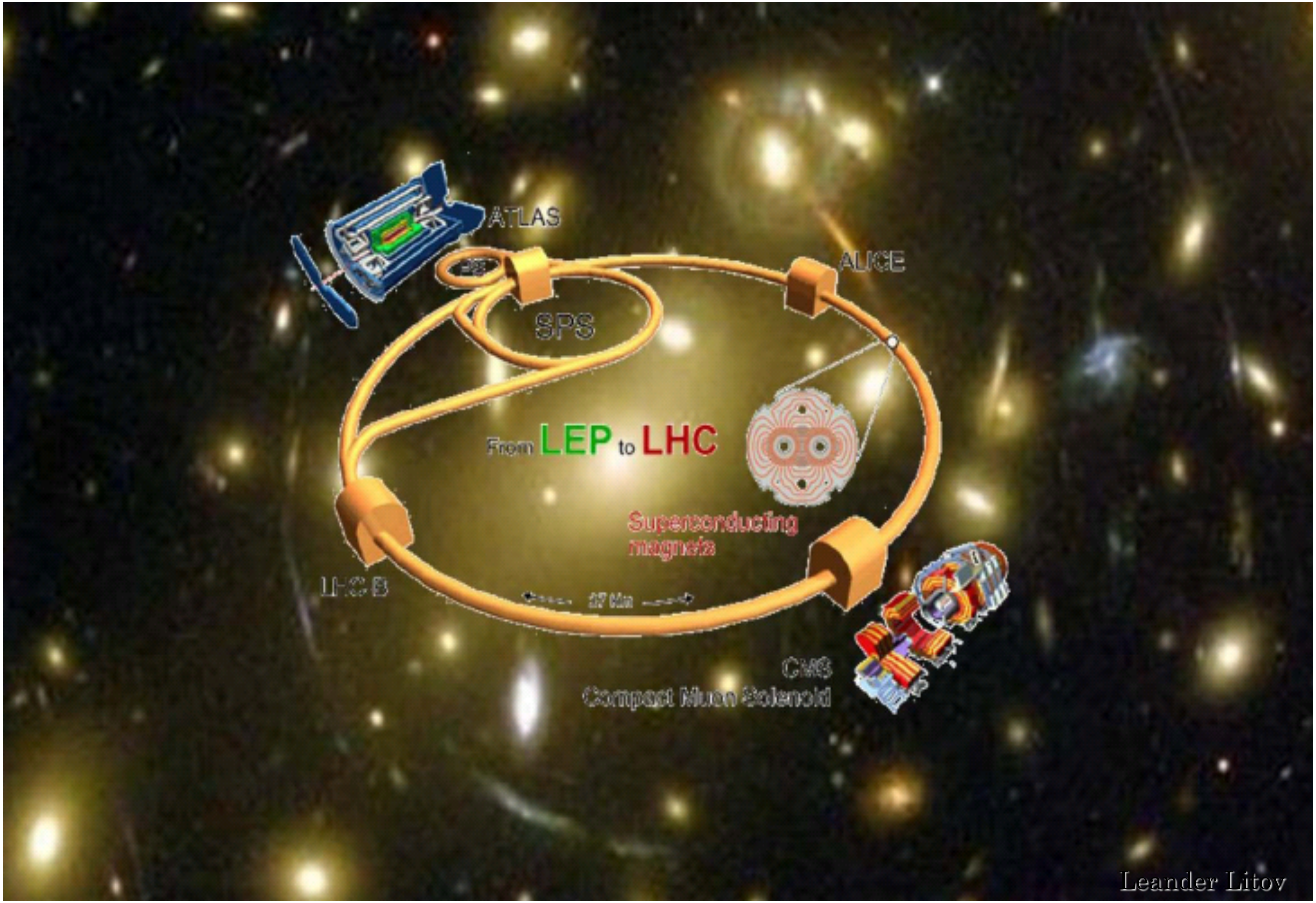
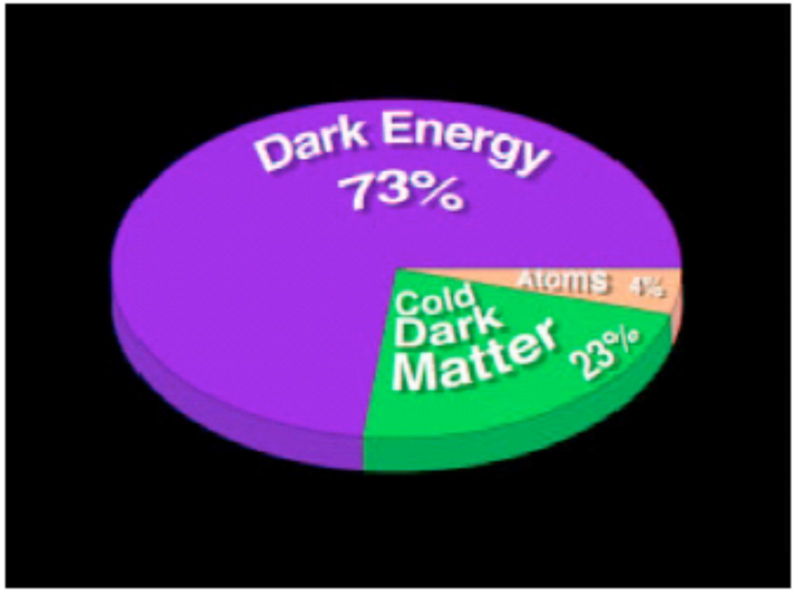
Cosmological Implications of LHC Searches

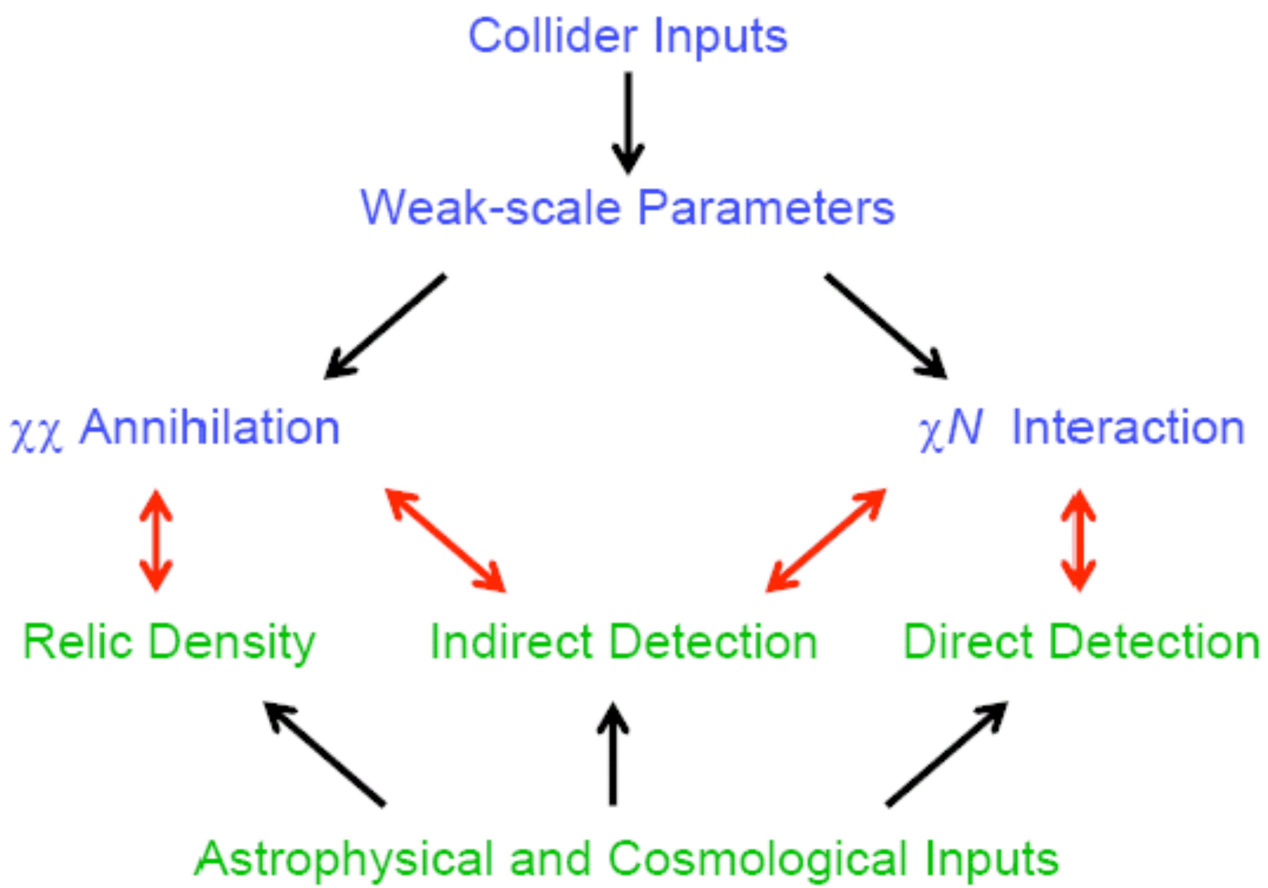


What is the nature of Dark Matter ?

WMAPping the Universe: Chart



Particle/Cosmo Interface



One known example
Big Bang Nucleosynthesis

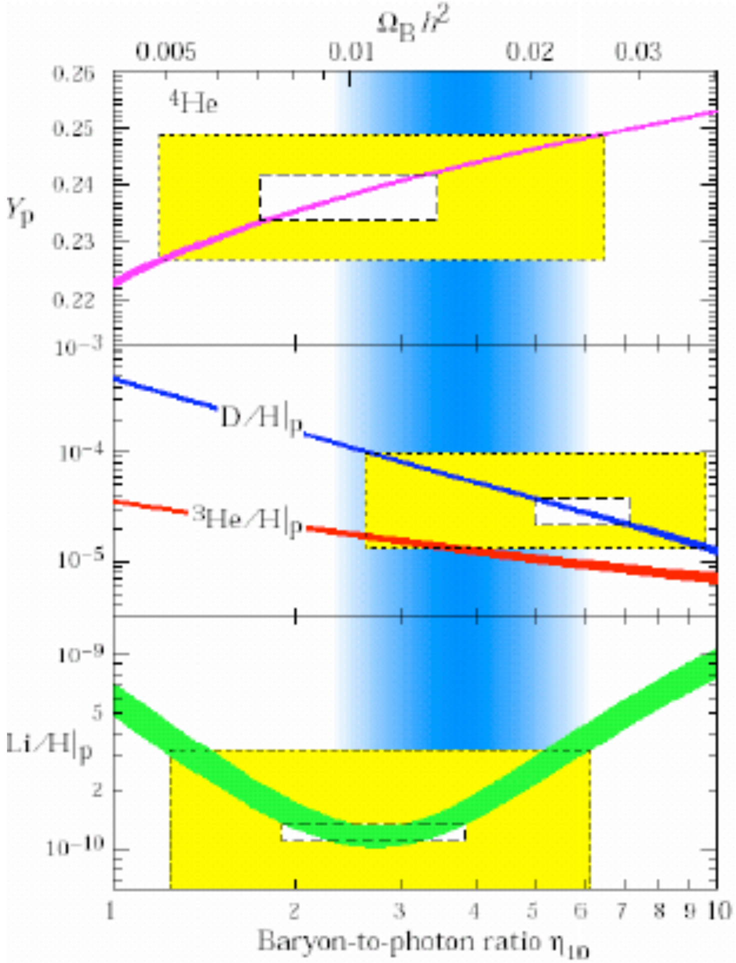
Consistency of

•Light elements properties from nuclear physics

•Light elements abundance from astrophysics

Gives the understanding of our Universe at

T = 1 MeV   t = 1 sec



TASI lectures on dark matter. Keith.A. Olive Published in *Boulder 2002, Particle physics and cosmology* 797-851 e-Print Archive: **astro-ph/0301505**

LHC program and cosmology

LHC will explore the high energy frontier to test the standard model and beyond .

• What is the origin of the particles' masses ? Is it the Higgs Mechanism ? Connection to Vacuum Energy?

•Is SM the ultimate theory for particle physics?

Ian_Shipsey
Maria_Spiropulu

The Standard Model describes everything that we have measured at colliders to extreme accuracy. But we know (cosmological observations, hierarchy …) that this is not the full picture and we extrapolate using our immagination.

Michelangelo Antonioni on Ferrara:
"...it is a city that you can only see partly
and the rest disappears [..in the fog]
and can only be imagined..."

BSM particles as Dark Matter Candidate

The list is very long and includes

The lightest supersymmetric particle (LSP) in SUSY with R-parity conservation

The lightest Kaluza-Klein (KK) excitation in models with extra dimensions and KK parity

The lightest T-odd state in the little Higgs model with T-parity

………….

All these WIMPS are electrically neutral and stable: if produced in high energy collisions they escape the detector. Their discovery relays on other new particles present in the theory and their subsequent decay into the dark matter candidate.

At LHC the generic signature is jets (plus leptons) plus large MISSING TRANSVERSE ENERGY.

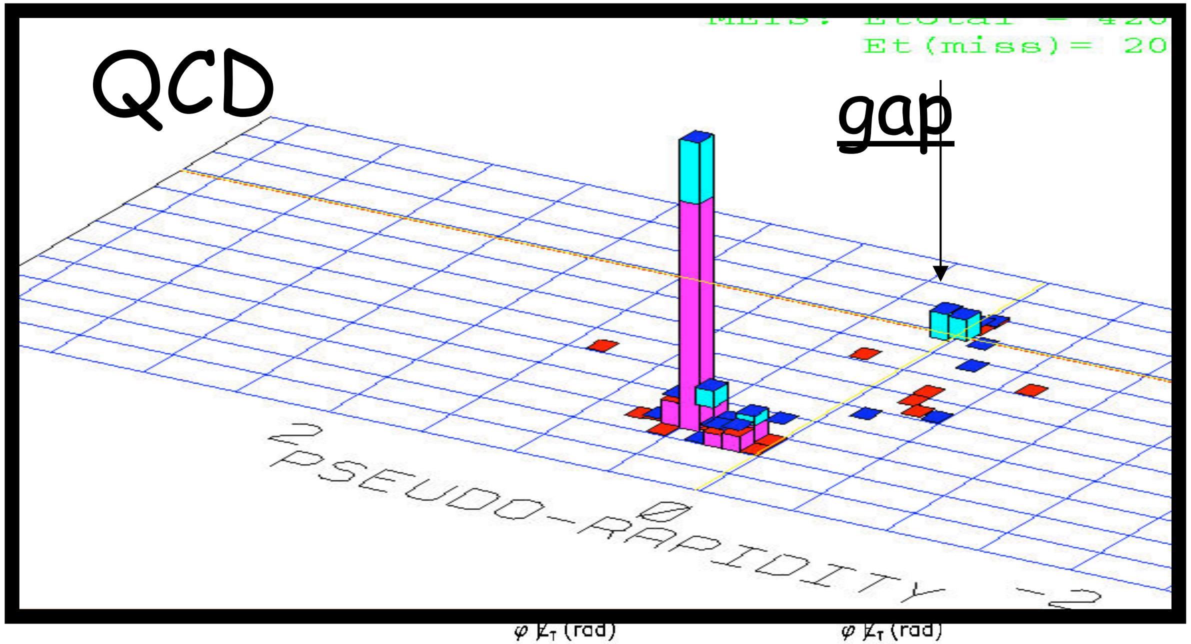
Missing Energy searches- the Experimental Challenge

Measuring Missing Energy is an experimental challenge because all "anomalies" in the measured event will contribute to the missing energy tail.

Unfortunately the "experimental" anomalies are more frequent than the "physics" anomalies !

Maria Spiropulu's thesis

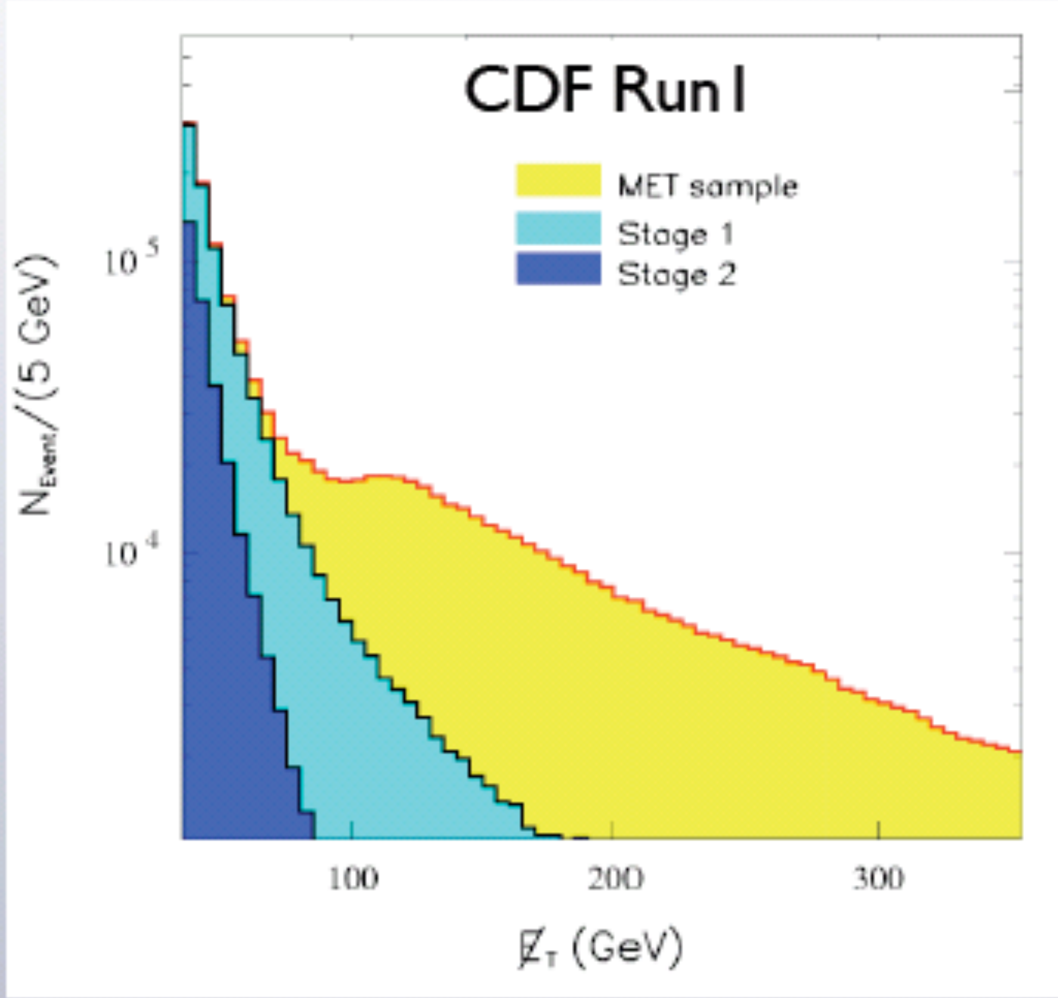
ME in CDF run 1 in QCD d-Jets Events



Run I MET Cleanup

- MET ≥ 35 GeV
- EOUT ≤ 10 GeV
- NOUT ≤ 5
- At least 1 central jet
- ECHF ≥ 0.175
- EEMF ≥ 0.1

Evts Passing Trigger: 2.5M
Evts After Cleanup: 300K



Missing Energy searches
After you have understood the detector

Main SM backgrounds to fight are:

- QCD production (very large x-section no intrinsic ME)
- Top-Antitop production (large cross section with ME)
- W/Z QCD associated production (large cross section with ME)

http://doc.cern.ch//archive/electronic/cern/preprints/lhcc/public/lhcc-2006-021.pdf sec 4.2.2

QCD Background

Reject two jets events and require missing energy not aligned with 2^{nd} or 3^{rd} jet

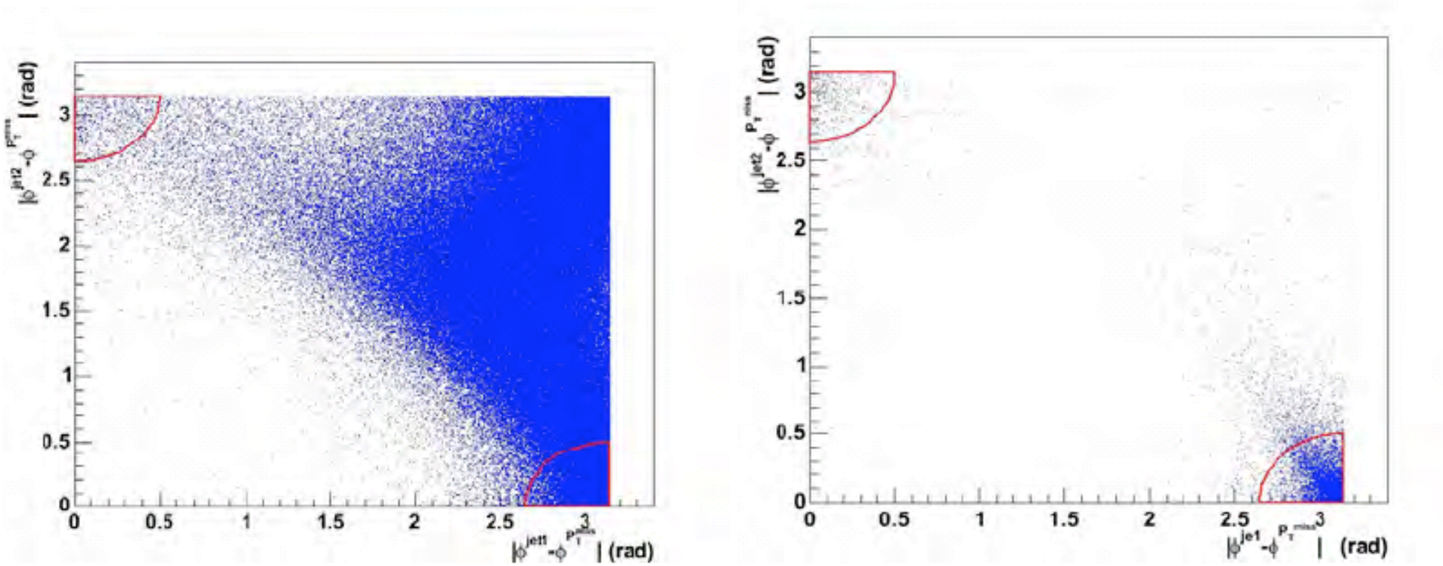


Figure 4.10: $\delta\phi_1$ versus $\delta\phi_2$ for (left) SUSY signal and (right) QCD dijet events

Events with MET from neutrino

Reject events with “lepton like” jet (kills W decays)

Normalize the background evaluated with MC using events when Z→ l+l-

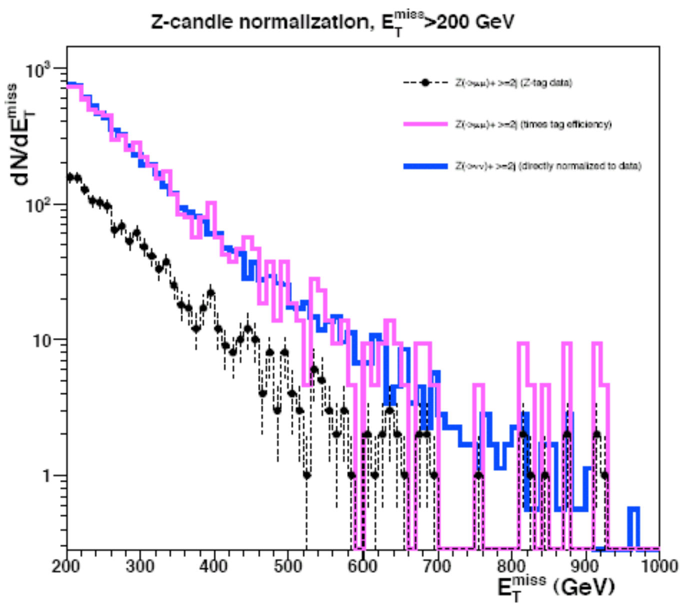
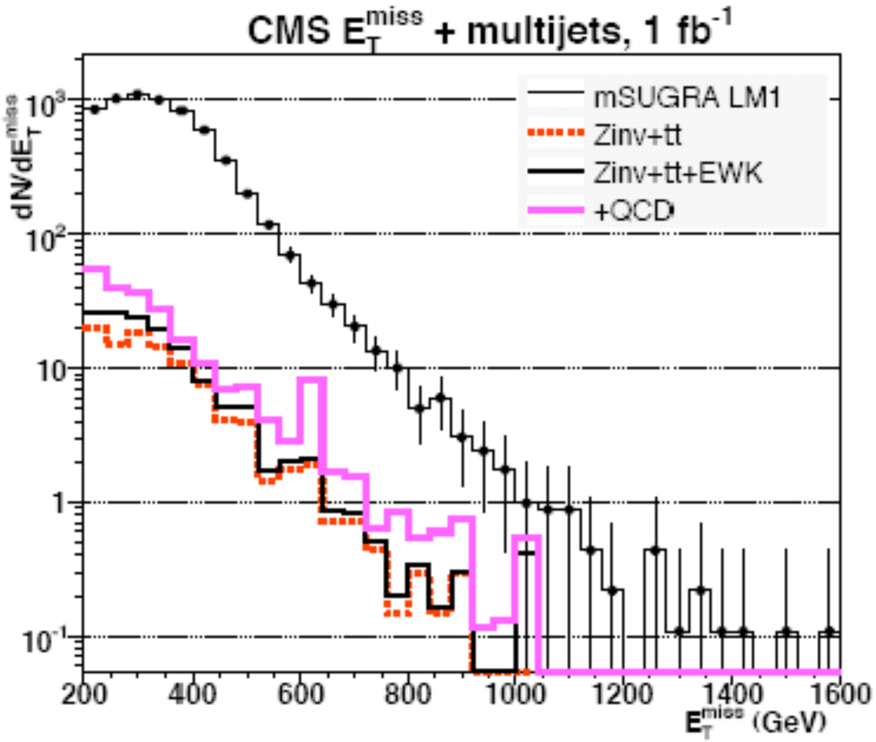


Figure 4.15: E_T^{miss} in $Z \to \mu\mu + \geq 2$ jets candle sample and normalised E_T^{miss} in $Z \to \nu\bar{\nu} + \geq 2$ jets sample.

Missing Energy Plot



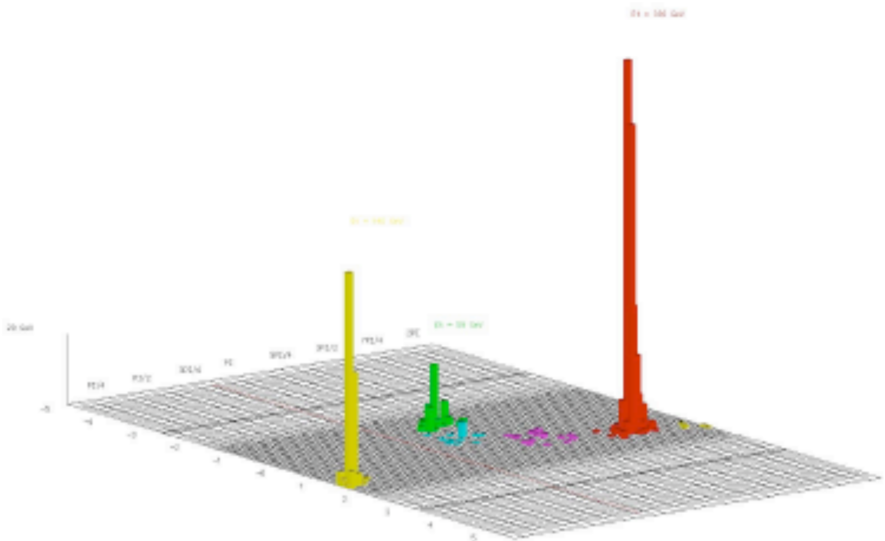
The ME from SM processes is compared to the that of production of SuperSymmetric Particles at LM1 Point (see later)

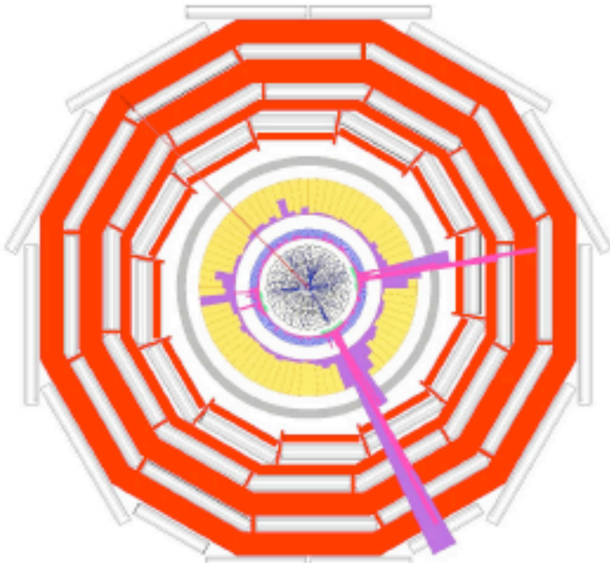
Signal is very large compared to background

One Simulated Event

E_T^{miss} **+jets candidate event display**

E_T^{miss}=360 GeV, $E_T(1)$=330 GeV, $E_T(2)$=140 GeV, $E_T(3)$=60 GeV





An Alternative analysis

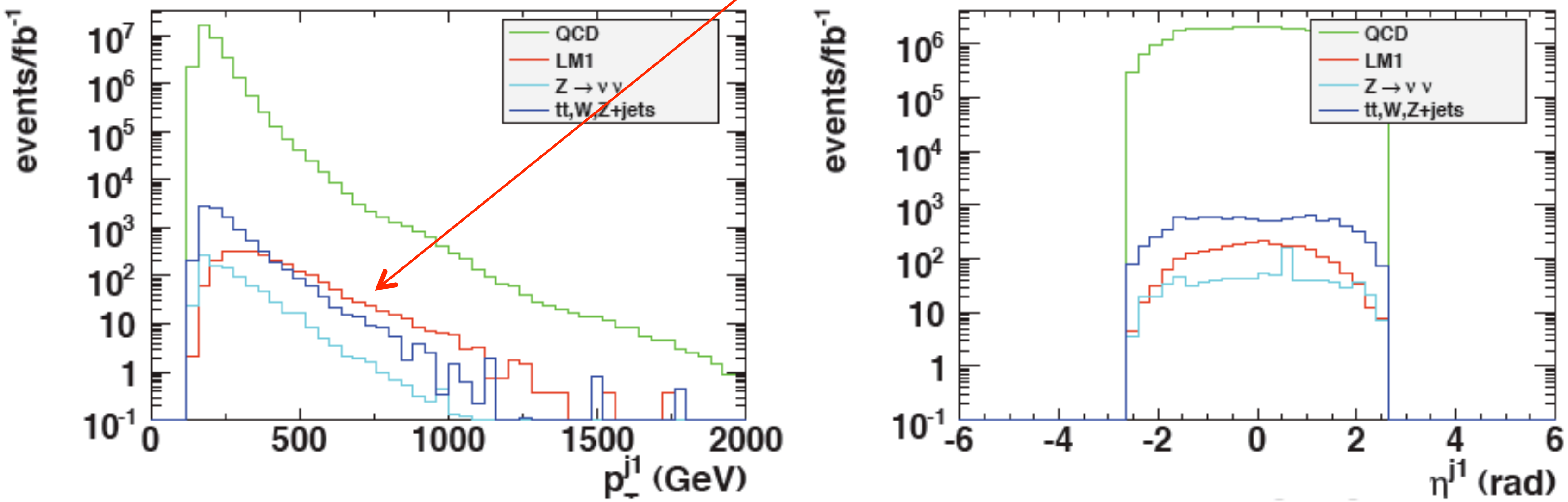
Missing energy is difficult to measure correctly, especially with a detector not fully understood. CMS has designed an analysis to identify the production of a pair of "new particles" each decaying into a quark and a WIMP . One example is the production of a pair of squarks followed by their decay into quark and neutralino. The topology of the final state is two acoplanar jets.

In this analysis it is possible to define kinematic variables that can discriminate between signal and background without relying on the missing energy measurement from the calorimeters.

http://cms-physics.web.cern.ch/cms-physics/public/SUS-08-005-pas.pdf

WIMPS in Di-jets (1)

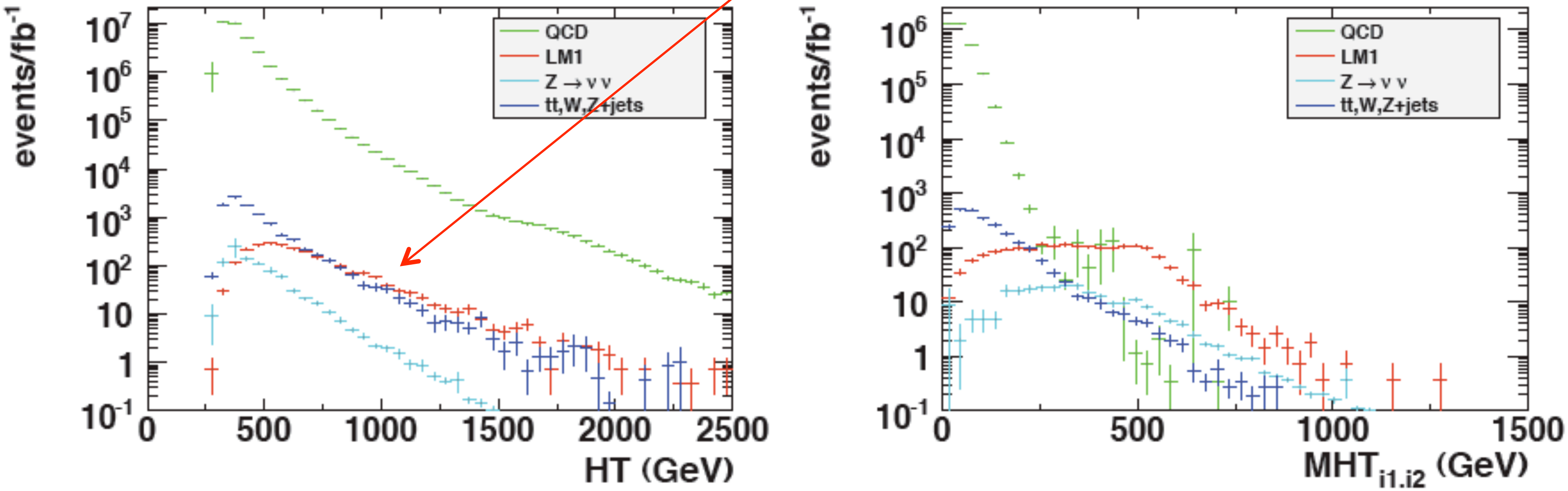
Expected WIMP contribution



After requiring two jets with pt >150 GeV we still have huge QCD background

WIMPS in Di-jets (2)

Expected WIMP contribution



After requiring two jets with pt >150 GeV we still have huge QCD background

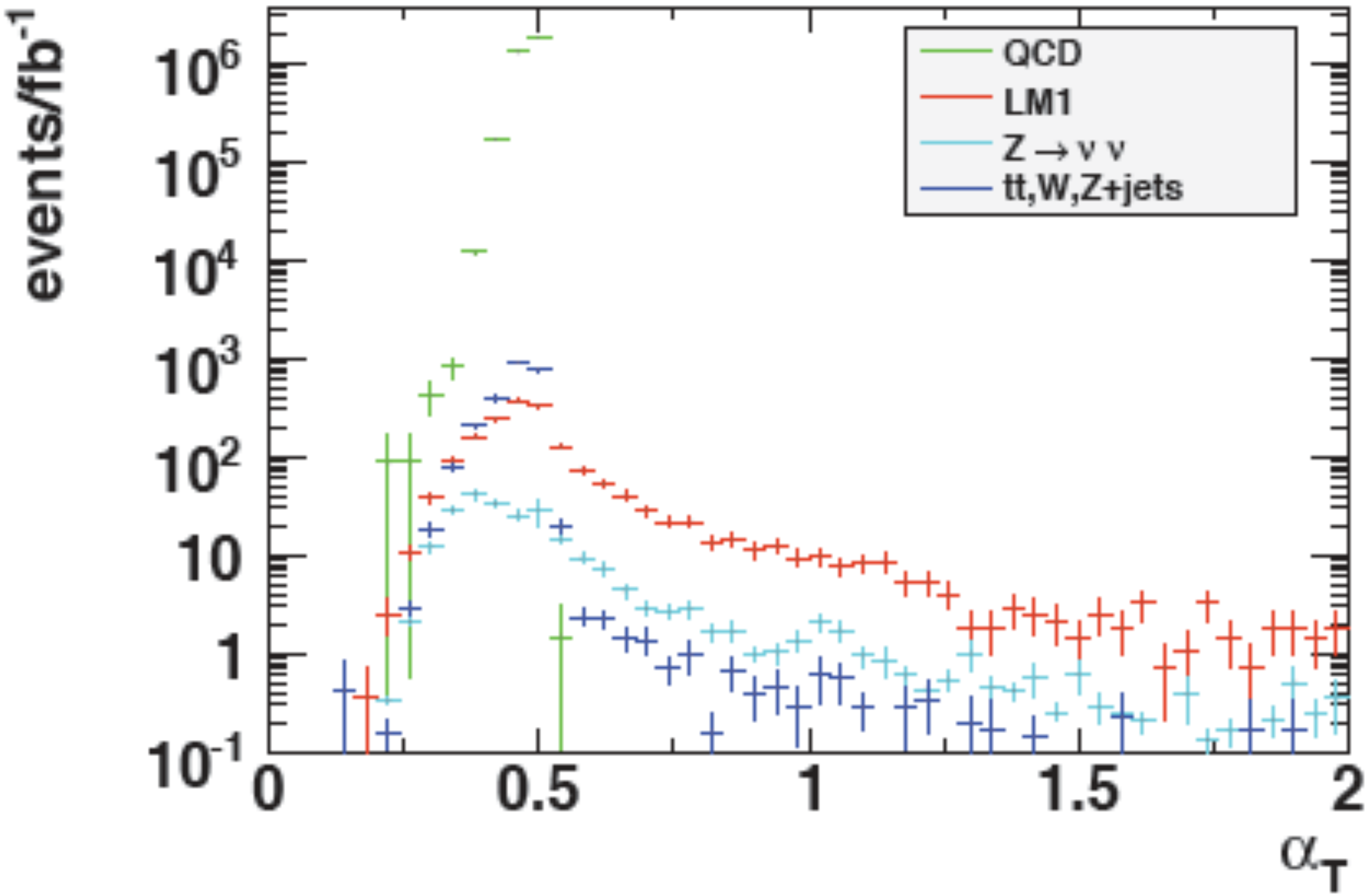
How to reduce the QCD background ?

It is however possible to define kinematic variables which separate between QCD events and signal-like events with real missing ET. In well measured QCD dijet events, transverse momentum conservation requires the pT of the two jets to be of equal magnitude and back-to-back These requirements do not apply to signal-like events where, the two squarks decay independently and therefore the resulting jet pT's can be of different magnitude and also their values are (largely) uncorrelated. The variable:

$$\alpha_T = \frac{E_T^{j2}}{\sqrt{2E_T^{j1}E_T^{j2}(1-\cos\Delta\phi)}} = \frac{\sqrt{E_T^{j2}/E_T^{j1}}}{\sqrt{2(1-\cos\Delta\phi)}}$$

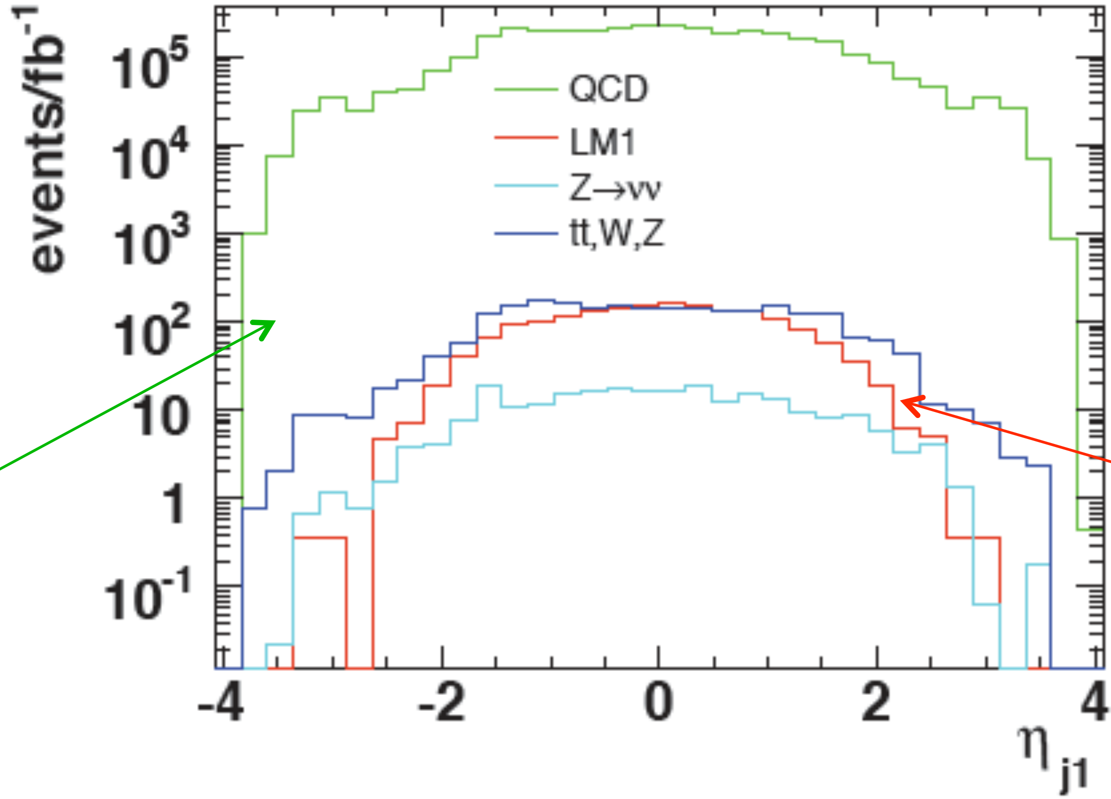
is particularly robust to exploit this separation

Distribution of alpha_T



Data Driven BKG estimation

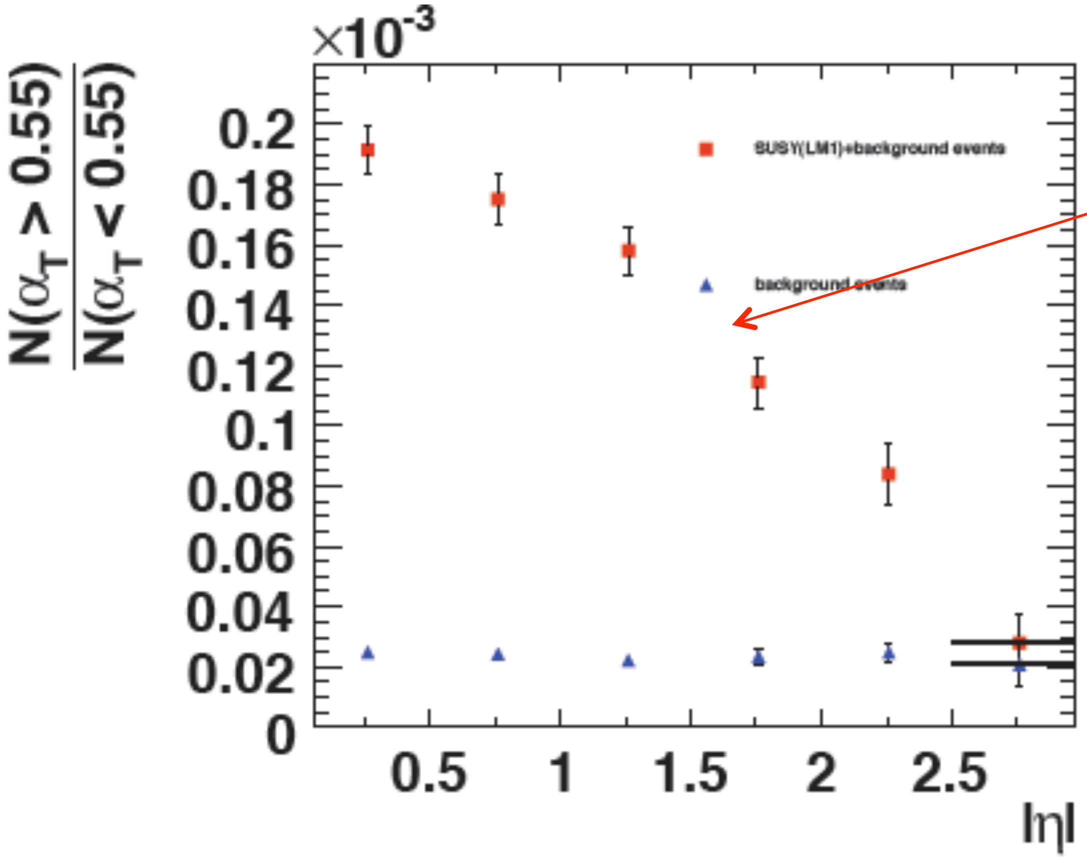
QCD production is more forward



Production of heavy objects is more central

All cuts applied except alpha_T

Data Driven BKG estimation



Decreasing distribution= signal is present

Flat distribution = only background

LONG Lived new particles that decay into WIMPS ?

There are a number of new physics scenarios which predict the existence of new heavy quasi-stable charged particles. One such theoretical scenario is “split supersymmetry” [N. Arkani-Hamed and S. Dimopoulos, JHEP 0506 (2005) 073].

Just like in many more traditional supersymmetric models, in split SUSY, copious gluino production is expected at the LHC via gg → g~g~ with rates approaching 1 Hz (at design luminosity) for the lightest gluino masses. Unlike traditional SUSY, however, there is a very large mass splitting between the new scalars and new fermions from which the theory gets its name. Gluinos can thus only decay through a highly virtual squark. The lifetime of the gluino can thus be quite long; the gluino may well be stable on typical LHC experimental timescales. Existing experimental constraints on the value of this lifetime are weak.

How to look for these particles ?

If long-lived gluinos are produced at CMS, they will hadronize into ~gg; ~gqq; ~gqqq states which are collectively known as “R-hadrons”. In analogy with their mesonic and baryonic counterparts some of these gluino bound states will be charged whilst others will be neutral. Those which are charged will lose energy via ionization as they traverse the CMS detector.

Some of them escape the detector as “heavy muons” , caracterized by “low” beta hence large ionization and “out of time”.-→ Search for slow and highly ionizing particles.

If energy loss is sufficient to bring a significant fraction of the produced particles to rest inside the CMS detector volume, they will decay seconds, day, or weeks later inside the detector . These decays will be out-of-time with respect to LHC collisions and may well occur at times when there are no collisions (e.g. beam gaps) or when there is no beam in the LHC machine (e.g. interfill period) → Search for decays in ainticoincidence with beam.

What happens to these particle interacting with matter ?

There are no experimental data !

A model has been developed in R.Mackeprang and A.Rizzi Eur. Phys. J 50 353-362 (2007)

Essentially the heavy (few 100 GeV mass) gluino closes the color lines with ordinary colored matter (g, q). It behaves like Heavy Atoms in matter and the loosely bound quarks and gluons can be exchanged in interaction with matter. So the R-hadron changes charge from neutral to charged, to multiple charged. R-Barions, that do not have anti-quark, are more "stable" than R-Mesons.

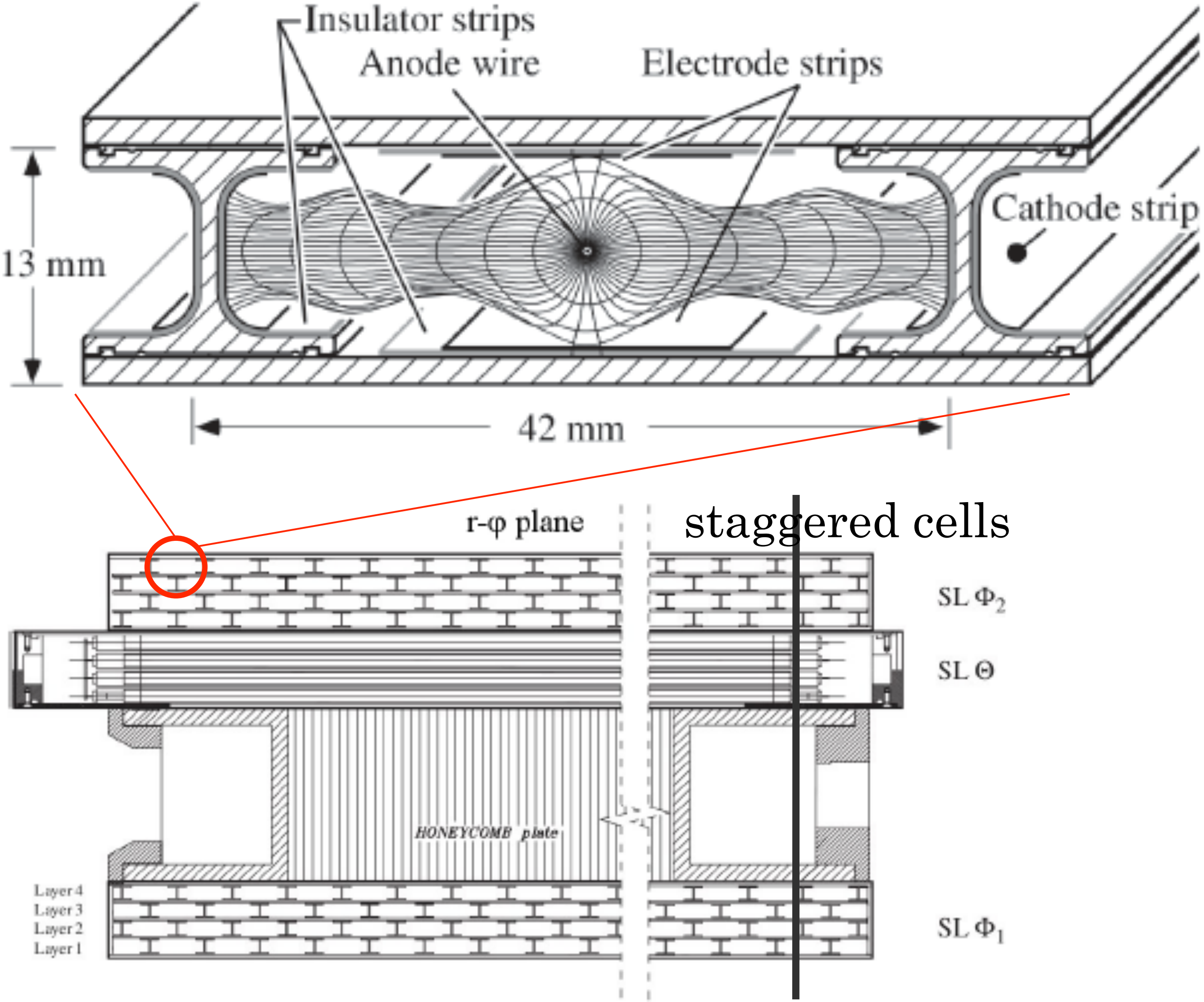
R-Hadron as a “Stable Particle”

The R-hadron produced in the collision will cross the CMS apparatus with large probability (20% only stops). This Heavy Stable Charged Particle (HSCP) will look like a slow and high momentum muon (β=P/E).

The key element of this analysis is the measurement of the velocity β of the HSCP. Two techniques to measure β have been developed, one based on time-of-flight measurement by the Drift Tube subsystem of the muon detector, and the other using specific ionization in the central Tracker detector.

http://cms-physics.web.cern.ch/cms-physics/public/EXO-08-003-pas.pdf

Timing in the CMS muon system



A particles crossing the detector out of time will produce a zig-zag pattern , imposing it to be a straight line one measures the time of crossing and hence β

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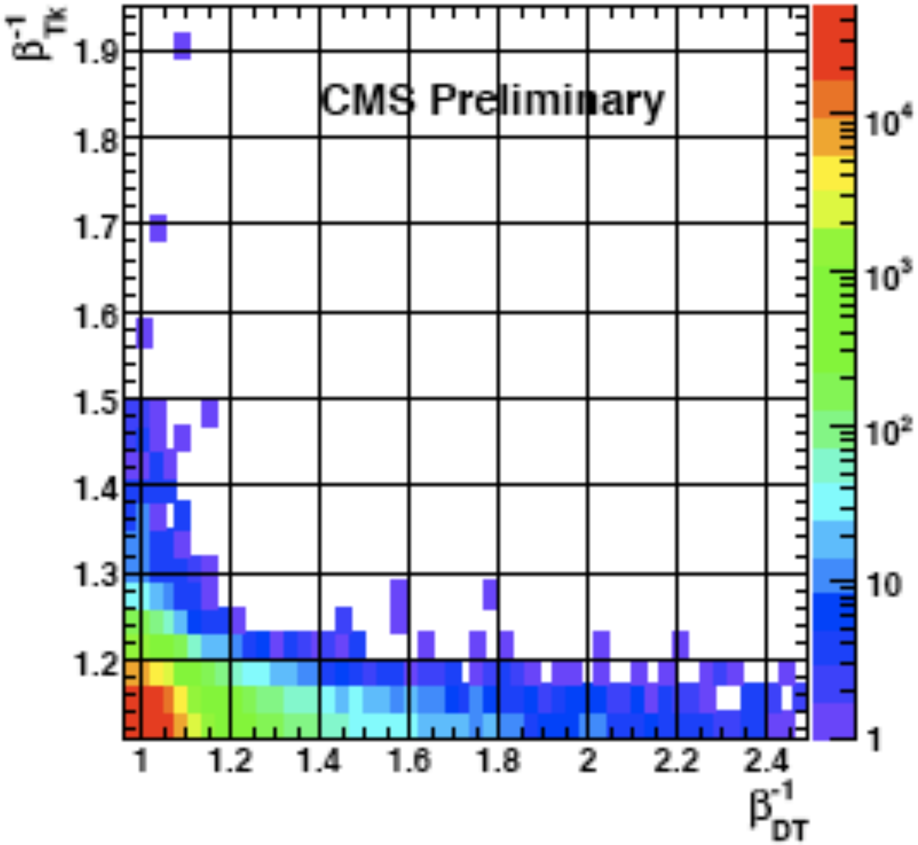
dE/dx in the Tracker

The CMS silicon tracker is able to measure the energy deposited by each hit (analog readout). After proper normalization this can be transformed into a dE/dx measurement. A track is typically associated with 15 hits thus giving a good estimate of the Most Probable Value (MPV) dE/dx . Since the ionization MPV depends on the β of the particle with an approximately β^2 dependence in the region $0.1 < \beta < 0.8 - 0.9$, we measure β from dE/dx .

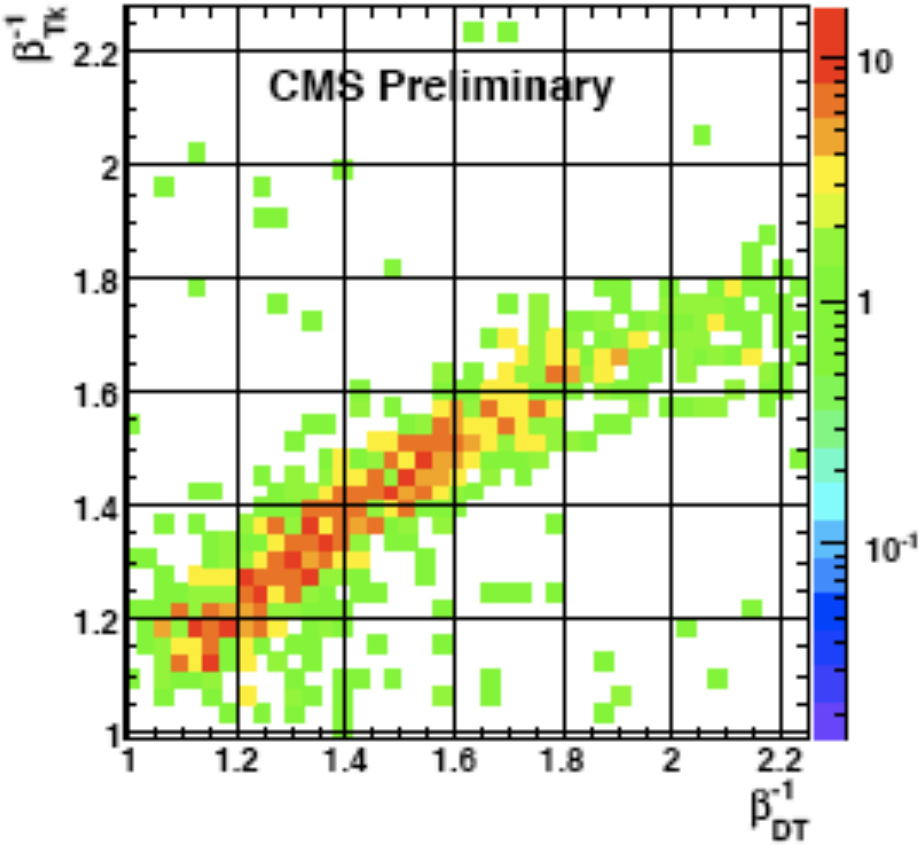
$$\beta^{-1} = \sqrt{K\frac{dE}{dx}},$$

Where K can be calibrated using proton tracks

Result



CMS Preliminary
β^{-1}_{Tk}
β^{-1}_{DT}
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1
1.2
1.4
1.6
1.8
2
2.2
2.4
10^4
10^3
10^2
10
1



CMS Preliminary
β^{-1}_{Tk}
β^{-1}_{DT}
2.2
2
1.8
1.6
1.4
1.2
1
1.2
1.4
1.6
1.8
2
2.2
10
1
10^{-1}

Result

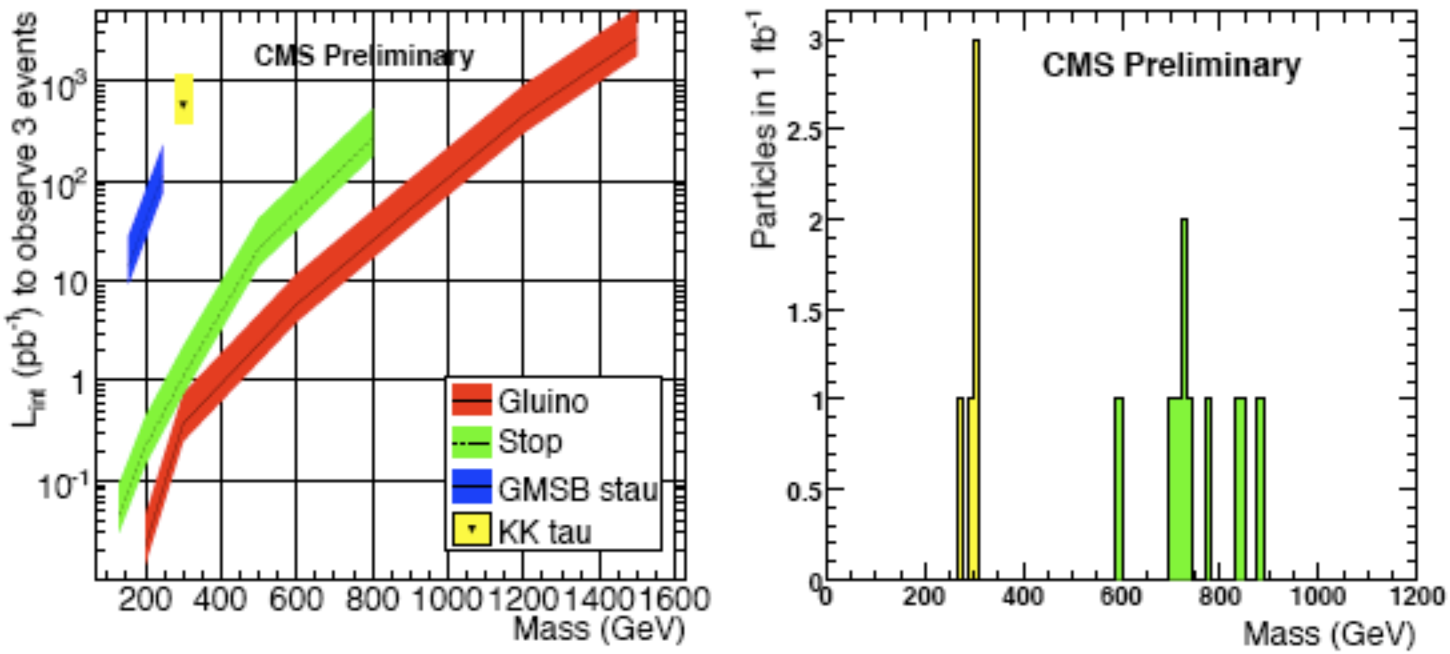
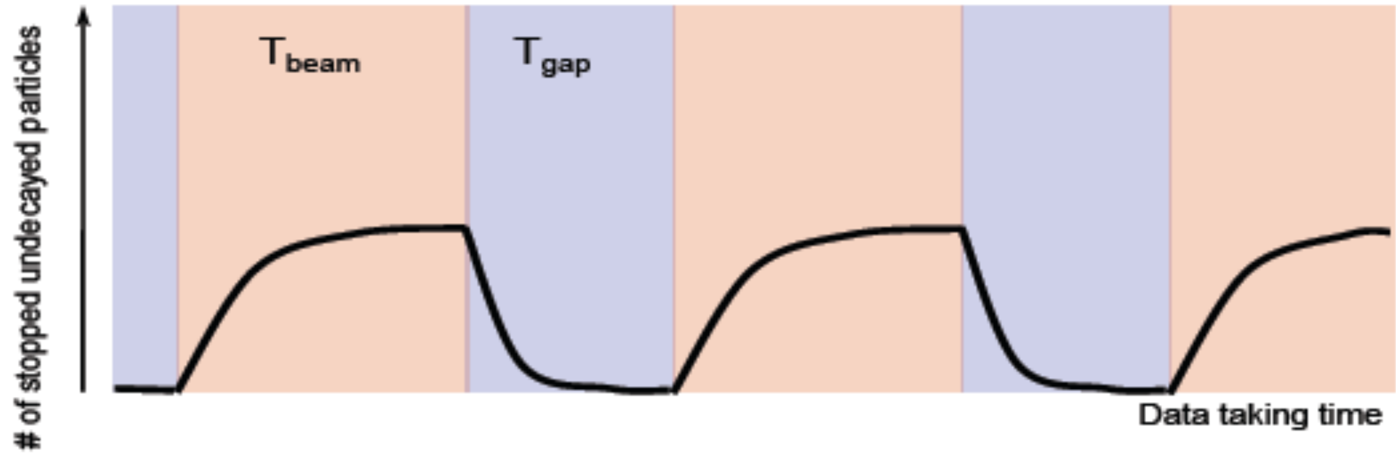


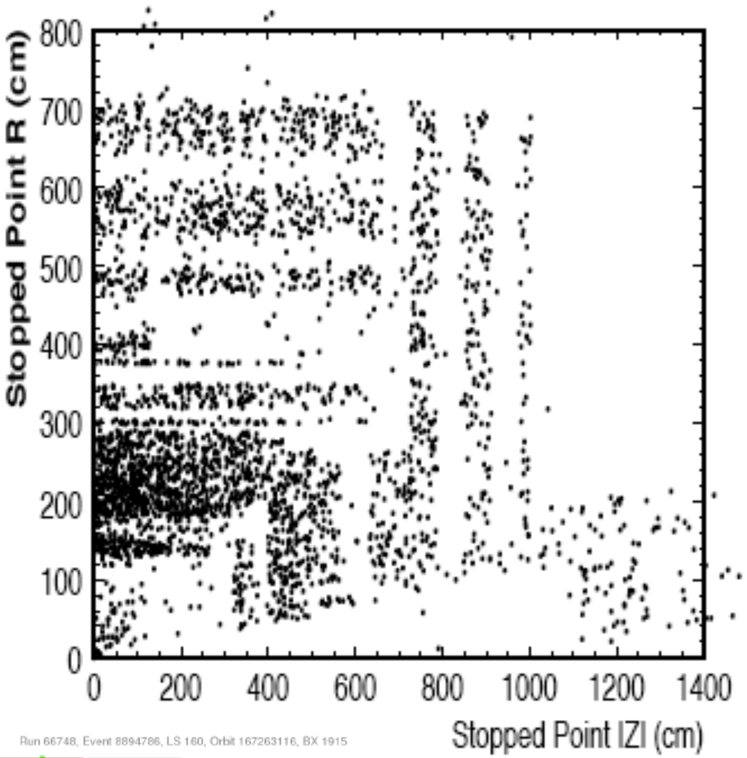
Figure 2: The left plot shows the integrated luminosity (pb^{-1}) needed for 3 events, for the four signal models (gluino full circles, stop full squares, KK tau empty circles, stau empty squares) as a function of HSCP mass. The right plot shows the reconstructed mass distribution with 1 fb^{-1} for two of the lowest cross section samples (300 GeV KK tau and 800 GeV stop).

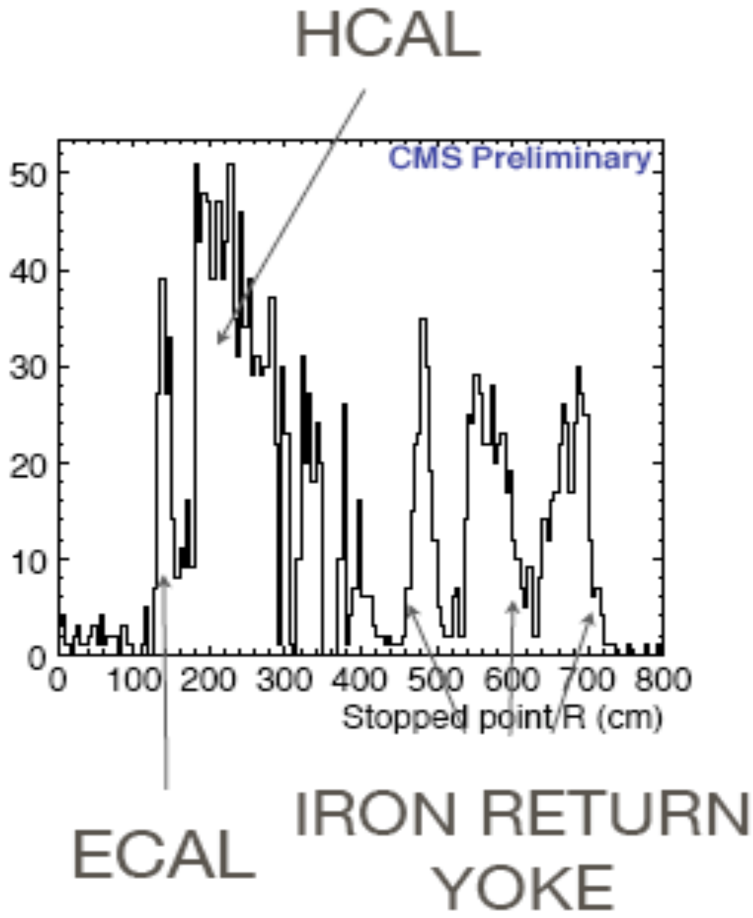
Search for stopped R-hadrons

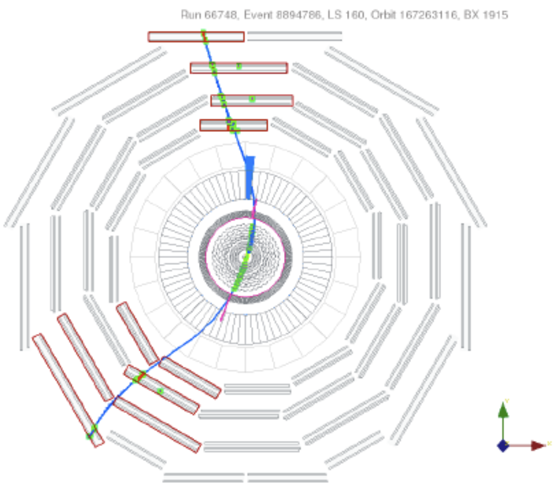


There are two competing effects: The R-hadron production ($\varepsilon\sigma$ L) that increase the stopped R-hadron density and the decay , whose rate is proportional to the density itself. This implies that one reaches a saturation level when enough R-hadrons have been stopped that the decay rate equals the production rate. The saturation density is $\varepsilon\sigma L\tau$.
Here ε is the stopping efficiency and τ is the lifetime.

Where do they stop in CMS ?



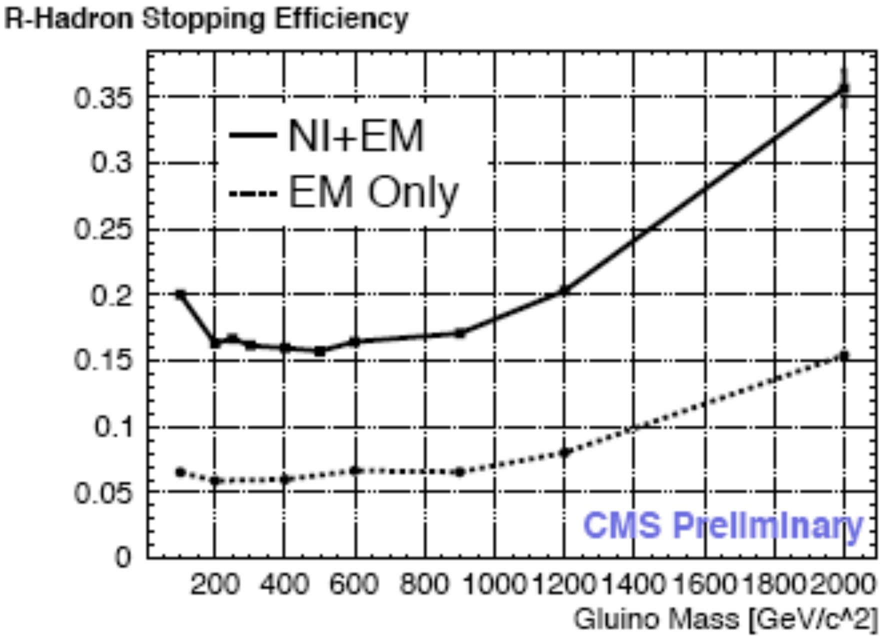




Stopping efficiency will be function of the beta at production (dE/dx) and particles will stop in the dense part of the detector.

Stopping efficiency

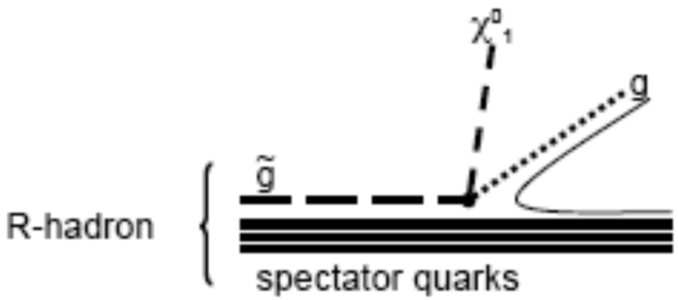
~15% **stopped** (depends on gluino mass)

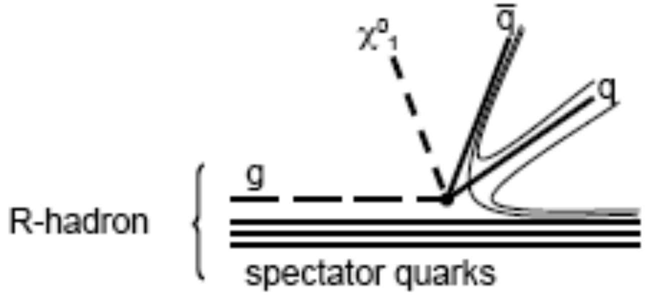


Flat in the mass range of interest,
low/high mass behaviour as expected

Do you know what drives the shape of this curve ?

Decay of the R-Hadron

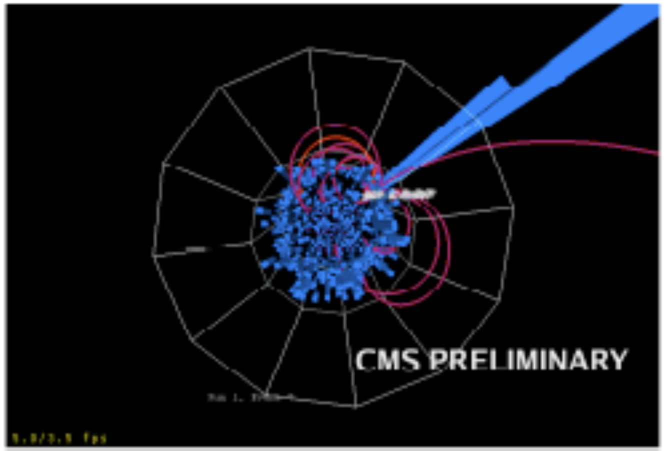


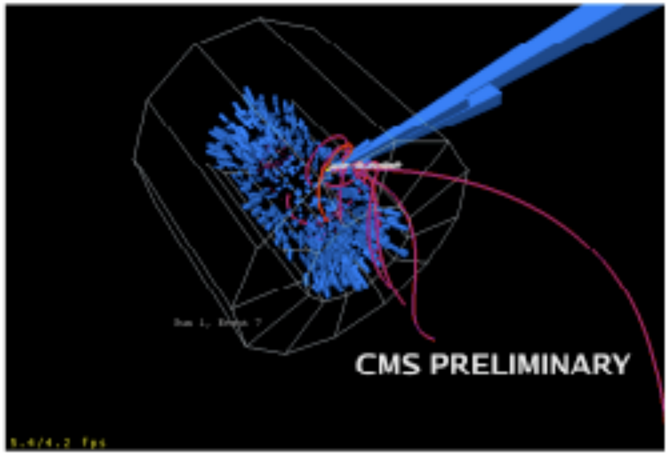


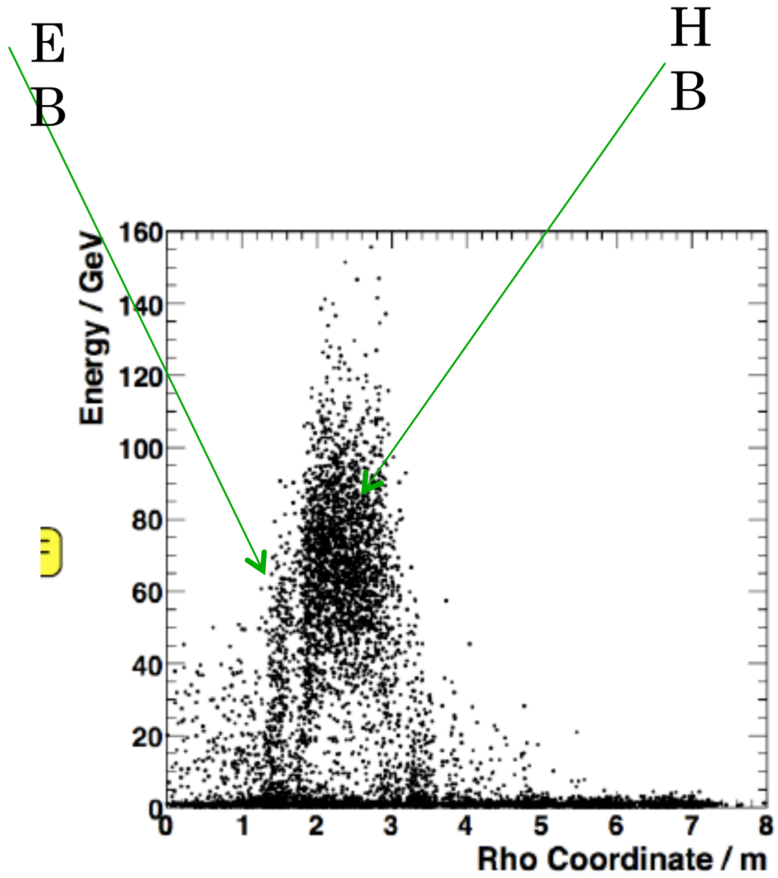
- R-hadron decay is essentially a gluino decay, quarks are spectators (though they play an important role in subsequent hadronization)
  - $m_R = m_{\tilde{g}} + (0.65\text{-}1.8)$ GeV depending on R-hadron flavour
    - Flavour changes occur frequently via NI but most likely to be stopped as Δ_g^{++} (4x dE/dx)
  - Use Pythia as particle gun to produce an R-hadron at rest
  - Use a customized "Vertex Smearing" module to translate (0,0,0) to stopping point (x_0,y_0,z_0)
- We then have Pythia decay the gluino via either the monjet or dijet modes, e.g.

$$\Delta_{\tilde{g}}^{++} \rightarrow \tilde{g}\, u(uu) \rightarrow g\, \chi_1^0\, u(uu) \qquad \Delta_{\tilde{g}}^{++} \rightarrow \tilde{g}\, u(uu) \rightarrow q\bar{q}\, \chi_1^0\, u(uu)$$

How do we detect the R-Hadron



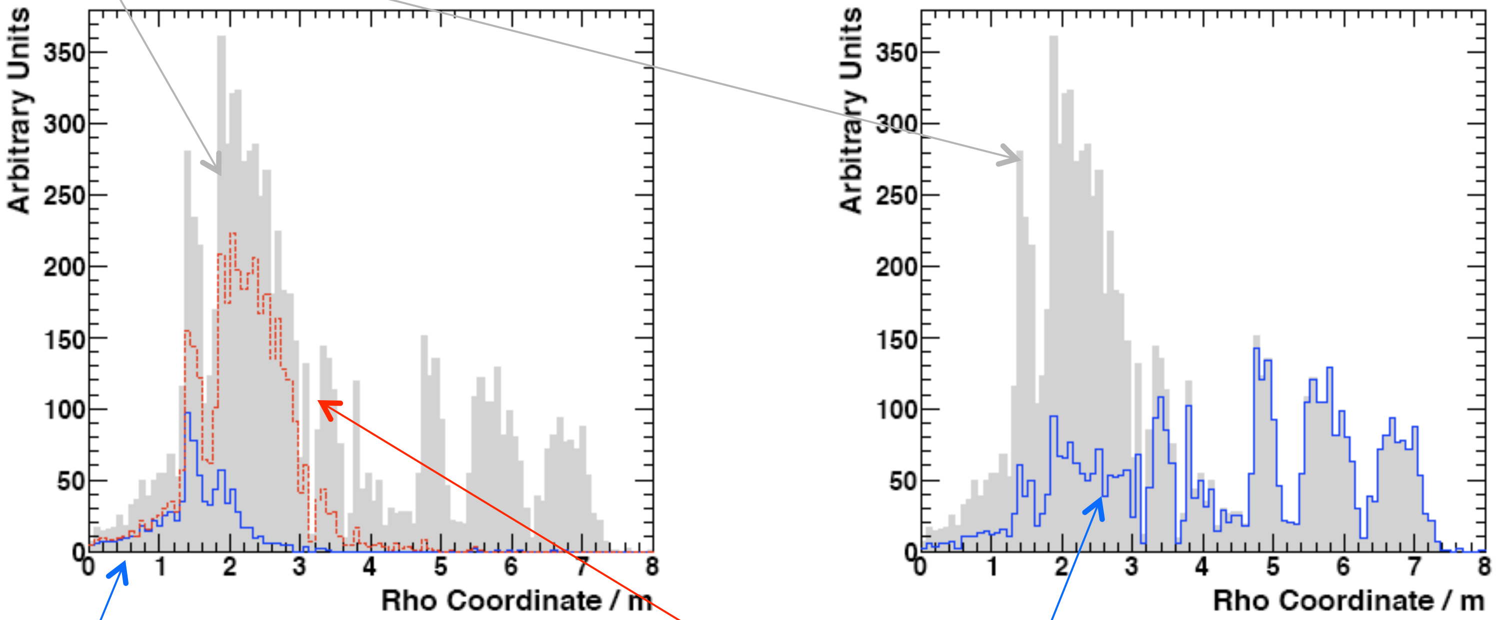




Energy deposited in the Hadron calorimeter barrel as function of the radial coordinate of the stopped gluino.

How to detect R-Hadron decay ?

Stopped gluinos



More than 5 GeV in any calorimeter

Less than 5 GeV in any calorimeter

More than 5 GeV in both calorimeters

Conclusion: Trigger on > 5 GeV in HCAL will be reasonably efficient

Trigger Rate

What is important when evaluating the trigger is its rate on the background and not on the signal. In this case (no beam) the rate can be measured in the events collected by CMS during the CRAFT Run (Cosmic ray).

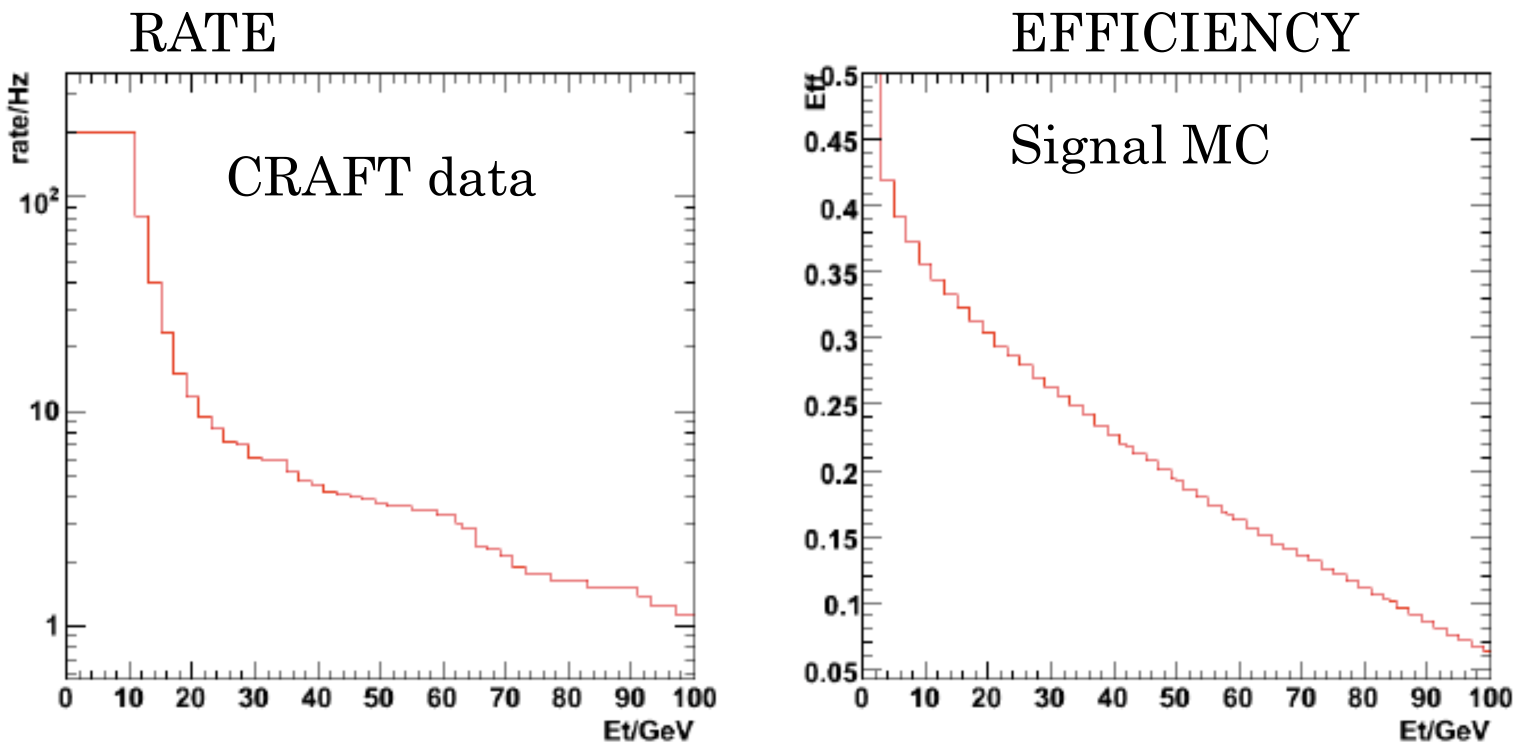
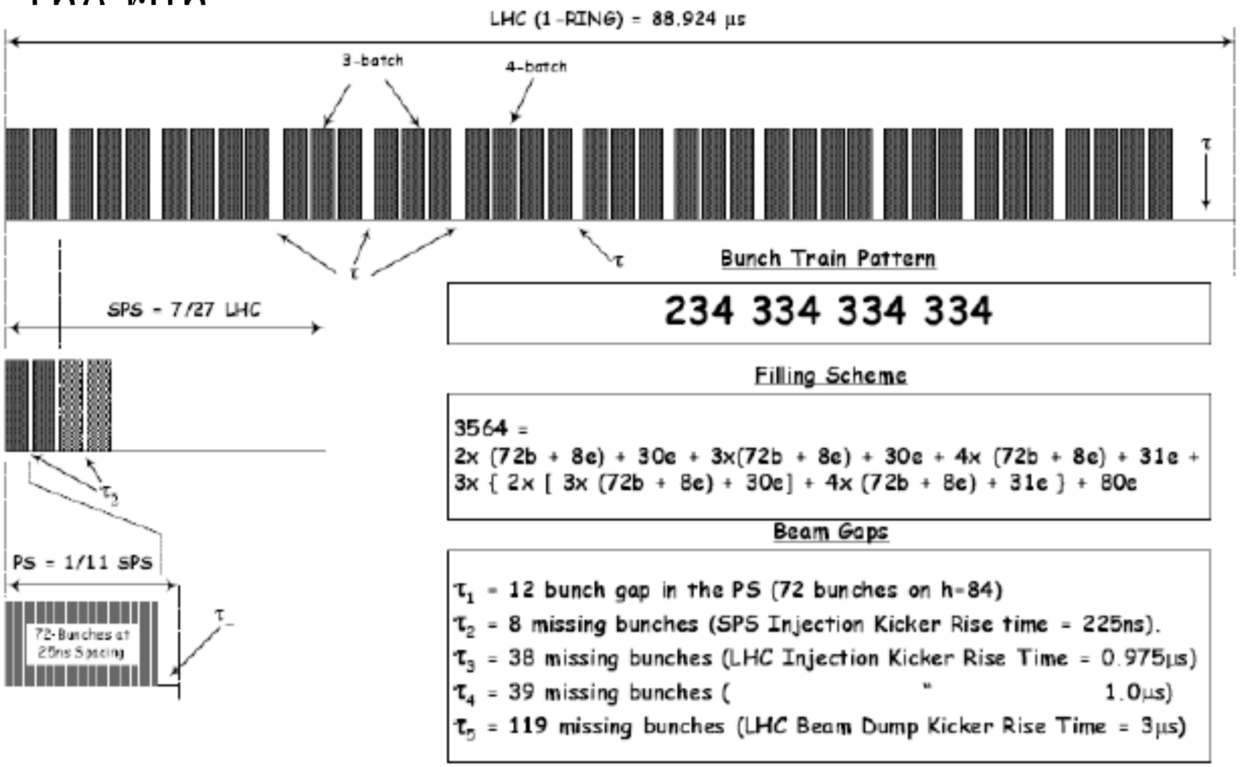


Figure 9: a) L1 trigger rate and b) efficiency, as functions of jet E_T threshold

When to Trigger ?

The trigger is applied in anticoincidence with the beam. After the beam has been dumped (inter-fill) but also in the beam gaps during the run



27 gaps of t_gap= 0.2 μs : 5.4 μs
11 gaps of t_gap= 1 μs : 11 μs ~20 μs ~ 20%
1 gap of t_gap= 3 μs : 3 μs

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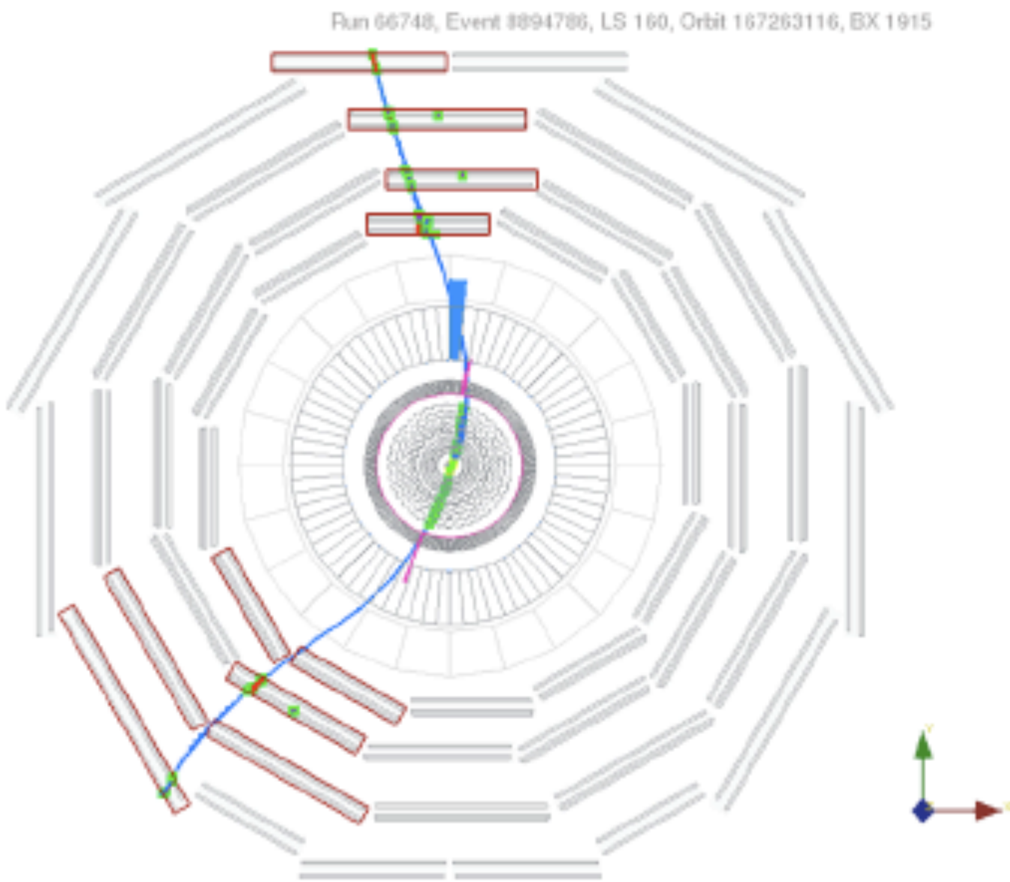
Background effects

- Since no beam, no physics backgrounds (from collisions), but still have:
  - **Instrumental Effects** (mostly HPD noise)
  - **Cosmic Rays**
- We have **measured** both these backgrounds with **CRAFT data**



Data taking mode

In order to evaluate discovery reach we need a model. In a very crude way we assume that we run for 12 h at constant luminosity L and that we have 12h of interfill.

Dependence of the signal counting rate on the lifetime for the experiment done in the beam gaps.

The beam gaps have length from 0.2 μs to 3 μs. If the lifetime is much smaller than 0.2 μs the signal will not be observed. If the lifetime τ is in the range from some μs to say 100 sec , the saturation level will be reached very quickly after the start of the run and data will be recorded for time intervals (gaps) much smaller than the lifetime.
The rate will be the
RATE = Gluino density * t_gap/τ.

Since the Gluino density (εσLτ) is proportional to the lifetime, the rate is constant independently of the lifetime.

Dependence of the reach on the Luminosity

This is a special experiment, since the signal rate changes linear with the luminosity while the background does not depend on the luminosity.

The sensitivity, i.e. the capability to see a signal above the expected background, is

$$\frac{S}{\sqrt{B}} \propto \frac{\mathcal{L} \times t}{\sqrt{t}} \propto \mathcal{L}\sqrt{t}$$

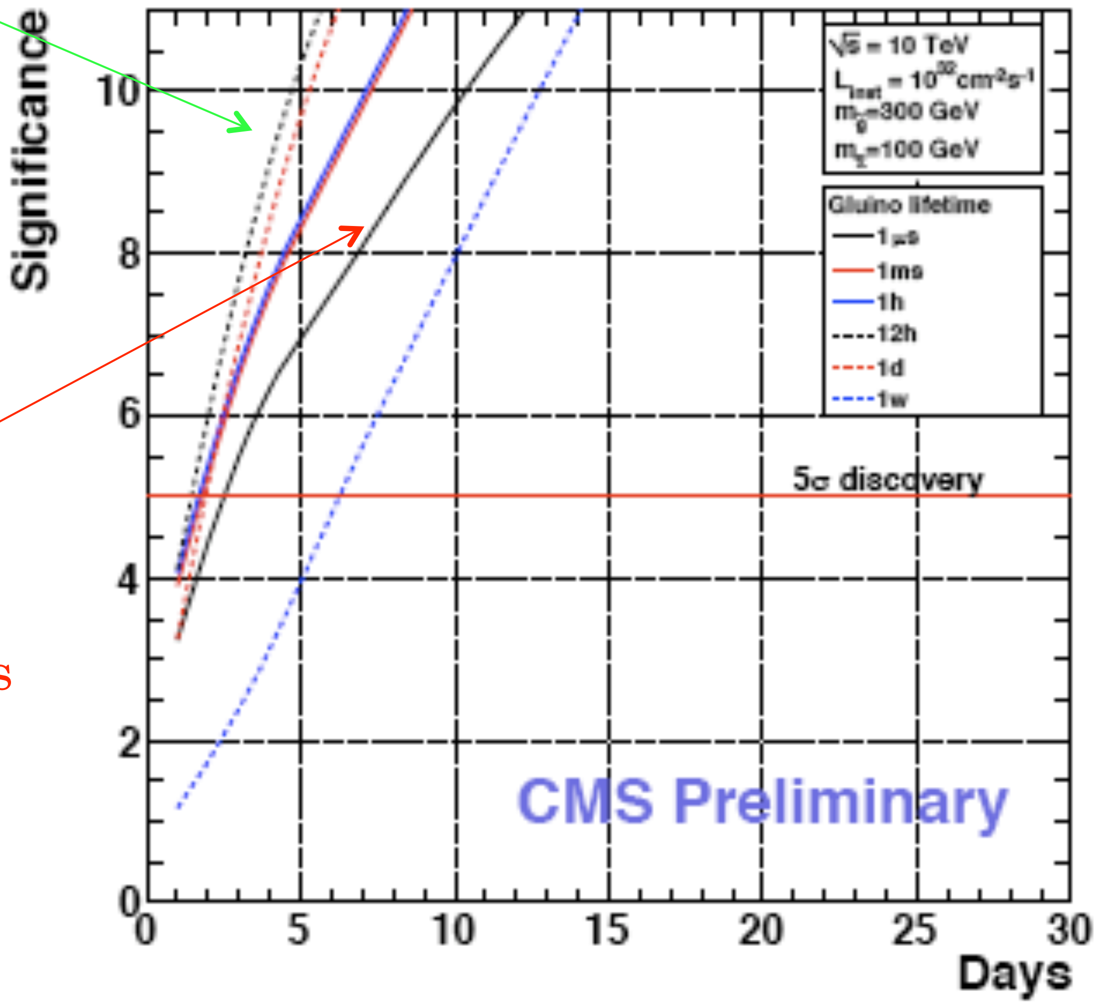
while in searches that have beam induced background the sensitivity scales as

$$\sqrt{\mathcal{L} \times t},$$

Reach at L=10^{32} cm^{-2} sec^{-1}

same sensitivity from 1 msec to 1 h

Get contribution from beam and inter fill run

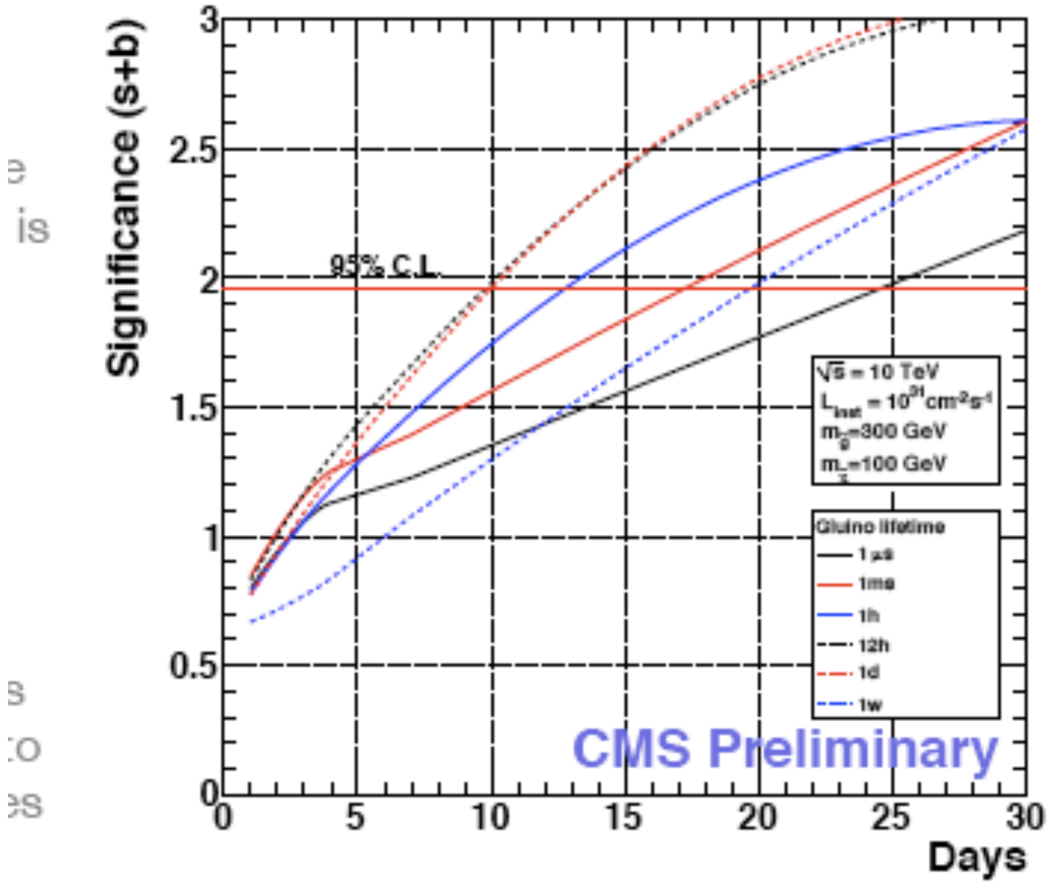


Combined Beam-Gap & Interfill periods

sensitivity decreases when τ becomes similar to t_gap

Reach at $L=10^{31}\ cm^{-2}\ sec^{-1}$

The sensitivity decreases by a factor of 10 and here I quote the 3 sigma instead of the 5 sigma



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WIMP s and Cosmology

We have seen various ways in which WIMPS can be detected at LHC.

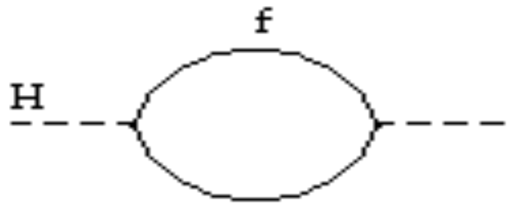
If we see a WIMP signal it will not be easy to understand which WIMP it is. Other measurement will be needed to identify which theory. This is a very new topic addressed recently in a number of papers. One good reference is

Missing energy look-alikes with 100 pb-1 at the LHC. Phys.Rev.D78:075008,2008. e-Print: arXiv:0805.2398 [hep-ph]

We will discuss now the case of Supersymmetry

Why SuperSymmetry ?

- Solution to the hierarchy problem (or why $m_w << m_P$)

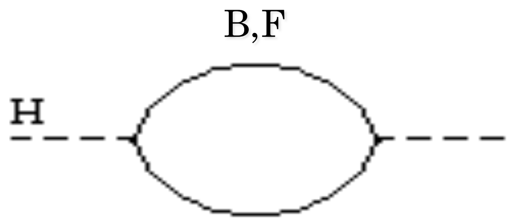


Quantum corrections to m_H are quadratically divergent in the SM

$$\delta m^2_{H,W} \simeq \mathcal{O}(\frac{\alpha}{\pi})\Lambda^2$$

Λ represents the scale where new physics beyond the Standard Model appears. If it is comparable to the Planck scale finite higgs mass implies a fine tuning of ~ 14 digits !

In SuperSymmetry there are equal numbers of bosons and fermions with identical couplings. Since bosonic and fermionics loops have opposite sign the one-loop correction becomes



$$\delta m^2_{H,W} \simeq \mathcal{O}(\frac{\alpha}{\pi})(m^2_B - m^2_F)$$

That is well behaving if : $|m^2_B - m^2_F| \lesssim 1 \text{ TeV}^2$

SuperSymmetry Particle Content

Every SM particle has a SUSY partner (sparticle) that are exactly same, but differ in spin by ½ .

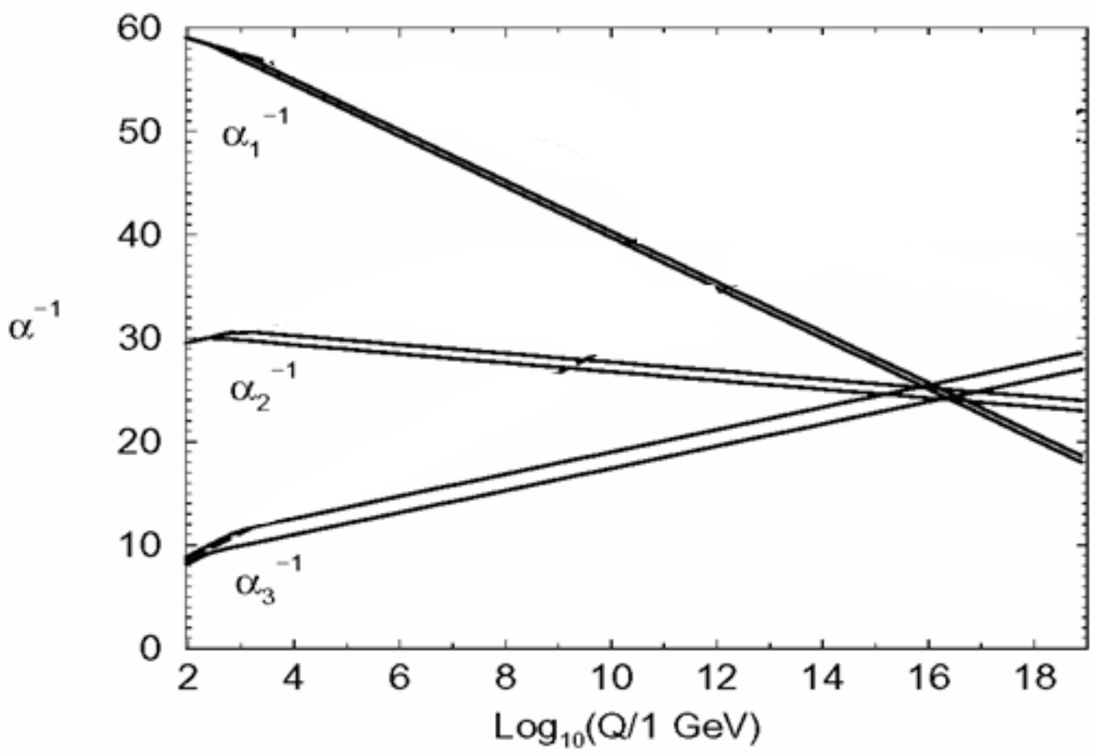
Names		spin 0	spin 1/2	$SU(3)_c \otimes SU(2)_L \otimes U(1)_Y$
squarks, quarks	Q	$(\tilde{u}_L \quad \tilde{d}_L)$	$(u_L \quad d_L)$	$(3,\ 2,\ \frac{1}{6})$
(×3 families)	U^c	$\tilde{u}_R^*$	$u_R^\dagger$	$(\bar{3},\ 1,\ -\frac{2}{3})$
	D^c	$\tilde{d}_R^*$	$d_R^\dagger$	$(\bar{3},\ 1,\ \frac{1}{3})$
sleptons, leptons	L	$(\tilde{\nu} \quad \tilde{e}_L)$	$(\nu \quad e_L)$	$(1,\ 2,\ -\frac{1}{2})$
(×3 families)	E^c	$\tilde{e}_R^*$	$e_R^\dagger$	$(1,\ 1,\ 1)$
Higgs, higgsinos	H_u	$(H_u^+ \quad H_u^0)$	$(\tilde{H}_u^+ \quad \tilde{H}_u^0)$	$(1,\ 2,\ \frac{1}{2})$
	H_d	$(H_d^0 \quad H_d^-)$	$(\tilde{H}_d^0 \quad \tilde{H}_d^-)$	$(1,\ 2,\ -\frac{1}{2})$

Names	spin 1/2	spin 1	$SU(3)_c \otimes SU(2)_L \otimes U(1)_Y$
gluino, gluon	$\tilde{g}$	g	$(8,\ 1,\ 0)$
wino, W	$\tilde{W}^\pm,\ \tilde{W}^0$	$W^\pm,\ W^0$	$(1,\ 3,\ 0)$
bino, B	$\tilde{B}^0$	B^0	$(1,\ 1,\ 0)$

Hints of SuperSymmetry (1)

- Strength of the different interactions as measured at LEP and their extrapolation to Plank Scale

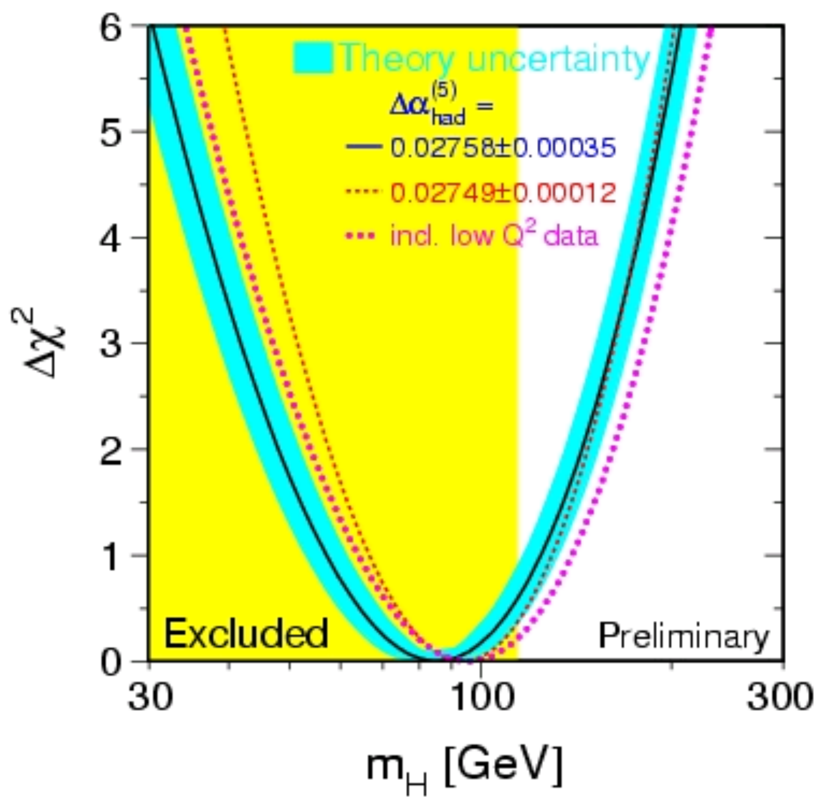
U. Amaldi, W. de Boer and H. Furstenau, Phys. Lett. B 260, 447 (1991);



Hints of SuperSymmetry (2)

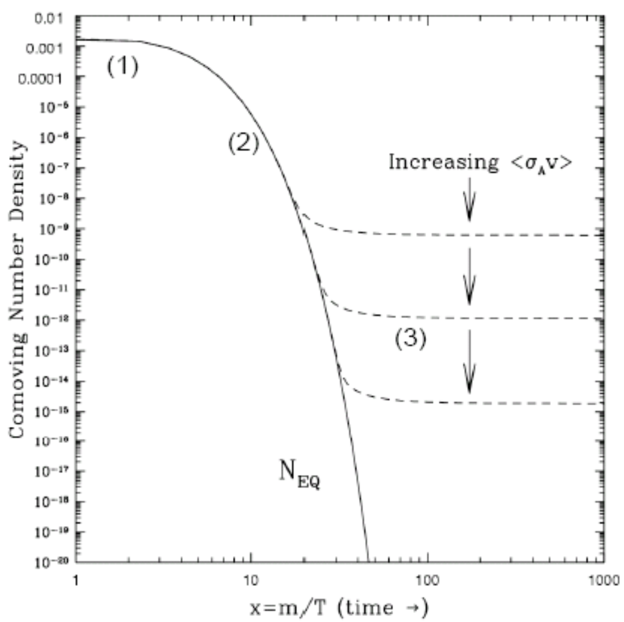
- Precision electroweak data prefer a relatively light Higgs Boson (as expected in SuperSymmetry)

  http://lepewwg.web.cern.ch/LEPEWWG/



Hints of SuperSymmetry (3)

- Astrophysical necessity of cold dark matter. LSP is expected to be stable in MSSM because of R parity conservation.



$$\Omega_\chi h^2 \simeq const. \cdot \frac{T_0^3}{M_{\rm Pl}^3 \langle \sigma_A v \rangle} \simeq \frac{0.1 \ {\rm pb} \cdot c}{\langle \sigma_A v \rangle}$$

Can work for typical weak cross section !

Constrained Minimal Super Symmetry
CMSSM

Important constraints have been provided by LEP and Tevatron (unsuccessful) searches

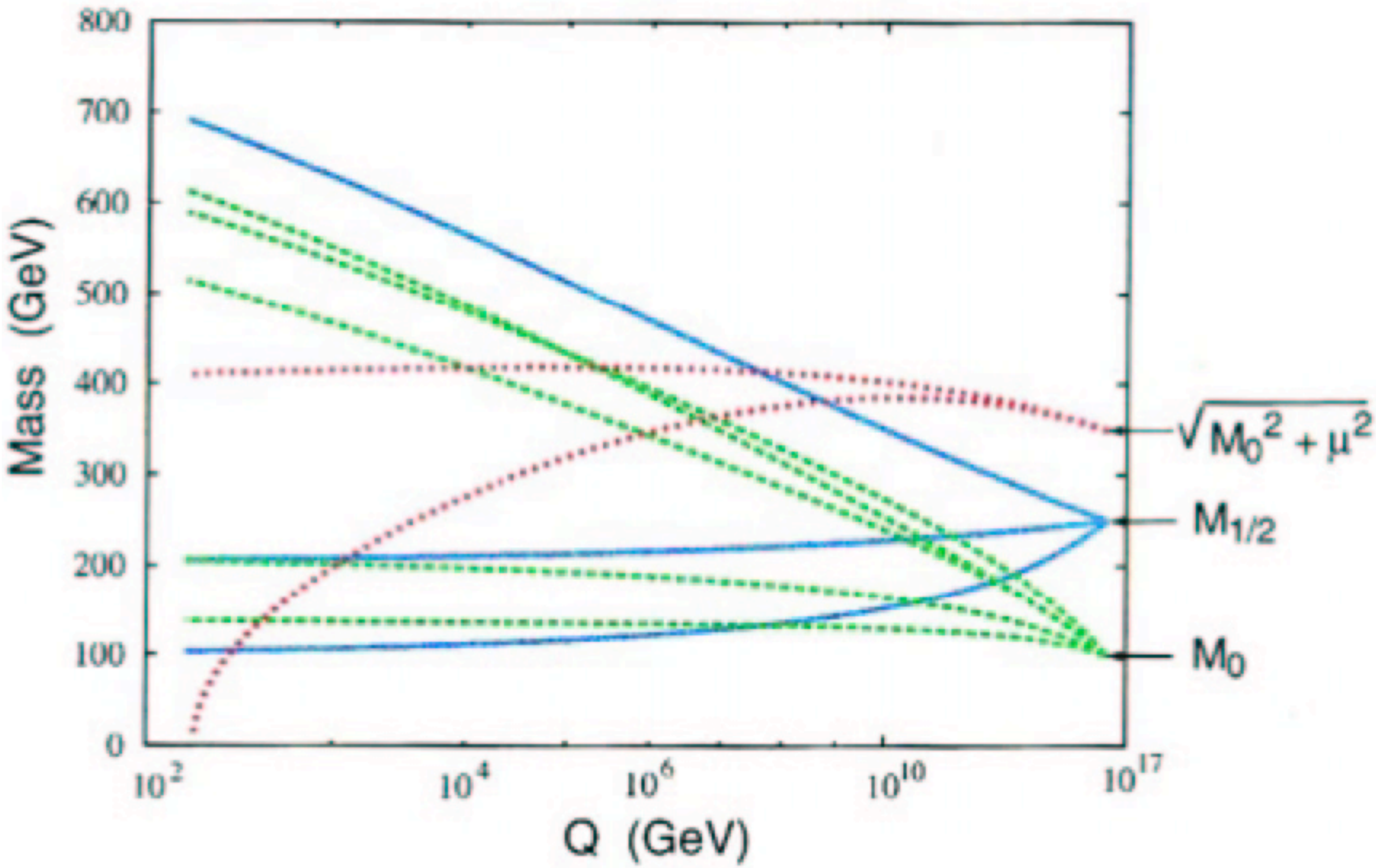
The results are compiled in terms of CMSSM where :

m_0, $m_{1/2}$:(common scalar and gaugino mass at GUT scale)
A: (common gaugino coupling at GUT scale)
$tan\beta$: ratio of vev of H_u and H_d
sign(m): m being the higgs mixing parameter.

Neutralino is the LSP

mSUGRA

Example of mSUGRA SUSY



CMS Reach (Atlas is similar)

(CMS Physics TDR 13.17)

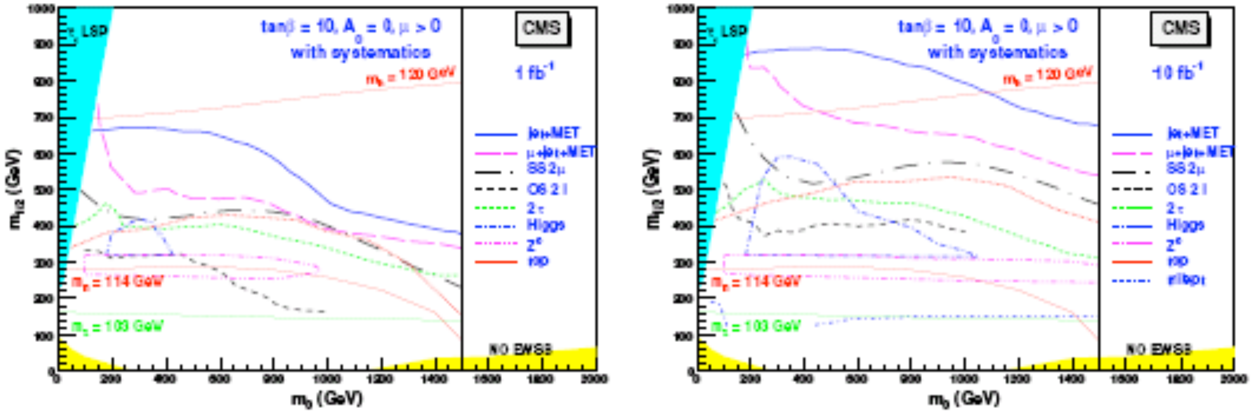


Figure 13.33: Regions of the m_0 versus $m_{1/2}$ plane showing CMS the reach when systematic uncertainties are included. (left) for 1 fb^{-1} integrated luminosity, except the Higgs case which assumes 2 fb^{-1}. (right) for 10 fb^{-1}.

How well can LHC constrain SUSY DM?

How well the relic density can be predicted from LHC data ?

Ideally one wants to match the WMAP precision !

The basic issues are the long (and competitive) decay chains and the presence of two invisible particles in the final state renders the direct measurement of sparticle masses through the detection of invariant mass peaks impossible.

Alternative techniques have therefore been developed, based on the exclusive identification of long cascades of two body-decays.

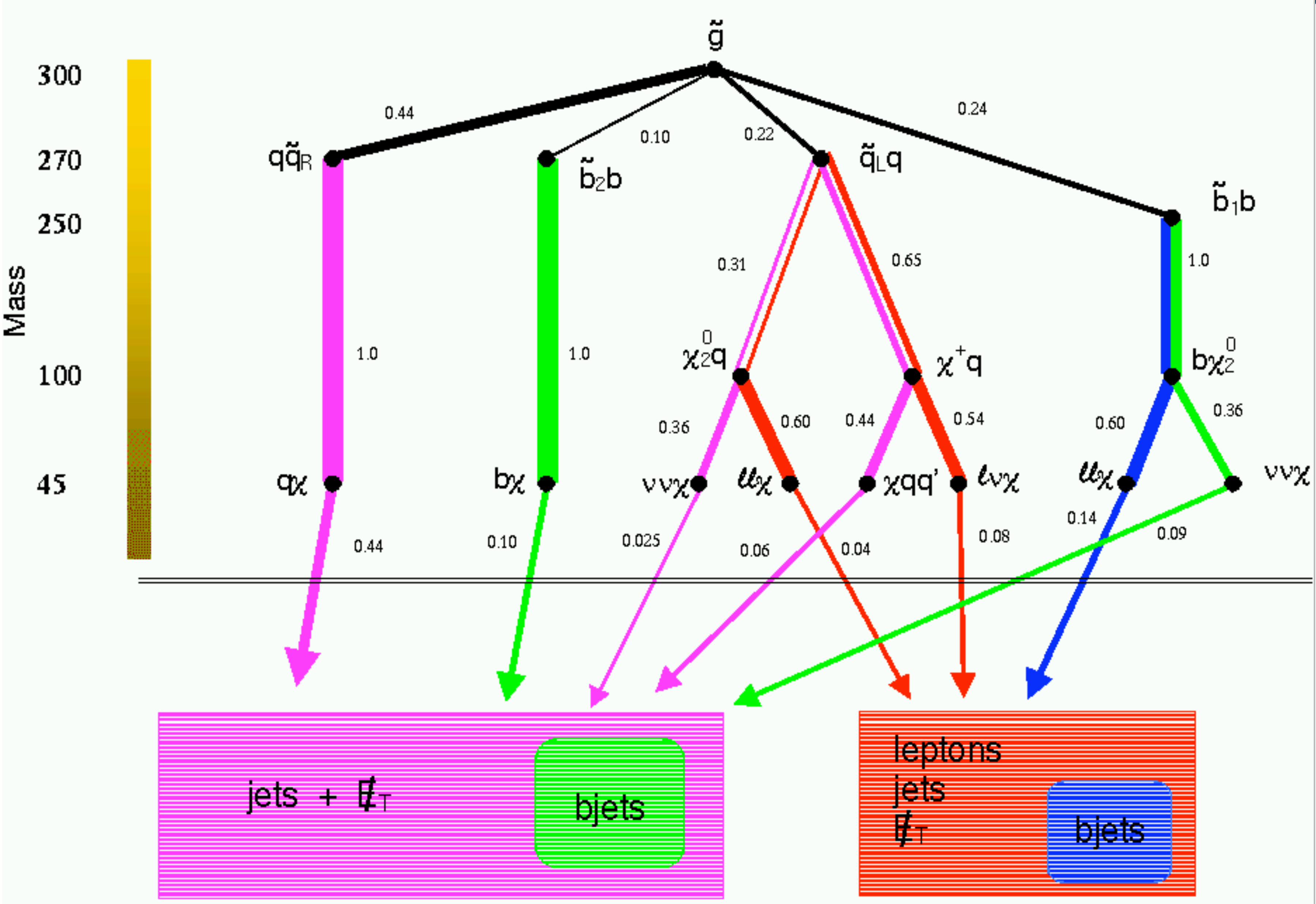
The problem is complex and has many facets. Let's study a specific example in the CMSSM:

G. Polesello and D. R. Tovey, Constraining SUSY Dark Matter with the ATLAS Detector at the LHC, JHEP 0405 (2004) 071 [arXiv:hep-ph/0403047].

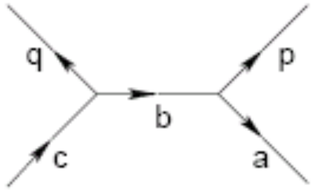
Study done in the bulk region at

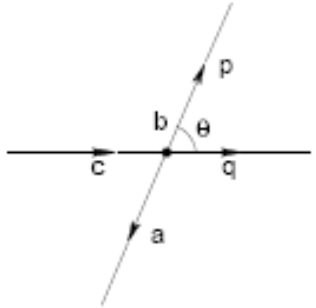
$m0 = 100$ GeV, $m1/2 = 250$ GeV, $A0 = -100$ GeV, $\tan\beta = 10$, $\mu > 0$

Gluino decay path examples



Cascade of successive two body decays





C→QB→QPA   Q and P are visible A is invisible

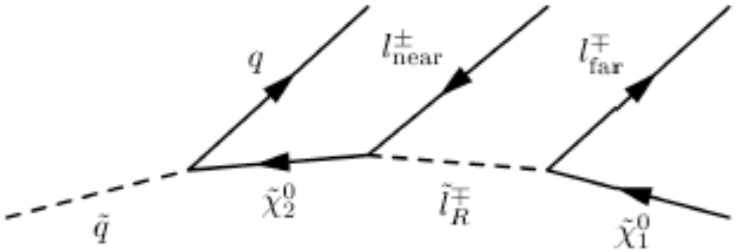
$$m_{pq}^2 = (E_p + E_q)^2 - (\vec{p_q} + \vec{p_q})^2 = m_p^2 + m_q^2 + 2(E_p E_q - |\vec{p_p}||\vec{p_q}|cos\theta)$$

m_{pq} has a maximum and a minimum depending on cosθ

The endpoints of the invariant mass distributions are known functions of the masses of the particle involved

One specific and case

$$
\begin{array}{l}
\tilde{q}_L \rightarrow \tilde{\chi}_2^0 \quad q \\
\qquad \hookrightarrow \tilde{\ell}_R^{\pm} \quad \ell^{\mp} \\
\qquad\qquad \hookrightarrow \tilde{\chi}_1^0 \quad \ell^{\pm}
\end{array}
$$

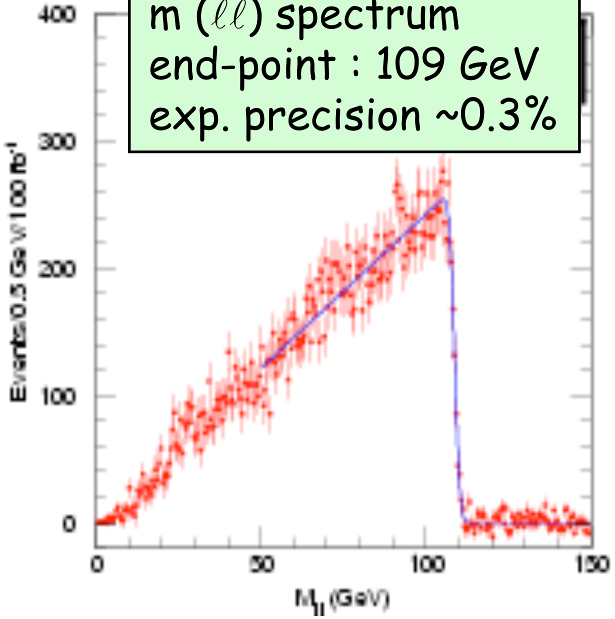


$$
(m_{\ell\ell}^{max})^2 = \frac{(m^2_{\tilde{\chi}_2^0} - m^2_{\tilde{\ell}_R})(m^2_{\tilde{\ell}_R} - m^2_{\tilde{\chi}_1^0})}{m^2_{\tilde{\ell}_R}}
$$

Assuming $m_l=0$

Typical algebraic structure: end points determined by differences of masses squared

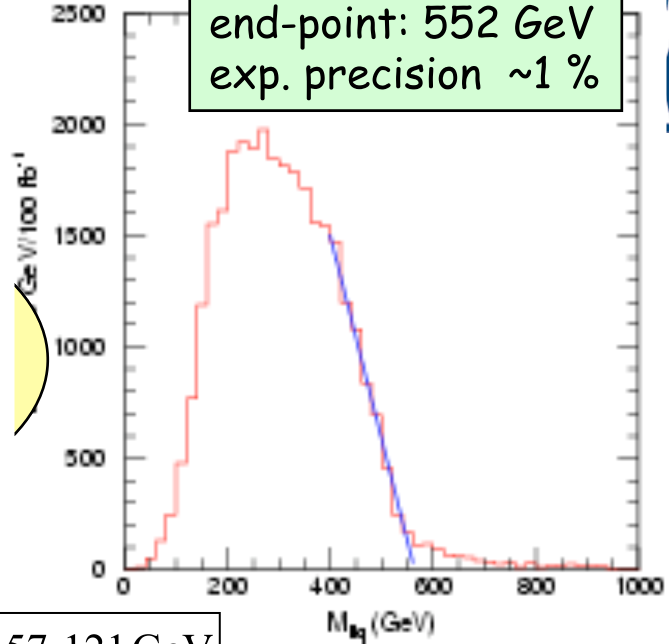
m ($\ell\ell$) spectrum
end-point : 109 GeV
exp. precision ~0.3%



Example of
a typical chain:

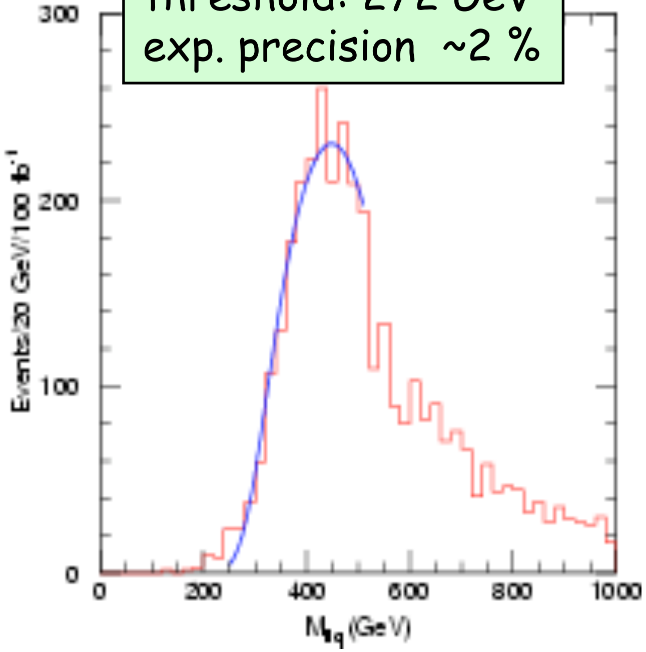
$$\tilde{q}_L \rightarrow \tilde{\chi}^0_2 \; q$$
$$\quad \hookrightarrow \tilde{\ell}^{\pm}_R \; \ell^{\mp}$$
$$\quad\quad \hookrightarrow \tilde{\chi}^0_1 \; \ell^{\pm}$$

m ($\ell\ell$j)^{min} spectrum
end-point: 552 GeV
exp. precision ~1 %



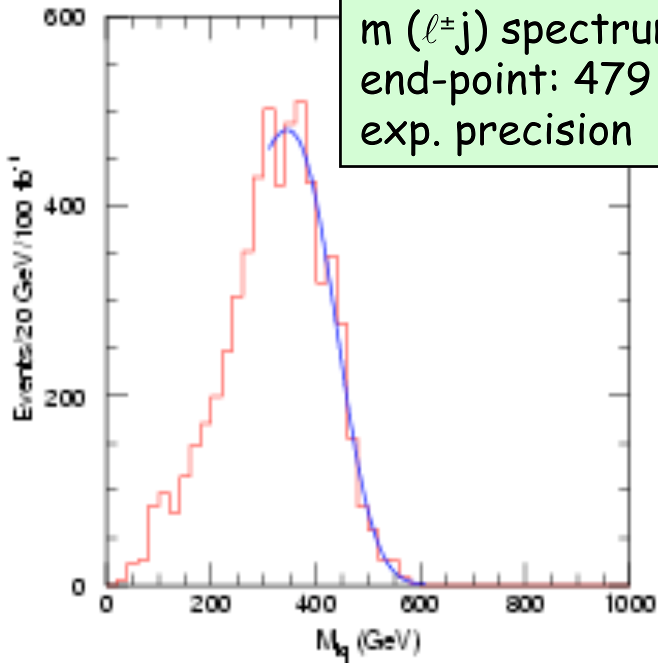
$m(\tilde{q}_L, \tilde{\chi}^0_2, \tilde{\ell}_R, \tilde{\chi}^0_1) = 690, 232, 157, 121$ GeV

m ($\ell\ell$j)^{max} spectrum
threshold: 272 GeV
exp. precision ~2 %



ATLAS
100 fb^{-1}

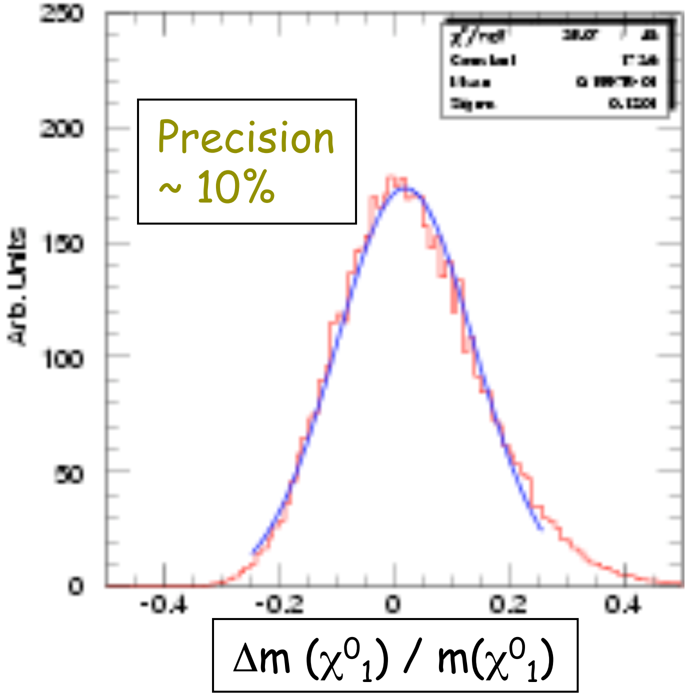
m ($\ell^{\pm}$j) spectrum
end-point: 479 GeV
exp. precision ~1 %



Putting all constraints together:

$\tilde{q}_L \to q\, \chi^0_2$
- $\to h\, \chi^0_1$
  - $\to bb$
- $\to \tilde{\ell}_R\, \ell$
  - $\to \ell\, \chi^0_1$

$m(bbj)$, $m(\ell\ell)$, $m(\ell\ell j)^{max}$, $m(\ell\ell j)^{min}$, $m(\ell j)$



Sparticle mass	Expected precision 100 fb^{-1}
squark left	± 3%
χ^0_2	± 6%
slepton mass	± 9%
χ^0_1	± 12%

Note : these errors are larger than from fit in mSUGRA, but here ~ no assumptions about model (constraints just from kinematics distributions).

- In general, long decay chains give multiple constraints on masses through kinematic distributions
- A large amount of information will be available in the data (only partially exploited here)
- Interpretation (e.g. squark left is source of χ^0_2 and not squark right) is model dependent
- For dark matter, it is important to measure also the LSP couplings

Fitting the measurements in CMSSM

The information in the experimentally measured spectra (more than those shown in the previous transparency) are fitted assuming the validity of CMSSM.

This introduces a MODEL DEPENDENCE that is not experimentally justified.

Once the 5 parameters of CMSSM are fitted the relic density can be computed from the calculated masses and couplings. They obtain a precision of 3% on the relic density.

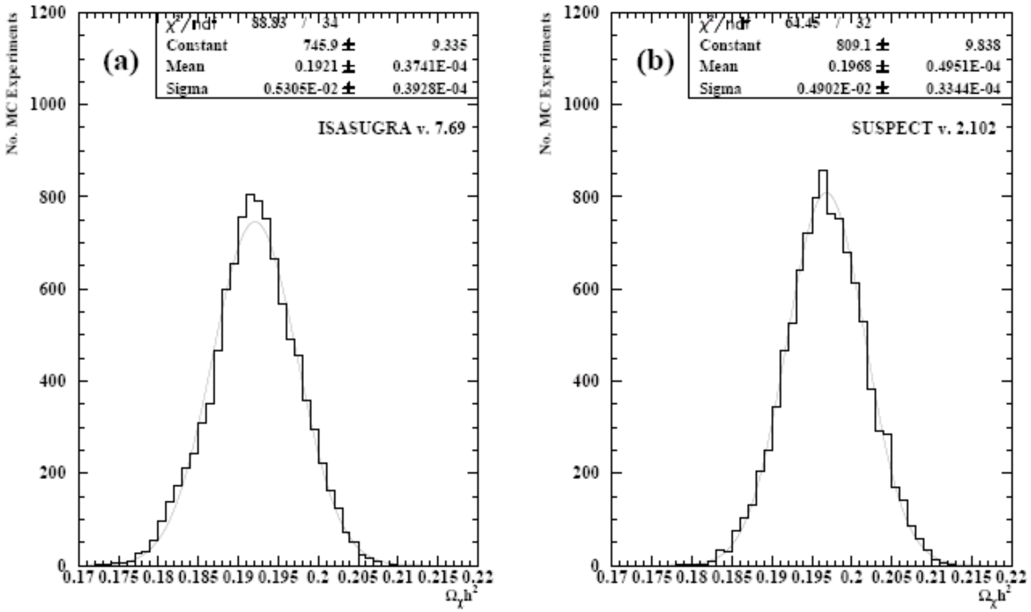


Figure 2: *Values for $\Omega_\chi h^2$ calculated from mSUGRA fits to the SPS1a invariant mass spectrum end-points described in the text. The distribution in Figure (a) was calculated by using results from* `ISASUGRA v.7.69` *fits as input to* `MICROMEGAS v.1.1.1` *interfaced to* `ISASUGRA v.7.69`. *The distribution in Figure (b) was calculated by using results from* `SUSPECT v.2.102` *fits as input to* `MICROMEGAS v.1.1.1` *interfaced to* `SUSPECT v.2.102`.

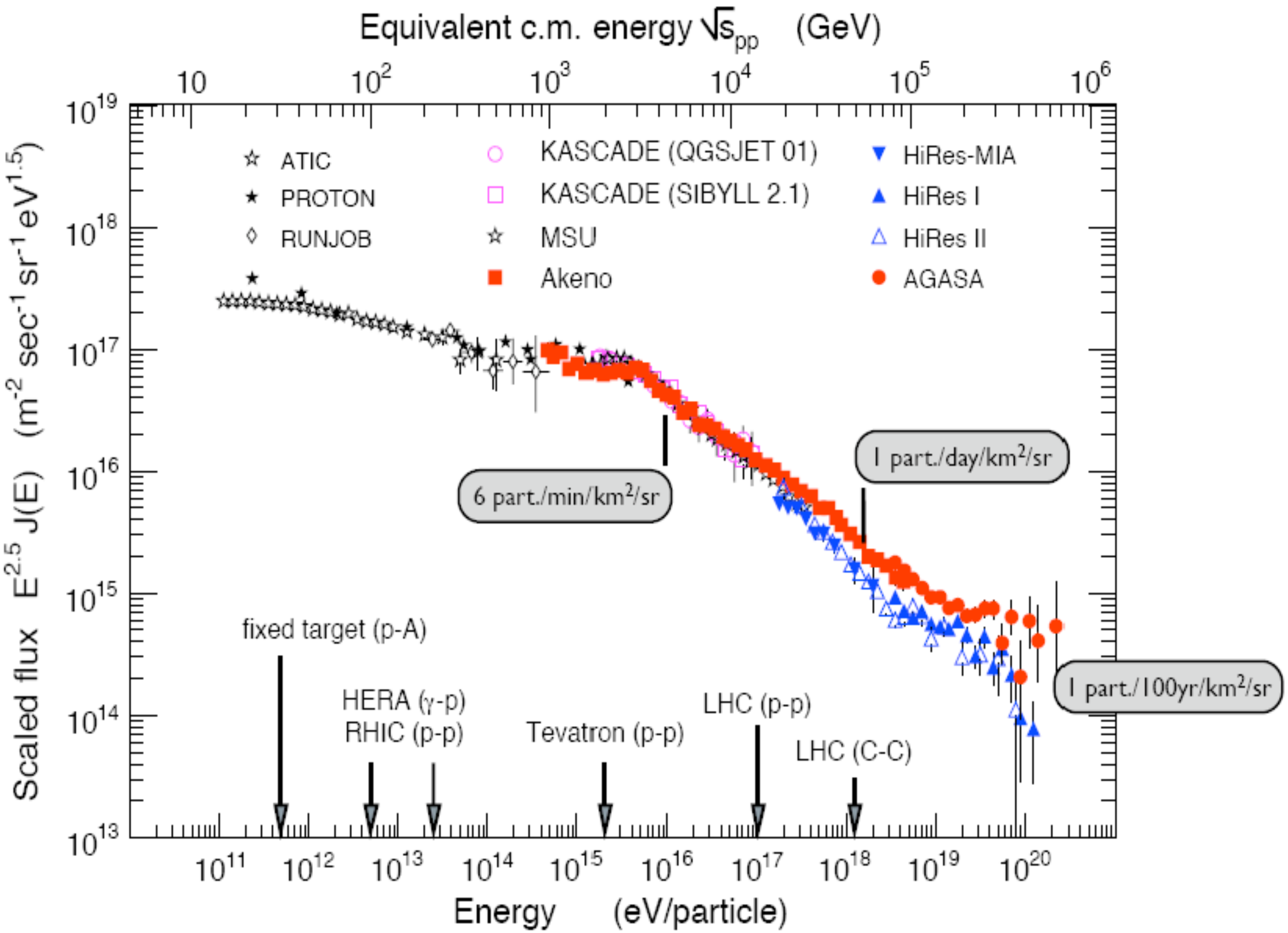
Conclusions on the possibility that LHC measures mass and annihilation x-section of the Neutralino

Let's assume that SUSY exists and that a missing energy excess is seen at LHC. The relic density of neutralinos can be calculated if one measures the neutralino mass and its annihilation rate.

These measurements are complex. The studies done so far show that the proposed techniques have some experimental limitations and that one has to bargain between model dependence and precision.

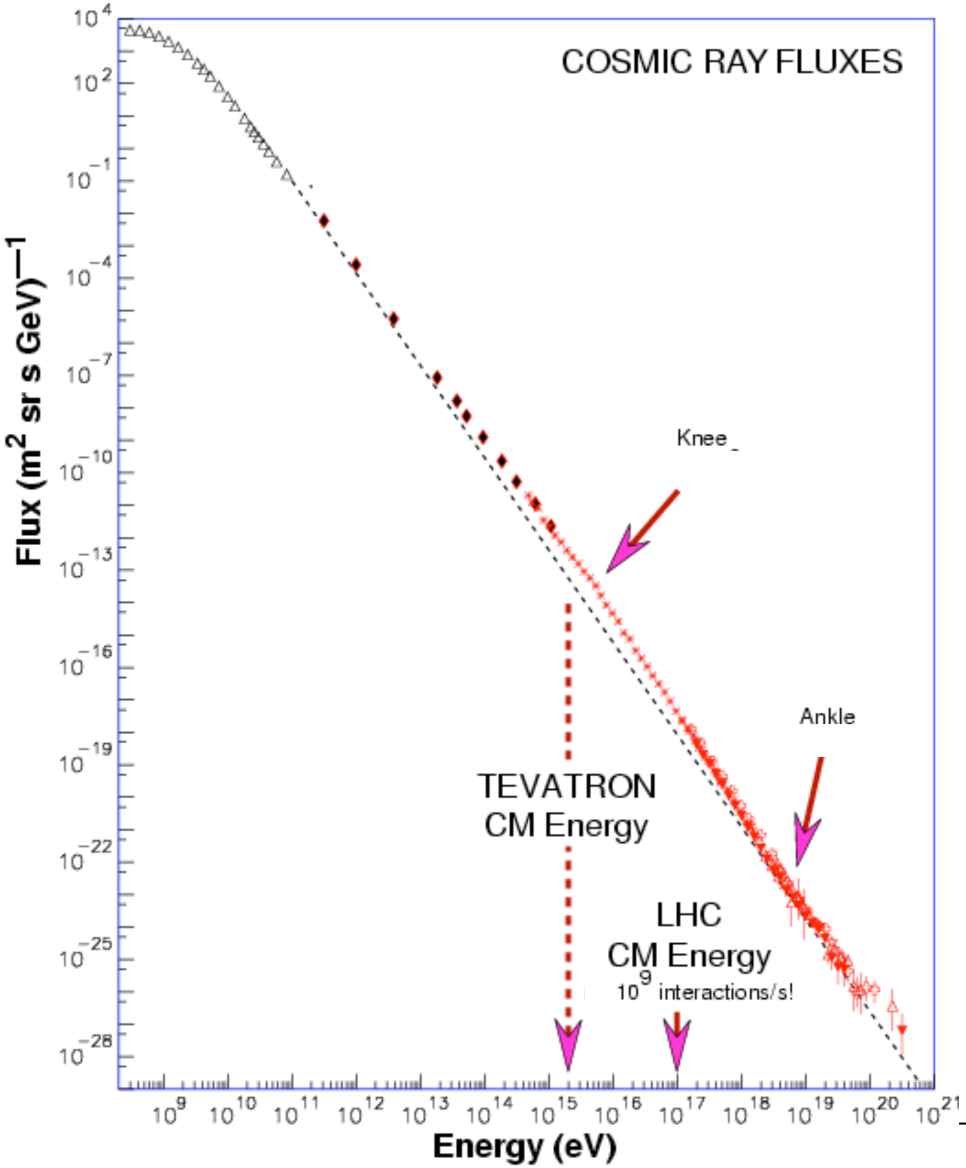
In addition there are region of the SUSY parameter space where the information is limited (eg: some sparticles are too heavy).

Cosmic Rays and Accelerators



❶ Cosmic rays

$\sqrt{s}$ = 14 TeV → corresponds to E ~ 100 PeV fixed target proton beam



LHC studies most relevant to HECR:

-- most energetic particles produced in the collisions

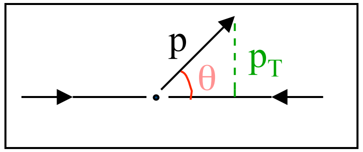
-- pp (and pA, AA) cross-sections

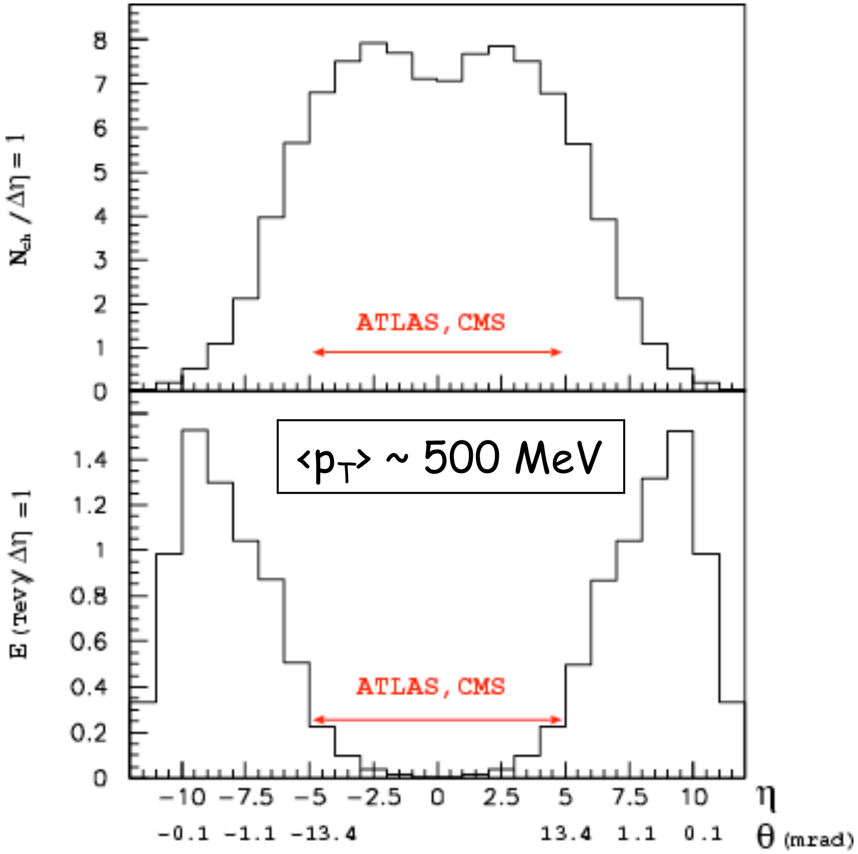
↓

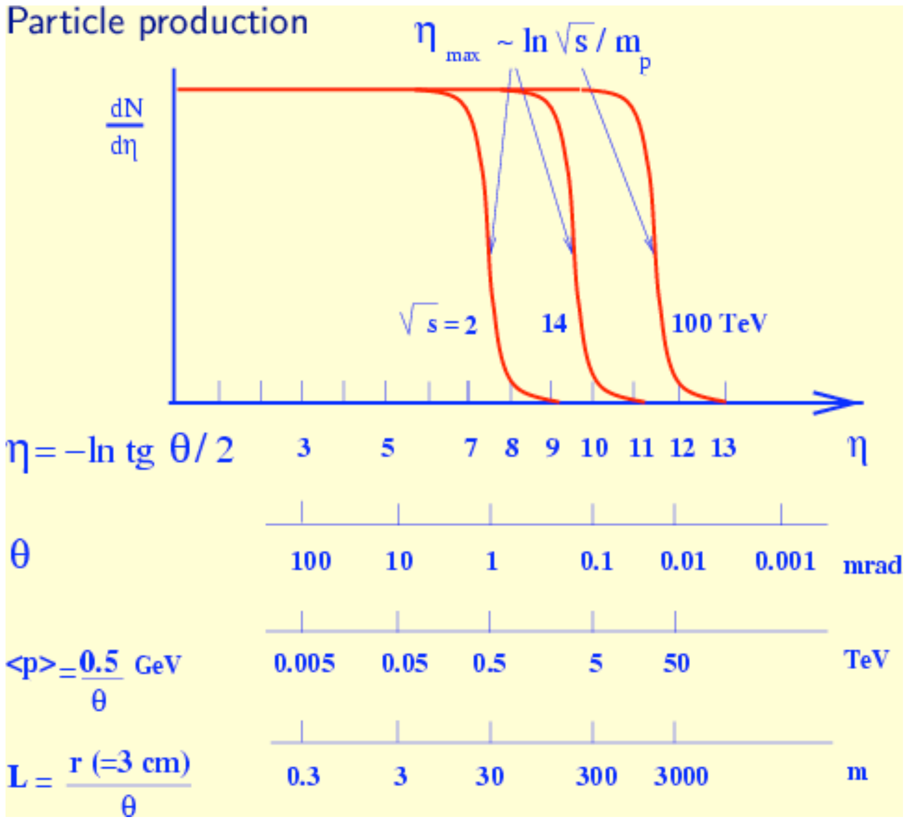
both require detection in the forward (low-p_T) regions

In addition : if (puzzling) spectrum beyond GZK cut-off originate from decay of new particles with $M_X > 10^{12}$ GeV, detailed studies of sparticle masses and decay patterns at TeV-scale important to deduce physics at high scale from observed cosmics spectra.

Charged particle multiplicity and energy in pp inelastic events at √s = 14 TeV







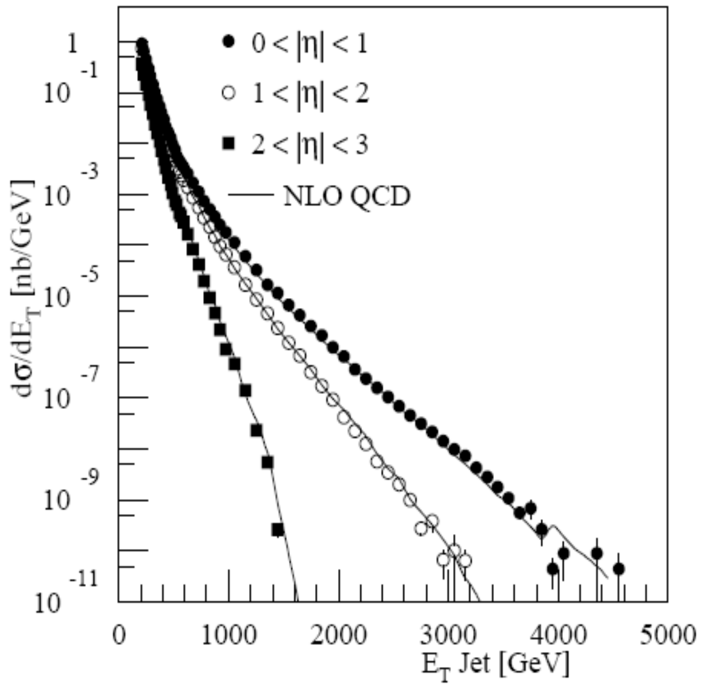
Baseline Detector Coverage

- ATLAS, CMS
  - → Tracking and muon system $|\eta| < 2.5$
  - → Calorimetry $|\eta| < 5$
- ALICE
  - → Tracking (TPC, vertexing) $|\eta| < 0.9$
    - and several other specialized detectors
  - → Muon spectrometer $2.4 < \eta < 4$
  - → Zero-Degree Calorimeter (ZDC)
- LHCb
  - → Forward spectrometer $1.9 < \eta < 4.9$
- TOTEM
  - → Roman Pots for leading protons
  - → Tracking for charged particles $3 < |\eta| < 7$
- LHCF
  - → Neutral particles at zero degrees

QCD Studies @ LHC

E.g. Jet Physics

Huge cross sections:
Eg for 1 fb^{-1} ~ 10000 events with E_T> 1 TeV
100 events with E_T> 2 TeV



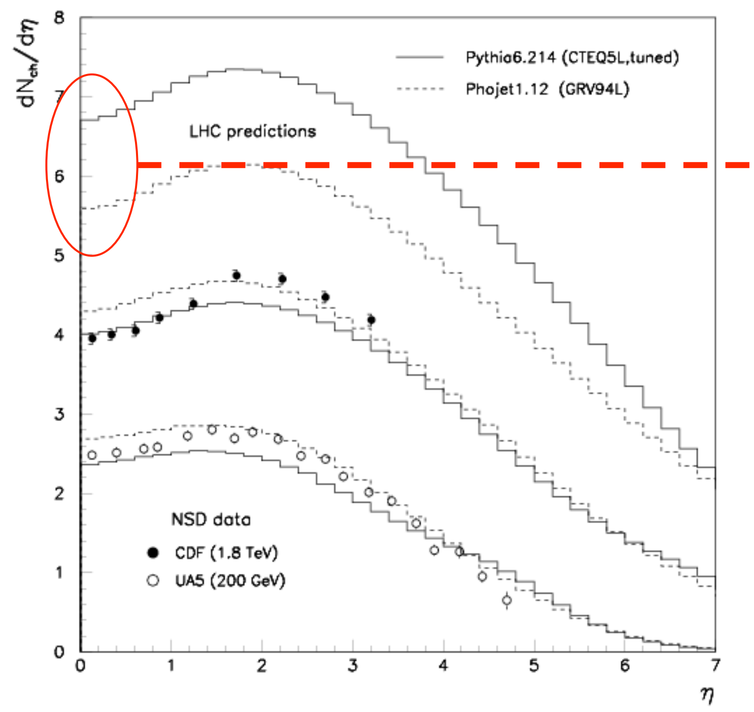
- PDFs
- Jet shape
- Underlying event
- α_s
- Diffraction
- BFKL studies
- low-x
- New physics?
- …

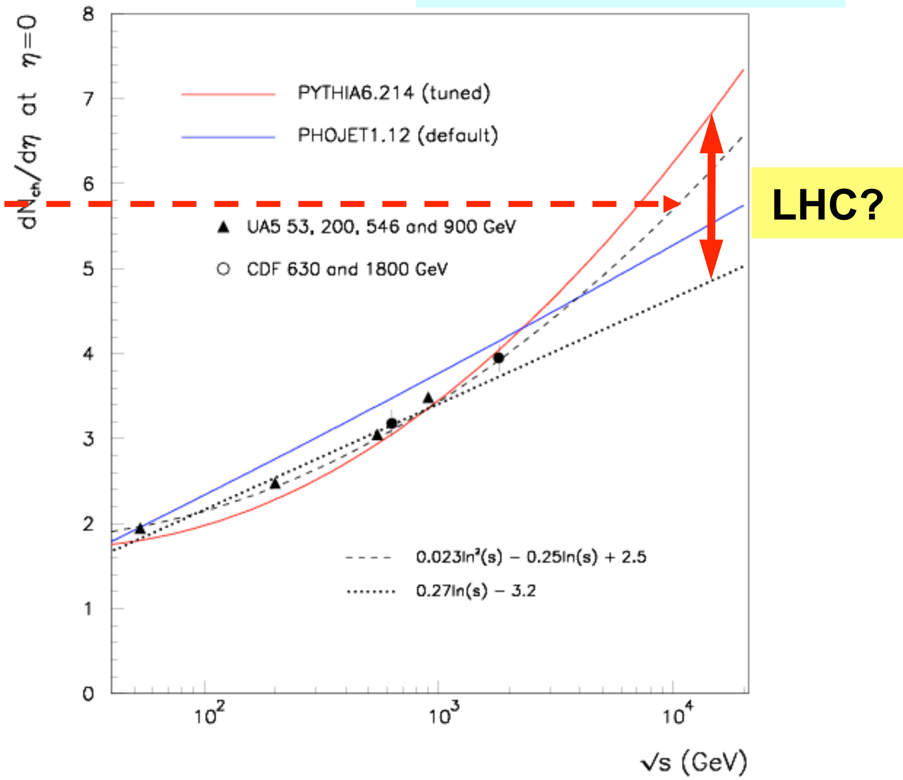
•Understanding QCD at 14 TeV will be one of the first topics at LHC

Early Minimum-Bias Measurements

Charged particle density

The pile-up for the future





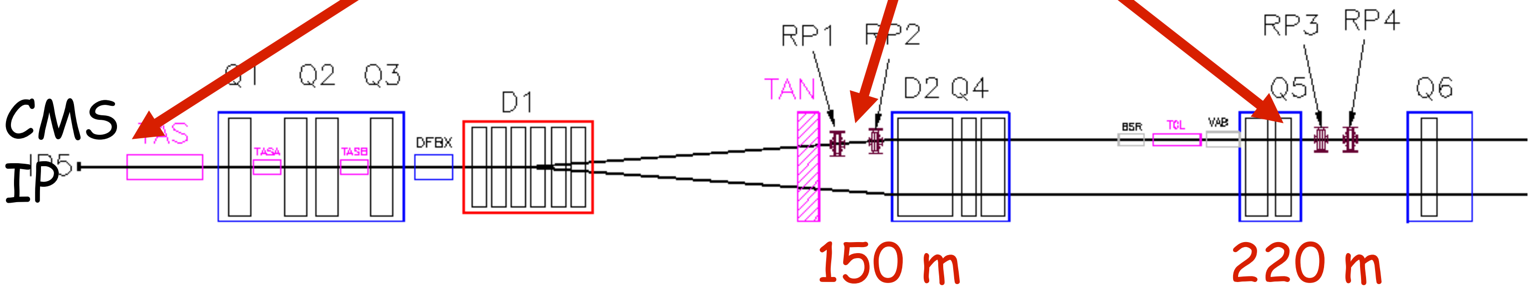
- Energy dependence of dN/dη ?
- Vital for tuning UE model (see later)
- Only requires a few thousand events.

- **PYTHIA models favour $\ln^2(s)$;**
- **PHOJET suggests a ln(s) dependence.**

Roman Pot Detectors (TOTEM)

TOTEM physics program: total pp, elastic & diffractive cross sections

Apparatus: Inelastic Detectors & Roman Pots (2 stations)

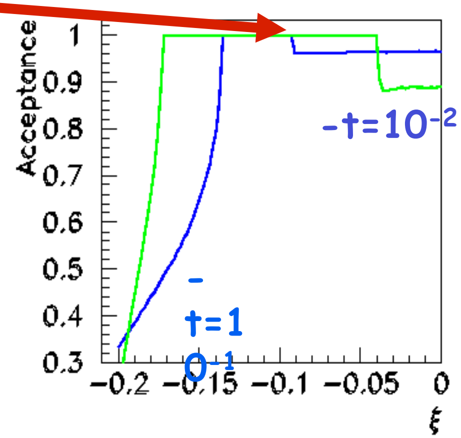


High β*(1540/other values): Low luminosity (few days or weeks)

>90% of all diffractive protons are seen in the Roman Pots.

Proton momentum measured with a resolution ~10^{-3}

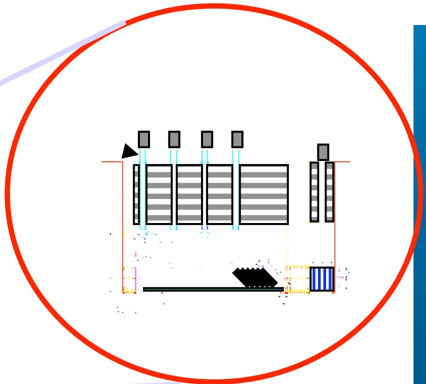
ξ = proton momentum loss



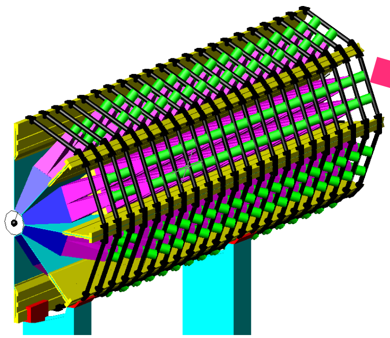
Forward Detectors in IP5: CMS/TOTEM

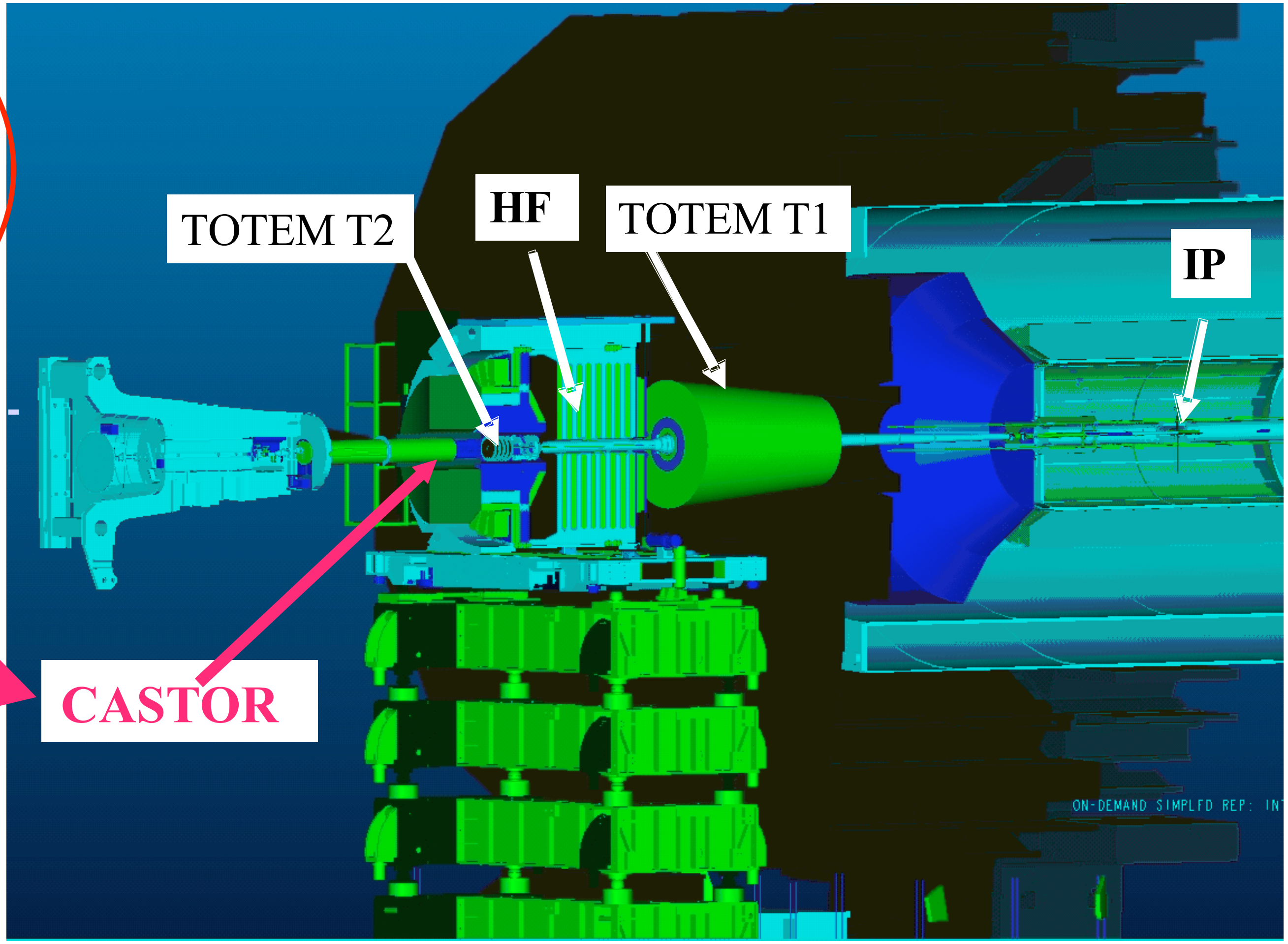
T1 3.1< η <4.7
T2 5.3<η <6.7
Castor 5.25<η <6.5

Extend the reach in η from |η|<5 to |η| <6.7
+ neutral energy at zero degrees



ZDC @ 140 m

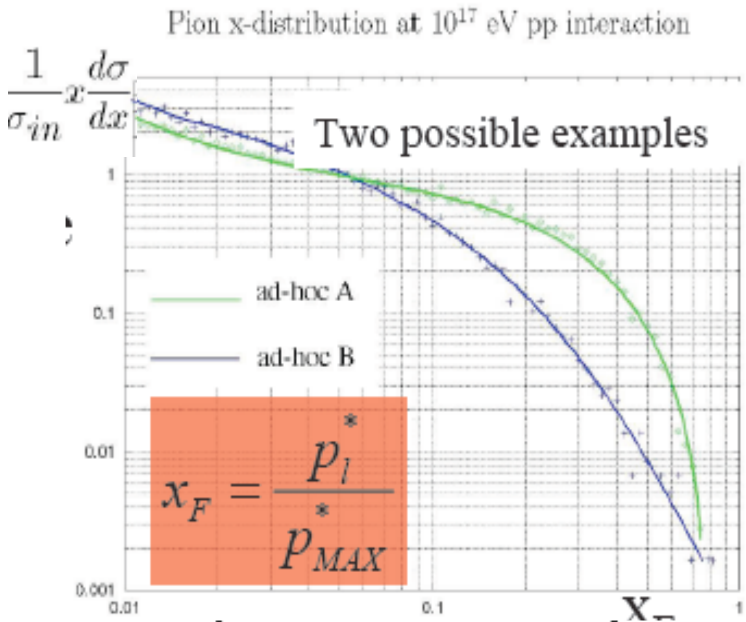


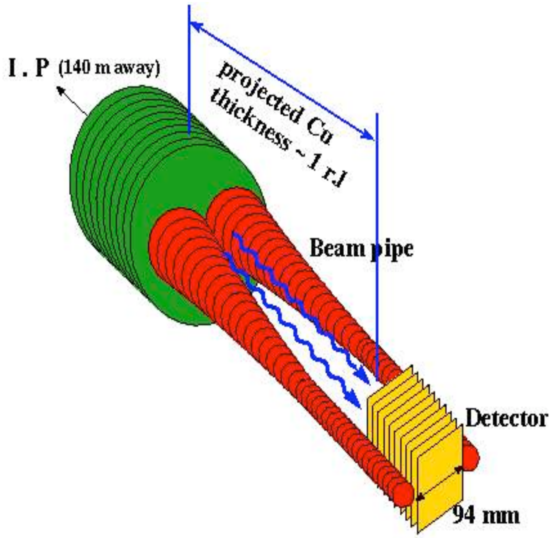


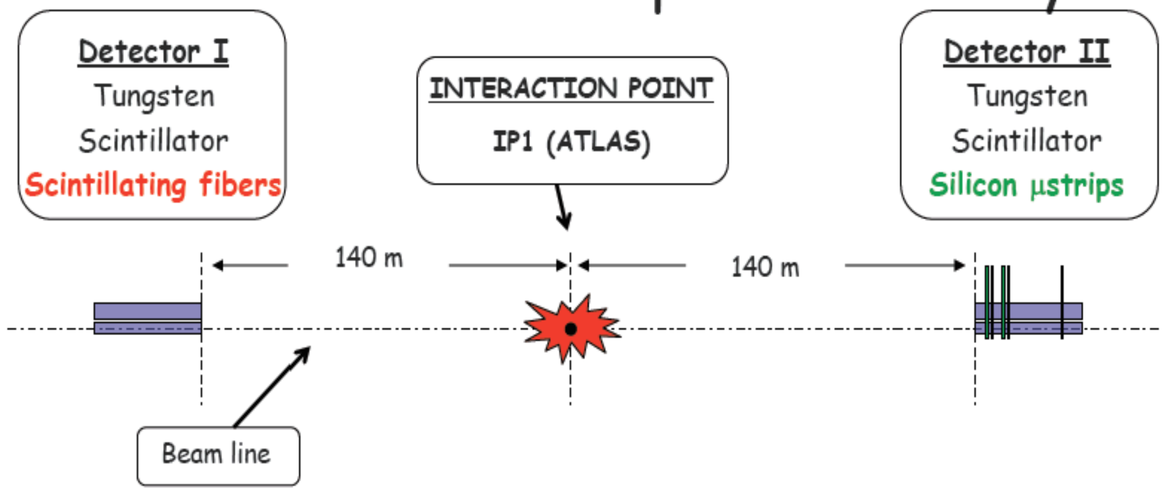
LHCf: an LHC Experiment for Astroparticle Physics

LHCf: measurement of photons and neutral pions and neutrons in the very forward region of LHC

Add an EM calorimeter at 140 m from the Interaction Point (IP1 ATLAS)
For low luminosity running

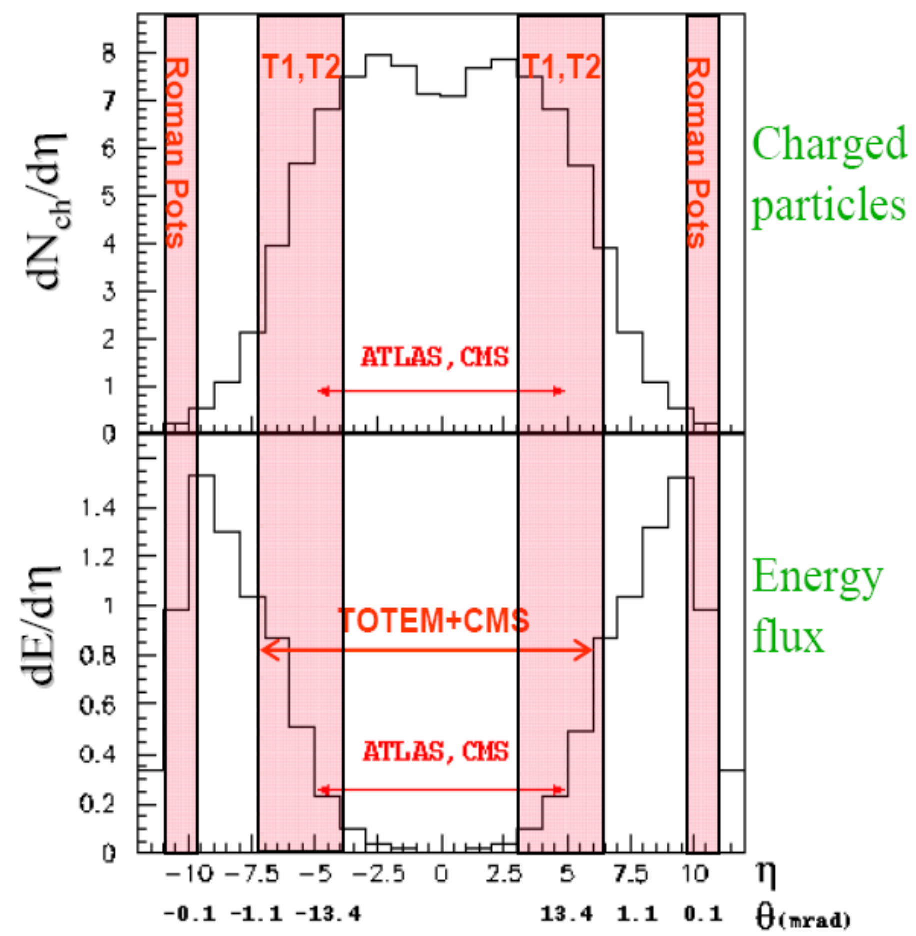


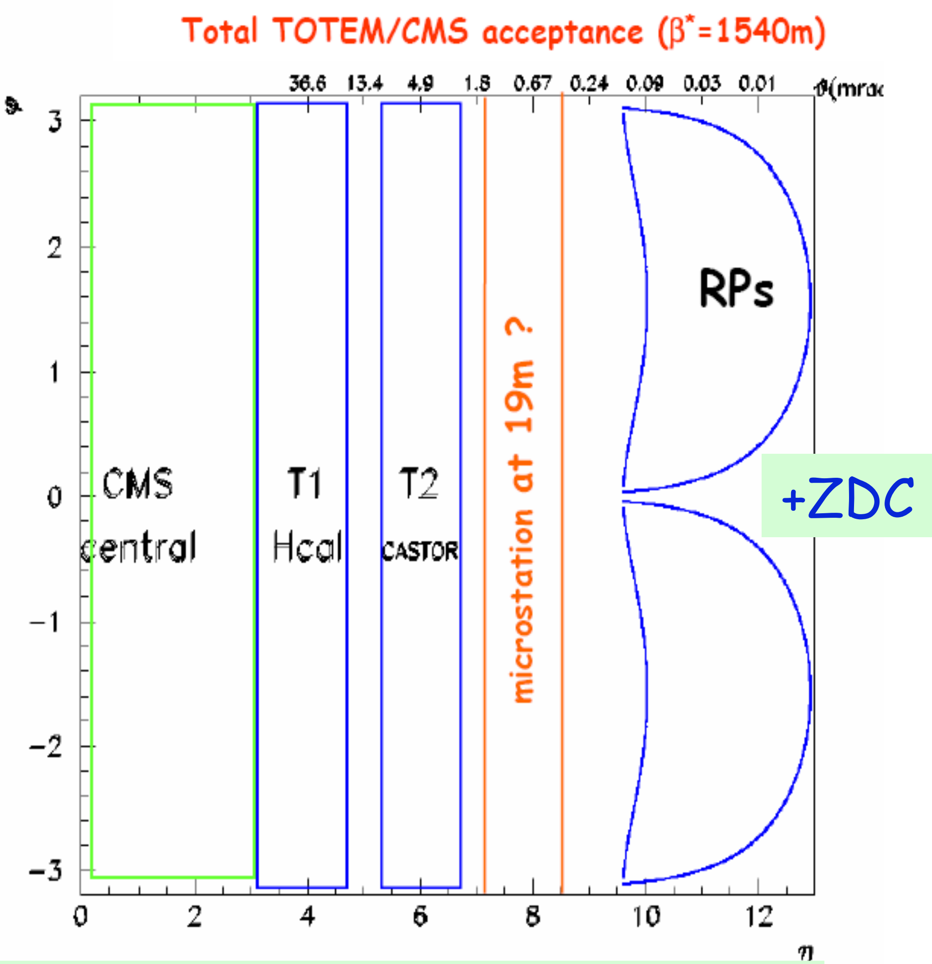




CMS/TOTEM: a "complete" LHC detector

CMS/TOTEM will be the largest acceptance detector ever built at a hadron collider





K. Eggert

Still studying other regions (19m, 25m, 50m…)

Conclusions

LHC will start “soon” (after 20 years of preparation) testing the TeV scale.

There are large and justified excitation and expectation. If it will prove that the hierarchy problem is solved by new physics, this new physics may have large impact on cosmology.

The most studied case is that of SuperSymmetry, but the LHC detectors are ready to observe a large set of new phenomena.

It is possible that soon we will produce at CERN the same Dark Matter that populates our Universe.

Thanks: A. de Roeck, F. Gianotti, P. Janot, M. Spiropulu