Boosting Strong Higgs Pair Production at the LHC

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Based on work in collaboration with Roberto Contino

Workplan discussion of the Higgs and BSM WG of the FCC Study
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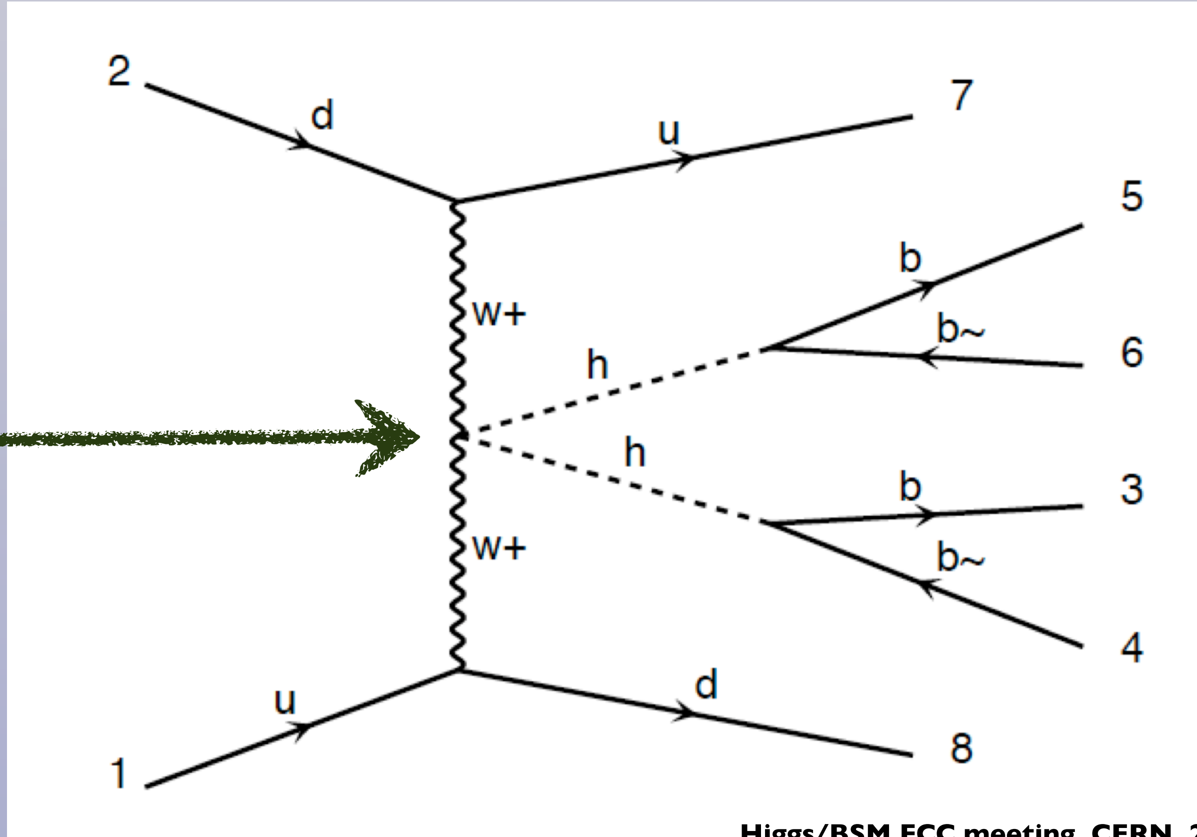
Motivation

- **Higgs pair production** is one of the most crucial processes for future LHC runs, since it allows to perform stringent tests of our understanding of electroweak symmetry breaking
- In the SM, the dominant process is gluon fusion, with ~**33 fb (~1.5 pb)** at **14 TeV (100 TeV):** direct sensitivity to the **Higgs trilinear coupling** λ_3
- Higgs pair production in **Vector-Boson Fusion** is small in the SM: **2 fb (80 fb)** at **14 TeV (100 TeV)**, yet provides unique information on the **hhVV coupling**
- VBF Higgs pair production can be **substantially enhanced** in scenarios where electroweak symmetry breaking is broken by new **strong dynamics** (like in composite Higgs models)
- Closely related process to the dynamics **WW scattering**

Unique direct sensitivity to the hhVV coupling and the the EWSB unitarization mechanism



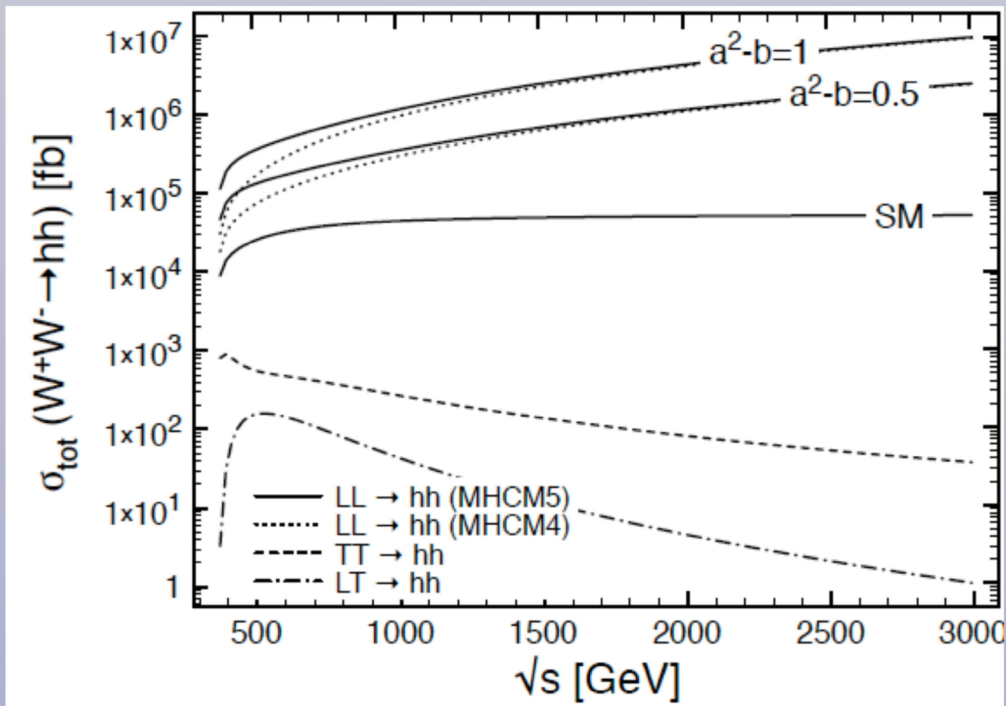
Strong Double Higgs Pair production

- In **composite Higgs models** with **new strong dynamics**, the predictions for **VBF Higgs pair production** at the hadron colliders can be substantially enhanced as compared to their SM values

$$\mathcal{L} = \frac{1}{2}(\partial_\mu h)^2 - V(h) + \frac{v^2}{4}\mathrm{Tr}\left(D_\mu\Sigma^\dagger D^\mu\Sigma\right)\left[1 + 2a\,\frac{h}{v} + b\,\frac{h^2}{v^2} + \dots\right] - m_i\,\bar{\psi}_{Li}\,\Sigma\left(1 + c\,\frac{h}{v} + \dots\right)\psi_{Ri} + \mathrm{h.c.}\,,$$

in SM, a=b

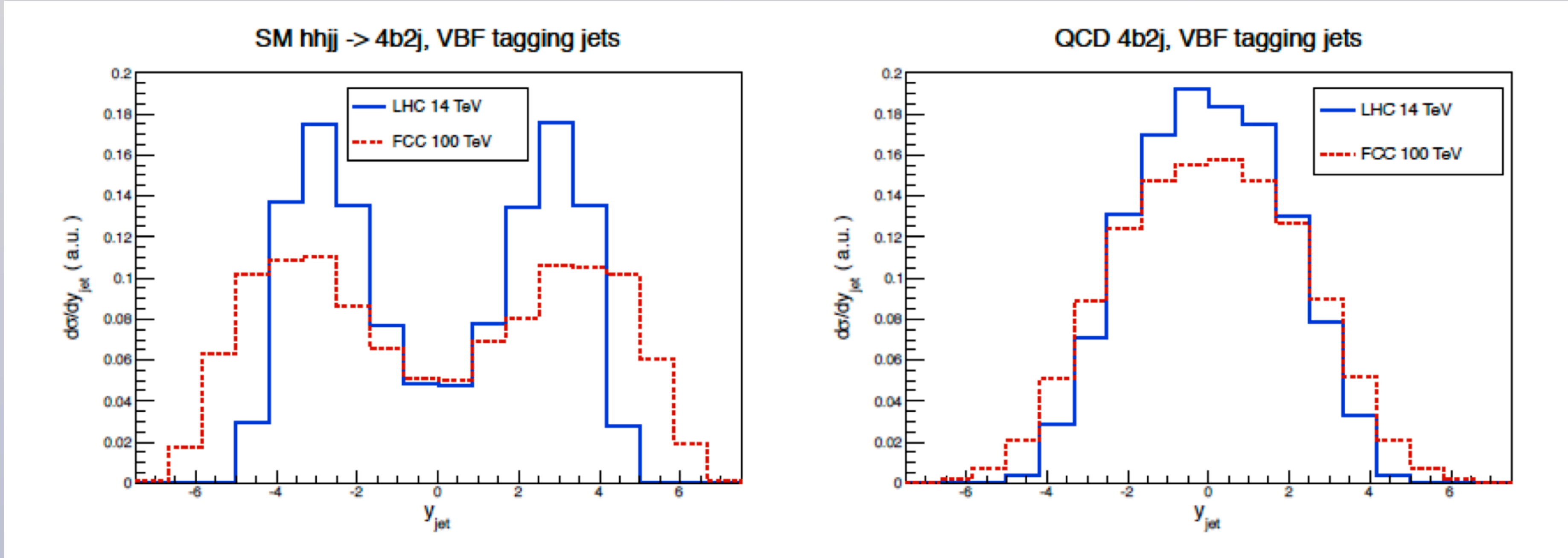
$$\frac{d\sigma_{LL\to hh}}{dt} \simeq \frac{(b-a^2)^2}{32\pi\, v^4}\,, \qquad \frac{d\sigma_{TT\to hh}}{dt} \simeq \frac{g^4(a^4+(b-a^2)^2)}{64\pi\, s^2}\,,$$



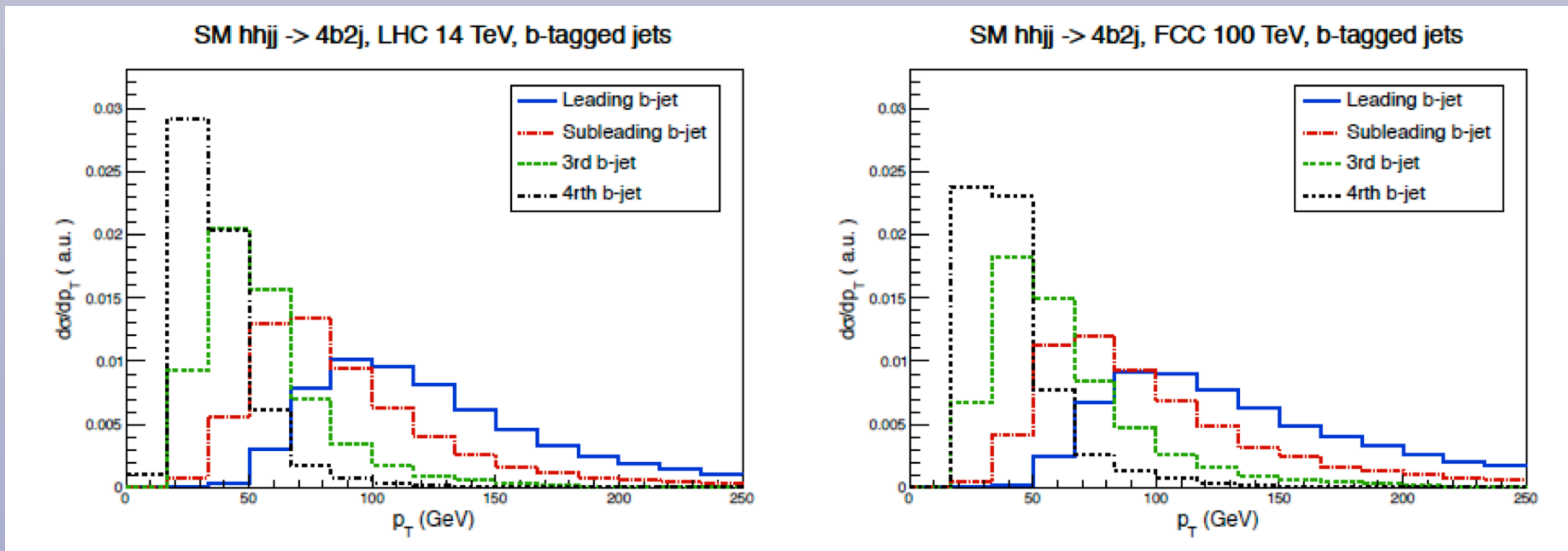
- Most **striking signature** is that the **new strong dynamics** lead to a much harder distribution in **M_{HH}** as compared to the SM
- Original feasibility study by **Contino, Grojean, Moretti, Piccinini and Rattazi in arxiv:1002.1011** assumed a **180 GeV Higgs** and focused on the dominant **WW final state**
- Our goal is to revisit the analysis for **m_H=125 GeV** for the final states with larger BR.
- For **b ≠ a**, Higgs pairs produced with **large boosts: jet substructure techniques** needed
- Even more crucial at a 100 TeV collider!

Selection and analysis cuts

Standard **VBF selection cuts** to suppress background (including **central jet veto**)
Instrumenting the FCC detectors up to **very forward rapidities** crucial to avoid efficiency loss



Threshold region challenging because moderate pt jets, huge background, but **sensitivity to c2v from boosted region**



Event rates at the LHC and the FCC

	LHC 14 TeV		FCC 100 TeV	
	σ (fb)	$N_{\rm ev}(3\,{\rm ab}^{-1})$	σ (fb)	$N_{\rm ev}(10\,{\rm ab}^{-1})$
Standard Model	0.10	300	4.53	45.3K
$c_V, c_{2V}, c_3 = 1.0, 0.0, 1.0$	2.45	7380	327	3.3M
$c_V, c_{2V}, c_3 = 1.0, 2.0, 1.0$	1.58	280	279	2.8M
$c_V, c_{2V}, c_3 = 1.0, 0.0, 0.0$	3.21	9630	357	3.6M
$c_V, c_{2V}, c_3 = 1.0, 0.0, -1.0$	4.11	12300	393	3.9M
$c_V, c_{2V}, c_3 = 1.0, 1.0, 0.0$	0.29	870	11.0	0.1M
MCHM5 $\xi = 0.2$	0.41	1230	38.6	0.4M
Higgs portal $c_3 = 3$	0.27	810	9.21	92K

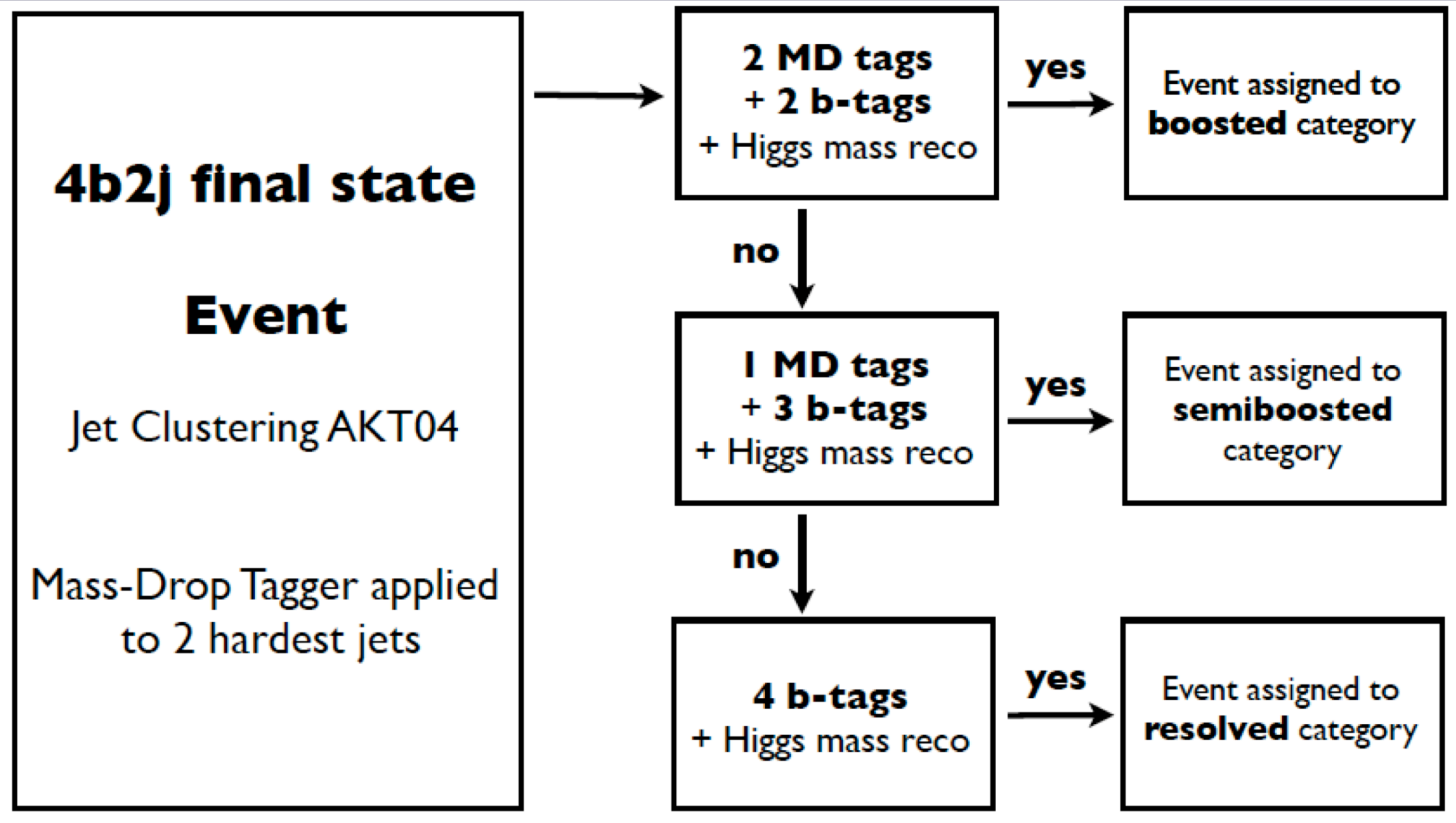
- Cross-sections for the **4b final state** after basic selection cuts
- Event rates enhanced when **hhVV** coupling modified, sensitivity to **new strong BSM dynamics**
- **From LHC to FCC: factor 40** increase in xsec for SM, up to **200 in BSM scenarios**
- At the FCC, **precision physics** possible with hh VBF

	$\delta\sigma^{\rm res}/\sigma^{\rm tot}$, Scenario B1 $[m_{hh}^{\rm min}, m_{hh}^{\rm max}]$ (TeV)			$\delta\sigma^{\rm res}/\sigma^{\rm tot}$, Scenario B2 $[m_{hh}^{\rm min}, m_{hh}^{\rm max}]$ (TeV)		
	[0.5, 1.5]	[1.5, 2.5]	[2.5, 5.0]	[0.5, 1.5]	[1.5, 2.5]	[2.5, 5.0]
LHC 14 TeV						
η	+13%	+ 57%	+70%	+3%	+13%	+39%
ρ	-7%	-23%	-42%	-2%	-7%	-17%
FCC 100 TeV						
η	+15%	+ 63%	+28%	+4%	+14%	+54%
ρ	-8%	-25%	-0.5%	-2%	-8%	-22%

- Also quantified in detail the **effects of resonances**
- Identified region where c2V can be robustly extracted even when resonances are included
- Use **MCHM5** as benchmark model

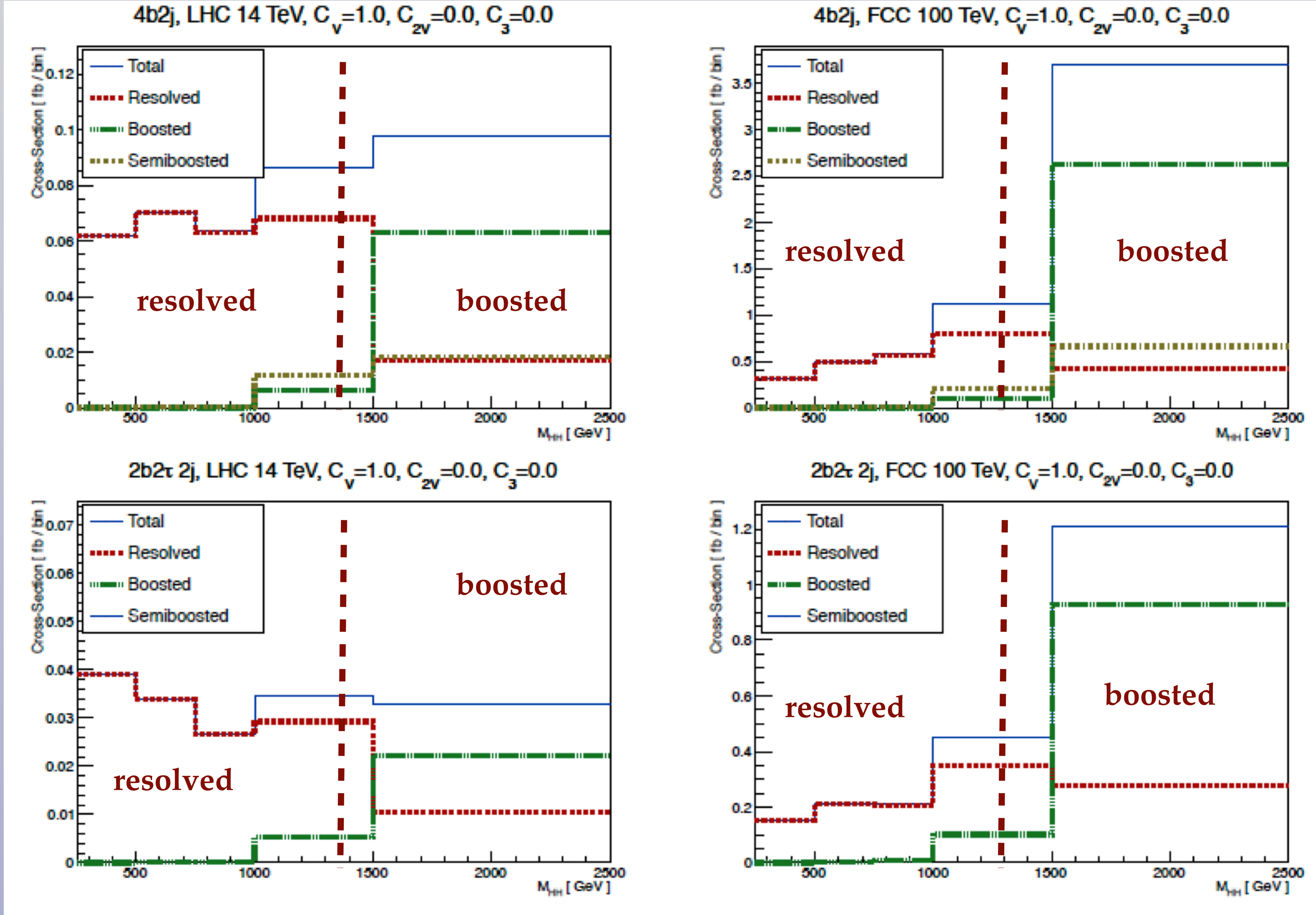
Analysis strategy

- To explore the **complete range of SM and BSM scenarios** we need to classify, on a event-by-event basis, **all possible signal topologies: boosted, semiboosted and resolved**
- This can be achieved using **scale-invariant resonance tagging** (arxiv:1303.6636)



Analysis strategy

- For m_{hh} close to threshold, the **resolved contribution** dominates, while large m_{hh} is the **boosted regime**
- At the LHC, resolved and boosted configurations **similar,** while at the FCC the **boosted regime dominates**
- Boosted techniques crucial since **large m_{hh}** is the region more sensitive to **new strong BSM dynamics**



Preliminary Results

- In the **4b final state,** 14 TeV with 300 fb^{-1} (3000 fb^{-1}) the **hhVV** coupling can be measured with **good precision: ~25-30% (10-15%)**
- As expected, the precision on the **Higgs trilinear coupling** is worse than in **gg->hh** (since backgrounds dominate *hh* threshold region)
- At the **FCC,** the **hhVV** coupling can be pinned down with **very high, few percent precision**
- We have included a 50% error in the backgrounds, to account for theory and experimental uncertainties
- Encouraging to begin to explore **Higgs pair-production in VBF** already at the **LHC Run II**
- **At the FCC we can do high precision physics** and improve our precision by an order of magnitude