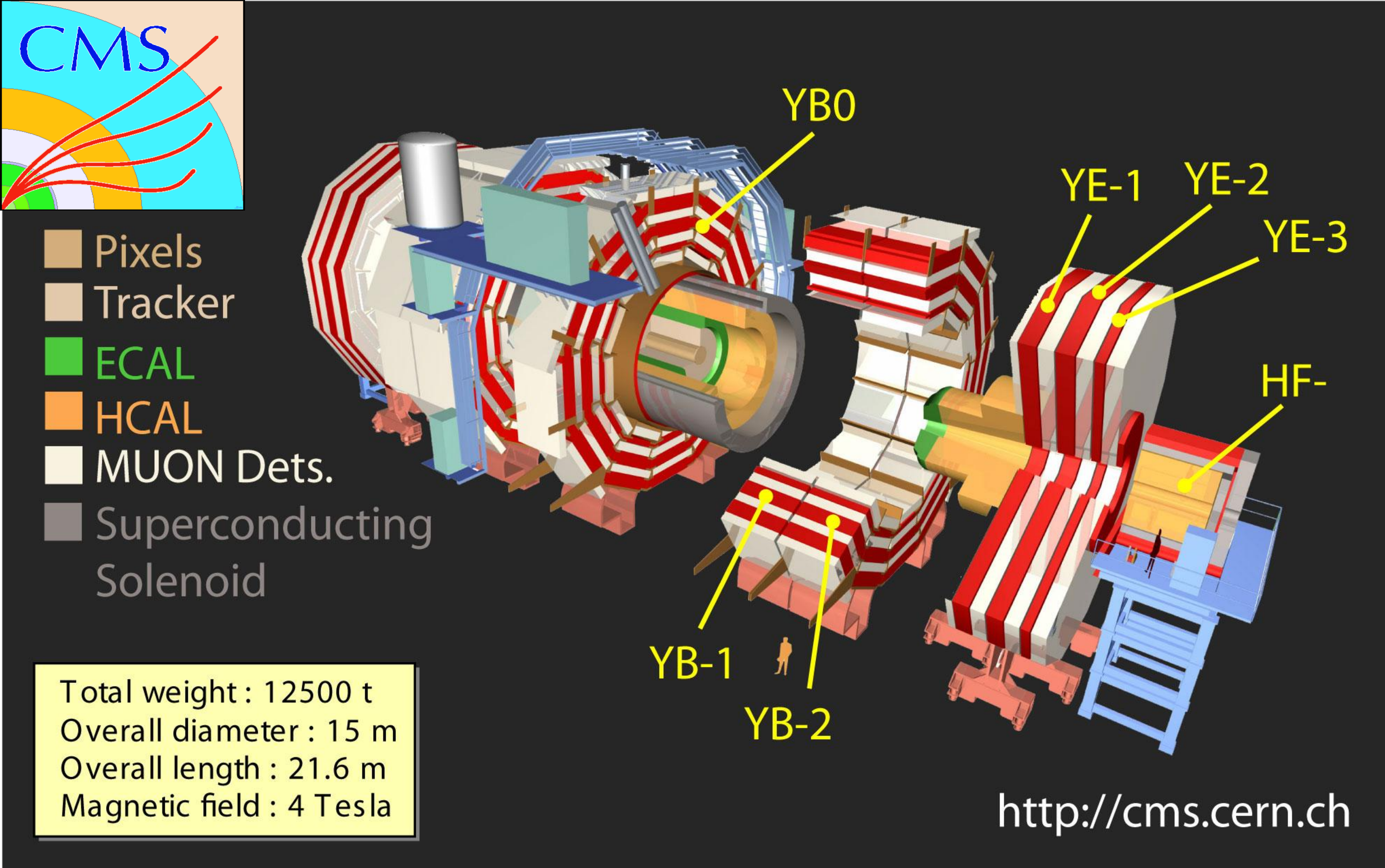
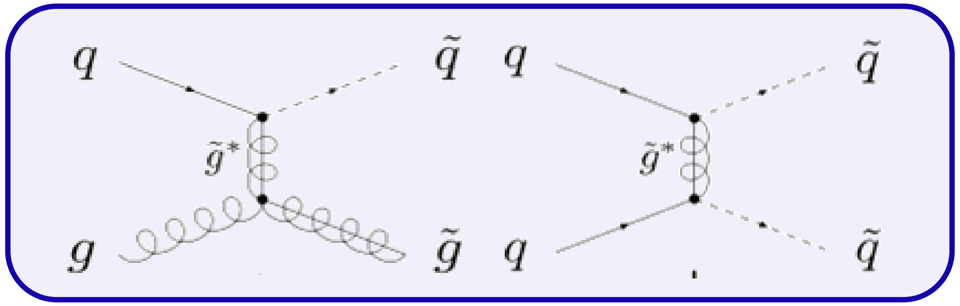
Searches for Supersymmetry at CMS

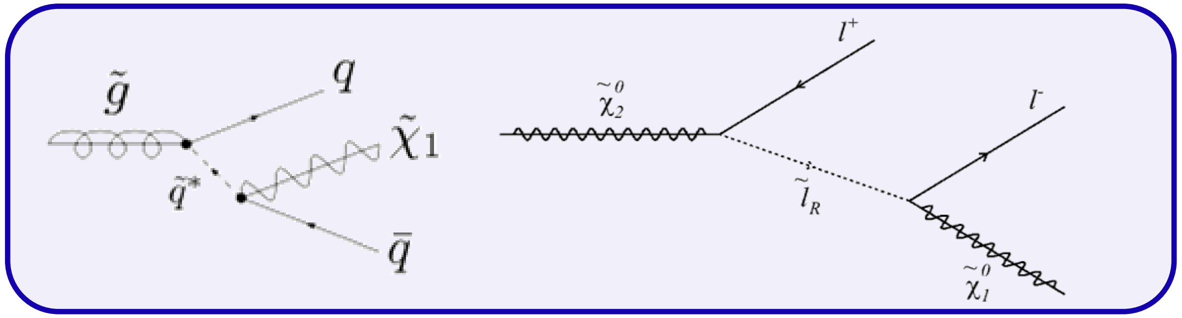
Robert Schöfbeck
on behalf of the CMS collaboration


CMS
YB0
YE-1
YE-2
YE-3
HF-
YB-1
YB-2
Pixels
Tracker
ECAL
HCAL
MUON Dets.
Superconducting Solenoid
Total weight : 12500 t
Overall diameter : 15 m
Overall length : 21.6 m
Magnetic field : 4 Tesla
http://cms.cern.ch

Missing E_T and jets at the LHC: SUSY

- at the LHC colored $\tilde{g}\tilde{g}$, $\tilde{g}\tilde{q}$ or $\tilde{q}\tilde{q}$ roduction will be dominant
- followed by cascade decays involving jets and (di-)leptons, photons, ...
- Under moderate assumptions (e.g. R-parity) there is a stable LSP
- If it is weakly ir $\tilde{\chi}_1^0$ cting like, e.g. the it
  - will escape detection producing large amounts of missing energy
  - would be a good dark matter candidate





MACSJ0025

Signature: jets + MET + X

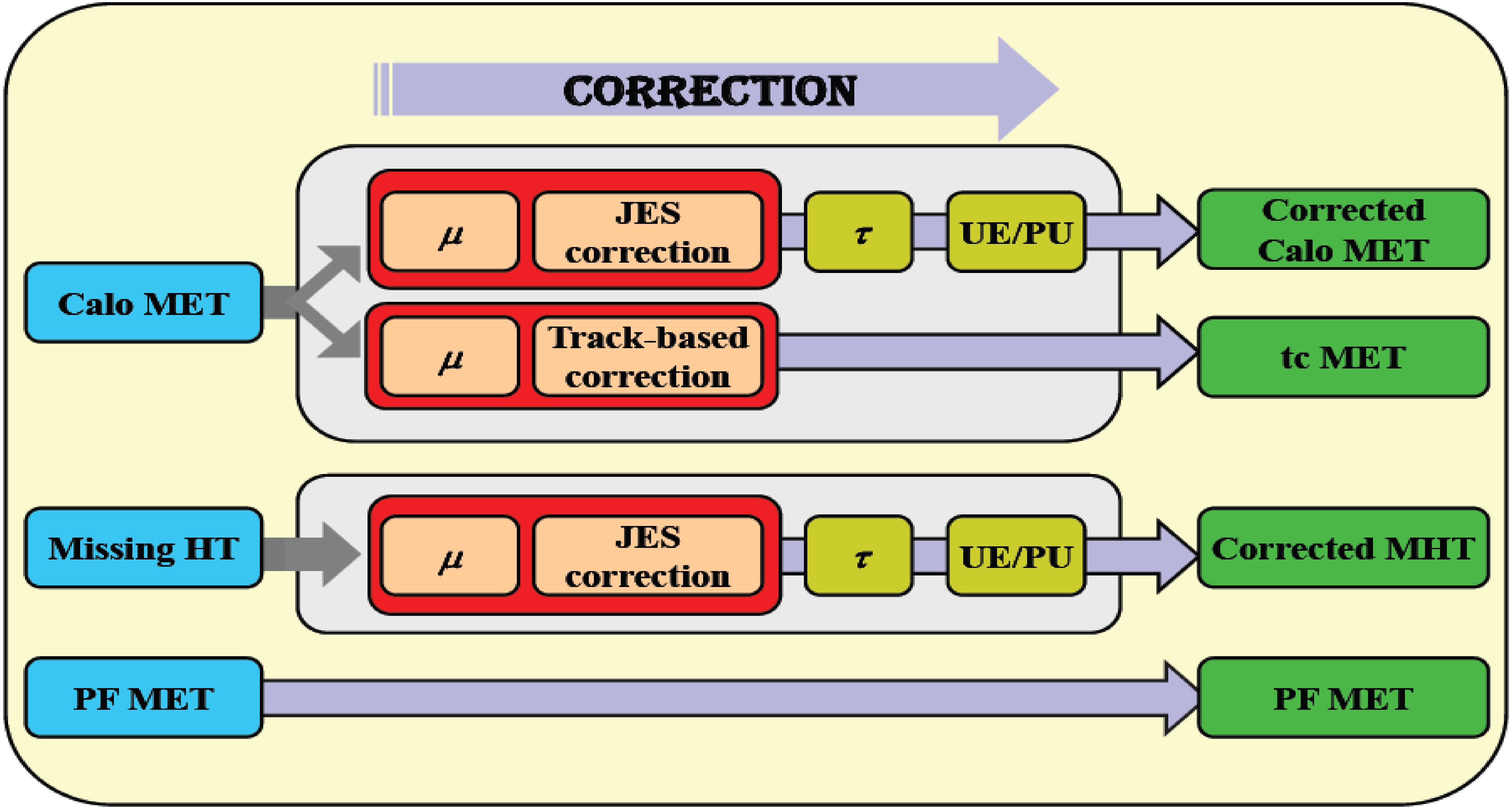
Cosmology + LHC

=

Exciting Motivation + Right Place&Timing

MET Results from 7TeV

work-flow of MET corrections



track based MET corrections

new physics could be close to the standard model in MET → accurate meas.

difficulties in calorimetry MET (non-linearity, material budget, high magnetic field)

- especially at low p_T: 10 GeV pion ~ 6 GeV response

Muon corrections (part of standard calo-MET corrections)

- identify muons
- subtract expected deposit for a MIP (~2GeV)
- add Muon-pt

Muon correction

$$
\begin{aligned}
\not{E}_T^{\mu} &= \not{E}_T^{\text{calo}} + \delta \not{E}_T^{\mu}, \\
&= -\sum_{\text{towers}} \vec{E}_T - \sum_{\substack{\text{good}\\\text{muons}}} \vec{p}_T + \sum_{\substack{\text{good}\\\text{muons}}} \vec{E}_T^{\text{MIP}}
\end{aligned}
$$

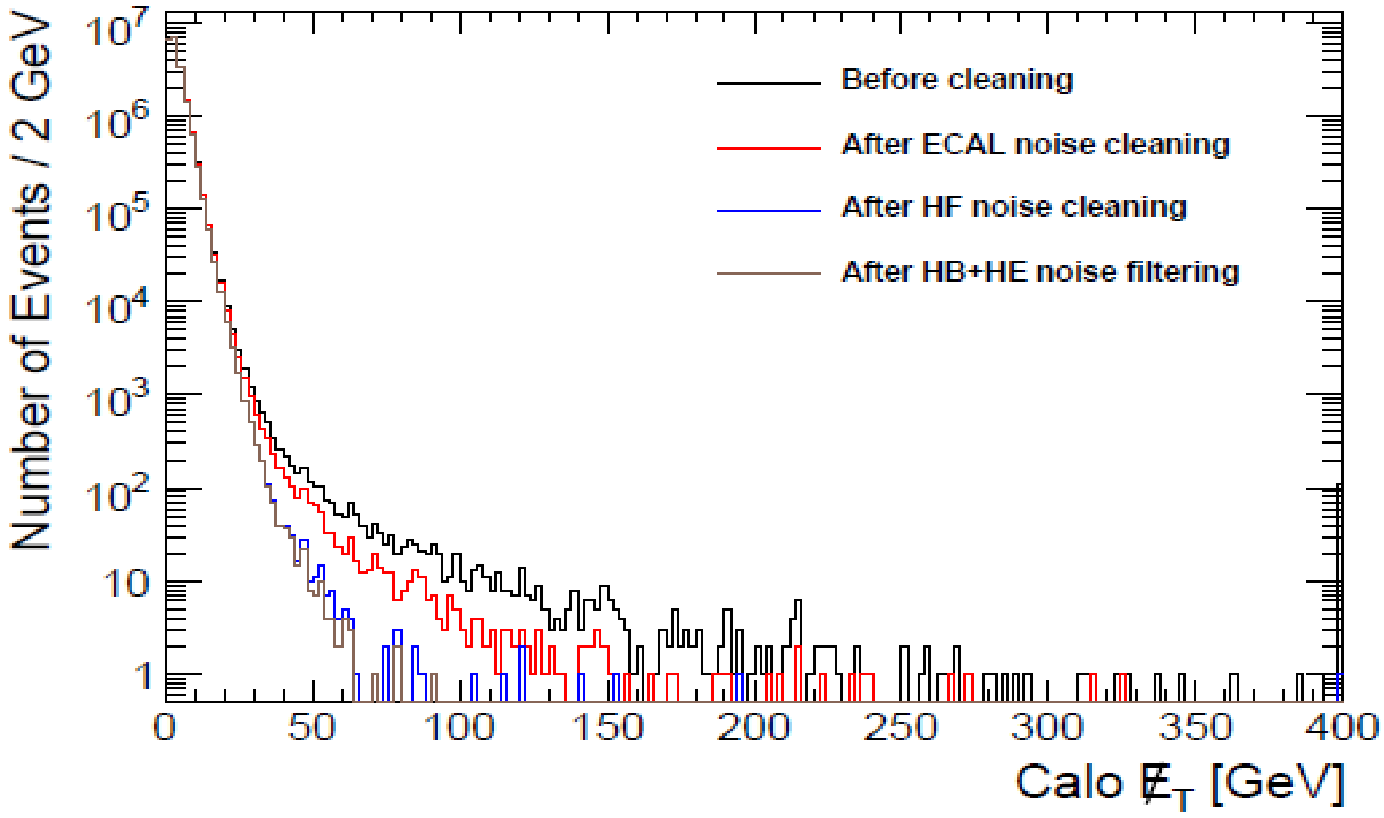
track based correction

$$
\begin{aligned}
\not{E}_T^{\text{tc}} &= \not{E}_T^{\mu} + \delta \not{E}_T^{\text{tc}}, \\
&= \not{E}_T^{\mu} + \sum_{\substack{\text{good}\\\text{tracks}}} \langle \vec{E}_T \rangle - \sum_{\substack{\text{good}\\\text{tracks}}} \vec{p}_T
\end{aligned}
$$

track corrected MET (tcMET)

- same spirit: at low pt remove calo-response making use of the a calorimetry response-function $\langle E_T \rangle$ determined from simulation

Noise cleaning in MET



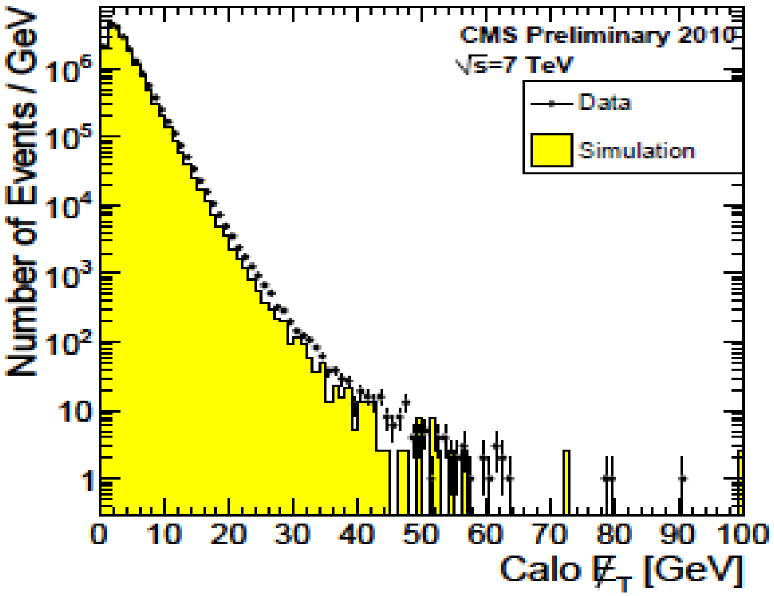
Basic strategy:

use unphysical **charge sharing** between neighboring channels in **space and/or depth** as well as **timing** and **pulse shape** information.

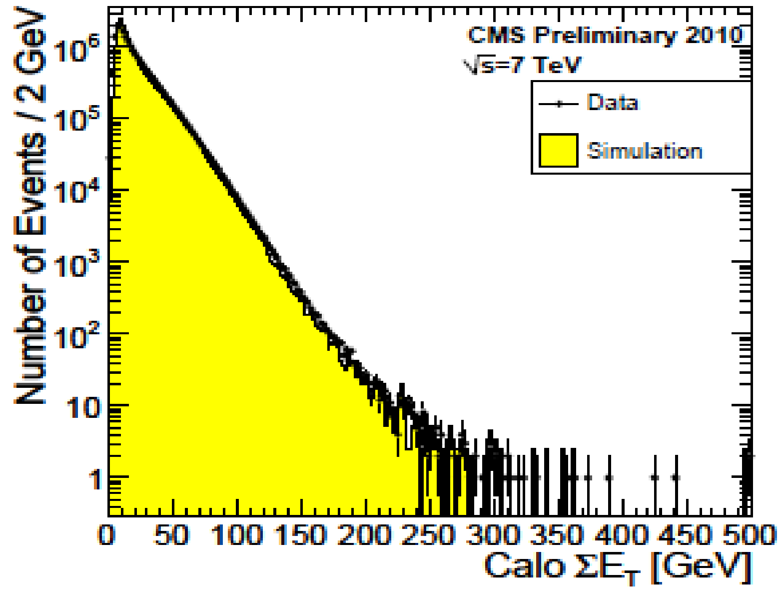
Once a **"hit"** in an HCAL tower or ECAL crystal is determined to be unphysical, it is **excluded from the reconstruction** of higher level objects like jets or MET

HBHE veto: RBX fires up to 72 channels; no signal in neighboring RBX

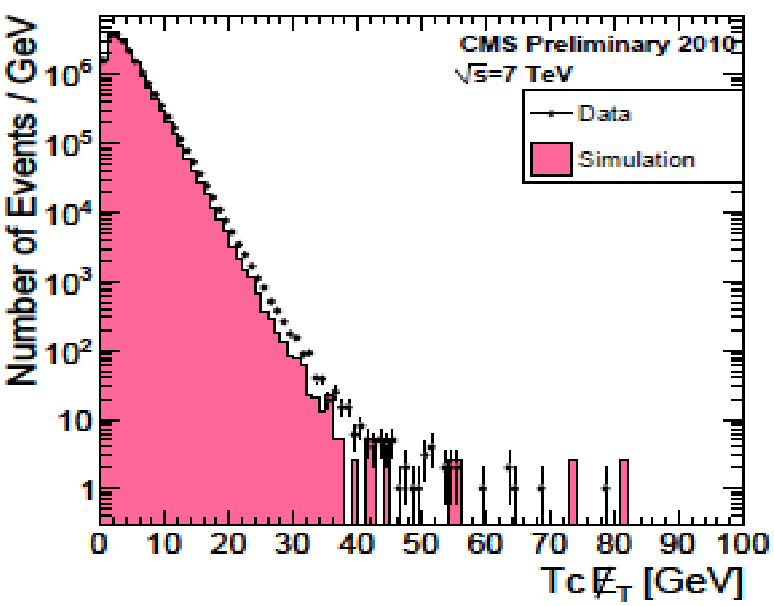
MET performance in CMS



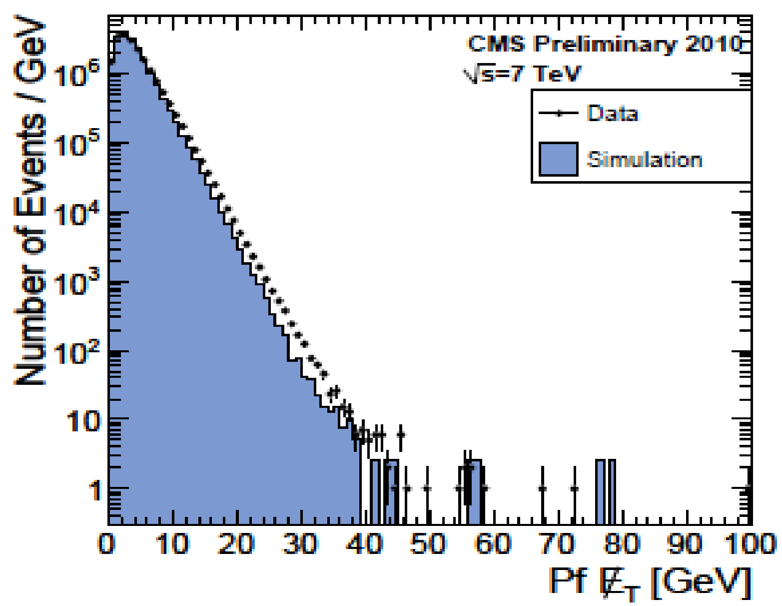
(a) calo$\not{E}_T$ distribution



(b) calo$\sum E_T$ distribution



(c) tc$\not{E}_T$ distribution



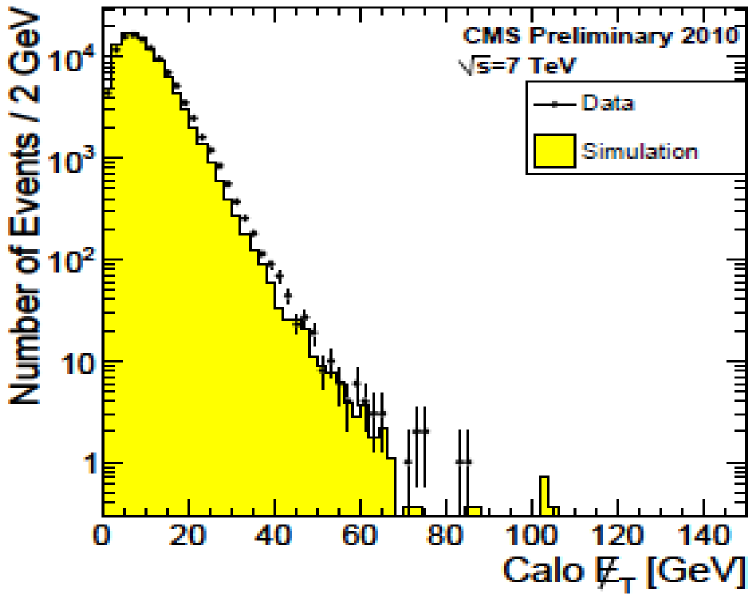
(d) pf$\not{E}_T$ distribution

Inclusive MET distributions for 3 different reconstruction algorithms (and, notouriosly difficult, Sum-E_T in Pythia Tune D6T)

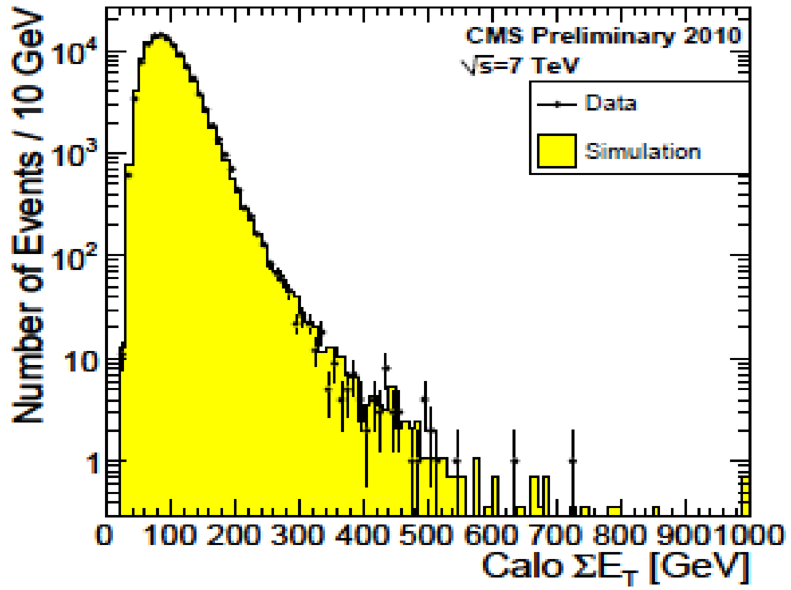
More than 6 orders of magnitude of **well-understood missing energy** after a few months into data-taking.

Main source of Data/MC disagreement of the slope: underestimations of HCAL energy in the simulation of the endcap

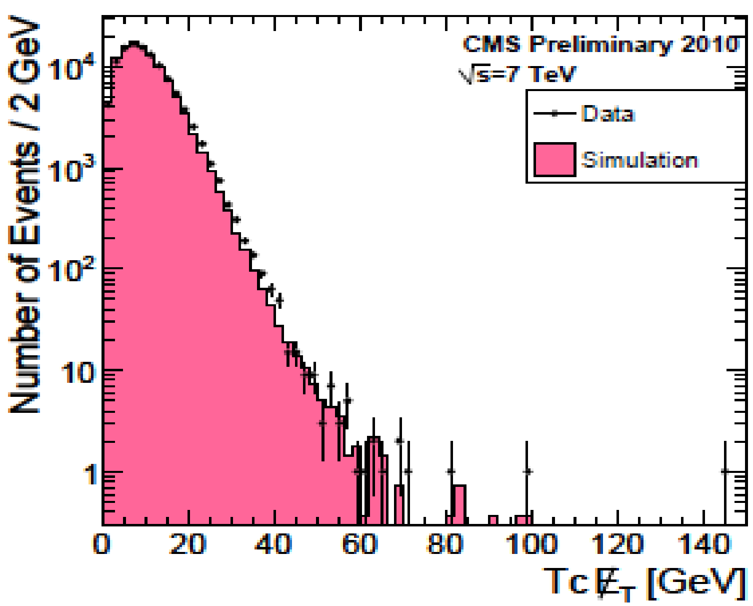
MET in dijet Events



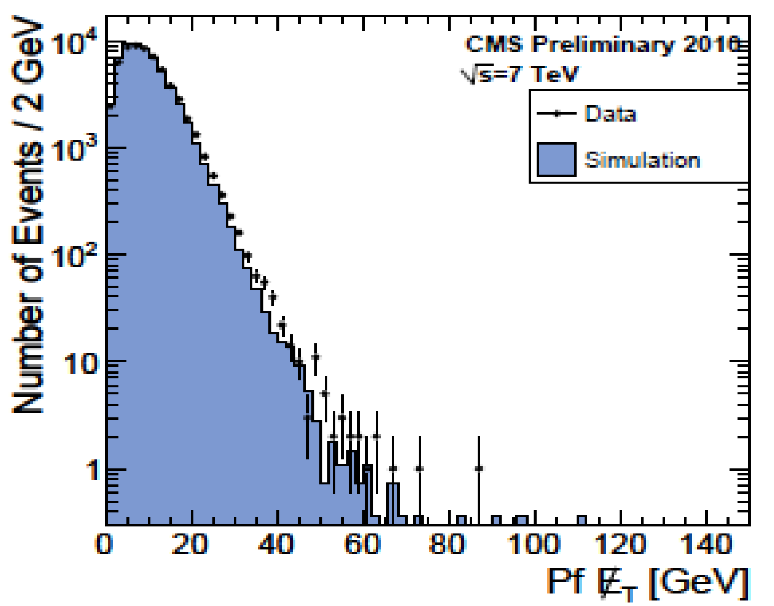
(a) calo$\not{E}_T$ distribution



(b) calo$\sum E_T$ distribution



(c) tc$\not{E}_T$ distribution



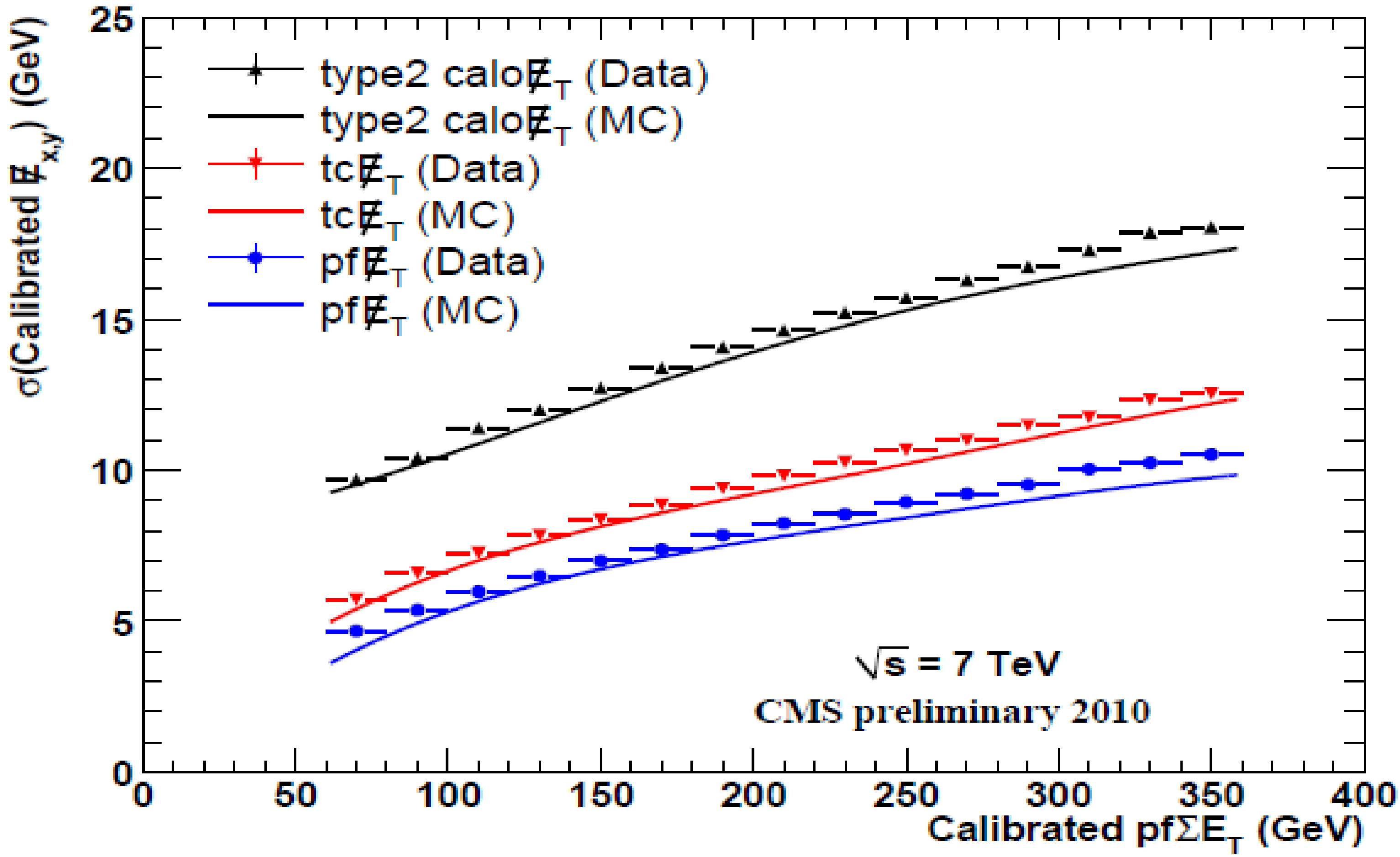
(d) pf$\not{E}_T$ distribution

DiJet MET distributions for 3 different reconstruction algorithms

Topological cleaning of data-sample by requiring at least two jets with $p_T > 25$ GeV and $|\eta| < 2.4$.

Good agreement for all quantities, especially sum-E_T

MET resolution



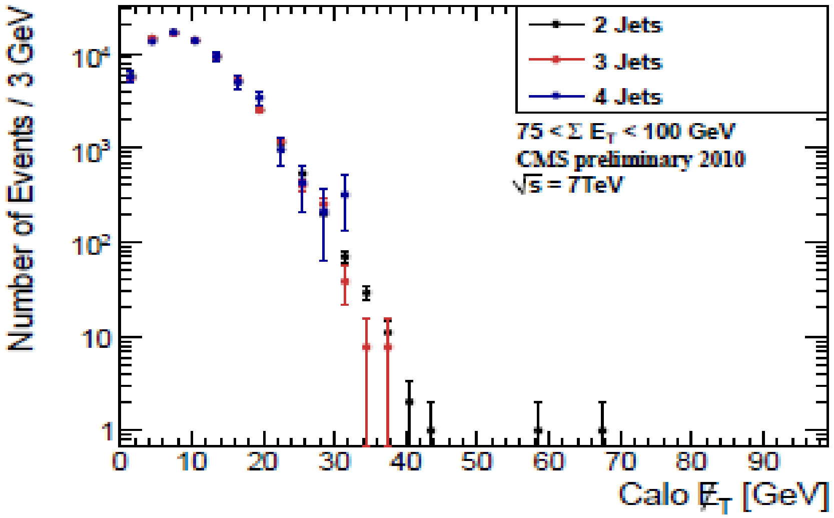
Comparing MET resolutions of different algorithms in Dijet Data

y-Axis: σ of Gaussian fit for $E_{T,miss,x,y}$, x-Axis: calibrated pF-sum-E_T

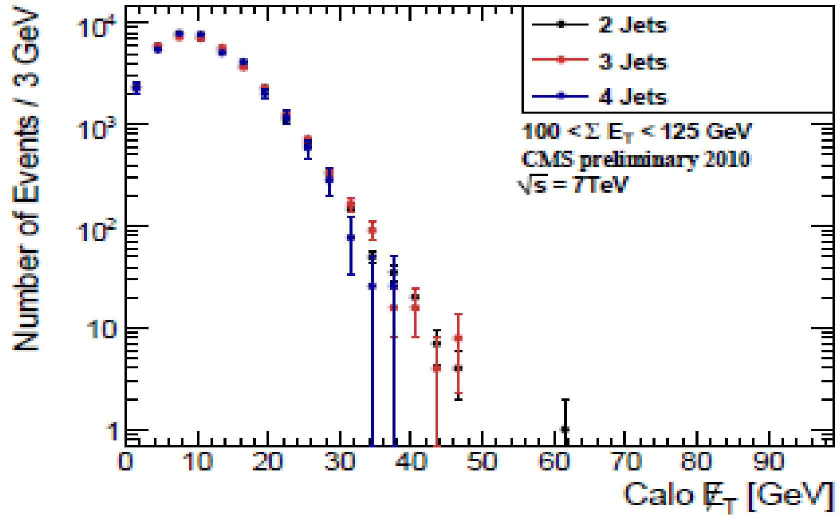
Tracker based algorithms improve MET resolution.

(Type-II corrected calorimetry MET includes jet-energy scale corrections applied to jets and to the remaining unclustered energy deposits.)

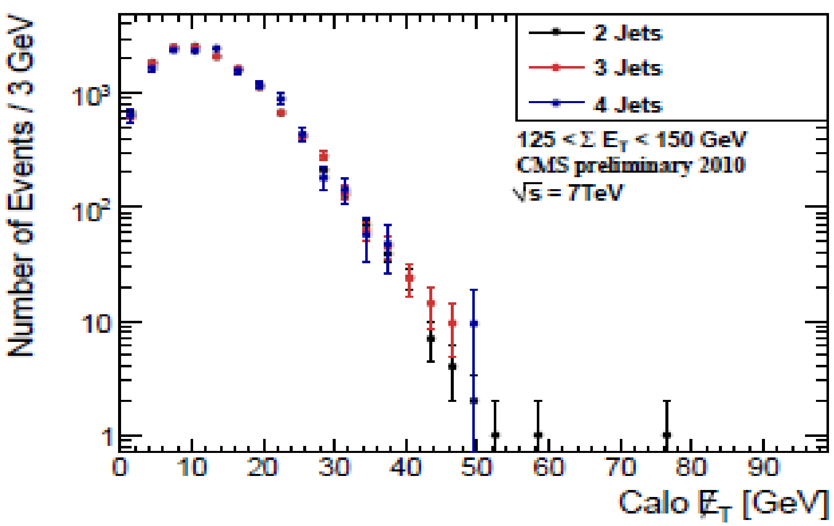
Towards SUSY



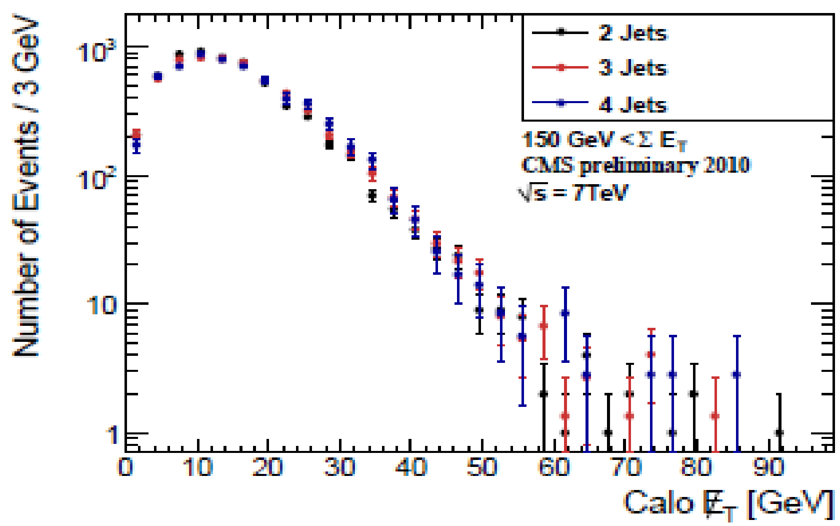
(a)



(b)



(c)



(d)

MET in multi-Jet Events

Compare MET shapes in bins of sum-E_T for different jet-multiplicities

Idea: MET is driven by sum-E_T, a meas. of hadronic activity

MET shapes vary with sum-E_T but not with how the energy is distributed among jets

Prospects & Commissioning of early SUSY searches

How do we search for Supersymmetry at CMS?

- We search for inclusive signatures
  MET + jets + anything (lepton(s), b's, (di-)photons, etc.)

- We do use the benchmarks mainly for motivation by theory,
  however we aim to avoid theoretical prejudices.

The most important signatures are

MET + exclusive jets
MET + inclusive jets
MET + jets + 1 lepton
MET + jets + SS di-leptons
MET + jets + OS di-leptons
MET + jets + trileptons
MET + jets + di-photons

For these signatures we develop data-driven background-estimations.
At present we do not focus on (immediate) interpretation of an excess, instead
are recent efforts to parametrize it (with e.g. an on-shell effective theory).

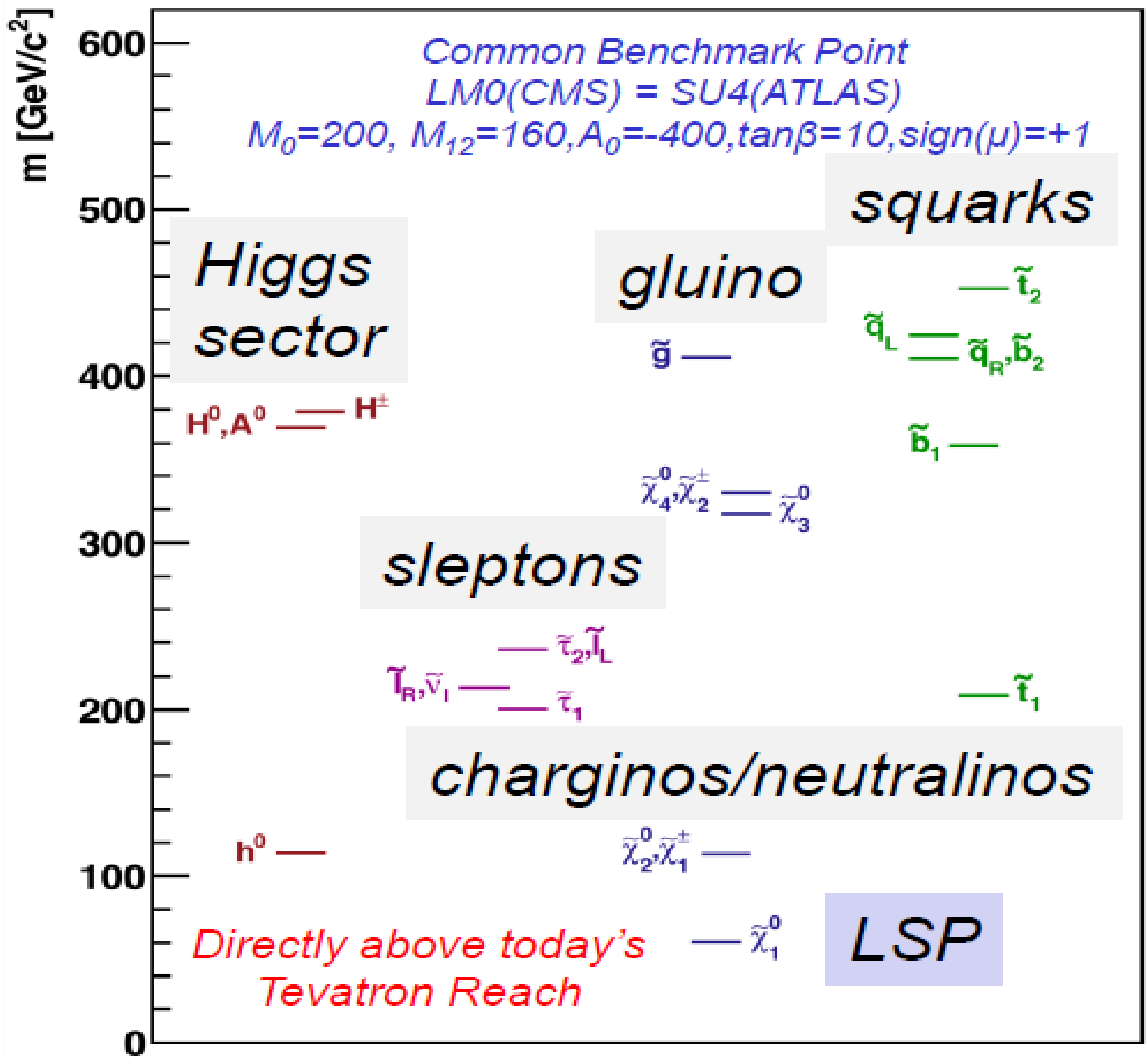
- In the past years we have tested strategies to suppress and measure SM backgrounds in detail using MC

- Used 11-65 nb^{-1} of 7 TeV data used for testing some of these methods in the available phase-space (not yet where we expect SUSY signal)

- Although QCD is not expected to be dominant background for some of the channels, it has poorly known (large!) cross sections, which need to be measured from data:

    - Suppressing QCD using topological observables
    - Predicting QCD contributions to MET
    - data-driven techniques to measure QCD backgrounds for lepton(s) , photon(s) + Jets in MET

benchmarking SUSY searches



5/05/2010 LHCC/A101 O. Buchmüller (ICL)

mSUGRA/CMSSM

4 parameters, 1 sign

m_0, $m_{1/2}$, tan β, sign μ, A_0

pro:

- studied very well
- not yet ruled out

con:

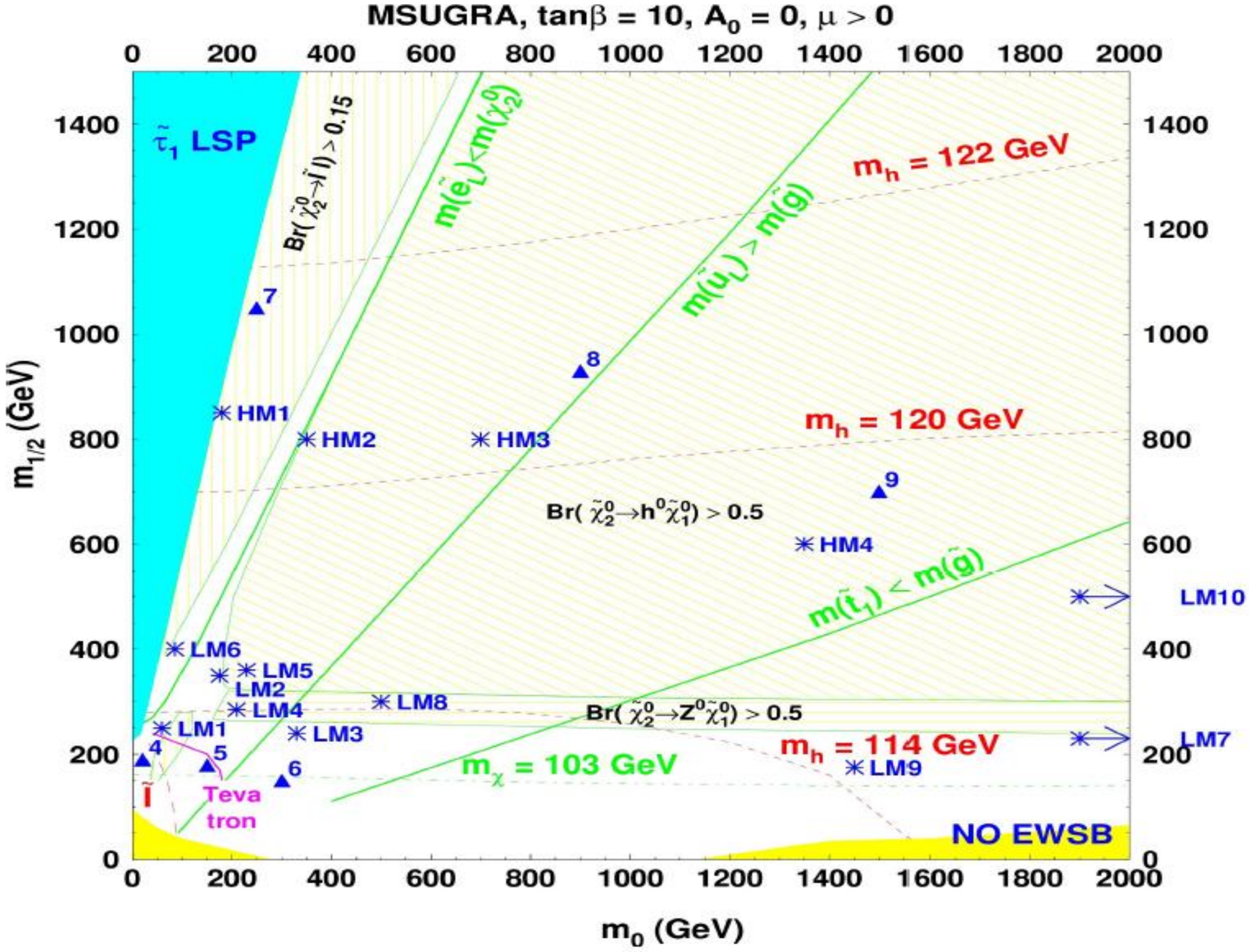
- restrictive ($M_{gluino} \sim 6\ M_{LSP}$)

Early searches should

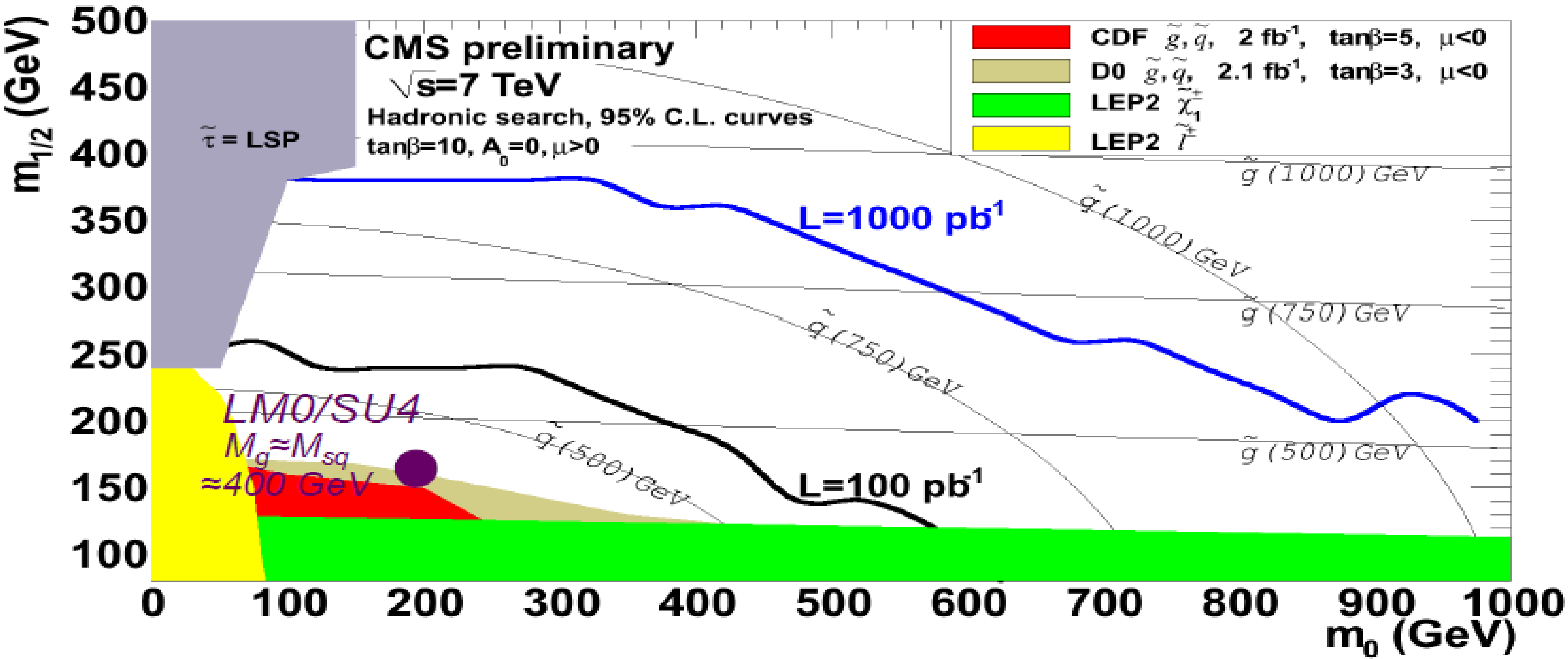
- be inclusive
- avoid detailed cut-tuning
- data-driven

A lot of effort is devoted to guarantee the latter

SUSY benchmarks in CMS



prospect for inclusive jets + MET



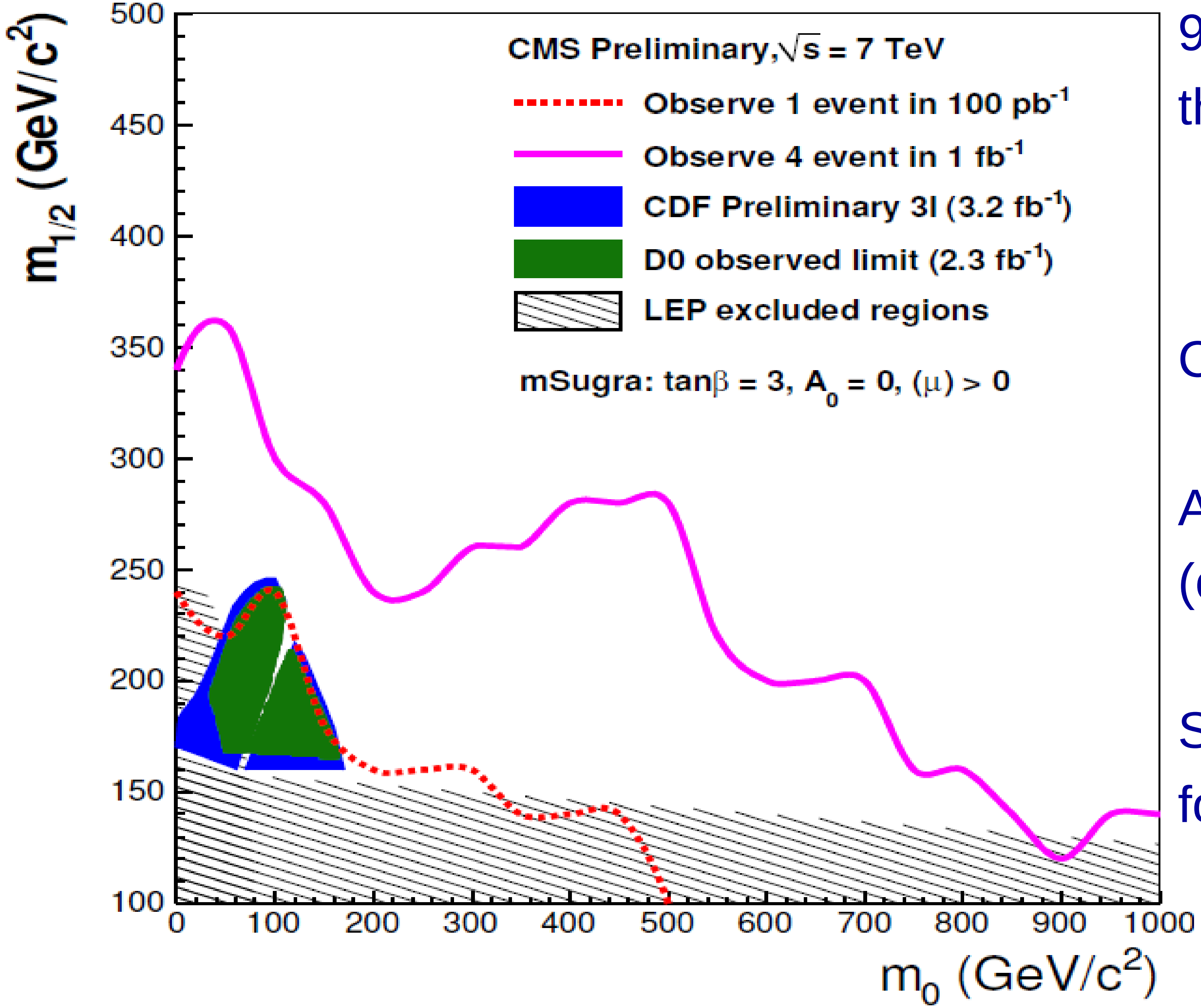
95% CL exclusion-contours of the all-hadronic searches (≥3j + MET + lep-veto)

50% uncertainty assumed on SM-Bkg. Surpass Tevatron at ~ $50 pb^{-1}$

no optimization of selection cuts

(Tevatron: different tanβ, more data, LEP: s-lepton and chargino searches)

same sign dilepton search



95% CL exclusion-contours of the same-sign di-lepton search

$\mu^{\pm}\mu^{\pm}, e^{\pm}e^{\pm}, e^{\pm}\mu^{\pm}$

CDF/D0 tri-lepton exclusions

Assume 1 event at $100pb^{-1}$ (or 4 Events at $1fb^{-1}$)

SM-Bkg ~ 0.4 (4) Events for $100pb^{-1}$ ($1fb^{-1}$)

Enter new territory with $100pb^{-1}$!

suppressing QCD with α_T

α_T uses jet-p_Ts and angular information but no MET $\alpha_T \equiv \frac{p_{T2}}{M_T}$

where M_T is the transversal mass of a dijet-system and $p_{T,2}$ its sub-leading transversal momentum.

In well-measured dijet events:

$\alpha_{T,\text{ di-jet}} < 0.5$

Multi-Jet- generalization:

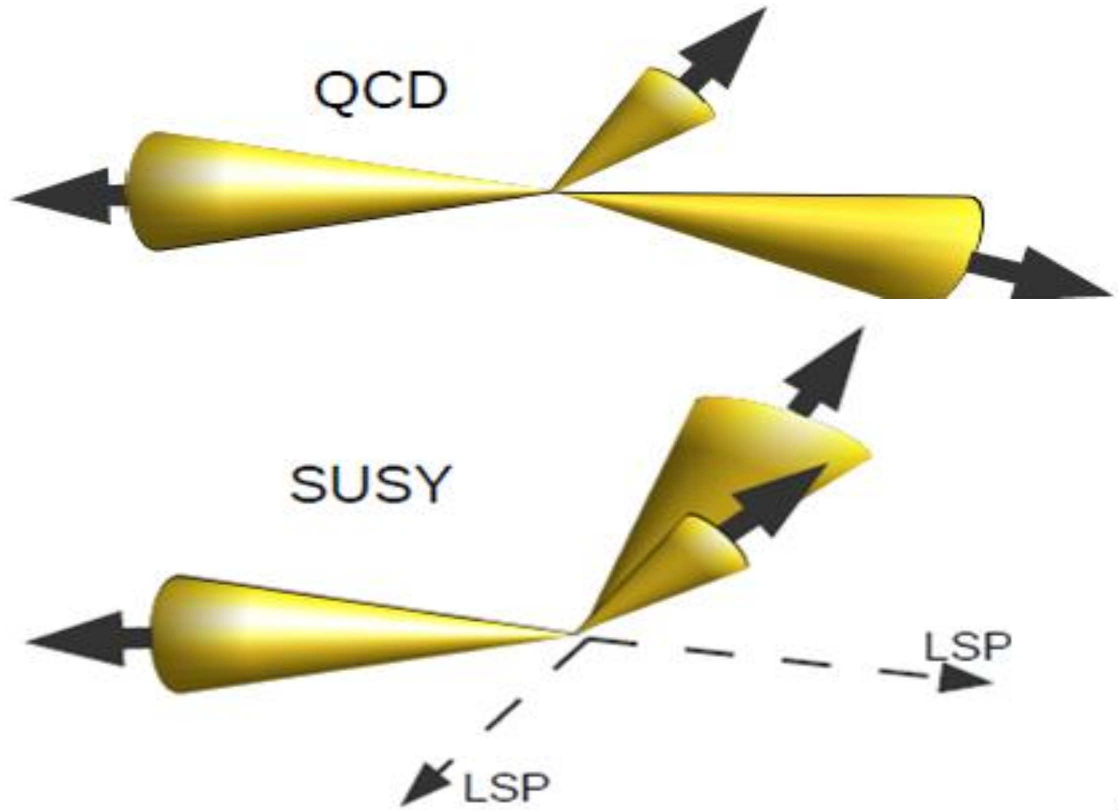
Partition the multi-jet system into pseudo-jets by minimizing ΔH_T

$$\alpha_T = \frac{1}{2}\frac{H_T - \Delta H_T}{\sqrt{H_T^2 - (MHT)^2}}.$$

$$\text{MHT} \equiv |\sum_{\text{jets } j} -\vec{p}_{Tj}|$$

$$H_T = \sum_{\text{jets } j} p_{Tj}$$

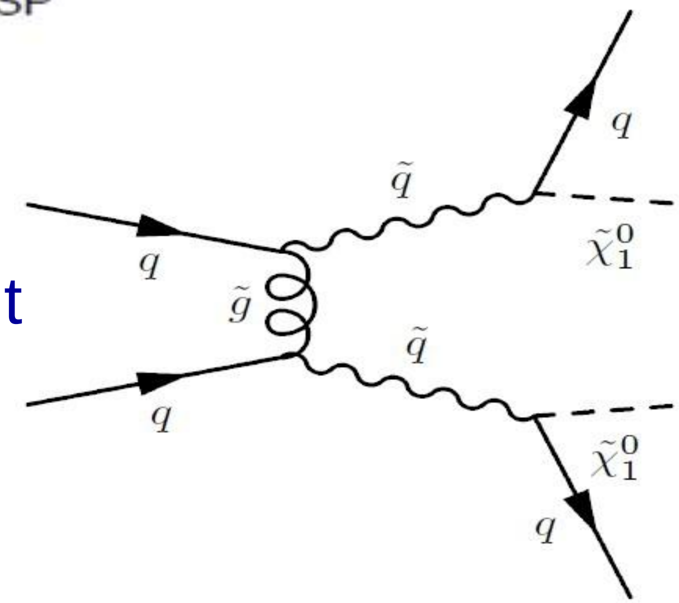
$$\Delta H_T = p_{T\text{pseudojet 1}} - p_{T\text{pseudojet 2}}$$



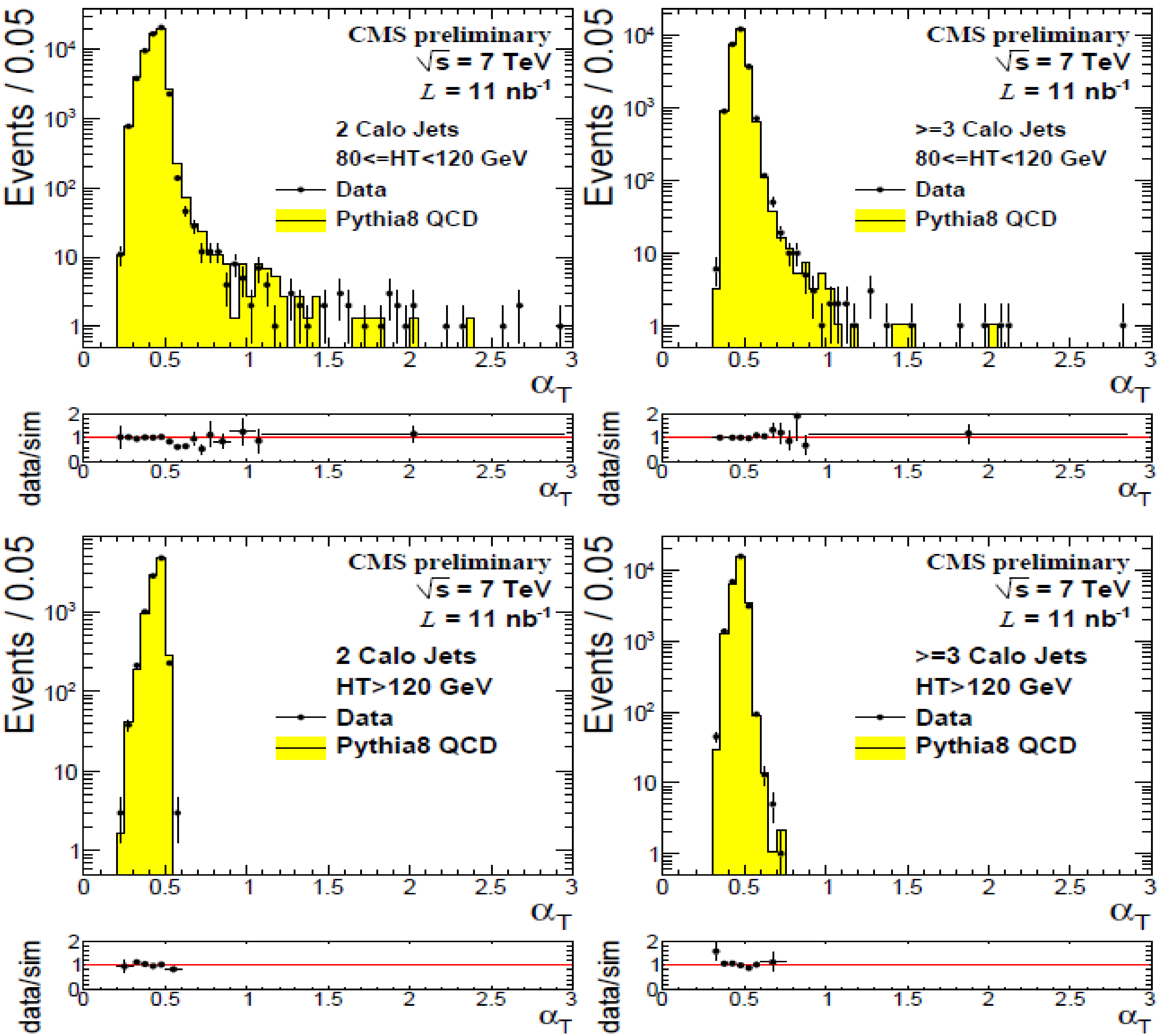
MC studies indicate powerful QCD rejection for a tightened cut

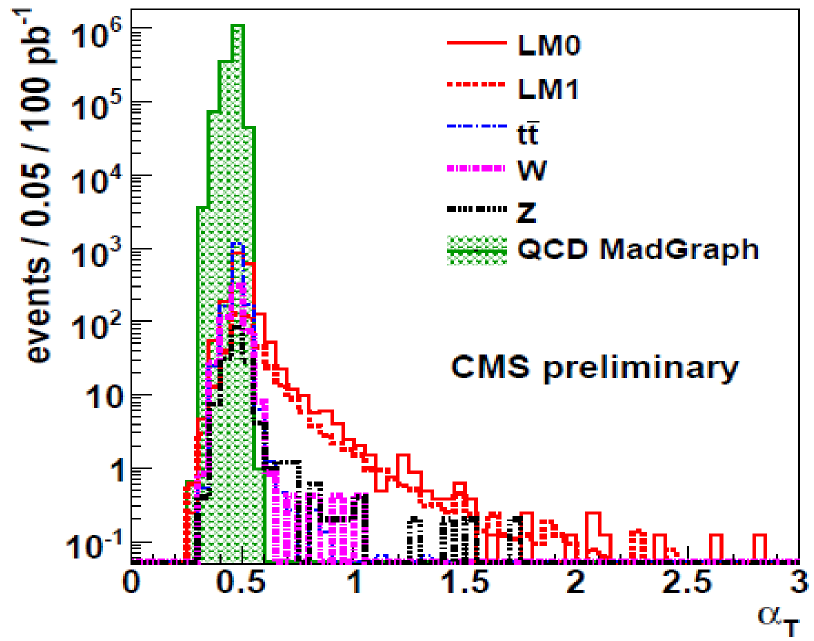
$\alpha_{T,\text{ multi-jet}} > 0.55$

Study α_T as a function of the scalar sum of jet-p_Ts (i.e. **HT**)



suppressing QCD with α_T

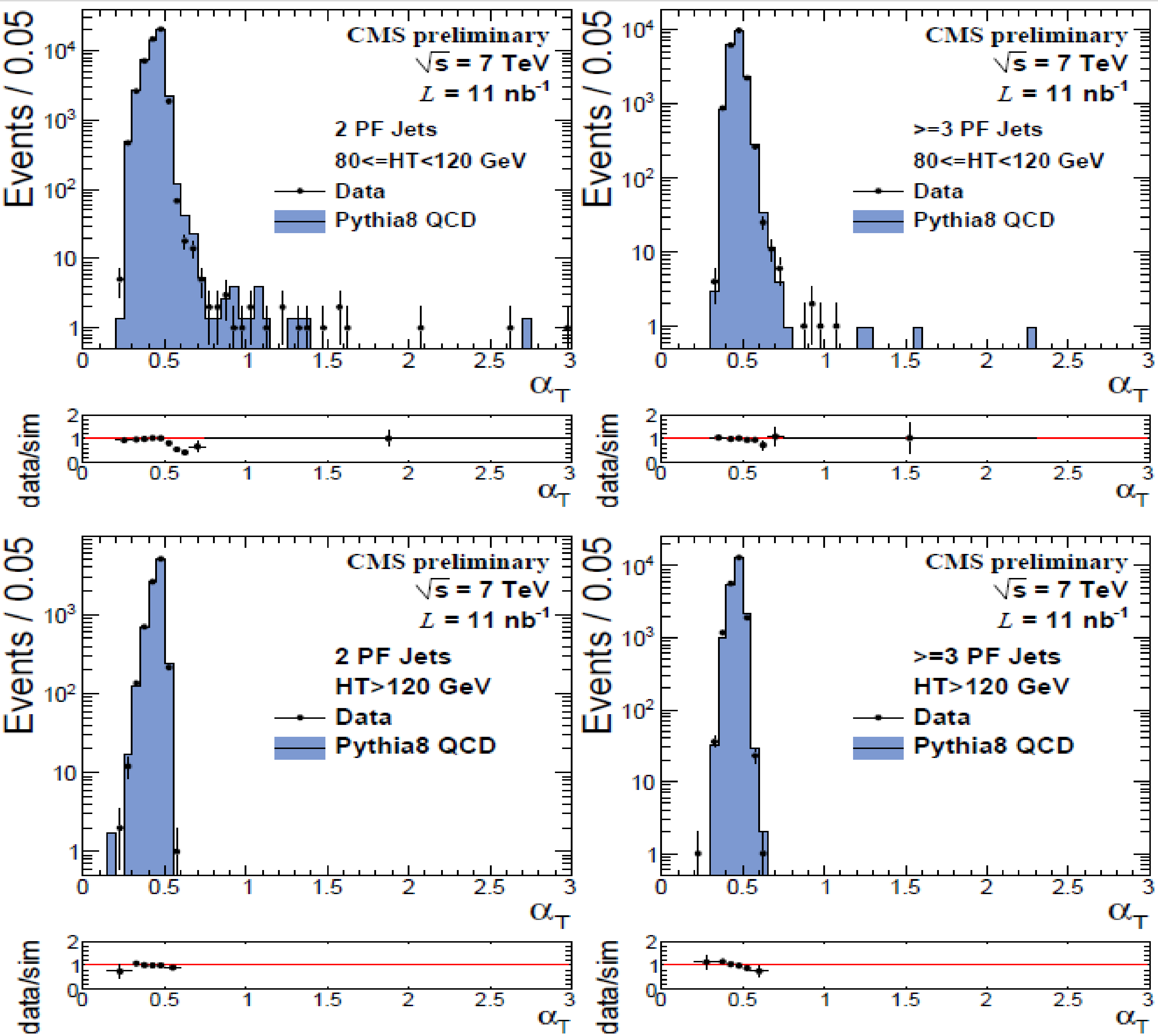




Top: MC simulation of α_T for 10TeV and two low-mass mSUGRA benchmarks (LM0, LM1)

Left: α_T for dijet and multi-jet Events for two bins in H_T for calorimetry jets and 7TeV

suppressing QCD with α_T



Left: Same plots for two bins in H_T for particle-flow jets.

Some tail for $\alpha_T > 0.55$ for both the dijet and the multi-jet bin for both Data and MC with low HT; some improvement when using particle-flow.

Dramatic improvement when increasing H_T

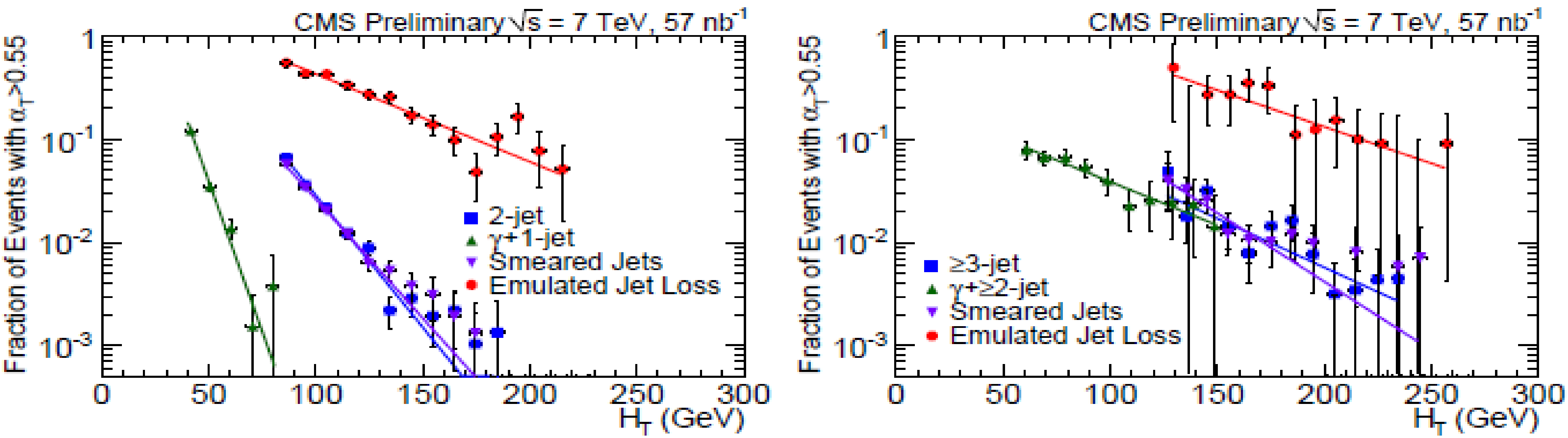
typical SUSY signal:

$H_T > 350$GeV

Study as a function of H_T

validating α_T on Data

Fraction of events with α_T > 0.55 in dijet and multi-jet bin



Blue: **jet-triggered** (p_T>15 GeV uncorrected) shows exponential dependence

Artificial degradation:

Red: Emulate jet-loss with a removal probability ~ 5-10 times the expectation

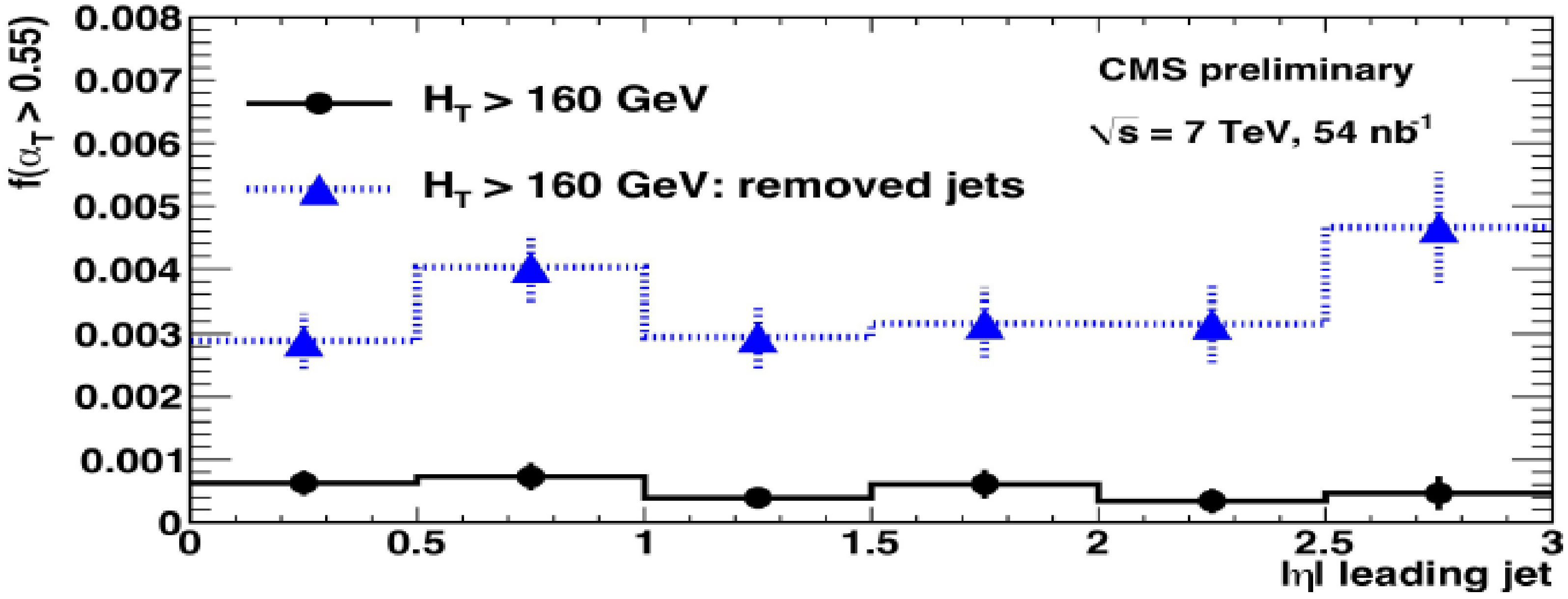
Green: γ-triggered, dominated by misidentified jets

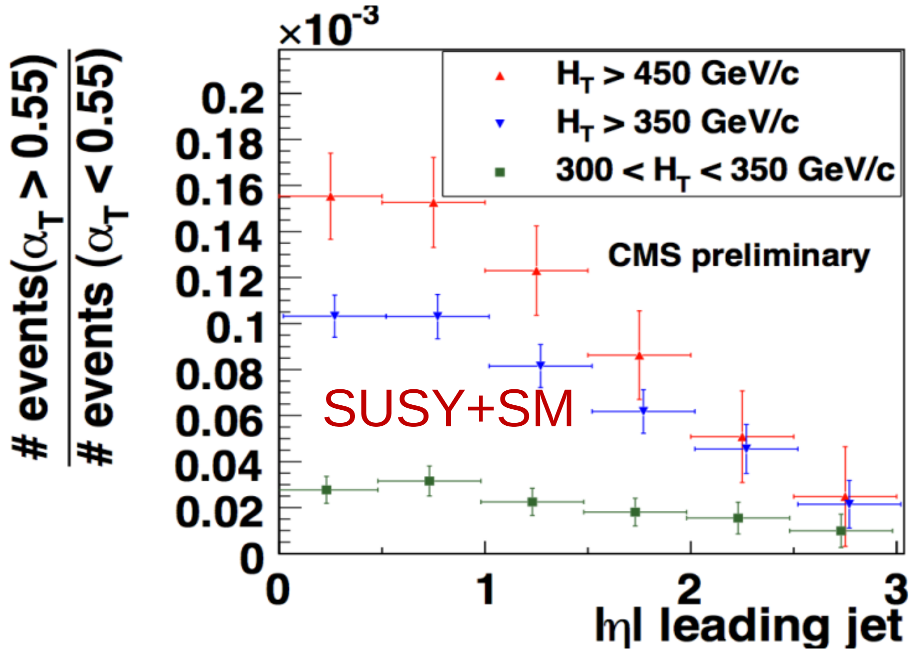
Violet: 10% of the jets are re-smeared with a one-sided Gaussian of $\sigma = 0.5\ p_T$

The failure fraction is a consistently decreasing function of H_T.

validating α_T on Data

Consider the fraction of events with $\alpha_T > 0.55$ as a function of |η| of the leading-jet





SUSY is produced **more centrally** than SM-backgrounds (right)

Aim to use this sideband in |η| of the leading jet to estimate remaining background.

The fraction of QCD events failing $\alpha_T < 0.55$ is uniform in |η| (**black**), even when introducing fake MET by artificially removing jets (**blue**).

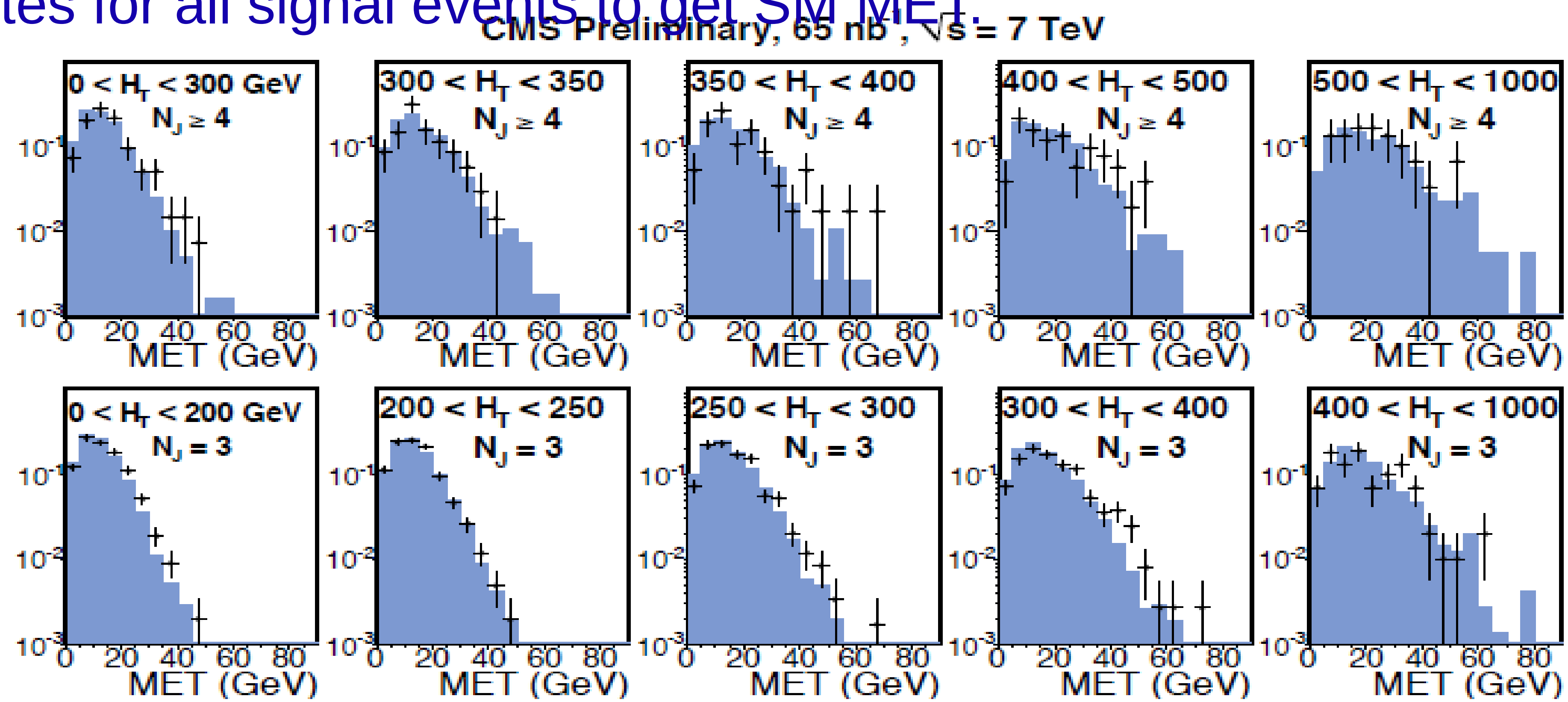
Estimating artificial MET on Data

Using **MET-templates** obtained from QCD-Events to predict **fake-MET** (jet-mismeasurement, noise, instrumental effects, ...)

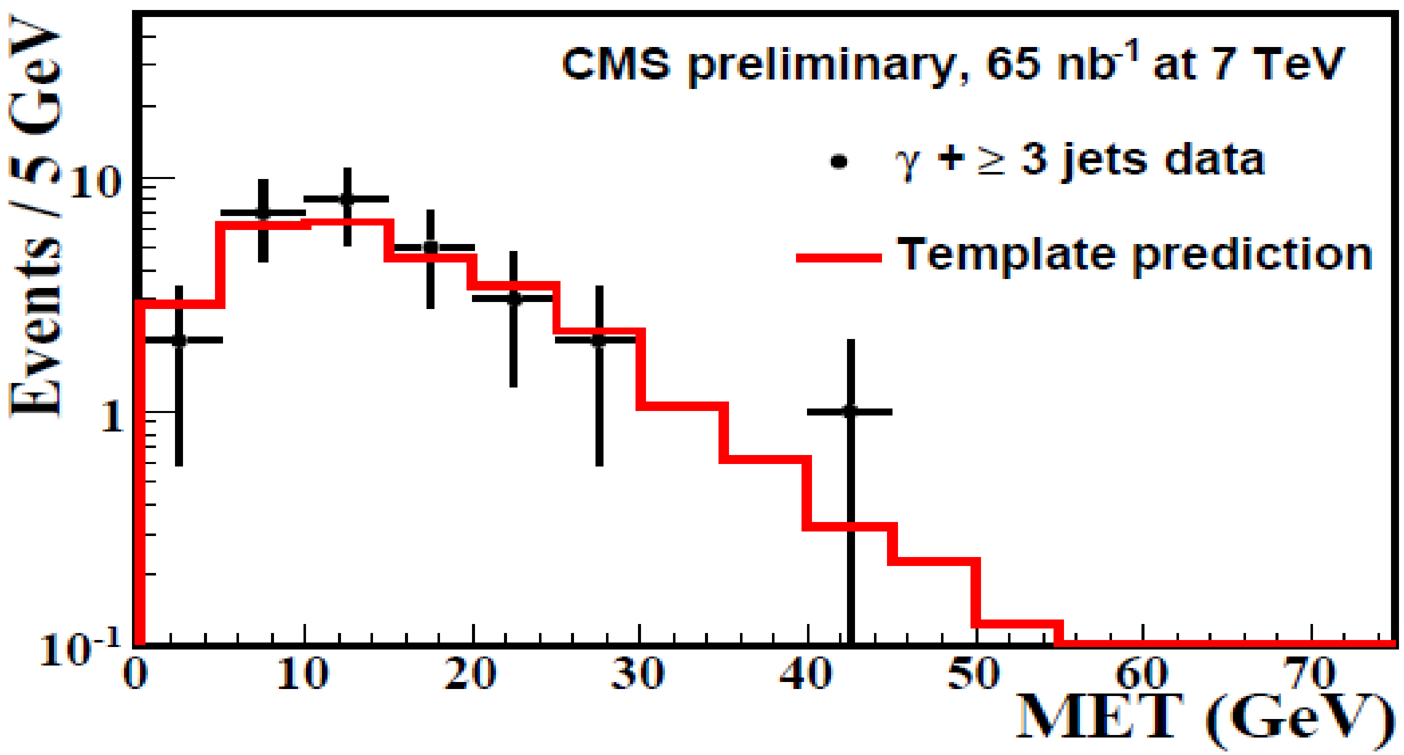
- Construct a pool of MET templates using multi-jet QCD events for each (N_J, H_T-bin) pair. Higher H_T leads to a larger tail in MET
- For each signal candidate events, measure N_J and H_T and pick a corresponding template
- Sum up the templates for all signal events to get SM MET.

Right: MET-templates for pF-MET in the 3- and 4-jet bin

Perform **closure test** on γ + jets (next slide)



Closure test of template method



Testing the prediction of the MET-distribution in γ + ≥3 jet Events.

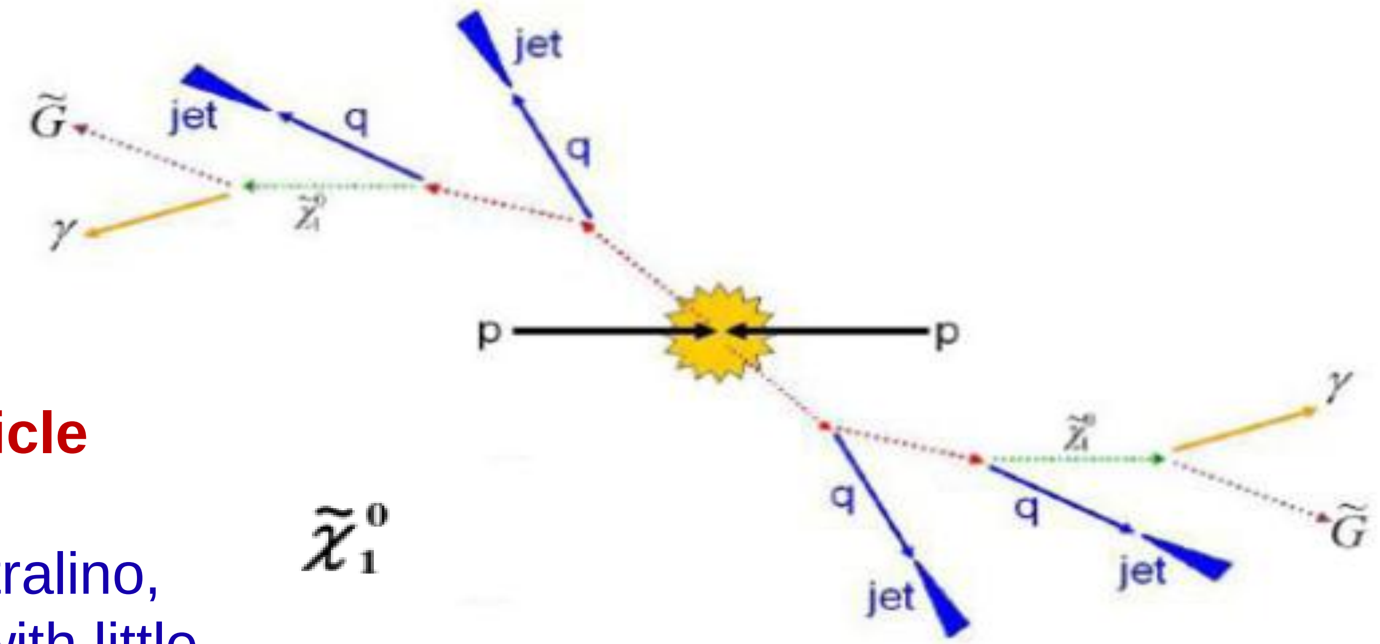
Kinematical effects are diluted at high N_J.

For **MET > 15 GeV** the predicted (12.5 Events) and the observed number of Events (11) are statistically consistent.

Gravity mediated SUSY breaking

In gravity mediated supersymmetry breaking, the lightest Supersymmetric Particle (LSP) is the **gravitino.**

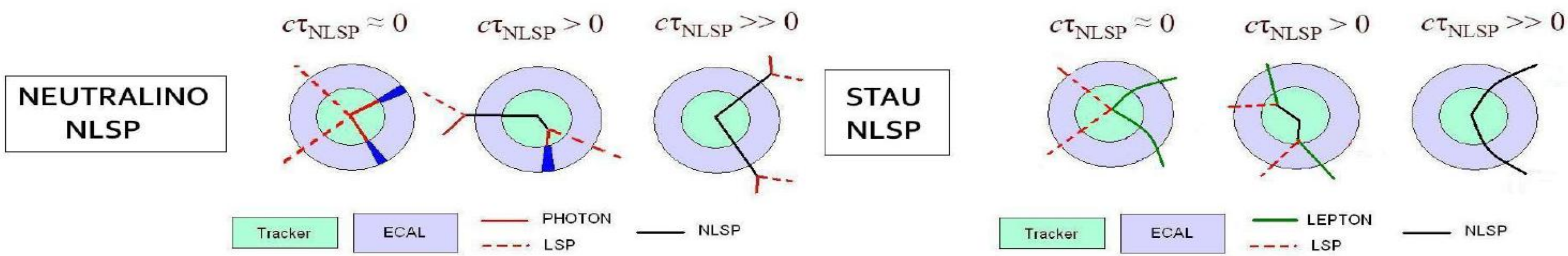
additional 1→2 SUSY vertex is the supersymmetrization of gravitational deflection of light



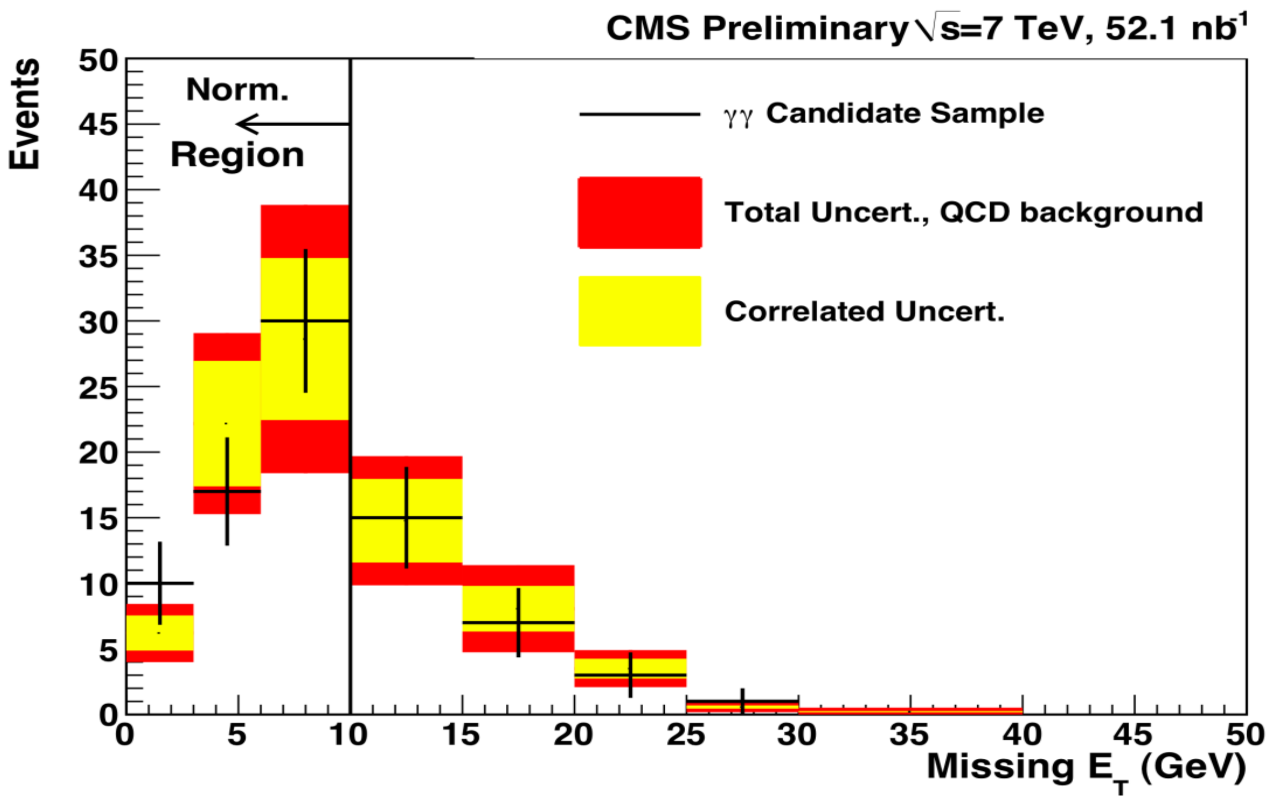
Next to Lightest Supersymmetric Particle

NLSP could be s-tau or the lightest Neutralino, giving rise to distinct collider signatures with little standard model background.

In case of a $\tilde{\chi}_1^0$ NLSP with short enough life-time, it will give rise to a **di-photon** signature. SM-Bkg. from qq → Zγγ and qq → Wγγ are negligible.



Estimating MET in 2γ Events



γγ+ MET is one of the early search channels
remaining backgrounds:
Wγ with the electron **mis-id as γ**
multi-jet (direct γγ) **+**
fake MET (dominant)

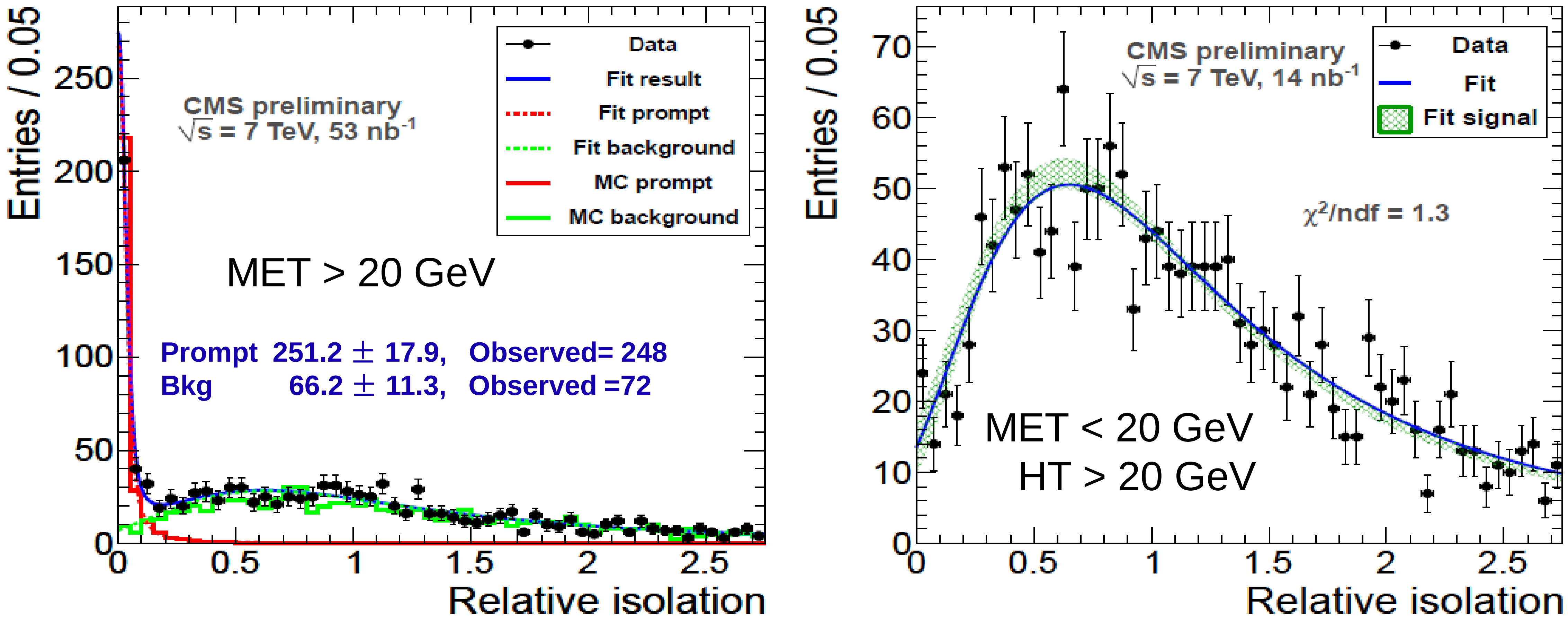
Prediction from fake-fake sample:

Measure MET distribution in a control sample with 2 fake photons, selected by inverting the isolation requirement.
Use number of selected events at MET < 10 GeV to normalize the measured templates (assume no new physics in low MET-region, reweight di-photon p_T spectrum)

Prediction consistent with number of observed events

For MET > 20 GeV:
Predicted = 4.2 ± 1.5
Observed = 4 events

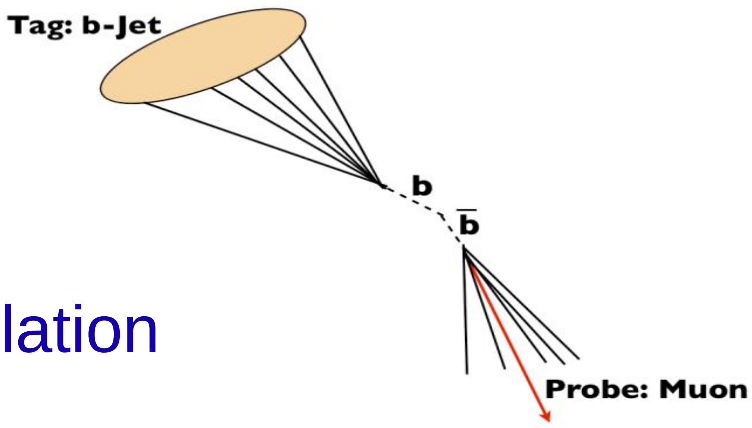
Isolation fit in Muon channel

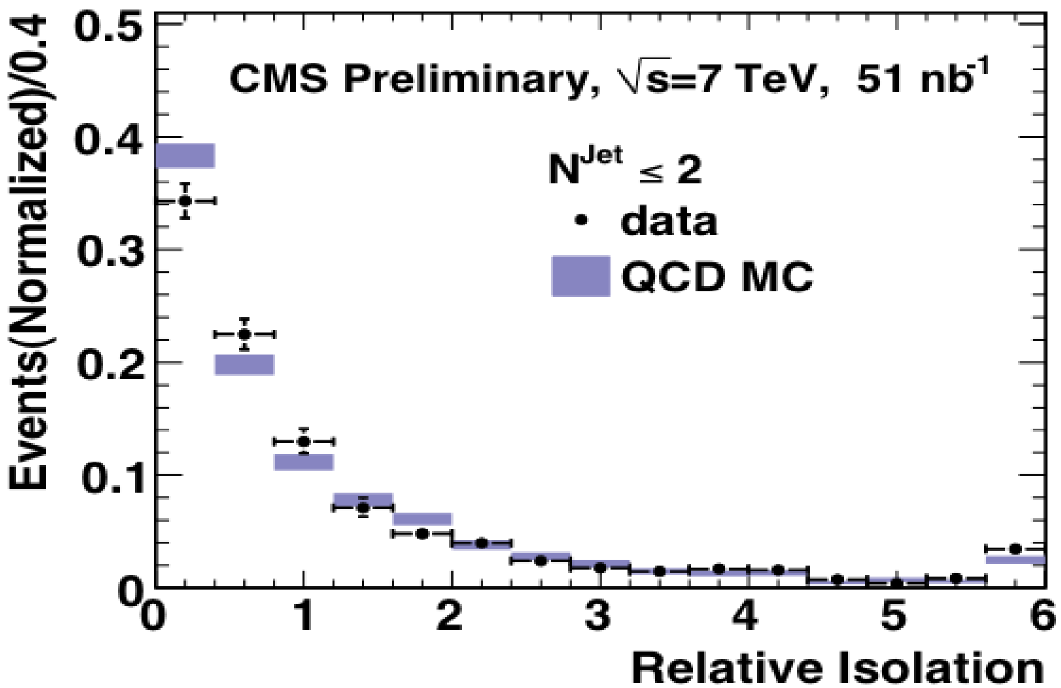


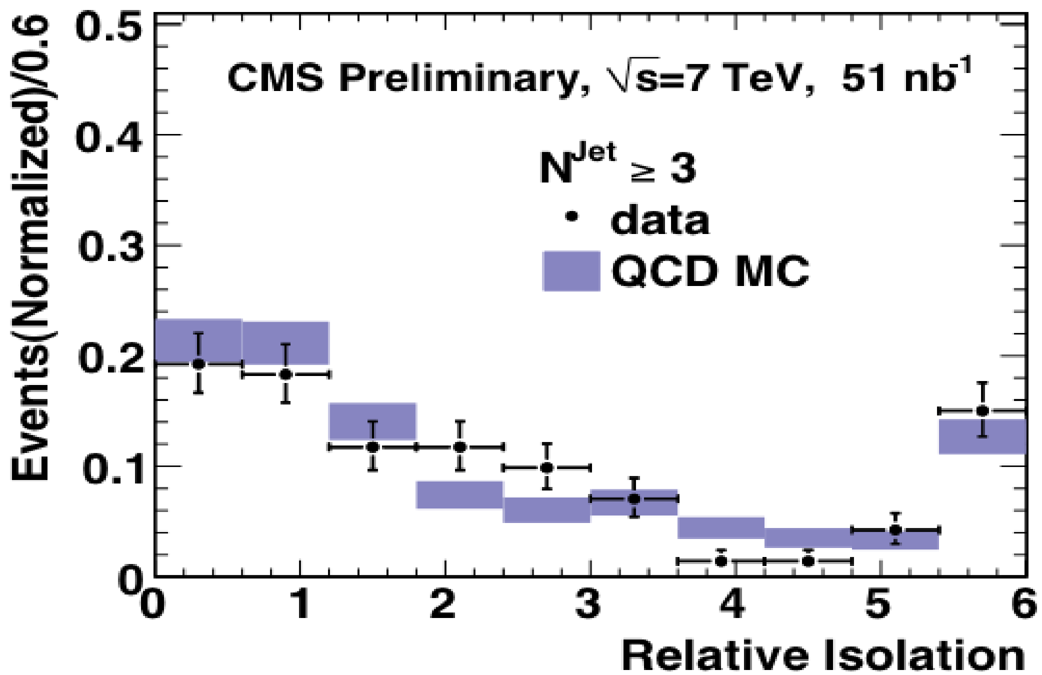
QCD contributes to μ + Jets+ MET signature : $p_T(\mu) > 10$ GeV, $|\eta| < 2.1$
mainly due to **heavy-flavor decays** to muons.
Left: peak from W → μν, tail from non-prompt Muons
Right: control sample used for fitting the relative Isolation to predict bkg. from non-prompt muons (2 parameter shape, low χ^2)

ttbar in the SS-μ-Channel

t-tbar is the dominant background for the same-sign (SS) di-μ signature shown above.
One μ comes from the W and the other from b-decays
Estimate TTbar bkg. from bb-bar sample
Employ Tag&Probe method on **bbar-**Events to measure isolation distribution of muons coming from heavy flavor decays.
One b-jet is used to tag the μ in the other hemisphere whose isolation properties are studied.

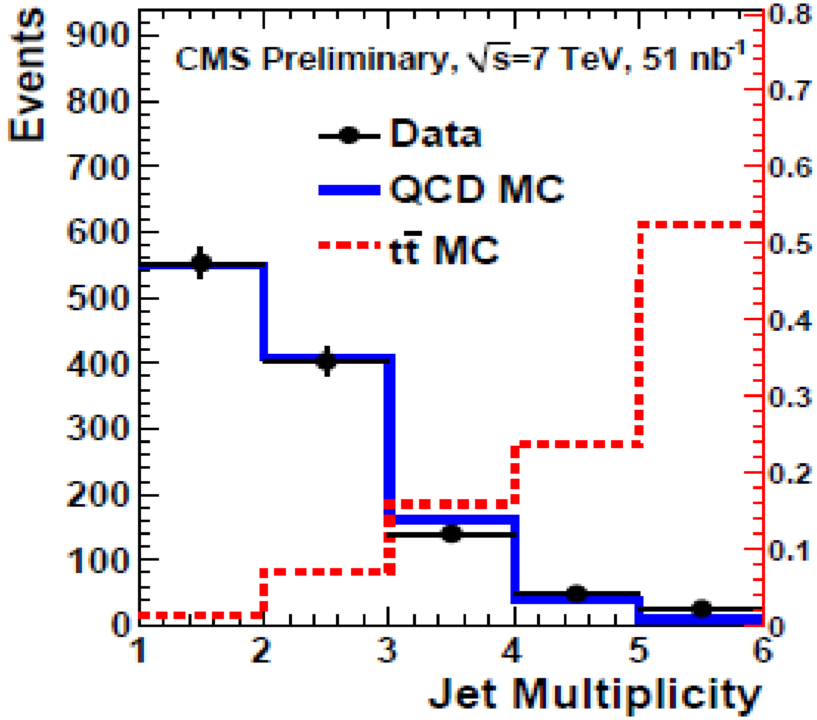


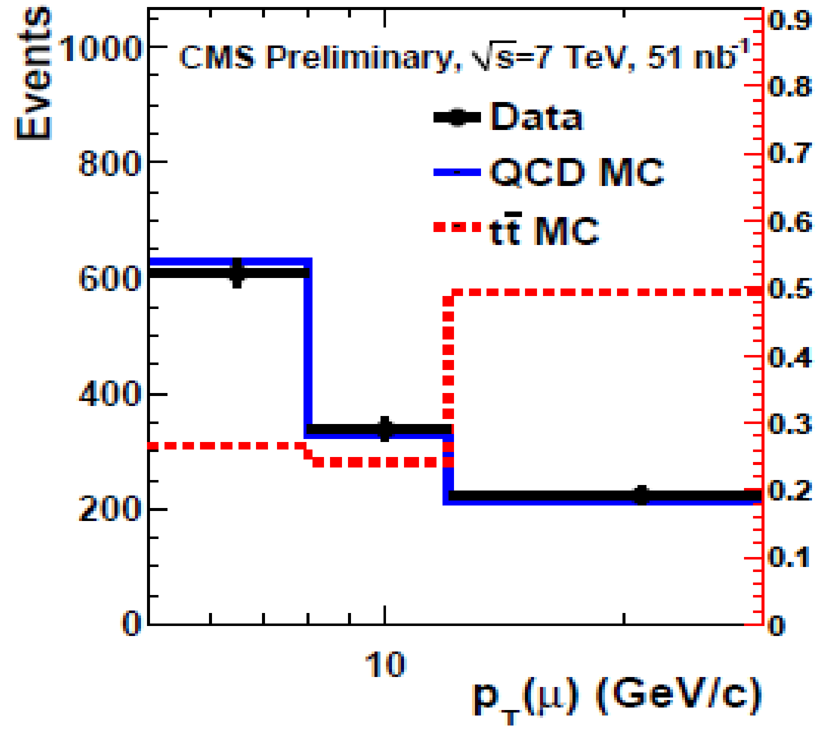




Measured Muon isolation from T&P for $N_J \leq 2$ (left) and $N_J \geq 3$ (right) in QCD

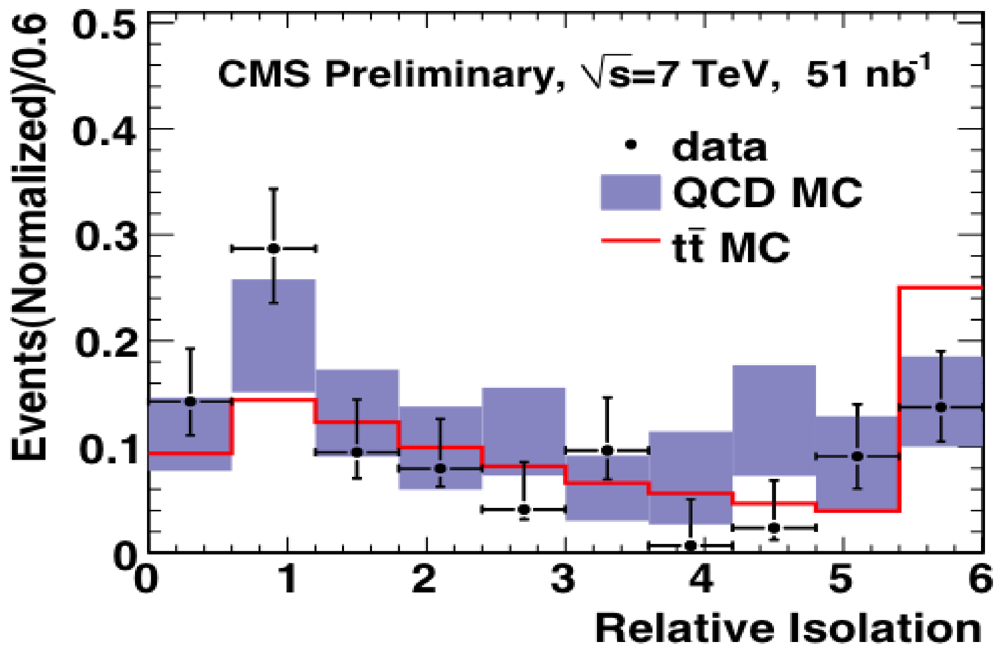
ttbar in the SS-μ-Channel





Reweight wrt. to jet-multiplicity and lepton-p_T to make the bb-sample a good ttbar-model.

Big differences in jet-multiplicity and lepton-p_T spectrum



Comparison of the isolation template for generator-truth for ttbar (red), QCD-estimate (blue) and from data.

Iso-prediction closes on MC
and agrees qualitatively, more statistics needed.

Conclusions

Missing transverse Energy

Very good agreement between data and MC

- Core and tail of MET well described over many orders of magnitude
- track based MET corrections improve performance
- Tails will be reduced with new cleaning

Supersymmetry

- Understanding of the SM background is the first step towards BSM searches
- Dedicated methods to suppress the backgrounds and data-driven techniques to measure them from data are in place.
- The first data collected by CMS at 7 TeV allowed us to test some of these methods; data confirms the performance of the methods obtained with MC
- LHC performs very well; as of **much** more (~ 43 pb^{-1}) data is available
  → plenty new results soon!

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Backup