

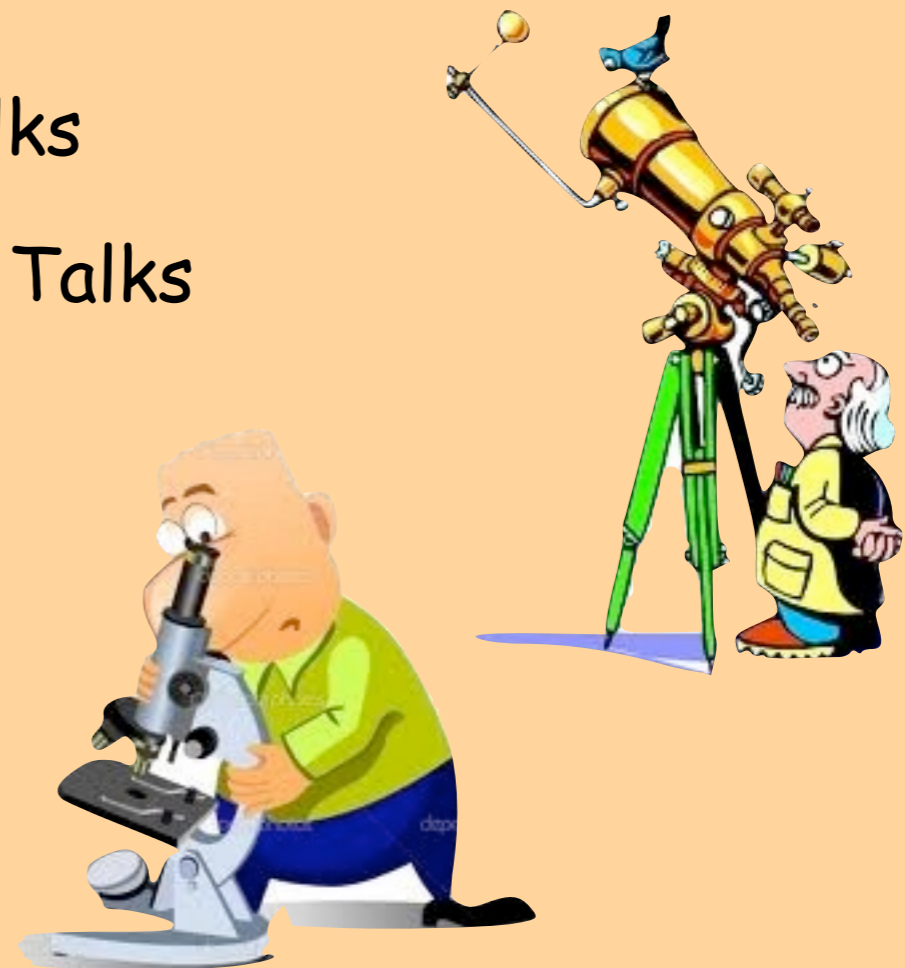
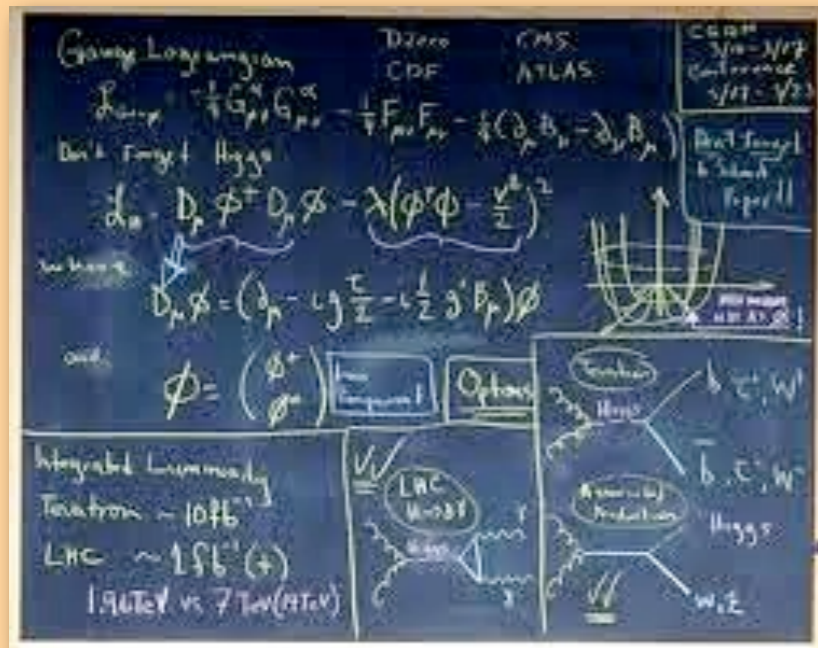
WG3: EW Physics and BSM Theory Summary

Maxime Gouzevitch, Anna Kaczmarska

Krzysztof Turzynski, Margarete Mühlleitner

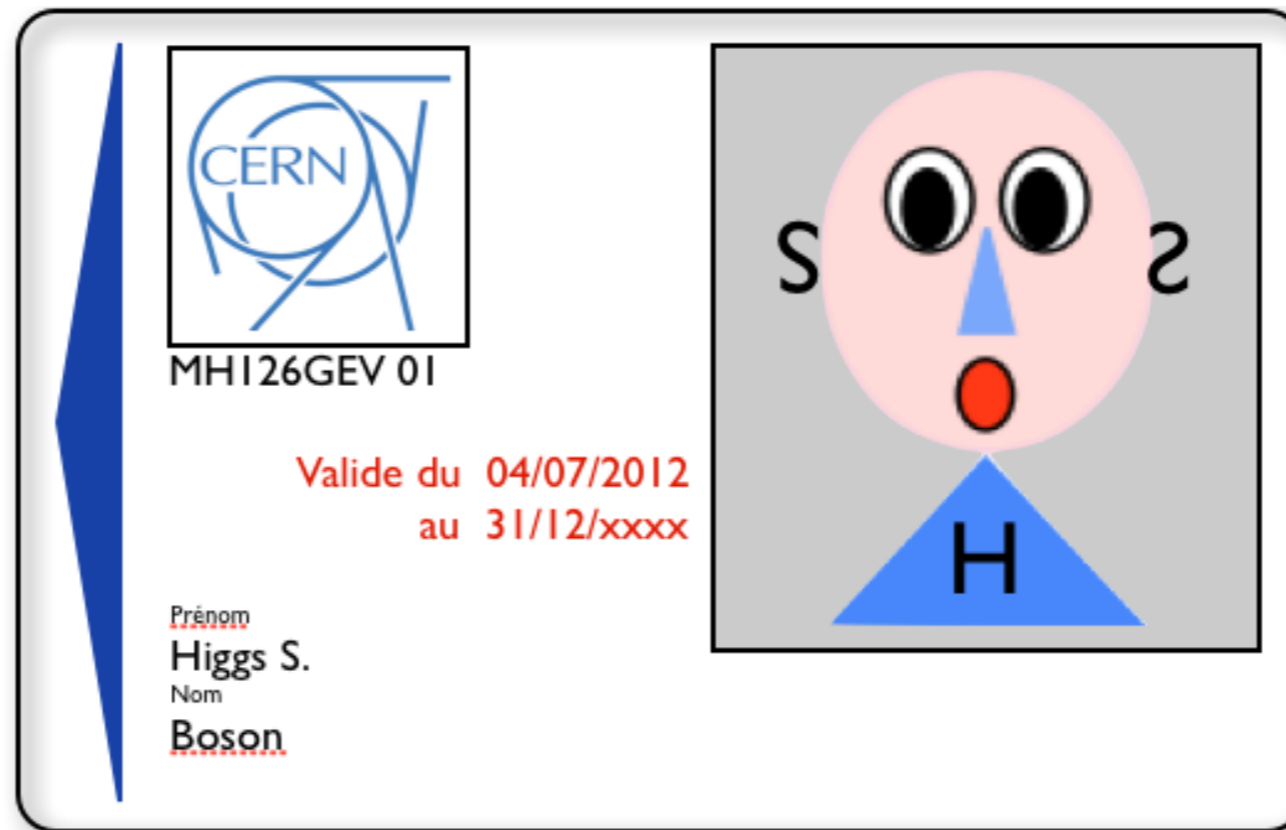
13 Theory Talks

24 Experimental Talks



Where Do We Stand?

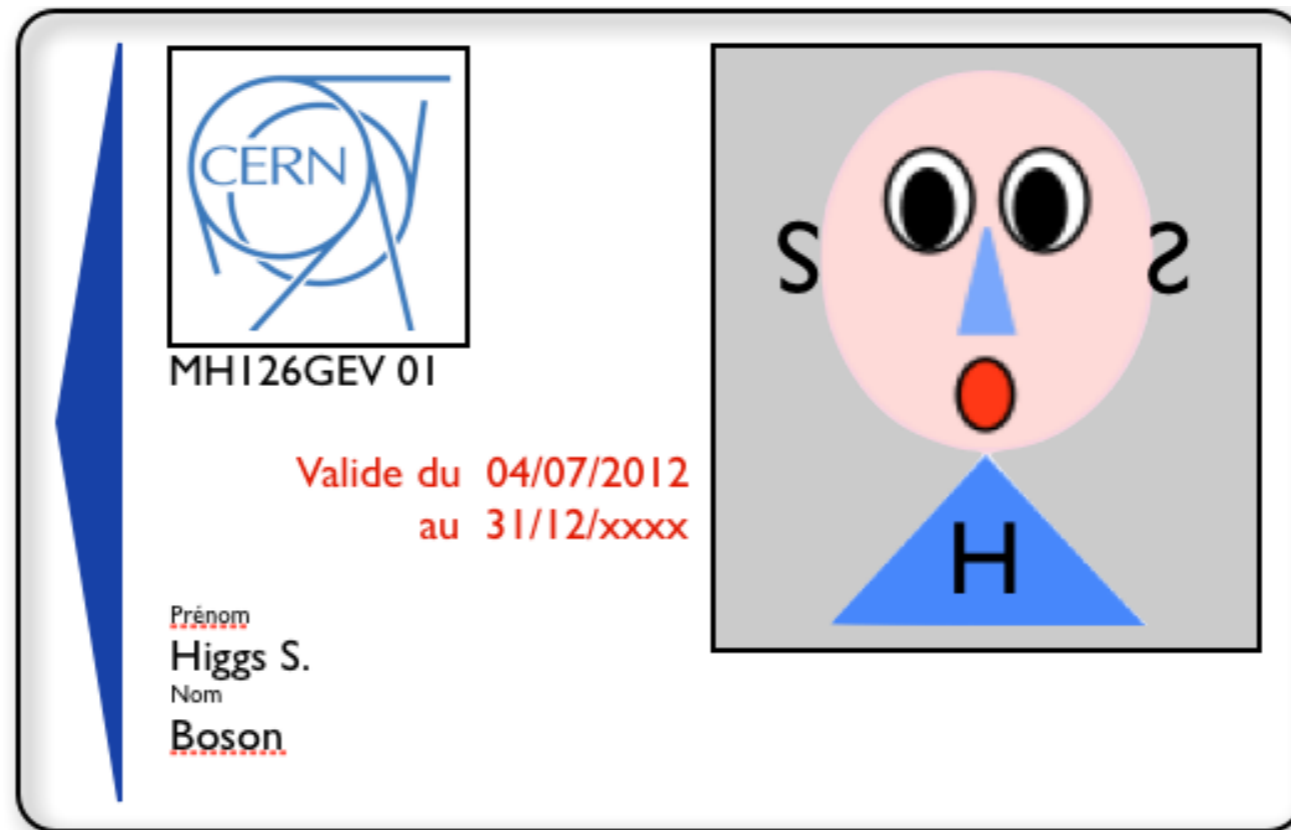
4th July 2012: Discovery of a scalar particle



Behaves very SM-like

Where Do We Stand?

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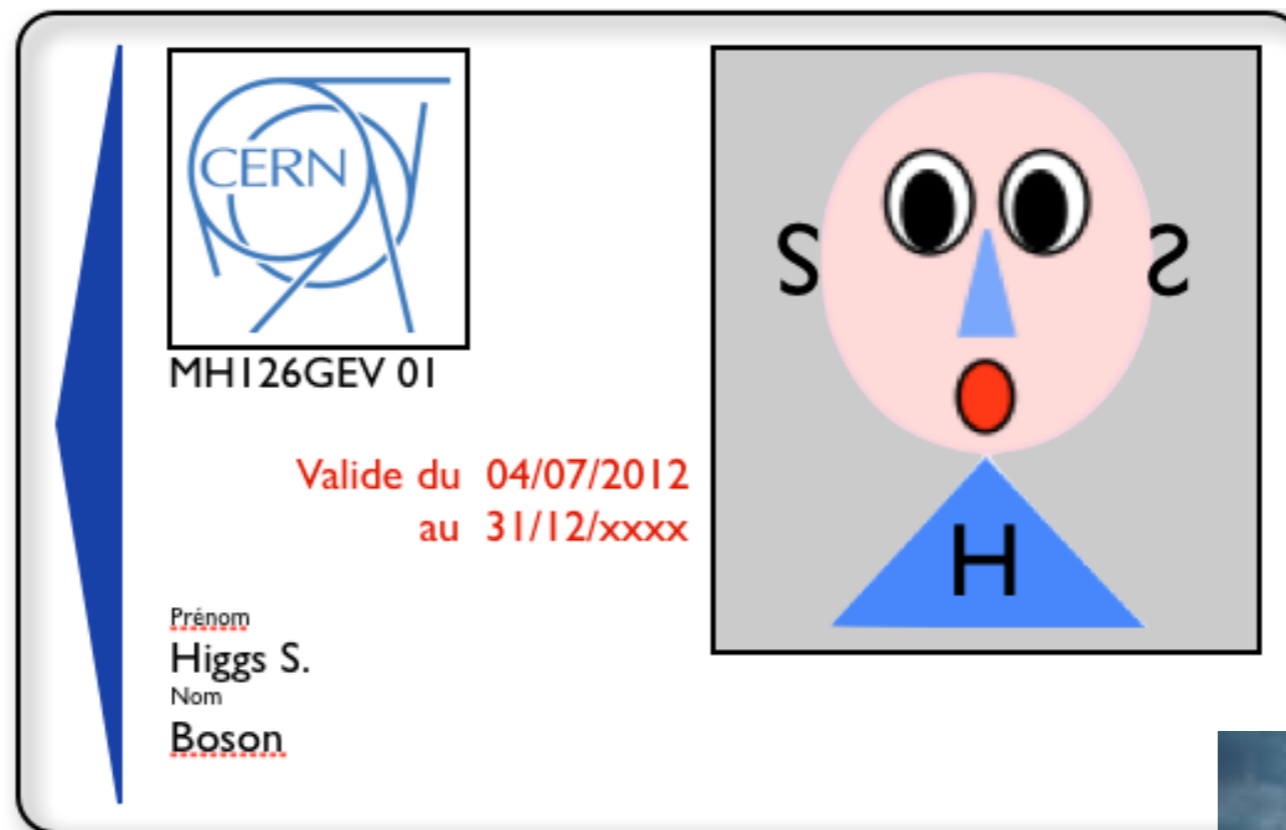


Behaves very SM-like

No direct hint of New Physics so far

Where Do We Stand?

4th July 2012: Discovery of a scalar particle



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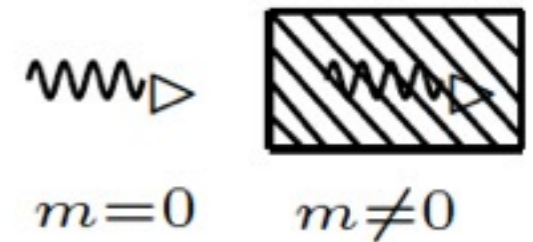
No direct hint of New Physics so far



What Have We Seen?

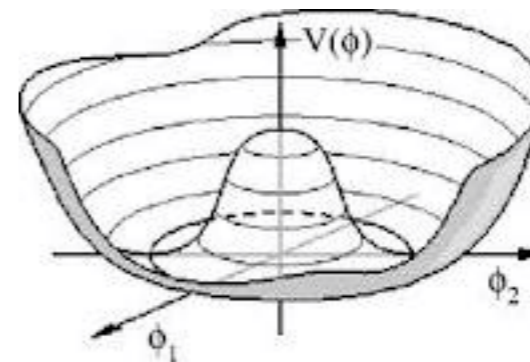
- ★ The production of a new particle with mass around 126 GeV
- ★ Is it the Standard Model Higgs boson?

* Higgs interactions with SM particles $g \sim \text{mass}$



* Spin and CP quantum numbers

* Higgs self-interactions



- ★ Is it a SM Higgs boson, a SUSY Higgs boson, a composite Higgs ...?

Rick S. Gupta: *BSM Primary Effects*

- ◆ Construction of dim-6 Lagrangian starting from measurable deformations (bottom-up)

$$\begin{aligned}\Delta\mathcal{L}_{\text{BSM}} = & \Delta\mathcal{L}_{\gamma\gamma}^h + \Delta\mathcal{L}_{Z\gamma}^h + \Delta\mathcal{L}_{GG}^h + \Delta\mathcal{L}_{ff}^h + \Delta\mathcal{L}_{3h} \\ & + \Delta\mathcal{L}_{VV}^h + \Delta\mathcal{L}_{ee}^V + \Delta\mathcal{L}_{qq}^V + \Delta\mathcal{L}_R^W + \Delta\mathcal{L}_{\text{dipole}}^V \\ & + \Delta\mathcal{L}_{g_1^Z} + \Delta\mathcal{L}_{\kappa\gamma} + \Delta\mathcal{L}_{\lambda\gamma} + \Delta\mathcal{L}_{3G} + \Delta\mathcal{L}_{4f} + \Delta\mathcal{L}_{\text{CPV}}\end{aligned}$$

- ◆ 18 primary deformations plus four-fermion deformations, MFV suppressed deformations, CP violating deformations
- ◆ All physical processes, e.g. $h \rightarrow Vff$, $pp \rightarrow Vh$, $VV \rightarrow h$, can be computed as a function of the BSM primary parameters using the above Lagrangian

Rick S. Gupta: *BSM Primary Effects*

- ♦ Construction of dim-6 Lagrangian starting from measurable deformations (bottom-up)

8 Higgs primaries

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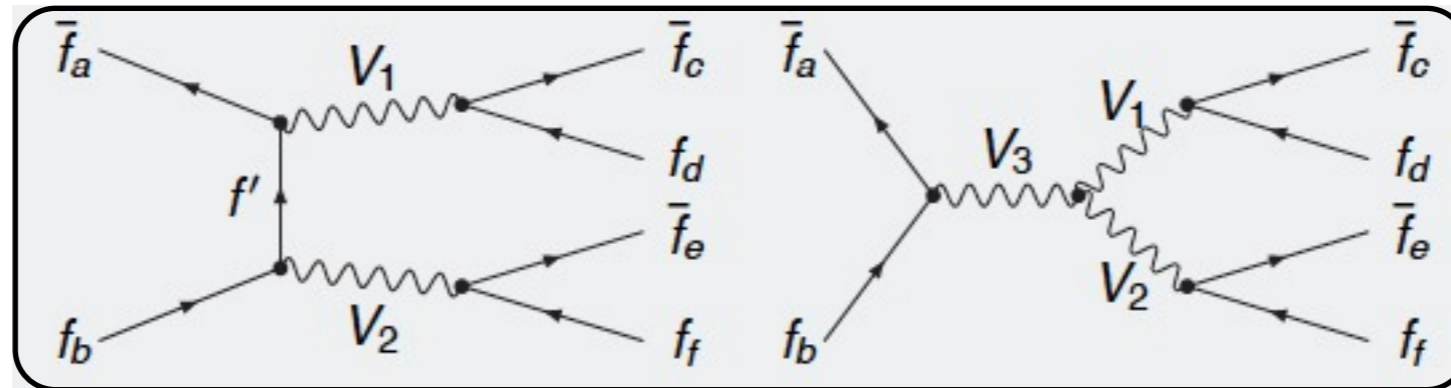
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3 TGC primaries

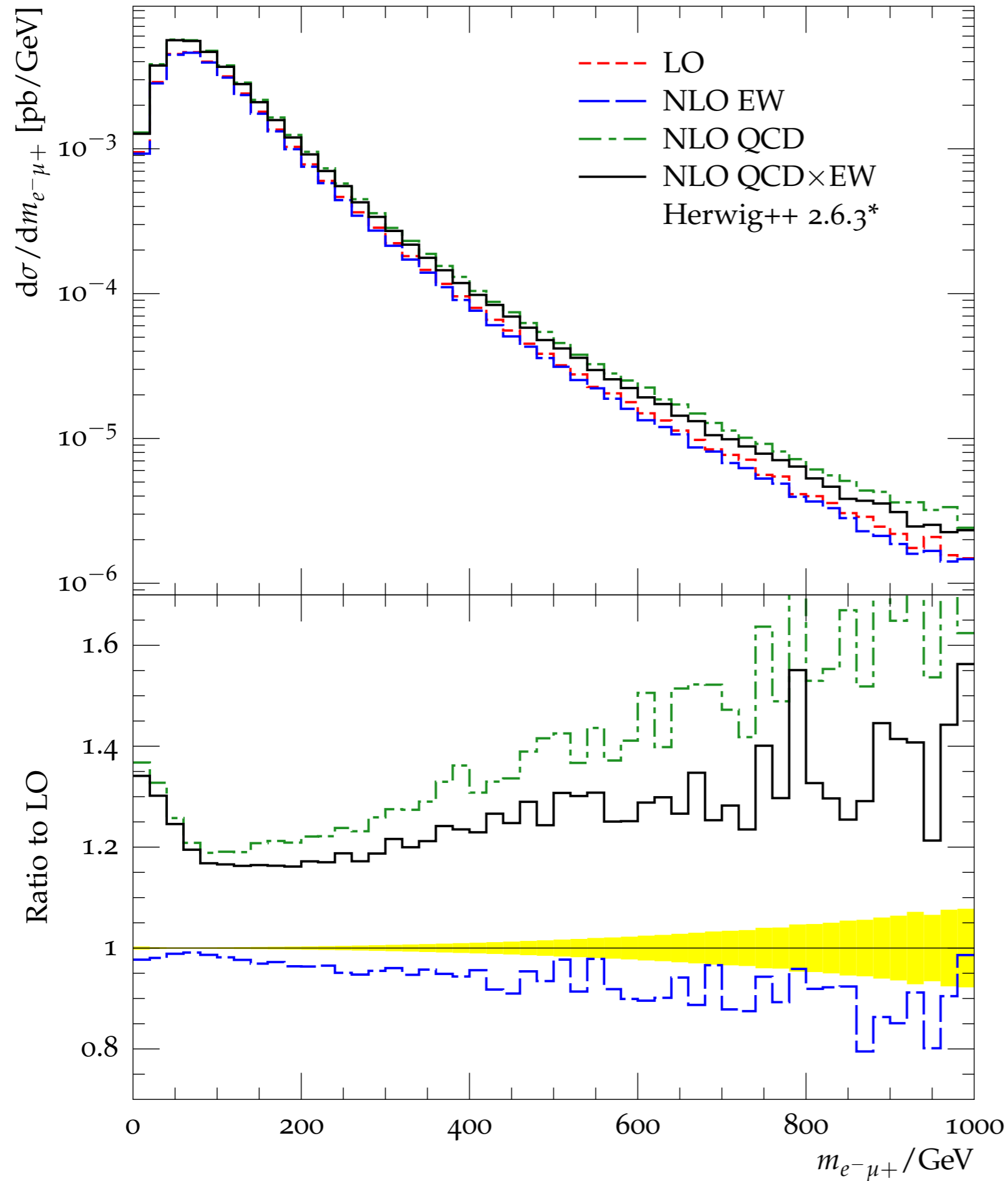
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Tobias Kasprzik: Vector Boson Pair Production at the \mathcal{LHC}



- * important **irreducible background** to incl Higgs production
- * probe **non-Abelian structure** of the SM
- * search **for anomalous couplings**
- * backgrounds to **New Physics searches**
- * need **precise theoretical predictions**

$pp \rightarrow e^- \bar{\nu}_e \mu^+ \nu_\mu$ at LHC, $\sqrt{s} = 13$ TeV



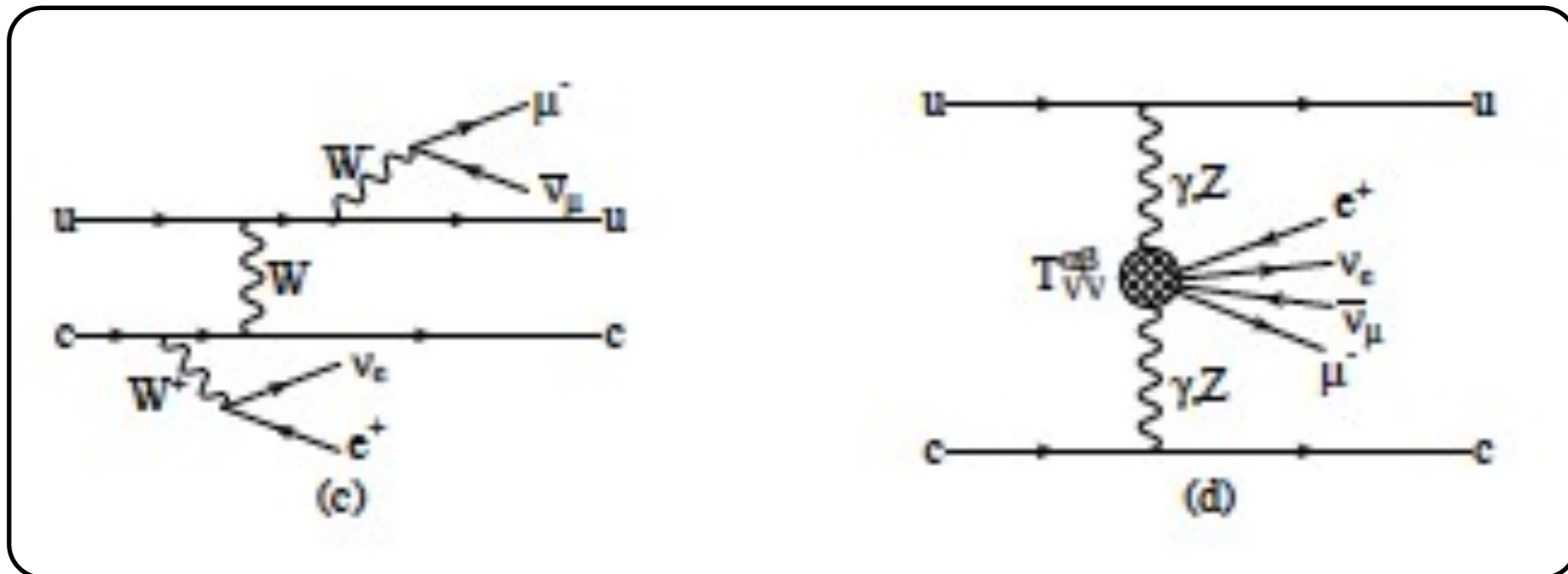
[Gieseke, Kasprzik, Kühn]

$\mathcal{E}W$ Corrections to V -Pair

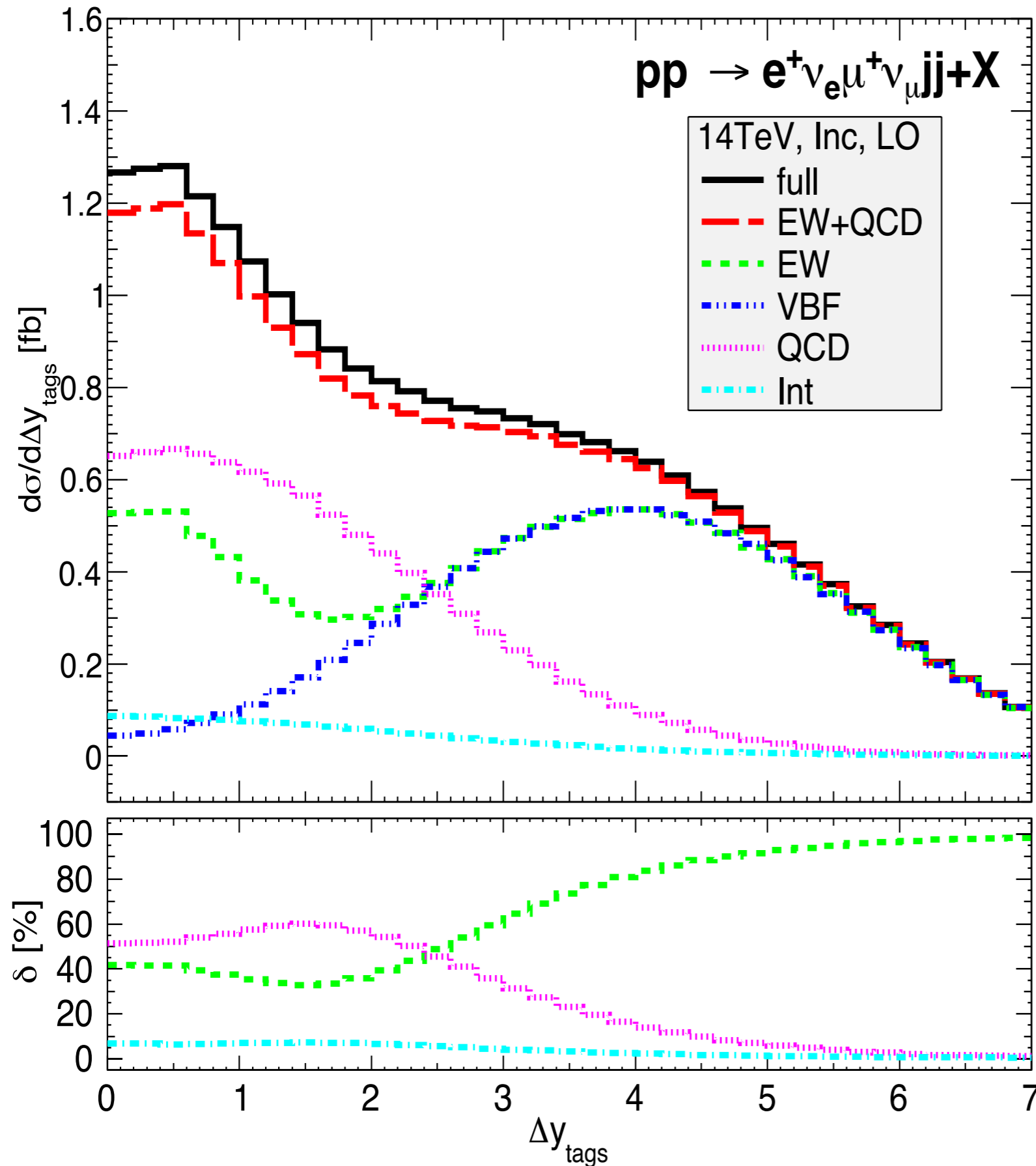
Production in HERWIG++

- 1) Inclusion of EW corrections into state-of-the-art Monte Carlo prediction using differential K-factors
- 2) Increasingly negative EW corrections for high invariant masses and transverse momenta
- 3) Assume factorization of EW and QCD corrections \rightarrow require back-to-back vector bosons \rightarrow jet veto to reduce hard QCD activity

Michael Rauch: Multi-Boson Production in Weak Boson Fusion



- * important process for testing the SM
- * constrain/discover anomalous quartic couplings
- * test unitarity
- * need precise theoretical predictions



1) VBF process characterized by two jets in forward regions \rightarrow large m_{jj} and large Δy_{jj}

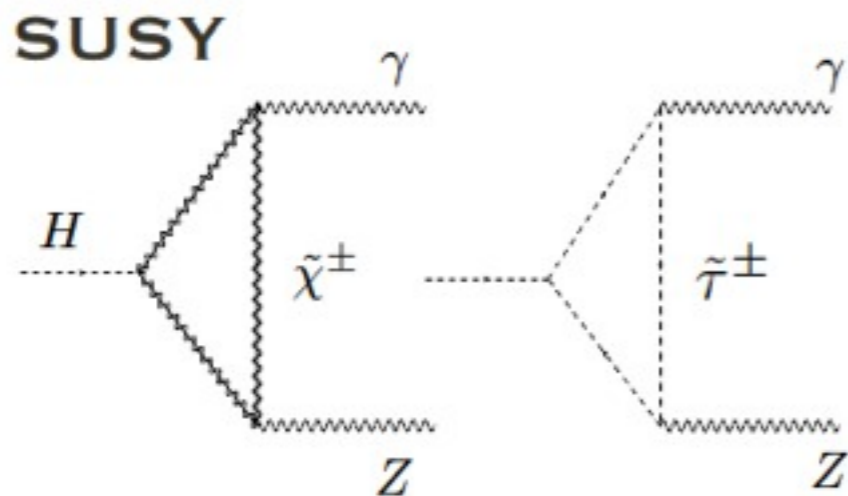
2) (irreducible) QCD-induced background small in this region, also QCD-EW interference very small;
for tight VBF cuts ($\Delta y_{jj} > 4$, $m_{jj} > 500 \text{ GeV}$, $y_1 \cdot y_2 < 0$) only 4% non-VBF contribution

Marta Luszczak: *Production of W^+W^- Pairs via Subleading Processes*

- Large contribution of photon induced processes
- Inelastic-inelastic photon-photon contribution large when photon treated as parton in the nucleon
- Resolved photon contribution are rather small
- Diffractive production with rapidity gap interesting by itself (could be measured ?)
- Diffractive contribution to inclusive cross section unclear
- In the future we have to include decays of W bosons

Veronica Sanz: Higgs Spin and CP at the \mathcal{LHC}

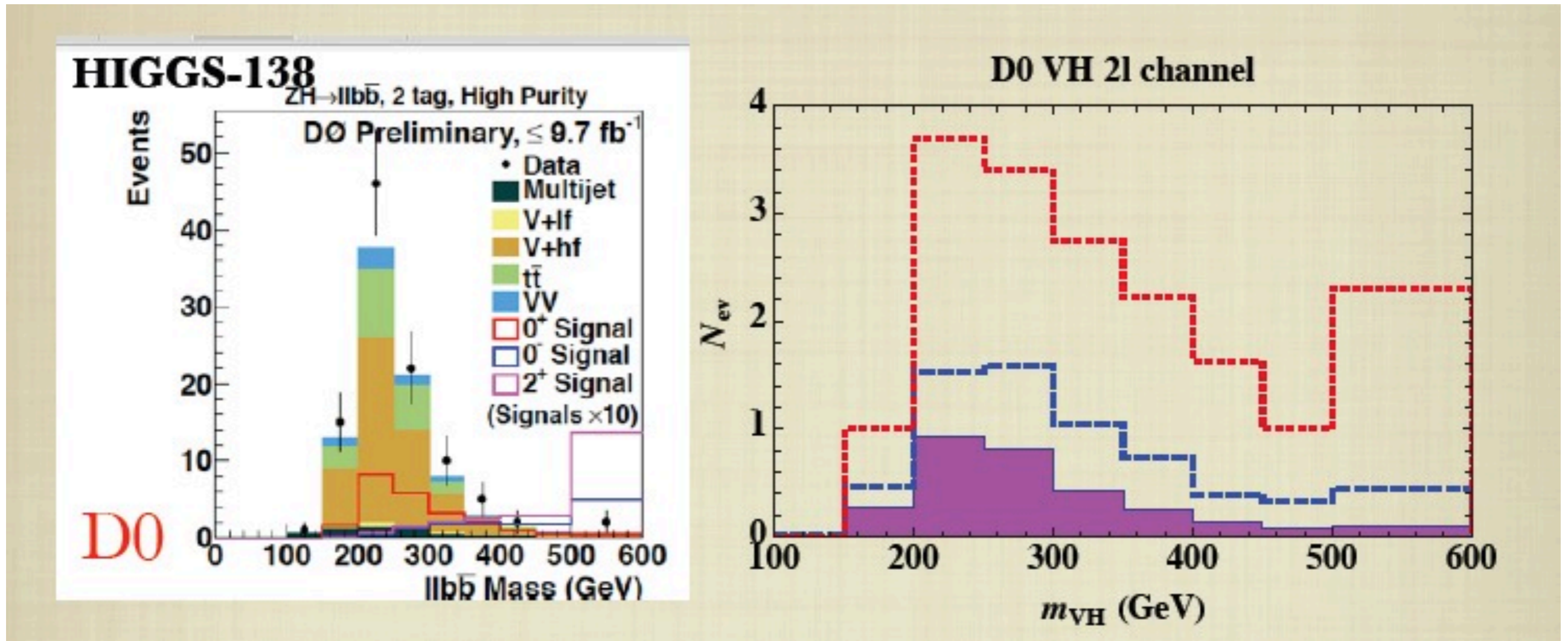
- * Non-SM Spin or CP ->
tensor structure of Higgs coupling changes
- * limits on KK graviton also applicable to spin-2 resonances
from strong interactions (e.g. technicolor) [Fok,Guimaraes,Lewis,Sanz]
- * heavy new physics -> Higgs EFT
similar kinematic features as when looking for Higgs QN



$$\begin{aligned}\mathcal{O}_W &= (D_\mu \Phi)^\dagger \widehat{W}^{\mu\nu} (D_\nu \Phi) \\ \mathcal{O}_B &= (D_\mu \Phi)^\dagger (D_\nu \Phi) \widehat{B}^{\mu\nu} \\ \mathcal{O}_{WW} &= \Phi^\dagger \widehat{W}^{\mu\nu} \widehat{W}_{\mu\nu} \Phi \\ \mathcal{O}_{BB} &= (\Phi^\dagger \Phi) \widehat{B}^{\mu\nu} \widehat{B}_{\mu\nu}\end{aligned}$$

- * need go beyond reporting signal strengths

Veronica Sanz: *Higgs Spin and CP at the LHC*



kinematics in associated production (pTV) already crucial for global fits

[Ellis,Sanz,You]

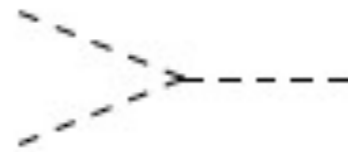
Julien Baglio: Theory Review of \mathcal{LHC} Triple Higgs Coupling Studies

The EWSB potential:

$$V(H) = \frac{1}{2!} \lambda_{HH} H^2 + \frac{1}{3!} \lambda_{HHH} H^3 + \frac{1}{4!} \lambda_{HHHH} H^4$$

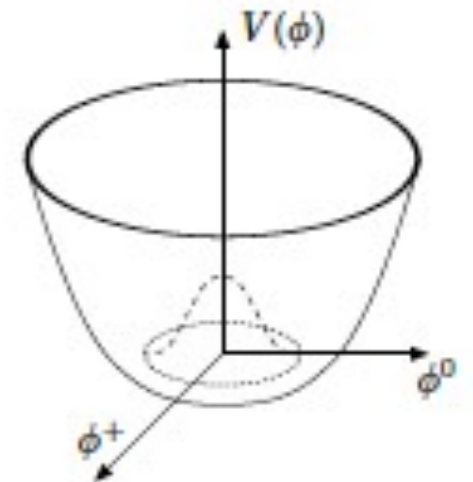
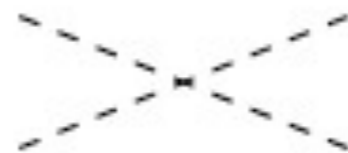
Trilinear coupling

$$\lambda_{HHH} = 3 \frac{M_H^2}{v}$$



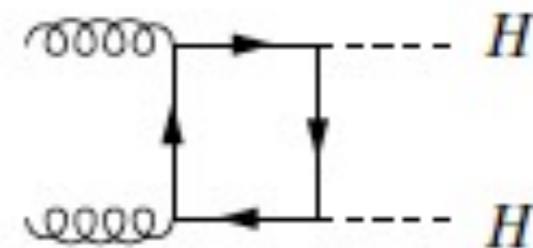
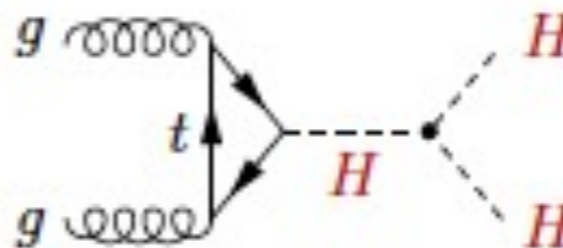
Quartic coupling

$$\lambda_{HHHH} = 3 \frac{M_H^2}{v^2}$$



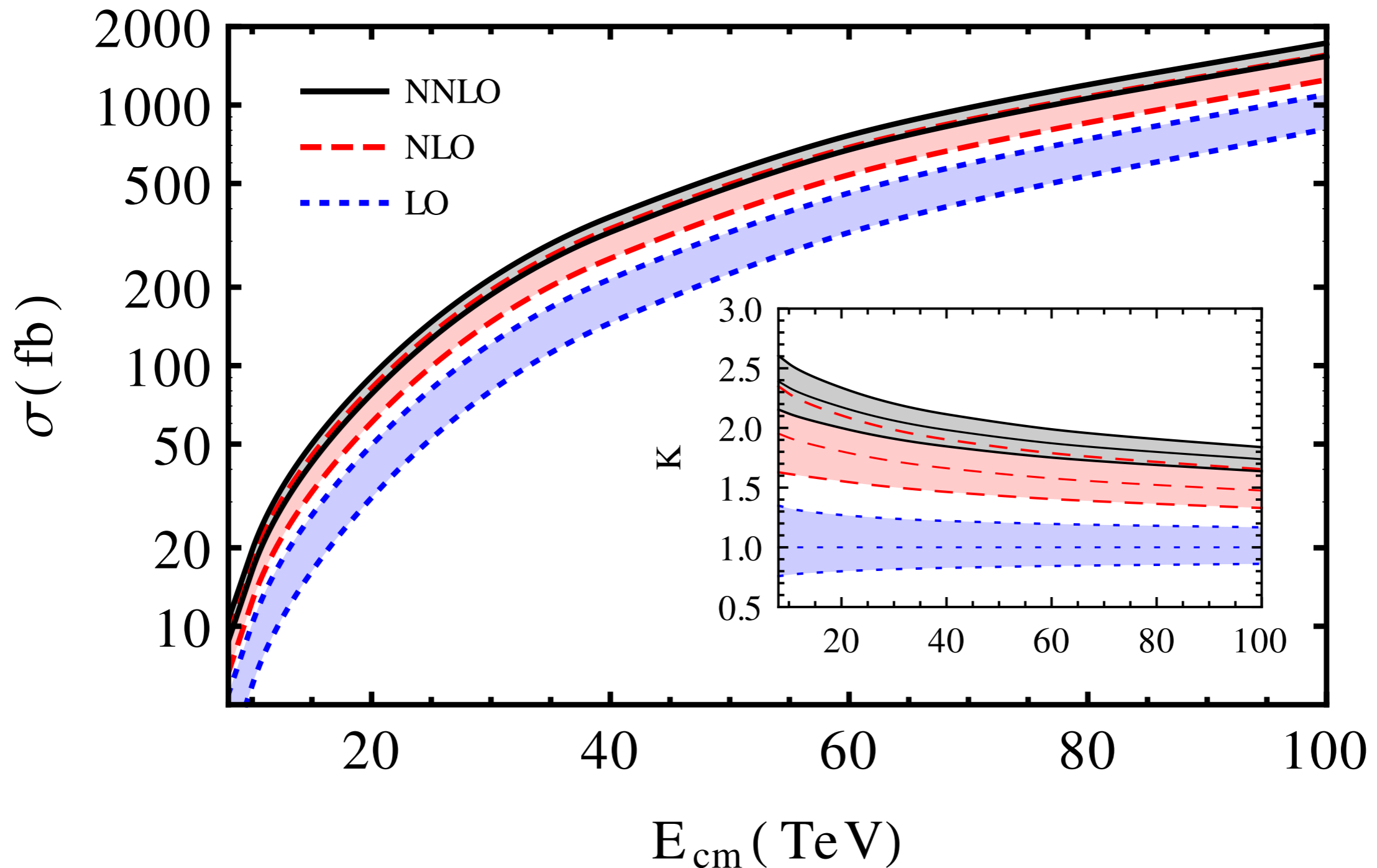
Measurement of Higgs self-couplings \rightarrow reconstruct Higgs potential

gluon gluon fusion - dominant process

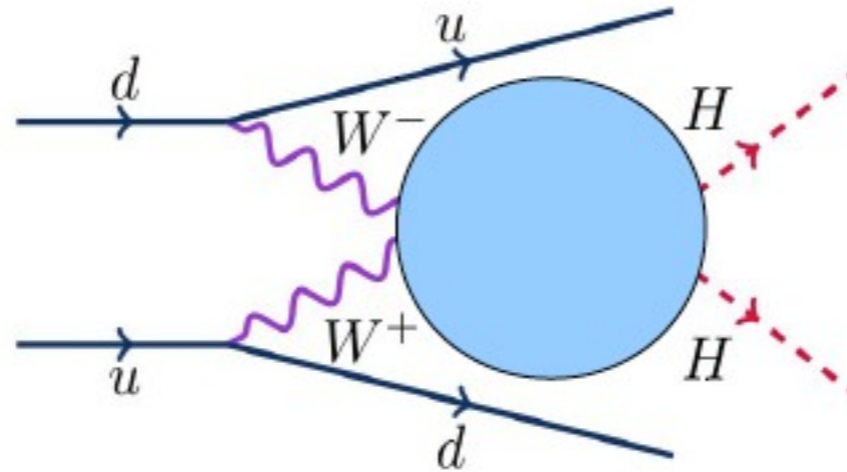


Julien Baglio: *Theory Review of \mathcal{LHC} Triple Higgs Coupling Studies*

[De Florian, Mazzitelli]

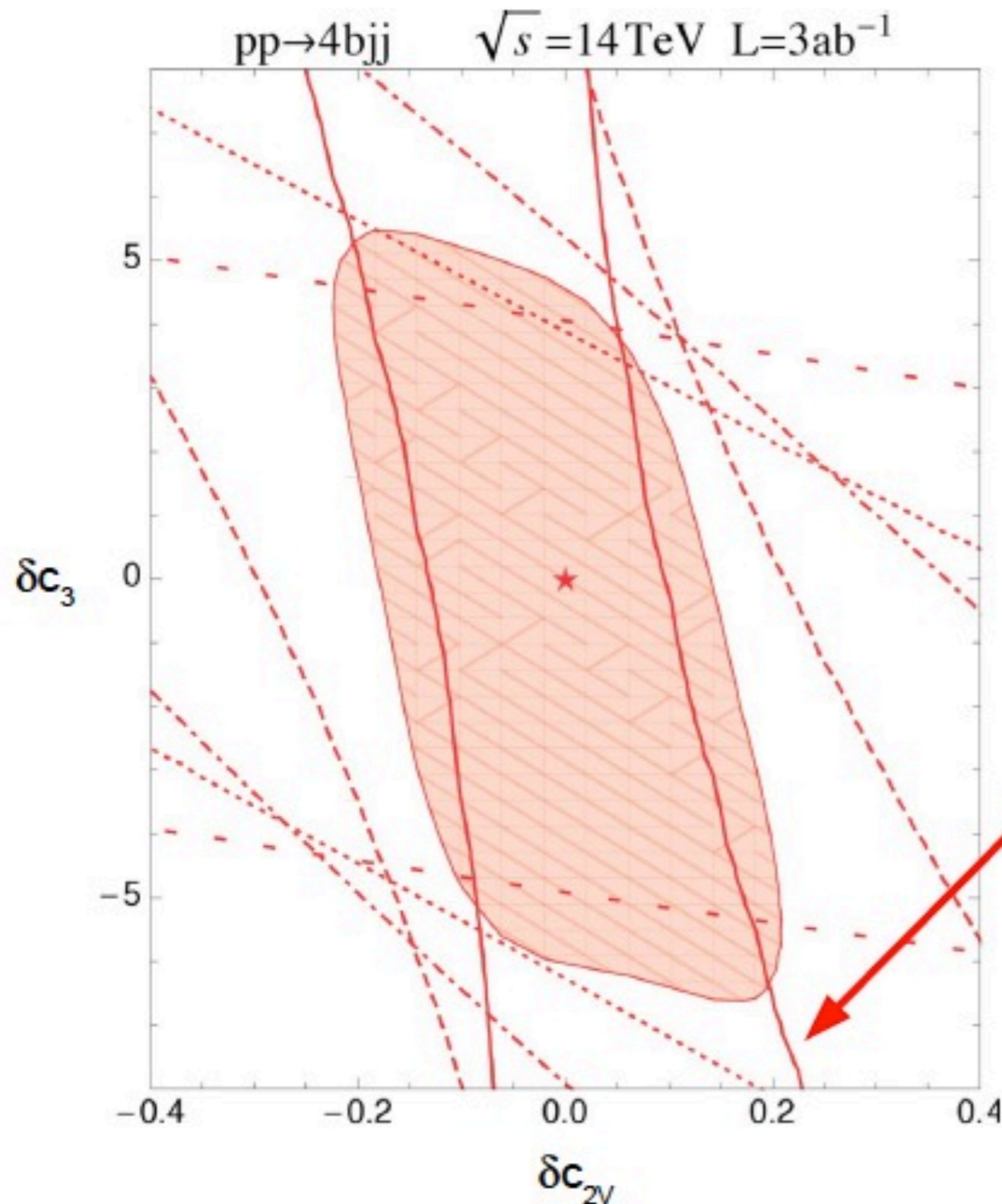


Andrea Massironi: *Higgs Pair Production via Vector Boson Fusion at the LHC*



- + Higgs pair production can be substantially enhanced in BSM
 - # on-shell resonance decaying into 2 Higgs bosons
 - # modified couplings
- + Resonant VBF di-Higgs search
- + Non-resonant VBF di-Higgs search at parton level
- + Non-resonant VBF di-Higgs search at hadron level

Andrea Massironi: Higgs Pair Production via Vector Boson Fusion at the LHC



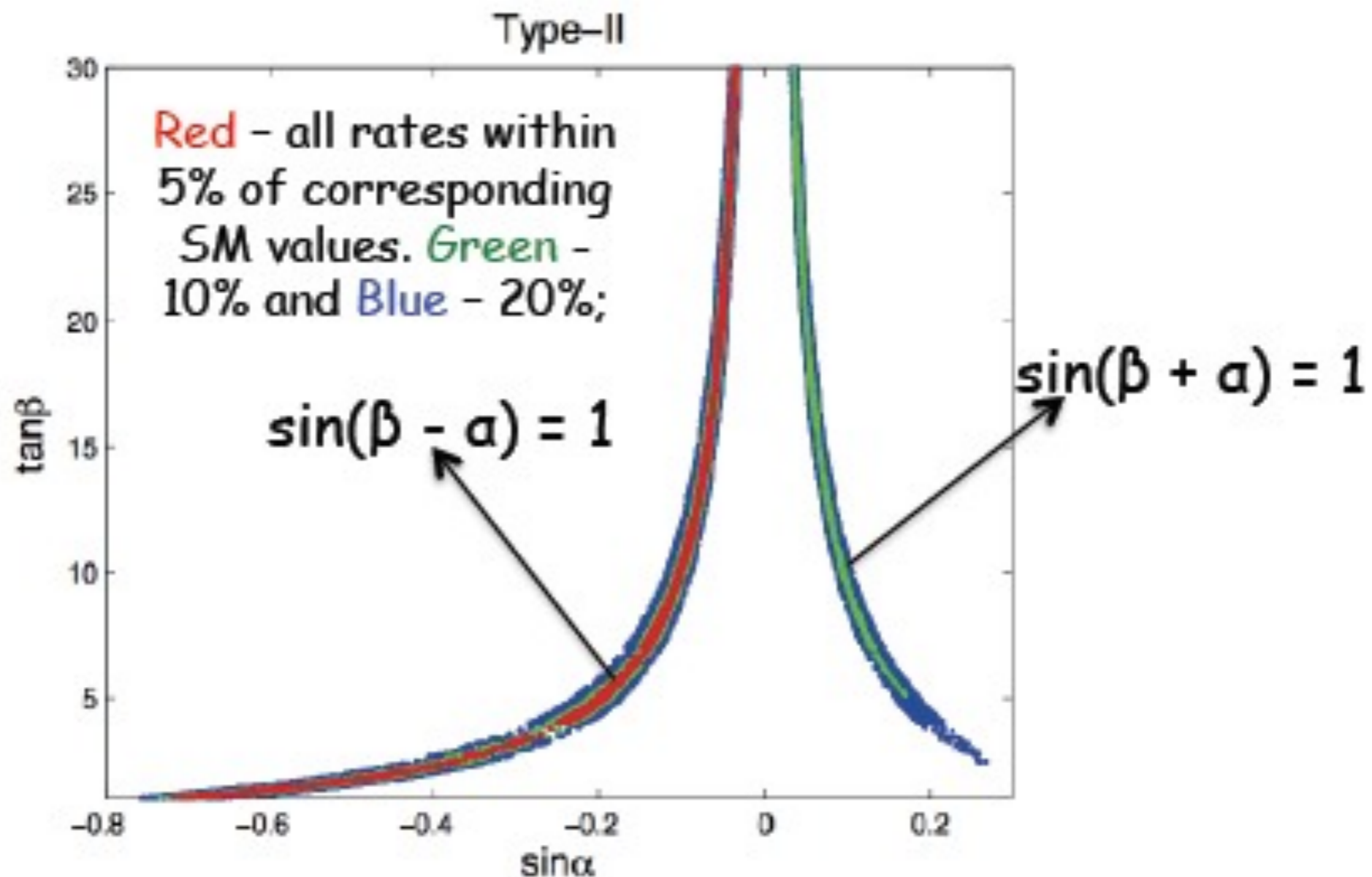
non-resonant VBF di-Higgs search
at hadron level

c_{2V} (HHVV vertex) only accessible
via VBF HH

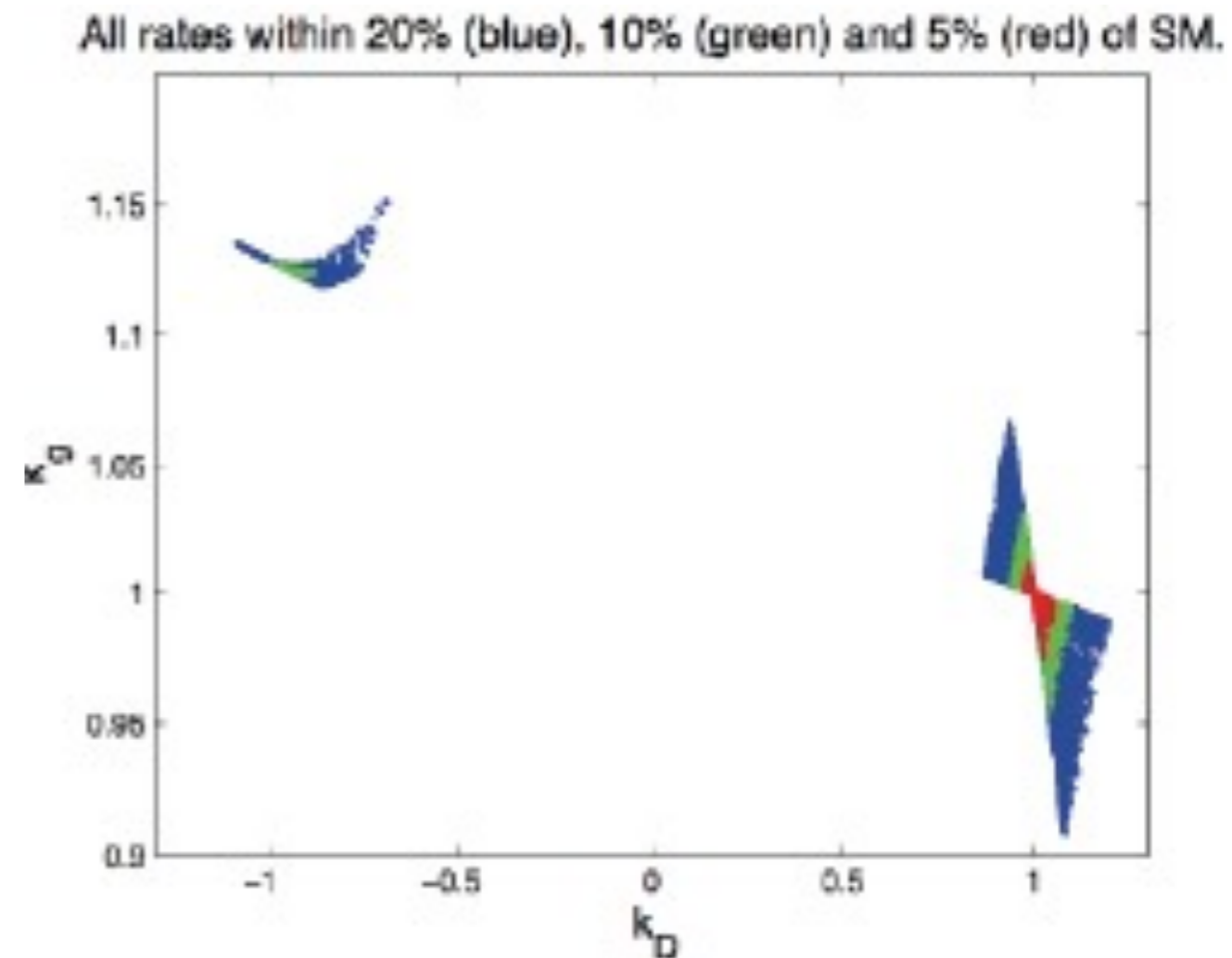
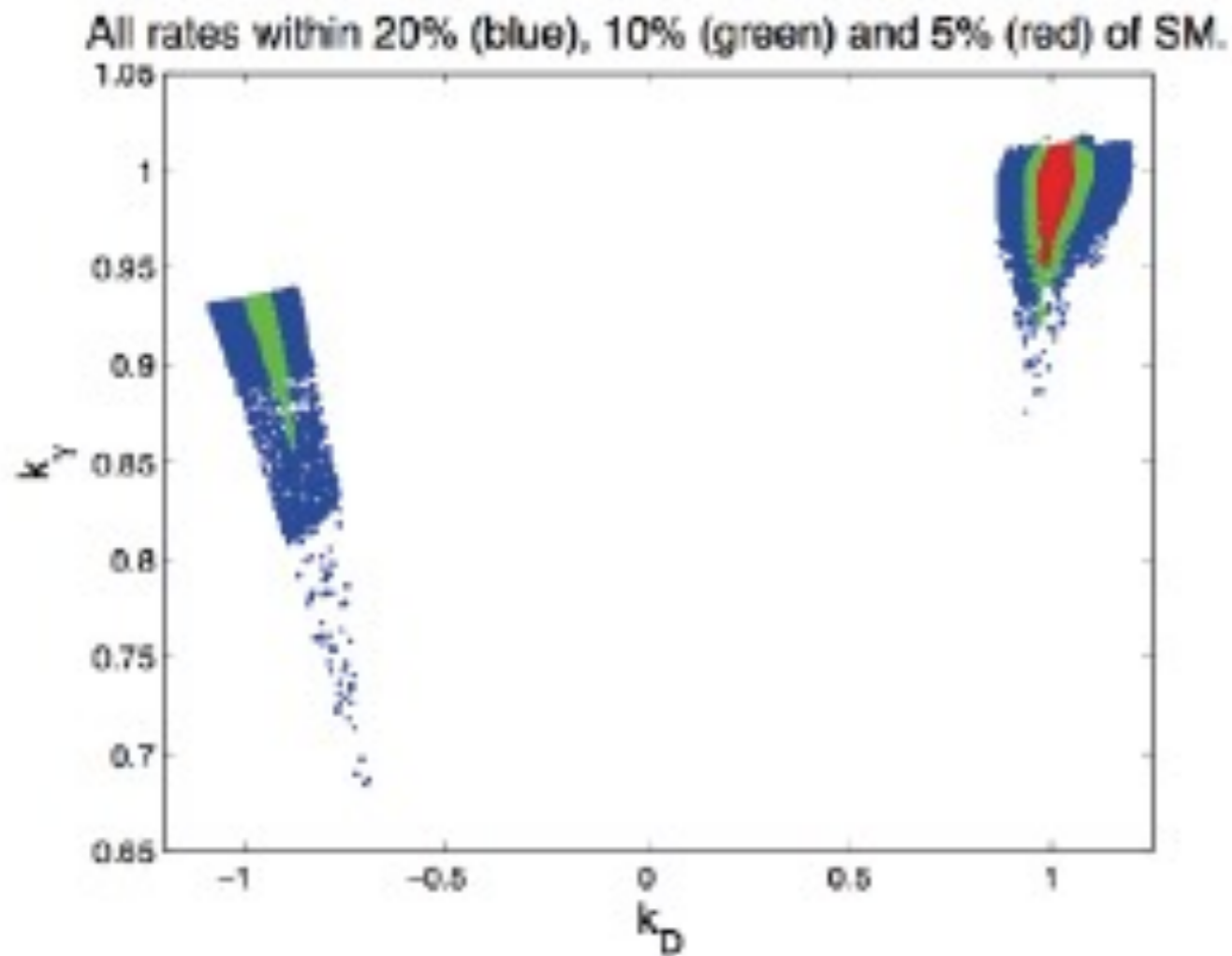
At HL-LHC deviations from the
SM value of c_{2V} can be probed at
the level of 20%

Rui Santos: $2\mathcal{HDM}$ after the 8 TeV run and the wrong-sign Yukawa Coupling

Wrong-sign Yukawa coupling - at least one of the couplings of h to down-type and up-type quarks is opposite in sign to the corresponding coupling of h to VV (in contrast with SM).



Rui Santos: $2\mathcal{HDM}$ after the 8 TeV run and the wrong-sign Yukawa Coupling



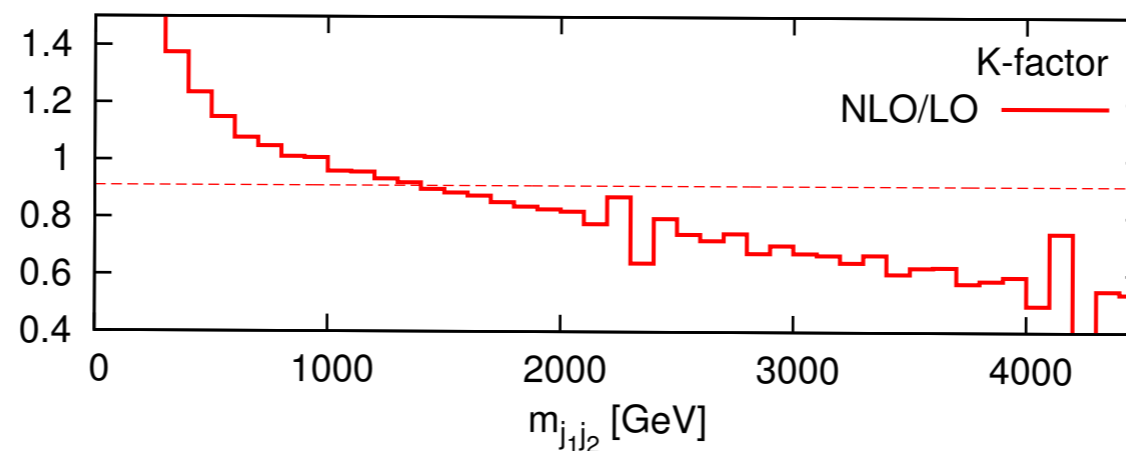
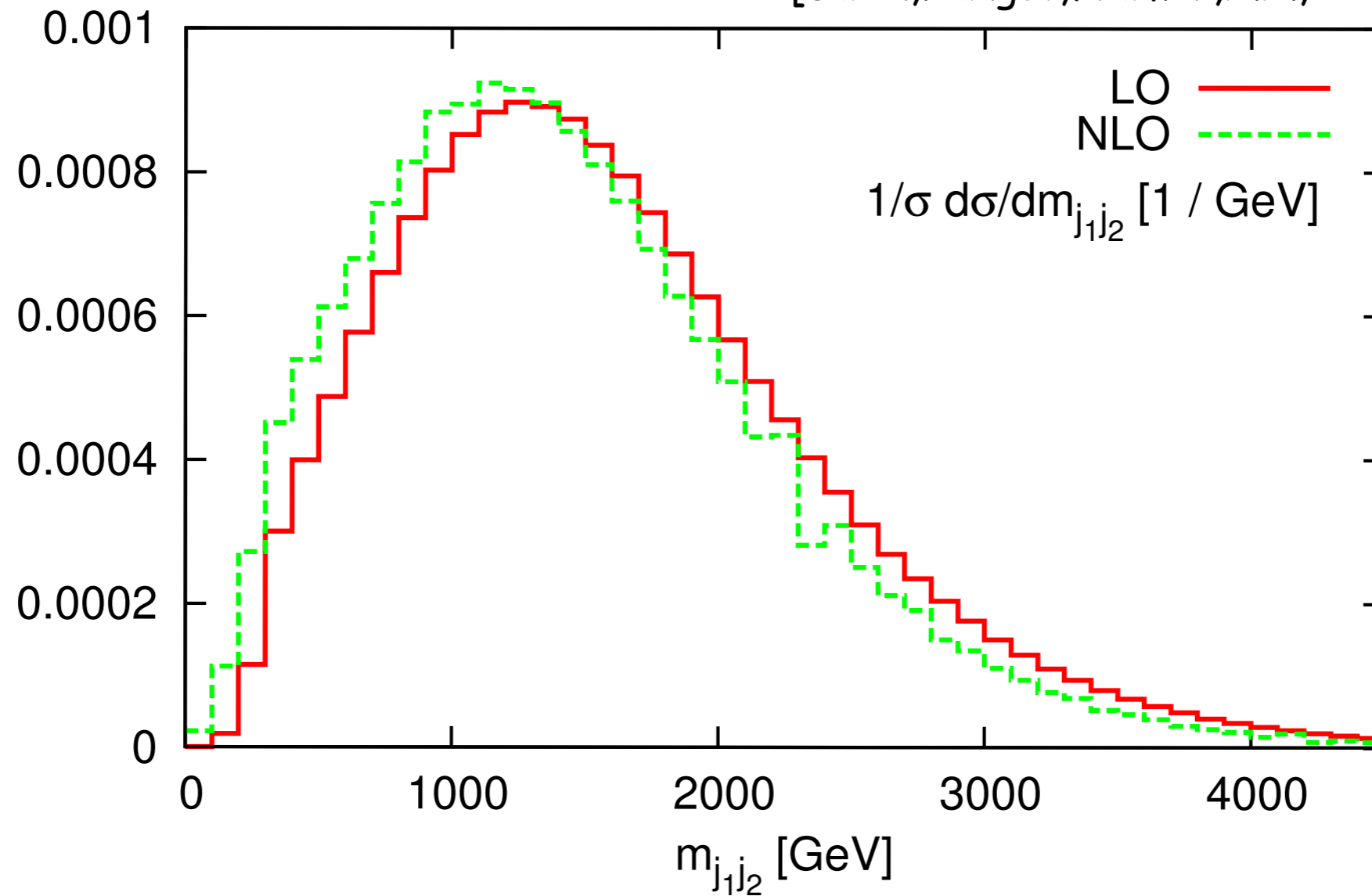
Looking at the Snowmass predictions, the wrong sign scenario $\kappa_D = -1$, can be excluded by measurements of κ_γ and κ_g .

Eva Popena: Squark Production and Decay at NLO Matched with Parton Showers

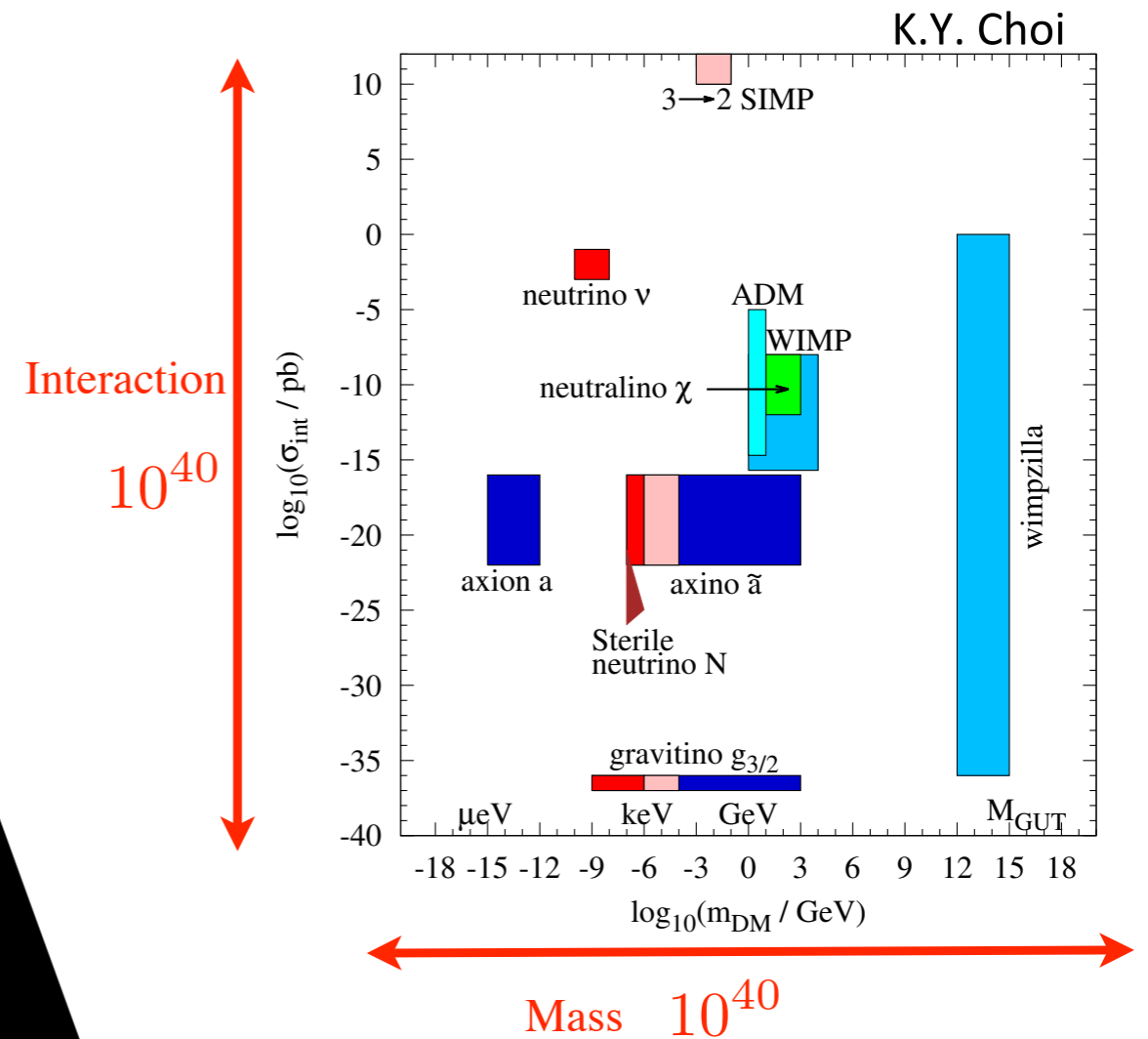
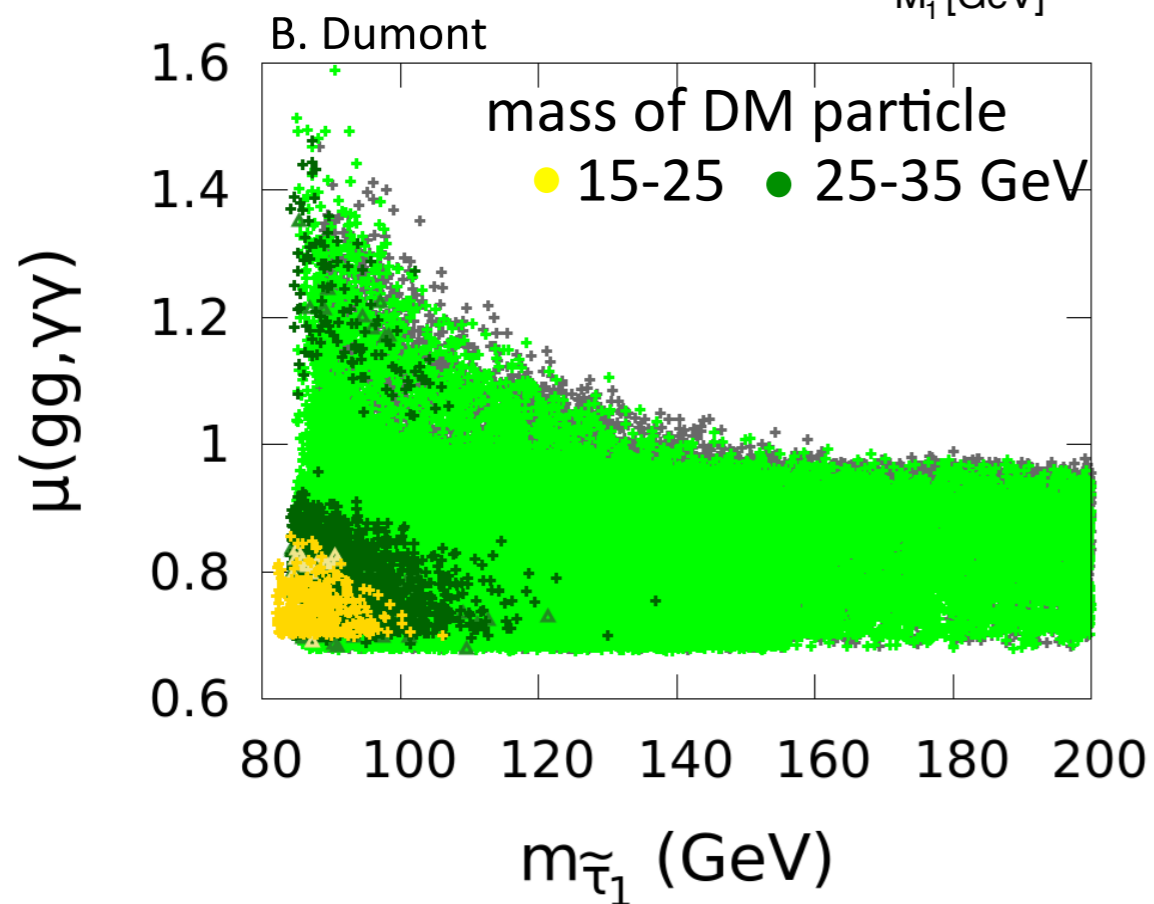
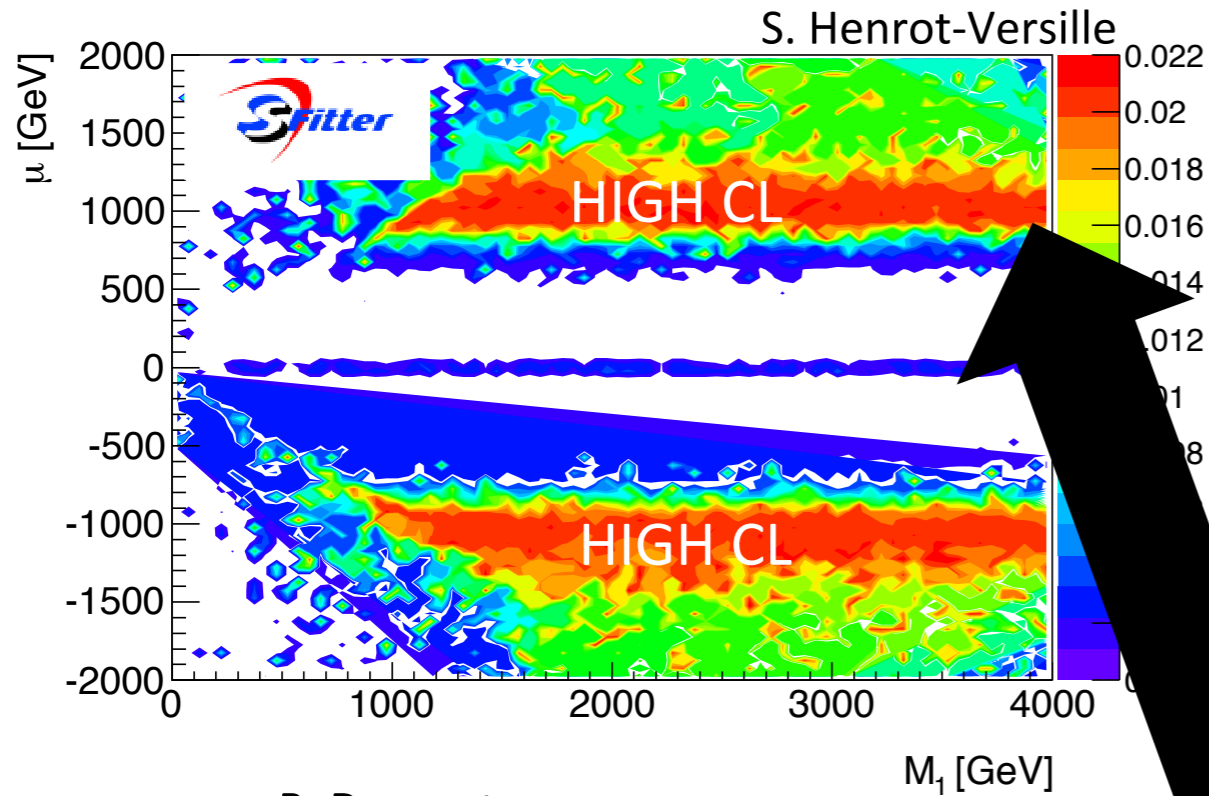
- Recalculation of SQCD NLO corrections to squark pair and squark-antisquark production: fully differential, w/o assumptions on mass spectrum, all subchannels individually
- NLO corrections change shape of distributions -> global K-factor not sufficient

Eva Popena: Squark Production and Decay at NLO Matched with Parton Showers

[Gavin, Hangst, Krämer, MM, Pellen, Popena, Spira]

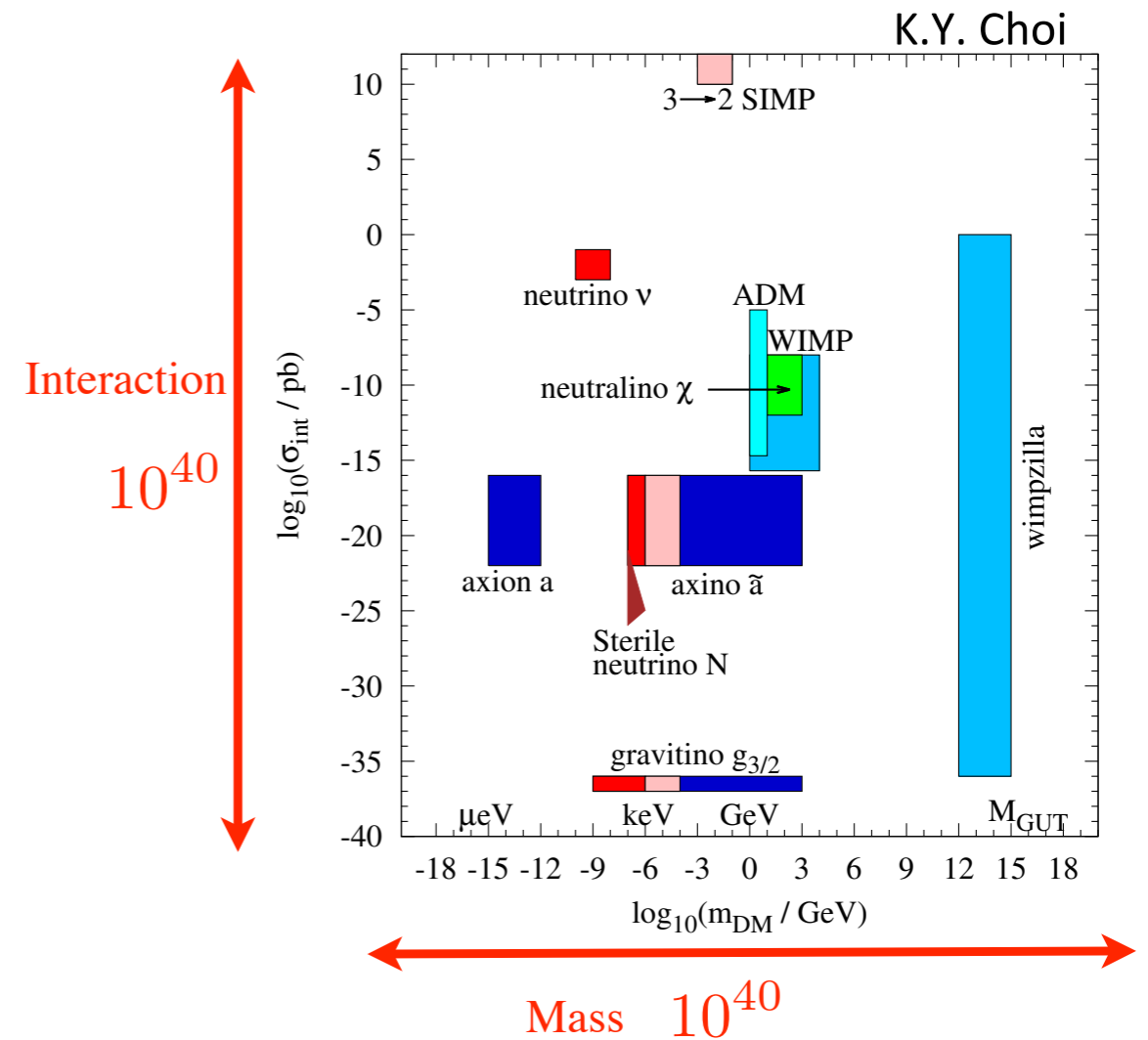
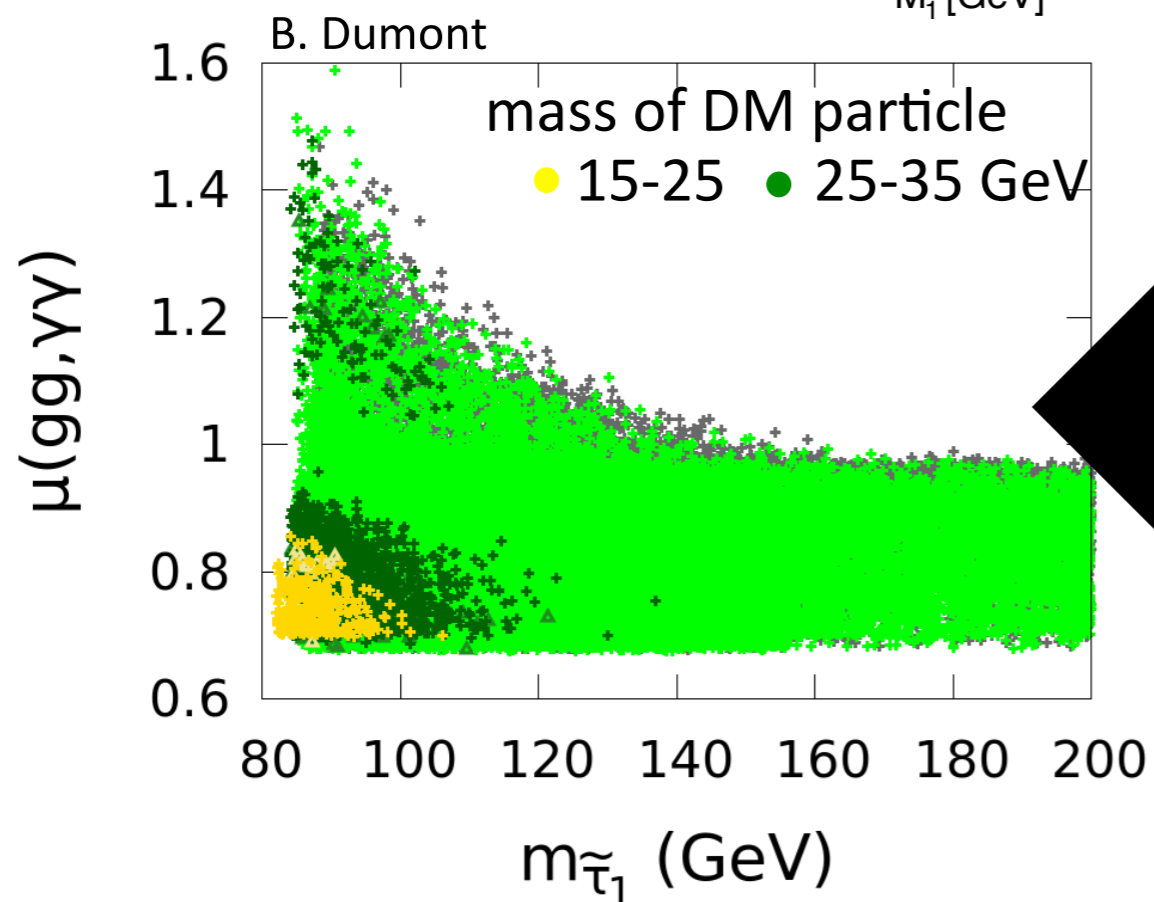
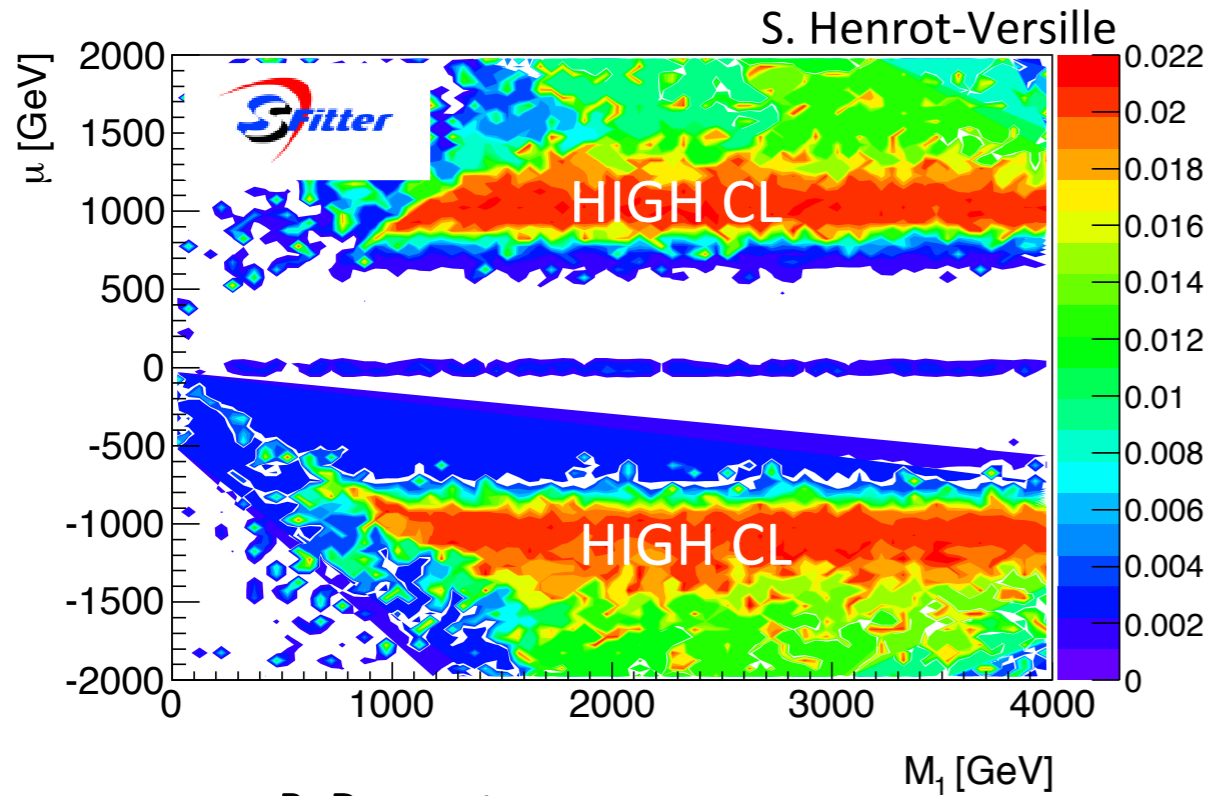


SUPERSYMMETRY VS DARK MATTER



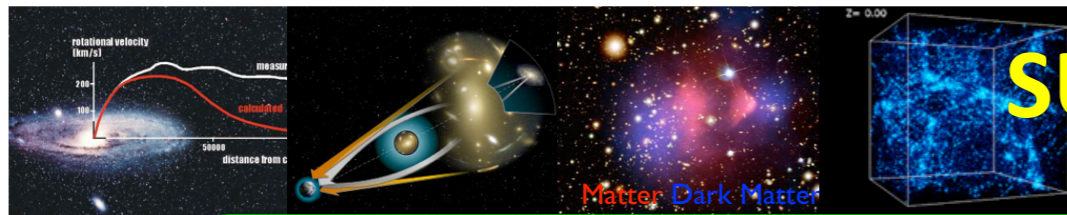
Multi-parameter scans:
(relatively) new allowed regions
of SUSY parameter space
with correct DM density
(esp. mixed bino/higgsino and
higgsino-like neutralino)

SUPERSYMMETRY VS DARK MATTER

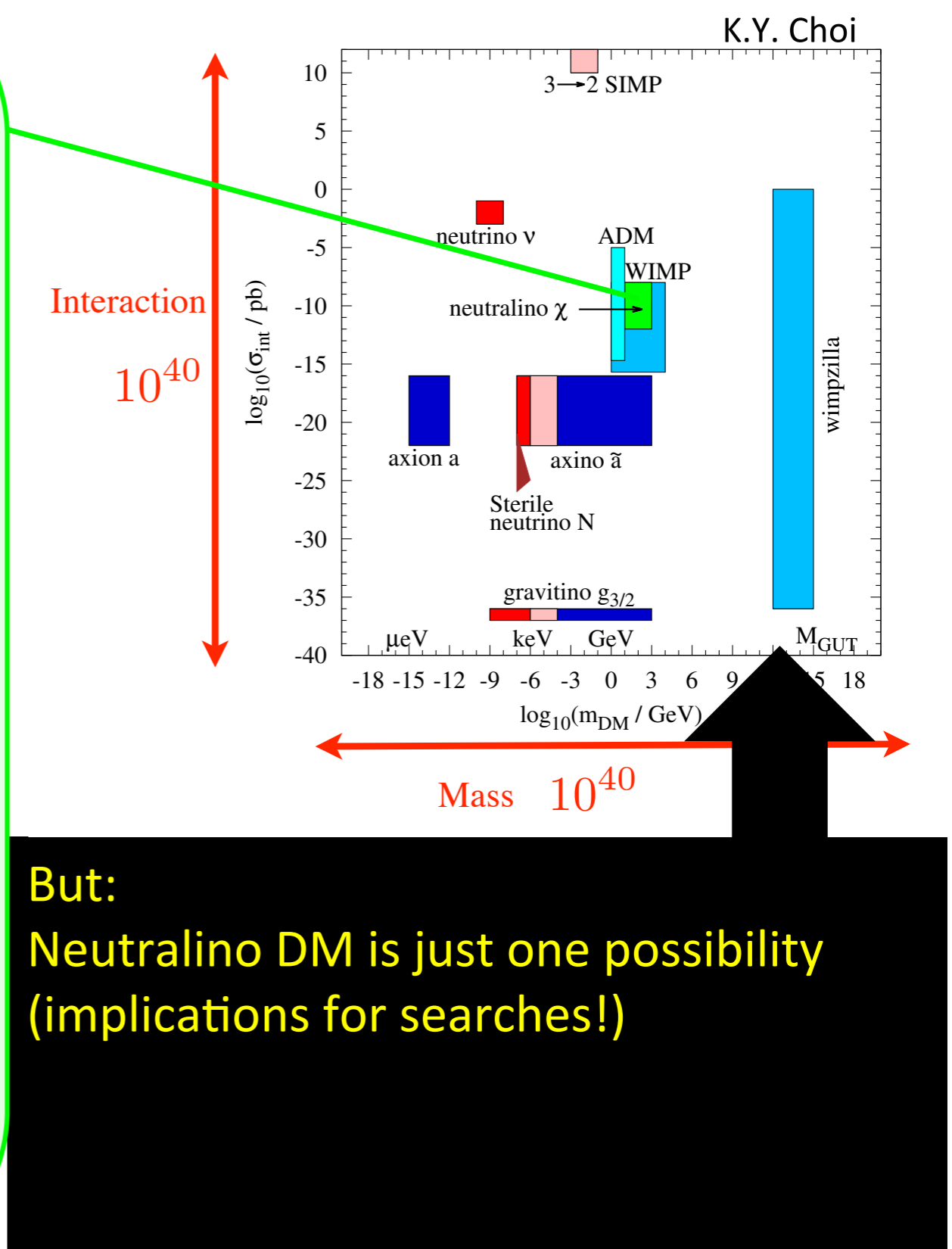
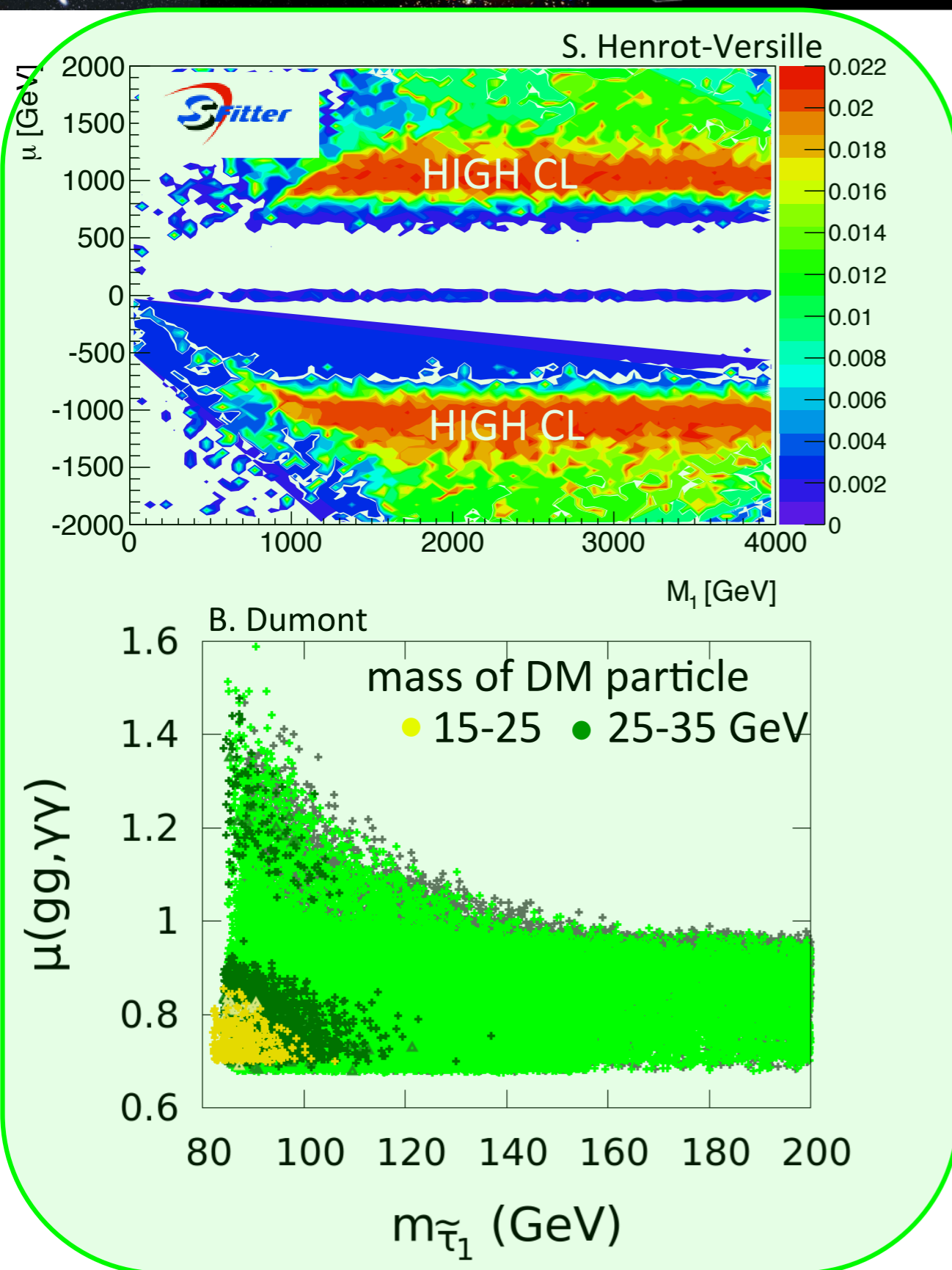


Multi-parameter scans:

- light $O(10)$ GeV neutralino DM,
- $m < 25$ GeV soon to be tested in direct detection experiments
- reduced $h \rightarrow \gamma\gamma$ (invisible decays to DM particle)

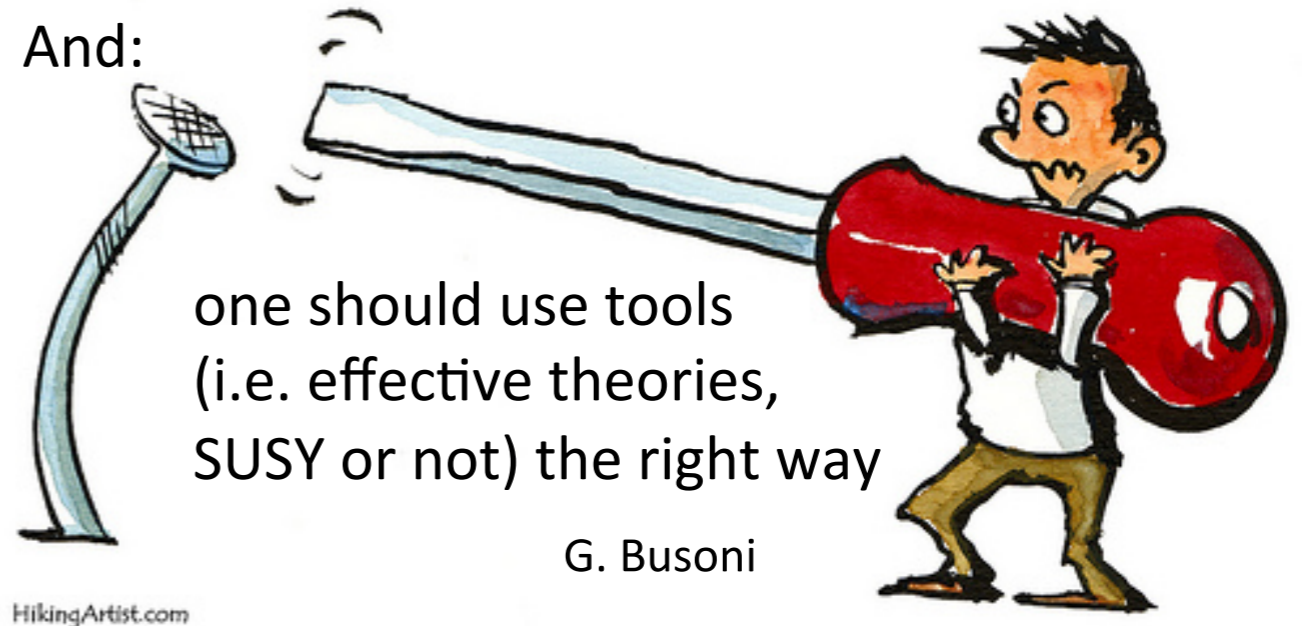
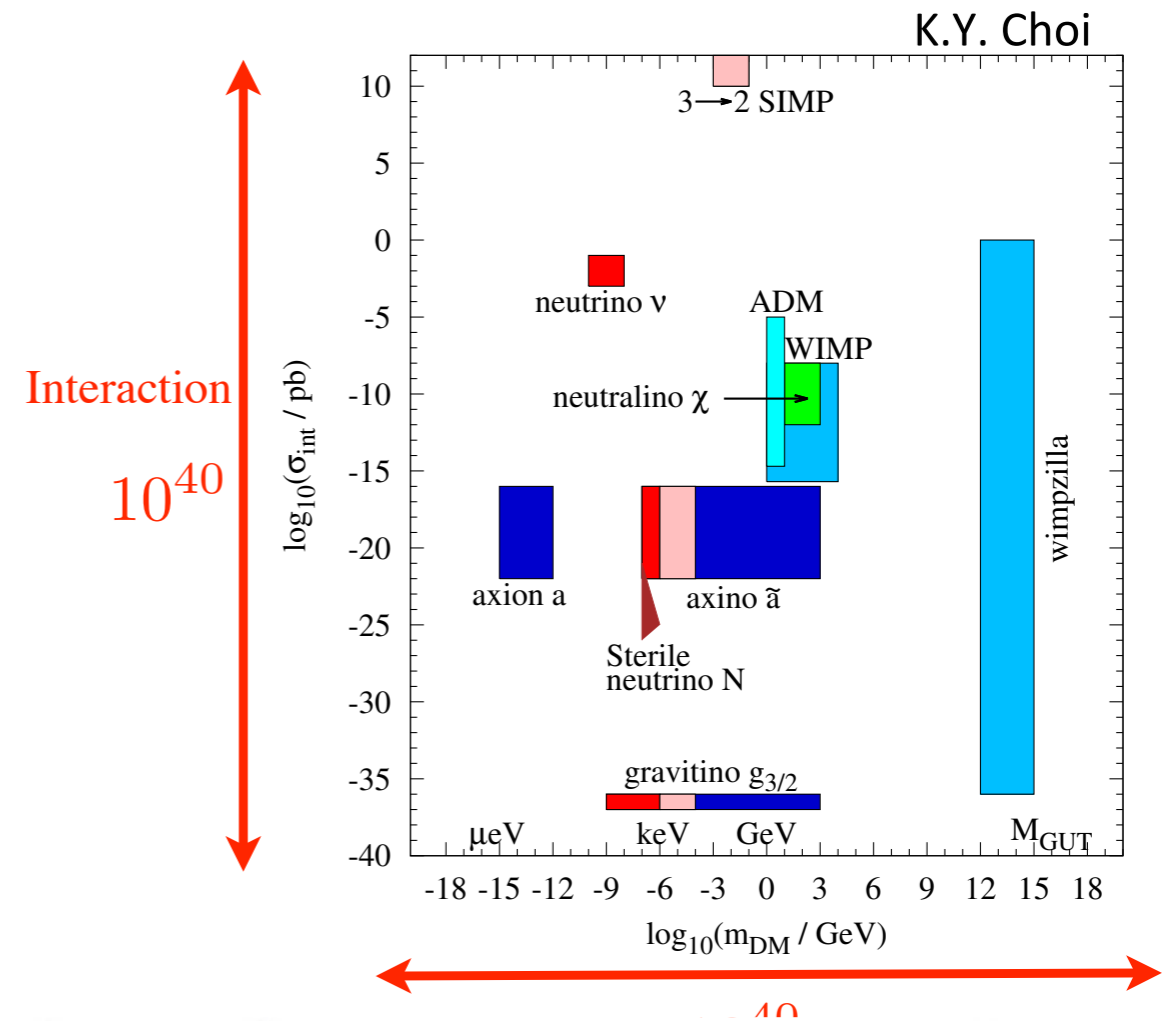
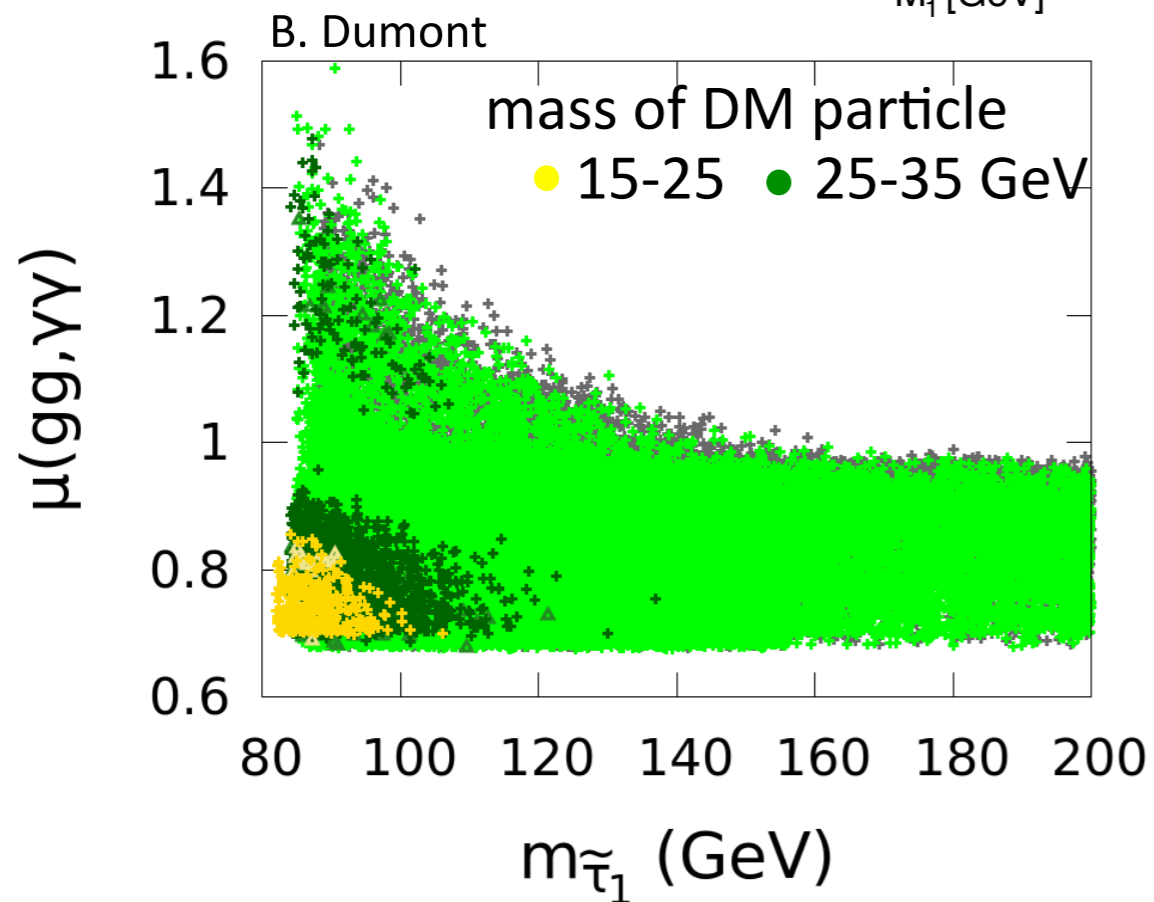
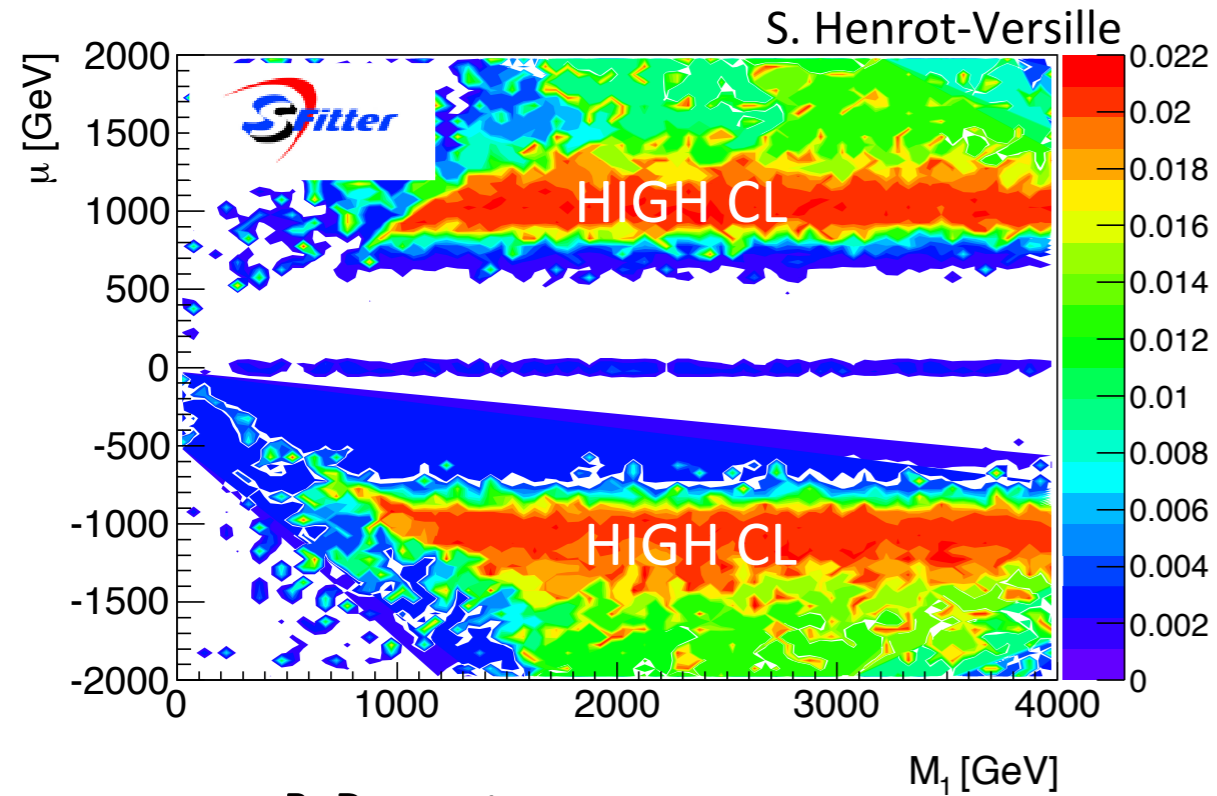


SUPERSYMMETRY VS DARK MATTER





SUPERSYMMETRY VS DARK MATTER



Thank you for your attention

Now to the experimental talks

	I	II	III	
Up-type quarks	u Up 1/3	c Charm 1/3	t Top 1/3	Y Photon 0
Down-type quarks	d Down 1/3	s Strange 1/3	b Bottom 1/3	g Gluon 0
Leptons	ν_e Electron neutrino 0	ν_μ Muon neutrino 0	ν_τ Tau neutrino 0	Z^0 Z boson 0
	e Electron 1/2	μ Muon 1/2	τ Tau 1/2	W^\pm W boson 1/2

