Stopped Gluinos at CMS: A signal which is much easier to find than to simulate

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IPPP/RAL meeting
September 10, 2007

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Brief Intro to this Physics ...

University of BRISTOL

- **Arkani-Hamed & Dimopolous** in JHEP 0506 073 (2005) discuss a set of models which are not motivated by a natural solution to the hierarchy problem as nearly all other BSM physics has been for the last 30 years
  - Their argument (in short) is that there is a much worse fine-tuning in cosmology with the cosmological constant (1 in 10^{60}) than in the electroweak theory (1 in 10^{30}) so we should worry about that one and not the one in the Higgs mechanism
- The models that come out of this sort of thinking are known as **split supersymmetry**
  - They are like normal susy but have a “split” mass hierarchy where the new fermions (e.g. gluinos) are TeV scale but the new bosons (e.g. squarks) are many orders of magnitude more massive and thus inaccessible at the LHC

Split SUSY - Gluino Phenomenology

- Gluinos could be copiously produced (as in standard SUSY) with rates approaching 1 Hz)

$$gg \rightarrow \tilde{g}\tilde{g}$$

- Unlike standard SUSY however, these gluinos (due to the "split") would only be able to decay through highly virtual squarks and might have lifetimes ranging from 10^{-6} sec to 300,000 years (constrained by cosmology) depending on mass

$$\tau = 3 \times 10^{-2} \mathrm{sec} \left(\frac{m_S}{10^9 \mathrm{GeV}}\right)^4 \left(\frac{1 \mathrm{TeV}}{m_{\tilde{g}}}\right)^5$$

  - They might well be stable on nominal CMS experimental timescales

  - In this case, as they traverse the detector they would become bound by QCD into "R-hadrons"

$$\tilde{g}q\bar{q} \quad \tilde{g}qqq \quad \tilde{g}g$$

“Traditional” Searches Difficult

- These R-hadrons (if charged) can be detected by looking for their anomalous slow passage through the detector (e.g. long time-of-flight, high-ionization)

- If neutral, can only be detected indirectly

- Unfortunately, even if charged at onset, can become neutral through nuclear interactions with detector material (e.g.)

$$\tilde{g}d\bar{d} \rightarrow \tilde{g}udd + u\bar{d}$$

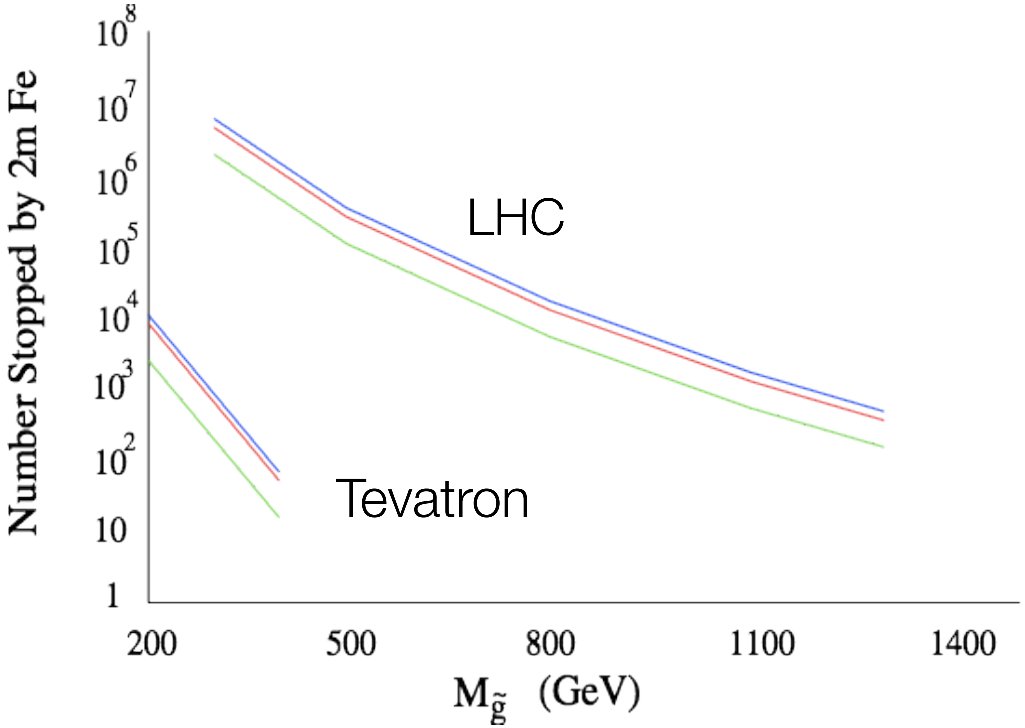
- This process could repeat several times during the gluinos flight

- Unknown fragmentation makes simulating/understanding such events difficult

Stopped Gluinos

- But, gluinos bound into R-hadrons will lose energy via ionization (if charged) and/or nuclear interactions
  - The charged ones (with velocities less than v in the expression below) will come to rest inside the detector volume, most likely in the calorimeters

$$v \leq \left(\frac{4x}{x_0}\right)^{\frac{1}{4}} \left(\frac{500\mathrm{GeV}}{m_{\tilde{g}}}\right)^{\frac{1}{4}}$$



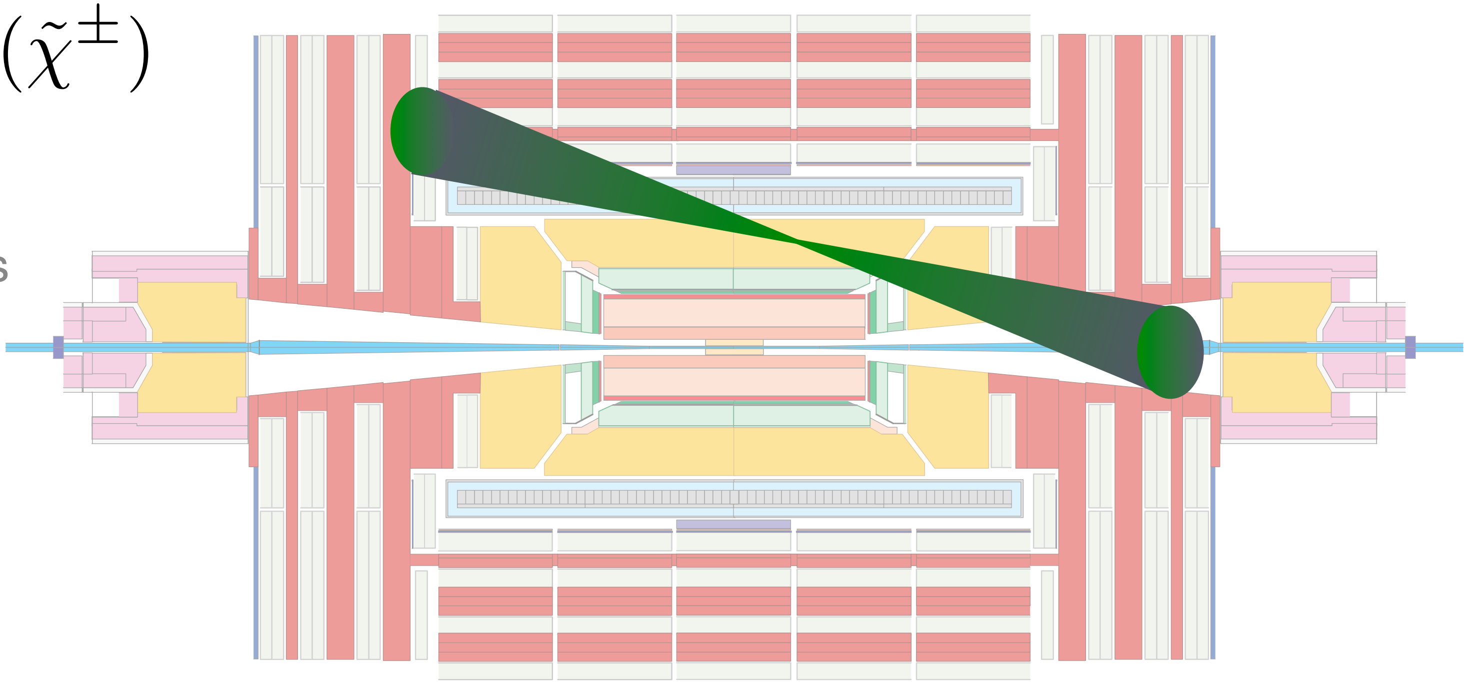
- In **hep-ph/0506242**,
- Authors estimate that as many as
  - 10^4 gluinos/fb^{-1} could be stopped in CMS

Searching for Stopped Gluinos Easier

- After some time (seconds, days, months, years) stopped gluinos would eventually decay (e.g.)

$$\tilde{g} \rightarrow q\bar{q}(q') + \tilde{\chi}^0(\tilde{\chi}^{\pm})$$

- These decays would shower in the calorimeters producing a **highly distinctive signature** (essentially jets that were randomly oriented with respect to the nominal interaction region)



- This signature has been looked for at D0 (public note no. 5058) using non-specific (jet) triggers that are in time with the colliding beams
  - Complicates things since with these triggers events are recorded (and reconstructed) out of time wrt to the gluinos decay
  - Also, sensitivity limited by beam produced backgrounds

In April, I (with collaborators from Maryland) made the following proposal to CMS

- Search for stopped gluino decays in-time with the decay using **a dedicated trigger that would be run whenever there is no beam in the LHC machine** (e.g. between fills where one might otherwise be running a cosmic trigger)
- The events would be triggered by a calorimeter trigger that would look for the unusual jet topology
- This approach has obvious advantages over the D0 search
  - In-time reconstruction
  - Essentially background free search (residual cosmic background easily estimated from cosmic data prior to collisions)
  - Could get results (signal or limits) well before detector & machine are understood well enough for traditional searches

Since then ...

- CMS now is planning to implement such a trigger and I have been studying how best to do so

- I wrote a toy simulation to explore what masses, lifetimes, susy-breaking scales, etc one could be sensitive to in a variety of beam operation scenarios

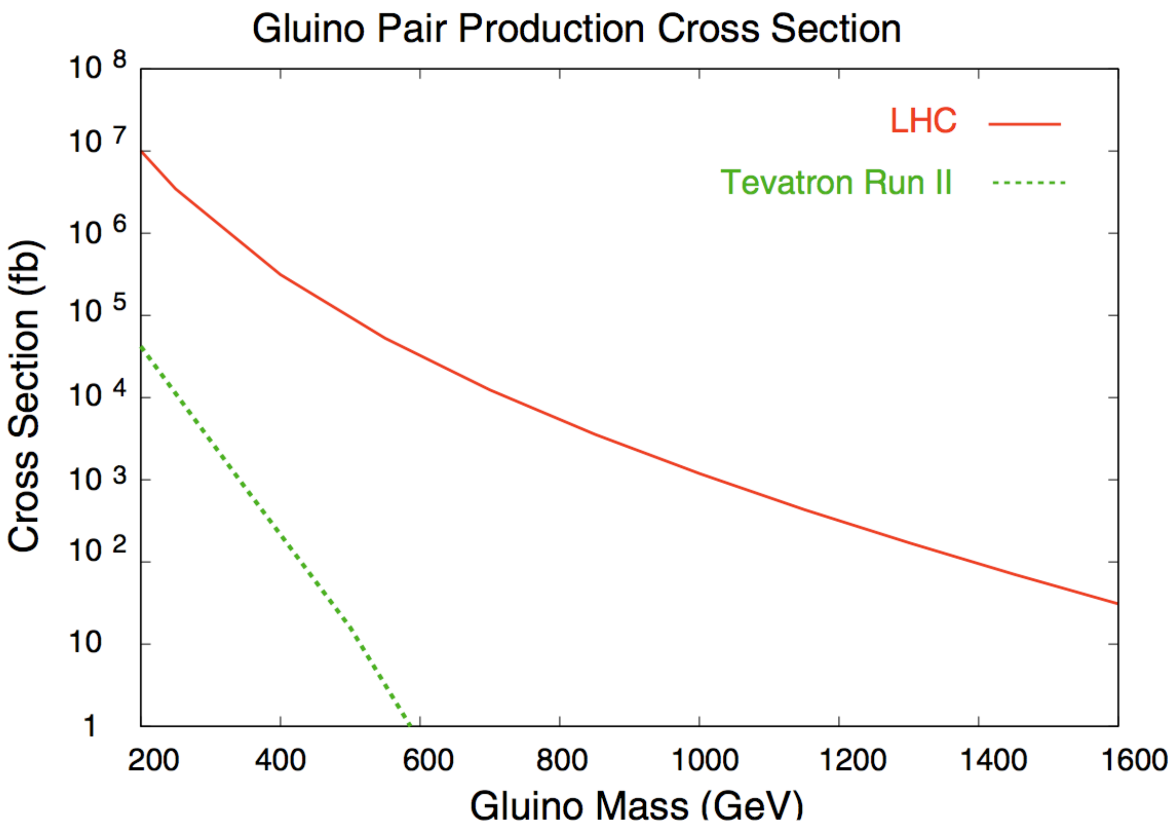
- My simulation is simple and based on known physics (essentially only Bethe-Bloch), useful to allow me to arrive at a quick & dirty understanding of some things as a function of the various parameters.

- It was not meant to replace (though is a useful cross-check on) more complicated (e.g. GEANT & CMSSW) codes

    - These tools will be needed to fully understand how to implement the proposed trigger and such work is in progress (B. Jones)

Possible Production Rates at 10^{32} (initial LHC luminosity)

- Copious production (up to 0.1 Hz at 10^{32}) at low masses but
- Cross-section drops quickly as a function of gluino mass
  - 1,000,000 fb for 300 GeV
    - 10x less at 500 GeV
    - 100x less at 700 GeV
    - 1000x less at 1100 GeV



hep-ph/0506242

A Simple Energy Loss Model to Estimate Number of these Gluinos which will be Stopped by CMS

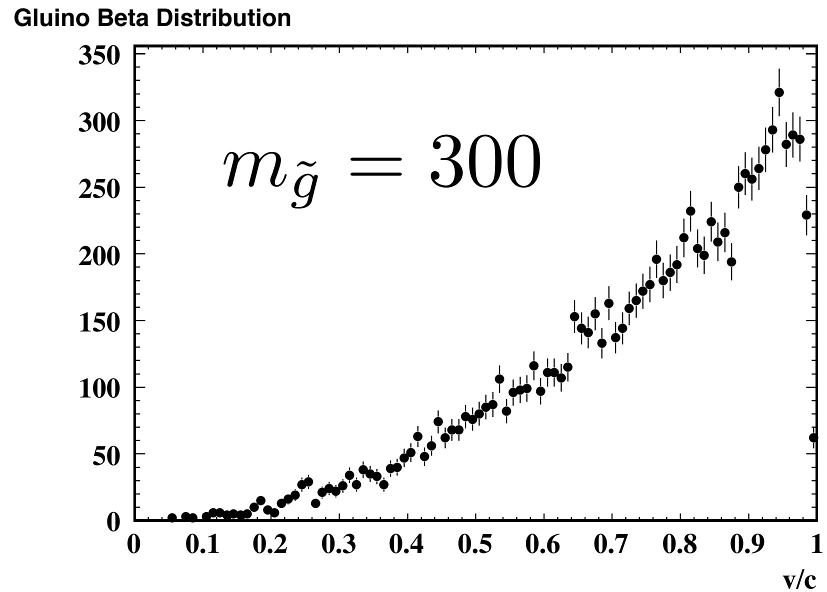
- I use PYTHIA to produce gluinos of a given mass
- I only do this to get the velocity (and some other kinematic) distributions for that mass which I subsequently use as a probability distributions in my toy model
- I use a modified PYTHIA which also hadronizes the gluinos into R-hadrons
    - For this study, I mostly ignore this, since the nuclear interaction is a negligible contribution to the energy loss (except in the cases that the hadron has flipped from neutral to charged and vice-versa which I do crudely simulate)
- Once the velocity is known the stopping distance can be calculated by integrating the Bethe-Bloch formula, assuming some stopping material

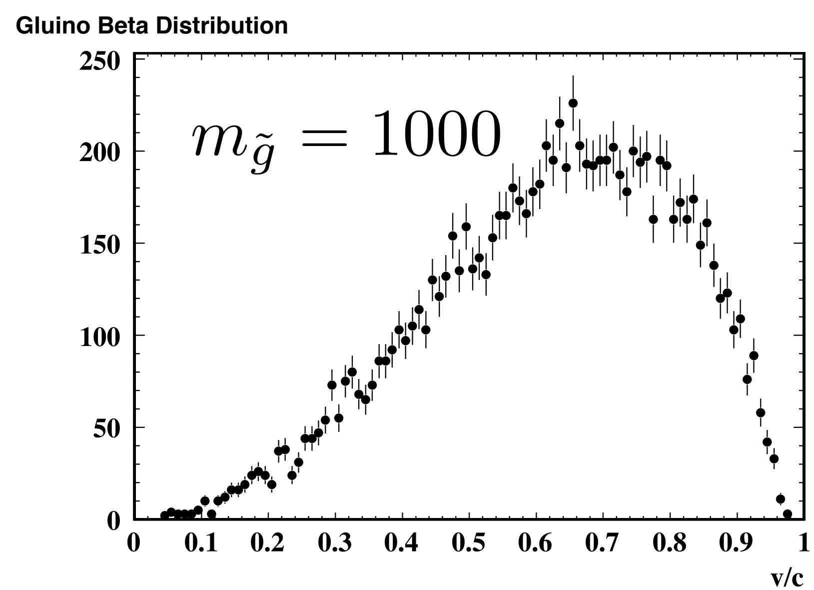
$$-\frac{dE}{dx} = K z^2 \frac{Z}{A} \frac{1}{\beta^2} \left[\frac{1}{2} \ln \frac{2 m_e c^2 \beta^2 \gamma^2 T_{\max}}{I^2} - \beta^2 - \frac{\delta(\beta\gamma)}{2} \right]$$

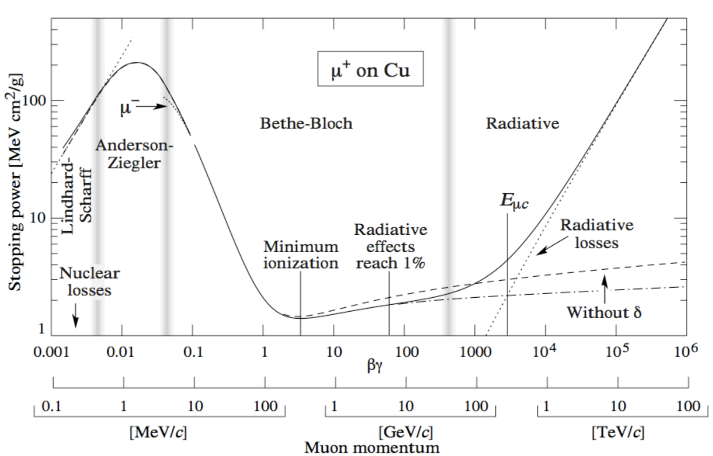
    - I use 23 cm of lead (crude ECAL) + 79 cm copper (crude HCAL)

Velocity Distributions

- For all masses, gluinos are produced with approximately the same average initial KE
- As you would expect, heavier gluinos are on average slower (and thus higher dE/dx) and thus stop more quickly
- This ranges from ~1% for m_{gluino} = 300 GeV to a few percent at higher masses







Simulation Steps

1. Choose a possible beam duty-cycle to study (e.g. 12h collisions, 12h no beam).
2. Poisson fluctuate the expected number of gluinos produced in 1 day with that duty-cycle assuming the cross-sections show previously and luminosity of 10^{32}.
3. Randomly assign a production time (relative to t=0 at first collision) for each gluino within the time window and keep track of it.
4. Throw against kinematic pdfs to simulate acceptance
5. Throw against velocity pdf to obtain beta with which to determine stopping distance.
6. Count number of gluinos for which this distance is less than that of CMS calorimetry (~1m) including factor of 2 to crudely account for charge/neutral flipping
7. For a given gluino lifetime, throw against an appropriate exponential to generate a decay time relative to the production time assigned in step 3.
8. Count how many gluinos stopped in step 6, decay in step 7 within the no-beam window (where the envisioned trigger will be run) for the given life-time and duty-cycle being studied.
9. Repeat for various masses, lifetimes, duty-cycles, etc.

Scenarios Scanned

- At the moment, I have no idea what the inter-fill operational scenario of the LHC will be (does anyone?)

- Anyway, as an initial study, I have done the following:

  - I have simulated one-month of data taking at 10^{32}

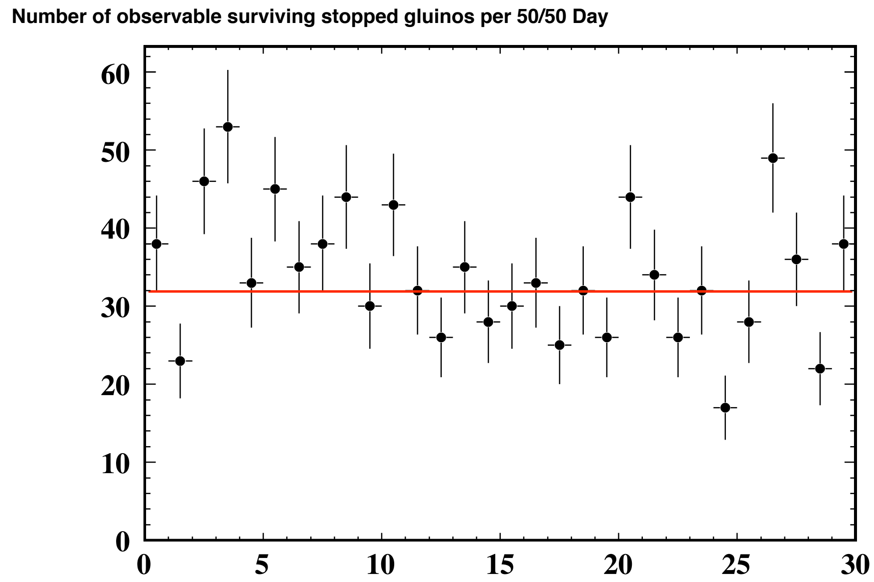
  - I have simulated duty-cycles of 6h/18h, 12h/12h, 18h/6h

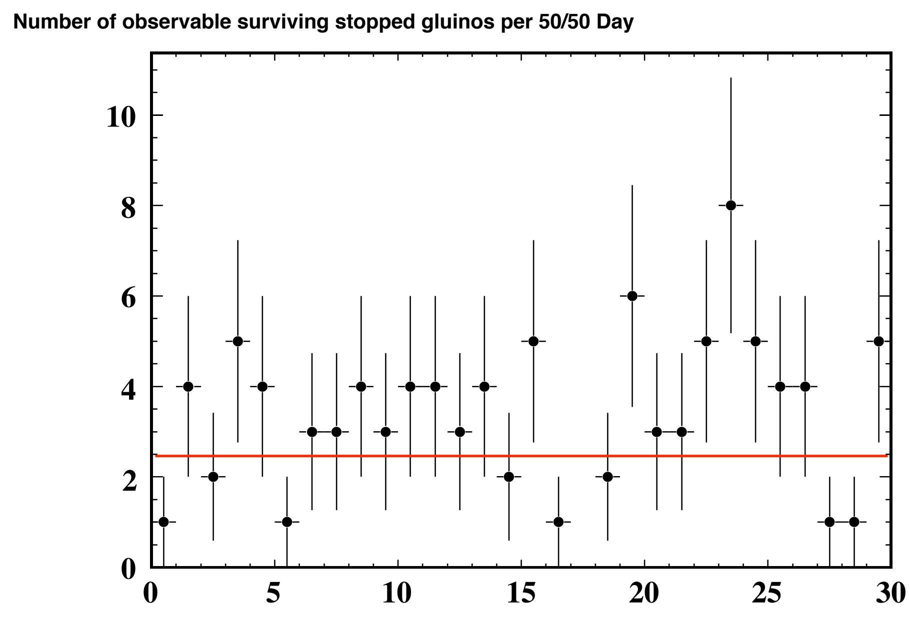
  - I have simulated gluino masses 300, 500, 700, 1000 GeV

  - I have simulated lifetimes ranging from 1h to 1wk

Number Observed Per Day in one Month @ 10^{32}

- 50% duty-cycle (12h beam-off)
- 12h lifetime
- For 300 GeV gluino, copious production rates mean could expect to see an average of ~30 decays per 12h beam-off period
  - Very easy discovery
- For 500 GeV, still have average of ~3 decays per 12h beam-off period
  - Easy discovery
- Heavier masses need more than a month @ 10^{32} to make a discovery

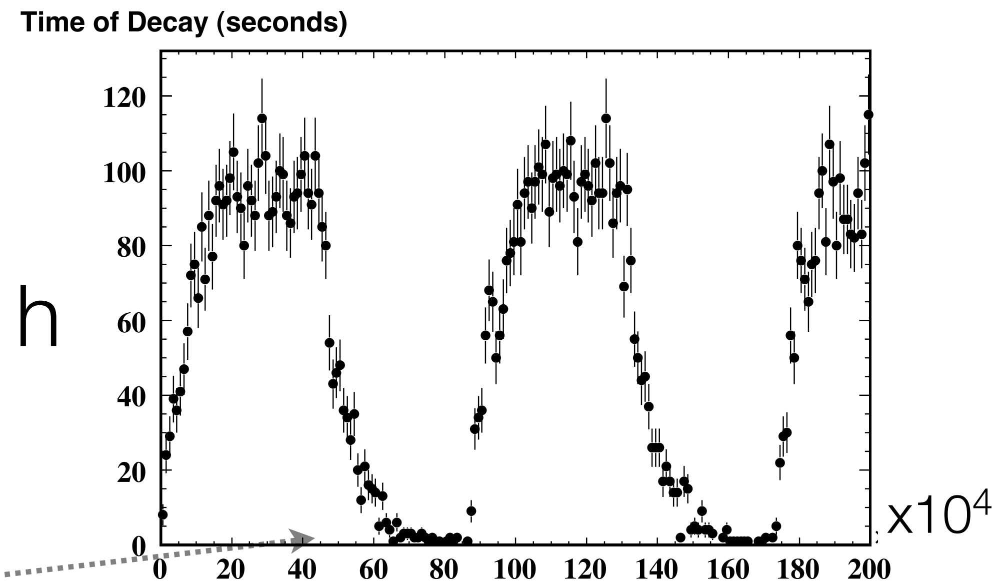




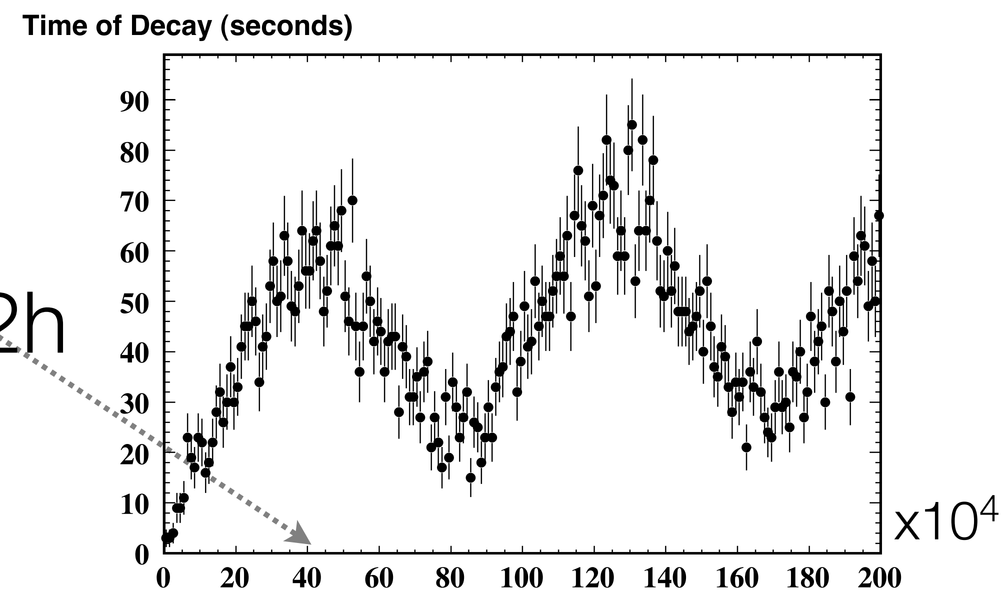
Number of Stopped Gluinos vs. Time

- Freezing the mass (300) and the duty-cycle (50%), I can vary the lifetime as illustrated in the plots on the right
- The plots at the right show 2.5 days worth of gluino production (12h when beam is on) followed by 12h of decay when beam is off for two different lifetimes (1h and 12h)
    - FYI 12h = 43,200 sec
- Note that by recording obs. no. of gluinos as a function of absolute time since t=0, **one can measure the lifetime** (which is related to the SUSY breaking scale)
    - BTW, to do this we will need to store unix time or some such in the event record

1h



12h



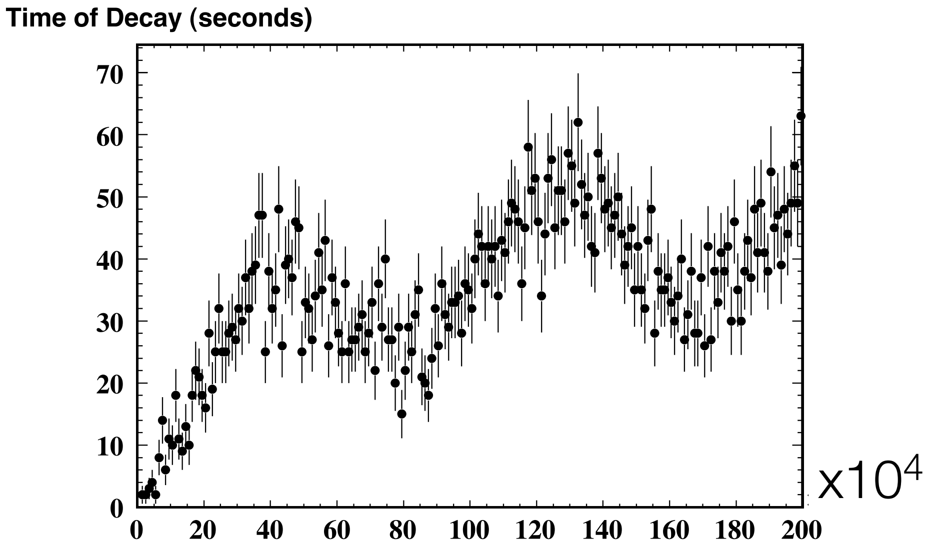
Number of Stopped Gluinos vs. Time (cont.)

- Here are plots for slightly longer lifetimes, 1d and 1wk

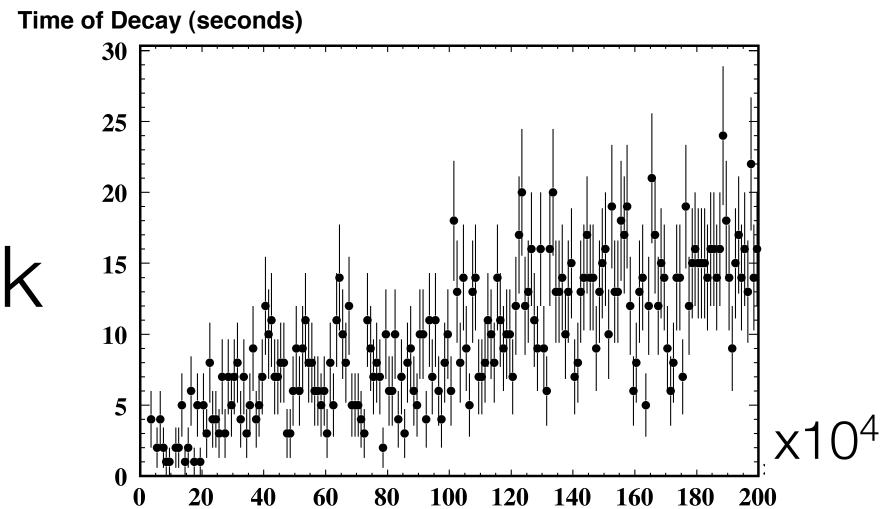
- Again, one could easily measure these lifetimes with 1 month data @ 10^{32}

- For longer lifetimes (month, year) we could still observe 300 GeV gluino events but it might take longer than a month to accurately measure the lifetime

1d



1wk



Varying Duty Cycle (6h/18h, 18h/12h)

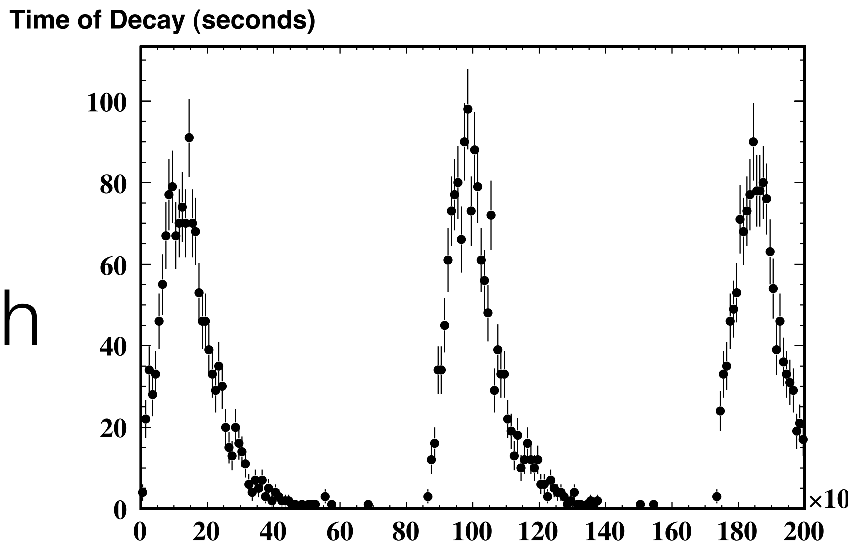
- Finally, I kept the mass (300) and lifetime (1h) fixed and varied the duty cycle from 50/50 to 25/75 and 75/25

- The plots at right illustrate the effect of this variation

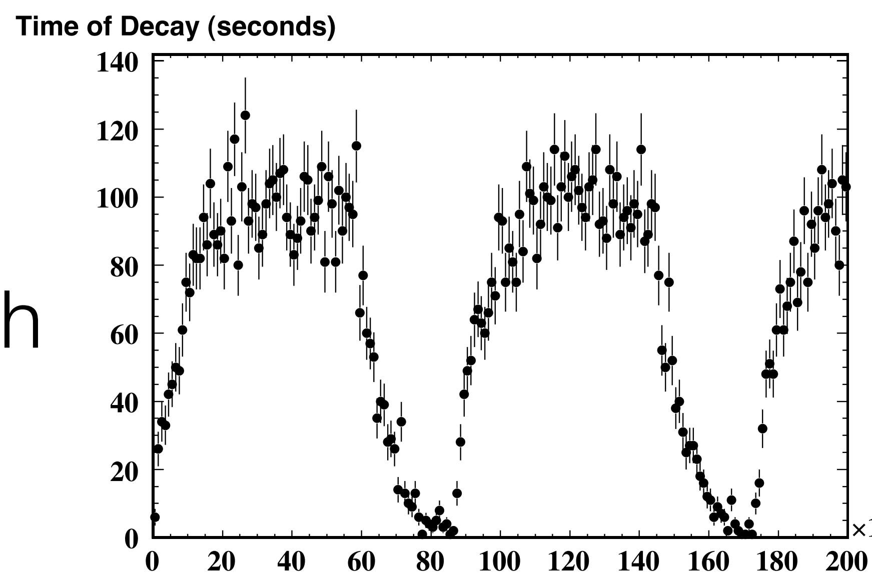
  - Obviously, in the first case you have had less collisions so you get less gluinos but you have a better chance of observing them in the 18h beam off window

  - In the second case, the reverse is true

6h/18h



18h/6h



How to do a full GEANT simulation of such events?

- As mentioned before, to observe the decay, provided a reasonable trigger threshold is set and the detector is live, should be relatively easy

- But to simulate such a decay (and it's reconstruction) is a little bit trickier ... since this decay will happen much much later than the normal simulation time-scale

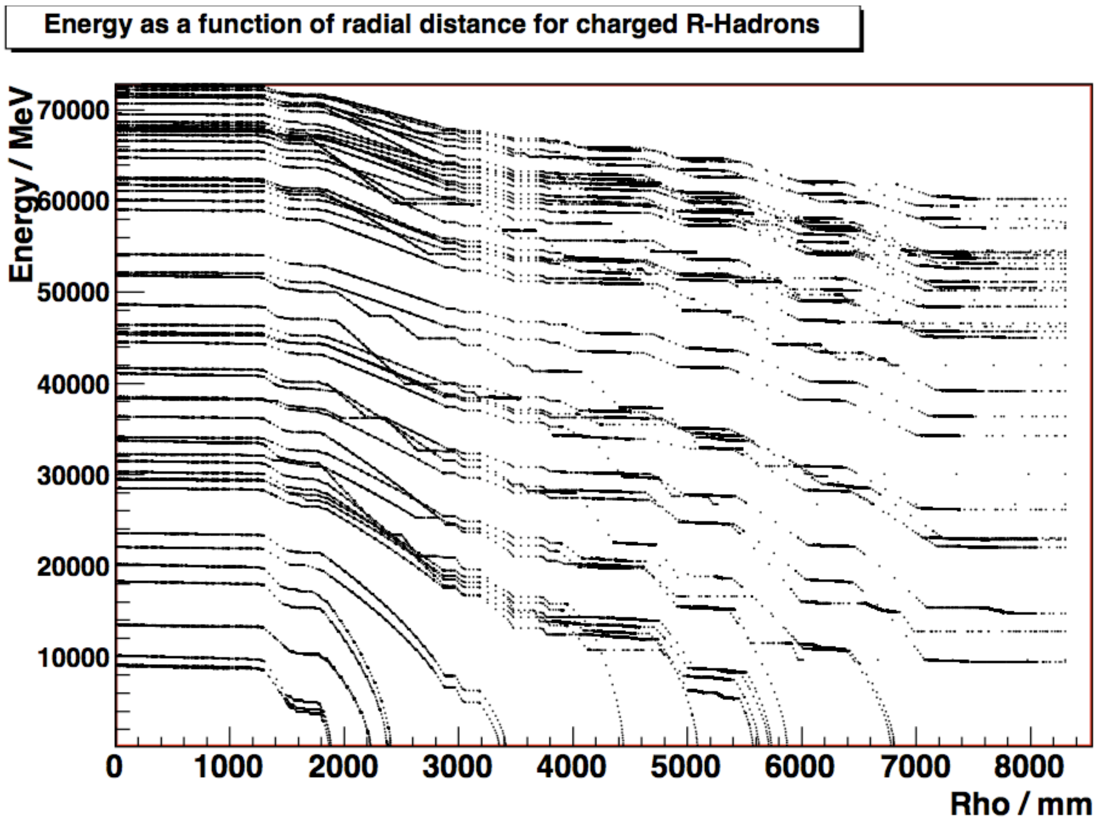
- We decided to study this by factorizing the problem

  1. Produce gluinos, allow them to hadronize and interact with the CMS detector, and possibly come to rest. Map out where in space this stopping occurs.

  2. Separately simulate the decay of such particles. Produce a gluino but translate its production vertex from (0,0,0) to a position determined by the above map. Decay that gluino instantaneously.

GEANT Simulation for Energy Loss in CMS

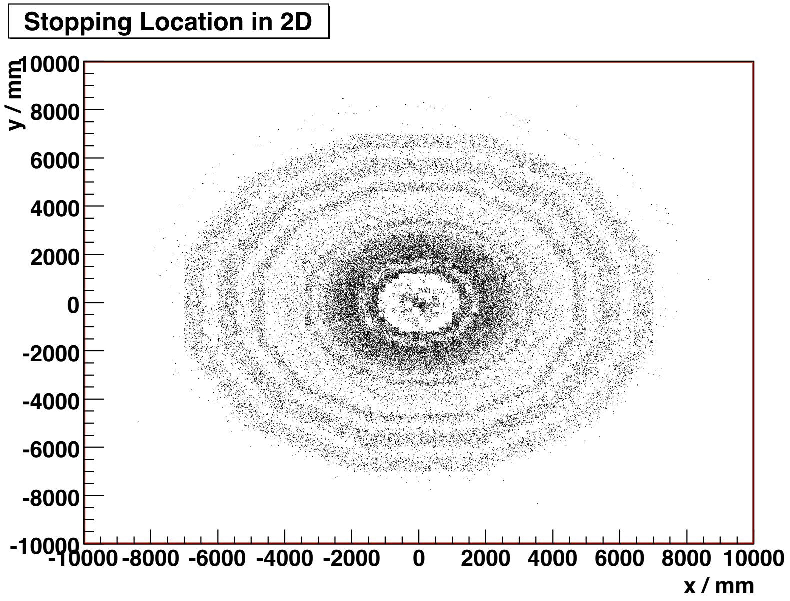
- For CMS, A. Rizzi, (**Eur.Phys.J.C50:353-362, 2007)** has implemented a model of heavy stable colored particle interactions with matter in GEANT
- We use* this implementation and "watch" an R-hadron's kinetic energy, when it has reached zero, i.e. stopped, we record that position

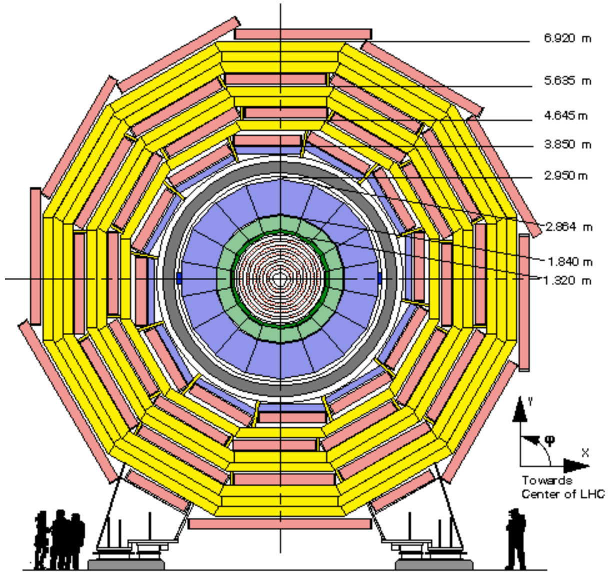


*actually, for consistency with my simple simulation, in the studies shown here the nuclear interactions have been "turned off"

Radial Stopping Location

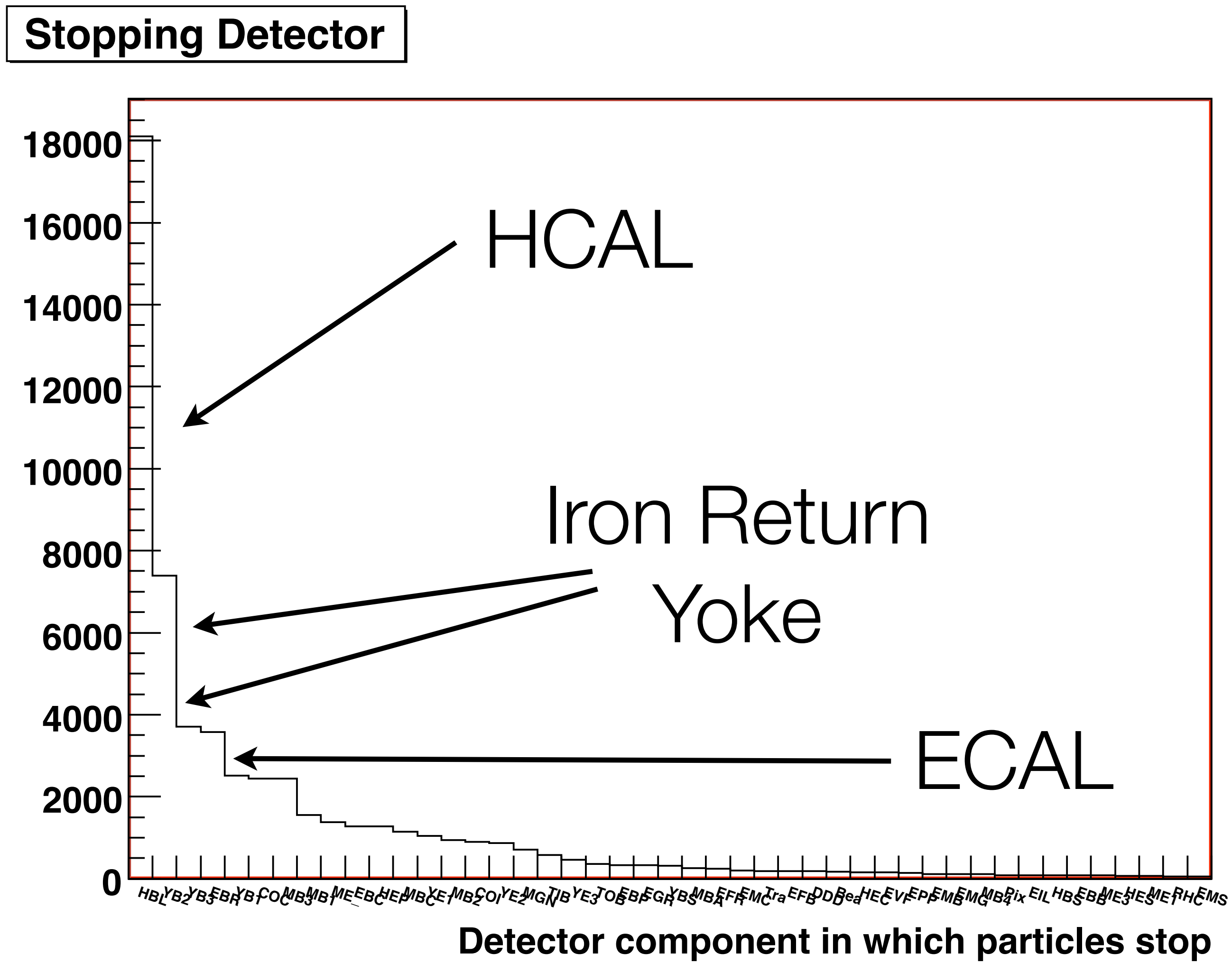
- The GEANT simulation confirms what we suspected from our simple simulation
  - Stopping rates of a few percent
  - Most of those stopped do so in the calorimeters or the iron of the return yoke
  - Heavier gluino masses, though produced significantly more rarely, stopped more easily





What fraction stops where?

- Though there is some dependence on mass*, roughly
  - ~5% stop in CMS's ECAL
  - ~55% stop in CMS's HCAL
  - ~40% stop in CMS's return yoke

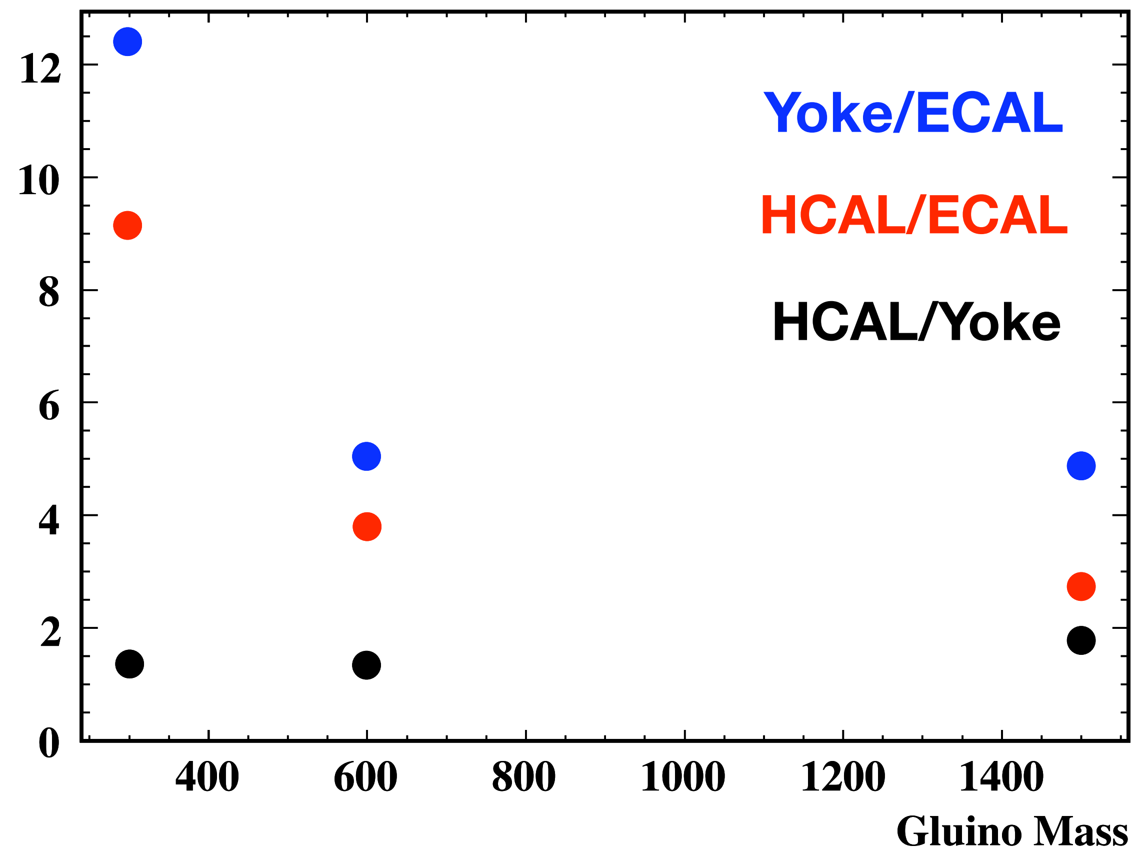


*this dependence can actually be exploited, see next slide

This in fact could be used to extract the gluino's mass

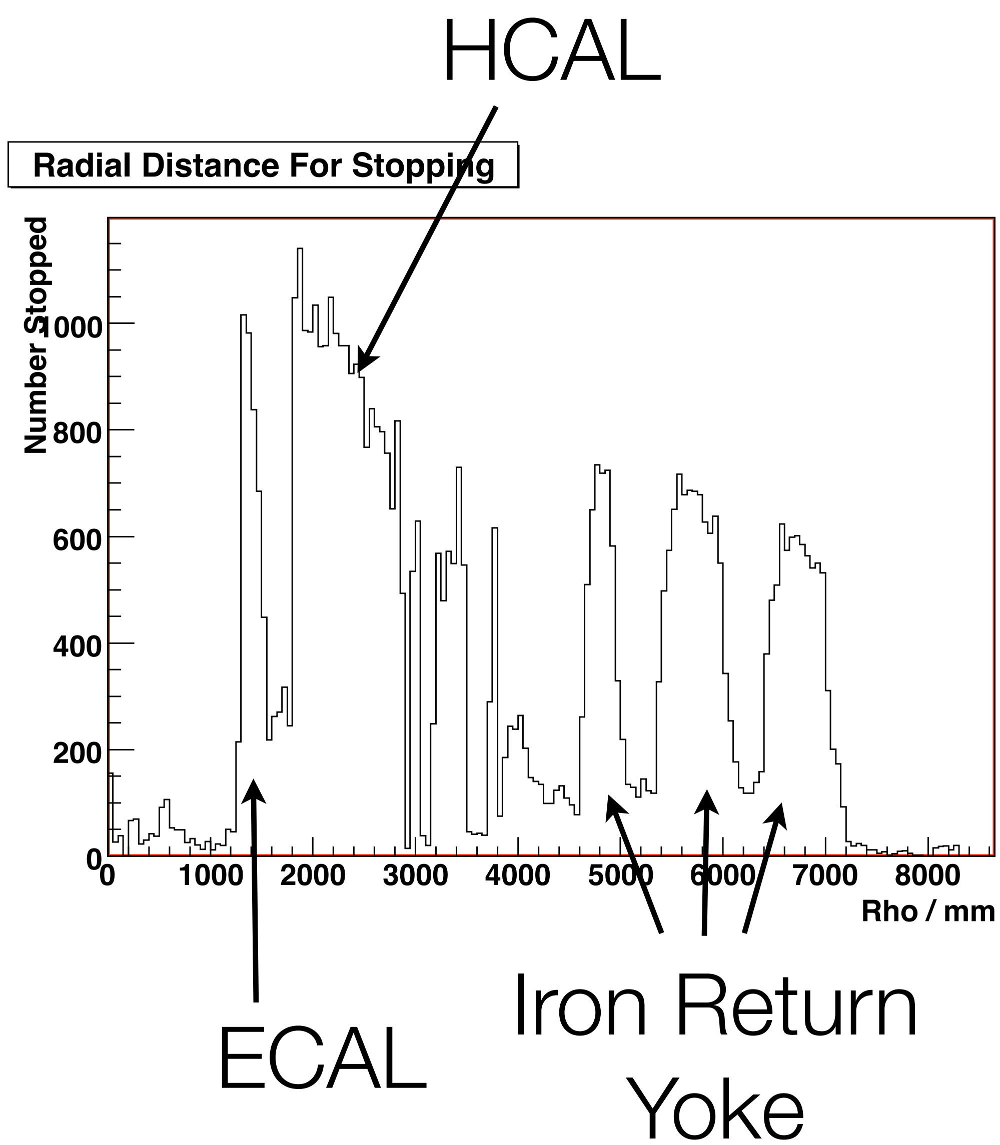
- Since the ECAL is the first detector that could stop it that the gluino will see, the ratio of those stopped in the ECAL to those stopped in some later encountered detector element is actually quite sensitive to the gluino mass

- The Yoke/ECAL ratio is the most sensitive since it has the largest lever arm



Now that we know where they will stop ...

- We use PYTHIA's `py1ent` to produce a single gluino at (0,0,0)
- We set its 4-momenta such that it is at rest
- We have PYTHIA decay the gluino the hadronize & shower the decay products as normal
    - Actually, I should say we intend to have PYTHIA do this, it is a work in progress at the minute
- We then translate the whole event to originate from a randomly chosen (V_x,V_y,V_z) weighted by the pdf obatined from the previous step (shown right)



Next Steps & Discussion

- As soon as we sort out how to decay these events, we will feed them to the CMS reconstruction to really see what they will look like at CMS so that we can design the trigger appropriately

- The reconstruction "should" have no trouble with these events since they will be in-time (as they will be in real life with the appropriate trigger) - we'll see

- In principle we can also use the same machinery to set limits on physics models if we fail to observe any events when the LHC starts next year

    - Do you guys (phenomenologists) think this is the best way to simulate this physics? Or do you have other ideas ...

Extra Slides

Sensitivity to Susy Breaking Scale

- In split susy, lifetime is related to the susy breaking scale as below:

$$\tau = 3 \times 10^{-2}\mathrm{sec}\left(\frac{m_S}{10^9\mathrm{GeV}}\right)^4\left(\frac{1\mathrm{TeV}}{m_{\tilde{g}}}\right)^5$$

- The plot at right shows what scales this kind of search is sensitive to (~10^8 - 10^{11})

- Blue = 1h, Green = 1d, Red = 1mo

- Complementary to those lifetimes accessible during collisions, down here