

WW,TGC AND INTERFERENCE @ CLIC

Davide Maria Lombardo
University of Geneva, 2018

SCIENTIFIC CONTEXT

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- ▶ BSM Exploration

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► BSM Exploration

- NP beyond the SM

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- EFT approach

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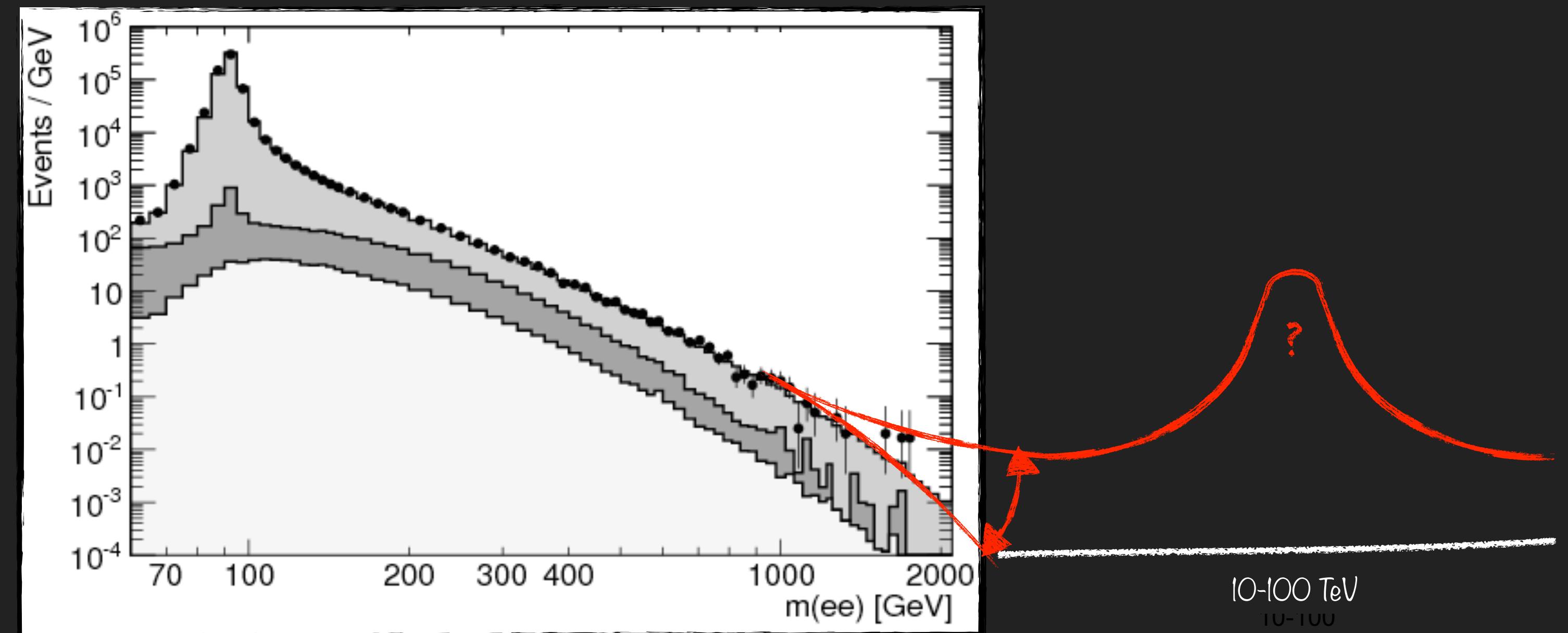
$$\begin{aligned}
 Amp &= SM + BSM = SM(1 + \delta_{BSM}) \\
 \delta_{BSM} &\sim \frac{E^2}{M^2} \quad \delta_{BSM} \ll 1 \\
 \sigma &\propto |Amp|^2 \sim SM^2(1 + \delta_{BSM} + \delta_{BSM}^2)
 \end{aligned}$$

The diagram consists of three mathematical equations. The first equation shows the total amplitude Amp as the sum of the Standard Model (SM) and Beyond Standard Model (BSM) contributions, plus a small correction δ_{BSM} . The second equation relates the Beyond Standard Model correction to the ratio of energy squared (E^2) to mass squared (M^2). The third equation shows the cross-section σ proportional to the square of the total amplitude, which is approximately equal to the square of the Standard Model amplitude plus the square of the Beyond Standard Model correction plus the product of the two corrections.

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- High-Energy precision program

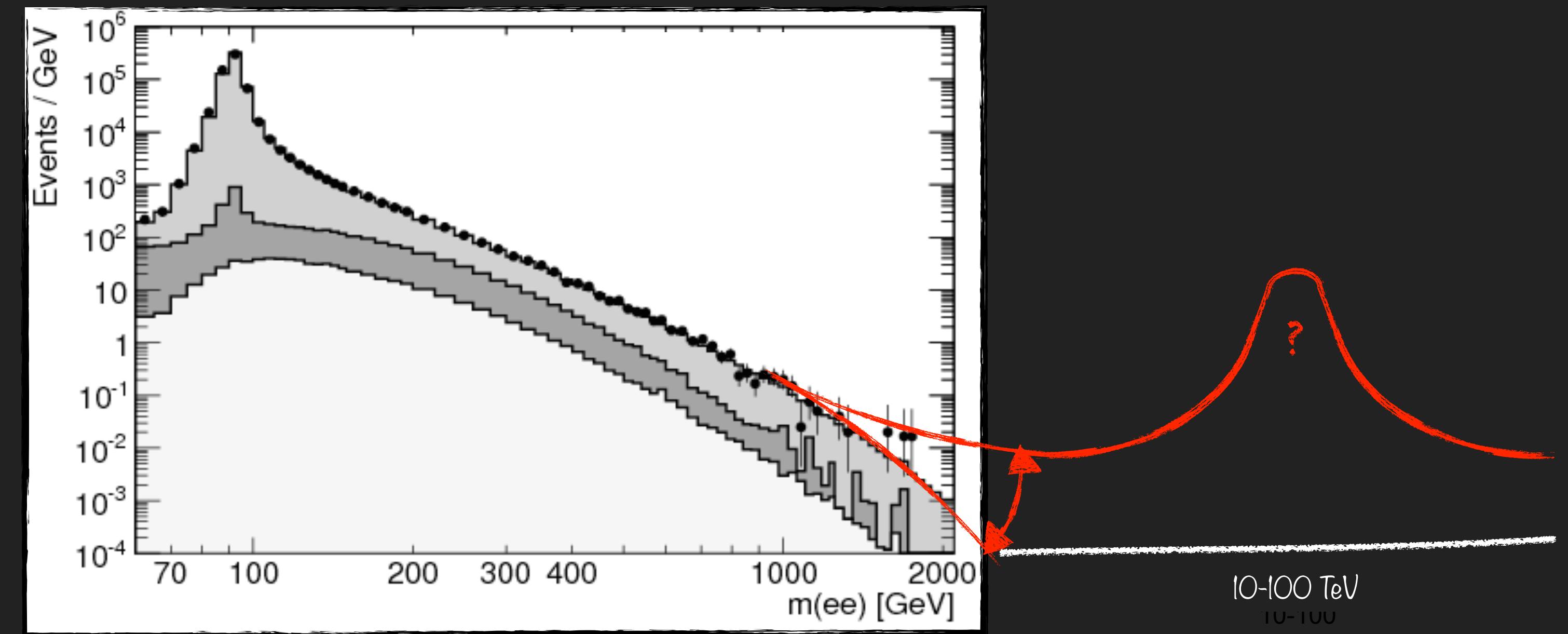


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► CLIC

$$Amp = SM + BSM = SM(1 + \delta_{BSM})$$

$$\delta_{BSM} \sim \frac{E^2}{M^2}$$

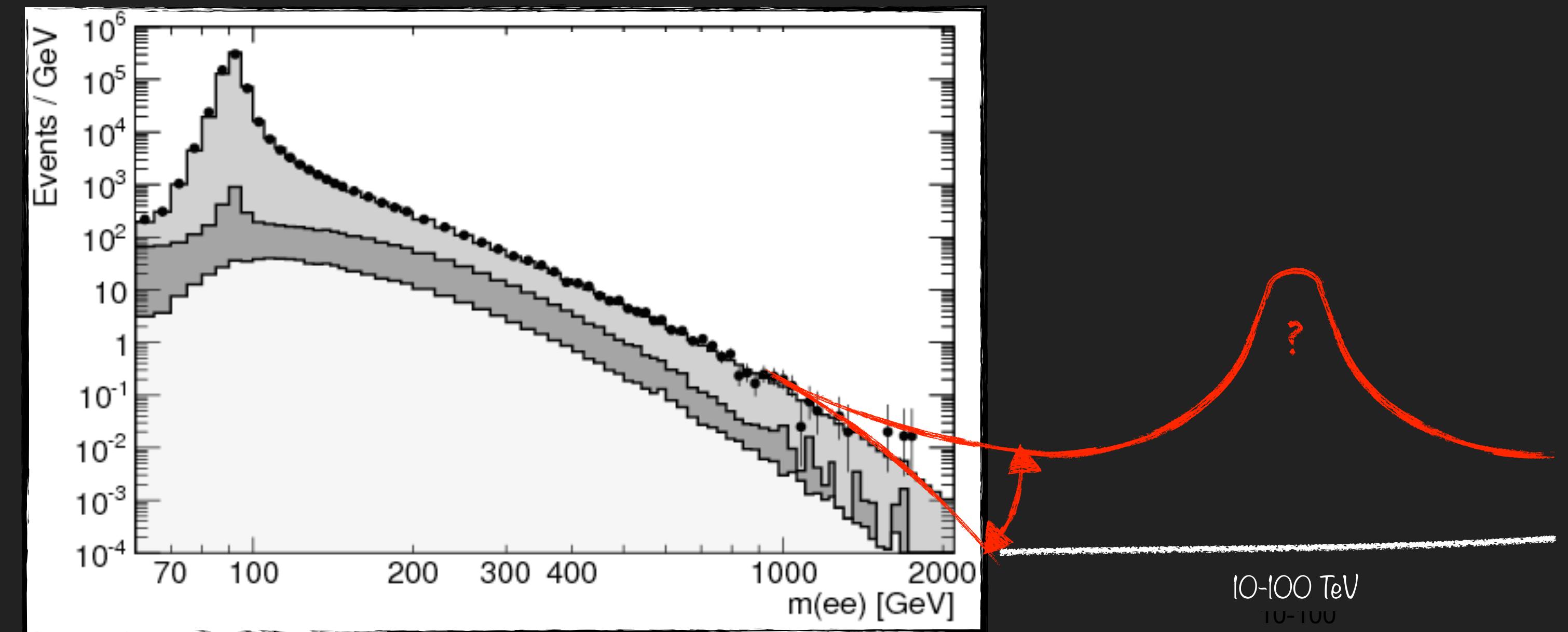
$\delta_{BSM} \ll 1$

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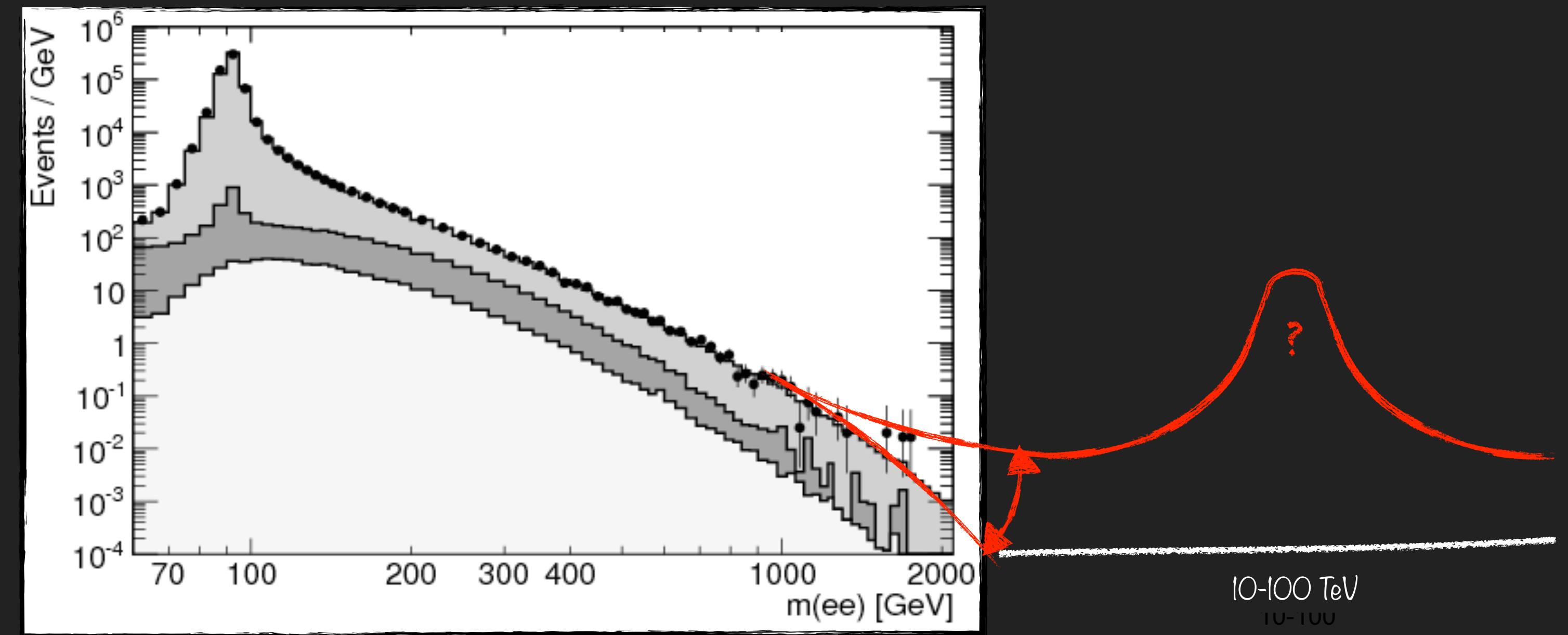
- Very Promising

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► CLIC

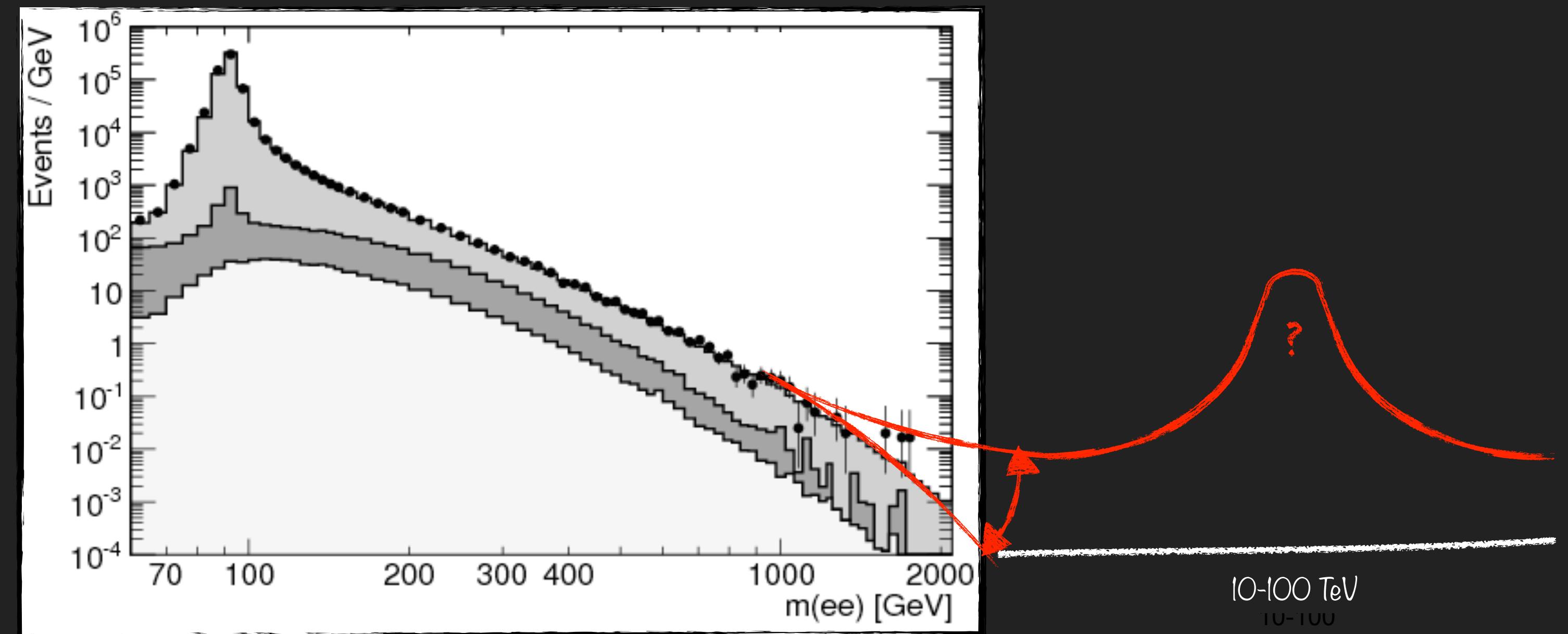
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- EFT approach
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► CLIC

- Very Promising
- High Energy
- Clean Environment

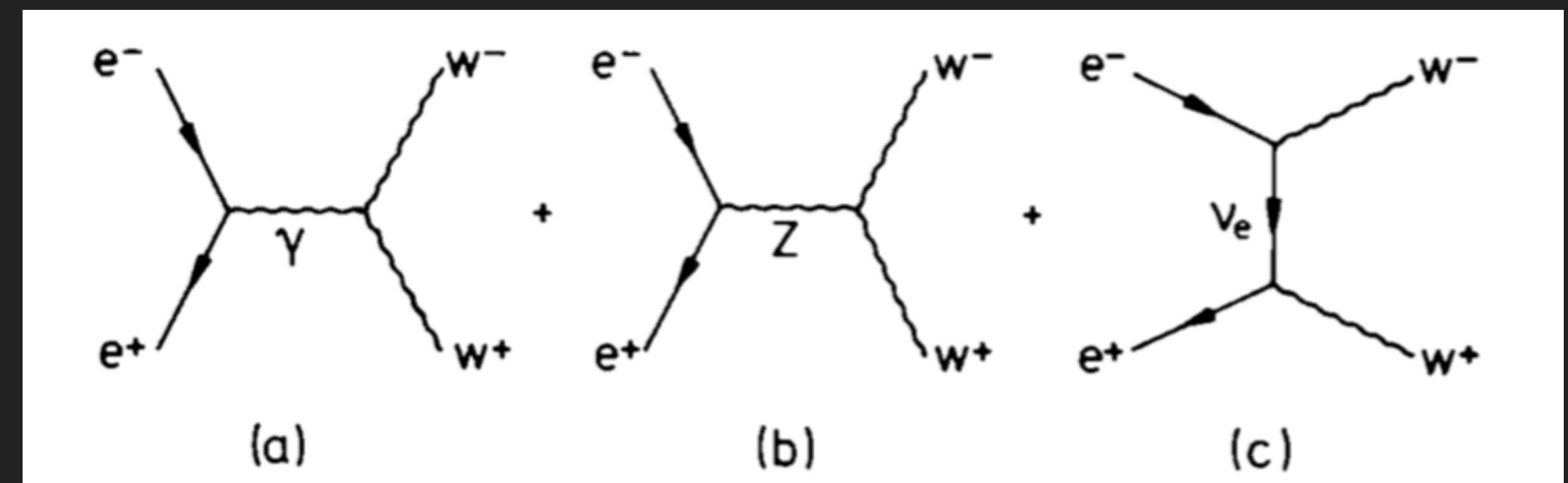
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DIBOSONS: WW

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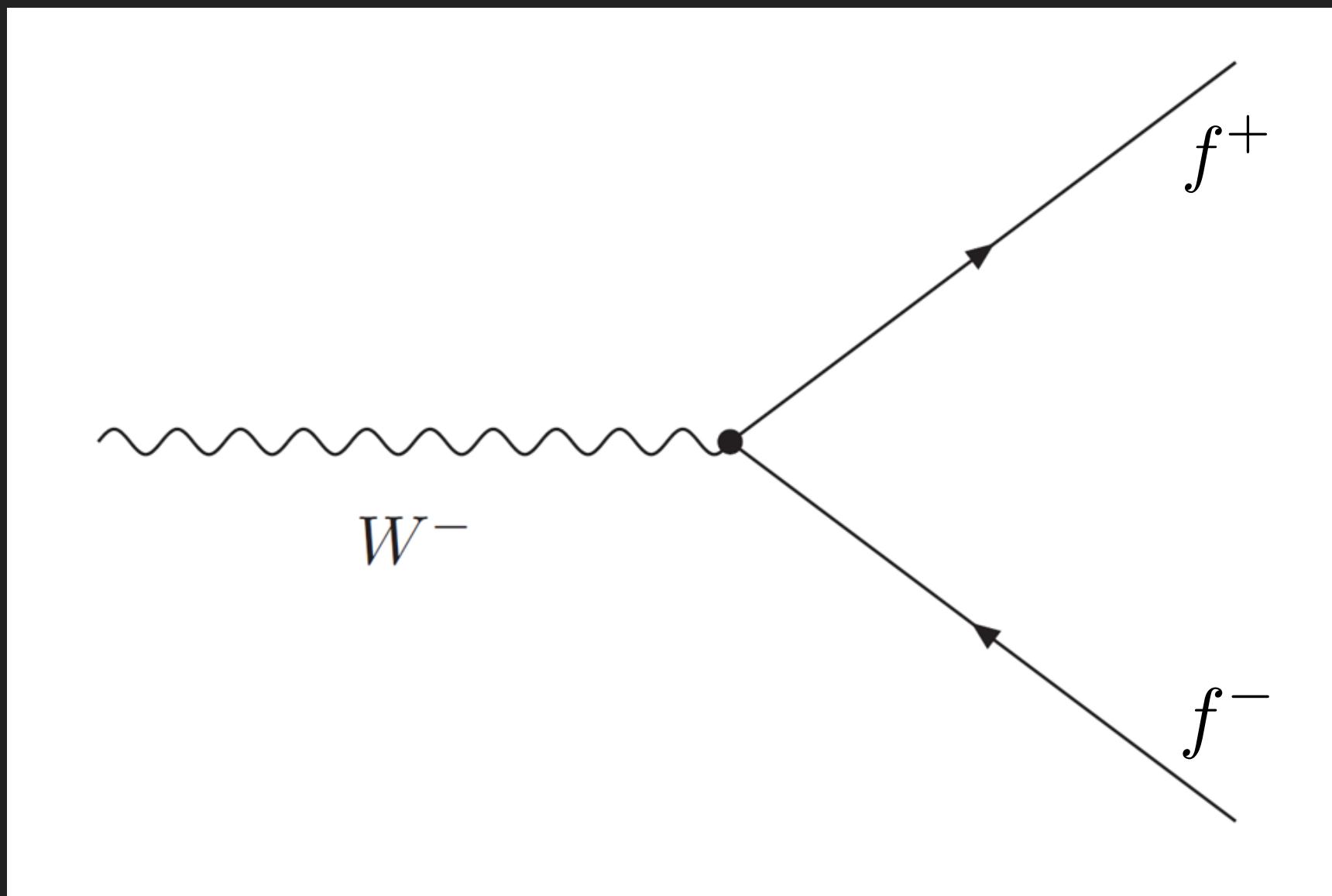
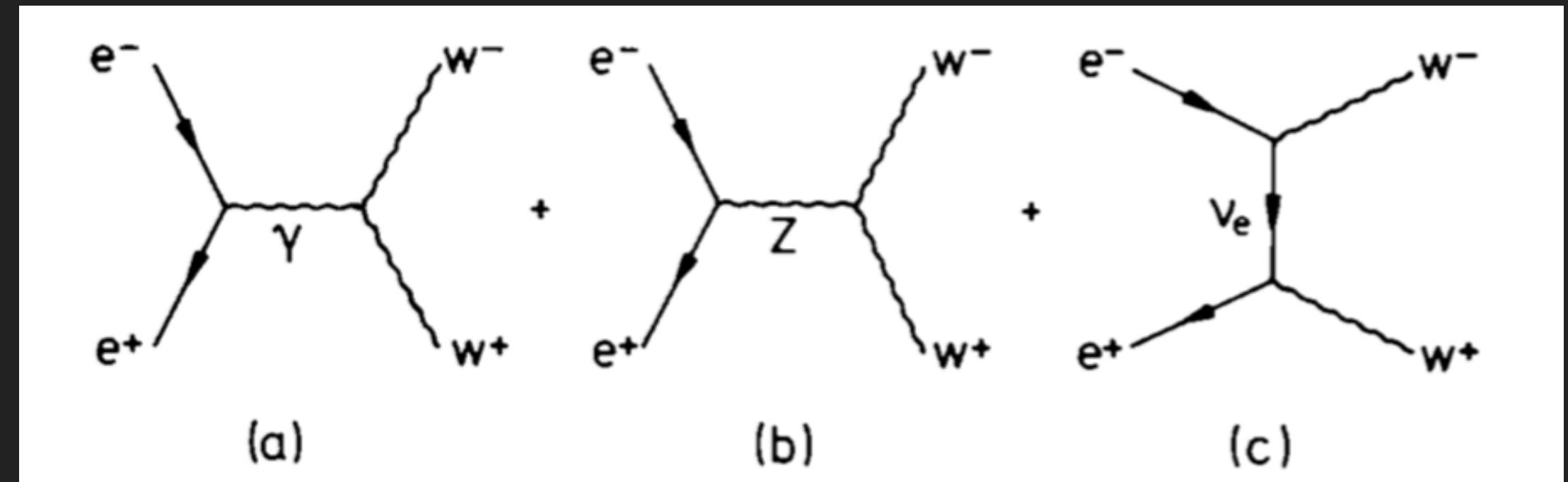
► $e^+ e^- \rightarrow W^+ W^-$



DIBOSONS: WW

3

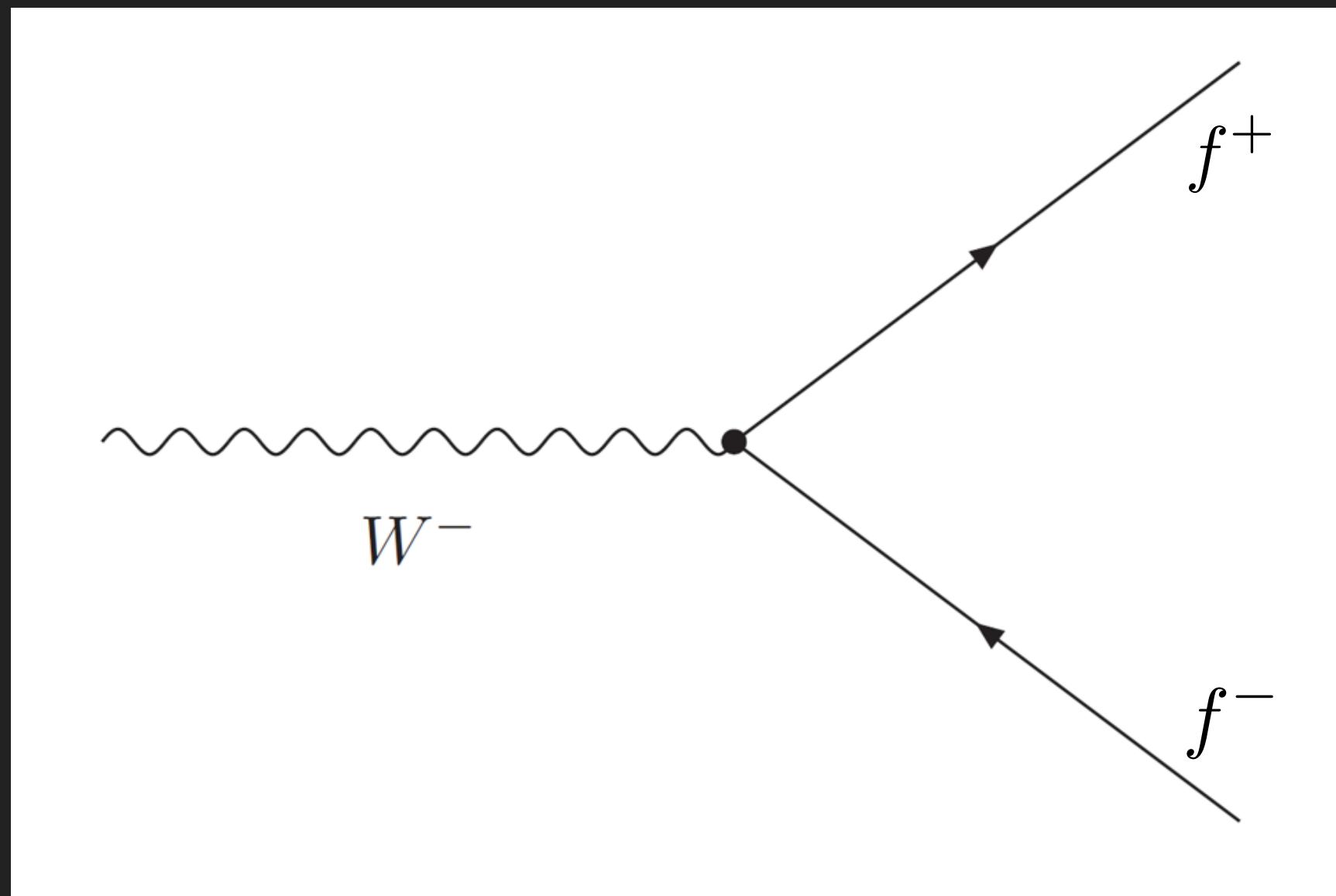
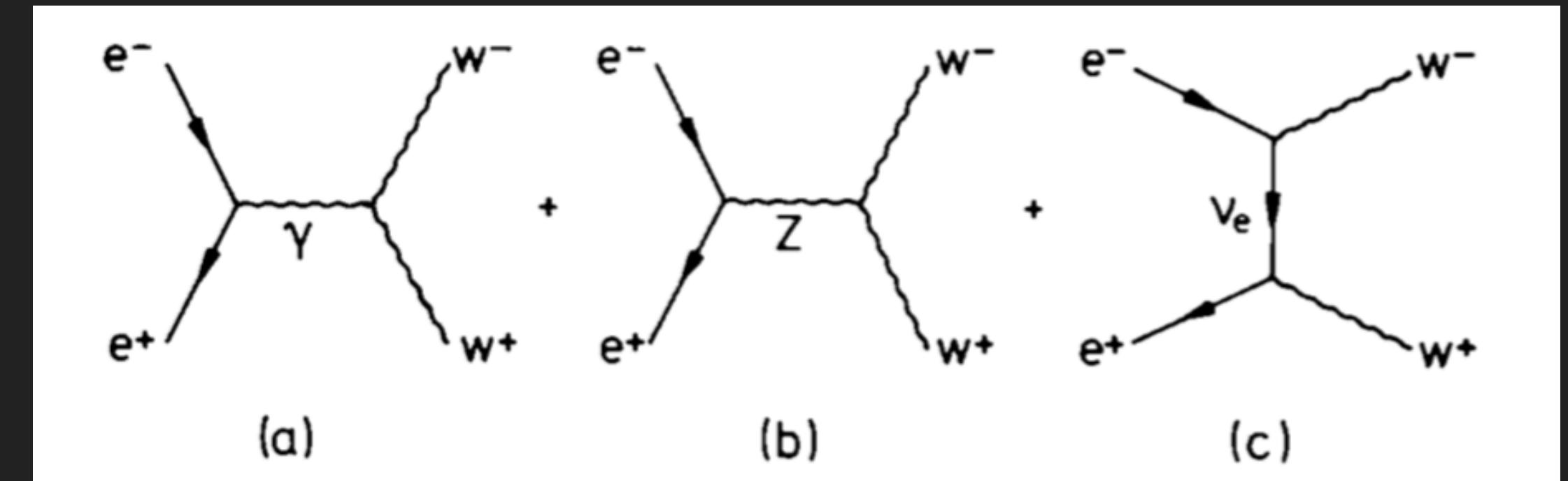
► $e^+ e^- \rightarrow W^+ W^- \rightarrow f^+ f^- f'^+ f'^-$



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- Fully Hadronic and Semileptonic Channels

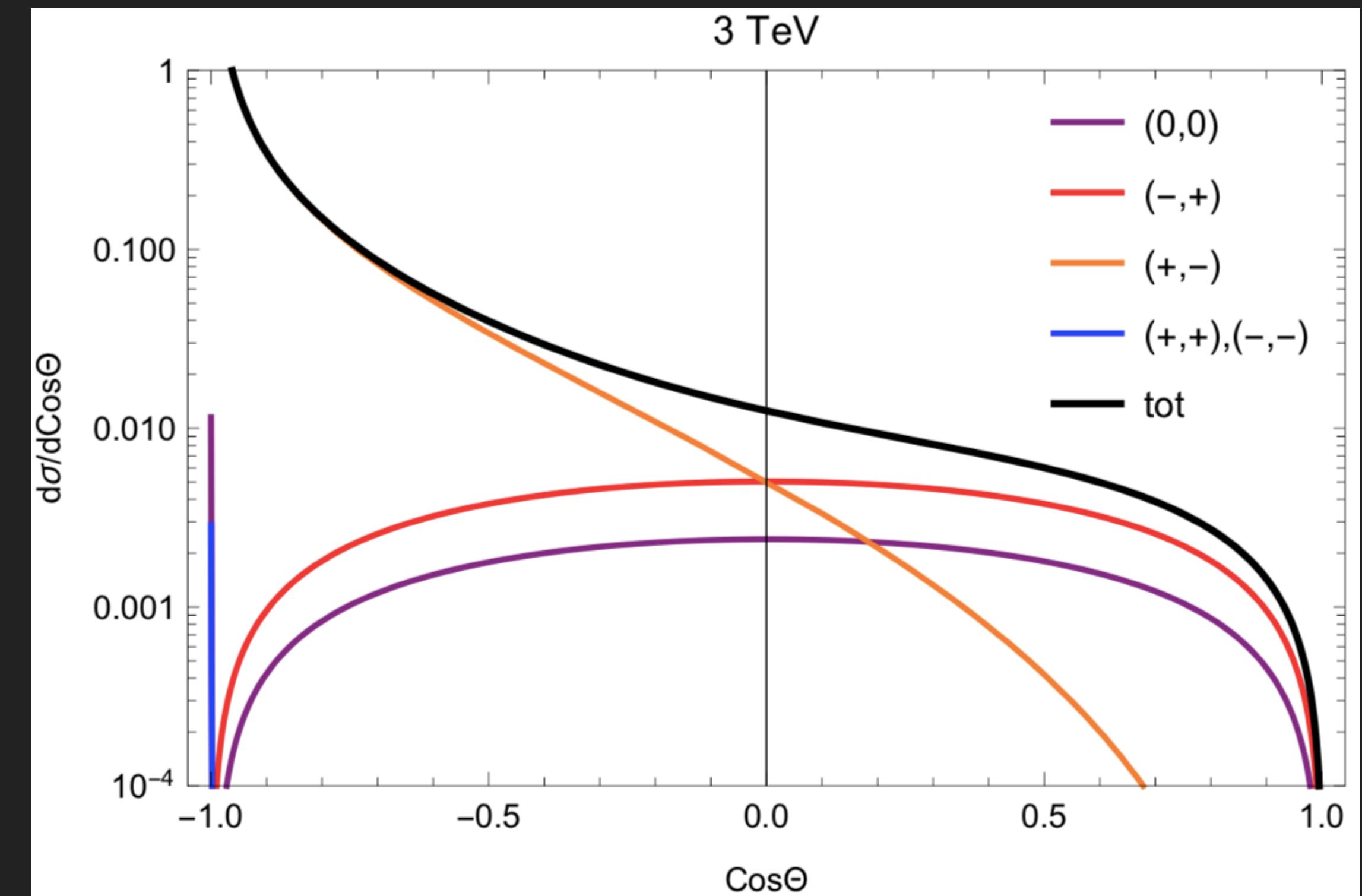
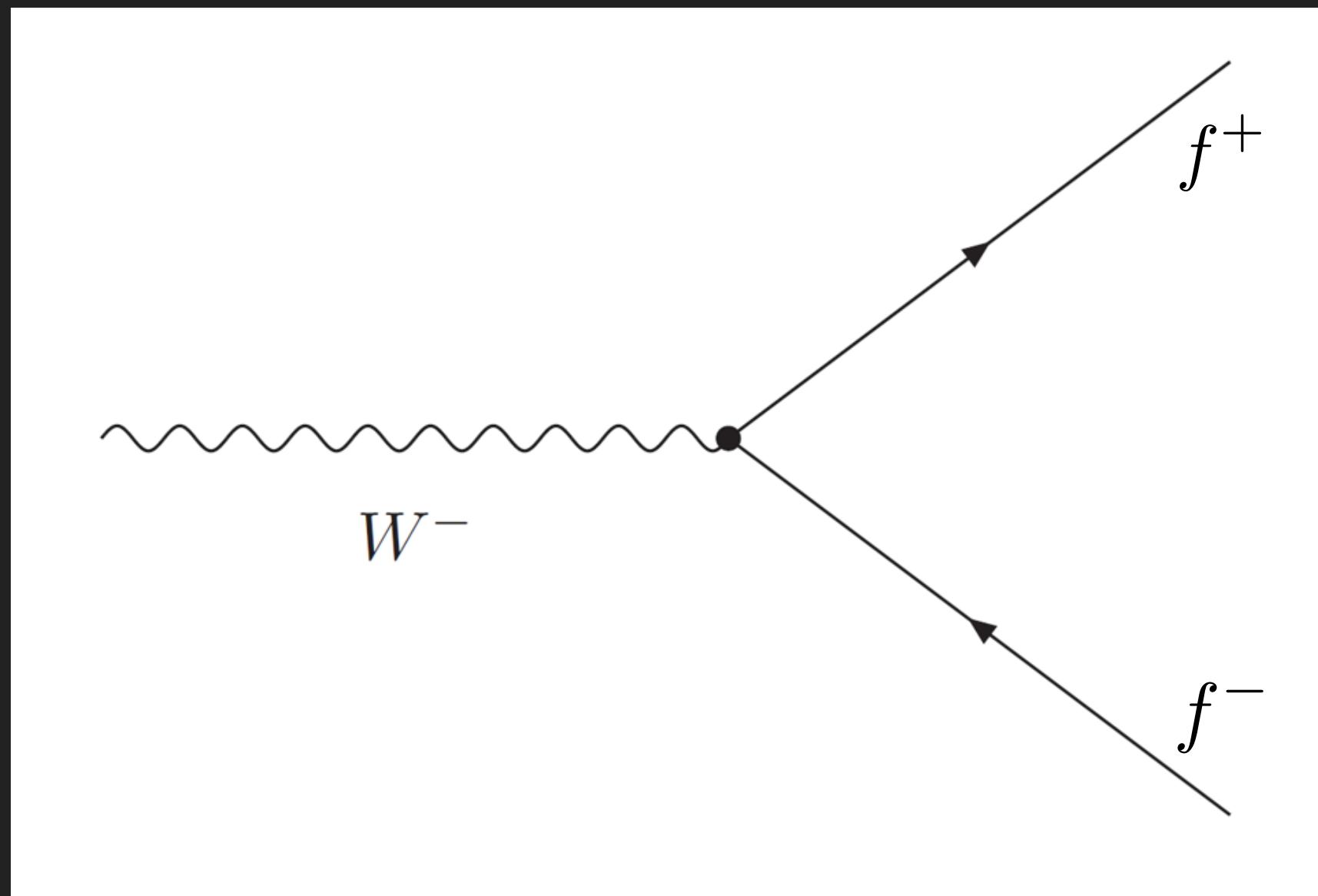
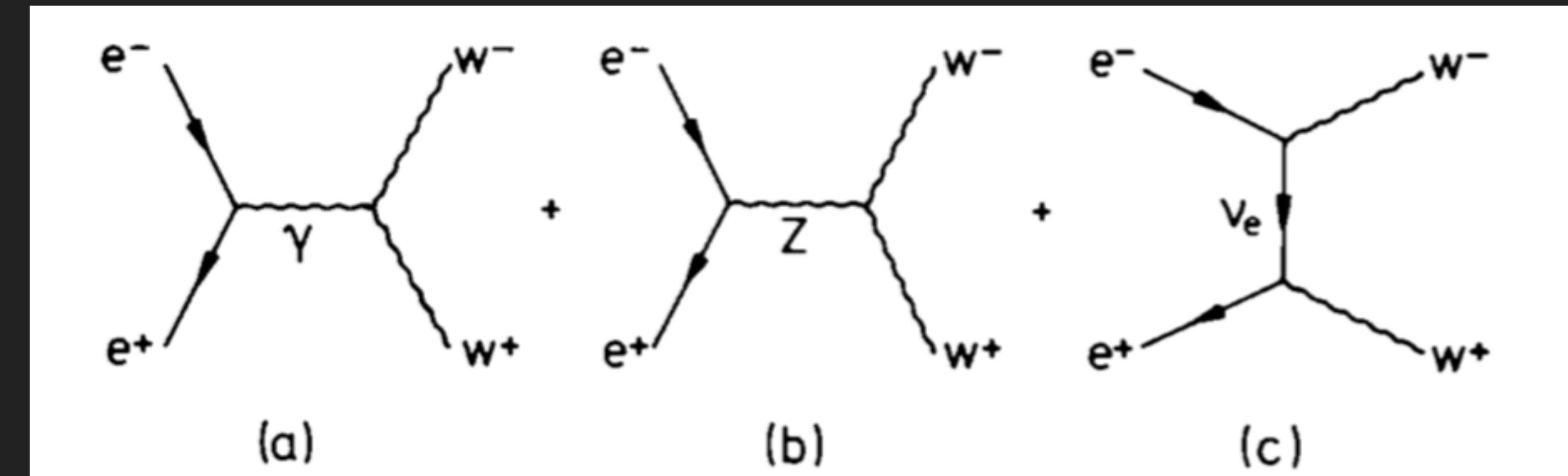


DIBOSONS: WW

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- Fully Hadronic and Semileptonic Channels

- Helicities matter in SM.....and in BSM also.



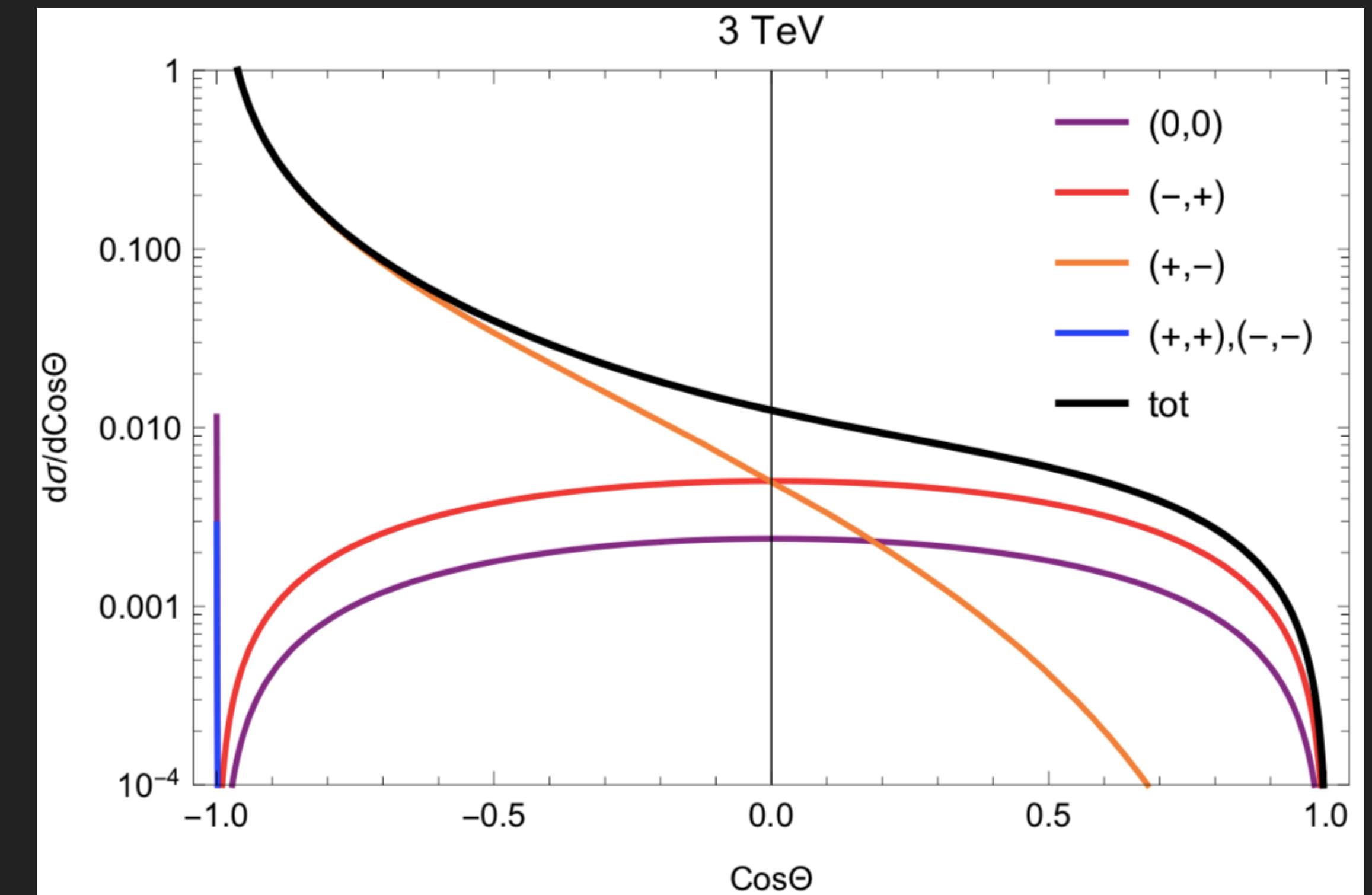
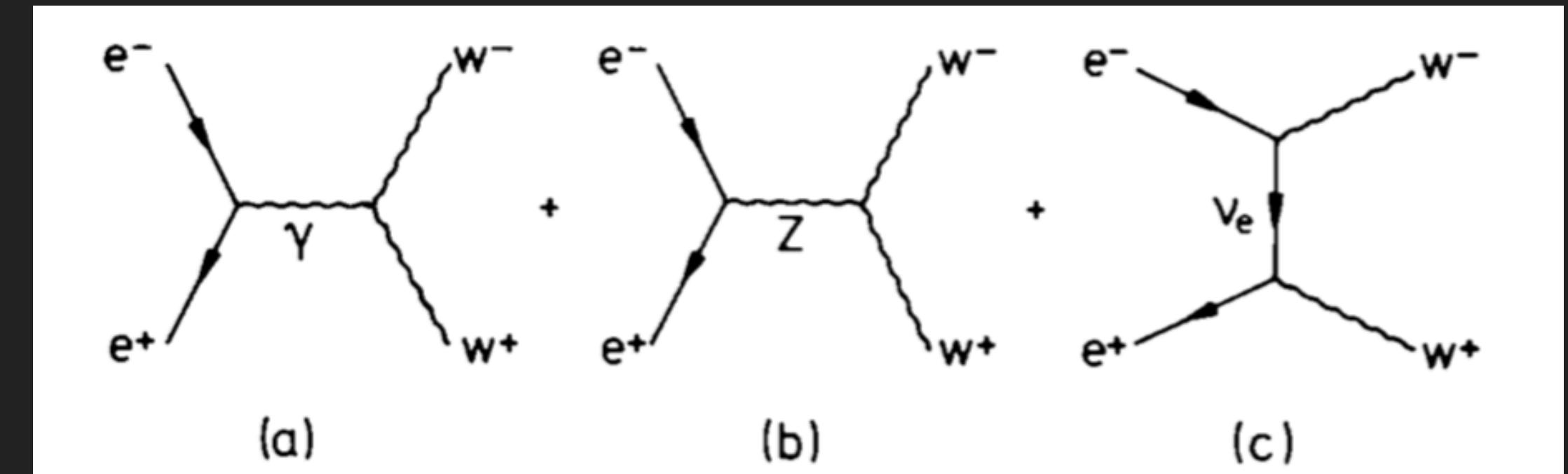
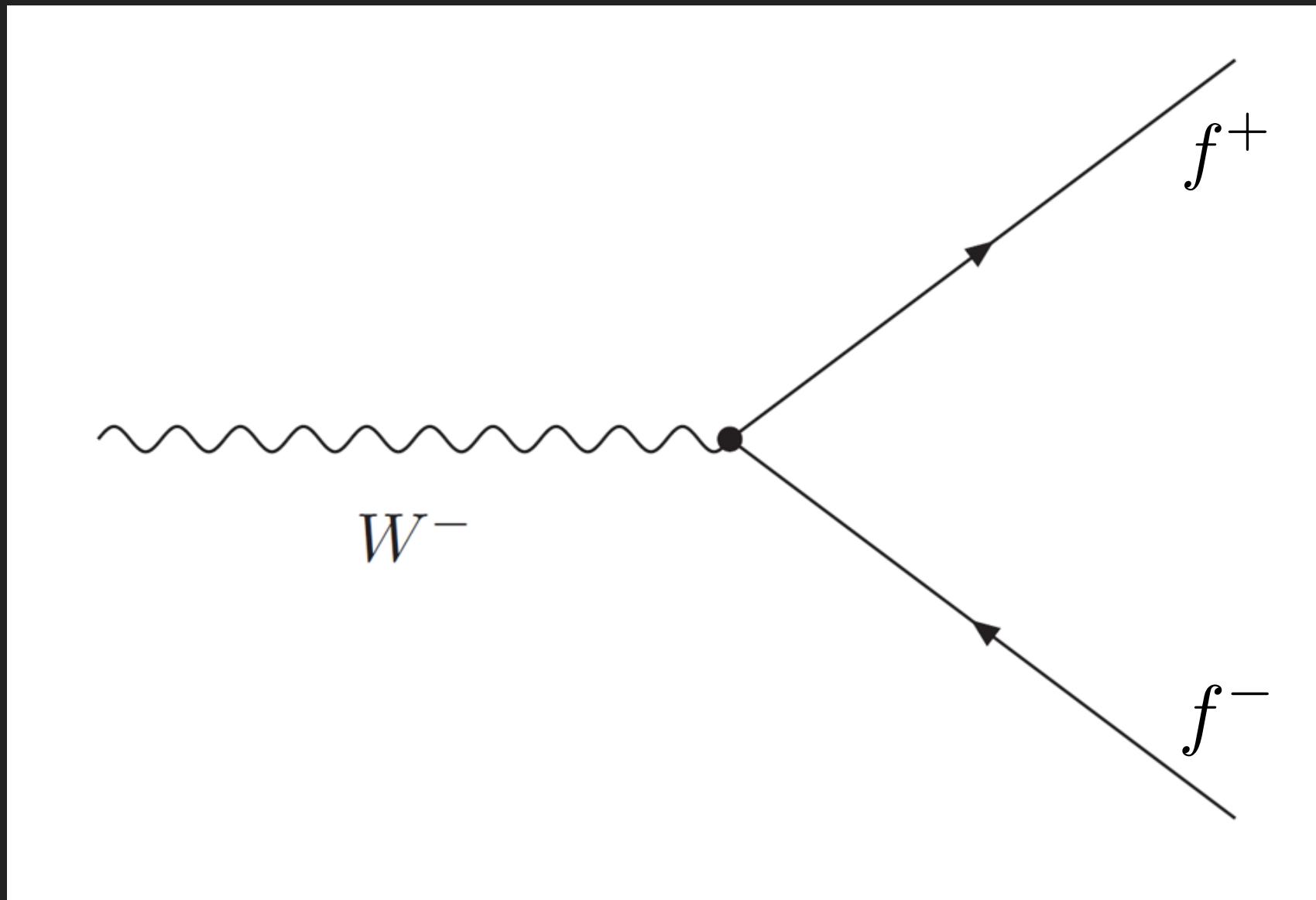
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- Fully Hadronic and Semileptonic Channels

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- New Physics in Transverse Polarizations

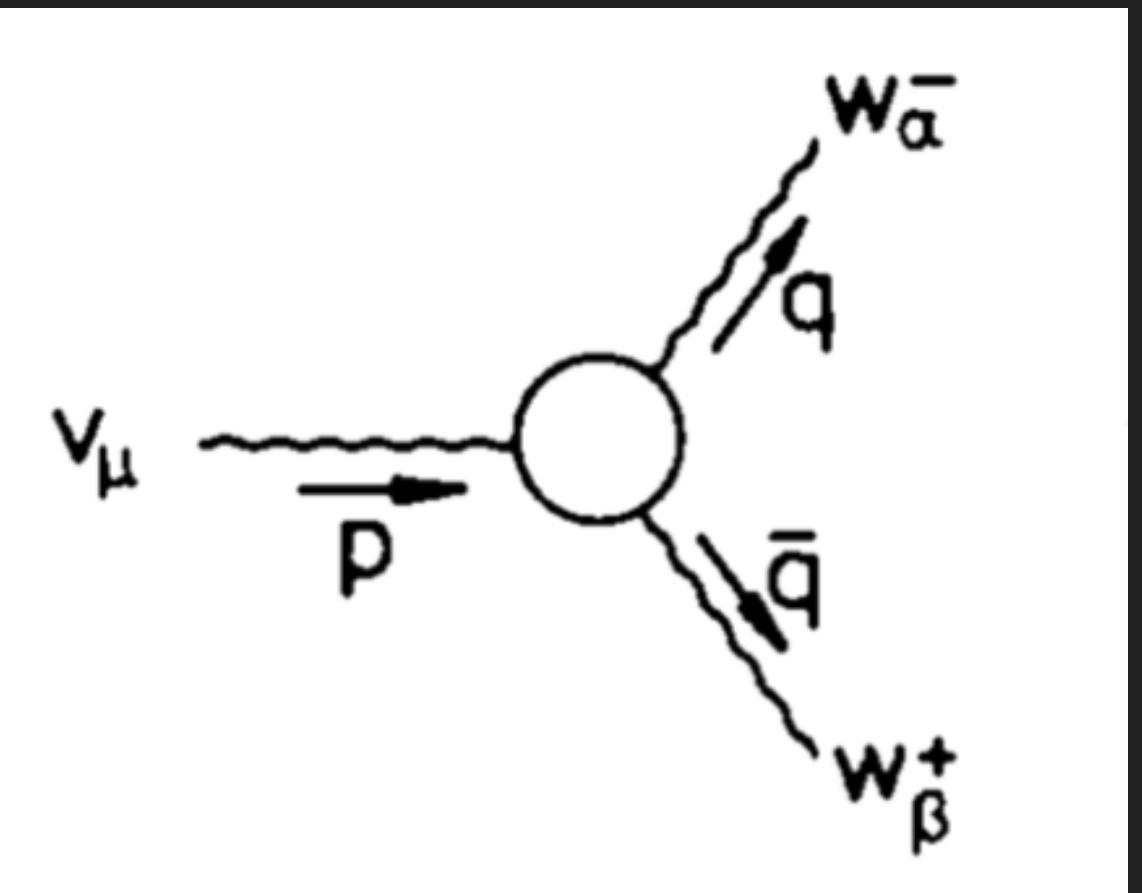


BSM EFFECT

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► Three Gauge Coupling: TGC

- Non Standard Modification of the Three Vector Bosons Interaction

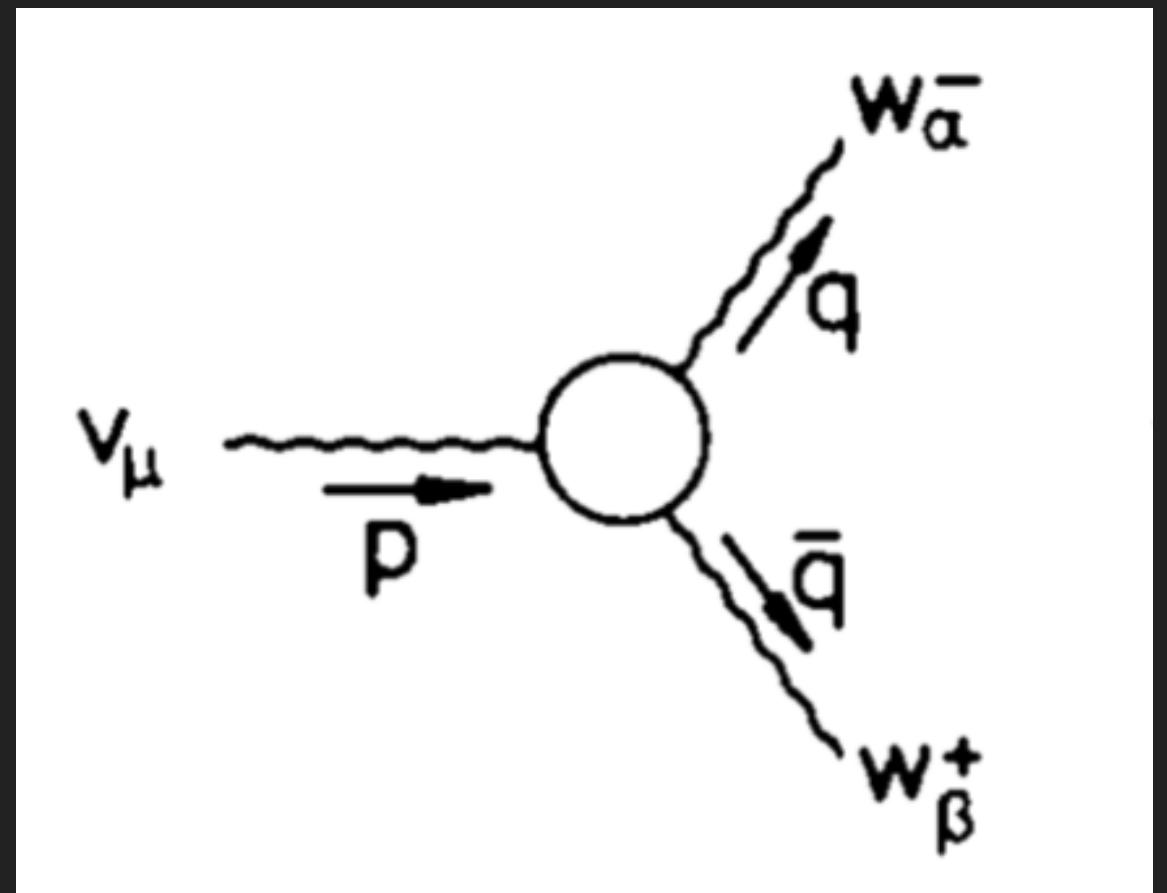


{Hagiwara, Peccei, Zeppenfeld - 1987}

BSM EFFECT

► Three Gauge Coupling: TGC

- Non Standard Modification of the Three Vector Bosons Interaction
- D=6 Effective Operators



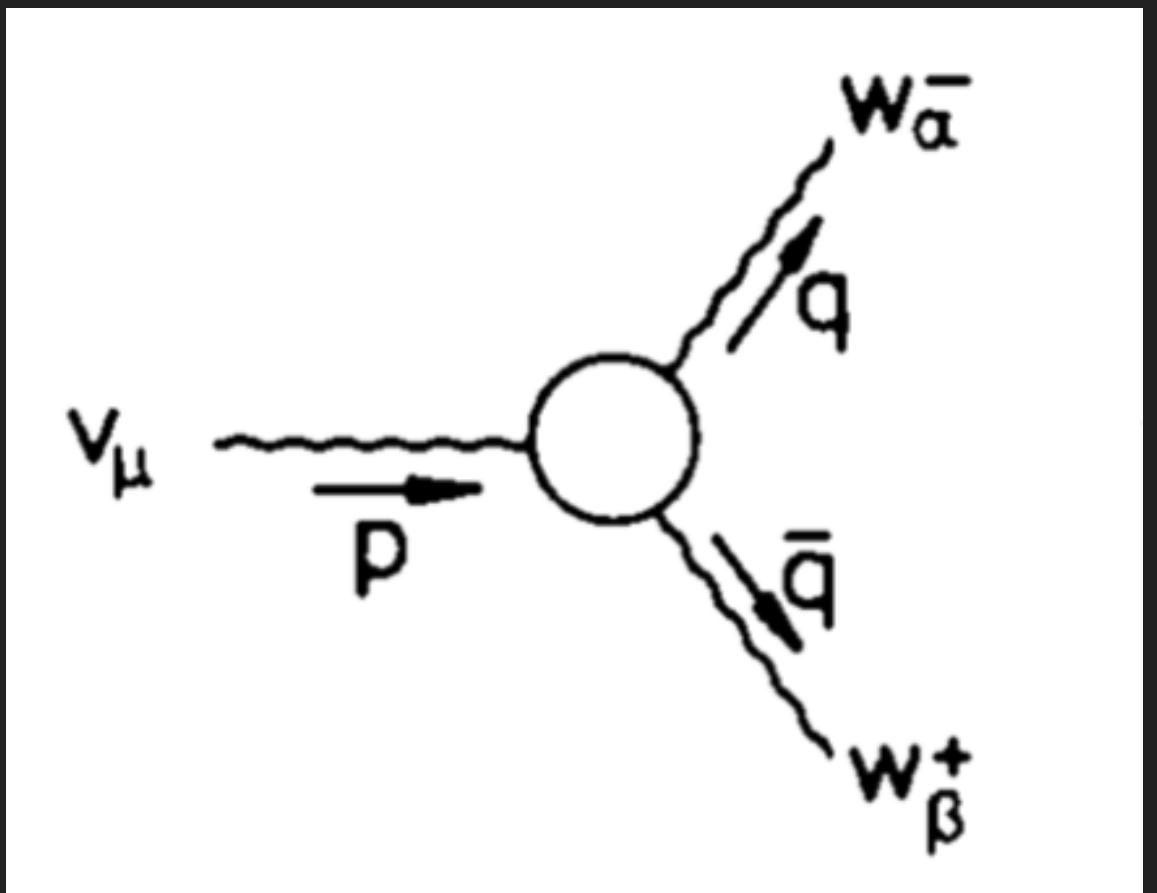
$$\begin{aligned} \Delta\mathcal{L}_{3V} = & ig\delta g_1^Z c_{\theta_W} Z^\mu (W^{-\nu} W_{\mu\nu}^+ - W^{+\nu} W_{\mu\nu}^-) + ig (\delta\kappa_Z c_{\theta_W} Z^{\mu\nu} + \delta\kappa_\gamma s_{\theta_W} A^{\mu\nu}) W_\mu^- W_\nu^+ \\ & + \frac{ig}{m_W^2} (\lambda_Z c_{\theta_W} Z^{\mu\nu} + \lambda_\gamma s_{\theta_W} A^{\mu\nu}) W_\nu^{-\rho} W_{\rho\mu}^+, \end{aligned}$$

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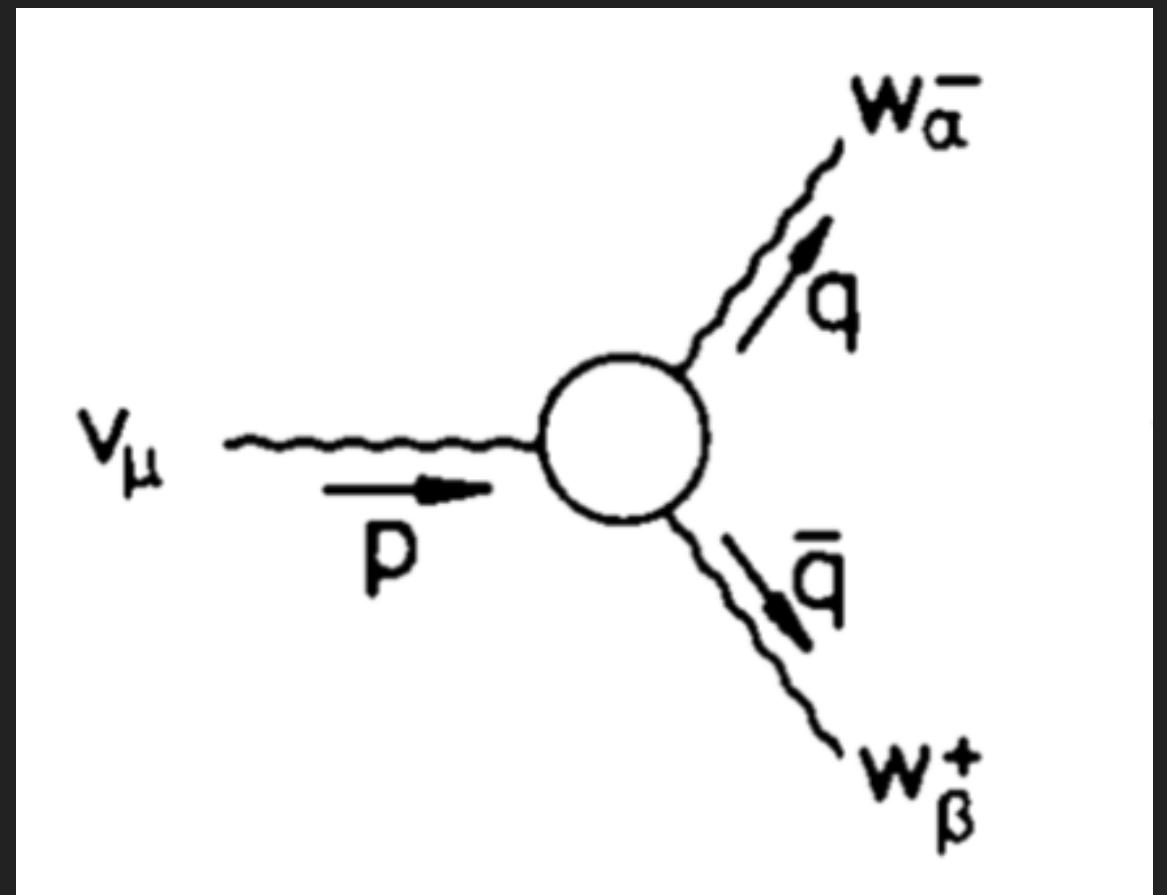
$$\lambda_\gamma = \lambda_Z = -c_{3W} \frac{m_W^2}{\Lambda^2}$$

{Hagiwara, Peccei, Zeppenfeld - 1987}

BSM EFFECT

► Three Gauge Coupling: TGC

- Non Standard Modification of the Three Vector Bosons Interaction
- D=6 Effective Operators
- c3W and Transverse Polarizations



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PROBLEM: NON INTERFERENCE

{Azatov, Contino, Machado, Riva - 2016}

PROBLEM: NON INTERFERENCE

$$\sigma \propto |Amp|^2 \sim SM^2(1 + \delta_{BSM} + \delta_{BSM}^2)$$

$1 \gg \delta_{BSM} \gg \delta_{BSM}^2 \implies$ Interference dominates

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PROBLEM: NON INTERFERENCE

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► Interference Counts

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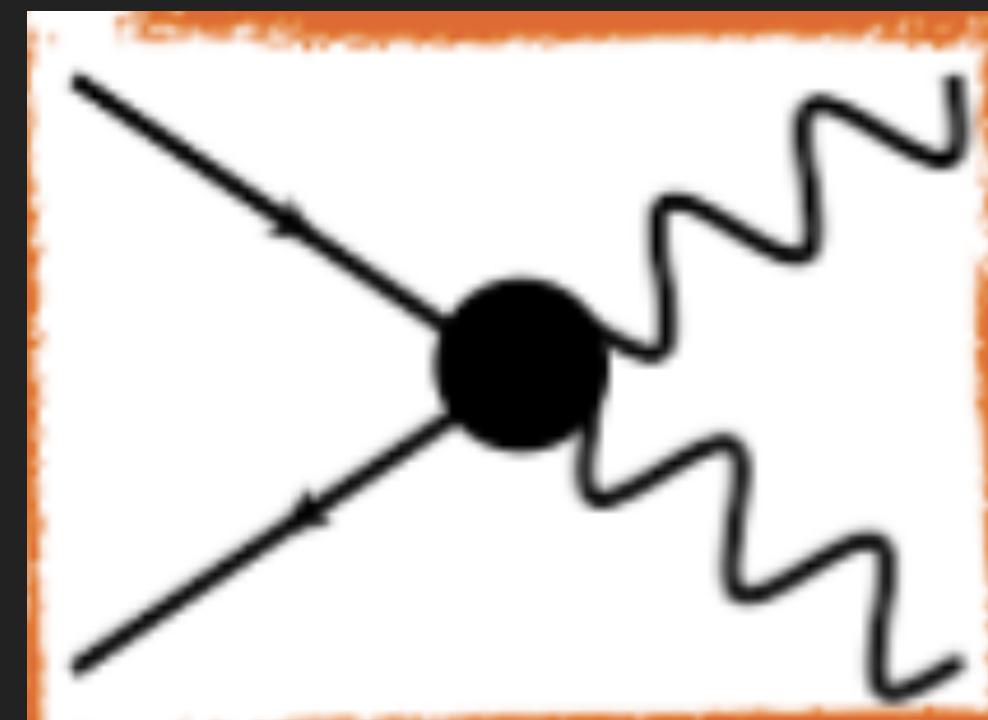
5

► Interference Counts

- $e e \rightarrow W W$: Final states Helicities

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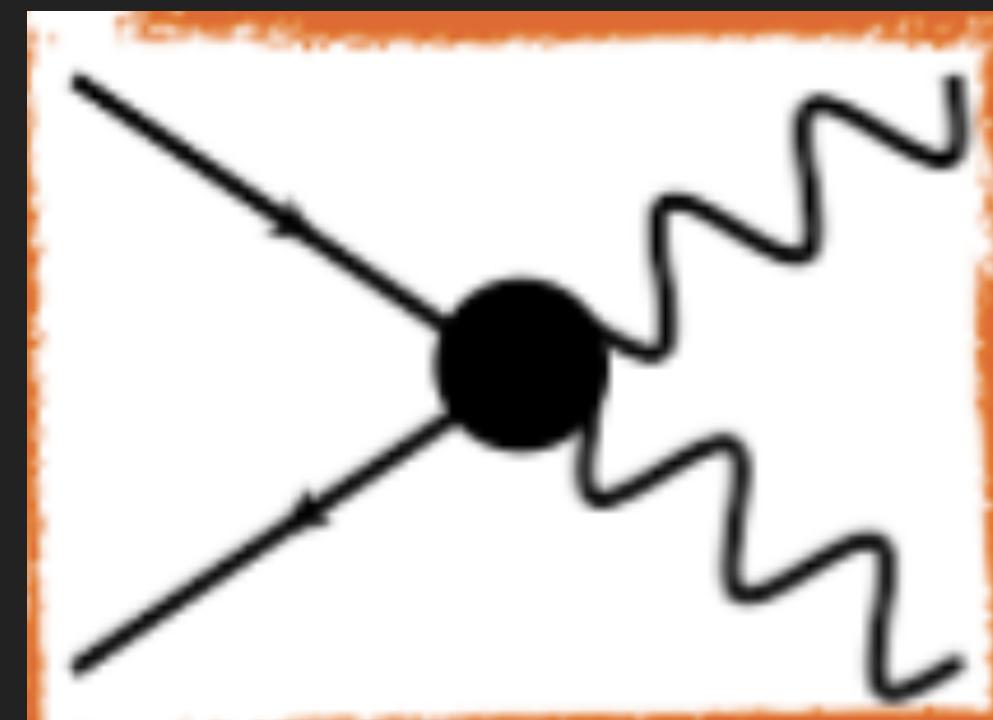
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- $e e \rightarrow W W$: Final states Helicities
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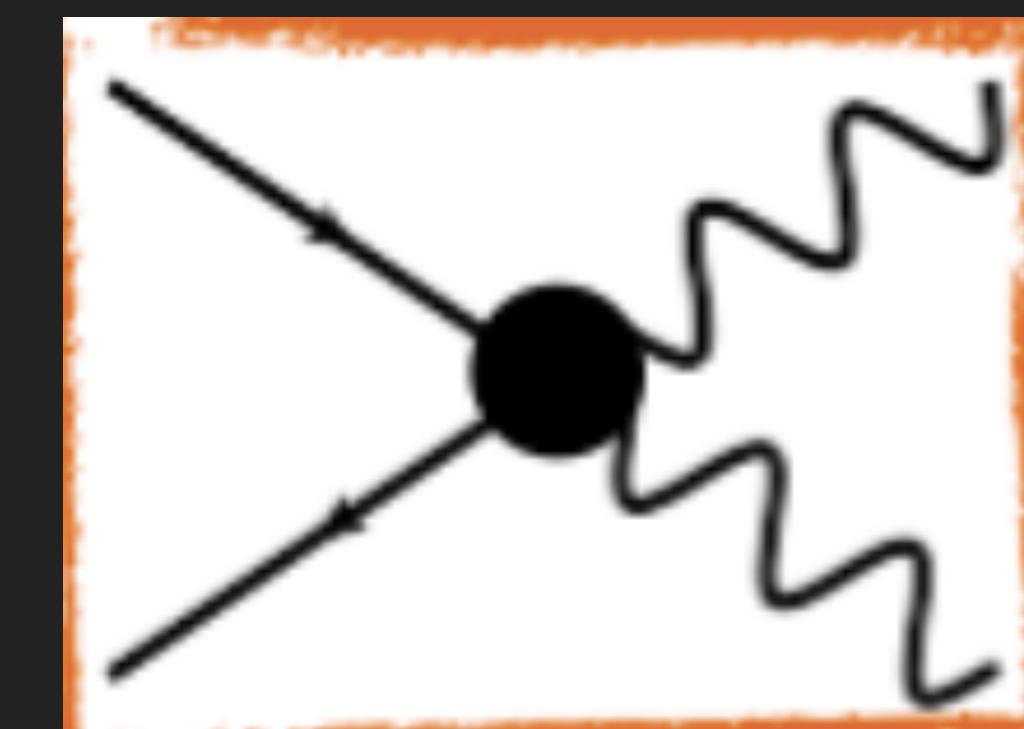
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A_4	$ h(A_4^{\text{SM}}) $	$ h(A_4^{\text{BSM}}) $
VVVV	0	4,2
VV $\phi\phi$	0	2
VV $\psi\psi$	0	2
V $\psi\psi\phi$	0	2



{Azatov, Contino, Machado, Riva - 2016}

PROBLEM: NON INTERFERENCE

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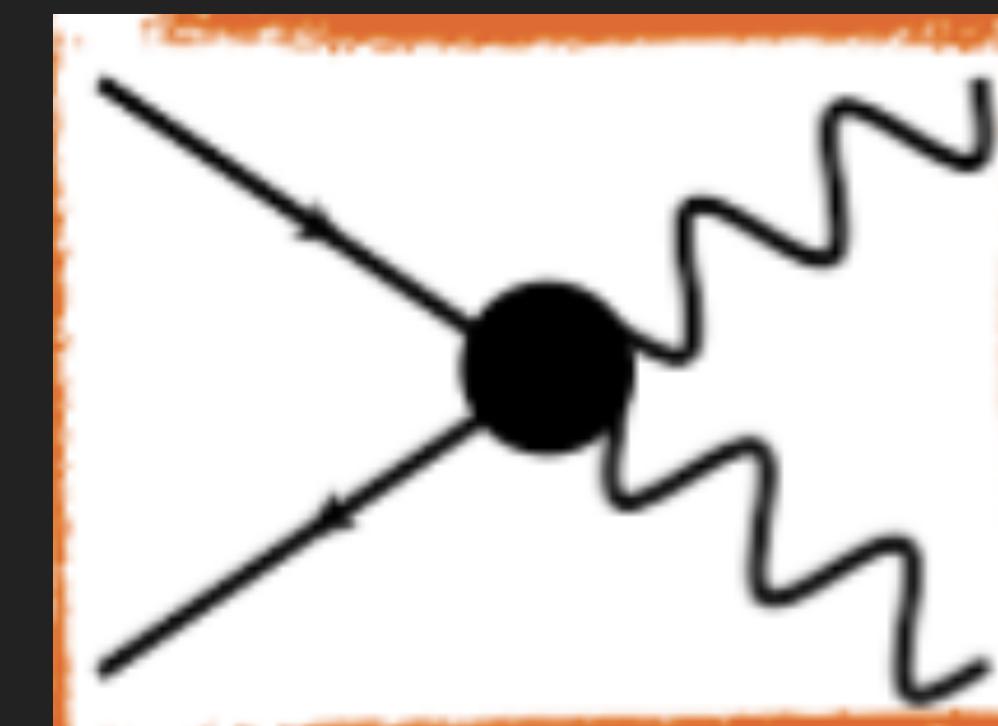
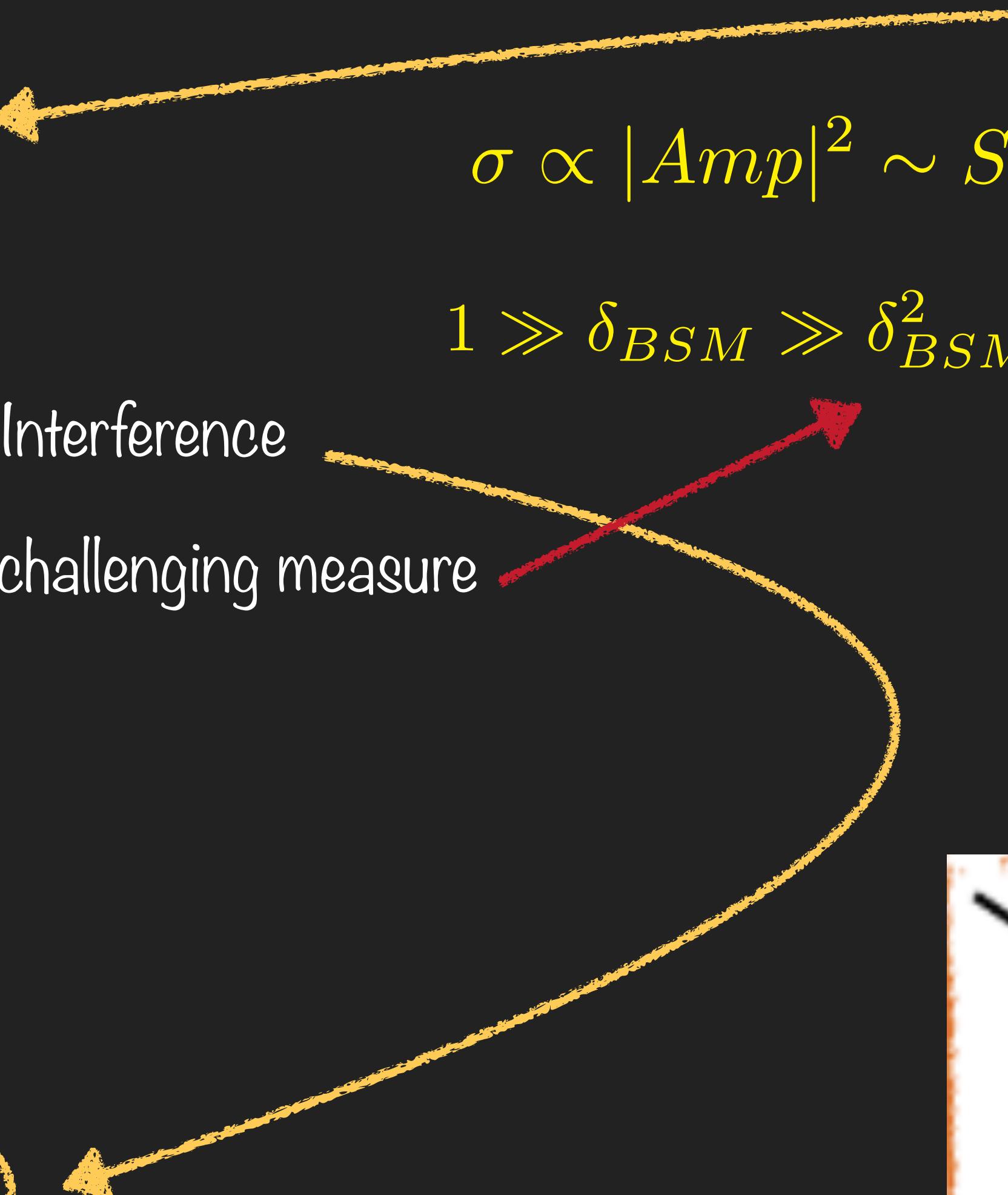
► Interference Counts

- ee \rightarrow WW: Final states Helicities
- SM Vs BSM: Different final States \rightarrow Non Interference
- Only Small quadratic Contribution \rightarrow Very challenging measure

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A POSSIBLE WAY OUT

6

{Panico, Riva, Wulzer - 2017}

A POSSIBLE WAY OUT

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► Interference Resurrection

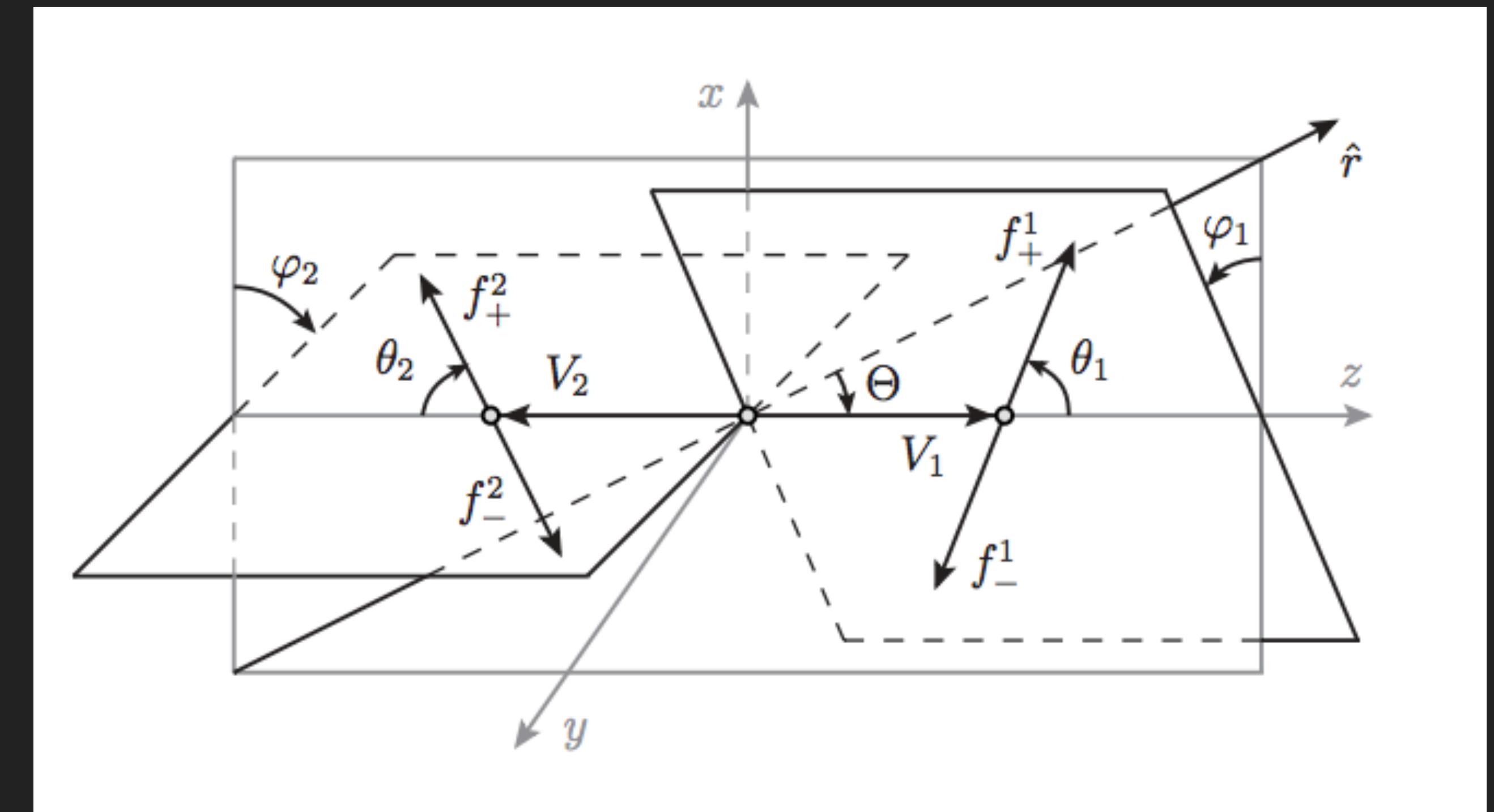
{Panico, Riva, Wulzer - 2017}

A POSSIBLE WAY OUT

6

► Interference Resurrection

- $ee \rightarrow WW \rightarrow ff', ff'$: Same fermionic final state



{Panico, Riva, Wulzer - 2017}

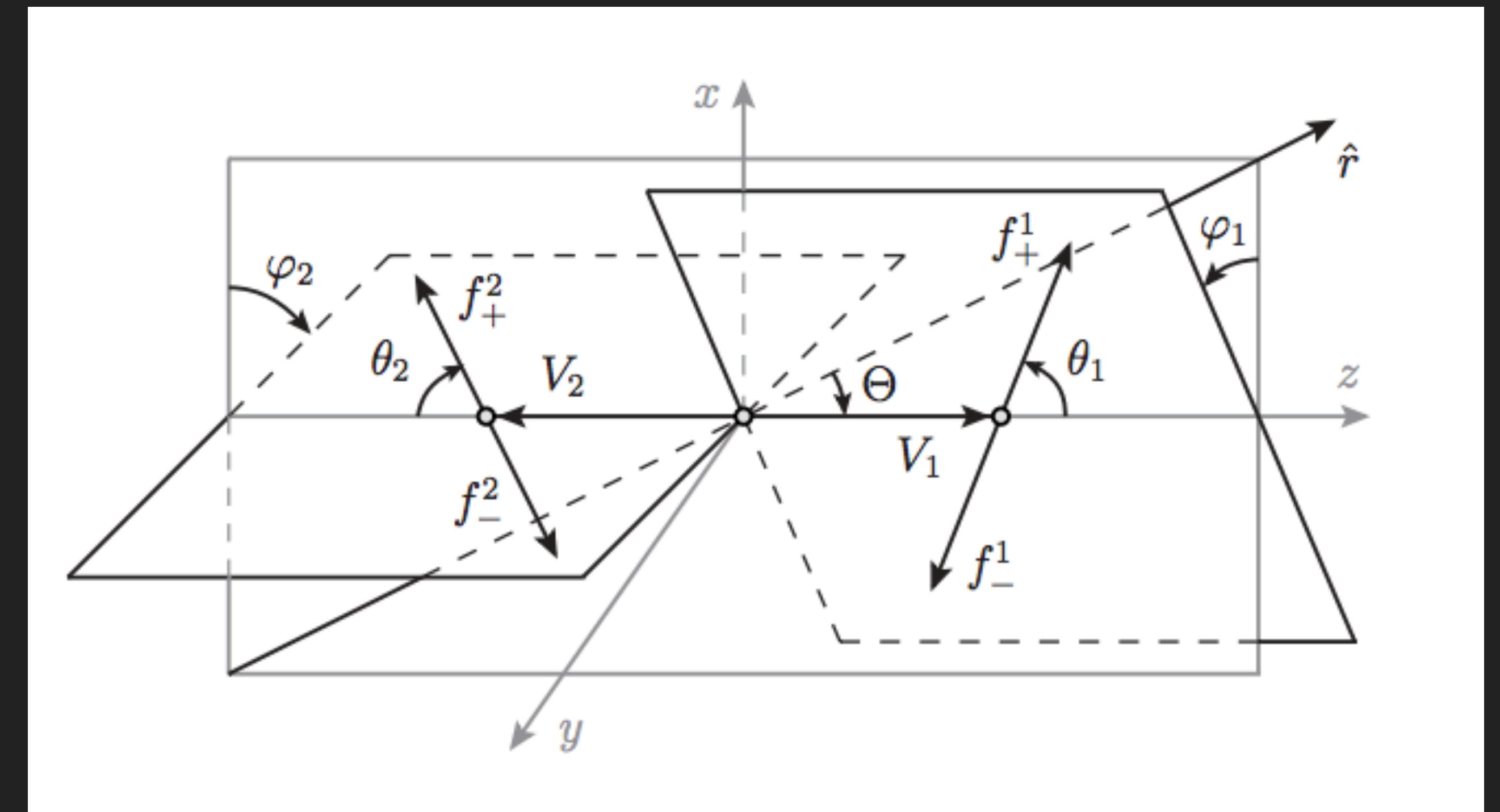
A POSSIBLE WAY OUT

► Interference Resurrection

- $ee \rightarrow WW \rightarrow ff', ff'$: Same fermionic final state

$$I_{\vec{h}\vec{h}'}(\vec{\varphi}) \propto \mathcal{A}_h^{SM} \mathcal{A}_{h'}^{BSM} \times \cos(\Delta\vec{h} \cdot \vec{\varphi})$$

$$\vec{h} = (h_{W_1}, h_{W_2}), \quad \vec{\varphi} = (\varphi_{W_1}, \varphi_{W_2})$$



{Panico, Riva, Wulzer - 2017}

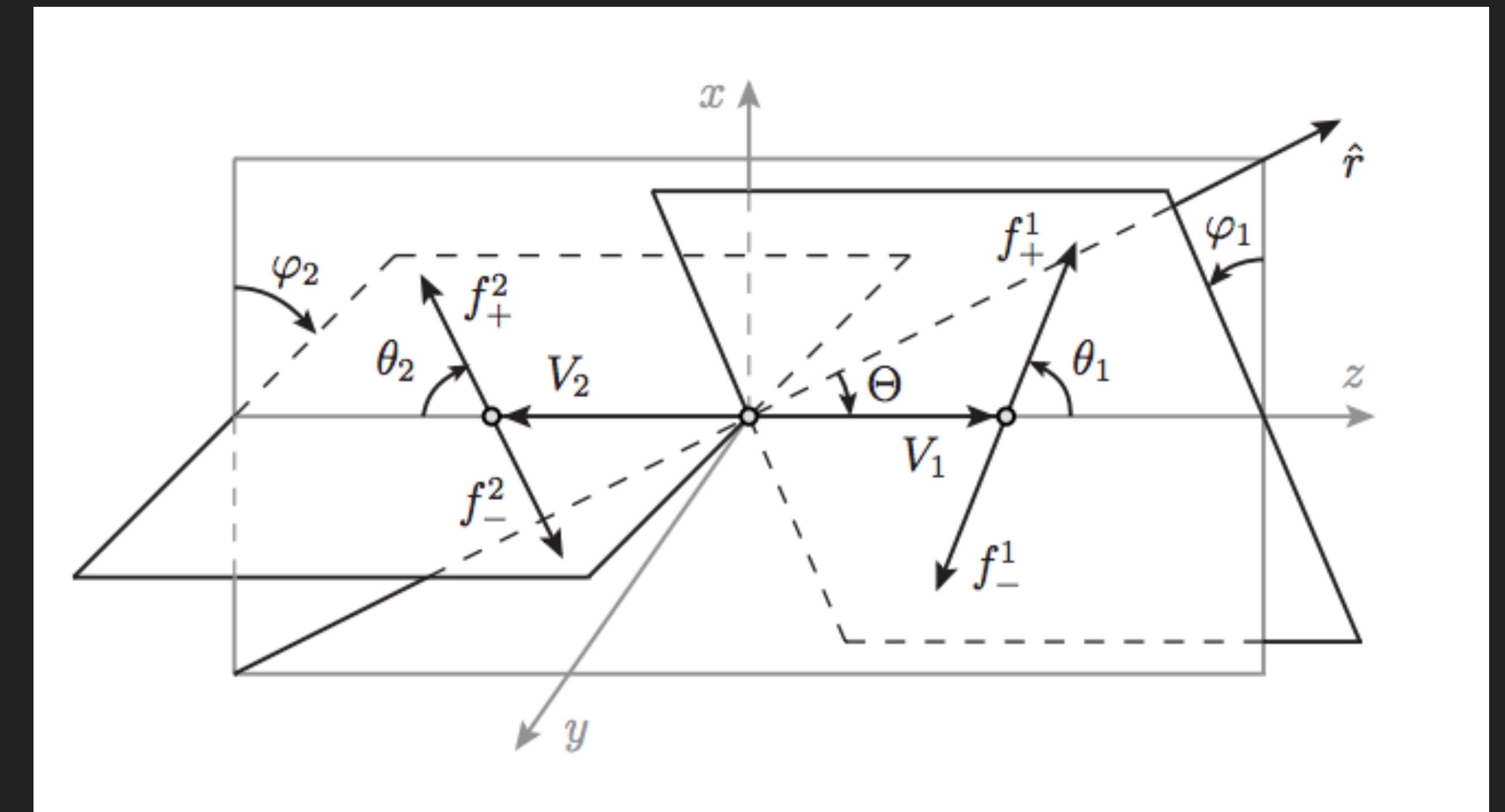
A POSSIBLE WAY OUT

► Interference Resurrection

- $ee \rightarrow WW \rightarrow ff', ff'$: Same fermionic final state
- Both Azimuthal angles Dependence

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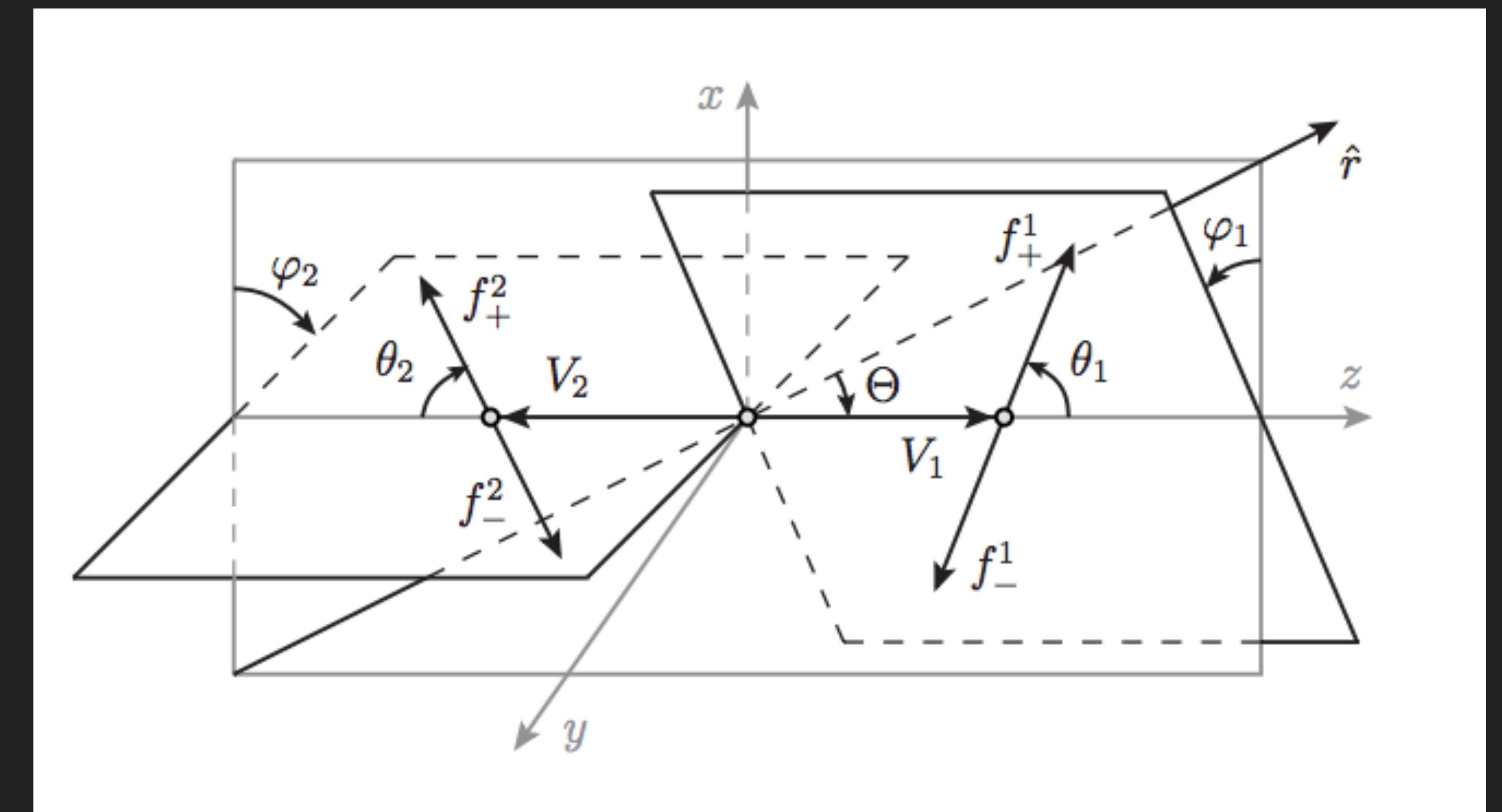
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- $ee \rightarrow WW \rightarrow ff', ff'$: Same fermionic final state
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- Solution: Non inclusive Measurements

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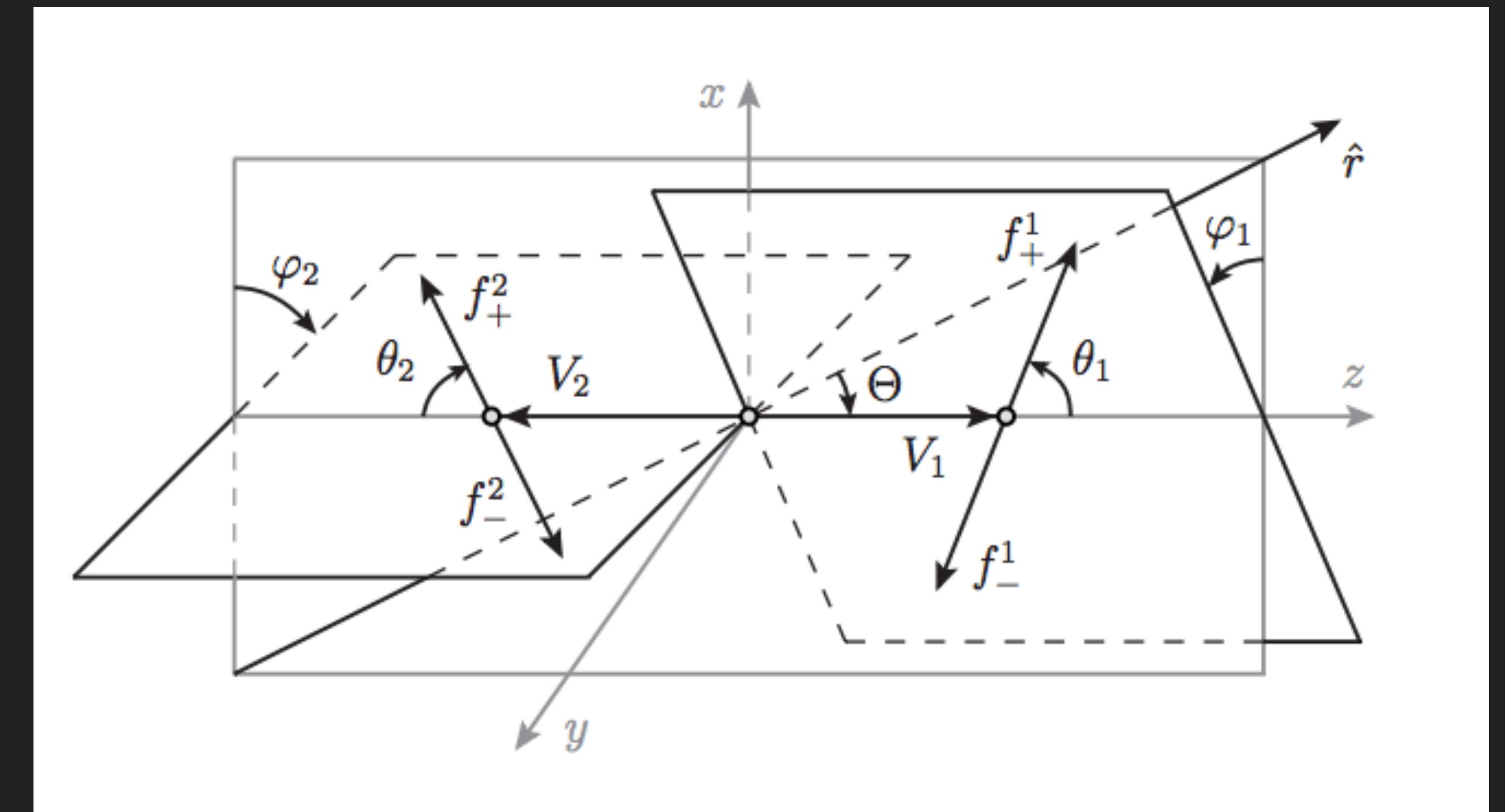
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$$\int I_{\vec{h}\vec{h}'}(\vec{\varphi}) d\vec{\varphi} = 0 \Rightarrow \text{Non Interference}$$

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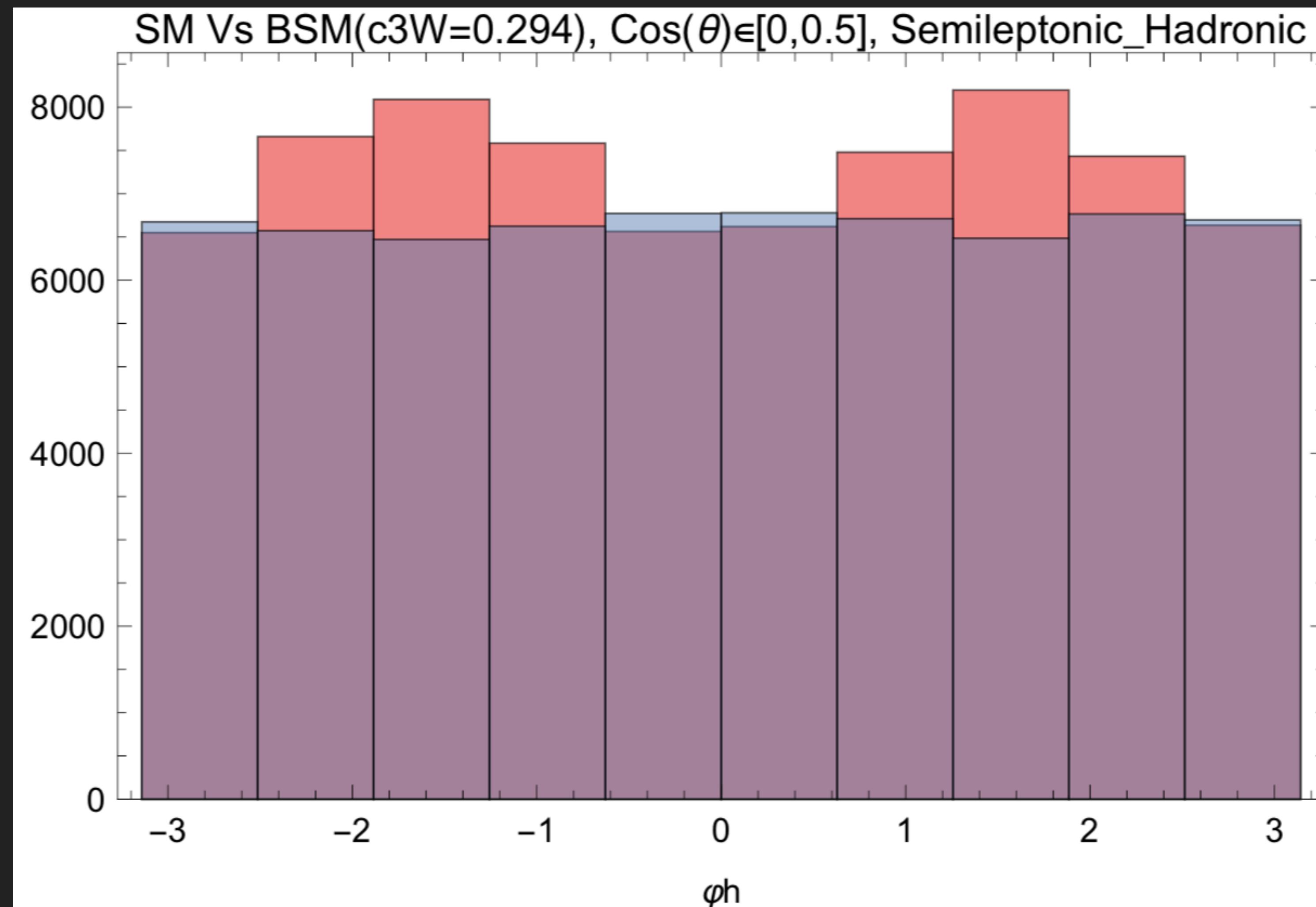
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BINNED DISTRIBUTIONS

BINNED DISTRIBUTIONS

7

► Interference Patterns

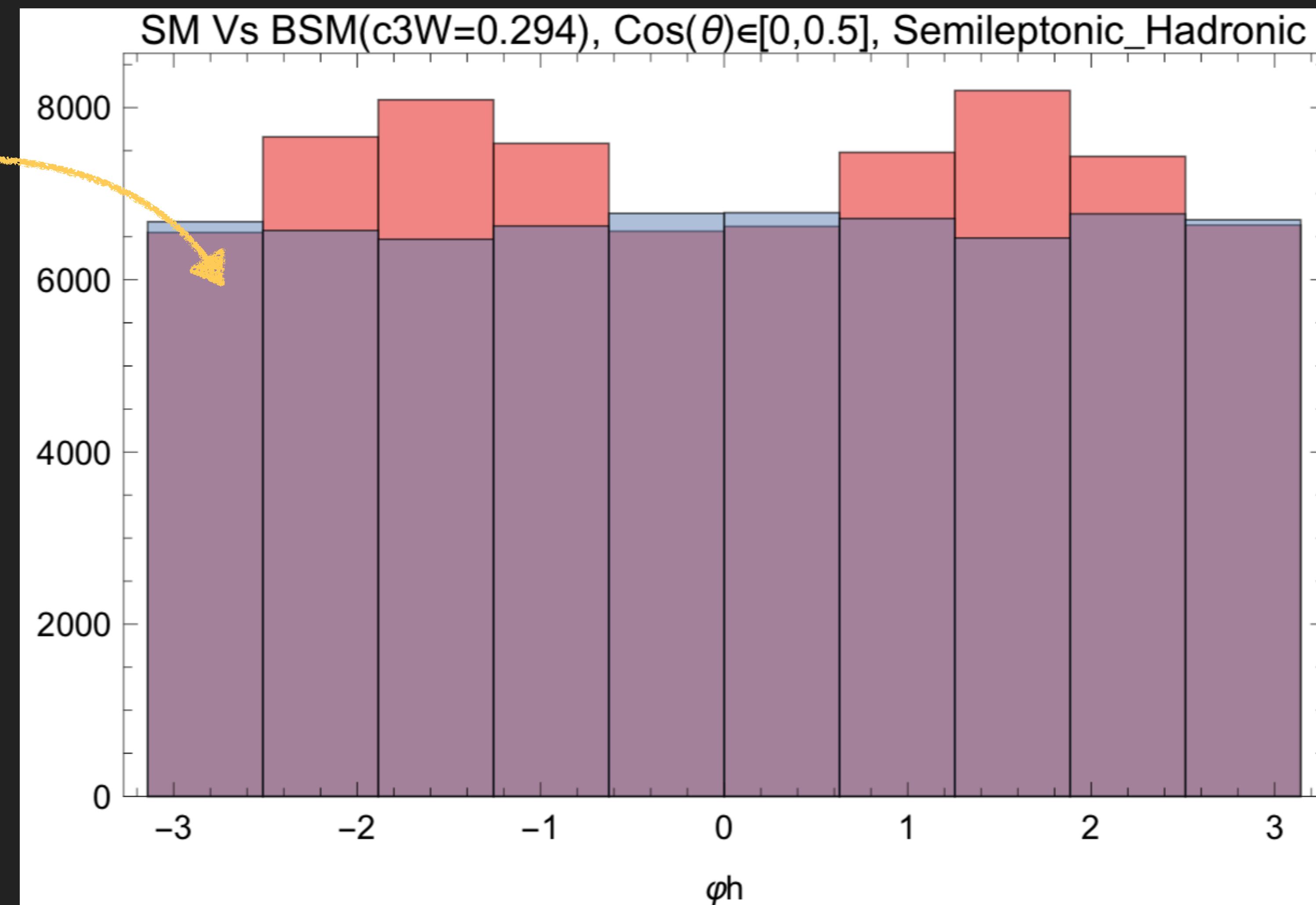


BINNED DISTRIBUTIONS

7

► Interference Patterns

Almost flat
SM
background

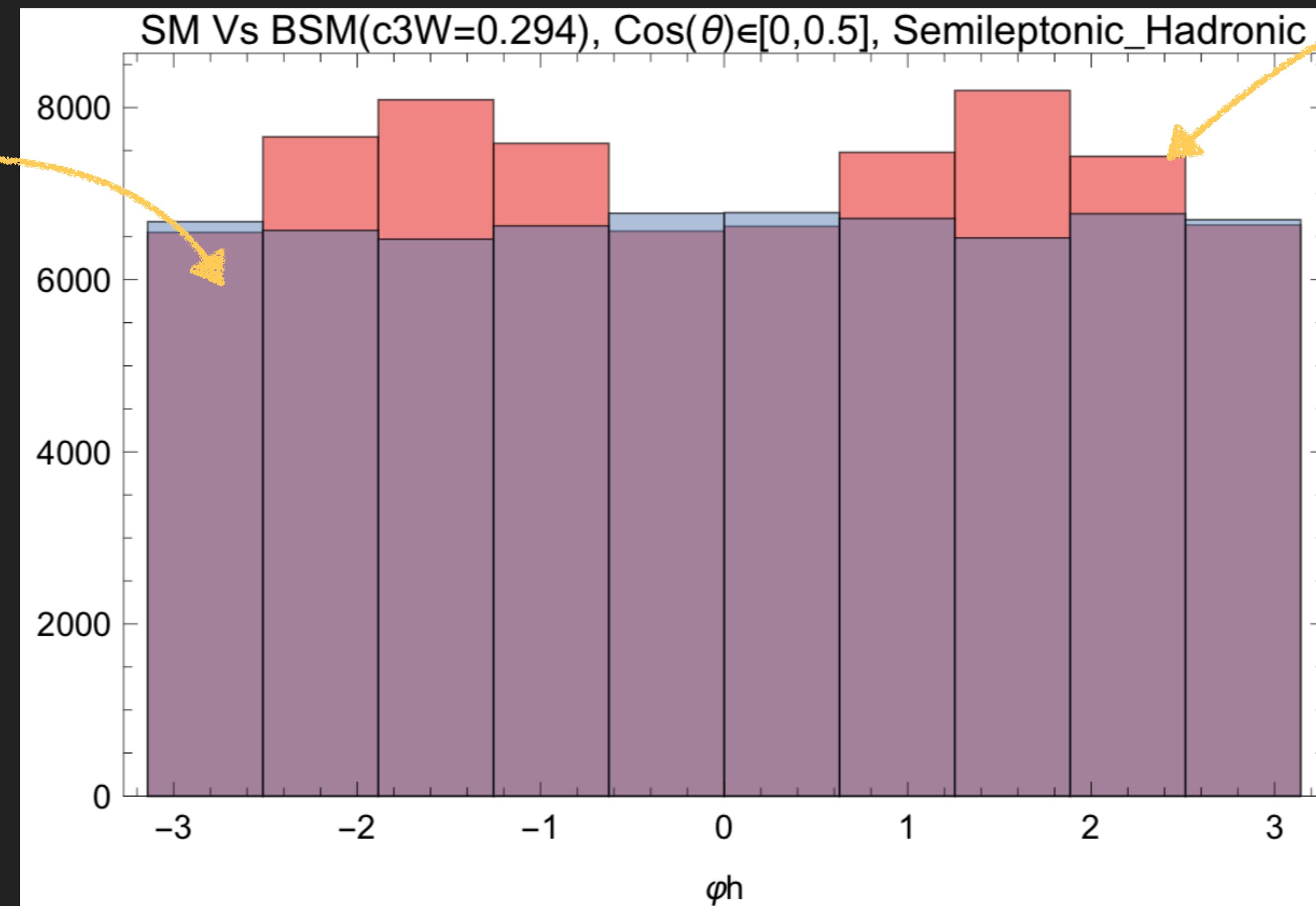


BINNED DISTRIBUTIONS

7

► Interference Patterns

Almost flat
SM
background



$$\mathcal{A}_{SM}\mathcal{A}_{BSM} \sim -\cos(\varphi)$$

SIMULATION

SIMULATION

8

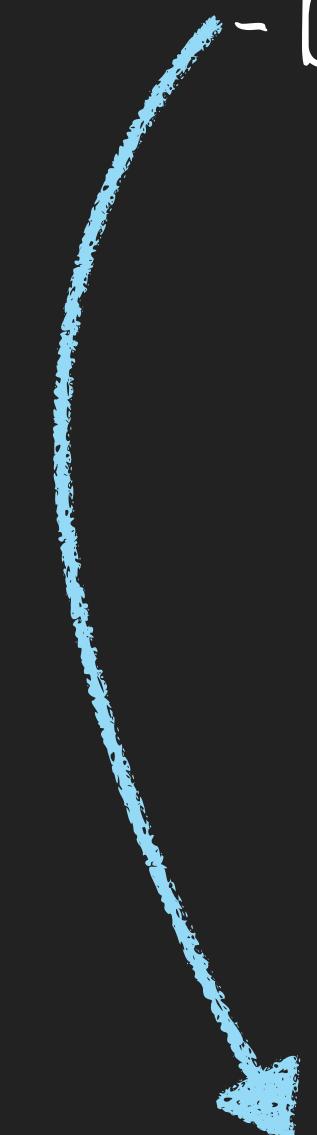
- ▶ Whizard

SIMULATION

8

► Whizard

- Different Energies and Luminosities



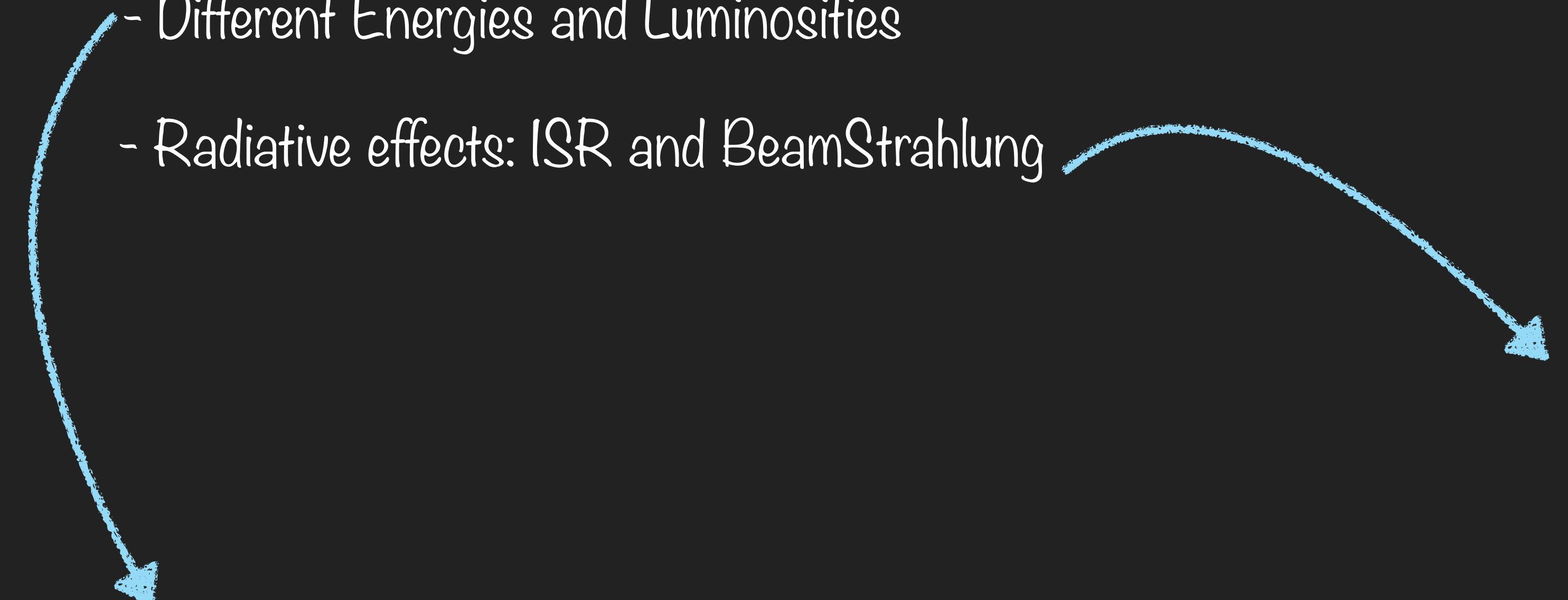
Energy (GeV)	Cut (GeV)	Luminosity (ab^{-1})
3000	2600	5
1400	1300	2.5
380	330	1

SIMULATION

8

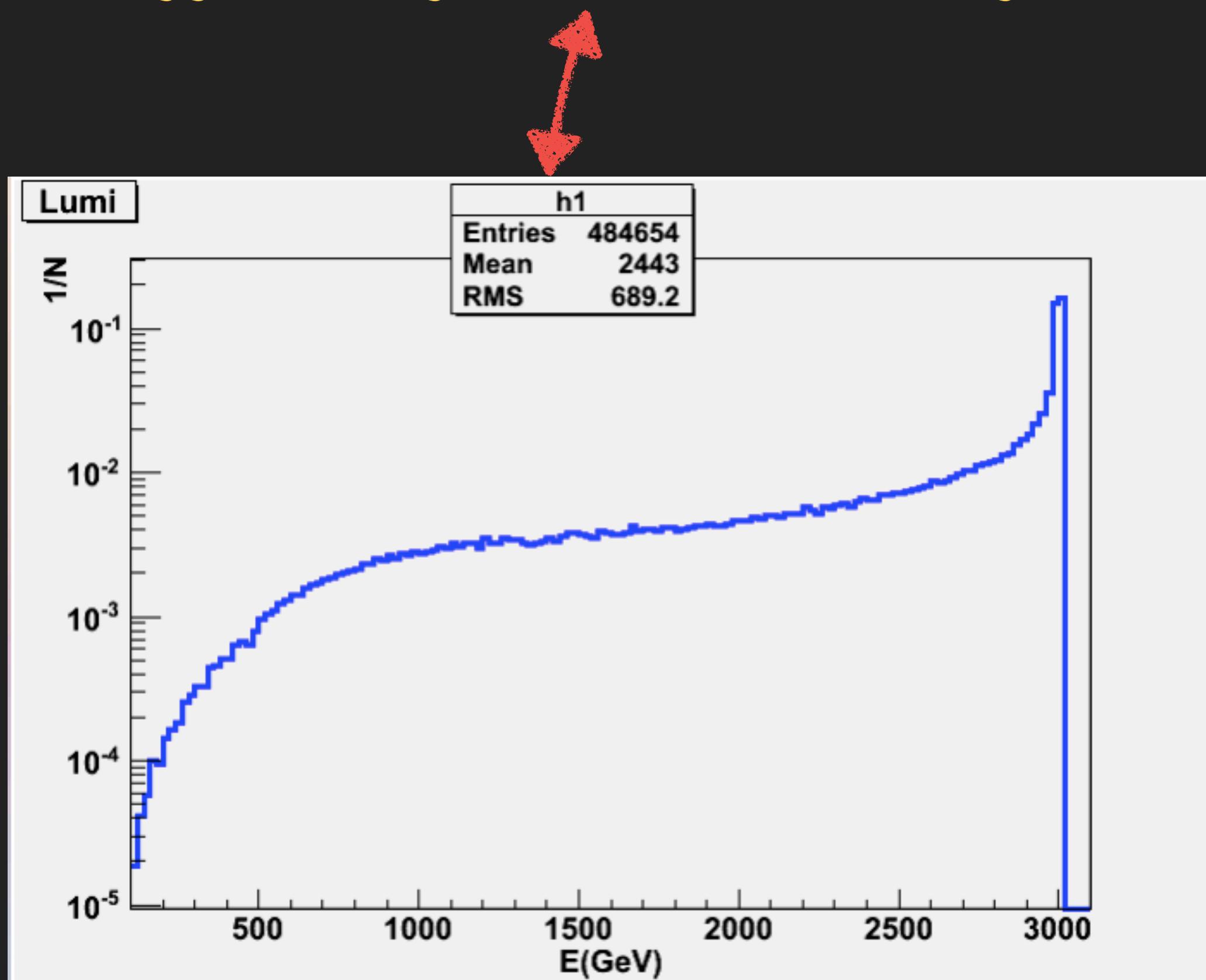
► Whizard

- Different Energies and Luminosities
- Radiative effects: ISR and BeamStrahlung



$$E \ll E_{\text{Max}} \Rightarrow \sigma_{SM} \uparrow \text{ and } \delta_{BSM} \downarrow$$

Bigger Background and Smaller Signal



SIMULATION

8

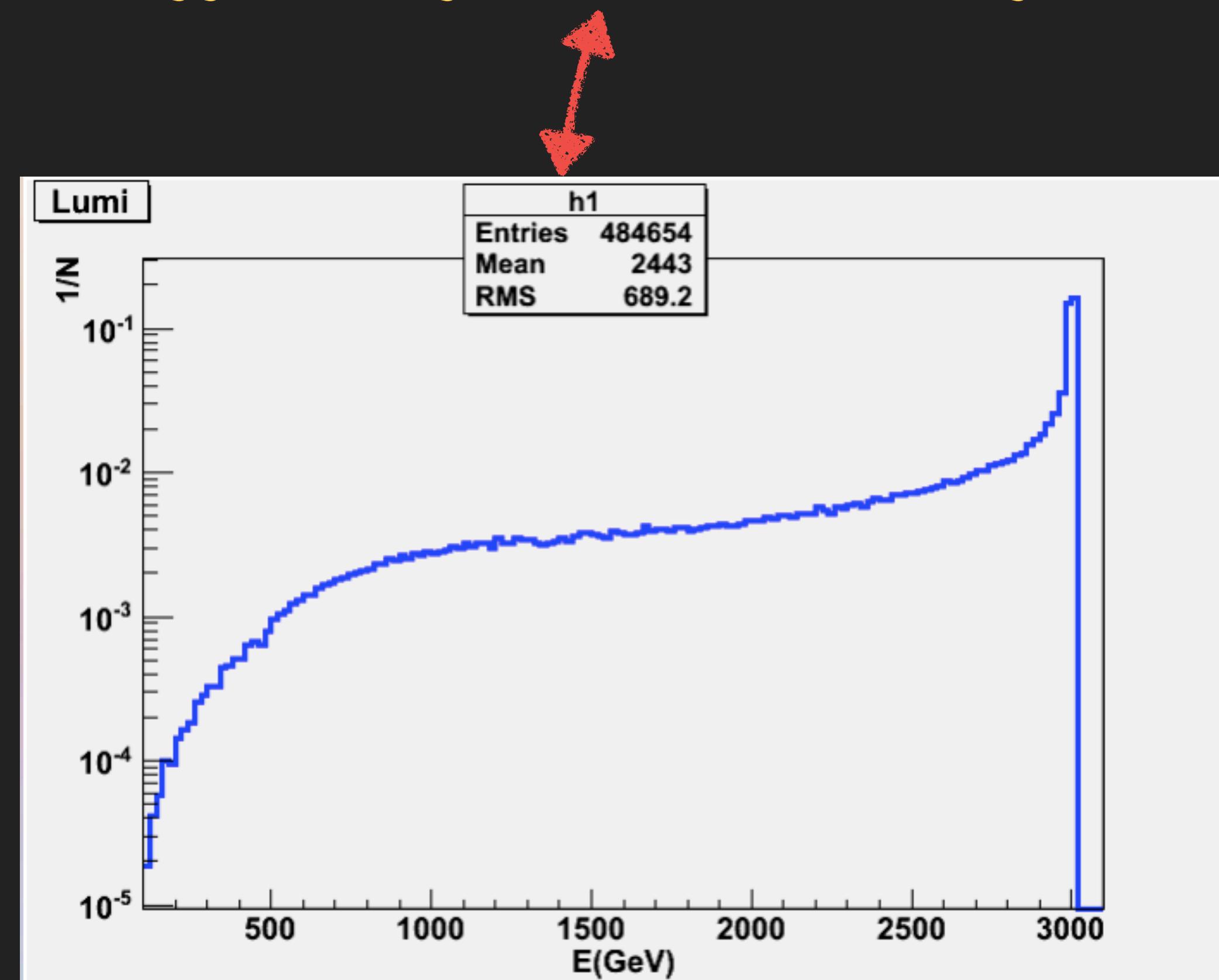
► Whizard

- Different Energies and Luminosities
- Radiative effects: ISR and BeamStrahlung
- Avoiding Radiation Drawbacks -> Only High-energy events

Energy (GeV)	Cut (GeV)	Luminosity (ab^{-1})
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1400	1300	2.5
380	330	1

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Bigger Background and Smaller Signal



ANALYSIS

ANALYSIS

9

► Events Distributions

ANALYSIS

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► Events Distributions

- Bounds on $c3W$ from chi $\hat{^2}$ study

► Events Distributions

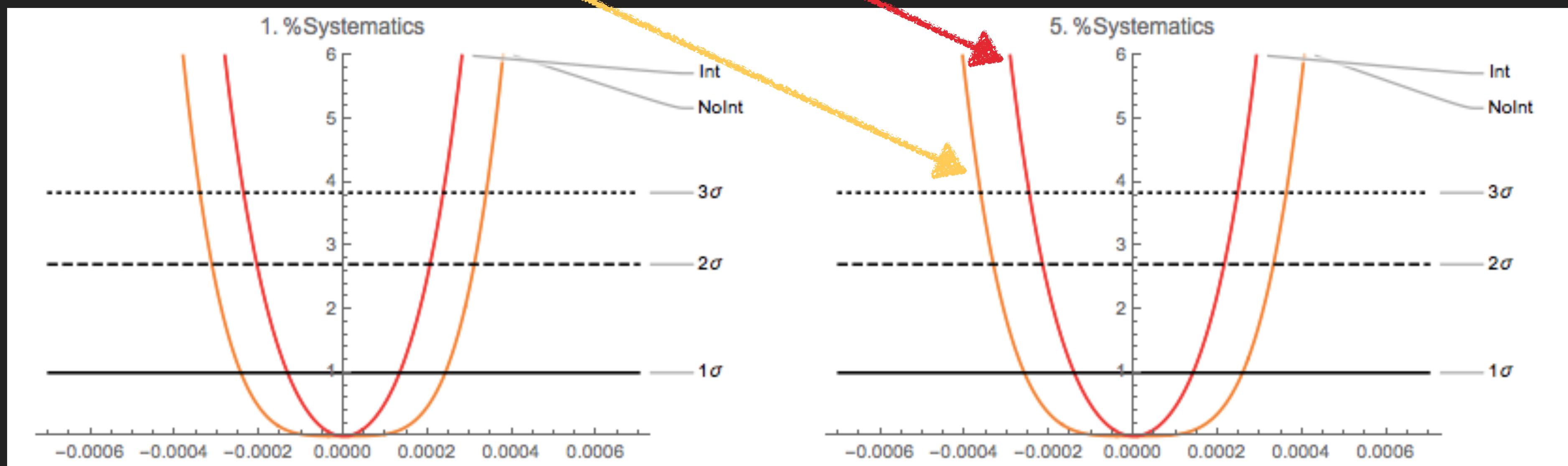
- Bounds on $c3W$ from χ^2 study
- Comparison between **Inclusive** and **Non Inclusive** distributions:

ANALYSIS

9

► Events Distributions

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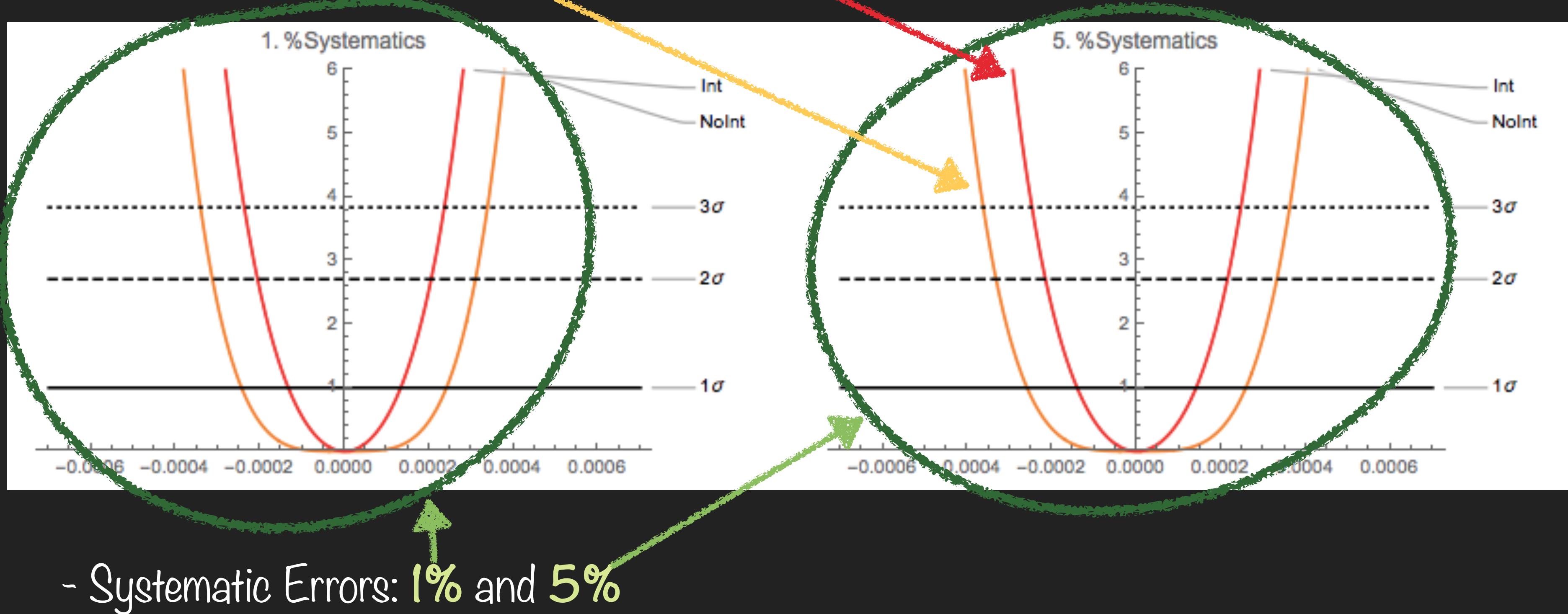


ANALYSIS

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► Events Distributions

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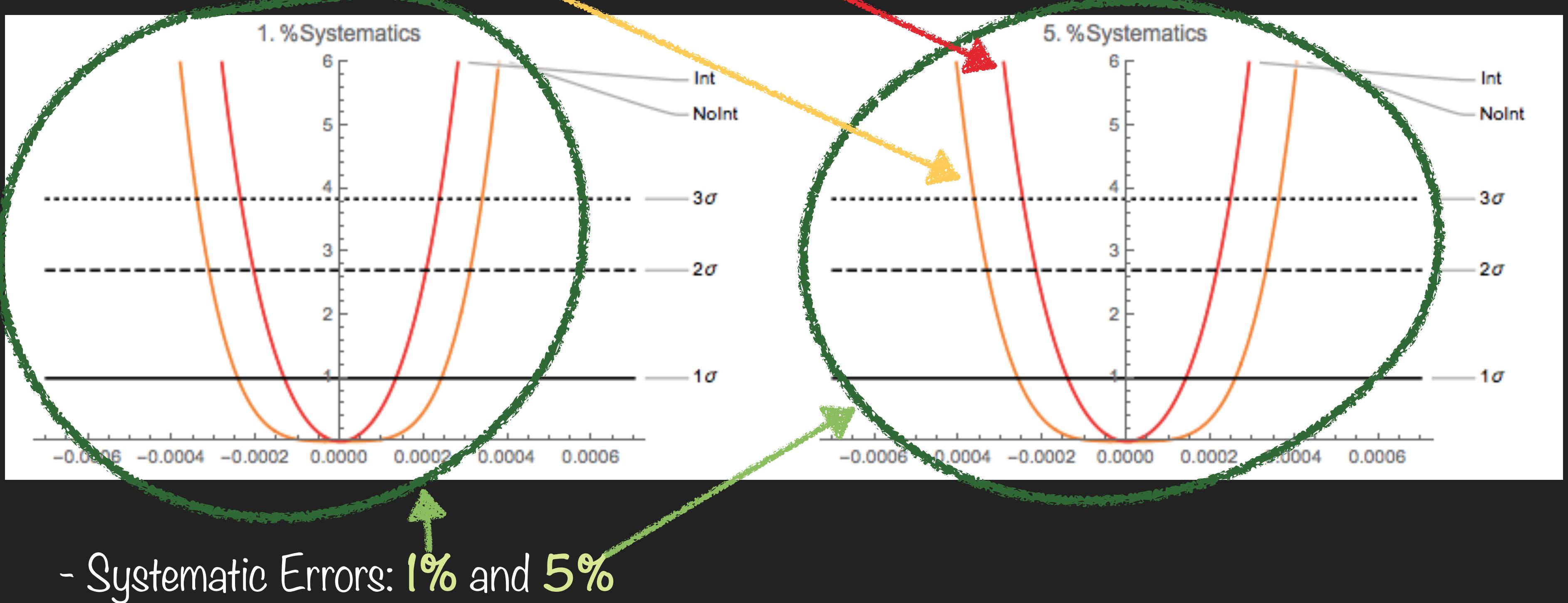


ANALYSIS

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- Bounds on $c3W$ from χ^2 study
- Comparison between **Inclusive** and **Non Inclusive** distributions:

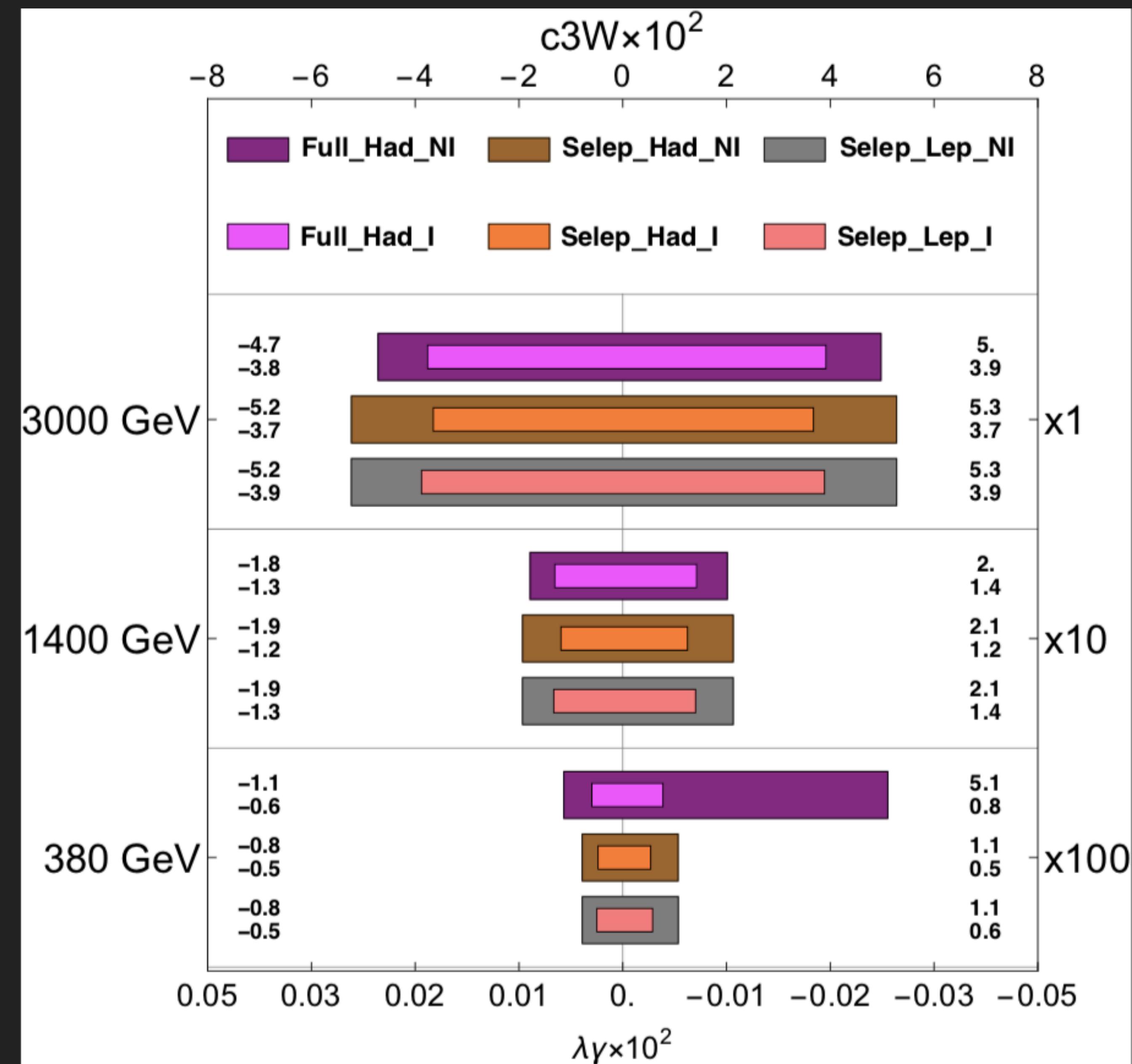


3SIGMA-BOUNDS

10

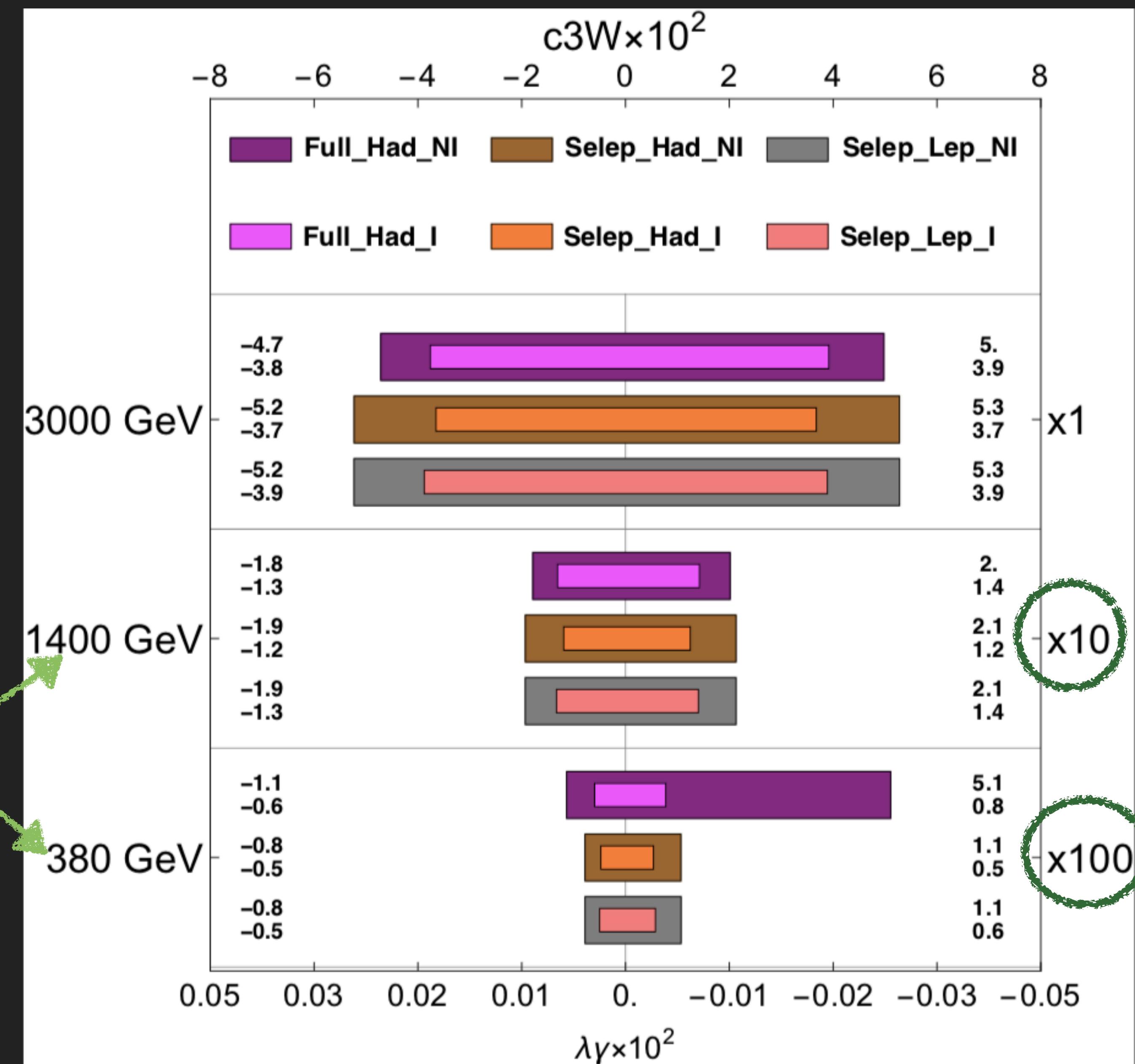
3SIGMA-BOUNDS

10



3SIGMA-BOUNDS

Actually
much Wider,
rescaled for
aesthetic
reasons



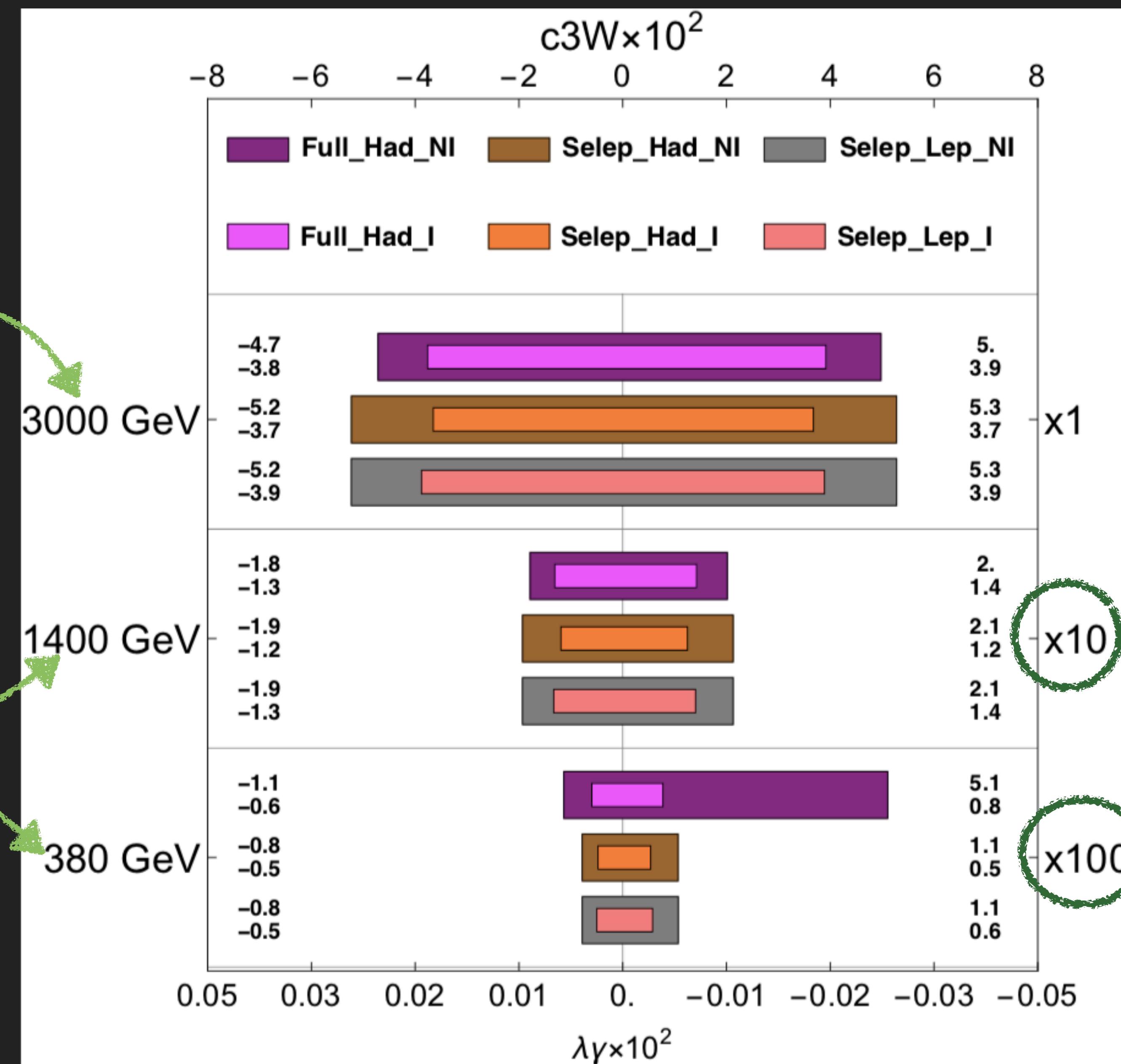
3SIGMA-BOUNDS

Best Energy
3000 GeV

Actually
much Wider,
rescaled for
aesthetic
reasons

1400 GeV

380 GeV



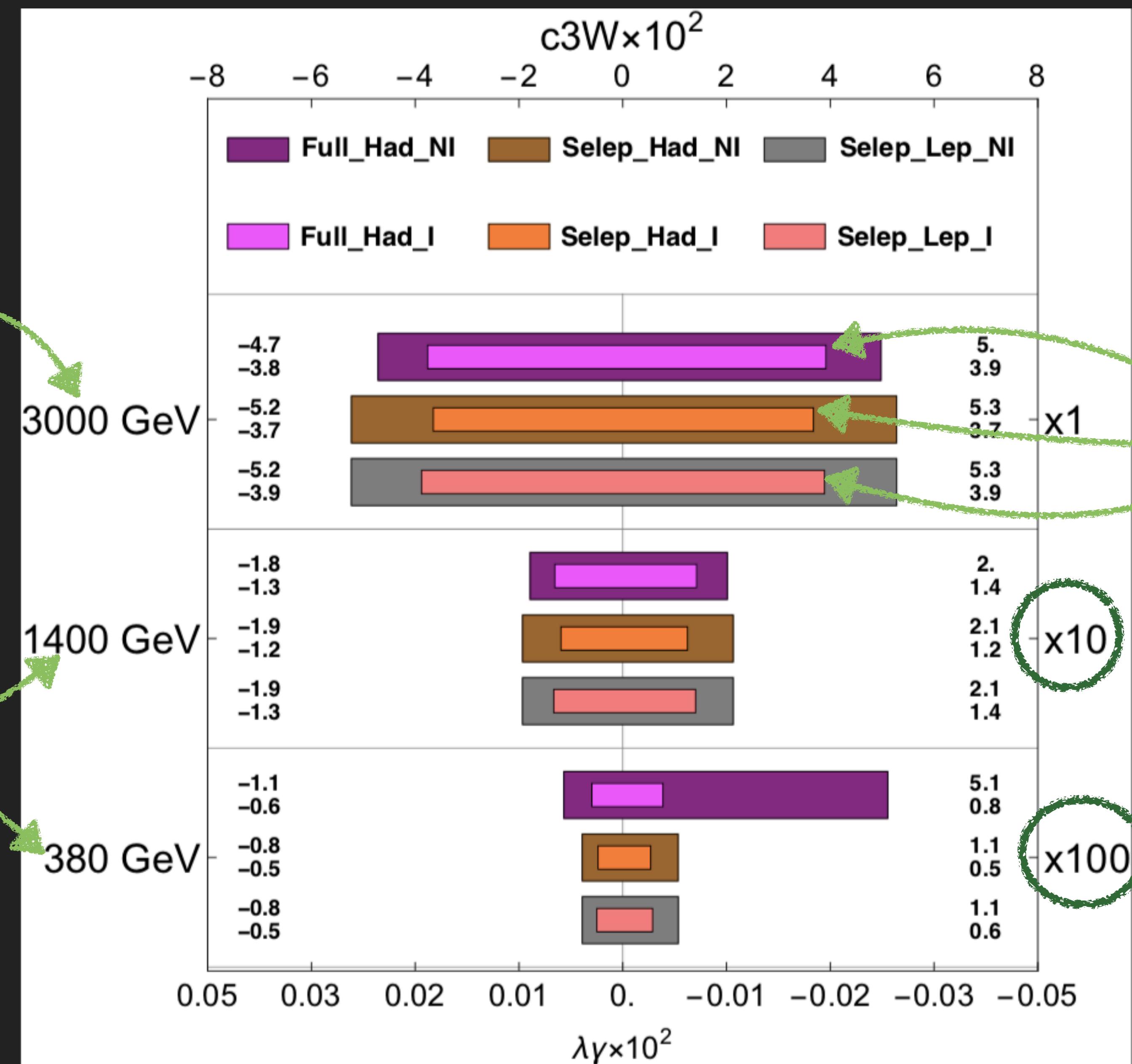
3SIGMA-BOUNDS

Best Energy
3000 GeV

Actually
much Wider,
rescaled for
aesthetic
reasons

1400 GeV

380 GeV



Much better
constraints
when
Interference is
taken into
account.....
like a factor 2
in the
Luminosity!

CONCLUSIONS

CONCLUSIONS

11

► Main Results

CONCLUSIONS

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- Recovering BSM-Interference via Non Inclusive Measurements in the Azimuthal angles

CONCLUSIONS

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► Future Proposals

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- Exploring other Physics effects encoded in the TGC parameters

CONCLUSIONS

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► Main Results

- Recovering BSM-Interference via Non Inclusive Measurements in the Azimuthal angles
- Competitive Bound on TGC parameter with CLIC technology

► Future Proposals

- Angular comprehensive distributions: both azimuthal and polar, to investigate correlations
- Exploring other Physics effects encoded in the TGC parameters
- Full Simulation in Progress {Maier and Robson}

THANKS FOR
YOUR
ATTENTION