CMS Theory Outreach

Maurizio Pierini
CERN

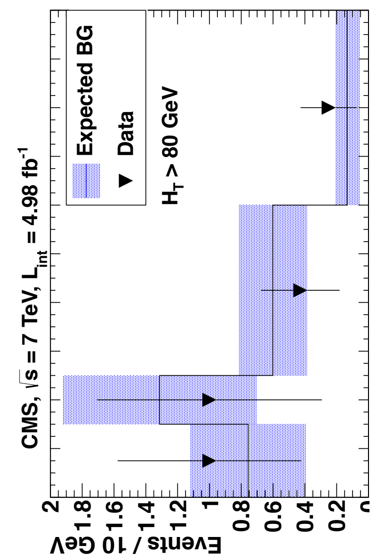
Outline

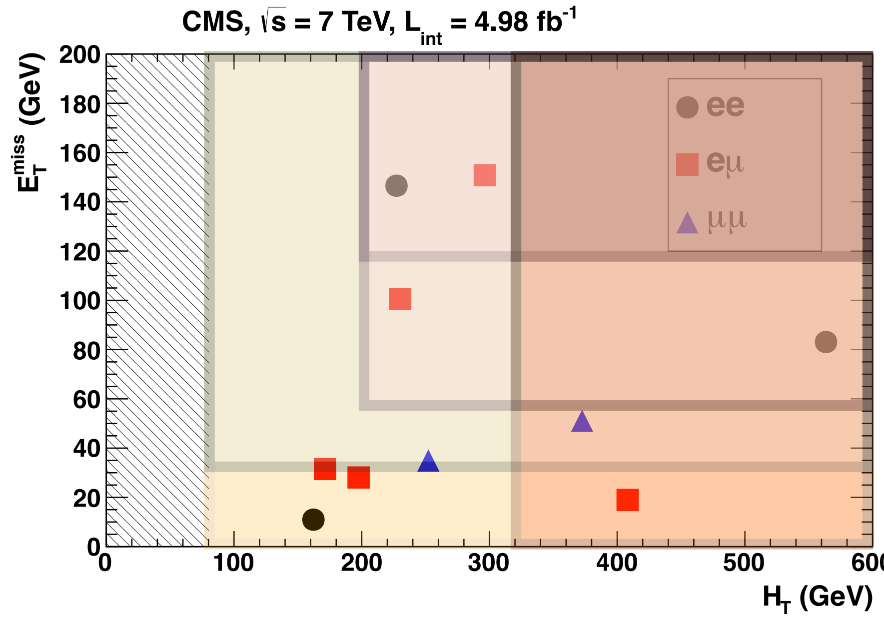
- I will discuss two examples of SUSY analyses and how they could be implemented in a phenomenology study
- I start with a simple cut&count case (SS Dilepton + btag)
- I then go to a combination of 6 mutually-exclusive razor analyses (Razor)
- For both I discuss how to derive the ingredients (efficiency and shape) and how to get the limit out
- When possible, I show a comparison between the outreach and the official results

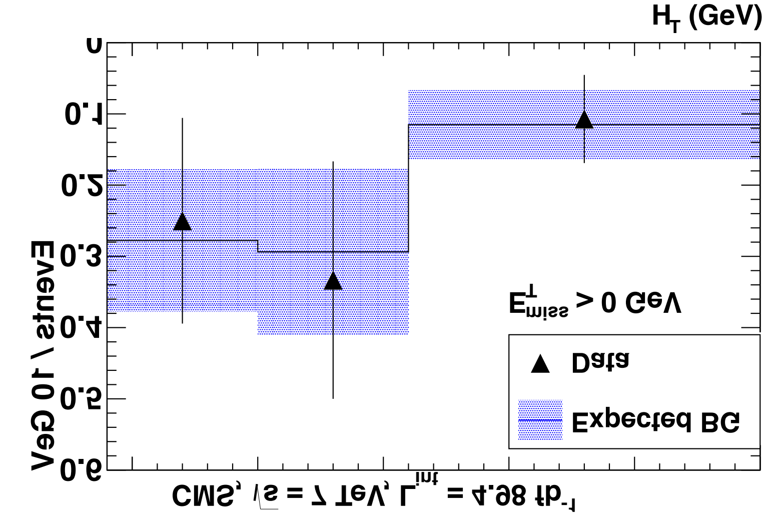
SS Dilep + Btag

The SS+Btag Analysis

- Look for events with two jets
- Requite two SS leptons (any flavor)
- Ask for two btags
- Counting experiment in eight overlapping regions of the HT vs MHT plane
- Quote the best of the eight limits

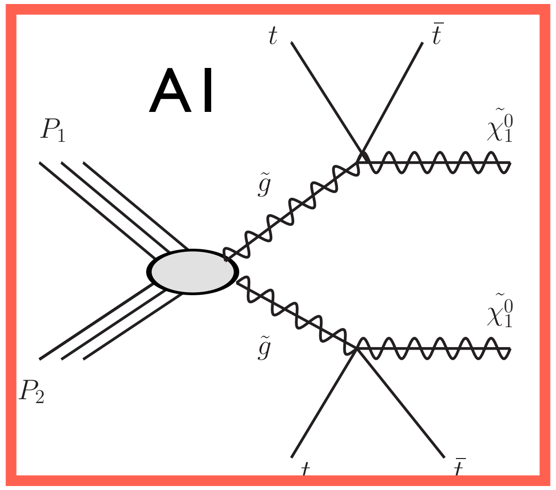


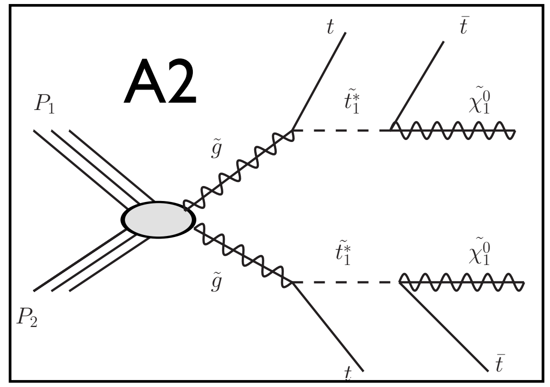


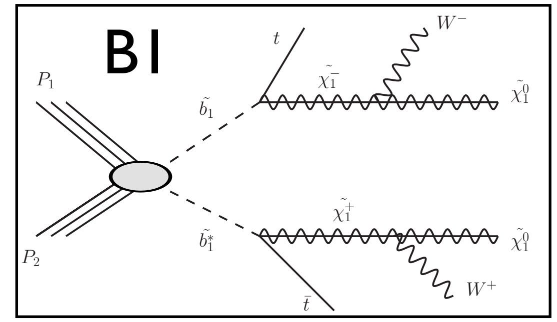


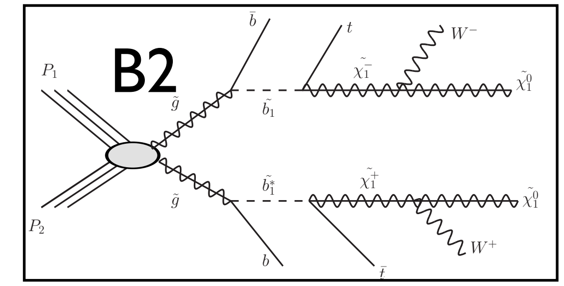
	SR0	SR1	SR2	SR3	SR4	SR5	SR6	SR7	SR8
No. of jets	≥ 2	≥ 2	≥ 2	≥ 2	≥ 2	≥ 2	≥ 2	≥ 3	≥ 2
No. of b-tags	≥ 2	≥ 2	≥ 2	≥ 2	≥ 2	≥ 2	≥ 2	≥ 3	≥ 2
Lepton charges	$++/--$	$++/--$	$++$	$++/--$	$++/--$	$++/--$	$++/--$	$++/--$	$++/--$
E_T^{miss}	> 0 GeV	> 30 GeV	> 30 GeV	> 120 GeV	> 50 GeV	> 50 GeV	> 120 GeV	> 50 GeV	> 0 GeV
H_T	> 80 GeV	> 80 GeV	> 80 GeV	> 200 GeV	> 200 GeV	> 320 GeV	> 320 GeV	> 200 GeV	> 320 GeV
Charge-flip BG	1.4 ± 0.3	1.1 ± 0.2	0.5 ± 0.1	0.05 ± 0.01	0.3 ± 0.1	0.12 ± 0.03	0.03 ± 0.01	0.008 ± 0.004	0.20 ± 0.05
Fake BG	4.7 ± 2.6	3.4 ± 2.0	1.8 ± 1.2	0.3 ± 0.5	1.5 ± 1.1	0.8 ± 0.8	0.15 ± 0.45	0.15 ± 0.45	1.6 ± 1.1
Rare SM BG	4.0 ± 2.0	3.4 ± 1.7	2.2 ± 1.1	0.6 ± 0.3	2.1 ± 1.0	1.1 ± 0.5	0.4 ± 0.2	0.12 ± 0.06	1.5 ± 0.8
Total BG	10.2 ± 3.3	7.9 ± 2.6	4.5 ± 1.7	1.0 ± 0.6	3.9 ± 1.5	2.0 ± 1.0	0.6 ± 0.5	0.3 ± 0.5	3.3 ± 1.4
Event yield	10	7	5	2	5	2	0	0	3
N_{UL} (12% unc.)	9.1	7.2	6.8	5.1	7.2	4.7	2.8	2.8	5.2
N_{UL} (20% unc.)	9.5	7.6	7.2	5.3	7.5	4.8	2.8	2.8	5.4
N_{UL} (30% unc.)	10.1	7.9	7.5	5.7	8.0	5.1	2.8	2.8	5.7

The SS+Btag Results

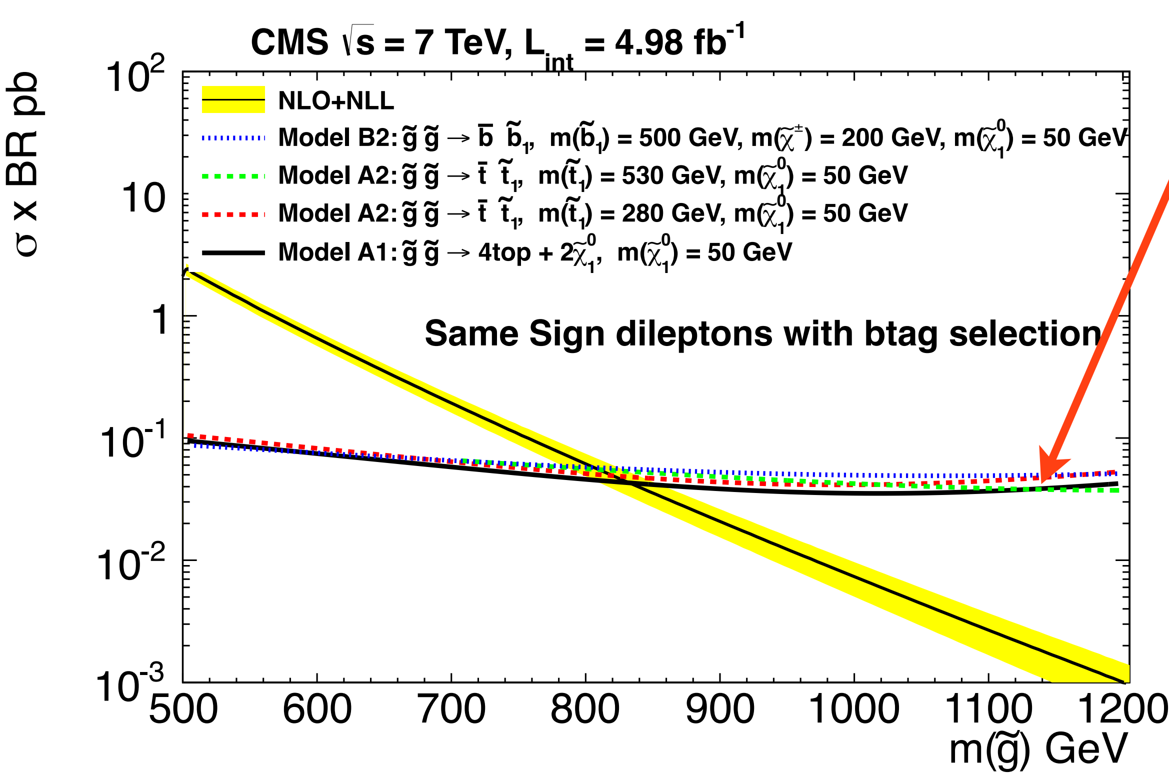


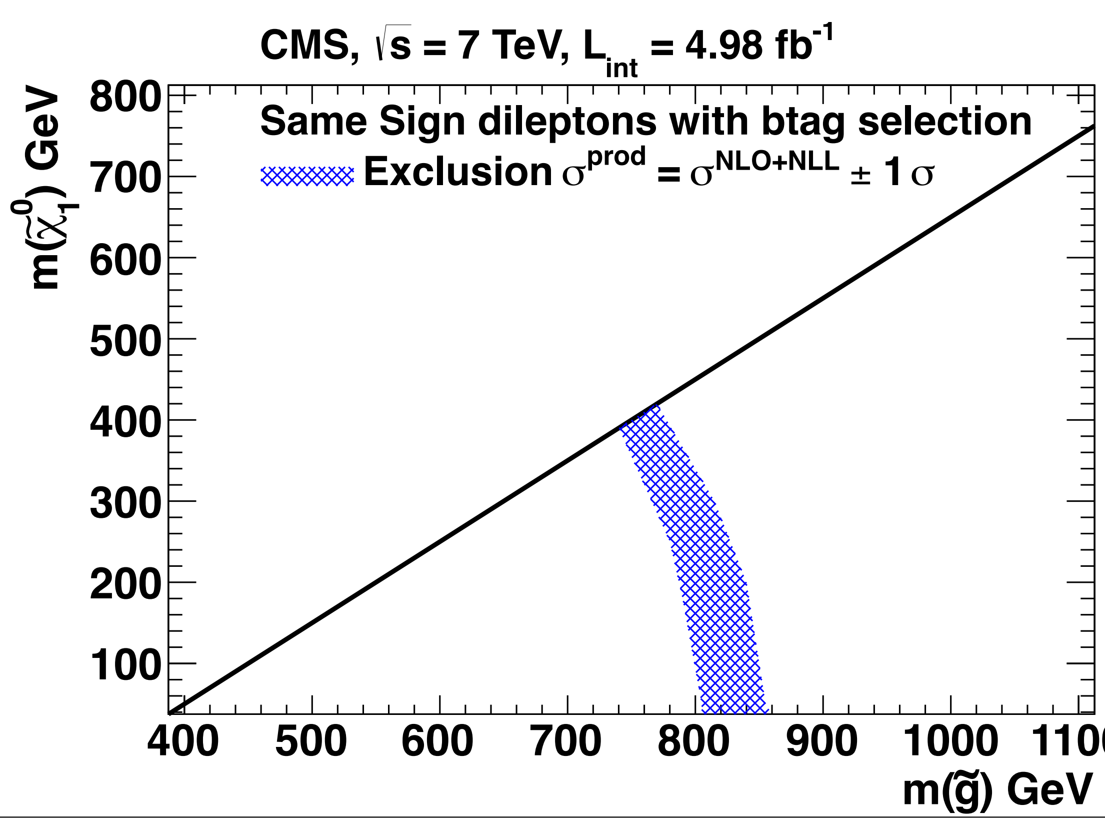






- No excess found
- Several models considered to put limits
- We will try to reproduce their A1 result for the specific case of $m(\tilde{\chi}^0)$=50 GeV

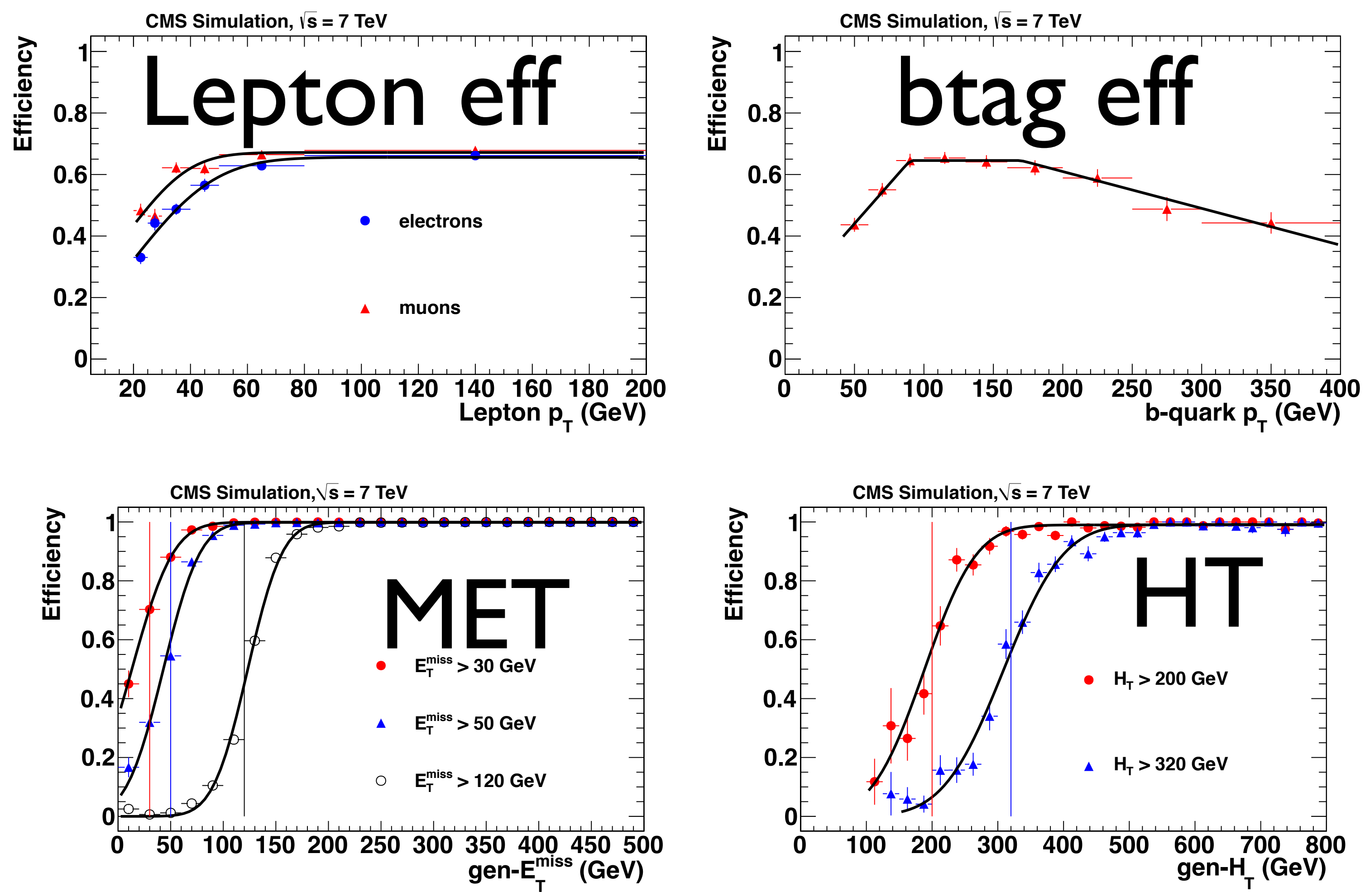




The Theory Outreach

CMS provides the information in the paper to reproduce the analysis

- Efficiency for each physics object, as a function of the pT of the generator-level particle

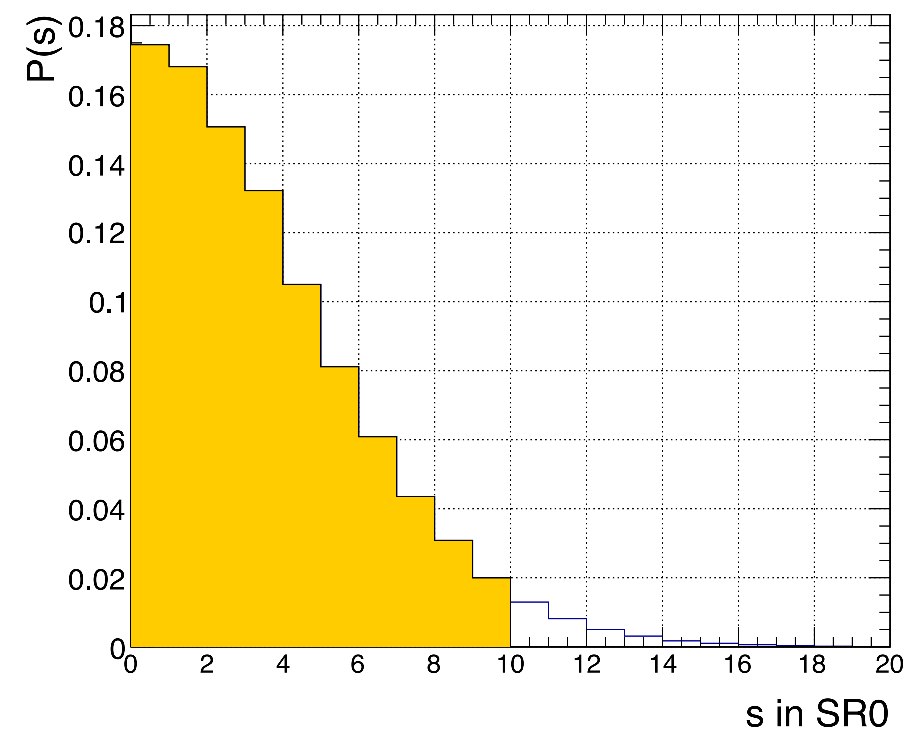


- Number of observed events, expected, and error on the expected

- A set of yield UL for different assumed errors, to calibrate the statistical method used offline

The procedure

$$P(s)=\int_0^{+\infty} db\ Poisson(n|s+b)\ LogNorm(b|b,\delta b)$$



To get the signal efficiency

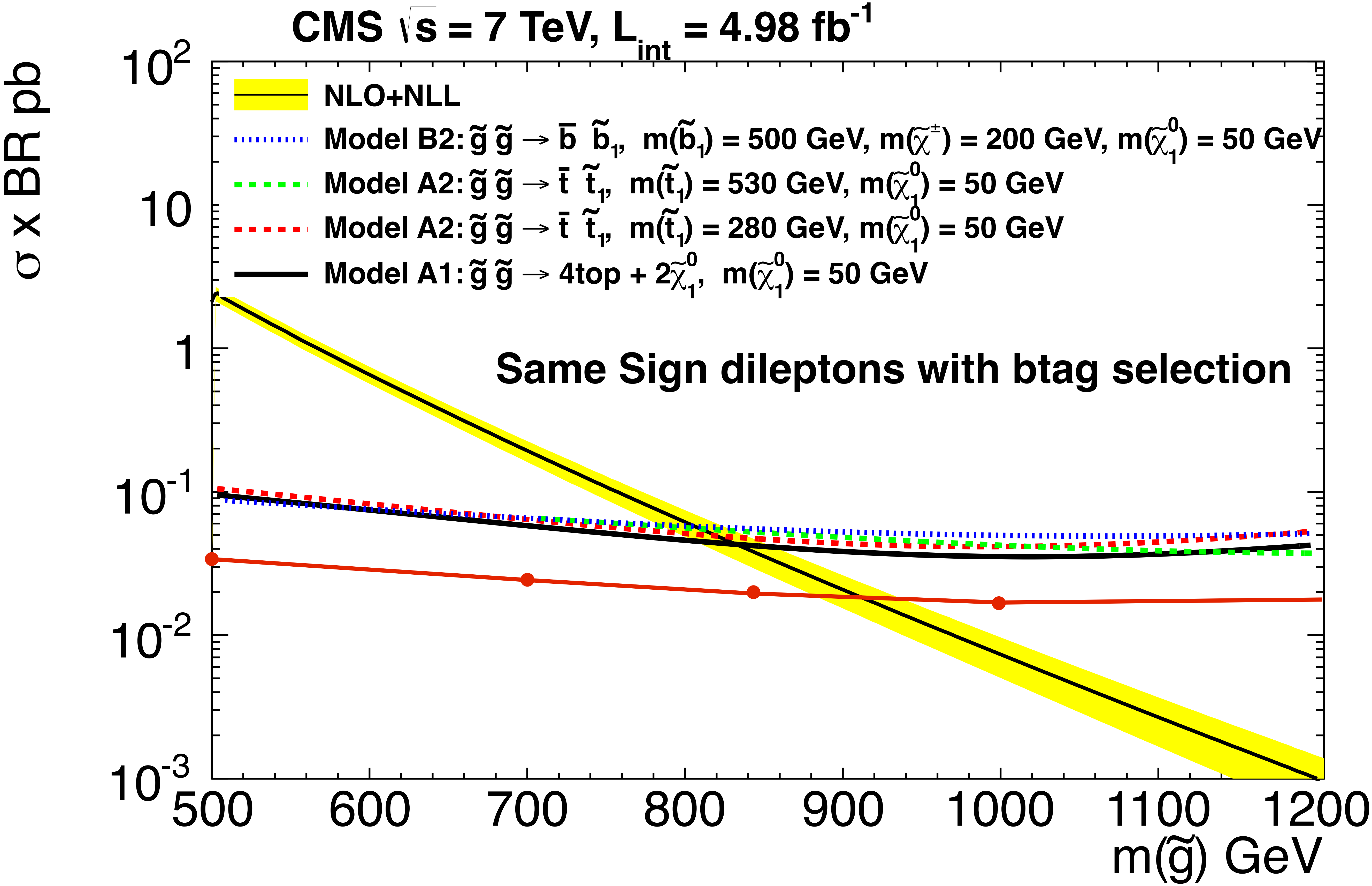
- Generate SUSY events for a given point of the SMS plane (I used pythia8 here)
- Reconstruct gen-jets (I used anti-Kt with R=0.5)
- Apply the analysis cuts at gen level
- Use hit OR miss to accept or reject the event

To evaluate the limit

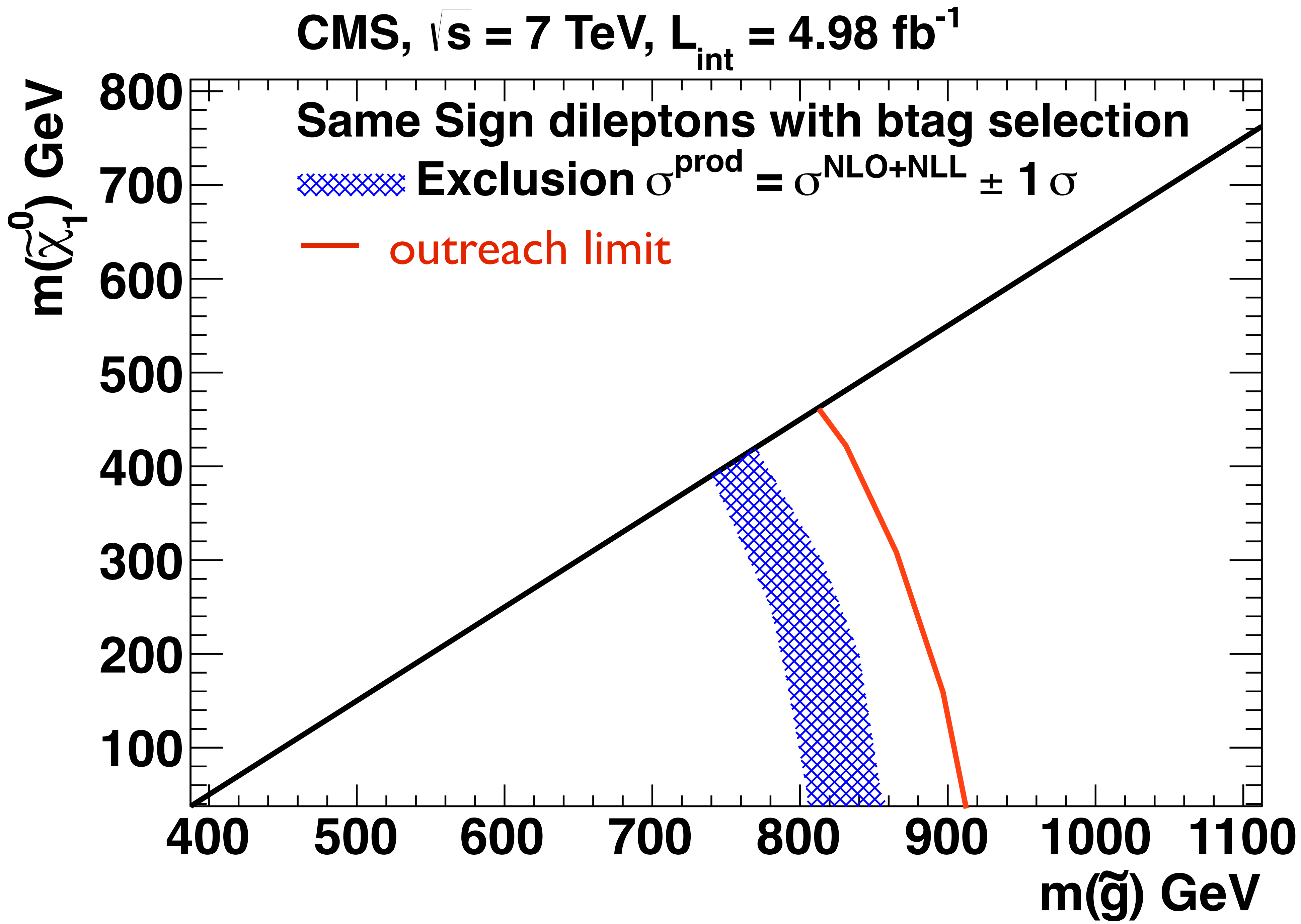
- Derive a posterior for the signal yield in each region
- Convolute that with a given error on the signal (I used 305 everywhere)
- Compute a 95% upper limit integrating the posterior
- This gives the quoted right answer within one event (most probably due to binning effects)

Region	quote UL	my UL
SR0	10.1	9.8
SR1	7.9	7.5
SR2	7.5	6.1
SR3	5.7	5.5
SR4	8.0	7.7
SR5	5.1	4.1
SR6	2.8	4.0
SR7	2.8	2.0
SR8	5.7	5.4

Comparison to official limit



Comparison to official limit

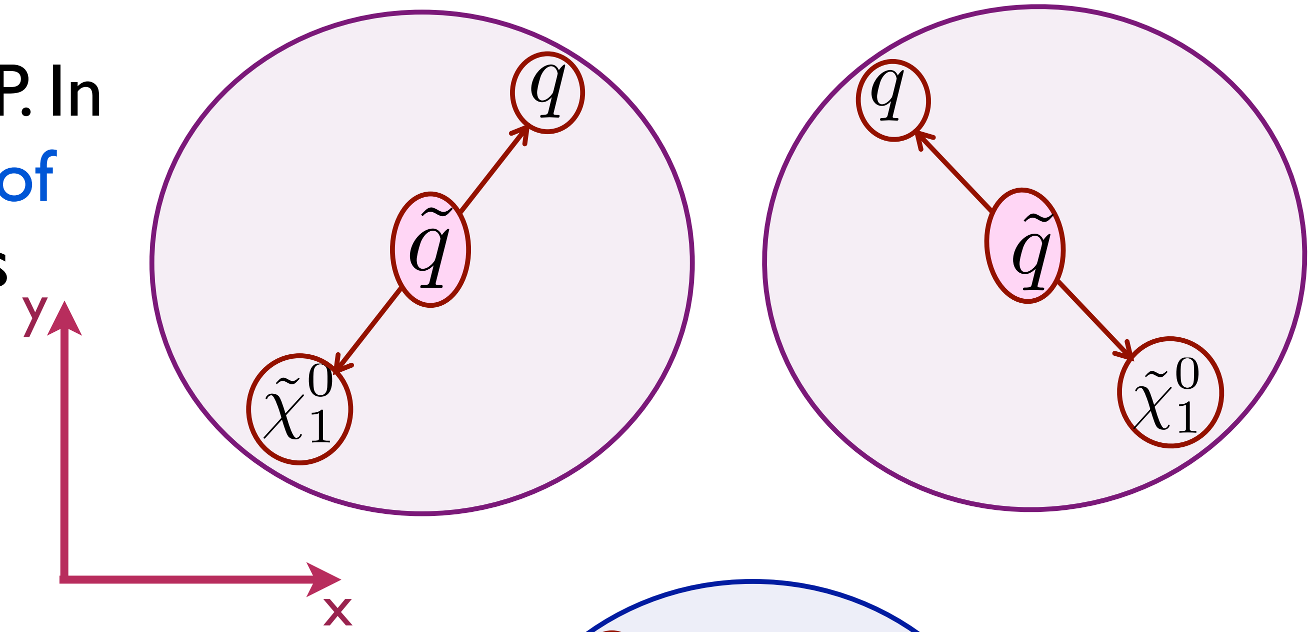


There is some problem somewhere, but a factor-three of (unfortunately on the "wrong" side) is not too bad for 1 day of work

Razor

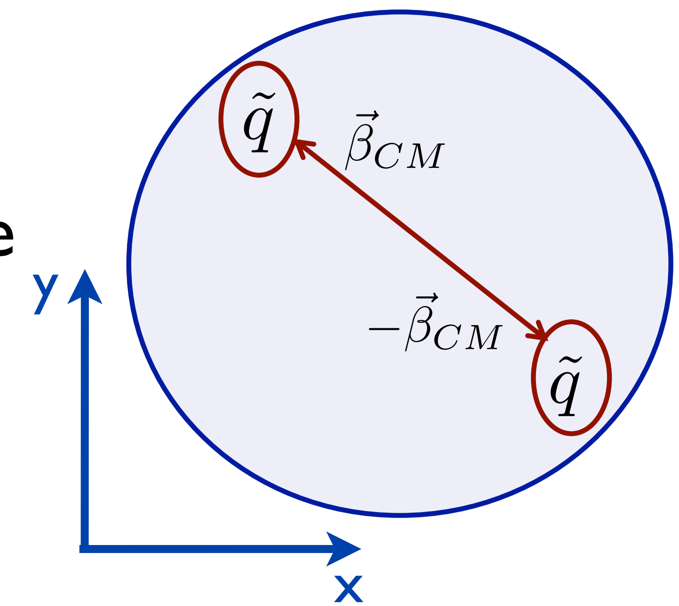
The Razor Frame

- 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

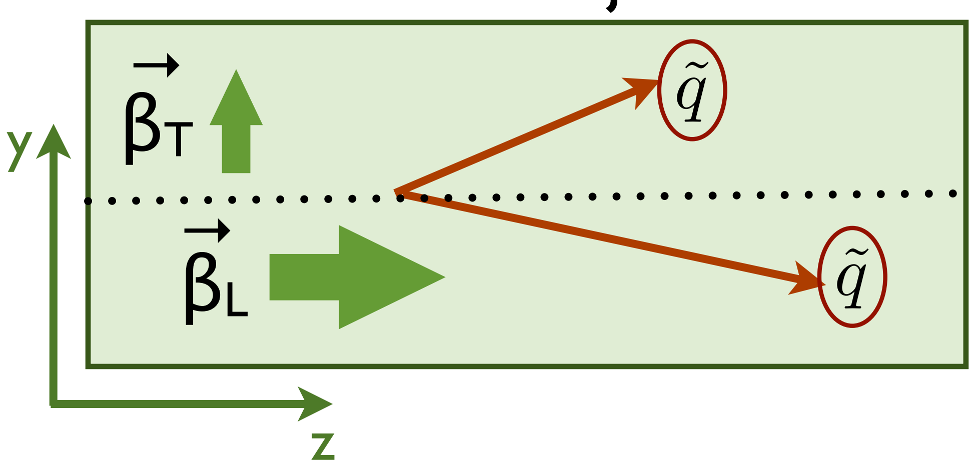


$$\boxed{M_\Delta \equiv \frac{M_{\tilde{q}}^2 - M_{\tilde{\chi}}^2}{M_{\tilde{q}}} = 2M_{\tilde{\chi}}\gamma_\Delta\beta_\Delta}$$

- 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

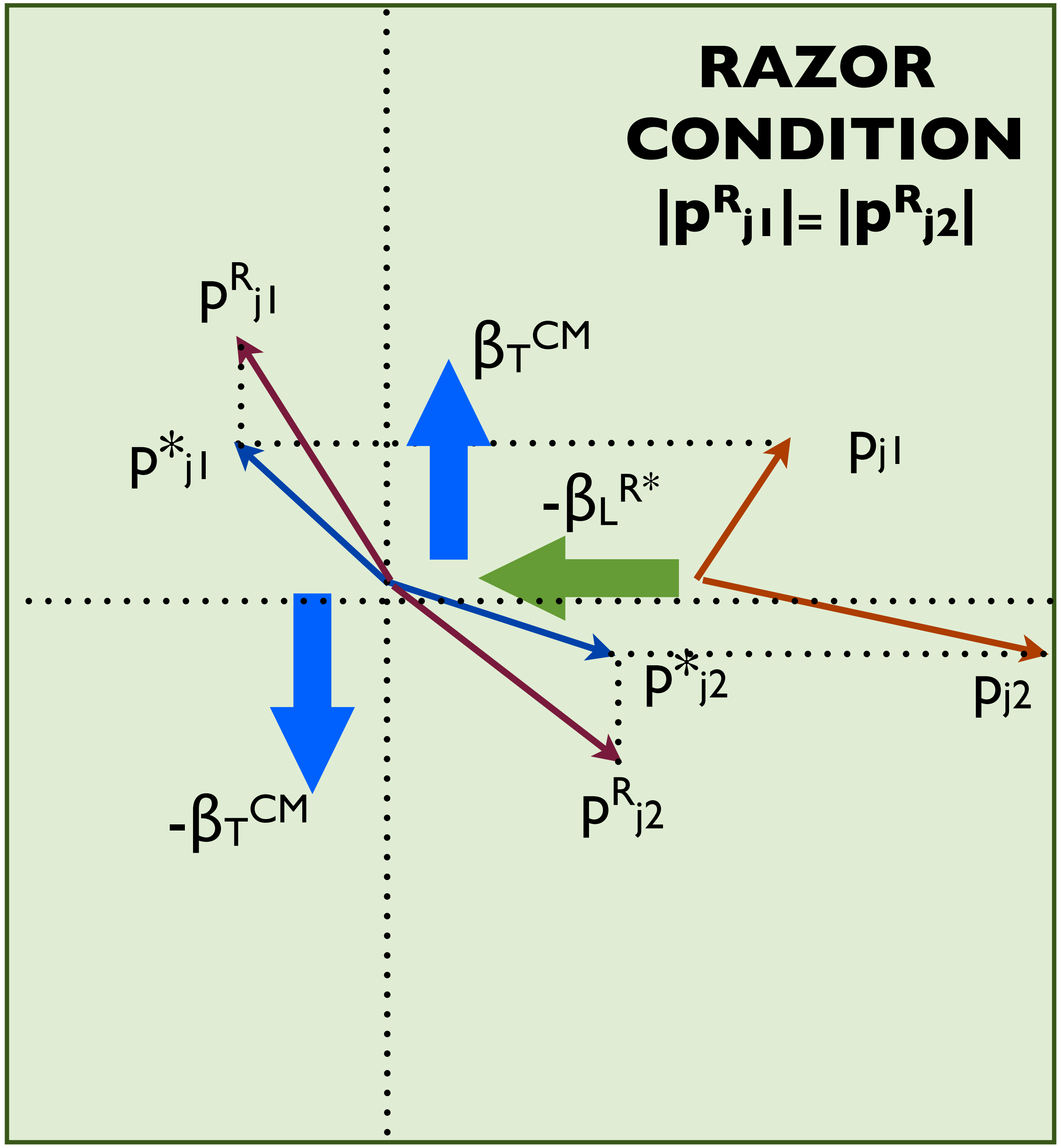
- In reality, the best we can do is to compensate the missing degrees of freedom with assumptions on the boost direction

  - 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

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

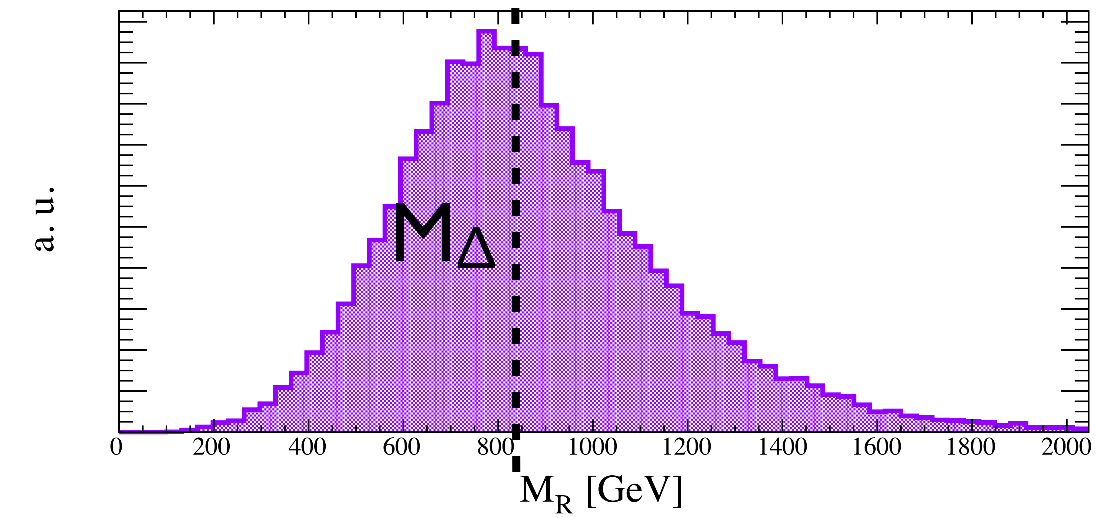


The Razor Variable

- M_R is boost invariant, even if defined from 3D momenta

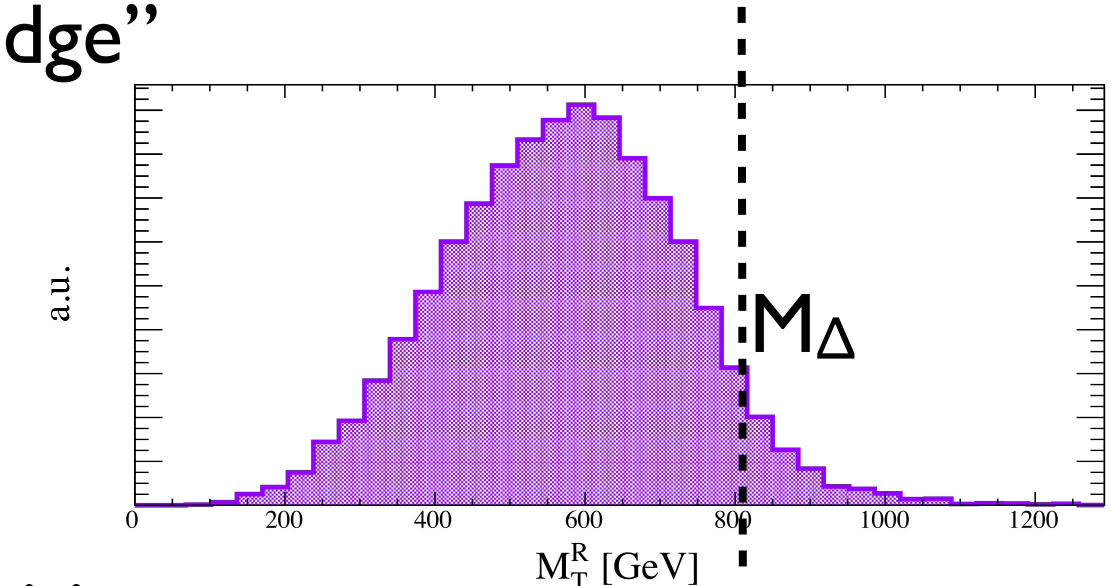
- No information on the MET is used

- 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

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



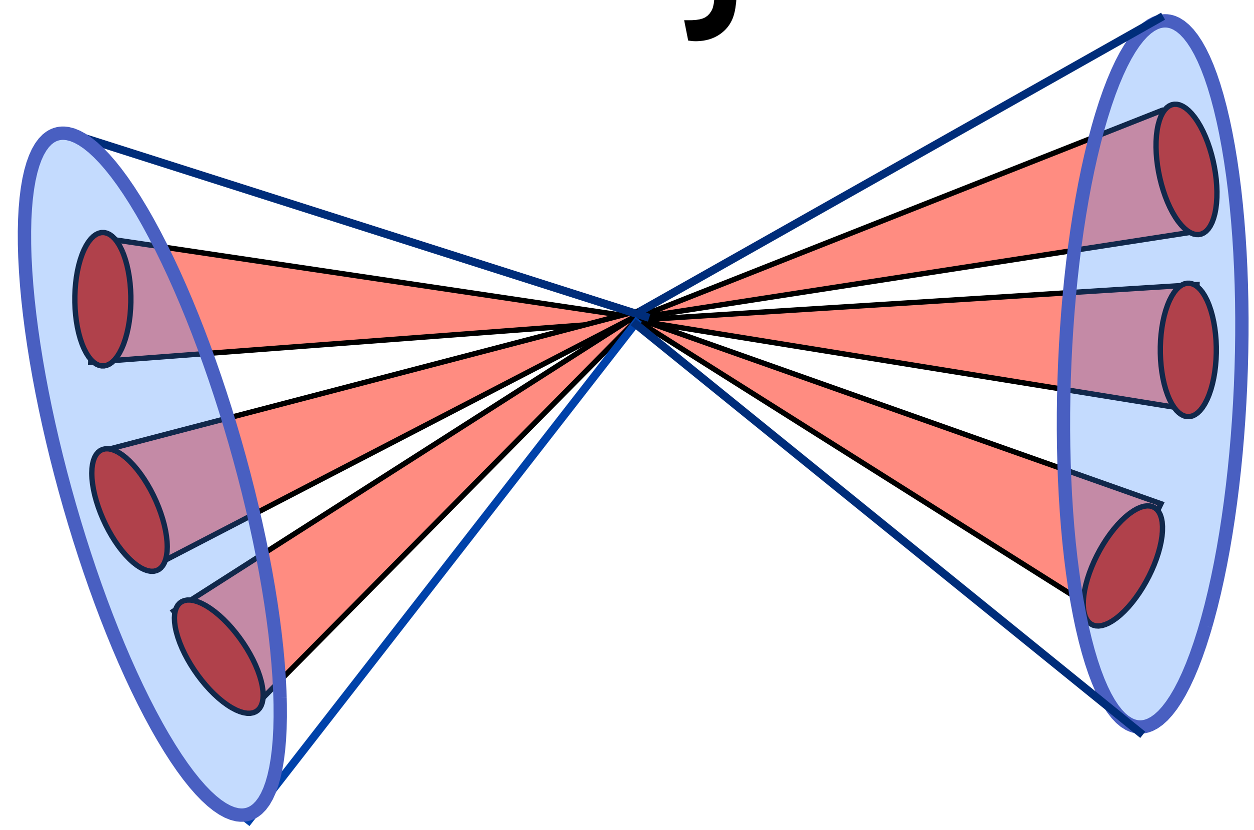
- M_T^R is defined using transverse quantities and it is MET-related

- 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)



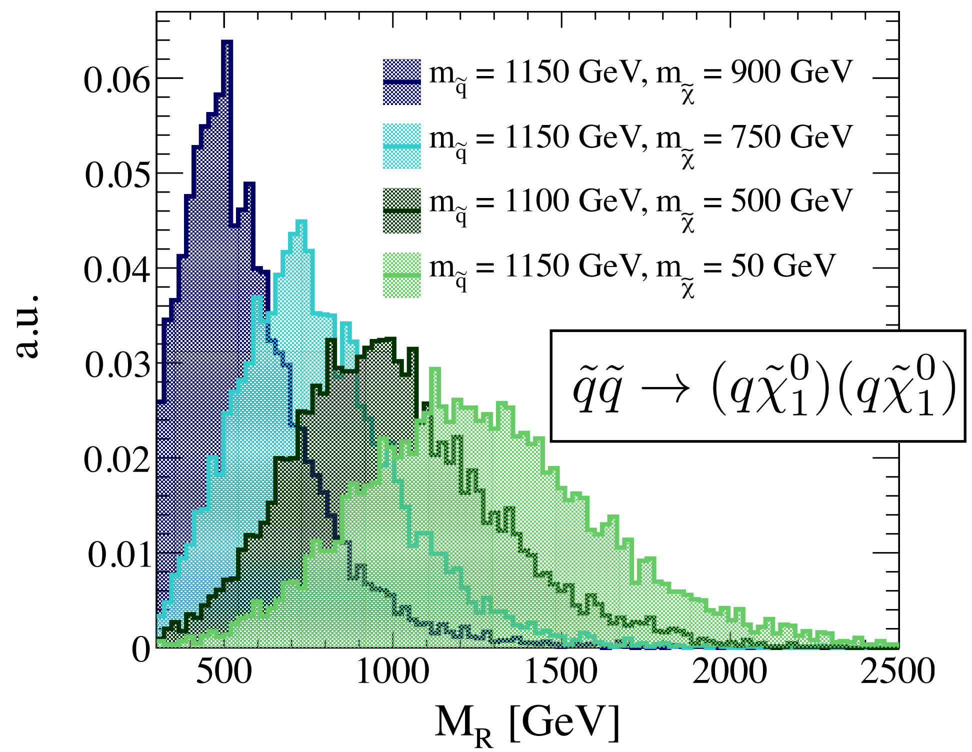
Several approaches used

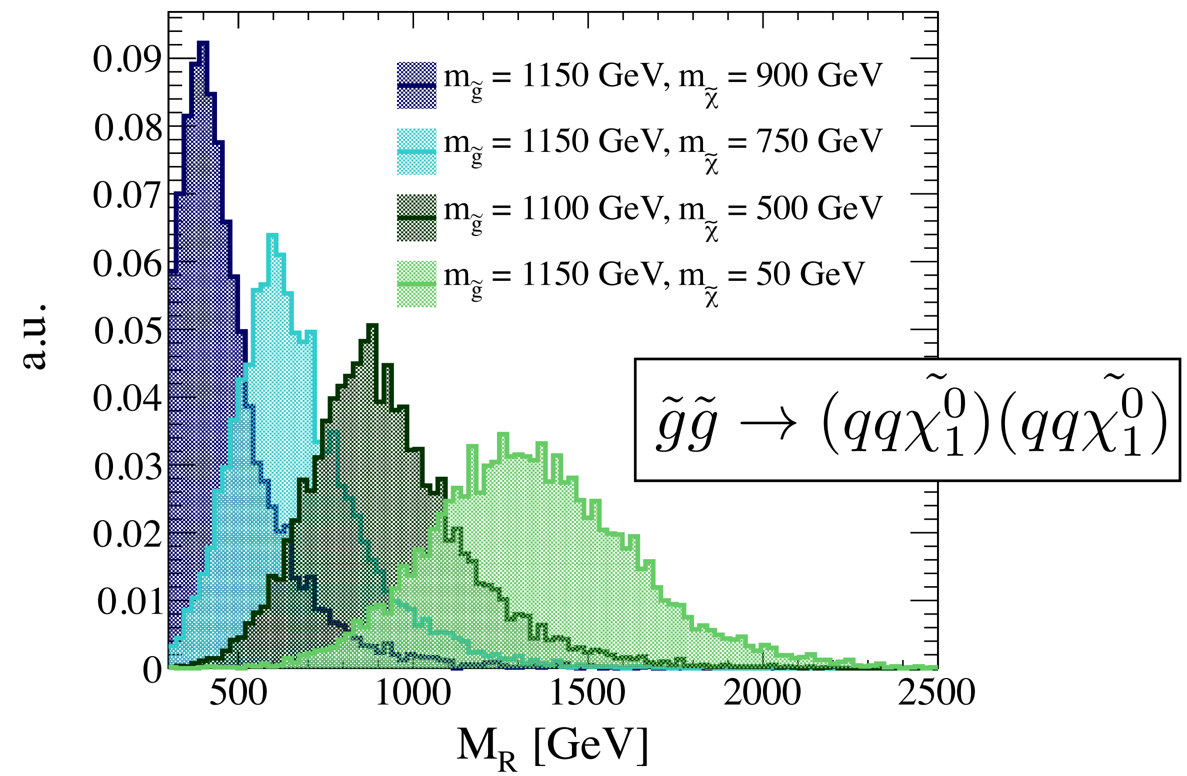
- minimizing the HT difference between the mega-jets (aT CMS)
- minimizing the invariant masses of the two jets (Razor CMS)
- minimizing the Lund distance (MT2 CMS)
- ...

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

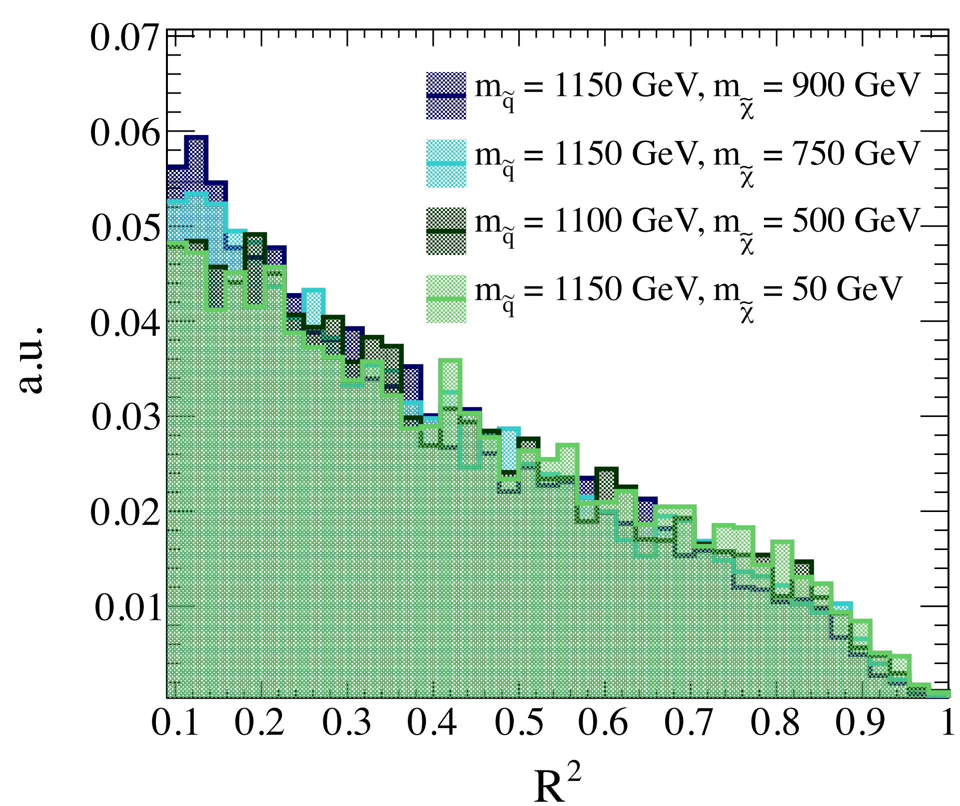
- Is the ultimate hemisphere definition out there (I am not aware of studies on this)?
- Could this improve the signal sensitivity in a significant way?

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

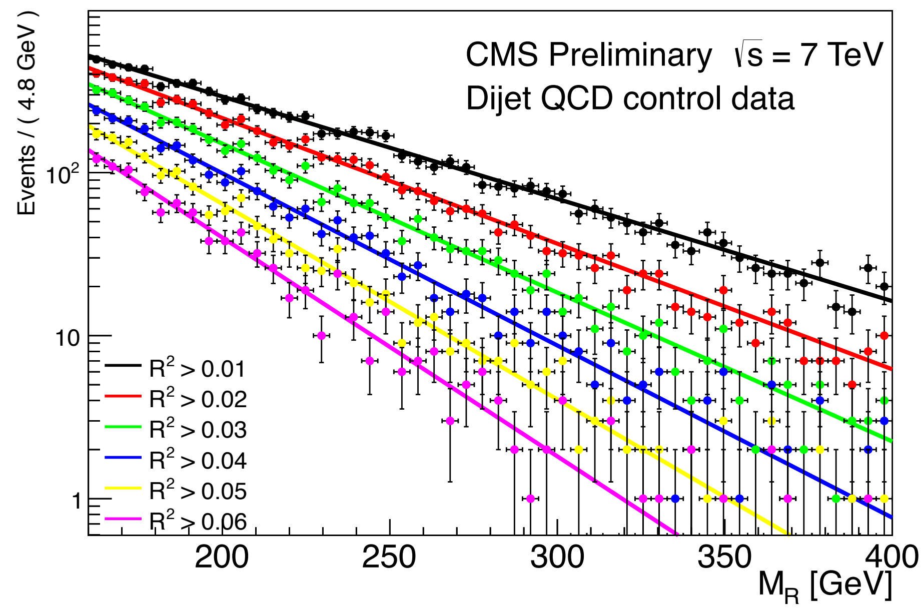
QCD data

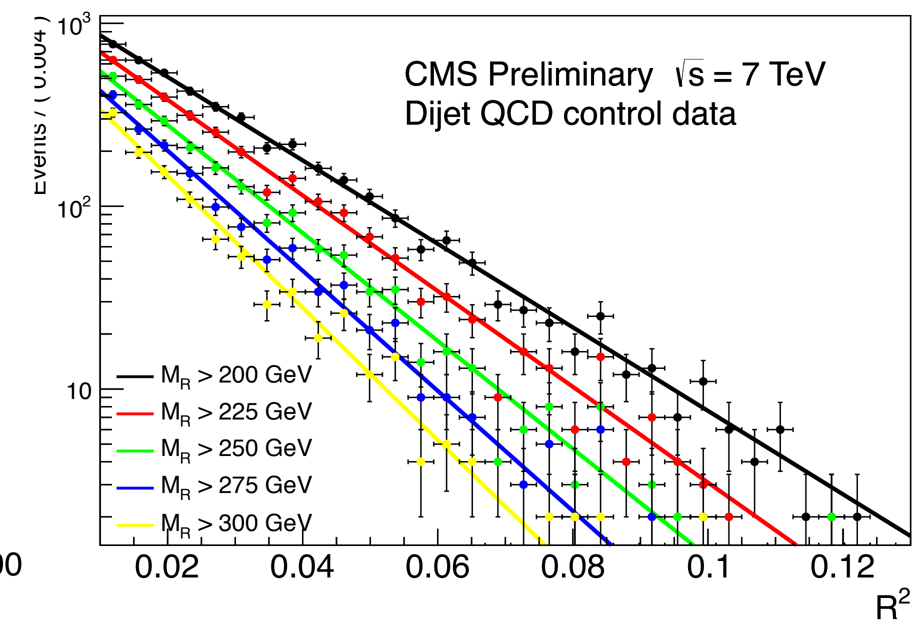
$$f(M_R) \sim e^{-kM_R}$$

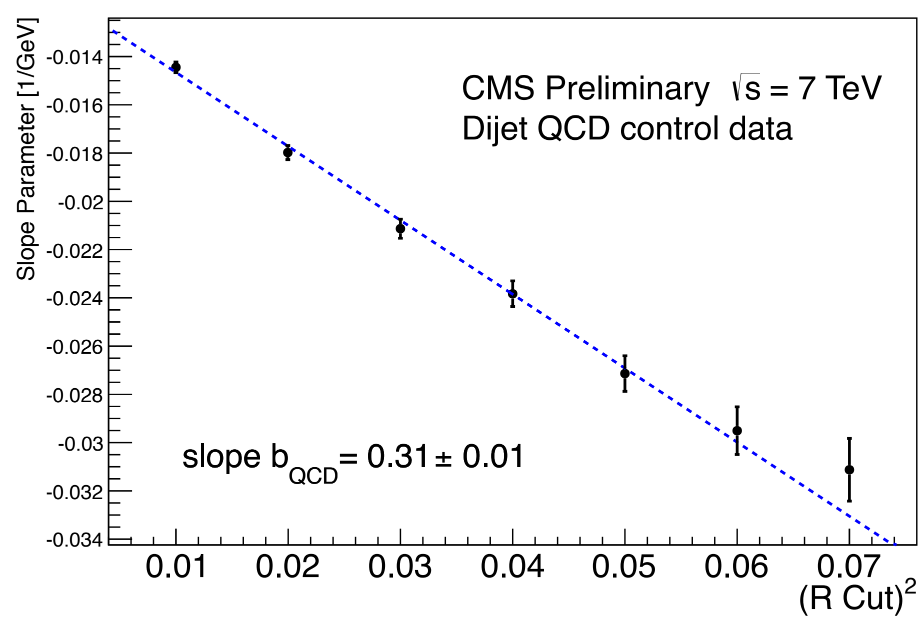
$$k = a + b\, R^2_{cut}$$

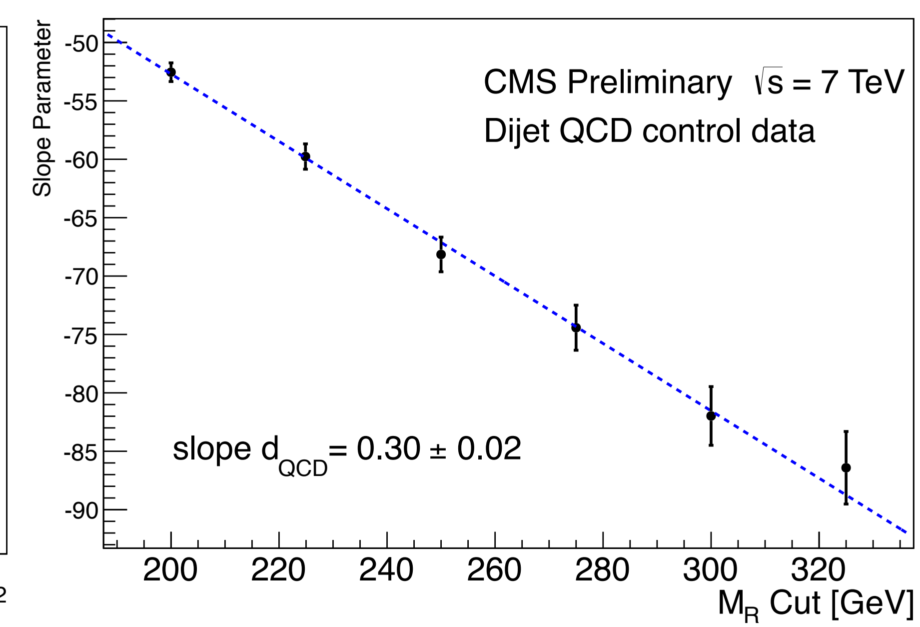
$$f(R^2) \sim e^{-kR^2}$$

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

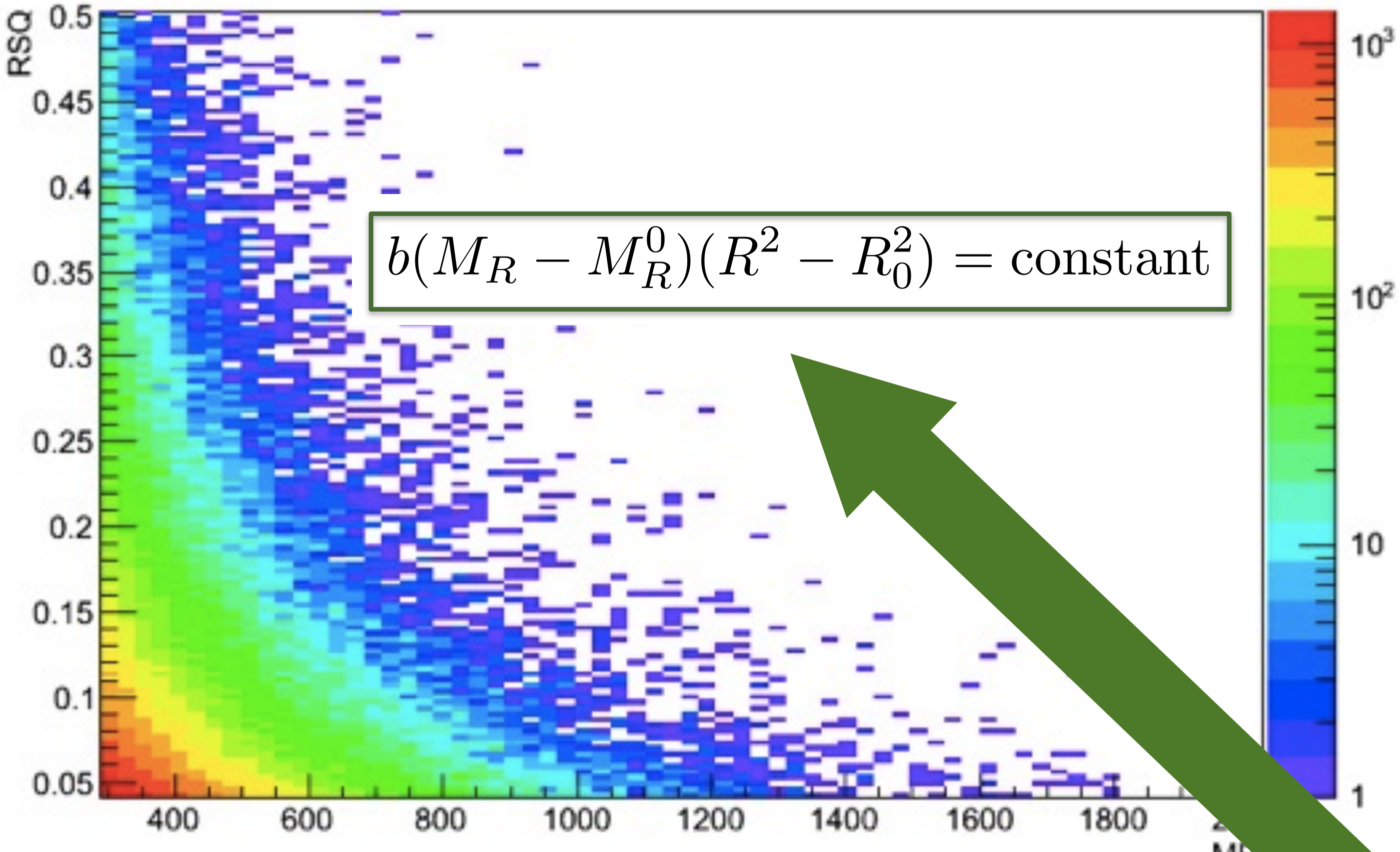








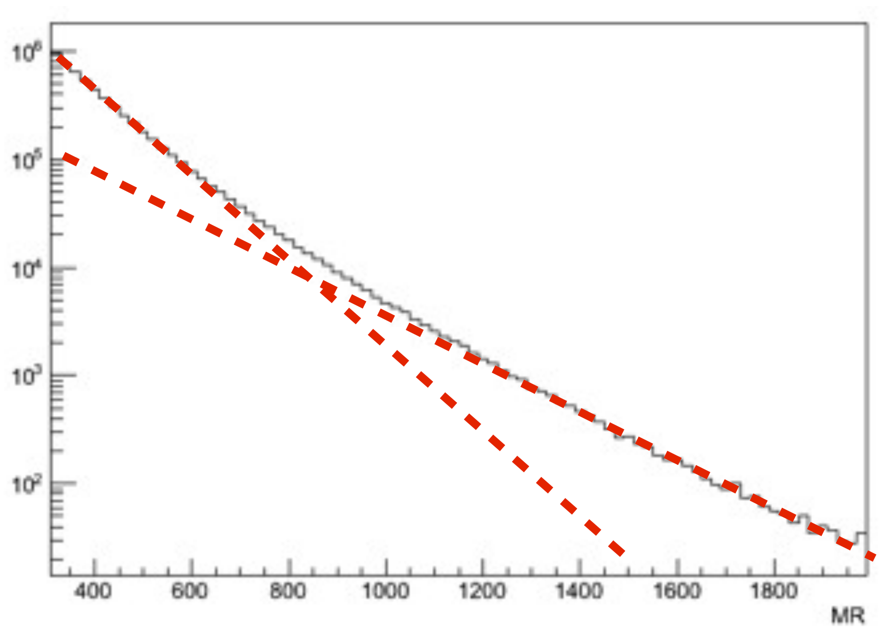
From 1D to 2D

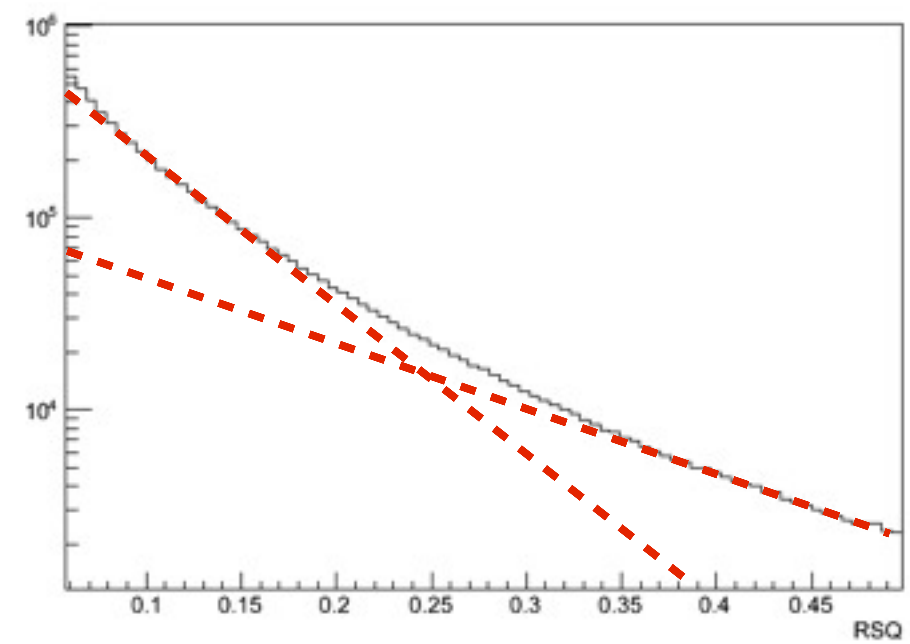


$$b(M_R - M_R^0)(R^2 - R_0^2) = \text{constant}$$

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

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



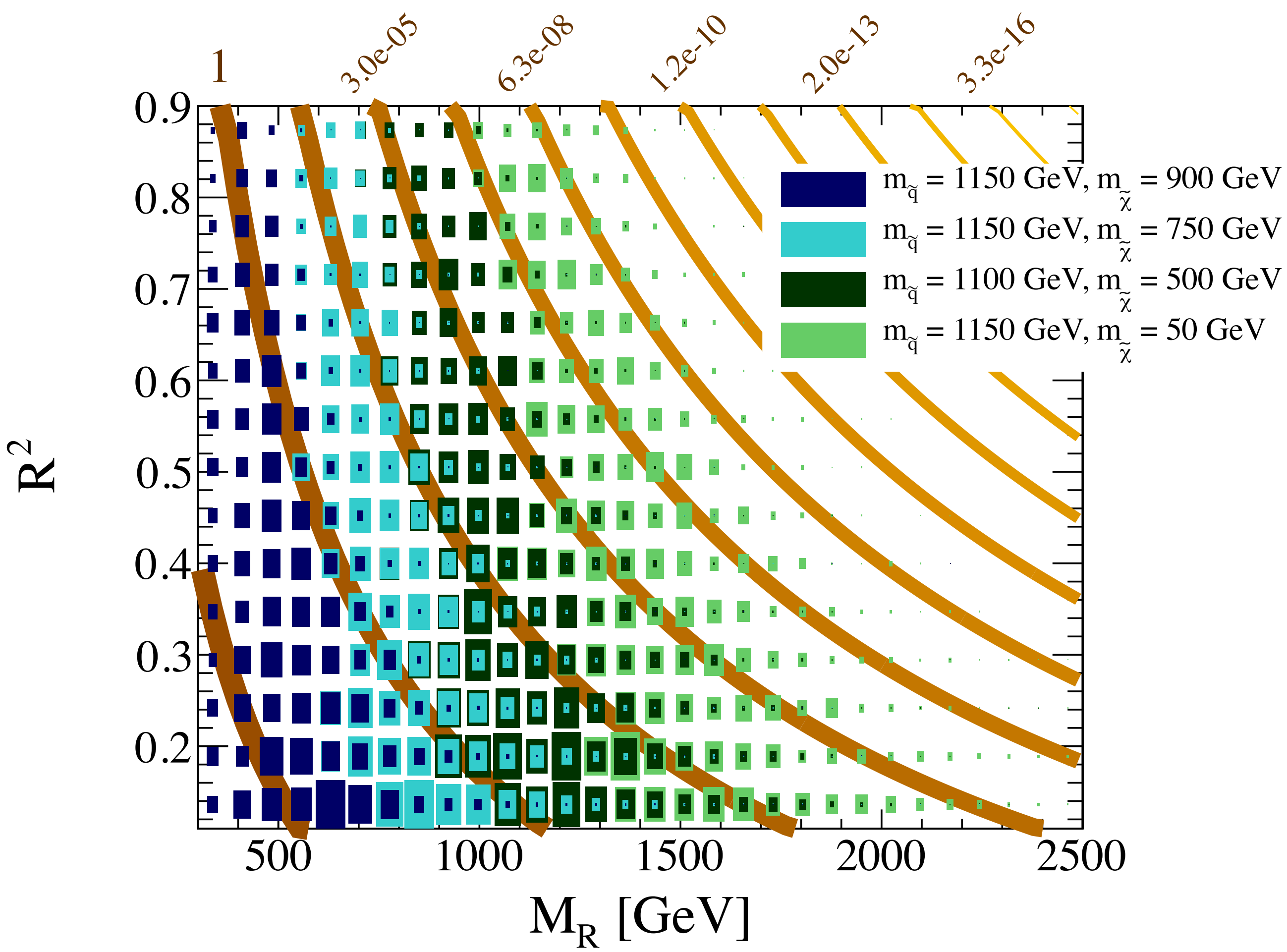


$$\int_{R^2_{cut}}^{+\infty} f(M_R, R^2)dR^2 \sim e^{-(a+bR^2_{cut})M_R}$$

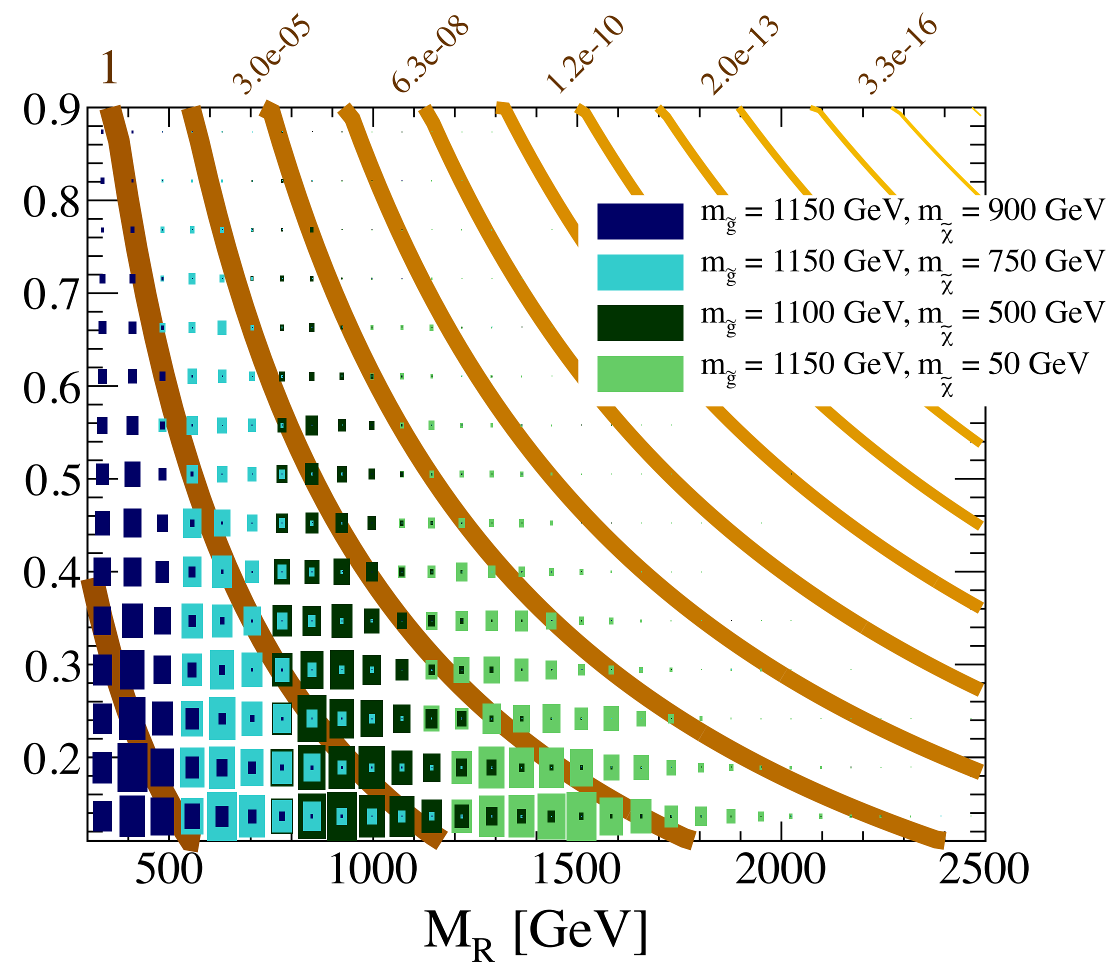
$$\int_{M_R^{cut}}^{+\infty} f(M_R, R^2)dM_R \sim e^{-(c+bM_R^{cut})R^2}$$

From 1D to 2D

$\tilde{q}\tilde{q} \to (q\tilde{\chi}^0_1)(q\tilde{\chi}^0_1)$



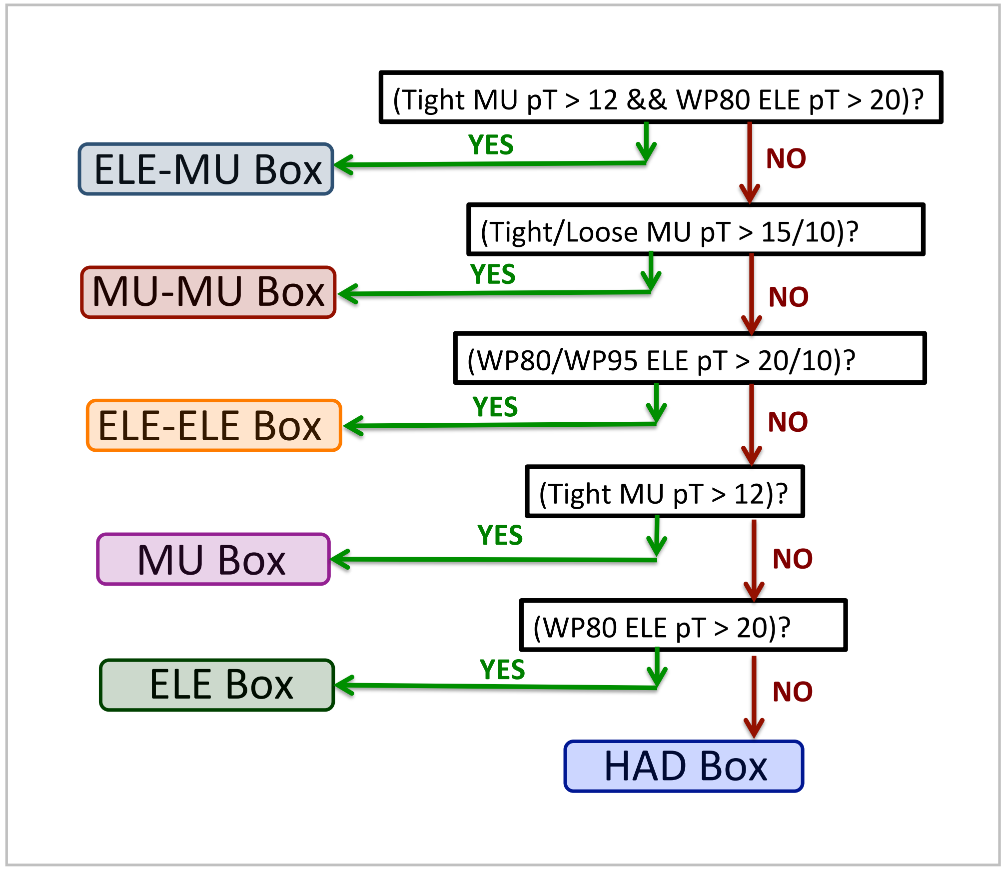
$\tilde{g}\tilde{g} \to (qq\tilde{\chi}^0_1)(qq\tilde{\chi}^0_1)$



- The drop on the 2D plane is fast for background, while signal increases
- The majority of the events is in the bottom-left edge of the plot
- We can use these events to predict the tail in the middle of the plot, by using this modeling of the correlation
- We cannot restrict ourselves to an interesting region, since any region of this plane is potentially interesting

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

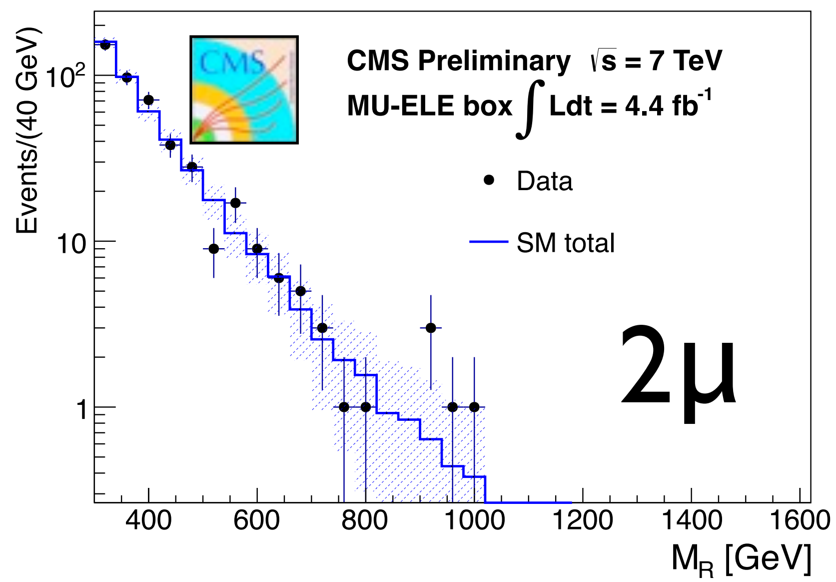


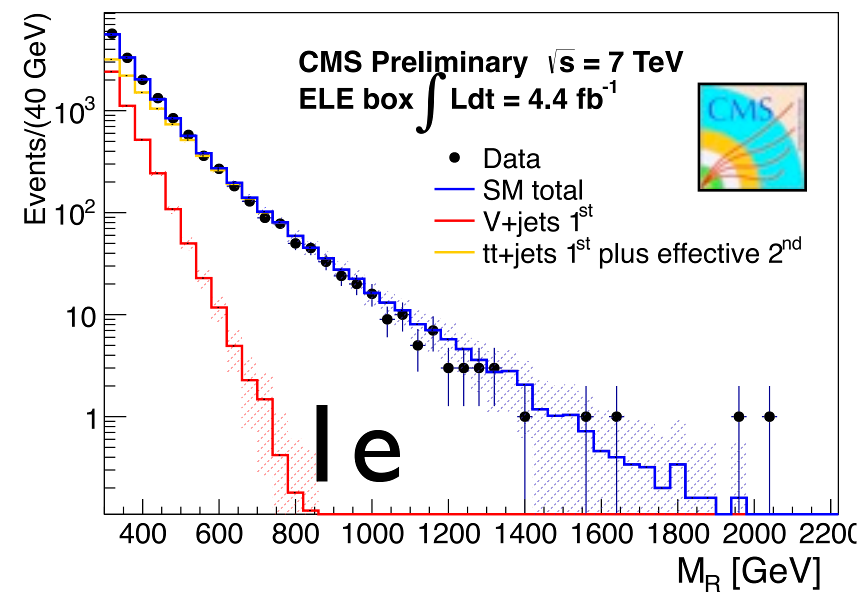
From Hadronic To Inclusive

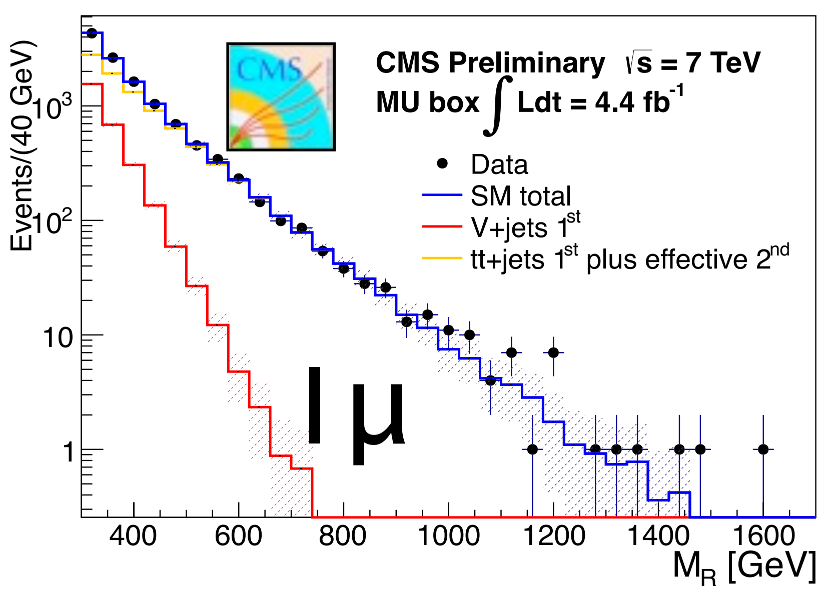
- Hadronic analyses use to veto leptons and use the vetoed sample as a bkg control sample (including signal contamination)

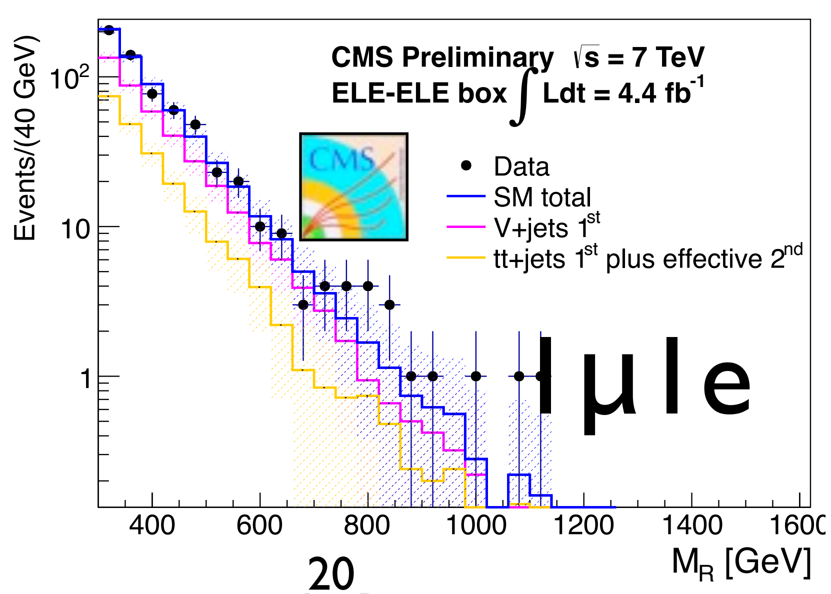
- Leptonic analyses look for a signal in a subset of this samples

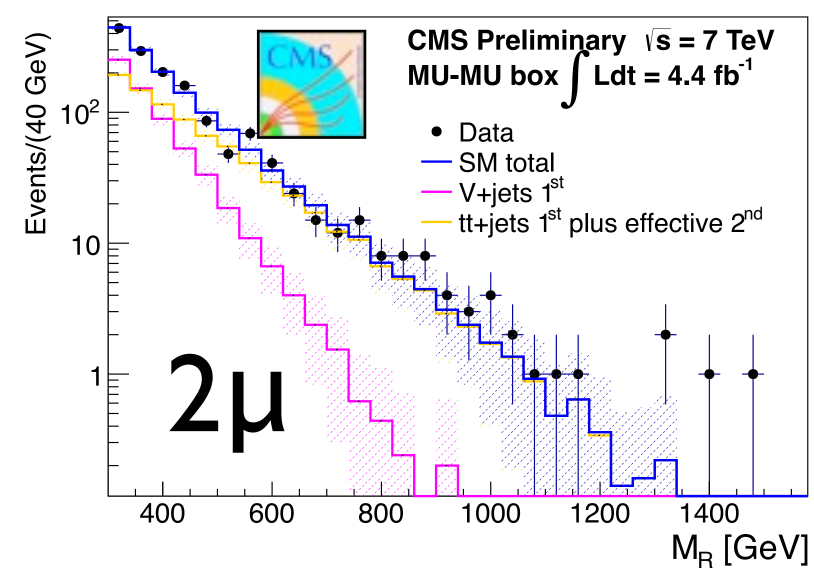
- Thinks can be sync'ed in a common analysis framework, as in the CMS Razor analysis











The ML fit

$$\mathcal{L} = \frac{e^{-(\sum_{SM} N_{SM})}}{N!} \prod_{i=1}^{N} (\sum_{SM} N_{SM} P_{SM}(M_R, R^2))$$

The background PDFs are given by

$$P_{SM}(M_R, R^2) = (1 - f_2^{SM}) \times F_{SM}^{1st}(R^2, M_R) + f_2^{SM} \times F_{SM}^{2nd}(R^2, M_R)$$

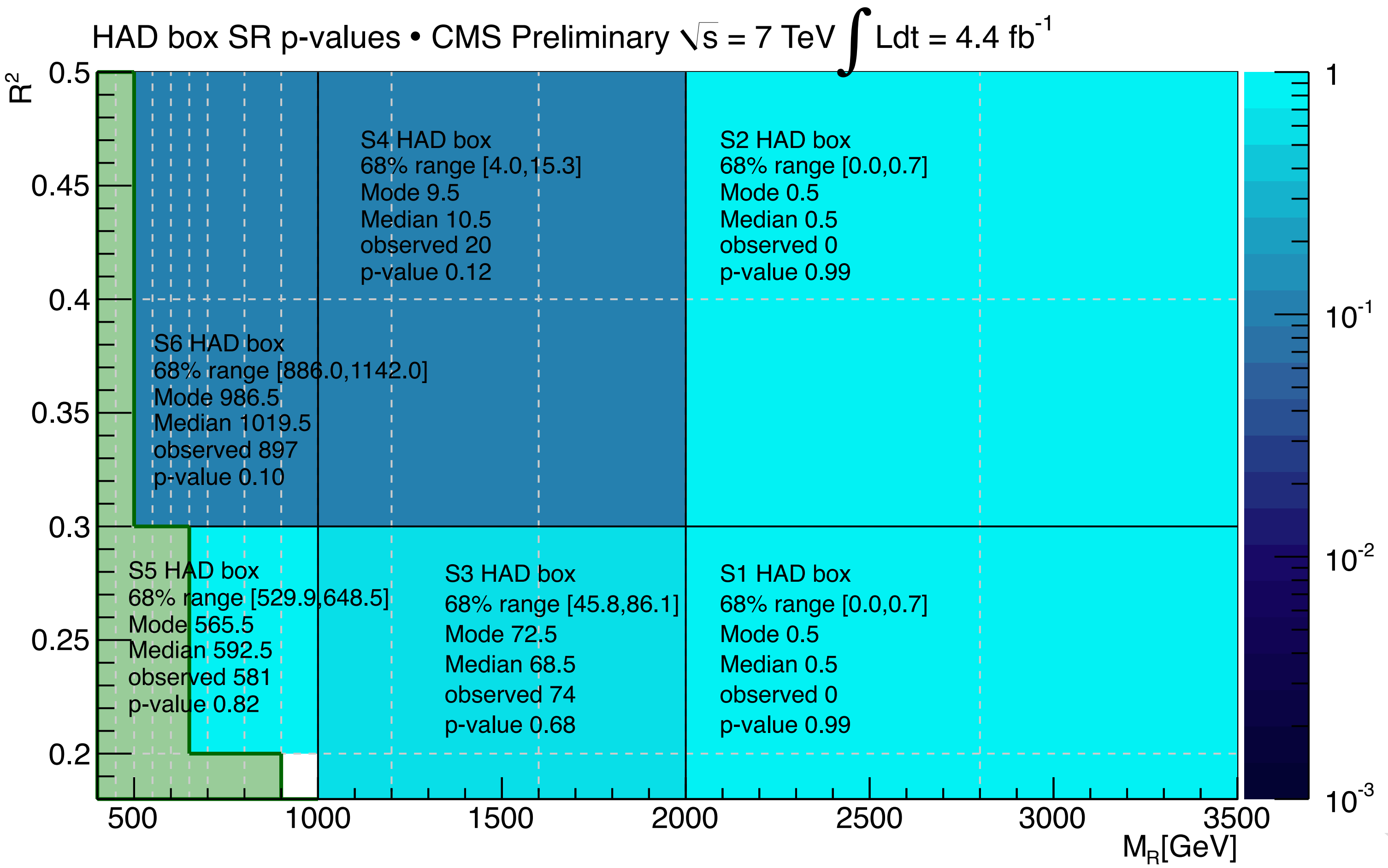
with

$$F(M_R, R^2) = \left[b(M_R - M_R^0)(R^2 - R_0^2) - 1\right] e^{-b(M_R - M_R^0)(R^2 - R_0^2)}$$

To guide the fit, the likelihood is multiplied by Gaussian penalty terms which force the shape parameters around our a-priori knowledge (May10 ReReco ~250 pb^{-1} b-tagged and b-vetoed samples)

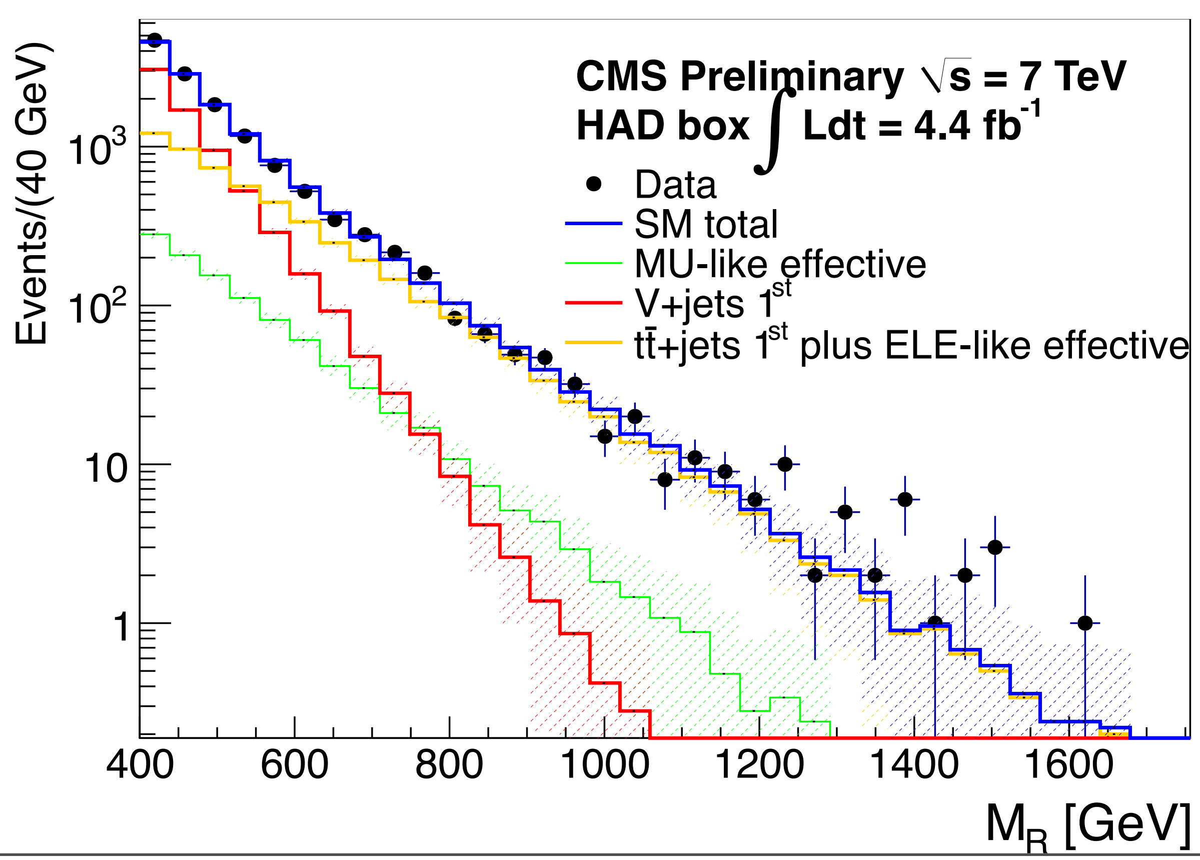
This helps the fit to converge and have limited impact on the fit at minimum (errors dominated by the fit, not the a-priori knowledge)

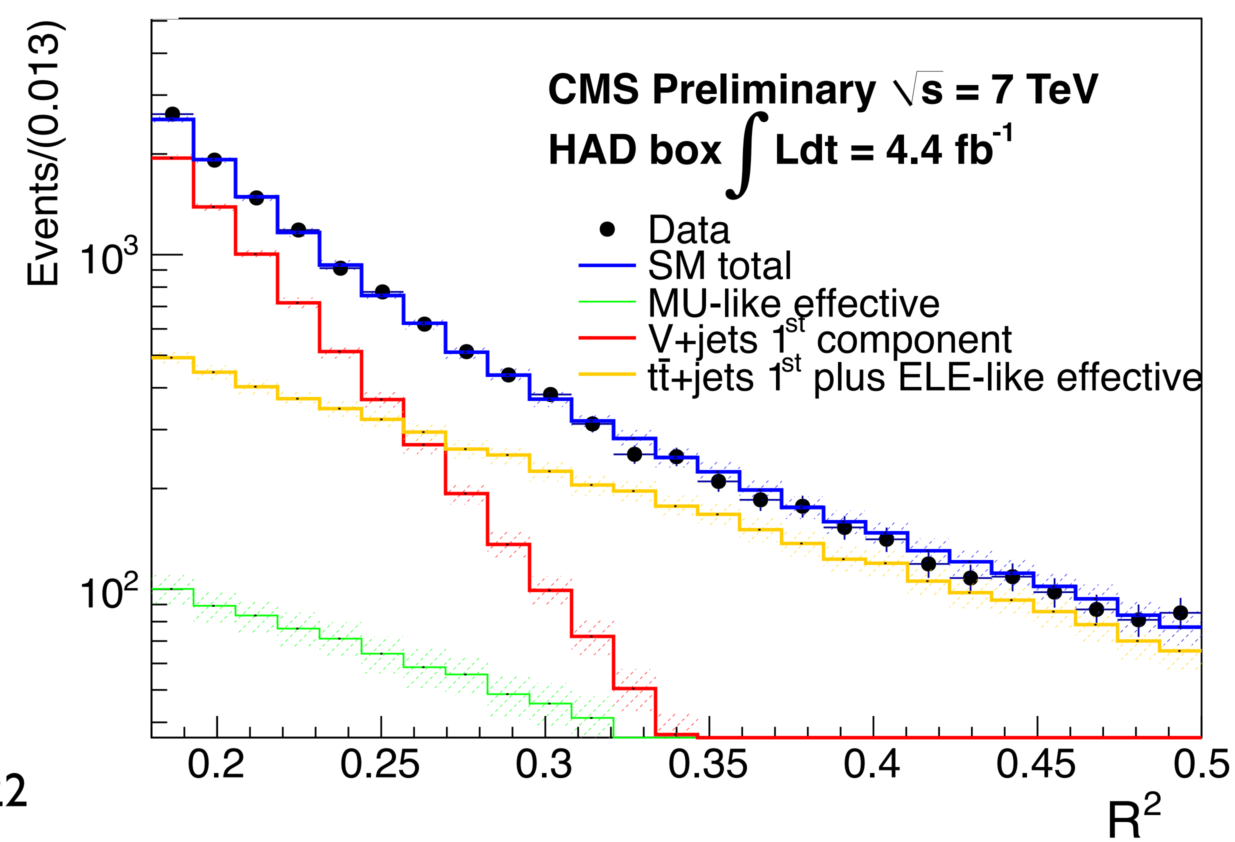
The ML fit



- 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

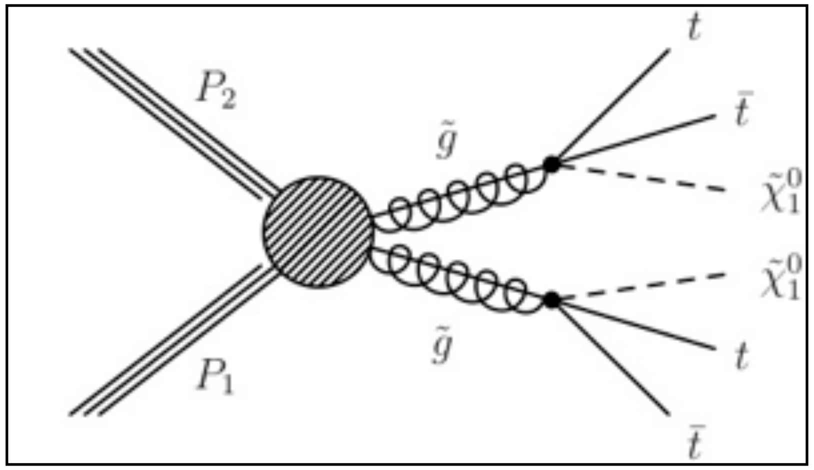
→we set limit on signal

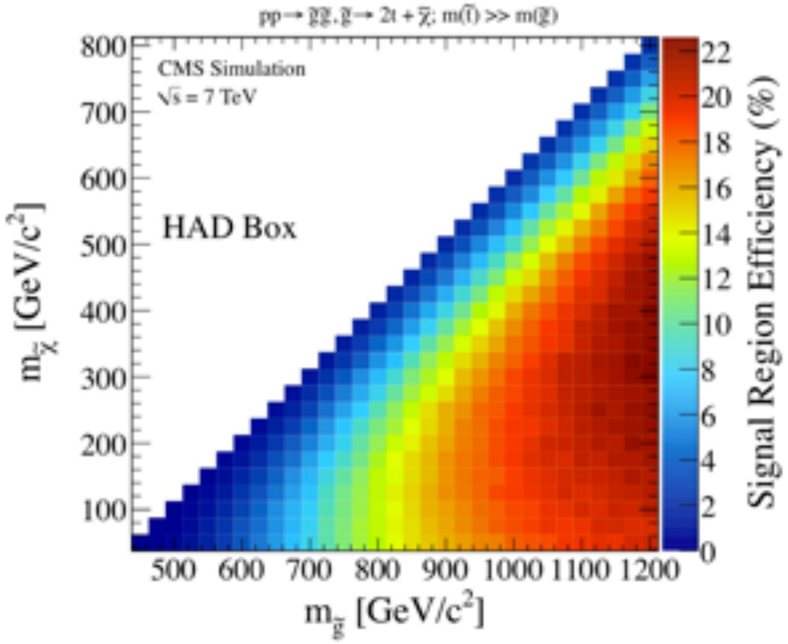


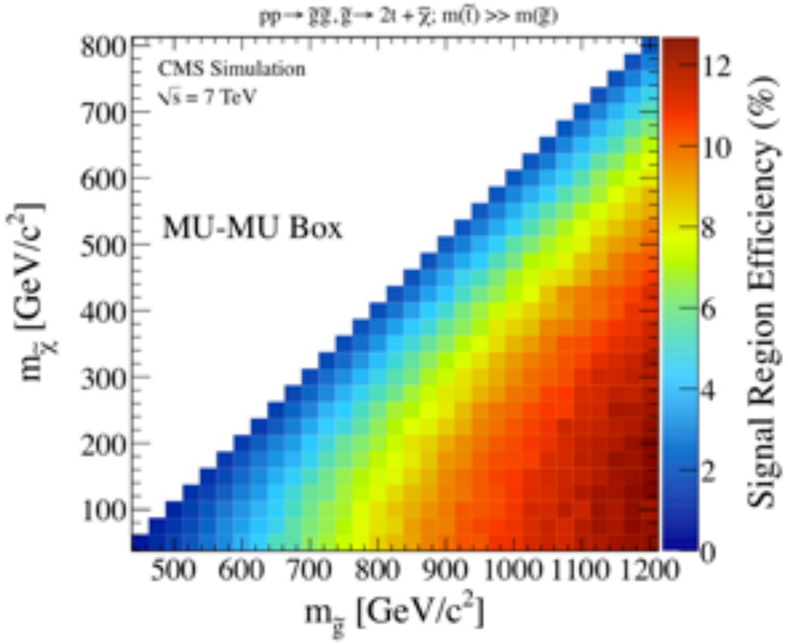


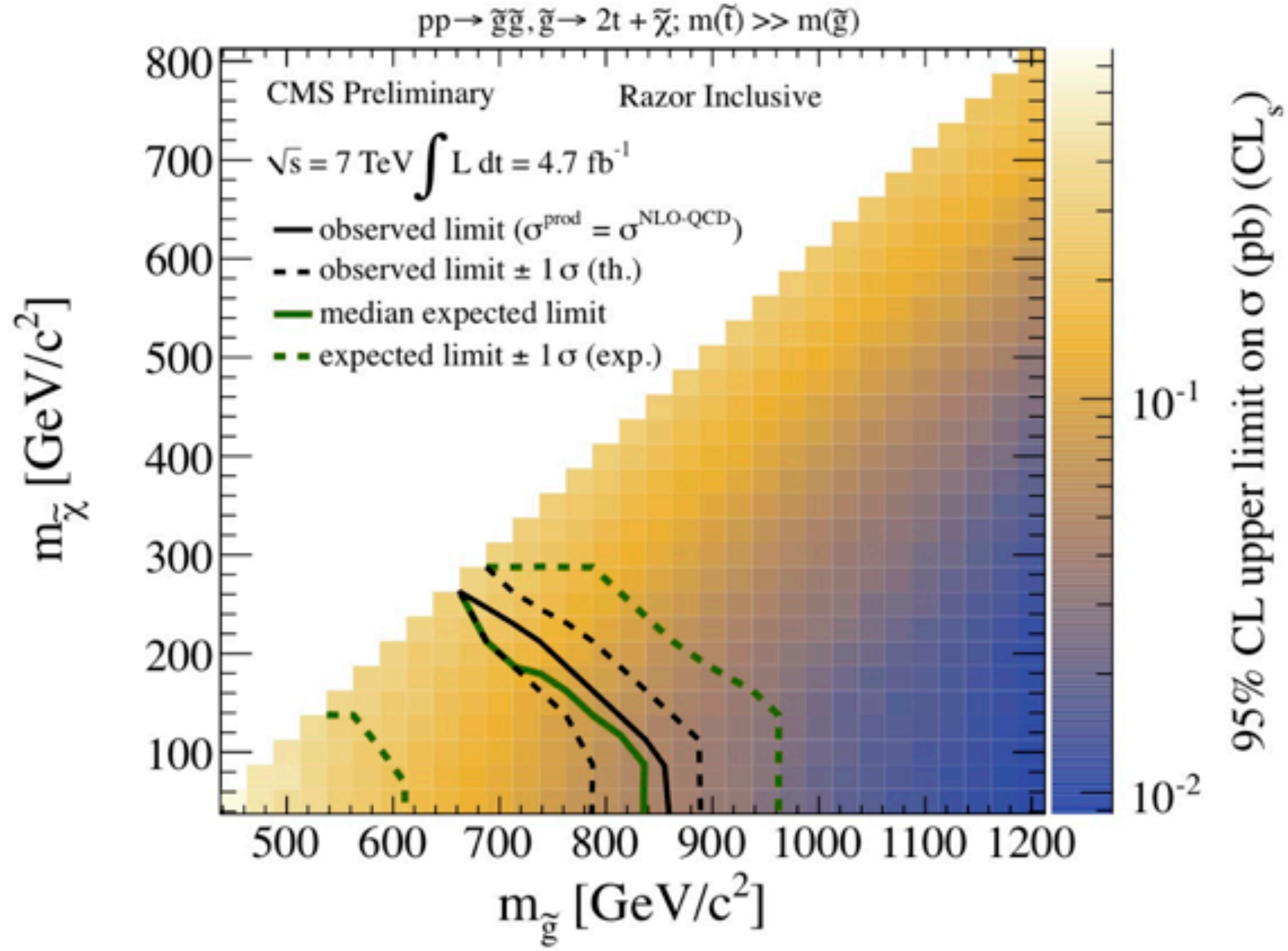
The Razor Results

- Result interpreted for several SMS
- All details will come in a long paper (now under approval)
- Here I consider the same 4top case I considered before (interesting interplay between boxes)







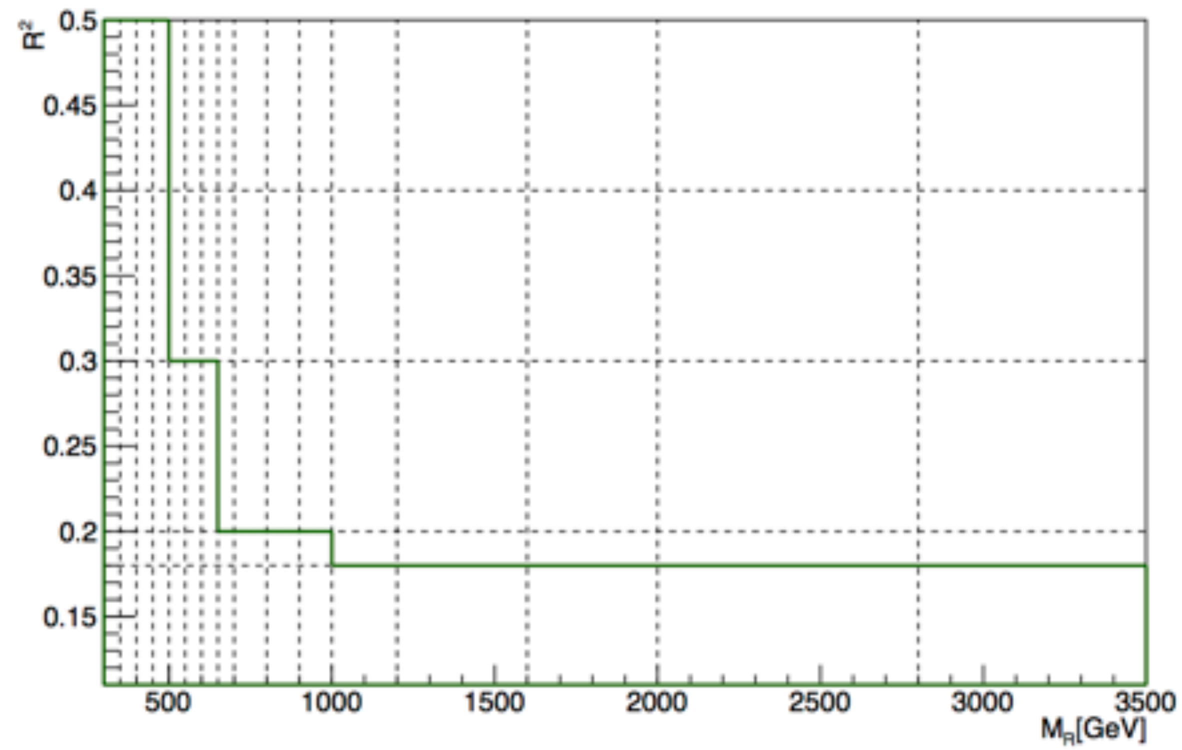


Blackboard Intermezzo

Statistics Tools

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

- A counting-experiment limit is easy to implement (e.g. 1D integral in Bayesian statistics)
- A shape analysis is more tricky. One needs the shape
- Giving the shape for an unbinned likelihood is a problem
- We provide instead tables of expected vs observed yields in 2D bins, which you can use to build an approximated likelihood



Had Box	Observed	Predicted Mode	Predicted Median	$b \pm \delta b$
bHad_4_3	56	64.5	64.5	64.3 ± 1.4
bHad_4_4	27	23.5	23.5	22.7 ± 1.1
bHad_5_3	30	39.5	39.5	38.6 ± 1.3
bHad_5_4	18	12.5	12.5	12.2 ± 0.8
bHad_6_3	21	23.5	23.5	23.4 ± 1.0
bHad_6_4	4	7.5	7.5	6.6 ± 0.8
bHad_7_2	44	57.5	58.5	57.6 ± 1.5
bHad_7_3	11	14.5	14.5	14.1 ± 0.8
bHad_7_4	1	3.5	3.5	3.3 ± 0.8
bHad_8_2	50	64.5	64.5	63.5 ± 1.5
bHad_8_3	18	14.5	14.5	13.9 ± 0.9
bHad_8_4	4	3.5	3.5	3.0 ± 0.7
bHad-9-2	18	29.5	29.5	28.7 ± 1.1
bHad_9_3	4	5.5	5.5	5.0 ± 0.7
bHad_9_4	2	1.5	1.5	0.7 ± 0.7
bHad_10_2	8	13.5	13.5	13.1 ± 0.9
bHad_10_3	2	2.5	2.5	1.7 ± 0.8
bHad_10_4	0	0.5	0.5	0.3 ± 0.3
bHad_11_1	6	14.5	14.5	14.3 ± 1.0
bHad_11_2	7	9.5	9.5	9.0 ± 0.8
bHad_11_3	0	1.5	1.5	0.8 ± 0.8
bHad_11_4	1	0.5	0.5	0.3 ± 0.3
bHad_12_1	6	5.5	5.5	5.0 ± 0.7
bHad_12_2	1	2.5	2.5	2.0 ± 0.7
bHad_12_3	1	0.5	0.5	0.3 ± 0.3
bHad_12_4	2	0.5	0.5	0.3 ± 0.3
bHad_13_1	0	0.5	0.5	0.3 ± 0.3
bHad_13_2	0	0.5	0.5	0.3 ± 0.3
bHad_13_3	0	0.5	0.5	0.3 ± 0.3
bHad_13_4	0	0.5	0.5	0.3 ± 0.3
bHad_14_1	0	0.5	0.5	0.3 ± 0.3
bHad-14-2	0	0.5	0.5	0.3 ± 0.3
bHad_14_3	0	0.5	0.5	0.3 ± 0.3
bHad_14_4	0	0.5	0.5	0.3 ± 0.3
bHad_15_1	0	0.5	0.5	0.3 ± 0.3
bHad-15-2	0	0.5	0.5	0.3 ± 0.3
bHad_15_3	0	0.5	0.5	0.3 ± 0.3
bHad_15_4	0	0.5	0.5	0.3 ± 0.3