Search for Heavy Stable Charged Particles in CMS

Piotr Traczyk
for the CMS Collaboration
27.08.2010 SUSY'10, Bonn

Introduction

- Theoretical motivation:
  - Heavy Stable Charged Particles (HSCP) appear in many BSM scenarios – SUSY, extra dimensions, GUT's etc.
  - Two main classes of particles:
    - Lepton-like, no strong interactions
    - Hadron-like, color-charged – hadronize to form "R-hadrons"
- Detector Signature - slowly moving high momentum particle, typically reconstructed and identified as a muon
  - High momentum track
  - Anomalously high rate of ionization energy loss (dE/dx)
  - High time-of-flight (*currently not used*)
  - Charge flipping (R-hadrons interacting with matter)

Analysis Overview

- Signature based search – look for high pT tracks with high dE/dx. Two analysis paths:
  - **Track+muon** – HSCP that get reconstructed as muons
  - **Track only** – others, eg. R-hadrons that become neutral etc.
- Theoretical models used for benchmark MC signal samples:
  - **Track+muon** – mGSMB stau with mass ~100-300 GeV
  - **Track only** – stop and gluino R-hadrons, masses ~130-900 GeV
- Triggers used in analysis:
  - Muon triggers (3 GeV p_T single μ, 0 GeV double μ)

    45-15% efficiency for R-Hadrons (low mass-high mass),
    >90% efficiency for staus
  - Trigger on other objects in event (Jet p_T>50 GeV, MET>45 GeV)

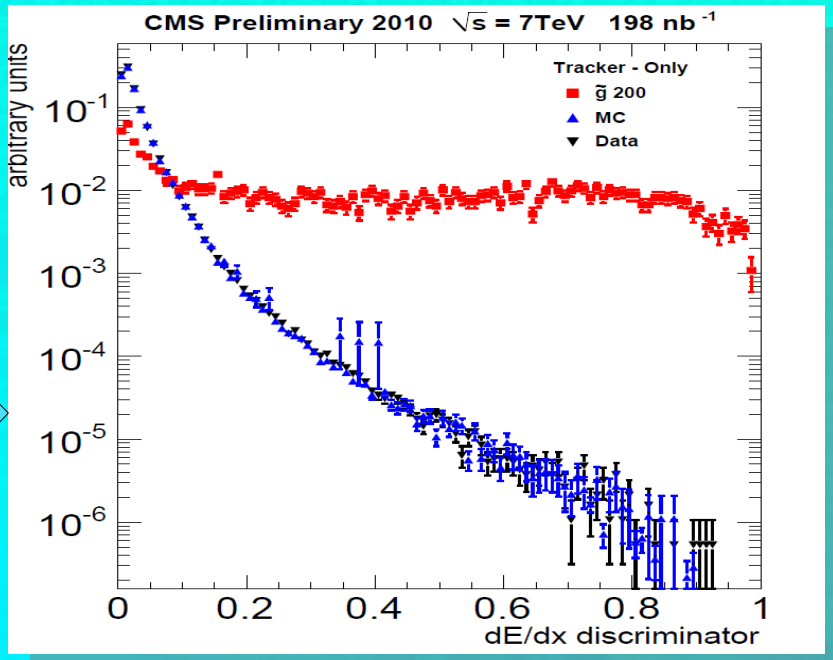
    25-85% efficiency for R-Hadrons (low mass-high mass),
    >60% efficiency for staus
  - Combined trigger efficiency: >50% for R-Hadrons, >95% for staus

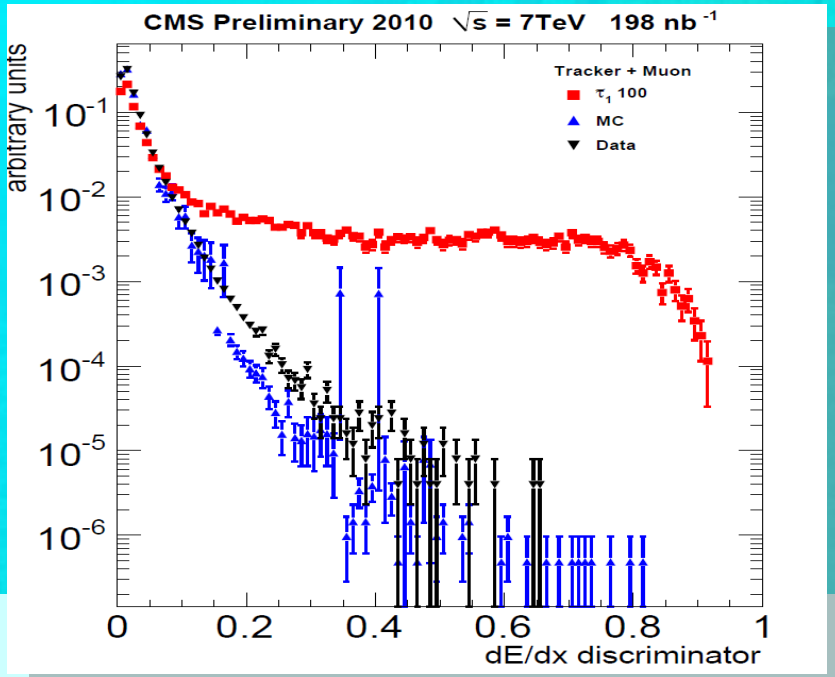
dE/dx reconstruction

- Energy loss is measured in the Silicon Strip Tracker
- Cluster charge interpreted in two ways:
  - **dE/dx discriminator**
    for discriminating between MIP **background** tracks and highly-ionising **signal**
  - **dE/dx harmonic estimator**
    for measuring ionization MPV to be used in HSCP mass reconstruction

$$I_h = \left(\frac{1}{N} \sum_i c_i^k \right)^{1/k} \quad \text{with } k = -2$$

c_i – hit #i charge per unit length





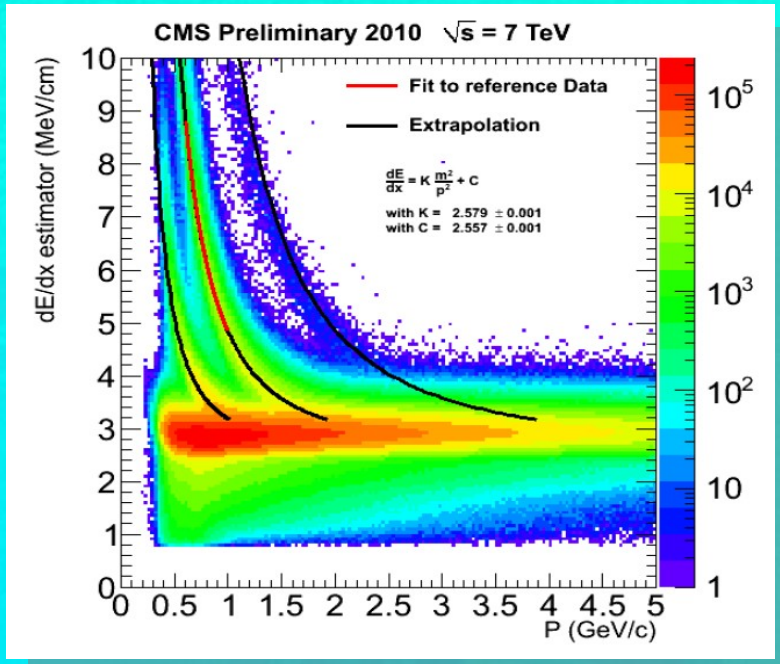
Mass reconstruction (Data)

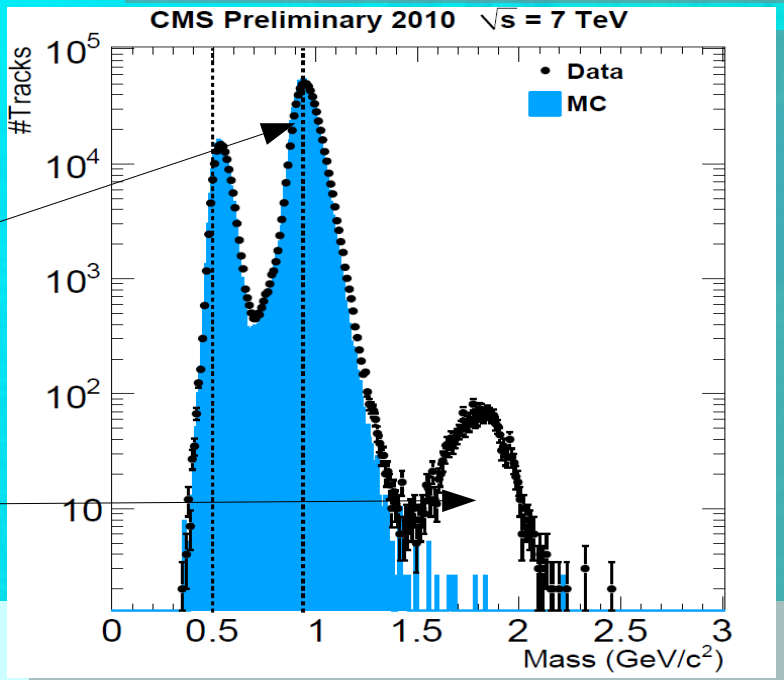
- Mass reconstruction tuned on high quality tracks from a minimum bias sample
  (≥12 strip hits, good primary vertex)
- dE/dx estimator:

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

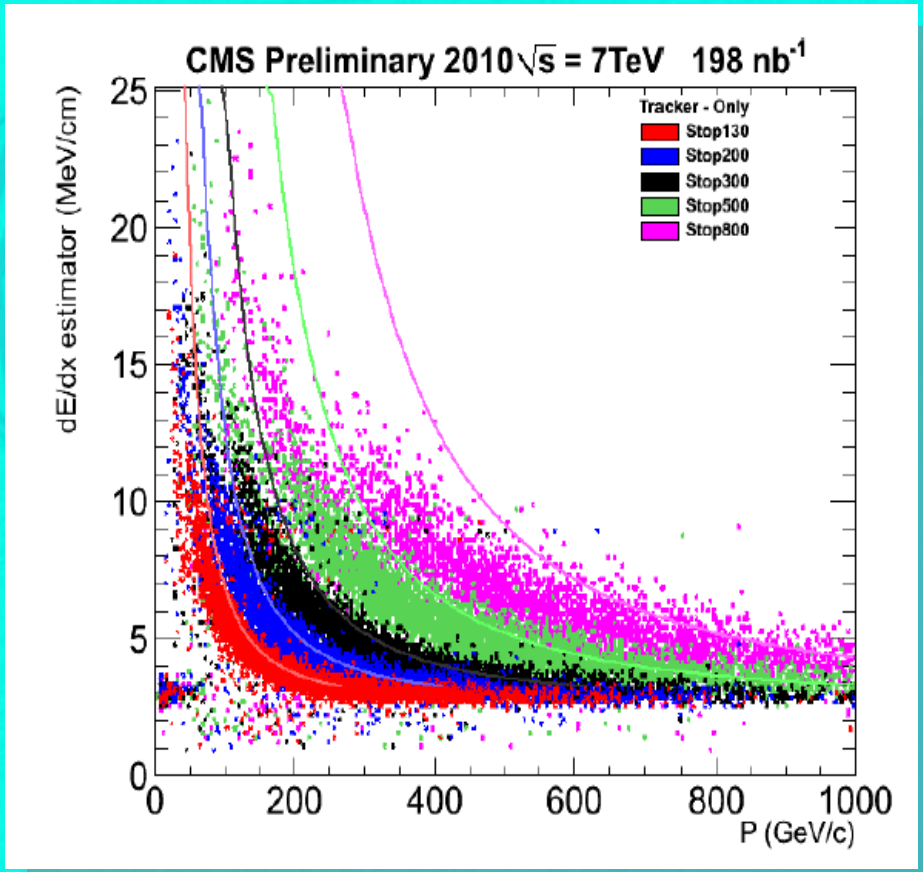
(approximating the Bethe-Bloch formula, good to 1% in the range $0.4<\beta<0.9$)

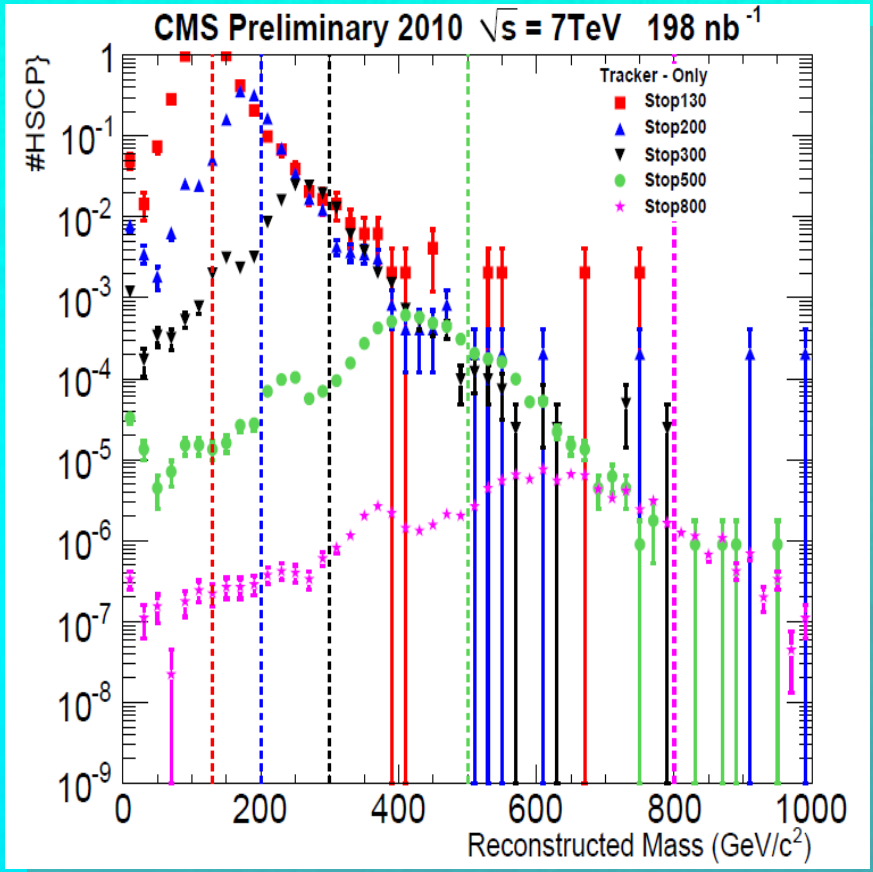
- *K* and *C* parameters extracted from the proton mass line
- New Physics in data (at least to Pythia) – deuteron





Mass reconstruction (Signal)

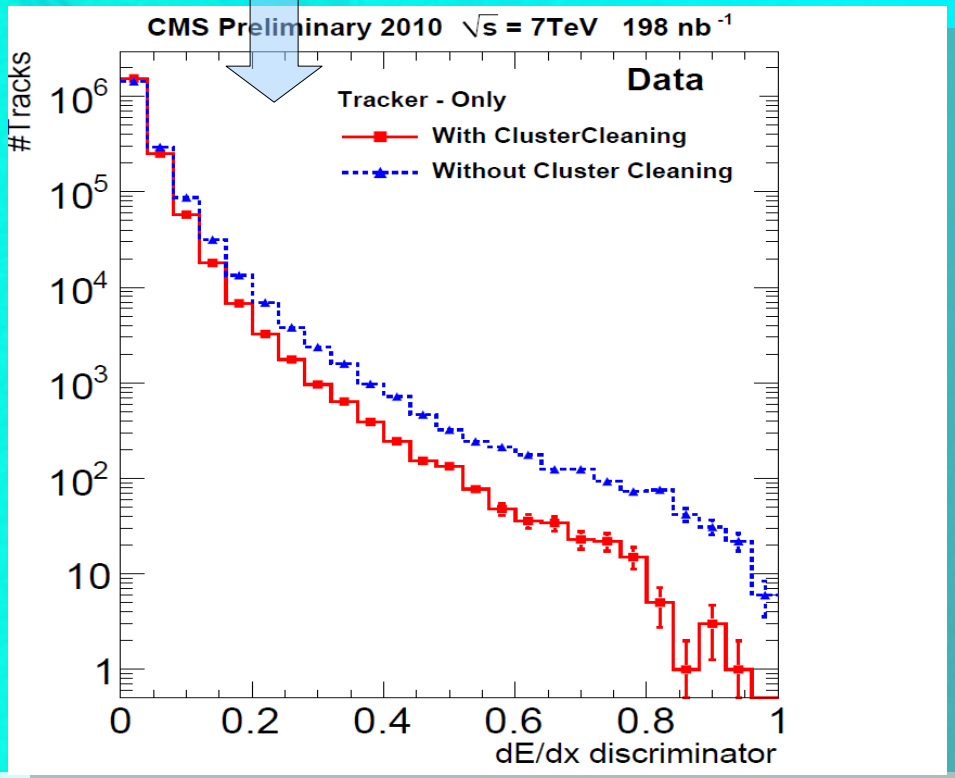


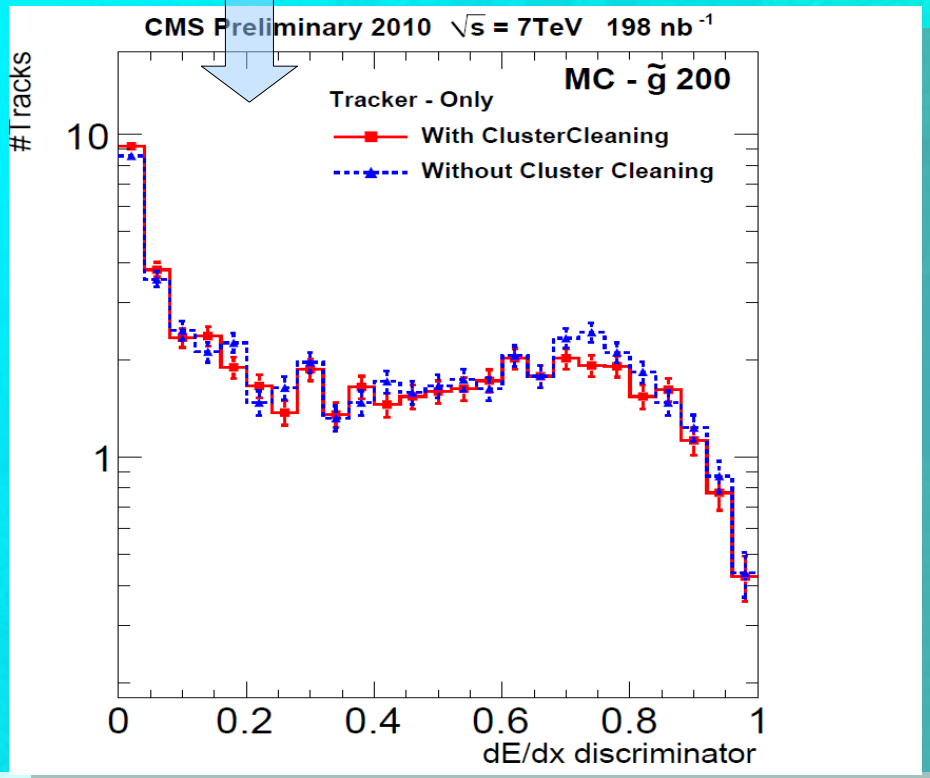


- At high masses the reconstruction is biased due to an ADC cut-off
- Not impacting the present analysis (counting experiment)

Cluster cleaning

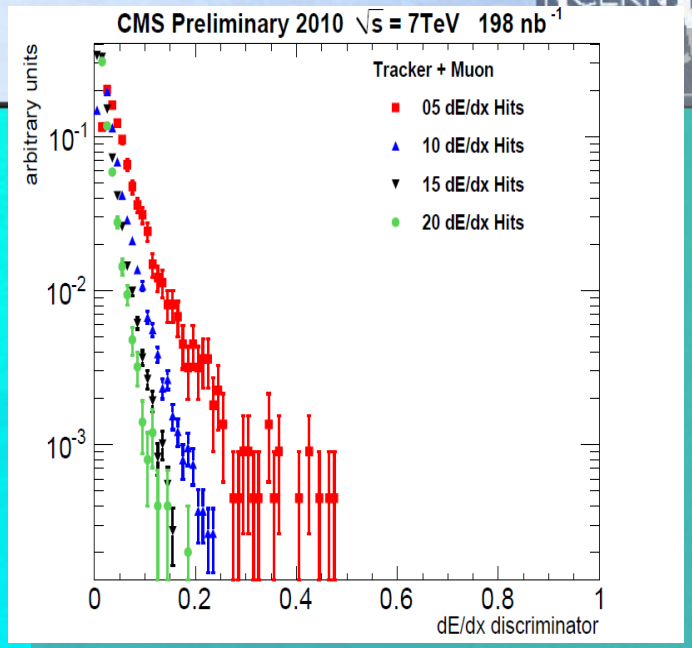
- Single tracks produce clusters distributed over 1-2 strips
- Cluster cleaning - remove track overlaps, nuclear interactions, δ-rays,...
- Remove clusters with:
  - Multiple maxima
  - >2 consecutive strips with comparable charge
- Reduces **background** tails, little effect on **signal**

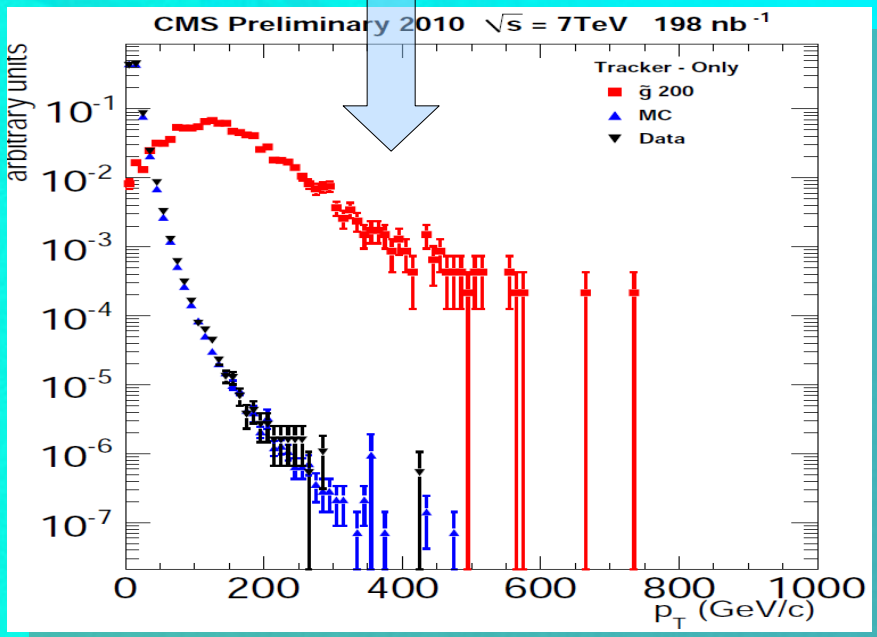


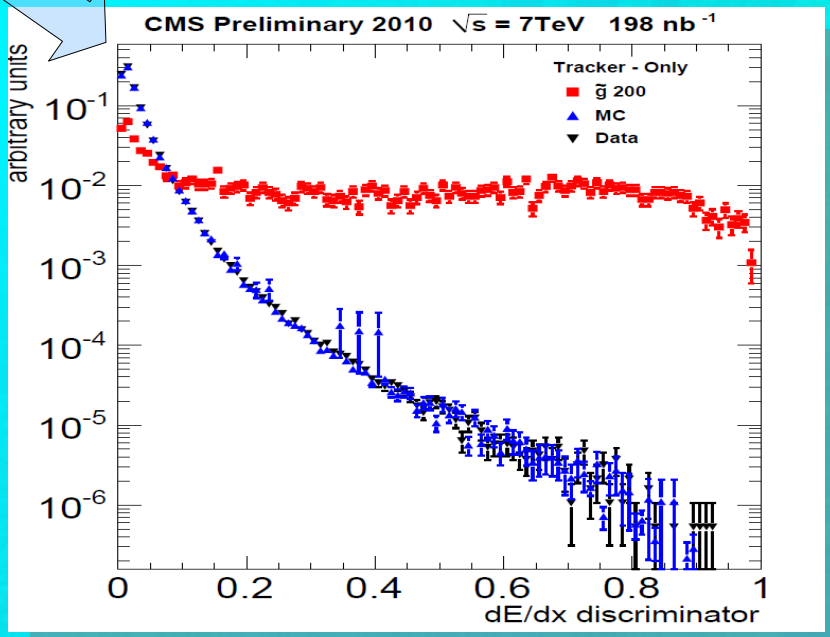


Event selection

- Preselect tracks with:
  - p_T>7.5 GeV, $\delta p_T/p_T$<15%, (muon ID/no muon ID)
  - Impact parameter <2.5mm, ≥3 Silicon Strip hits
- Apply cluster cleaning
- Split into subsamples by η and **nHits**
- Cut on track **p_T** and **dE/dx discriminator**



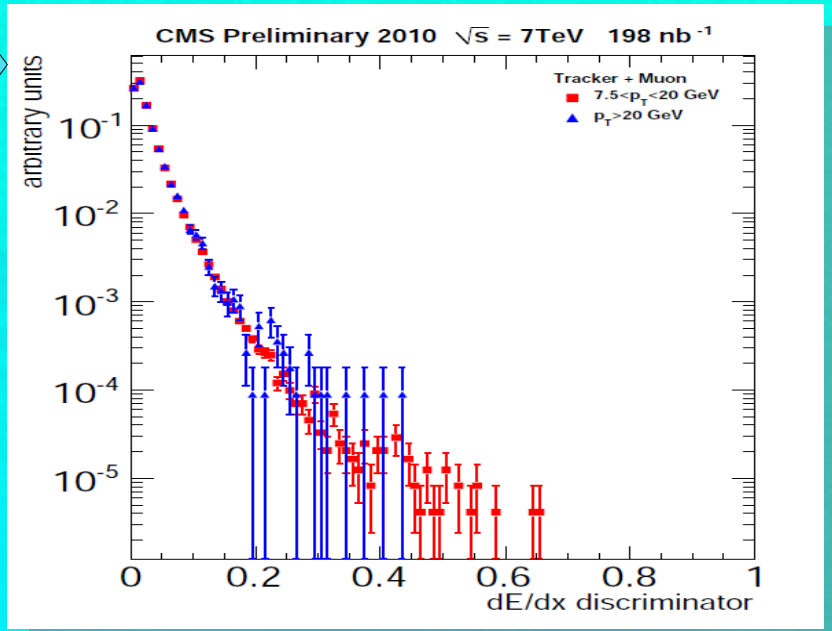


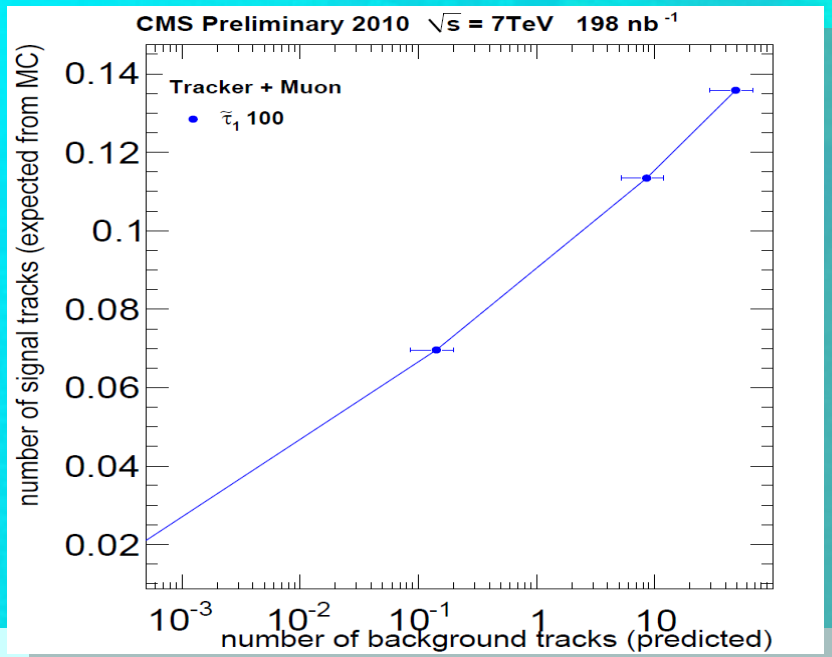


- cuts chosen per subsample, factor 2x S/B ratio improvement

Selection optimization

- Independence of $\mathbf{p_T}$ and **dE/dx** selection cuts allows a data-driven background estimation via the ABCD method
- Cut placement does not impact strongly signal yield – optimize for constant background rejection across nHits and η subsamples
- Two sets of selections – tight (signal search) and loose (control sample)



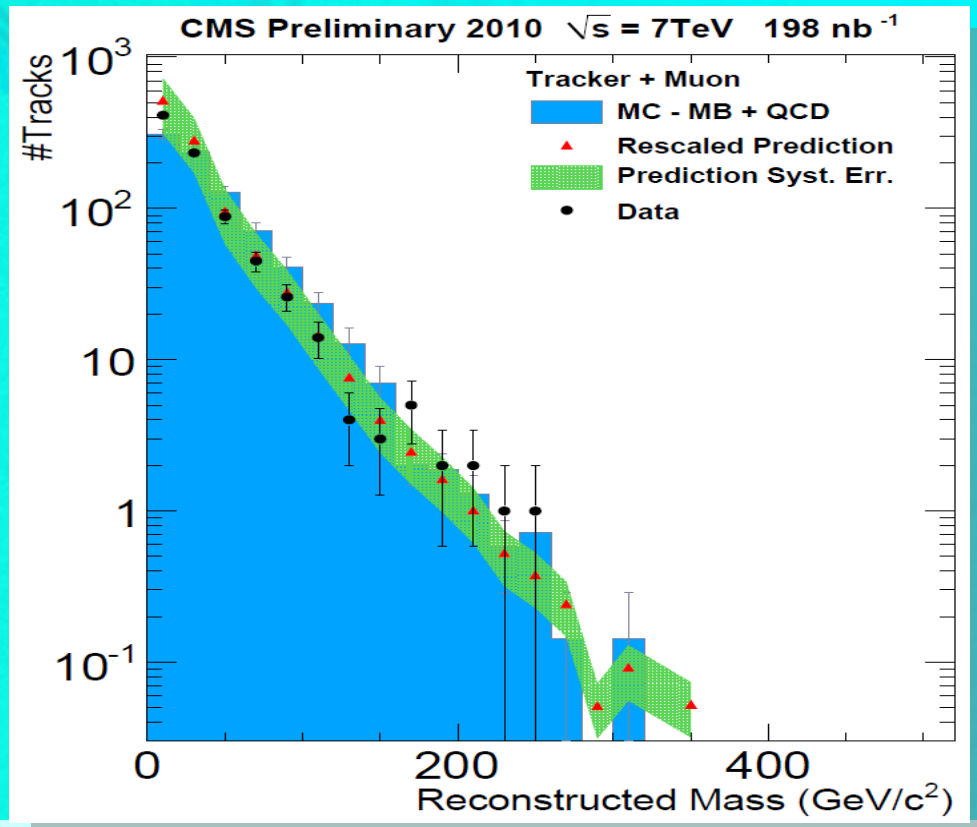


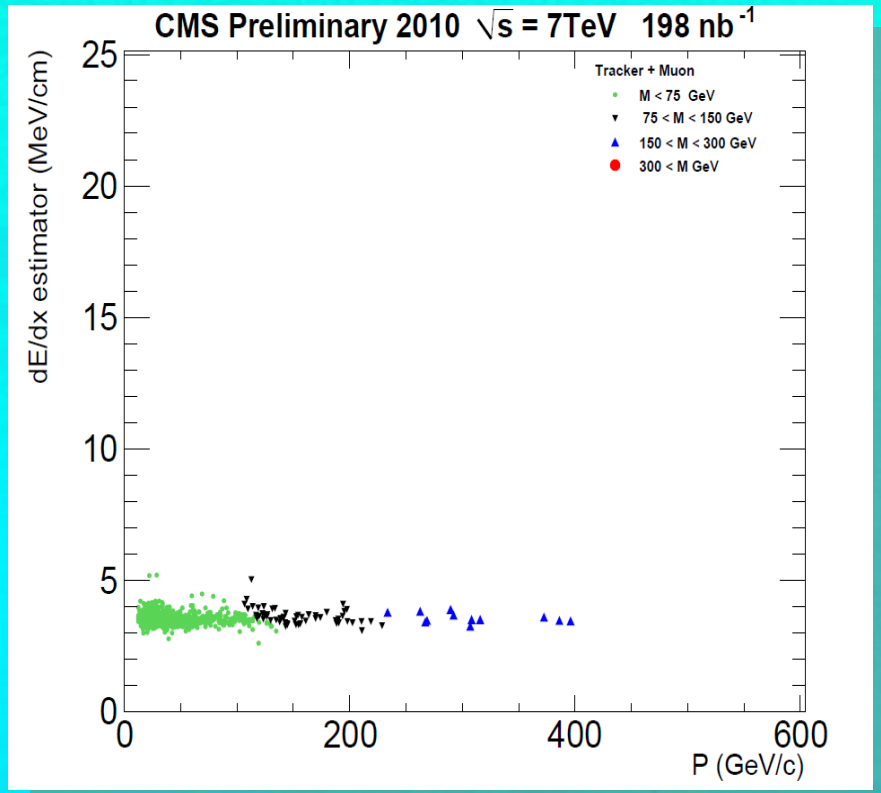
LOOSE	ϵ_{p_T}	p_T^{cut}	ϵ_I	I_{as}^{cut}
Tracker+Muon	$10^{-1.0}$	7.7 - 25.9	$10^{-1.5}$	0.0036 - 0.4521
Tracker only	$10^{-2.0}$	7.9 - 67.4	$10^{-2.0}$	0.0037 - 0.5293
TIGHT	ϵ_{p_T}	p_T^{cut}	ϵ_I	I_{as}^{cut}
Tracker+Muon	$10^{-3.0}$	7.7 - 125.9	$10^{-3.0}$	0.0036 - 0.6526
Tracker only	$10^{-4.0}$	7.9 - 259.0	$10^{-3.5}$	0.0037- 0.8901

Results (tracker+muon, loose)

- Good agreement between data, background MC and background prediction from data:

LOOSE	Exp.	Obs.	Exp. in full spectrum	Obs. in full spectrum
Tracker+Muon	82 ± 33	77	1007 ± 200	838
Tracker Only	108 ± 38	122	184 ± 250	260

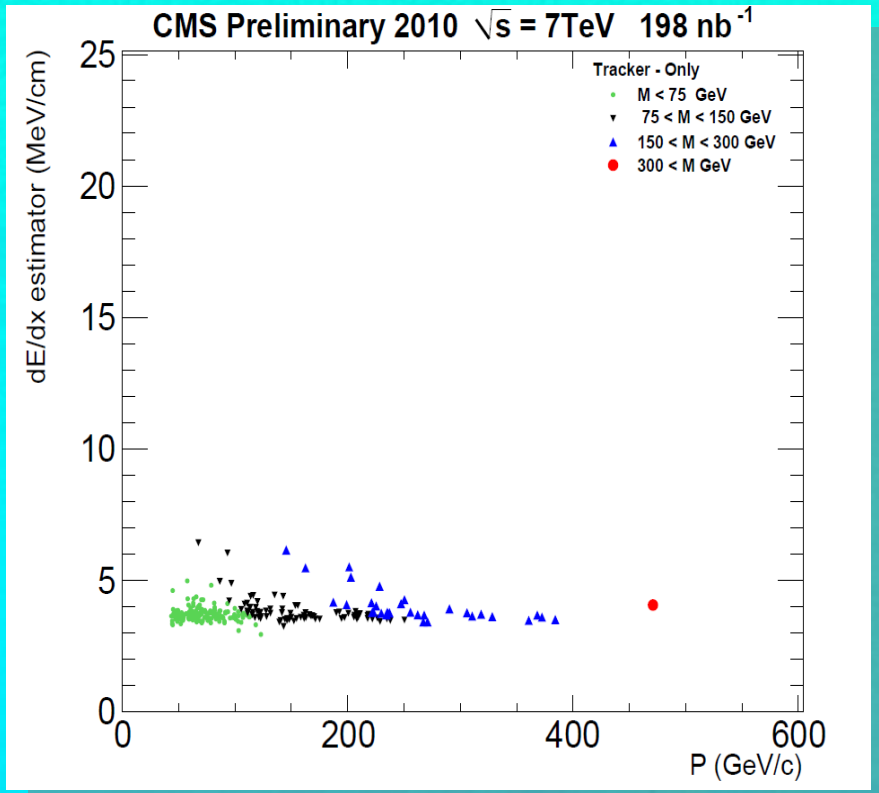


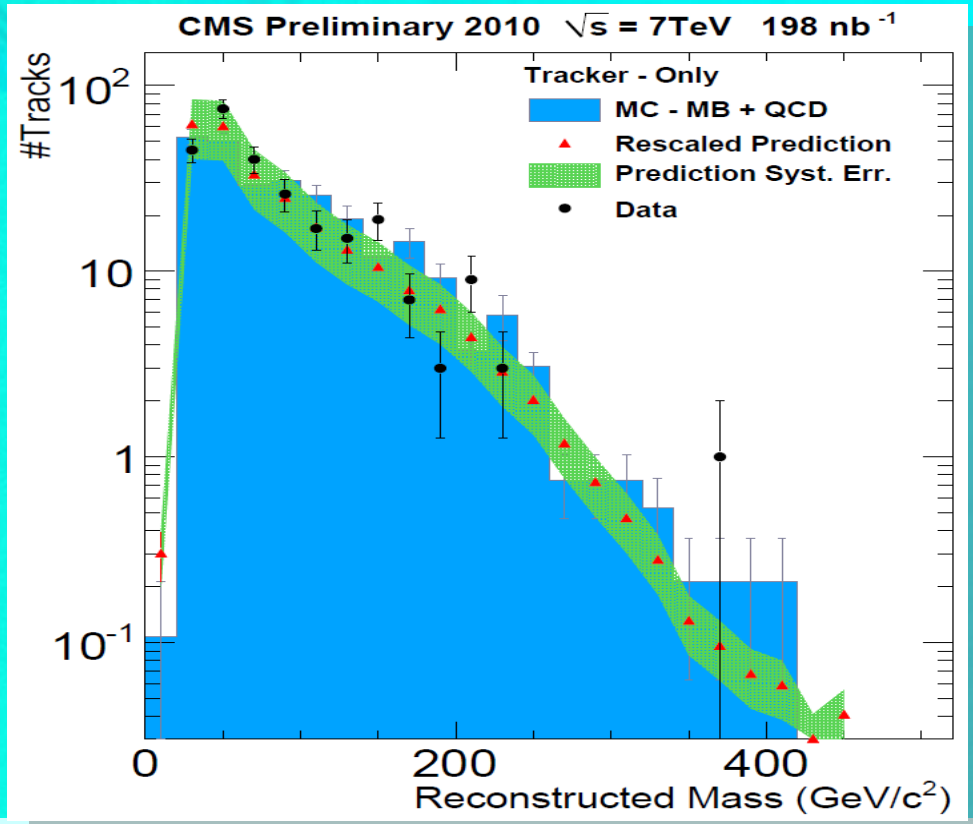


Results (tracker only, loose)

- Good agreement between data, background MC and background prediction from data:

LOOSE	Exp.	Obs.	Exp. in full spectrum	Obs. in full spectrum
Tracker+Muon	82 ± 33	77	1007 ± 200	838
Tracker Only	108 ± 38	122	184 ± 250	260

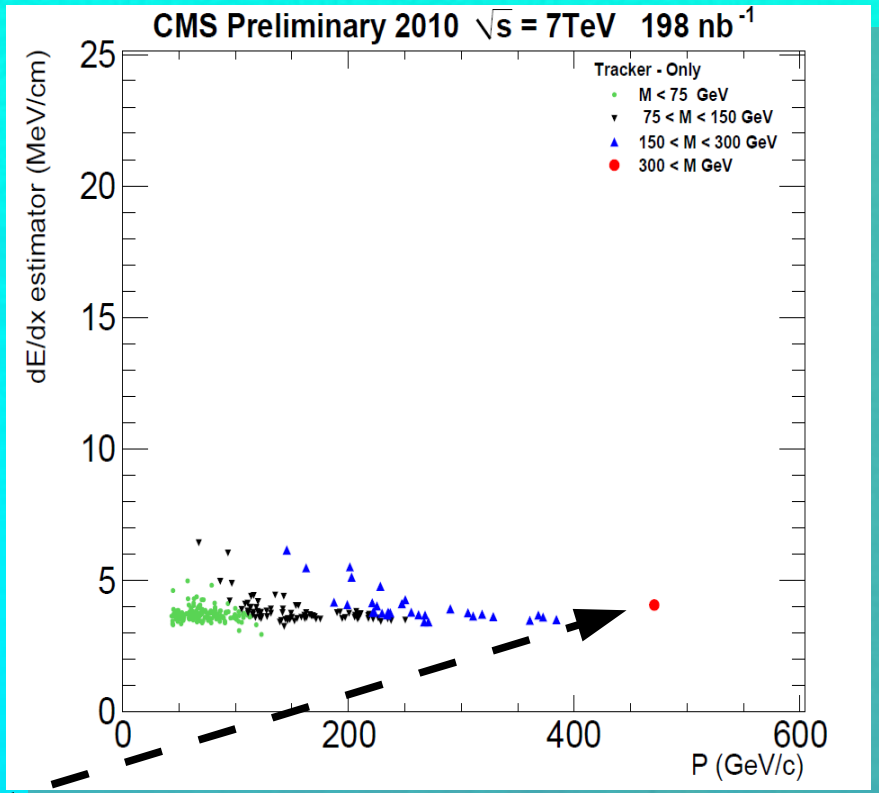


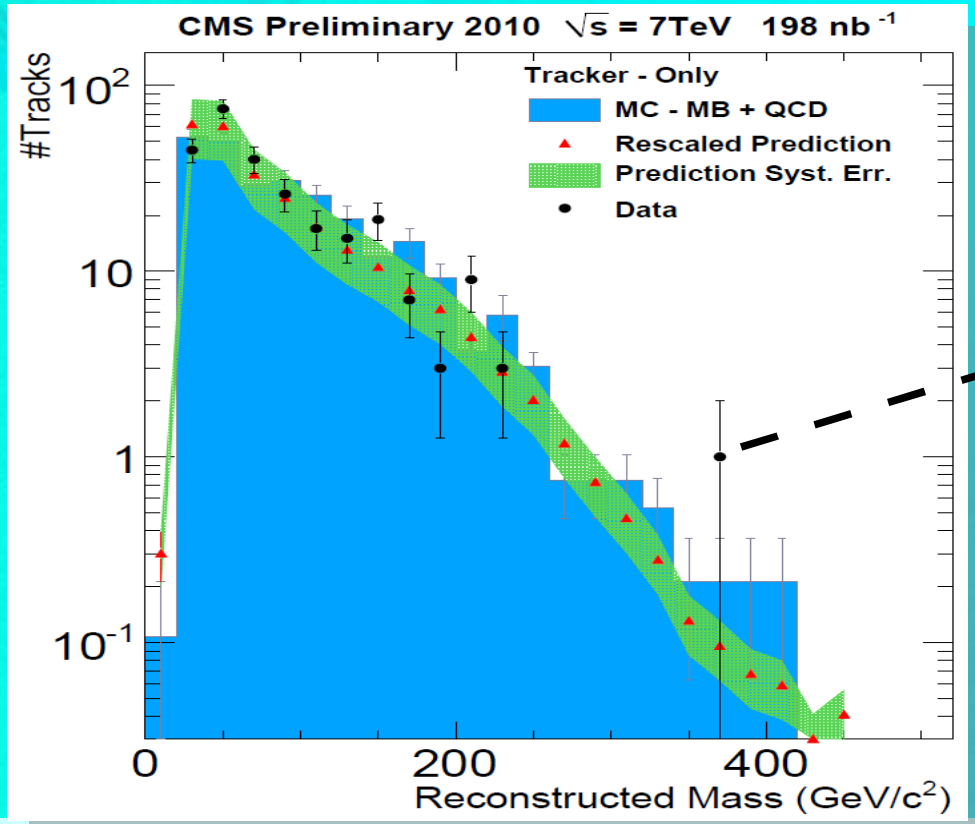


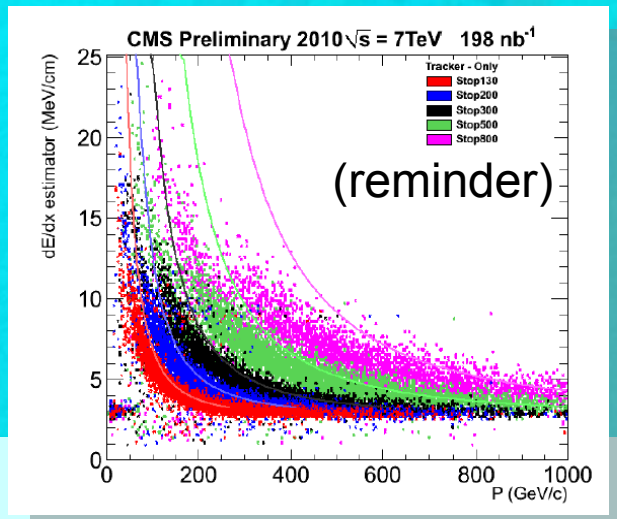
Results (tracker only, loose)

- Good agreement between data, background MC and background prediction from data:

LOOSE	Exp.	Obs.	Exp. in full spectrum	Obs. in full spectrum
Tracker+Muon	82 ± 33	77	1007 ± 200	838
Tracker Only	108 ± 38	122	184 ± 250	260







Systematics

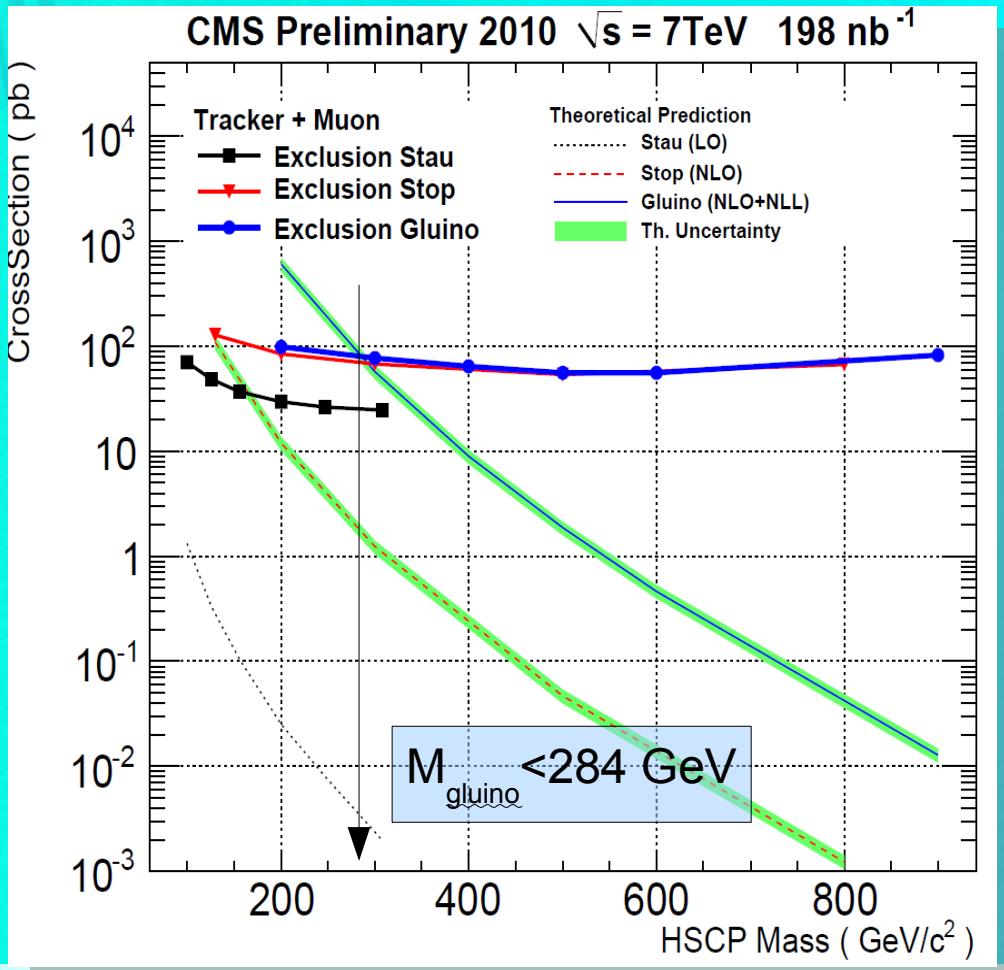
- Search performed as a counting experiment in the reconstructed mass range of 75-1200 GeV
- 95% C.L. limits computed with a fully Bayesian method with lognormal prior for nuisance parameter integration; assuming zero expected background events

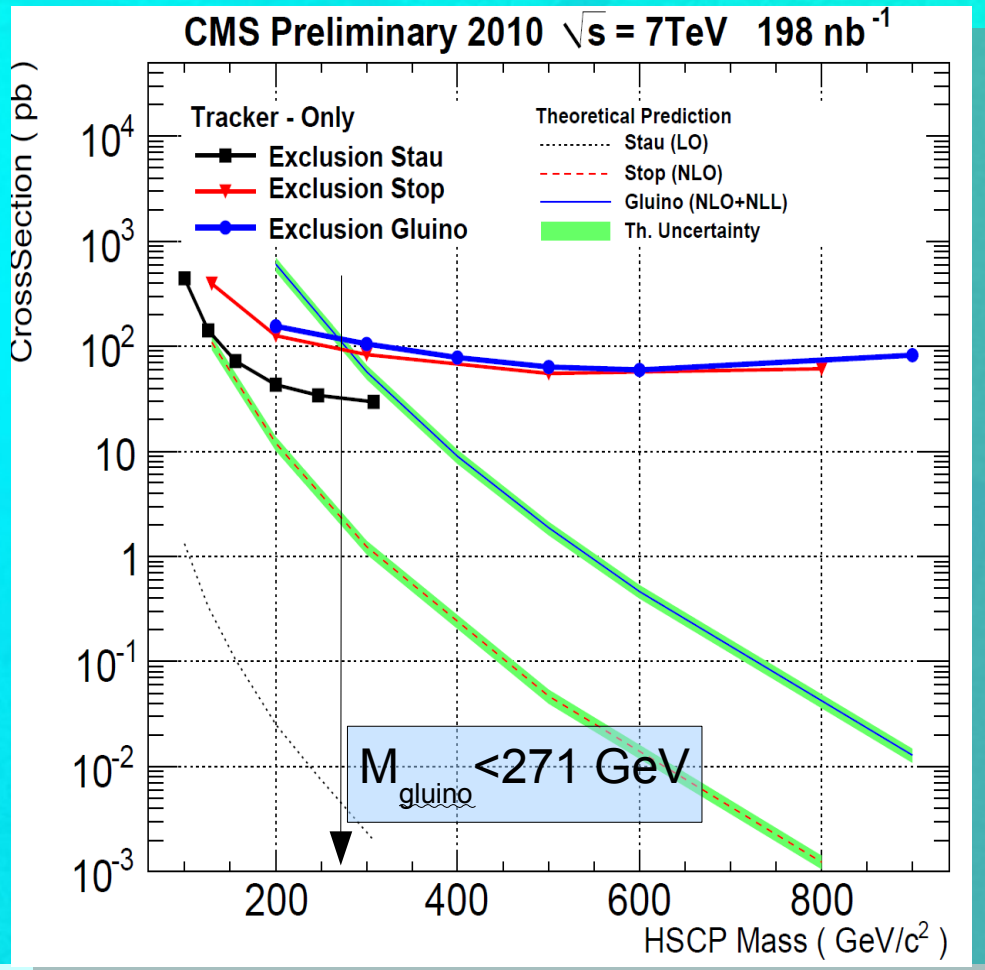
Source of Systematic Error	Relative Uncertainty (%)
Theoretical cross section	15 ($\tilde{t}_1$and $\tilde{g}$)
Expected background	36(Tk) ; 40 (Tk+Mu)
Integrated luminosity	11
Trigger efficiency	15
Muon reconstruction efficiency	5
Track reconstruction efficiency	< 5
Momentum scale	< 5
Ionization energy loss scale	< 3 (8 for 100 GeV/c^2 $\tilde{\tau}_1$)
Total uncertainty on signal acceptance	20

Results (tight selection)

- Null result – set 95% CL limits on stau, stop and gluino cross-section

TIGHT	Exp.	Obs.	Exp. in full spectrum	Obs. in full spectrum
Muon-like	0.153 ± 0.061	0	0.249 ± 0.050	0
Tk-only	0.060 ± 0.021	0	0.060 ± 0.011	0





Conclusions

- Search for both hadron- and lepton-like HSCP performed in CMS with 198 nb^{-1} of 7 TeV LHC data
- Signature-based analysis looking for highly ionizing, high momentum tracks in the Silicon Tracker
- Two versions of the analysis, with and without the requirement of having the track identified as a muon in the Muon System
- Obtained 95% C.L. limits on benchmark model cross-sections
- Excluded Gluino R-Hadrons with masses smaller than ~280 GeV
- http://cdsweb.cern.ch/record/1280690/files/EXO-10-004-pas.pdf

Backup

dE/dx discriminator

- Modified Smirnov-Cramer-von Mises estimator:

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

P_i – Probability for a MIP to produce charge smaller or equal to the observed one (for the observed path in silicon)
N – number of track hits in the Silicon Strip Tracker (ordered with increasing P_i)

- The P_i probability values were measured with p_T>5 GeV track from minimum bias collisions