

aMC@NLO phenomenology at the LHC

Marco Zaro, CP3 - UCLouvain

in collaboration with

*Rikkert Frederix, Stefano Frixione, Fabio Maltoni, Roberto Pittau, Paolo Torrielli, Valentin Hirschi
& the MadGraph5 Team*

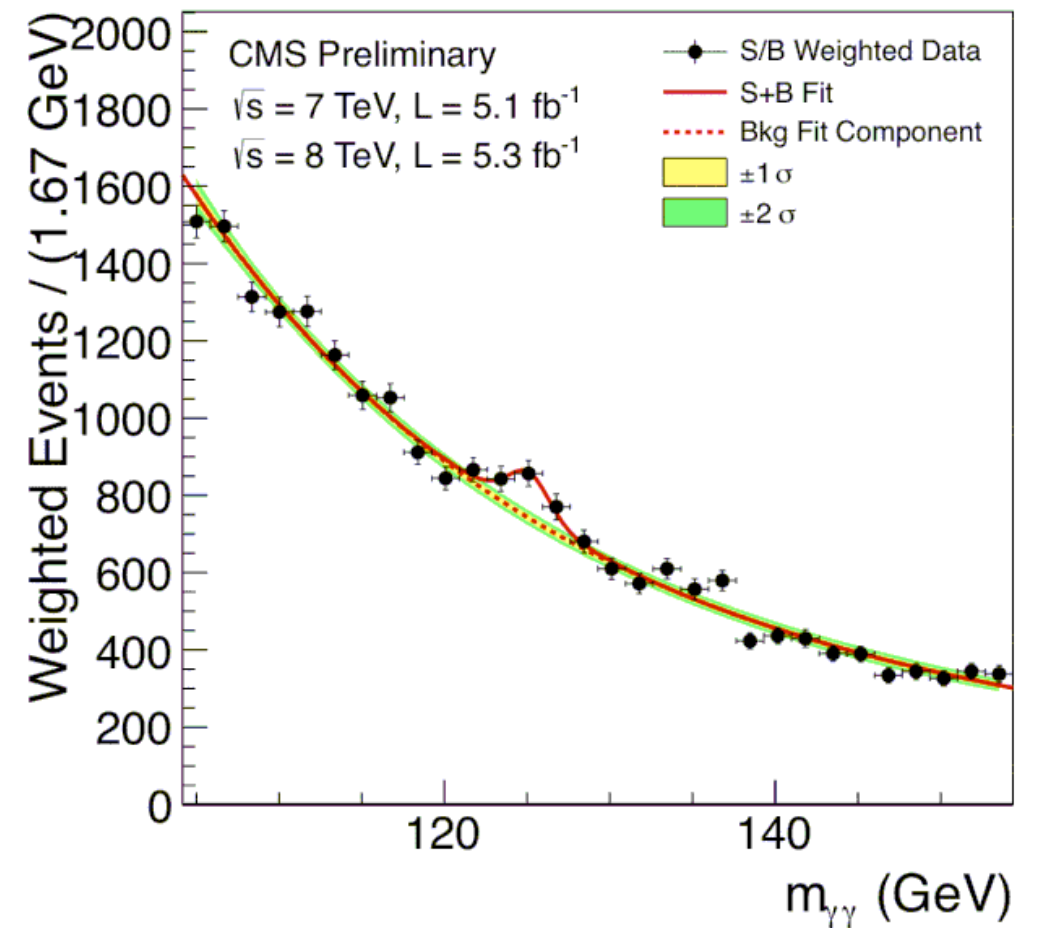
CP3 Lunch Semiar

December 12th, 2012

Dawn of the precision LHC era

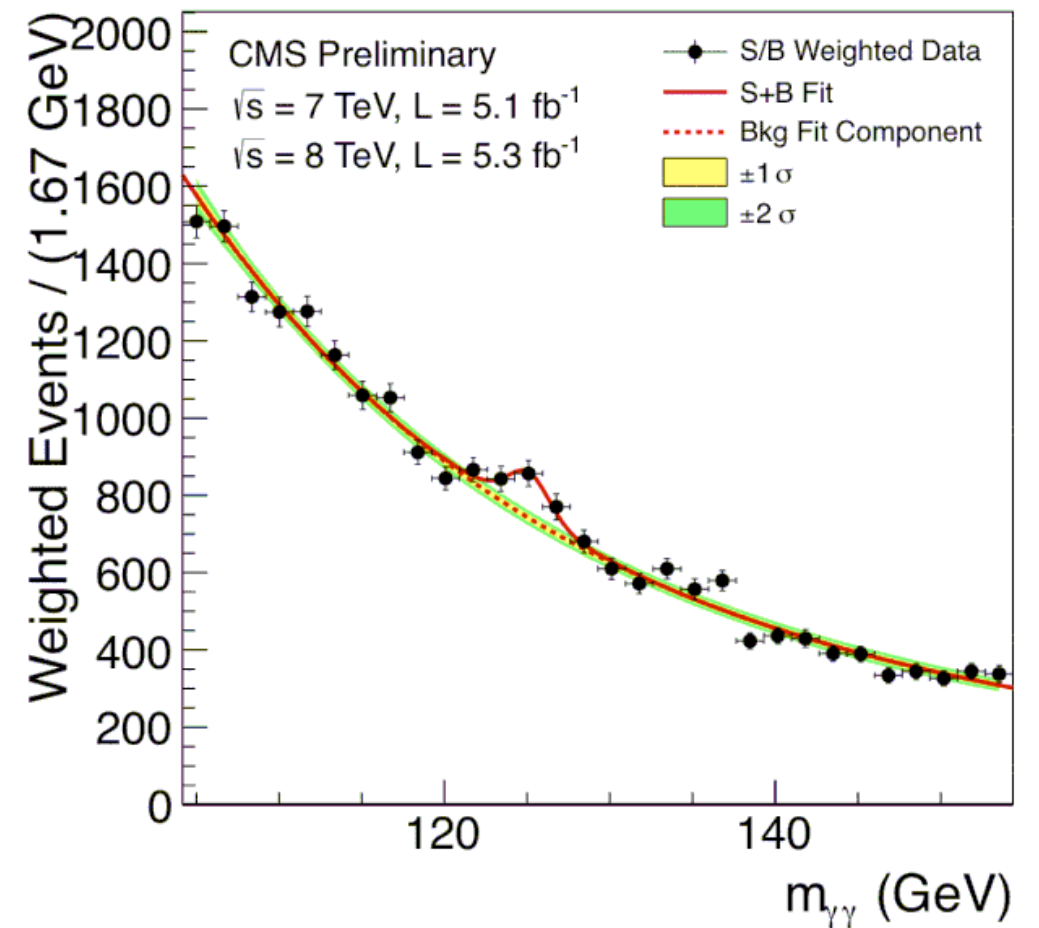
Dawn of the precision LHC era

- July 4th: evidence for a new boson



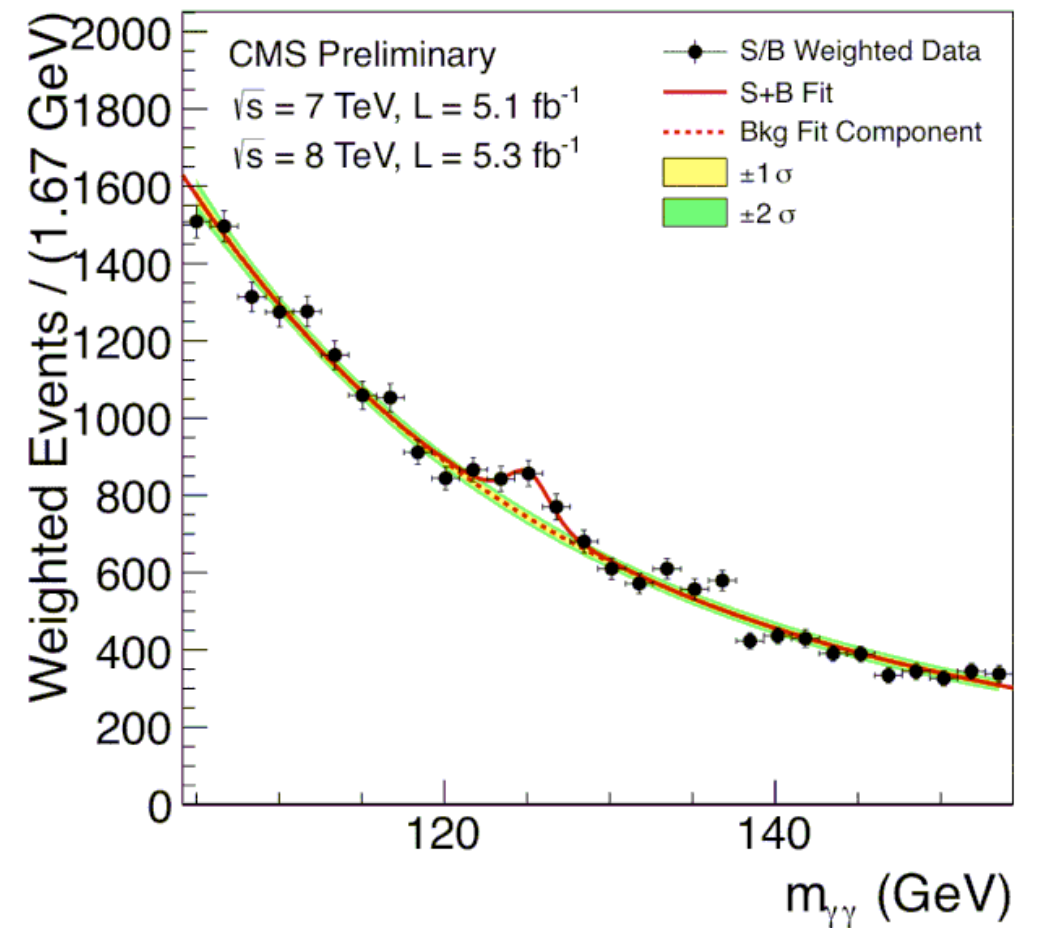
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- Is it the Higgs boson?



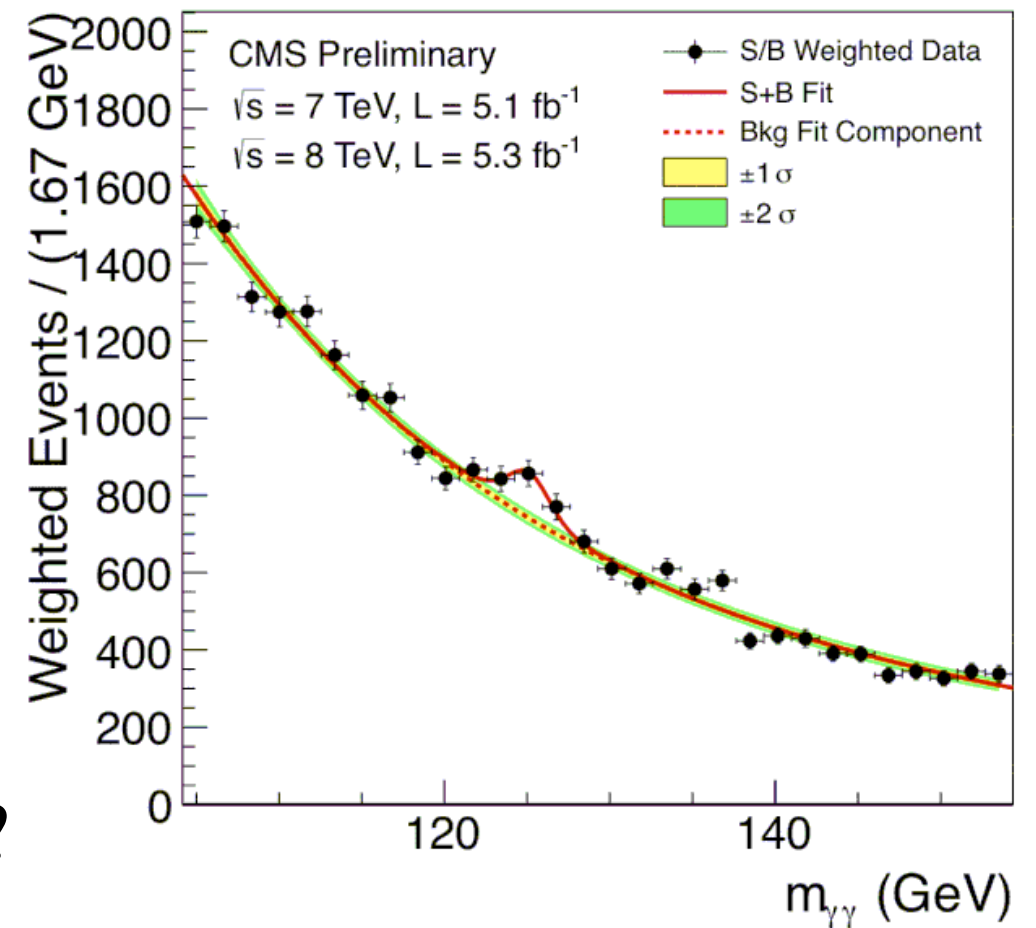
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 - Is it the SM Higgs boson?



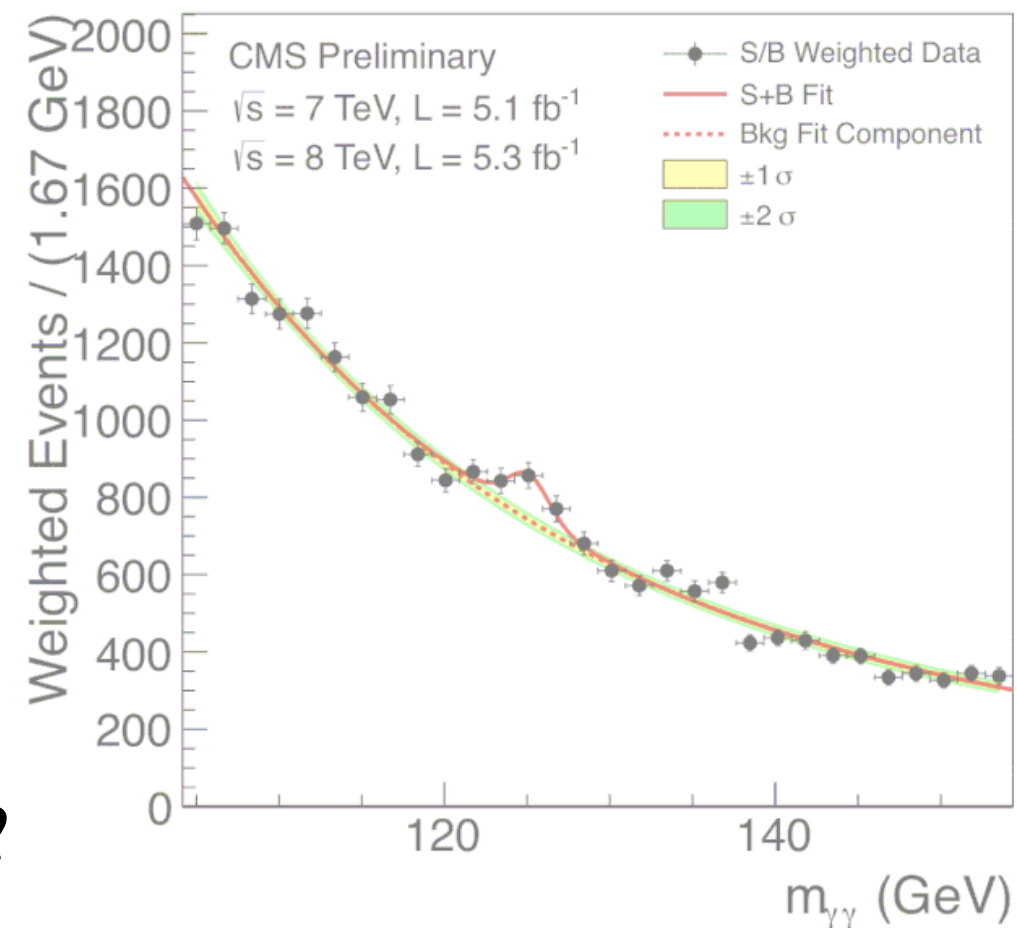
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- July 4th: evidence for a new boson
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 - What is its mass?
 - Is it really spin 0?
 - C-P-CP even or odd?
 - How does it couple to other particles?



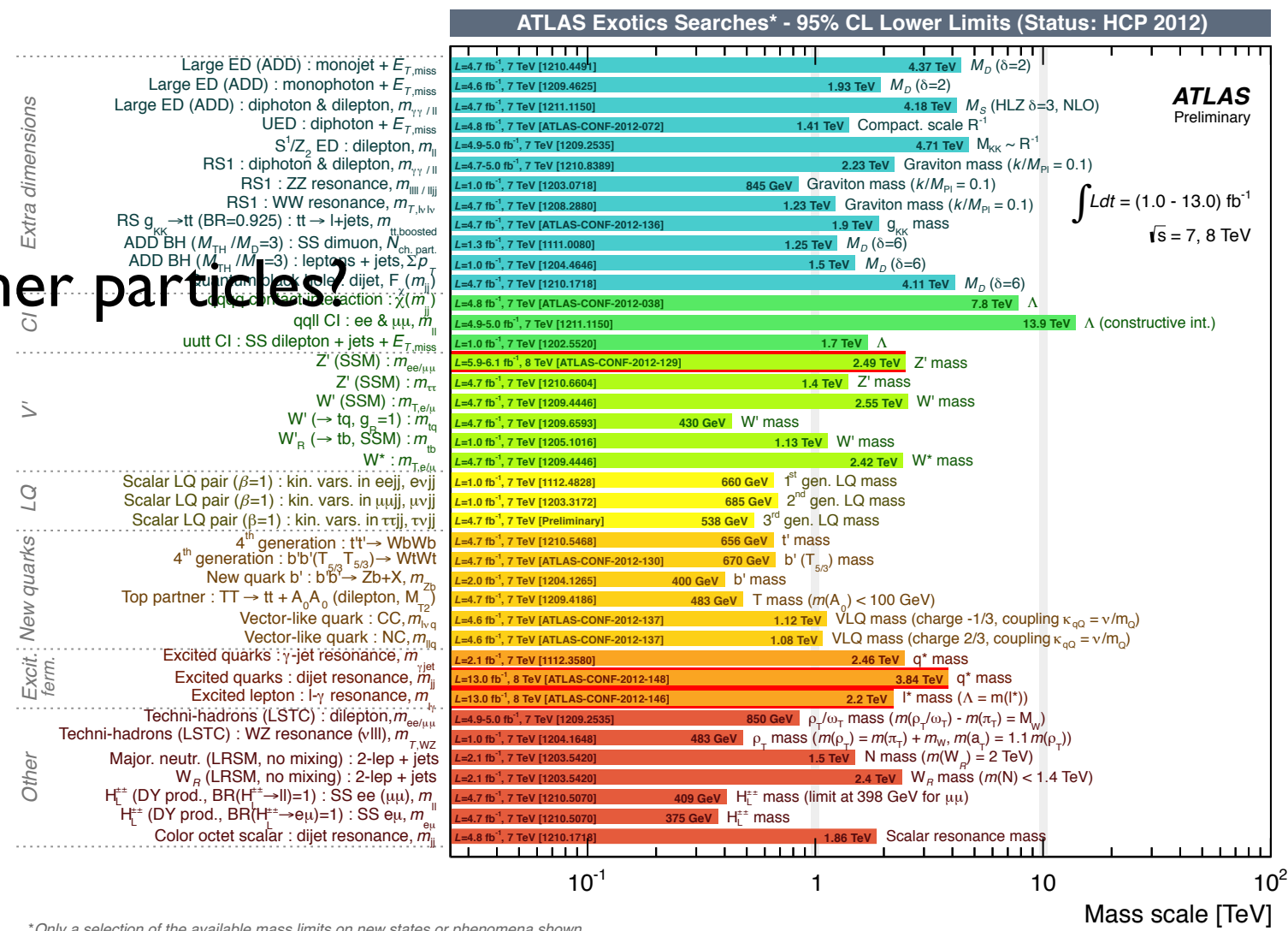
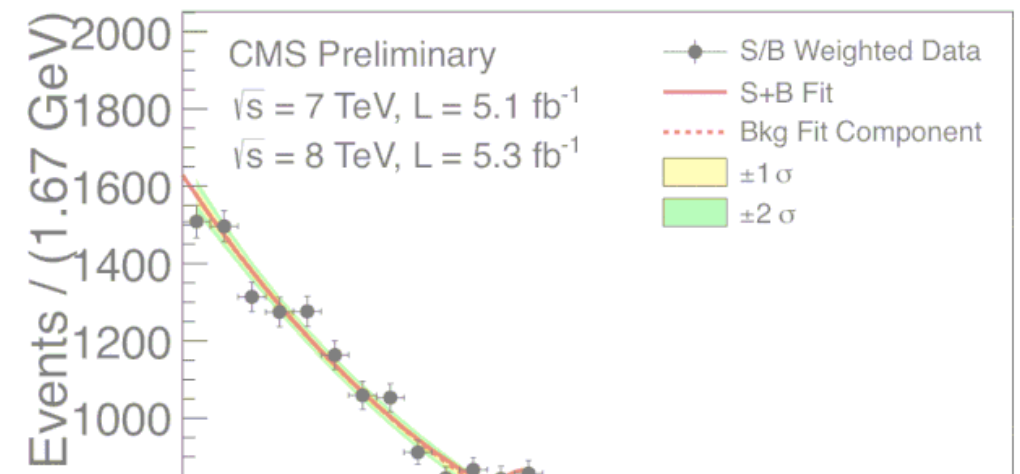
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ATLAS Preliminary

$\int L dt = (1.0 - 13.0) \text{ fb}^{-1}$
 $\sqrt{s} = 7, 8 \text{ TeV}$

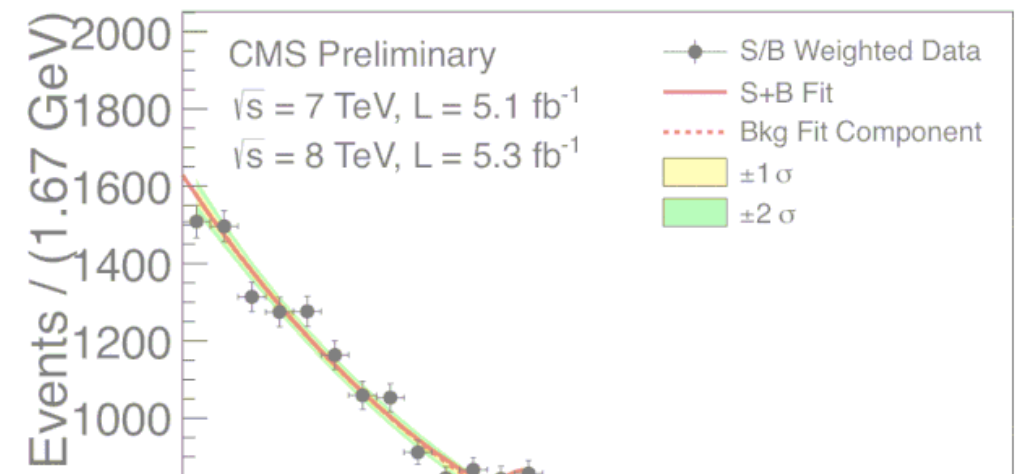
Mass scale [TeV]

10⁻¹ 1 10 10²

Wednesday 12 December 2012

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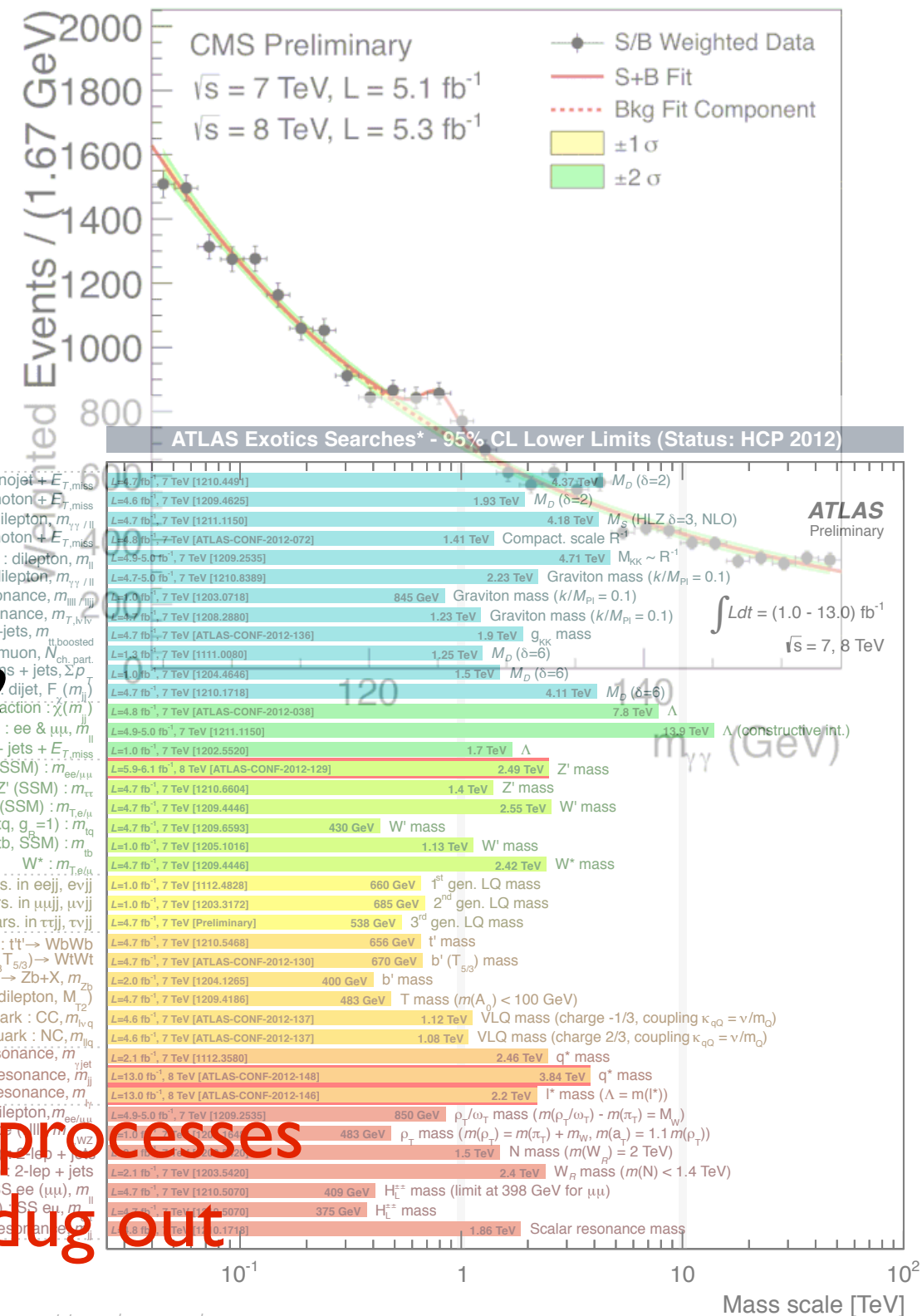
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Lots of background processes
Tiny signal to be dug out

The exp'lists request

Could you please, Mr.Theorist, provide us accurate and realistic predictions for signal and backgrounds?



The answer:



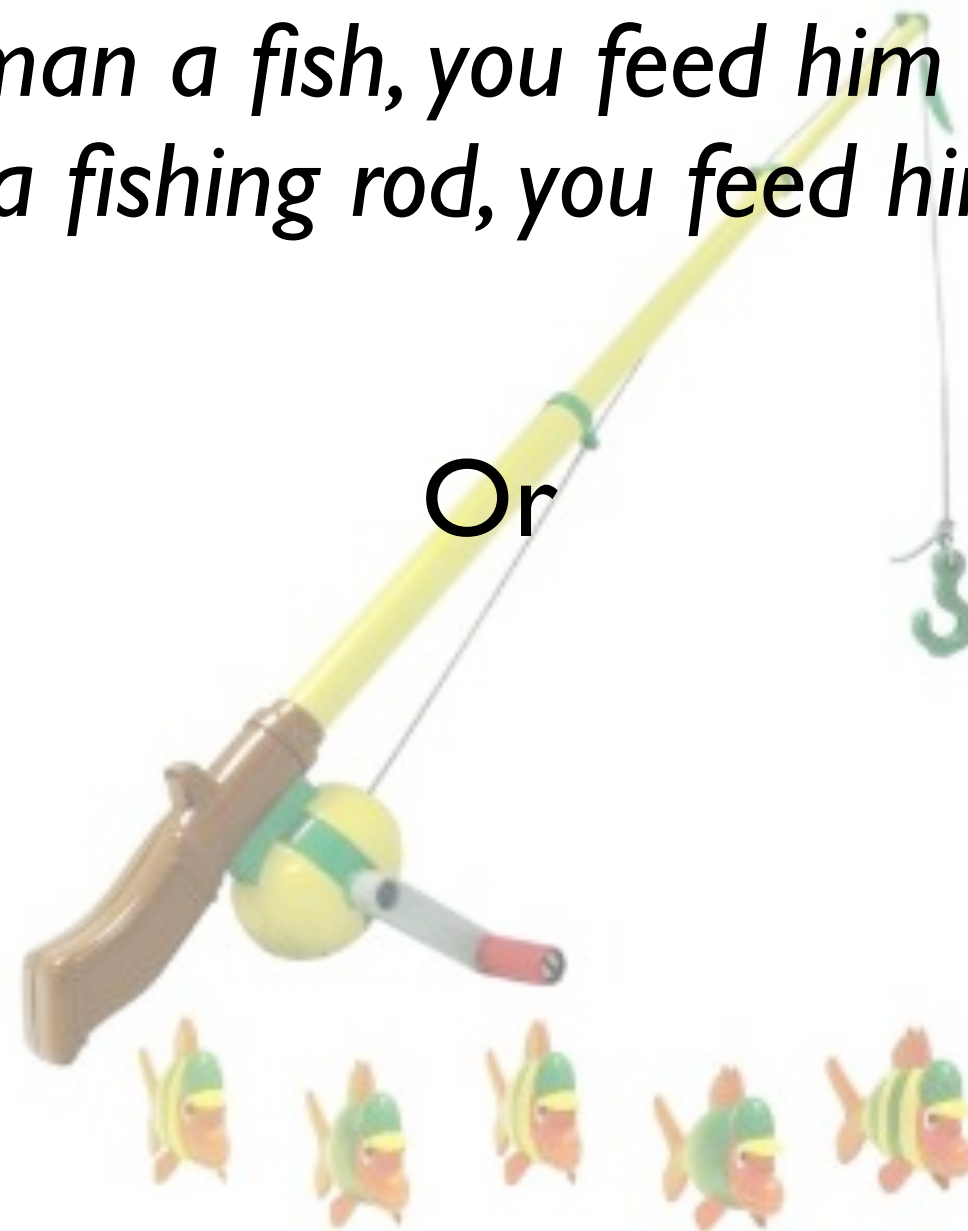
The answer:

If you give a man a fish, you feed him for a day. But if you give him a fishing rod, you feed him for a lifetime



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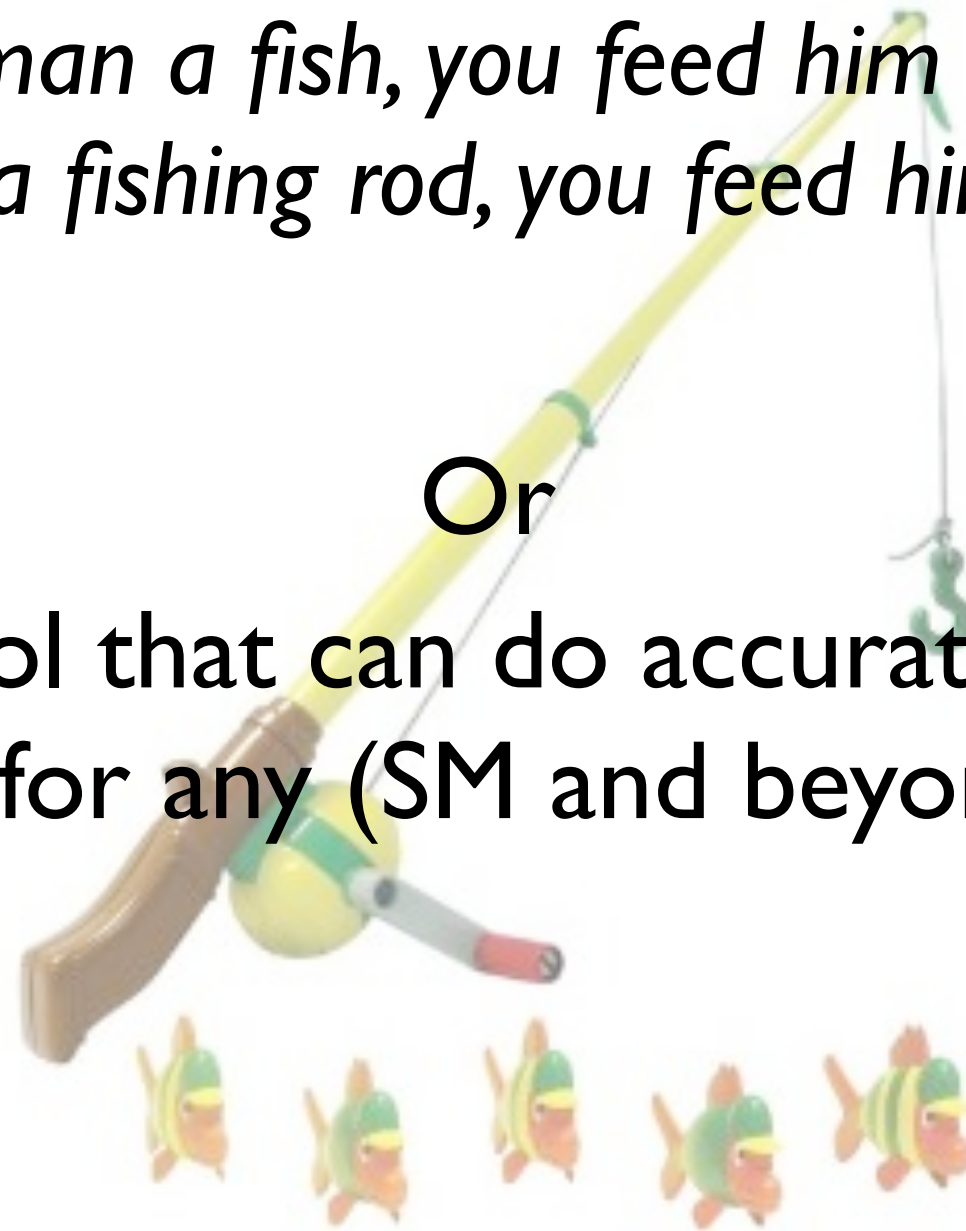


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Or

Provide a tool that can do accurate and realistic simulations for any (SM and beyond) process...

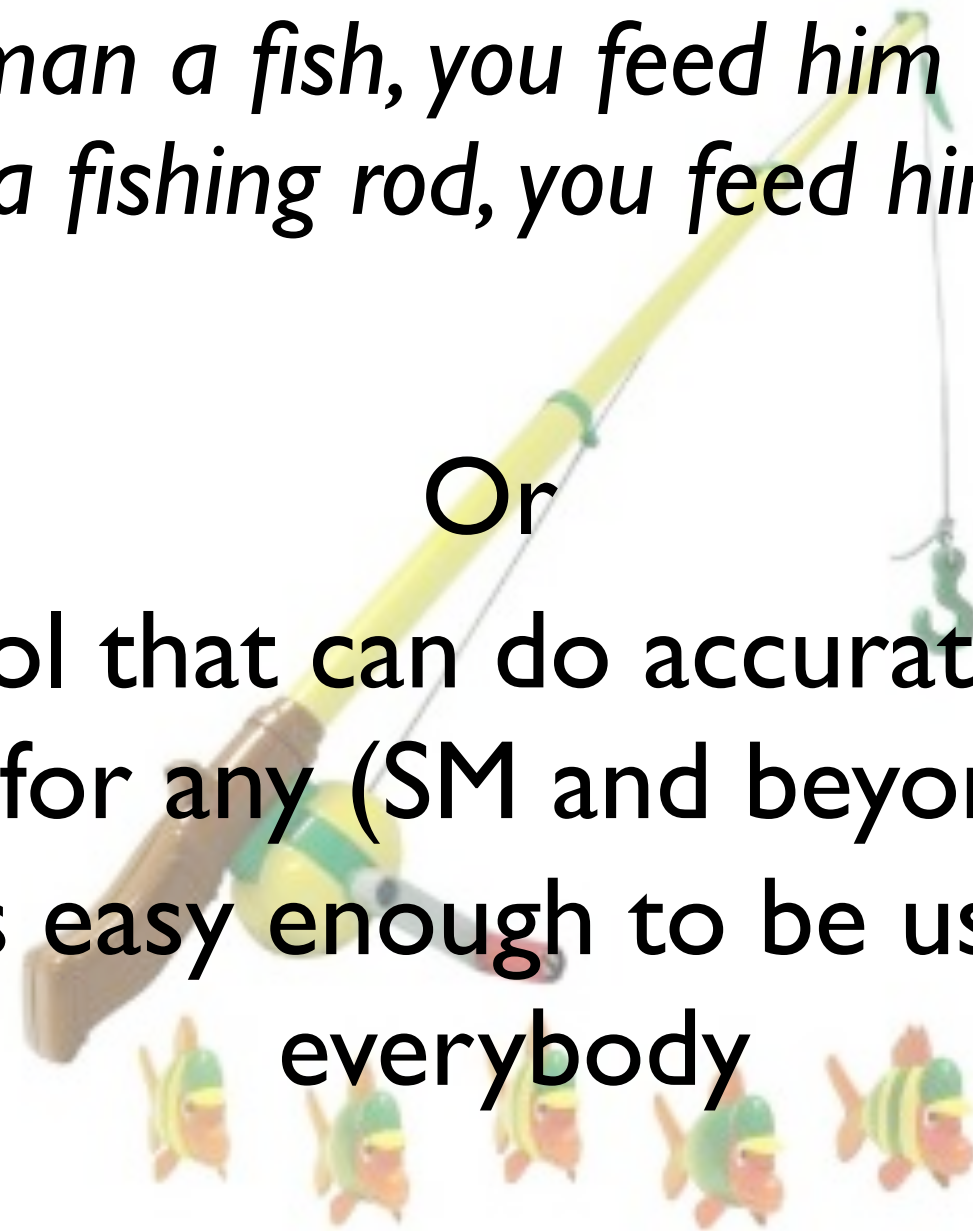


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Or

Provide a tool that can do accurate and realistic simulations for any (SM and beyond) process...
...and which is easy enough to be used by (almost) everybody



Say it again?!?

- Accurate
 - Reliable prediction of total rates
 - Reliable assessment of uncertainties
- Realistic
 - That simulates what we actually see at experiments
- For any (SM and beyond) process
 - Automatic
 - Linkable to any model
- Easy to use

Accurate predictions at hadron colliders



Accurate predictions at hadron colliders:

$$\sigma = \int dx_1 dx_2 f_a(x_1, \mu_F^2) f_b(x_2, \mu_F^2) \sigma_{ab}(x_1, x_2, \alpha_s(\mu_R^2))$$

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Parton distribution functions:

- fit from data
- process independent

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Parton distribution functions:

- fit from data
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Short distance (partonic) cross-section

- known order by order in pert. theory
- process dependent

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$$\sigma_{ab} = \sigma_0 + \alpha_s \sigma_1 + \alpha_s^2 \sigma_2 + \dots$$

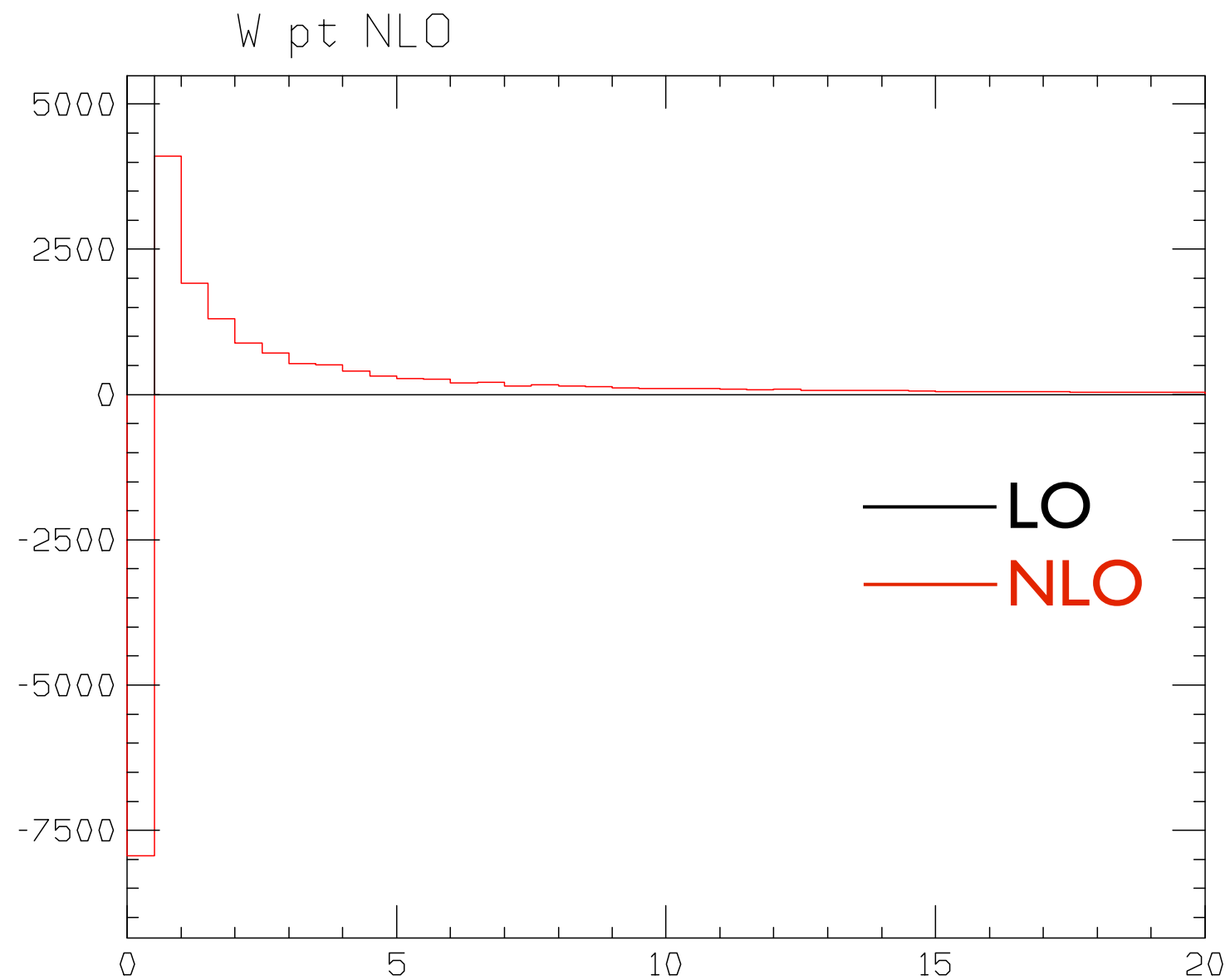
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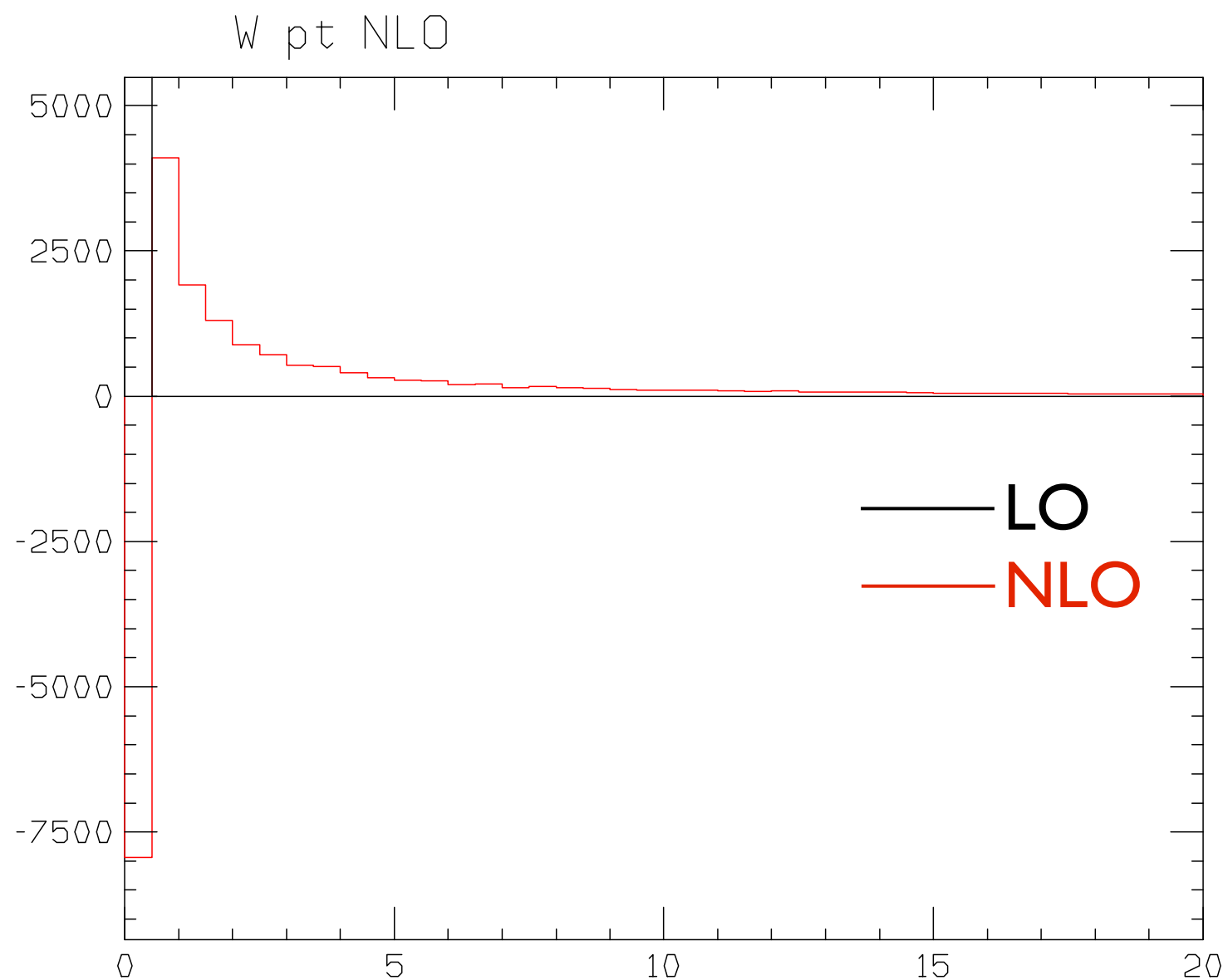
$$\sigma_{ab} = \overset{\text{LO}}{\sigma_0} + \overset{\text{NLO}}{\alpha_s \sigma_1} + \overset{\text{NNLO}}{\alpha_s^2 \sigma_2} + \dots$$

- Inclusion of higher orders improves data/theory agreement
- Inclusion of higher orders reduces TH errors
- NLO mandatory
 - Reliable predictions of rates and uncertainties
- Still not all observables are well behaved at fixed order

W boson pt



W boson pt



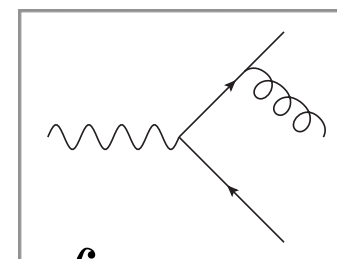
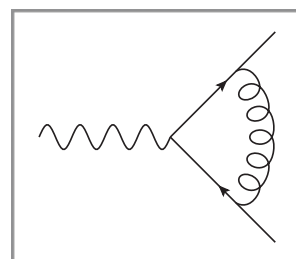
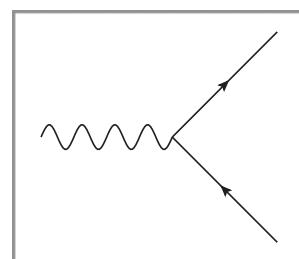
back on this later...

NLO: how to?

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$$d\sigma_{NLO}^n = d\sigma_{LO}^n + d\sigma_V^n + \int d\Phi_1 d\sigma_R^{n+1}$$

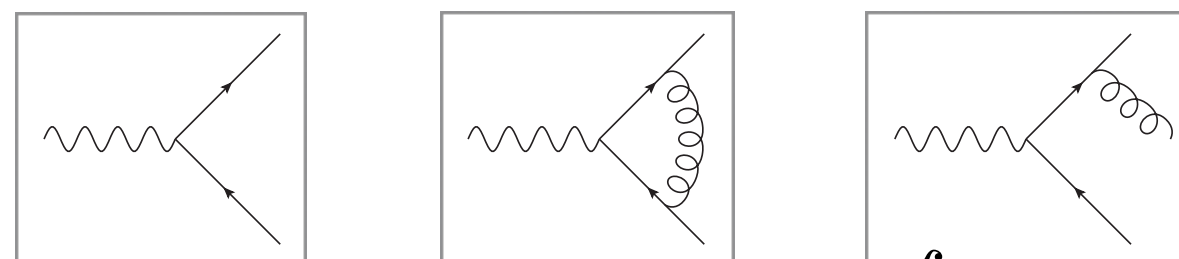
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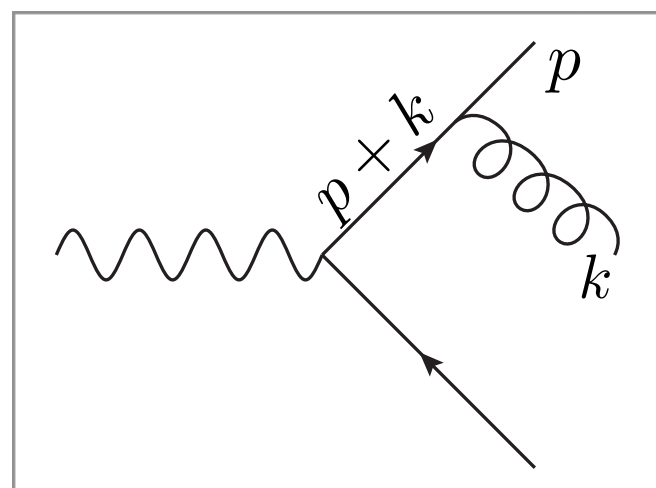
- Warning! Real emission ME is divergent!
 - Divergences cancel with those from virtuals (in $D=4-2\epsilon$)
 - Need to cancel them before numerical integration (in $D=4$)

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- Warning! Real emission ME is divergent!
- Divergences cancel with those from virtuals (in $D=4-2\epsilon$)
- Need to cancel them before numerical integration (in $D=4$)
- Structure of divergences is universal:



$$(p+k)^2 = 2E_p E_k (1 - \cos \theta_{pk})$$

- Collinear singularity:

$$\lim_{p//k} |M_{n+1}|^2 \simeq |M_n|^2 P^{AP}(z)$$

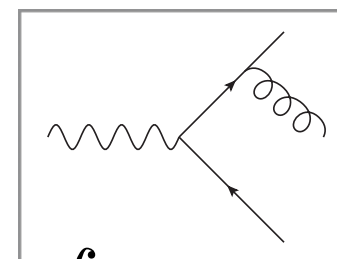
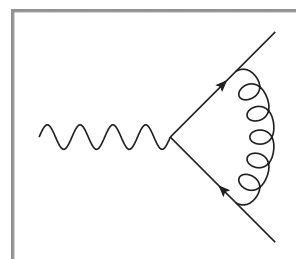
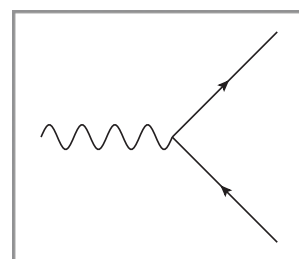
- Soft singularity:

$$\lim_{k \rightarrow 0} |M_{n+1}|^2 \simeq \sum_{ij} |M_n^{ij}|^2 \frac{p_i p_j}{p_i k p_j k}$$

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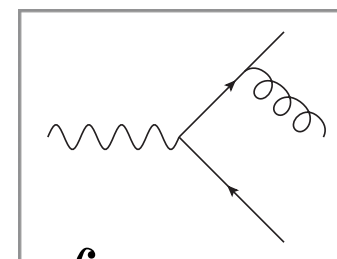
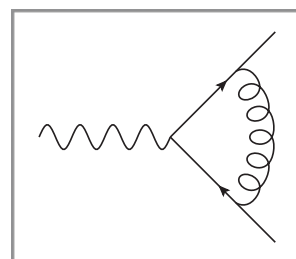
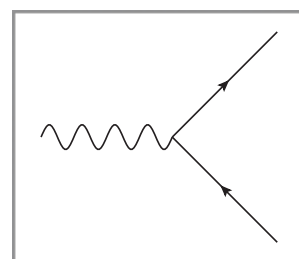


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$$d\sigma_{NLO}^n = d\sigma_{LO}^n + d\sigma_V^n - \int d\Phi_1 C + \int d\Phi_1 (C + d\sigma_R^{n+1})$$

- Add local counterterms in the singular regions and subtract its integrated finite part (poles will cancel against the virtuals)
- The n and $n+1$ body integral now are perfectly finite in 4 dimension
- Can be integrated numerically

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How to do this in an efficient way?

The FKS subtraction

Frixione, Kunszt, Signer, arXiv:hep-ph/9512328

- Soft/collinear singularities arise in many PS regions
- Find parton pairs i, j that can give collinear singularities
- Split the phase space into regions with one collinear sing
- Soft singularities are split into the collinear ones

$$|M|^2 = \sum_{ij} S_{ij} |M|^2 = \sum_{ij} |M|_{ij}^2 \quad \sum S_{ij} = 1$$

$$S_{ij} \rightarrow 1 \text{ if } k_i \cdot k_j \rightarrow 0 \quad S_{ij} \rightarrow 0 \text{ if } k_{m \neq i} \cdot k_{n \neq j} \rightarrow 0$$

- Integrate them independently
 - Parallelize integration
 - Choose ad-hoc phase space parameterization
- Advantages:
 - # of contributions $\sim n^2$
 - Exploit symmetries: 3 contributions for $x, y > n_g$

What about loops?

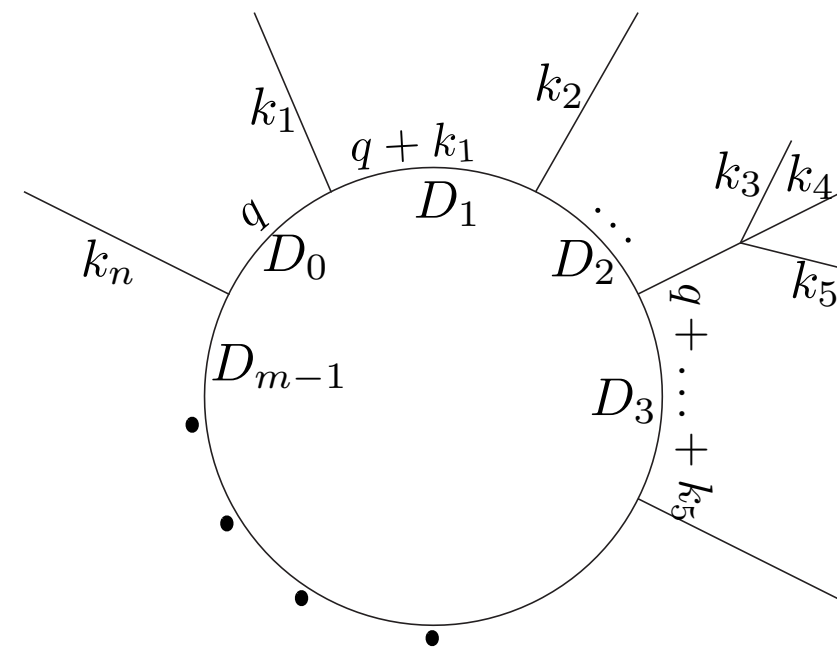
- Several methods/tools to compute loop amplitudes are available
 - Generalized unitarity (BlackHat, Rocket)
Bern, Dixon, Dunbar, Kosower, hep-ph/9403226 +
Ellis, Giele, Kunszt 0708.2398, +Melnikov 0806.3467
 - Integrand reduction (CutTools, Samurai)
Ossola, Papadopolulos, Pittau, hep-ph/0609007, del Aguila, Pittau, hep-ph/0404120
Mastrolia, Ossola, Reiter, Tramontano, 1006.0710
 - Tensor (Passarino-Veltman) reduction (Golem)
Passarino, Veltman, 1979; Denner, Dittmaier, hep-ph/0509141
Binoth, Guillet, Heinrich, Pilon, Reiter 0810.0092

The OPP Method

Ossola, Papadopoulos, Pittau, arXiv:hep-ph/0609007 & arXiv:0711.3596

- Passarino & Veltman reduction:
 - Write the amplitude at the integrand level as linear combination of 1-...-4-point scalar integrals

$$\begin{aligned}
 A(q) = & \sum_{i_0 < i_1 < i_2 < i_3}^{m-1} d(i_0 i_1 i_2 i_3) D_0(i_0 i_1 i_2 i_3) \\
 & + \sum_{i_0 < i_1 < i_2}^{m-1} c(i_0 i_1 i_2) C_0(i_0 i_1 i_2) \\
 & + \sum_{i_0 < i_1}^{m-1} b(i_0 i_1) B_0(i_0 i_1) \\
 & + \sum_{i_0}^{m-1} a(i_0) A_0(i_0) \\
 & + R
 \end{aligned}$$



- Do this at the integrand level

The OPP Method

Ossola, Papadopoulos, Pittau, arXiv:hep-ph/0609007 & arXiv:0711.3596

$$A(\bar{q}) = \frac{N(q)}{\bar{D}_0 \bar{D}_1 \cdots \bar{D}_{m-1}}, \quad N(q) = \sum_{i_0 < i_1 < i_2 < i_3}^{m-1} \left[d(i_0 i_1 i_2 i_3) + \tilde{d}(q; i_0 i_1 i_2 i_3) \right] \prod_{i \neq i_0, i_1, i_2, i_3}^{m-1} D_i$$

$$+ \sum_{i_0 < i_1 < i_2}^{m-1} \left[c(i_0 i_1 i_2) + \tilde{c}(q; i_0 i_1 i_2) \right] \prod_{i \neq i_0, i_1, i_2}^{m-1} D_i$$

$$+ \sum_{i_0 < i_1}^{m-1} \left[b(i_0 i_1) + \tilde{b}(q; i_0 i_1) \right] \prod_{i \neq i_0, i_1}^{m-1} D_i$$

$$+ \sum_{i_0}^{m-1} \left[a(i_0) + \tilde{a}(q; i_0) \right] \prod_{i \neq i_0}^{m-1} D_i$$

$$+ \tilde{P}(q) \prod_i^{m-1} D_i.$$

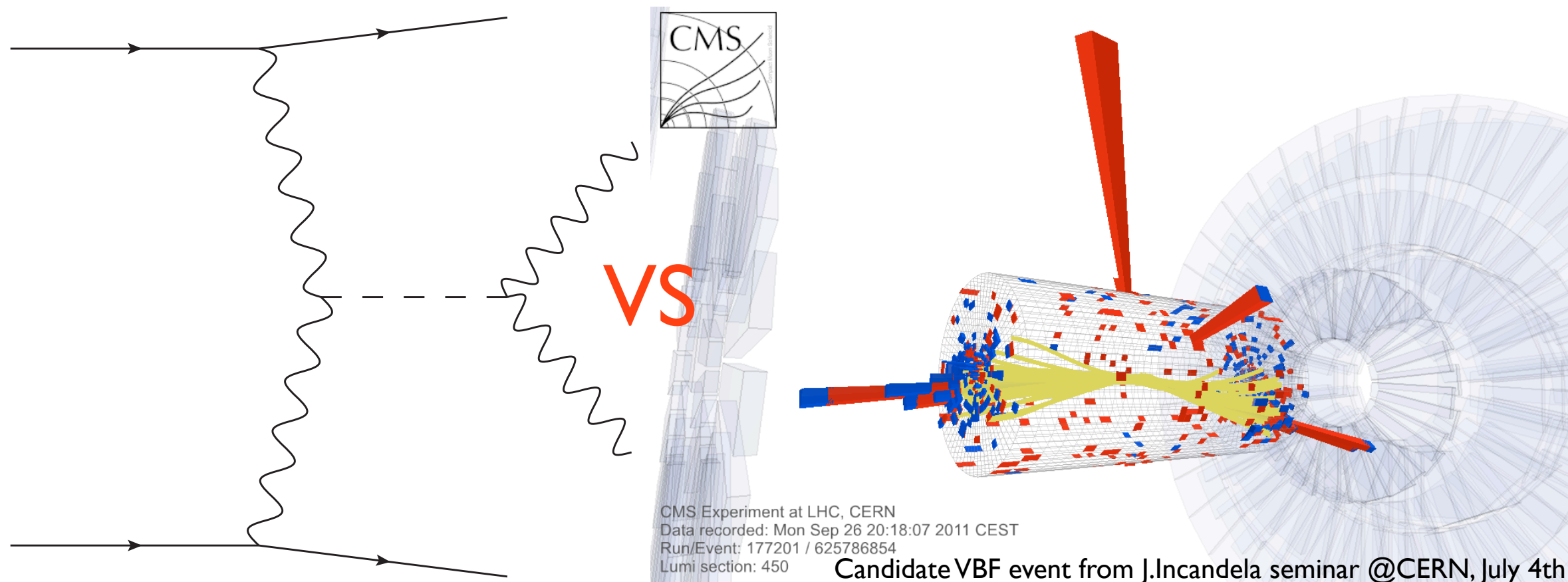
- Sample the numerator at complex values of the loop momenta in order to reconstruct the a, b, c, d coefficients and part of the rational terms (R1)
- Use CutTools: fed with the loop numerator outputs the coefficients of the scalar integrals and CC rational terms (R1)
- Add R2-rational terms/UV counterterms (process-independent)

Realistic predictions at hadron colliders



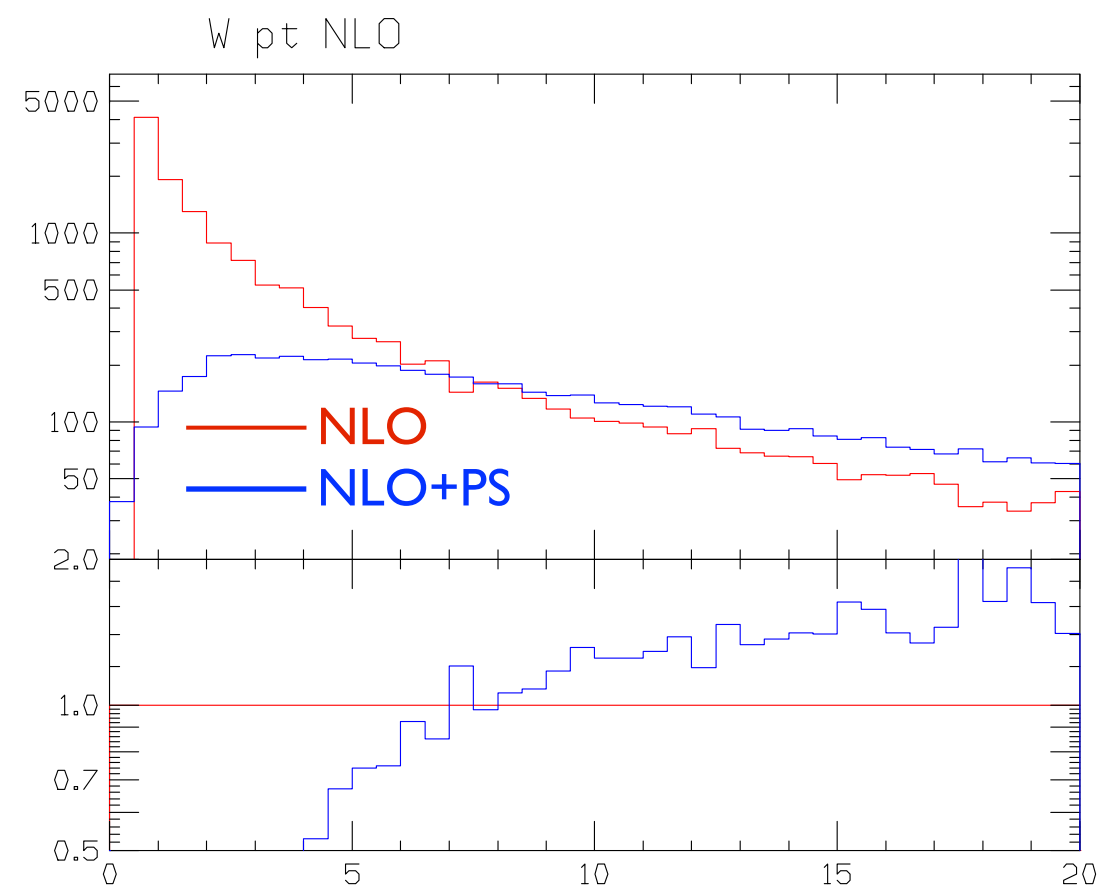
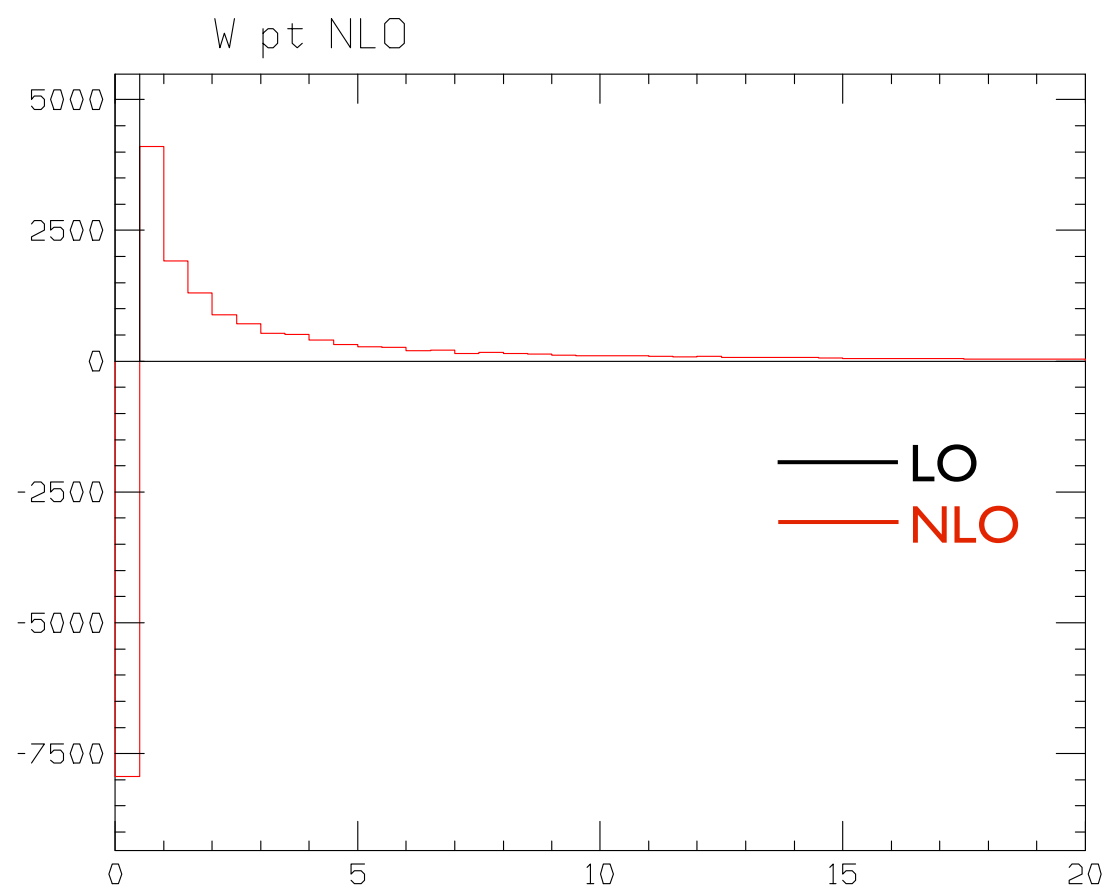
E. Hopper, *Rooms by the sea* 1951

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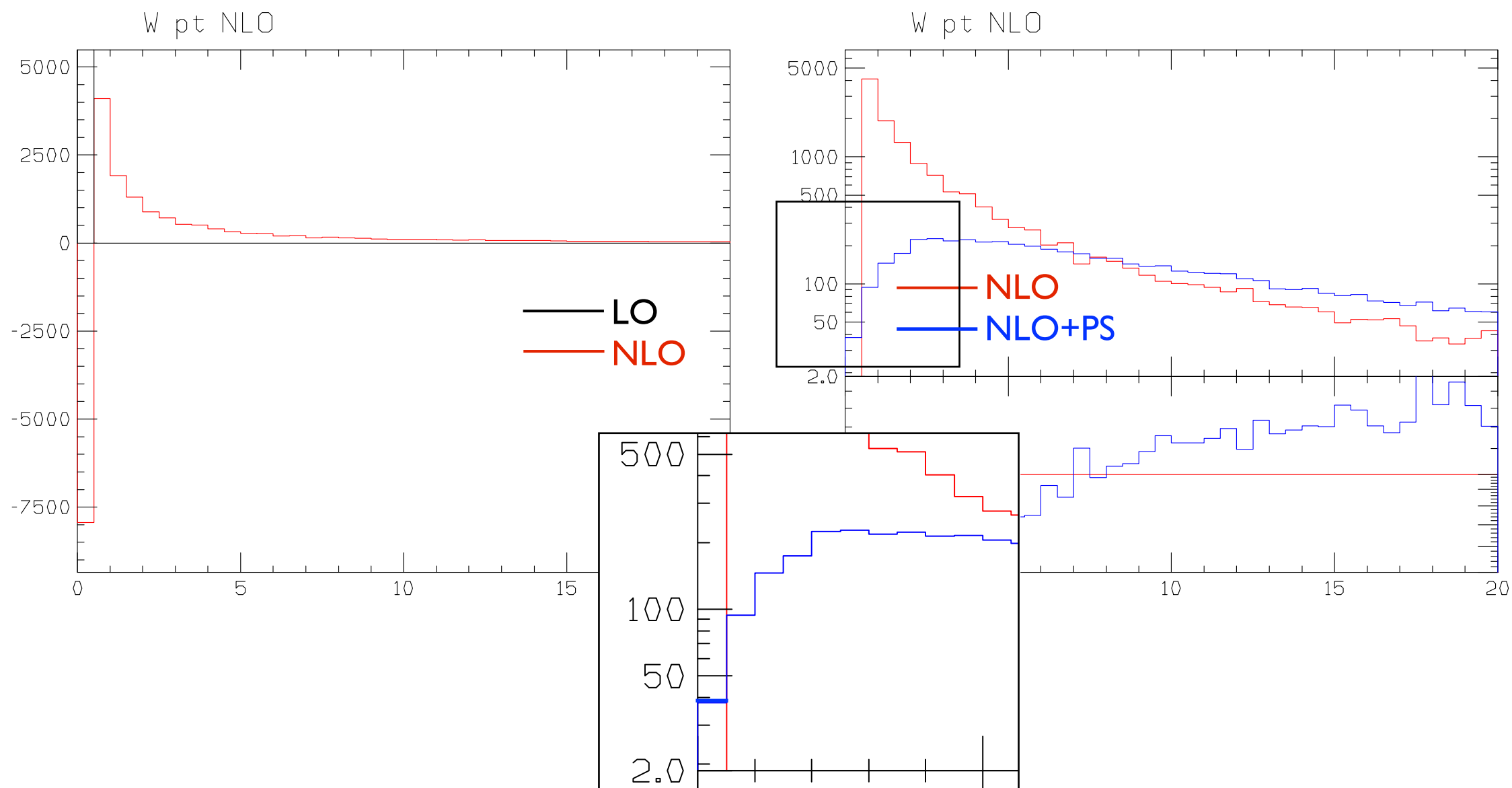


- Parton level does not catch all the complexity that we see
- Matching to shower/hadronization MC needed
 - This also cures fixed orders ill-behaved observables

W boson pt (cont'd)



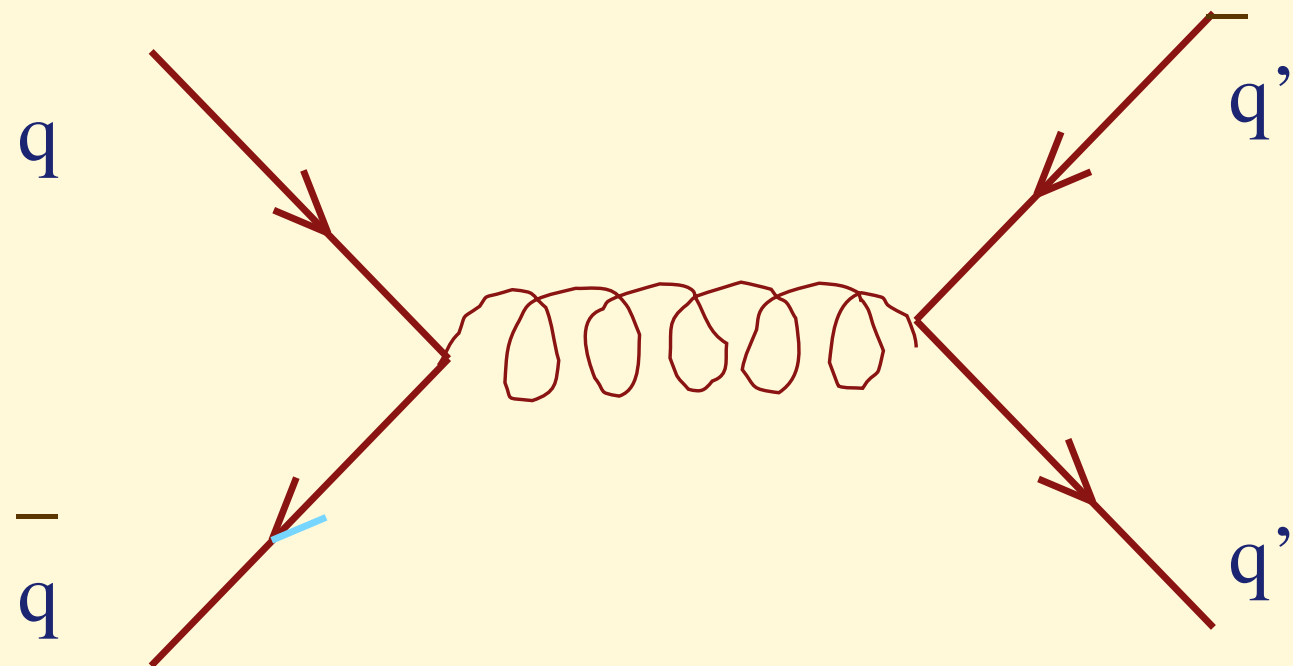
W boson pt (cont'd)



What is a 'parton shower'?

- Ordinary generators (e.g. MadGraph) are based on matrix-elements with $O(\text{few})$ external legs (quarks/gluons)
- At hadron colliders we probe states with $O(\text{many})$ final state particles (hadrons)
- The parton shower (+ hadronization) fills the gap
 - More partons are generated via soft/collinear approximations
 - Partons are clustered together into color singlets, from which hadrons are generated

I: Generate the parton-level hard event

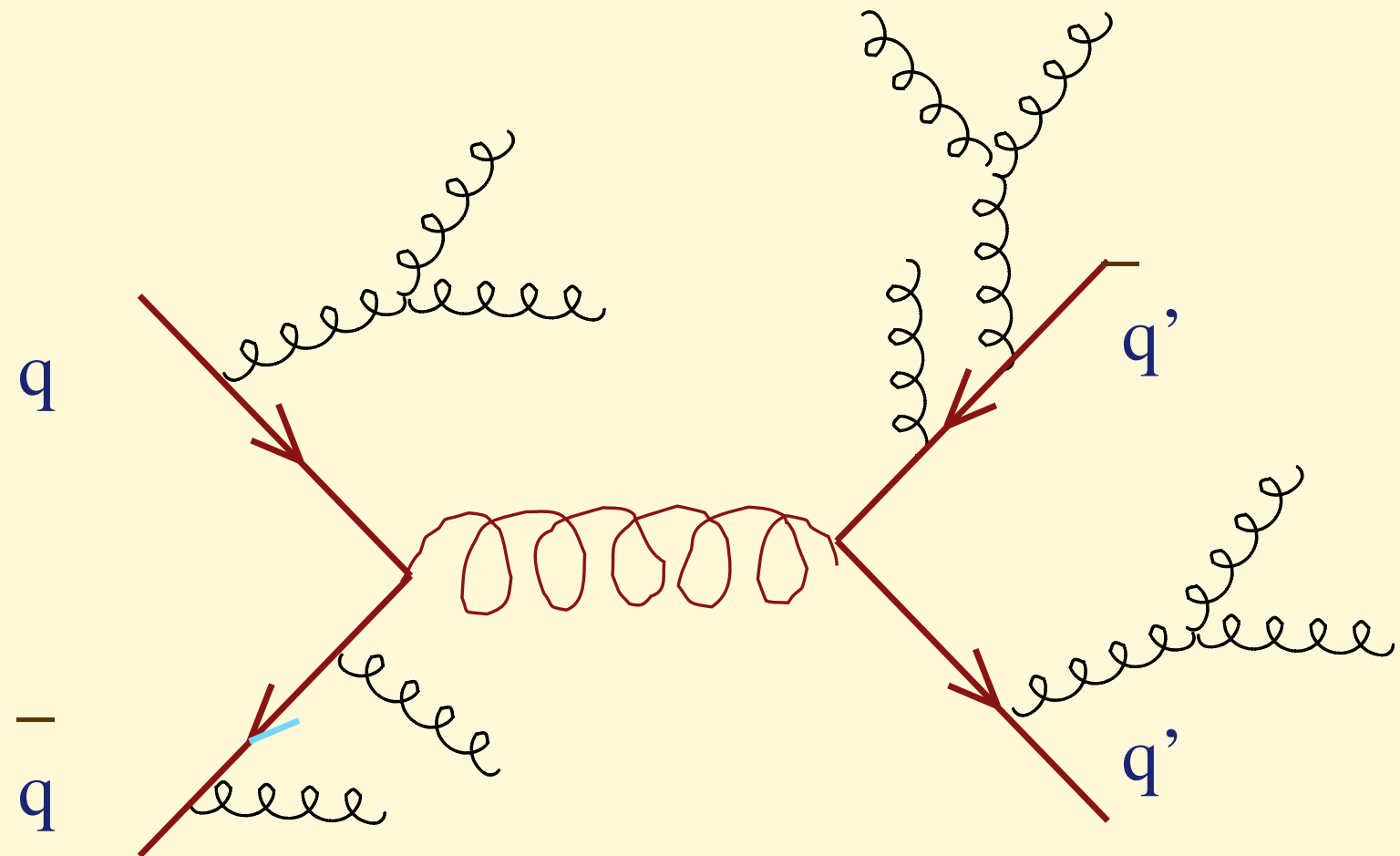


Slides from M.L.Mangano

II: Develop the parton shower

1. Final state

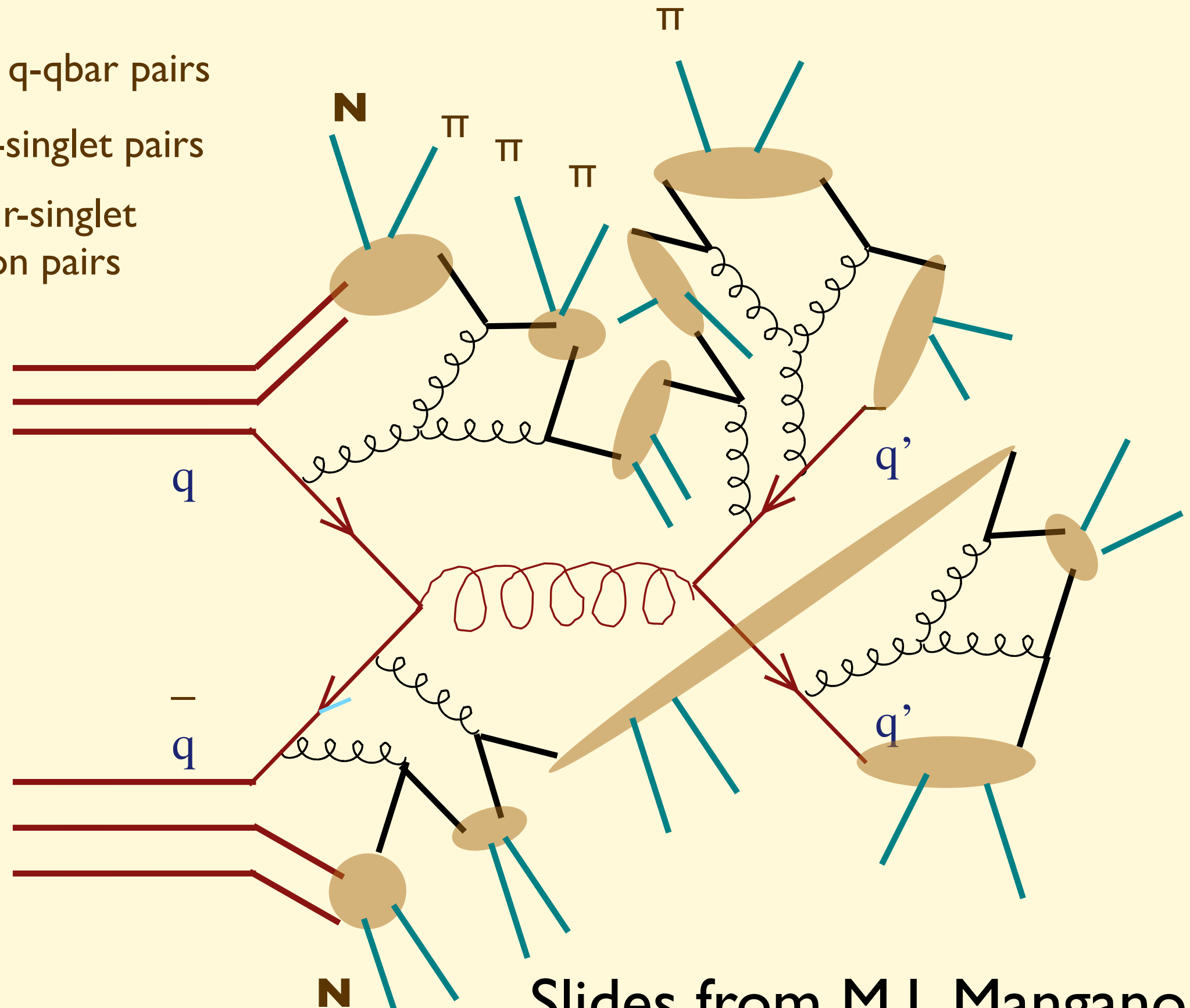
2. Initial state



Slides from M.L.Mangano

III: Hadronize partons

1. Split gluons into q - q bar pairs
2. Connect colour-singlet pairs
3. Decay the colour-singlet clusters into hadron pairs



Slides from M.L.Mangano

Matching

PS & NLO computations

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 - Blind generation of n and $n+1$ body events + shower is affected by double counting (also $n+1$ ME is divergent)

$$\frac{d\sigma^{\text{"MC@NLO"}}}{dO} = \left[\int d\Phi_n (B + V) \right] I_{MC}^n(O) + \left[\int d\Phi_{n+1} R \right] I_{MC}^{n+1}(O)$$

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- One must avoid double counting the exact real/virtual MEs with the approximated ones from the Sudakov

MC@NLO:

Frixione, Weber, arXiv:hep-ph/0204244

- Add MC counterterms in the cross-section computation

$$\frac{d\sigma^{\text{MC@NLO}}}{dO} = \left[\int d\Phi_n (B + V + \int d\Phi_1 \text{MC}) \right] I_{MC}^n(O) + \left[\int d\Phi_{n+1} (R - \text{MC}) \right] I_{MC}^{n+1}(O)$$

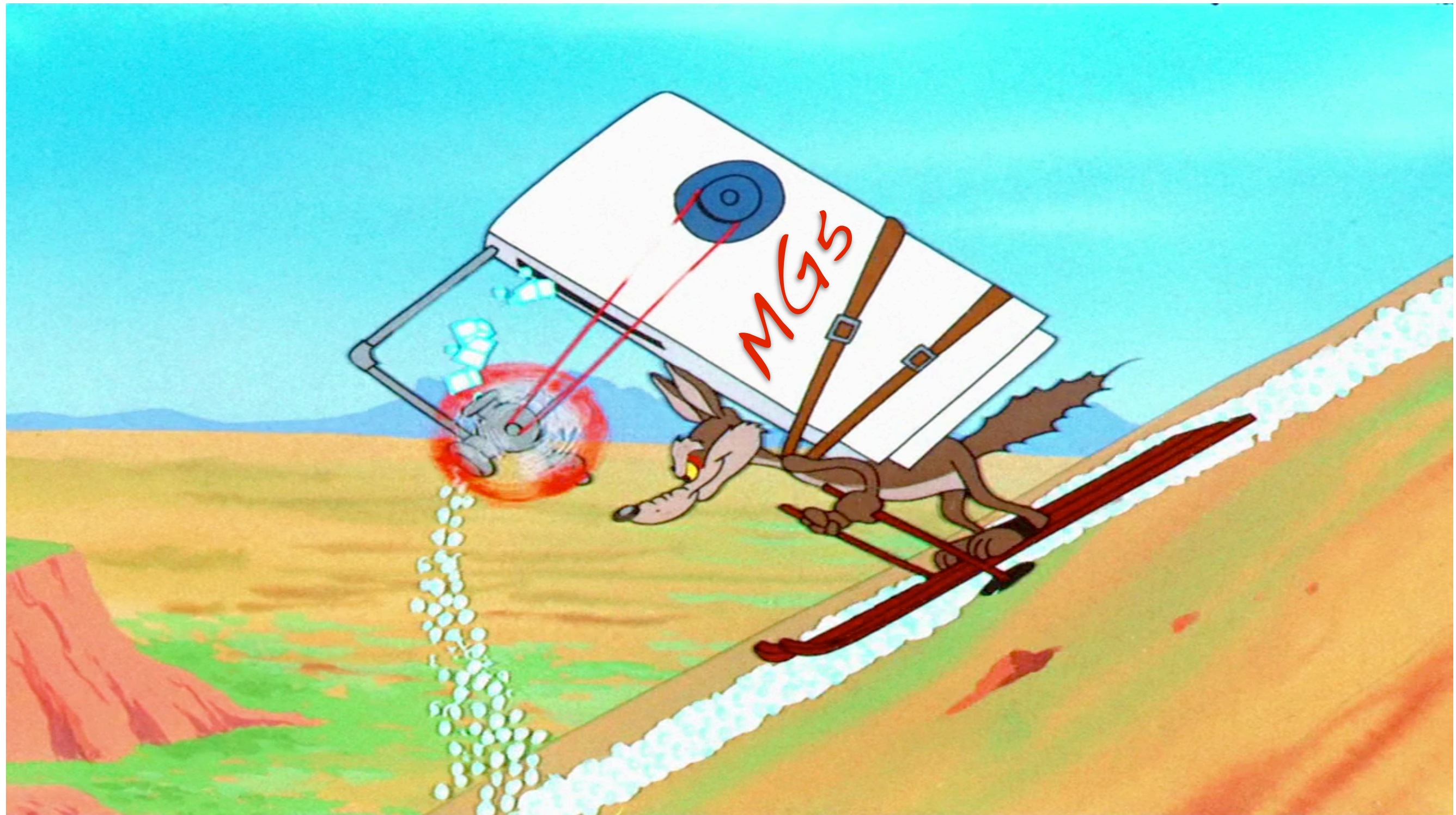
- The “shower operator” is related to MC as

$$I_{MC}^k = \Delta + \Delta d\Phi_1 \frac{MC}{B} + \dots \quad \Delta = \exp \left[- \int d\Phi_1 \frac{MC}{B} \right]$$

- So, NLO normalization of the total cross-section is kept
- MC acts as a local soft/collinear counterterm
 - Suitable for numerical integration
- Can generate unweighted (up to sign) events
- MC is PS dependent

$$MC = J \frac{1}{t_{MC}} \frac{\alpha_s}{2\pi} P(z^{MC}) B$$

Automation



Automation

- Time for coding/debugging a new process@NLO: $O(1)$ year
- Trade time spent for coding/debugging with time to do real physics
- Once building blocks are tested, results are almost “correct by definition”
- Automatic tools can be used as black-boxes. No need of knowing what the tool is actually doing for you

Automation with MadGraph5

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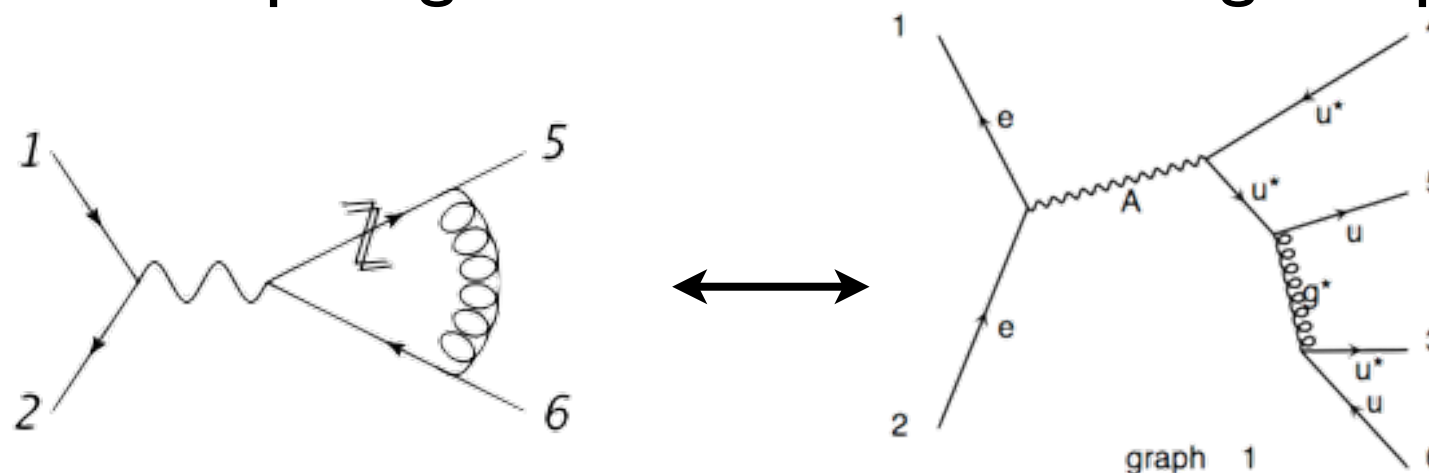
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 - What about the virtuals?

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 - Think of loop diagrams as trees with two glued particles

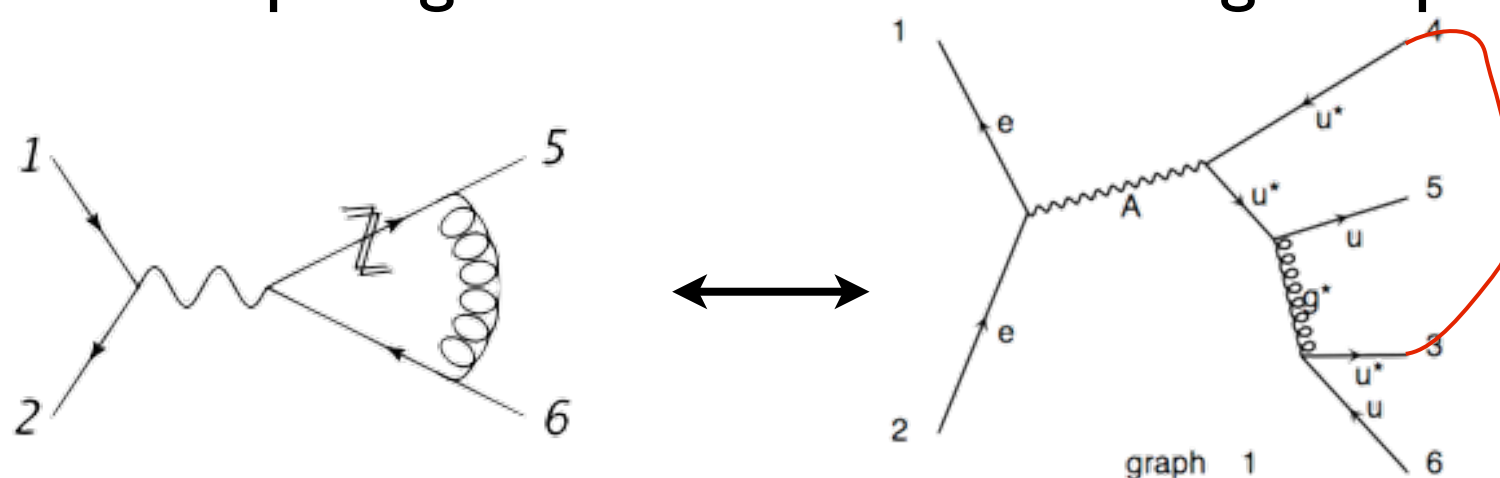
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- **Con**: Can generate only tree-level matrix elements
 - What about the virtuals?
 - Think of loop diagrams as trees with two glued particles



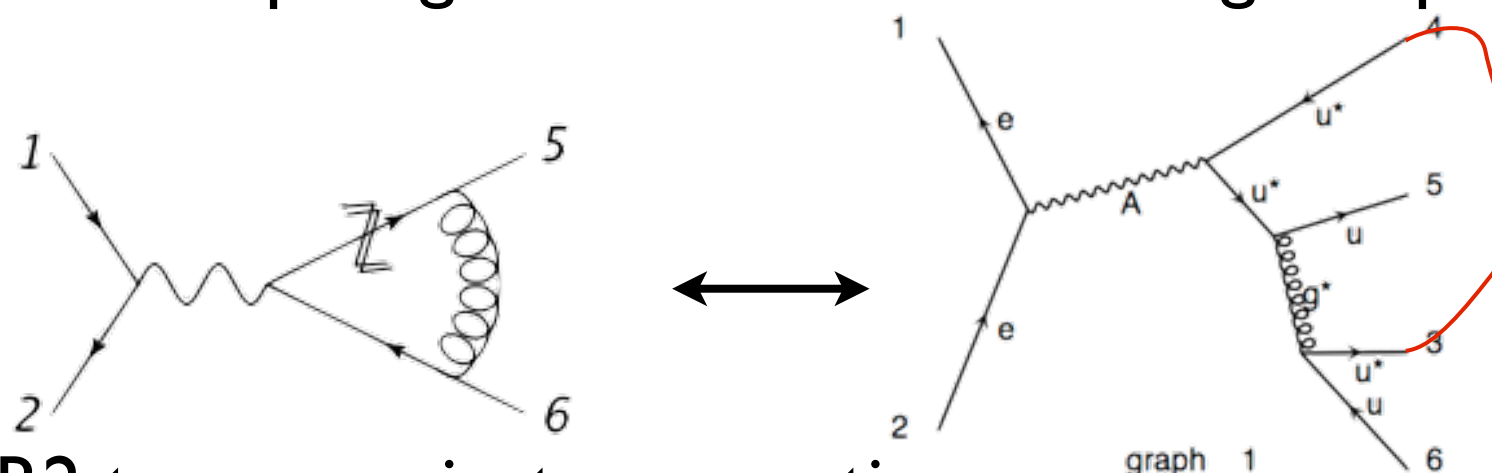
Automation with MadGraph5

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- UV/R2 terms are just new vertices

MadLoop & MadFKS

Hirschi, et al. arXiv:1103.0621

Frederix, Frixione, Maltoni, Stelzer, arXiv:0908.4272

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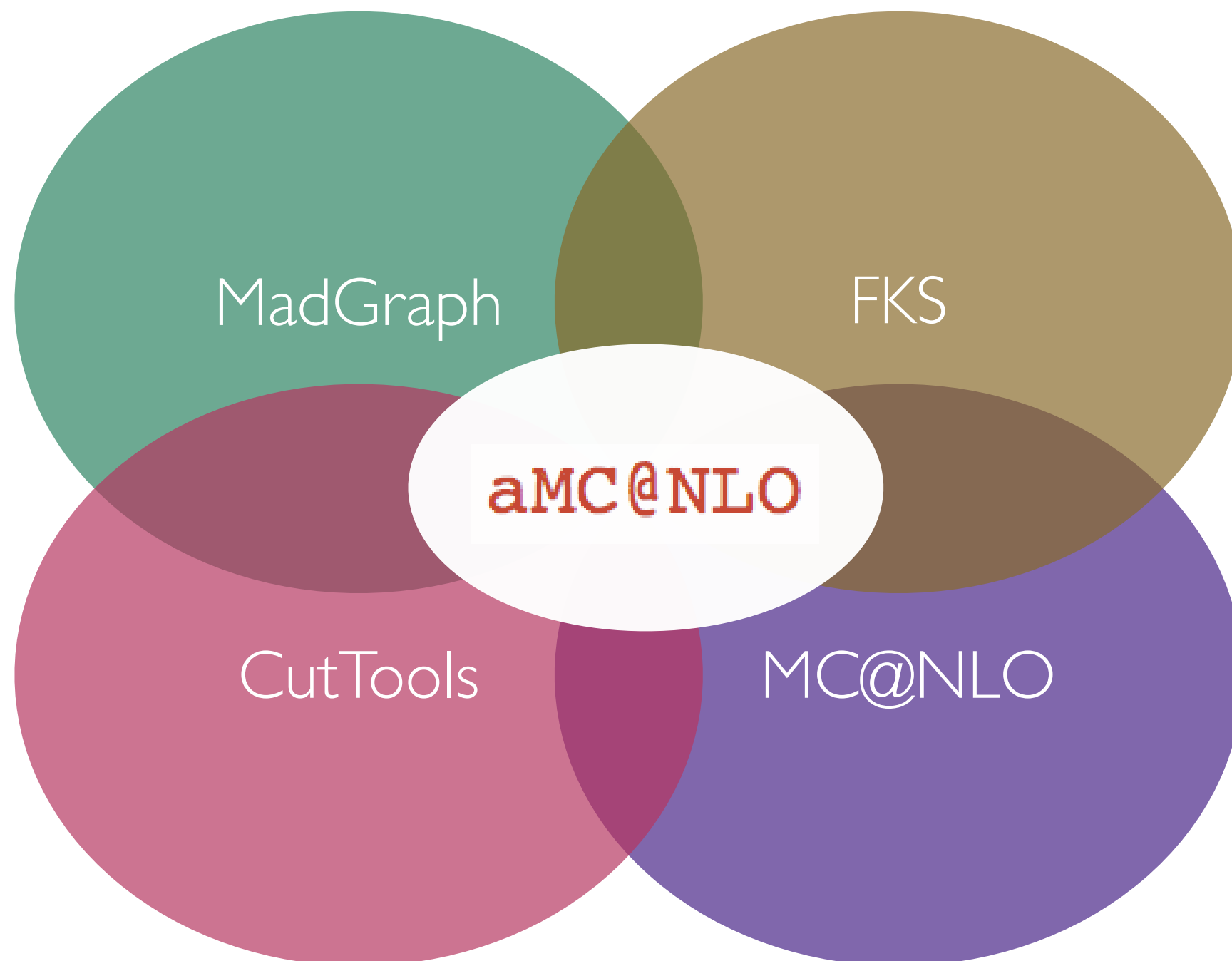
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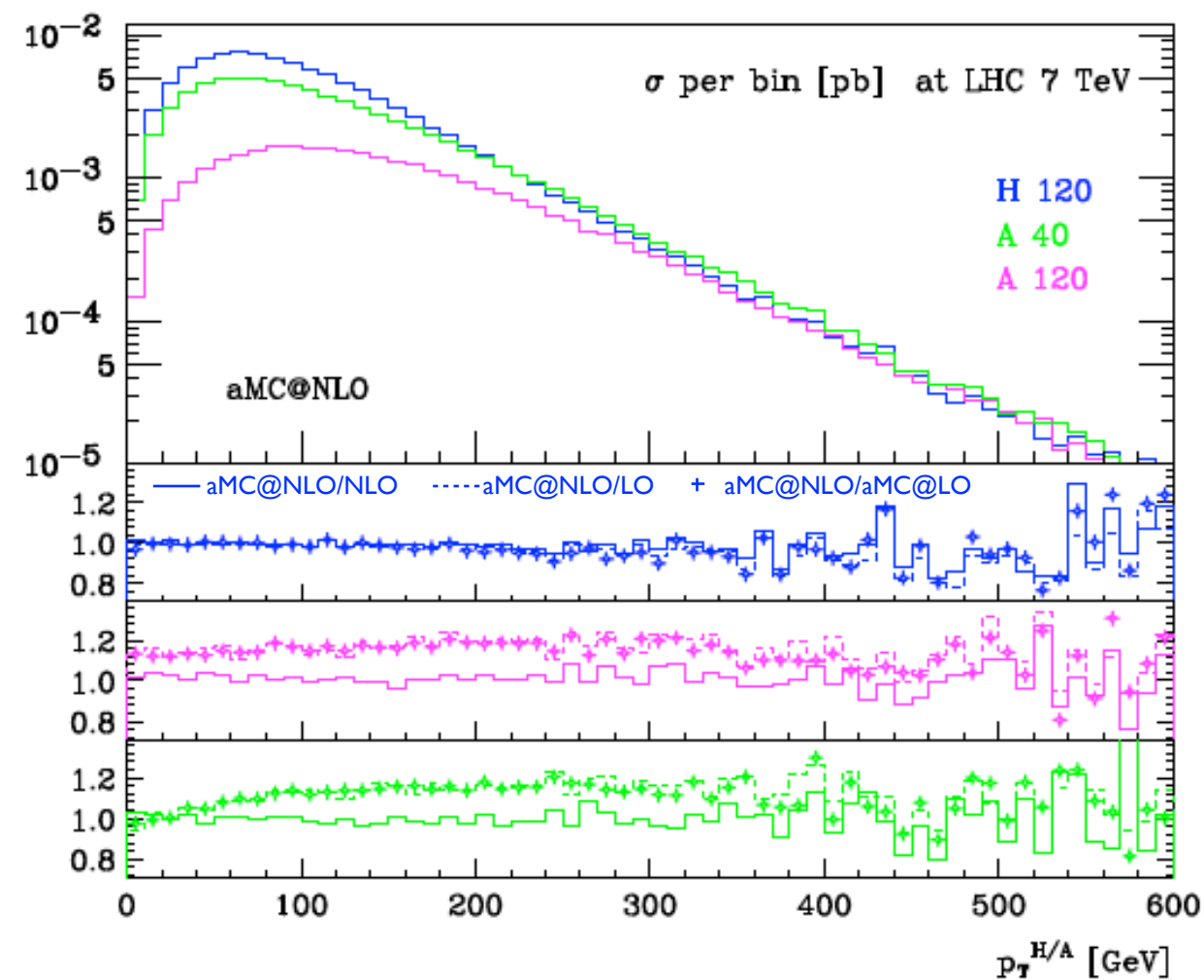
- **MadLoop:**
 - Computes the loop numerator for any given amplitude and feeds it to CutTools
 - Adds R2/UV counterterms (coded as new vertices)
- **MadFKS:**
 - Computes the real and born MEs and counterterms (color- and spin-linked borns)
 - Links the virtuals from MadLoop or via BLHA
 - Organizes the integration of n and $n+1$ body cross-section
 - Generates events to be showered



Physics results (with MG4)

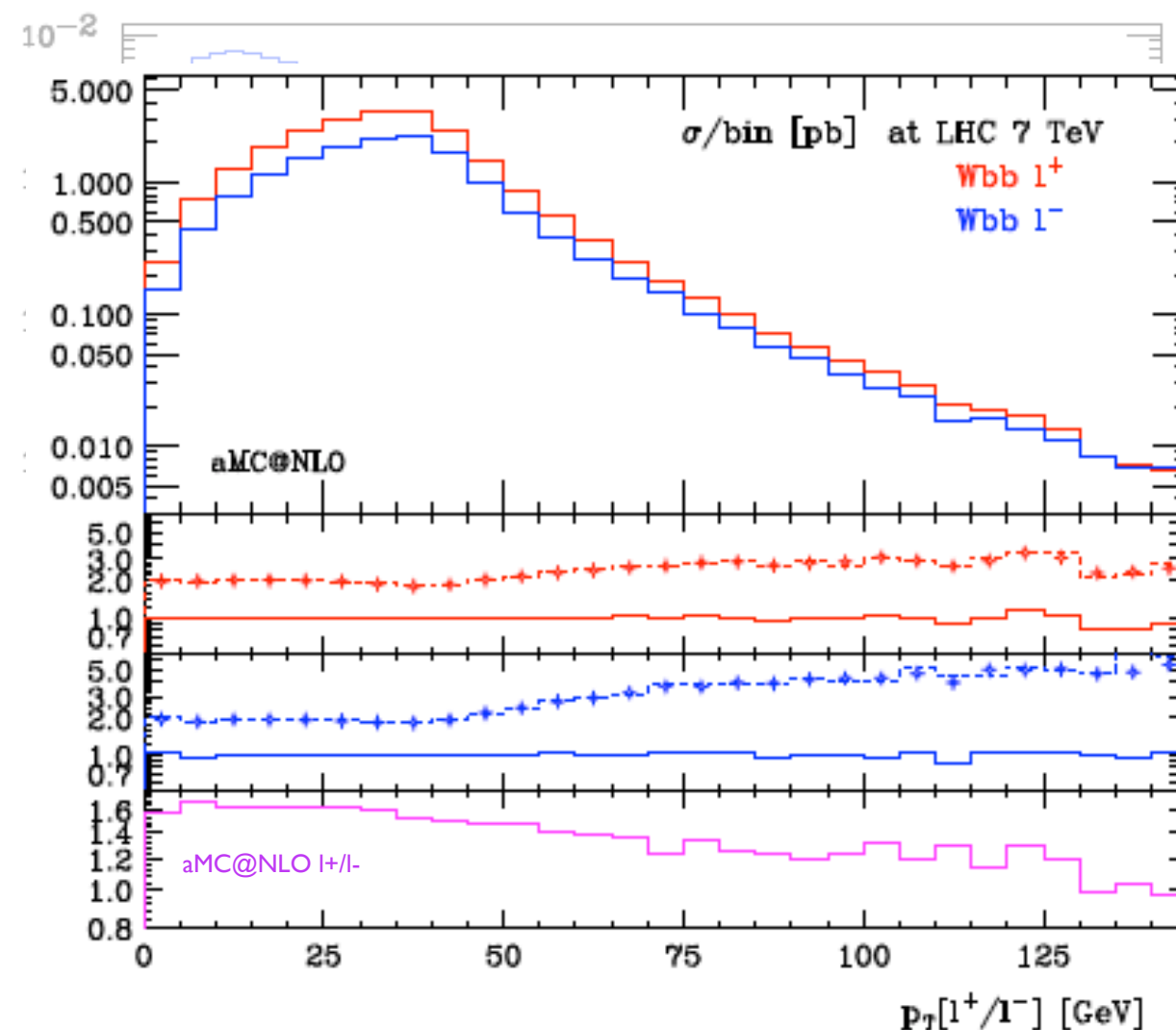
Physics results (with MG4)

- ttH/ttA , arXiv:1104.5613



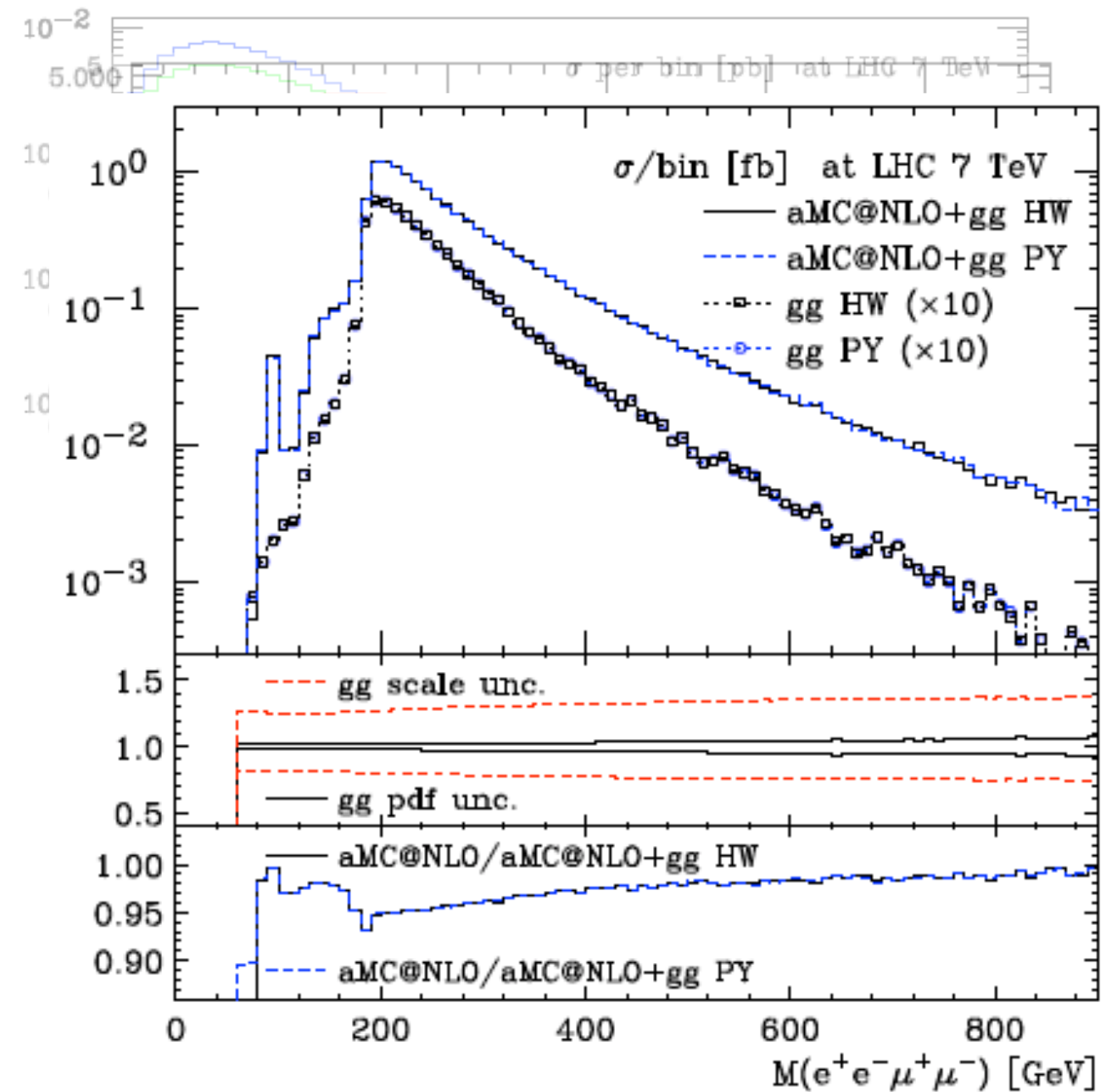
Physics results (with MG4)

- $t\bar{t}H/t\bar{t}A$, arXiv:1104.5613
- Vbb , arXiv:1106.6019



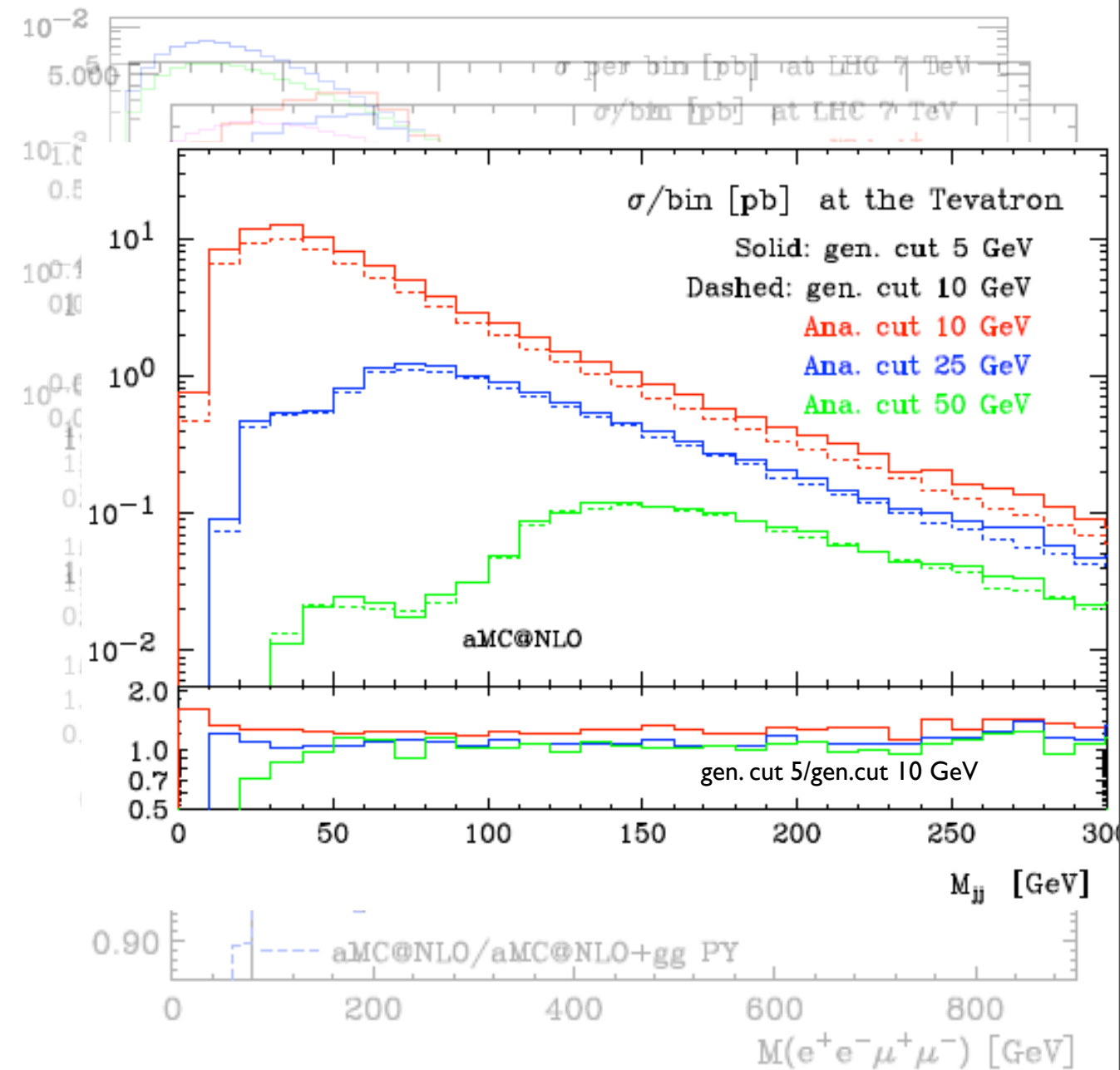
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 - Scales uncertainties included via reweighting
 - Added Pythia counterterms



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- 4 leptons, arXiv:1110.4738
- Scales uncertainties included via reweighting
- Added Pythia counterterms
- Wjj , arXiv:1110.5502



aMC@NLO beta version (in MG5 v2.0)

MadGraph5 project files : MadGraph5

lp MadGraph5 project files : MadG... +

https://launchpad.net/madgraph5/+download

Google

The MadGraph Matrix Element Generator version 5

Overview Code Bugs Blueprints Translations Answers

Download project files

MadGraph5 » MadGraph5 project files

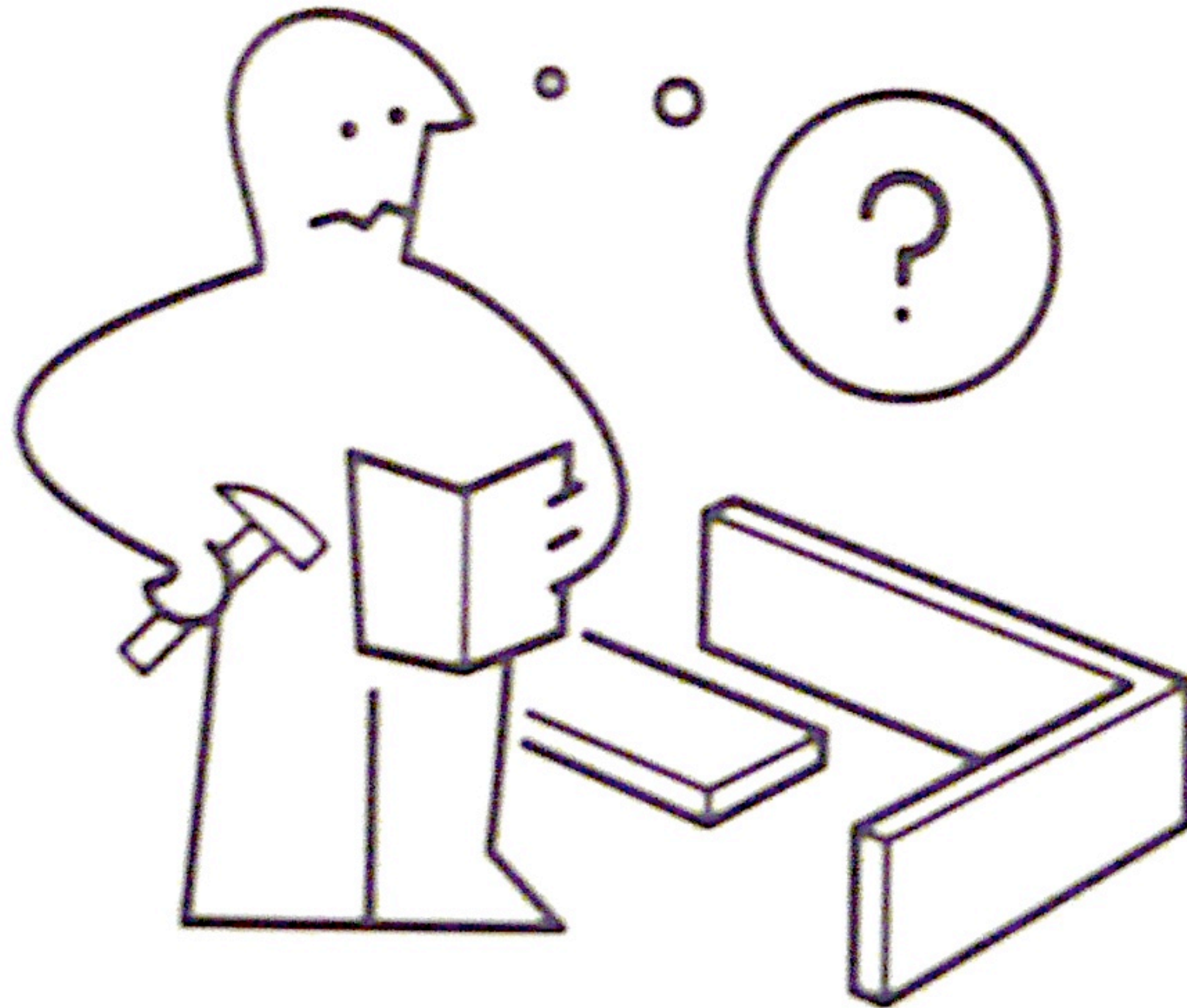
[How do I verify a download?](#)

1.5.0 (beyond HELAS) release from the trunk series released 2012-09-29

Release information

File	Description	Downloads
MadGraph5_v1.5.5.tar.gz (md5, sig)	MadGraph 5 v. 1.5.5	296 last downloaded today
MadGraph5_v2.0.0.beta1.tar.gz (md5)	MG5 v2.0.0.beta1	216 last downloaded today
Total downloads:		512

User friendliness

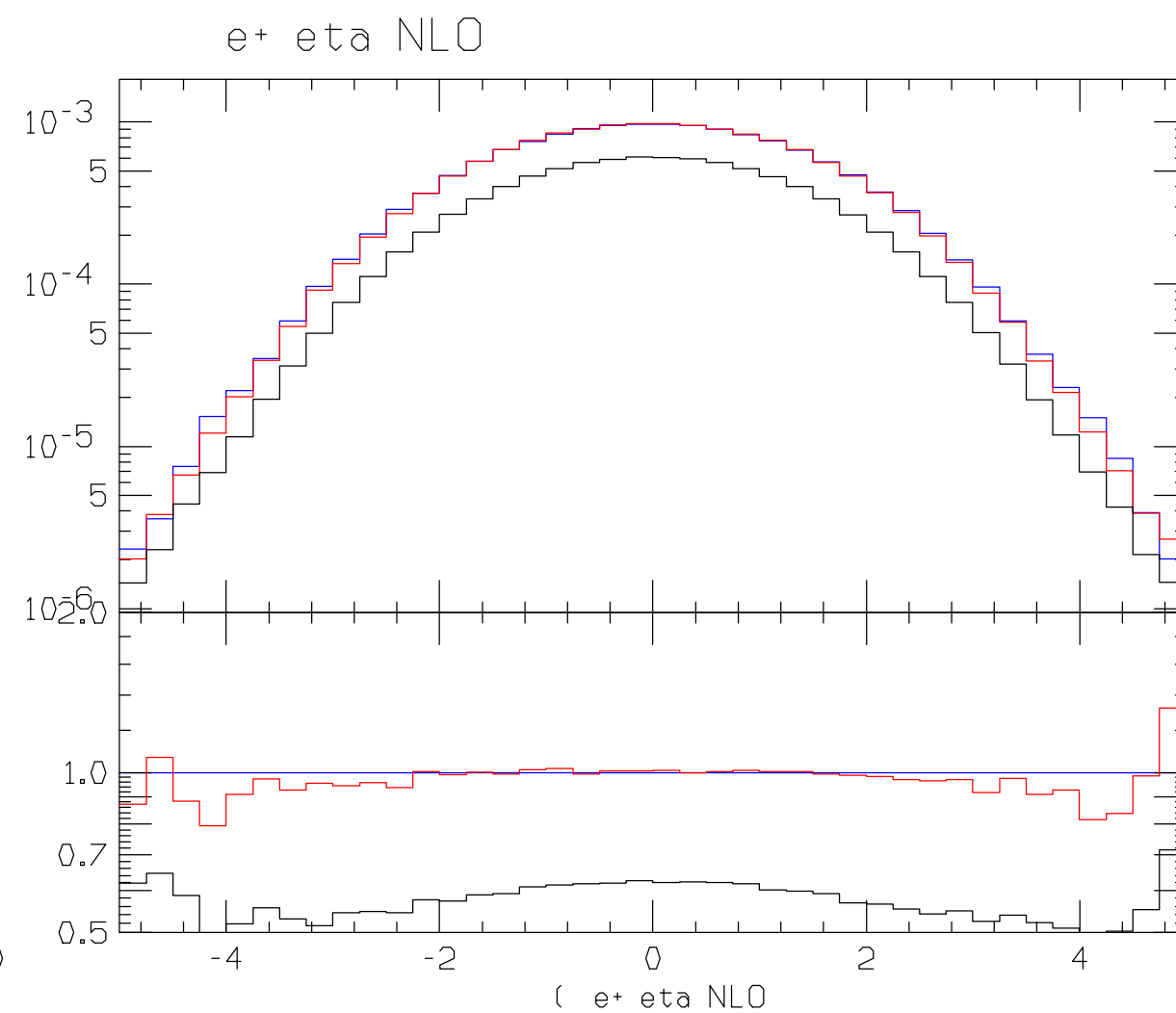
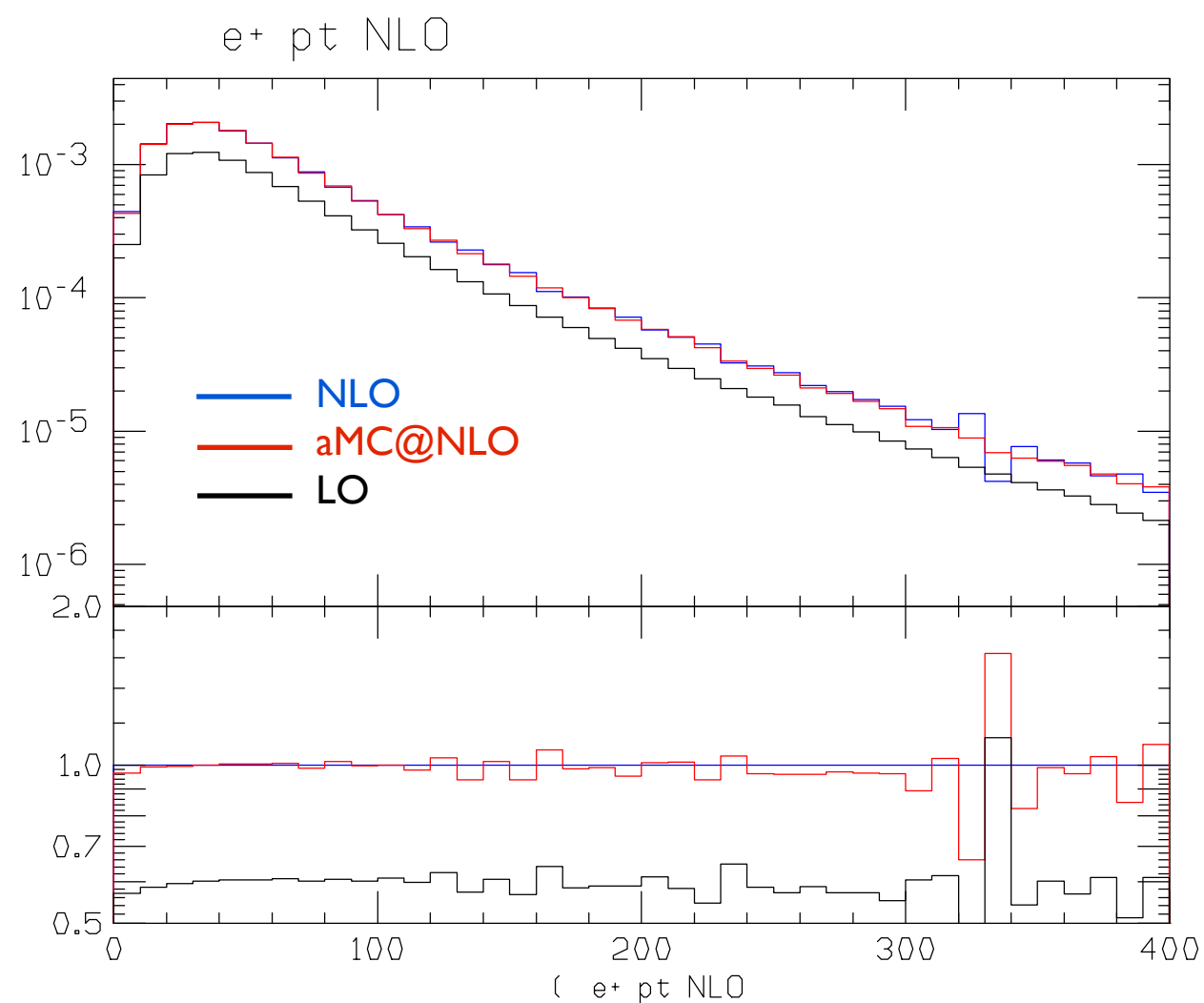


Just a bunch of commands...

```
./bin/mg5  
(> install MCatNLO-utilities)  
> generate p p > t t~ w+ [QCD]  
> output myppttw  
> launch
```

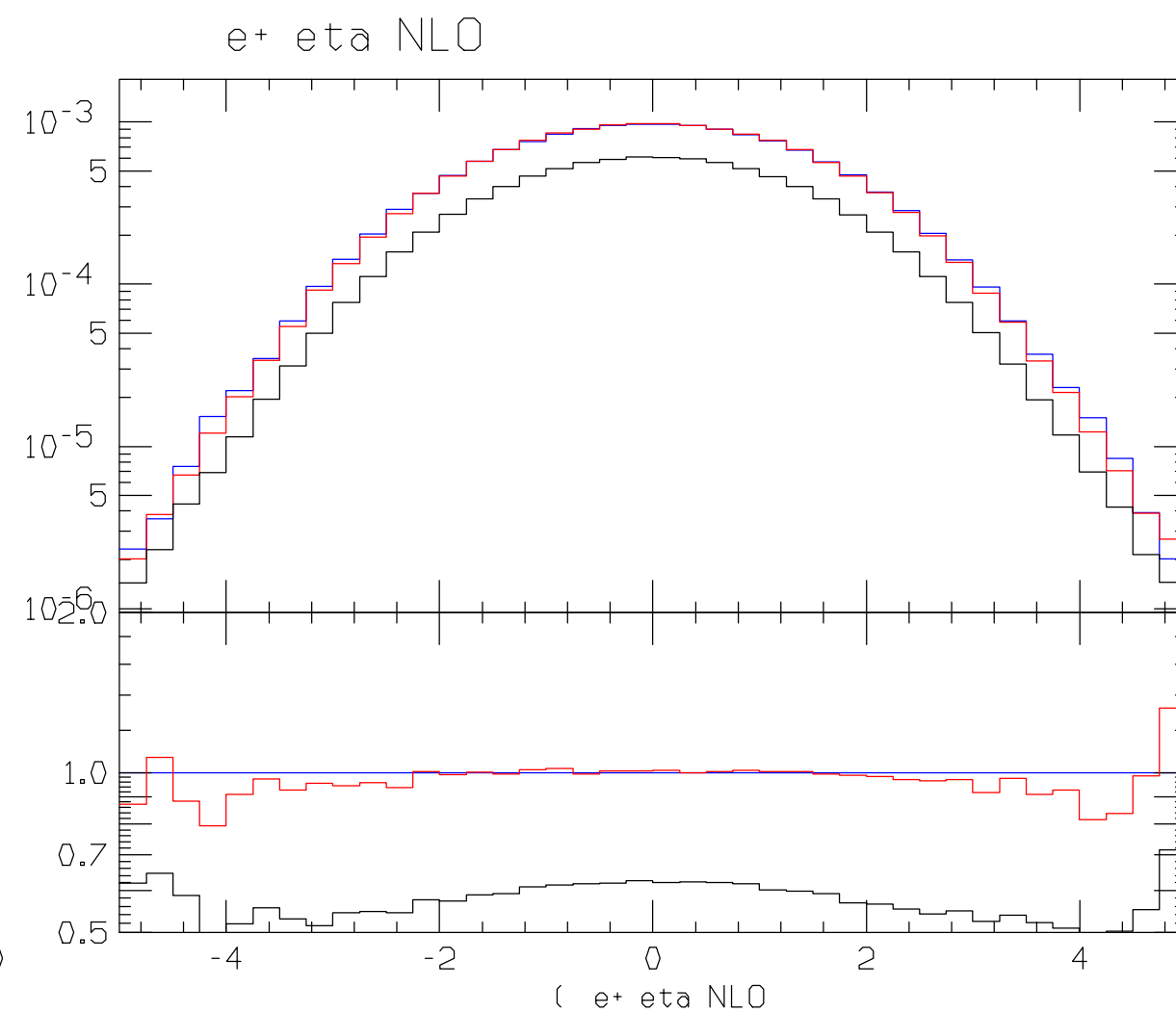
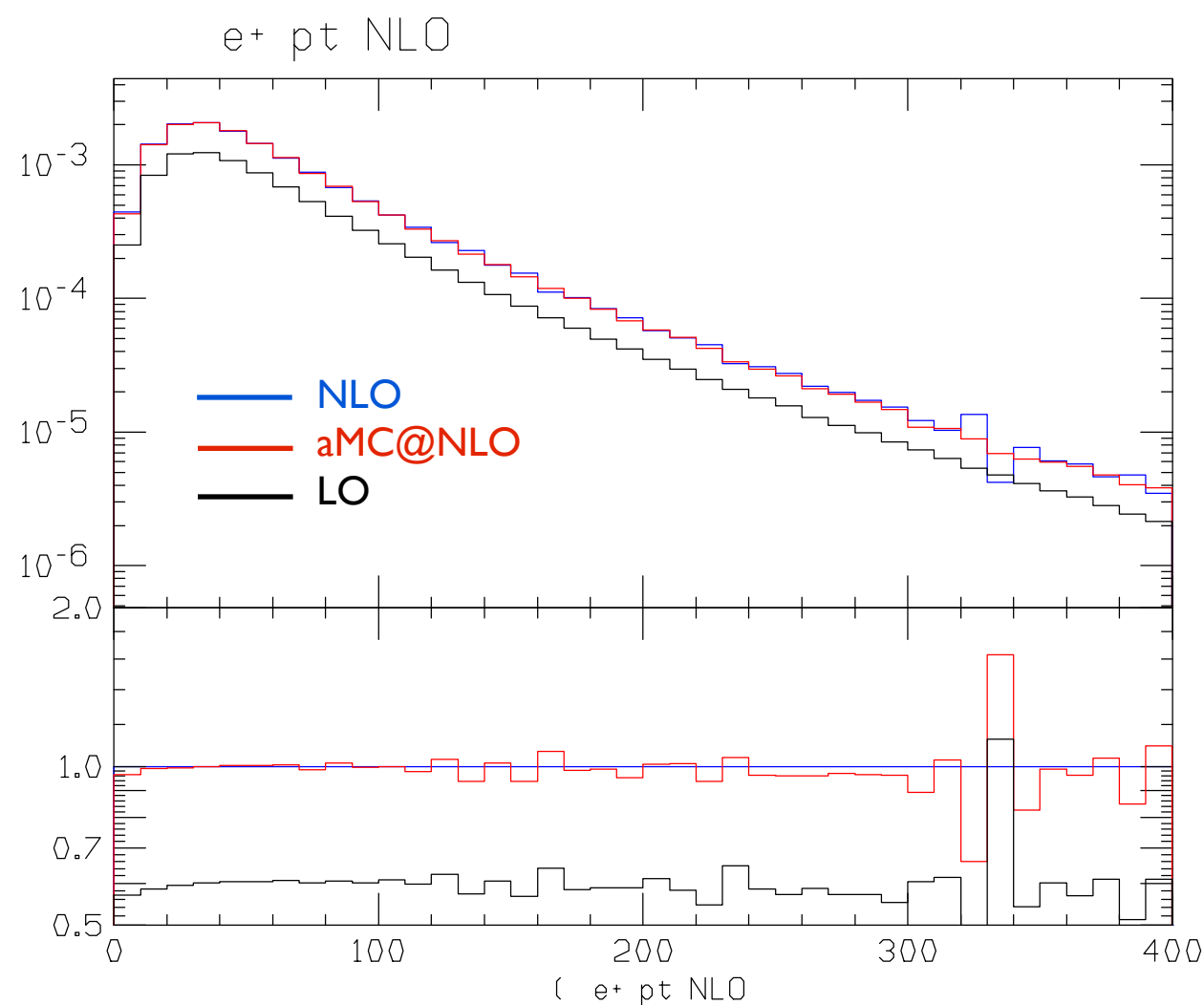
There we go!

e^+ from W decay



There we go!

e^+ from W decay



Integration/event generation and analyse
made in < 1 day!

Applications...



Applications...



Higgs Physics (I): Spin/CP studies

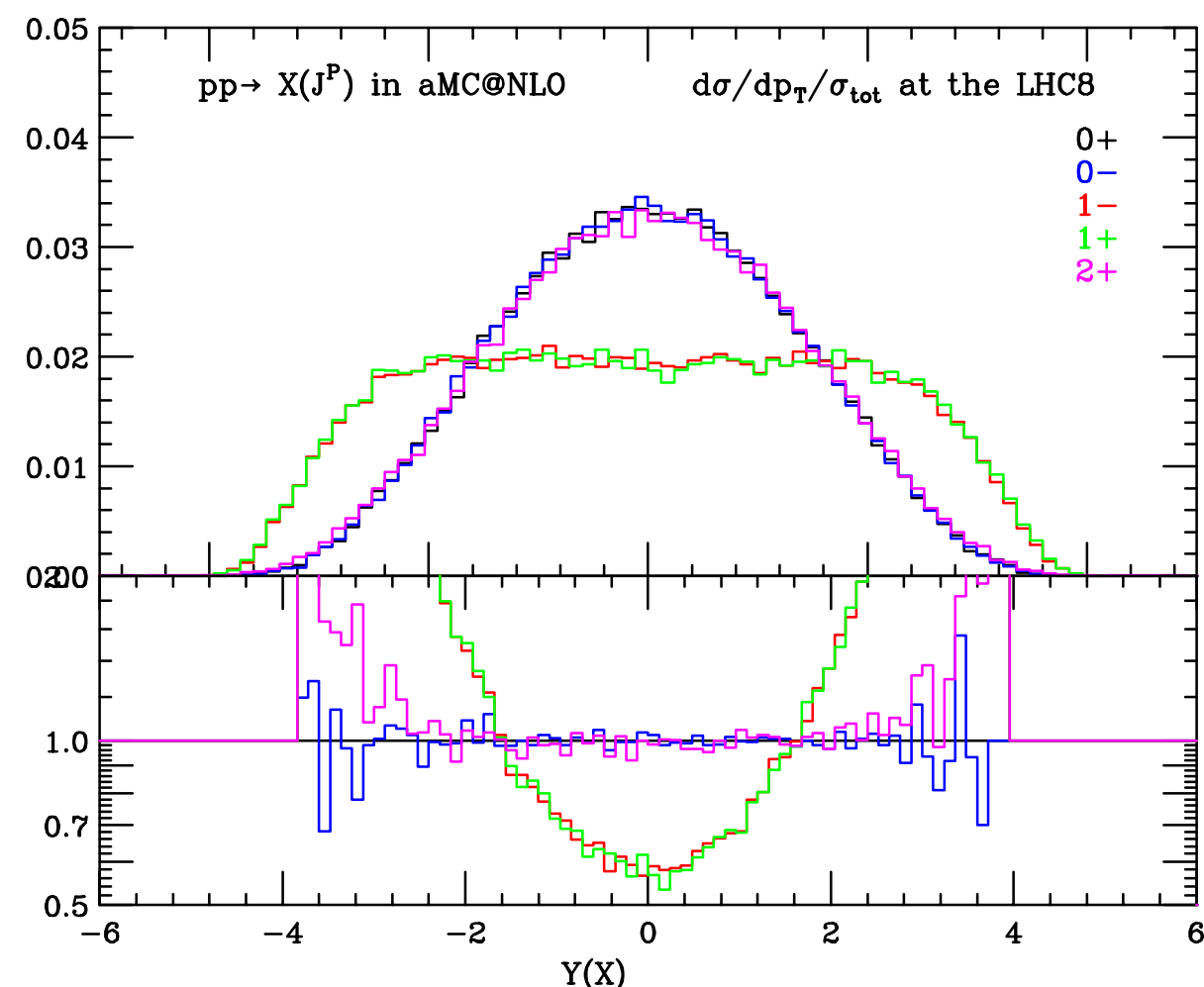
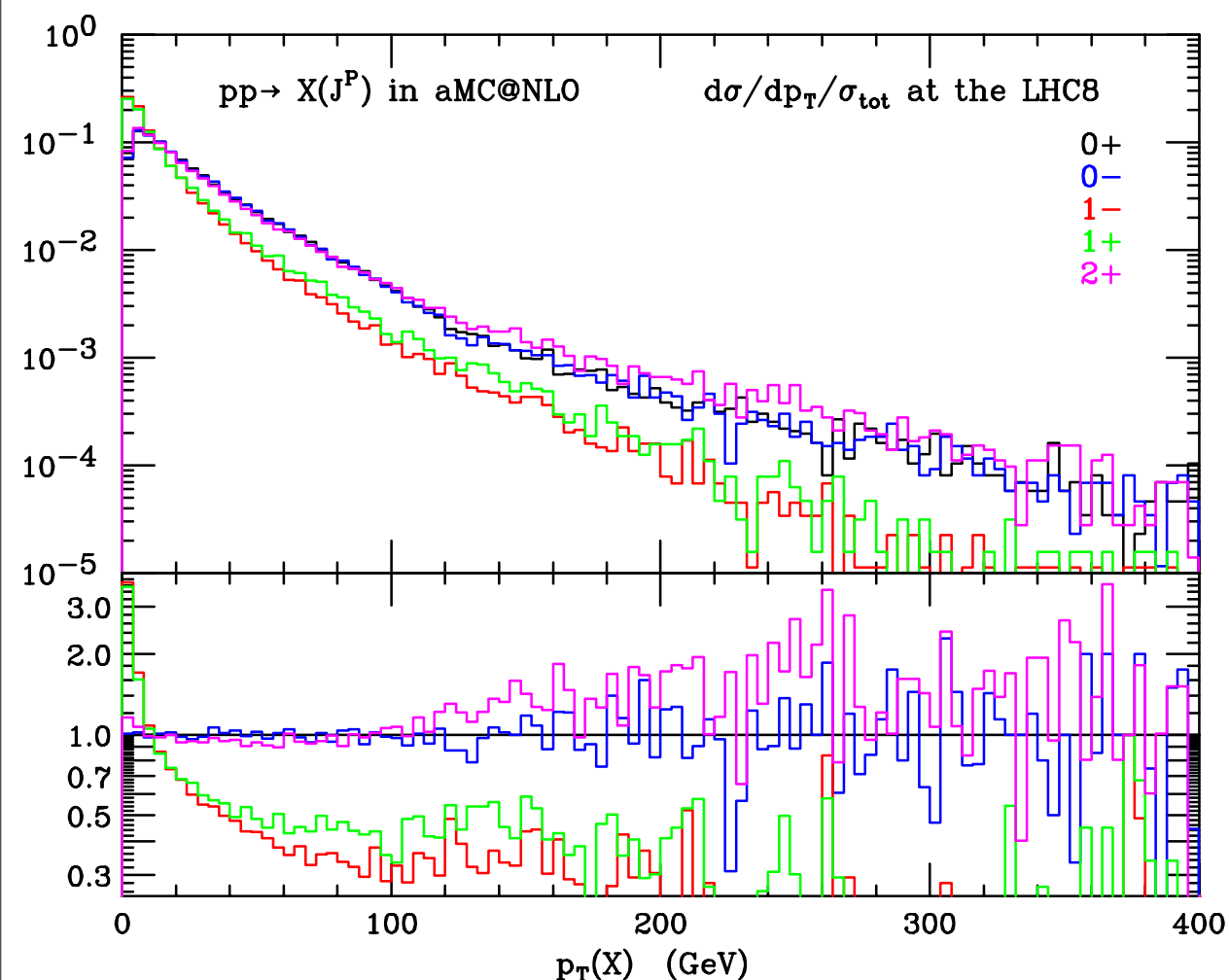
In collaboration with:

P.Artoisenet, P. de Aquino, R. Frederix, F. Maltoni, M.K. Mandal, P. Mathews, V. Ravindran, S. Seth, P.Torrielli

- Spin / CP properties of the new resonance have to be determined
- This can be done automatically with MG5 / aMC@NLO
- Strategy:
 - Study $0^+ 0^- 1^+ 1^- 2^+$ final states ($2 \Rightarrow 1$) both with aMC@NLO and MLM-matched LO
 - Use aMC@NLO to validate LO sample
 - Check observables related to X
 - Use LO to study decay correlations
- Plots from Fabio's slides at 'Higgs mini-workshop' and HC2012

Higgs Physics (I): Spin/CP studies

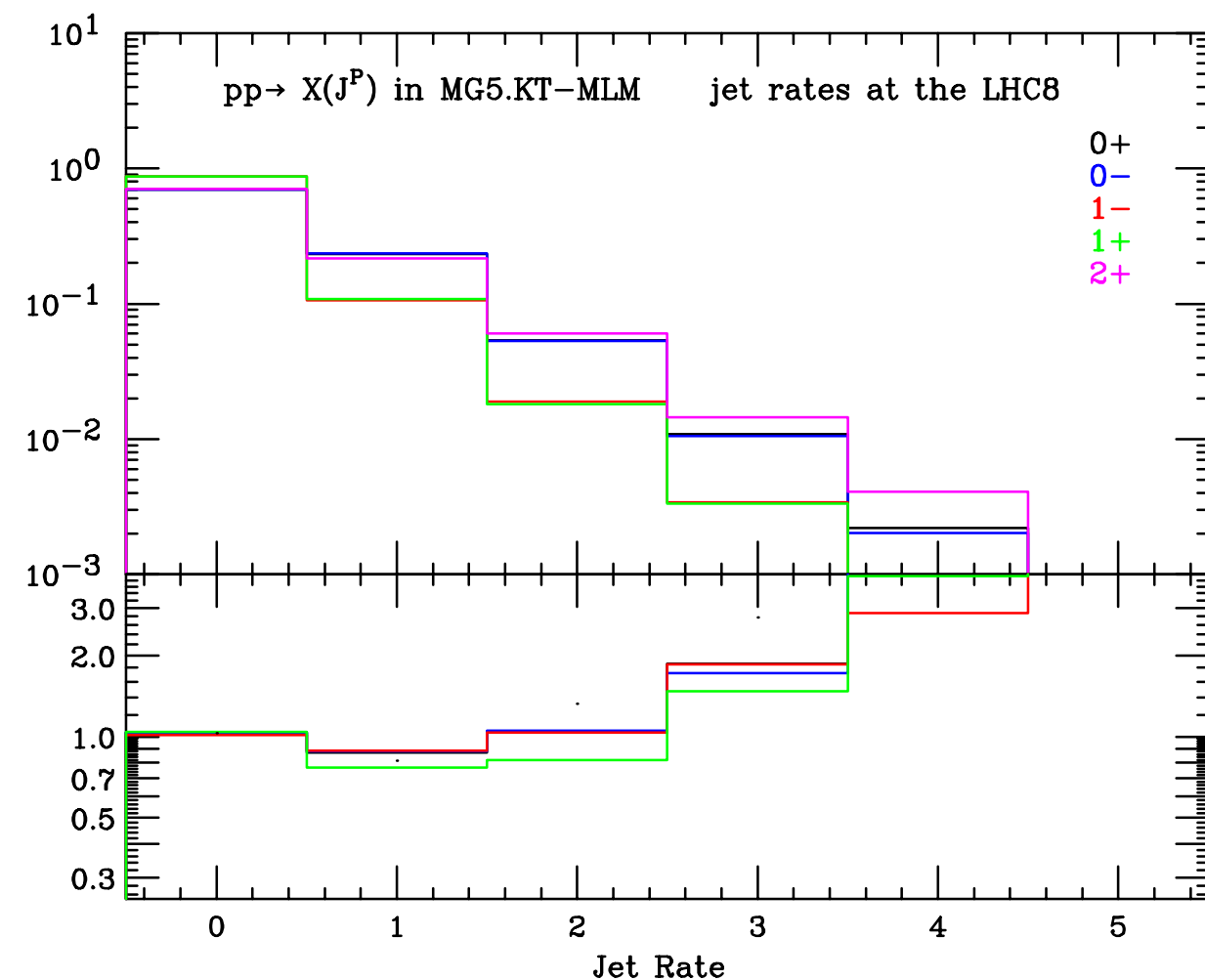
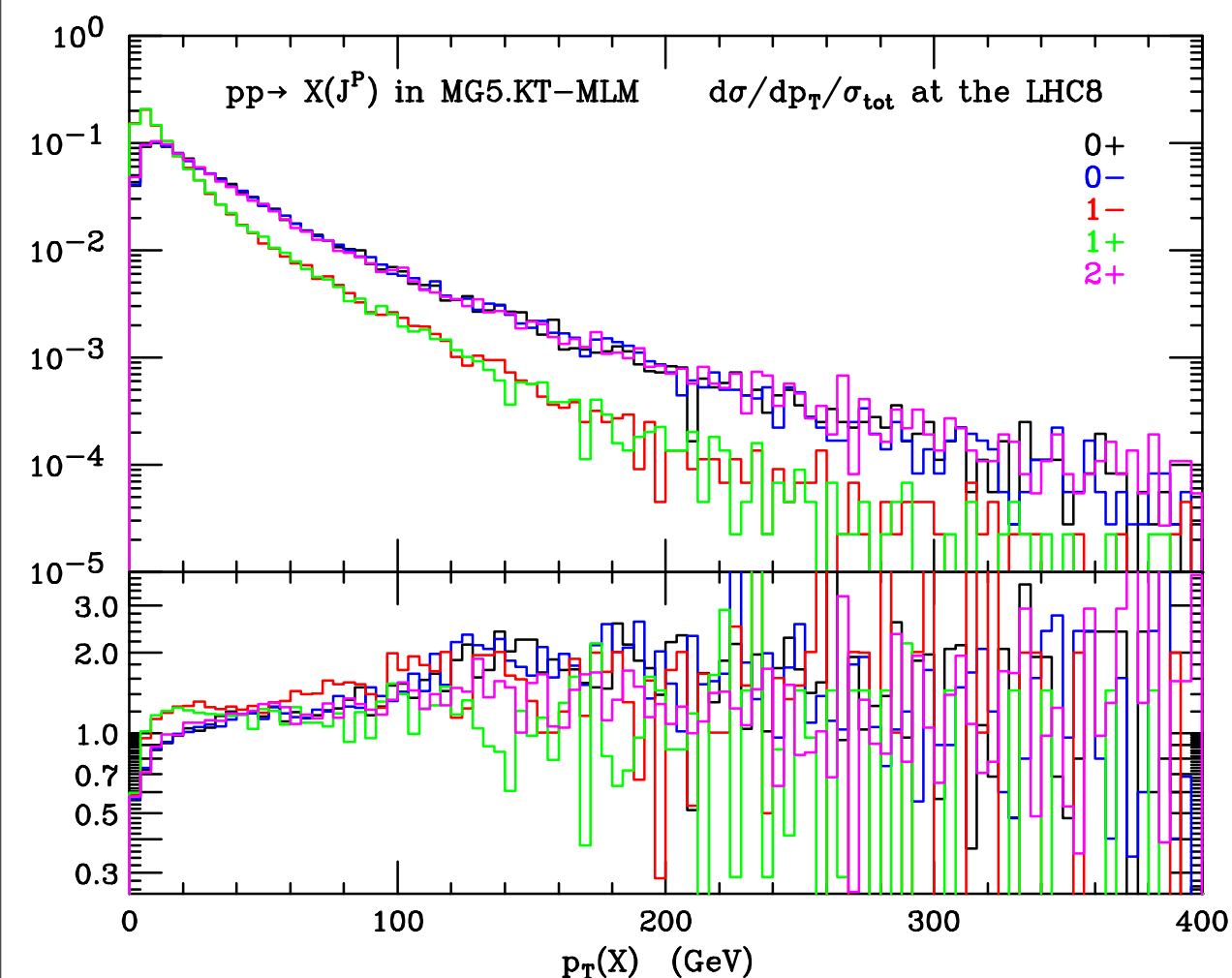
Resonance P_t/Y



Differences between 0-2 and 1 mainly driven
by different initial states

Higgs Physics (I): Spin/CP studies

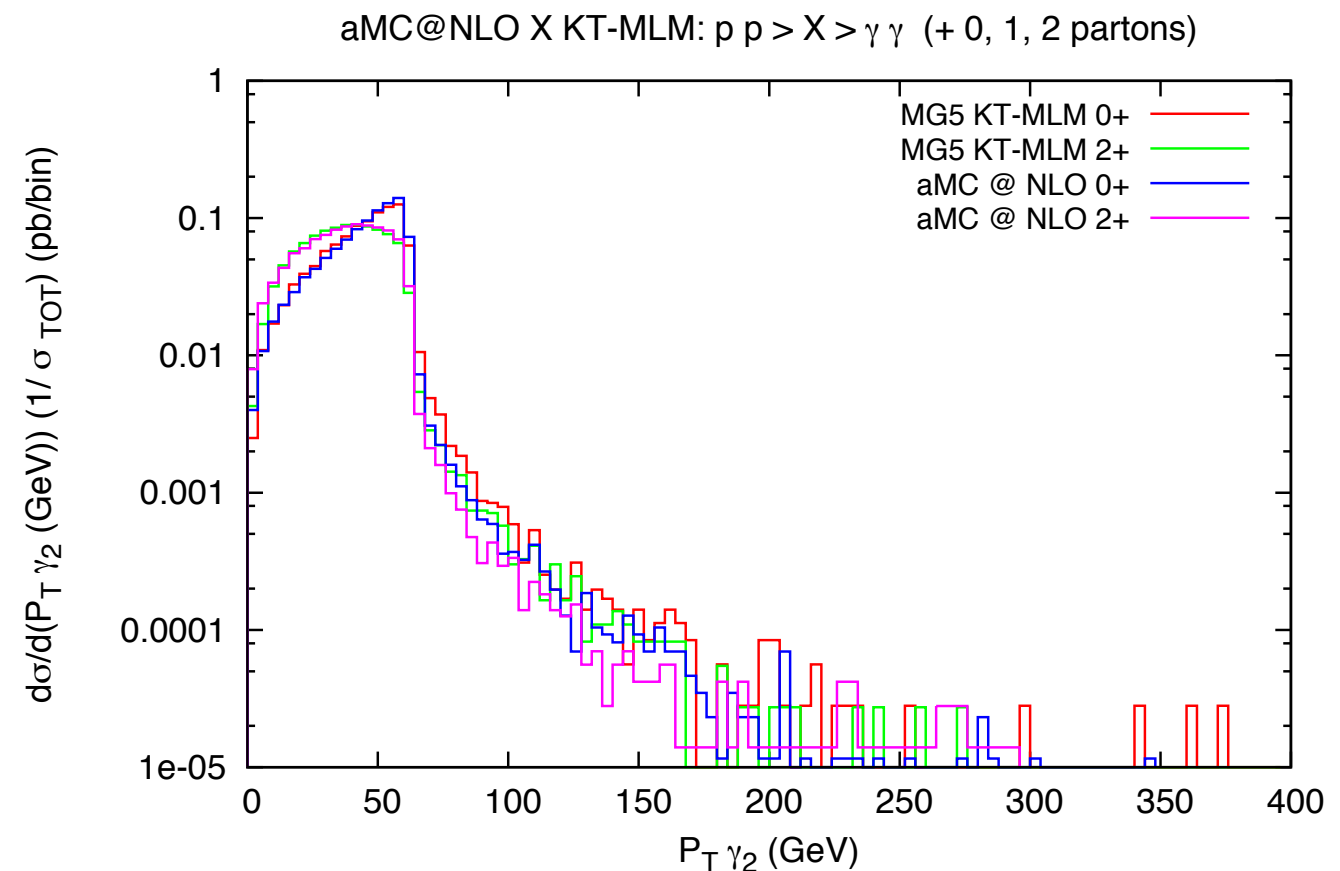
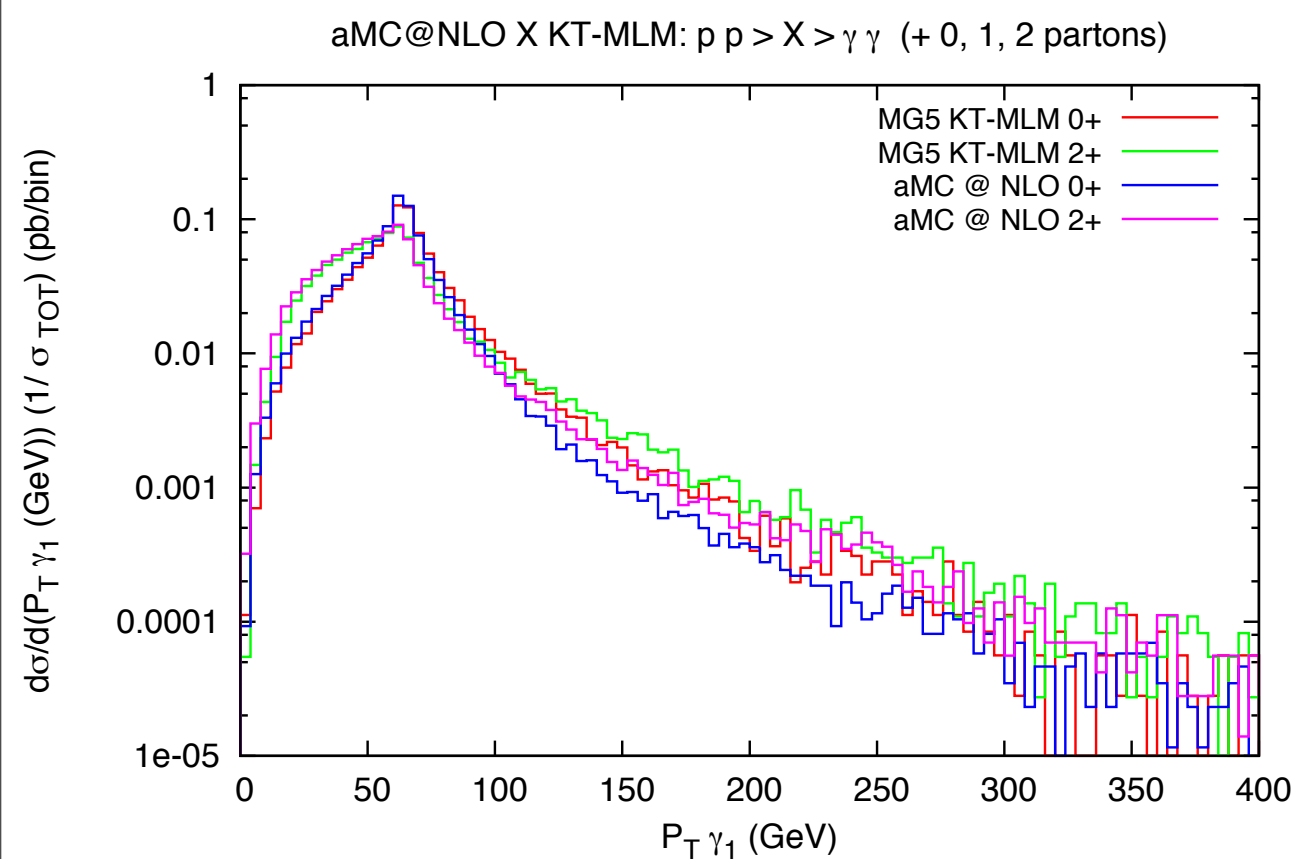
Matched samples, ratios/aMC@NLO (lower inlays)



Matched samples are harder (as they should be)

Higgs Physics (I): Spin/CP studies

Photons P_T (0+, 2+ only)



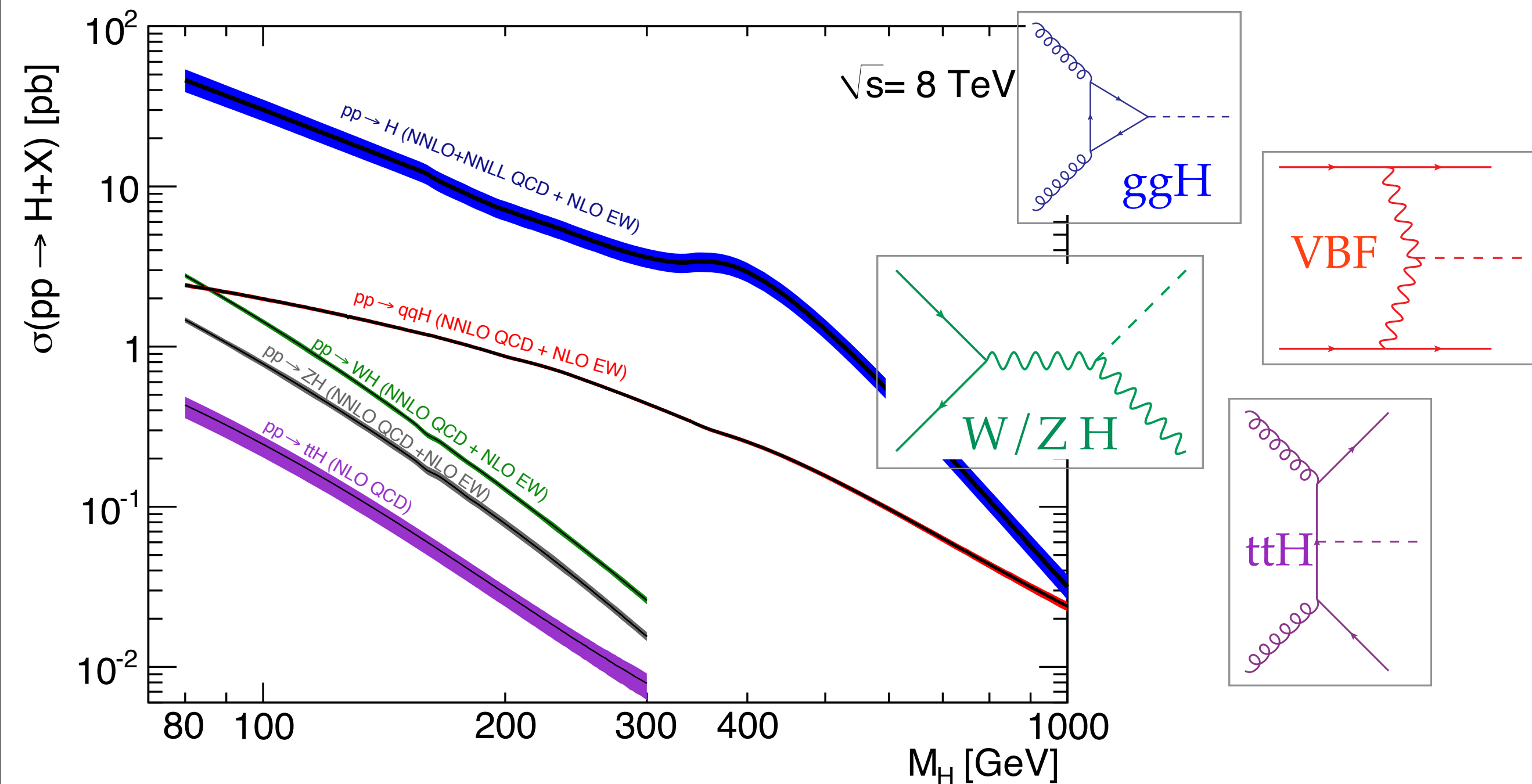
Nice difference between spin 0 and spin 2
Nice agreement between MLM and aMC@NLO

Higgs Physics (I): Spin/CP studies

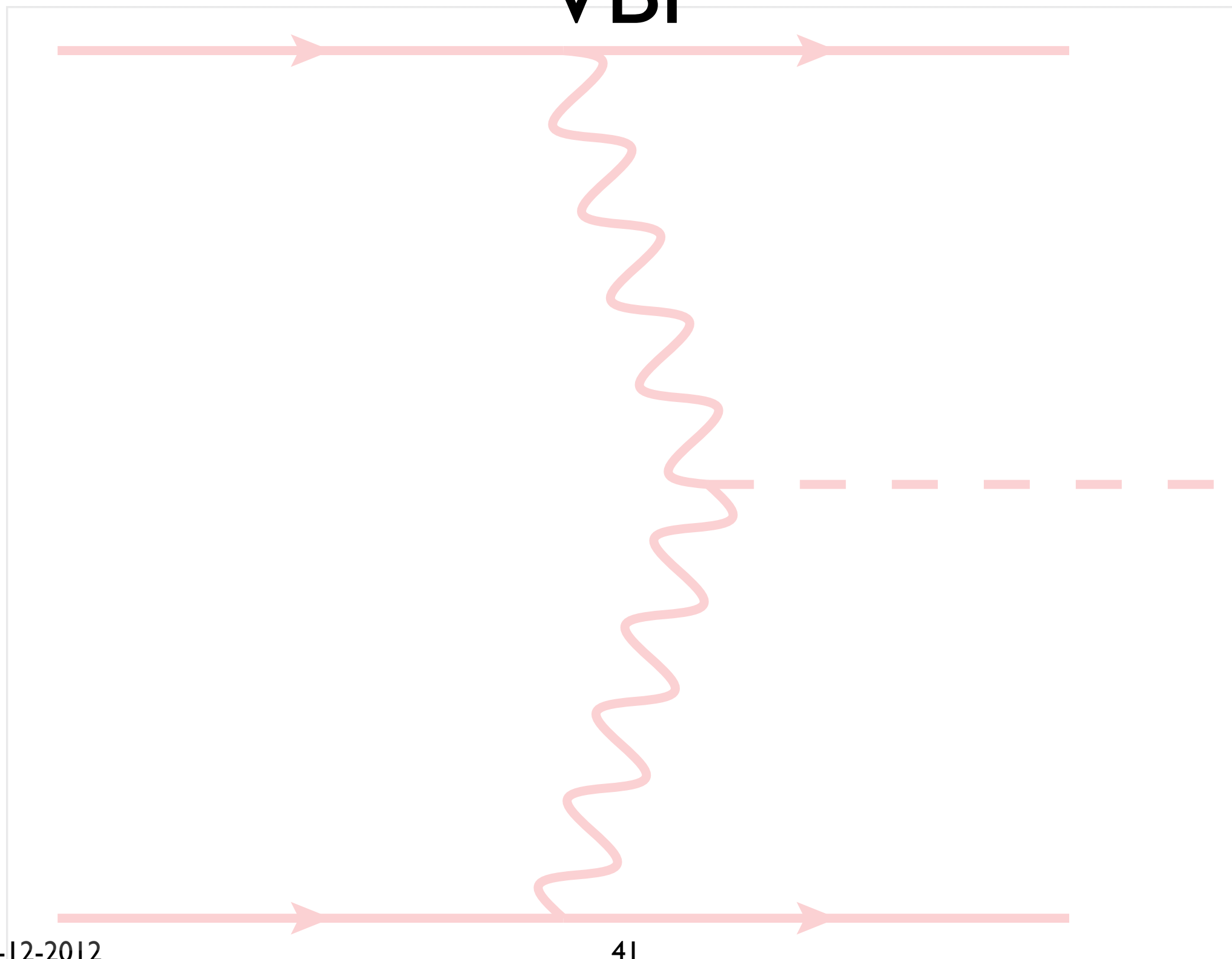
- Codes available at <http://amcatnlo.cern.ch>

Process	Codes	Plots	Extra info
Higgs characterization. Comparison plots: pt of the "Higgs" rapidity of the "Higgs" jet rates			
$pp \rightarrow 0^+ + X$	Code	aMC@NLO+Pythia aMC@NLO+Herwig	Virtuals coded by hand by R. Frederix and M. Zaro from the known analytic results. Scalar resonance. Process generated in the HEFT model
$pp \rightarrow 0^- + X$	Code	aMC@NLO+Pythia aMC@NLO+Herwig	Virtuals coded by hand by R. Frederix and M. Zaro from the known analytic results. Pseudo scalar resonance. Process generated in the HEFT model
$pp \rightarrow 1^- + X$	Code	aMC@NLO+Pythia aMC@NLO+Herwig	Fully automatic in aMC@NLO. Vector resonance (Obtained from the Z using only vector coupling to quarks).
$pp \rightarrow 1^+ + X$	Code	aMC@NLO+Pythia aMC@NLO+Herwig	Fully automatic in aMC@NLO. Pseudo vector resonance (Obtained from the Z using only axial coupling to quarks).
$pp \rightarrow (2^+ \rightarrow \gamma\gamma) + X$	Code	aMC@NLO+Pythia aMC@NLO+Herwig	Virtuals Provided by Frederix et al. arXiv:1209.6527 Code generated using the RS model. Spin 2 (graviton like)
More to come soon...			

Higgs Physics (II): VBF

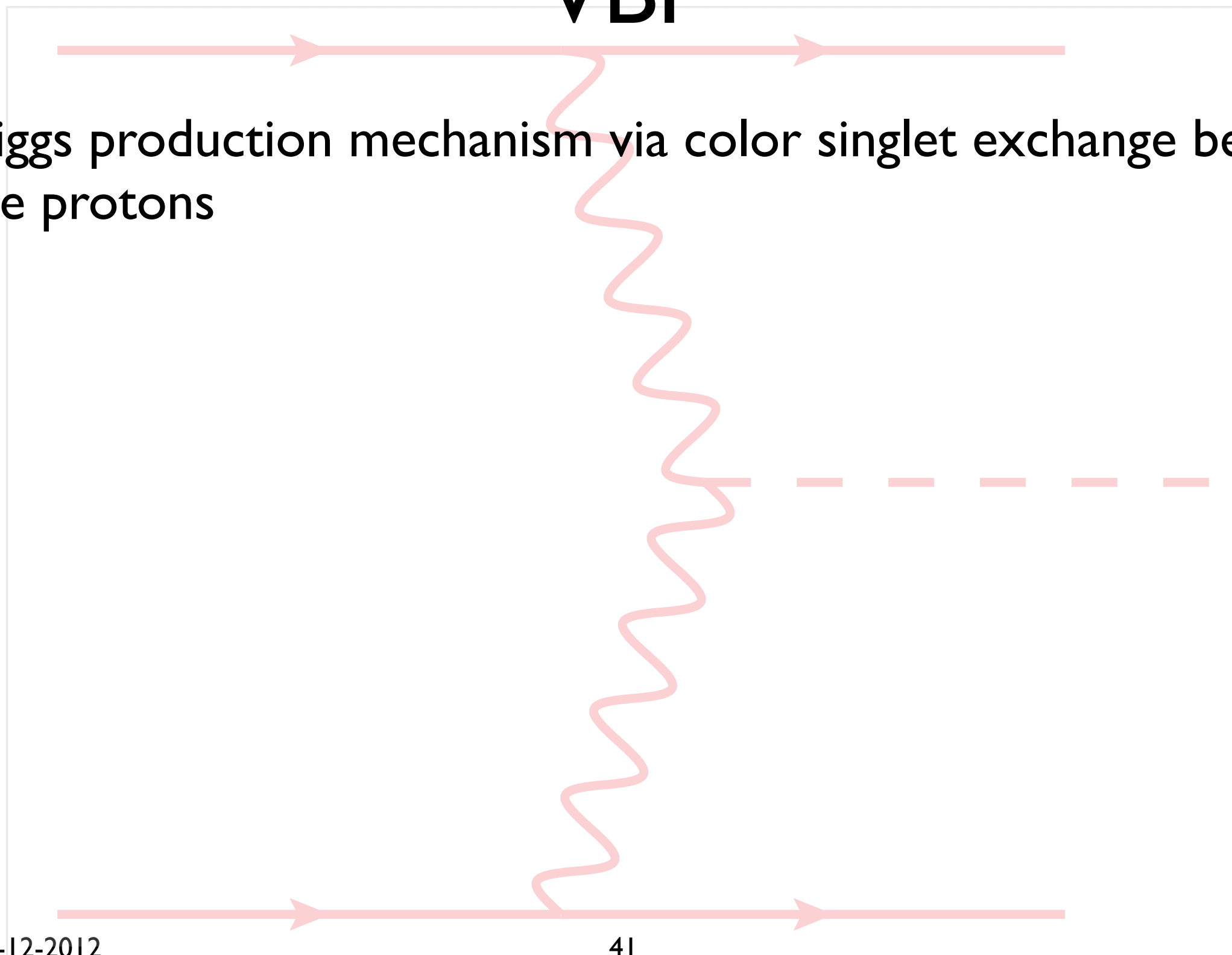


Higgs Physics (II): VBF



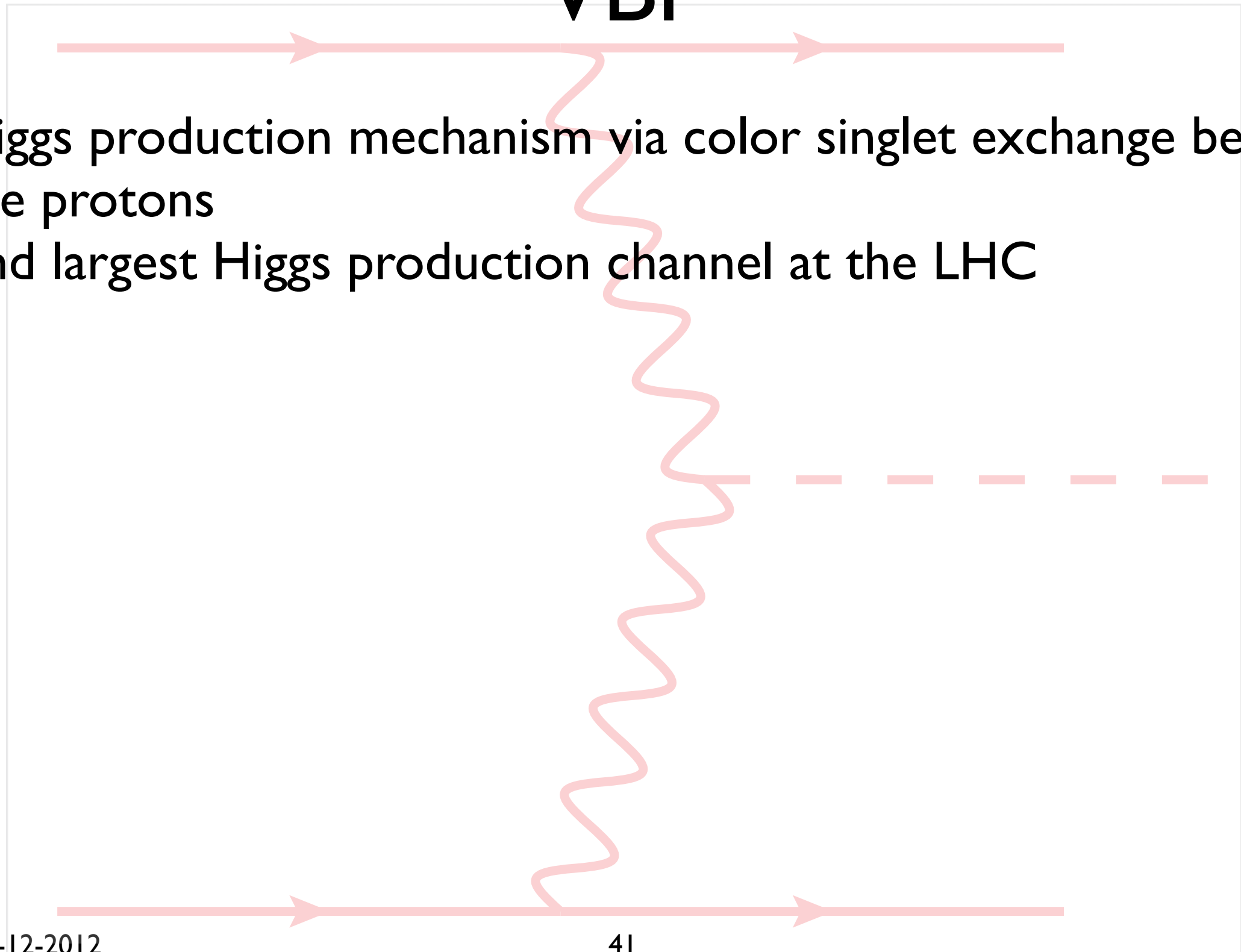
Higgs Physics (II): VBF

- Higgs production mechanism via color singlet exchange between the protons



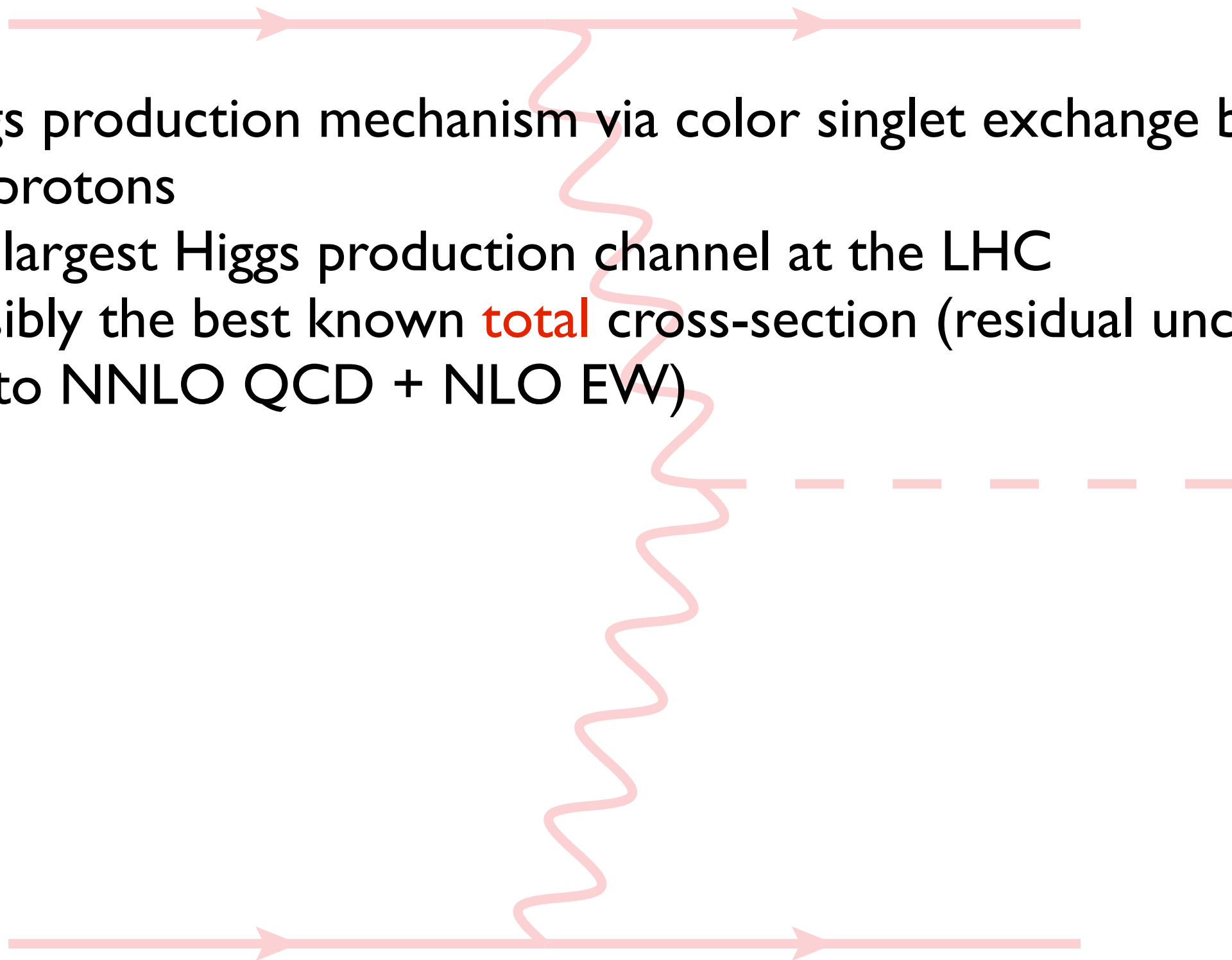
Higgs Physics (II): VBF

- Higgs production mechanism via color singlet exchange between the protons
- 2nd largest Higgs production channel at the LHC

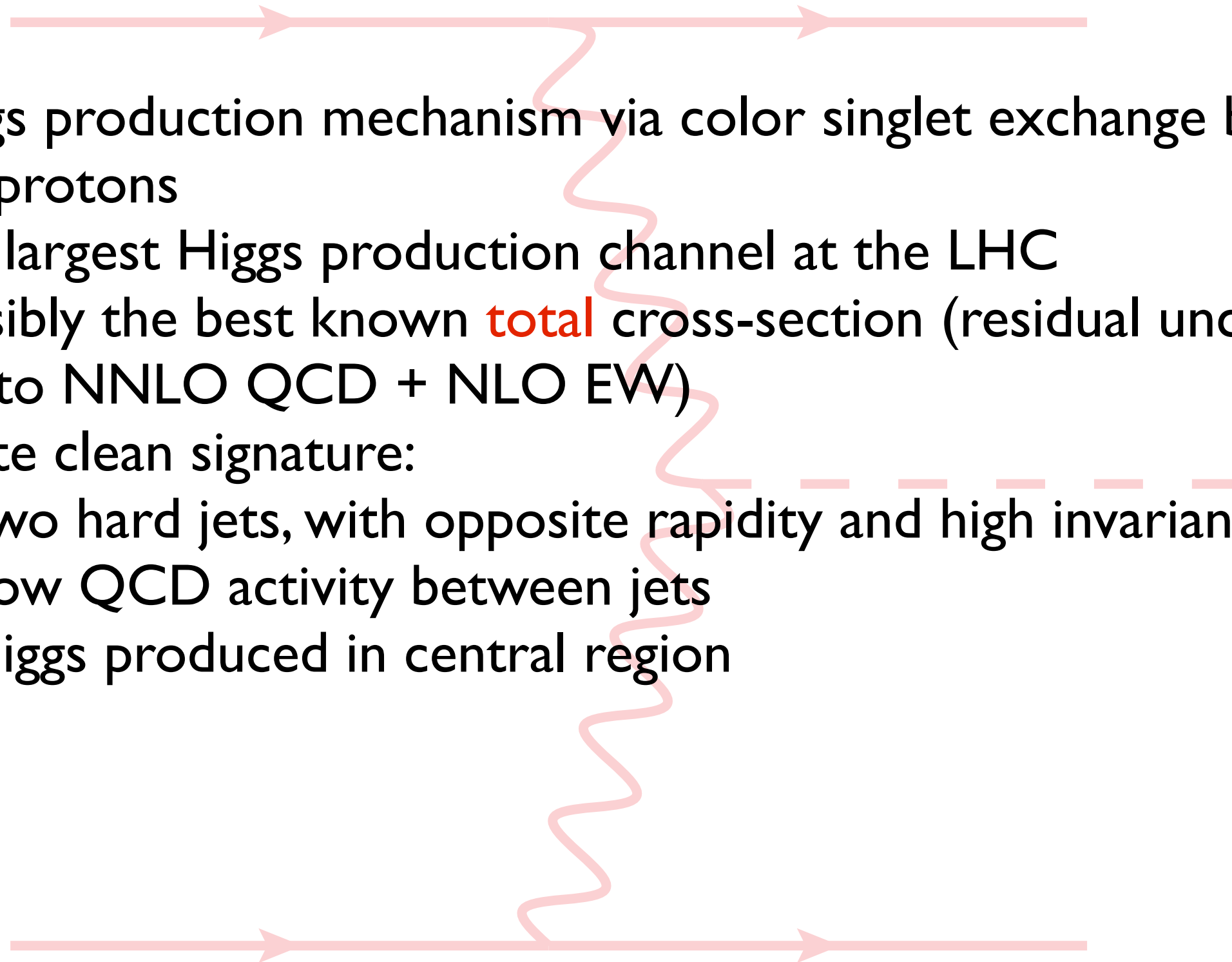


Higgs Physics (II): VBF

- Higgs production mechanism via color singlet exchange between the protons
- 2nd largest Higgs production channel at the LHC
- Possibly the best known **total** cross-section (residual unc. $\sim 2\%$) (up to NNLO QCD + NLO EW)

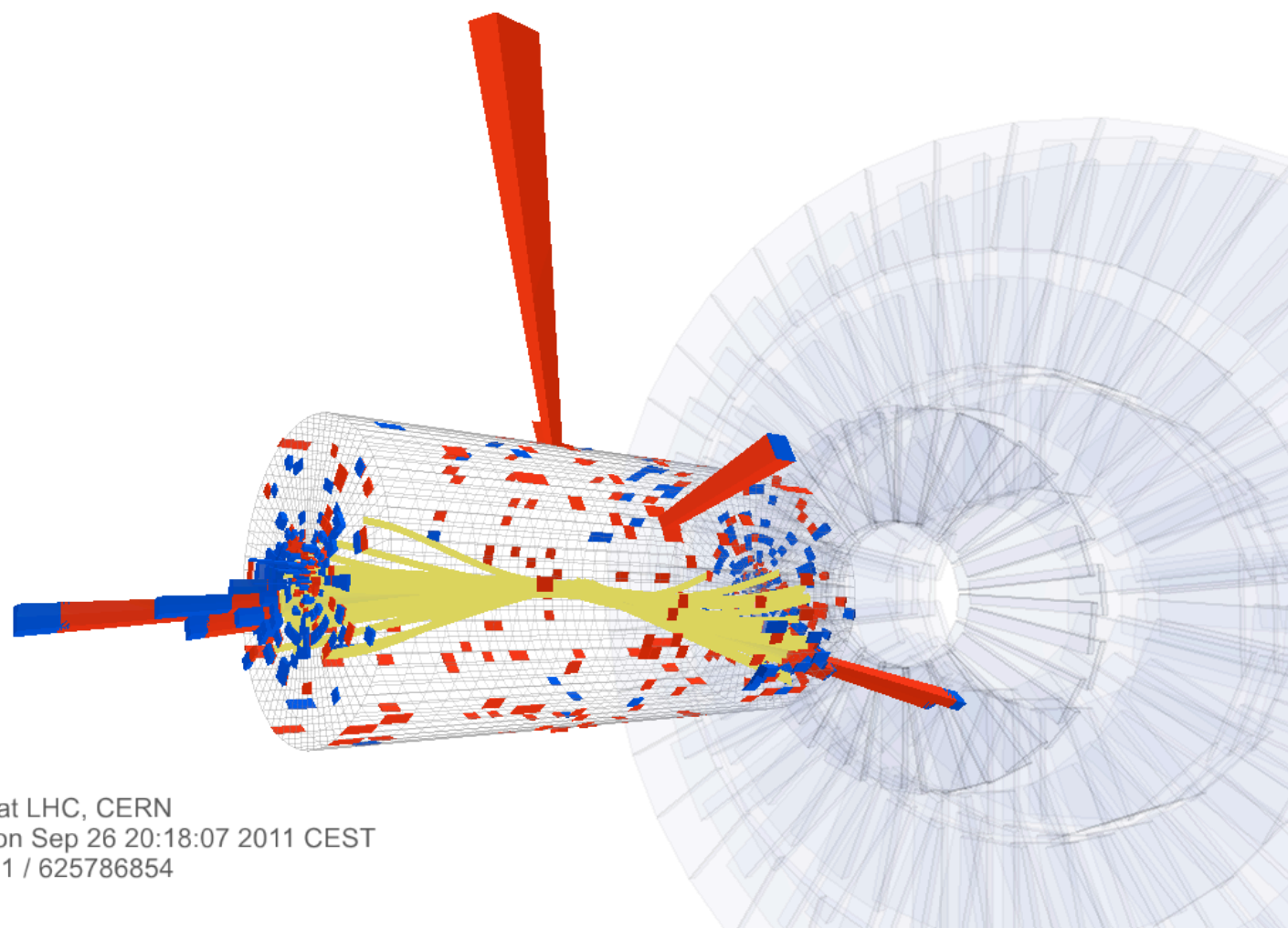
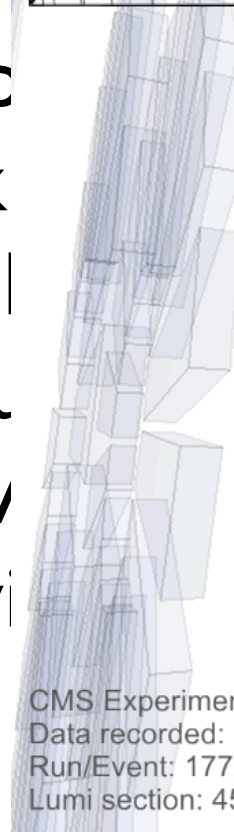
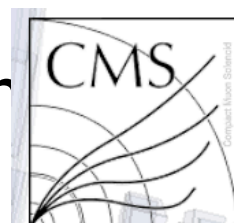


Higgs Physics (II): VBF

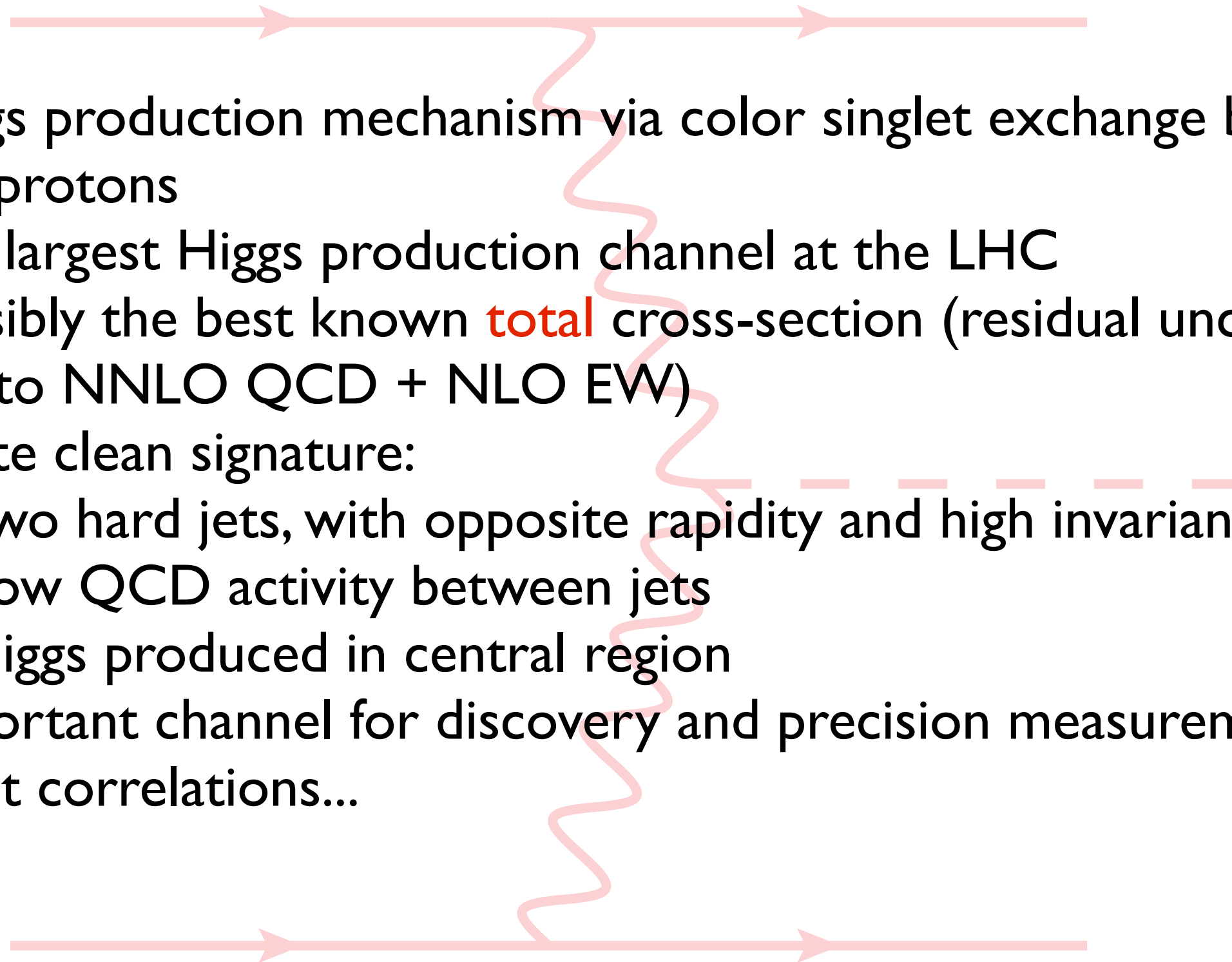
- 
- The diagram illustrates the VBF (Vector Boson Fusion) production mechanism for a Higgs boson. It shows two incoming protons (represented by horizontal red arrows) interacting via a color singlet exchange (represented by a wavy red line). This exchange results in two outgoing protons (horizontal red arrows) and a Higgs boson (represented by a dashed red line).
- Higgs production mechanism via color singlet exchange between the protons
 - 2nd largest Higgs production channel at the LHC
 - Possibly the best known **total** cross-section (residual unc. $\sim 2\%$) (up to NNLO QCD + NLO EW)
 - Quite clean signature:
 - Two hard jets, with opposite rapidity and high invariant mass
 - Low QCD activity between jets
 - Higgs produced in central region

Higgs Physics (II): VBF

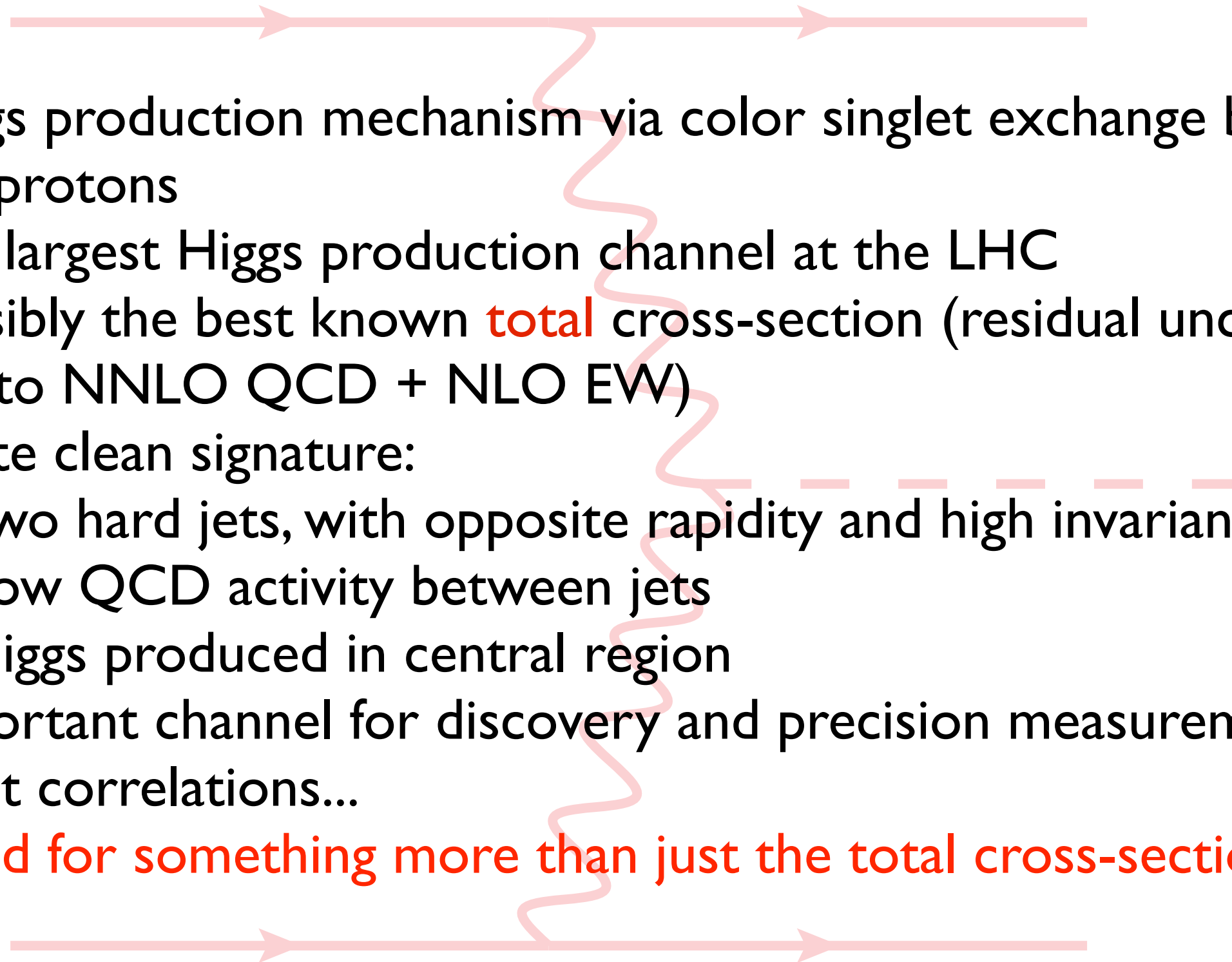
- Higgs production via the protons
- 2nd largest Higgs p
- Possibly the best k (up to NNLO QCD)
- Quite clean signature
 - Two hard jets, w
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Higgs Physics (II): VBF

- 
- The diagram illustrates the VBF (Vector Boson Fusion) production mechanism for a Higgs boson. Two incoming protons, represented by horizontal red arrows at the top and bottom, interact via the exchange of two vector bosons (W or Z), shown as wavy red lines. These bosons then fuse to produce a Higgs boson, represented by a dashed red line. The Higgs boson subsequently decays into two photons, shown as dashed red lines.
- Higgs production mechanism via color singlet exchange between the protons
 - 2nd largest Higgs production channel at the LHC
 - Possibly the best known **total** cross-section (residual unc. $\sim 2\%$) (up to NNLO QCD + NLO EW)
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 - Important channel for discovery and precision measurements
 - Jet correlations...

Higgs Physics (II): VBF

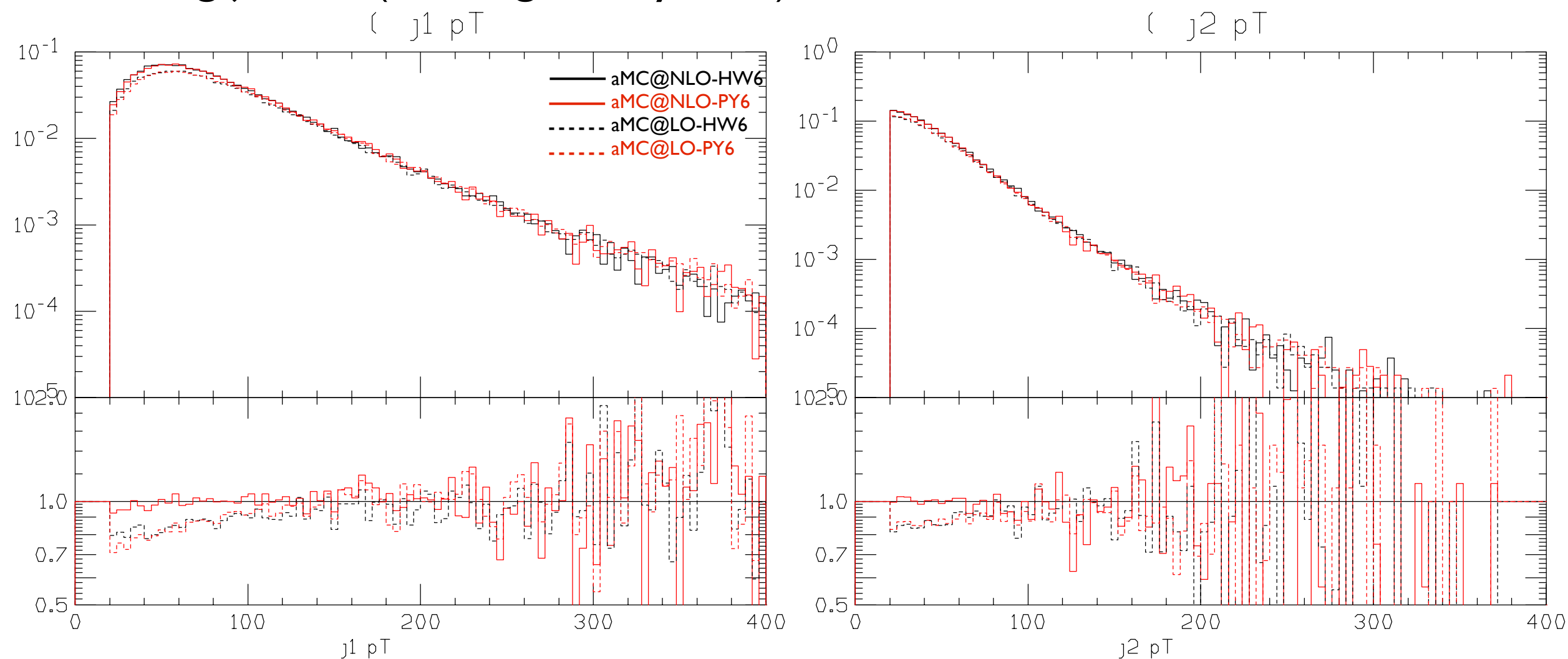
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- Higgs production mechanism via color singlet exchange between the protons
 - 2nd largest Higgs production channel at the LHC
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 - Quite clean signature:
 - Two hard jets, with opposite rapidity and high invariant mass
 - Low QCD activity between jets
 - Higgs produced in central region
 - Important channel for discovery and precision measurements
 - Jet correlations...
 - **Need for something more than just the total cross-section...**

VBF in aMC@NLO

- Fully differential final states are explored
- Comparison between different PSMC helps in understanding uncertainties
- Plots are still preliminary*....

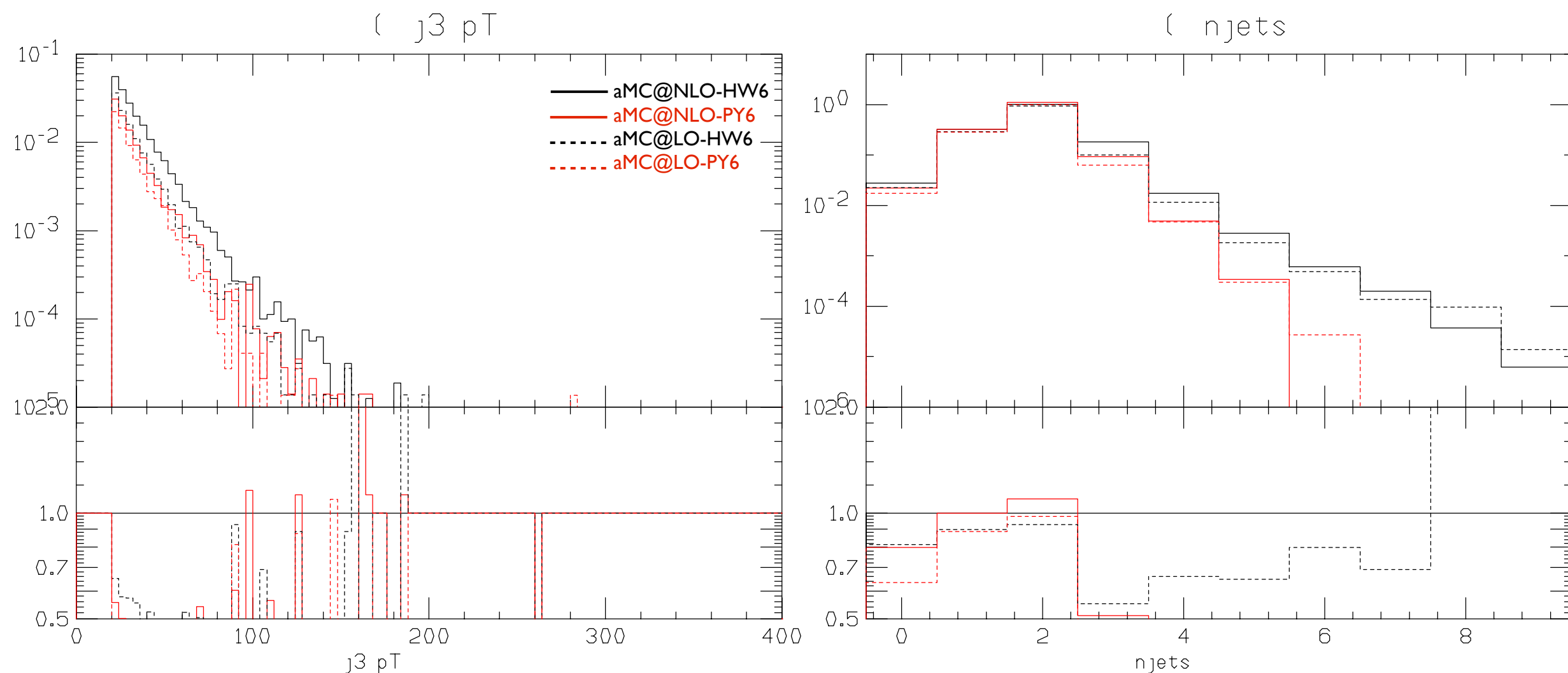
VBF in aMC@NLO

Leading jets Pt (Herwig6 vs Pythia6)



VBF in aMC@NLO

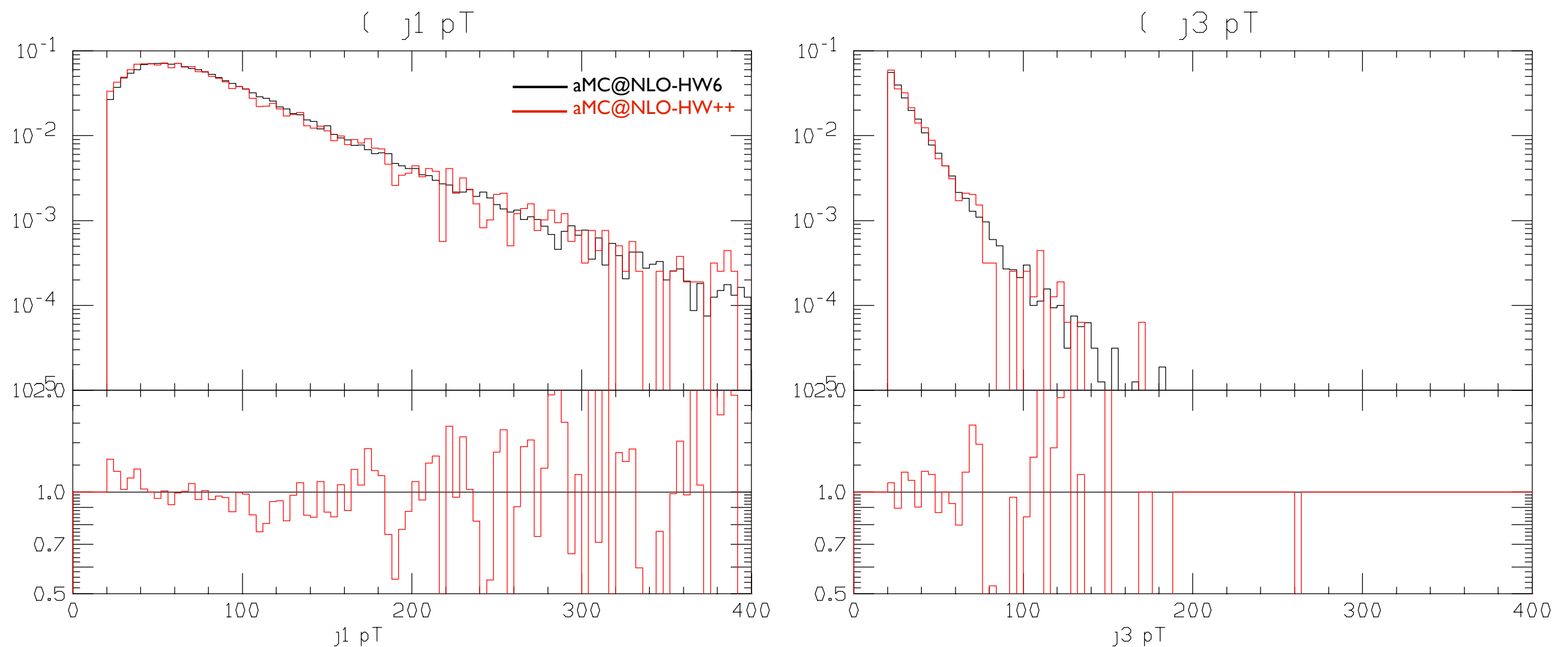
Third jet Pt and jet rates (Herwig6 vs Pythia6)



Differences to be investigated (*)

VBF in aMC@NLO

Hwerig++ (results shown at last HXSWG meeting)



Better agreement for 3rd jet

Conclusions

- Realistic and accurate predictions needed for LHC precision physics
- Powerful and generic techniques available for NLO computation
- MC@NLO formalism allows NLO+PS
- Automatic MC@NLO to carry on all this automatically
- Code public and available (beta2 soon!)
- Very interesting application to Higgs physics
- Stay tuned on <http://amcatnlo.cern.ch>!

Extra slides



Going BSM



Going BSM

FR: Christiansen, Duhr, arXiv:0806.4194

UFO: Degrande et al. arXiv:1108.2040

ALOHA: Mattelaer et al. arXiv:1108.2041

- The FeynRules/UFO/ALOHA interface provides a straight way to use any model, starting from the Lagrangian
- FR extracts the Feynman rules from the Lagrangian
- UFO creates a Python module that can be linked to any ME generator (e.g. MadGraph)
 - Particles
 - Parameters
 - Vertices
 - Lorentz structures
- ALOHA writes the HELAS wavefunctions
 - Output available in c++, Fortran, Python

FR/UFO/ALOHA developments

- Automatic R2/UV from FR
- Feynman gauge
- HELAS amplitudes with complex masses
- HELAS amplitudes in multiple precision
- Spin 3/2
- ...

MadSpin

Ongoing projects: production + decay

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- How to deal with unstable final state particles (e.g. top) @NLO?

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 - Generate full process with only stable particles ($p p \rightarrow l+l- \nu \bar{\nu} b \bar{b}$)
 - Includes spin correlations, off-shell effects, non resonant contributions, ...
 - Needs special treatment of intermediate resonances (e.g. cpx mass)
 - Computationally very expensive
 - Only needed when background is enhanced or when aiming at very high precision

Ongoing projects: production + decay

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Anything in between?

Spin correlations made easy:

MadSpin

Artoisenet, Frederix, Mattelaer, Rietkerk

Spin correlations made easy:

MadSpin

Artoisenet, Frederix, Mattelaer, Rietkerk

- Wish-list:
 - For a given event sample (LO or MC@NLO), include the decay of any final state particle
 - Keep spin correlations
 - Generate decayed unweighted events

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 - Read event
 - Generate decay kinematics
 - Reweight the event with ratio $|M_{P+D}|^2 / |M_P|^2$
 - Or do secondary unweighting
 - Generate many decay configurations until

$$|M_{P+D}|^2 / |M_P|^2 > \text{Rand}() \max \left(|M_{P+D}|^2 / |M_P|^2 \right)$$

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$$|M_{P+D}|^2 / |M_P|^2 > \text{Rand}() \max \left(|M_{P+D}|^2 / |M_P|^2 \right)$$
- This has already been done for $t \bar{t}$ and singletop

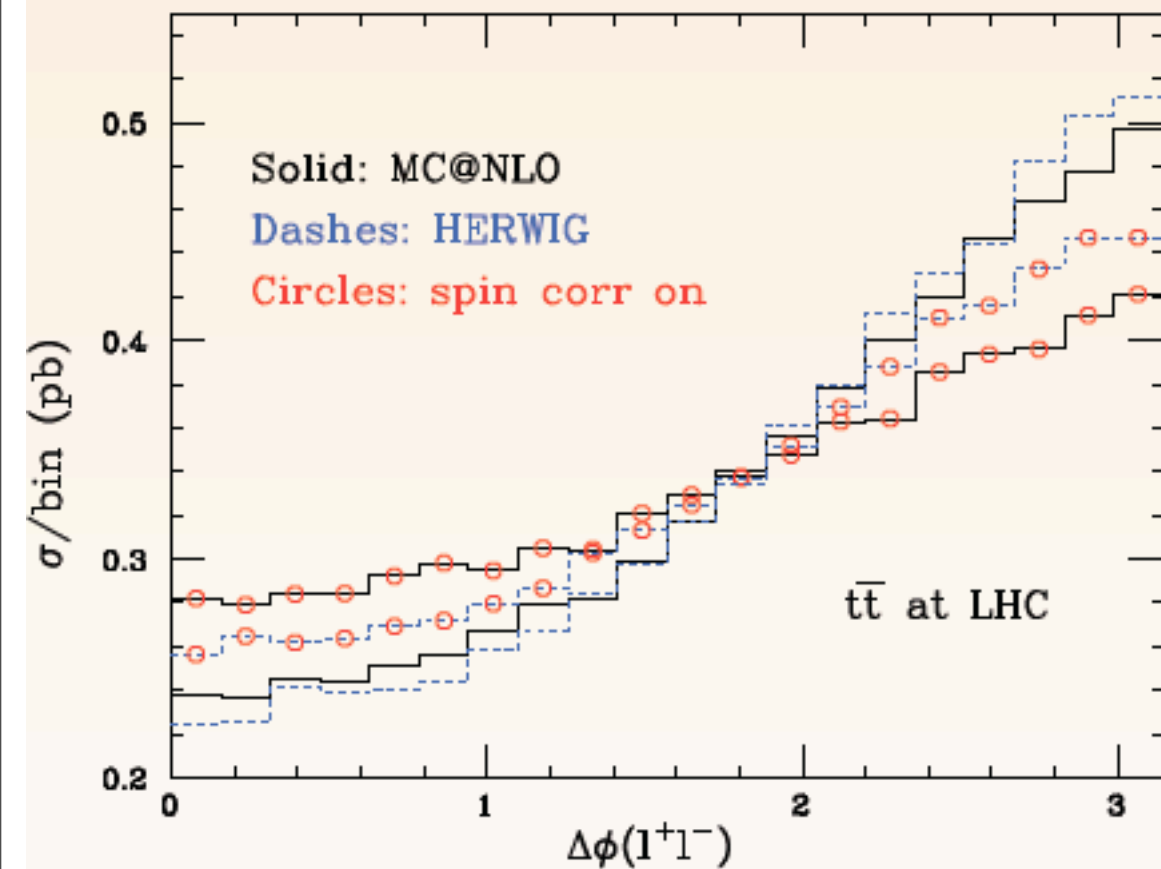
Frixione, Leenen, Motylinski, Webber, arXiv:hep-ph/0702198

Spin correlations made easy: MadSpin

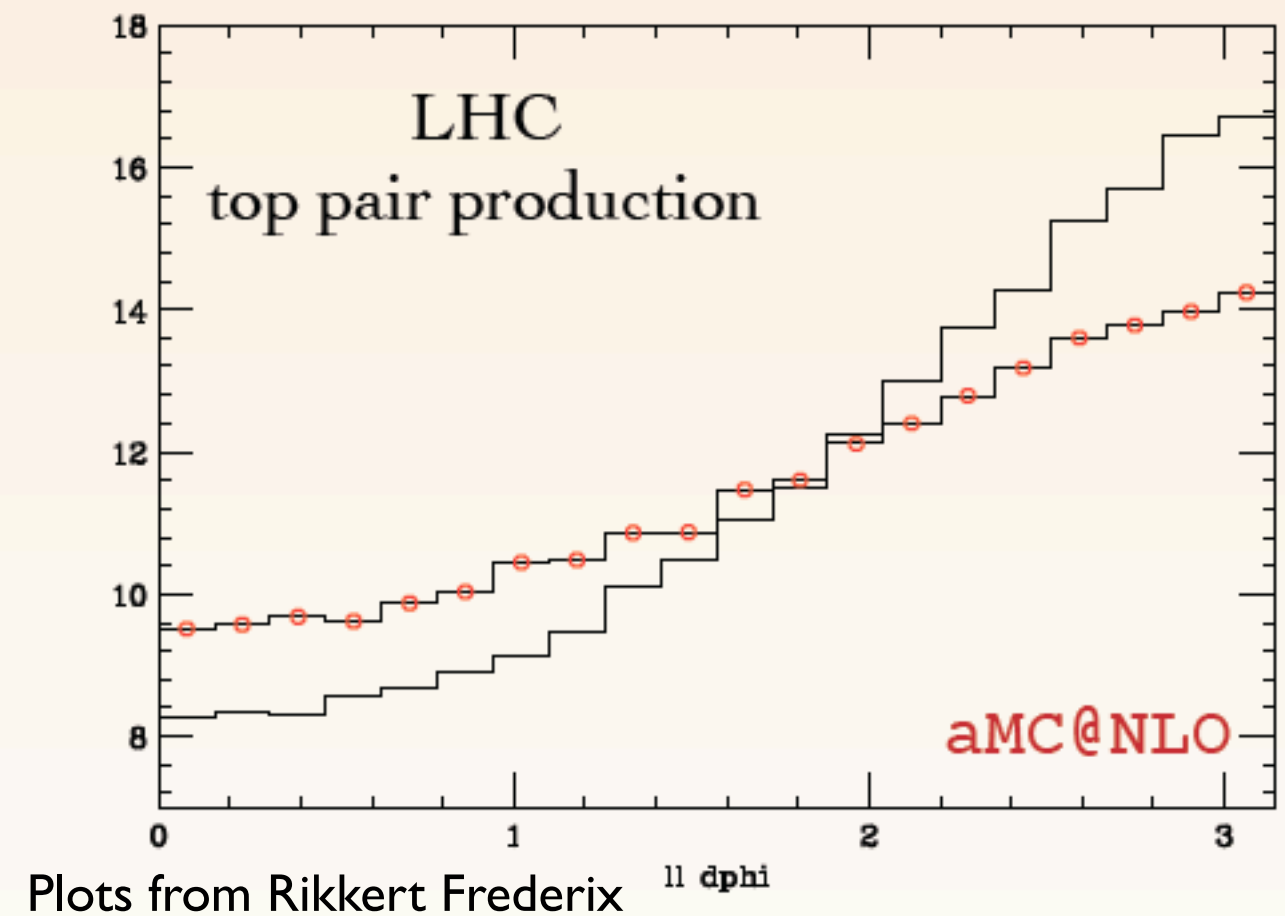
- How to deal with MC@NLO events?
- Spin correlations usually have tiny effects on observables
 - Include them at tree level
- For H ($n+1$ body) events, use decayed real-emission matrix-element
- For S (n body) events, use decayed born matrix-element
- This guarantees NLO accuracy for observables related to production (e.g. top pt)
- This includes all spin correlation for observables related to production + decay (apart non-factorizable ones)

Validation

Frixione, Laenen, Motylinski
& Webber, hep-ph/0702198



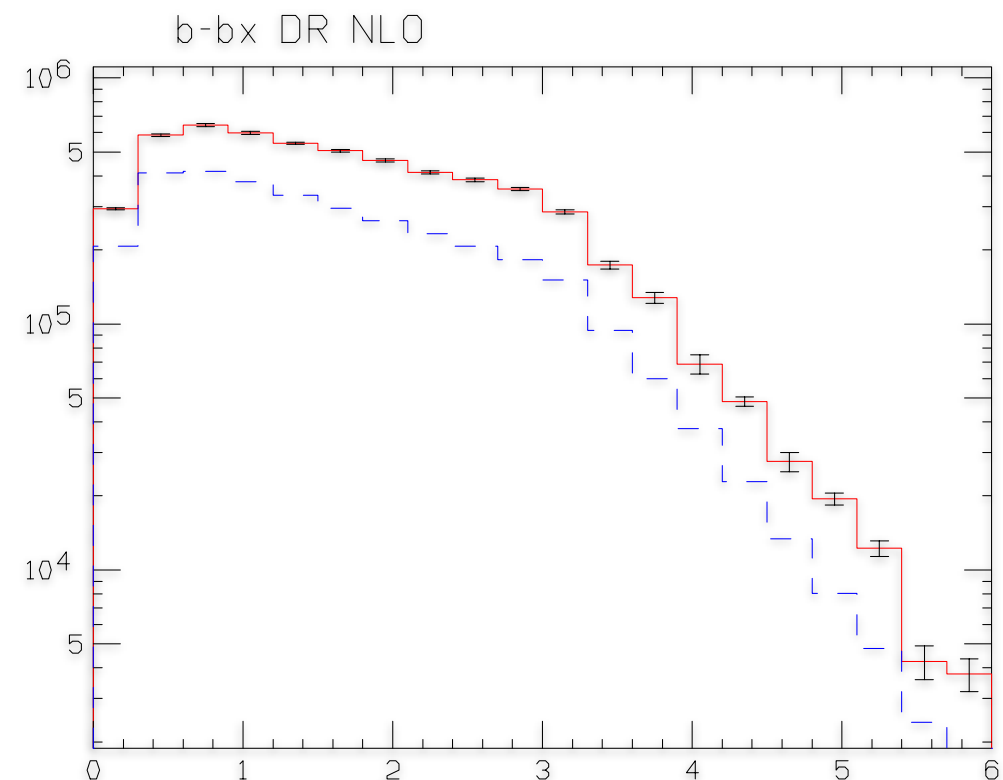
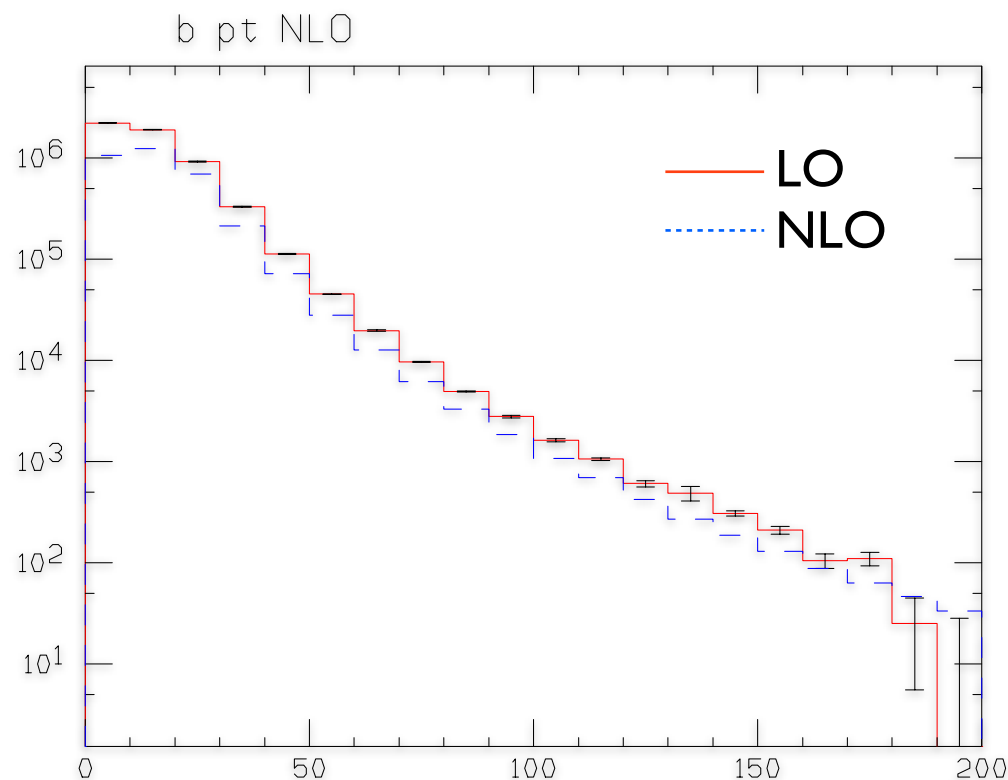
aMC@NLO+DecayPackage



Parton level results

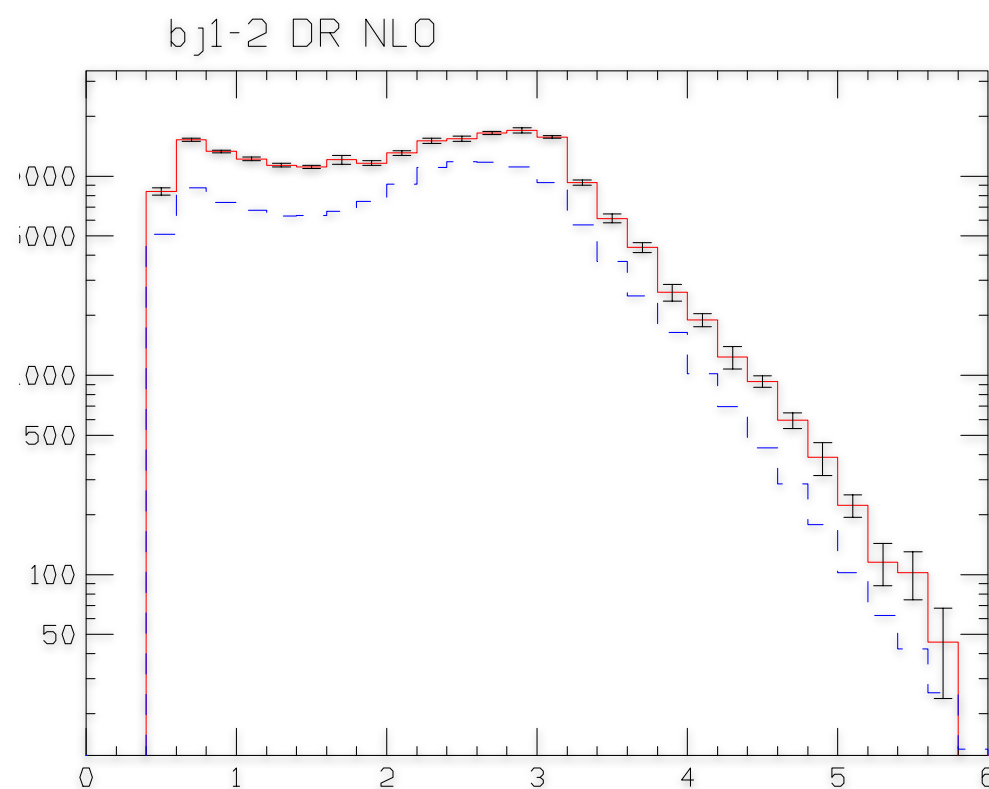
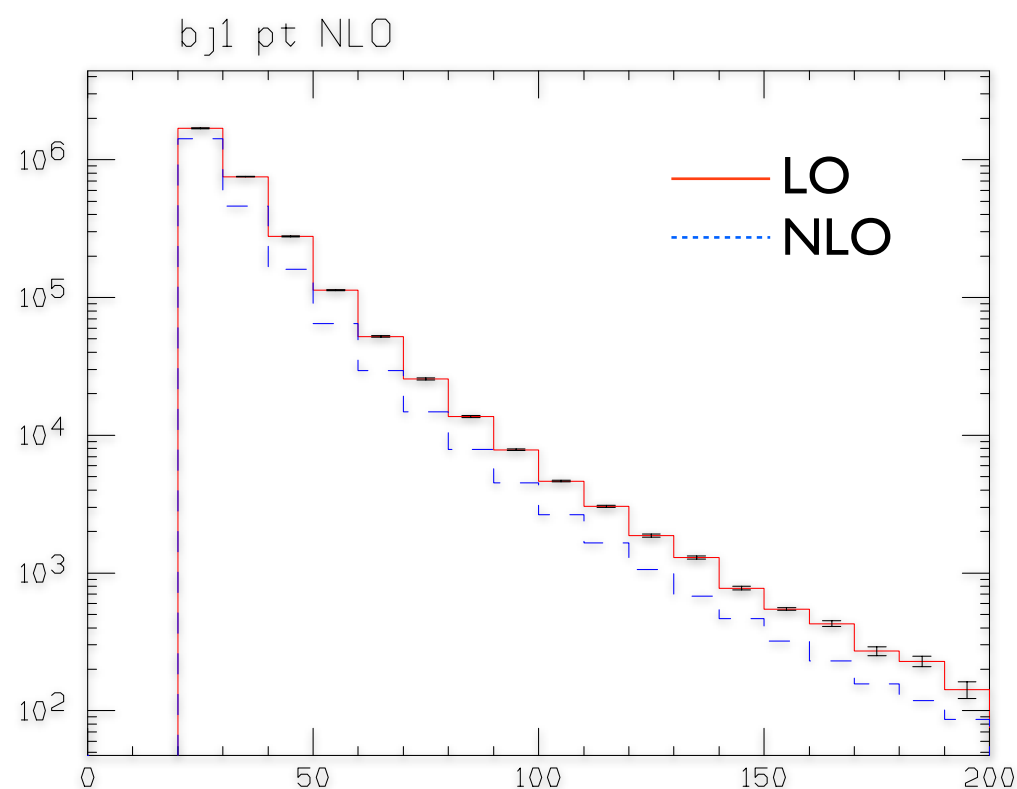
bbj@NLO

- Virtuals from Dittmaier, Weinzierl, Uwer (arXiv:0810.0452)
 - validated against MadLoop5
- 4 flavour scheme (and PDF)
- Kt algo for jets, $R=0.5$, $p_t > 20$ GeV
- K factor ~ 2



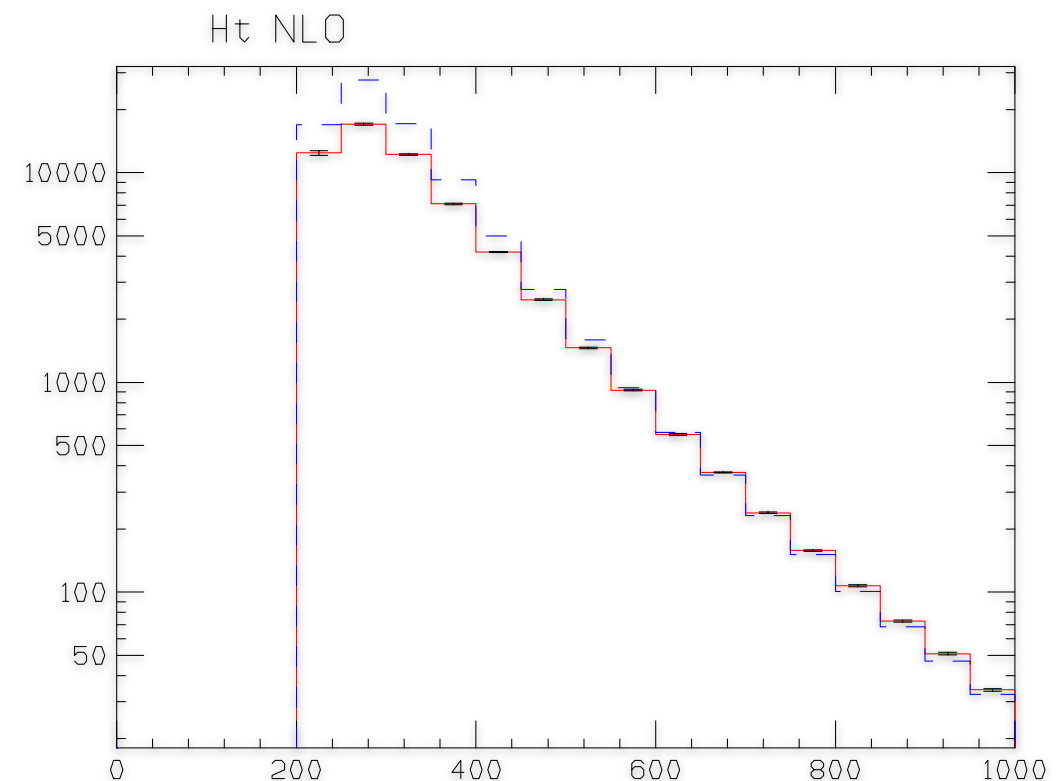
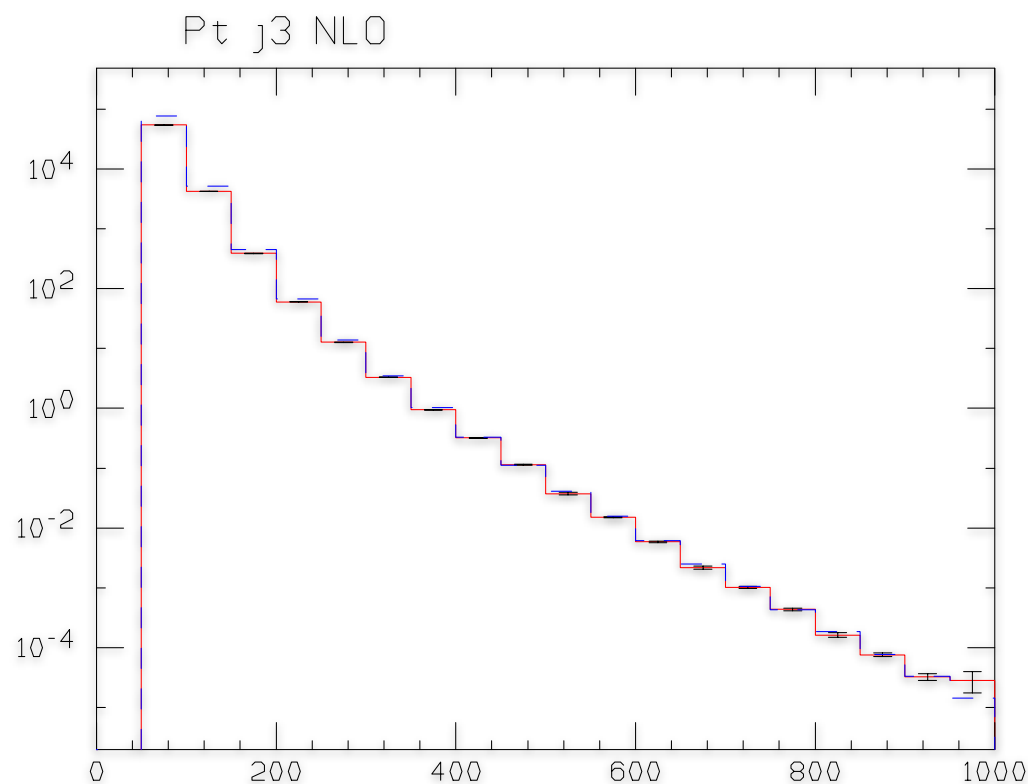
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3 jets production@NLO

- Virtuals from NGLuon (Badger, Biedermann, Uwer, arXiv:1011.2900) via MadFKS BLHA interface
- Validated against numbers in arXiv:1112.3940 (BlackHat coll.)
- anti-kt, $R=0.4$, pt leading (others) > 80 (60) GeV

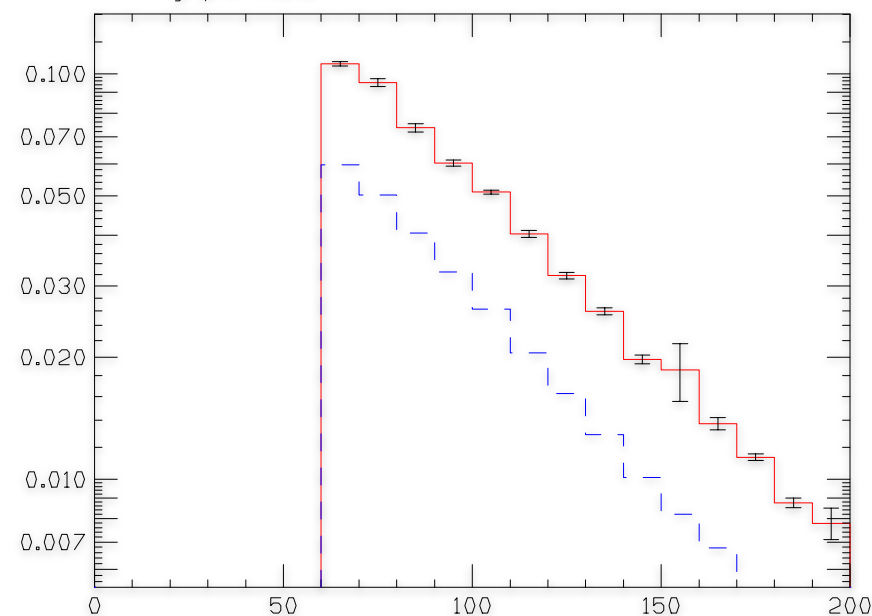


- Code for 4 jets ready

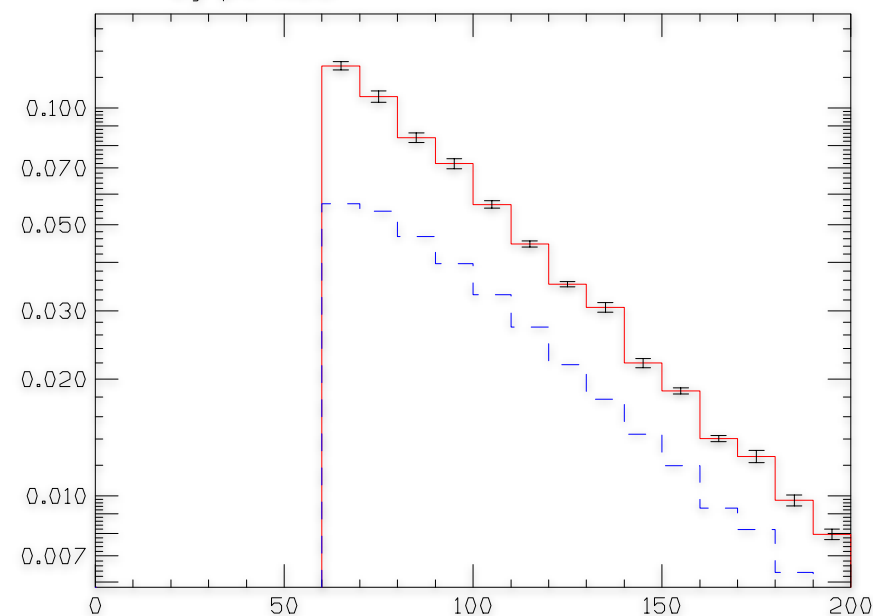
Wbj@NLO

- Whole code from aMC@NLO
- 5 flavour scheme (j can be b)
- Need to impose special cuts in order to have finite cross-section
 - Ask for >2 jets, at least one containing a b, but not bb

j pt NLO



bj pt NLO



bj2 pt NLO

