HZ associated production in gluon-gluon fusion

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with
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based on arXiv:1503.01656

MadGraph5_aMC@NLO Femto workshop
IPMU
27/3/15

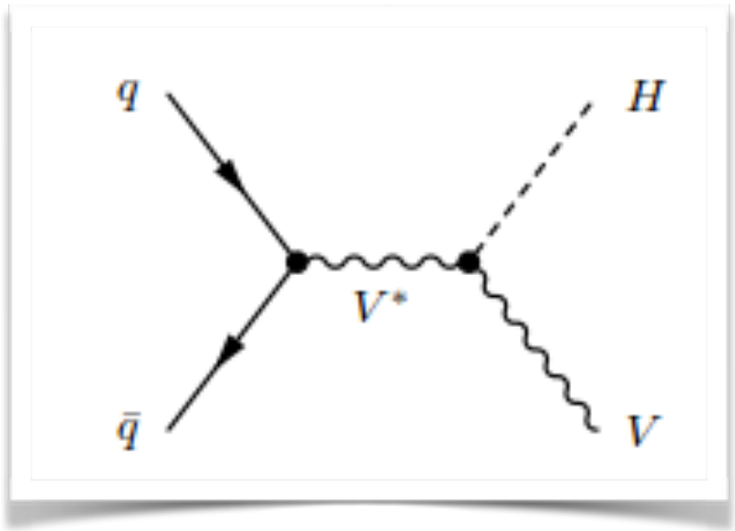
Outline

- Introduction to VH production
- ZH production in gluon fusion
  - Parton-level results
  - Merging and matching
- Zϕ production in the 2HDM
- Outlook

ZH production

LHC precision Higgs measurements:

Higgs-strahlung: WH and ZH



Drell-Yan component

LO: qq $\mathcal{O}(\alpha_w^2)$

Drell-Yan corrections known up to NNLO: Hamberg, Neerven, Matsuura, '91, Harlander, Kilgore, '02, Brein, Djouadi, Harlander, '04

Experimental searches with H decaying to bb:

ATLAS and CMS: small excess above the background only hypothesis (arXiv:1409.6212 and arXiv:1310.3687)

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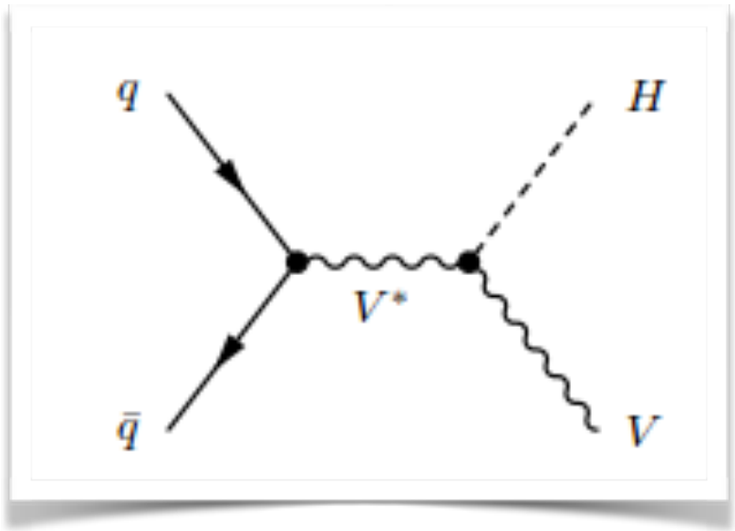

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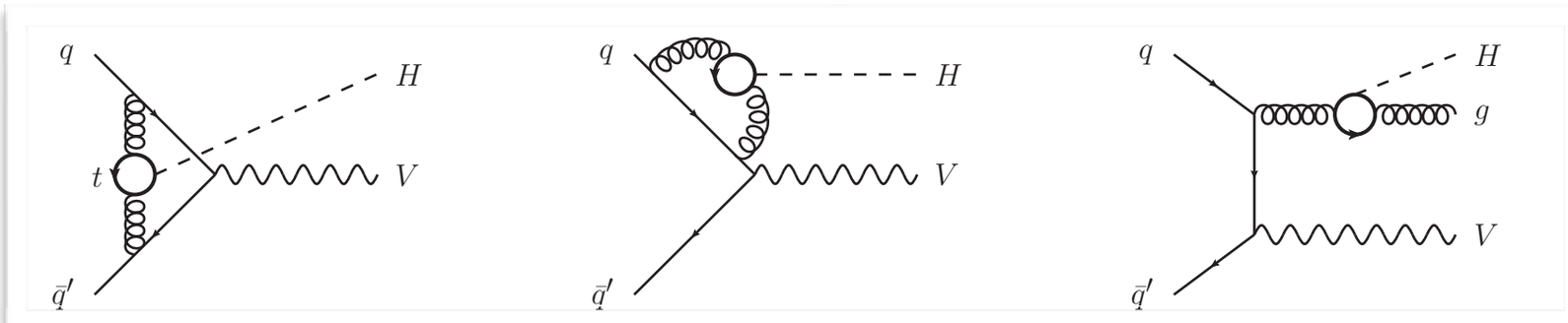
Higher-order corrections

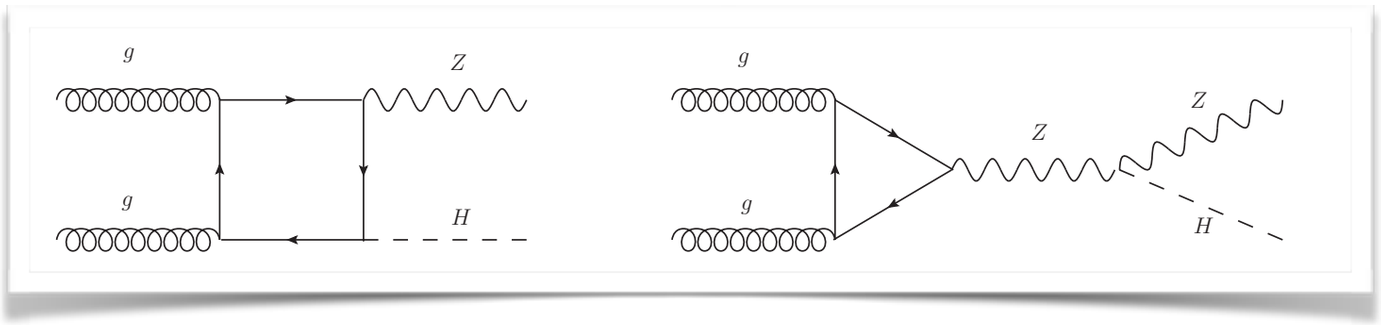
Additional NNLO contributions at $\mathcal{O}(\alpha_w^2 \alpha_s^2)$:
1) qq top-induced contributions:



Interference with the LO and NLO Drell-Yan amplitude

Brein, Harlander, Wiesemann, Zirke ‘11

2) Gluon fusion contribution



Purely virtual
IR and UV finite

NNLO HZ cross-section

Contribution σ[fb]	8TeV	14TeV
Total	386	885
Drell-Yan	364	801
Gluon-fusion	17.6	70.6
Top-induced	4.93	13.0

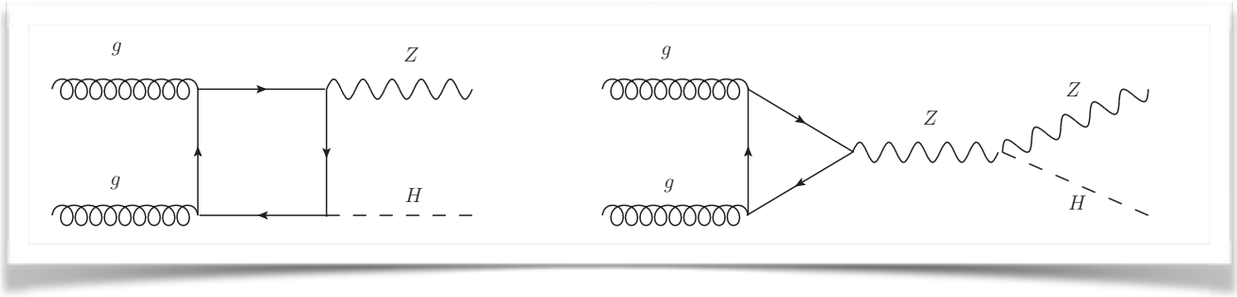
→ ~10% of the NNLO at LHC14

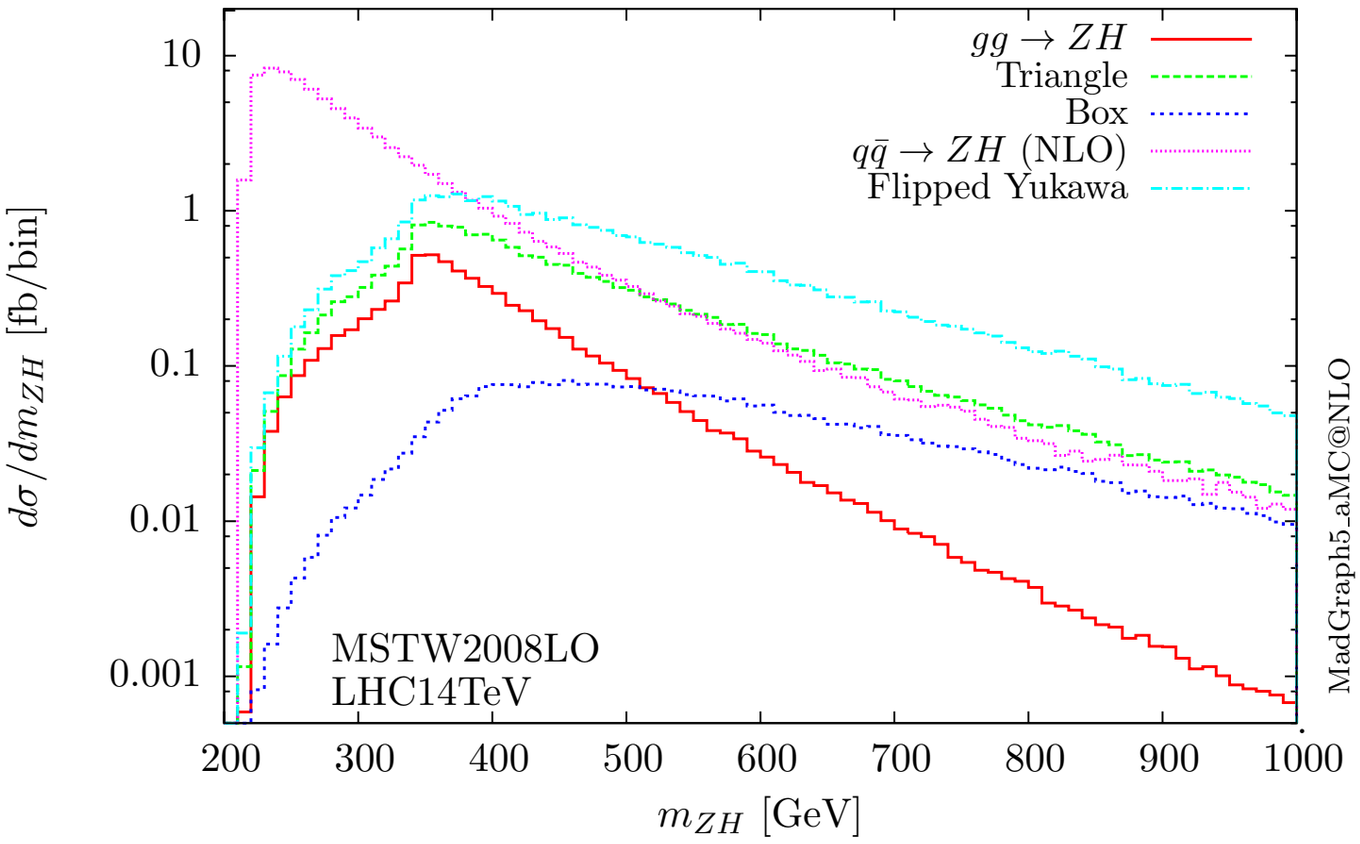
From vh@nnlo (Brein, Harlander, Zirke '12)

gg is basically a LO channel:
Large gluon fusion scale uncertainty (~30%) dominates the NNLO uncertainty

→ Need for more accurate predictions in this channel

HZ in gluon fusion





Why do we care about the gg contribution?

- Large uncertainties ~30%
- Large k-factors
- Different distribution shapes from the Drell-Yan contribution (boosted searches)

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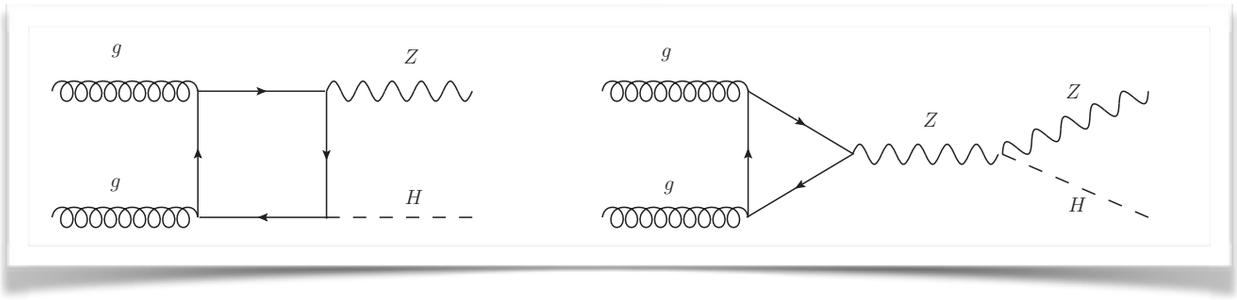

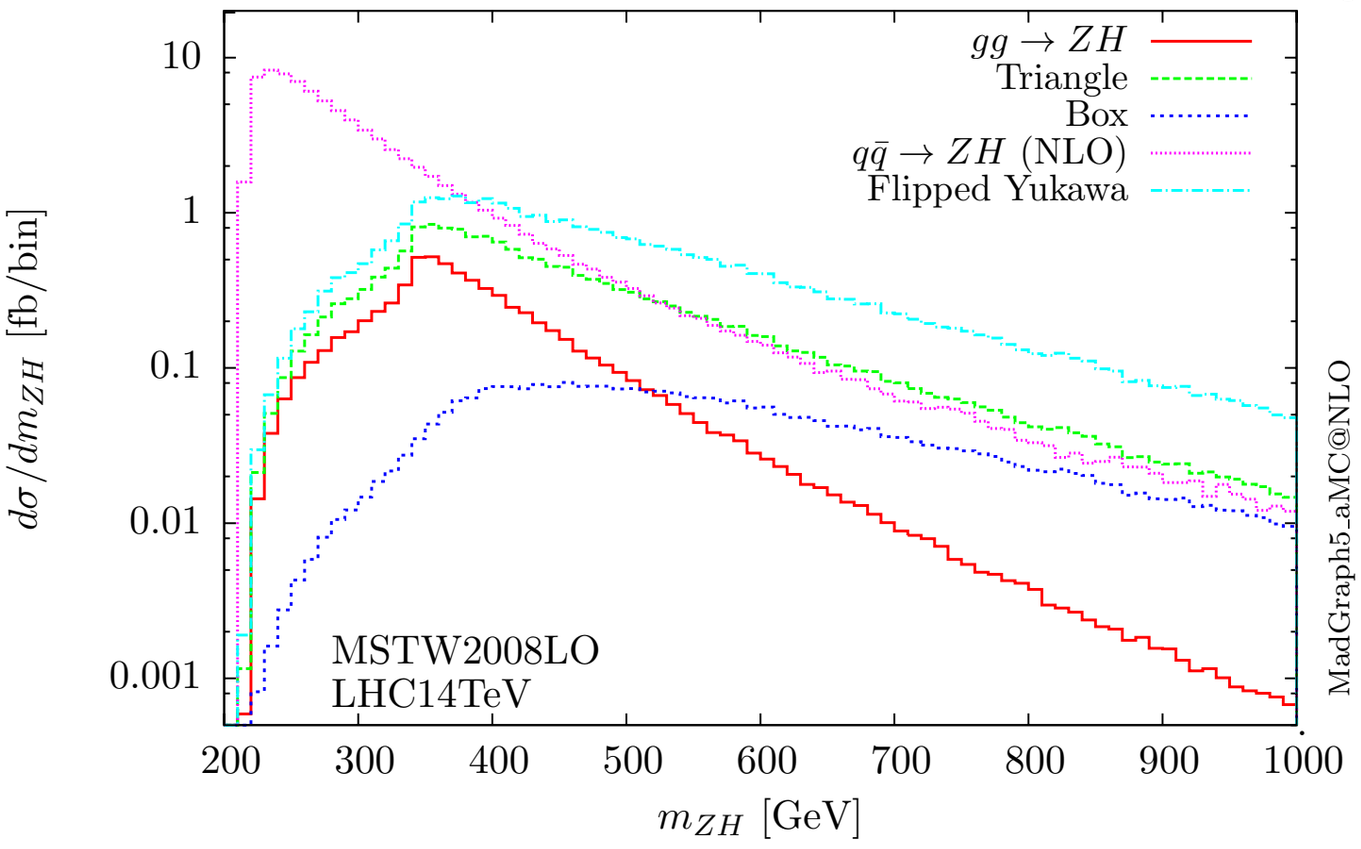

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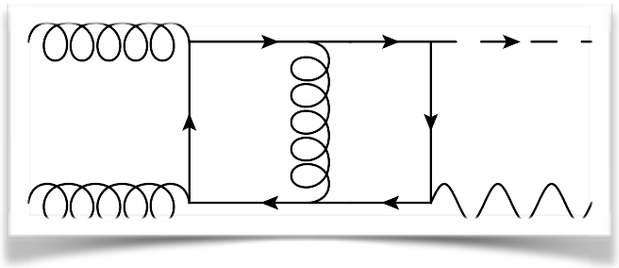
Destructive interference between the triangle and the box

→ Sensitivity on the relative phase of the HVV and Htt couplings

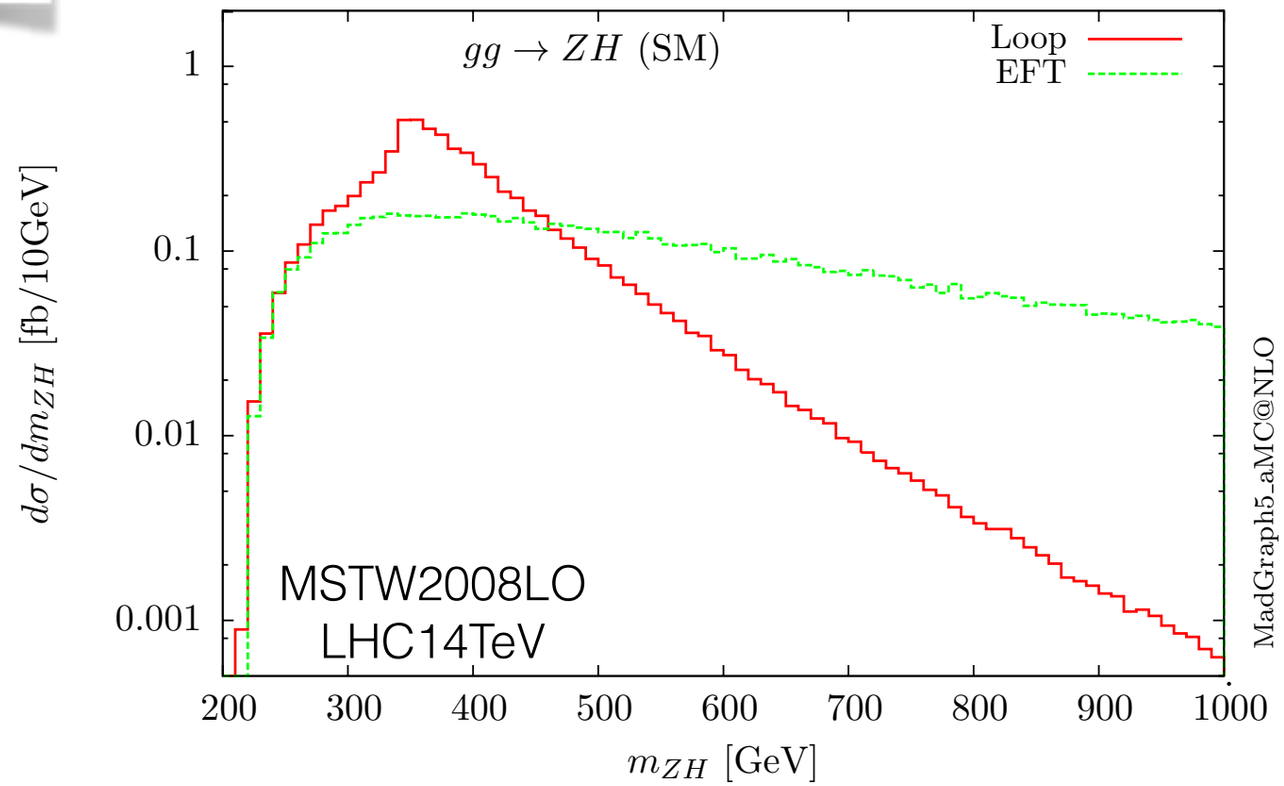
HZ in gluon fusion beyond LO
(formally part of ZH at N³LO)

NLO?



Multiscale 2-loop amplitudes results not available

EFT? $m_t \to \infty$



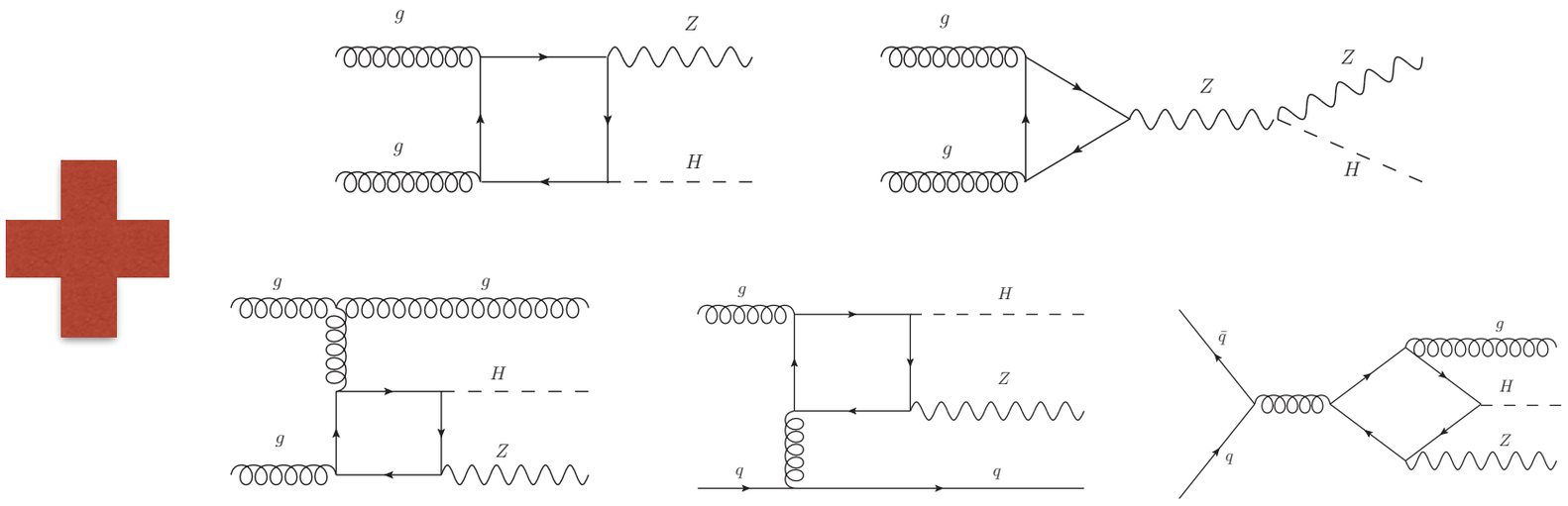
NLO k-factor obtained in the EFT: L. Altenkamp et al. ’13
Large k-factors of ~2, reduced scale uncertainty
Soft Gluon Resummation: Harlander, Kulesza, Theeuwes, Zirke ’14

ZH in gluon fusion

Ideally: Fully differential exact NLO computation
+ Matching to PS (MC@NLO)

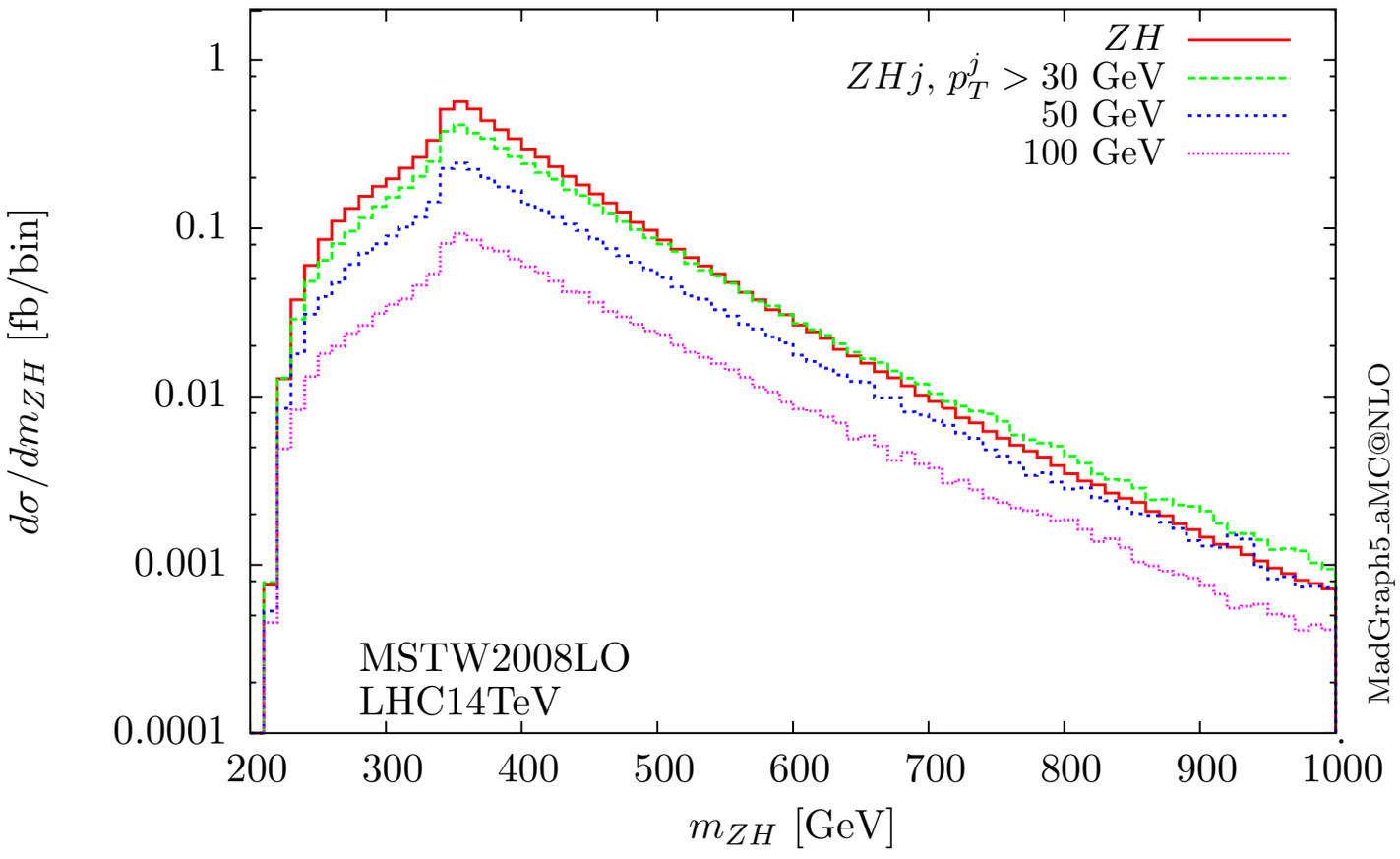
Available: 1) Total cross-section results:
infinite top mass limit k-factor

2) LO parton-level differential results for ZH and ZHj (gluon-fusion related)



Parton-level results (1)

m_{ZH} for gg>ZH and ZHj with different cuts on the jet p_T



ZHj with different jet pT cuts

- 30GeV 57.9fb
- 50GeV 35.3fb
- 100GeV 14.5fb

Bulk of the cross-section remains at ~$2M_t$

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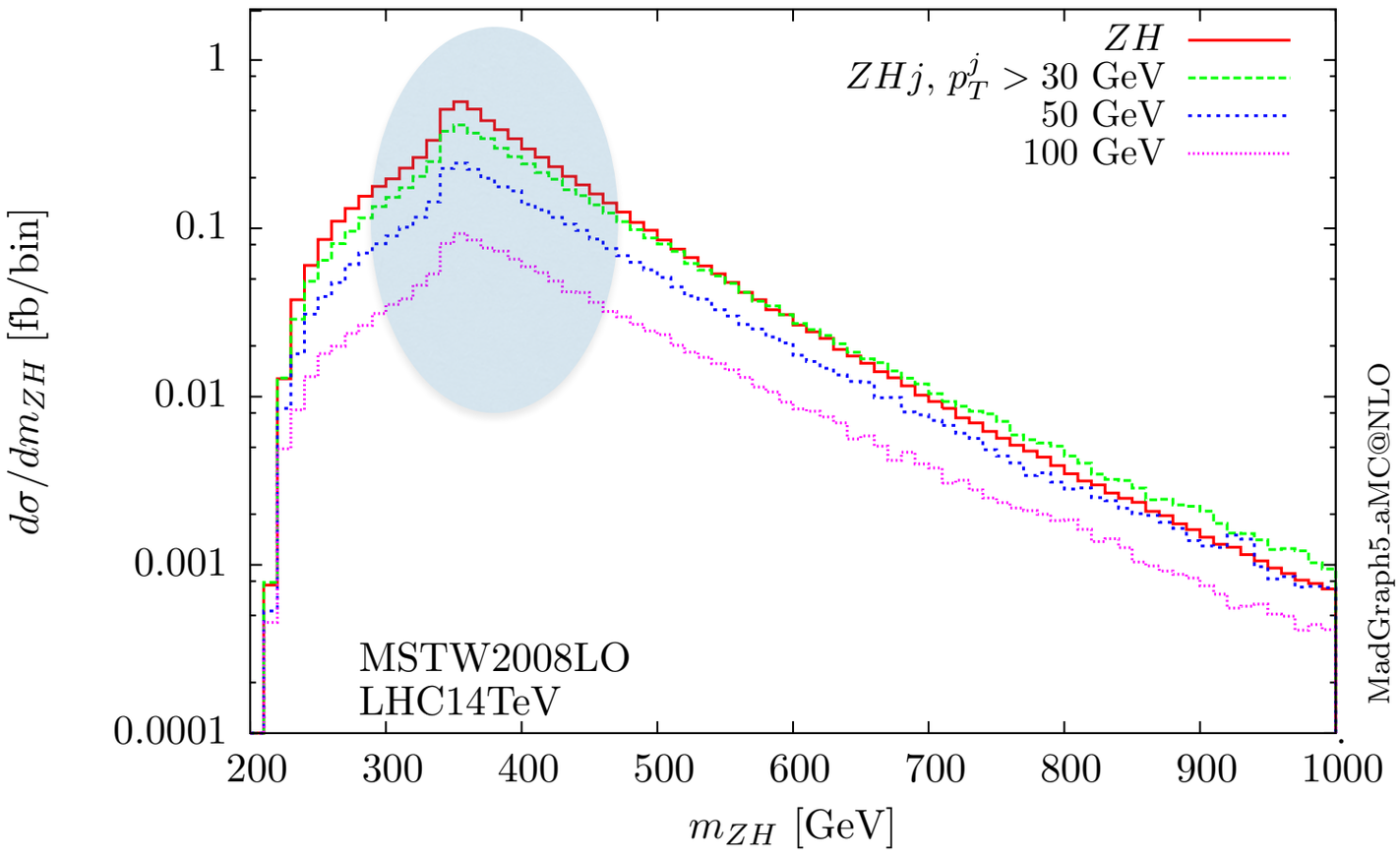

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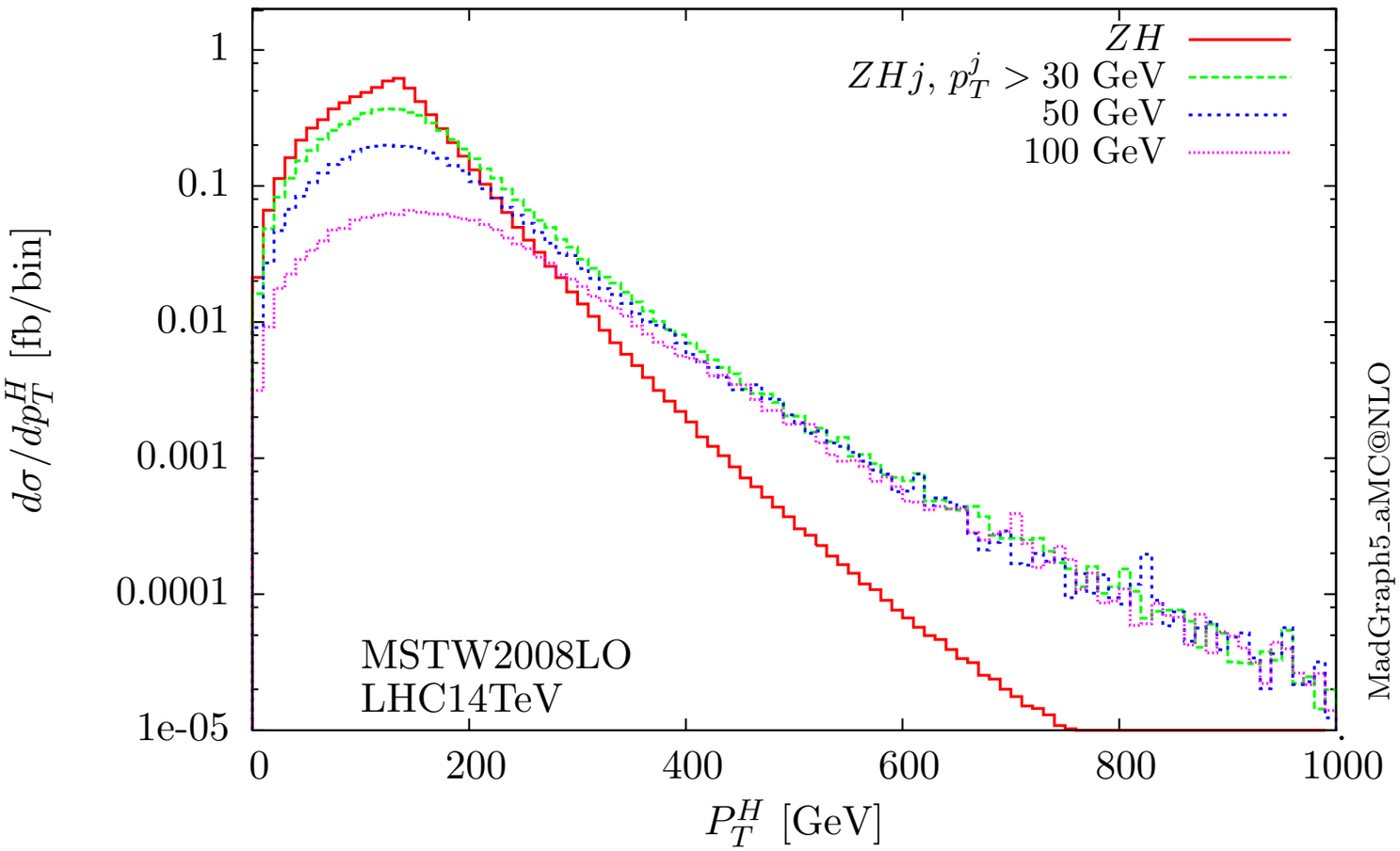
Higgs p_T for gg>ZH and ZHj with different cuts on the jet p_T



Extra jet contribution taking over above 400GeV

New kinematic configurations? **hard jet**

High p_T region insensitive to the jet p_T cut

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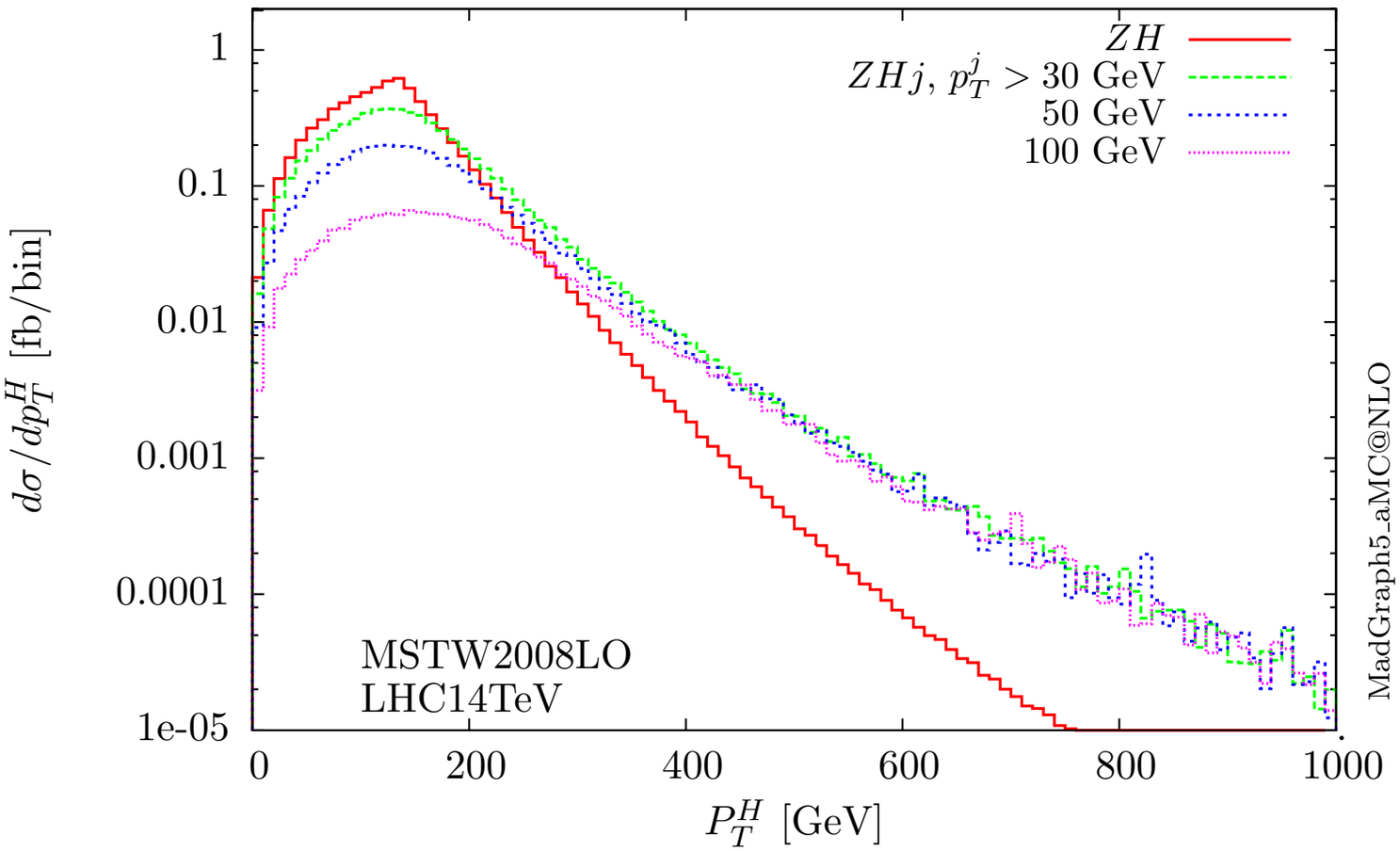

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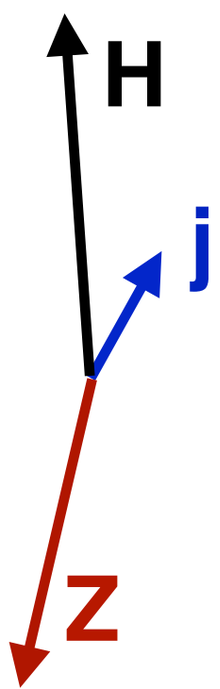

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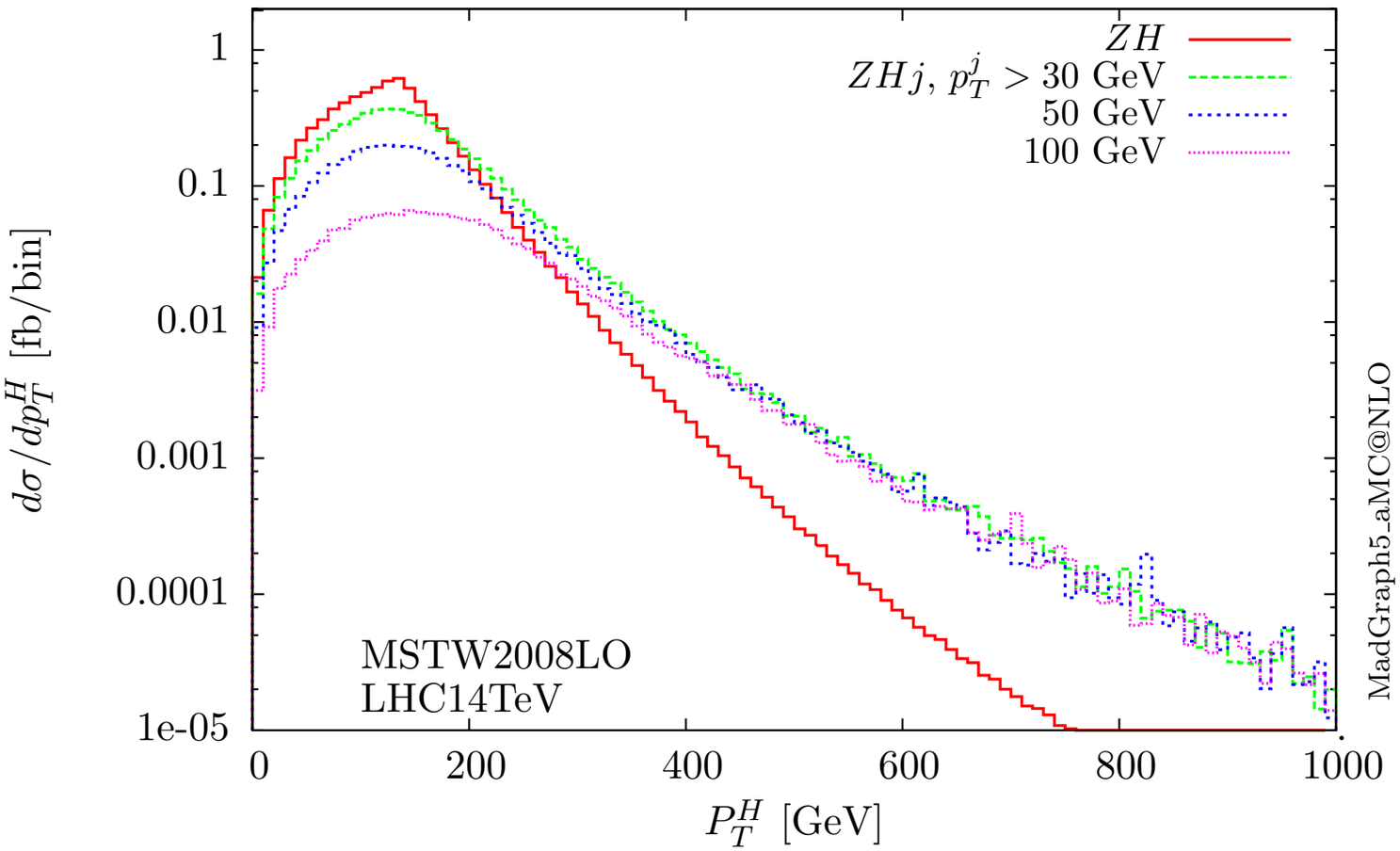

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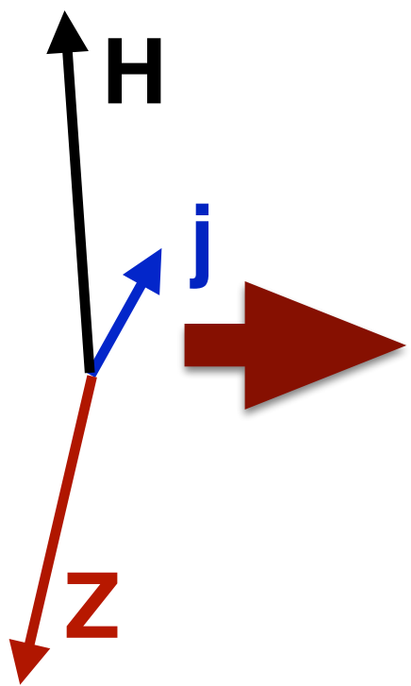

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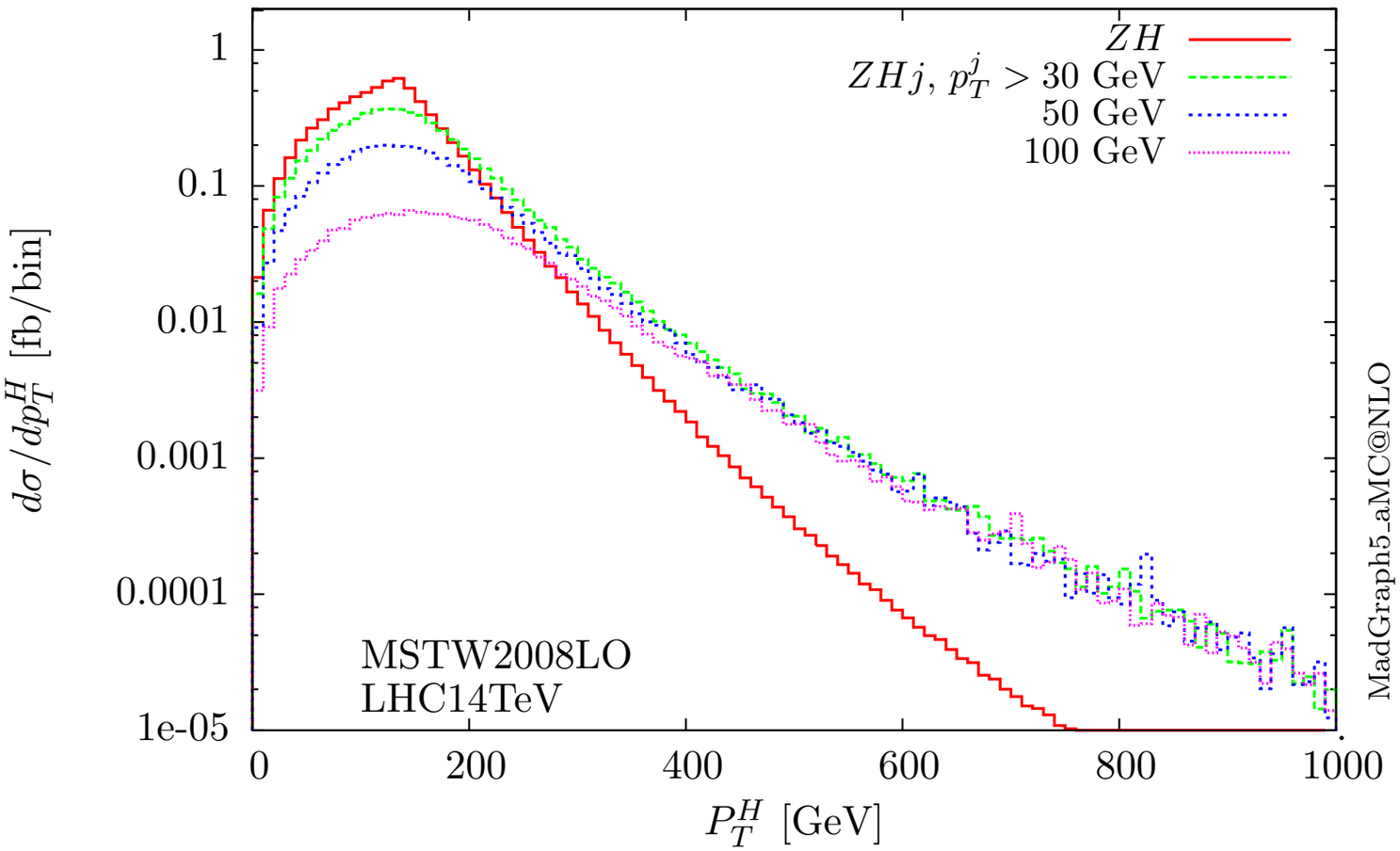

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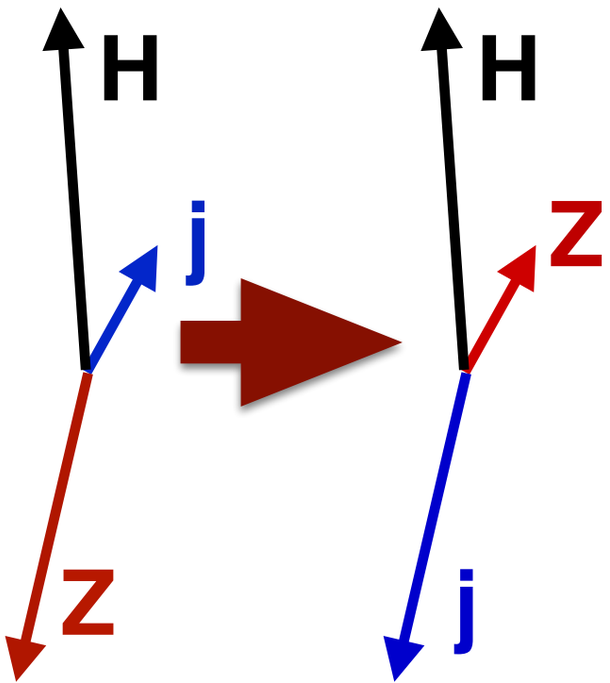

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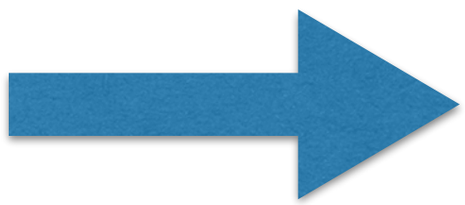
Merging-Matching in gluon fusion

More realistic description of the distribution shapes?

Merging-Matching



Consistent combination of 0 and 1jet multiplicities and matching to PS

Technical setup

Merging-matching in MG5_aMC@NLO/Pythia8:

1) Loop-induced process

(Before the loop automation: see Olivier's talk)

Reweighting approach:

- Tree-level event generation with some EFT (infinite top mass limit)
- Reweight on an event by event basis based on $|M_{exact}|^2/|M_{EFT}|^2$
- Loop amplitudes: MadLoop

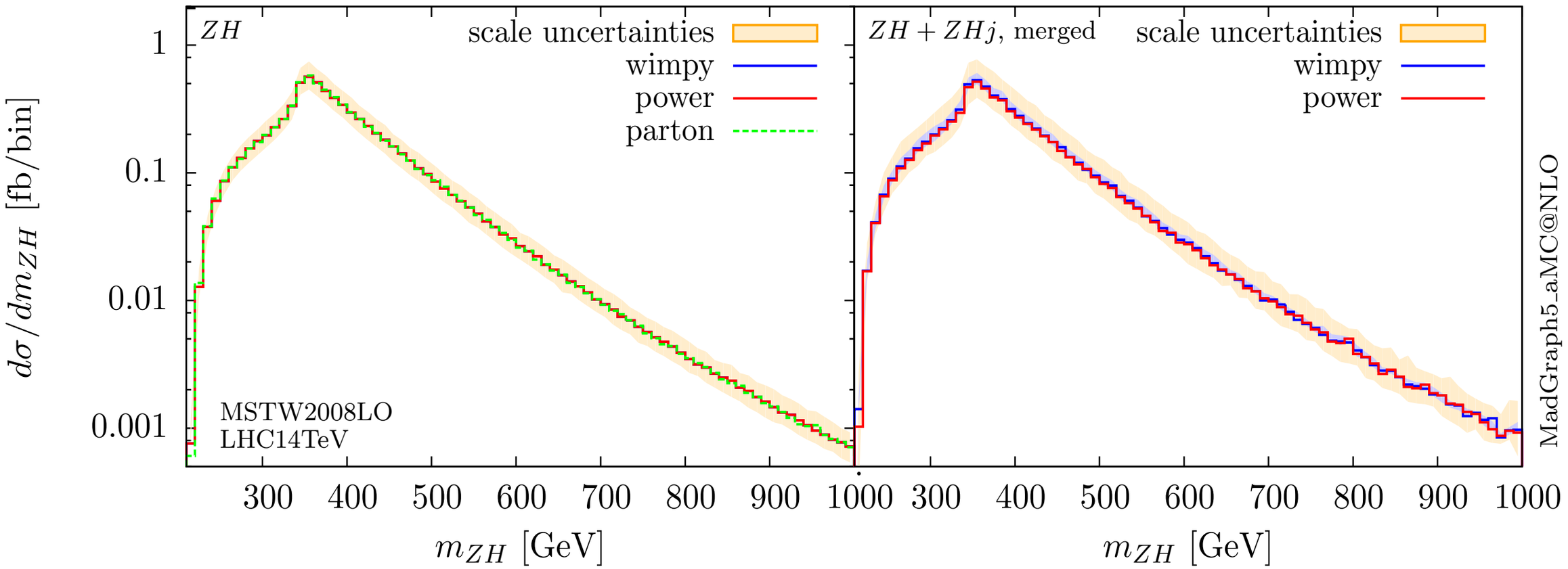
2) **PYTHIA8.2: PT-ordered showers**

Recent implementation of merging-matching in Pythia8.2 allows:

- MLM matching (kT-MLM + shower-kT)
- CKKW-L
- UMEPS
- FxFx
- UNLOPS

Merging-matching results (1)

Invariant mass of the HZ system



shower scale choice

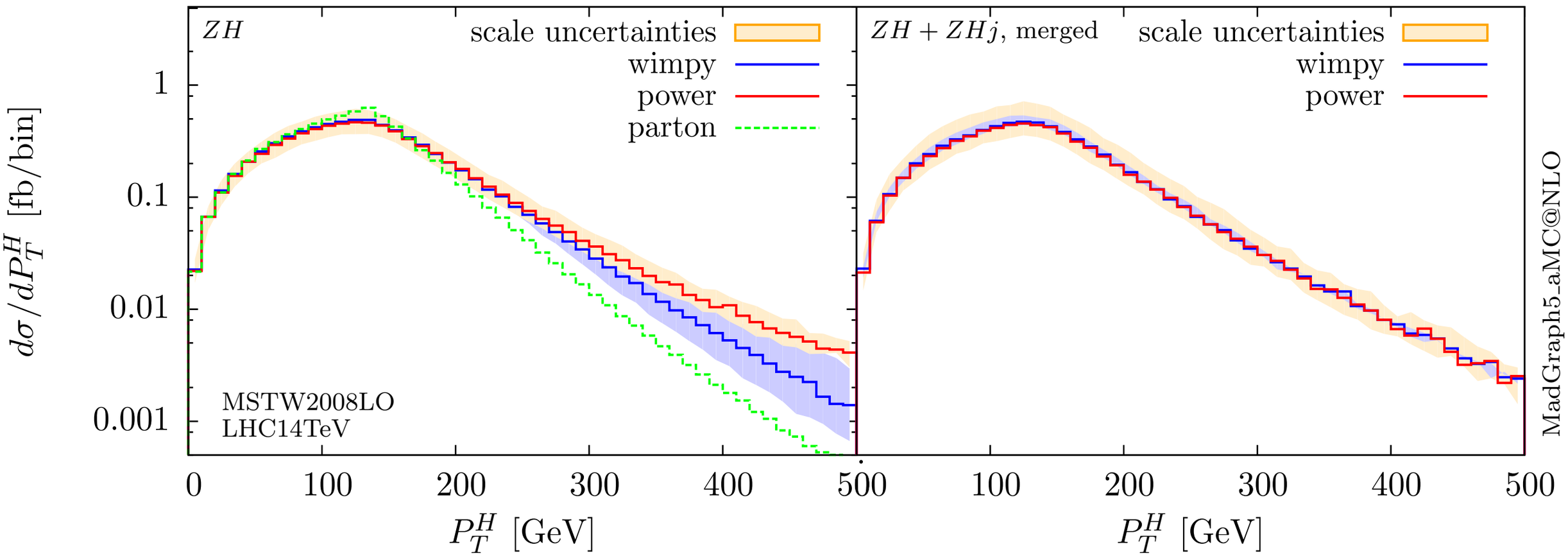
- $\mu_f = m_{ZH}$ 'wimpy-shower'
- $\sqrt{s}/2$ 'power-shower'

Merged results: MLM
Shower-KT
QCut=30GeV

Shower/merging insensitive observable:
no significant shape variation

Merging-matching results (2)

Higgs P_T



Shower scale variation bands:

$\mu_f/2<\mu_{PS}<2\mu_f$

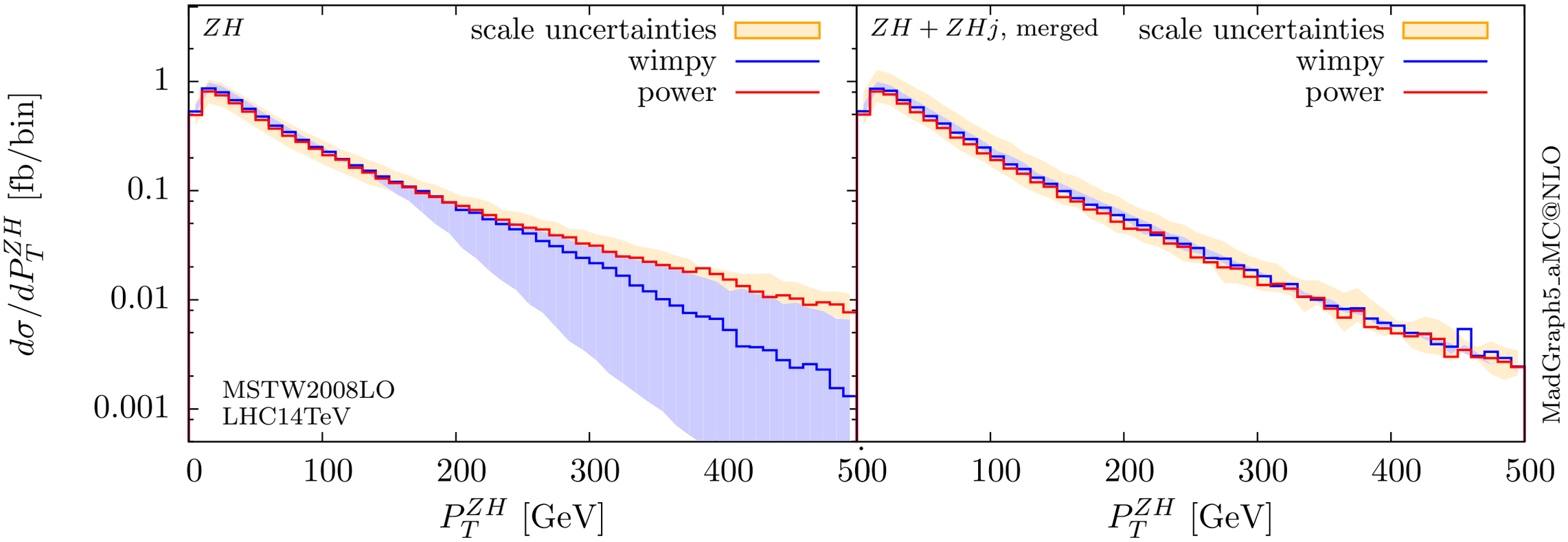
Shower-sensitive observable

Merged results: Stable

Non-merged: Large shower uncertainty

Merging-matching results (3)

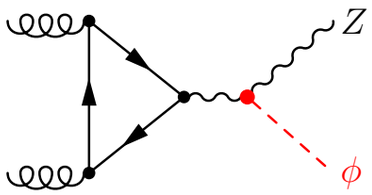
P_T of the HZ system

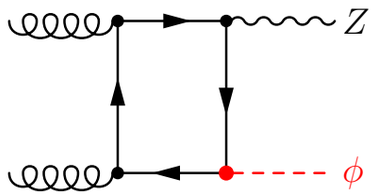


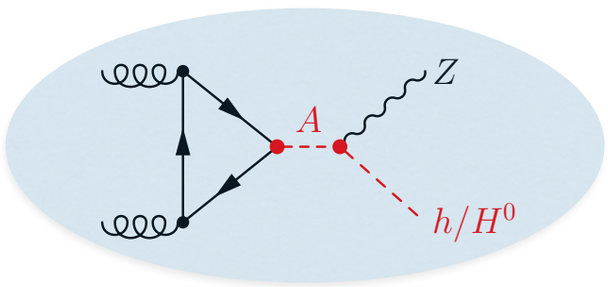
Extremely shower-sensitive observable (=0 at parton level)
Merged results: Stable

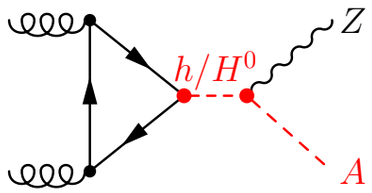
No big shape changes but significant reduction of shower related uncertainty

gluon induced Zϕ in the 2HDM



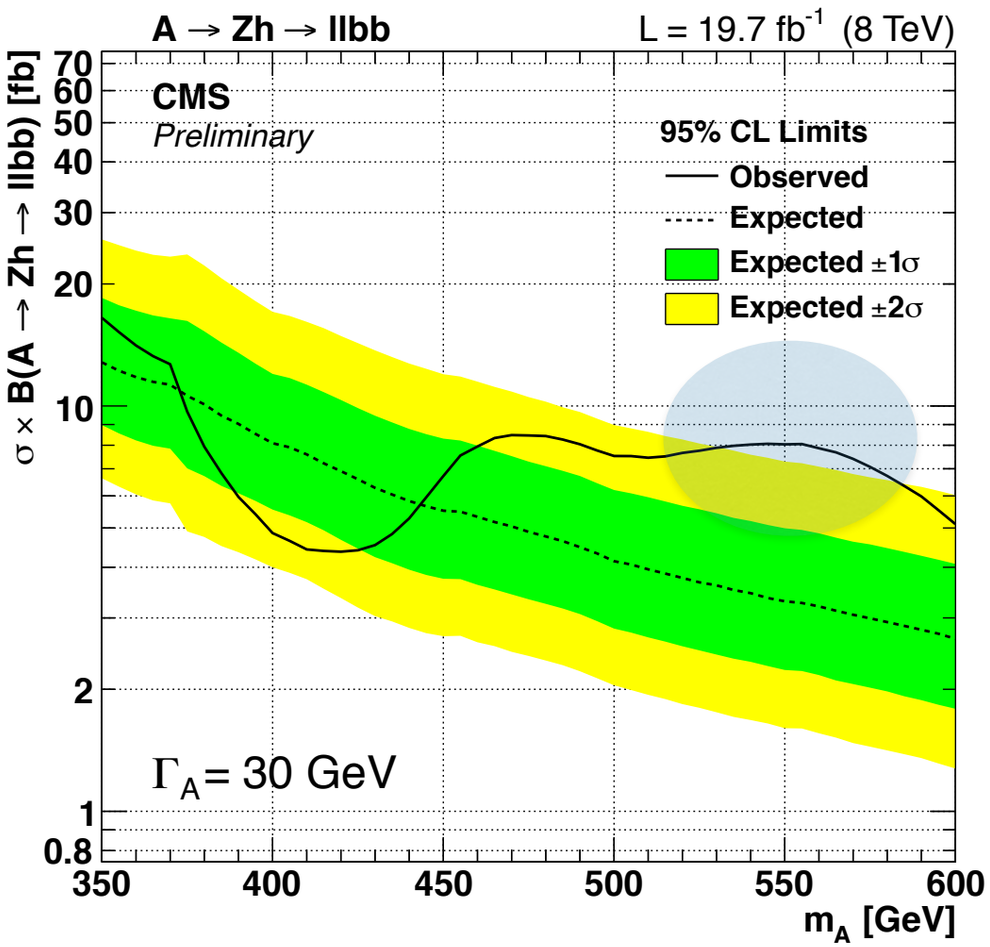






CMS search for heavy pseudoscalar decaying to Zh and 2HDM interpretation: exclusion limits

Possibility of resonances



CMS-PAS-HIG-14-011

Zϕ in 2HDM scenarios

Non-excluded 2HDM benchmarks

	$\tan\beta$	α/π	m_{H^0}	m_{A^0}	$m_{H^\pm}$	m_{12}^2
B1	1.75	-0.1872	300	441	442	38300
B2	1.20	-0.1760	200	500	500	-60000
B3	1.70	-0.1757	350	250	350	12000

	$gg \to Zh^0$	$gg \to ZH^0$	$gg \to ZA^0$
B1	$113\ ^{+30\%}_{-21\%}$	$686\ ^{+30\%}_{-22\%}$	$0.622\ ^{+32\%}_{-23\%}$
B2	$85.8\ ^{+30.1\%}_{-21\%}$	$1544\ ^{+30\%}_{-22\%}$	$0.869\ ^{+34\%}_{-23\%}$
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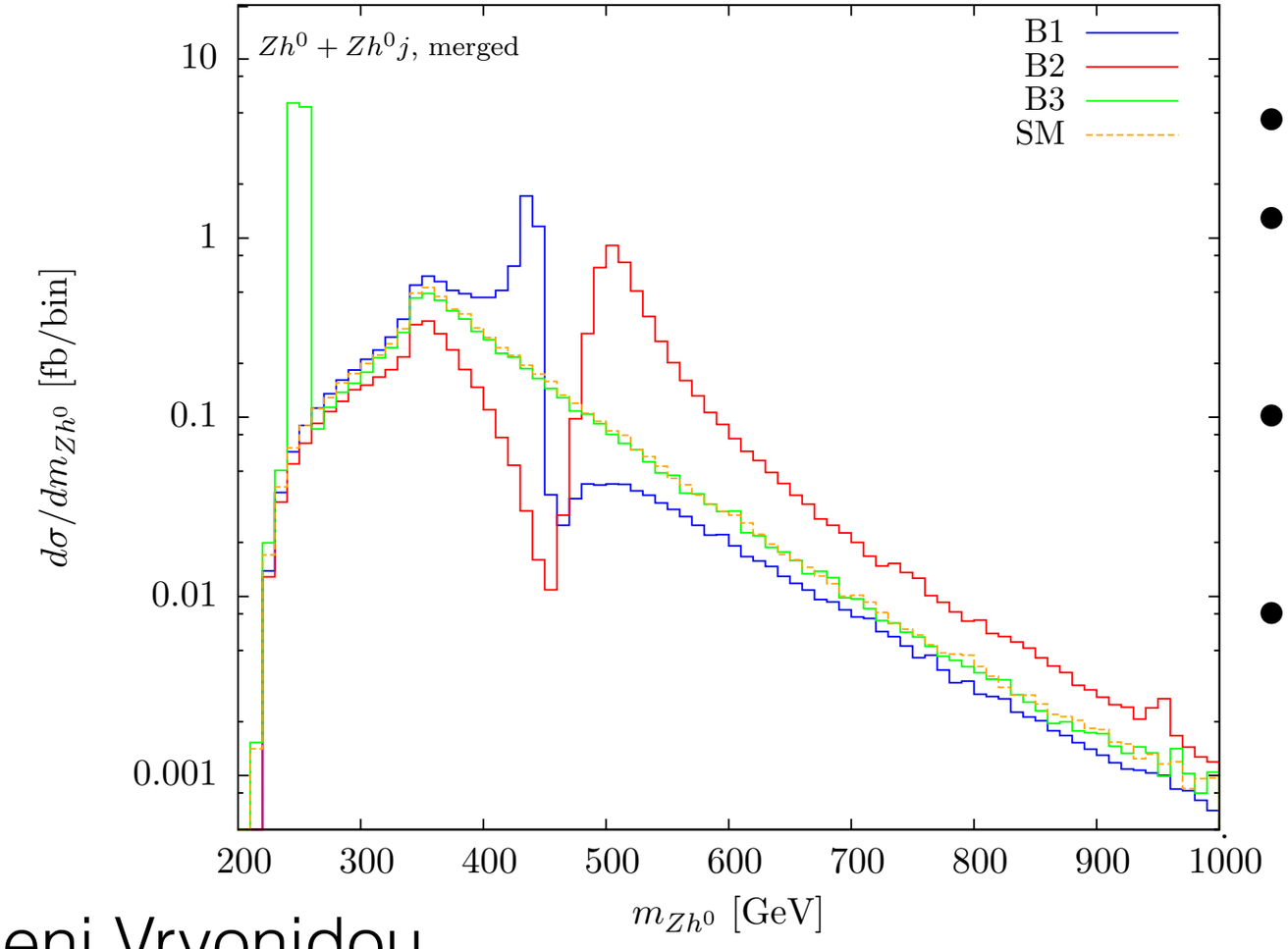

- Resonance peaks in ZH mass
- Interference with SM-like diagrams
- Small Higgs couplings modifications
- Production of ZA and ZH at the picobarn level

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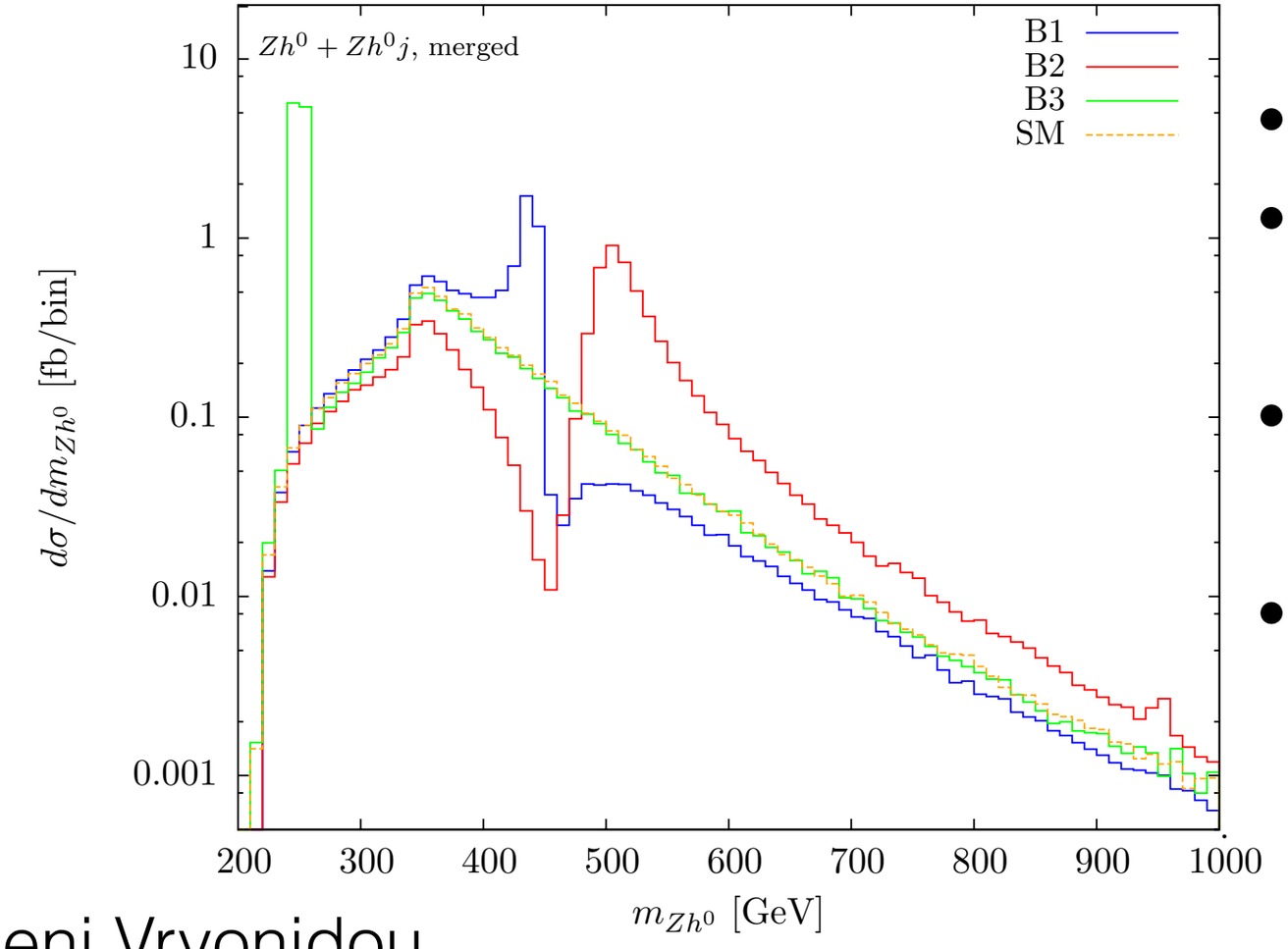

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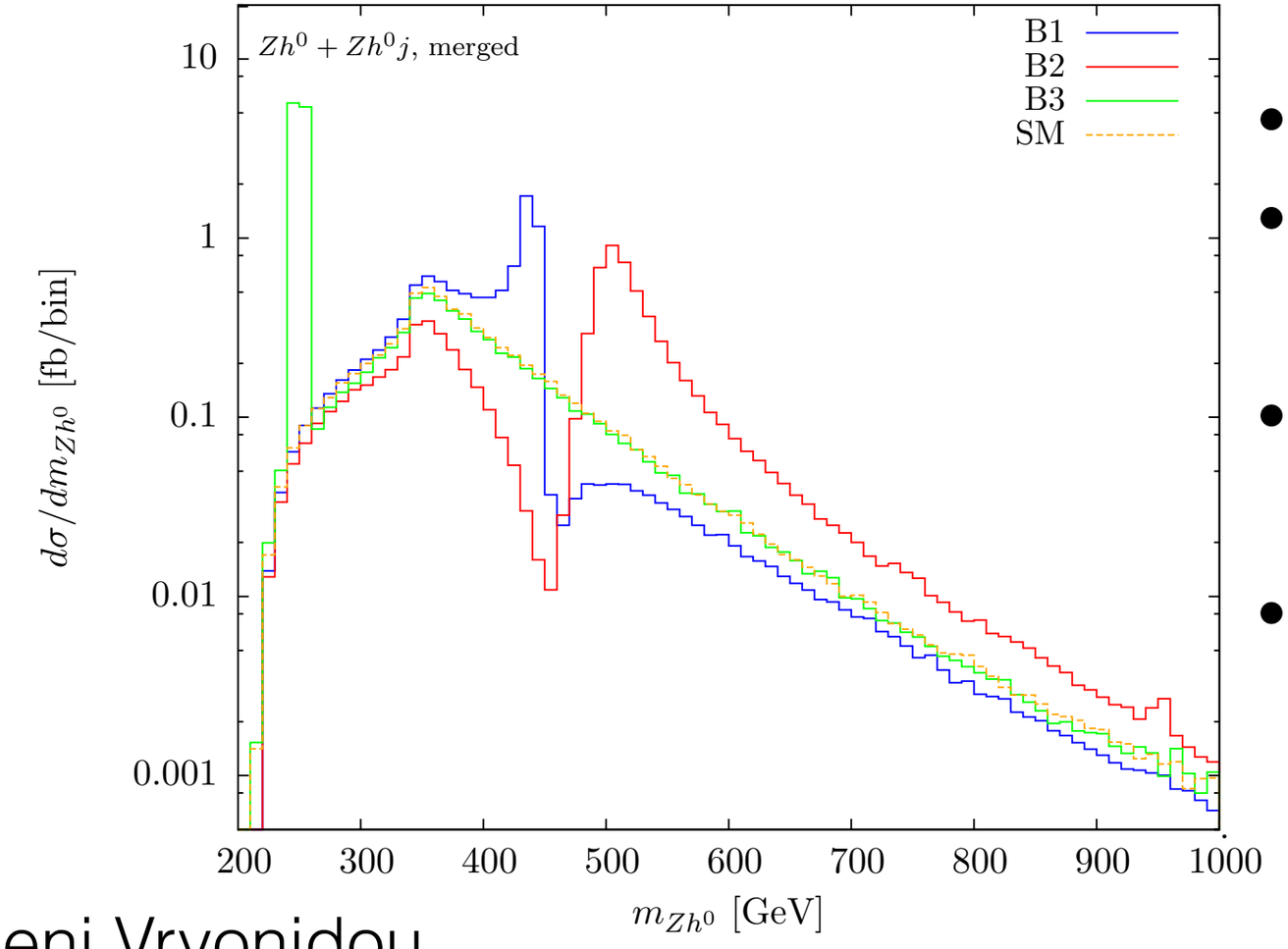

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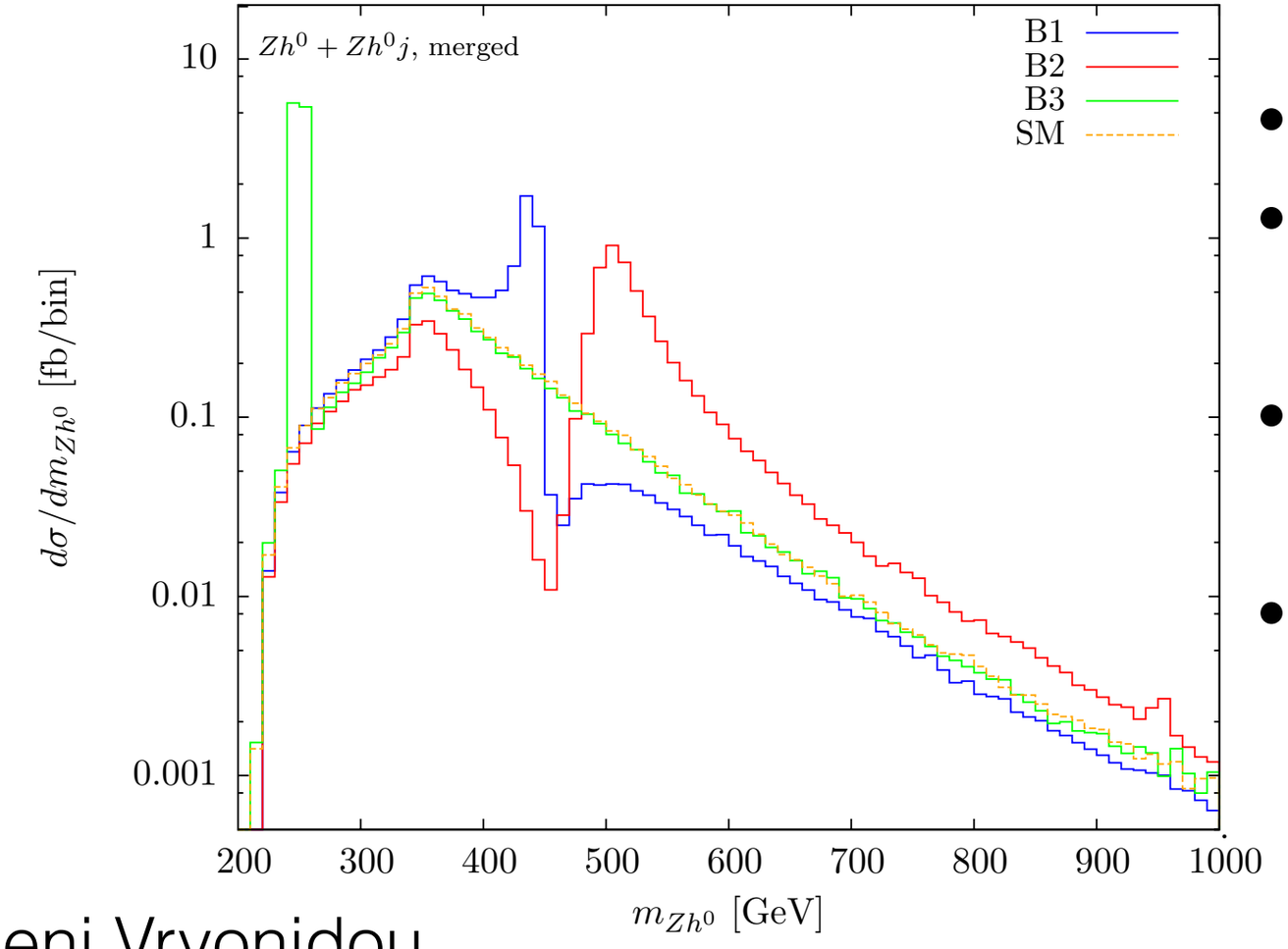

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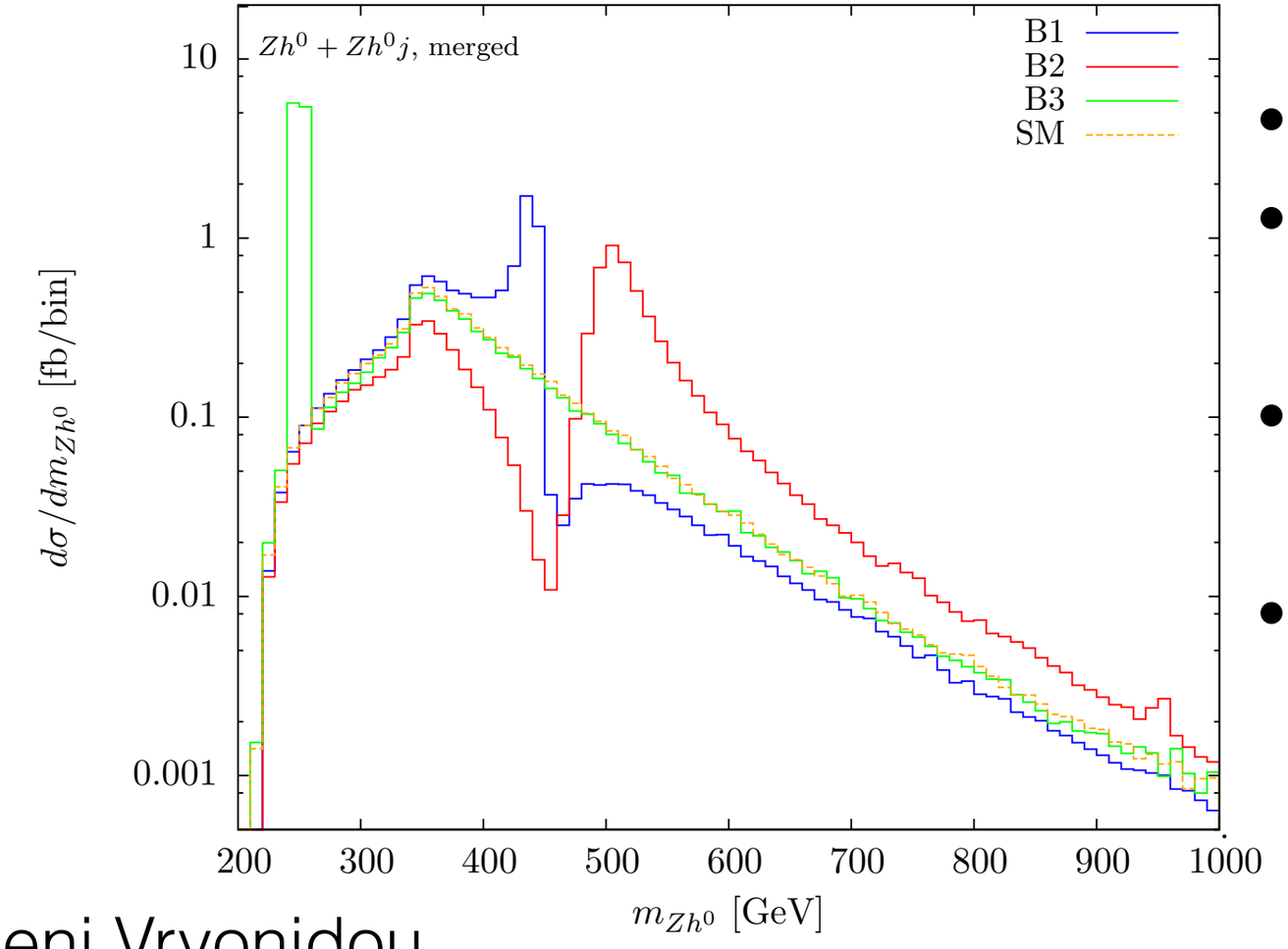

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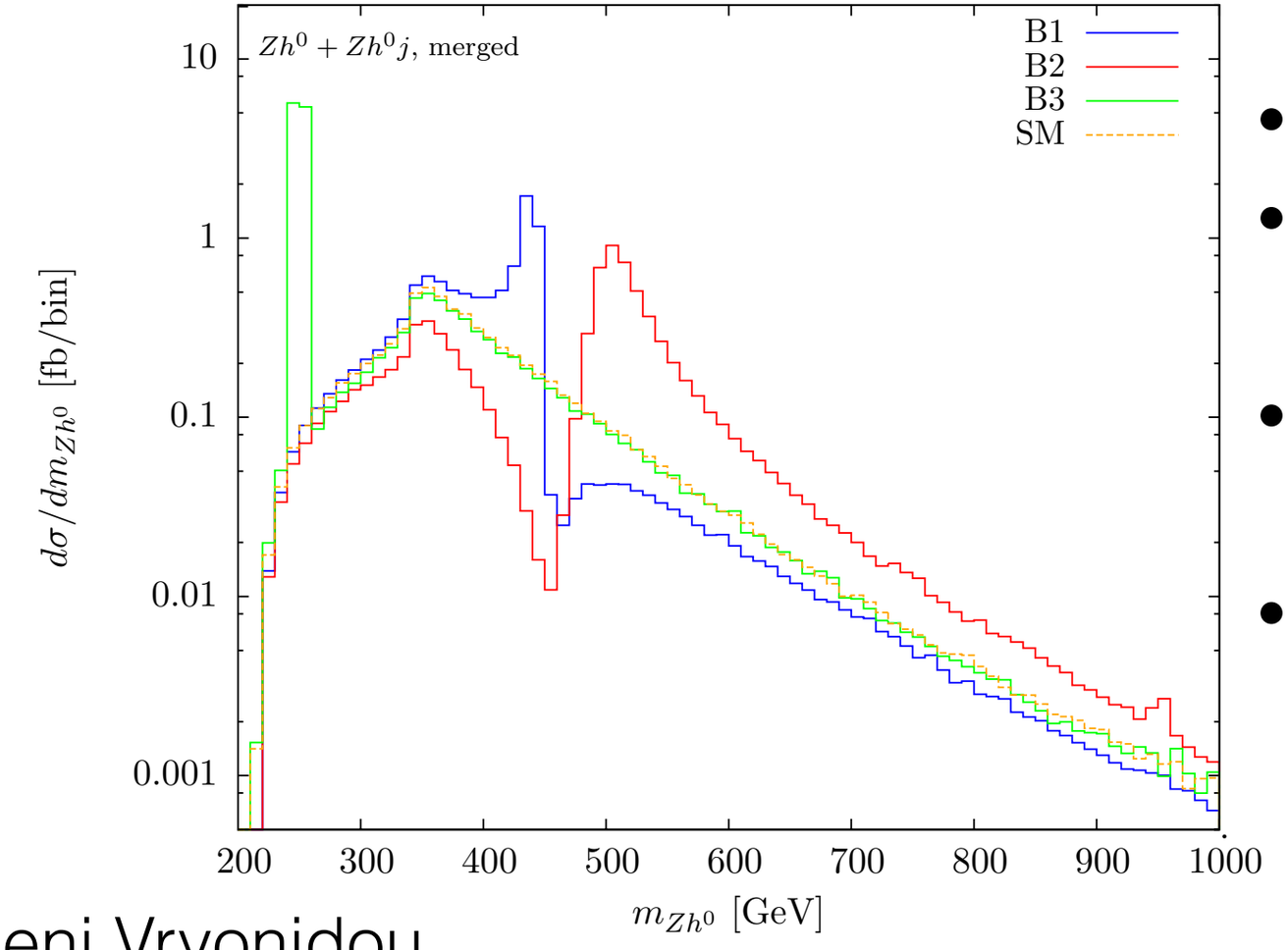
	$gg \to Zh^0$	$gg \to ZH^0$	$gg \to ZA^0$
B1	$113\ ^{+30\%}_{-21\%}$	$686\ ^{+30\%}_{-22\%}$	$0.622\ ^{+32\%}_{-23\%}$
B2	$85.8\ ^{+30.1\%}_{-21\%}$	$1544\ ^{+30\%}_{-22\%}$	$0.869\ ^{+34\%}_{-23\%}$
B3	$167\ ^{+31\%}_{-19\%}$	$0.891\ ^{+33\%}_{-21\%}$	$1325\ ^{+28\%}_{-21\%}$



- Resonance peaks in ZH mass
- Interference with SM-like diagrams
- Small Higgs couplings modifications
- Production of ZA and ZH at the picobarn level

Zϕ in 2HDM scenarios

Non-excluded 2HDM benchmarks

	$\tan\beta$	α/π	m_{H^0}	m_{A^0}	$m_{H^\pm}$	m_{12}^2
B1	1.75	-0.1872	300	441	442	38300
B2	1.20	-0.1760	200	500	500	-60000
B3	1.70	-0.1757	350	250	350	12000

	$gg \to Zh^0$	$gg \to ZH^0$	$gg \to ZA^0$
B1	$113\ ^{+30\%}_{-21\%}$	$686\ ^{+30\%}_{-22\%}$	$0.622\ ^{+32\%}_{-23\%}$
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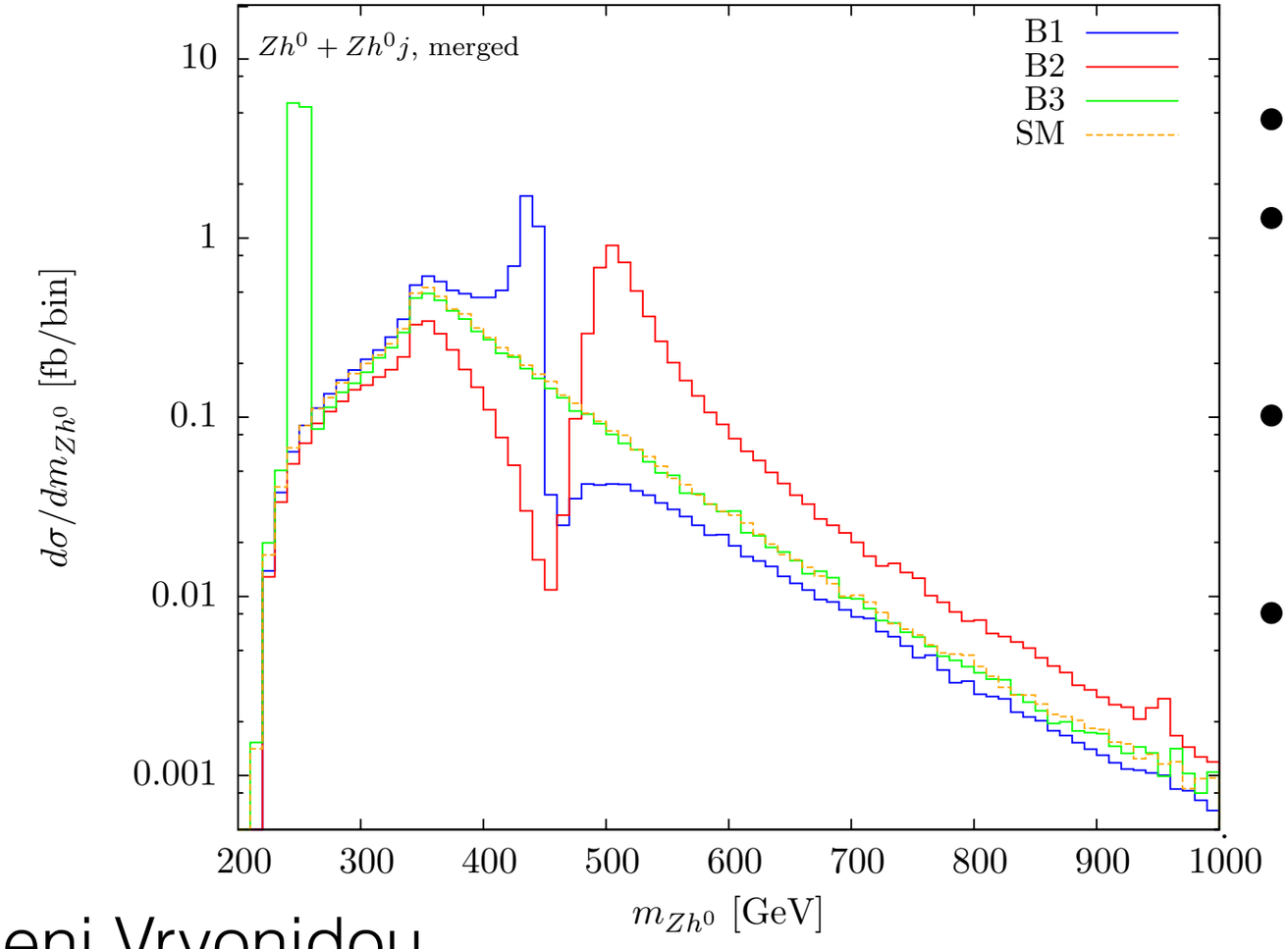

- Resonance peaks in ZH mass
- Interference with SM-like diagrams
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Conclusions-Outlook

- Higgs associated production yet to be measured accurately at the LHC
- Gluon-gluon fusion component important for high p_T searches at the LHC
- Additional jet ZHj loop amplitudes contributing significantly in the high Higgs p_T region
- More accurate description achieved by merging and matching of 0 and 1-jet amplitudes
- Interesting possibilities in the 2HDM: resonant production and decay of the heavier states

Thank you for your attention