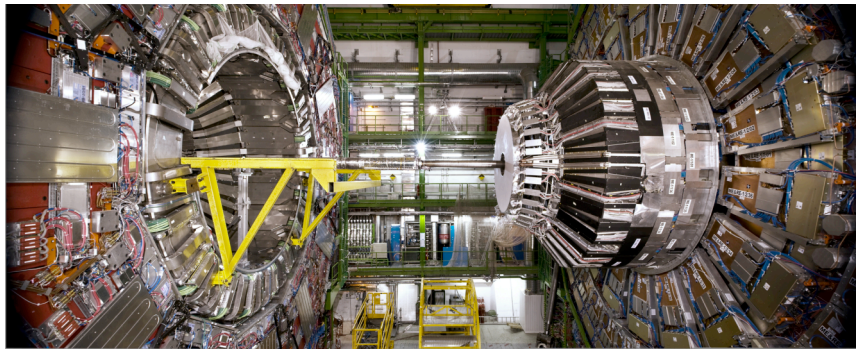
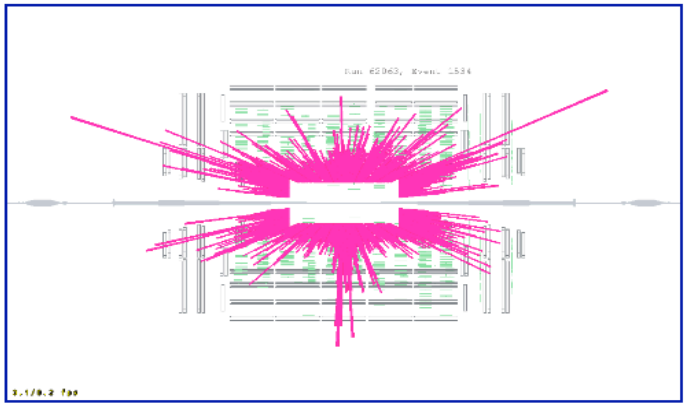
Early searches for new physics in CMS

Filip Moortgat (ETH Zurich)
for the CMS Collaboration



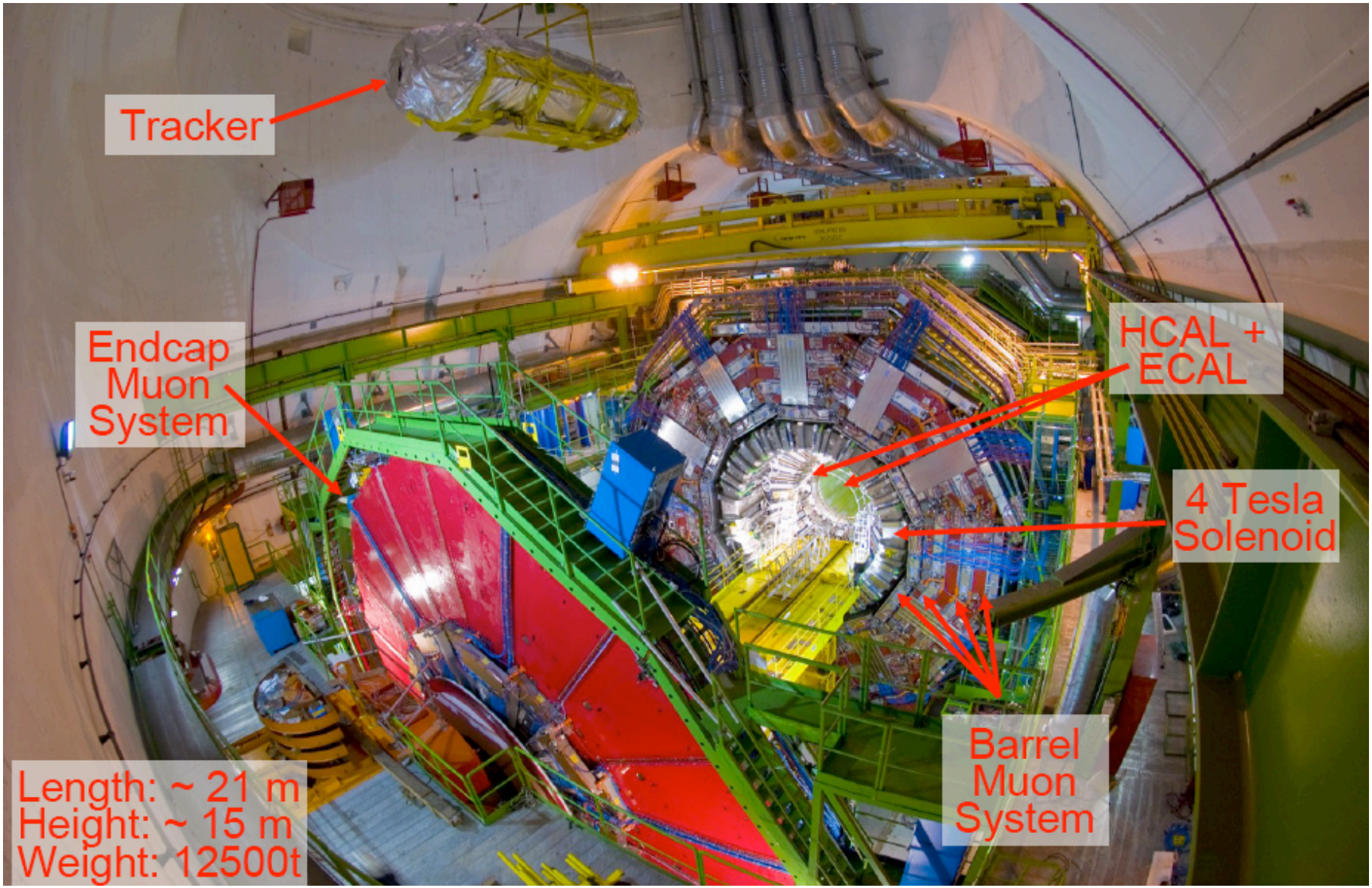


BF2008, Terra Incognita, From LHC to Cosmology,
November 6 - 8, 2008

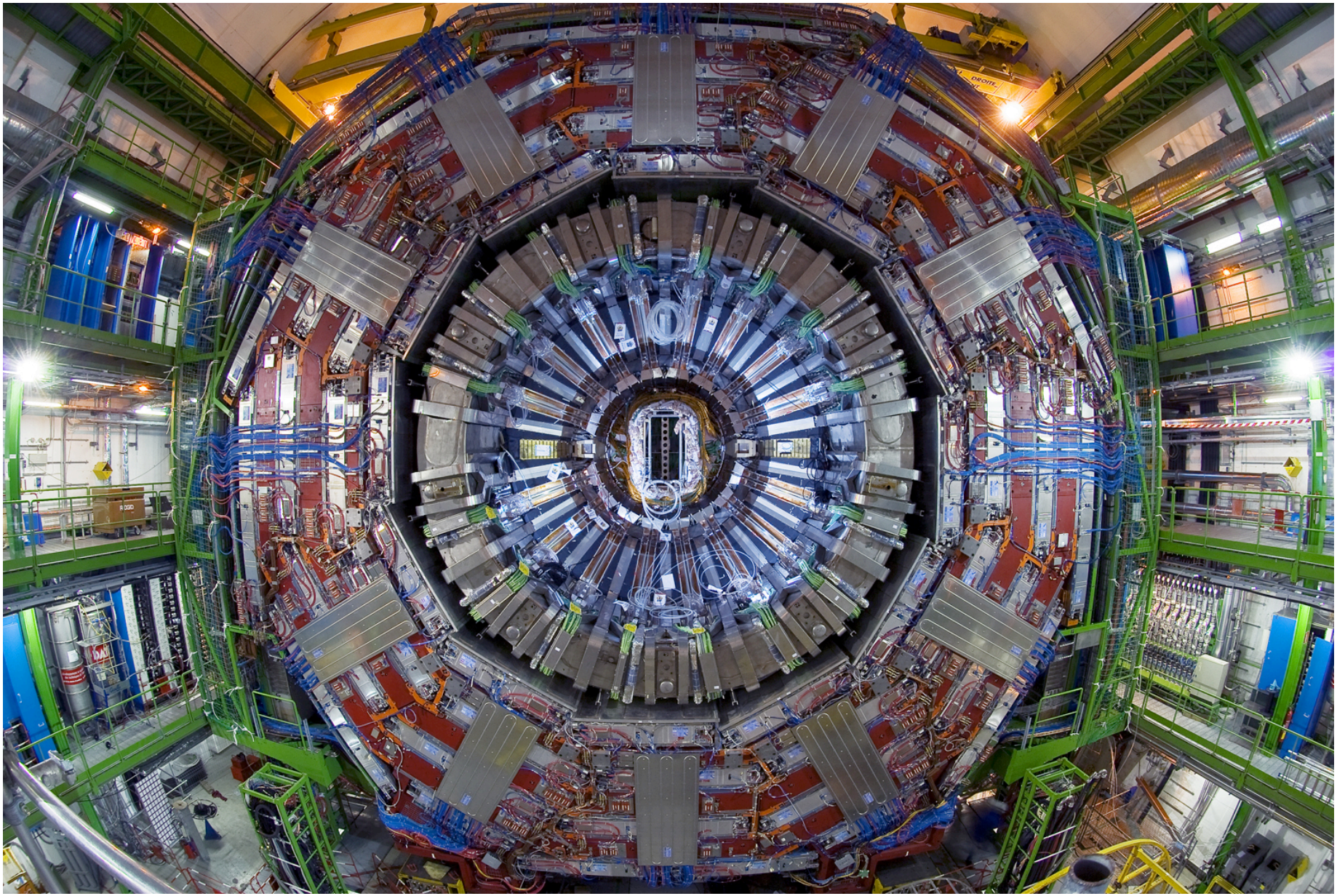
Outline

- Physics commissioning of CMS
  - CMS construction: the final act
  - commissioning status & plans
- Early prospect for discovering new physics
  - Exotica
  - SUSY
  - Higgs (selected results)

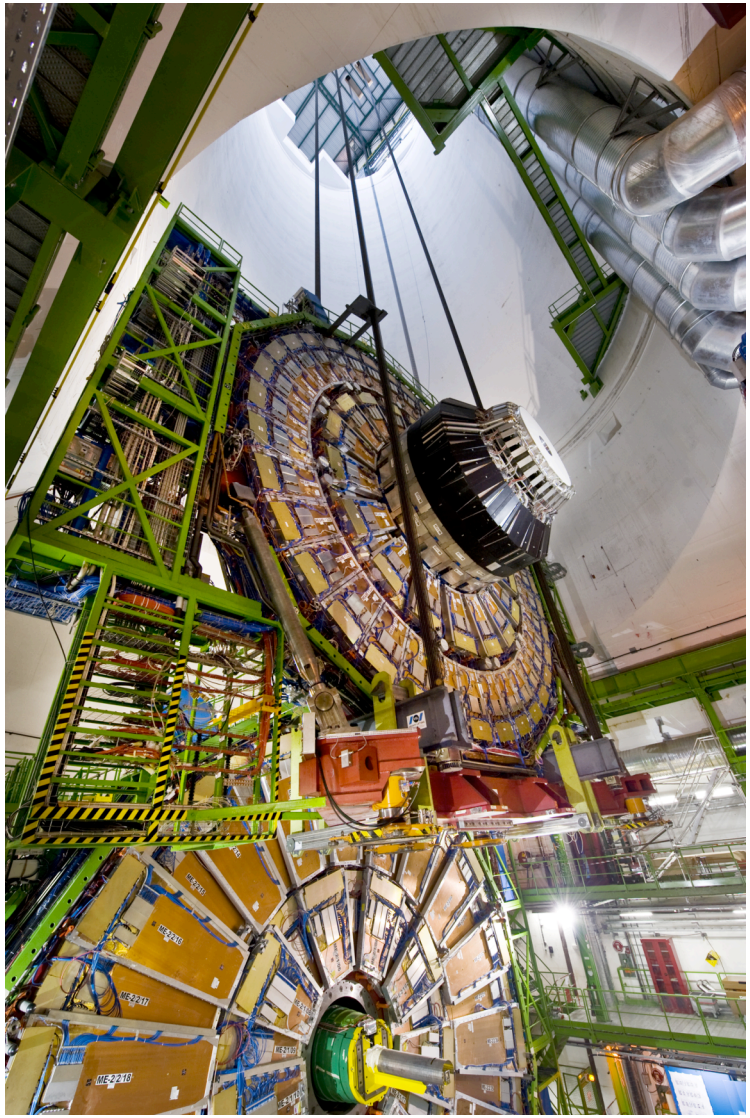
The CMS detector



Final Act : CMS after Tracker installation

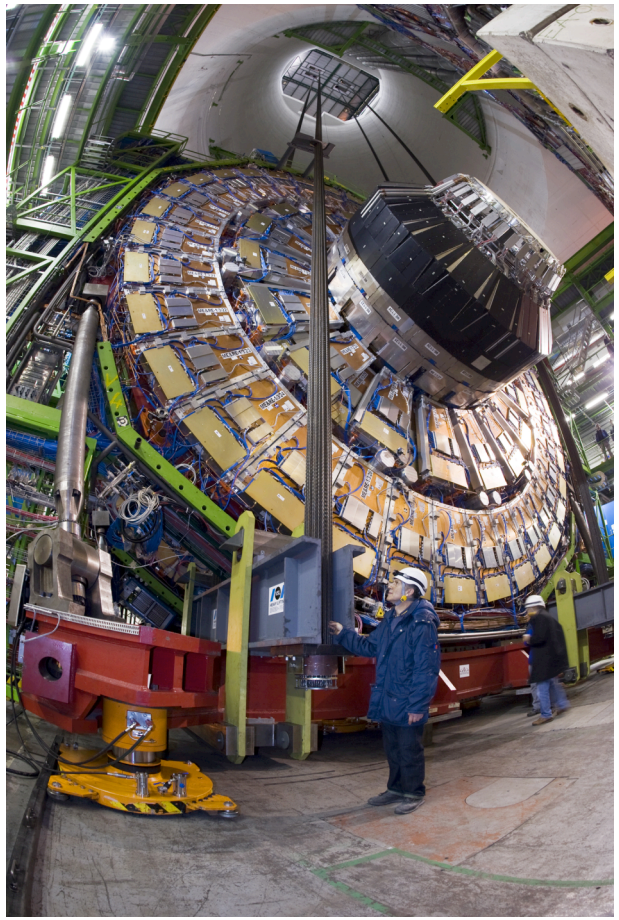


Final Act: lowering of the last wheel

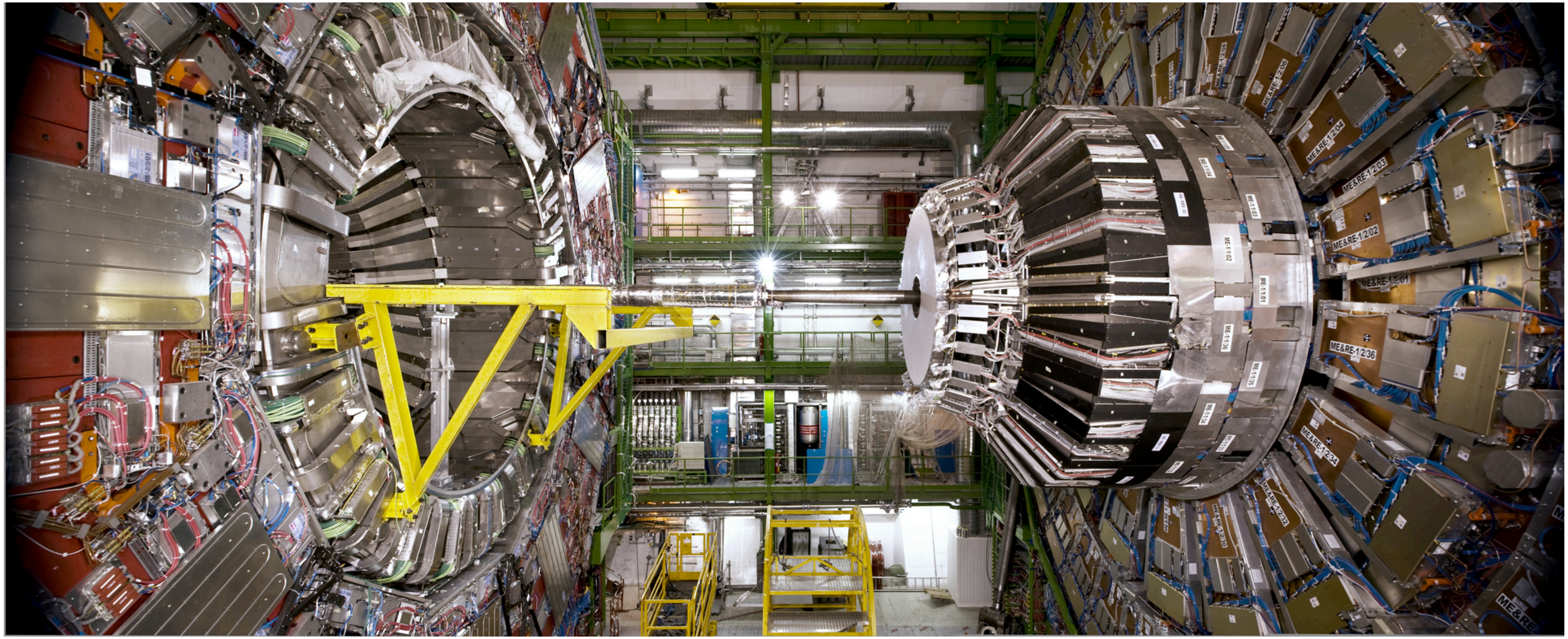


First physics law tested: gravity

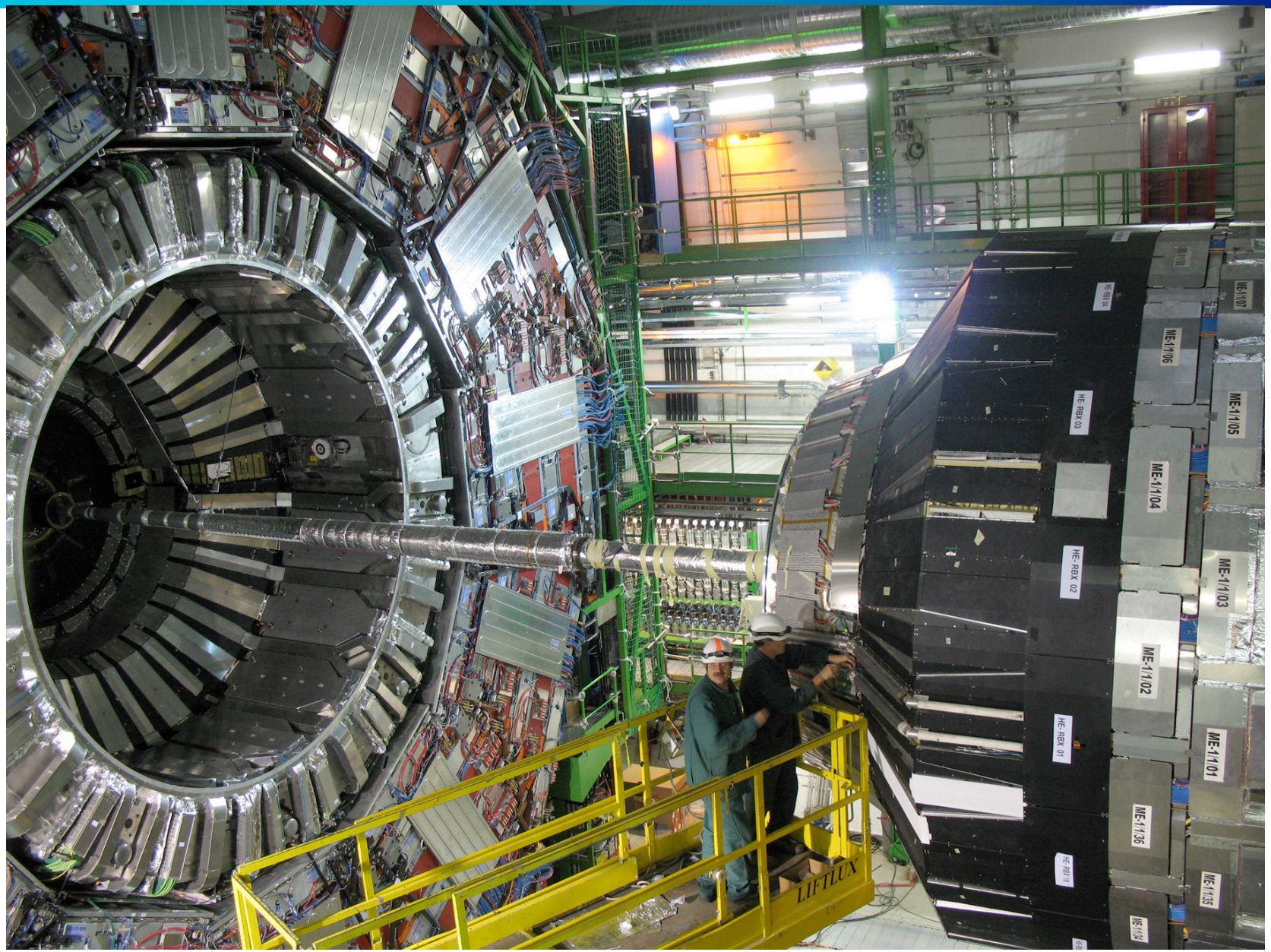
F = m*g
confirmed!



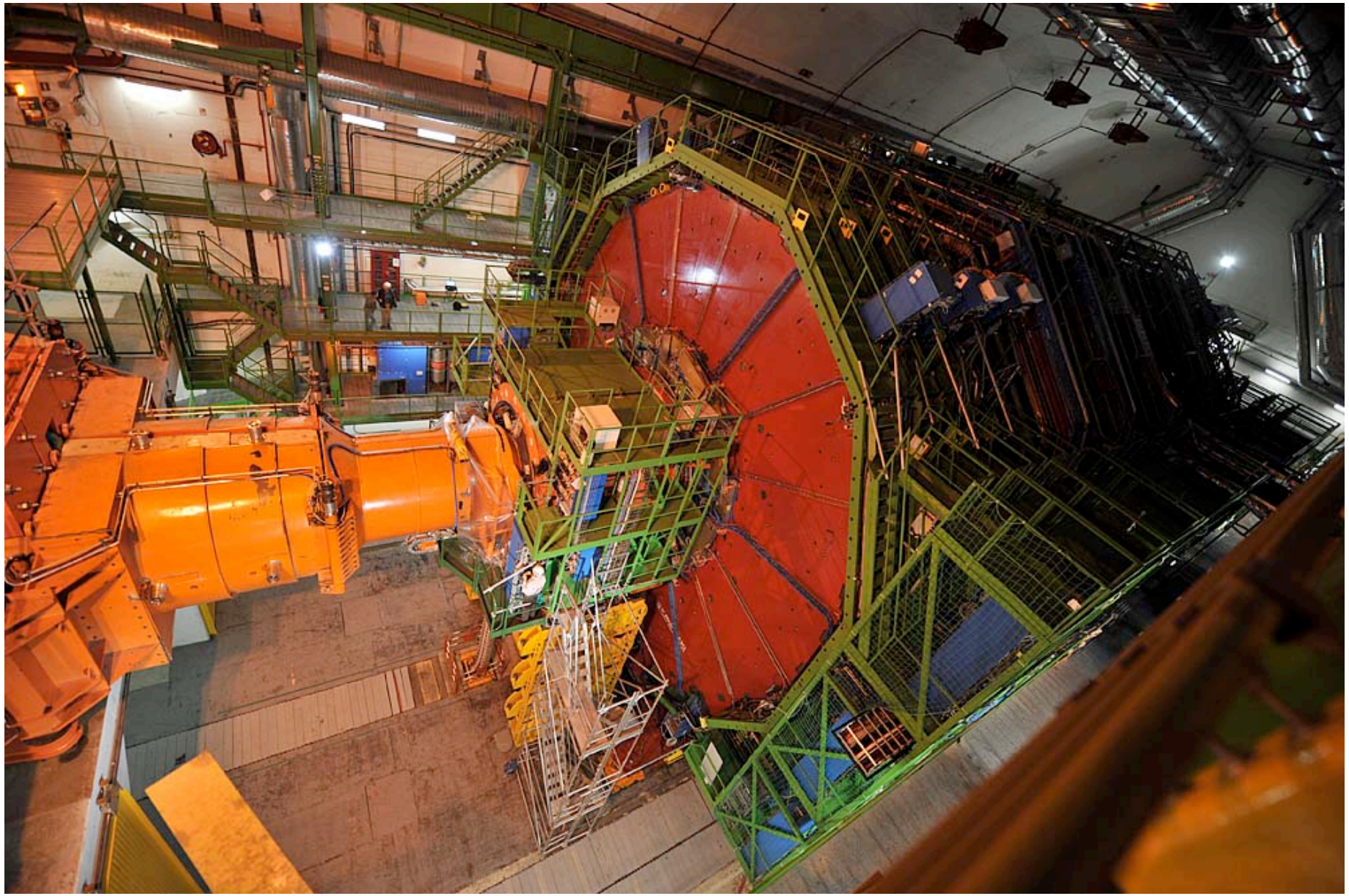
Final Act: beampipe installed



Final Act: preparing for closure

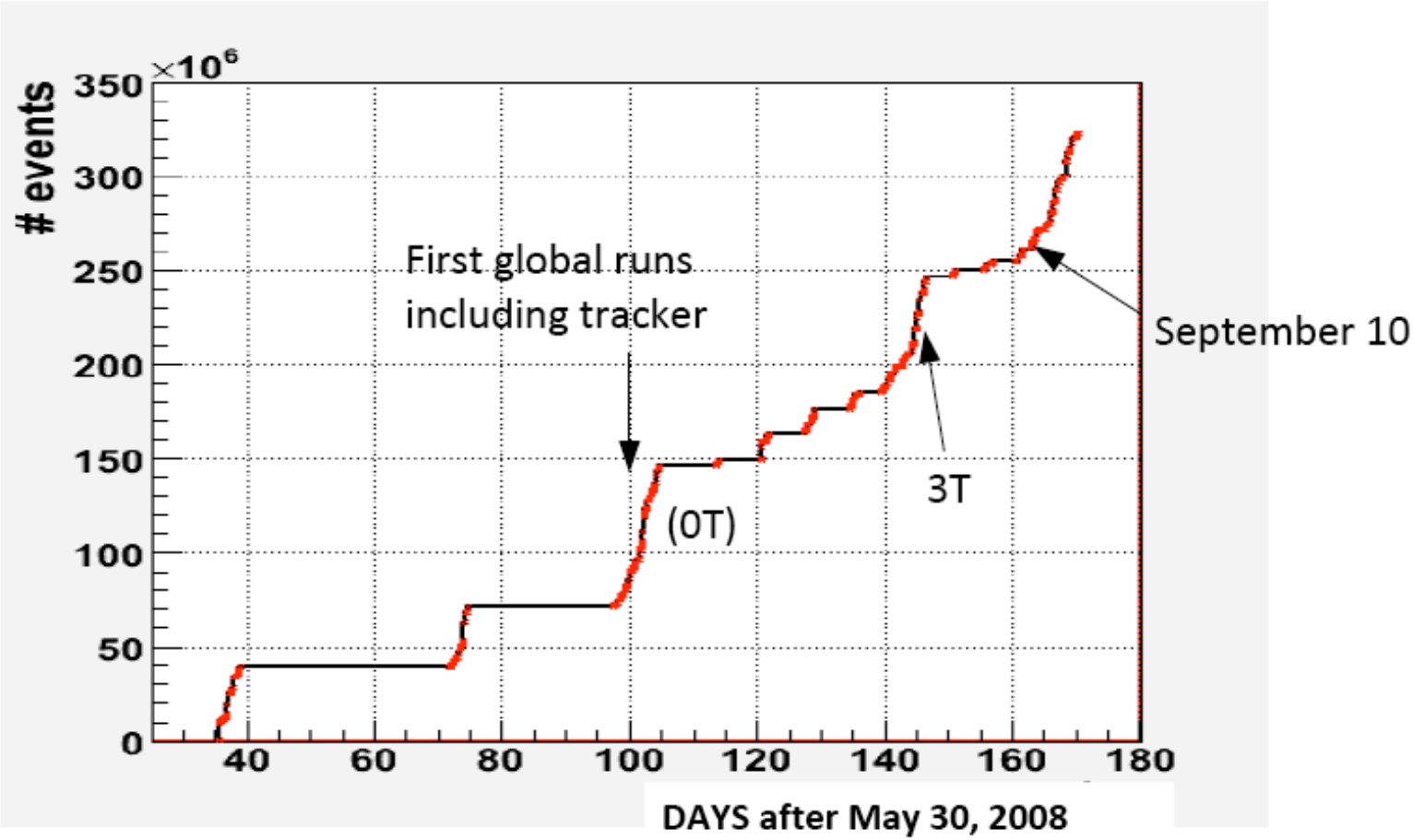


Final Act: CMS closed for collisions

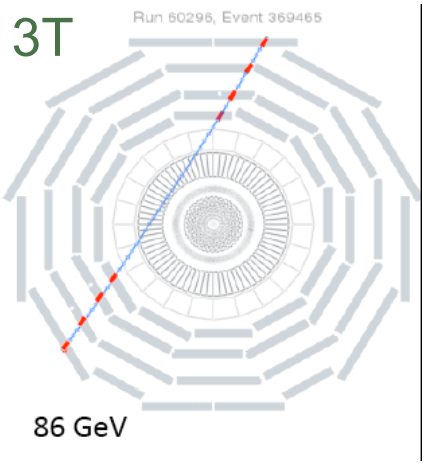


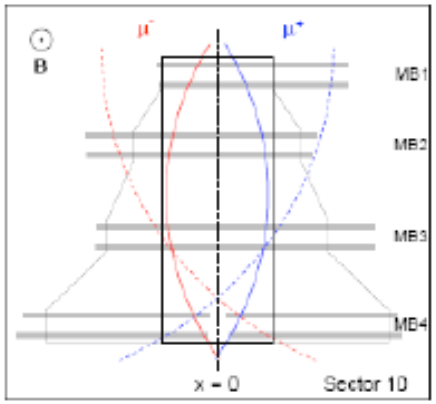
(Cosmic) Data taken in 2008

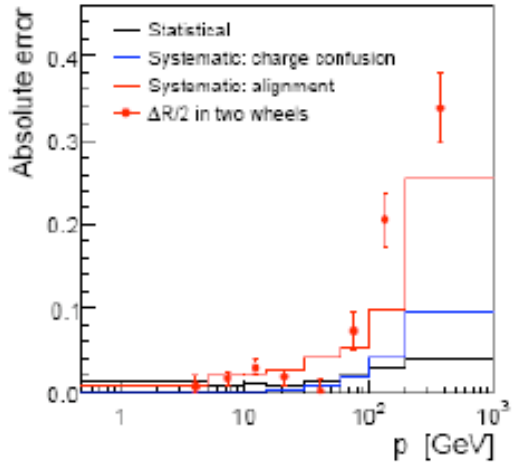
Cosmic events collected by CMS during 2008:



Ex: charge ratio of cosmic muons



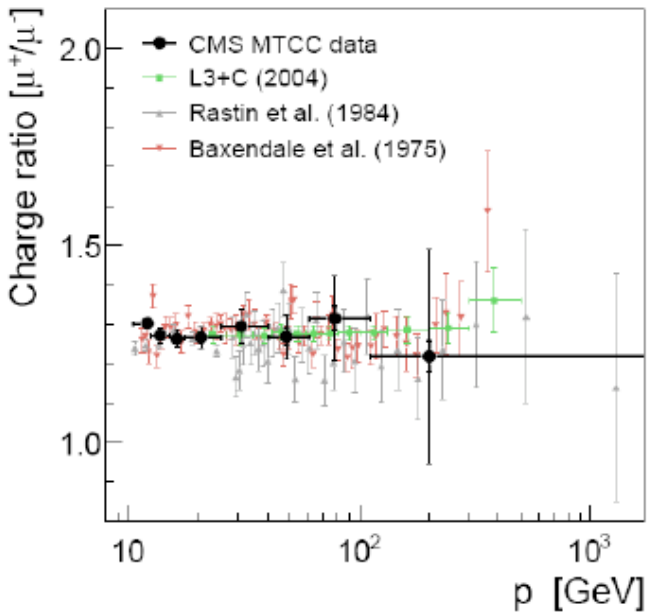




- dedicated cosmic muon reconstruction using the Drift Tube muon chambers
- after applying survey alignment and unfolding the charge confusion effect:

$$\langle R \rangle = 1.282 \pm 0.004(\text{stat}) \pm 0.007(\text{syst})$$

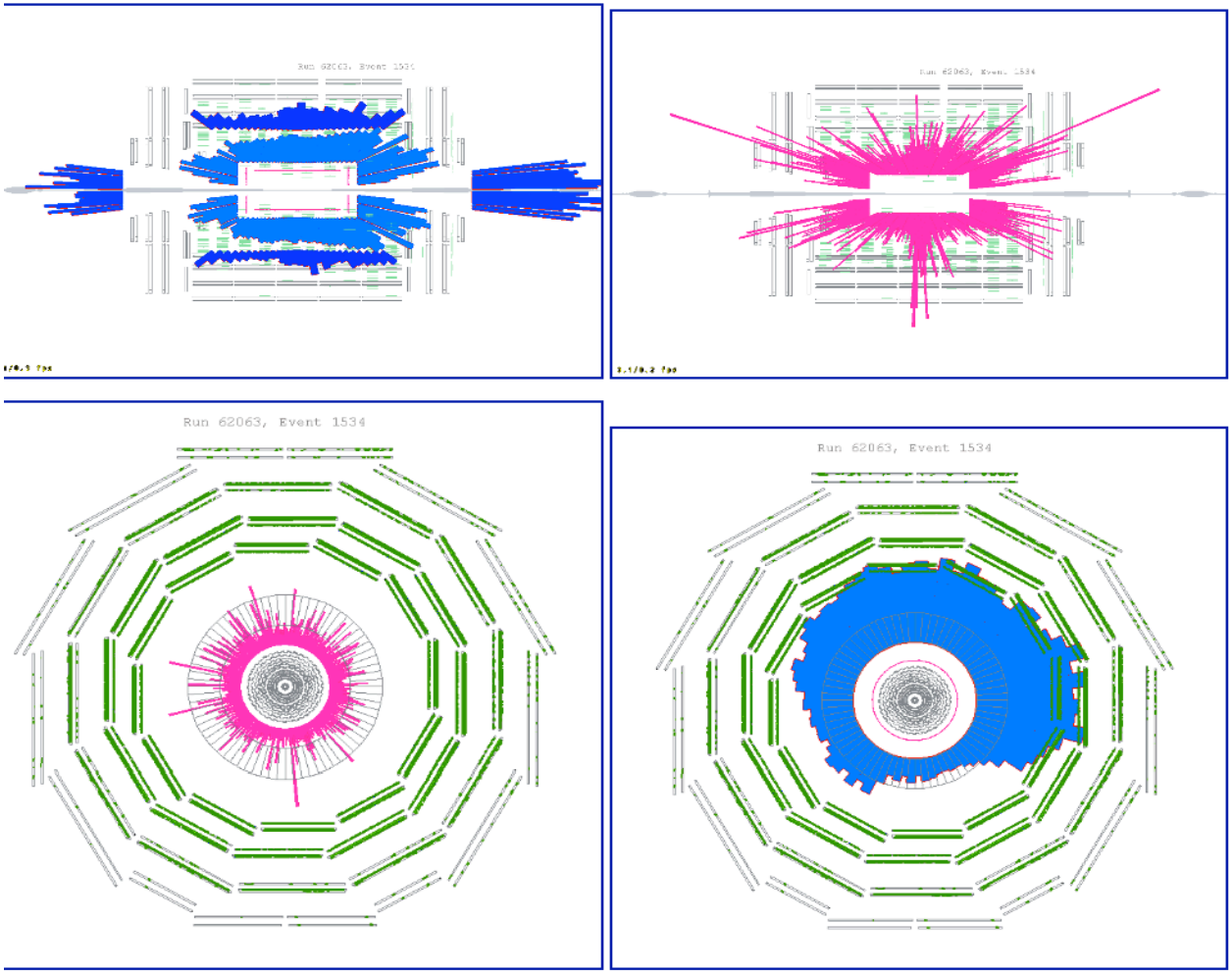
Again, no new physics …



Splash events

~2.10^9 protons on collimator ~150 m upstream of CMS

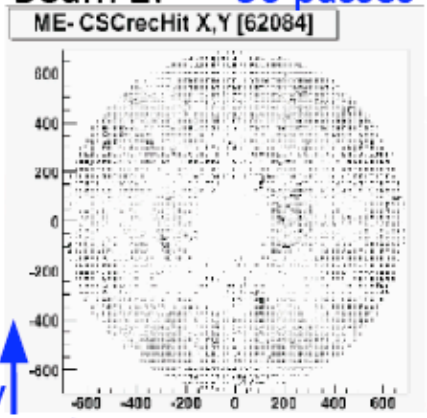
ECAL- pink; HB,HE - light blue; HO,HF - dark blue; Muon DT - green; Tracker Off



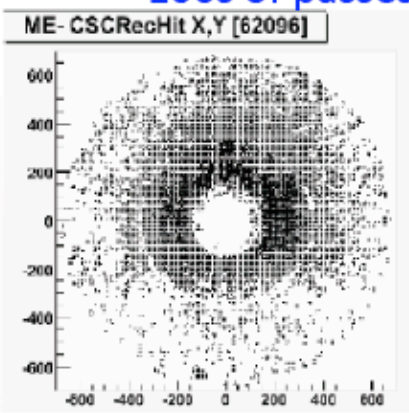
Beam halo events

Beam quality improving from run to run:

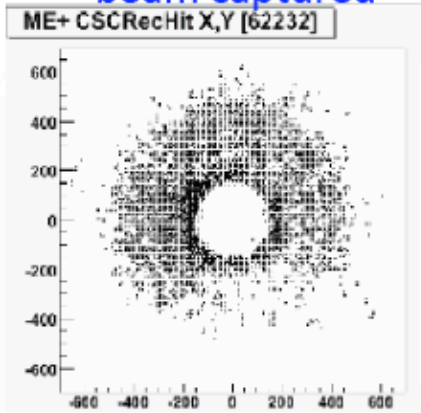
Beam 2: 50 passes

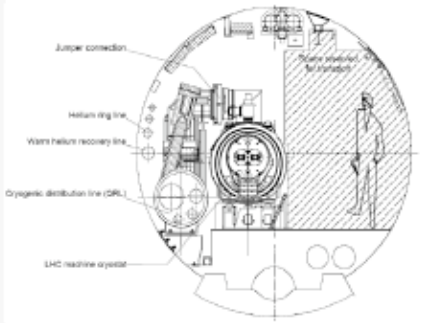


100s of passes



beam captured

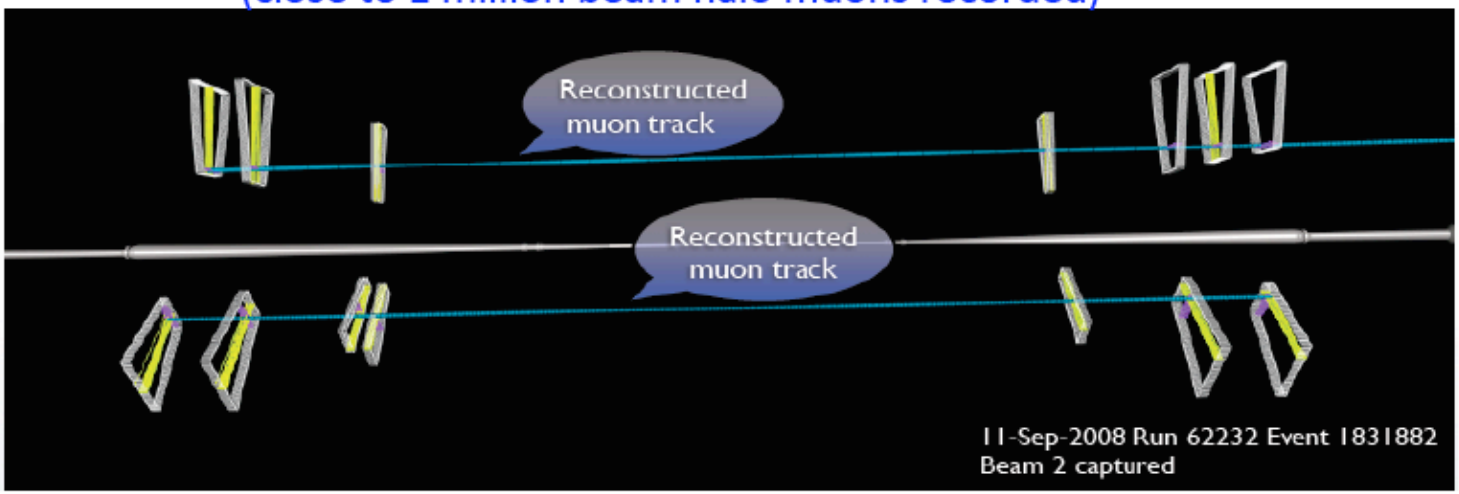




y

x

(close to 1 million beam halo muons recorded)

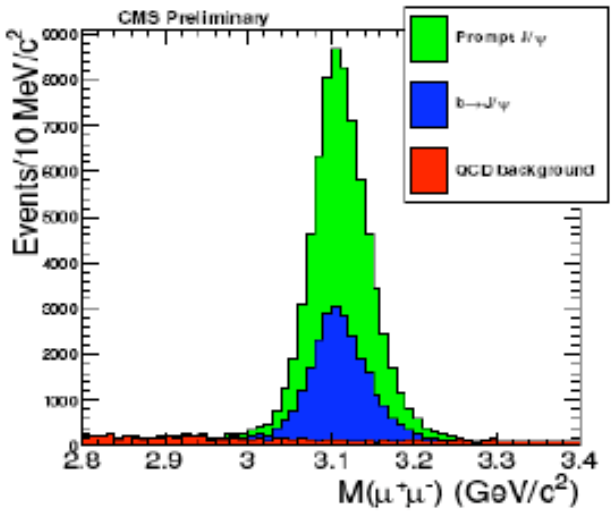


First few pb^{-1}

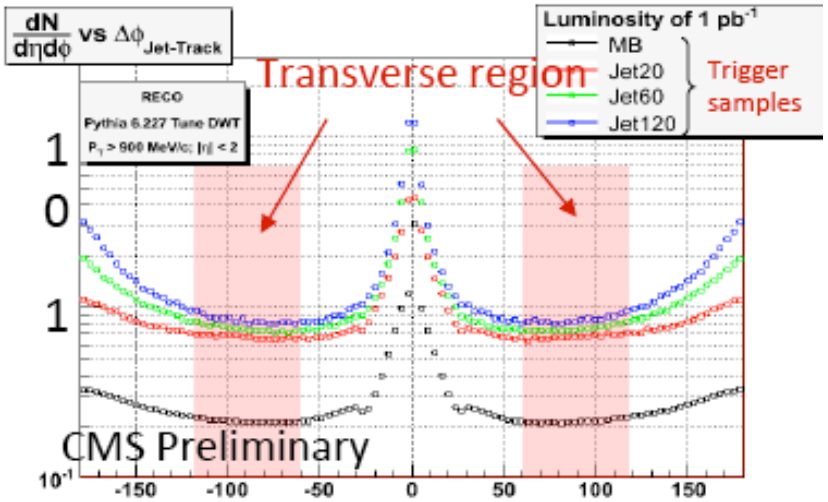
- Highest priority: commission reconstruction of basic physics objects: electrons, muons, photons, jets … b-tagging, τ-tagging, Missing Transverse Energy (MET).

- First physics measurements possible with a few pb-1 and initial alignment & calibration:

Low mass resonances:



Min bias and underlying event:



10 pb^{-1}

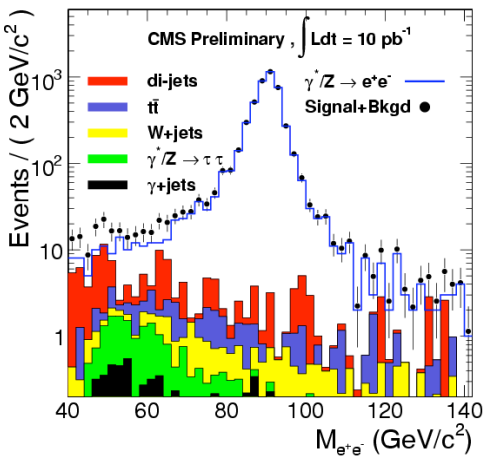
- re-discover the Standard Model candles: *W, Z, top*

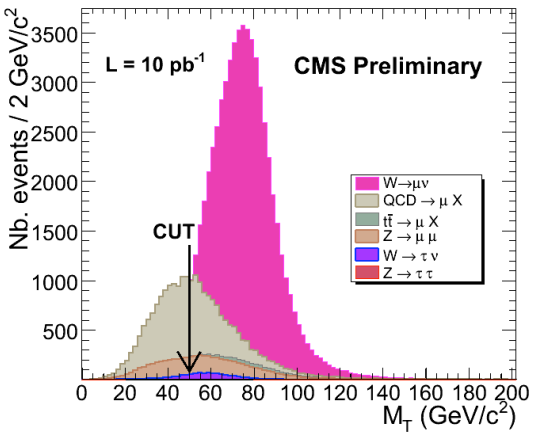
  in 10 pb-1 of data: 10^5 W $\rightarrow$ l ν (l = e, μ)

  2×10^4 Z$\rightarrow$ ll (l =e, μ)

  10^3 ttbar $\rightarrow$ μ+X

  use them to establish detector & physics objects performance
- commission data-driven background techniques and tune Monte Carlo simulation





→ talk by D. Bourlikov

100 pb^{-1} to 1 fb^{-1}

- refine Standard Model measurements
- start looking for New Physics:

  - Higgs: H->WW, H->ZZ

  - "SUSY": jets+MET
    lepton(s)+jets+MET

  - High mass resonances or spectrum deviations, heavy stable charged particles, displaced vertices, non-pointing photons, …

→ talk by A. Askew

Some examples …

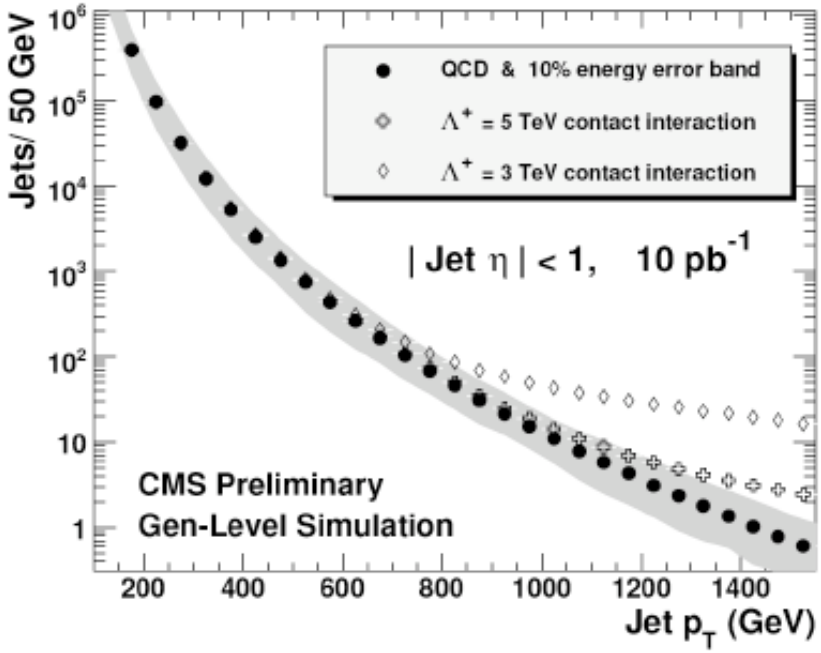
Model	Mass reach	Luminosity (fb^{-1})	Early Systematic Challenges
Contact Interaction	$\Lambda < 2.8$ TeV	0.01	Jet Eff., Energy Scale
Z' ALRM SSM LRM E6, SO(10)	 M ~ 1 TeV M ~ 1 TeV M ~ 1 TeV M ~ 1 TeV	 0.01 0.02 0.03 0.03 – 0.1	Alignment
Excited Quark	M ~0.7 – 3.6 TeV	0.1	Jet Energy Scale
Axigluon or Colouron	M ~0.7 – 3.5 TeV	0.1	Jet Energy Scale
E6 diquarks	M ~0.7 – 4.0 TeV	0.1	Jet Energy Scale
Technirho	M ~0.7 – 2.4 TeV	0.1	Jet Energy Scale
ADD Virtual G_{KK}	M_D~ 4.3 - 3 TeV, n = 3-6 M_D~ 5 - 4 TeV, n = 3-6	0.1 1	Alignment
ADD Direct G_{KK}	M_D~ 1.5-1.0 TeV, n = 3-6	0.1	MET, Jet/photon Scale
SUSY Jet+MET+0 lepton Jet+MET+1 lepton Jet+MET+2 leptons	M ~1.5 – 1.8 TeV M ~0.5 TeV M ~0.5 TeV M ~0.5 TeV	1 0.01 0.1 0.1	MET, Jet Energy Scale, Multi-Jet backgrounds, Standard Model backgrounds
mUED	M ~0.3 TeV M ~ 0.6 TeV	0.01 1	ibid
RS1 di-jets di-muons	 M_{G1}~0.7- 0.8 TeV, c=0.1 M_{G1}~0.8- 2.3 TeV, c=0.01-0.1	 0.1 1	 Jet Energy Scale Alignment

R. Cavanaugh

Contact Interactions

Di-jets:

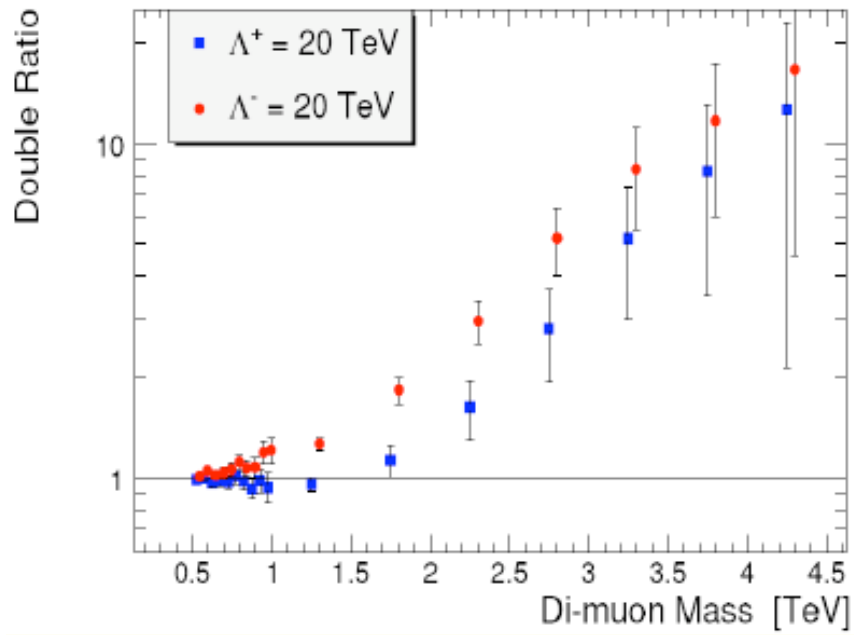
excess in the high Pt jet rate



	95% CL Excluded Scale			5σ Discovered Scale		
Luminosity	100 pb^{-1}	1 fb^{-1}	10 fb^{-1}	100 pb^{-1}	1 fb^{-1}	10 fb^{-1}
Λ^+(TeV)	<6.2	<10.4	<14.8	<4.7	<7.8	<12.0

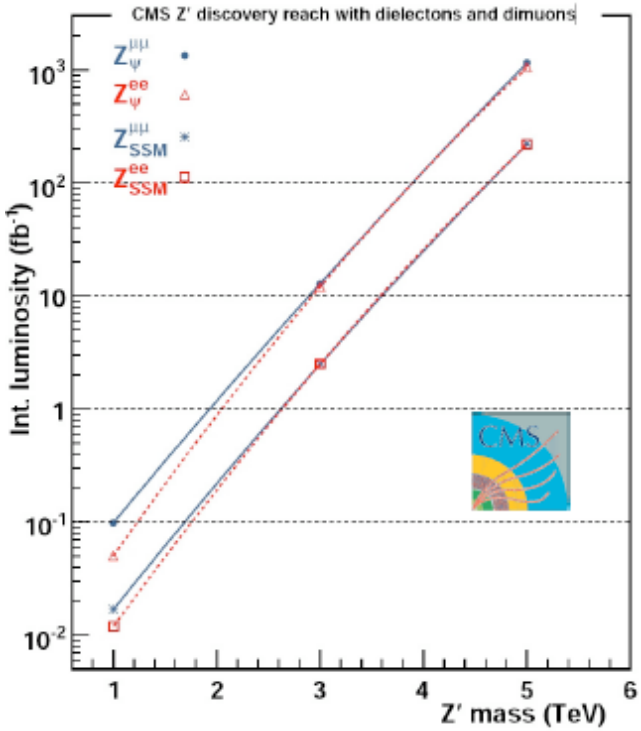
Di-muons:

excess in the high energy mass region

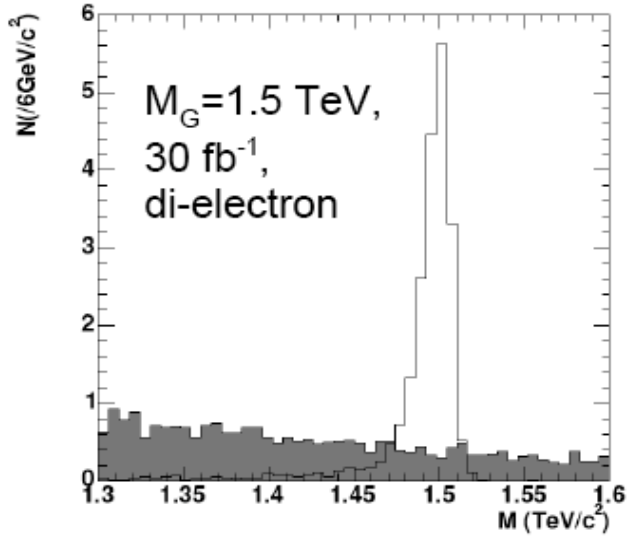


Di-lepton resonances

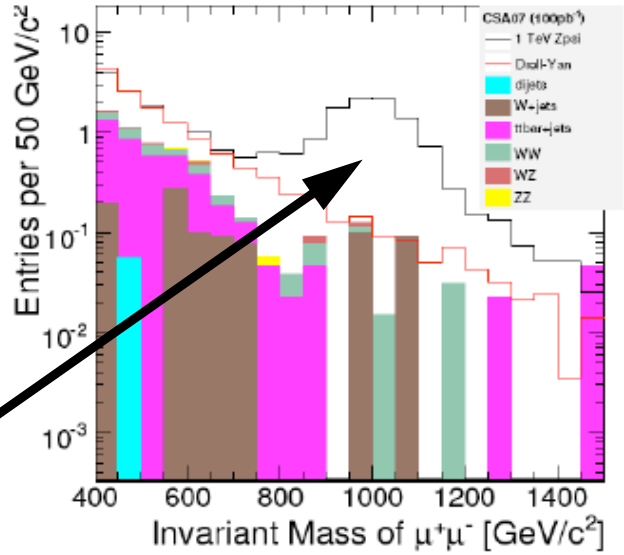
- Z' occurs in many BSM models
- clear signatures: peaks in dilepton invariant mass, negligible backgrounds



ee



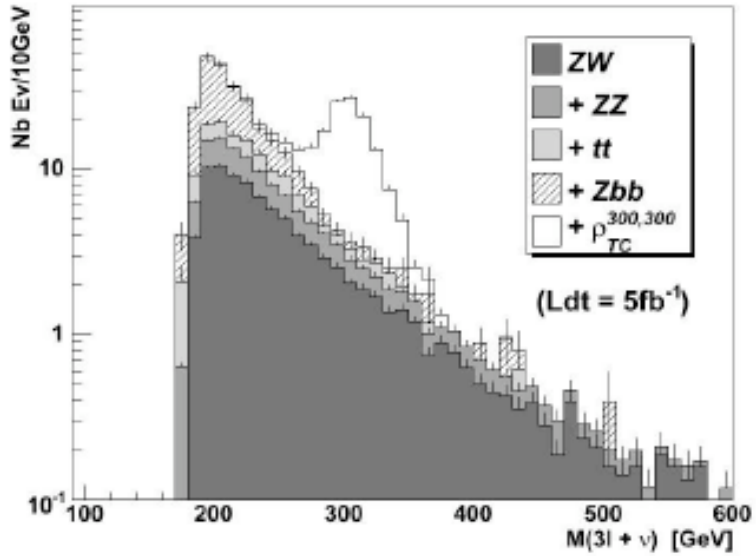
μμ



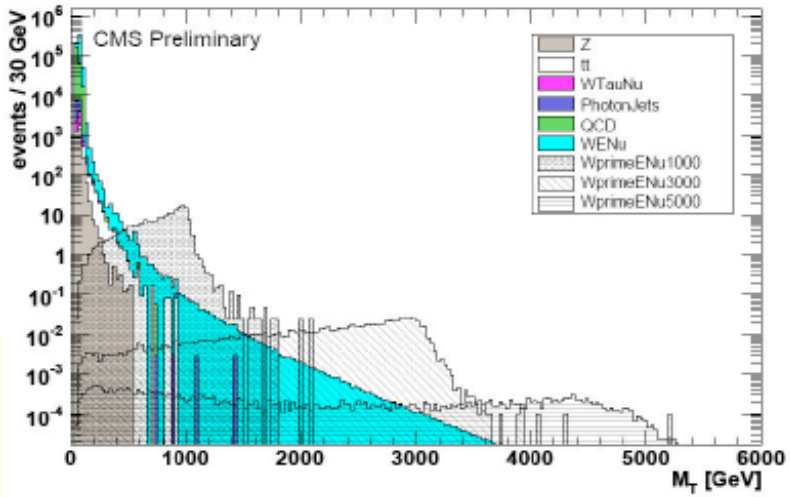
100pb^{-1}

Technicolor and W'

- $\rho^{+}_{TC} \rightarrow W+Z \rightarrow 3l+\nu$
  - 3 leptons with W and Z kinematics
  - Background: VV (V=W,Z), Zbb, tt



- W' $\rightarrow$ l+ν
  - lepton + large MET
  - Backgrounds: WW/Z, tt



Sensitivity with 100 pb^{-1} (40 pb^{-1}) incl. systematic uncertainties
Evidence: m(W') ~ 2.5 TeV (2 TeV)
Discovery: m(W') ~ 2 TeV (1.3 TeV)
Exclusion: m(W') ~ 2.2 TeV (1.5 TeV)

Heavy Stable Charged Particles

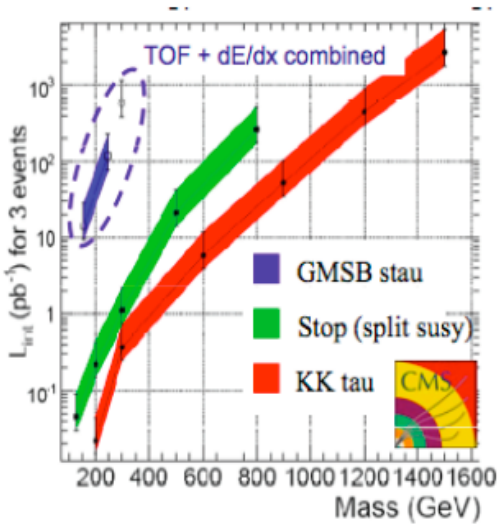
Lepton-like HSCP

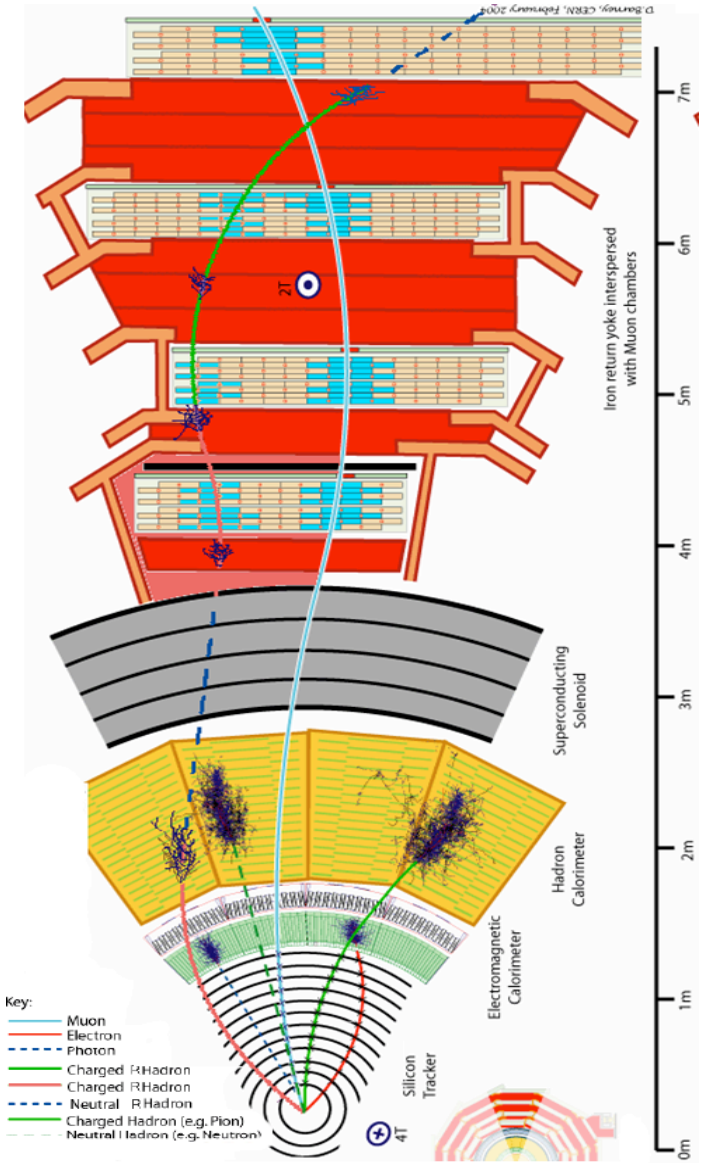
- Can penetrate the whole detector
- High ionization energy loss
- Delayed with respect to lightspeed particles

R-Hadron-like HSCP

- Heavy parton behaves as a spectator
- Does not shower in the calorimeters
- The charge can change in hadronic interactions with matter while crossing the detector

Early discovery possible:



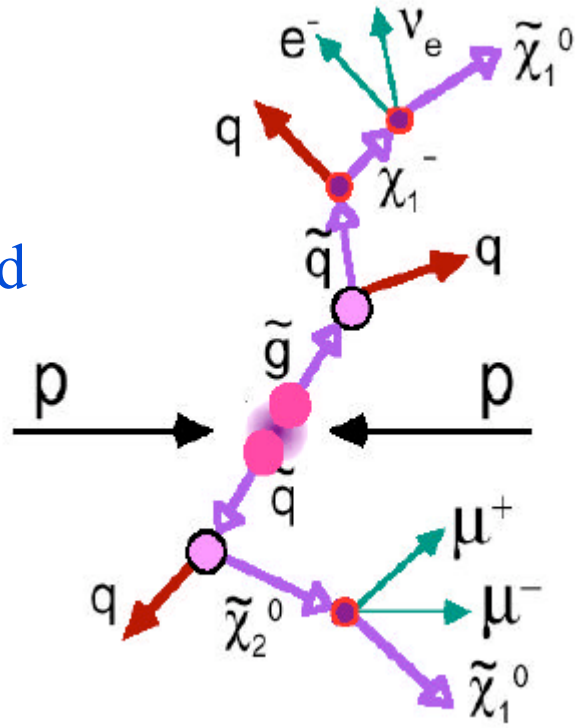


Generic SUSY signatures

General characteristics of R-parity conserving SUSY:

- sparticles pair produced and LSP stable
  → large amount of missing transverse energy

- coloured sparticles are copiously produced and cascade down to the LSP with emission of many hard jets and sometimes leptons



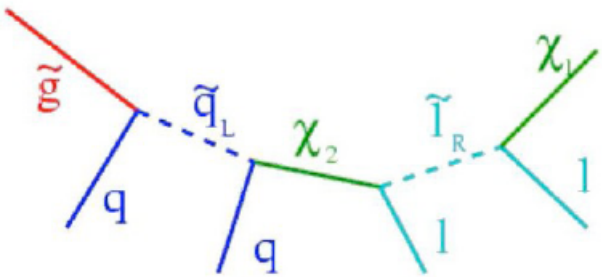
→ Generic SUSY signatures are
E_T^{miss} + multi-jets (and multi-leptons)

Same signature: UED, Little Higgs with T-parity, …

A typical SUSY selection

Event selection :

- large missing E_T (MET): O(> 200 GeV) (→ LSP)
  MET challenging to control at startup
- at least 3 hard jets (→ cascade decays)
  3 may not always be optimal
- N leptons (according to investigated topology)
  growing N: reduces QCD background
- angular or event shape variables for background rejection
  top background probably the most challenging



Main backgrounds: tt+jets, W+jets, Z+jets, QCD (multijet)

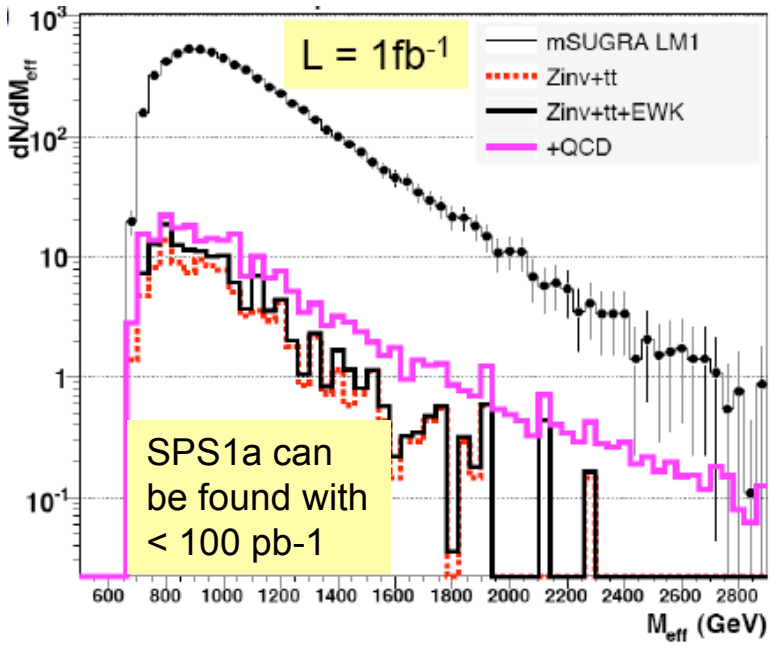
Inclusive analysis: jets + MET

$N_{leptons}$=0 : largest signal cross section, but beware of QCD!

Efficiency for e.g. SPS1a: 13%

Event Selection:

- MET > 200 GeV
- ≥ 3 jets (|η| < 1.7/3/3) with E_T > 180/110/30 GeV
- HT (= $E_{T,j2}$+$E_{T,j3}$+$E_{T,j4}$+MET) > 500 GeV
- indirect lepton veto
- cleanup and QCD rejection (see next slide)



Main backgrounds:

- QCD multijets: MET due to mis-measurements or jet resolution
- Z+jets: Z→νν irreducible
- tt+jets: hadronic or lost lepton(s)
- W+jets: hadronic or lost lepton

Early data: cannot trust simulation → determine backgrounds from data

QCD rejection and cleanup

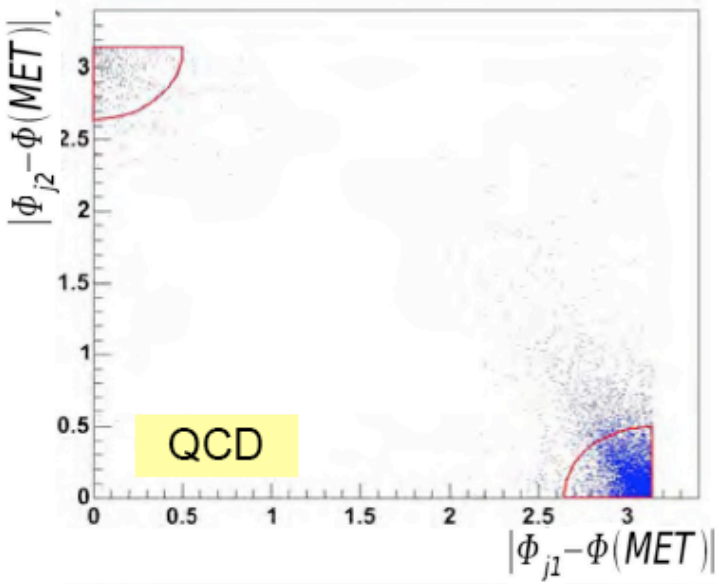
QCD rejection:

- MET in QCD is due to mismeasured jets
- Suppression via topological cuts:

$$R_{1,2} = \sqrt{\Delta\Phi_{1,2}^2 + (\pi - \Phi_{2,1})^2} > 0.5$$

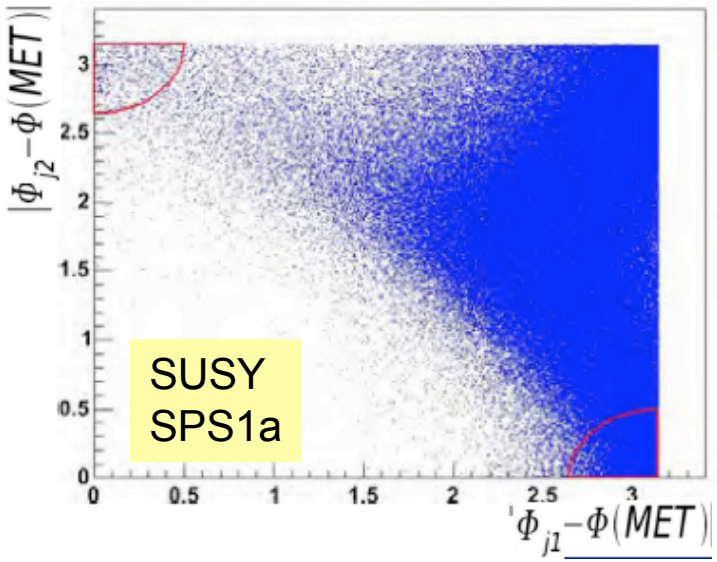
$$\text{with } \Delta\Phi_{1,2} = |\Phi_{j1,j2} - \Phi(MET)|$$

i.e. MET is along or opposite jet



Cleaning against beam halo, cosmics, calo noise:

- good primary vertex
- event electromagnetic fraction: $\frac{\sum_{jets} p_T^j \cdot EMF^j}{\sum p_T^j} > 0.1$
- event charged fraction: $\frac{\sum_{tracks} p_T^t}{p_T^{jet}} > 0.175$

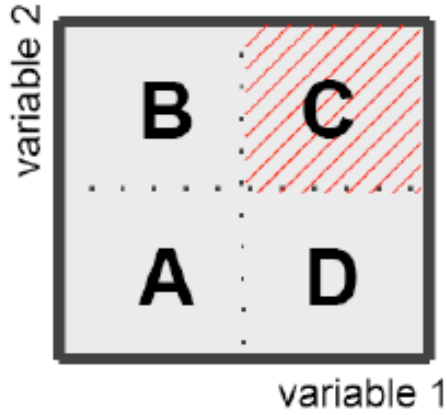


QCD estimation

- previous studies (Physics TDR) estimated backgrounds using Monte Carlo
- now, data-driven methods being explored
- often “ABCD” method used:

Idea:
IF variable 1
and variable 2
are uncorrelated:

$$C = D \cdot \frac{B}{A}$$



Avoid signal contamination in A,B,D

- variables for hadronic search: MET, Rsum, $\Delta\phi$(jj), $\Delta\phi$(hemisphere), …
- variables for leptonic search: lepton isolation, impact parameter, MET, …
- correlations to be studied

Irreducible: Z →υυ

Data-driven estimation from Z+jets

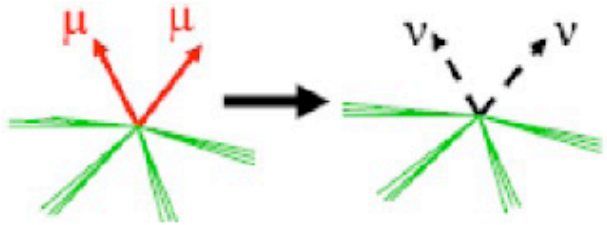
"standard candle": use Z→ μμ

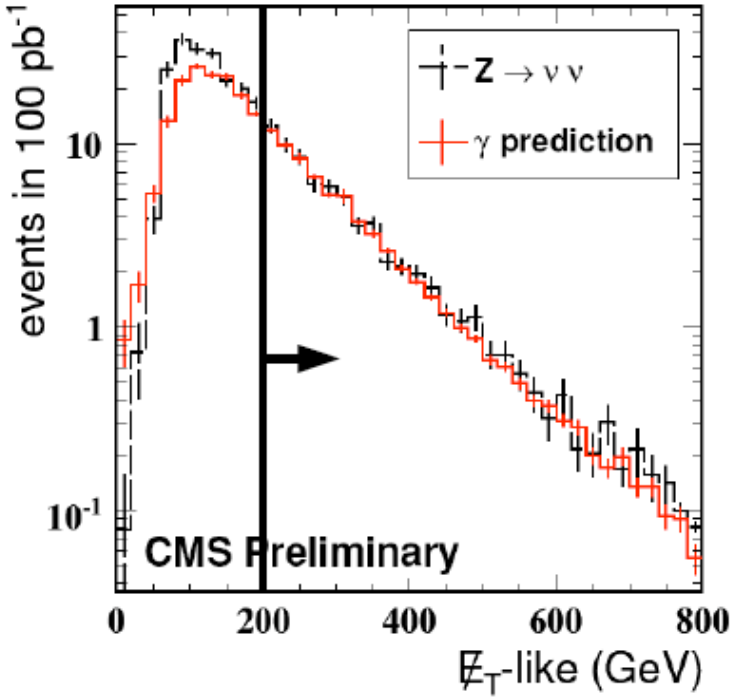
- replace leptons by neutrinos (and correct for acceptance using MC)
- total uncertainty ~20% for 1fb^{-1} statistics limited: BR(Z→ μμ) = 1/6 BR(Z→ νν)

New: data-driven estimation from W,γ+jets

assumption: bosonic events at high Pt look similar → use W,γ+jets

- gain in statistics (→ 100 pb^{-1} analyses) σ(W+2j) = 3 σ(Z+2j) = 0.8 σ(γ+2j)
- complementary to the above (other backgrounds/other triggers)
- beware of signal contamination





$Z \to \nu\nu$ background estimate (100 pb^{-1})	
MC-truth	35
From γ+jets	29 ± 3 (stat) ±5 (sys)
From W+jets	35 ± 10 (stat) ±8 (sys) ±3 (theory)

New: di-jet + MET

Robust extension of full-hadronic search

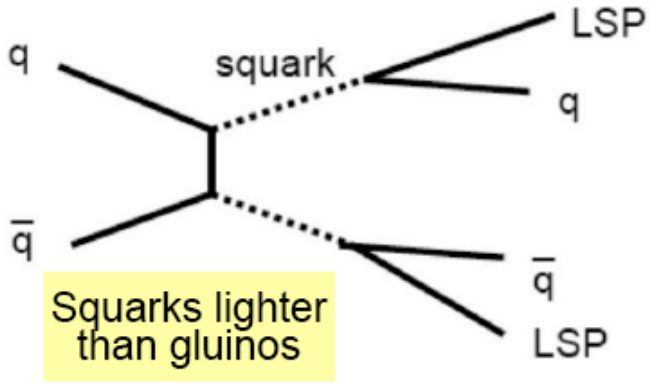
Event selection:

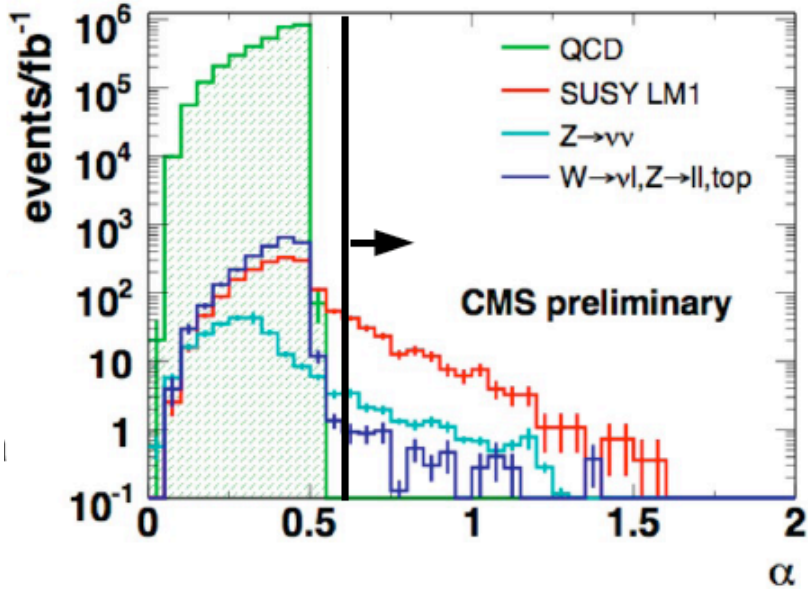
- 2 jets with $P_T > 50$ GeV, lepton veto
- $P_{T,j1}+P_{T,j2} > 500$ GeV
- angular/acceptance cuts for cleaning
- new variable (Randall/Tucker-Smith):

$$\alpha = \frac{E_{T\,j2}}{M_{j1\,j2}} = \frac{E_{T\,j2}}{\sqrt{2E_1E_2(1-\cos\theta)}} > 0.55$$

Note:

- calorimetric MET not (directly) used
- dominant backgrounds:
  QCD and $Z\rightarrow\nu\nu$; estimate from data





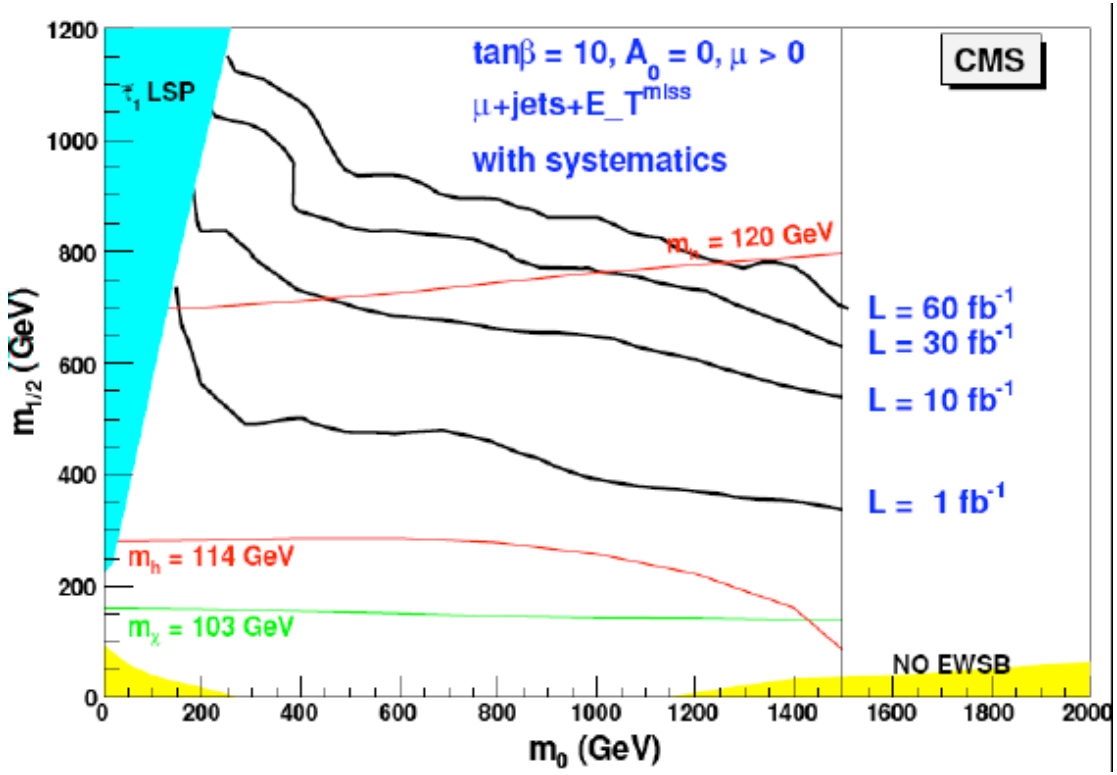
SPS1a discovery within 100 pb^{-1}

Lepton + jet + MET

Event selection:

- ≥ 1 isolated muon with P_T> 30 GeV
- $E_{T,j1}$ & $E_{T,j2}$ > 440 GeV, $E_{T,j3}$ > 50 GeV
- MET > 130 GeV
- single/di-muon trigger
- angular cuts for MET cleaning

Cut optimization via genetic algorithm on 10fb^{-1}

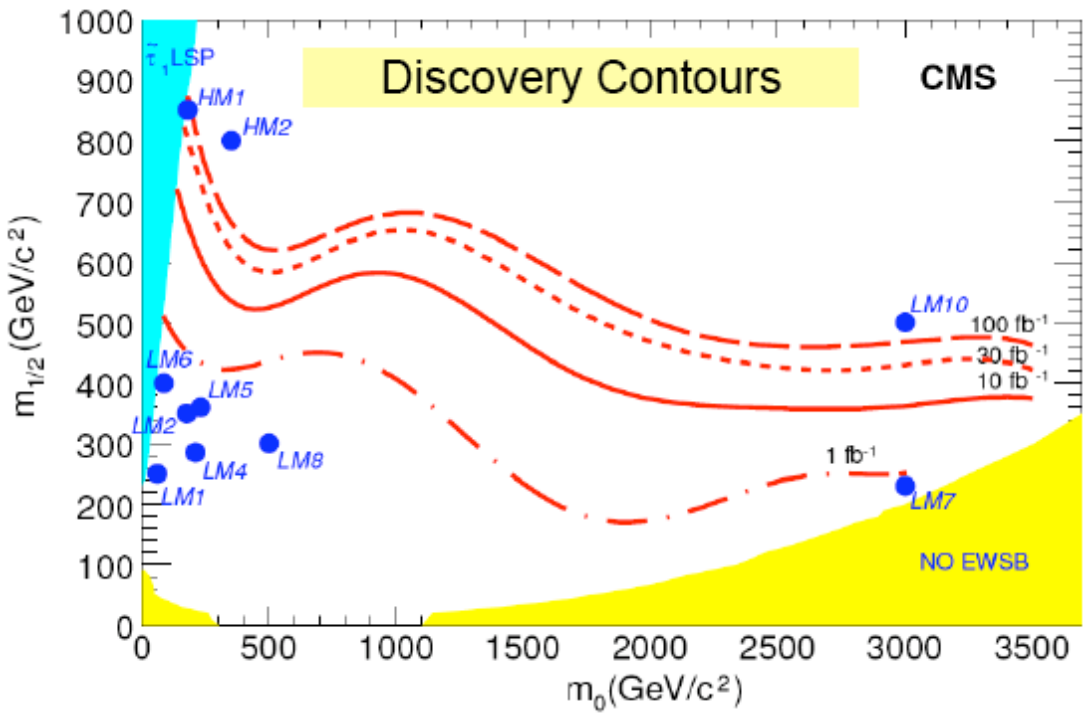


Early SUSY discovery in leptonic channels possible!

Same-sign leptons + jet + MET

Event selection:

- ≥ 2 isolated same-sign muons with P_T > 10 GeV
- ≥ 3 jets with E_T > 175/130/55 GeV
- MET > 200 GeV
- single/di-muon trigger



Note:

- almost no SM background σ(W+W+): 17 fb
- muon trigger expected to be most robust at startup
- complementary to hadronic channel

Opposite-sign dileptons

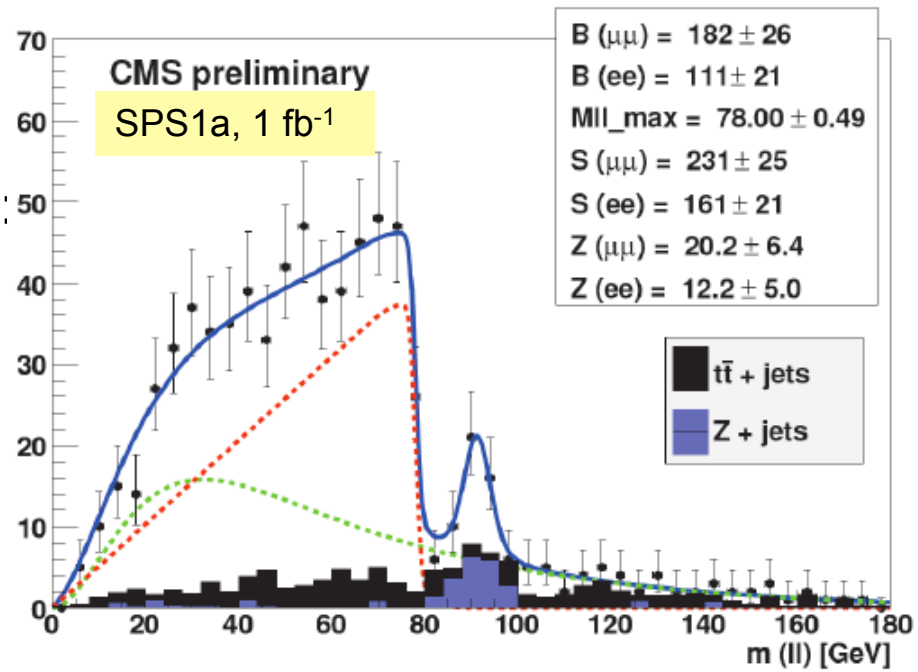
Extra power: also use the shape of the distribution!

- Distinctive triangular shape of $\tilde{\chi}_2^o \rightarrow \ell^{\pm}\ell^{\mp}\tilde{\chi}_1^o$
- Enpoint reflects mass hierarchy $m_{\ell\ell}^{max} = m_{\tilde{\chi}_2^o}\sqrt{1-\frac{m_{\tilde{\ell}_R}^2}{m_{\tilde{\chi}_2^o}^2}}\sqrt{1-\frac{m_{\tilde{\chi}_1^o}^2}{m_{\tilde{\ell}_R}^2}}$
- Data-driven background estimate:
  tt and diboson background from eμ data (BR(ee)=1/2 BR(eμ))
- Unbinned fit to data (7 parameters):

$$F(m) = N_{sig}S(m) + N_{bkg}B(m) + N_Z Z(m)$$

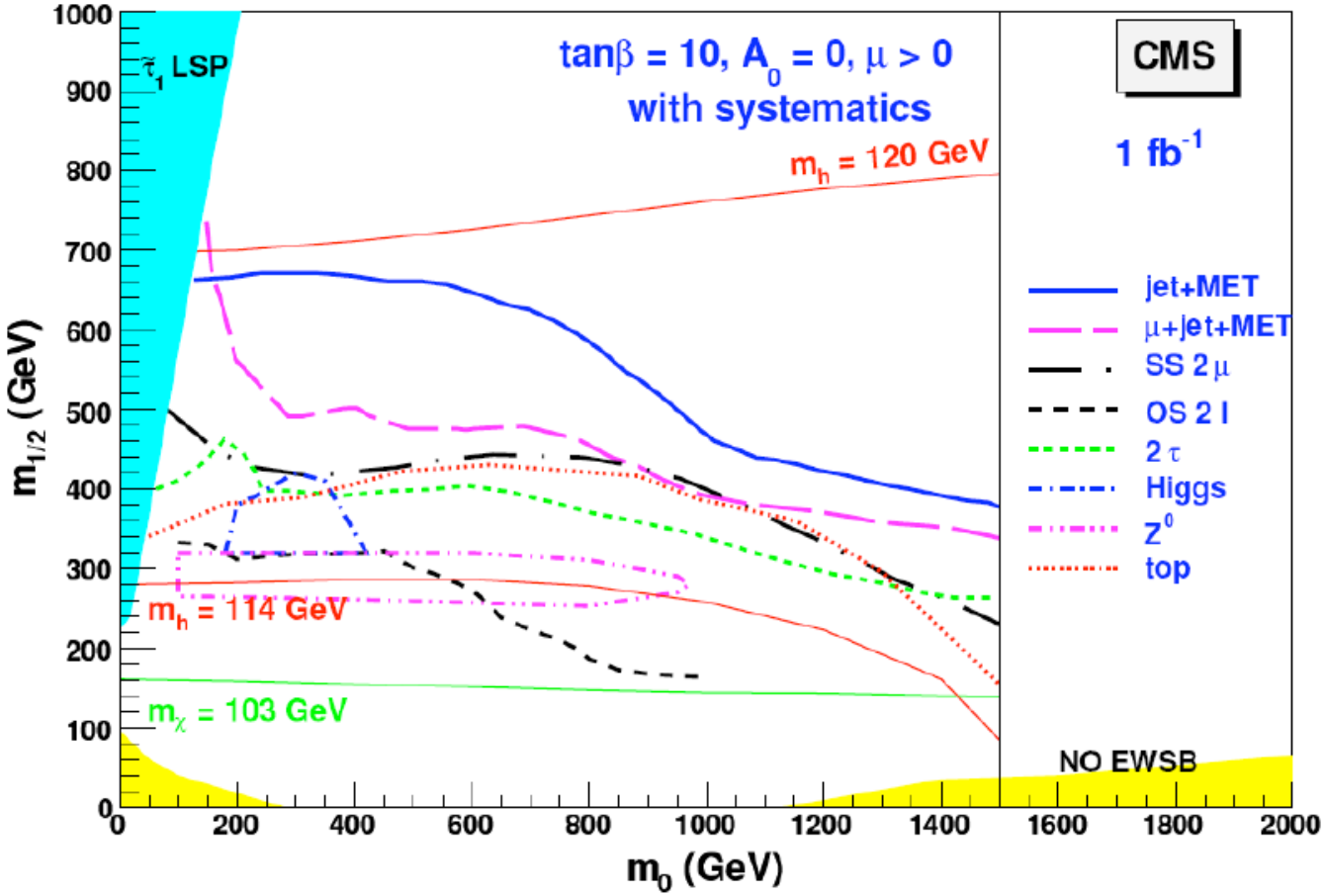
Signal Model | Bkg from data | Z peak

$$\Delta m_{ee}^{max} = \pm 1.07(stat.) \pm 0.36(syst.)GeV$$
$$\Delta m_{\mu\mu}^{max} = \pm 0.75(stat.) \pm 0.18(syst.)GeV$$



SUSY discovery potential

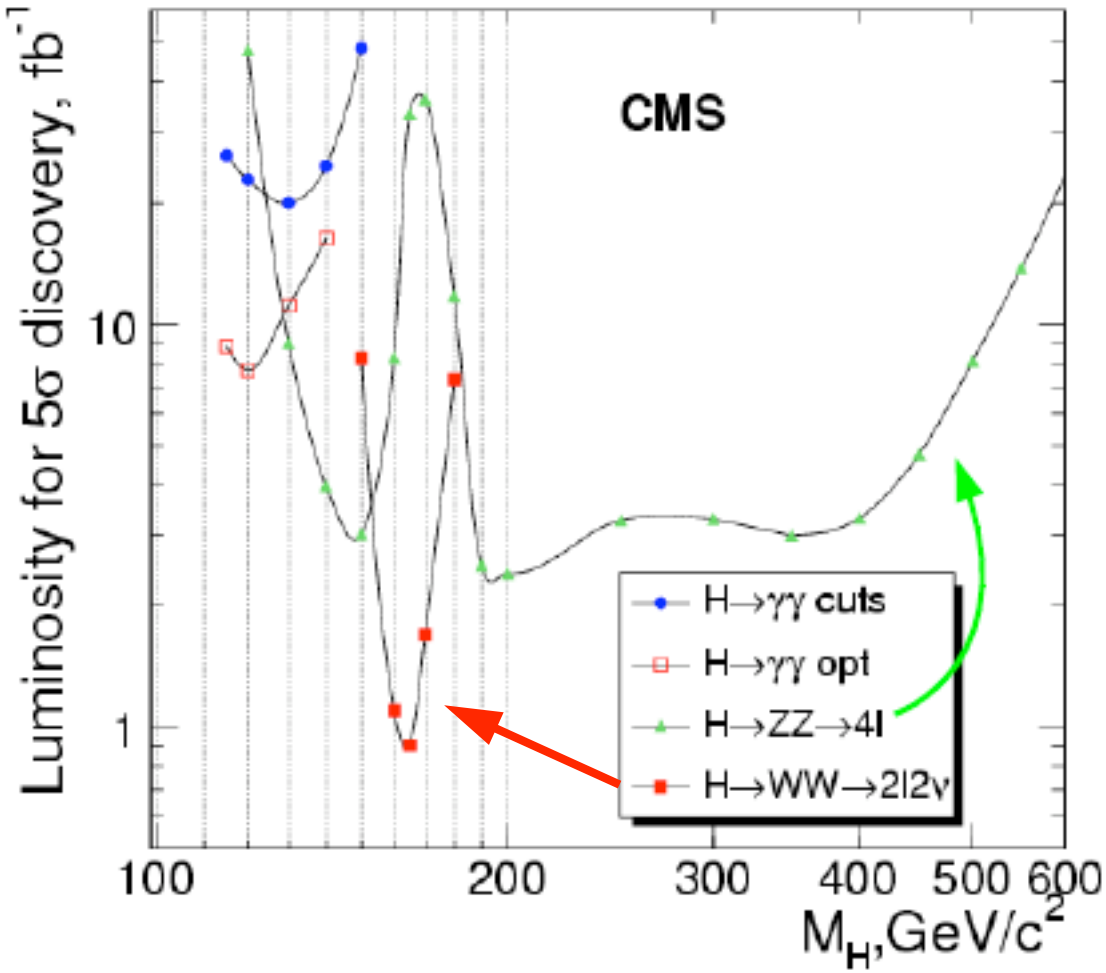
To summarize: many complementary channels for 1 fb^{-1}:



Early SM Higgs searches

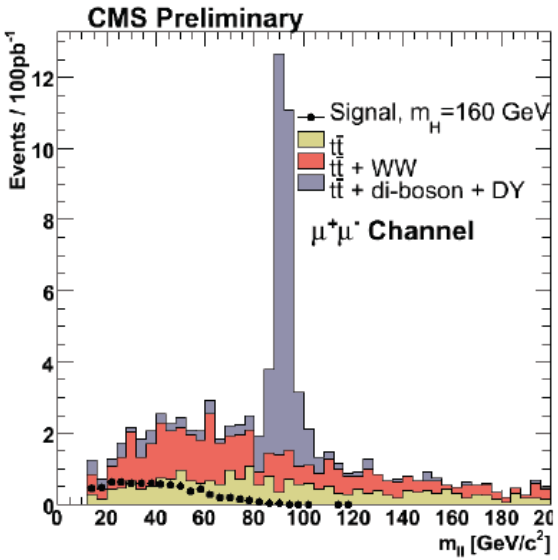
5-sigma discovery:

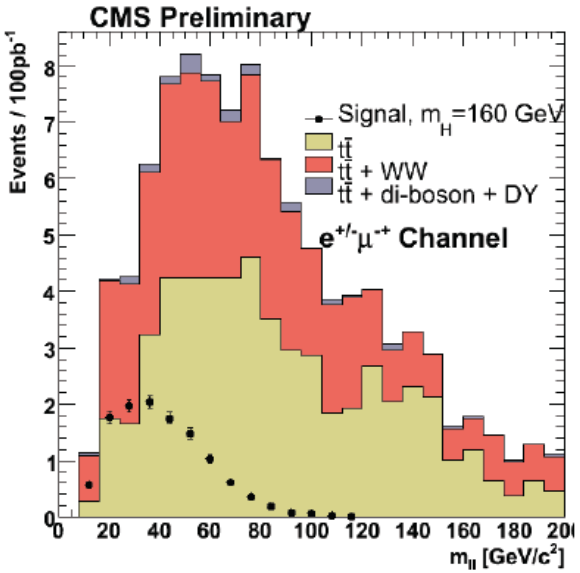
- with 1 fb^{-1}: $H \rightarrow WW$ around m_H=165 GeV
- with few fb^{-1}: also $H \rightarrow ZZ$
- $H \rightarrow \gamma\gamma$ will take longer …



H → WW

- no mass peak, so need precise knowledge of background
- hence, development of data-driven techniques



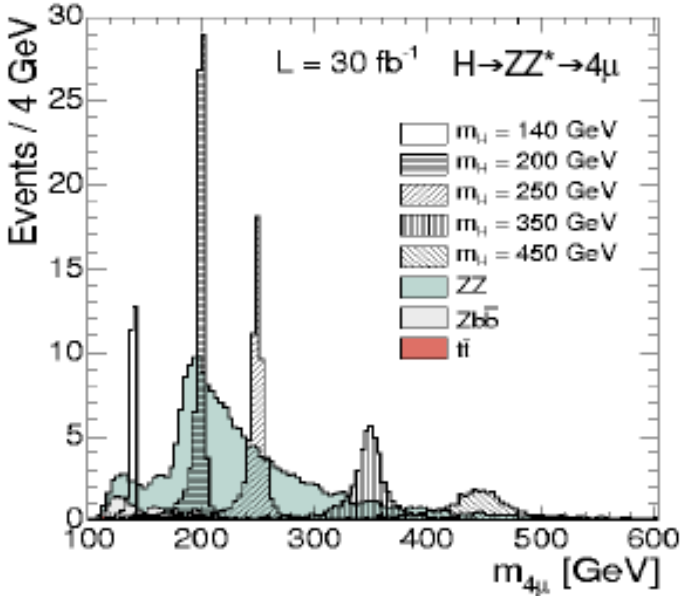


backgroud rejection : isolation, jet veto, MET, $d\phi(ll)$, …

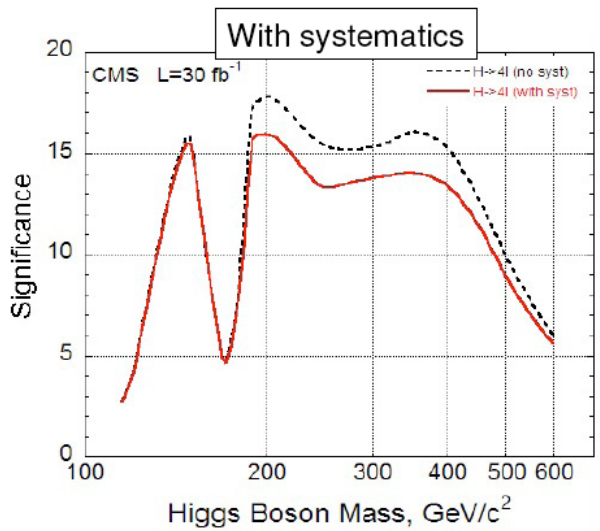
- ongoing studies:
  - measuring fakes rates and background contamination from data
  - understanding systematic uncertainties from data

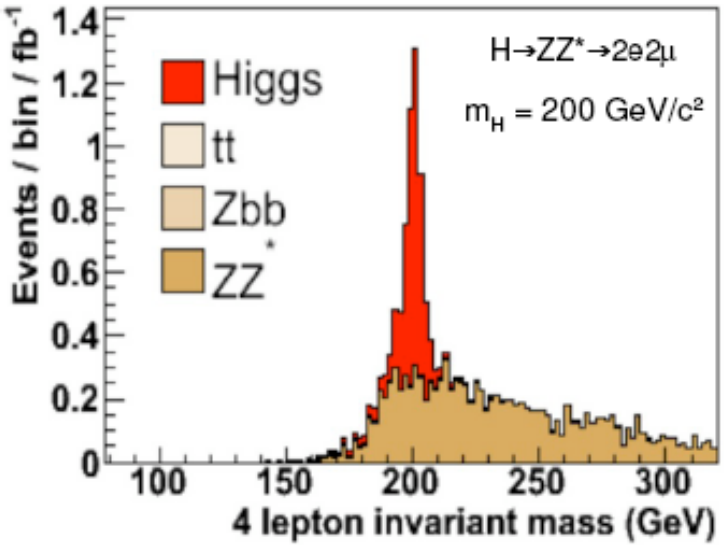
H → ZZ

- 4 leptons, means (efficiency)^4!
- main backgrounds: ZZ/γγ, Zbb, tt
- tools for background suppression: lepton isolation, vertexing and impact parameter

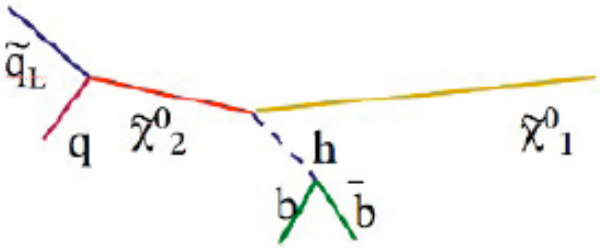


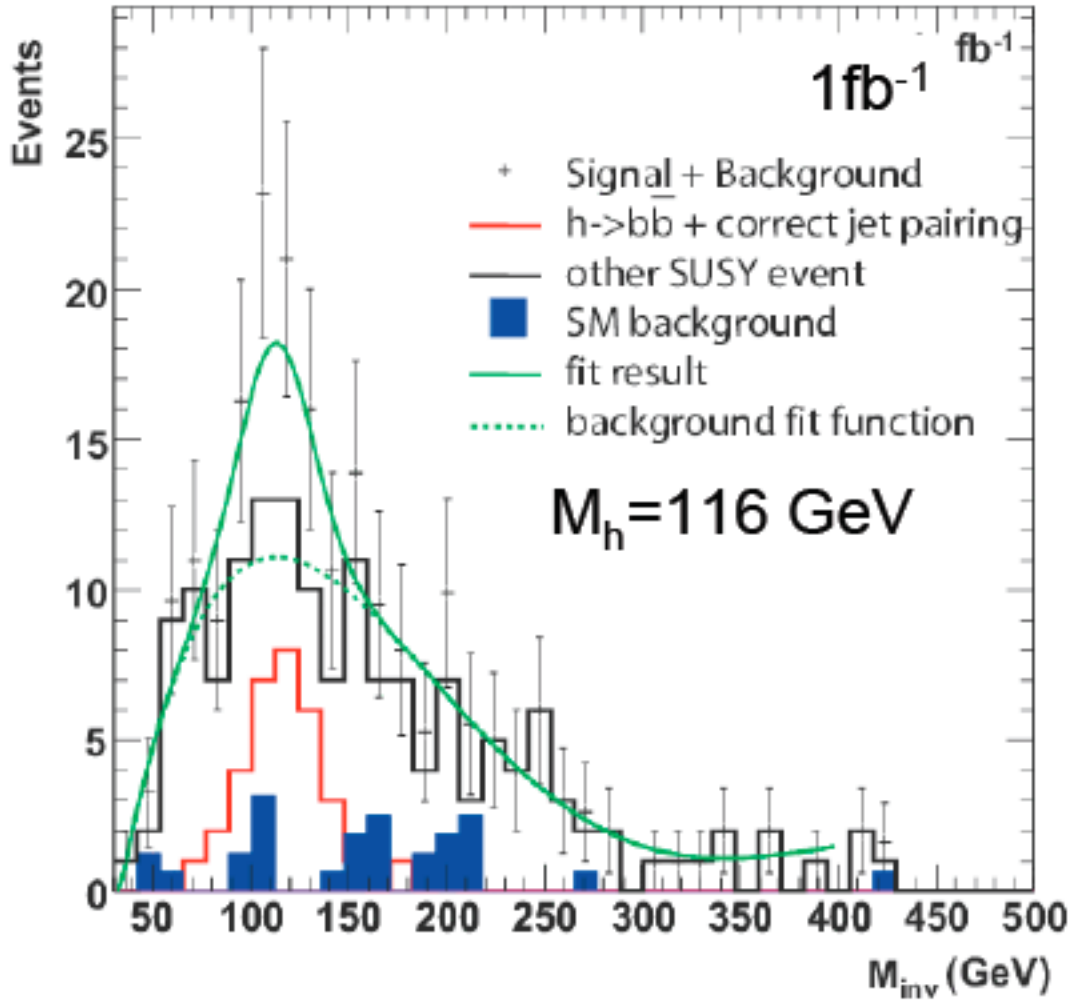
$S \sim \sqrt{L}$





Higgs in SUSY?





interesting possibility:
first observation of light Higgs could be in SUSY cascades …

B-tagging and good di-jet resolution are crucial

Summary

- the CMS detector is ready for data taking

- CMS is being commissioned with cosmic muons, beam halo muons, splash events, … (anything we get!)

- they way we'll approach the early collision data:

  - understand the detector & physics objects
  - re-discover the Standard Model
  - then look for New Physics

- CMS is ready to study a multitude of signatures for NP

- exciting days ahead after the winter shutdown