Isospin Breaking for Dark Matter

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Natural Sciences

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Der Wissenschaftsfonds.

Strongly-interacting dark matter

- Nature of dark matter yet unclear
- Mostly indirect astronomical information
- Dark matter density profiles in galaxies (cusp-vs-core problem) allow for/suggest large cross sections between dark matter particles
  - Large in relation to dark matter mass

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- Possibility: QCD-like dark sector
  - Or even more complex...
  - Collider signatures: Dark showers,...

Candidate theory

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  - Still not too restrictive

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[Hochberg et al.,'14]

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- Possibility: Allowing $3 \to 2$ processes
  - "SIMP" miracle
  - E.g. by a Wess-Zumino-Witten term
  - Does not need very light dark hadrons
    - Relevant scale: Dark Yang-Mills scale

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  - Does not need very light dark hadrons
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- Requires some (quasi-)stable hadron
  - Depends on SM coupling

Candidate theory

- Sp(4) Yang-Mills theory

Candidate theory

[Kogut et al.’00, Holland et al.’03,Bennet et al.’17,’19]

- Sp(4) Yang-Mills theory
- 2 fundamental fermions
  - Non-degenerate masses favorable for dark matter phenomenology
  - Pseudo-real gauge group: Quarks and antiquarks related

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3 0^- ($\sim\bar{q}q$) 2 0^+ ($\sim qq$)

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Kulkarni et al., unpublished]

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$$U(4=2N_f) \xrightarrow{Anomaly} SU(4) \xrightarrow{D\chi SB} Sp(4) \xrightarrow{Non-degenerate\,masses} SU(2)\times SU(2)$$

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3 0^- (~$\bar{q}$q) 2 0^+ (~qq)

0^- and 0^+ pairs degenerate
0^- singlet

Candidate theory

[Kulkarni et al., unpublished]

- Rich hadron phenomenology
  - Many more states
  - Identification of dark matter candidate by SM coupling
    - If remaining symmetry unbroken: Degenerate pairs of 0^+ and 0^-
    - 0^- singlet can decay

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    - If remaining symmetry unbroken: Degenerate pairs of 0^+ and 0^-
    - 0^- singlet can decay
- Collider/cosmology/astrophysics determined at very low scales/time-like physics
  - Requires input to effective theories
  - Spectra, low-energy constants, phase shifts…
  - Rich lattice program

Lattice simulations

- Simulations use the HiREP code at fixed m_{1^-}/m_{0^-}
  - Sp(4) derivative → see 1909.12662 and 1712.04220 and several talks in this session

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Lattice simulations

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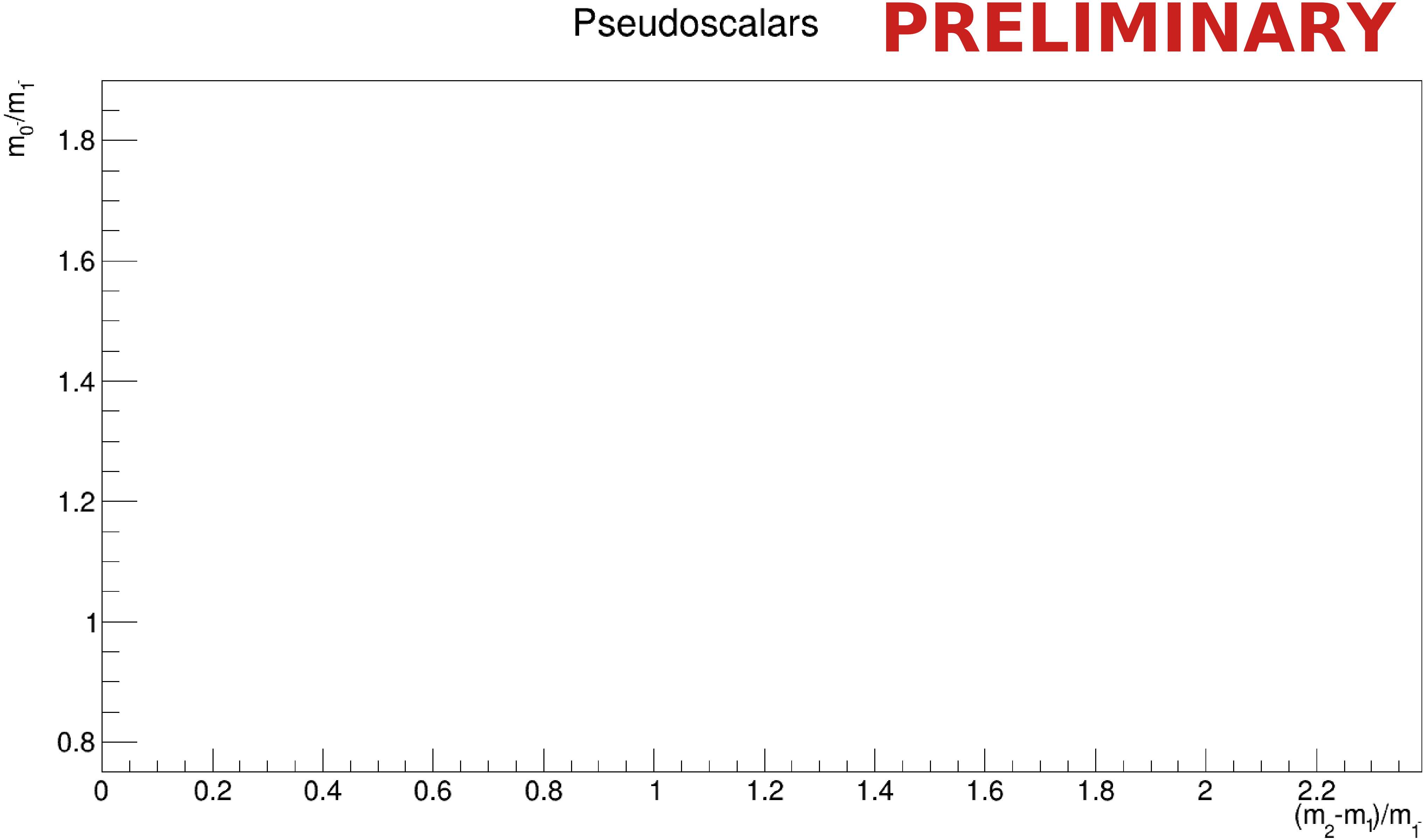
- Mass splitting directly in the Dirac operator
  - Both in generation of configurations and operators
- Phenomenology suggest large tree-level masses → much easier to simulate than in QCD
  - Disconnected contributions still need to be fully included, but likely are irrelevantly small

Results: Pseudoscalars

Degenerate results: Bennett et al. 1912.12662

PRELIMINARY



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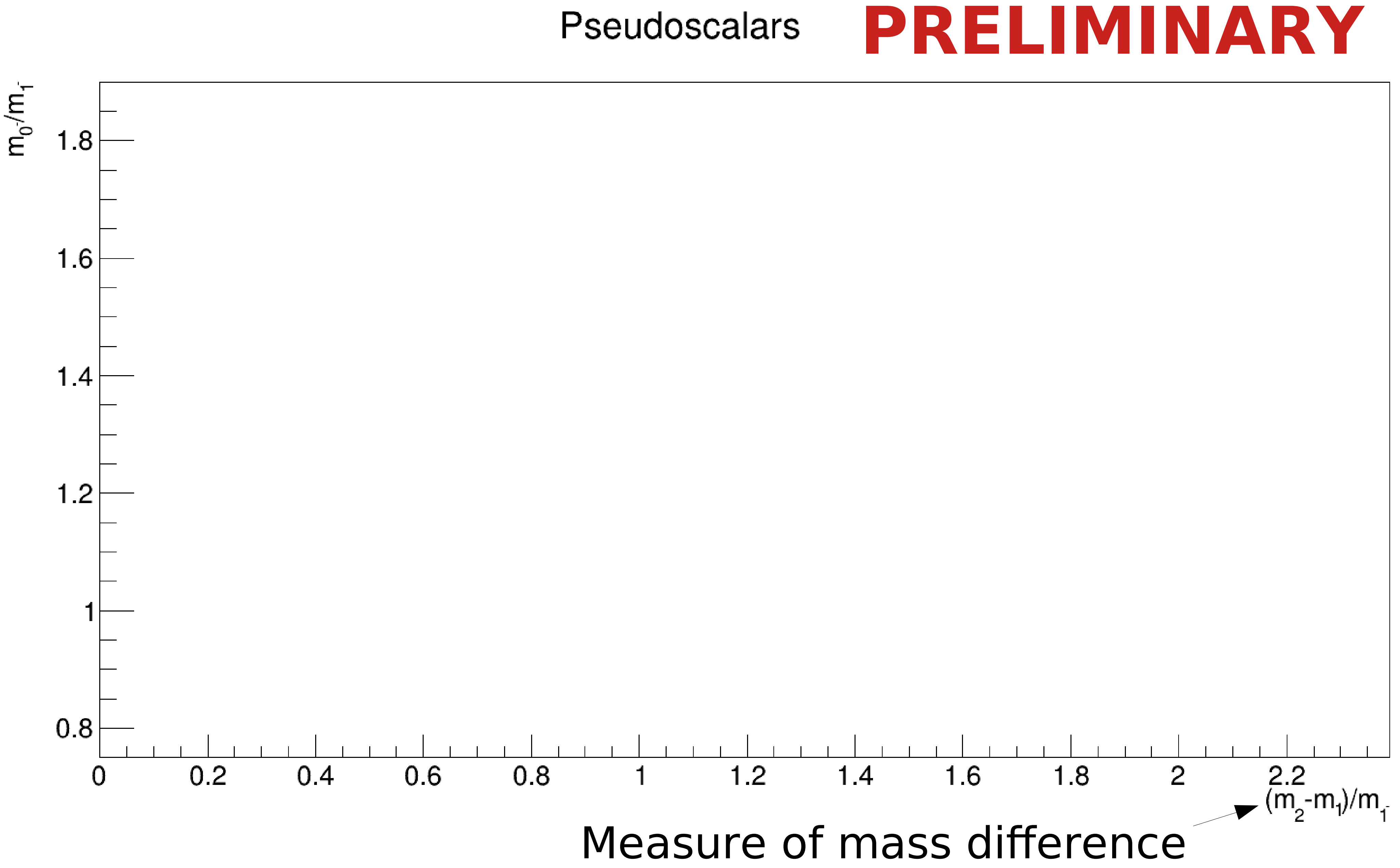

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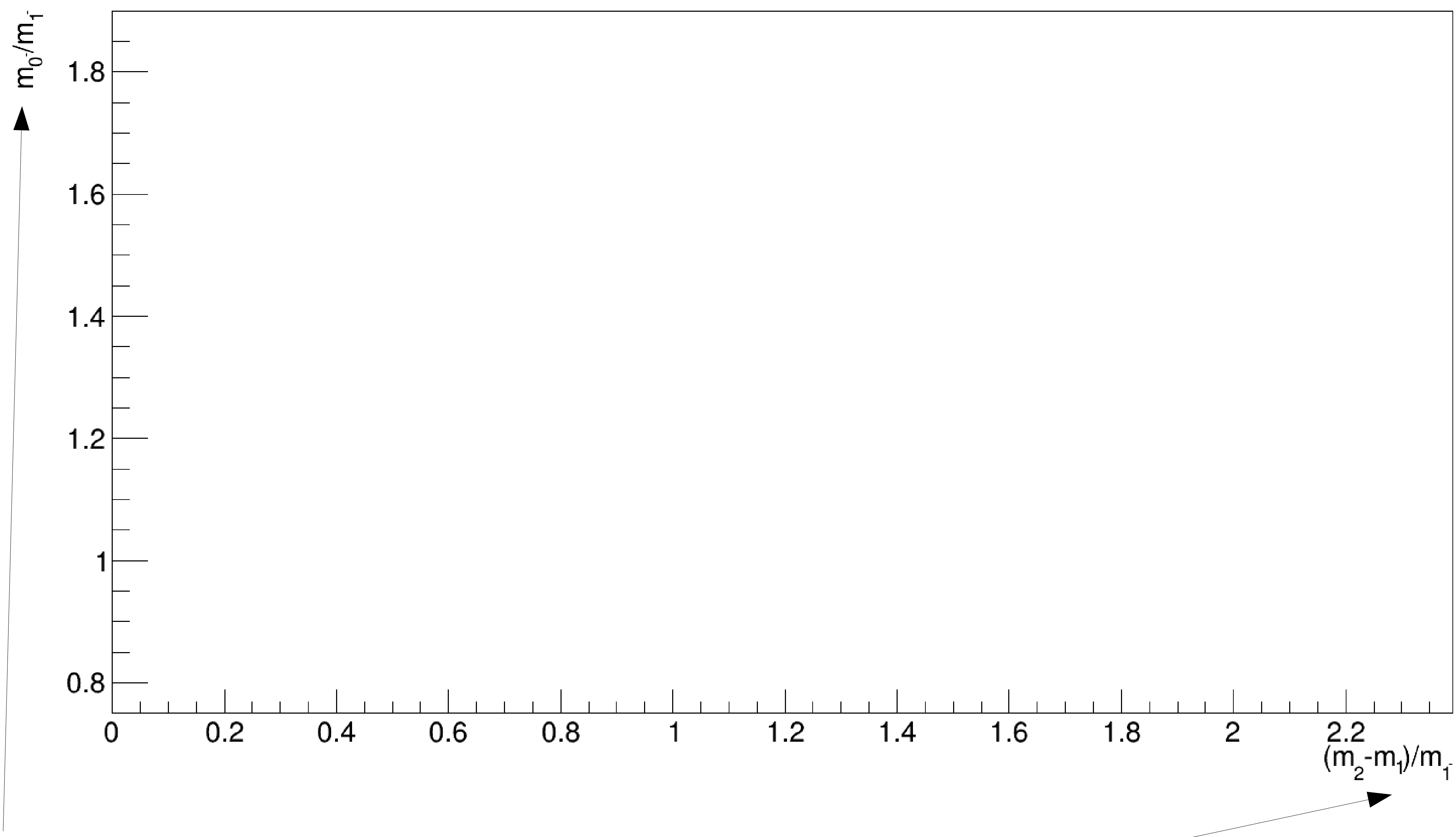

In units of the vector mass at degeneracy

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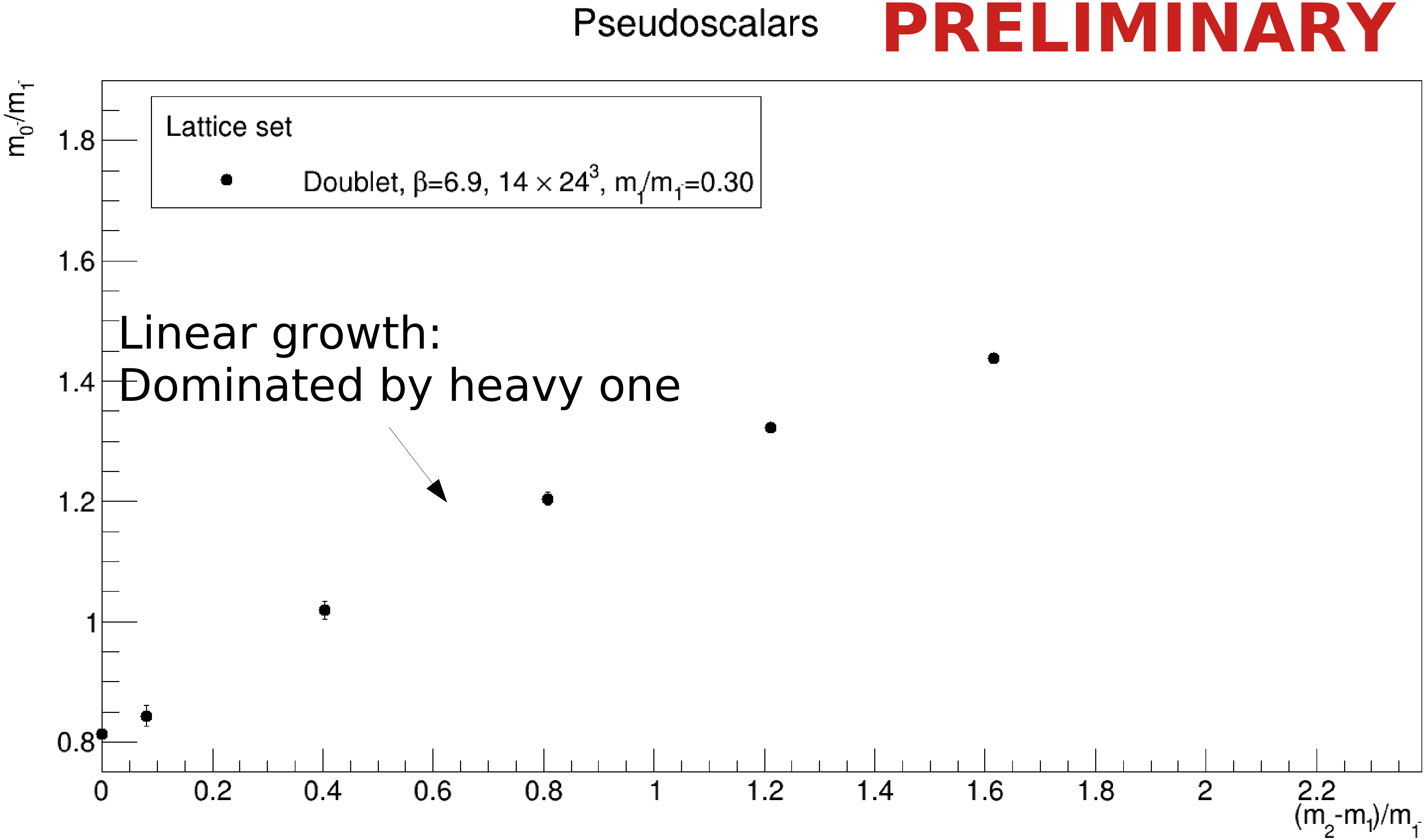
PRELIMINARY

Linear growth:
Dominated by heavy one



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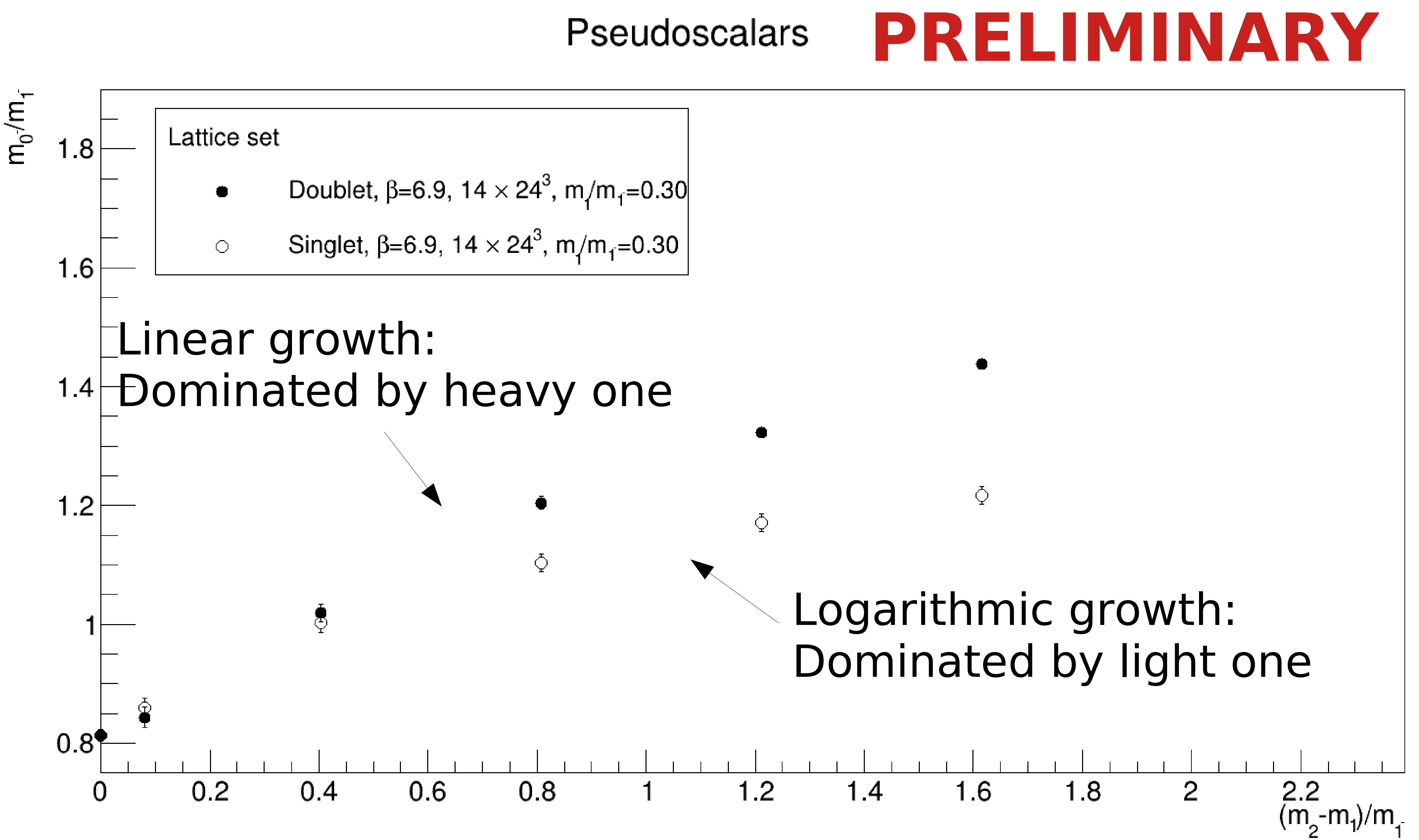

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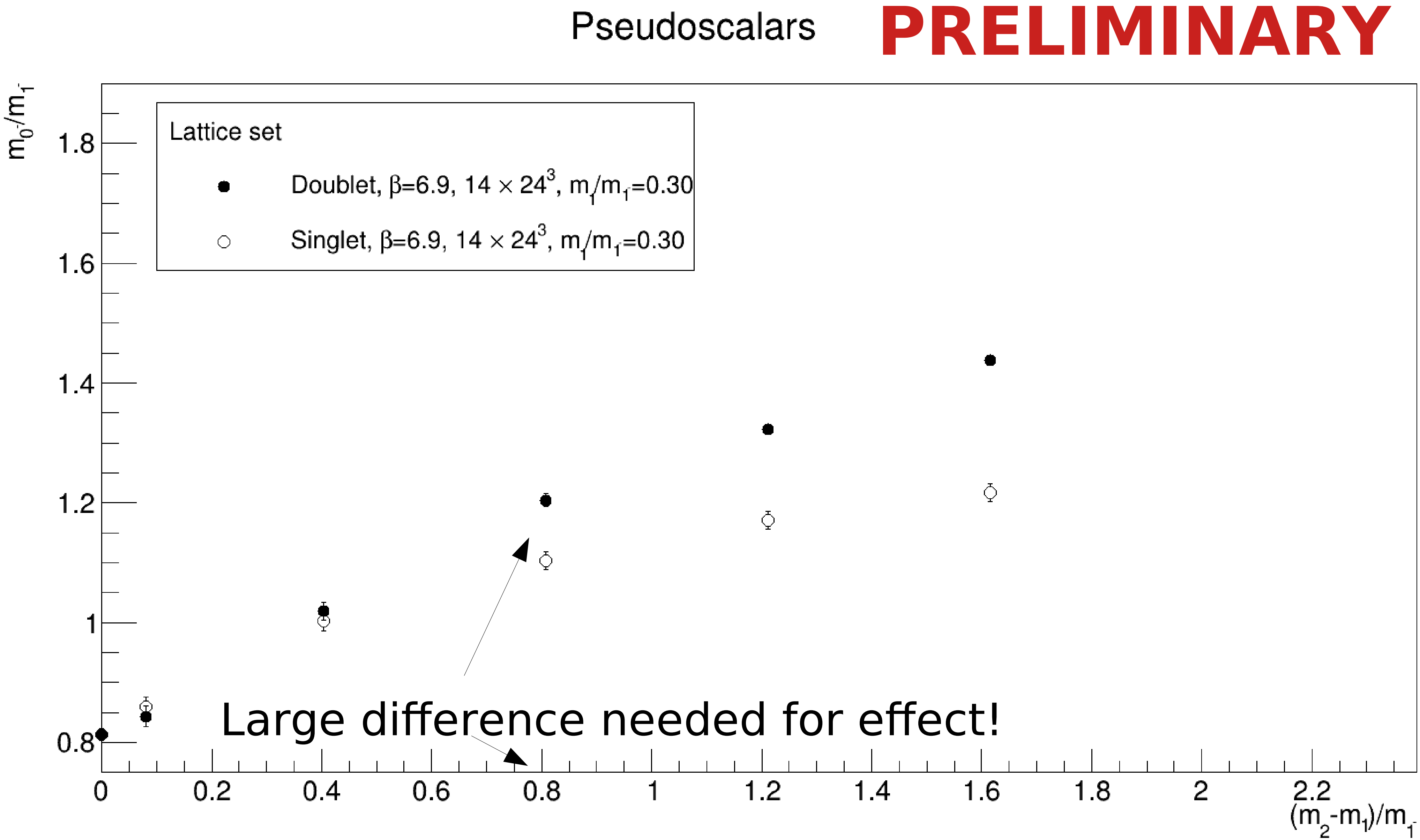

Large difference needed for effect!

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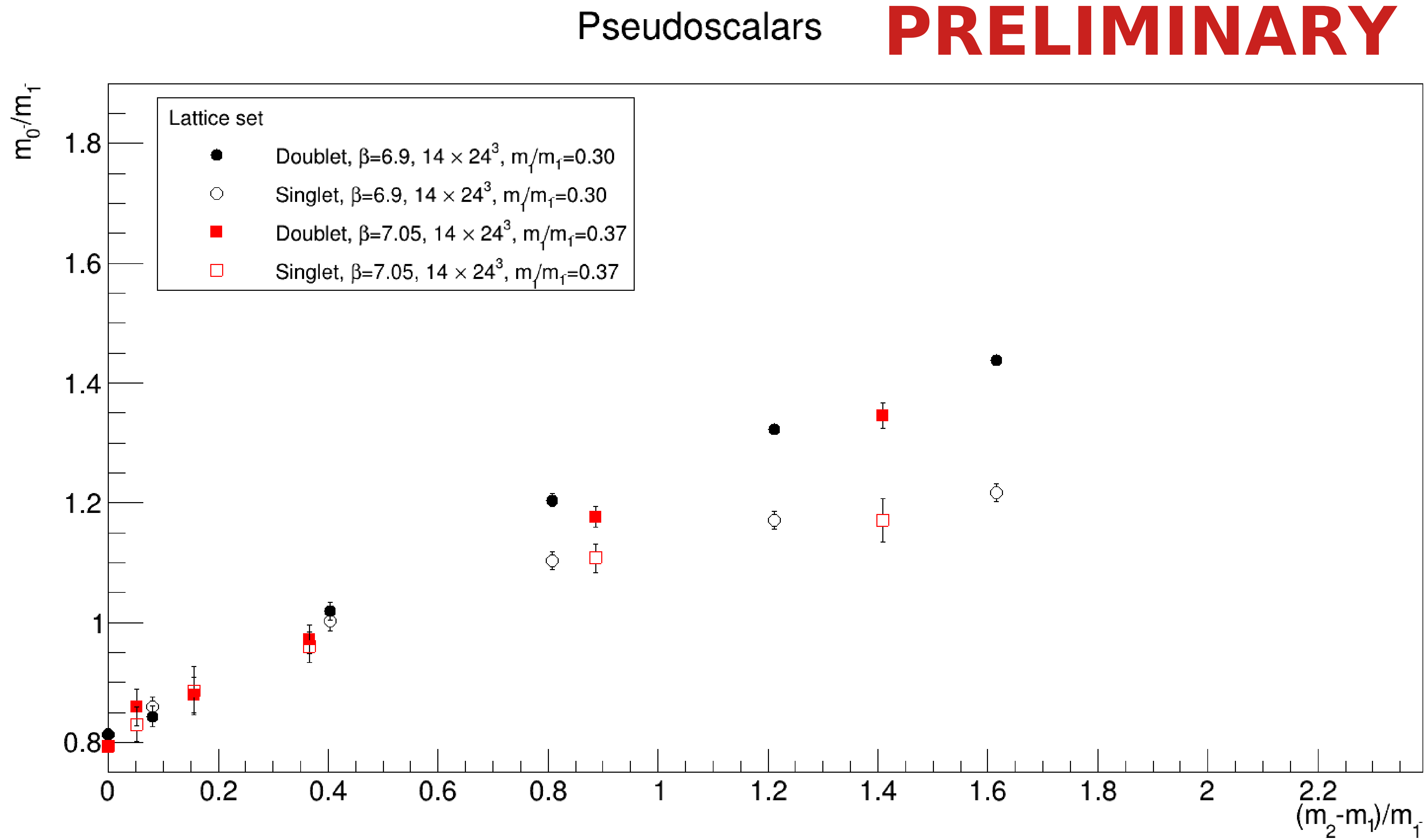

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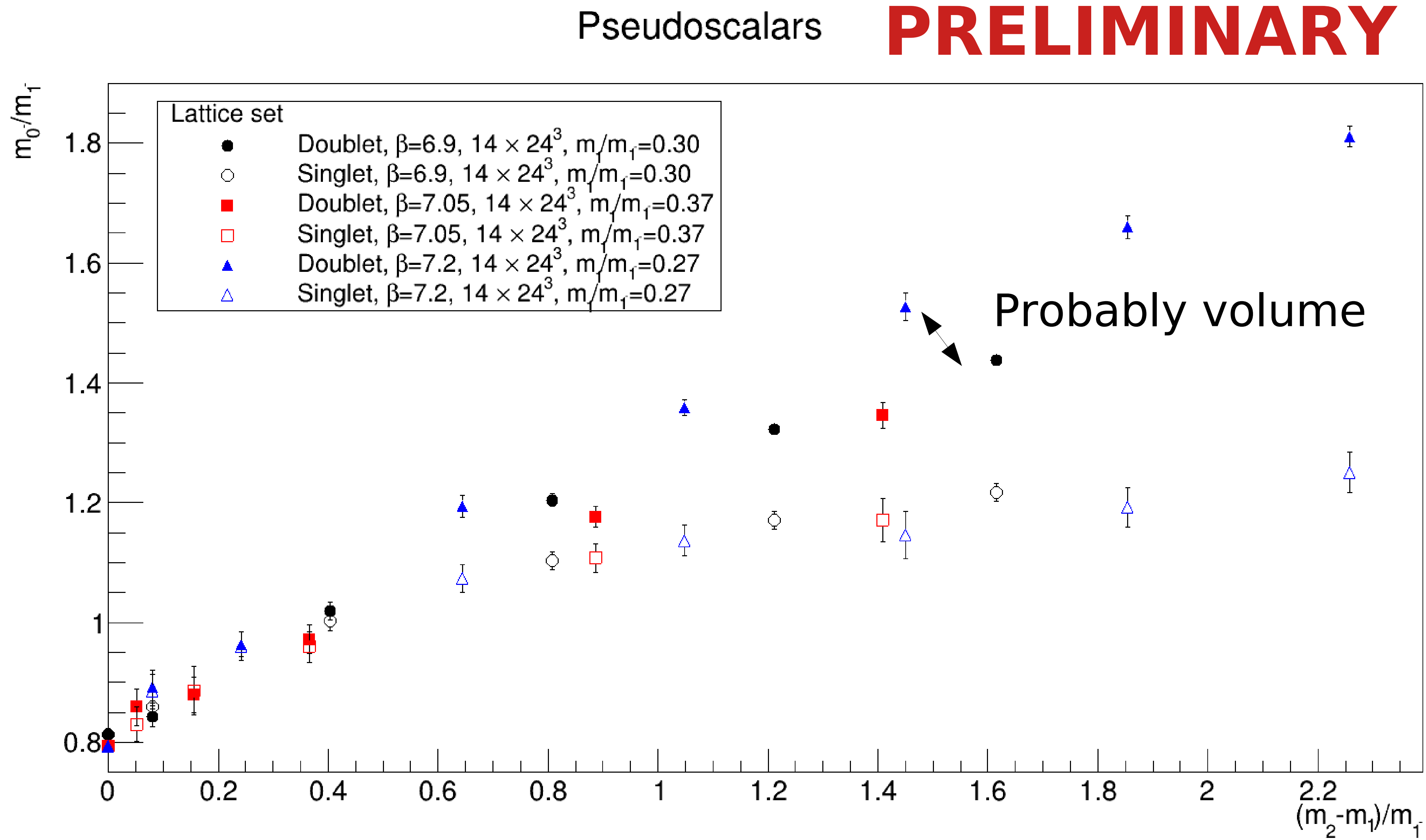
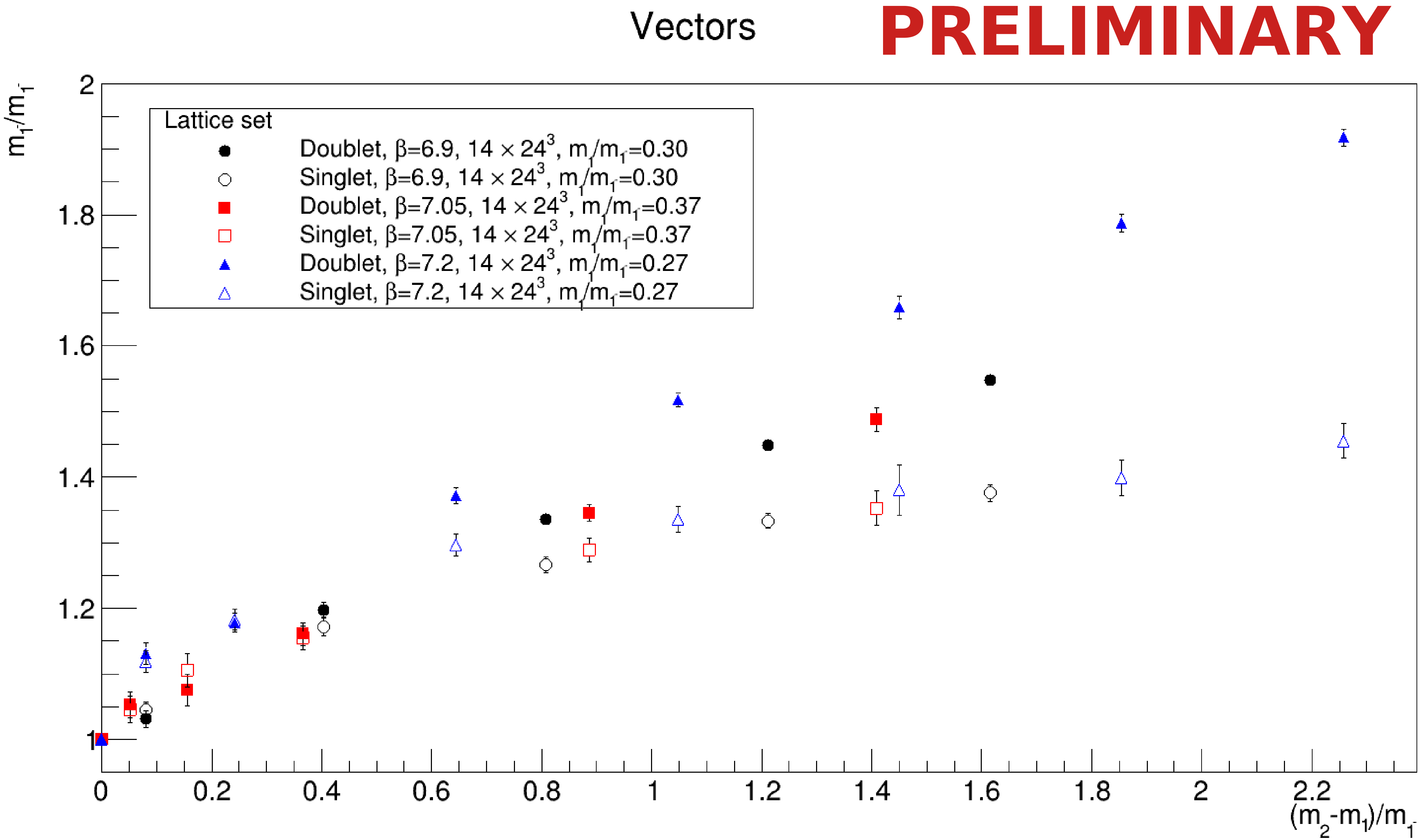


Results: Vectors

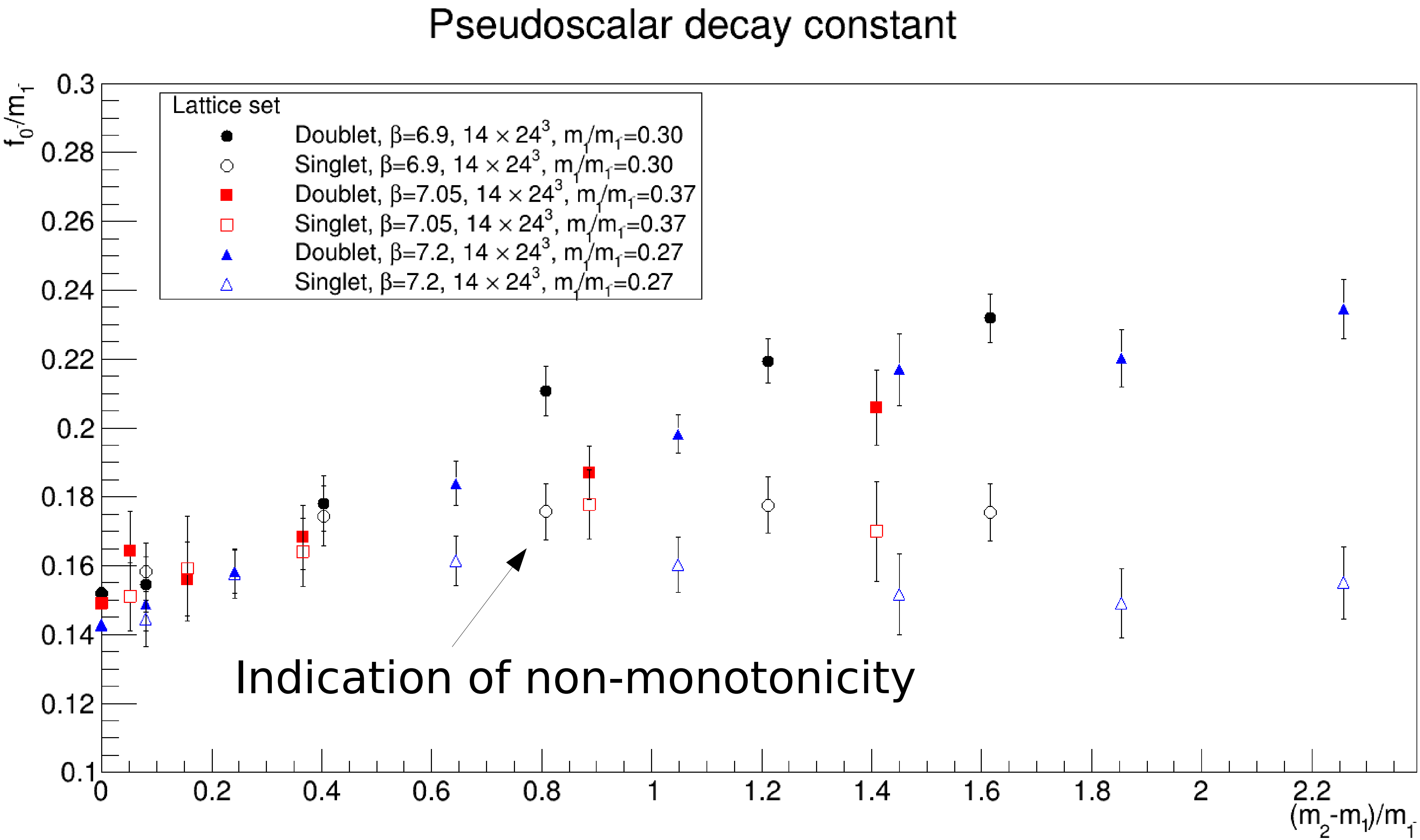
Degenerate results: Bennett et al. 1912.12662



Extremely similar! - Probably because of heavy fermions...

Results: Decay constants

Degenerate results: Bennett et al. 1912.12662



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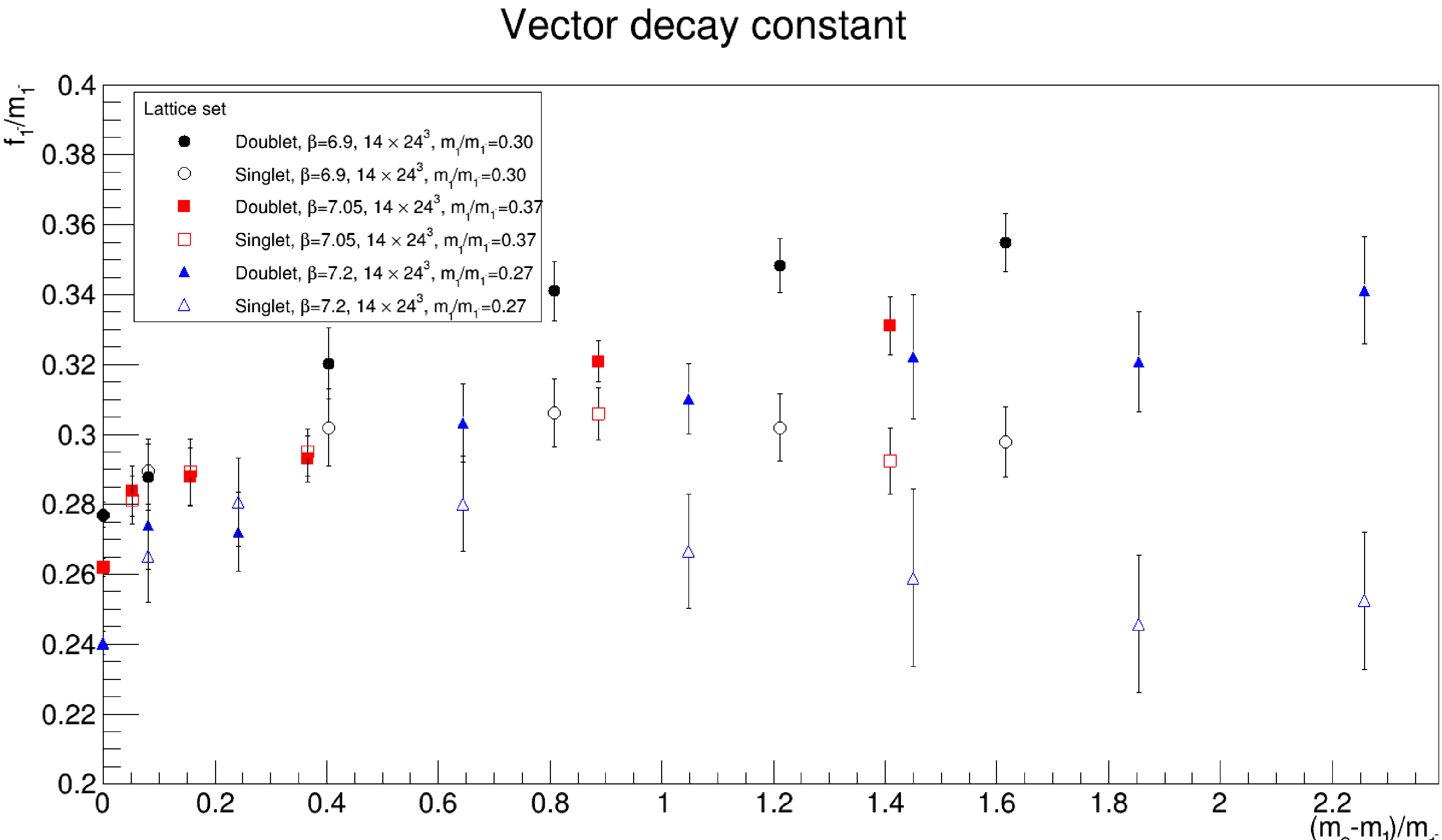

Also relatively similar...

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Summary

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  - Heavy fermion case
  - Relevant to (strongly-interacting) dark matter physics

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- Mass splitting/isospin breaking beyond QCD
  - Heavy fermion case
  - Relevant to (strongly-interacting) dark matter physics
- Mass splittings at hadronic level differ from quark mass splittings
- Vector and pseudoscalar similar