Search for SUSY at the LHC with the Razor

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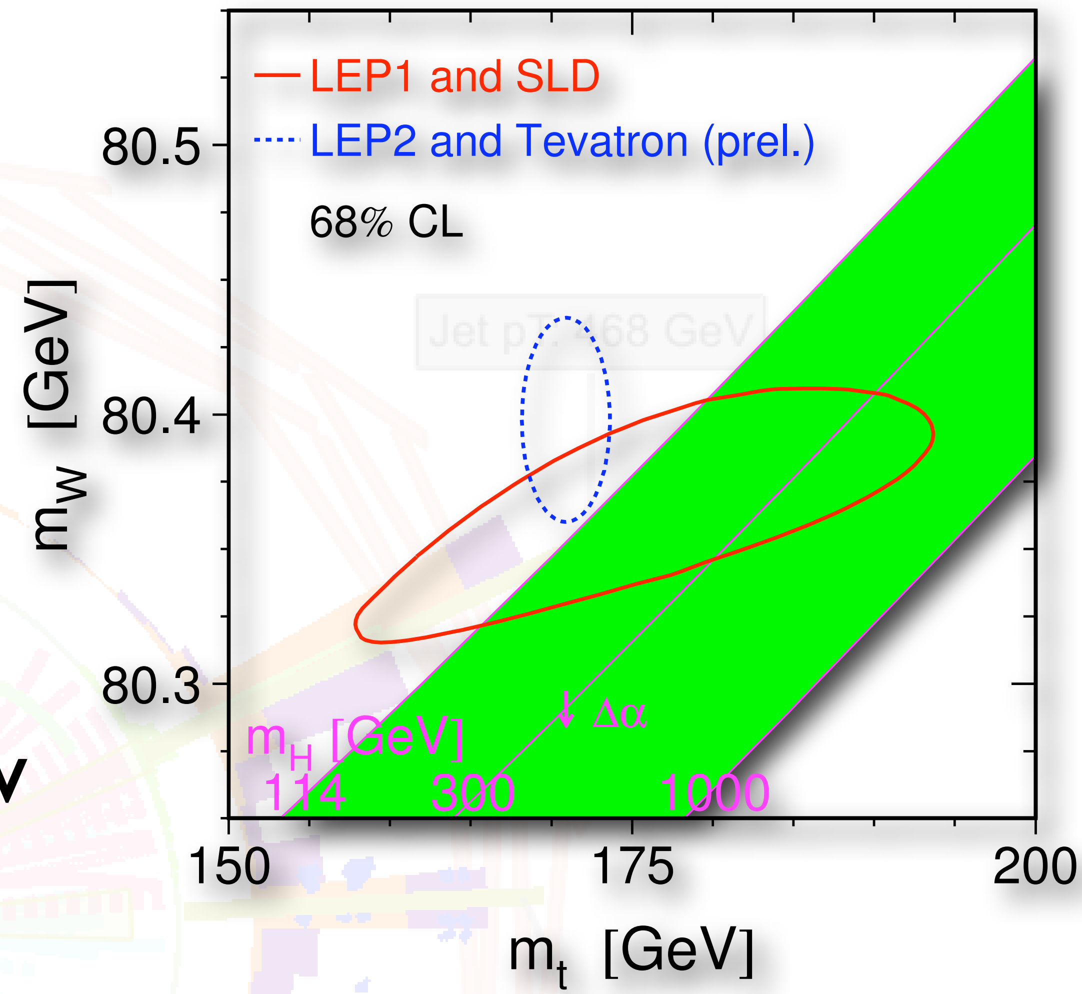
This Is An Interesting Time

- The LHC is taking data at 8 TeV. 14 TeV collisions are in our lifetime
- Neutrino Physics gives us something new every few years
- We have perspectives to explore the high-intensity frontier with a new generation of meson factories
- Plank is up in the sky, mapping the universe. And it is not alone up there (Fermi, AMS)
- A puzzling picture is emerging from DM detection underground

But Why are We Doing All This?

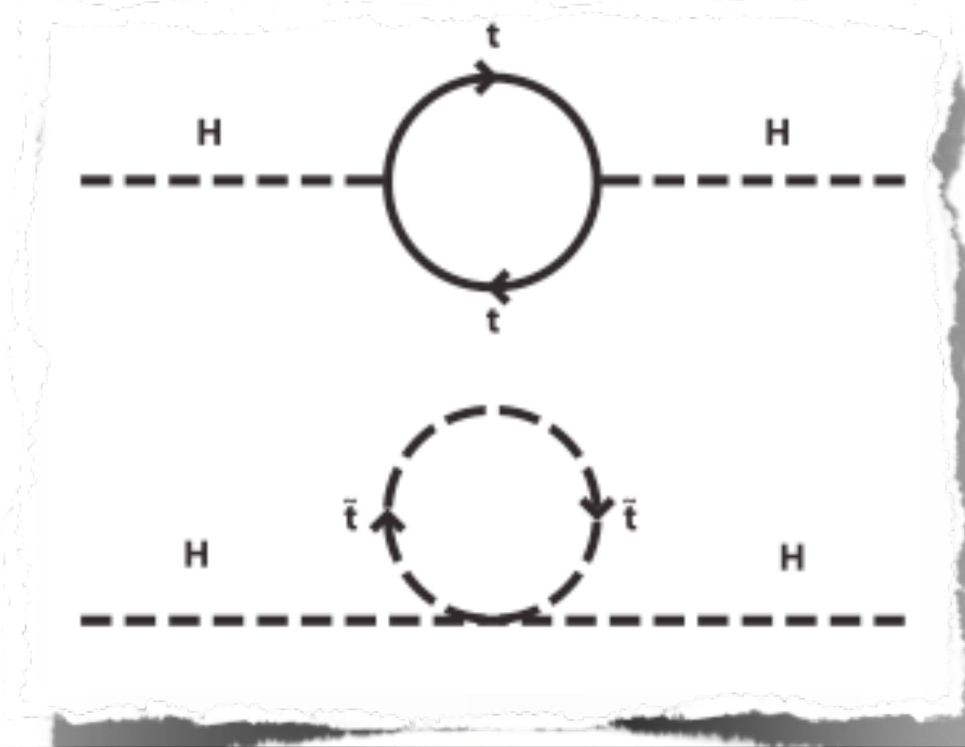
- The Standard Model works. It works well. So why are we so desperately looking for its failure?



- As we see it, the Standard Model is a tool to describe low-energy phenomena in nature. Not the complete book of instructions on how nature works
- We cannot be happy about that. We want to know more...
- So we managed to find three main reasons why we are unhappy with the SM
- And we built the LHC based on them

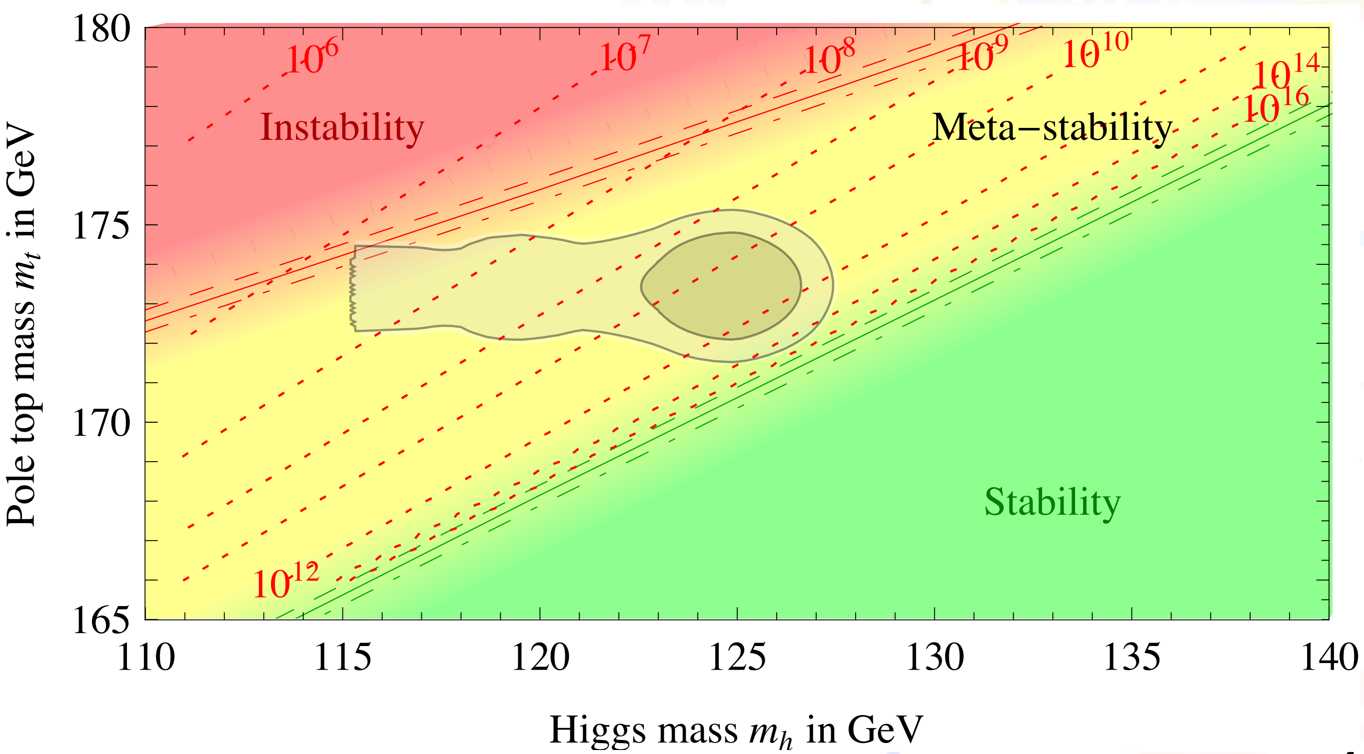
The Higgs is Too Light ...

Even assuming that nothing happens to the SM until we reach the Plank scale (gravity is the new physics there), we would expect the Higgs mass to diverge to the NP scale, because of quadratic divergences. We usually invoke Supersymmetry to cancel these divergences



But is the Higgs really too light?

arXiv:1112.3022v1



"For a Higgs mass in the range 124–126 GeV, and for the current central values of the top mass and strong coupling constant, the Higgs potential develops an instability around 10^{11} GeV, with a lifetime much longer than the age of the Universe. However, taking into account theoretical and experimental errors, stability up to the Planck scale cannot be excluded."

The Higgs is Too Light ...

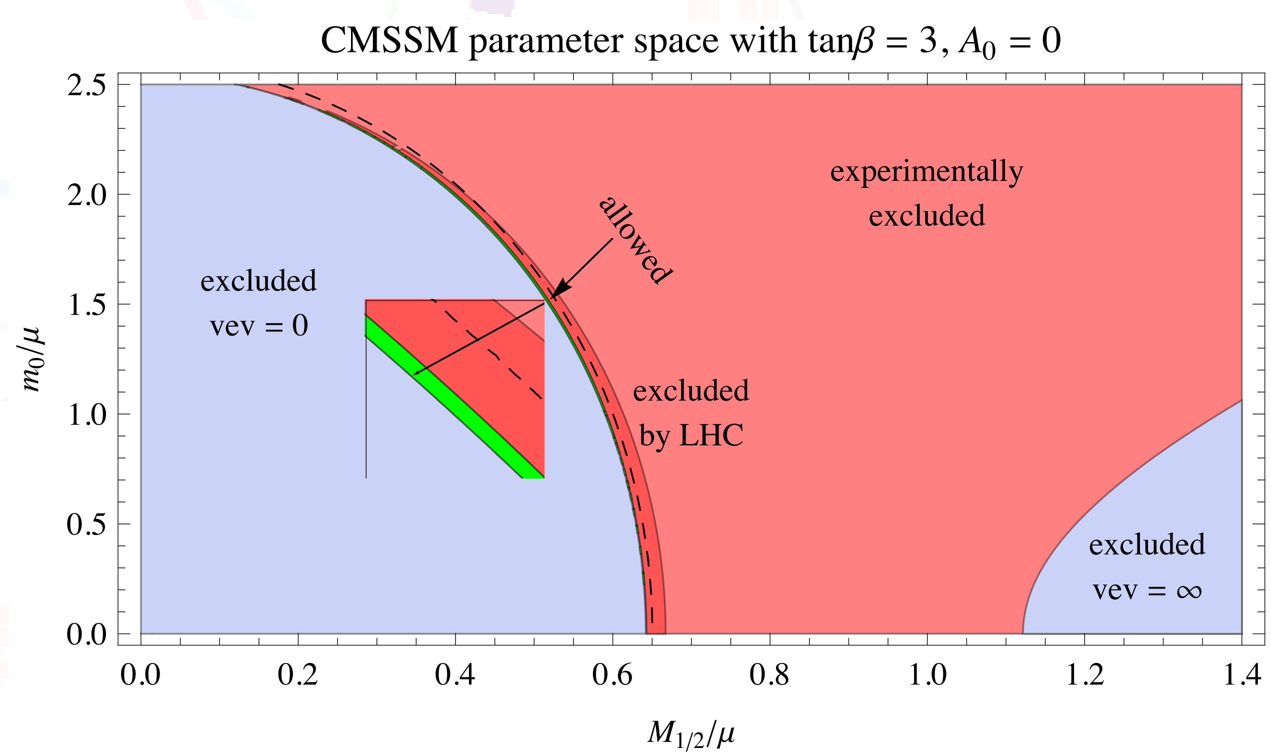
- Naturalness was a good discovery tool in the past

> - the cancellation of QED divergences gave us the positron
> - the GIM mechanism gave us the charm quark
> - ...

- Then the cosmological constant broke the good score, and we decided that we could live with this (anthropic or not)

This is a big cancellation: 1 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000

- What if eventually naturalness is just a big prejudice which is misguiding us? After all, the fine-tuning fixer (natural SUSY) is not in good shape after LEP...

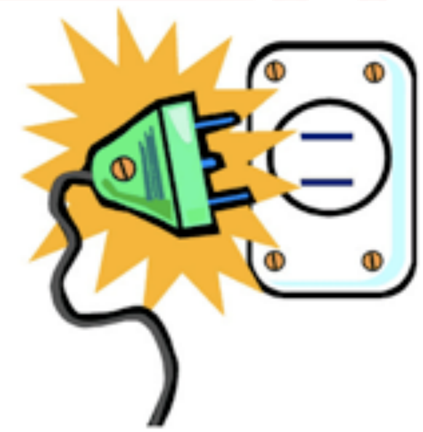


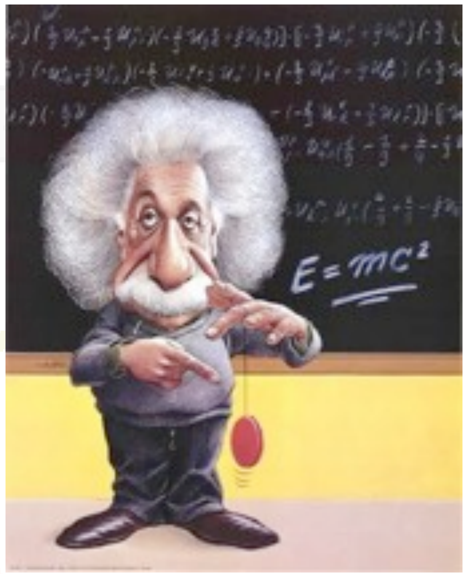
- Not sure of this is a reason... But we have others

Grand Unification

Big discoveries in physics have moved us from a complicate to a simplified picture, unifying different concepts under a more general point of view

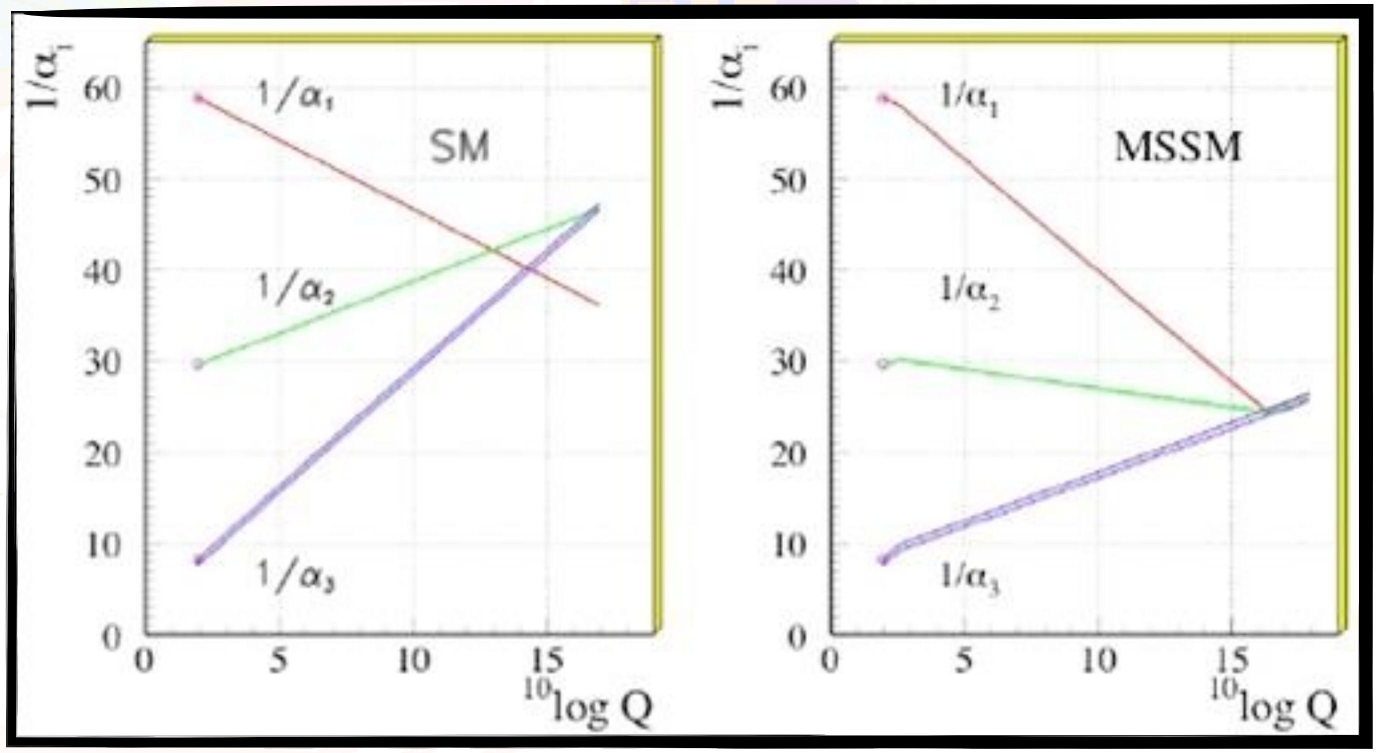
- electricity and magnetism
- space and time
- waves and particles
- bosons and fermions (... maybe...)





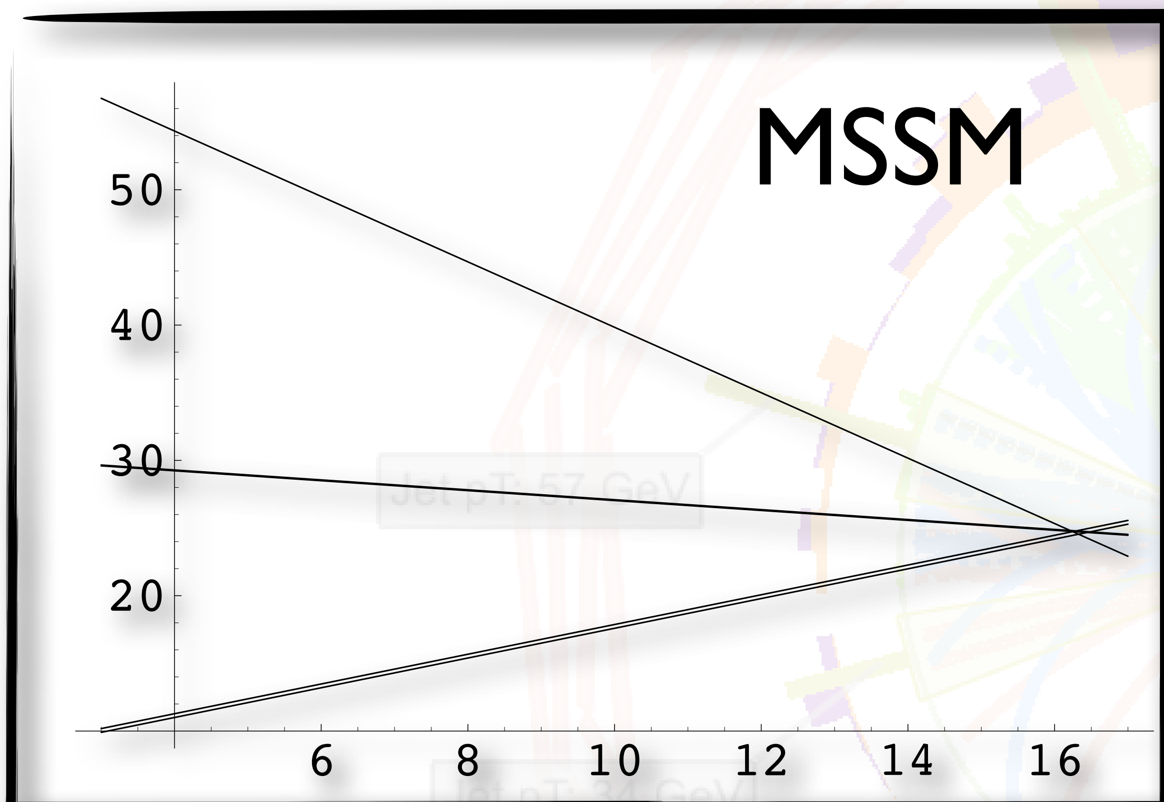
We know that the three forces we have don't unify to one.

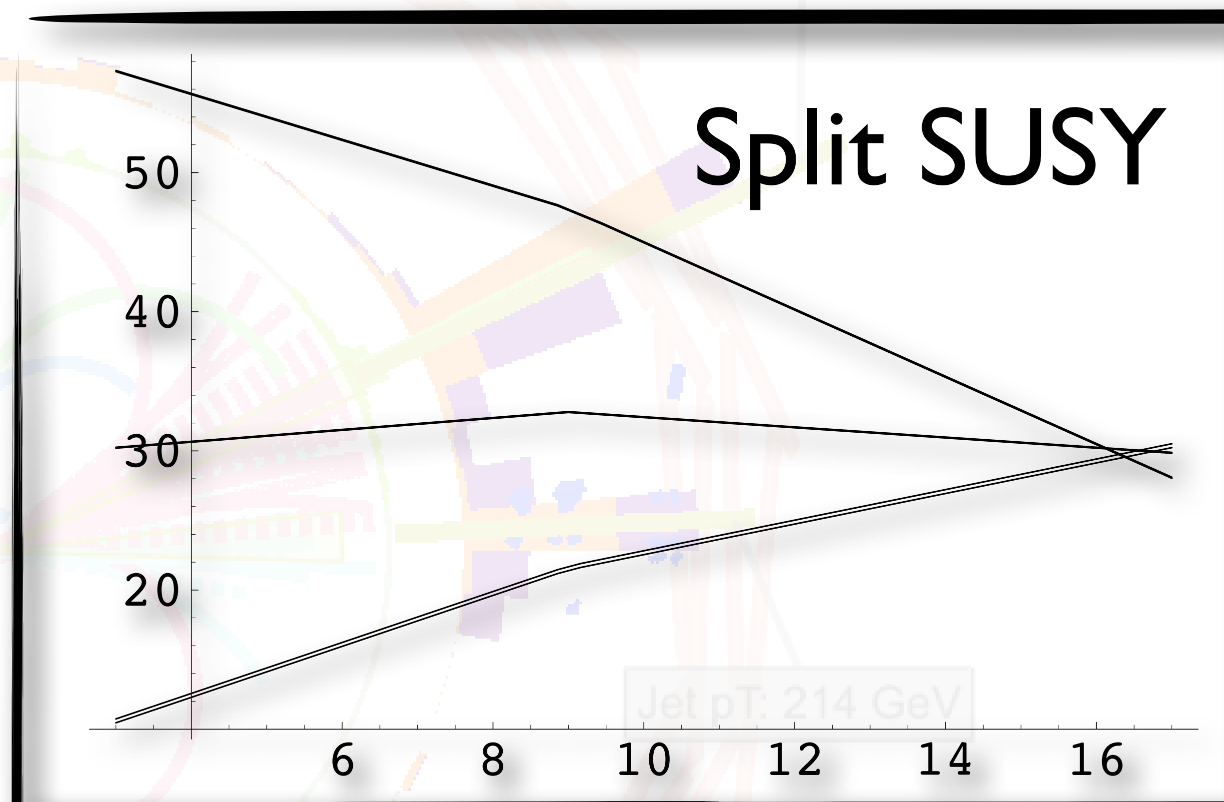
We know they do adding extra ingredients, as in SUSY



Grand Unification

Unification is not an exclusive feature of SUSY, and not all the SUSY spectrum is needed for the unification. Just keeping the gauginos (split SUSY) unification happens as in MSSM

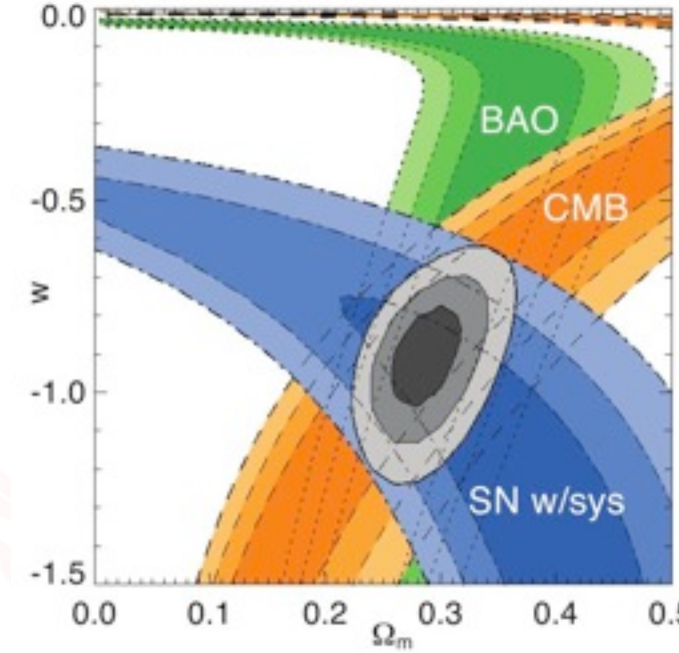


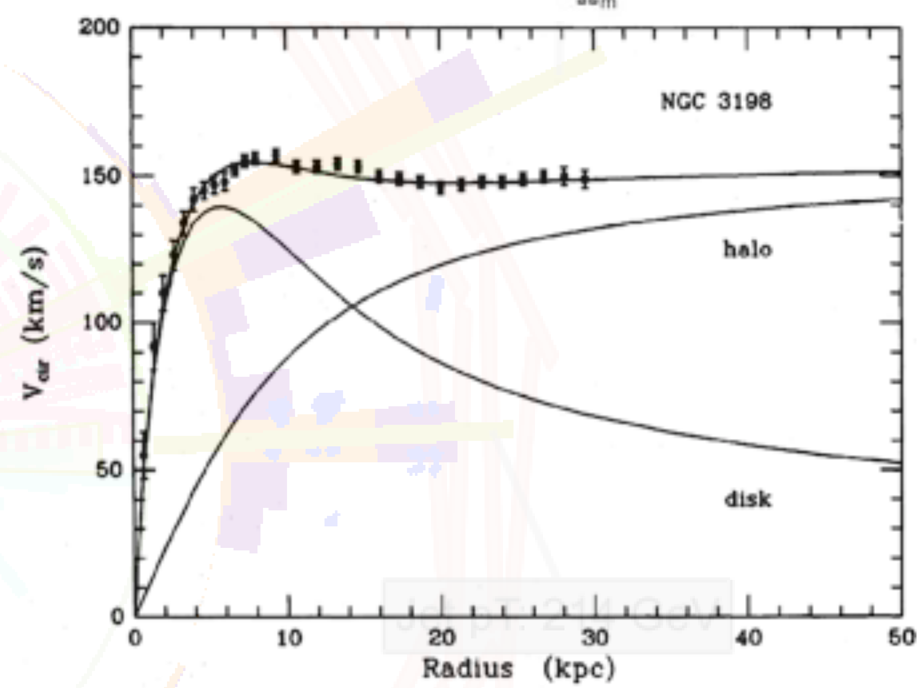


We can say that Unification is a theoretical prejudice too
But it is a prejudice with a better score than naturalness so far
And, in any case, it works even if one gives up with naturalness

Dark Matter

Cosmology most popular picture predicts much more matter than what we can see
This confirms what observed in rotation curves





The dynamic of the bullet-cluster collision suggest that DM is indeed due to particles

The DM abundance points to an EW-like cross section (the WIMP "miracle")

This is a more solid reason to expect a breaking of the SM, since it is supported by observations...

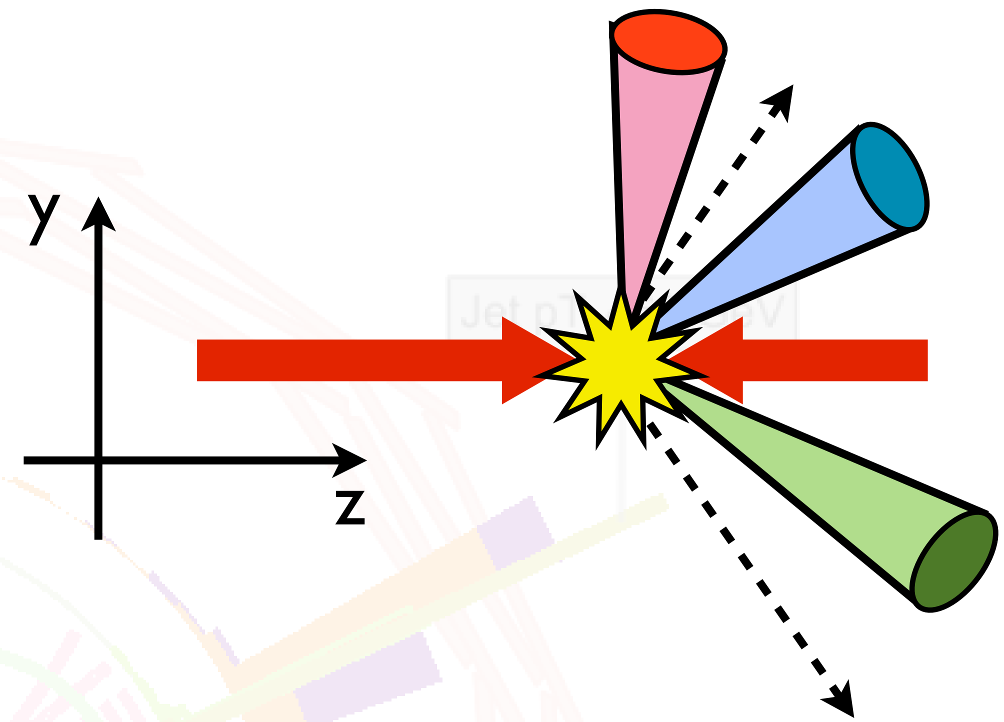
So DM is what we are looking for @LHC

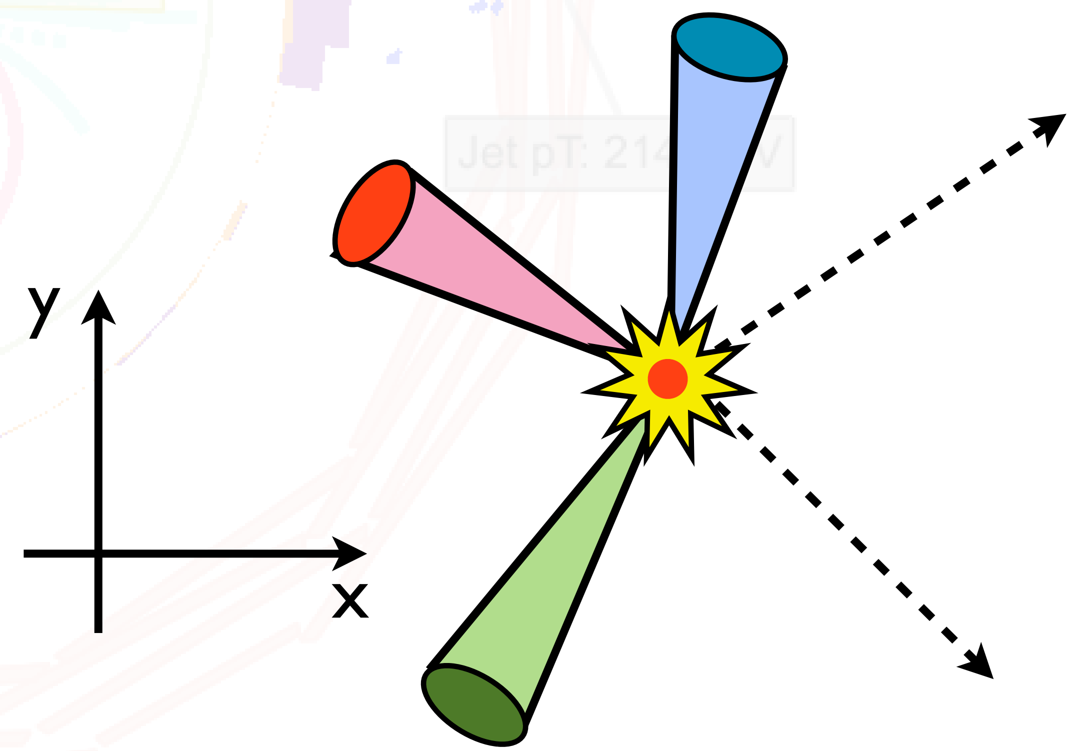
DM Production in Cascade@LHC

- If the DM particle is the lightest of a new set of particles with a conserved quantum number (e.g. SUSY with R-parity) we could observe a pair of DM particles produced in the cascade of heavier particles (e.g. squarks and gluinos)

- In this case the cascade produces the object to trigger on (jets, leptons, photons, etc)

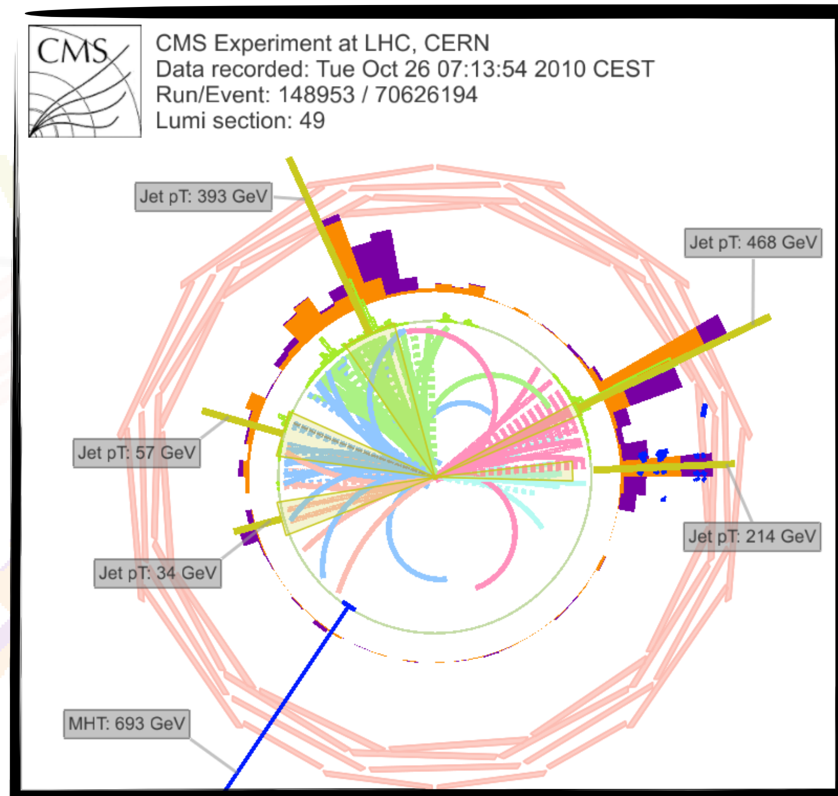
- The unbalancing on the transverse plane allows to access the events through missing energy



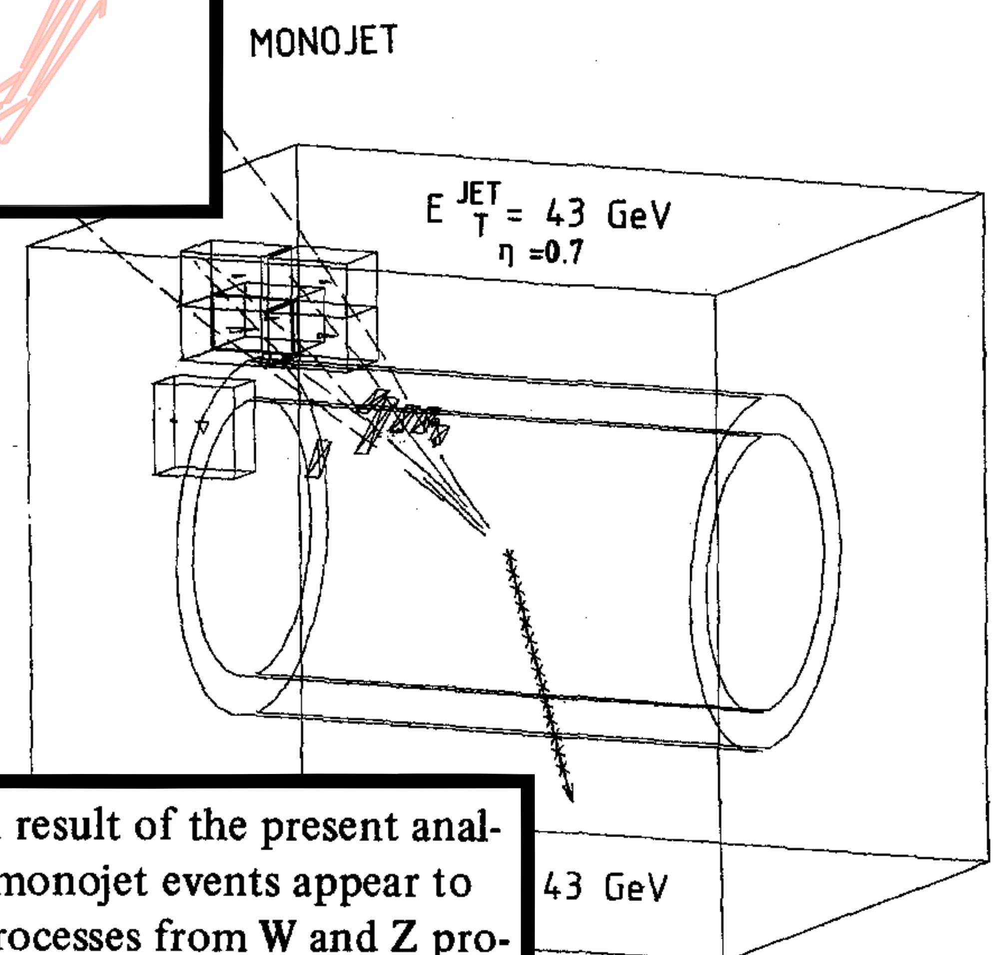


Looking for DM at Collider

- We are already seeing events like this. Not so many, unfortunately



- This is how SUSY was discovered already once (but then someone came out with a background prediction ...)



- We know more than that: we have two heavy neutrinos. And we should use this fact....

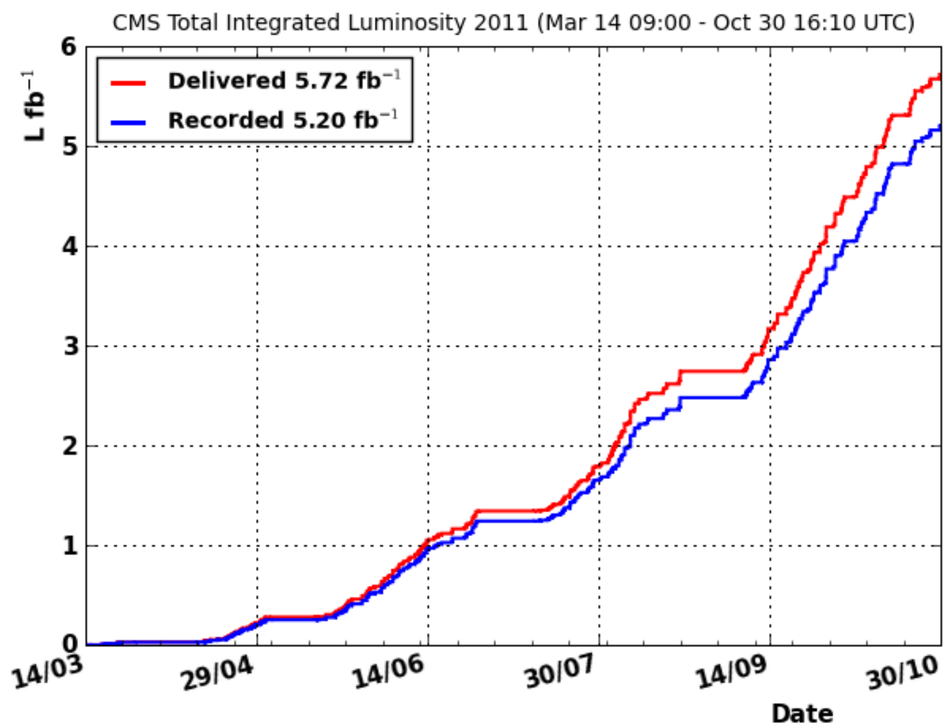
5. Discussion. The main result of the present analysis is that the UA1 1984 monojet events appear to be well described by SM processes from W and Z production and decay. Our calculation is based on a perturbative analysis of W, Z + 0, 1, 2 jet production.

What Do We Need?

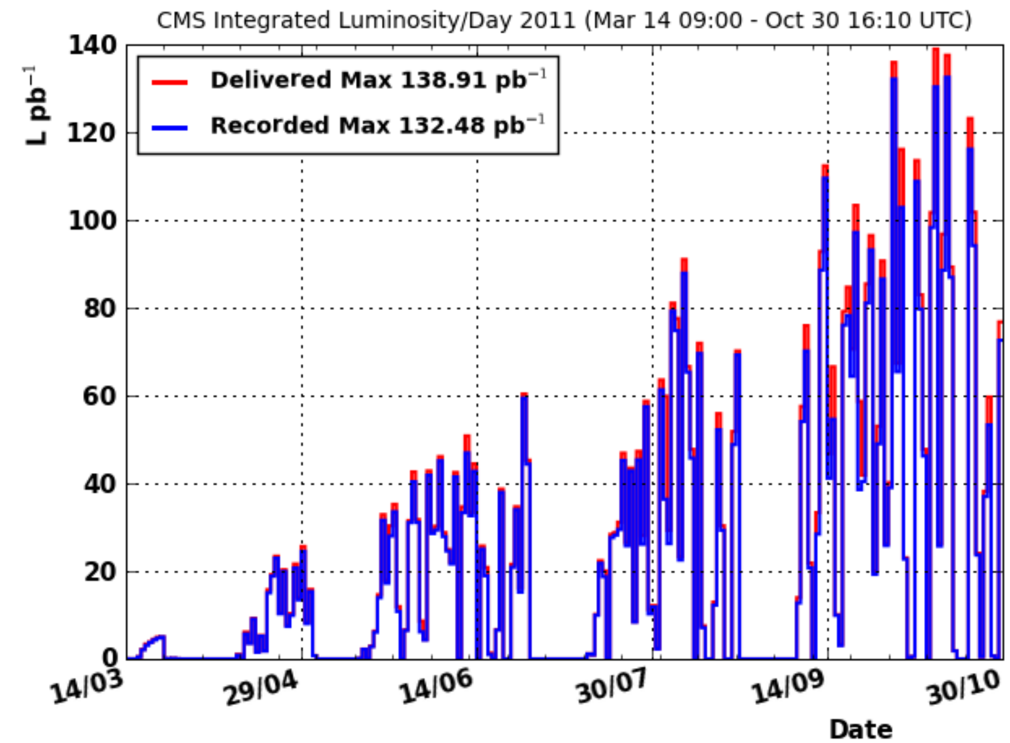
- A high-energy collider, to produce the heavy particles that decay to DM
- A hermetic detector (or two, even better), to be sure that the observed missing energy is really missing
- An event selection that allows to keep the SM backgrounds under control
- A set of kinematic variables that exploit as much as possible the specific signature we are after

The LHC

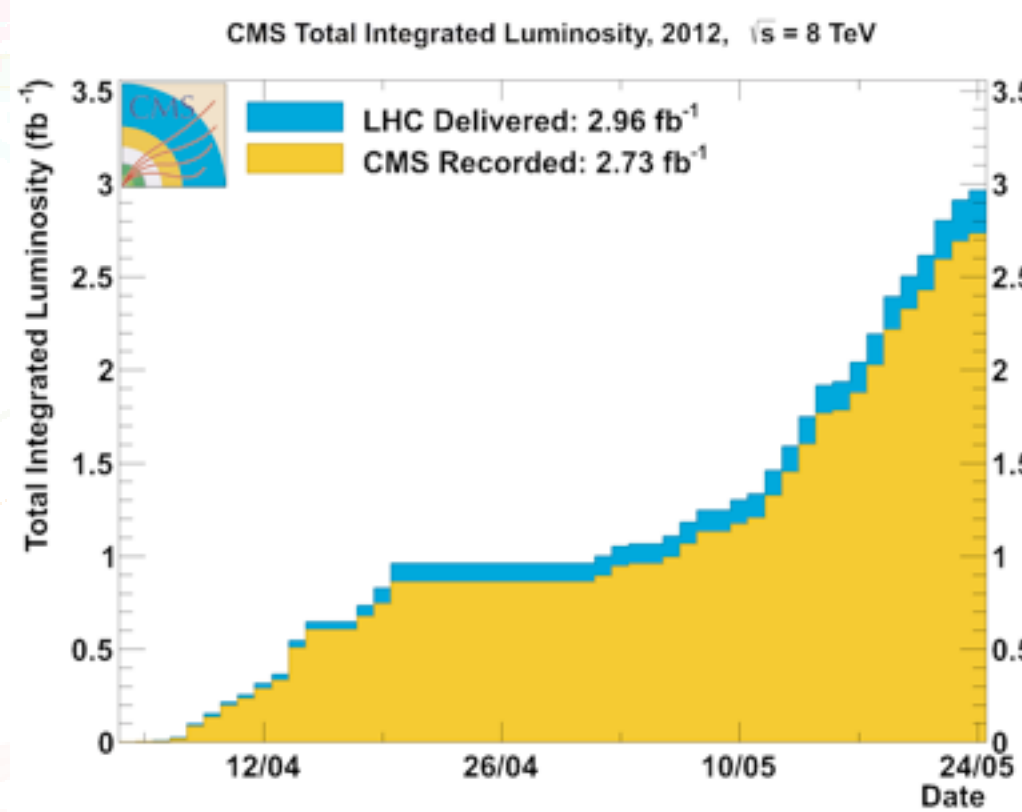
Total integrated luminosity



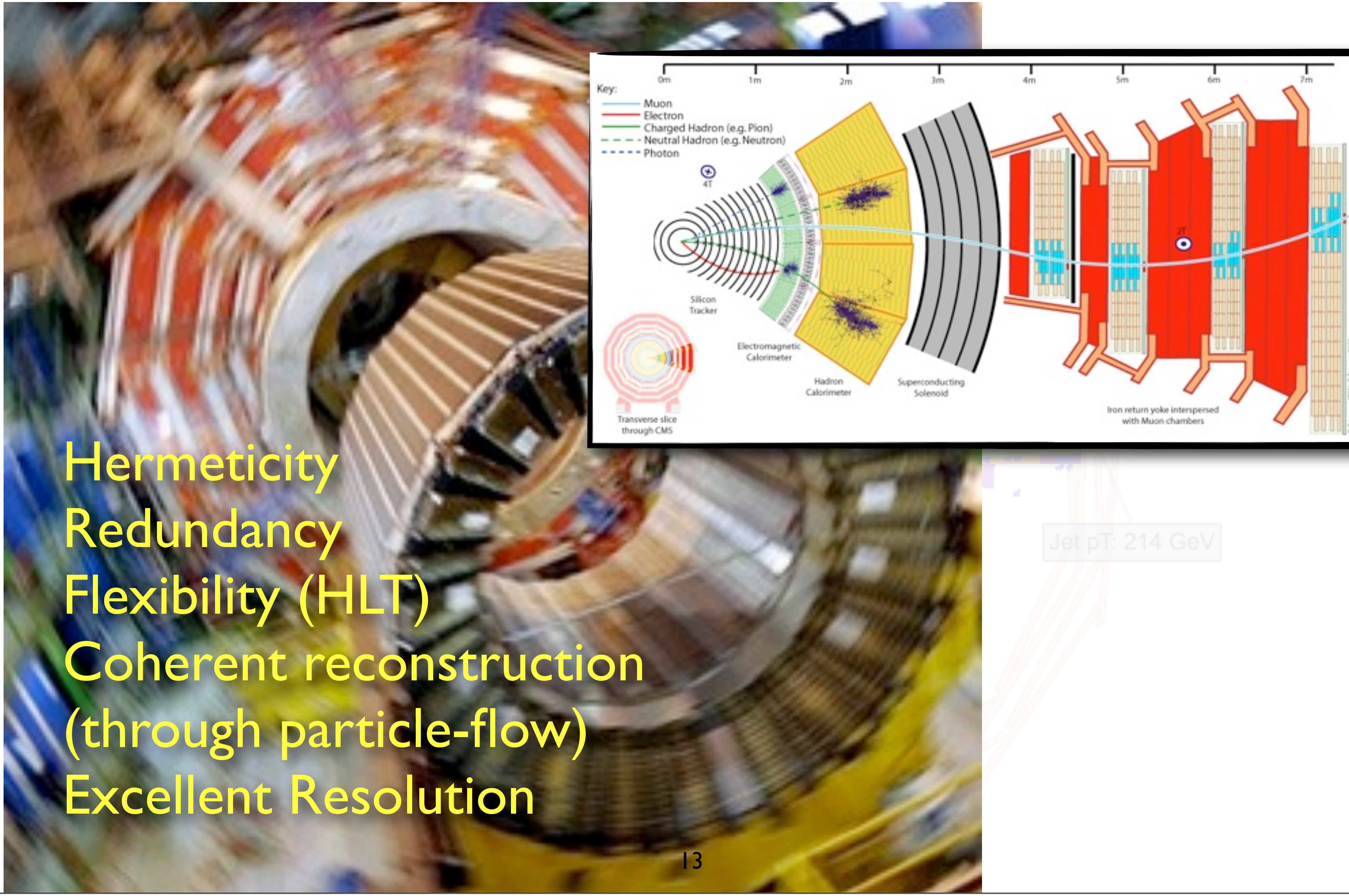
Integrated luminosity/day



LHC running close to design condition for beam intensity. Integrated 5 fb^{-1} @ 7 TeV in one year.
Expected three times more for 2012, at 8 TeV
Detectors 90% efficient (remarkable for a hadron collider, remarkable for so big detectors)
Operation has been more successful than what one could have imagined
With this luminosity we can potentially exclude processes with cross sections O(1-10 fb). And we are indeed getting there...

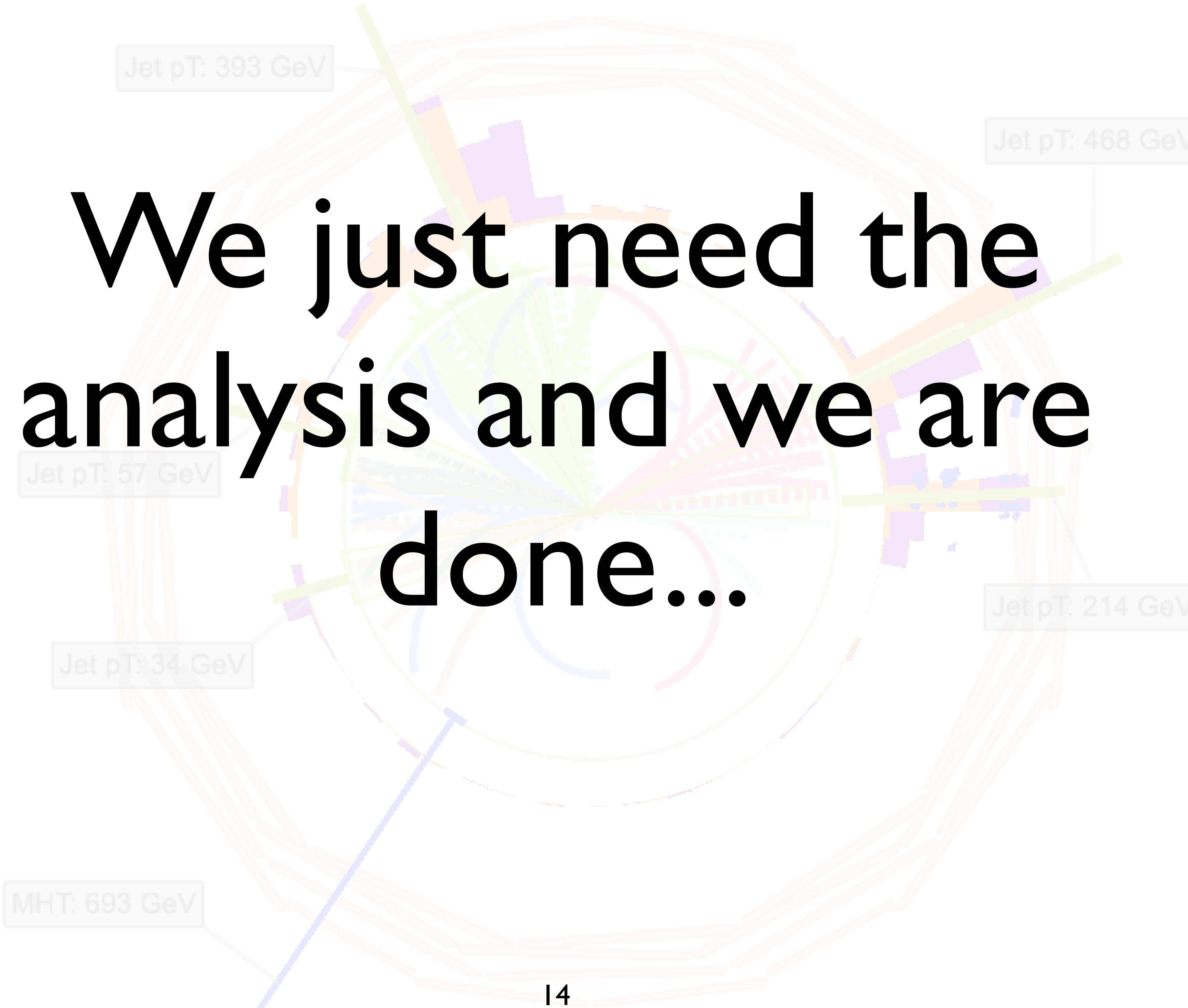


CMS

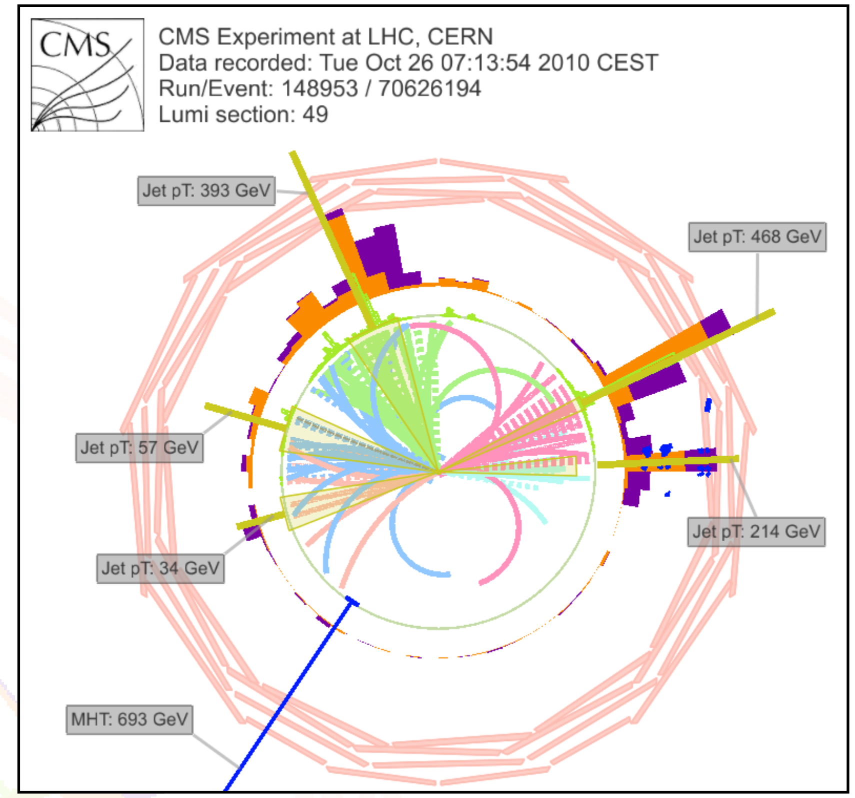


Hermeticity
Redundancy
Flexibility (HLT)
Coherent reconstruction (through particle-flow)
Excellent Resolution

We just need the analysis and we are done...



A “classic” SUSY search

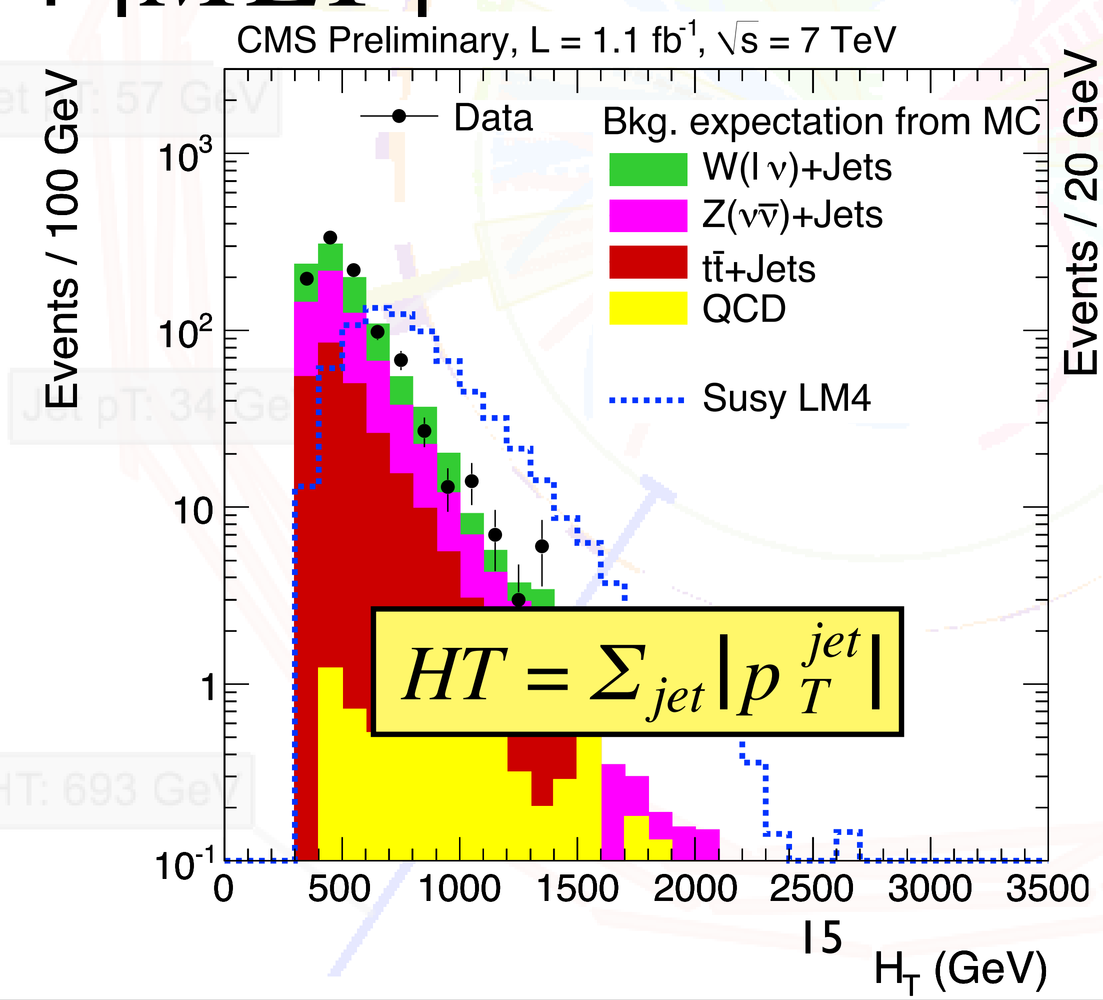


<u>The typical signature</u>: a lot of energy seen in the detector, recoiling against a lot of MET

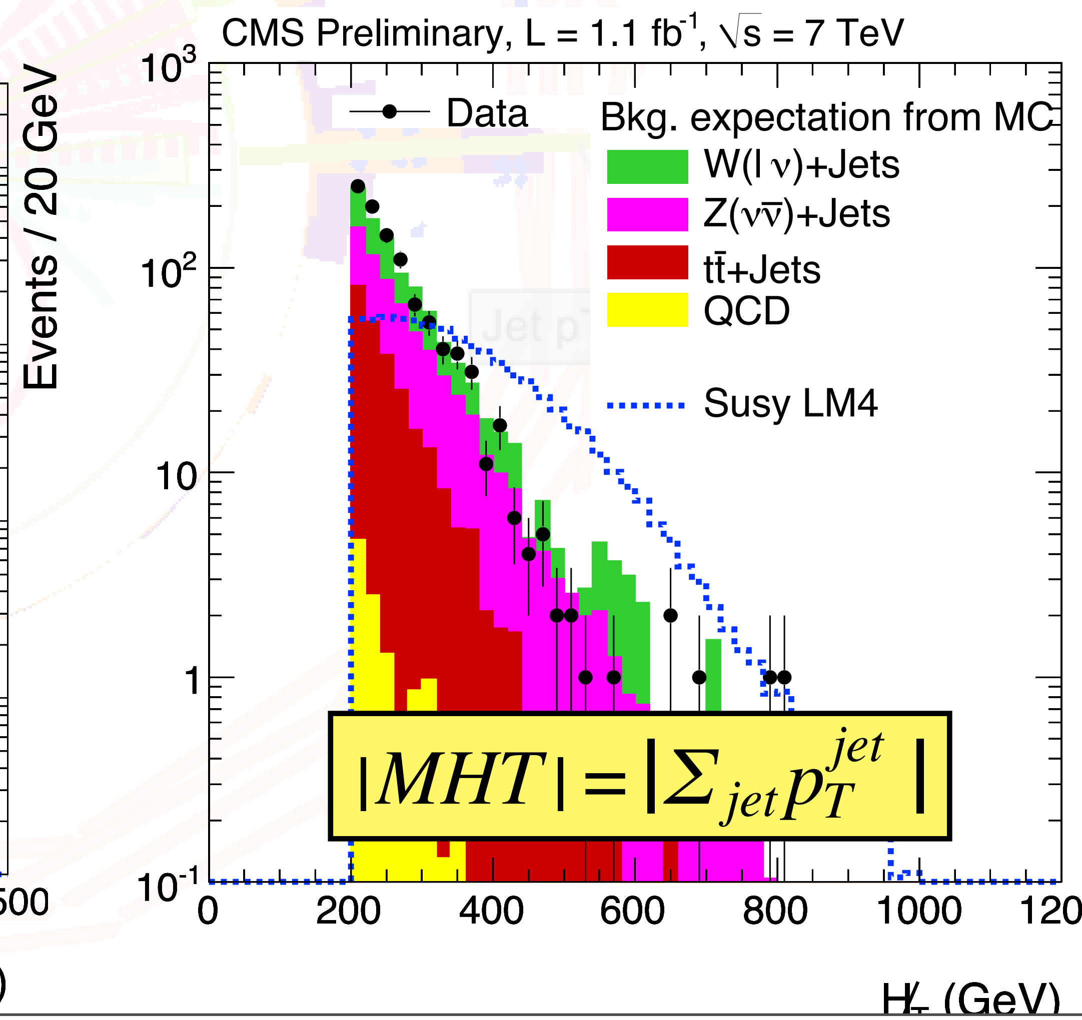
<u>Several variables to quantify this behavior:</u>

$$|MET| = |\Sigma_{cell} E_T^{cell}|$$

$$m_{eff} = HT + |MET|$$

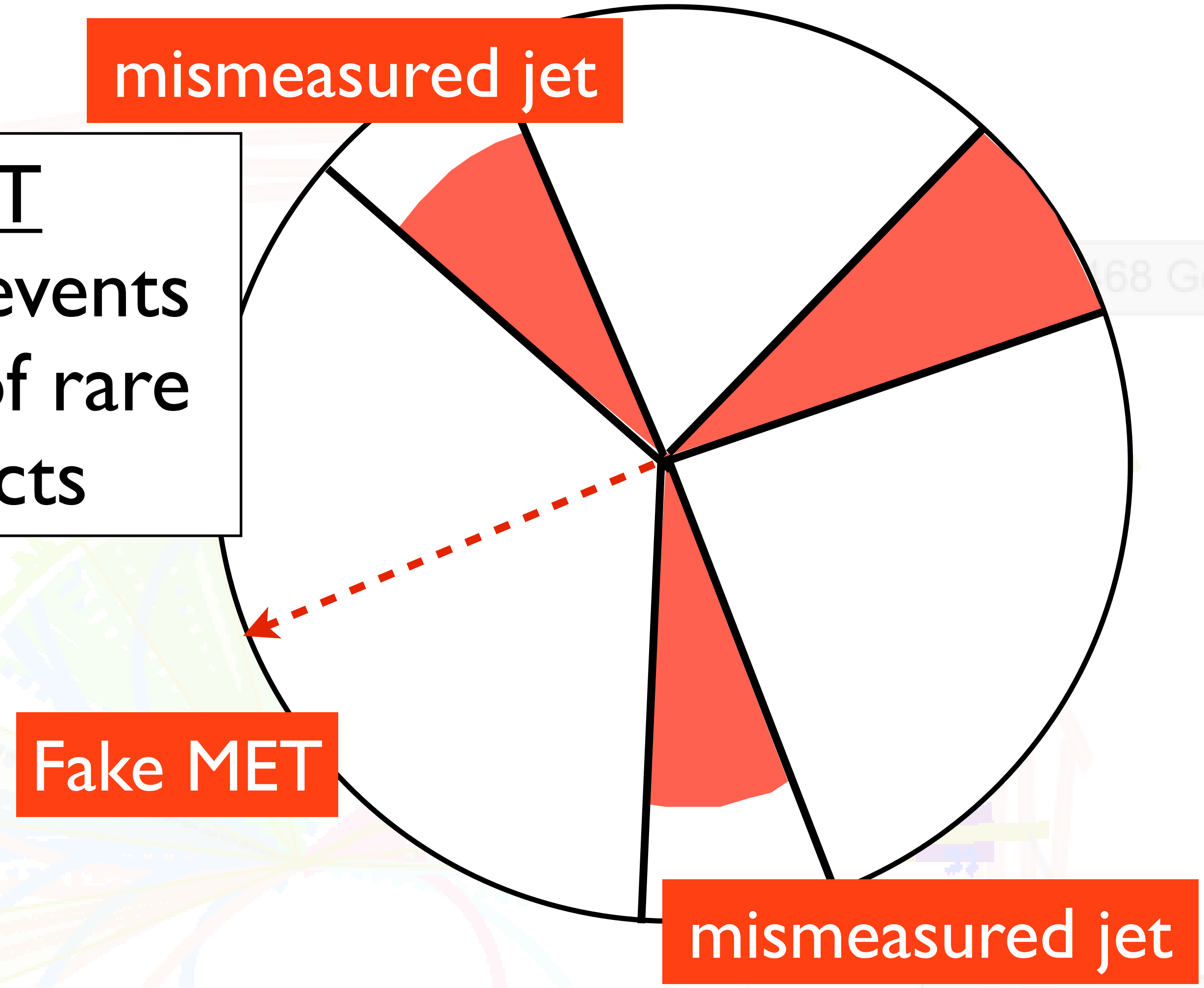


$$HT = \Sigma_{jet} |p_T^{jet}|$$

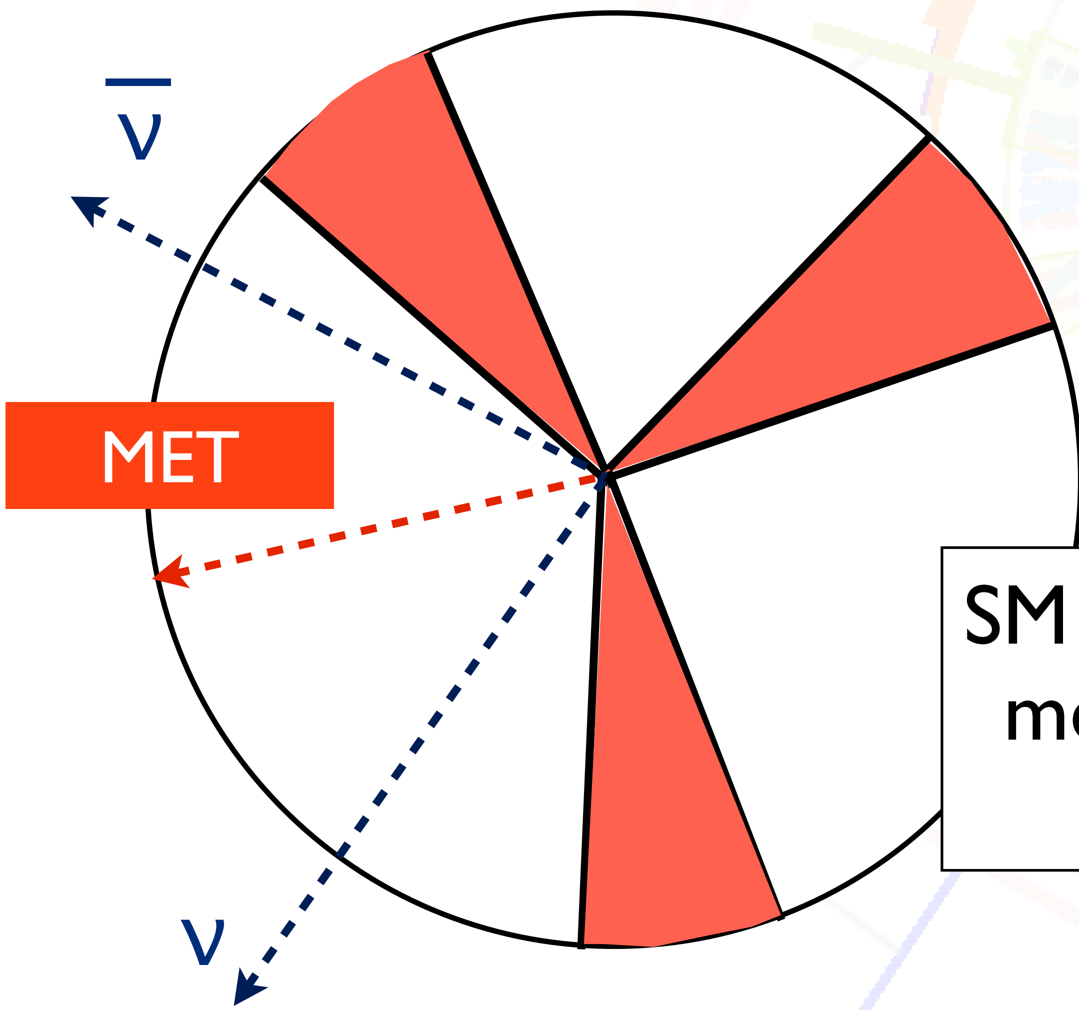


$$|MHT| = |\Sigma_{jet} p_T^{jet}|$$

Bkg To Fight



QCD with fake MET
related to pathological events require understanding of rare detector-related effects



SM processes with real MET, e.g. $Z(\nu\nu)$+jets measurable from control samples defined on data

QCD prediction

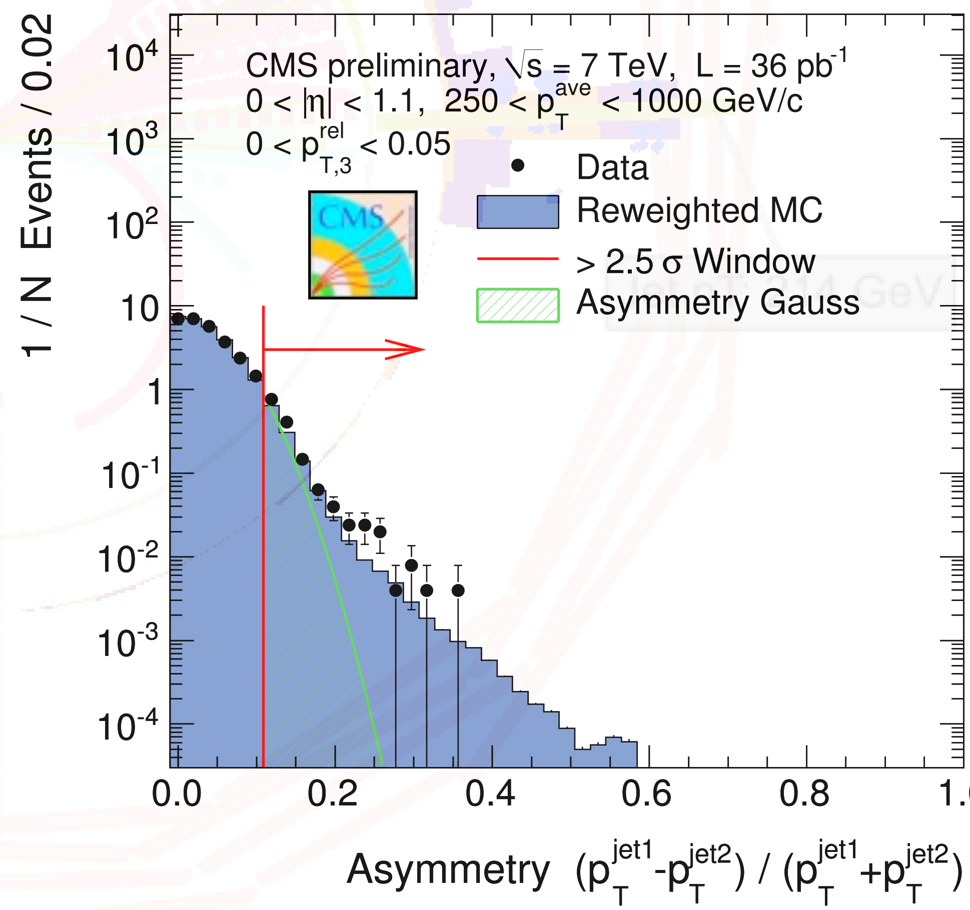
Background prediction:

QCD	Re-balance and smear
$W(\ell\nu) + \text{jets},\ t\bar{t}$	Use μ control sample
$Z(\nu\nu) + \text{jets}$	Use γ+jets and Z(μ μ)+jets control samples

Search for high p_T jets, high HT and high MHT

QCD multi-jet events do not intrinsically populate the phase-space defined by our requirements on scale and angle -- BUT, mis-measurements of jets can result in large measured MHT

QCD multi-jet background predicted by 'smearing' balanced (no MHT) events with measured resolution functions



QCD Killing

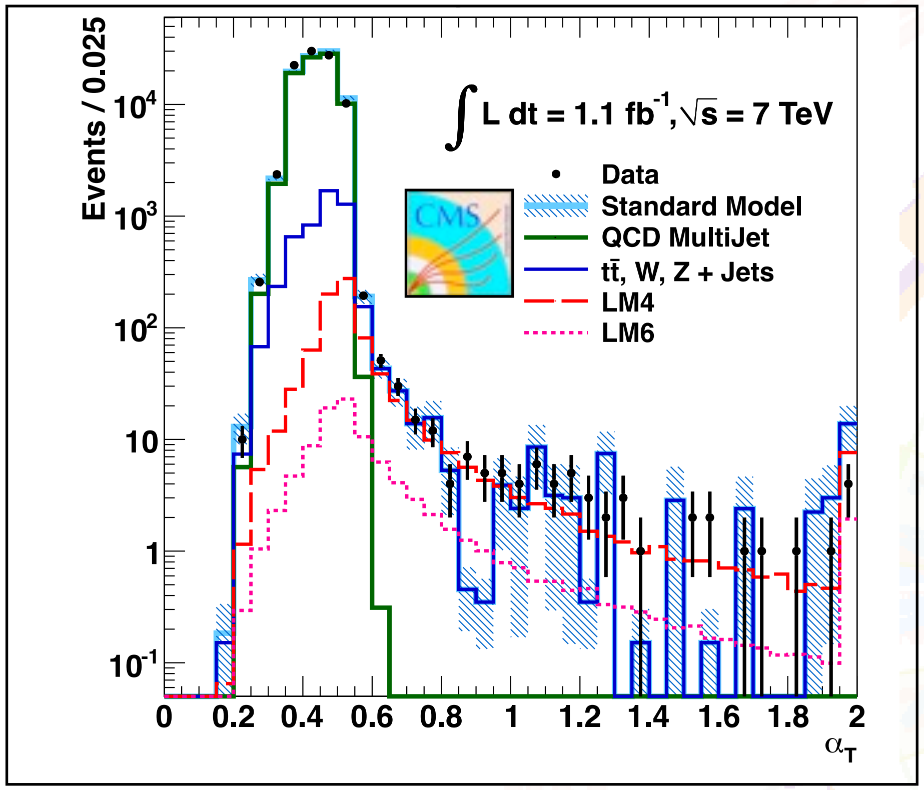
- Predicting the QCD bkg is the more problematic task of a "classic" analysis
- New approaches proposed to reduce the QCD to negligible level and deal with the residual SM background through data-driven control samples
- Different layers of extra assumptions give different signal vs. background separation
- So far, we did not use anywhere the assumption that the MET originates from two missing particles. This is the key to get something more out of our data

α_T: Killing QCD

$$\alpha \equiv \frac{p_{T2}}{m_{jj}}.$$

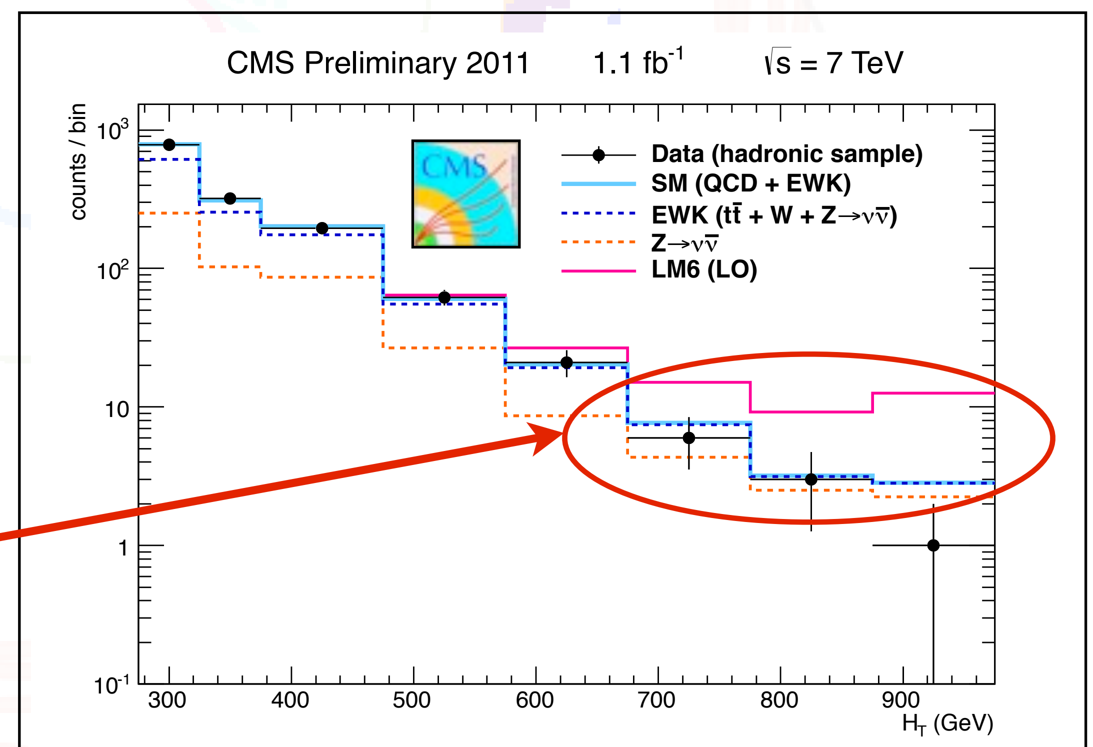
$$\alpha_T = \frac{E_T^{\text{jet}_2}}{M_T} = \frac{E_T^{\text{jet}_2}}{\sqrt{\left(\sum_{i=1}^{2} E_T^{\text{jet}_i}\right)^2 - \left(\sum_{i=1}^{2} p_x^{\text{jet}_i}\right)^2 - \left(\sum_{i=1}^{2} p_y^{\text{jet}_i}\right)^2}}$$

Randall & Tucker-Smith



- αT = 0.5 for perfectly balanced dijet events
- αT<0.5 for dijet + mismeasurements
- EW main bkg after αT cut
- QCD events could leak to αT>0.5 because of detector effects (rare)
- large fraction of signal events removed (efficiency vs purity)

- After αT cut the signal looks similar to bkg in αT
- another variable needs to be used to characterize the signal
- Back to the "classic" paradigm": HT used by CMS



A Few Considerations

- The analyses are sensitivity to DM production in cascade, but the interpretation in terms of DM is not trivial (highly model dependent)

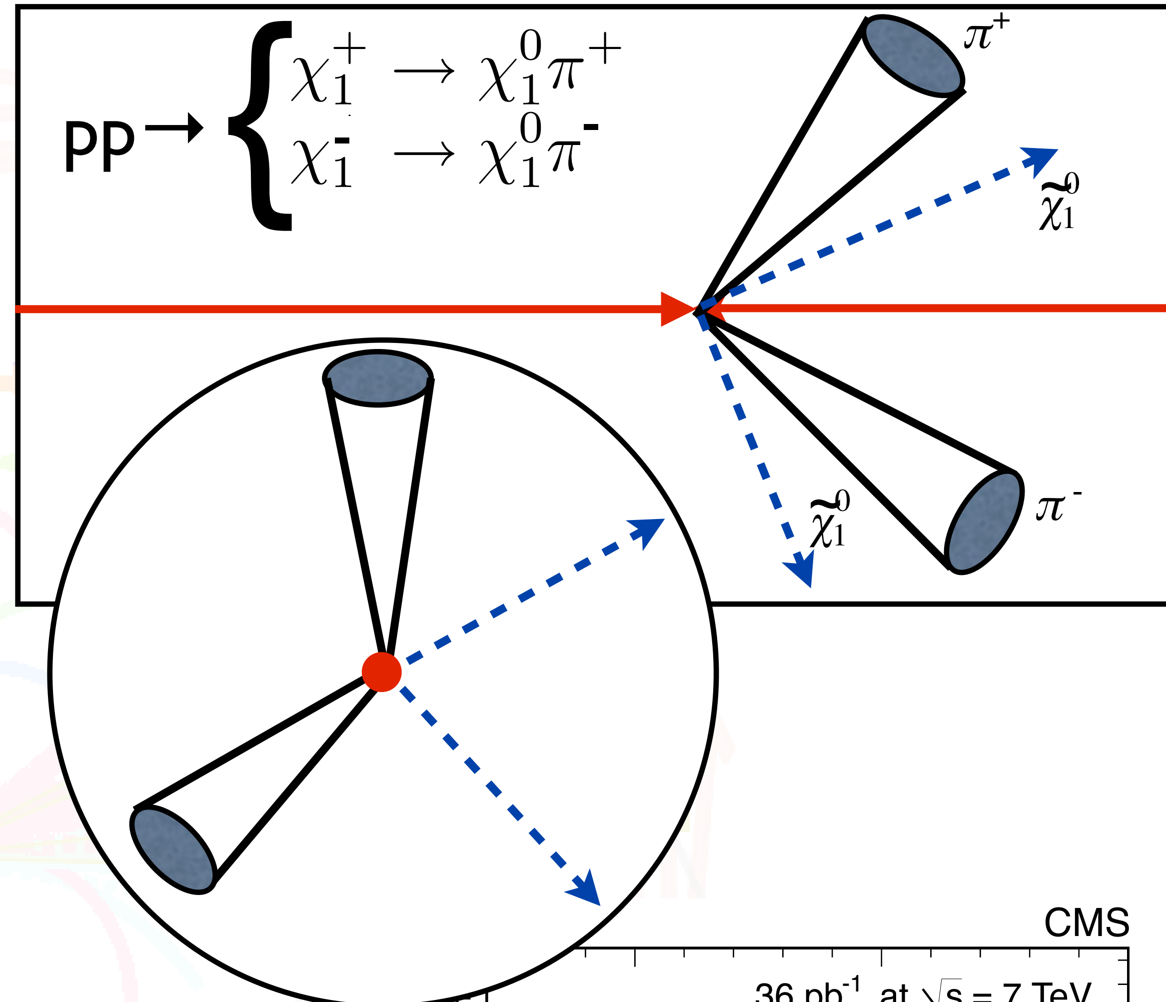
- The 1st-fb^{-1} analyses tell us that produced SUSY particles are "in average" heavier than what (naively) expected. This confirms NP-scale lower bounds a-la-UTfit dating back to 2005

- Light SUSY particles are still possible if stop is much lighter than other squarks

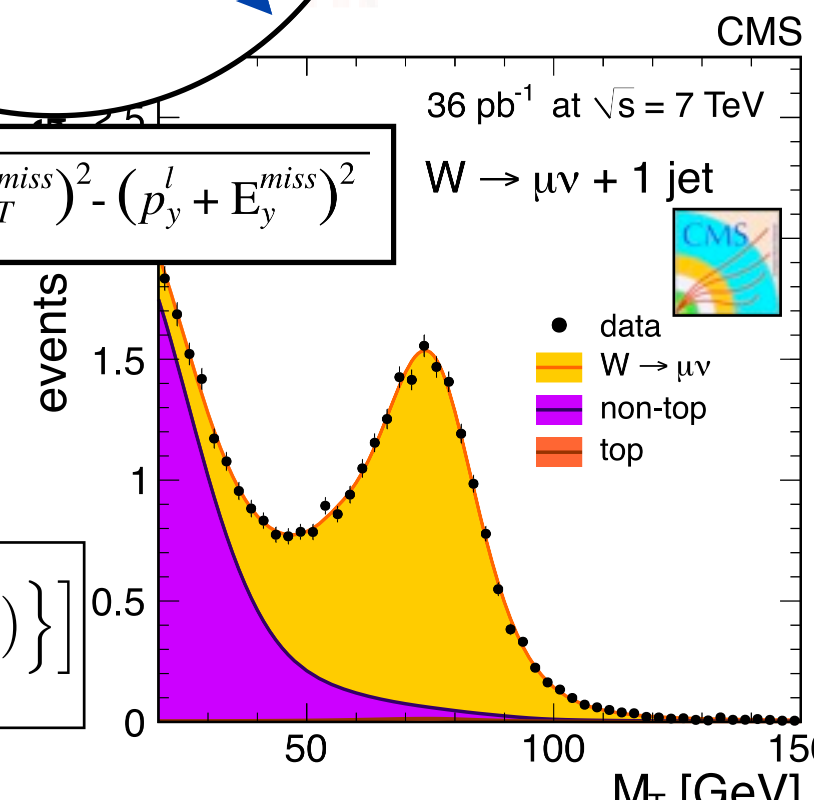
- Nowhere we used the fact that we look for TWO DM particles produced so far...

M_{T2}: two missing particles

- We are looking for events with two undetected neutral particles leaving the detector
- We measure the sum of their pT as MET
- This is similar to the detection of the W, for which the edge of the mT distribution is used
- The presence of two missing particles make the picture more complicated. With some reasoning (see backup) one gets



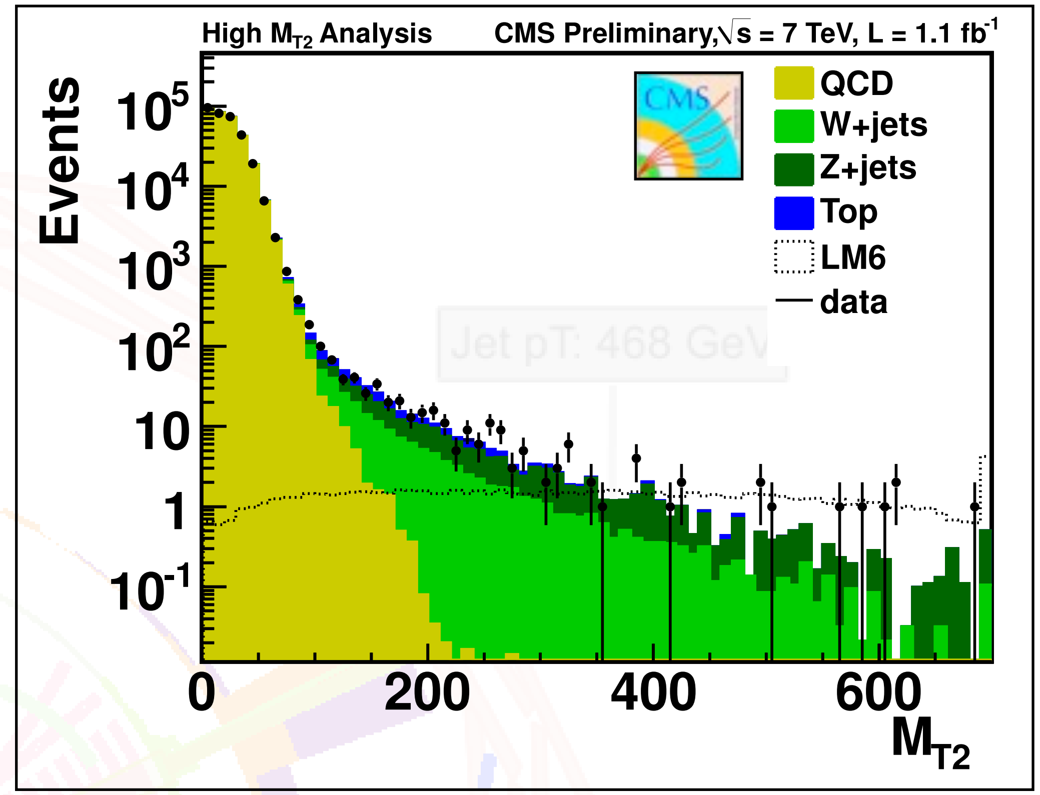
$$M_T = \sqrt{E_T^l E_T^{miss} - (p_x^l + E_T^{miss})^2 - (p_y^l + E_y^{miss})^2}$$



$$m_{T2}^2(\chi) \equiv \min_{\not{q}_T^{(1)} + \not{q}_T^{(2)} = \not{p}_T} \left[\max \left\{ m_T^2(\mathbf{p}_T^{\pi^{(1)}}, \not{q}_T^{(1)}; \chi),\ m_T^2(\mathbf{p}_T^{\pi^{(2)}}, \not{q}_T^{(2)}; \chi) \right\} \right]$$

M_{T2}: two missing particles

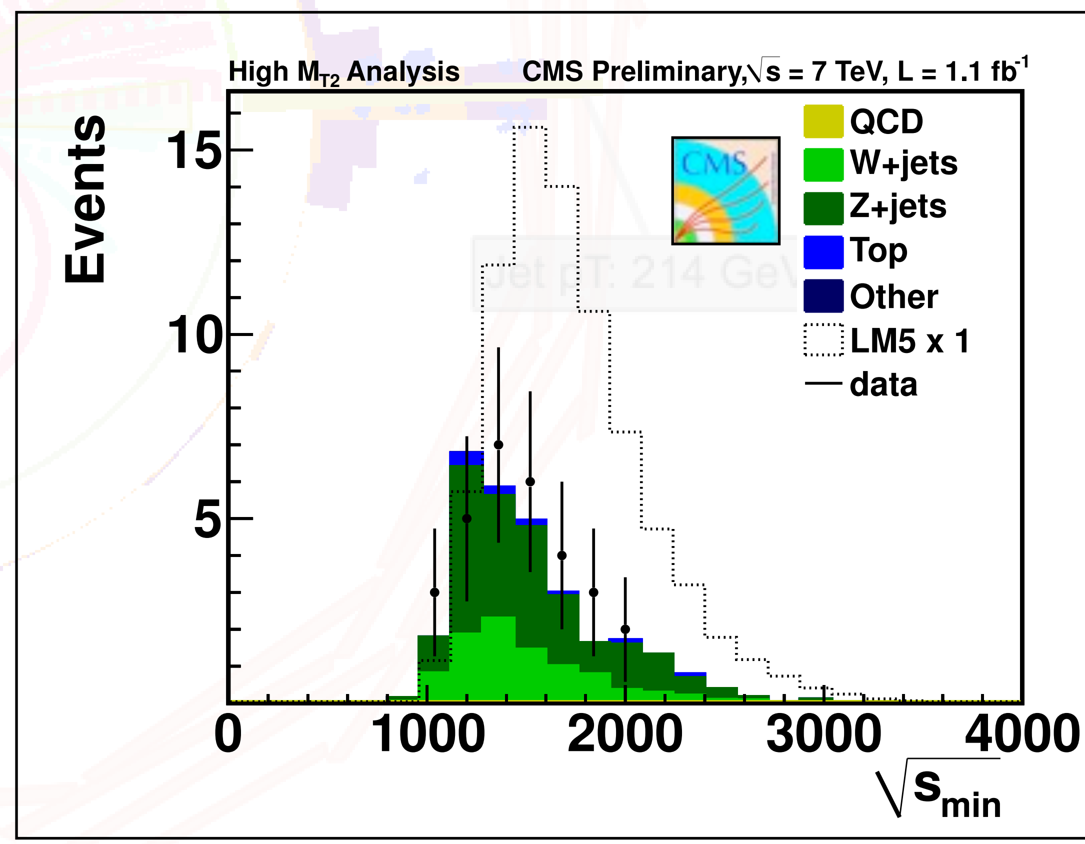
- M_{T2} is found to be useful for searches, since it allows to reduce QCD to negligible level



- Assume a mass value (eg mLSP=0)
- Assume that the visible system in has 0 mass
- An analytical expression for M_{T2} is found

$$(M_{T2})^2 = 2A_T = 2p_T^{vis(1)} p_T^{vis(2)} (1 + cos\phi_{12})$$

- The edge is lost but we have an α_T-like variable to kill the QCD



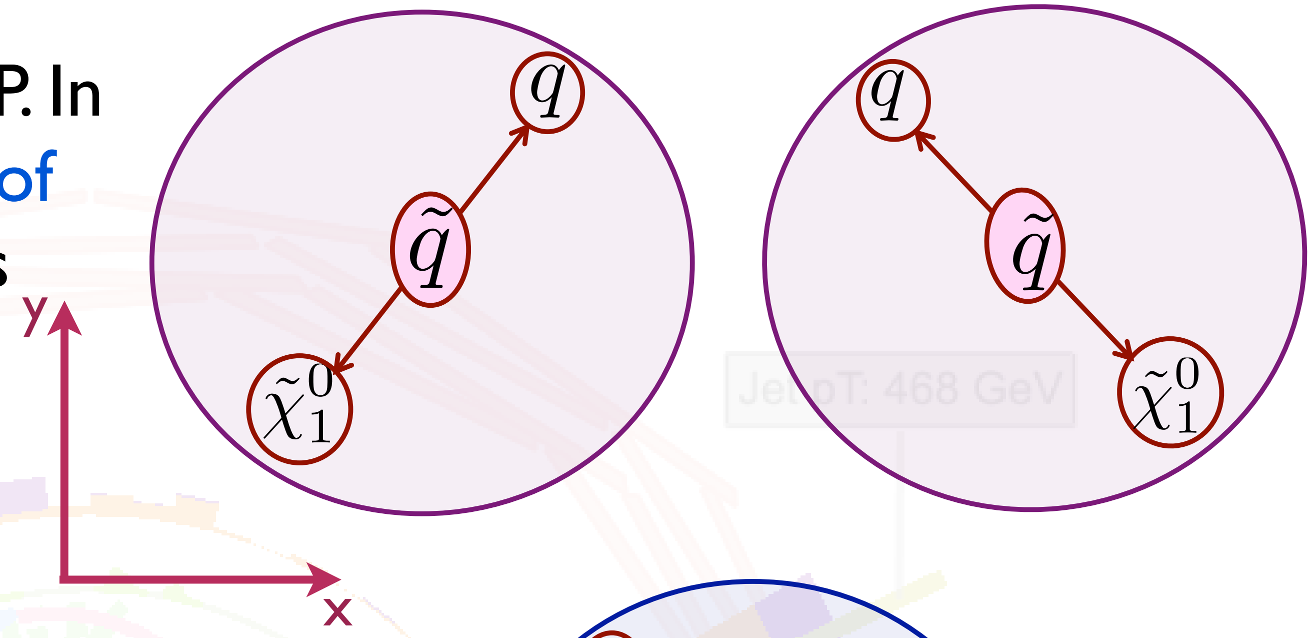
- Other variables could be used to characterize the signal, in case of a discovery. CMS would use $\sqrt{s}_{min}$ for that

$$\sqrt{s}_{min}(M_{miss,min}) = \sqrt{M_{vis}^2 + P_{T,vis}^2} + \sqrt{M_{miss,min}^2 + \not{E}_T{}^2}$$

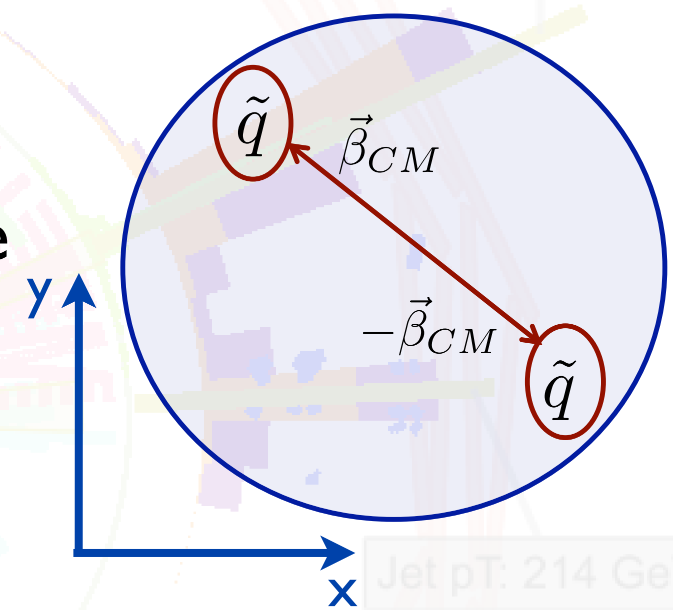
The Razor Frame

- Two squarks decaying to quark and LSP. In their rest frames, they are two copies of the same monochromatic decay. In this frame p(q) measures M_Δ

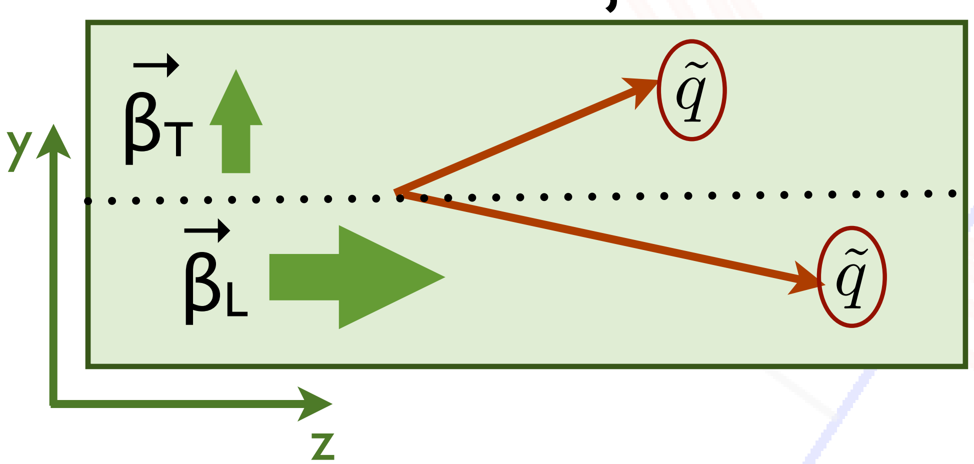
$$M_\Delta \equiv \frac{M_{\tilde{q}}^2 - M_{\tilde{\chi}}^2}{M_{\tilde{q}}} = 2M_{\tilde{\chi}}\gamma_\Delta\beta_\Delta$$



- In the rest frame of the two incoming partons, the two squarks recoil one against each other.



- In the lab frame, the two squarks are boosted longitudinally. The LSPs escape detection and the quarks are detected as two jets

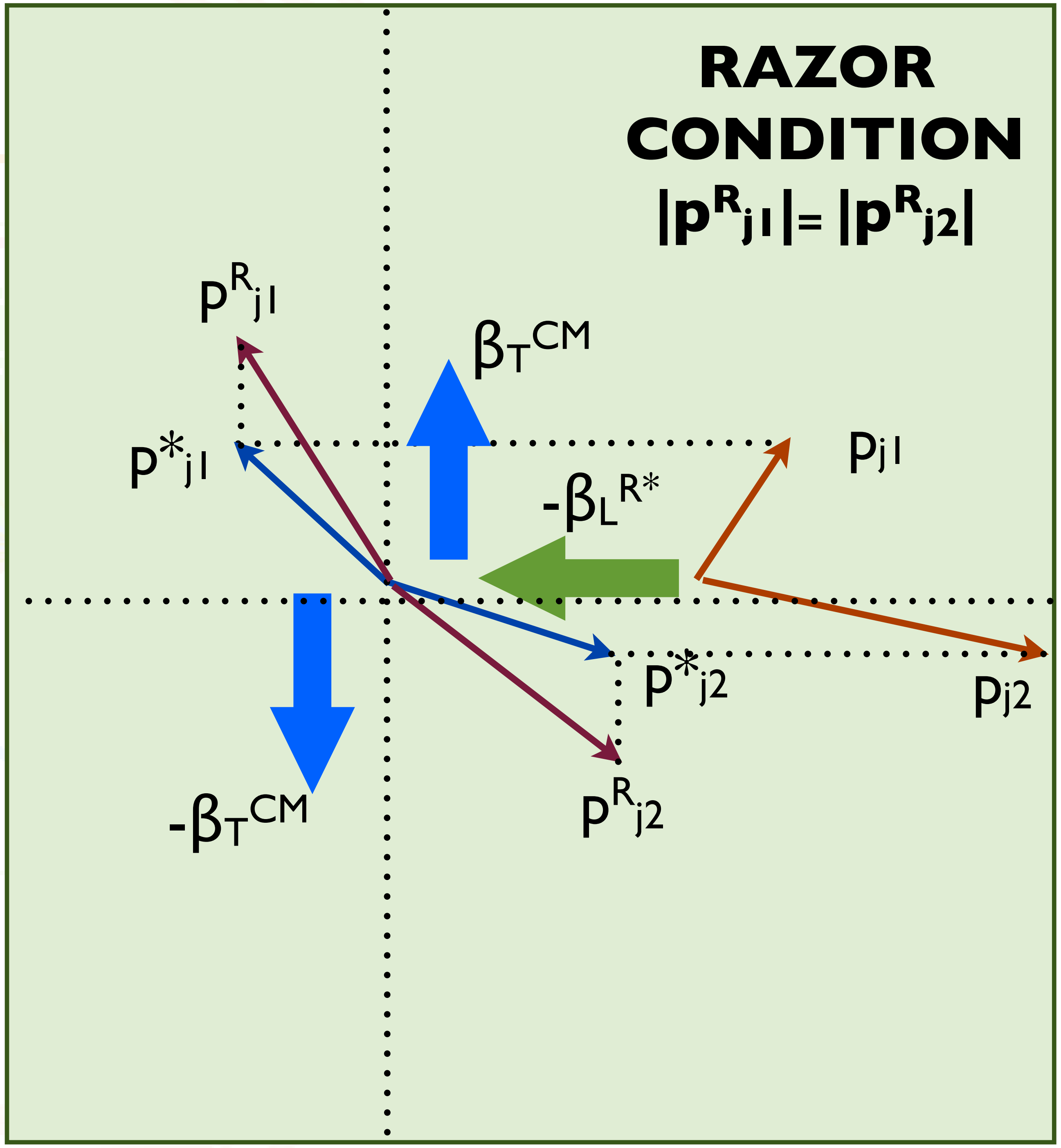


If we could see the LSPs, we could boost back by β_L, β_T, and β_{CM}
In this frame, we would then get
$|p_{j1}| = |p_{j2}|$
Too many missing degrees of freedom to do just this

The Razor Frame

- In reality, the best we can do is to compensate the missing degrees of freedom with assumptions on the boost direction

- The parton boost is forced to be longitudinal
- The squark boost in the CM frame is assumed to be transverse



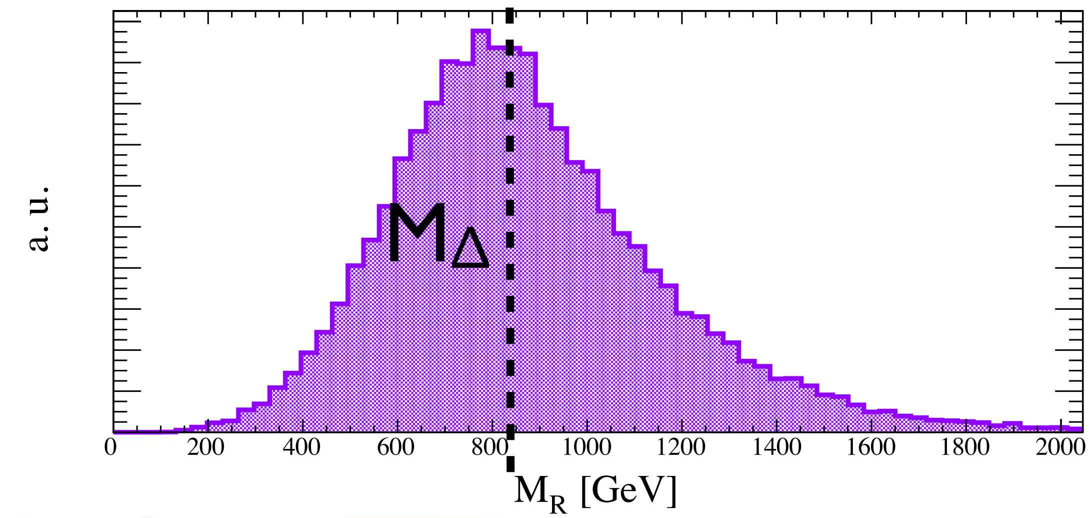
- We can then determine the two by requiring that the two jets have the same momentum after the transformation

- The transformed momentum defines the M_R variable

$$M_R \equiv \sqrt{(E_{j_1} + E_{j_2})^2 - (p_z^{j_1} + p_z^{j_2})^2}$$

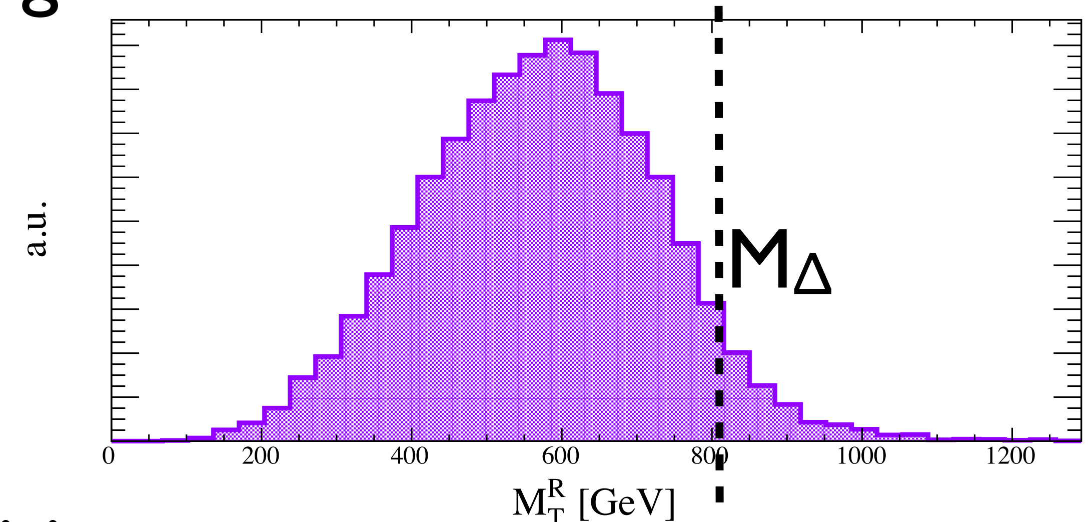
The Razor Variable

- M_R is boost invariant, even if defined from 3D momenta
- No information on the MET is used
- The peak of the M_R distribution provides an estimate of M_Δ



- M_Δ could be also estimated as the “edge” of M_T^R

$$M_T^R \equiv \sqrt{\frac{E_T^{miss}(p_T^{j1}+p_T^{j2}) - \vec{E}_T^{miss}\cdot(\vec{p}_T^{\,j1}+\vec{p}_T^{\,j2})}{2}}$$

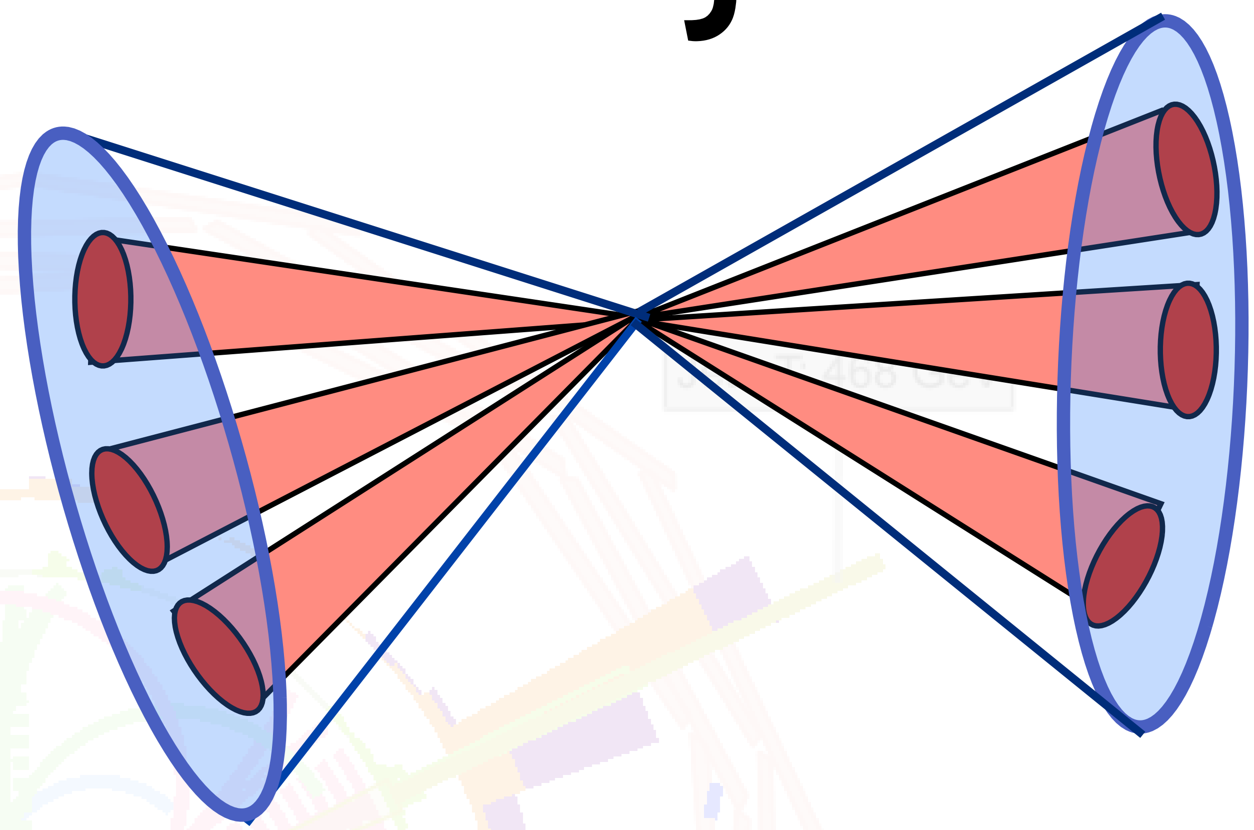


- M_T^R is defined using transverse quantities and it is MET-related
- The Razor (aka R) is defined as the ratio of the two variables

$$R \equiv \frac{M_T^R}{M_R}$$

From DiJet To MultiJets

- The "new" variables rely on the dijet +MET final state as a paradigm
- All the analyses have been extended to the case of multijet final states clustering jets in two hemispheres (aka mega-jets)



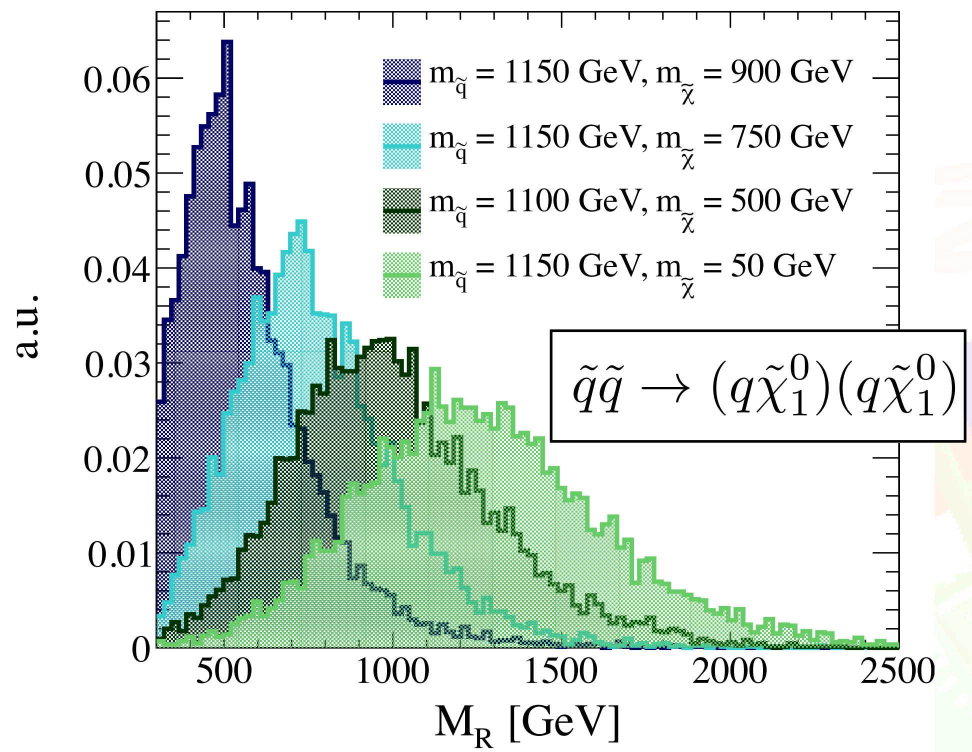
<u>Several approaches used</u>

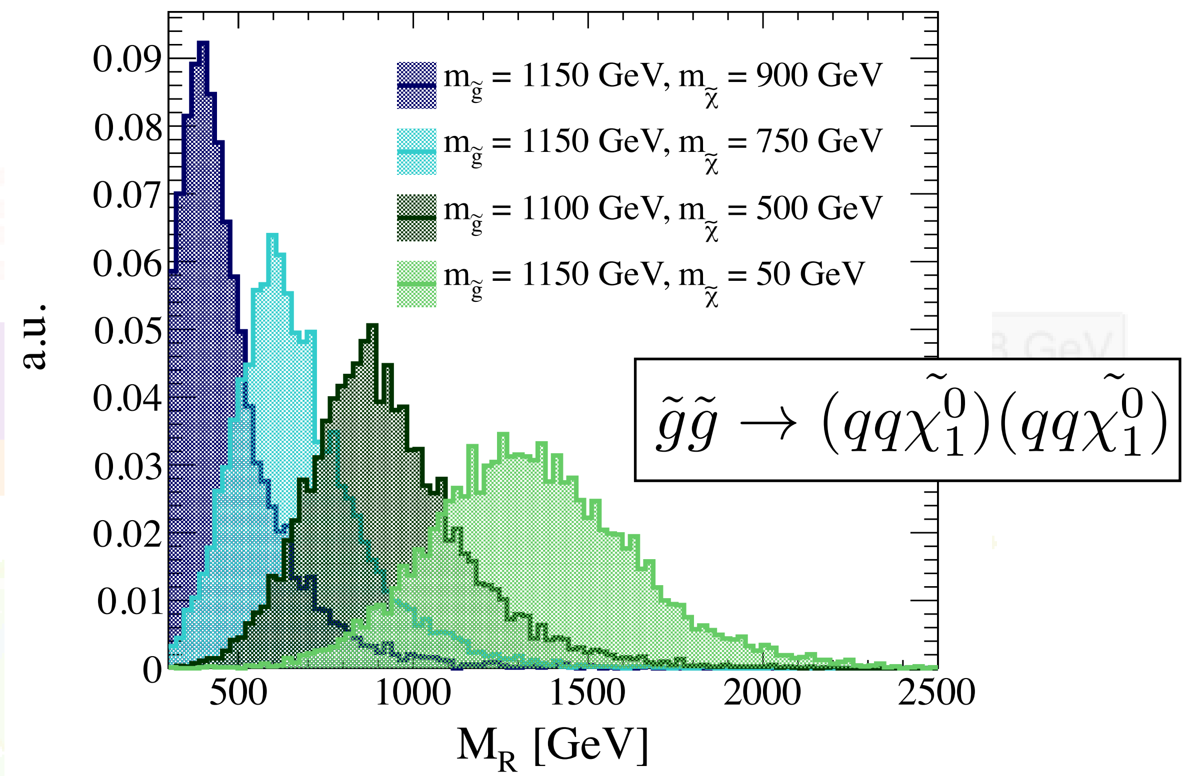
- minimizing the HT difference between the mega-jets (aT CMS)
- minimizing the invariant masses of the two jets (Razor CMS)
- minimizing the Lund distance (MT2 CMS)
- ...

$$(E_i - p_i cos\theta_{ik})\frac{E_i}{(E_i + E_k)^2} \leq (E_j - p_j cos\theta_{jk})\frac{E_j}{(E_j + E_k)^2}$$

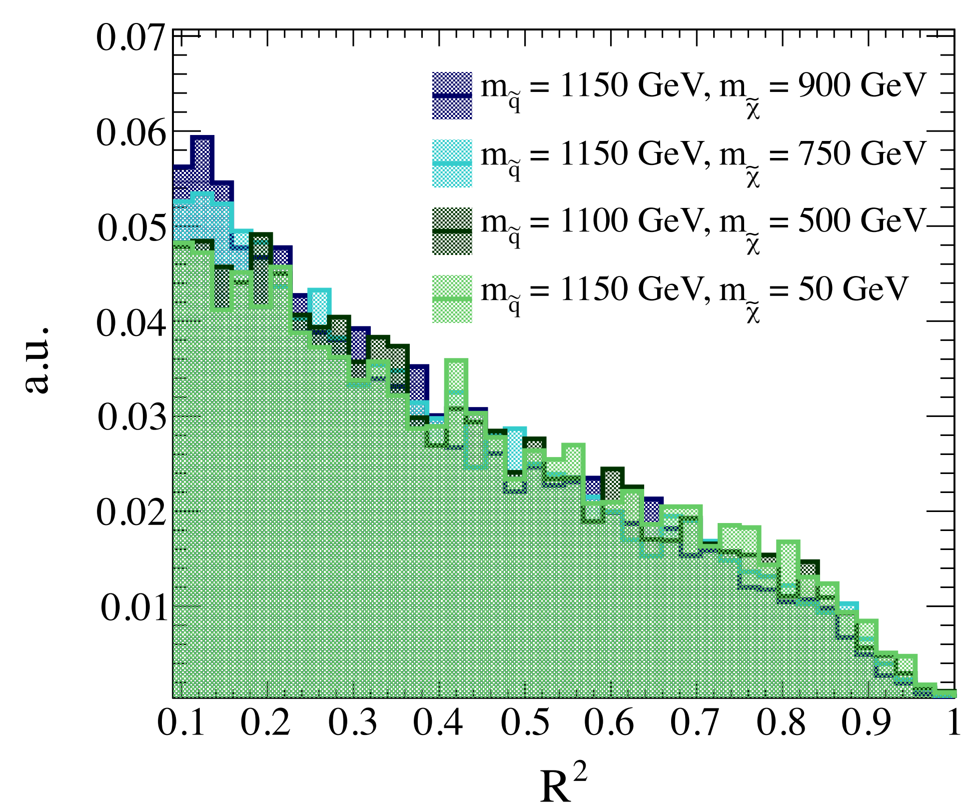
- Is the ultimate hemisphere definition out there (I am not aware of studies on this)?
- Could this improve the signal sensitivity in a significant way?

SUSY Search As a Bump Hunting





- Peaking signal at $M_R \sim M_\Delta$ (discovery and characterization)
- R^2 is determined by the topology, but not changes too much vs particle masses



1D Background Model

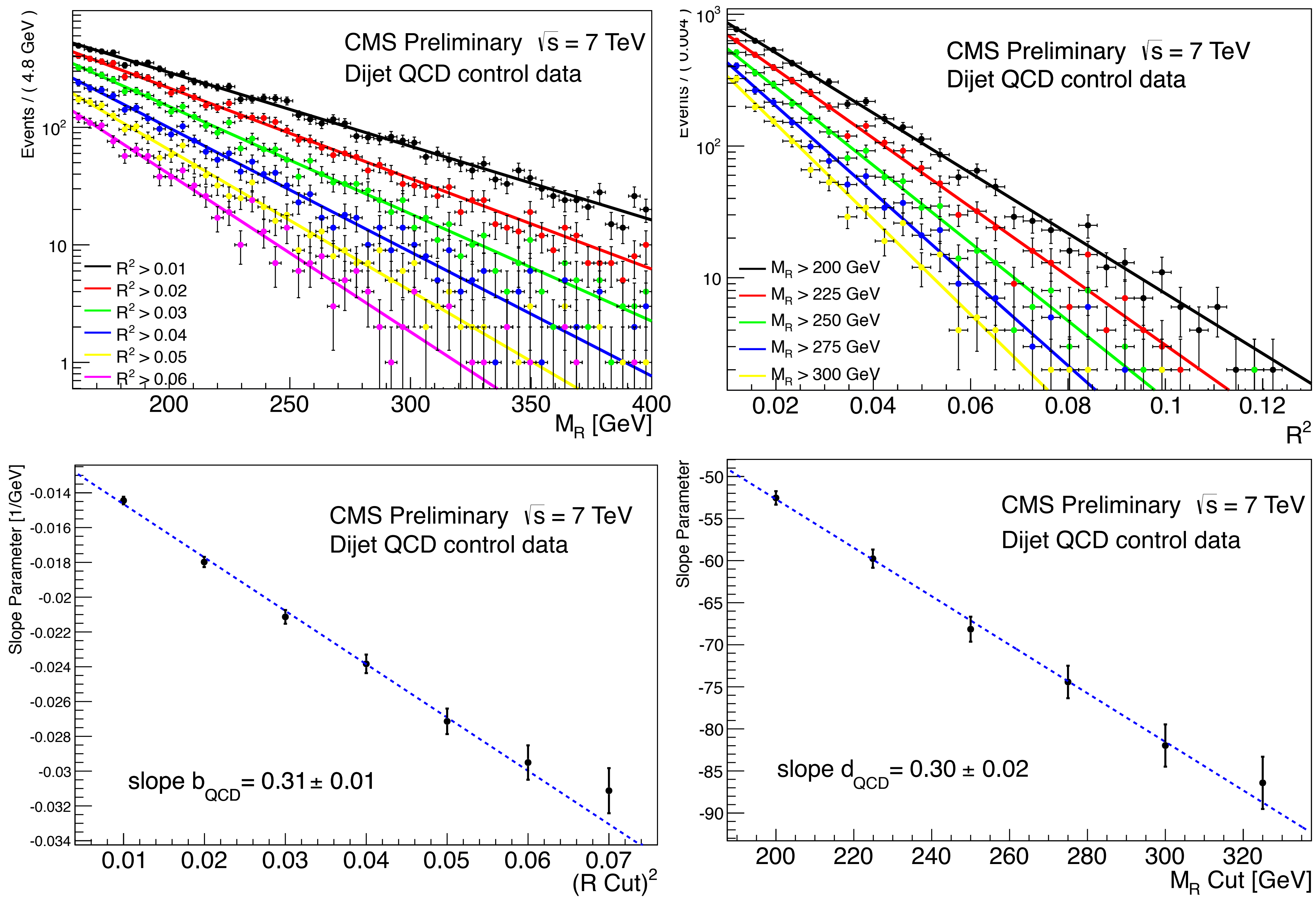
QCD data

$$f(M_R) \sim e^{-kM_R}$$

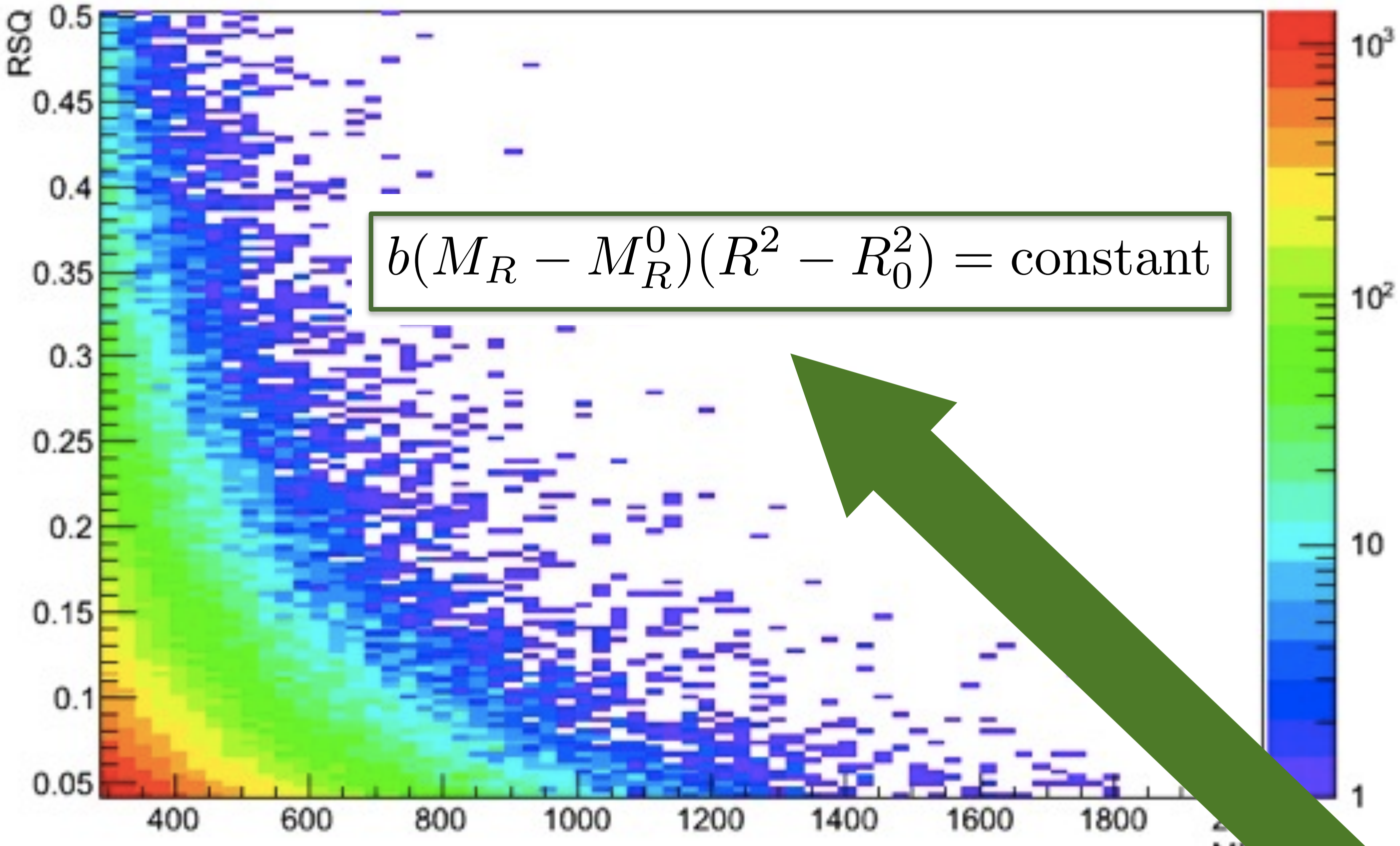
$$k = a + b\,R^2_{cut}$$

$$f(R^2) \sim e^{-kR^2}$$

$$k = c + b\,M_R^{cut}$$



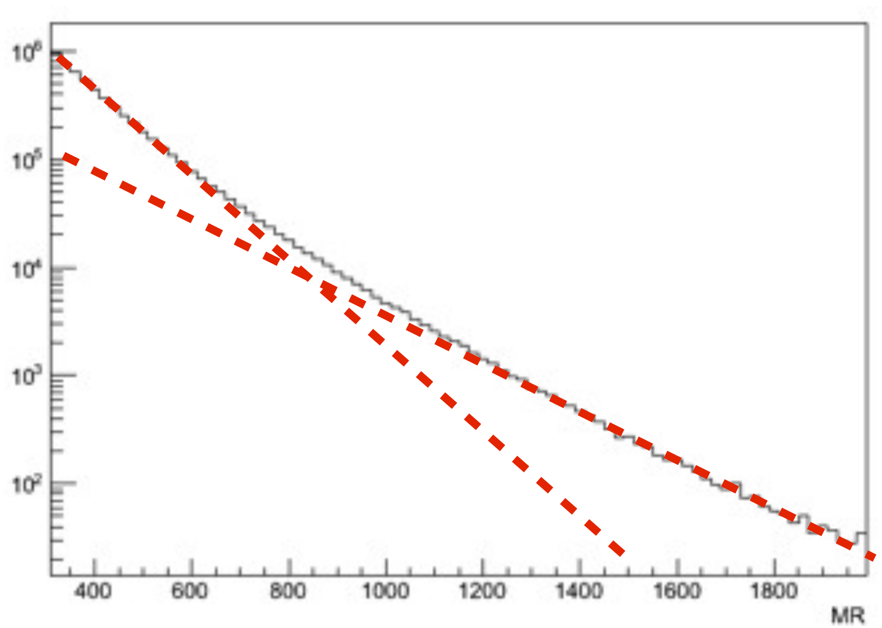
From 1D to 2D

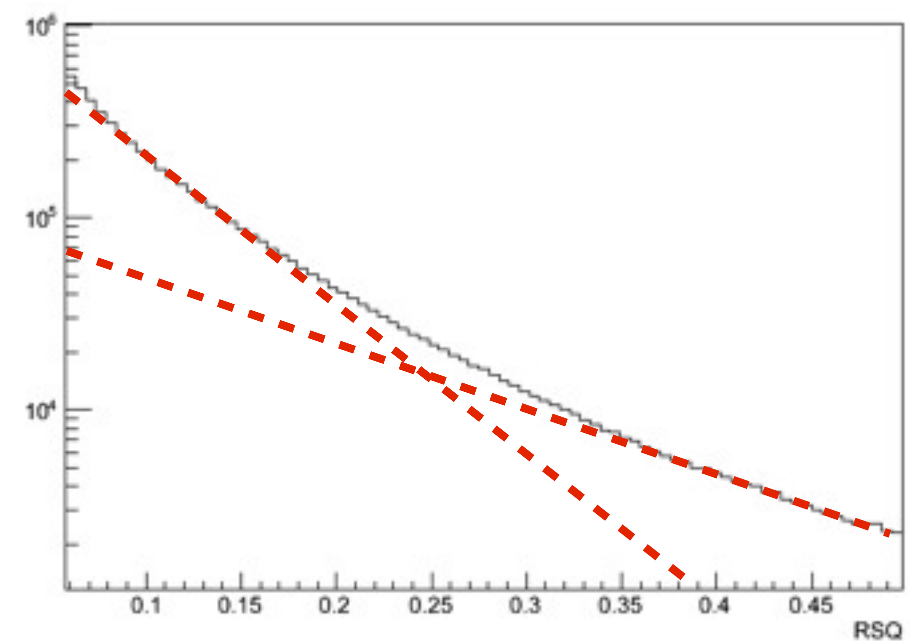


$$b(M_R - M_R^0)(R^2 - R_0^2) = \text{constant}$$

Each Bkg components (Z+jets, W+jets, tt+jets) well described by the sum of two of these pdfs

$$f(M_R, R^2) = [b(M_R - M_R^0)(R^2 - R_0^2) - 1]e^{-b(M_R - M_R^0)(R^2 - R_0^2)}$$

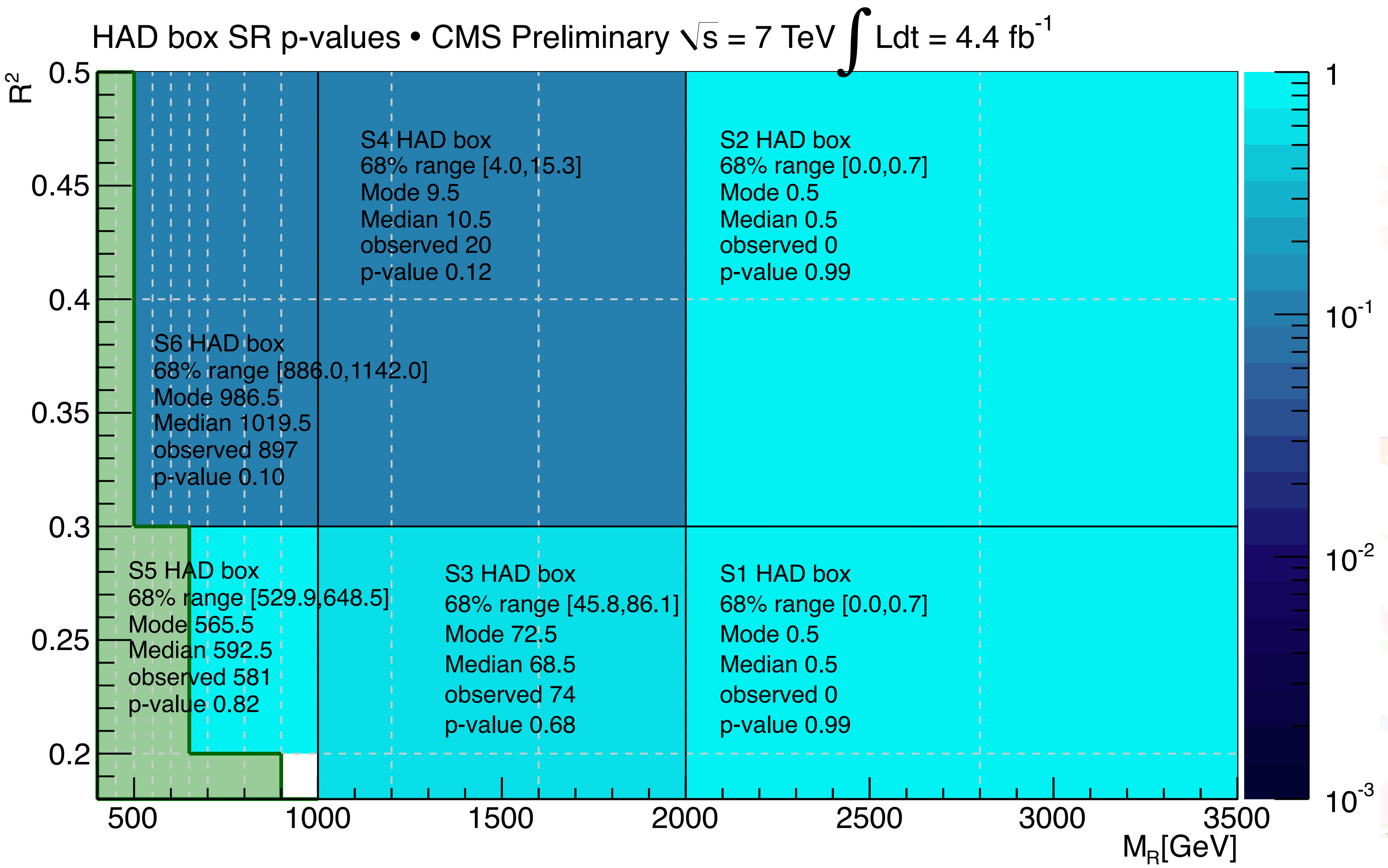




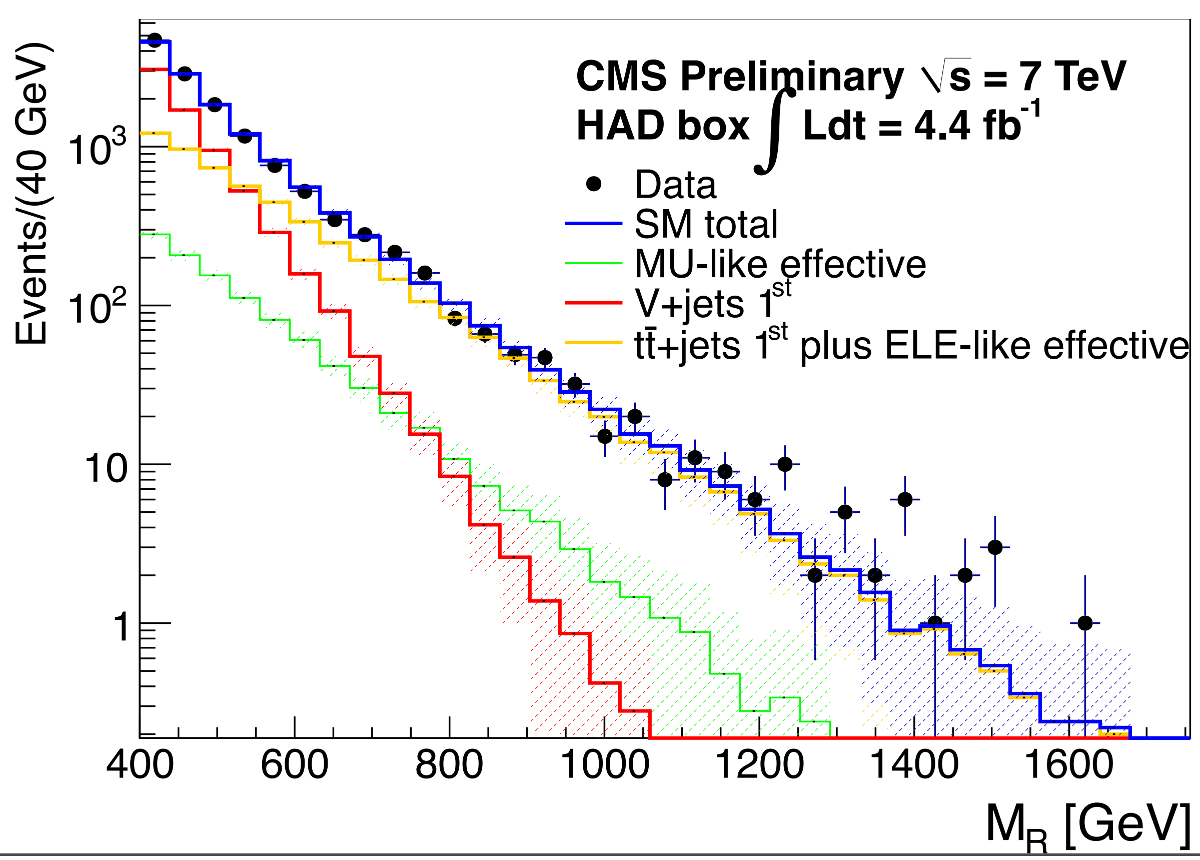
$$\int_{R^2_{cut}}^{+\infty} f(M_R, R^2) dR^2 \sim e^{-(a+bR^2_{cut})M_R}$$

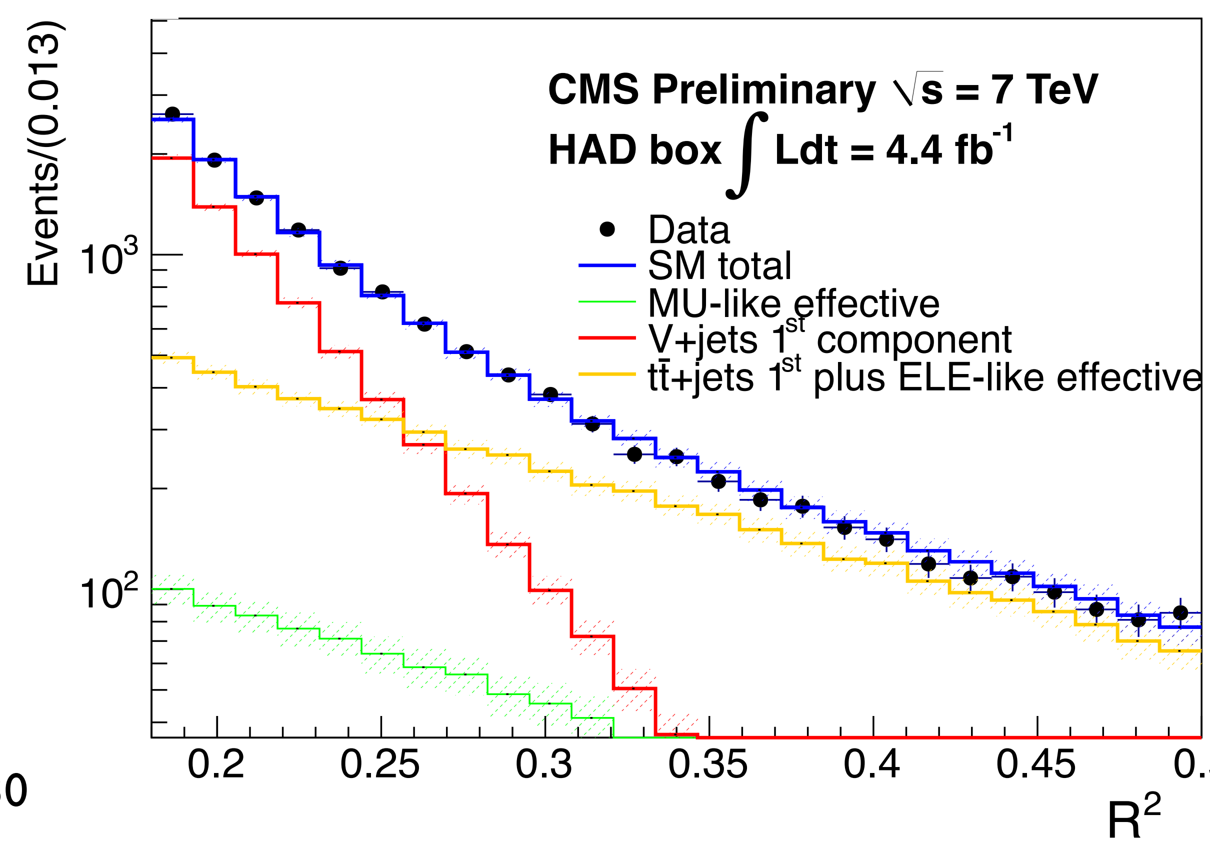
$$\int_{M_R^{cut}}^{+\infty} f(M_R, R^2) dM_R \sim e^{-(c+bM_R^{cut})R^2}$$

Data vs Bkg Prediction



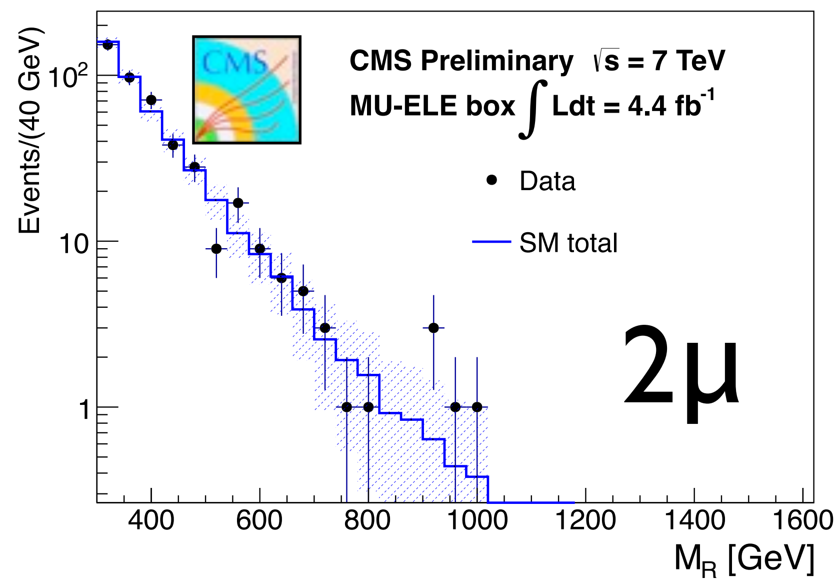
- Determine the bkg shape from a fit to the fit region
- Extrapolate to the signal-sensitive region
- Compare data with bkg model extrapolating to the full region
- Data and MC agree well
→we set limit on signal

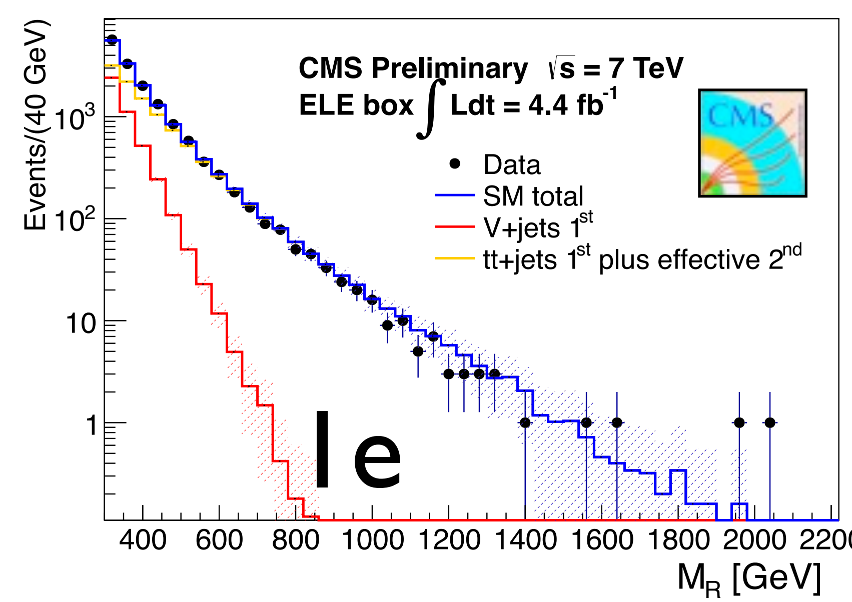


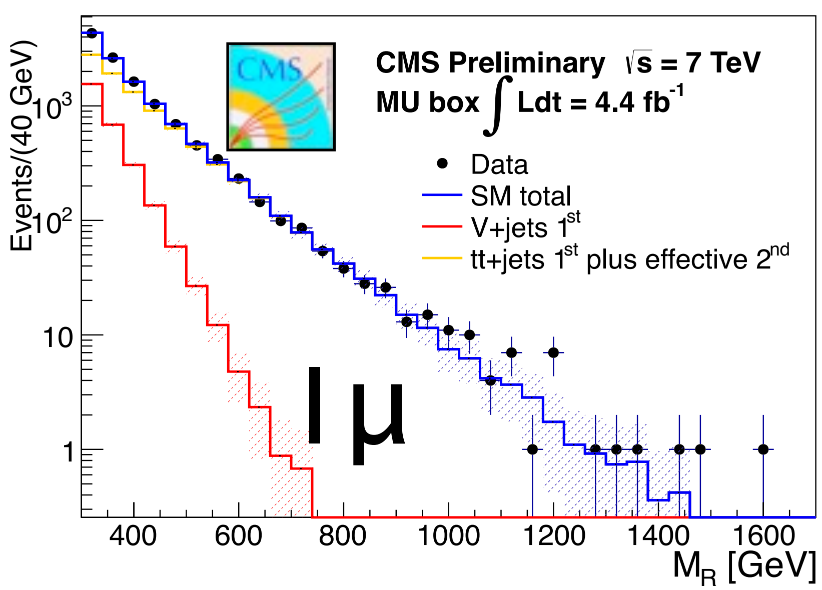


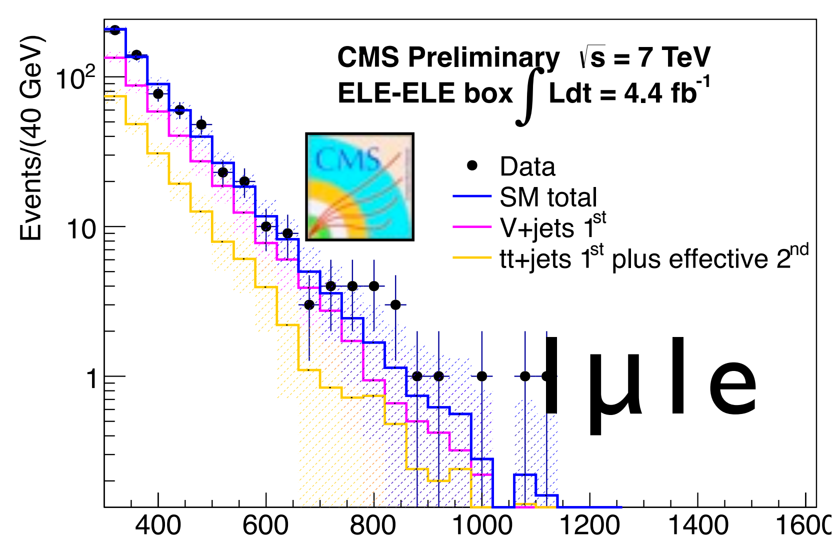
From Hadronic To Inclusive

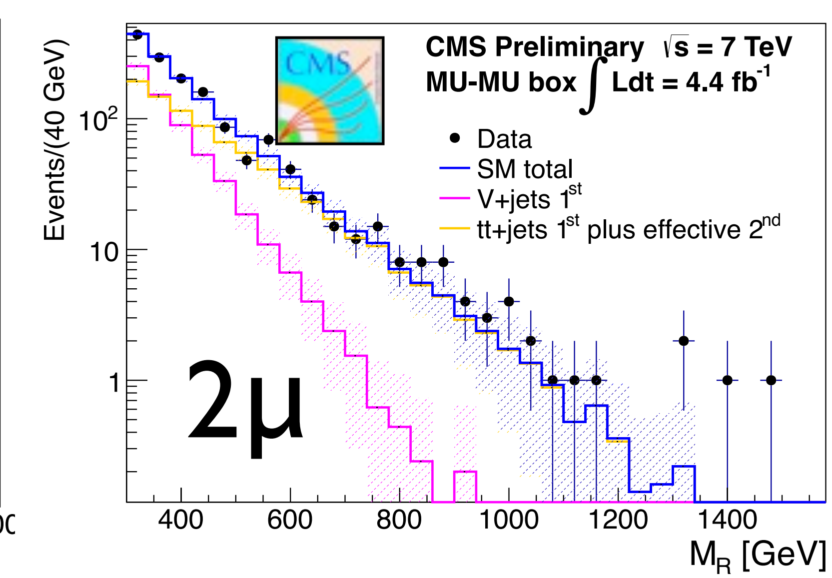
- Hadronic analyses use to veto leptons and use the vetoed sample as a bkg control sample (including signal contamination)
- Leptonic analyses look for a signal in a subset of this samples
- Thinks can be sync'ed in a common analysis framework, as in the CMS Razor analysis



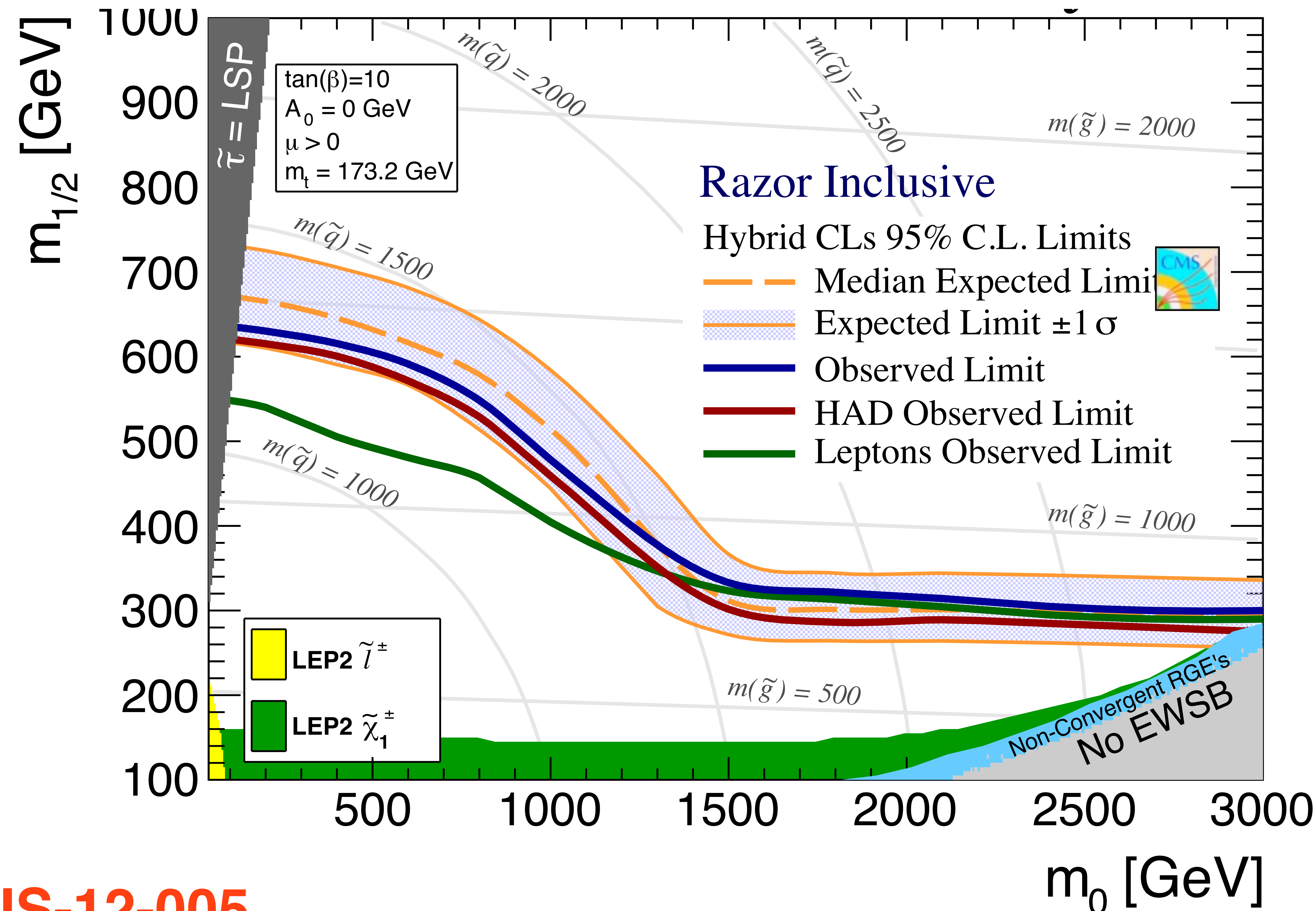








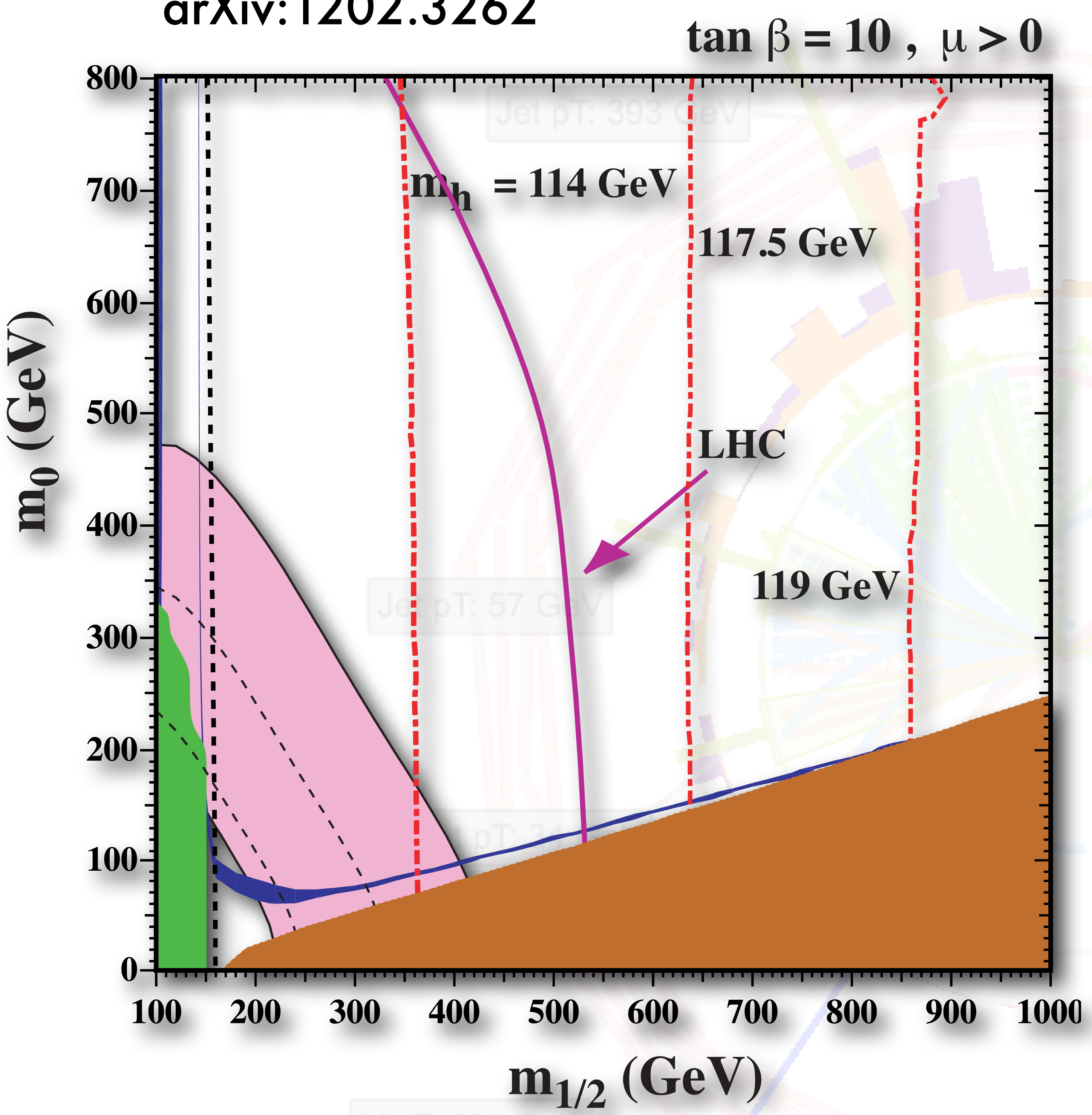
CMSSM Limit With 2011 Data

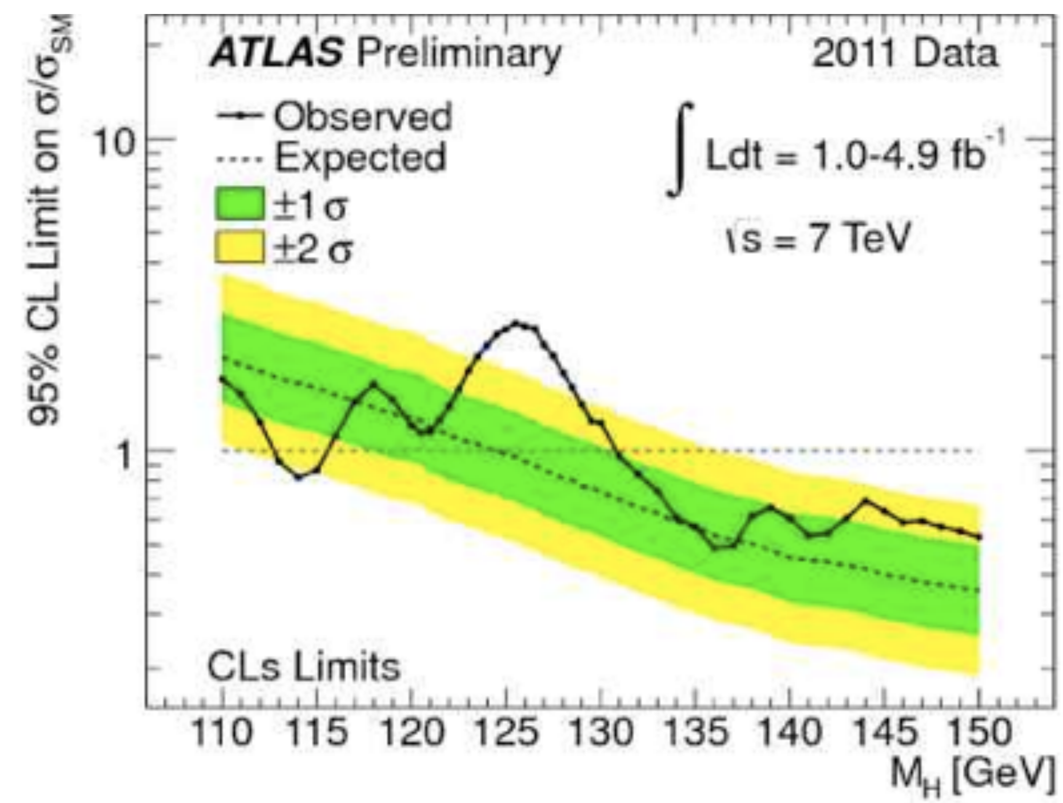


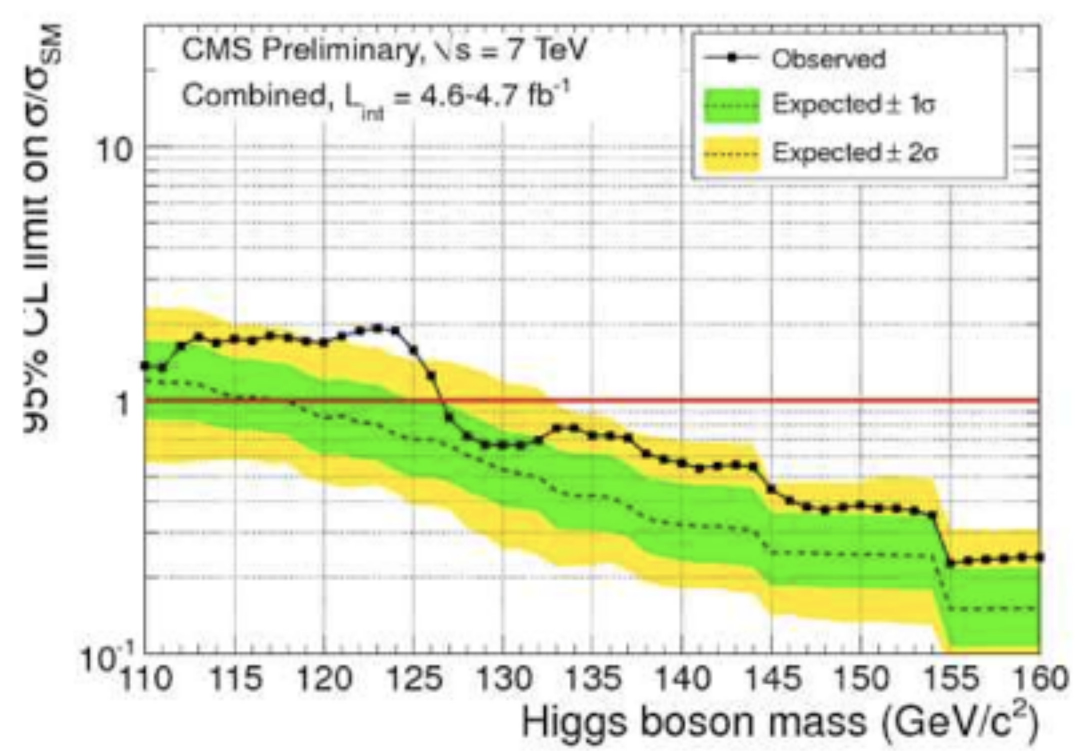
SUS-12-005

But We Knew That...

arXiv:1202.3262



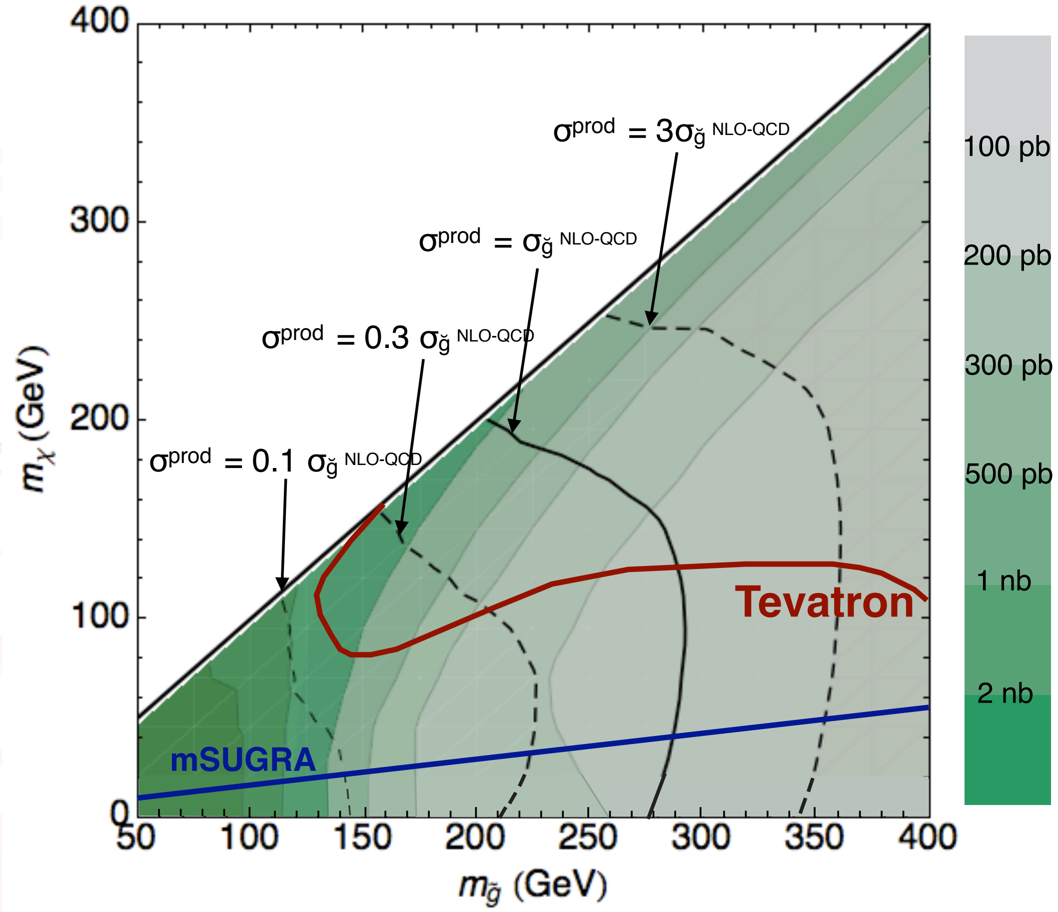


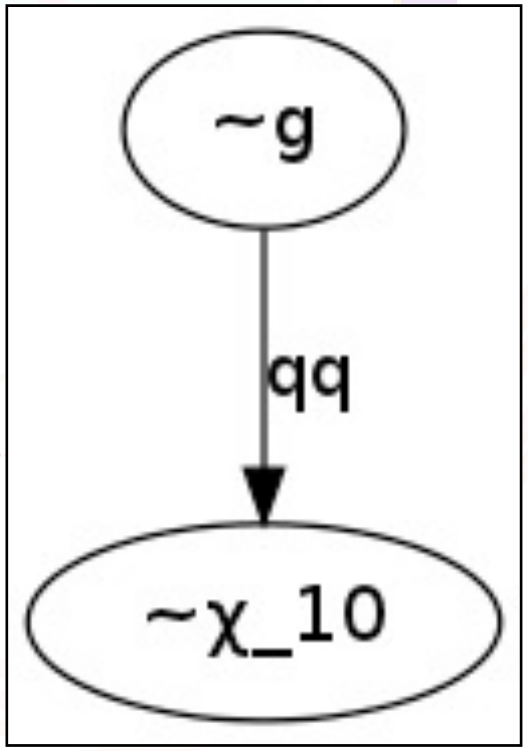


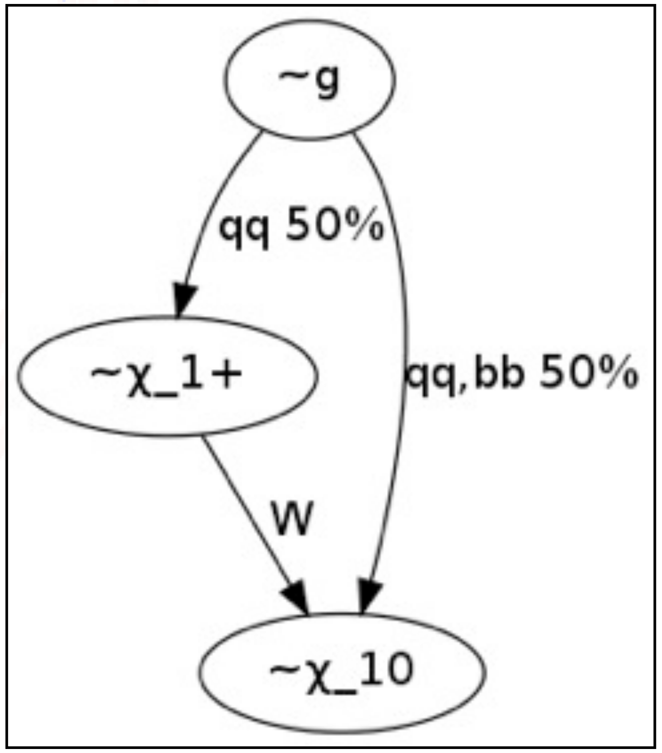
The Simplified Models

- The CMSSM is an established paradigm to present searches
- On the other hand, it is characterized by very peculiar features (eg mass ratios) which makes the result difficult to generalize

- The experiments decided to focus on a limited set of *simplified* models, in which two sparticle are produced, decaying to visible particles + 2 LSPs
- At most an intermediate step is allowed, such that a few decay chains specify the full model
- Result is presented as the max excluded cross section vs masses of produced particle and LSP



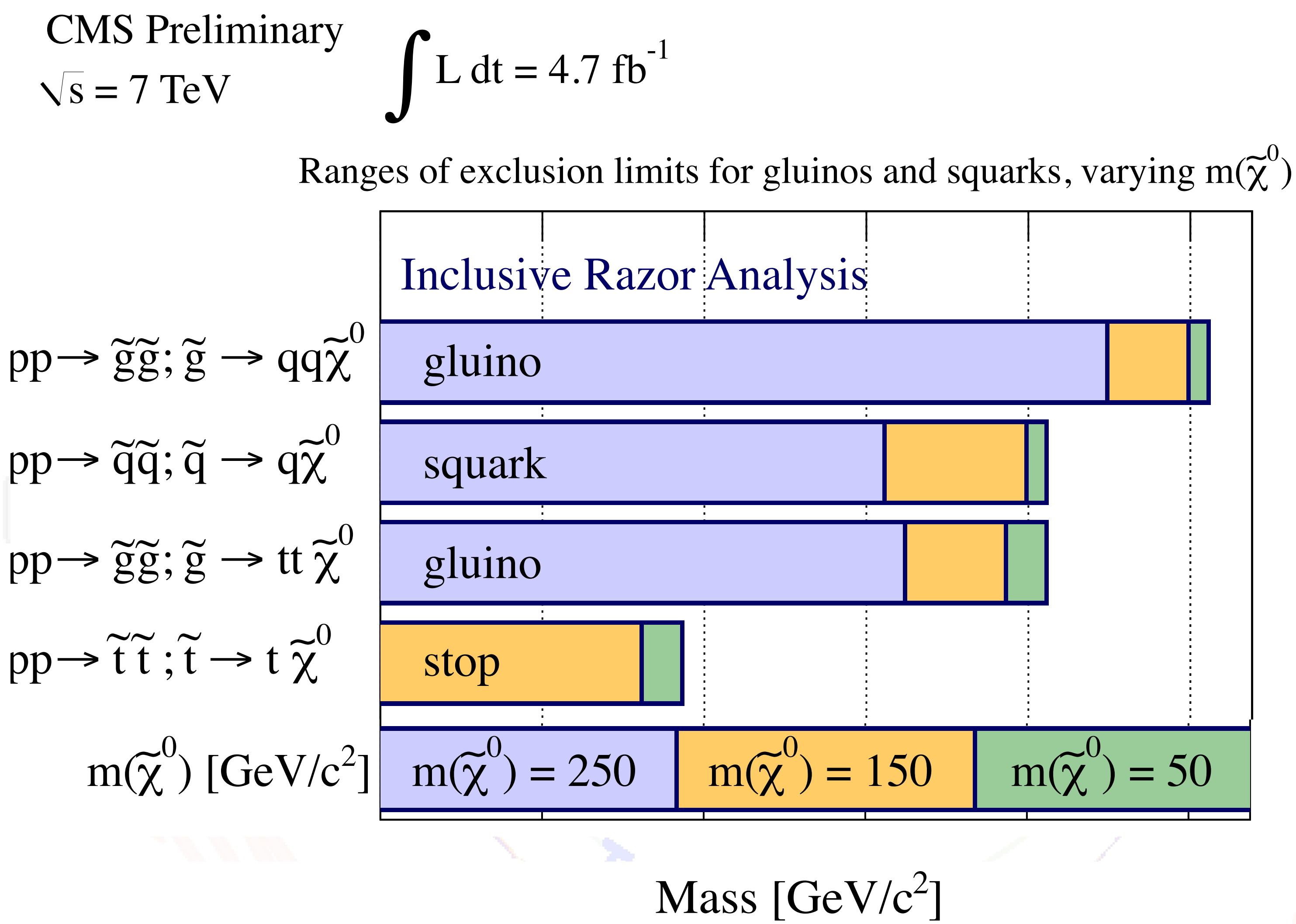




Friday, May 25, 12

The Simplified Models

The inclusive nature of the analysis allows us to put bounds on many models
Unfortunately the plots are not public (so I cannot tell you what the limits are)
But I can give you a “feeling” of the relevance this analysis on the full picture



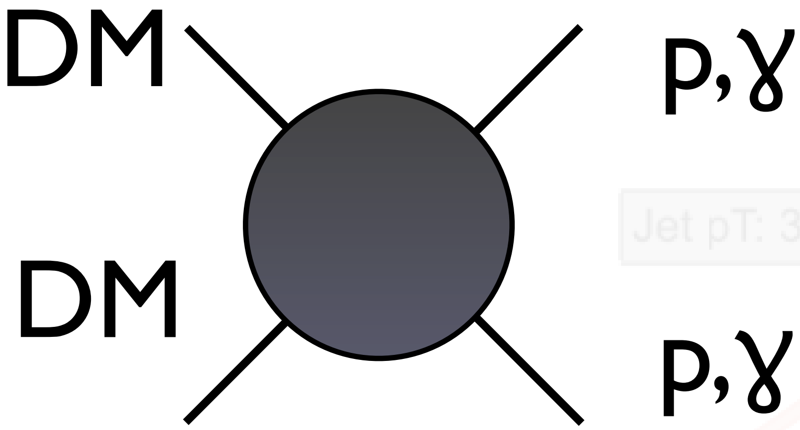
For the same reason I cannot show you how adding a btag requirement to the selection improves the limits for models with b’s in the final state (approved analysis, but not yet the result)

The New Thing

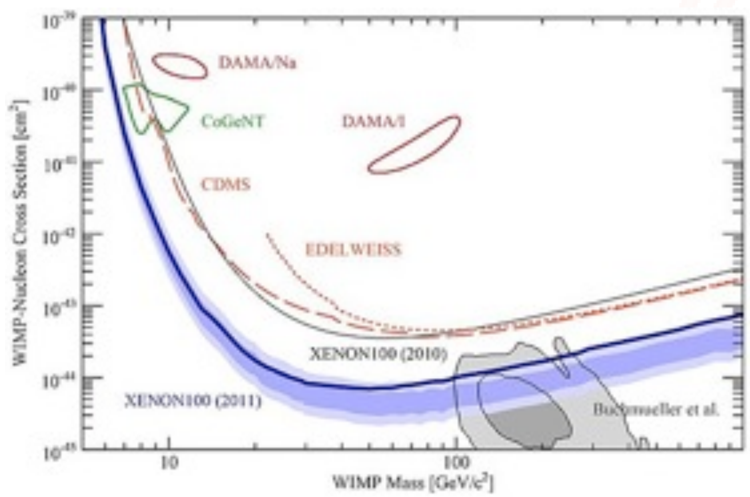
- The razor analysis is something new under many aspects
  - ★ It's new from the point of view of the variables: the kinematic features of the topology under study are fully used
  - ★ It's new from the point of view of the strategy (for a hadron collider): this is the first time that an unbinned fit with analytical functions a-la-BaBar is used for a high-pT search @hadron colliders.
  - ★ It's new from the point of view of the final state: as a matter of fact, this is an inclusive search and it is sensitive to any final state. This will be maximally exploited with the SMS interpretation
- We are trying to put a full physics program out of this new strategy (stop and sbottom production, multijet, GMSB-like SUSY, tau-enriched final state, light stop, top partners) and theorists are helping us with new ideas

And What about DM direct production @LHC?

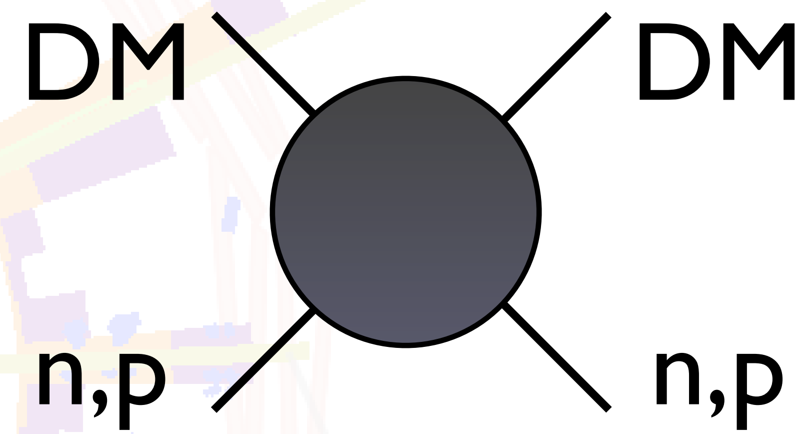
DM searches

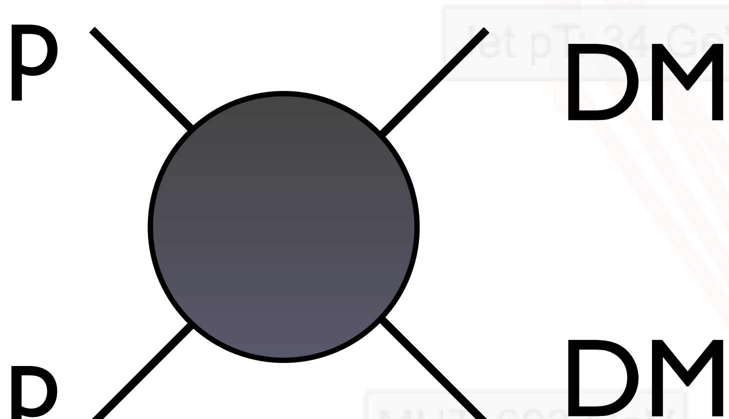


DM pairs can annihilate in space and give us excesses of photons, anti-protons, etc (as recently claimed)

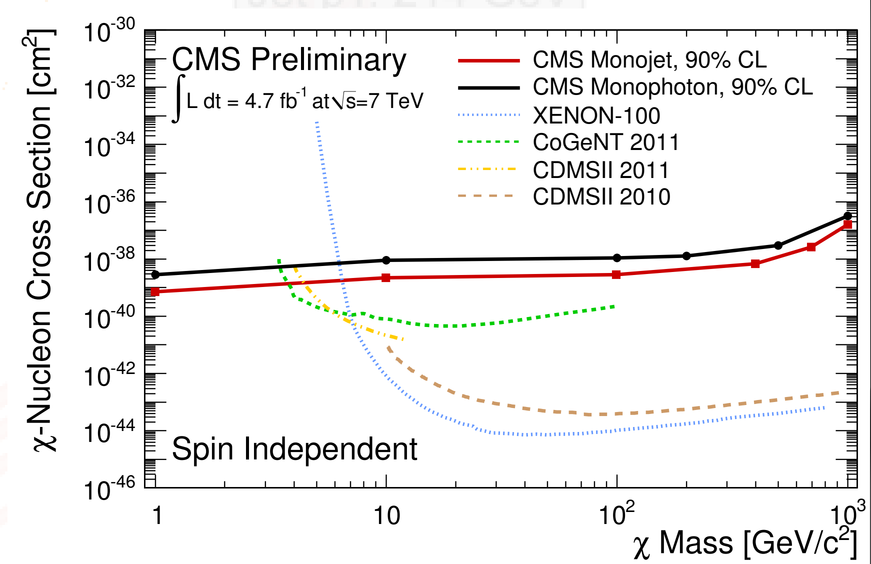


DM pairs can scatter on nucleons in experiments underground (as claimed since long time)





DM pairs can be produced in pp collisions @LHC (nobody claimed that yet...)



DM production at Collider

- In production: one can imagine different mechanisms. For instance the case of a heavy mediator in s-channel, which can be integrated out using OPE. In this case the leading operator (vectorial vs axial vs etc) has a "memory" of the origin of the mediator (as in OPE for EW theory with 4-fermions a-la-Fermi)

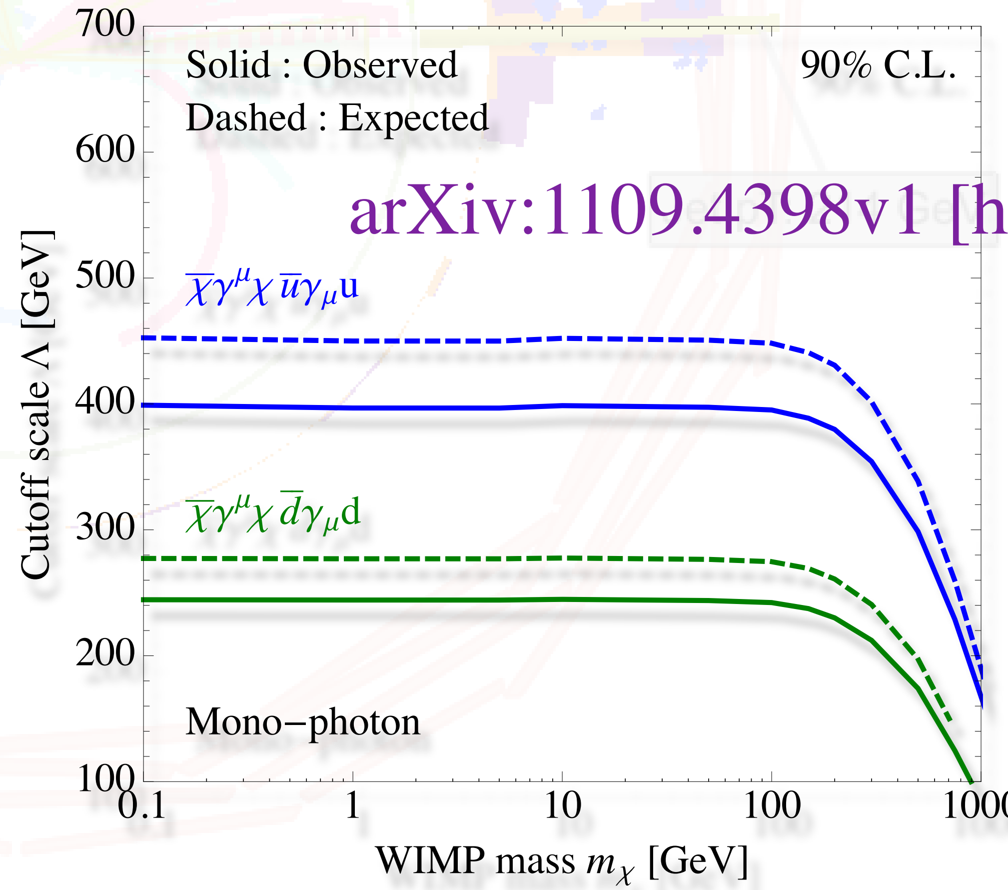
- In cascade: the big picture strongly depends on the underlying model. The production xsec depend on the mother particle, not on the DM. The detectability of this signal implies a large-enough mass split between DM and mother particle, such that triggerable objects (jets, leptons, etc) are produced in cascade

$$\mathcal{O}_V = \frac{(\bar\chi\gamma_\mu\chi)(\bar q\gamma^\mu q)}{\Lambda^2}, \quad \text{V, s-ch}$$

$$\mathcal{O}_A = \frac{(\bar\chi\gamma_\mu\gamma_5\chi)(\bar q\gamma^\mu\gamma_5 q)}{\Lambda^2}, \quad \text{A, s-ch}$$

$$\mathcal{O}_t = \frac{(\bar\chi P_R q)(\bar q P_L \chi)}{\Lambda^2} + (L \leftrightarrow R) \quad \text{S, t-ch}$$

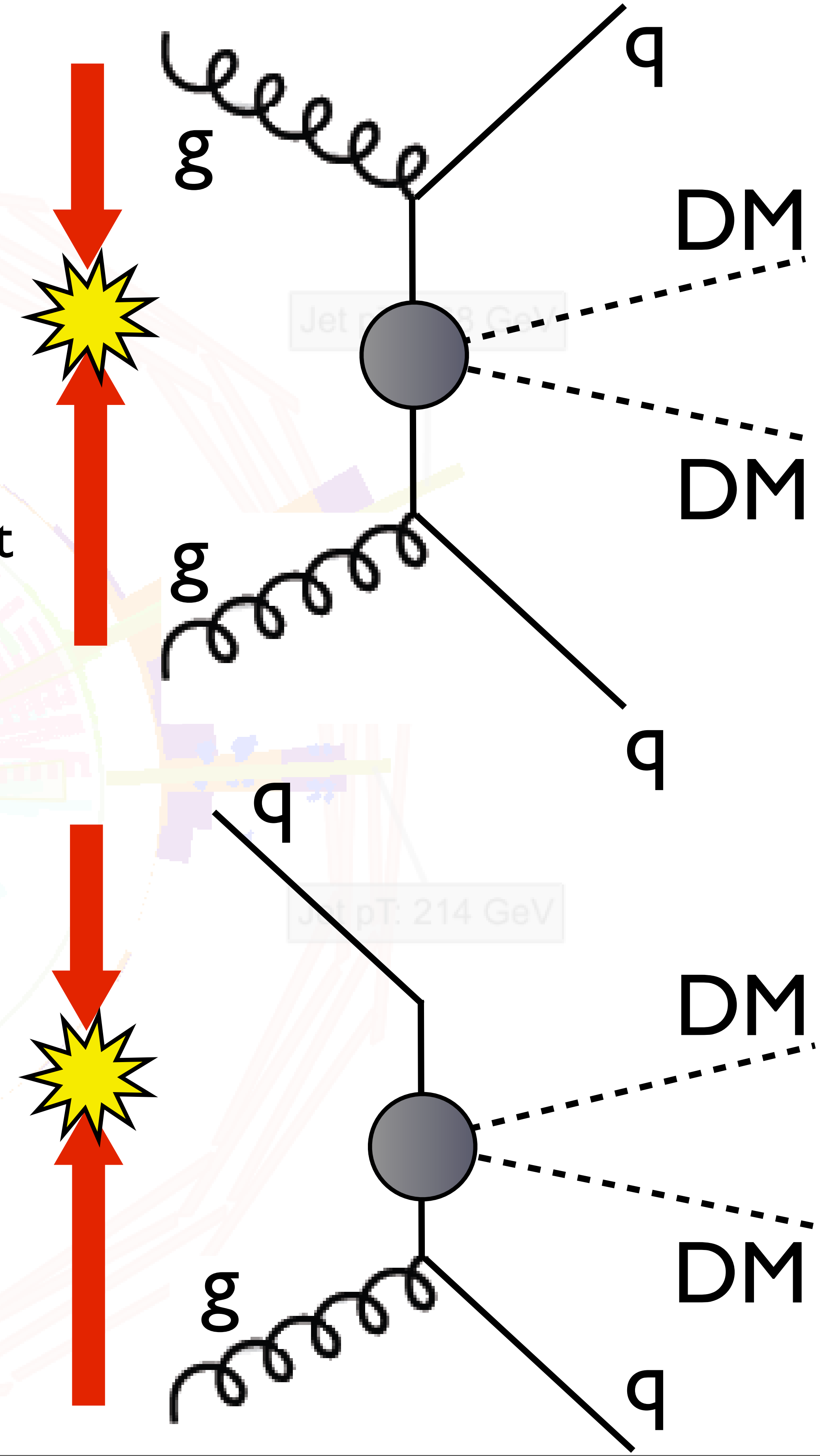
$$\mathcal{O}_g = \alpha_s \frac{(\bar\chi\chi)\left(G^a_{\mu\nu}G^{a\mu\nu}\right)}{\Lambda^3} \quad \text{S, s-ch}$$



arXiv:1109.4398v1 [hep-ph]

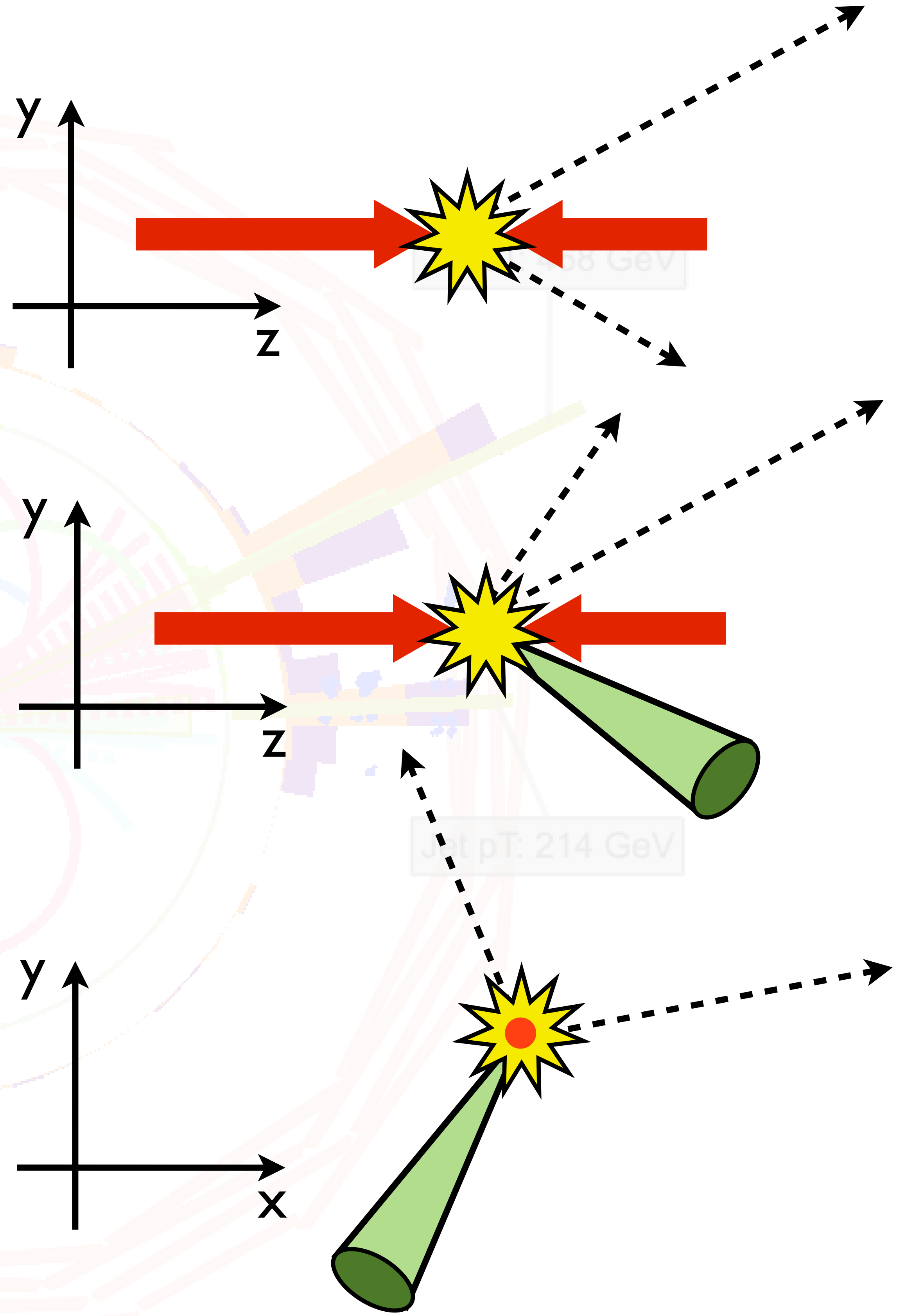
Searches at the LHC

- The ATLAS and CMS experiments @LHC are multipurpose experiments
- Their main goal is the investigation of the EW symmetry breaking mechanism. The search for the Higgs boson is the first step along this path
- Due to the detector design, the Higgs boson is not the only thing we can look for
- Many things can emerge from the collision of two protons. DM is just another item in along shopping list (including KK resonances, top partners, SUSY particles, leptoquarks, heavy neutrinos, etc.)
- Being a proton collider at high energy, the LHC is essentially a gluon collider. This means that the most of the DM could be pair-produced only with associated jets. Other processes (e.g. qg) become competitive



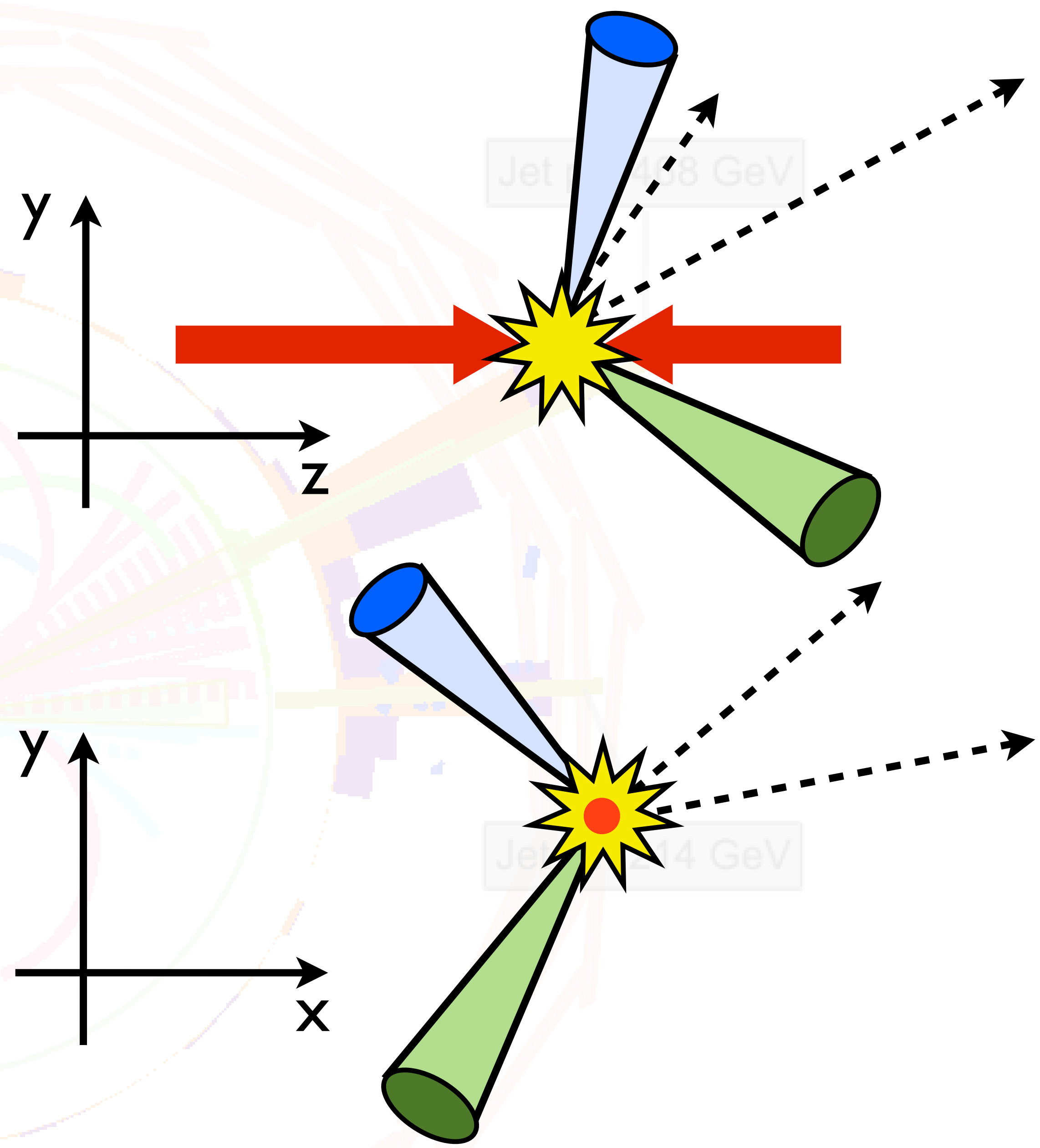
DM Direct Production@LHC

- LHC could pair-produce DM particles in pp invisible collisions.
- We can trigger these events only in presence of some detector activity connected to it
- The emission of one jet or photon in the collision (initial state radiation, ISR) let us access these events
- The unbalancing on the transverse plane allows to access the events through missing energy



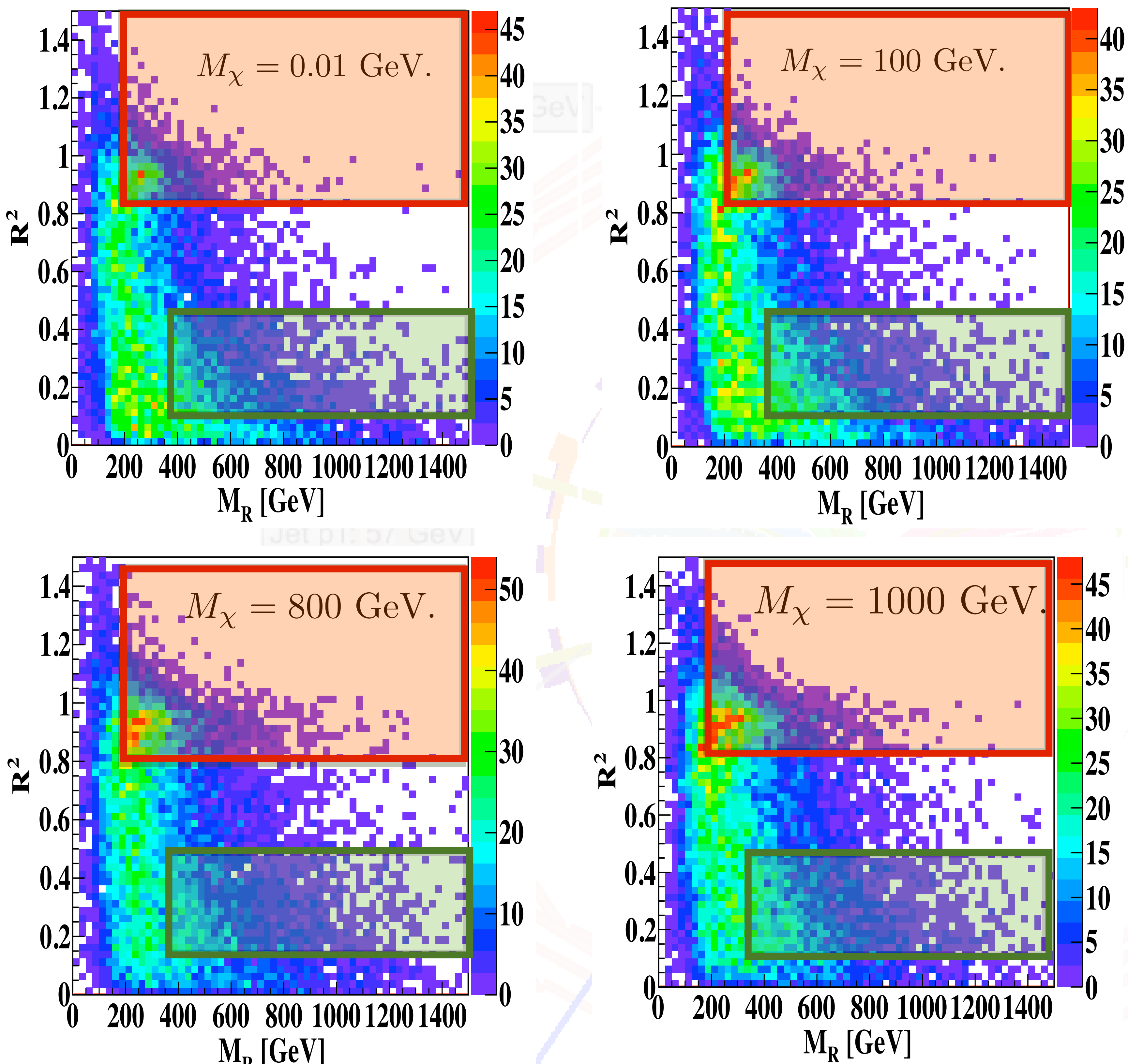
DM with Double ISR

- In a large fraction of the events, DM direct production comes with double ISR
- This is why the monojet analyses don't veto the presence of a second jet
- On the other hand (as for the "classic" vs Razor searches) one can do more
- With double ISR we go back to the case of 2jets + 2 missing particles: we can use again the razor, but with some difference



Patrick J. Fox, 1, Roni Harnik, Reinard Primulando, and Chiu-Tien Yu
arXiv:1203.1662v1 [hep-ph] 8 Mar 2012

Direct DM on Razor plane



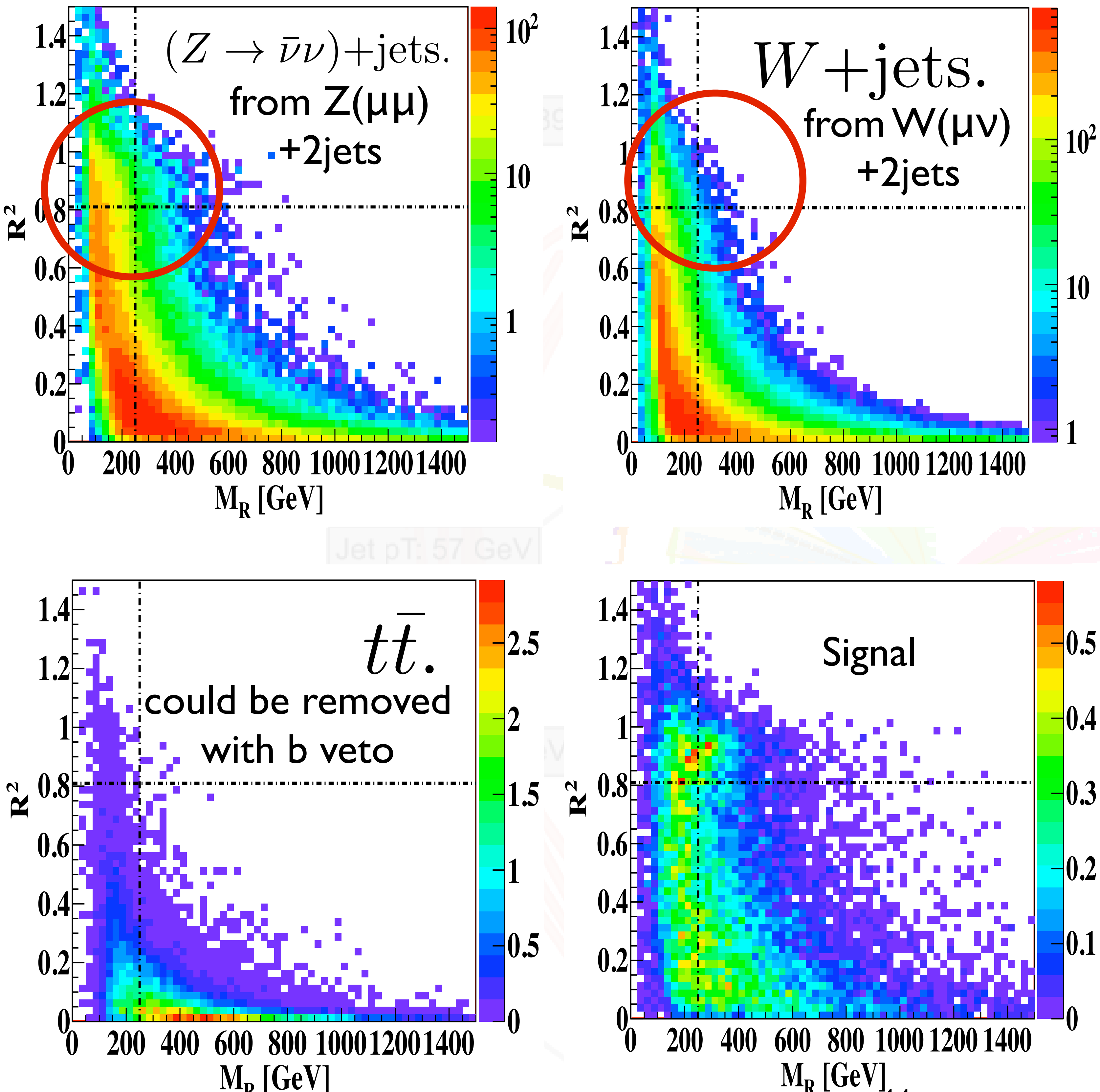
There is some signal in the region explored by the current search, but it's a tail on a tail (difficult to see)

On the other hand, the signal is more abundant at low M_R and large R^2

Background suppressed by the drop in R^2, despite the low value of M_R

Background cannot be modeled analytically in that region (see next slide)

Background from SM



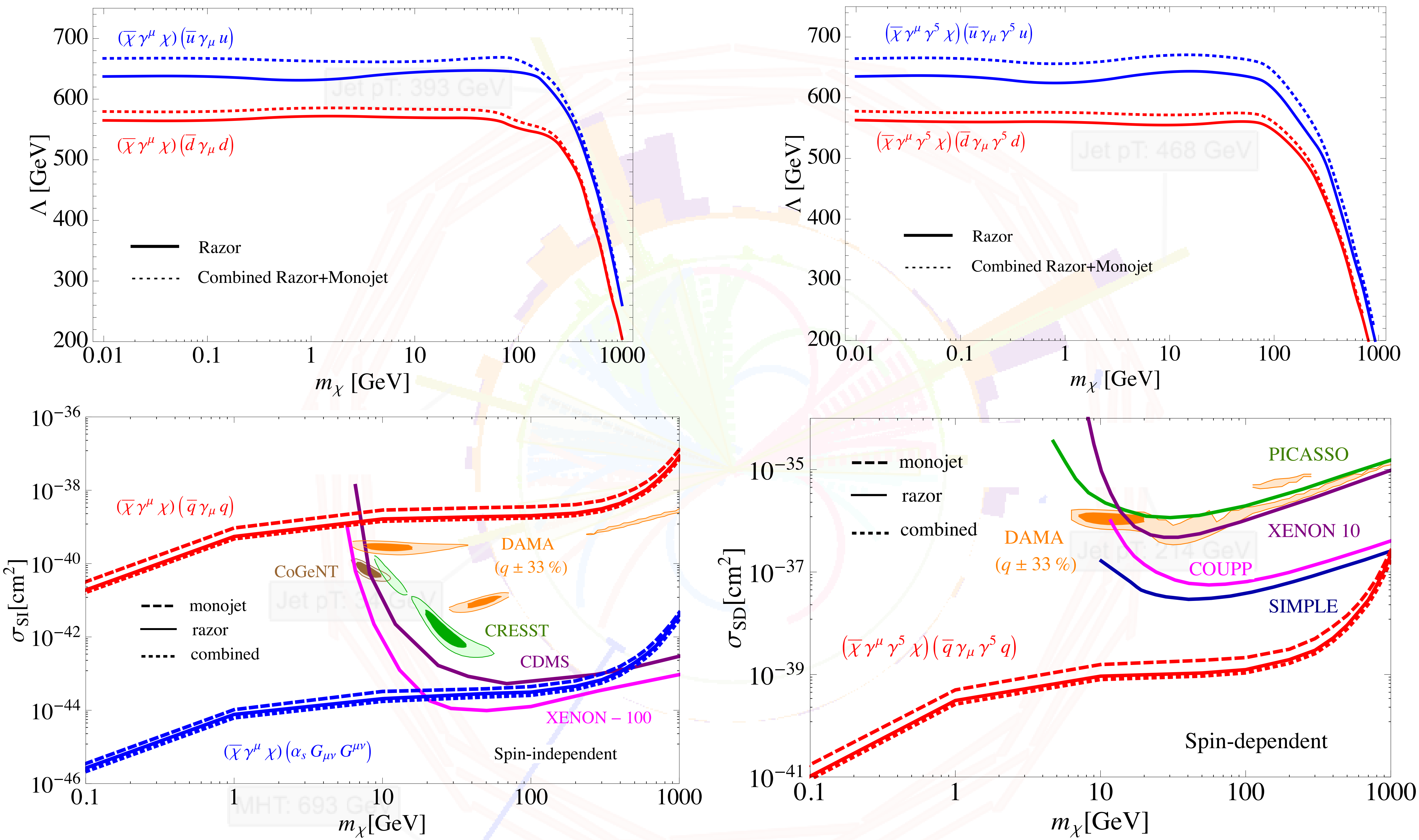
The analytical parameterization breaks because we go close to the threshold for R

We can instead use a template 2D histogram from the background using 2m and 1m control samples (rescaling by efficiency from MC)

ttbar can be eliminated with a bjet veto

The big challenge is the trigger. Region is mangled by 2011 trigger. But it will be possible to look there with 2012 triggers (improved design)

Expected Sensitivity

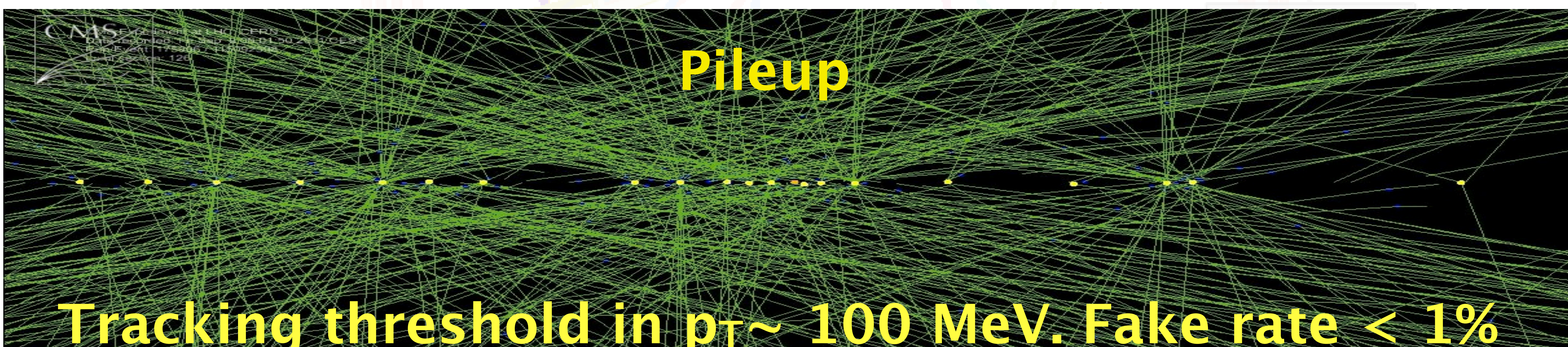


Perspectives

- We are now considering a razor search in the high-R^2/low-M_R region
- The analysis is more complicated, since the bkg analytical model breaks in that region
- We need to use a template histogram for the bkg
- We can use 1m and 2m samples as control sample (as in monojet analysis) to predict the background shapes
- We will try to have results by the Summer

Conclusion

- LHC operations have been a great success so far
- But still missing a big physics result
- 2012 should be the year for the final word on Higgs
- We are keeping our eyes open in all possible direction
- The increase of beam energy could open new perspectives
- But this comes with worse environmental conditions, pileup challenging us from data taking to event cleanup to analysis



Basic/Incomplete Bibliography

- ATLAS SUSY results

  https://twiki.cern.ch/twiki/bin/view/AtlasPublic/SupersymmetryPublicResults

- CMS SUSY results

  https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS

- A few papers
  - Original paper on α http://arxiv.org/pdf/0806.1049
  - Modified α_T paper by CMS http://cdsweb.cern.ch/record/1149915/files/SUS-08-005-pas.pdf
  - MT2 http://arXiv.org/pdf/hep-ph/0304226 http://arxiv.org/pdf/0810.5576v2
  - $\sqrt{s}_{min}$ http://www.arxiv.org/pdf/1006.0653
  - Razor http://arxiv.org/pdf/1006.2727

Backup


Jet pT: 393 GeV
Jet pT: 468 GeV
Jet pT: 57 GeV
Jet pT: 214 GeV
Jet pT: 34 GeV
MHT: 693 GeV

M_{T2}: two missing particles

- If we could see all the particles, we could compute

$$m^2_{\chi_1^+} = m^2_\pi + m^2_{\chi_1^0} + 2\left[E_T^\pi E_T^{\chi_1^0}\cosh(\Delta\eta) - \mathbf{p}_T^\pi \cdot \mathbf{p}_T^{\chi_1^0}\right]$$

- If we could measure $p_T(X^0)$, but not $p_z(X^0)$, the best we could do would be

$$m_T^2(\mathbf{p}_T^\pi, \mathbf{p}_T^{\chi_1^0}; m_{\chi_1^0}) \equiv m^2_{\pi^+} + m^2_{\chi_1^0} + 2(E_T^\pi E_T^{\chi_1^0} - \mathbf{p}_T^\pi \cdot \mathbf{p}_T^{\chi_1^0})$$

- Since cosh>1, $m_T \leq m$, the equality holding for both $p_z(X^0)=0$. This means that $\max(m_T)$ has an "edge" at m

- For each event we have two values of m_T (two copies of the same decay). Both are such that $m_T<m$. This means that $\max(m_T(1), m_T(2))<m$

- We only know $p_T(X^0_1)+ p_T(X^0_2)=E_T^{miss}$. A wrong assignment of the missing momenta brakes the $m_T<m$ condition. But the condition would hold for the correct assignment. This means that $\min(m_T)<m_T(\text{true})<m$.

- This defined m_{T2} as

$$m^2_{T2}(\chi) \equiv \min_{\not{q}_T^{(1)}+\not{q}_T^{(2)}=\not{p}_T}\left[\max\left\{m_T^2(\mathbf{p}_T^{\pi^{(1)}}, \not{q}_T^{(1)};\chi),\ m_T^2(\mathbf{p}_T^{\pi^{(2)}}, \not{q}_T^{(2)};\chi)\right\}\right]$$

M_{T2}: two missing particles

- The variable we have is a function of the mass of the LSP

- <u>SUSY characterization:</u>

  - Scan the LSP mass and look for the edge developing in your sample of SUSY events (if you have one...)

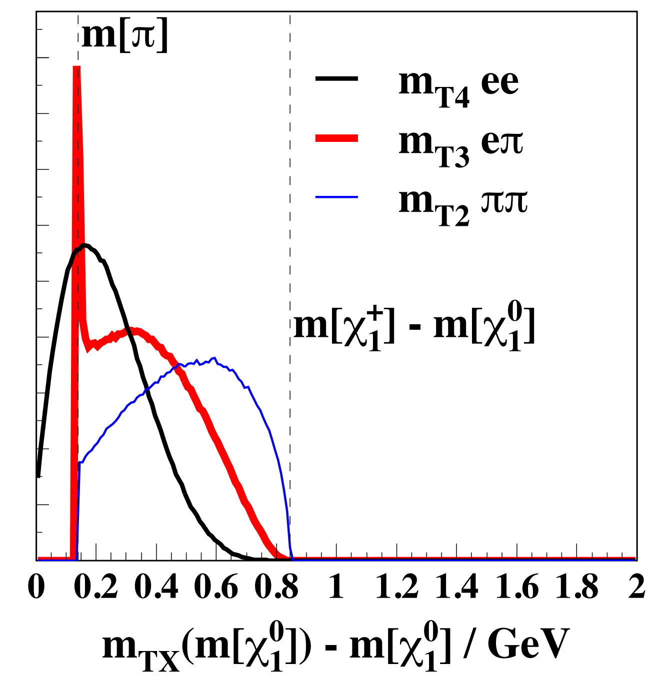


Figure 3: *Simulations of* $m_{TX}(m_{\chi_1^0}) - m_{\chi_1^0}$ *for* $X = 2, 3, 4$ *using a simple phase-space Monte-Carlo generator program for a pair of decays* $\tilde{q} \to \chi_1^+ q$ *followed by* $\chi_1^+ \to \chi_1^0\ \pi$ *or* $\chi_1^+ \to \chi_1^0\ e\ \nu_e$*. As the number of invisible particles increases, the proportion of events near the upper limit decreases. Within the figure, subscripts are indicated by square brackets.*

- <u>SUSY search:</u>

  - Assume a mass value (eg mLSP=0)
  - Assume that the visible system in has 0 mass
  - An analytical expression for M_{T2} is found

$$(M_{T2})^2 = 2A_T = 2p_T^{vis(1)} p_T^{vis(2)} (1 + cos\phi_{12})$$

  - The edge is lost but we have an α_T-like variable to kill the QCD