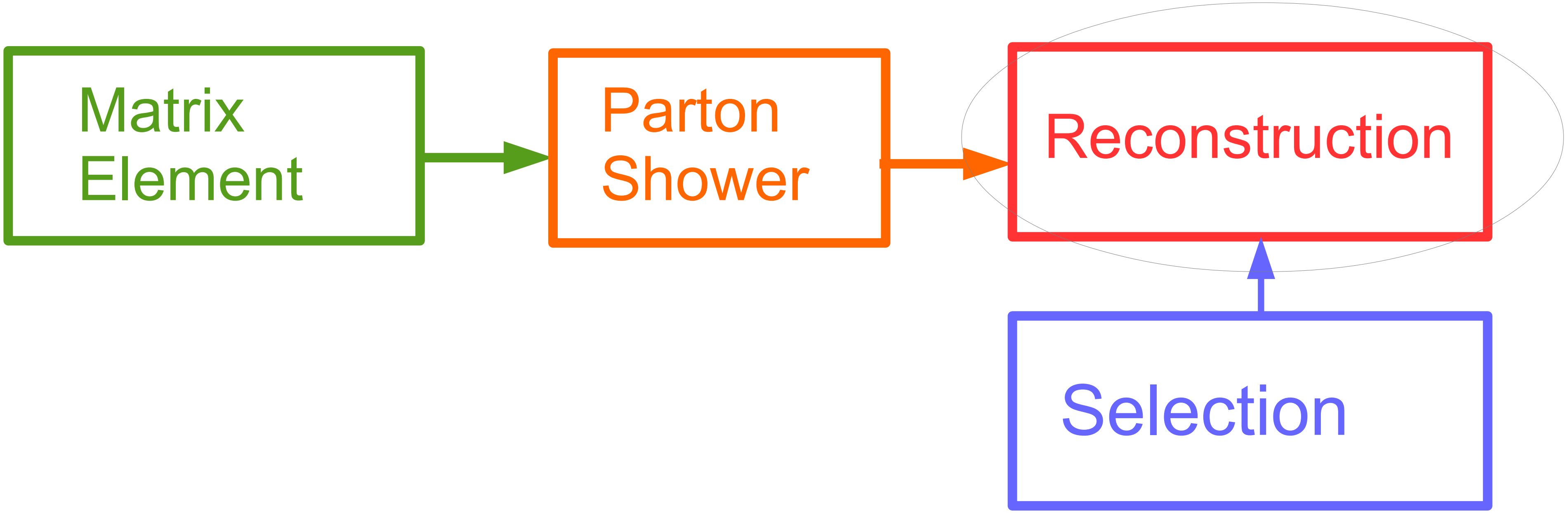
- Chain from ME to Reconstruction



Our reconstructed cross section for our sample is : 26.2 fb

Back tracking

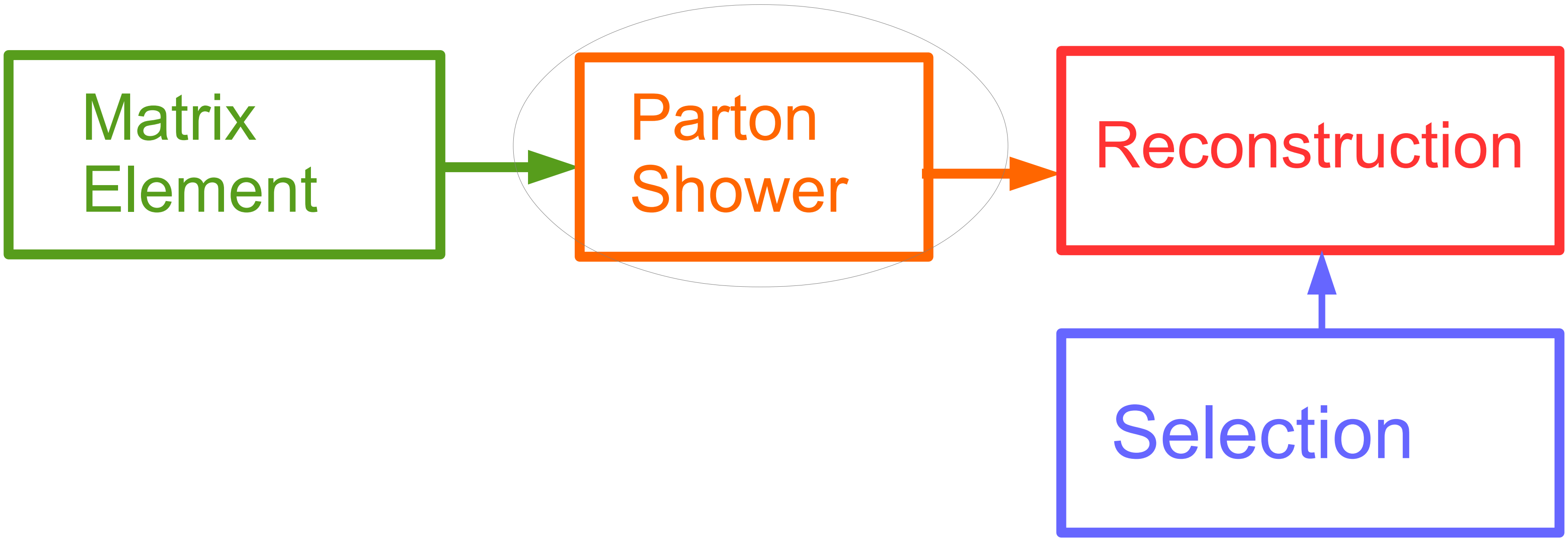
- Chain from ME to Reconstruction



Our reconstructed cross section for our sample is : 26.2 fb
(-25% for other processes/selection)

Back tracking

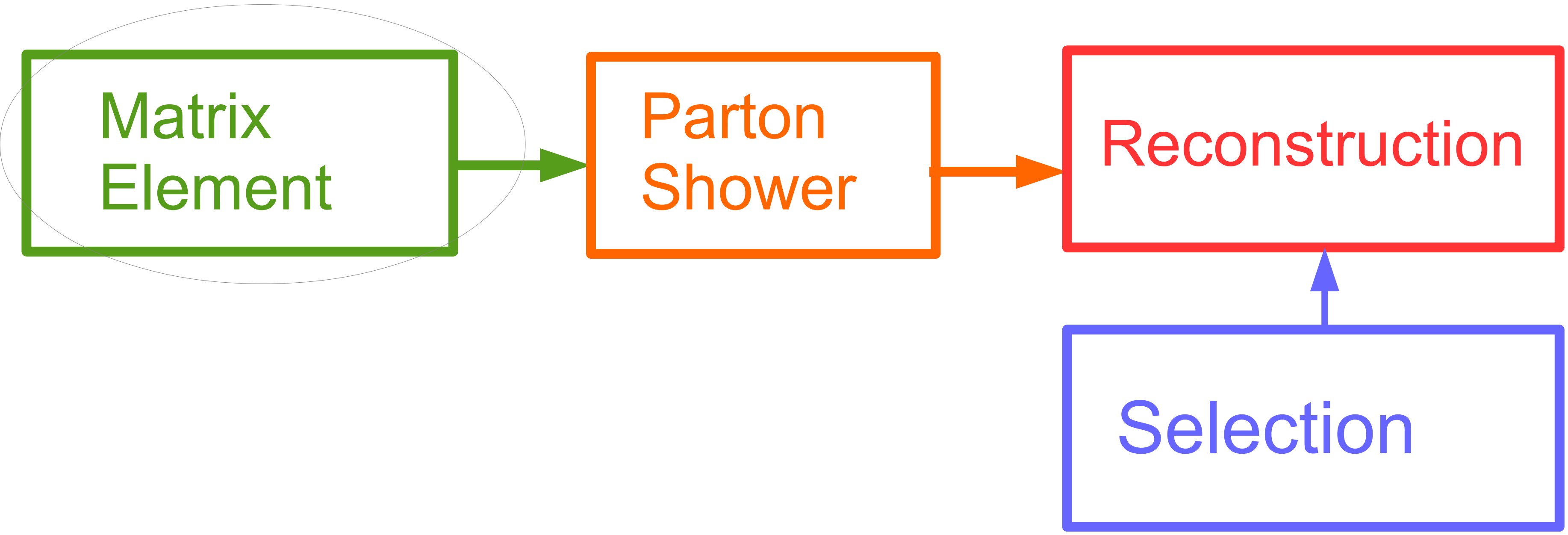
- Chain from ME to Reconstruction



Our parton shower level cross section for p_T Higgs > 450 GeV is : 20.8 fb
(-25% reco smearing pushes lower p_T Higgs to higher p_T)

Back tracking

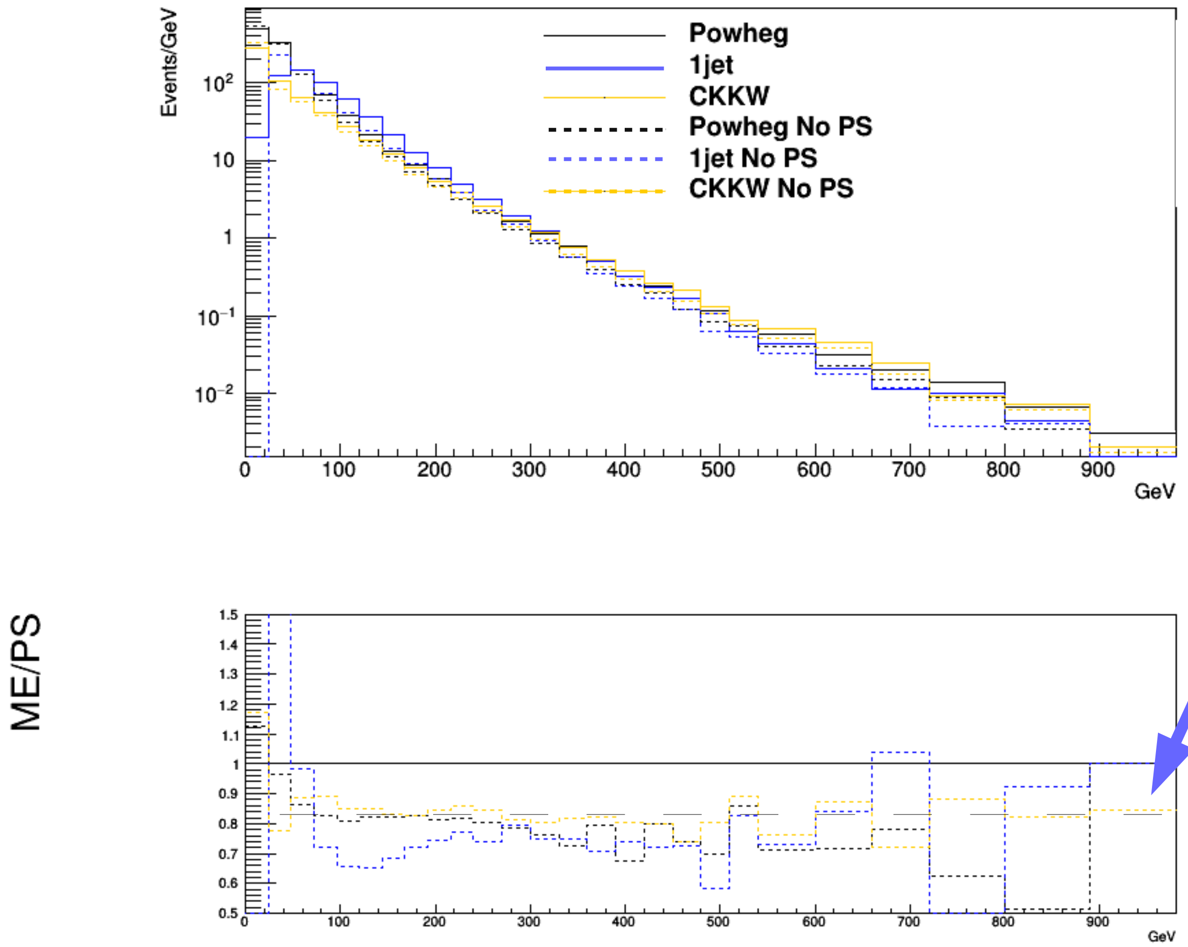
- Chain from ME to Reconstruction



Our ME level cross section for
p_T Higgs > 450 GeV is : 15.1 fb
(-35% parton shower pushes low p_T to higher p_T) Reminder table is : 8.9 fb

Impact of parton shower

- Parton shower has a noticeable effect
  - Parton shower correction: switch cut from ME to PS
    - PS defined as the visible di-mu p_T from simulated $H \to \mu\mu$



Effect is roughly 35% (1/0.73)

Consistent reduction
Equivalent to a shift of 5-10% in boson p_T
(30 GeV at 400 GeV)

More details From ME to Reco

- A reco cut at 450 is equivalent to a gen cut at 430
  - This is an increase in yield of 22% (Powheg)
    - Yield is 1.30/1.08=1.22 for (p_T > 450 GeV)/(p_T > 430 GeV)
- Parton shower cut of 430 equivalent to ME of 400
    - Yield diff is 1.30/0.982=1.33 (Powheg)
- Total variation from ME to reco is >1.6

Lets Scan A few options

- Finally lets consider a few generation options:
  - For each we will turn off NNLO/NLO and BR
    - This amounts to scaling things down by factor of 1.5
  - We will then apply a reco correction of 1/1.22 down
  - Compute the yield before parton shower
  - Compare with the LO ME from MCFM w/NNDPF
    - Note we checked the table (about 5% higher)
- We will do this for :
  - Powheg normalized to N^3LO(the CMS default)
  - CKKW 0-2jet merged w/NNLO+NLO k-factors
  - 1 Jet with finite top mass w/NNLO+NLO k-factors
  - 2jet with finite top mass w/NNLO+NLO k-factors

Migration Matrix

- Reminder :
  - Reco correction : scale down by 1/1.25
  - LO is yield/BR(H→bb)/NLO k-factor/NNLO

MCFM 1 jet with m_t (→ ME Corr)

Process	Cut	yield	Yield LO (inclusive)	Reco Corr	PS2ME Corr	ME Corr
Powheg	400	38.2	26.4	21.0	13.8	11.8
CKKW	400	42.2	29.2	23.4	17.4	11.8
1j	400	33.4	23.1	18.4	11.4	11.8
2j	400	50.3	34.8	27.8	20.4	11.8
Powheg	450	19.7	13.6	10.9	8.0	6.4
CKKW	450	26.2	18.1	14.4	10.5	6.4
1j	450	20.2	13.9	11.2	6.4	6.4
2j	450	30.1	20.8	16.6	11.5	6.4

The numbers from last most column are from first slide

Migration Matrix

- Summary :
  - Our numbers are about 5%-40% higher

    These are on the edge of our quoted unc. W/ table
  - The impact of parton shower is a large effect

MCFM 1 jet with m_t

Process	Cut	yield	Yield LO (inclusive)	Reco Corr	PS2ME Corr	ME Corr
Powheg	400	38.2	26.4	21.0	13.8	11.8
CKKW	400	42.2	29.2	23.4	17.4	11.8
1j	400	33.4	23.1	18.4	11.4	11.8
2j	400	50.3	34.8	27.8	20.4	11.8
Powheg	450	19.7	13.6	10.9	8.0	6.4
CKKW	450	26.2	18.1	14.4	10.5	6.4
1j	450	20.2	13.9	11.2	6.4	6.4
2j	450	30.1	20.8	16.6	11.5	6.4

The numbers from last most column are from first slide

Summary

- A new higgs analysis at high p_T is performed
  - The higgs p_T prediction is an important benchmark
  - Attempt to compute a p_T spectrum that into account
    - NNLO corrections and finite top mass effects
- Understanding the different stages of calculation
  - Quoted cross section at reco has many different effects
    - Consider only the a Higgs jet with p_T > 450 GeV
  - Backtracking to generator level gives a 50% reduction
  - Backtracking to ME level gives an additional 30%
  - Comparisons with 1 jet ME are withing 50%