The Abdus Salam International Centre for Theoretical Physics

United Nations Educational, Scientific and Cultural Organization
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2263-18

Beyond the Standard Model: Results with the 7 TeV LHC Collision Data

19 - 23 September 2011

Search for New Long-Lived Particles with the CMS Experiment

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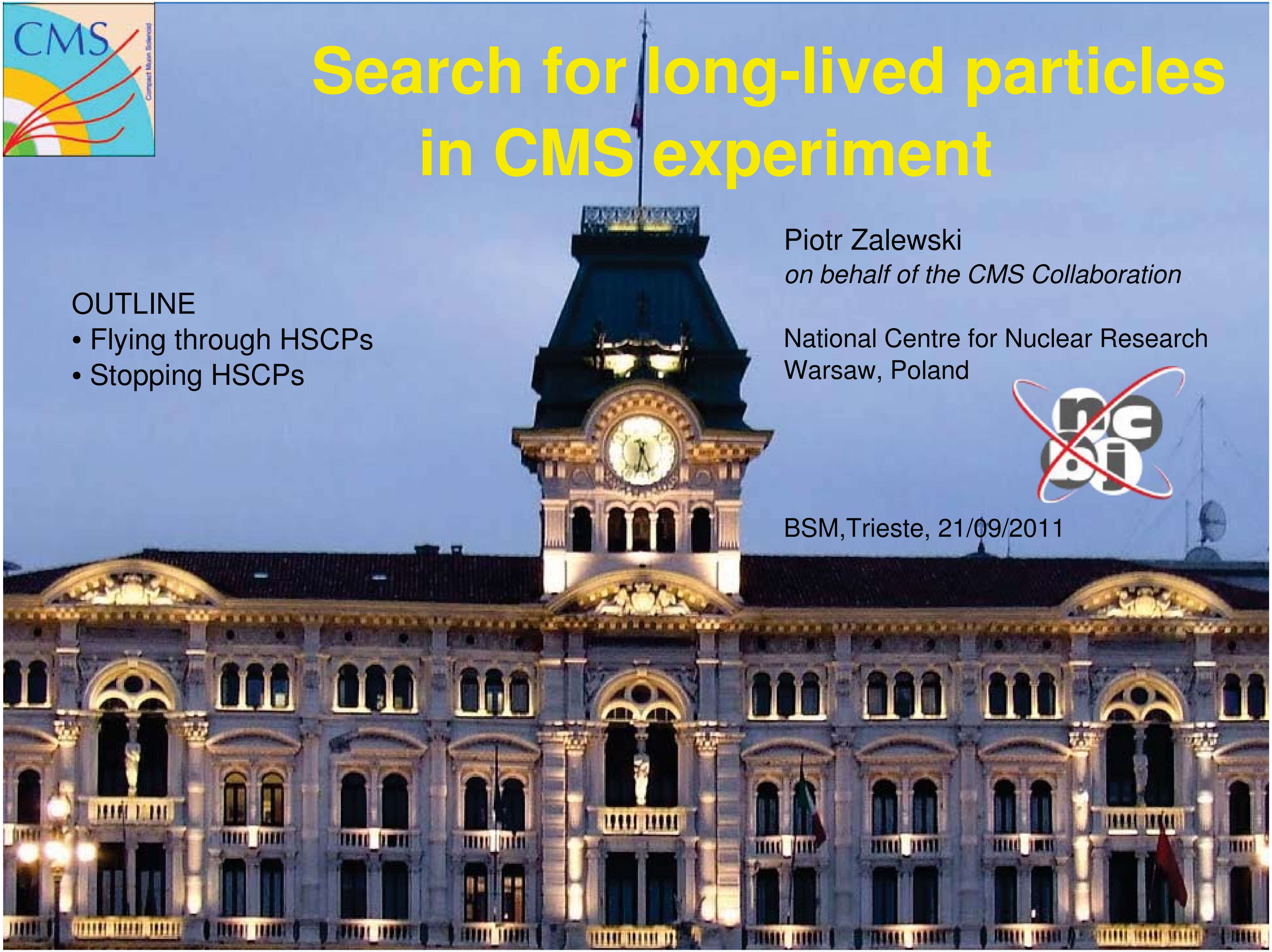
Search for long-lived particles in CMS experiment



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on behalf of the CMS Collaboration

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OUTLINE
• Flying through HSCPs
• Stopping HSCPs

BSM,Trieste, 21/09/2011

Introduction

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HSCPs - heavy quasi-stable charged particles (or CHAMPs – charged massive particles) are hipotetical objects that appear in various extensions of the standard model (SM).

As the first such object stau (slepton) NLSP of the GMSB model have been proposed, but such (lepton-like) NLSPs are predicted by many variants of the MSSM in which gravitino or axino plays the role of the LSP, as well as in other BSM extensions arising from a new symmetry, a weak coupling, a kinematic constraint, or a potential barrier (HSCP is always the next to the lightest new particle).

If the lifetime of such particle produced at LHC is longer than a few nanoseconds, the particle will travel over distances that are comparable or larger than the size of a typical particle detector, it clould be regarded as stable from the detection point of view.

Among different types of HSCPs there is a distinct class of so called R-hadrons. These are hadronized semi-stable gluinos or squarks (stops, sbottoms) predicted by split-SUSY (among other models). These particles could hadronize as charged or neutral and could change they sign inside detectors.

Recent models of nuclear interactions of R-hadrons traveling through matter, favors a scenario of charge suppression. In this model the majority of R-hadrons containing a gluino, or bottom squark, are expected to emerge as neutral particles after traversing a typical detector.

The idea & trigger

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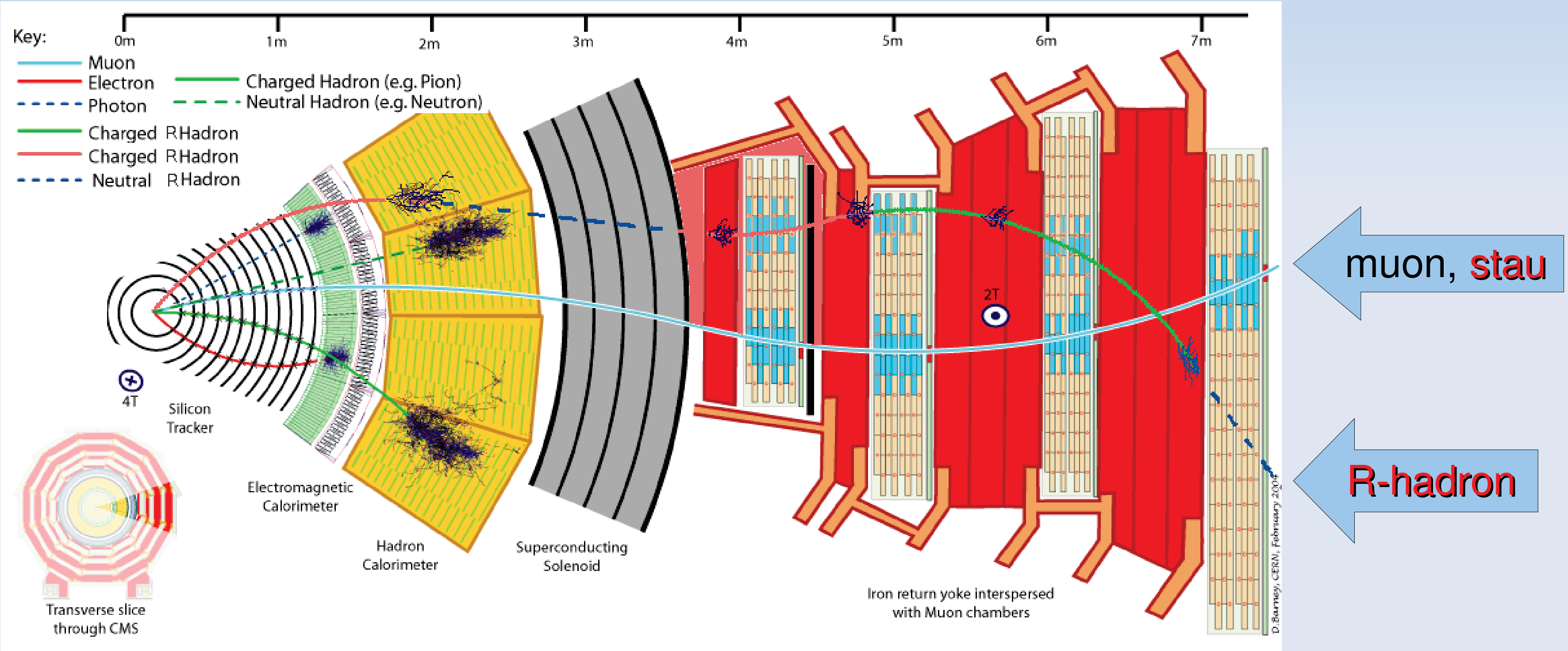
HSCP could be slow enough to
- be late with respect to relativistic muons;
- give higher d*E*/d*x* than MIPs.

Two strategies for flying through HSCPs:
- tracker only (d*E*/d*x* only) analysis;
- tracker + TOF in the muon system analysis.



Triggers:
- MET (particle flow) > 150 GeV
- single muon p_T > 30 GeV/c
- special BX0+BX1 muon trigger (RPC)

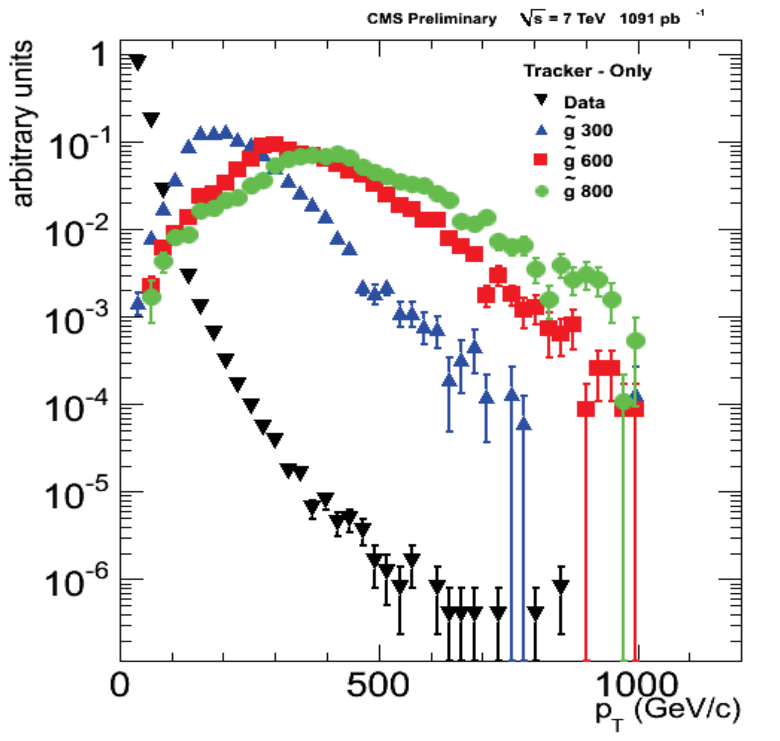
Selection

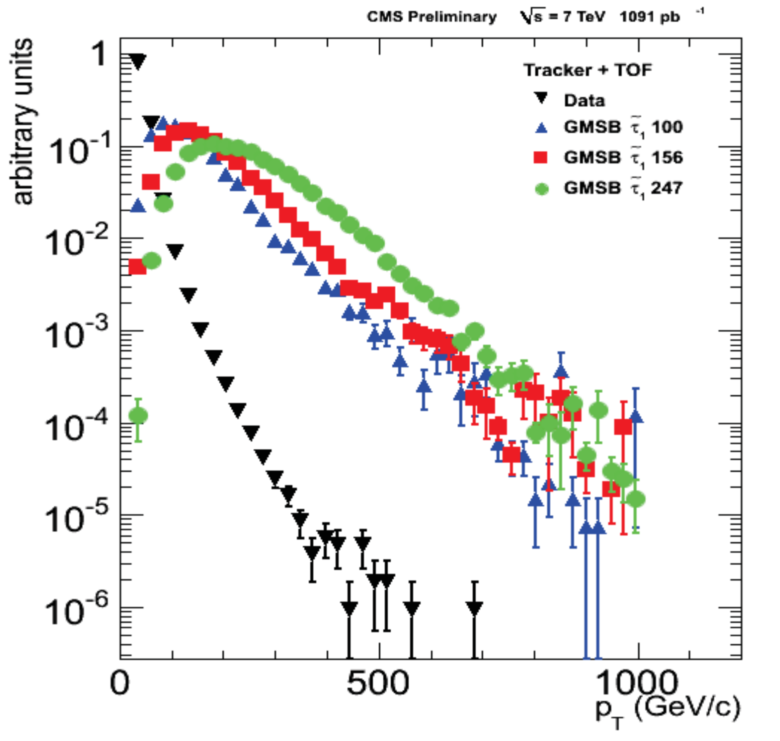
- p_T > 35 GeV/c ---------------------------------->
- track χ^2/NDOF < 5;
- $|\eta|$ < 1.5;
- 3d impact parameter < 2cm;
- at least 2 hits in the pixel detector
- at least 11 hits in the inner tracker;
- less than 20% hits missing (in tracker);
- at least 4 tracker hits after cleaning;

- I_h > 3 MeV/cm (d*E*/d*x* above MIP; see next slide)

- loose isolation: in the cone ΔR < 0.3
  - less than 50 (100 Tk+TOF) GeV/c (tracks);
  - sumECAL/sumHCAL < 0.3 (0.6 Tk+TOF)

- *Tracker+TOF additional selection:*
  - $1/\beta > 1$;
  - error($1/\beta$) < 0.07;
  - NDOF($1/\beta$) > 7

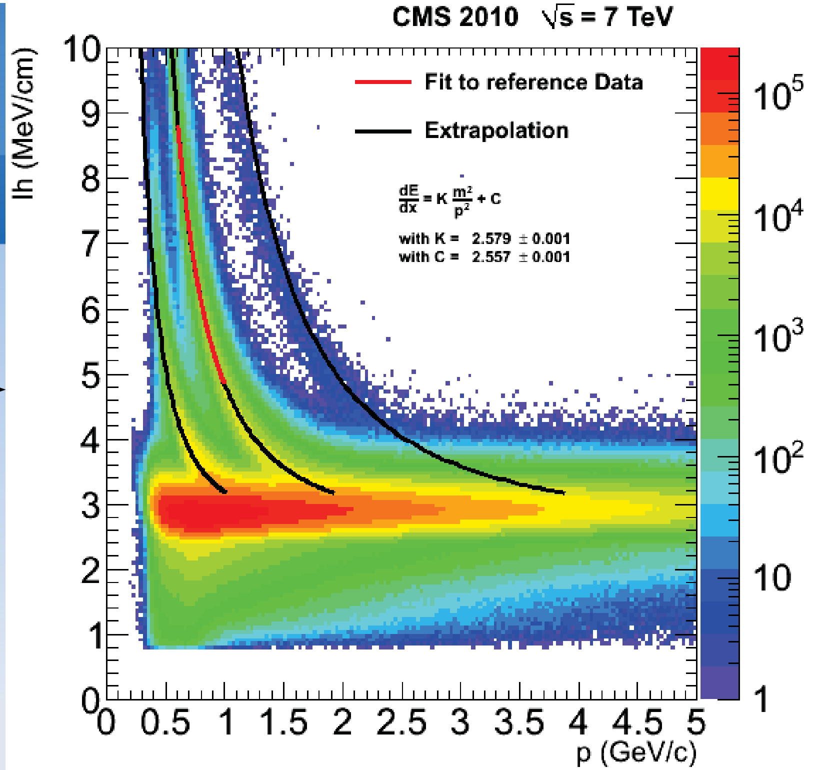




dE/dx in tracker

An estimator:

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



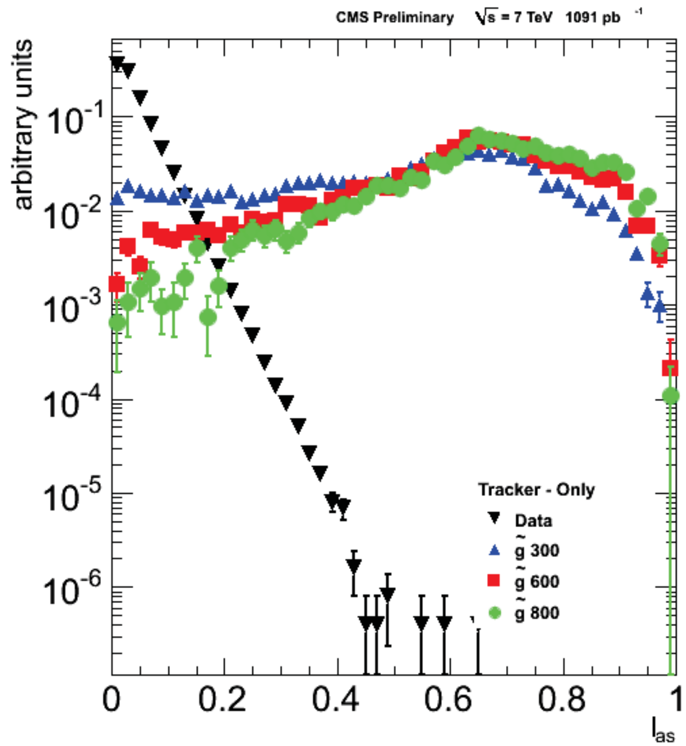
via relation:

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

K = 2.559 MeV cm^{-1} c^{-2}
C = 2.772 MeV cm^{-1}

is used to estimate the mass of the HSCP canadidate, whereas value of a discriminator:

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



is used to obtain signal and control regions.
P_i is the probability that MIP will give signal smaller than recorded for a given hit i.

Tracker only results

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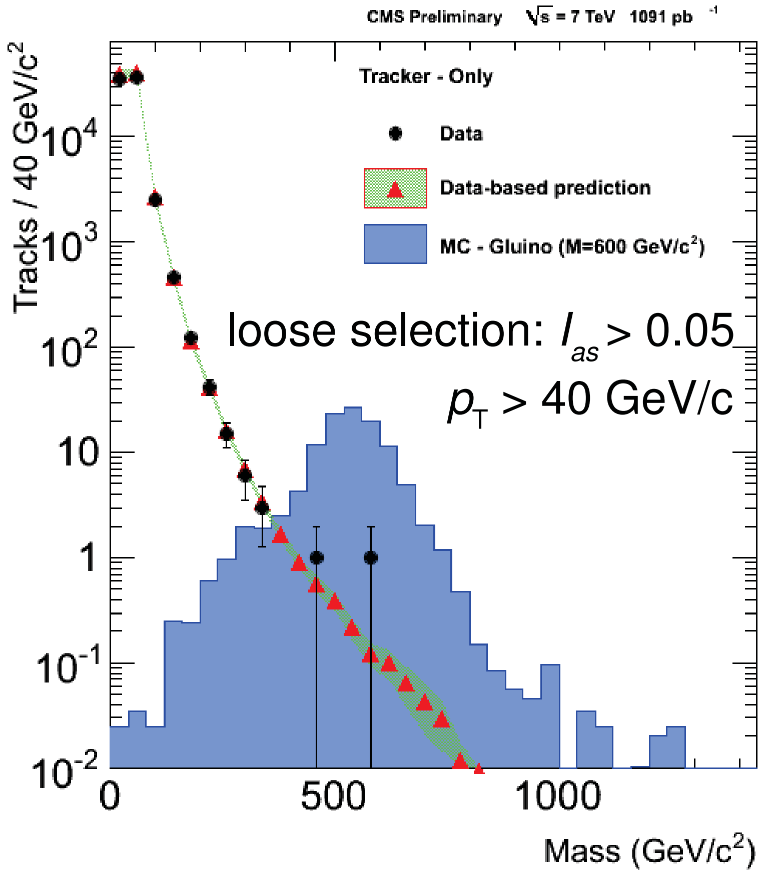
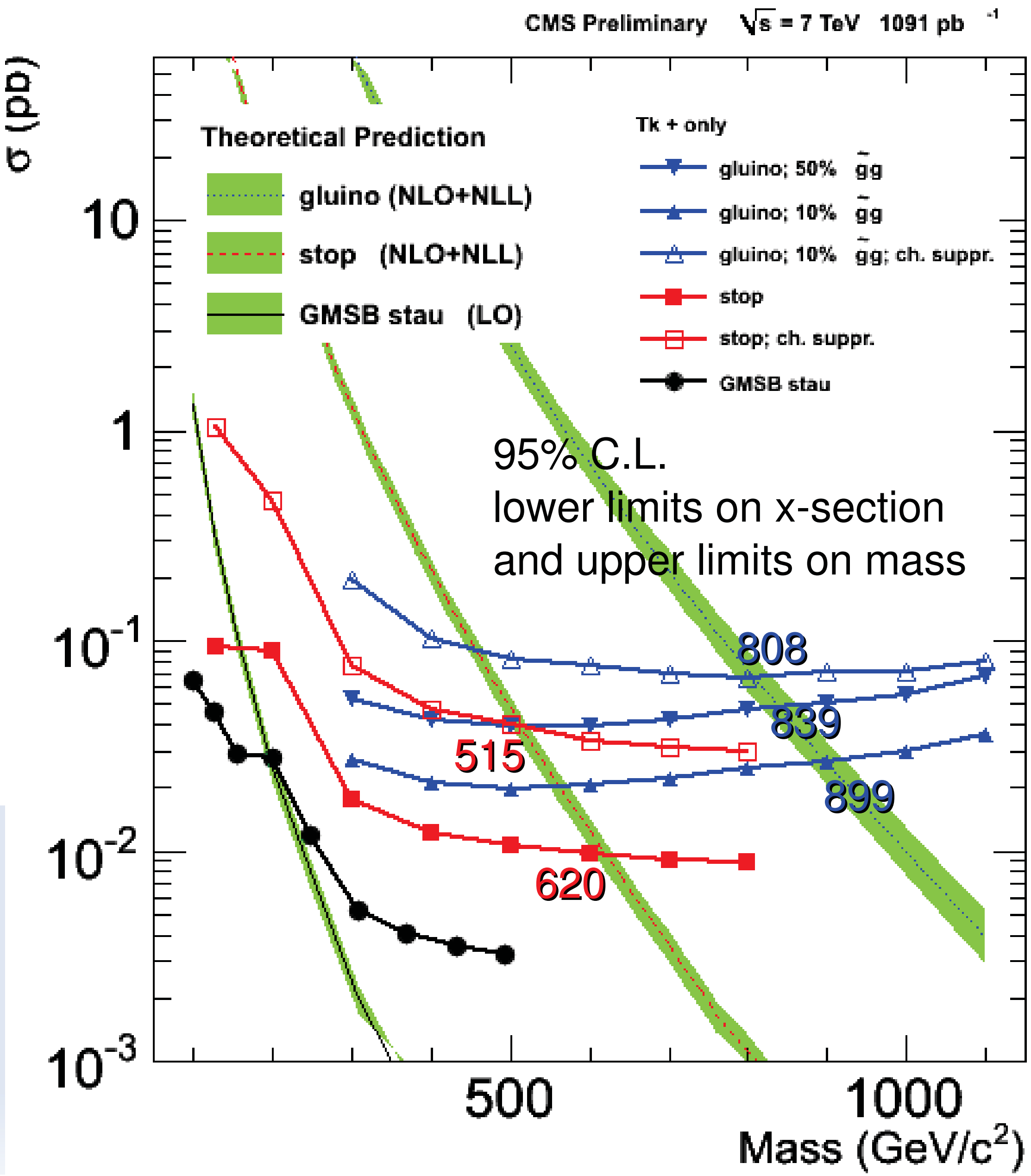


Background estimate via ABCD method because p_T and I_{as} are independent.

Counting experiment {p_T, I_{as}, mass(I_h)} selection optimized for each point →



TOF by the muon system

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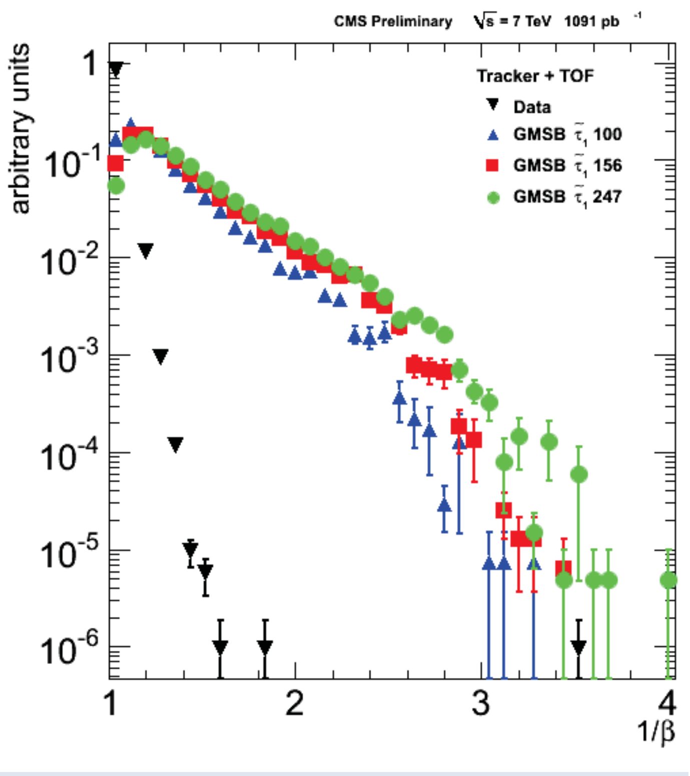
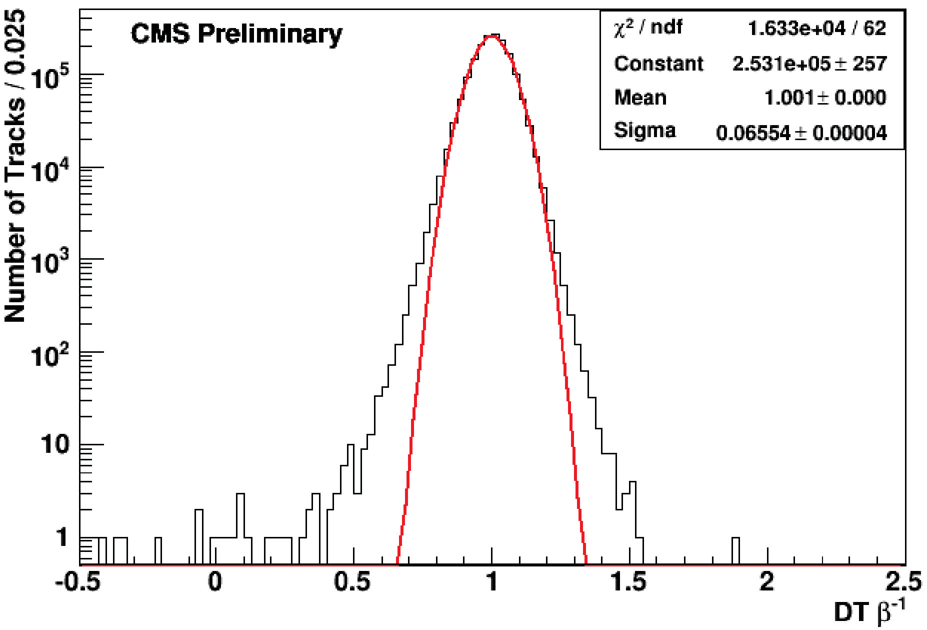
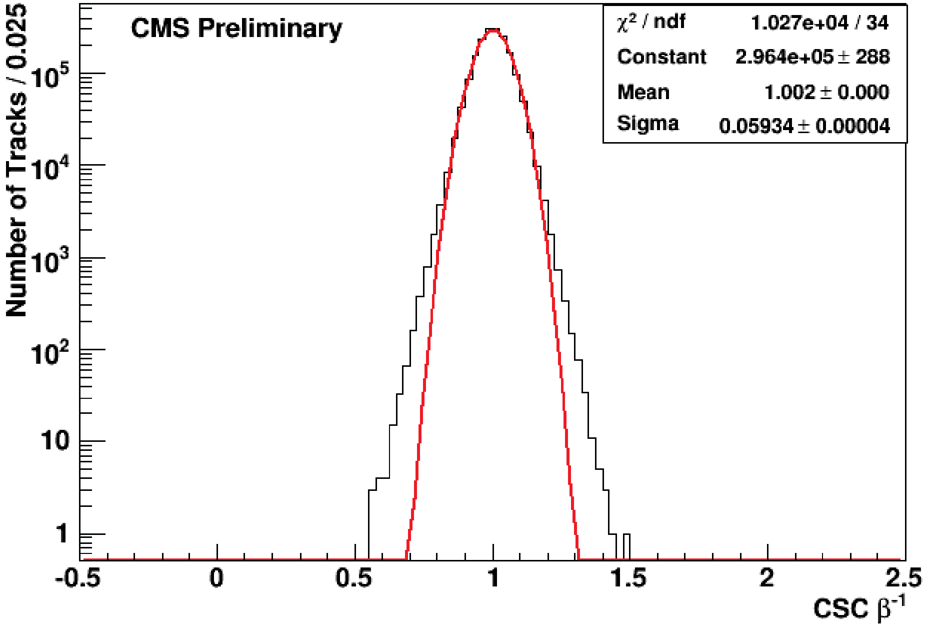


$$\frac{1}{\beta} = 1 + \frac{c\delta_t}{L}$$

Relation between candidate velocity and the time delay *delta_t* at a distance *L.*

The third idependent measurement (if aplicable).





Tracker + TOF results

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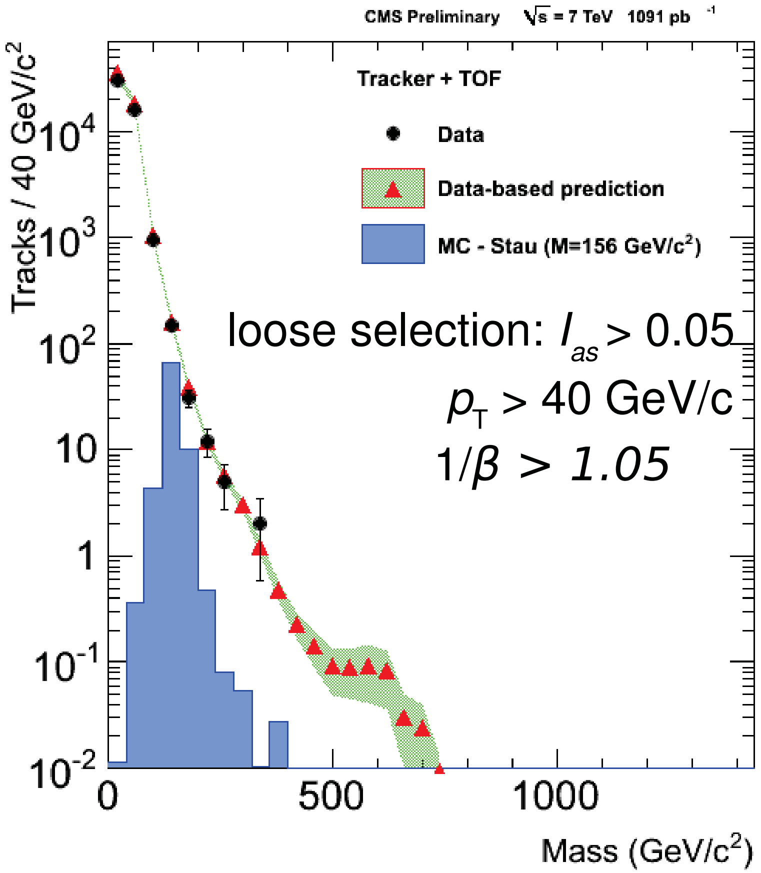
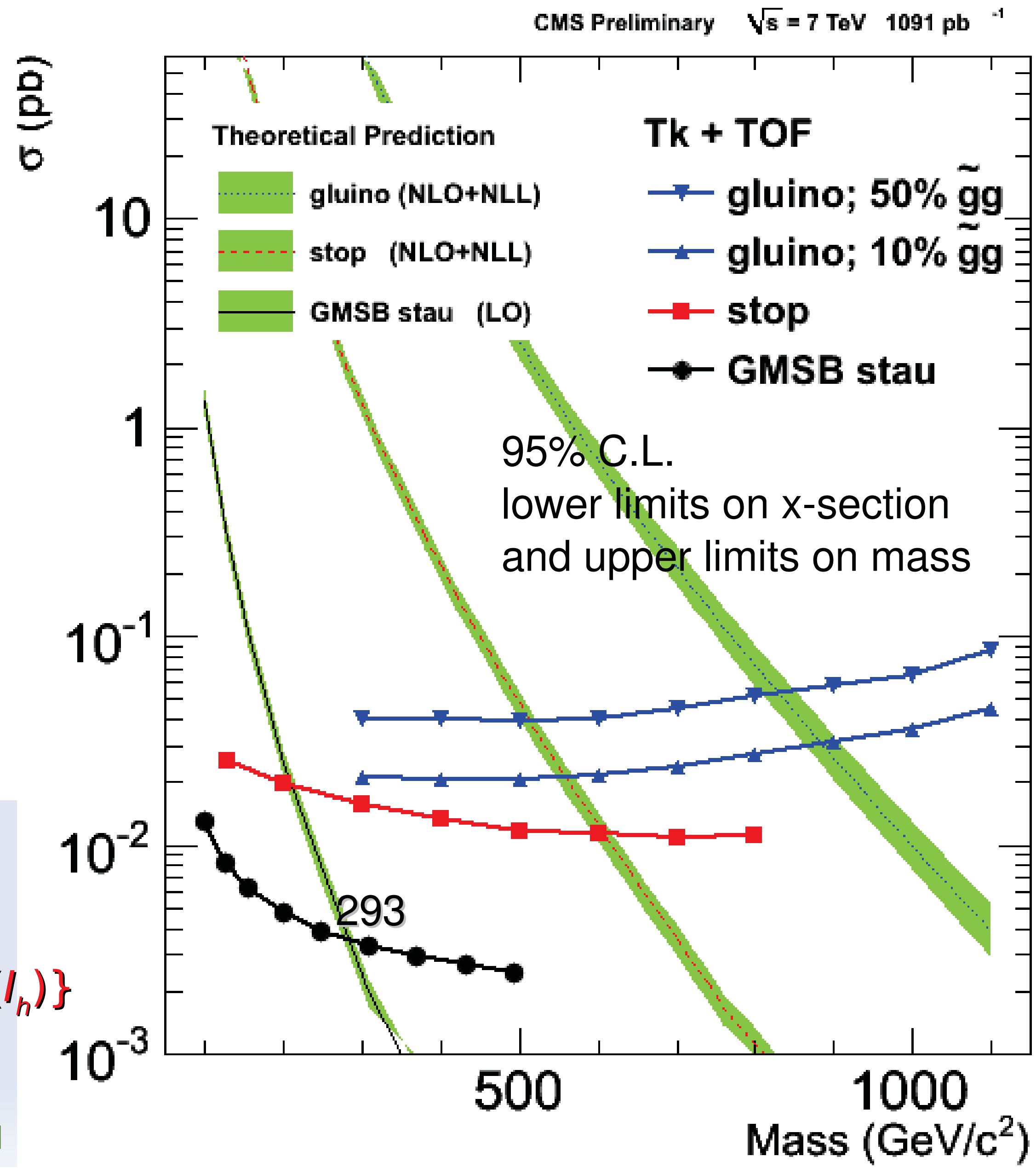
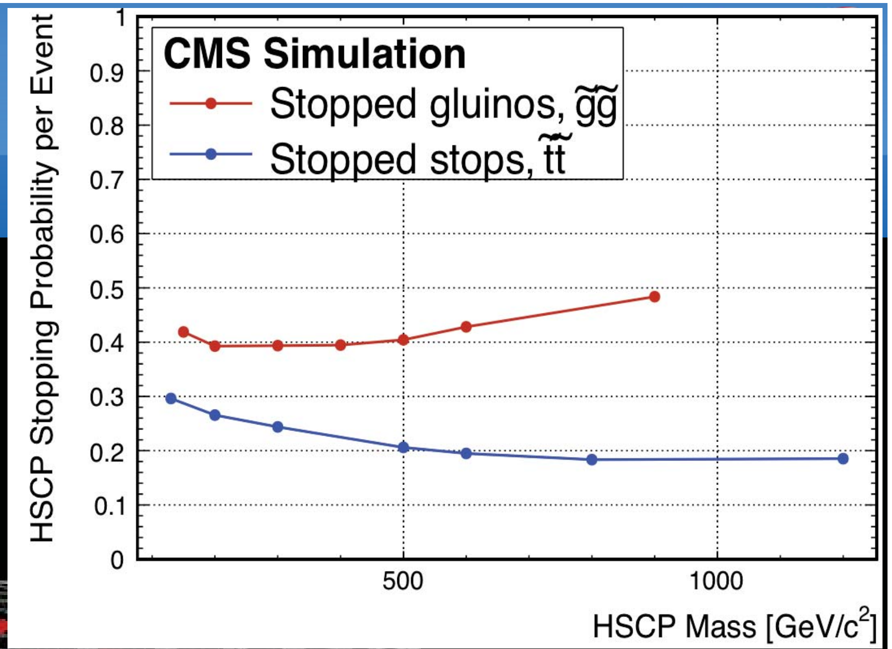




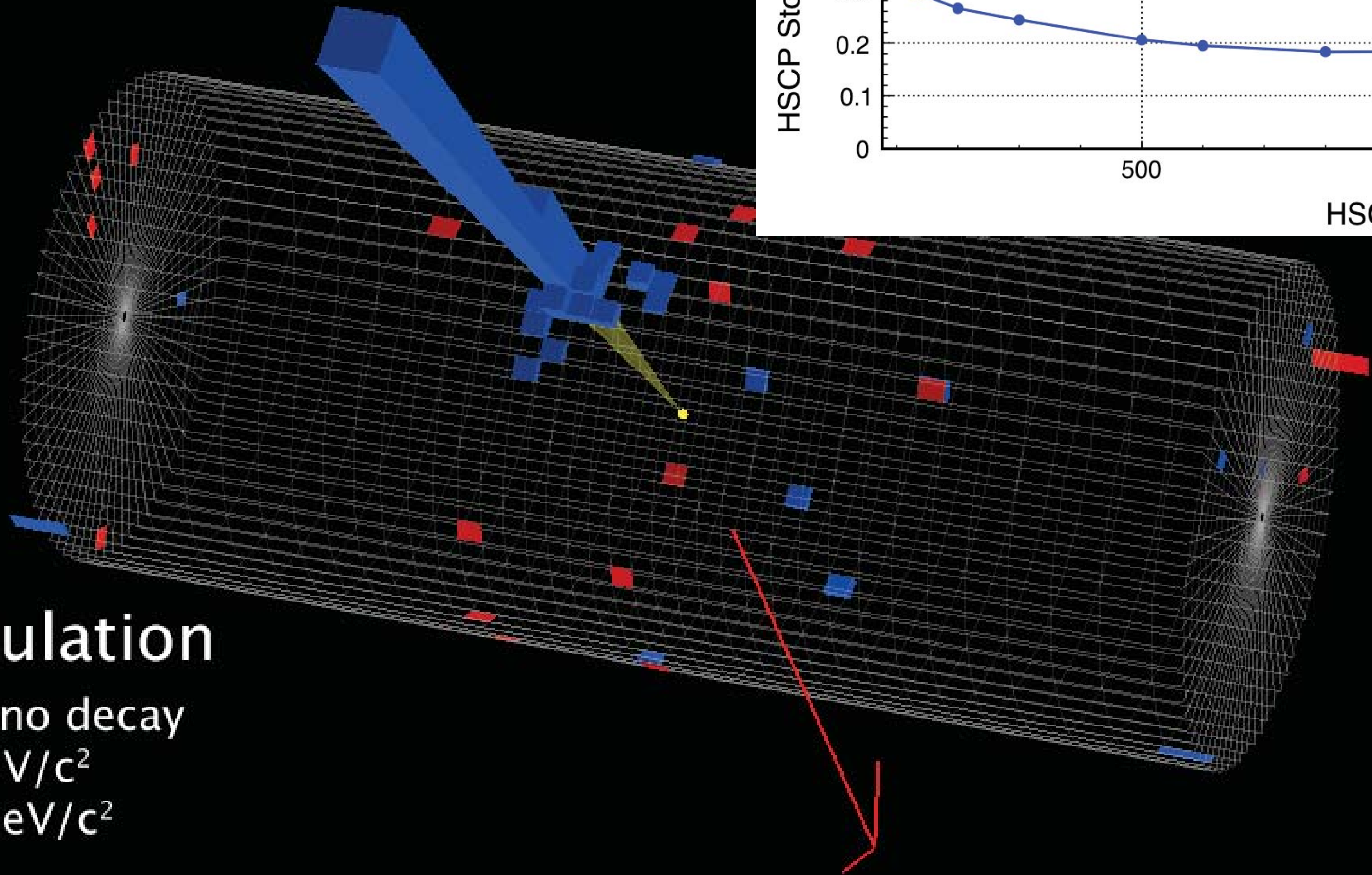
Background: extended ABCD method because p_T, I_{as} and $1/\beta$ are independent

Counting experiment $\{p_T, I_{as}, 1/\beta, \text{mass}(I_h)\}$
selection optimized for each point →

Stopped HSCP



Slowest HSCPs could stop in the detector.
The stopping power is greater for R-hadrons.



CMS Simulation

Stopped gluino decay
$m_{\tilde{g}}$ = 300 GeV/c^2
$m_{\tilde{\chi}_1^0}$ = 200 GeV/c^2

Stopped R-hadron will decay after lifetime dependent delay.
Decays inside calorimeters could give trigger when there is no BX.

Trigger + offline veto & cleaning

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Jet trigger in coincidence with "no beam" condition:

- 32 GeV E_T threshold at L1 and 50 GeV energy treshold at HLT
- veto both BPTX (beam position and timing) monitors +-1 BX
- $|\eta| < 3$
- veto L1 endcap beam halo trigger (+-1 BX)

Offline veto:

- veto +-2 BX any beam activity
- veto any reconstructed beam halo event
- veto any event with primary vertex
- veto any event with at least 1 muon

Cleaning and noise rejection:

- standard cleaning and noise rejection
- $|\eta| < 1$
- reconstructed jet energy > 70 GeV
- spacial distribution of the deposits requirements
- pulse time shape requirements

Background rate (see next slide) & signal efficiency (quoted with Respect to the fraction of events in which at least one gluino stops anywhere in the CMS) for gluino 500 GeV and neutralino 400 GeV.

Selection Criteria	Background Rate (Hz)	Signal Efficiency %
trigger	21.5 ± 0.008	31.3
BX veto	8.61 ± 0.005	31.3
Vertex veto	8.61 ± 0.005	31.3
Halo veto	8.28 ± 0.0049	31.2
Cosmic veto	8.19 ± 0.0049	26.8
Noise veto	6.79 ± 0.0044	26.2
$E_{jet} > 70$ GeV	$2.63 \pm 0.028 \times 10^{-2}$	14.6
$n60_{jet} < 6$	$2.63 \pm 0.028 \times 10^{-2}$	14.5
$n90_{jet} > 3$	$2.33 \pm 0.082 \times 10^{-3}$	13.3
$nTowiPhi < 5$	$4.0 \pm 1.1 \times 10^{-5}$	13.3
$E_{iphi}/E_{jet} < 0.95$	$2.3 \pm 2.3 \times 10^{-5}$	13.3
$R_1 > 0.15$	$2.3 \pm 2.3 \times 10^{-5}$	13.4
$0.1 < R_2 < 0.8$	$2.3 \pm 2.3 \times 10^{-5}$	13.4
$0.3 < R_{peak} < 0.7$	$1.7 \pm 0.7 \times 10^{-5}$	13.3
$R_{outer} < 0.3$	$1.7 \pm 0.7 \times 10^{-5}$	13.3

Analysis strategy

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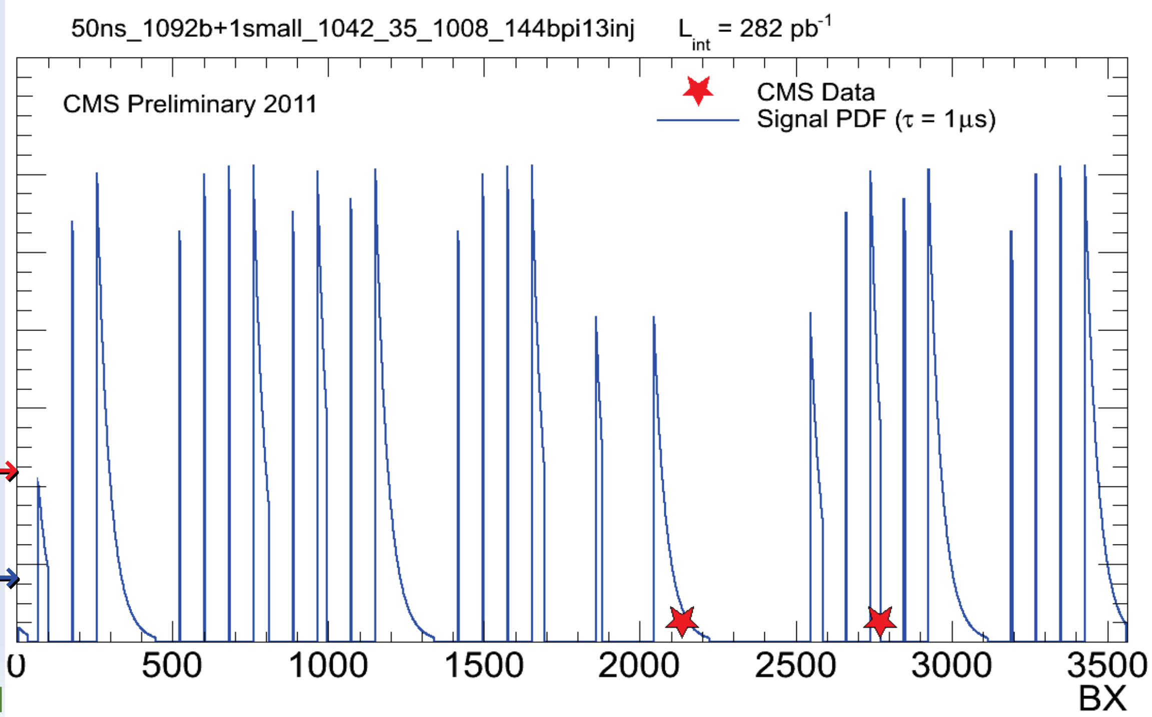
The search is performed using data recorded between April and July 2011. During this period the LHC instantaneous luminosity was increased to over 10^{33} cm^{-2} s^{-1}.
Since we search in gaps between colliding bunches, this has an effect on the amount of time that can be used → → → for the search which comes out to be 168 hours (and 886 pb^{-1}).

$N_{bunches}$	$N_{collision}$ (in CMS)	f_{live}
228	214	85%
336	322	78-79%
480	424	68%
624	598	61%
768	700	50-51%
912	874	44%
1092	1042	33%
1104	1042	32%
1236	1180	25%

We use the 2010 data as a control sample which allows to estimate background rate (see the table in the previous slide).
2010A: 3.6 pb^{-1}, 10^{28} cm^{-2} s^{-1}, 328 hours
2010B: 36 pb^{-1}, 10^{32} cm^{-2} s^{-1}, 97 hours

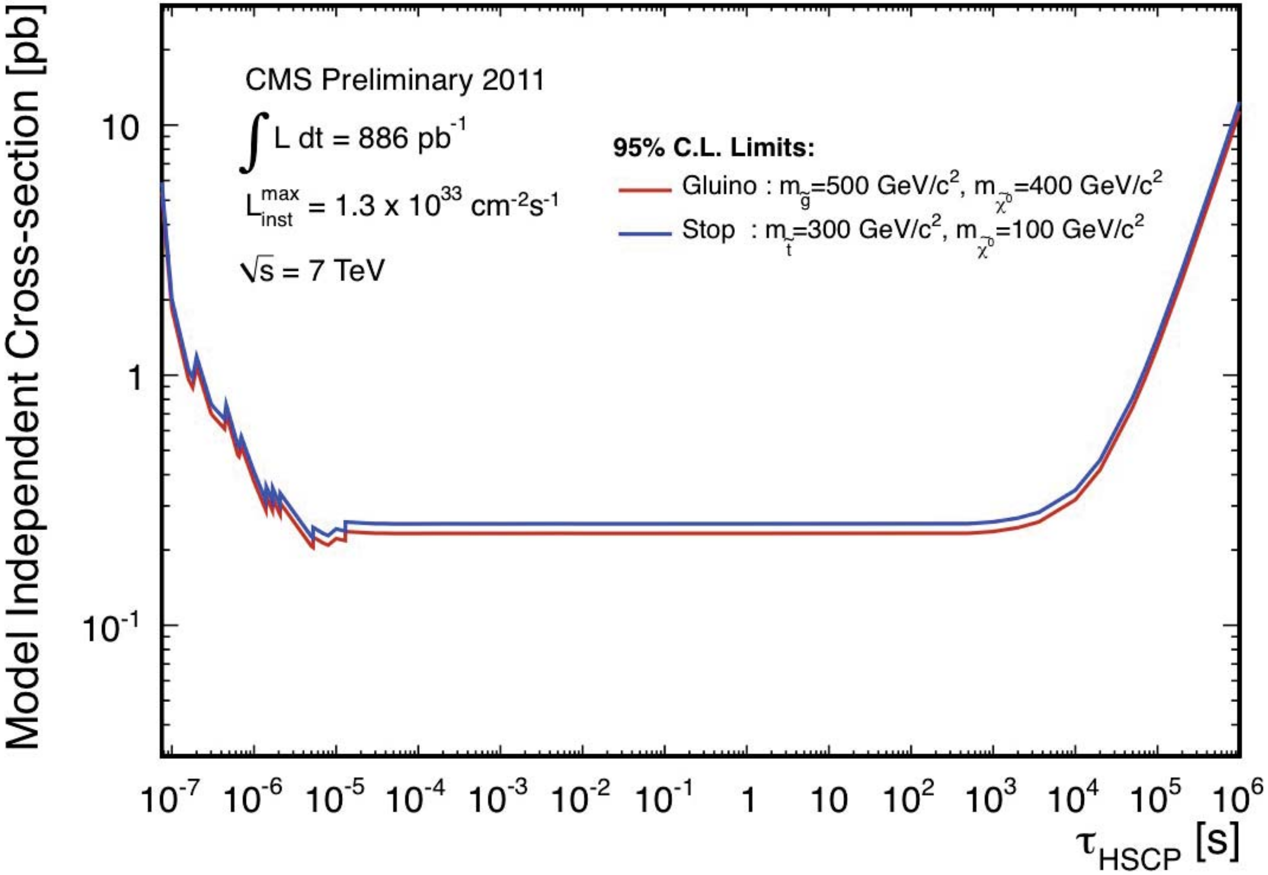
Counting experiment
lifetime τ from 75 ns to 10^6 s
for τ < orbit=89 μs: window (0, 1.3 τ)

Time profile analysis → → → → → → →
is performed in addition for τ < 1 ms
(signal PDF for τ = 1 μs) →



Results

Model independent
95% C.L. Limits
on HSCP pair production
times the probability
of either HSCP to stop,
as a function of
HSCP lifetime (top)
and mass (bottom).



Selection efficiency as a function of HSCP and neutralino masses. Efficiency is quoted here with respect to the fraction of events in which one of the two produced HSCP stops anywhere in the whole CMS detector.

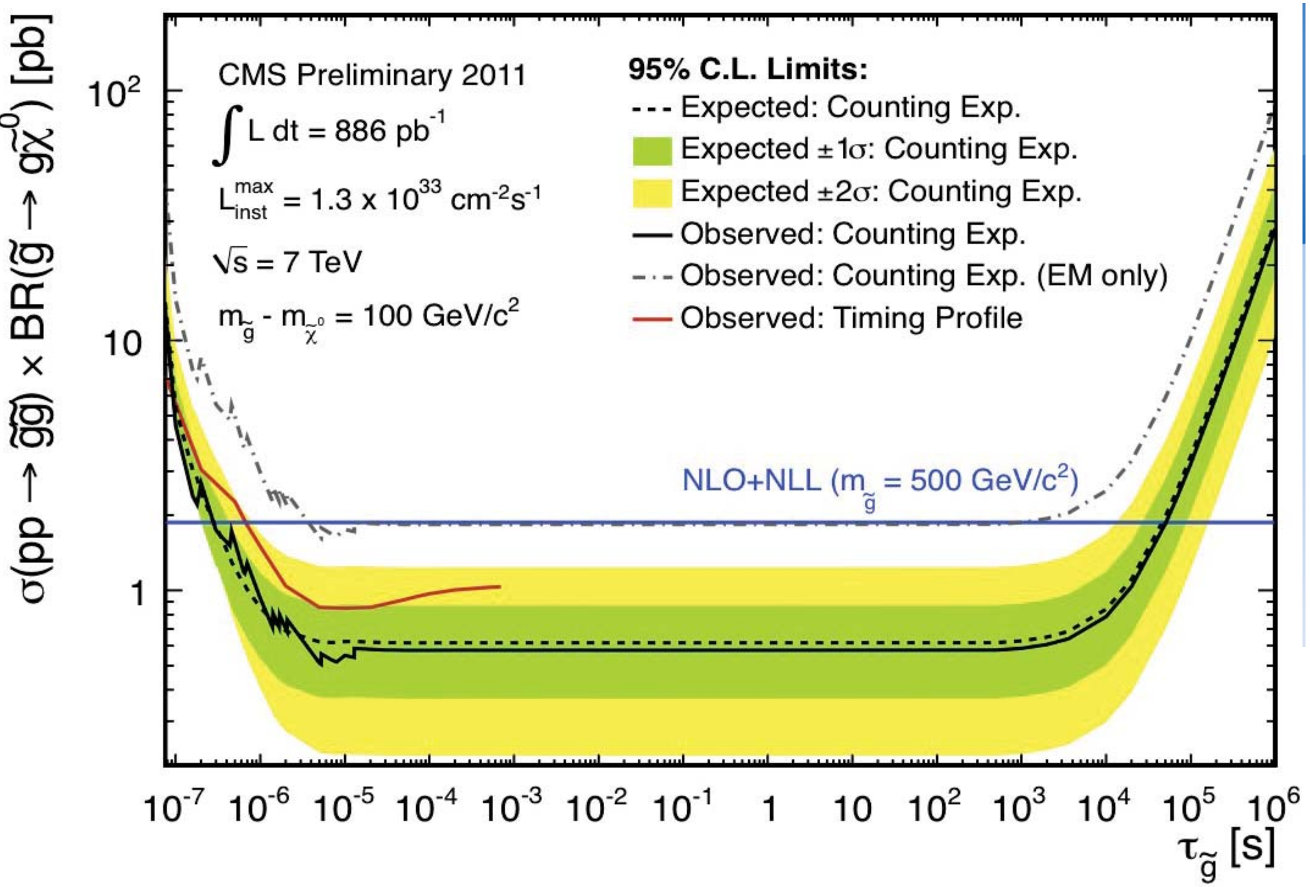
$m_{\tilde{g}}$ (GeV/c^2)	$M_{\tilde{\chi}}$ (GeV/c^2)	efficiency (% of stopped)
300	200	12.0%
400	300	13.2%
500	400	13.3%
600	500	13.3%
900	800	13.1%
$m_{\tilde{t}}$ (GeV/c^2)	$M_{\tilde{\chi}}$ (GeV/c^2)	efficiency (% of stopped)
300	100	12.1%

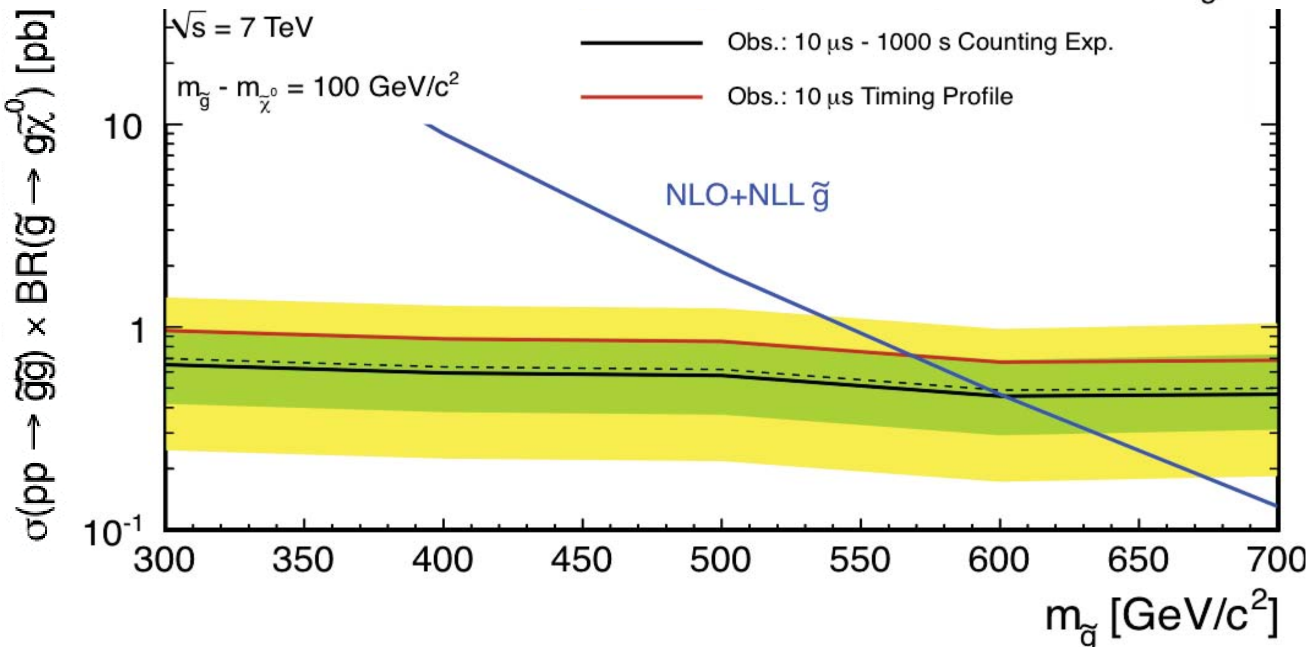
background rate: (1.7+- 0.7) $10^{-5}\ s^{-1}$

gluino

Top: expected and observed 95% C.L. limits on gluino pair production x-section (using the “cloud model” of R-hadron interactions) as a function of gluino lifetime from both counting experiment and the time profile analysis.
Errors include statistical plus systematic uncertainties.
The structure observed Between 10^{-6} s and 10^{-4} s is due to the number of observed events incrementing when crossing boundaries between lifetime bins.

Bottom: the same as a function of gluino mass.

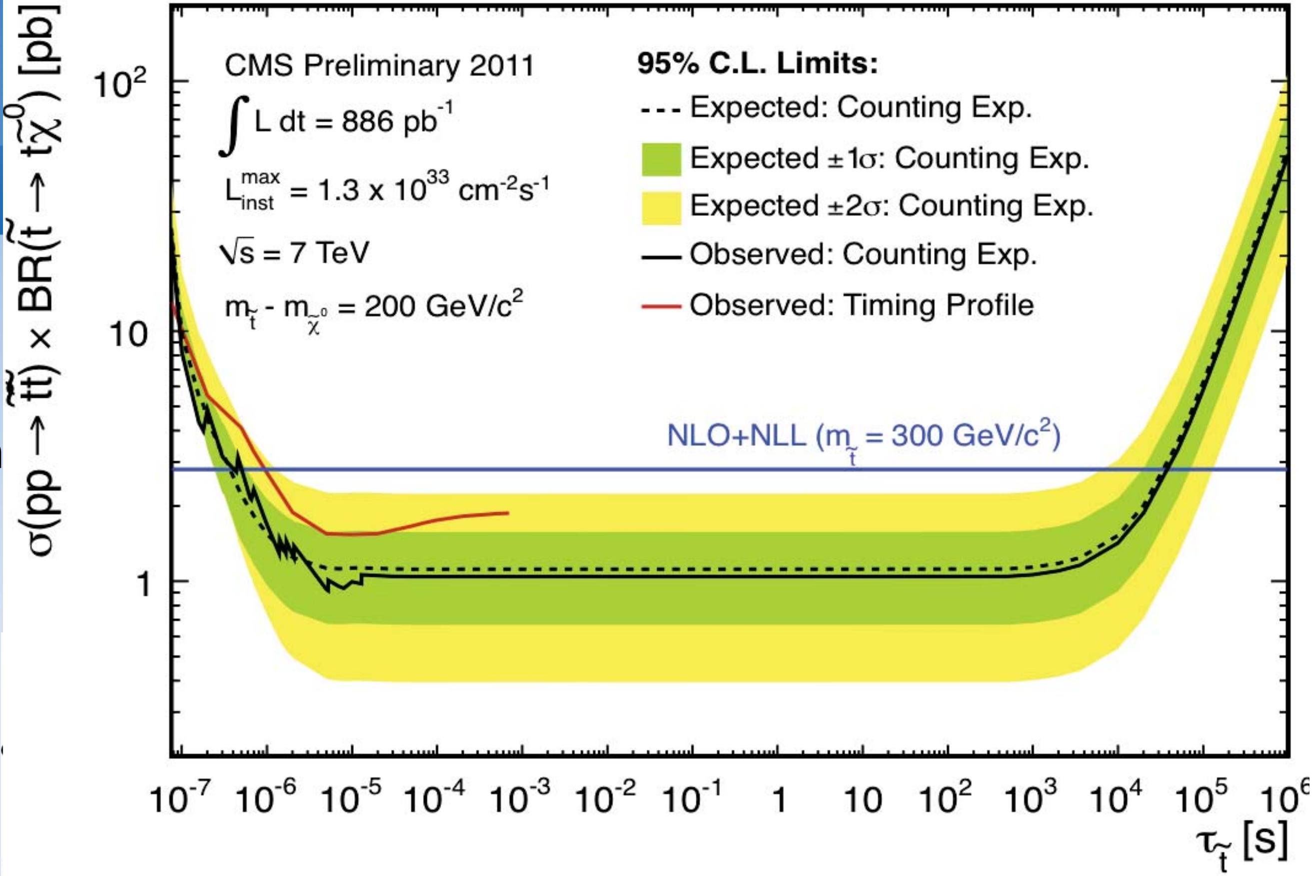


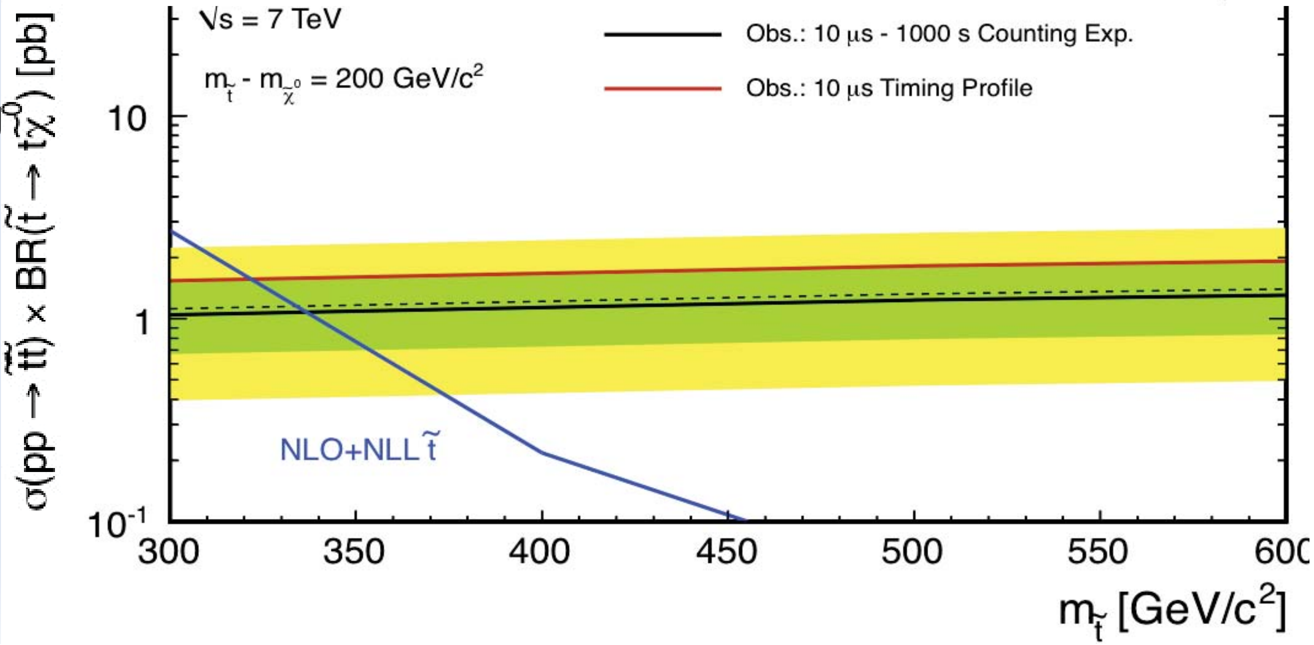


stop

Top: expected and observed 95% C.L. limits on stop pair production x-section (using the “cloud model” of R-hadron interactions) as a function of stop lifetime from both counting experiment and the time profile analysis.
Errors include statistical plus systematic uncertainties.
The structure observed Between 10^{-6} s and 10^{-4} s is due to the number of observed events incrementing when crossing boundaries between lifetime bins.

Bottom: the same as a function of stop mass.





Summary

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We searched for HSCPs flying through the CMS detector (tracker only & tracker + TOF analyses) as well as for HSCP stopping in the CMS calorimeters.

We have not (yet) found any excess above predicted via data driven methods background.

Stringed limits are set at 95% C.L. Level. We exclude:
- gluino mass < 899 GeV (charge suppression scenario: 808 GeV)
- stop mass < 620 GeV
- stau (GMSB) mass < 293 GeV

and for stopped HSCP analysis we exclude:
- gluino with lifetimes from 10 ms to 1000 s and mass < 601 GeV
- stop with lifetimes from 10 ms to 1000 s and mass < 337 GeV

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResults

References

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[1] *Search for Heavy Stable Charged Particles in pp collisions at sqrt(s) = 7 TeV*; CMS-PAS-EXO-11-022
[2] *Search for Stopped Heavy Stable Charged Particles in pp collisions at sqrt(s) = 7 TeV;* CMS-PAS-EXO-11-020
[3] *Search for Heavy Stable Charged Particles in pp collisions at sqrt(s) = 7 TeV*; CMS-EXO-10-011; J. High Energy Phys.03 (2011) 024
[4] *Search for Stopped Gluinos in pp collisions at sqrt(s) = 7 TeV*; arXiv:1011.5861; CMS-EXO-10-003; DOI: 10.1103/PhysRevLett.106.011801

`https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResults`