Searches for long-lived particles at CMS

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On behalf of the CMS Collaboration

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Long-Lived particles at CMS

- **Short lifetime ($c\tau$ < ~100cm)**
  - Displaced Leptons — Not shown here — 10.1007/JHEP02(2013)085
  - Displaced Photons — Not shown here — j.physletb.2013.04.027
  - Displaced Jets New — PAS-EXO-12-038

- **Stable or Long lifetime ($c\tau$ > ~100cm)**
  - Long-Lived charged particles — arXiv: 1305.0491 (accepted by JHEP)
  - Stopped or delayed particles — Not shown here — JHEP08(2012)026

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Search for Displaced Jets

Displaced Jets in a nutshell

- **Signature : ≥2Jets containing majority of tracks associated to a secondary vertex**
- **First CMS results in this channel**
- **Full 8TeV dataset** was used : 18.6 fb^{-1}@8TeV
- **Signal Model** :
  - **gg→H→XX→(qq) (qq)**
  - M_H = [200, 400, 1000]GeV M_X = [50, 150, 350]GeV **$c\tau_X$ = [3, 30, 300]cm**
- **Expected Backgrounds:**
  - Multjet events (mostly QCD), nuclear interactions, B Hadrons, etc.

- **Dedicated Trigger:**
  - Sum Jet p_T > 300GeV
  - ≥2Jets with p_T>60GeV, |η|<2, ≤ 2 Prompt Tracks carrying ≤ 15% of Jet energy ($|d_{XYZ}|$<300μm)
- **Pre-Selection → Used to populate signal AND control regions**
  - Jet p_T>60GeV, |η|<2
  - Build a secondary vertex (SV) using jet displaced tracks ($|d_{XY}|$>500μm)
  - SV : χ^2 < 5, Mass>4GeV, pT>8GeV, incompatibility with Primary vertex > 8σ, …
- **Selection**
  - Jet1: #(Prompt Tracks) and Jet energy fraction they carry
  - Jet2: #(Prompt Tracks) and Jet energy fraction they carry
  - Secondary vertex : Likelihood Discriminant (LD) based on 4 vertex variables (#tracks, RMS, …)

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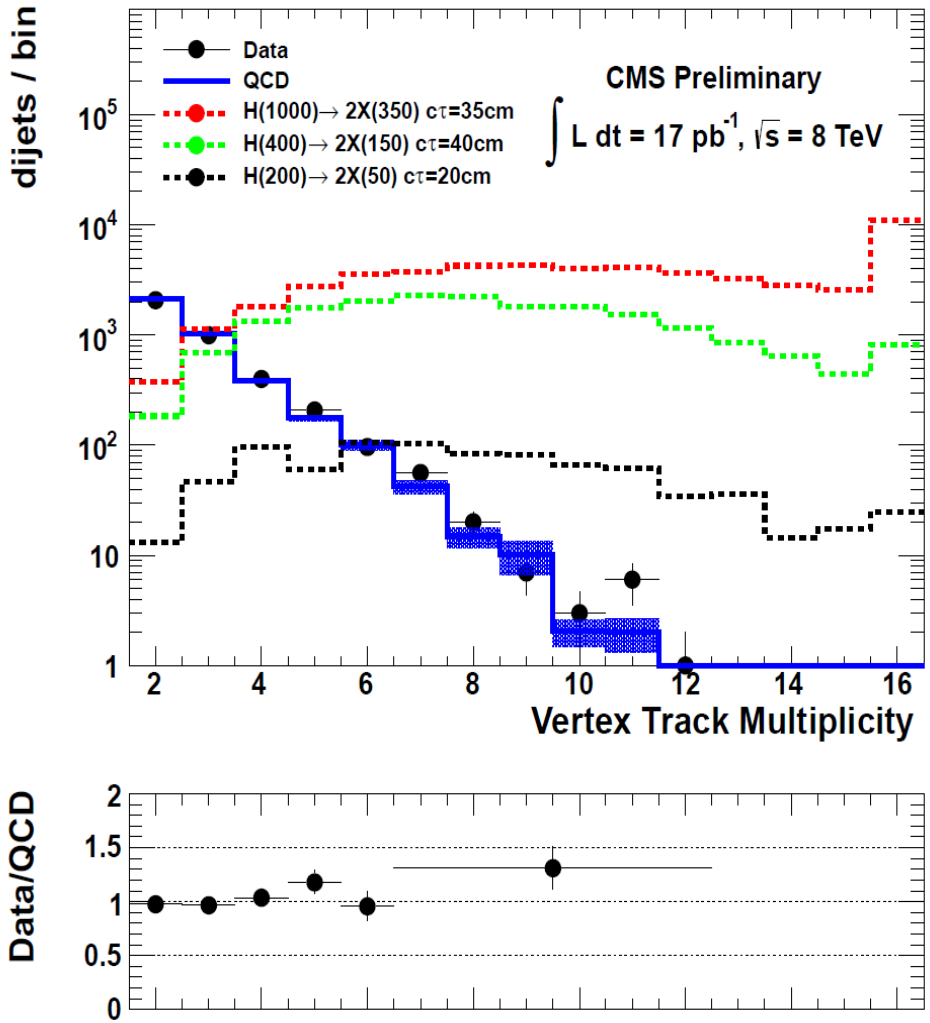
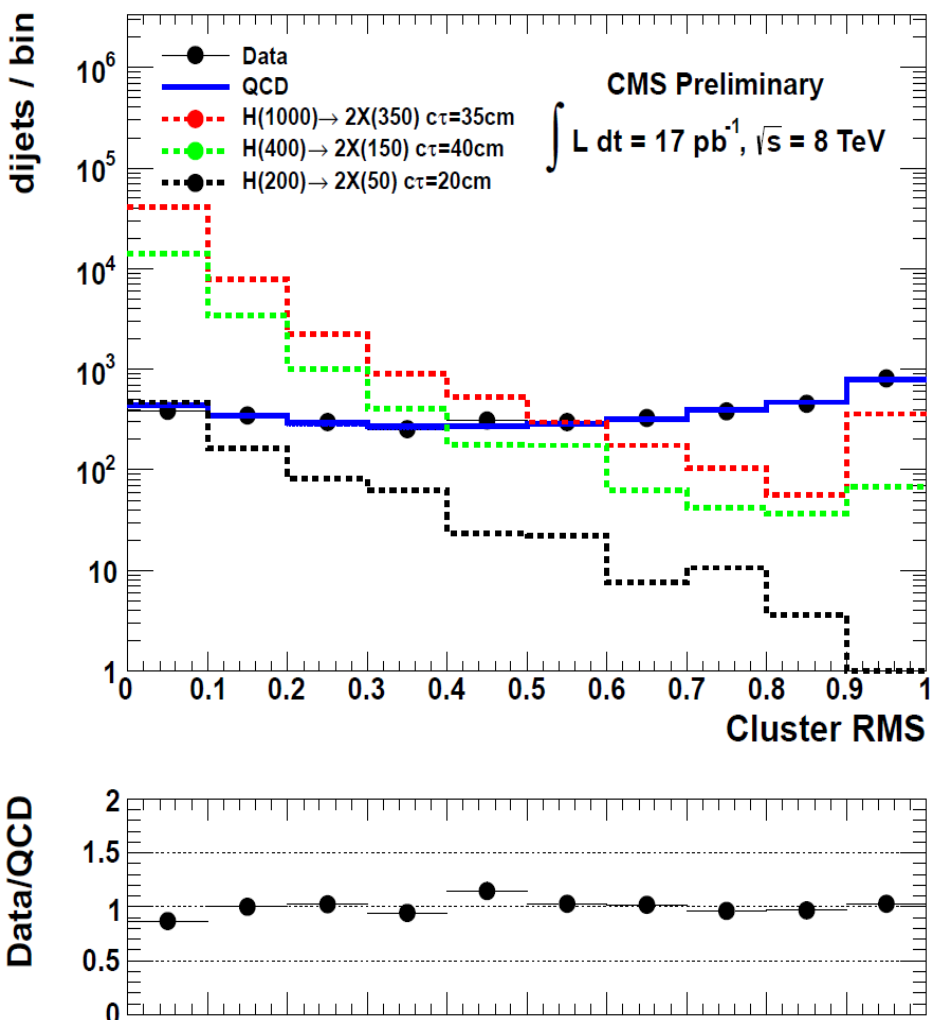
Two variables used in the LD





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Search Results

- Background prediction:
  - ABCD technique used since selection variables are uncorrelated
    - Jet1 properties
    - Jet2 properties
    - Secondary Vertex properties

- Search
  - Cut&count technique is used
  - Two selections are used
    - optimized for L_{XY} < 20cm
    - optimized for L_{XY} > 20cm
  - Data are compatible with background prediction

$\mathbf{L_{xy}}$	$< \mathbf{20\ cm (low)}$	$> \mathbf{20\ cm (high)}$
prompt tracks	≤ 1	≤ 1
prompt energy fraction	< 0.15	< 0.09
vertex/cluster disc.	> 0.9	> 0.8
expected background	$1.60 \pm 0.26(stat.) \pm 0.51(syst.)$	$1.14 \pm 0.15(stat.) \pm 0.52(syst.)$
observed	**2**	**1**

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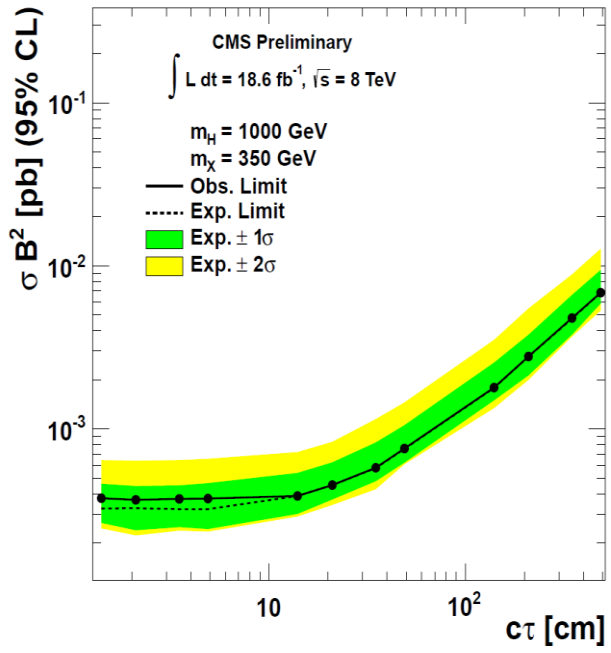
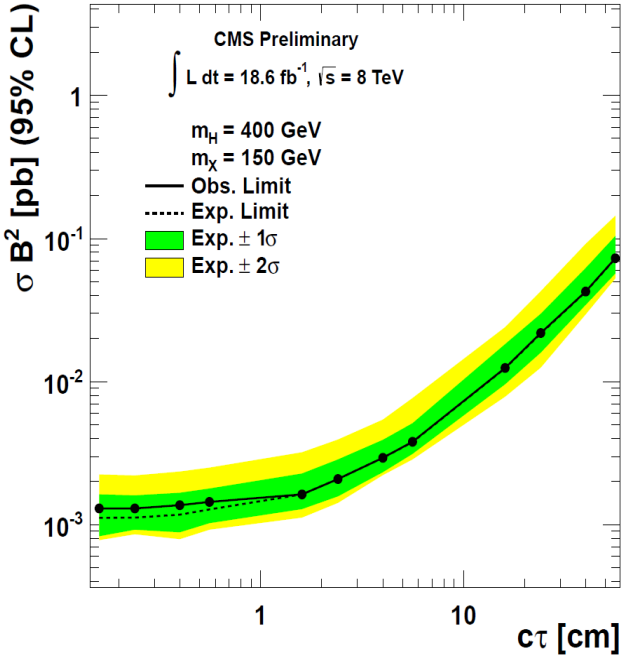
Limits

- Limits on σ(gg→H→XX) x B(X→qq) x B(X→qq)
- Signal acceptance and reconstruction efficiency for X→qq are provided for results reinterpretation in different models
  - Efficiencies available for q='uds', q='c' and q='b'

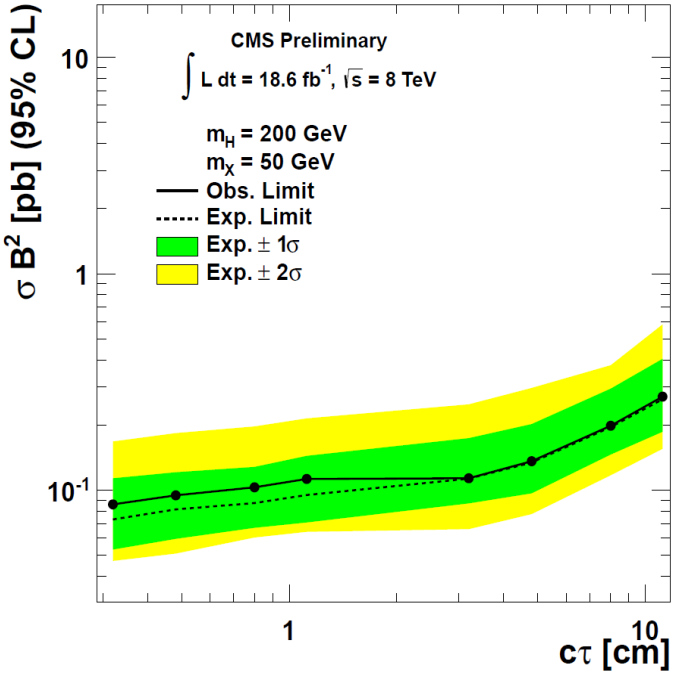
mH = 1000GeV
mX = 350GeV



mH=400GeV
mX=150GeV



mH=200GeV
mX=50GeV



- Many more results in PAS-EXO-12-038

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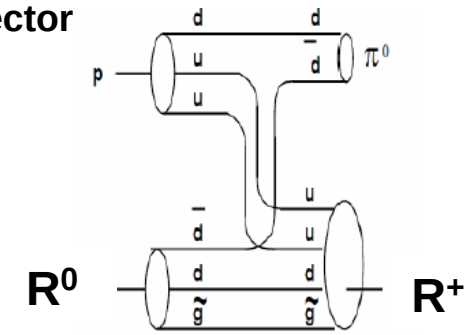
Long-Lived Charged Particles

Long-Lived Charged Particles

- Signature
  - Heavy and (Quasi-)Stable → Slowly moving particles (β<1)
  - Charged → **High dE/dx in the Tracker**
    → **Long TimeOfFlight to the Muon System**
- Signal Models
  - Stau particles
    - |Q=e| in GMSB (SPS7)
    - e/3 ≤ |Q| ≤ 8e pair production (neutral under $SU(2)_L$)
  - Gluino (spit SUSY) and Stop (large gluino masses limit)
    - Form R-hadrons containing a massive parton,
    - Large uncertainty on the hadronization model (fraction of gluino balls, f =10%?) and on charge flipping
    - **Electric charge can change while interacting with the detector**
      - → **Specific searches are needed**



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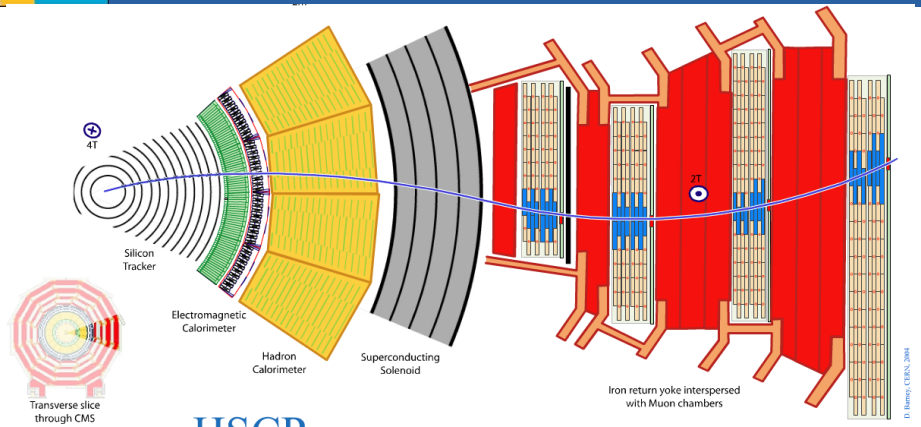
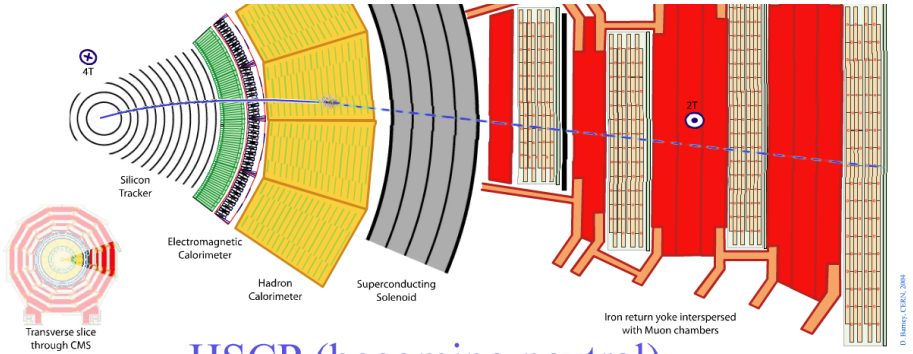
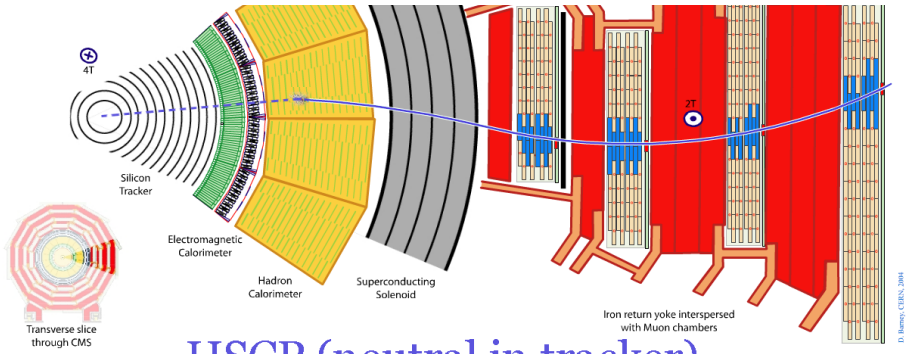
Search for particles with |Q|=e



--- HSCP



--- HSCP (becoming neutral)



--- HSCP (neutral in tracker)

- **Tracker+TOF**
  - **Global Muons**
  - p_T + dE/dx + TOF
  - particles staying charged
- **Tracker-Only**
  - **Tracks**
  - p_T + dE/dx
  - particles becoming neutral
- **Muon-only**
  - **Stand alone muon (STA)**
  - p_T (muon) + TOF
  - particles becoming charged

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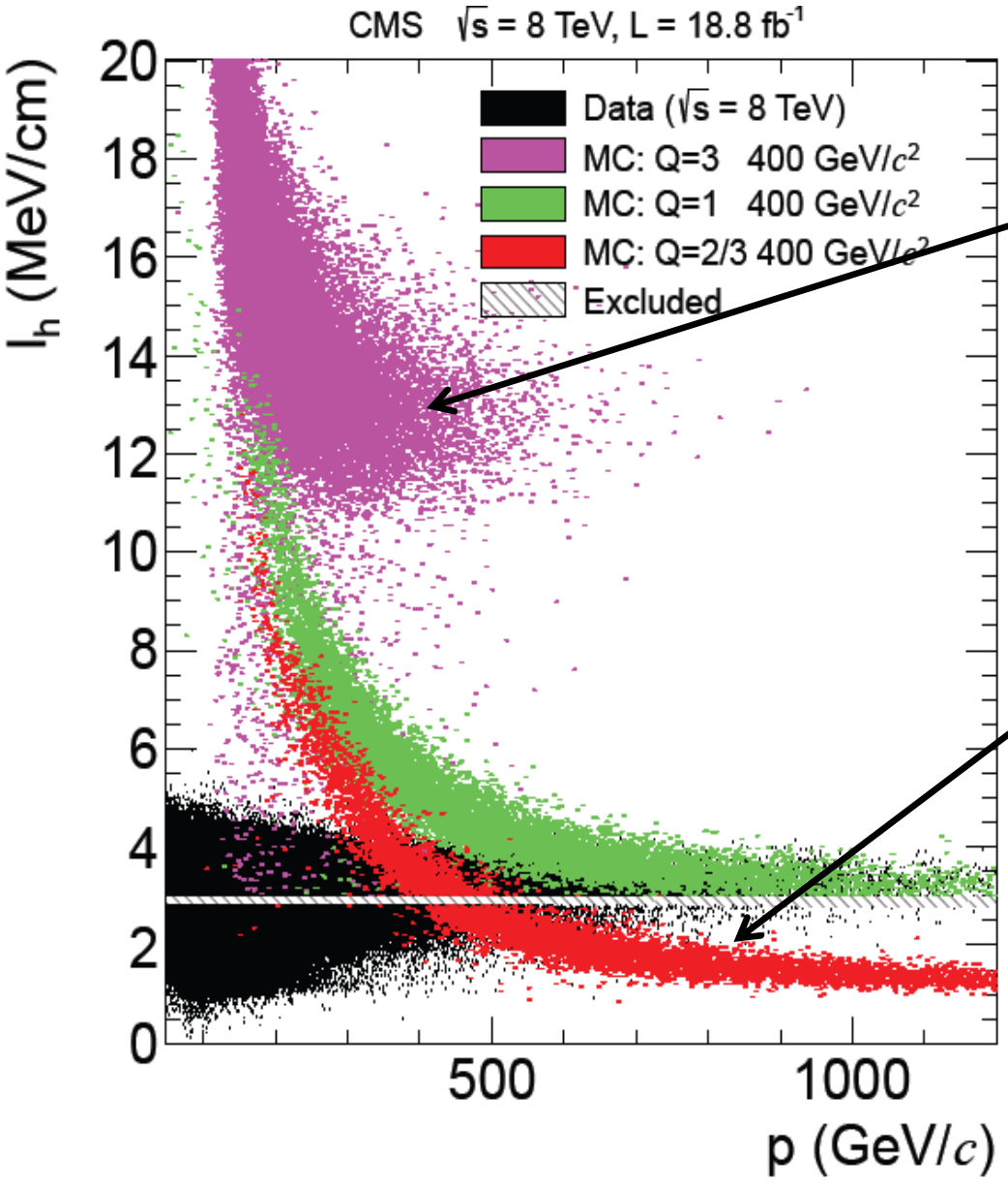
Search for particles with |Q|≠e



- **Multiply charged particles**
  - **Global Muons**
  - dE/dx + TOF
  - Do not use pT
    - $p_T^{reco} \sim p_T^{true} / Q$

- **Fractionnaly charged particles**
  - **Tracks**
  - p_T + dE/dx
  - dE/dx lower than for SM particles
  - Do not use TOF to remain as inclusive as possible

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The search in a nutshell

- Full datasets were used : 5.0 fb^{-1}@7TeV + 18.8 fb^{-1}@8TeV

- Triggers:
  - Mu p_T >40 → for always charged HSCPs
  - MET >150 → for neutral or delayed HSCPs
  - STA Mu p_T>70 & MET>65 → for neutral in tracker HSCPs (only used for Muon-only ana.)

- Pre-selection
  - Basic cleaning done to get reasonable candidates
  - Main goal is to get good control samples to be used for background prediction.
  - pT>45GeV, |η|<2.1, |dxy| and |dz|<0.5cm, #Hits>7, very loose isolation, cosmic veto, etc…

- Selection
  - **Track p_T** : Inner tracker transverse momentum
  - **Muon 1/β** : measured by muon system (DT+CSC):
  - **Track I_{as}** : Incompatibility of the track energy loss w.r.t MIP expected dE/dx (Could be higher or lower dE/dx than a MIP)

  - Actual thresholds optimized to lead to best discovery reach for a class of models

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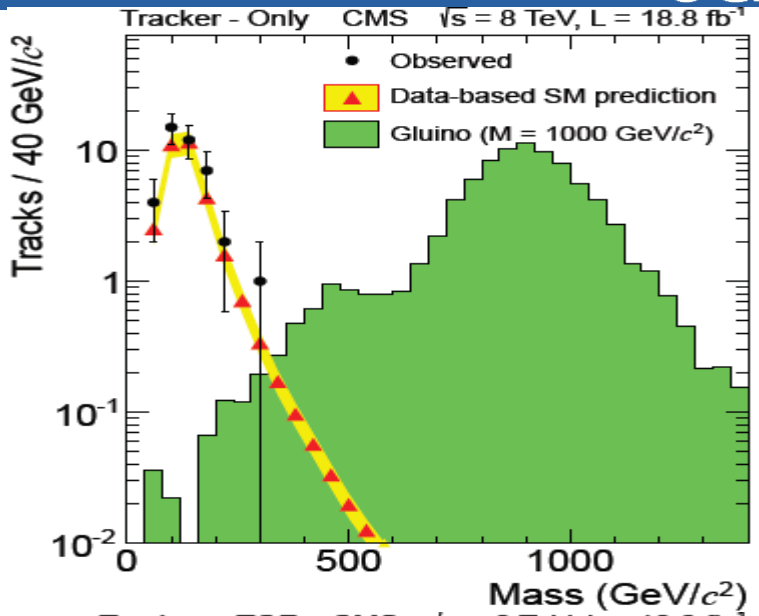
Background prediction

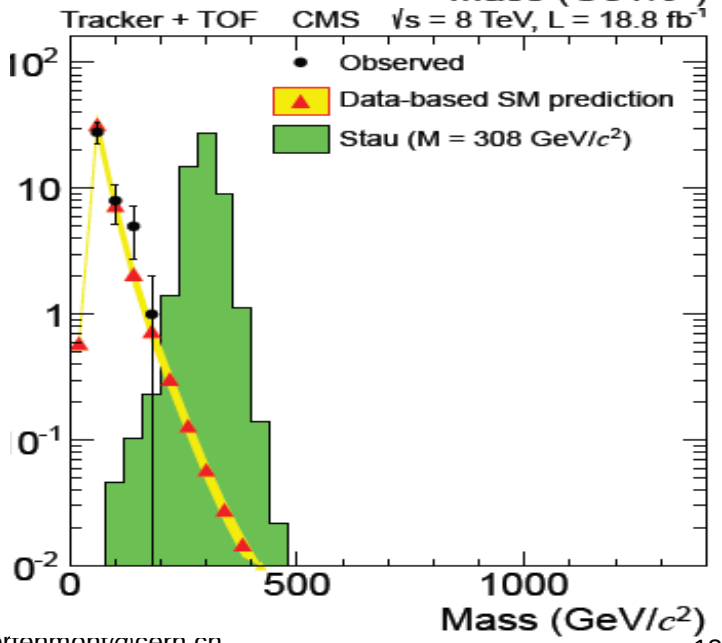
- ABCD-technique used
  - pT, dE/dx and 1/β variables
  - Uncorrelated for backgrounds
  - Fully correlated for signal…

  - 2 or 3 variables are used
    - Tk-Only →pT+dE/dx
    - Tk+TOF →pT+dE/dx+1/β
    - Mu-Only →pT +1/β
    - multi. charged → dE/dx+1/β
    - frac. charged →pT+dE/dx

  - For Tk-Only and Tk+TOF analyses,
    - Predict the mass spectrum using particle momentum and dE/dx P.D.F.

$$dE/dx \cong K\frac{m^2}{p^2} + C$$





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Results → No evidences of signal

- **Counting experiment**
- **No evidences for new physics**

	Selection criteria				Number of events $\sqrt{s} = 7$ TeV		$\sqrt{s} = 8$ TeV	
	p_T (GeV/c)	$I_{as}^{(\prime)}$	$1/\beta$	Mass (GeV/c^2)	Pred.	Obs.	Pred.	Obs.
Tracker-only	>70	>0.4	–	>0	7.1 ± 1.5	8	33 ± 7	41
				>100	6.0 ± 1.3	7	26 ± 5	29
				>200	0.65 ± 0.14	0	3.1 ± 0.6	3
				>300	0.11 ± 0.02	0	0.55 ± 0.11	1
				>400	0.030 ± 0.006	0	0.15 ± 0.03	0
Tracker+TOF	>70	>0.125	>1.225	>0	8.5 ± 1.7	7	44 ± 9	42
				>100	1.0 ± 0.2	3	5.6 ± 1.1	7
				>200	0.11 ± 0.02	1	0.56 ± 0.11	0
				>300	0.020 ± 0.004	0	0.090 ± 0.02	0
Muon-only	>230	–	>1.40	–	–	–	6 ± 3	3
$\|Q\| > 1e$	–	>0.500	>1.200	–	0.15 ± 0.04	0	0.52 ± 0.11	1
$\|Q\| < 1e$	>125	>0.275	–	–	0.12 ± 0.07	0	1.0 ± 0.2	0

- **Set limits on**
  - **Cross-sections at 7TeV and 8TeV**
  - **Mass**

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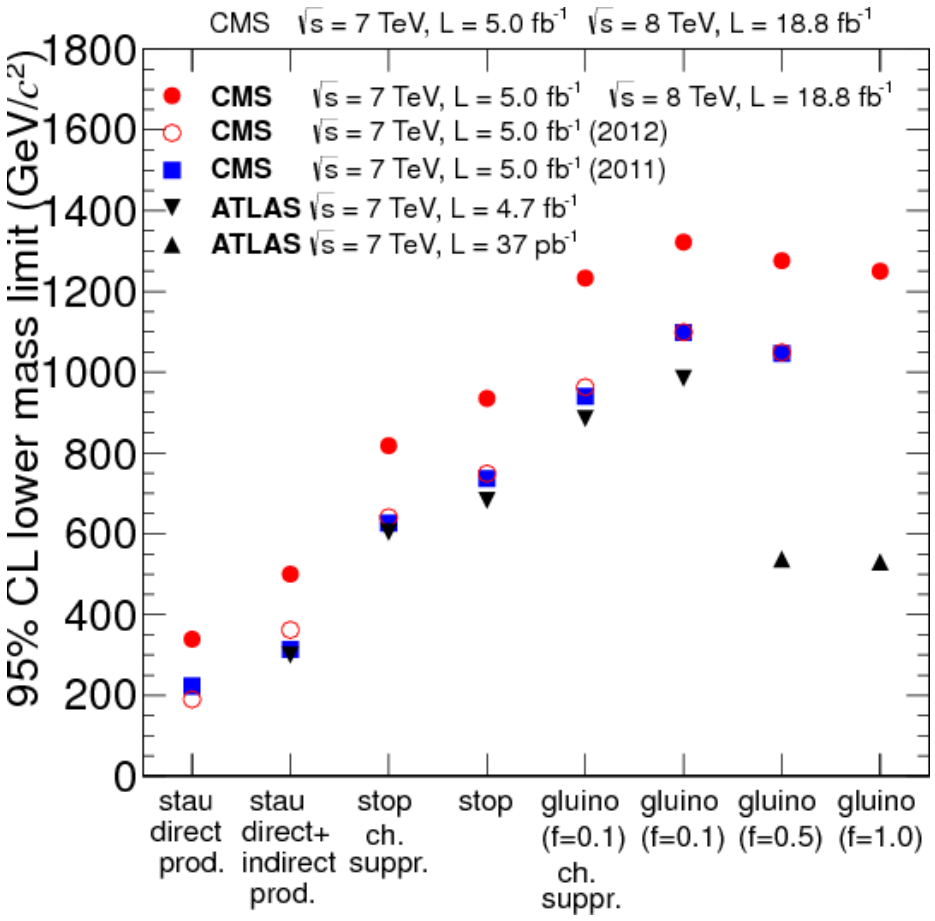
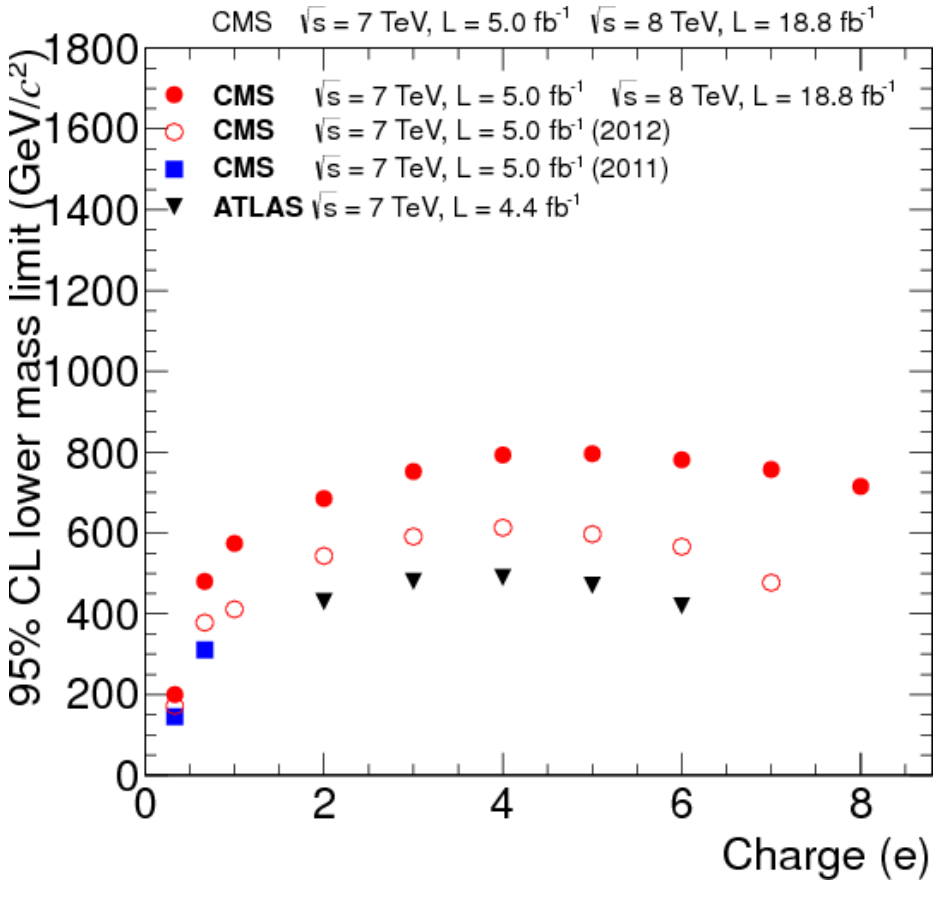
Mass Limit Summary





- Best limits to date on several long-lived particle classes
- M_{Gluino} > 1322GeV, M_{Stop} > 935GeV
- First CMS limits on gluino fully hadronizing into gluino balls (f=100%).
- Many more results in [arXiv: 1305.0491]

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Conclusion

Summary

- **CMS has a strong research program for Long-lived particles**

- **Displaced Jets (18.6fb^{-1}@8TeV)**
  - First CMS results on displaced jets
  - No excess observed
  - Set limit on a H→XX→(qq)(qq) (benchmark)
  - PAS contains material for results reinterpretation

- **Long-Lived Charged Particles (18.8fb^{-1}@8TeV + 5fb^{-1}@7TeV)**
  - Analyses performed using pT, dE/dx, TOF variables
  - No excess observed
  - Most stringent limits to date were set on
    - Leptons with $e/3 \leq |Q| \leq 8e$
    - Gluino (split SUSY) and Stop
      - Charge flipping, 10 to 100% Gluino-balls, 2 nuclear interaction scenarios

- **Results shown are available** https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsEXO

- **Stay tuned for more long-lived physics results**

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Thank you….

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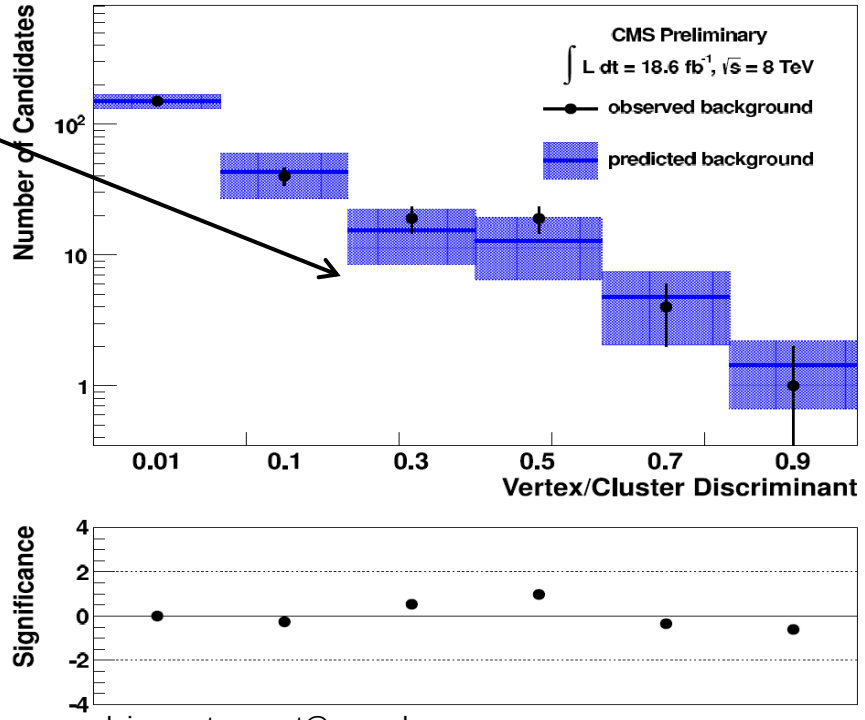
Backups

Background prediction

- 3D-ABCD-technique used since the 3 selection variables are uncorrelated for backgrounds and fully correlated for signal.
  - Jet1 properties
  - Jet2 properties
  - Secondary Vertex properties
- Signal region H is predicted using control regions: **$H=BCD/A^2$**
  - Systematic uncertainty evaluated using other combination of regions:
  - H=FG/B or EG/C or EF/D or DG/A or BE/A or CF/A

- A **control region** is used to check the background prediction on data
- Consider dijet pairs that have <#missing hits per track> > 2 instead of <#missing hits per track> < 2 for the signal region
- A good agreement is found between data and background prediction



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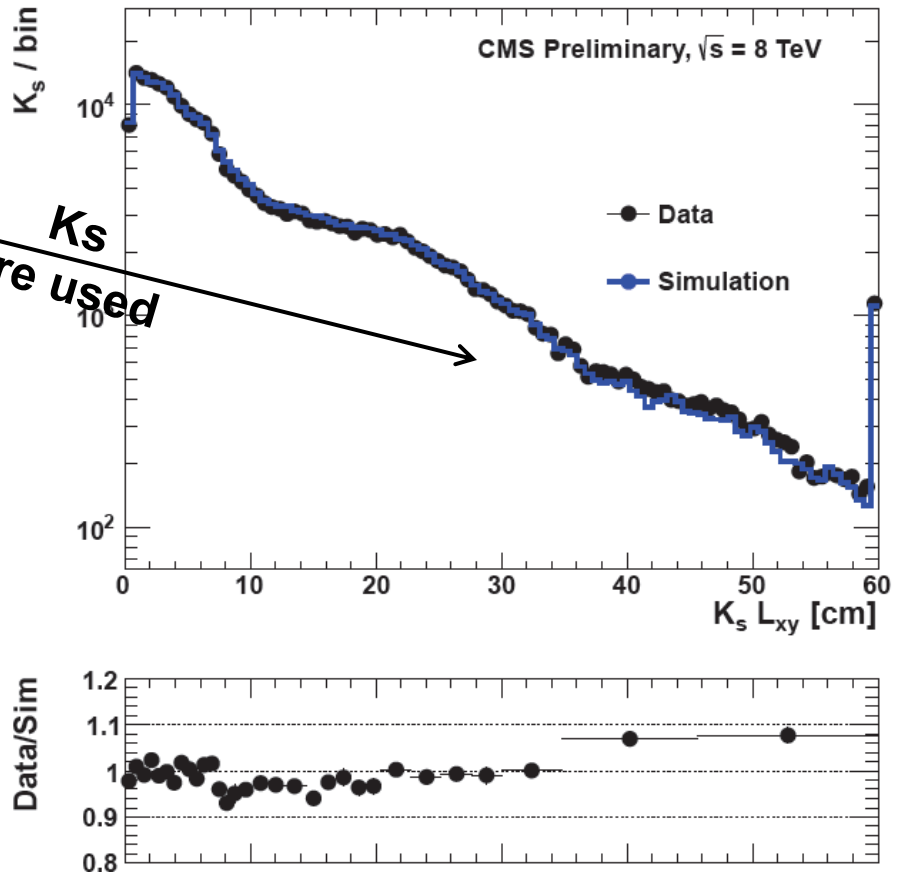
Displaced Jets: Syst. Uncertainties

- Systematic uncertainties on Signal Efficiency

Source	Uncertainty
Pile-up modelling	2%
Jet energy scale	3–5%(*)
Jet momentum bias	1–5%
Trigger efficiency	6%
Tracking efficiency	4%
Total	8–10%

Ks are used



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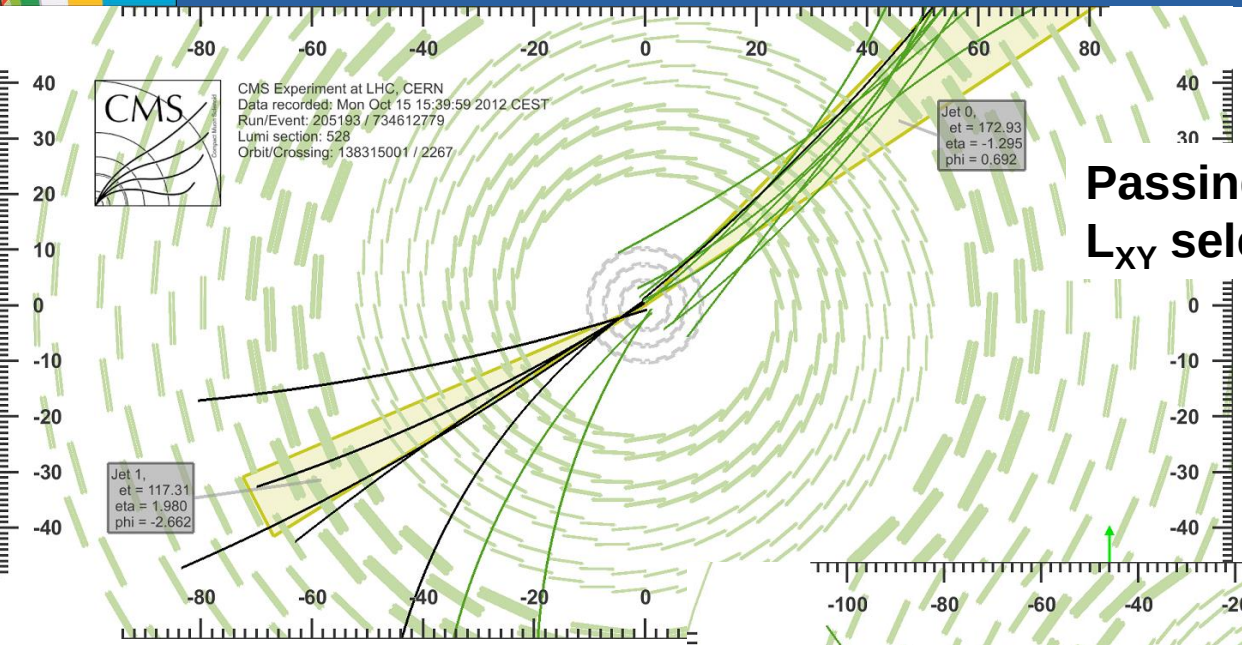
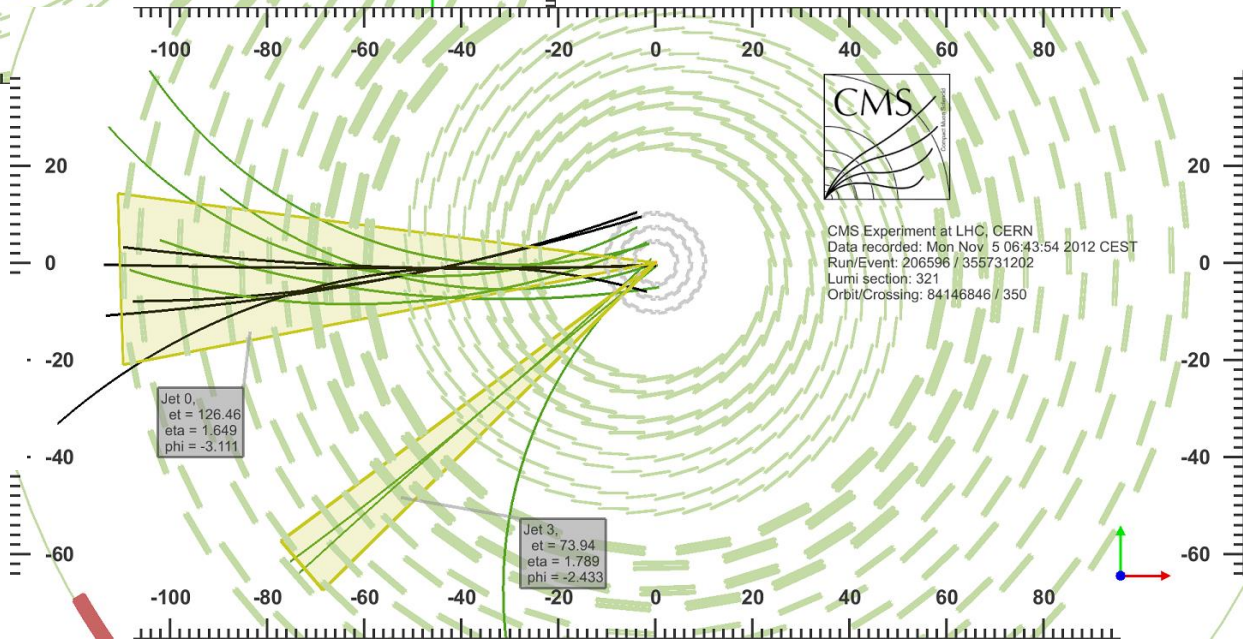
Displaced Jets: Syst. Event Display



Passing low L_{XY} selection

Passing low and high L_{XY} selections



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HSCP: Uncertainties

- **Uncertainty is evaluated model by model**

Signal acceptance	$\|Q\| < 1e$	Tracker-only	Tracker+TOF	$\|Q\| > 1e$	Muon-only
— Trigger acceptance	<16%	<7%	<7%	<6%	7%
— Track momentum scale	< 10%	<4%	< 3%	<10%	<10%
— Track reconstruction eff.	<25%	<2%	<2%	<2%	–
— Ionization energy loss		<18%	<15%	<12%	–
— Time-of-flight	–	–	<2%	<15%	<3%
— Muon reconstruction eff.	–	–	2%	2%	2%
— Pile-up	<2%	<2%	<2%	<2%	<4%
— Detector material	<1%	<1%	<1%	20%	<1%
Total signal acceptance	<31%	<32%	<31%	<29%	<13%
Expected collision bckg.	20%	20%	20%	20%	20%
Expected cosmic ray bckg.	50%	–	–	–	80%
Integrated luminosity	2.2% (4.4%) for $\sqrt{s} = 7$ (8) TeV				

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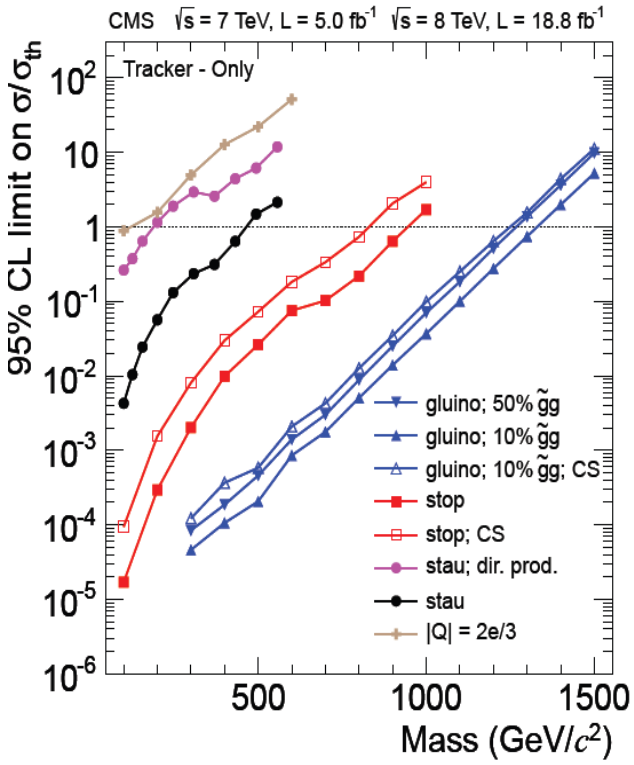
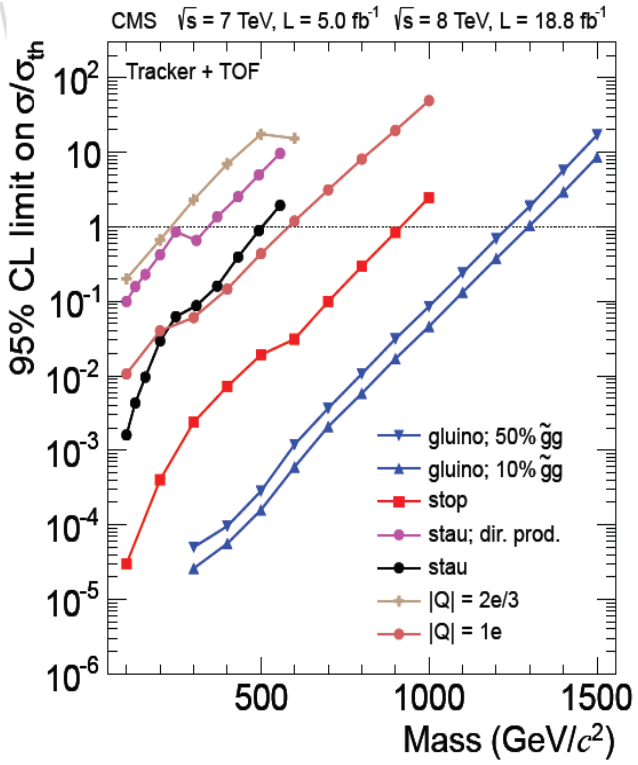
HSCP Limit setting

- **Counting experiment**
  - **For Tk-Only and TkTOF, counts in a mass window [$M_{reco} - 2\sigma_{reco}$, +inf]**
- **Set limit on cross-sections (at 7 and 8 TeV) and on Signal Stength**

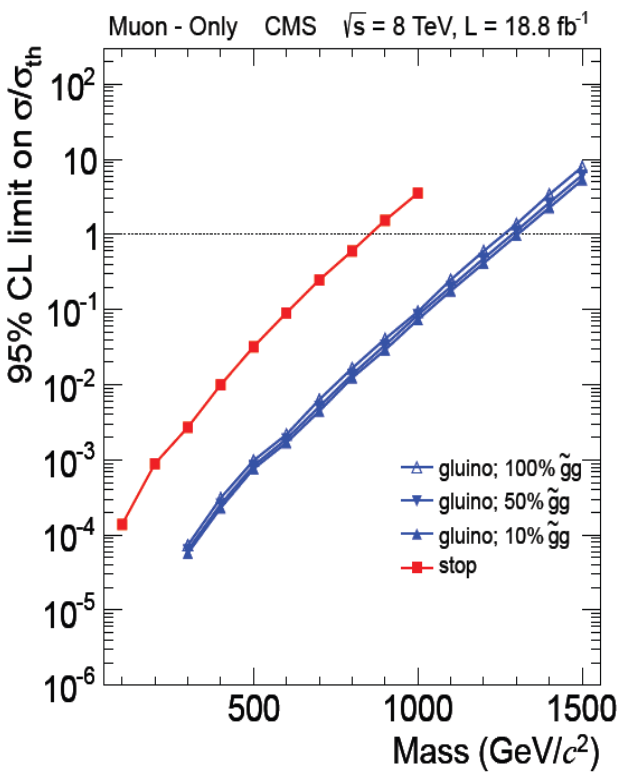
TK-Only



TK+TOF



Muon-Only



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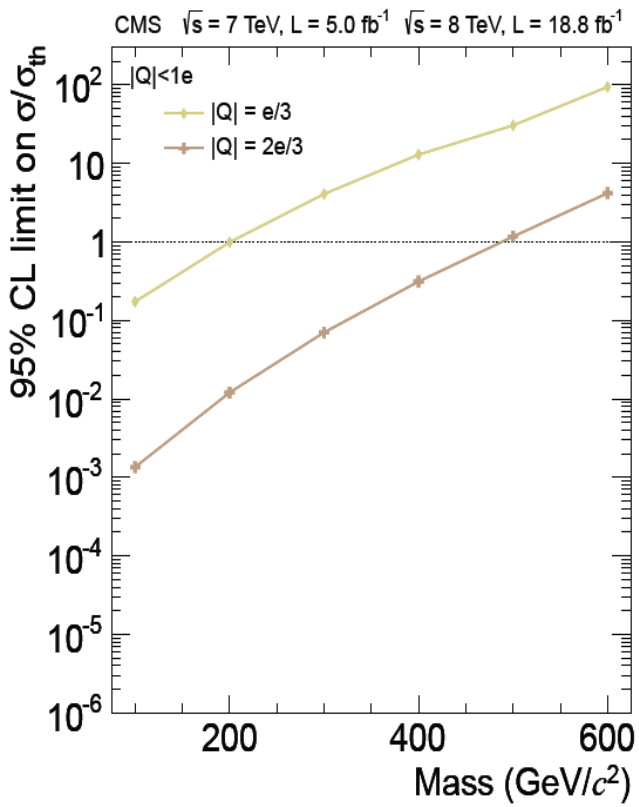
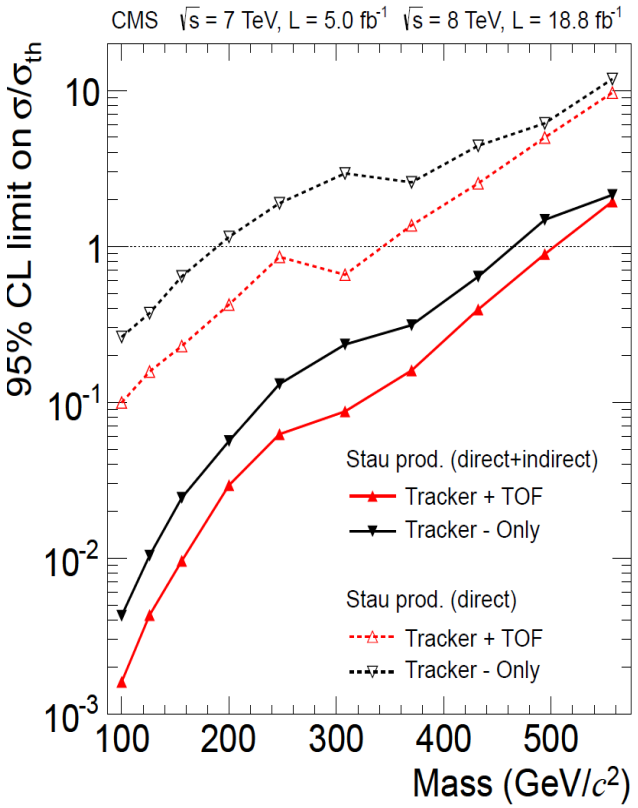
HSCP Limit setting

(Stau in GMSB)

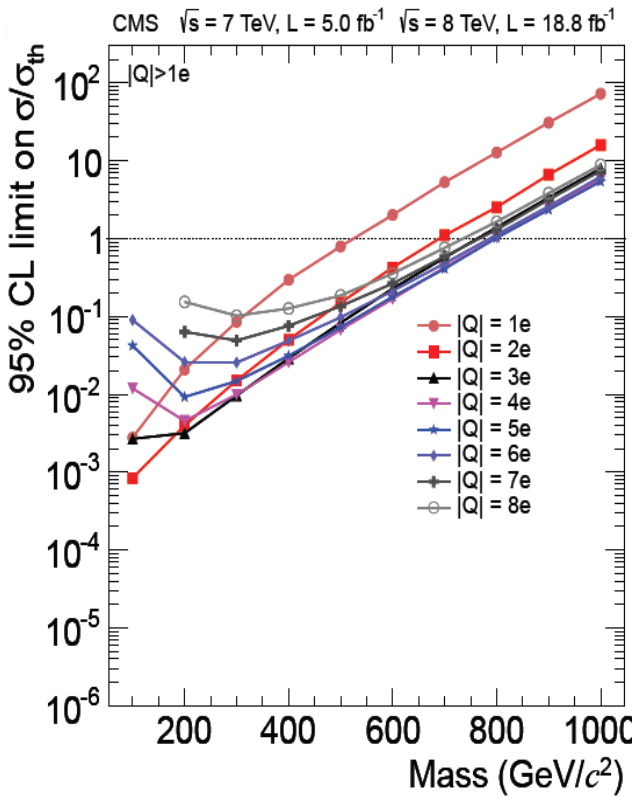
|Q| < e



|Q| = e



|Q| > e



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HSCP Limit setting

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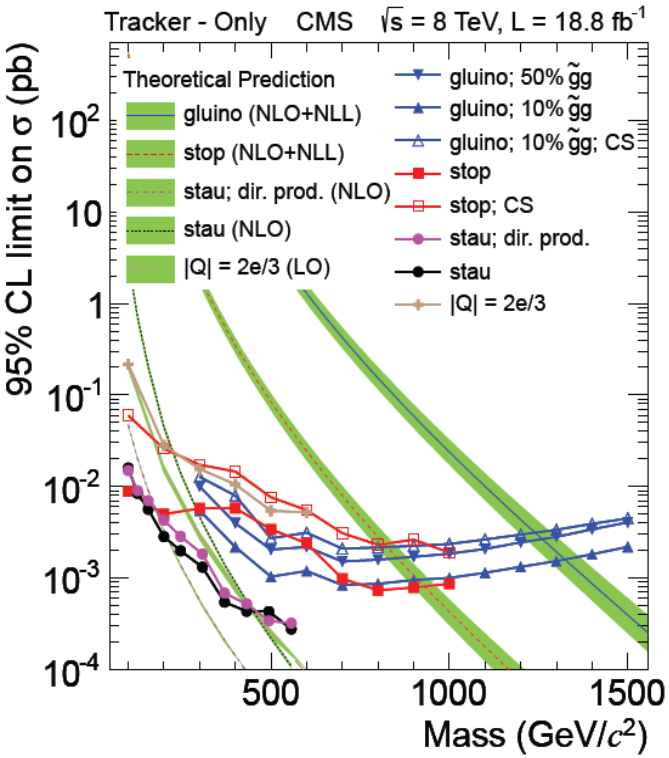
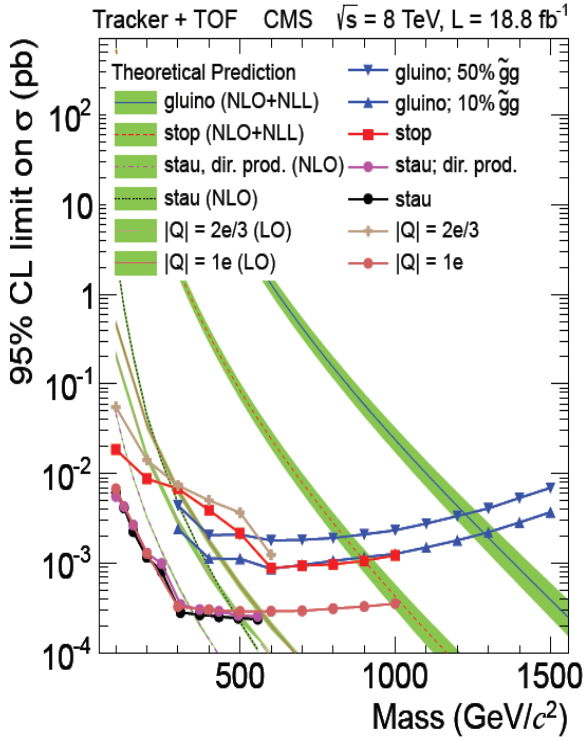
  - **For Tk-Only and TkTOF, counts in a mass window [$M_{reco} - 2\sigma_{reco}$, +inf]**

- **Set limit on cross-sections (at 7 and 8 TeV) and on Signal Stength**

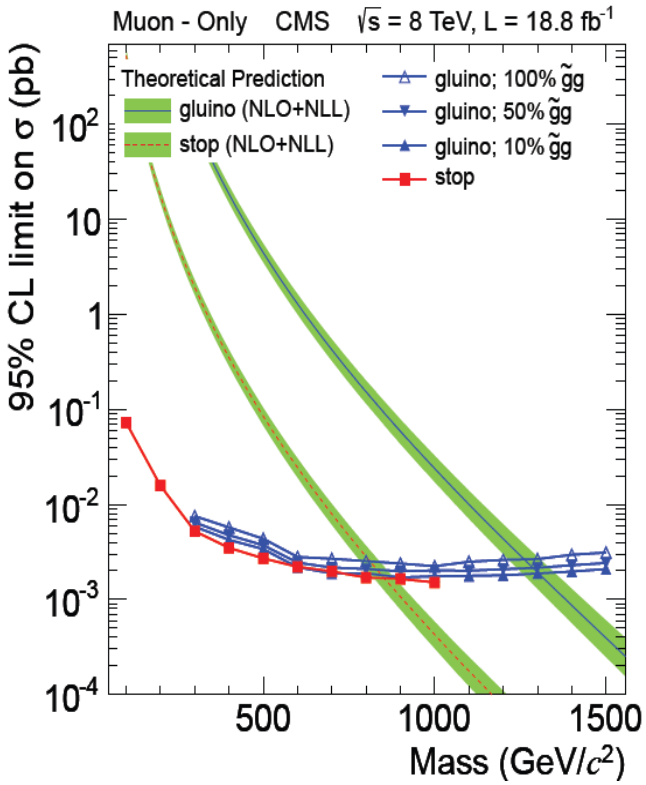
TK-Only



TK+TOF



Muon-Only



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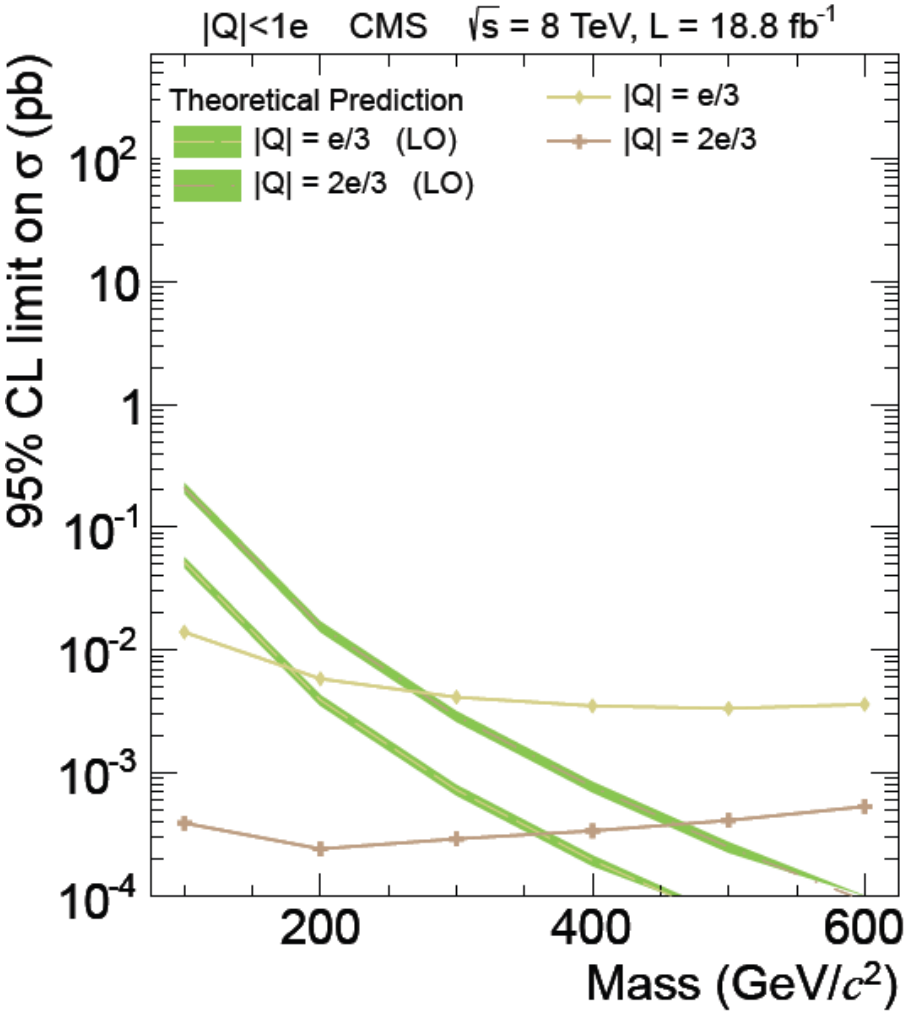
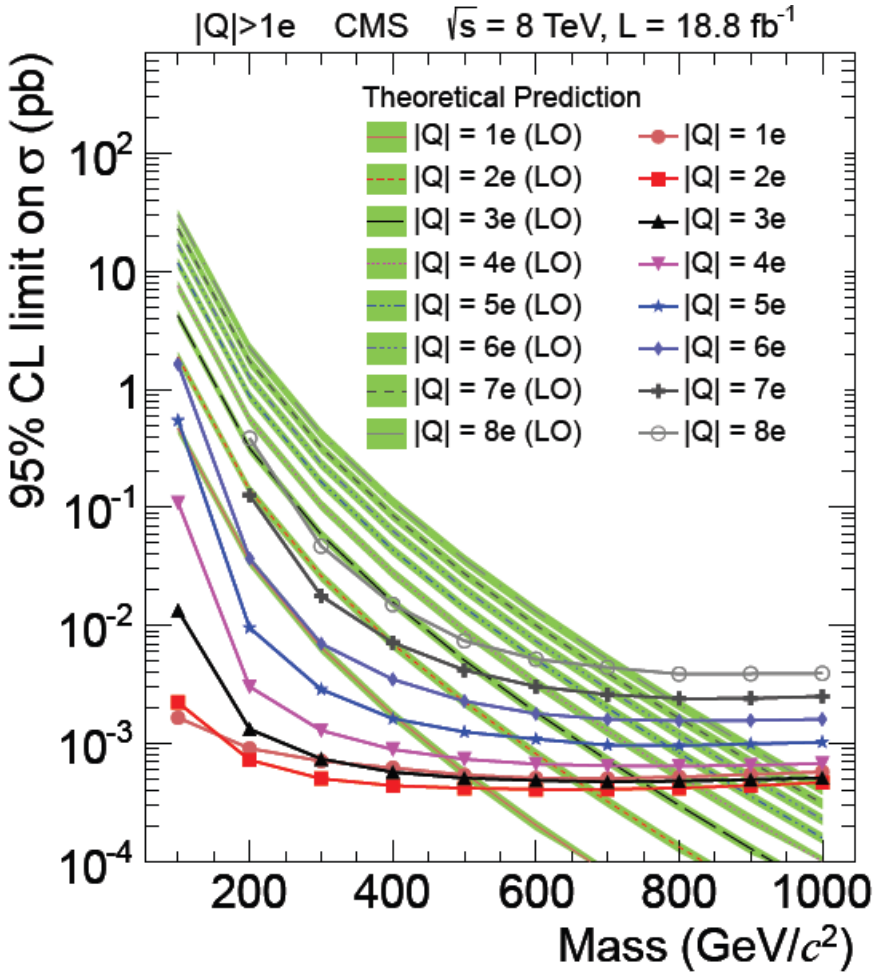
HSCP Limit setting

|Q| < e



|Q| > e



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