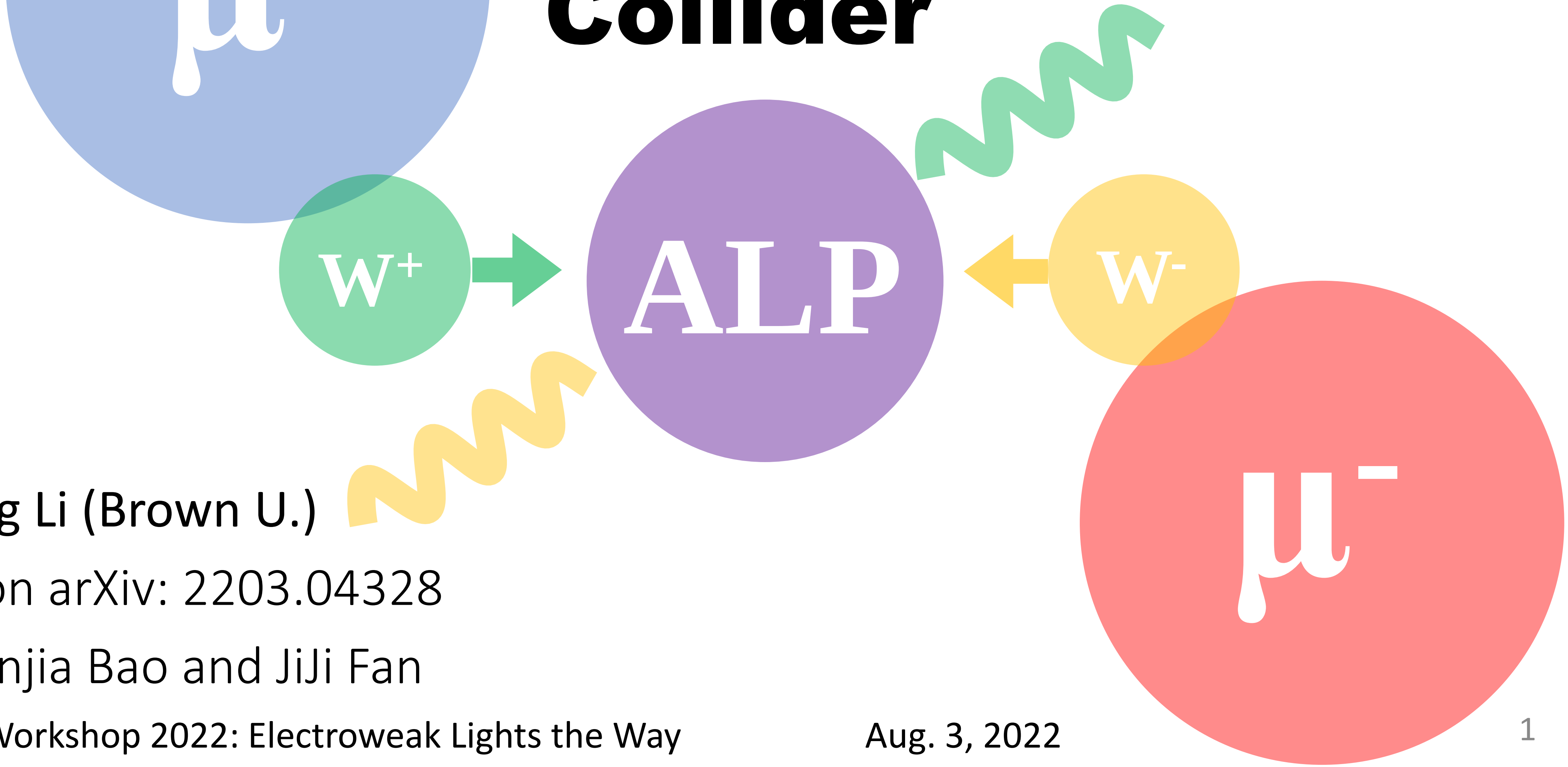
Electroweak ALP Searches at a Muon Collider

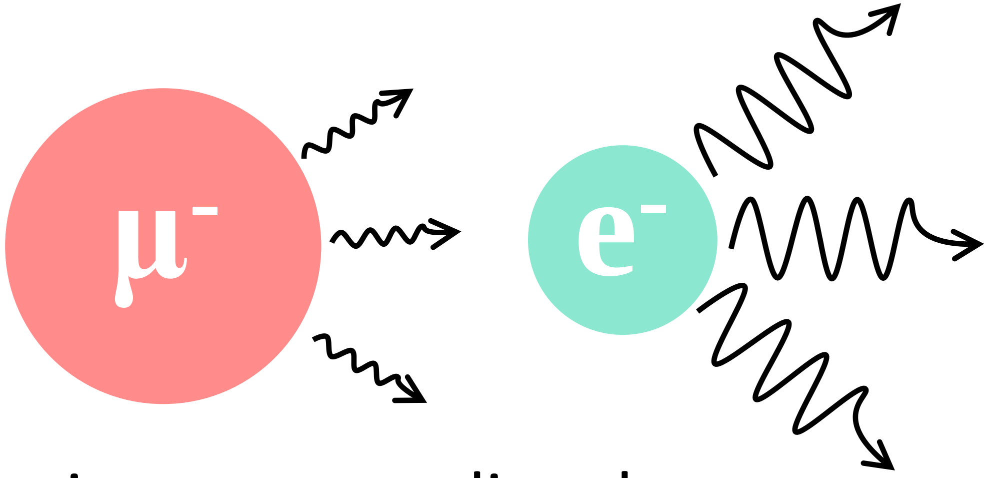


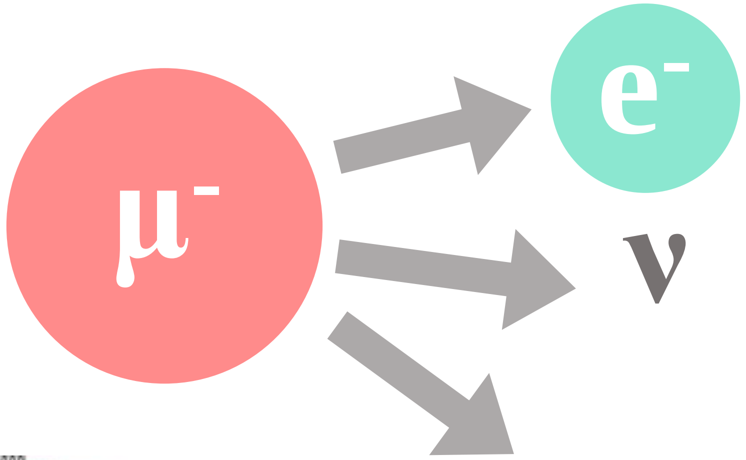
Lingfeng Li (Brown U.)

Based on arXiv: 2203.04328

with Yunjia Bao and JiJi Fan

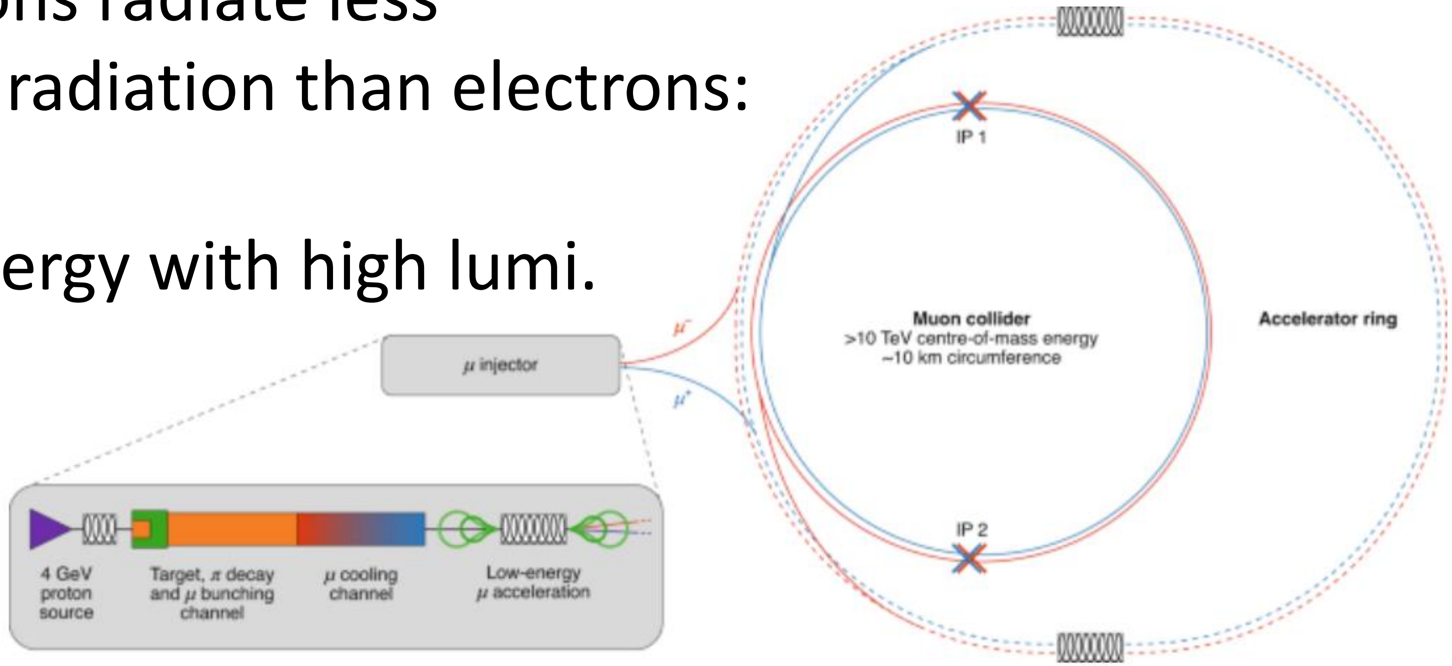
Muon Collider: why & why not yet





Heavier muons radiate less synchrotron radiation than electrons:

TeV-scale energy with high lumi. possible



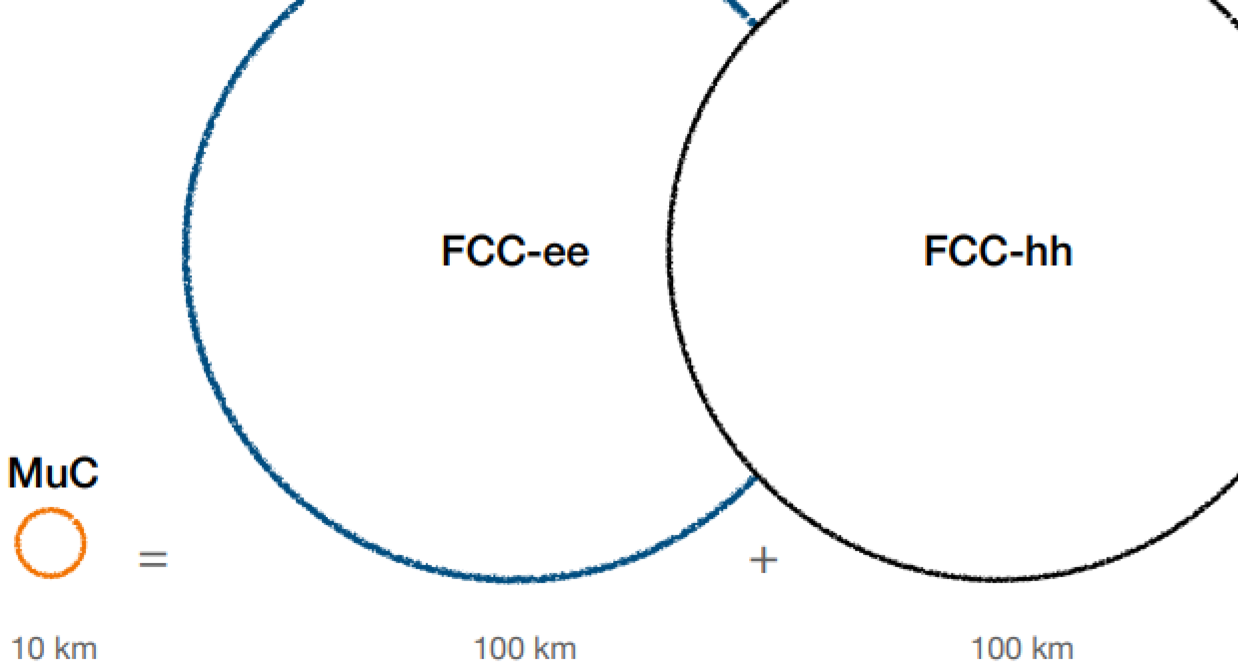
Muons DECAY!
Lifetime is 2ms:

Extreme challenges in the design

Muon collider physics

The essentials

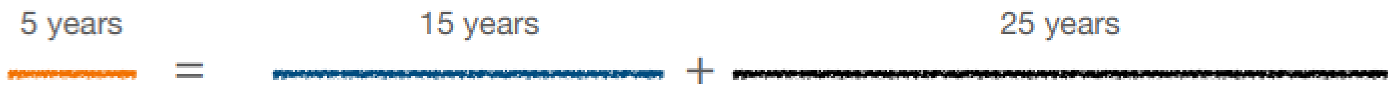
1] O(10) TeV Energy small two-in-one collider:

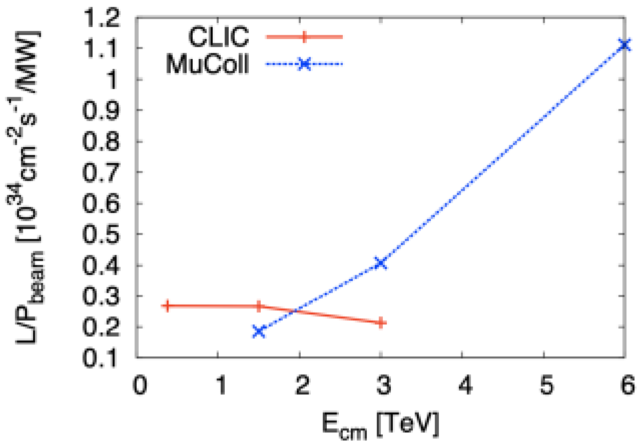


x

t

2] Luminosity growing with energy:





From Fabio Maltoni’s talk during the Snowmass EF workshop

⇒MuC is an SSTC = Space-Time Compact Collider

MuC10: 10 TeV, 10 iab, 10 times smaller and 10 times quicker than the FCC

From Mark Palmer's talk during the Snowmass EF workshop

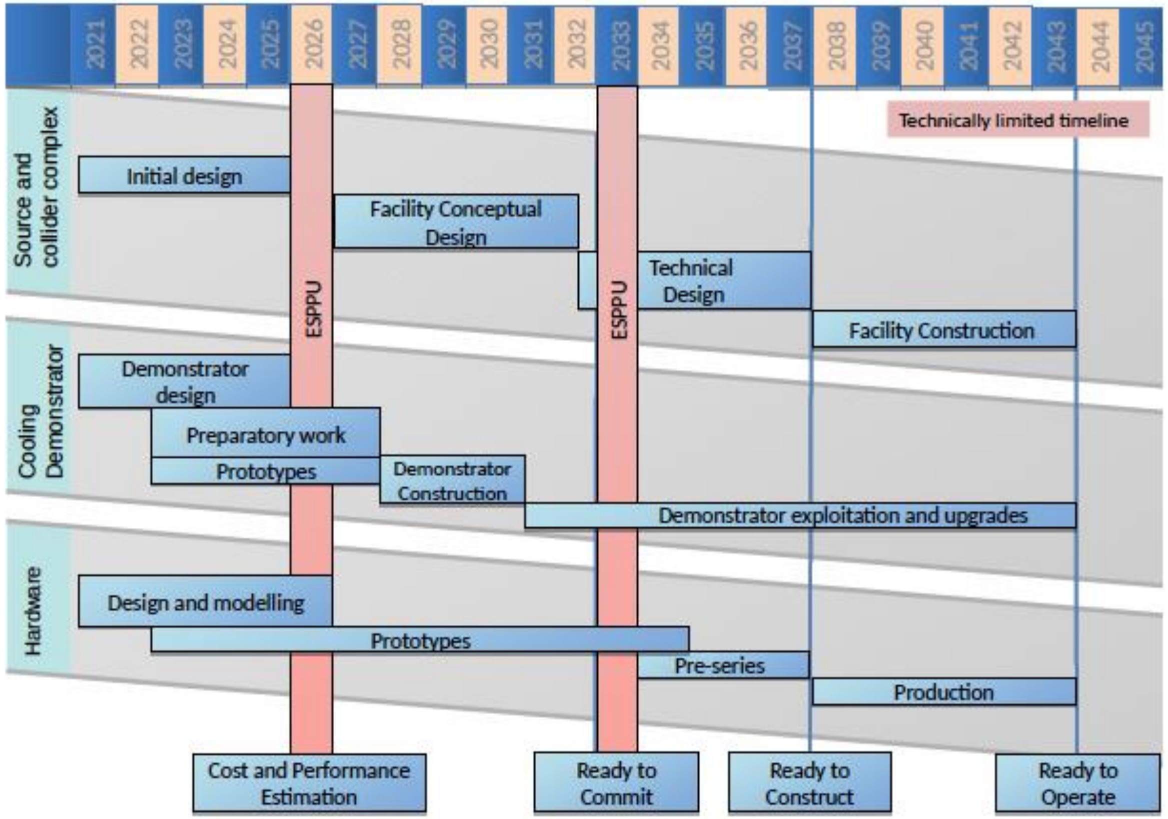


Fig. 5.3: A technically limited timeline for the muon collider R&D programme.

Still futuristic, need a very long time and substantial investment for the R&D:

The best candidate for the next-to-next-generation collider?

Currently at technology readiness level 2 at most (out of 9 total levels)!

Relative Level of Technology Development	Technology Readiness Level	Brief Description
Research to prove feasibility	3	Analytical and experimental critical function and/or characteristic proof of concept
	2	Technology concept and/or application formulated
Basic technology research	1	Basic principles observed and reported

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Axion and ALP

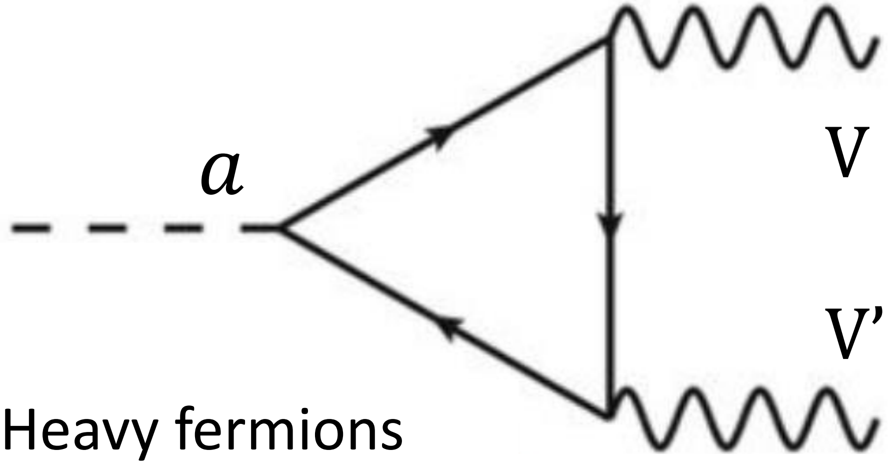
(QCD) axion: a (pesudo) goldstone boson coming from a broken global (PQ) symmetry at a scale f_a. Motivated by the strong CP problem.

Axion-like-particle (ALP): similar but not directly related to QCD, can show up anywhere.

Heavy electroweak ALP

$$\mathcal{L} = \frac{1}{2}\left[(\partial a)^2 - m_a^2 a^2\right] + \left(\frac{g_1}{4\pi}\right)^2 C_{BB}\frac{a}{f_a}B_{\mu\nu}\widetilde{B}^{\mu\nu}$$
$$+ \left(\frac{g_2}{4\pi}\right)^2 C_{WW}\frac{a}{f_a}W^i_{\mu\nu}\widetilde{W}^{i;\mu\nu} + \left(\frac{g_1}{4\pi}\right)\left(\frac{g_2}{4\pi}\right)C_{BW}\frac{a}{f_a}B_{\mu\nu}\widetilde{W}^{3;\mu\nu},$$

Similar to Higgs → Zγ, can arise from a dim-7 EFT operator.

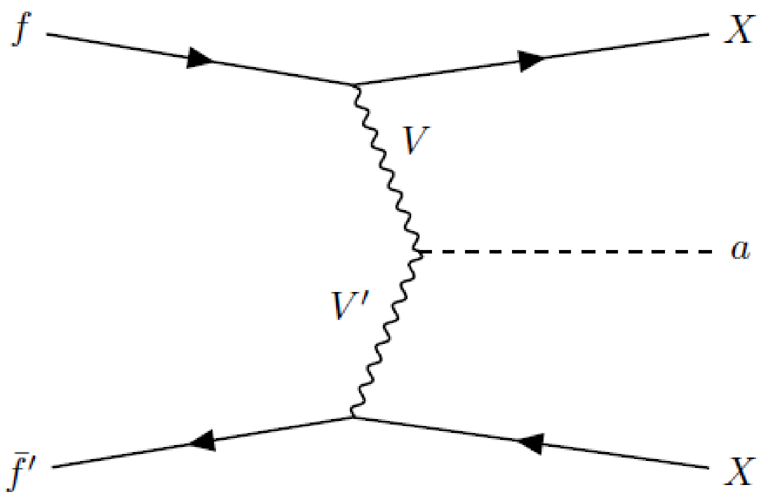


Heavy fermions

- m_a: O(TeV), compatible with the muon collider energy.
- $\frac{g_{1,2}^2}{(4\pi)^2}$: The coupling & loop factor

Heavy & Elusive: The right target for a muon collider!

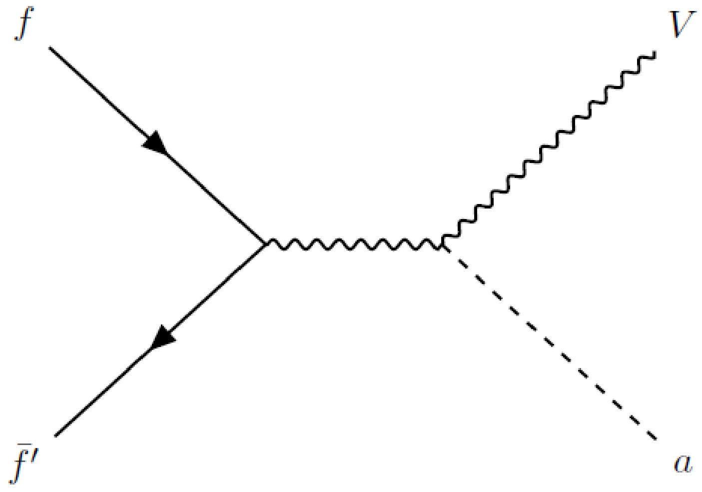
Primary ALP Production Modes



The VBF process:
"Muon collider is also a vector boson collider"

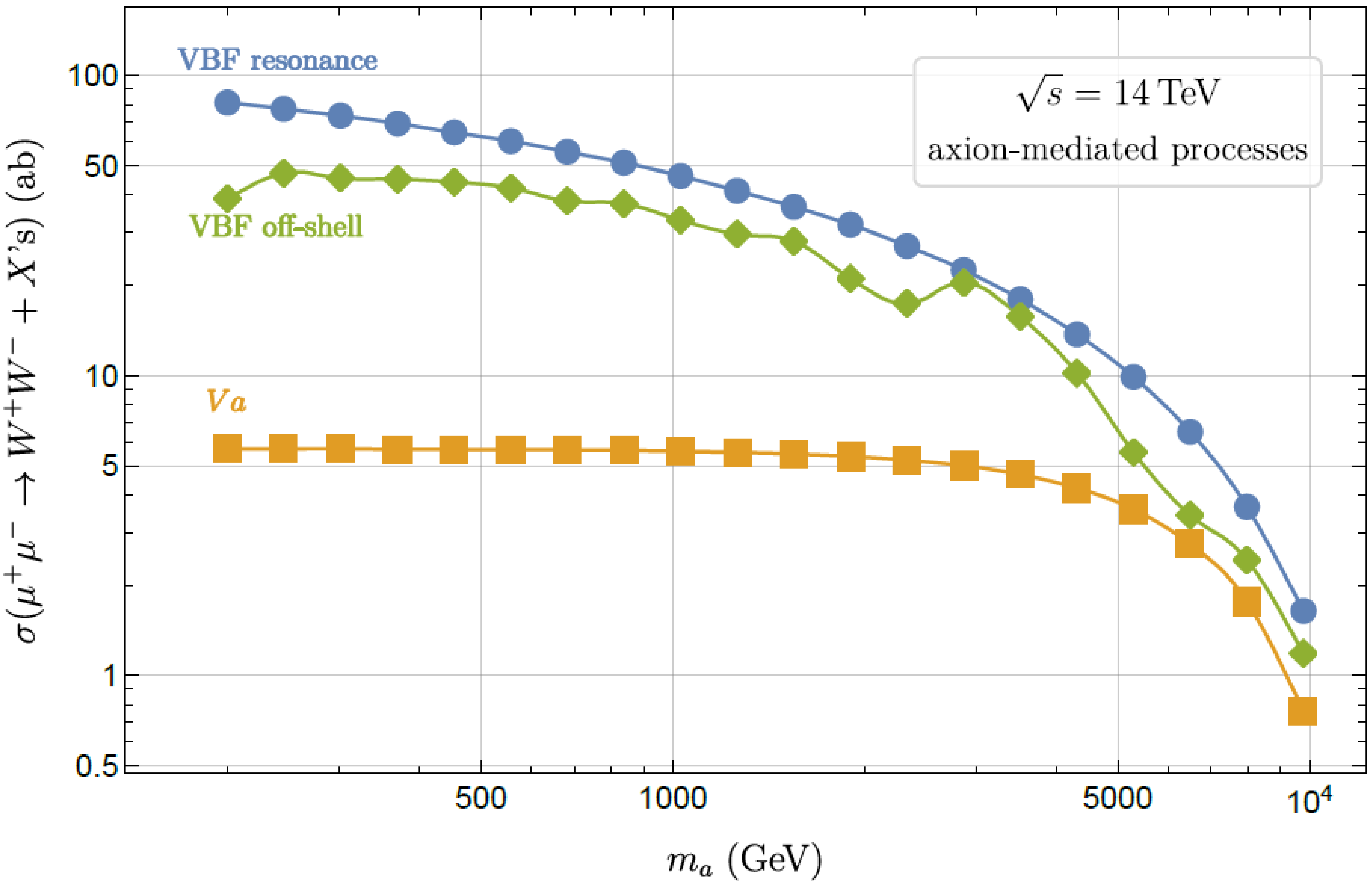
- Large Xsec, grows with $\sqrt{s}$

A. Costantini, F. De Lillo, F. Maltoni, L. Mantani, O. Mattelaer, R. Ruiz et al., 2005.10289 and T. Han, Y. Ma, K. Xie, 2007.14300 and H. Al Ali et al., 2143.14043 and many more

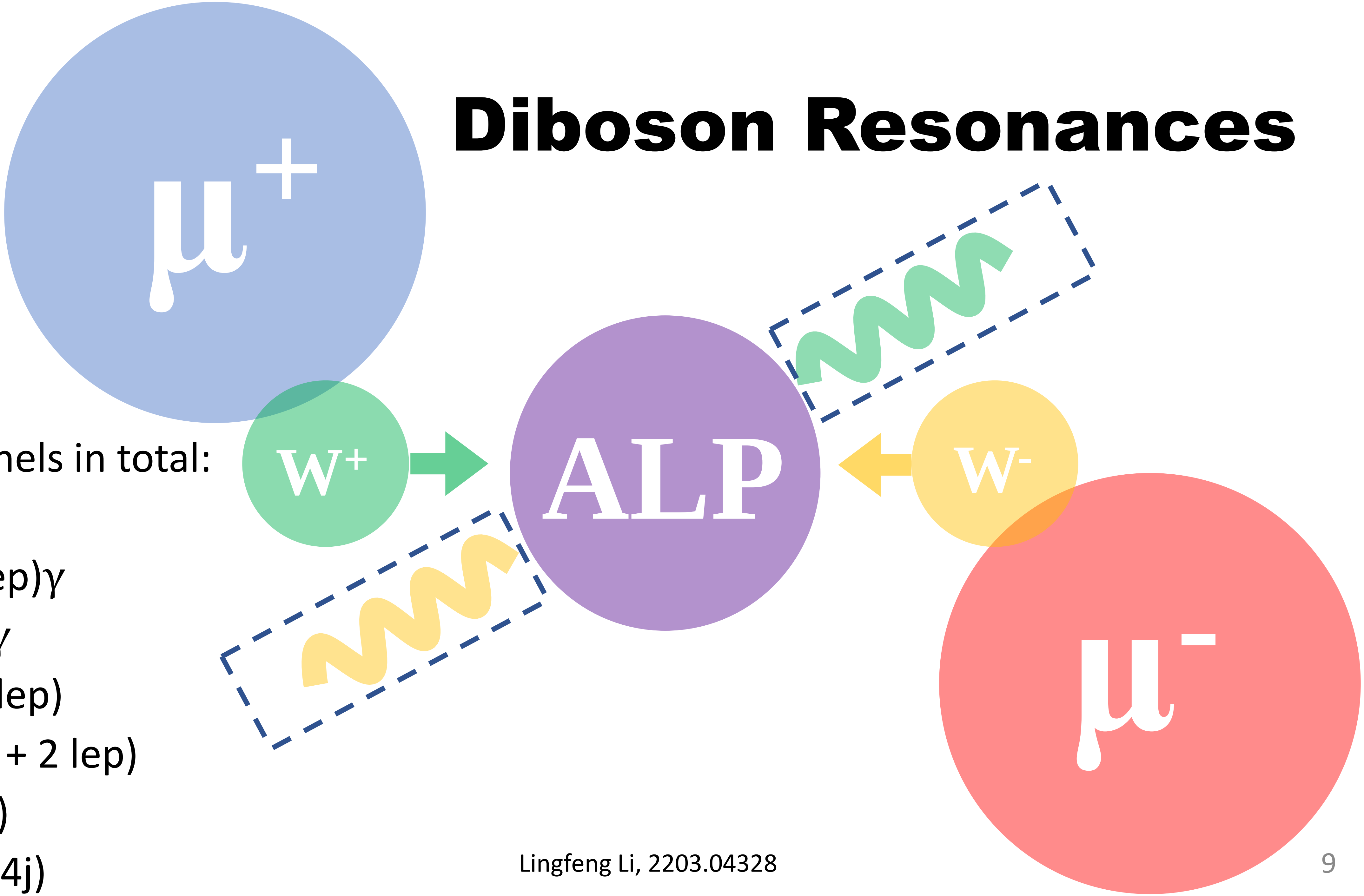


The associated production:

- Xsec drops with $\sqrt{s}$
- Produces heavy ALP upto $m_a \approx \sqrt{s}$


VBF resonance
VBF off-shell
Va
$\sqrt{s} = 14\,\text{TeV}$
axion-mediated processes
$\sigma(\mu^+\mu^- \to W^+W^- + X\text{'s})$ (ab)
m_a (GeV)
100
50
10
5
1
0.5
500
1000
5000
10^4

Diboson Resonances



7 channels in total:

- ➢$\gamma\gamma$
- ➢Z(2 lep)γ
- ➢Z(2j)γ
- ➢ZZ(4 lep)
- ➢ZZ(2j + 2 lep)
- ➢ZZ(4j)
- ➢WW(4j)

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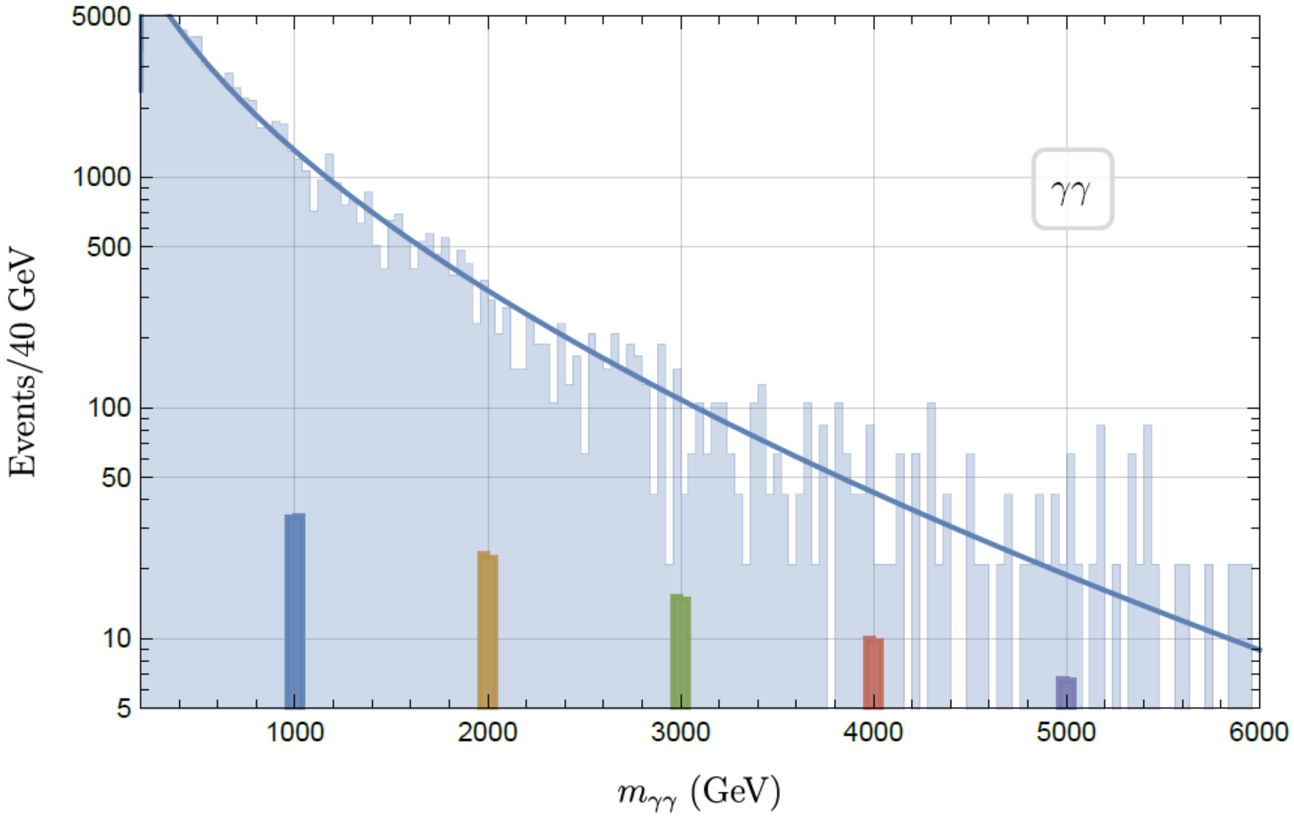
VBF Resonance Search

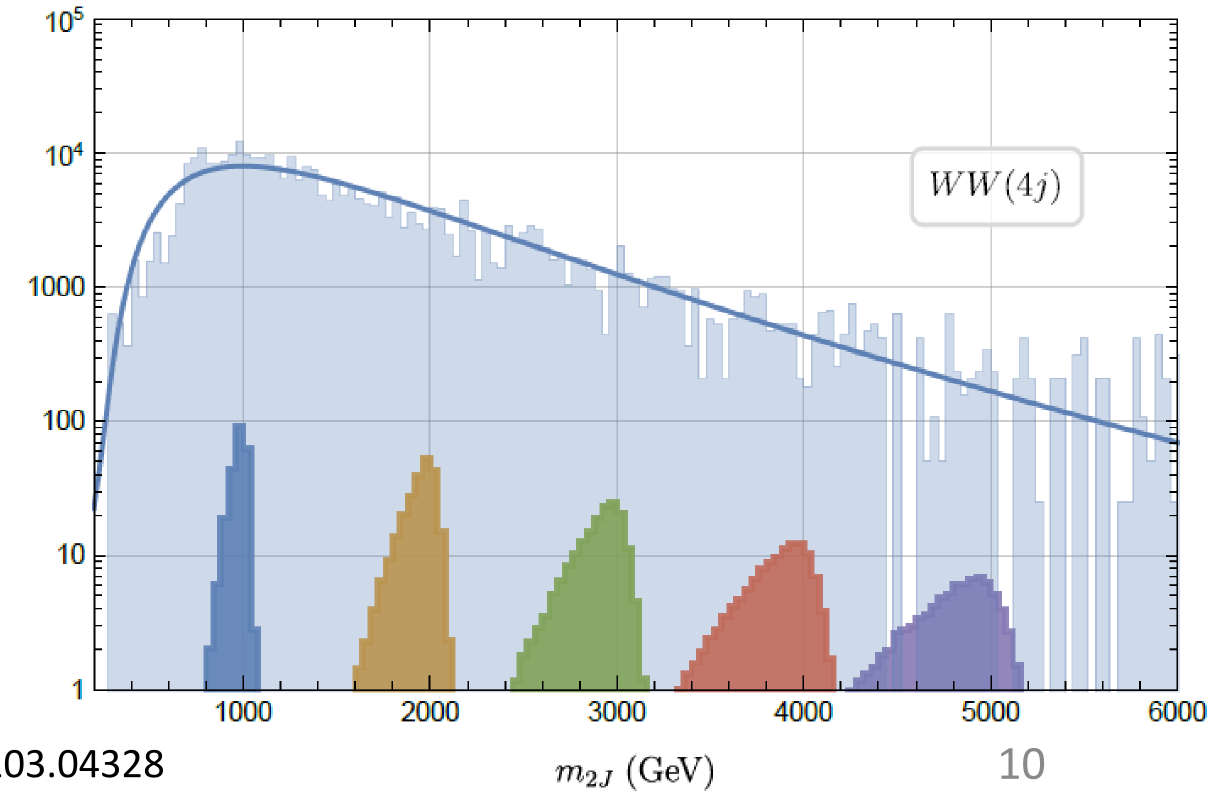


↑: Diphoton

- Cleanest background (VBF WW→ γγ)
- Sharpest resonance peaks

↓: WW(4j)

- Highest background (VBF γγ → WW)
- Wide peaks due to jet resolution



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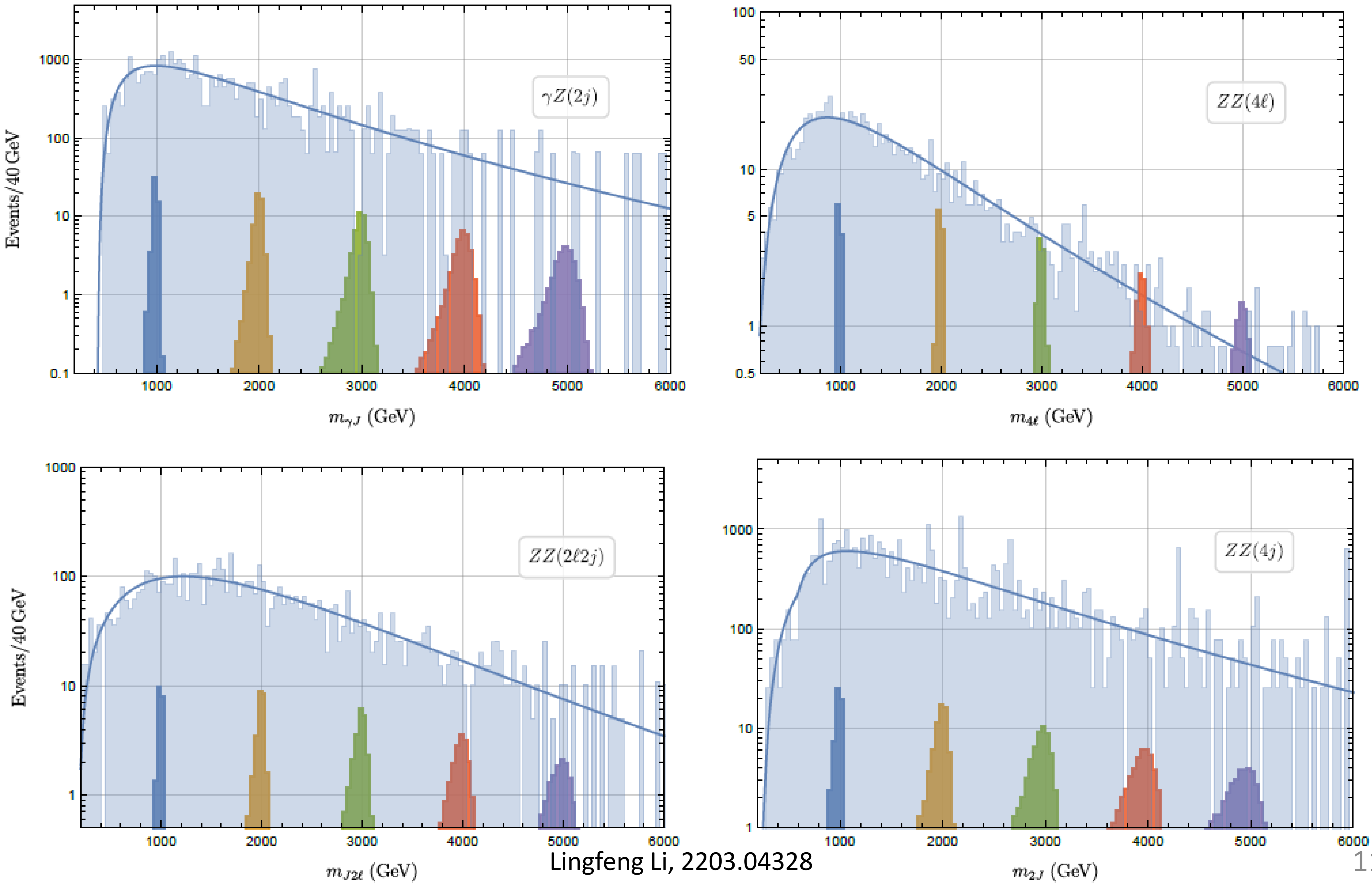

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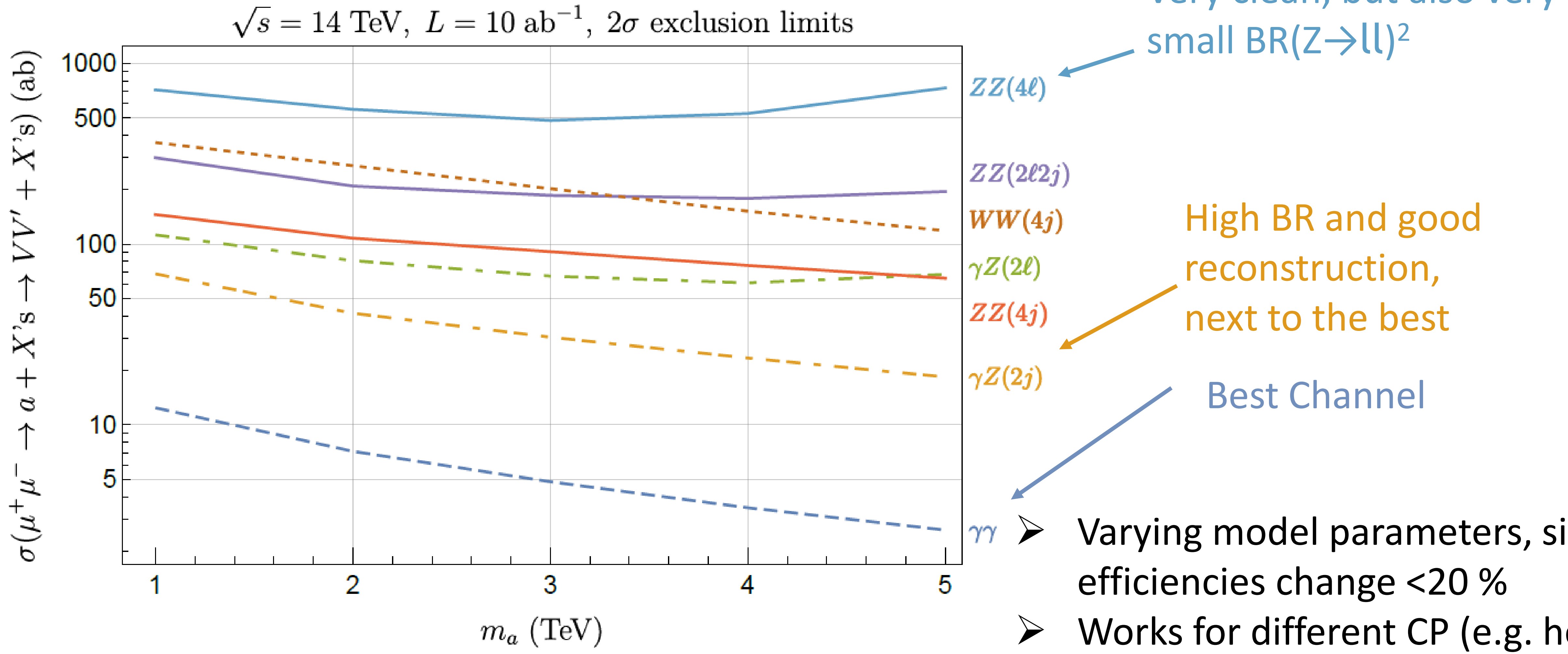
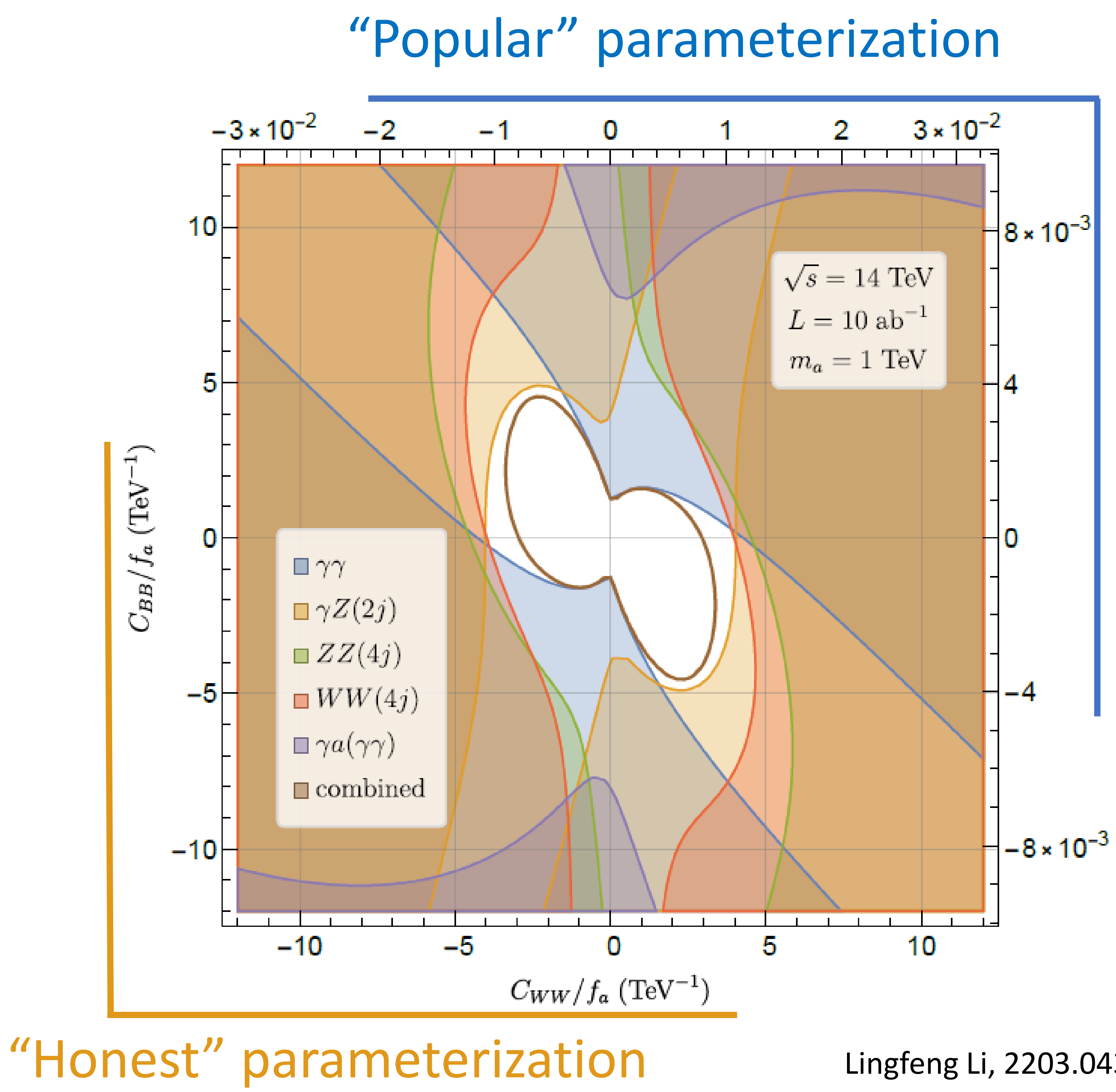
Xsec Limits Always < 1 fb!



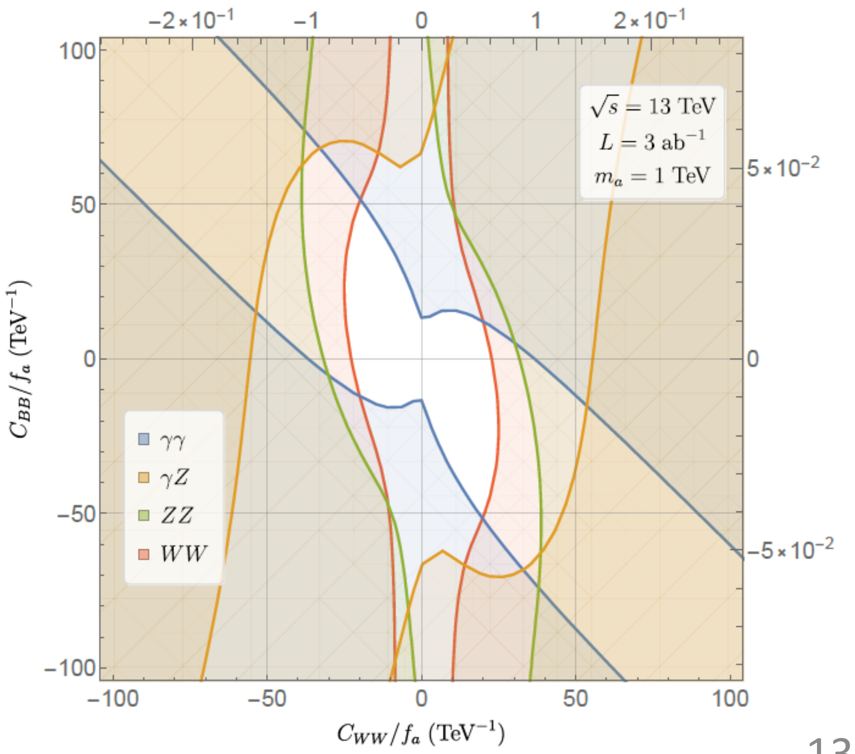
Good for Any Diboson Resonance

- Varying model parameters, signal efficiencies change <20 %
- Works for different CP (e.g. heavy Higgs) and spin (e.g. Z's)
- Result compatible with [T. Han, T. Li, X. Wang, 2203.05484]

Lingfeng Li, 2203.04328



- Lead by two best VBF channels
- ALP + associated photon is subdominant
- Orders of magnitude better than HL-LHC



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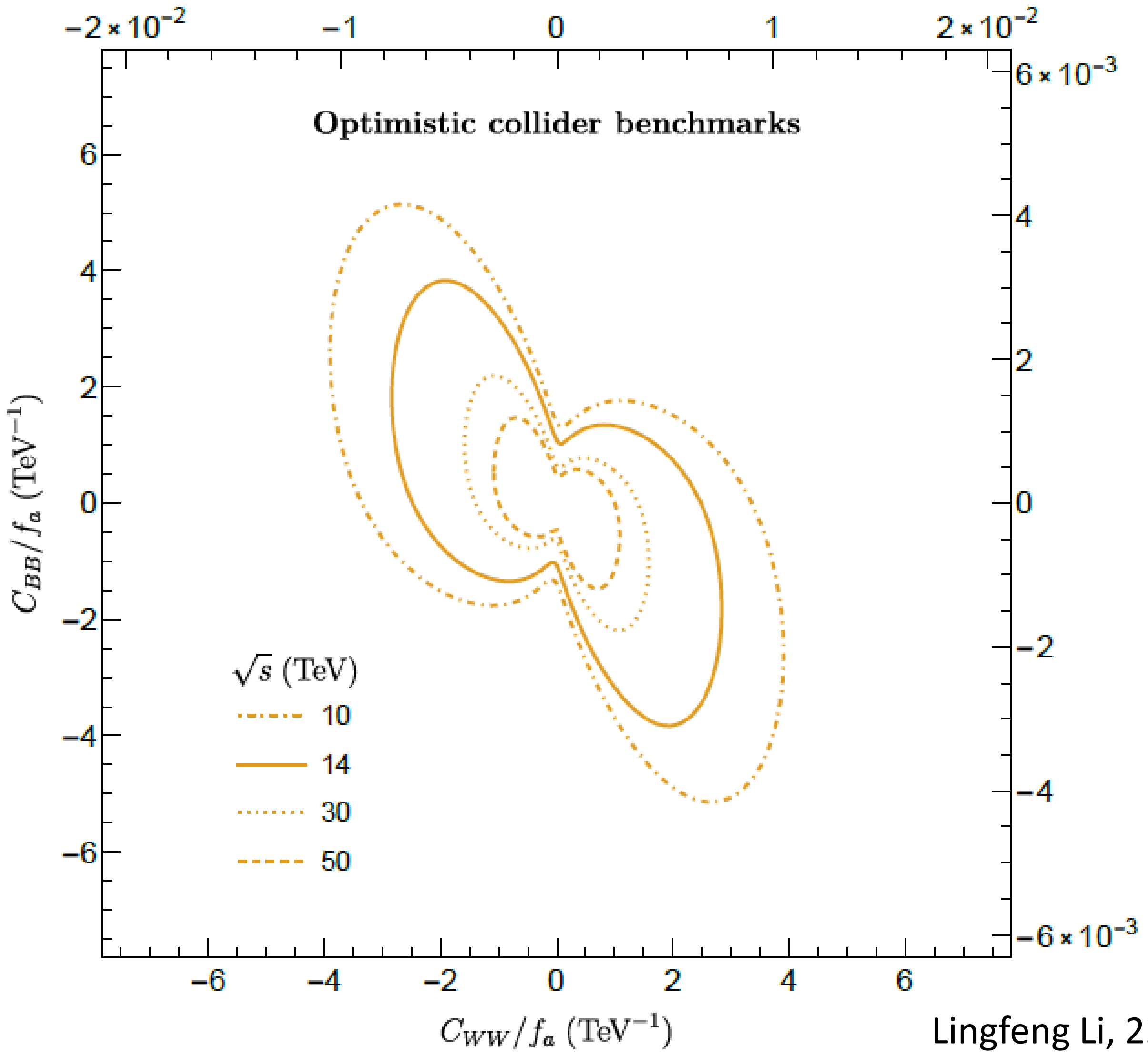
Different Benchmarks



- Larger Xsec with improved energy
- Luminosity also increases
- Reach to higher masses

$$\sqrt{s} = 10,\ 14,\ 30,\ 50\quad \text{TeV}\,,$$
$$L_{\text{con}} = 10,\ 10,\ 10,\ 10\quad \text{ab}^{-1}\,,$$
$$L_{\text{opt}} = 10,\ 20,\ 90,\ 250\ \text{ab}^{-1}\,.$$

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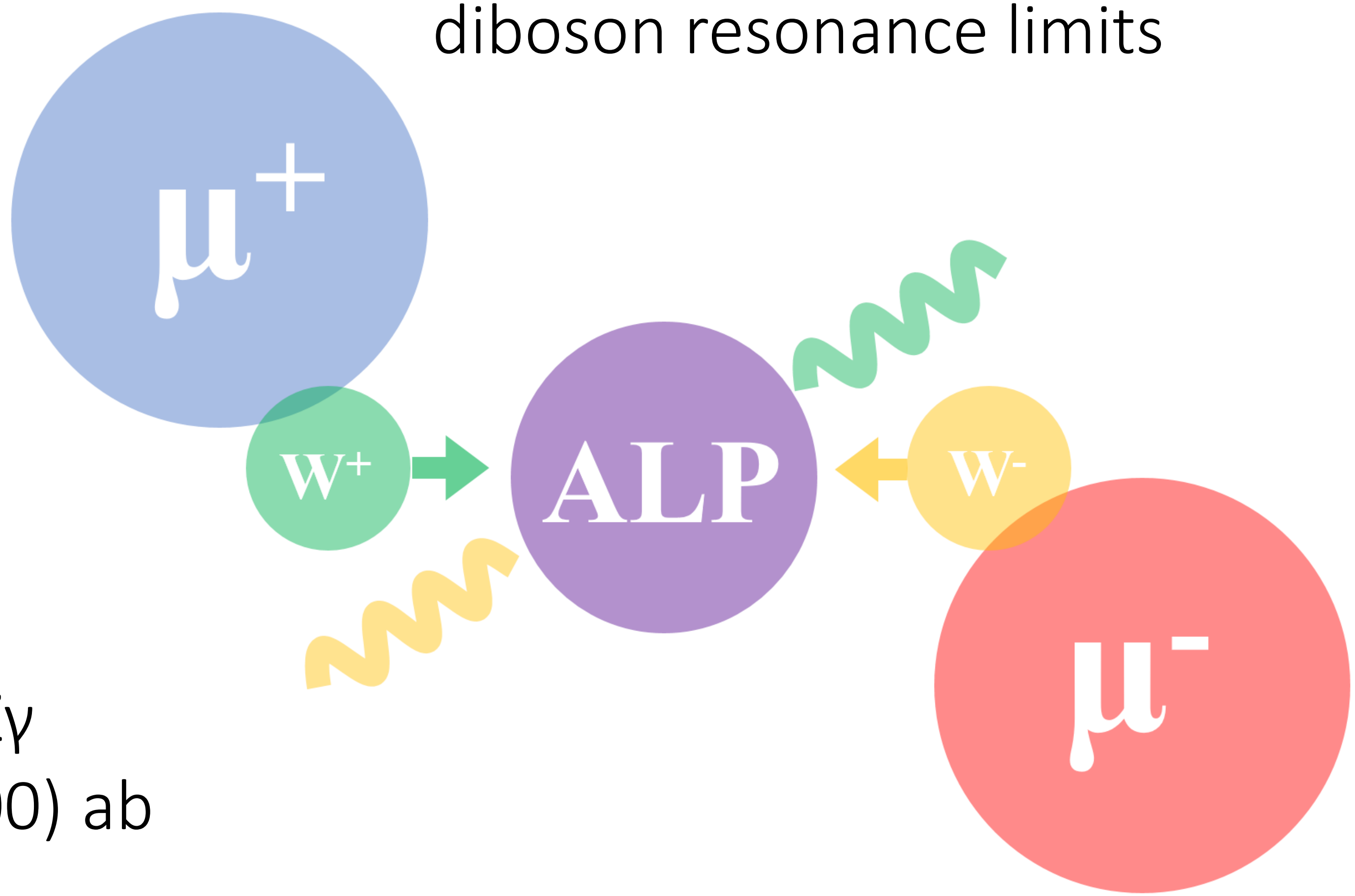
Summary

*: We provide model independent diboson resonance limits

A high-energy muon collider is also a boson collider with large production rates



Clean channels as γγ and Zγ constraint Xsec to O(10-100) ab

Reaches the elusive TeV-scale ALP efficiently