Experimental challenges for long-lived fourth generation

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CMS
Compact Muon Solenoid

outline

- introduction
  - ★why think about long lifetimes?
- current direct searches
  - ★ignoring long lifetimes?
- searches for long-lived exotic particles
  - ★displaced leptons
  - ★heavy stable charged particles
  - ★can we learn anything for 4th generation?
- conclusion
  - ★is long-lived 4th generation experimentally accessible?
  - ★how to proceed?

introduction

- small mixing between 4th and 3rd generation could lead to long-lived states

$$\Gamma^{Q_1}_{2,W} = \frac{G_F (m_{Q_1})^3}{8\pi\sqrt{2}} |V_{Q_1 Q_2}|^2 I_{2\,\mathrm{body}}(m_{Q_2}/m_{Q_1}, m_W/m_{Q_1})$$

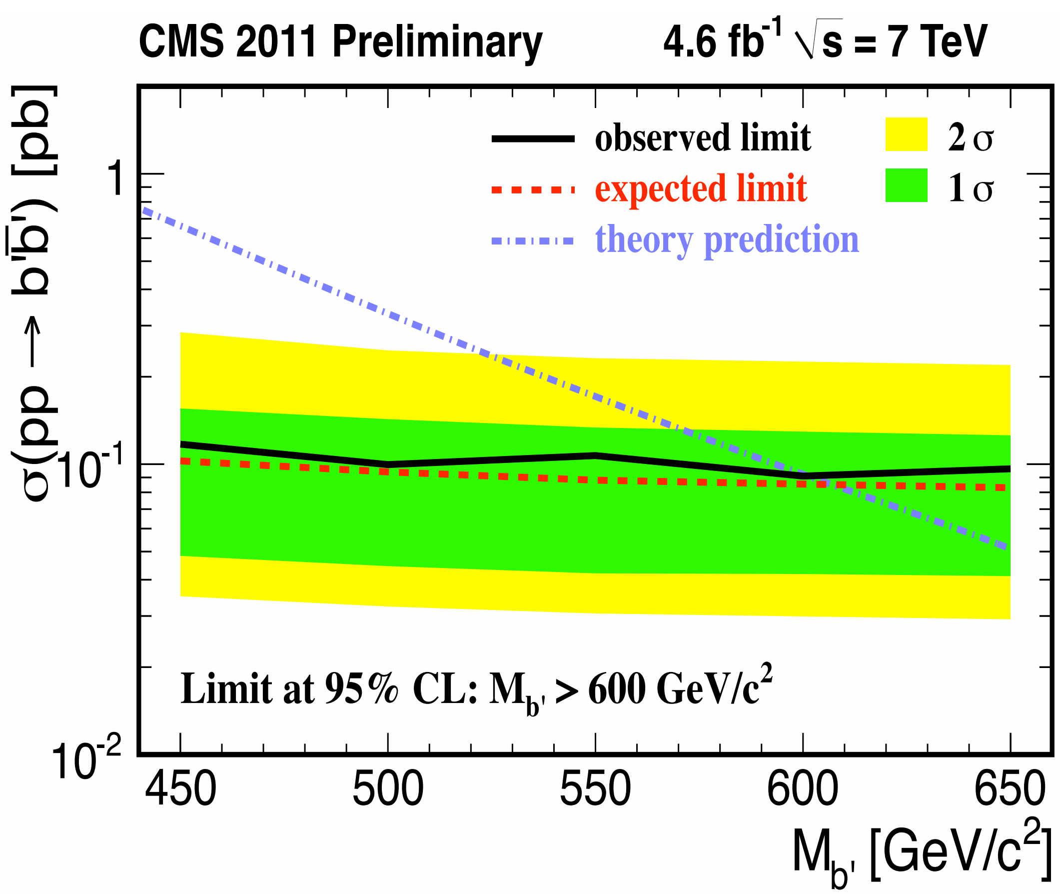
- heavy mesons like $(t'\overline{q})$ or quarkonia $(b'\overline{b'})$ could be formed (or heavy leptons)

- short lifetimes: immediate decay (no experimental difference to prompt decay)
- intermediate: decay within detector (displaced vertex)
- long lifetimes: heavy high-momentum ionizing particle propagating through full detector

current searches

example: CMS search for b’ pairs:

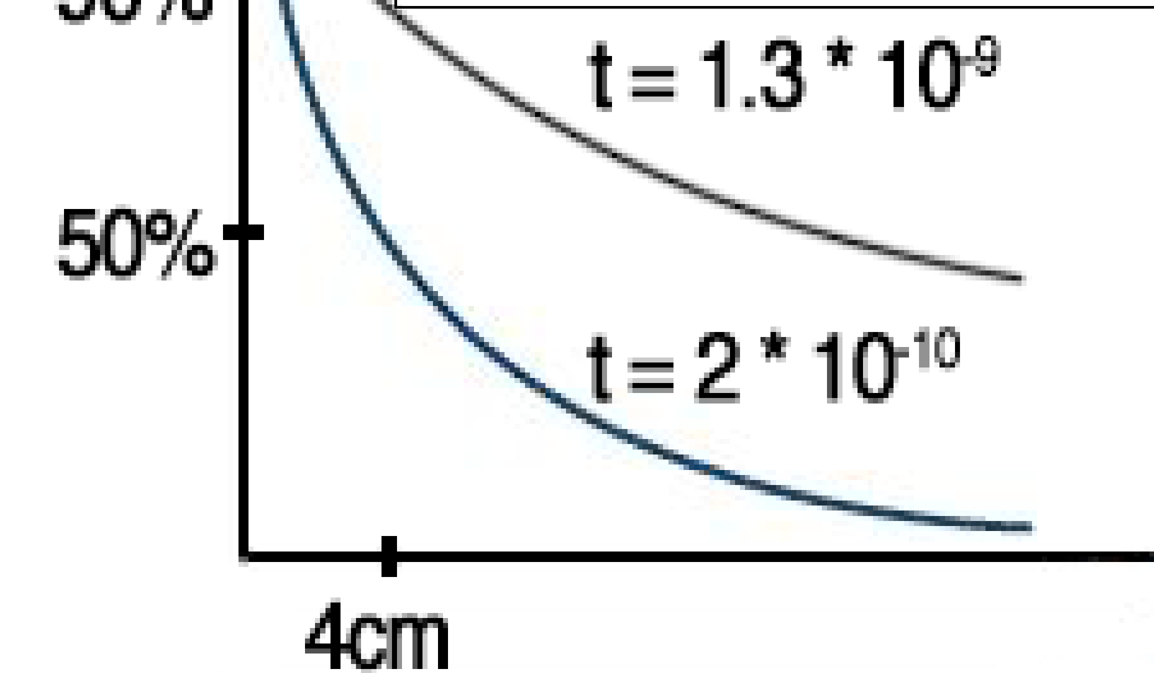
- observed **12** same-sign di-lepton events with b-tagged jet
- standard b-tagging is **inefficient** beyond 1st pixel layer (4cm)



exponential decay:

example: m=500GeV p_t=500GeV

50% events lost for $\tau=2\cdot10^{-10}$s
90% events lost for $\tau=1.3\cdot10^{-9}$s
99% events lost for $\tau=1.3\cdot10^{-8}$s
(including the Lorentz factor)



displaced leptons

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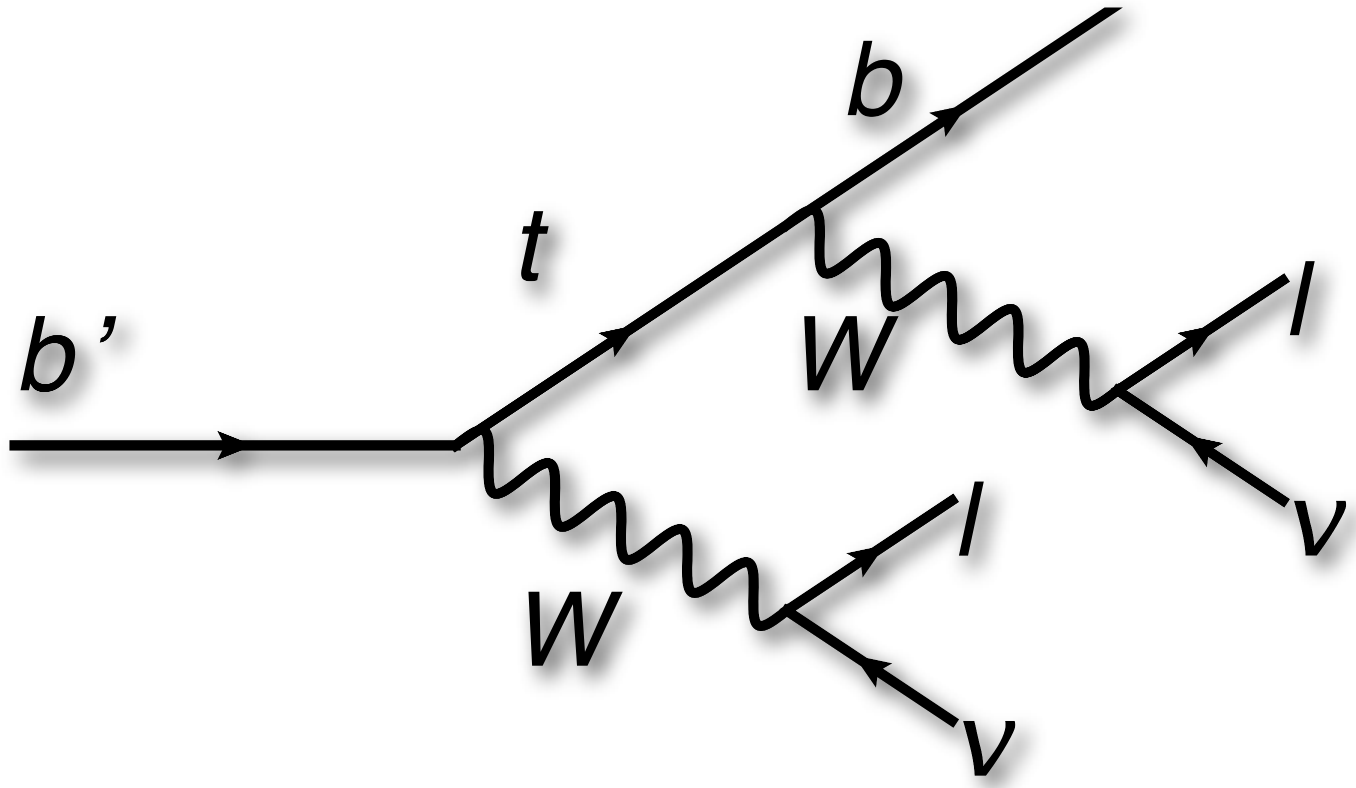
- CMS search for $X \rightarrow l^+l^-$, where e.g. $H^0 \rightarrow XX$
- X is spinless long-lived neutral particle
- topology of two leptons from one displaced vertex **in the tracker**

- topology of a di-leptonic b' decay is similar



....should have a closer look....

displaced leptons: challenges

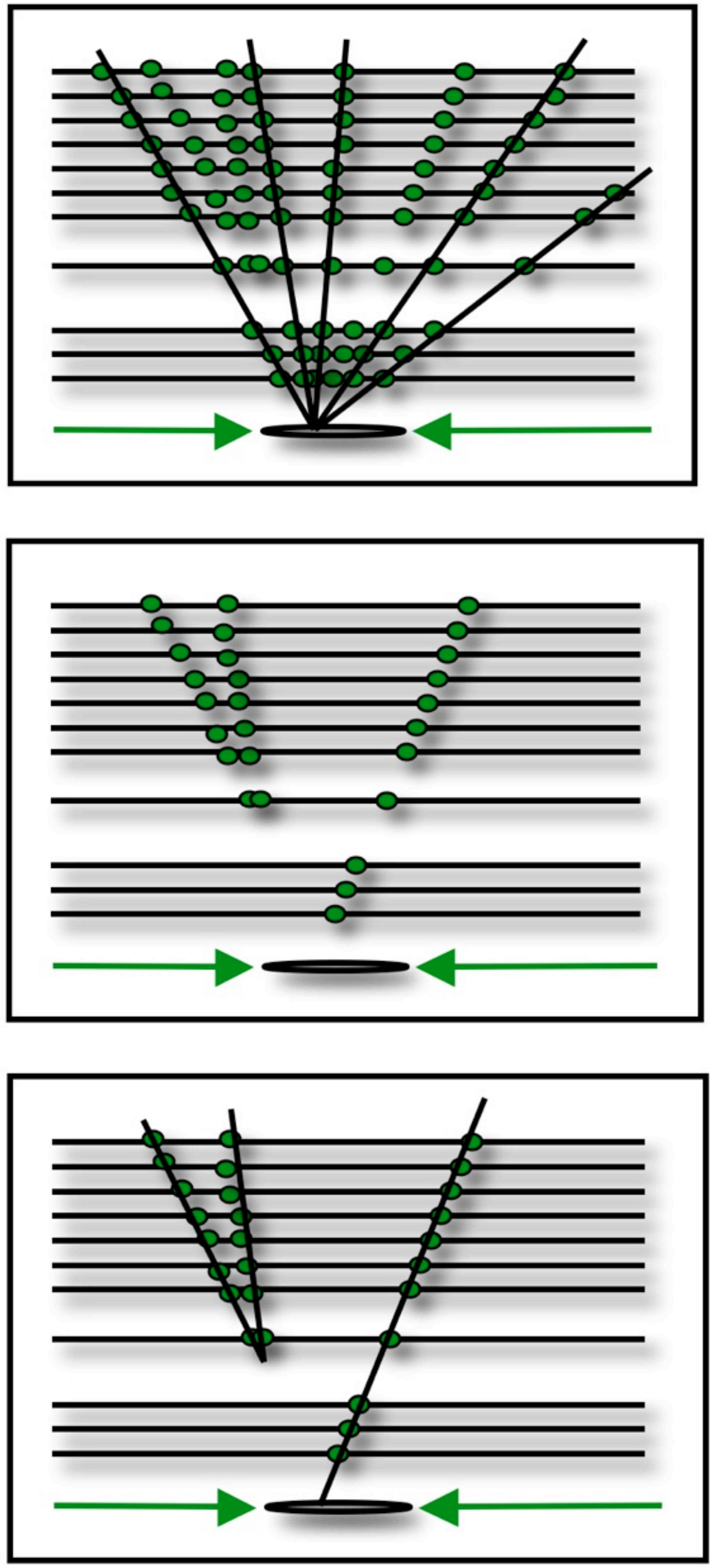
displaced track reco: iterative tracking

six iterations:

- propagate seed outwards, search new hits
- assigned hits are removed from the list
- filter tracks to remove fakes or bad tracks
- repeat with remaining hits

differences in seeding:

- first two iterations: pixel pairs or pixel triplets, p_t>0.9GeV
- third iteration: pixel triplets, low momentum tracks
- fourth iteration: pixel + strip layers as seeds (find displaced tracks)
- fifth, sixth iterations: strip pairs (for tracks lacking pixel hits)



efficiency measurement

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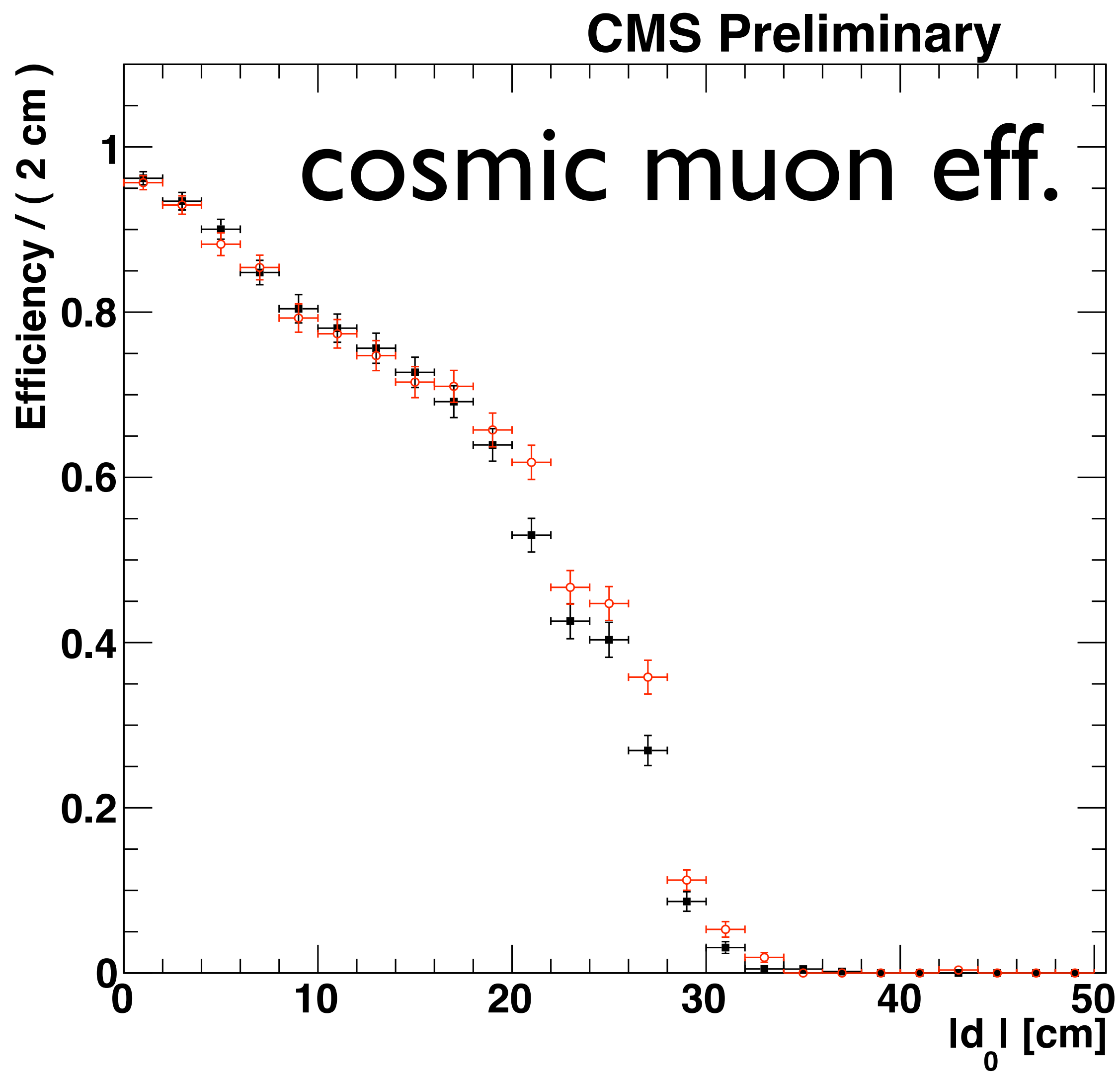
three methods for displaced tracks:

- cosmic muons
  - ⋆reconstructed (tagged) from muon chambers only
  - ⋆matched to tracker tracks
  - ⋆agrees with simulation to 10%
- embedding method
  - ⋆simulated displaced muons embedded into a real data event
  - ⋆measures how often high occupancy affects tracking eff.
- validation with K_s
  - ⋆K_s lifetime measurement in 1% agreement with world average



event selection

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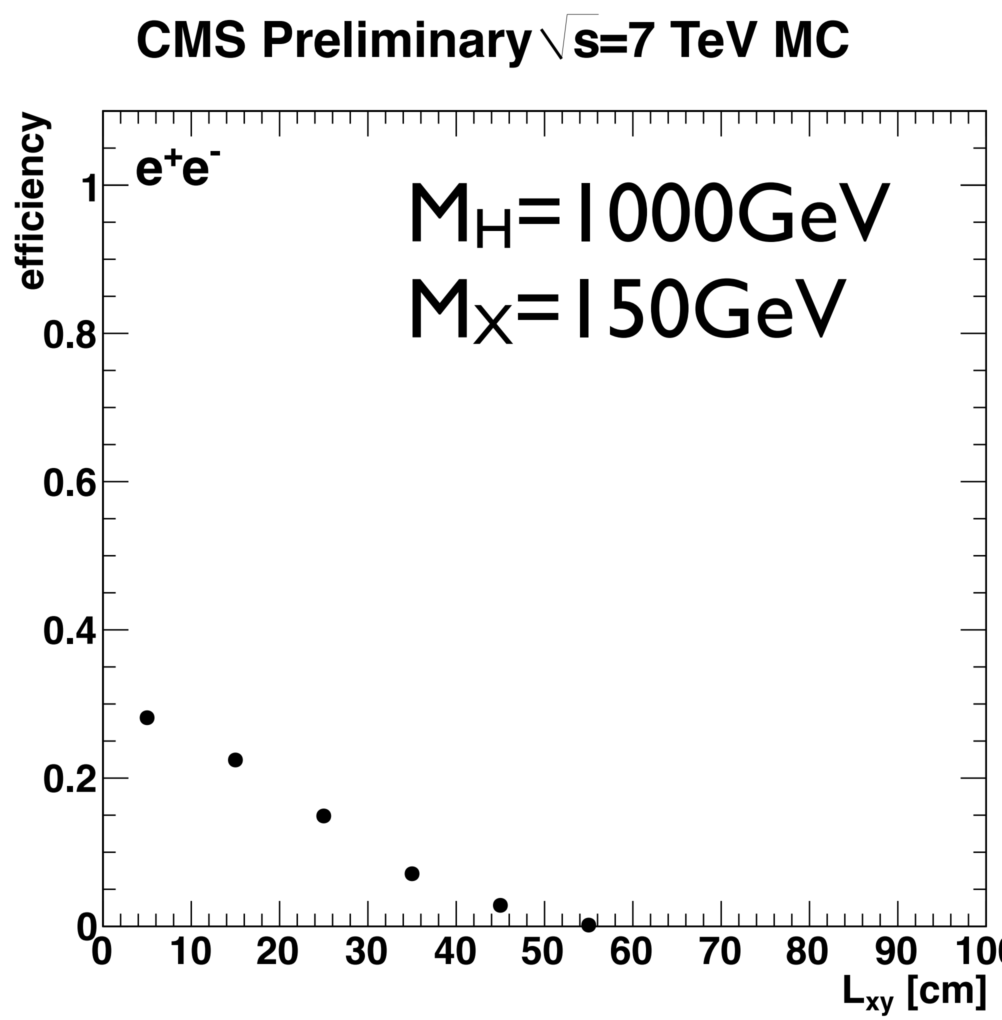
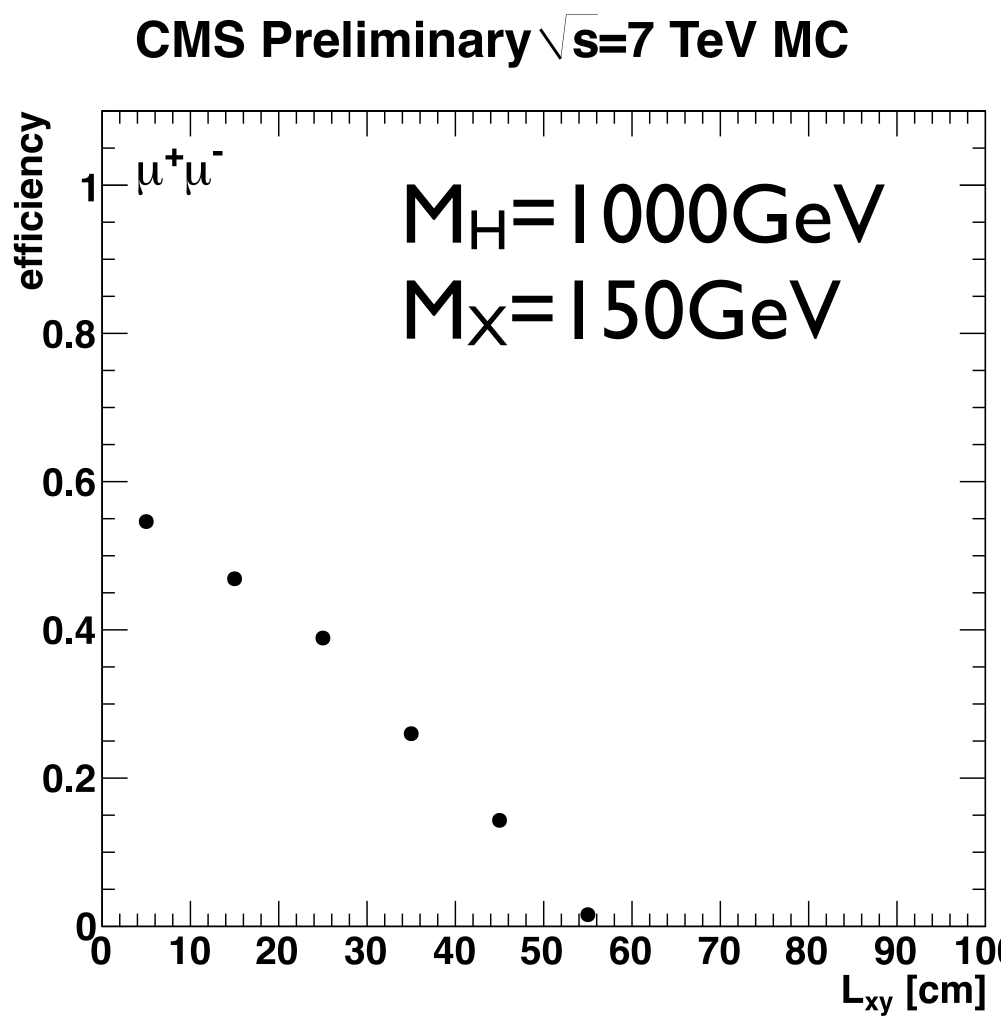
- two opposite sign isolated leptons
- $p_t > 38$ (25) GeV for electrons (muons)
- $|d_0/\sigma| > 3$ (2) for el. (mu.), reject prompt background
- vertex fit with two lepton tracks $X^2/ndf < 5$
- di-lepton momentum collinear with vertex direction

→ **this is the cut that kills b'**





mass distribution

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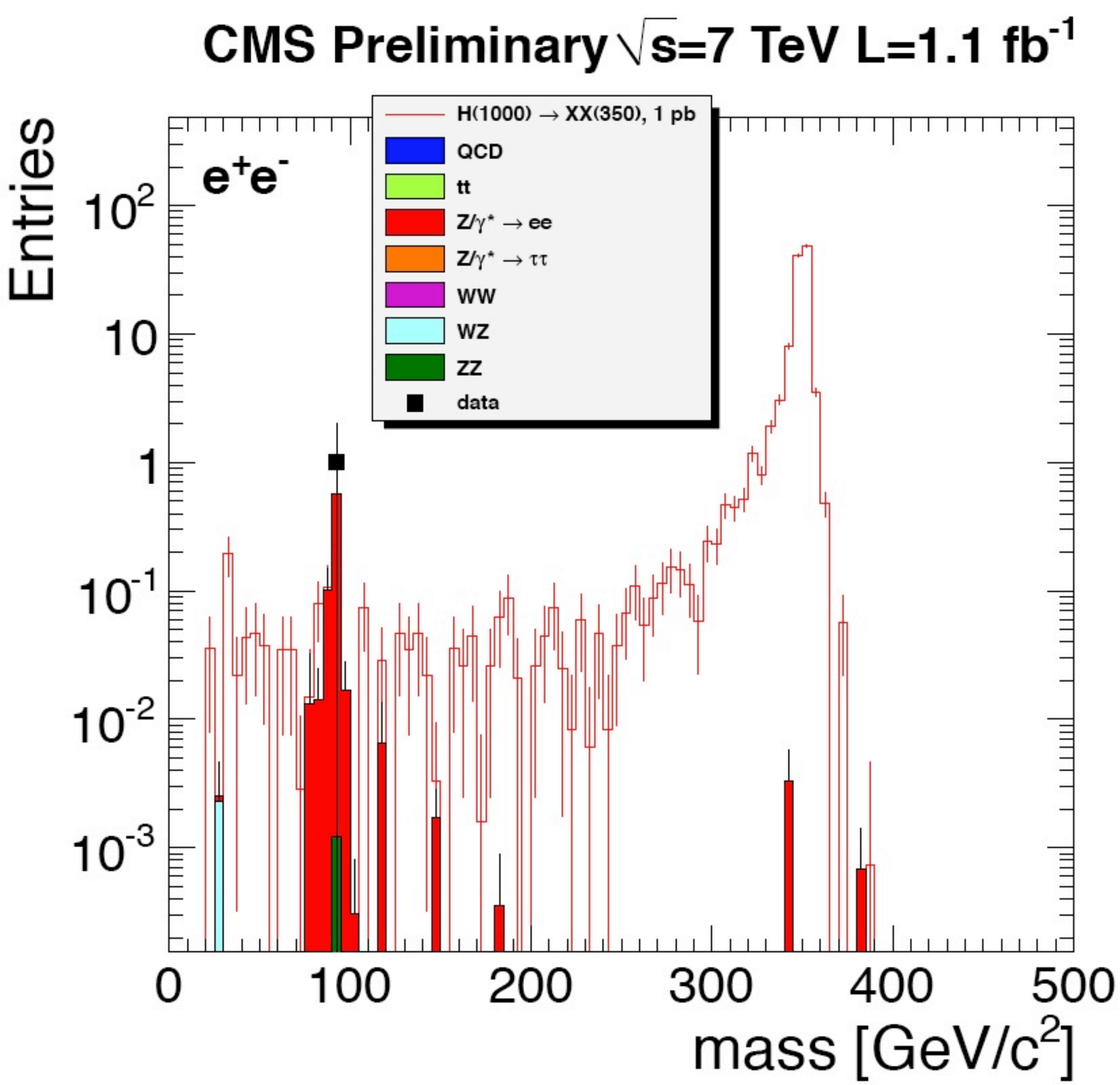

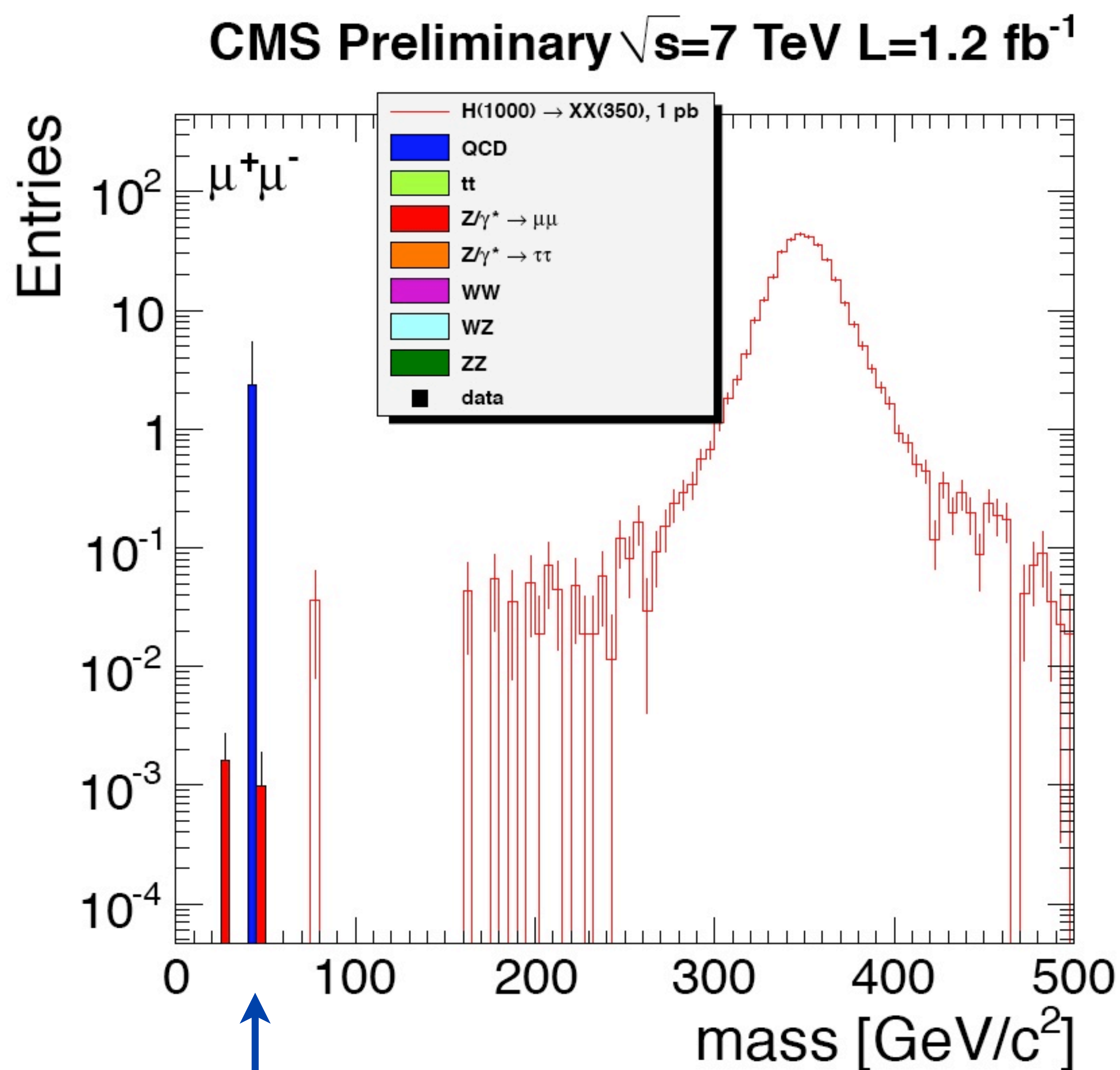

1 observed event in data at Z peak

one simulated event with large weight

limits

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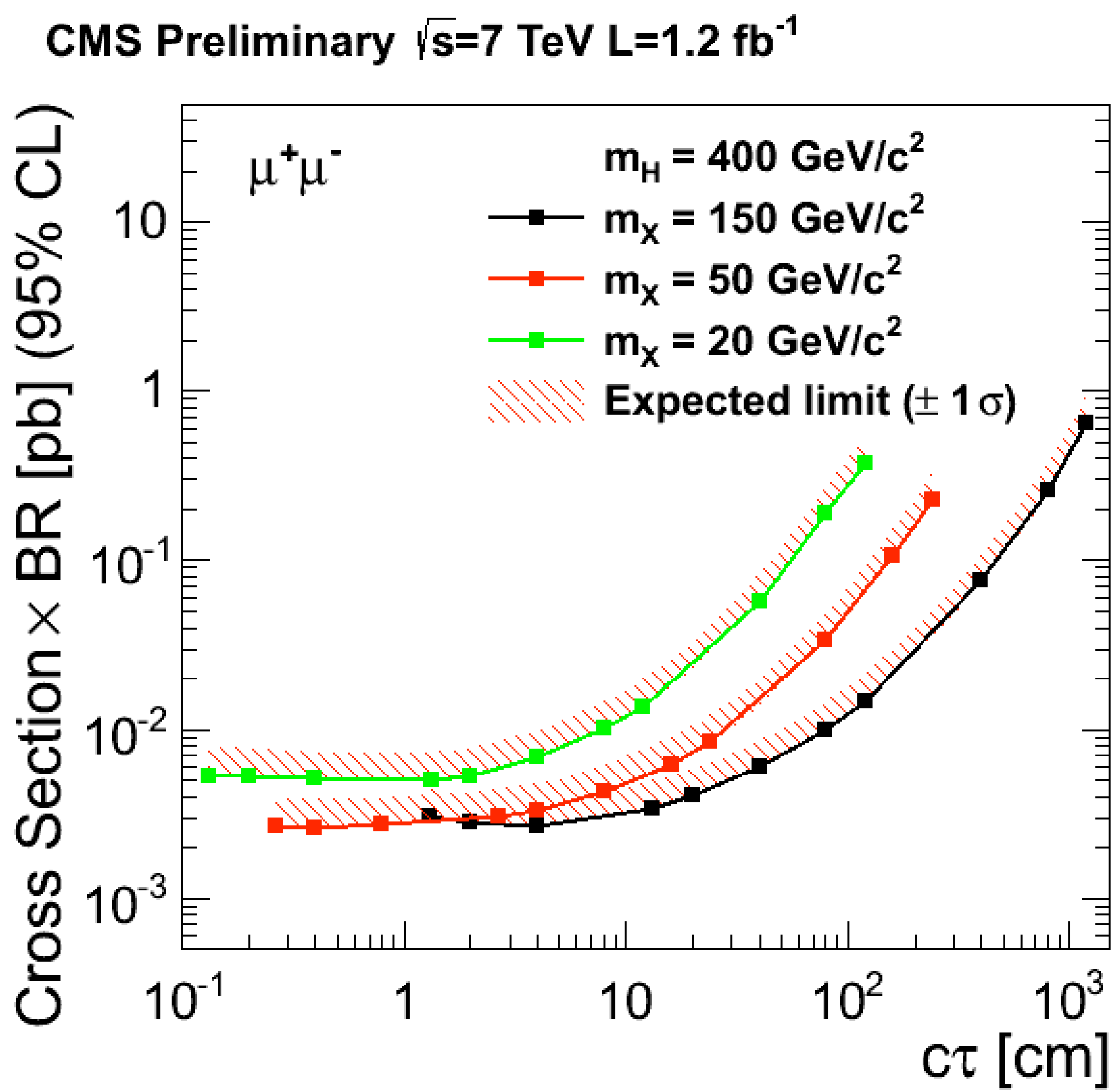
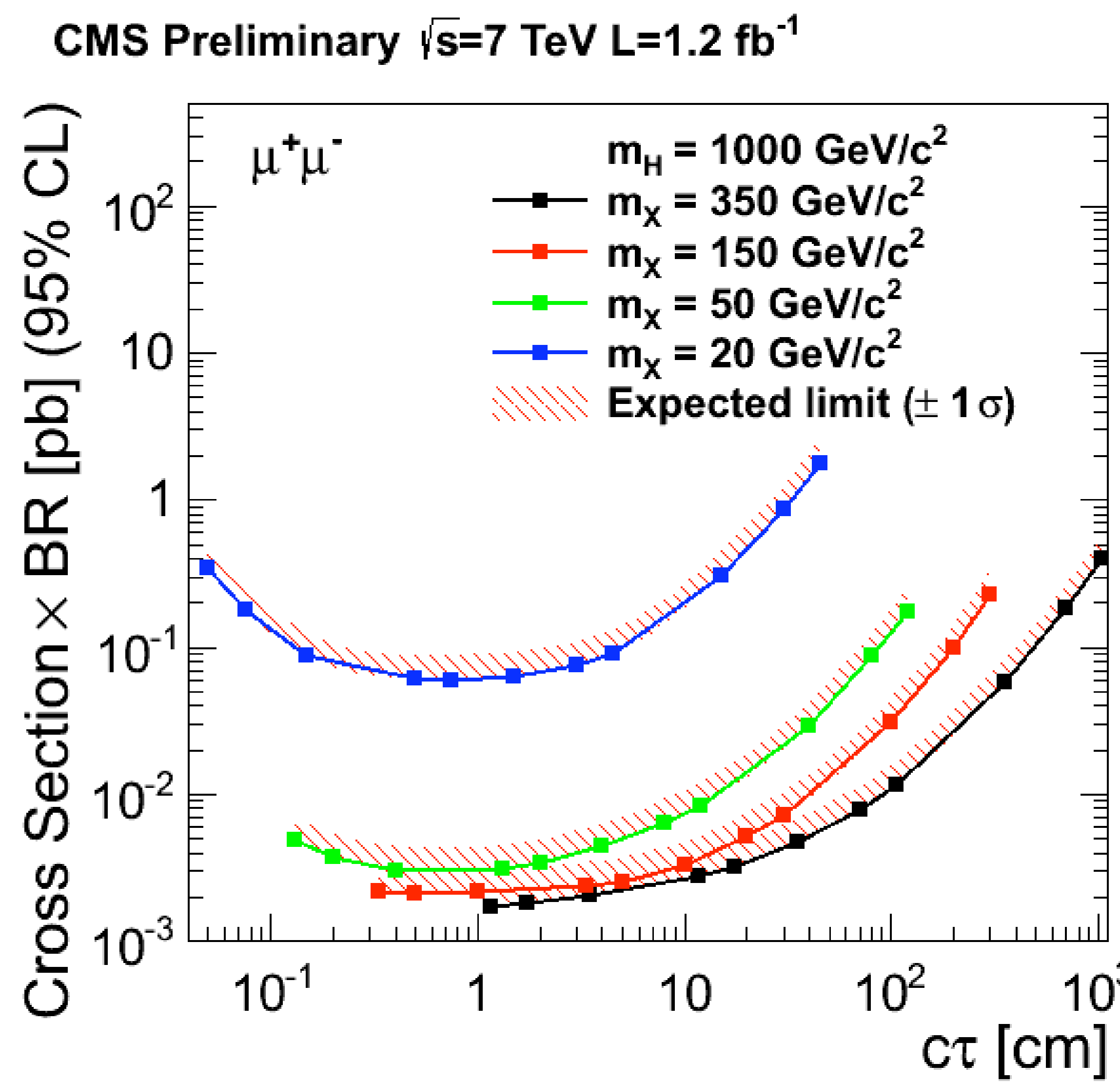




for comparison: σ*BR(dileptons) for b' pair production:

$m_{b'}$=400 GeV	0.11 pb
$m_{b'}$=500 GeV	0.026 pb
$m_{b'}$=600 GeV	0.0074 pb

what do we learn, plans?

- limits are **in the range** of 4th gen. cross-sections!!!

- limits are not applicable to 4th gen. due to cuts that would reject b'
- 4th gen. has different kinematics, acceptance, etc...

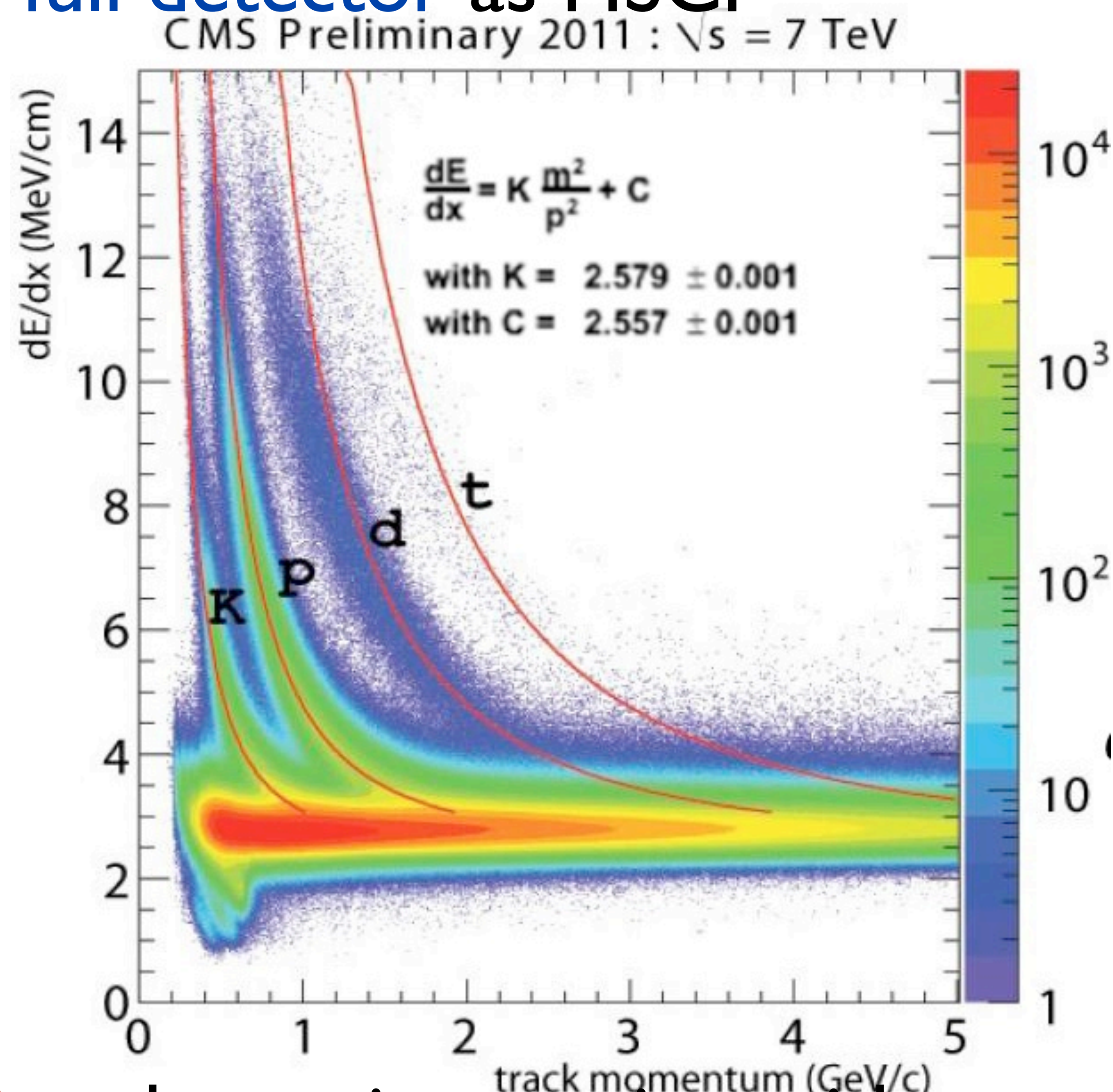
- it is worth including 4th gen. to these existing searches, effort should be moderate

- discussions with CMS working group ongoing

- to be continued (with results??) at next workshop...

heavy stable charged particles

- bound q' state propagates through full detector as HSCP



- directly observable through distinctive signature:
  - high **momentum**
  - large **energy loss** (ionization) dE/dx
  - long **time-of-flight** (TOF)

- many searches assume particles to reach the muon system (HSCP identified as muon)

- new studies favor charge suppression due to interaction with matter (calorimeter) ➔ HSCP not identified as muon

- CMS search done with and without muon system

principle

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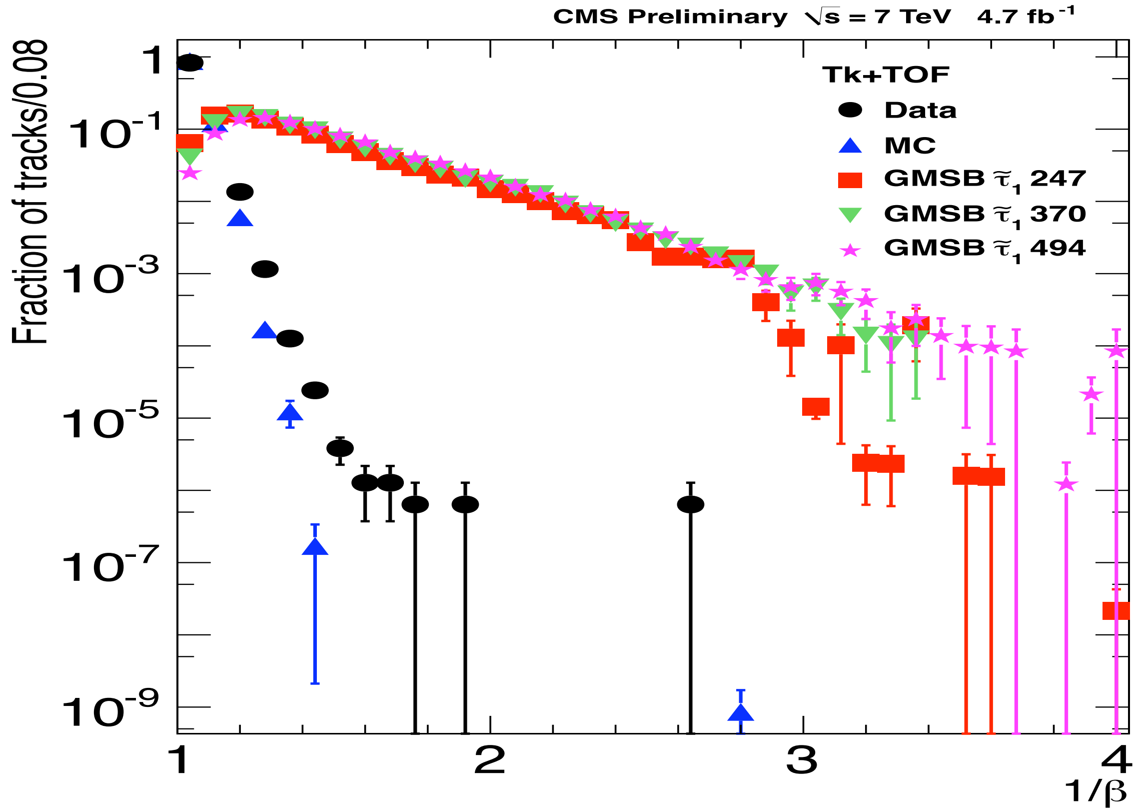
- **trigger**: high-p_t muon or high missing energy
- TOF from off-time arrival δ_t in muon chamber

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

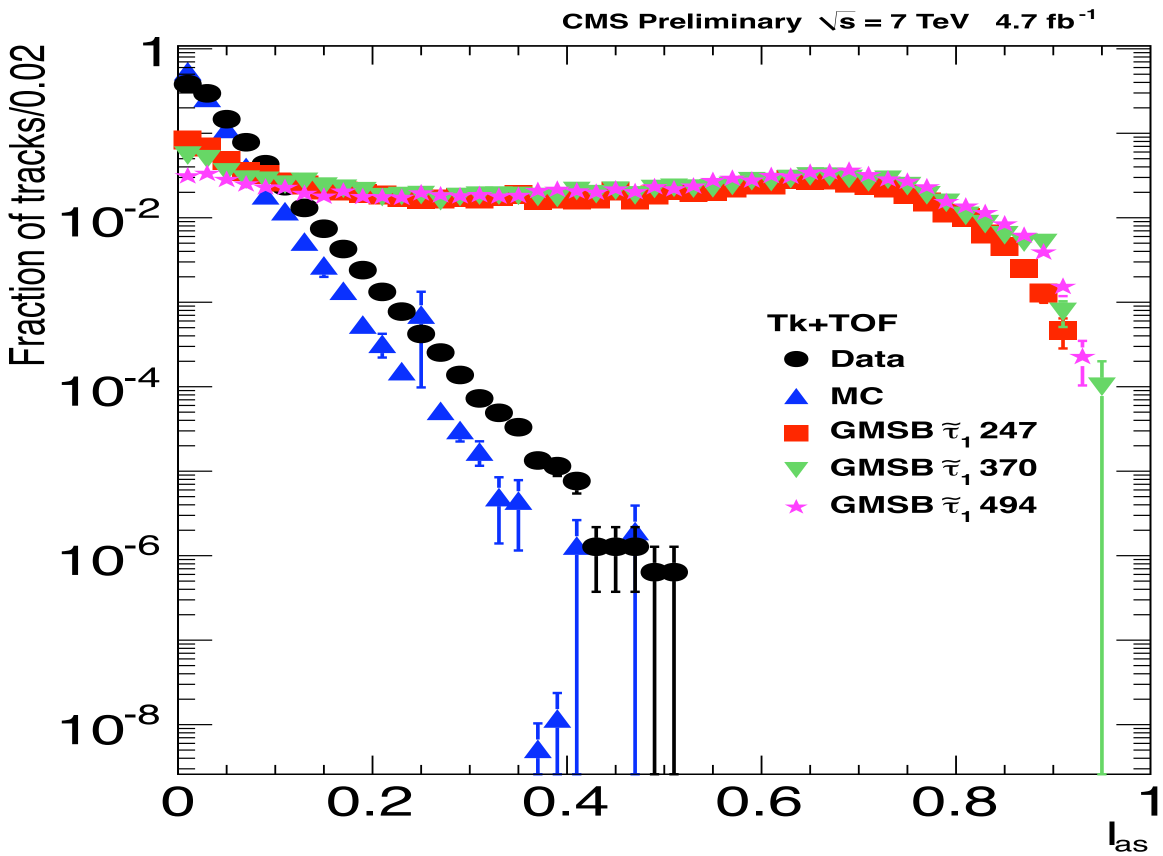


- dE/dx estimators from charge deposited in silicon detectors

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

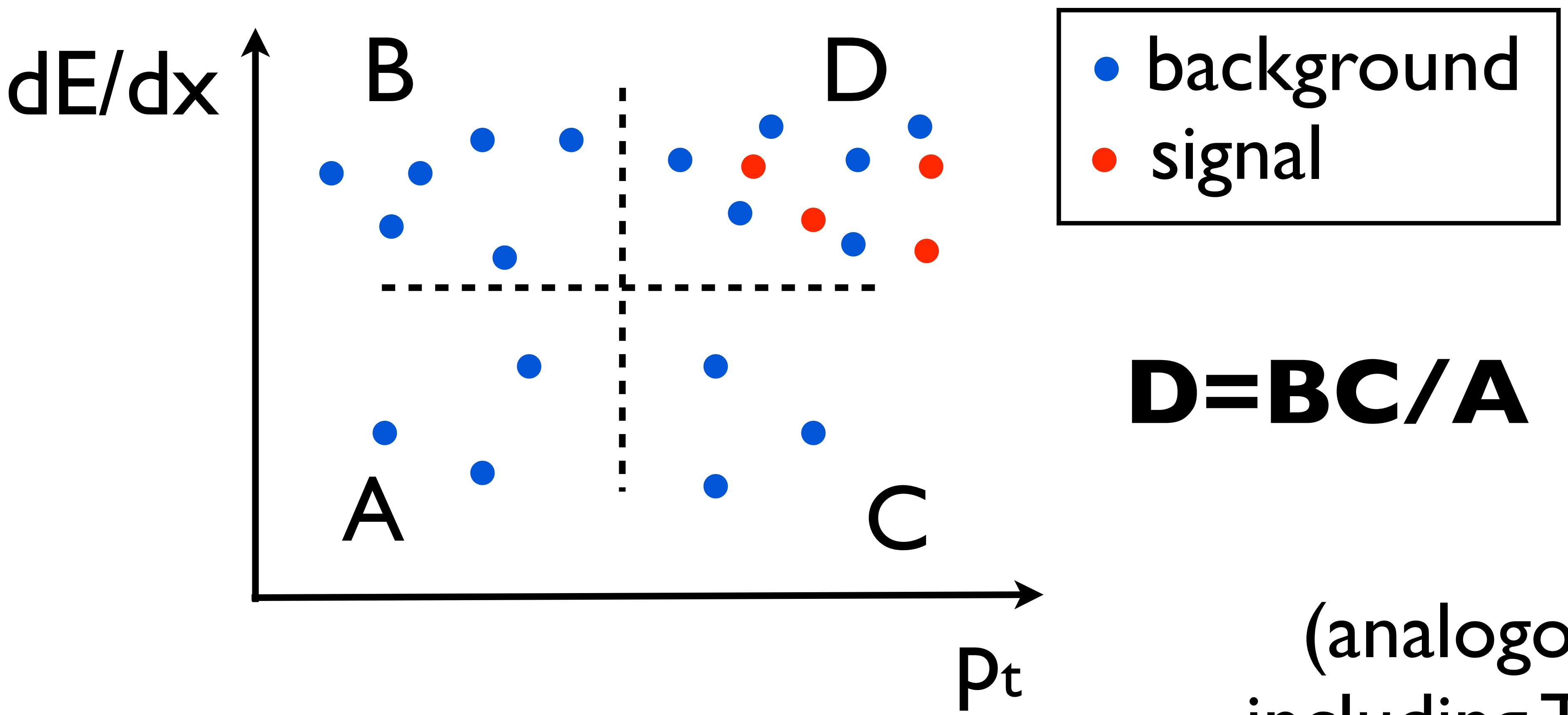
$$I_{as} = \frac{3}{N} \times \left(\frac{1}{12N} + \sum_{i=1}^{N}\left[P_i \times \left(P_i - \frac{2i-1}{2N}\right)^2\right]\right)$$

(P_i=probability for a MIP to produce charge deposit smaller than the i-th)



background determination

- p_t and dE/dx uncorrelated for background
- use ABCD method to predict background in the signal region



D=BC/A

(analogously including TOF...)

mass determination

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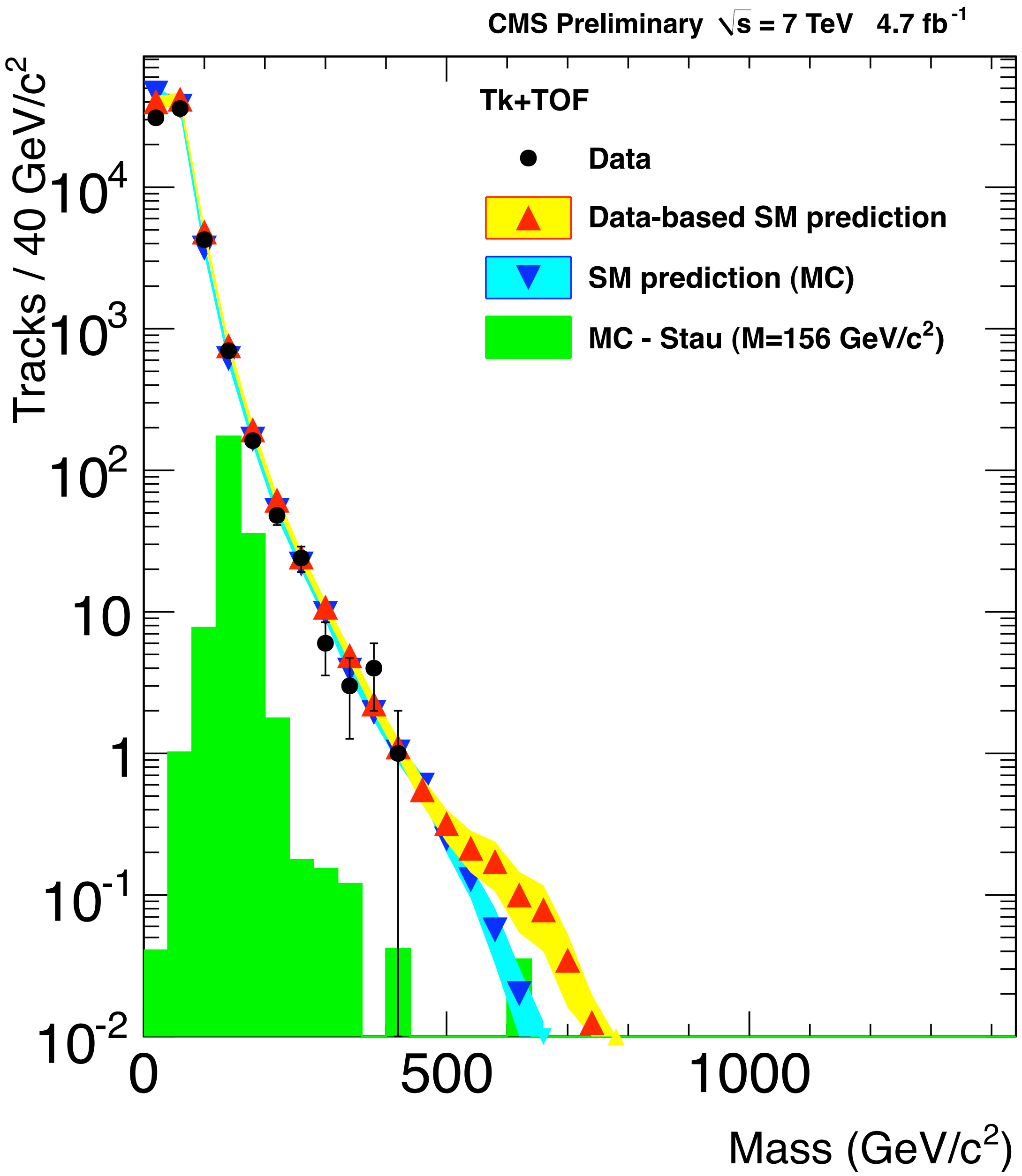
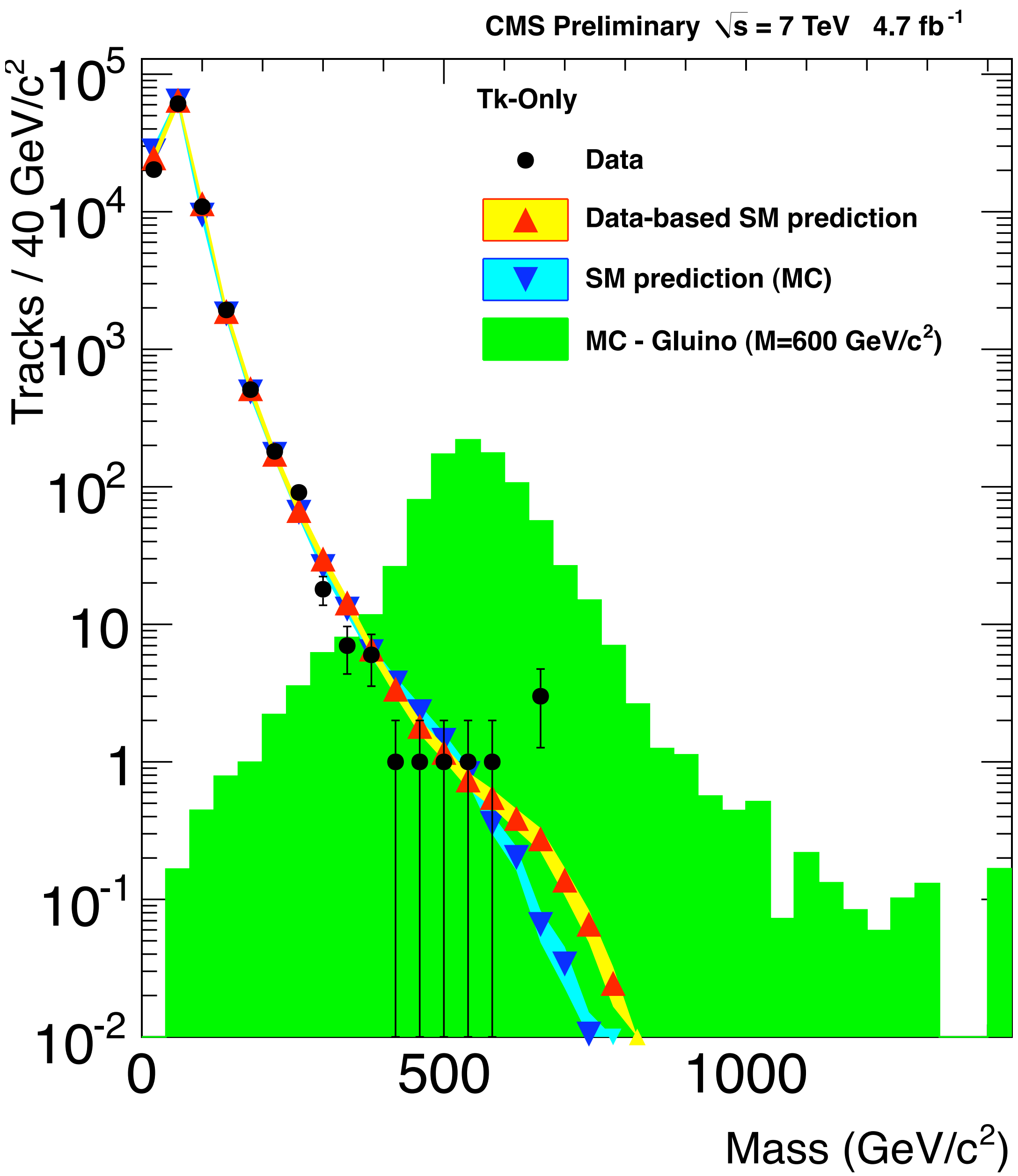
calculate mass from dE/dx and momentum: $I_h = K\frac{m^2}{p^2} + C$





limits

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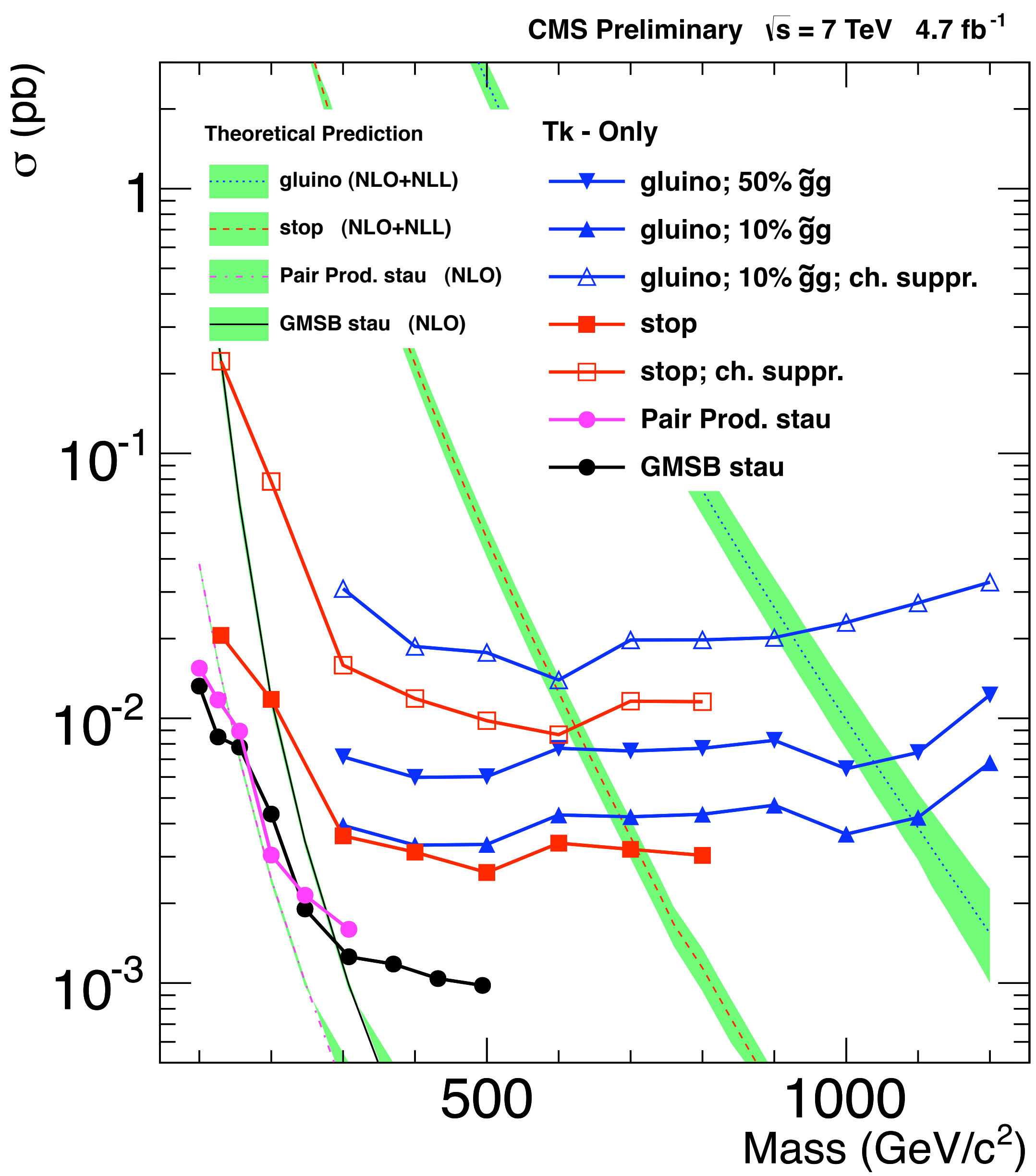
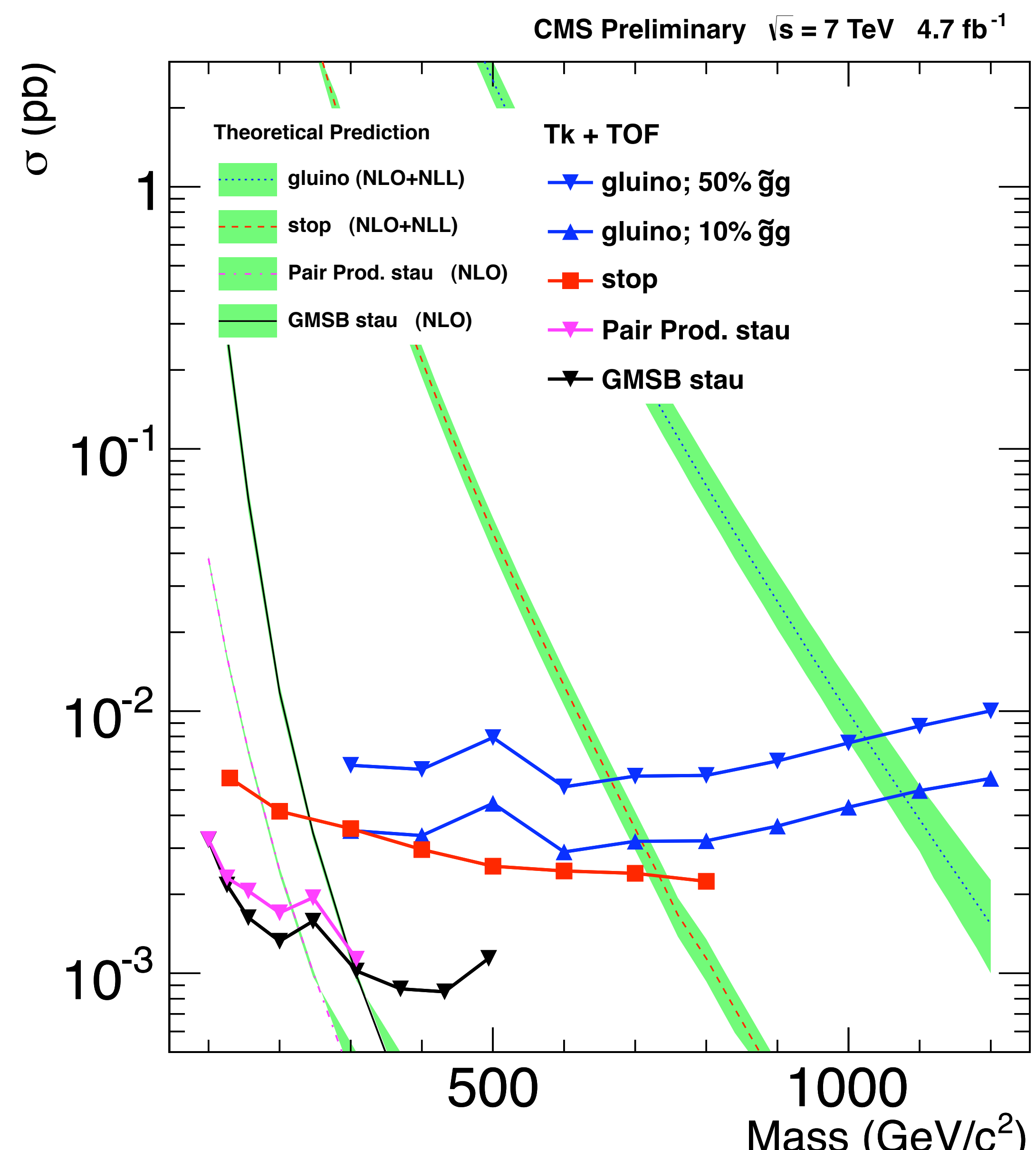
tracker only



tracker + muon TOF



for comparison

σ(b') pair production:

$m_{b'}$=400 GeV	1.41 pb
$m_{b'}$=500 GeV	0.33 pb
$m_{b'}$=600 GeV	0.092 pb

conclusions

- current direct searches ignore long-lived option
  (existing limits could be much waker if 4th gen. has lifetime)

- long-lived exotica searches ongoing
- they have impressive sensitity (in the range of 4th gen x-sections)
- they will be extended to also cover 4th gen.
  (simple re-interpretation not straightforward)

- discussions with CMS working groups ongoing

- goal: 2D limits (mass-lifetime)

- derive limits on $V_{b't}$

BACKUP SLIDES

HSCP systematics

Source of Systematic Error	Relative Uncertainty (%)
Signal efficiency	
Trigger efficiency	5
Muon reconstruction efficiency	5
Track reconstruction efficiency	< 2
Track momentum scale	< 5
Ionization energy loss scale (I_{as})	$[5, 10]$
Ionization energy loss scale (I_h)	< 1
Total uncertainty on signal acceptance	$[10, 15]$
Expected background	10
Integrated luminosity	6