Constraining anomalous HVV interactions at proton and lepton colliders

Yaofu Zhou
Johns Hopkins University

The 2014 Phenomenology Symposium
May 5, University of Pittsburg

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Constraining anomalous *HVV* interactions at proton and lepton colliders

Ian Anderson,[1] Sara Bolognesi,[1] Fabrizio Caola,[1] Yanyan Gao,[2] Andrei V. Gritsan,[1] Christopher B. Martin,[1] Kirill Melnikov,[1] Markus Schulze,[3] Nhan V. Tran,[2] Andrew Whitbeck,[1] and Yaofu Zhou[1]

[1]*Department of Physics and Astronomy, Johns Hopkins University, Baltimore, Maryland 21218, USA*

[2]*Fermi National Accelerator Laboratory (FNAL), Batavia, Illinois 60510, USA*

[3]*Argonne National Laboratory (ANL), Lemont, Illinois 60439, USA*

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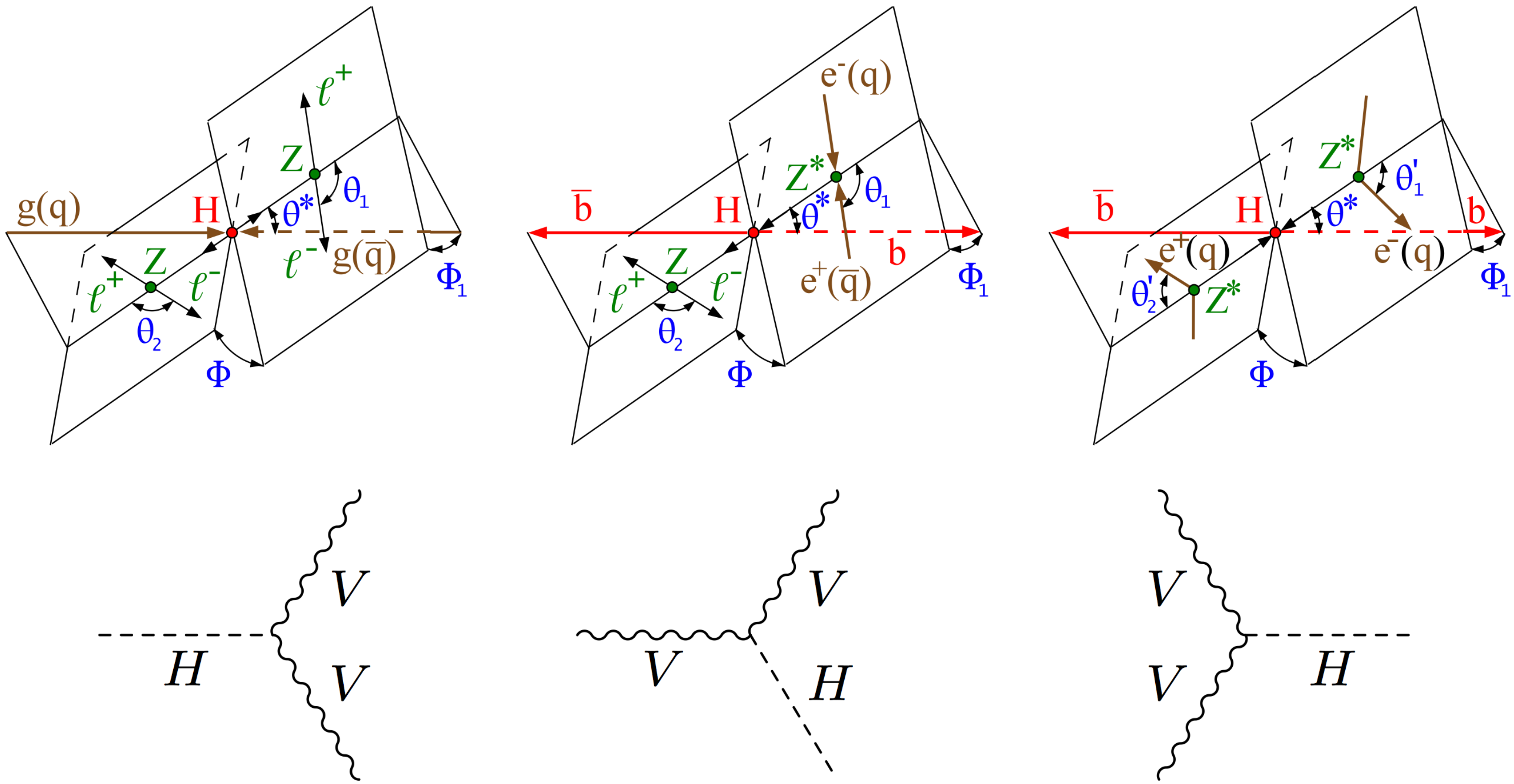
g(q)
H
Z
ℓ^+
ℓ^-
θ^*
θ_1
θ_2
$g(\bar{q})$
Φ
Φ_1
$\bar{b}$
b
Z^*
$e^-(q)$
$e^+(\bar{q})$
$e^+(q)$
θ'_1
θ'_2
V
V
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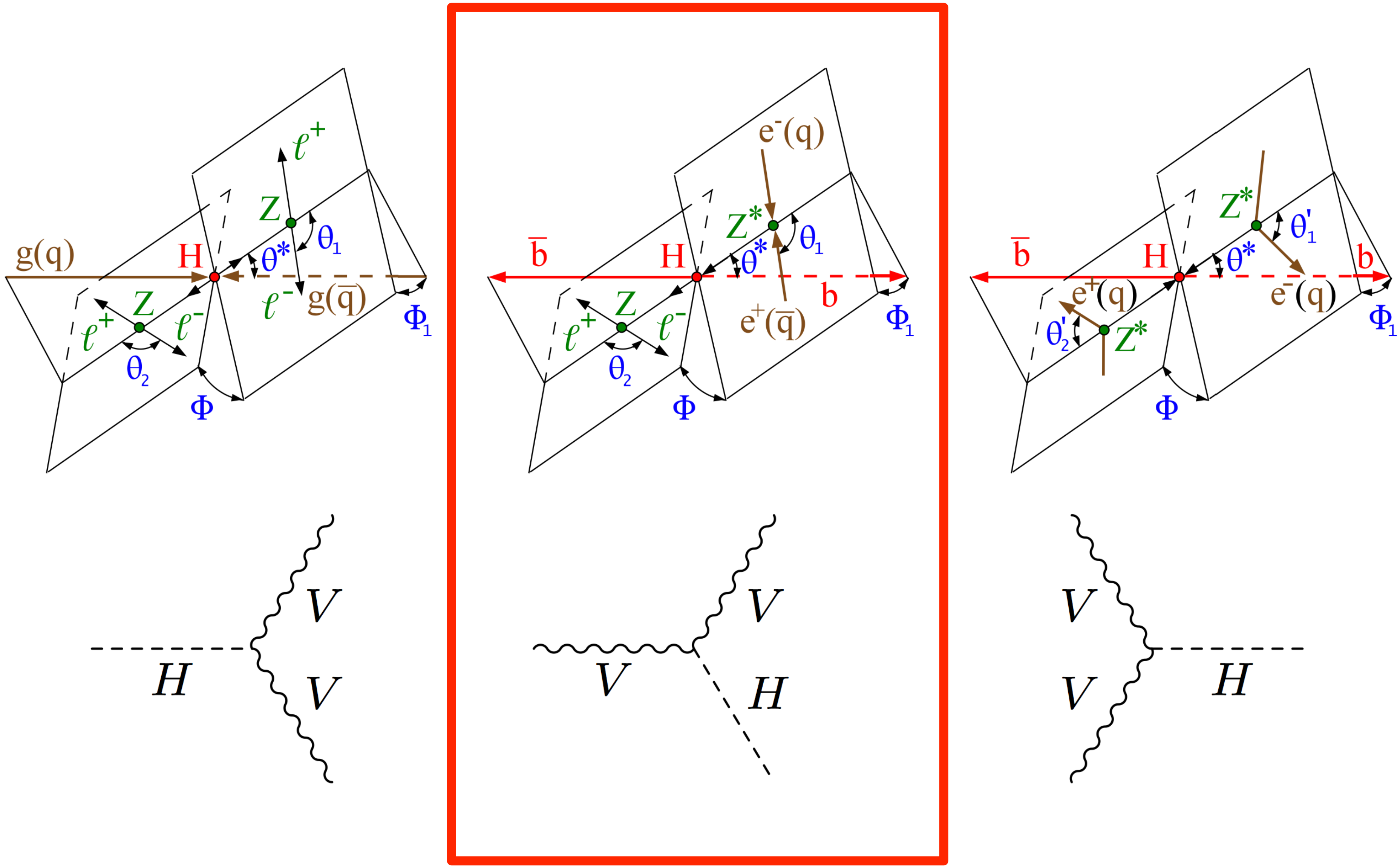

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Constraining pseudoscalar HZZ interactions in Higgs production in association with Z

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Parameterizing HVV anomalous couplings

$$A(X \to V_1 V_2) = v^{-1} \epsilon_1^{*\mu} \epsilon_2^{*\nu} \left(\boxed{a_1 g_{\mu\nu} m_H^2} + a_2\, q_\mu q_\nu + a_3 \epsilon_{\mu\nu\alpha\beta}\, q_1^\alpha q_2^\beta \right)$$

$$a_1 = \boxed{g_1^{(0)} \frac{m_V^2}{m_X^2}} + \frac{s}{m_X^2} \left(2g_2^{(0)} + g_3^{(0)} \frac{s}{\Lambda^2} \right)$$

g_1=2 for SM

$$a_2 = - \left(2g_2^{(0)} + g_3^{(0)} \frac{s}{\Lambda^2} \right) , \quad a_3 = -2g_4^{(0)},$$

$$s = q_1 q_2 = \frac{m_X^2 - m_1^2 - m_2^2}{2}$$

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$g_{2,3}$ for higher-dimensional operators

$$f_{gi} = \frac{|g_i|^2 \sigma_i}{|g_1|^2 \sigma_1 + |g_2|^2 \sigma_2 + |g_4|^2 \sigma_4}$$

$$\phi_{gi} = \arg \left(g_i / g_1 \right)$$

Similar definitions for f_{ai} and Φ_{ai}

JHUGenerator

- Unweighted/weighted .lhe events and histograms for processes involving generic (Q^2, Λ-dependent) HVV couplings.
  - pp > H > V^*V > 4f
  - pp > V^* > VH > 4f
  - (polarized) e+ e- > Z^* > ZH > 4f
  - pp > (HVBF) > H+2j
  - pp > H+j, 2j
  - .lhe events involving H > H decay chain (e.g. H > V^*V > 4f)
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- http://www.pha.jhu.edu/spin/

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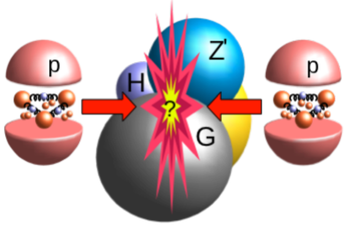

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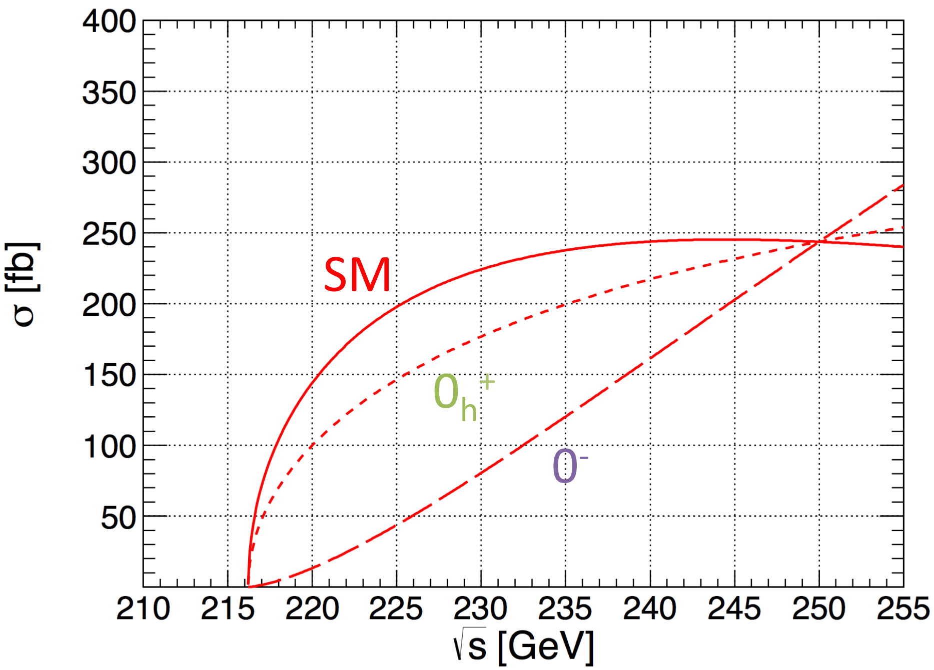
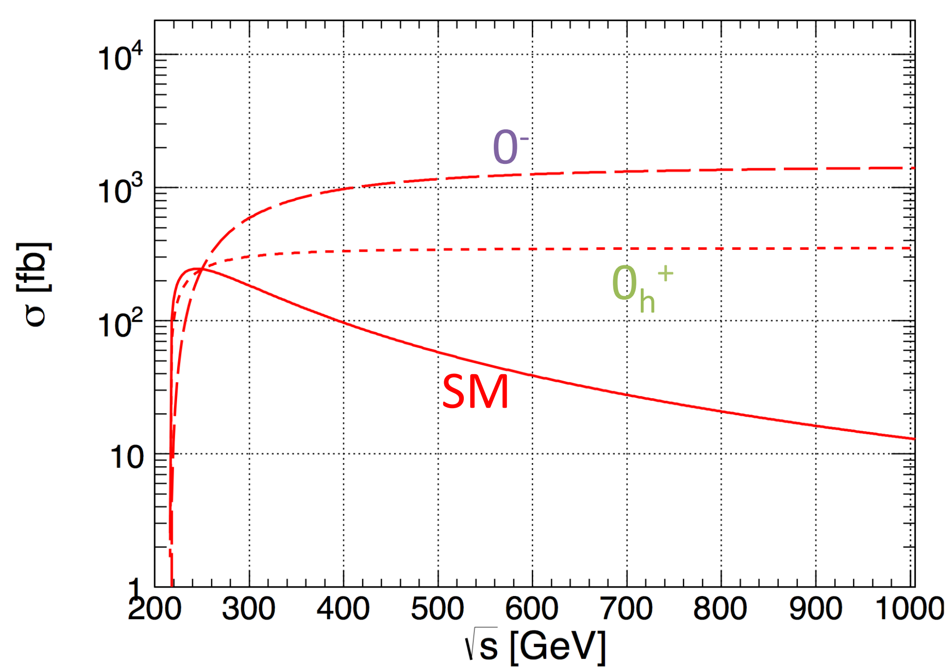
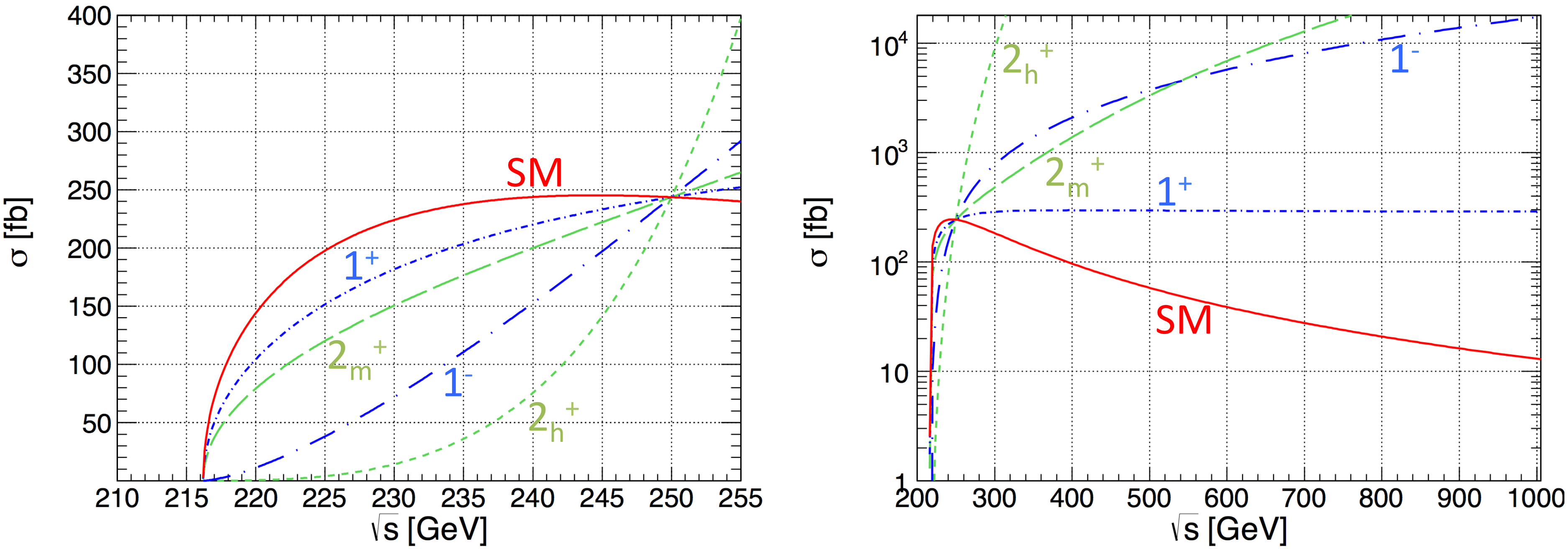
Threshold behavior of $e+e- > Z^* > ZH > l+l-bb\sim$

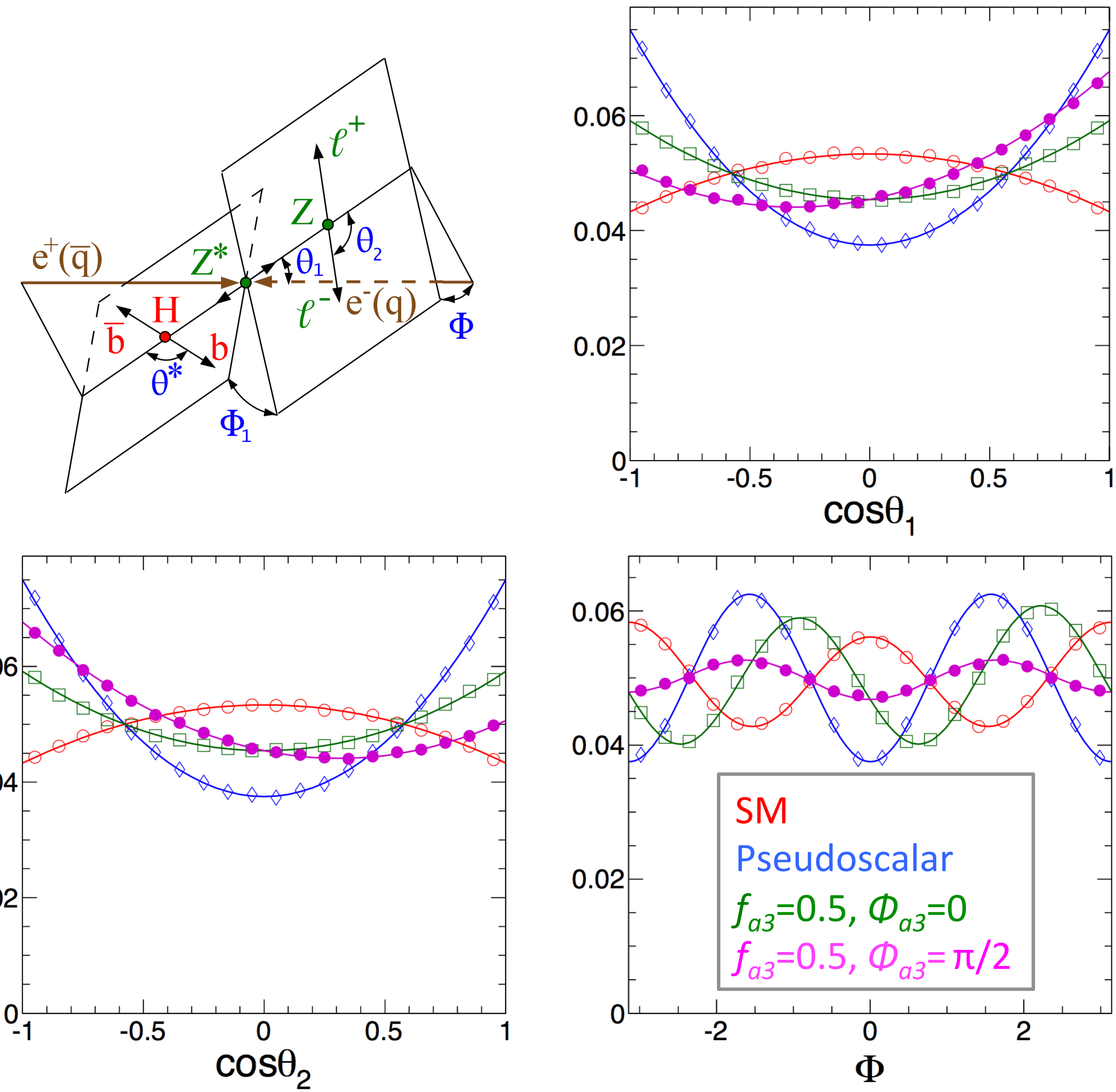




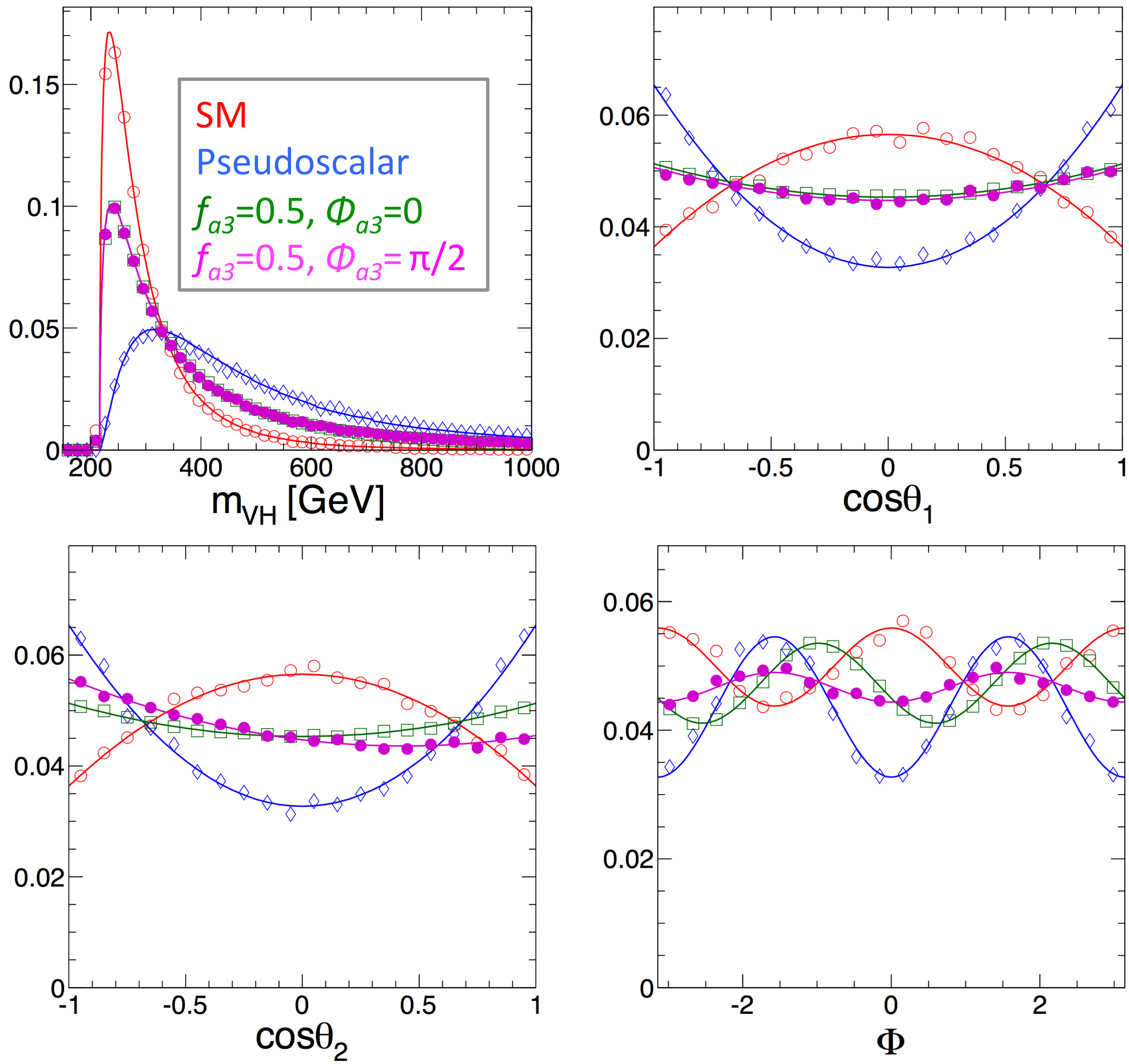
Threshold behavior of e+e- > Z* > ZX > l+l-bb~



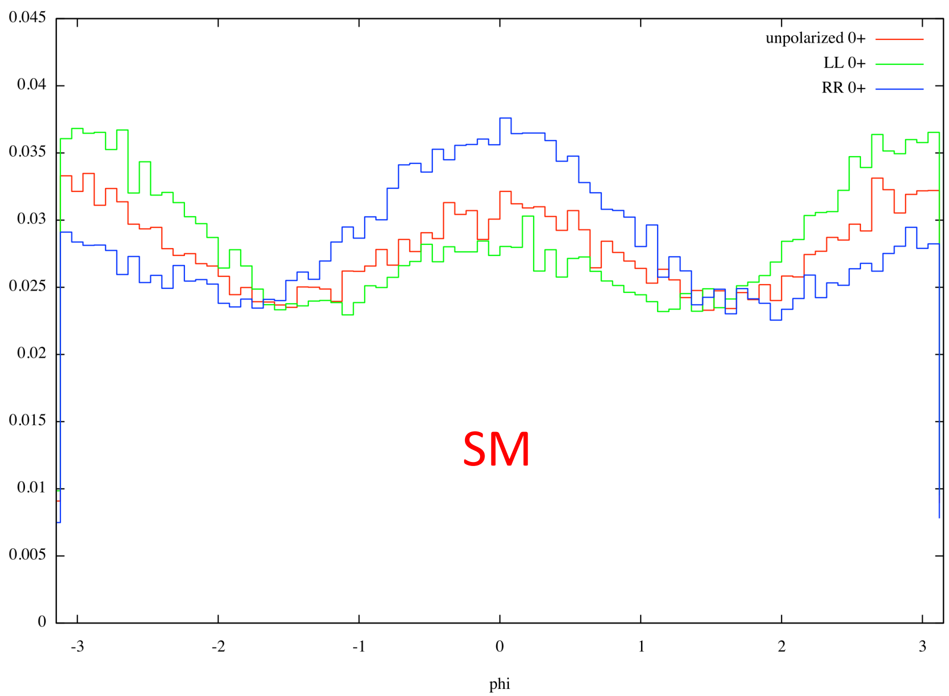
Kinematics of e+e- > Z* > ZH > l+l-bb~

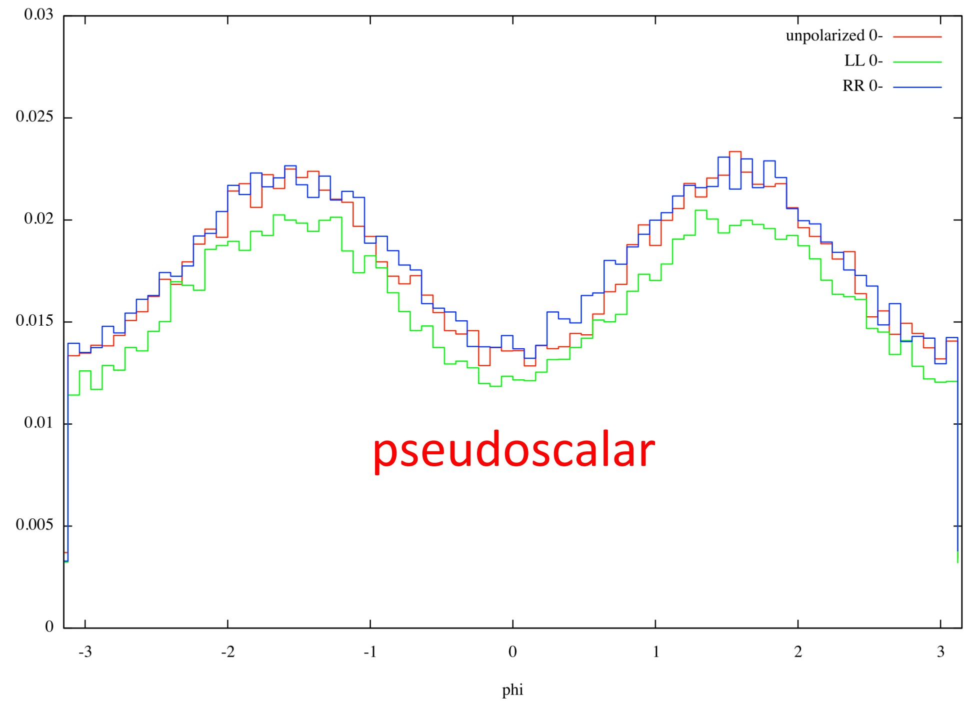


Kinematics of pp > Z* > ZH > l+l-bb~



Kinematics of polarized e+e- > Z* > ZH > l+l-bb~





Matrix Element Likelihood Analysis (MELA)

- Construct discriminant *D* using matrix elements of models to be separated (and PDF);
- Generate large sample of events and generate distribution of *D* for each model;
- Fit data against distribution of *D* for measurement, or fit realistic simulated events to study experimental sensitivity.

Matrix Element Likelihood Analysis (MELA)

$$D_{0^-} = \frac{\mathcal{P}_{0^+}}{\mathcal{P}_{0^+} + \mathcal{P}_{0^-}} = \left[1 + \frac{\mathcal{P}_{0^-}(m_1, m_2, \vec{\Omega})}{\mathcal{P}_{0^+}(m_1, m_2, \vec{\Omega})}\right]^{-1}$$

$$D_{CP} = \frac{\mathcal{P}_{\mathrm{int}}(m_1, m_2, \vec{\Omega}; \phi_{a3})}{\mathcal{P}_{0^+}(m_1, m_2, \vec{\Omega}) + \mathcal{P}_{0^-}(m_1, m_2, \vec{\Omega})}$$

$$D_{\mathrm{bkg}} = \left[1 + \frac{\mathcal{P}_{\mathrm{bkg}}(m_1, m_2, \vec{\Omega})}{\mathcal{P}_{0^+}(m_1, m_2, \vec{\Omega})}\right]^{-1}$$

$p \sim |M|^2$, PDF

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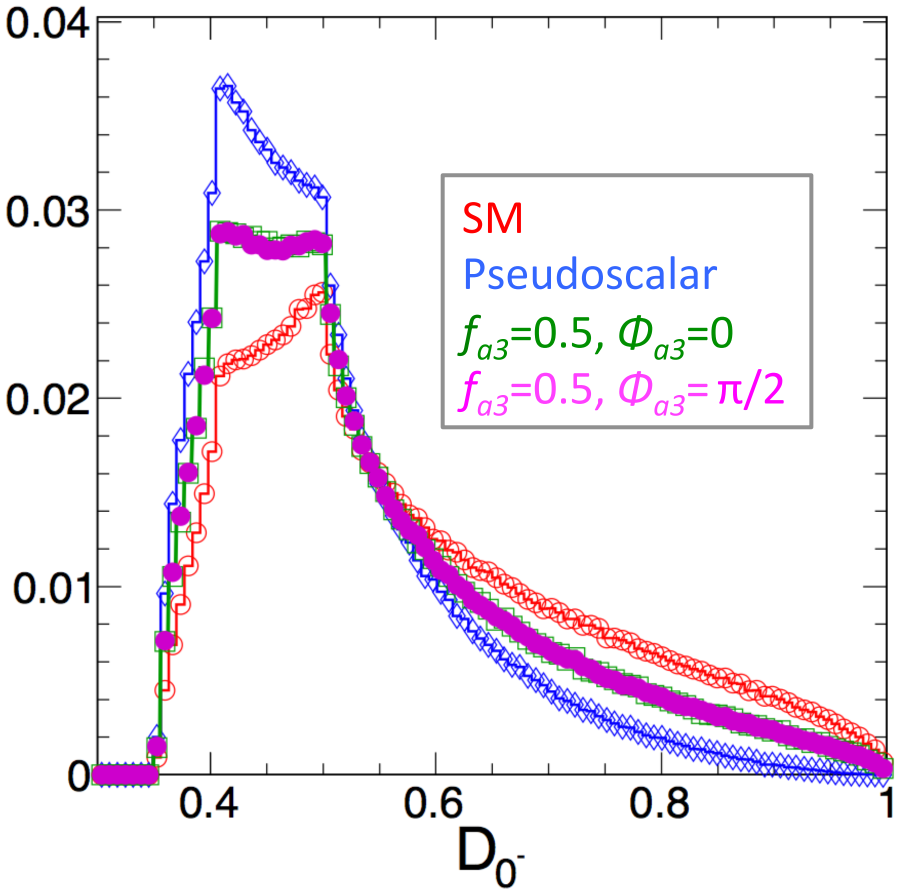
Separates, e.g. HVBF from H+2j

$p \sim |M|^2$, PDF

MELA Example: pp/e+e- > Z^* > ZH > l+l-bb~



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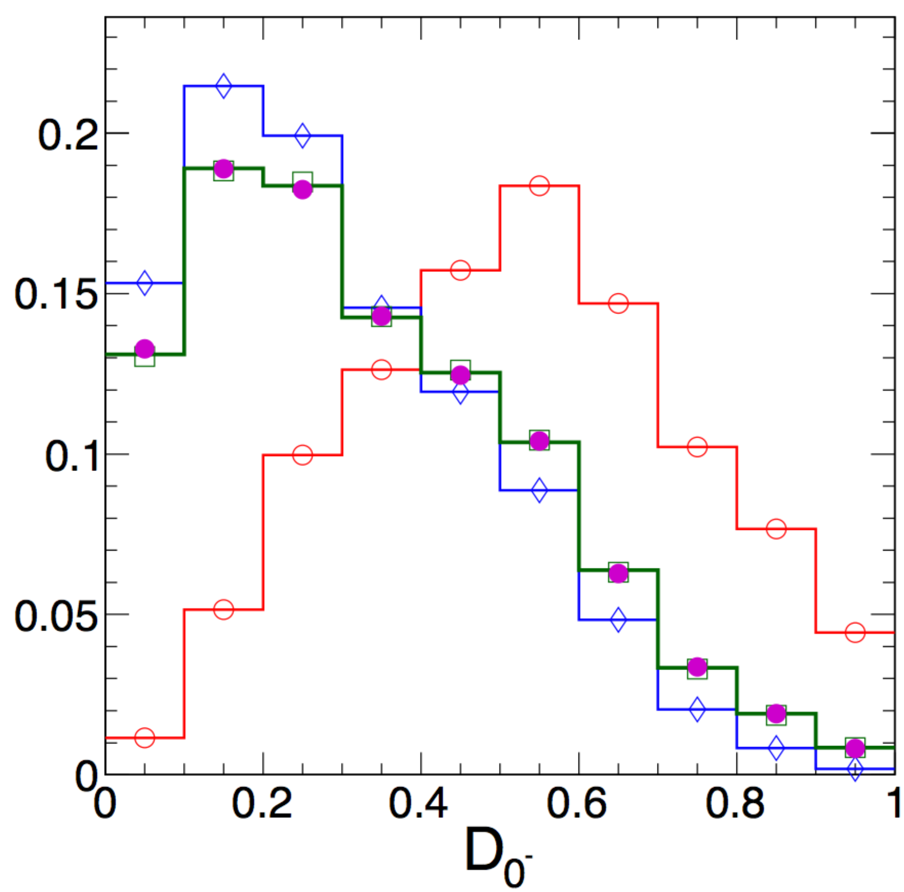
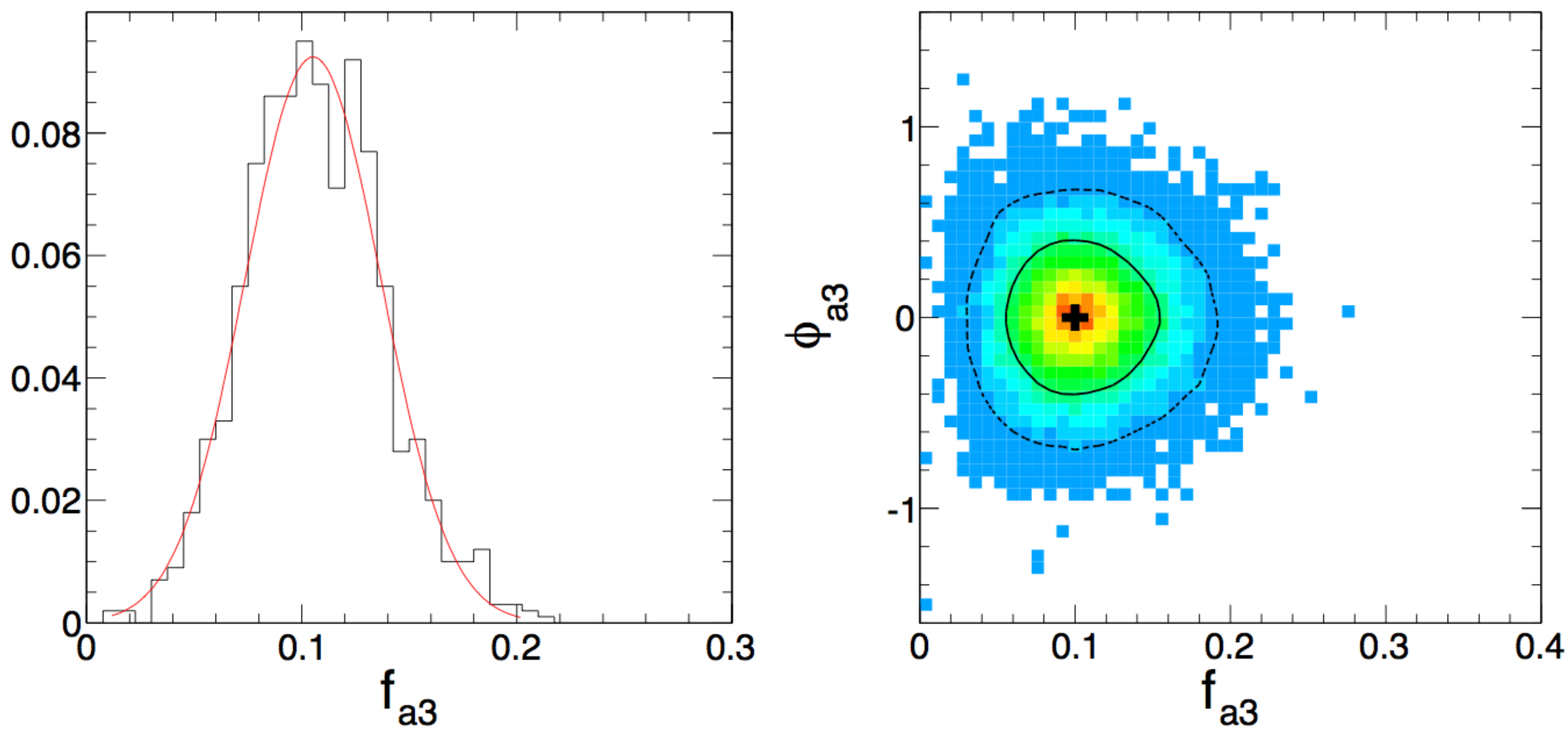


pp > Z^* > ZH > l+l-bb~

MELA Example: f_{a3}=0.117, Φ_{a3}= 0, by D_{0-}



Summery: Events vs. Collider Options

collider	energy	$\int \mathcal{L} dt$ (fb^{-1})	production	σ (fb)	decay	$\sigma \times \mathcal{B}$ (fb)	N_{prod}	N_{reco}	f_{jet}
pp	14 TeV	3000	$gg \to H$	49850	$H \to ZZ^* \to 4\ell$	6.23	18694	5608	0.1
pp	14 TeV	3000	$V^*V^* \to H$	4180	$H \to ZZ^* \to 4\ell$	0.52	1568	470	0.6
pp	14 TeV	3000	$W^* \to WH$	1504	$H \to ZZ^* \to 4\ell$	0.19	564	169	0.5
pp	14 TeV	3000	$Z^* \to ZH$	883	$H \to ZZ^* \to 4\ell$	0.11	331	99	0.5
pp	14 TeV	3000	$t\bar{t} \to t\bar{t}H$	611	$H \to ZZ^* \to 4\ell$	0.08	229	69	1.0
pp	14 TeV	3000	$V^*V^* \to H$	4180	$H \to \gamma\gamma$	9.53	28591	8577	0.6
pp	14 TeV	3000	$Z^* \to ZH$	883	$H \to b\bar{b},\ Z \to \ell\ell$	34.3	102891	690	–
e^+e^-	250 GeV	250	$Z^* \to ZH$	240	$H \to b\bar{b},\ Z \to \ell\ell$	9.35	2337	1870	–
e^+e^-	350 GeV	350	$Z^* \to ZH$	129	$H \to b\bar{b},\ Z \to \ell\ell$	5.03	1760	1408	–
e^+e^-	500 GeV	500	$Z^* \to ZH$	57	$H \to b\bar{b},\ Z \to \ell\ell$	2.22	1110	888	–
e^+e^-	1 TeV	1000	$Z^* \to ZH$	13	$H \to b\bar{b},\ Z \to \ell\ell$	0.51	505	404	–
e^+e^-	250 GeV	250	$Z^*Z^* \to H$	0.7	$H \to b\bar{b}$	0.4	108	86	–
e^+e^-	350 GeV	350	$Z^*Z^* \to H$	3	$H \to b\bar{b}$	1.7	587	470	–
e^+e^-	500 GeV	500	$Z^*Z^* \to H$	7	$H \to b\bar{b}$	4.1	2059	1647	–
e^+e^-	1 TeV	1000	$Z^*Z^* \to H$	21	$H \to b\bar{b}$	12.2	12244	9795	–

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Summery: Sensitivity vs. Process

process description					MC simulation parameters						expected precision			
collider	energy	mode	σ_2/σ_1	σ_4/σ_+	$\lvert g_2/g_1\rvert$	$\lvert g_4/g_+\rvert$	f_{a2}	f_{a2}^{dec}	f_{a3}	f_{a3}^{dec}	δf_{a2}	$\delta f_{a2}^{\mathrm{dec}}$	δf_{a3}	$\delta f_{a3}^{\mathrm{dec}}$
any	any	$H \to ZZ^*$	0.362	0.153	0	1.20		0		0.18		–		0.06
					0	0.67		0		0.06		–		0.02
					0.78	0		0.18		0		0.088		–
					0.42	0		0.06		0		0.014		–
any	any	$H \to WW^*$	0.776	0.322	0	1.76		0		0.50		–		–
					1.13	0		0.50		0		–		–
any	any	$H \to \gamma\gamma, gg$	N/A	1.0	N/A	1.0		0		0.50	3σ dev. from SM	–		–
any	any	$H \to Z\gamma$	N/A	1.0	N/A	1.0		0		0.50		–		–
pp	14 TeV	$gg \to H$	N/A	1.0	N/A	1.0	0	0	0.50	0.50		–	0.50	0.50
		$(H \to ZZ^*)$			N/A	1.0	0	0	0.50	0.50		–	0.16	0.16
pp	14 TeV	$V^*V^* \to H$	14.0	11.3	0	0.299	0	0	0.50	0.013		–	0.190	7×10^{-3}
		$(H \to ZZ^*)$			0	0.109	0	0	0.12	0.0018		–	0.036	6×10^{-4}
pp	14 TeV	$V^*V^* \to H$	14.0	11.3	0	0.109	0	0	0.12	0.0018		–	0.04	7×10^{-4}
		$(H \to \gamma\gamma)$			0	0.052	0	0	0.030	0.0004		–	0.009	1.3×10^{-4}
pp	14 TeV	$V^* \to VH$	76.1	46.8	0	0.145	0	0	0.50	0.0032		–	0.32	3×10^{-3}
	$(V \to q\bar{q}', H \to ZZ^*)$				0	0.095	0	0	0.30	0.0014		–	0.10	6×10^{-4}
pp	14 TeV	$V^* \to VH$	76.1	46.8	0	0.061	0	0	0.15	0.0006		–	0.09	4×10^{-4}
	$(V \to \ell^+\ell^-, H \to b\bar{b})$		3000 fb^{-1}		0	0.049	0	0	0.10	0.0004		–	0.029	1.2×10^{-4}
e^+e^-	250 GeV	$Z^* \to ZH$	34.1	8.07	0	0.117	0	0	0.10	2×10^{-3}		–	0.032	7×10^{-4}
			250 fb^{-1}		0.057	0	0.10	1.2×10^{-3}	0	0	0.033	4×10^{-4}		–
e^+e^-	350 GeV	$Z^* \to ZH$	84.2	50.6	0	0.0469	0	0	0.10	3×10^{-4}		–	0.031	1.1×10^{-4}
			350 fb^{-1}		0.025	0	0.05	2×10^{-4}	0	0	0.015	7×10^{-5}		–
e^+e^-	500 GeV	$Z^* \to ZH$	200.8	161.1	0	0.0263	0	0	0.10	1.1×10^{-4}		–	0.034	4×10^{-5}
			500 fb^{-1}		0.024	0	0.10	2×10^{-4}	0	0	0.033	7×10^{-5}		–
e^+e^-	1 TeV	$Z^* \to ZH$	916.5	870.8	0	0.0113	0	0	0.10	2×10^{-5}		–	0.037	8×10^{-6}
			1000 fb^{-1}		0.014	0	0.15	7×10^{-5}	0	0	0.049	3×10^{-5}		–

Summery

- JHUGenerator
- Constraining pseudoscalar coupling by kinematics of $V^* > VH$
- Matrix Element Likelihood Analysis
- Thank you!