Probing Higgs self-couplings at the FCC

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Probing the EWSB mechanism

- ✦ Establishing the SM nature of the electroweak symmetry breaking mechanism
  - ✤ Finding a Higgs is the first step ✅
  - ✤ Deriving the form of the scalar potential is necessary ❌
- ✦ Establishing the SM nature of the Higgs boson ?
  - ✤ Measurements of the Yukawa interaction strengths (*i.e.*, the fermion masses)

✦ The scalar potential

$$V_{\rm h} = \frac{m_h^2}{2} h^2 + (1+\kappa_3)\lambda_{hhh}^{\rm SM} v h^3 + \frac{1}{4}(1+\kappa_4)\lambda_{hhhh}^{\rm SM} h^4 \quad \text{with} \quad \lambda_{hhh}^{\rm SM} = \lambda_{hhhh}^{\rm SM} = \frac{m_h^2}{2v^2}$$

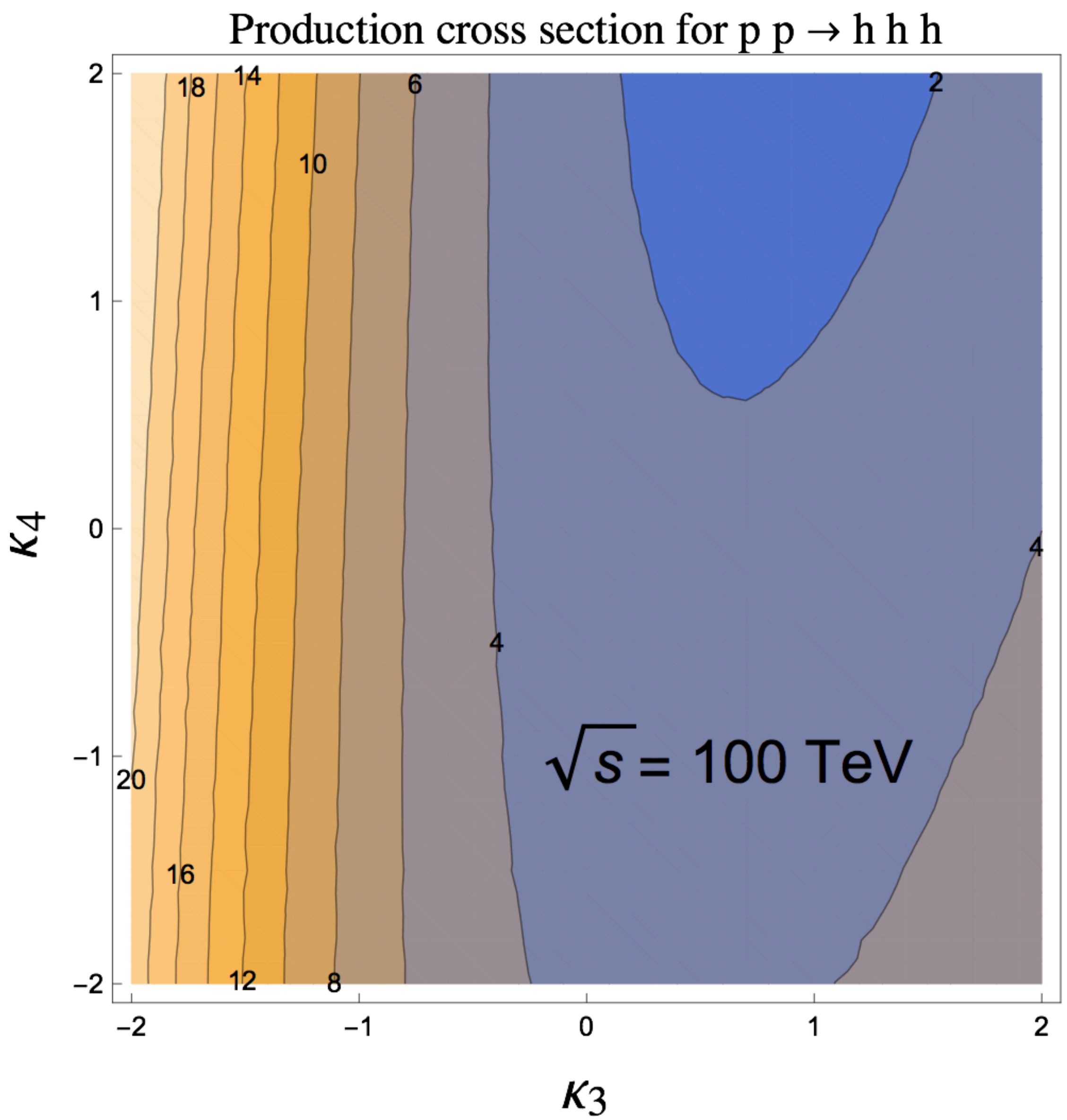
Measured

is $\kappa_3 = 0$?
Di-Higgs production
at the LHC can help

is $\kappa_4 = 0$?
No way for the LHC
(hhh cross section of ~0.01 fb)

Idea: probing triple-Higgs production at the FCC → Sensitivity to both κ parameters

Triple Higgs production at the FCC



- ✦ Triple Higgs production total rate
  - Small in the Standard Model (~ 3-4 fb)
  - Could be much larger with new physics
- ✦ Dependence on the κ parameters
  - κ_3: very strong
    - ➢ Can reach 20 fb for large and negative values
  - κ_4: milder (but not negligible)

Could it be constrained?

Considered triple Higgs signals

✦ Decay modes with the larger branching ratios

- 4 b-jets and a 2 W's (22%): boosted techniques?
  - ➢ see the di-Higgs case at the LHC
- 6 b-jets (19.5%): boosted techniques or angular information?
  - ➢ see the di-Higgs case at the LHC

Necessitates FCC detector details → Study of other channels

✦ Decay in the 4b + 2γ channel

- Clean, low background (*cf.* the diphoton)
- Small branching fraction (0.232%)
- Only studied channel so far [Papaefstathiou & Sakurai] [Chen, Yan, Zhao, Zhong & Zhao]

✦ Decay in the 4b + 2τ channel

- Large branching fraction (6.46%)
- Not studied yet, but the 2b+2τ channel is interesting in the di-Higgs case at the LHC

Why not at the FCC?

The 4b + 2γ channel: generalities

✦ Simulation details

- ✤ Parton-level study + smearing of the four-momenta (*à la* ATLAS)
- ✤ b-tagging performance: two LHC-inspired working points
  - ★ Very efficient (70%) with larger fake rates (18%, for c-jets, 1% for lighter jets)
  - ★ Less efficient (60%) with smaller fake rates (1.8%, for c-jets, 0.1% for lighter jets)

How good should the b-tagging be to observe a triple-Higgs signal

✦ Selection strategy for 20 ab^{-1}

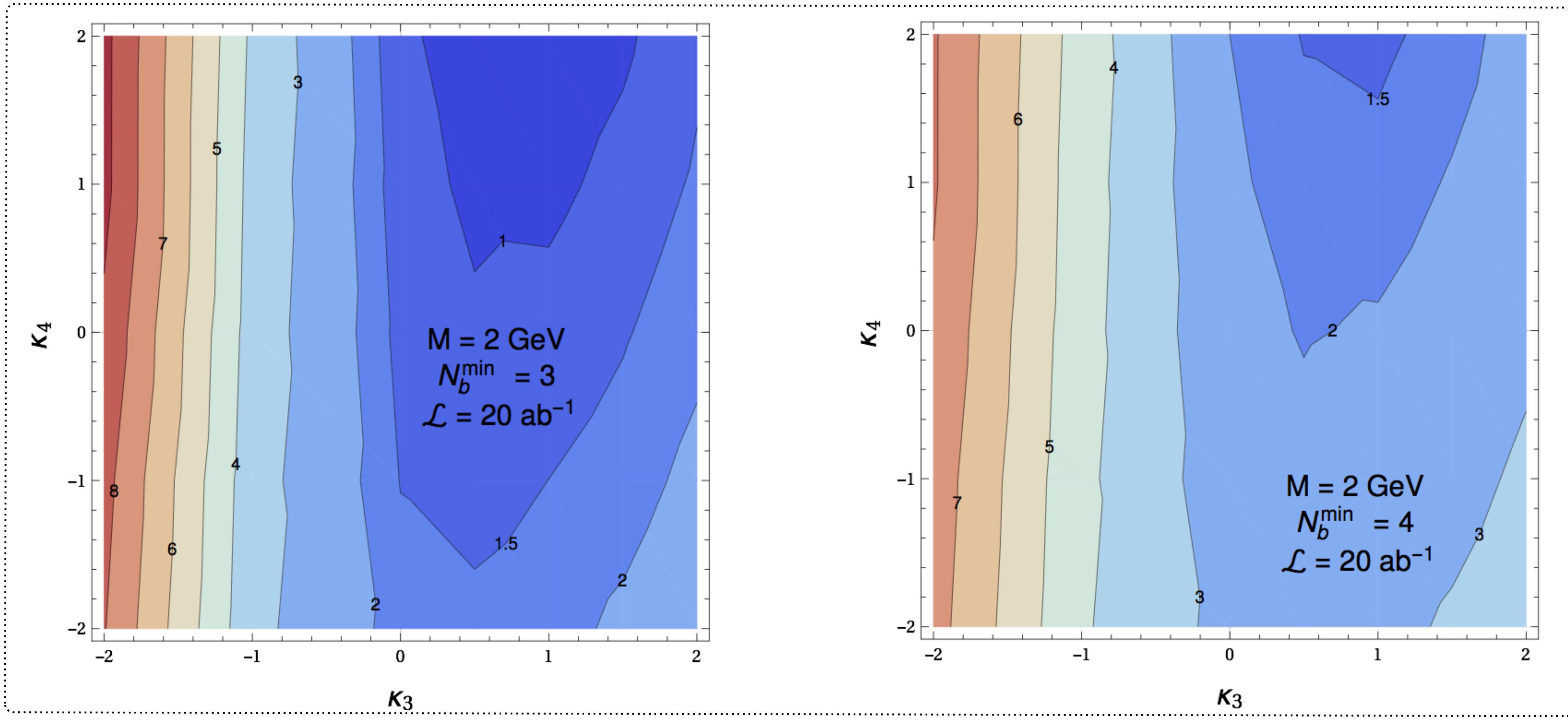
- ✤ Four jets (with an invariant mass smaller than 600 GeV), 2 photons
- ✤ Two dijet systems compatible with a Higgs ($m_{jj} \in [105, 140]$ GeV)
- ✤ The diphoton system compatible with a Higgs ($m_{\gamma\gamma} \in [125-M, 125+M]$ GeV)

What is the best M-value?

- ✤ At least $N_b^{\rm min}$ b-tagged jets

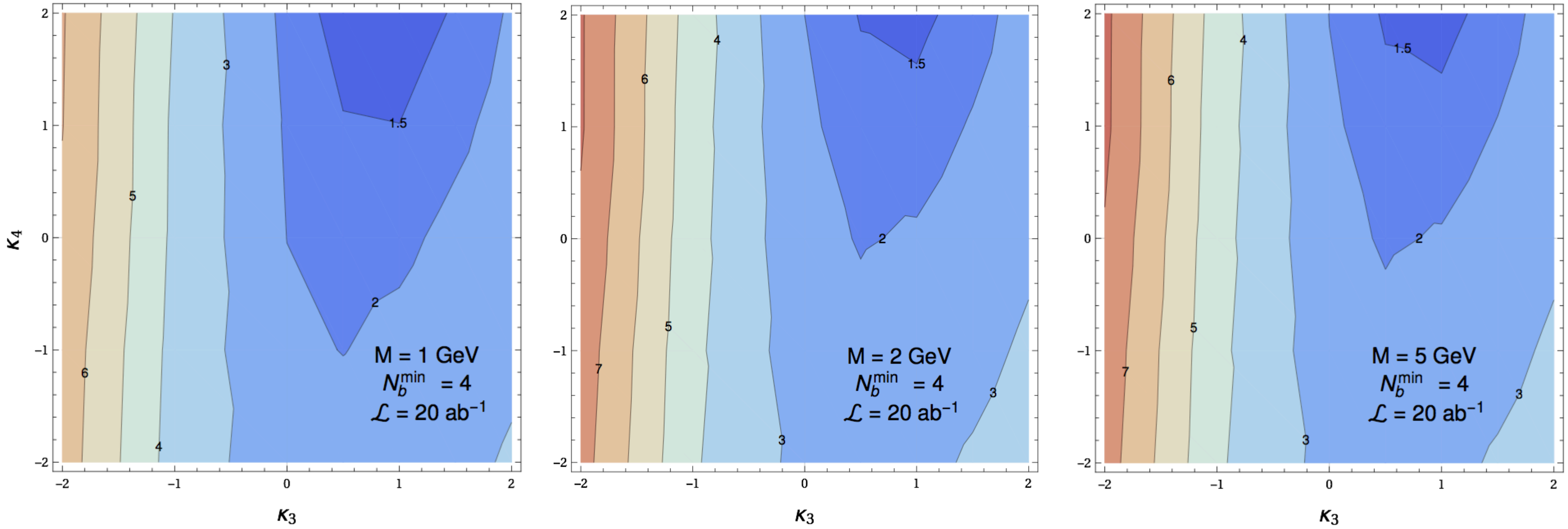
What is the best choice?

The 4b + 2γ channel: b-tagging considerations



- A low fake rate is primordial for a good sensitivity (1.8%/0.1% for a 60% efficiency)
  - Requiring at least 4 b-jets gives slightly better results
    (the background efficiency drops faster than the signal one)
  - Poorer results for a fake rate of 18%/1% for a 70% efficiency
    - ★ Better signal acceptance
    - ★ Much worse background contamination due to the fakes

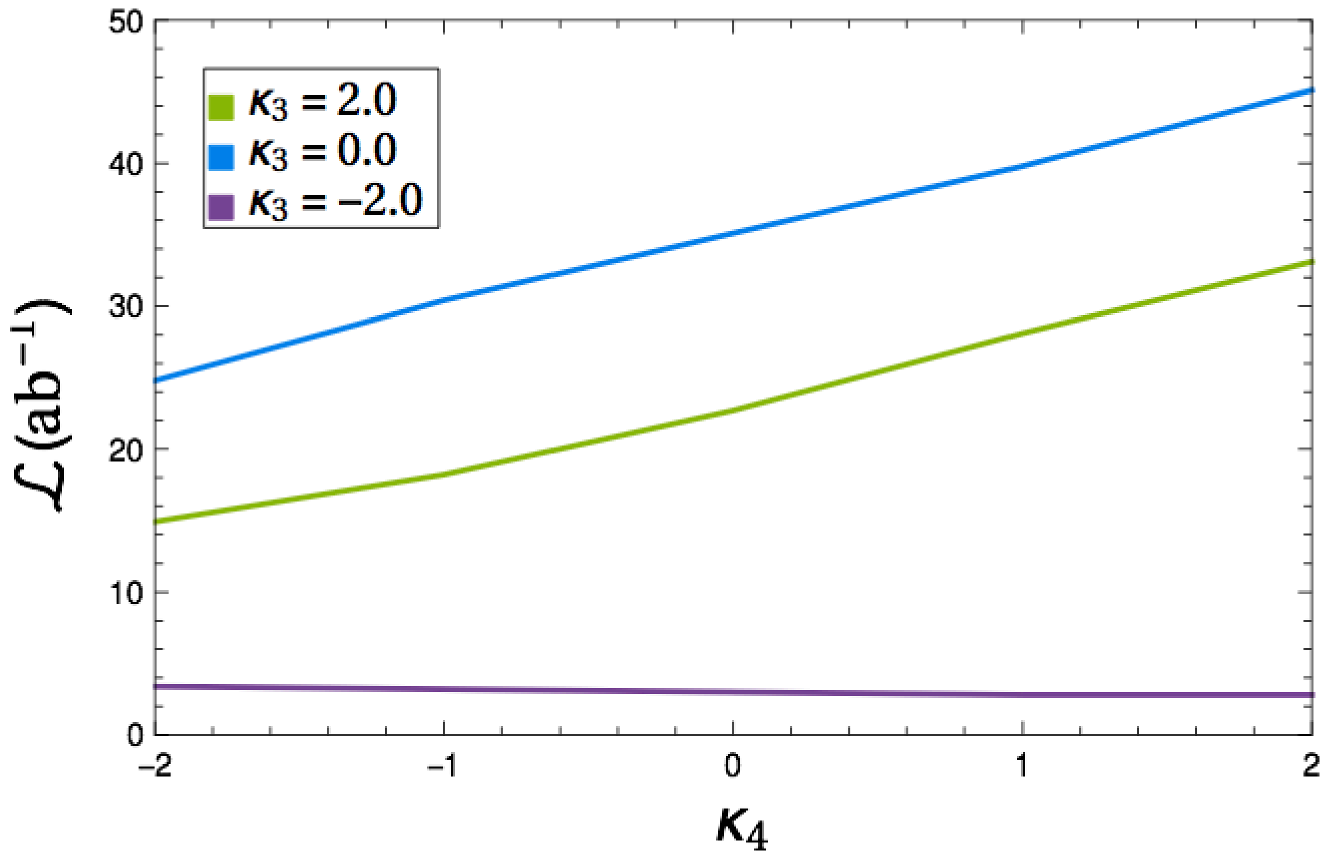
The 4b + 2γ channel: diphoton mass resolution



- ✦ Photons with a p_T greater than 20 GeV are very well reconstructed ($\sigma/E \sim 0.1/\sqrt{E}$)
  - ✤ A loss of signal efficiency implies to maintain M not too small
  - ✤ A too large M implies a more important background contamination
    - ★ However, mild effects on the sensitivity

M = 2 GeV gives the best results

The 4b + 2γ channel: luminosity goals for 3σ



- ✤ At least 4 b-tags
- ✤ M = 2 GeV
- ✤ b-tagging: 60% / 1.8% / 0.1%

✦ Large and negative κ_3 ⇔ huge cross section ⇔ BSM hints reachable with low luminosity

✦ Other κ_3 values ⇔ more luminosity is required

- ✤ The scanned region of the parameter space cannot be entirely covered

The 4b + 2τ channel: generalities

✦ Simulation details

✤ Parton-level study + smearing of the four-momenta (*à la* ATLAS)

✤ b-tagging performance: two LHC-inspired working points

★ Very efficient (70%) with larger fake rates (18%, for c-jets, 1% for lighter jets)

★ Less efficient (60%) with smaller fake rates (1.8%, for c-jets, 0.1% for lighter jets)

✤ tau-tagging performance: two LHC-inspired working points

★ Very efficient (80%) with a small fake rate (0.1%)

★ More conservative (50%) with a larger fake rates (1%,)

How good should the b- and tau-tagging be to observe a triple-Higgs signal

✦ Selection strategy for 20 ab^{-1}

✤ Four jets, 2 taus

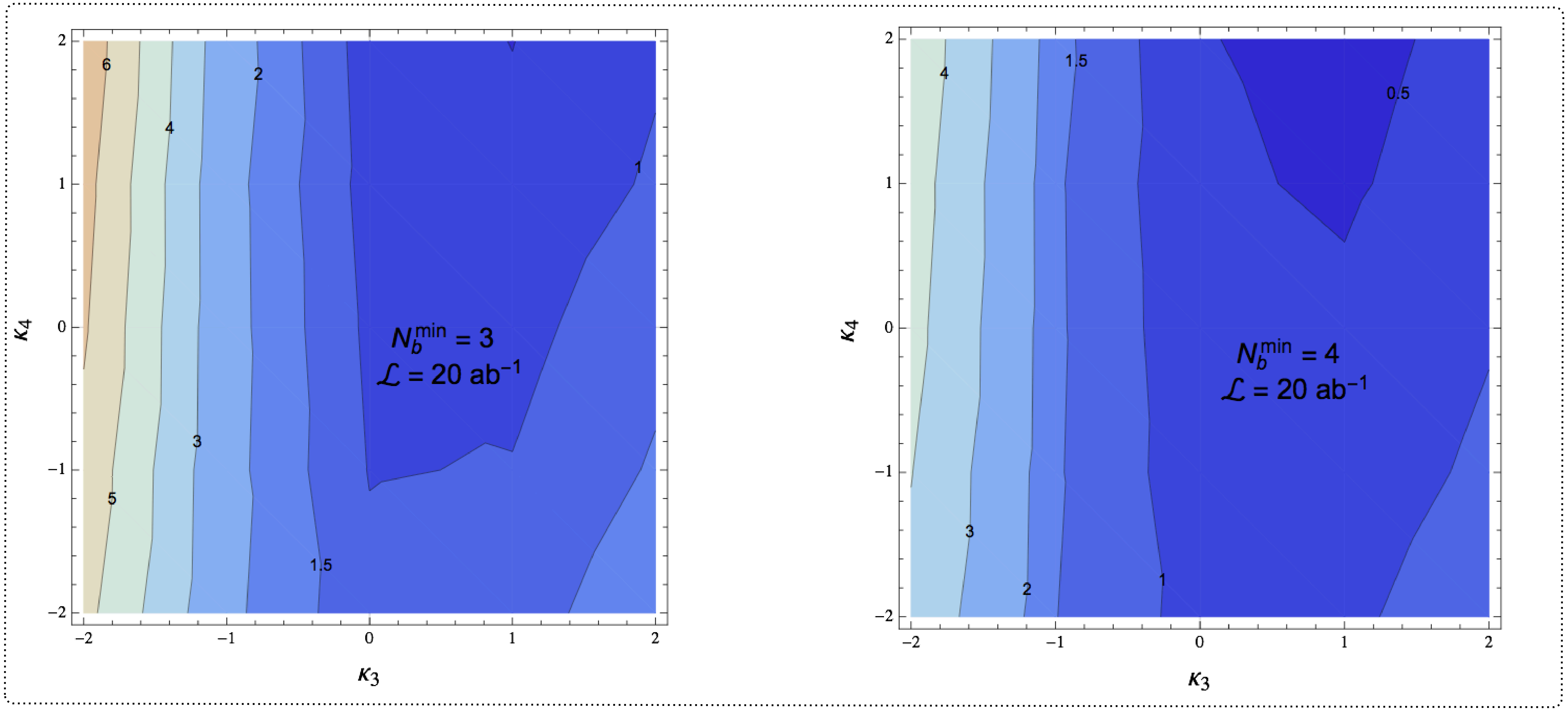
✤ Two dijet systems compatible with a Higgs ($m_{jj} \in [105, 140]$ GeV)

✤ The ditau system compatible with a Higgs ($m_{\tau\tau} \in [115, 135]$ GeV)

✤ At least $N_b^{\min}$ b-tagged jets

What is the best choice?

The 4b + 2τ channel: b- and tau-tagging



- A good b-tagging efficiency is primordial (70% for an 18% / 1% fake rate)
  - Requiring at least 3 b-jets gives slightly better results (better signal efficiency)
  - Smaller fake rate and efficiency: the signal efficiency drops faster than the background one
- A very efficient tau-tagger is primordial (80% for a 0.1% fake rate)
  - All sensitivity is lost for a more conservative choice of (50% / 1%)

Summary

✦ We considered triple Higgs production at the FCC

- Decay in the $4b + 2\gamma$ and $4b + 2\tau$ channels
- Effects of the b-tagging and tau-tagging performances on the sensitivity
- Effect of the diphoton mass resolution

✦ The diphoton channel yields the best sensitivity

- Controlling the b-tagging fake rate is mandatory
- The diphoton mass requirement cannot be too tight
- A good fraction of the parameter space can be covered (but not the SM case)
  - ★ A small part even with a few ab^{-1}

✦ The ditau channel could be complementary

- An excellent tau-tagger is required