NEW PHYSICS EFFECTS IN ANOMALOUS GAUGE BOSON VERTICES

Gero von Gersdorff

Planck 2014, Paris

Based on Work with S. Fichet, O. Kepka, B. Lenzi, C. Royon, M. Saimpert

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INTRODUCTION

Indirect Bounds on New Physics

- Precision Measurements important (and complementary) way to narrow down possible New Physics Models
- Very successful in past and present
  - SM predicts couplings of W/Z to fermions $\Rrightarrow$ EWPT
  - In SM, flavour and CP violation restricted to the W coupling $\Rrightarrow$ no FCNC in SM
  - All couplings of Higgs Boson predicted
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Large BSM effects

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Precision

Small SM effects

Large BSM effects

- Every New Physics model leaves characteristic fingerprint on such quantities
- Integrate out New Phyiscs ⇛Effective Field theory analysis
- New Physics effects summarized by higher dim operators (dim-6, dim-8...)

Anomalous Gauge Boson Couplings I

- Gauge Boson Self interactions are another SM sector that can be subject to precision scrutiny

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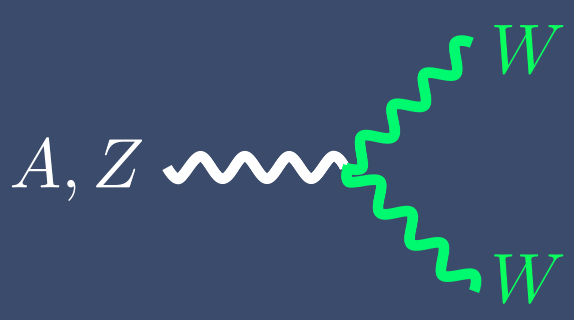
- Constrained ~ few % (LEP, LHC)



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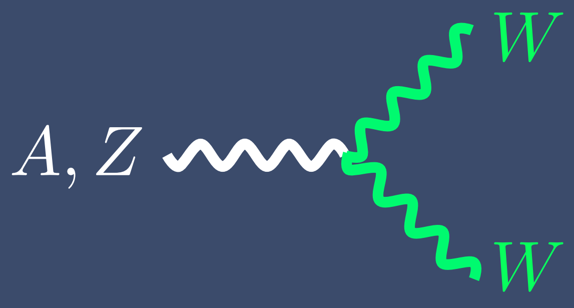

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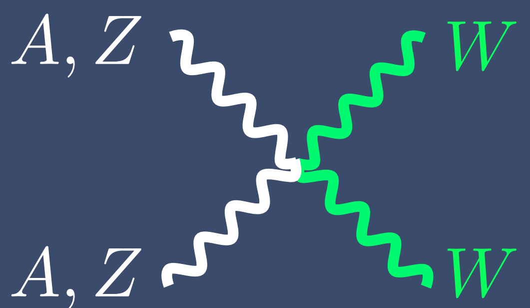
- New tensor structures at dim-8



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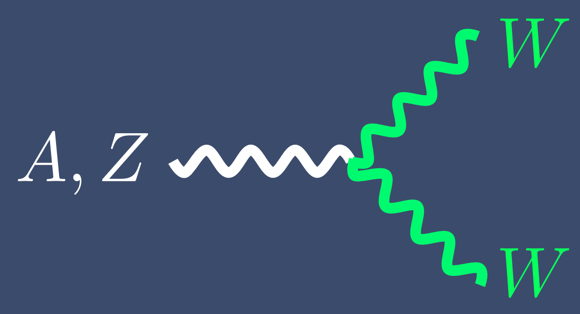

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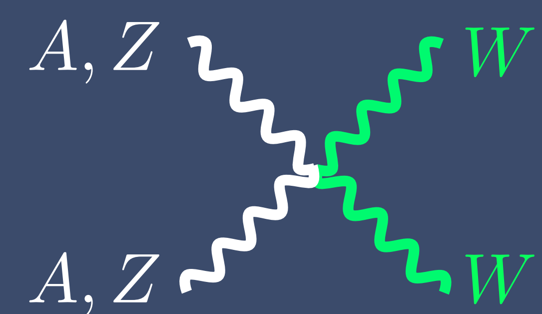

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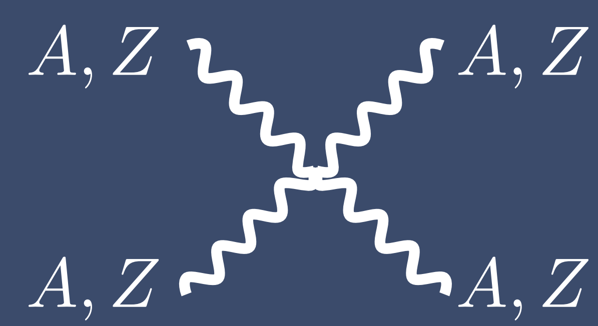

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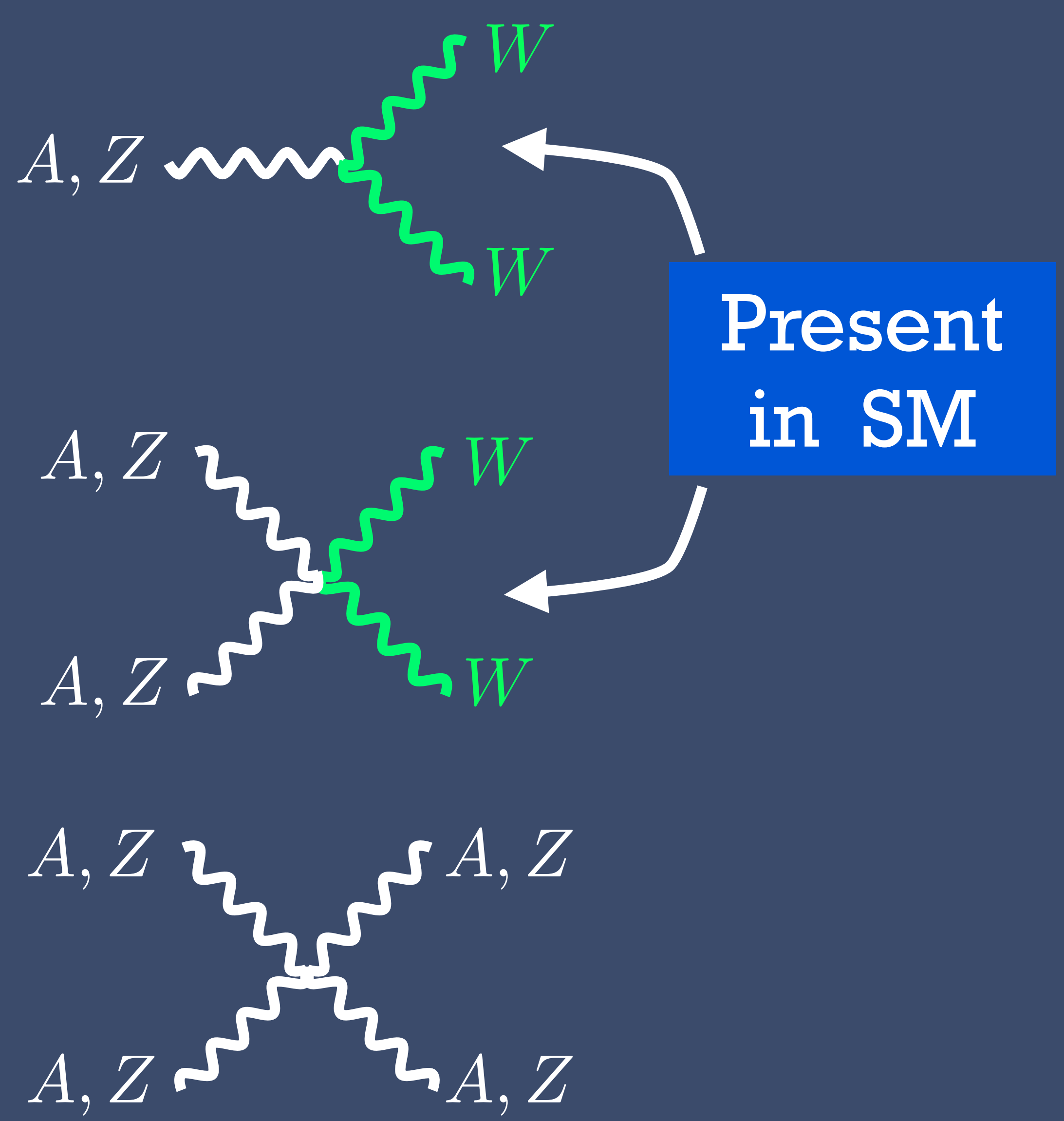

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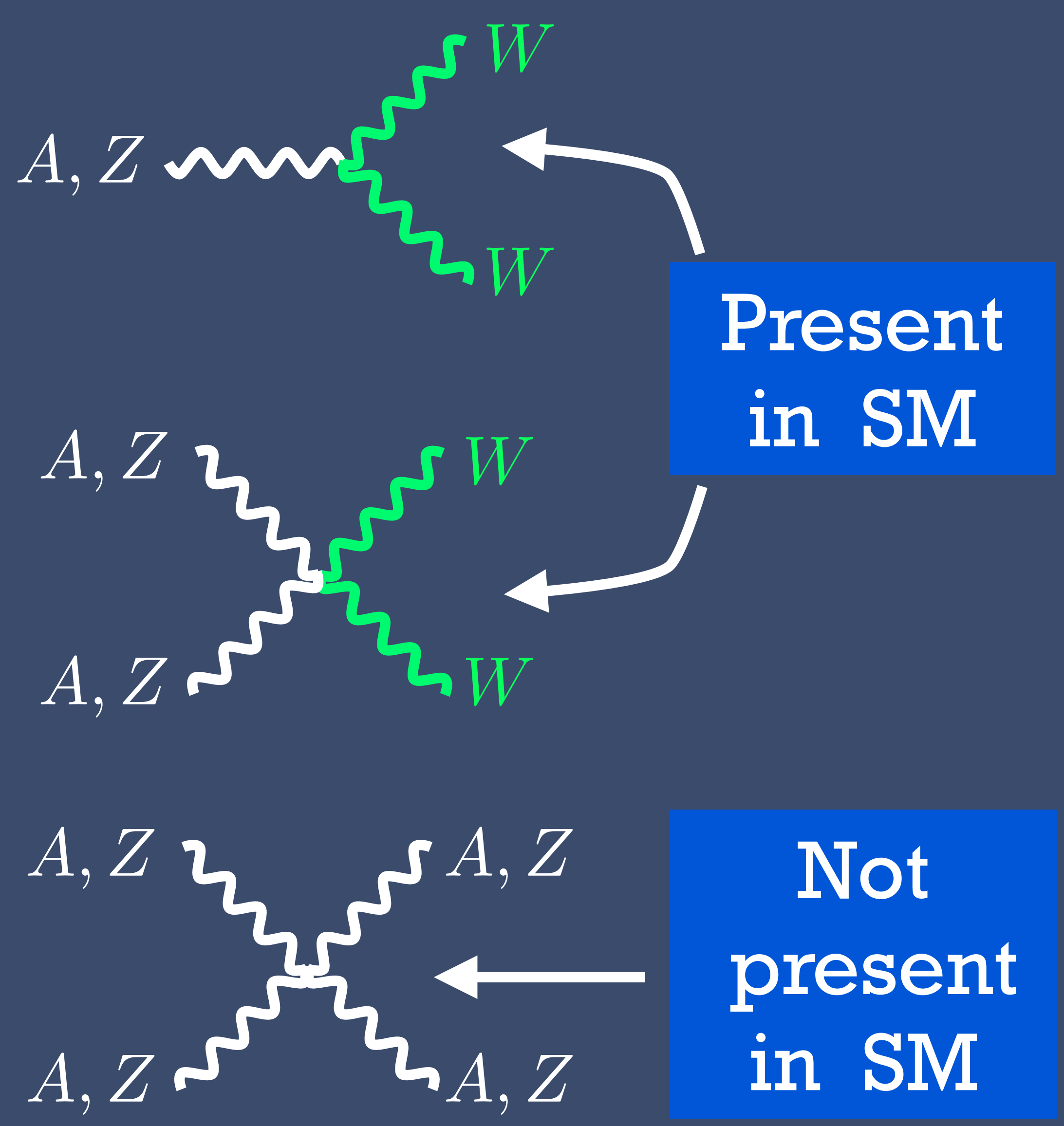

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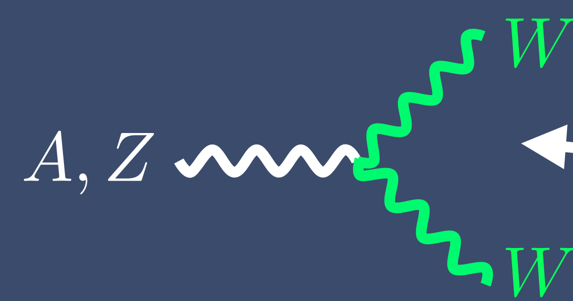

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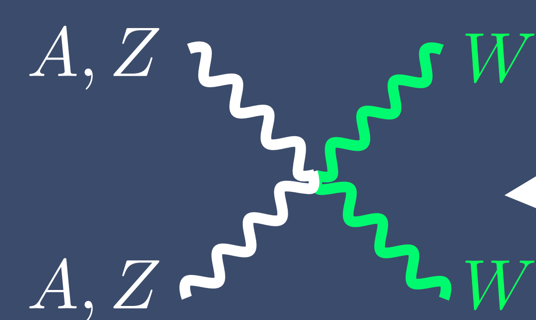

Present in SM

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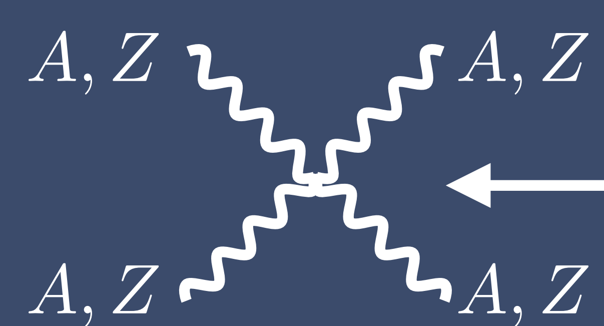
- Only from dim-8

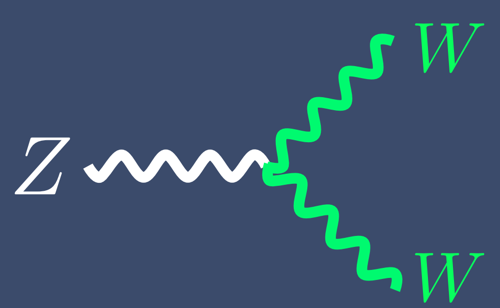


Not present in SM

Gupta '11, Fichet+GG '13

Anomalous Gauge Boson Couplings II

- There are also various tensor structures to take into account
- Example: Charged TGV, various NP contribution from dim-6



$$Z_{\mu\nu} W^+_\mu W^-_\nu \qquad Z_\mu W^+_{\mu\nu} W^-_\nu \qquad \sim \frac{v^2}{\Lambda^2} \qquad E < v < \Lambda$$

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- The ones most strictly constrained (LEP) are the first kind
- LHC energies allow to access the second kind....

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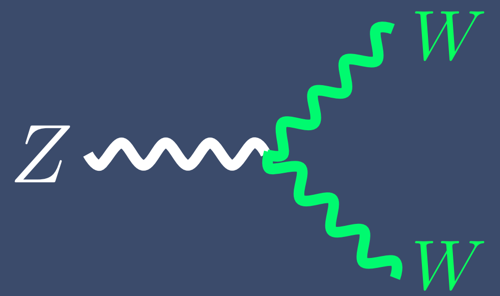

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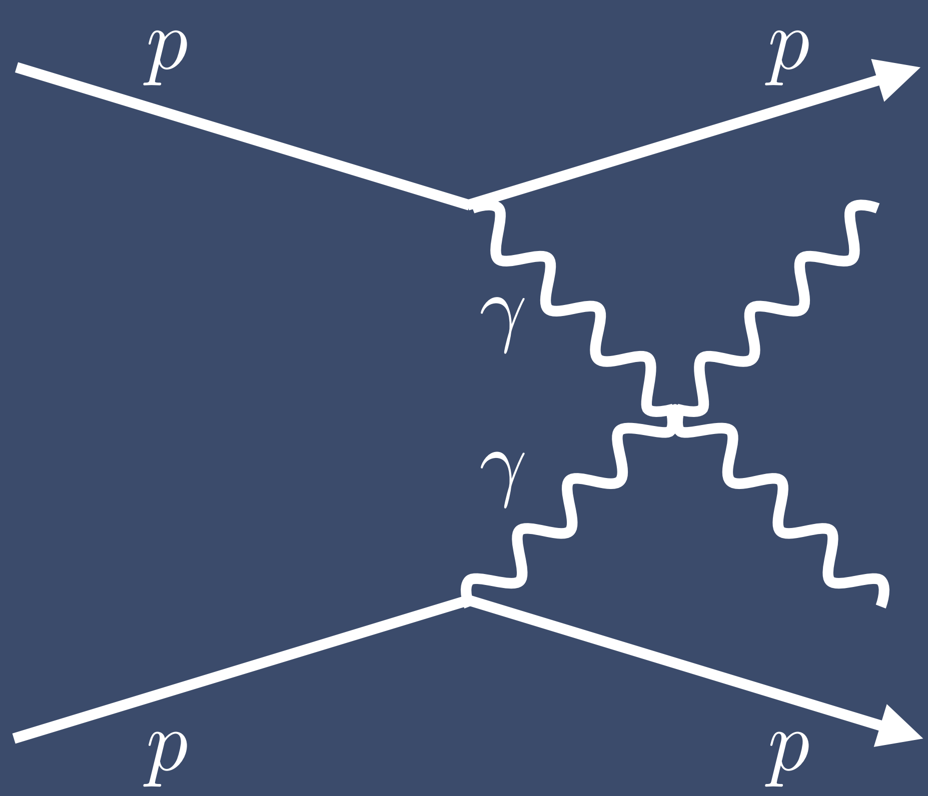
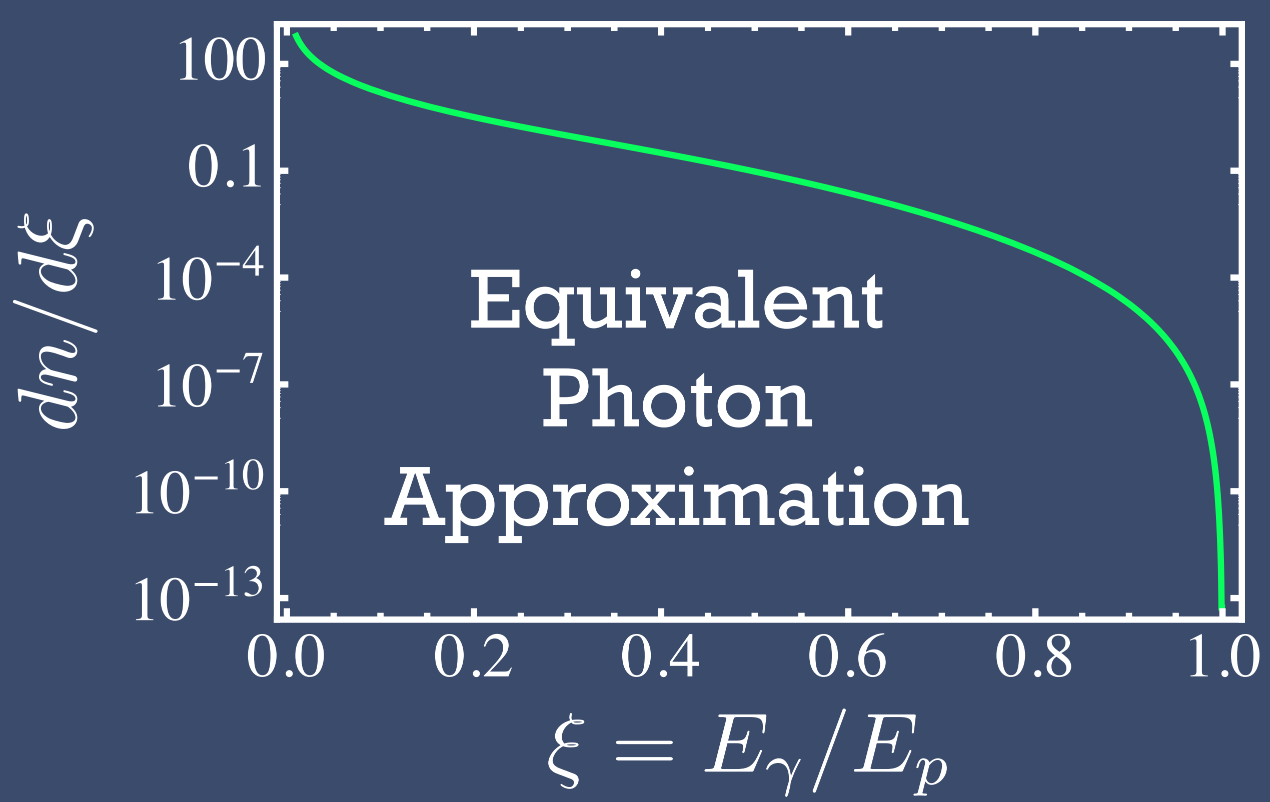
- Anomalous gauge couplings involving photons grow most strongly with energy (need field strength)

QGC and Proton Tagging at the LHC

- Quartic Gauge Couplings involving photons can be probed in diffractive processes at the LHC (protons remain intact!)





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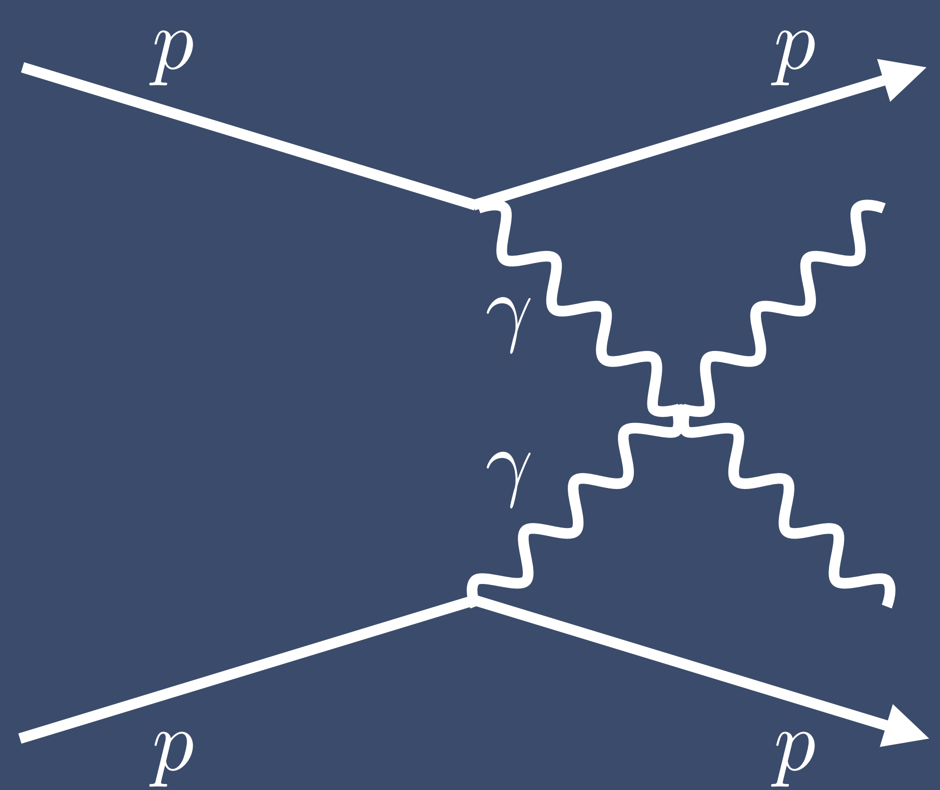

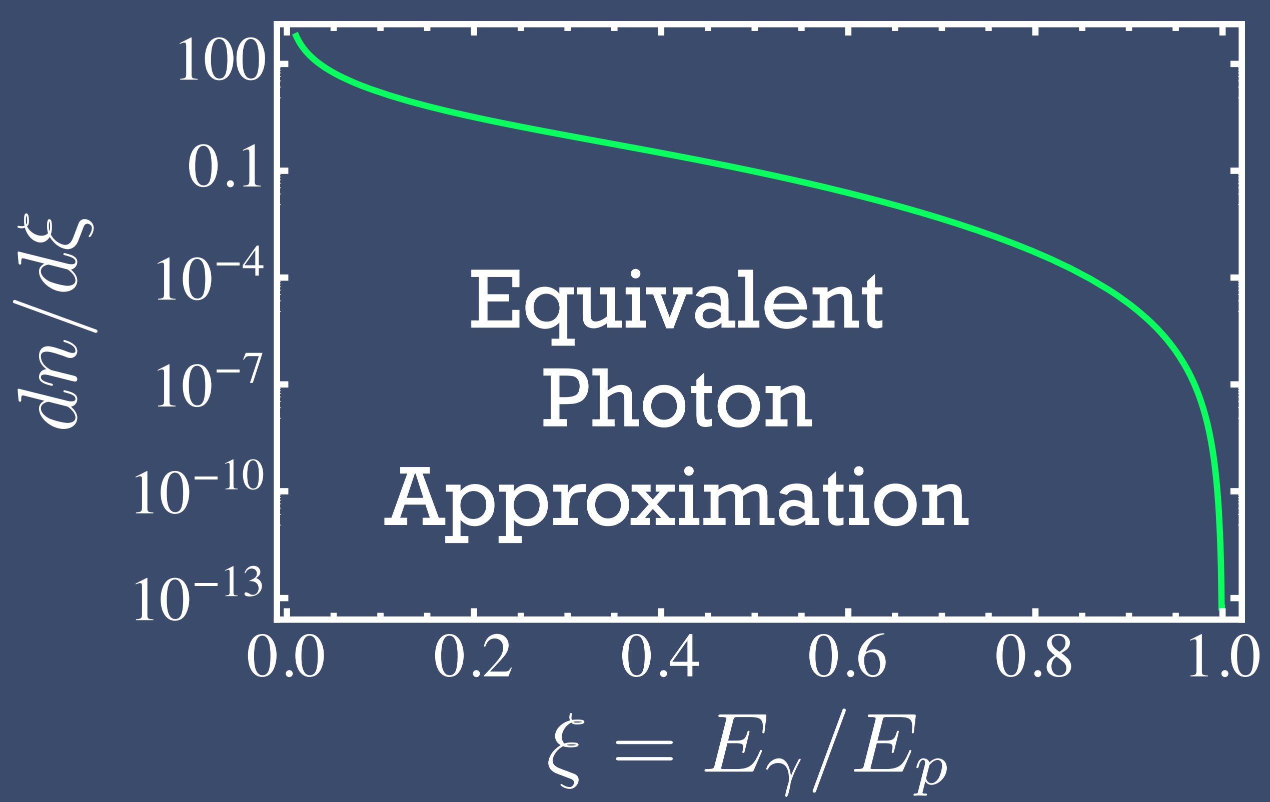

- The intact protons can be measured in Forward Detectors
- Complete kinematic information of incoming photons available
- Powerful strategy to suppress background
- Foward Detector acceptance cuts typically $0.015 < \xi < 0.15$

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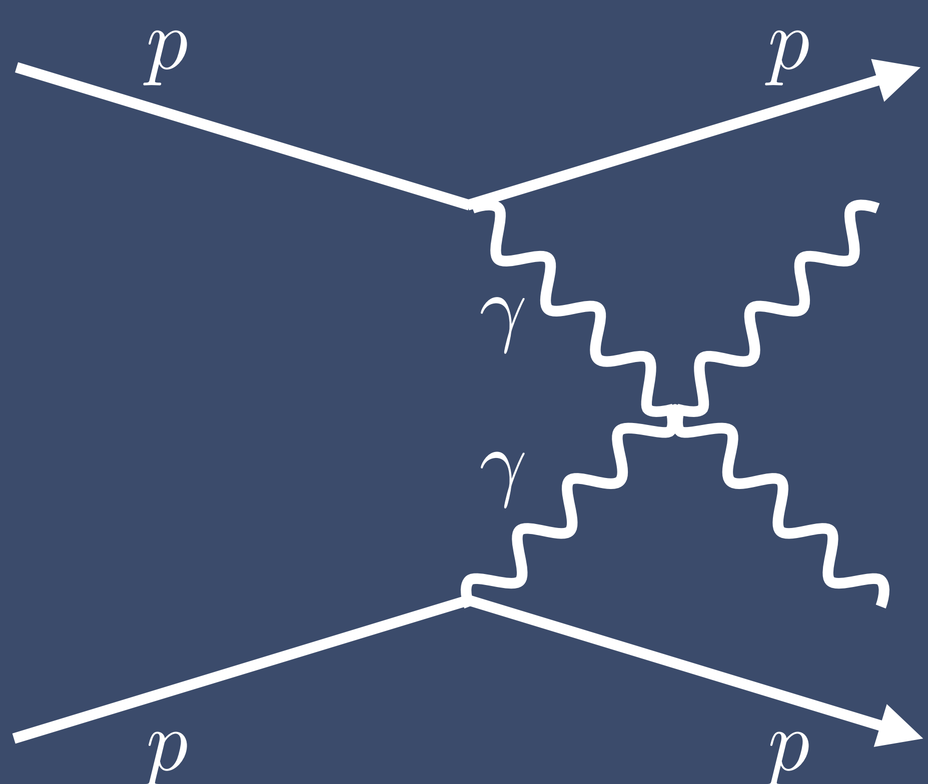

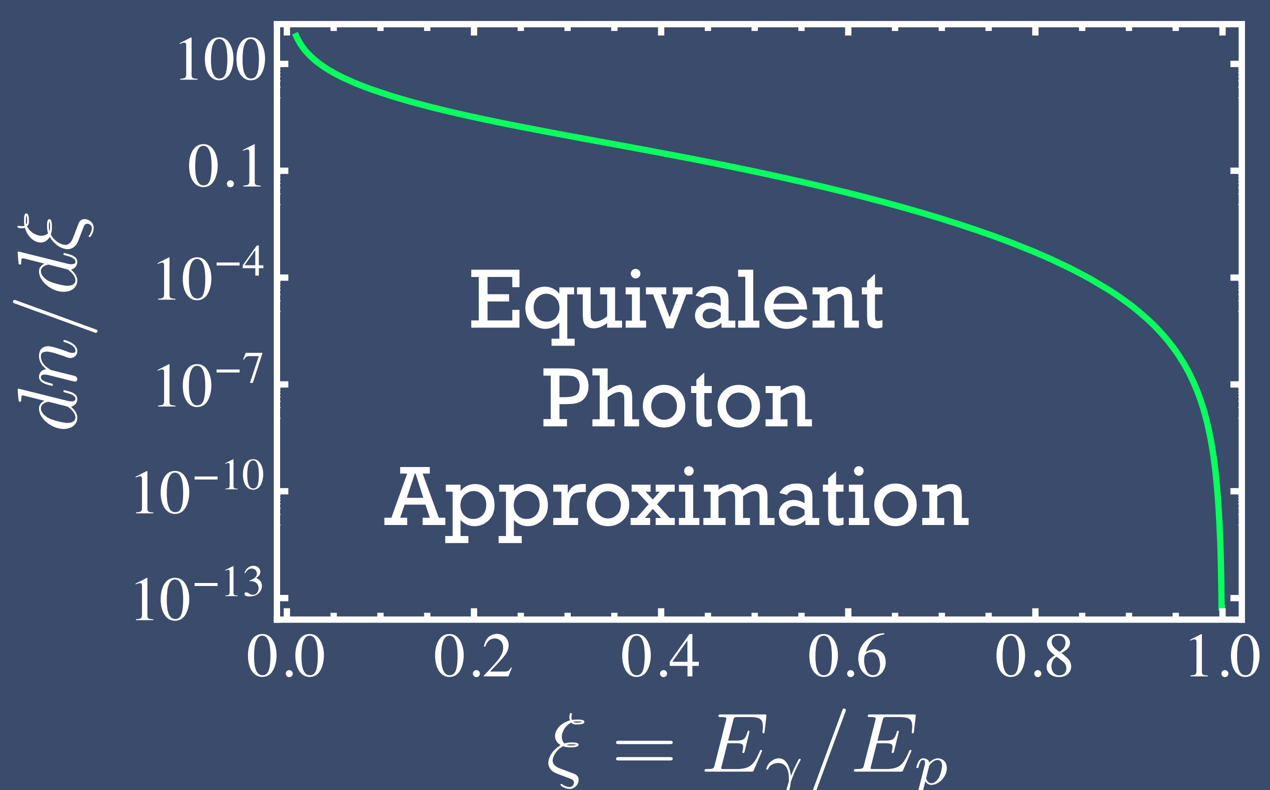

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$\boxed{E_\gamma \lesssim 1 \text{ TeV}}$

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LIMITS FROM EFT

EFT of 4 Photon Interactions

- Focus on AAAA (AAZZ and AAWW see [Chapon et al '12])
- EFT for 4-photon interaction contains two dim-8 structures

$$\mathcal{L}_{4\gamma} = \zeta_1 \left(F_{\mu\nu}F^{\mu\nu}\right)^2 + \zeta_2 \, F_{\mu\nu}F^{\nu\rho}F_{\rho\sigma}F^{\sigma\mu}$$

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- Cross section has a simple form

$$\frac{d\sigma}{d\Omega} = \frac{1}{16\pi^2 \, s}(s^2+t^2+st)^2 \left[48\zeta_1^2 + 40\zeta_1\zeta_2 + 11\zeta_2^2\right]$$

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- Unitarity breaks down for $\zeta_i s^2 \gtrsim 2\pi$
- Demanding unitarity for LHC energies $\Rightarrow$ $\zeta_i \lesssim 10^{-10}\mathrm{GeV}^{-4}$
- In explicit models EFT breaks down before that!
- LHC sensitivities to ζ_i are ~$10^{4\text{-}5}$ better than unitarity bound

RESULTS OF SIMULATION

- Projected sensitivities at the 14 TeV LHC with realistic cuts:

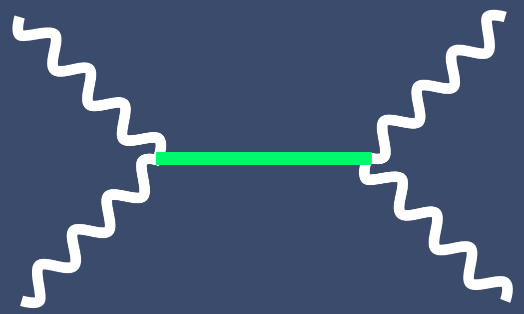
Luminosity	300 fb^{-1}	300 fb^{-1}	300 fb^{-1}	3000 fb^{-1}
pile-up (μ)	50	50	50	200
coupling (GeV^{-4})	≥ 1 conv. γ 5 σ	≥ 1 conv. γ 95% CL	all γ 95% CL	all γ 95% CL
ζ_1 f.f.	$1. \cdot 10^{-13}$	$9. \cdot 10^{-14}$	$5. \cdot 10^{-14}$	$2.5 \cdot 10^{-14}$
ζ_1 no f.f.	$3.5 \cdot 10^{-14}$	$2.5 \cdot 10^{-14}$	$1.5 \cdot 10^{-14}$	$7. \cdot 10^{-15}$
ζ_2 f.f.	$2.5 \cdot 10^{-13}$	$1.5 \cdot 10^{-13}$	$1. \cdot 10^{-13}$	$4.5 \cdot 10^{-14}$
ζ_2 no f.f.	$7.5 \cdot 10^{-14}$	$5.5 \cdot 10^{-14}$	$3. \cdot 10^{-14}$	$1.5 \cdot 10^{-14}$

Fichet, GG, Kepka, Lenzi, Royon, Saimpert '13

- Limiting factor is low number of events, not background
- Possible improvements
  - Inelastic case (pro: higher flux; con: higher background)
  - Heavy - Ion (Pb - p or Pb - Pb) $\Rrightarrow$ enhanced photon flux, see corresponding SM analysis: D'Enterria + Da Silveira '13

Effective Operators at Tree Level

- 4-Photon operators generated from neutral BSM particles via non-renormalizable interactions
- Simplified model approach



$$\mathcal{L}_{\gamma\gamma} = f_{0^+}^{-1}\,\varphi\,F_{\mu\nu}^2 + f_{0^-}^{-1}\,\tilde{\varphi}\,F_{\mu\nu}\tilde{F}_{\mu\nu} + f_2^{-1}\,\varphi_{\mu\nu}\,F_{\mu\rho}F_{\nu\rho} \qquad \Rrightarrow \qquad \zeta_i = b_i\,\frac{1}{(fm)^2}$$

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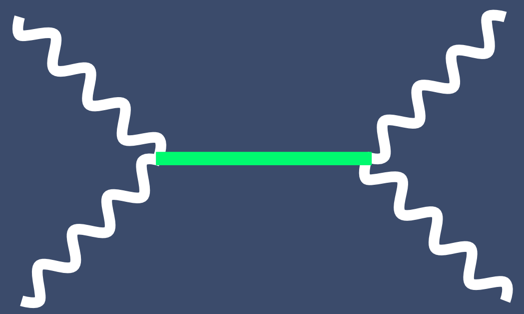

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s^P:	0^+	0^-	2
$b_1(s)$	$\frac{1}{2}$	-1	$-\frac{1}{8}$
$b_2(s)$	0	2	$\frac{1}{2}$

- Examples
  - (strongly coupled) Dilaton [1)]

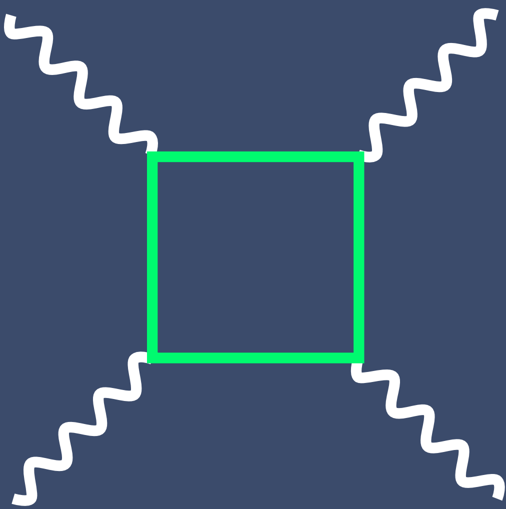
    $$f^{-1} = \frac{\pi}{m} \quad \Rrightarrow \quad m \lesssim 6\,\mathrm{TeV}$$

  - KK Graviton $\frac{m}{\sqrt{\kappa}} \lesssim 5\,\mathrm{TeV}$

1) Needs sizable explicit conformal breaking [Chacko et al '13, Bellanzini et al '13]

Effective Operators from Loops

- 4-Photon effective operators can be generated from loops of particles of mass m, charge $Q_{\text{eff}} = N^{1/4}Q$ and spin s
- Euler Heisenberg Lagrangian for arbitrary[1)] spin s:



$$\zeta_i = c_i \frac{\alpha^2 Q_{\text{eff}}^4}{m^4} \qquad c_i \sim s^5$$

Fichet + GG, in progress

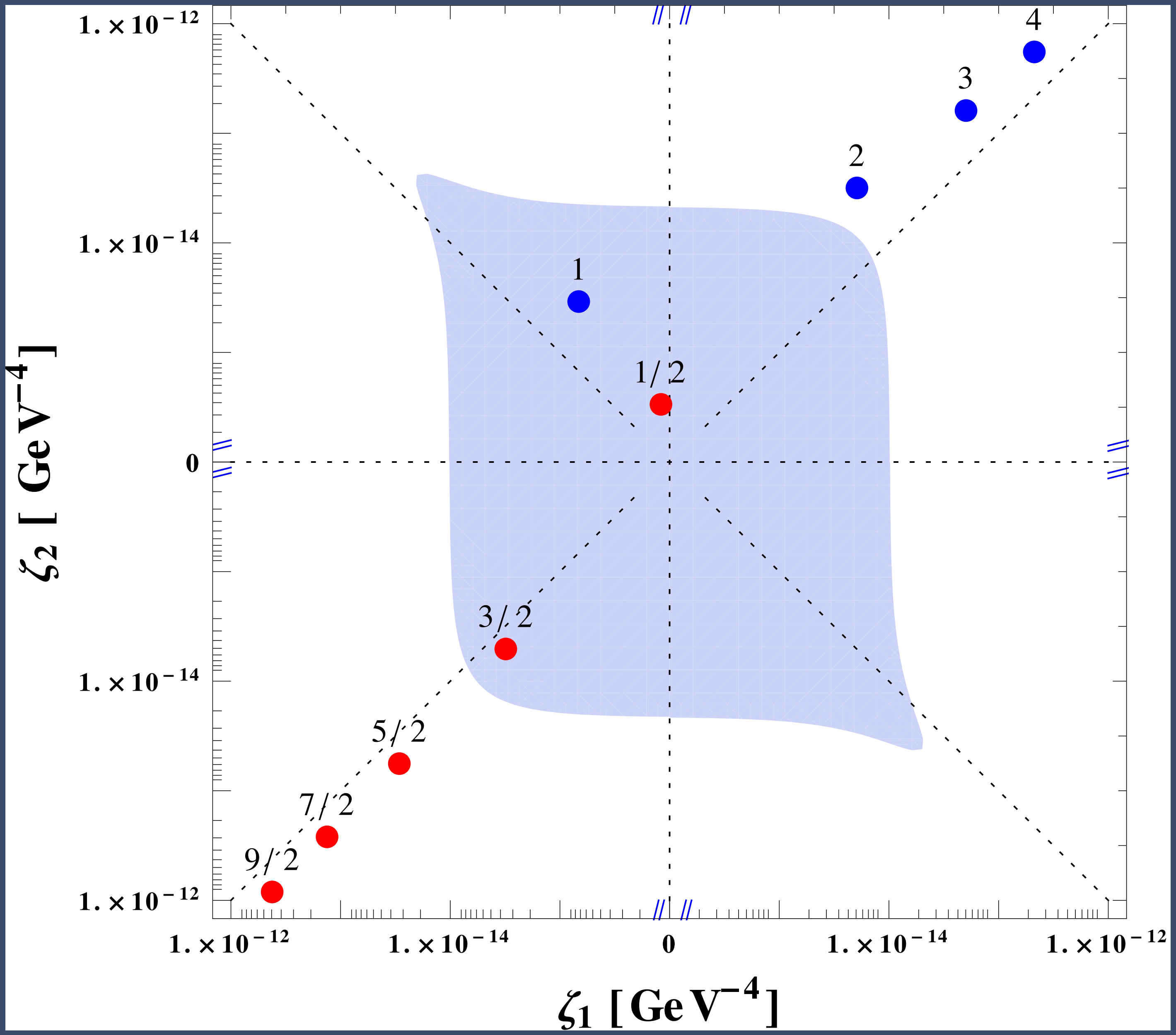
s:	0	$\frac{1}{2}$	1	…
$c_1(s)$	$\frac{1}{288}$	$-\frac{1}{36}$	$-\frac{5}{32}$	…
$c_2(s)$	$\frac{1}{360}$	$\frac{7}{90}$	$\frac{27}{40}$	…

- Strong increase with charge $\sim Q^4$
- Strong increase with spin $c_i \sim s^5$
- Exotic resonances of high s, Q, present in many BSM scenarios
- Can (partially) compensate small electromagnetic coupling

1) Assuming g=2 as suggested by unitarity arguments [Ferrara, Porrati, Telegdi '92]

Higher Spin Resonances

- Dots mark resonances of spin s, mass m = 1 TeV, $Q_{\text{eff}} = 3$ (sensitivity in the white region)



Projected Sensitivity

s	m/Q_{eff} (GeV)
0	70
1/2	100
1	180
3/2	290
2	400

BEYOND EFT

Full Amplitude Calculation

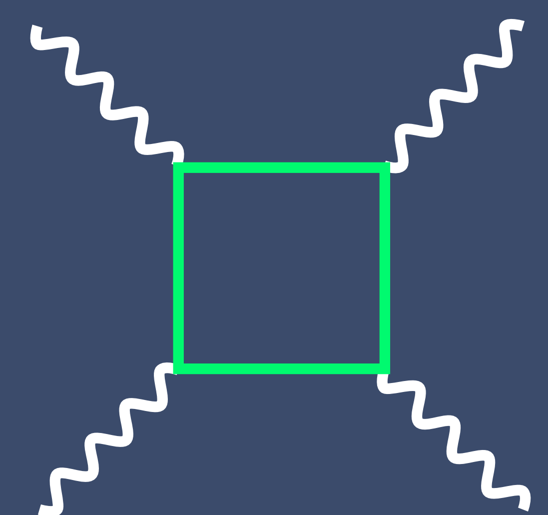
- For sufficiently low NP mass m the pair production threshold can be reached

$$2m < \sqrt{s_{\max}} \approx 2\text{TeV}$$

- Below $m = 1$ TeV the EFT cannot be trusted

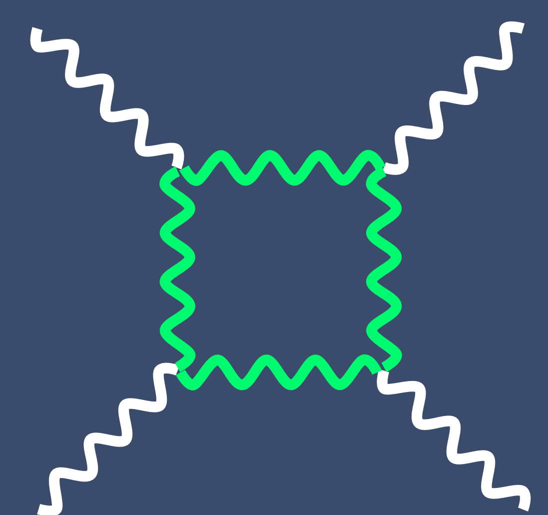
- Fermion and vector loops have been computed for all energies

Costantini et al '71, Jikia + Tkabladze '93



s, t, u

- The results only depend on mass m and effective charge $Q_{\text{eff}} = N^{1/4}Q$, N is multiplicity
- Reduces to EFT result at low energy



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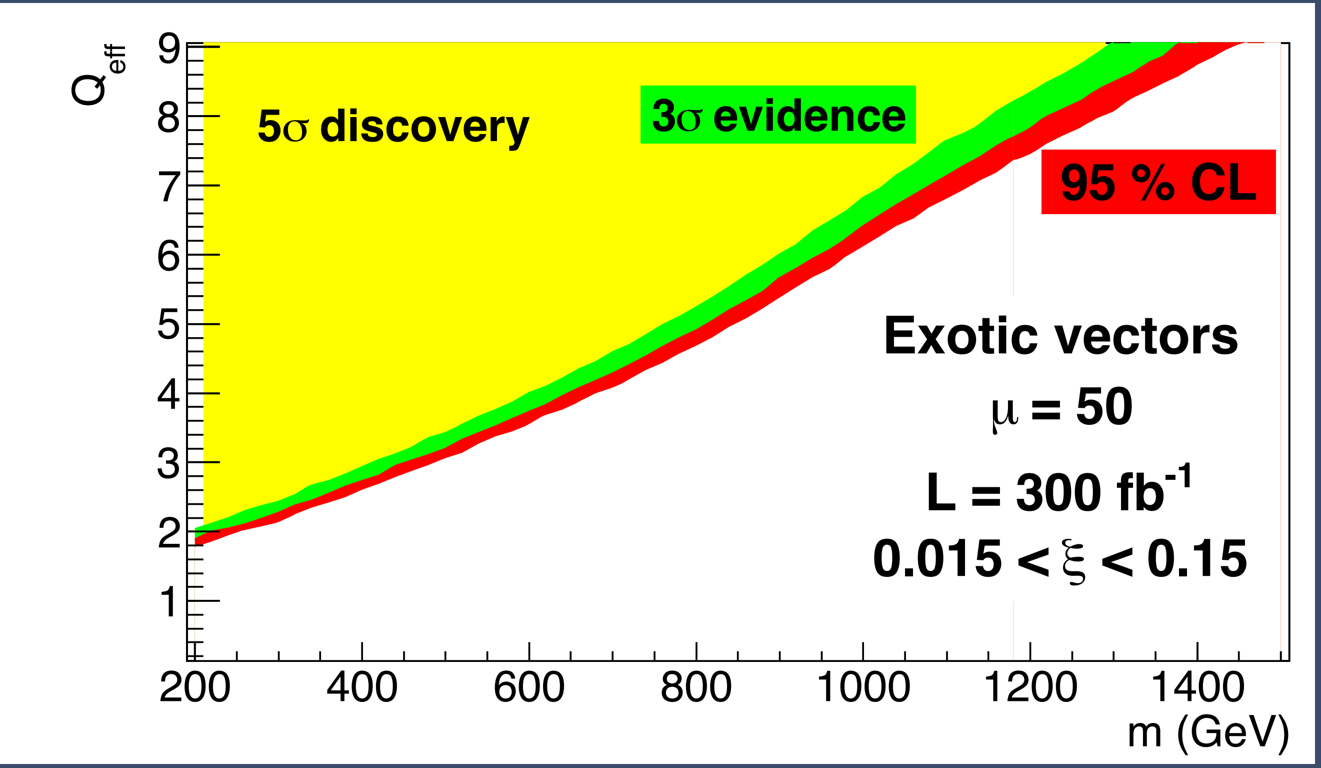
Full Amplitude results (preliminary)

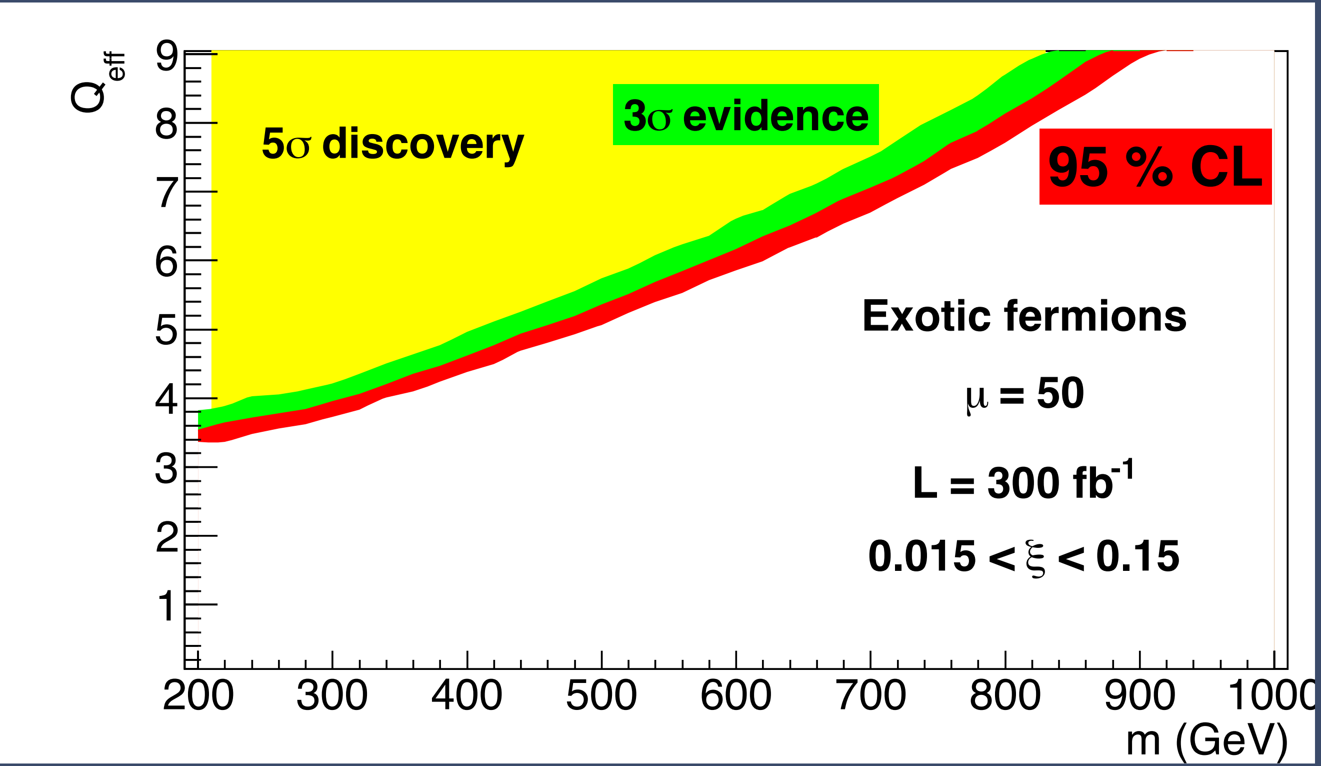
Fichet, GG, Kepka, Lenzi, Royon, Saimpert (in preparation)

- Projected exlcusion / discovery for 300 1/fb
- Slight improvements at lower mass

  (sensitive to larger values of m/Q_{eff})

- Model-independent bounds
- Again higher sensitivity expected for higher spin resonances





LIMITS ON WARPED EXTRA DIMENSIONS

WED: Leading Constraints

- Warped Extra Dimensions strongly constrained from EWPT
- Depend on Higgs localization and brane kinetic terms (BKT)

$$S = 2\pi \frac{1+\nu}{2+\nu} \left(\frac{3+\nu}{2+\nu} + (r + r') \right) \frac{v^2}{\tilde{k}^2}$$

$$T = \frac{\pi V}{c_w^2} \frac{(1+\nu)^2}{(3+2\nu)(2+\nu)} \left(1 + \frac{r'}{V} \right) \frac{v^2}{\tilde{k}^2}$$

- $\tilde{k}$: infrared scale
- $V \approx 35$: volume fo the ED
- $r,\ r'$: BKT
- $\nu = 0\ (\nu = \infty)$: describe bulk (brane) Higgs

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- Most recent global fits put very strong limits on mKK

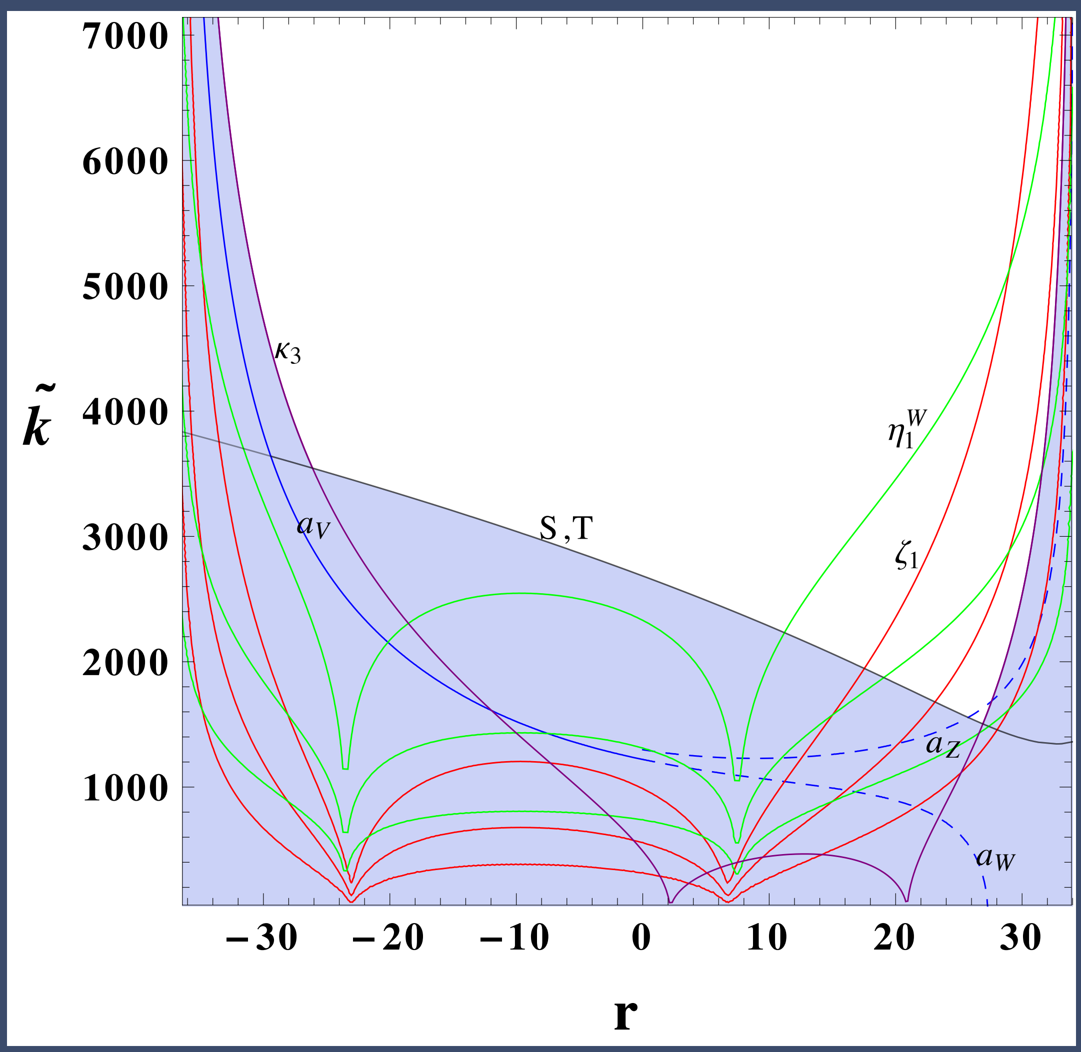
  Fichet + GG ’13, Agashe et al ’13
- Bulk Higgs as good as custodial
- BKT can lower these limits

  Davoudiasl et al ’02, Carena et al ’02

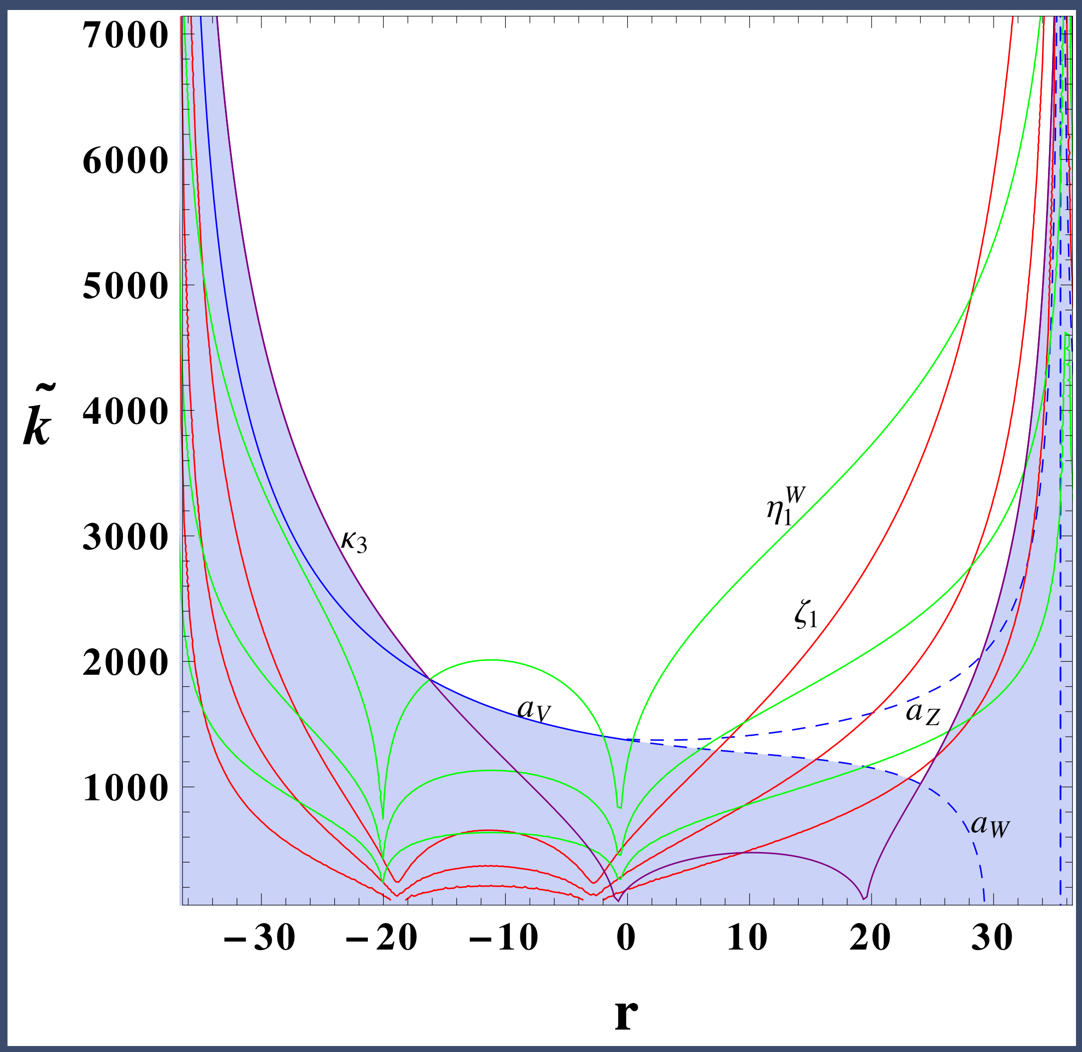
m_{KK}/TeV	brane	bulk
minimal	14.7	8.1
custodial	7.7	6.6

WED: Subleading Constraints

- BKT allow for parameter regions where EWPT are subdominant
- Existing bounds: TGV (AWW, ZWW), Higgs (hZZ, hWW)
- Future limits from QGV (AAWW, AAAA)



no custodial



custodial

Fichet + GG '13

CONCLUSIONS

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- Precision Physics is complementary to direct searches in the hunt for New Physics at the LHC
- Anomalous Quartic Gauge interactions can be probed at the LHC with proton tagging
- EFT approach: 4-photon interactions (dim-8 operators) can be constrained at the level of $\sim 10^{-14}$ GeV^{-4}
- Can be translated into various model independent limits on charged and neutral NP states (mass, spin, charge)

- Warped Extra Dimensions increasingly constrained from EWPT (Best case scenario $m_{KK} \sim 6.6$ TeV without BKT)
- BKT can lower these bounds, but subleading constraints from Higgs and gauge boson couplings become important

BACKUP

Magnetic Monopoles

- Magnetic Monopoles do not have a local UV description
- Proposal: at low energy use standard QED with the replacement

$$e \to g = \frac{2\pi}{e}$$

Ginzburg+Schiller '98

- Strongly coupled theory (unitarity is ok though for LHC energies)

- Sensitivities:
  - $s = 0$: $m < 6$ TeV
  - $s = 1/2$: $m < 9$ TeV
  - $s = 1$: $m < 16$ TeV

Backgrounds and Cuts

- Main Backgrounds
  - Exclusive (W+quark loops, double gluon exchange, ...)
  - Double Pomeron Exchange (DPE)
  - Non diffractive production, intact protons from pile-up

Cut / Process	Signal	Excl.	DPE	e^+e^-, dijet + pile-up	$\gamma\gamma$ + pile-up
$0.015 < \xi < 0.15$, $p_{T1,2} > 50$ GeV	20.8	3.7	48.2	$2.8 \cdot 10^4$	$1.0 \cdot 10^5$
$p_{T1} > 200$GeV, $p_{T2} > 100$ GeV	17.6	0.2	0.2	1.6	2968
$m_{\gamma\gamma} > 600$ GeV	16.6	0.1	0	0.2	1023
$p_{T2}/p_{T1} > 0.95$, $\|\Delta\phi\| > \pi - 0.01$	16.2	0.1	0	0	80.2
$\sqrt{\xi_1\xi_2 s} = m_{\gamma\gamma} \pm 3\%$	15.7	0.1	0	0	2.8
$\|y_{\gamma\gamma} - y_{pp}\| < 0.03$	15.1	0.1	0	0	0

14 TeV, 300 fb^{-1}