GREEN HEP

DOING PARTICLE PHYSICS WITH THE BEAM SWITCHED OFF

CHRISTOPHER S. HILL

UNIVERSITY OF BRISTOL

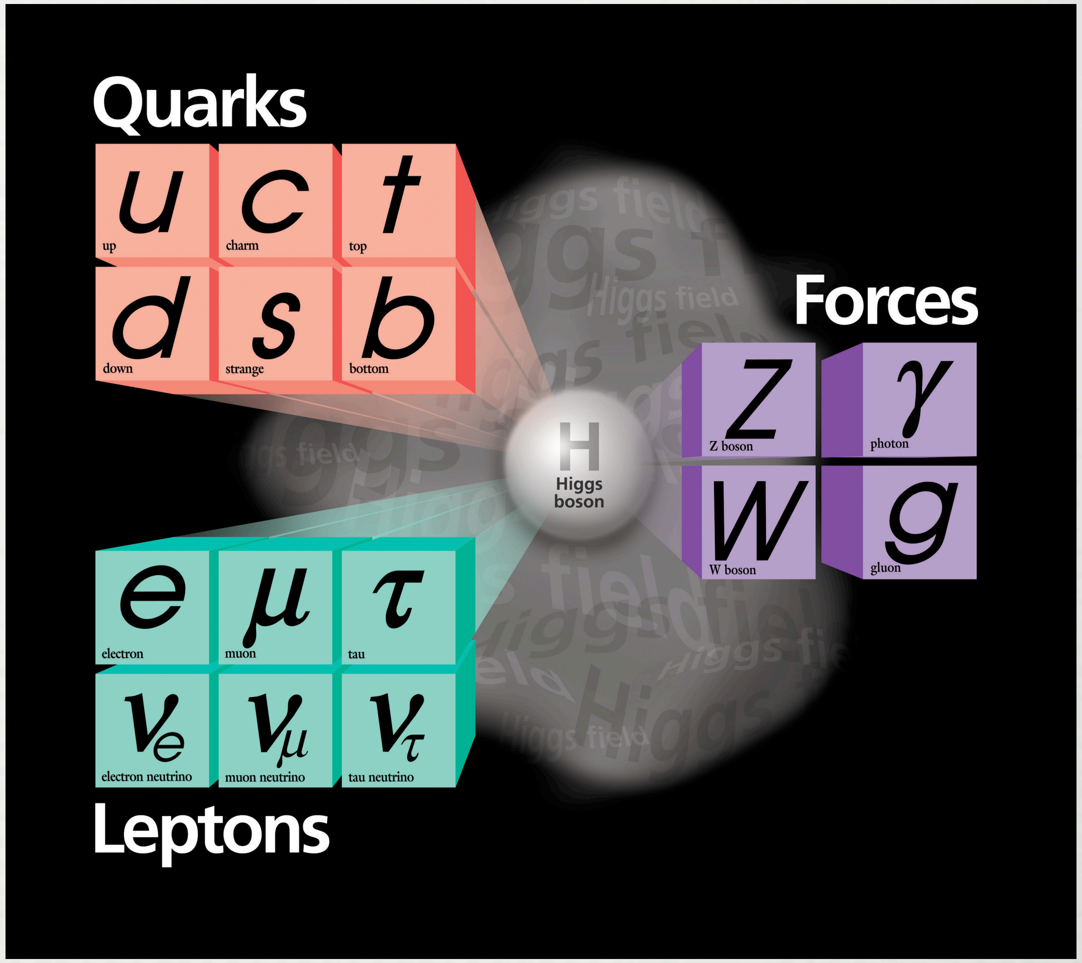
WARWICK PARTICLE PHYSICS SEMINAR, 1 MAY 2008

WHAT DID HE JUST SAY?

- THERE ARE A NUMBER OF SCENARIOS FOR NEW PHYSICS AT THE LHC WHICH INVOLVE THE PRODUCTION OF NEW QUASI-STABLE CHARGED PARTICLES
  - I'LL TELL YOU ABOUT THE SCENARIO THAT I FIND MOST INTERESTING (NOT THAT NATURE CARES ONE BIT ABOUT WHAT I THINK)
  - EVERYTHING THAT FOLLOWS COULD EQUALLY WELL APPLY TO ANY OTHER MODELS THAT HAVE STABLE CHARGED PARTICLES
- IT IS MY ASSERTION THAT THESE PARTICLES ARE BEST SEARCHED FOR LONG AFTER THE COLLISIONS HAVE OCCURRED ... I.E. WHEN THE BEAM IS OFF
  - I'LL TELL YOU ABOUT MY PLANS TO DO THIS AT CMS

WHY DO WE EXPECT NEW PHYSICS @ LHC?

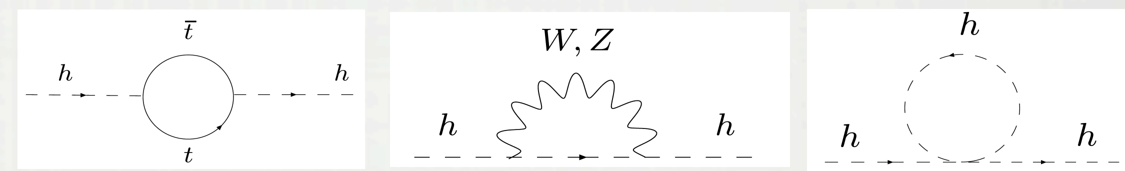
- ☐ STANDARD MODEL OBVIOUSLY NOT A COMPLETE THEORY
  - ☐ NO DESCRIPTION OF GRAVITY
  - ☐ REQUIRES EXISTENCE OF (AS YET) UNOBSERVED HIGGS BOSON TO GIVE FERMIONS MASS
  - ☐ RESULTANT HIERARCHY PROBLEM



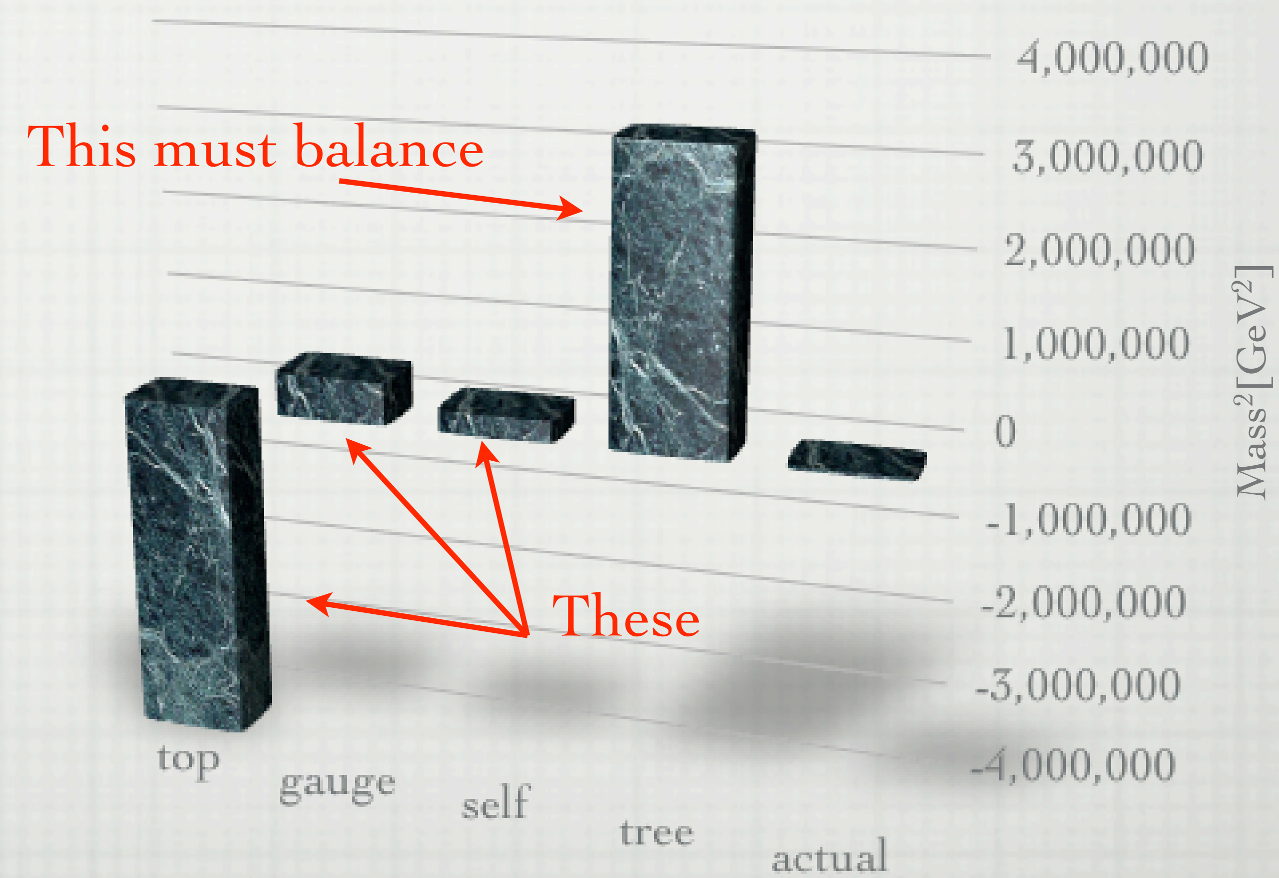
IT IS THIS PROBLEM WHICH MANY BELIEVE HOLDS THE KEY TO NEW PHYSICS AT THE LHC, LET'S SPEND A SLIDE ON IT ...

HIERARCHY PROBLEM

- CAN'T THE SM BE VALID UP TO THE SCALE WHERE GRAVITY IS IMPORTANT?
  - $M_{PLANCK} \approx 10^{19}$ GEV
- NOT EASILY, EVEN FOR MUCH LOWER ENERGY SCALES ($\Lambda_{CUTOFF} \sim 10$ TEV)
- INCREDIBLE FINE-TUNING REQUIRED IN LOOP CORRECTIONS TO HIGGS MASS
  - $\Delta M^2_H \propto \Lambda^2_{CUTOFF}$

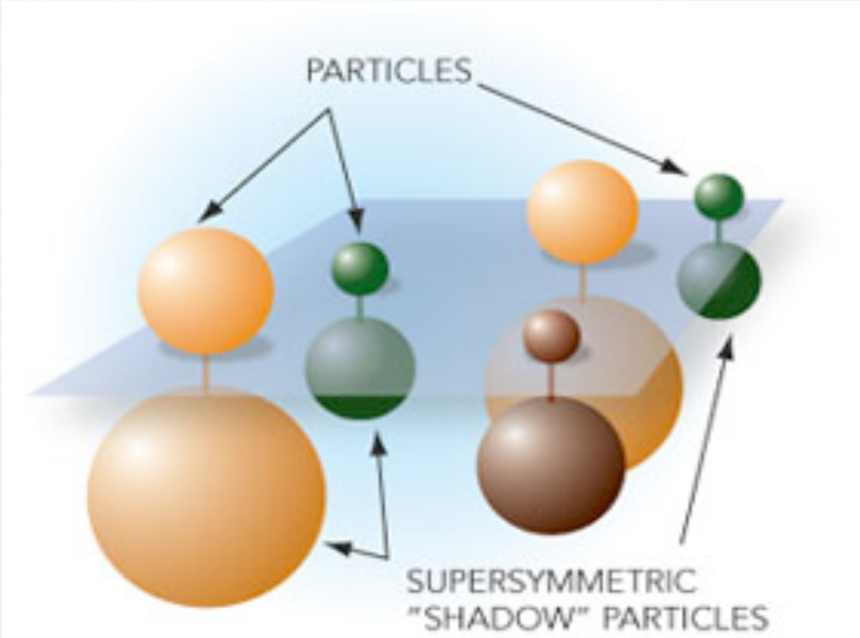


$$m_H^2 \approx (200\ GeV)^2 = m_H^{2\ tree} + \delta m_H^{2\ top} + \delta m_H^{2\ gauge} + \delta m_H^{2\ self}$$



"NATURAL" SOLUTIONS
NO AD HOC FINE-TUNING

- WIDE VARIETY OF THEORETICAL SOLUTIONS TO THE HIERARCHY PROBLEM
  - ONE FAVOURED IDEA IS SUPERSYMMETRY (SUSY)
- EACH BOSONIC PARTICLE HAS A FERMIONIC SUPERPARTNER AND VICE-VERSA
- THESE CONTRIBUTE WITH OPPOSITE SIGN TO LOOP CORRECTIONS ON THE PREVIOUS SLIDE PROVIDING CANCELLATION OF THE PROBLEMATIC TERMS
  - THIS IS AN EXAMPLE OF A NATURAL SOLUTION TO THE HIERARCHY PROBLEM

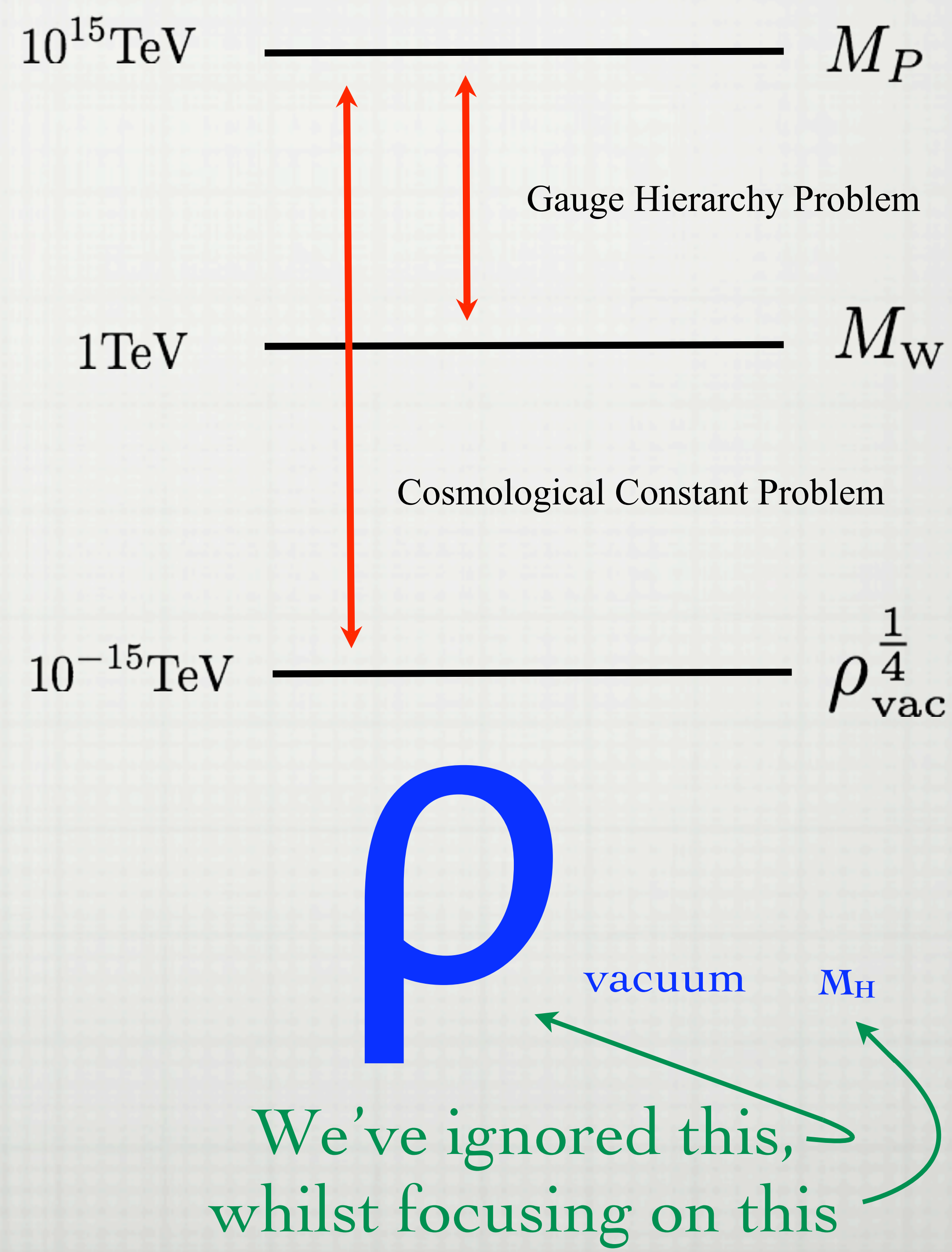


$$\delta {m^2}_H + (-\delta {m^2}_H) = 0$$

NEARLY ALL NEW PHYSICS MODELS FOR THE PAST 30 YRS HAVE BEEN GUIDED BY THIS "PURSUIT OF NATURALNESS"

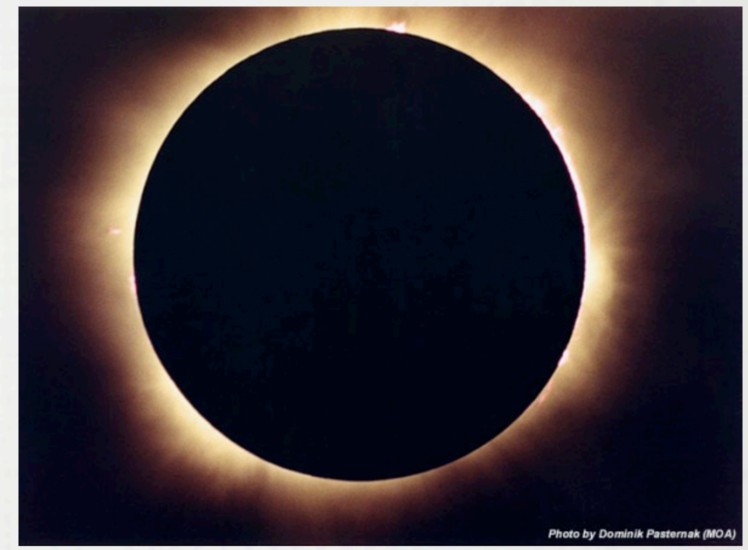
WORSE FINE-TUNINGS IN NATURE

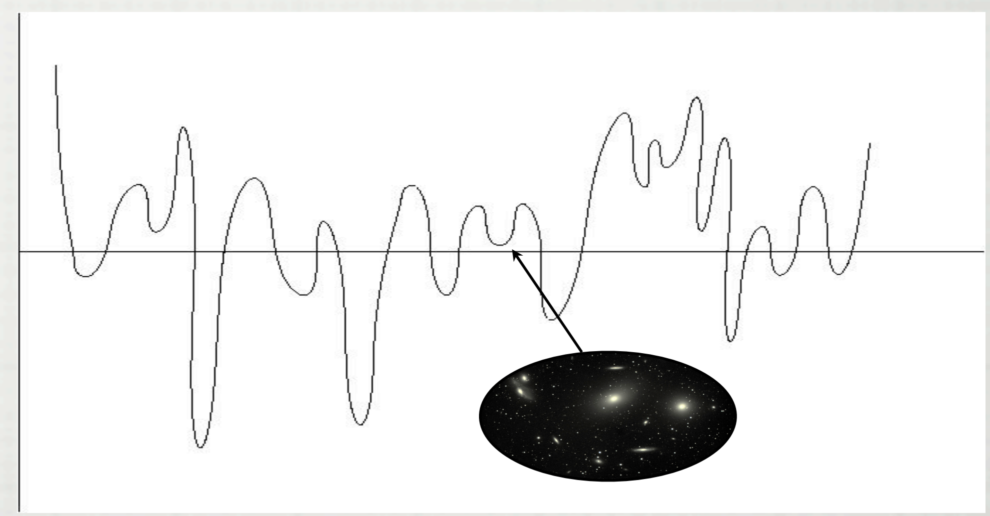
- WHEREAS THE ELECTROWEAK FINE-TUNING IS 1 IN 10^{15}
- THE COSMOLOGICAL FINE-TUNING IS MORE LIKE 1 IN 10^{60}
  - THIS PROBLEM IS BOTH MUCH LARGER AND MUCH MORE PROBLEMATIC (IF THE COSMOLOGICAL CONSTANT WERE 10-100 TIMES ITS MEASURED VALUE, GALAXIES WOULD NEVER HAVE FORMED)
- ONE "EXPLANATION" FOR THIS IS A (SOMEWHAT CONTROVERSIAL*) STATISTICAL ONE THAT COMES FROM STRING THEORY



COINCIDENCE OR PHYSICS?

- WHAT IF THE COSMOLOGICAL FINE-TUNING WAS JUST A COINCIDENCE?
- LIKE THE APPARENT SIZES OF THE SUN AND MOON?
  - WHICH IS A COINCIDENCE THAT IS STATISTICALLY REASONABLE GIVEN THE NUMBER OF CELESTIAL OBJECTS
- THE SAME COULD BE TRUE FOR COSMOLOGICAL FINE-TUNING (AND EVEN MORE SO FOR THE COMPARATIVELY MINOR ELECTROWEAK ONE) IF THERE WERE ENOUGH UNIVERSES
  - STRING THEORY "LANDSCAPE" PROVIDES SUCH A POSSIBILITY





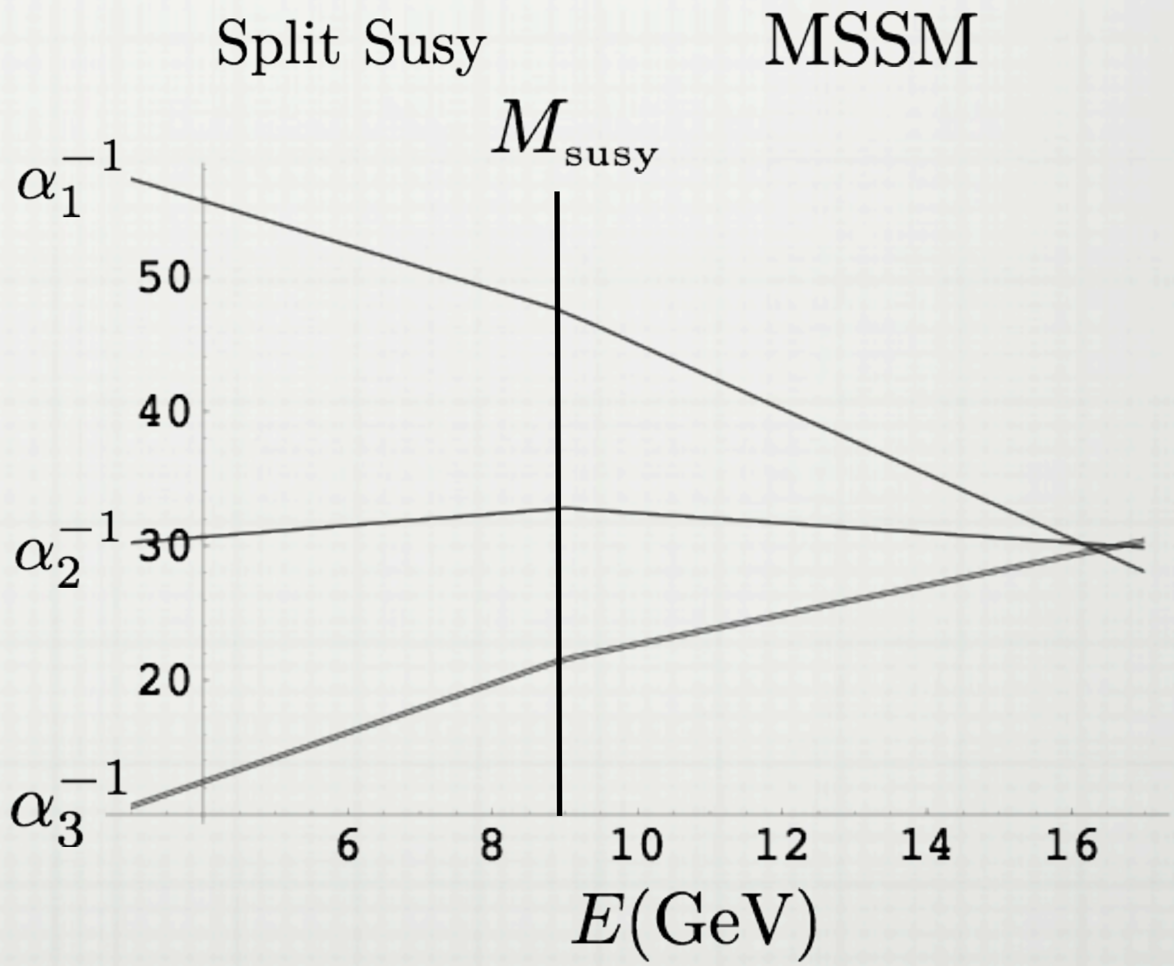
IT TURNS OUT THERE MAY BE > 10^{100} VACUA, MORE THAN ENOUGH!

SHOPPING LIST

- ☐ FREED FROM SOLVING THE FINE TUNING PROBLEM, WHAT WOULD ONE LIKE FROM A BSM THEORY?
  - ☐ DARK MATTER CANDIDATE
  - ☐ GAUGE COUPLING UNIFICATION
  - ☐ PROTON STABILITY
  - ☐ NO FCNC'S OR PROBLEMATIC CP VIOLATION

SPLIT SUPERSYMMETRY

- N. ARKANI-HAMED & S. DIMOPOULOUS PROVIDE A MODEL WHICH HAS THESE PROPERTIES
    - **JHEP 0506:073,2005**
- IT PRESERVES THE DESIRABLE ASPECTS OF TRADITIONAL SUSY BUT WITHOUT ITS USUAL PROBLEMS
- THEY CALL IT "SPLIT SUSY"



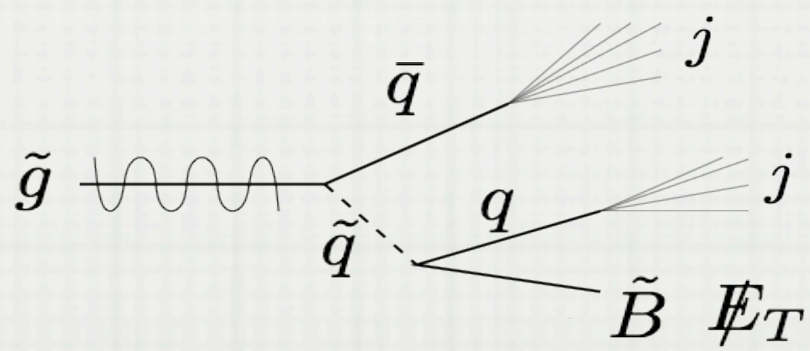
HIGH SUSY BREAKING SCALE LEADS TO "SPLIT" IN MASSES OF SCALARS & FERMIONS AND A RADICALLY DIFFERENT LHC PHENOMENOLOGY

SPLIT SUSY 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") CAN ONLY DECAY THROUGH HIGHLY VIRTUAL SQUARKS AND MIGHT HAVE LIFETIMES RANGING FROM TINY FRACTIONS OF A SECOND TO MANY THOUSANDS OF YEARS



  - 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

- 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-IONISATION)
  - IF NEUTRAL, CAN ONLY BE DETECTED INDIRECTLY
- UNFORTUNATELY, EVEN IF CHARGED AT ONSET, CAN BECOME NEUTRAL THROUGH NUCLEAR INTERACTIONS WITH DETECTOR MATERIAL (E.G.)

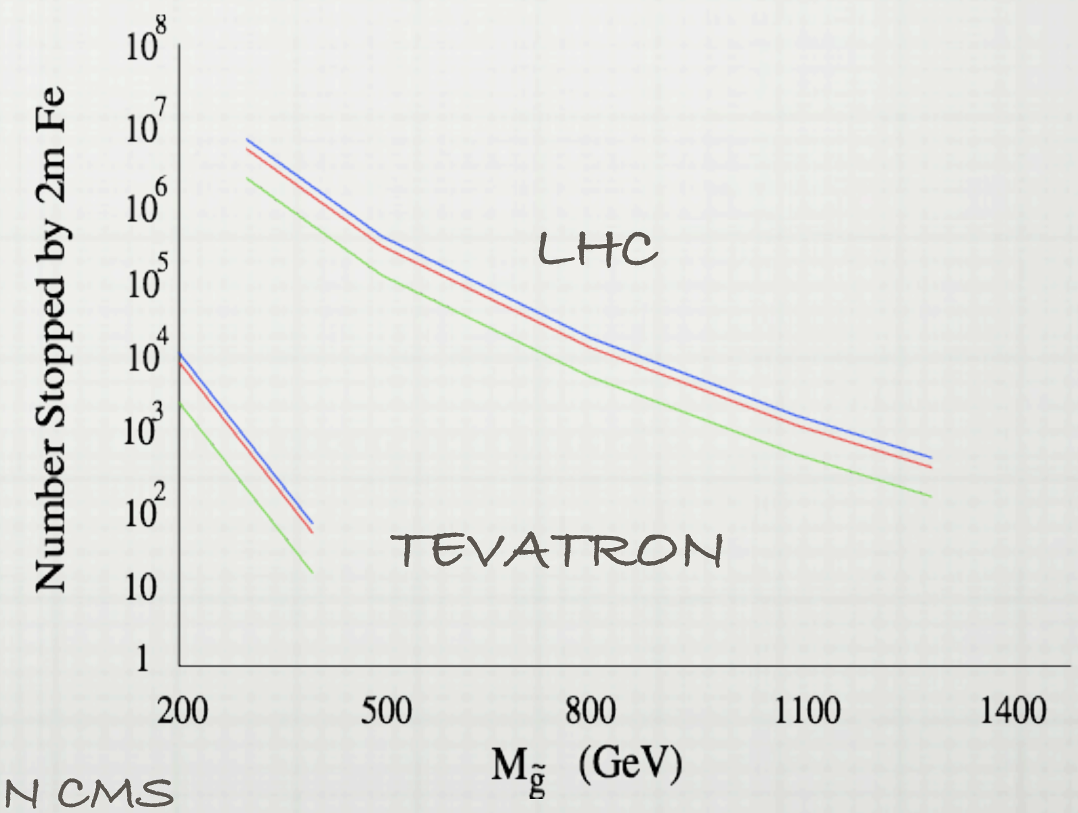
$$\tilde{g}d\bar{d} \rightarrow \tilde{g}udd + u\bar{d}$$

  - THIS PROCESS COULD REPEAT SEVERAL TIMES DURING THE GLUINOS FLIGHT
- UNKNOWN HADRONISATION, FRAGMENTATION, ETC. MAKES SIMULATING/UNDERSTANDING SUCH EVENTS DIFFICULT

STOPPED GLUINOS

- BUT, GLUINOS BOUND INTO R-HADRONS WILL LOSE ENERGY VIA IONISATION (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

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

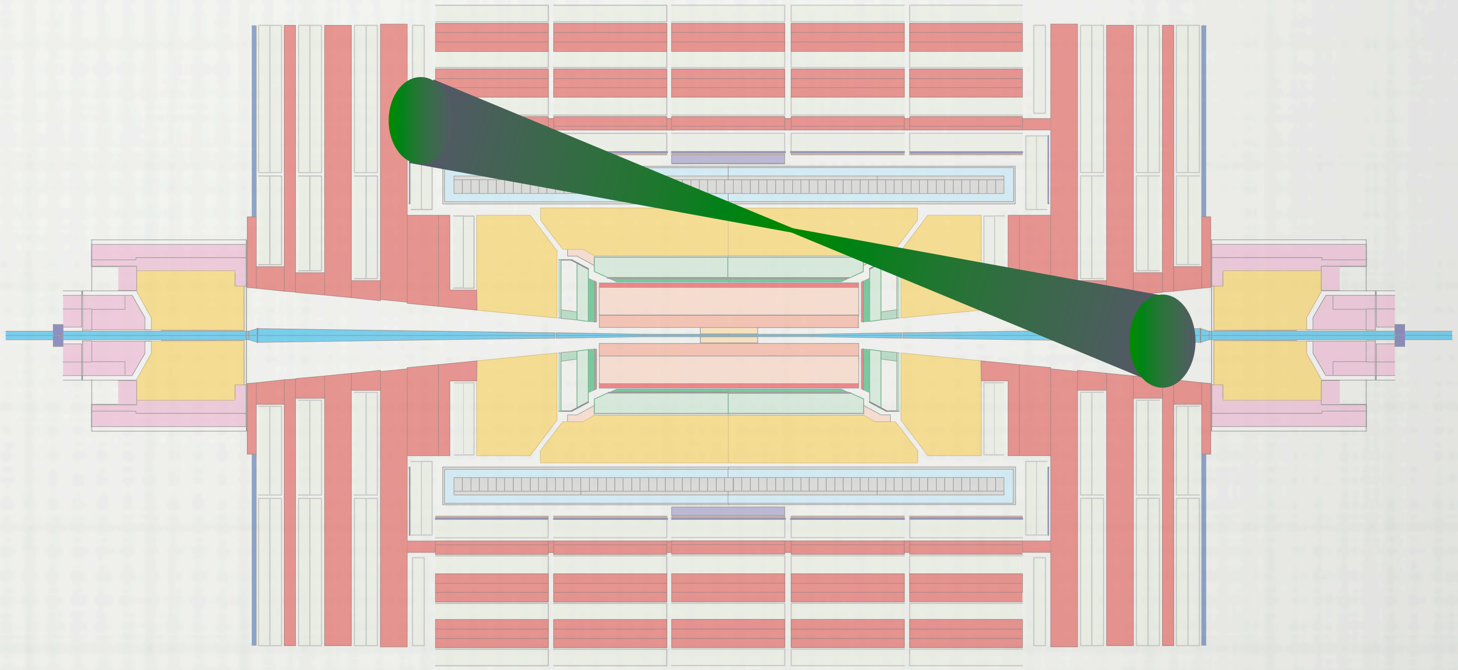


- IN HEP-PH/0506242,
- AUTHORS ESTIMATE THAT AS MANY AS
  - 10^4 GLUINOS/FB^{-1} COULD BE STOPPED IN CMS

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 (PRL 99, 131801, 2007) 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

MY* PROPOSAL FOR 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
  - POTENTIALLY IN-TIME RECONSTRUCTION (THOUGH THIS TURNS OUT NOT TO BE AN ISSUE AT CMS)
  - ESSENTIALLY BACKGROUND FREE SEARCH
  - COULD GET RESULTS (SIGNAL OR LIMITS) WELL BEFORE DETECTOR & MACHINE ARE UNDERSTOOD WELL ENOUGH FOR TRADITIONAL SEARCHES

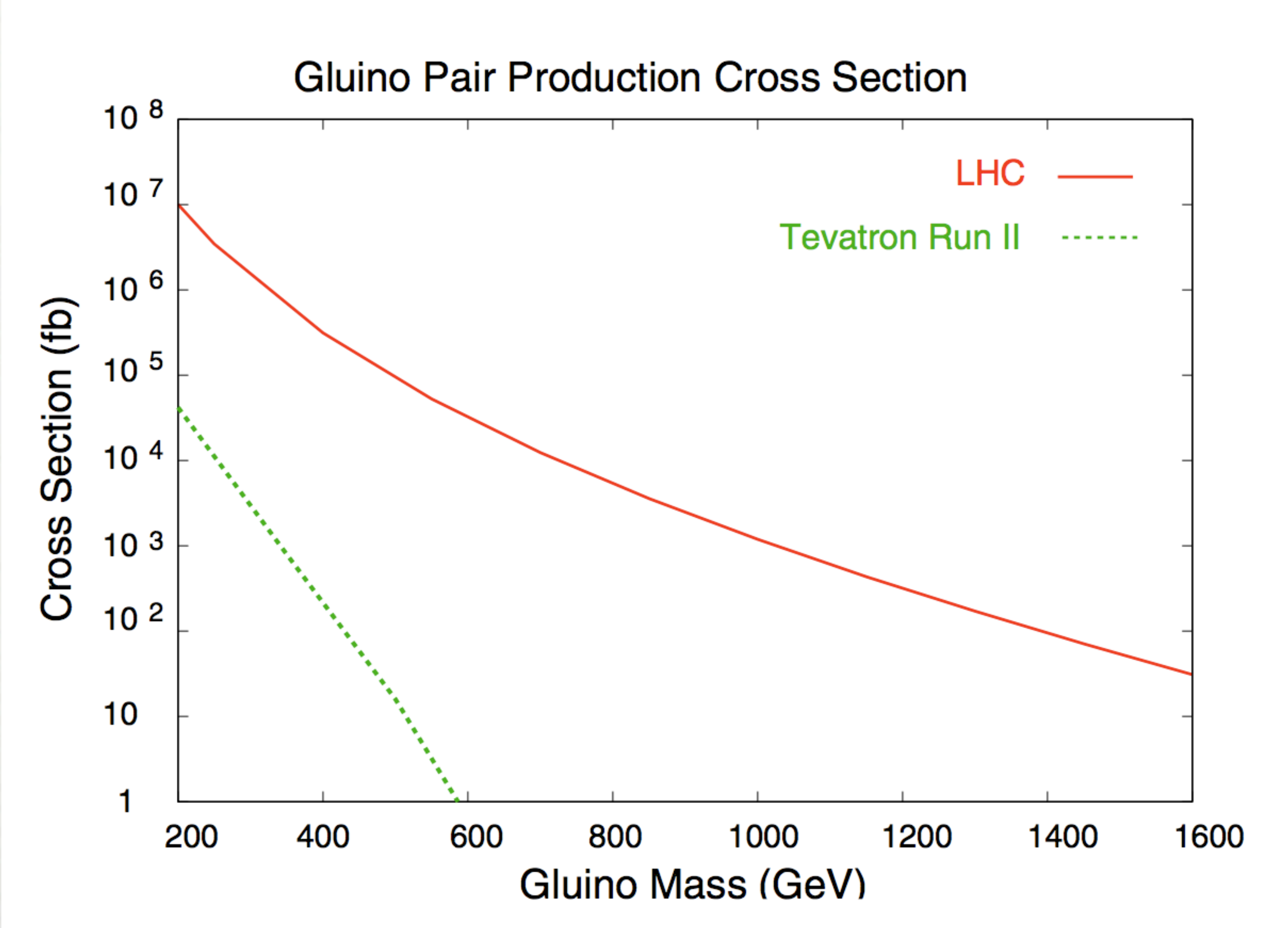
*JOINED BY A. SKUJA (MARYLAND)

SINCE THIS PROPOSAL LAST APRIL

- CMS NOW IS PLANNING TO IMPLEMENT SUCH A TRIGGER AND I (AND OTHERS) HAVE BEEN STUDYING HOW BEST TO DO SO
- FIRSTLY, 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 MORE COMPLICATED TOOLS HAVE BEEN USED TO FULLY UNDERSTAND HOW TO IMPLEMENT THE PROPOSED TRIGGER, MORE ON THAT LATER (THOUGH SOME OF THE RESULTS I CAN'T SHOW YOU)

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 R-HADRON ENERGY LOSS MODEL

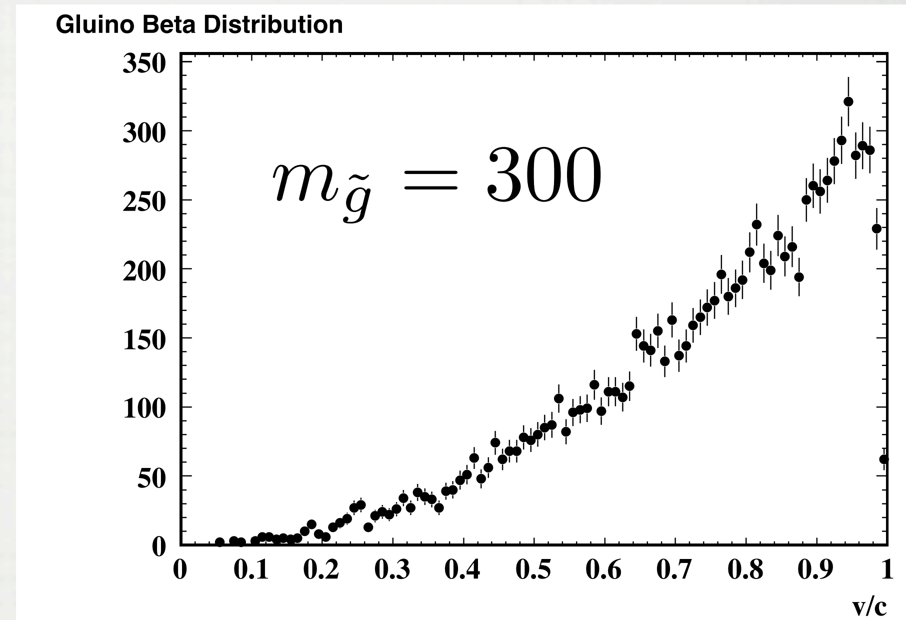
- I USE PYTHIA TO PRODUCE GLUINOS OF A GIVEN MASS
- I ONLY DO THIS TO GET THE VELOCITY (AND SOME OTHER KINEMATIC) DISTRIBUTIONS FOR THAT MASS WHICH I SUBSEQUENTLY USE AS A PROBABILITY DISTRIBUTIONS IN MY TOY MODEL
- I USE A MODIFIED PYTHIA WHICH ALSO HADRONISES THE GLUINOS INTO R-HADRONS
    - FOR THIS 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

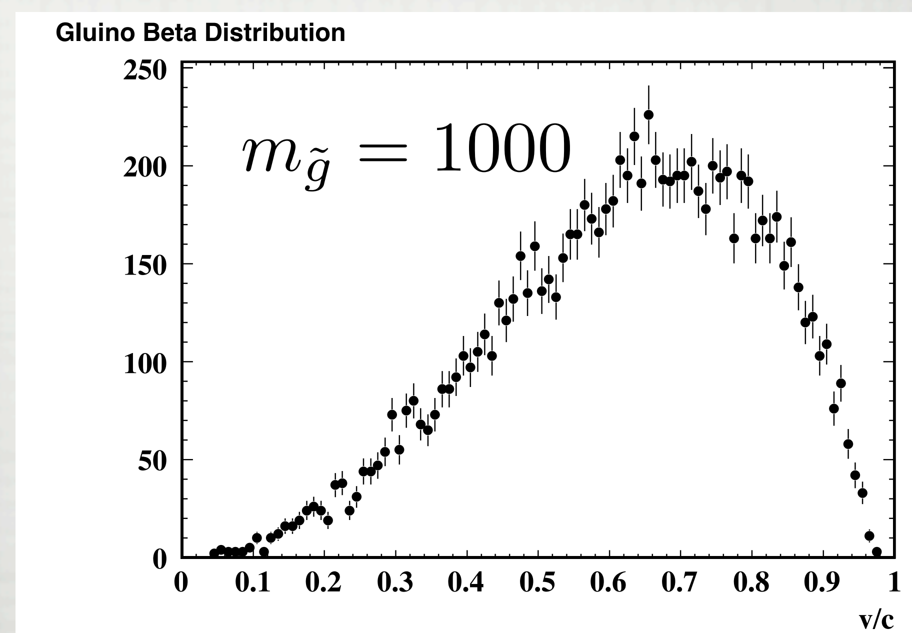
$$-\frac{dE}{dx} = Kz^2\frac{Z}{A}\frac{1}{\beta^2}\left[\frac{1}{2}\ln\frac{2m_ec^2\beta^2\gamma^2T_{\max}}{I^2} - \beta^2 - \frac{\delta(\beta\gamma)}{2}\right]$$

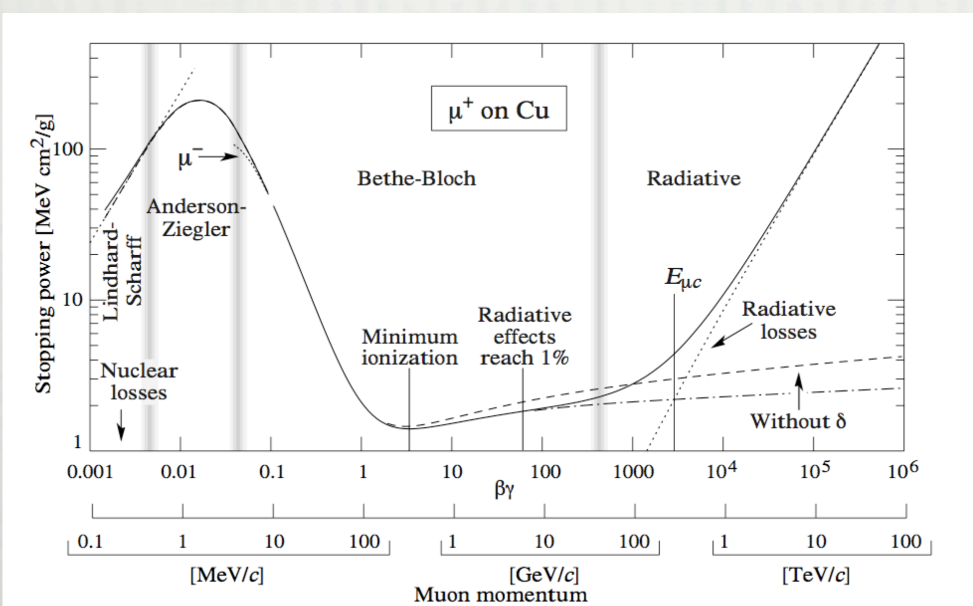
    - I USE 23 CM OF LEAD (CRUDE ECAL) + 79 CM COPPER (CRUDE HCAL)

VELOCITY DISTRIBUTIONS

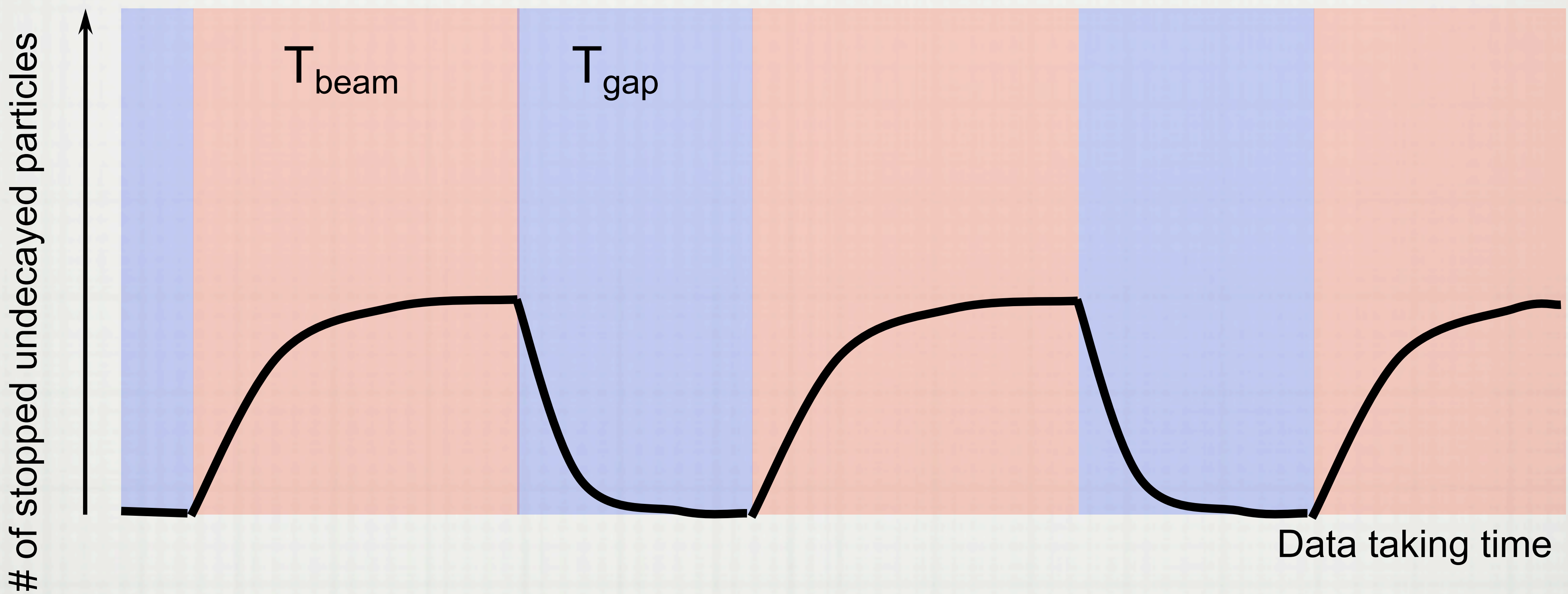
- AS YOU WOULD EXPECT, HEAVIER GLUINOS ARE ON AVERAGE SLOWER (AND THUS HIGHER DE/DX)
  - BUT OWING TO THEIR LARGER KE, DESPITE THIS THEY ARE HARDER TO STOP
- WITH THIS SIMPLIFIED ENERGY LOSS MODEL, GET STOPPING "EFFICIENCY" OF SEVERAL PERCENT (WITH SLIGHT MASS DEPENDENCE)







OPERATIONAL TIMING STRUCTURE



If $\tau \ll T_{beam}$

$$\sigma_{effective} = [\sigma_{production} \bullet \varepsilon_{stop}] \bullet \varepsilon_{reco} \bullet \frac{\tau}{T_{beam} + T_{gap}} \bullet \left(1 - e^{-\frac{T_{gap}}{\tau}}\right)$$

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 AND DECAYED 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.

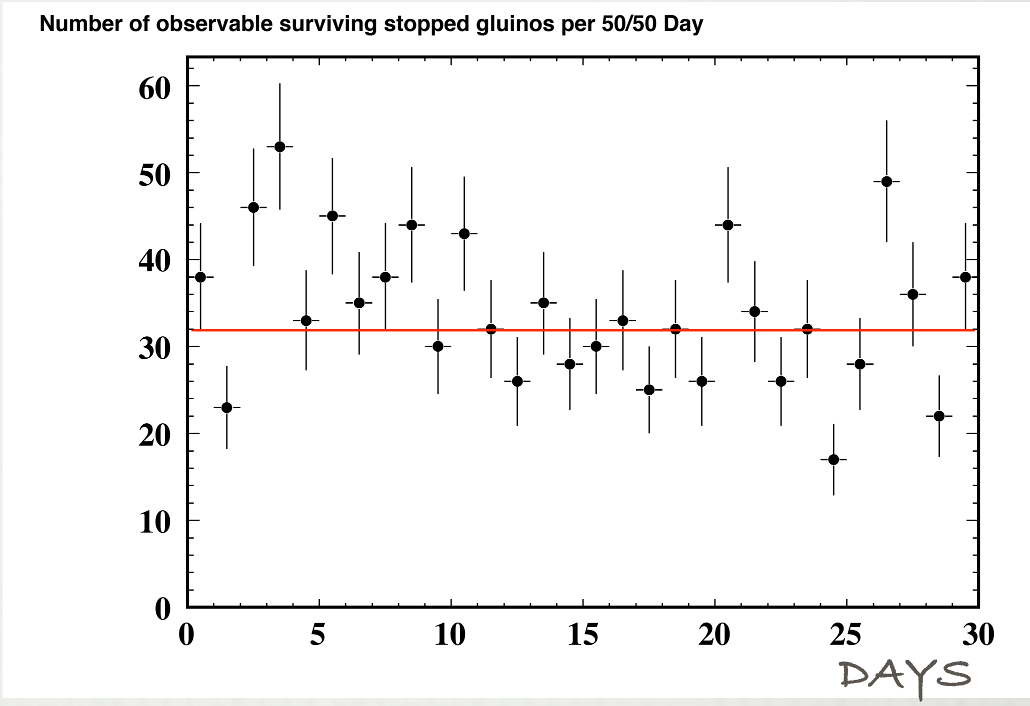
9. REPEAT FOR VARIOUS MASSES, LIFETIMES, DUTY-CYCLES, ETC.

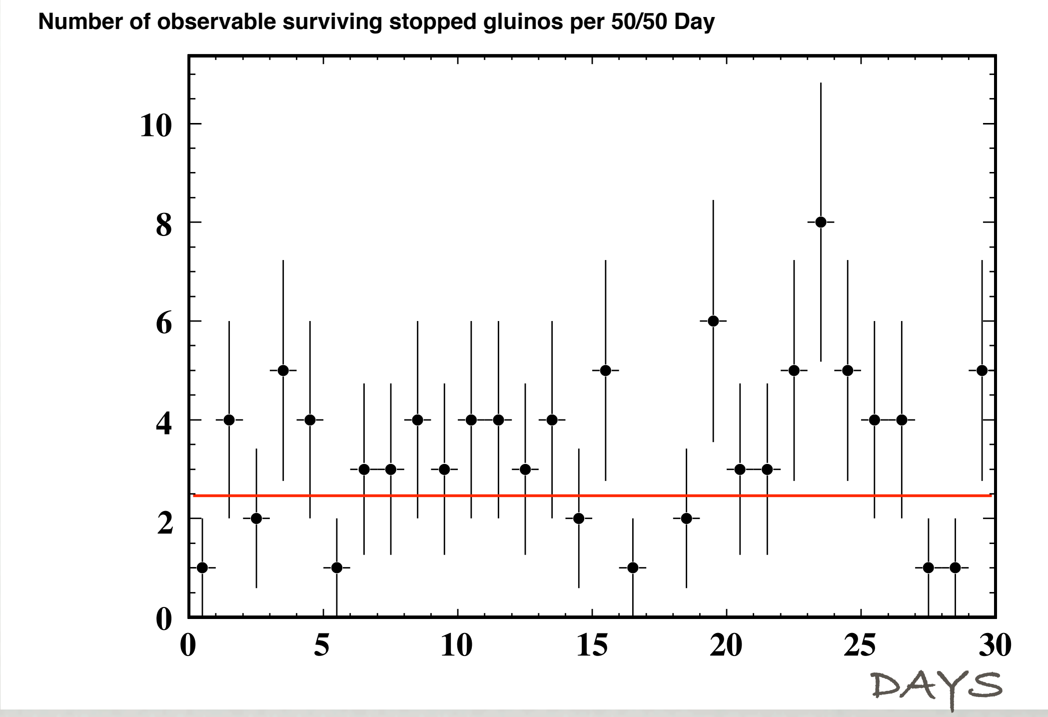
SCENARIOS SCANNED

- 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}

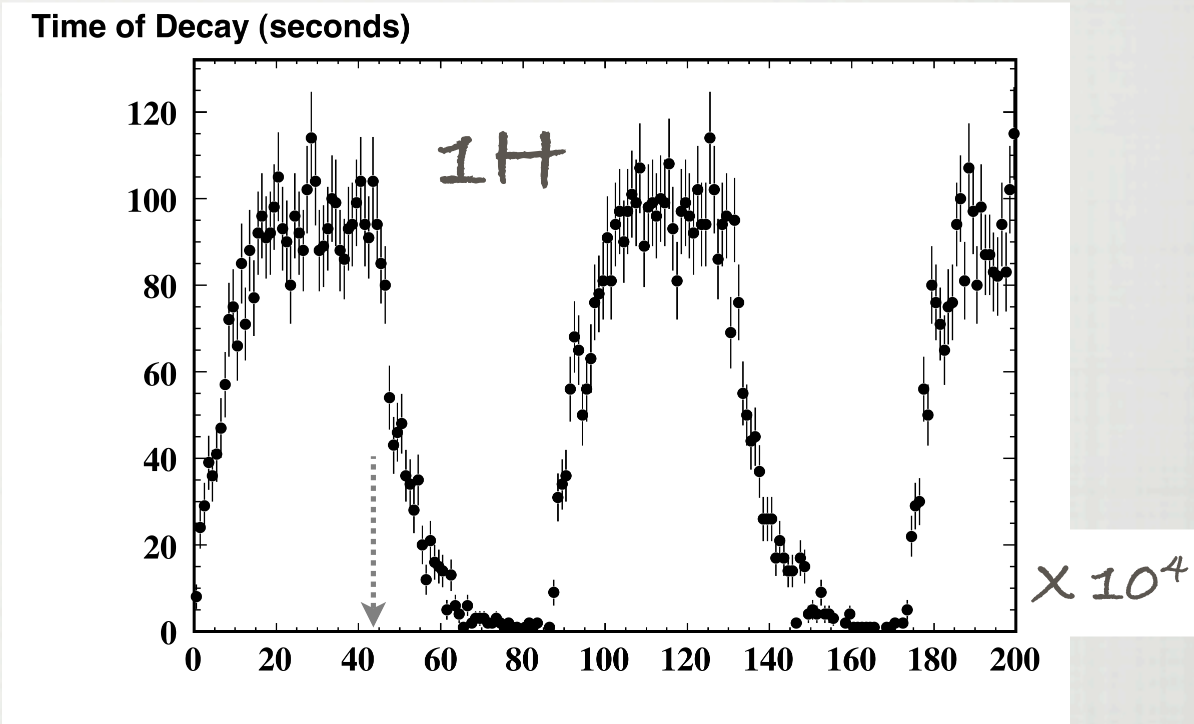
- 50% DUTY-CYCLE (12H BEAM-OFF)
- 12H LIFETIME
- FOR 300 GEV GLUINO, COPIOUS PRODUCTION RATES MEAN COULD EXPECT TO SEE AN AVERAGE OF ~30 DECAYS PER 12H BEAM-OFF PERIOD
  - VERY EASY DISCOVERY
- FOR 500 GEV, STILL HAVE AVERAGE OF ~3 DECAYS PER 12H BEAM-OFF PERIOD
  - EASY DISCOVERY
- HEAVIER MASSES NEED MORE THAN A MONTH @ 10^{32} TO MAKE A DISCOVERY

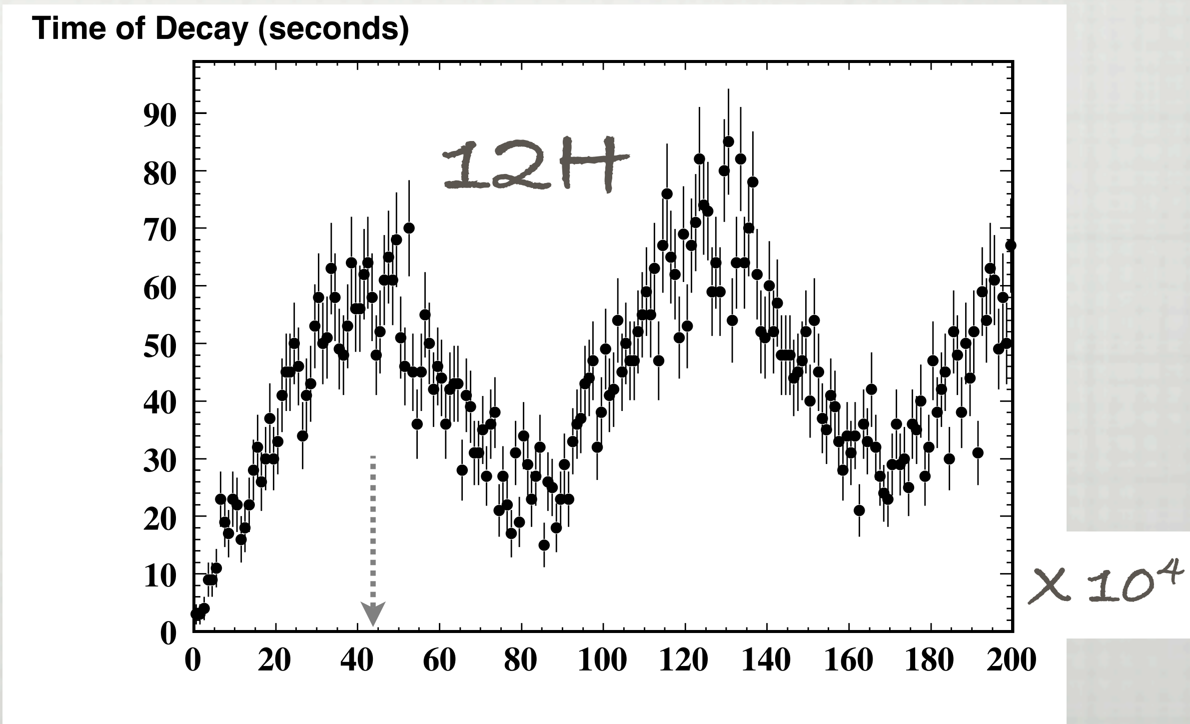




NUMBER OF STOPPED GLUINOS VS. TIME

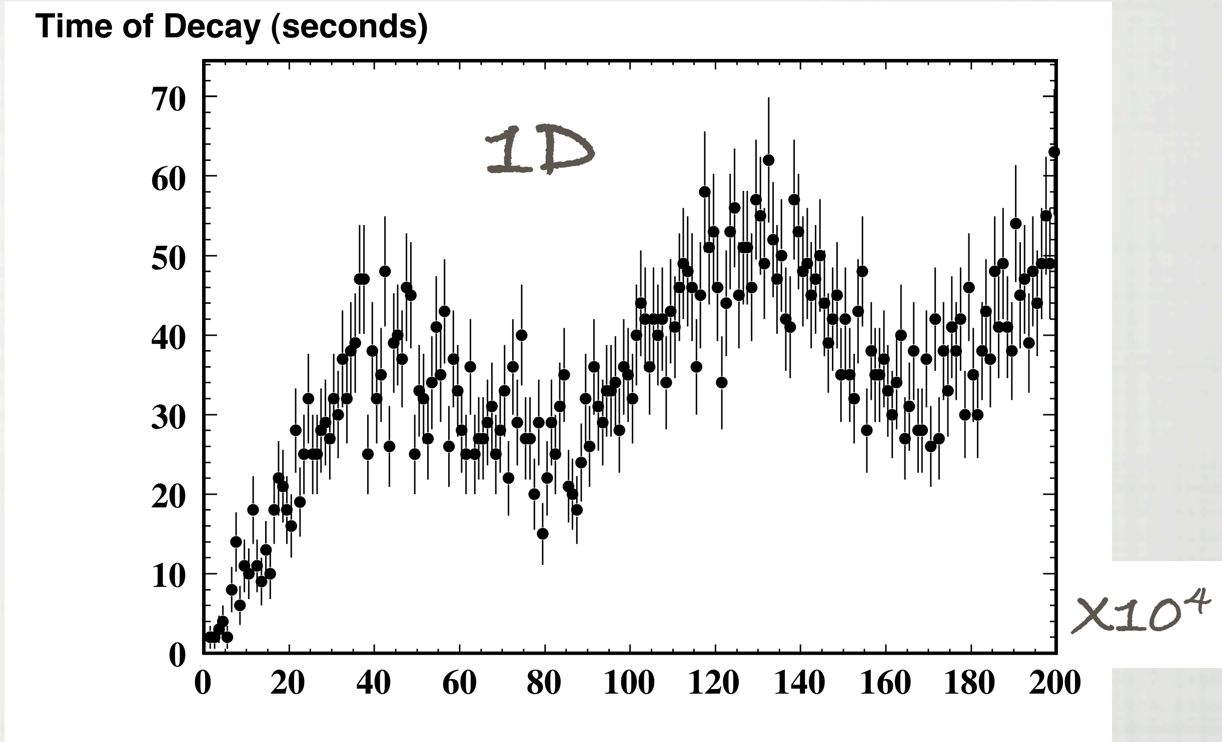
- FREEZING THE MASS (300) AND THE DUTY-CYCLE (50%), I CAN VARY THE LIFETIME AS ILLUSTRATED IN THE PLOTS ON THE RIGHT
- THE PLOTS AT THE RIGHT SHOW 2.5 DAYS WORTH OF GLUINO PRODUCTION (12H WHEN BEAM IS ON) FOLLOWED BY 12H OF DECAY WHEN BEAM IS OFF FOR TWO DIFFERENT LIFETIMES (1H AND 12H)
  - FYI 12H = 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

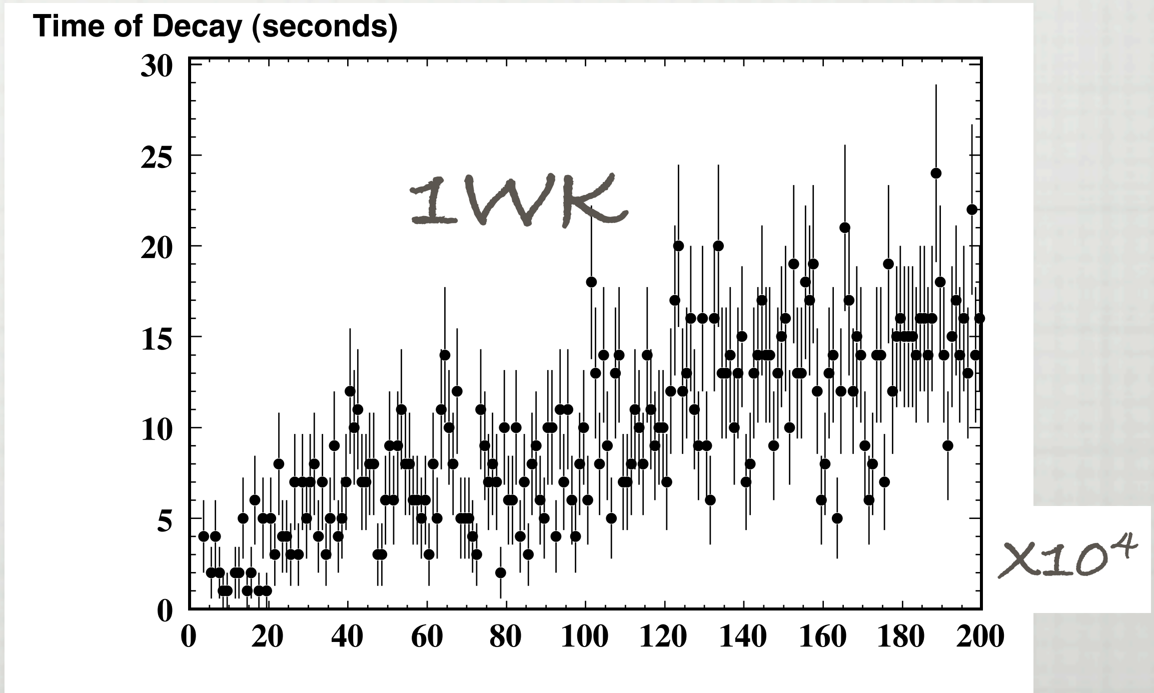




NUMBER OF STOPPED GLUINOS VS. TIME (CONT.)

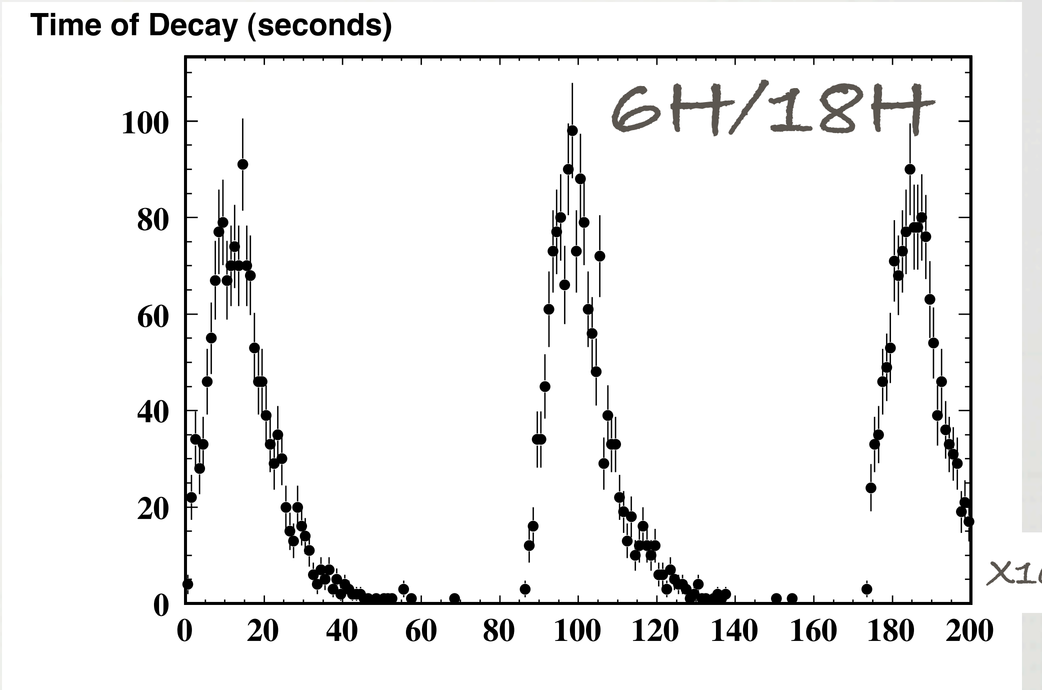
- HERE ARE PLOTS FOR SLIGHTLY LONGER LIFETIMES, 1D AND 1WK
- AGAIN, ONE COULD EASILY MEASURE THESE LIFETIMES WITH 1 MONTH DATA @ 10^{32}
- FOR LONGER LIFETIMES (MONTH, YEAR) WE COULD STILL OBSERVE 300 GEV GLUINO EVENTS BUT IT MIGHT TAKE LONGER THAN A MONTH TO ACCURATELY MEASURE THE LIFETIME

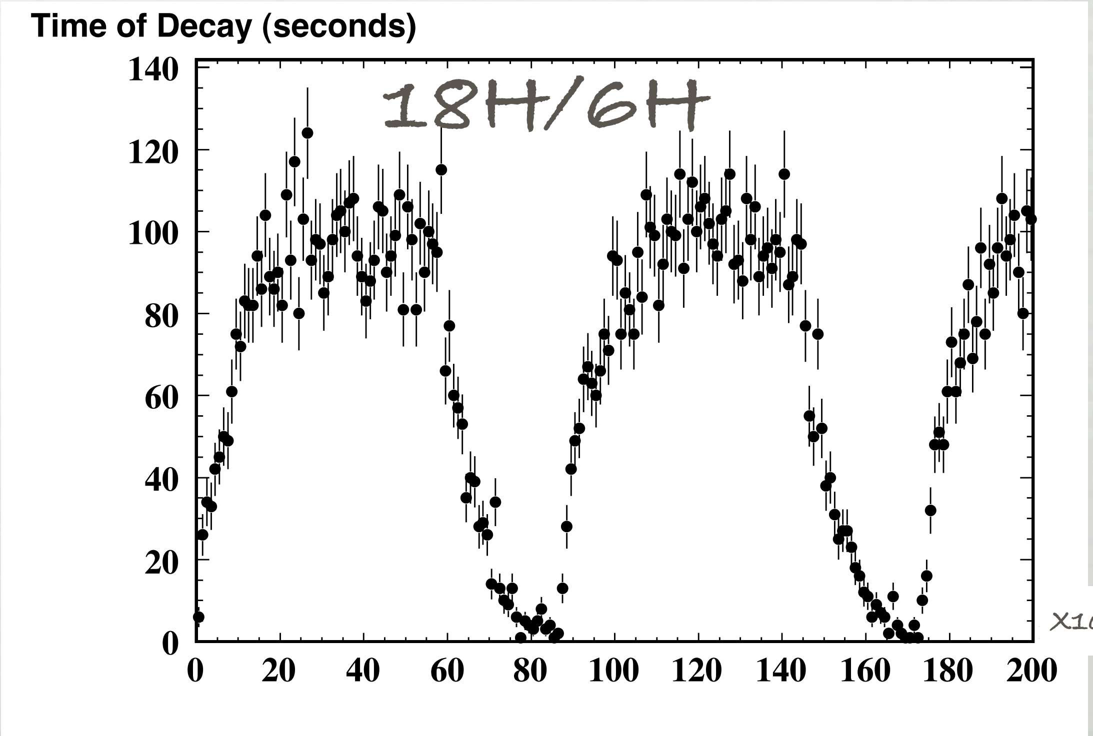




VARYING DUTY CYCLE (6H/18H, 18H/12H)

- 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





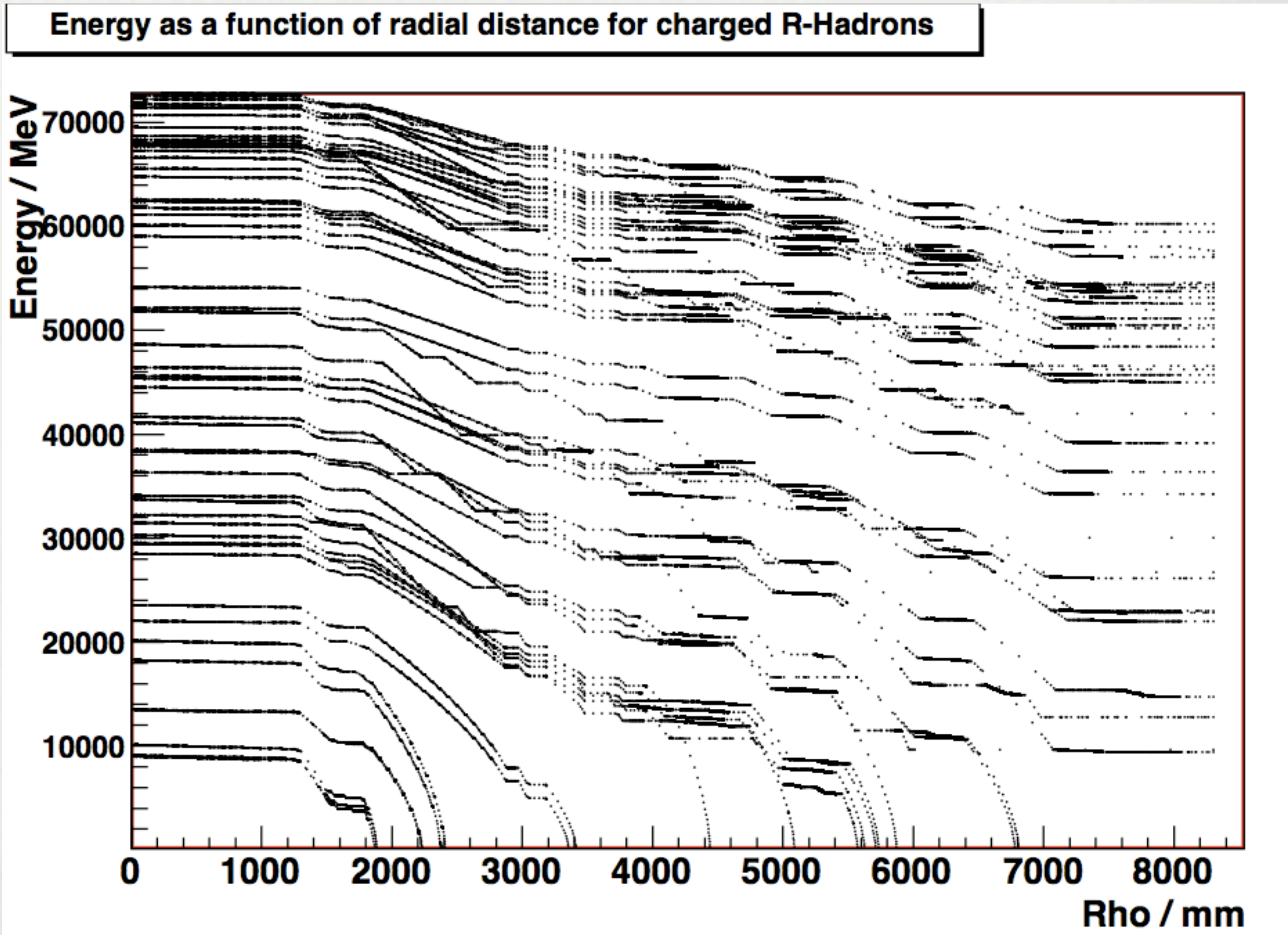
HOW TO DO A FULL GEANT SIMULATION OF SUCH EVENTS?

- IN ACTUALITY, TO OBSERVE THESE DECAYS SHOULD BE RELATIVELY EASY
  - PROVIDED A REASONABLE TRIGGER THRESHOLD SET & DETECTOR LIVE
- 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 FACTORISING THE PROBLEM

1. PRODUCE GLUINOS, ALLOW THEM TO HADRONISE 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

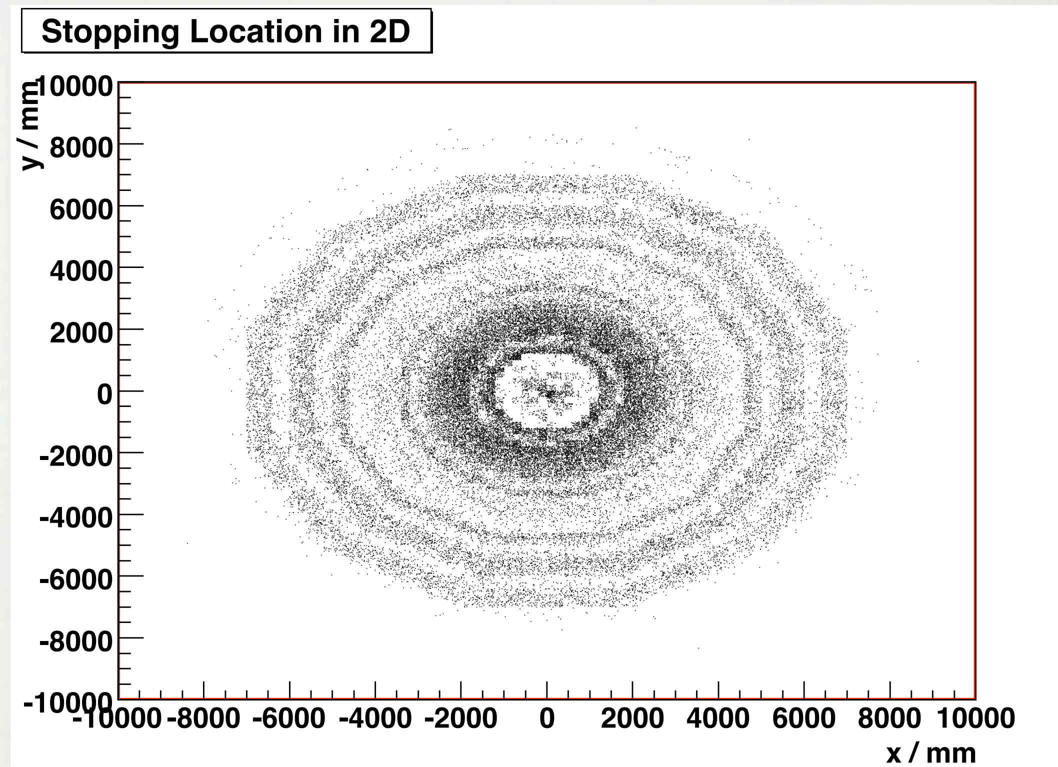
- FOR CMS, A. RIZZI, (EUR.PHYS.J.C50:353-362, 2007) HAS IMPLEMENTED A SCHEME FOR HEAVY STABLE COLOURED PARTICLE INTERACTIONS WITH MATTER IN GEANT
  - BASED ON SO-CALLED "CLOUD" MODEL
- WE USE* THIS IMPLEMENTATION AND "WATCH" AN R-HADRON'S KINETIC ENERGY, WHEN IT HAS REACHED ZERO, I.E. STOPPED, WE RECORD THAT POSITION

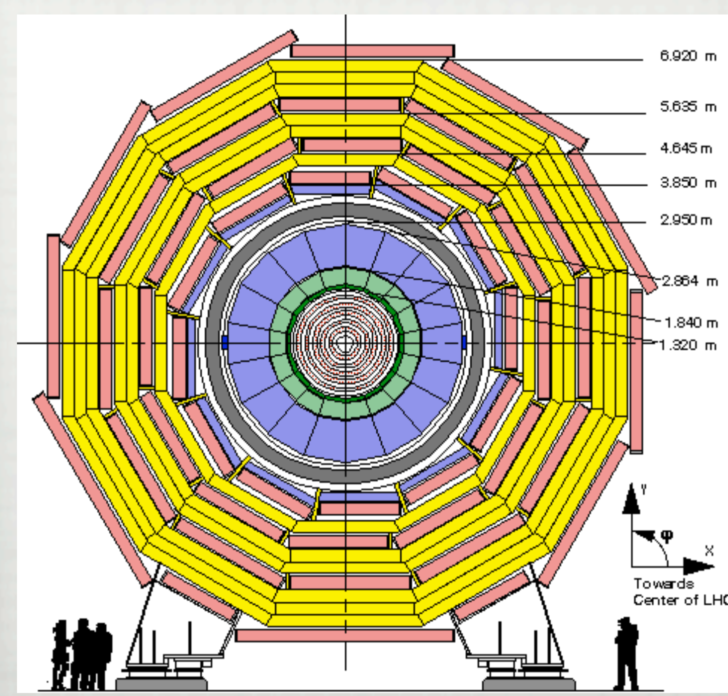


*ACTUALLY, FOR CONSISTENCY WITH MY SIMPLE SIMULATION, IN THE STUDIES SHOWN HERE THE NUCLEAR INTERACTIONS HAVE BEEN "TURNED OFF"

RADIAL STOPPING LOCATION

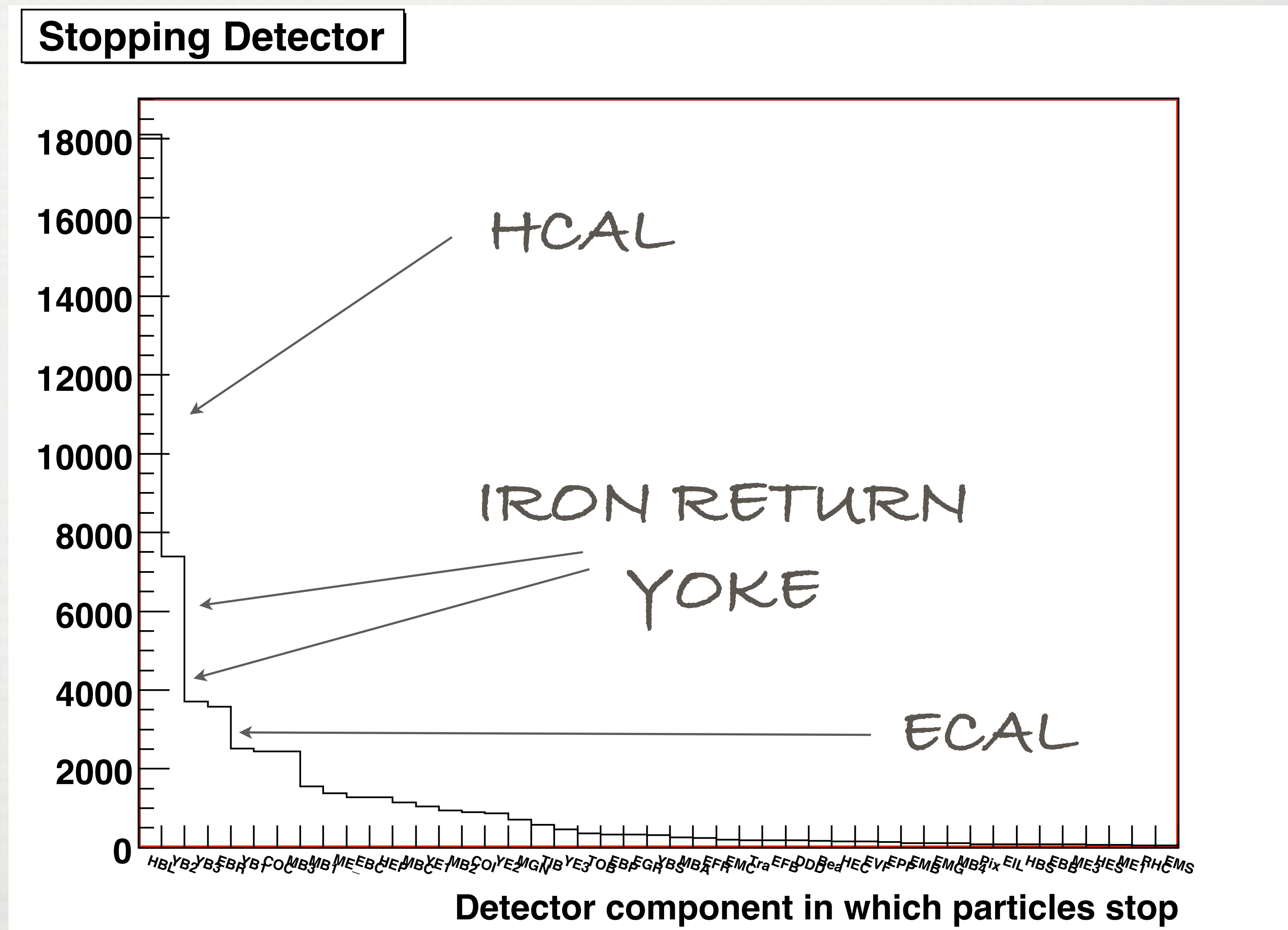
- THE GEANT SIMULATION CONFIRMS WHAT WE SUSPECTED FROM OUR SIMPLE SIMULATION
  - STOPPING RATES OF A FEW PERCENT
  - MOST OF THOSE STOPPED DO SO IN THE CALORIMETERS OR THE IRON OF THE RETURN YOKE
  - HEAVIER GLUINO MASSES, THOUGH PRODUCED SIGNIFICANTLY MORE RARELY, STOPPED MORE EASILY





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



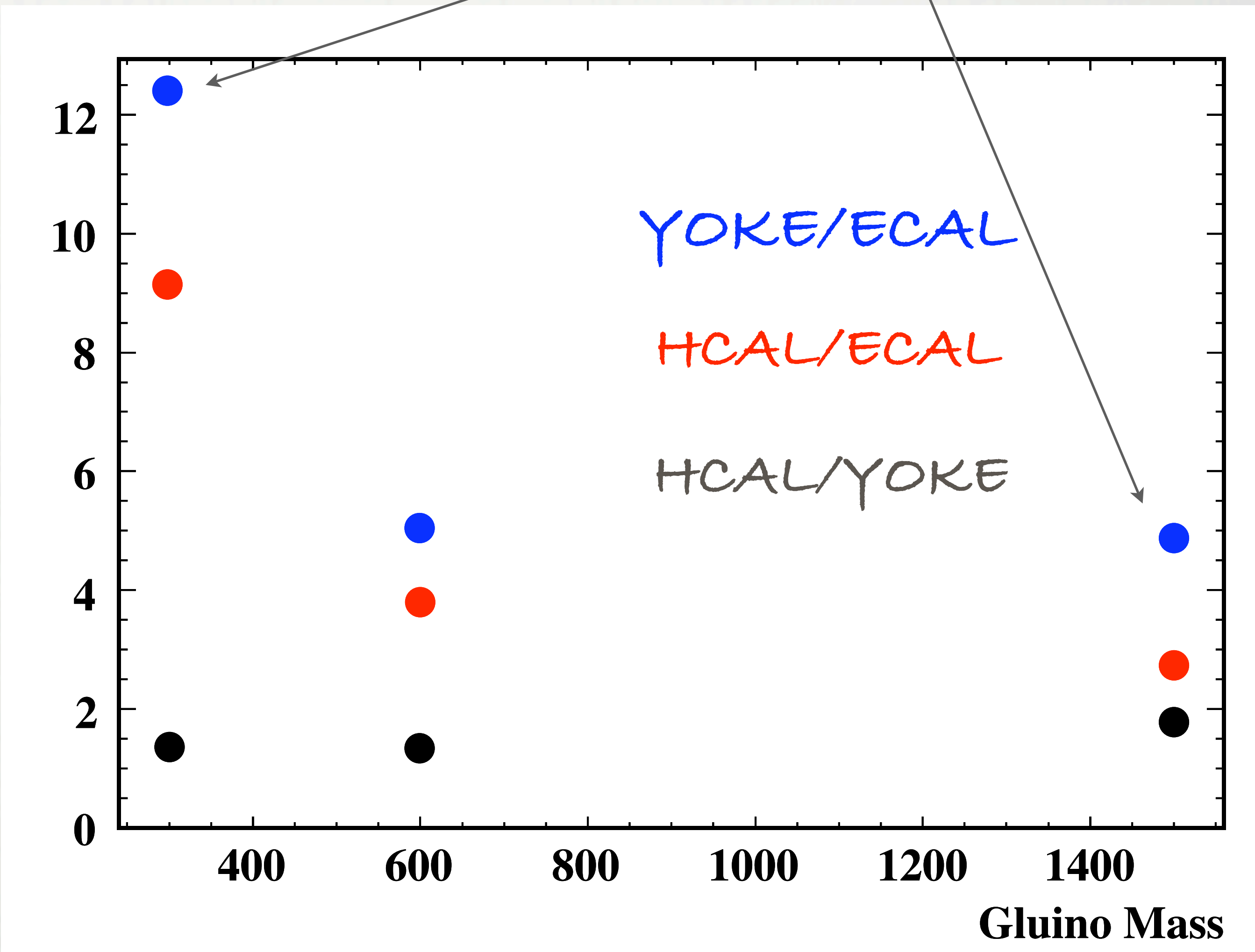
*THIS DEPENDENCE CAN ACTUALLY BE EXPLOITED, SEE NEXT SLIDE

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

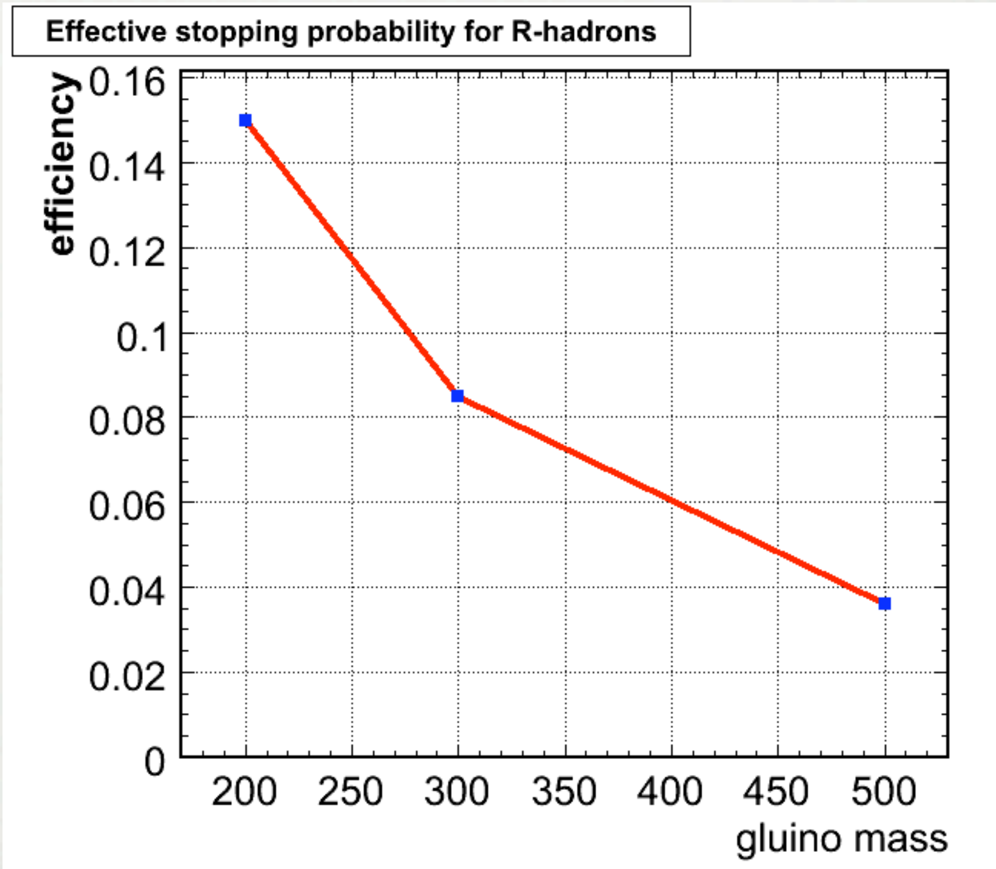
- THE YOKE/ECAL RATIO IS THE MOST SENSITIVE SINCE IT HAS THE LARGEST LEVER ARM

E.G. COMPARE THESE



HOW DO HADRONIC INTERACTIONS CHANGE THINGS?

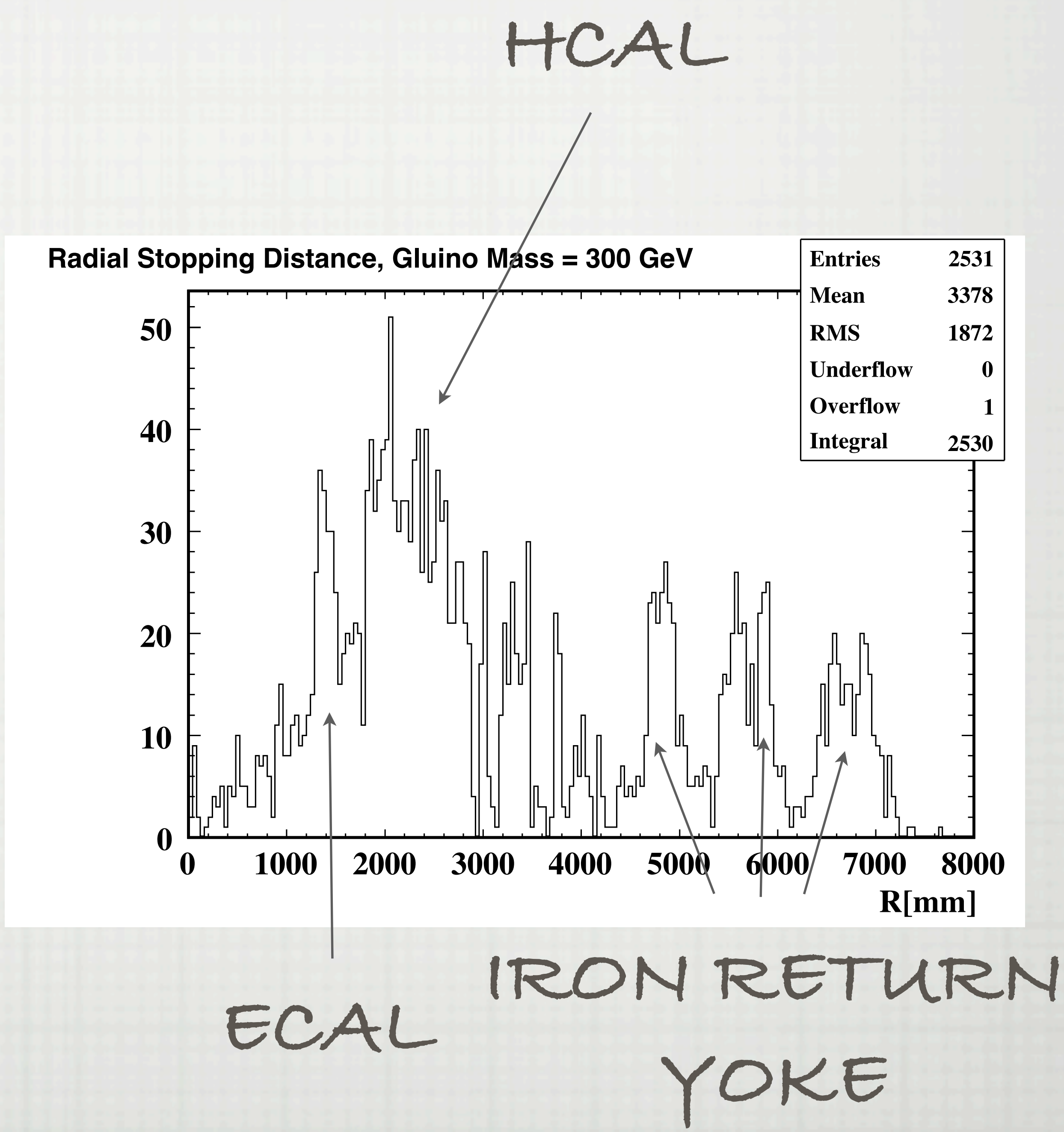
- IF WE NOW TURN ON THE NUCLEAR INTERACTIONS, WE OBSERVE ROUGHLY THE SAME DISTRIBUTION OF STOPPING LOCATIONS AS WE DID PREVIOUSLY
- THE STOPPING RATES, HAVE HOWEVER, SIGNIFICANTLY INCREASED
  - WHILE THERE IS SOME EXTRA ENERGY LOSS THROUGH NUCLEAR INTERACTIONS, THIS IS OFFSET BY THE FACT THAT SOMETIMES THE R-HADRON IS NEUTRAL ... WHAT IS HAPPENING?
- IT IS DUE TO THE FORMATION OF DOUBLY CHARGED R-BARYONS



These doubly charged states (R-hadron analogue of Δ^{++}) lose energy 4x faster, and are thus the most likely to be stopped

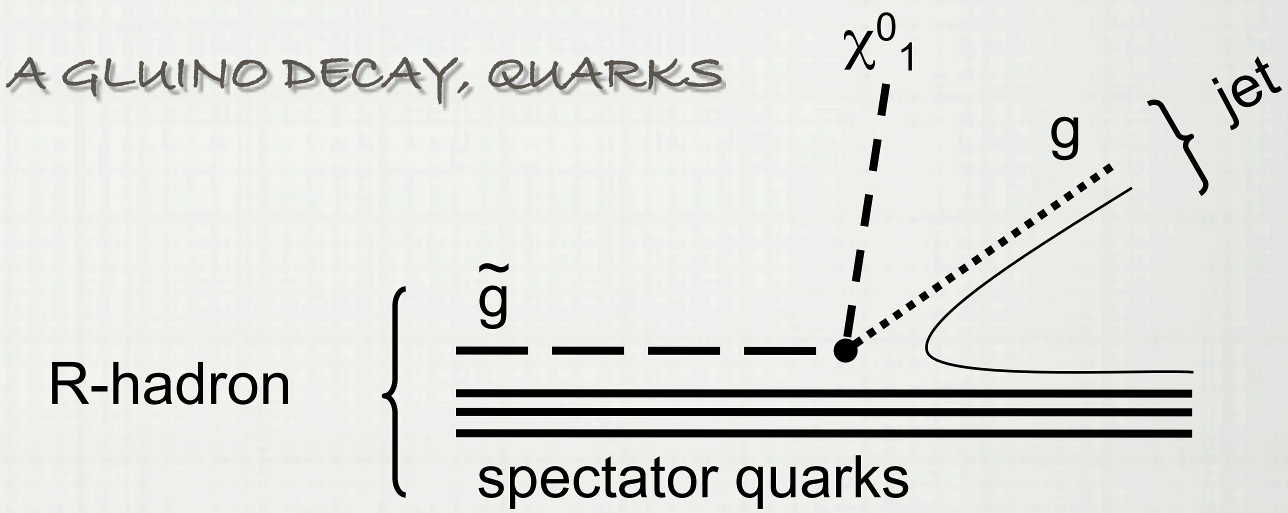
NOW THAT WE KNOW WHERE THEY WILL STOP ...

- WE USE PYTHIA AS A PARTICLE GUN TO PRODUCE A SINGLE R-HADRON, OF A GIVEN MASS, AT (0,0,0)
- WE SET ITS 4-MOMENTA SUCH THAT IT'S AT REST
- WE THEN TRANSLATE THE R-HADRON TO ORIGINATE FROM A RANDOMLY CHOSEN (V_X,V_Y,V_Z) WEIGHTED BY THE MAP OBTAINED PREVIOUSLY
- NEXT WE HAVE PYTHIA DECAY THE R-HADRON AND HADRONISE & SHOWER THE DECAY PRODUCTS AS NORMAL



R-HADRON DECAY SIMULATION DETAILS

- R-HADRON DECAY IS ESSENTIALLY A GLUINO DECAY, QUARKS ARE SPECTATORS



- $M_{\tilde{G}} = M_R$ - 2 GEV
- THE COLOUR STATE OF THE SPECTATOR QUARKS ACTUALLY EFFECTS THE GLUON/QUARK JET FORMATION
  - THUS, DECAYING STAND-ALONE GLUINO IS NOT ENOUGH, NEED TO SIMULATE THE ENTIRE BARYONIC SYSTEM
- THANKS TO STEVE MRENNA, WE PUT TOGETHER CUSTOM DECAY TABLES THAT ALLOW PYTHIA TO DO WHAT WE NEED
  - WE DECAY THE WHOLE COLOURLESS (GLUINO+QUARK +DIQUARK) SYSTEM

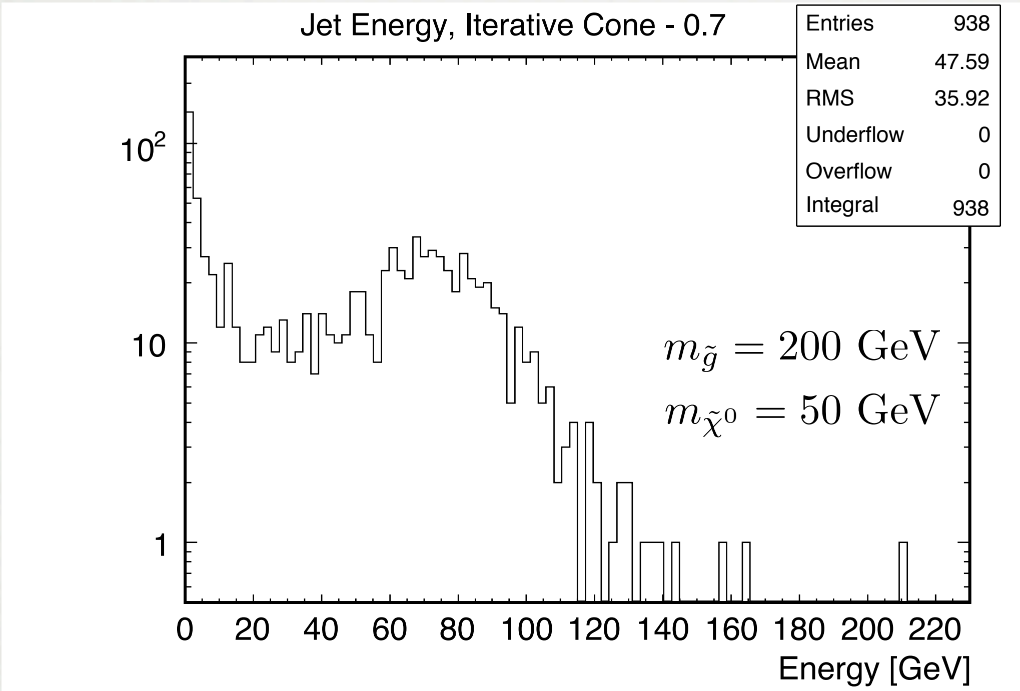
$$\text{R-hadron} \rightarrow \tilde{g}\ q\ (qq)$$
$$\hookrightarrow g\ \chi^0_1$$

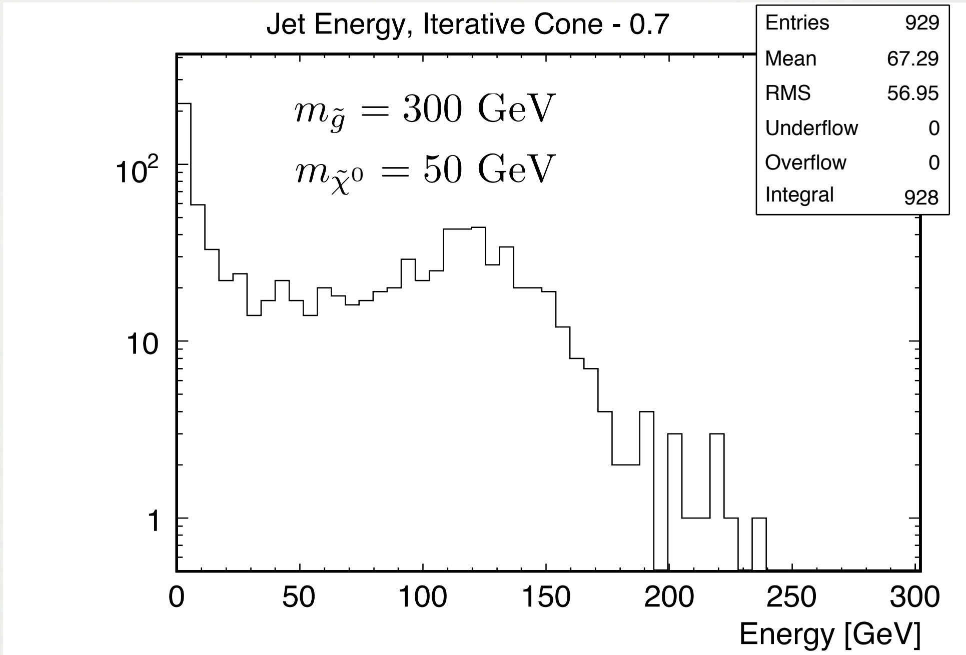
RECONSTRUCTION?

- CAN WE RECONSTRUCT THESE EVENTS?
  - NOT STRICTLY NECESSARY AS LONG AS CAN TRIGGER ... BUT WOULD BE NICE
- WE HAVE RUN THE STANDARD CMS RECO SEQUENCE (THOUGH WE ONLY ATTEMPT CALORIMETRY + JET RECONSTRUCTION)
  - AND SURPRISINGLY, WE FIND SIGNIFICANT ENERGY DEPOSITS IN THE CALORIMETER AND CAN IN MOST CASES RECONSTRUCT A JET OR TWO
- INTERESTINGLY THOUGH, AS YOU SAW PREVIOUSLY, A SIGNIFICANT NUMBER OF GLUINOS ARE STOPPED BEYOND THE CALORIMETRY - VERY RARELY DO THESE PUNCH BACK THROUGH TO THE CALORIMETER AND DEPOSIT SIGNIFICANT RECONSTRUCTABLE ENERGY*

*IF WE WANT TO RECORD THIS CLASS OF EVENTS, WE'LL PROBABLY NEED A MUON CHAMBER TRIGGER

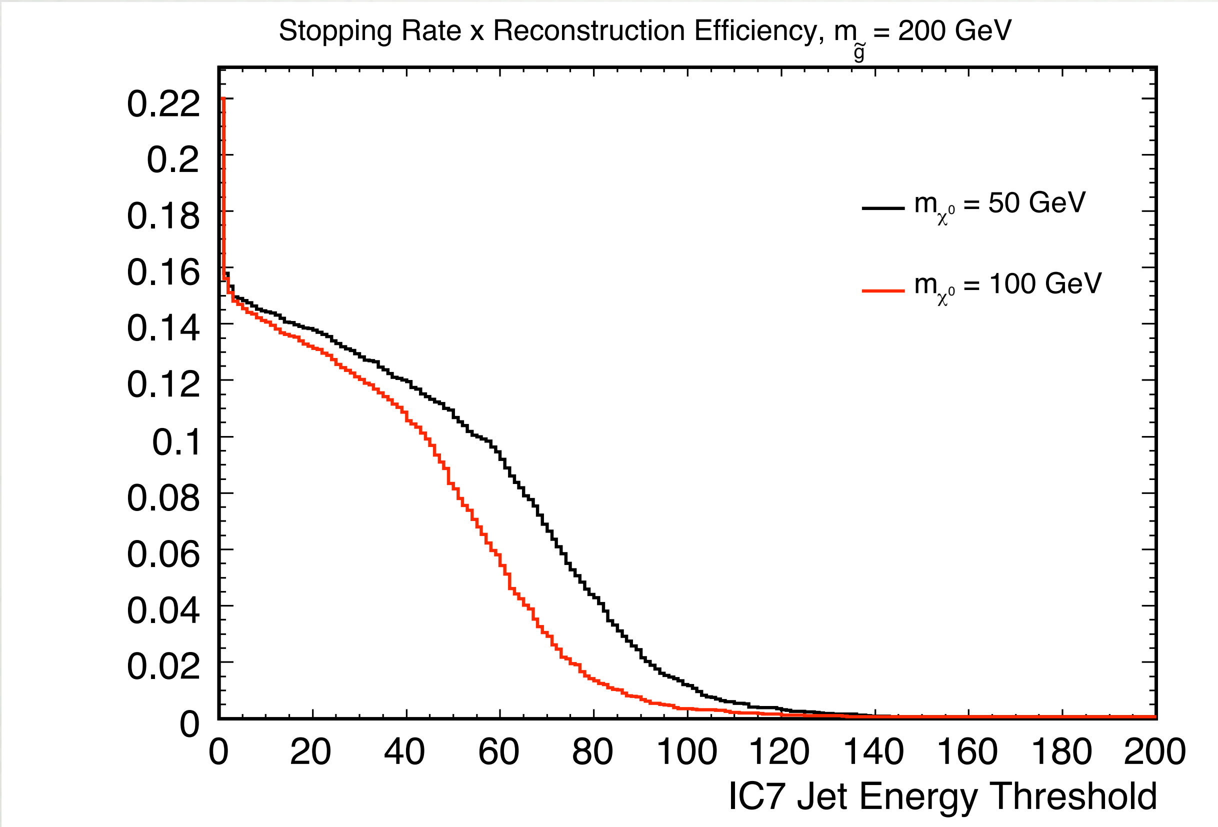
JET RECO RESULTS

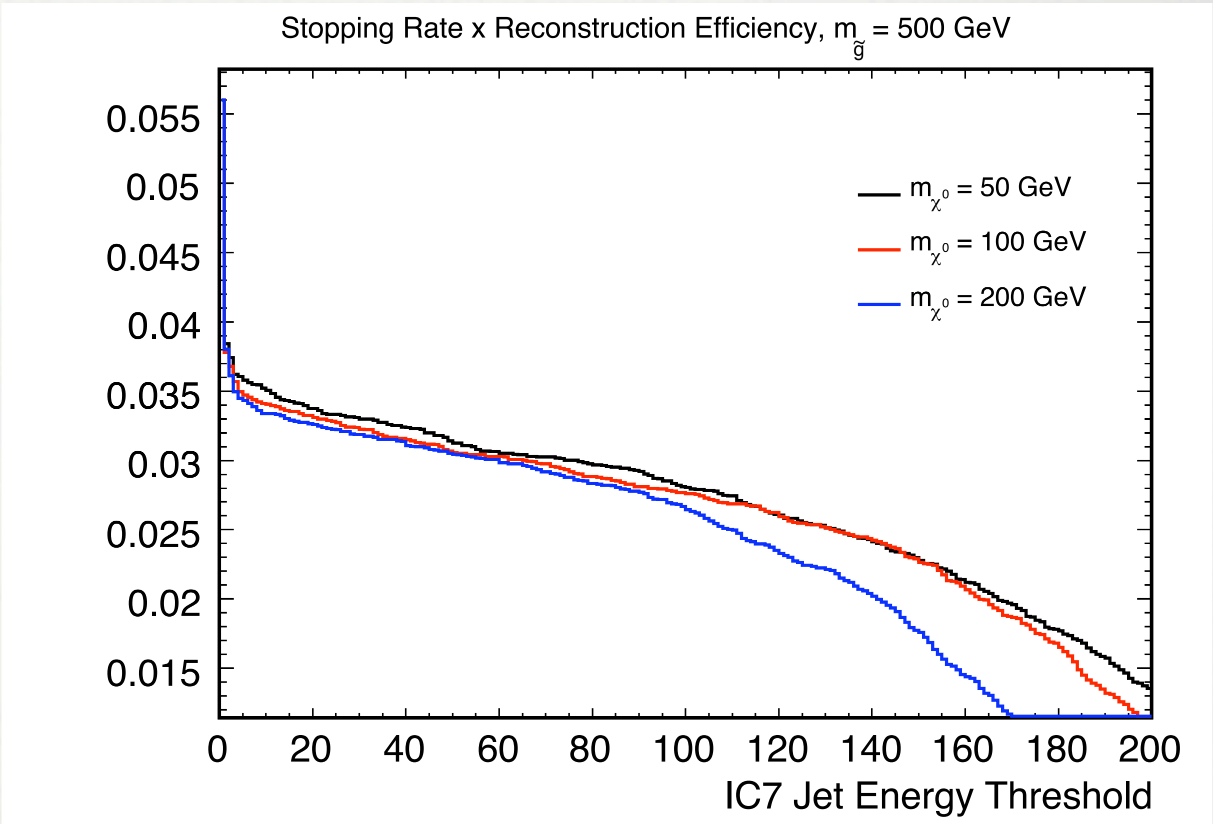




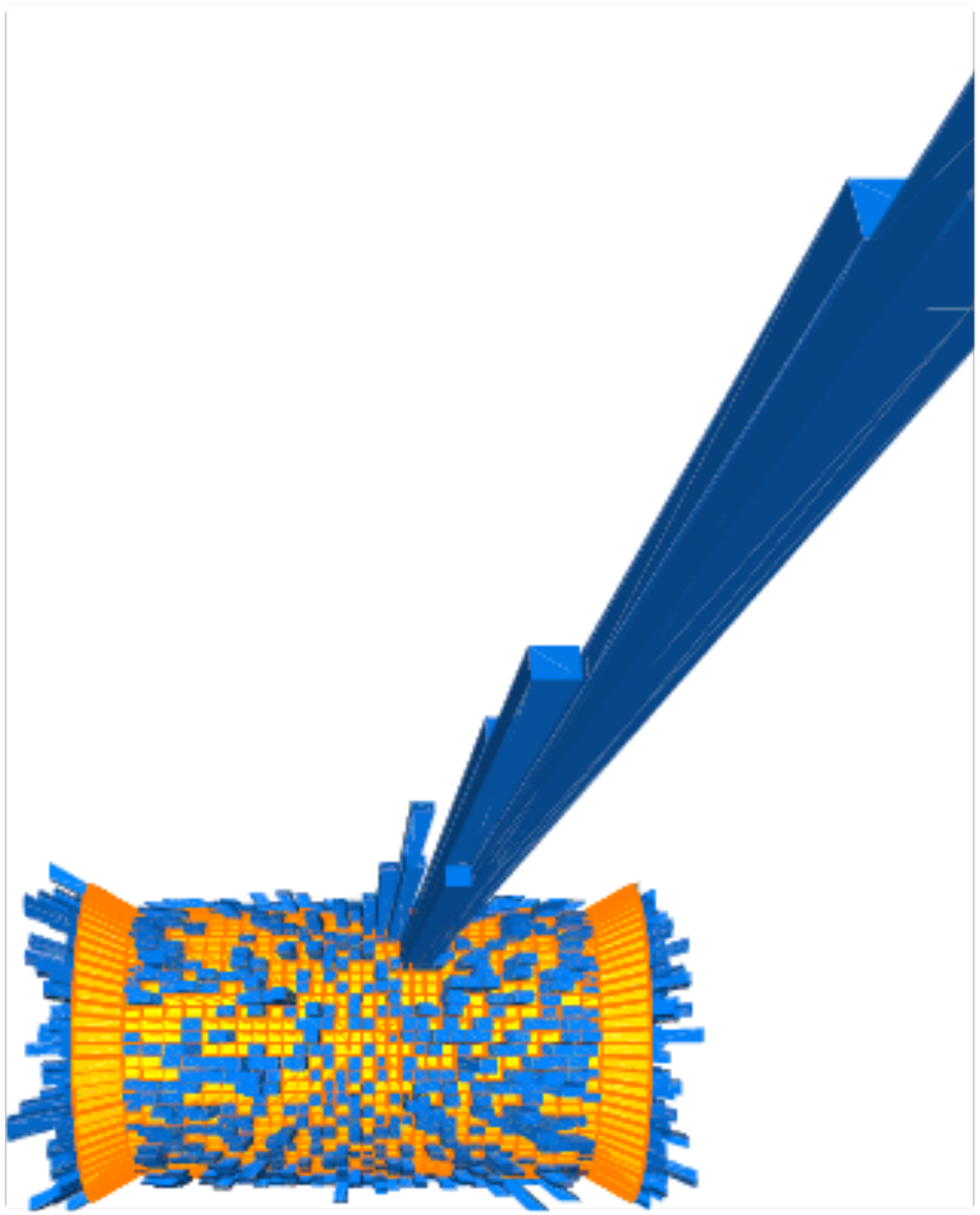
- USING AN ITERATIVE CONE ALGORITHIM, R = 0.7
- SIGNIFICANTLTY ENERGETIC JETS ARE FOUND IN MOST CASES
- THERE IS, OF COURSE, SOME DEPENDENCE ON THE SUSY POINT CONSIDERED DUE TO AMOUNT OF VISIBLE ENERGY IS AVAILABLE

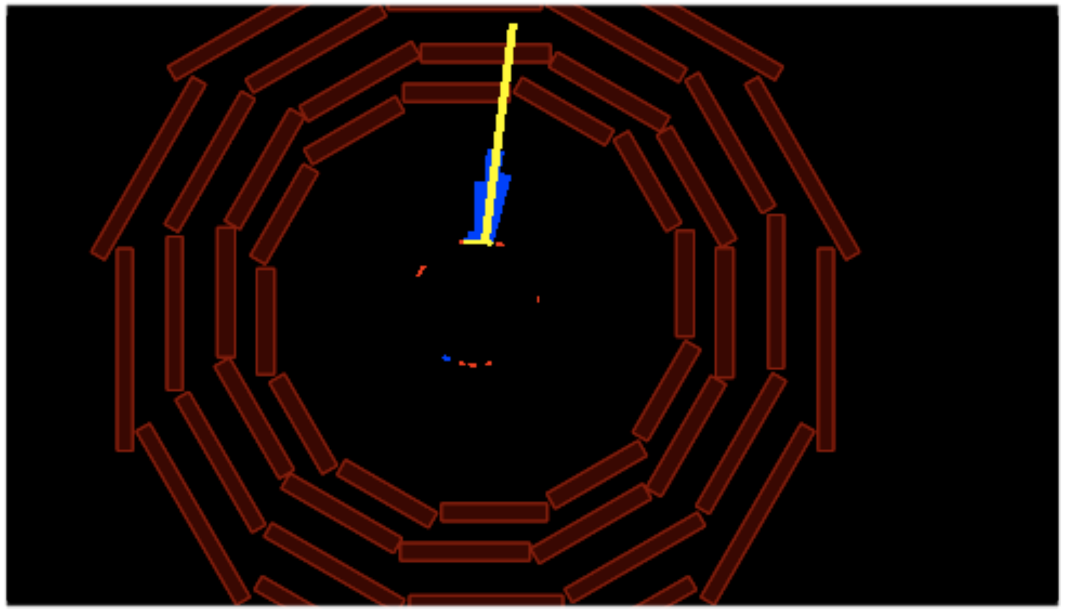
DEPENDENCE OF GLUINO MASS ON RECONSTRUCTION EFFICIENCY

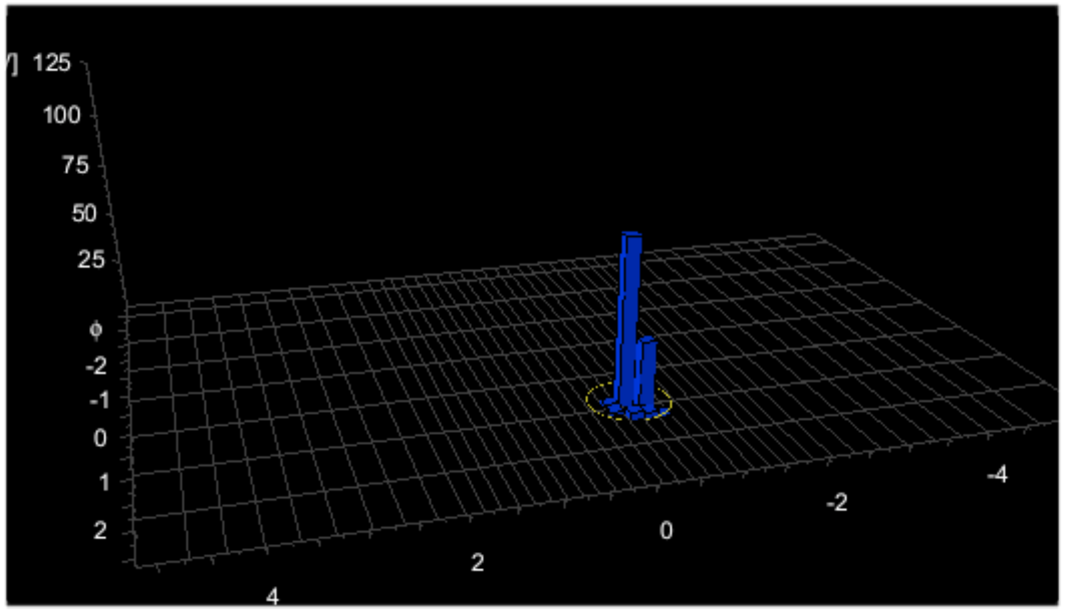




AS YOU WOULD EXPECT THE HEAVIER THE GLUINO, AND THE MORE VISIBLE ENERGY IN THE DECAY, THE HIGHER THE THRESHOLD MAY BE SET

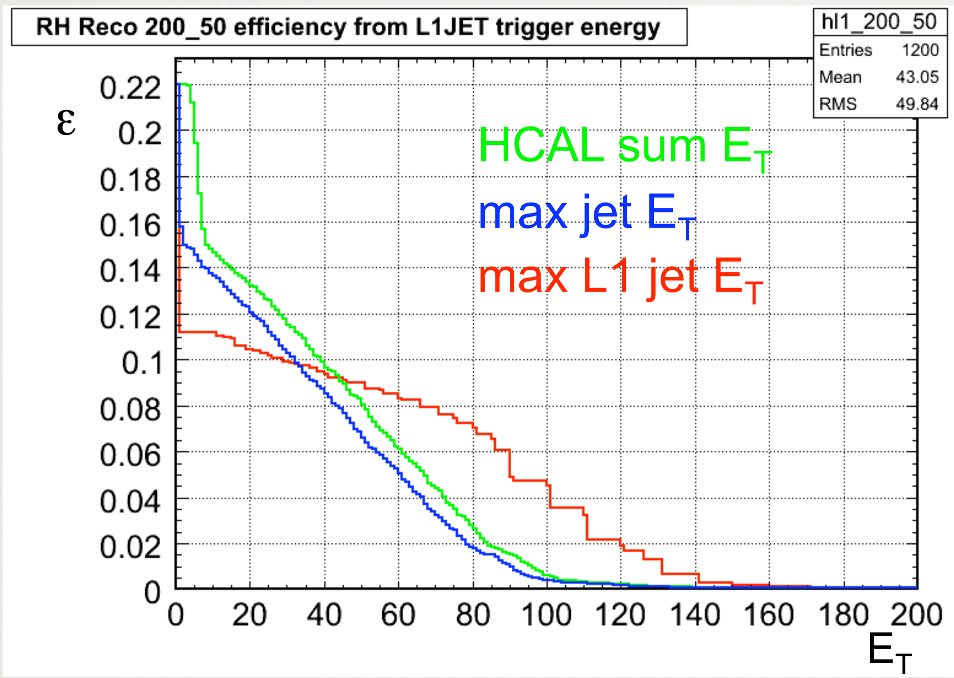


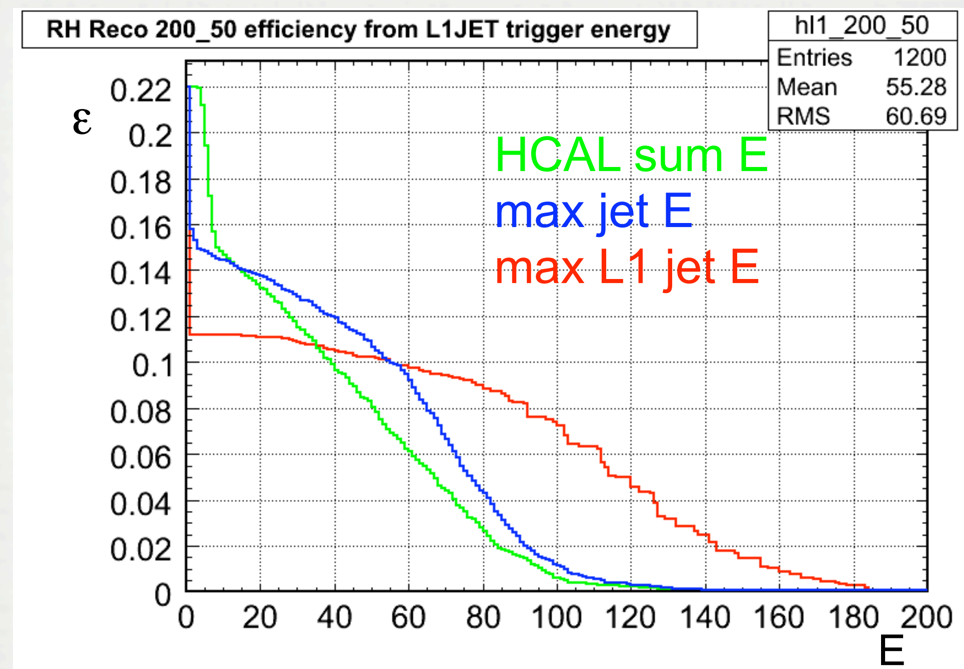




VERY DISTINCTIVE EVENTS AS EXPECTED!

JET TRIGGER STUDIES



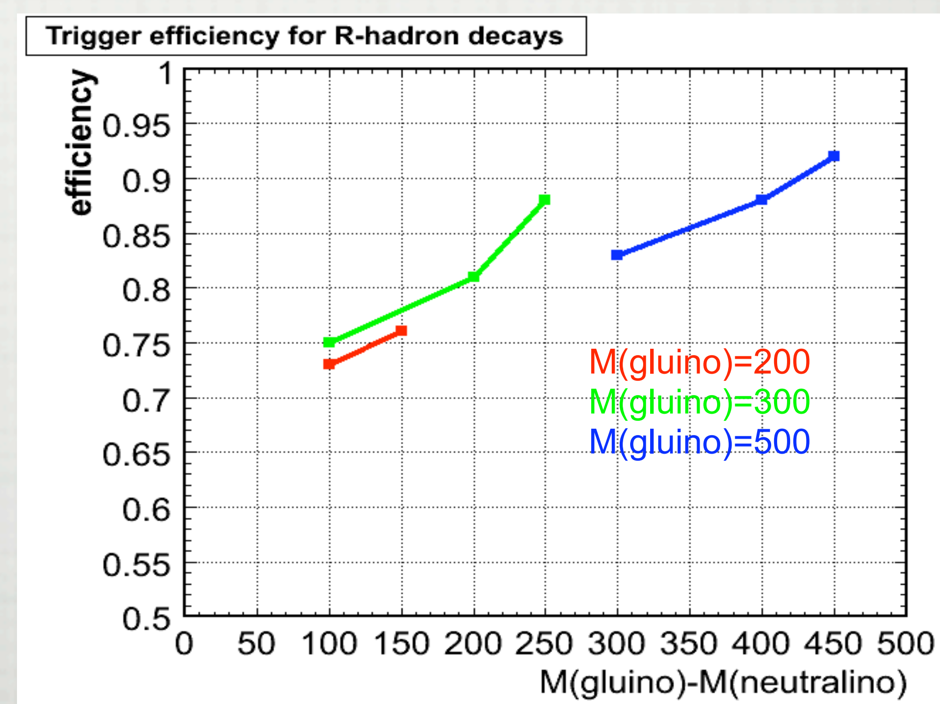


E OR E_T?

- USING THE CMS L1 TRIGGER EMULATOR, WE HAVE STUDIED JET TRIGGER EFFICIENCIES

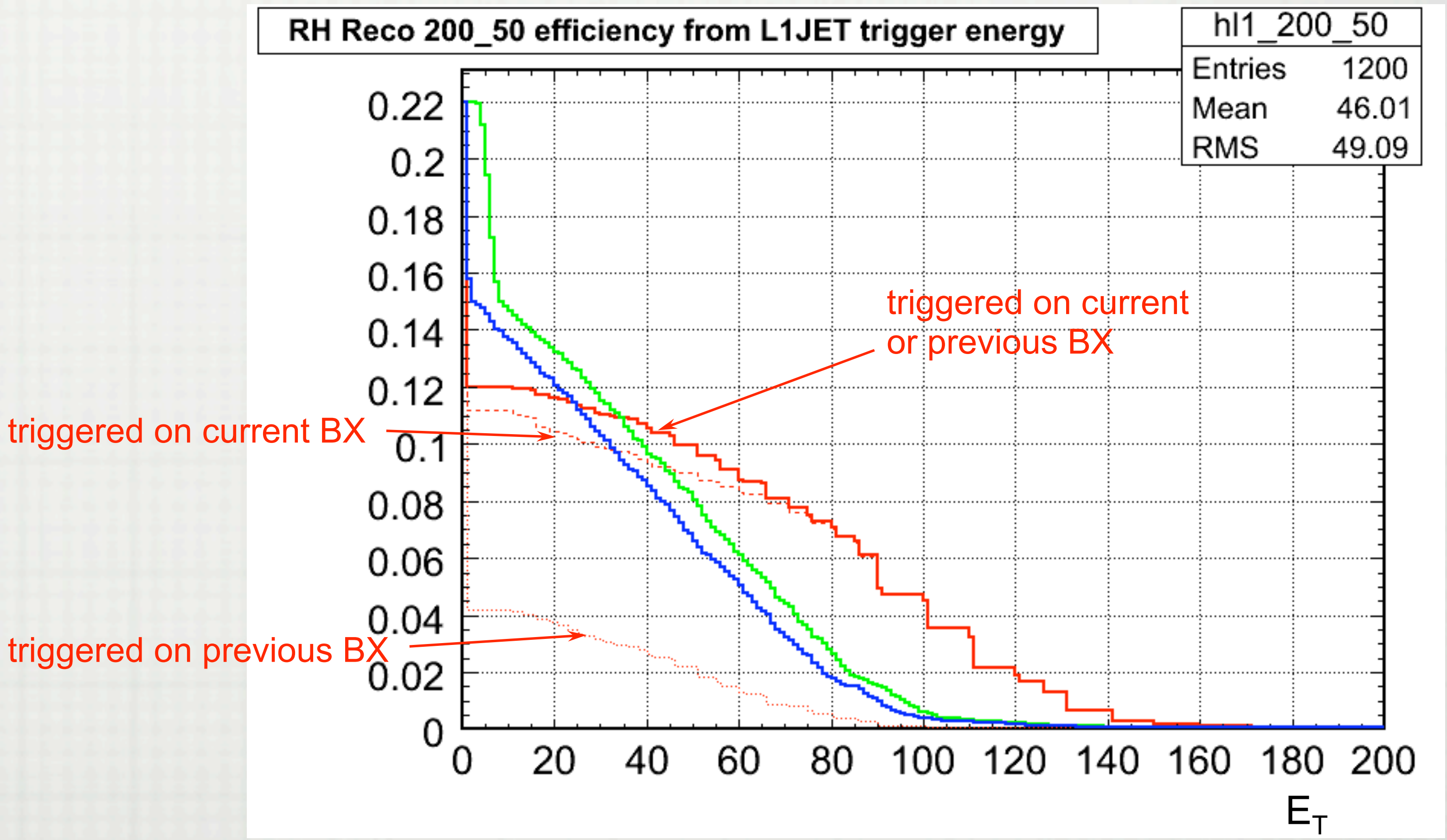
- WE FIND HIGH EFFICIENCY, INDEPENDENT OF MASS, AT ALL REASONABLE THRESHOLDS

  - DOESN'T MATTER MUCH WHETHER WE CONSIDER E OR E_T



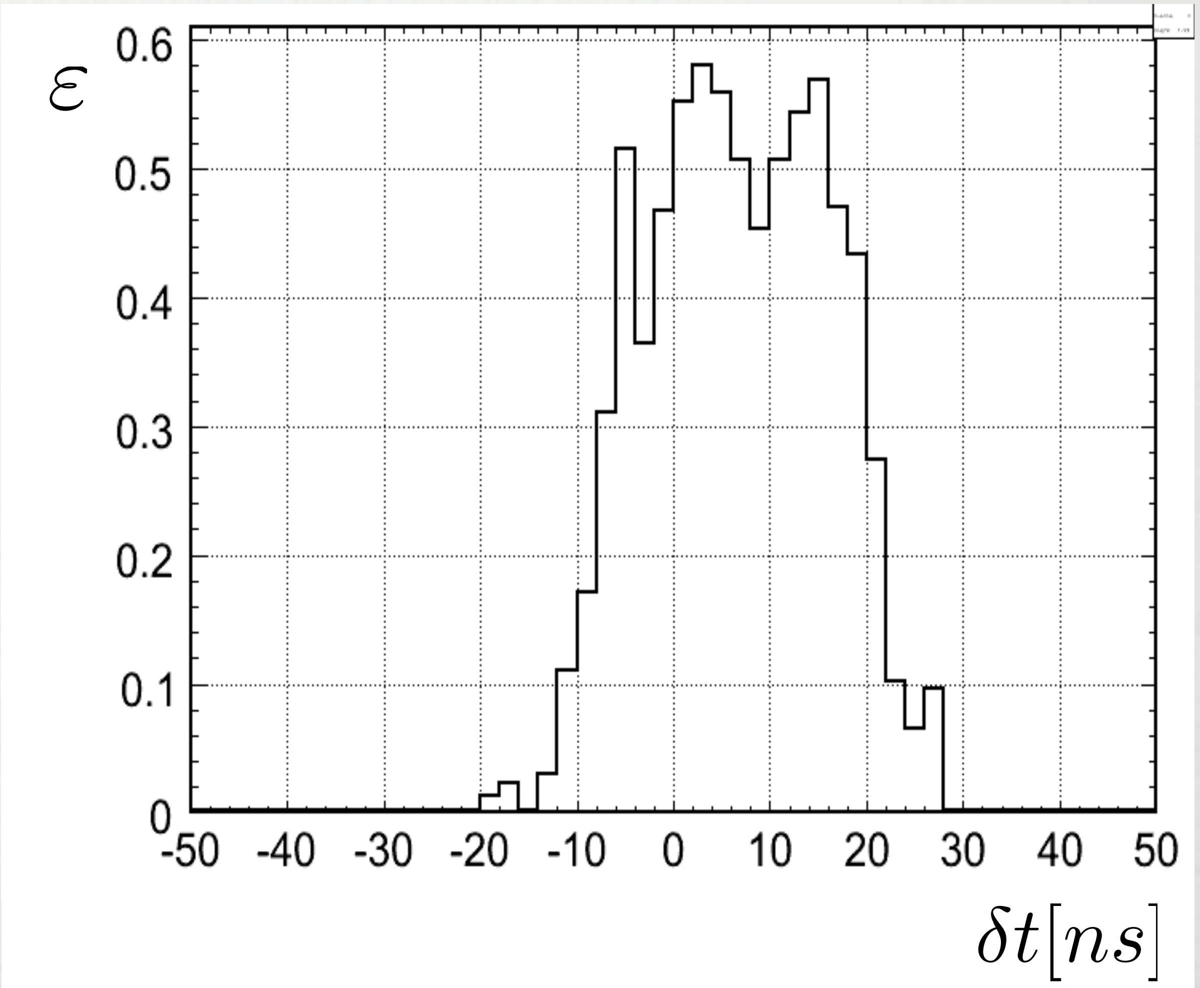
AN ARTIFACT OF OUR TREATMENT OF TIMING

- NORMALLY PARTICLES TAKE SEVERAL NS TO REACH THE CALORIMETERS
  - THE RESPONSE OF THE CALORIMETER ELECTRONICS IS ACCORDINGLY DELAYED RELATIVE TO THE BX TIME BY THIS FLIGHT TIME
- IN OUR SIMULATION, WE INSTANTLY TRANSLATE R-HADRONS TO THE CALORIMETER CAUSING SOME EVENTS TO (ARTIFICIALLY) APPEAR IN PREVIOUS BX



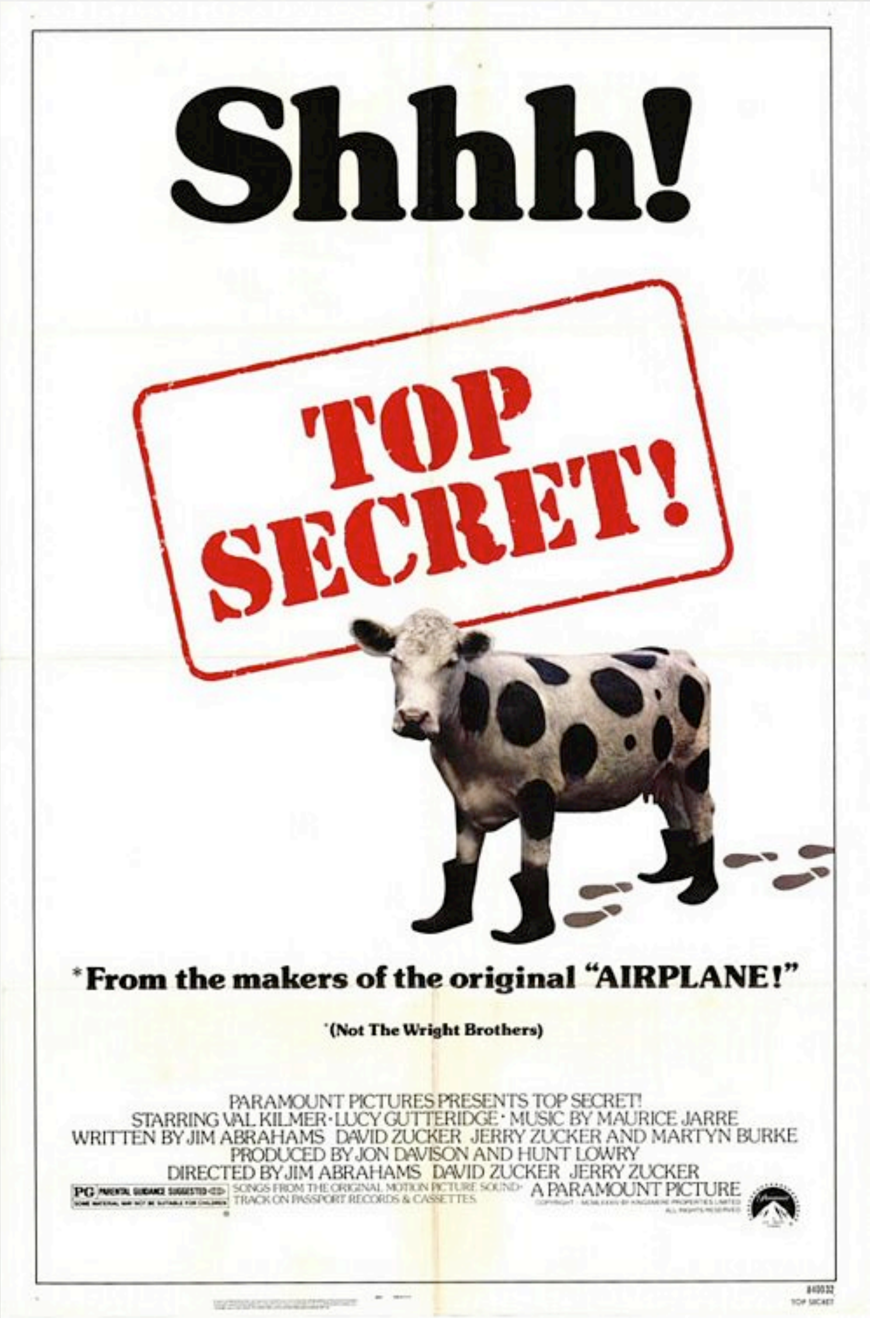
TRIGGER SYNCHRONISATION

- SINCE DECAY IS UNCORRELATED WITH LHC CLOCK (TO WHICH CALORIMETER ELECTRONICS ARE TIMED INTO), EXPECT SOME ENERGY LOSS
- WE HAVE SIMULATED THIS EFFECT BY SMEARING DECAY TIME UNIFORMLY ACROSS BX WINDOW
- WE OBSERVE NO SIGNIFICANT EFFICIENCY DEGRADATION DUE TO THIS TIME SMEARING



UPDATED OPERATIONAL SCENARIO RESULTS

- WE HAVE REPEATED THE DECAY TIME/ OBSERVABILITY STUDIES I SHOWED YOU PREVIOUSLY, BUT NOW
  - INCORPORATING THE FULL GEANT SIMULATION, INCLUDING NUCLEAR INTERACTIONS FOR R-HADRONS THAT I HAVE SHOWN YOU
  - AS WELL AS THE TRIGGERING AND RECONSTRUCTION EFFICIENCY OBTAINED FROM THE FULL CMS SIMULATION WHICH I HAVE SIMILARLY SHOWN
- UNFORTUNATELY, RESULTS OBTAINED WITH FULL CMS SIMULATION MUST BE APPROVED BEFORE BEING SHOWN OUTSIDE THE COLLABORATION
  - BUT I CAN SAY THAT THESE STUDIES LARGELY CONFIRM OUR EXPECTATION THAT THIS SIGNAL IS A FIRST WEEK OF DATA KIND OF SEARCH



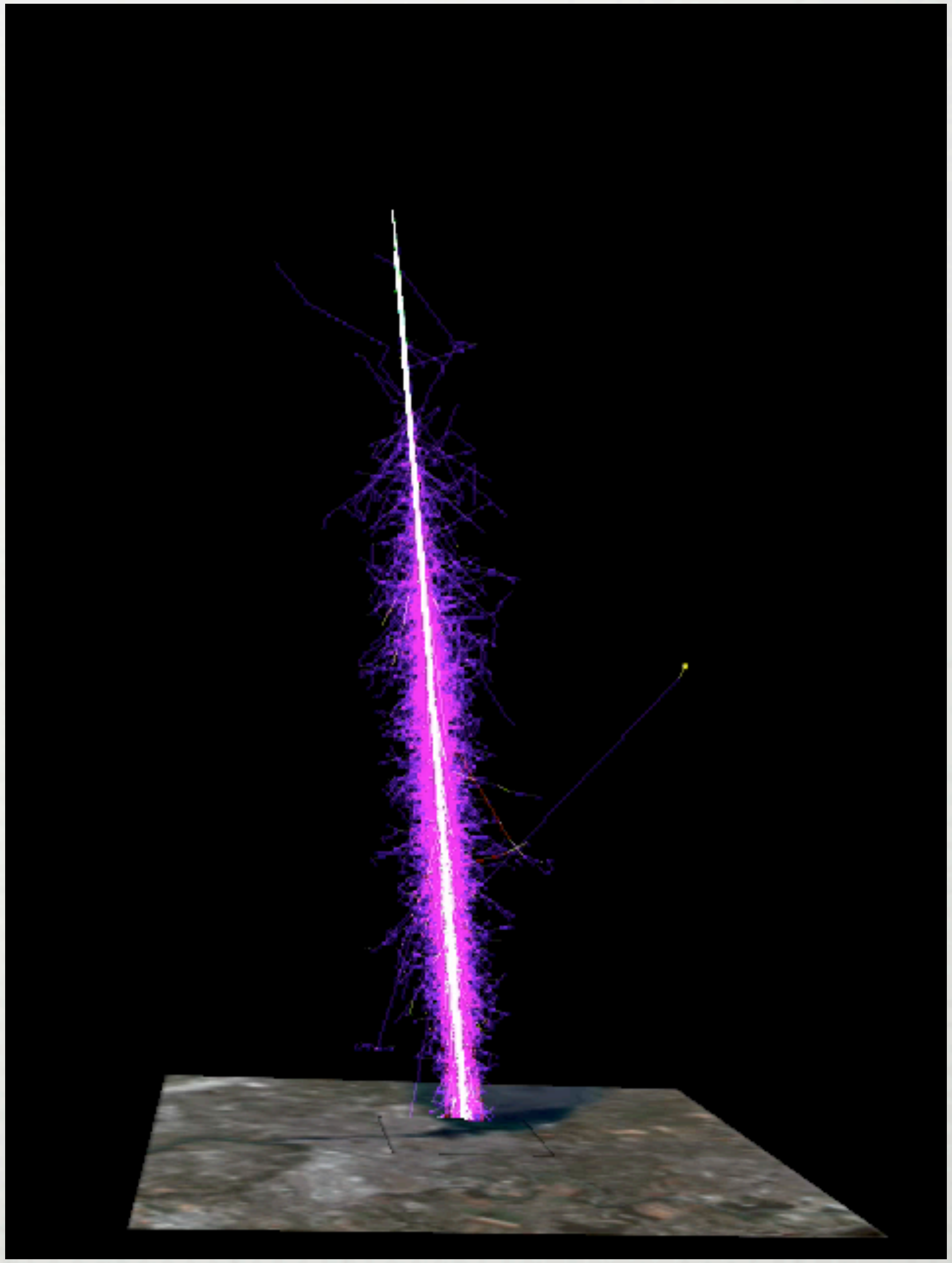
BACKGROUNDS

- SINCE THESE DATA WILL BE COLLECTED WITH THE BEAM OFF

- ONLY SIGNIFICANT PHYSICS (AS OPPOSED TO INSTRUMENTAL) BACKGROUND SOURCE WILL BE COSMIC RAY SHOWERS

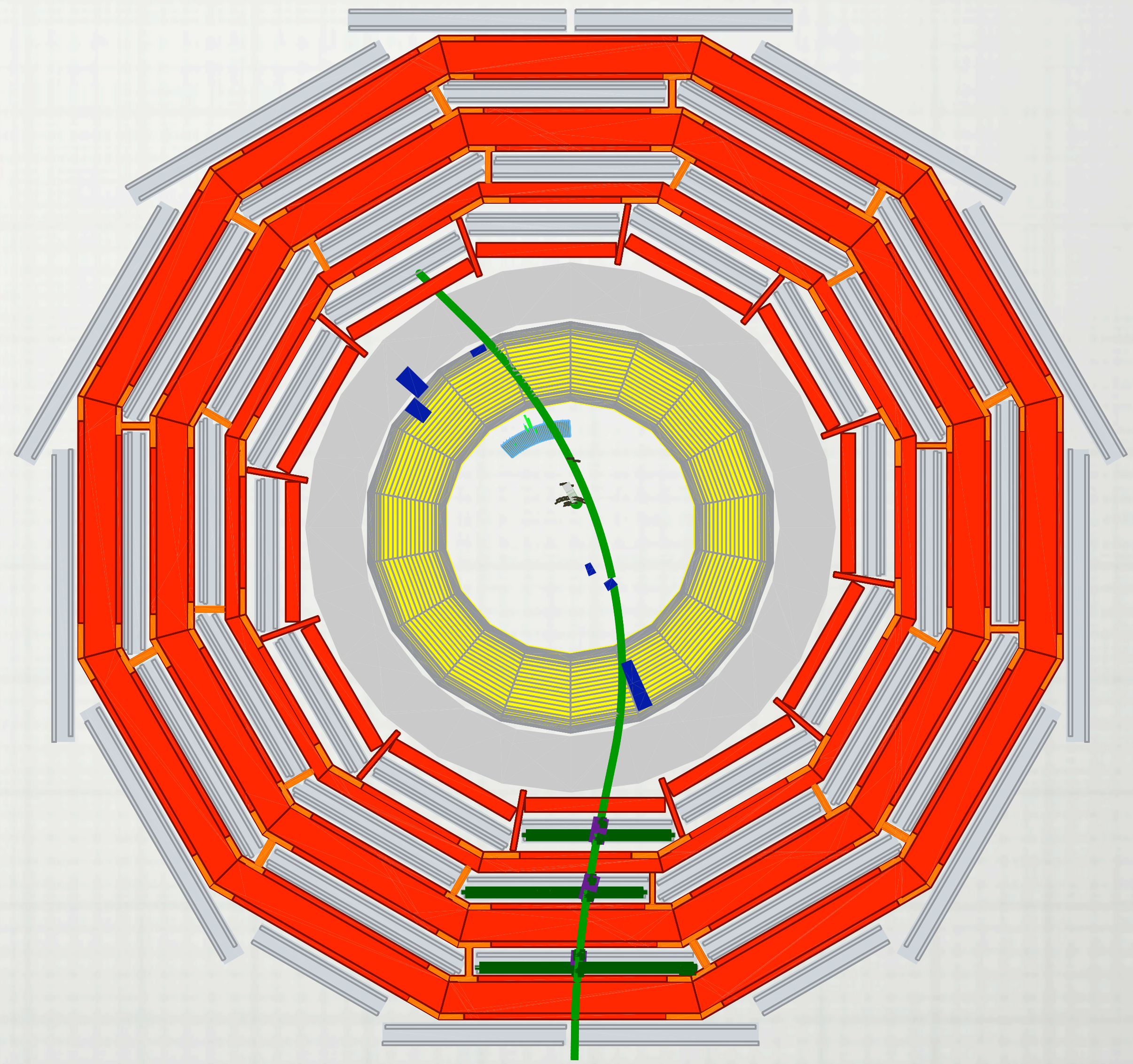
  - THE RATE OF THESE WILL BE LOW SINCE CMS IS 100 METERS UNDERGROUND

  - NO PROBLEM FOR TRIGGER



BACKGROUND ESTIMATION

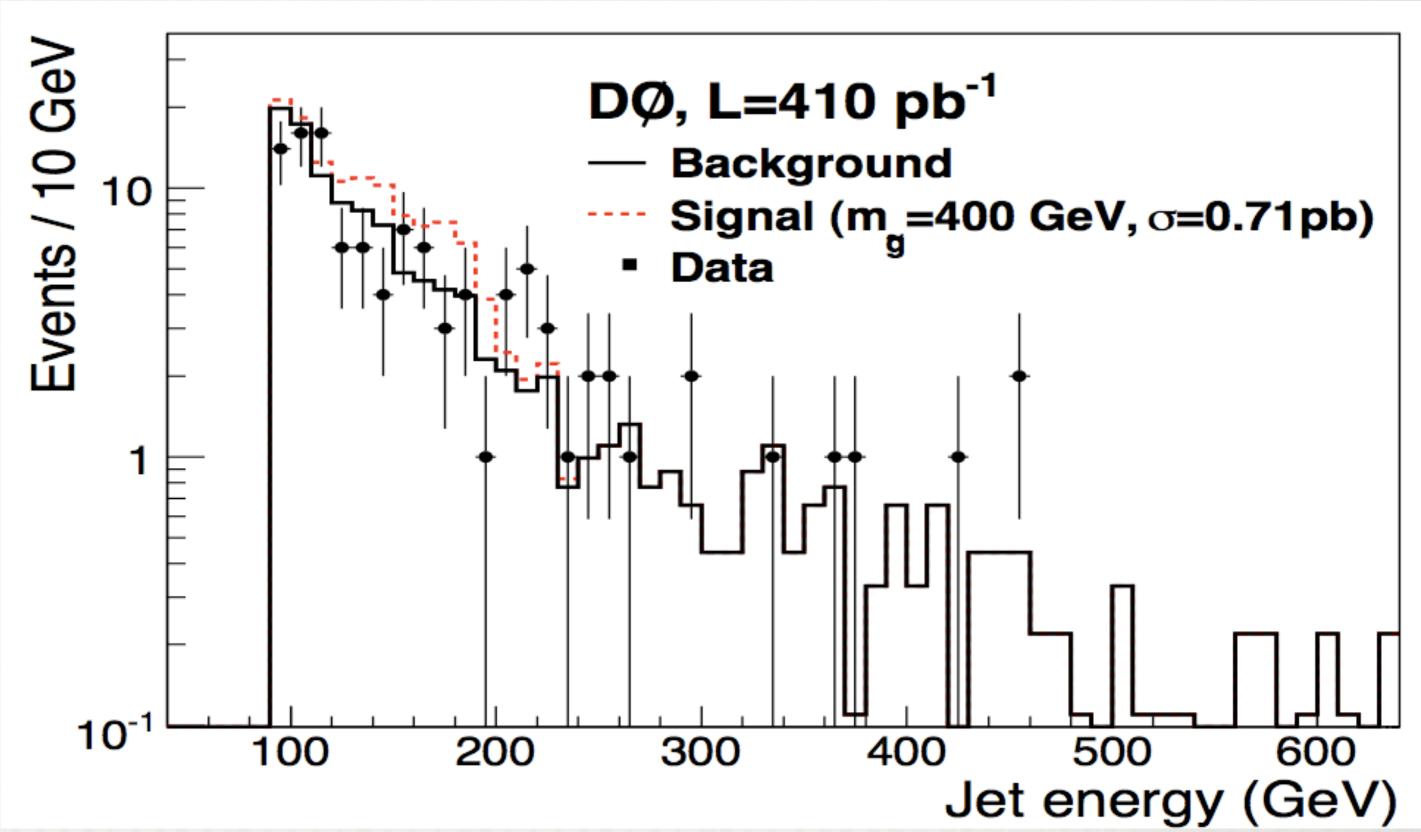
- THE COSMIC BACKGROUND WILL BE ESTIMATED FROM PRE-COLLISION COSMIC DATA ONCE CMS IS FULLY OPERATIONAL AT POINT 5
  - OBVIOUSLY, NO SIGNAL IN THESE DATA
- THIS WILL HAPPEN THIS SUMMER
- INSTRUMENTAL BACKGROUNDS CAN BE RULED OUT STATISTICALLY
  - E.G. WE KNOW (OR WILL KNOW) HPD NOISE RATE
    - O(1) HZ ABOVE 20 GEV



WHAT CAN WE LEARN FROM RECENT DO PAPER?

PHYS. REV. LETT. 99, 131801 (2007)

- THIS PAPER PRESENTS A NICE SEARCH FOR STOPPED GLUINOS USING JET DATA FROM DO RECORDED
- UNLIKE OUR PROPOSED TRIGGER, THEY HAD OUT-OF-TIME TRIGGERING AND RECONSTRUCTION INEFFICIENCIES AS WELL AS BEAM RELATED BACKGROUNDS
- THEY'RE PRIMARY BACKGROUND HOWEVER, WAS (AS WILL BE THE CASE FOR US) COSMIC RAYS THAT SHOWER IN THE CALORIMETER



As mentioned, we will derive our cosmic background estimate simply by running our trigger before any collisions have occurred … but until we have this sample, maybe (just for fun) we can scale from D0's estimate?

BACKGROUND GUESSTIMATE, SCALING FROM FIG 1. OF D0 PRL

Assume volume of CMS's calorimeters are 2x that of D0's (total guess)

Assume fraction of cosmic rays that shower in D0's calorimeters will be same as the fraction that will shower in CMS's

Assume cosmic ray flux is attenuated by a factor of 3 at CMS due to being 100m underground

D0's data were collected over 22 months, with say 80% detector efficiency and say 30% downtime (total guess) = 1 year

So I get that the cosmic background at CMS in a week of our trigger with 50% livetime should be, roughly:

80 events from Fig. 1 x 2 x 1/3 x 1/12 x 1/4 x 0.5
= 0.55 events/wk. at CMS

SENSITIVITY TO SUSY BREAKING SCALE

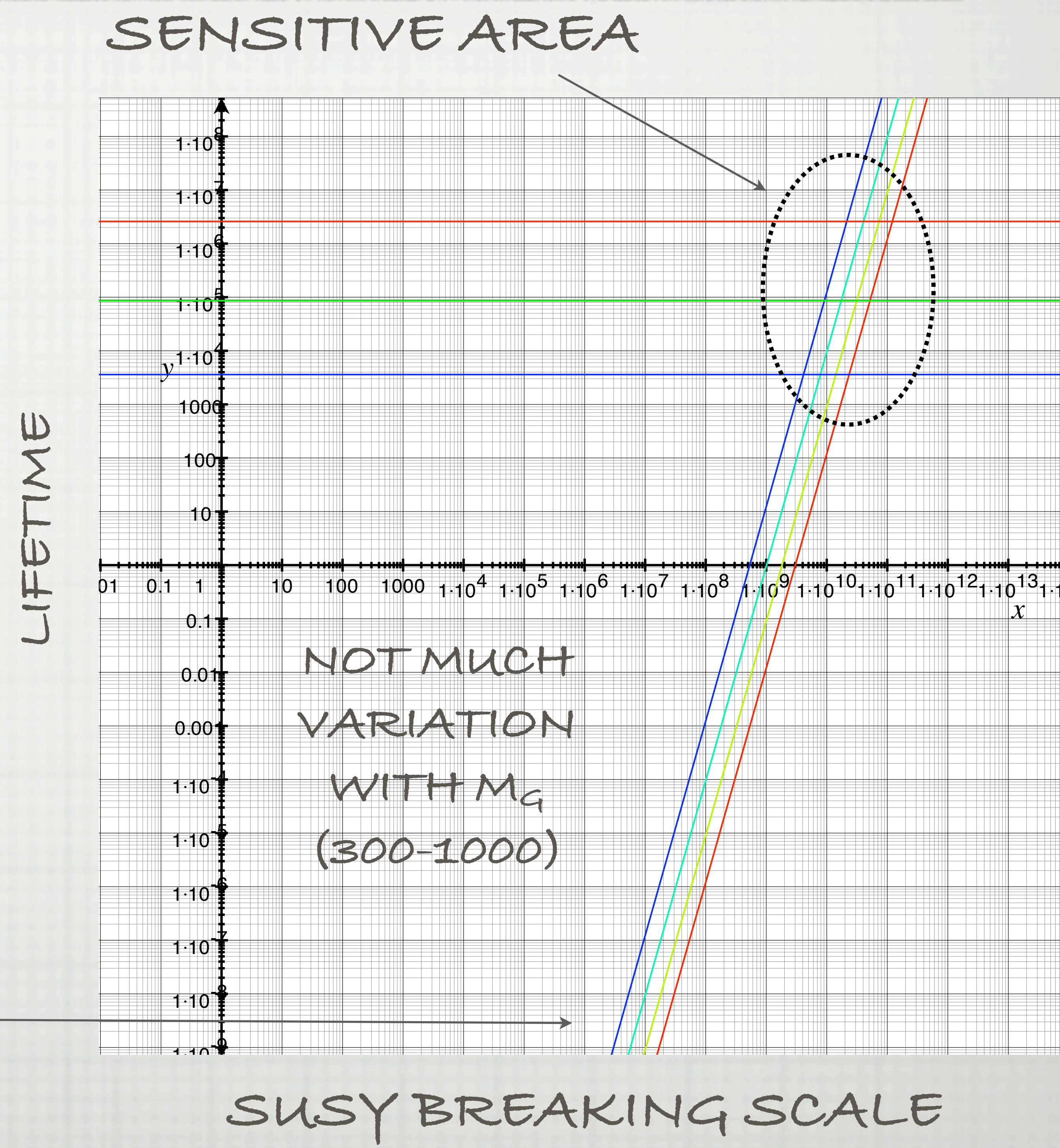
- IN SPLIT SUSY, LIFETIME IS RELATED TO THE SUSY BREAKING SCALE AS BELOW:

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

- THE PLOT AT RIGHT SHOWS WHAT SCALES THIS KIND OF SEARCH IS SENSITIVE TO ($\sim 10^8$ - 10^{11})

- BLUE = 1H, GREEN = 1D, RED = 1MO

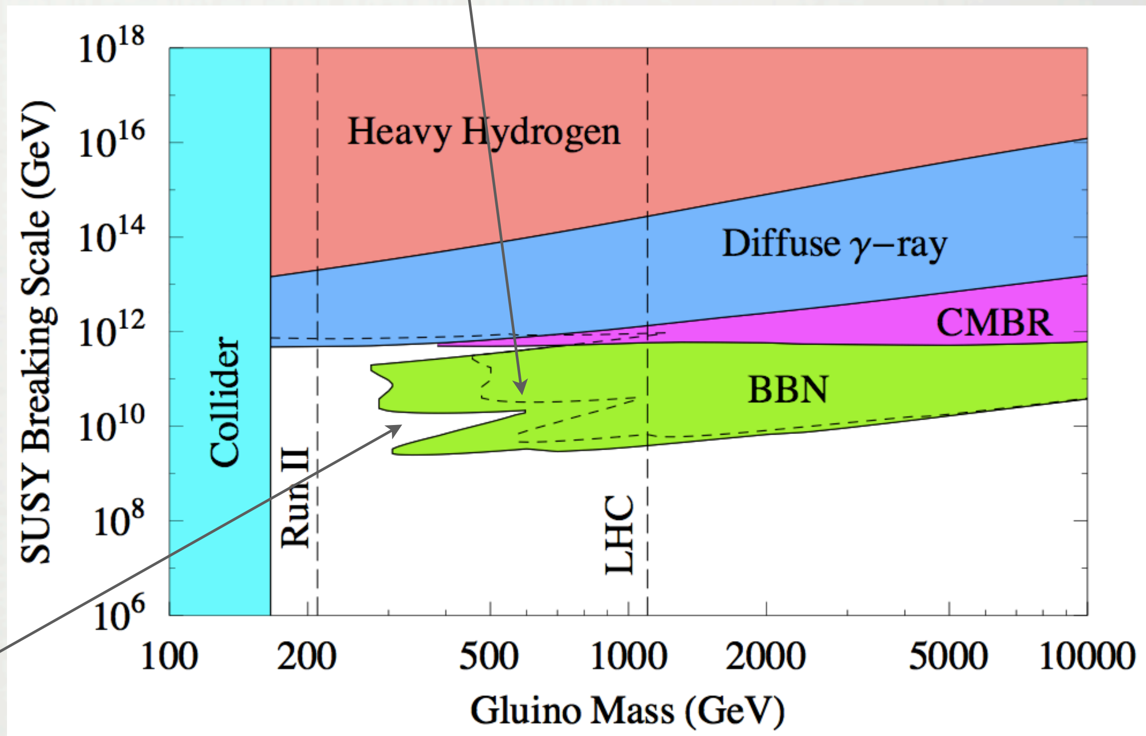
- COMPLEMENTARY TO THOSE LIFETIMES ACCESSIBLE DURING COLLISIONS, DOWN HERE



INDIRECT CONSTRAINTS ON THE LIFETIME

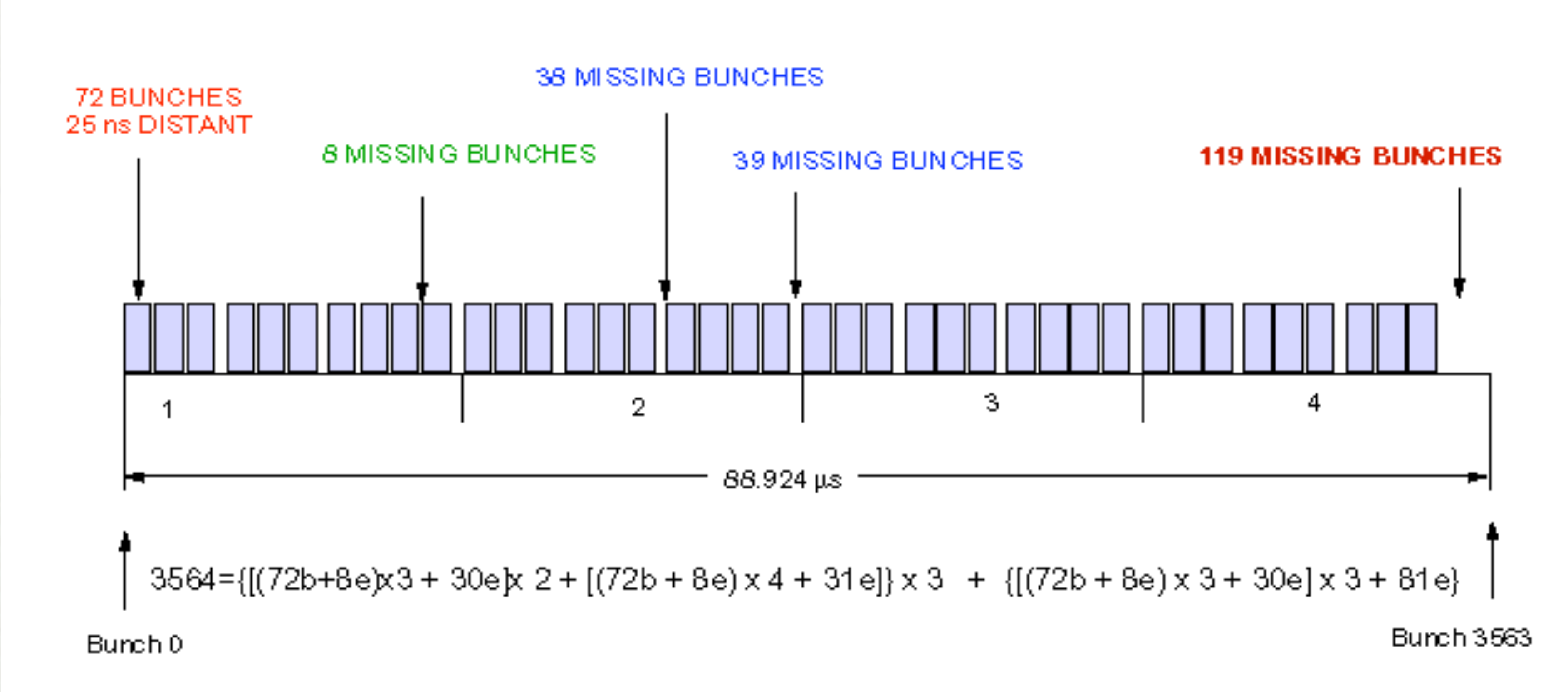
- A. ARVANITAKI ET AL (Phys.Rev.D72:075011,2005) SET LIMITS FROM VARIOUS SOURCES ON POSSIBLE GLUINO MASSES & SUSY BREAKING SCALES (AND THUS LIFETIMES)
- IF GLUINO MASS > 300 GEV (500 WITH DIFFERENT ASSUMPTIONS) STRONGEST CONSTRAINTS COME FROM BIG BANG NUCLEOSYNTHESIS (BBN)
  - LIFETIME < 100 SECONDS
  - UNLESS IN THESE HOLES IN THE EXCLUSION CURVE
  - N.B. THESE CALCULATIONS RELY ON <u>HIGHLY SPECULATIVE</u> R-HADRON CROSS-SECTIONS

ALTERNATIVE ASSUMPTIONS ABOUT UNKNOWN R-HADRON INTERACTIONS



IF MASS < 300 (500) GEV, LIFETIME LIMIT IS WEAK, 10^6 YEARS

CAN LOOK AT THE ABORT GAPS TOO



- A MORE (EXPERIMENTALLY) AMBITIOUS PROGRAMME INVOLVES RUNNING A SIMILAR TRIGGER IN THE ABORT GAPS
- SENSITIVE TO SHORTER LIFETIMES, HIGHER MASSES, DIFFERENT SUSY BREAKING SCALES
- WE HOPE TO HAVE THIS TRIGGER ALSO IMPLEMENTED (AT SOME POINT) IN CMS

SUMMARY & OUTLOOK

- QUASI-STABLE CHARGED PARTICLES MIGHT BE PRODUCED AT THE LHC
  - THESE COULD BE SPLIT SUSY GLUINOS, WHICH I HOPE I'VE SHOWN IS AT LEAST AN INTRIGUING POSSIBILITY
- IN ANY CASE, SOME FRACTION OF THESE WILL COME TO REST IN CMS
  - THESE CAN EASILY BE OBSERVED VIA A CALORIMETER TRIGGER RUN WHEN THERE IS NO BEAM
- RATES ARE SUCH THAT IF THEIR MASS IS LIGHT (< 500) , AND LIFETIME REASONABLE (1H - 1 MO.) A DISCOVERY COULD BE MADE IN THE EARLIEST PHASE OF THE LHC ERA
  - MASS & LIFETIME CAN EASILY BE MEASURED, GIVING EXPERIMENTAL ACCESS TO THE SUSY-BREAKING SCALE
- SHOULD BE A FUN WAY TO FIRST PHYSICS AT THE LHC