University of BRISTOL

Searches for Long Lived Particles with CMS

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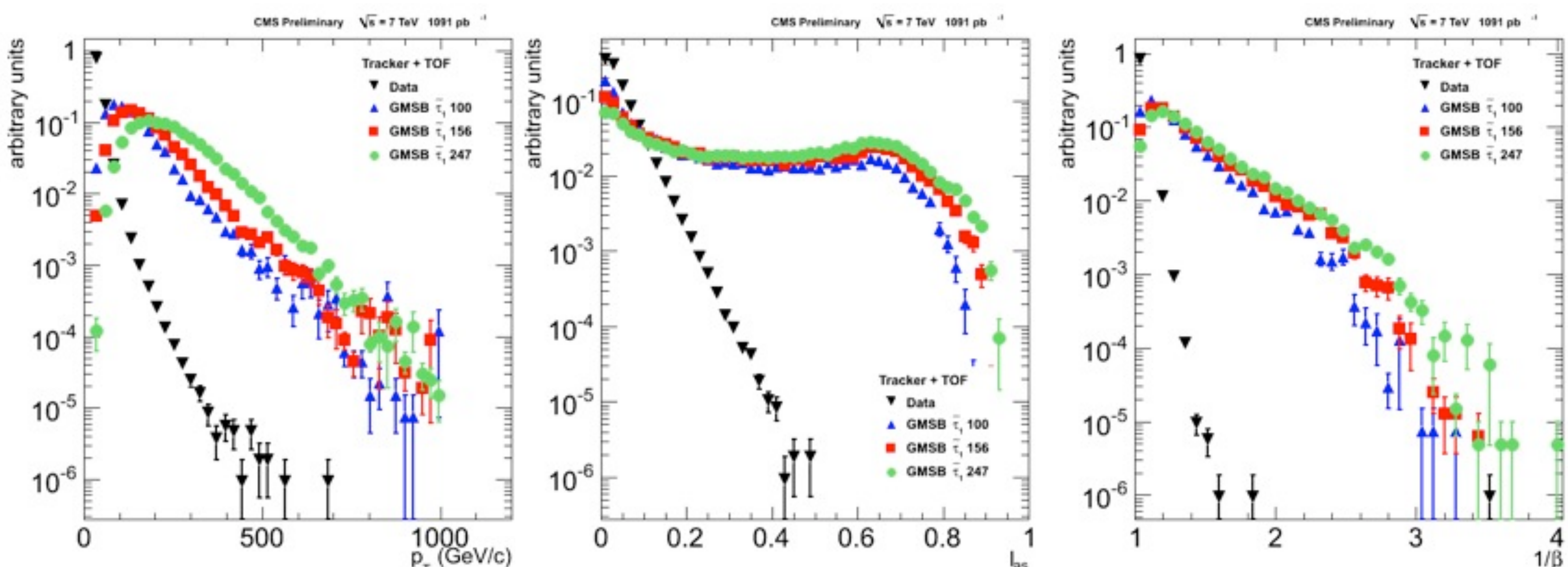
Searches for Long Lived Particles at CMS

- Heavy stable charged particles
  - Look for **highly ionising tracks**
  - Also use **time-of-flight** measured in muon system
- Stopped particles
  - Particles stopped in detector that decay later
  - Search for **out of time decays** in calorimeters
- Displaced vertices
  - Long lived neutral decaying to pairs of leptons
  - Look for high impact parameter tracks, and **displaced vertices**
- Displaced photons
  - Long lived neutral decaying to photons
  - Use time of flight, shower shape, or **converted photons with high impact parameter**
- Results presented here use 1-2 fb^{-1} from the 2011 dataset

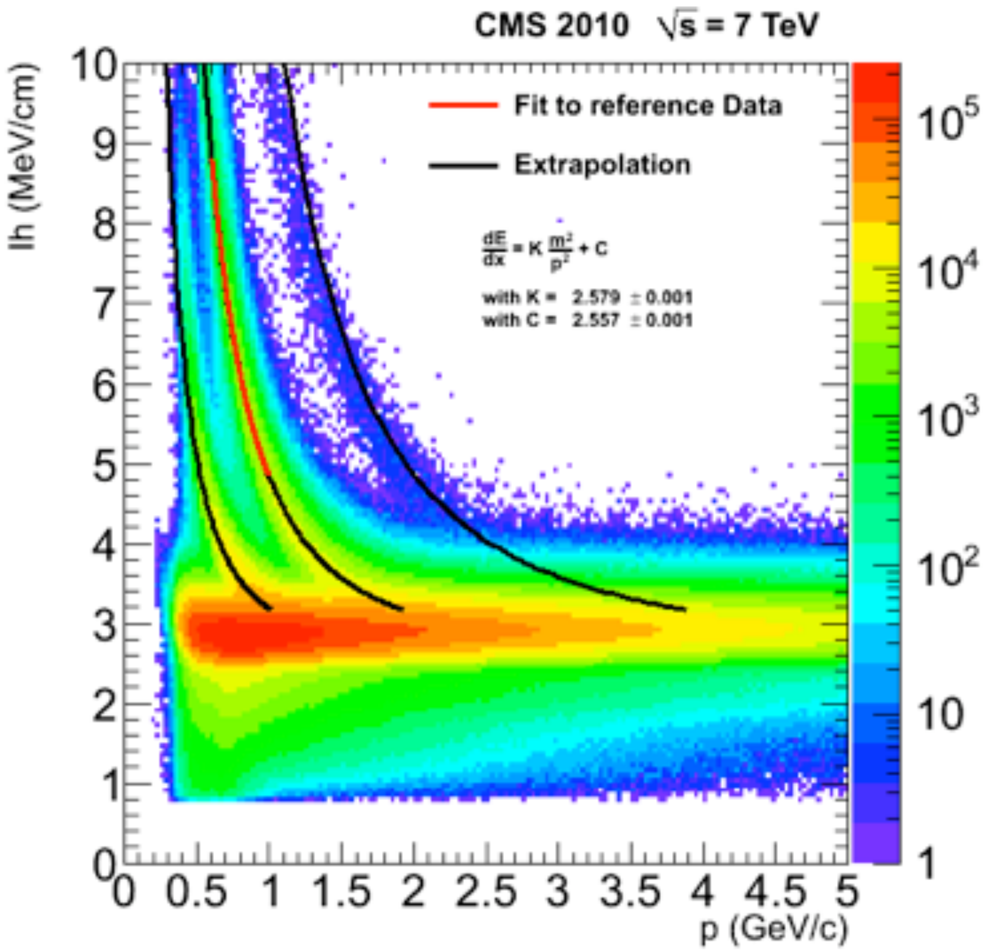
Heavy Stable Charged Particles : Selection

- Search for heavy, stable, charged particle
  - High momentum, but slow moving and highly ionising
  - Gluino and stop R-hadrons, and long-lived stau in GMSB
- Looking for tracks with high p_t, high dE/dx, large time-of-flight
  - Measure time of flight in muon system
- R-hadrons may change flavour/charge during nuclear interactions with matter
  - Therefore perform searches for tracks both **with and without muon TOF**
  - Use muon and MET triggers to cover both scenarios

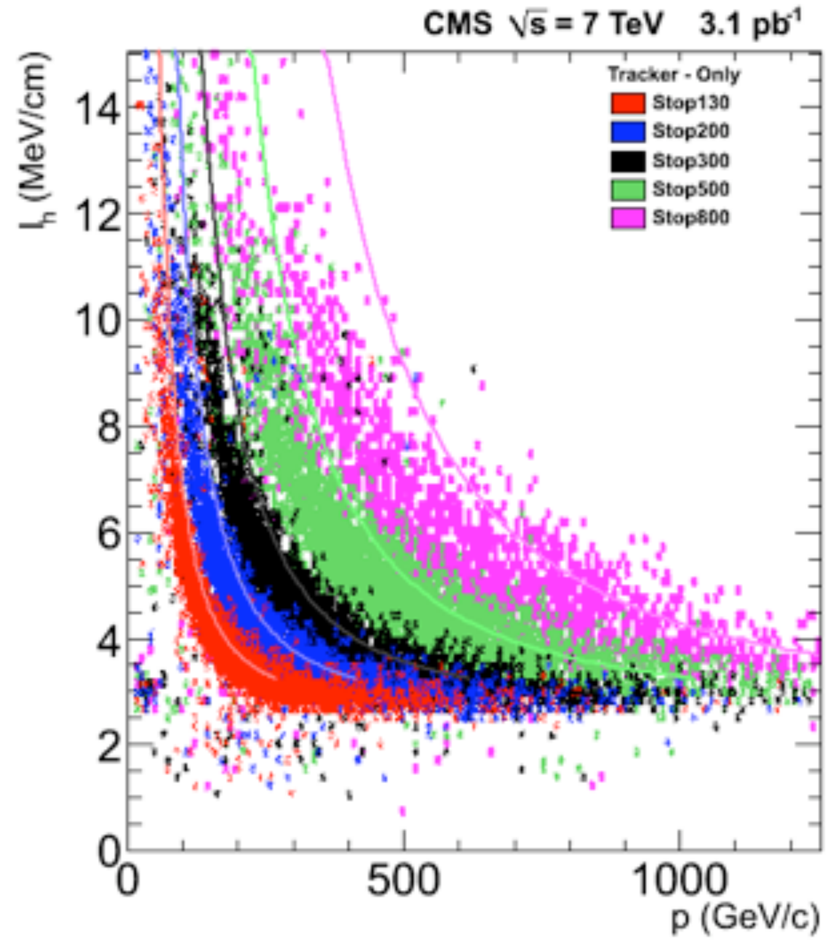


p_T dE/dx $1/\beta$

HSCP : Mass Reconstruction



min-bias data

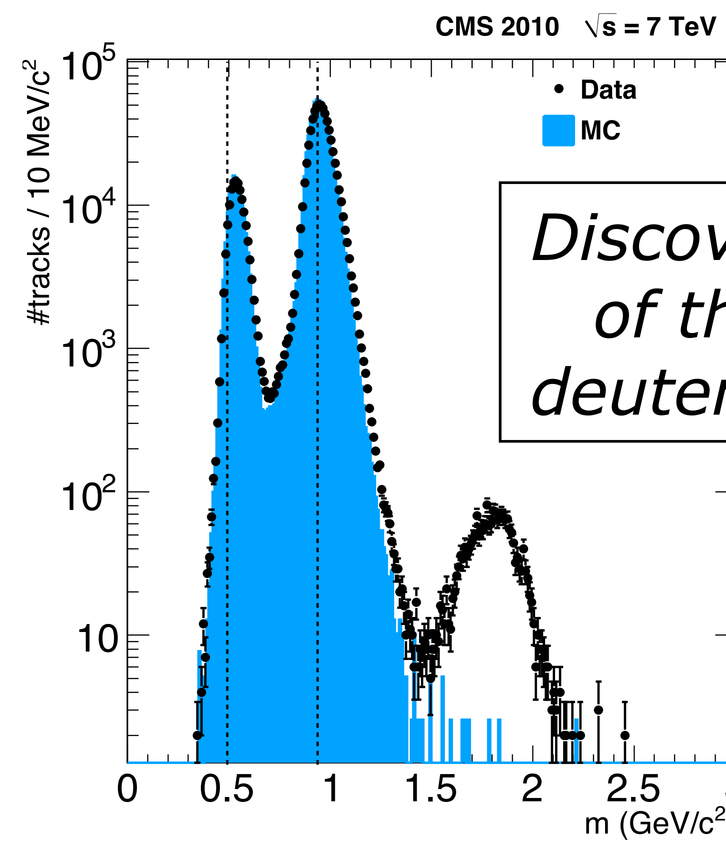


...and stop MC

- Mass reconstruction
  - Approximate Bethe-Bloch formula before minimum

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

  - Extract parameters K, C by fitting to the proton line
  - Reverse to compute higher masses

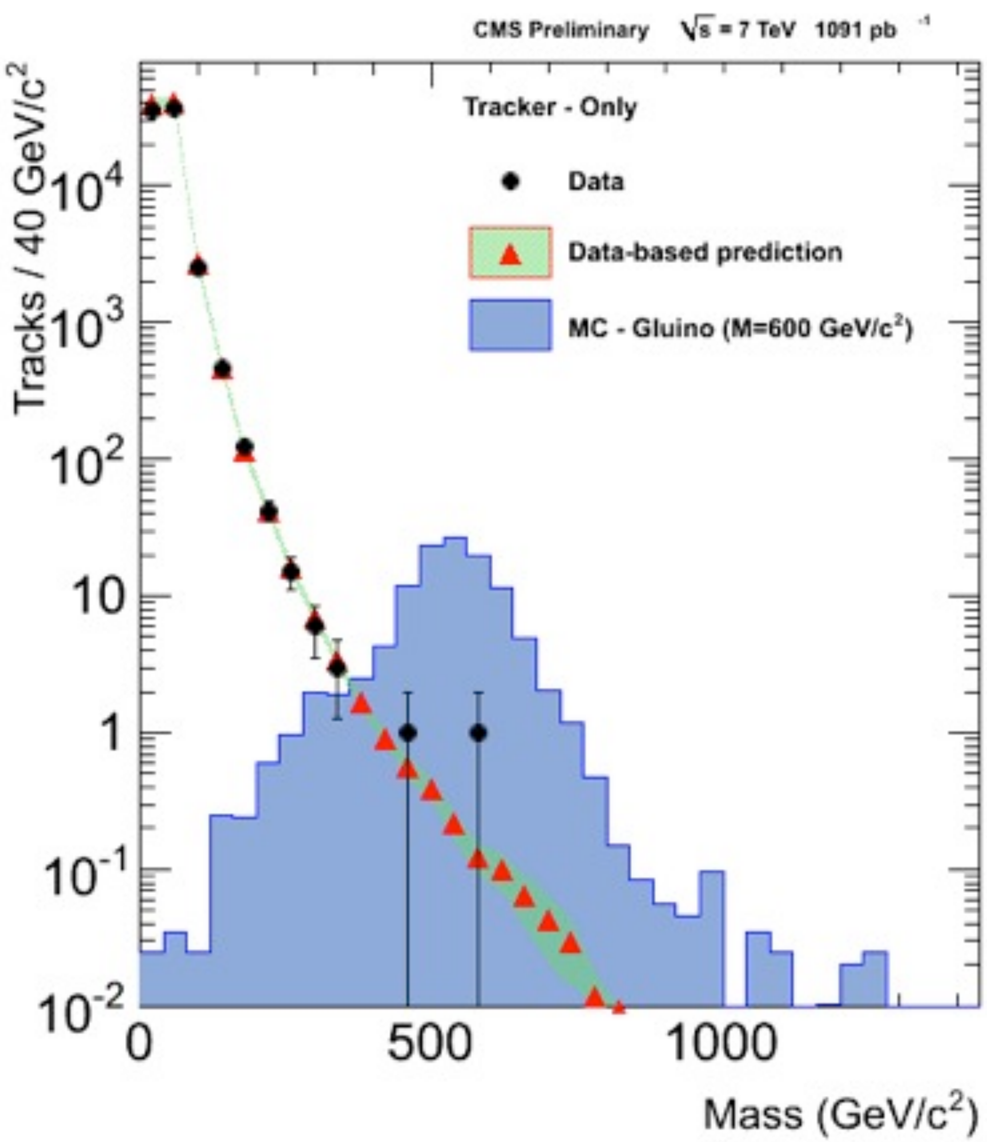


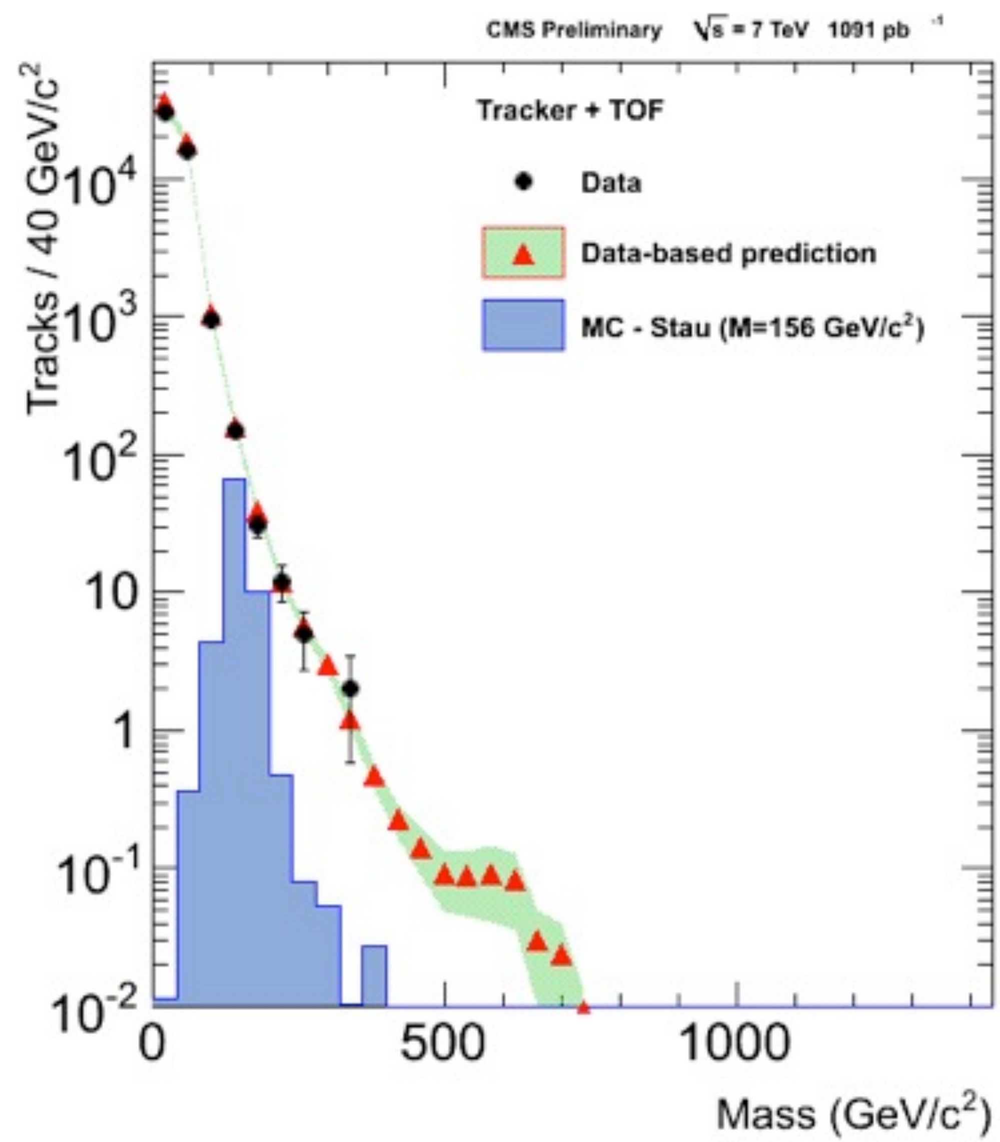
Discovery of the deuteron!

HSCP : Background

- Select candidate tracks using p_t, dE/dx, (TOF), mass
  - Optimised for each signal MC point

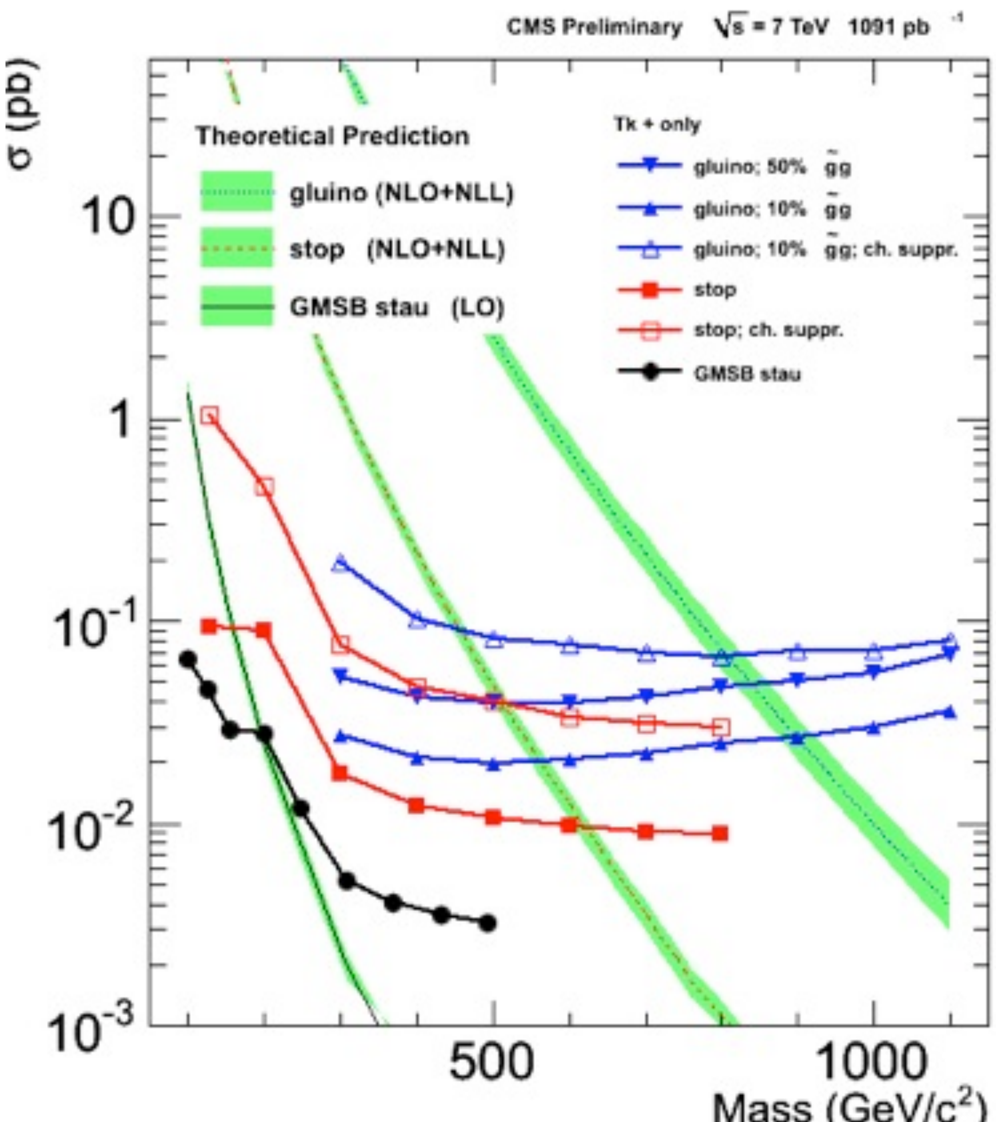
- Background estimated using a data-driven method
  - ABCD technique, extended to 3 variables for Track+TOF analysis
  - Good agreement with observation in a loose selection, shown below

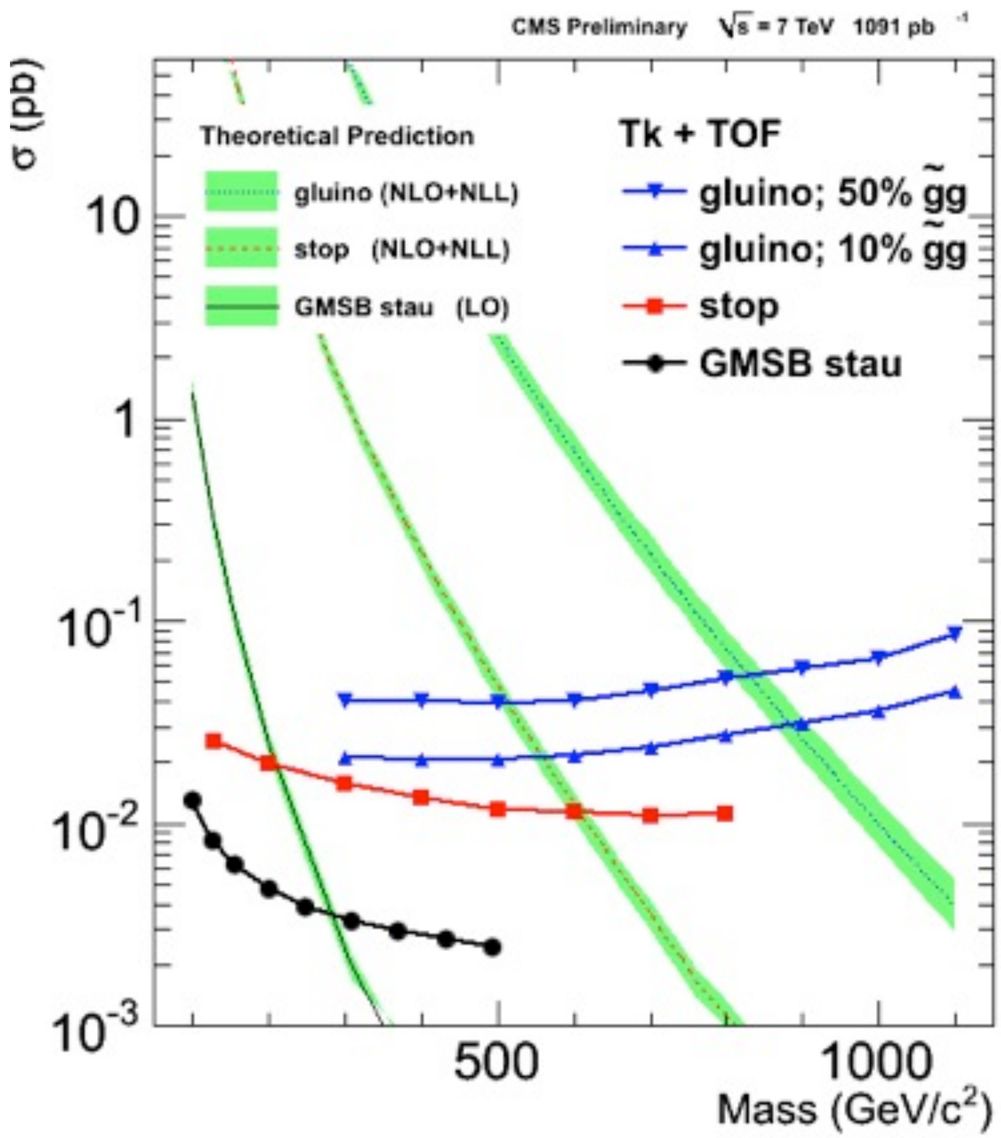




HSCP : Results

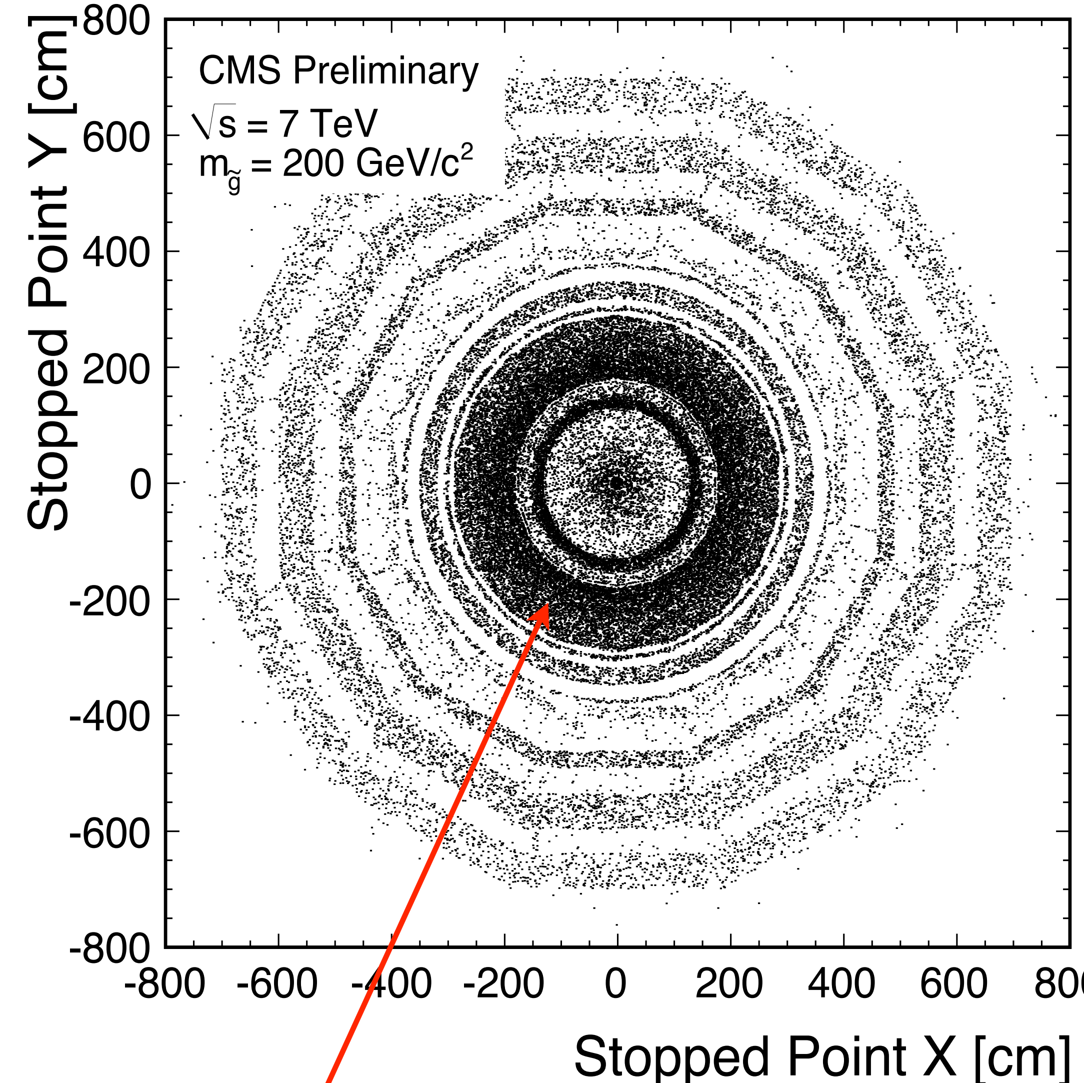
- No significant excess observed for any signal point
  - Place limits on production cross-section for **gluino**, **stop** and **stau**
- Different models of R-hadron interactions
  - Cloud model - Eur. Phys. J. C50 (2007) 353
  - "Charge suppressed" model - neutral R-hadrons remain neutral
- Initial fraction of $\tilde{g}g$ - free parameter of the theory
  - Gluino limit presented for 10% and 50%



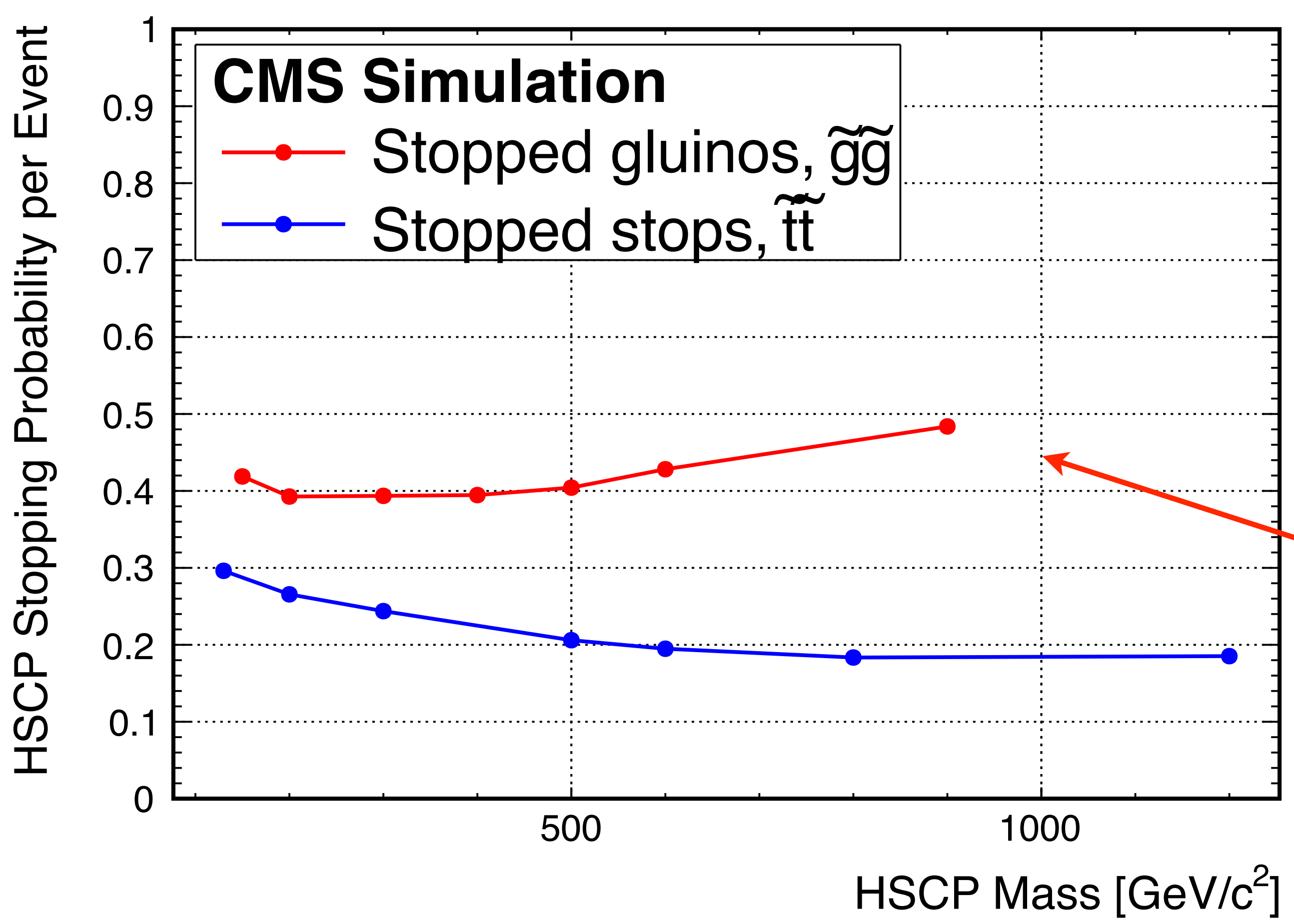


Stopped Particles

- Complementary search to the previous analysis
  - If a highly ionising particle loses sufficient energy while traversing the detector, it may **come to rest**
  - Then **decay some time later**
- Search for these decays during periods when no collisions are expected
  - Minimising backgrounds
- Observation would allow measurement of lifetime



We search in CMS HCAL



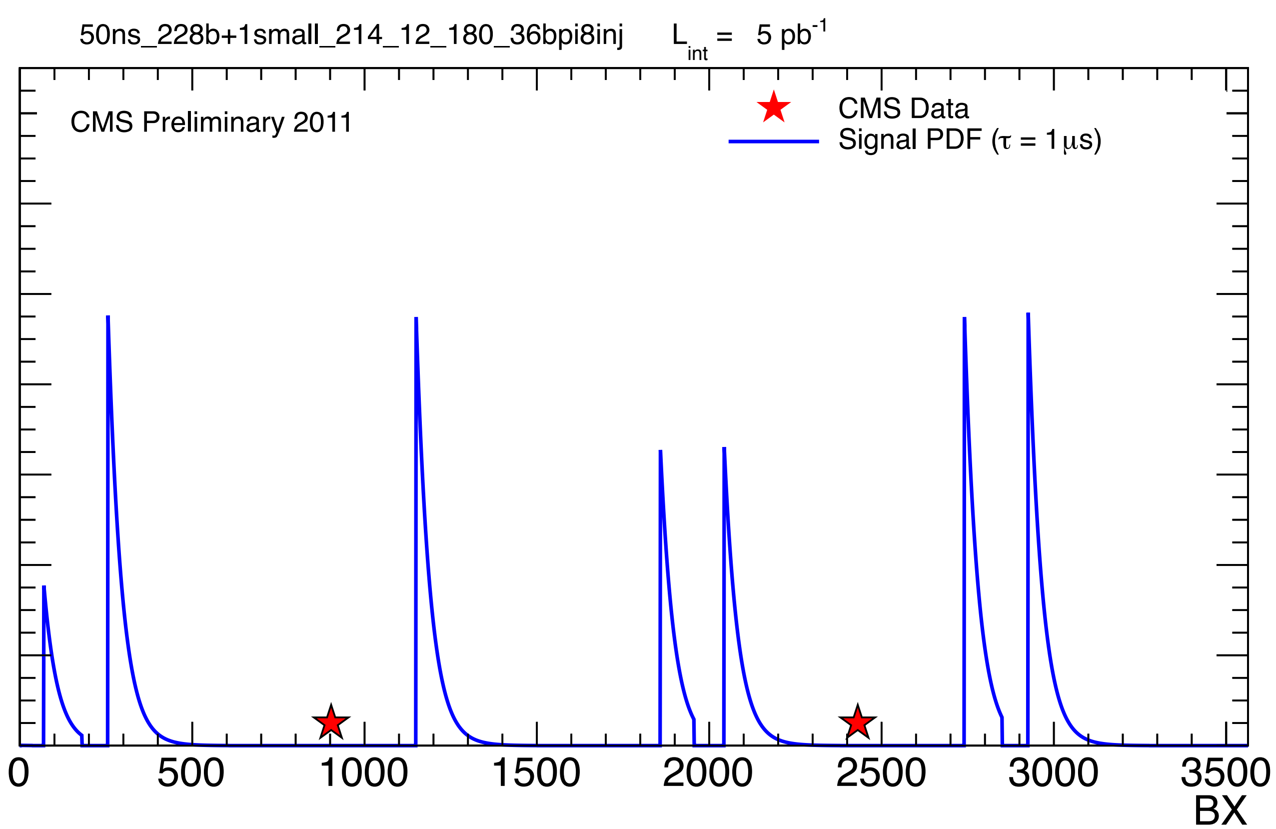
Probability for one of a pair of R-hadrons to stop somewhere in CMS

Stopped Particles : Analysis

- Use a dedicated jet trigger with "no bunch" condition from beam position monitors
- Backgrounds from instrumental effects, beam backgrounds and cosmic rays
  - Reject using cosmic and beam halo ID, jet topology and calorimeter pulse shape cuts
  - Reduce event rate to O(10^{-5} Hz)
  - Observe constant rate since ~September 2010

Time profile analysis

- Event time for signal has distinctive shape
- Background is flat in time
- Use signal and background event time PDFs to estimate S and B contributions



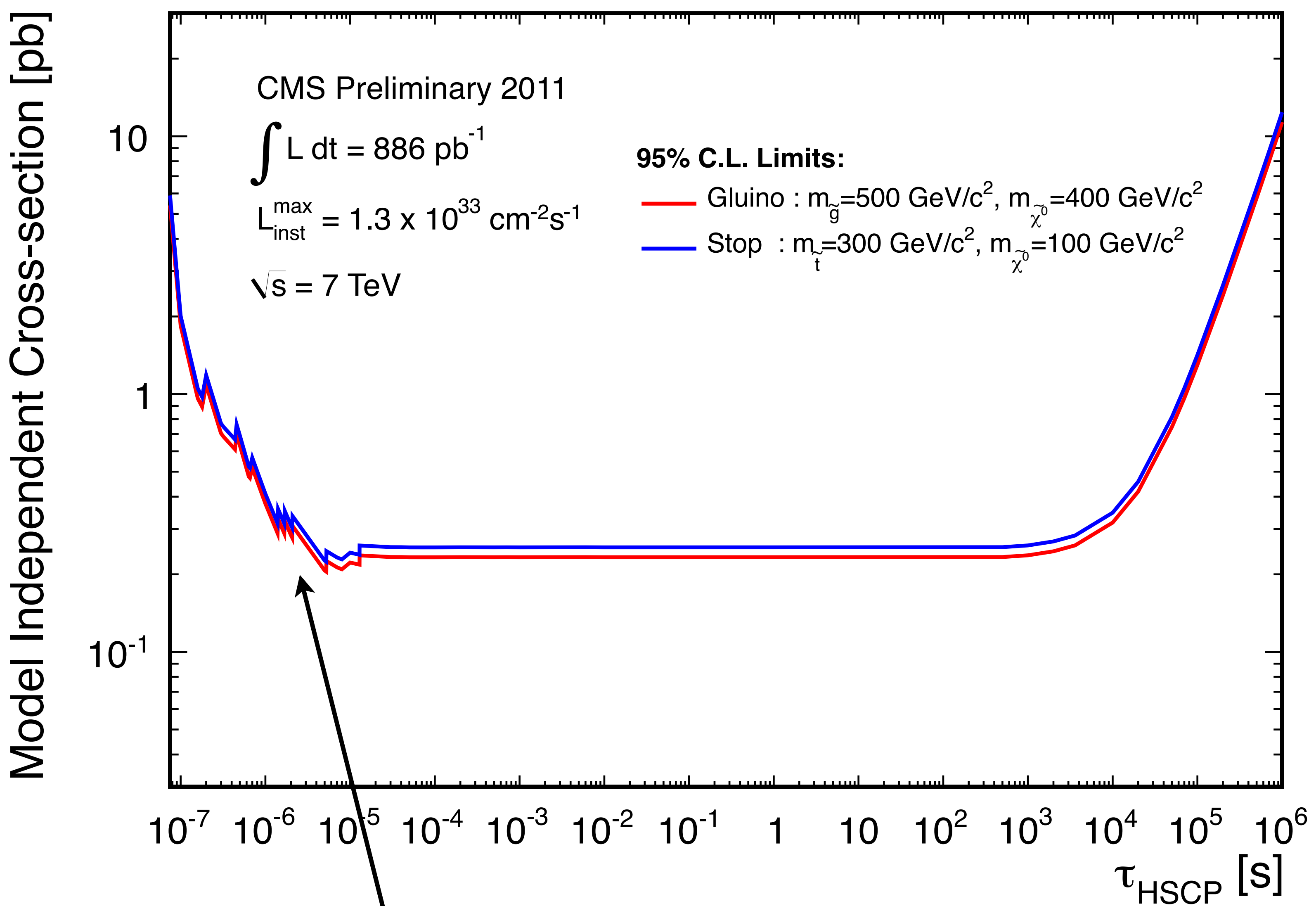
Counting Experiment

- Estimate background rate from data taken in late 2010
- Perform counting experiment in bins of lifetime
- For small τ, select events in a window ~1.3 τ after each collision, to avoid integrating excess background
- Use a toy MC to calculate the effective luminosity for each lifetime bin

Stopped Particles : Results

- Model independent result
  - No assumption made about model of interactions with matter
- τ < few 100 ns
  - Decays occur during vetoed BXs
- $\tau < T_{orbit}$ (~10^{-4} s)
  - Decays occur within the orbit, but we optimise the time window
- $T_{orbit} < \tau < T_{fill}$ (~10^{4} s)
  - Accept events over the full orbit - sensitivity plateau
- $\tau > T_{fill}$
  - Lose sensitivity as increasing fraction of decays occur post-fill

Cross-section × BR × stopping probability

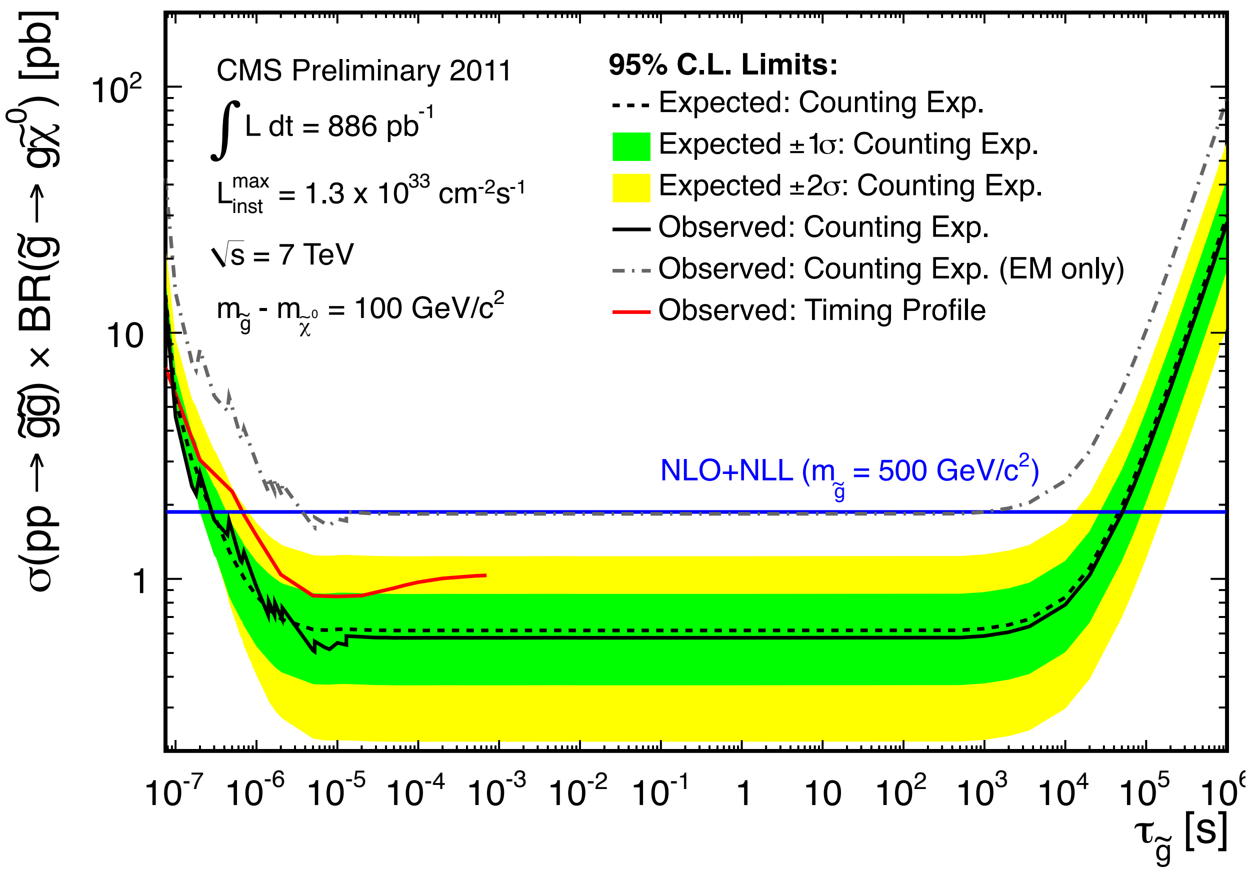


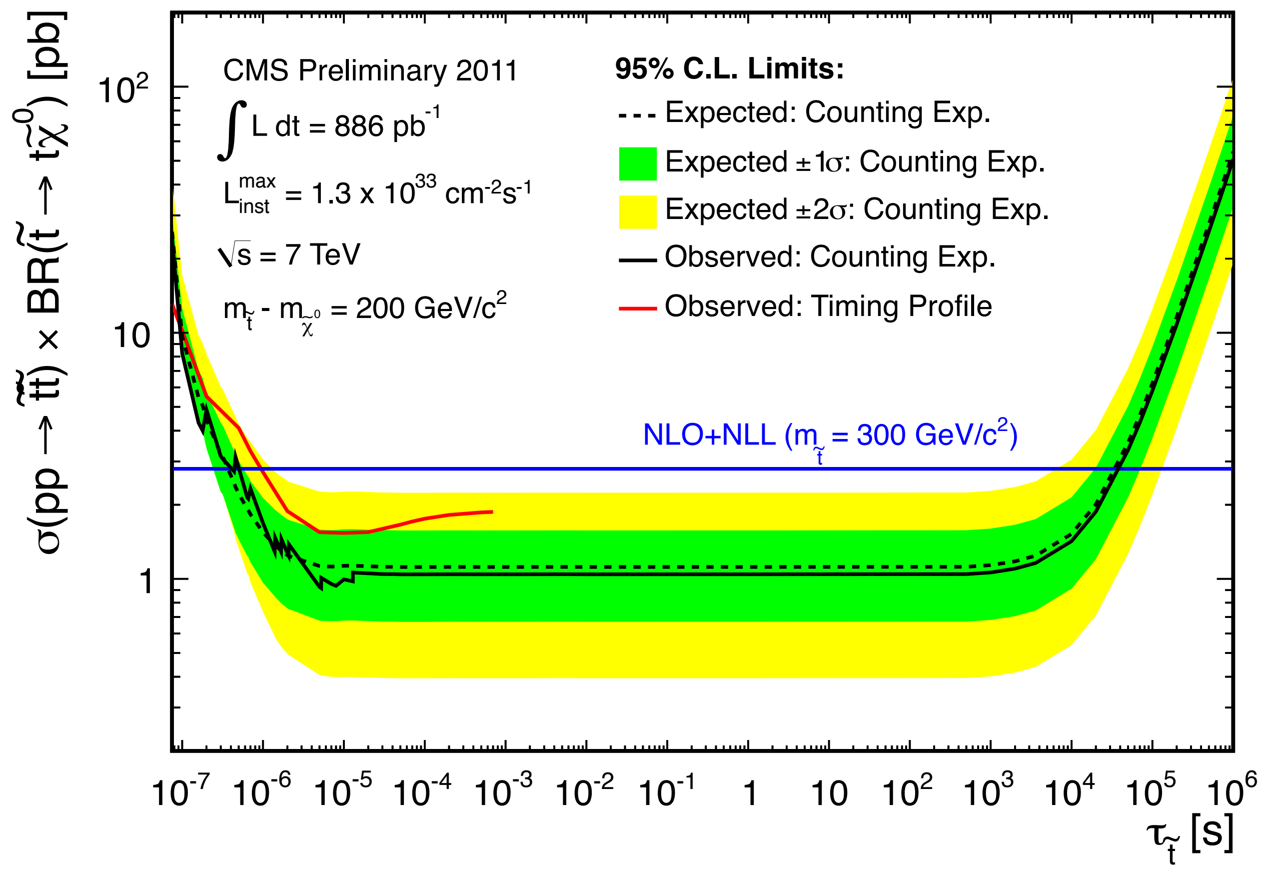
Steps occur between time-windows as N_{obs} increments for each observed event

Stopped Particles : Results

- Place limits on production cross-section × branching fraction
  - Take stopping probability from MC
  - For cloud model, and EM interactions only

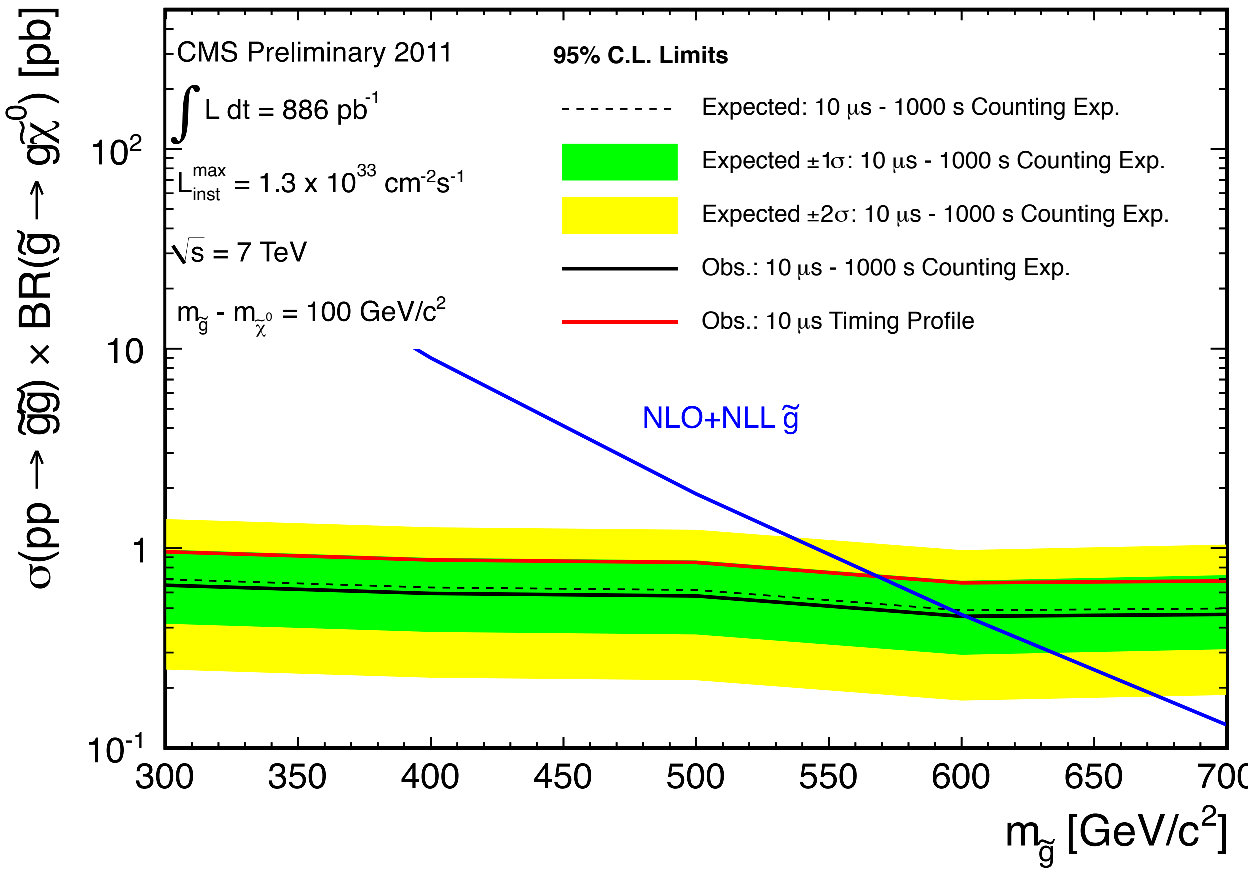
- Place limits on gluino and stop
  - Assume $\tilde{g} \rightarrow g\, \tilde{\chi}^0$ and $\tilde{t} \rightarrow t\, \tilde{\chi}^0$ with fixed mass difference between $\tilde{g}/\tilde{t}$ and $\tilde{\chi}^0$

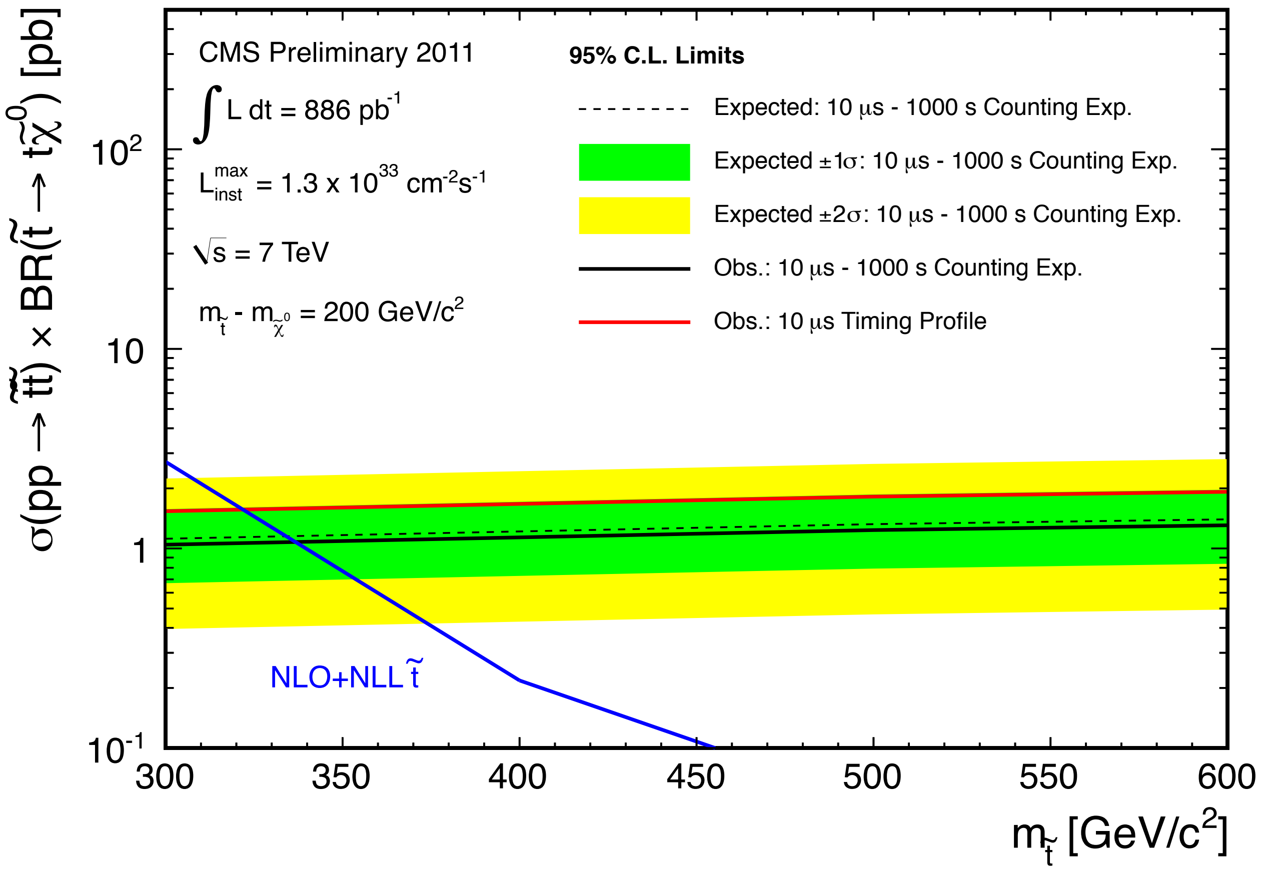




Stopped Particles : Results

- Present limits as function of gluino/stop mass
  - For the "plateau" in lifetime limit
- Stopping probability and trigger/reco efficiency is roughly flat
- Place lower limits on mass for lifetimes between 10μs and 1000s
  - $m_{\tilde{g}} > 601$ GeV/c^2
  - $m_{\tilde{t}} > 337$ GeV/c^2





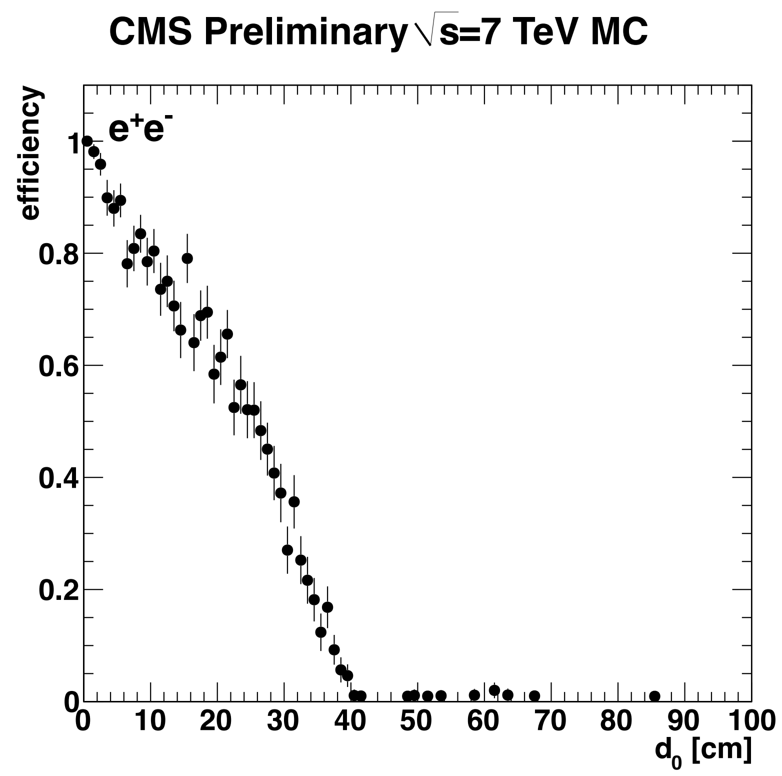
Displaced Leptons

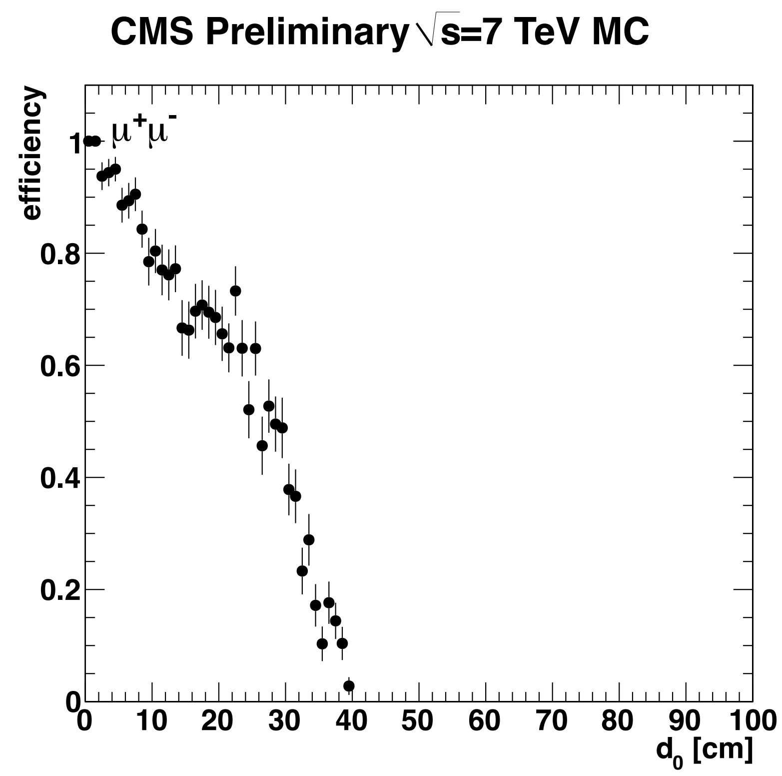
- Search for neutral objects decaying to electron/muon pairs
- Consider a simple case : $H^0 \rightarrow 2X,\ X \rightarrow \ell^+\ell^-$
  - Where X is a spin-0 long-lived particle
- Find tracks with large transverse impact parameter
  - Using an iterative tracking procedure
  - Prompt tracks first, remove used hits and work outwards
- Associate displaced tracks with a muon/electron trigger
  - Require moderate p_t (38/25 GeV for e/μ) and isolation
  - Reject prompt tracks by cutting on *transverse impact parameter significance*
- Identify X candidates
  - Fit all oppositely charged, like flavour, track pairs to common vertex
  - Require vertex well displaced from beam line (cut on *decay length significance*, L_{XY}/σ)
  - Apply topological cuts to reject cosmic and prompt backgrounds
- Search for resonances in invariant mass spectrum of X candidates

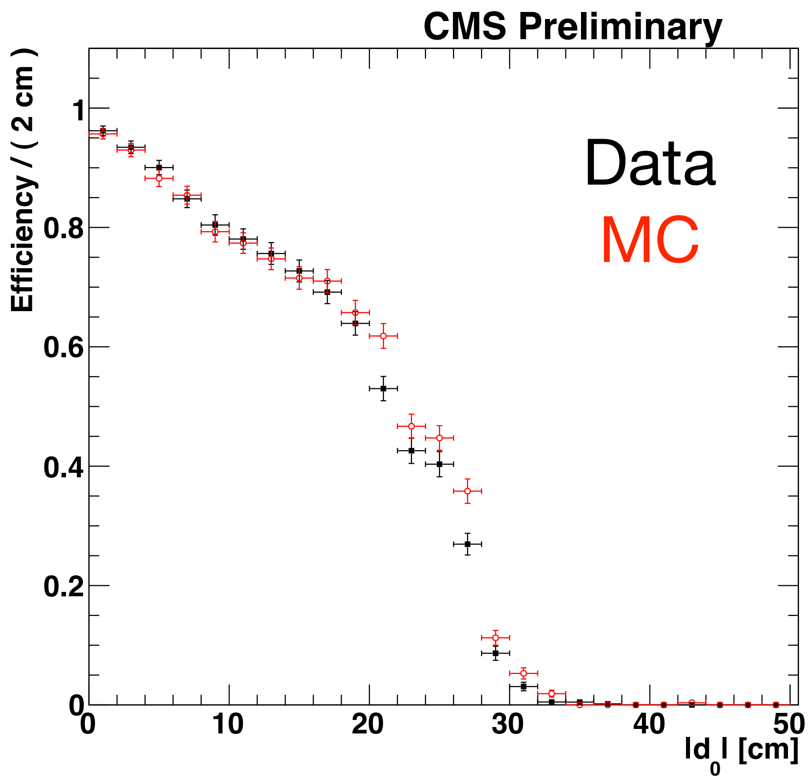
Displaced Leptons : Tracking Efficiency

Identifying displaced tracks is cornerstone of the analysis

Efficiency from MC as a function of transverse impact parameter (electrons and muons) →







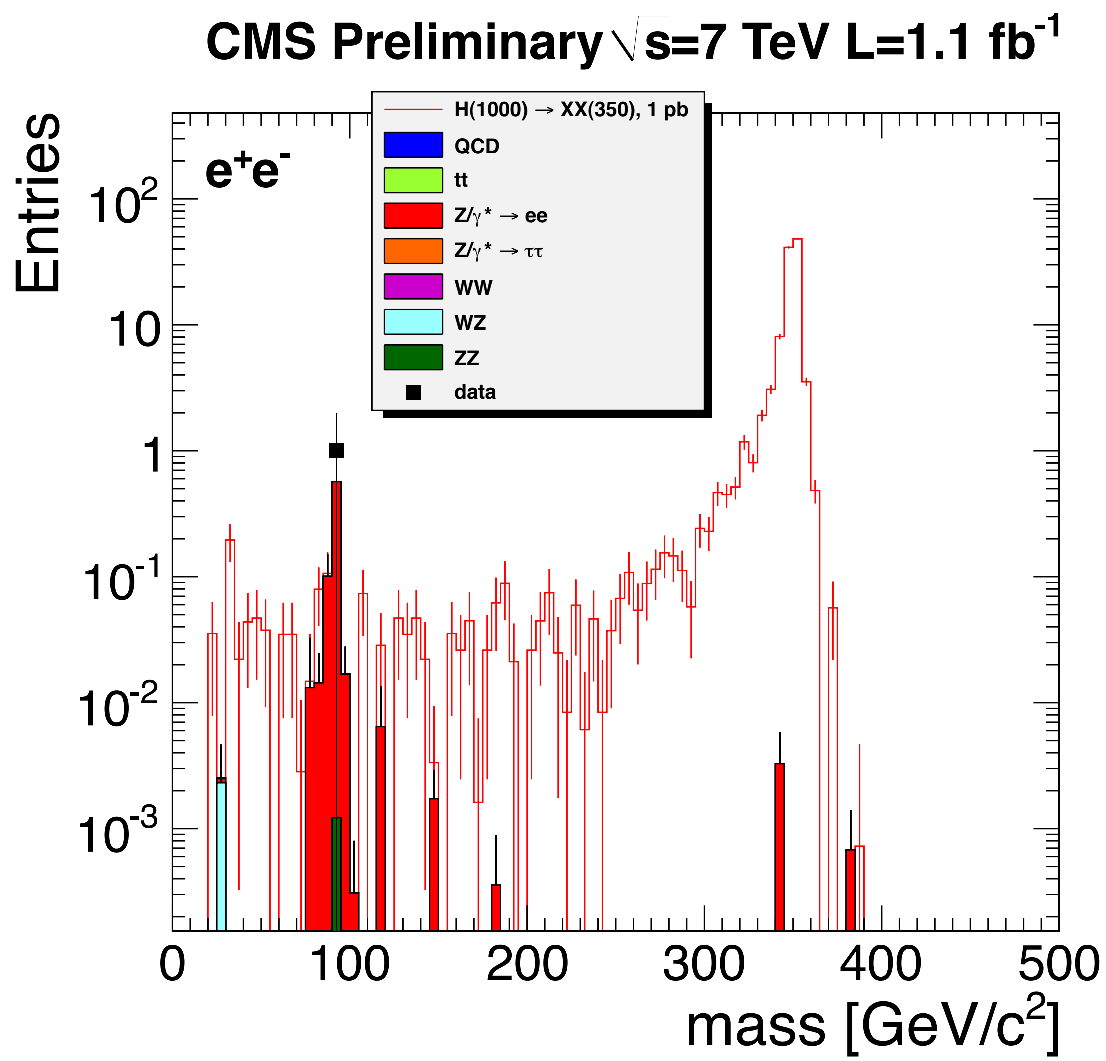
← *Efficiency measurement with cosmic muons*

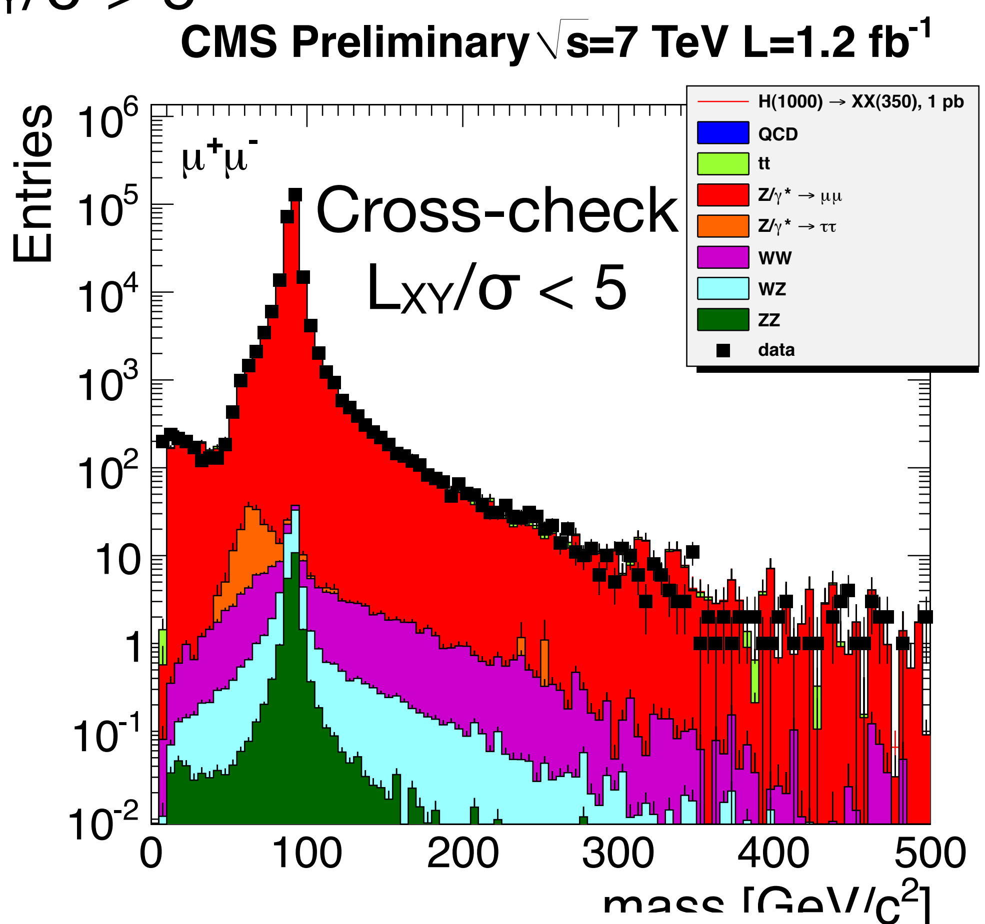
Data-MC difference used to assign 20% systematic on dilepton reconstruction efficiency

Also cross-check using simulated displaced tracks embedded in pp data

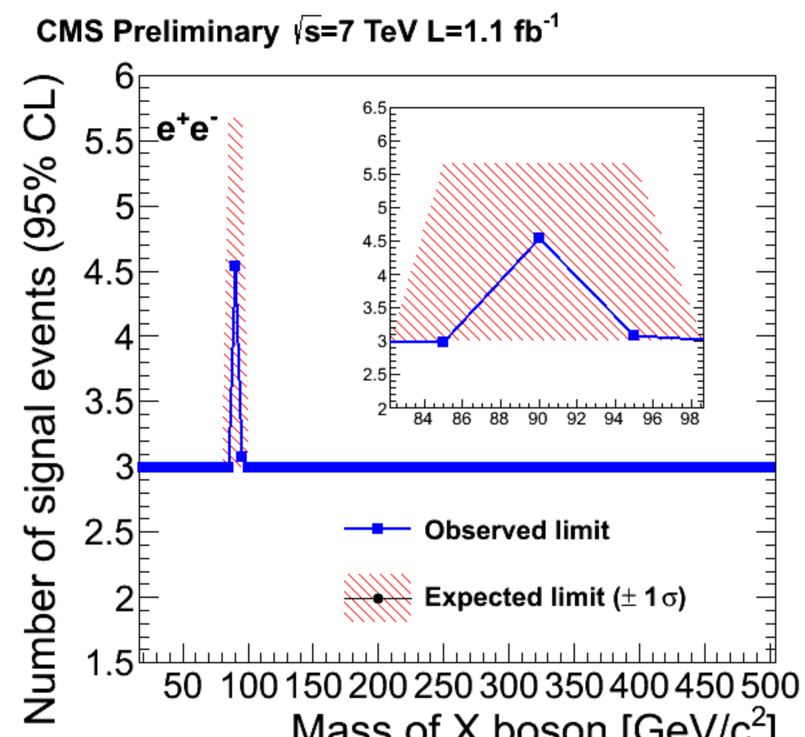
Displaced Leptons : Analysis

- Look for pairs of tracks with compatible vertex, with $L_{XY}/\sigma > 5$
  - ie. not compatible with prompt production
- Estimate background using MC



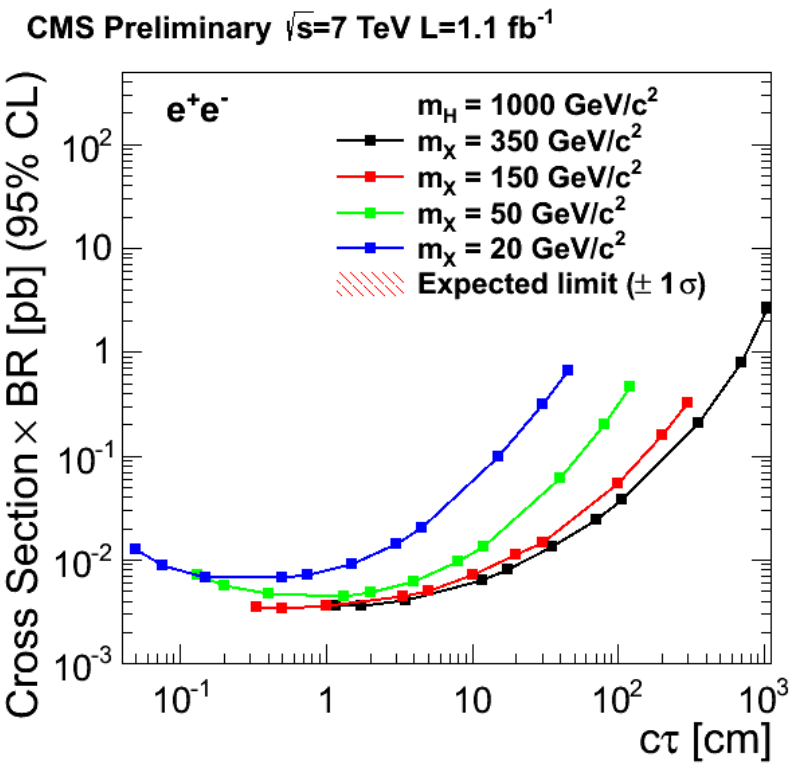


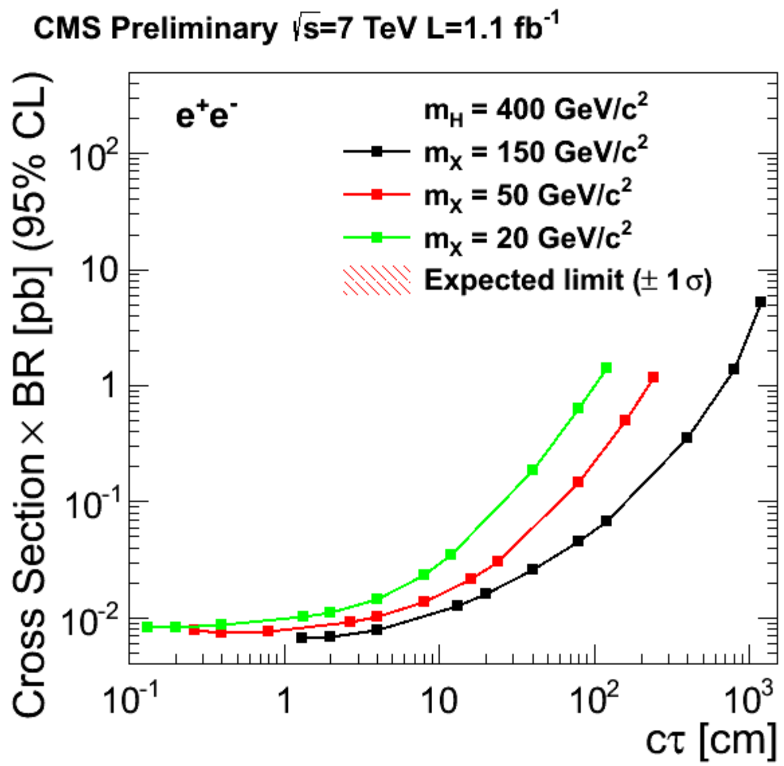
- Place limit on number of X candidates
  - Electrons - expect 0.79 +/- 0.99, around m_Z
  - Muons - expect 0.02 +/ 0.76, observe 0



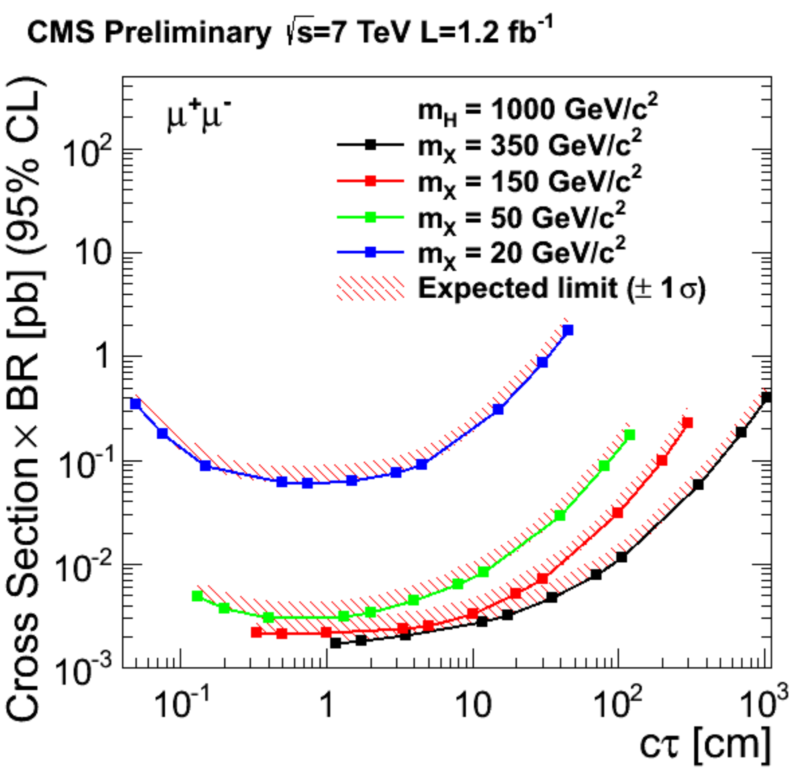
Displaced Leptons : Results

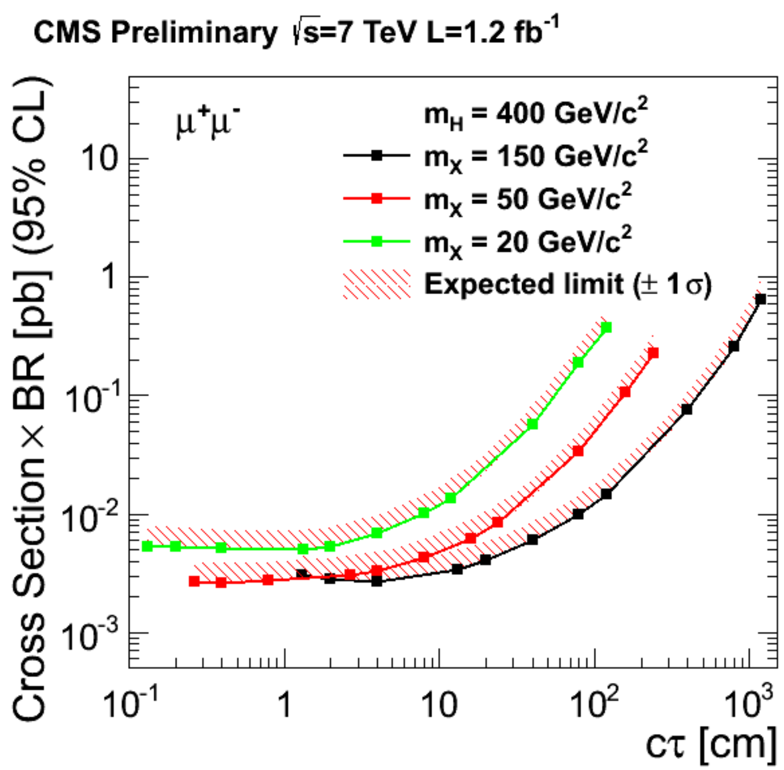
- Finally, present limits for a range of m_H, m_X

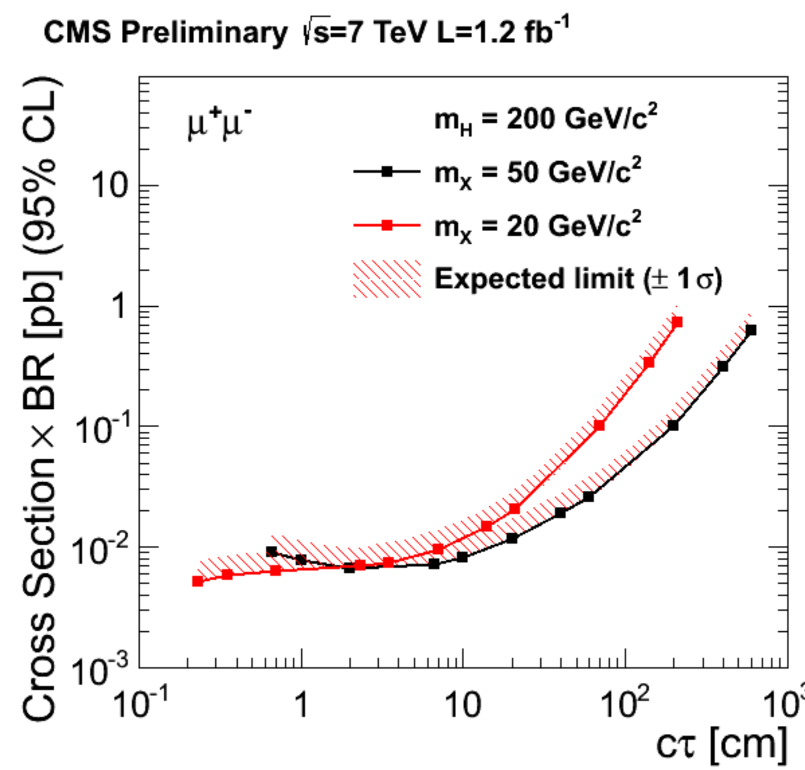




Electron channel not sensitive to m_H = 200 GeV/c^2

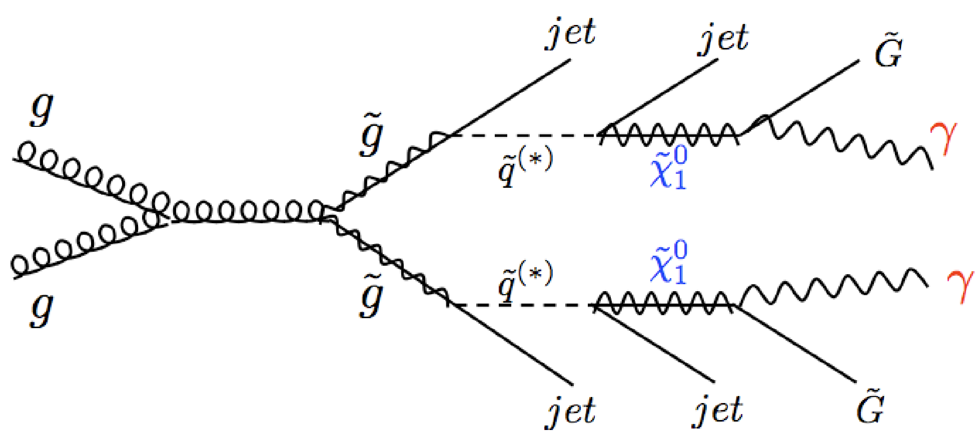




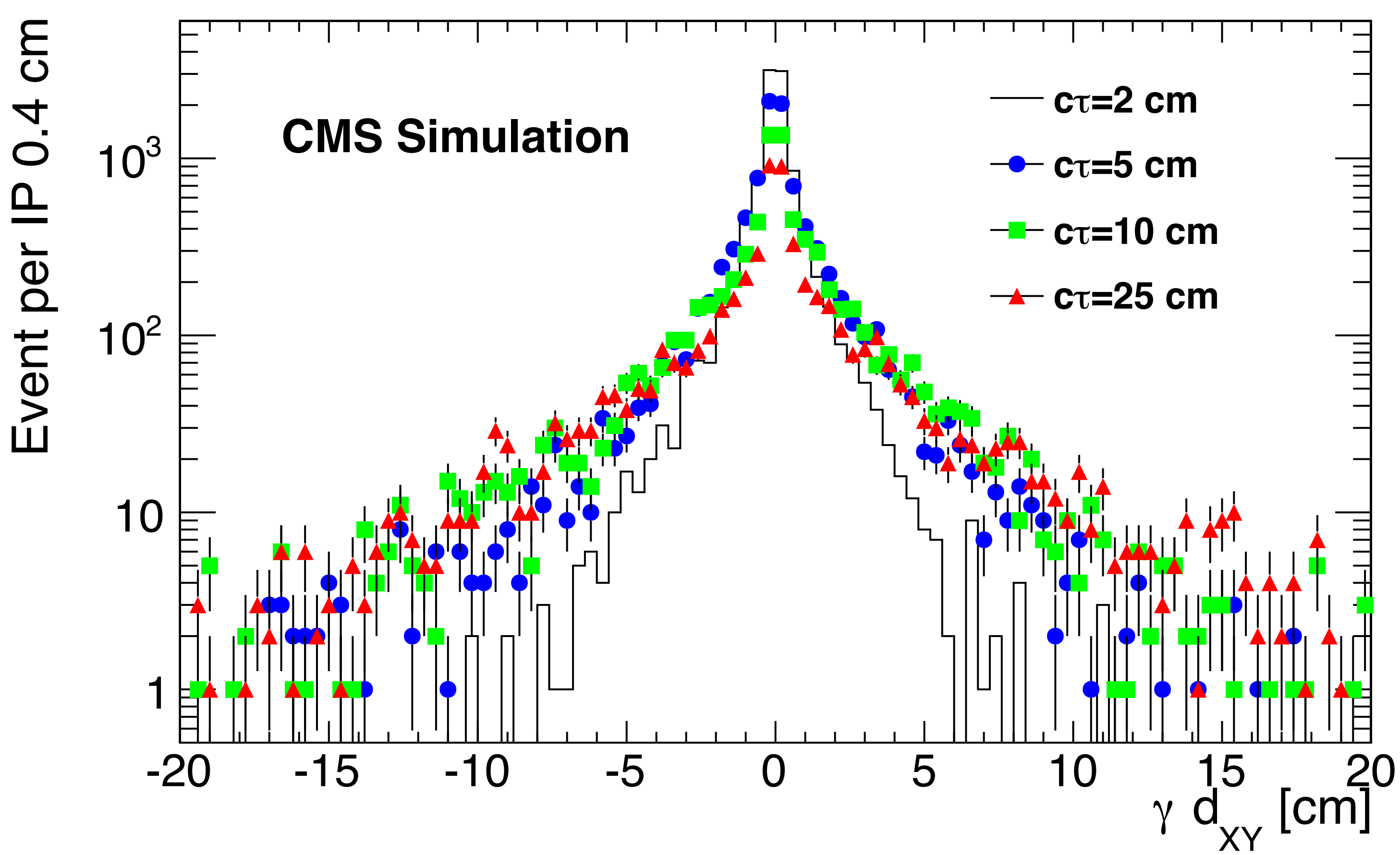


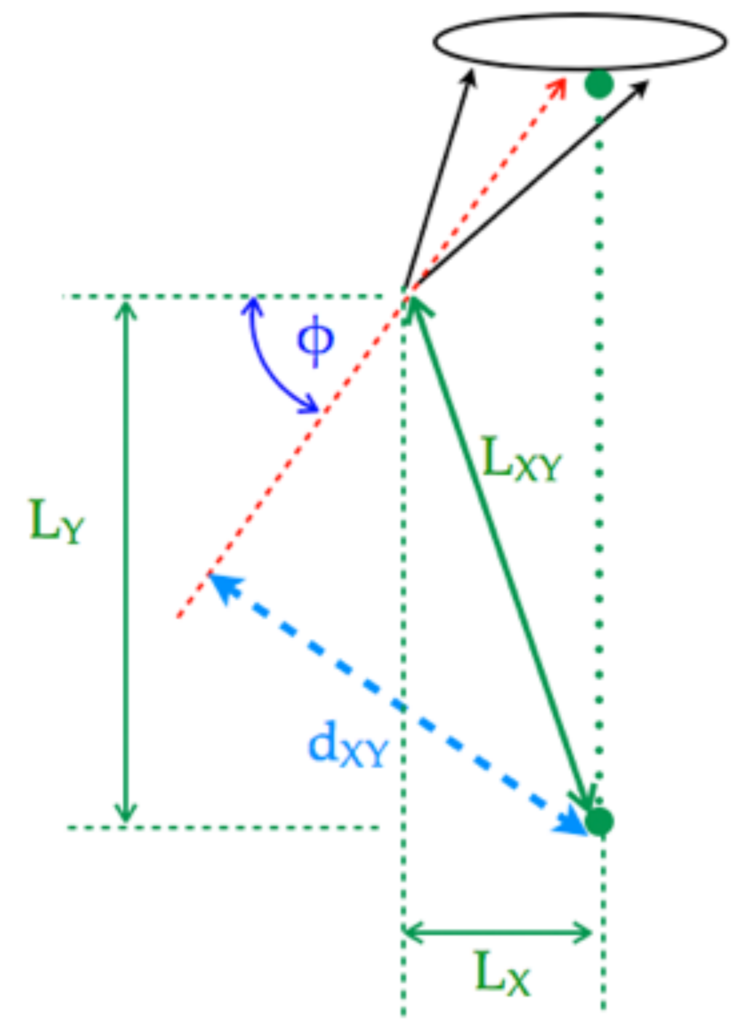
Displaced Photons

- Search for long lived particle decaying to photons
- Motivated by GMSB : long-lived $\chi_0 \rightarrow \gamma + G$
- Can use time-of-flight, photon shower shape

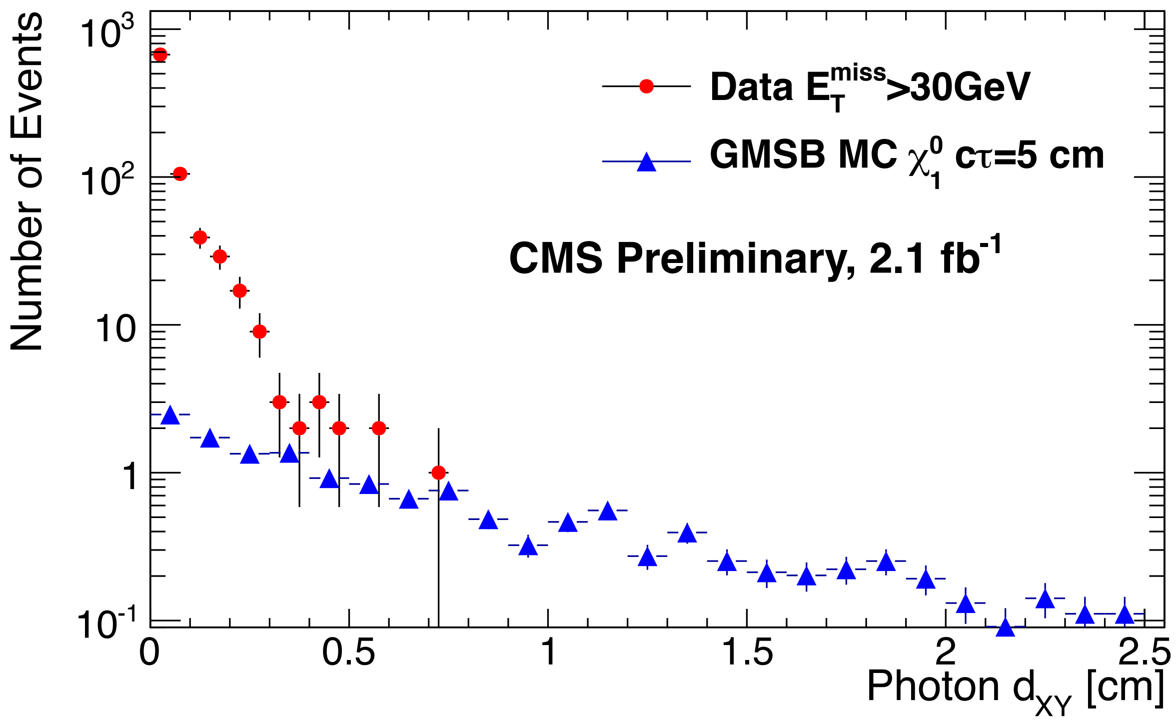


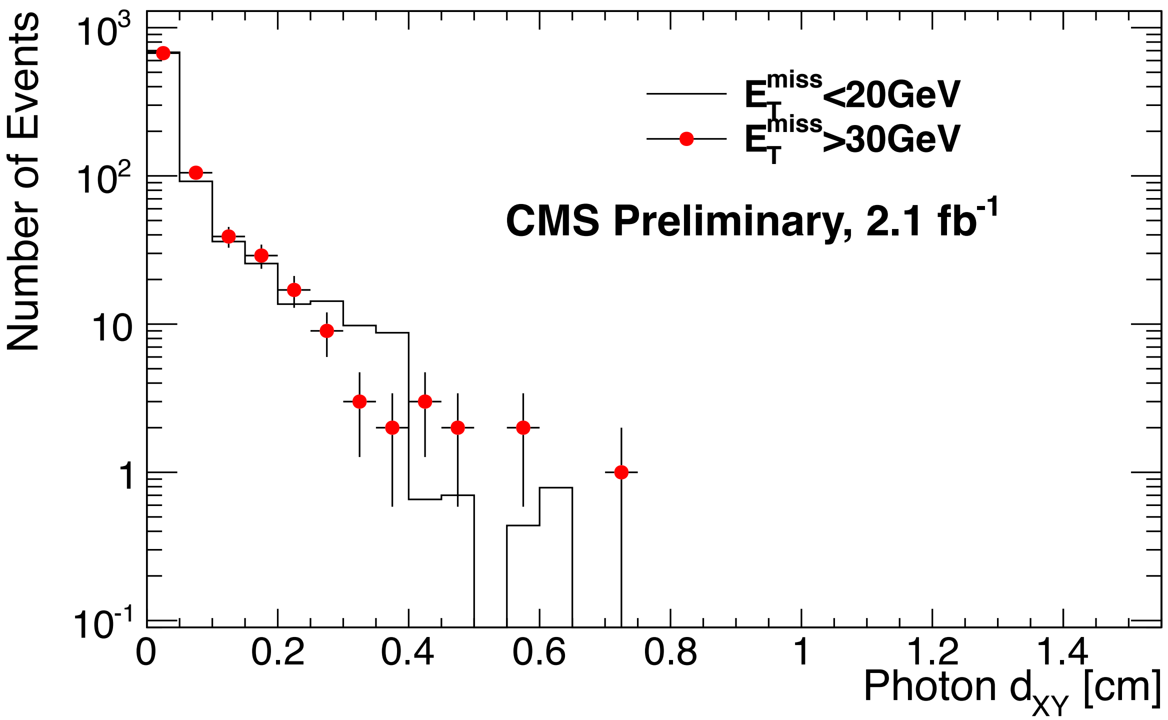
- Here, use converted photons
  - Require *2 photons* (> 45 GeV) + 2 jets (> 80/50 GeV)
  - Reconstruct photon impact parameter d_{XY} using conversion tracks



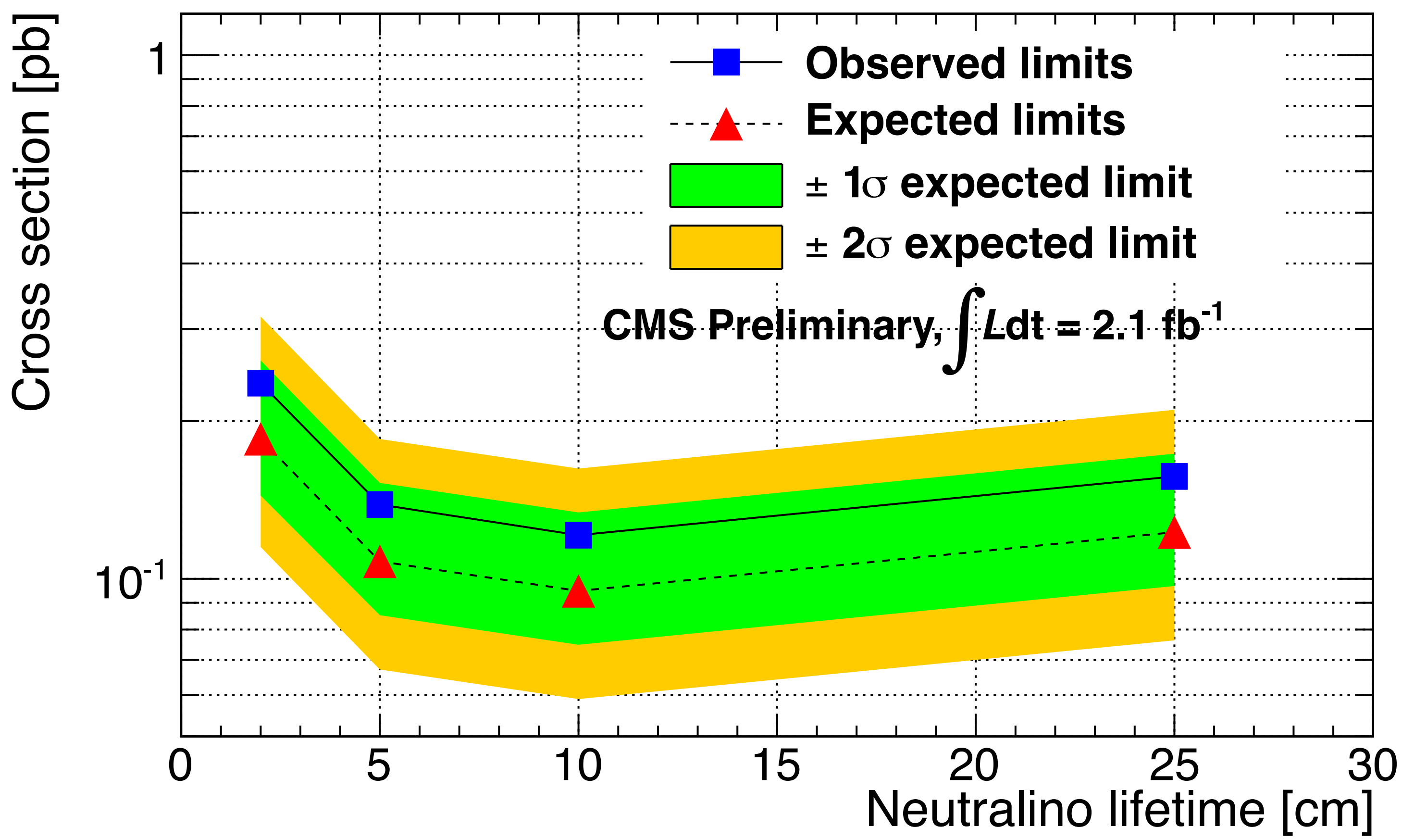


Displaced Photons : Result





- Estimate background using low E_t^{miss} control region
- Counting experiment in signal region, $d_{XY} > 0.6$
- Sensitive to cτ ~ 5-30 cm
  - Can extend this using calorimeter time-of-flight measurement



Summary & Conclusions

- Currently employ a range of methods to search for long lived particles
  - Highly ionising tracks
  - Late arriving muons
  - Decays of stopped particles
  - Track pairs with displaced vertices
  - High impact parameter photons
- 5 fb^{-1} updates on all these coming soon
- But we still a wide range of signature space to explore
  - Displaced vertices with other decay modes - qq, bb, ττ, ... combinations
  - Charged particles that decay in the detector - kinked tracks etc.
  - Trackless jets
  - Fractionally/multiply charged particles
  - Monopoles
- Hope to start covering at least some of this with the 2012 data