

Long-lived BSM particle searches at MoEDAL

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(University of Warsaw)

in collaboration with:

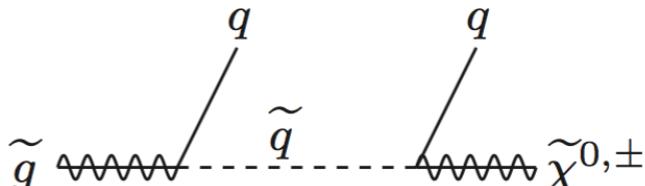
Oscar Vives, Roberto Ruiz De Austri,
Judita Mamuzic, Arka Santra, Vasiliki Mitsou

Long-lived (charged) particles in SUSY models:

- Split SUSY
 $(m_{\tilde{q}} \gg m_{\tilde{g}})$

long-lived \tilde{g}

$$c\tau_{\tilde{g}} = \mathcal{O}(1 - 10) \text{ cm} \times \left(\frac{\Delta m}{10 \text{ GeV}} \right)^{-5} \left(\frac{\tilde{m}}{10 \text{ TeV}} \right)^4$$



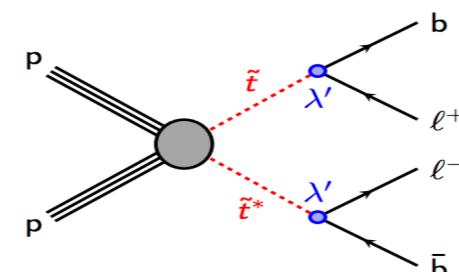
- Gravitino LSP

Anything: e.g. $\tilde{\tau}$

$$\tau_{\tilde{f}} = 6 \times 10^{-12} \text{ sec} \cdot \left(\frac{m_{3/2}}{10 \text{ eV}} \right)^2 \left(\frac{m_{\tilde{f}}}{100 \text{ GeV}} \right)^{-5}$$

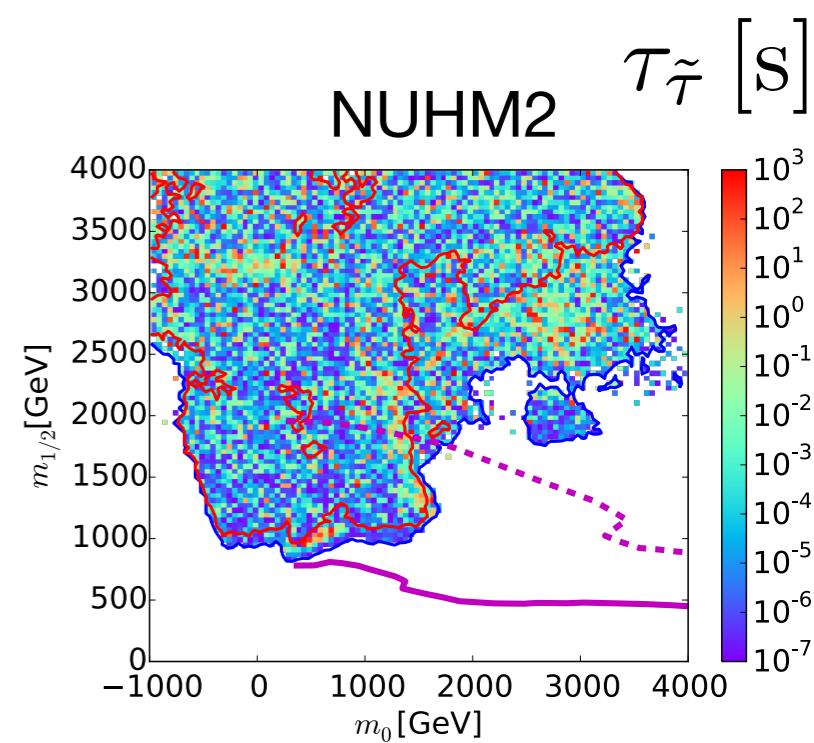
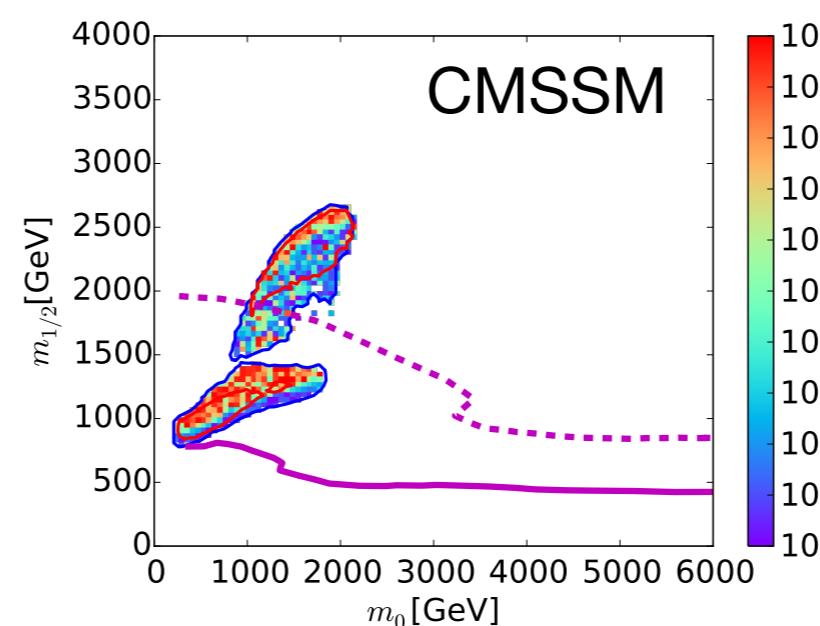
- RPV

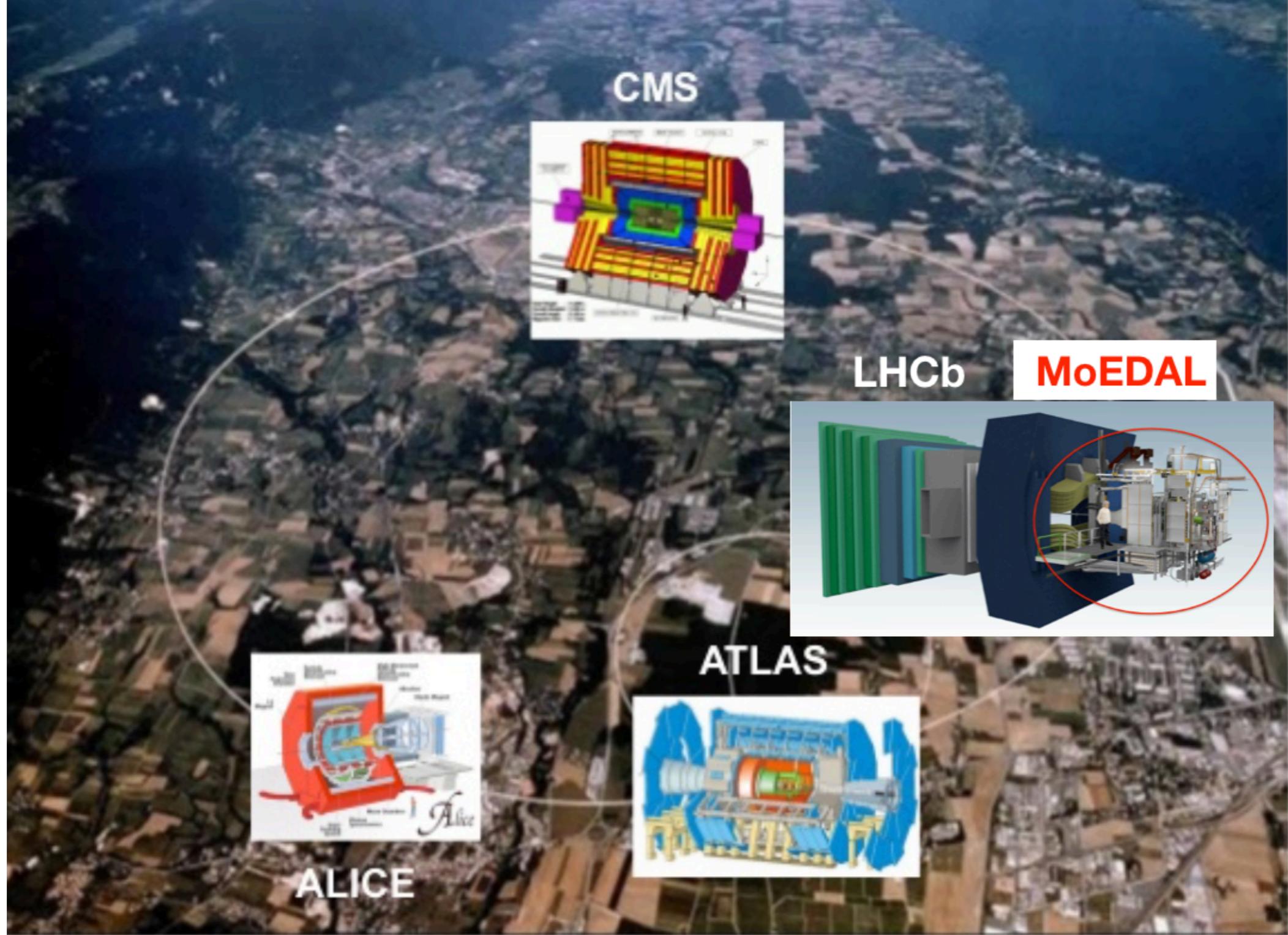
Anything: e.g. \tilde{t}



- Stau-Coannihilaton

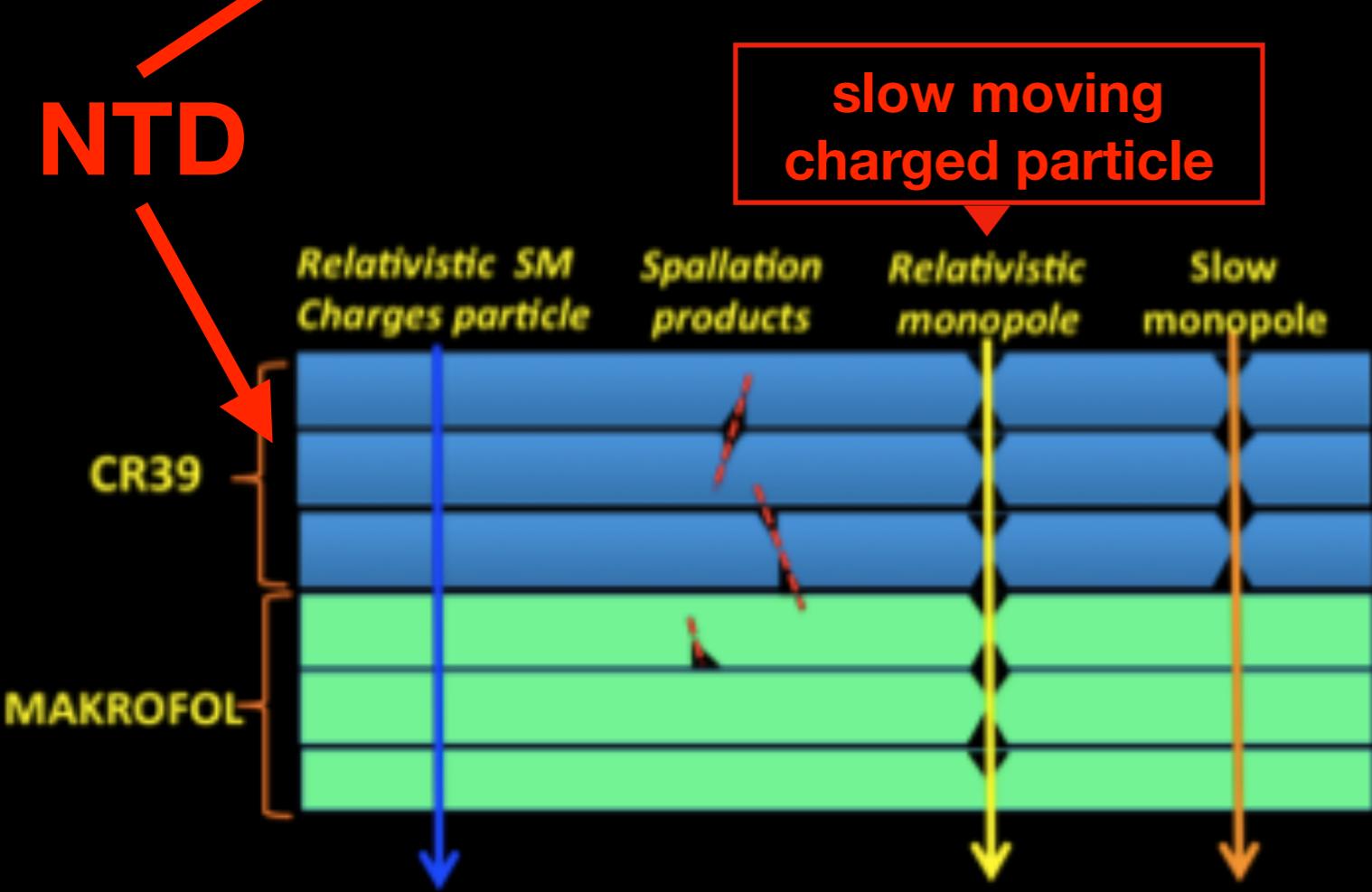
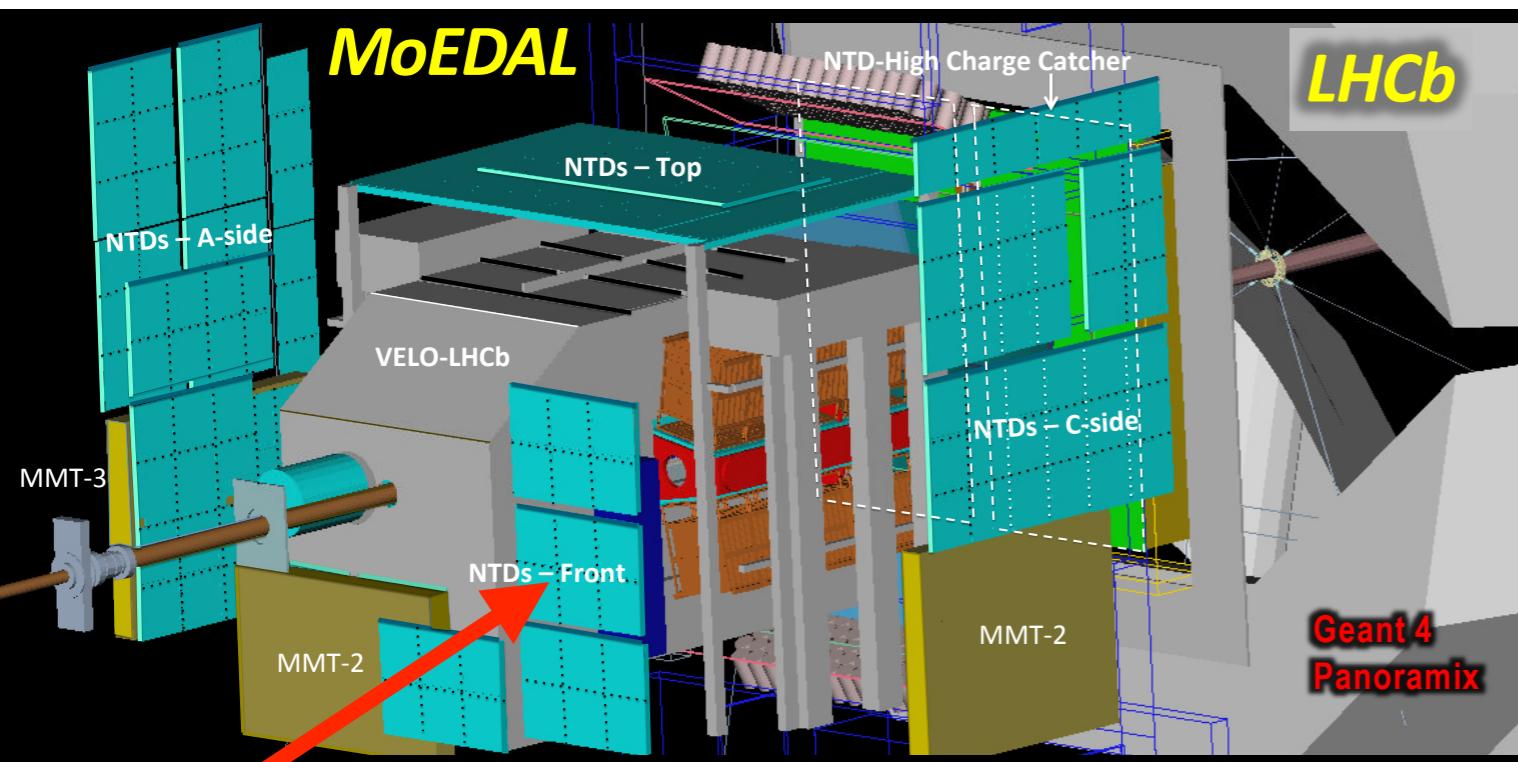
long-lived $\tilde{\tau}$





- **Independent searches** (with very different systematics, environment, assumptions, ..) **are important** for robust science.
- There could be a model which is sensitive for MoEDAL but not much for ATLAS/CMS.

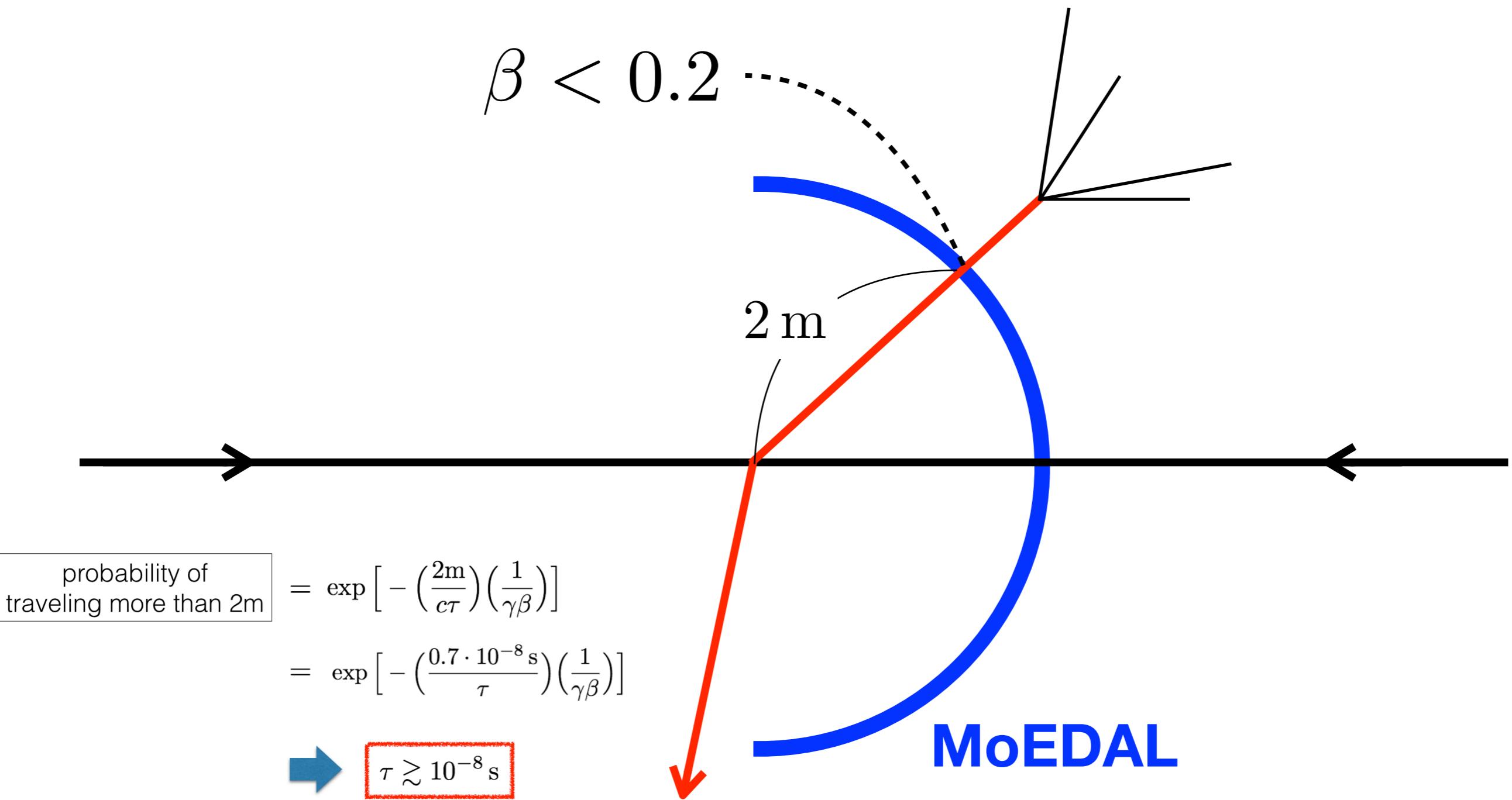
Signatures at MoEDAL

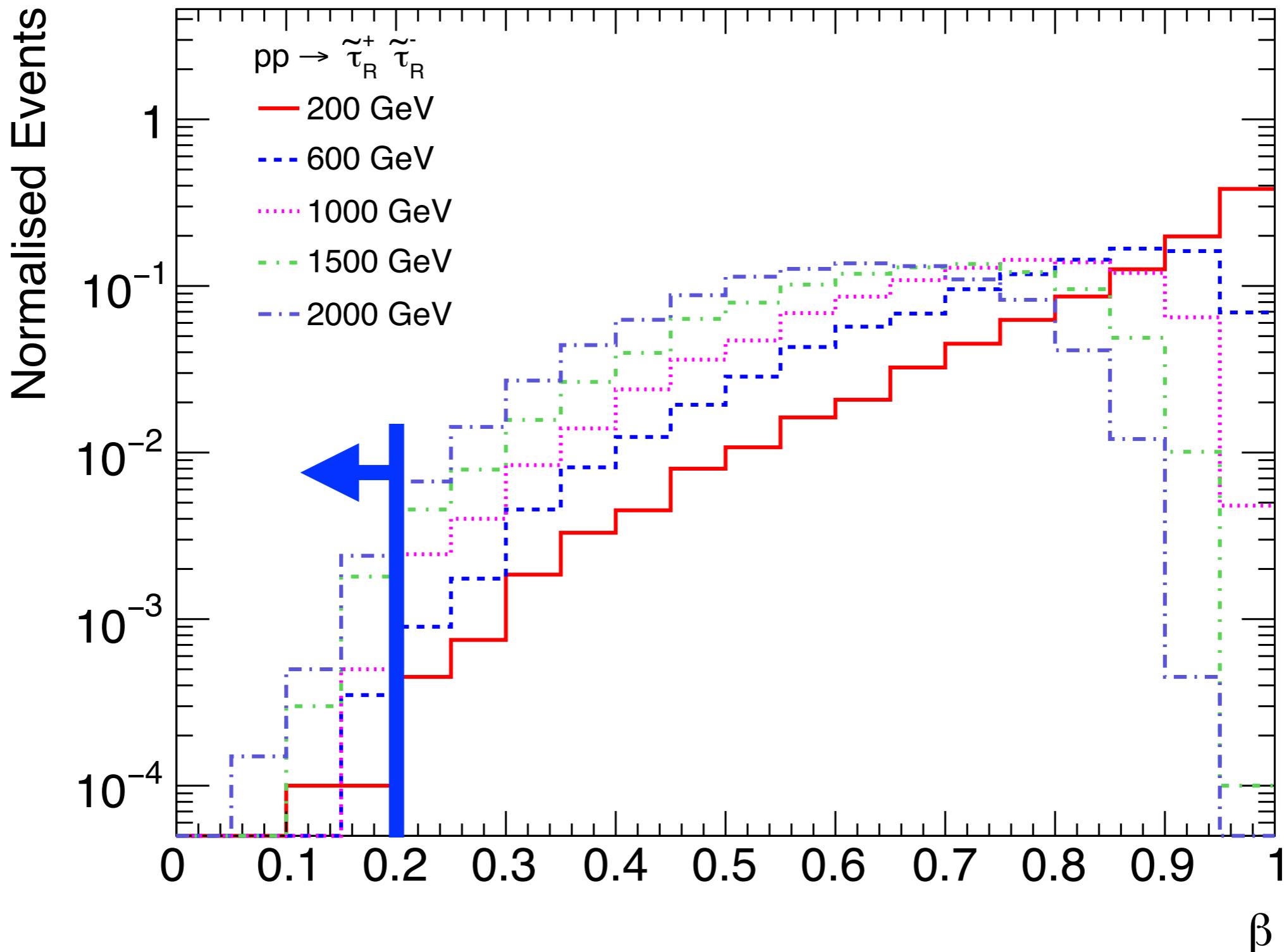


- MoEDAL is primarily designed to look for Magnetic Monopoles (MMs)
- MoEDAL deploys Nuclear Track Detectors (NTD) ~2m away from the interaction point, and only MMs or slow moving charged particles can punch through the detector, leaving the etching signature
- Essentially no SM background.

MoEDAL can detect a singly charged particle if it has a low velocity: $\beta < 0.2$.

The particle must pass the detector shell located **2m** away from the interaction point.

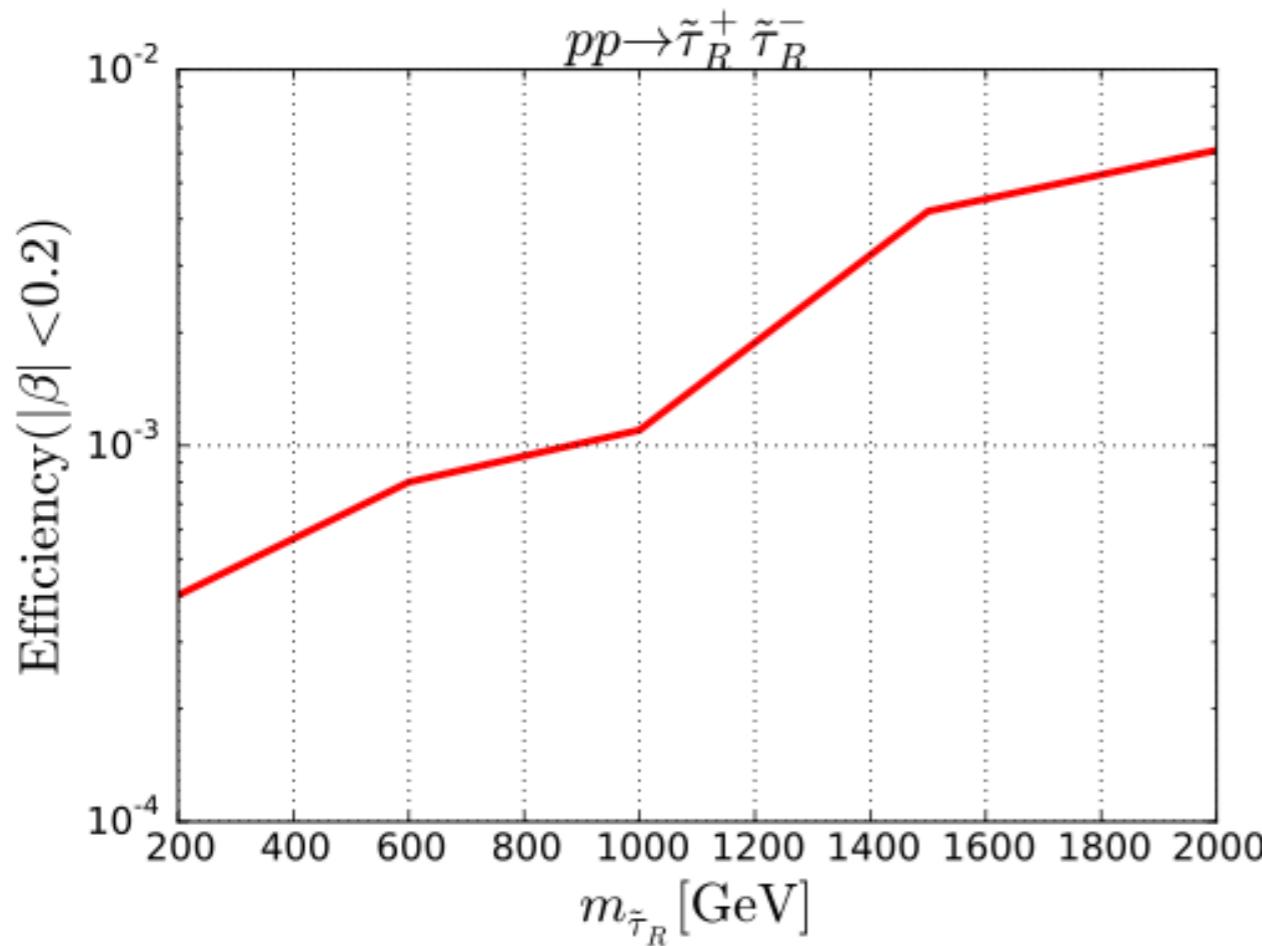




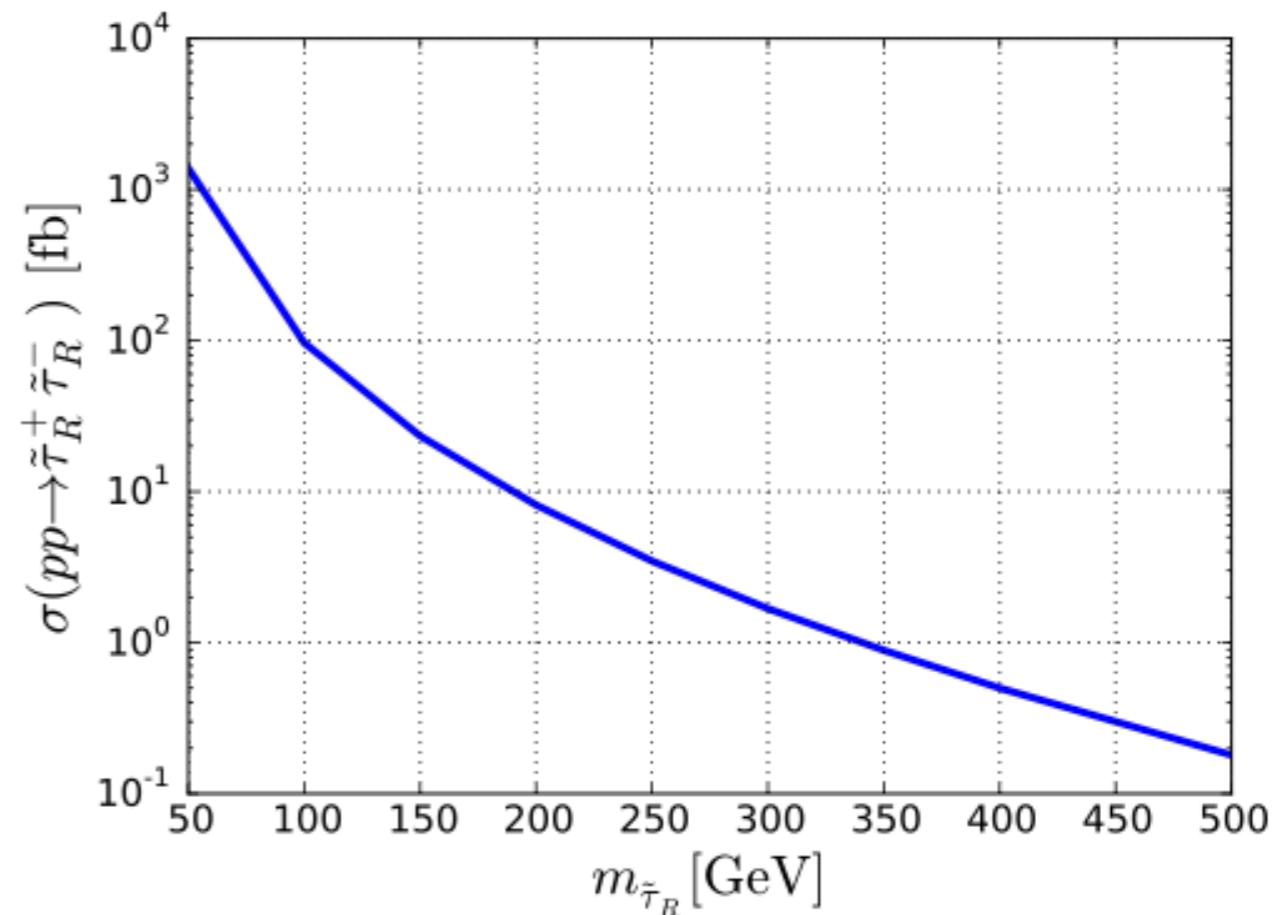
Typically β is not small...

We need a **heavy** particle.

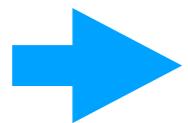
Signal Efficiency ($\beta < 0.2$)



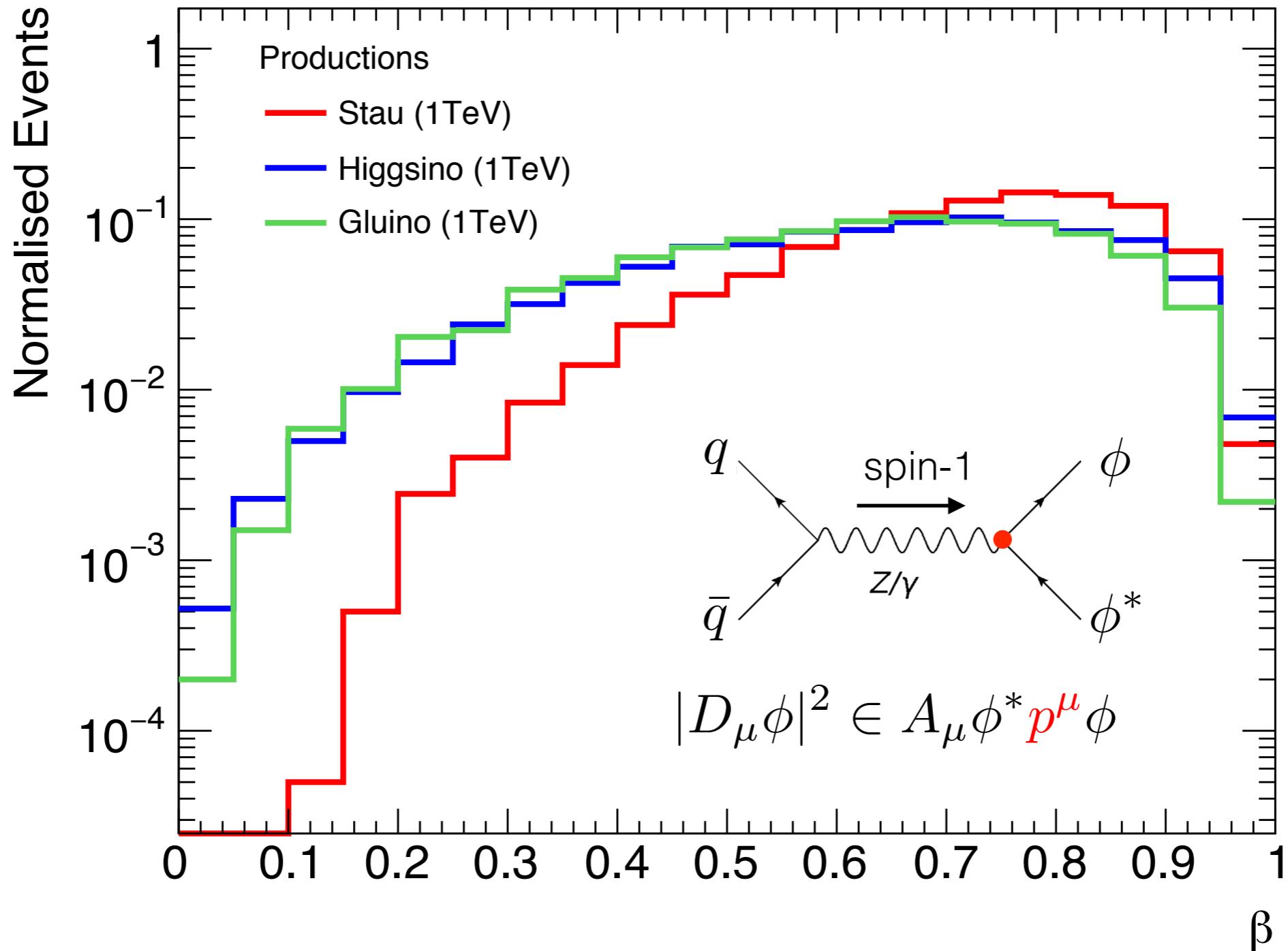
Signal Cross-Section



$$\epsilon \cdot \sigma \sim (\text{few } 10^{-3}) \cdot (\text{few } 100 \text{ fb}^{-1}) \quad (\text{for } m_{\tilde{\tau}} > 100 \text{ GeV})$$



MoEDAL is insensitive to stau direct production.



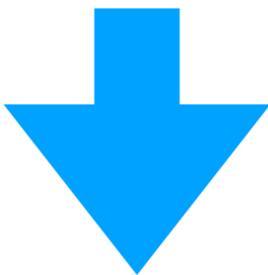
The velocity is smaller for **fermion** pair production.
(s-wave)

MoEDAL is better at:

heavy

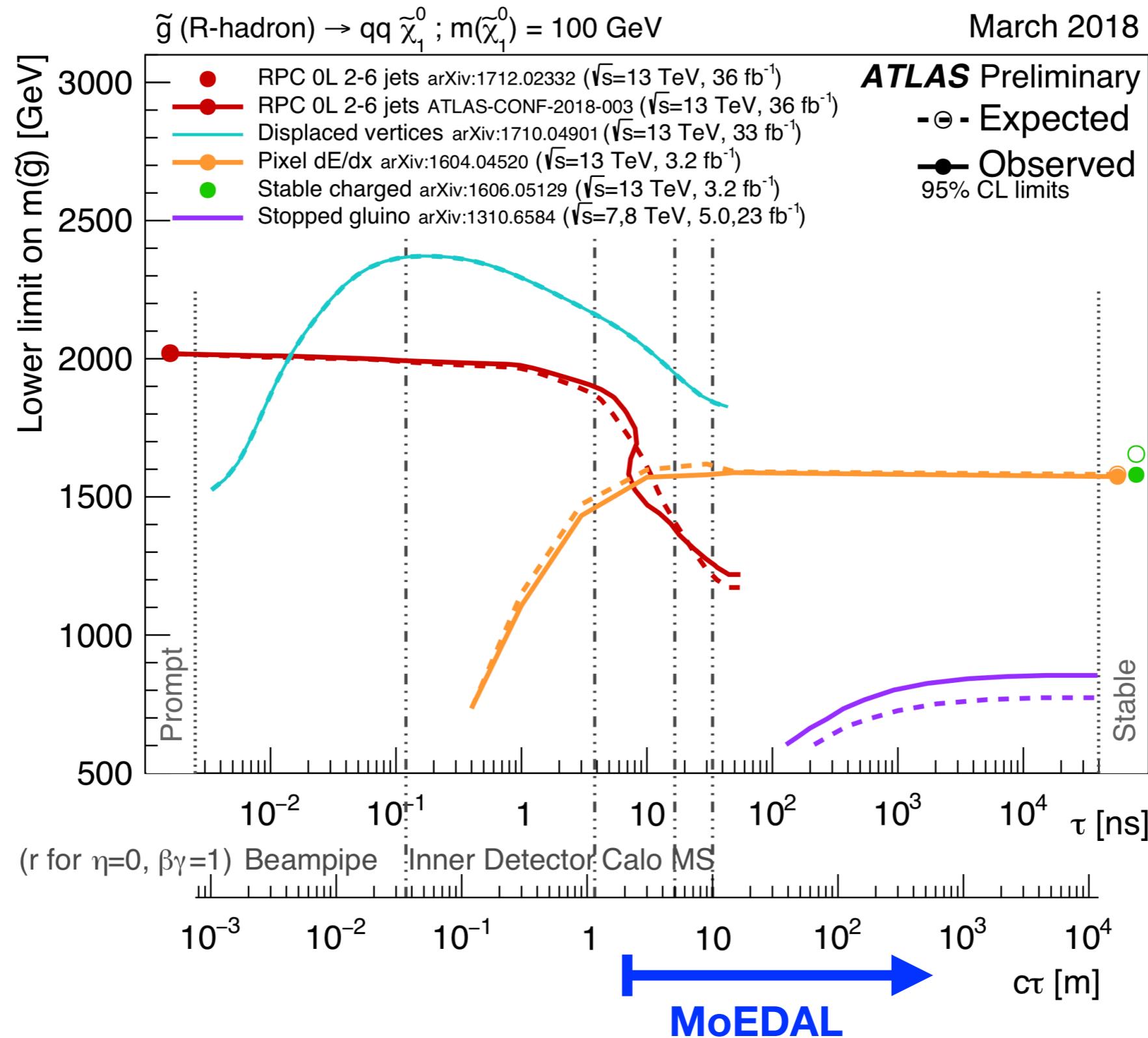
fermion

with **large cross-section**



gluino pair production would serve the best scenario.

Long-lived gluino have been constrained by ATLAS/CMS

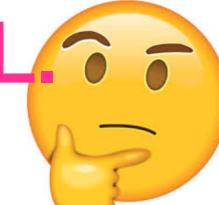


Long-lived particle searches

	ATLAS/CMS	MoEDAL
Analyses	not simple , involving several detector components, triggers	simple 
Background	very small mainly from mismeasurements	almost BG free 
Signal Efficiency	$\sim 0.5 - 0.05$	~ 0.01 ($\beta < 0.2$) 
Luminosity		$\sim 5\%$ of ATLAS/CMS 

In ordinary scenarios,

ATLAS/CMS expects ~200 times more events than MoEDAL.



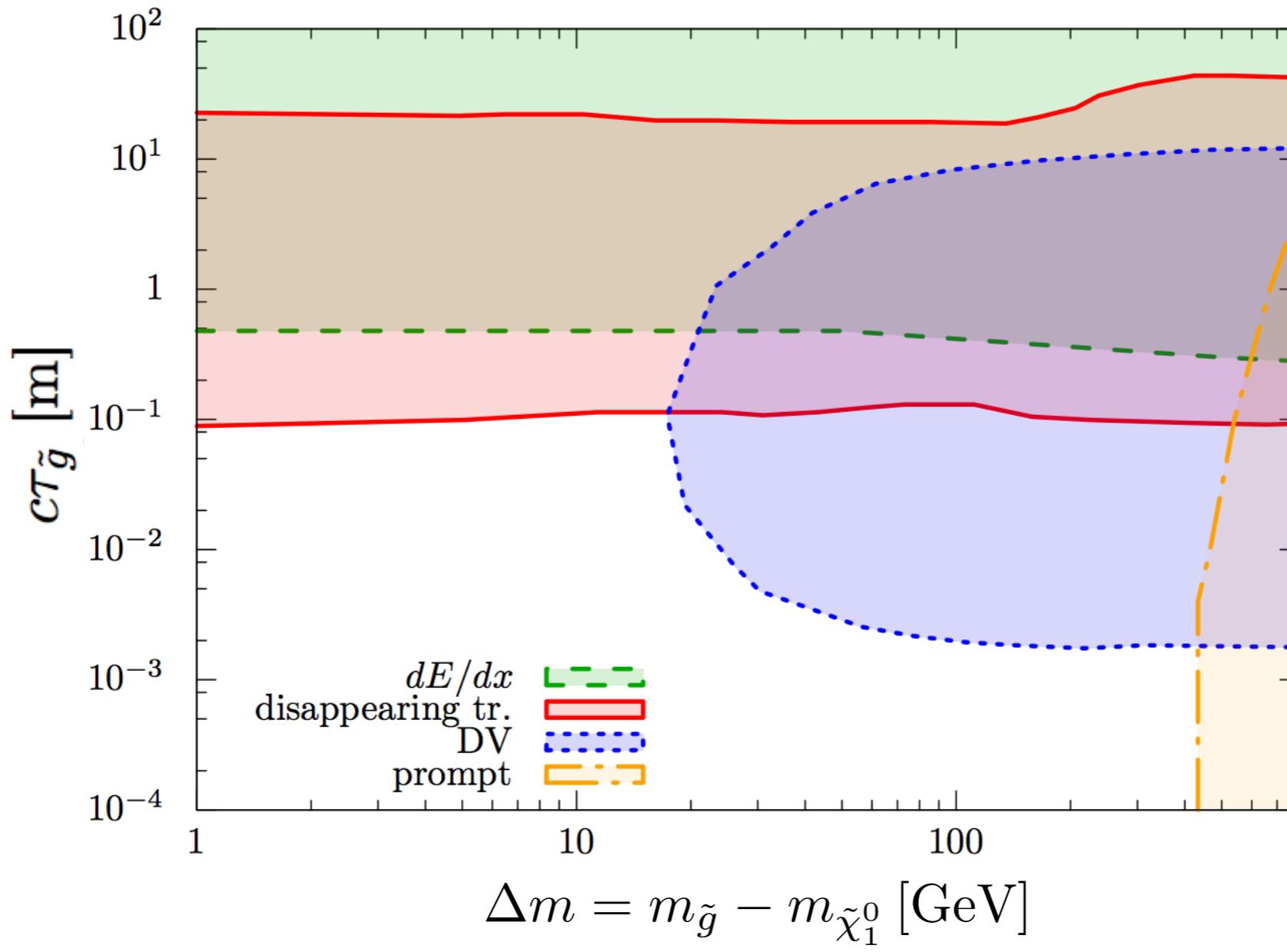
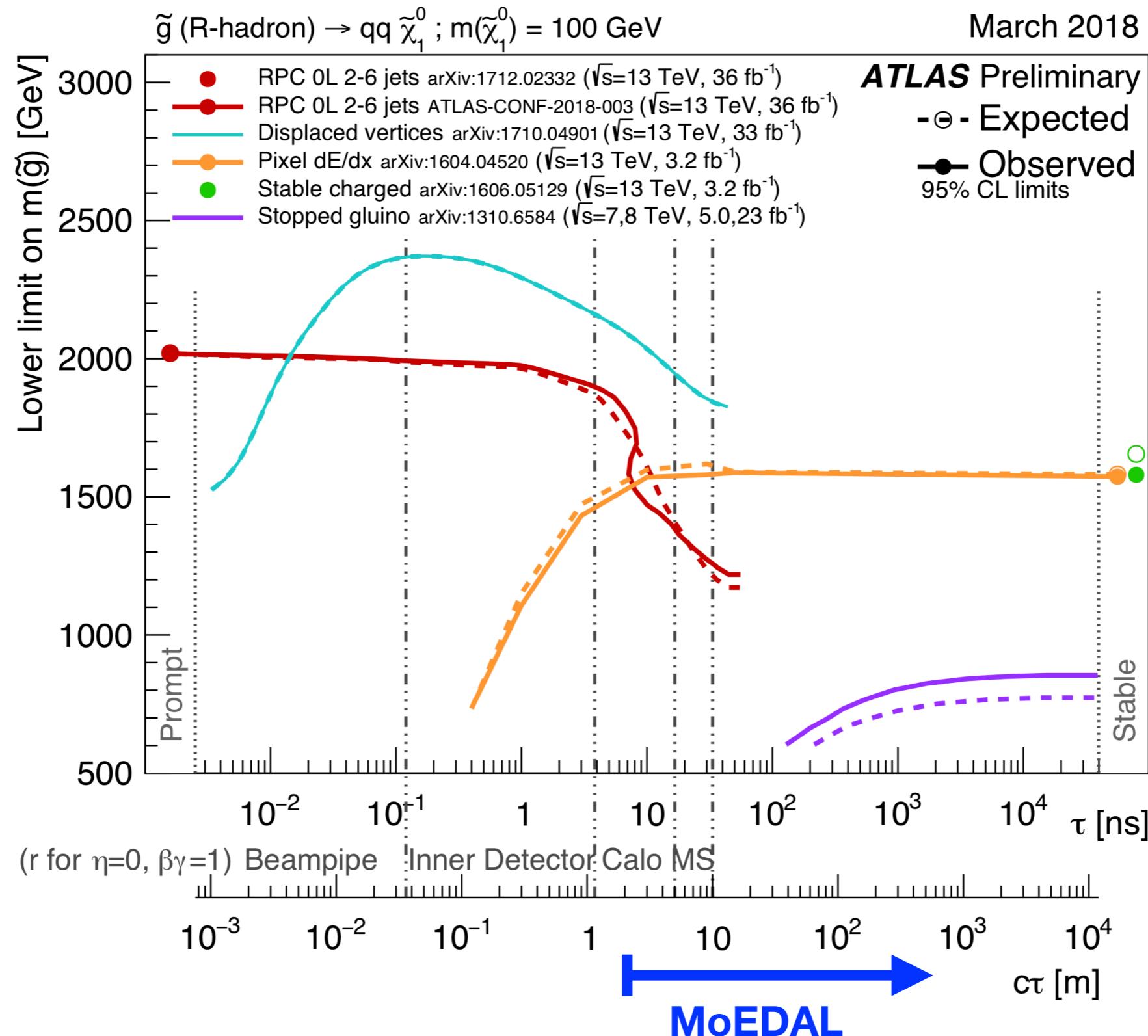


Figure 4: Testable regions of the gluino-LSP mass difference Δm and the gluino decay length $c\tau_{\tilde{g}}$ from the dE/dx , disappearing track, displaced vertex, and prompt inclusive searches at 13 TeV LHC with an integrated luminosity of 40 fb^{-1} . Here we fix the gluino mass to be 1.5 TeV.

**Compressed spectrum *evades*
displaced vertices and prompt searches**

Long-lived gluino have been constrained by ATLAS/CMS



MoEDAL should be compared with **Pixel dE/dx analyses**

An example of dE/dx analyses:

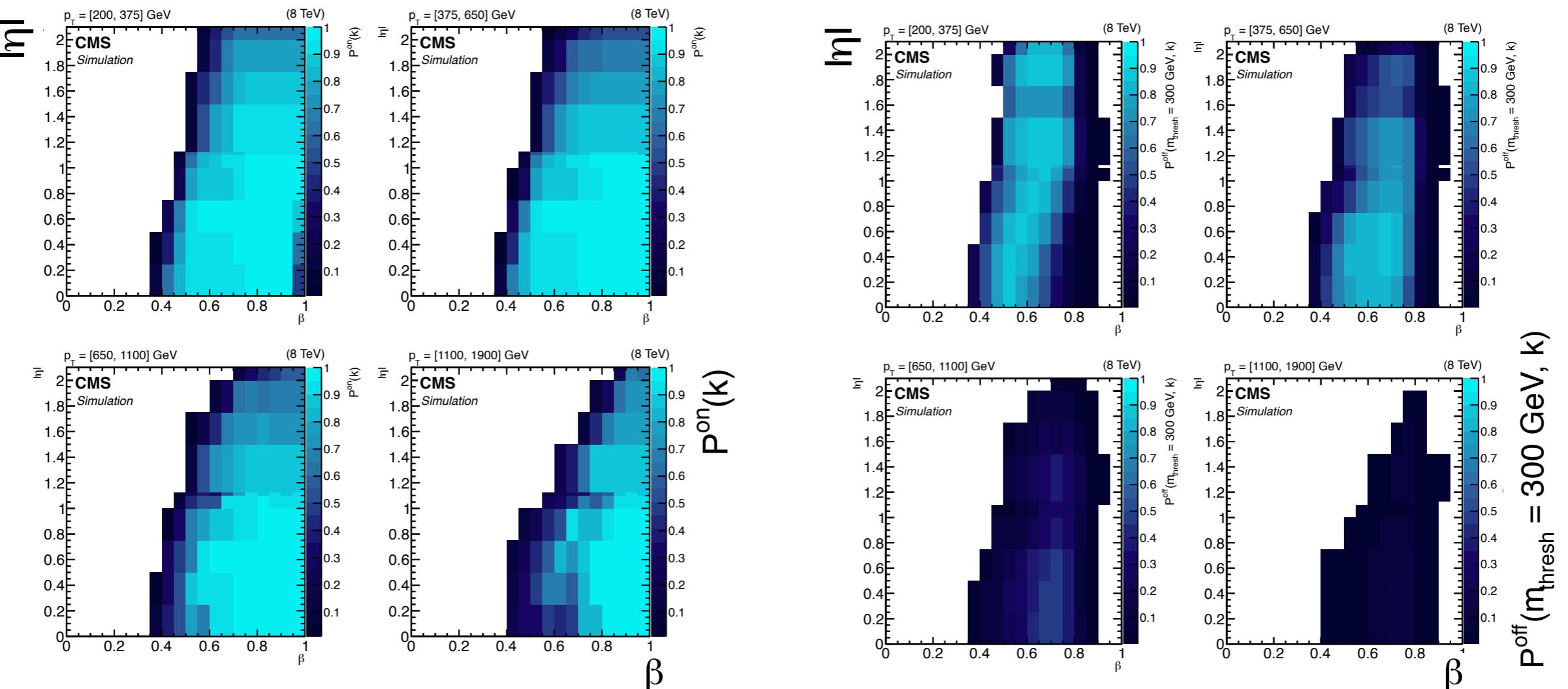
CMS 7/8 TeV [1305.0491]

	tracker+TOF	tracker-only
$ \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
$\sum p_T^{\text{trk}}(\Delta R < 0.3)$ (GeV/c)		<50
# dE/dx measurements		>5
dE/dx strip shape test	yes	
$E_{\text{cal}}(\Delta R < 0.3) / p$	<0.3	
I_h (MeV/cm)		>3.0
ΔR to another track		—

- A recipe to recast the CMS dE/dx search is given by CMS in [1502.02522]
- The key idea is to estimate the total acceptance from the acceptance on each particles:

$$\mathcal{A}_{\text{tot}} = 1 - (1 - \mathcal{A}_1)(1 - \mathcal{A}_2)$$

acceptance
for particle i $\rightarrow \mathcal{A}_i = P_i^{\text{on}}(k_i)P_i^{\text{off}}(k_i)$



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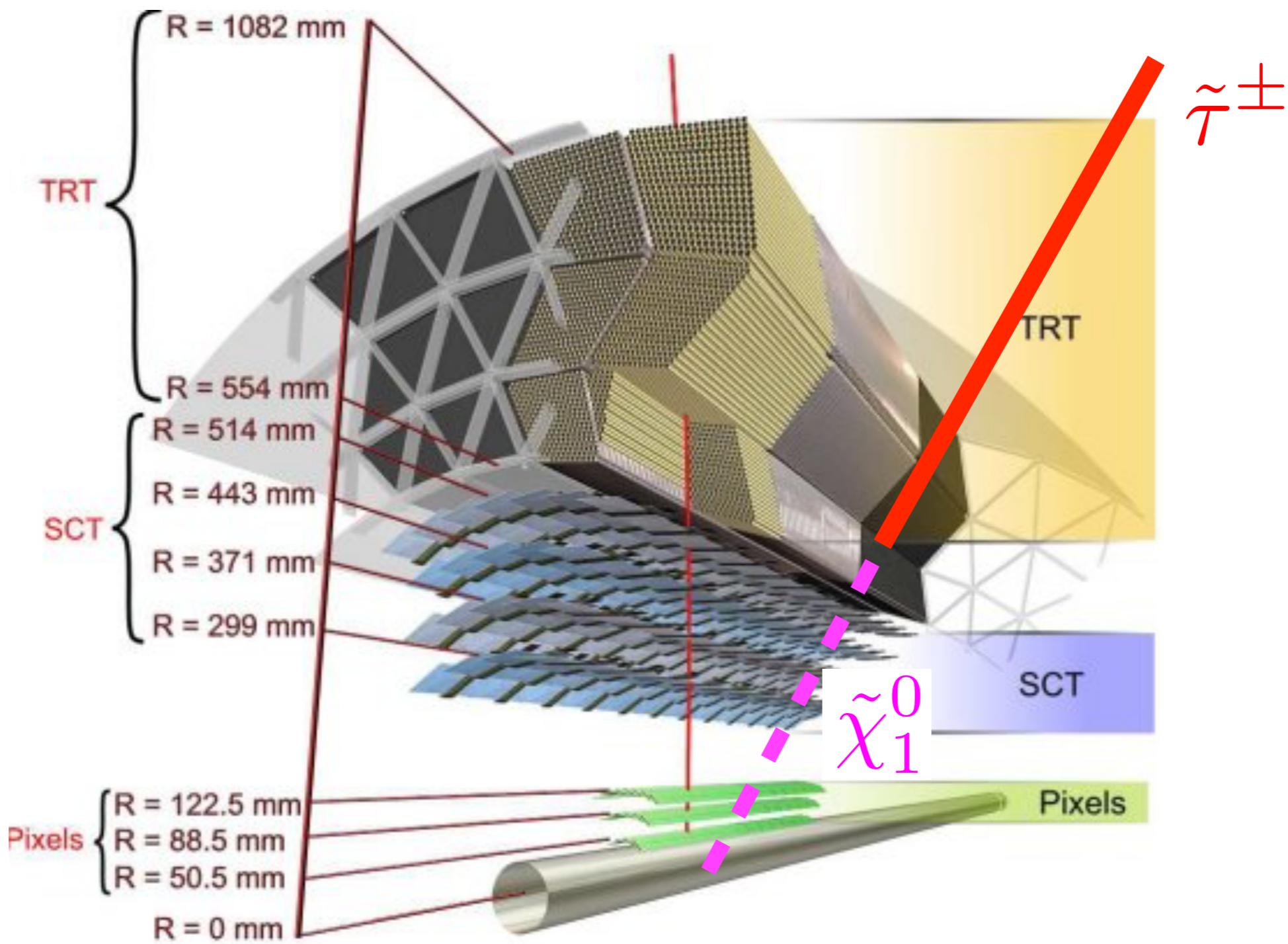
charged particle must be present in the pixel detector

Compressed

$$\tilde{g} \rightarrow q \bar{q} \tilde{\chi}_1^0, \quad \tilde{\chi}_1^0 \rightarrow \tau^\mp \tilde{\tau}_1^\pm$$

long-lived

collider-stable



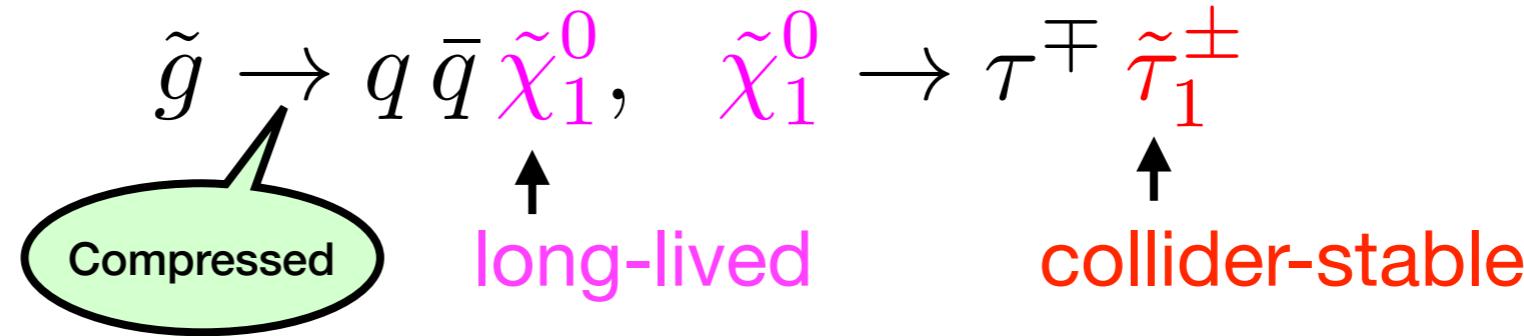
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ΔR to another track		—

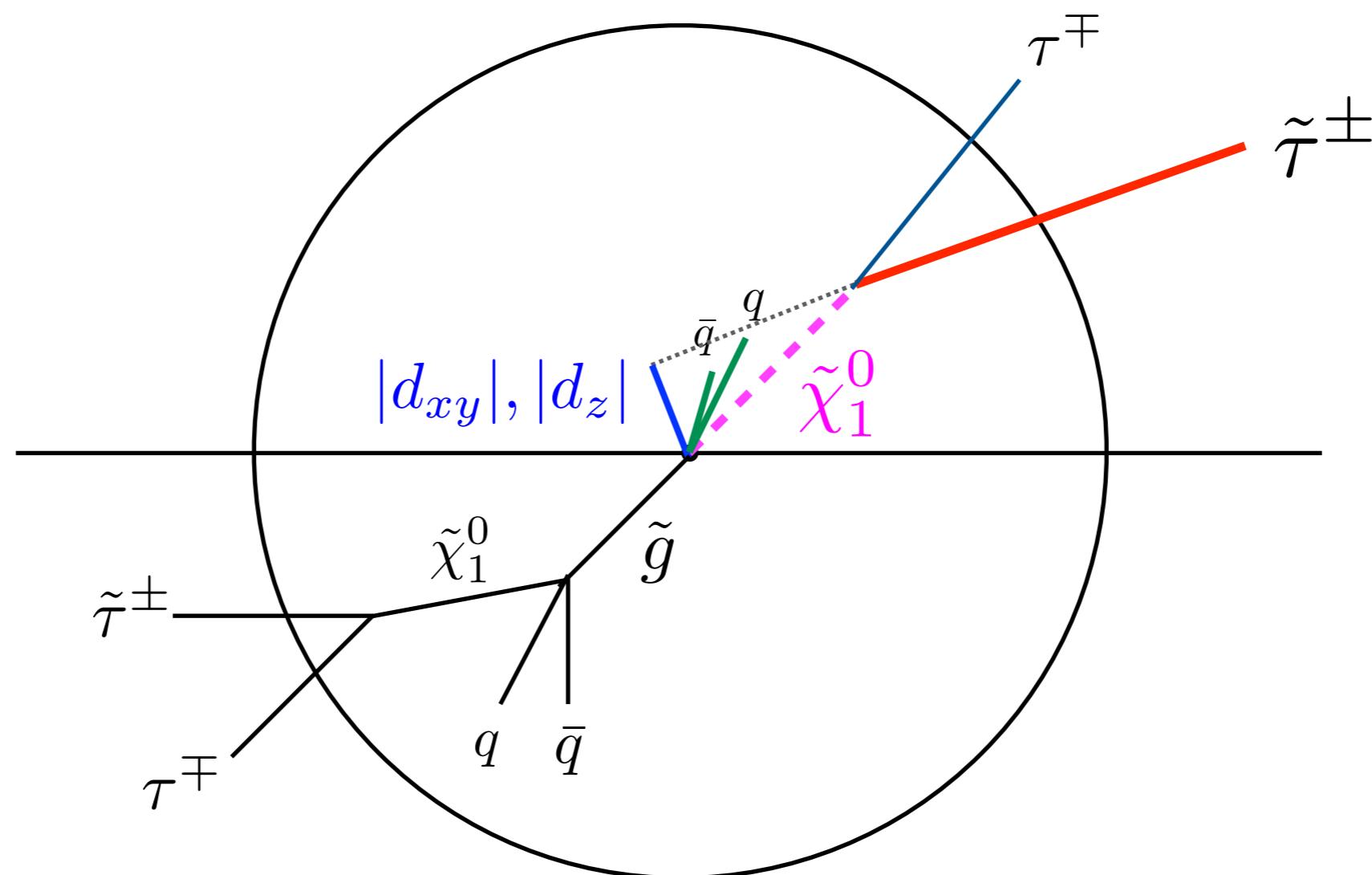
long-lived particle must point to the primary vertex

charged particle must be present in the pixel detector



Neutralino is long-lived despite a *large mass gap*.

$$(m_{\tilde{\chi}_1^0} - m_{\tilde{\tau}_1^\pm} = 300 \text{ GeV})$$

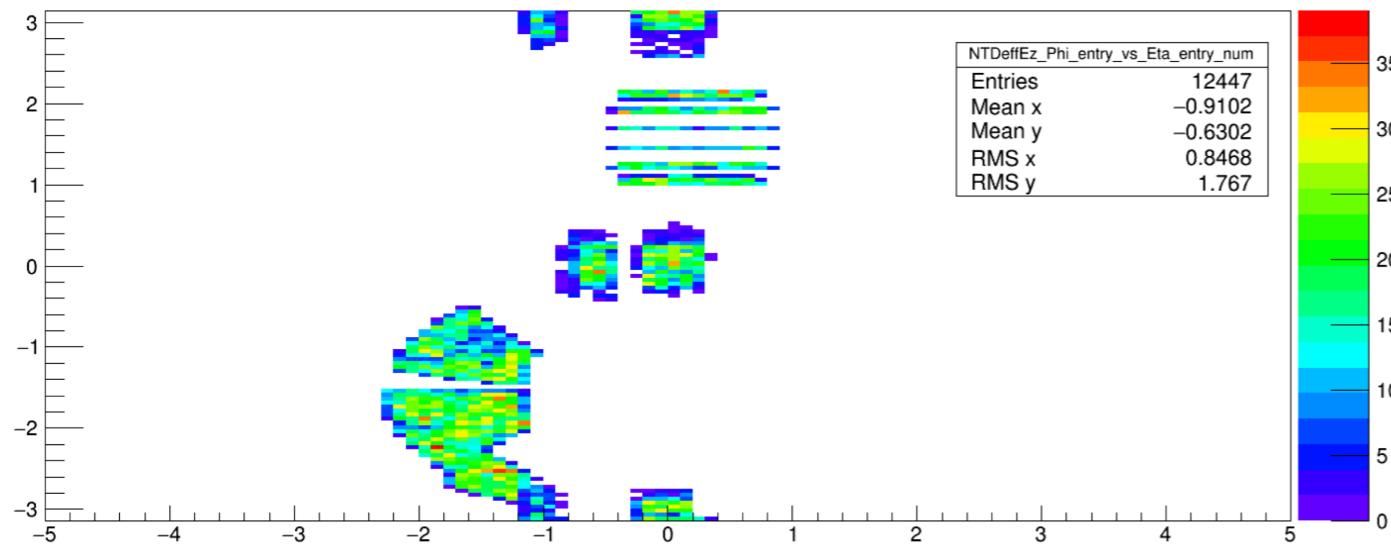


CMS suffers twice: (1) no pixel hit, (2) too large impact parameters

Simulation for MoEDAL

Daniel Felea

position of Nuclear Track Detector (NTD)



- taking into account the geometrical coverage of NTD

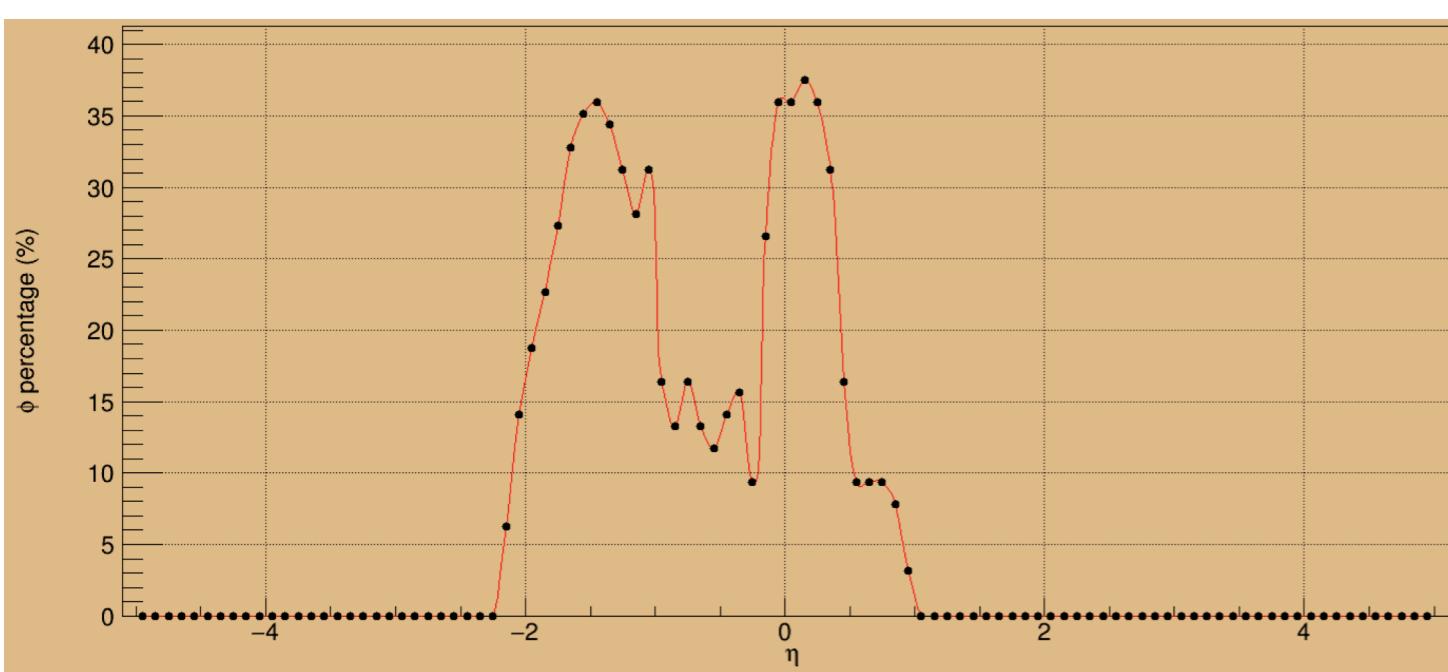
$$\int A(\eta) d\eta \simeq 18.7\%$$

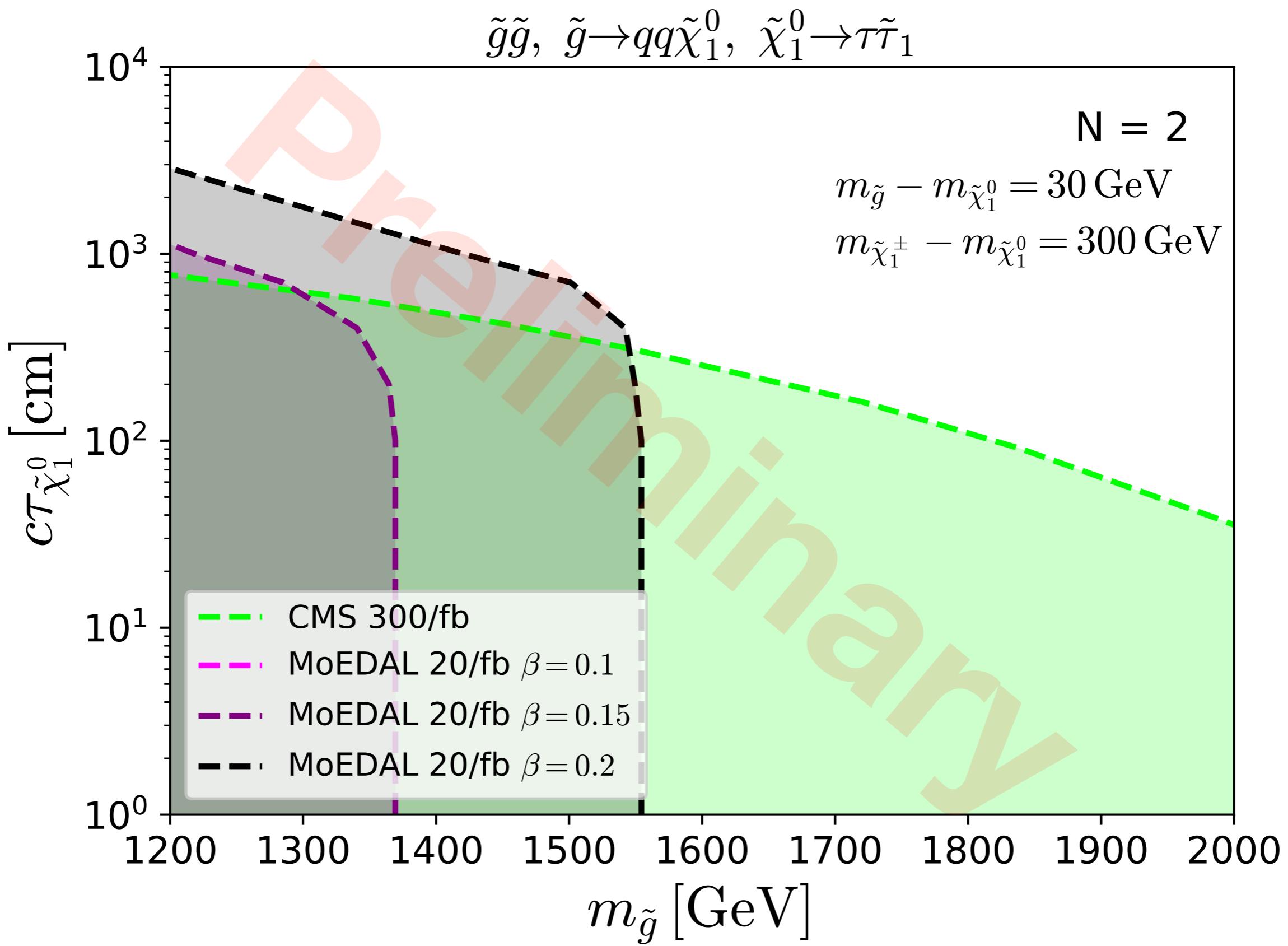
- efficiency is modelled by

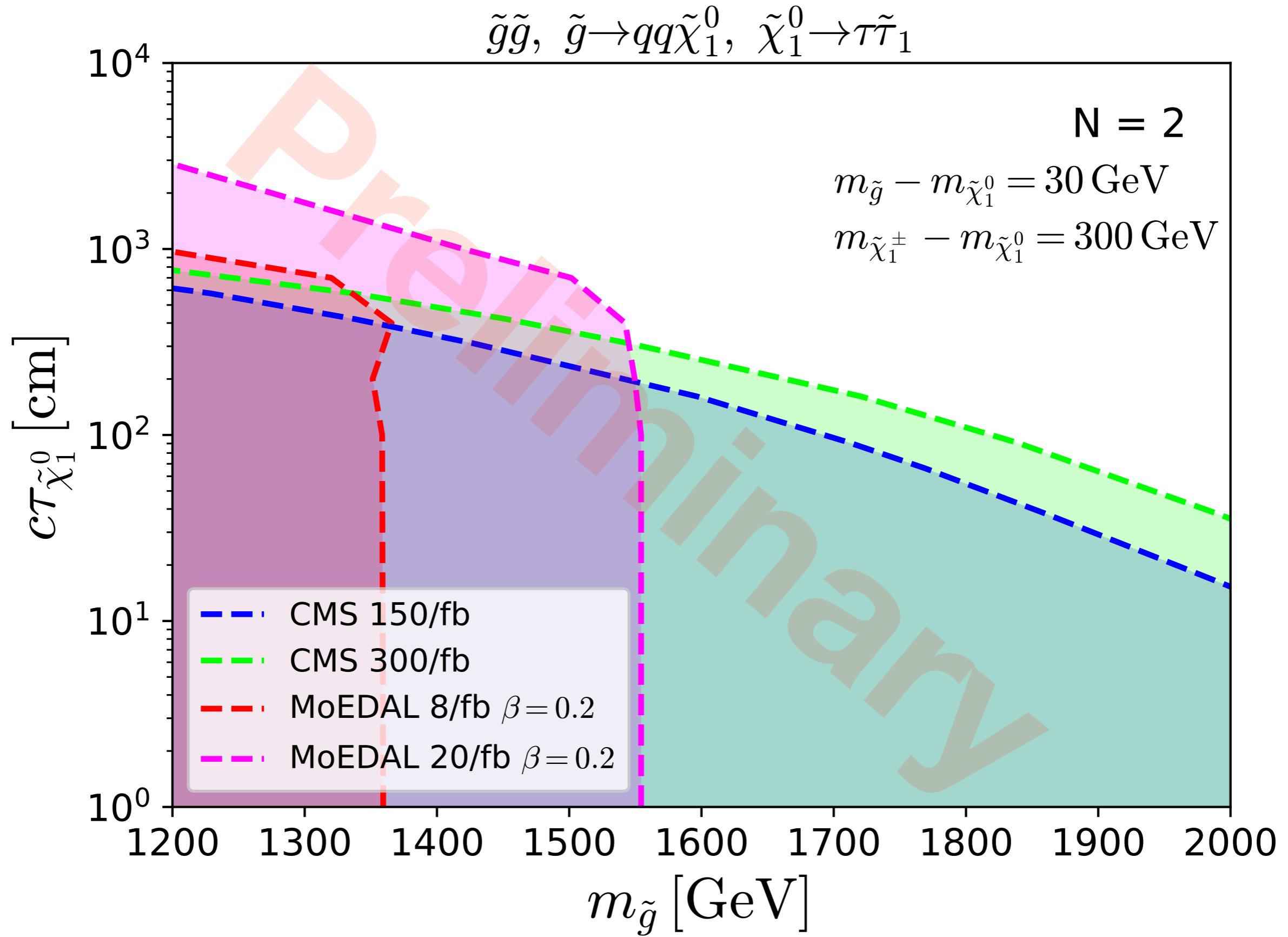
$$\epsilon = \begin{cases} 1 & \beta < \beta_{\text{thr}} \\ 0 & \beta \geq \beta_{\text{thr}} \end{cases}$$

$$\beta_{\text{thr}} = 0.1, 0.15, 0.2$$

- 2 signal events ($N=2$) is used as the discovery criterion







Conclusion

- It is important to look for long-lived BSM particles independently from ATLAS/CMS; in a experiment that has very different systematics, environment, assumptions, ..
- MoEDAL requires ($\beta < 0.2$), implying it is sensitive to a production of heavy fermions with a large cross-section:  **Gluinos!**
- MoEDAL efficiency is about an order of magnitude smaller than ATLAS/CMS dE/dx analyses, and the luminosity is $\sim 5\%$ of ATLAS/CMS:  **Need to look for holes in the ATLAS/CMS analyses.**
- dE/dx analyses require (1) the charged particle to point the primary vertex, (2) a hit in the Pixel detector.
- In a model with long-lived neutralino, we showed MoEDAL may explore the region that is not sensitive to the current ATLAS/CMS analyses.

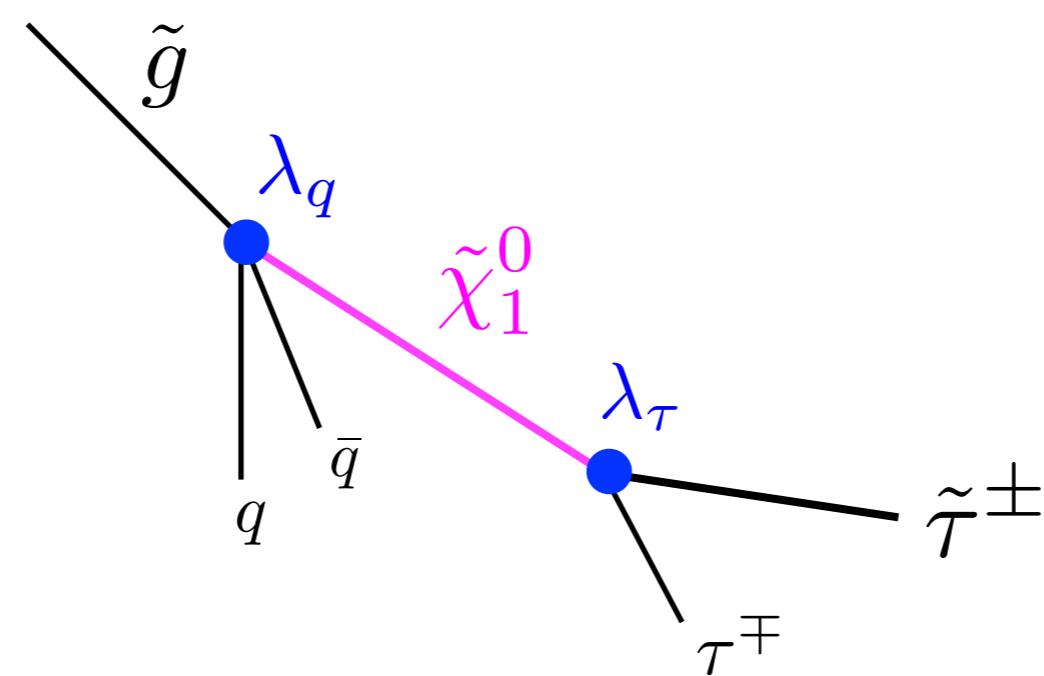
Backup

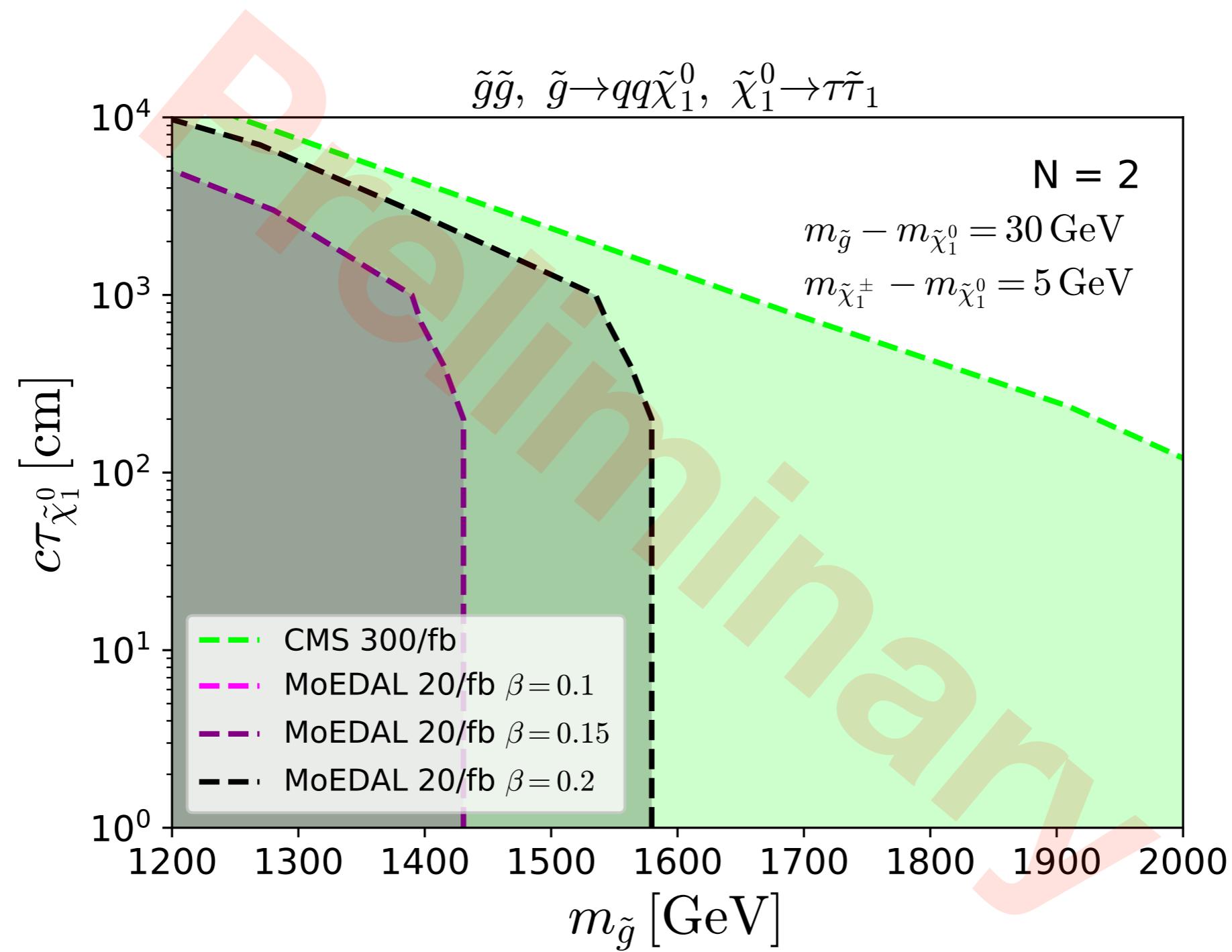
$$\tilde{g} \rightarrow q \bar{q} \tilde{\chi}_1^0, \quad \tilde{\chi}_1^0 \rightarrow \tau^\mp \tilde{\tau}_1^\pm$$

- How can one realise this simplified model?
- How can one make neutralino long-lived keeping a large mass gap?

An example: introduce a doublet D (and \bar{D}): $D = (\tilde{\chi}_1^0, \tilde{\chi}^-)$

$$W \ni \lambda_q Q d_R^c D + \lambda_\tau L \tau_R^c D$$





(1502.02522)

Table 2: Signal acceptance estimated from the fast technique and with the full simulation of the detector, as well as the corresponding expected and observed cross section limits. Results are provided for both the pair production and the inclusive production of staus as predicted by the GMSB model. The mass threshold, the corresponding expected background and the observed numbers of events is also shown.

Mass (GeV)	m_{thresh} (GeV)	Predicted backgrounds	Data counts	Full simulation			Fast technique		
				Acc.	Exp. (fb)	Obs. (fb)	Acc.	Exp. (fb)	Obs. (fb)
Pair production of staus									
126	0	44 ± 9	42	0.24	4.38	4.11	0.24	4.53	4.24
156	0	44 ± 9	42	0.28	3.66	3.43	0.29	3.81	3.57
200	100	5.6 ± 1.1	7	0.34	1.06	1.28	0.35	1.08	1.30
247	100	5.6 ± 1.1	7	0.40	0.90	1.09	0.40	0.93	1.13
308	100	5.6 ± 1.1	7	0.46	0.77	0.93	0.47	0.79	0.96
370	200	0.56 ± 0.11	0	0.53	0.41	0.31	0.53	0.42	0.32
494	200	0.56 ± 0.11	0	0.61	0.36	0.27	0.62	0.37	0.28
745	300	0.09 ± 0.02	0	0.66	0.24	0.24	0.67	0.25	0.24
1029	300	0.09 ± 0.02	0	0.58	0.28	0.27	0.59	0.28	0.27
Inclusive production of staus									
126	0	44 ± 9	42	0.25	4.22	3.95	0.25	4.43	4.15
156	0	44 ± 9	42	0.32	3.21	3.01	0.32	3.38	3.16
200	100	5.6 ± 1.1	7	0.41	0.87	1.05	0.42	0.90	1.09
247	100	5.6 ± 1.1	7	0.50	0.72	0.87	0.50	0.76	0.91
308	100	5.6 ± 1.1	7	0.56	0.64	0.77	0.56	0.67	0.81
370	200	0.56 ± 0.11	0	0.60	0.36	0.27	0.60	0.37	0.28
494	200	0.56 ± 0.11	0	0.66	0.33	0.25	0.65	0.35	0.26
745	300	0.09 ± 0.02	0	0.67	0.24	0.23	0.67	0.25	0.24
1029	300	0.09 ± 0.02	0	0.58	0.28	0.27	0.58	0.29	0.28

