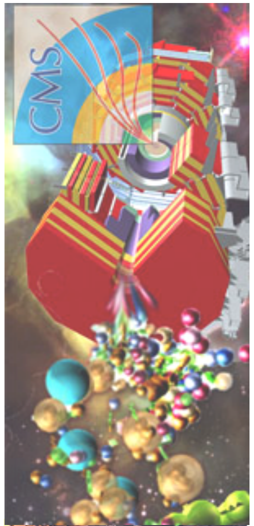
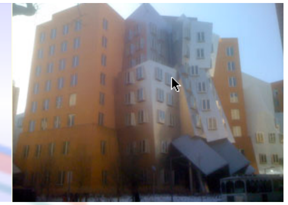




Analysis summary and outlook for 1 fb^{-1} at CMS

Nicola De Filippis

Politecnico and INFN Bari

Open questions in particle physics

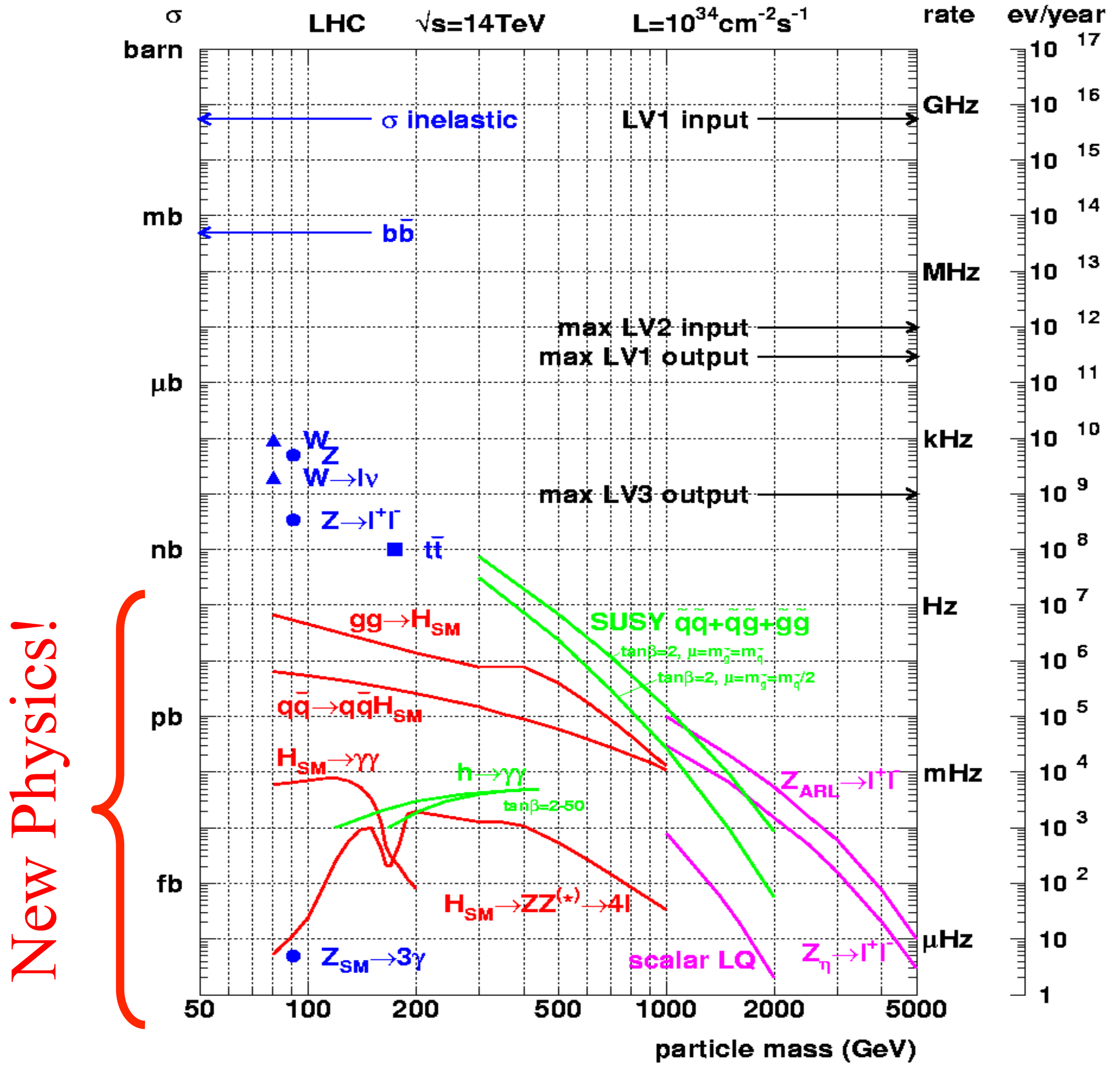
- Is the Higgs mechanism to generate weak boson and fermions masses real ?

- How to solve the problem of the hierarchy between the EWK scale and the GUT or Planck scale ?

- Are the electroweak and strong forces unified at some GUT scale ?

- Is the supersymmetry realized in nature ? Do the SUSY particles exist ? Can they explain the dark matter ?

- Do extra dimensions exist?



LHC can provide some answers and hints for new physics

Roadmap to new physics

- Detector and physics object commissioning:
  - muons, electrons, b-jet, jet, photons, MET

(Tiziano Camporesi)

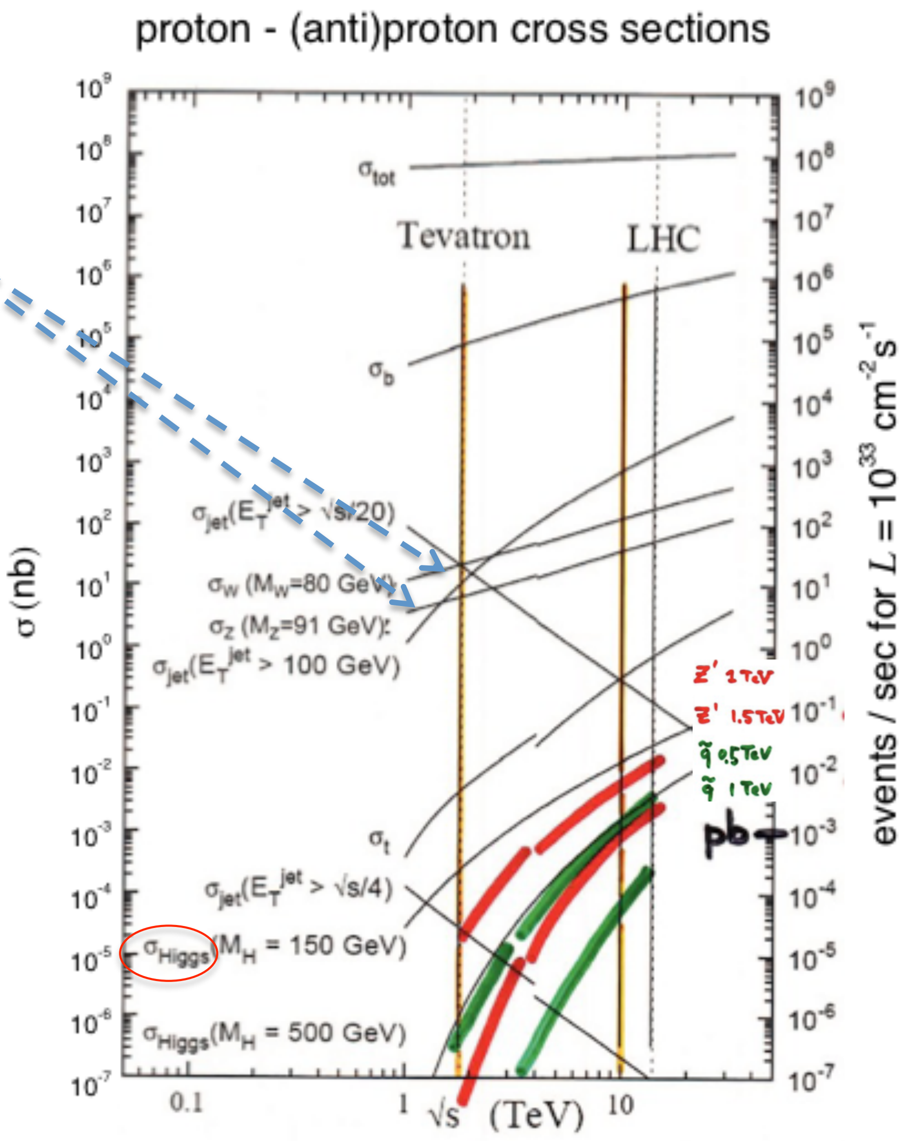
- Standard "candles" from **data**: **W/Z**
  - W→lν and Z→ll are standard candles to assess performances of detectors and of the reconstruction/identification algorithms.

- W/Z+jets and ttbar, then di-bosons (WW, ZZ WZ) as backgrounds for searches

Prospective studies for 1 fb^{-1}

New Physics!

- Standard Model **Higgs** searches:
  - H→WW, H→ZZ, H→γγ
- Supersymmetry hints:
  - Multiple jets + leptons, di-jets
- Beyond the Standard model:
  - Z′, G, 4th generation, etc.



LHC vs Tevatron

For M_X > 140 GeV/c^2:

-- gg at 7 TeV > 20x than at Tevatron → higher rate for Higgs production

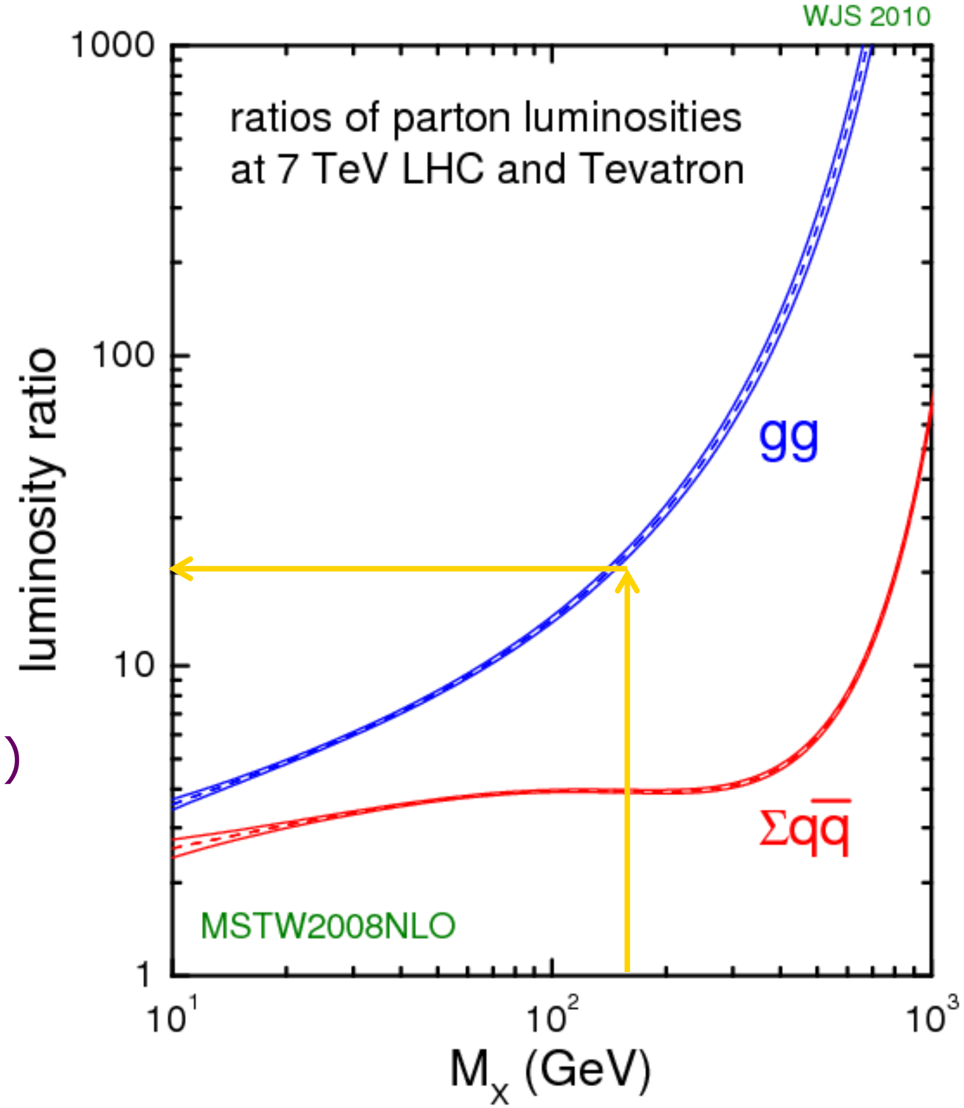
-- qqbar rises relatively slowly → irreducible backgrounds (WW, ZZ) increases slowly → S/N rises → LHC competitive with Tevatron at 1fb^{-1}

For M_X < 140 GeV/c^2:

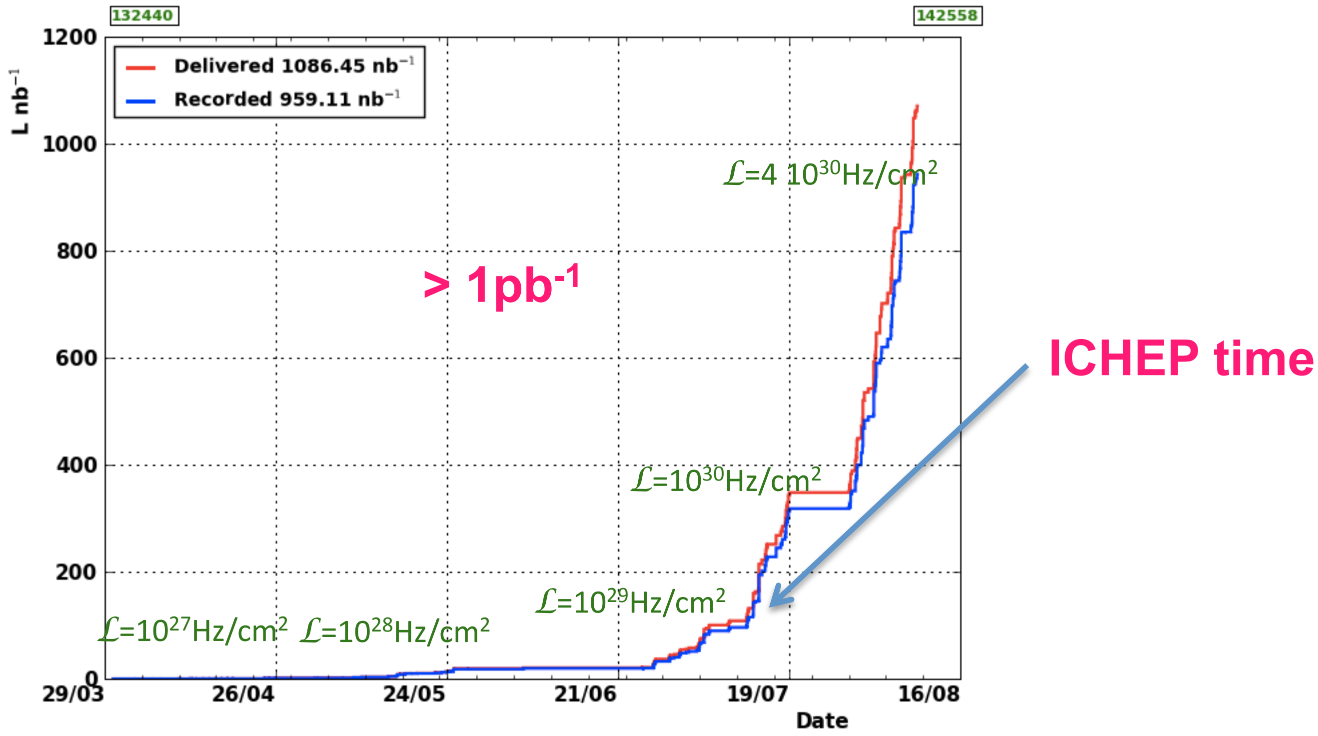
-- slow rise in qqbar lumi → compared to at Tevatron, Higgs-strahlung (pp → VH) rate @ 7 TeV not much larger

-- major backgrounds are W/Z+bb & tt which rise sharply due to rapid rise in gg ⇒ small signal rate & poor S/N

James Stirling

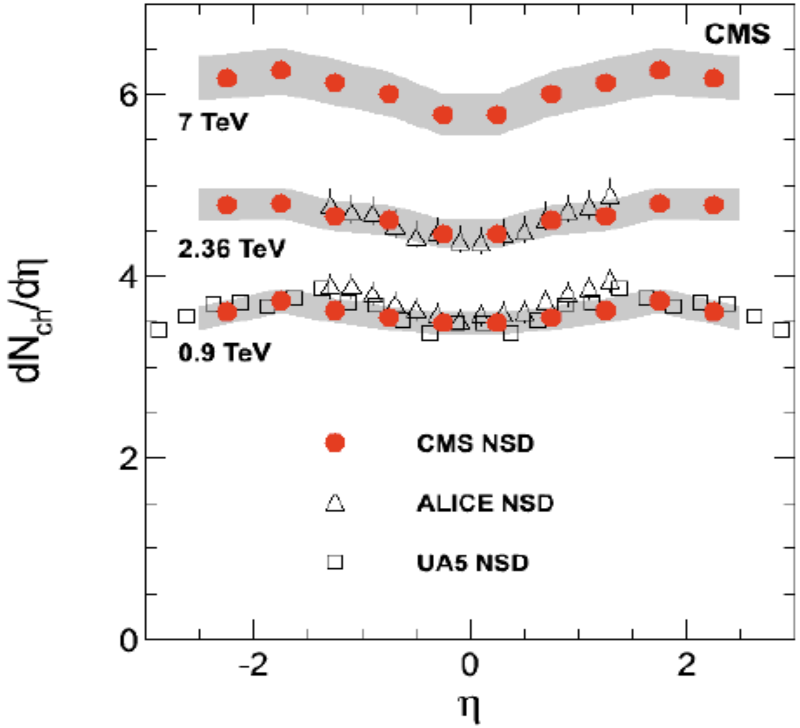


Early Physics results



Charged hadrons and underlying event

Wei Li



N_{ch} at $|\eta|<0.5$

0.9 TeV: $3.48 \pm 0.02\ (\text{stat.}) \pm 0.13\ (\text{syst.})$

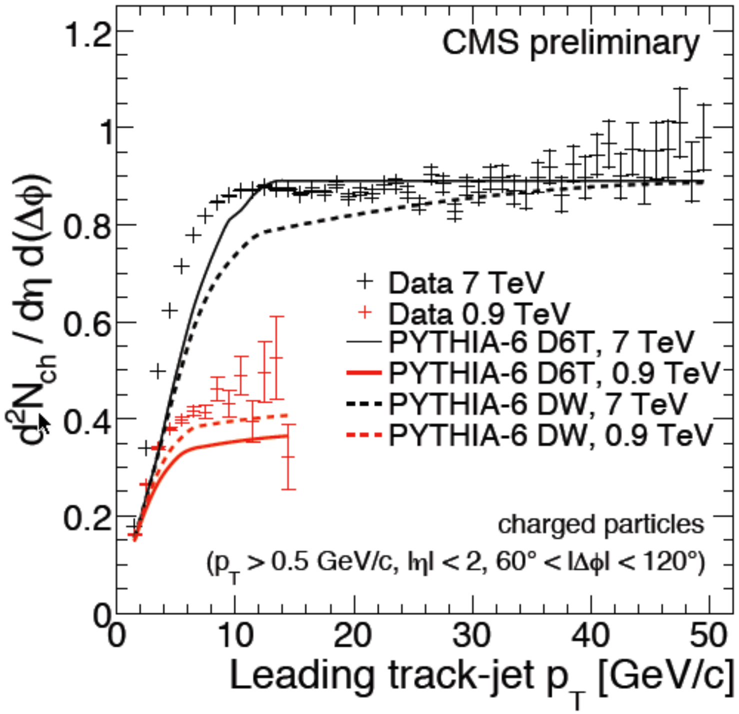
2.36 TeV: $4.47 \pm 0.04\ (\text{stat.}) \pm 0.16\ (\text{syst.})$

7 TeV: $5.78 \pm 0.01(\text{stat}) \pm 0.23(\text{syst})$

➤ 3 methods (pixel clusters, pixel tracklets, tracks)

➤ rate increase with √s underestimated by MC tunes

Mohammed Zakaria



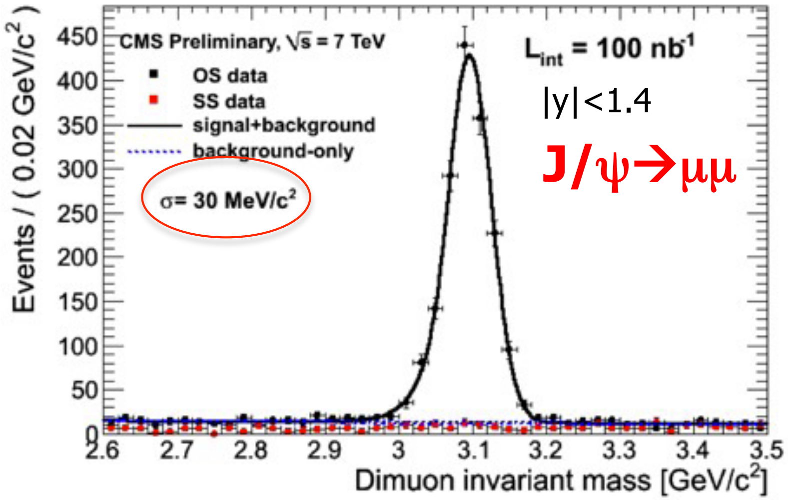
Underlying event in transverse region w.r.t. to leading track/jet:

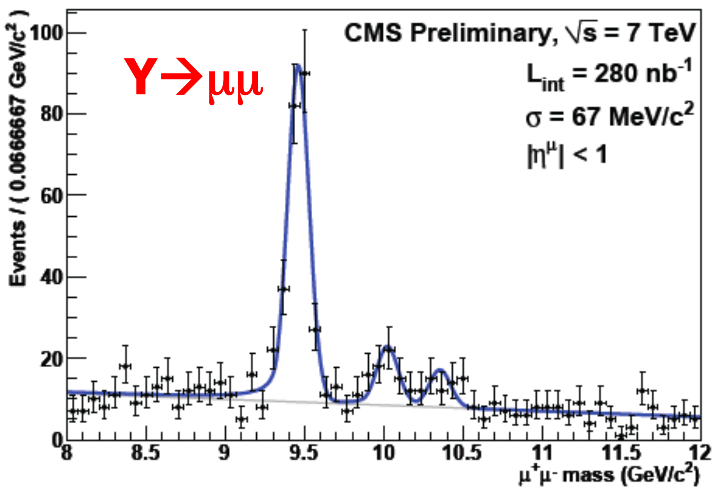
➤ underestimation of track multiplicity at low p_T^{lead}

➤ rise 0.9→7 TeV described only qualitatively by MC tunes

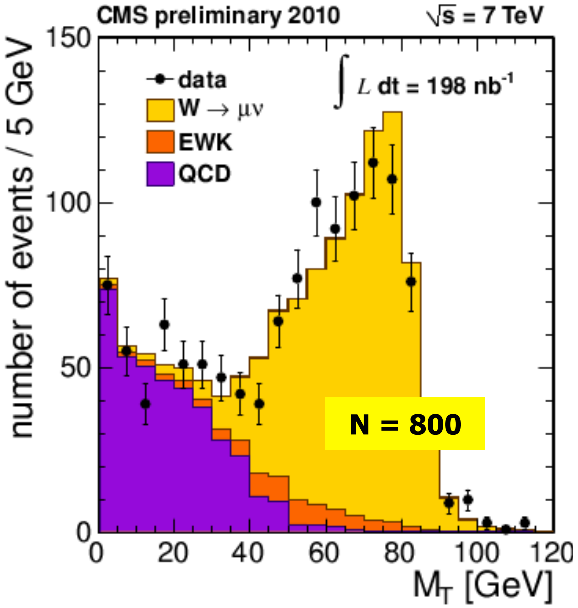
J/ψ, Υ, W and Z

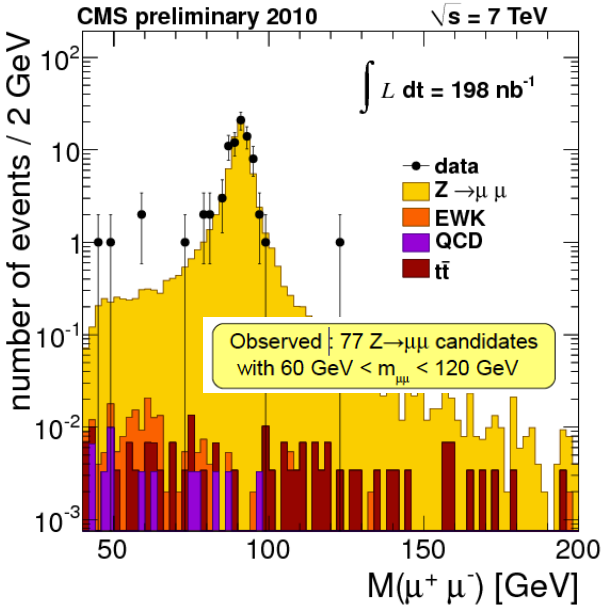
Matthew Scott Rudolph

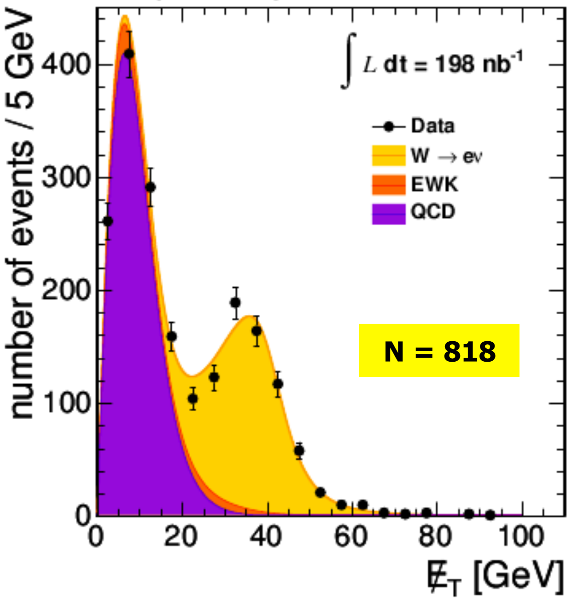


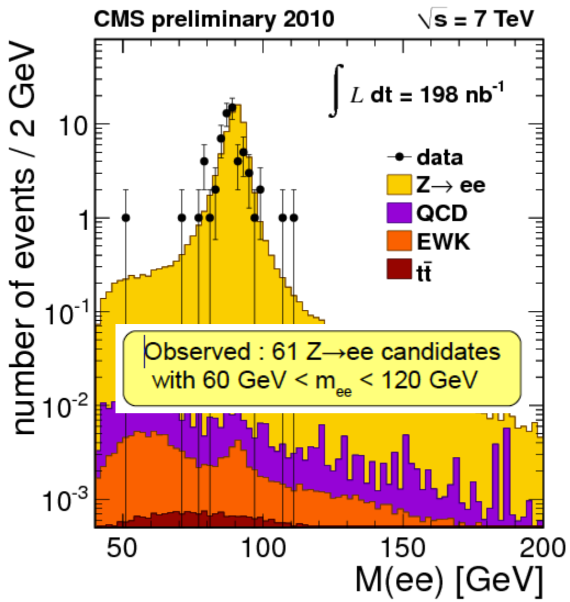


Jeremy Werner

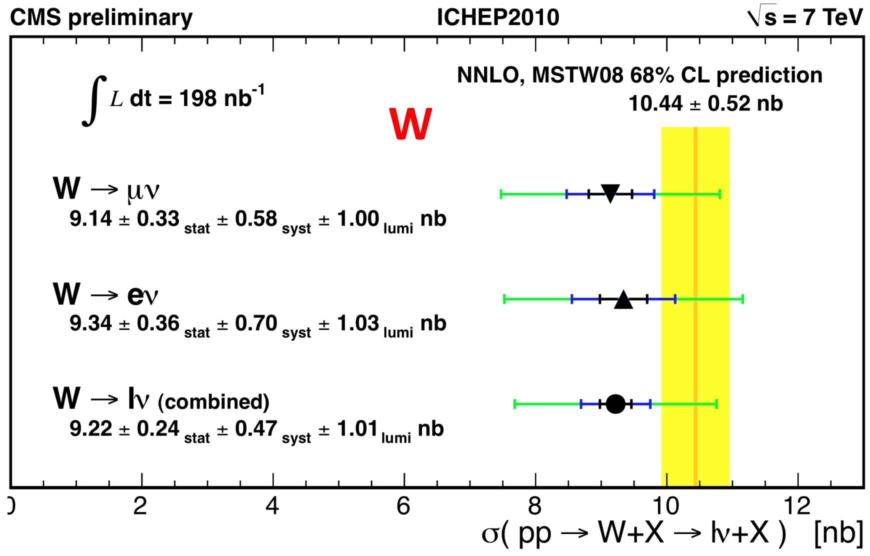


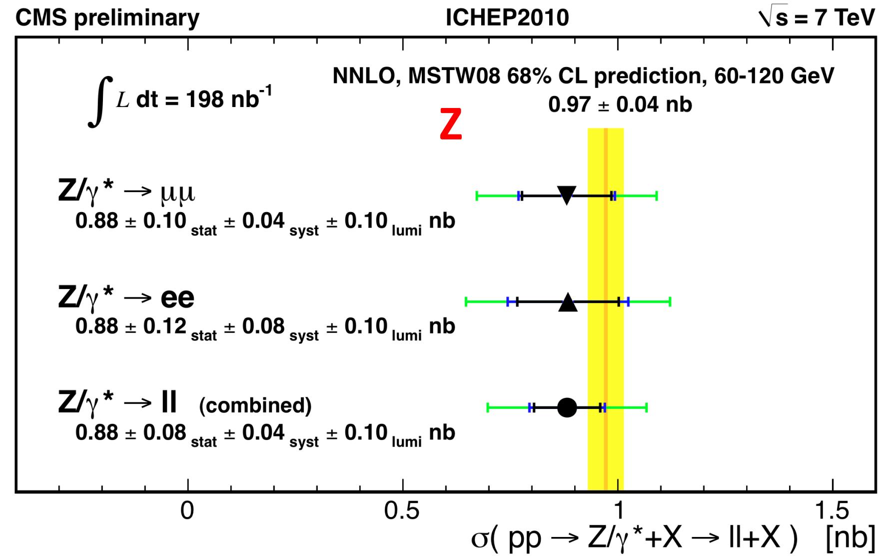


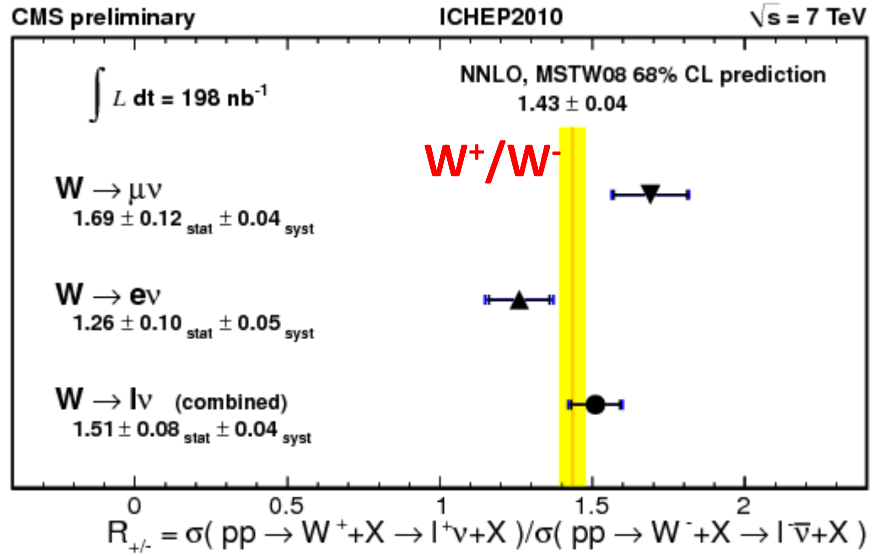


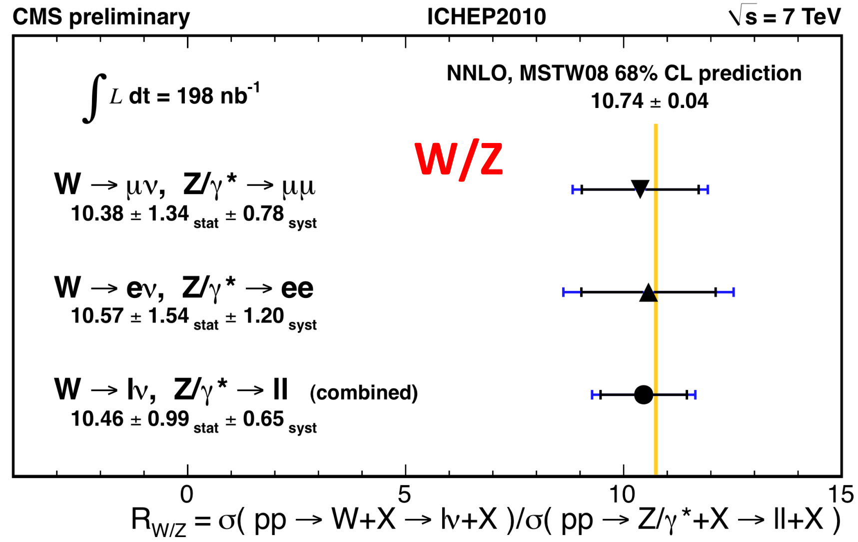


W/Z cross section and W^+/W^- ratio



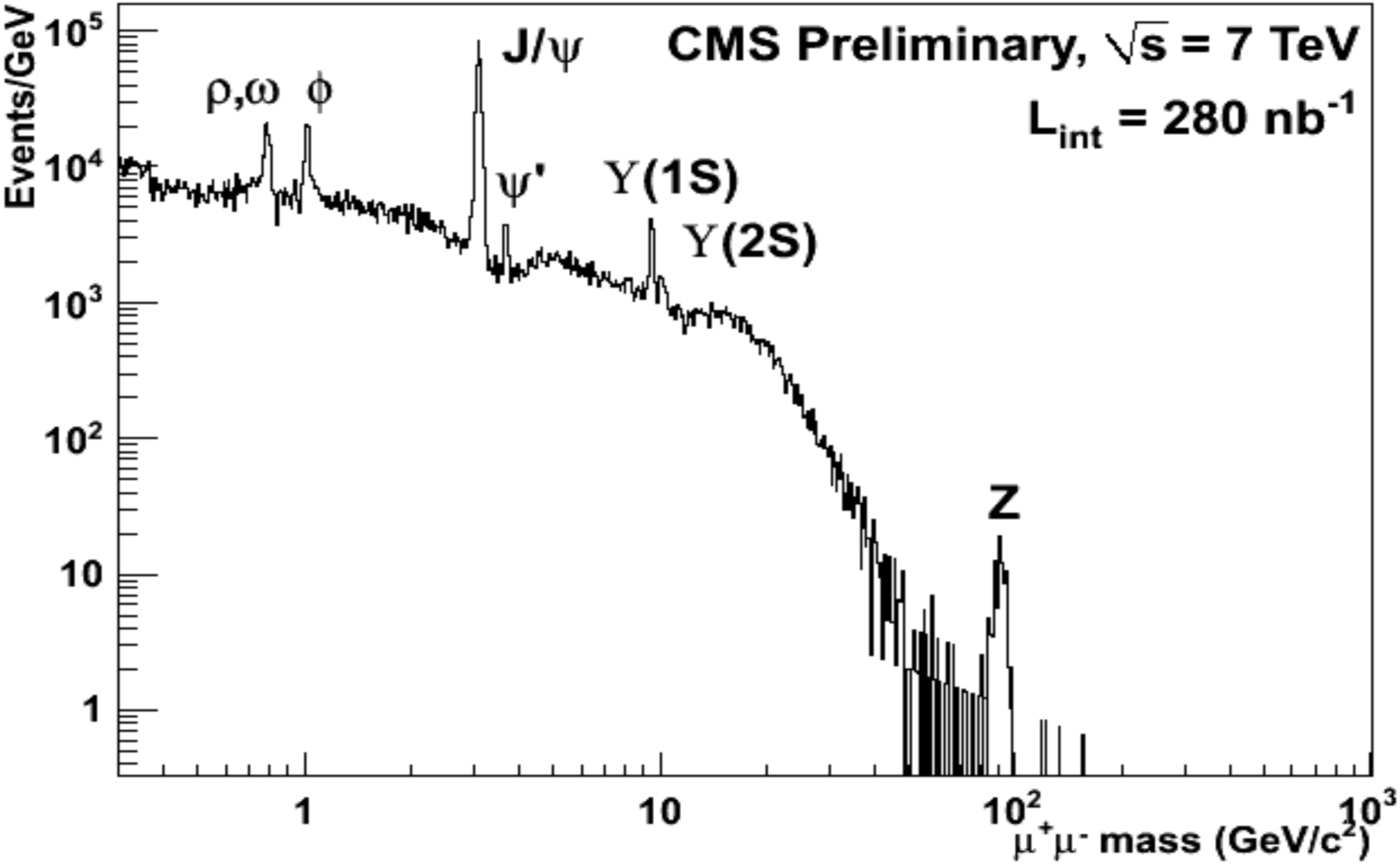






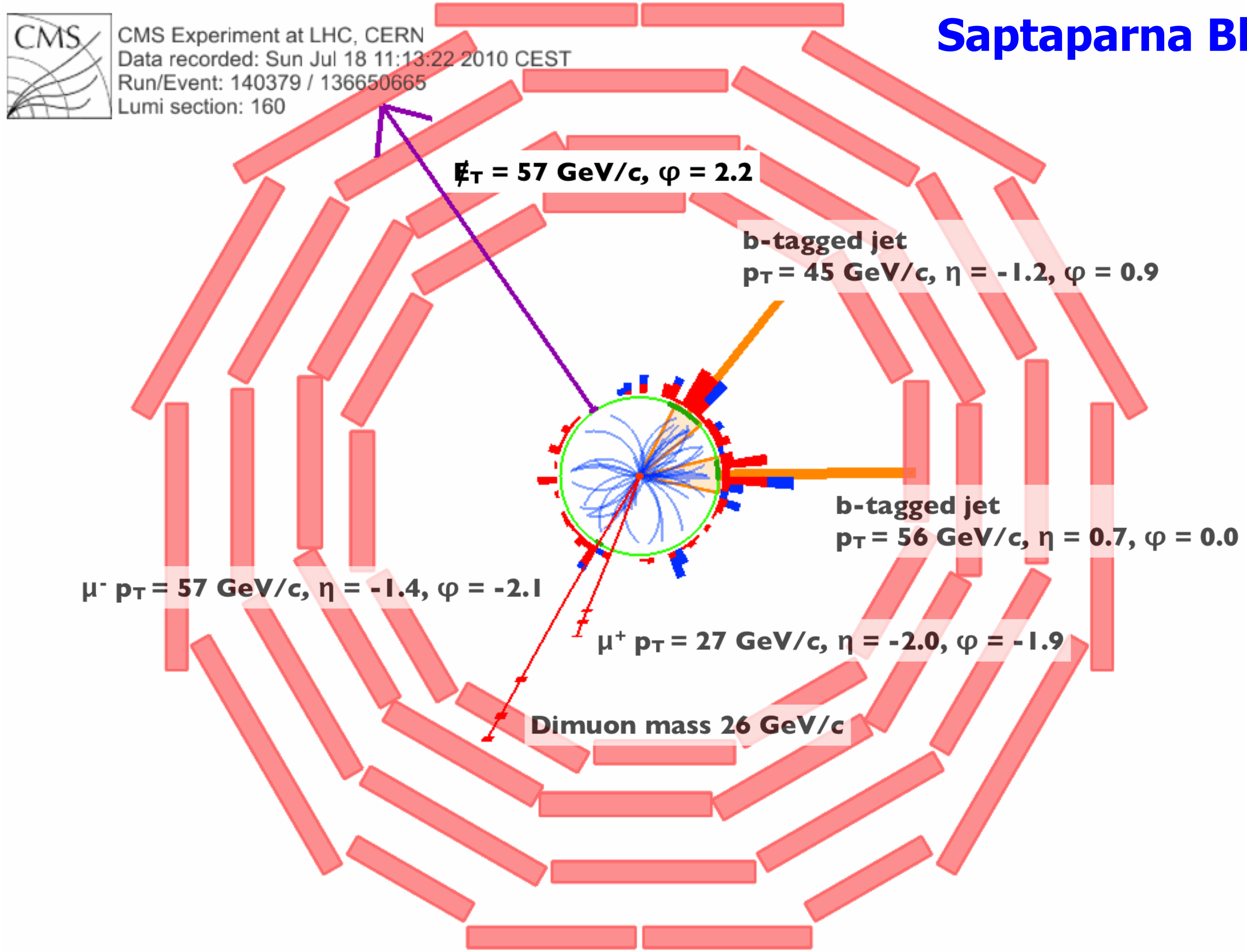
Renata Rodriguez

Di-muon spectrum



μμ + jets candidate: first top?

Saptaparna Bhattacharya



m(μμ) = 26 GeV/c^2, MET=57 GeV, two high p_T Jets, both with b-tagging

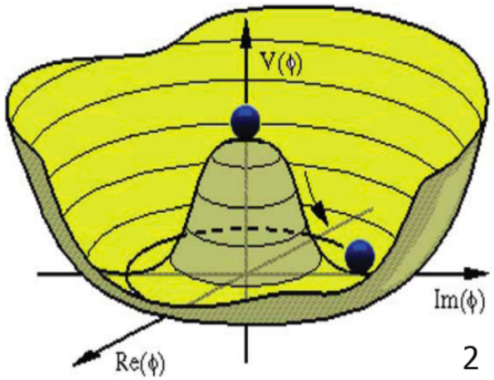
Reconstr. mass in the range 160–220 GeV/c^2 (consistent with m_{top})

Outlook for 1 fb^{-1}

Caveat:

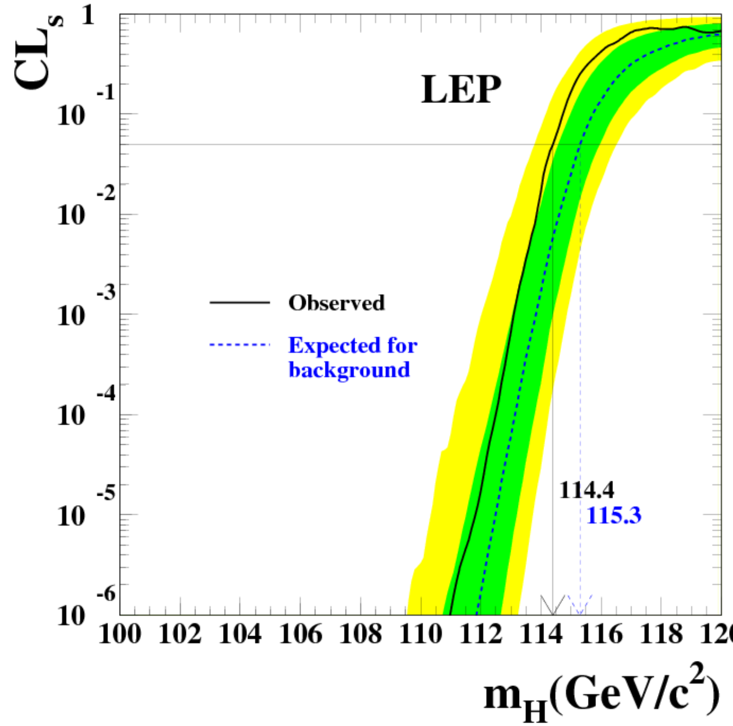
- only a selection of results will be shown
- since public studies at **10/14 TeV** event yield are rescaled by the ratio of **7 TeV/14(10) TeV cross sections/PDF**
- No corrections for higher acceptance at smaller $\sqrt{s}$, up to ~20%
- No corrections for improvements in reconstruction (efficiencies, resolution)
- systematic uncertainties also rescaled **conservatively**

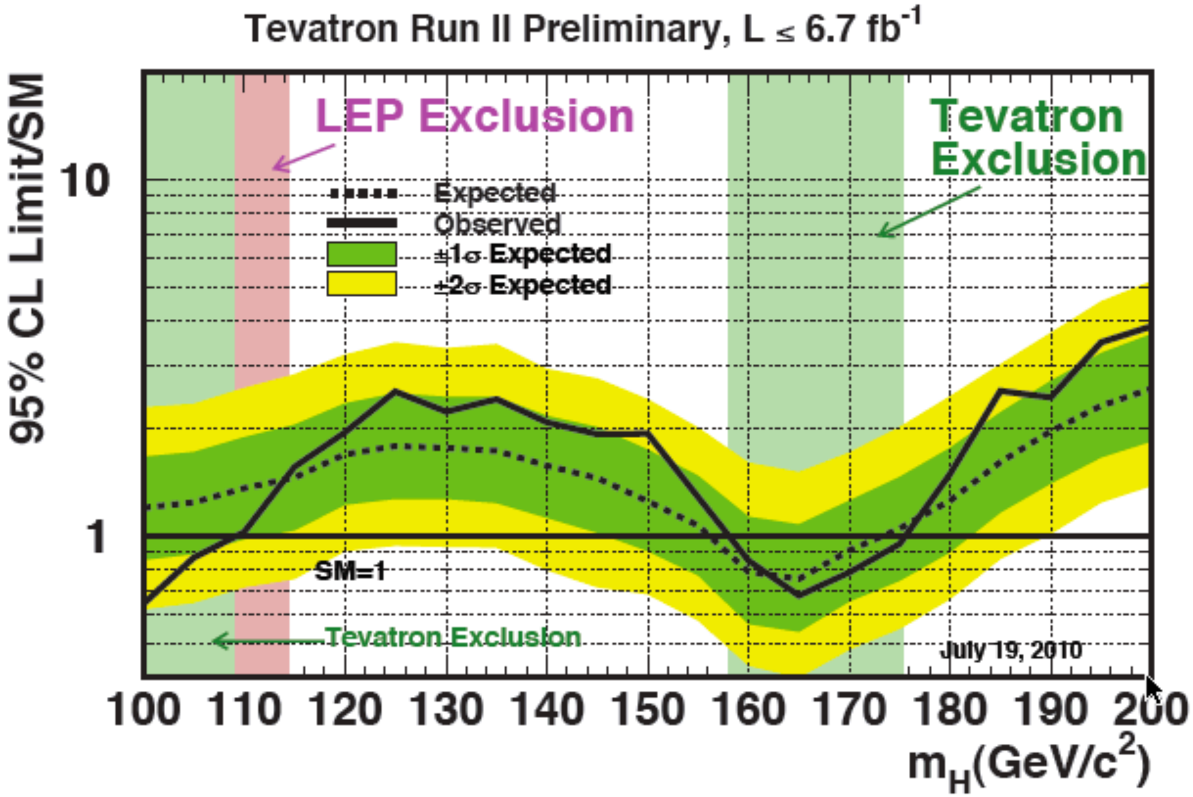
Searches for Standard Model Higgs



Experimental constraints on SM Higgs

LEP: direct search
m_H < 114.4 GeV/c^2 excluded
at 95% CL

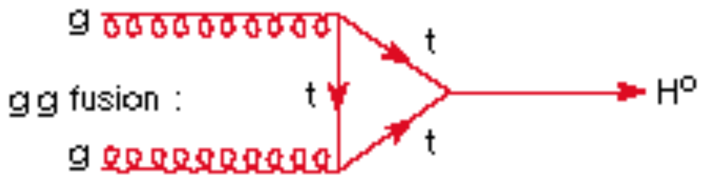


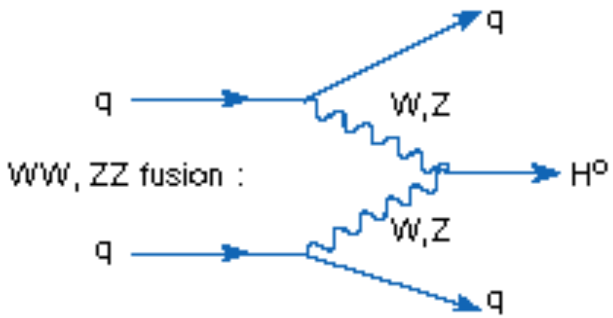


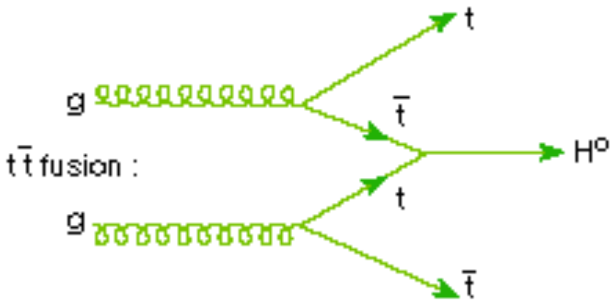
TEVATRON Run II:

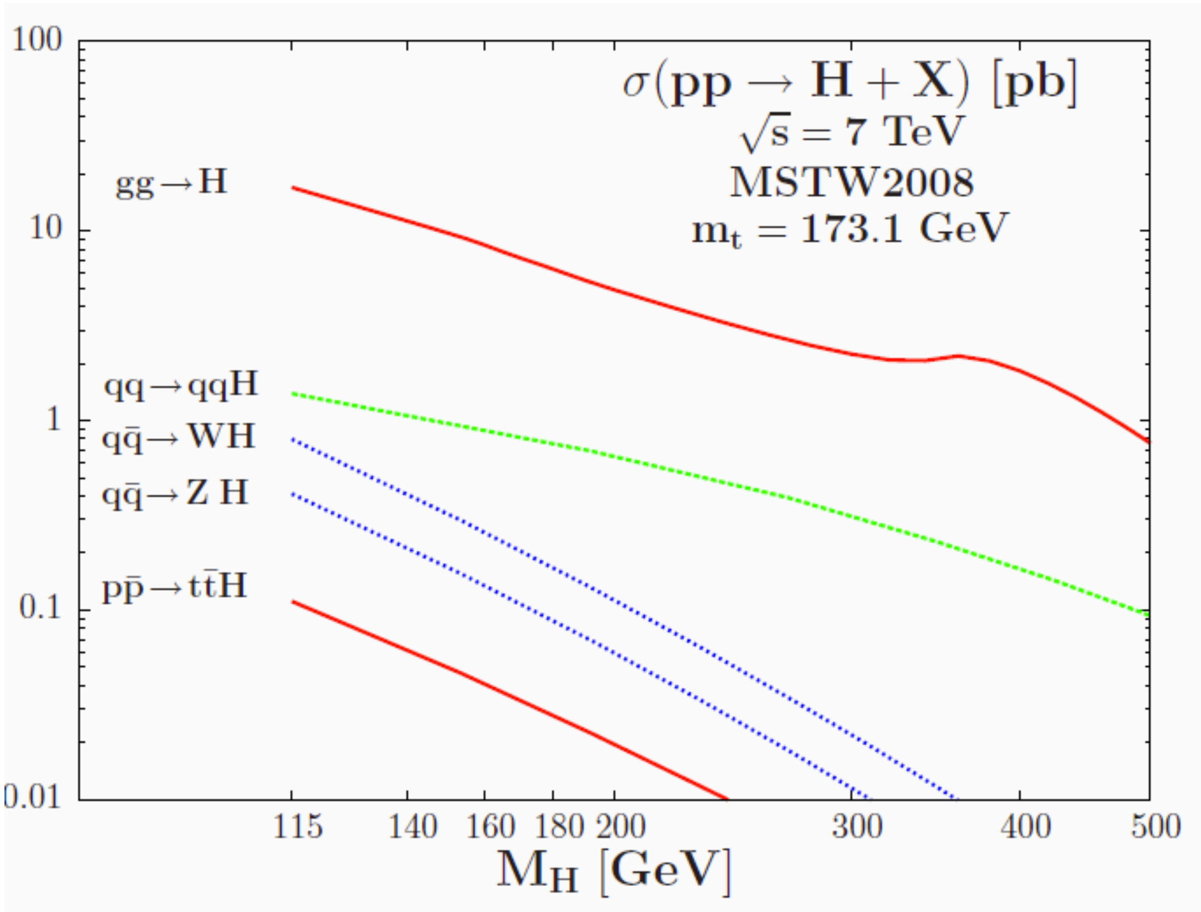
158 < m_H < 175 GeV/c^2
excluded at 95% CL

SM Higgs production at LHC

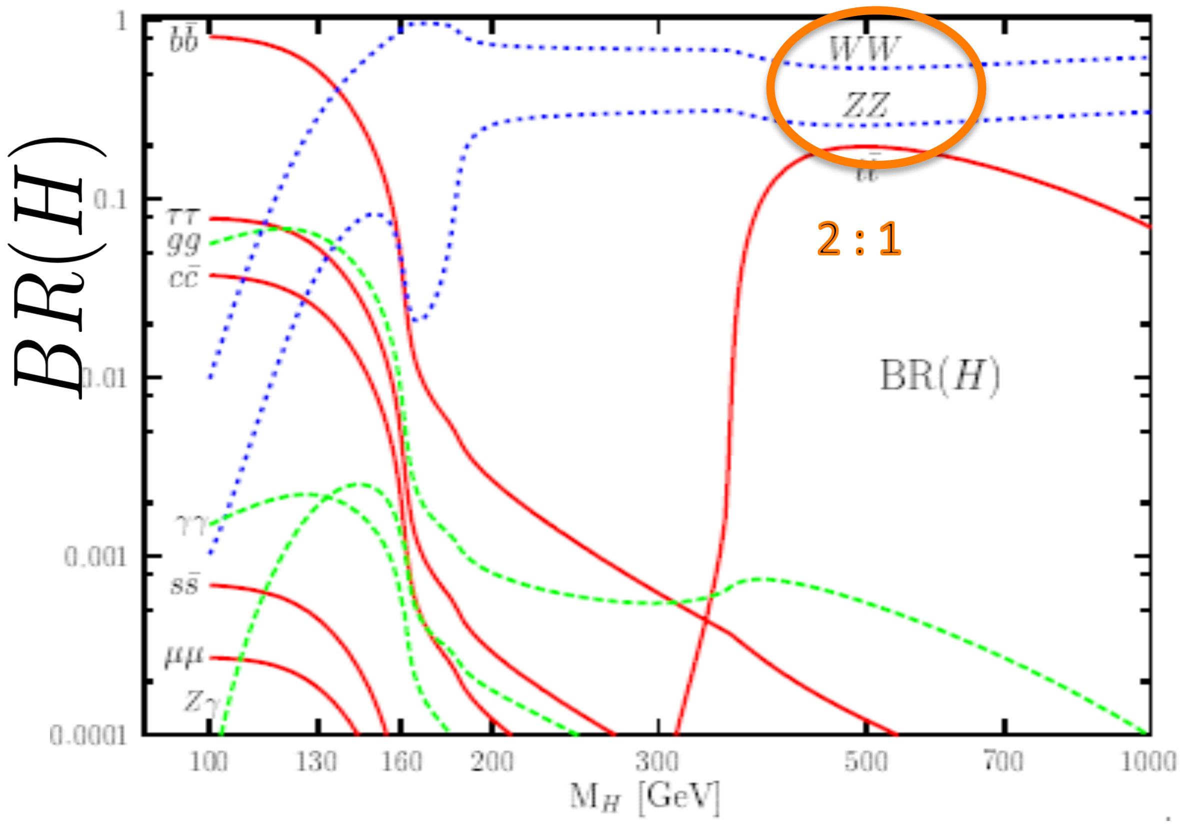








Higgs decay modes



M_H <140-150 GeV:

➤ H→bb:
Dominant mode….but crippling QCD background…exploitable in ttH or VH associated modes

➤ H→ττ
Exploitable at low M_H in the VBF production mode

➤ H→γγ
Complementary mode at low M_H via loop diagrams, low BR but excellent γID, γ iso

M_H >125-130 GeV:

➤ H→WW:
Dominant mode; llνν channel optimal for $M_H=2M_W$; lνqq' channels exploitable at large M_H or through VBF

➤ H→ZZ: Small BR but "**golden channel**" for a discovery in 4l

H→WW→2l2ν in a nutshell

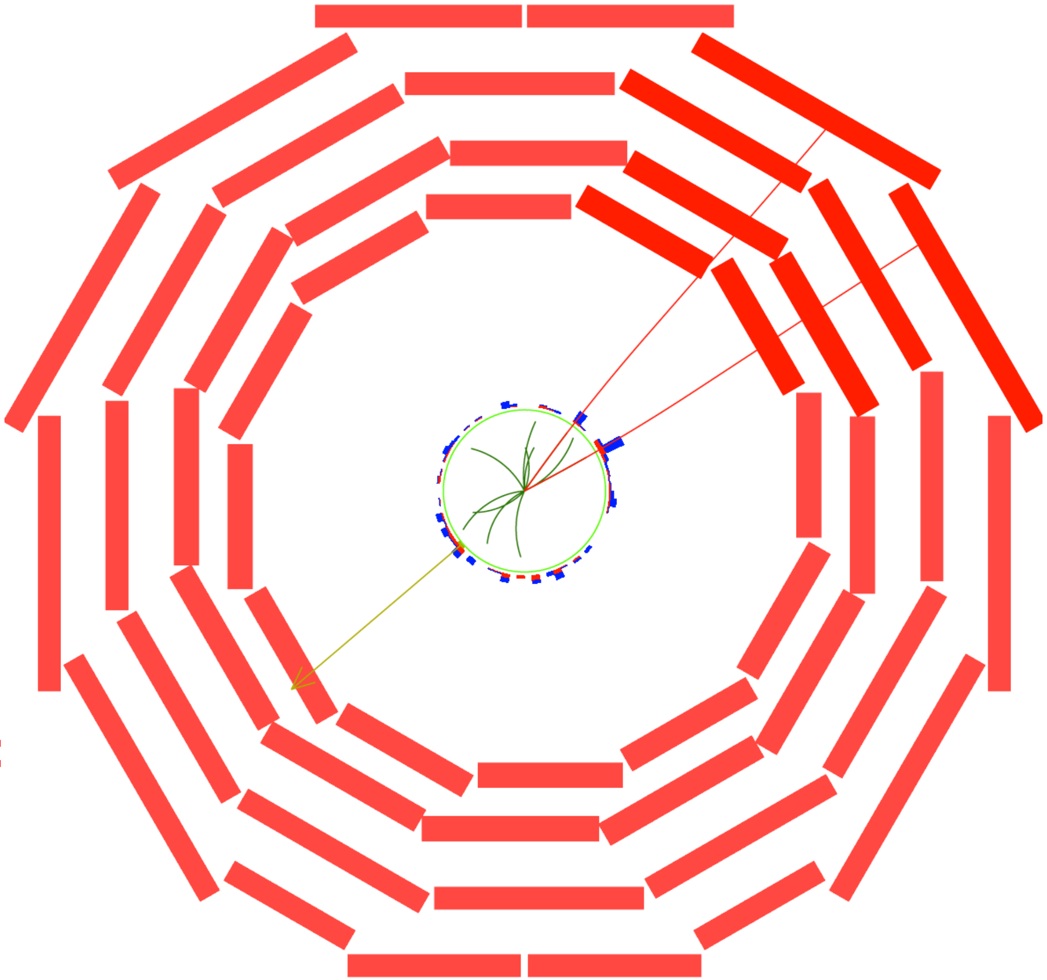
- Signatures: 2 isolated high p_T leptons + MET, no hard jet in the central region, no mass peak

- Backgrounds: tt, DY, WW, tW, W+jets

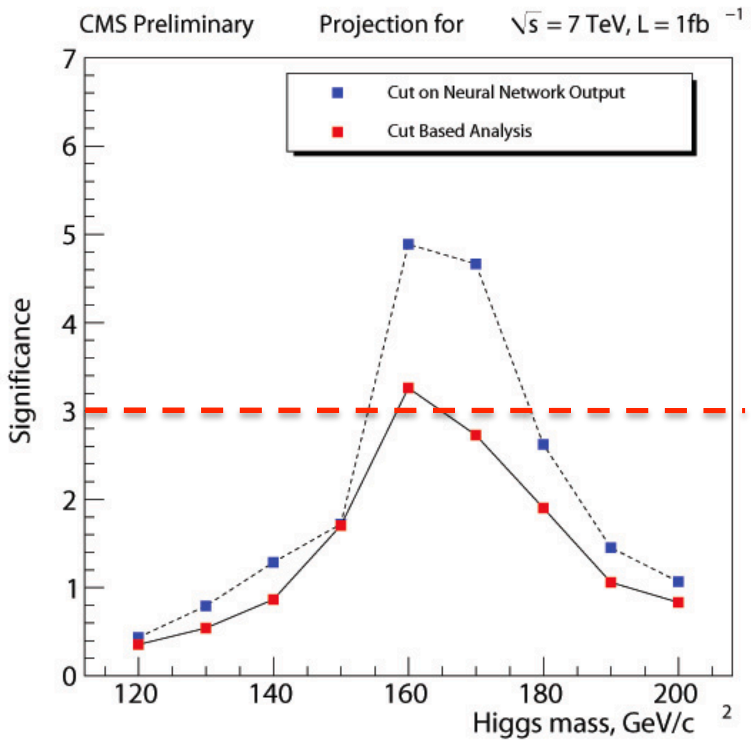
- Selection strategy:
  - single lepton triggers + muon/ele
  - isolated leptons opp. charge, p_T
  - Central jet veto
  - Angular correlations btw leptons related to the **scalarity** of the H
  - Di-lepton mass, MET, leptons p_T

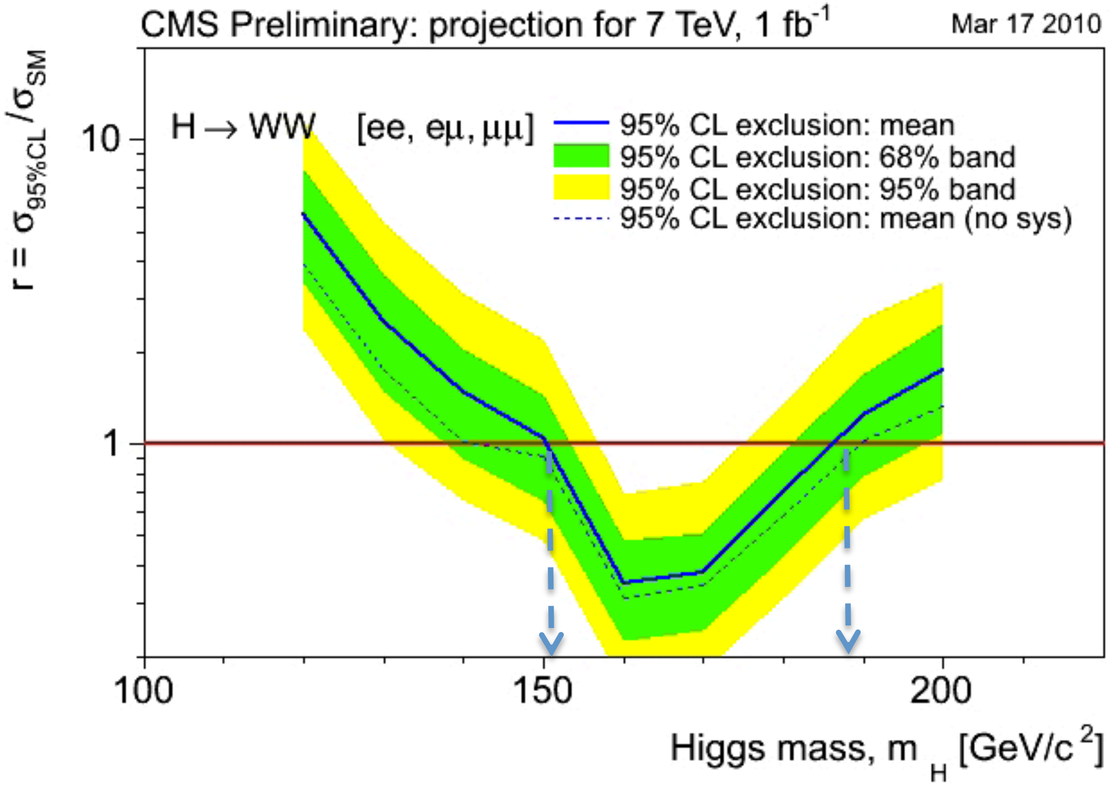
- cut based and MVA approaches

- Main challenge = control from data of:
  - MET measurement and fake rate
  - tt and WW bkg



H→WW→2l2ν sensitivity





CMS discovery 3-5σ
sensitivity : near 160 GeV

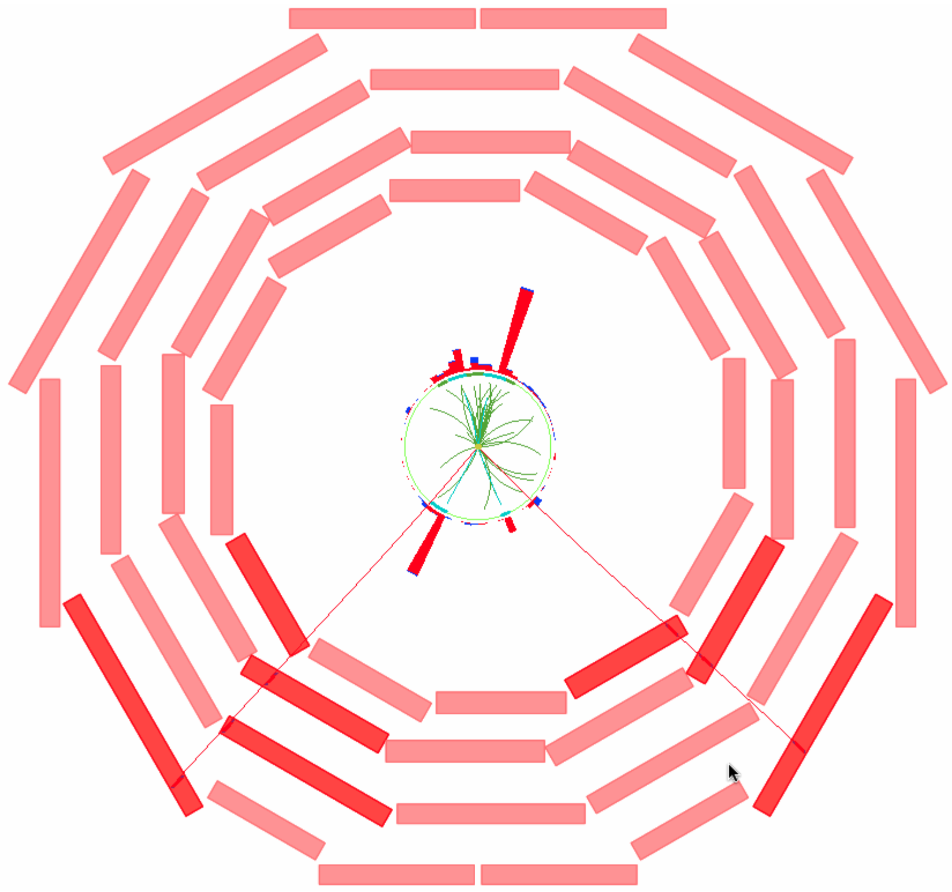
CMS expected exclusion range : [150-185]

$H \rightarrow ZZ \rightarrow 4l$ in a nutshell

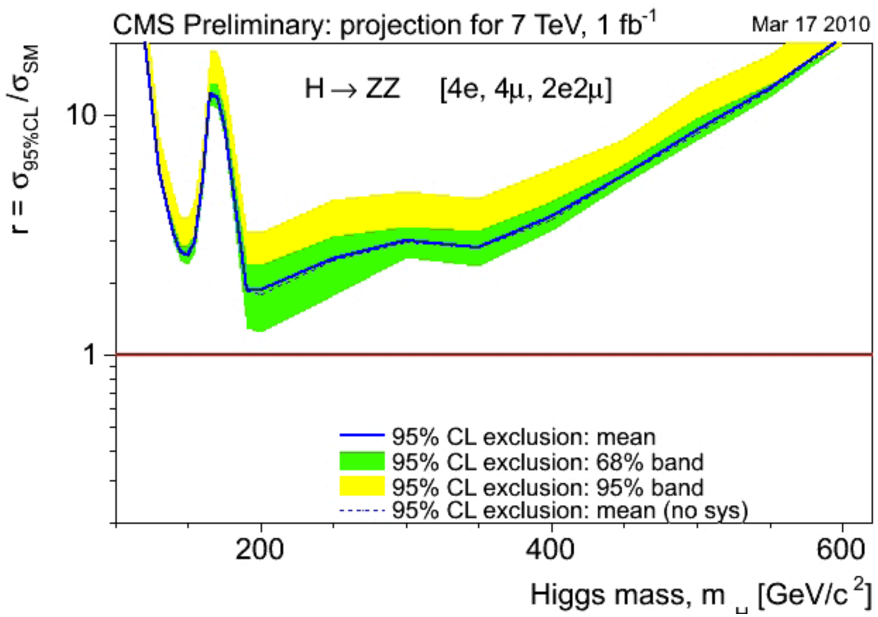
- Signatures: **4e, 4mu and 2e2mu** final state
- Backgrounds:
  - ZZ , Zbb, tt and tt+jets, Z+jets, W+jets, QCD
- Selection strategy:
  - Single & double lepton triggers
  - lepton id and charge matching
  - tight isolation (against tt, Zbb)
  - impact parameter (against Zbb/tt)
  - m_Z and m_{Z*} constraint
- Control from real data of
  - the lepton-related efficiencies
  - the estimation of ZZ and Zbb rate

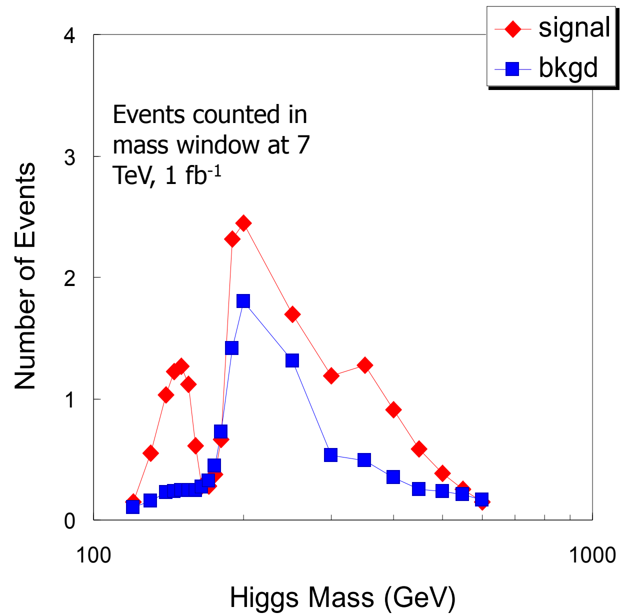
→ **Baseline cut-based analysis,**
m_H-independent

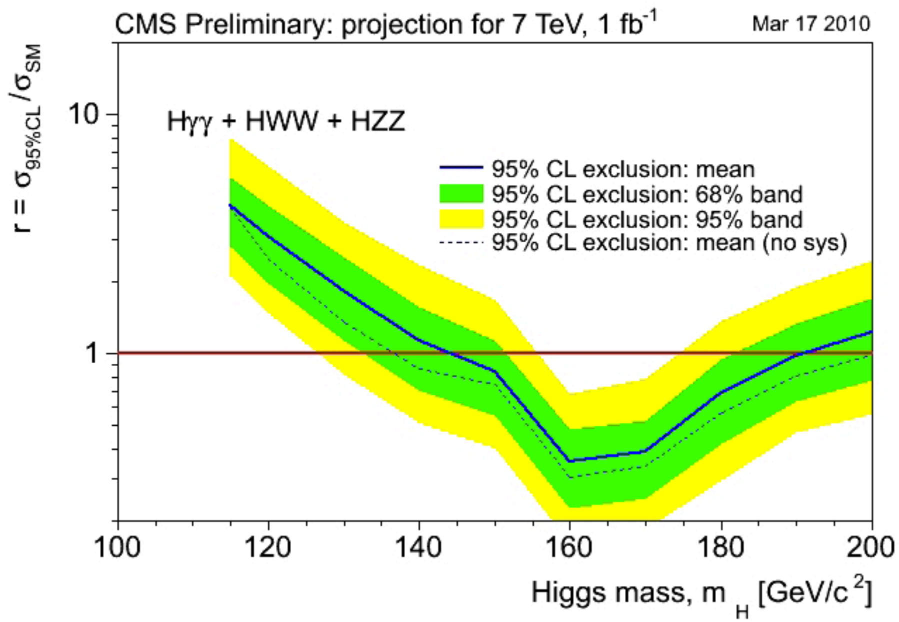
$H \rightarrow ZZ^* \rightarrow e^+e^-\mu^+\mu^-$



H→ZZ→4l sensitivity + combination



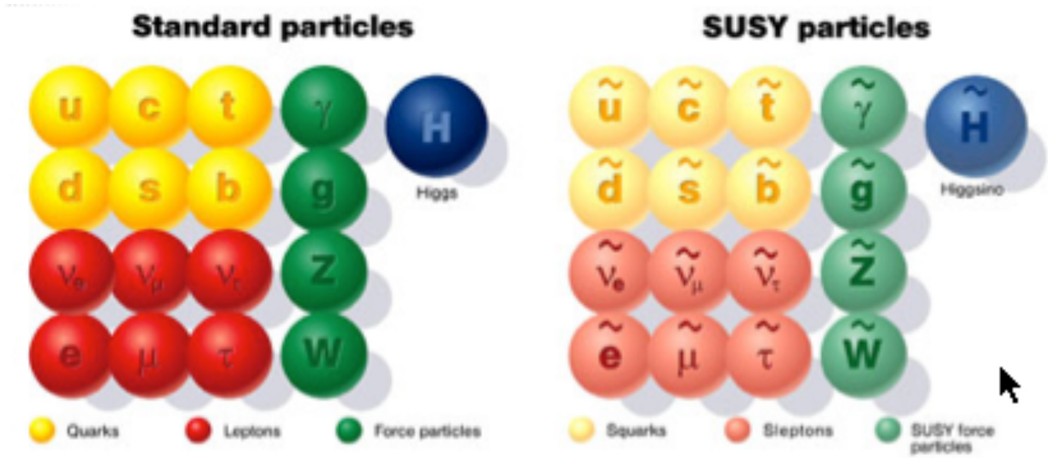




SM Higgs excluded in the range:

$145 < M_H(GeV/c^2) < 190$ at 95 C.L.

Searches for supersymmetry

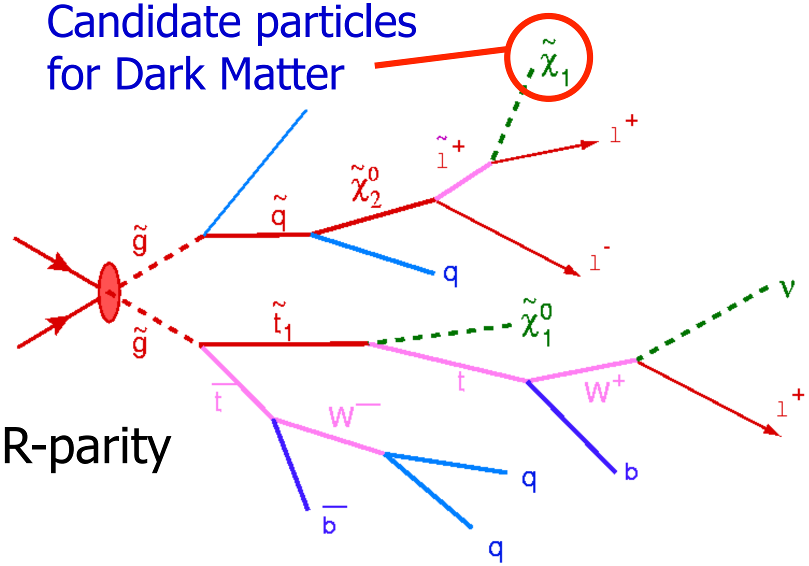


SUSY particles and experimental signatures

$\left[u,d,c,s,t,b\right]_{L,R}$	$\left[e,\mu,\tau\right]_{L,R}$	$\left[\nu_{e,\mu,\tau}\right]_L$	Spin $\frac{1}{2}$
$\left[\tilde{u},\tilde{d},\tilde{c},\tilde{s},\tilde{t},\tilde{b}\right]_{L,R}$	$\left[\tilde{e},\tilde{\mu},\tilde{\tau}\right]_{L,R}$	$\left[\tilde{\nu}_{e,\mu,\tau}\right]_L$	Spin 0
g $\underbrace{W^{\pm},H^{\pm}}$	$\underbrace{\gamma,Z,H_1^0,H_2^0}$		Spin 1 / Spin 0
$\tilde{g}$ $\tilde{\chi}^{\pm}_{1,2}$	$\tilde{\chi}^0_{1,2,3,4}$		Spin $\frac{1}{2}$

Spectrum of new particles predicted, partner of SM particles

Candidate particles for Dark Matter



Event topologies of SUSY events:

- multiple jets, often energetic
- + possibly some lepton
- + missing E_T
- multi-leptons + missing E_T

Most studies done in the context of **MSSM** with R-parity conservation, squarks and gluinos heavy

-- SUSY breaking scenarios considered:

- **mSUGRA - minimal SuperGravity**
- GMSB - Gauge Mediated SUSY Breaking
- etc

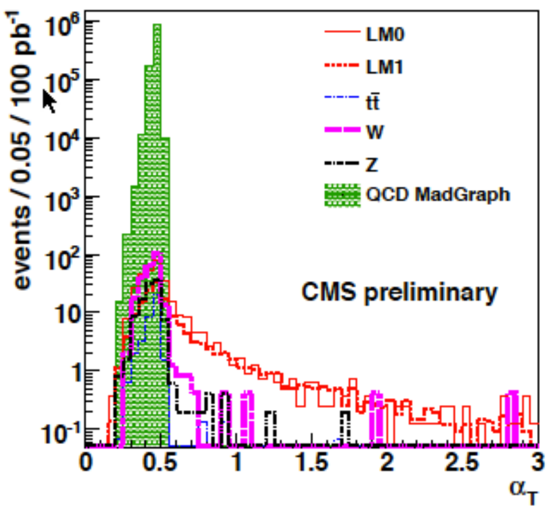
Exclusive multi-jets analysis

Event topologies with **n (n = 2 . . . 6) high p_T hadronic jets + missing energy signature**

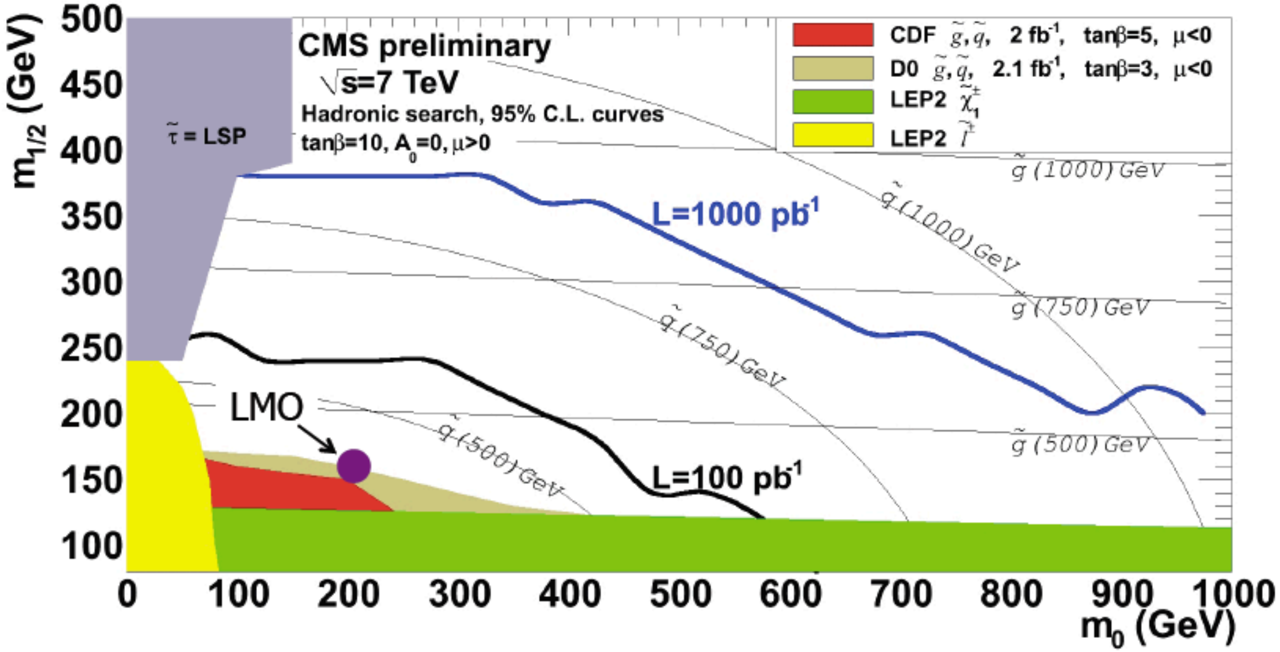
Main background: QCD multi-jet + missing energy

Kinematical variables used to suppress the QCD bkg:

2-jets case: $\alpha_T = E_T^{j2} / M_T$



e.g. all-hadronic searches (≥ 3 jets + MET + e/μ veto)



- 95% CL exclusion limits assuming 50% systematics on SM background
- Sensitivity >> previous experiments (~50 pb^{-1} to surpass Tevatron)

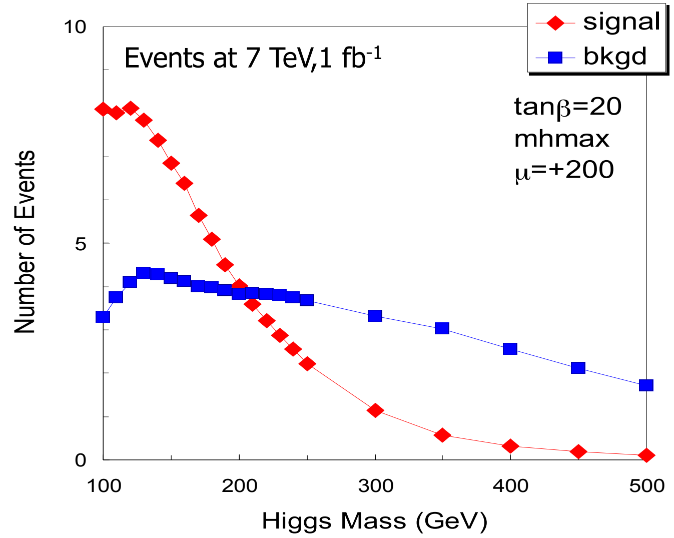
MSSM A/H→ττ

Due to tan²β enhancement o the coupling to down type fermions, w.r.t. SM:

-- the A/H→bb and A/H→ττ dominant

-- the production mainly through gg→bbA/H at large tanβ

-- A/H→ττ can give two leptons, lepton+ τ-jet or two τ-jets in the final state

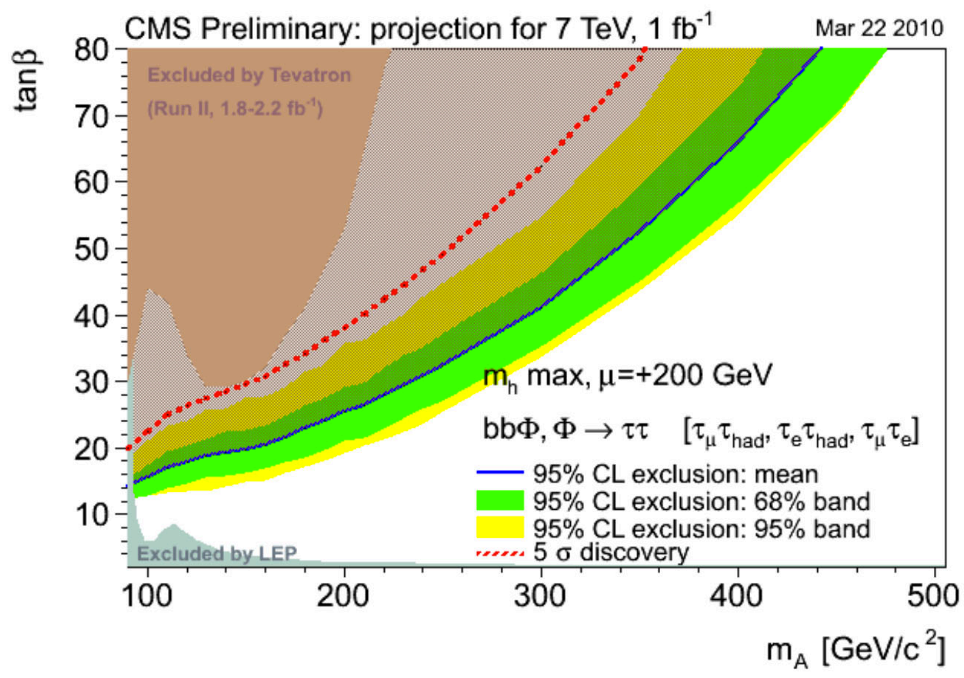


Analysis strategy based on:

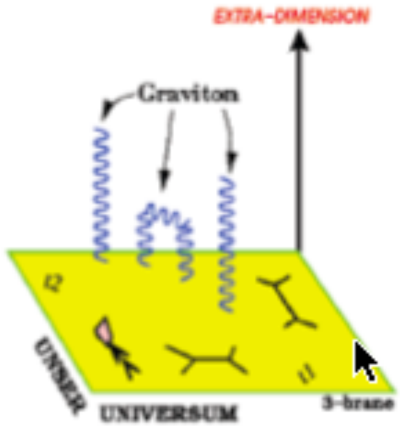
- Isolated pairs of $(\tau_{had}\ \tau_\mu)$, $(\tau_{had}\ \tau_e)$, $(\tau_e\ \tau_\mu)$
- cut on MET, 1 tagged b-jet, veto extra jets
- Build ττ-mass using collinear approx
- Count events in sliding ττ-mass window

Dominant backgrounds: tt , Zbb, Zcc

The **discovery** can be possible for tanβ>20 and the **exclusion** limit is expected to reach down to tanβ~15



Searches for exotica



TeV resonances: Z'→e^+e^-

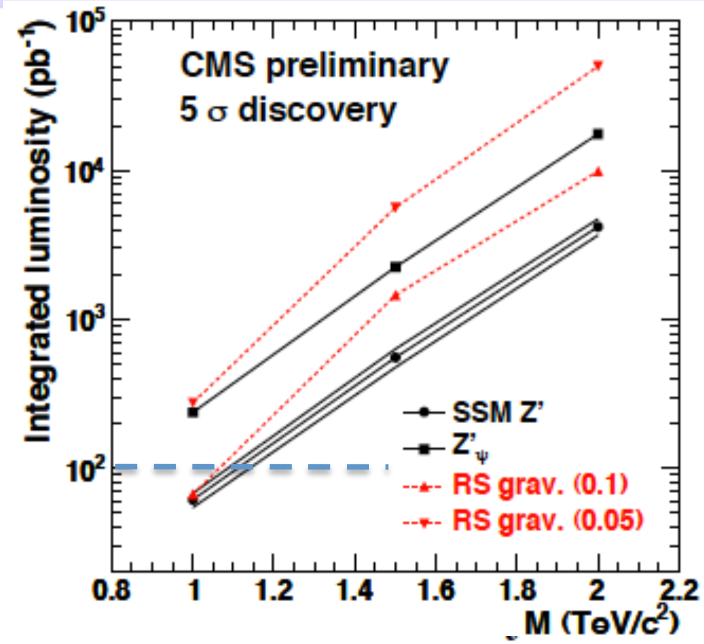
Massive gauge bosons expected in several models; **Z'** in SSM (sequential standard model), **G** in Randall-Sundrum model

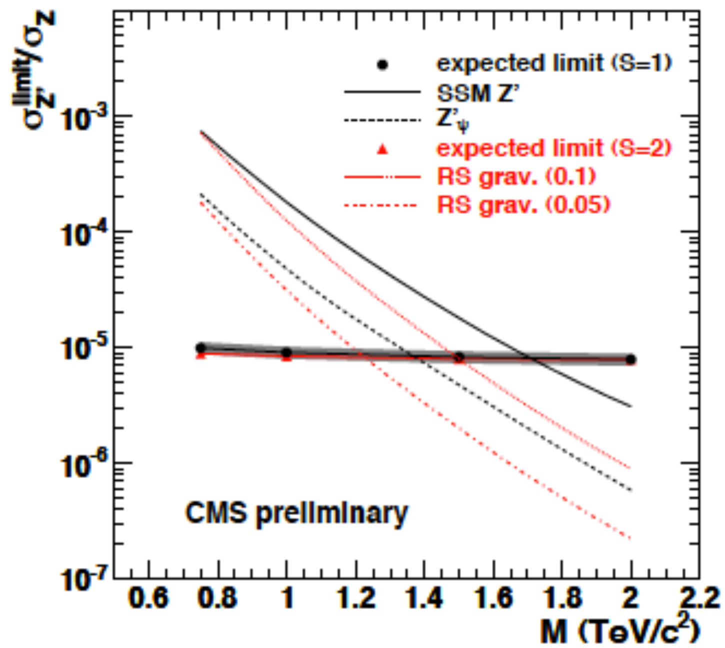
Background: DY, tt, tW, WW, QCD, W+jets, γ+jets, $\gamma\gamma$

Fundamental:
-- measurement of DY cross section and the contribution of the tail fundamental

Tevatron limits:
-- Z': 700-900 GeV/c^2 (depending on the model) for Z' bosons
-- RS gravitons: 900 (300) GeV/c^2 for c = 0.1 (0.01)

→ sensitivity of the Tevatron searches superseded with about 100 pb^{-1} of 7 TeV data.





Heavy stable charged particles: from data

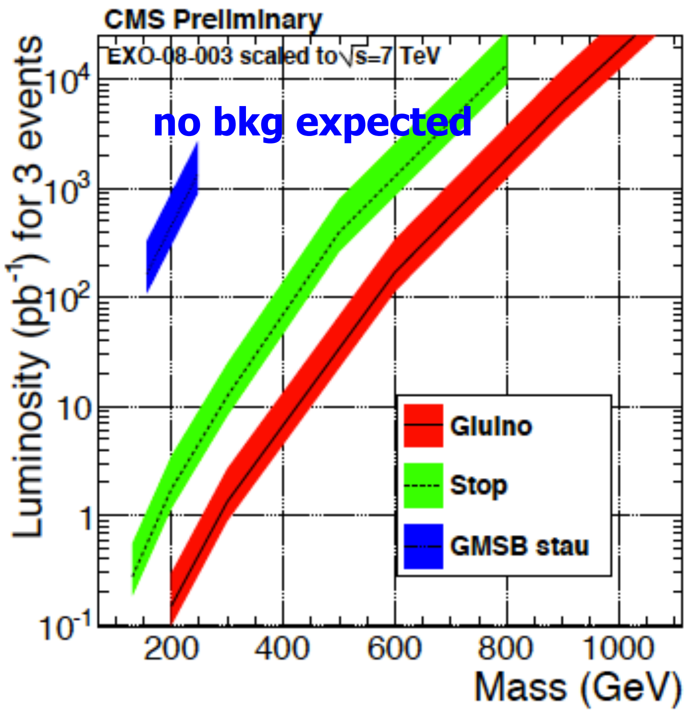
Salvatore Rapproccio

Topologies:

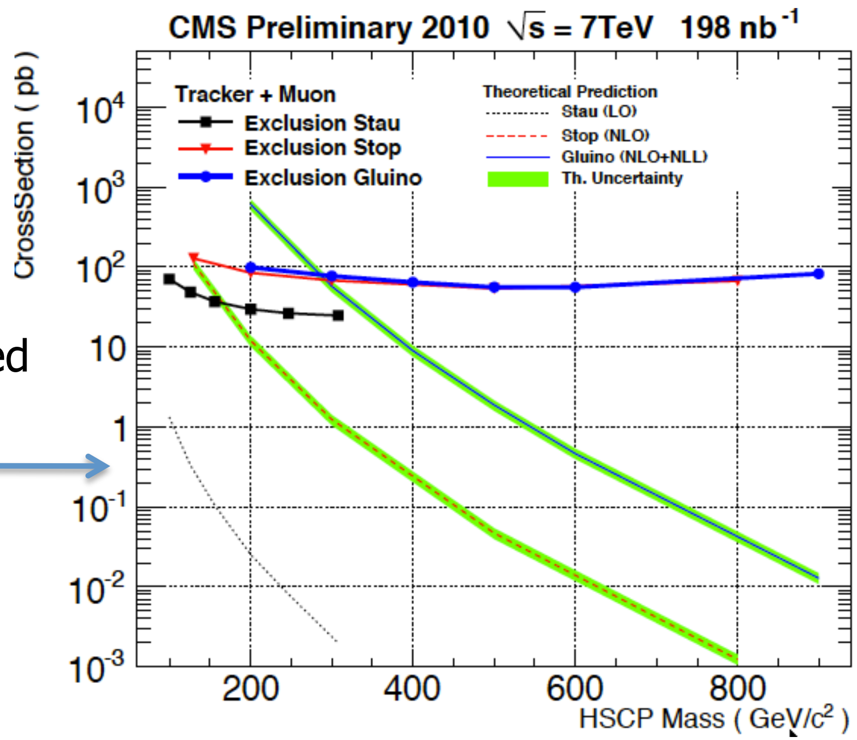
- **Leptons-like** HSCPS (sleptons and stau in SUSY models with GMSB / sleptons in UED)
- HSCPs with **strong** charge (long-lived gluino, stop) hadronize in **R-hadrons**

Technique: look for tracks with high p_T, high dE/dx in Silicon Tracker

Discovery potential at 7 TeV



198 nb^{-1} data
No event observed
→ 95% CL exclusion



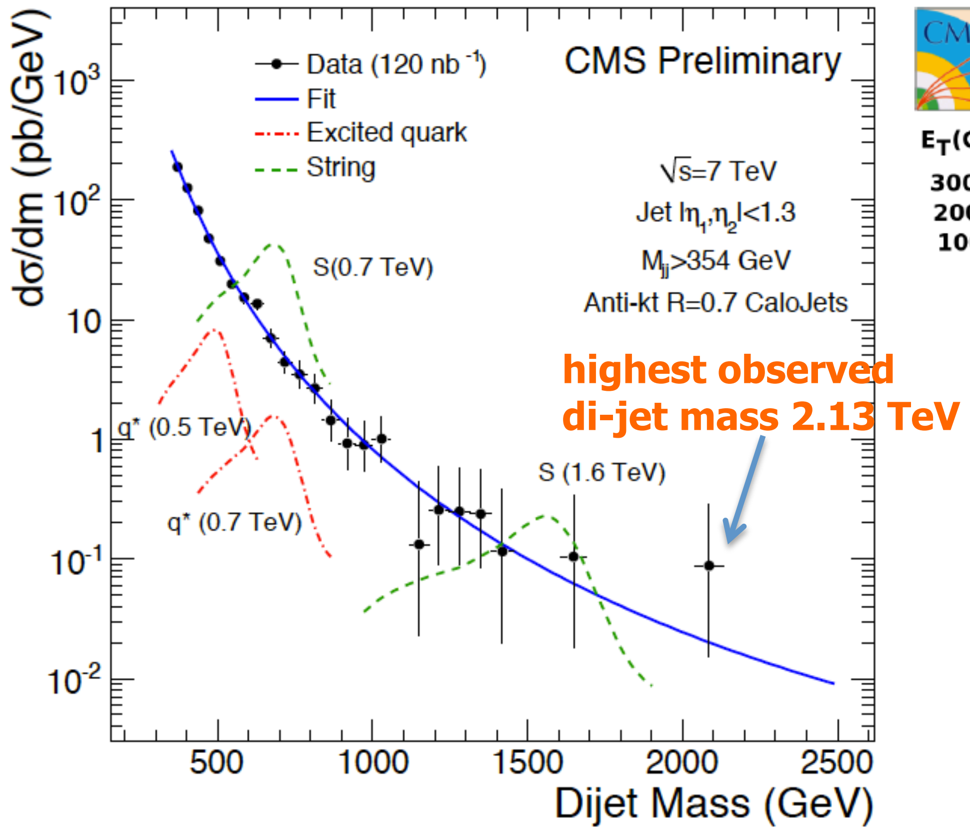
Limits on gluinos from HSCP analysis **284** GeV

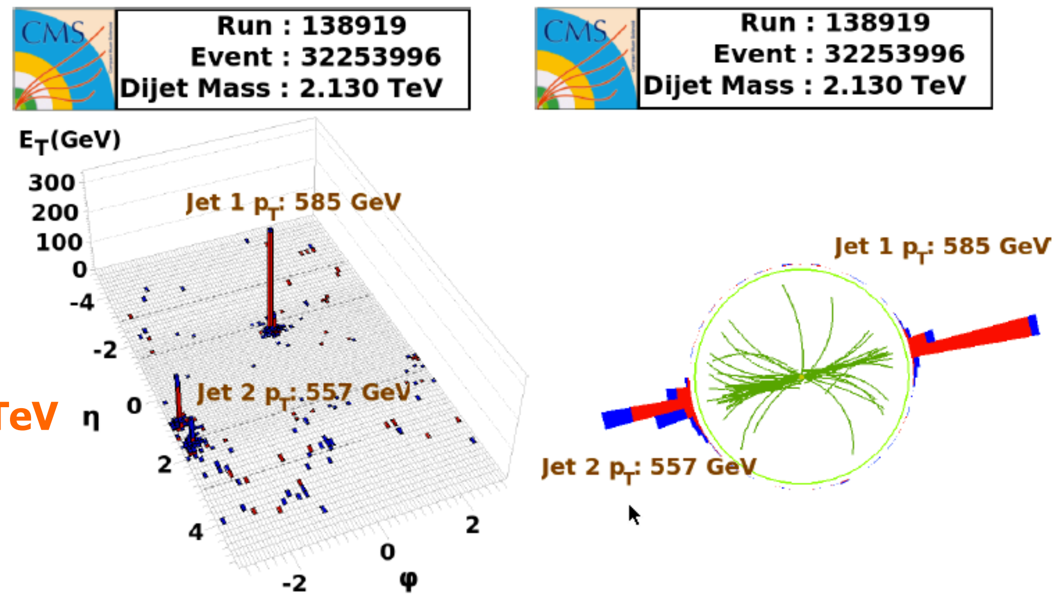
Di-jet resonances: from data

Salvatore Rapproccio

Search for **new massive objects** that couple to quarks (q) and gluons (g) → di-parton resonance qq, qg, gg → resonant structures in the di-jet →

Measure of the di-jet mass differential cross section for central jets $|\eta_1, \eta_2|<1.3$





95% exclusion limits for:

- string resonances with mass < 1.67 TeV
- excited quarks with mass < 0.59 TeV
- axigluons with mass < 0.52 TeV

Summary/Conclusions

At 7 TeV with luminosity of O(200 nb^{-1}) CMS:

- commissioned the physics objects and validated basic algorithms
- measured the cross section of W and Z, their ratio and the W^+/W^- asymmetry
- found first potential top candidates
- excluded gluinos from HSCP analysis up to 284 GeV
- etc….

At 7 TeV with luminosity of O(1 fb-1) CMS :

- will probe supersymmetry in multi-jet, same-sign di-lepton topologies, MSSM higgs
- will probe beyond SM predictions i.e. extra dimension, leptoquarks, 4^{th} fermion generation, contact interaction, etc..
- will begin to explore a sizable range of **SM Higgs mass**:
  - SM Higgs discovery sensitivity : [160-170] GeV/c^2
  - SM Higgs exclusion range : [140-200] GeV/c^2

Sensitivity comparable or larger than Tevatron for several analyses even with 100 pb^{-1} lumi

Just at the start of an exciting time

Backup slides

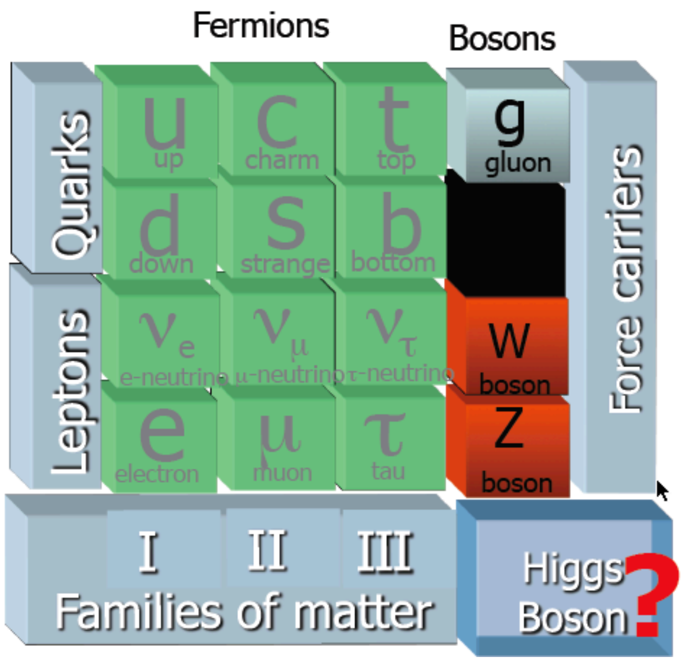
The path of particle physics

Starting point: **Standard model**

- ➢ Standard Model predictions verified with impressive accuracy:
  observables: $M_{Z,}$, Γ_Z, $\sigma^{pole}_{adr.}$ $A_{FB}^{pole,l}$, M_W, G_W, g_V, g_A, $sen^2\theta_W$, etc…

But

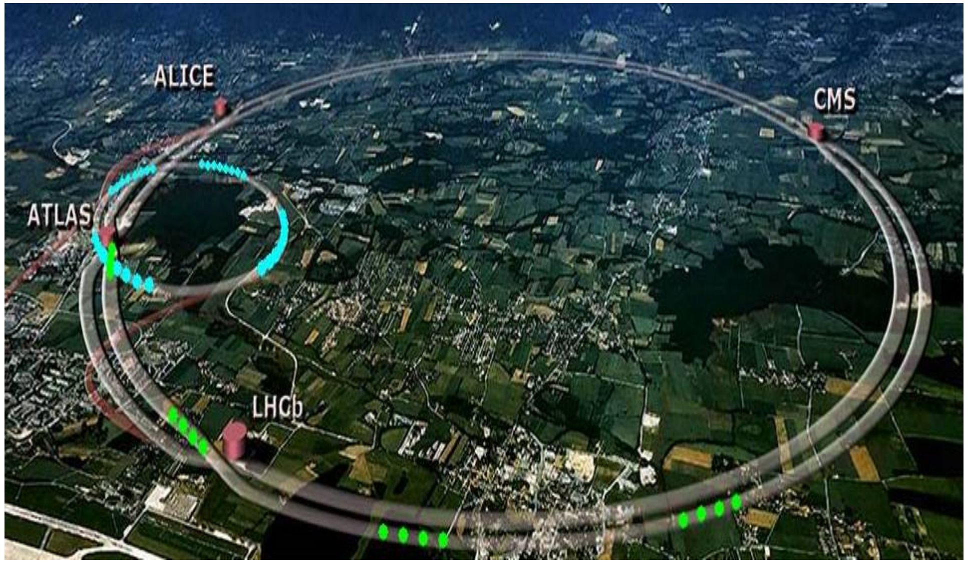
- ➢ Spontaneous symmetry breaking to allow for massive W and Z bosons without breaking the gauge invariance →
  - 18 parameters + Higgs mass
  - problems like the divergence of the m^2_H contribution from radiative corrections, the hierarchy of masses, the number of lepton families, the origin of the CP violation, etc..

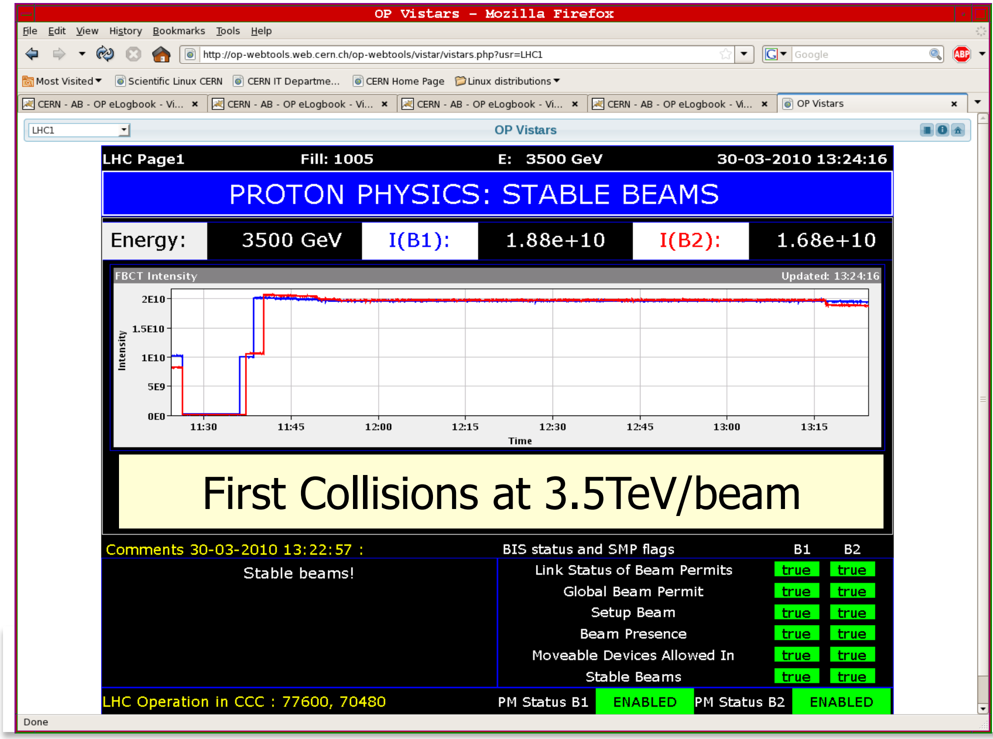


Possible solutions:

- ➢ supersymmetric models:
  MSSM, mSUGRA, etc…
- ➢ extra-dimension and string theories:
  Randall-Sundrum model, etc..
- ➢ other exotic models……

The LHC machine





Circumference (km)	26.7
Number of superconducting Dipoles	1232
Length of Dipole (m)	14.3
Dipole Field Strength (Tesla)	8.4
Operating Temperature (K)	1.9
Current in dipole sc coils (A)	13000
Beam Intensity (A)	0.5
Beam Stored Energy (MJoules)	362
Number of particles per bunch	1.15×10^{11}
Number of bunches per beam	2808
Crossing angle (μrad)	285
Bunch length (cm)	7.55
Norm transverse emittance (μm rad)	3.75
Beta function at IP 1,2,5,8 (m)	0.55,10,0.55,10

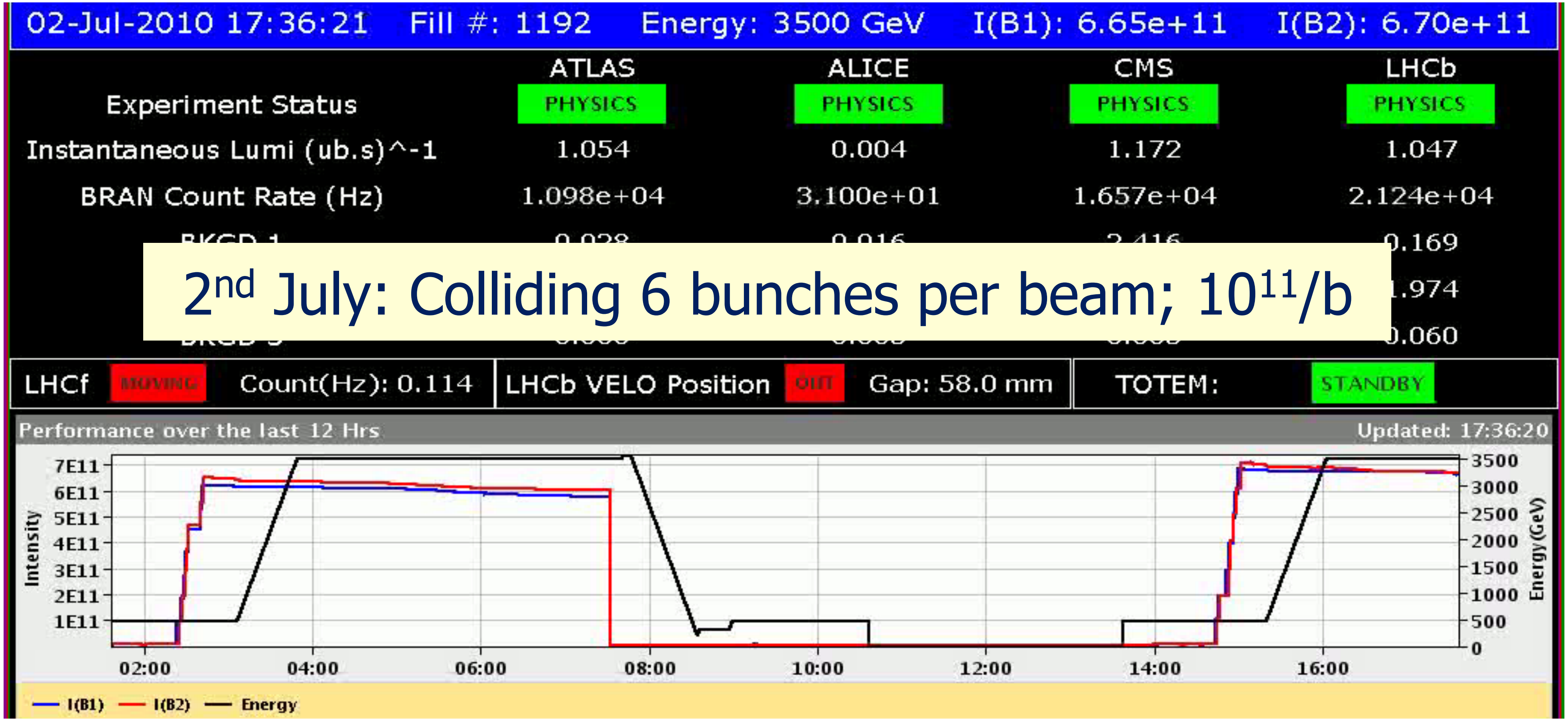
$$L = \frac{N_b^2 n_b f_{rev} \gamma_r}{4\pi \varepsilon_n \beta *} F$$

N_b = number of proton per bunch
n_b = number of bunches

f_{rev} = rotation frequency (~ 11Hz)
F = crossing angle factor

Rms transverse beam size $= \sqrt{\varepsilon \ \beta / \gamma}$
ε_n = renorm. transverse emittance
$\beta *$ = optics at beam crossing (m)
γ_r = relativistic factor

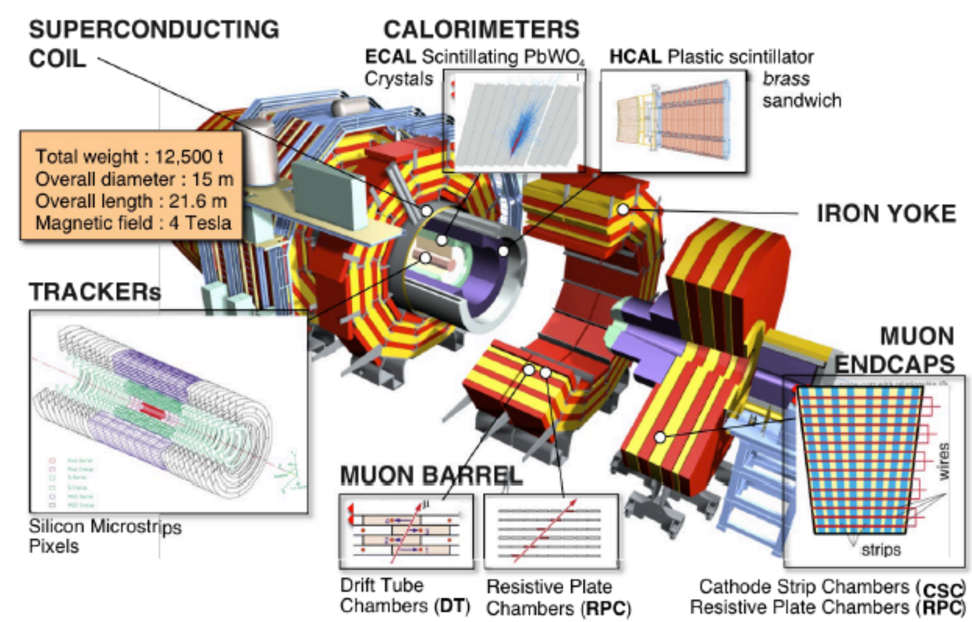
The LHC machine (2)

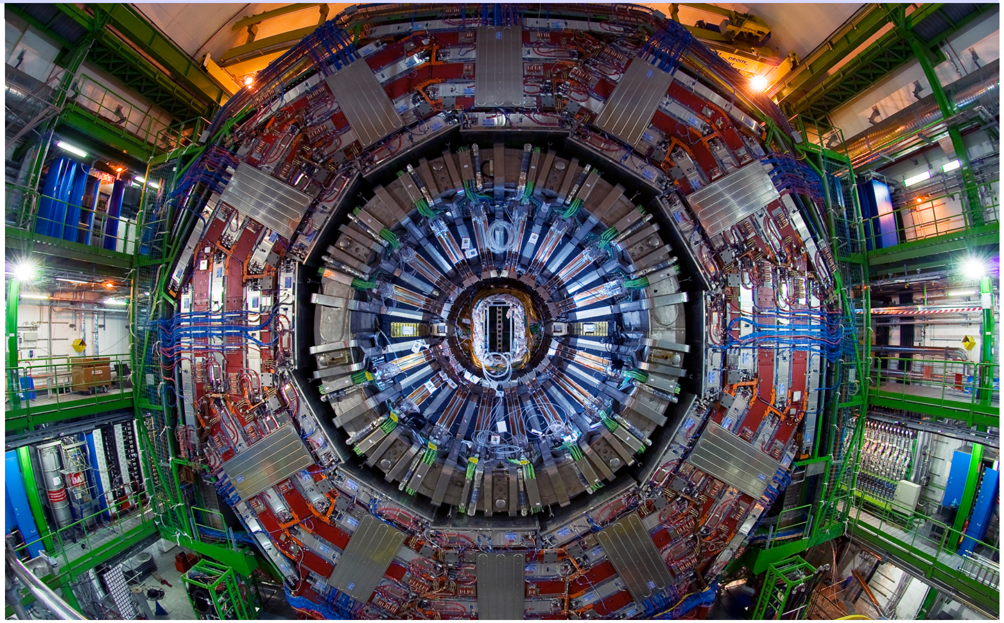


2nd July: Colliding 6 bunches per beam; 10^{11}/b

New Record Lumi > $1e^{30}$ cm^{-2} s^{-1}

CMS in a nutshell





|η|<2.5 : Tracker

$$\sigma / p_T \approx 10^{-4} p_T \oplus 0.005$$

|η|<4.9 : EM Calorimeter

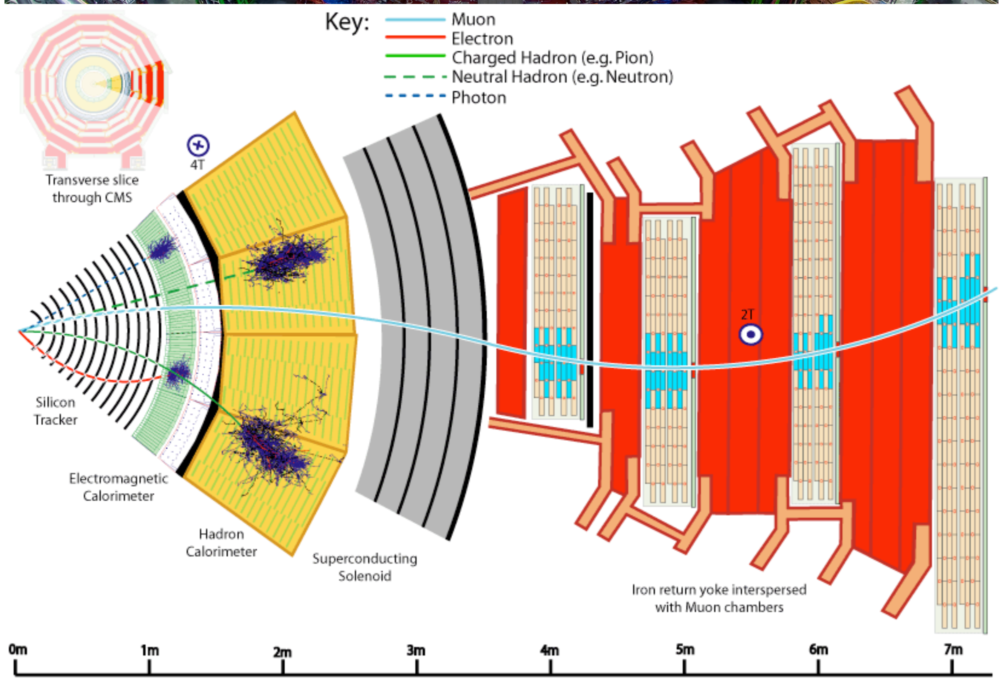
$$\sigma / E \approx 0.03/\sqrt{E} + 0.003$$

|η|<4.9 : HAD Calorimeter

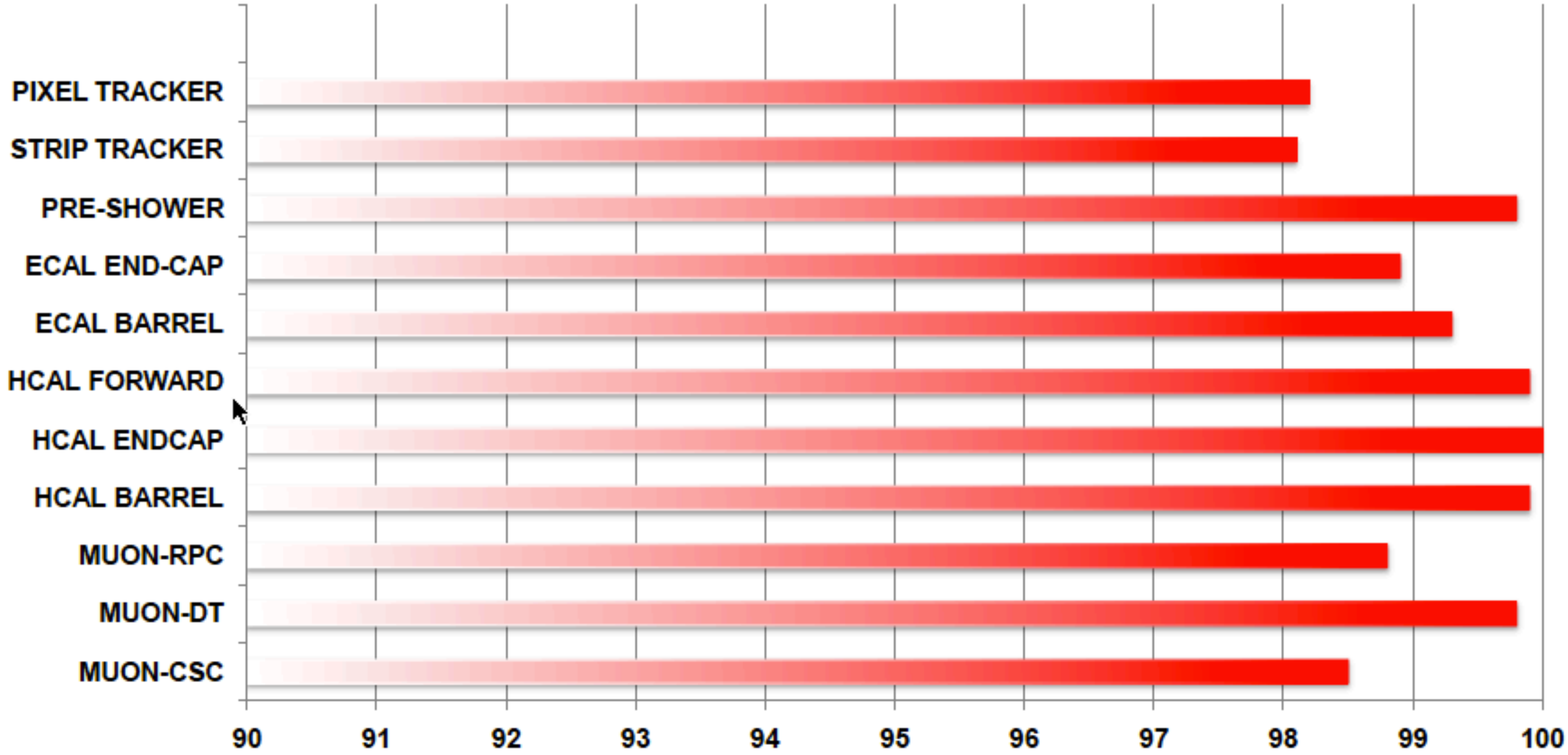
$$\sigma / E \approx 1.0/\sqrt{E} + 0.05$$

|η|<2.4 : Muon spectrometer

$$\sigma / p_T \approx 0.10 \quad (1\,TeV\ muons)$$



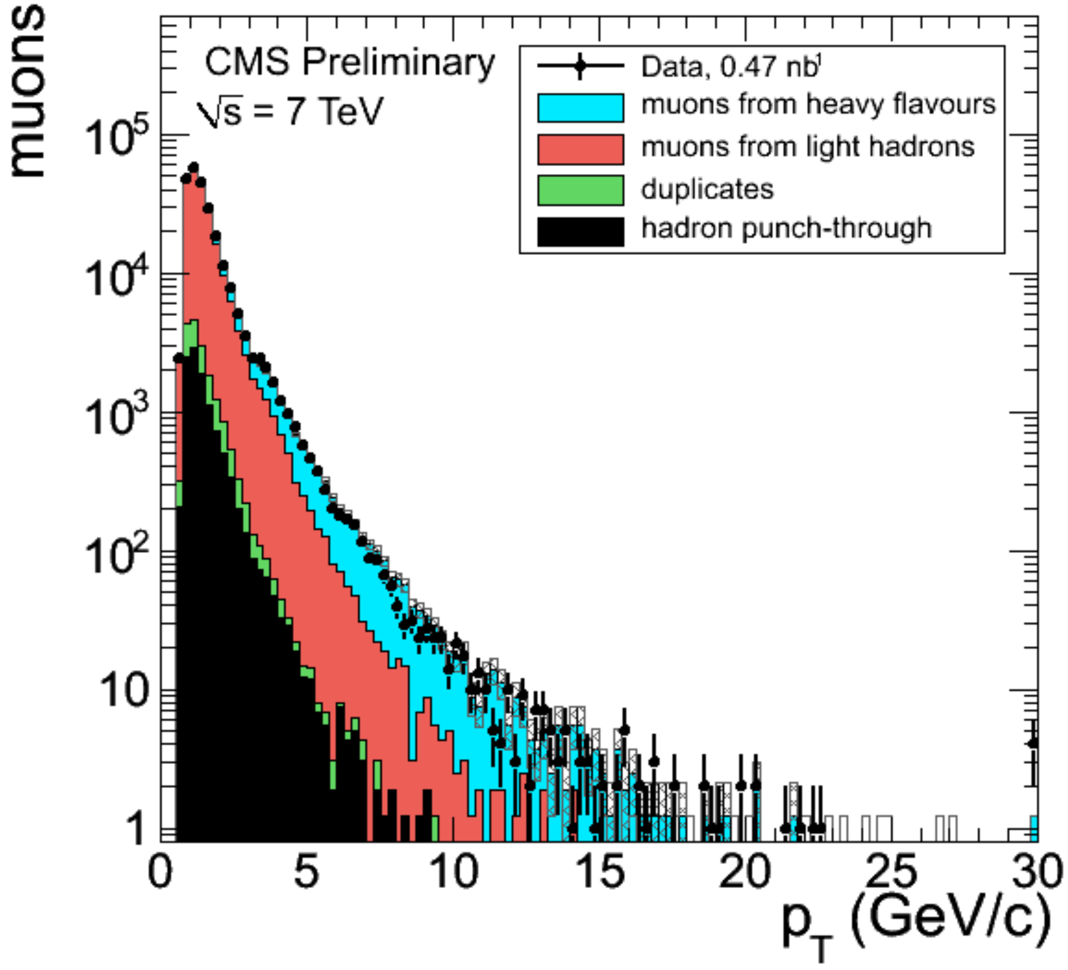
CMS sub-detector operational status

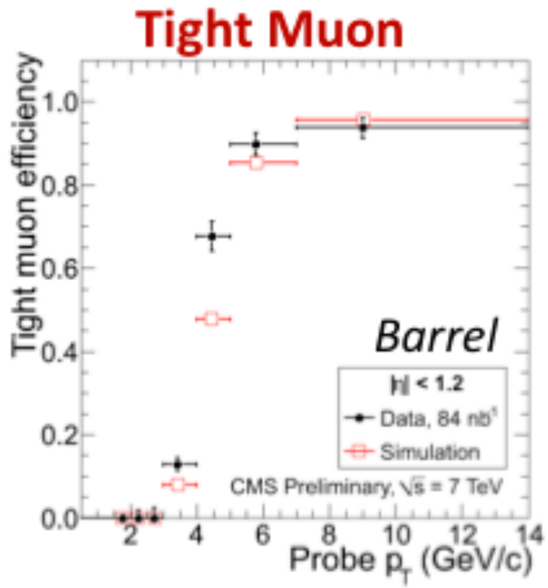


	MUON-CSC	MUON-DT	MUON-RPC	HCAL BARREL	HCAL ENDCAP	HCAL FORWARD	ECAL BARREL	ECAL END-CAP	PRE-SHOWER	STRIP TRACKER	PIXEL TRACKER	
Series1	98.5	99.8	98.8	99.9	100	99.9	99.3	98.9	99.8	98.1	98.2	

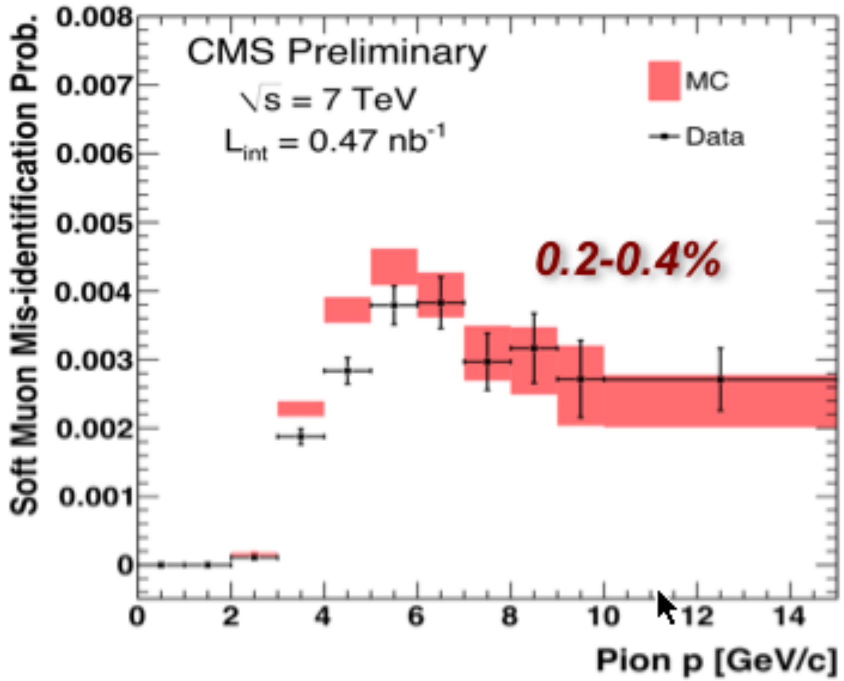
Commissioning of physics objects

Physics objects: Muons





Tag & Probe with muons from J/ψ



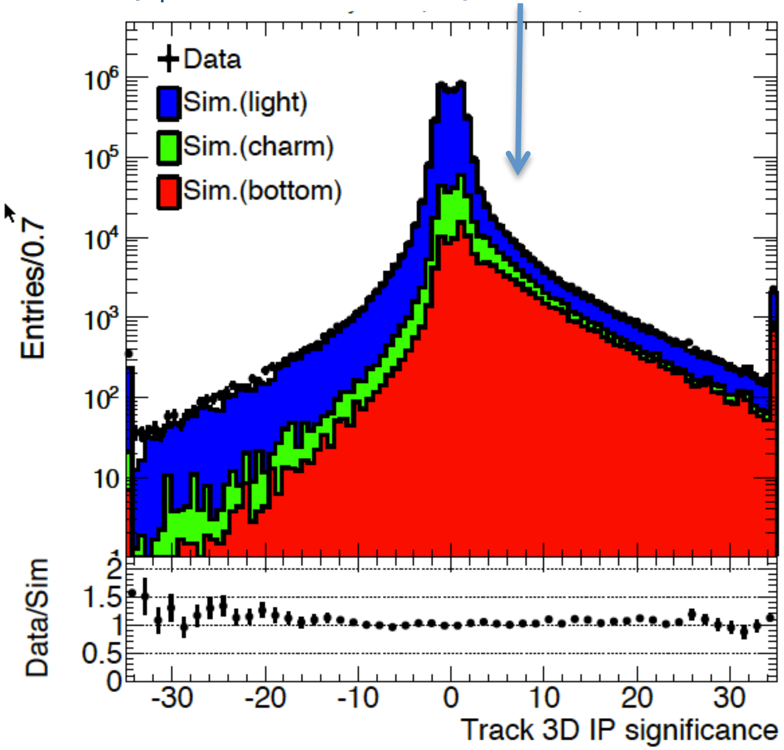
Mis-id probability for muons from pions from identified K_s,ϕ

Physics objects: b-jet

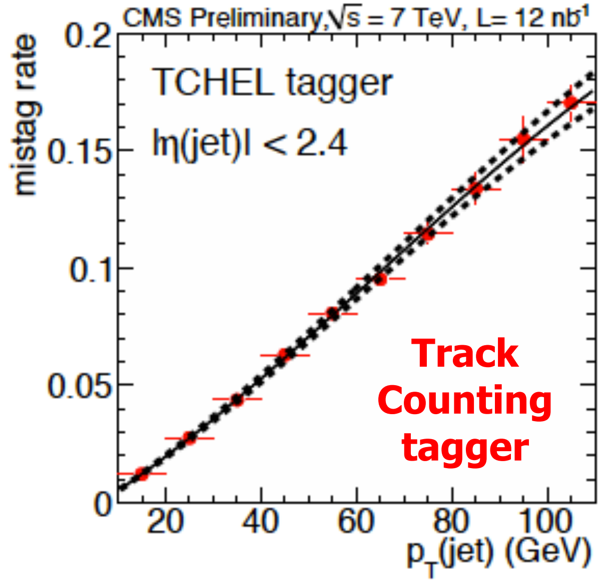
Several different b-tagging algorithms fully validated:

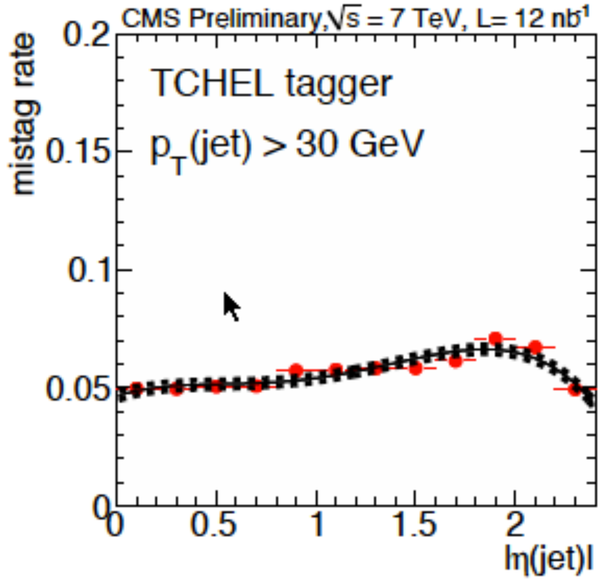
- Track counting
- Secondary vertex tagger
- Jet probability

3D impact parameter significance for all tracks with p_T>1GeV belonging to jets with p_T > 40 GeV and $|\eta|$ < 2.5



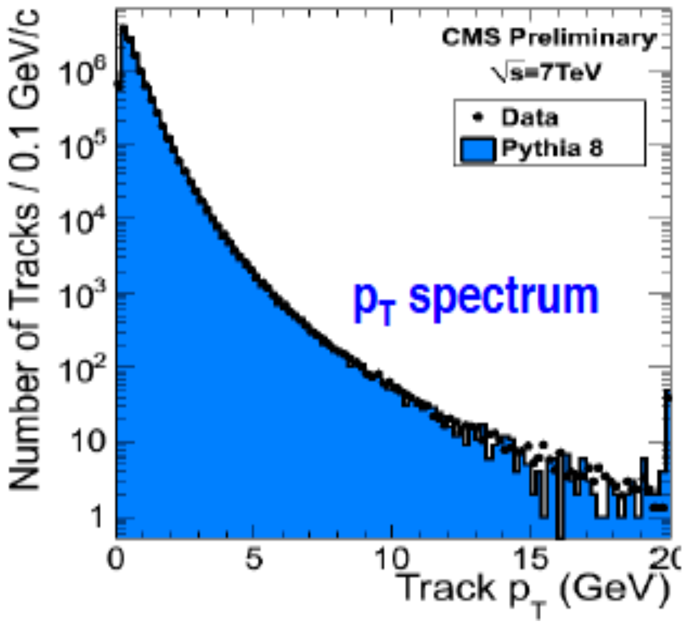
Mis-tag rate:
rate of jets tagged with "b-taggers" obtained for tracks with the negative impact parameters

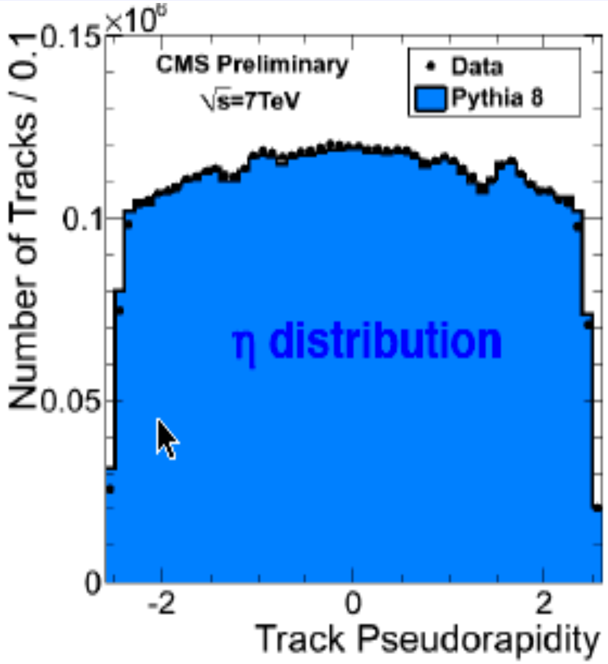


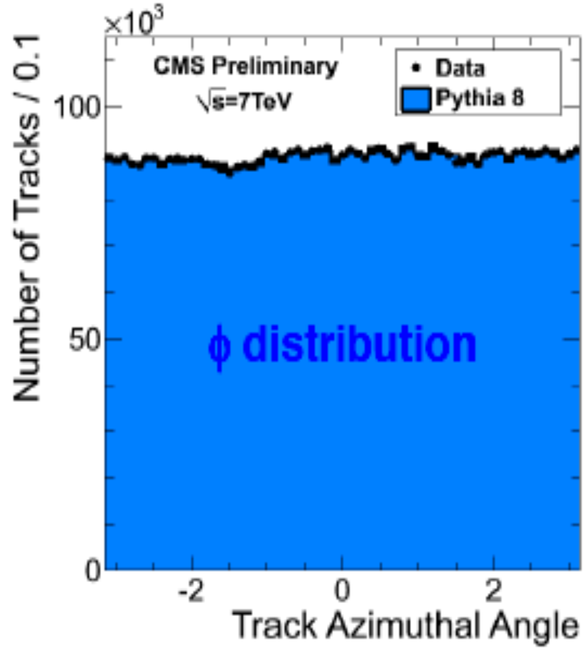


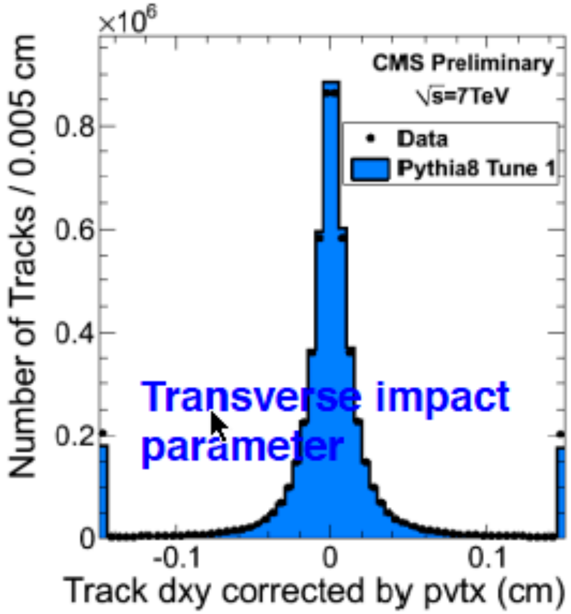
so good results thanks also to excellent alignment and tracking performance

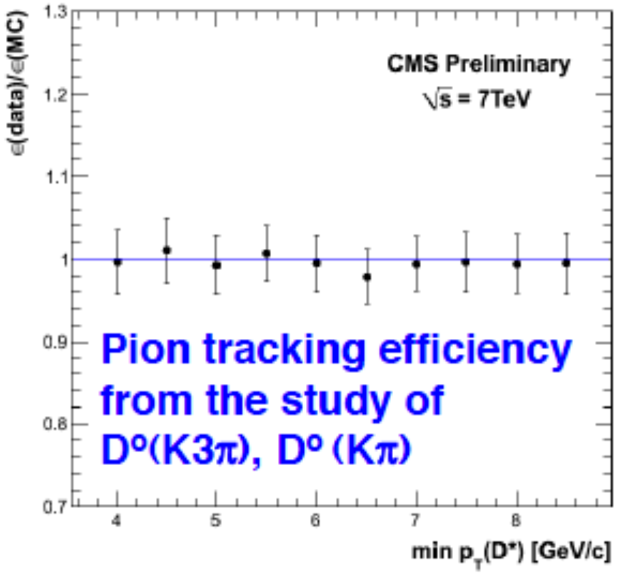
Physics objects: Tracks

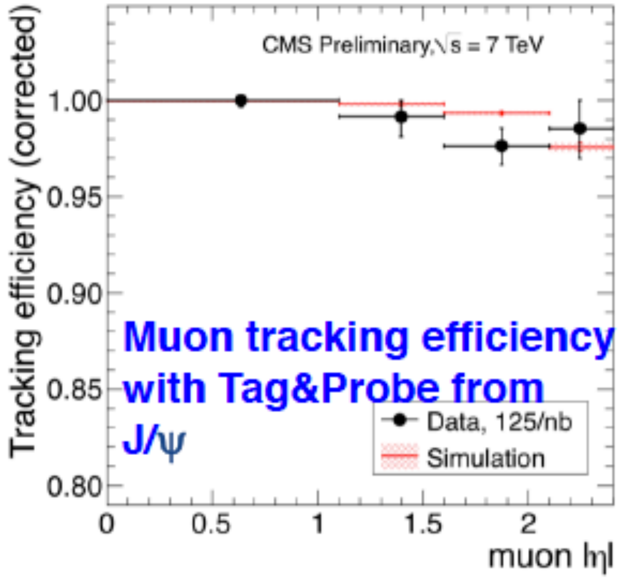




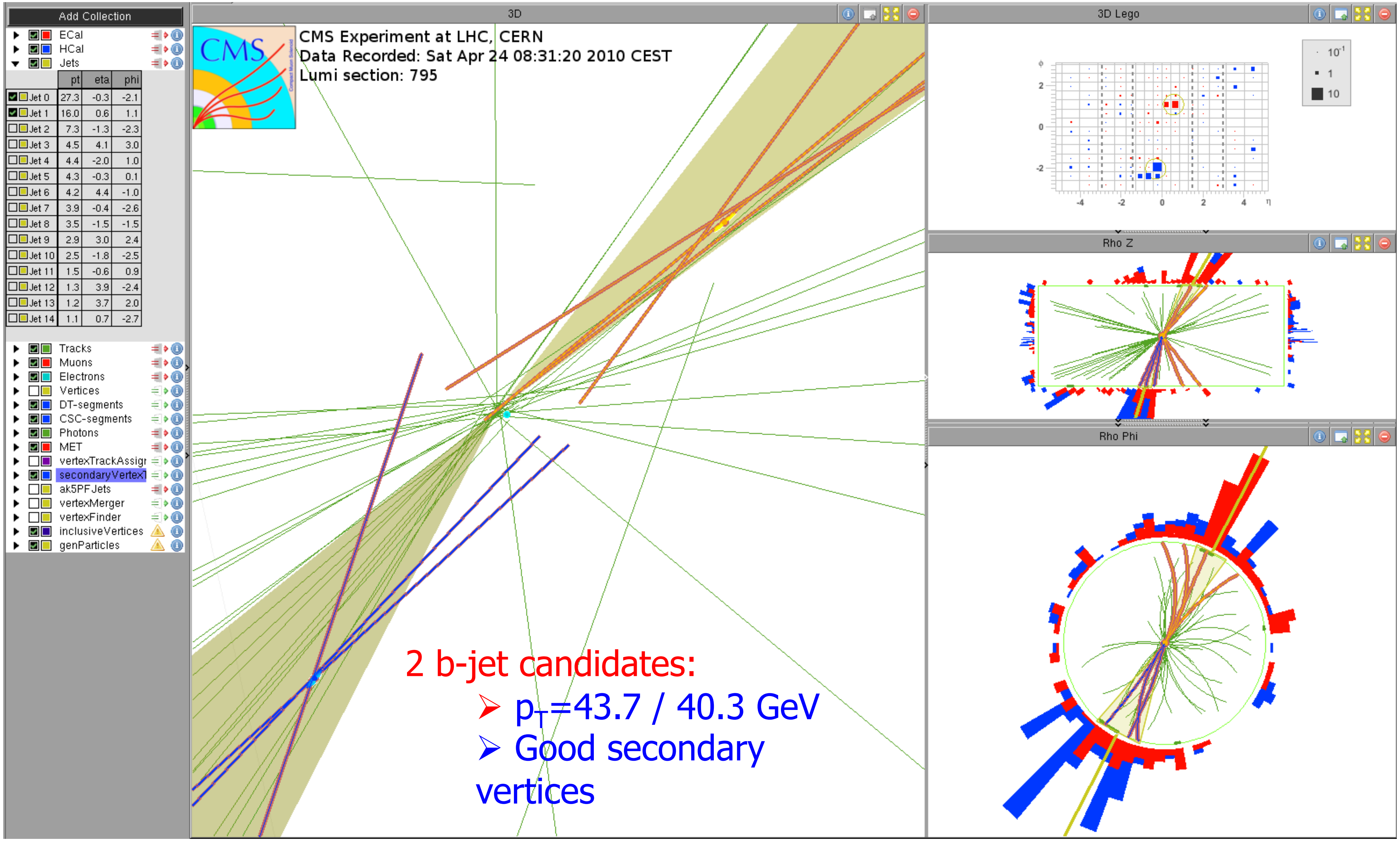








Physics objects: b-jet candidates

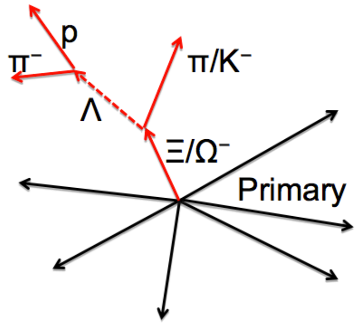


2 b-jet candidates:

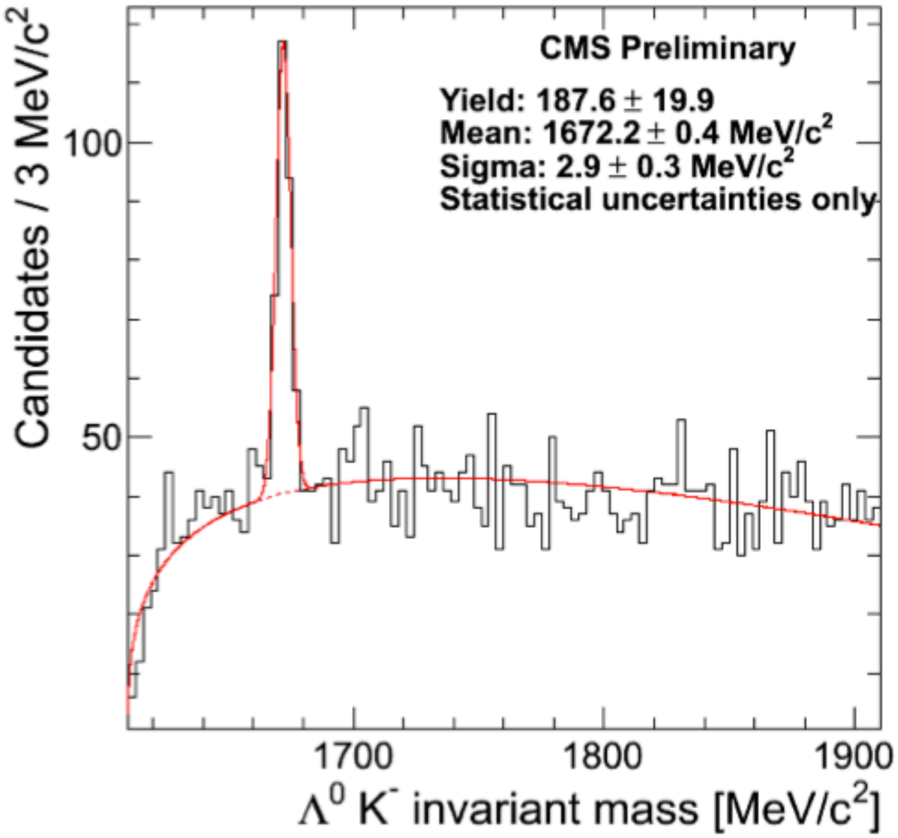
- p_T=43.7 / 40.3 GeV
- Good secondary vertices

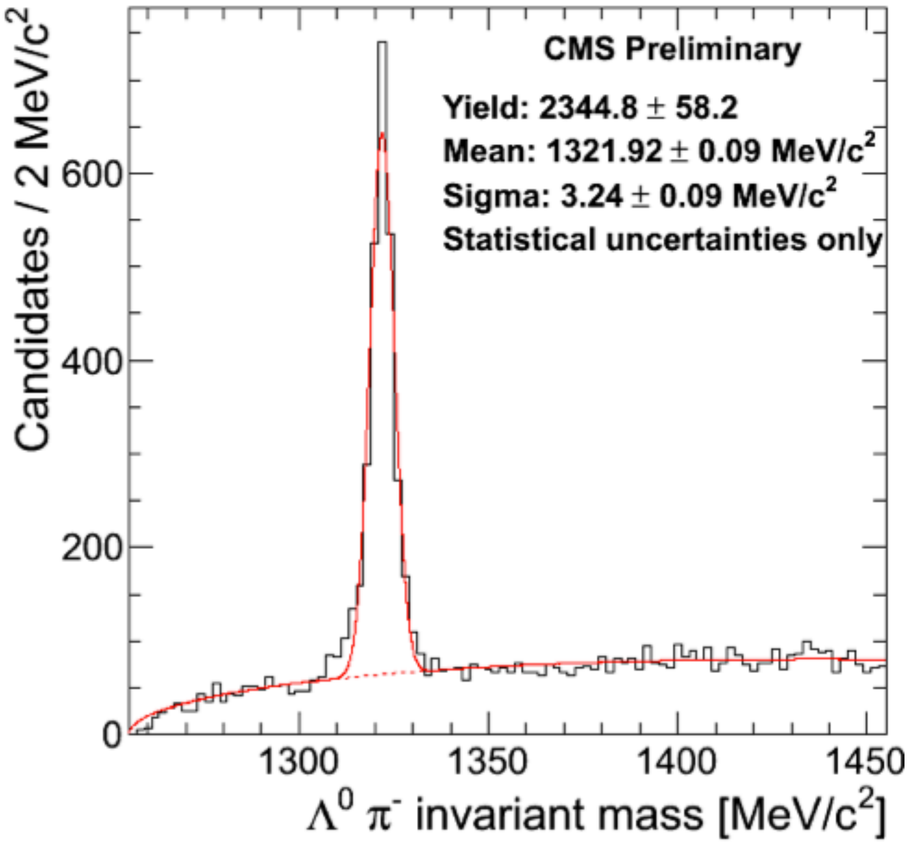
First results: low mass resonances

- Tracks displaced from primary vertex ($d_{3D} > 3\sigma$)
- Common displaced vertex ($L_{3D} > 10\sigma$)

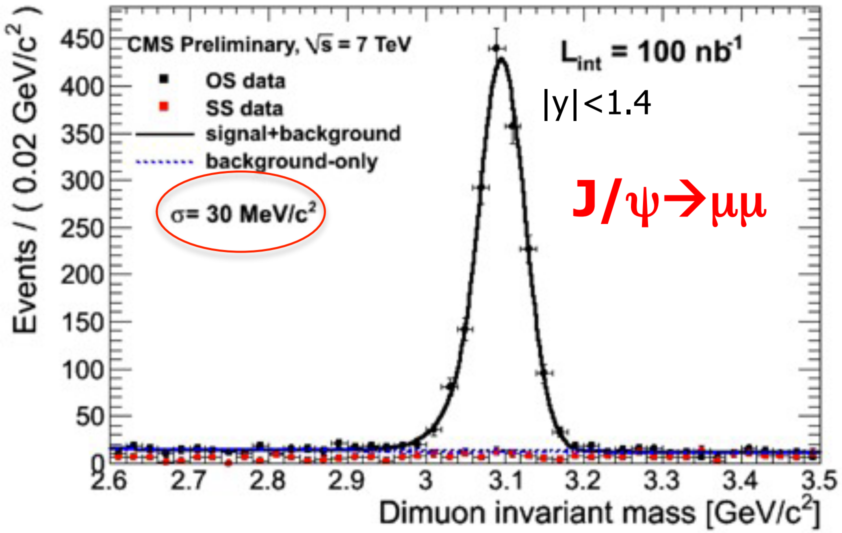


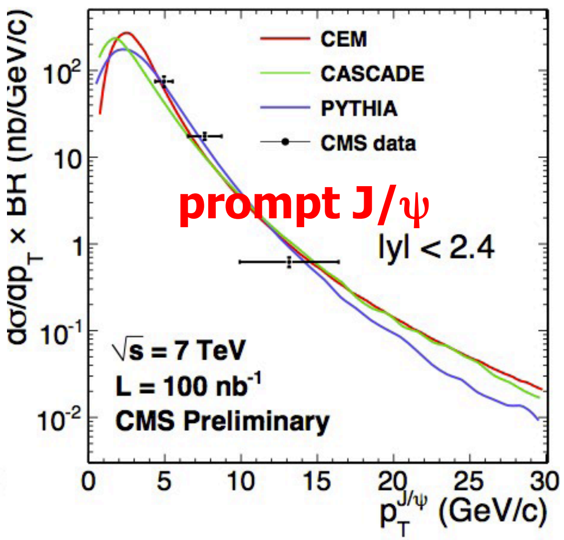
Invariant mass distribution for different combinations ($\Omega^{\pm} \to \Lambda K^{\pm}$ or $\Xi^{\pm} \to \Lambda\pi^{\pm}$) fit to a common vertex.

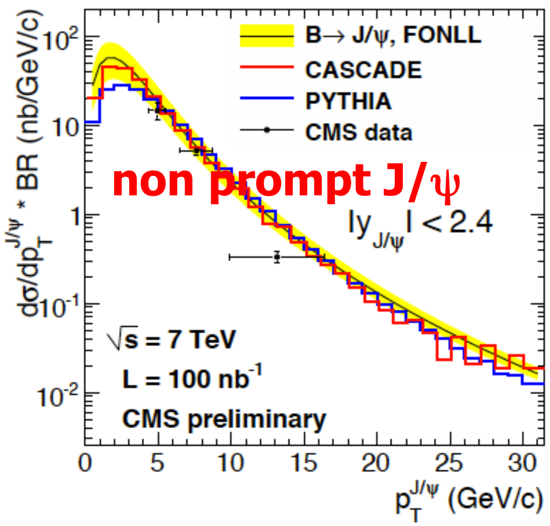




J/ψ and Υ







$\sigma^{j/\psi}_{INCL}$ * BR= **289.1 ±16.7(stat)±60.1(syst) nb** (p_T within 4-30GeV/c, $|\eta|<2.4$)

For non prompt j/ψ : σ_{NP}* BR= **56.1±5.5(stat)±7.2(syst) nb** (p_T within 4-30GeV/c, $|\eta|<2.4$)

Systematics:

Efficiency

- T&P using J/ψ, binning effects and factorization assumption using MC

Acceptance

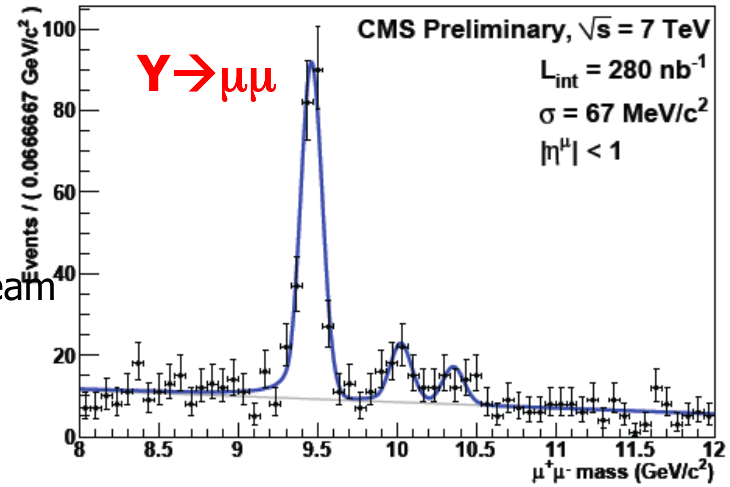
- p_T spectrum shape, FSR, momentum scale and resolution, beam spot position, material effects

Yield extraction

- validated with toy MC studies, effect of modified PDF

b fraction fit

- residual misalignment, pseudo proper time PDF, resolution function



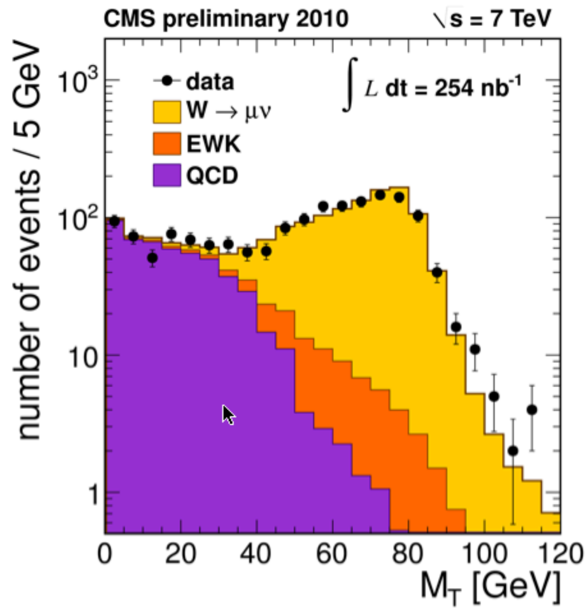
σ(Υ(1S)X)·BR(Υ(1S)→ μ μ)=**(8.3±0.5±0.9±1.0) nb**

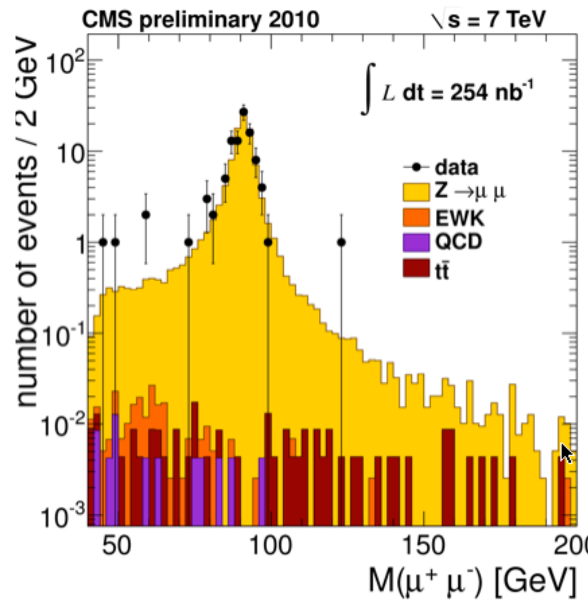
σ(Υ(2S)X)+ σ(Υ(3S)X)]/ σ(Υ(1S)X)=**0.44 ±0.06±0.07**

W and Z

Muons

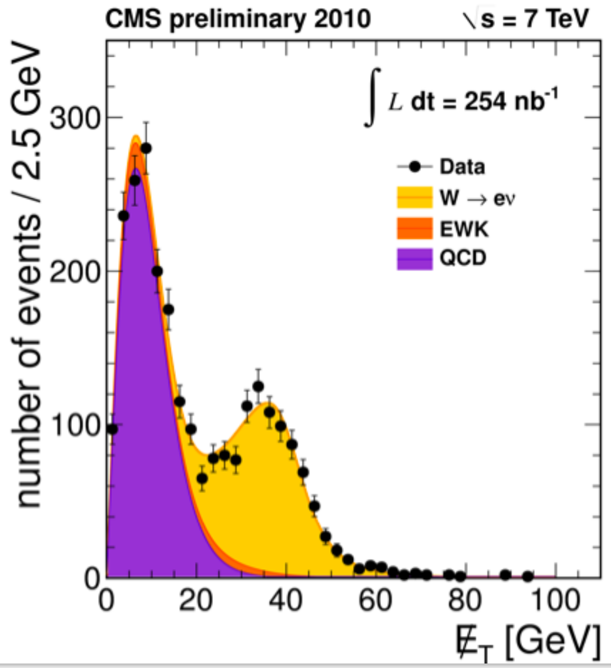
- Kinematics
  - For W, $p_T > 9$ GeV, $|\eta| < 2.1$
  - For Z, $p_T > 20$ GeV, one $|\eta| < 2.4$
- Good quality muon track
  - Hits in pixels, strip tracker, muon system)
  - χ^2/dof < 10
- Z measurement requires only track isolation of 3 GeV in a cone
- For W measurement, use a relative isolation in a cone of $\Delta R < 0.3$

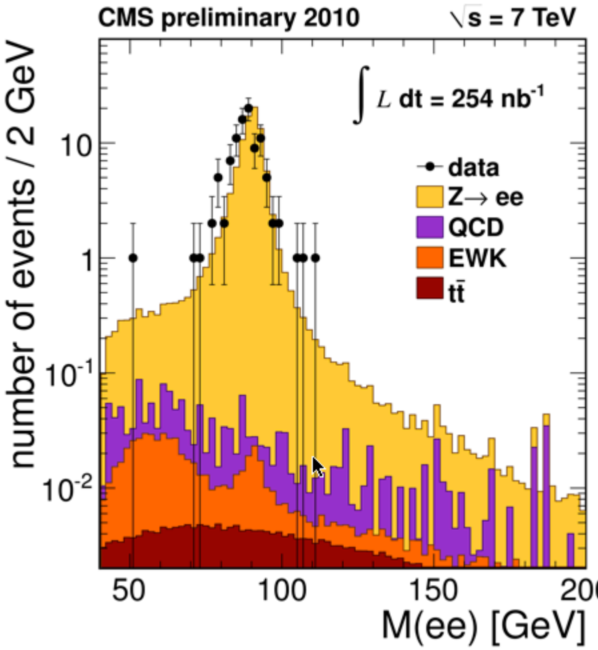




Electrons

- Kinematics
  - $p_T > 20$ GeV
  - $0.0 < |\eta| < 1.442$
  - $1.566 < |\eta| < 2.5$
- Specialized track reconstruction to deal with potential large bremsstrahlung
- Electron identification requirements on shower shape variables
- Isolation requirements in tracker ECAL, HCAL





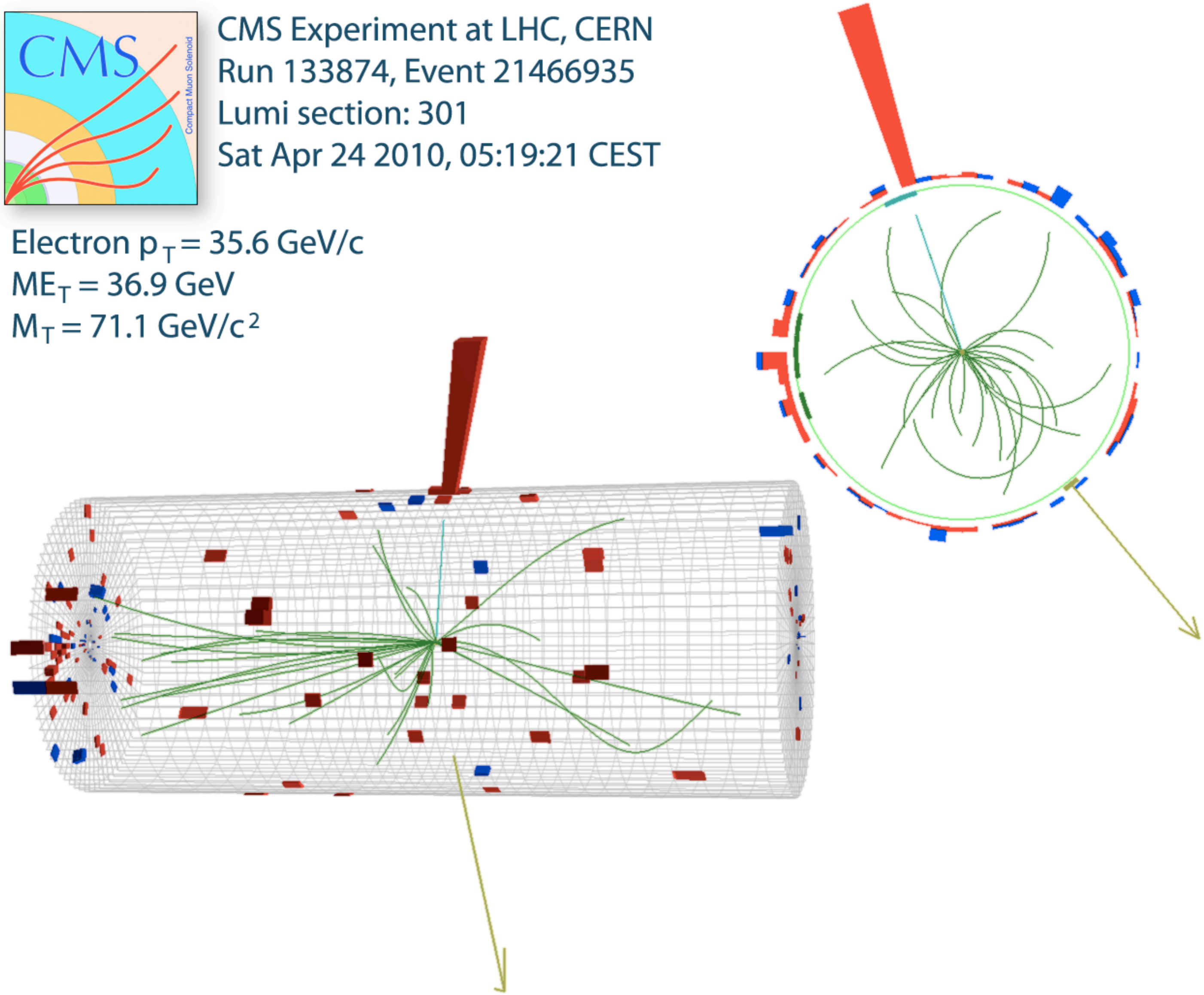
Systematic uncertainties on W/Z

- Efficiencies and scales studied in Z and W events via T&P
- Background uncertainties from cut inversion studies and control samples
- PDF uncertainties evaluated via CTEQ66, MSTW08NLO, NNPDF2.0 sets

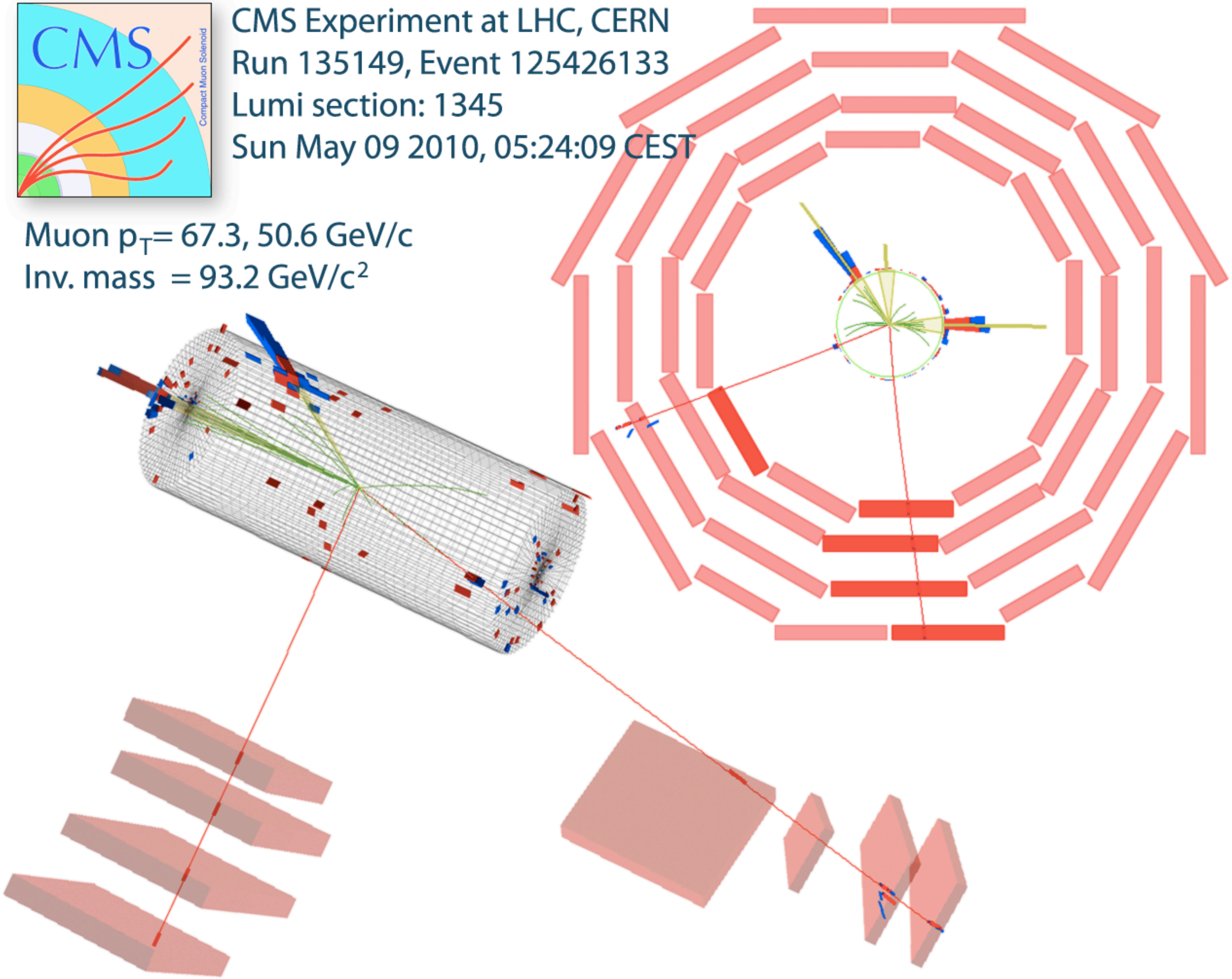
Source	$W \to \mu\nu$ (%)	$W \to e\nu$ (%)
Lepton reconstruction	3.0	6.1
Trigger Efficiency	3.2	0.6
Isolation Efficiency	0.5	1.1
Momentum/energy scale	1.0	2.7
MET scale and resolution	1.0	1.4
Background subtraction	3.5	2.2
PDF uncertainty in acceptance	2.0	2.0
Other theoretical uncertainties	1.4	1.3
Total systematic error	6.3	7.7
Luminosity uncertainty	11.0	11.0

Source	$Z \to \mu\mu$ (%)	$Z \to ee$ (%)
Lepton reconstruction	2.5	7.2
Trigger Efficiency	0.7	-
Isolation Efficiency	1.0	1.2
Momentum/energy scale	0.5	-
PDF uncertainty in acceptance	2.0	2.0
Other theoretical uncertainties	1.6	1.3
Total systematic error	3.8	7.7
Luminosity uncertainty	11.0	11.0

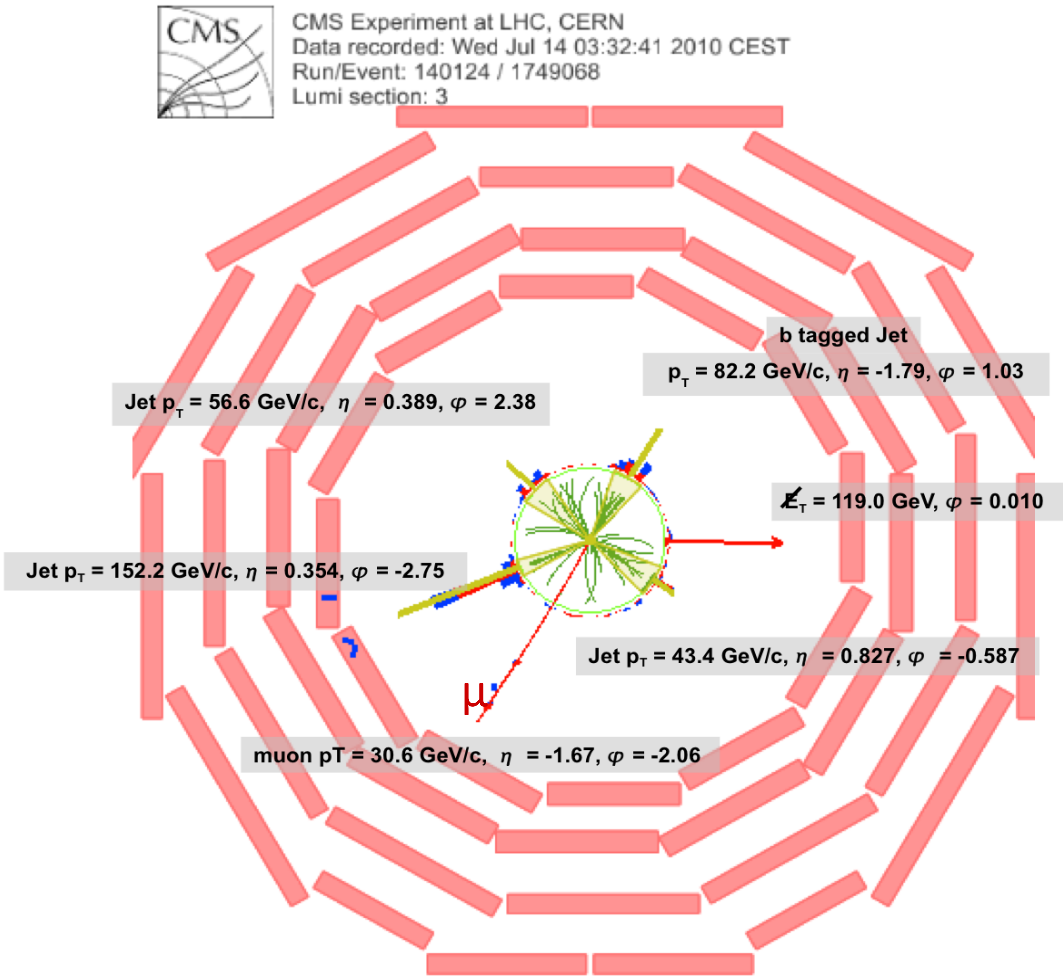
W→eν candidate



Z→μμ candidate



μ + jets candidate: first top?



Event passes all cuts of full selection

1 high-momentum muon

significant MET > 100

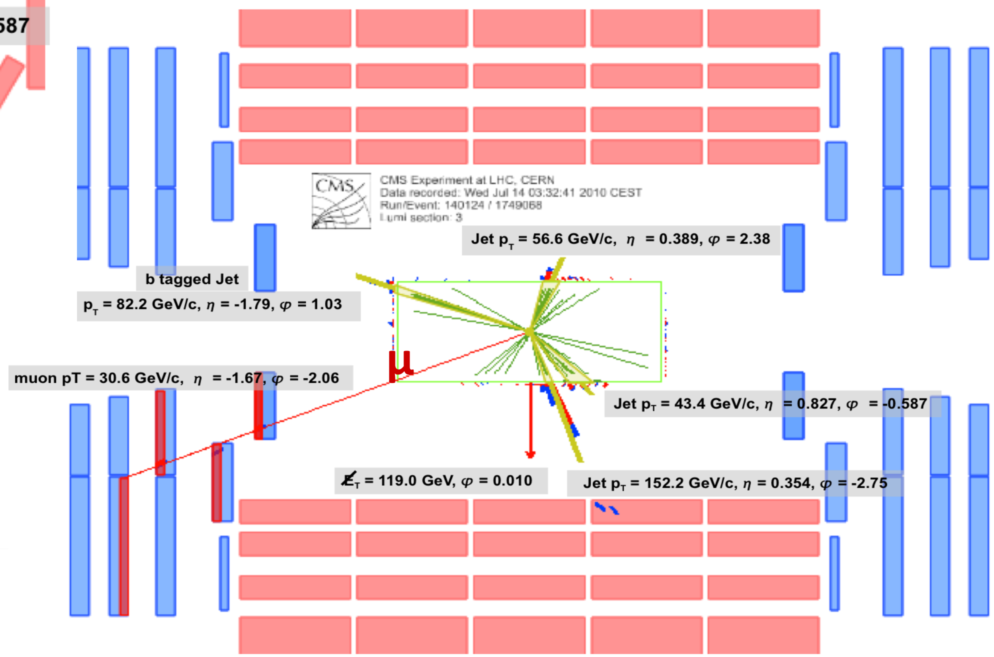
m_T(W) = 104 GeV/c^2

4 high-p_T jets,

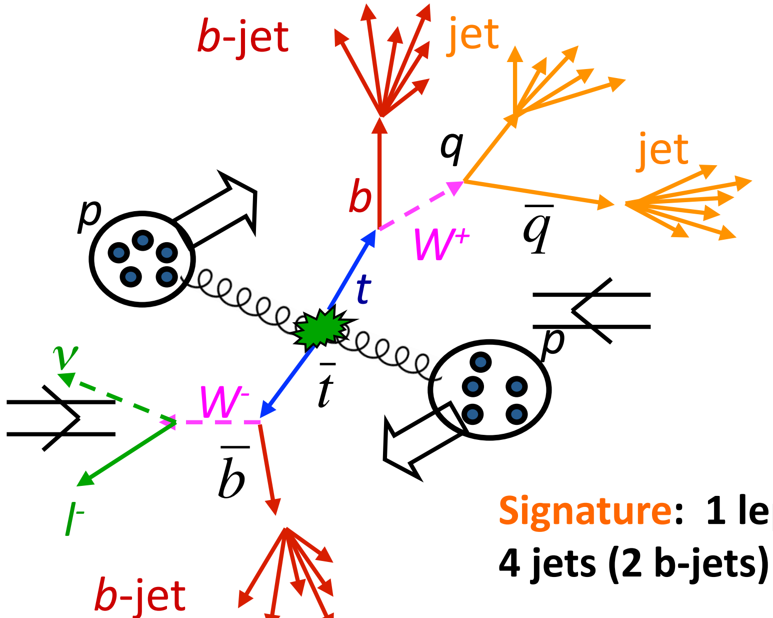
one of which with good *b*-tag

reconst. top mass around 210 GeV/c^2

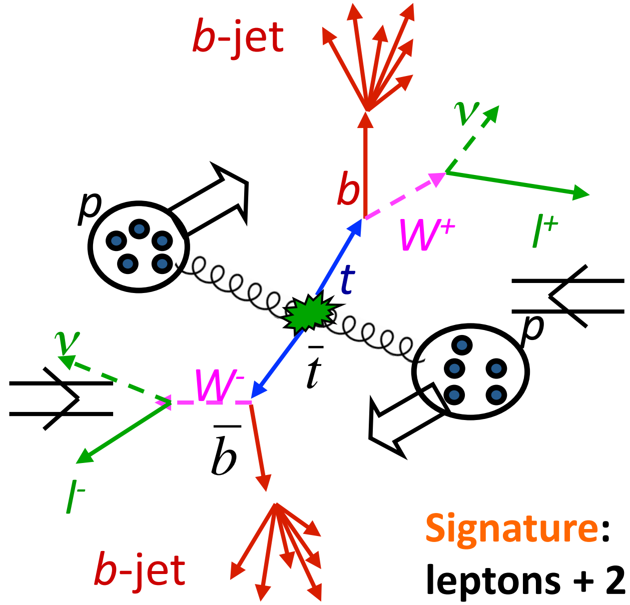
masses of 2 untagged jets (3 possible comb.): 104, 105, 151 GeV/c^2



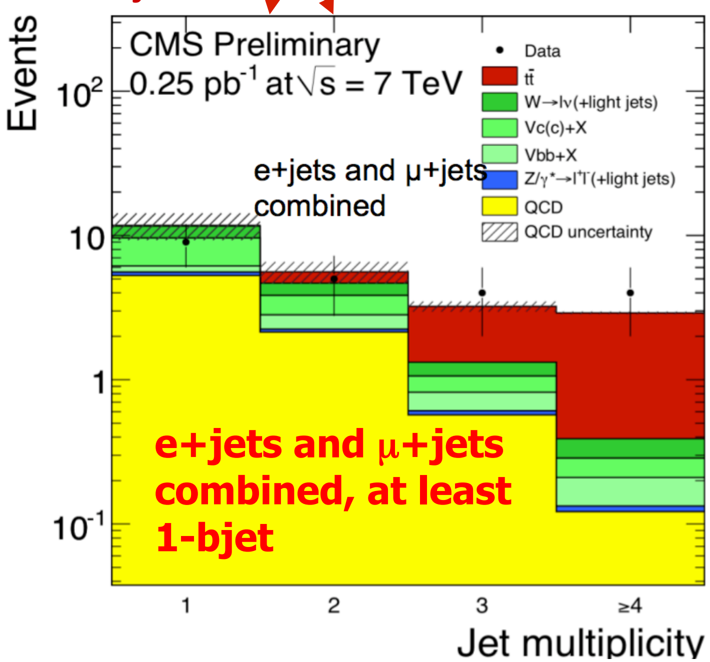
Searching for top quark

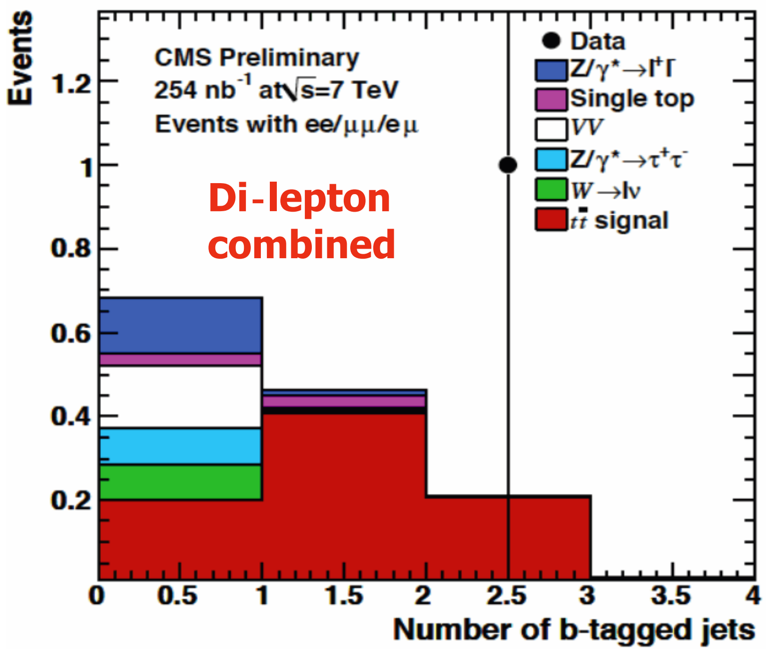


Signature: 1 lepton + 4 jets (2 b-jets)

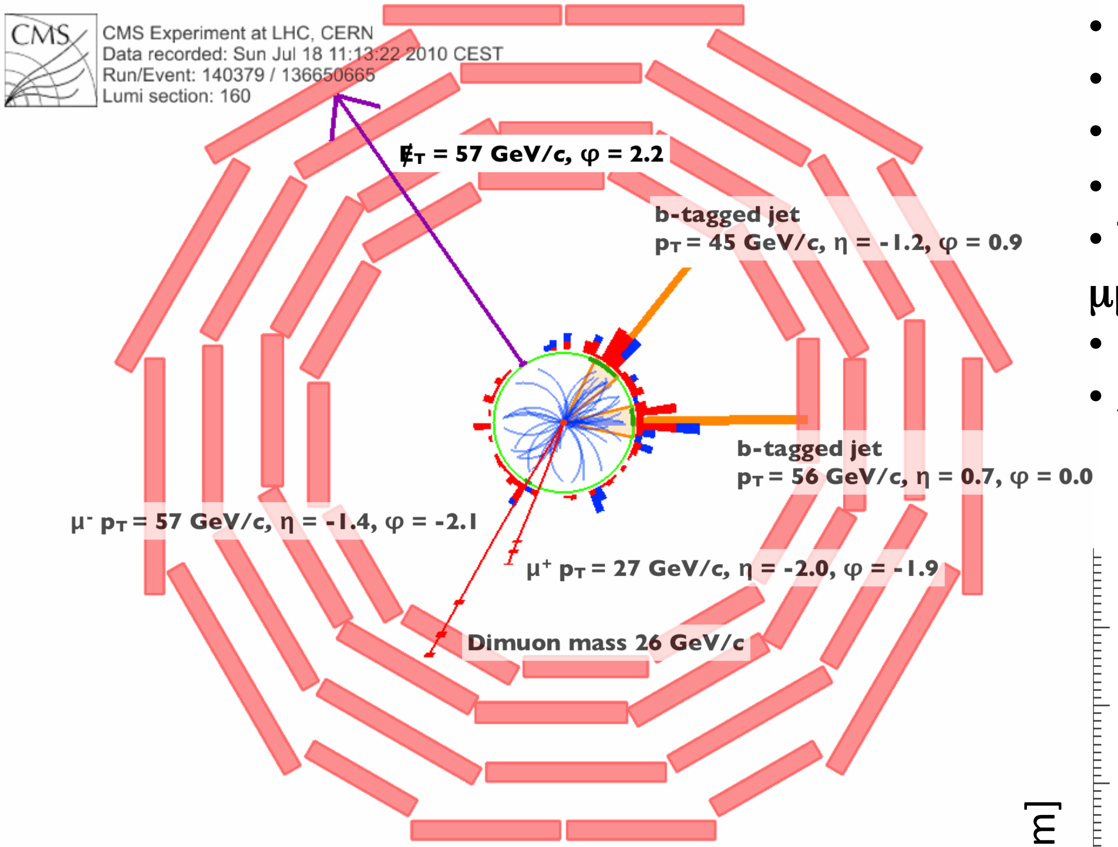


Signature: 2 leptons + 2 b-jets

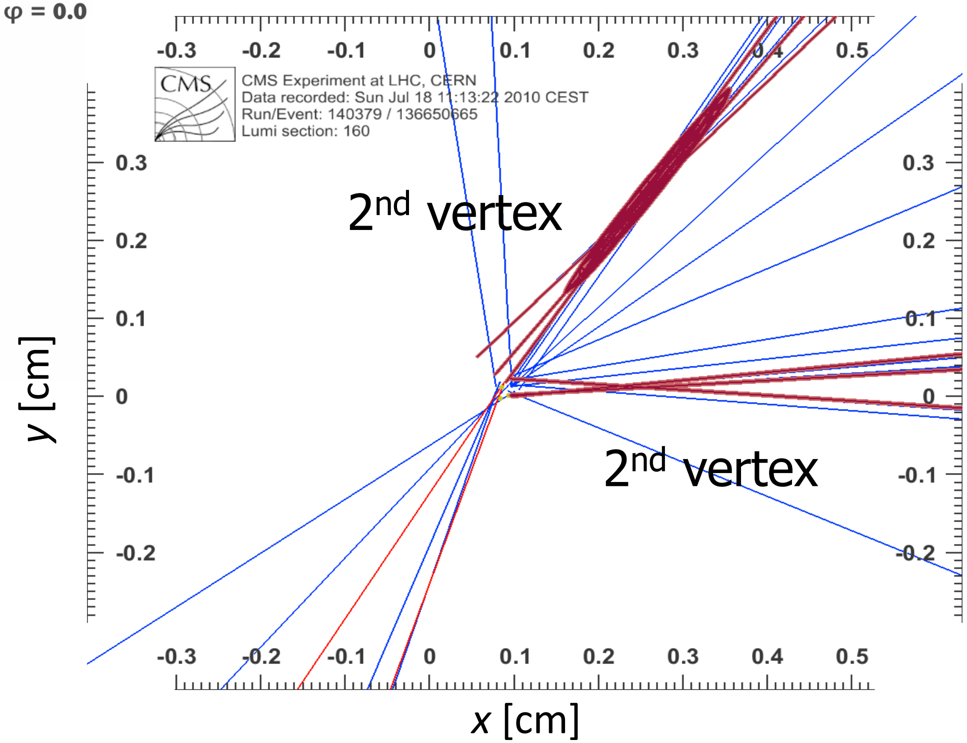




$\mu\mu$ + jets candidate: first top?



- HLT: $p_T(\mu)>9$ GeV/c , $p_T(e)>15$ GeV/c
- 2 prompt isolated lept. with $p_T>20$ GeV/c
- e: $|\eta|< 2.4$, μ: $|\eta|< 2.5$
- Comb Rel Iso < 15 %
- Track Corrected MET> 30(20) GeV for ee/ $\mu\mu$ ($e\mu$)
- Z Boson veto in 76-106 GeV/c^2
- AKt5 Jets $|\eta|<2.4$, E_T>30GeV



m($\mu\mu$) = 26 GeV/c^2, MET=57 GeV, two high p_T Jets, both with b-tagging

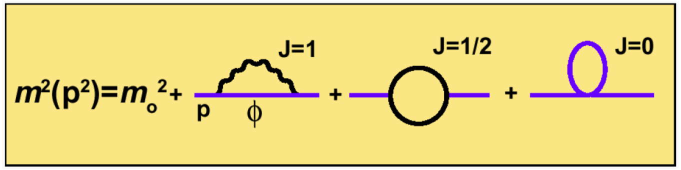
Reconstr. mass in the range 160–220 GeV/c^2 (consistent with m_{top})

Theoretical constraints on SM Higgs

Unitarity:

$$M_H < 700 - 800\ GeV/c^2$$

Triviality (Higgs self-coupling remains finite and blows up at some scale Λ):

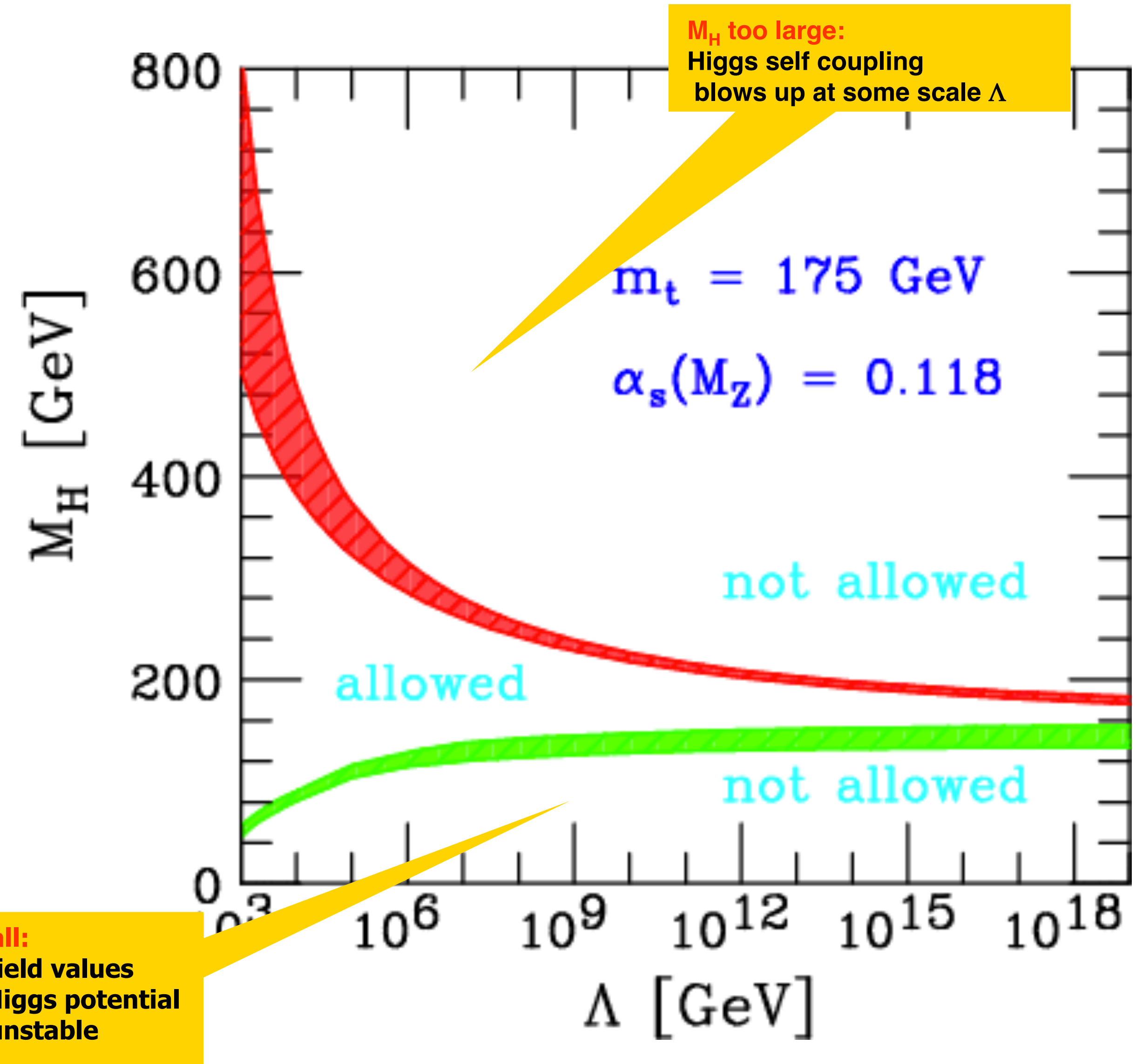


$$M_H^2 < \frac{4\pi^2 v^2}{3\ln(\Lambda/v)}$$

Stability of vacuum:

$$M_H^2 > \frac{4m_t^4}{\pi^2 v^2}\ln(\Lambda/v)$$

Λ = cut-off scale



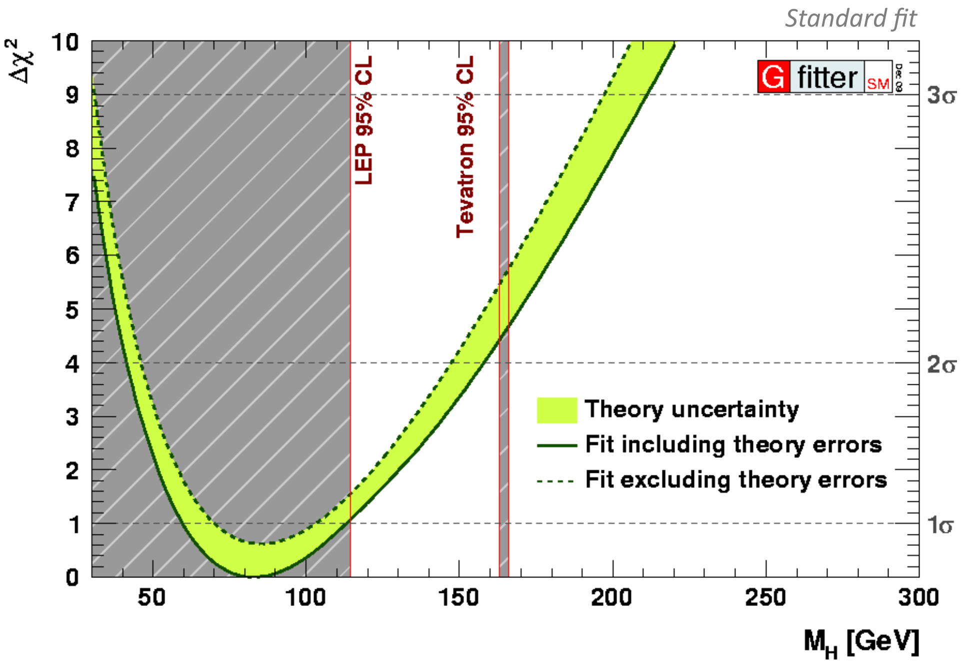
Constraints on SM Higgs from EW precision data

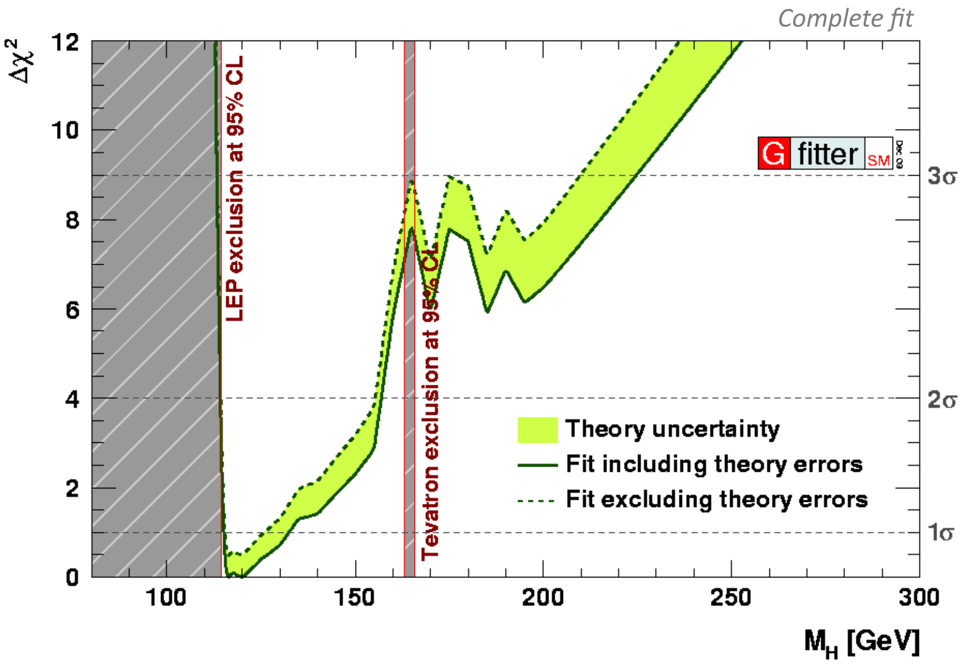
M_H from Standard fit: (all data except for direct Higgs searches)

- Central value $\pm1\sigma$: $M_H = 83^{+30}_{-23}$ GeV
- 2σ interval: [42, 158] GeV

M_H from Complete fit: (all data including direct Higgs searches)

- Central value $\pm1\sigma$: $M_H = 119^{+13}_{-4.0}$ GeV
- 2σ interval: [114, 157] GeV





H→γγ: basic concepts

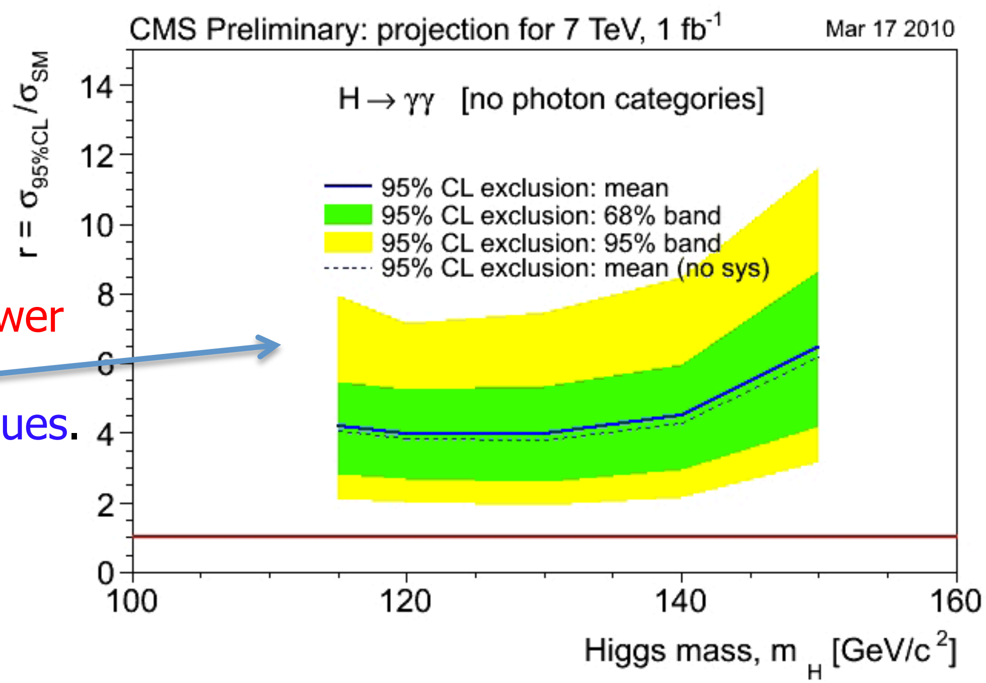
Important channel for Higgs with 110< m_H<140 GeV because **clear signature** but small B.R. (0.2%)

Backgrounds:

irreducible (gg→γγ, qqbar, qg→γγ, pp→γ+jets (2 prompt γ)
reducible (pp→γ+jets (1 prompt γ + 1 fake γ), pp→jets (2 fake γ), fake γ from π^0→γγ

Analysis strategy based on:

- trigger (double photon HLT)
- photon reconstruction
- primary vertex reconstruction
- photon isolation
- categories of events based on the photon shower shape (R_9) to optimize s/b
- look for a peak with cut-based or MVA techniques.



Pros: Clean photon ID, projected 0.7% mass resolution.
Cons: High background rate; state-of-art ECAL calibration needed.

4^{th} fermion generation: impact on higgs

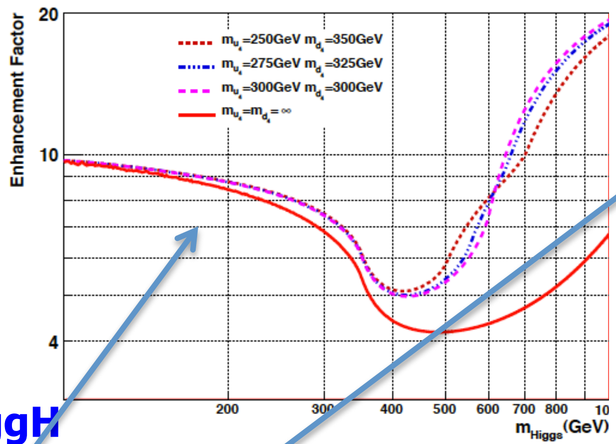
Main constraints:

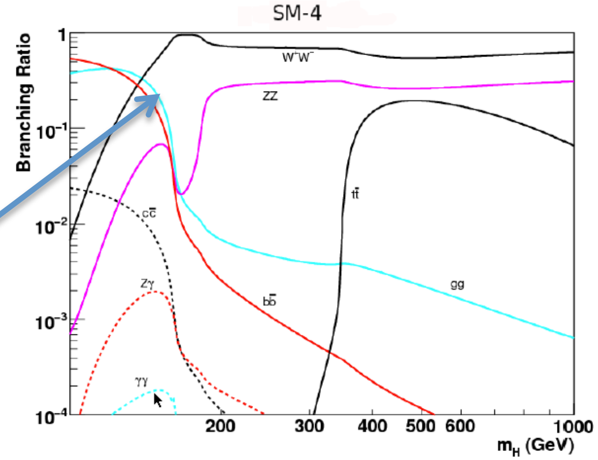
- Invisible Z width at LEPI:
  $M_{\nu 4}$>50 GeV
- Direct searches at Tevatron:
  $M_{\nu 4}$>256 GeV
- LEP2 bounds for unstable ν4 :
  $M_{\nu 4}$>100 GeV

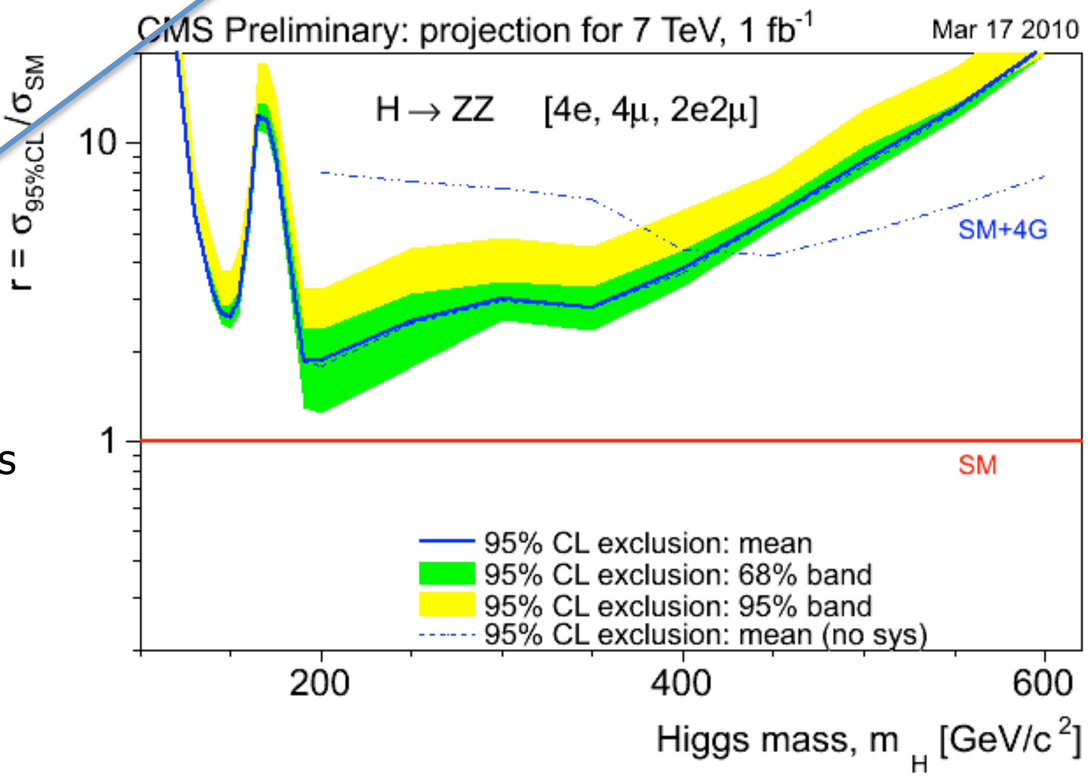
Additional quarks enhance by x3 ggH coupling:

- Higgs production **cross sections**:
  - gg→H enhanced by ~**x9**!
  - VH and VBF remain at SM rate
- Higgs decay **BRs**:
  - H→gg significantly increased at low mass
  - H→WW and H→ZZ dominant modes for m_H>135 GeV

Current Tevatron m_H limit extend to :
131<M_H<204 GeV/c² excl.@ 95% C.L..



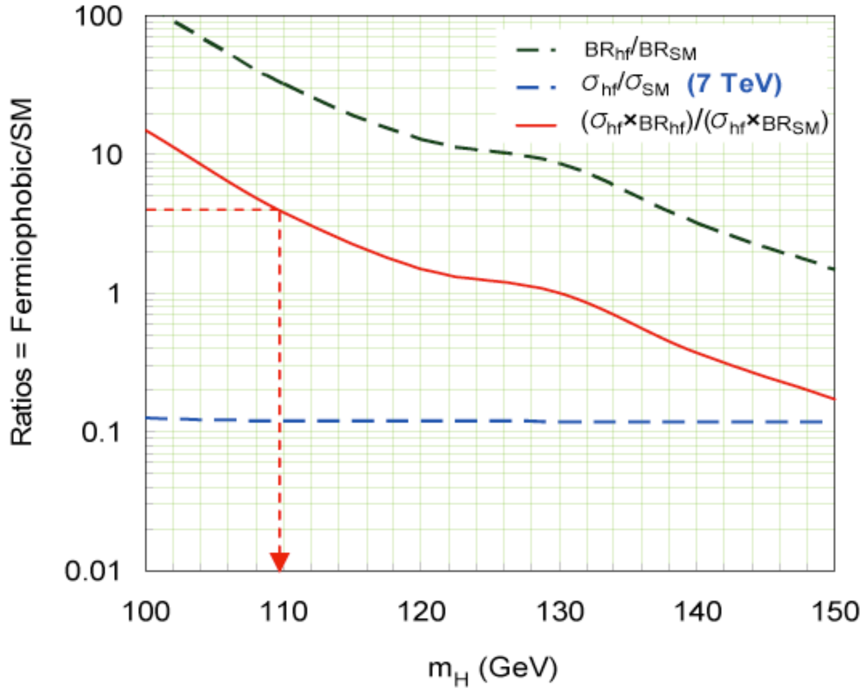




Fermio-phobic Higgs

- There are models with an Higgs responsible for the EWK symmetry breaking but does not couple with fermions

- Fermio-phobic h_f:
  - loss of cross section (VBF+VH only, no gg)
  - gain in BR $h \rightarrow \gamma\gamma$ (no $h_f \rightarrow bb$)
  - overall gain in s·BR for low masses



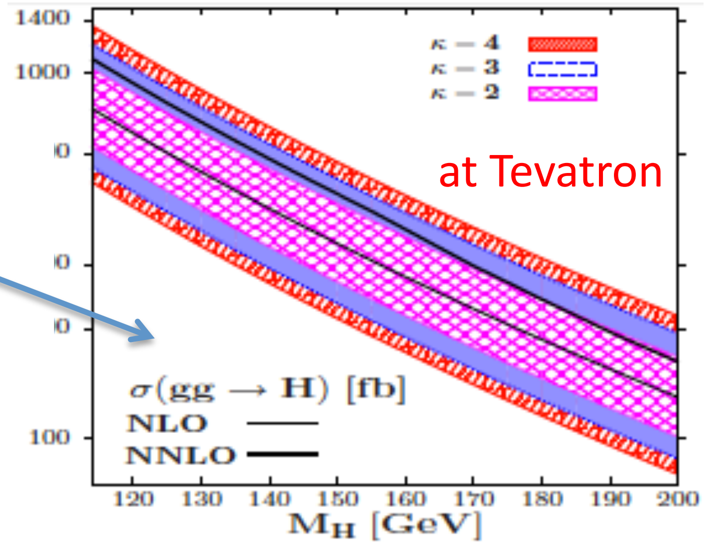
- $H \rightarrow \gamma\gamma$ upper limit (m_H=120 GeV/c^2) at 7 TeV and 1 fb^{-1} is about 4 s_{SM}

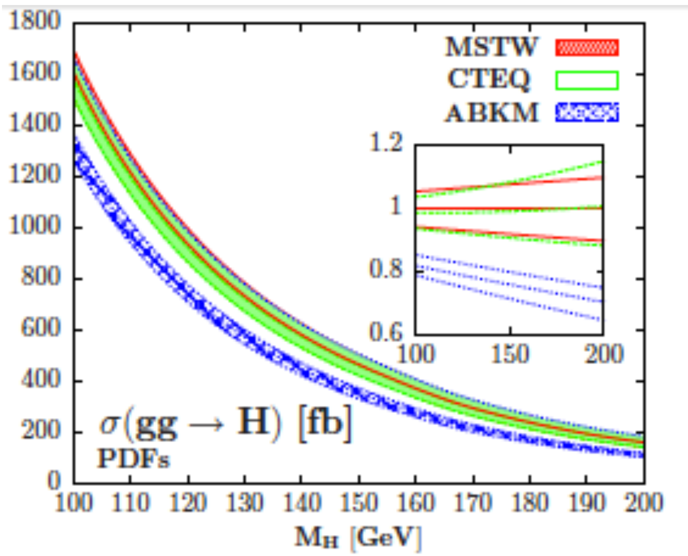
- **Projection:** with 7 TeV, 1fb^{-1},
  CMS could exclude up to m_H<110 GeV (since the yield $\sigma(pp \rightarrow h_f)$ x $BR(h_f \rightarrow \gamma\gamma)$ for the fermio-phobic Higgs boson at 7 TeV is >4 for m_H<110 GeV)

Impact of theoretical uncertainties

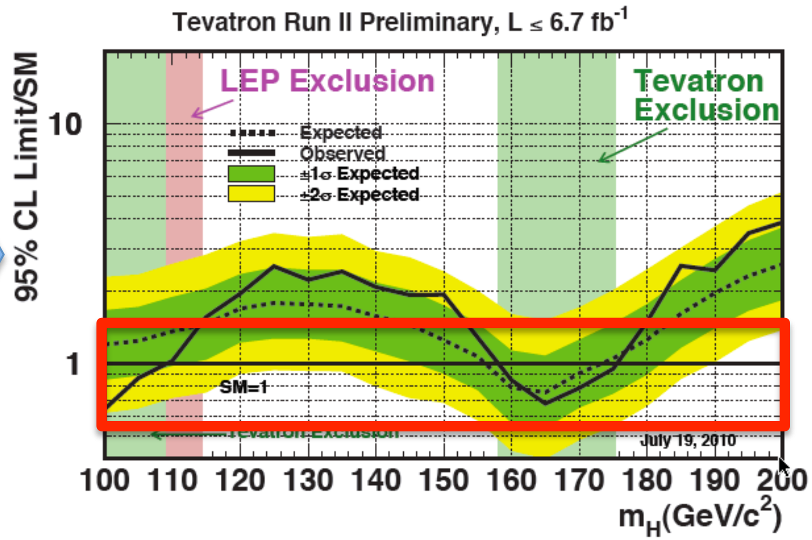
Cross section uncertainty from:

- cross section through NNLO QCD
- renormalization/factorization scale
- parton densities
- inclusion of exact quark mass effects through NLO
- inclusion of known electroweak corrections

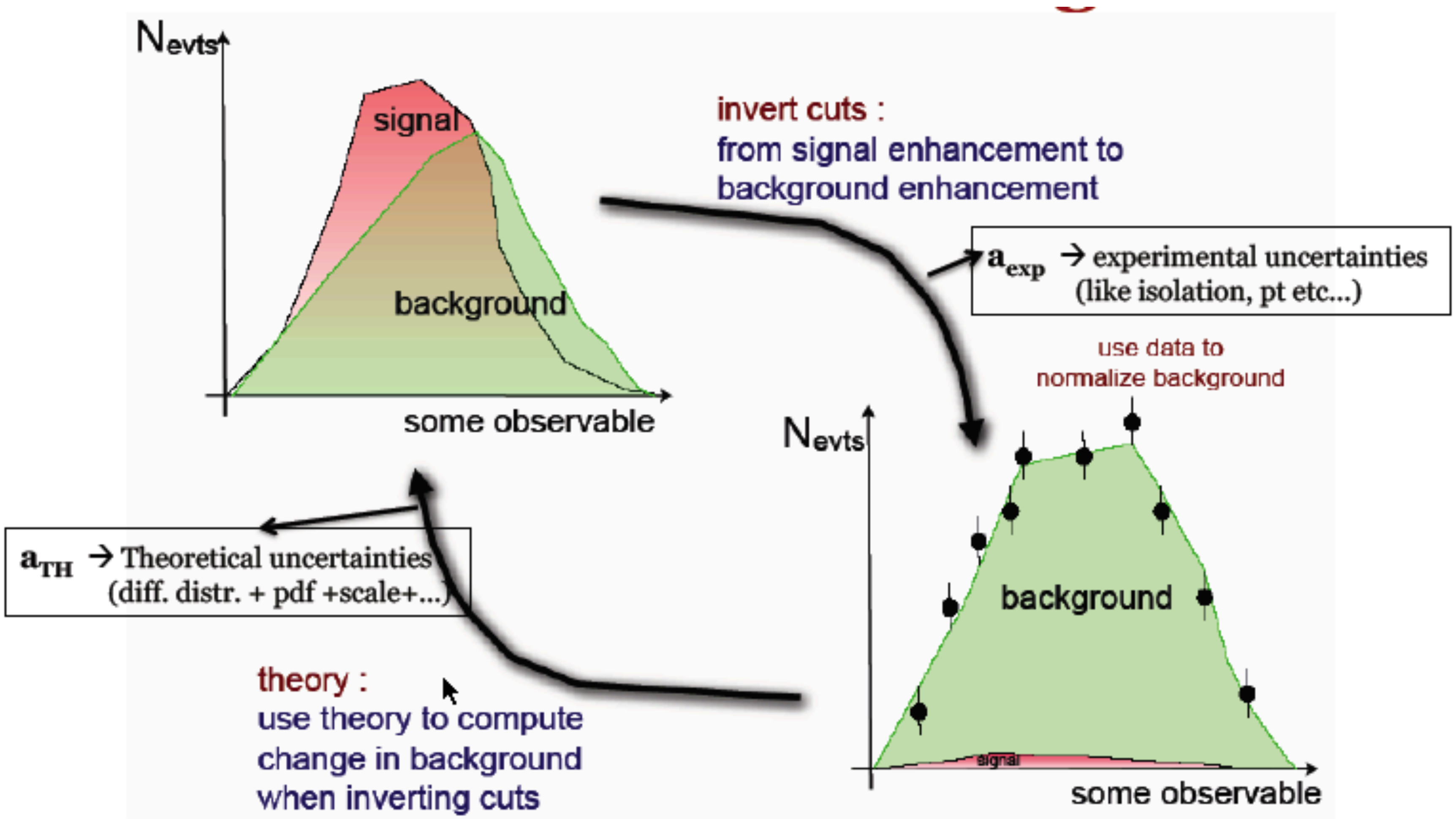




gg → H: ±40% uncertainty at Tevatron (20% at LHC)



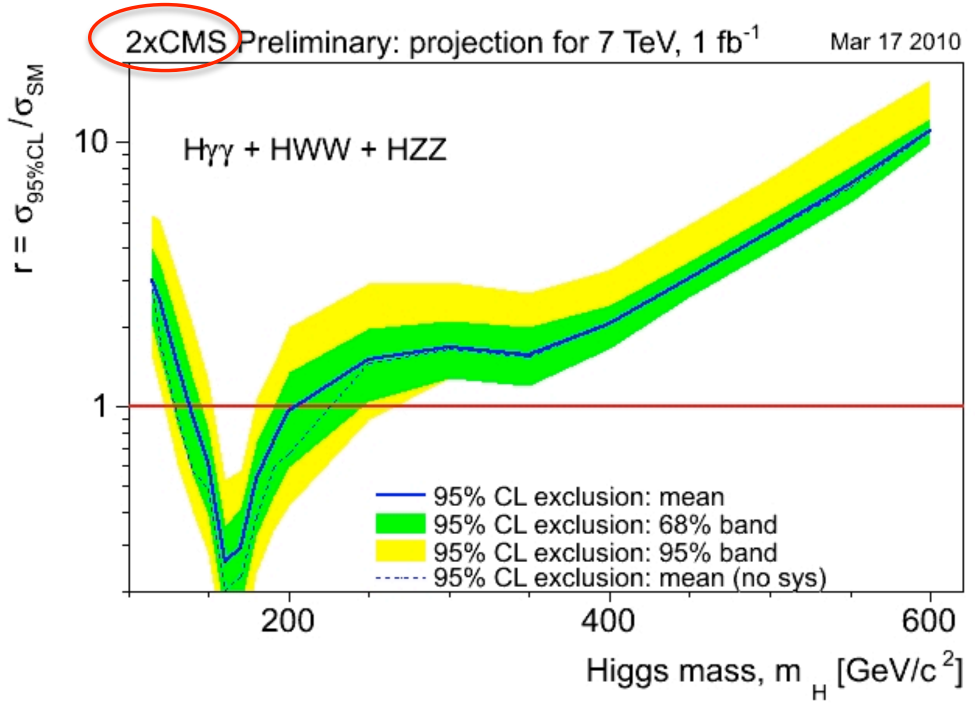
Background control from data

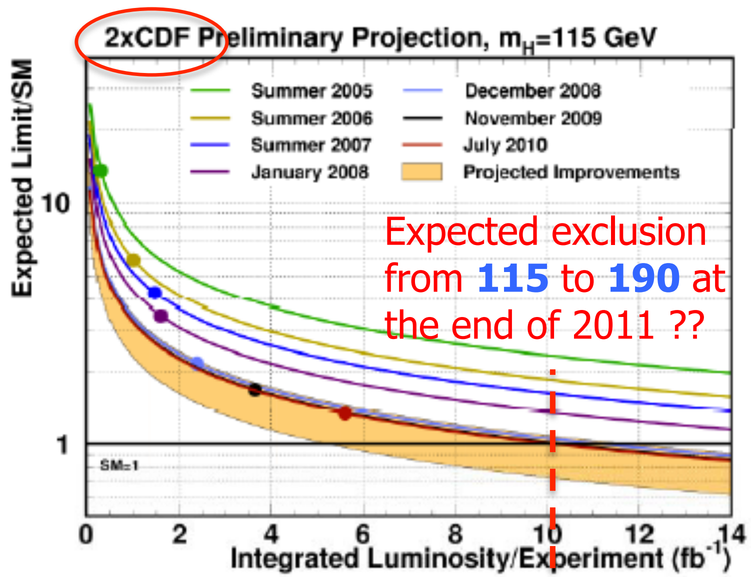


- $N^B_{(\text{signal region})} = a_{exp} * a_{TH} * N^B_{\text{control region}}$

a_{exp} - uncorr between exp
a_{TH} - 100% correlated

Analysis combination: LHC vs Tevatron



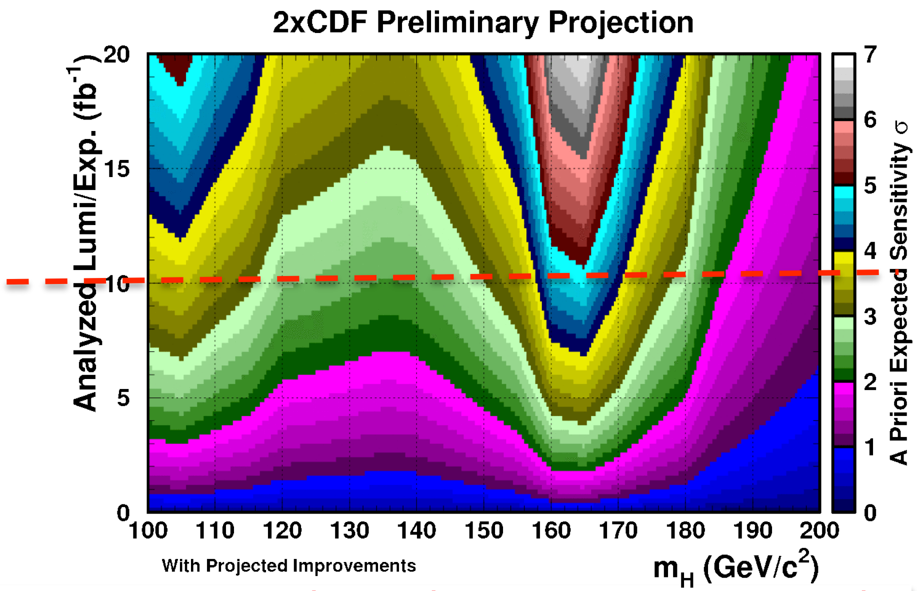


The expected exclusion mass range for the SM Higgs is $140<m_H<200$ GeV

but…

-- projection are very conservative

-- we are moving towards combining analysis for other channels to gain sensitivity



> 2.4σ expected over the entire mass range at the end of 2011 ??

What is SUSY?

Supersymmetry (SUSY) : Symmetry between

Bosons $\leftrightarrow$ Fermions

Q |Fermion⟩ $\rightarrow$ |Boson⟩

Q |Boson⟩ $\rightarrow$ |Fermion⟩

Simplified examples:

Q |top, t⟩ $\rightarrow$ |scalar top, $\tilde{t}$⟩

Q |gluon, g⟩ $\rightarrow$ |gluino, $\tilde{g}$⟩

Unbroken SUSY: All particles in a multiplet have the same mass

Reality: $m_e \neq m_{\tilde{e}} \Rightarrow$ SUSY is broken . . .

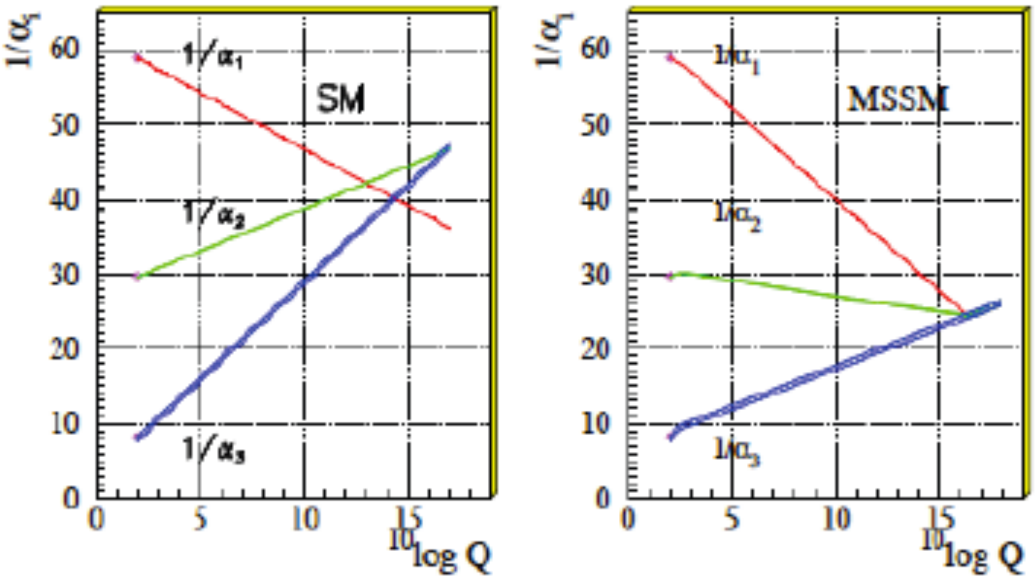
. . . via soft SUSY-breaking terms in the Lagrangian (added by hand)

SUSY particles are made heavy: $\boxed{M_{\mathrm{SUSY}} = \mathcal{O}(1\ \mathrm{TeV})}$

Five reasons as a SUSY motivation

1.) Stability of the Higgs mass against higher-order corr.
2.) Unification of gauge couplings: Not possible in the SM, but in the MSSM (although it was not designed for it.)
3.) Spontaneous symmetry breaking via Higgs mechanism is automatic in SUSY GUTs
4.) SUSY provides CDM candidate
5.) . . .

Unification of the Coupling Constants in the SM and the minimal MSSM



mSUGRA benchmark points

Characterized e.g. in CMSSM

$m_0, m_{1/2}, \tan\beta, A_0, sign(\mu)$

$m_{1/2}$	:	Common gaugino mass at the GUT scale
m_0	:	Scalar mass parameter at the GUT scale
A_0	:	Trilinear coupling at the GUT scale
$\tan\beta$	:	Ratio of Higgs VEVs at the weak scale
$\mathrm{sgn}(\mu)$	:	Sign of higgsino mass parameter at the weak scale

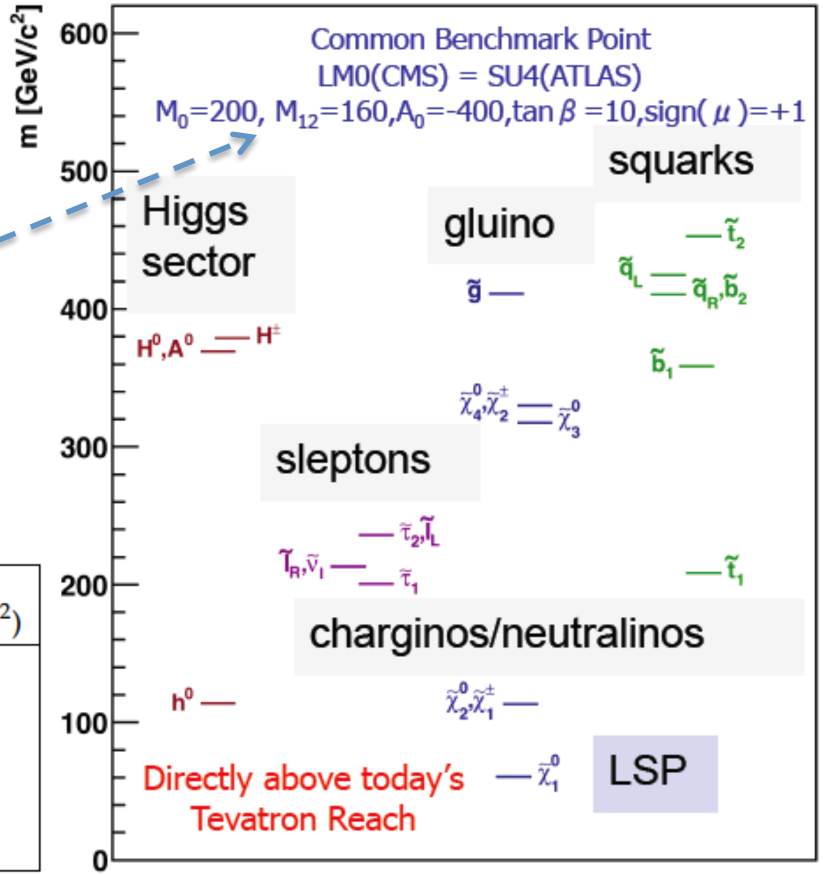
Advantage:

- Only four free parameters (when sign(μ) fixed)
- One of the most studied incarnations of the MSSM
- Not yet ruled out by data

Disadvantage:

- Not fully representative of SUSY (e.g. fixed mass relation between M_{gluion} and M_{LSP})

Note: The alternative approach of using M_{gluino} vs M_{squark} exploits the same mass relation and thus is also very CMSSM-like !



Sample	m_0 (GeV/c²)	$m_{1/2}$ (GeV/c²)	A_0	$\tan\beta$	sign(μ)	σ LO (pb)	lightest $\tilde{q}$ (GeV/c²)	χ_1^0 (GeV/c²)
LM0	200	160	-400	10	+	110	207	60
LM1	60	250	0	10	+	16.1	410	97
LM2	185	350	0	35	+	2.4	582	141
LM3	330	240	0	20	+	11.8	446	94
LM4	210	285	0	10	+	6.7	483	112
LM5	230	360	0	10	+	1.9	603	145

Same-sign di-lepton analysis

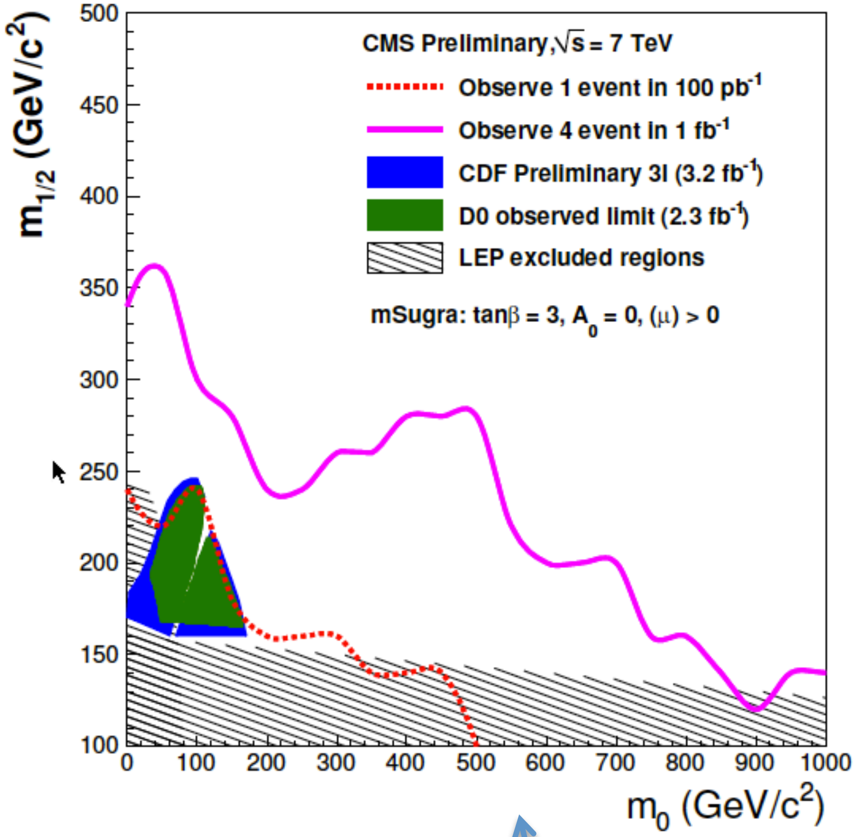
Signature: SS di-lepton + missing E_T

Background:

-- the Standard Model does not produce same-sign, isolated di-lepton very frequently apart from **ttbar**

-- spurious sources of SS di-lepton events from charge mis-measurement or heavy flavor decays

95% C.L. upper limit contour



Combining $\mu^\pm\mu^\pm$, $e^\pm e^\pm$, $\mu^\pm e^\pm$

TeV resonances: $Z' \rightarrow e^+e^-$

Massive gauge bosons expected in several models; **Z'** in SSM (sequential standard model), **G** in Randall-Sundrum model Phys. Rev. Lett. **83** (1999) 3370–3373

Main bkg: DY, tt, tW, WW, QCD, W+jets, γ+jets, $\gamma\gamma$

Some features:

-- E_T>25 GeV, identification and isolation criteria

-- high energy deposition in ECAL crystals (response of ECAL for E_T>300 GeV not tested in test beam) evaluated by using energy deposits in surrounding crystals

-- measurement of DY cross section and the contribution of the tail fundamental

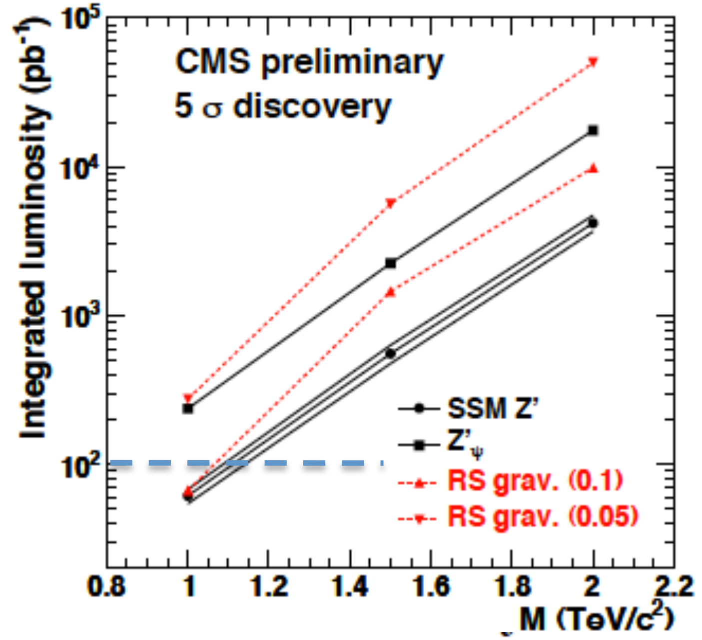
-- efficiency checked using Tag & Probe with Z from data and in DY tail for M>120 GeV/c^2 → 4% system. uncertainty

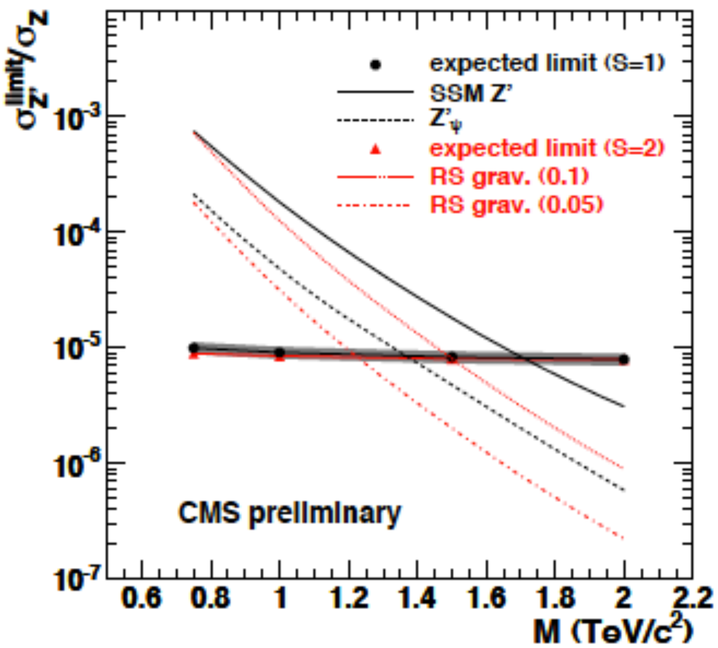
Tevatron limits:

-- Z': 700-900 GeV/c^2 (depending on the model) for Z' bosons

-- RS gravitons: 900 (300) GeV/c^2 for c = 0.1 (0.01)

→ sensitivity of the Tevatron searches superseded with about 100 pb^{-1} of 7 TeV data.



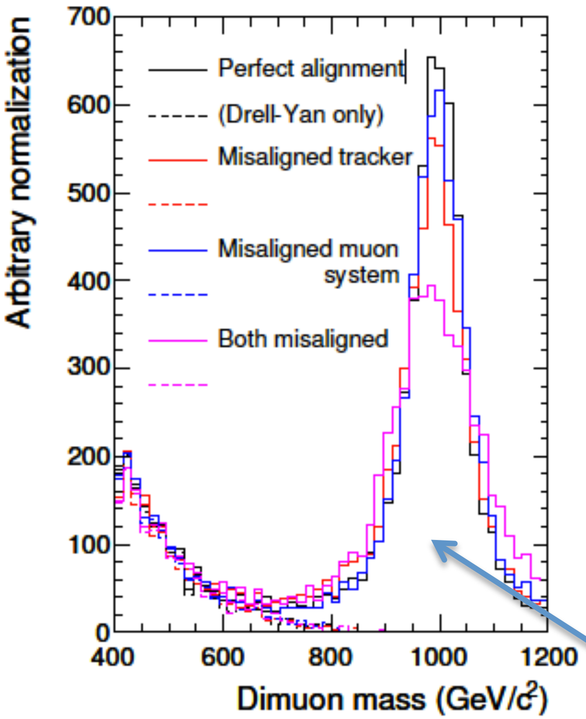


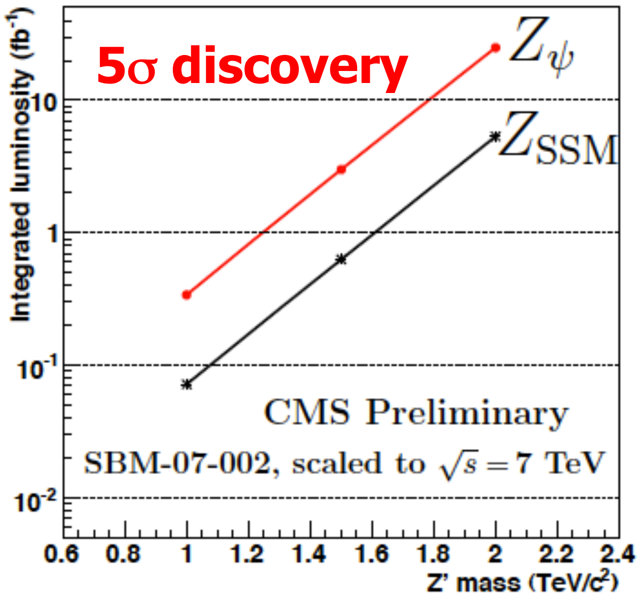
TeV resonances: Z'→$\mu^+\mu^-$

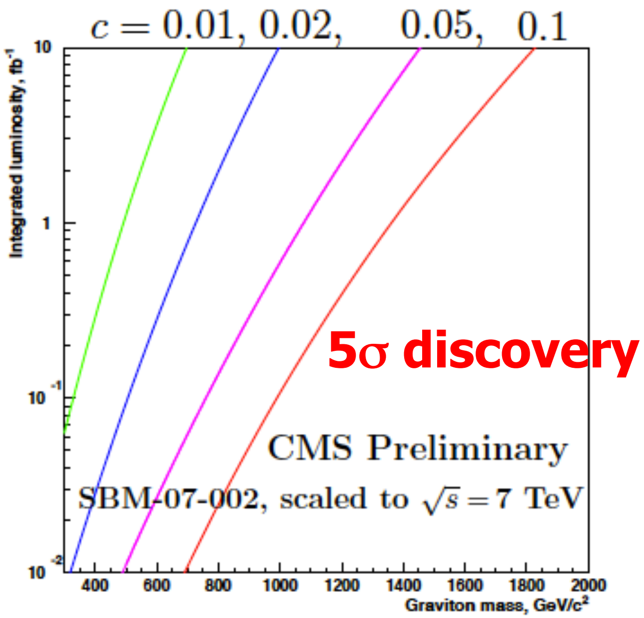
Background sources: DY, inclusive jets, W+jets, Z+jets, ttbar

Detector misalignment
→ an important effect
(long lever arms are needed to resolve small track curvatures).

Tag-and-probe method to measurements of reconstruction and trigger efficiencies for high-p_T muons is demonstrated







1 TeV Z_{SSM}

RS gravitons with the coupling constant c of 0.01, 0.02, 0.05, and 0.1

HSCP: stopped gluinos from data

Search, for the decays of long-lived particles that have stopped in the detector (e.g. gluinos in "split supersymmetry" models → R-hadrons → will decay seconds, day, or weeks later)

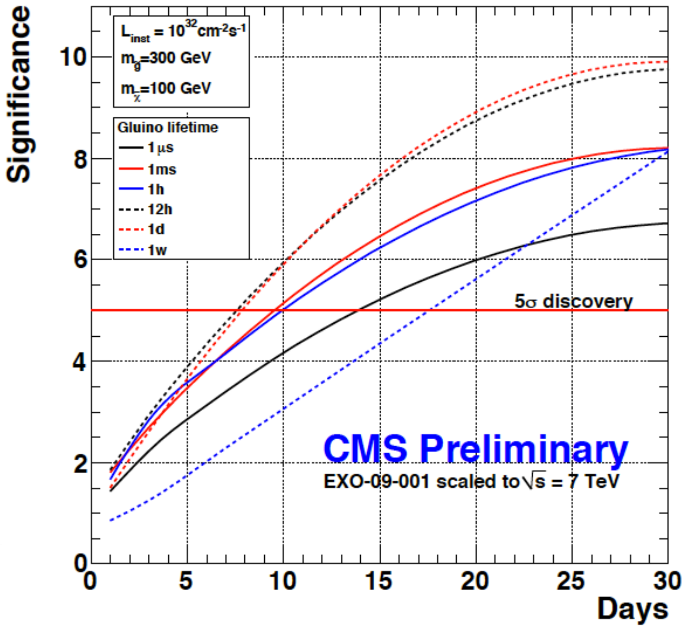
- Use a dedicated calorimeter trigger to search during periods when **no collisions**
  - in gaps between filled bunches during an LHC fill, and between LHC fills
  - trigger includes a no-beam condition using beam position and timing monitors
- **Backgrounds:** instrumental effects, cosmic rays, out of time beam triggers

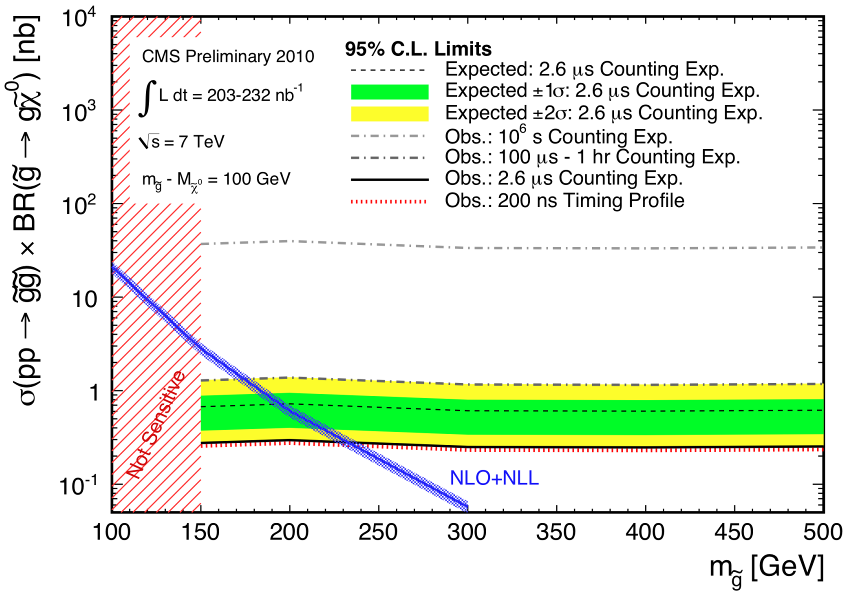
Analysis:

- counting experiment in bins lifetime, τ
- analysis of the distribution of observed event times.

For a given lifetime hypothesis, calculate a PDF for signal event time, using the delivered luminosity profile

Discovery potential





Gluino masses are excluded
up to 229 GeV (τ=200 ns)
up to 225 GeV (τ=2.6 μs)
up to 200 GeV (120 ns<τ<6 μs)

HSCP: stopped gluinos from data

Search for the decays of long-lived particles that have "stopped" in the detector (e.g. gluinos in "split supersymmetry" models, $\mathrm{BR}(\tilde{g} \to g\tilde{\chi}_1^0) = 100\%$)
→ R-hadrons → will decay seconds, day, or weeks later)

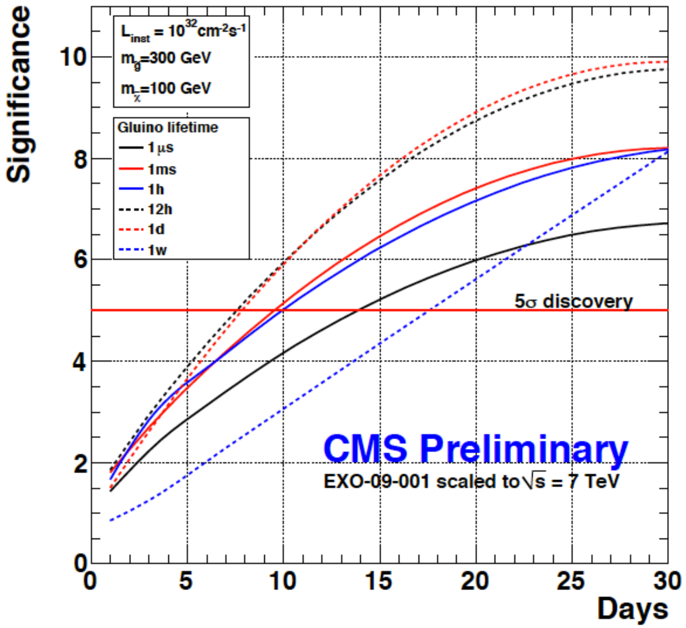
search during periods when **no collisions**
- in gaps between LHC fills

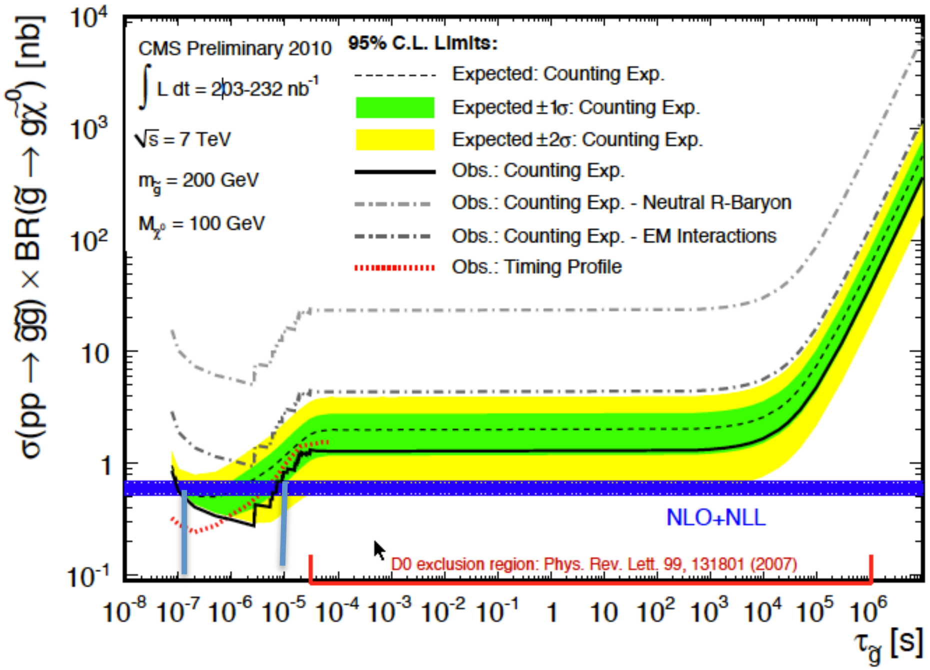
Salvatore Rapproccio

➤ **Backgrounds:** instrumental effects, cosmic rays, out of time beam triggers

➤ **Analysis:**
- counting experiment in bins lifetime, τ
- analysis of the distribution of observed event times.

Discovery potential





Extend Tevatron limit for gluino mass of 200 GeV (120 ns<τ<6 μs)

Heavy stable charged particles: from data

Topologies:

Salvatore Rapproccio

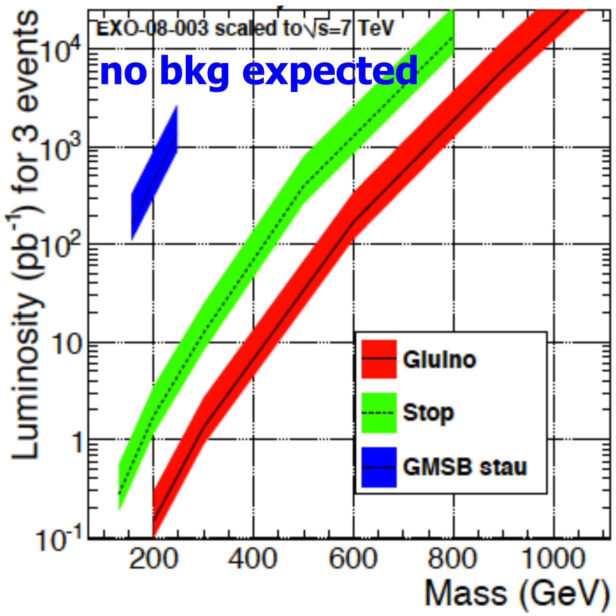
- **Leptons-like** HSCPS (sleptons and stau in SUSY models with GMSB / sleptons in UED)

- HSCPs with **strong** charge (long-lived gluino, stop) hadronize by combining with light quarks or gluons in **R-hadrons (R-barions, R-mesons, R-gluonball)** → hadronic interaction with the matter, highly penetrating and likely be identified as a muon

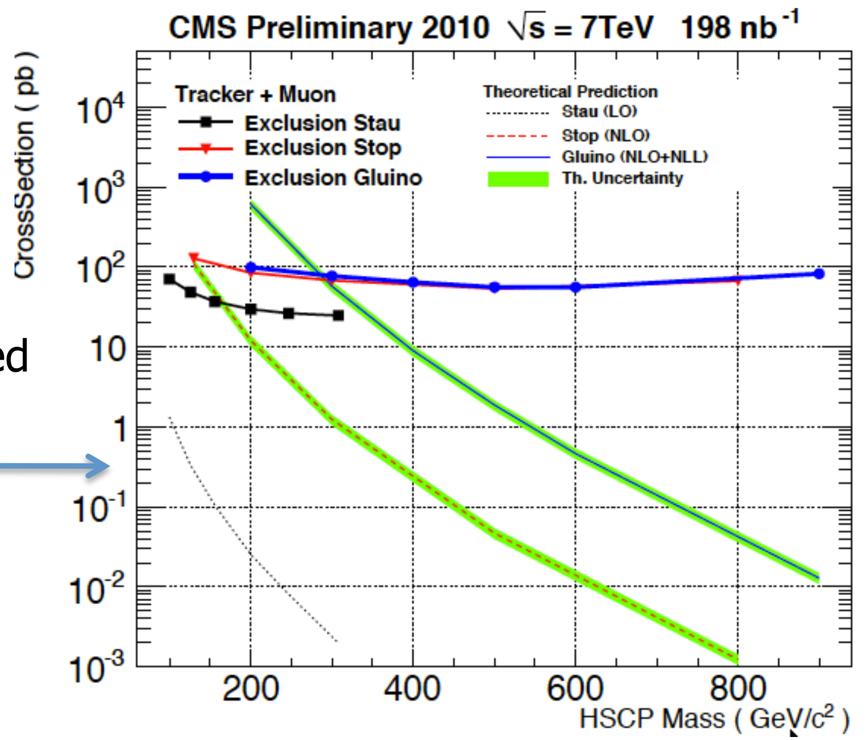
Signature: a low velocity particle with a high momentum of few hundred GeV
Two techniques to measure β by:

- measuring TOF with the Barrel Muon Drift Tube
- measuring dE/dx with the Si-tracker + muon ID

Discovery potential at 7 TeV:



198 nb^{-1} data
No event observed
→ 95% CL exclusion



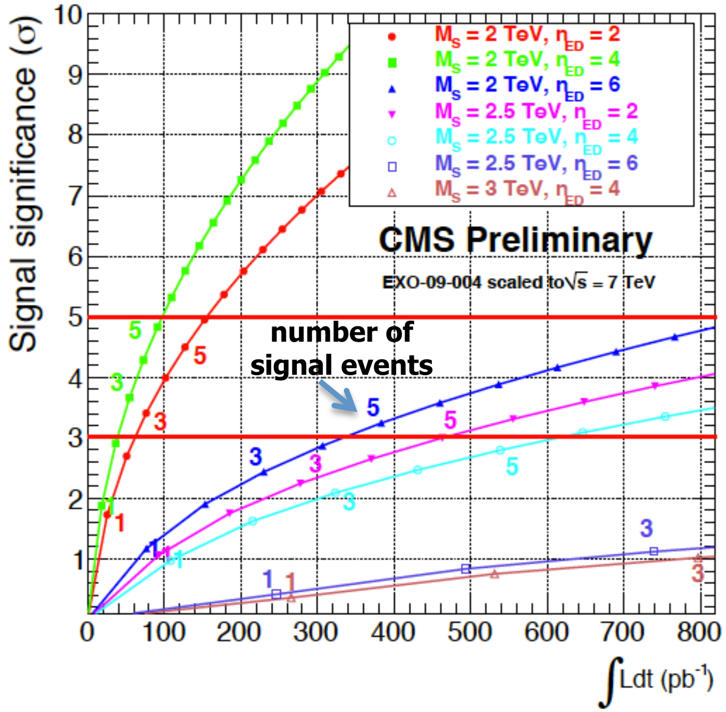
Limits on gluinos from HSCP analysis **284** GeV

Large extra dimension and RS di-photon

Compact large Extra Dimensions (ED) are an intriguing solution of the hierarchy problem of the SM → original model from Arkani-Hamed, Dimopoulos, and Dvali (**ADD**)

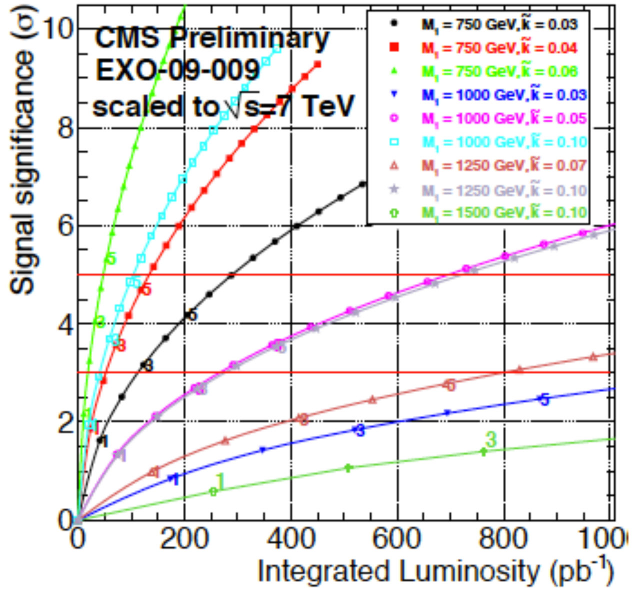
Graviton acting as a propagator in a Drell-Yan like processes → production of pair of photons.

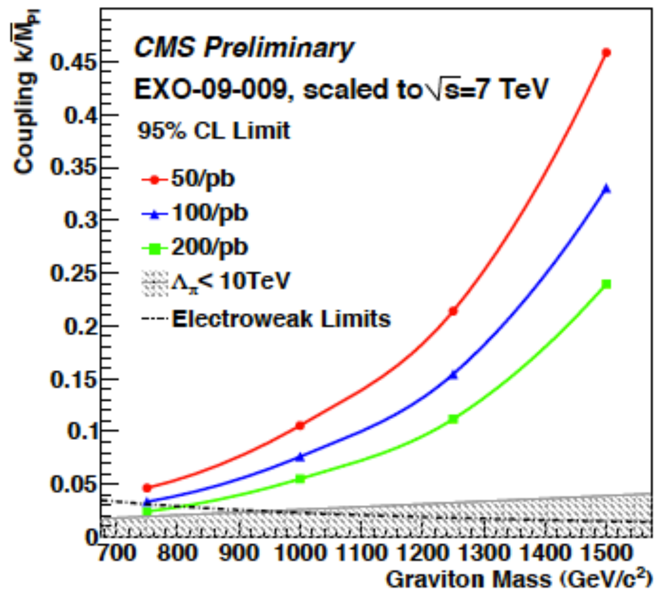
Interference with the SM diagrams → enhancement of the invariant mass spectrum of the di-photon system, particularly at high masses



Large extra-dimension

Randall-Sundrum graviton





Even with **50 pb^{-1}** of 7 TeV data, the sensitivity surpasses the current Tevatron limits

Large extra dimension in monojet

Signature: High-p_T jet in the central region of the detector, recoiling back-to-back in the transverse plane with a E_T^{miss} of similar magnitude (probe for the discovery of large extra dimensions in the framework of the ADD model)

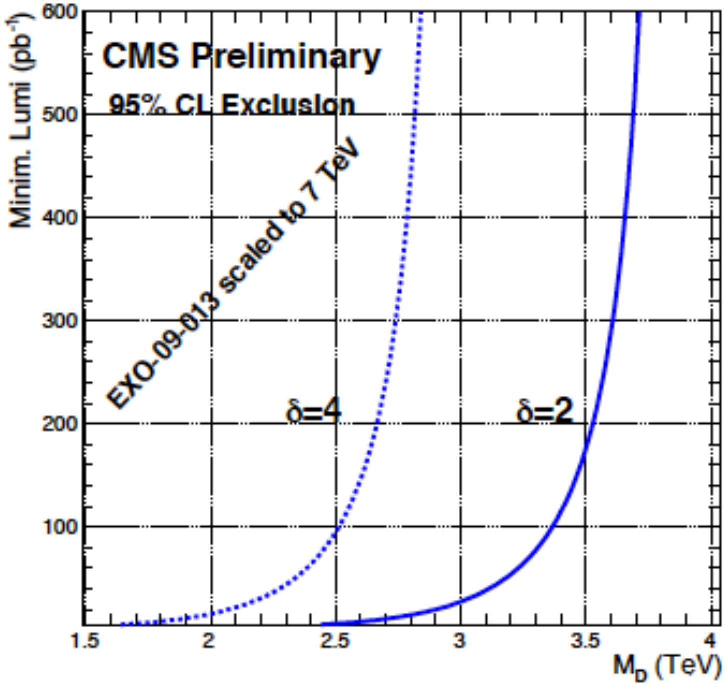
Background: Z+jets production, with $Z \rightarrow \nu\nu$, W+jets (with not reconstructed lepton) + QCD di-jets, ttbar and single top

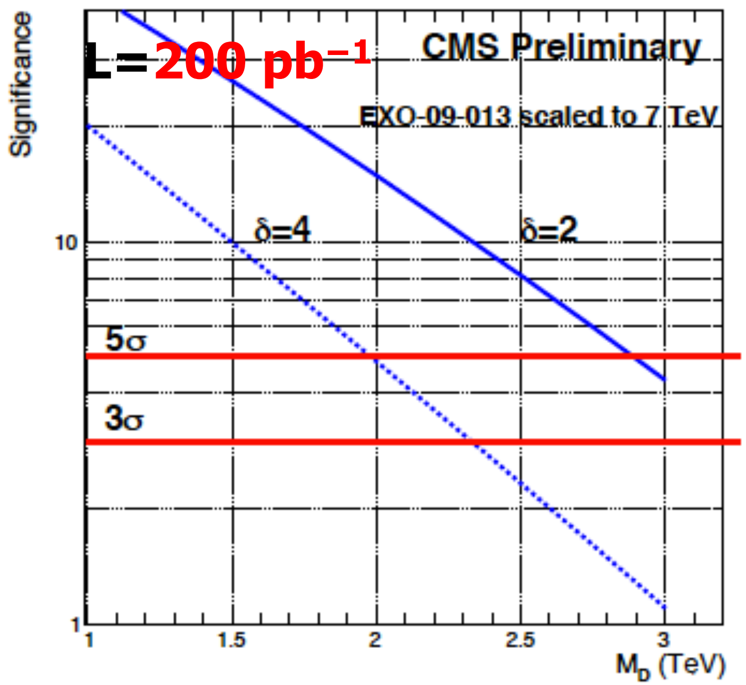
Discriminating variable:

$$MHT = \left| \sum_{p_T(\text{jet})_i > p_T^0} \vec{p}_T(\text{jet})_i \right|$$

Systematic effects:

- jet energy resolution and direction
- jet energy scale

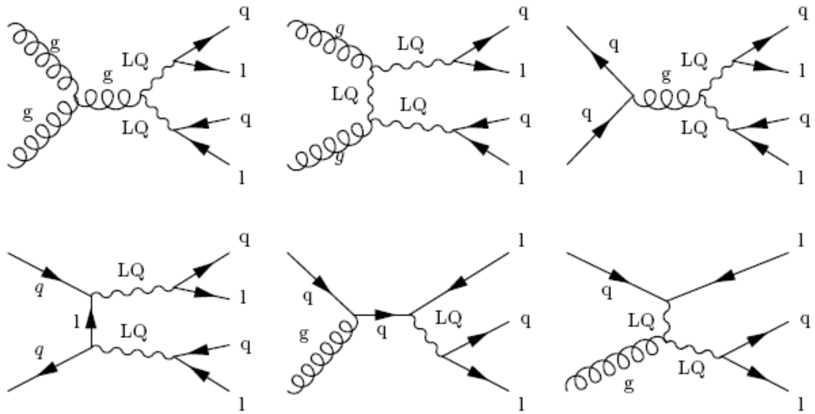




Even with as little as 10 pb^{-1} of integrated luminosity the sensitivity is expected to surpass that at the Tevatron

Leptoquarks

The quark-lepton observed symmetry between leptons and quarks has motivated the search for **leptoquarks** (LQ):



- LQ are hypothetical bosons carrying both quark and lepton quantum numbers and fractional electric charge.
- LQ could decay into any combination of a lepton and a quark
- 3 generations of LQ, each LQ coupling to a lepton and a quark from the same SM generation.
- LQ can either be produced in pairs by the strong interaction or in association with a lepton via the leptoquark-quark-lepton coupling.

Final states **with two highly energetic leptons + two jets and no missing transverse energy**

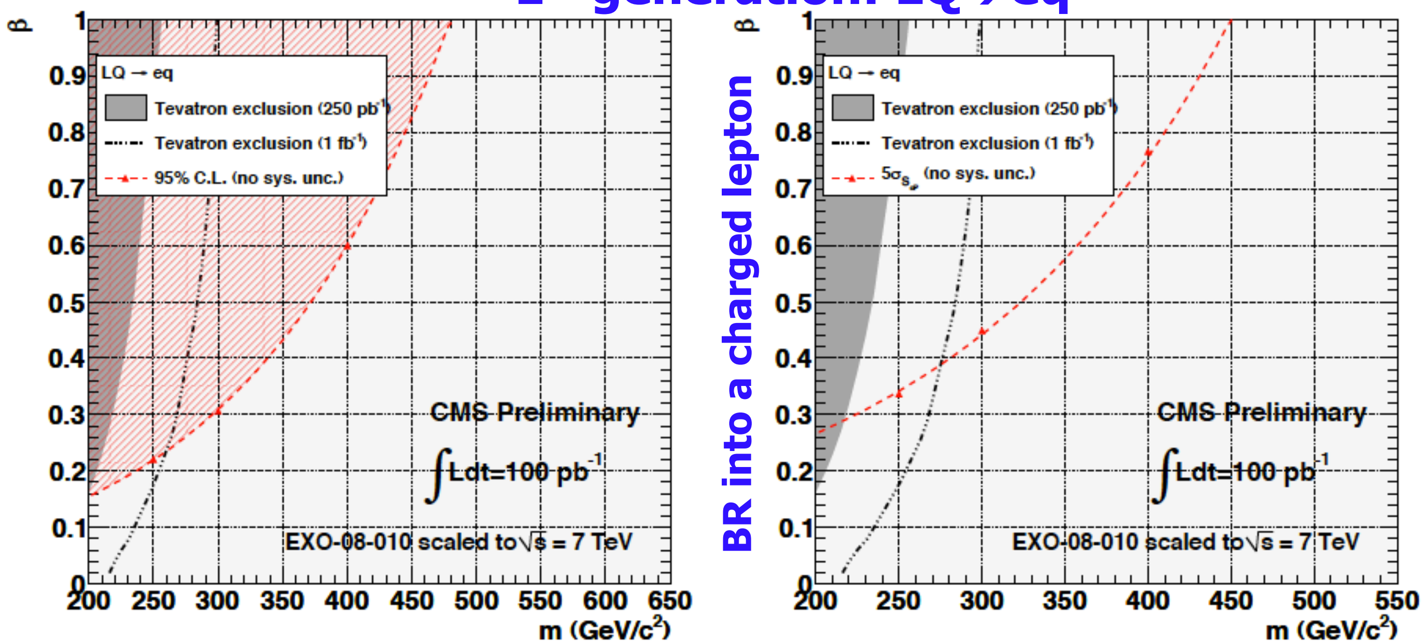
Bkg:

- tt +jets, VV+jets and Z/γ + jets
- QCD multi-jet production, where two jets are misidentified as leptons

Discriminating variable:

S_T, the scalar sum of the transverse momenta of the two leading muons and jets.

1^{st} generation: LQ→eq



4^{th} quark/lepton generation

- Phase in CKM can give CP violation but is too small to cope with the asymmetry between matter to antimatter → 4^{th} lepton generation (b′, t′)
- Searches at Tevatron gave m(b′) > 268 GeV at 95 % C.L.

CMS searches for b′ in $pp \to b'\bar{b}' \to t\bar{t}W^+W^-$

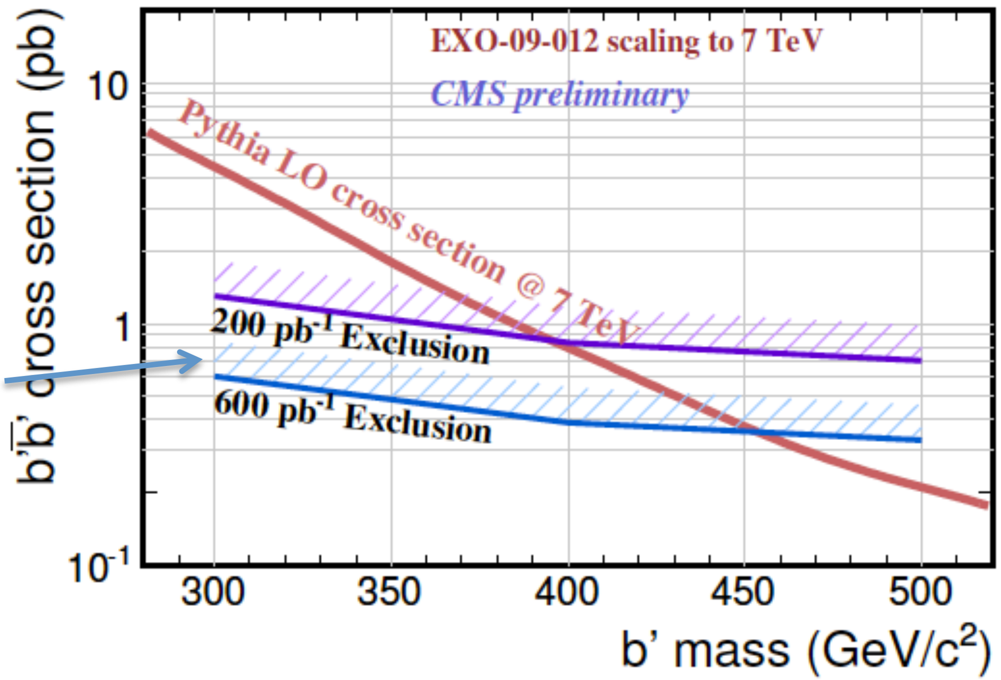
W→lν or W→di-jet

Signatures: same sign di-lepton and tri-lepton (plus jets)

Background from SM expected to be small → data driven method for the bkg estimation

UL @95% C.L. on the σ(pp→ b′b′)

Just **100 pb^{-1}** of 7 TeV data, CMS sensitivity is expected to surpass the current Tevatron lower b′ 95% C.L. mass limit of 325 GeV

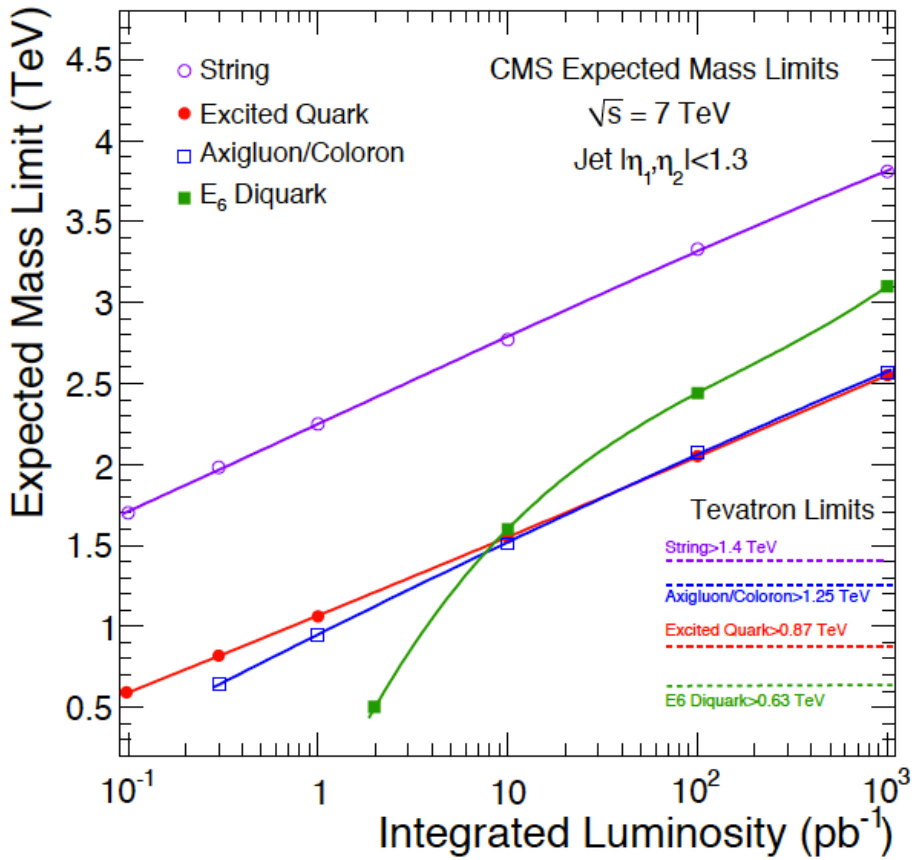


Di-jet resonances

Search for **new massive objects** that couple to quarks (q) and gluons (g)
→ di-parton resonance qq, qg, gg → resonant structures in the di-jet

Several model of quark compositeness:

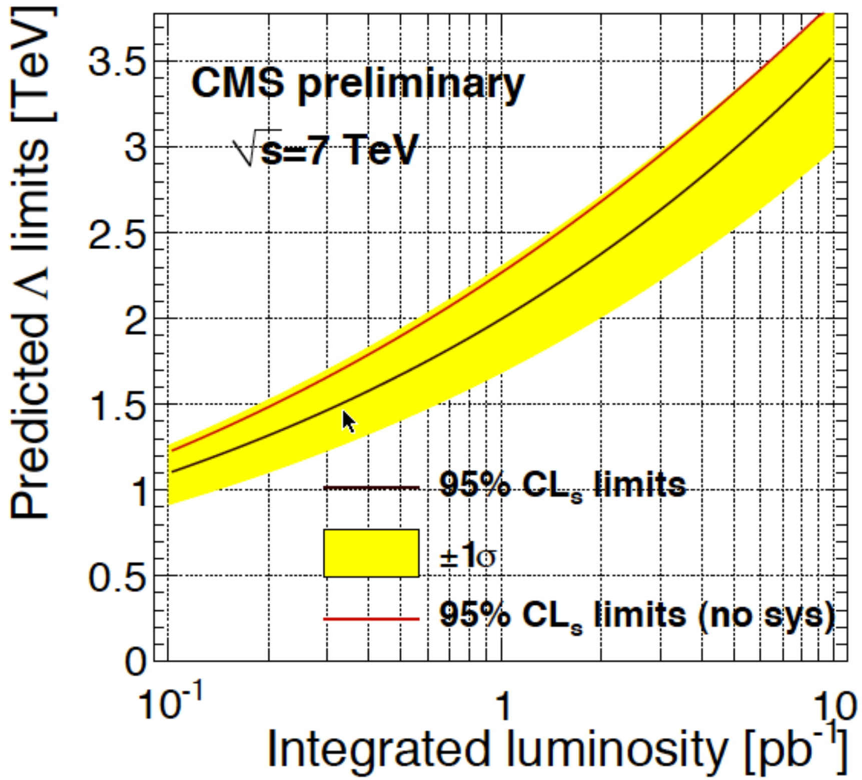
Model Name	X	Color	J^P	$\Gamma/(2M)$	Final-state Partons
String	S	mixed	mixed	0.003-0.037	$q\bar{q}$, qq, gg and qg
Axigluon	A	Octet	1^+	0.05	$q\bar{q}$
Coloron	C	Octet	1^-	0.05	$q\bar{q}$
Excited Quark	q*	Triplet	$1/2^+$	0.02	qg
E_6 Diquark	D	Triplet	0^+	0.004	qq
RS Graviton	G	Singlet	2^+	0.01	$q\bar{q}$, gg
Heavy W	W′	Singlet	1^-	0.01	$q\bar{q}$
Heavy Z	Z′	Singlet	1^-	0.01	$q\bar{q}$



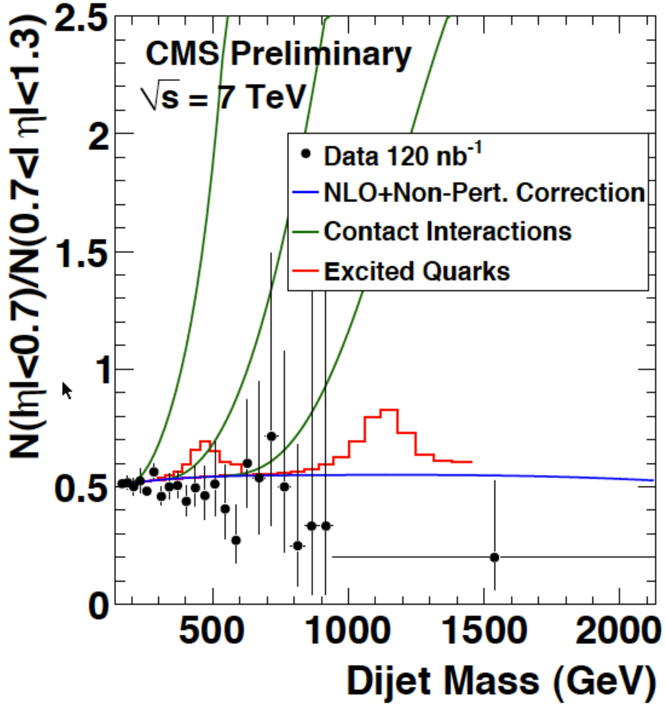
Quark compositeness via di-jet centrality ratio

Centrality ratio= ratio of the number of events with both leading jets within $|\eta| < 0.7$ to that within $0.7 < |\eta| < 1.3$ → a measure of the angular distribution of the di-jet and is sensitive to deviations from the SM.

Method: compare the measured centrality ratio vs di-jet invariant mass to predictions from QCD and QCD plus a quark contact interaction → the **expected lower limit on the contact interaction scale Λ** as a function of integrated luminosity



Real data



With 120 nb^{-1} data at 7 TeV:
Λ < 1.9 TeV excluded at 95% C.L