The Physics of Yang-Mills-Higgs Theory

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Why Yang-Mills-Higgs Theory?

- “The Higgs” physics
  - Residual non-perturbative effects?
    - Additional bound states
    - Field-theory: State space, triviality...

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  - Limits of perturbation theory
    - Light Higgs
    - Heavy Higgs

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- Generic Higgs physics
  - Limits of perturbation theory
    - Light Higgs
    - Heavy Higgs
- Scalar QCD
  - How generic are QCD features?

The Higgs sector as a gauge theory

- The Higgs sector is a gauge theory

$$L=-\frac{1}{4}W_{\mu\nu}^{a}W_{a}^{\mu\nu}$$

$$W_{\mu\nu}^{a}=\partial_{\mu}W_{\nu}^{a}-\partial_{\nu}W_{\mu}^{a}+gf_{bc}^{a}W_{\mu}^{b}W_{\nu}^{c}$$

- Ws W_{μ}^{a}

- Couplings g, v, λ and some numbers f^{abc} and t_{a}^{ij}
  - Alternative: Inverse gauge coupling β
- No QED: Ws and Zs are degenerate

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$$D^{ij}_\mu = \delta^{ij} \partial_\mu - i g W^a_\mu t^{ij}_a$$

- Ws W^a_μ
- Higgs h_i
- Couplings g, v, λ and some numbers f^{abc} and t_a^{ij}
  - Alternative: Inverse gauge coupling β, hopping parameter κ and self-coupling λ
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Symmetries

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- Local SU(2) gauge symmetry
  - Invariant under arbitrary gauge transformations $\varphi^a(x)$

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- Global SU(2) Higgs custodial symmetry
  - Acts as right-transformation on the Higgs field only

$$W^a_\mu \rightarrow W^a_\mu \qquad h_i \rightarrow h_i + a^{ij} h_j + b^{ij} h^*_j$$

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    [Fröhlich et al. '80, 't Hooft '80, Bank et al. '79, Maas '12, Maas et al. '13]
    - 0^+ singlet is the physical Higgs
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  - Six channels
    - Singlet: 0^+ (Higgs)
    - Triplet: 1^- (W)

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    - Triplet: 1^- (W), 0^+

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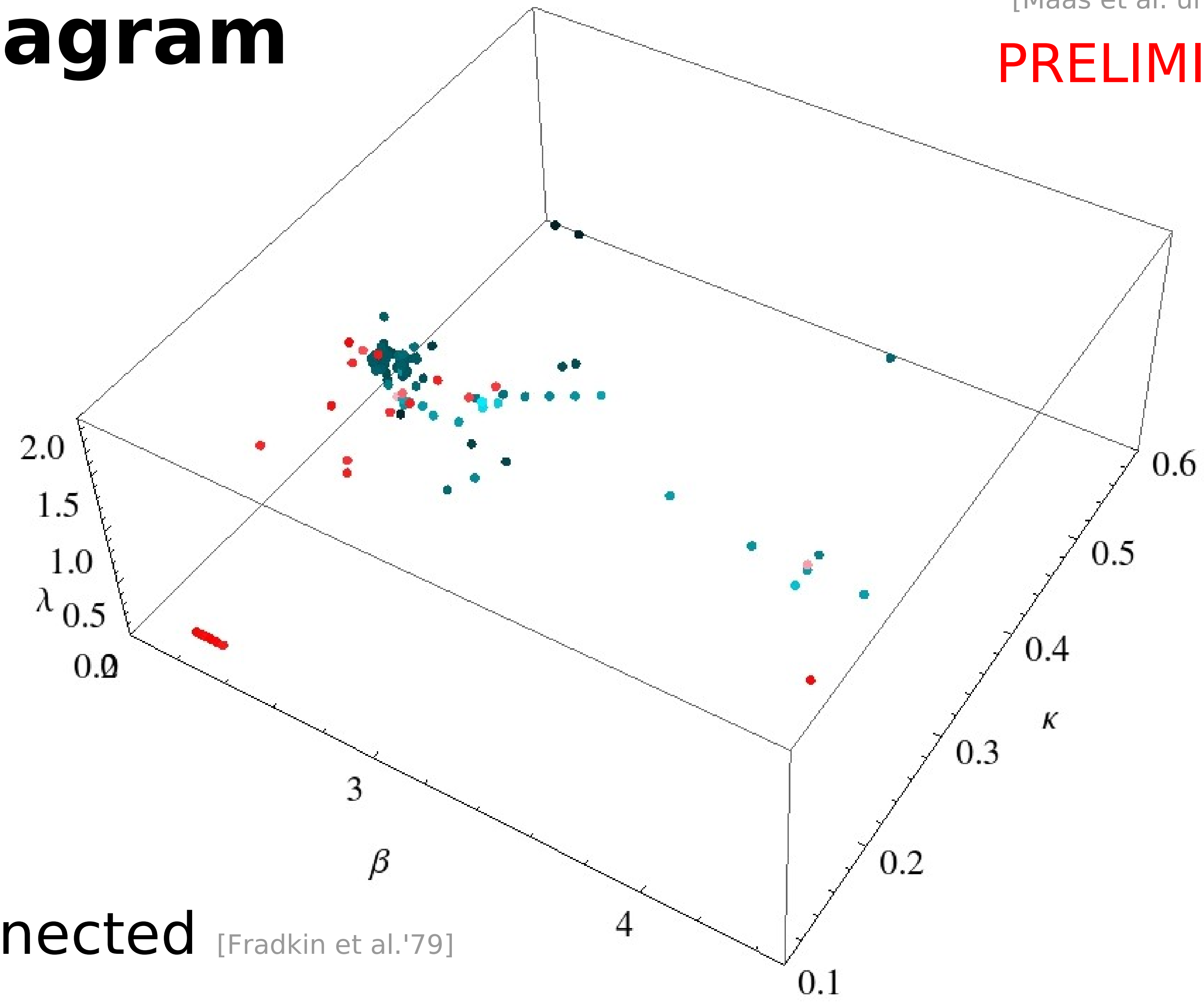
  - Six channels
    - Singlet: 0^+ (Higgs), 0^- (MSSM), 2^+ (Graviton), 1^- (Z')
    - Triplet: 1^- (W), 0^+ (MSSM)

Phase diagram

[Maas et al. unpublished]

PRELIMINARY



- Simply connected [Fradkin et al.'79]

Phase diagram

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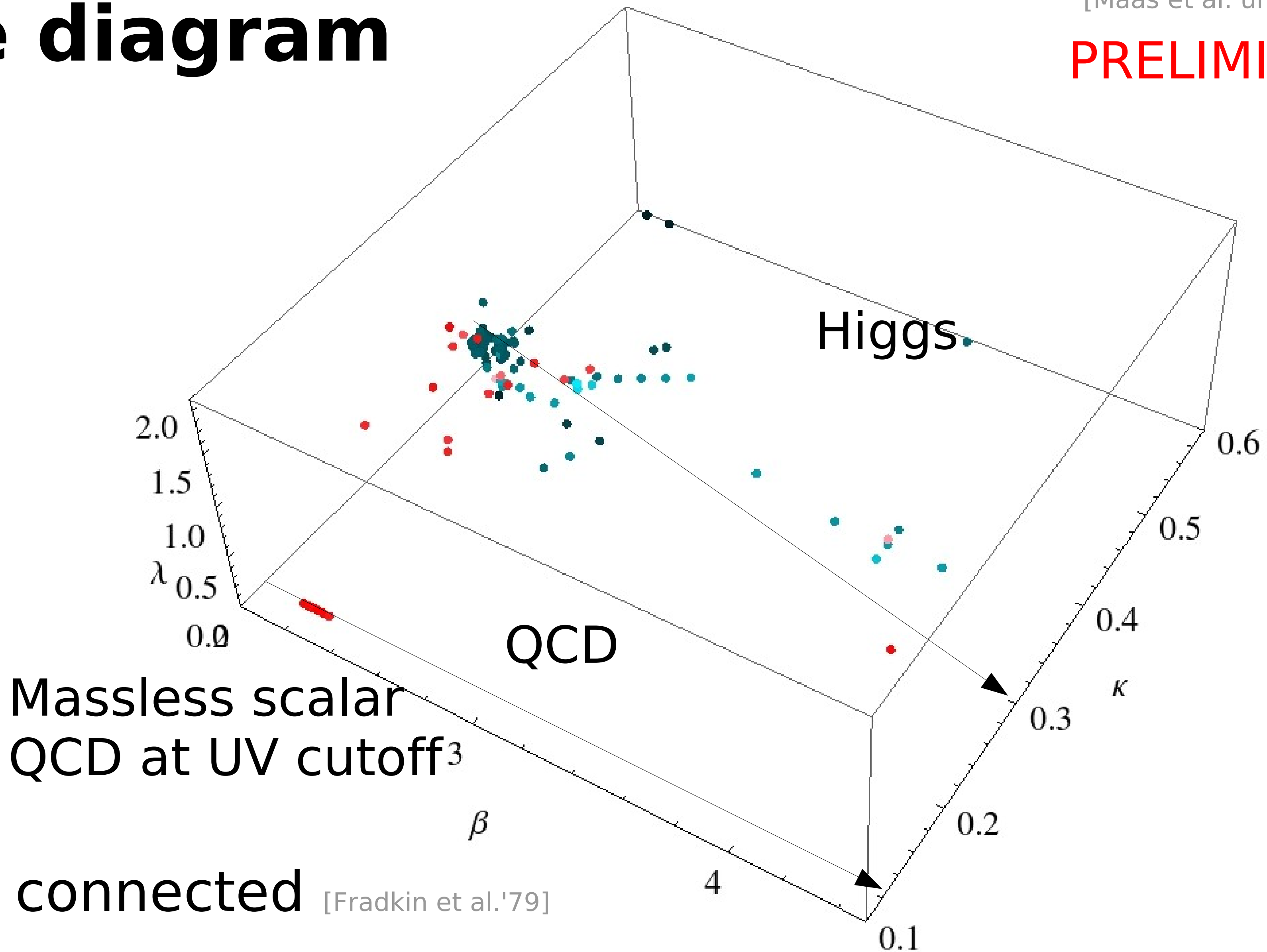

- Simply connected [Fradkin et al.'79]
- QCD-like physics: Higgs lighter, otherwise W
  [Langguth et al. PLB'85, Evertz et al. PLB'86]
- First question: Why?
  - Contradicts perturbation theory at weak coupling

'Massless' scalar QCD

[Maas et al. Unpublished
β=2.241 κ=0.125 λ=0, 24^4]

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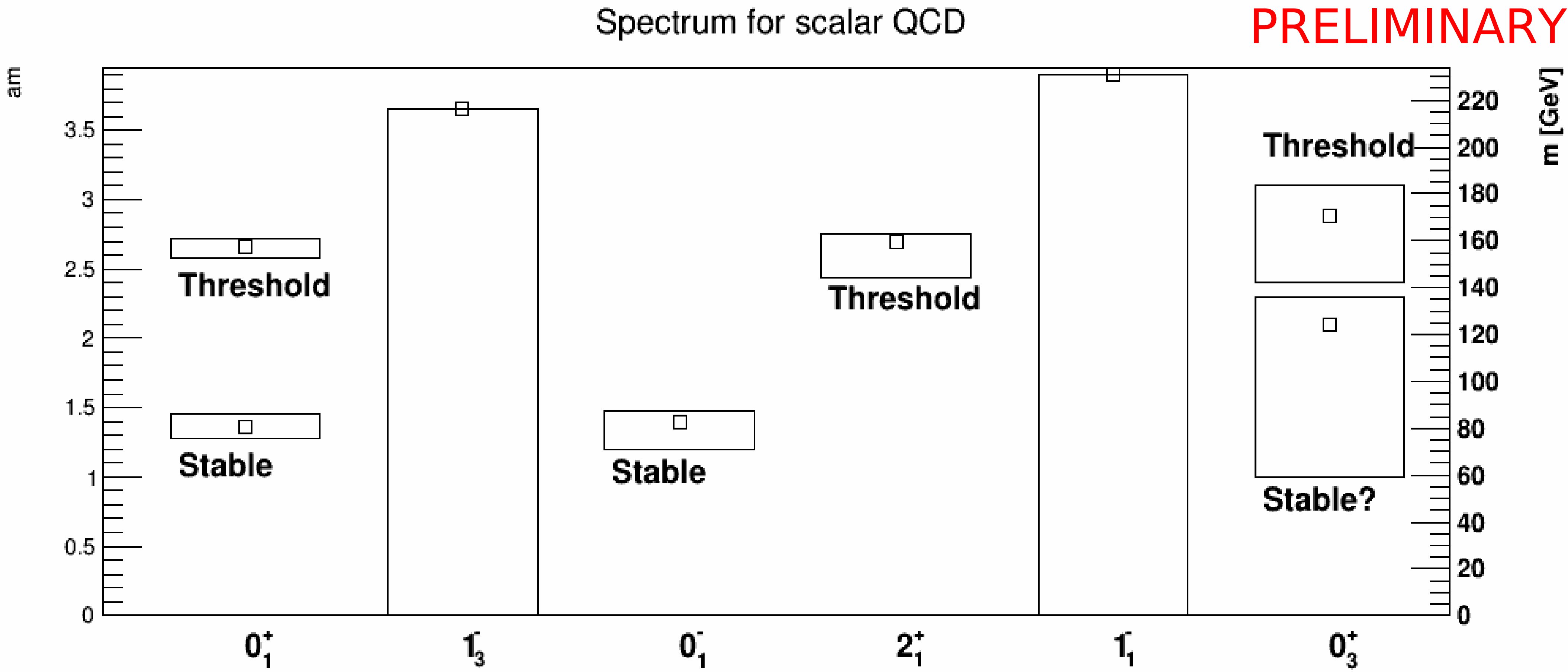

- No light modes
- Vectors states very heavy – as in Yang-Mills theory
- Normal ordering in $0^+ \sim 0^- < 2^+$

QCD with scalar self-interaction

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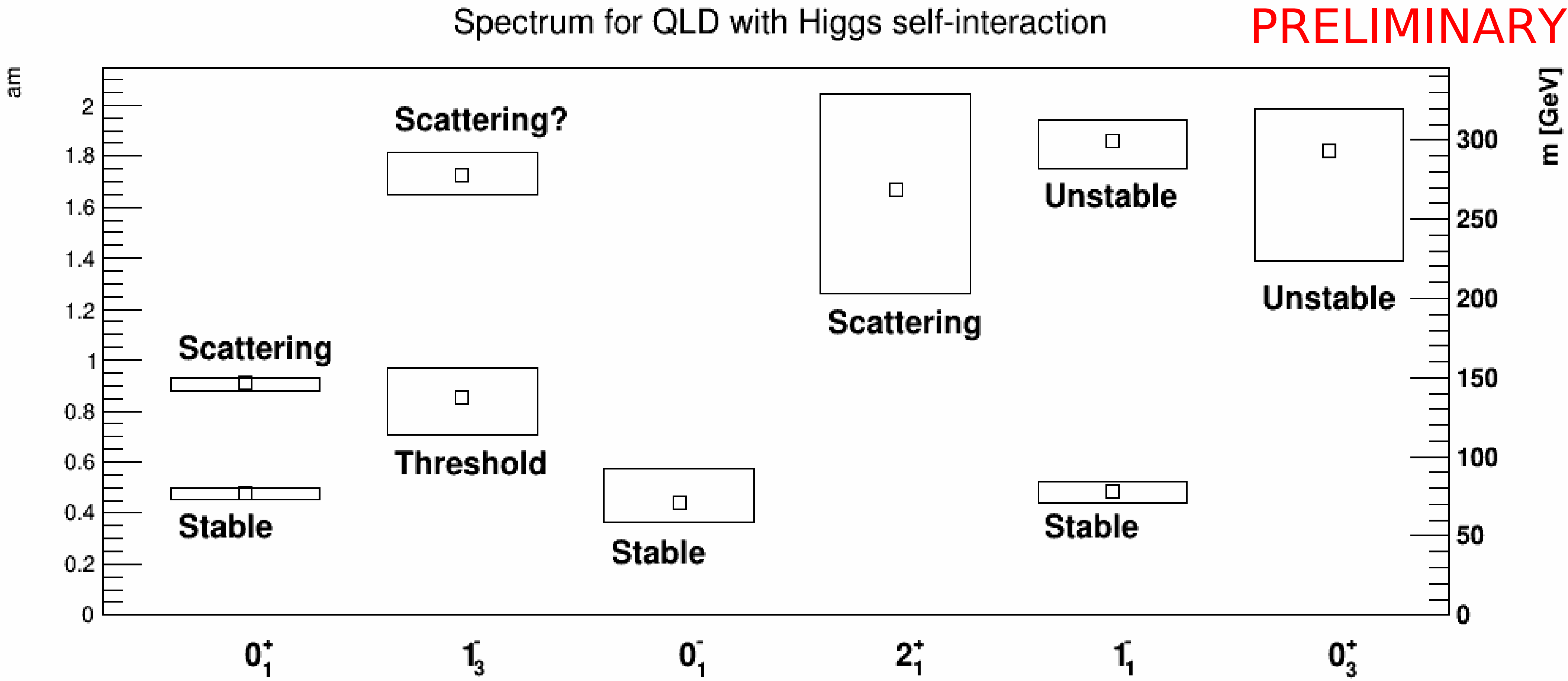
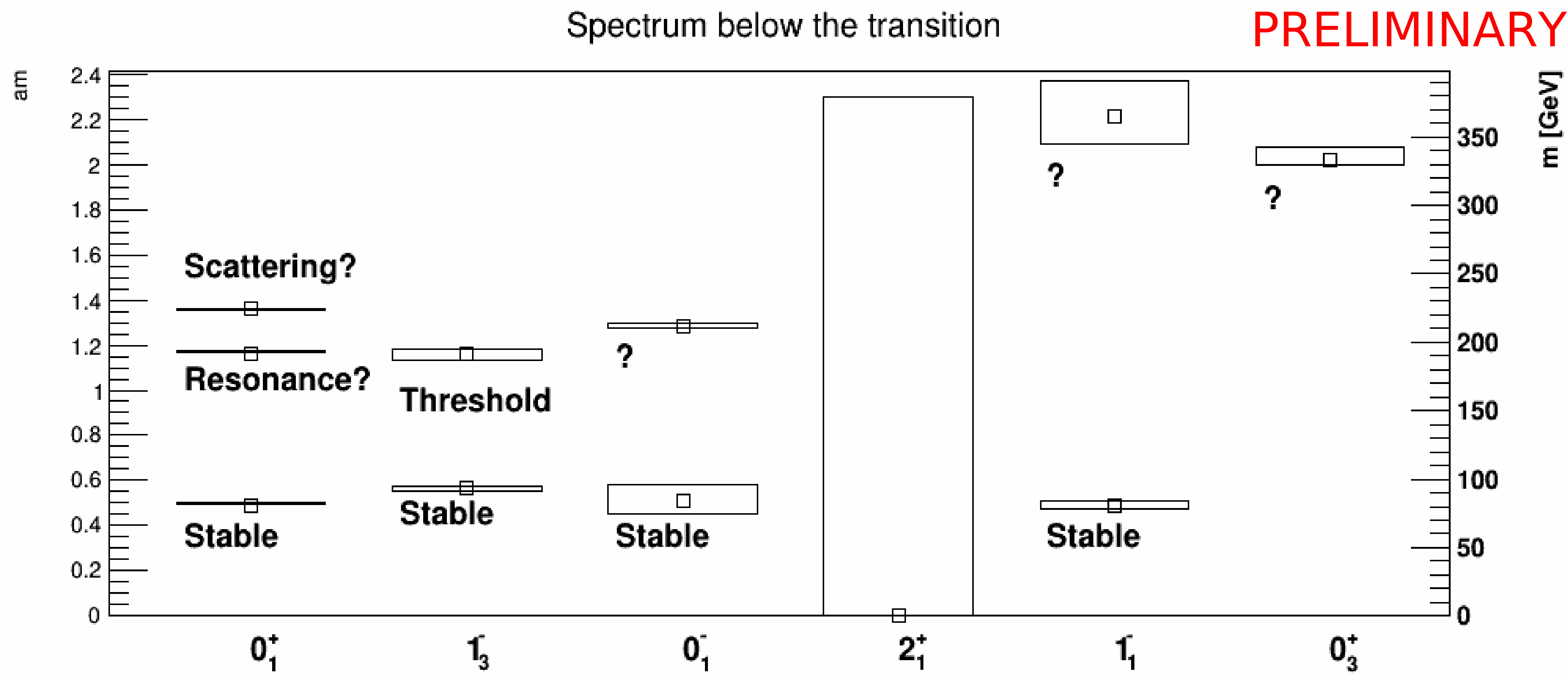


[Maas et al. Unpublished
β=2.3095 κ=0.2668 λ=0.5254, 24^4]

- Vector states become lighter
- Custodial singlets dominate physics

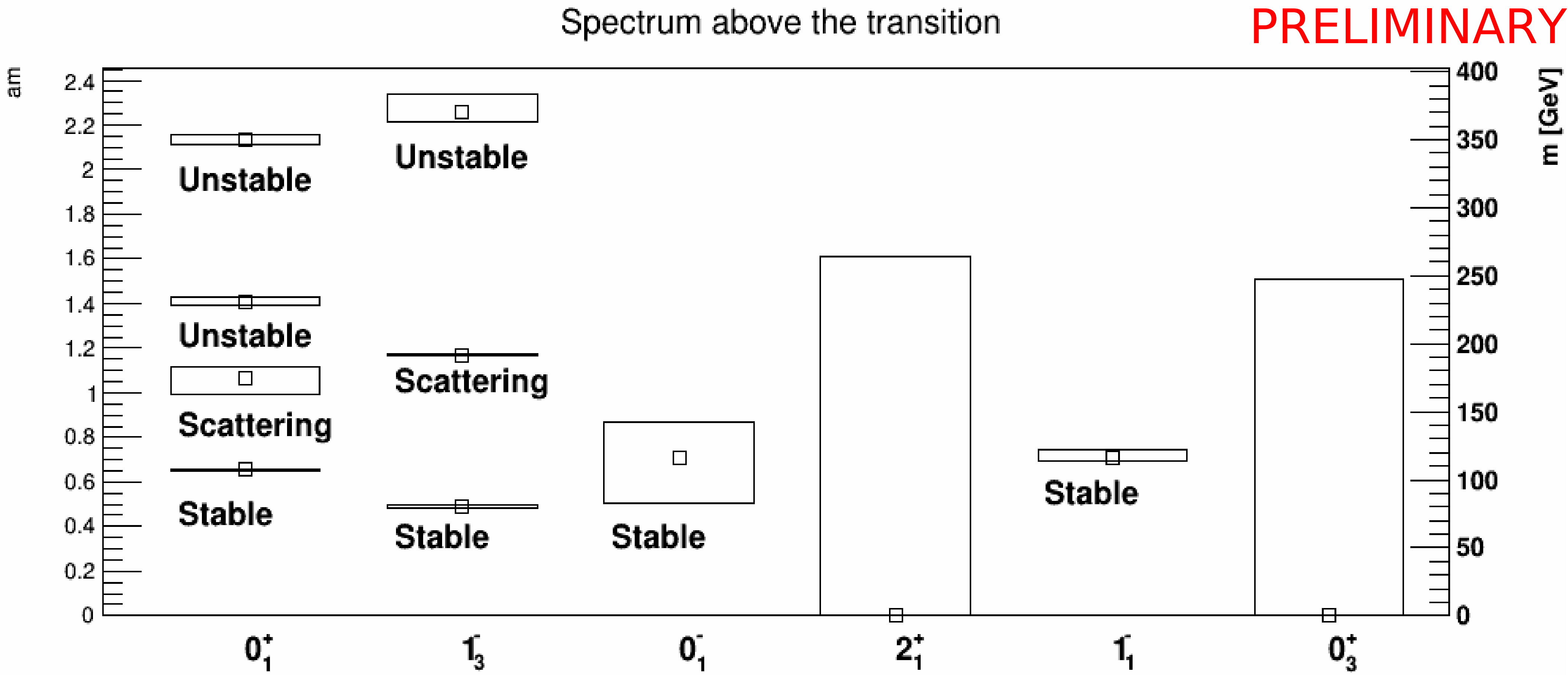
Below transition



[Maas et al. Unpublished
β=2.2171 κ=0.3182 λ=1.046, 24^4]

- Many stable states
- Vectors become stable

Above transition



[Maas et al. Unpublished
β=2.2847 κ=0.3152 λ=1.098, 24^4]

- Very similar to below transition
- Spectrum rather insensitive to Higgs-like/QCD-like physics

At the "physical point"

[Maas et al. Unpublished
β=2.7984 κ=0.2954 λ=1.317, 24^4]

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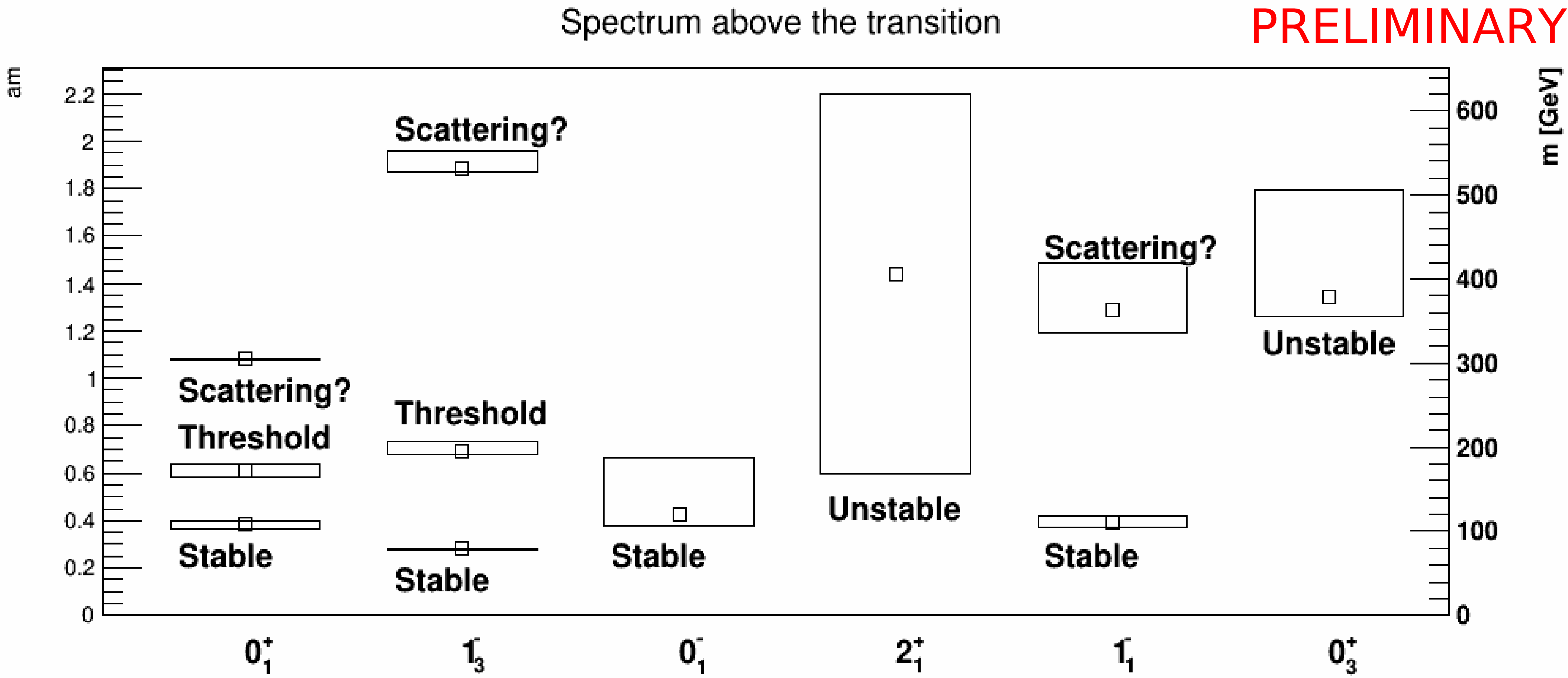

- Different from electroweak sector
  - Much faster running gauge coupling [Maas et al.'13]
- Additional (almost) stable states may be possible, but not necessary [Wurtz et al.'13]

Above threshold

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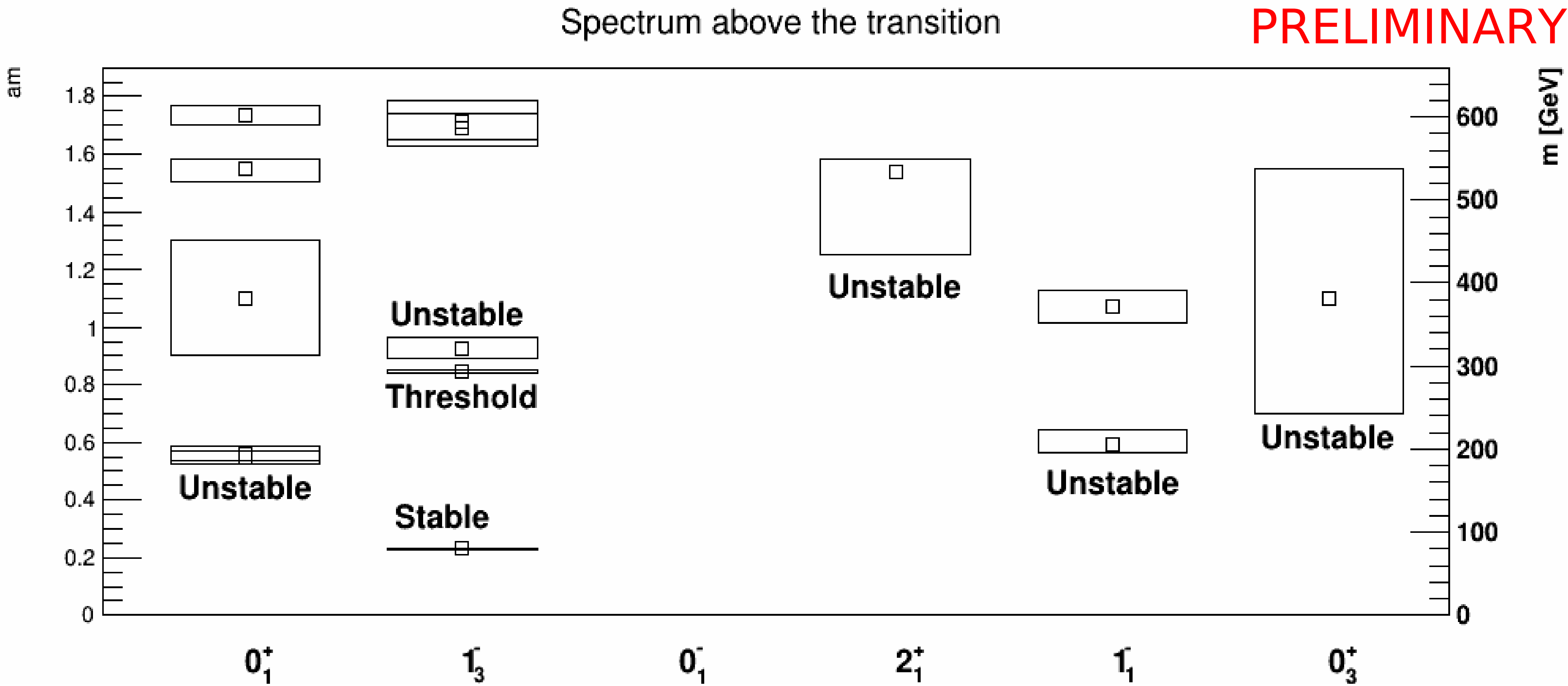

[Maas et al. Unpublished β=4 κ=0.3 λ=1, 24^4]

- Essentially only “Ws” left
- Physics similar to that of weakly interacting, massive photons

Development in the Higgs channel

[Maas et al. Unpublished, 24[4]]

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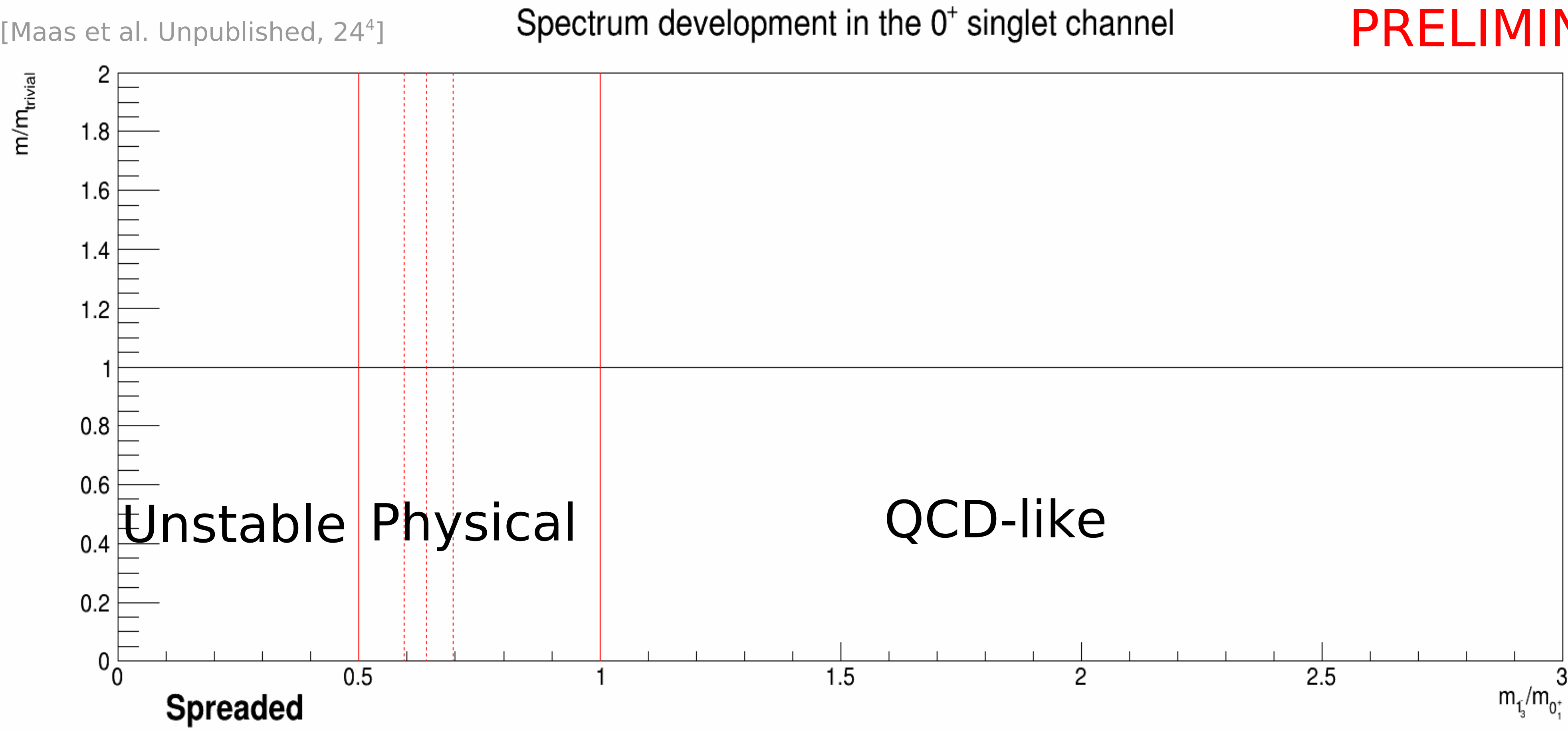
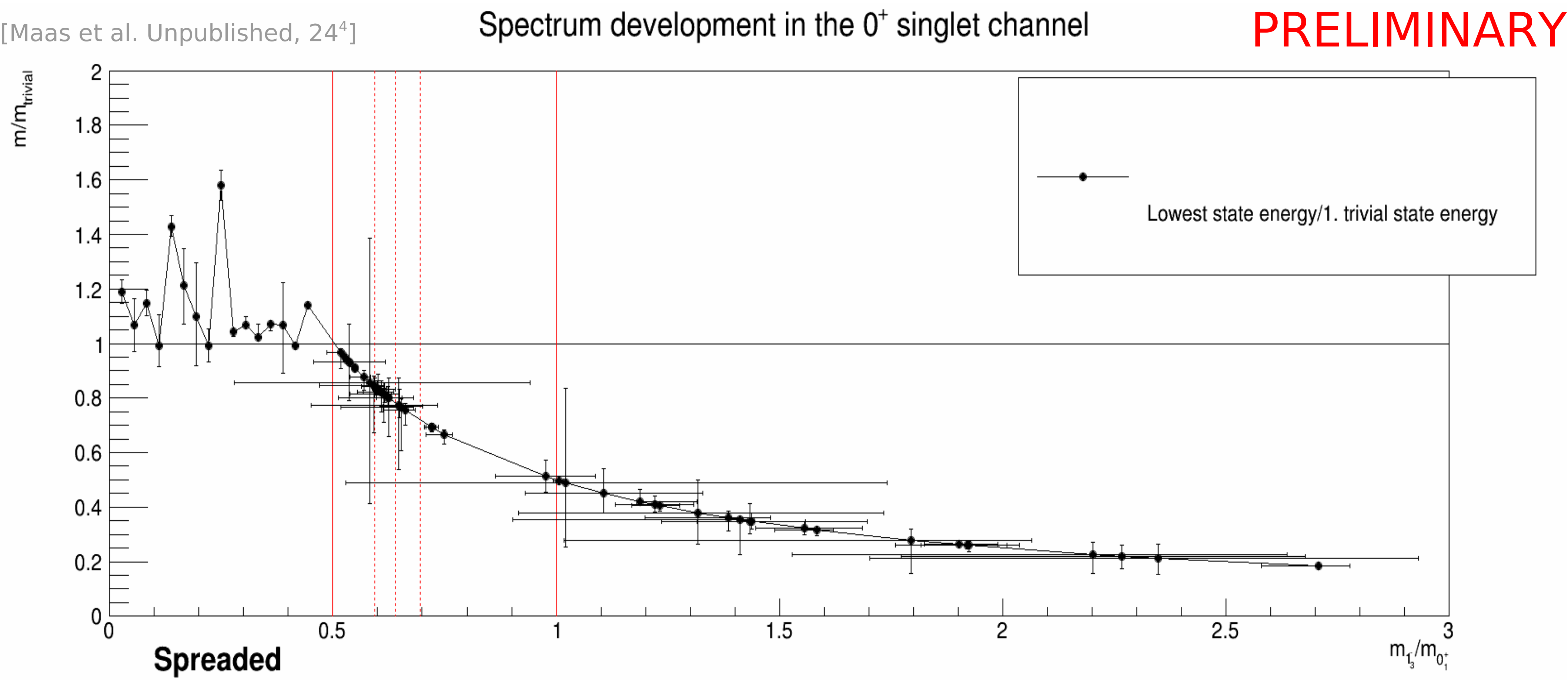


- Three distinct regions

Development in the Higgs channel

[Maas et al. Unpublished, 24[4]] PRELIMINARY



- Base-line
- Lowest state as expected above threshold: 2 almost non-interacting ”Ws”

Development in the Higgs channel

[Maas et al. Unpublished, 24[4]]

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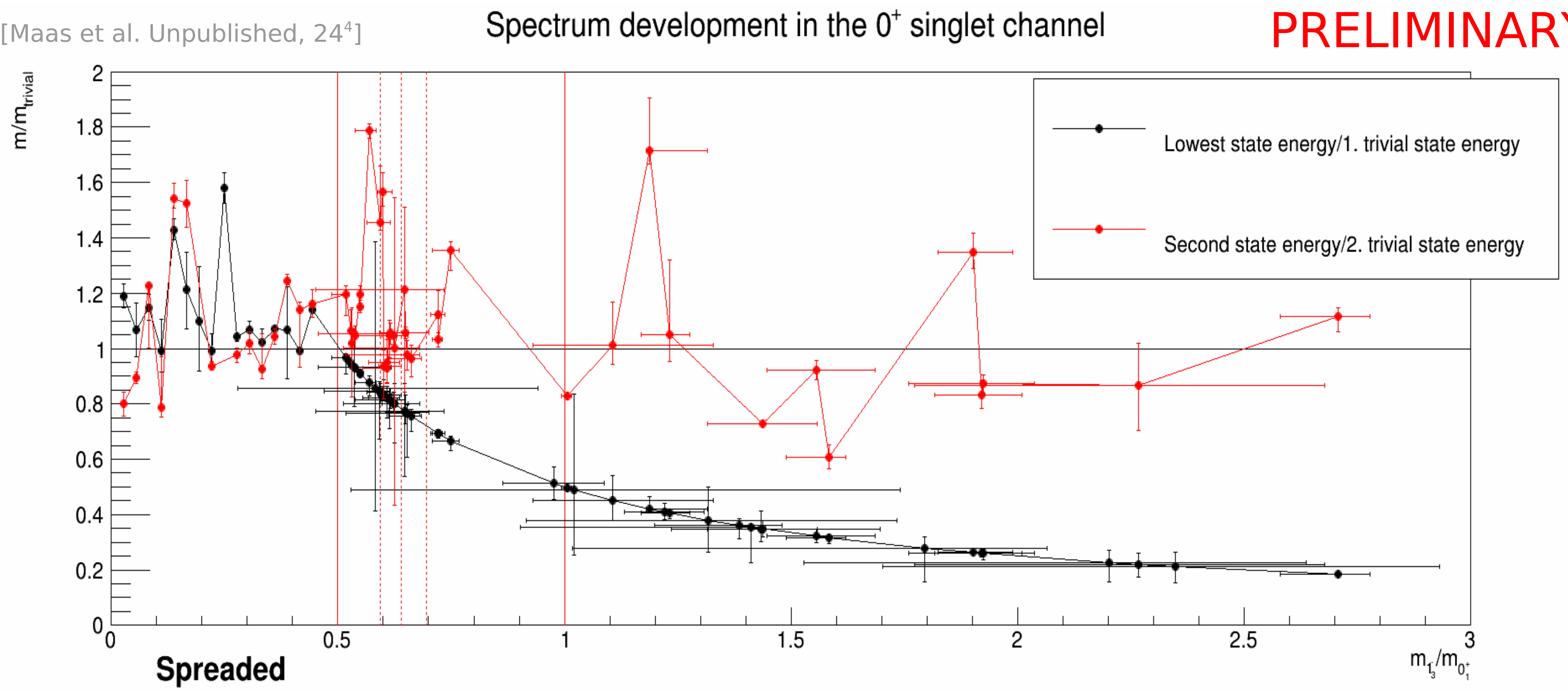

- Next state within errors essentially trivial throughout
- No discernible resonances

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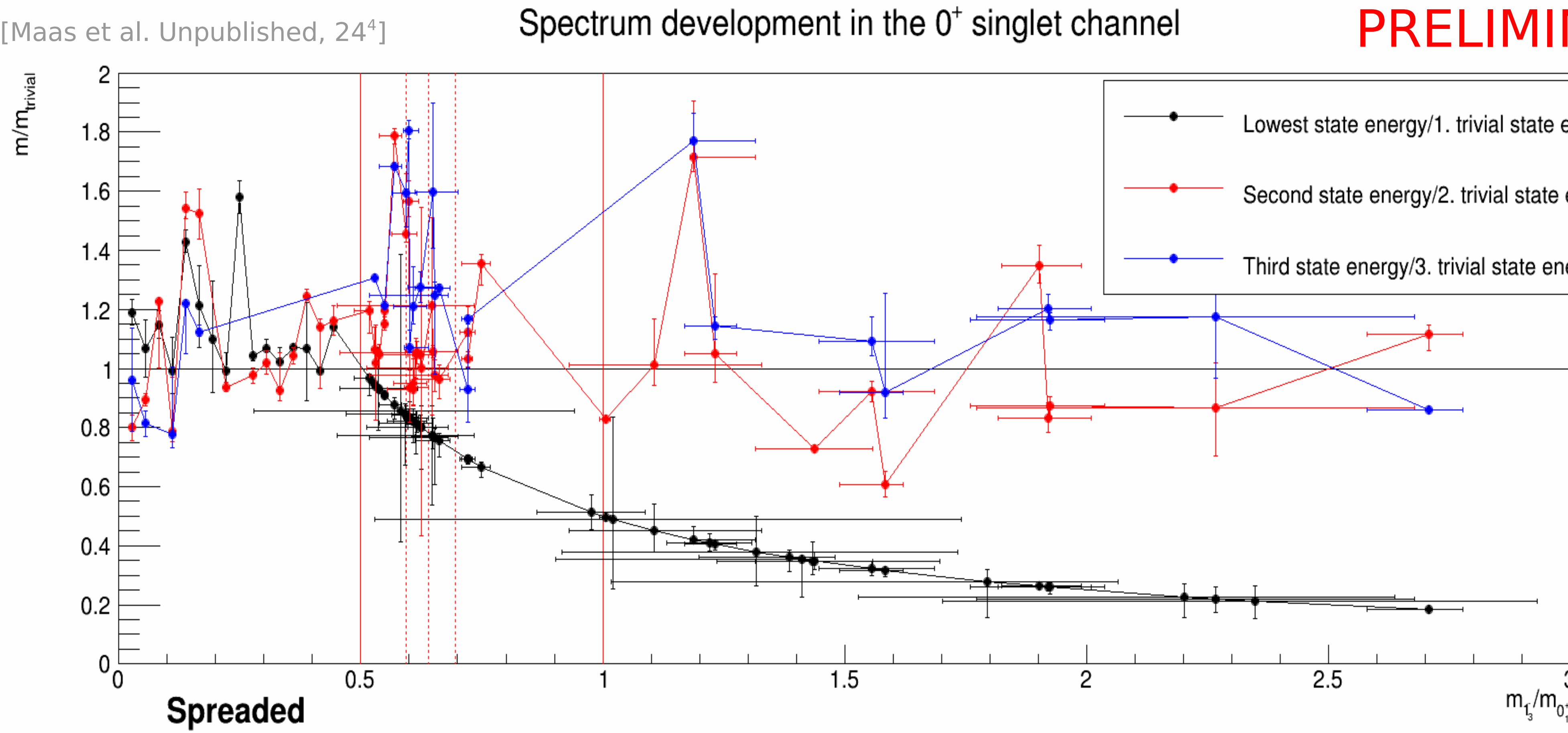

- Next state within errors essentially trivial throughout
- No discernible resonances
- Also true for the next level
- Different from perturbation theory

Summary

- Many questions about Yang-Mills-Higgs theory remain
  - Why is there no light-"Higgs" Higgs case?
  - Why are there no discernible Regge trajectories or excited states even at large coupling?
  - Why can there be no almost-stable "Higgs" above the 2-"W" threshold?
  - Why is there so little physical difference between the "Higgs" and "Confinement" pseudo phases?
  - Under which conditions can there be additional states at the physical point?
  - Just looking in the wrong corner of the phase diagram? Other lattice artifacts? Bad operator basis?
- Yang-Mills-Higgs theory is a prototype for BSM physics – it should be understood