The Matrix Element Method and MadWeight

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J. Alwall, A. Freytas, OM: PRD83:074010
P.Artoisenet, V.Lemaître, F. Maltoni, OM: JHEP 1012:068

Motivations

- Both LHC and Tevatron search for Higgs and NP !
  - How to identify new particles?
  - How to measure particle properties?
- Especially difficult in presence of missing Energy
- Is there a way to optimise the information which can be extracted from a event sample?

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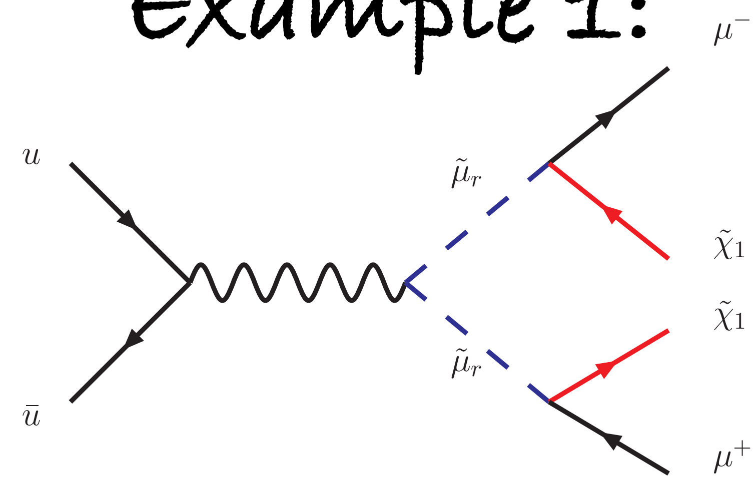
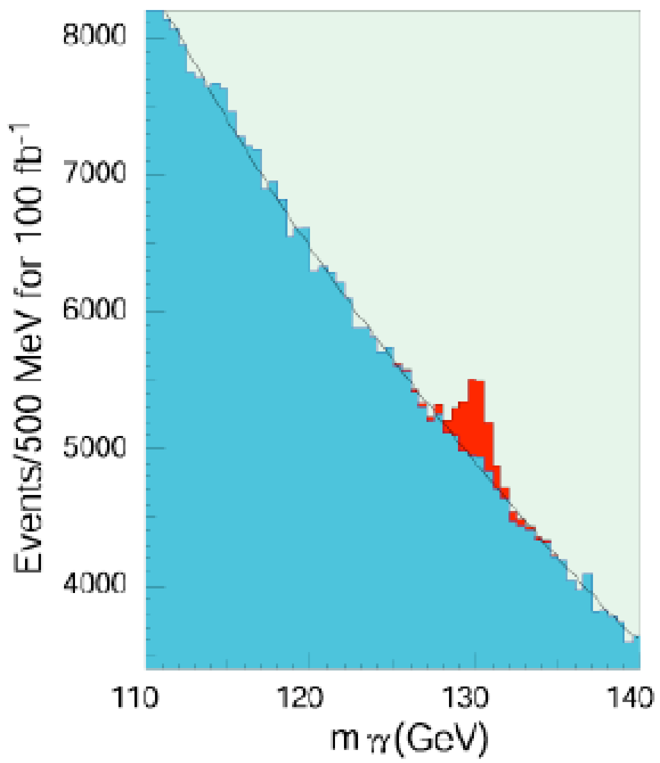


Example 2:



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YES Many

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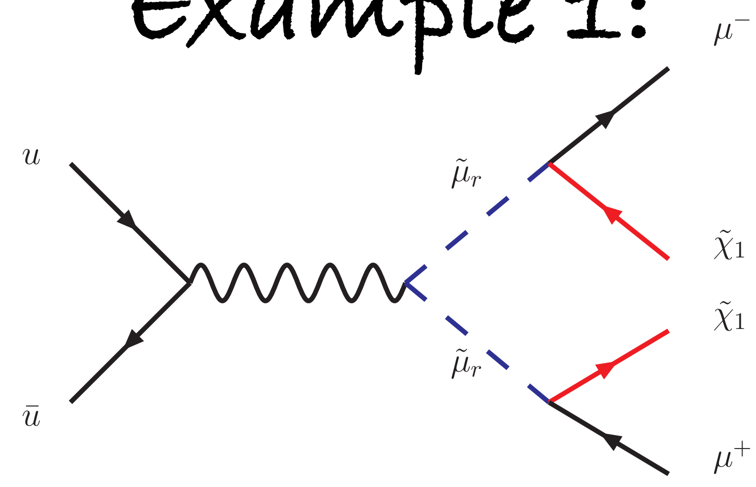

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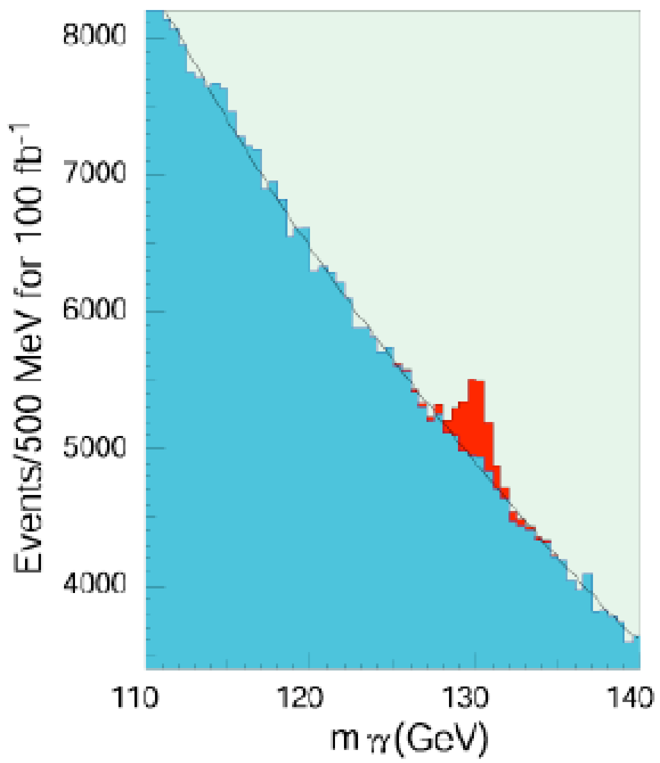
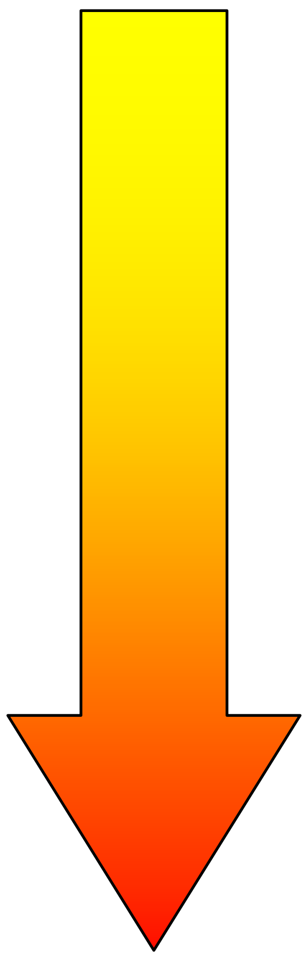


Types of Technique

Few
assumptions



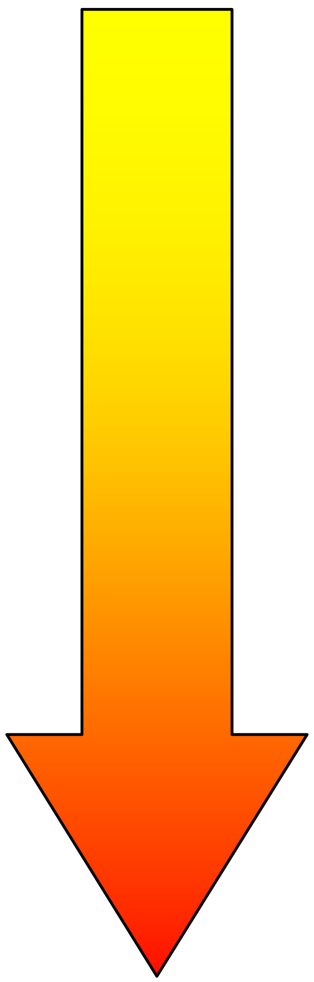
Many
assumptions

- Missing transverse momentum
- M_eff, H_T
- s Hat Min
- M_T
- M_TGEN
- M_T2 / M_CT
- M_T2 (with “kinks”)
- M_T2 / M_CT (parallel / perp)
- M_T2 / M_CT (“sub-system”)
- “Polynomial” constraints
- Multi-event polynomial constraints
- Whole dataset variables
- Cross section
- Max Likelihood / Matrix Element

Slide from Lester: arXiv:1004.2732

Types of Technique

Vague
conclusions



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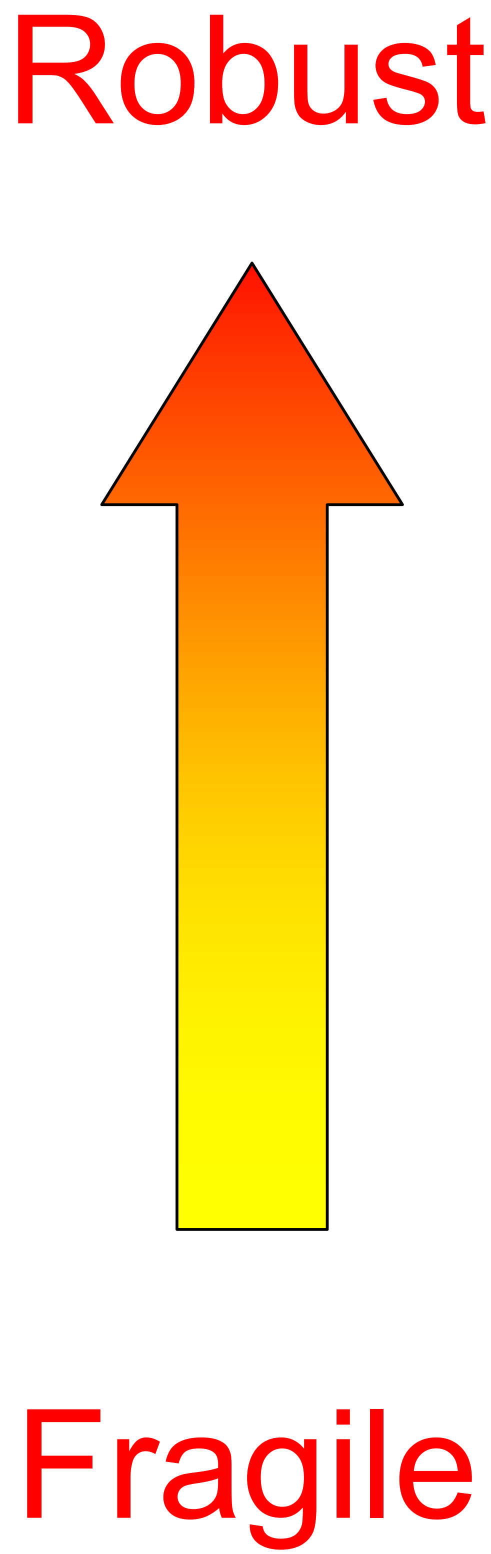

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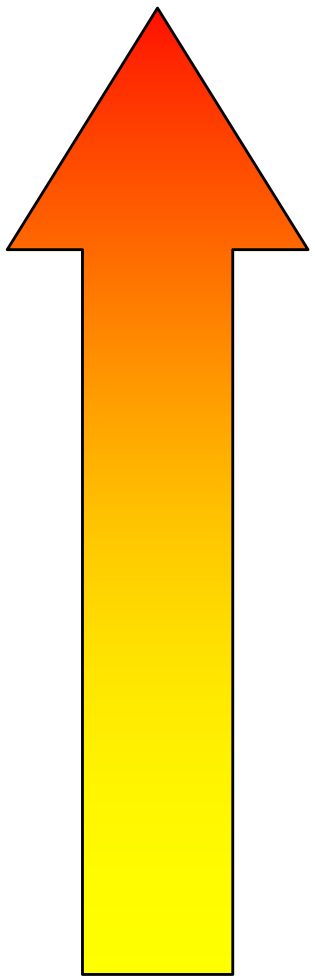
Types of Technique

Robust



Fragile

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Outline

- Introduction to Matrix Element re-weighting
- Examples of studies / investigations
  - mass determination : smuon pair production
  - discriminating Hypothesis
  - ISR effects: pp > H > W+ W-
  - DMEM: m_{tt} in fully leptonic channel
- Conclusions

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- Associate to each experimental event characterised by $\boldsymbol{p}^{vis}$, the probability $\mathcal{P}(\boldsymbol{p}^{vis}|\alpha)$ to be produced and observed following a theoretical assumption α

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$$\mathcal{P}(\boldsymbol{p}^{vis}|\alpha) = \frac{1}{\sigma_\alpha^{vis}} \int d\Phi dx_1 dx_2 |M_\alpha(\boldsymbol{p})|^2 W(\boldsymbol{p}, \boldsymbol{p}^{vis})$$

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- $\int d\Phi dx_1 dx_2$ is the phase-space integral
- σ_α^{vis} is the cross-section (after cuts)

Matrix Element Method

- Most common and important use is to combine those in a Likelihood

$$L(\alpha) = \prod_{i=1}^{N} \mathcal{P}(\boldsymbol{p}_i^{vis}|\alpha)$$

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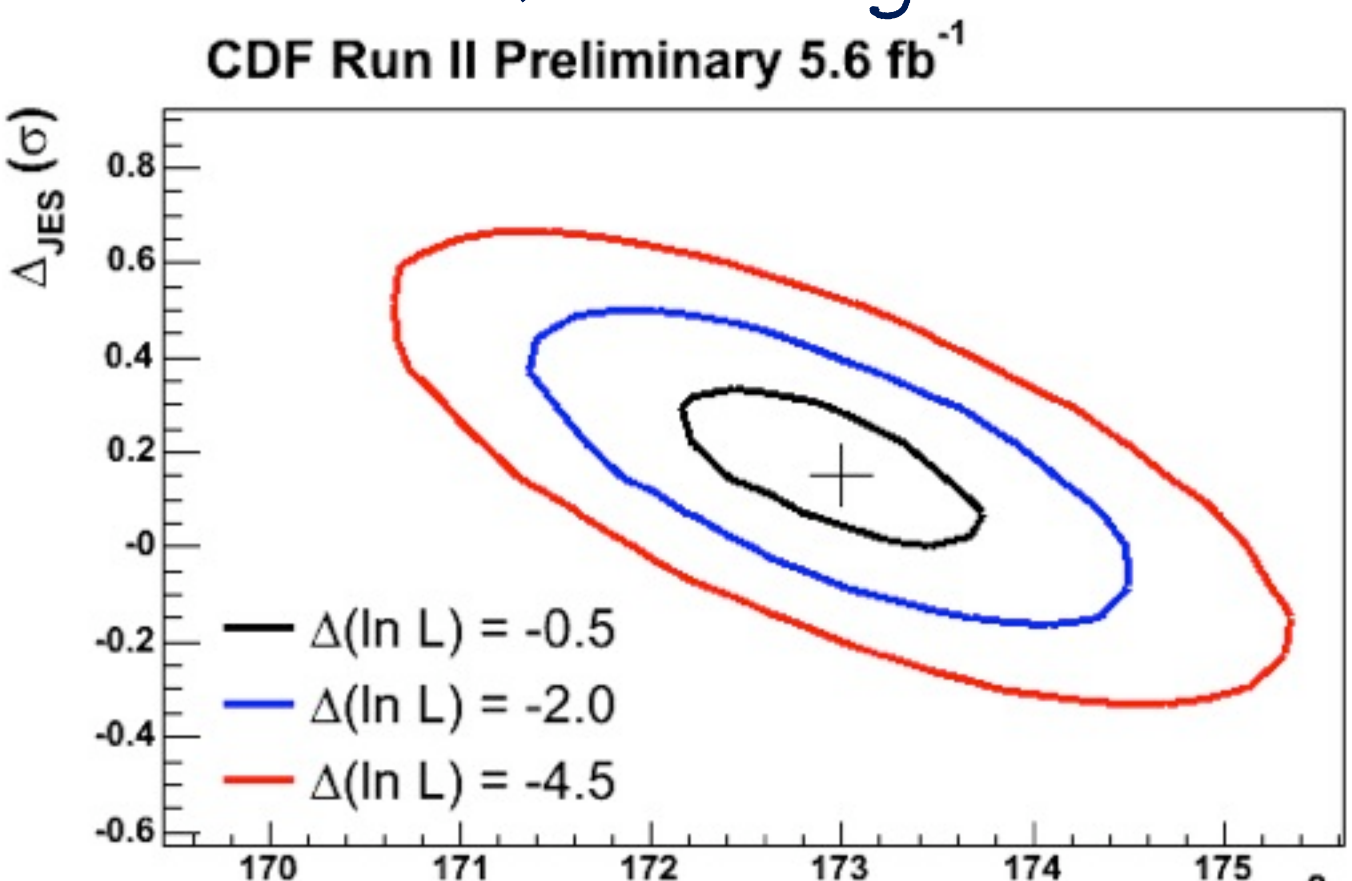

Semi-leptonic decay

$$m_{top} = 173.0 \pm 1.2\text{GeV}$$

CRITICS OF THE METHOD

- The Likelihood methods builds the BEST discriminating variable
- Fully Model dependent
- Transfer Function approximation
  - Factorize for each parton
  - Not valid for hard radiation
- Pure LO approximation
- Strong sensitivity in analysis cut
- Computing time ($N_{event} * N_{th}$ integrals)

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How to evaluate those weights?

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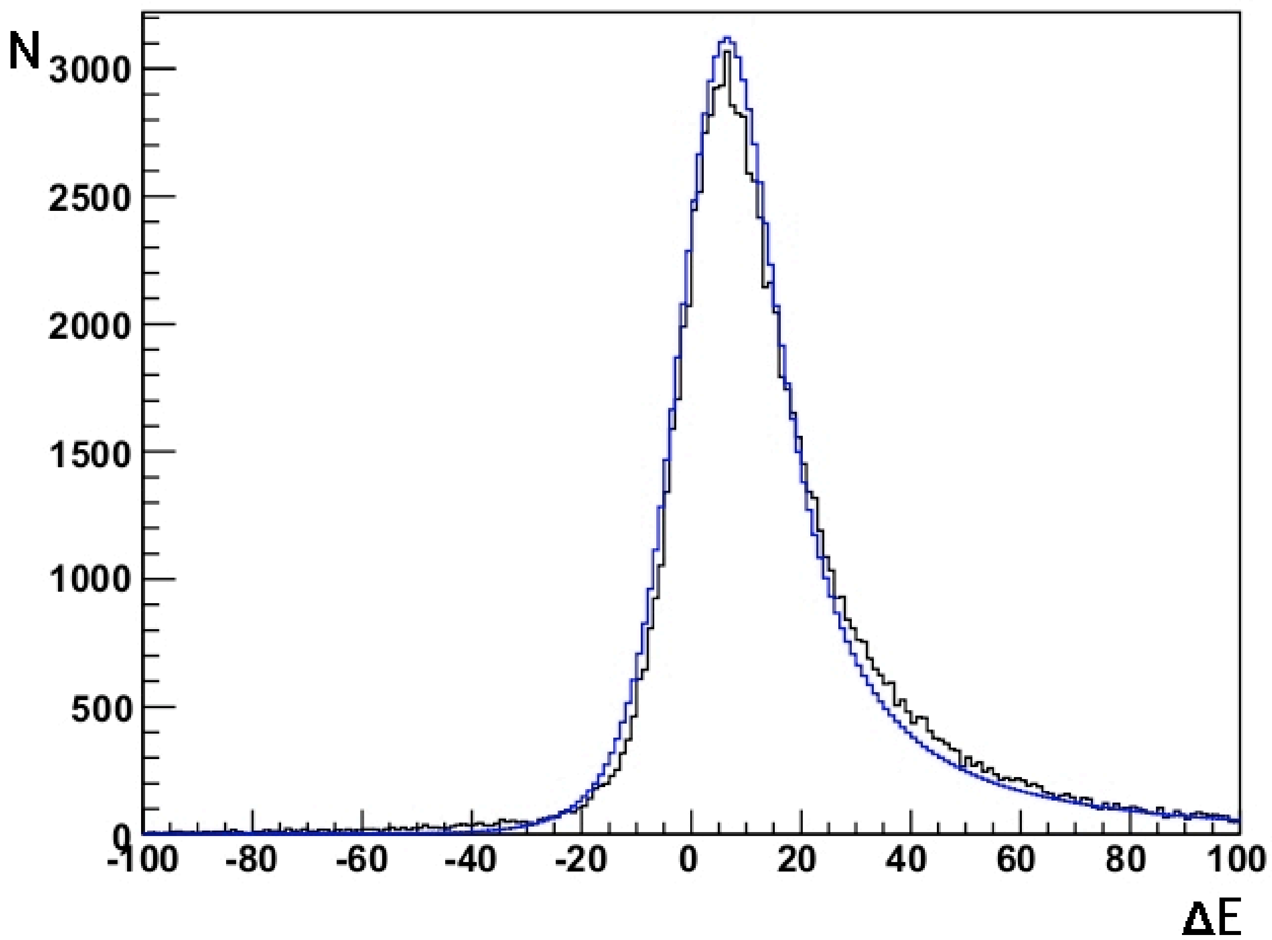

- Each partonic particles has it's own Transfer functions

$$W(\boldsymbol{x}, \boldsymbol{y}) \approx \prod_i \frac{1}{\sqrt{2\pi}\sigma_i} e^{-\frac{(x_i - y_i)^2}{2\sigma_i^2}}$$

- Forbids any additional jets and therefore NLO.

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- Need a specific integrator: MadWeight

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Difficult point: Numerical Integration

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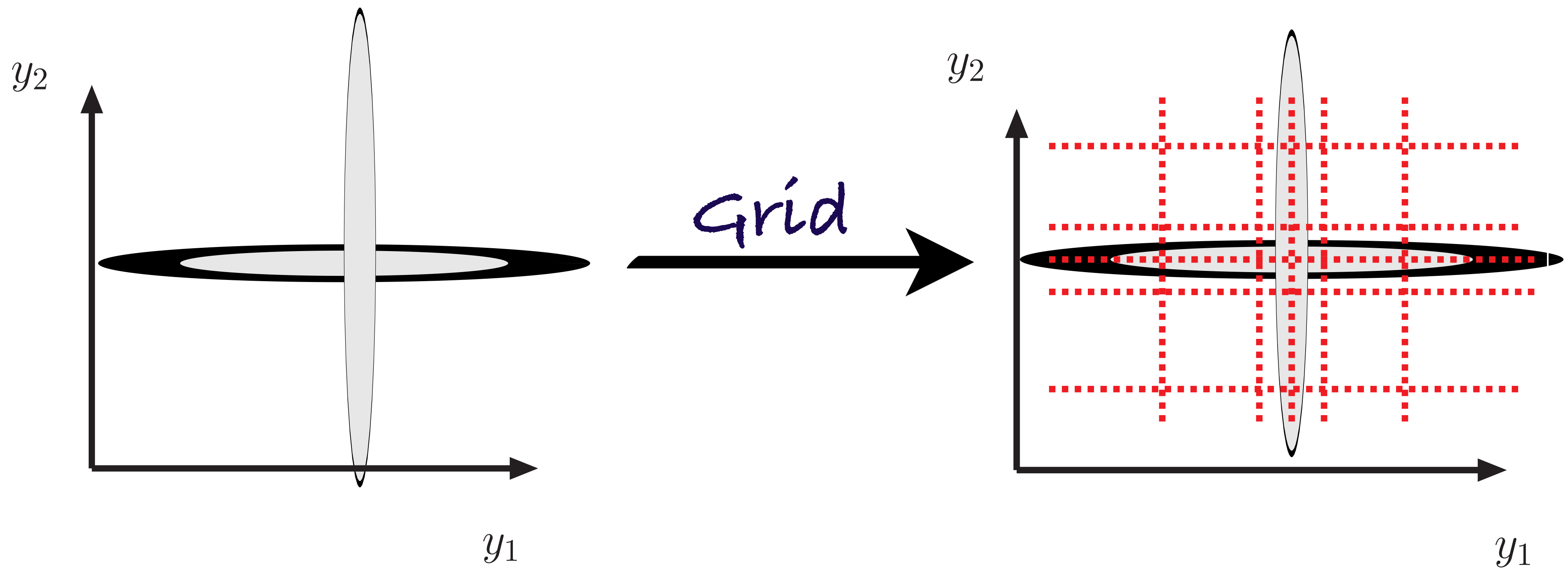
Difficult point: Numerical Integration

- Presence of sharp functions
  - Breit-Wigner
  - TF linked to angular observables

- The choice of the parameterisation has a strong impact on the efficiency



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  → The technique is efficient

Monte-Carlo Integration

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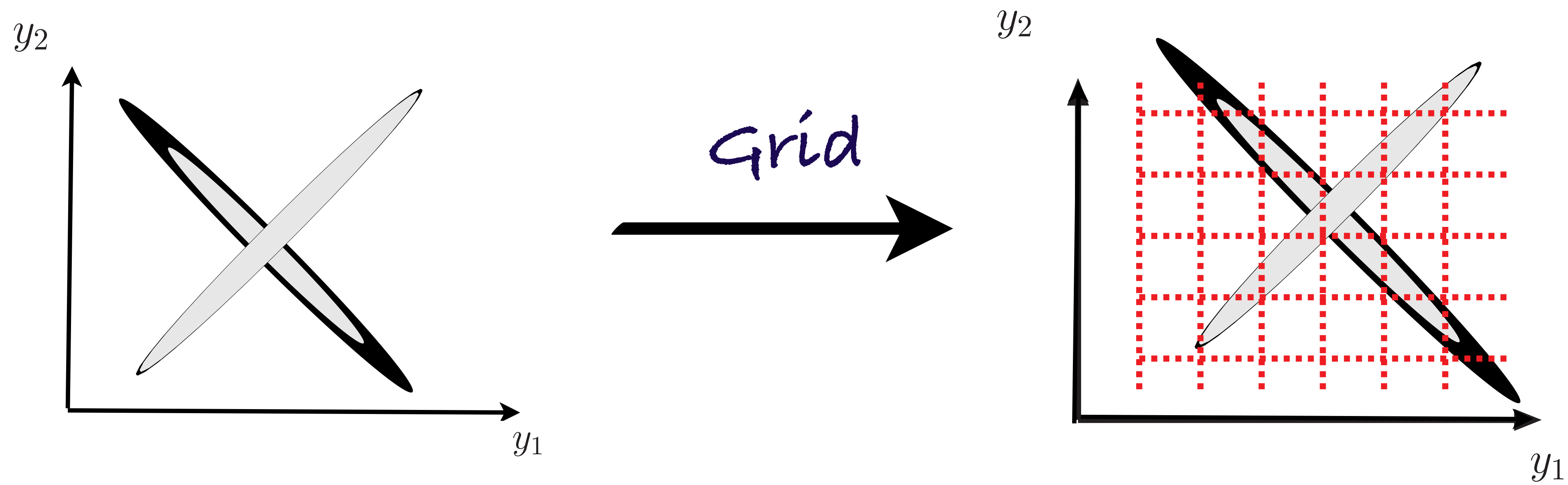

- The adaptive Monte-Carlo Techniques picks points everywhere
  → The integral converges slowly

Monte-Carlo Integration

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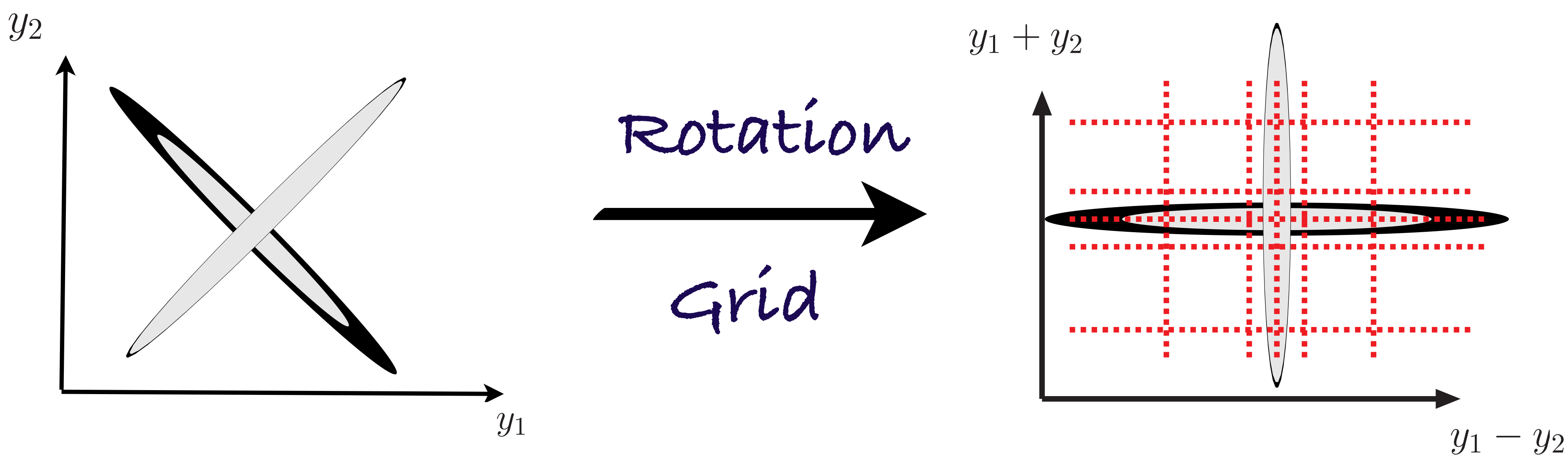

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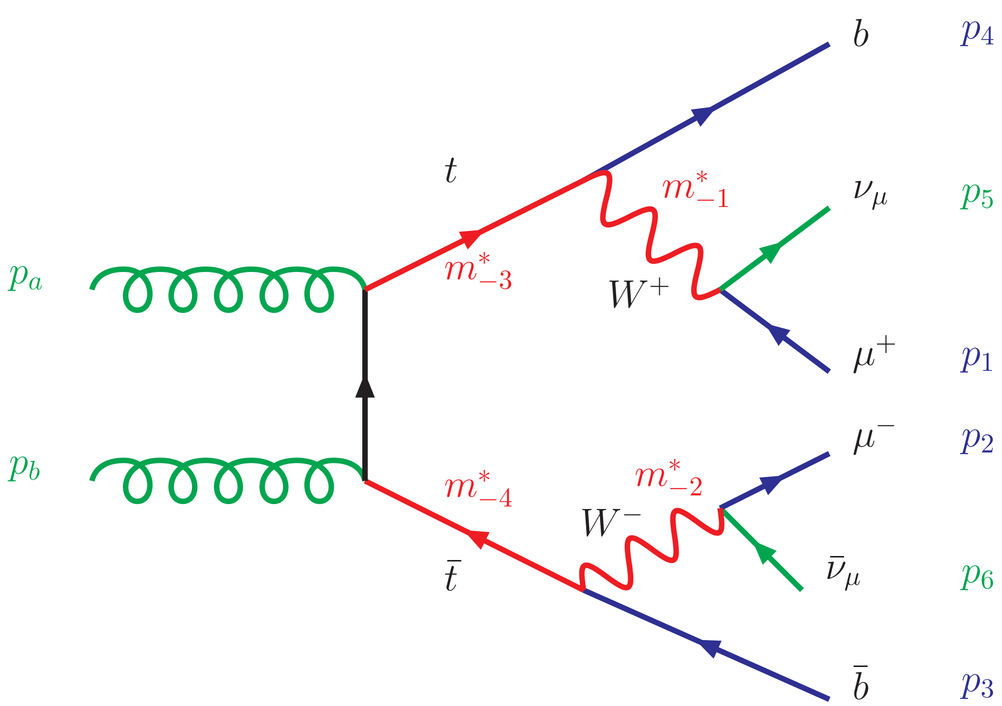

- degrees of freedom 16
  - 2: pdf
  - 3 x 6: final states
  - -4: energy-momentum conservation
- peaks 16
  - 4: Breit-Wigner
  - 3 x 4: visible particles

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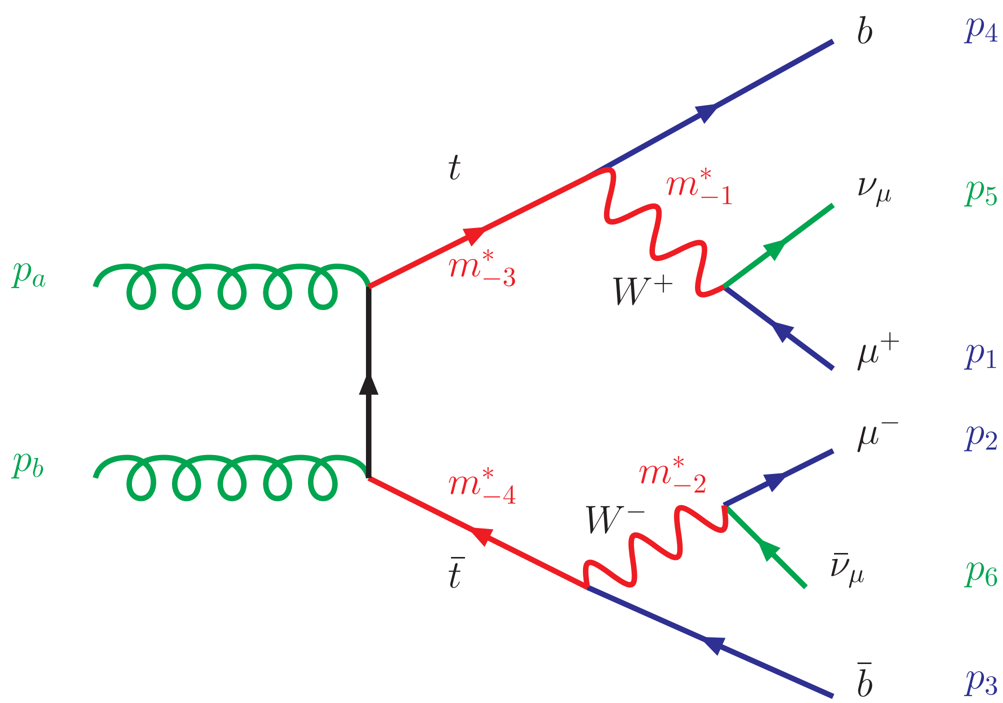

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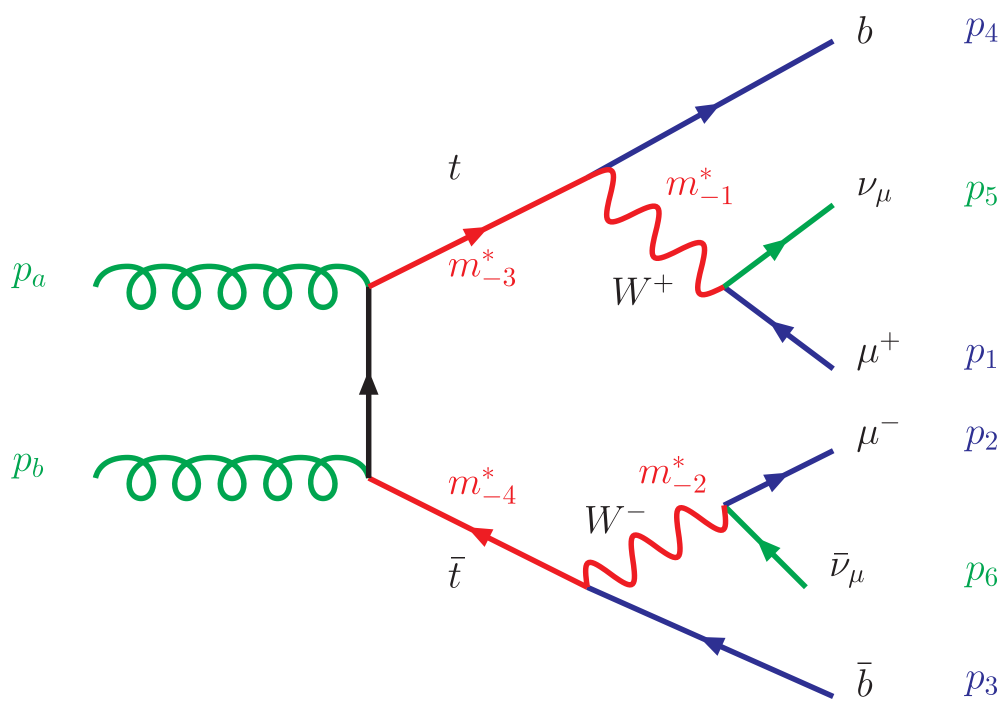

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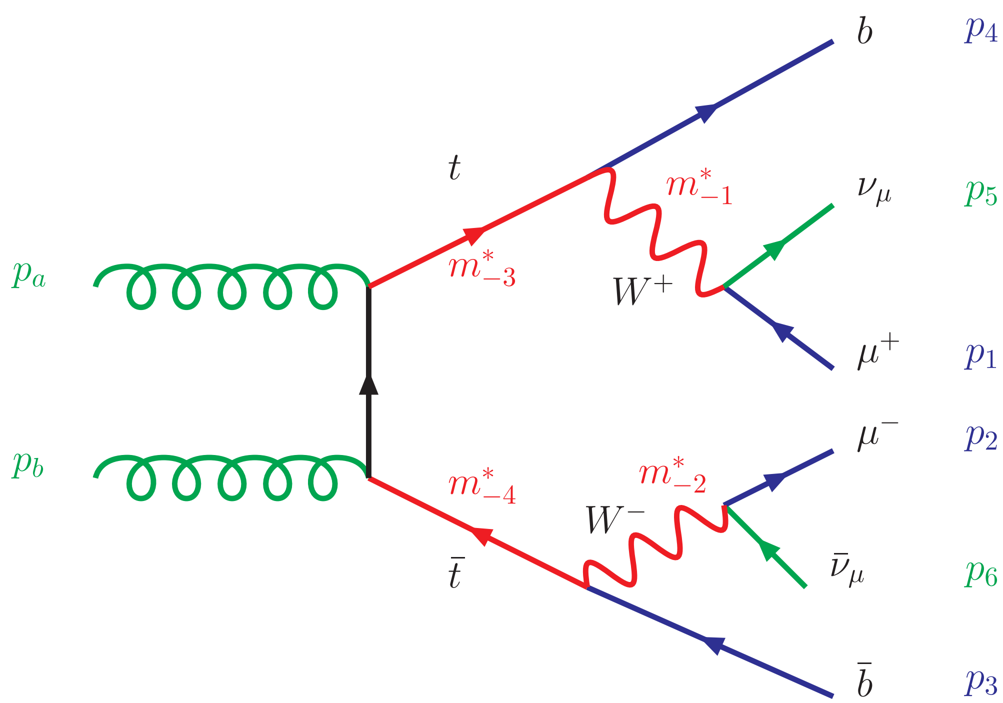

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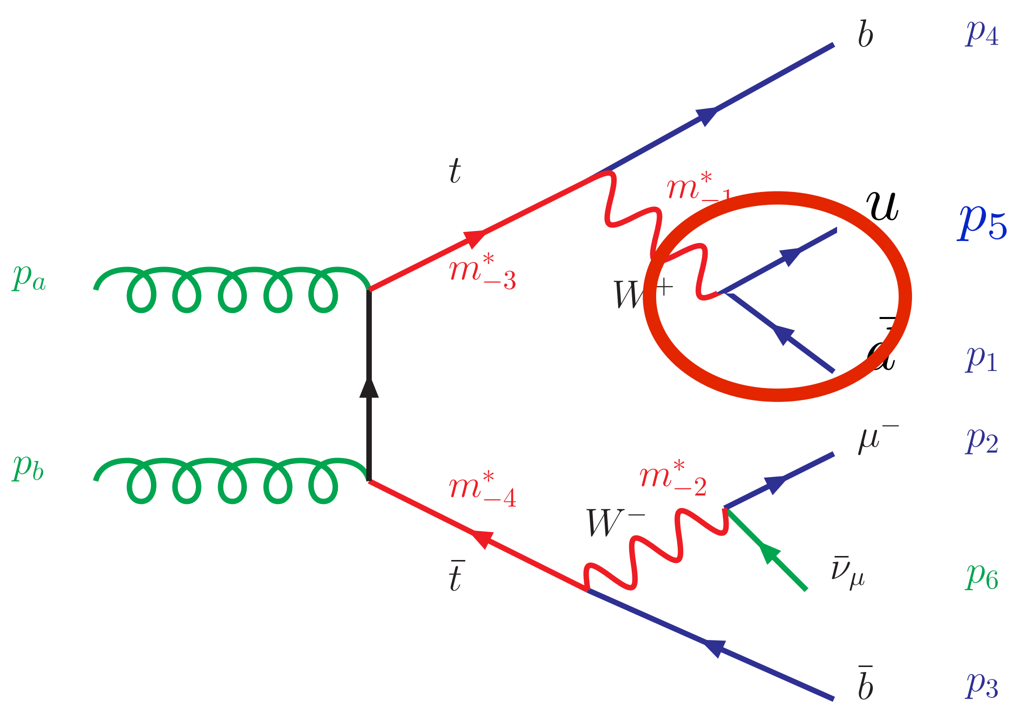
Pass to →

$$d\phi = \prod_{i=1}^{4} d\theta_i d\phi_i d|\boldsymbol{p}_i| \prod_{j=1}^{4} dm^{*2}_{-j} \times J$$

- Second Example: semi-leptonic top quark pair



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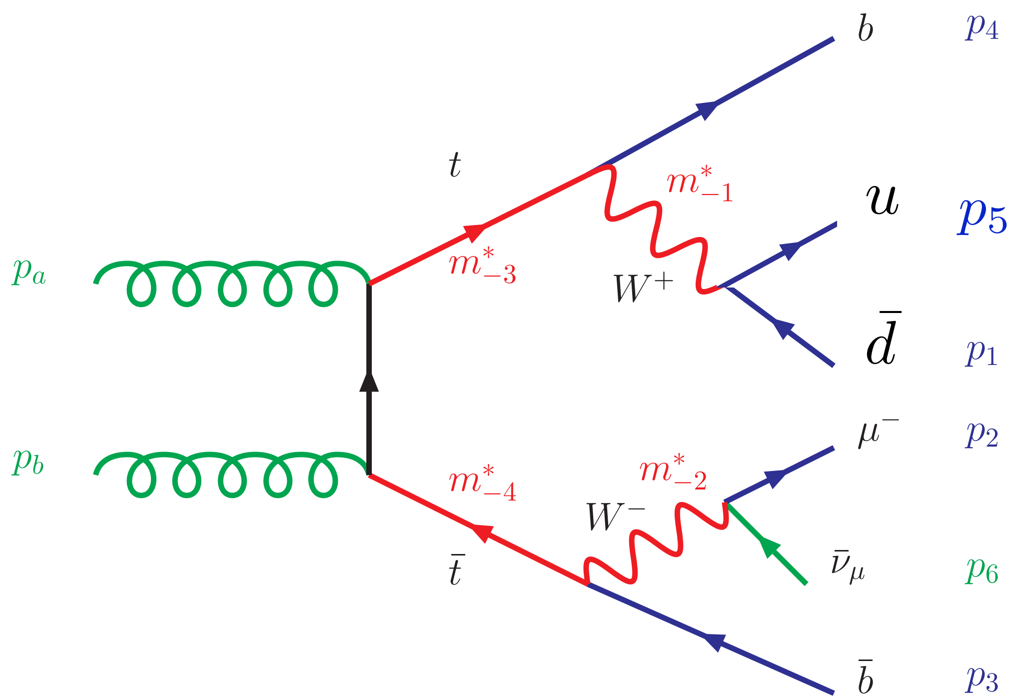

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→ 3 peaks unaligned

→ Multi-channel

MADWEIGHT

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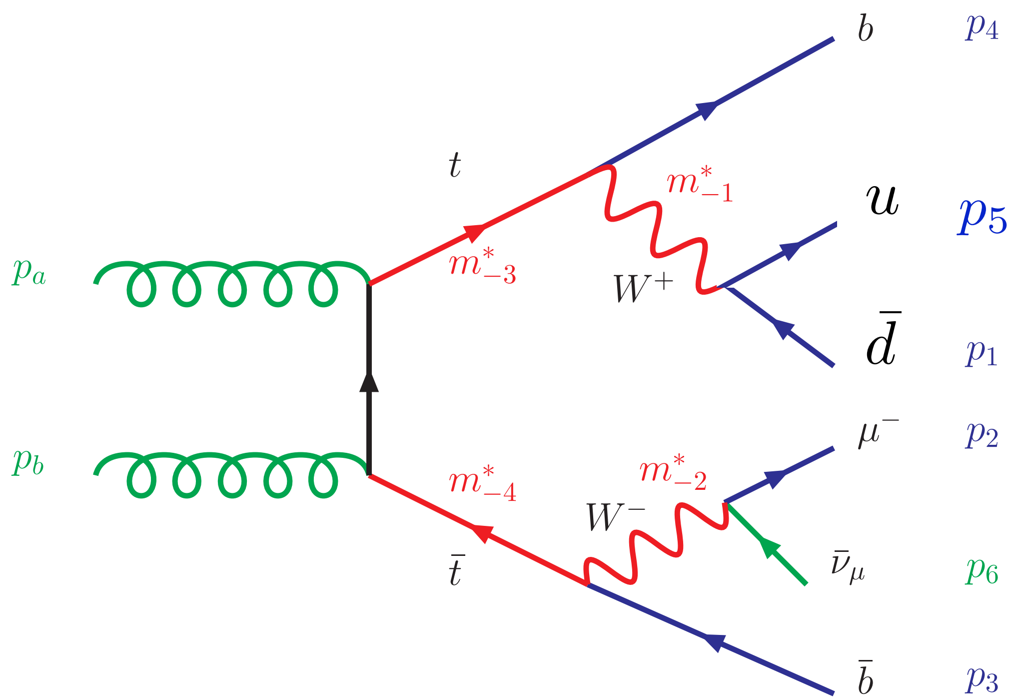

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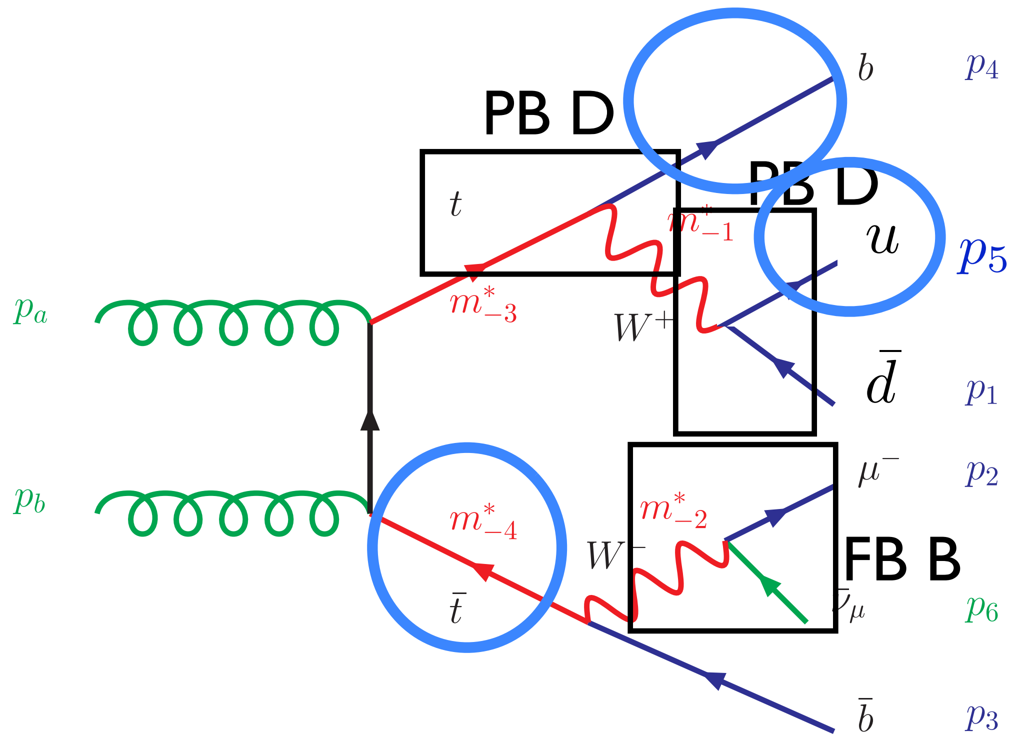

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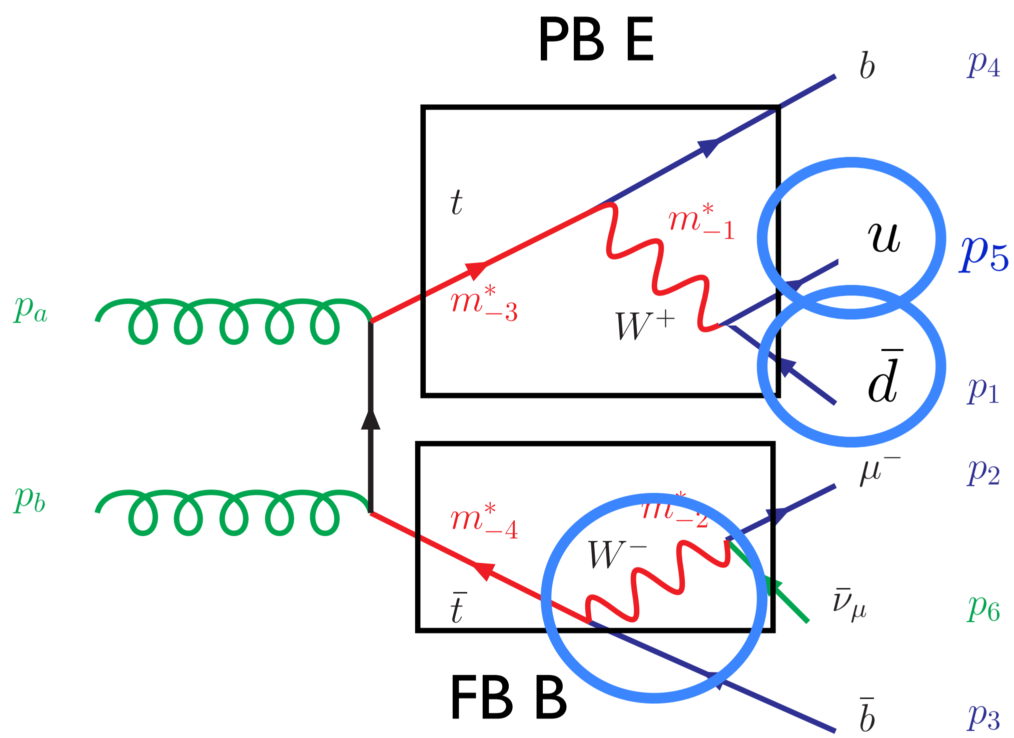

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MADWEIGHT

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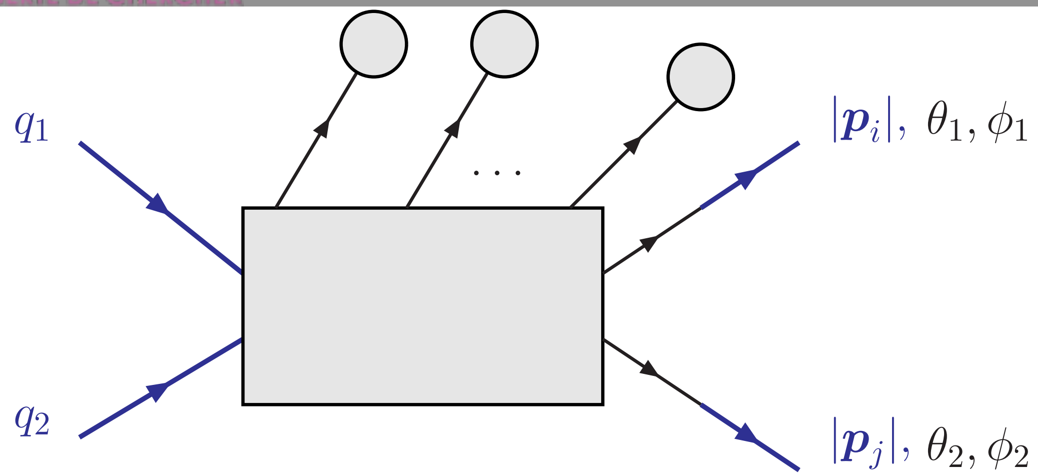
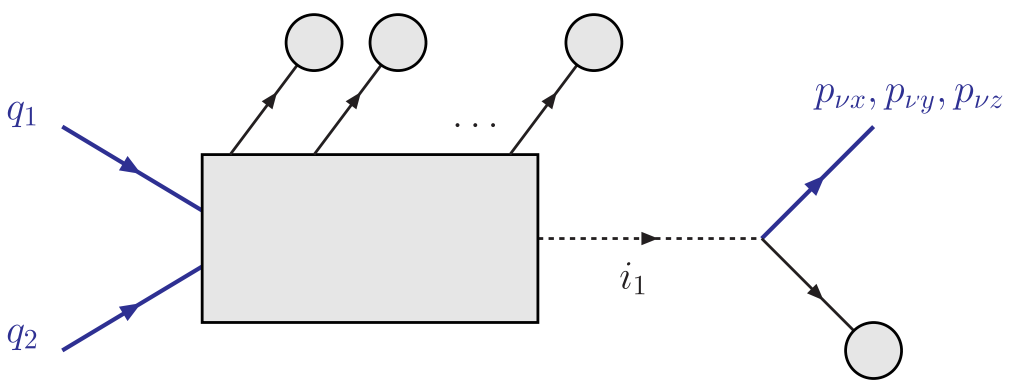
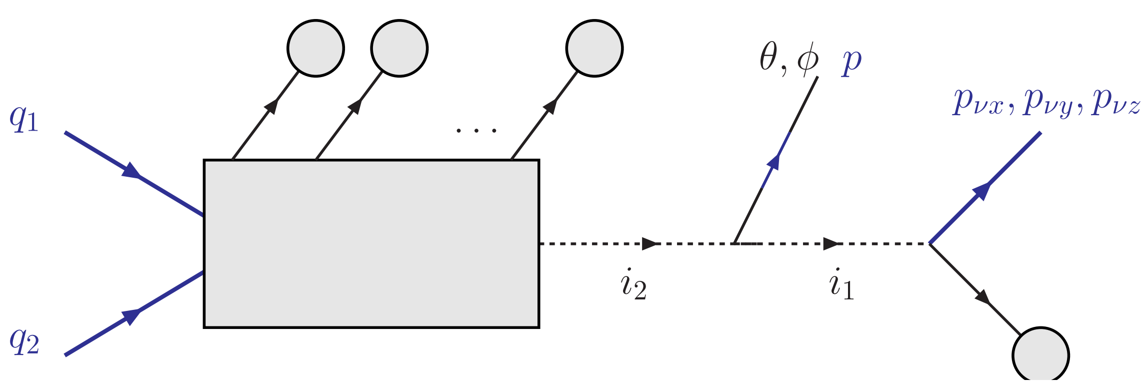
MadWeight



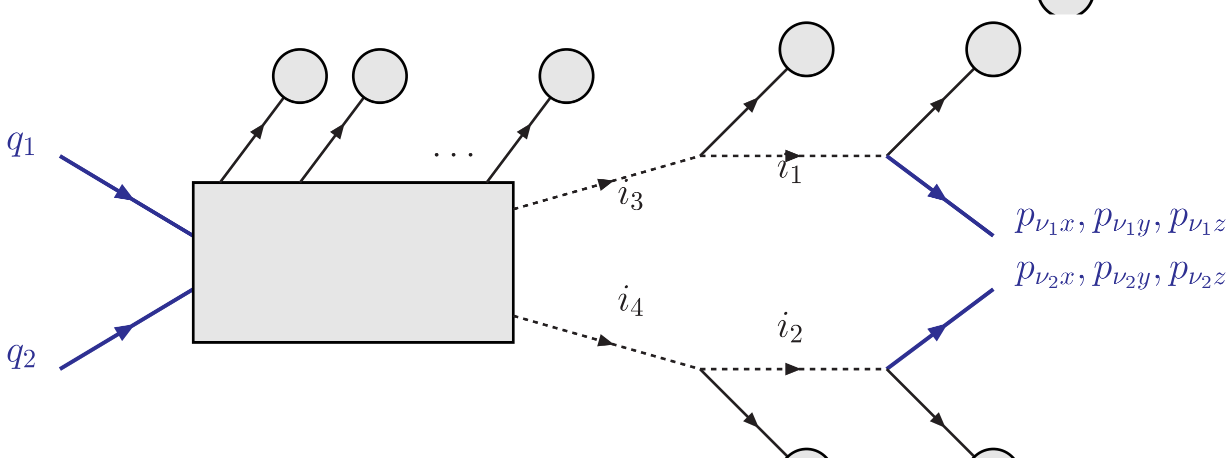
fully hadronic / leptonic process



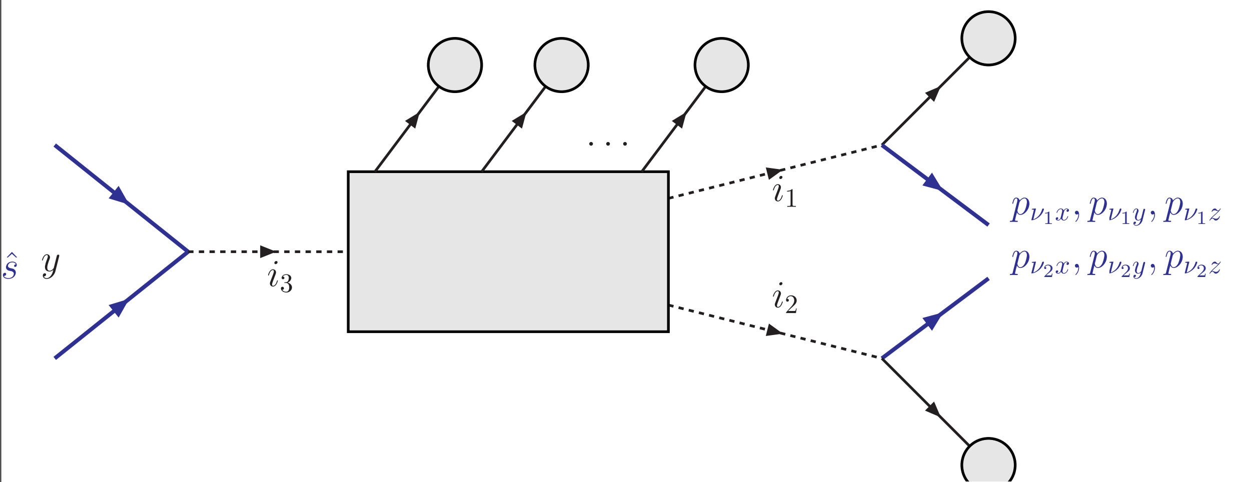
W production



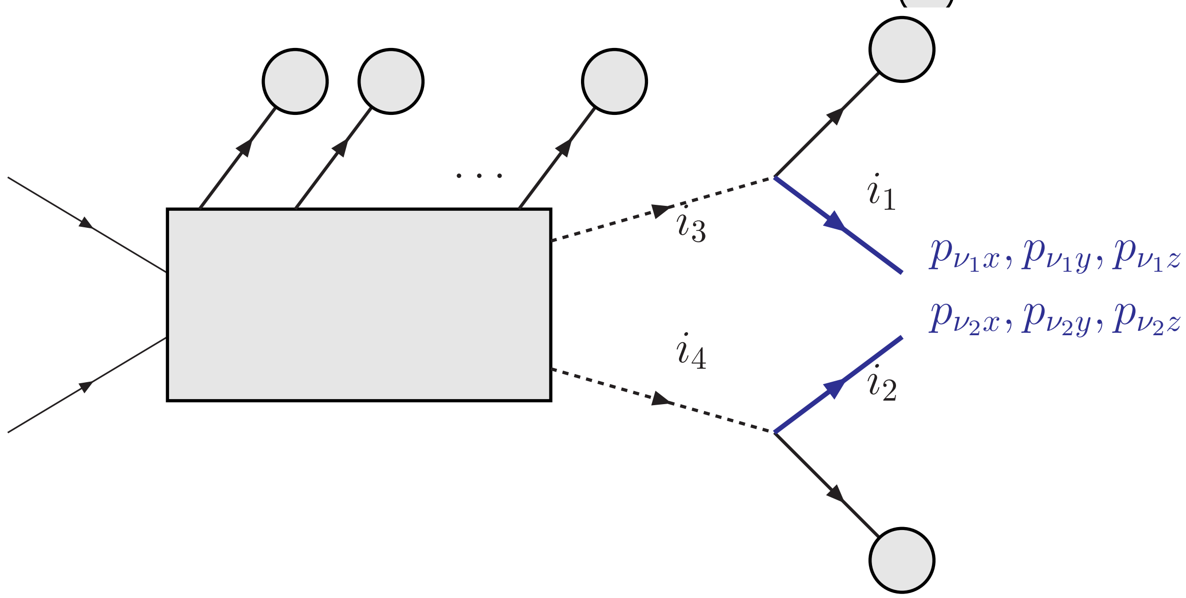
semi-leptonic top quark pair



Fully leptonic top quark pair



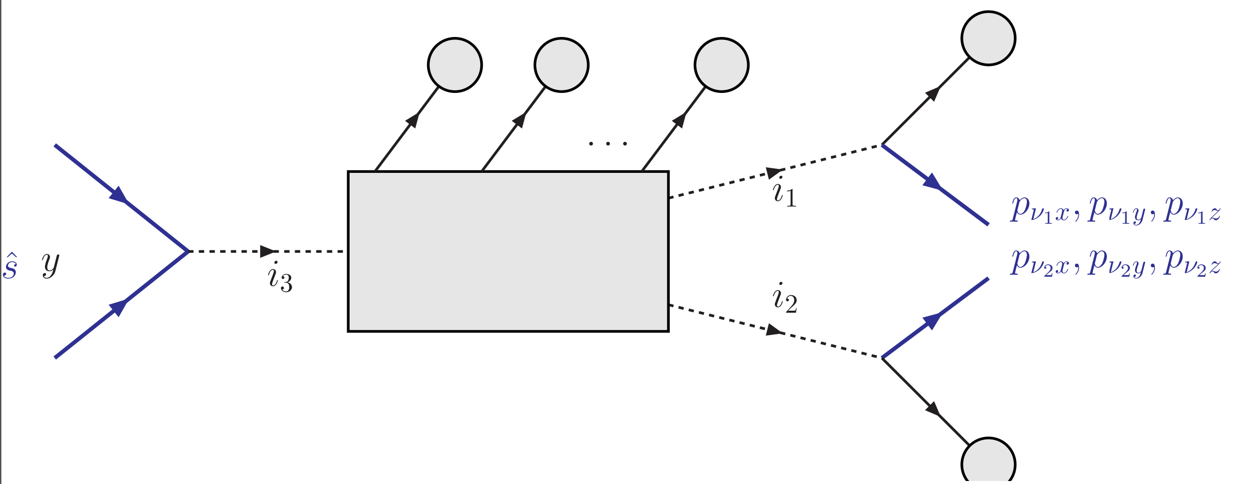
Higss production decaying in W



Class F

W+ W- production

MadWeight



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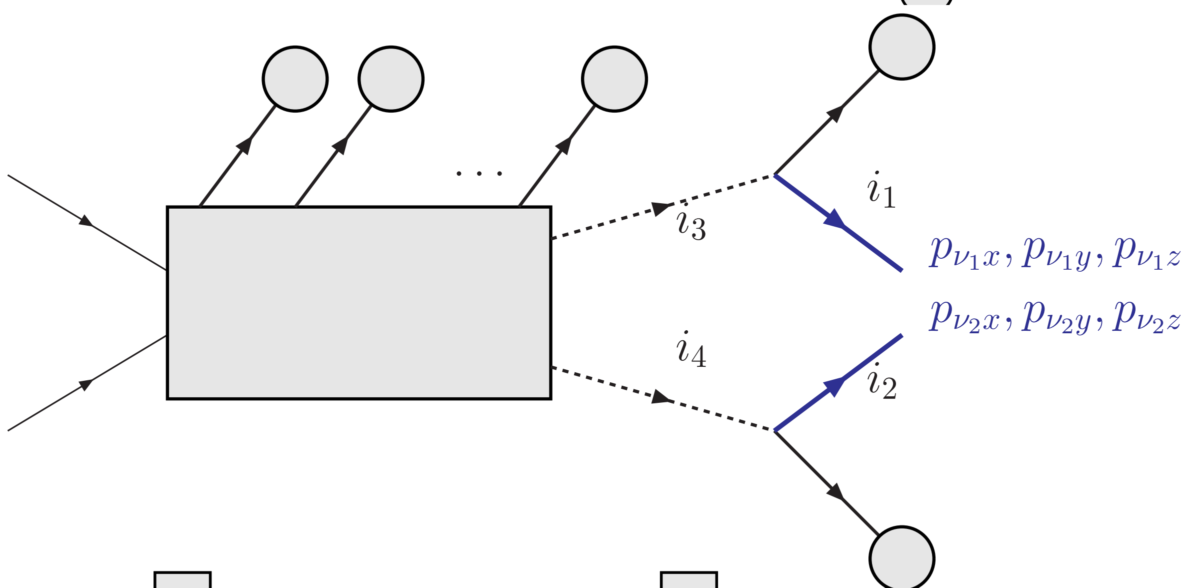

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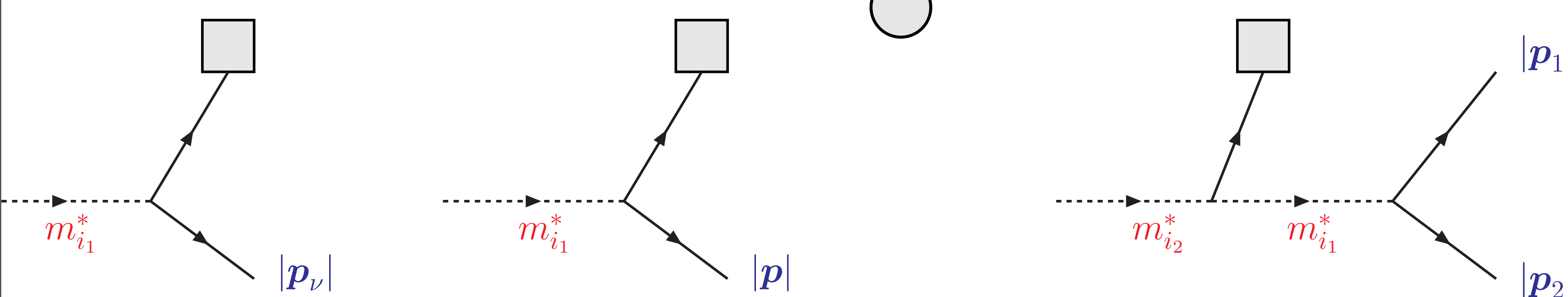

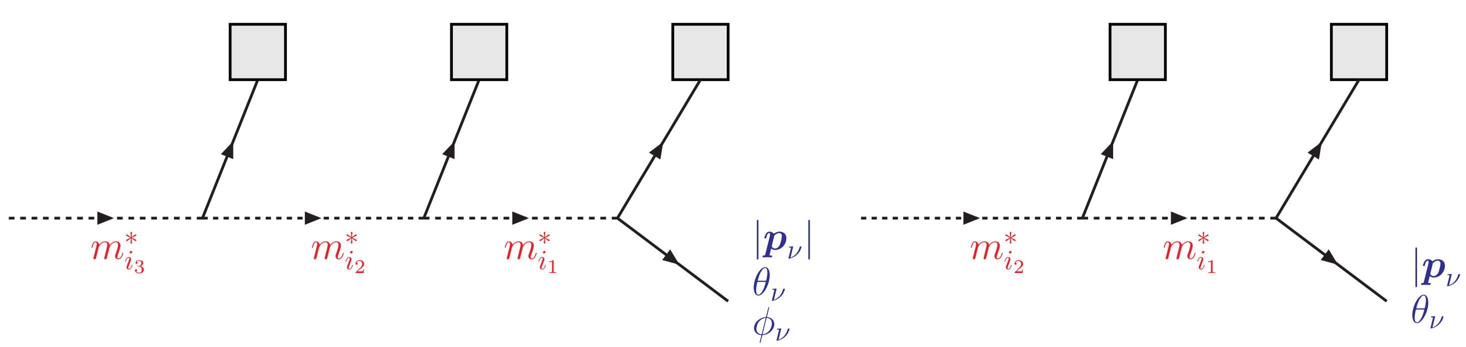

Lot of possibility to have more complex process

+1 W

+1 Z

+ ...

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  - mass determination : smuon pair production
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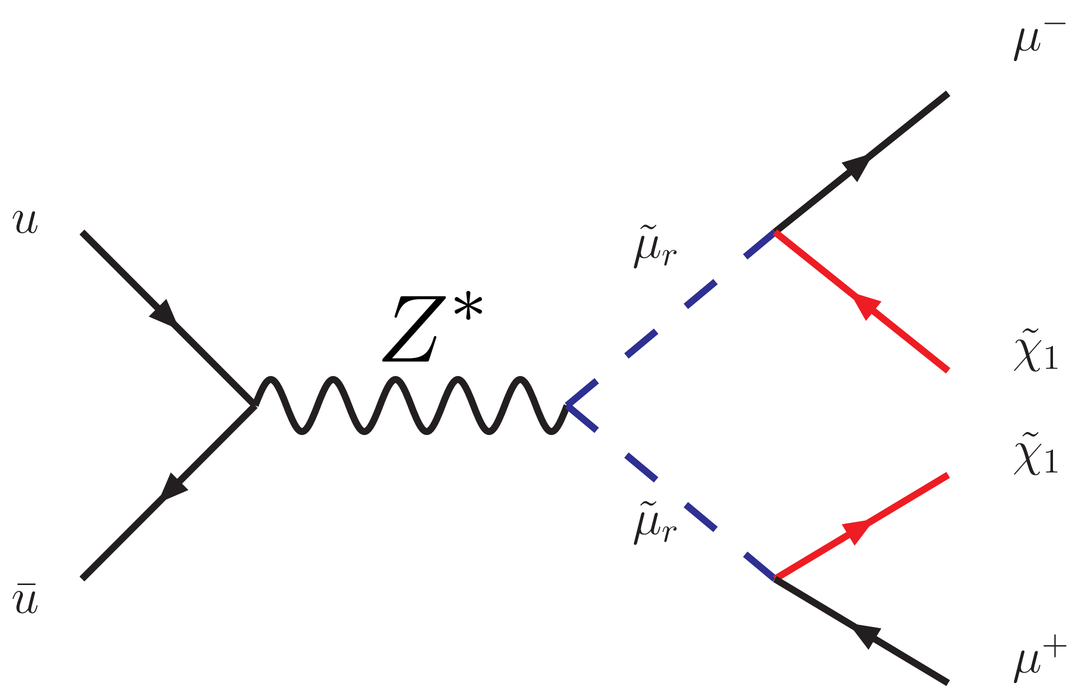
(Crazy?) scenario: We observe only Two muon + MET



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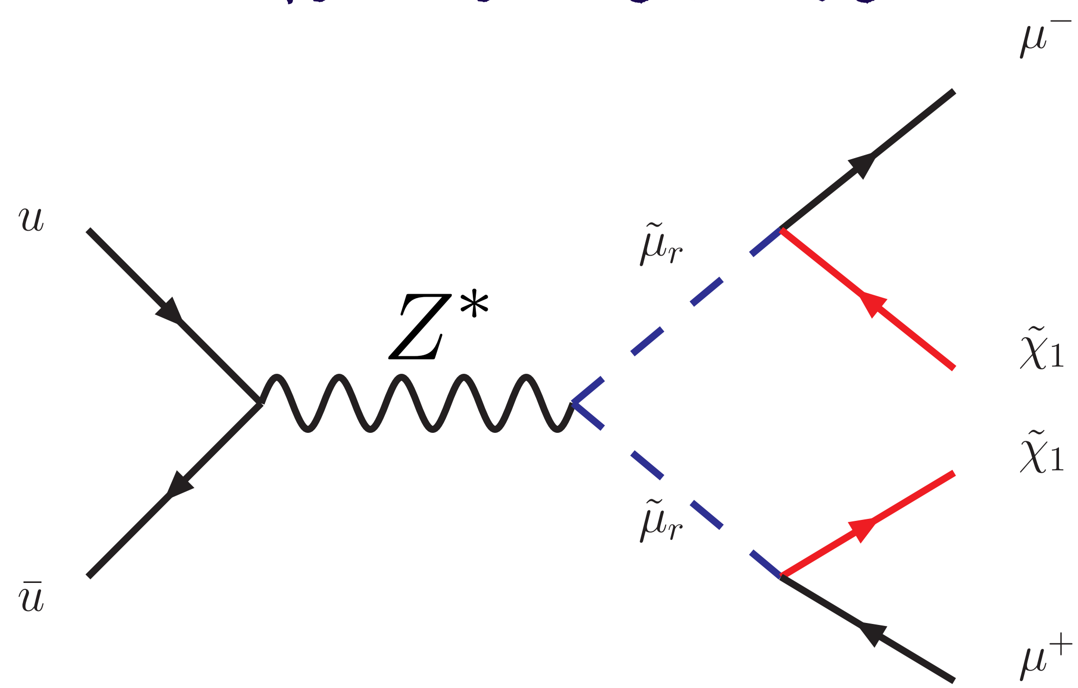
How to measure smuon mass and LSP mass?



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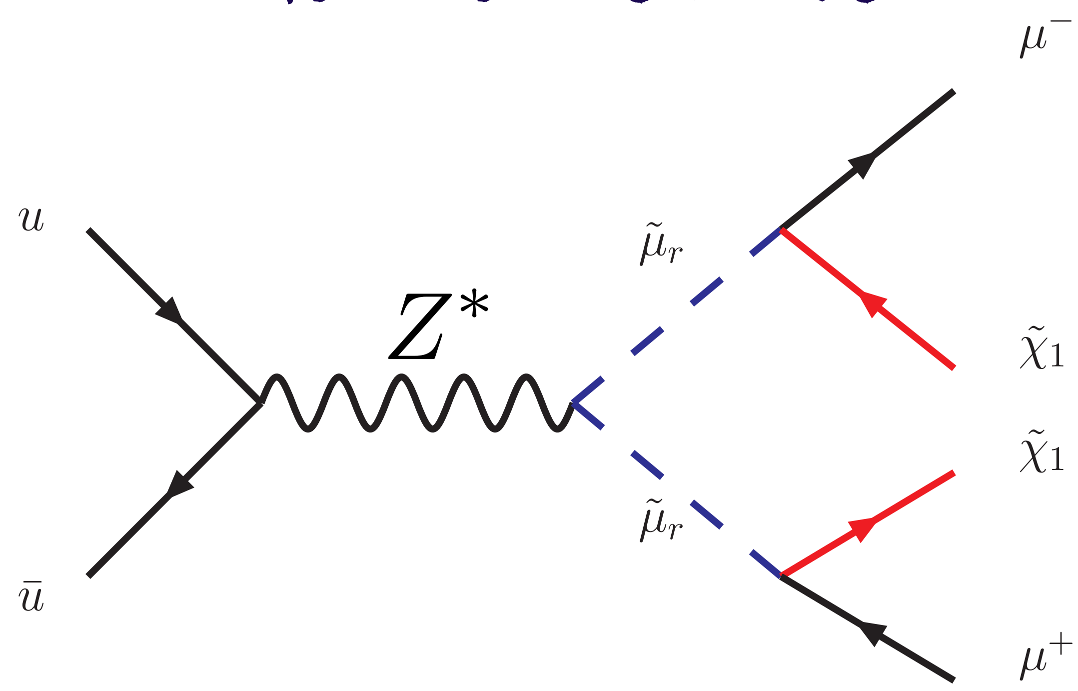

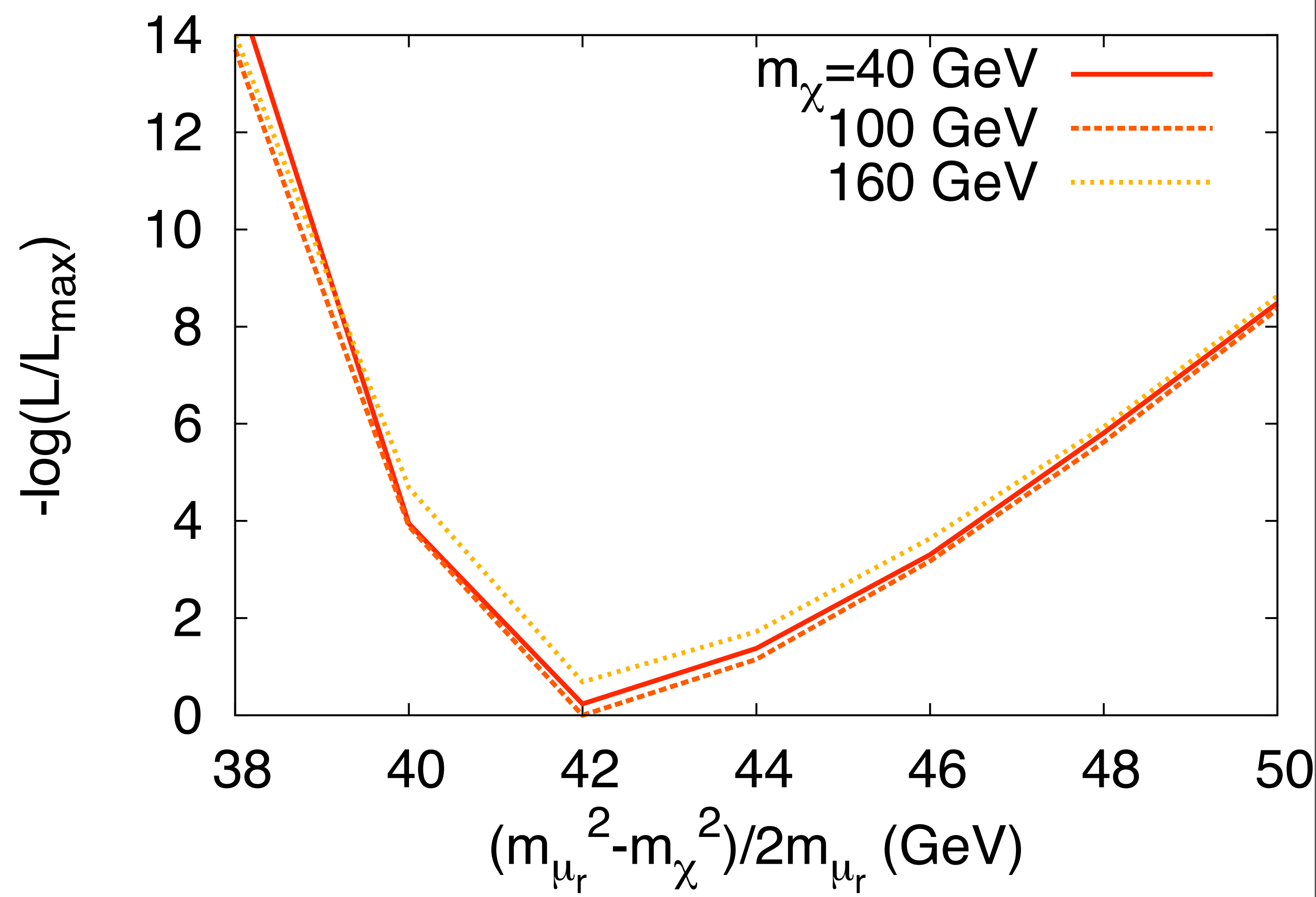

- 50 (Monte-Carlo) events

$$M_{\tilde{\mu}} = 150\text{GeV}$$
$$M_{\tilde{\chi}} = 100\text{GeV}$$

$$(M_{\tilde{\mu}}^2 - M_{\tilde{\chi}}^2)/2M_{\tilde{\mu}} = 42\text{GeV}$$

Mass determination

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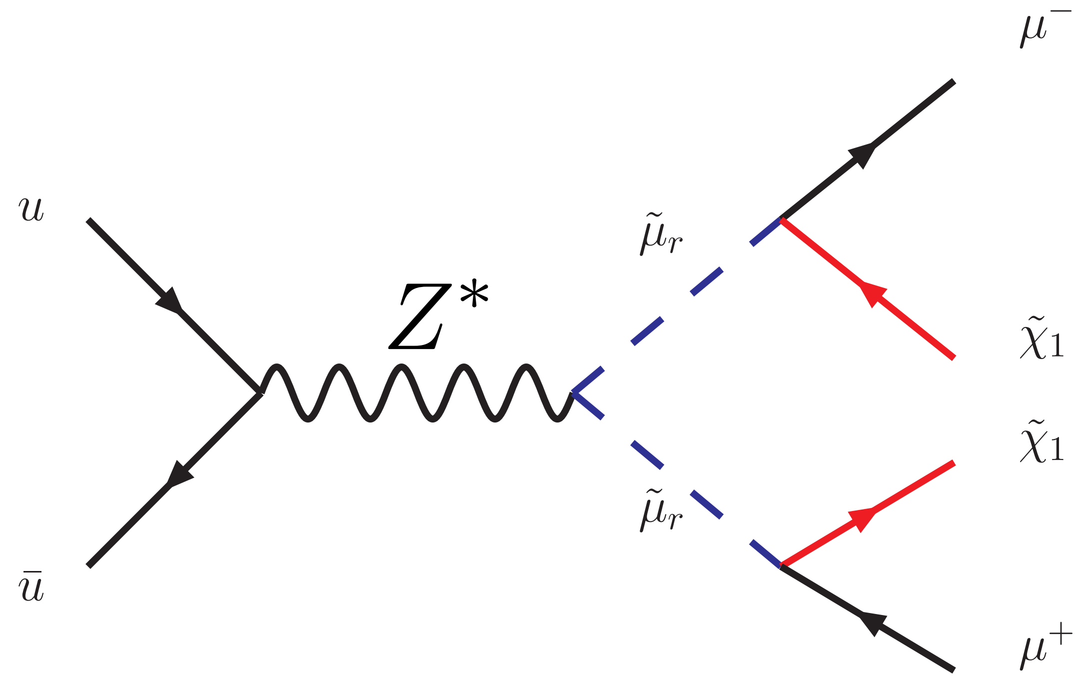

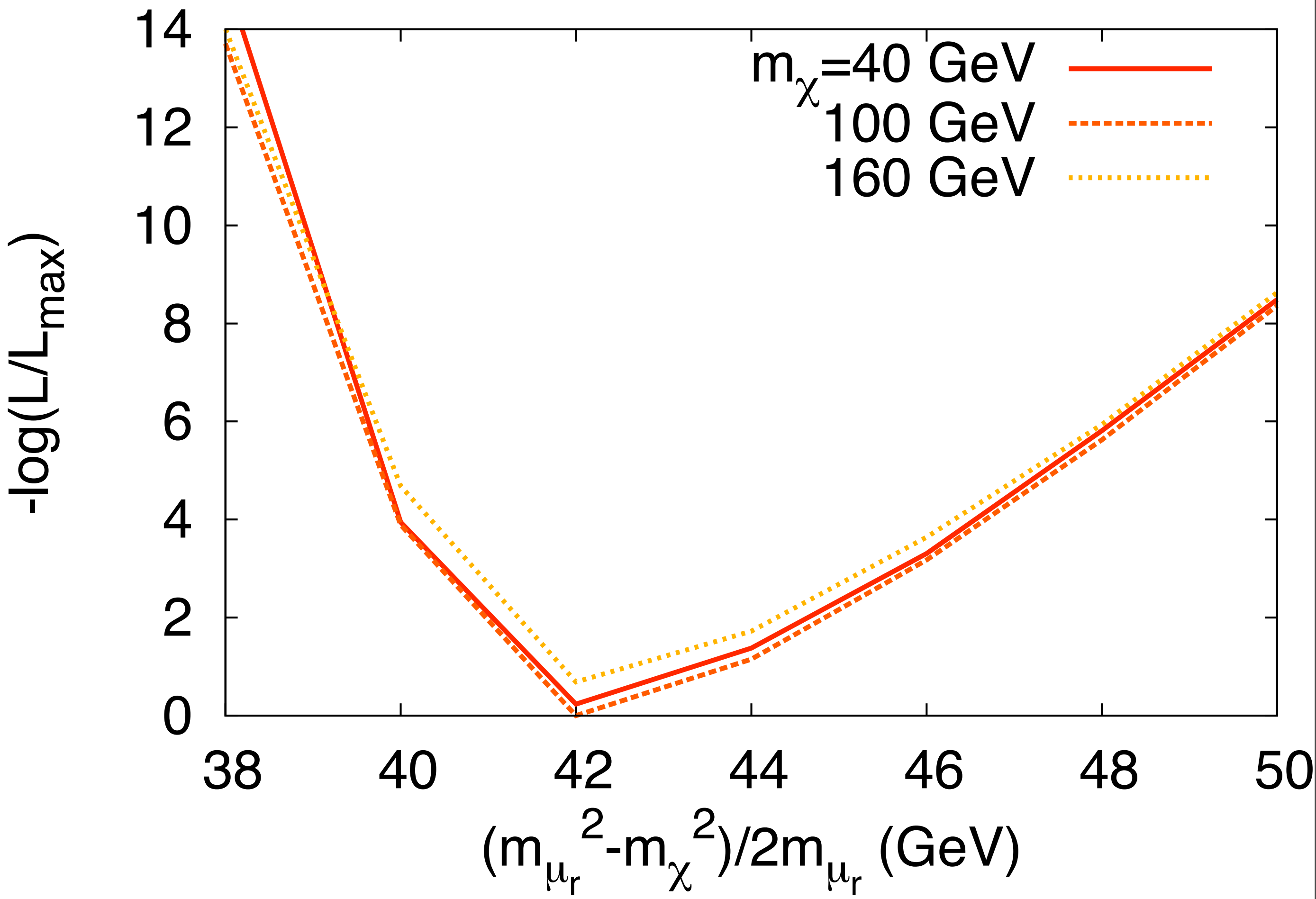

Energy in the rest frame

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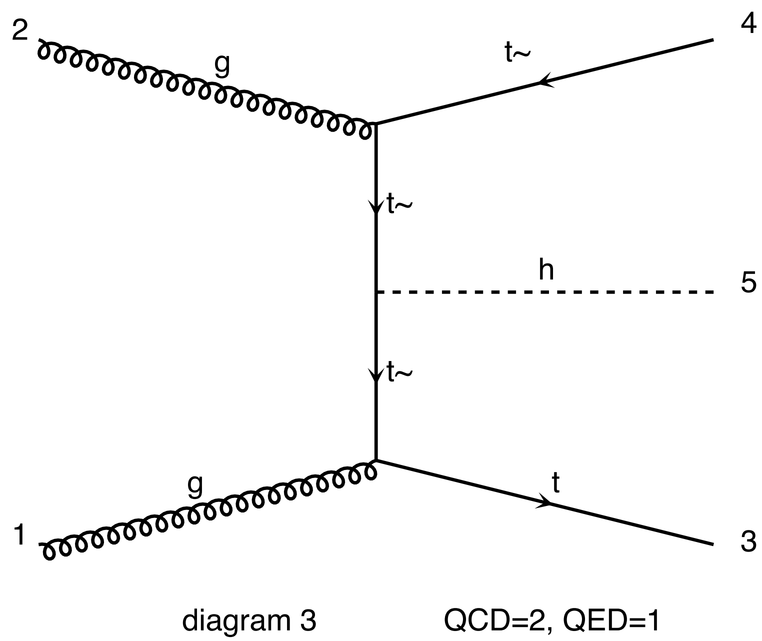
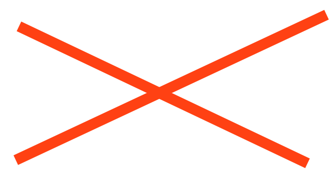
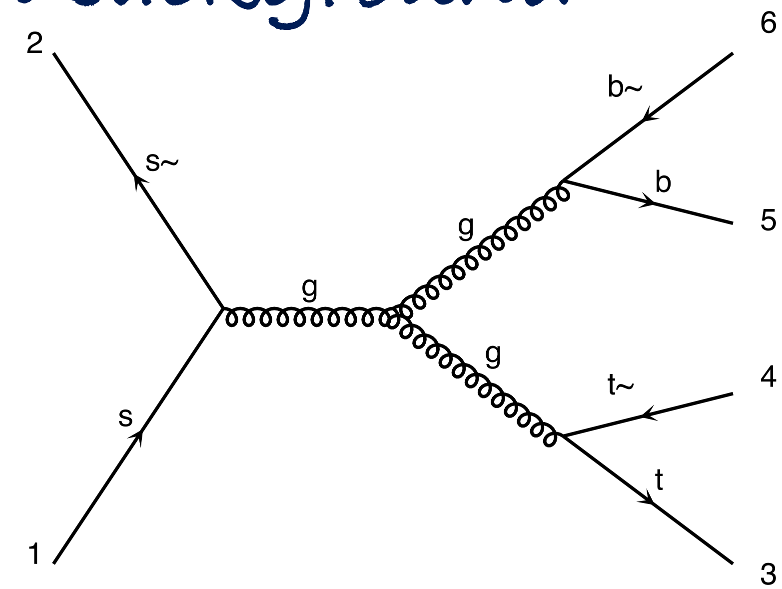
TT + Higgs

- Discriminate t t~ Higgs from background







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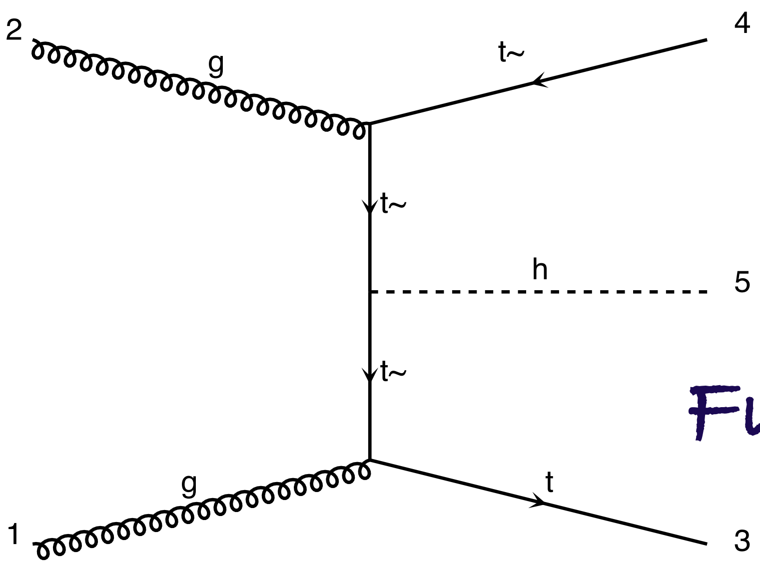
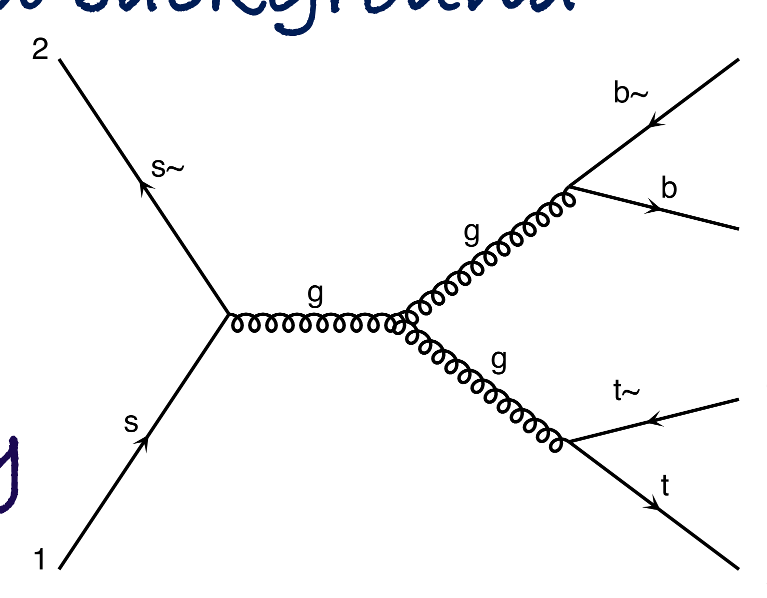


diagram 3 QCD=2, QED=1

Fully leptonic decay



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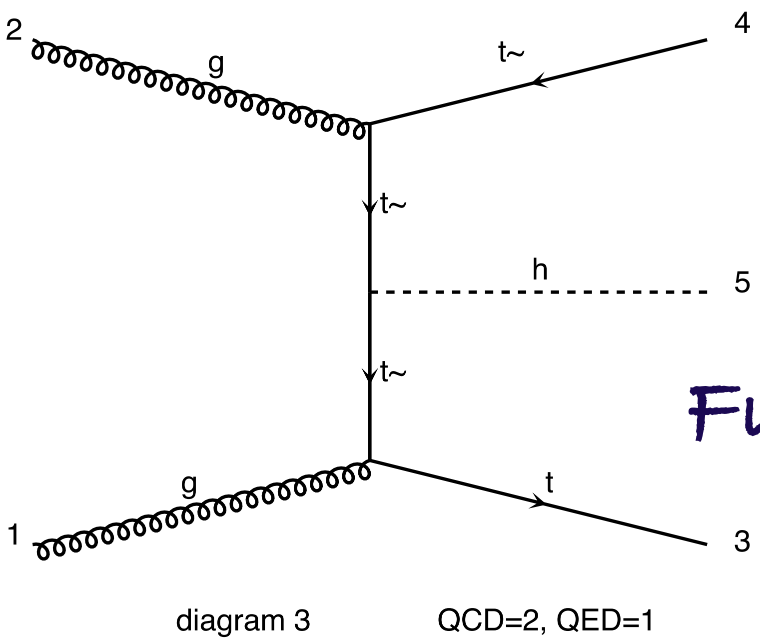

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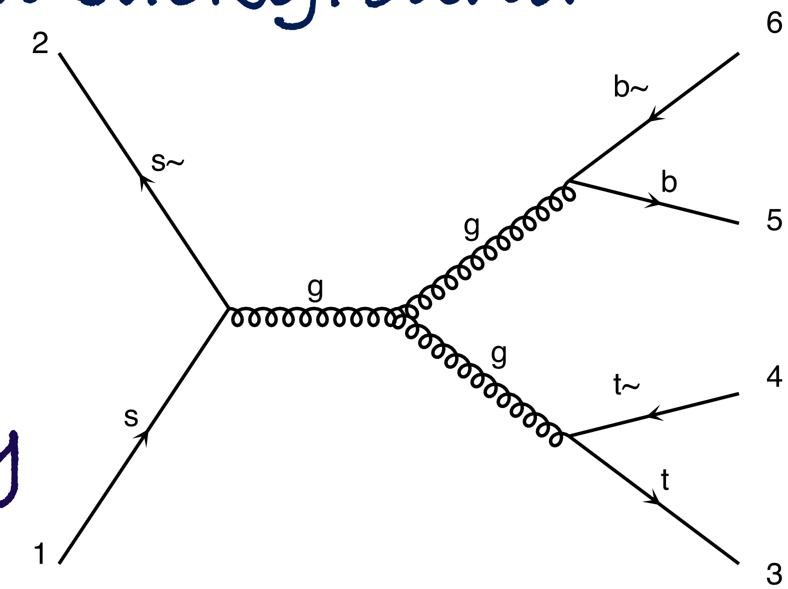
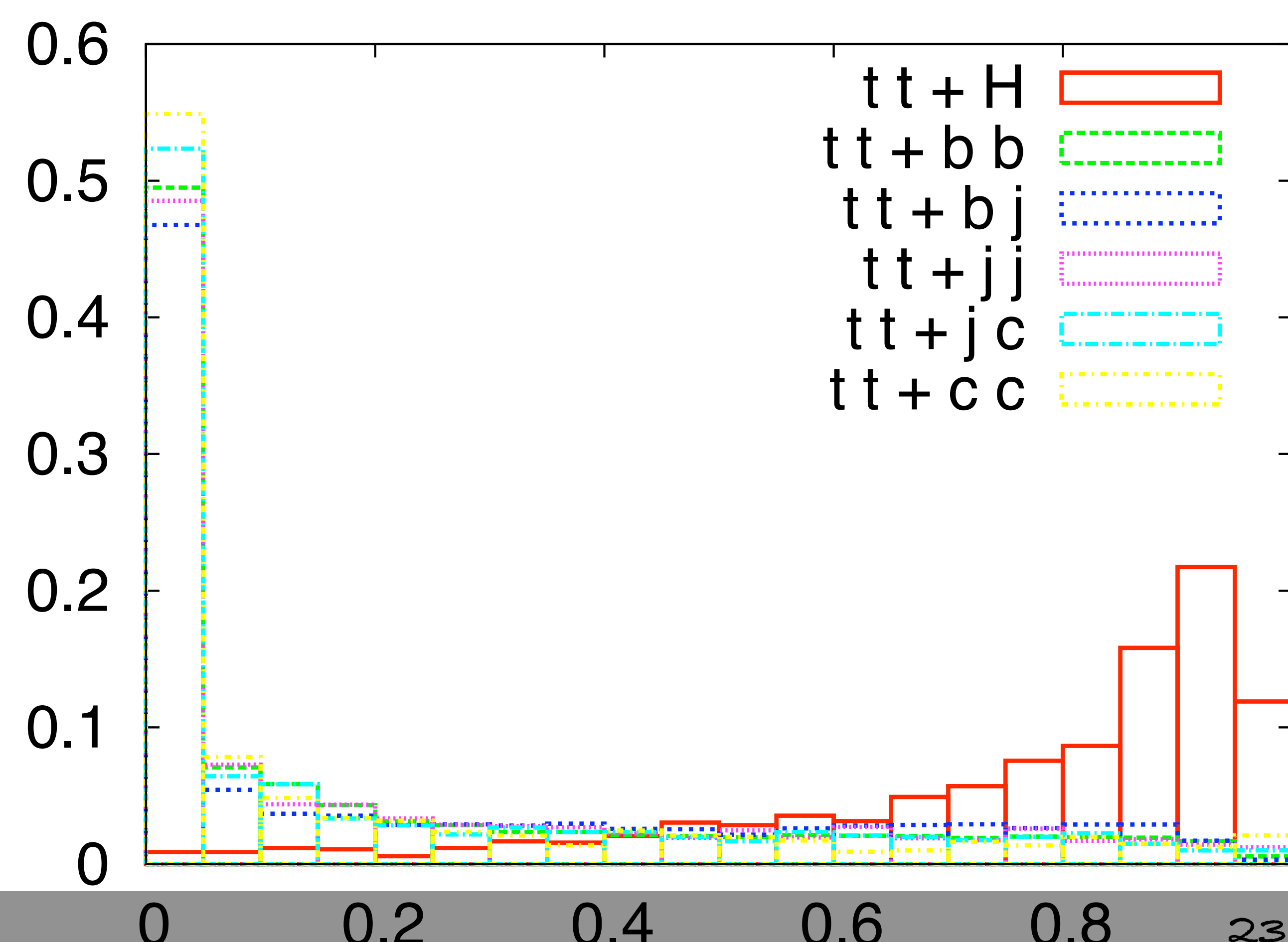


- define discriminant:

$$d = \frac{P_S}{P_S + P_{BG}}$$

Probability for one event to have a given discriminant value



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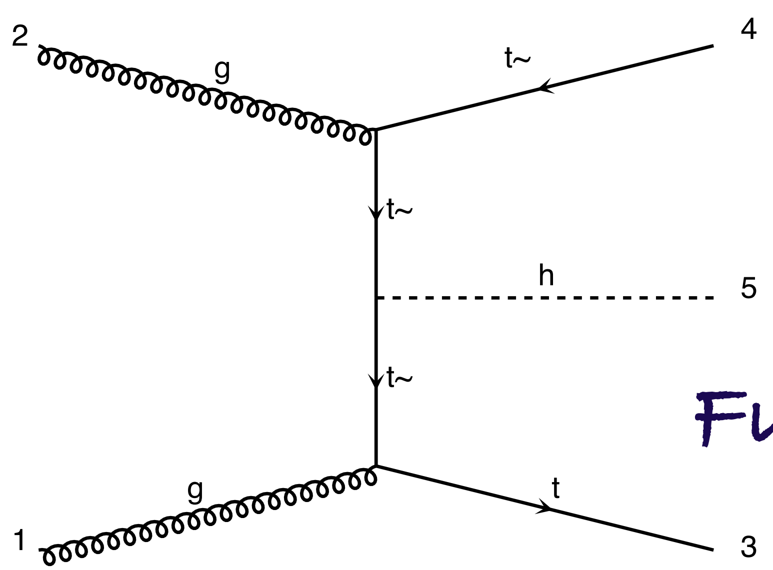

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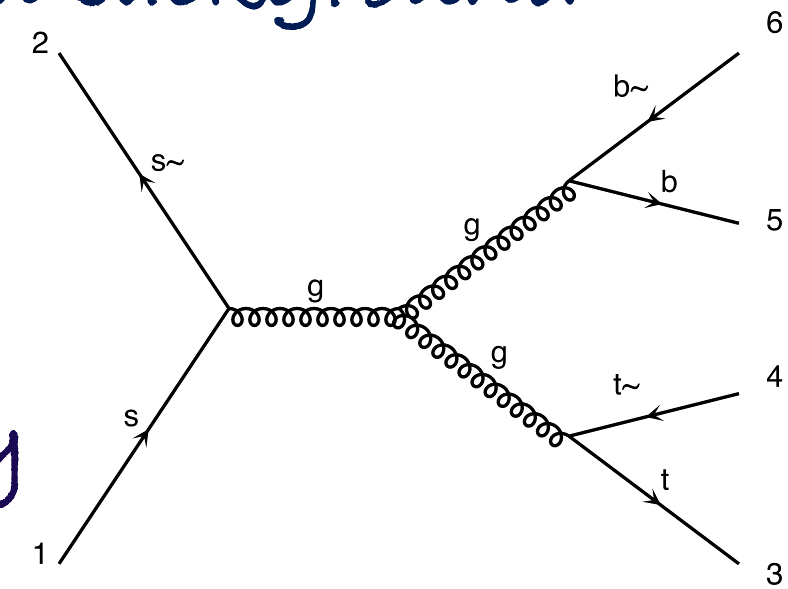

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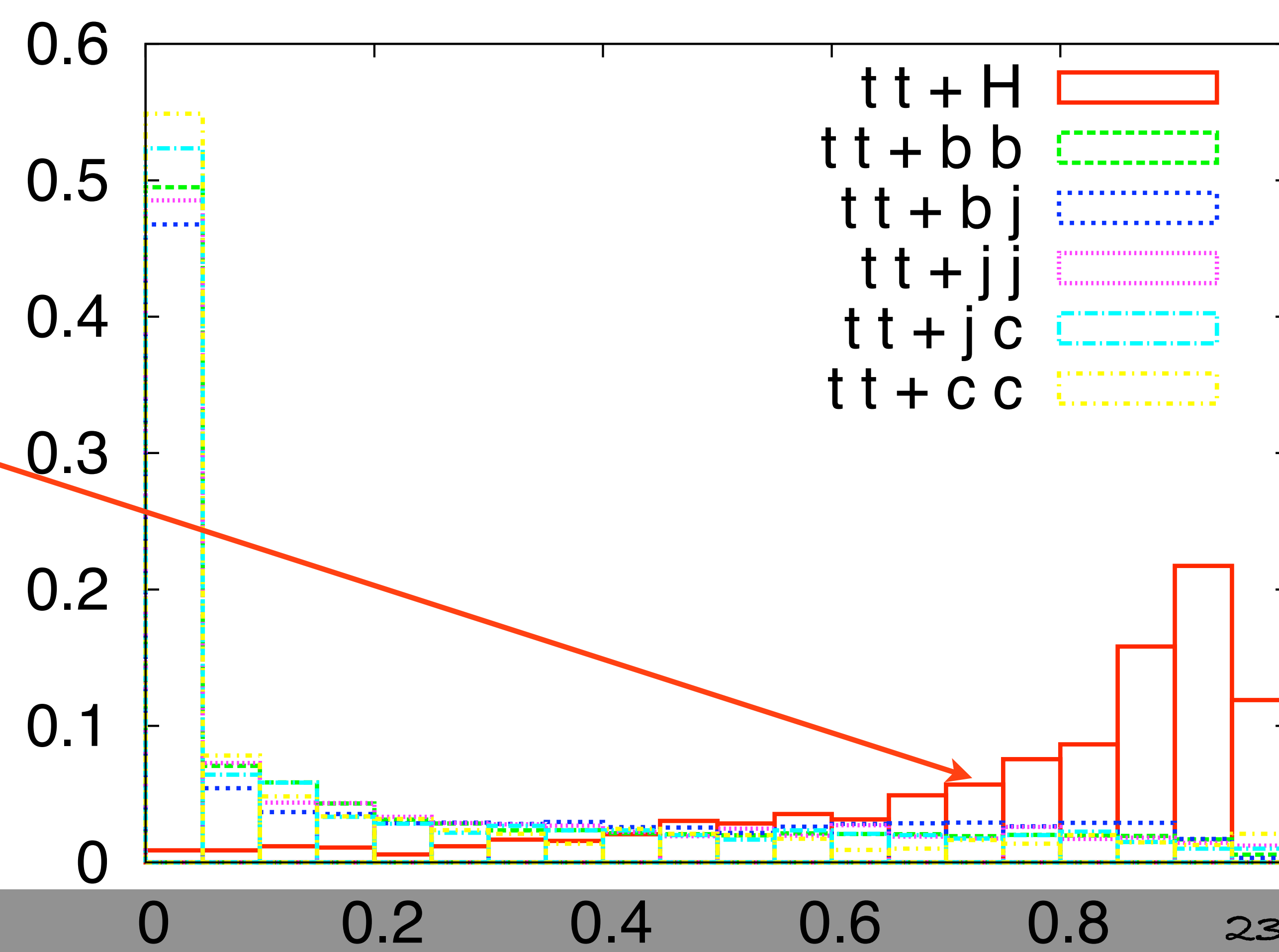

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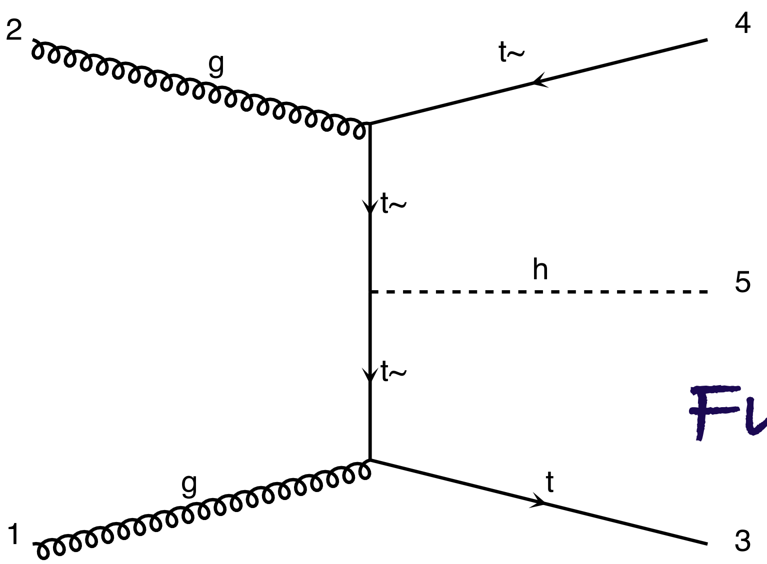

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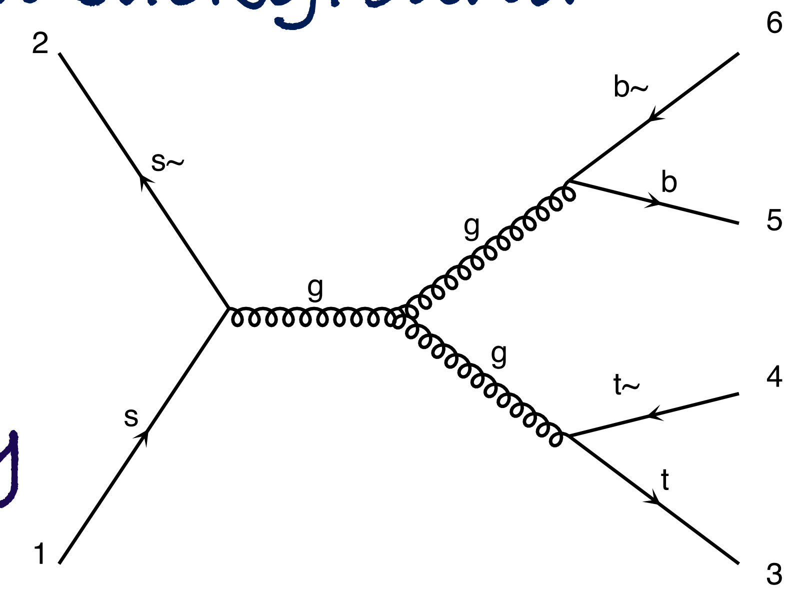

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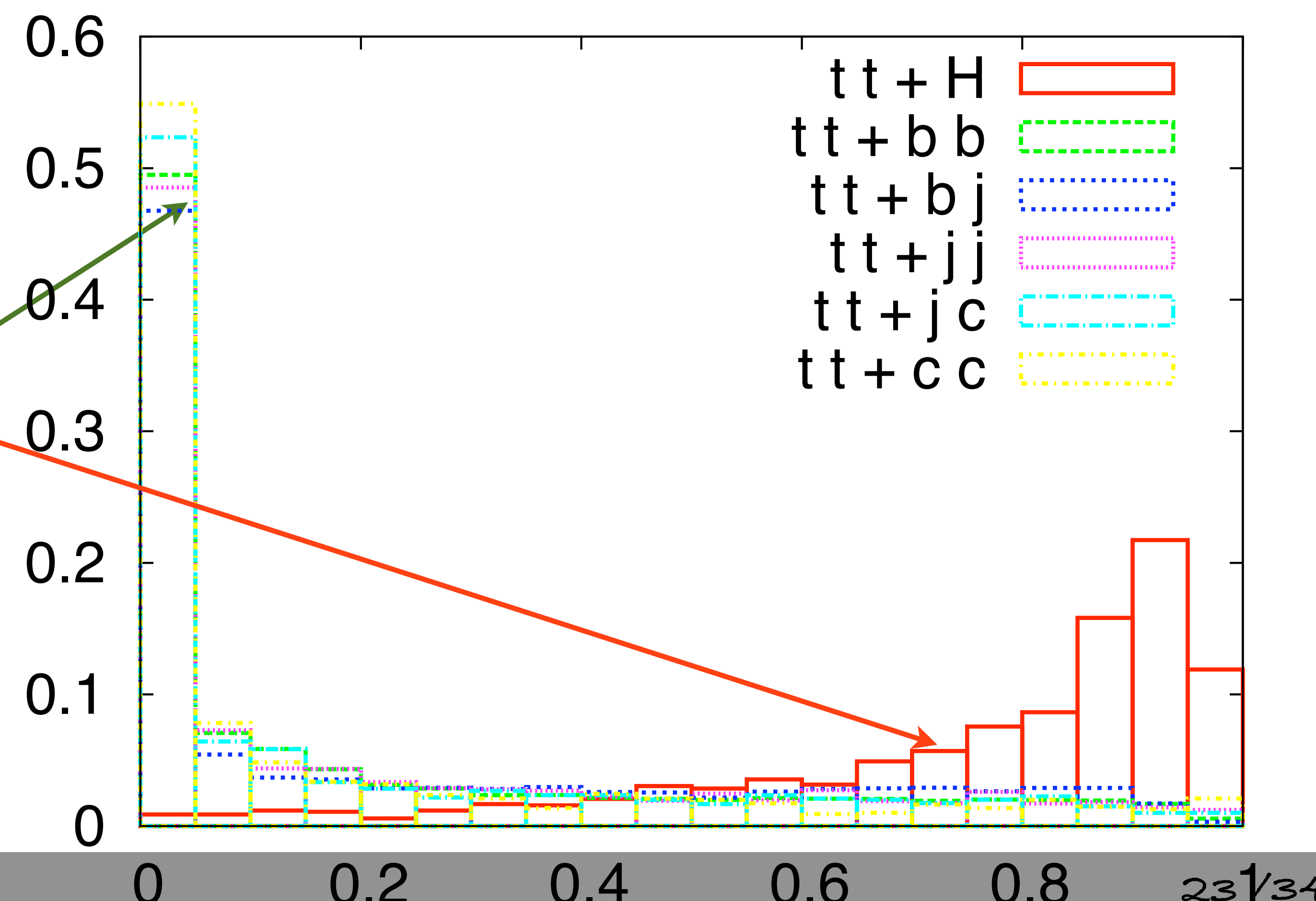

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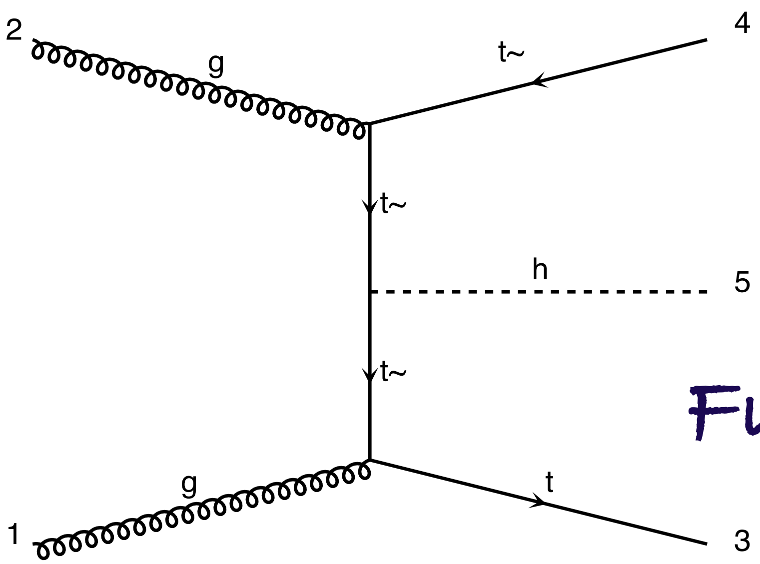

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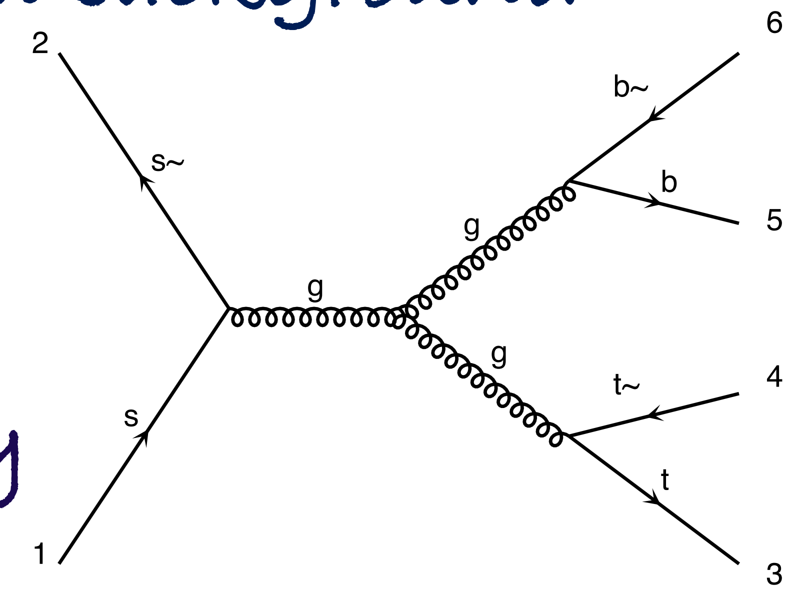

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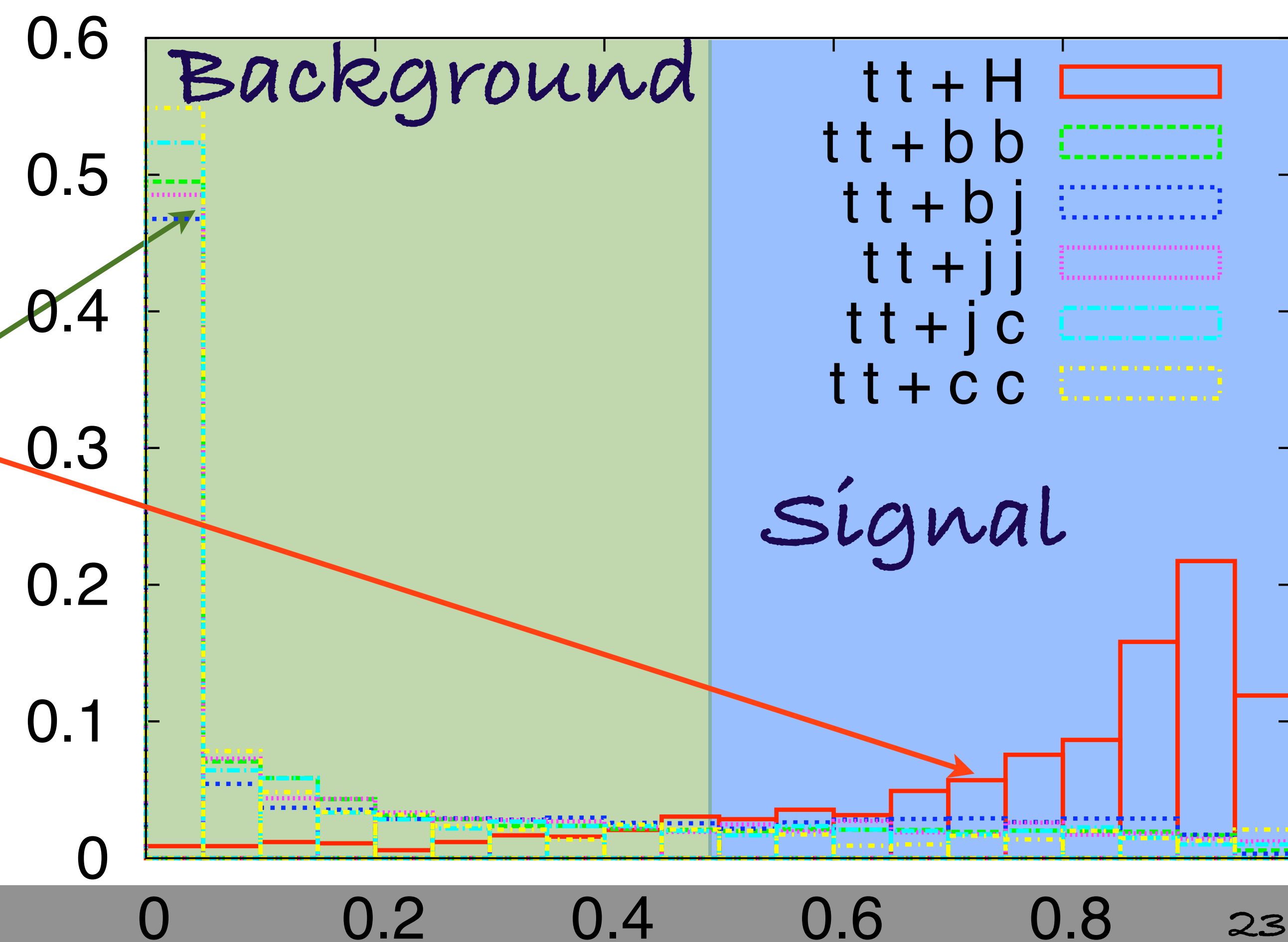

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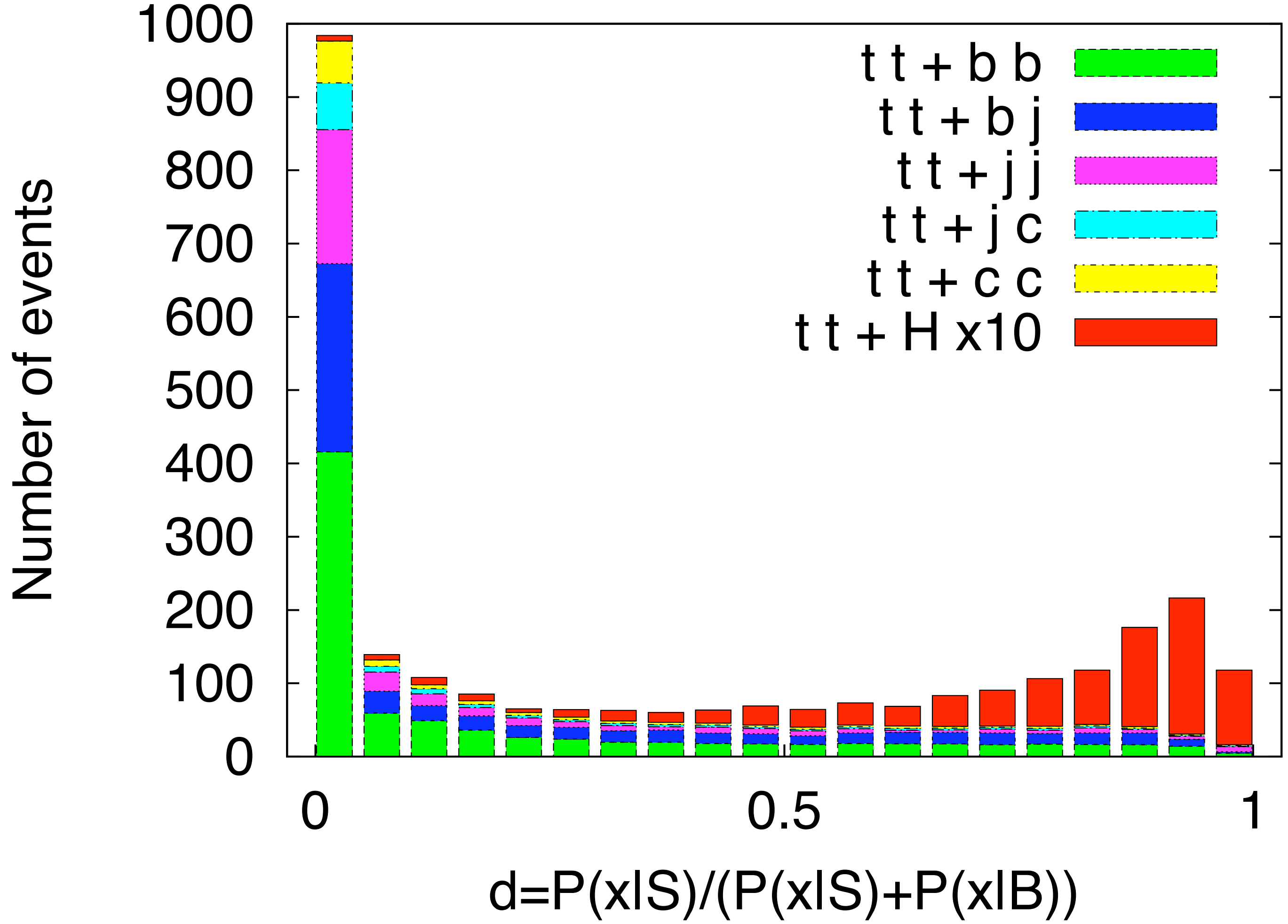

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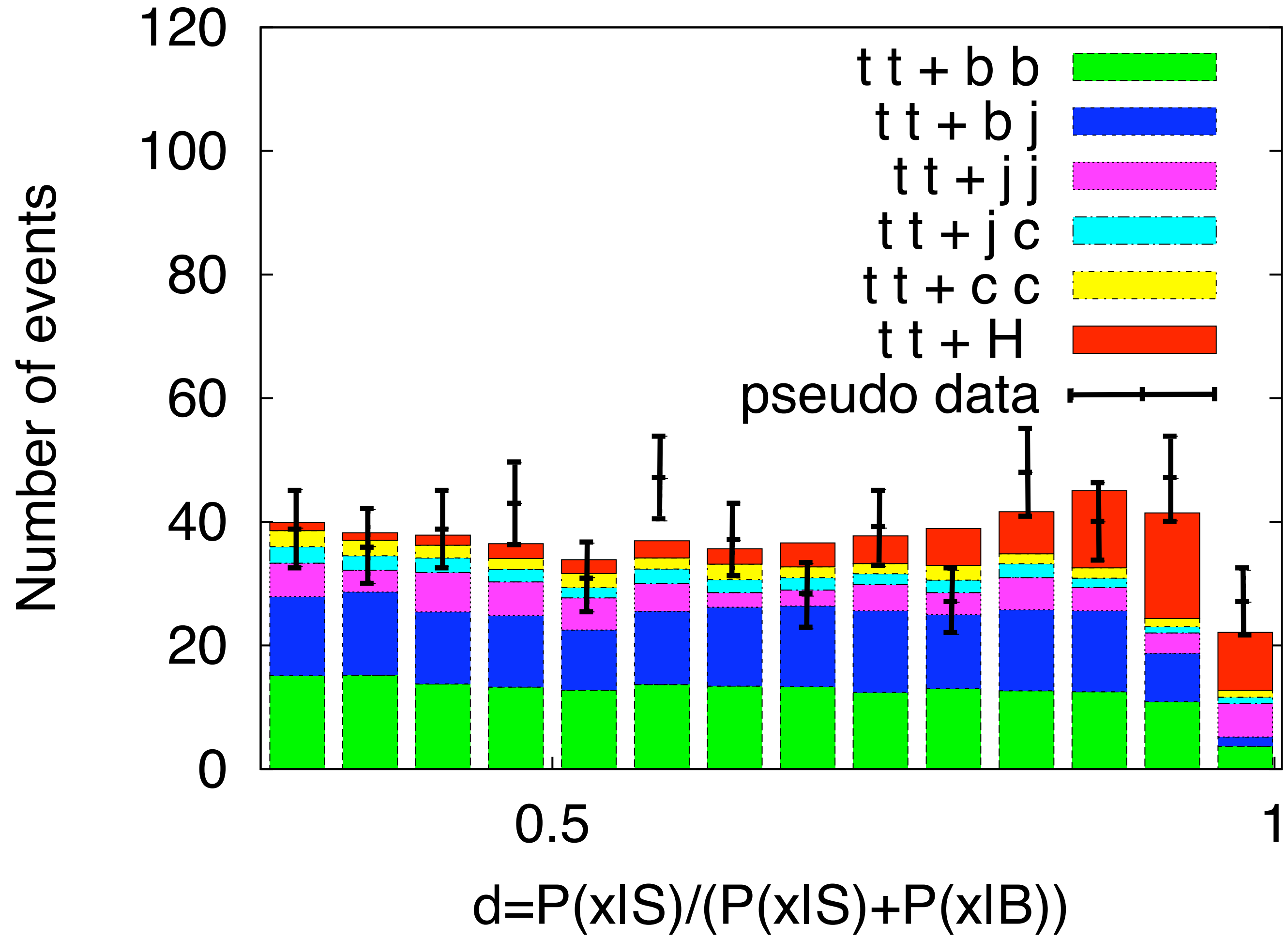

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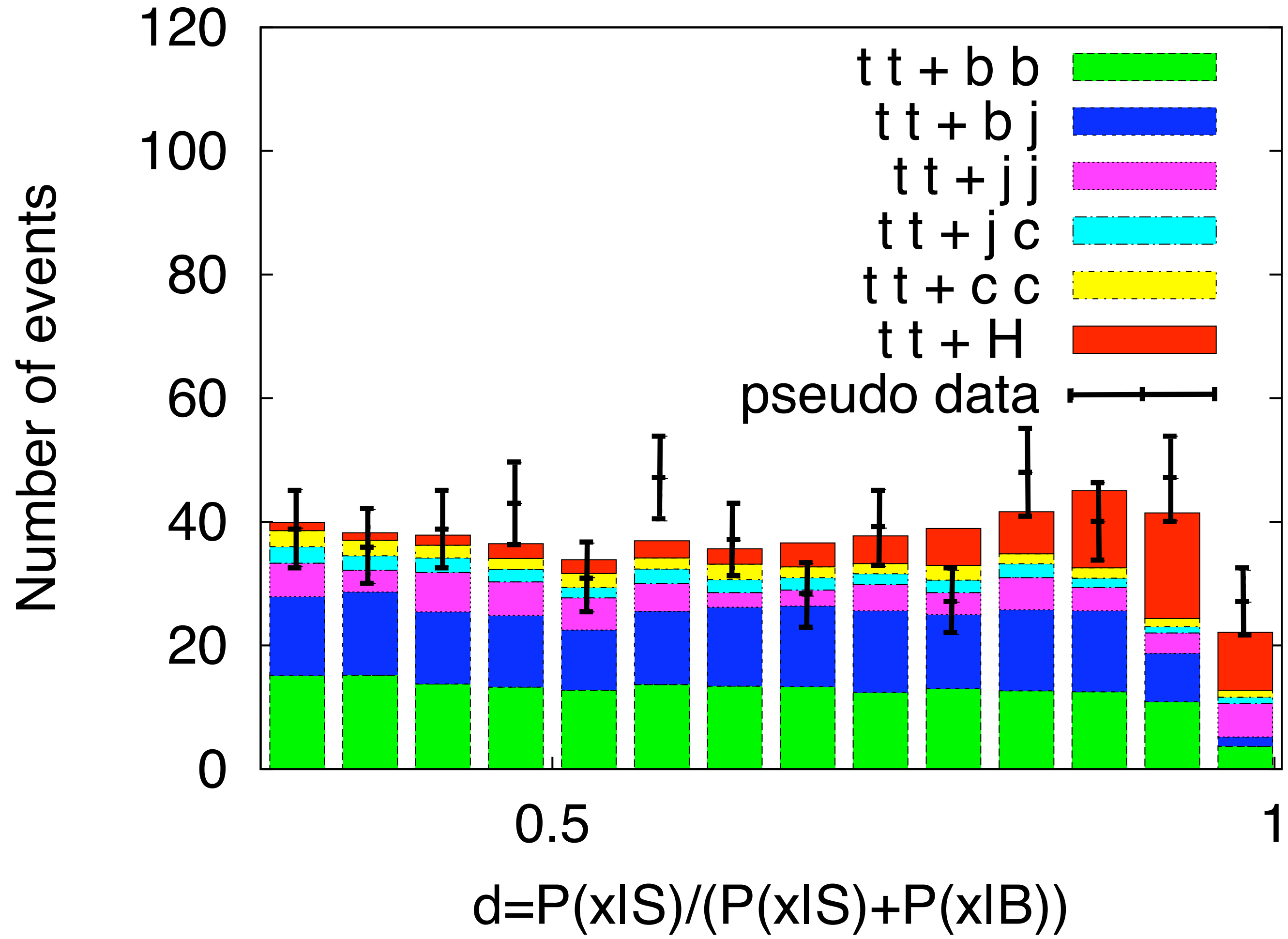
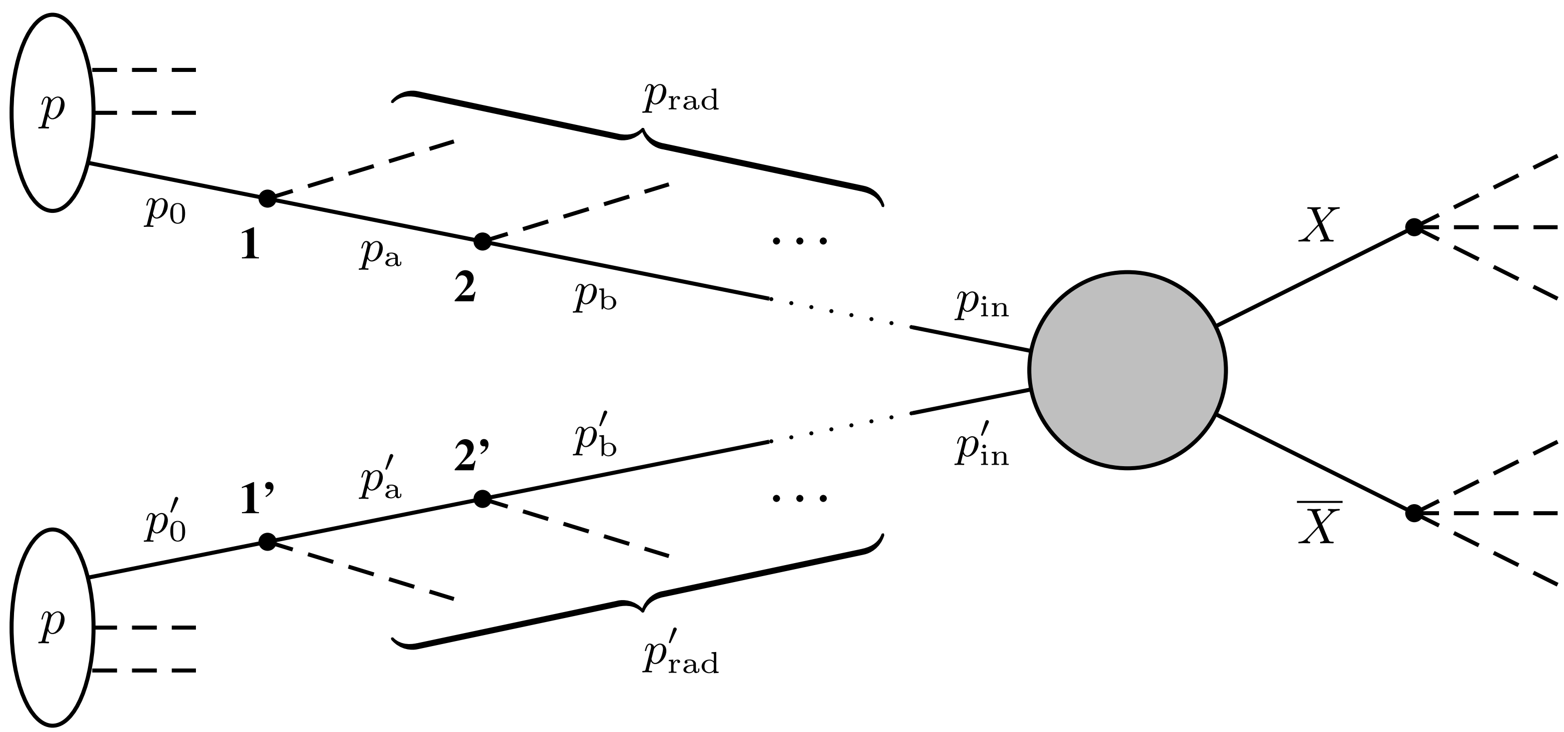


$$\frac{N_{mes}}{N_{expected}} = 0.95 \pm 0.25$$

- Examples of studies / investigations
  - mass determination : smuon pair production
  - Discriminating Hypothesis
  - ISR effects: pp > H > W+ W-
  - DMEM: in fully leptonic channel

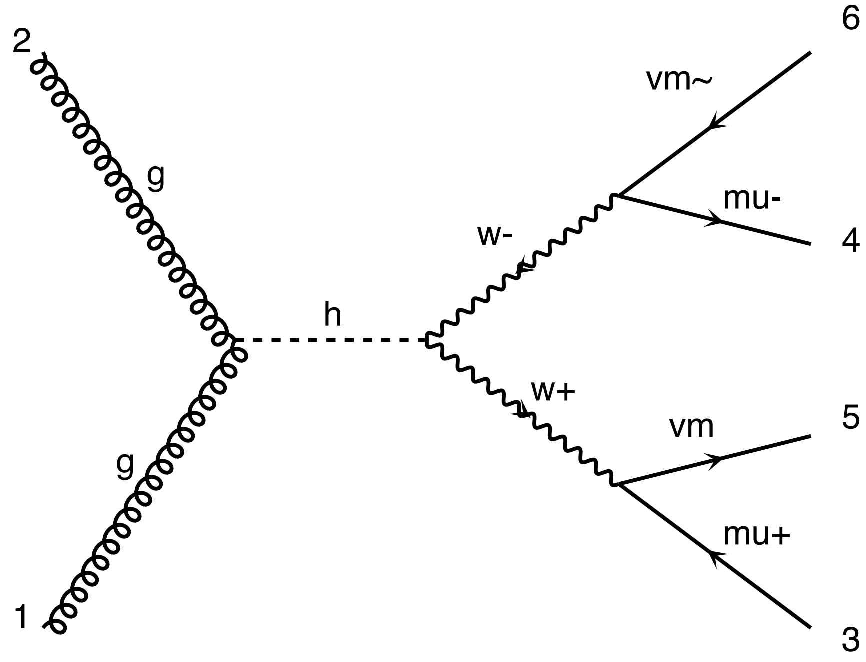
Initial State Radiation



- Main effect: induce a total transverse momentum

J. Alwall, A. Freytas, OM: PRD83:074010

Initial State Radiation



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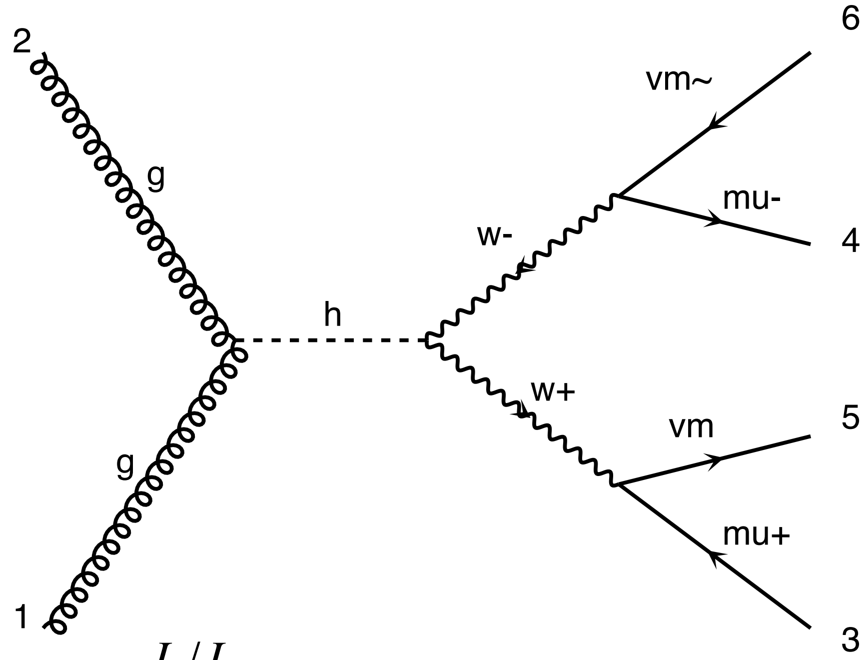

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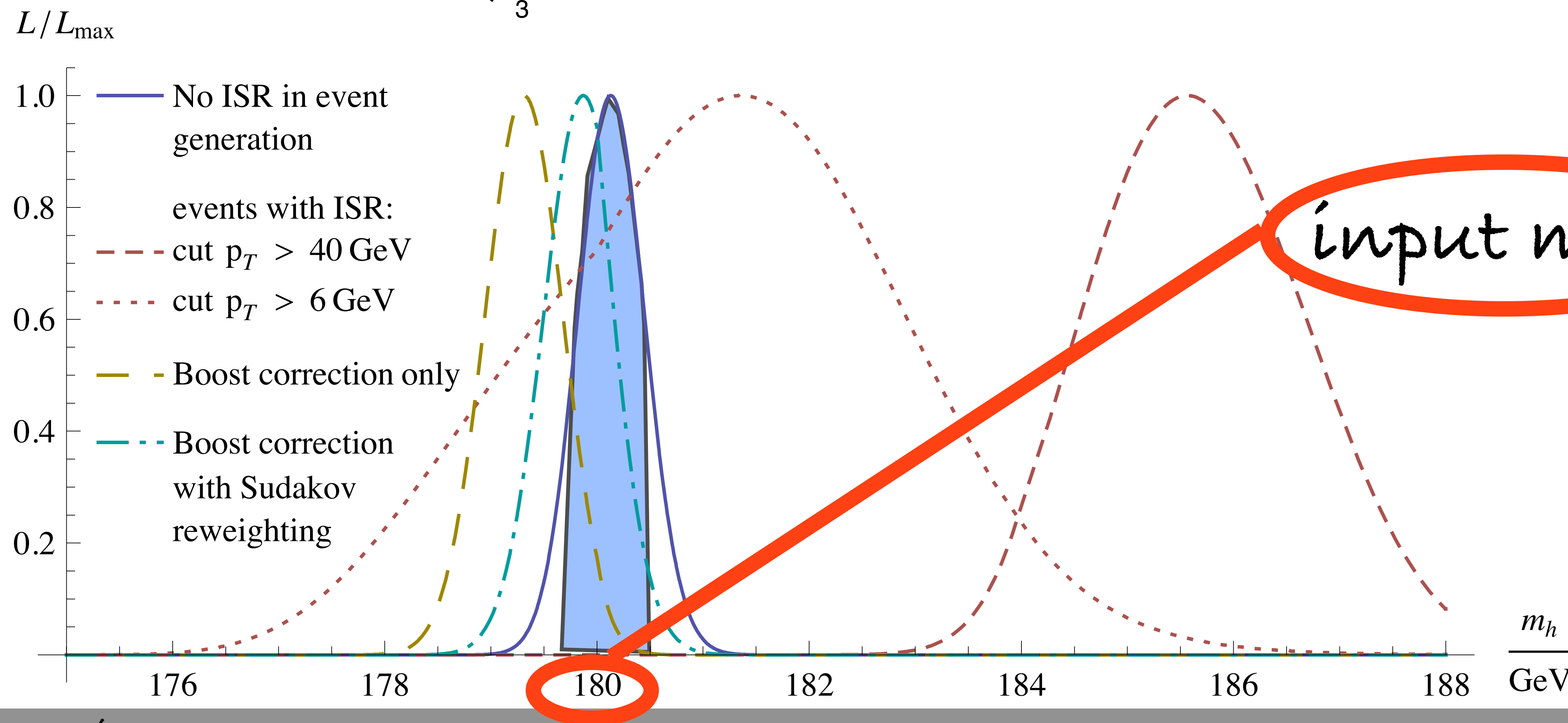
- No ISR → No Bias



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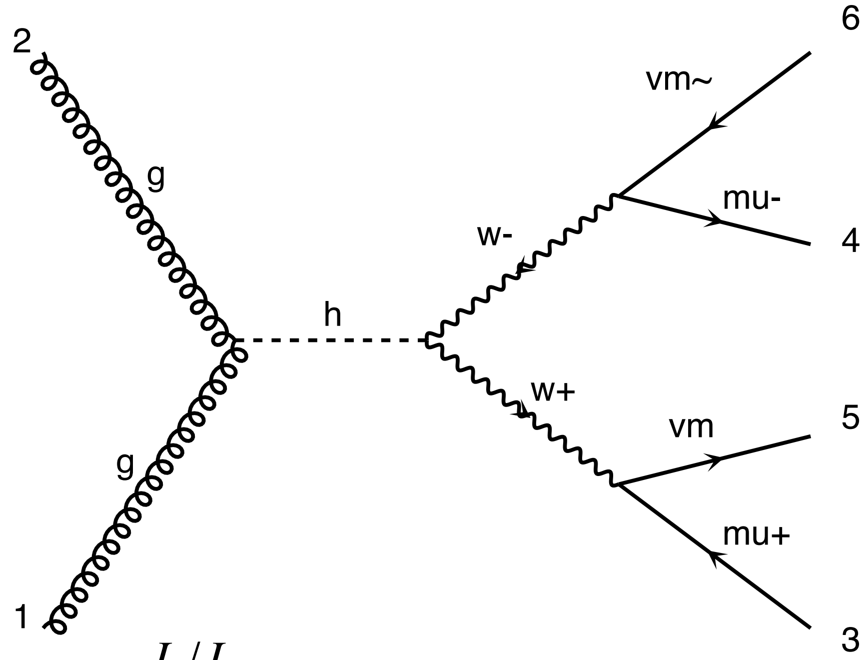
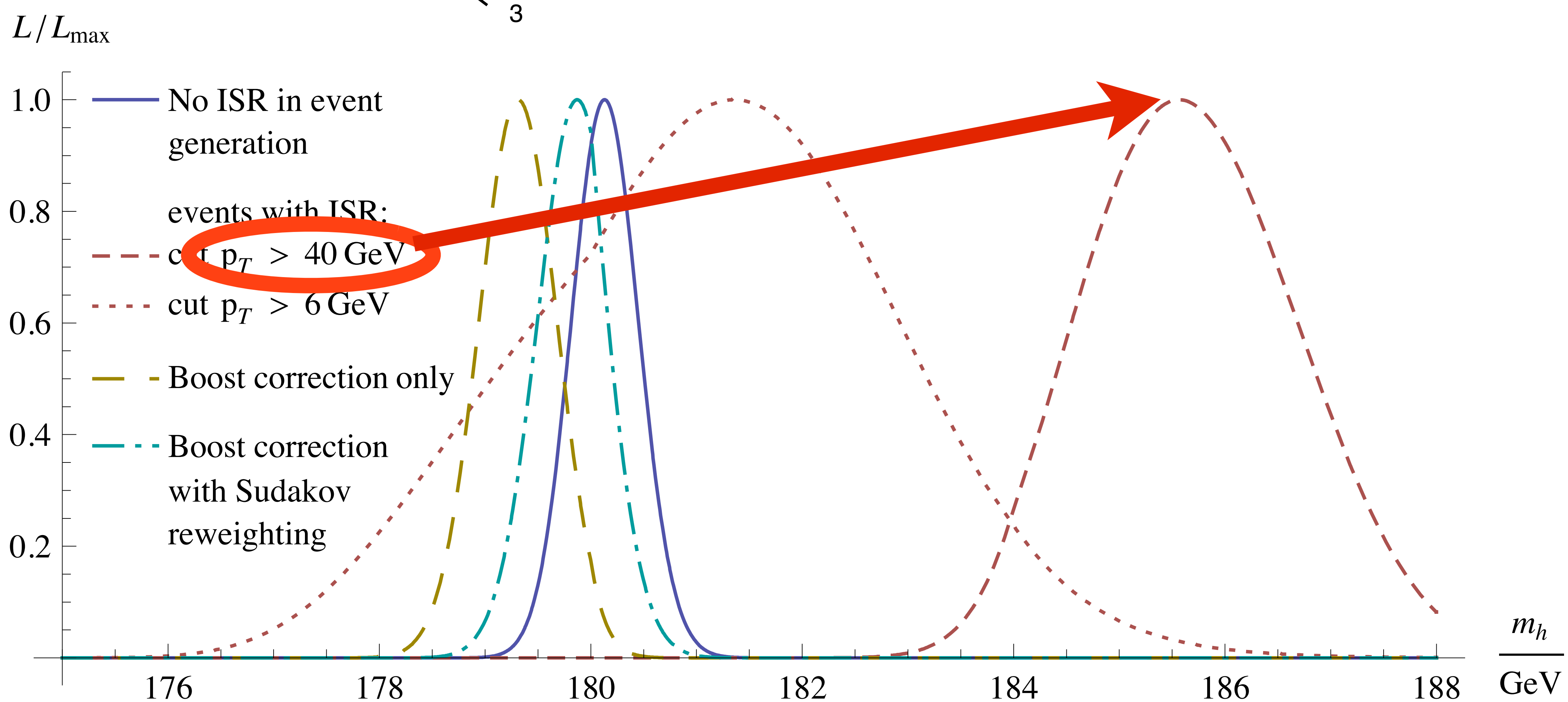


- Study the ISR on Higgs production at LHC (14 TeV) at parton level (no hadronization)
- Large Veto → Large bias



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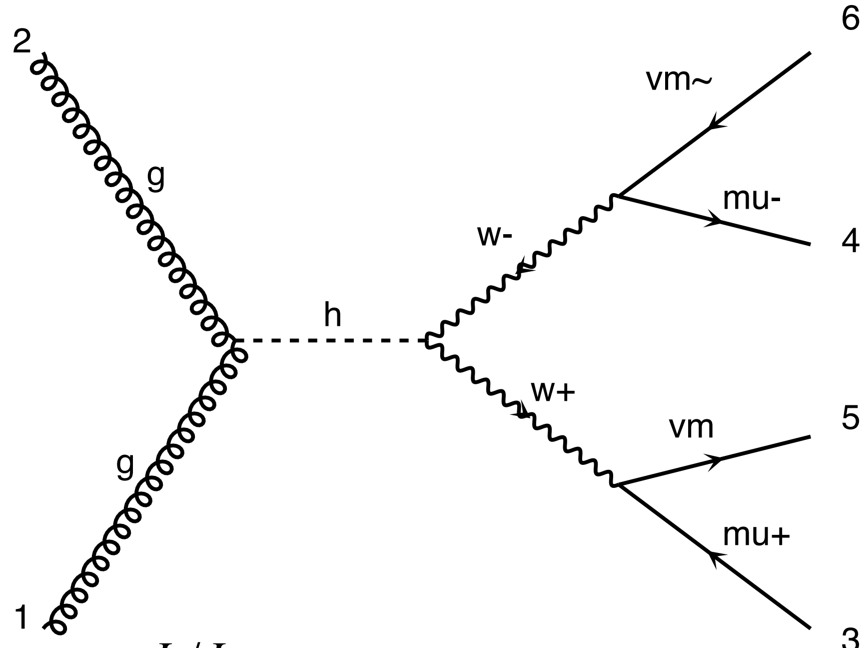

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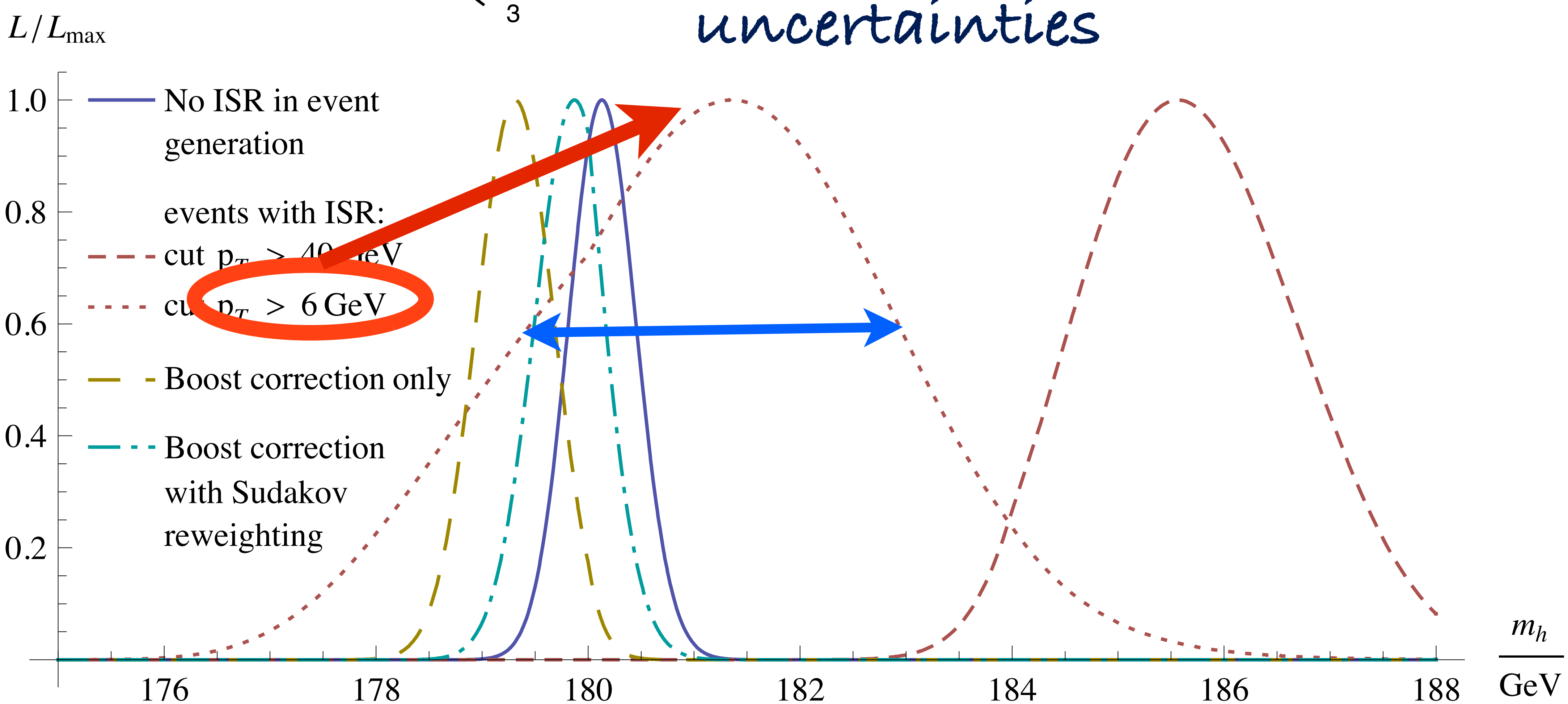
- smaller veto → smaller bias but larger statistical uncertainties



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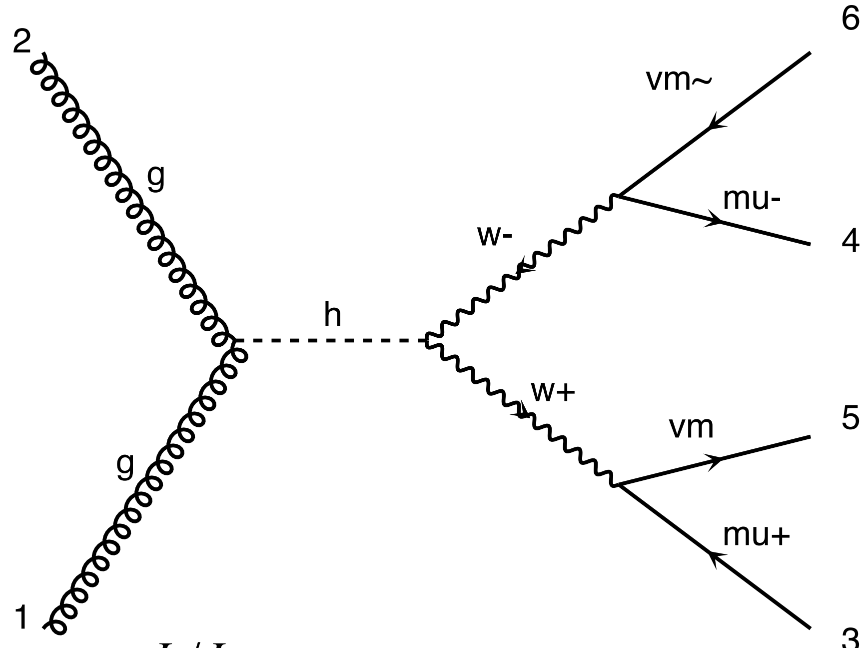
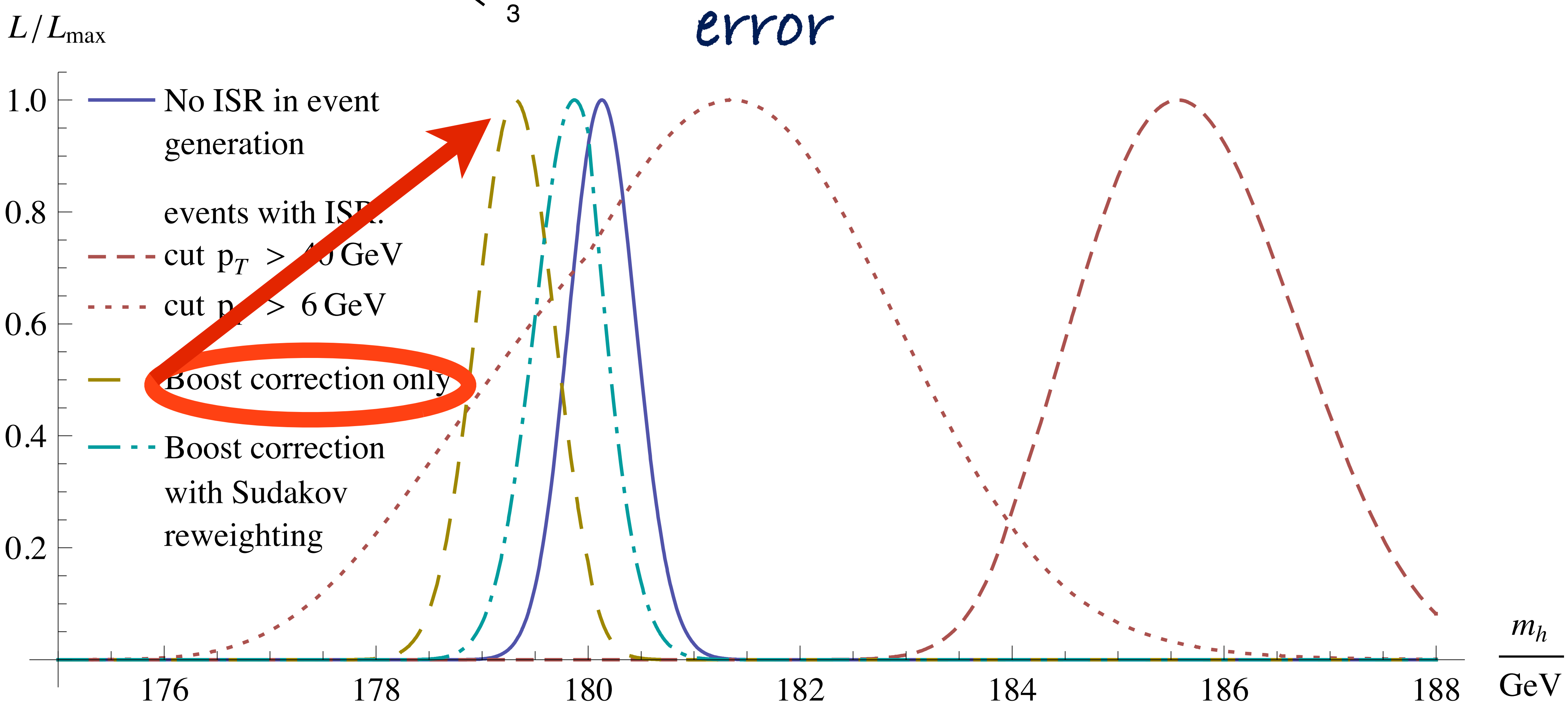


- Study the ISR on Higgs production at LHC (14 TeV) at parton level (no hadronization)
- Use the ISR to boost the momenta → small bias/ error



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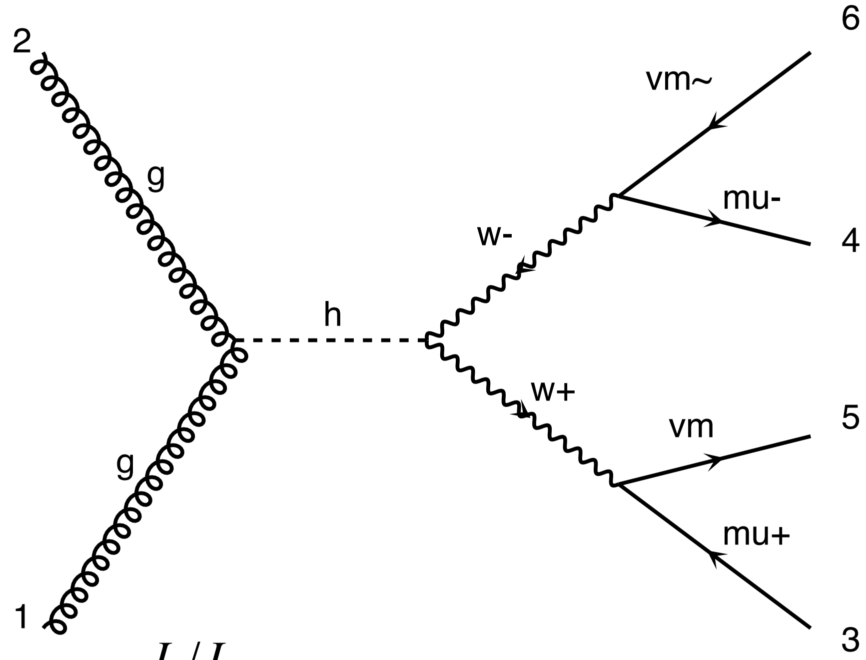
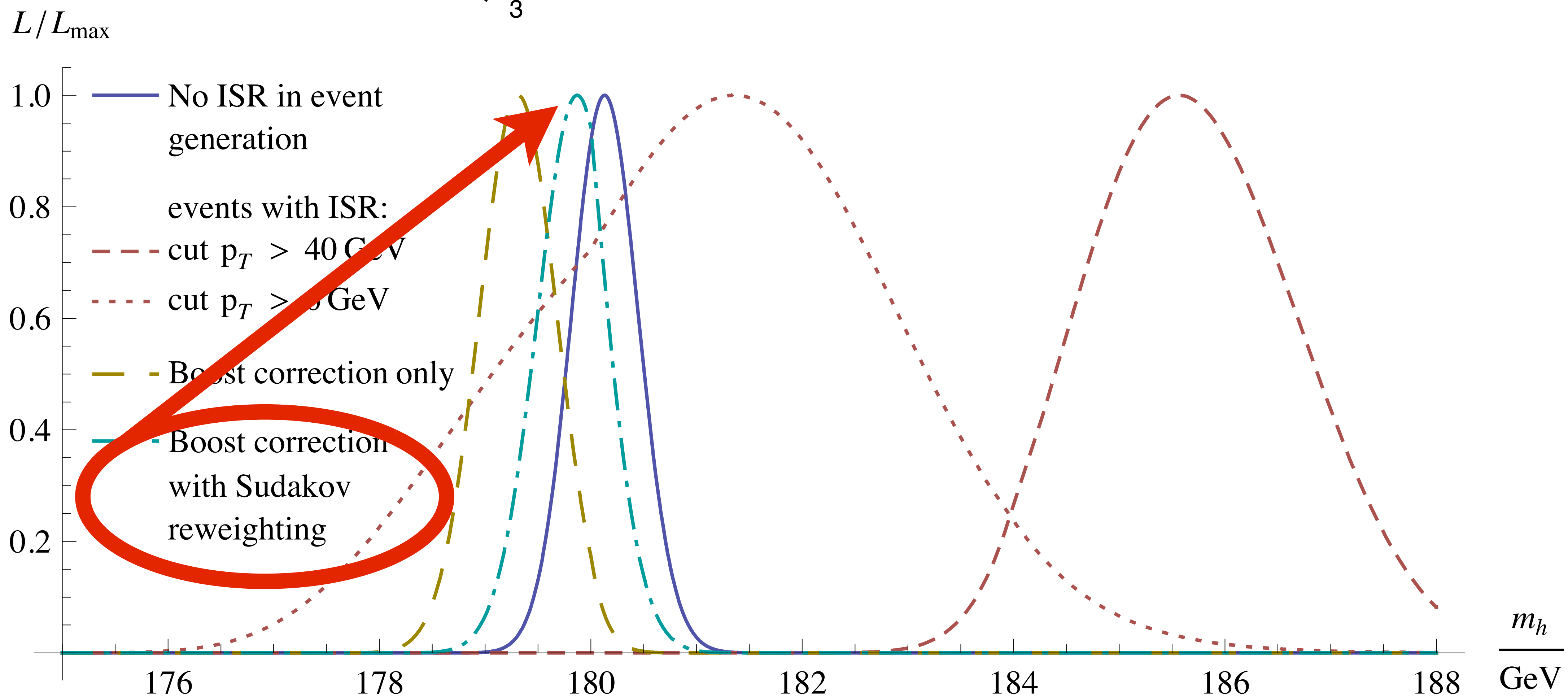


- Study the ISR on Higgs production at LHC (14 TeV) at parton level (no hadronization)

- Add the Sudakov Factor
  → No significative bias



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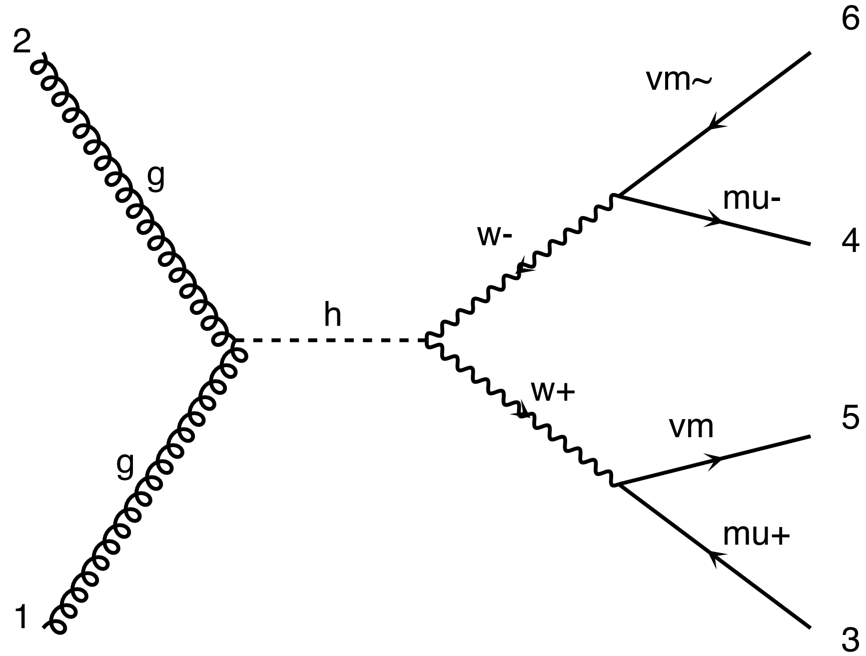
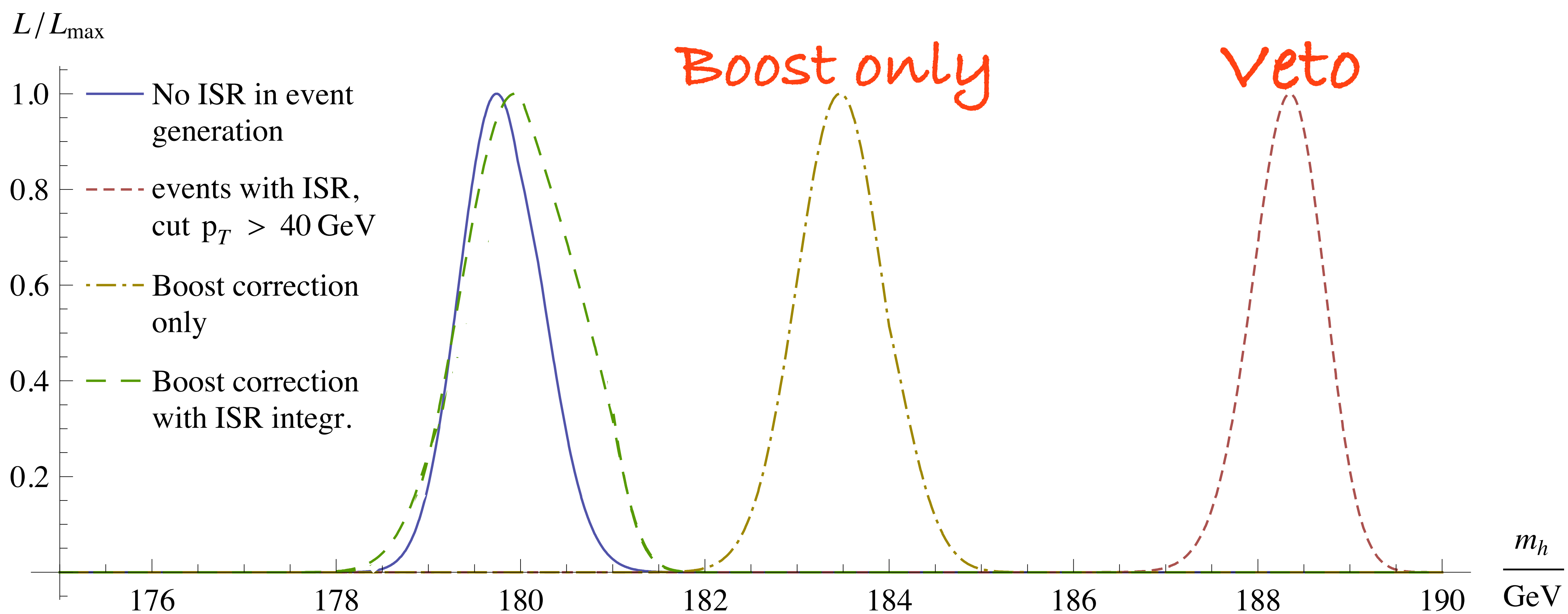


- Study the ISR on Higgs production at LHC (14 TeV) at detector level



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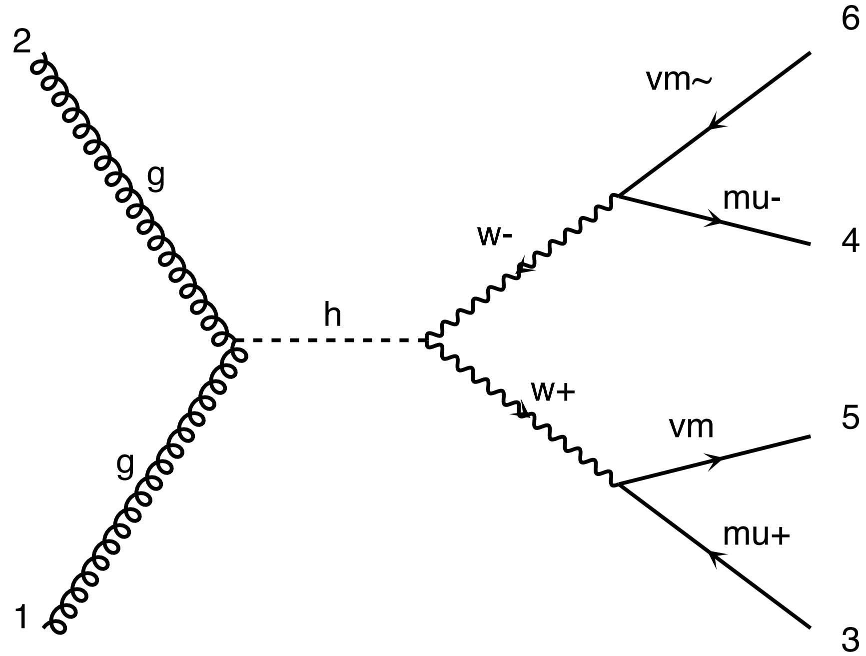
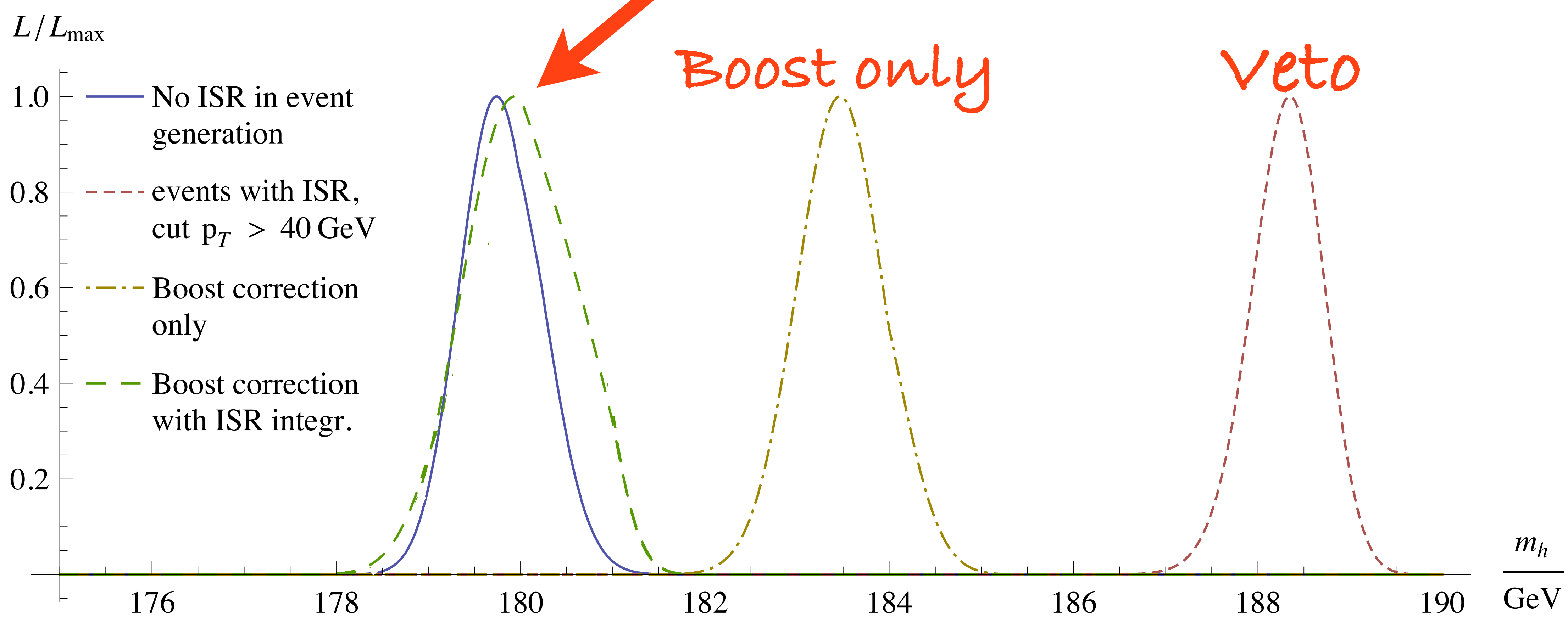


- Study the ISR on Higgs production at LHC (14 TeV) at detector level
- Introduce ISR transfer functions



- Examples of studies / investigations
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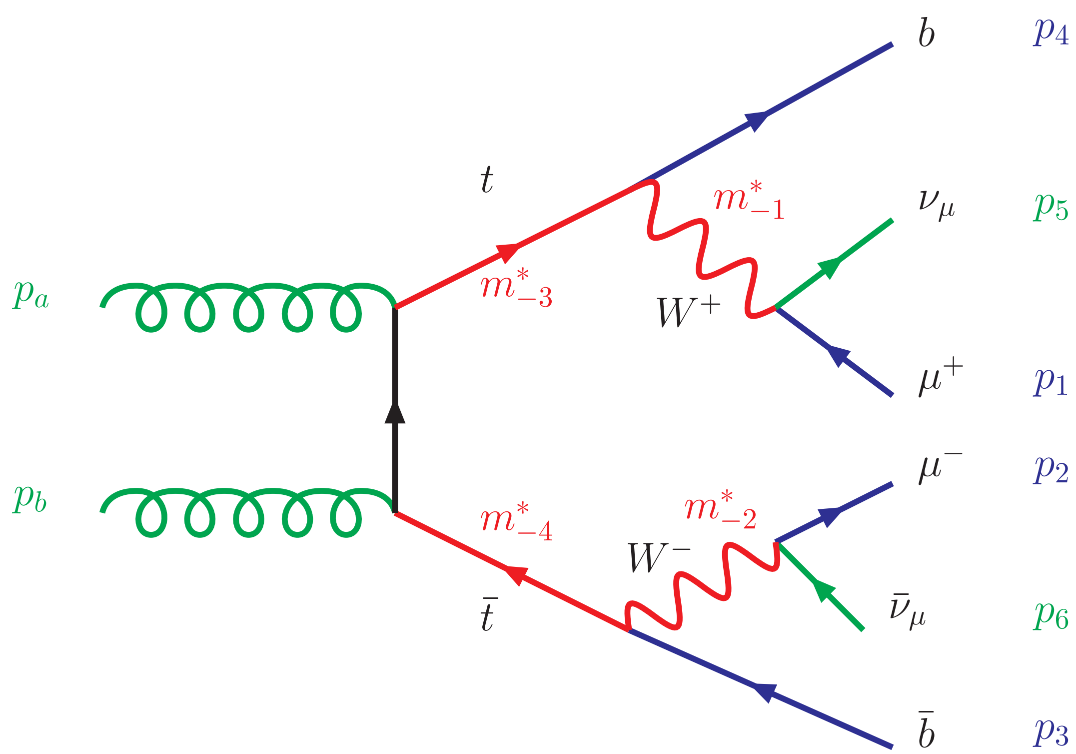
  - **DMEM: m_{tt} in fully leptonic channel**

Differential Cross Section



- Need the parton configuration
- uses a series of constraints (kinematical fit)
- use $\frac{1}{\mathcal{P}}\frac{\partial \mathcal{P}}{\partial Z}$ as discriminator

OM: UCL Thesis

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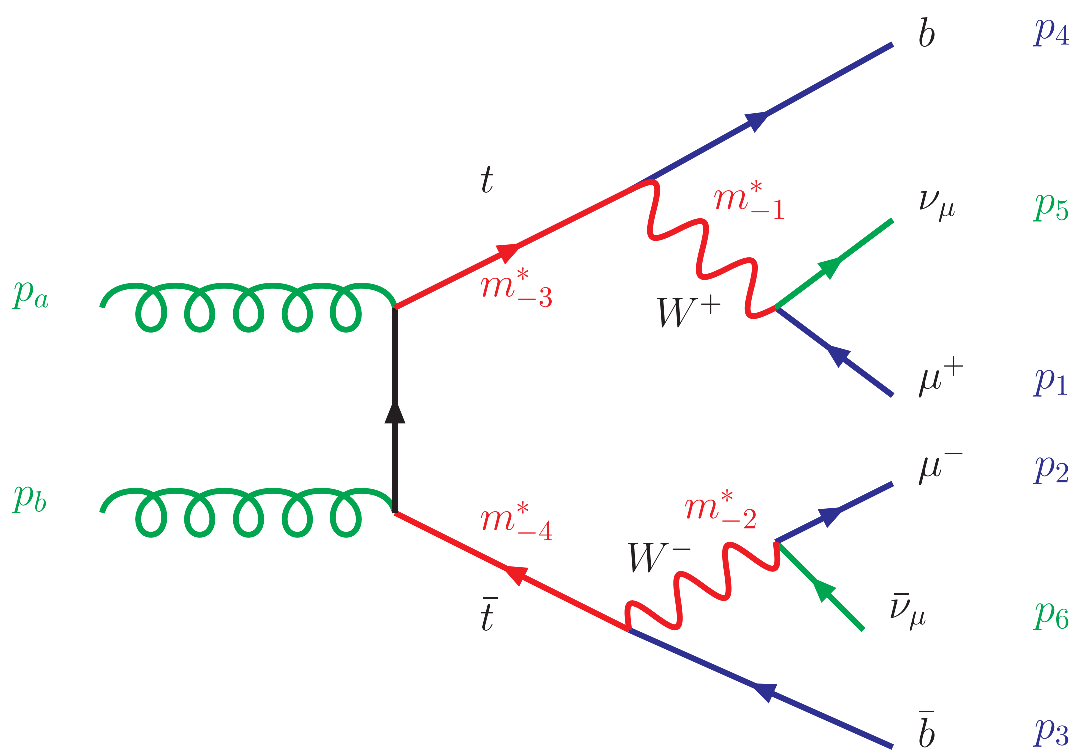

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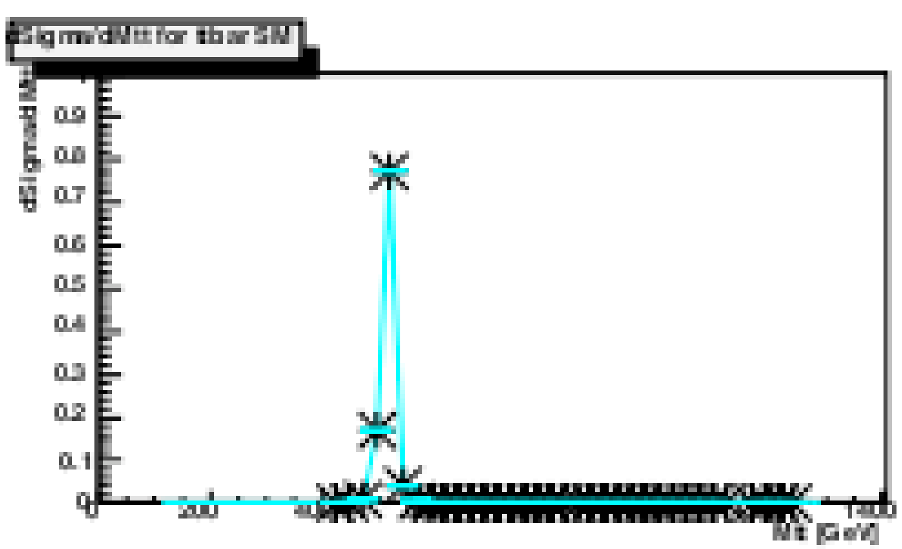
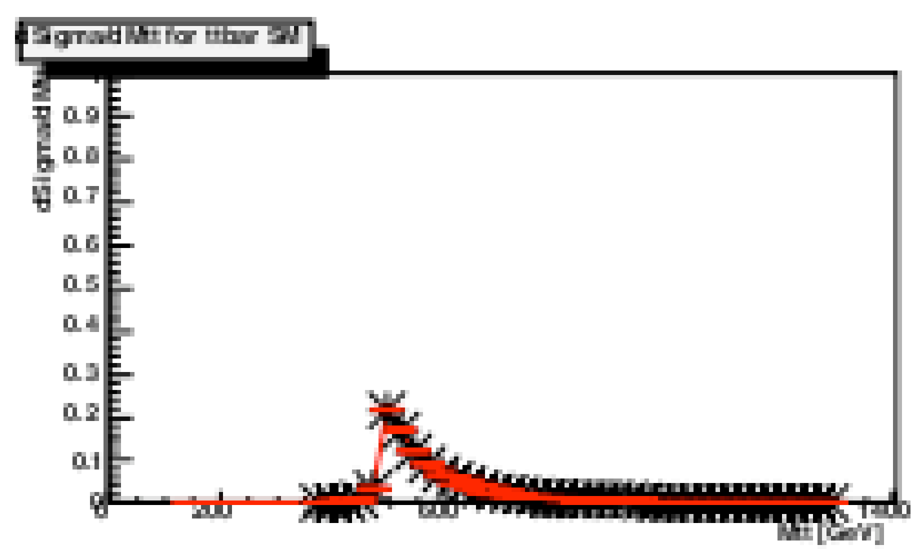
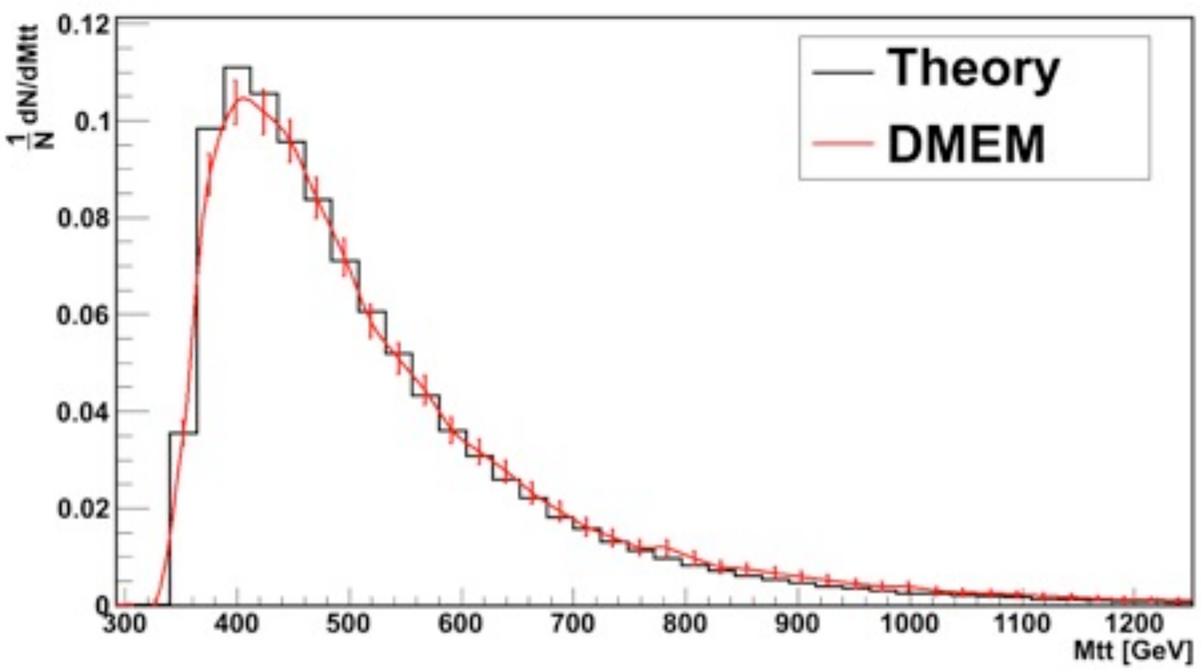
We use the full inference



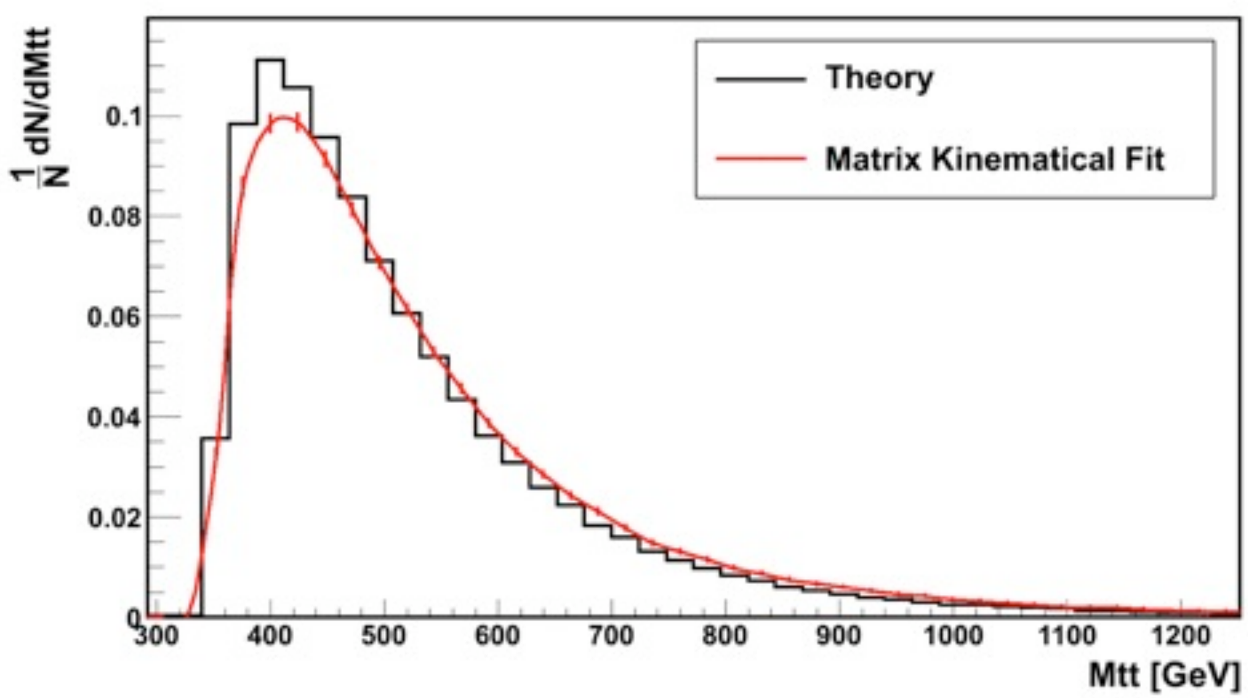


OM: UCL Thesis

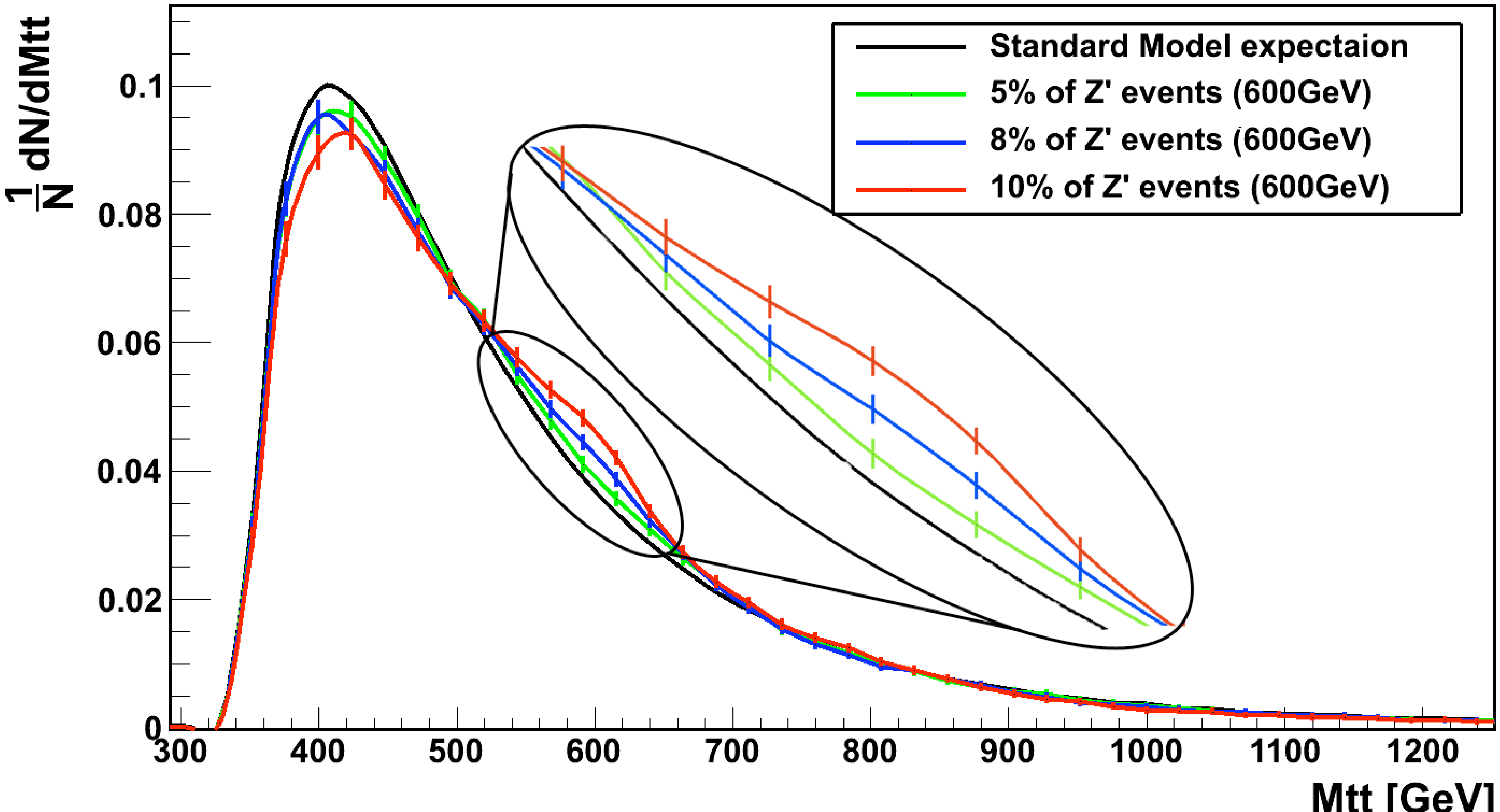
partonic level



reconstructed level



- What if the sample is not a SM one? For example if a heavy Z exists (600 GeV).



Only Use SM matrix Element!!!

Conclusion

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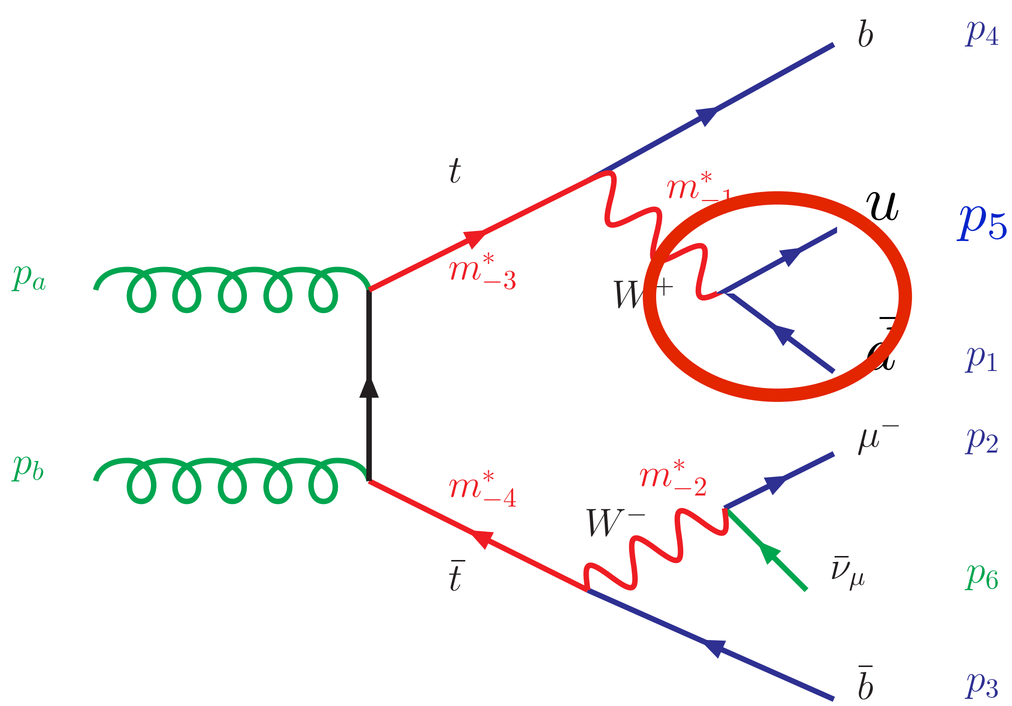
Backup slide

MADWEIGHT

- Second Example: semi-leptonic top quark pair



- degrees of freedom 16
- peaks 19

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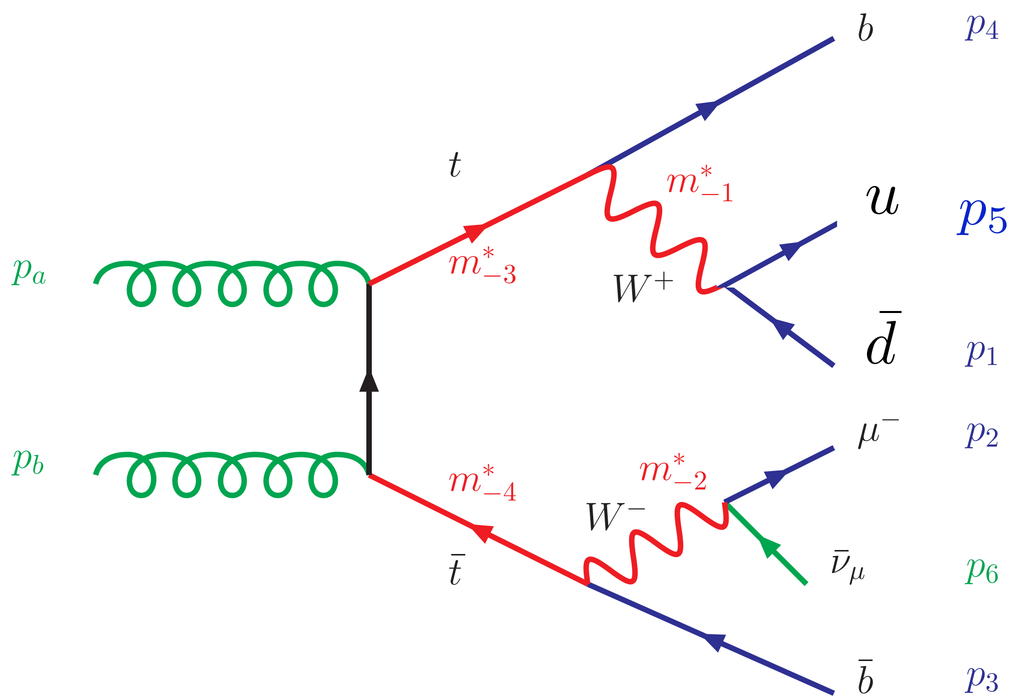

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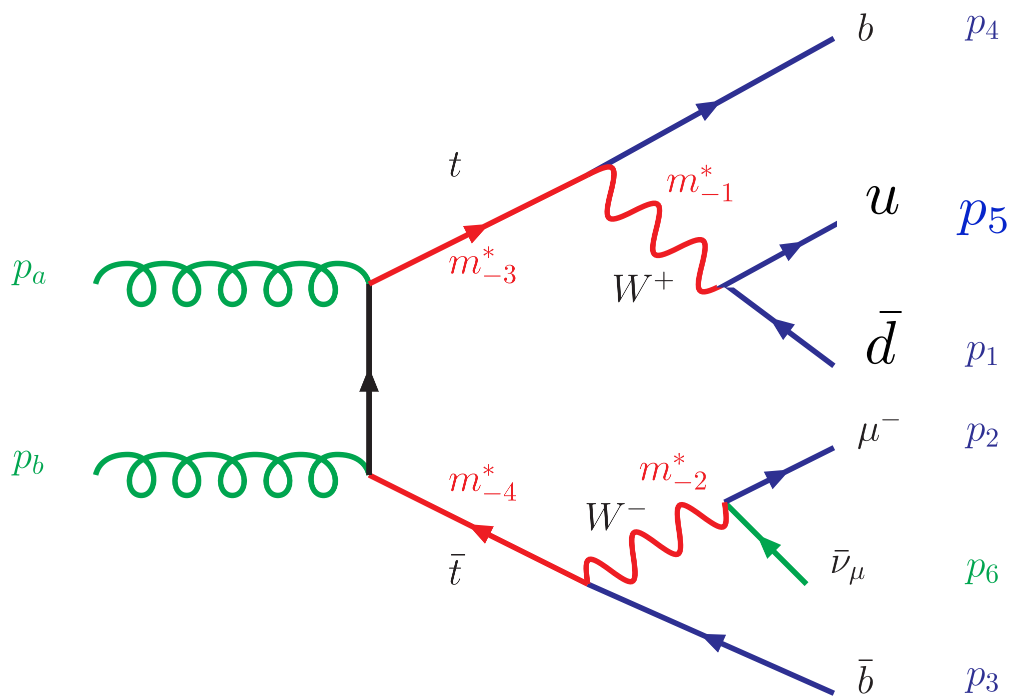

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MADWEIGHT

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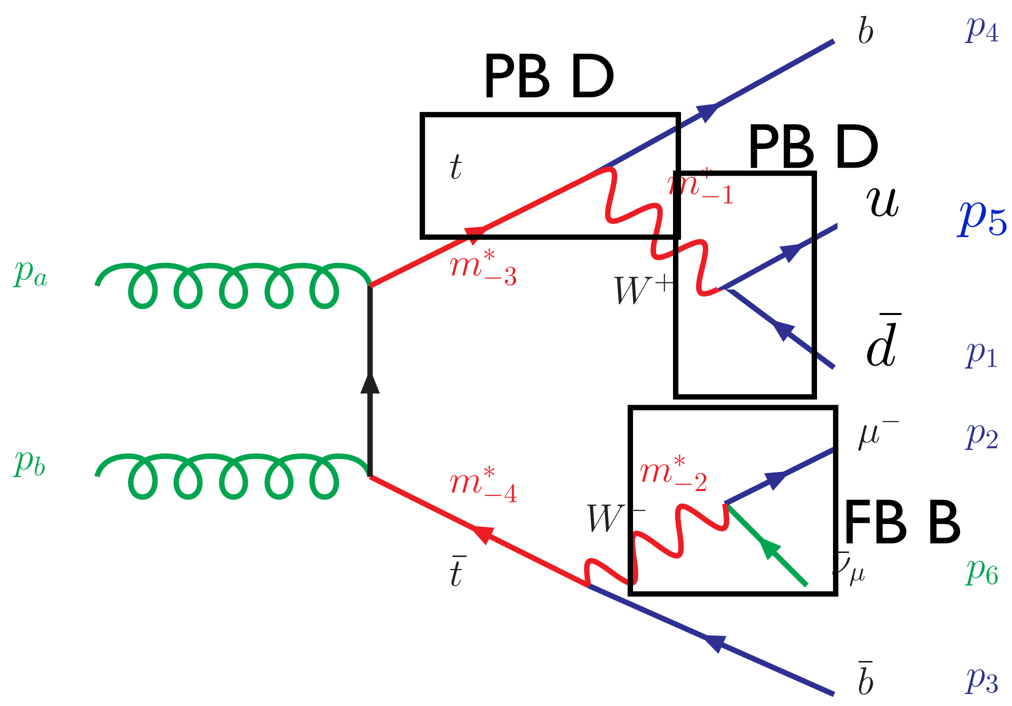

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Pass to →

$$d\phi = \prod_{i=1}^{5} d\theta_i d\phi_i \prod_{j=1}^{3} d|\boldsymbol{p}_i| \prod_{k=1}^{3} dm^{*2}_{-k} \times J$$

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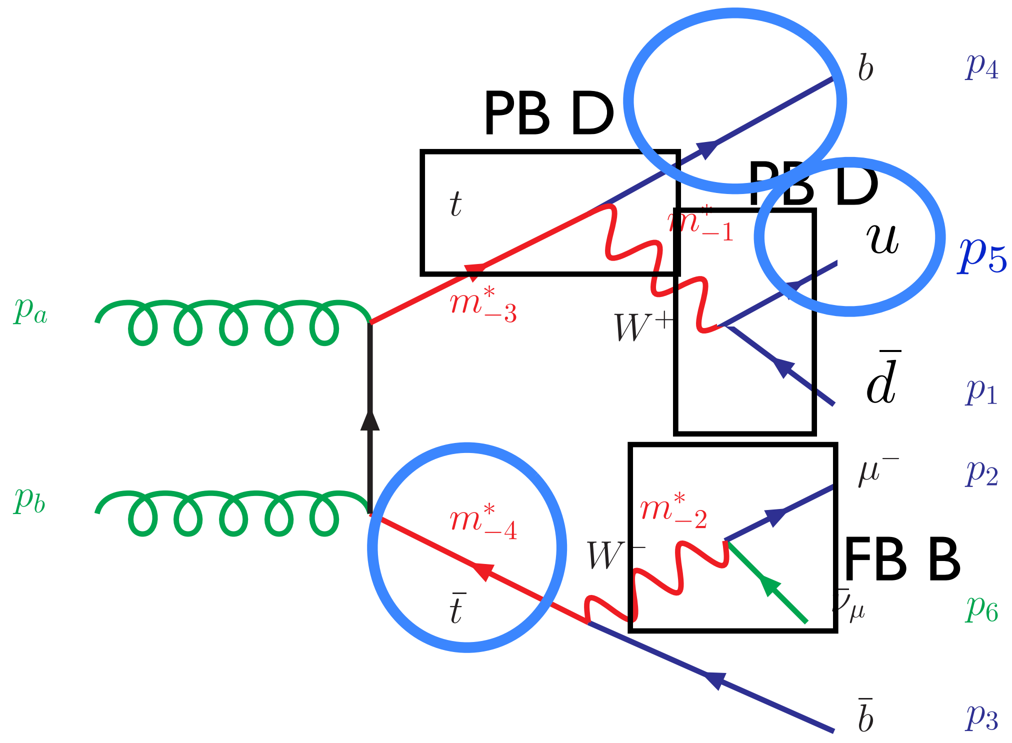

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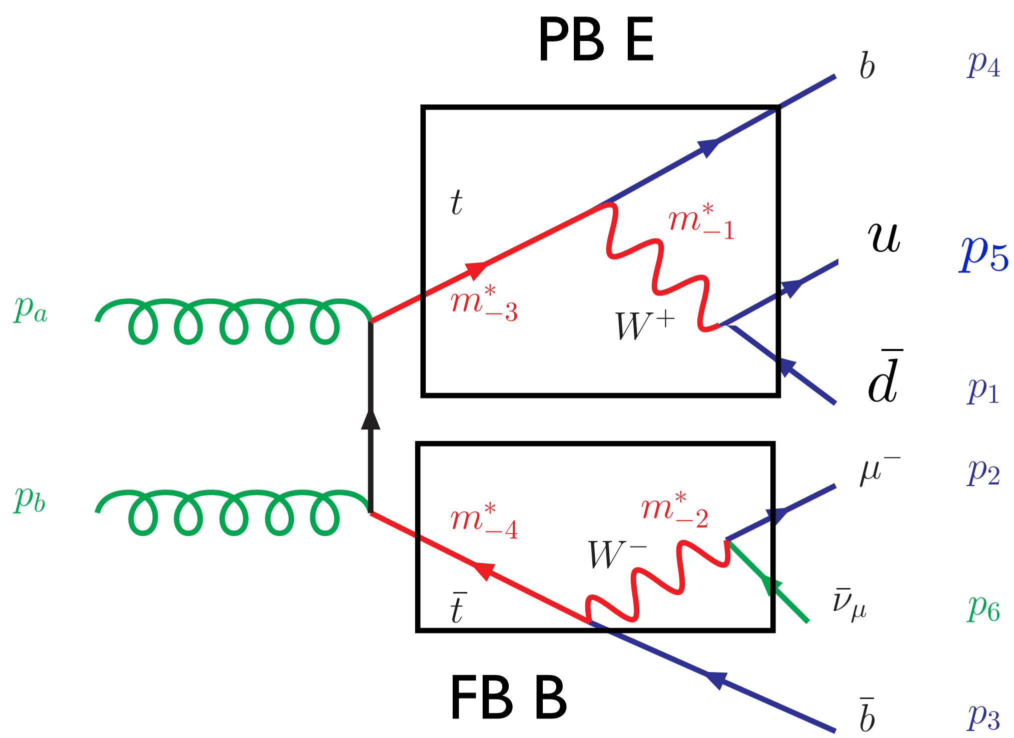

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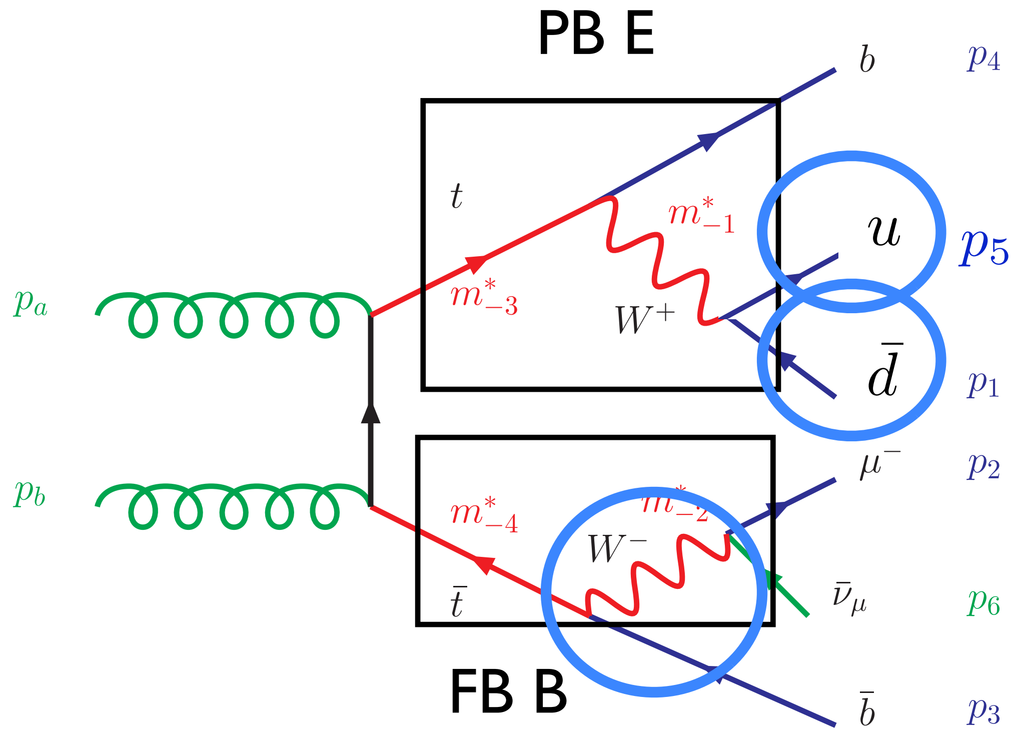
$$d\phi = \prod_{i=1}^{5} d\theta_i d\phi_i \prod_{j=2}^{4} d|\boldsymbol{p}_i| \prod_{k=1,k\neq 2}^{4} dm^{*2}_{-k} \times J$$

- Second Example: semi-leptonic top quark pair



- degrees of freedom 16
- peaks 19

→ 3 peaks unaligned

→ Multi-channel

$$d\phi = \prod_{i=1}^{5} \frac{d^3 p_i}{(2\pi)^3 2E_i} \frac{d^3 p_6}{(2\pi)^3 2E_6} dx_1 dx_2 \delta^4(p_a + p_b - \sum_j p_j)$$

Pass to →

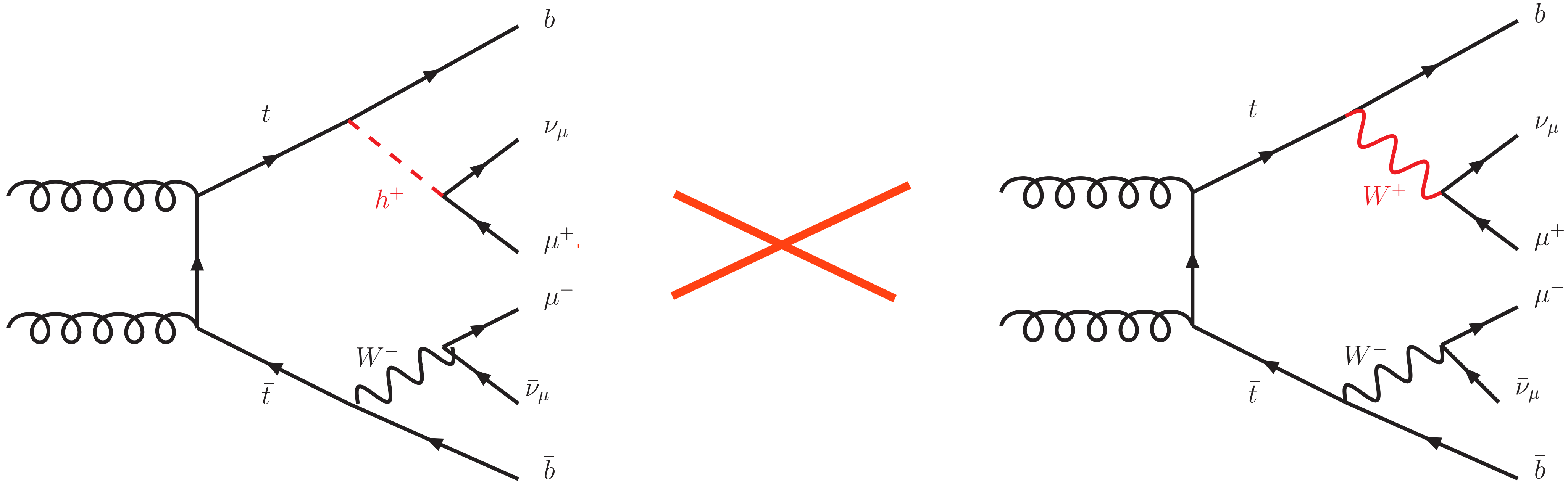
$$d\phi = \prod_{i=1}^{5} d\theta_i d\phi_i \prod_{j=2}^{4} d|\boldsymbol{p}_i| \prod_{k=1,k\neq 2}^{4} dm^{*2}_{-k} \times J$$

MadWeight

- the phase-space is split into blocks, each of them is associated to a specific local change of variables
- 12 blocks, i.e. 12 analytic changes of variables have been defined in our code.
- MadWeight finds automatically
  - the optimal partition of the PS into blocks
  - computes the weights using the corresponding PS parametrisation

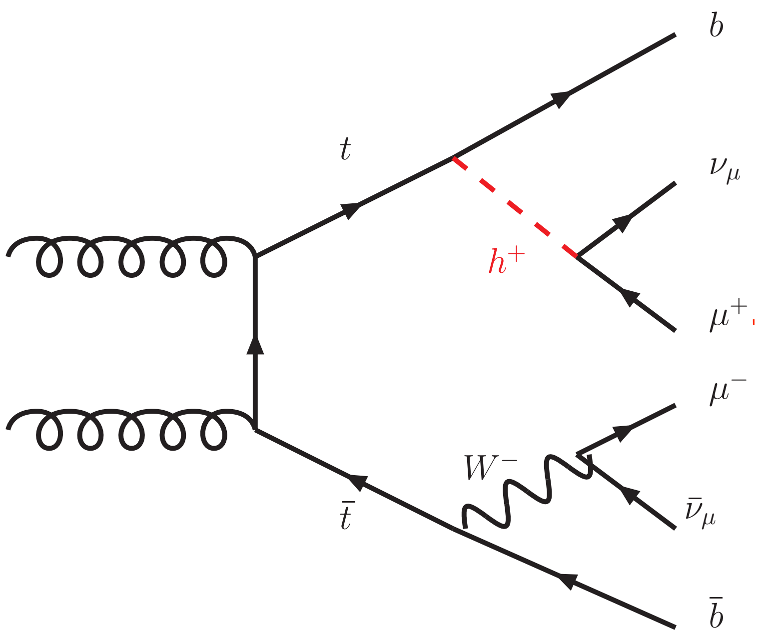
Signal/Background

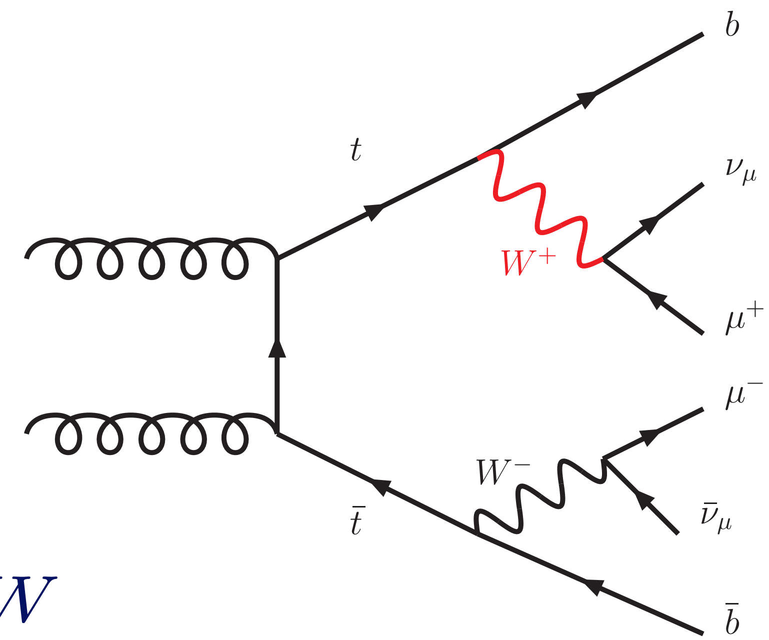
- Estimate Charged Higgs contribution



Signal/Background

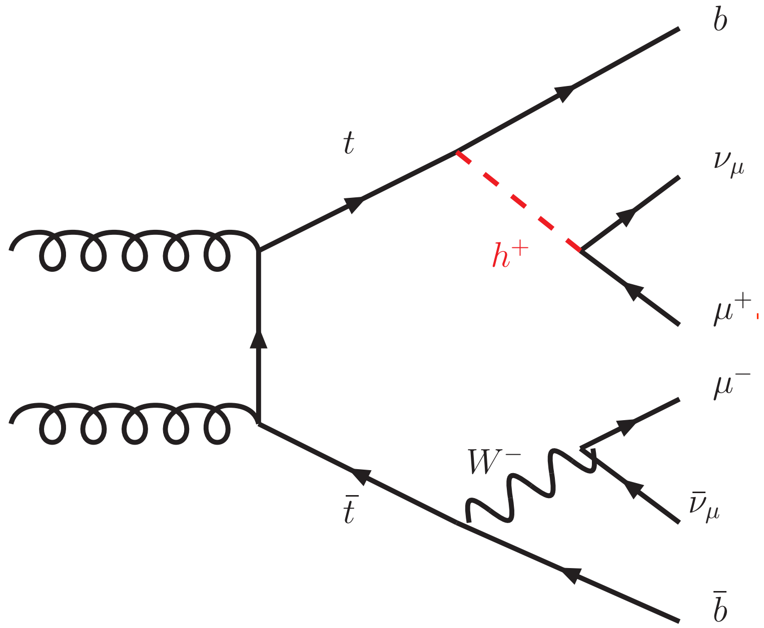
- Estimate Charged Higgs contribution

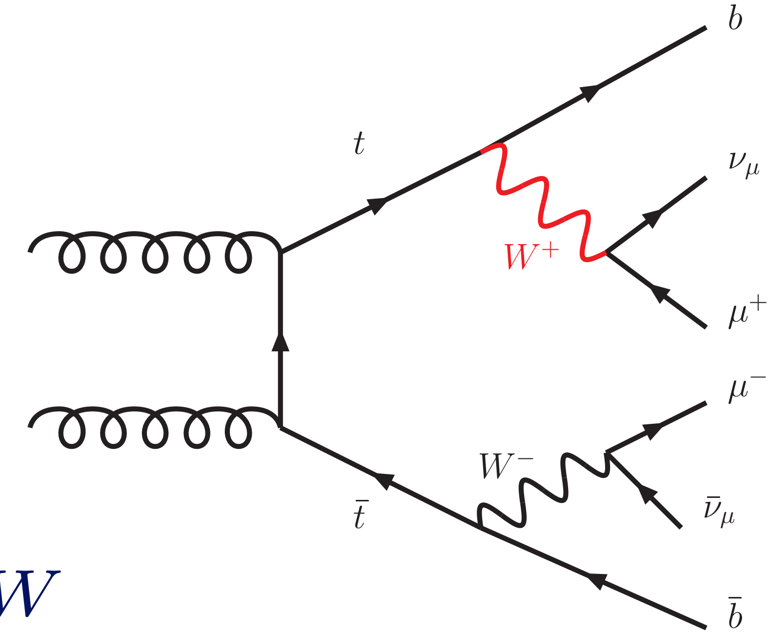




$$M_{H^+} = M_W$$

- Estimate Charged Higgs contribution





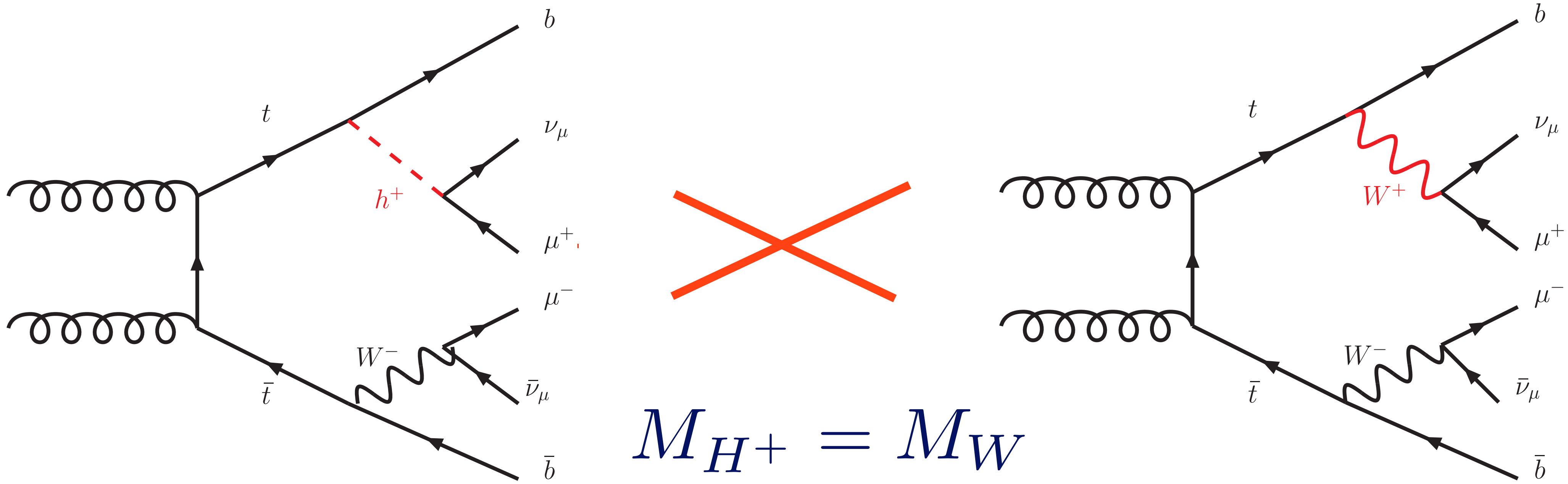
$$M_{H^+} = M_W$$

- define discriminant:

$$d = \frac{P_S}{P_S + P_{BG}}$$

Signal/Background

- Estimate Charged Higgs contribution

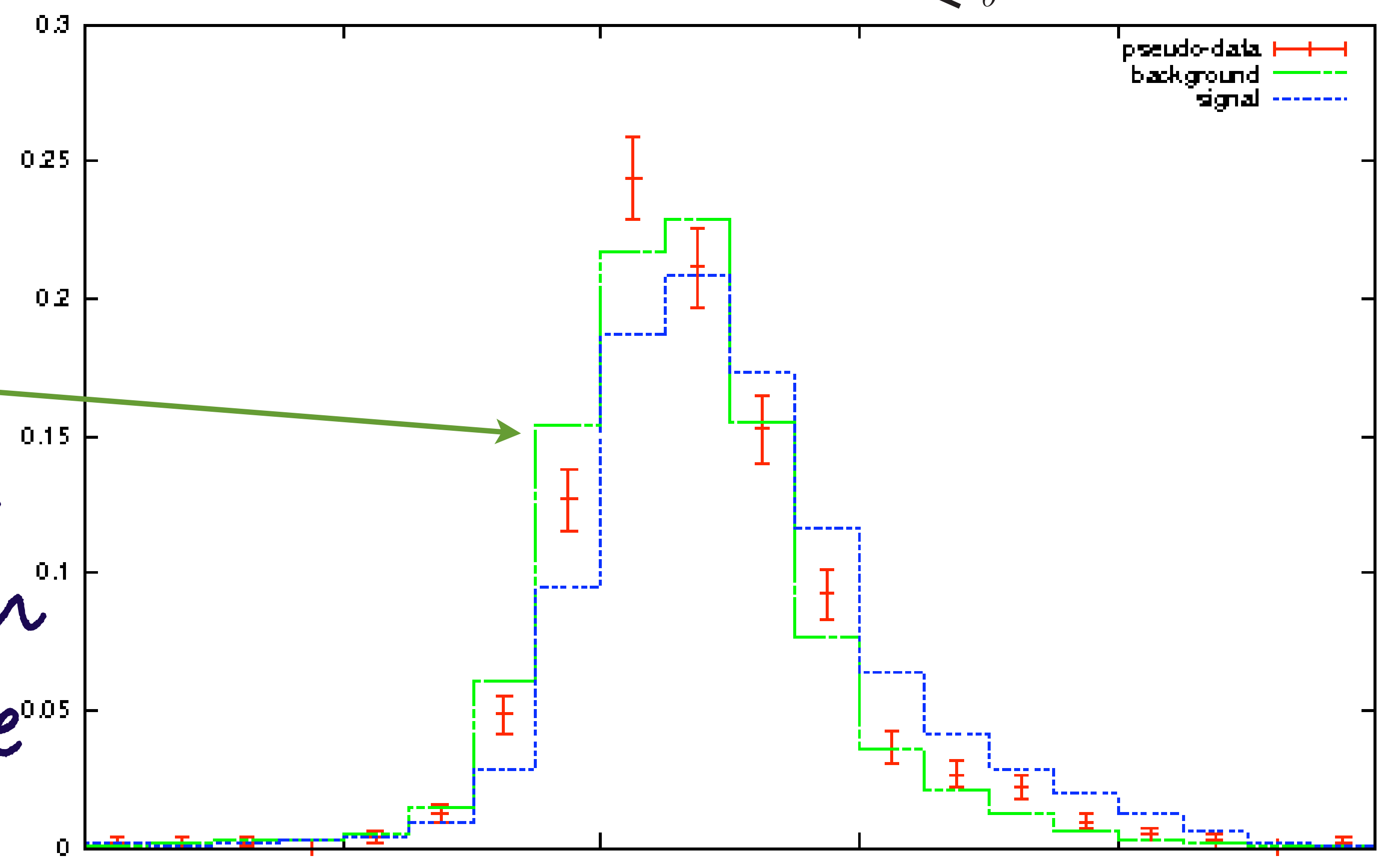


$$M_{H^+} = M_W$$

- define discriminant:

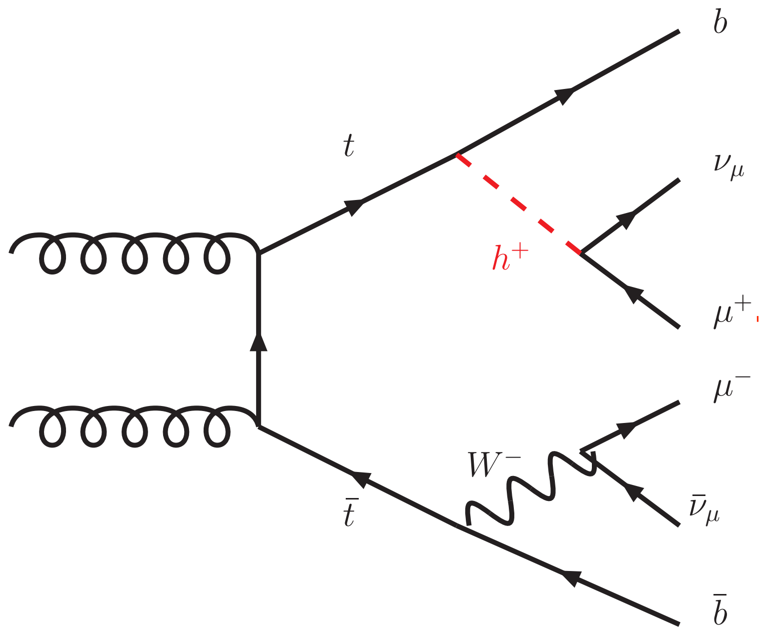
$$d = \frac{P_S}{P_S + P_{BG}}$$

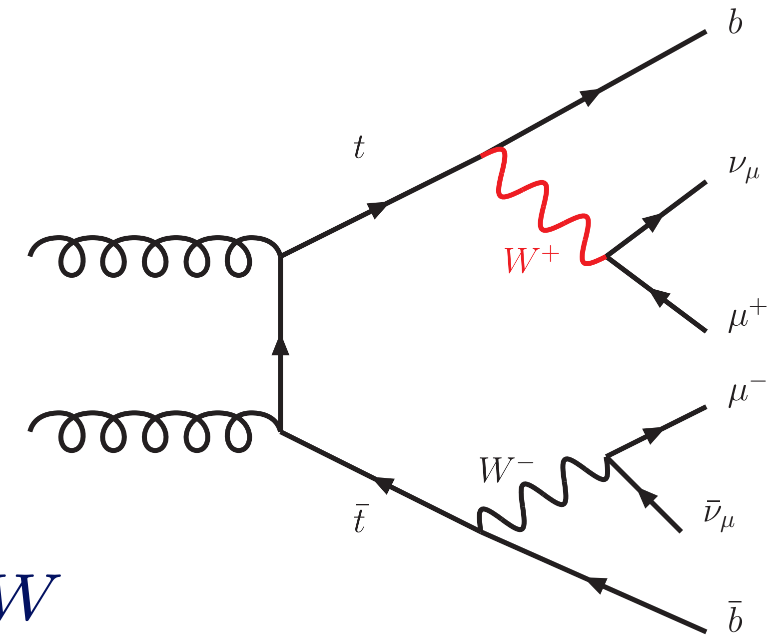
- SM Monte-Carlo:
  Probability for one event to have a given discriminant value



Signal/Background

- Estimate Charged Higgs contribution





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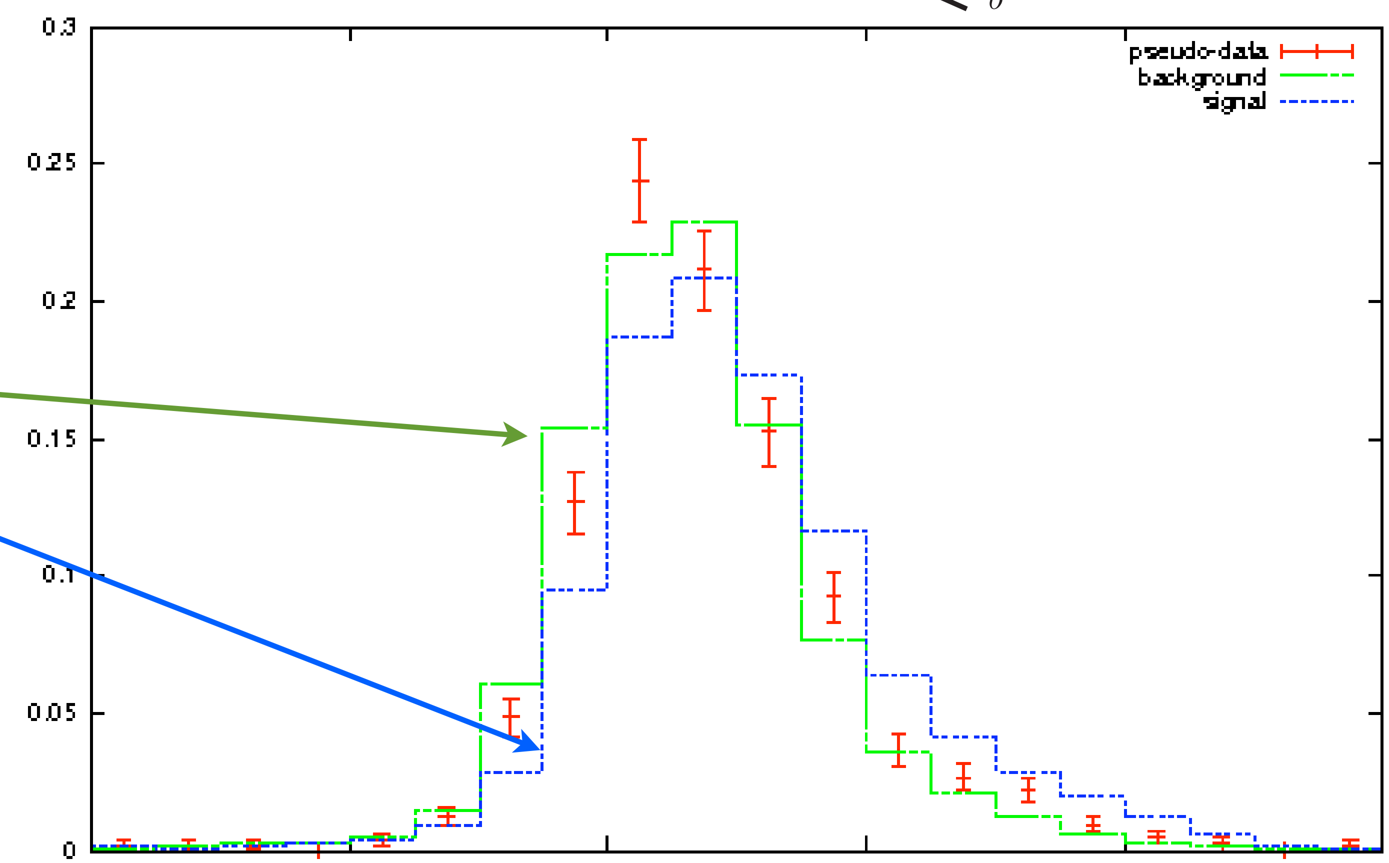
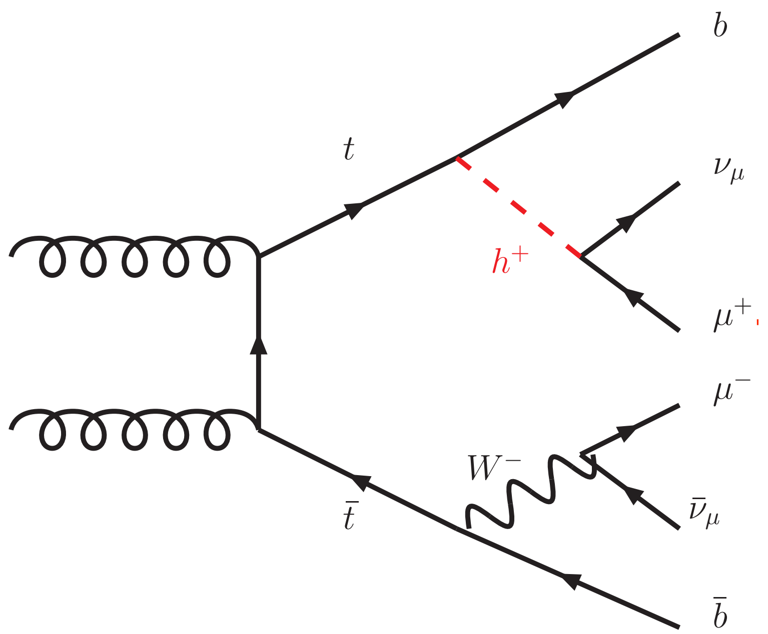
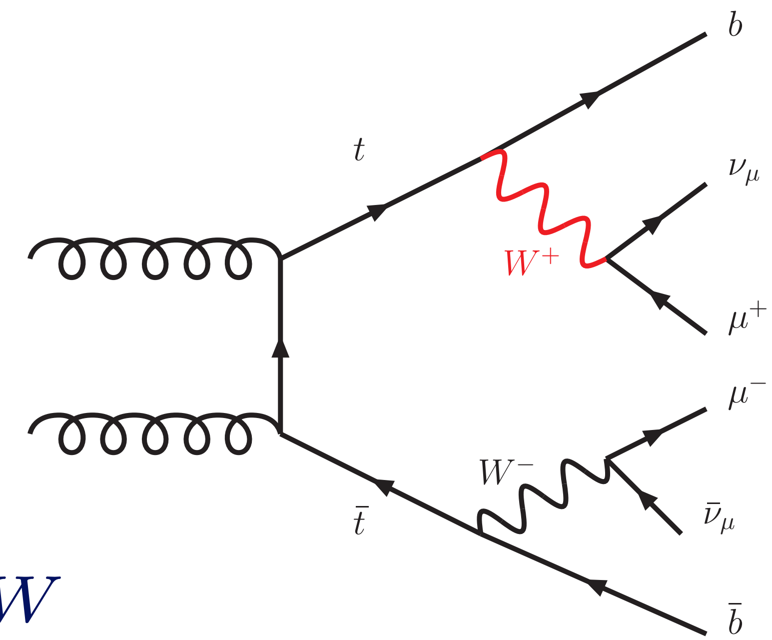
- SM Monte-Carlo:
- Signal Monte-Carlo



Signal/Background

- Estimate Charged Higgs contribution





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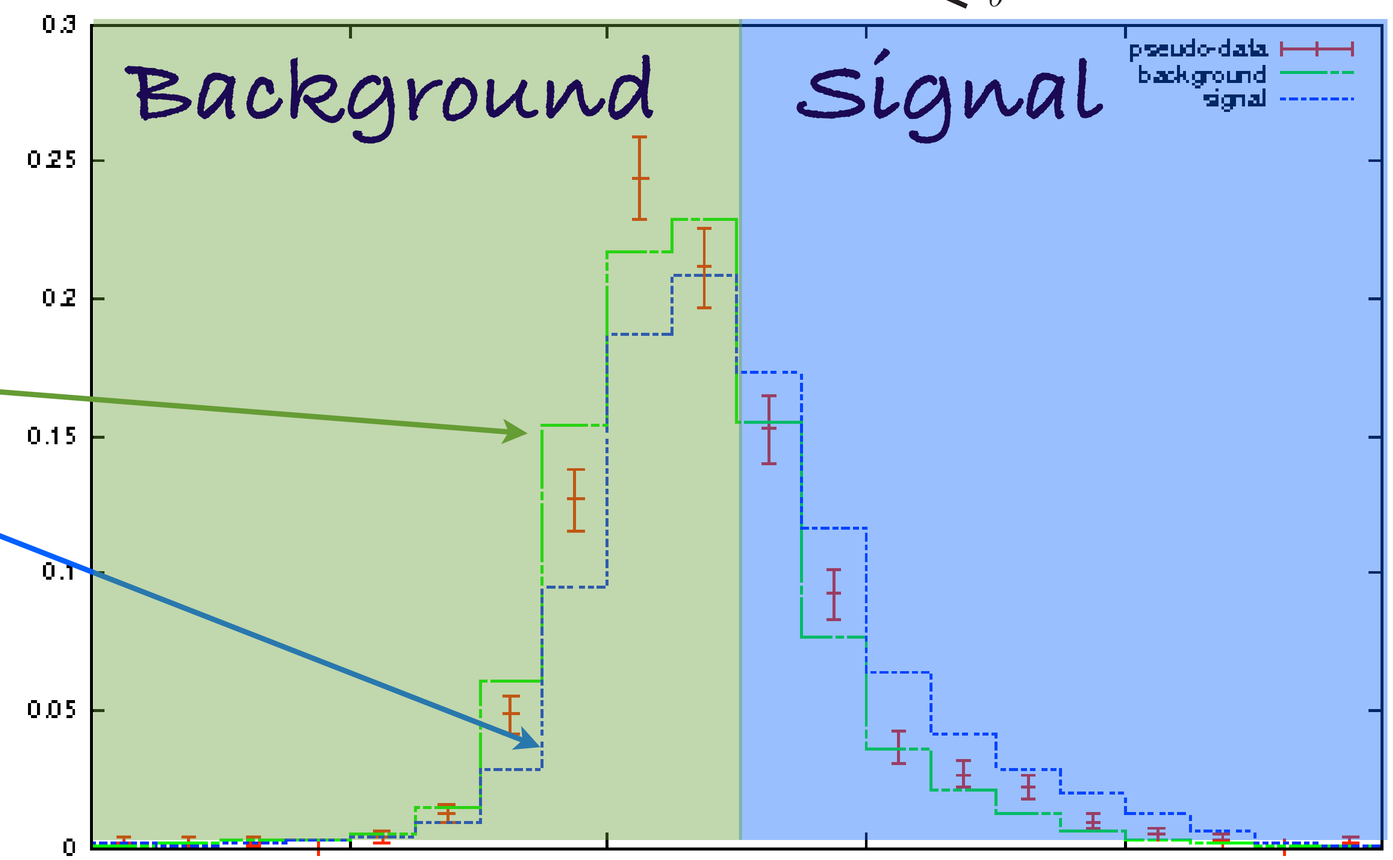
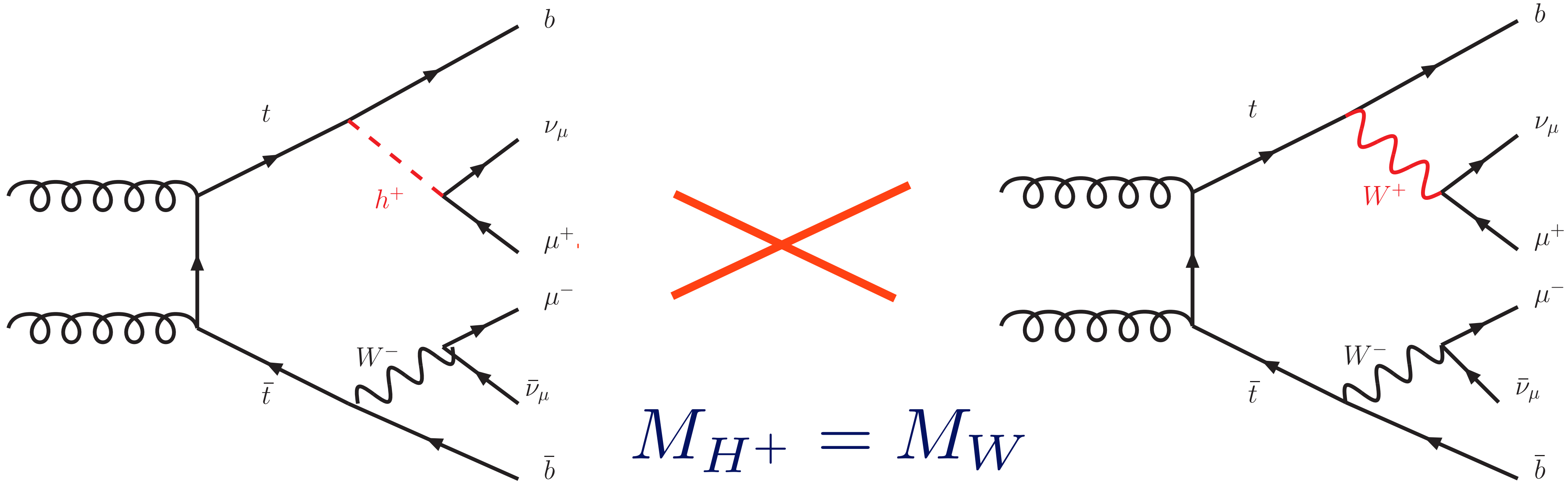
- SM Monte-Carlo:
- Signal Monte-Carlo



Signal/Background

- Estimate Charged Higgs contribution



$$M_{H^+} = M_W$$

- define discriminant:

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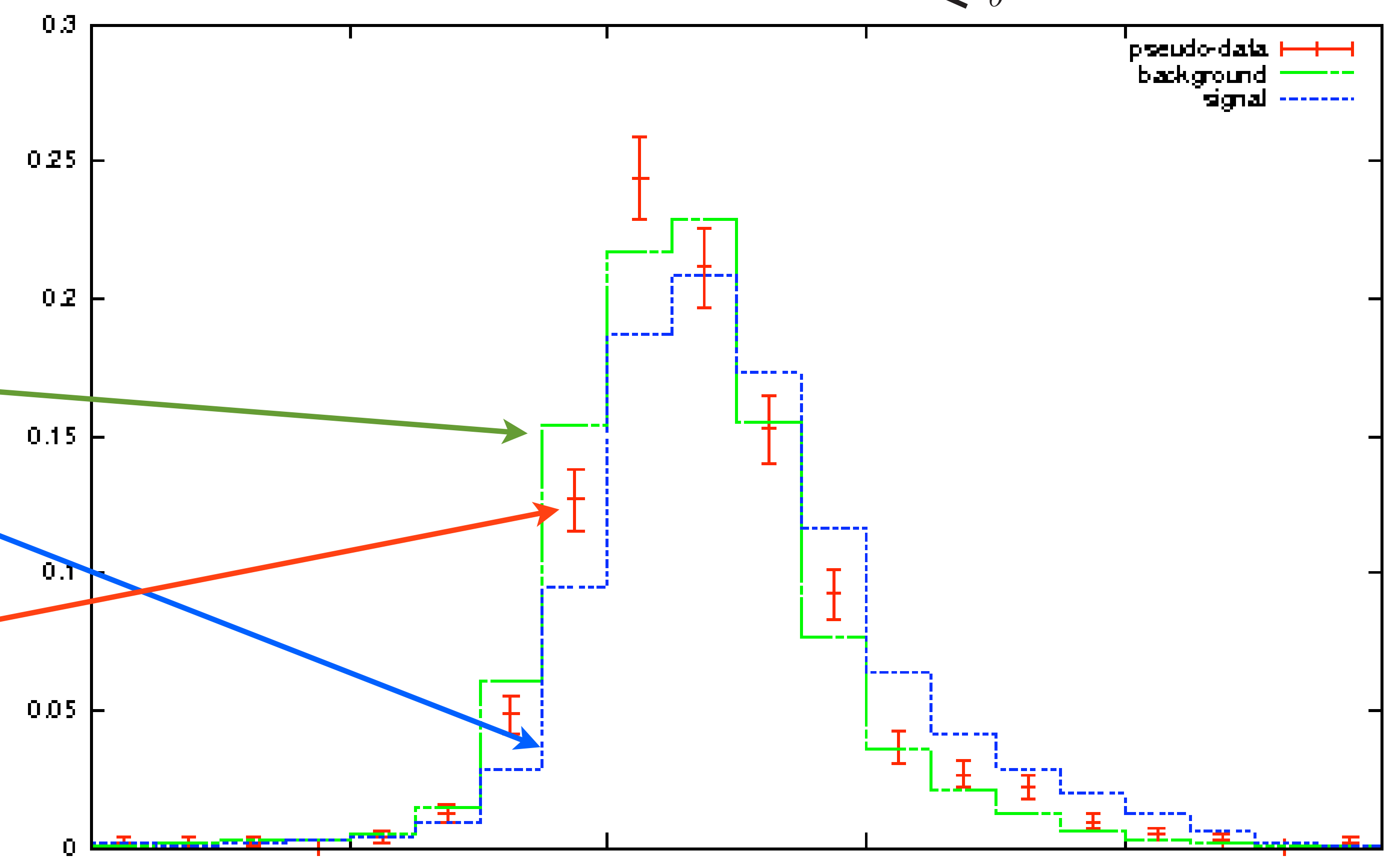
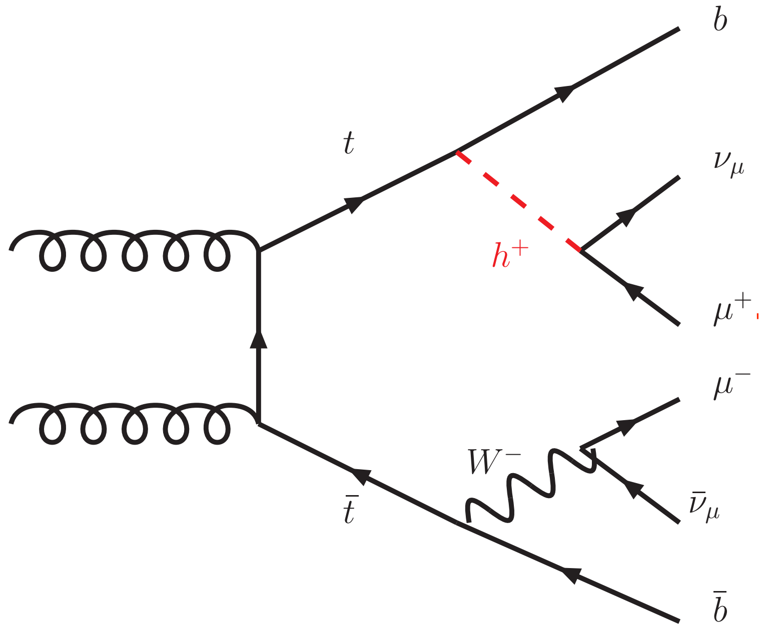
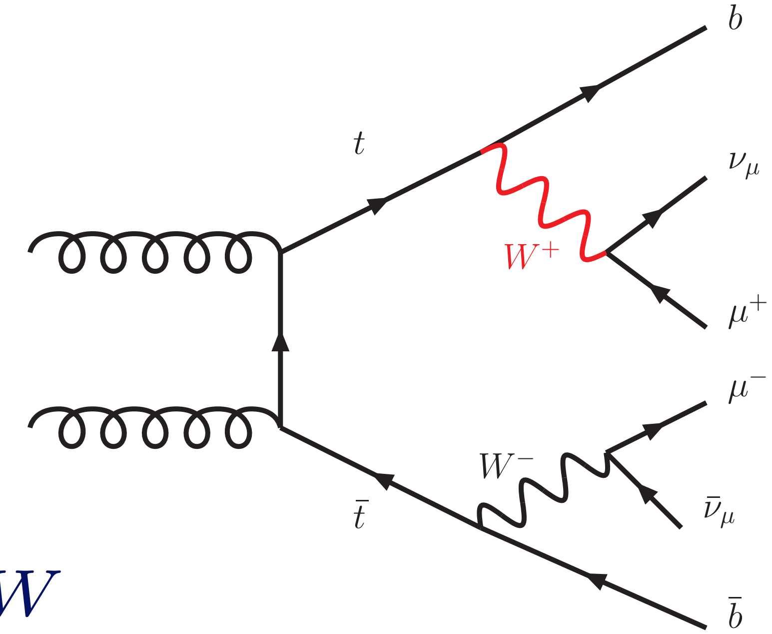
- SM Monte-Carlo:
- Signal Monte-Carlo
- Pseudo-events



Signal/Background

- Estimate Charged Higgs contribution





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- SM Monte-Carlo:
- Signal Monte-Carlo
- Pseudo-events

$$\sigma_S = 1.7 \pm 0.4 pb$$