Search for SUSY in the hadronic channel

For the CMS collaboration,
Gheorghe Lungu
The Rockefeller University

Outline

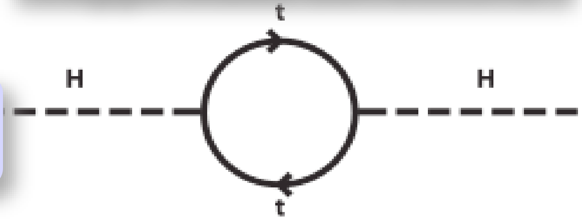
- Motivation
- The CMS experiment
- SUSY at CMS
- Event clean-up
- Inclusive multi-jet + MET search
    - Background estimation
    - Discovery potential
- Exclusive dijet search
- Exclusive n-jet search
- Conclusions

Motivation

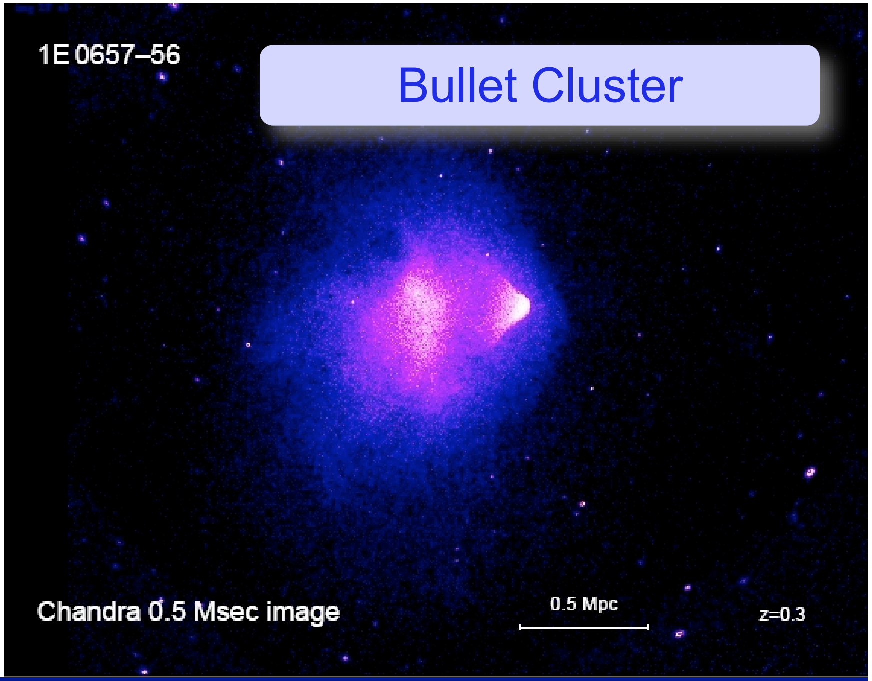
- ***Why SUSY?***
  - *Offers natural solutions to the hierarchy and fine-tuning problems in SM*
  - *Provides a dark matter candidate*
- ***Why the hadronic channel?***
  - *Largest production rates*
  - *Check the leptonic modes*

Higgs Mass corrections

Standard Model



SUSY



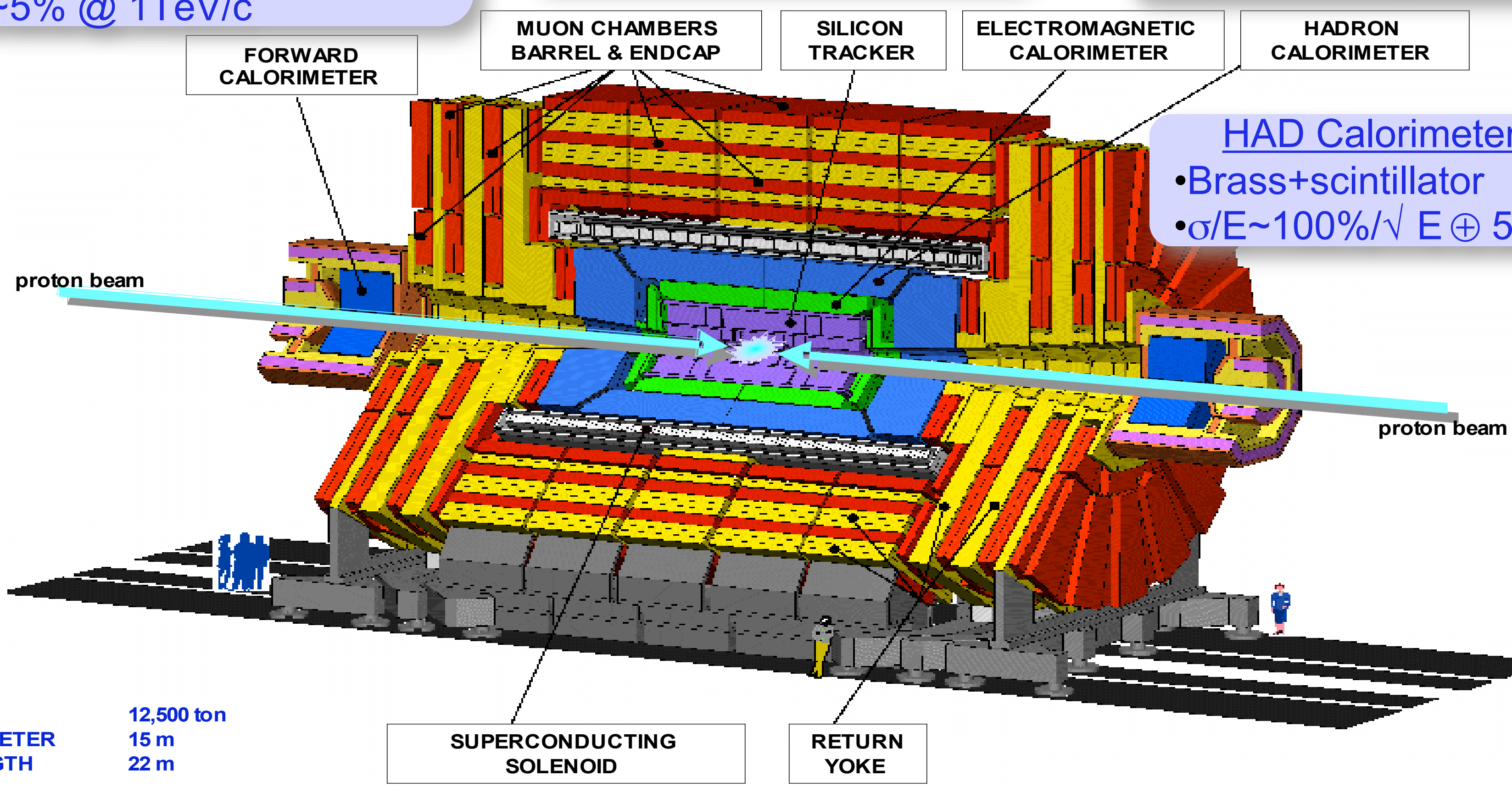
Bullet Cluster

CMS detector

Muon detector
- drift tube (DT)
- cathode-strip (CSC)
- resistive plate (RP)
- $\sigma/p_T \sim 5\%$ @ 1TeV/c

Inner Tracker
- Si (pixels, strips)
- $\sigma/p_T \sim 1.5\times10^{-4} p_T \oplus 0.005$

EM Calorimeter
- PbWO4 crystals
- $\sigma/E \sim 3\%/\sqrt{E} \oplus 0.5\%$

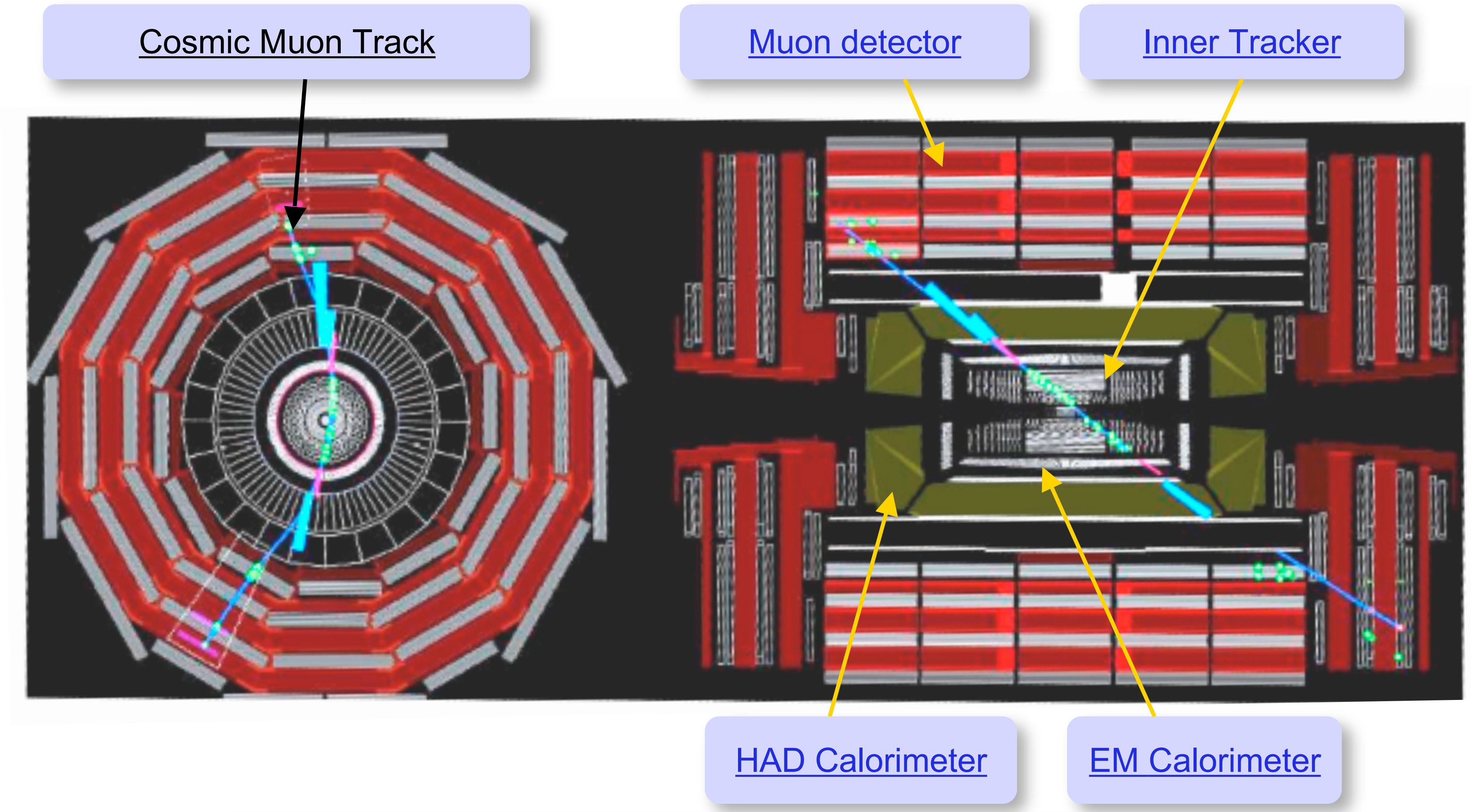


HAD Calorimeter
- Brass+scintillator
- $\sigma/E \sim 100\%/\sqrt{E} \oplus 5\%$

TOTAL WEIGHT	12,500 ton
OVERALL DIAMETER	15 m
OVERALL LENGTH	22 m

- Magnetic field: 4T solenoid + 2T return yoke

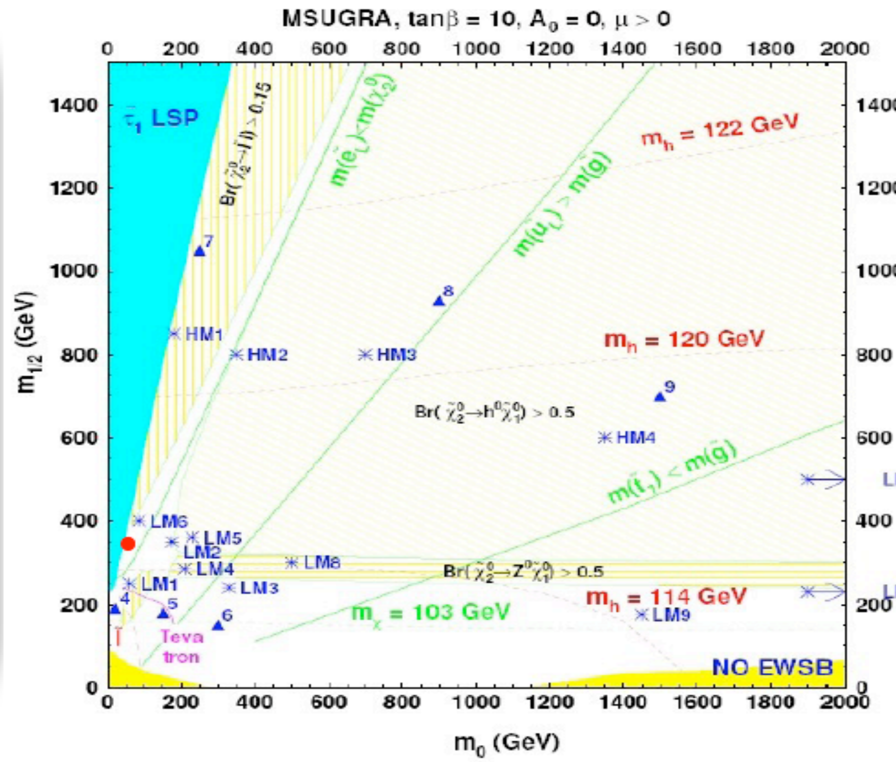
Cosmics Data From CMS Detector



CMS detector is ready for collisions data

SUSY at CMS

- **Strategy**
  - *Model-independent searches based on physics objects in the final state*
    - *Jets, leptons, MET, photons*
  - *Data-driven background estimation*
  - *Optimization based on a set of benchmark points*
    - *cover well the phase space beyond Tevatron excluded regions*
- **Hadronic searches**
  - *Inclusive jets + MET*
  - *Exclusive dijet*
  - *Exclusive n-jet*



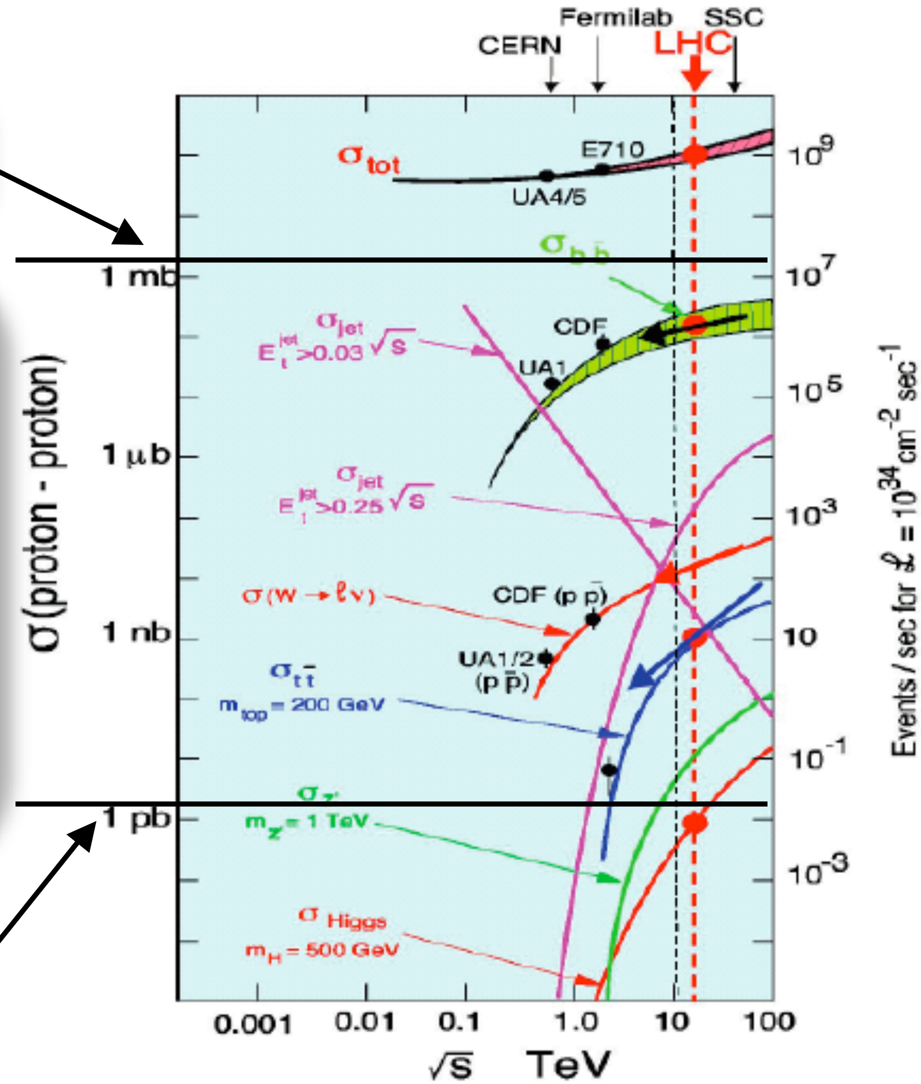
Sample	m_0 (GeV)	$m_{1/2}$ (GeV)	A_0	$\tan\beta$	sign(μ)	σ NLO (pb)	(LO) (pb)	lightest $\tilde{q}$ (GeV)	χ_1^0 (GeV)
LM1	60	250	0	10	+	54.86	(43.28)	410 ($\tilde{t}_1$)	97
LM2	185	350	0	35	+	9.41	(7.27)	582 ($\tilde{t}_1$)	141
LM3	330	240	0	20	+	45.47	(34.20)	446 ($\tilde{t}_1$)	94
LM4	210	285	0	10	+	25.11	(19.43)	483 ($\tilde{t}_1$)	112

SM background

SM QCD

- *SM processes are dominant*
  - QCD cross-section ~ 5.6×10^{10} pb
  - Z+jets cross-section ~ 15×10^{3} pb
  - Ttbar cross-section ~ 800 pb
  - SUSY LM1 cross-section ~ 42 pb
- *Develop <u>data-driven methods</u> to estimate the backgrounds*
  - Minimizes systematic errors from differences between data and MC
  - Self-calibrating

SUSY LM1



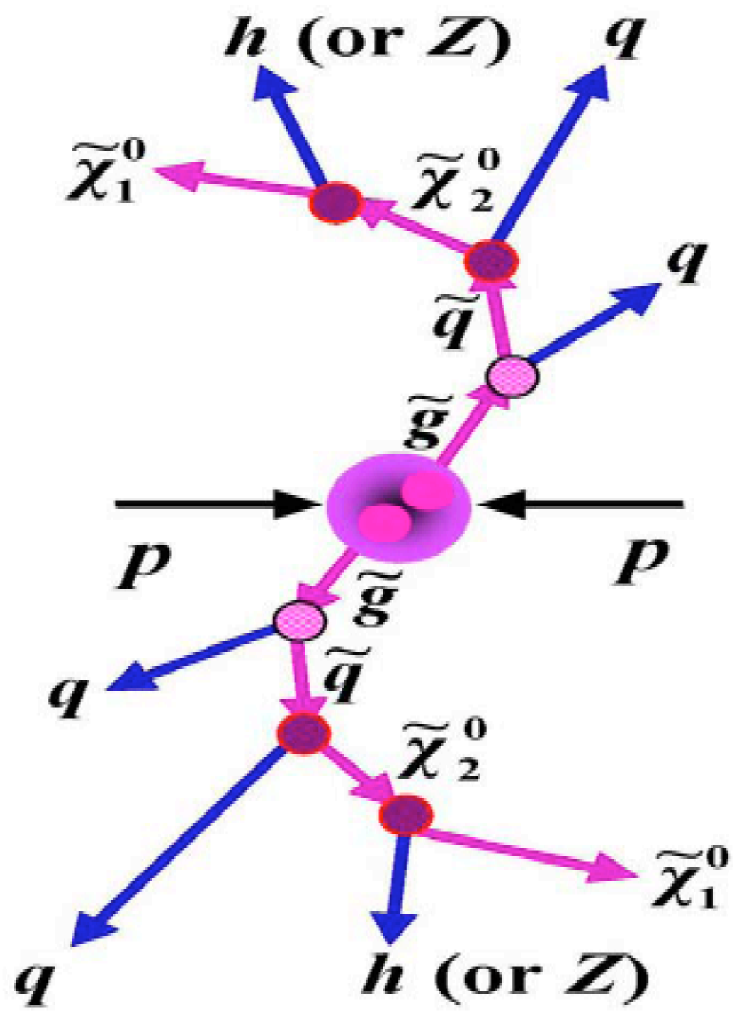
Event clean-up

- Remove bad events due to electronic noise
  - Methods based on pulse shapes and timing
  - Optimized using comics data
- Remove contributions from beam halo and cosmics
  - Require common vertex for main physics objects
  - Event ElectroMagnetic Fraction (EEMF)
    - $(\Sigma P_t^{jets} EMF^{jets})/(\Sigma P_t^{jets}) > 0.1$
  - Event Charged Fraction (ECHF)
    - $<(\Sigma P_t^{tracks})^{jet}/P_t^{jet})>_{jets} > 0.175$
- Jets and MET tune-up
  - Use zero-suppressed calorimeter
  - Correct jets energy based on dijet balance
  - Correct MET for muons and calorimeter effects

Inclusive Jets+MET search

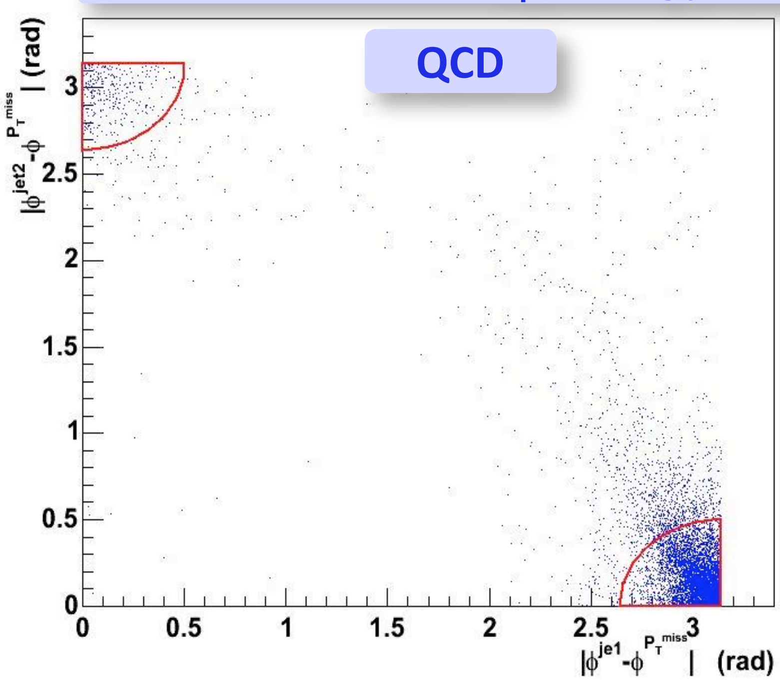
Event selection

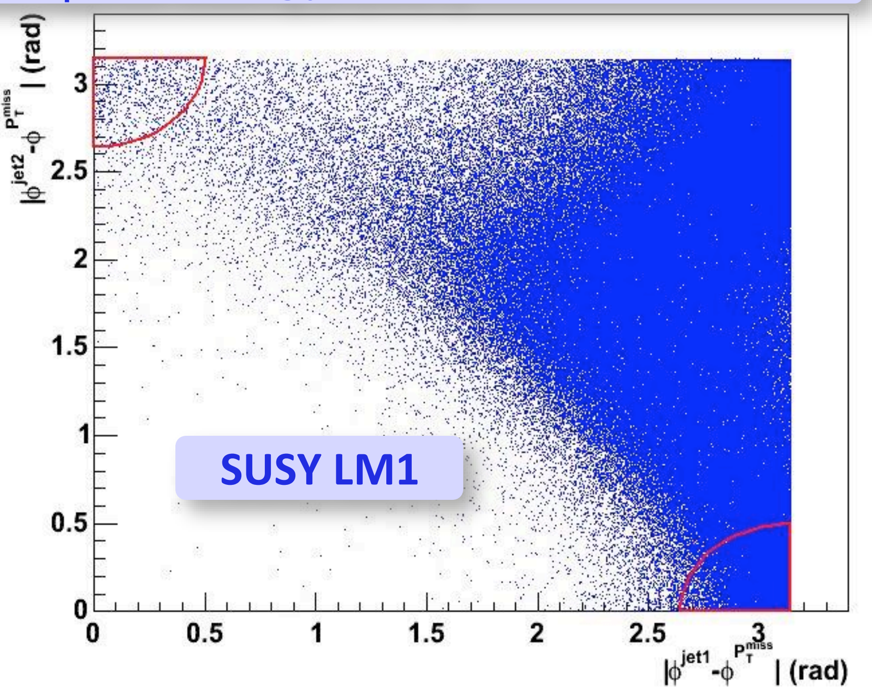
- Online (trigger)
  - L1 HT (sum of L1jets) > 200 GeV
  - HLT HT>350 GeV & MET>65 GeV
- Offline
  - At least 3 jets with ET > 30 GeV
  - Remove electrons/photons
    - EM fraction < 0.9
  - First Jet ET > 180 GeV
  - 2nd Jet ET > 110 GeV
  - $|\eta| < 3$, $|\eta_{1st\ jet}|<1.7$
  - No isolated tracks
    - Reduces top quark pairs, W events
  - MET > 200 GeV
  - $ET_2+ET_3+ET_4+MET > 500$ GeV



Reducing QCD background

Δφ(leading jet,MET) VS Δφ(sub-leading jet,MET)



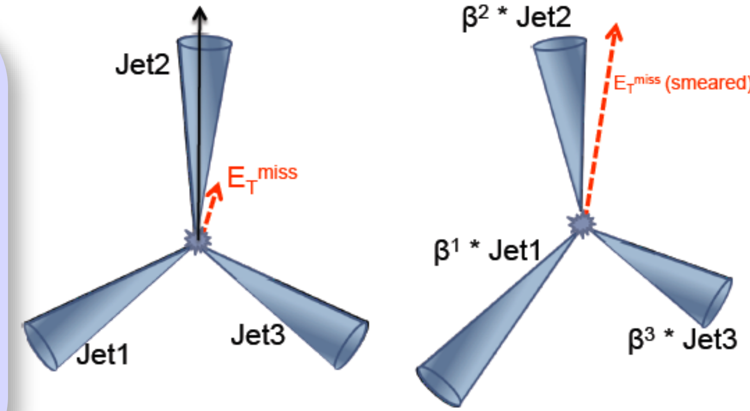


- MET in QCD events tends to be along a jet
  - mis-measurements, noise, dead cells, backgrounds
- "True" MET comes from LSP, ν
- Use φ angles between MET and 2 leading jets
- *Removes ~80% QCD, Keeps ~90% SUSY*

Residual QCD background estimation

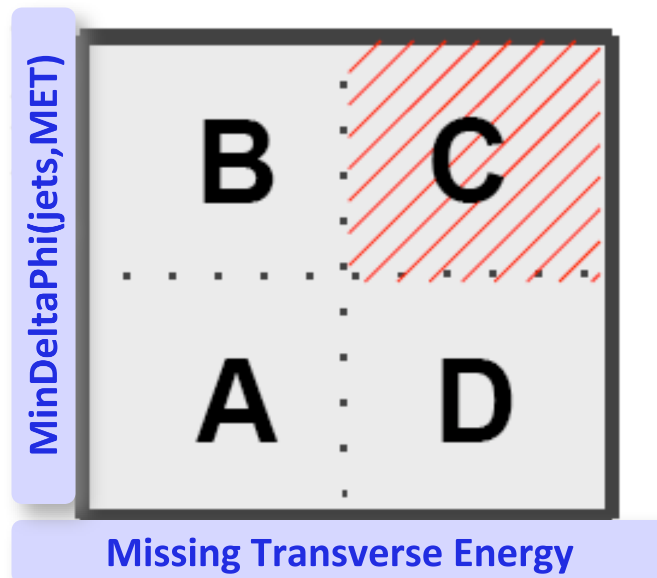
Smearing Method

- Select multi-jet events with MET along one of the jets
- *Define response* $R=1-p_T^{jet}cos(jet,MET)/|p_T^{jet}+MET\ |^2$
- *Parametrize R* in a subset of events *MET > 60 GeV*
- *Smear jets with R in events from orthogonal subset*
- Normalize to size of QCD data with low MET



ABCD Method

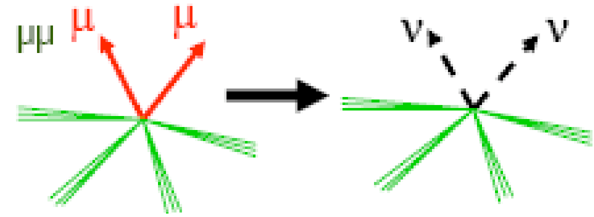
- Find two observables *uncorrelated for QCD*
- Divide the plane in four regions A,B,C,D
    - C is the signal region
- *The numbers of QCD events satisfy: C = D x B/A*
- It is crucial to have *little signal content* in the other 3 regions
    - *Difficult to find such observables*
    - *Otherwise need to remove signal from A,B,D*

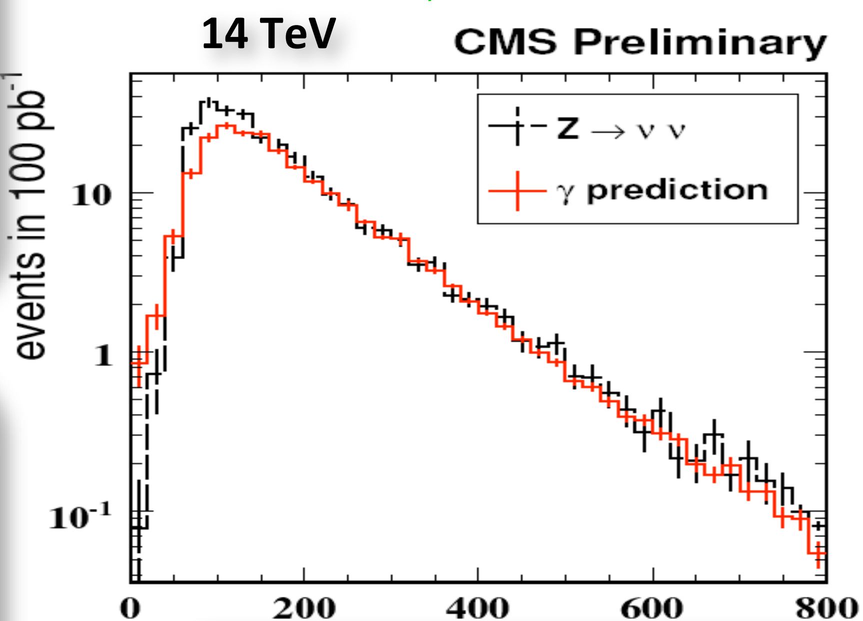


Z->νν background estimation

- ***Use Z(→ee or μμ)+jets events***
  - Lepton ID efficiency determined in data (tag&probe method)
  - Cons: small cross-section
  - Pros: little background, low systematics
  - *5% accuracy with 1.5 fb^{-1}*

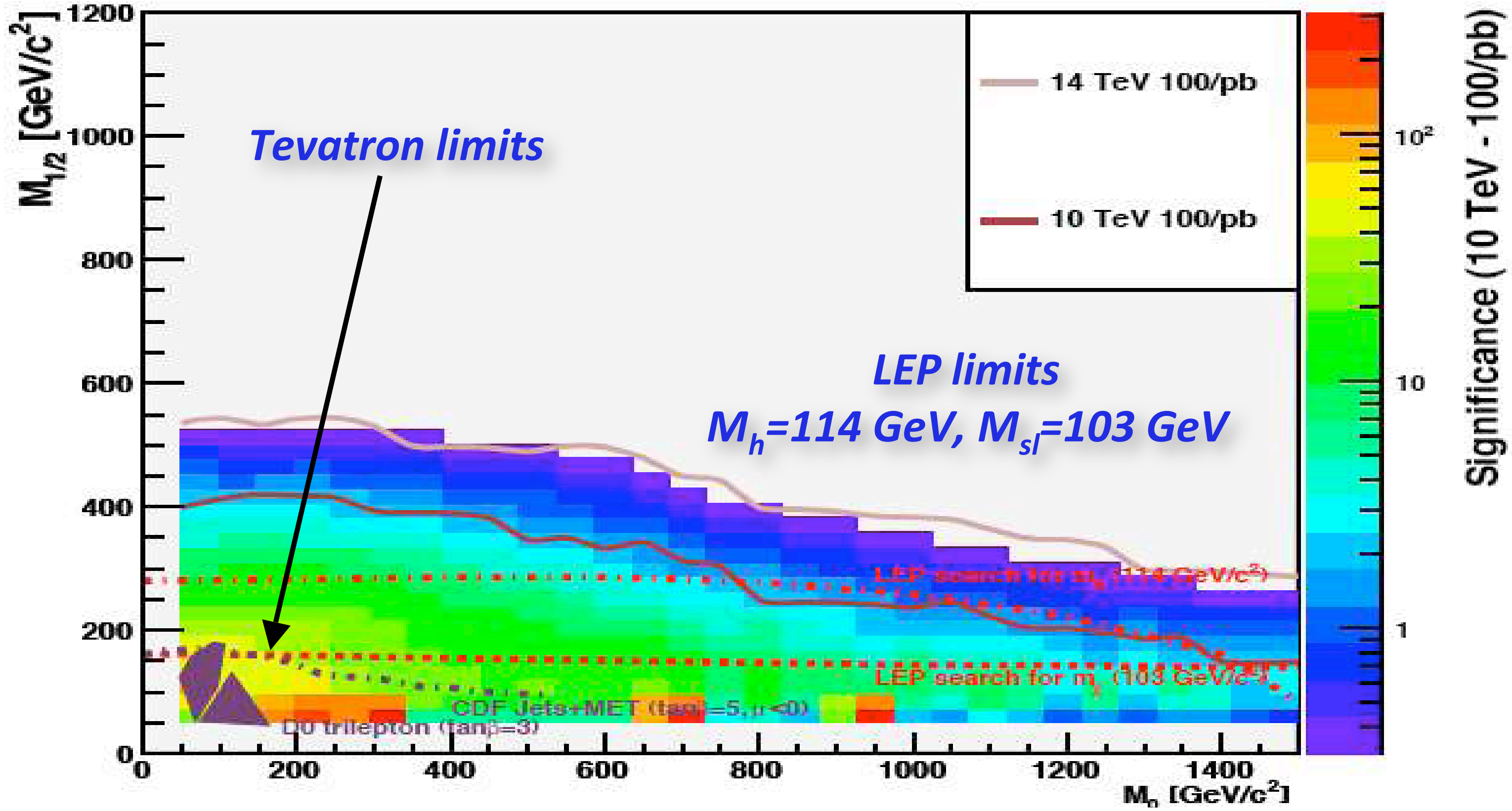
- ***Use photon+jets events***
  - After removing photon, similar shape for MET > 150 GeV
  - Pros: Large cross-section
  - Cons: uncert. on normalization
    - Different diagrams for γ than for Z
  - *10% accuracy with 100pb^{-1}*





Missing Transverse Energy

mSUGRA Sensitivity Reach

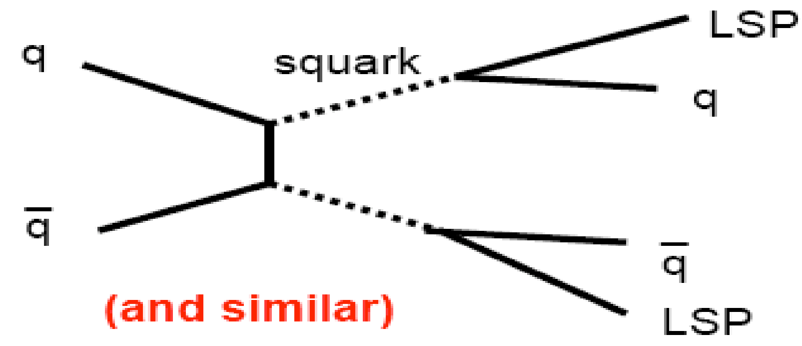


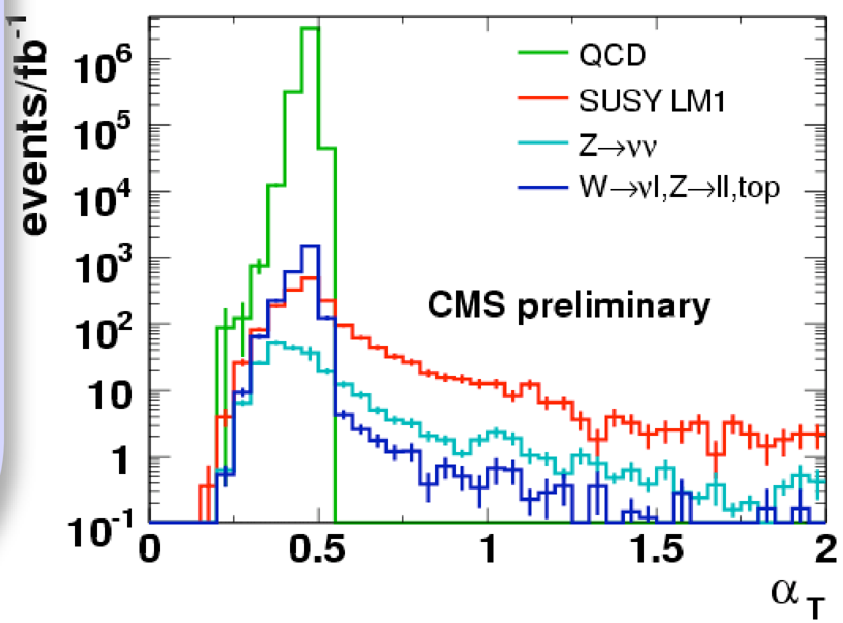
$t\bar{t}$,single top	$Z(\rightarrow \nu\bar{\nu})$+ jets	$(W/Z,WW/ZZ/ZW)$ + jets	QCD
56 ± 11(sys) ± 7.5(stat)	48 ± 3.5 (all)	33 ± 2.5 (all)	107 ± 25(sys) ±10(stat)

Discovery possible with 50pb^{-1} of well understood data!

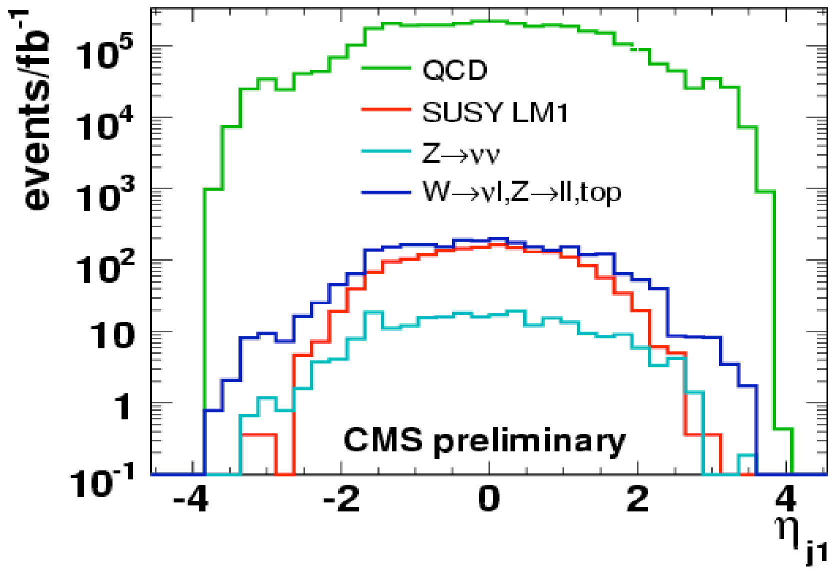
Search in the two jets channel

- *Features*
  - *Two squarks decay straight to two quarks and two neutralinos*
    - Mass squark < mass gluino
  - Large dijet QCD production
- *Analysis Strategy*
  - *Inspired by L.Randall, D.Tucker-Smith, introduce the variable α_T*
    - $E_T^{2nd\text{-}jet}/M_T(j1,j2)$
  - *Expect α < 0.5 for QCD*
- *Event Selection*
  - 2 jets with Pt > 50 GeV
    - 3rd jet Pt < 50 GeV
  - Lepton Pt < 10 GeV
  - HT > 500 GeV
  - α_T < 0.55
- *Remarks:* ***No cut on MET!***

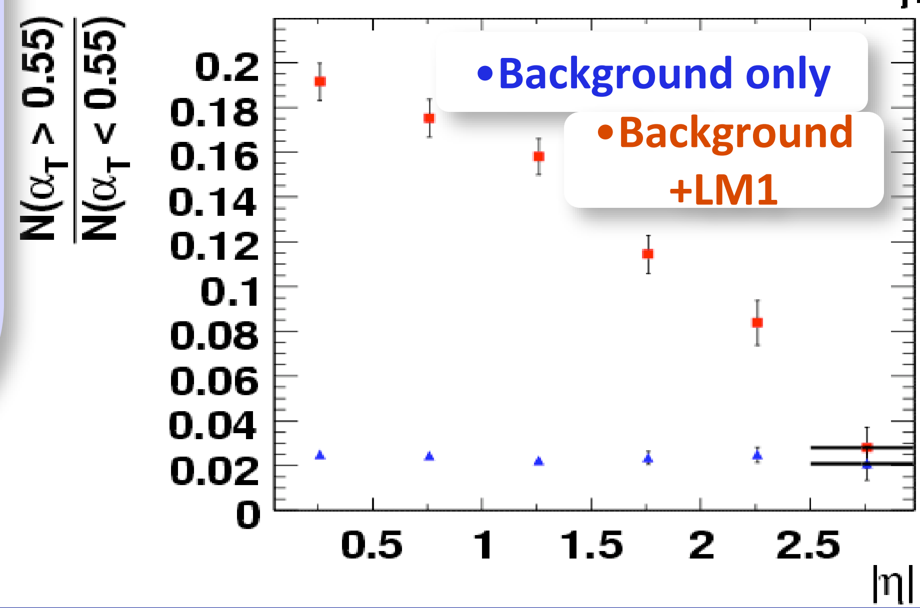




Residual background estimation



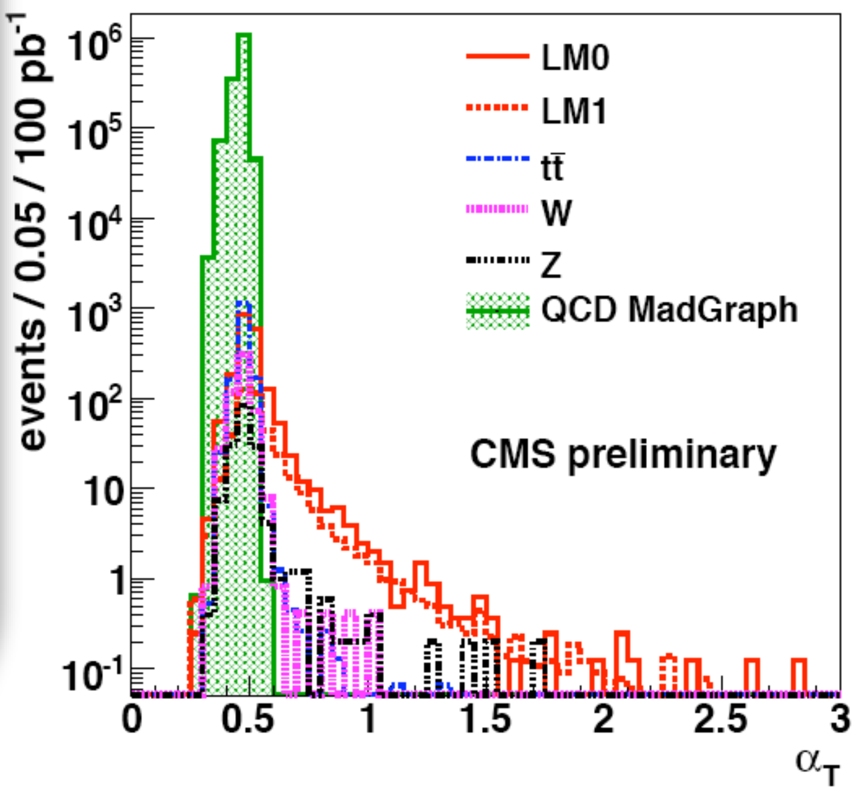
- *ABCD-like method*
  - α_T and $|\eta_1|$ are not correlated
  - Backgrounds tend to be more forward
  - Signal region: $|\eta_1|<2.5$, $\alpha_T>0.55$
- *Expected S/B ~ 6*
  - LM1@100 pb^{-1} ~ 44 events
  - Background ~ 8 events



Search in the n-jets channel

- *Generalize α_T from 2-jet case to n-jet*
  - *Studies done for n=3,4,5,6*
  - Combine jets in 2 groups such that $\Delta HT = HT_1 - HT_2$ is minimal
- *Event selection*
  - Jet ET > 50 GeV, $|\eta| < 3$
  - 1st and 2nd jet ET>100 GeV, $|\eta_1|<2$
  - Lepton Pt < 10 GeV
  - HT > 350 GeV
  - $\alpha_T > 0.55$
  - $MHT/MHT_{30} < 1.25$
    - MHT=vectorial sum of jet PT
    - MHT_{30}=MHT from jets PT > 30 GeV
- *Background estimation similar to 2-jet case*
- *Expected S/B ~ 6*
  - LM1 @ 100 pb^{-1} ~ 52
  - Background ~ 8

$$\alpha_T = \frac{H_T - \Delta H_T^{min}}{2M_T}$$



Conclusions

- Model independent searches driven by the physics objects in the events
- A lot of effort towards removing bad events and understanding physics quantities
- Inclusive and exclusive analyses have been developed
- Focus on estimating the SM background using data-driven techniques
- Great SUSY discovery potential in the all-hadronic channel
    - With less than 100 pb^{-1} of good data at 10 TeV of total energy
- Eagerly awaiting first collisions this fall