Searching for SUSY LLPs at MoEDAL

Oscar Vives
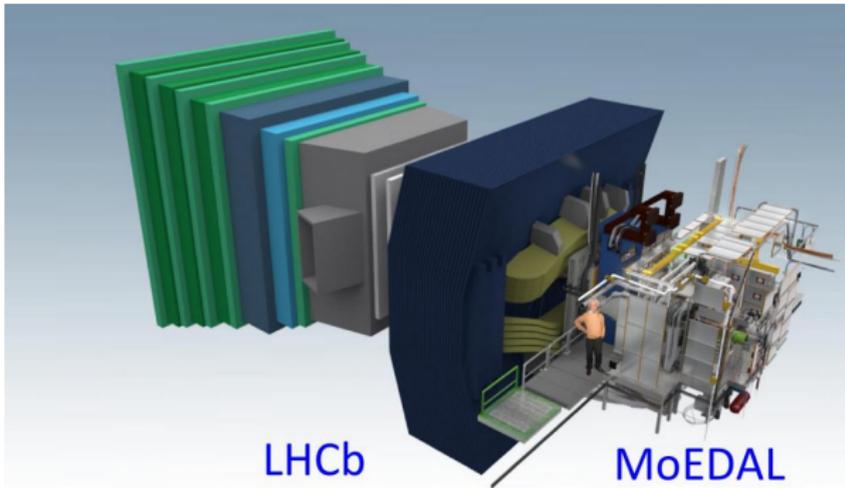
MoEDAL detector

- LT-NTD: Low-threshold Nuclear Tracking Detector, $z/\beta \gtrsim$ 5-10
- HCC-NTD: Very High Charge Catcher NTD, $z/\beta \gtrsim$ 50
- TimePix: TimePix radiation background monitor
- MMT: Monopole Trapping detector

MoEDAL detector
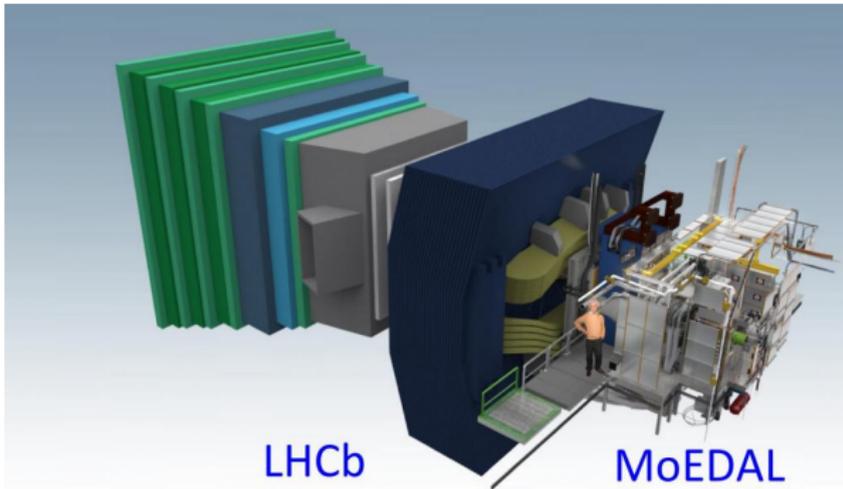
- Mostly **passive** detectors; no trigger, no readout
- Largest deployment of passive Nuclear Track Detectors (NTDs) at an accelerator
- First time that trapping detectors are deployed as a detector

High Ionization in NTDs

Bethe-Bloch formula:

$$-\frac{dE}{dx} = K\frac{z^2}{\beta^2}\frac{Z}{A}\left[\frac{1}{2}\log\frac{2m_e^2\beta^2\gamma^2\,T_{\max}}{I^2} - \beta^2 - \frac{\delta}{2}\right]$$

- Magnetic Monopoles: large ionization, 68.5^2 times higher than minimum ionizing particles.
- HCLLP: Any heavy charged long-lived particle should be slow moving and leave a track in NTDs.

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Complementary to ATLAS and CMS searches
  a) No triggers   b) No timing   c) No background

Heavy SUSY LLPs at MoEDAL

MoEDAL can detect *SUSY* particles with $c\tau \gtrsim 1$ m:

- Sleptons: $\tilde{\tau}$ in GMSB with gravitino LSP or coannihilation region in CMSSM with $m_{\tilde{\tau}} - m_{\chi_1^0} < m_\tau$.
- R-hadrons: meta-stable gluinos in Split SUSY or stop NLSPs with gravitino LSP....
- Charginos: in AMSB χ_1^+ and χ_1^0 degenerate.

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High Ionization in NTDs

Slow particles & multiple charge $\quad \Rightarrow \quad \frac{z}{\beta} \gtrsim 5$
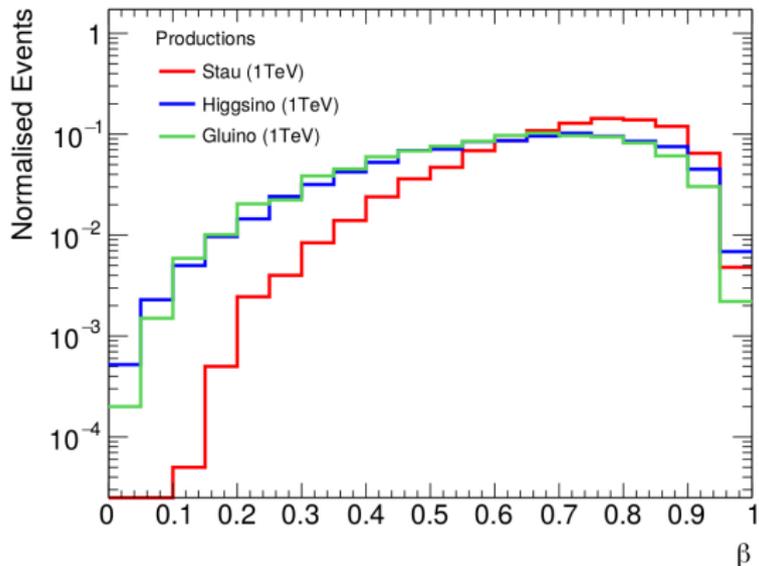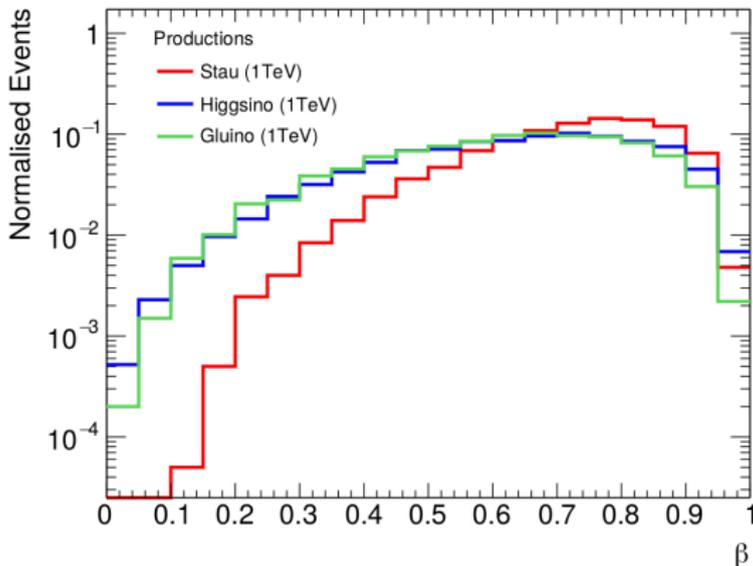
⟹   Study stau detection through gluino production

Long-lived charged particles at LHC

Specific searches for long-lived particles at ATLAS and CMS.

- Searches of displaced jets. PRD 97 052012 (2018), PRD 99 032012 (2019): E_T^{miss}(hadr.)> 180 GeV, $m_{\mathrm{DV}} > 10$ GeV, 0.4 cm$< d_{xy} < 30$ cm

- Searches of displaced lepton pais. PRD 92 012010 (2015), PRD 99 012011 (2019), PRD 91 052012 (2015): muon signal or $E_T^{\mathrm{miss}} > 75$ GeV and jet of $p_T > 110$ GeV, 1.0 cm$< d_{xy}$ and hits in silicon and SCT.

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Work in progress . . .

Searches for long-lived charged particles in pp collisions JHEP 07 122 (2013) CMS

$|\eta|$	<2.1
p_T (GeV/c)	>45
d_z and d_{xy} (cm)	<0.5
σ_{p_T}/p_T	<0.25
Track χ^2/n_d	<5
# Pixel hits	>1
# Tracker hits	>7
Frac. Valid hits	>0.8
$1/\beta$	>1 (...)

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Similar in *ATLAS* and *CMS* analysis.

$$\boxed{\tilde{g} \to jj\chi_1^0 \to jj\pi\tilde{\tau}_1}$$

- Long-lived neutralino in χ_1^0–$\tilde{\tau}_1$ coannihilation $\Rightarrow$ No pixel hit.
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$\tilde{g}\tilde{g}, \ \tilde{g} \rightarrow qq\tilde{\chi}_1^0, \ \tilde{\chi}_1^0 \rightarrow \tau\tilde{\tau}_1$

N = 2

$m_{\tilde{g}} - m_{\tilde{\chi}_1^0} = 30\,\mathrm{GeV}$

$m_{\tilde{\chi}_1^0} - m_{\tilde{\tau}_1} = 300\,\mathrm{GeV}$

PRELIMINARY

- - - CMS 150/fb
- - - CMS 300/fb
- - - MoEDAL 6.7/fb $\beta = 0.2$
- - - MoEDAL 30/fb $\beta = 0.2$

$c\tau_{\tilde{\chi}_1^0}$ [cm] (vertical axis)

$m_{\tilde{g}}$ [GeV] (horizontal axis)

ANITA staus??

- ANITA, balloon-borne on Antarctic. Polarized radio emission from e.m. component of cosmic-ray showers $\rightarrow \tau$ leptons.
- Can distinguish reflected (on ice) from earth-emerging events. Parent τ zenit angle determined with $0.3°$.
- 4 flights of ~ 30 days, $h \sim 30$ km. ANITA-1 and ANITA-3 trig. HPol and VPol (UHECR's), ANITA-2 VPol (bett. ν accept.).

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$$\Downarrow$$

Two Anomalous Anita Events (AAE) observed:

- $\varepsilon_{cr} \simeq 0.6$ **EeV** (0.6×10^9 **GeV**)
- **upgoing through** $l_{\mathrm{earth}} \sim 6000$ **km**
- **on ANITA-1 and ANITA-3**
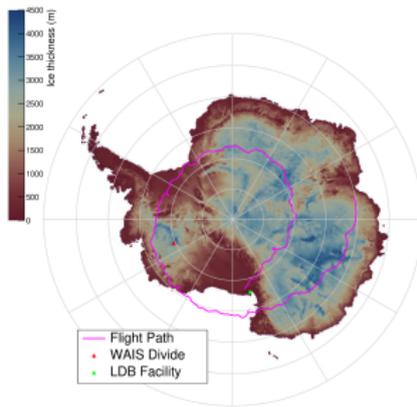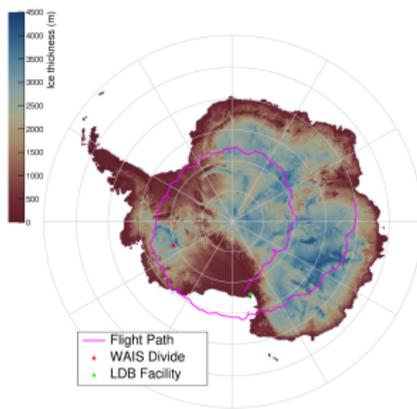
Properties of the ANITA Anomalous Events

Property	AAE 061228	AAE 141220
Flight & Event	ANITA-1 #3985267	ANITA-3 #15717147
Date & Time (UTC)	2006-12-28 00:33:20	2014-12-20 08:33:22.5
Equatorial coordinates	R.A. $282.14°$, Dec. $+20.33°$	R.A. $50.78°$, Dec. $+38.65°$
Energy ε_{cr}	0.6 ± 0.4 EeV	$0.56^{+0.30}_{-0.20}$ EeV
Zenith angle z'/z	$117.4°$ / $116.8° \pm 0.3°$	$125.0°$ / $124.5° \pm 0.3°$
Earth chord length, l	5740 ± 60 km	7210 ± 55 km
Mean int. length ($\varepsilon_\nu = 1$ EeV)	290 km	265 km
$p_{\mathrm{SM}}(\varepsilon_\tau > 0.1\,\mathrm{EeV})$	4.4×10^{-7}	3.2×10^{-8}
$p_{\mathrm{SM}}(z > z_{\mathrm{obs}})\,\varepsilon_\tau > 0.1$ EeV	6.7×10^{-5}	3.8×10^{-6}

Not possible in SM !!

$l_\nu(0.6\,\mathrm{EeV}) \simeq 100$ km, only steep events seen.
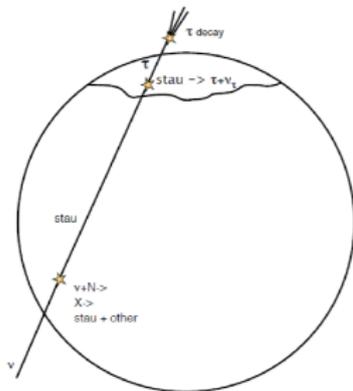
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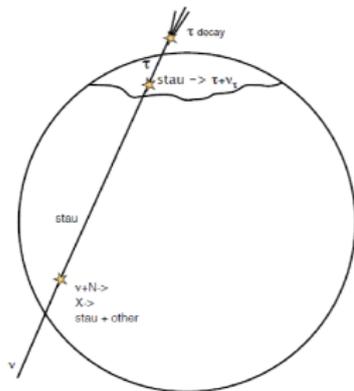
- Range of UHE HSCP $\sim 10^4$ Km (interactions slow it to rest)
- For $m_{\tilde{\tau}} \simeq 500$ GeV and $\tau_{\tilde{\tau}} \simeq 10$ ns, reduces γ after 6000 Km, decays close to the surface for $\theta \simeq 120°$!!

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• Can they be produced at the end of a gluino chain??

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MoEDAL

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Complete analysis at **MoEDAL**

Conclusions

- MoEDAL complementary to ATLAS and CMS in HSCPs searches.

- Strong constraints on metastable SUSY particles.

- Possible signal of stau production in high-energy cosmic rays.

- ANITA has seen two events compatible with electroweak production of staus, $\lesssim 1$ TeV.

- For light coloured sparticles, MoEDAL could constrain these processes.