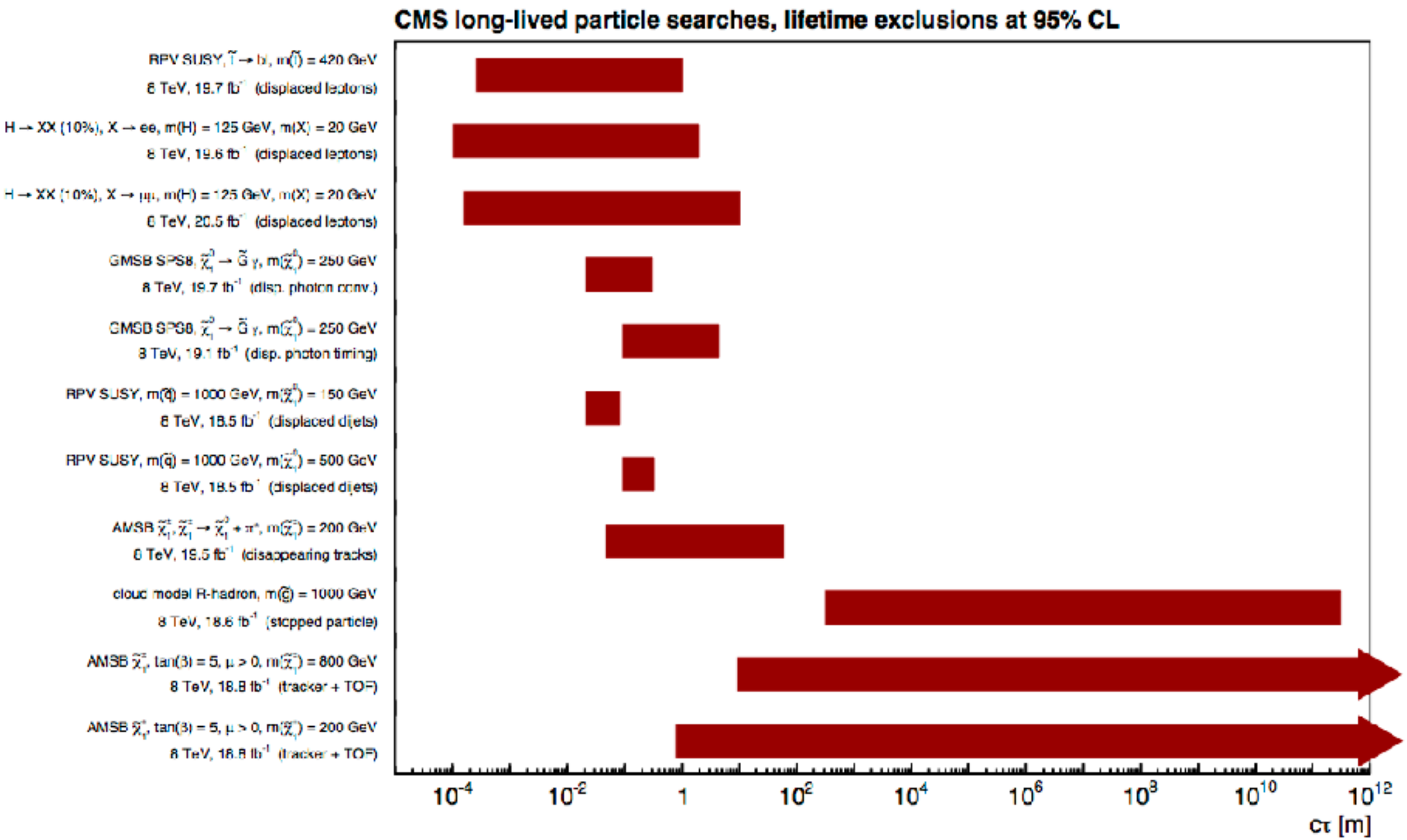
Decays to dark sector particles at CMS: long-lived signatures

Ted Kolberg (Florida State University)

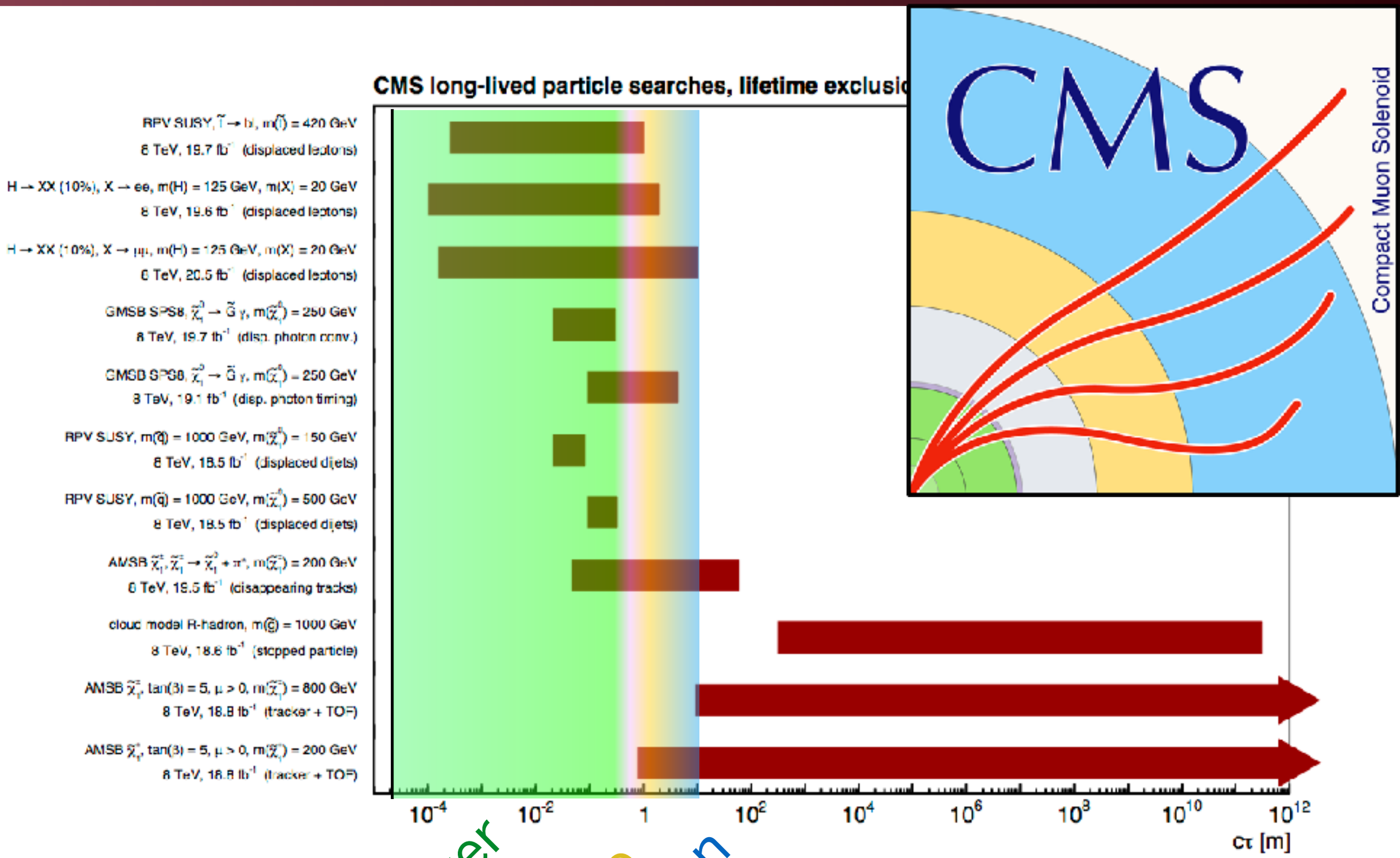
Dark Interactions 2016, BNL

Long-lived: Run I summary



cover ~ 16 orders of magnitude in lifetime

How we do it

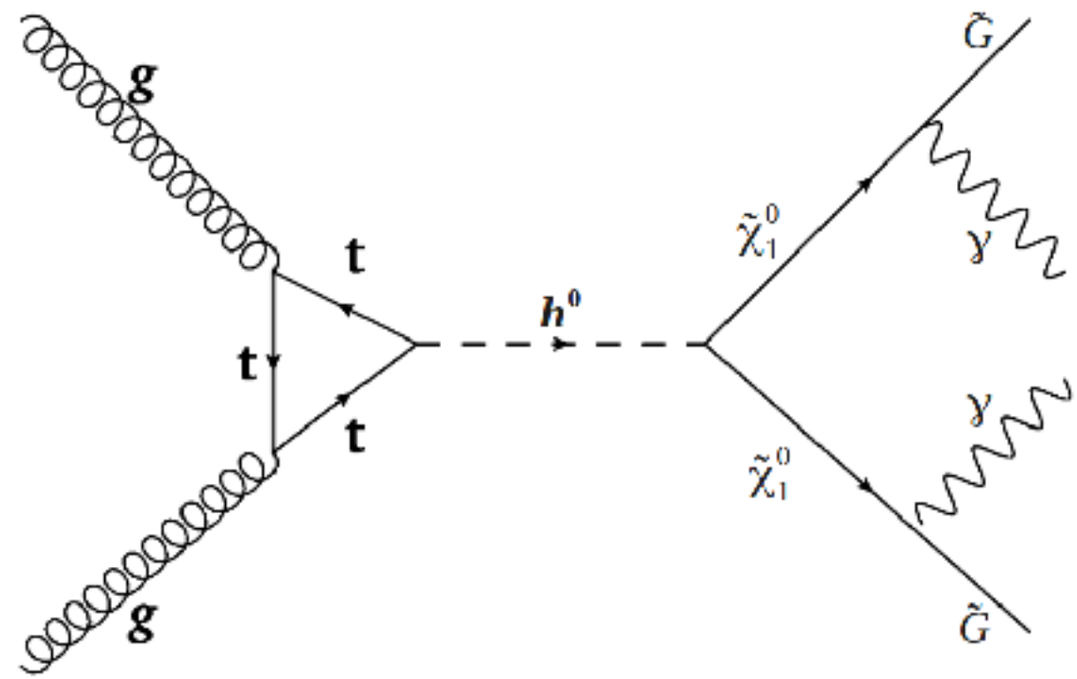


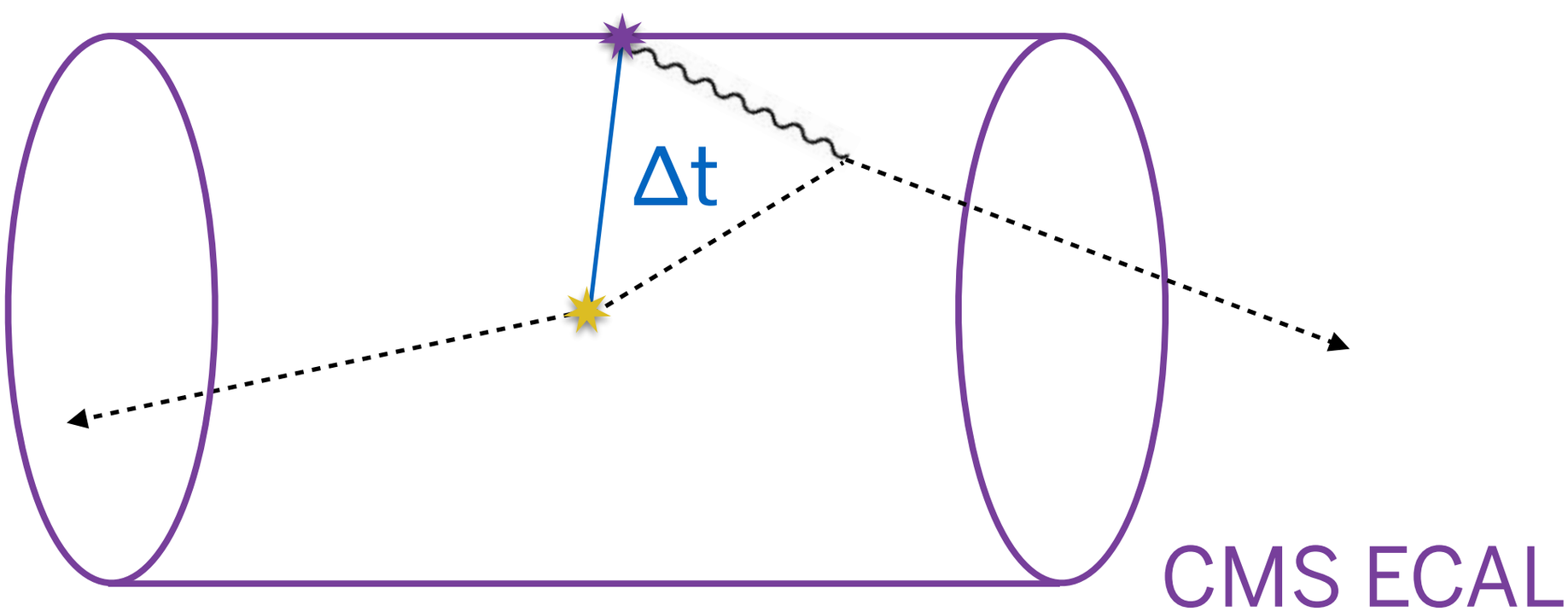
disp. decays: tracker calo muon stopped or stable

Long-lived searches at 8 TeV

- Displaced photon + MET (timing)

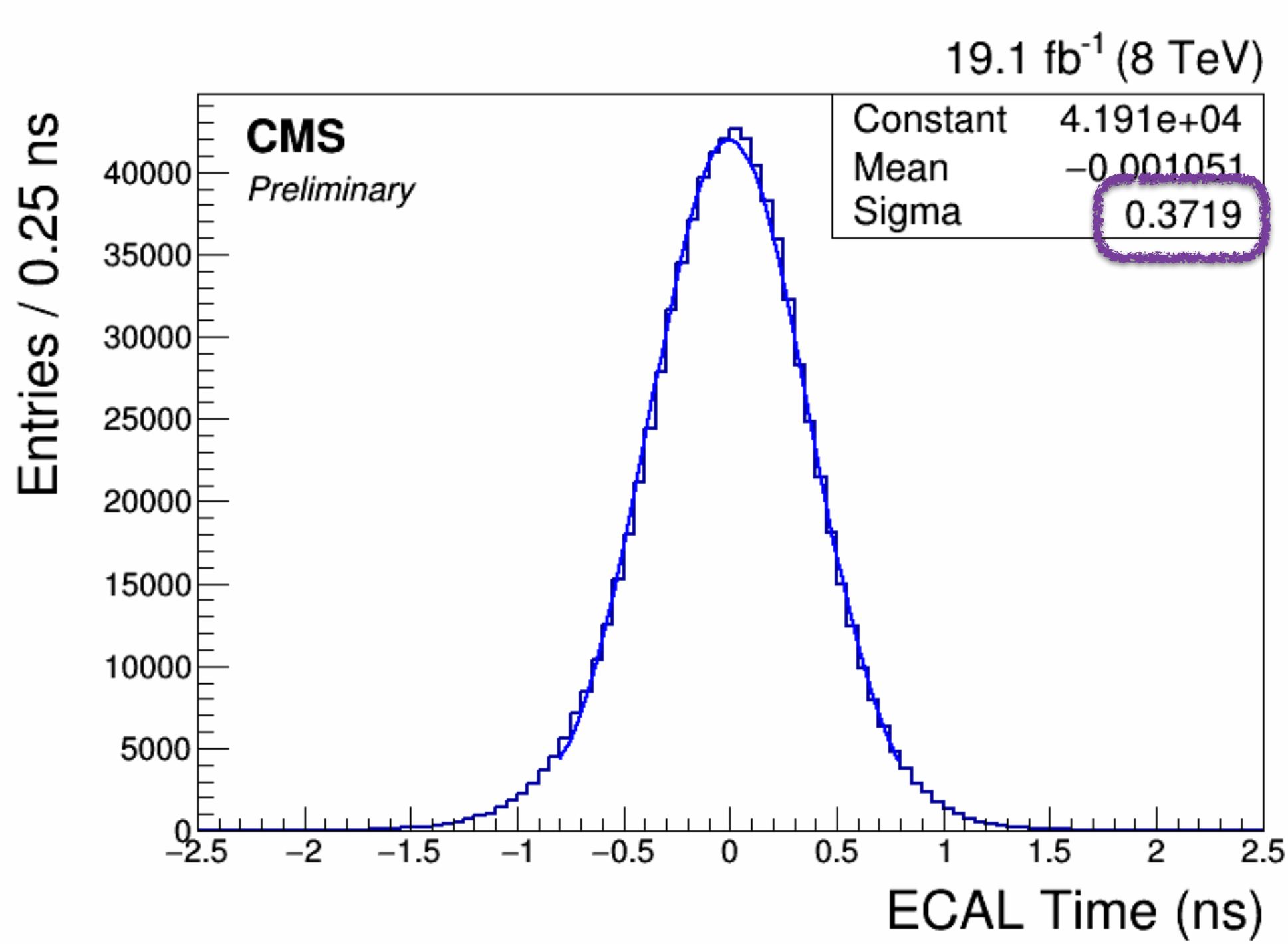
Photon + MET (timing)



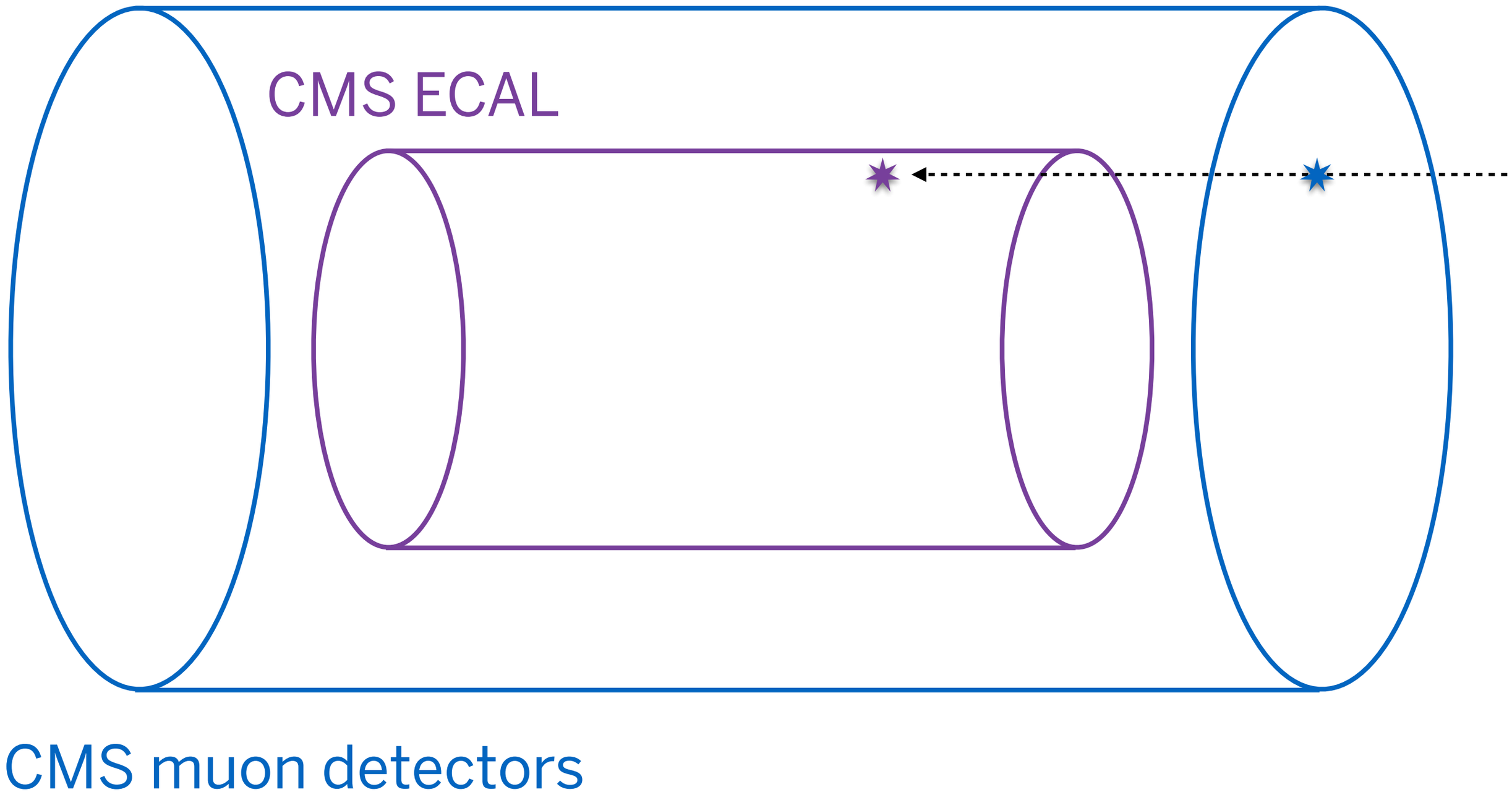


[https://cds.cern.ch/record/2063495]

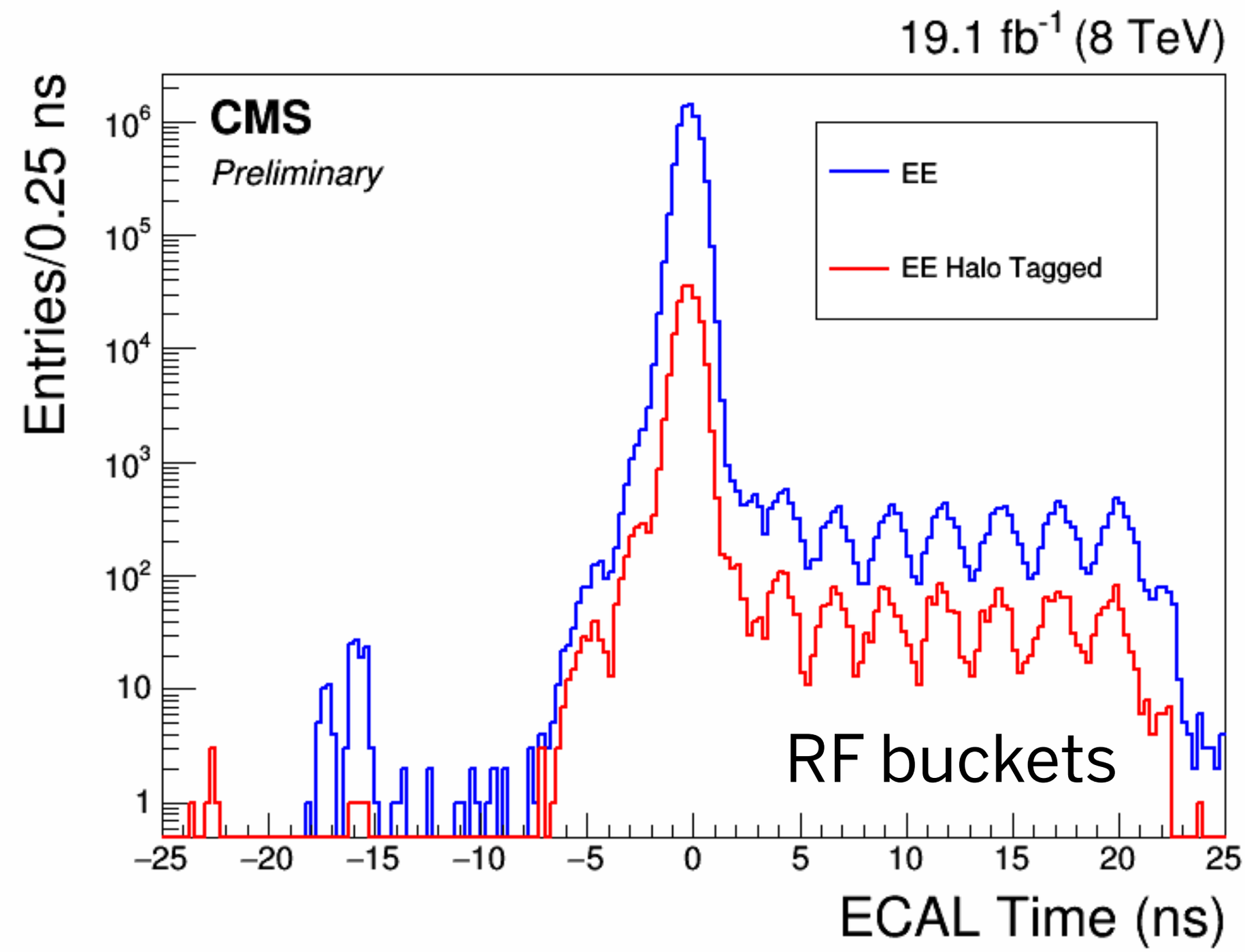
Photon + MET (timing)



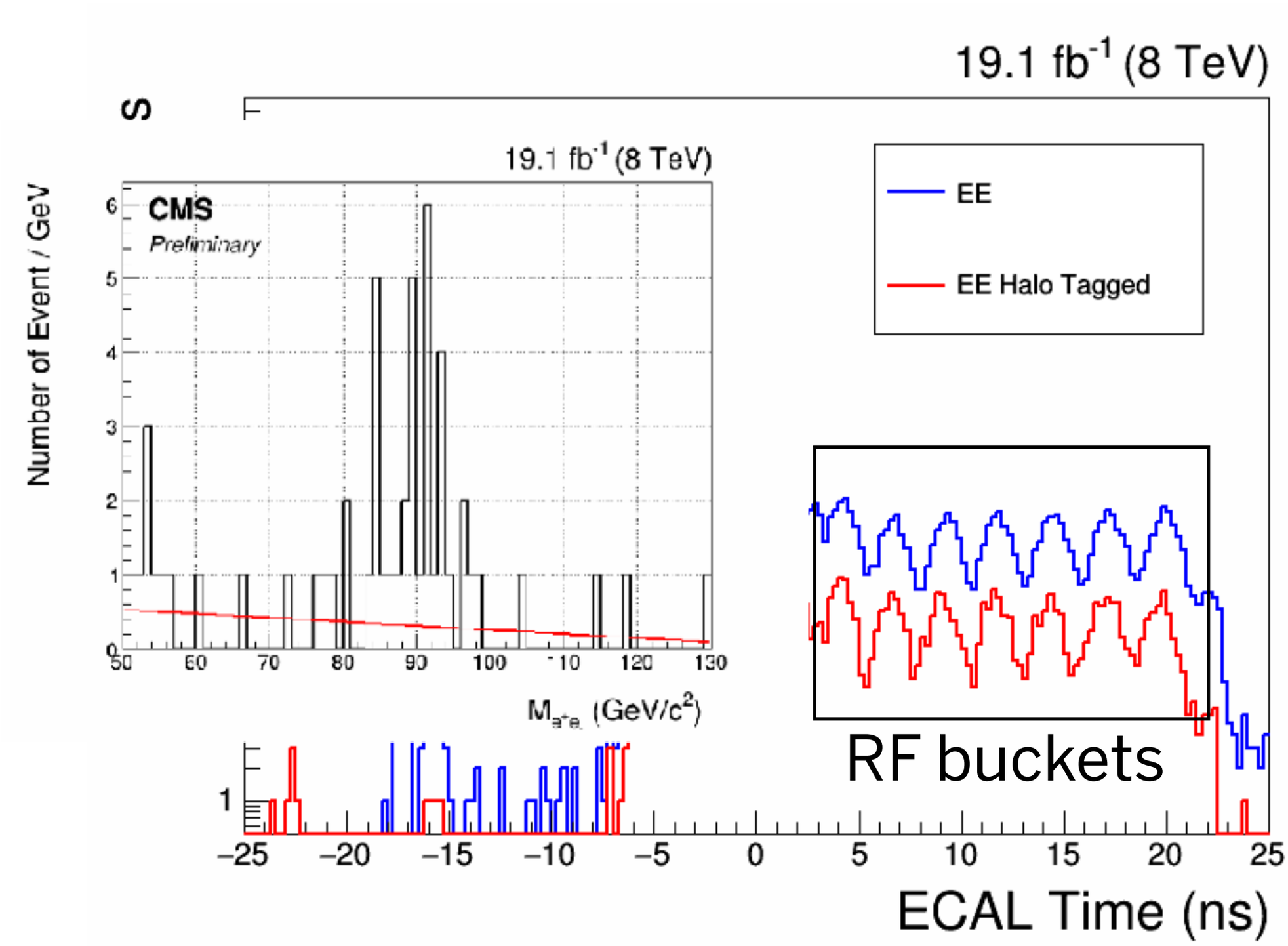
Beam halo background



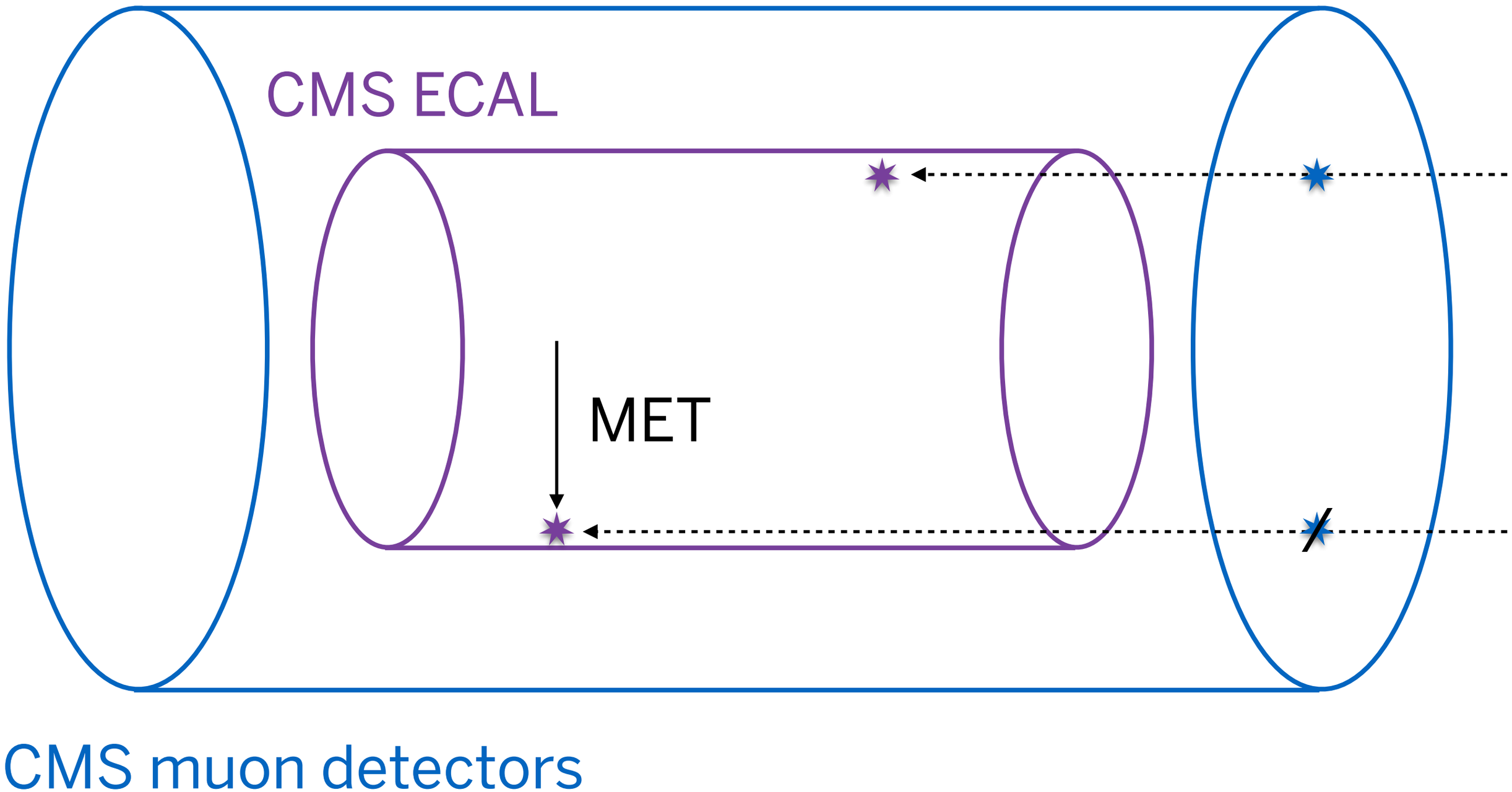
Halo timing


19.1 fb^{-1} (8 TeV)
CMS
Preliminary
EE
EE Halo Tagged
RF buckets
Entries/0.25 ns
ECAL Time (ns)
10^6
10^5
10^4
10^3
10^2
10
1
−25
−20
−15
−10
−5
0
5
10
15
20
25

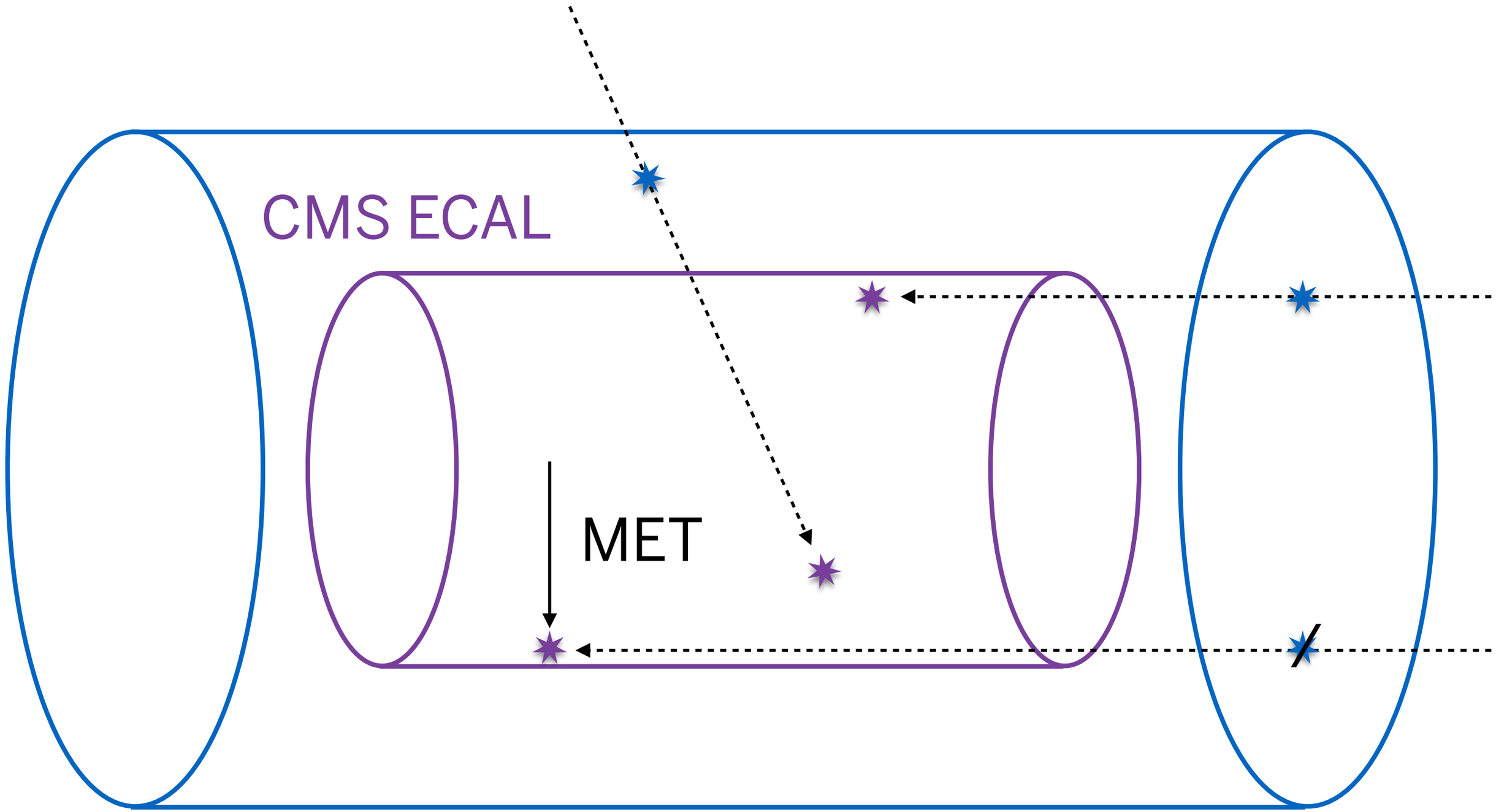
Halo timing


19.1 fb^{-1} (8 TeV)
CMS
Preliminary
Number of Event / GeV
$M_{e^+e^-}$ (GeV/c^2)
EE
EE Halo Tagged
RF buckets
ECAL Time (ns)

Beam halo background

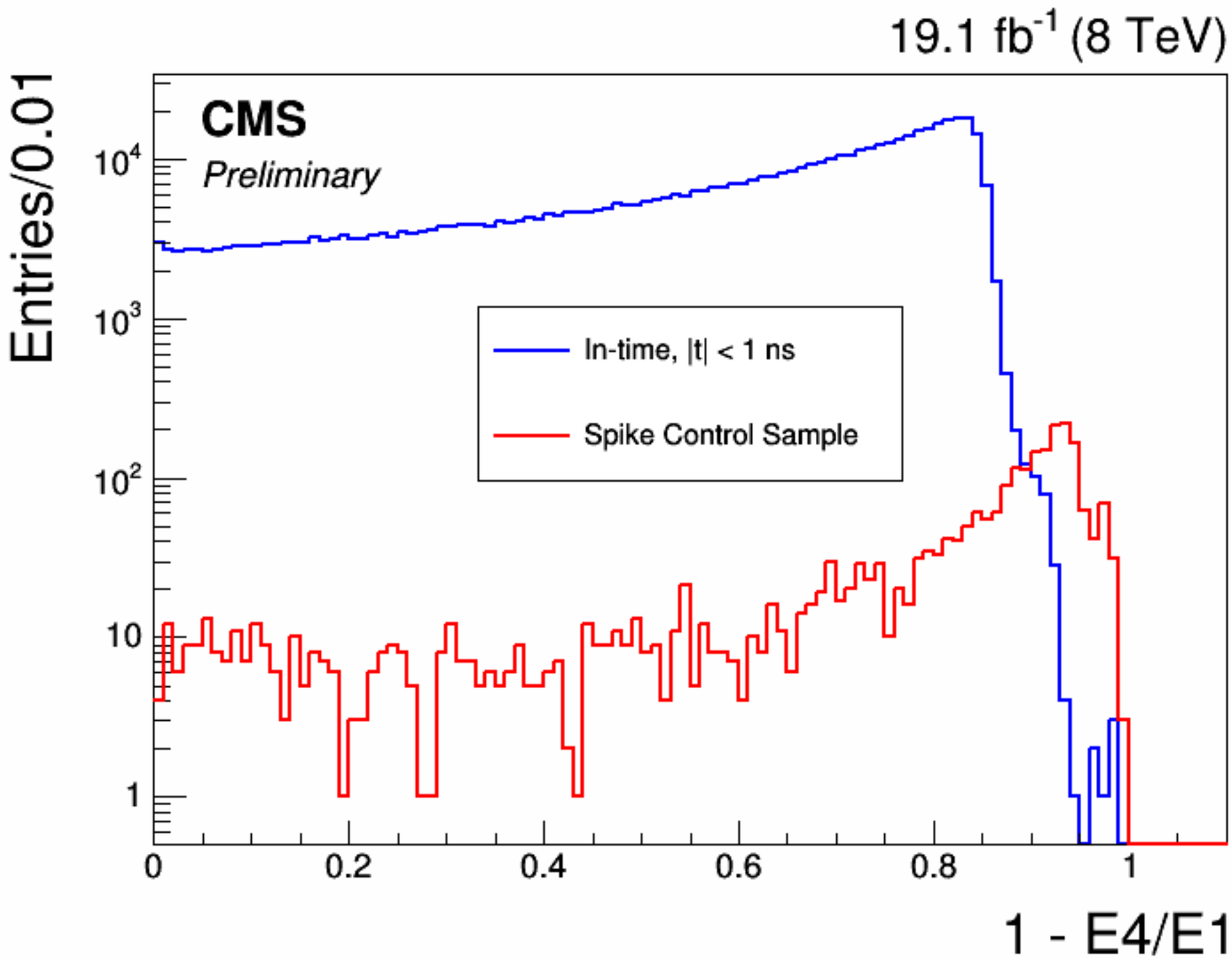


Cosmic background

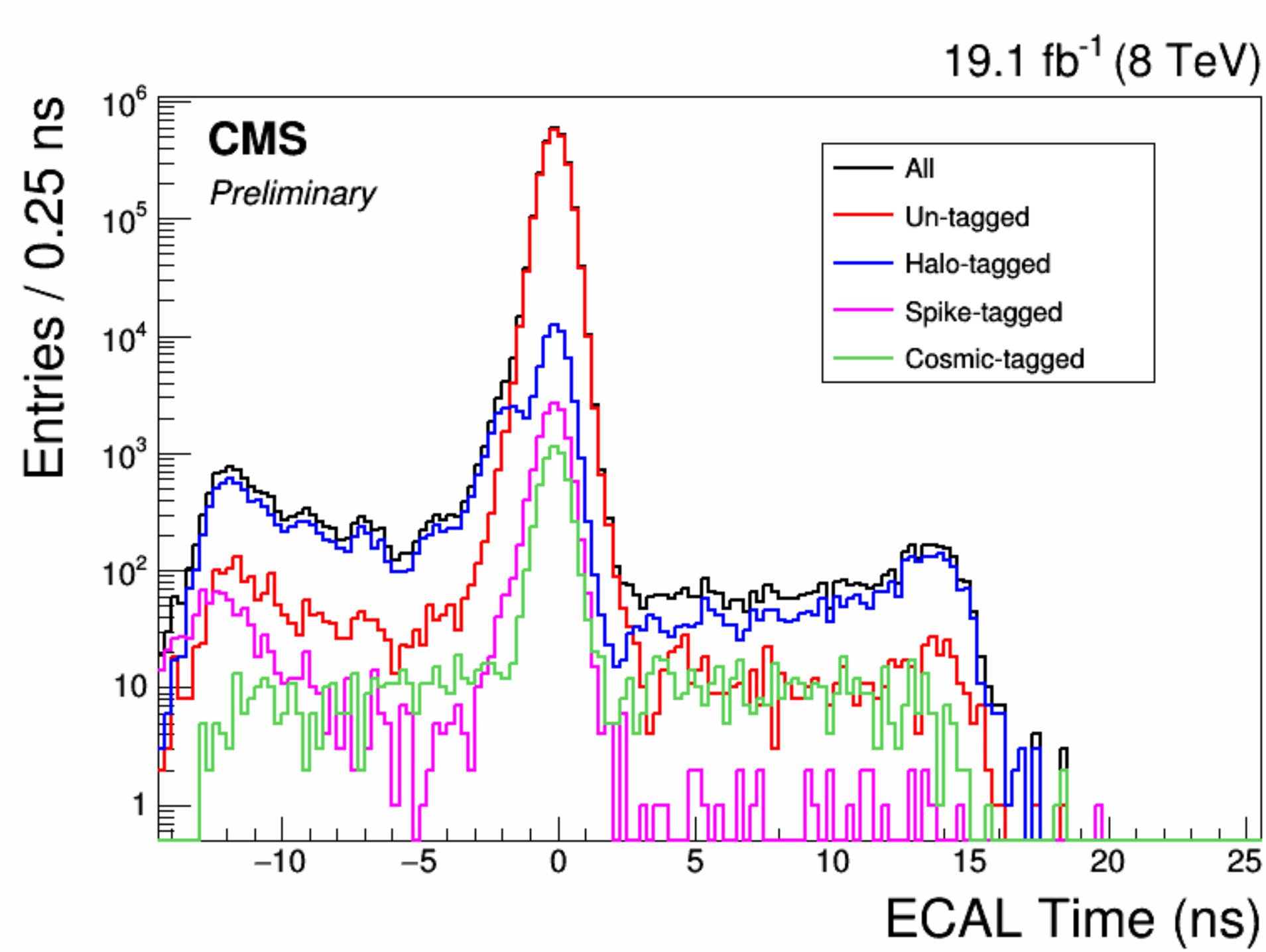


CMS muon detectors

ECAL APD hits

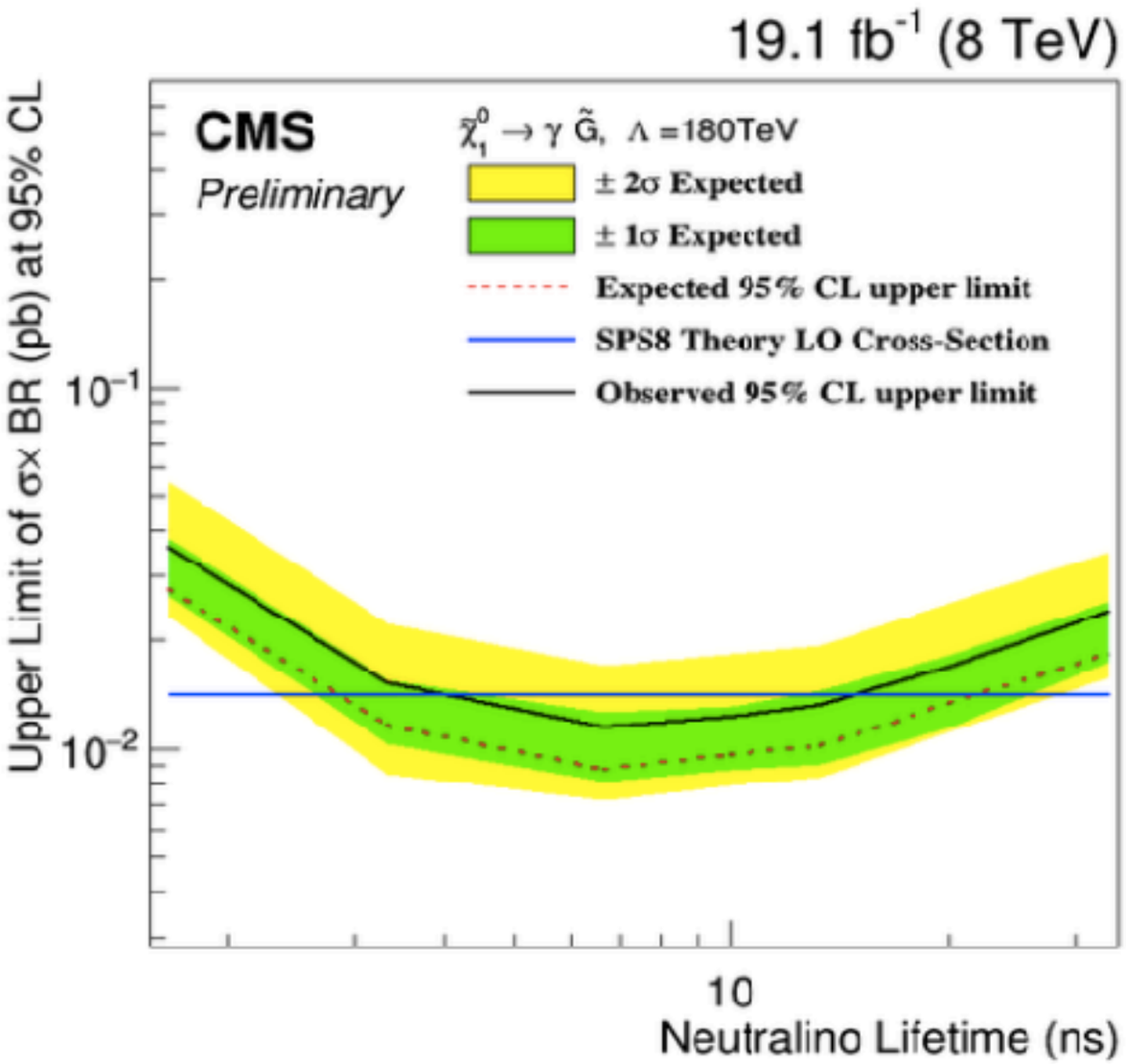


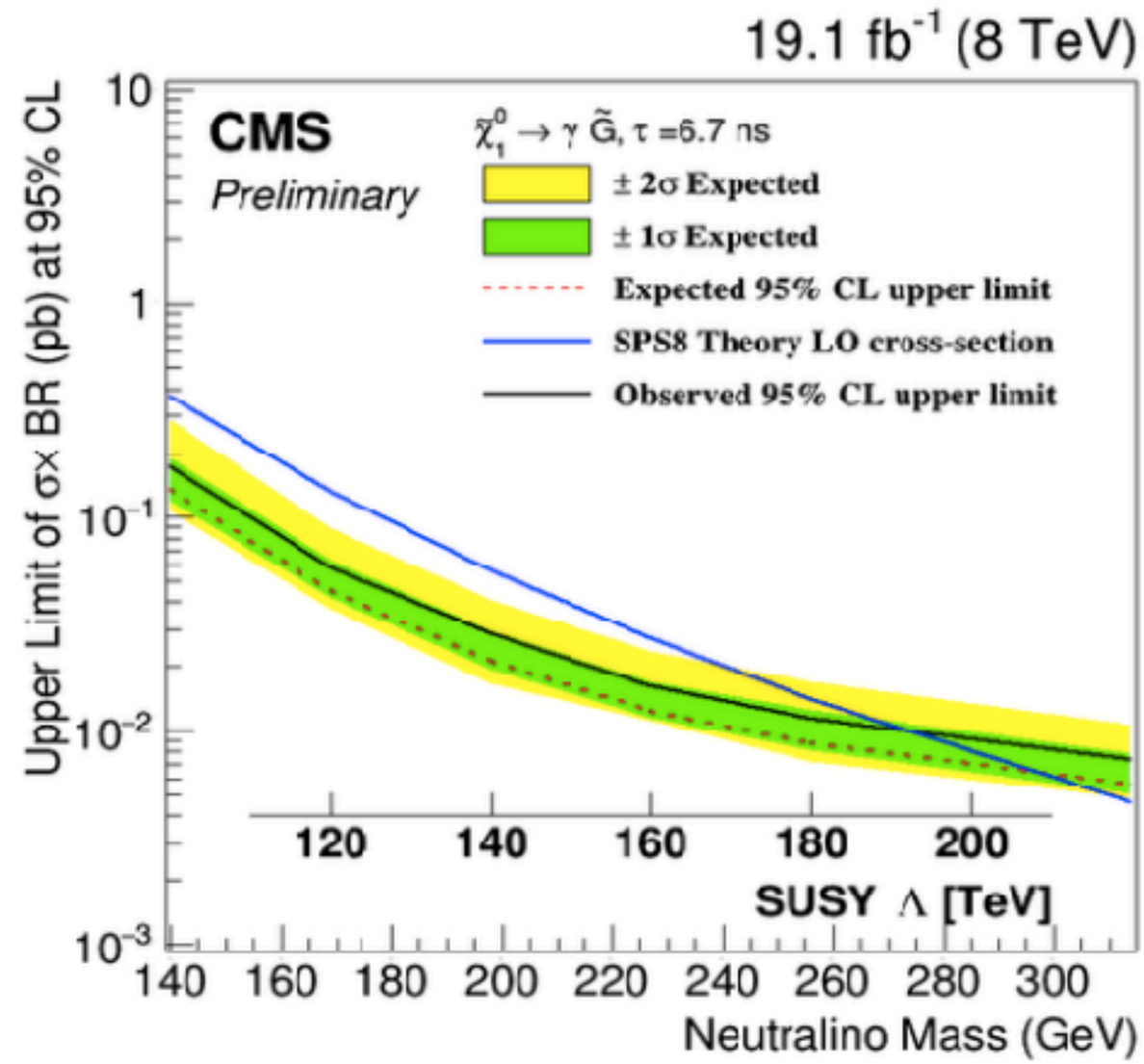
Photon + MET (timing) bkgs.



Photon + MET (timing): results

0.37 events expected, 1 observed

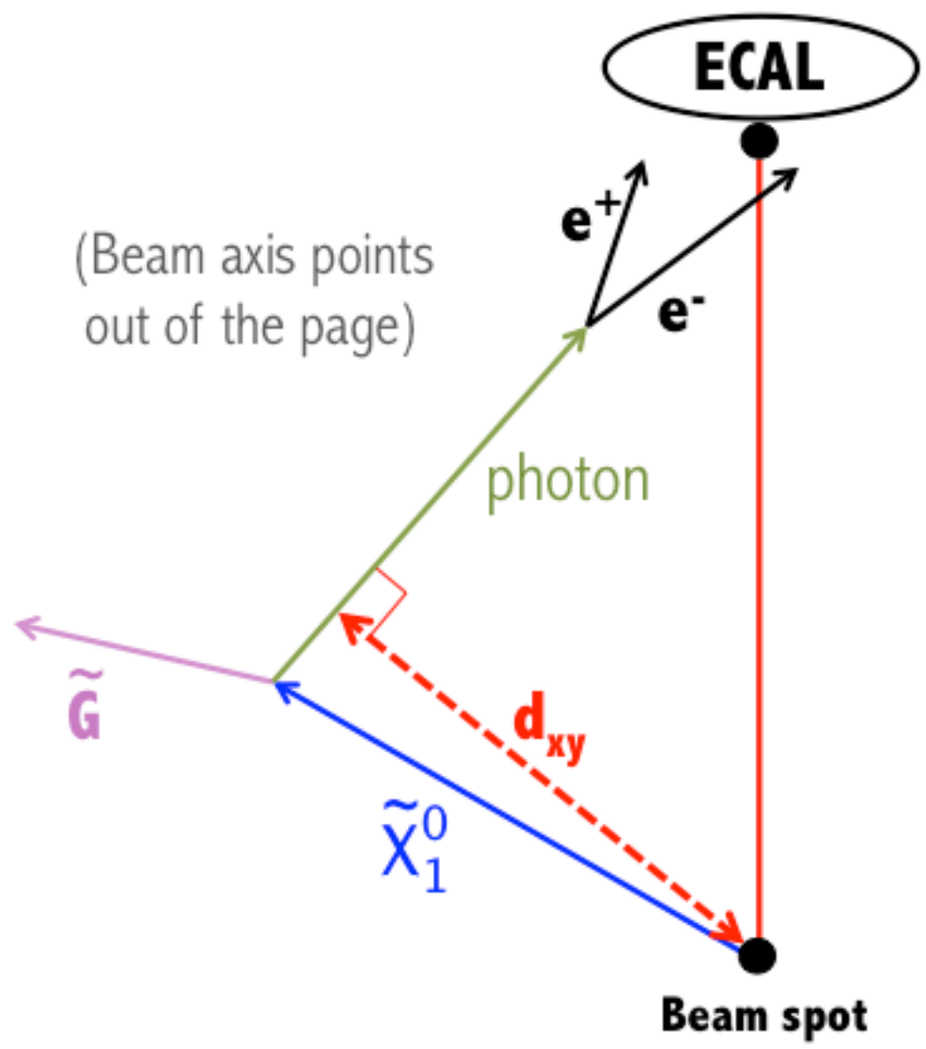




Long-lived searches at 8 TeV

- Displaced photon + MET (timing)
- Displaced photon + MET (conversion)

Displaced photon (conversion)

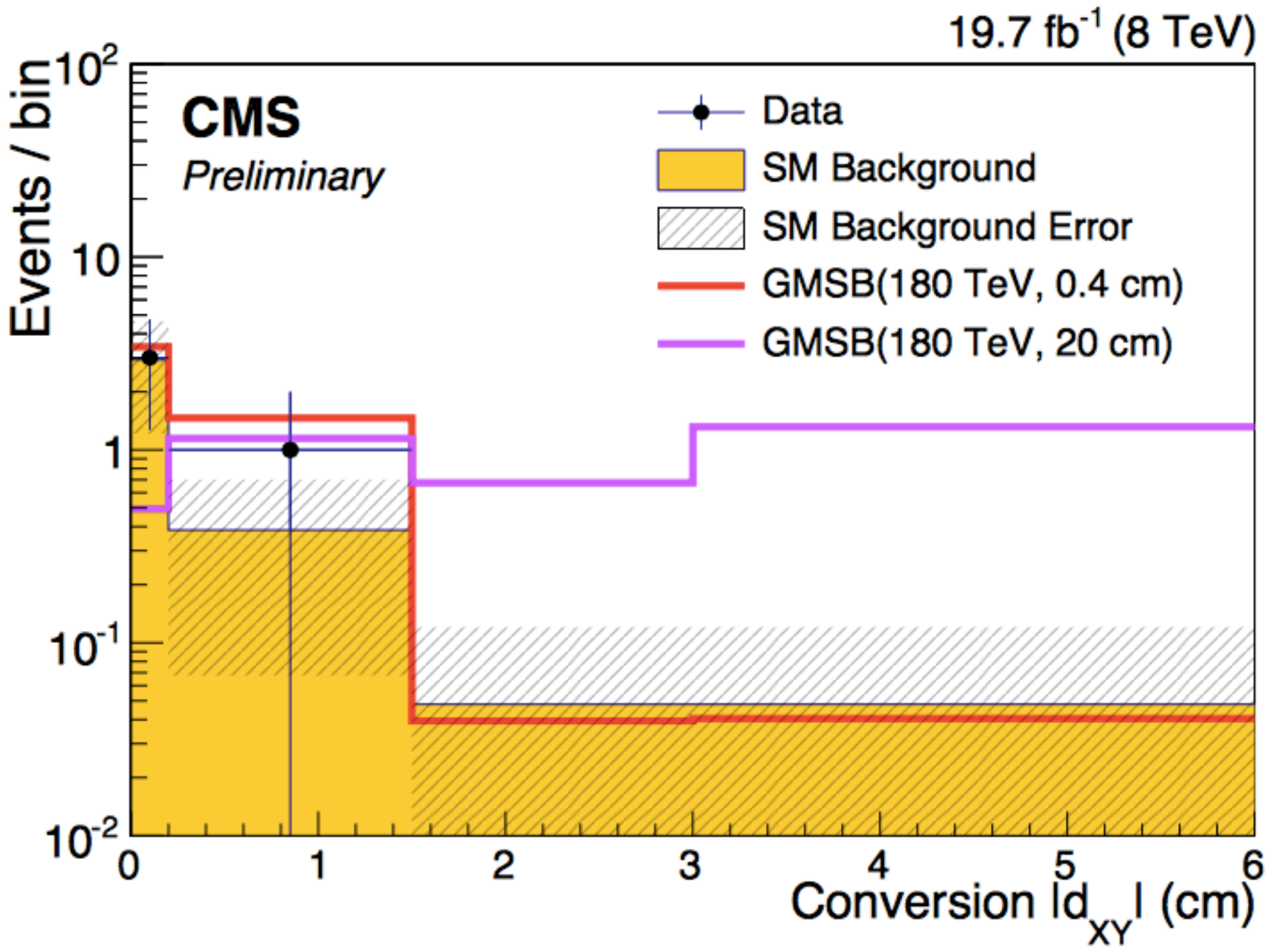


main background: mis-measured γ + jet

[http://cds.cern.ch/record/2019862?ln=en]

Conversion results

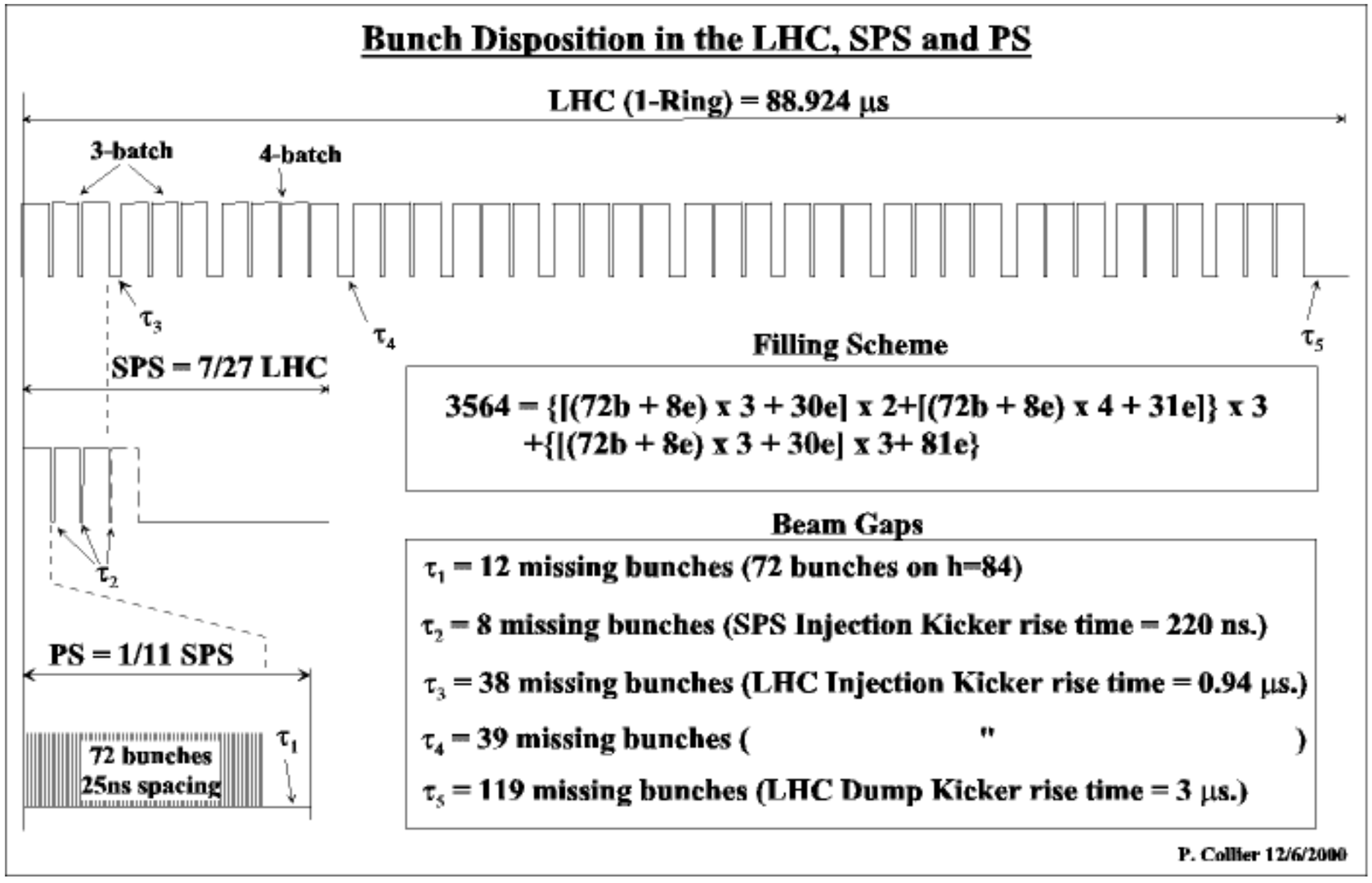
d_{xy} distribution estimated from CR of γ + jet events with no MET



Long-lived searches at 8 TeV

- Displaced photon + MET (timing)
- Displaced photon + MET (conversion)
- Stopped particles

Stopped particles



> 1 BX away from collision (+ after fill)

[http://dx.doi.org/10.1140/epjc/s10052-015-3367-z]

Stopped particles: signature

- ‘jet’ without collision
- beam halo veto
- cosmic ray veto
- electronic noise in calorimeters

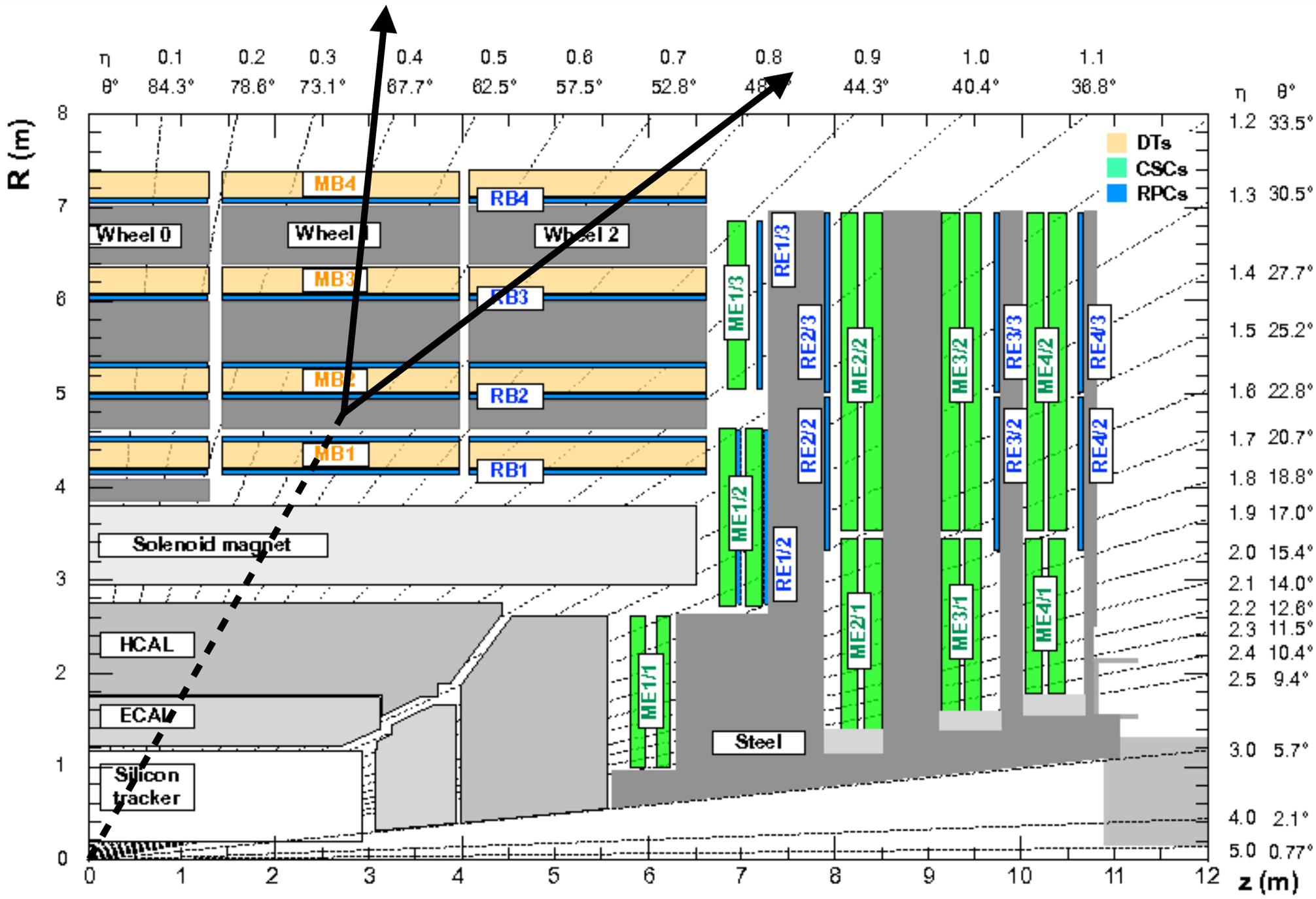
Stopped particles: results

Lifetime hypothesis	L_{eff} (fb^{-1})	Trigger livetime (s)	Expected bkg.	Observed
50 ns	0.121	5.0×10^4	$0.66^{+0.18}_{-0.07}$	0
75 ns	0.271	1.0×10^5	$1.3^{+0.4}_{-0.2}$	3
100 ns	0.512	2.0×10^5	$2.6^{+0.7}_{-0.5}$	3
1 μs	2.864	8.4×10^5	$11.0^{+3.0}_{-2.1}$	6
10 μs	3.885	1.0×10^6	$13.1^{+3.6}_{-2.4}$	10
100 μs	3.972	1.0×10^6	$13.2^{+3.6}_{-2.5}$	10
10^3 s	3.868	1.0×10^6	$13.2^{+3.6}_{-2.5}$	10
10^4 s	3.004	1.0×10^6	$13.2^{+3.6}_{-2.5}$	10
10^5 s	1.727	1.0×10^6	$13.2^{+3.6}_{-2.5}$	10
10^6 s	1.181	1.0×10^6	$13.2^{+3.6}_{-2.5}$	10

Long-lived searches at 8 TeV

- Displaced photon + MET (timing)
- Displaced photon + MET (conversion)
- Stopped particles
- Displaced dimuons (muon system)

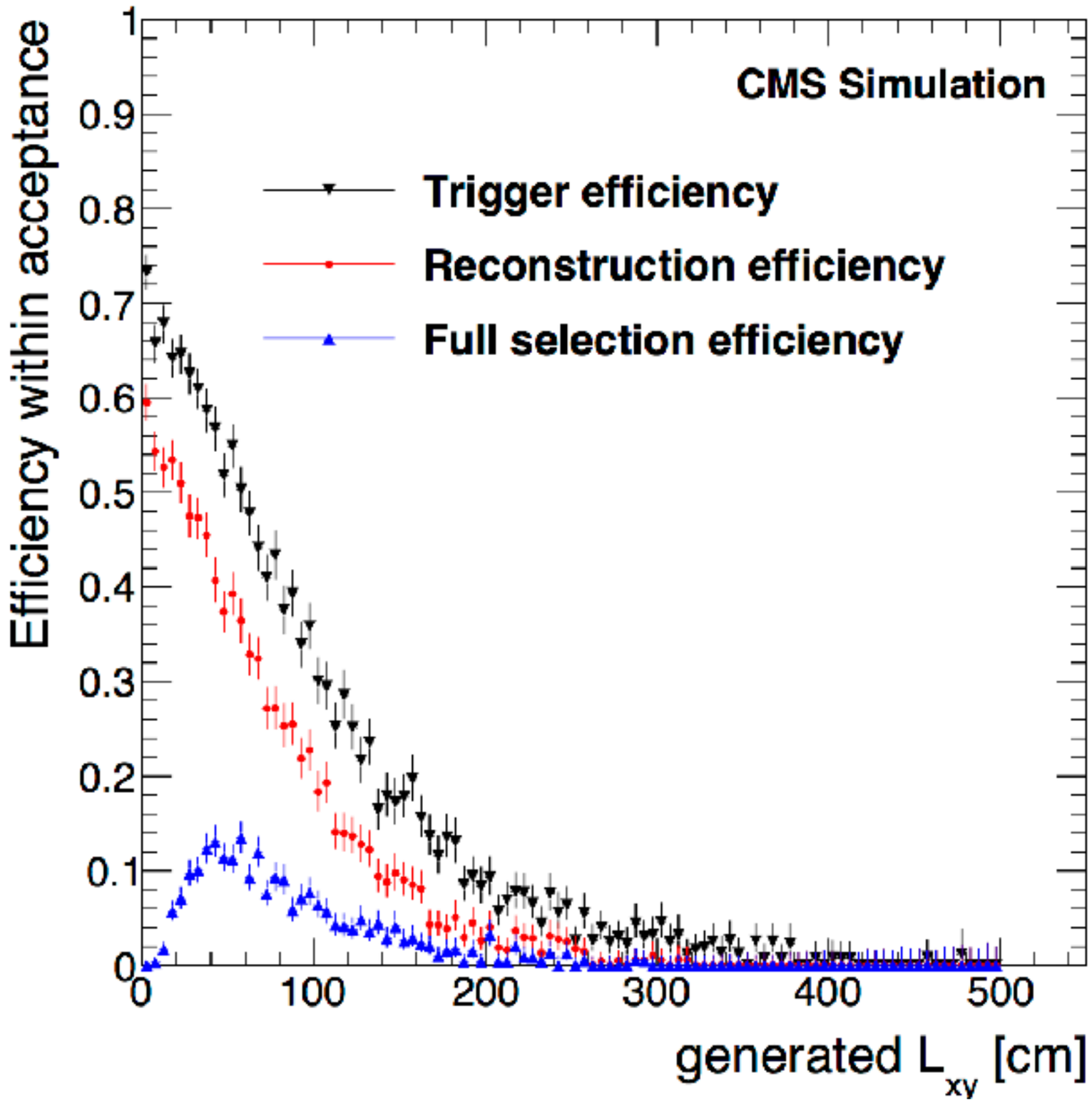
Displaced dimuons



essentially background-free

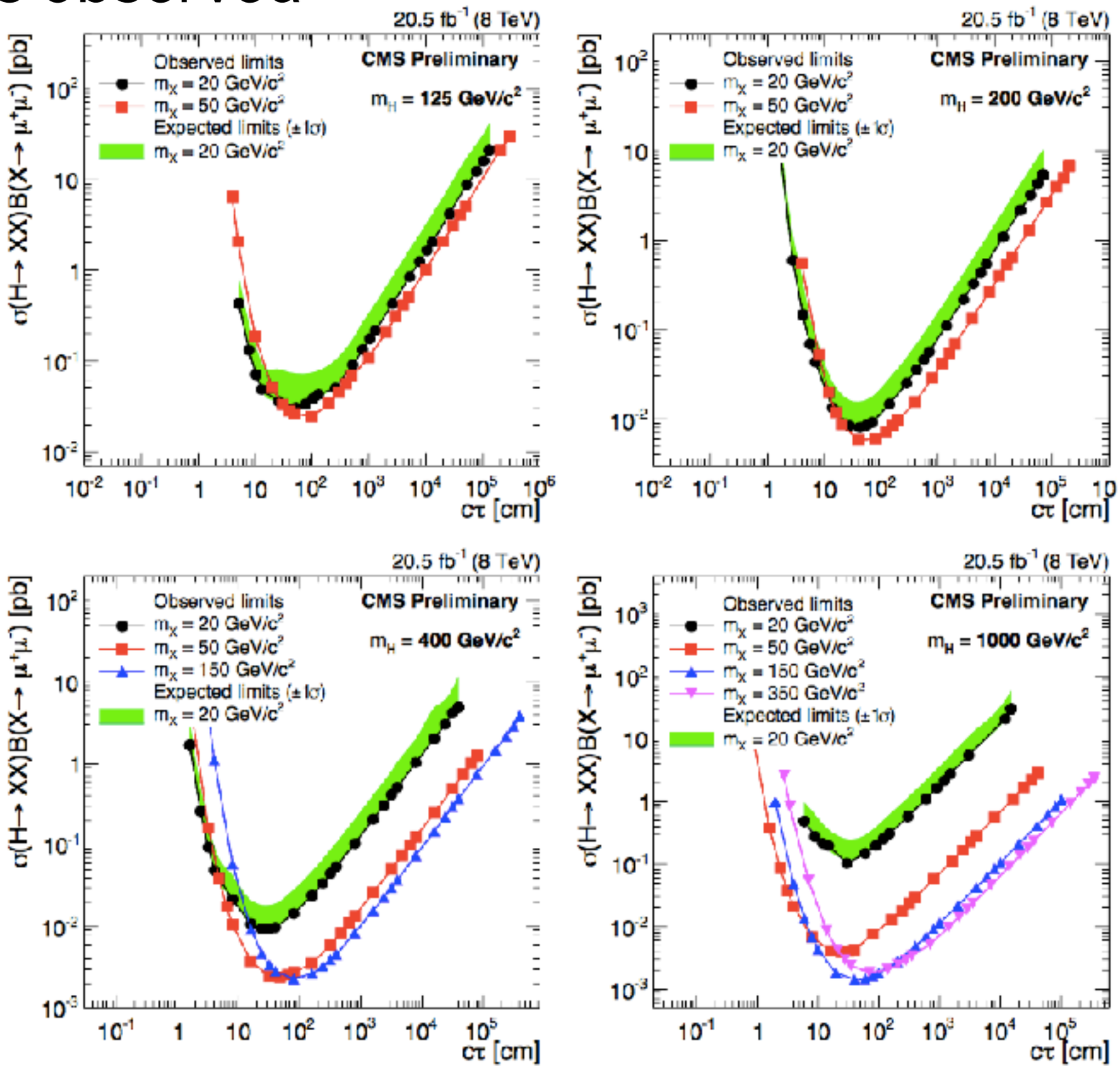
[https://cds.cern.ch/record/2005761?ln=en]

Muon-only trigger and reco



Displaced dimuon: results

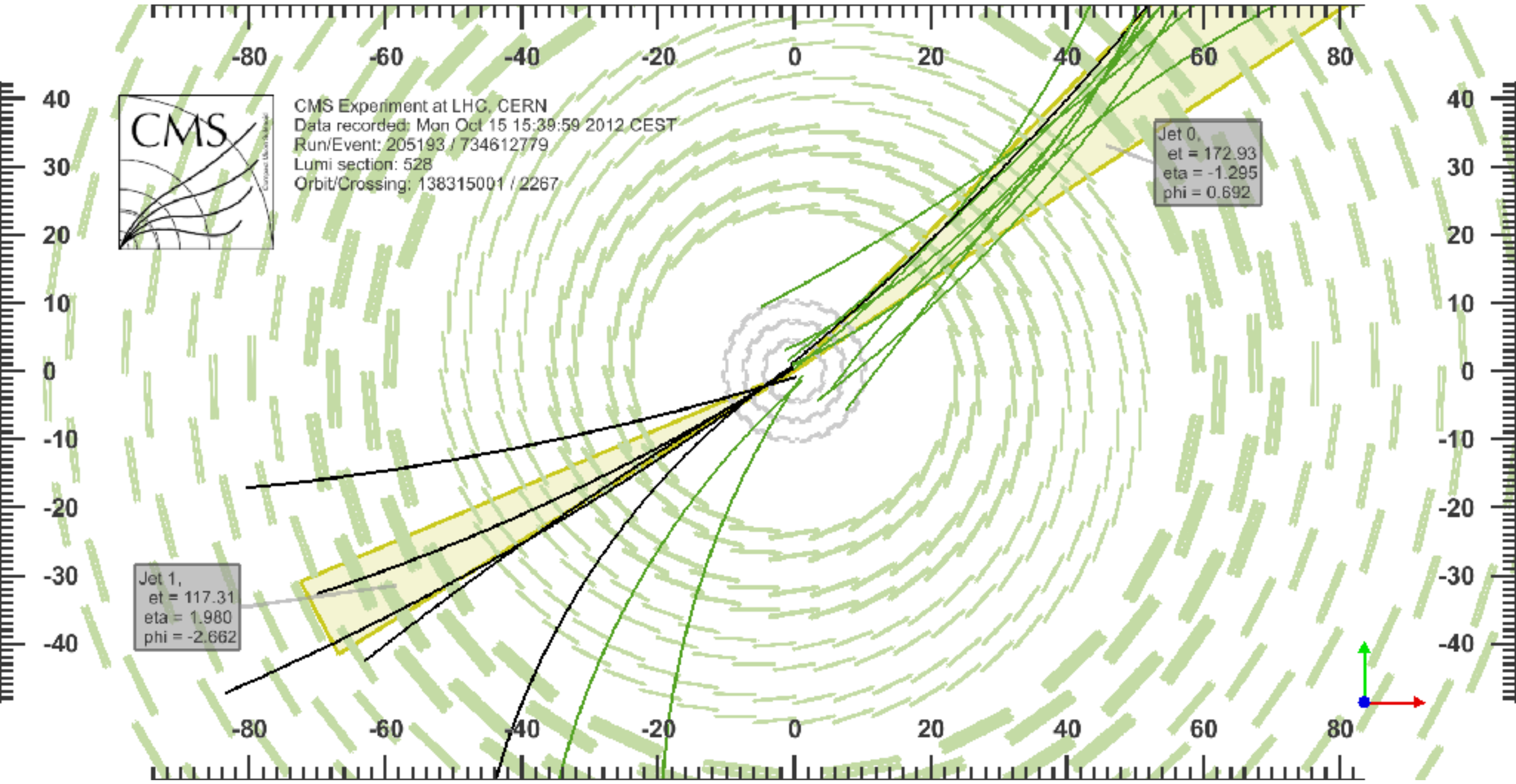
No events observed



Long-lived searches at 8 TeV

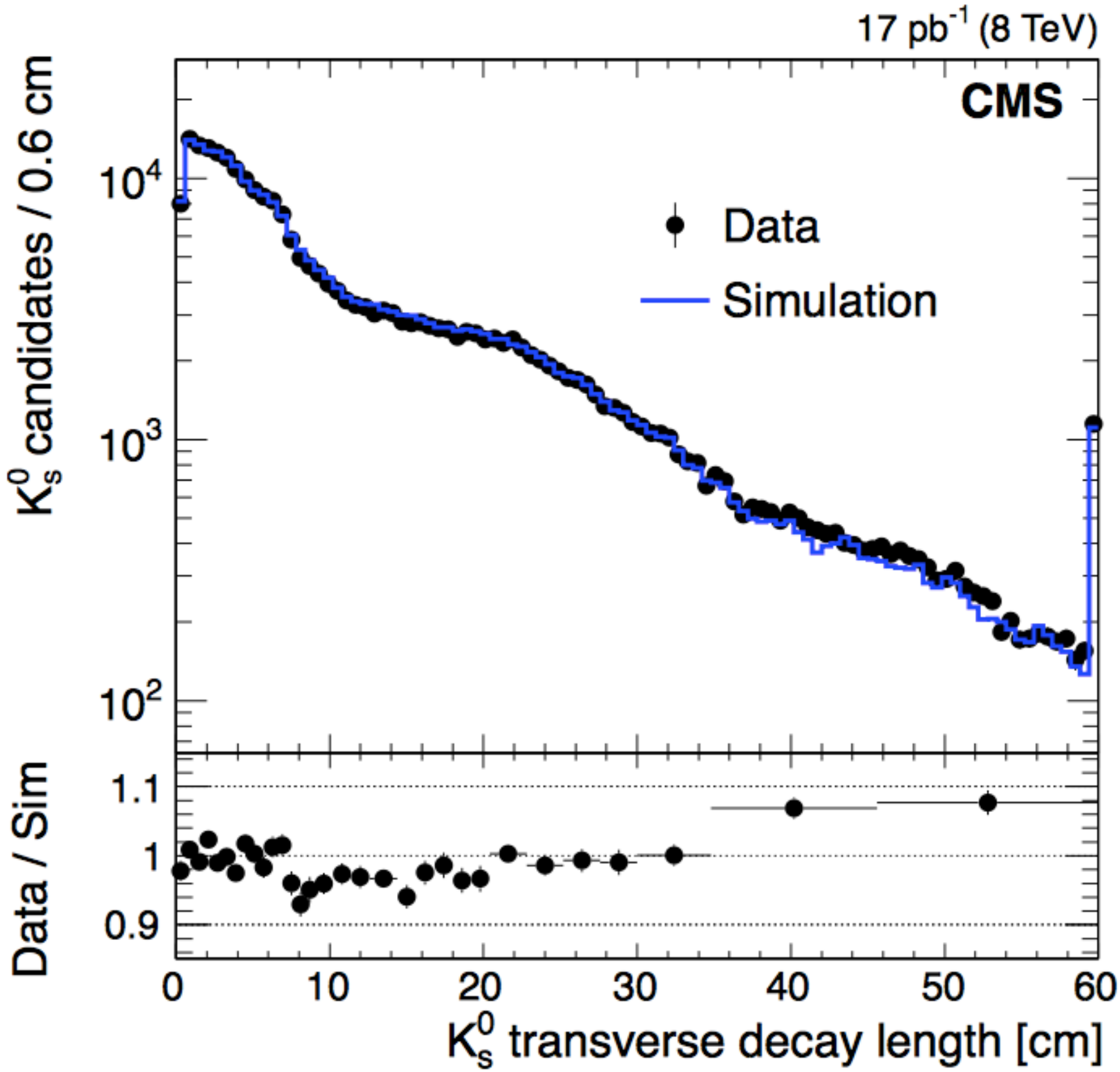
- Displaced photon + MET (timing)
- Displaced photon + MET (conversion)
- Stopped particles
- Displaced dimuons (muon system)
- Displaced dijets

Displaced dijets

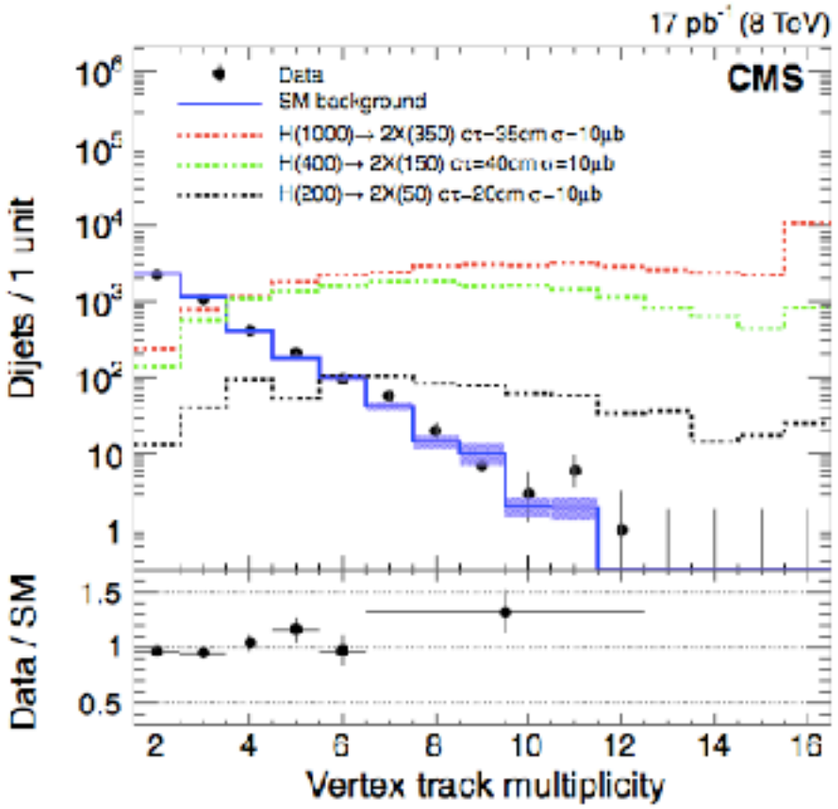


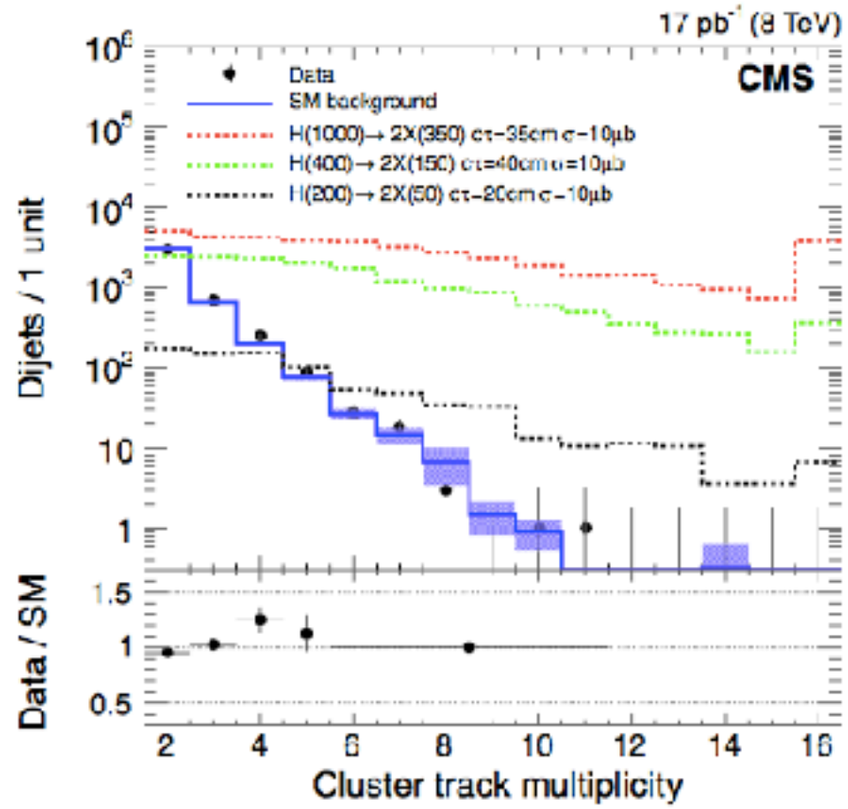
[http://journals.aps.org/prd/abstract/10.1103/PhysRevD.91.012007]

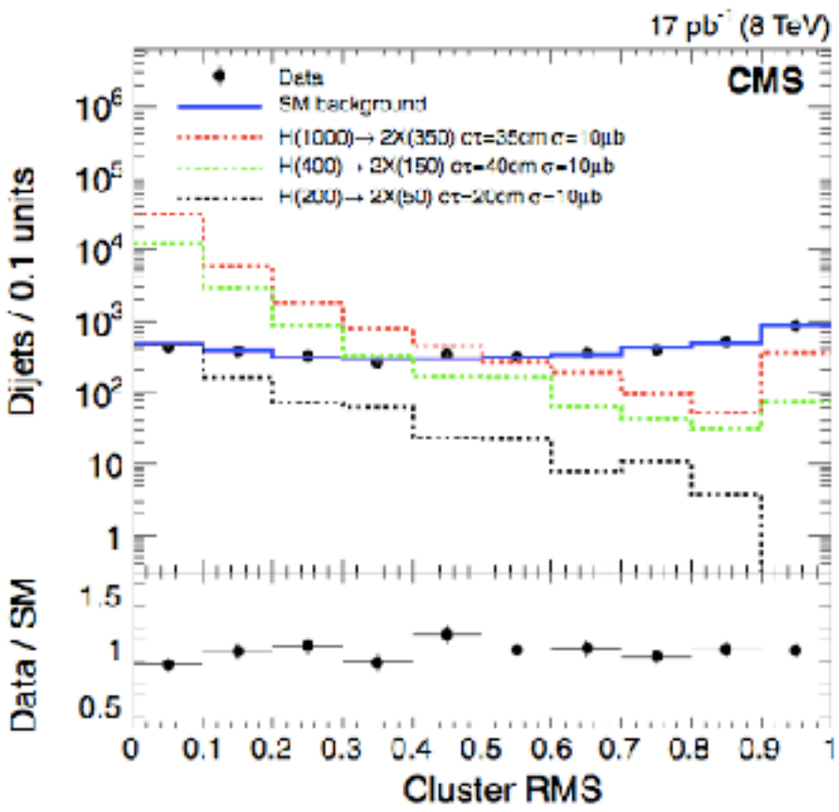
Displaced dijets — background

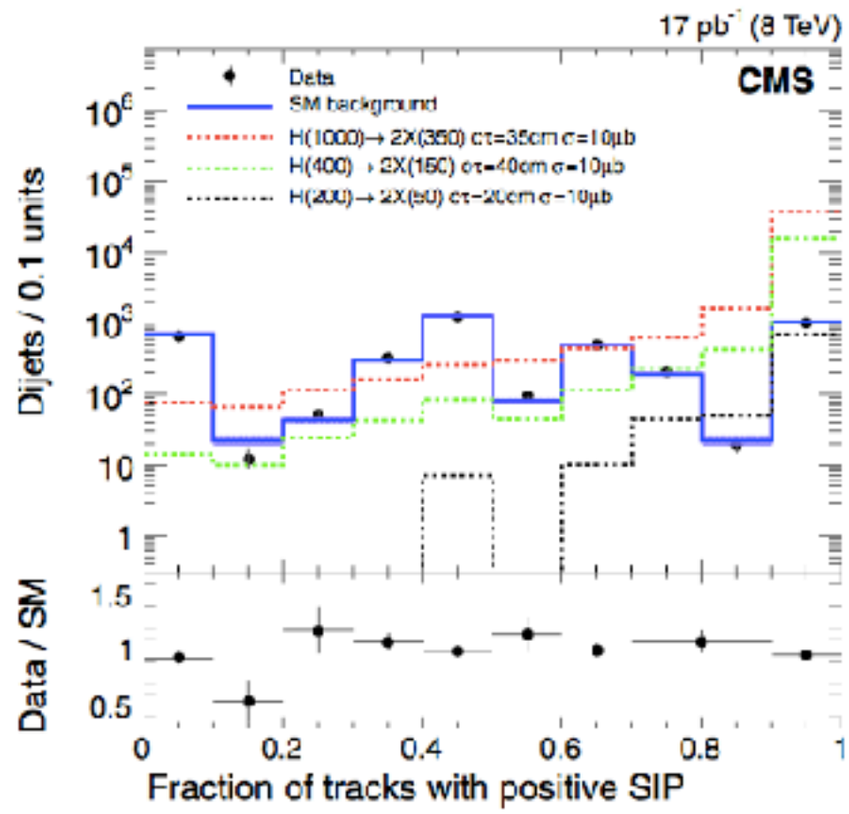


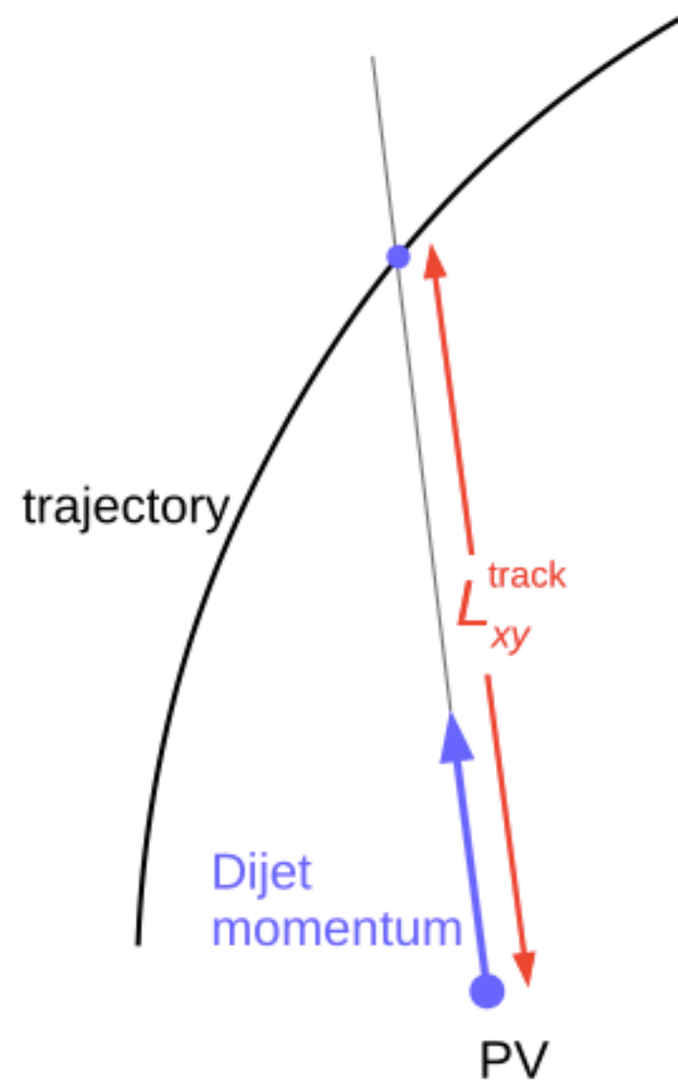
Displaced dijet: signal variables





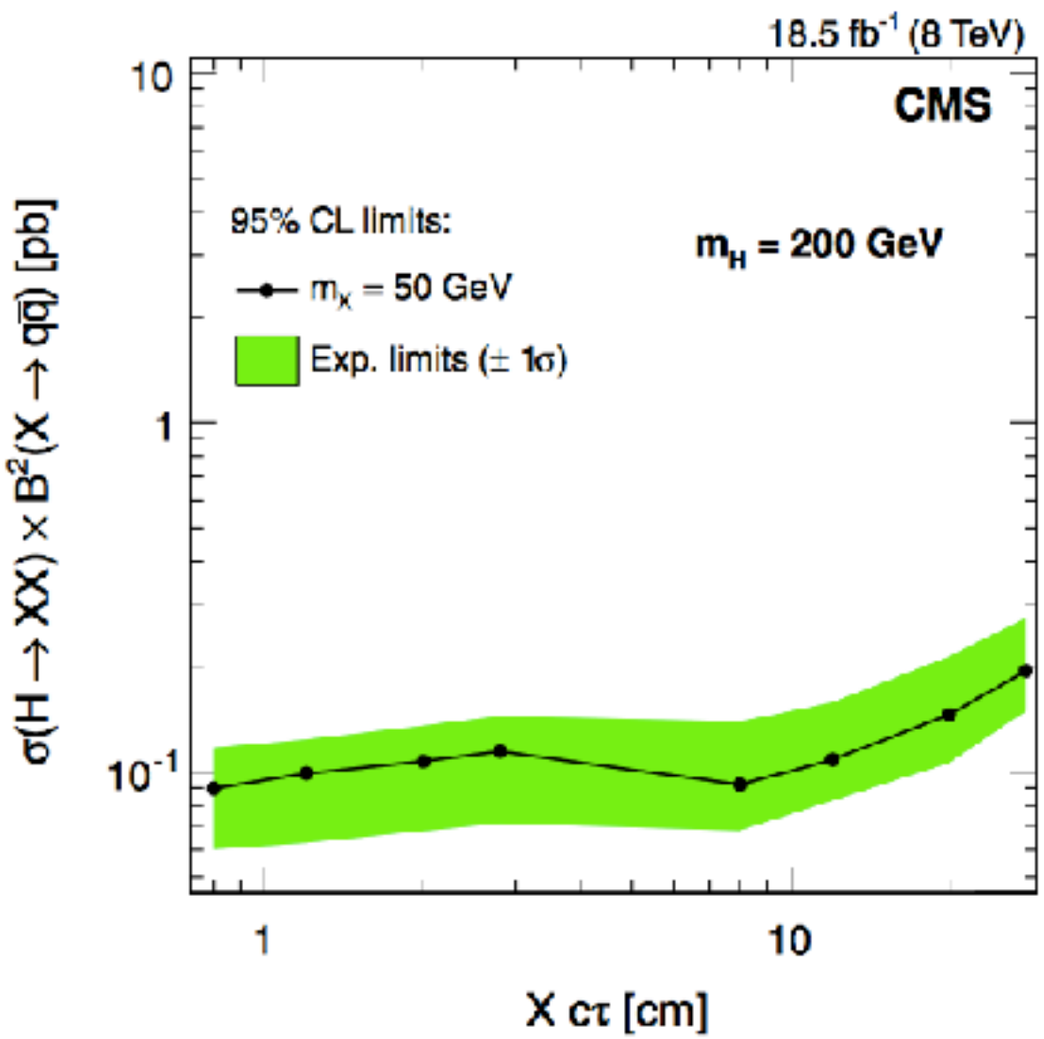


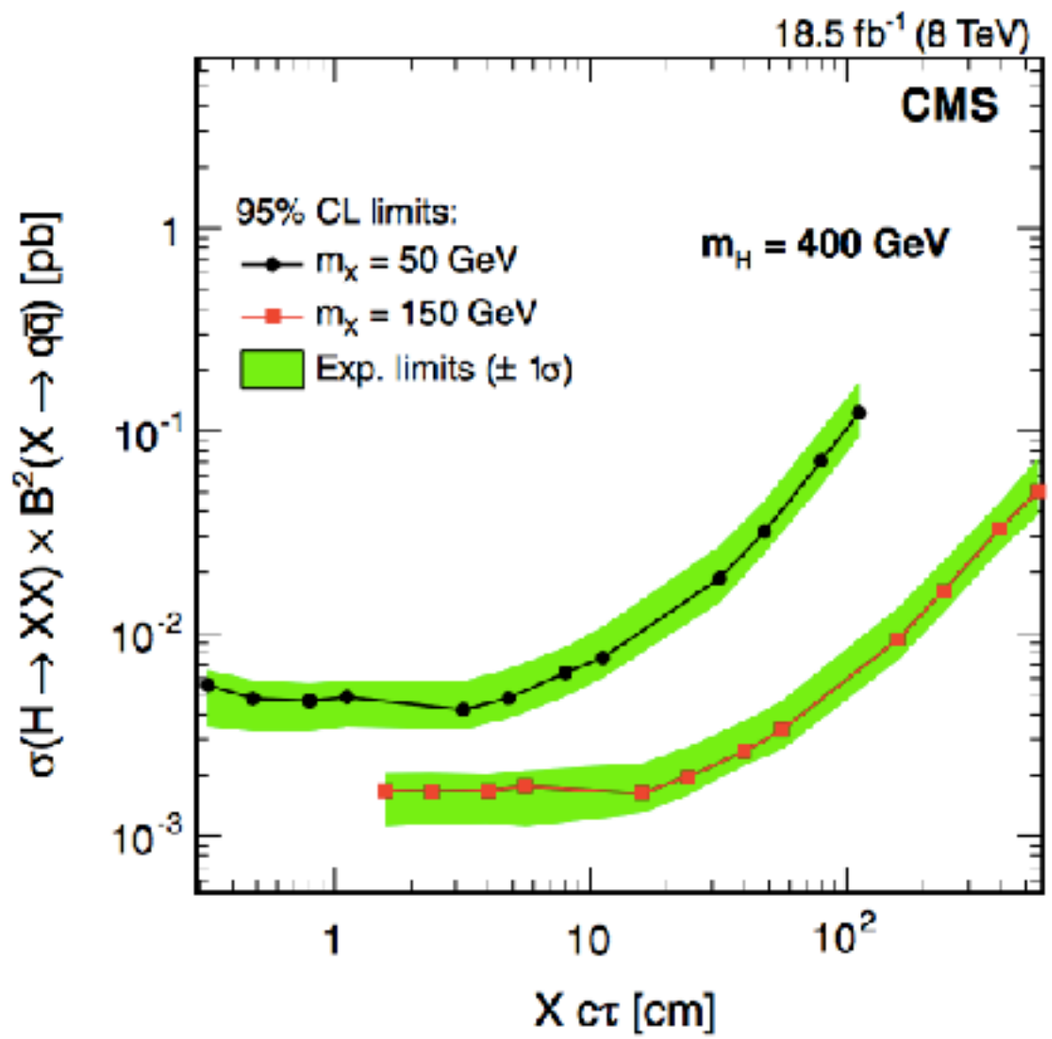




Displaced dijet — results

	low $\langle L_{xy} \rangle$ selection	high $\langle L_{xy} \rangle$ selection
Number of prompt tracks for each jet	≤ 1	≤ 1
Prompt track energy fraction for each jet	< 0.15	< 0.09
Vertex/cluster discriminant	> 0.9	> 0.8
Data events	2	1
Expected background	$1.56 \pm 0.25 \pm 0.47$	$1.13 \pm 0.15 \pm 0.50$

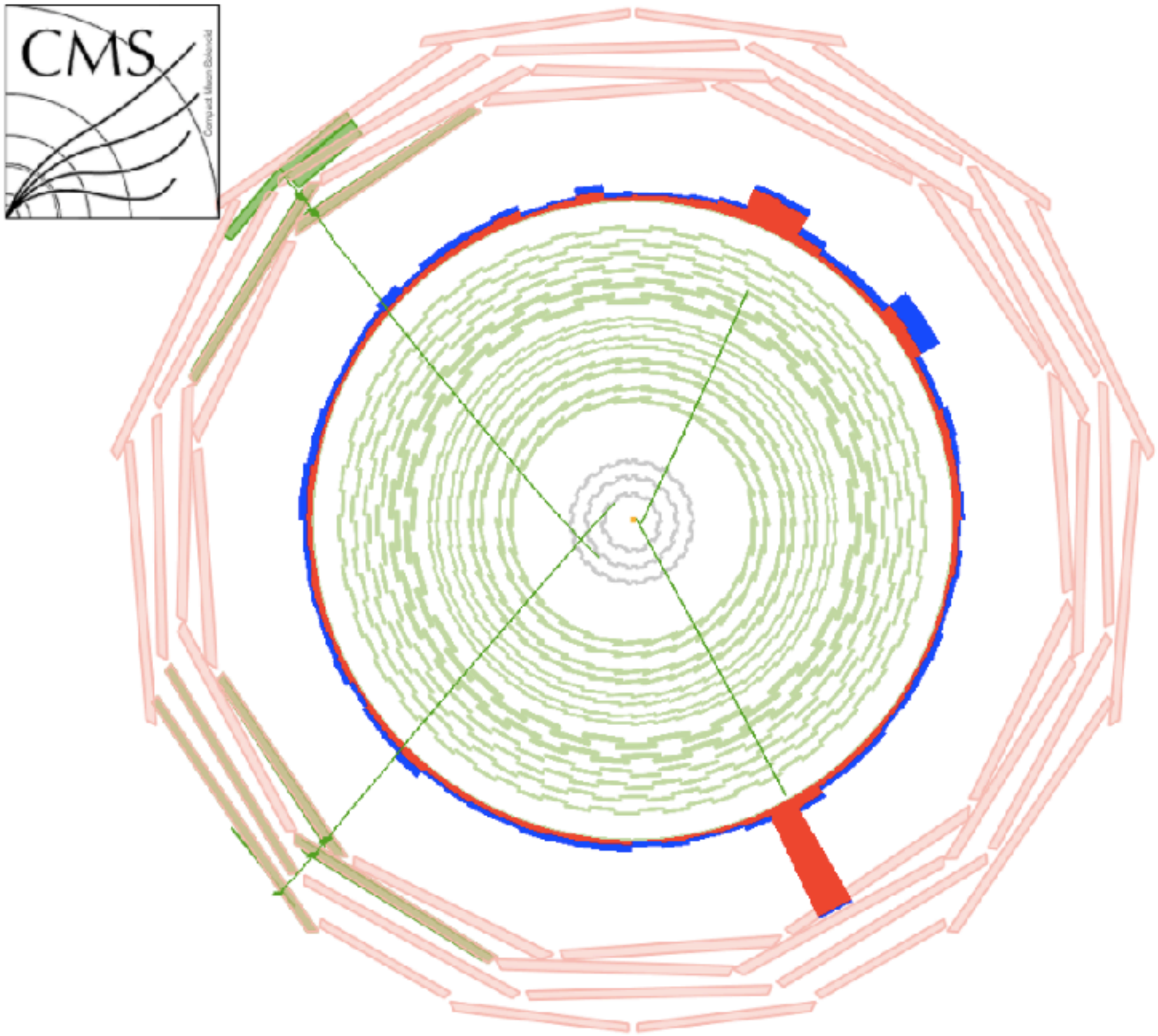




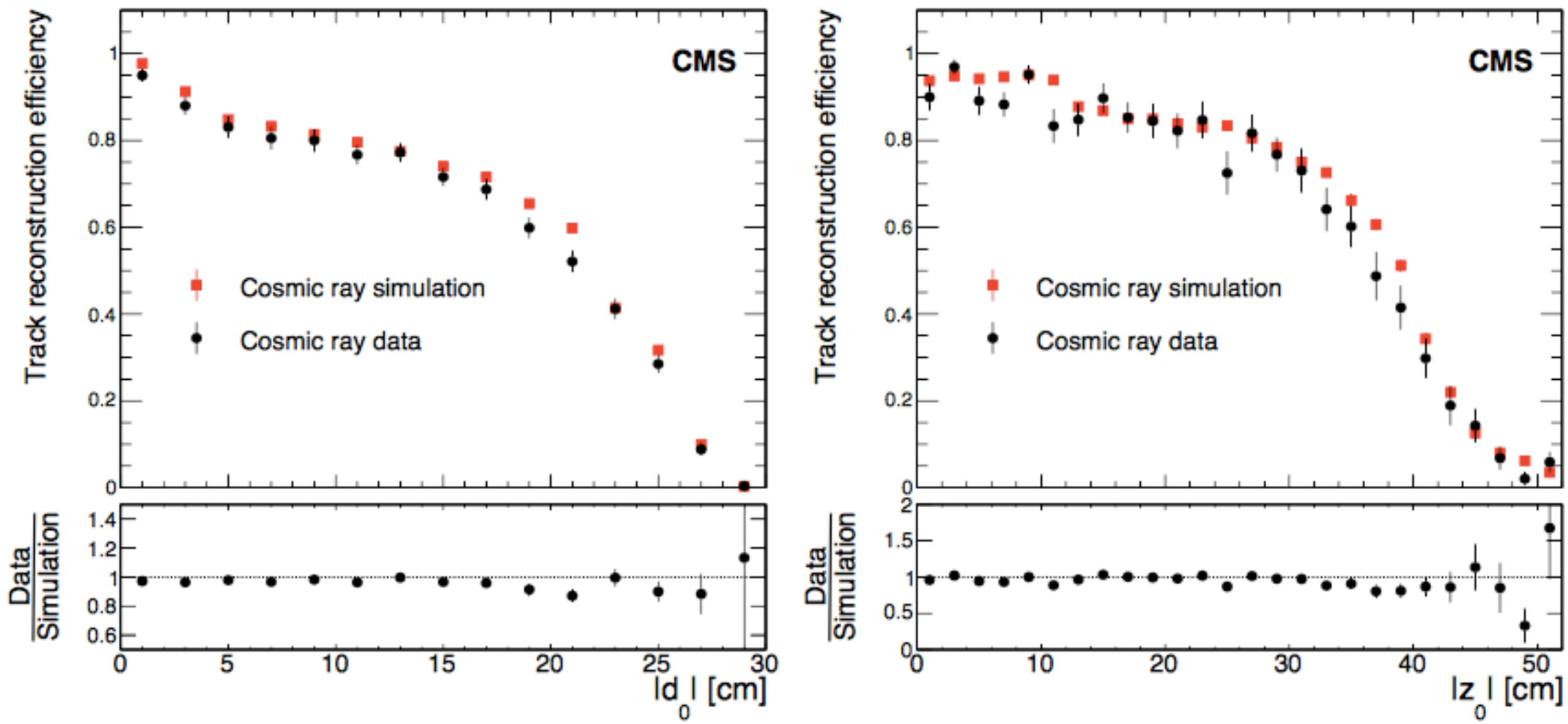
Long-lived searches at 8 TeV

- Displaced photon + MET (timing)
- Displaced photon + MET (conversion)
- Stopped particles
- Displaced dimuons (muon system)
- Displaced dijets
- Displaced dileptons (tracker)

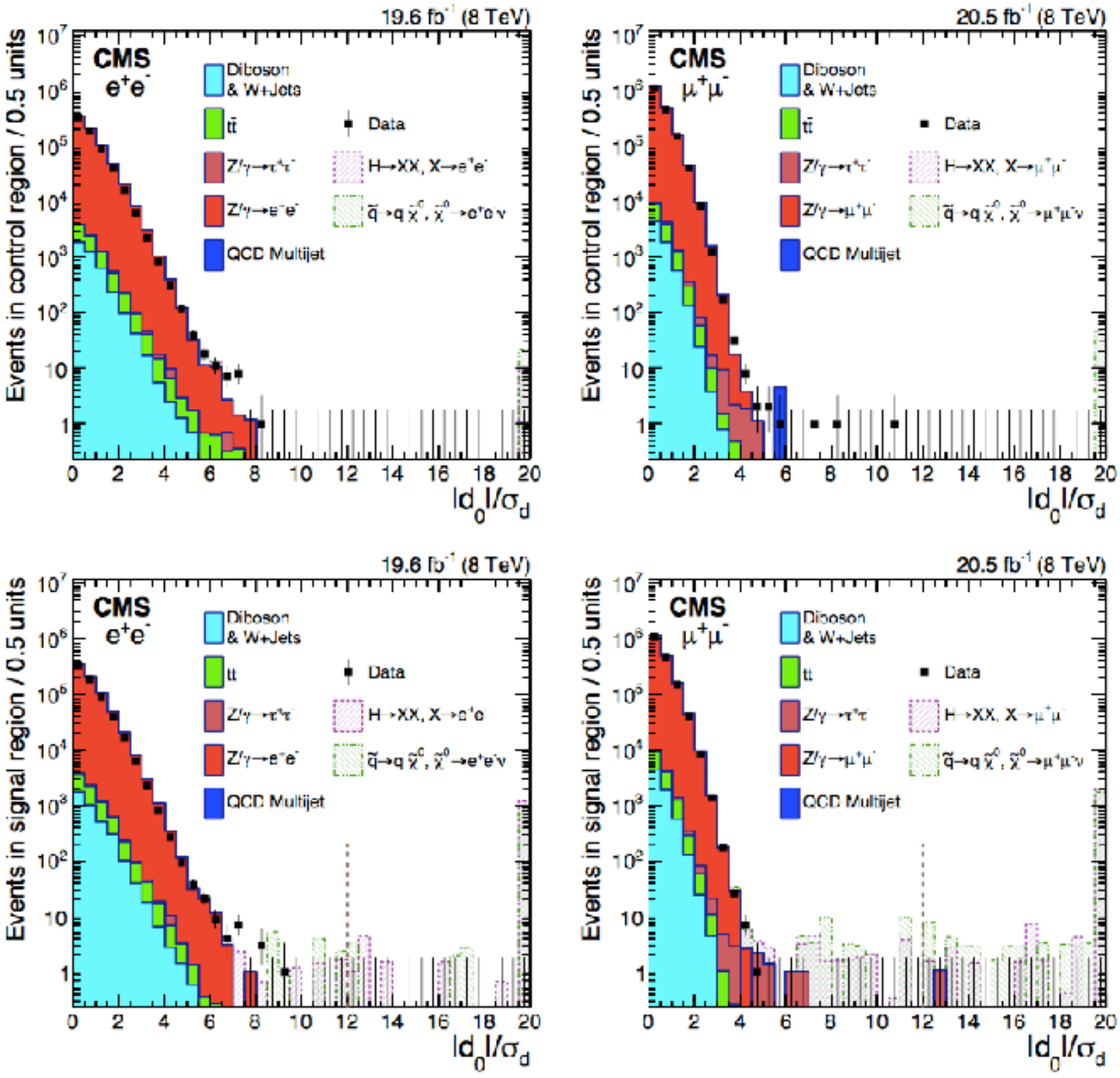
Pairs of displaced dileptons



Displaced lepton tracking eff.



Background estimation

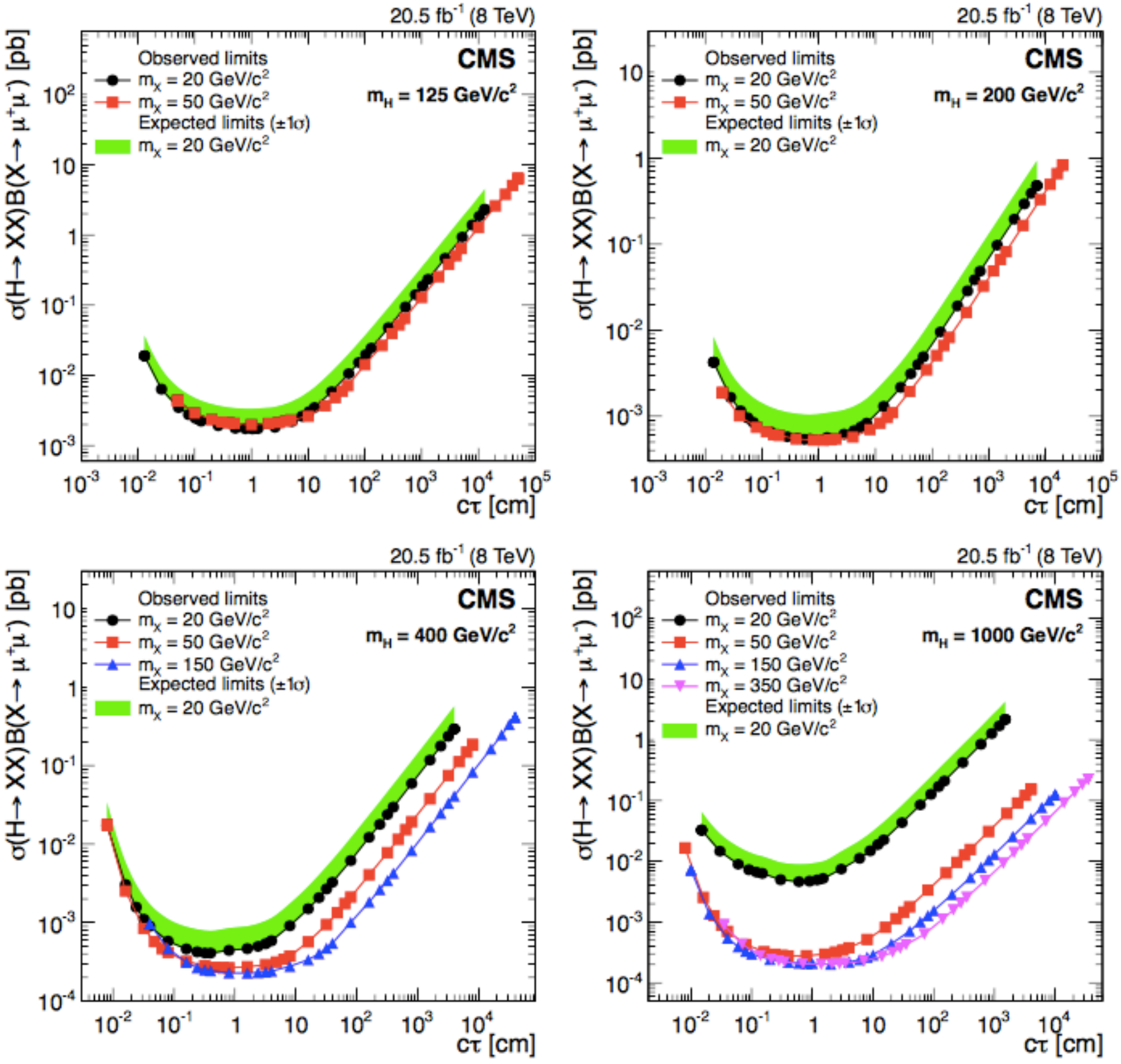


angle between PV and dilepton

$\Delta\varphi > \pi/2$
CR

$\Delta\varphi < \pi/2$
SR

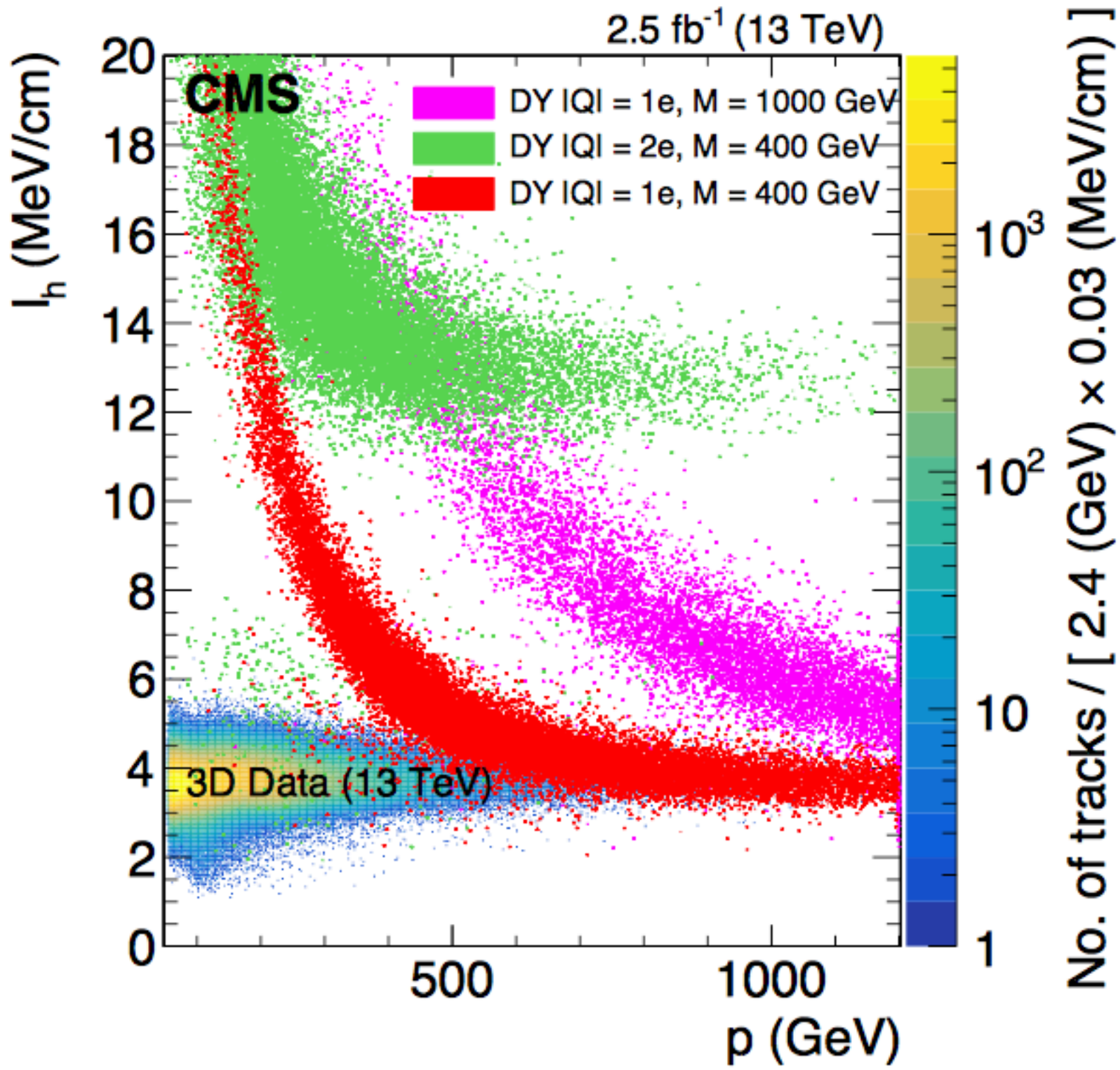
Displaced dileptons — results



Long-lived searches at 13 TeV

- Heavy Stable Charged Particles (HSCPs)

HSCPs: energy loss



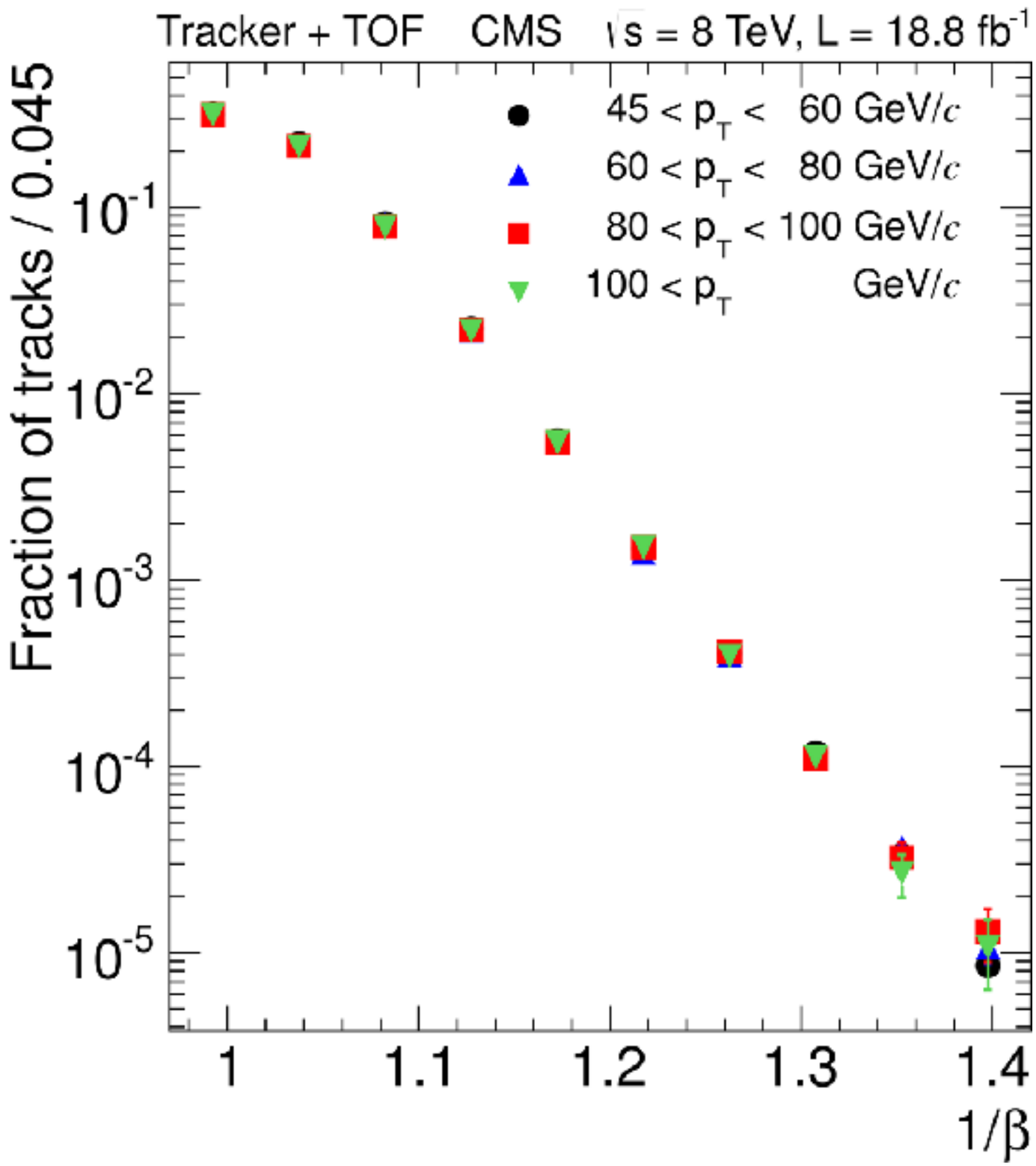
$$I_{as} = \frac{3}{N} \times \left(\frac{1}{12N} + \sum_{i=1}^{N} \left[P_i \times \left(P_i - \frac{2i-1}{2N} \right)^2 \right] \right)$$

$$I_h = \left(\frac{1}{N_{85\%}} \sum_{i}^{N_{85\%}} c_i^{-2} \right)^{-1/2}$$

$$I_h = K \frac{m^2}{p^2} + C$$

[https://cds.cern.ch/record/2205281]

HSCPs: TOF



$$\beta^{-1} = 1 + \frac{c\delta_t}{L}$$

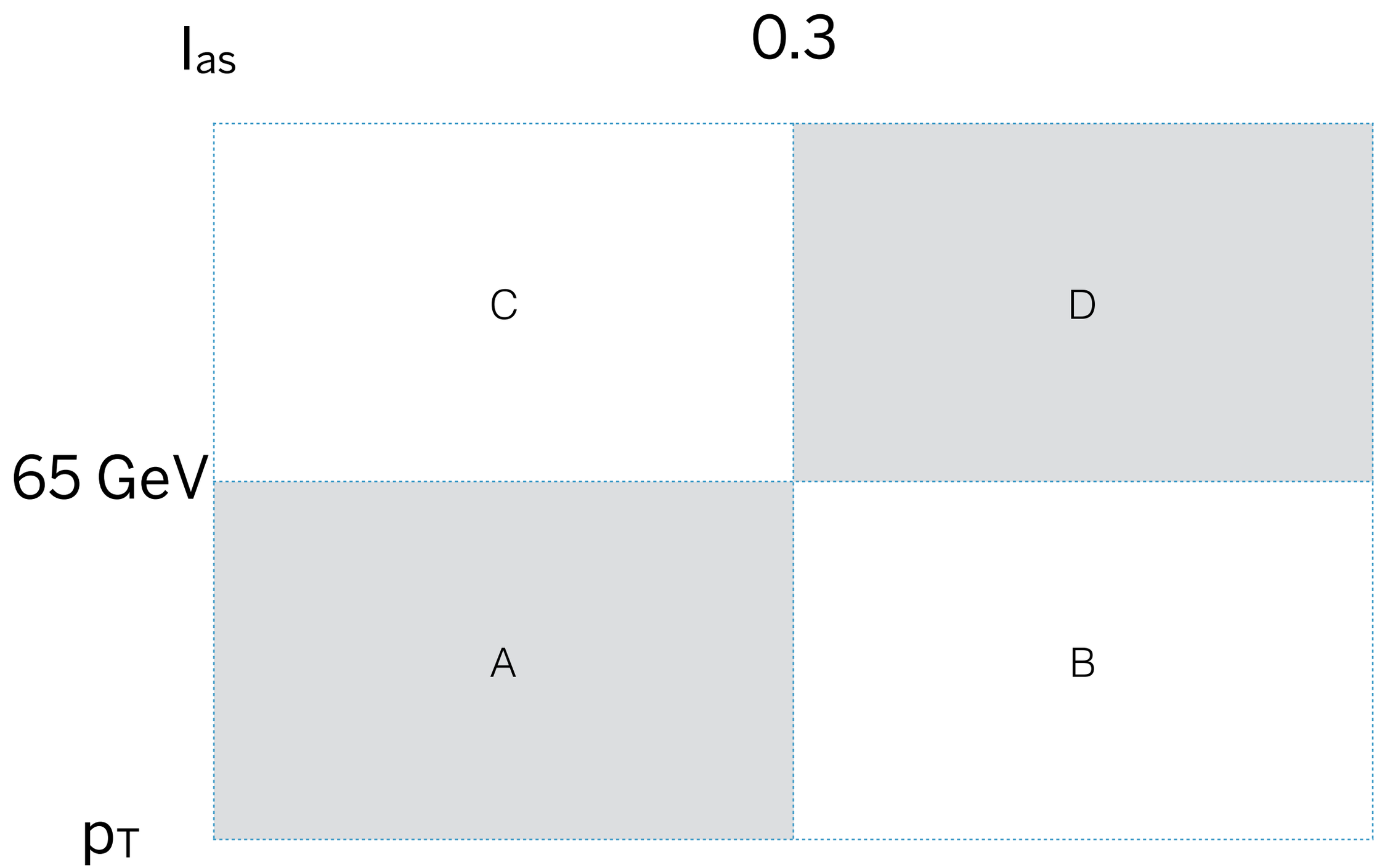
$$w_i = \frac{(n-2)}{n}\frac{L_i^2}{\sigma_{\mathrm{DT}}^2}$$

(central)

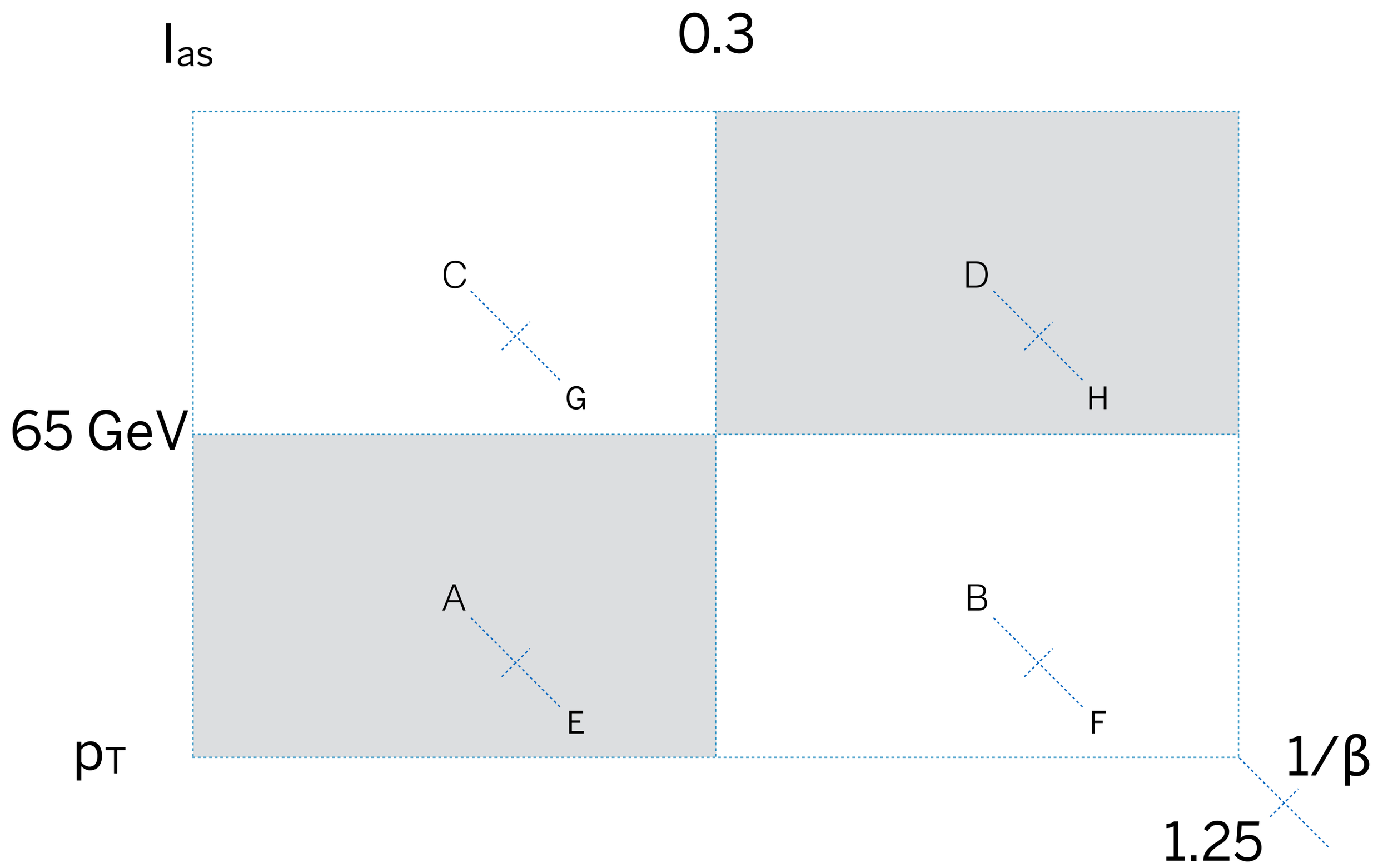
$$w_i = \frac{L_i^2}{\sigma_i^2}$$

(forward)

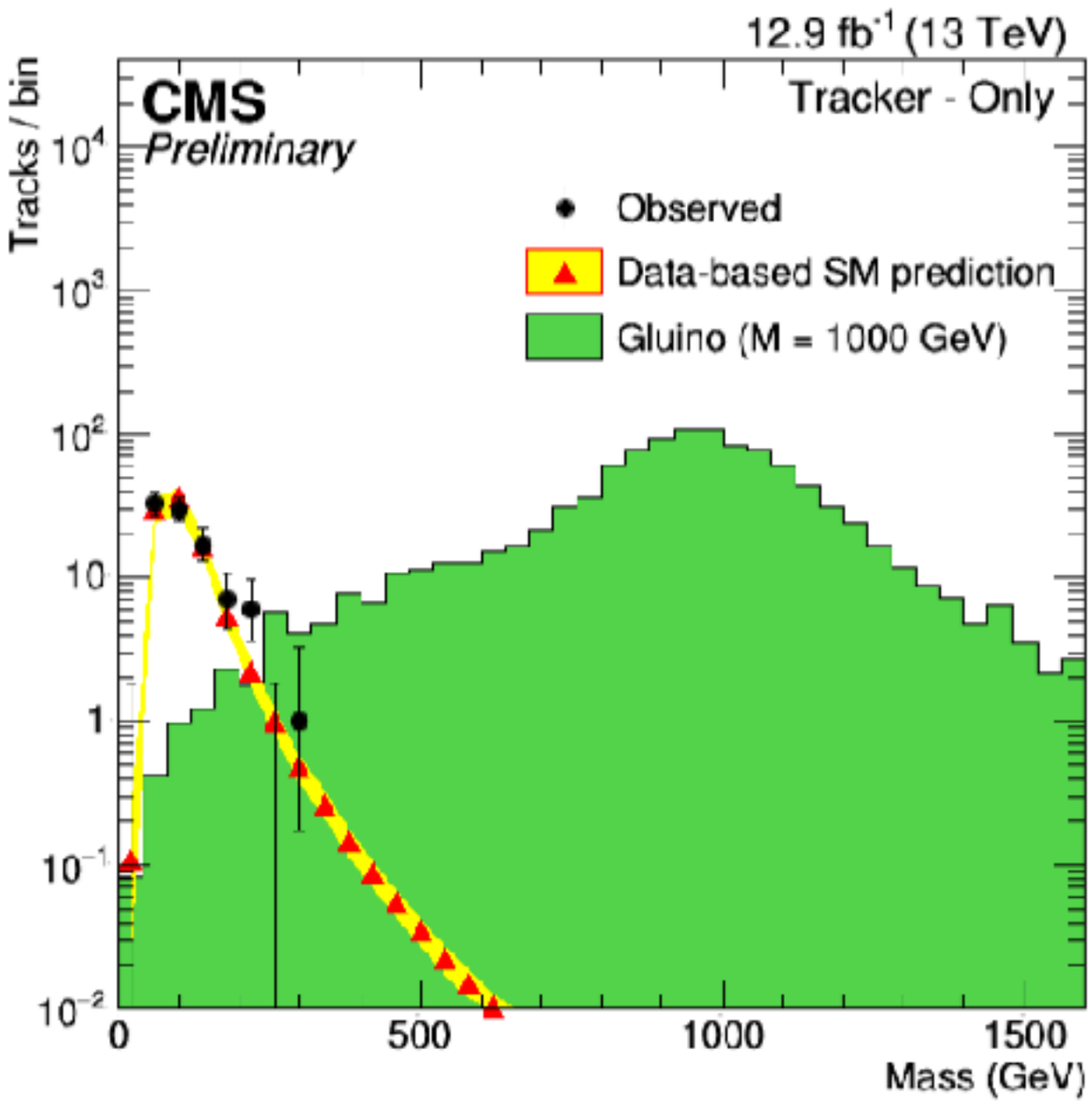
HSCPs: backgrounds (tracker only)

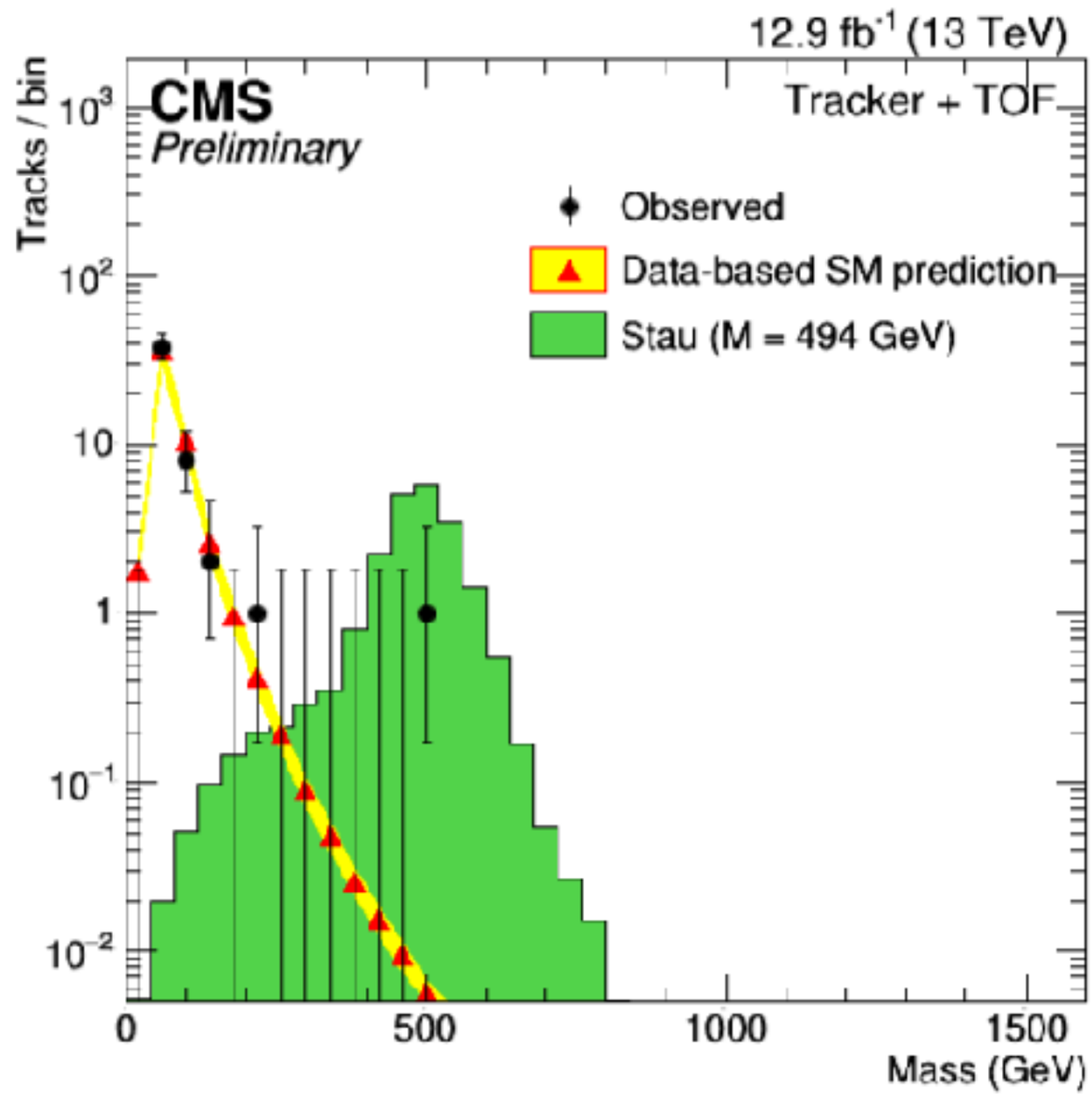


HSCPs: backgrounds (TOF)

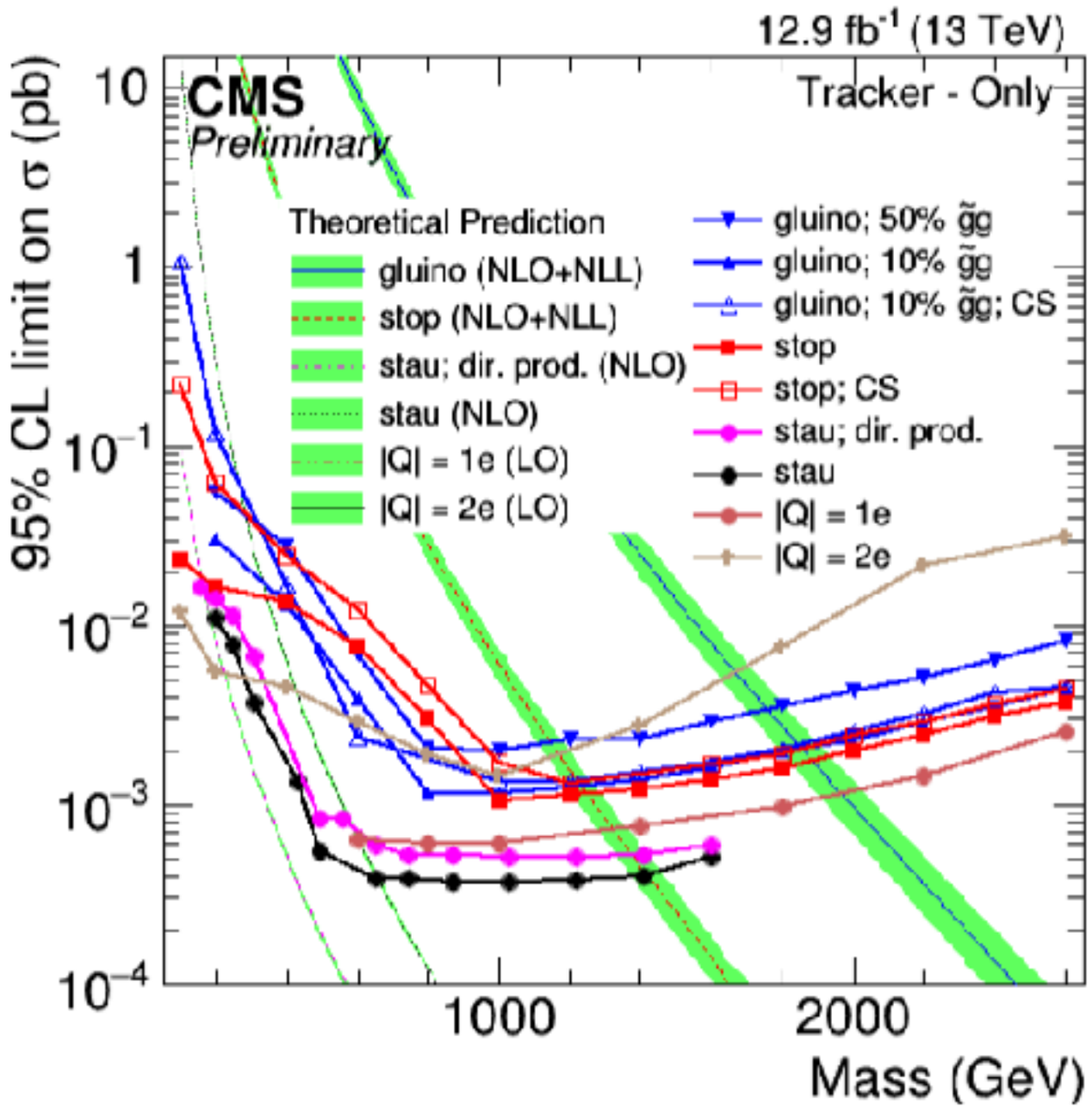


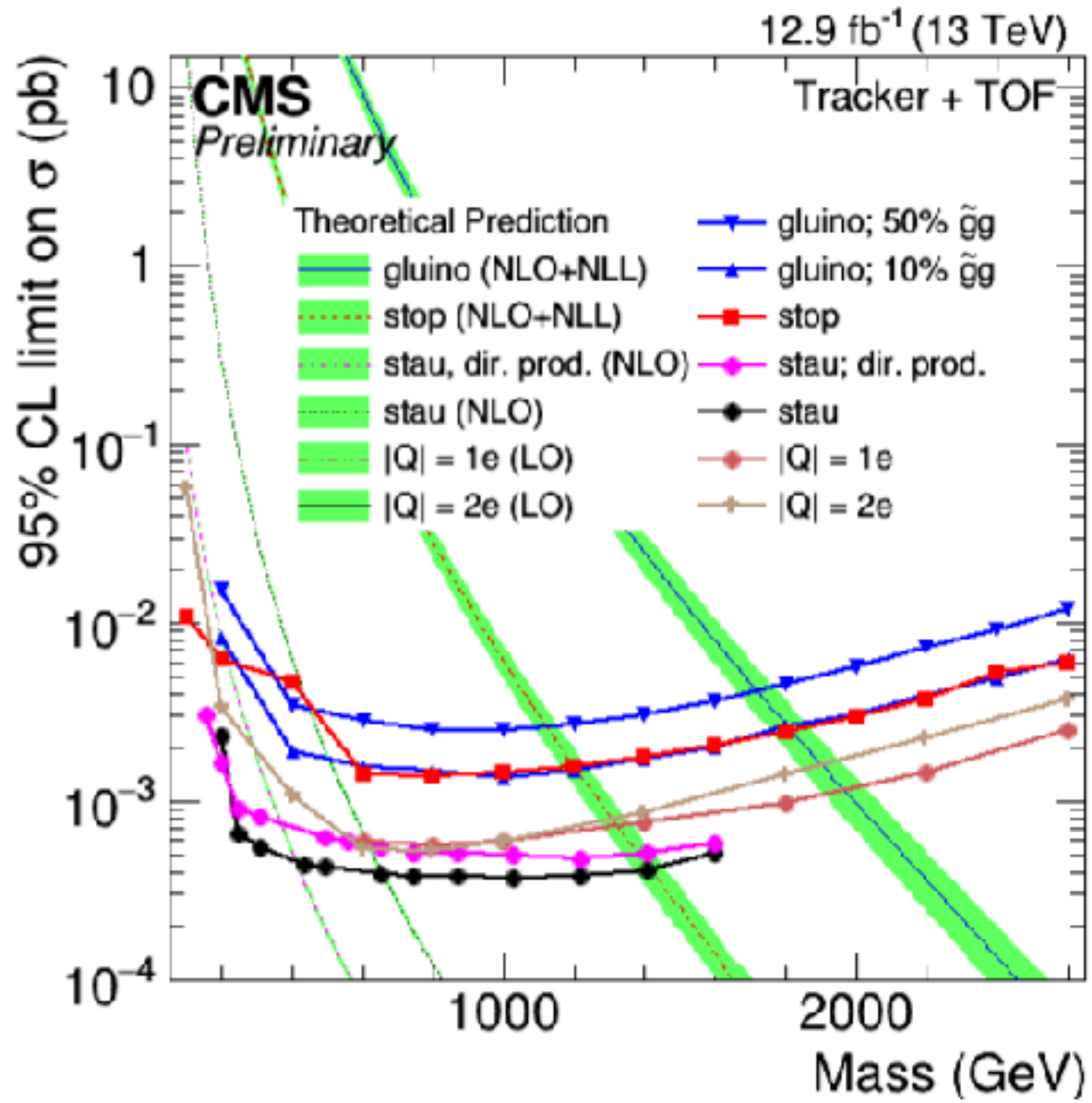
HSCPs: results





HSCPs: results

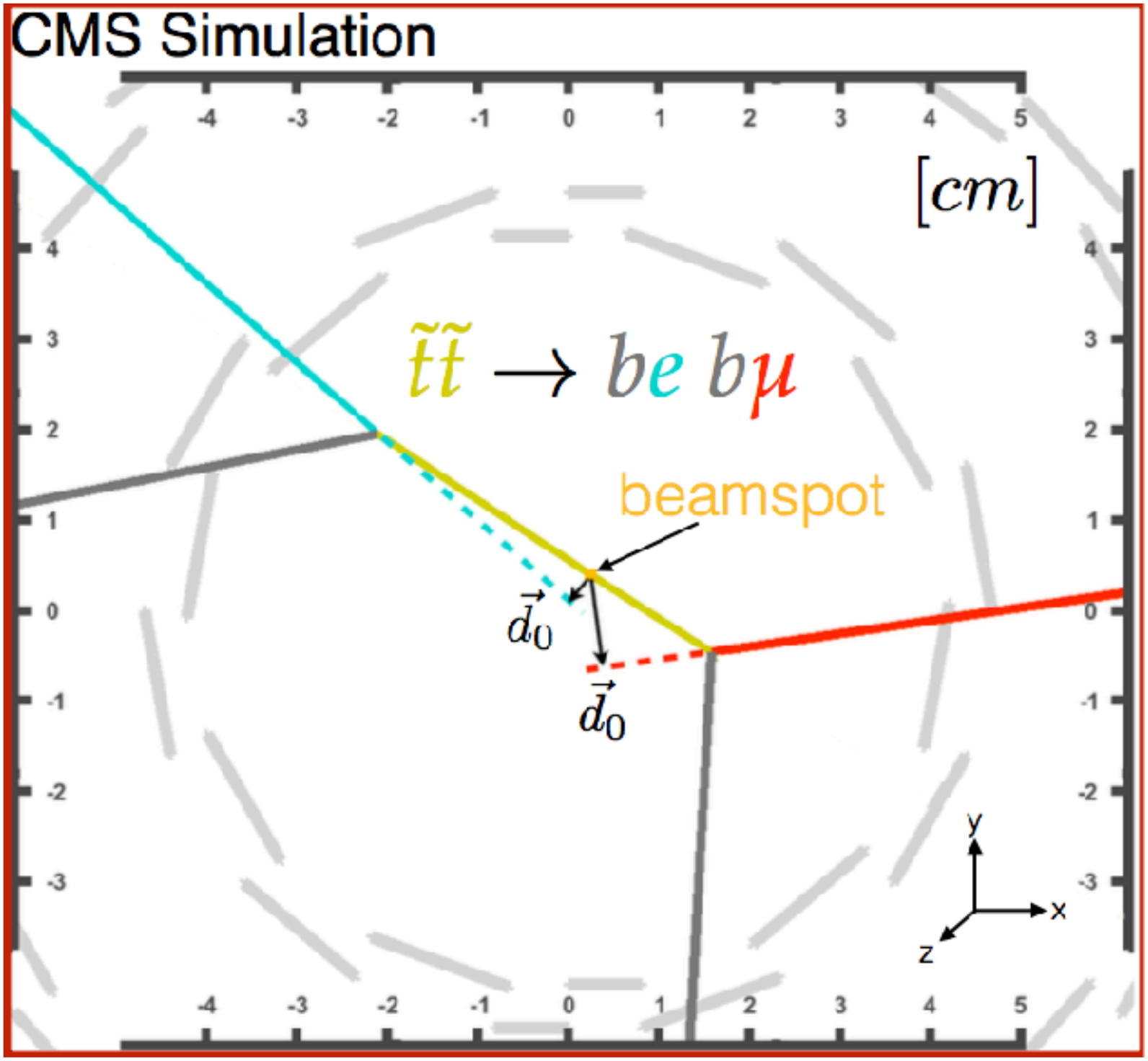




Long-lived searches at 13 TeV

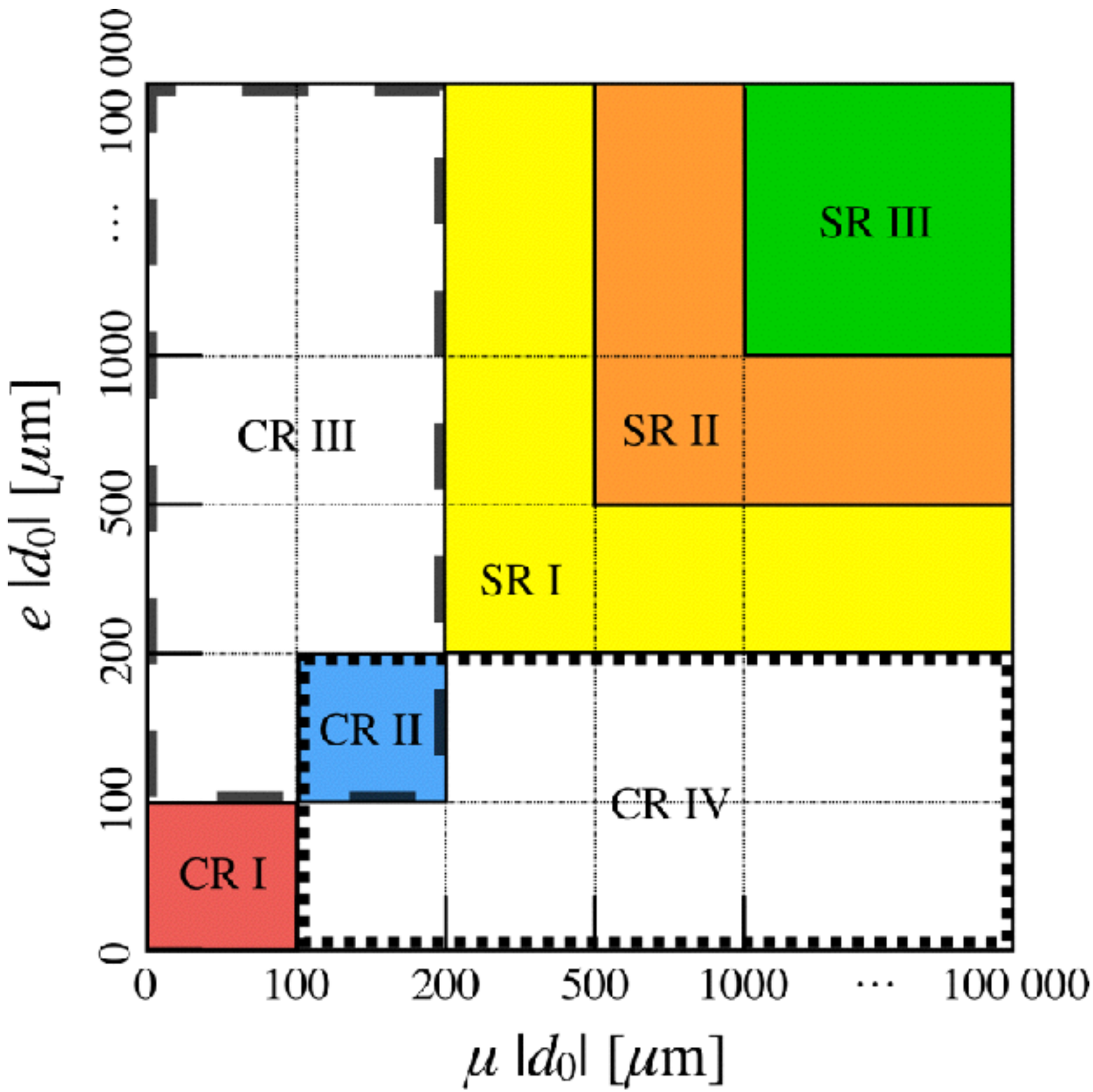
- Heavy Stable Charged Particles (HSCPs)
- Displaced leptons — eμ channel

Displaced leptons (eμ)

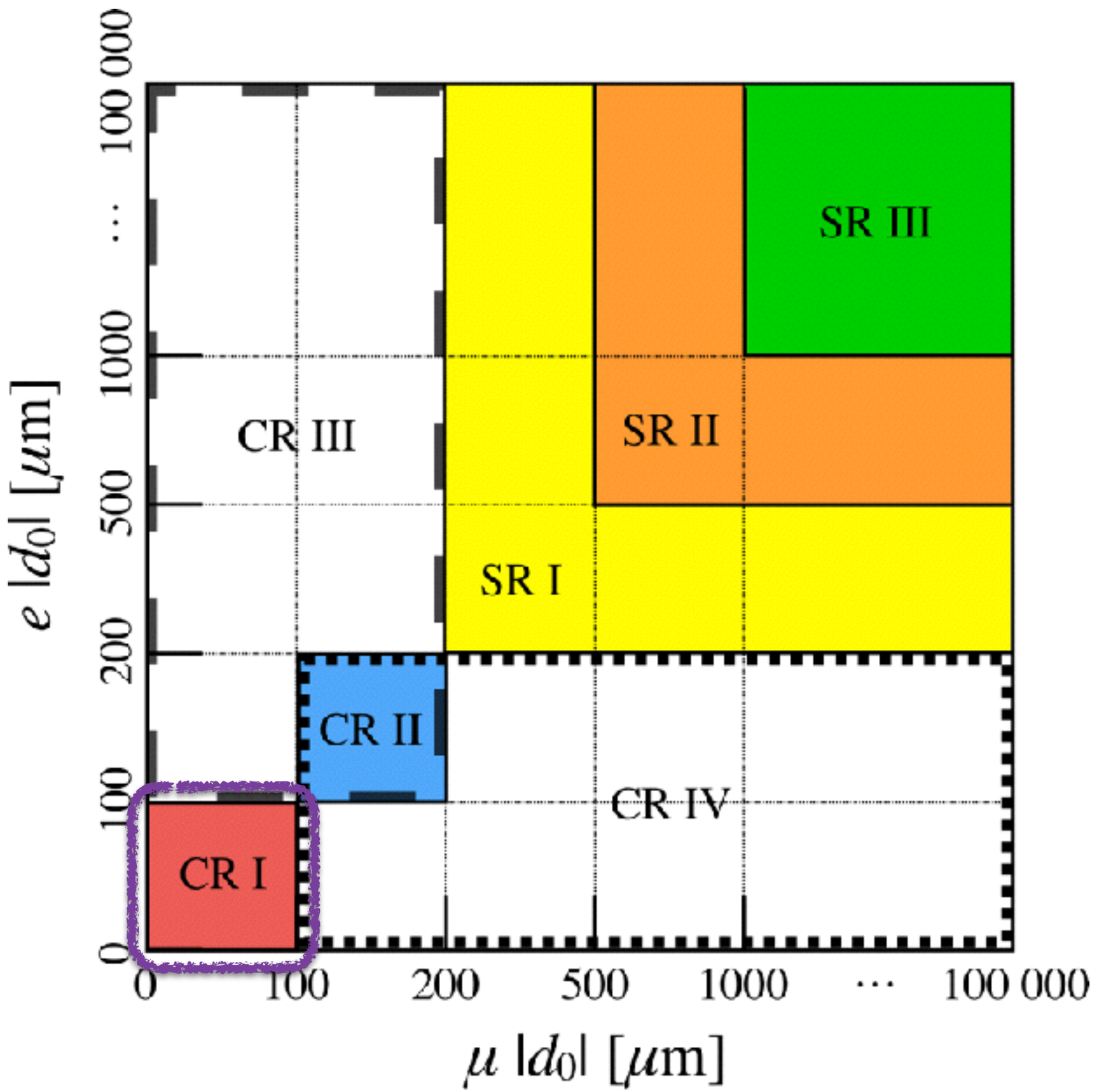


[https://cds.cern.ch/record/2205146]

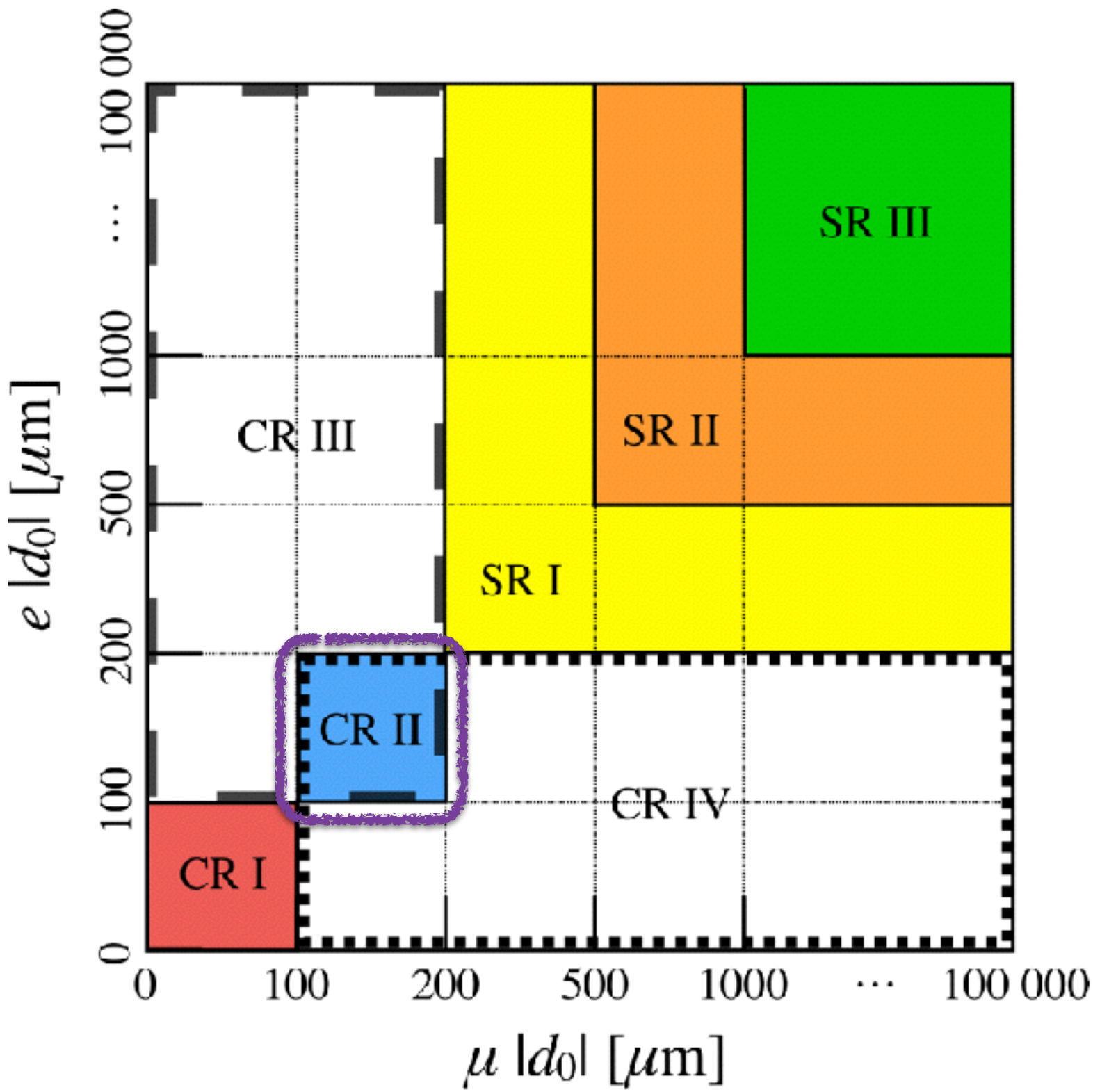
Displaced leptons: strategy



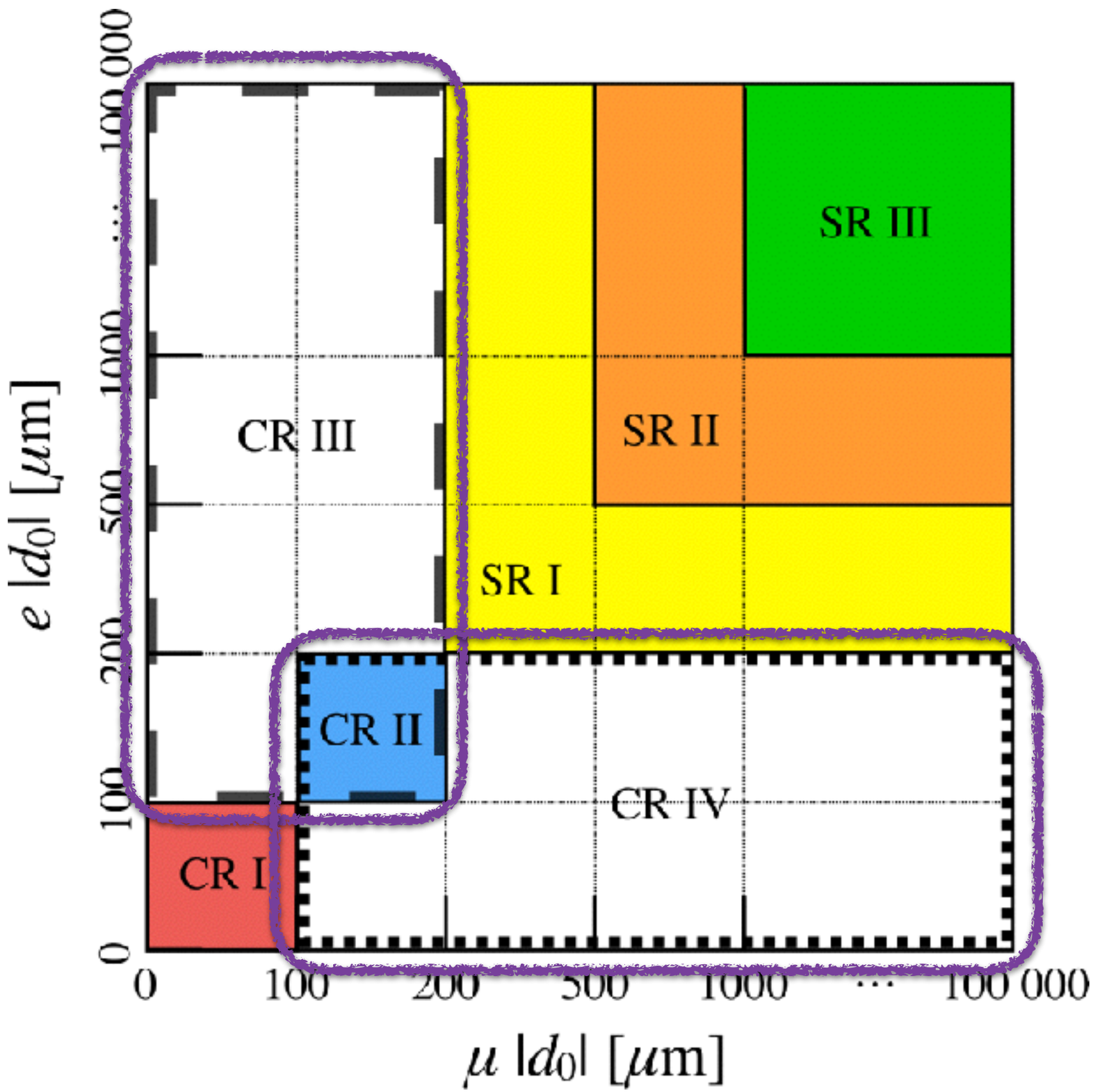
Displaced leptons: strategy



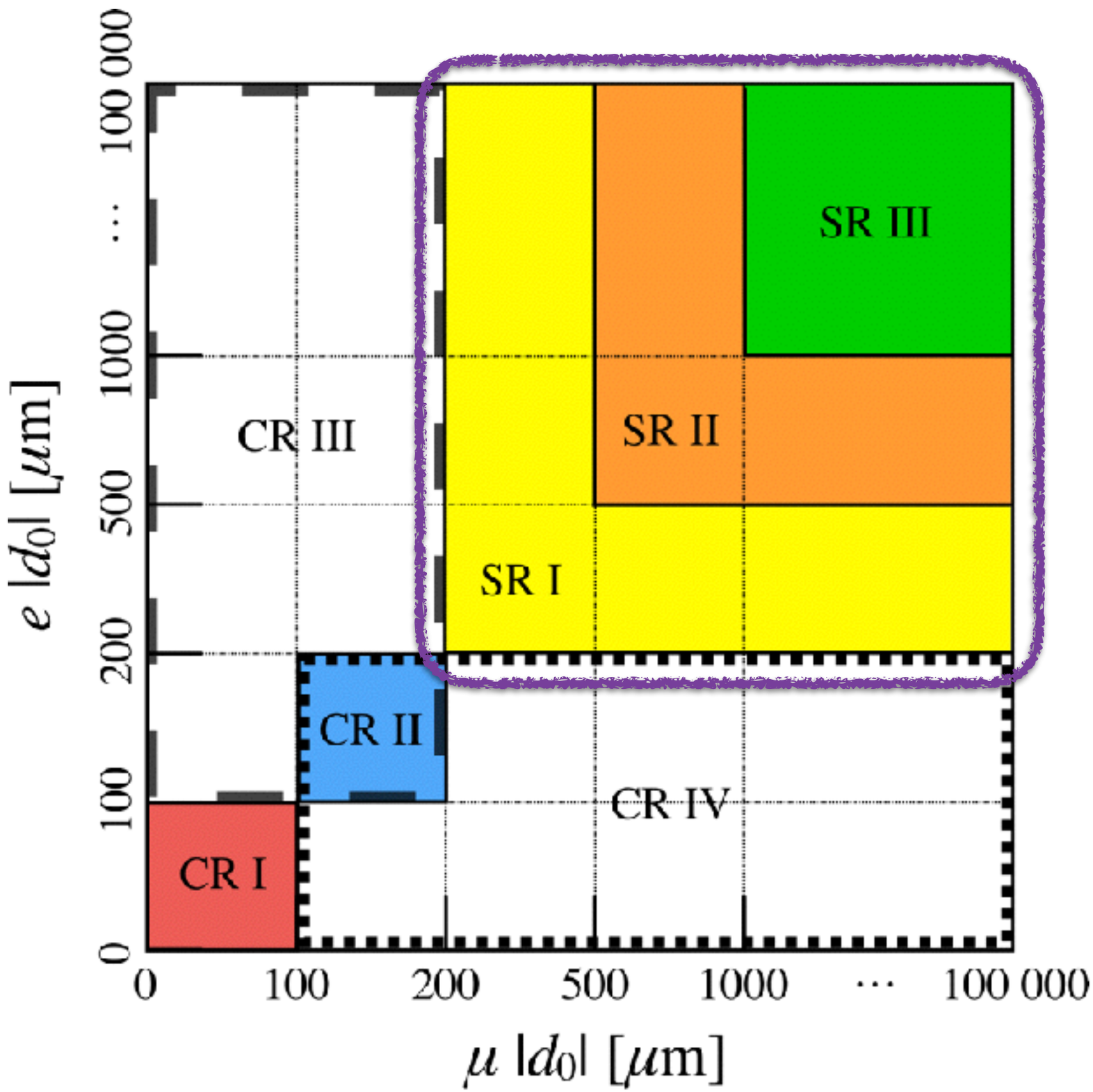
Displaced leptons: strategy



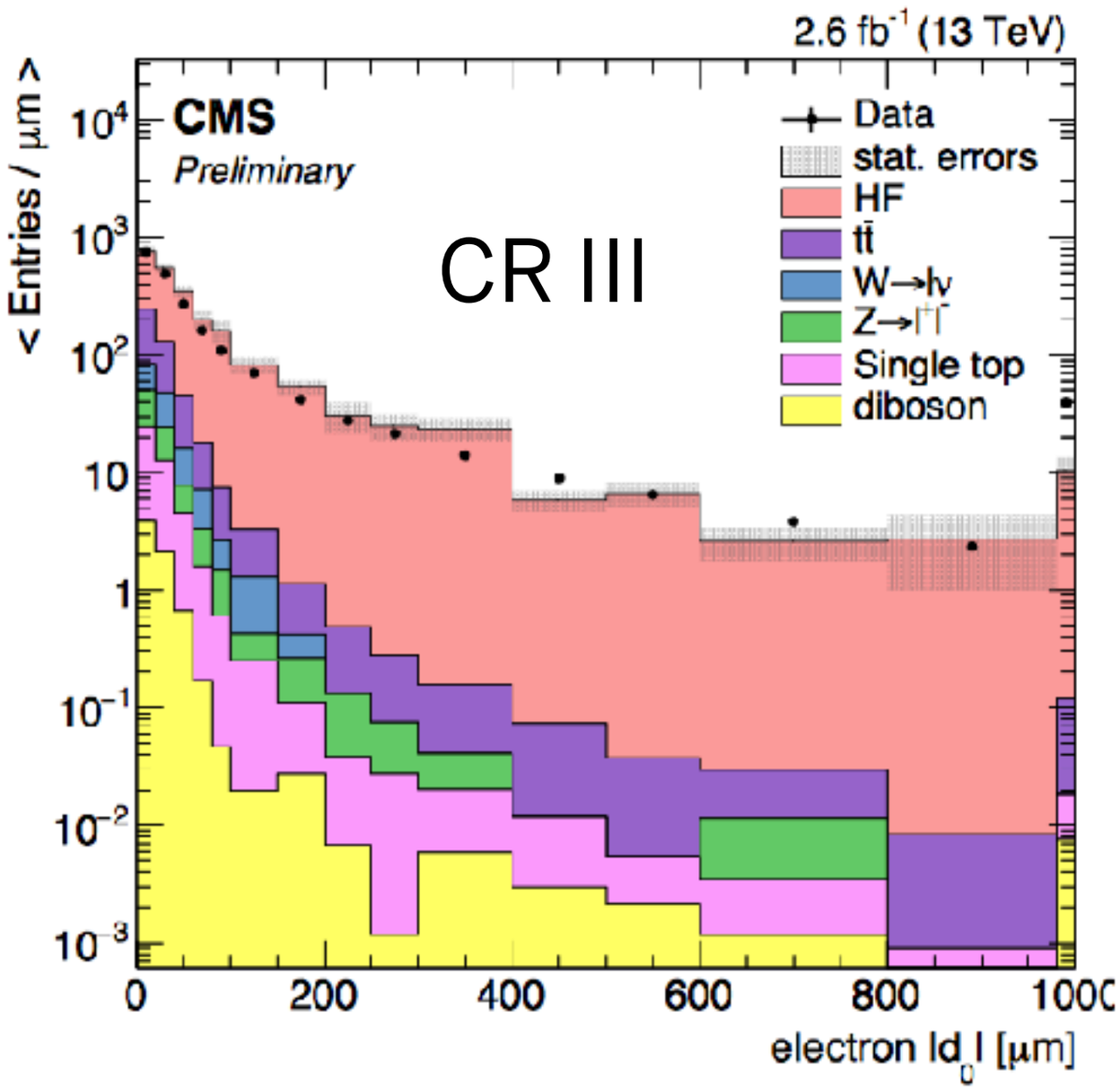
Displaced leptons: strategy



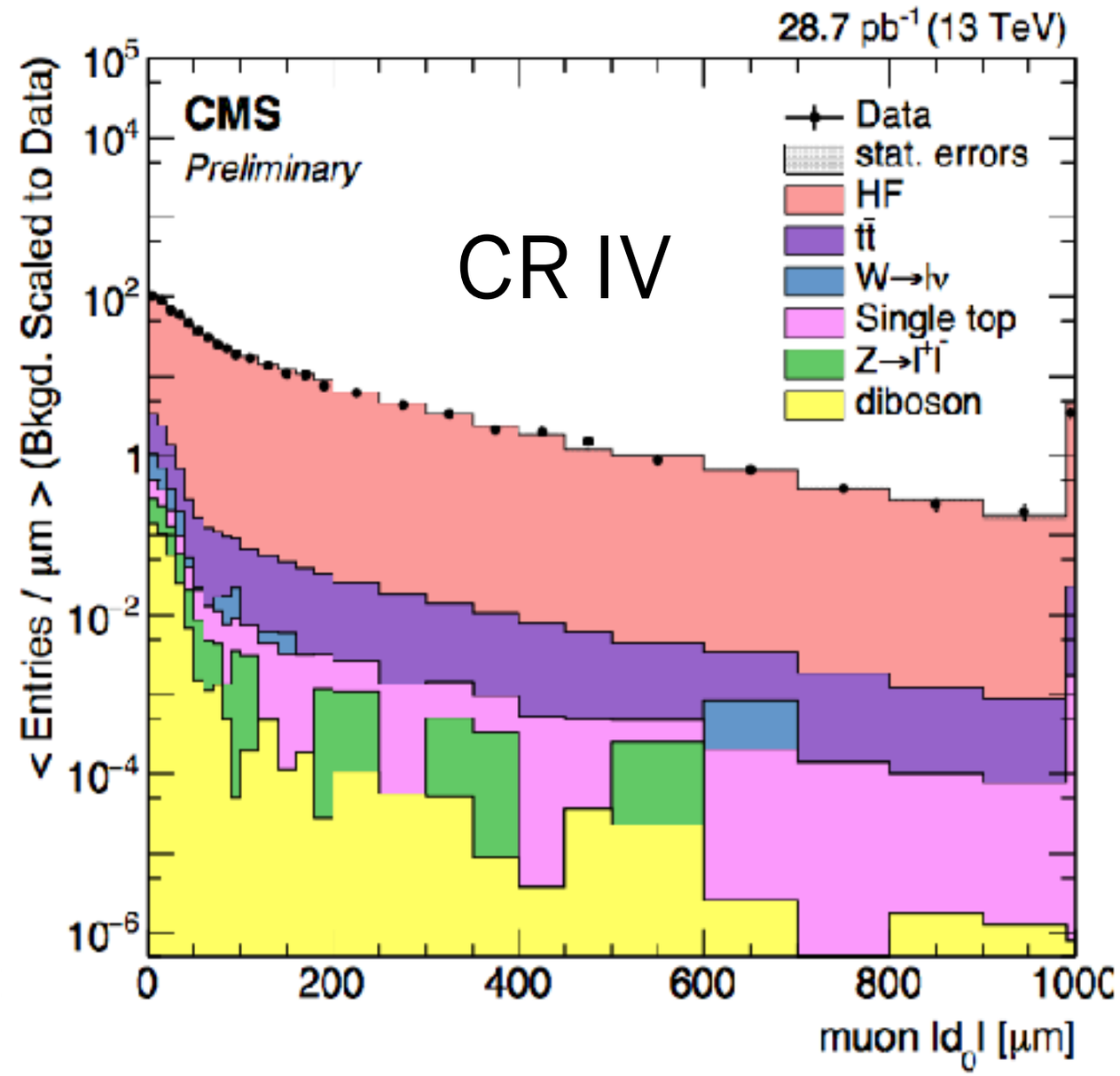
Displaced leptons: strategy



Displaced e(μ) modeling

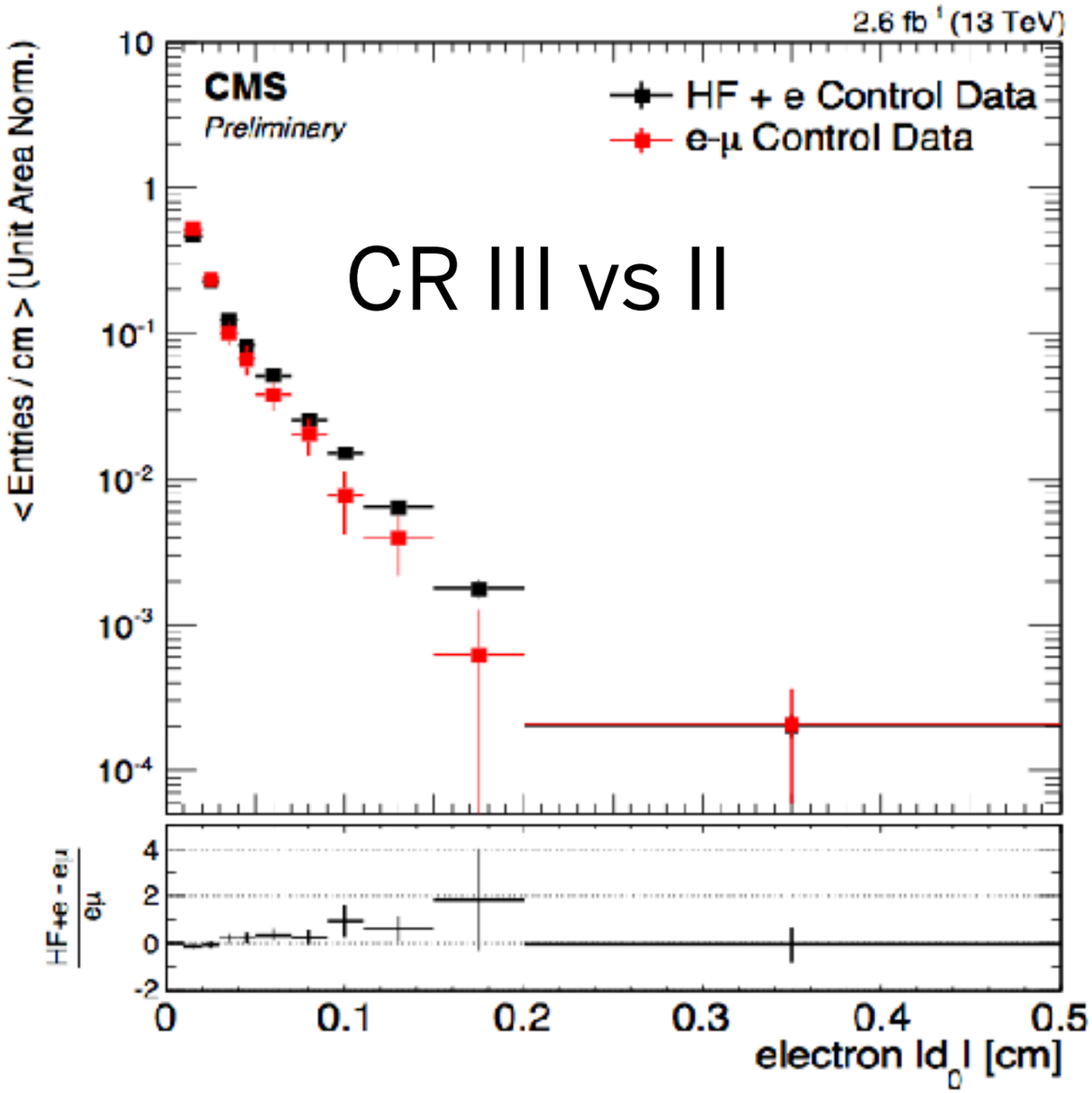


displaced e

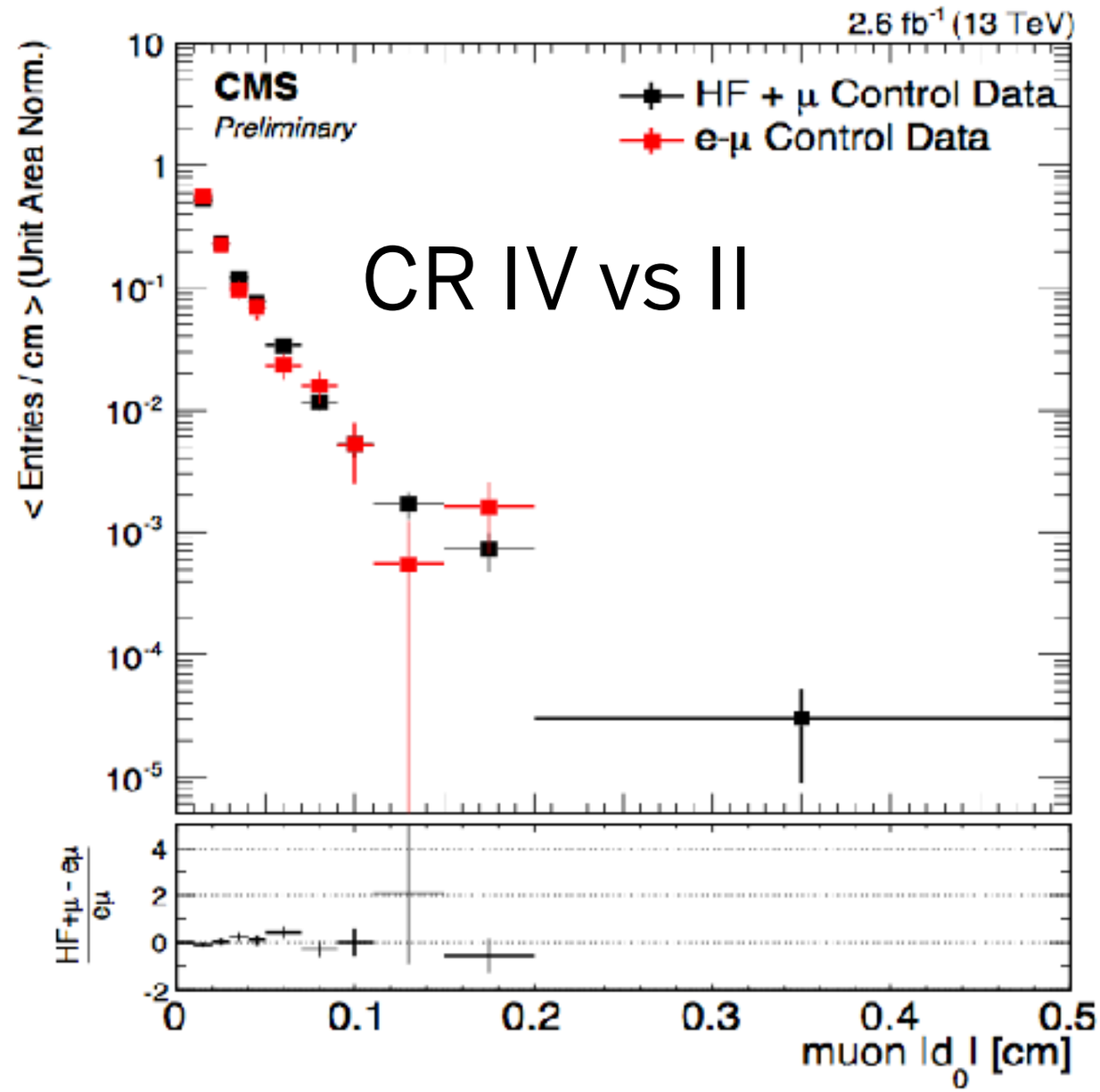


displaced μ

Displaced e(μ) modeling



displaced e

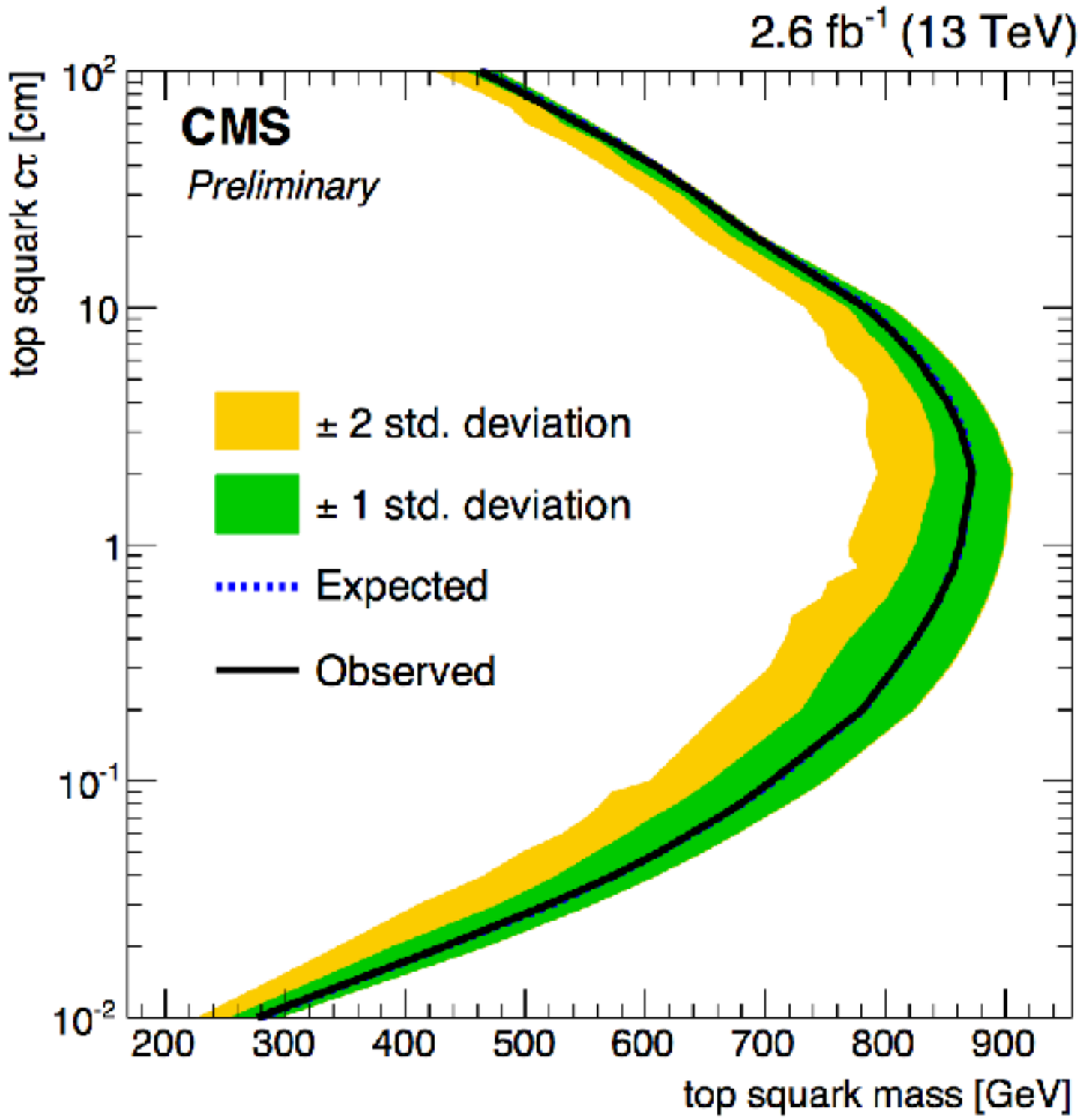


displaced μ

Displaced eμ: results

Event Source	Search Region I	Search Region II	Search Region III
$W \to l\nu$	$(1.1 \pm 0.5) \times 10^{-3}$	$(2.4 \pm 1.7) \times 10^{-5}$	$(0.25 \pm 0.29) \times 10^{-5}$
single top	$(8.4 \pm 1.2) \times 10^{-3}$	$(35 \pm 12) \times 10^{-5}$	$(1.50 \pm 0.91) \times 10^{-5}$
diboson	$(18.2 \pm 5.8) \times 10^{-3}$	$(39 \pm 25) \times 10^{-5}$	$(4.0 \pm 4.6) \times 10^{-5}$
$Z \to ll$	$(115 \pm 25) \times 10^{-3}$	$(100 \pm 160) \times 10^{-5}$	$(69 \pm 71) \times 10^{-5}$
$t\bar{t}$	$(60.6 \pm 5.1) \times 10^{-3}$	$(226 \pm 25) \times 10^{-5}$	$(8.0 \pm 1.6) \times 10^{-5}$
non-HF sum	$(203 \pm 26) \times 10^{-3}$	$(410 \pm 170) \times 10^{-5}$	$(82 \pm 71) \times 10^{-5}$
data-driven HF	< 3.0	< 0.50	< 0.019
total background	< 3.2	< 0.50	< 0.020
observation	1	0	0
$pp \to \tilde{t}_1 \tilde{t}_1^* (M_{\tilde{t}_1} = 700\,\text{GeV})$			
$c\tau = 0.1\,\text{cm}$	3.8 ± 0.2	0.94 ± 0.06	0.16 ± 0.02
$c\tau = 1\,\text{cm}$	5.2 ± 0.4	4.1 ± 0.3	7.0 ± 0.3
$c\tau = 10\,\text{cm}$	0.8 ± 0.1	1.0 ± 0.1	5.8 ± 0.2
$c\tau = 100\,\text{cm}$	0.009 ± 0.005	0.03 ± 0.01	0.27 ± 0.03

Displaced eμ: results



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- Systematic re-interpretation of prompt search results in terms of long lived signatures