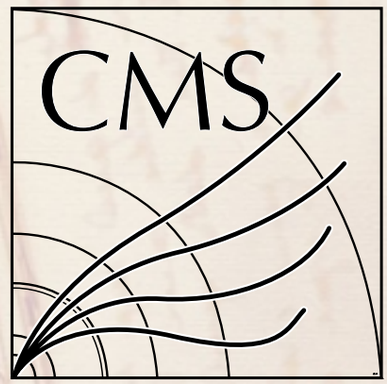
CMS results on searches for long-lived particles

Ted Kolberg (FSU) for the CMS collaboration

Aspen, 26 March 2018



Overview

Focus on four recent results:

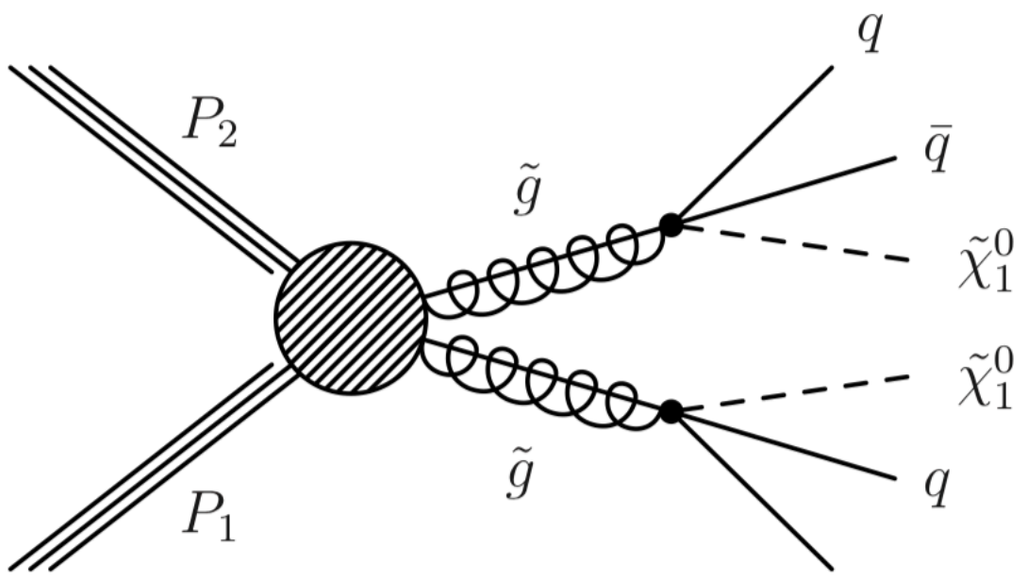
- α_T long-lived interpretation [CMS-SUS-16-038]
- Disappearing track [CMS-EXO-16-044]
- Stopped particles, muon channel [CMS-EXO-17-004]
- Inclusive displaced jets [CMS-EXO-16-003, accepted by PLB]

Conclude with a few remarks about what to expect in the next years.

α_T long-lived: motivation

$$\alpha_T = E_T^{j_2} / M_T$$

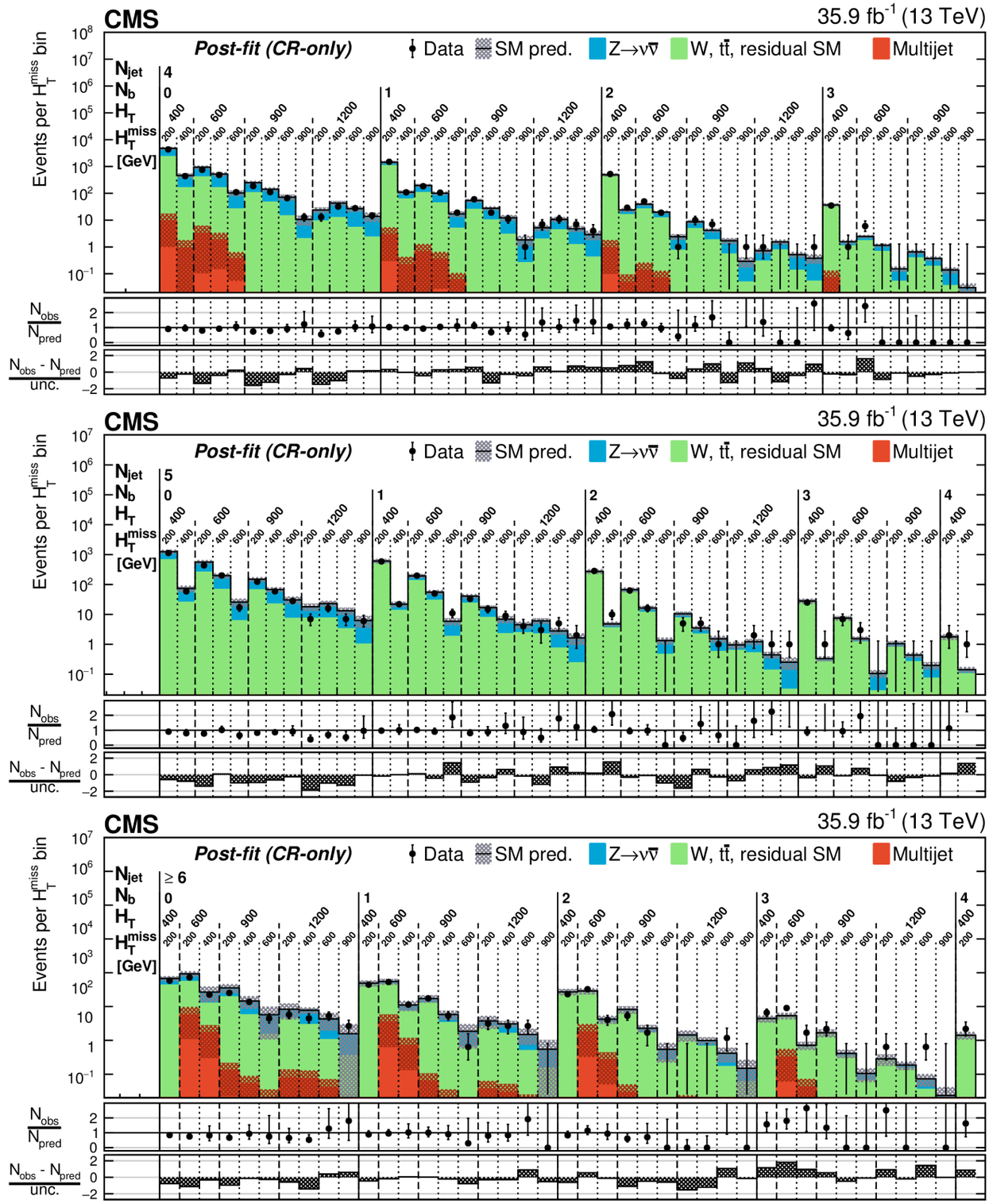
- Long history in CMS SUSY analysis.
- Overlap of prompt and displaced techniques?
- Short and long lifetimes.



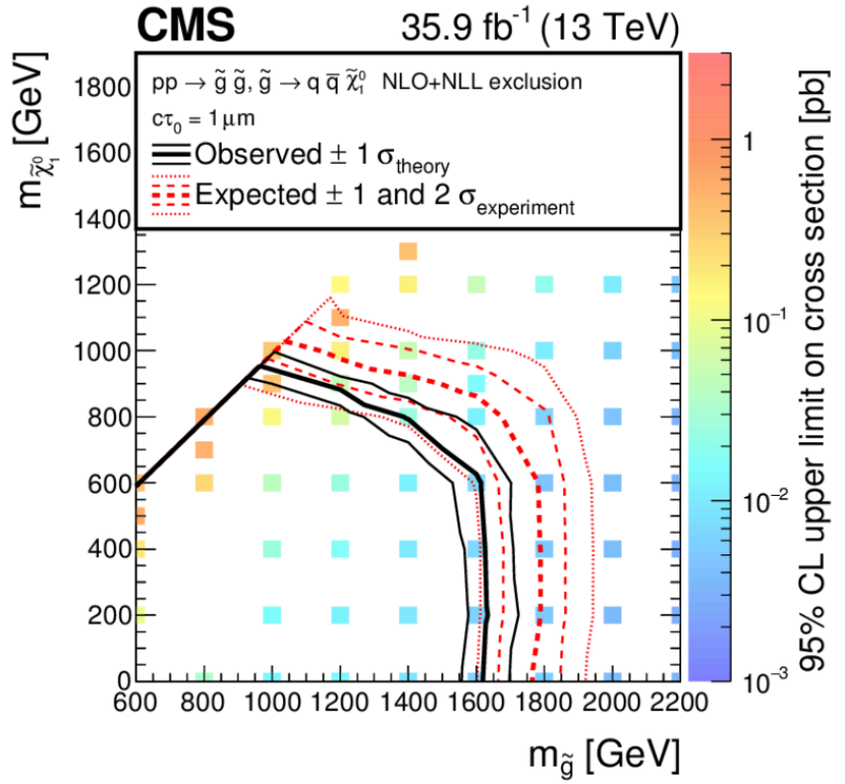
"T1qqqqLL"

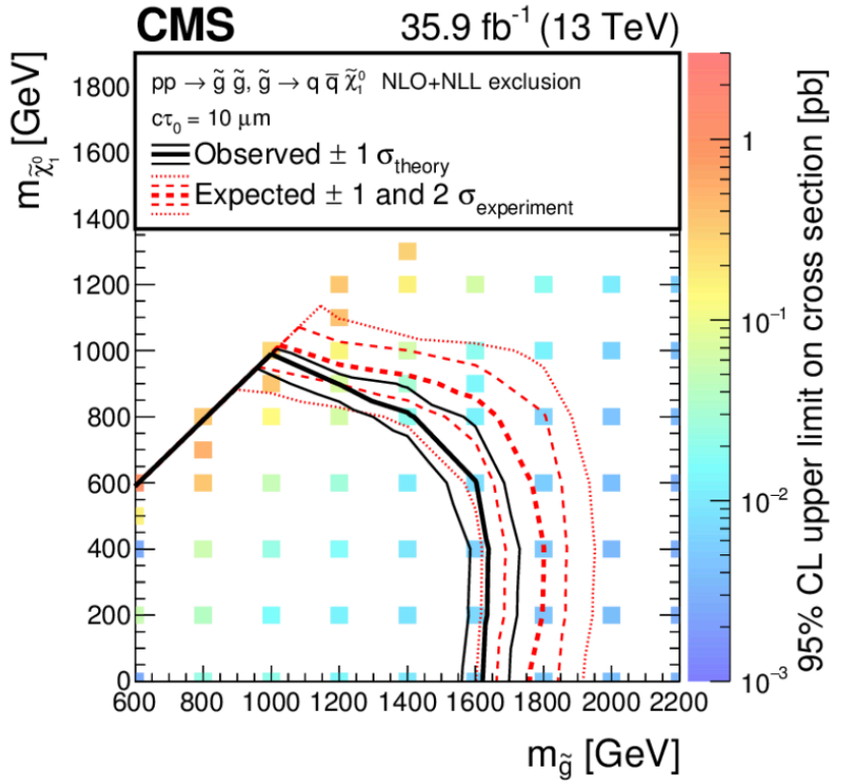
α_T long-lived: highly optimized

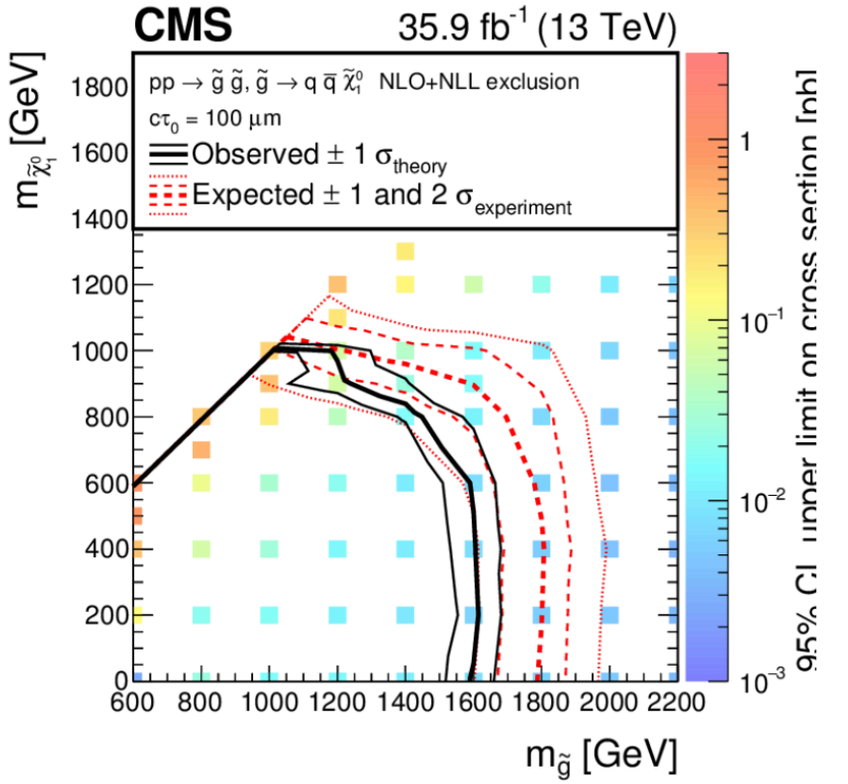
n_{jet}	n_b	H_T [GeV]				
		200	400	600	900	1200
1	0	200	400	600	900	—
1	1	200	400	600	—	—
$\geq 2a$	0	200	200, 400	200, 400, 600	200, 900	—
$\geq 2a$	1	200	200, 400	200, 400, 600	200, 900	—
$\geq 2a$	2	200	200, 400	200, 400, 600	200, 900	—
$\geq 2a$	≥ 3	200	200, 400	200, 400, 600	—	—
2	0	200	200, 400	200, 400, 600	200, 400, 600, 900	200, 400, 600, 900
2	1	200	200, 400	200, 400, 600	200, 400, 600, 900	200, 400, 600, 900
2	2	200	200, 400	200, 400, 600	—	—
3	0	200	200, 400	200, 400, 600	200, 400, 600, 900	200, 400, 600, 900
3	1	200	200, 400	200, 400, 600	200, 400, 600, 900	200, 400, 600, 900
3	2	200	200, 400	200, 400, 600	200, 400, 600, 900	200, 400, 600, 900
3	3	200	200, 400	200, 400, 600	—	—
4	0	—	200, 400	200, 400, 600	200, 400, 600, 900	200, 400, 600, 900
4	1	—	200, 400	200, 400, 600	200, 400, 600, 900	200, 400, 600, 900
4	2	—	200, 400	200, 400, 600	200, 400, 600, 900	200, 400, 600, 900
4	≥ 3	—	200, 400	200, 400, 600	200, 400, 600, 900	—
5	0	—	200, 400	200, 400, 600	200, 400, 600	200, 400, 600, 900
5	1	—	200, 400	200, 400, 600	200, 400, 600	200, 400, 600, 900
5	2	—	200, 400	200, 400, 600	200, 400, 600	200, 400, 600, 900
5	3	—	200, 400	200, 400, 600	200, 400, 600	—
5	≥ 4	—	200, 400	—	—	—
≥ 6	0	—	200	200, 400	200, 400, 600	200, 400, 600, 900
≥ 6	1	—	200	200, 400	200, 400, 600	200, 400, 600, 900
≥ 6	2	—	200	200, 400	200, 400, 600	200, 400, 600, 900
≥ 6	3	—	200	200, 400	200, 400, 600	200, 400, 600, 900
≥ 6	≥ 4	—	200	—	—	—



α_T long-lived: interpretations

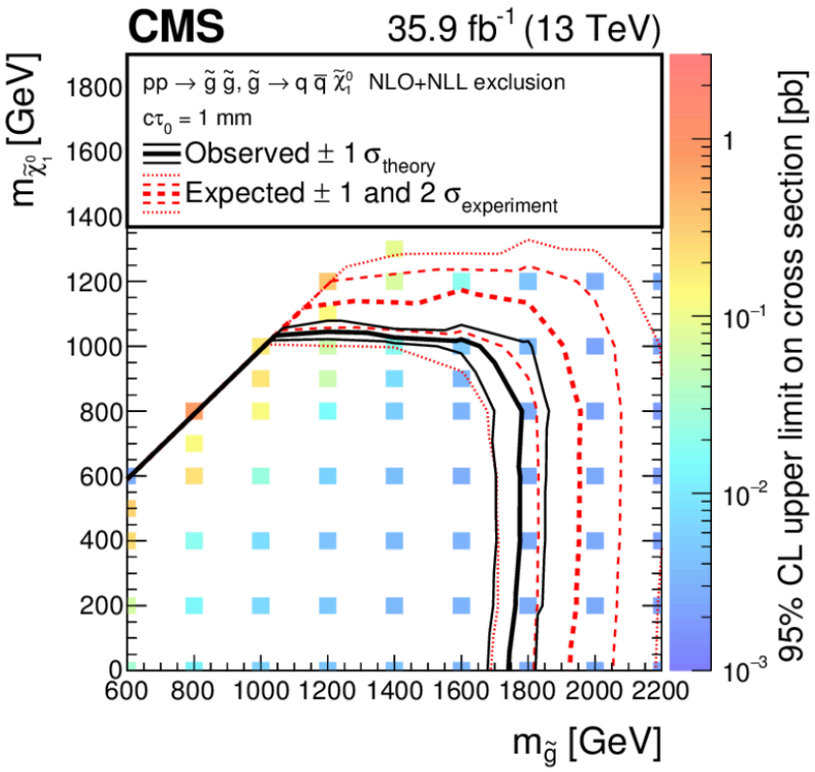


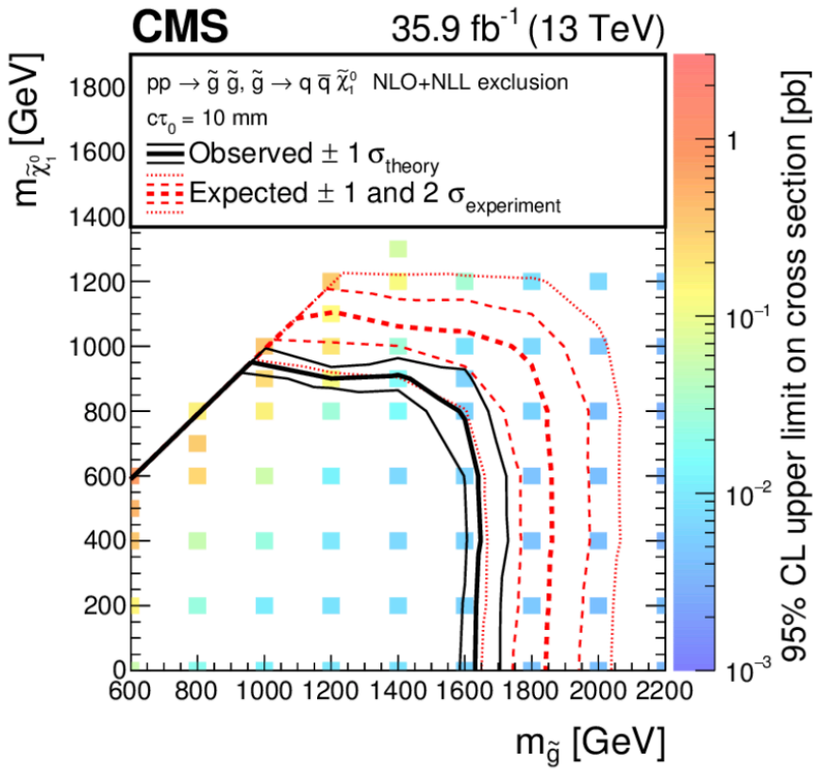


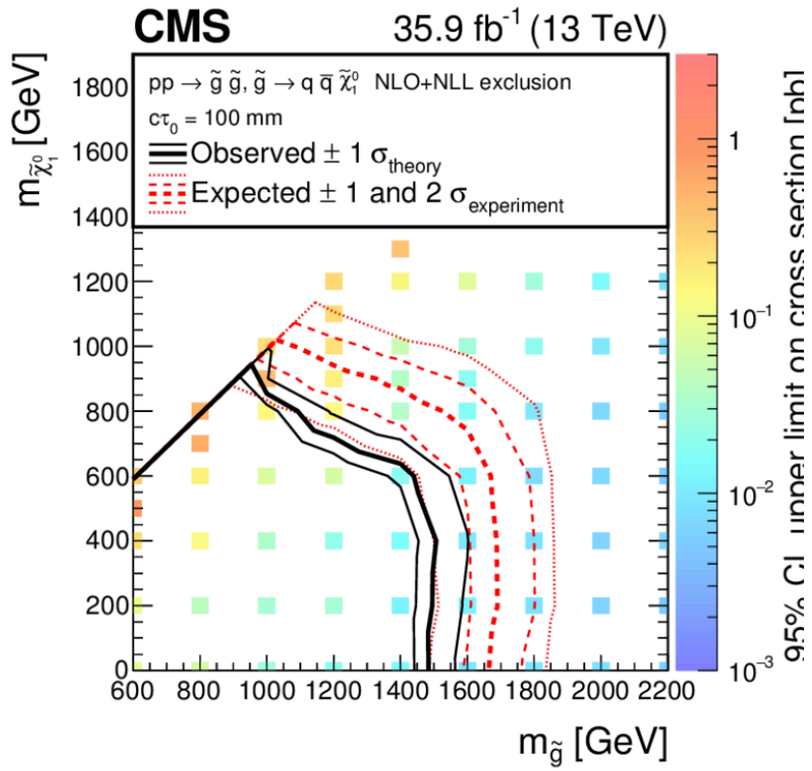


Prompt-like

α_T long-lived: interpretations

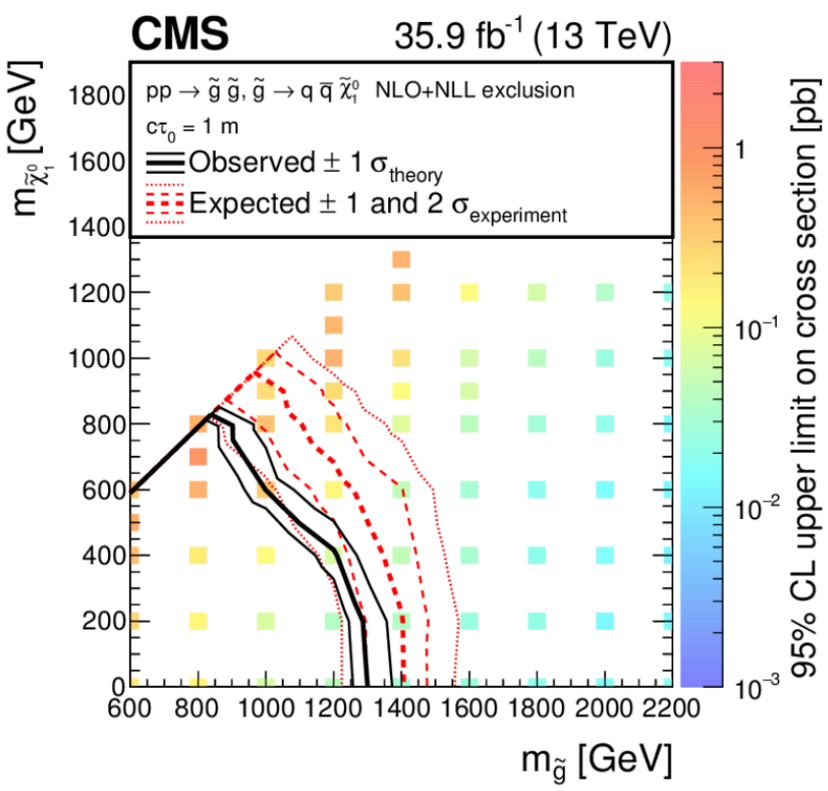


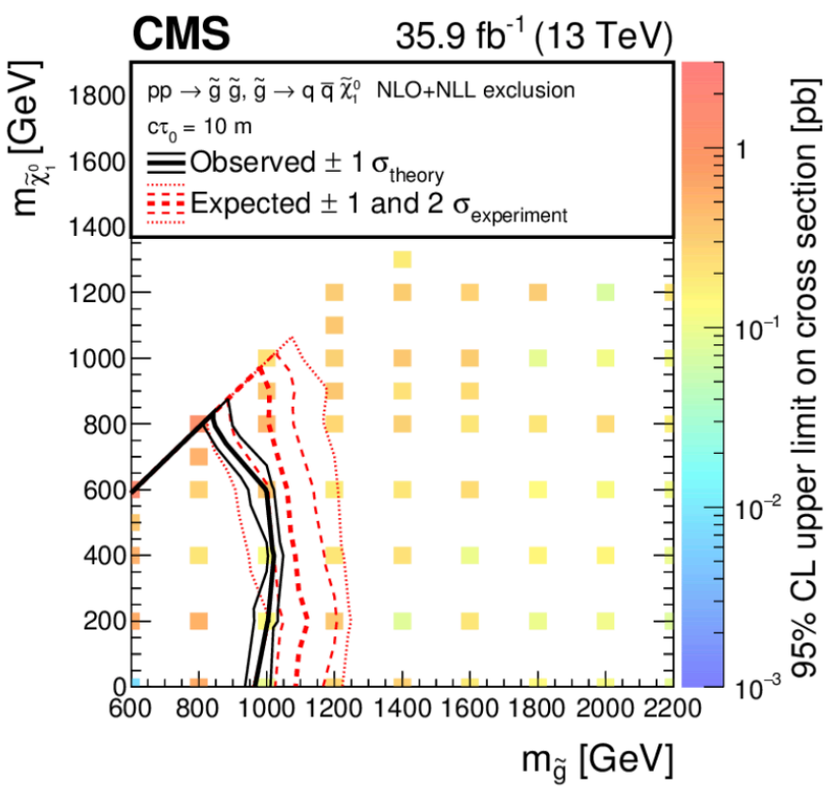


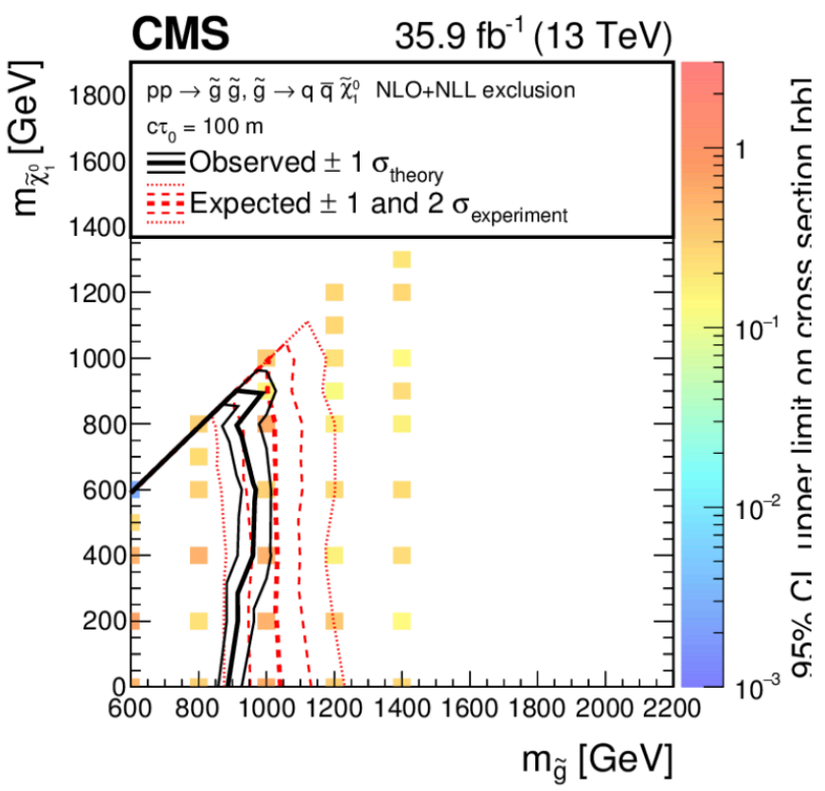


Losing acceptance of jets

α_T long-lived: interpretations

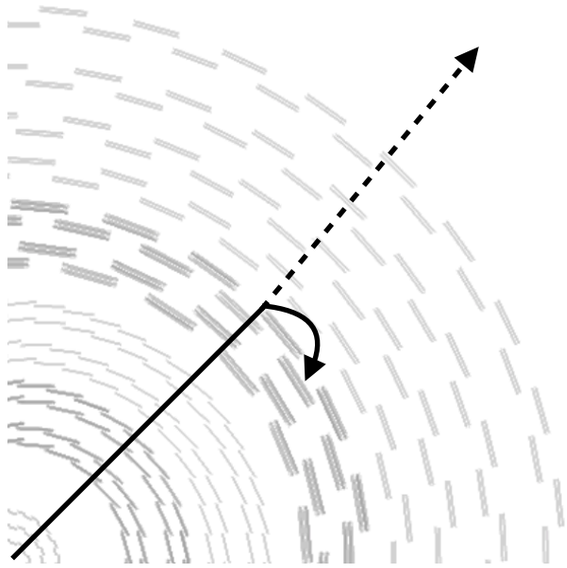






ISR+MET

Disappearing track: motivation



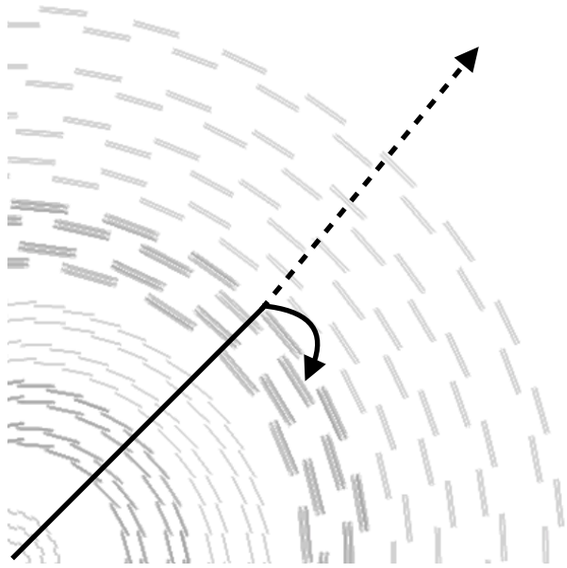
Very small (≲ 100s MeV) mass splitting

long lived state

typically too soft to fully reconstruct.

AMSB, GMSB, etc.

Disappearing track: challenges



A spectacular signal of new physics, but...

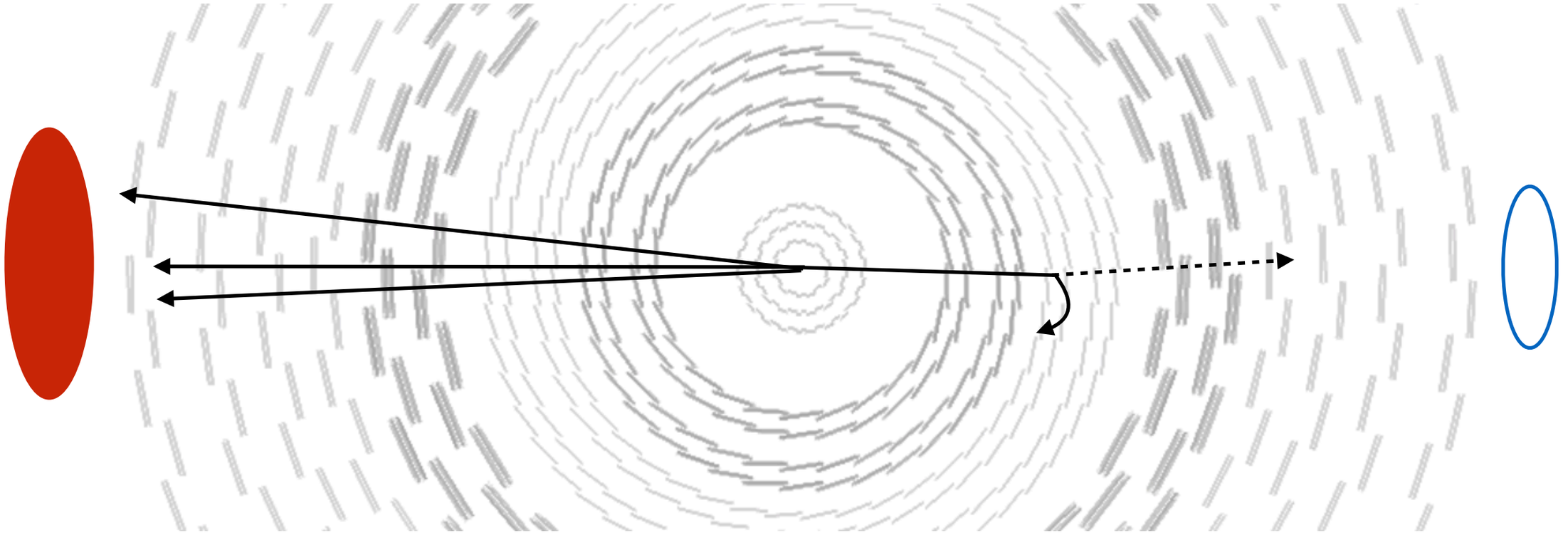
- Low cross section production mechanisms for L1.
- Pattern recognition failures.
- Material interactions.

Disappearing track: trigger

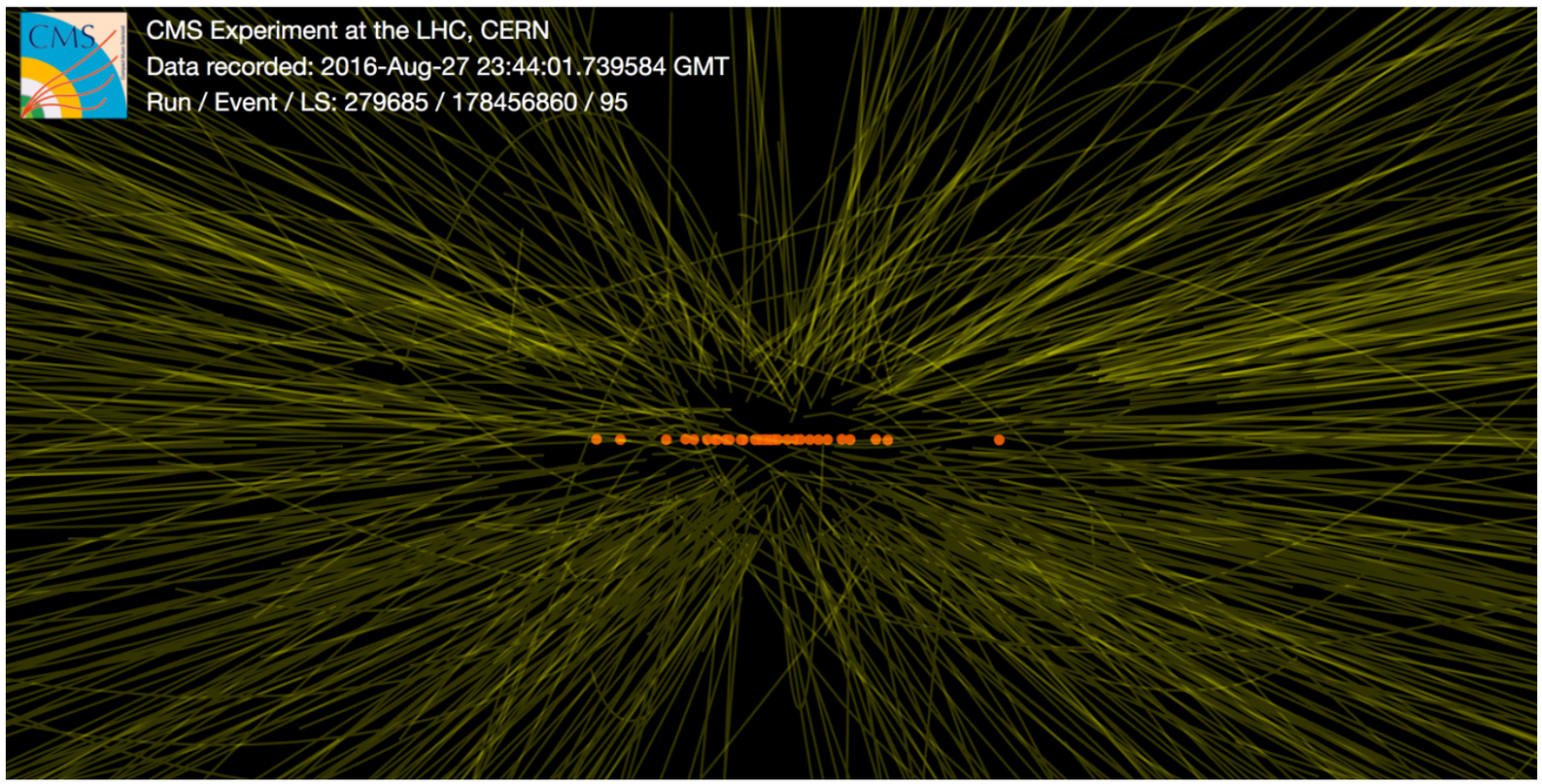
Missing energy produced by an ISR jet.

High momentum isolated track at the HLT.

MET > 75 GeV, iso. track p_T > 50 GeV



Disappearing track: backgrounds

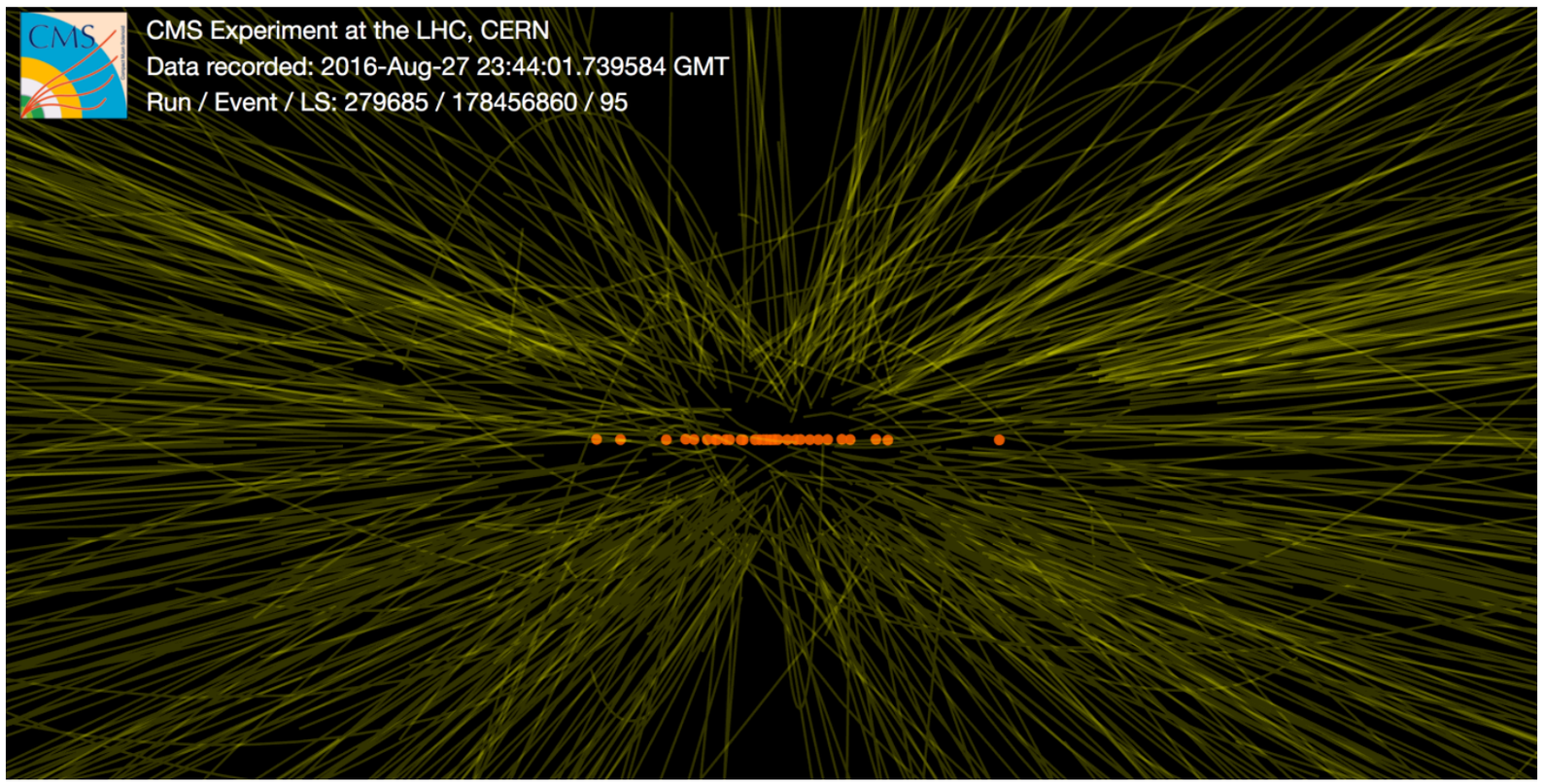


'Spurious tracks'

A random combinations of hits.

Can pass the isolation requirement.

Disappearing track: backgrounds



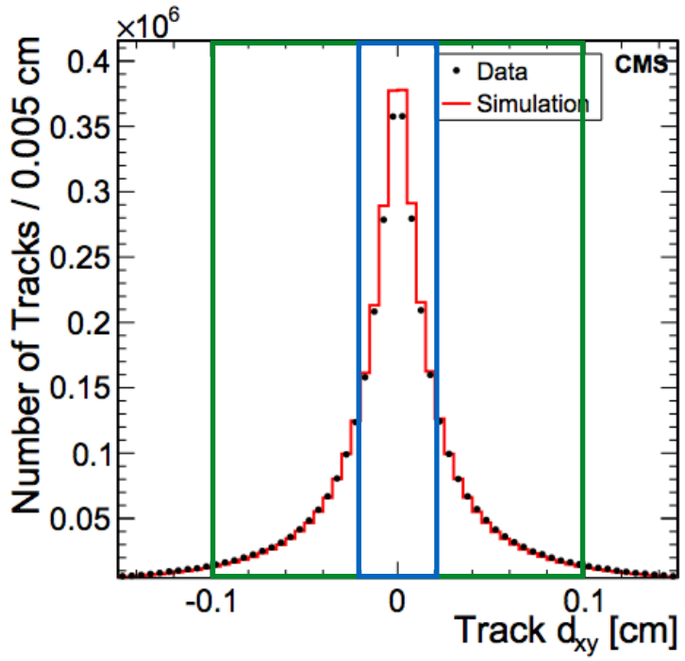
At least seven (three) tracker (pixel) hits, and no missing inner hits.

Transverse impact parameter consistent with the PV.

Disappearing track: backgrounds

- Clean sample of $Z \rightarrow \mu\mu$.
- Sideband selection.
- Measure the probability for spurious tracks.
- Transfer factor to pass the impact parameter requirement.

$$N_{est}^{spurious} = N_{basic}^{ctrl} P_{spurious}$$



Disappearing track: backgrounds

Real high momentum isolated tracks are primarily leptons.

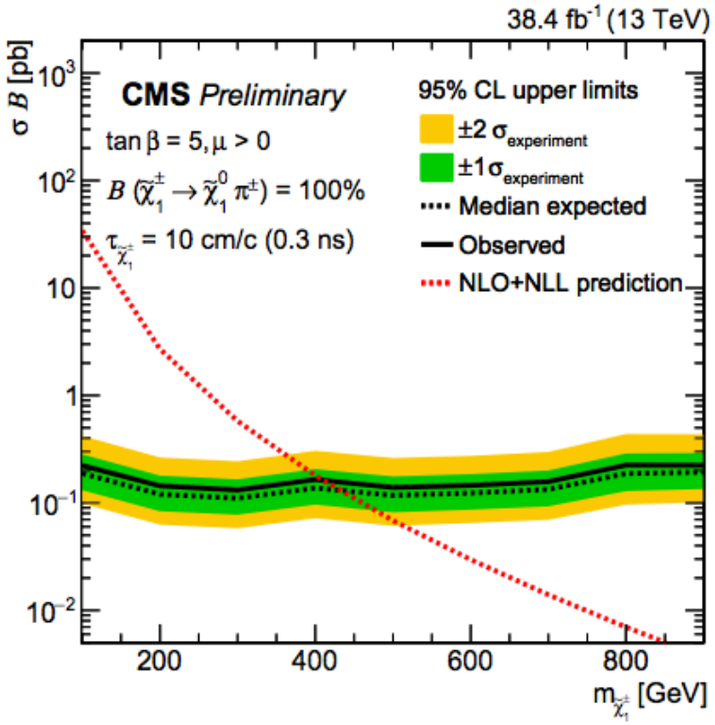
Product of two probabilities:

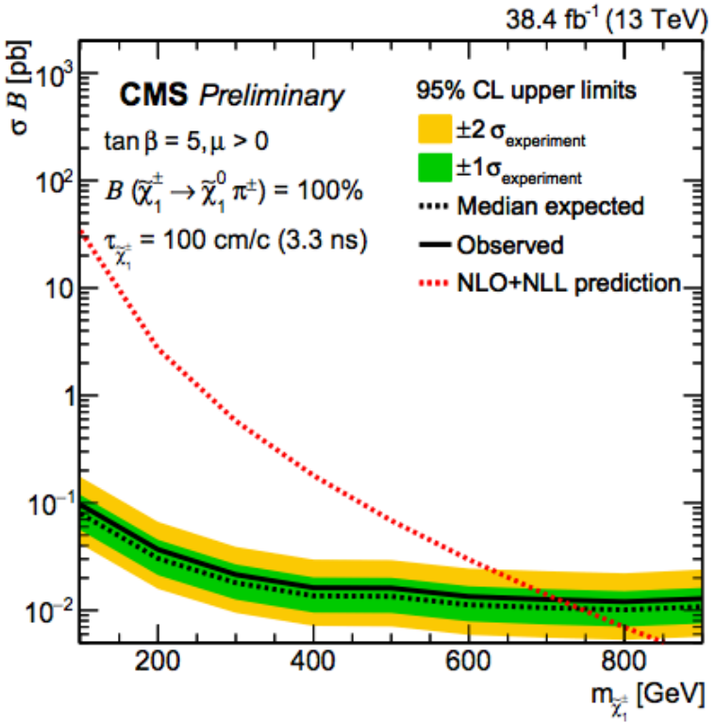
- Not to be reconstructed, and
- … pass the isolated track and MET requirements.

Disappearing track: results

Run period	Estimated number of background events			Observed events
	Leptons	Spurious tracks	Total	
2015	0.1 ± 0.1	$0^{+0.1}_{-0}$	0.1 ± 0.1	1
2016A	$2.0 \pm 0.4 \pm 0.1$	$0.4 \pm 0.2 \pm 0.4$	$2.4 \pm 0.5 \pm 0.4$	2
2016B	$3.1 \pm 0.6 \pm 0.2$	$0.9 \pm 0.4 \pm 0.9$	$4.0 \pm 0.7 \pm 0.9$	4
Total	$5.2 \pm 0.8 \pm 0.3$	$1.3 \pm 0.4 \pm 1.0$	$6.5 \pm 0.9 \pm 1.0$	7

Disappearing track: interpretation





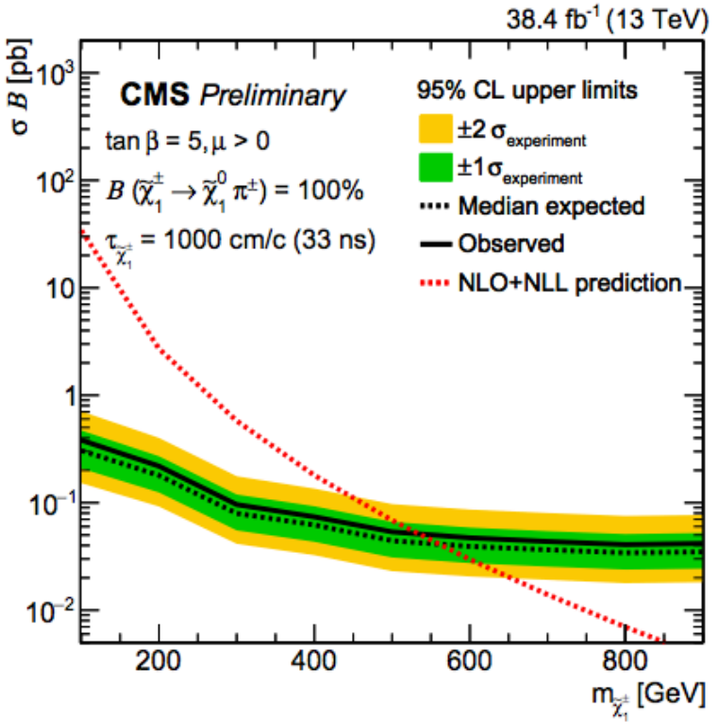
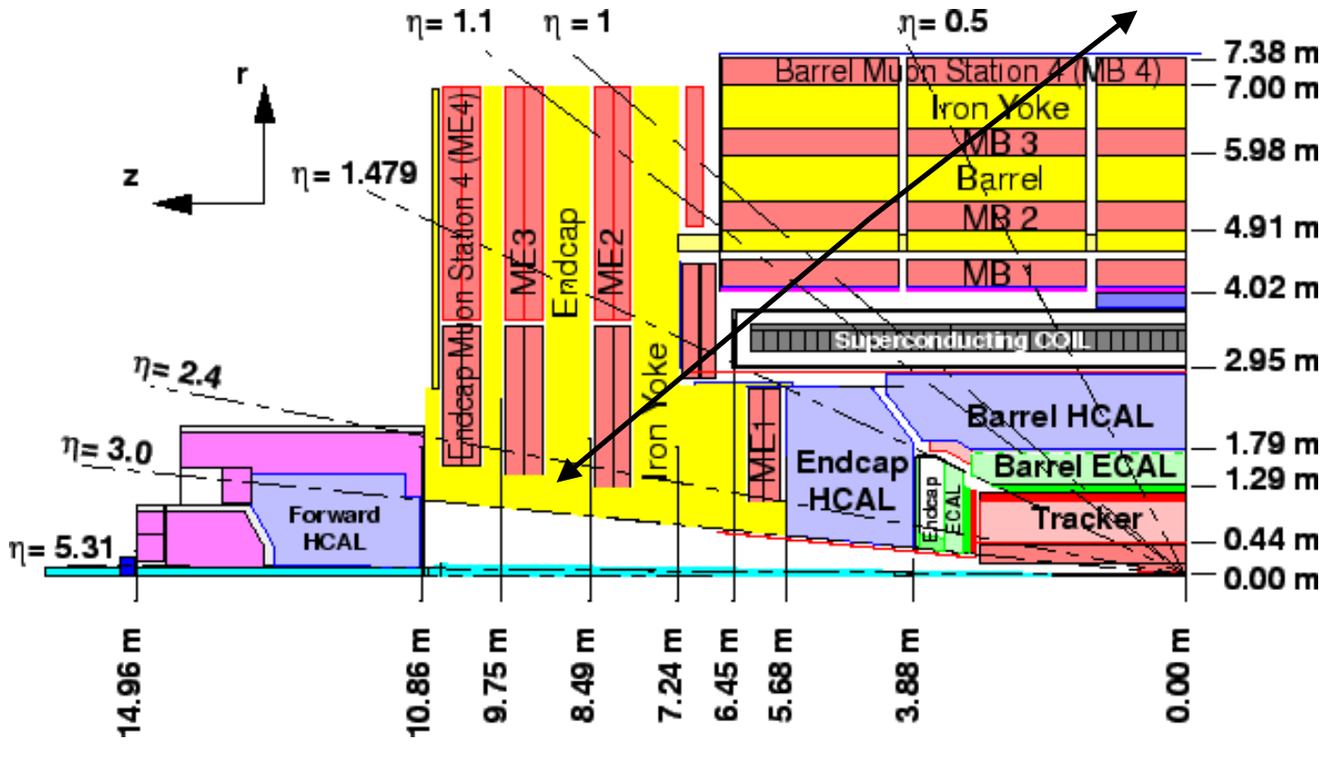


Figure 3: The expected and observed 95% CL upper limits on the product of the cross section of direct chargino production and branching fraction to $\tilde{\chi}_1^0\pi^\pm$ as a function of chargino mass for various chargino lifetimes. The direct chargino production cross section includes both $\tilde{\chi}_1^0\tilde{\chi}_1^\pm$ and $\tilde{\chi}_1^\pm\tilde{\chi}_1^\mp$ production in roughly a 2:1 ratio across all chargino masses considered.

Stopped particle: motivation

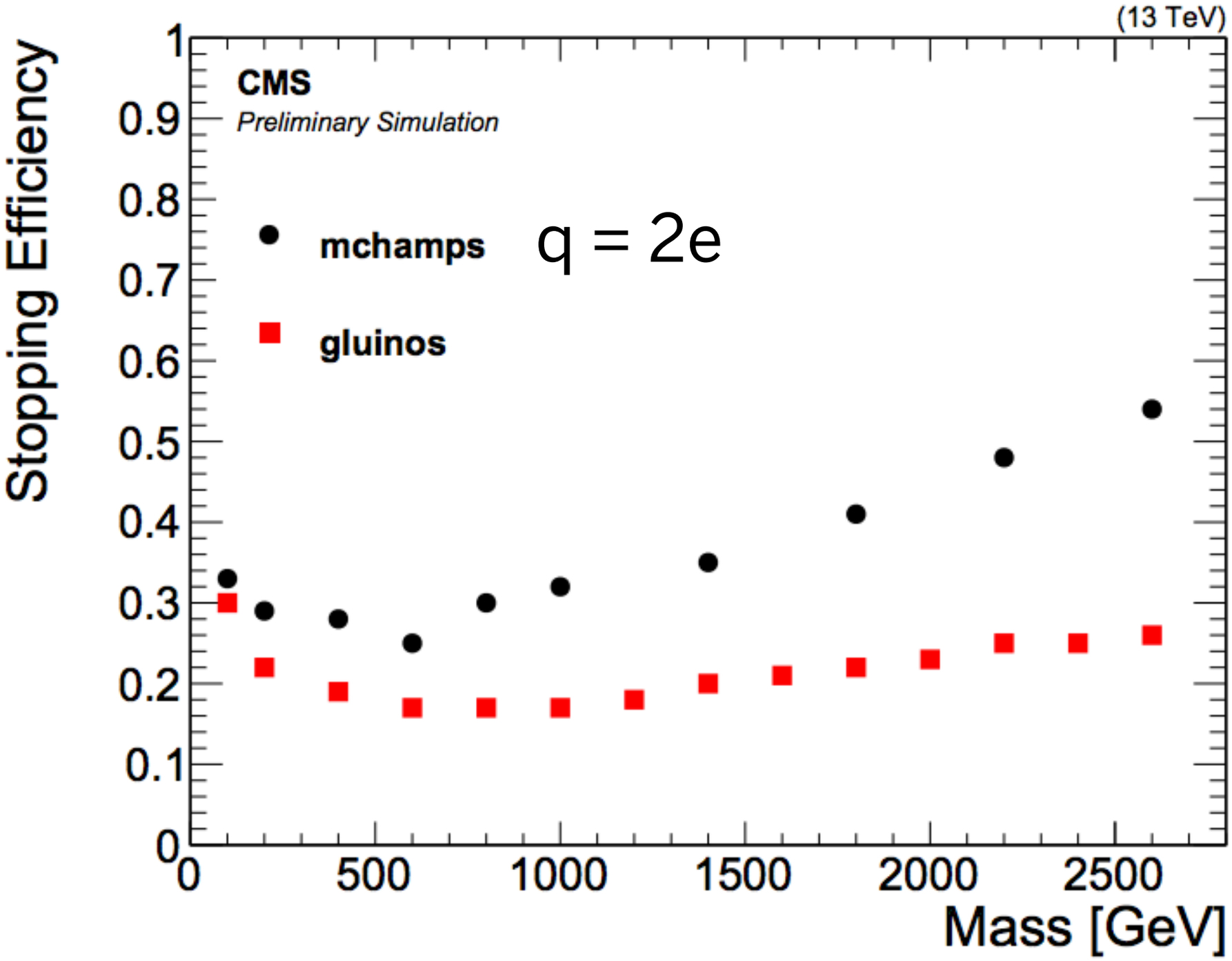


LLPs may come to rest and decay seconds, days, or weeks later.

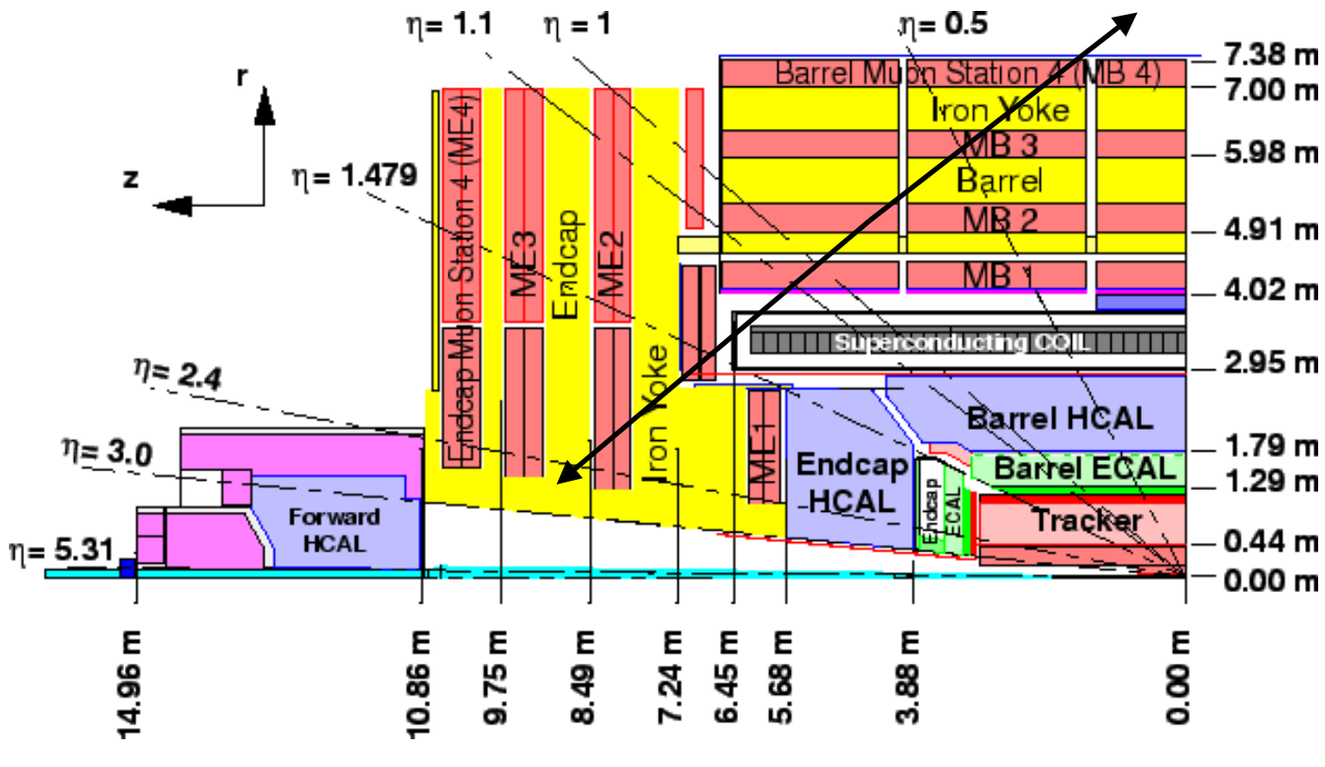
CMS limit of 1 TeV on long-lived gluinos [EPJC 75 (2015) 151] (dijet decay).

What if they decay leptonically? Gluinos, MCHAMPs, etc...

Stopped particles: P_{stop}



Stopped particle: challenges



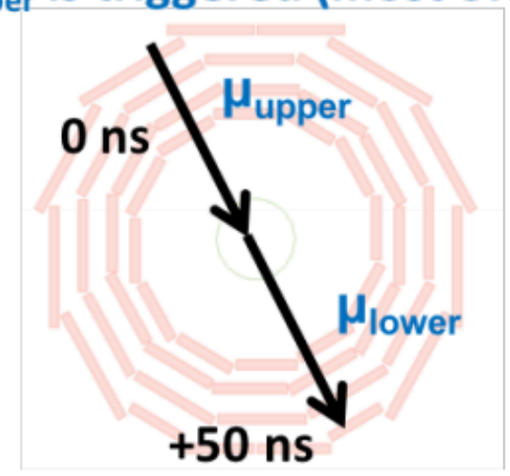
Analysis requires care:

- Trigger for out-of-time muons.
- Maximize the live time.
- Cosmic rays.

Stopped particle: identification

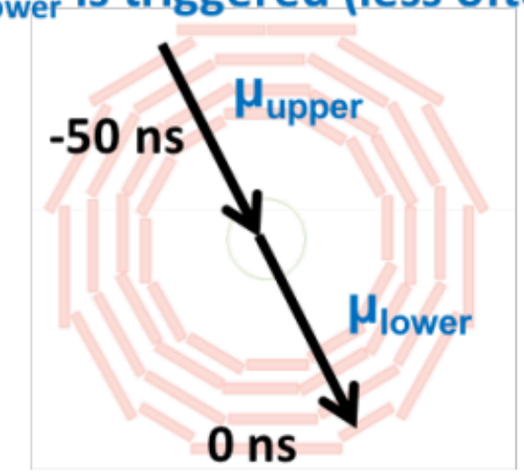
Cosmics

μ_{upper} is triggered (most often)

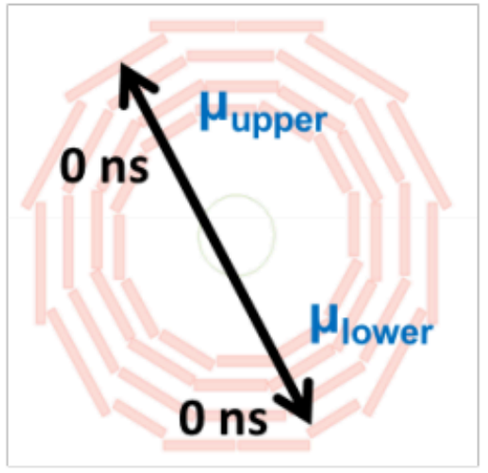


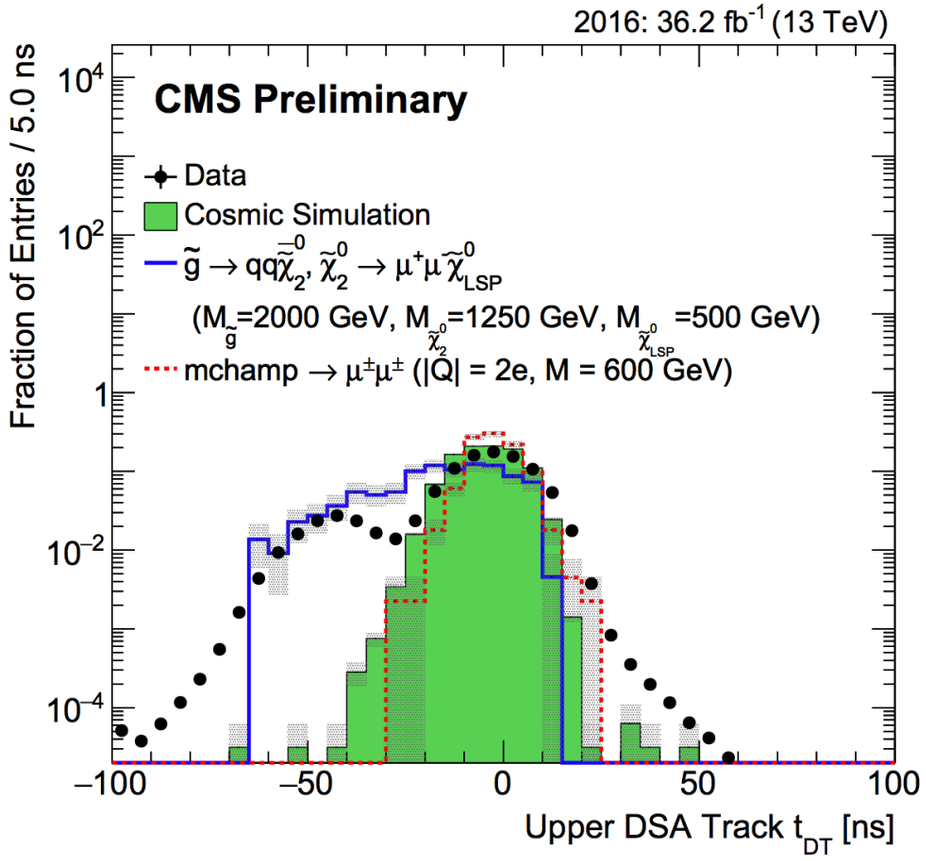
Cosmics

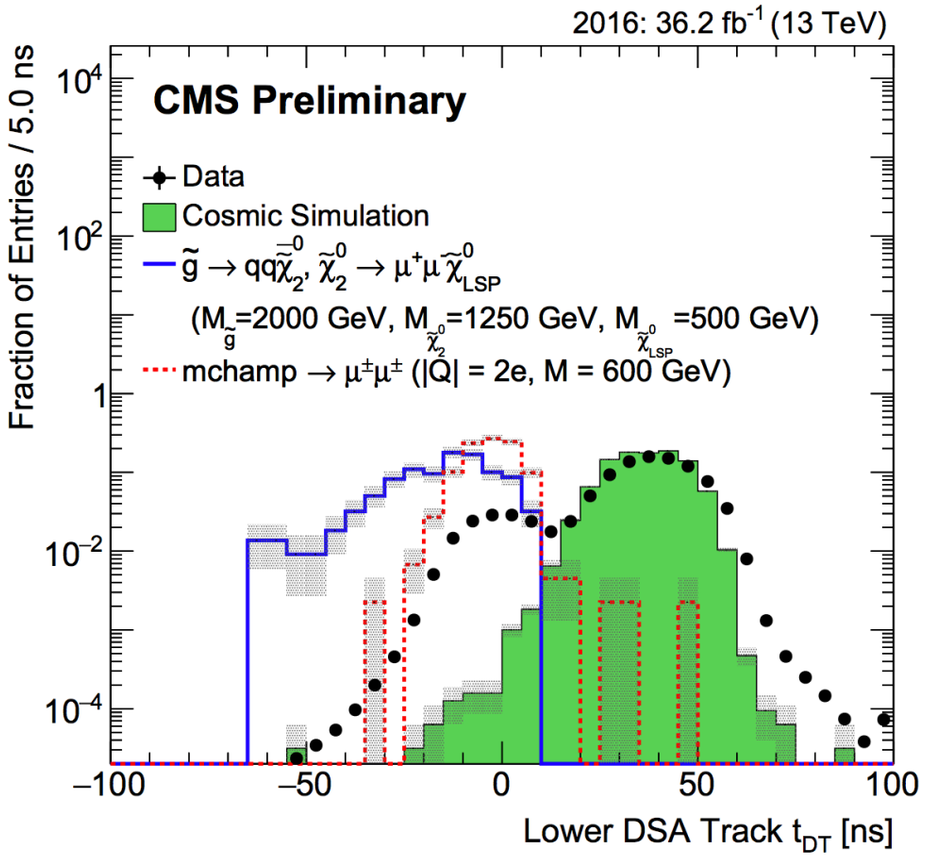
μ_{lower} is triggered (less often)



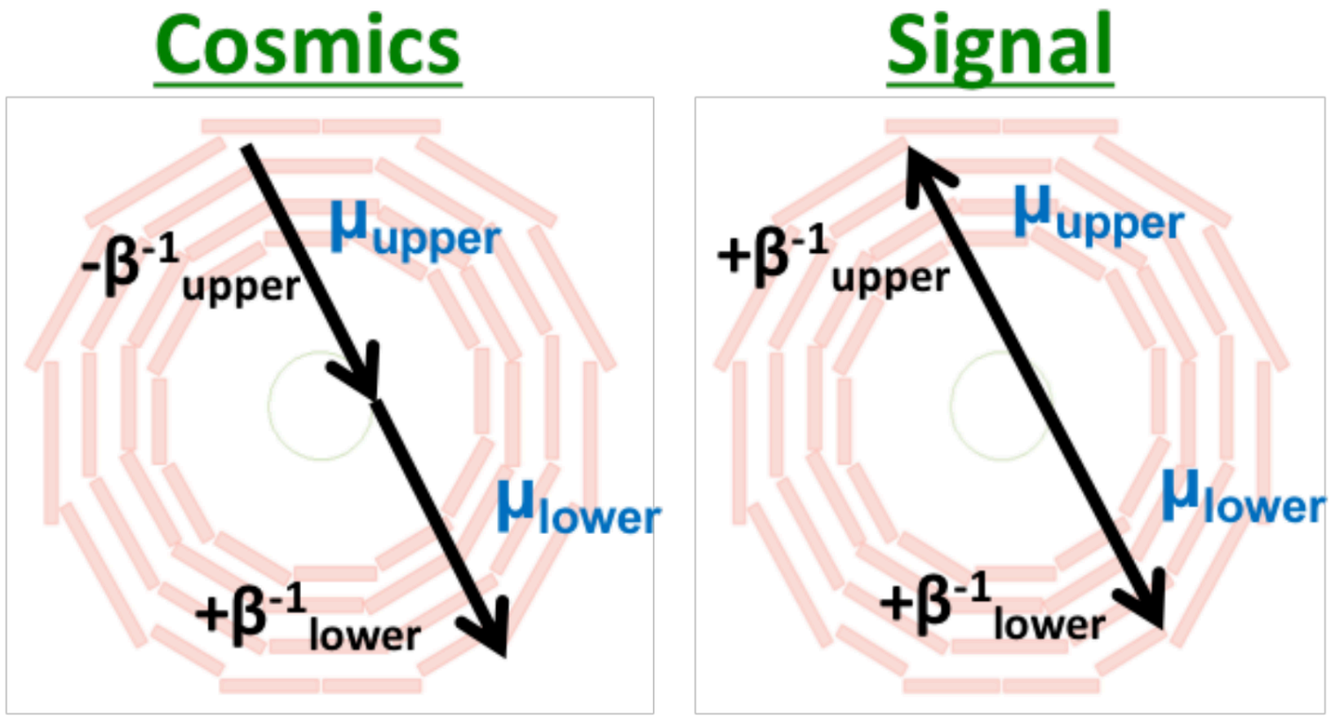
Signal

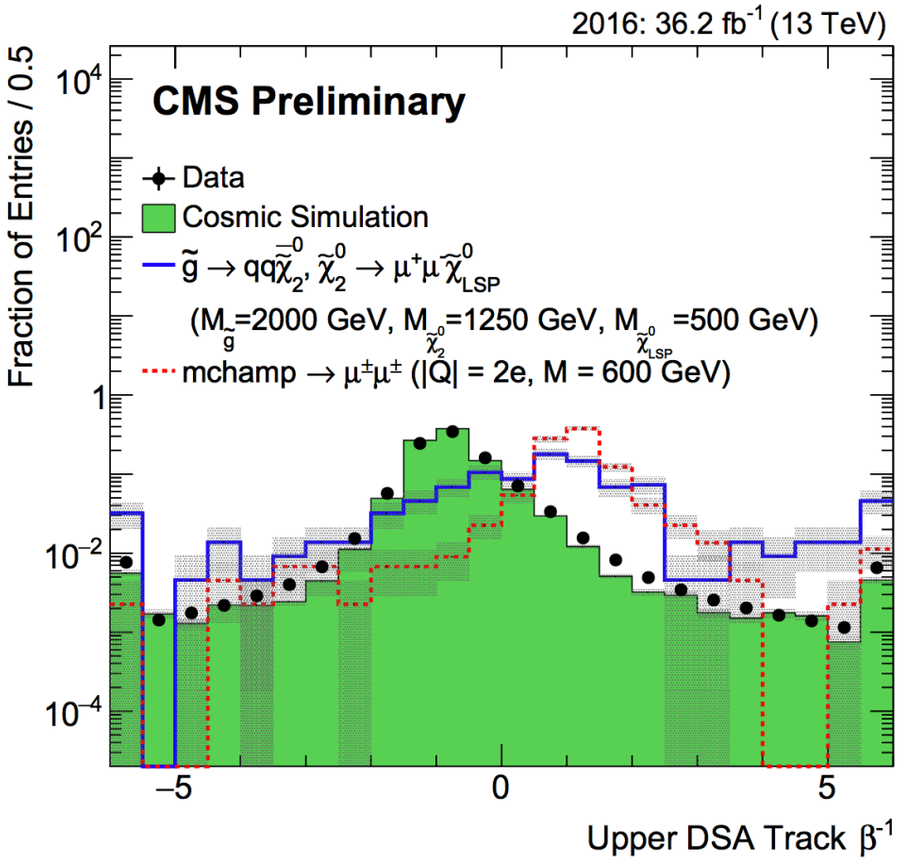


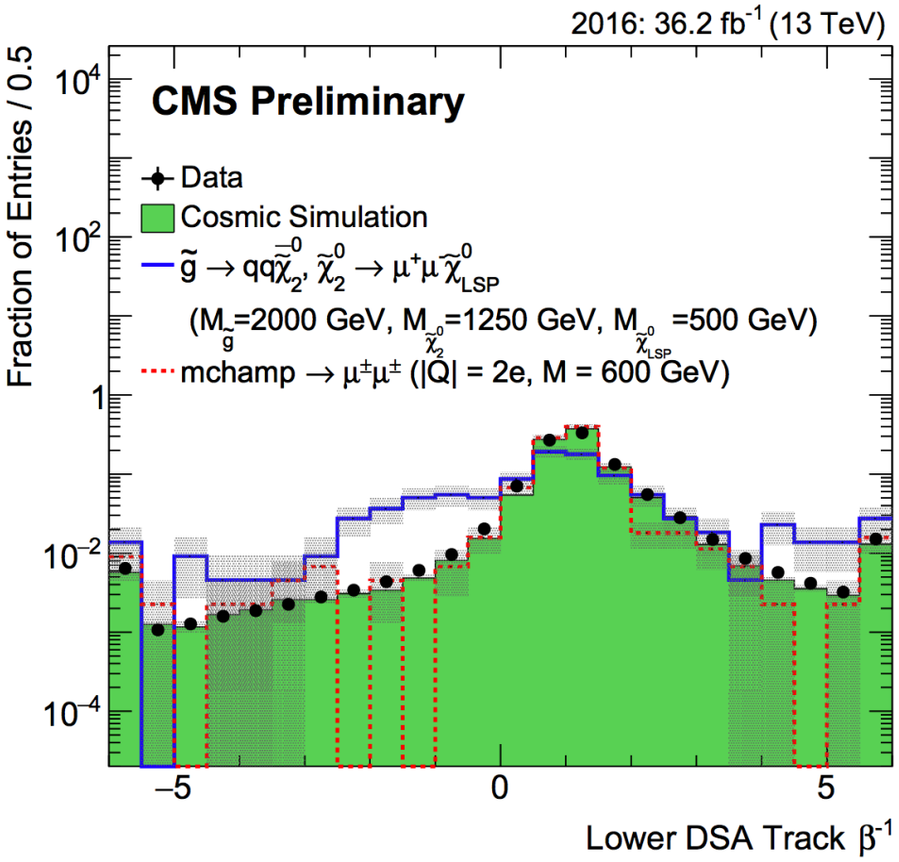




Stopped particle: identification







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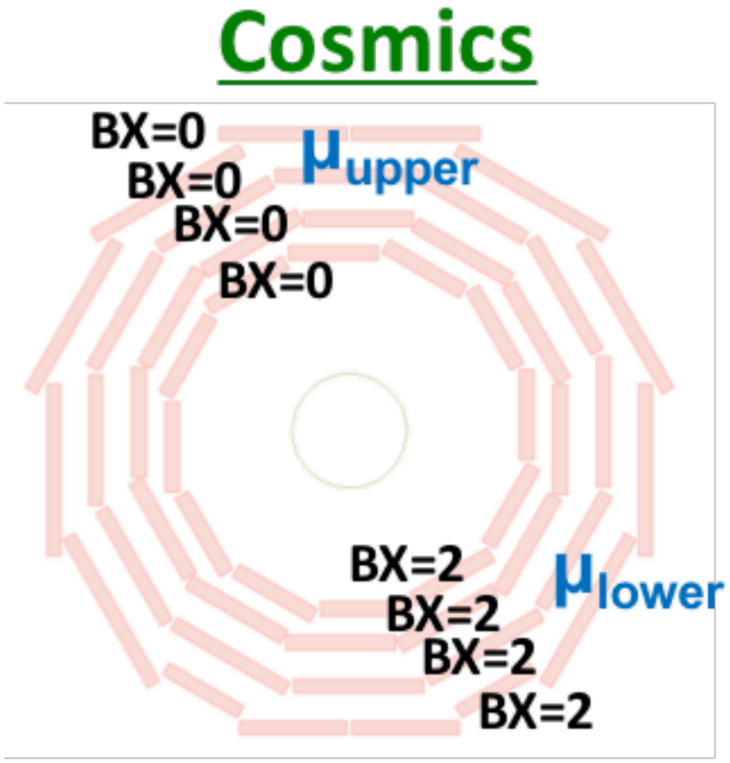
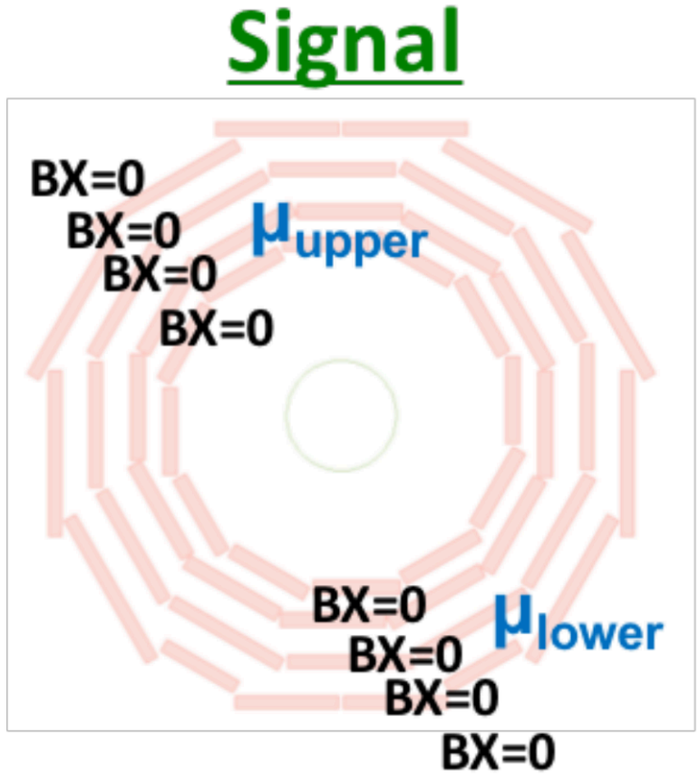
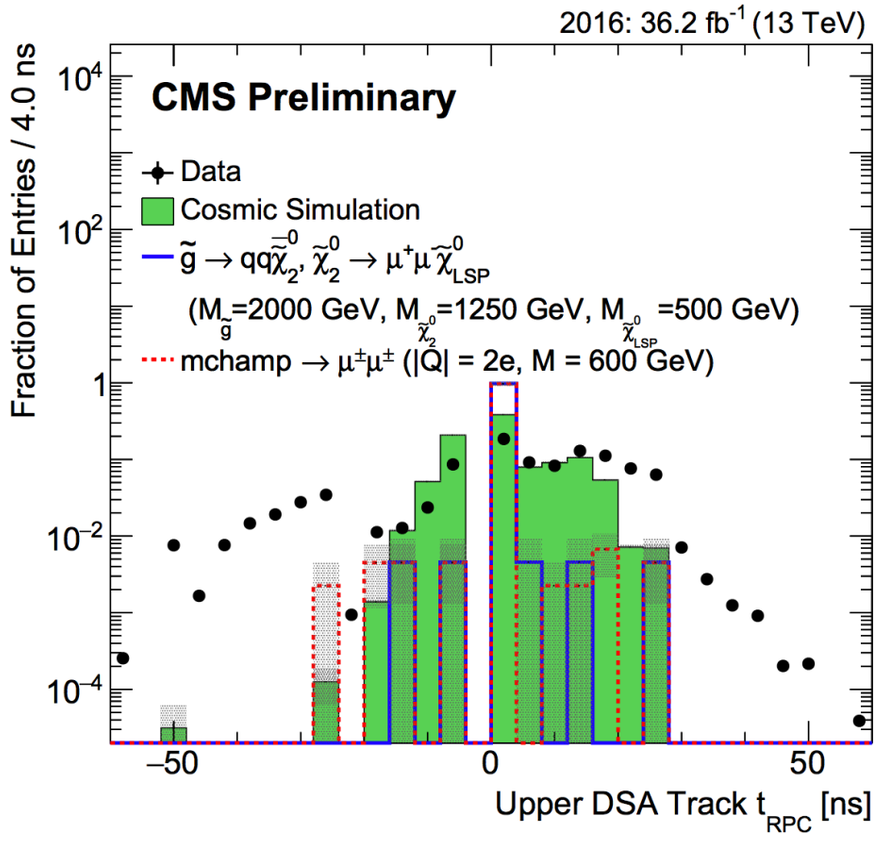
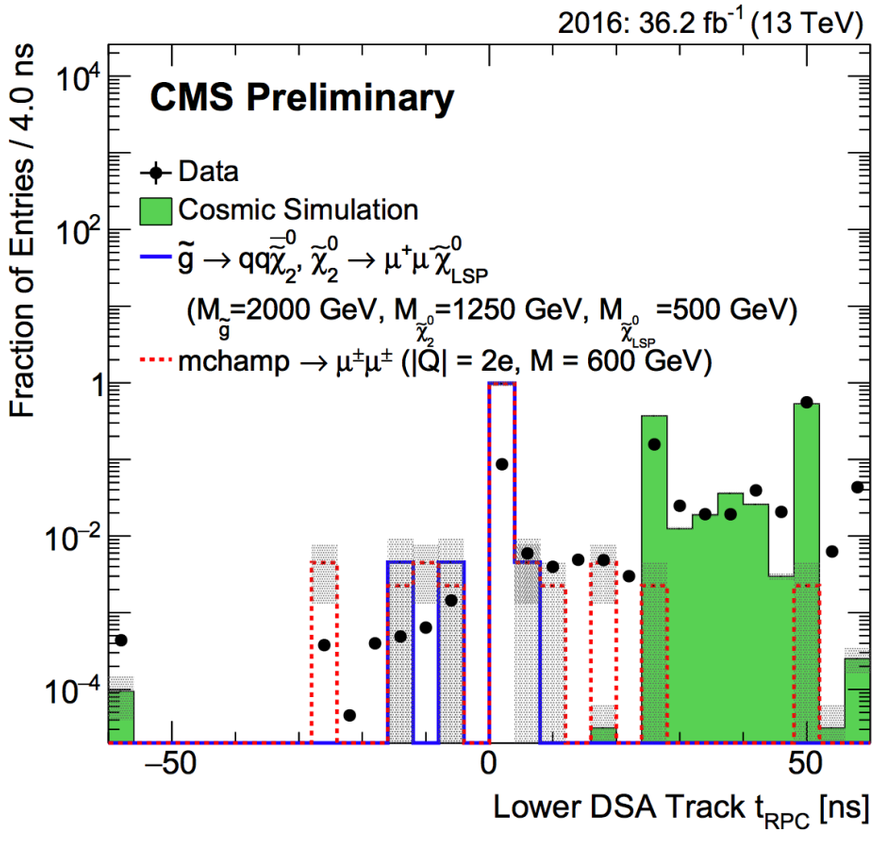








Stopped particle: triggering

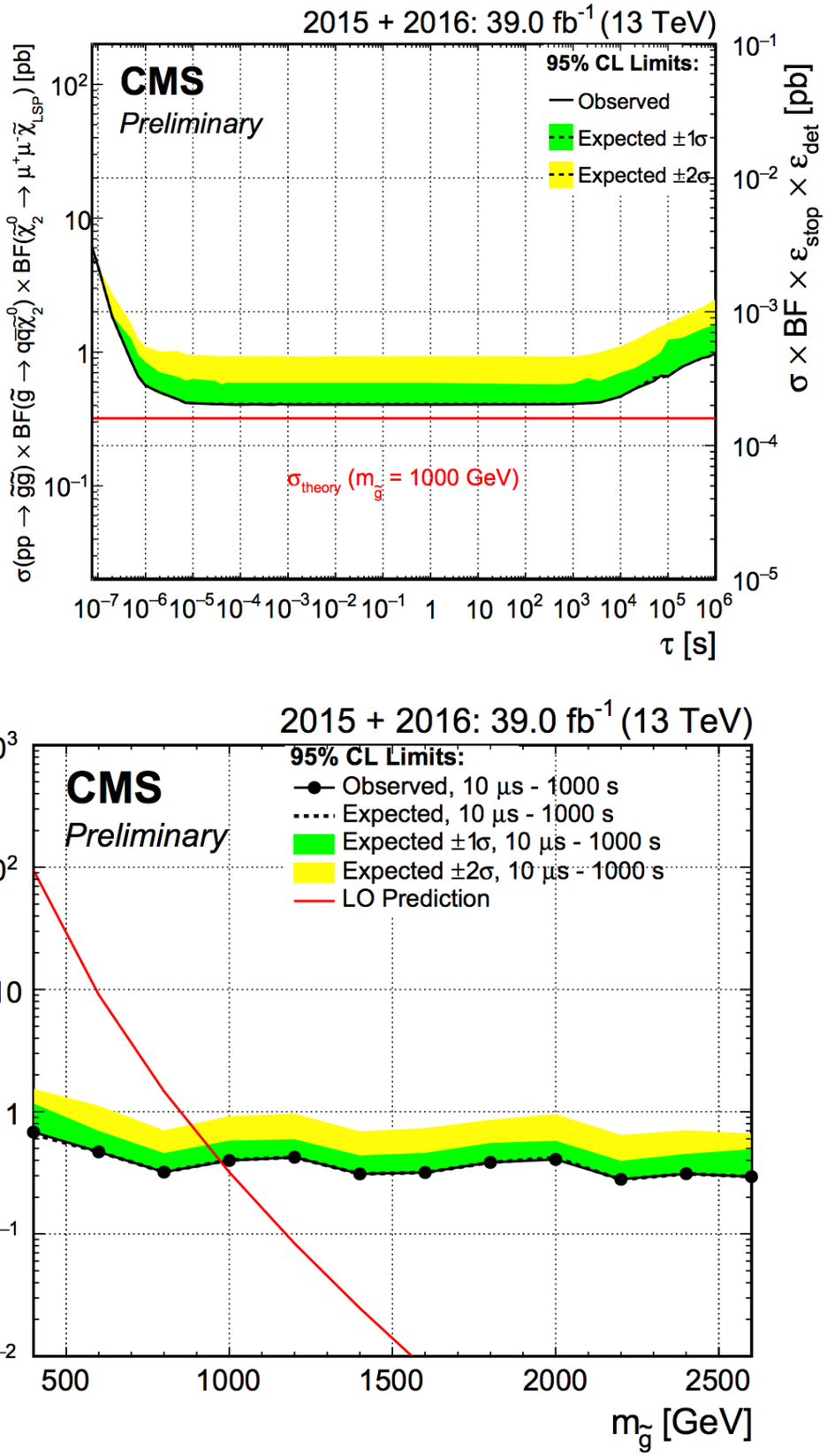
- Require at least one μ with Δt(collision) > 50 ns.
- pT > 35 (40) GeV in 2015 (2016).
- Livetime of 155 (489) hours in 2015 (2016).

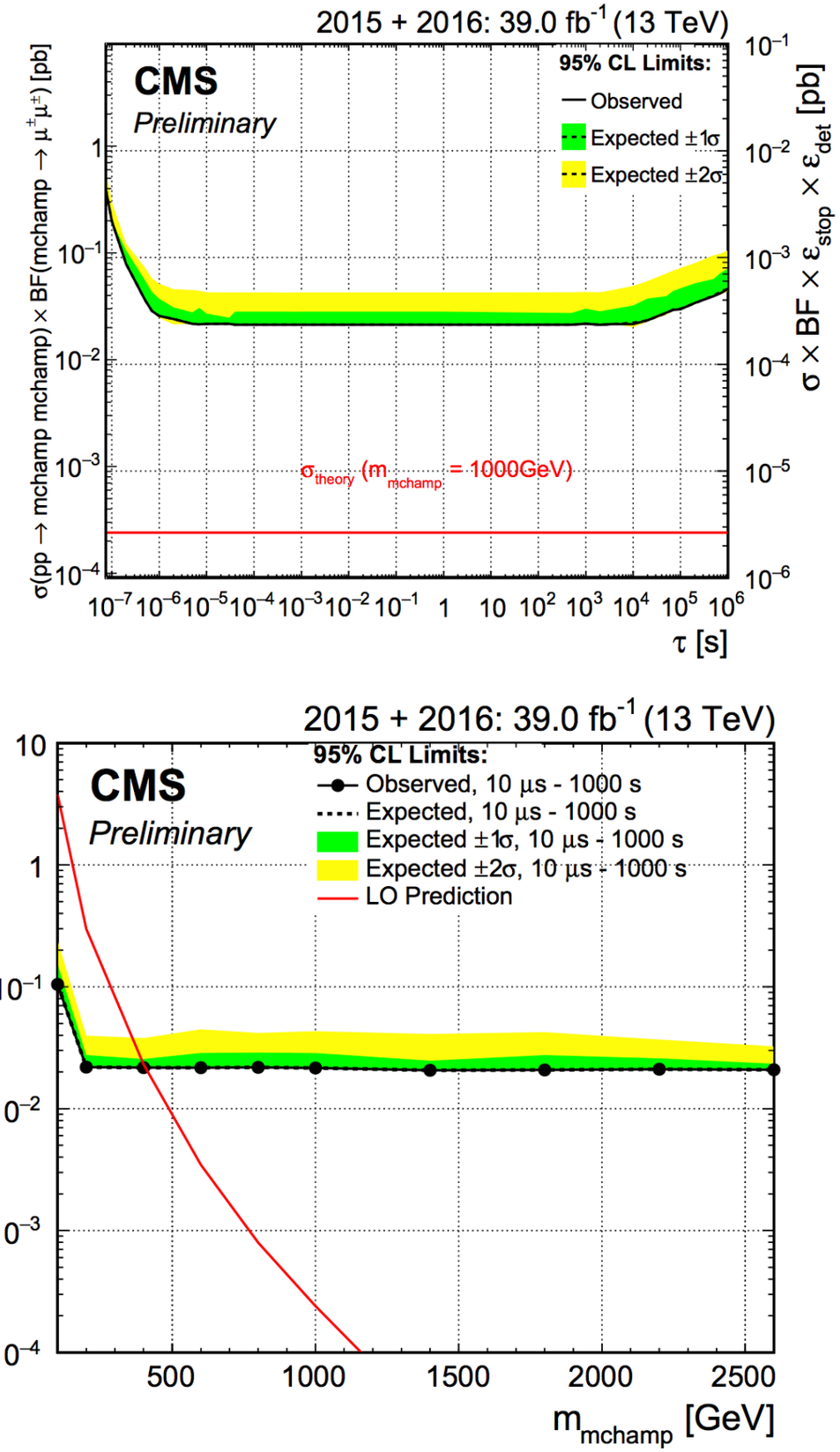
Stopped particle: results

Table 4: Counting experiment results for different lifetimes, for 2016 data.

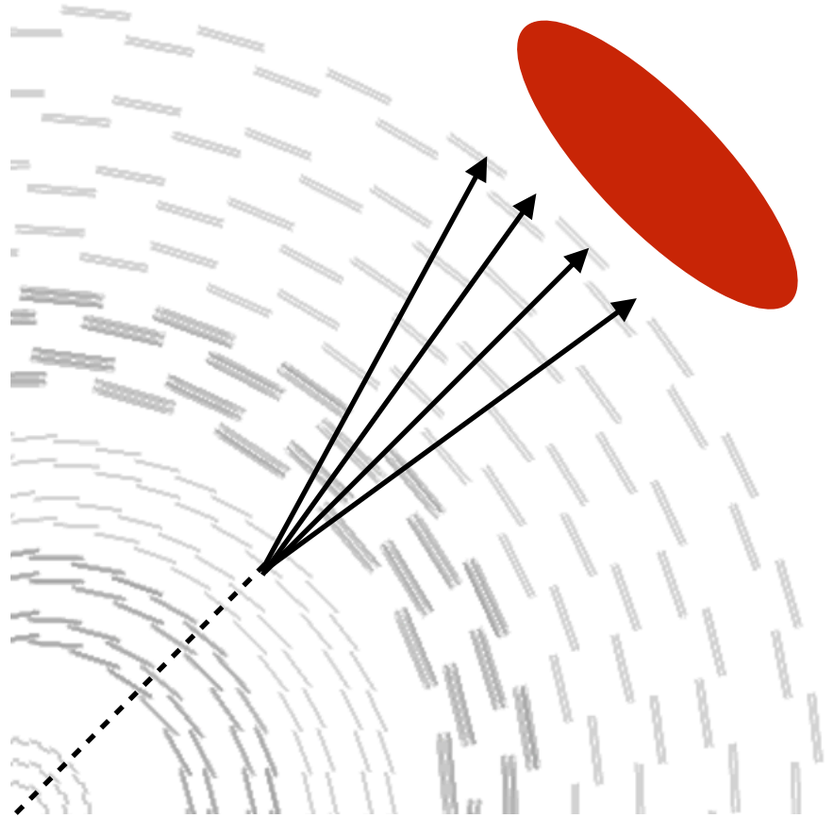
Lifetime [s]	Effective Luminosity [fb^{-1}]	Trigger Livetime [hr]	Expected Background	Observed Events
10^{-7}	1.27	68	0.06 ± 0.00 (stat)$\pm$ 0.05 (syst)	0
10^{-6}	9.95	422	$0.36 \pm 0.01 \pm 0.29$	0
10^{-5}	13.34	581	$0.49 \pm 0.02 \pm 0.39$	0
10^{-4}	13.67	589	$0.50 \pm 0.02 \pm 0.40$	0
1	13.67	589	$0.50 \pm 0.02 \pm 0.40$	0
10^{3}	13.55	589	$0.50 \pm 0.02 \pm 0.40$	0
10^{4}	11.75	589	$0.50 \pm 0.02 \pm 0.40$	0
10^{5}	8.26	589	$0.50 \pm 0.02 \pm 0.40$	0
10^{6}	5.61	589	$0.50 \pm 0.02 \pm 0.40$	0

Stopped particle: interpretations



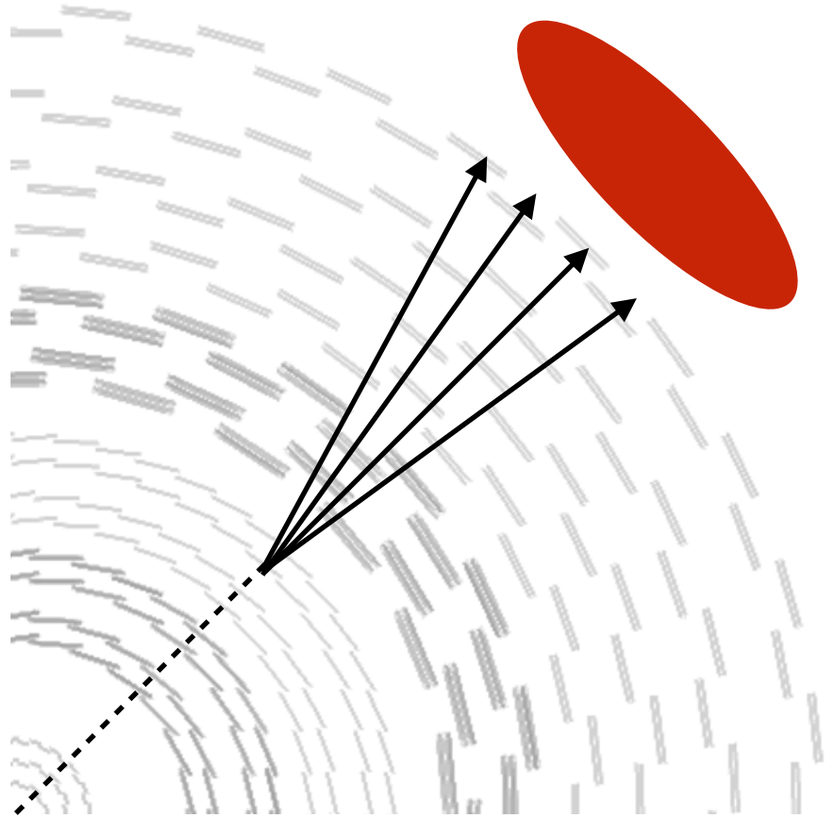


Displaced jets: motivation



- Many models predict displaced jets, with more emerging.

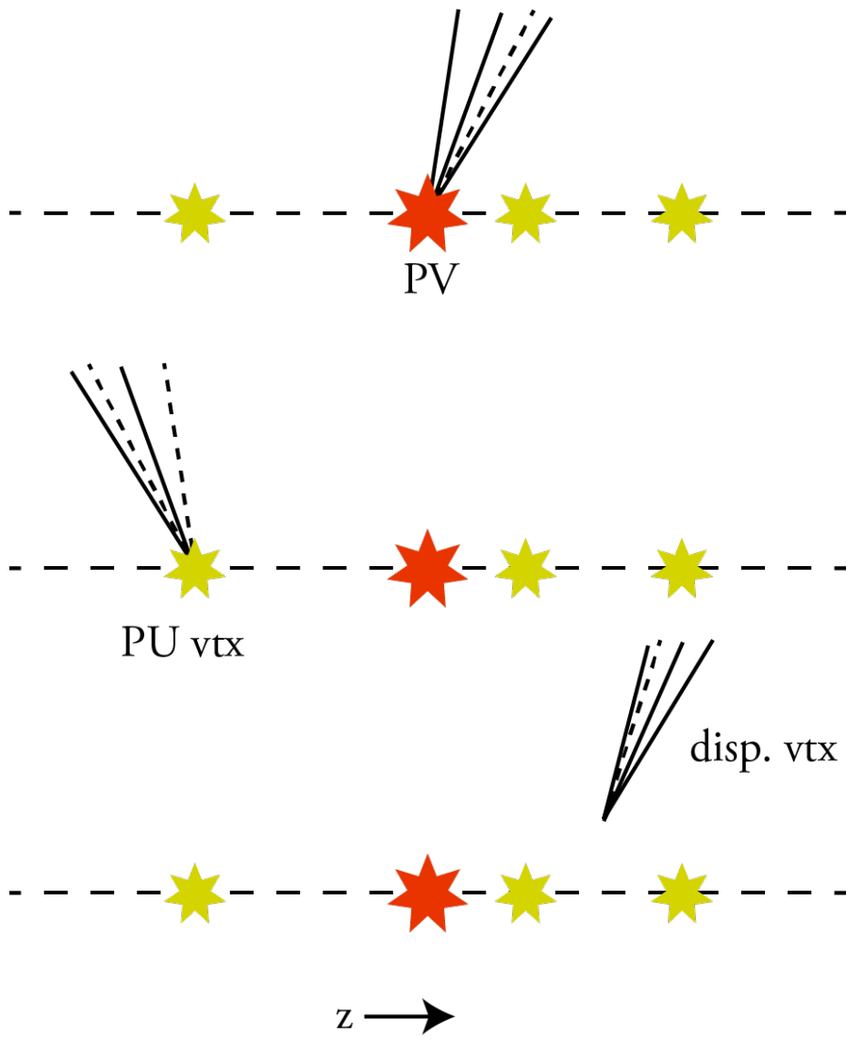
Displaced jets: challenges

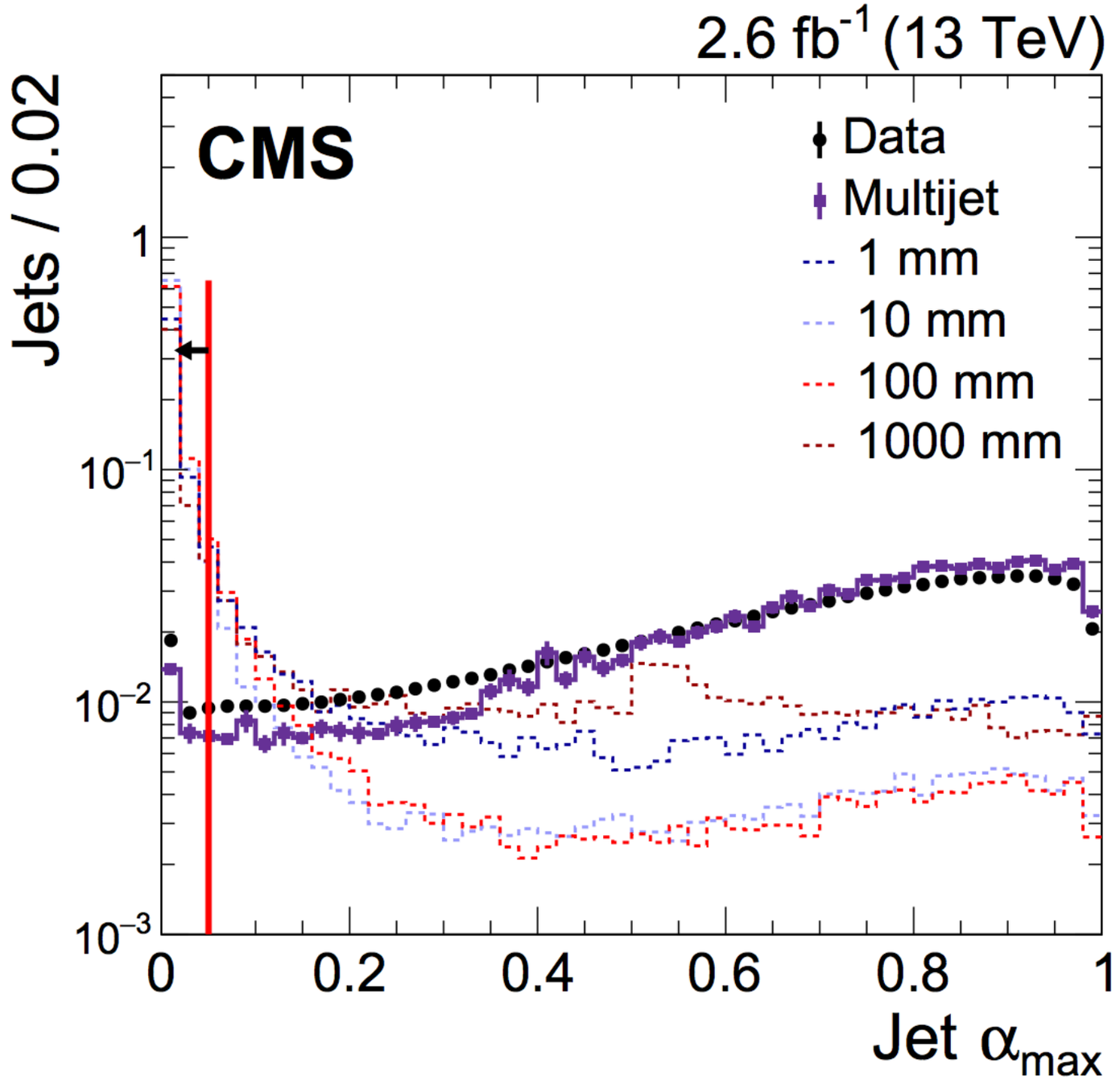


- Trigger.
- PF or calo jets?
- Background.

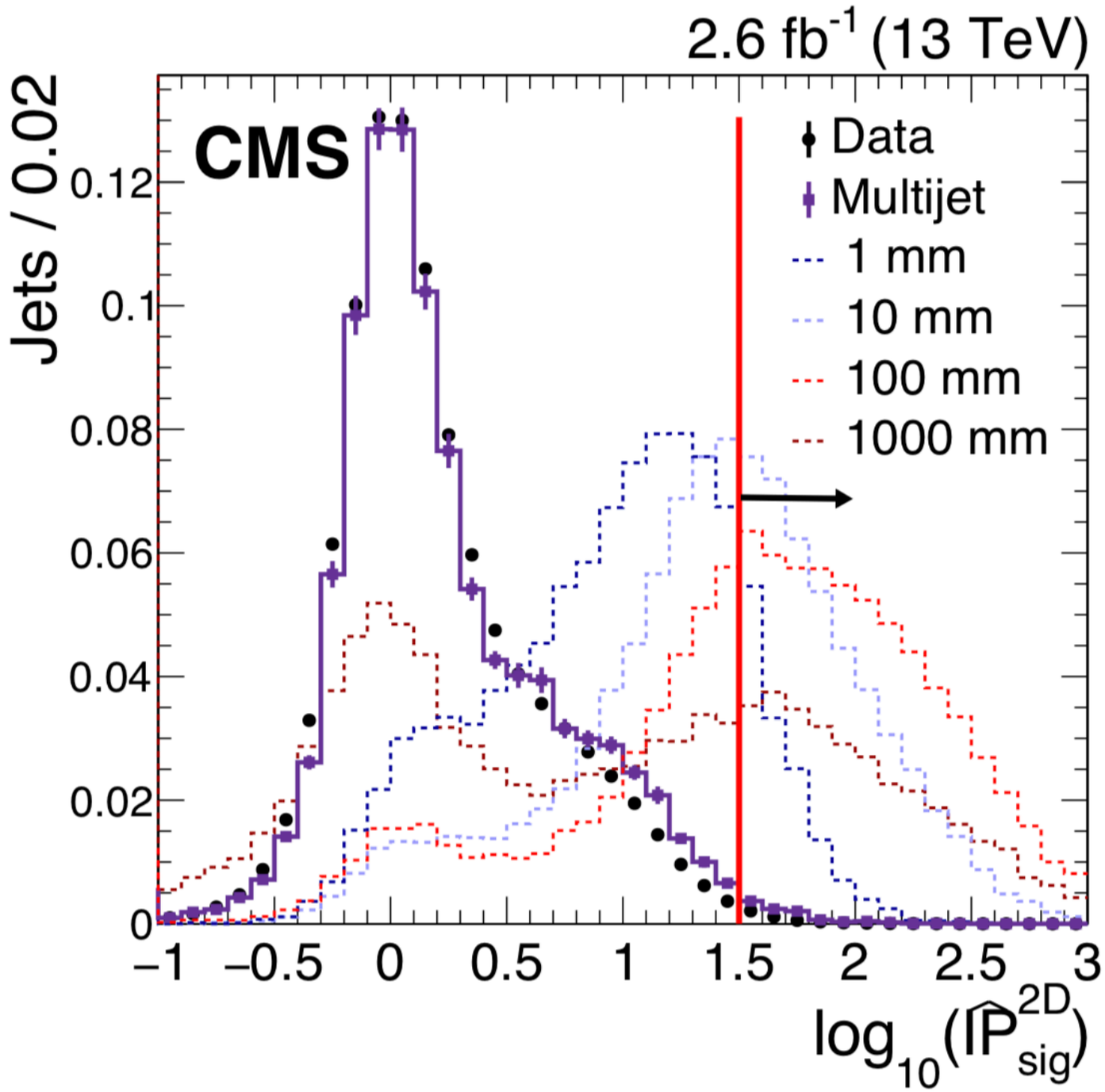
Displaced jets: identification

$$\alpha_{jet}(PV) = \frac{\sum_{\text{tracks}\in\text{PV}} p_T^{tracks}}{\sum_{\text{tracks}} p_T^{tracks}}$$

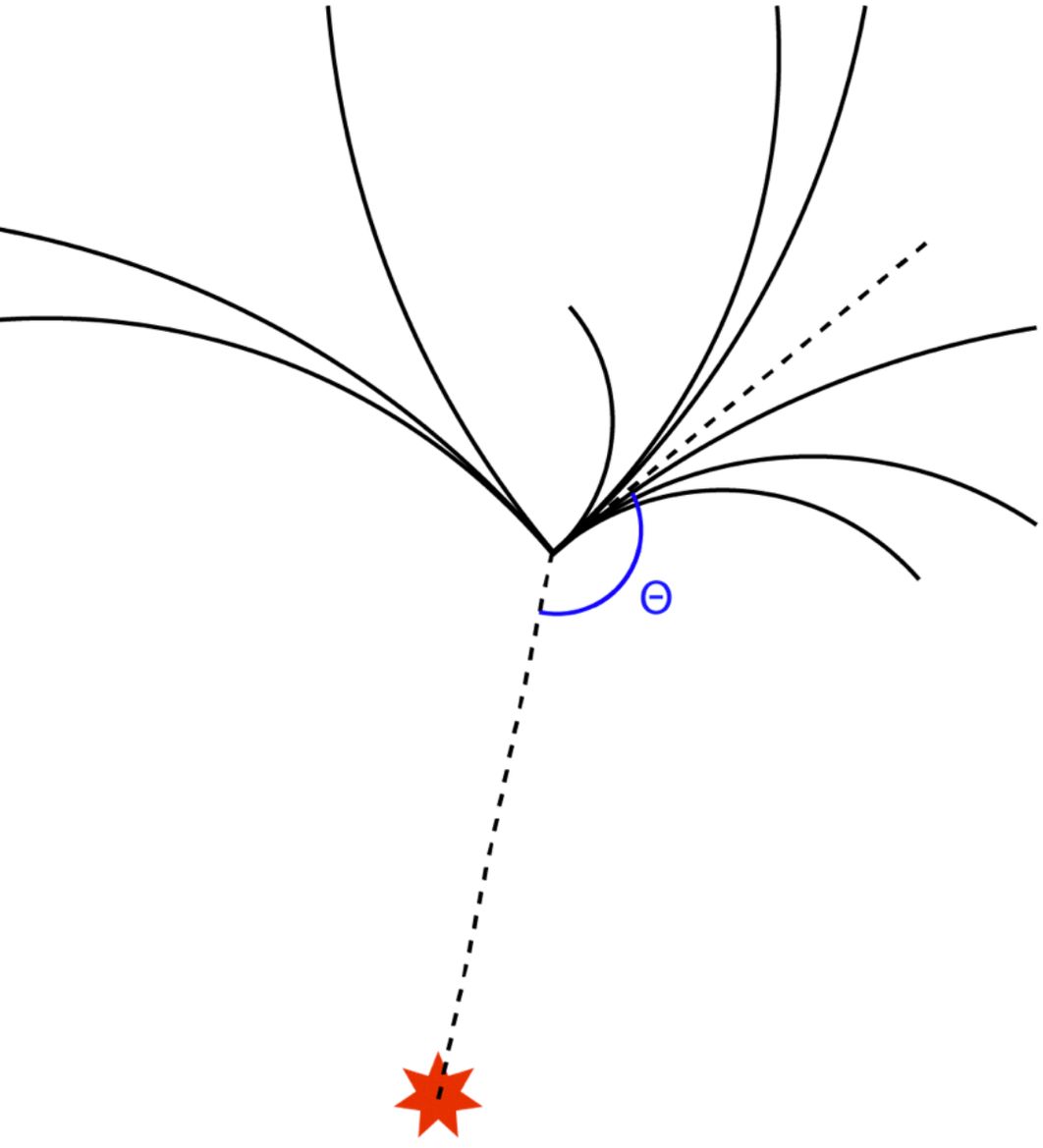


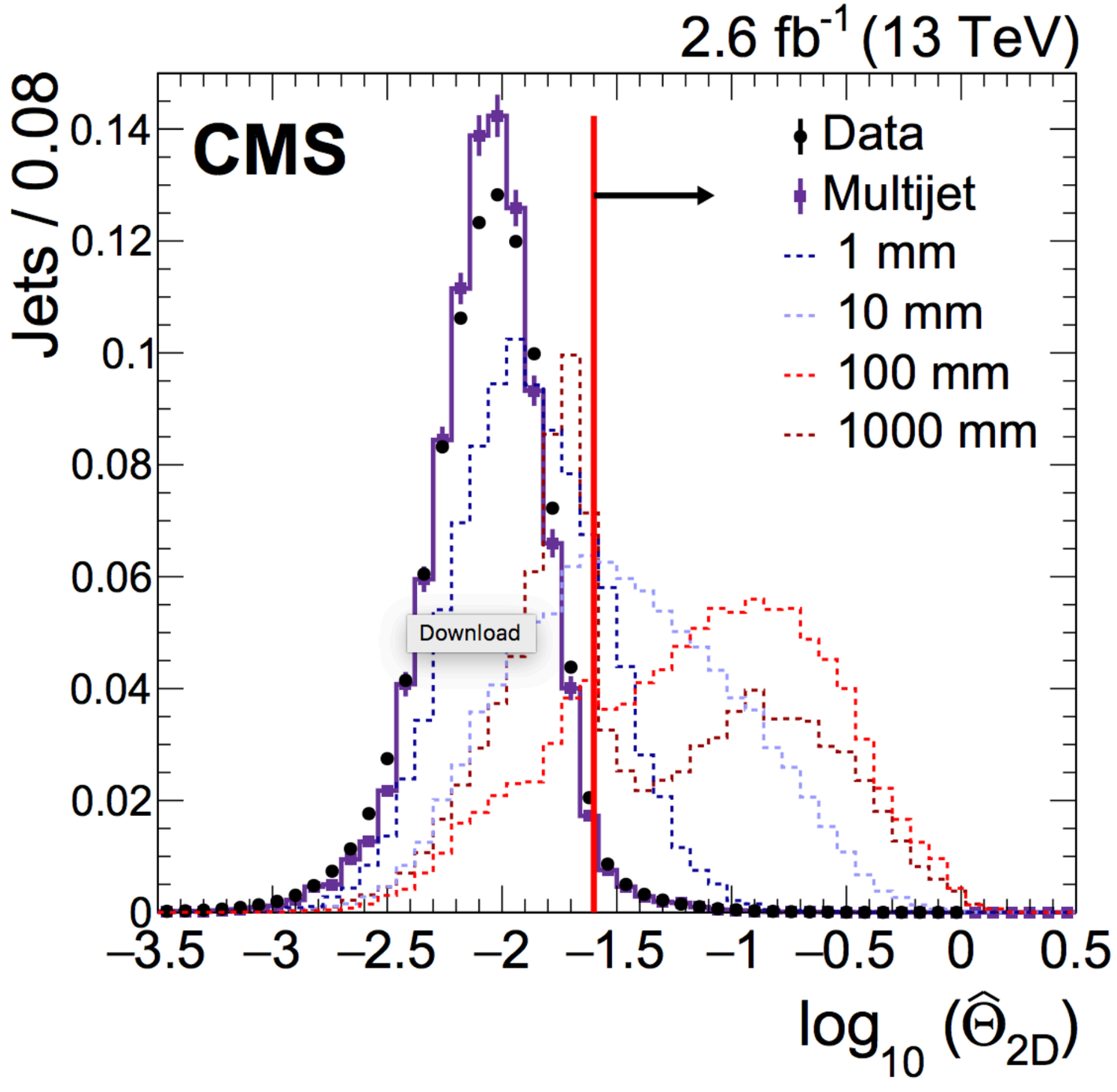


Displaced jets: identification

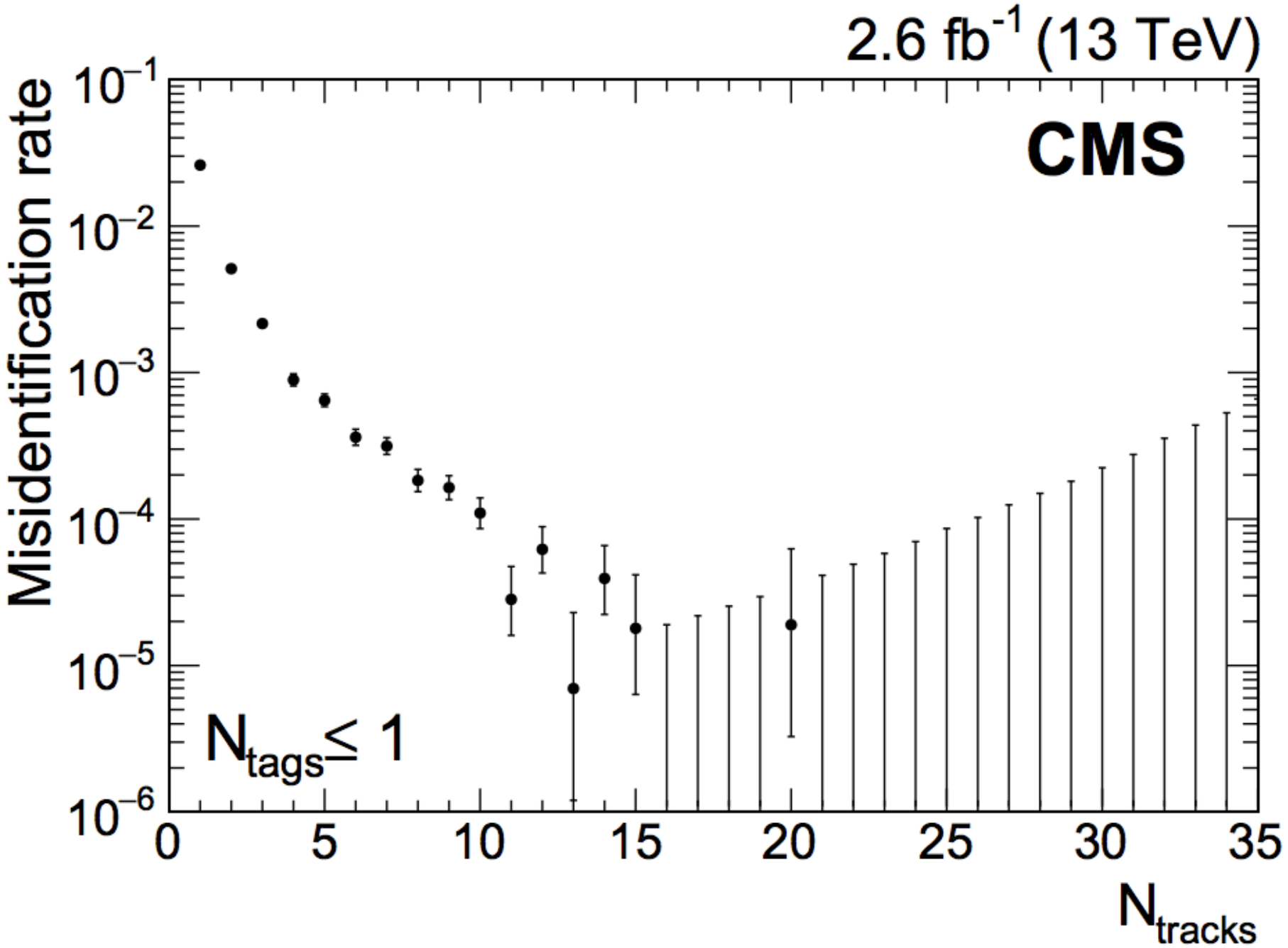


Displaced jets: identification





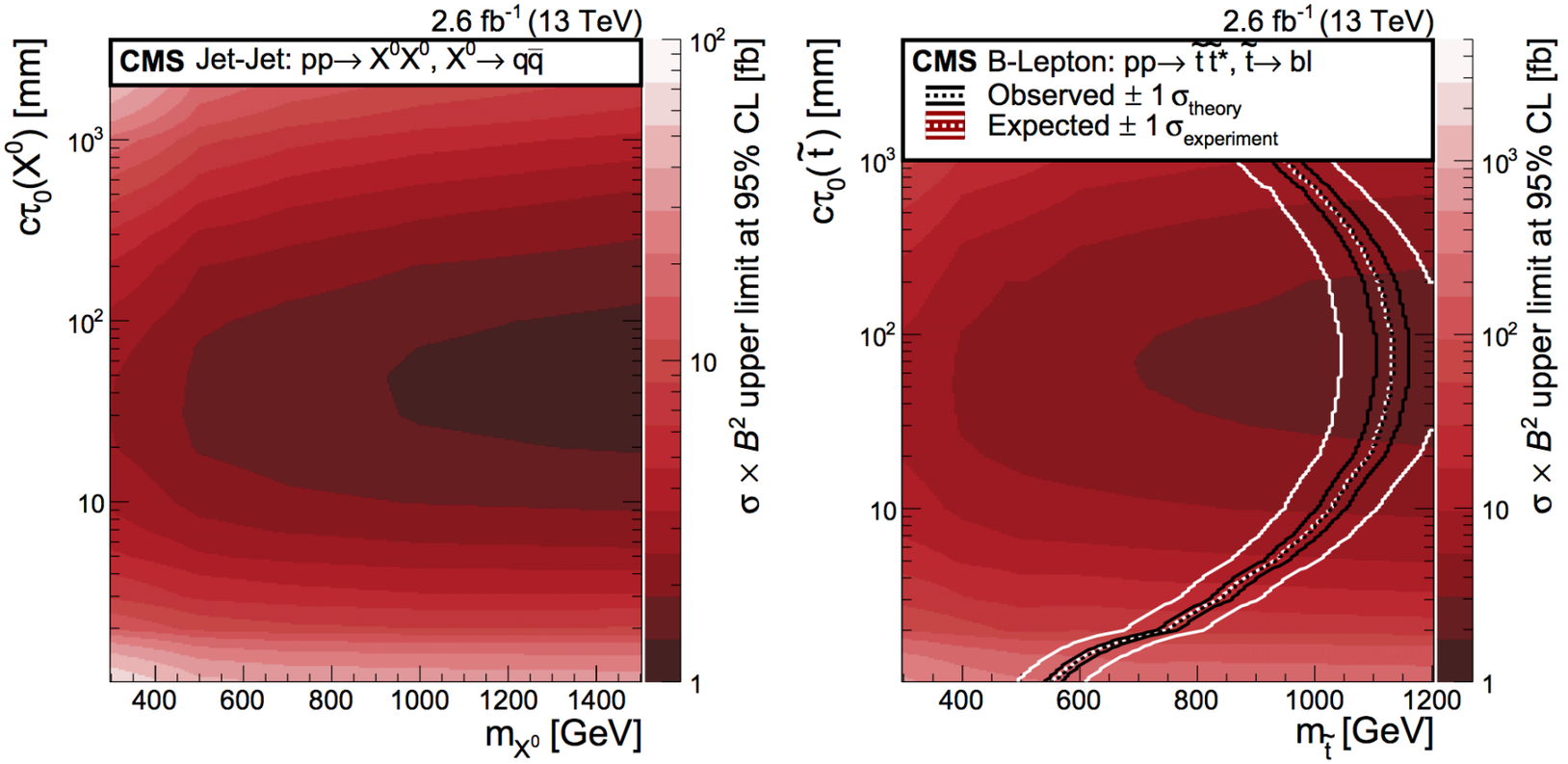
Displaced jet: background

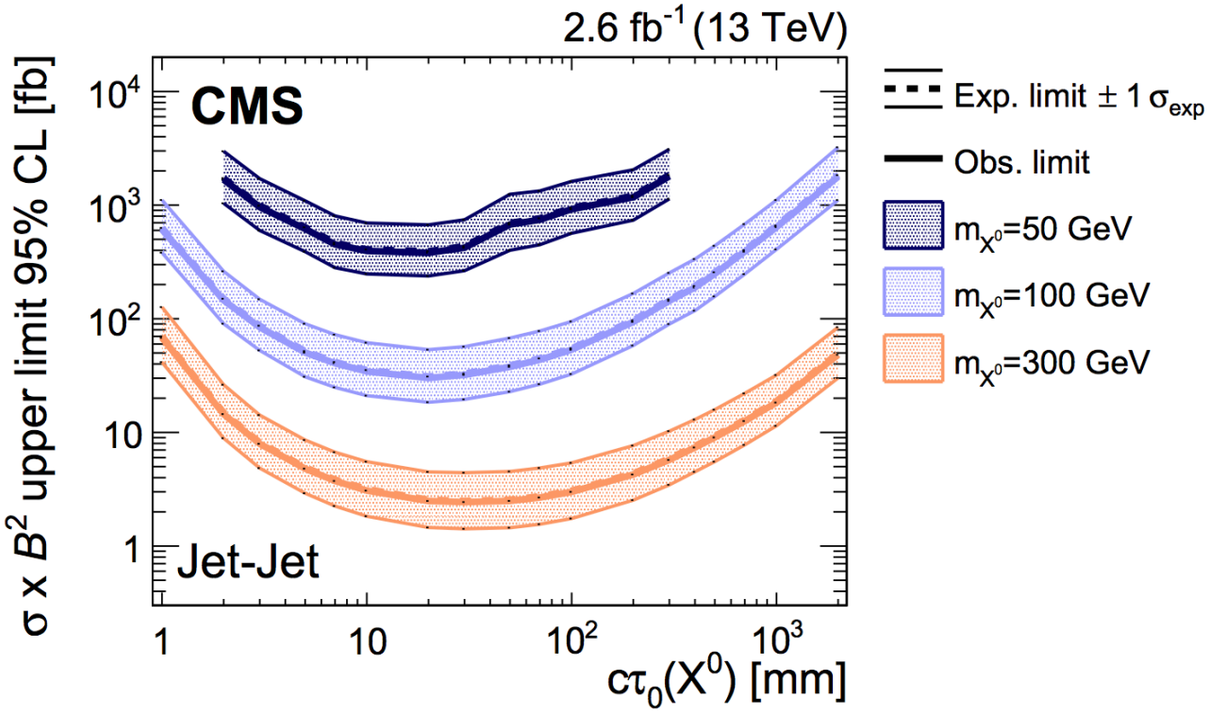


Displaced jet: results

N_{tags}	Expected	Observed
2	1.09 ± 0.16	1
≥ 3	$(4.9 \pm 1.0) \times 10^{-4}$	0

Displaced jet: interpretations





A look ahead

You can expect results in this area to improve much faster than luminosity accumulates:

- LL (re)interpretations of searches will be more common.
- Currently person-power limited.
- Cross-triggering opportunities.
- Upgrades.