# Searches at CMS

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*on behalf of the CMS collaboration*

Planck 2010 – CERN, June 3, 2010

# Outline

- Introduction

- The CMS detector

- Preparing for searches

- "LHC Run I" prospects for searches (non-exhaustive)

  ‣ **Higgs, SUSY and others**

- Conclusions

- Searches rely on all aspects of the reconstruction

  ▸ **electrons, photons and muons**

  ▸ **jets, total hadronic activity**

  ▸ **missing energy (especially tails)**

- Commissioning these "Physics objects" is crucial

  ▸ **will start with current status**

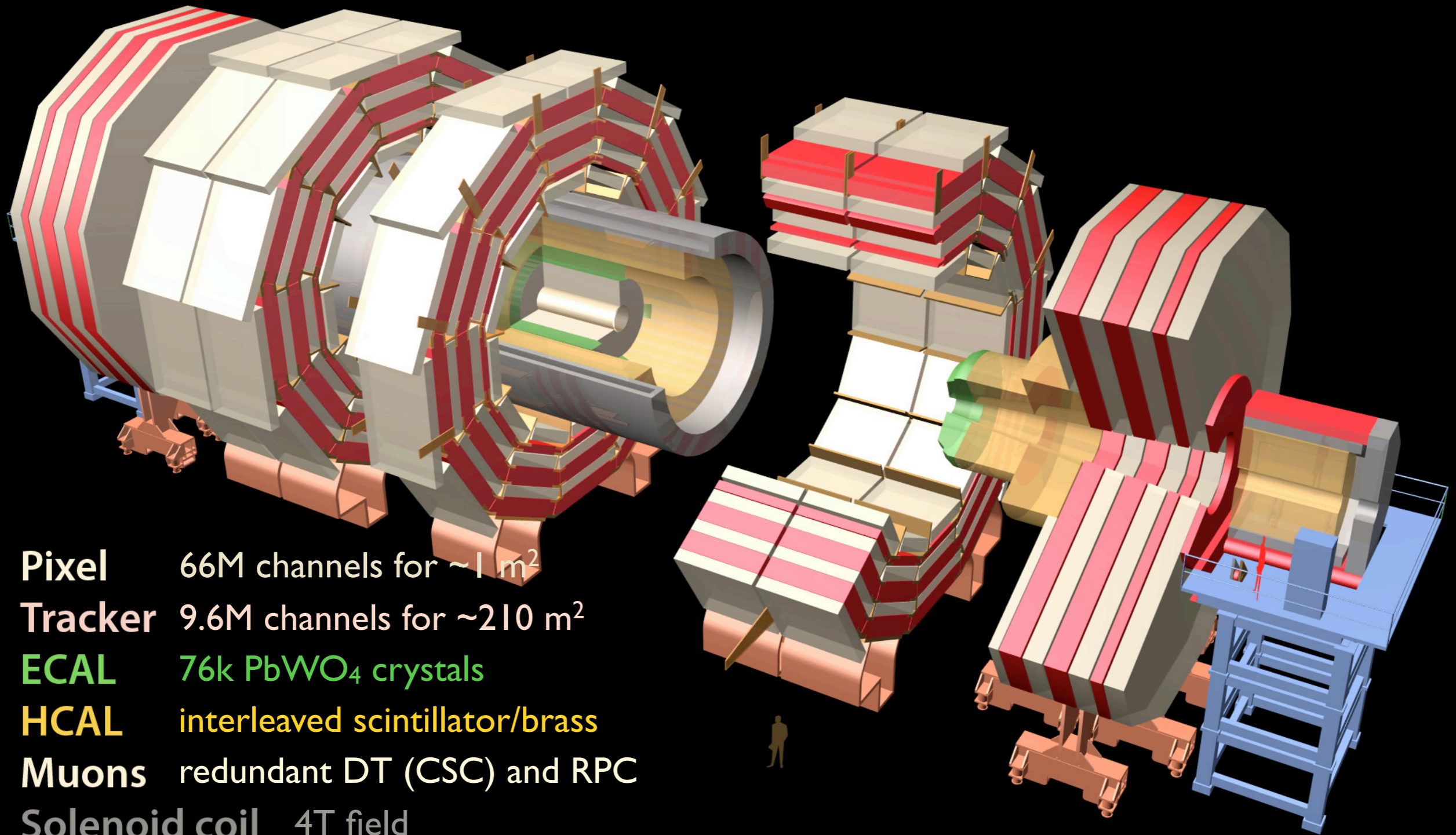    ▪ on data!

  ▸ **then switch to prospects for searches**
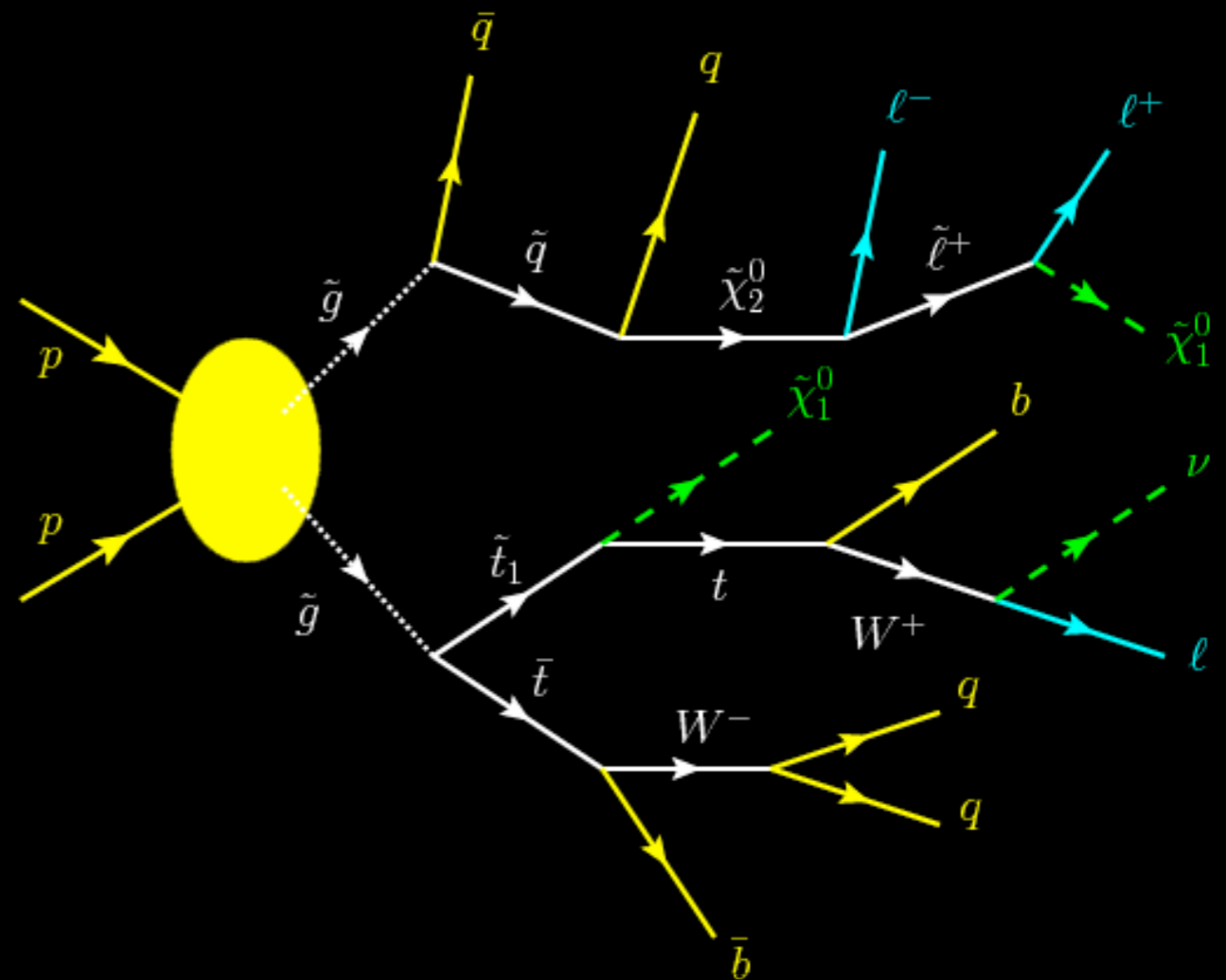
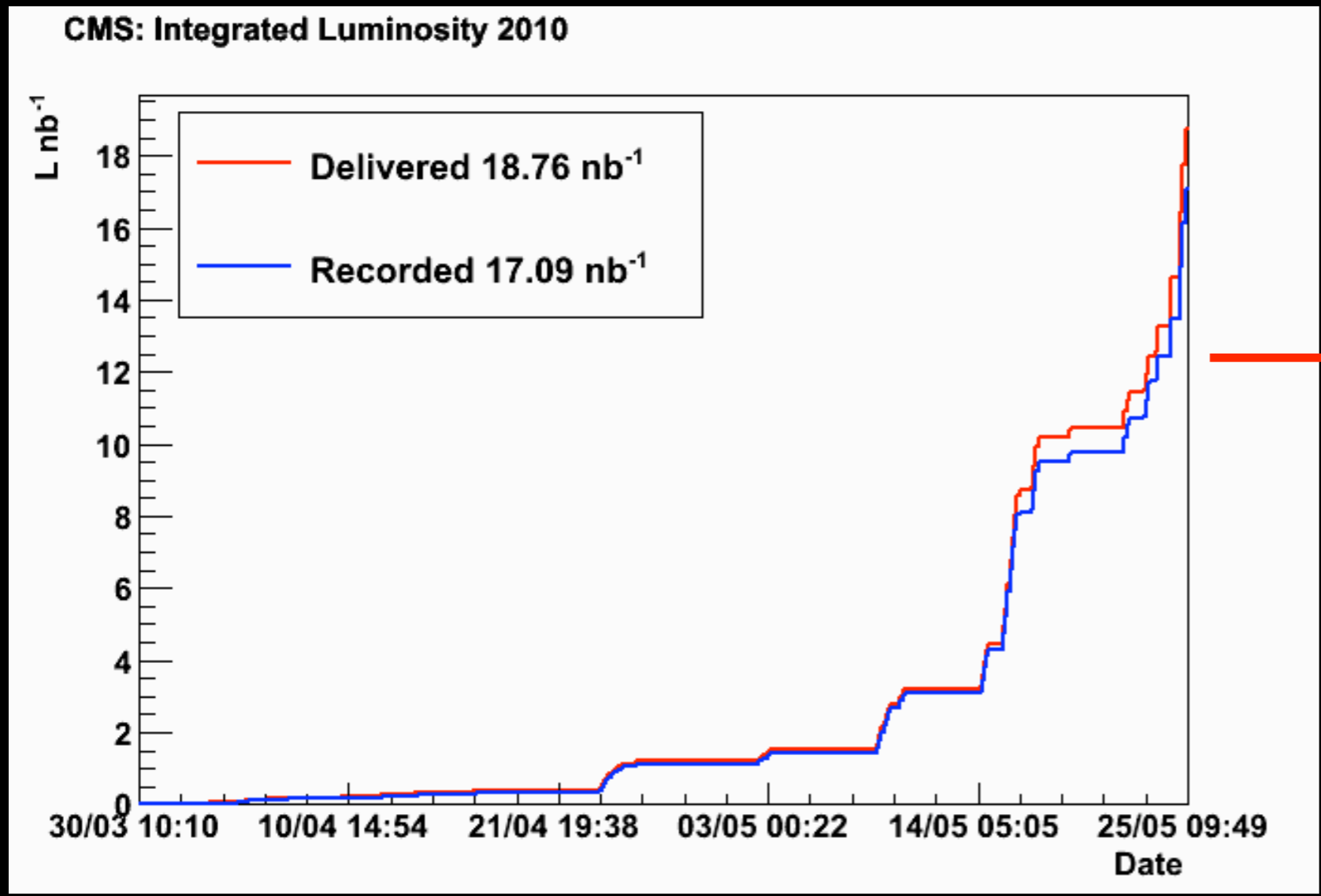A "typical" SUSY event
many jets, leptons and missing energy

# The Compact Muon Solenoid

Φ

| | |
|---|---|
| **Total weight** | **12500 t** |
| **Overall diameter** | **15 m** |
| **Overall length** | **21.6 m** |



**Pixel**    66M channels for ~1 m$^2$

**Tracker**    9.6M channels for ~210 m$^2$

**ECAL**    76k PbWO$_4$ crystals

**HCAL**    interleaved scintillator/brass

**Muons**    redundant DT (CSC) and RPC

**Solenoid coil**    4T field

# Integrated luminosity



CMS: Integrated Luminosity 2010

Delivered 18.76 nb⁻¹
Recorded 17.09 nb⁻¹

| Luminosity | Physics reach |
|---|---|
| 1 mb⁻¹ | UE, MB |
| 1 µb⁻¹ | Jets, Heavy flavour |
| 1 nb⁻¹ | W, Z |
| 1 pb⁻¹ | ttbar |
| 10 pb⁻¹ | Dijets, HSCP,... |
| 100 pb⁻¹ (2010) | W', Z', low-mass SUSY |
| 1 fb⁻¹ (2011) | SUSY, MSSM Higgs |

Data taking efficiency: ~92%
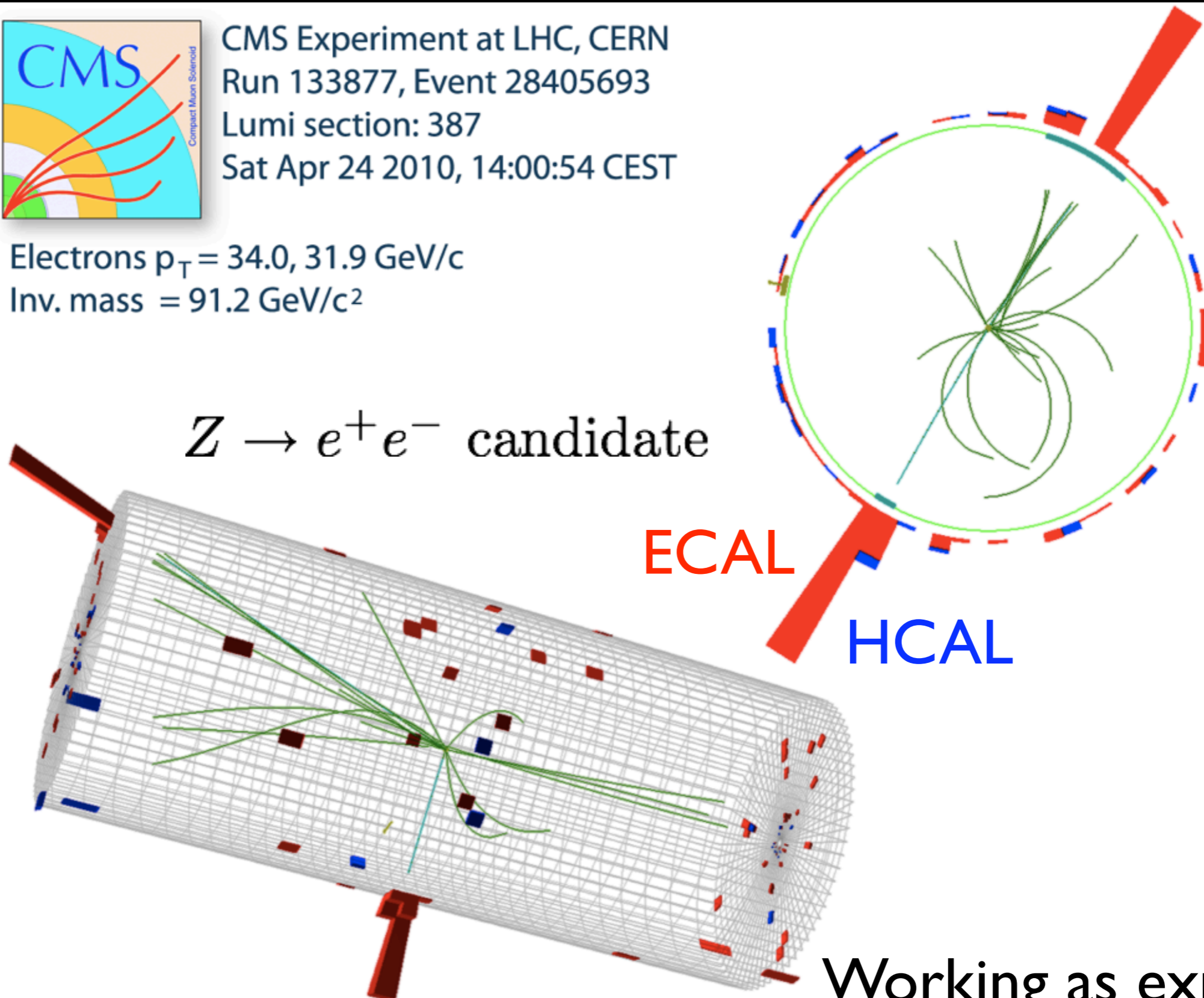in *first* 2 months!

CMS Experiment at LHC, CERN
Run 133877, Event 28405693
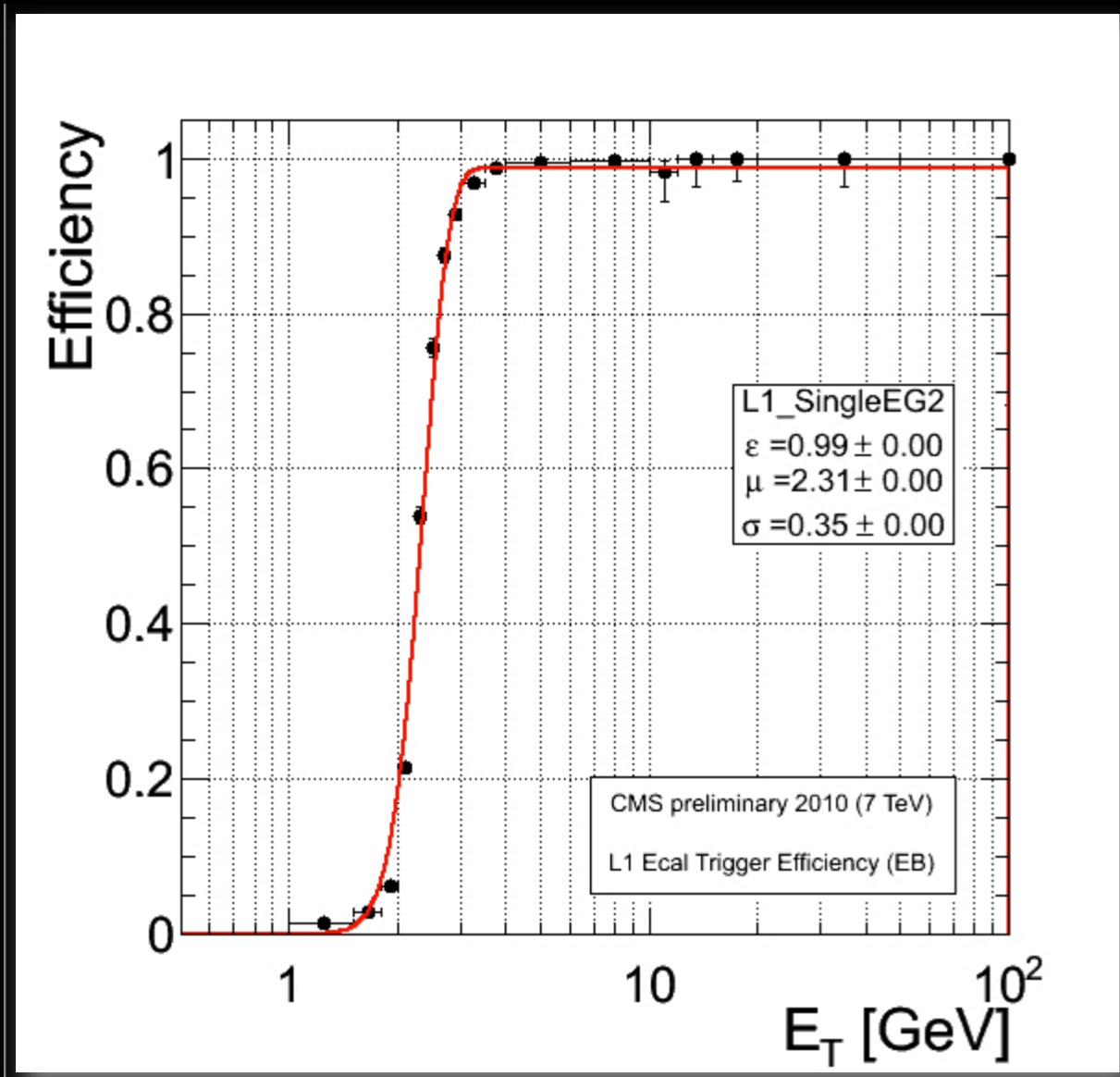Lumi section: 387
Sat Apr 24 2010, 14:00:54 CEST

Electrons $p_T = 34.0, 31.9$ GeV/c
Inv. mass $= 91.2$ GeV/c²

$$Z \rightarrow e^+ e^- \text{ candidate}$$

ECAL

HCAL

Working as expected...

https://twiki.cern.ch/twiki/bin/view/CMS/PublicPhysicsResultsEWK

# Triggers
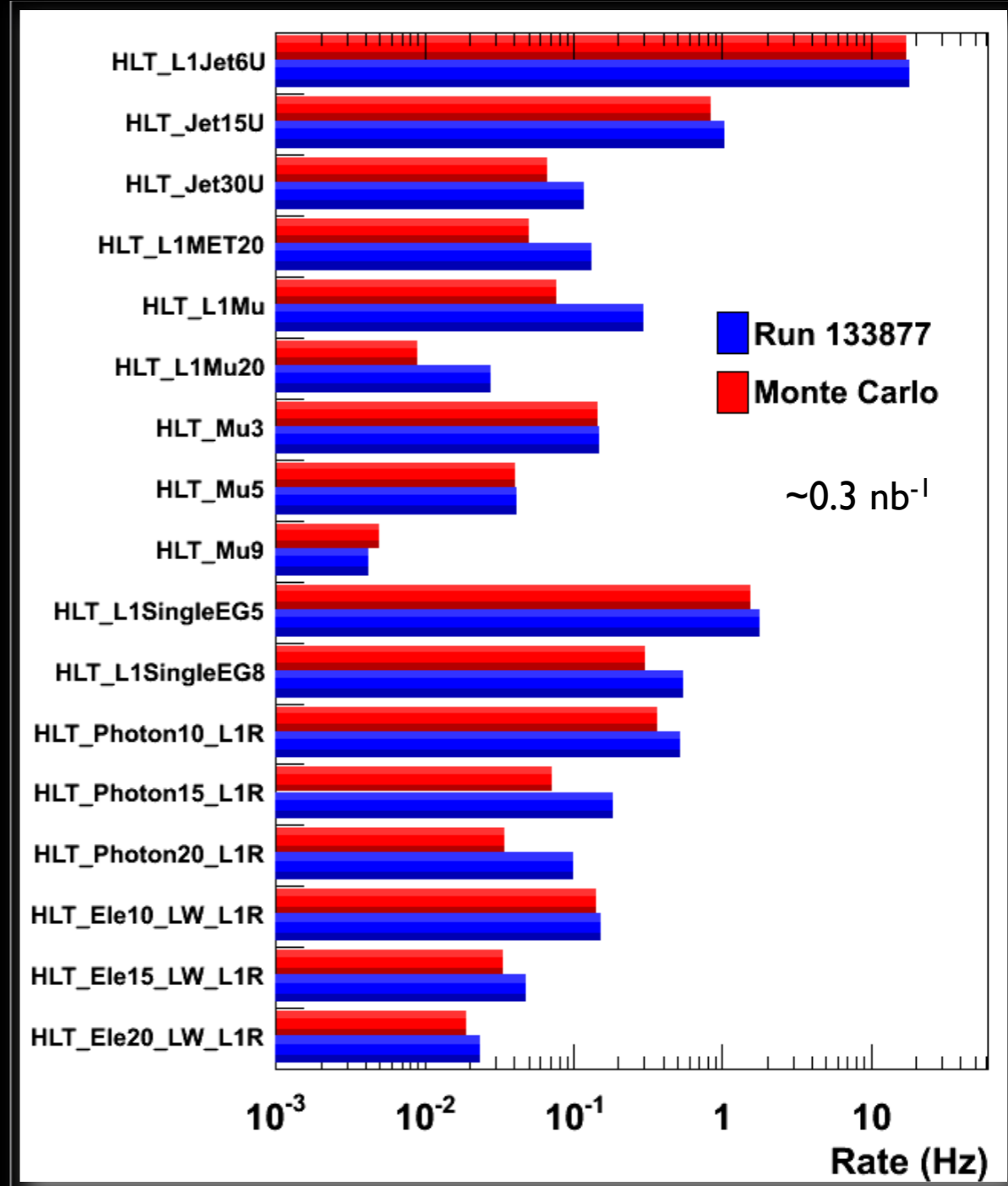


L1 turn-on curve
electron-photon trigger with $E_T > 2$ GeV

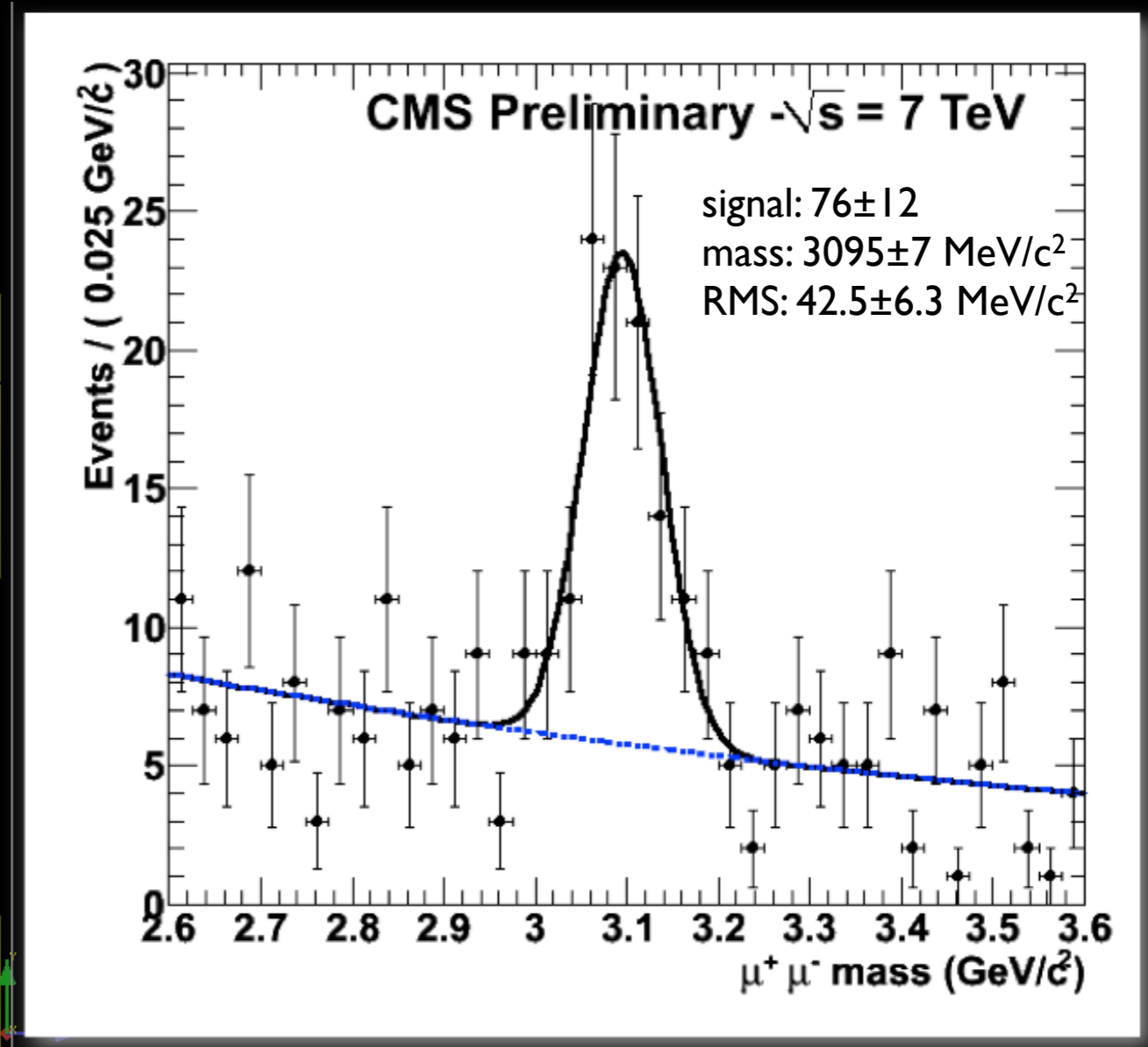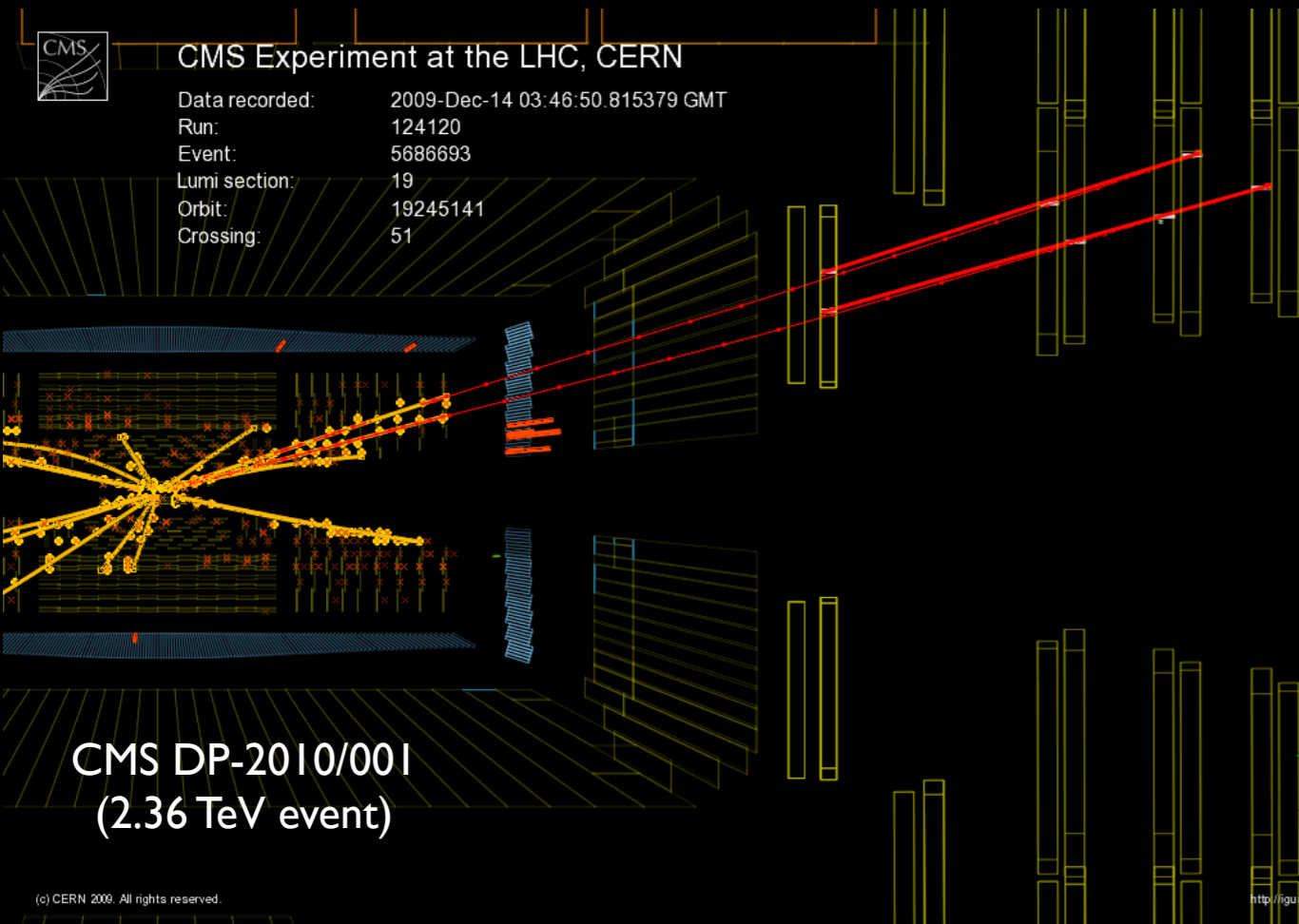High-level trigger rates
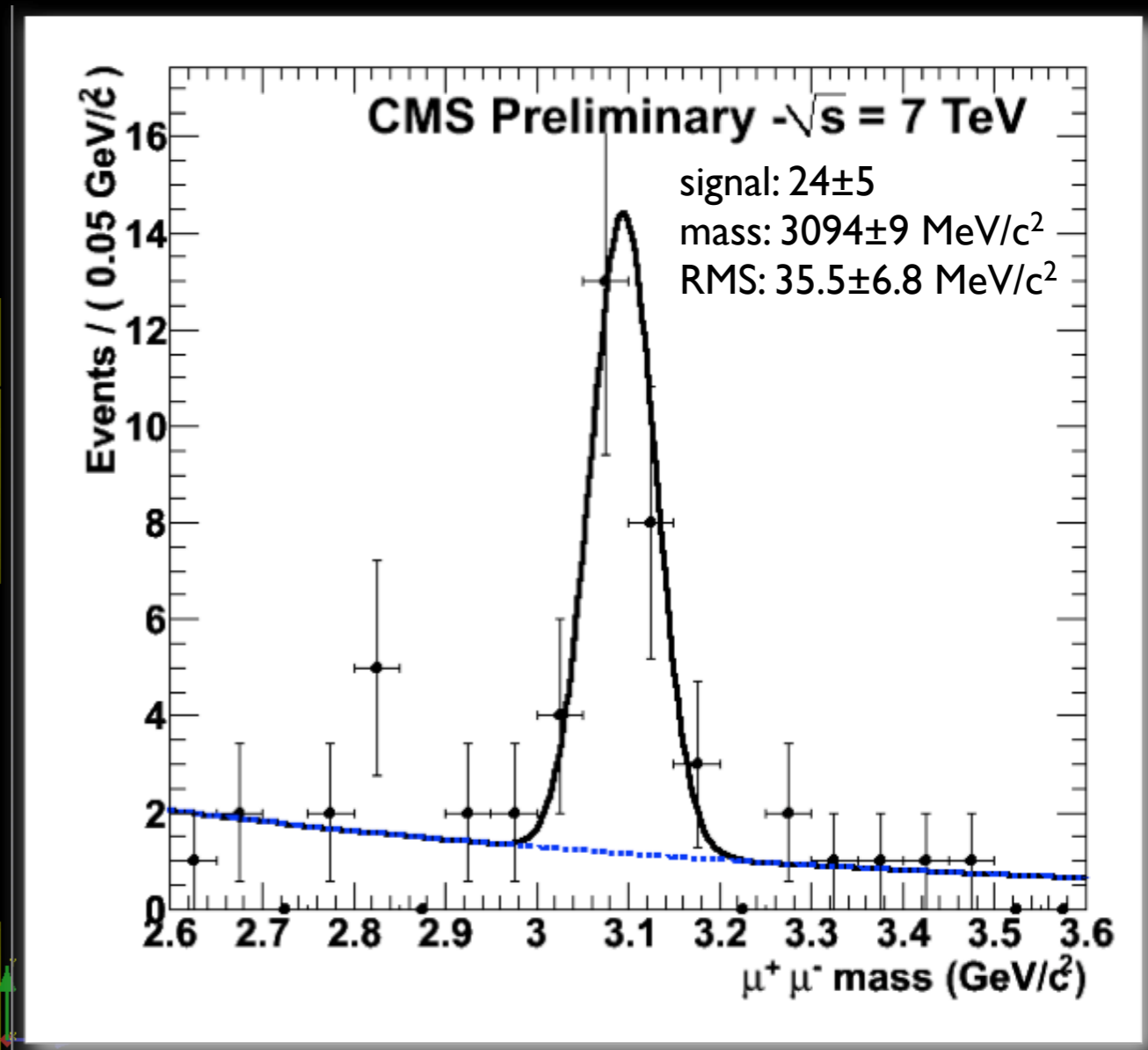Data/MC comparison

➟ **Working as expected**

# Muons

- ## Dimuon resonances

  ▸ **J/ψ is the first of a list including the Z boson (and beyond?)**

CMS Experiment at the LHC, CERN

Data recorded:      2009-Dec-14 03:46:50.815379 GMT
Run:                124120
Event:              5686693
Lumi section:       19
Orbit:              19245141
Crossing:           51

CMS DP-2010/001
(2.36 TeV event)

**CMS Preliminary - √s = 7 TeV**

signal: 76±12
mass: 3095±7 MeV/c$^2$
RMS: 42.5±6.3 MeV/c$^2$

Events / ( 0.025 GeV/c$^2$ )

$\mu^+ \mu^-$ mass (GeV/c$^2$)

Dimuon mass

# Muons

$\Phi$

- Dimuon resonances

  ▸ **J/ψ is the first of a list including the Z boson (and beyond?)**



CMS DP-2010/001
(2.36 TeV event)



signal: 24±5
mass: 3094±9 MeV/c$^2$
RMS: 35.5±6.8 MeV/c$^2$
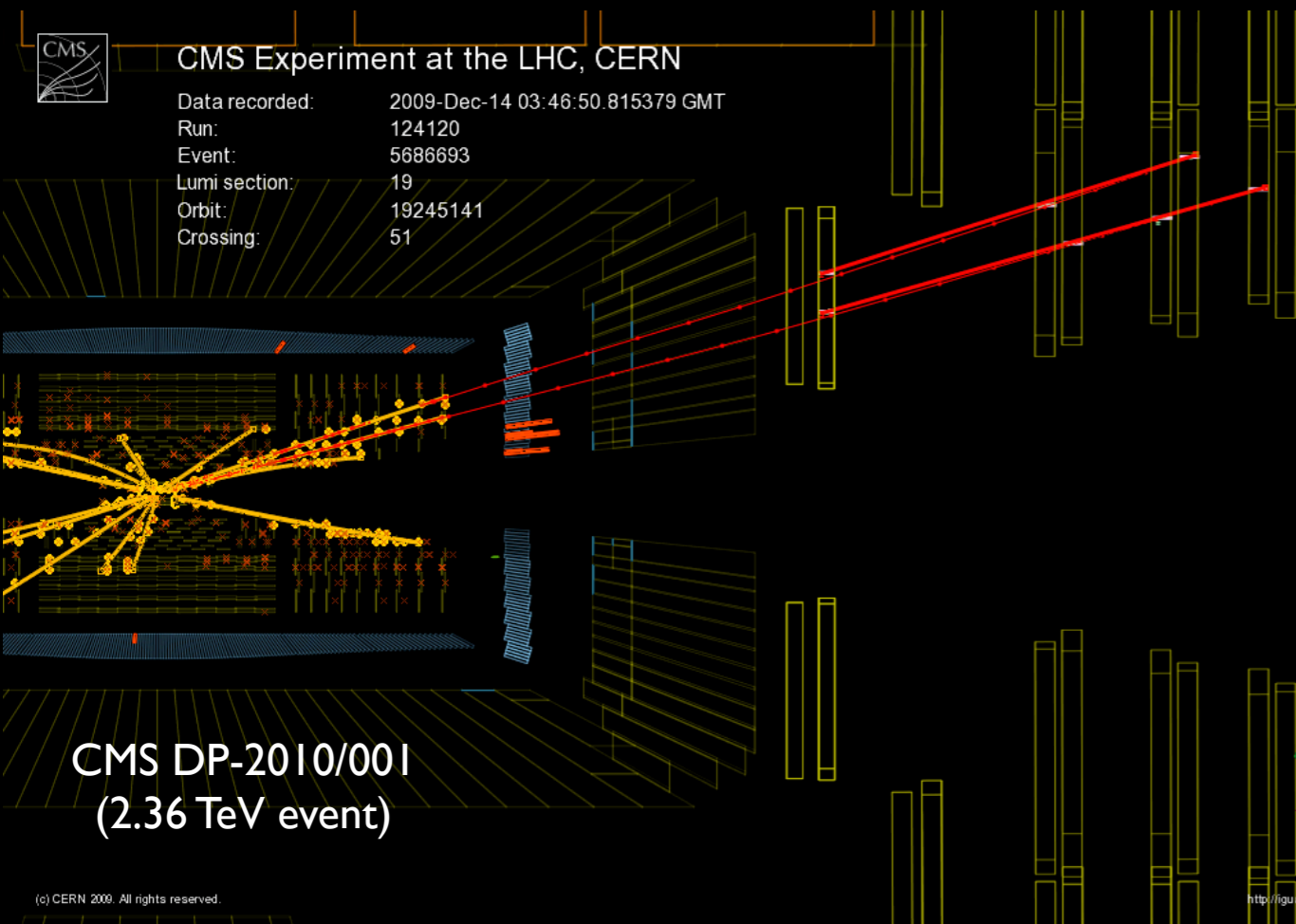
Dimuon mass
with tighter selection
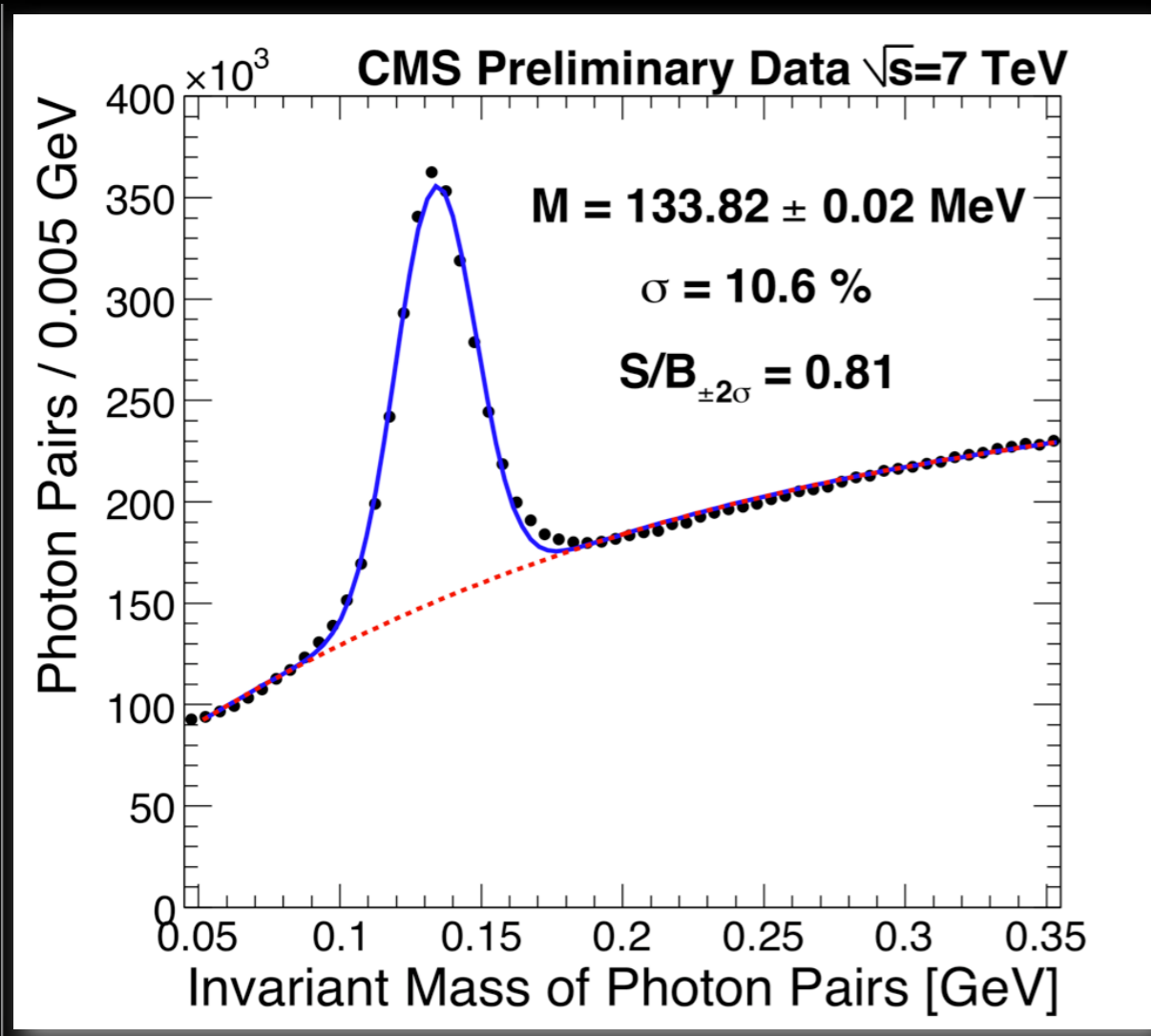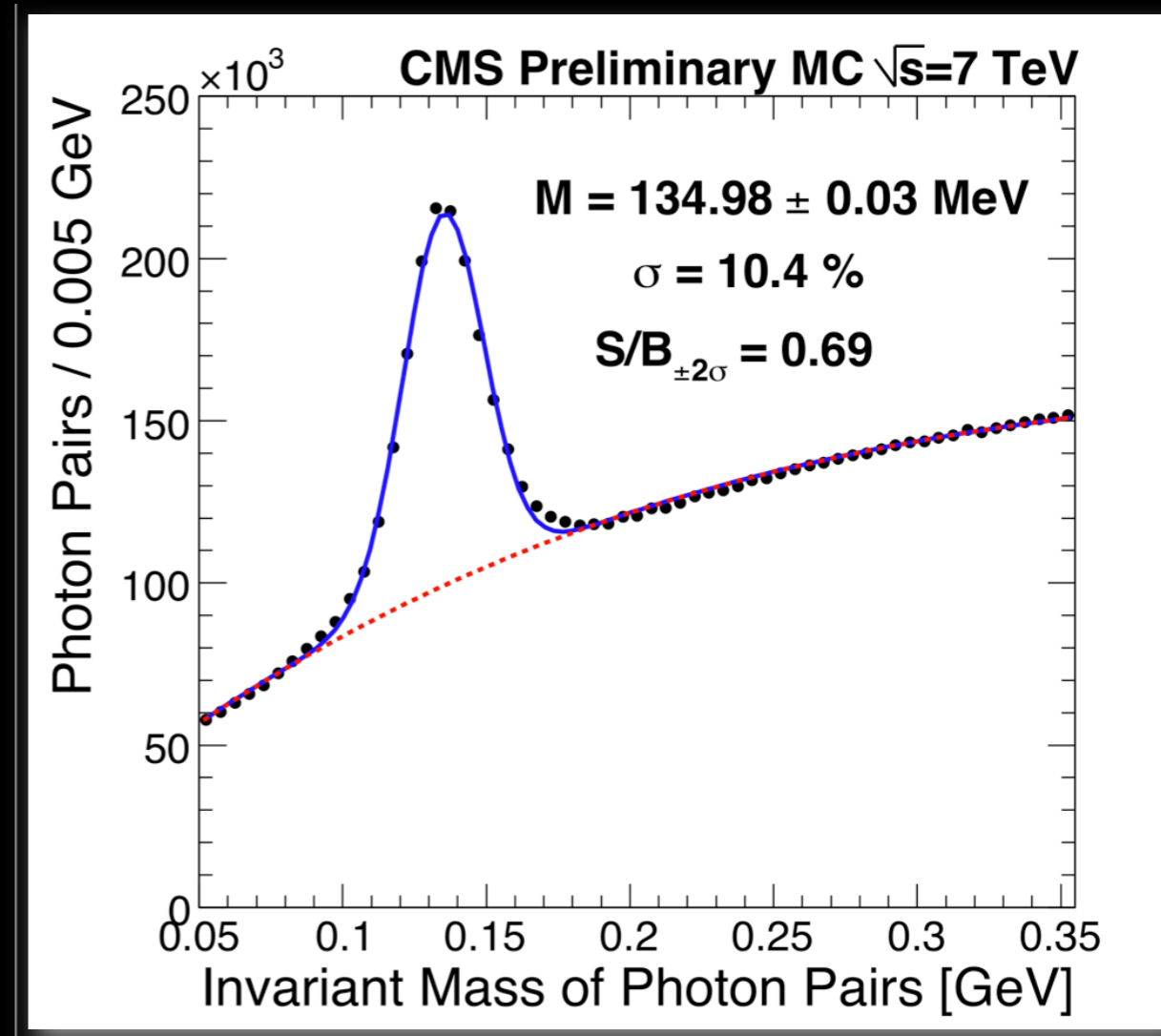
# Electrons and photons

## $\pi^0$ mass peak



γγ invariant mass in **data**

γγ invariant mass in **simulation**

# Electrons and photons

## η mass peak



γγ invariant mass in **data**

γγ invariant mass in **simulation**

# Electrons and photons
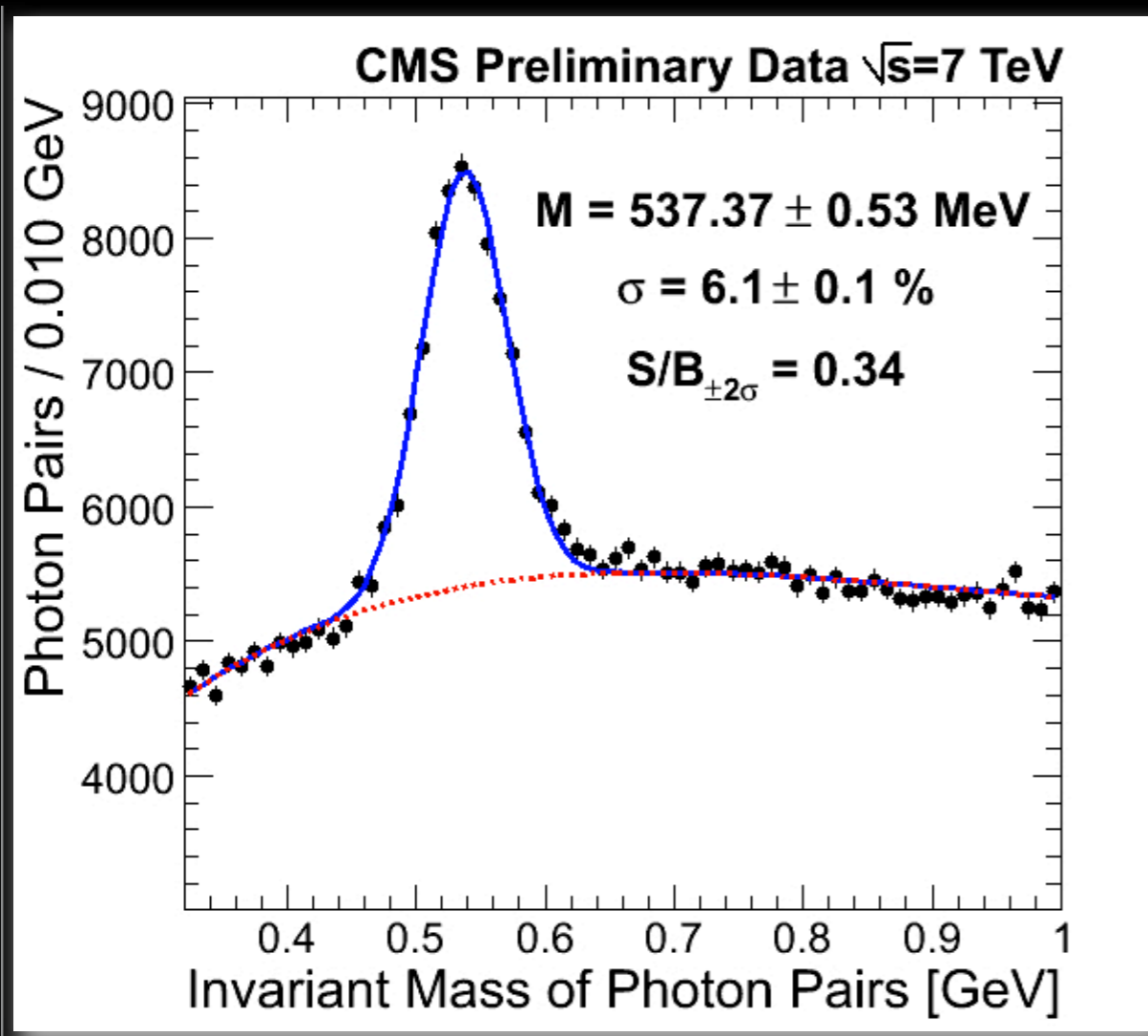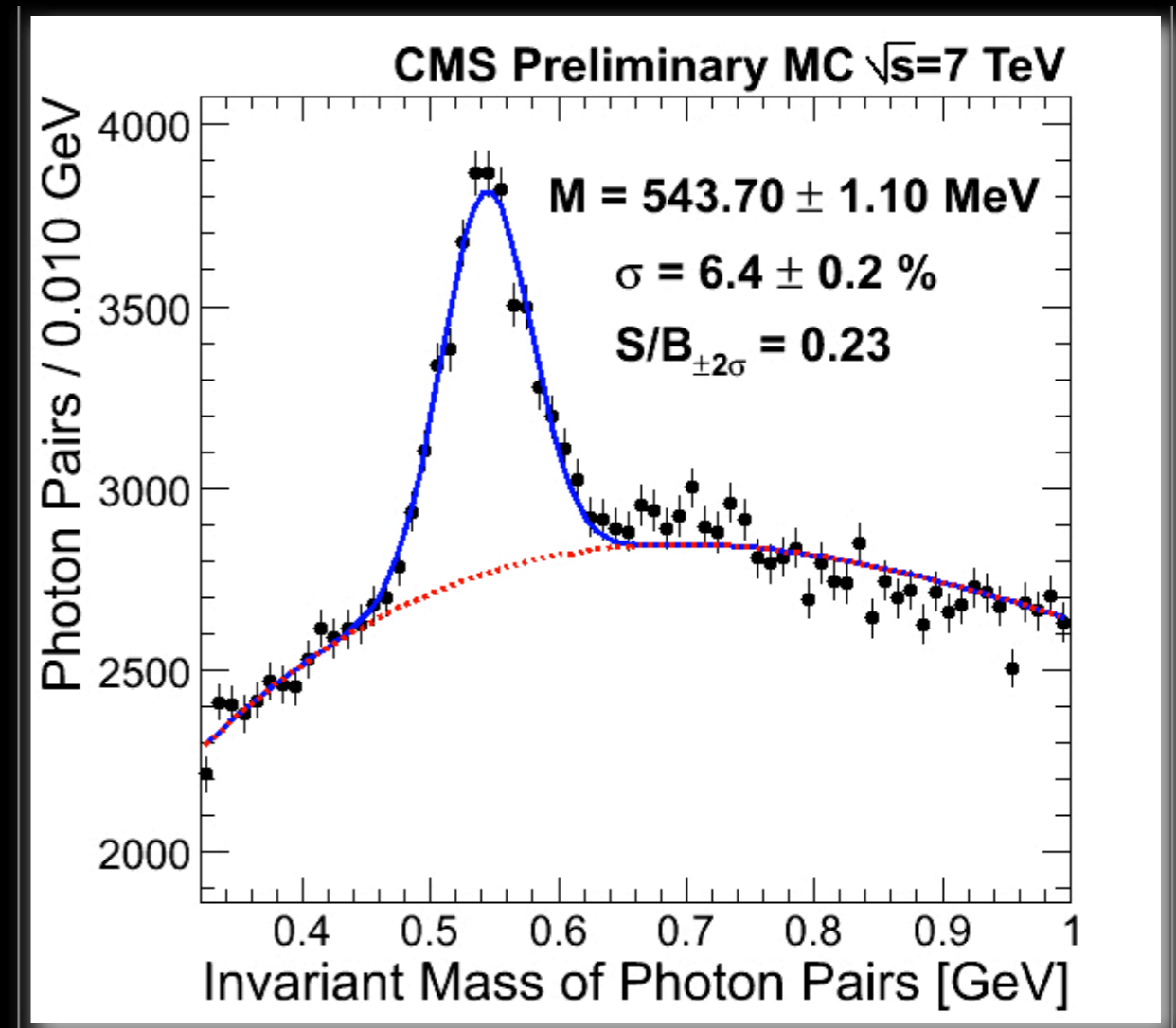
## π⁰ mass peak – a different perspective...
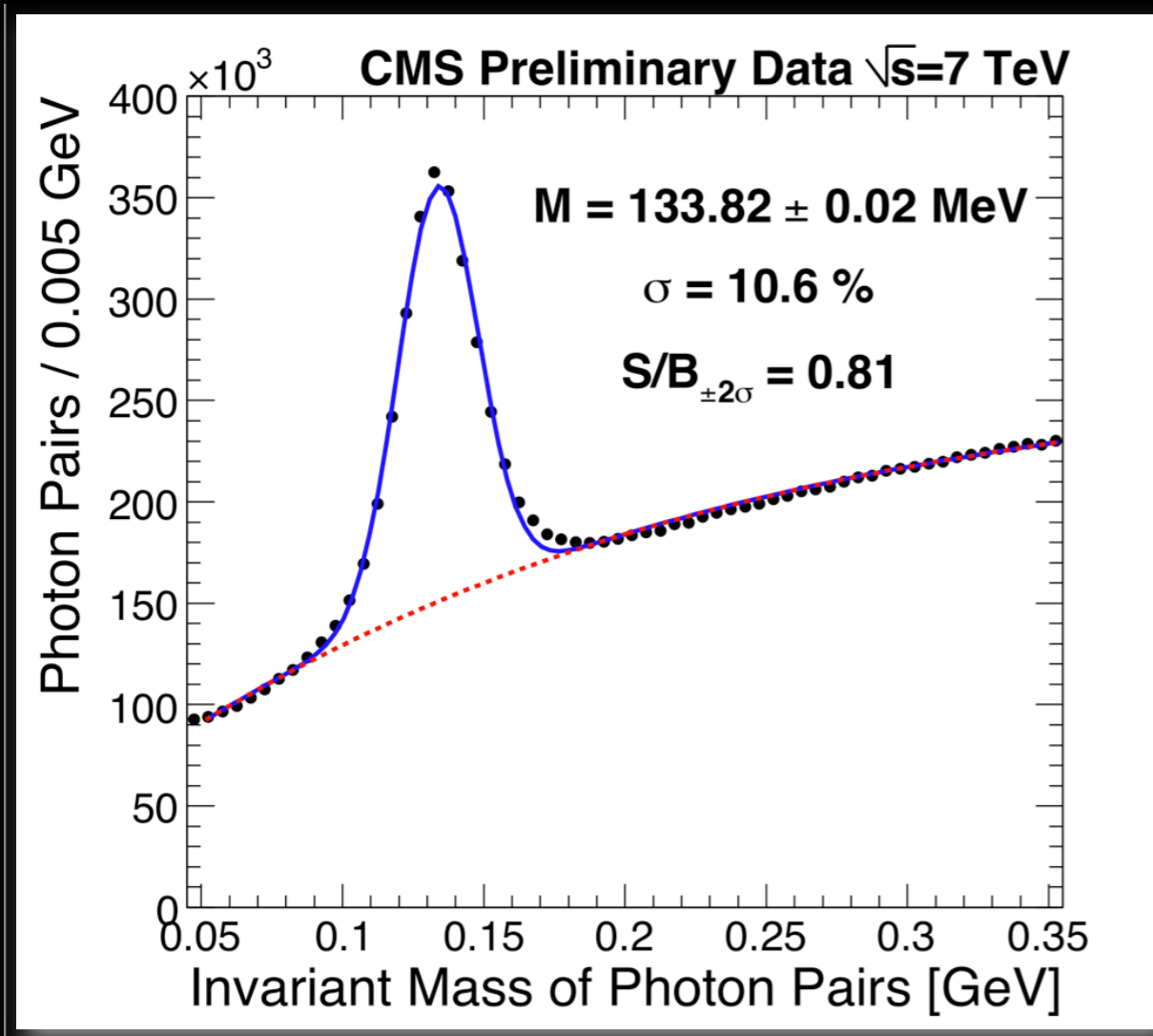


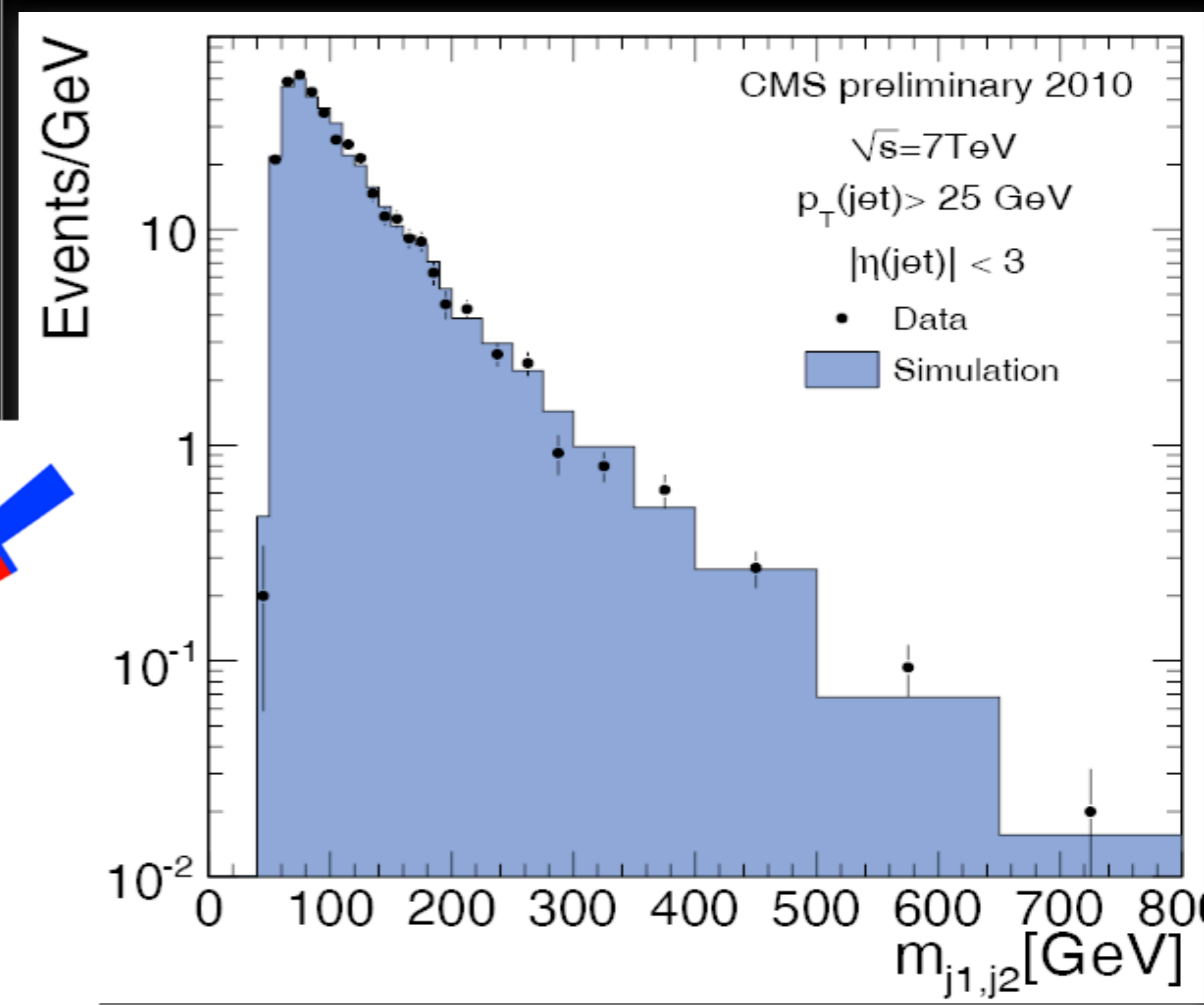γγ invariant mass in **data**
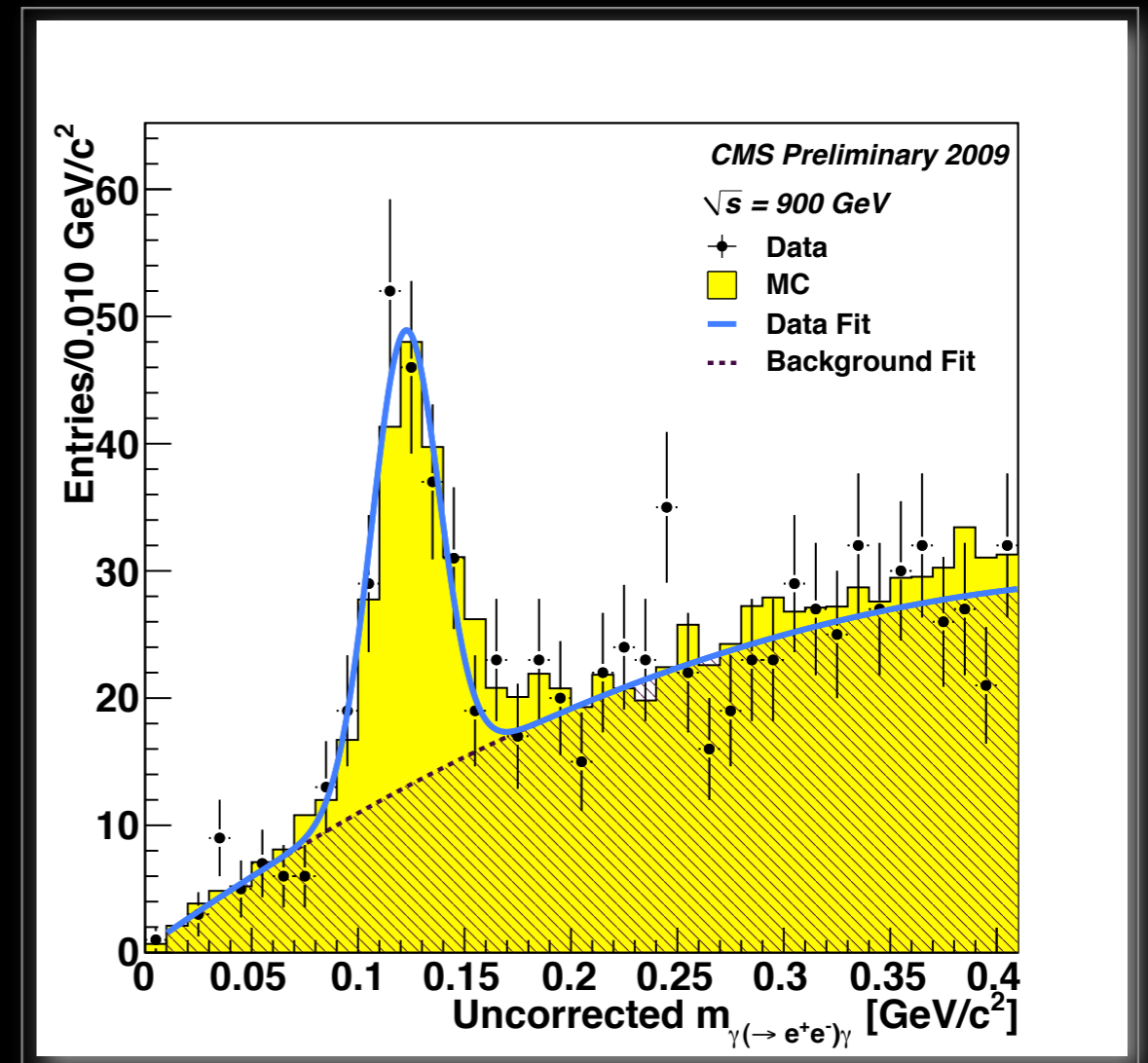


Same, with one photon reconstructed
as a **conversion**
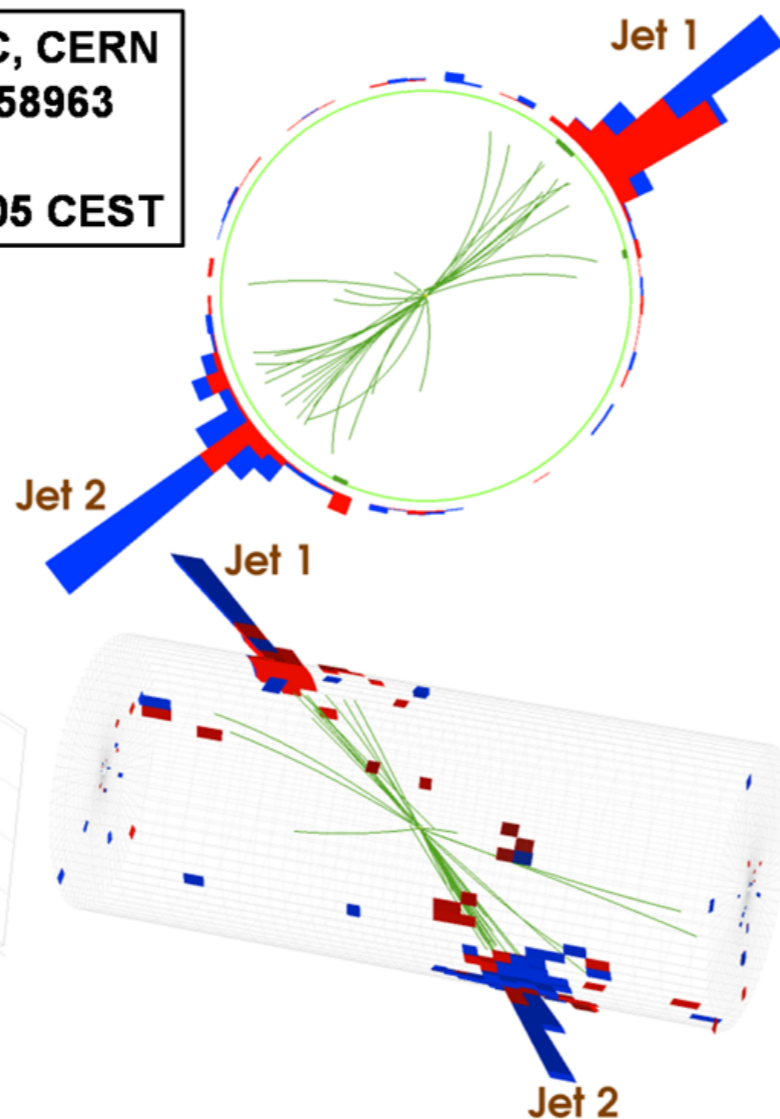Comparison between **data** and simulation

- ## Dijet event mass already approaching 1TeV
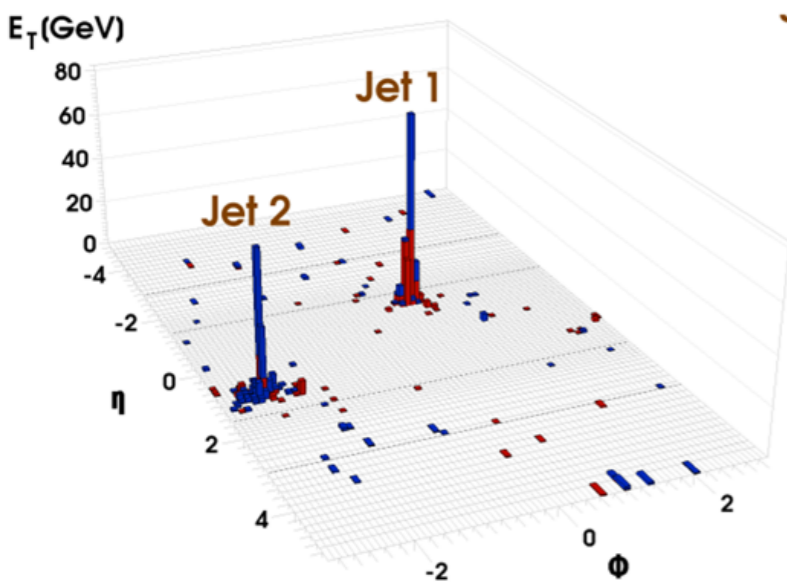
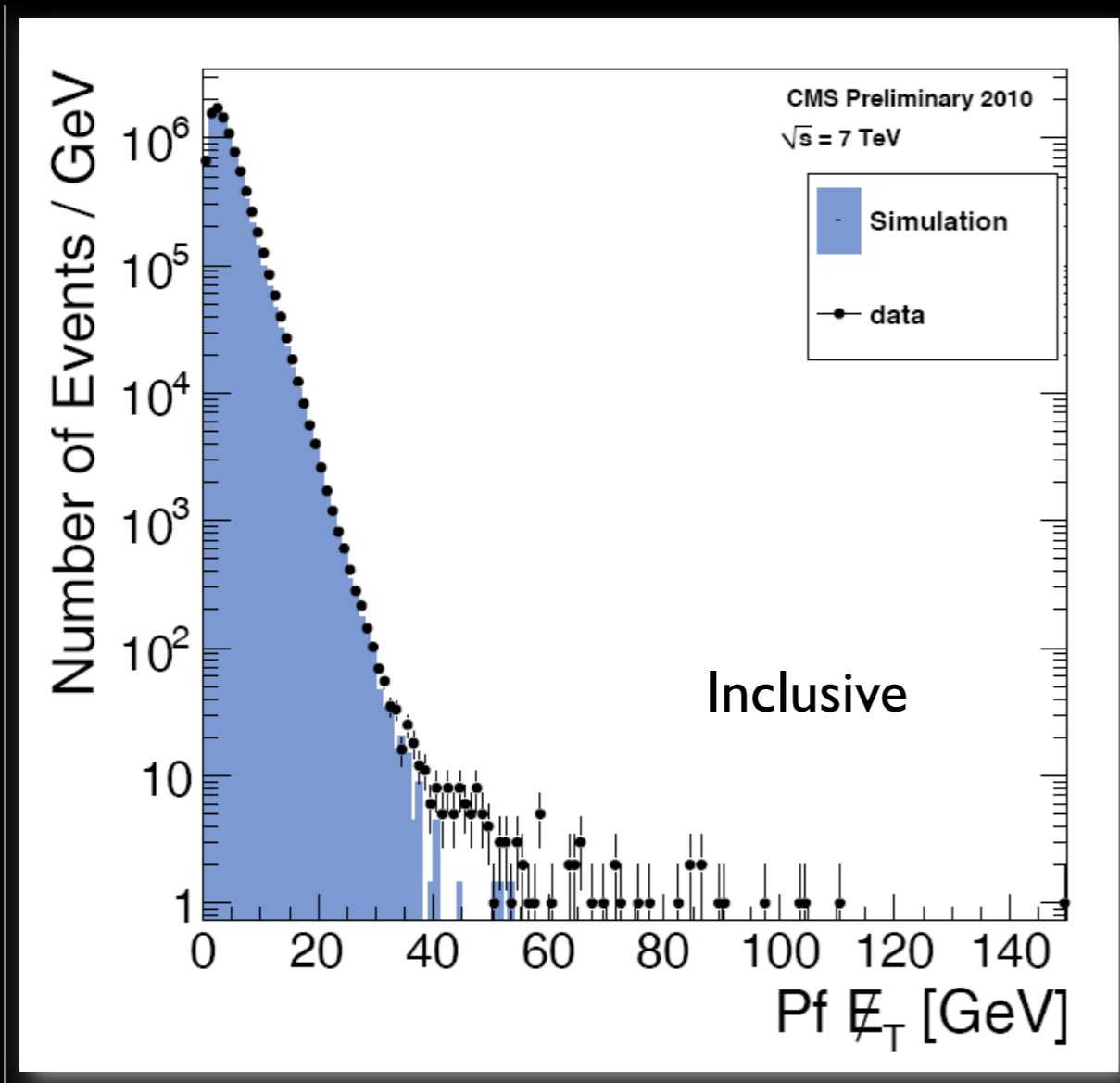  ▶ **good prospects for dijet searches!**



CMS Experiment at LHC, CERN
Run 133450   Event 16358963
Lumi section:  285
Sat Apr 17 2010, 12:25:05 CEST

Jet 1 $p_T$: 253 GeV
Jet2  $p_T$: 244 GeV
Dijet Mass: **764** GeV



CMS preliminary 2010
$\sqrt{s} = 7\text{TeV}$
$p_T(\text{jet}) > 25$ GeV
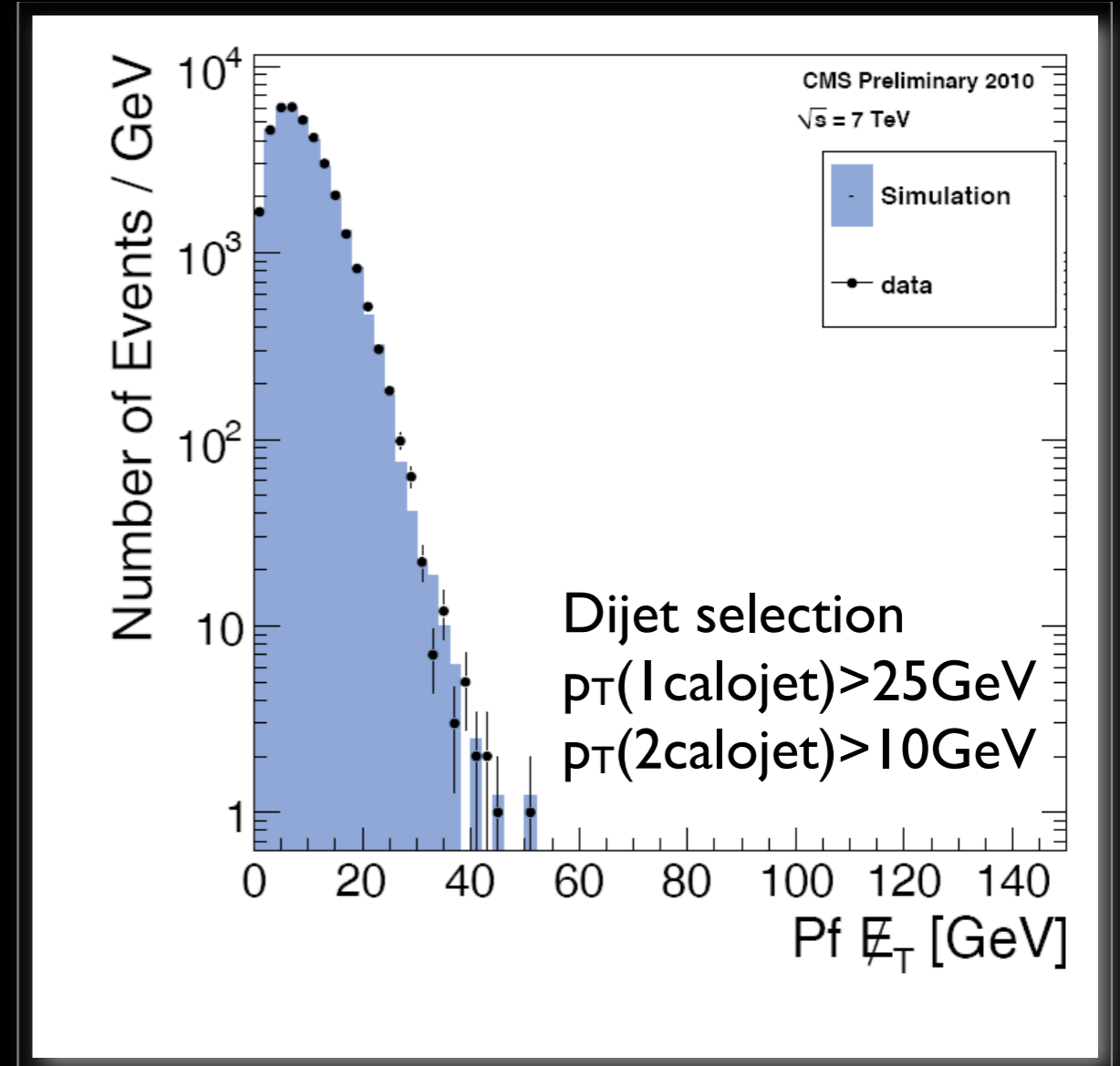$|\eta(\text{jet})| < 3$
• Data
▮ Simulation

Dijet event mass
data/simulation comparison

CMS DP-2010/014

## Particle flow: combining information from all sub-detectors



Inclusive MET distribution
Particle flow reconstruction

MET distribution in dijet events
Particle flow reconstruction

➠ **Steep drop over 6 orders of magnitude!**

N.B. Noise cleaning has improved even more since then.

# b-tagging

## Pixel detector allows for good z resolution
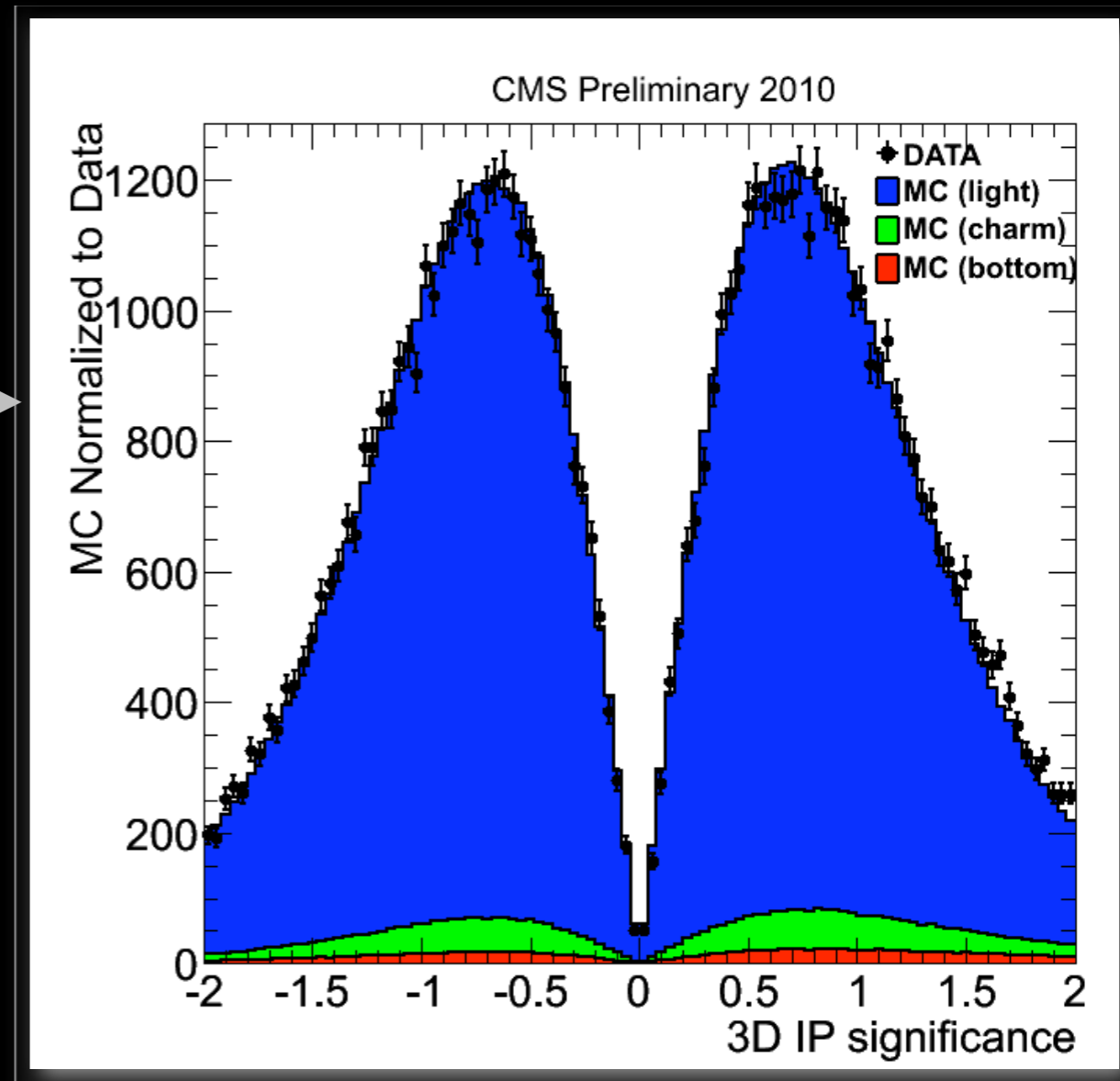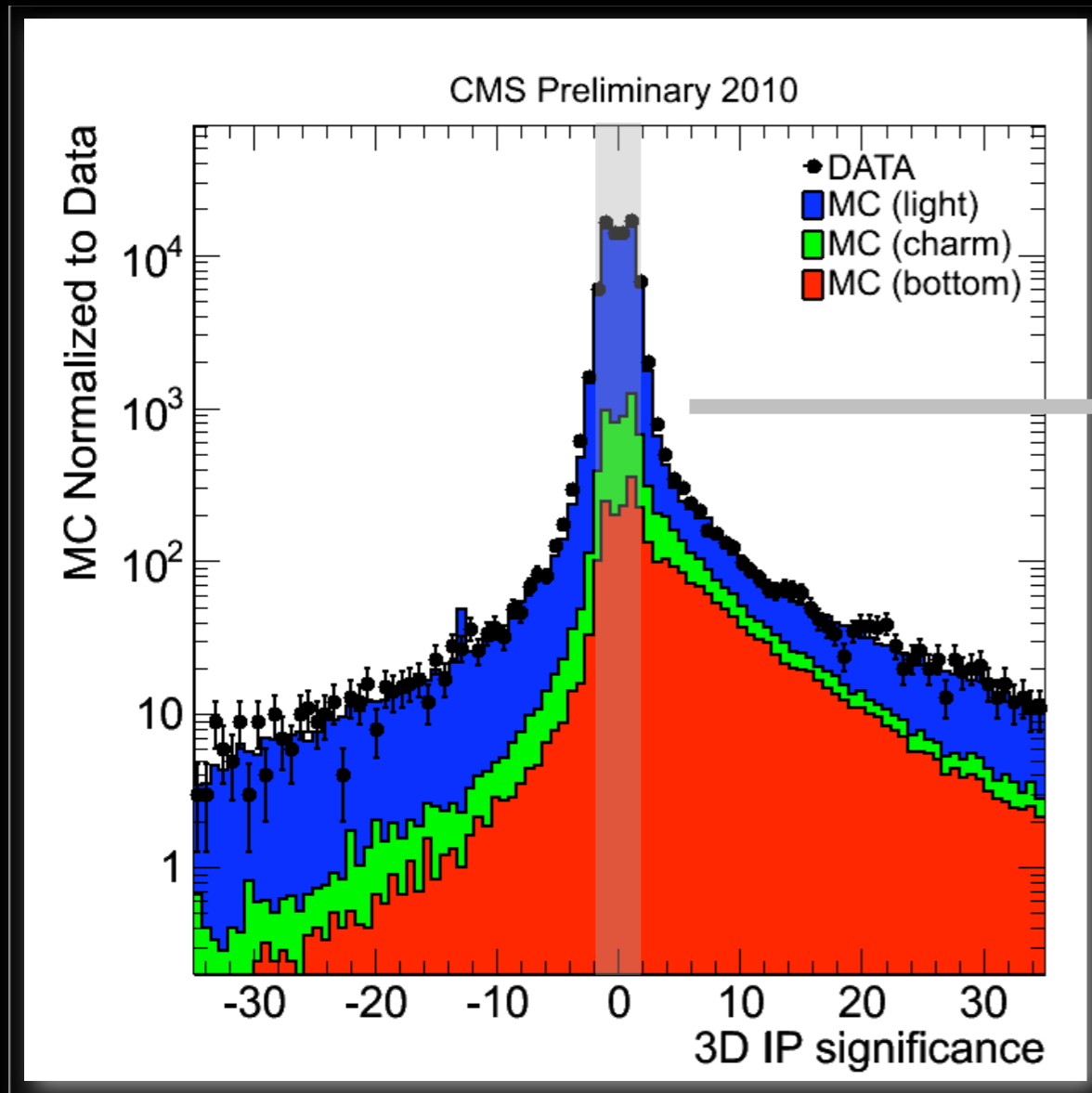
3D impact parameter significance
Comparison between data and simulation

Same, zoomed in central region
Symmetric for short lifetimes

**➠ Good prospects for searches with b-jets!**

**double b-jet candidate**
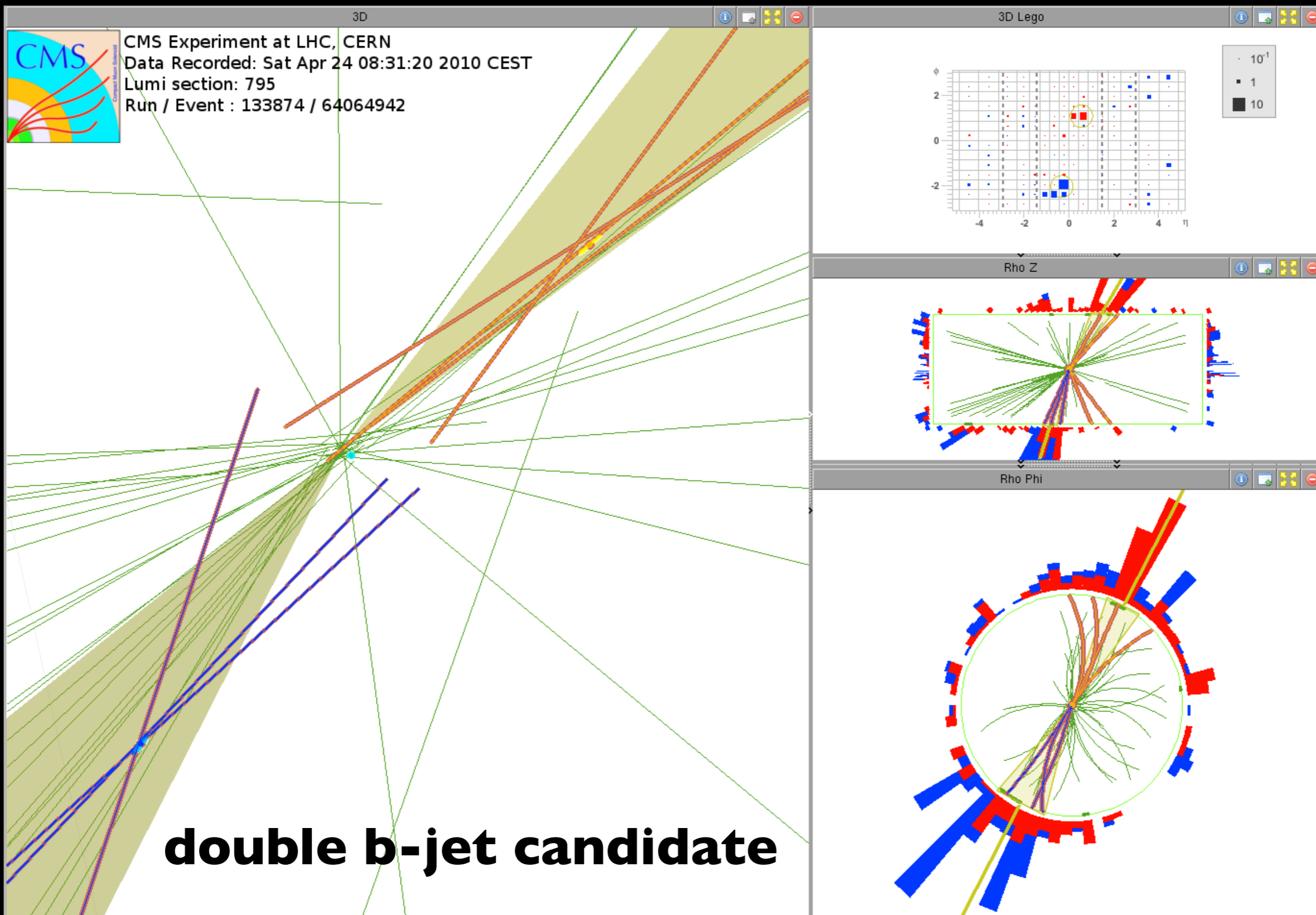
# Switching to searches...

- CMS is performing very well
  - ▸ **Now checked on 7 TeV data!**

- Now switching to expectations on searches
  - ▸ **this will be based on simulations...**
    - ■ recent estimates at 7 TeV (CMS NOTE-2010/008)
  - ▸ **... but simulations have shown *very good agreement* with reality!**

- Disclaimer
  - ▸ **these remain predictions**
  - ▸ **in particular: prediction of the systematic errors**

# Heavy Stable Charged Particles

- Exploit distinct signature

  ▸ **low velocity, high momentum**

  ▸ **use muon timing and tracker dE/dx to identify candidates**

  ▸ **10 TeV result scaled to 7 TeV**

  ▸ **Probing 0.5 TeV with 100 pb⁻¹**
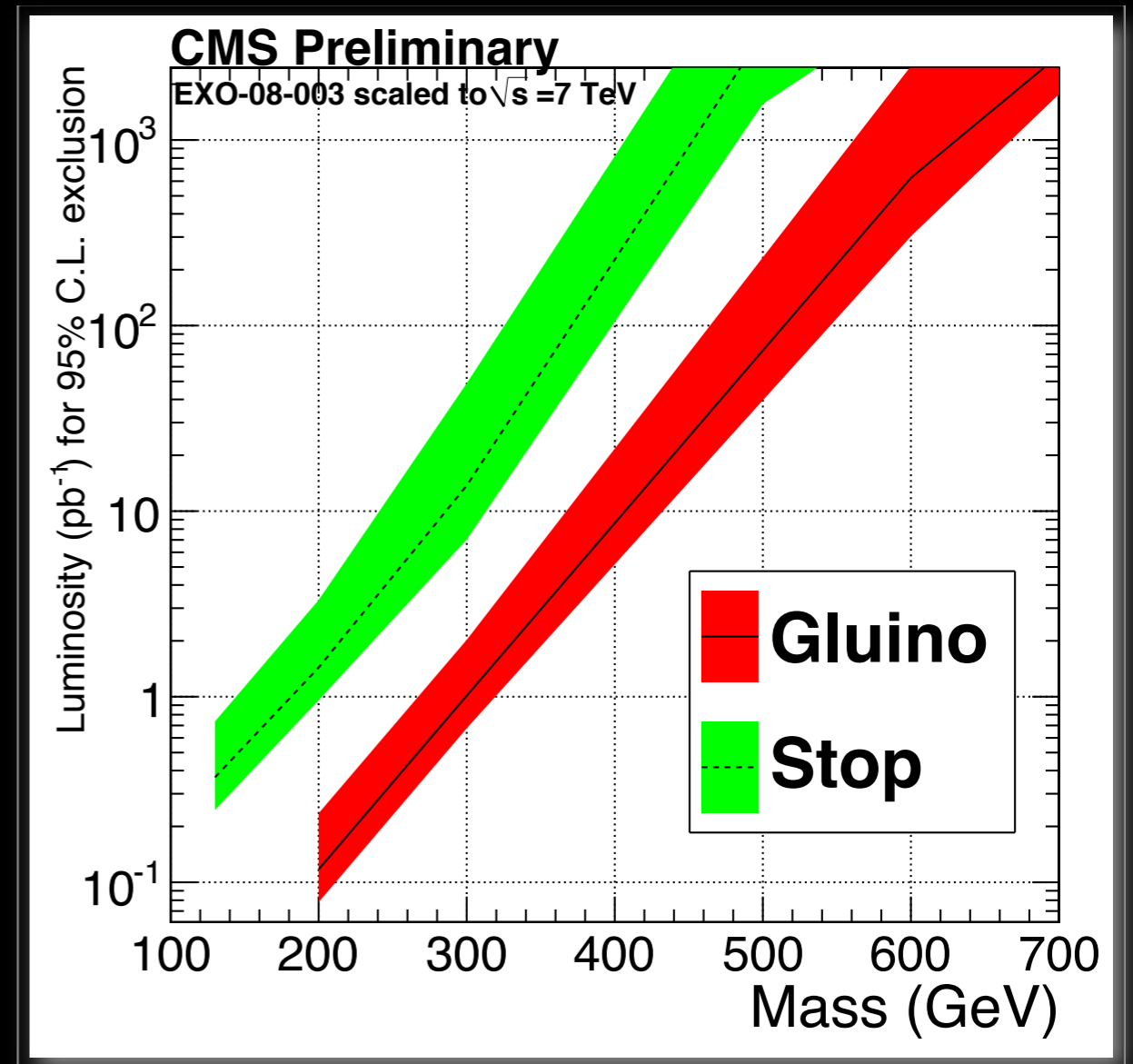


95% C.L. exclusion limit for HSCP searches at 7TeV

# Heavy Stable Charged Particles
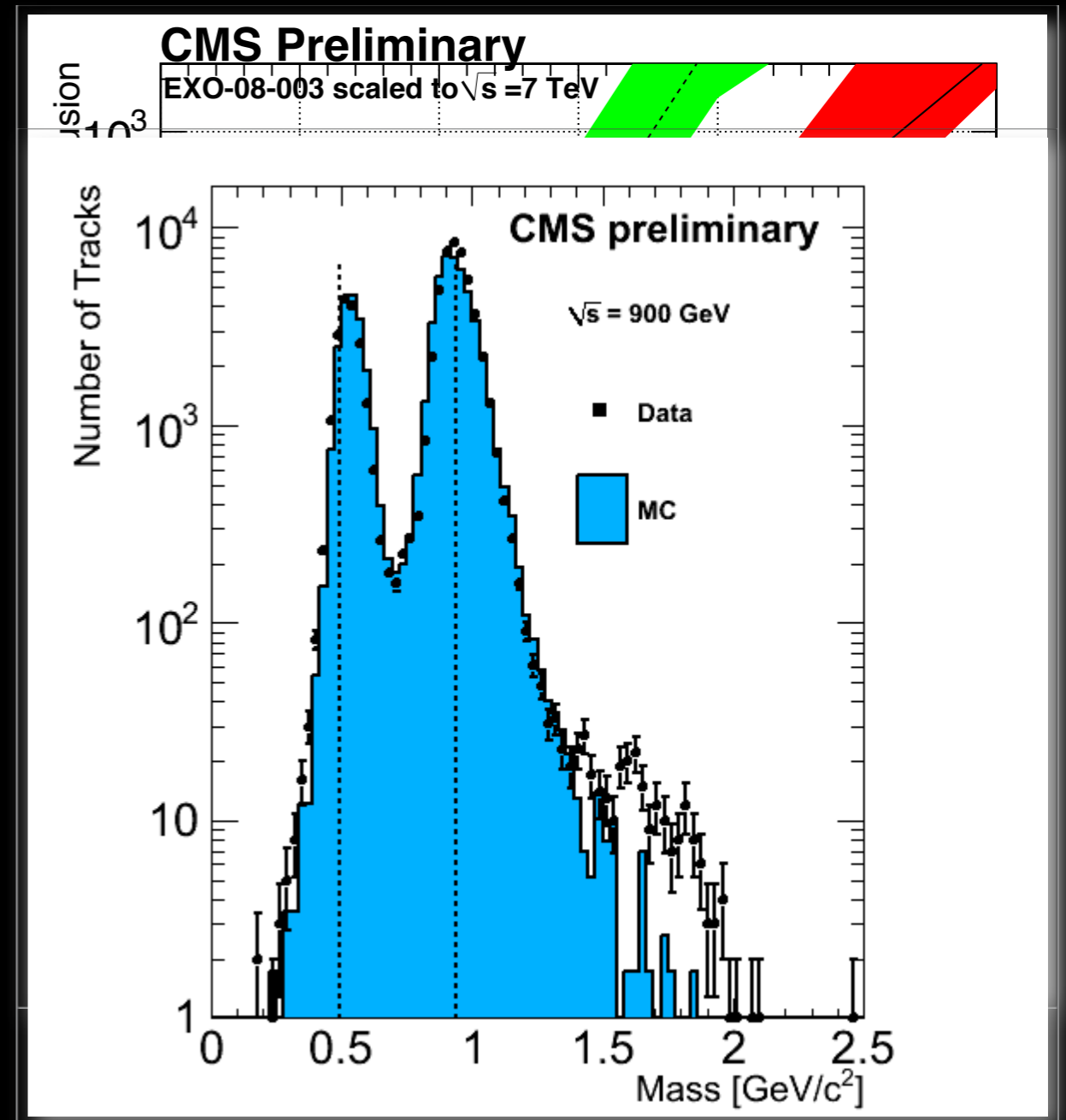
- Exploit distinct signature

  ▸ **low velocity, high momentum**

  ▸ **use muon timing and tracker dE/dx to identify candidates**

  ▸ **10 TeV result scaled to 7 TeV**

  ▸ **Probing 0.5 TeV with 100 pb⁻¹**

- Side-note

  ▸ **dE/dx commissioned!**

  - Kaons, protons and deuterons

    - the latter is not present in MC...



Mass reconstruction from tracker dE/dx

- Predicted in many extensions of the Standard Model

  ▸ **background is low and well understood (mainly Drell-Yan)**

  ▸ **10 TeV result scaled to 7 TeV**

- Already sensitivity at 1 TeV with 50–100 pb$^{-1}$
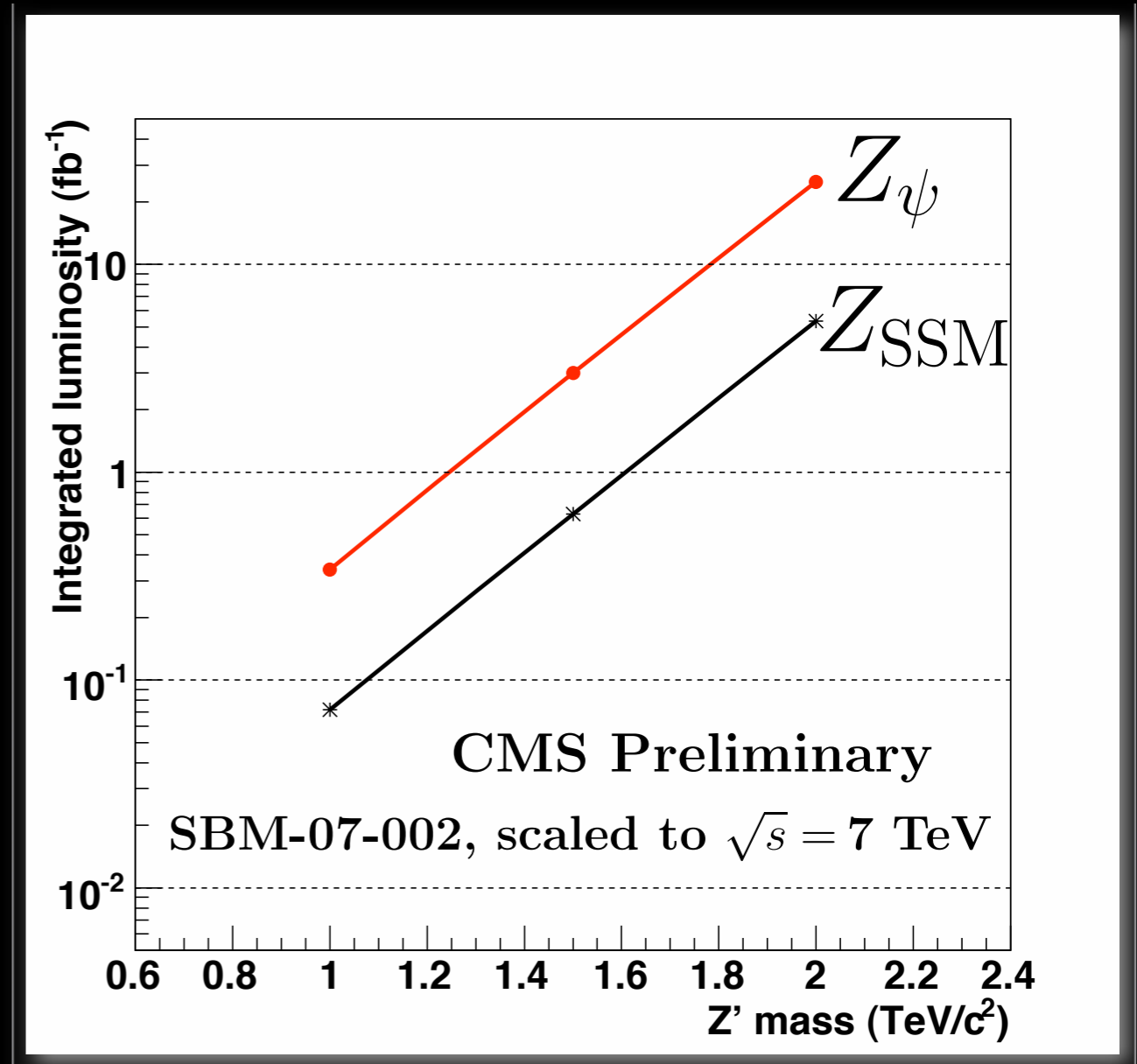


5σ discovery reach as a function of mass
μμ channel
(scaled from 10 TeV to 7 TeV)

# High mass dilepton resonances

- Predicted in many extensions of the Standard Model

  ▸ **background is low and well understood (mainly Drell-Yan)**

  ▸ **10 TeV result scaled to 7 TeV**

- Already sensitivity at 1 TeV with 50–100 pb$^{-1}$
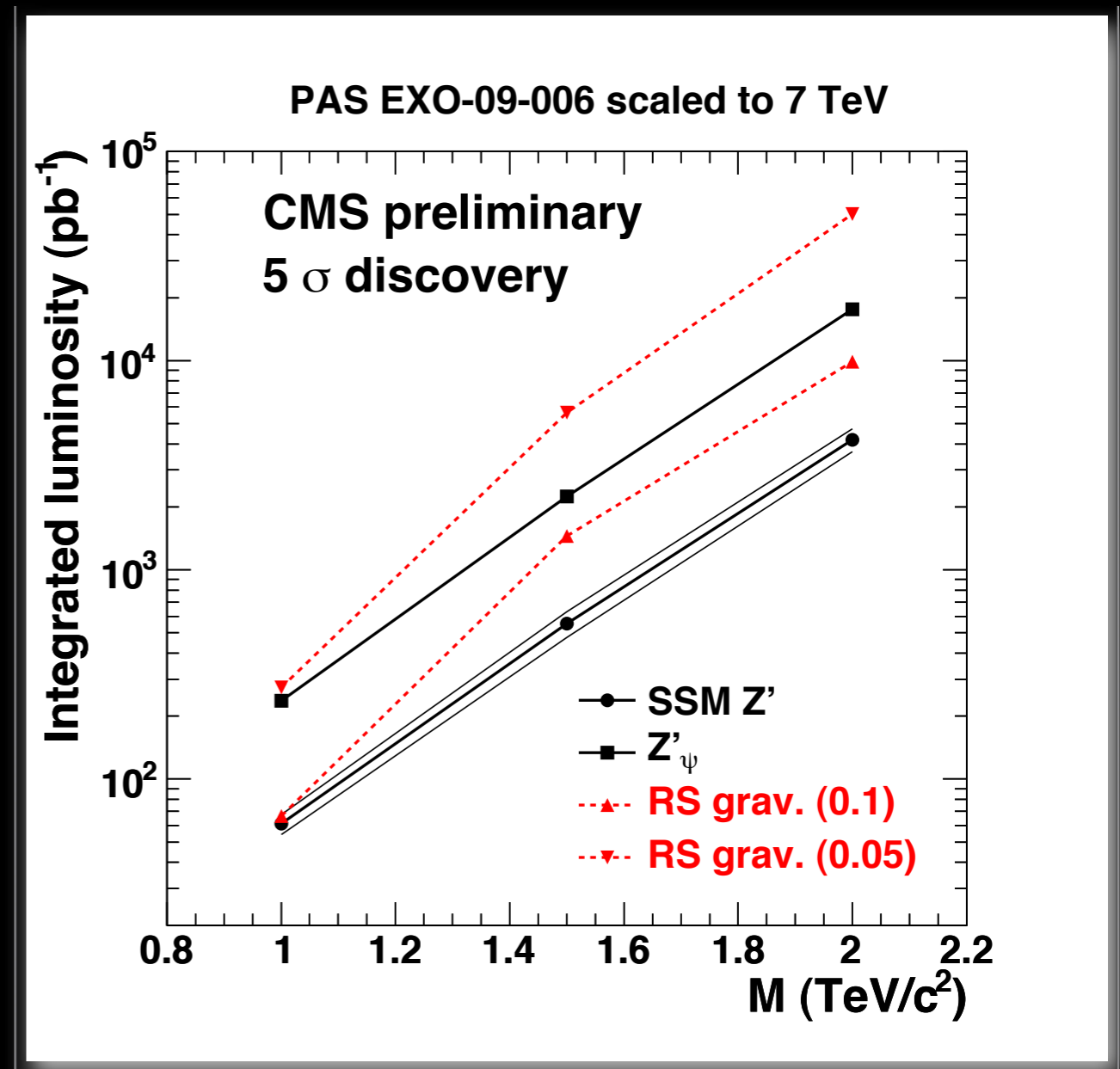


5σ discovery reach as a function of mass
ee channel
(scaled from 10 TeV to 7 TeV)

# Supersymmetry – SS dileptons

- Search with like-sign dileptons

  ▶ **combines µµ, µe and ee channels**

  ▶ **very low background, but very low number of events**

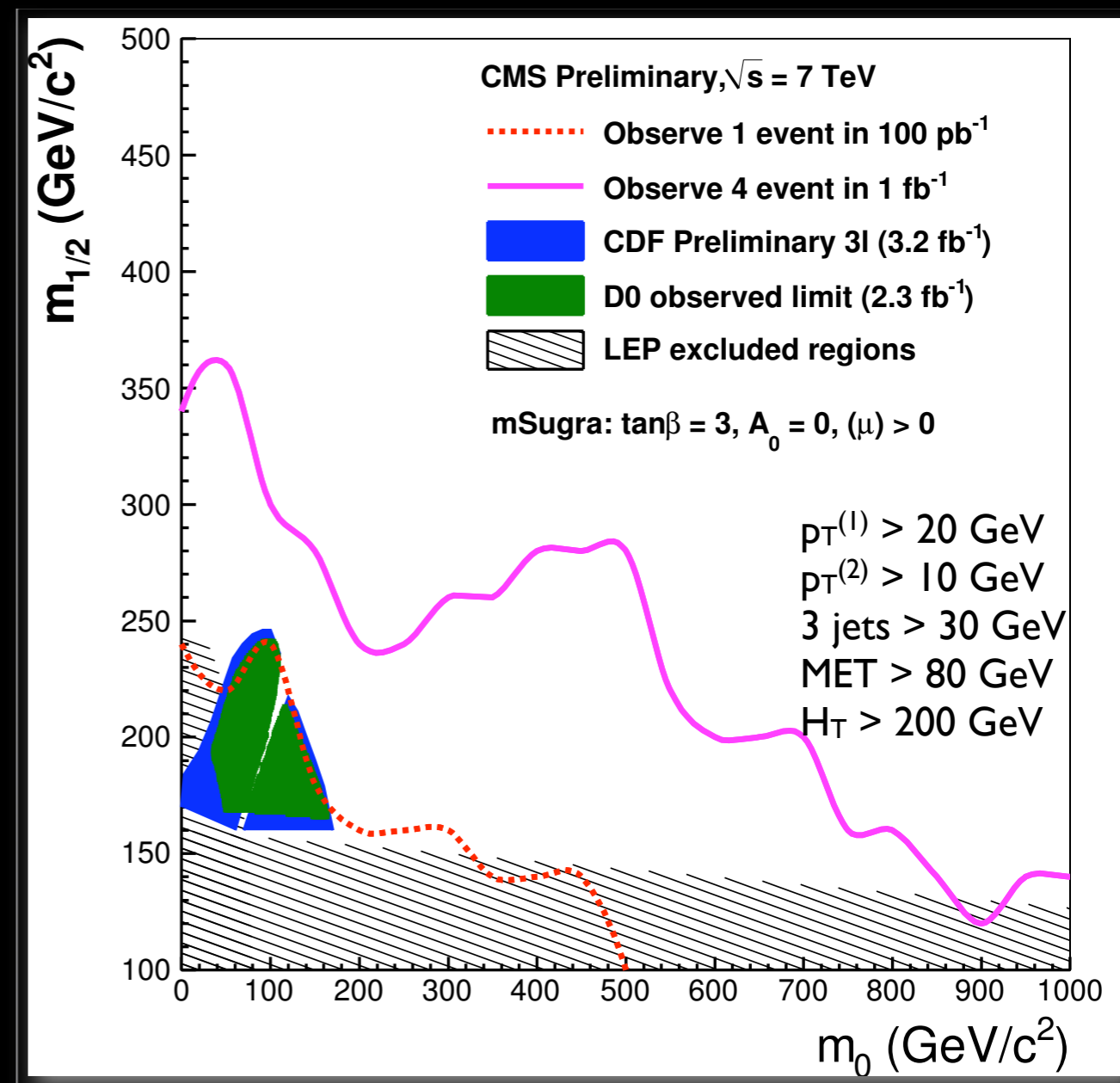  ▶ **main background is top-antitop**

    ■ estimated from fake rate and charge mis-identification

    ■ expect <1 (4) event in 100/pb (1/fb)

  ▶ **done with 7 TeV simulation**

    ■ in a grid in the mSugra parameter space

- Will enter (exclude) new territory this year!



**CMS Preliminary,$\sqrt{s}$ = 7 TeV**

- - - - Observe 1 event in 100 pb$^{-1}$

——— Observe 4 event in 1 fb$^{-1}$

■ CDF Preliminary 3l (3.2 fb$^{-1}$)

■ D0 observed limit (2.3 fb$^{-1}$)

▨ LEP excluded regions

mSugra: $\tan\beta = 3$, $A_0 = 0$, $(\mu) > 0$

$p_T^{(1)} > 20$ GeV
$p_T^{(2)} > 10$ GeV
3 jets > 30 GeV
MET > 80 GeV
$H_T > 200$ GeV

95% exclusion limits for like-sign dilepton search expressed in the mSugra parameter space
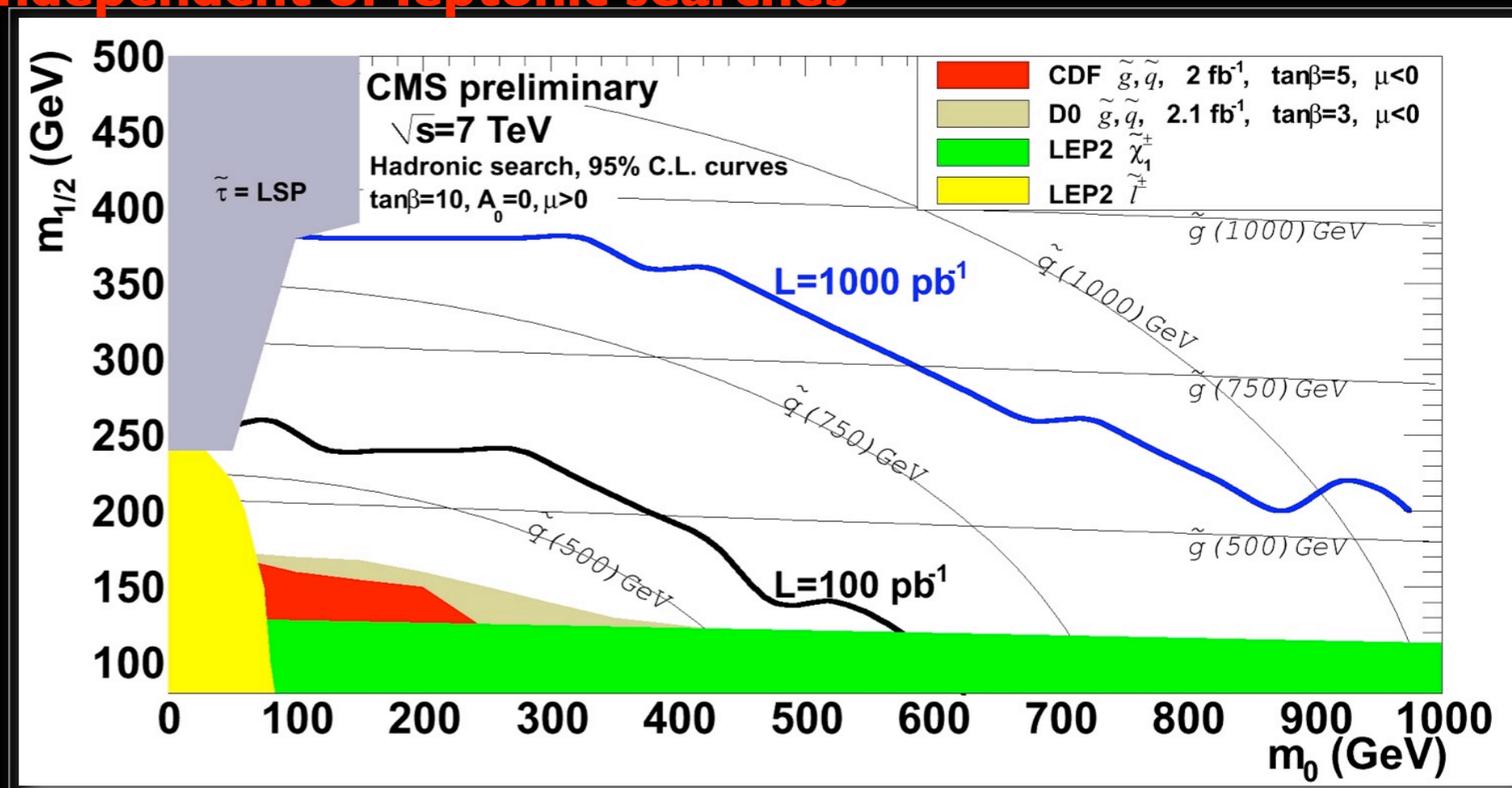
- Inclusive search with jets and missing energy

  ▸ **higher efficiency on SUSY, more backgrounds**

    ◾ sensitive to systematic uncertainties estimate (here: estimate 50% on backgrounds)

  ▸ **veto on leptons: independent of leptonic searches**

  ▸ **done with 7 TeV simulation**

- New territory with less than 100/pb already!



95% exclusion limits for searches with jets and missing energy
expressed in the mSugra parameter space
assumes 50% syst. uncertainty on backgrounds

# Supersymmetry – perspective

- Prediction of the preferred CMSSM parameter space

  ▸ **from global fit to more than 30 collider and non-collider observables**

# Supersymmetry – perspective
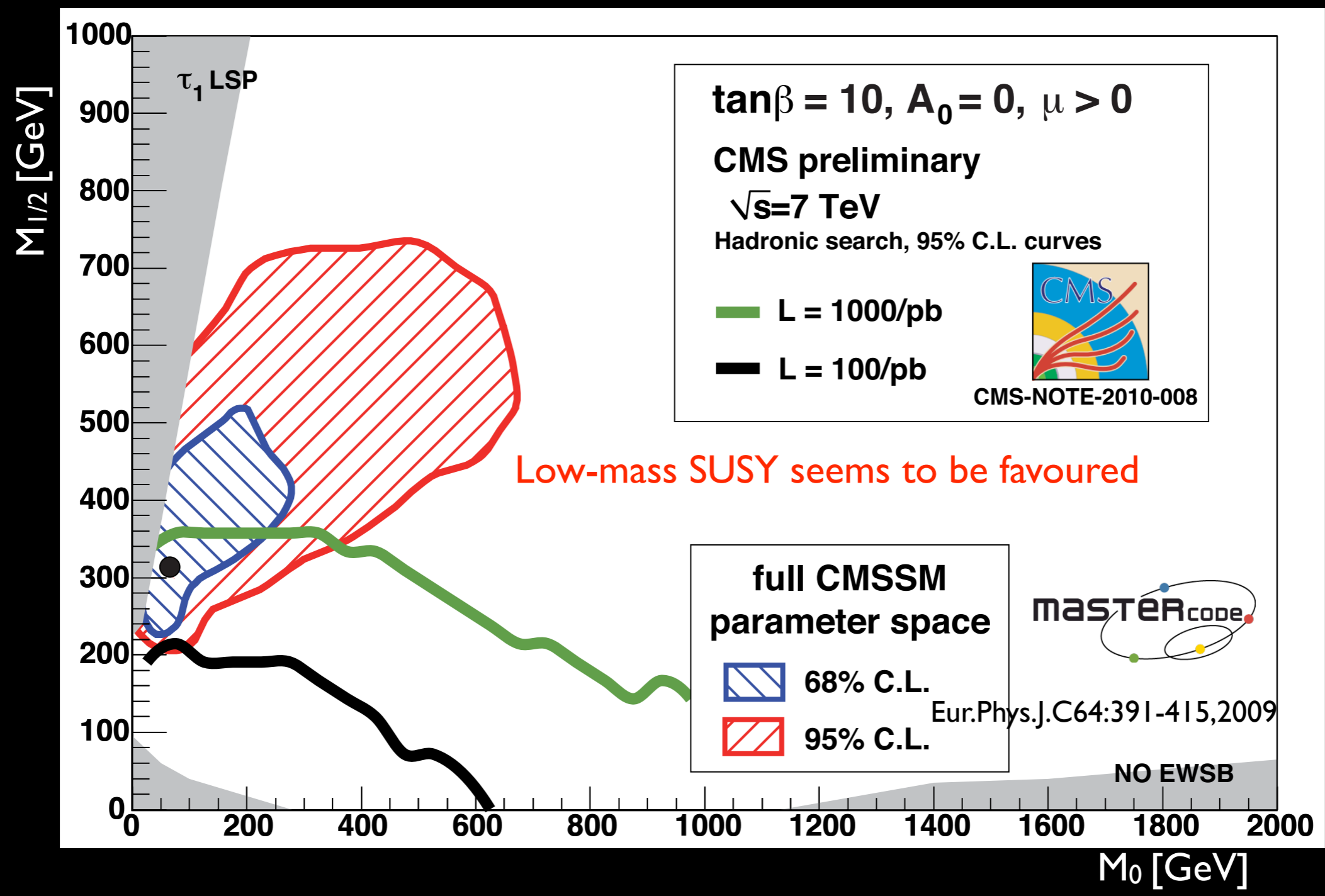
- Prediction of the preferred CMSSM parameter space

▸ **from global fit to more than 30 collider and non-collider observables**
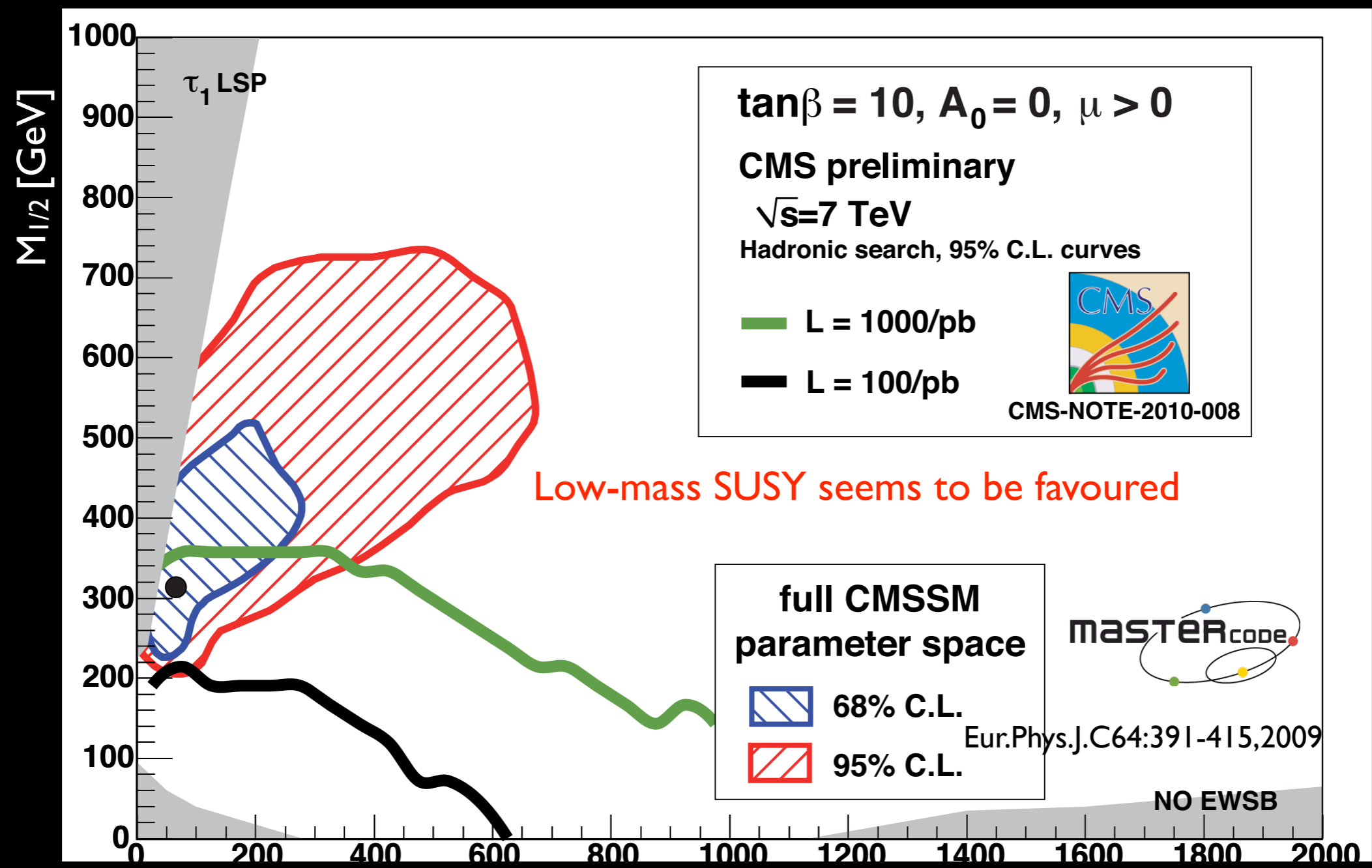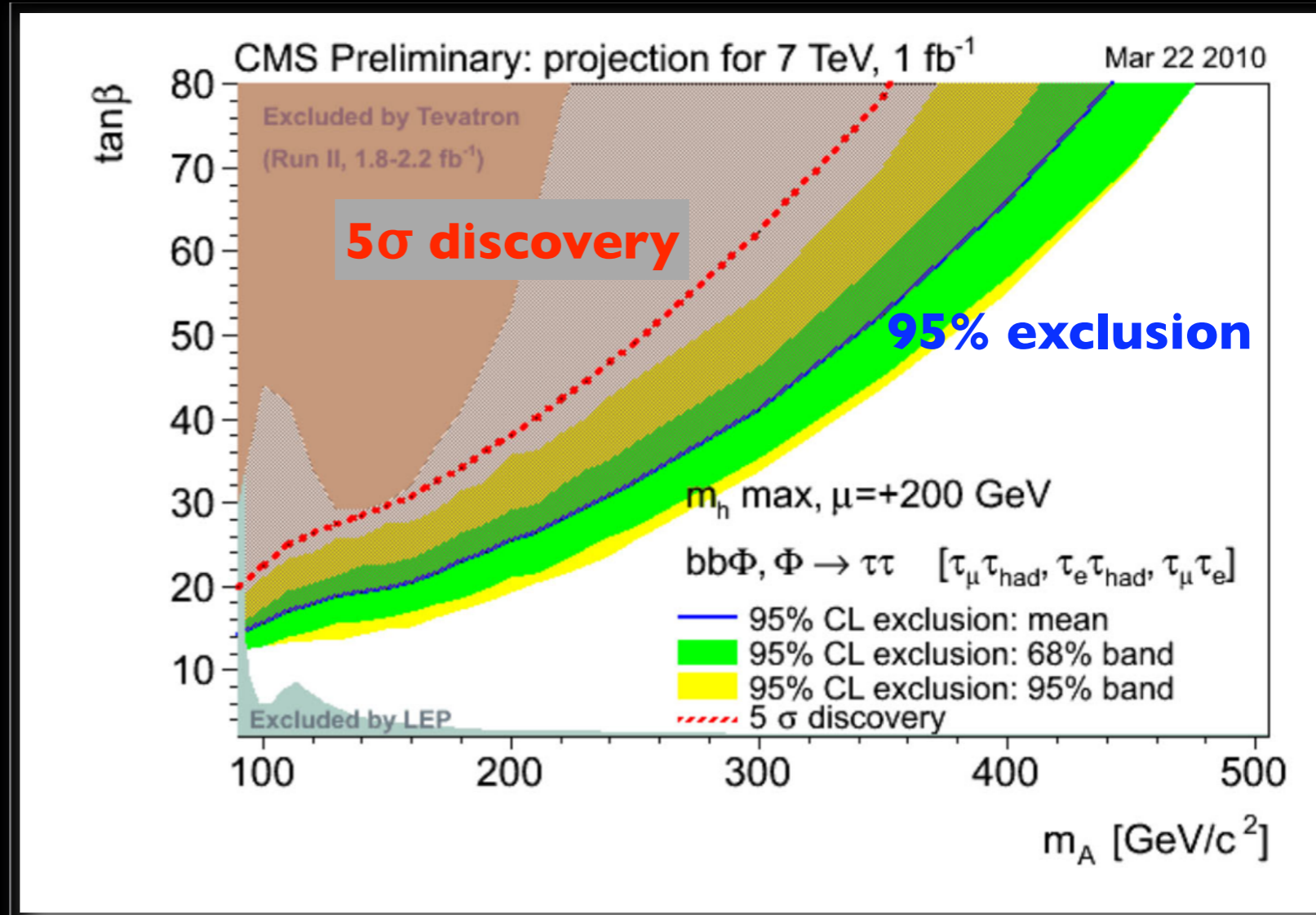


➡ **Good prospects for SUSY searches!**

▸ **Associated production with b-jets**

▸ **combining three ττ channels**

   ■ with at least one leptonic decay: $\tau_{had}\tau_\mu$, $\tau_{had}\tau_e$, $\tau_e\tau_\mu$

▸ **cross-sections scaled from 14 TeV to 7 TeV**

● Large range covered, down to tanβ ~ 15 at low $m_A$



Expected sensitivity to the MSSM Higgs boson
in the ττ channel

# Conclusions

**Φ**

- CMS has entered data analysis in full swing!

  ▸ **detector performance is very good...**

  ▸ **... and as expected from simulations**

  ▸ **... in all aspects crucial to searches beyond the Standard Model**

- Prospects for searches:

  ▸ **significant portion of new territory will be *probed* with 1/fb**

    ■ and only small fraction of searches shown here!

  ▸ **will already *enter* new territory very soon**

  ▸ **good prospects for "LHC Run 1"**

- This is only the beginning

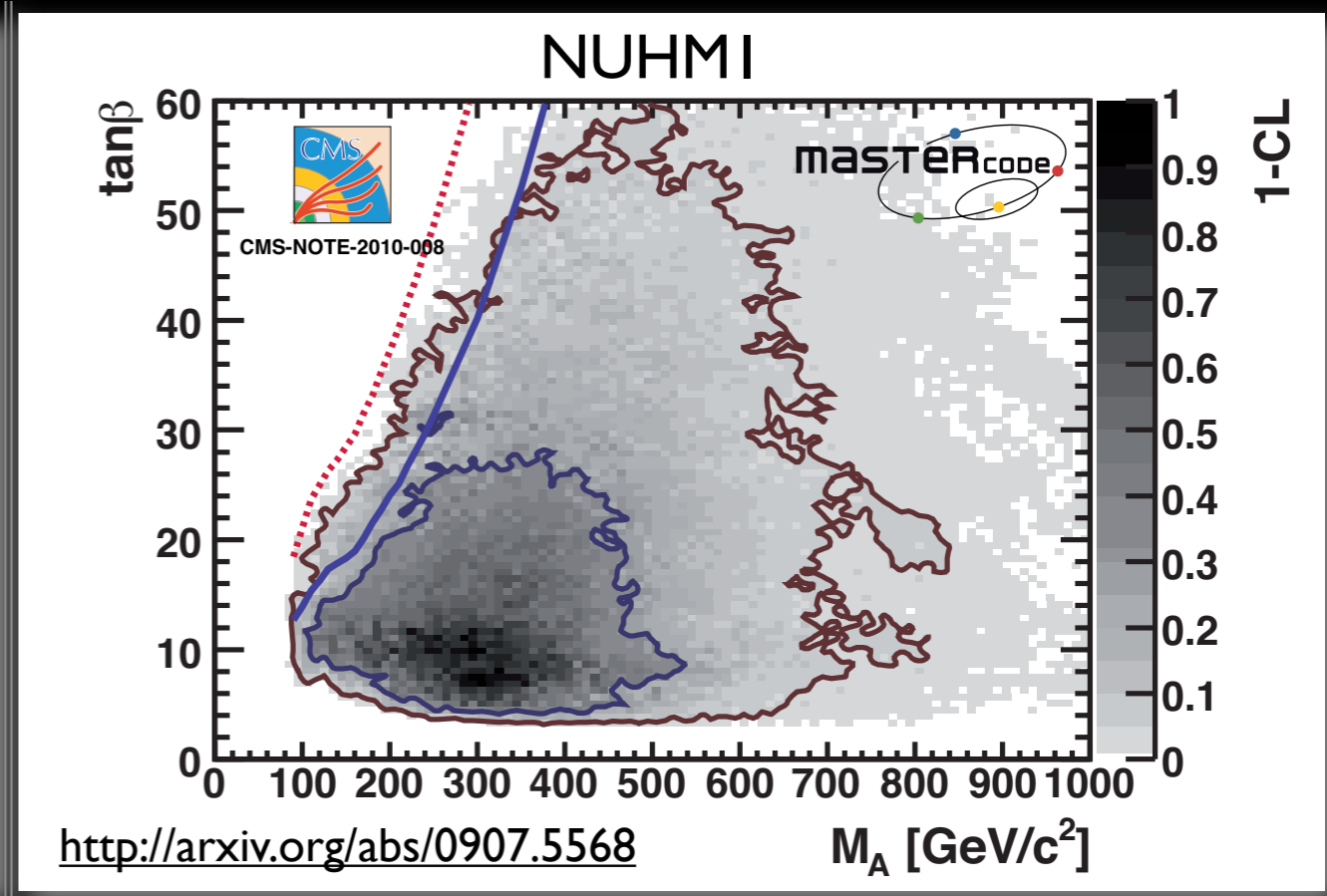  ▸ **stay tuned for new results on data very soon**

# Backup

# Dijet ratio
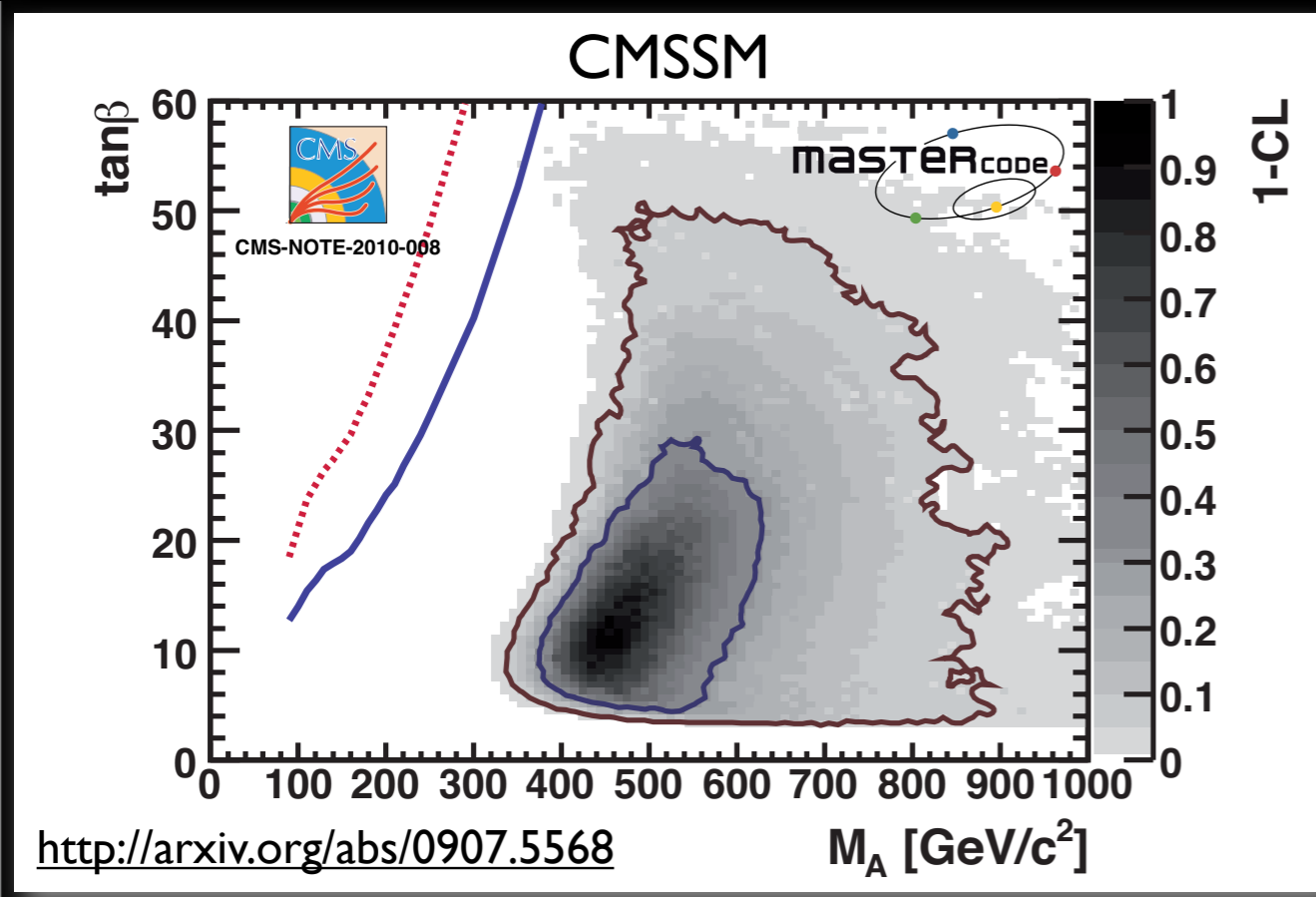
Φ
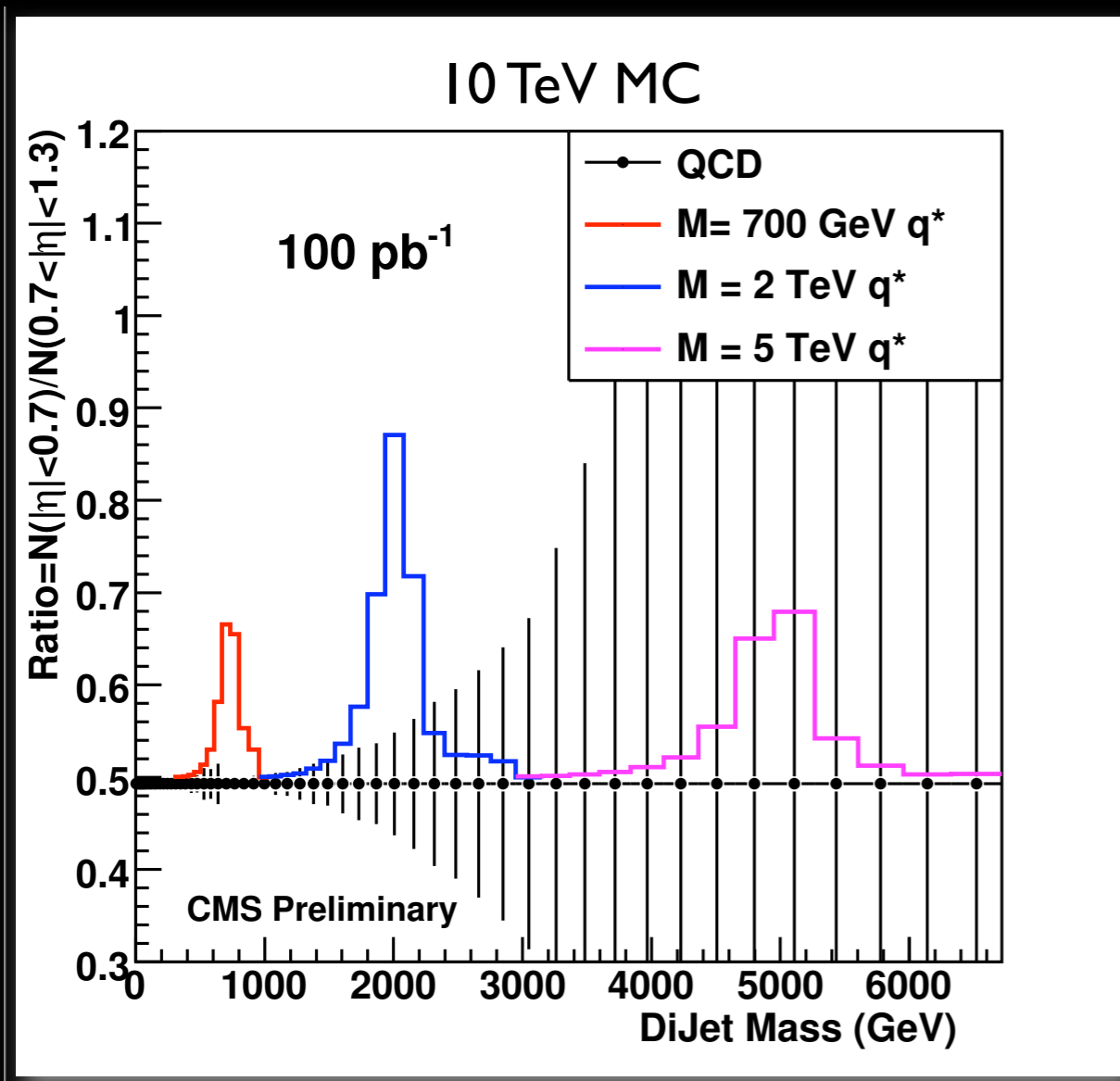
Dijet ratio for excited quarks
compared to QCD.
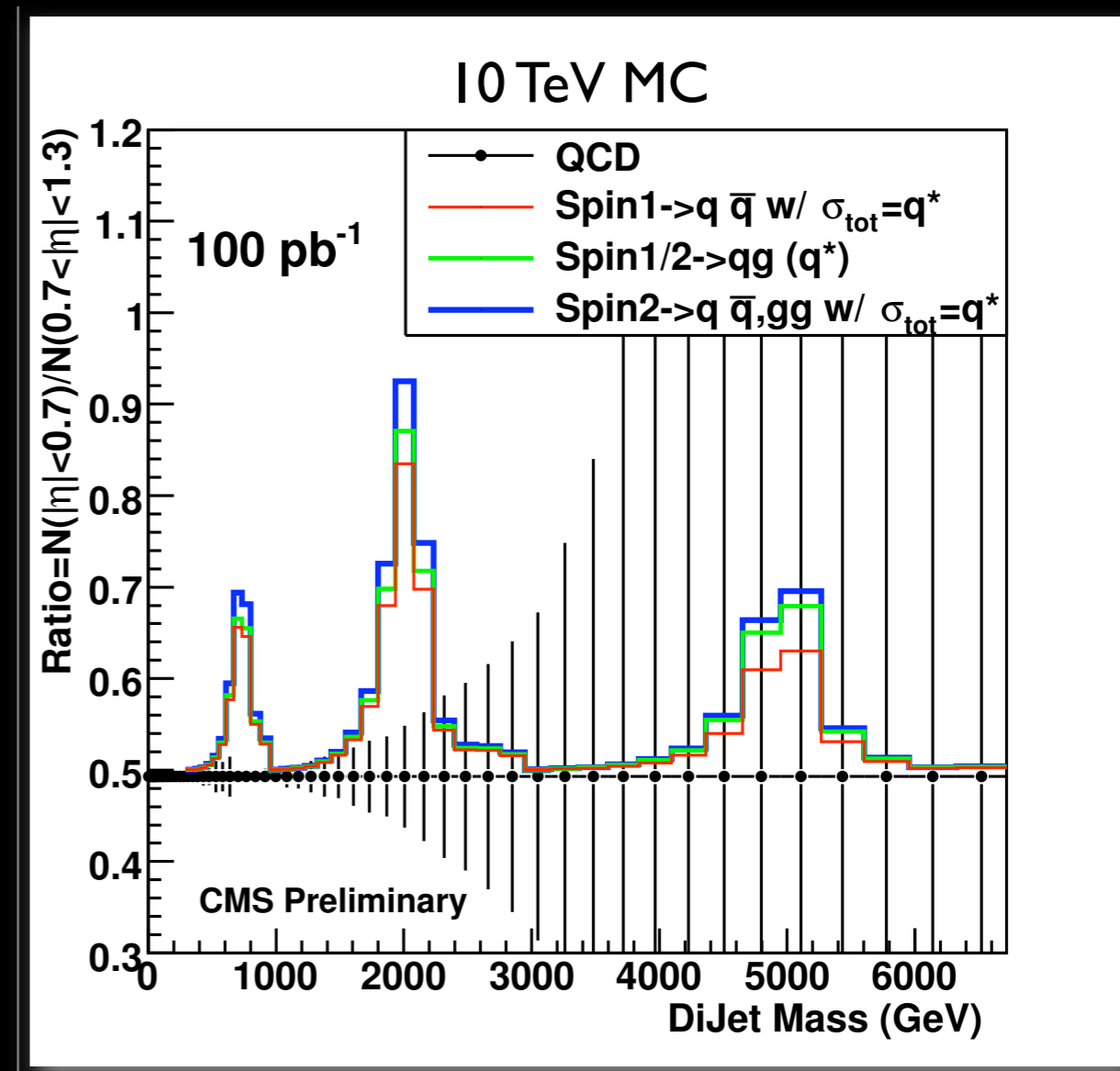
Spin dependence at
fixed signal rate of dijet ratio from resonances

Global fit prediction (red: 95% CL, blue: 68% CL)   Global fit prediction (red: 95% CL, blue: 68% CL)

CMSSM parameter space                                NUHM1 parameter space

CMS reach (red: 5σ – blue: 95% exclusion)            CMS reach (red: 5σ – blue: 95% exclusion)

- Gain in luminosity with energy

  - **pp→H(→WW/ZZ): mainly gg**

    - factor 15–20

  - **Z' at 1 TeV (qq)**

    - factor 50–100 (!)