Long Lived Exotics

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Long Lived Particles : Motivation

- Many new physics scenarios predict heavy long-lived particles
  - Some flavours of SUSY predict long-lived gluino, stop, stau
  - Hidden valley models
  - Certain GUTs
  - Lifetimes around 100-1000s are of particular interest in cosmology
    - **May explain the ^{6}Li, ^{7}Li abundance discrepancy** between measurement and conventional nucleosynthesis

- Need a wide range of experimental techniques
  - Particle may be neutral or charged
  - May experience strong force (important for R-hadrons that may change flavour/charge)
  - May decay inside or outside detector

- 1. Displaced vertices *New!*
  - Search for **electron/muon pairs originating from displaced vertex**
  - With high invariant mass
- 2. Highly ionising particles
  - Search for **high p_t, high dE/dx tracks** in tracker
  - With and without muon ID and **time-of-flight**
- 3. Stopped particles
  - Heavy, quasi-stable, charged particles may stop in the detector
  - Look for **out-of-time decays of particles that have stopped** in the calorimeter

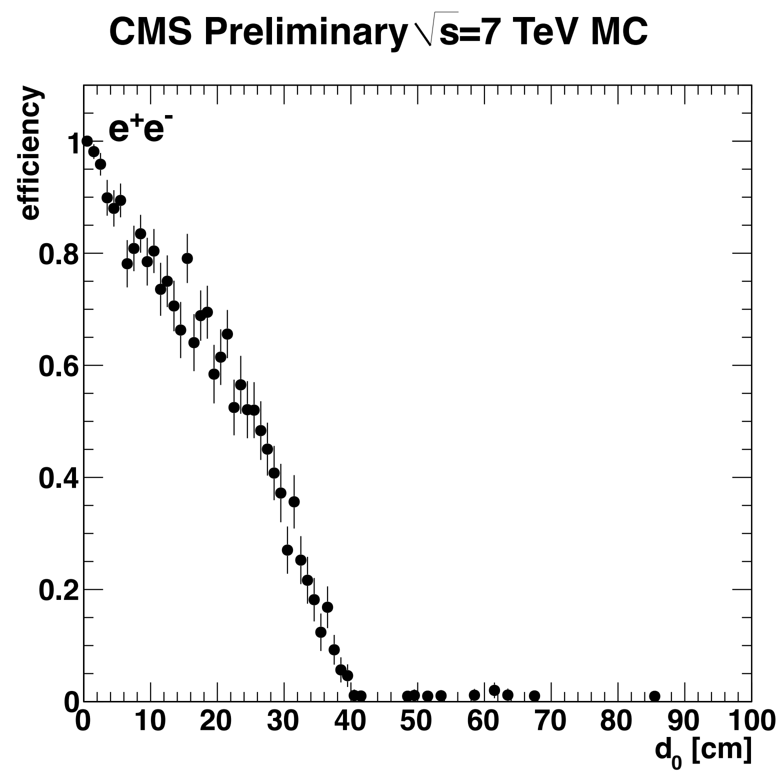
Displaced Leptons

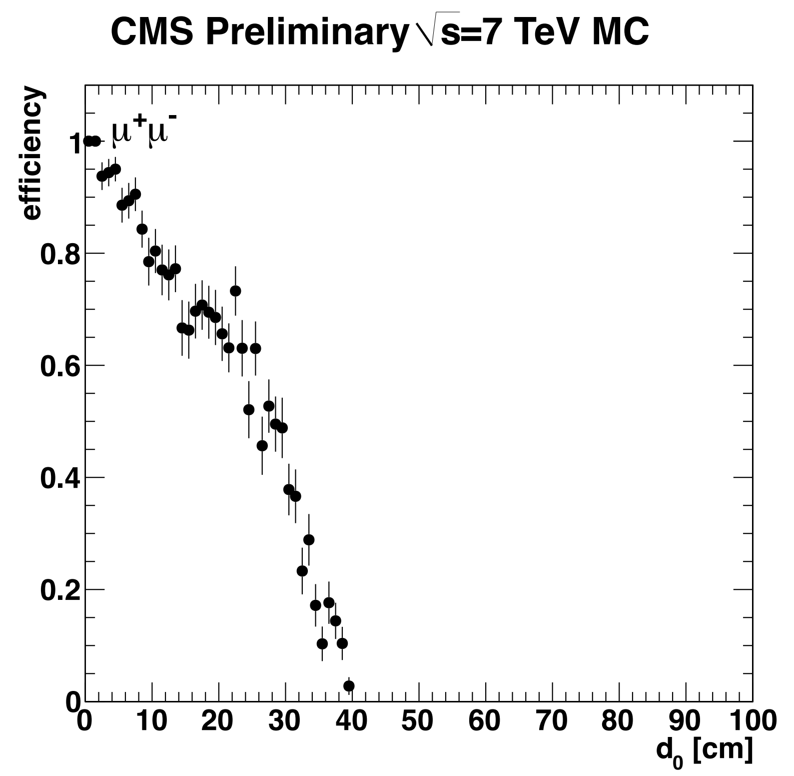
- Search for neutral objects decaying to electron/muon pairs
- Consider a simple case : $H^0 \rightarrow 2X,\ X \rightarrow \ell^+\ell^-$
  - Where X is a spin-0 long-lived particle
- Find tracks with large transverse impact parameter
  - Using an iterative tracking procedure
  - Prompt tracks first, 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*)
  - Apply topological cuts to reject cosmic and prompt backgrounds
- Search for resonances in invariant mass spectrum of X candidates

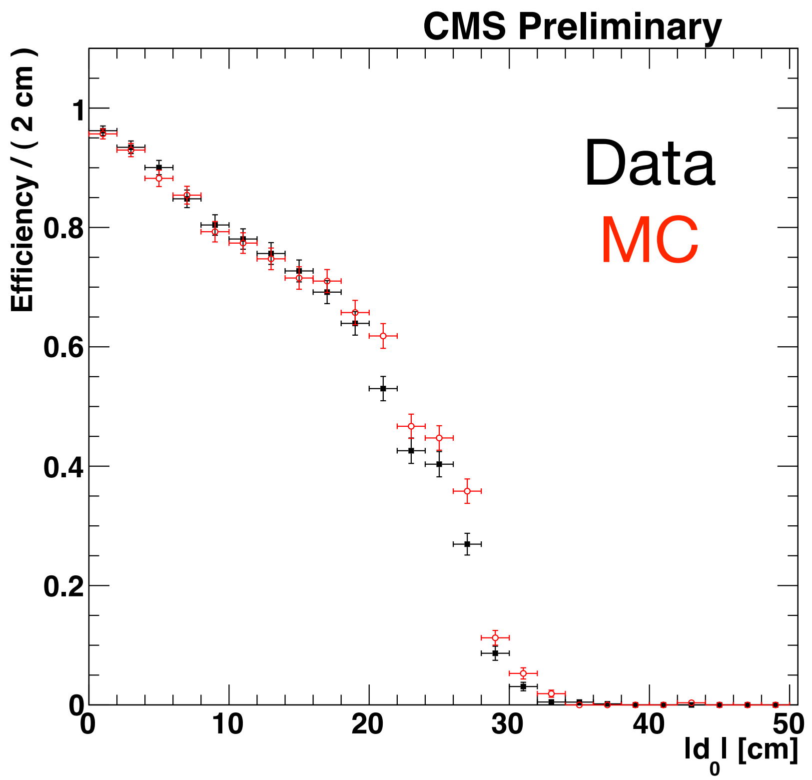
Displaced Leptons : Tracking Efficiency

Identifying displaced tracks is cornerstone of the analysis

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







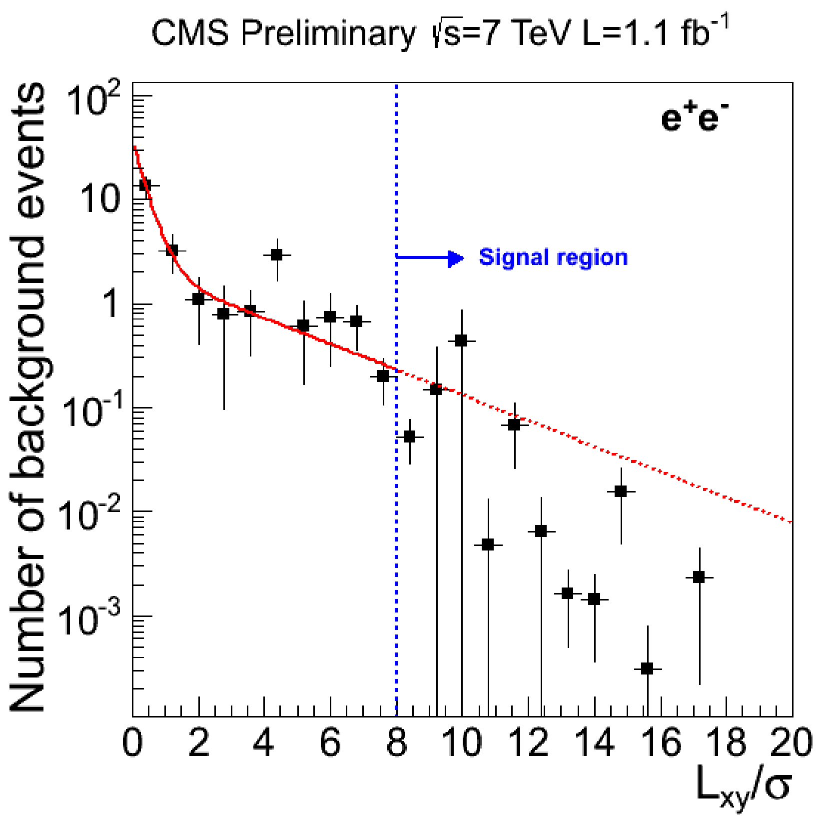
Efficiency measurement with cosmic muons

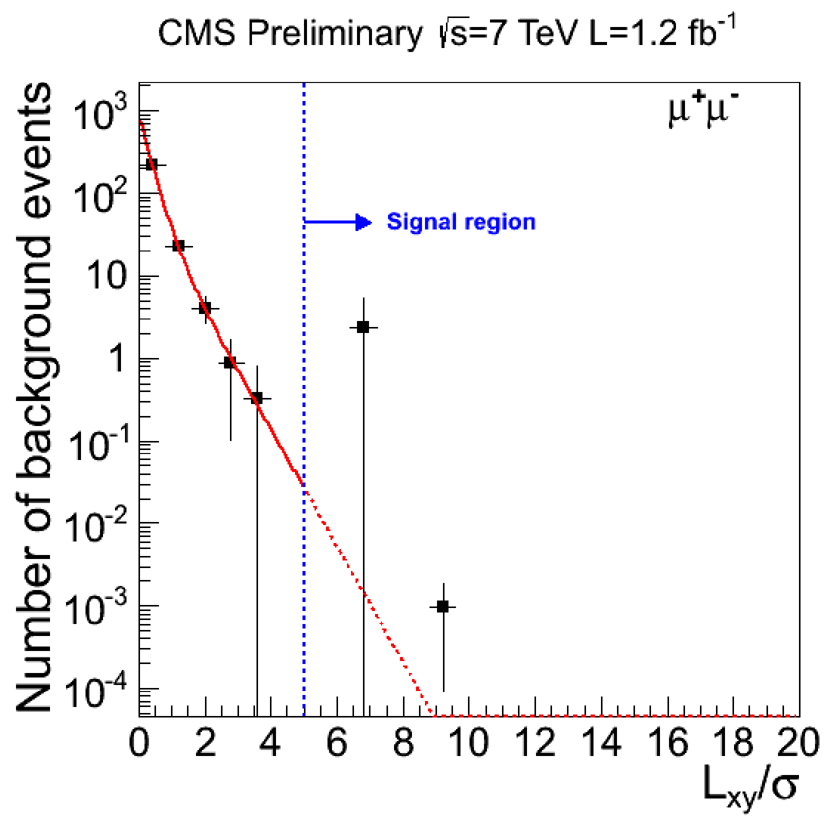
Data-MC difference used to assign 20% systematic on dilepton reconstruction efficiency

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

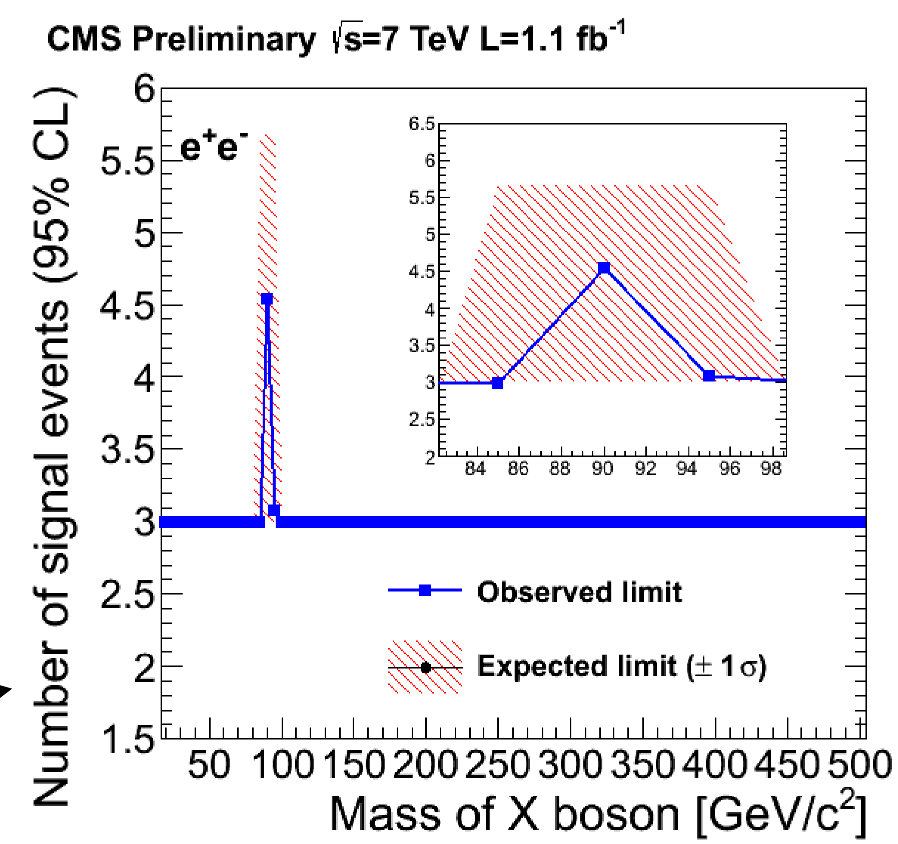
Displaced Leptons : Analysis

- Background estimated using a data-driven method
  - Fit the observed *decay length significance* and extrapolate
  - Difference with MC prediction used for systematic
  - (MC models data well in control region, but low stats in signal region)



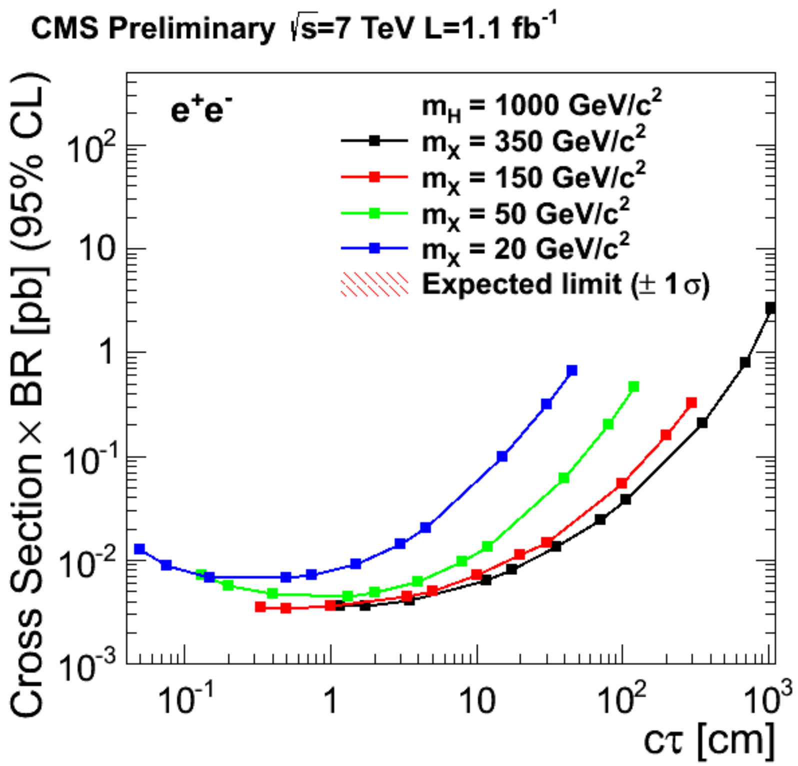


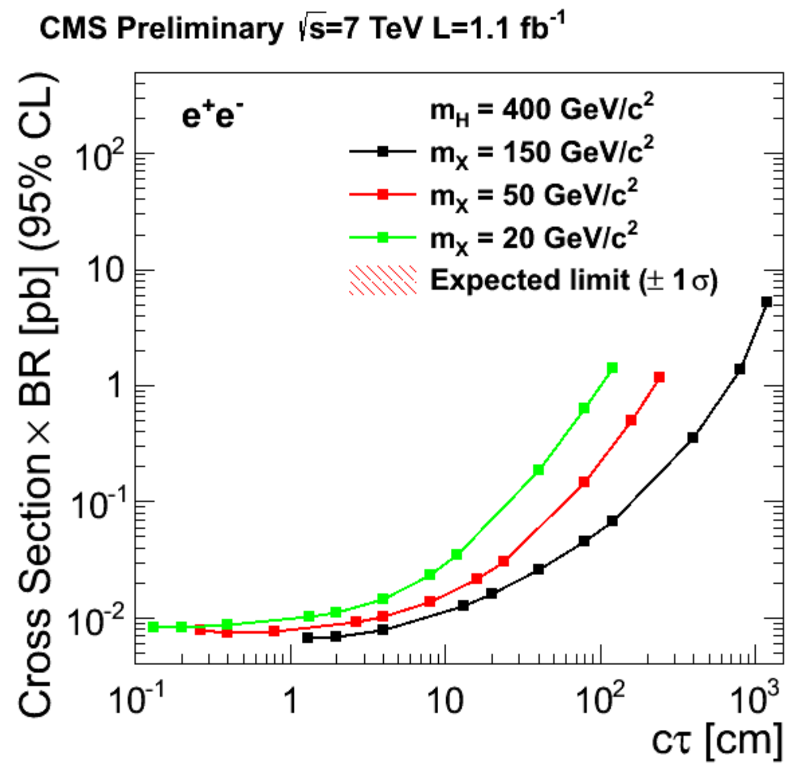
- Place limit on number of X candidates as function of m_X
  - Muons - expect, and observe, zero events
  - Electrons - expect some background around the Z



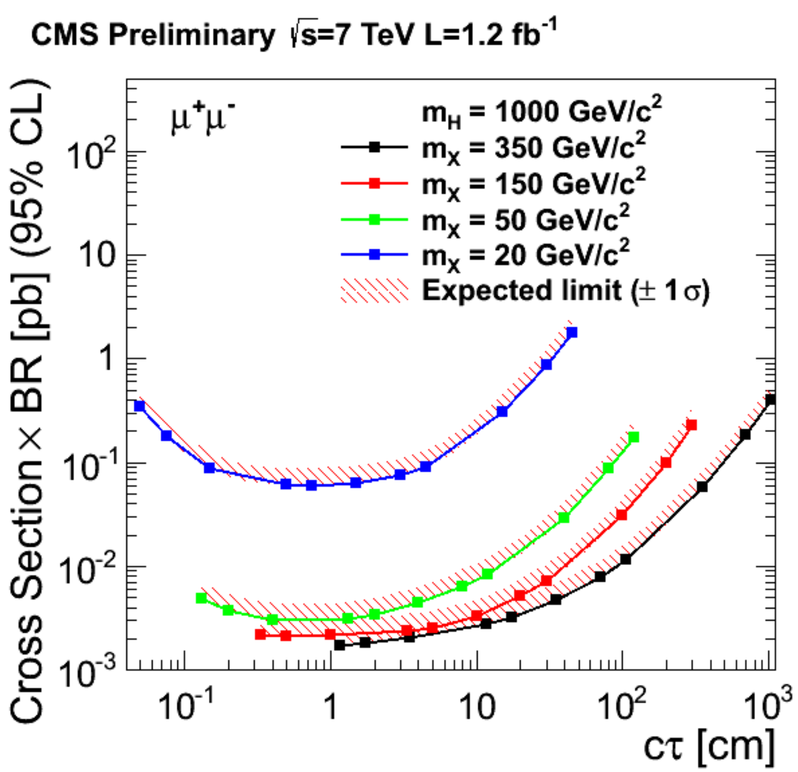
Displaced Leptons : Results

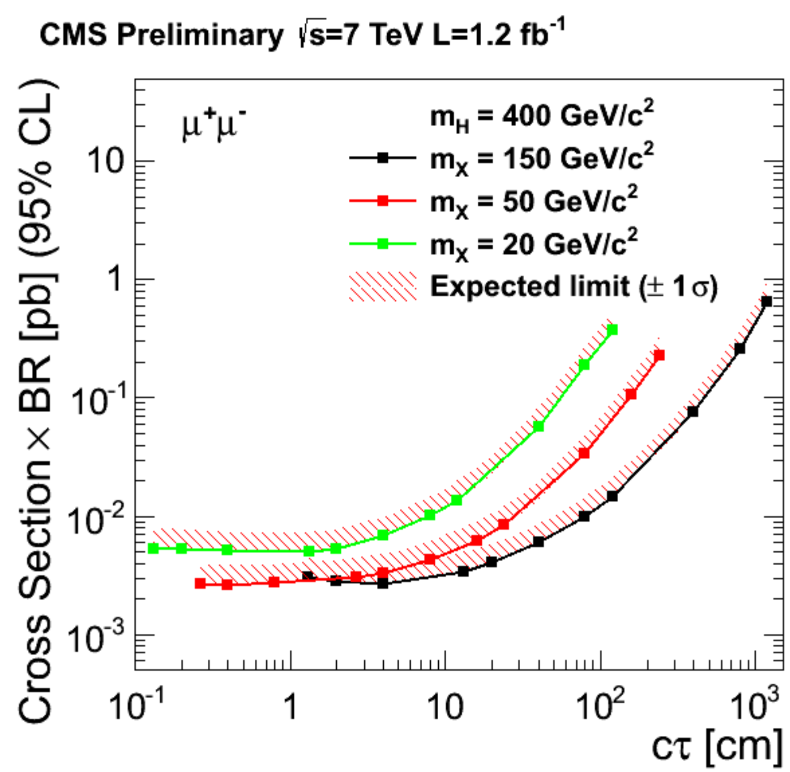
- Finally, present limits for a range of m_H, m_X

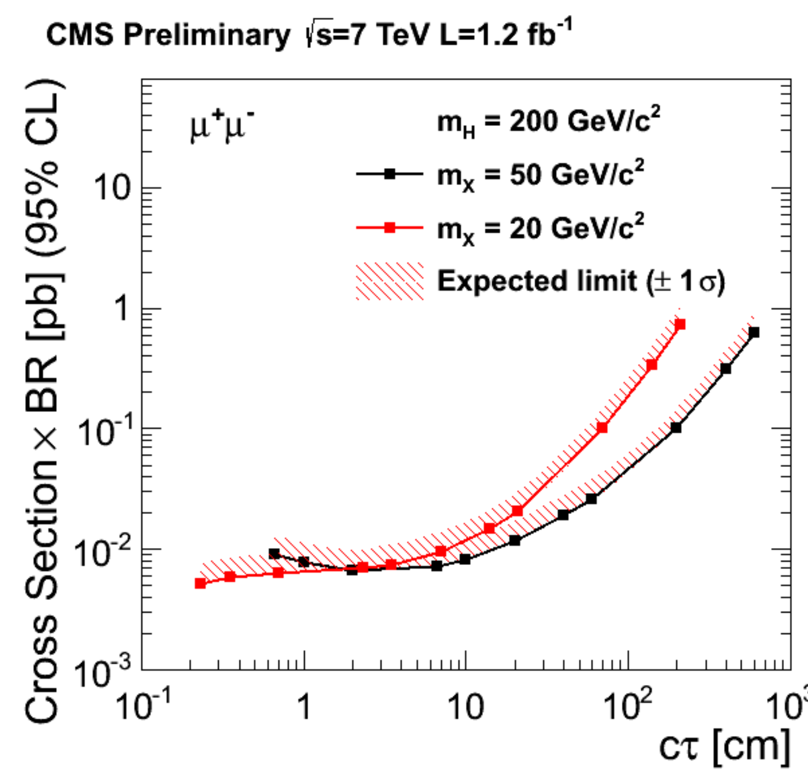




Electron channel not sensitive to m_H = 200 GeV/c²



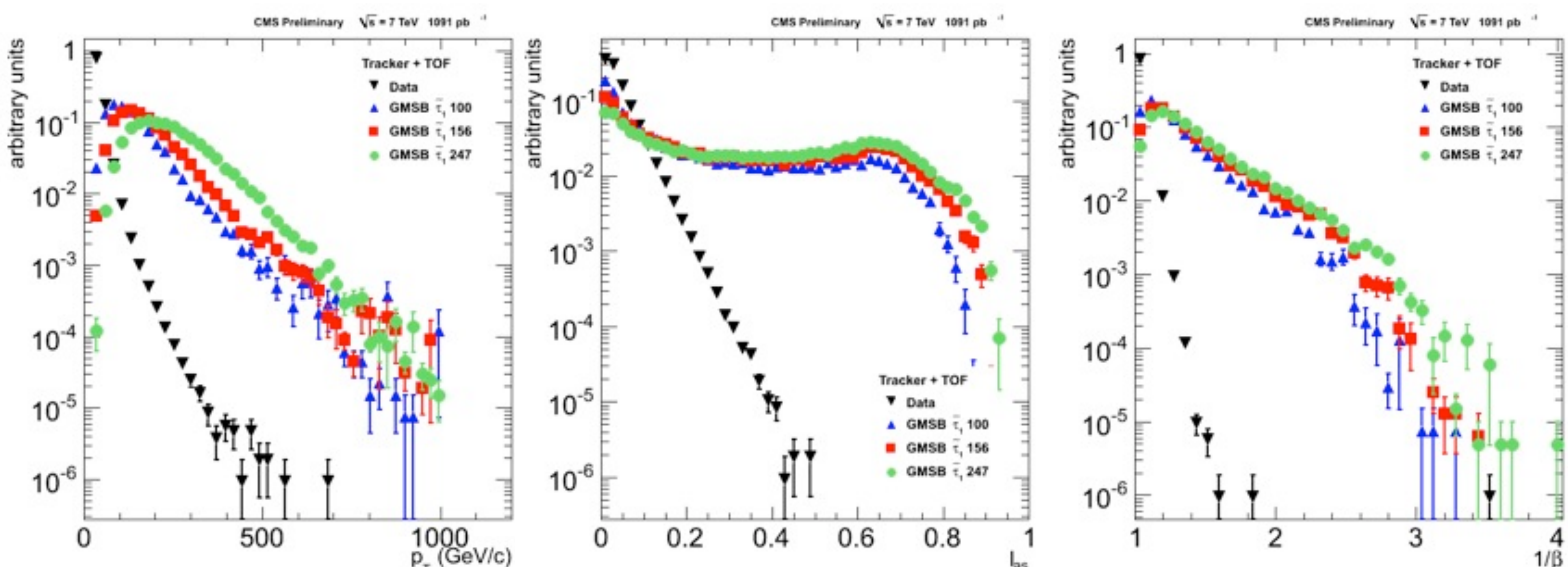




Highly Ionising Particles : Selection

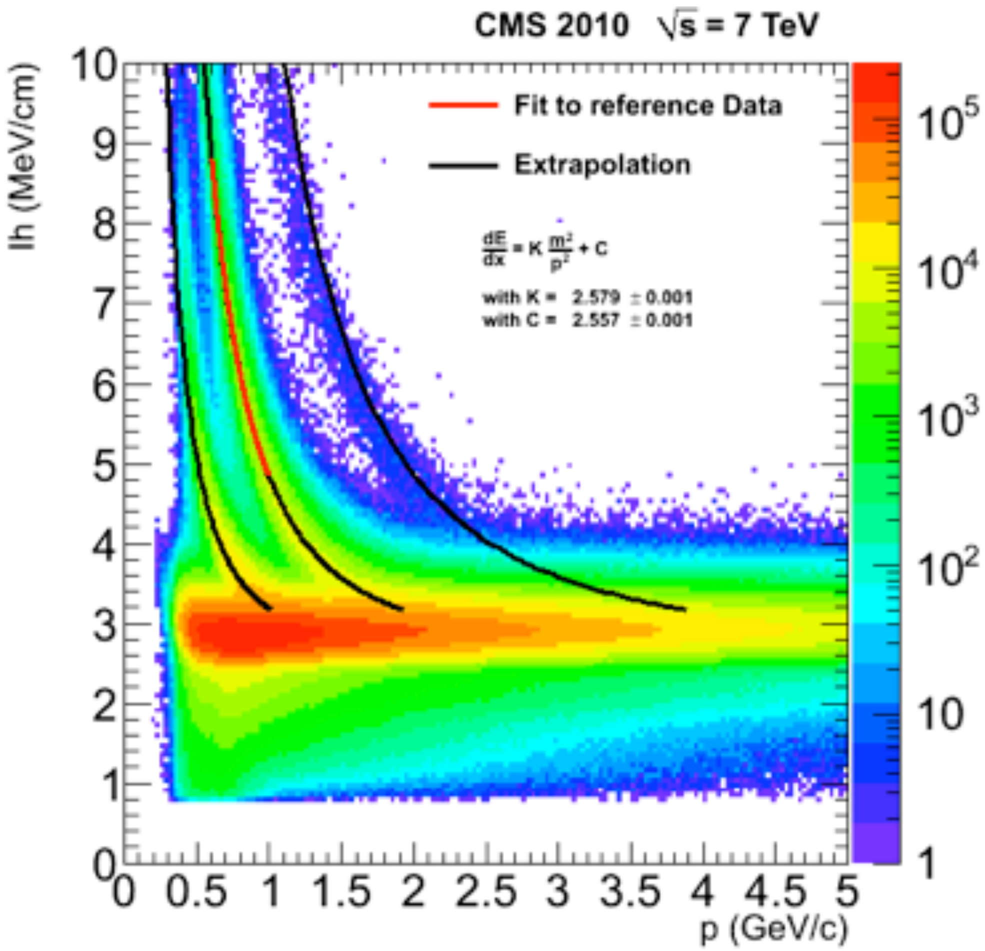
- Search for heavy, stable, charged particle
  - High momentum, but slow moving and highly ionising
  - Gluino and stop R-hadrons, and long-lived stau in GMSB *New!*
- Looking for tracks with high p_t, high dE/dx, large time-of-flight
  - Measure time of flight in muon system *New!*

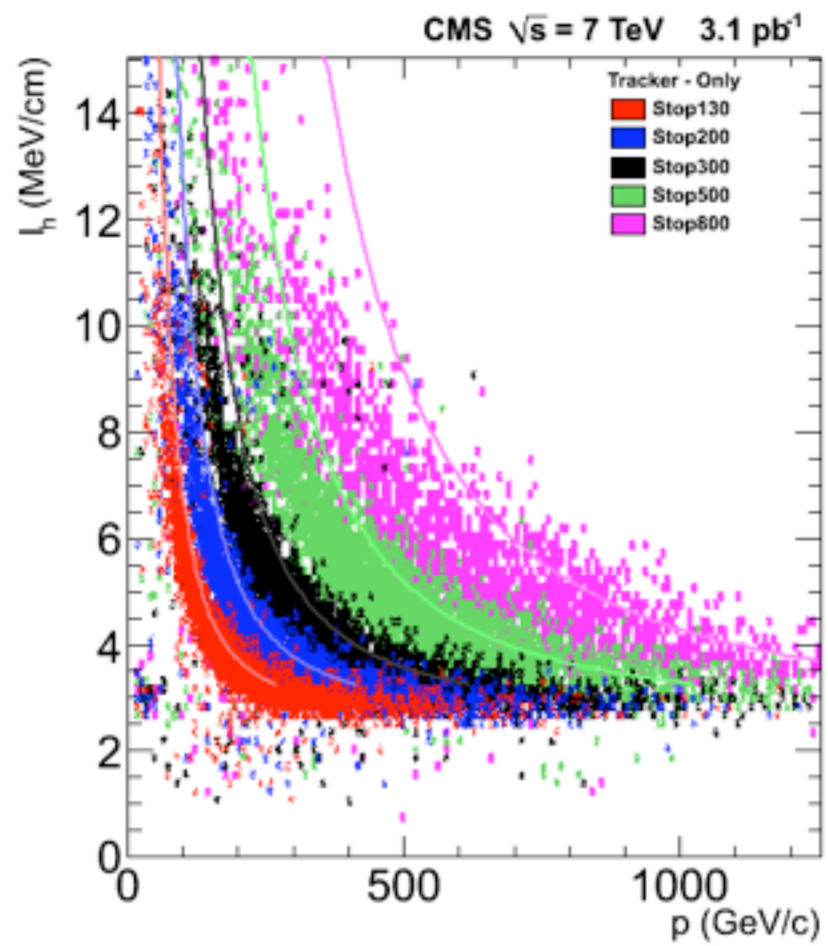
- R-hadrons may change flavour/charge during nuclear interactions with matter
  - Therefore perform searches for tracks both **with and without muon TOF**
  - Use muon and MET triggers to cover both scenarios



p_T dE/dx $1/\beta$

Mass Reconstruction



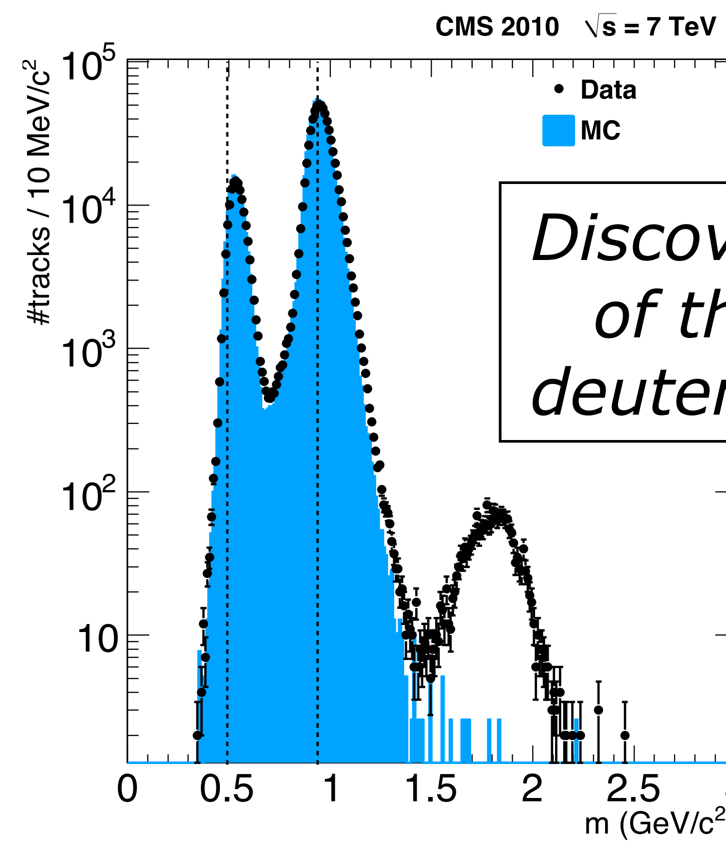


min-bias data *...and stop MC*

- Mass reconstruction
  - Approximate Bethe-Bloch formula before minimum

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

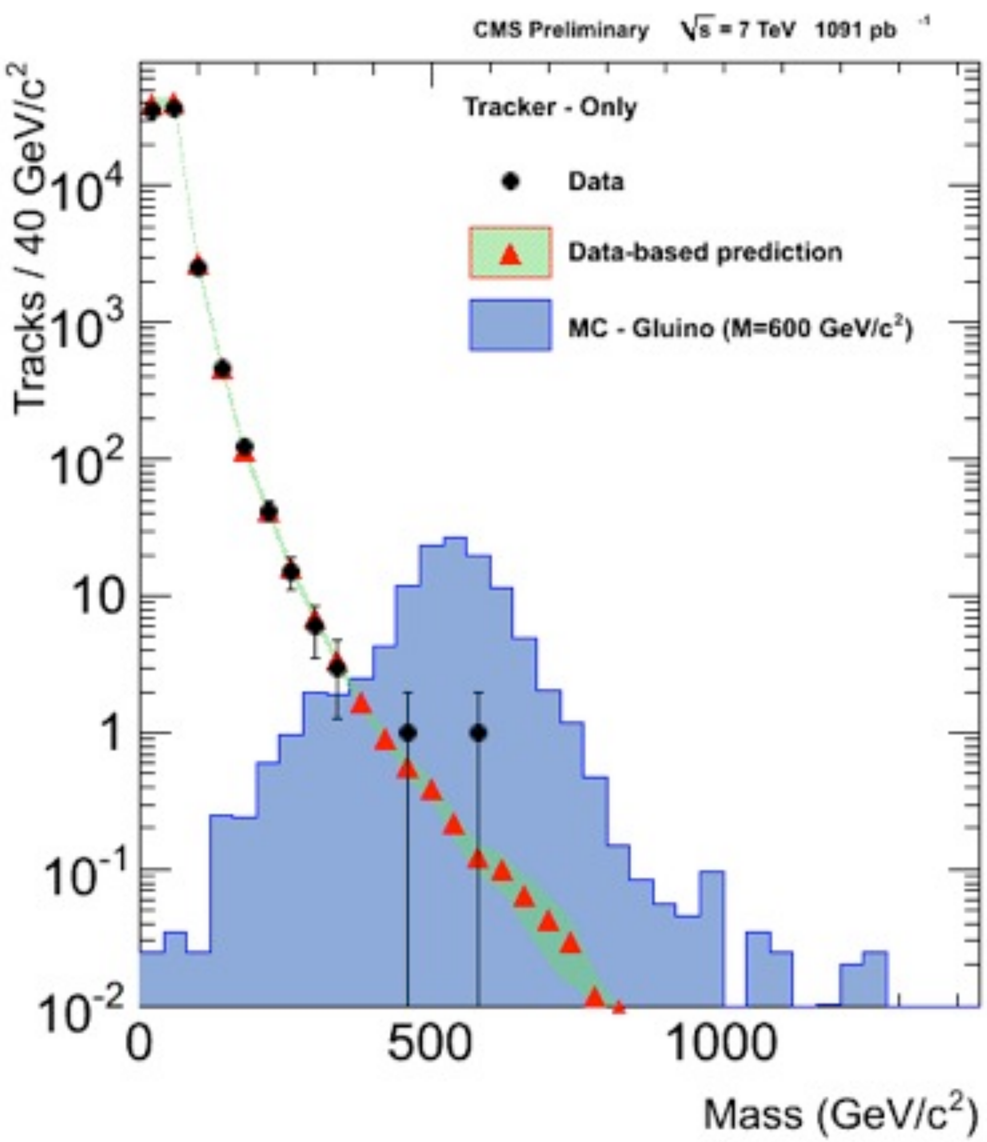
  - Extract parameters K, C by fitting to the proton line
  - Reverse to compute higher masses

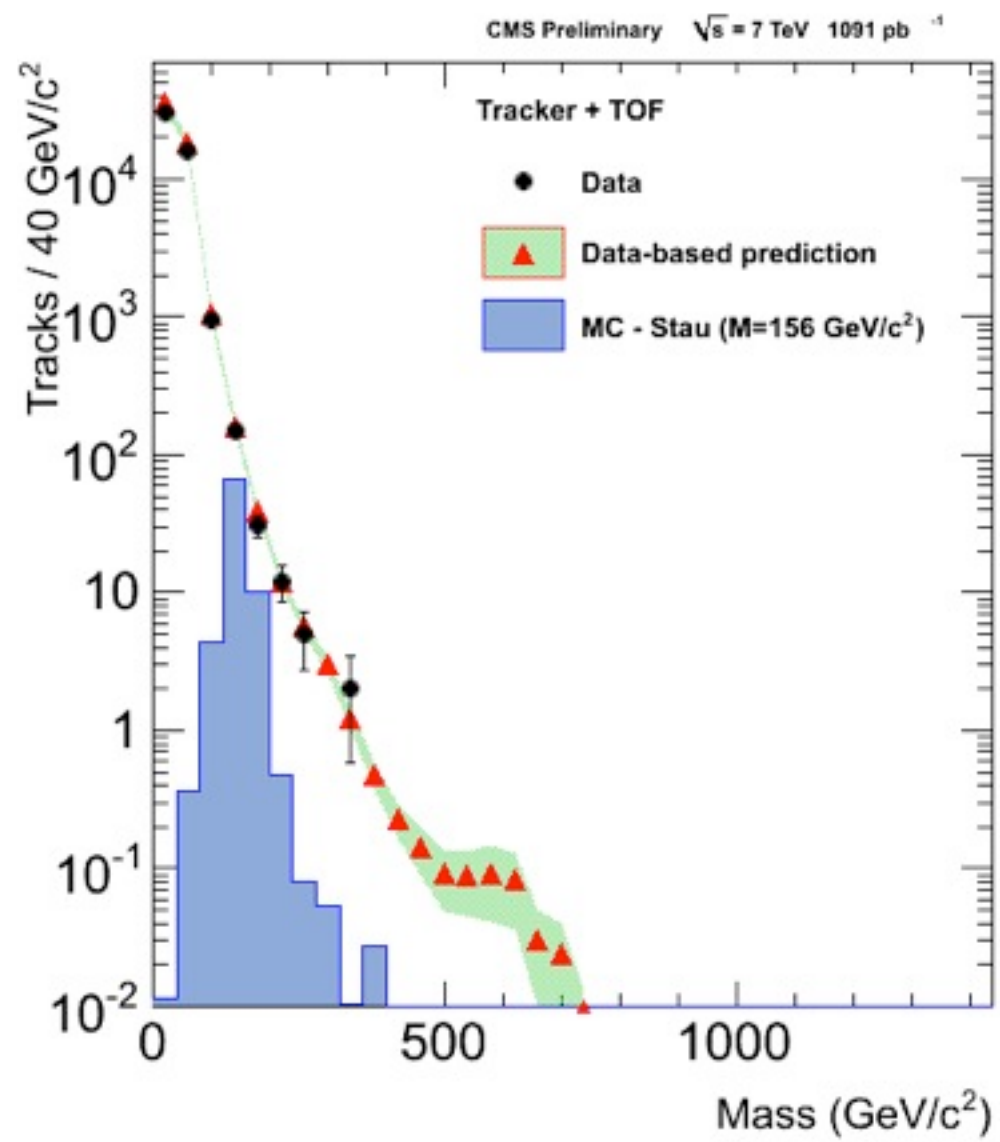


Discovery of the deuteron!

Highly Ionising Particles : Background

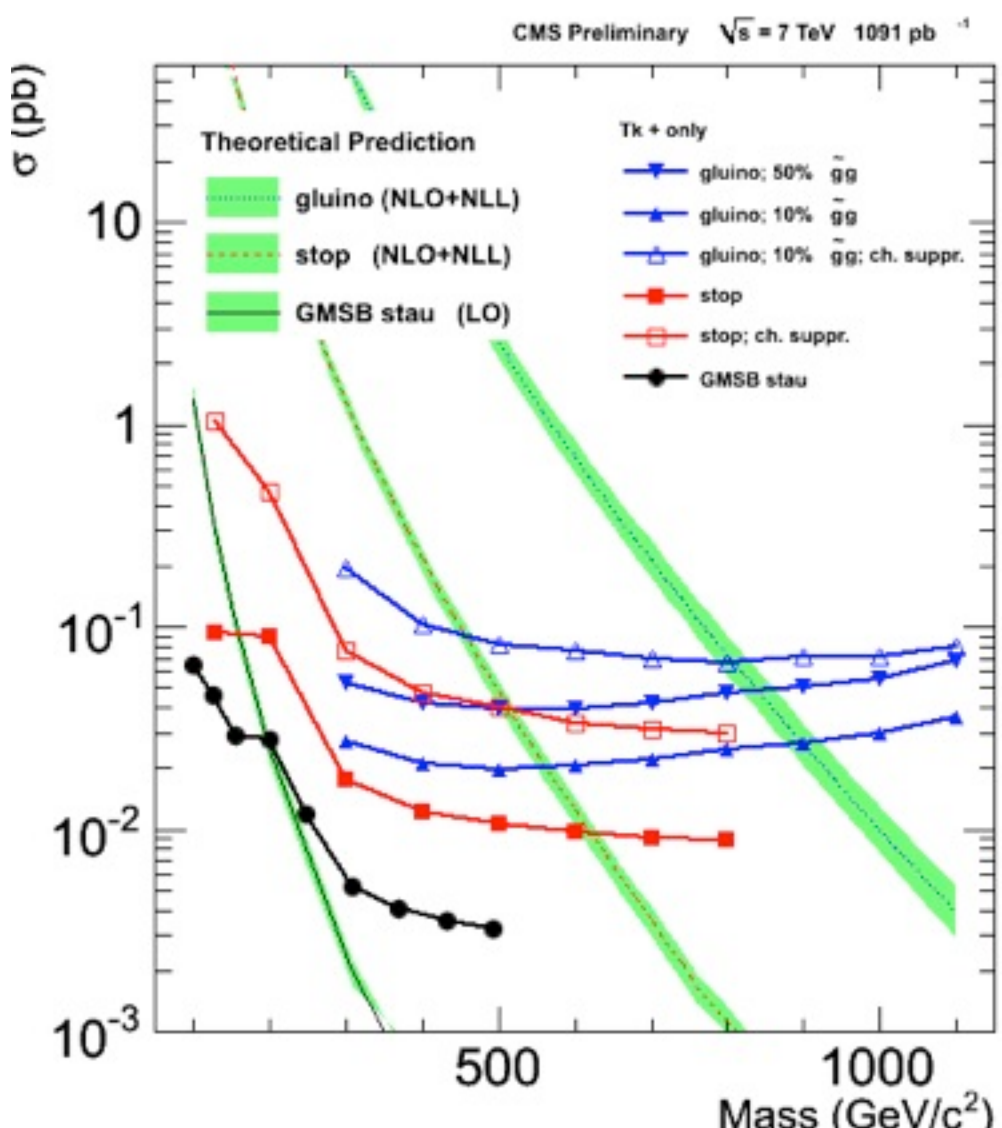
- Select candidate tracks using p_t, dE/dx, (TOF), mass
  - Optimised for each signal MC point
- Background estimated using a data-driven method
  - ABCD technique, extended to 3 variables for Track+TOF analysis
  - Good agreement with observation in a loose selection, shown below

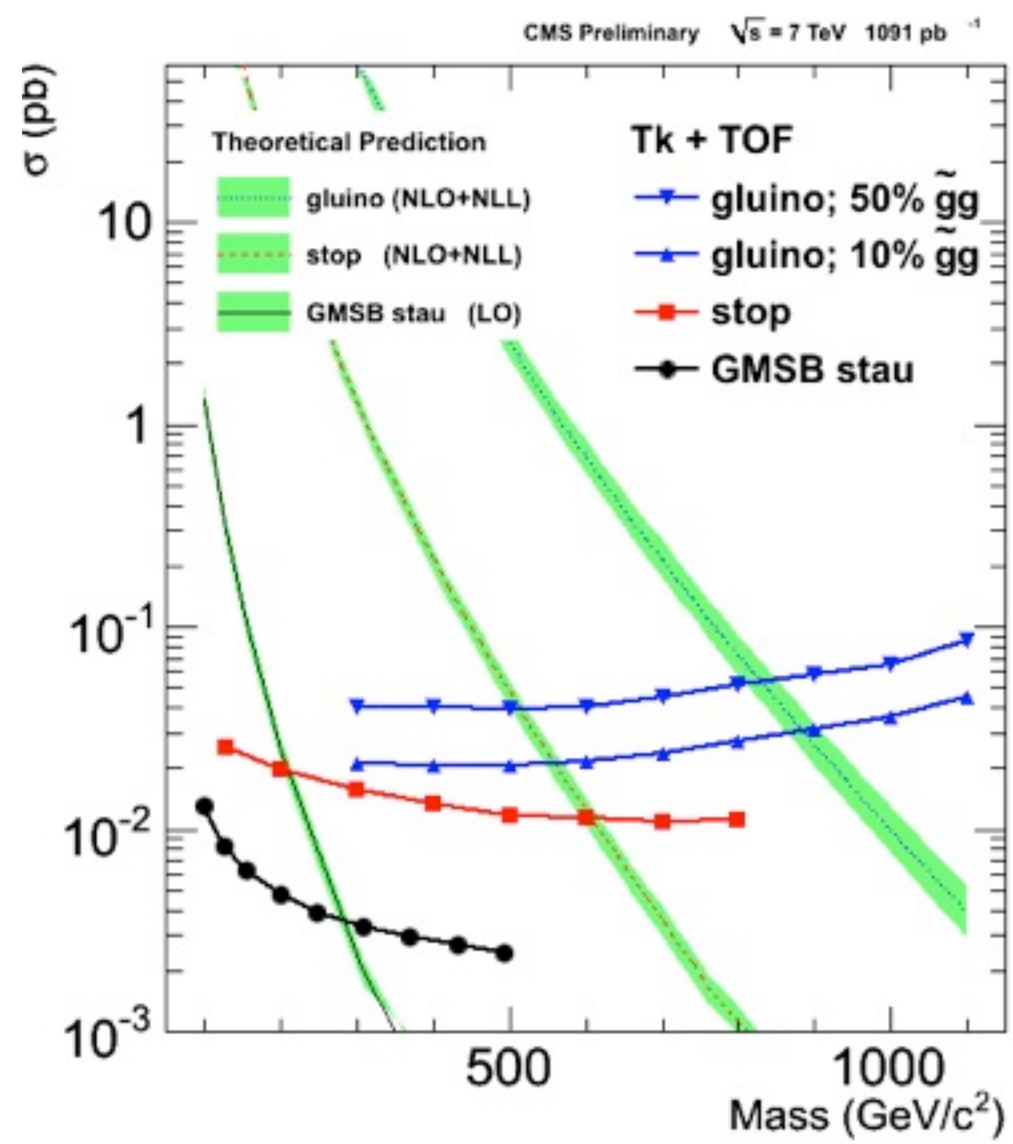




Highly Ionising Particles : Limits

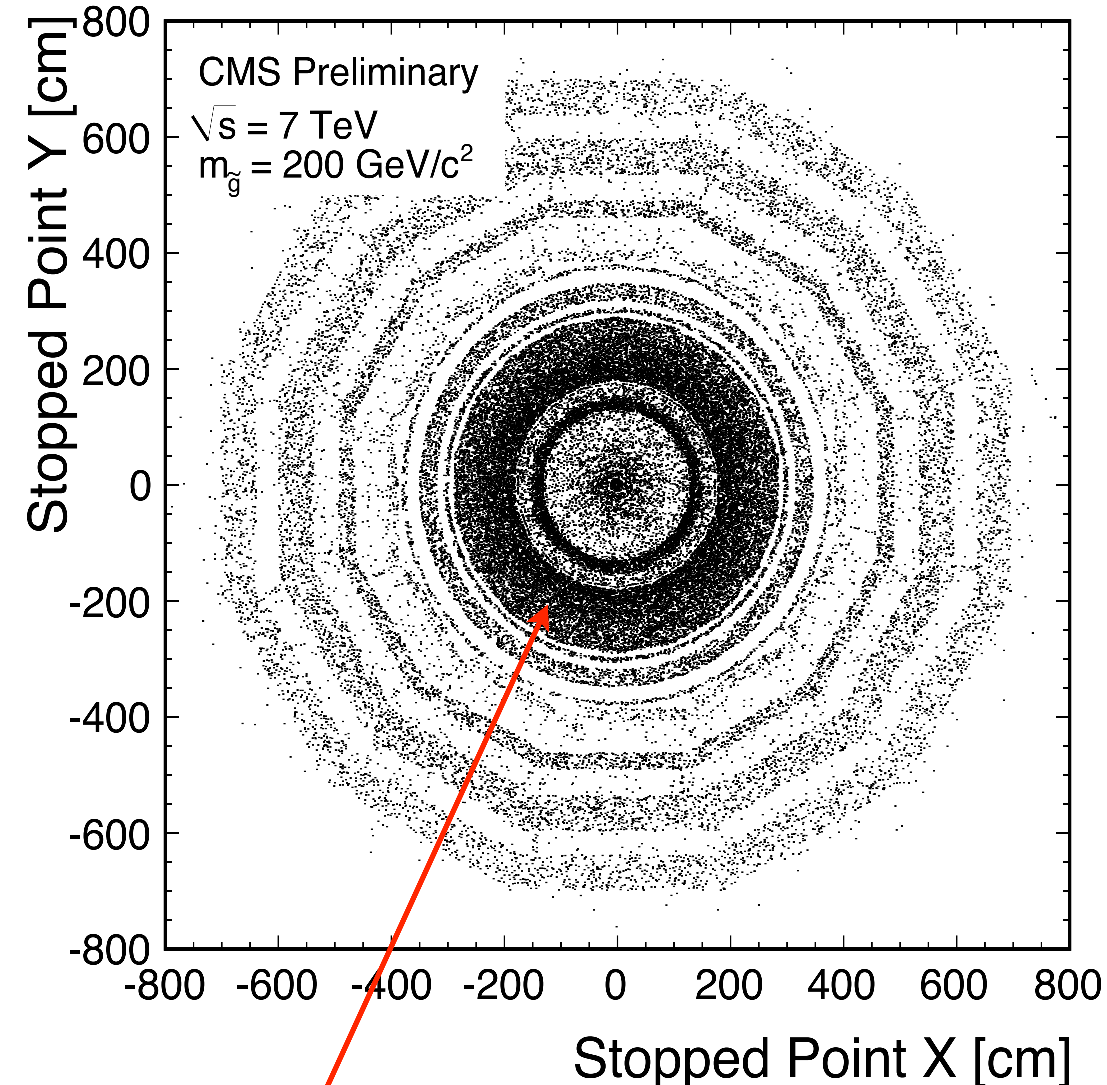
- No significant excess observed for any signal point
  - Place limits on production cross-section for **gluino**, **stop** and **stau**
- Different models of R-hadron interactions
  - Cloud model (Eur. Phys. J. C50 (2007) 353)
  - "Charge suppressed" model - neutral R-hadrons remain neutral
- Initial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



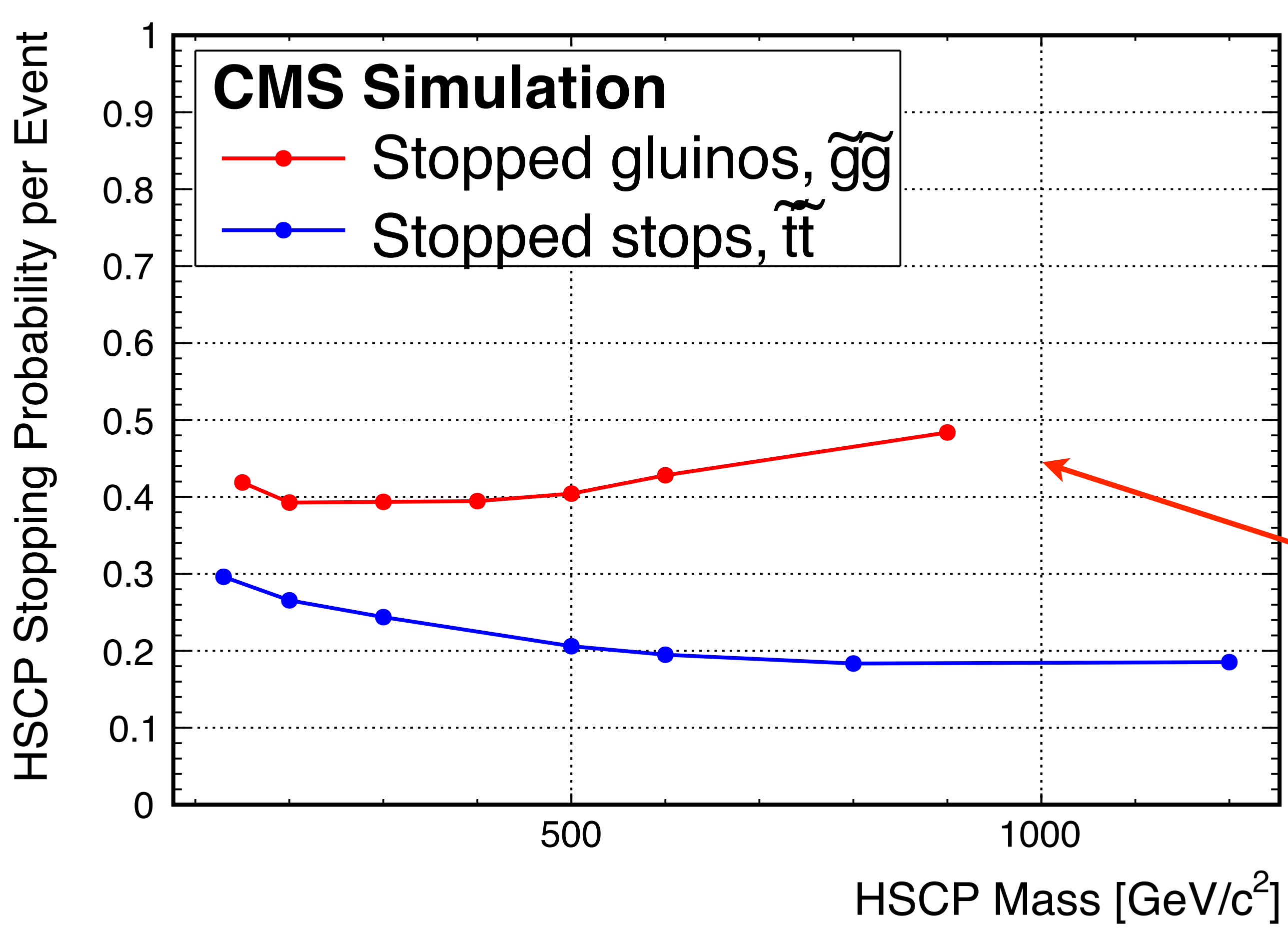


Stopped Particles

- 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



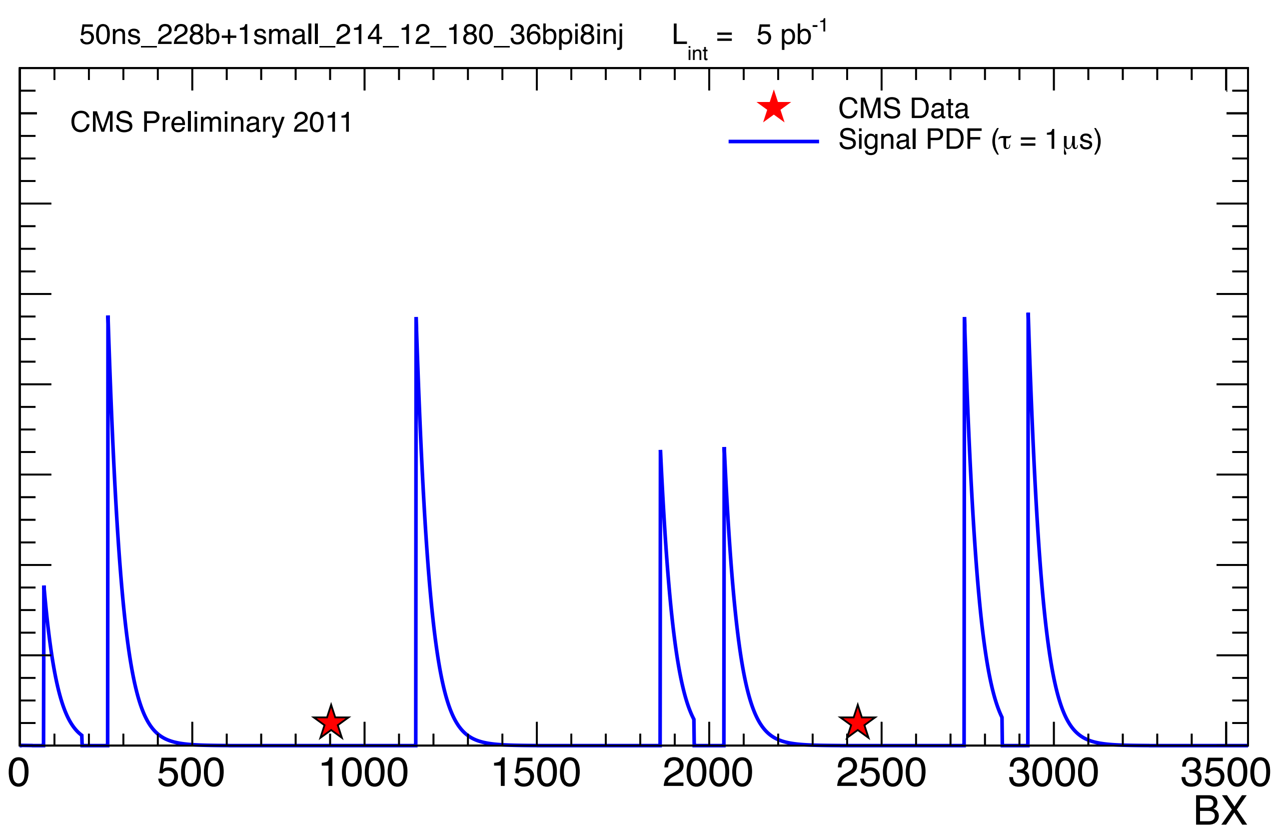
Probability for one of a pair of R-hadrons to stop somewhere in CMS

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



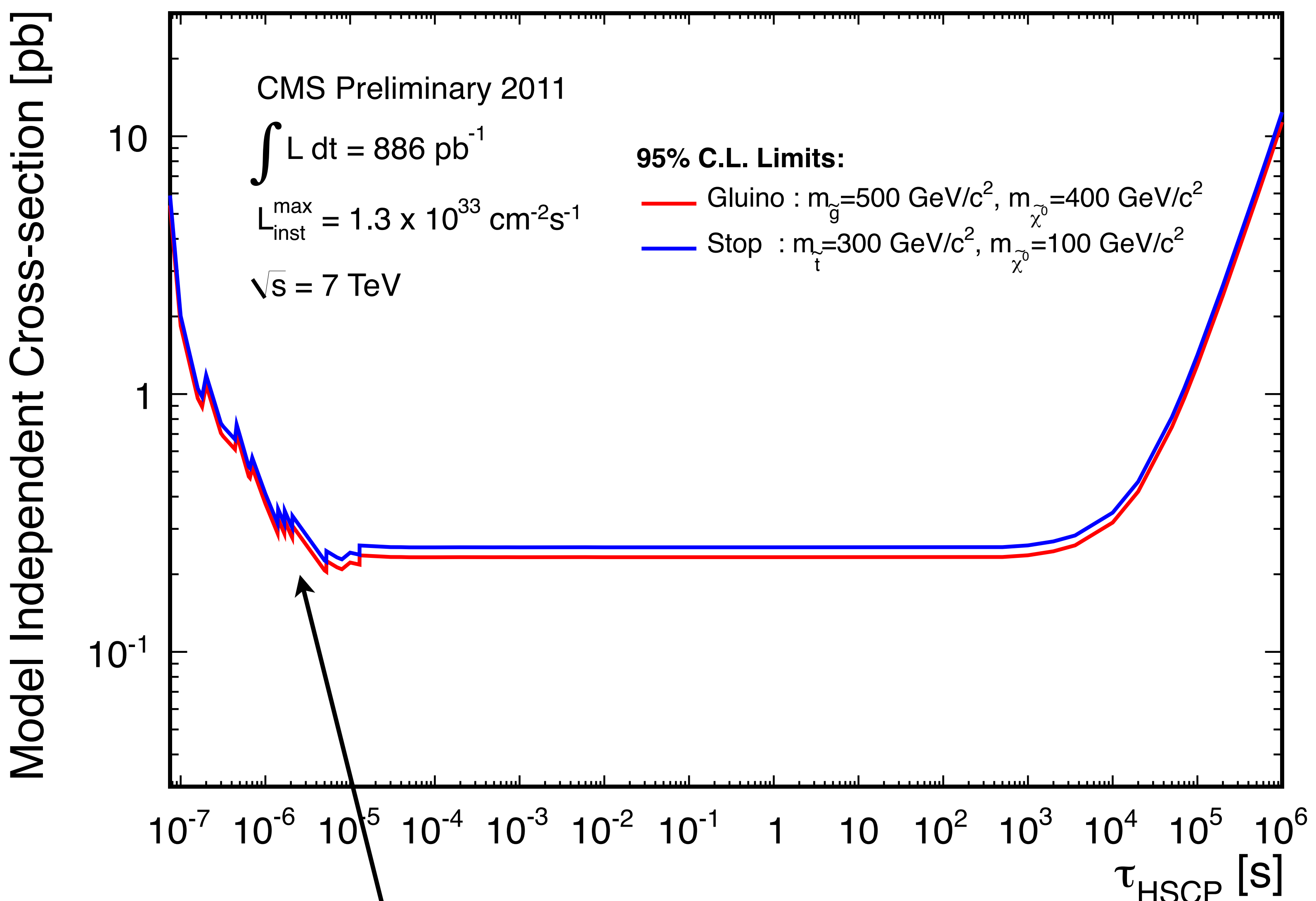
Counting Experiment

- 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

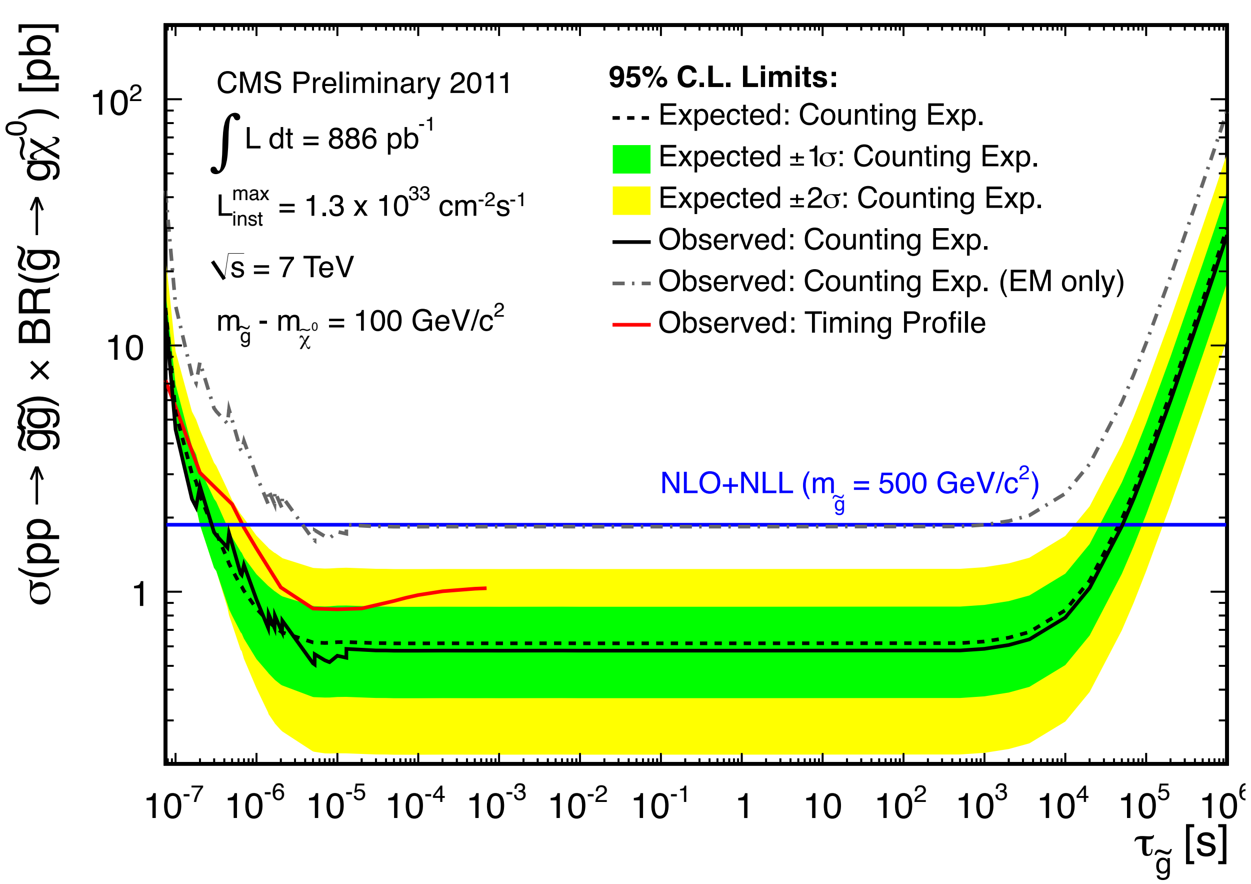
Cross-section × BR × stopping probability

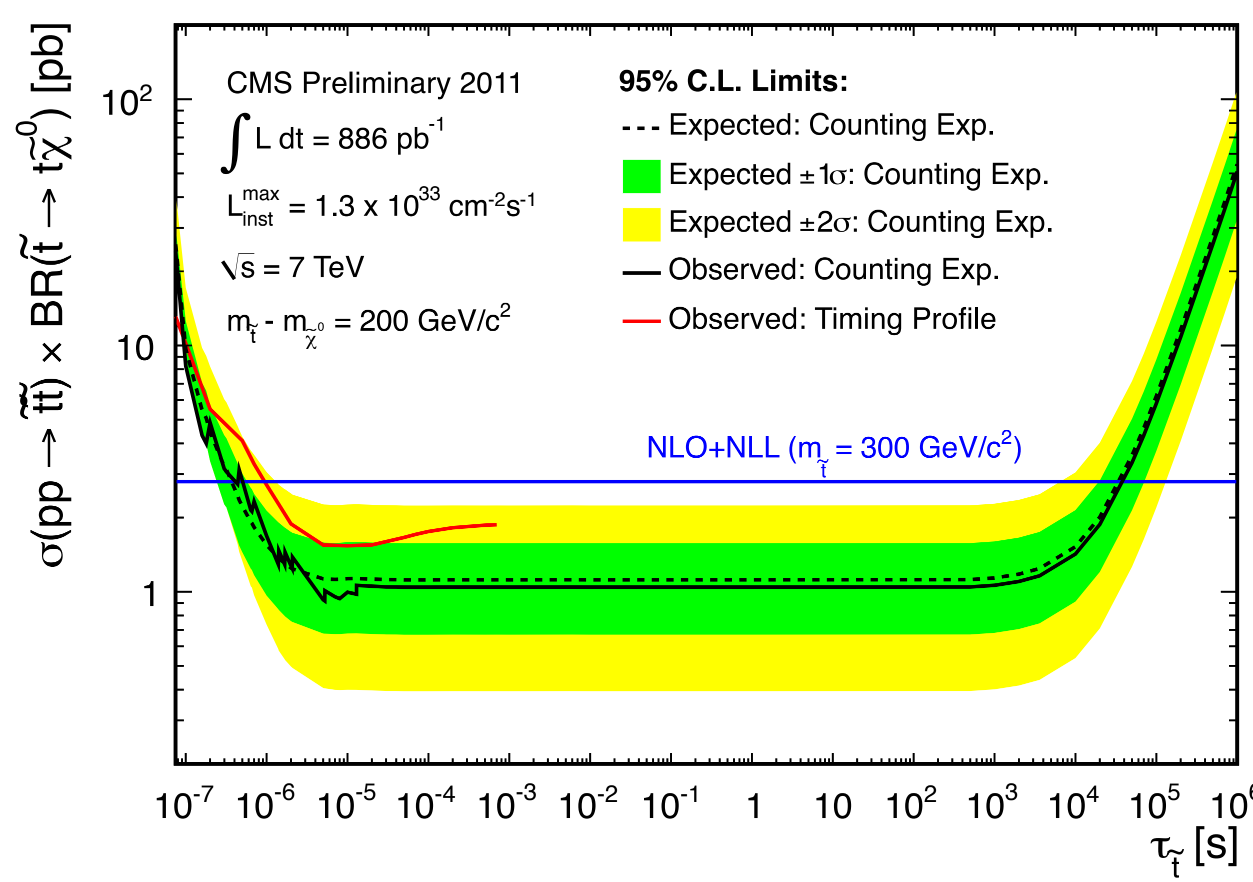


Steps occur between time-windows as N_{obs} increments for each observed event

Stopped Particles : Results

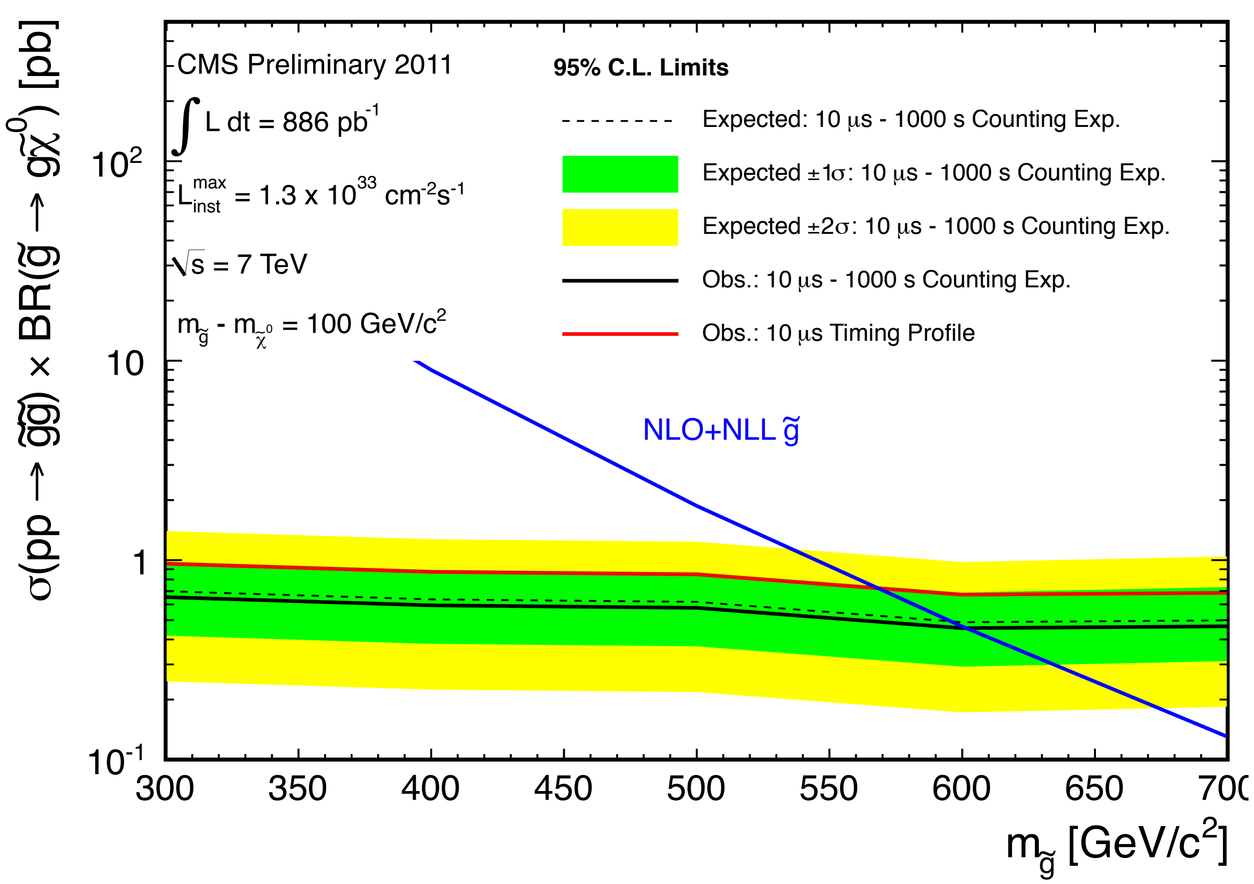
- Place limits on production cross-section × branching fraction
  - Take stopping probability from MC
  - For cloud model, and EM interactions only
- Place limits on gluino and stop
  - Assume $\tilde{g} \to g\,\tilde{\chi}^0$ and $\tilde{t} \to t\,\tilde{\chi}^0$ with fixed mass difference between $\tilde{g}/\tilde{t}$ and $\tilde{\chi}^0$

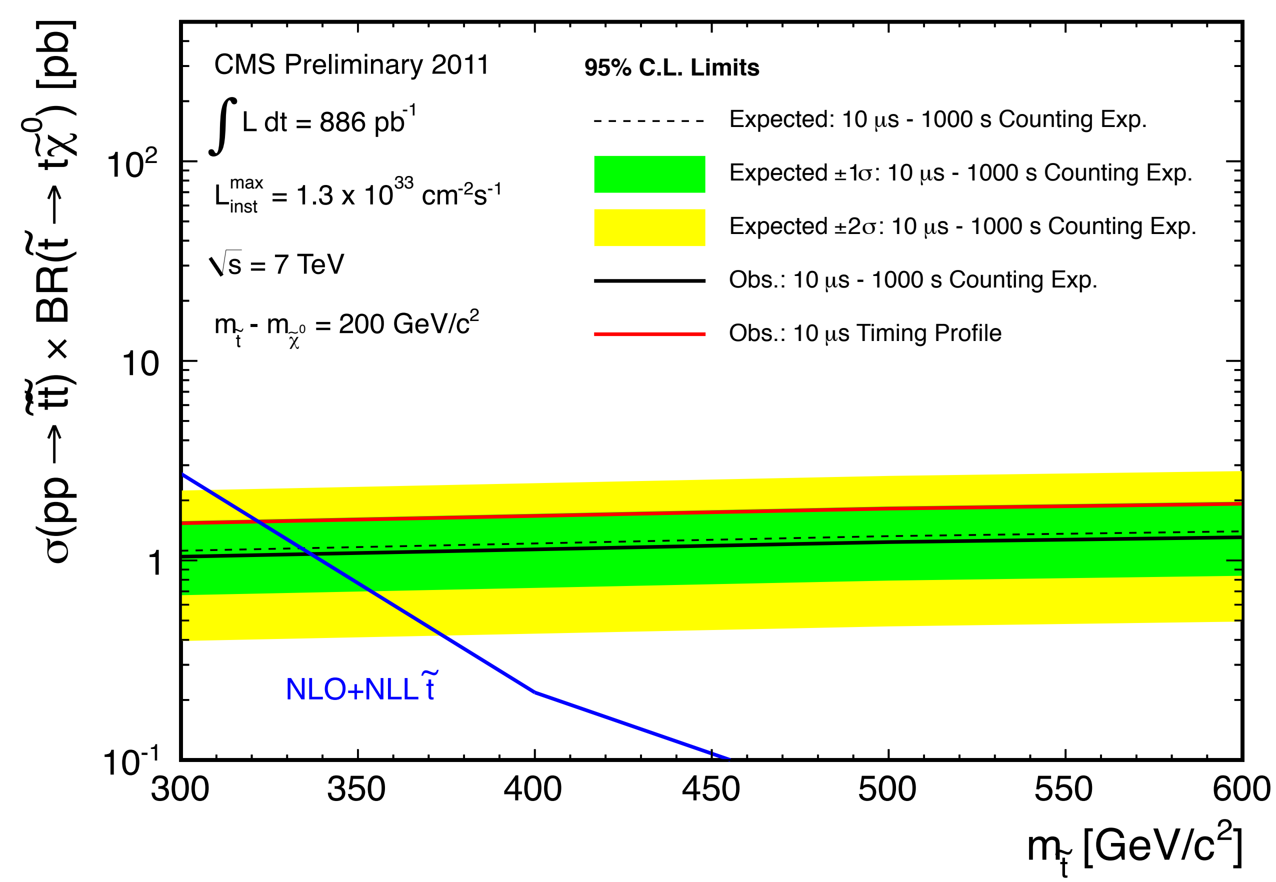




Stopped Particles : Results

- 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





Summary

- We search for long lived particles using a wide range of techniques
  - Displaced vertices
  - Highly ionising tracks
  - Decays of stopped particles

- No discoveries - yet...

- More information
  - Displaced leptons
    - http://cdsweb.cern.ch/record/1369210/files/EXO-11-004-pas.pdf (to be made available soon!)
  - Highly ionising tracks
    - http://cdsweb.cern.ch/record/1369210/files/EXO-11-022-pas.pdf
  - Stopped Particles
    - http://cdsweb.cern.ch/record/1369210/files/EXO-11-020-pas.pdf