Neutrino masses from a pseudo-Dirac bino and its detection prospects

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Neutrino masses

- observation of neutrino oscillations ⇒ non-vanishing neutrino masses
- explain smallness of neutrino mass & testable model
  → variants of type I seesaw like **inverse seesaw**
- ISS: right-handed neutrinos form pseudo-Dirac pairs, lepton number is (approximately) conserved
  → lepton number violating effects (light neutrino masses) are naturally suppressed

Neutrino masses

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- ISS: right-handed neutrinos form pseudo-Dirac pairs, lepton number is (approximately) conserved
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- **challenge**: explanation of the texture needed in the neutrino mass matrix, suppression of lepton number violating effects

  possible solutions: identify lepton number breaking parameter with scalar vev in gauged $B-L$ or $U(1)_D$ symmetry [De Romeri, Fernandez-Martinez, JG, Machado, Niro '17, Ballett, Hostert, Pascoli '19, JG, Pierre '19]

Biνo model

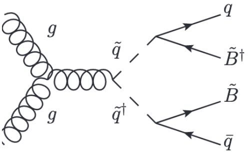
- augment $U(1)_R$-symmetric SUSY model with Dirac gauginos to $U(1)_{R-L}$ symmetry [Coloma, Ipek '16]
- small gaugino Majorana masses are generated by $U(1)_{R-L}$-violating effects (gravitino mass) → suppression of light neutrino masses
- bino and its Dirac partner → automatically form a pseudo-Dirac pair, play the role of RH neutrinos in ISS, the **biνo**
- **differences** to traditional ISS: no right handed neutrinos are needed, particles needed for neutrino mass generation can be produced in decays of colored particles

Biνo phenomenology

Based on *"Biνo phenomenology at the LHC"*
in collaboration with Seyda Ipek and Patrick J. Fox
JHEP **03** (2019), 073, arXiv:1901.09284
and
"Long-lived biνo at the LHC,"
in collaboration with Seyda Ipek
JHEP **05** (2021), 020, arXiv:2103.0125.

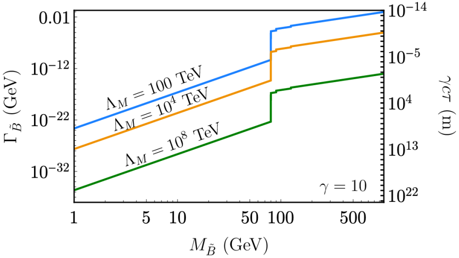
Biνo phenomenology [JG, Ipek '21]

- leading biνo production channel



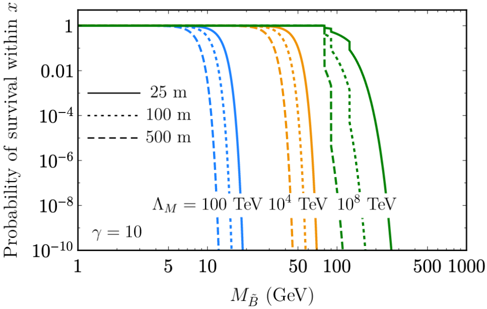
- Biνo decay channels: $BR(\tilde{B} \to Wl/Z\nu/h\nu) \approx 1/3$

- decay rates:
  - light biνo ($m_{\tilde{B}} < m_Z,\ m_W,\ m_h$): $\Gamma^{light} \simeq \kappa \frac{G_F^2 M_{\tilde{B}}^7}{192\pi^3 \Lambda_M^2}$
  - heavy biνo ($m_{\tilde{B}} > m_Z,\ m_W,\ m_h$): $\Gamma^{light} \simeq \frac{M_{\tilde{B}}^3}{\Lambda_M^2}$



Biνo phenomenology [JG, Ipek ’21]

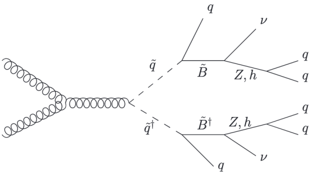
- probability of biνo survival



- lengths corresponding to ATLAS, MATHUSLA, FASER

Biνo results: low Λ_M [Fox, JG, Ipek '19]

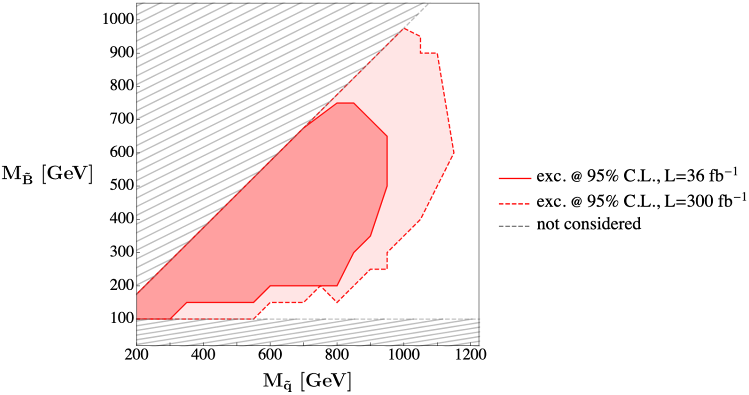
- constraints on low messenger scale $\Lambda_M \sim 100$ TeV $\Rightarrow$ biνo decays inside ATLAS
- largest BR$\sim$ 20% to 6j+MET $\neq$ standard search for particles involved in neutrino mass mechanism (e.g. heavy neutrinos)



- recast 6jet+MET search from ATLAS [ATLAS-CONF-2017-022]

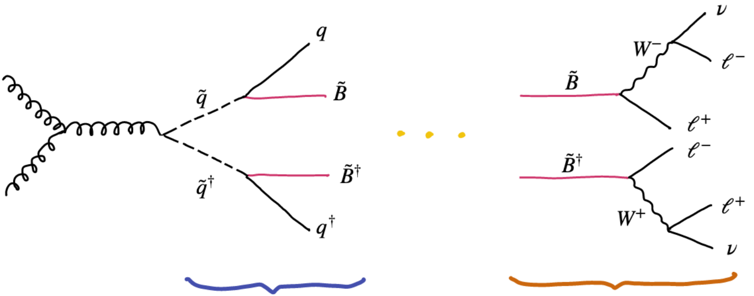
Biνo results: low Λ_M [Fox, JG, Ipek '19]

- recast 6jet+MET search from ATLAS [ATLAS-CONF-2017-022] using Madanalysis code from [Asadi, Buckley, DiFranzo, Monteux, Shih '17]



Biνo results: high Λ_M [JG, Ipek '21]

higher messenger scale $\Rightarrow$ biνo decays inside LLP experiments

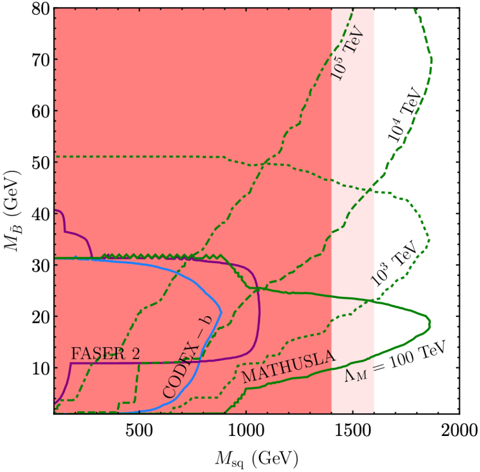


jets+MET final state
at ATLAS and CMS

decay to charged leptons at
MATHUSLA, CODEX-b or FASER

Biνo results: high Λ_M [JG, Ipek '21]

- light biνo



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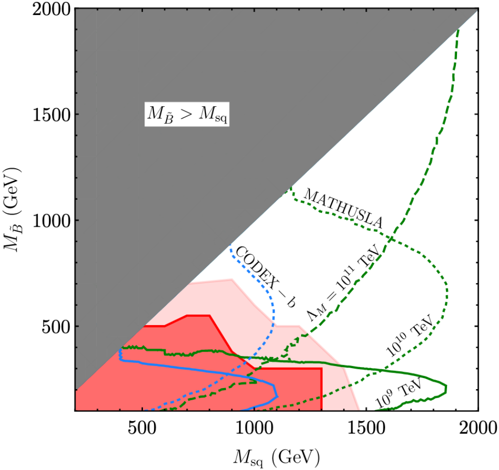


Biνo results: LFV [Coloma, Ipek '16]

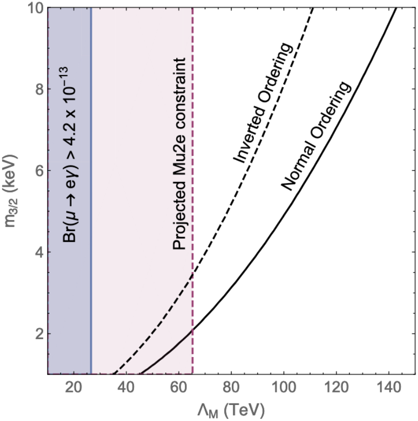
- constraints from lepton flavour violation
- BR($\mu \to e\gamma$) constrains $v^2/(2\Lambda_M^2) f_e f_\mu^* \to \Lambda_M > 30$ TeV
- light neutrino masses

$$m_1 = 0$$

$$m_2 = \frac{m_{3/2} v^2}{\Lambda_M^2}(1-\rho)$$

$$m_3 = \frac{m_{3/2} v^2}{\Lambda_M^2}(1+\rho),$$

$$\rho \simeq 0.7$$



Summary & conclusions

- presented SUSY model which naturally gives rise to ISS neutrino mass matrix pattern
- particles related to neutrino mass mechanism testable at LHC and dedicated LLP experiments
- complementarity between collider searches and LFV searches to probe parameter space

End of the talk

Thank you for your attention!

[All artwork by Sandbox Studio, Chicago]

Backup: Biνo model [Coloma, Ipek '16]

- in $U(1)_R$-symmetric supersymmetric models: superpartners have +1 R-charges, SM fields are not charged under $U(1)_R$ → Gaugino Majorana masses forbidden
- Dirac masses for gauginos: adjoints with opposite R-charges are introduced
- extend $U(1)_R$ to $U(1)_{R-L}$ to allow for neutrino mass terms

Biνo model [Coloma, Ipek '16]

- SUSY broken in hidden sector that communicates with the visible sector at messenger scale $\Lambda_M \to$ **Dirac mass** for the bino $\tilde{B}$, Dirac partner singlino S

$$\int d^2\theta c \frac{W'_\alpha}{\Lambda_M} W^\alpha_{\tilde{B}} \Phi_S \to \frac{cD}{\Lambda_M} \tilde{B} S = M_{\tilde{B}} \tilde{B} S$$

- $U(1)_{R-L}$ broken by supergravity → Majorana masses for bino and singlino via anomaly mediation generated (proportional to gravitino mass $m_{3/2}$)

$$m_{\tilde{B}} \sim m_S \sim \frac{1}{16\pi^2} m_{3/2} \ll M_{\tilde{B}}$$

Backup: Biνo model

- singlino and bino form pseudo Dirac fermion $\Psi^T = (\tilde{B}, S^\dagger)$ $\rightarrow$**biνo**
- interactions of bino with lepton doublet

$$\frac{f_i}{\Lambda_M^2} \int d^2\theta W'_\alpha W_{\tilde{B}}^\alpha H_u L_i \rightarrow \frac{f'_i M_{\tilde{B}}}{\Lambda_M} h_u \tilde{B} l_i$$

- not enough freedom to give mass to at least two SM neutrinos → singlino interaction like $\Phi_S H_u L_i$
- not charged under $U(1)_{R-L}$, needs to be induced a $d = 5$ Kähler potential term with $\phi = 1 + \theta^2 m_{3/2}$

$$\int d^2\theta d^2\bar{\theta} \phi^\dagger \frac{d_i \Phi_S H_u L_i}{\Lambda_M} \rightarrow \frac{d_i m_{3/2}}{\Lambda_M} h_u S l_i$$

Backup: Biνo model

- neutrino mass matrix

$$M_\nu = \begin{pmatrix} 0_{3\times 3} & Yv & Gv \\ Y^T v & m_{\tilde{B}} & M_{\tilde{B}} \\ G^T v & M_{\tilde{B}} & m_S \end{pmatrix}$$

$Y_i = f_i M_{\tilde{B}}/\Lambda_M$, $G_i = d_i m_{3/2}/\Lambda_M$, for ISS: $G \ll Y$

- $m_1 = 0,\ m_2 = \frac{m_{3/2} v^2}{\Lambda_M^2}(1-\rho),\ m_3 = \frac{m_{3/2} v^2}{\Lambda_M^2}(1+\rho)$
- parametrically

$$m_\nu \simeq (2-20)\times 10^{-2}\ \text{eV} \left(\frac{m_{3/2}}{10\ \text{keV}}\right)\left(\frac{100\ \text{TeV}}{\Lambda_M}\right)^2$$