CMS: Recent Results & Prospects

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U. Wisconsin

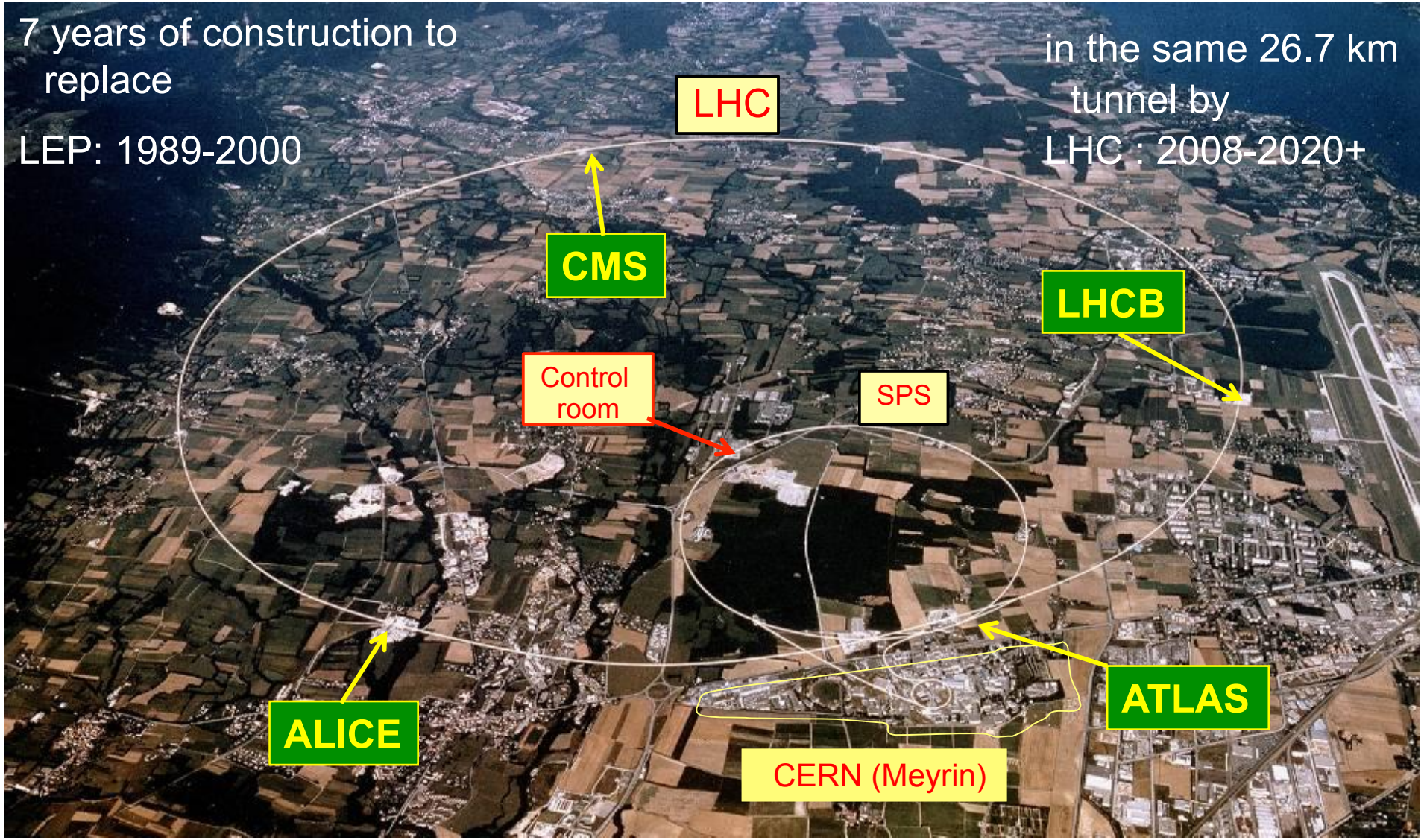
PSAPS Meeting

IIT, November 19, 2010

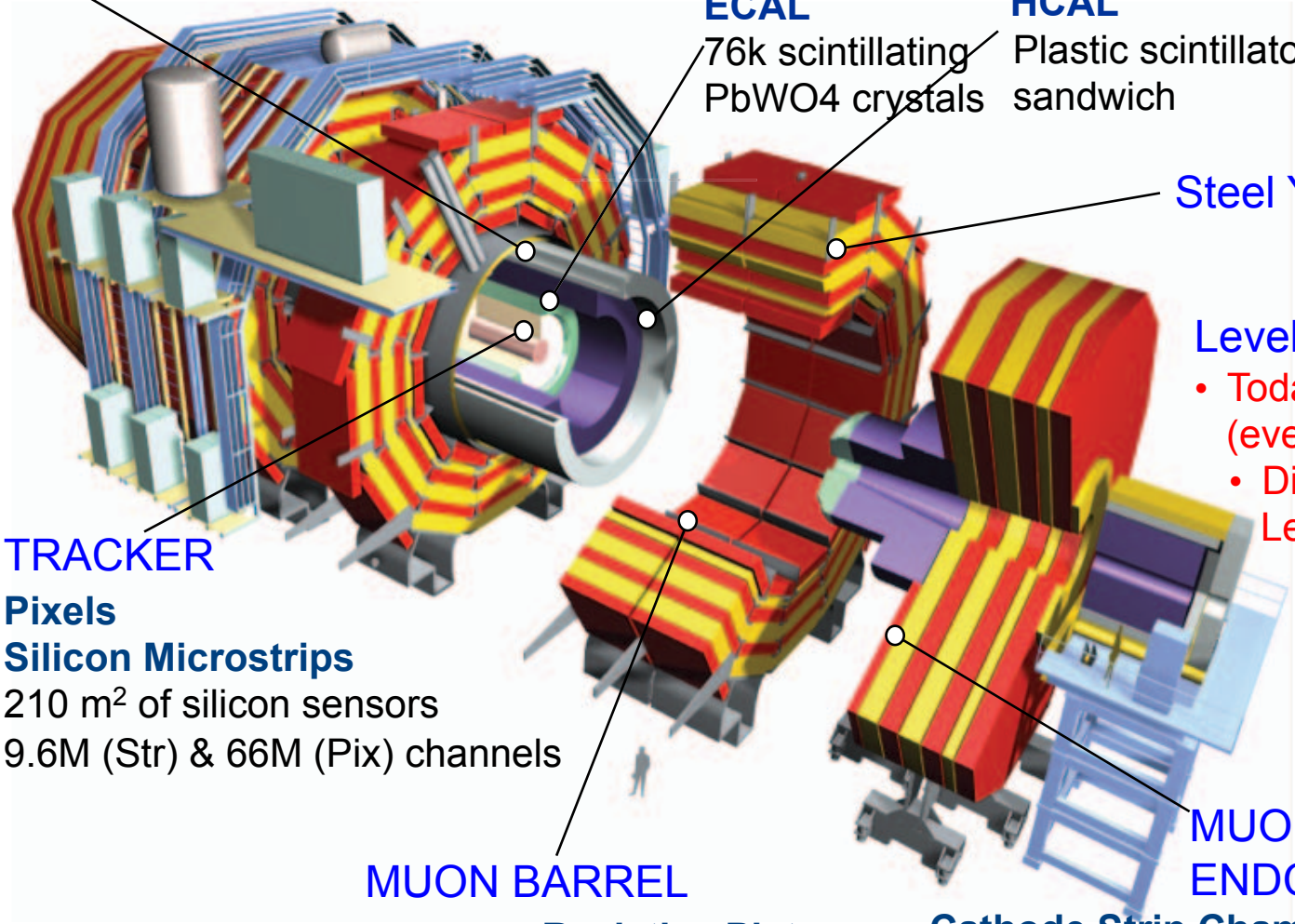
Outline:

- Results from first proton run at 7 TeV
- First results from Heavy Ions
- Prospects for running in next 2 years

The CERN & LHC Complex



CMS Detector Design



Superconducting Coil, 4 Tesla

CALORIMETERS

ECAL
76k scintillating PbWO4 crystals

HCAL
Plastic scintillator/brass sandwich

Steel YOKE

Level-1 Trigger Output
- Today: 50 kHz (eventually100 kHz)
  - Directly feeds Higher Level Trigger CPU farm

TRACKER

Pixels

Silicon Microstrips
210 m^2 of silicon sensors
9.6M (Str) & 66M (Pix) channels

MUON BARREL

Drift Tube Chambers (DT)

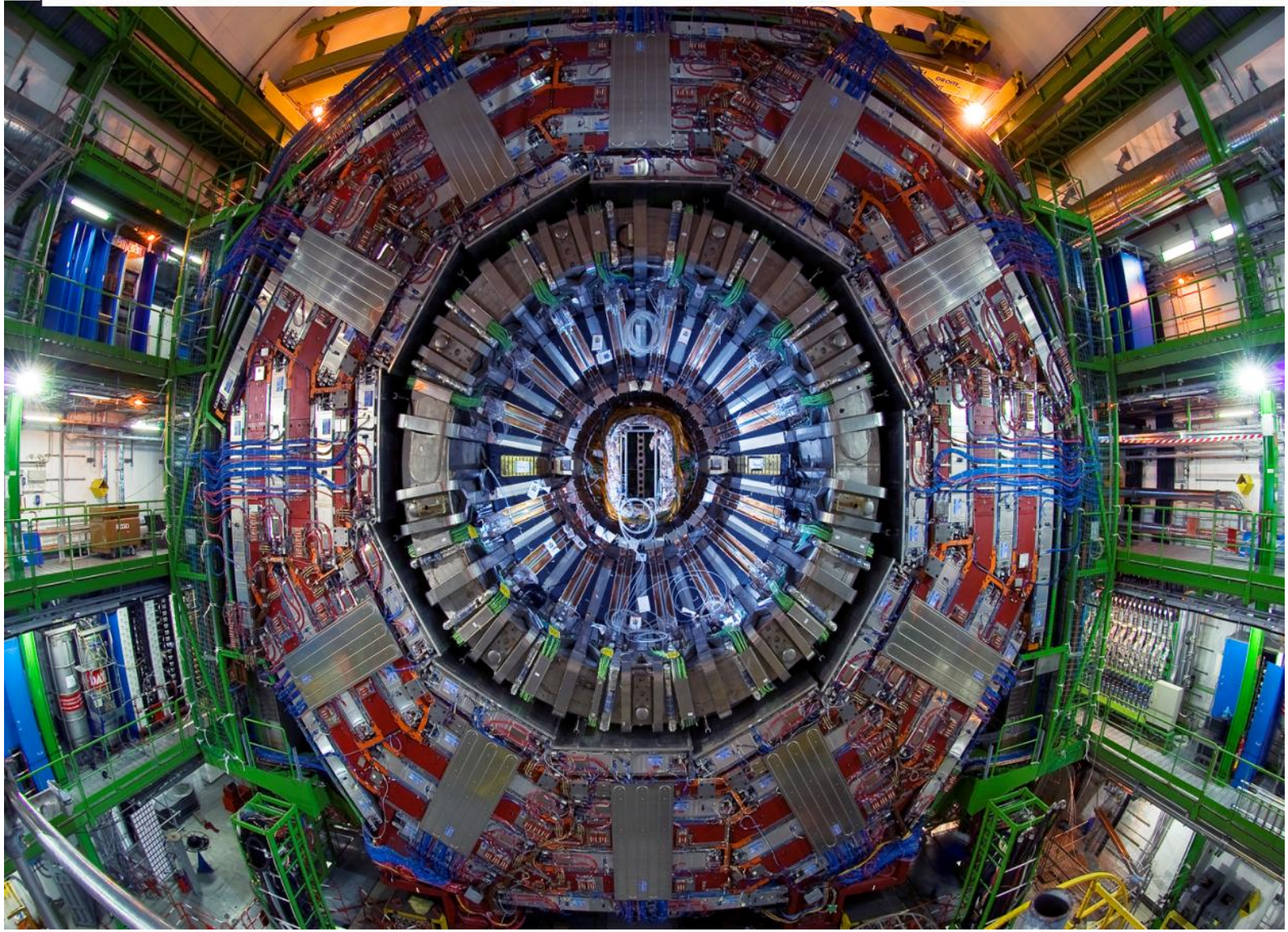
Resistive Plate Chambers (RPC)

MUON ENDCAPS

Cathode Strip Chambers (CSC)

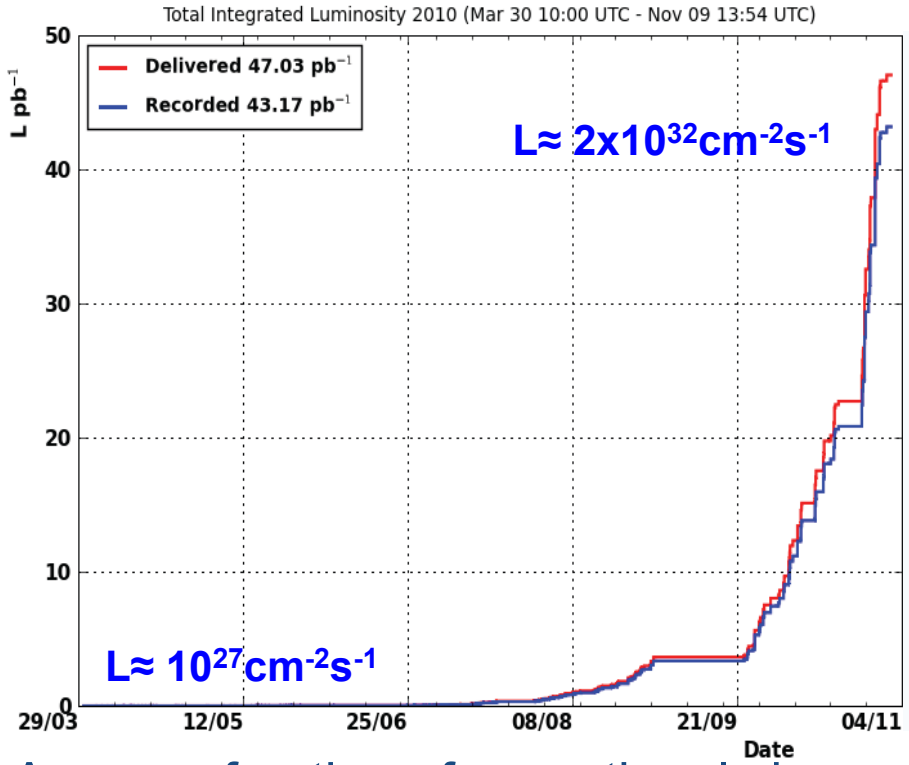
Resistive Plate Chambers (RPC)

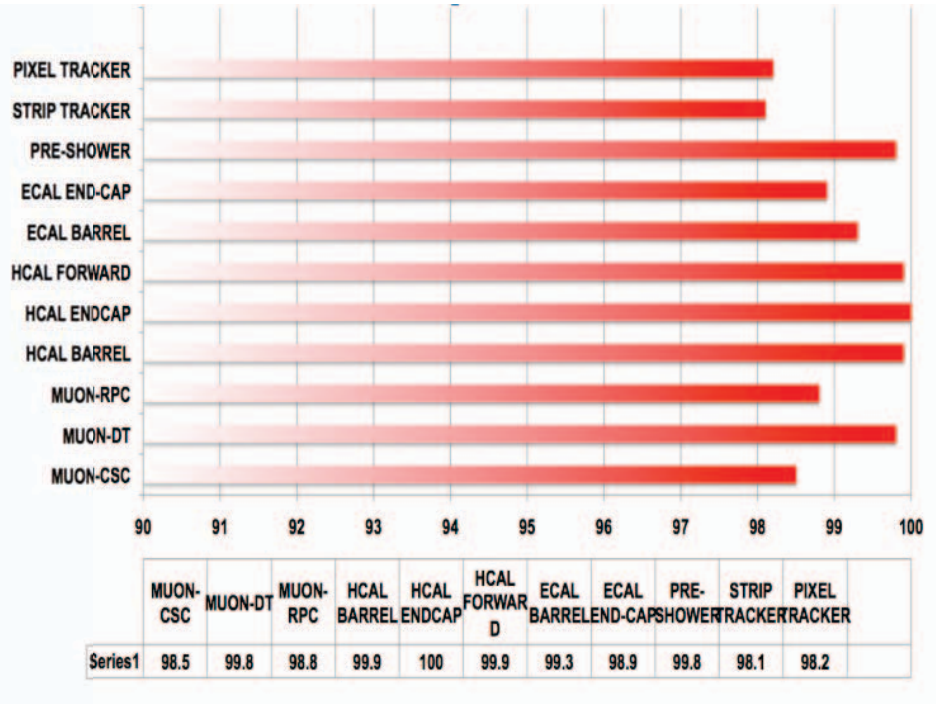
CMS in the Cavern



LHC & CMS operations in 2010

About **47pb^{-1}** delivered by LHC and **~43pb^{-1}** of data collected by CMS. Overall data taking efficiency **~92%. 6pb^{-1}** of data integrated in a good fill**.** Excellent performance in coping with more than 5 order of magnitude increase in instantaneous luminosity.

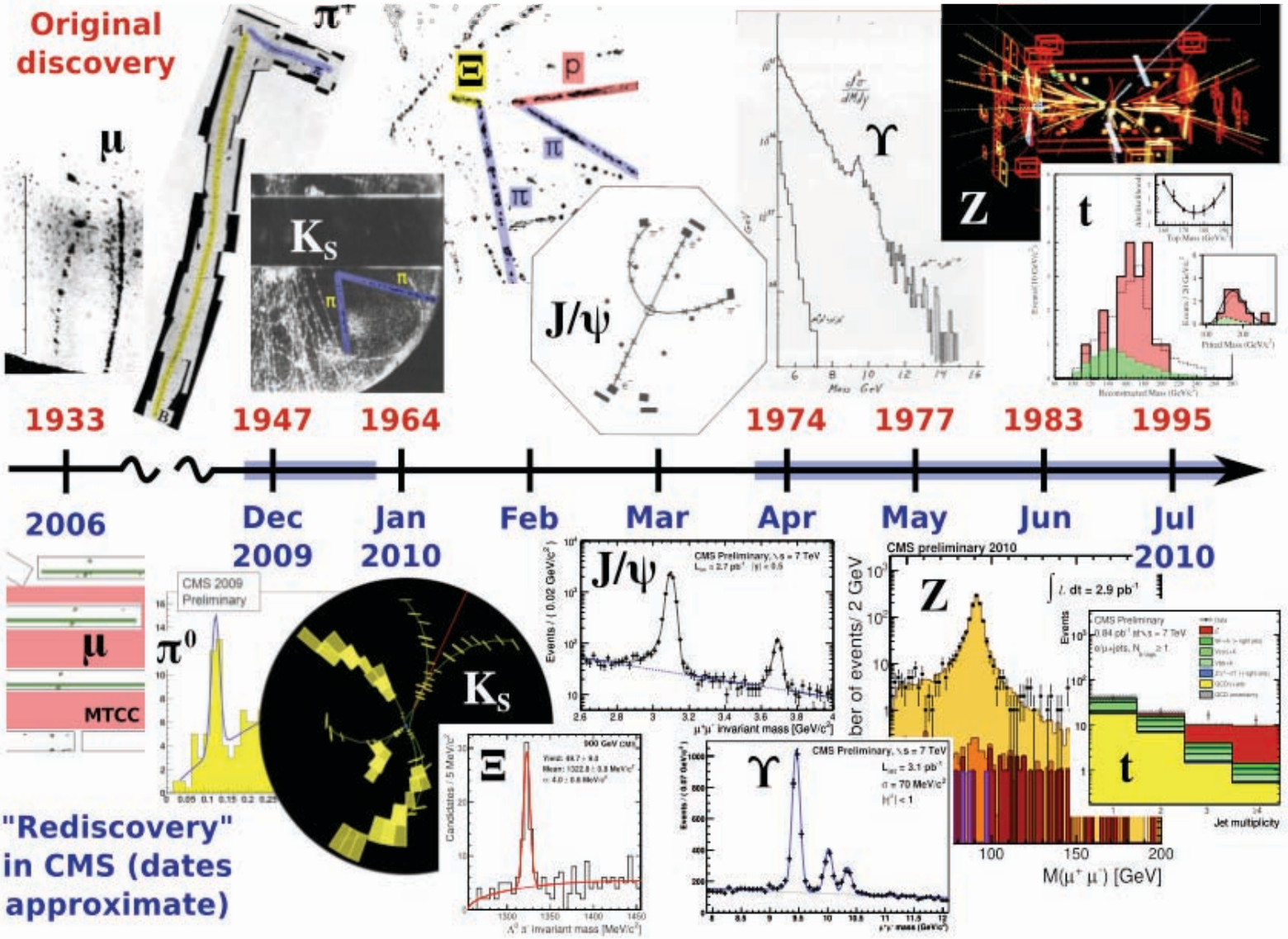




	MUON-CSC	MUON-DT	MUON-RPC	HCAL BARREL	HCAL ENDCAP	HCAL FORWARD	ECAL BARREL	ECAL END-CAP	PRE-SHOWER	STRIP TRACKER	PIXEL TRACKER
Series1	98.5	99.8	98.8	99.9	100	99.9	99.3	98.9	99.8	98.1	98.2

Average fraction of operational channels per CMS sub-system **>99%.**

Re-discovering the Standard Model at 7 TeV



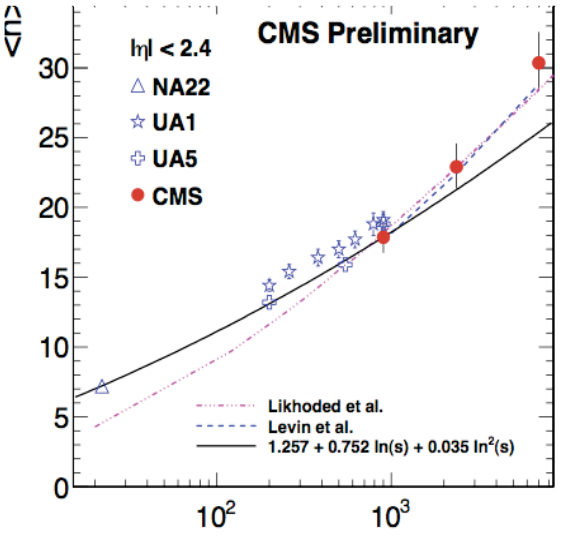
Minimum bias and soft QCD

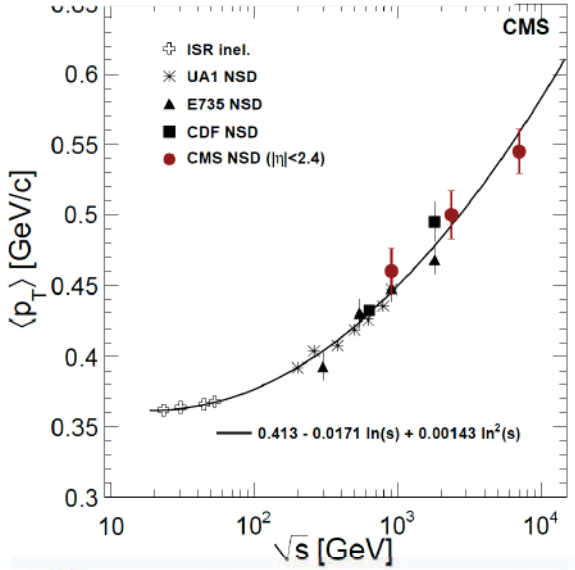
Measurements at 0.9, 2.36 and 7 TeV. Careful check of the scaling of particle multiplicity and $\langle p_T \rangle$ vs energy.

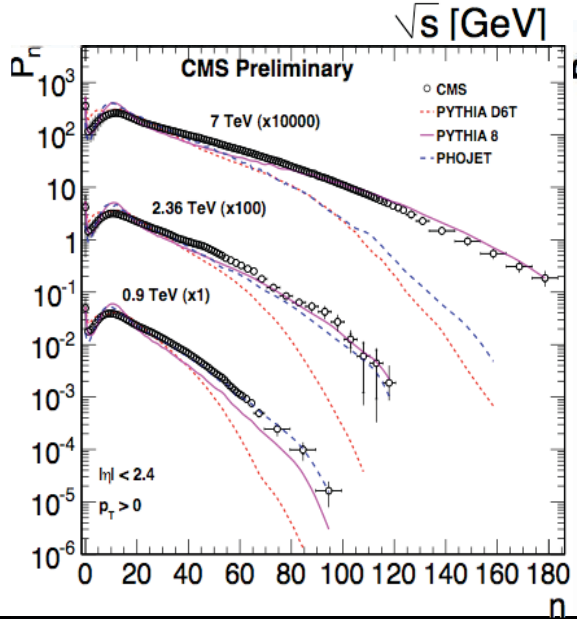
Really soft QCD (p_T tracks down to 50MeV).

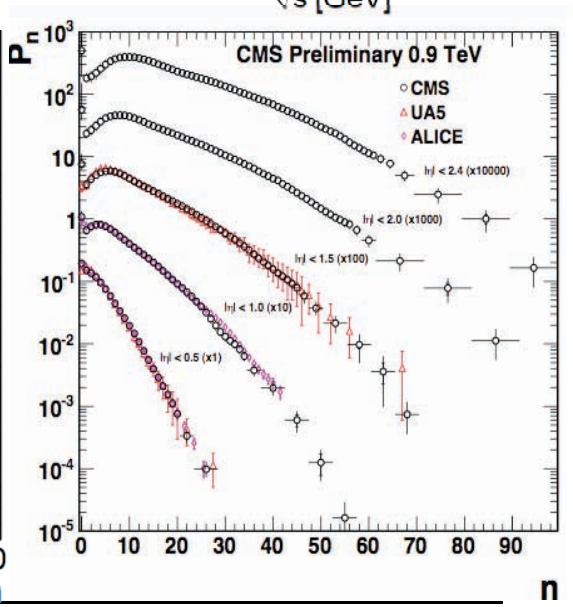
Rise of the particle density in data stronger than extrapolations from lower energies and model predictions.

Careful tuning effort of the MC generators is ongoing. Marginal impact on high p_T physics.



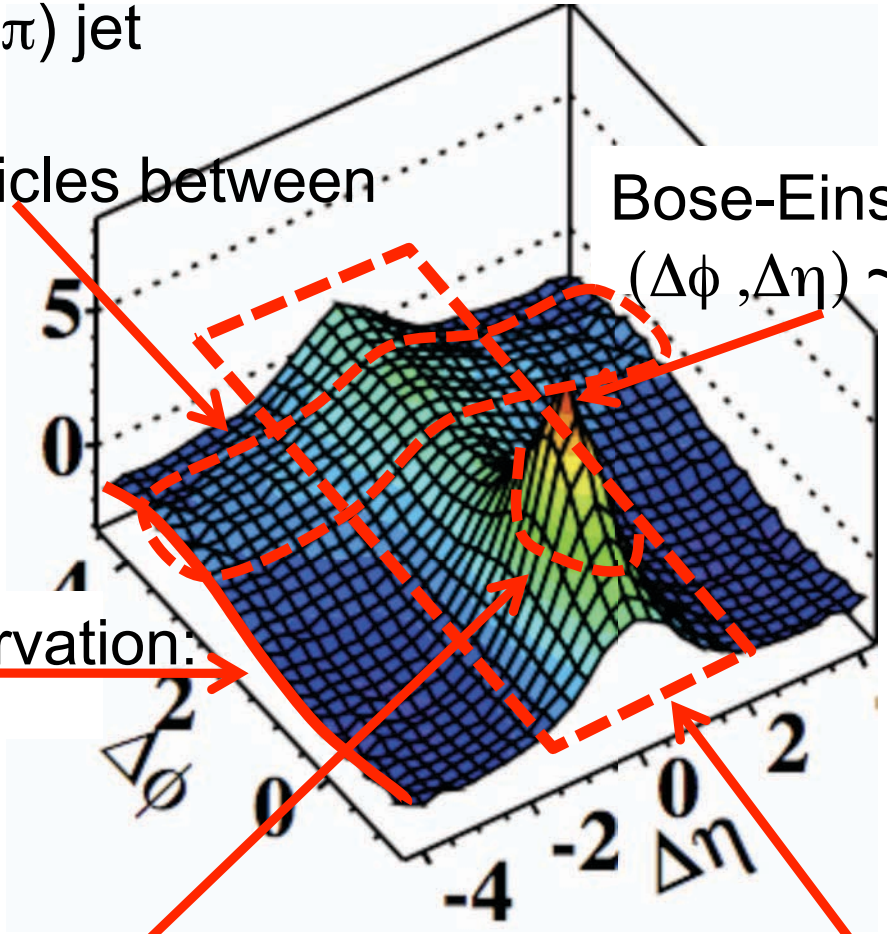






Angular Correlation Functions

"Away-side" ($\Delta\phi \sim \pi$) jet correlations:
Correlation of particles between back-to-back jets



Bose-Einstein correlations:
$(\Delta\phi, \Delta\eta) \sim (0,0)$

TWO-PARTICLE CORRELATIONS AS FUNCTION OF AZIMUTHAL (ΔΦ) & PSEUDO-RAPIDITY (Δη) SEPARATION

Momentum conservation:
$\sim -\cos(\Delta\phi)$

"Near-side" ($\Delta\phi \sim 0$) jet peak:
Correlation of particles within a single jet

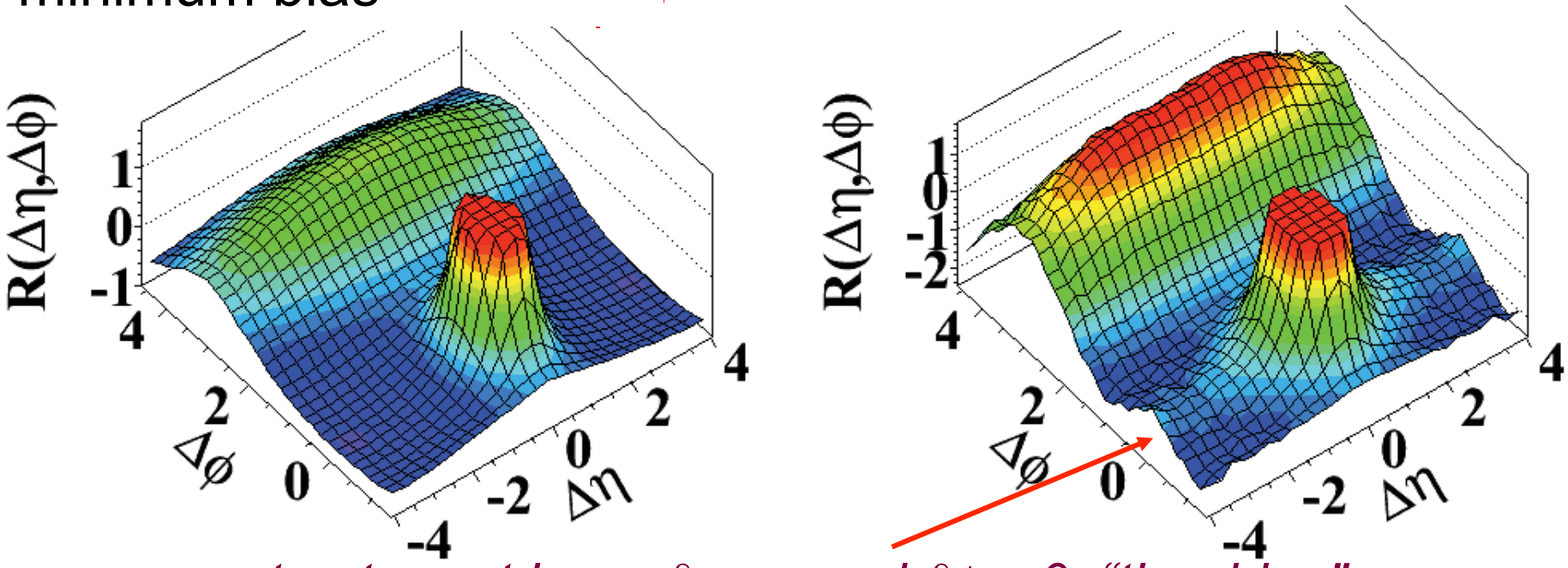
Short-range correlations ($\Delta\eta < 2$):
Resonances, string fragmentation, "clusters"

Long-range, near-side correlations in high multiplicity events

Intermediate p_T: 1-3 GeV/c:

minimum bias

high multiplicity (N>110)



structure at large $\delta\eta$ around $\delta\phi \sim 0$: "the ridge"

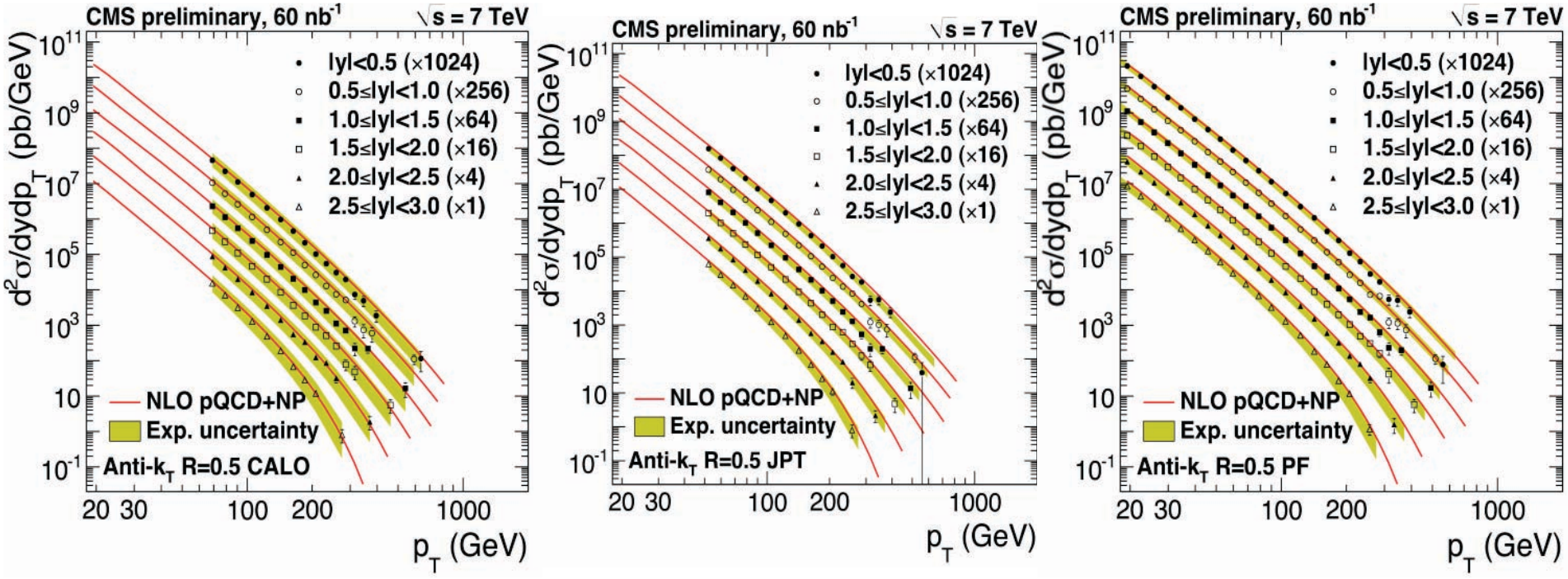
- **signal grows with event multiplicity**
- **biggest effect for $1 < p_T < 3$ GeV/c**
- **resembles effects seen in heavy-ion collisions at high energies**
- **Never seen before in proton collisions**

Inclusive jet cross section

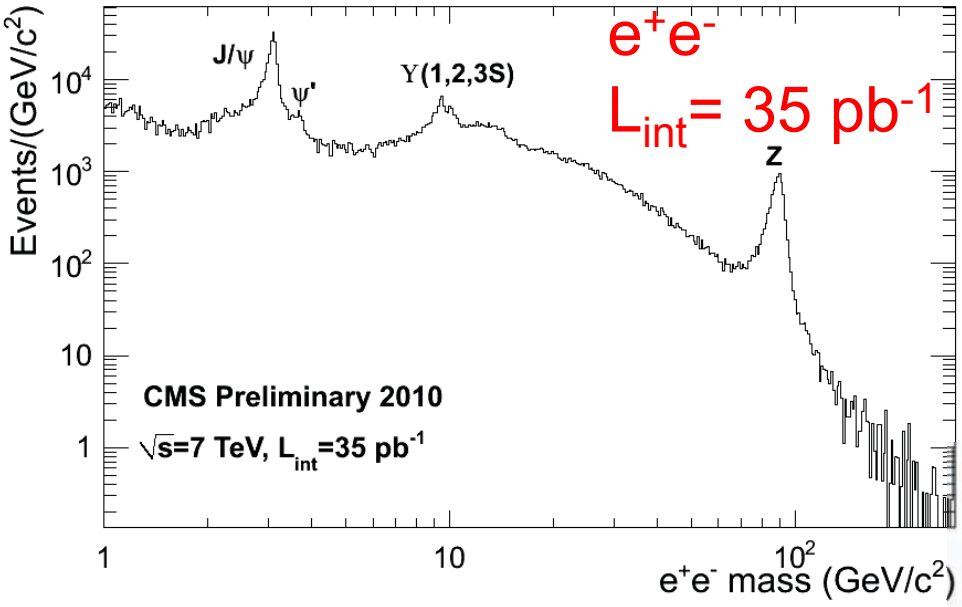
Inclusive jet p_T spectra produced for all three jet approaches used in CMS: Calorimeter, Jet Plus Tracks and Particle Flow

All results are in good agreement with NLO theory.

With the new Particle Flow approach the distributions can be extended to a low p_T value of 18 GeV.

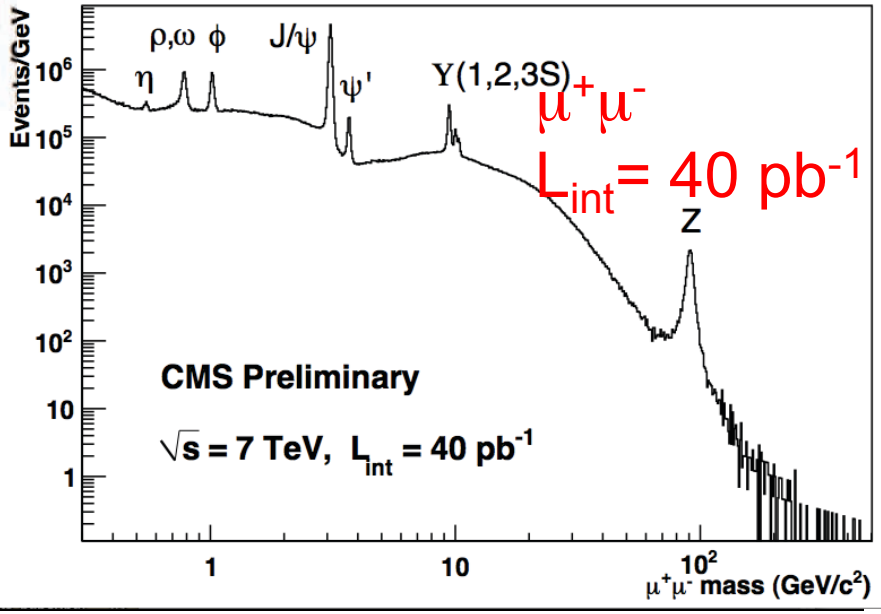


Invariant mass distributions

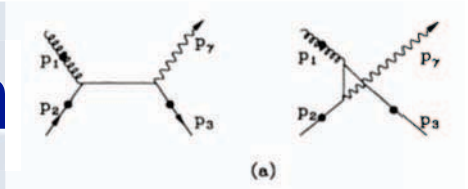


← e^+e^- widths:
J/Ψ 52 MeV
Υ 149 MeV

$\mu^+\mu^-$ widths: →
J/Ψ 30 MeV
Υ 67 MeV



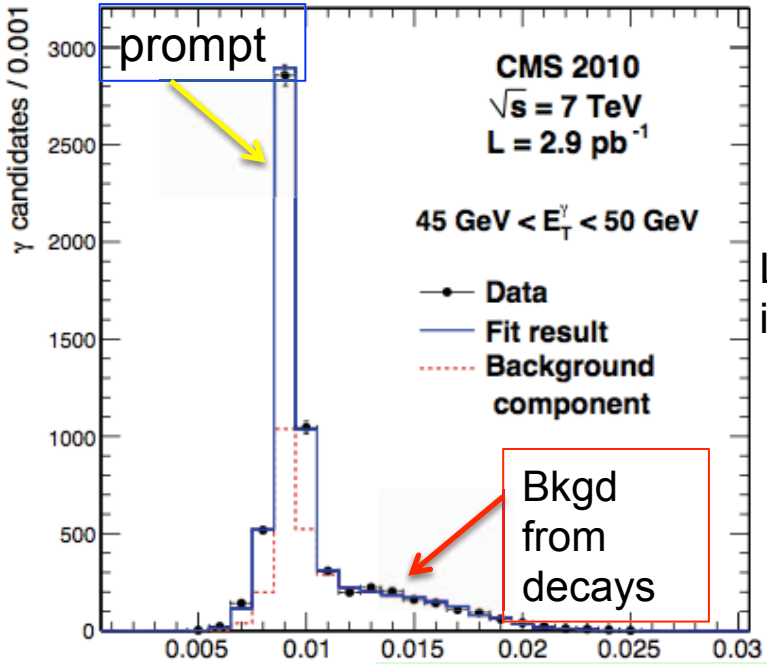
QCD: prompt γ production

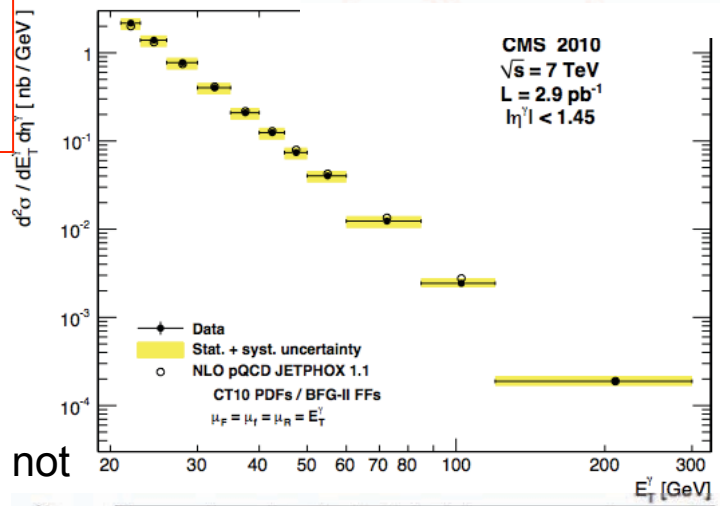


$$\sigma^2_{\eta\eta} = \frac{\sum_{\substack{crystal-i \\ in\,5x5 \\ aroundmx}} \omega_i \left(\eta_i - \bar{\eta}\right)^2}{\sum_{crystal-i} \omega_i}$$

Discri variable: $\sigma_{\eta\eta}$

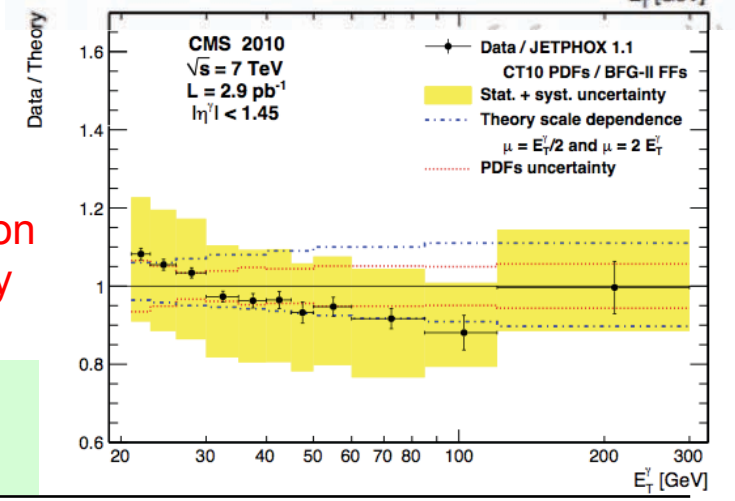
$$\omega_i = \max\left(0, 4.7 + \ln\left(E_i / E_{5x5}\right)\right)$$





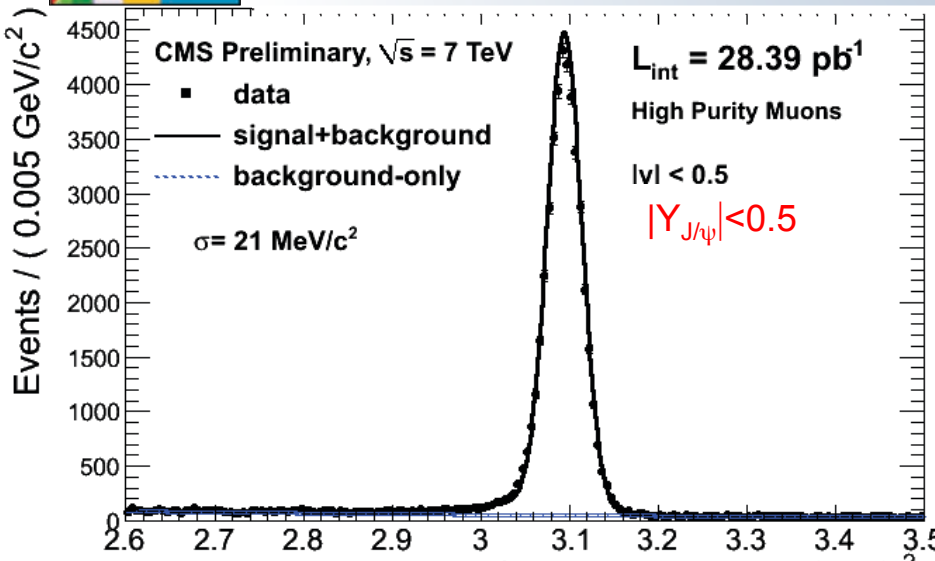
Lumi error (11%) not included

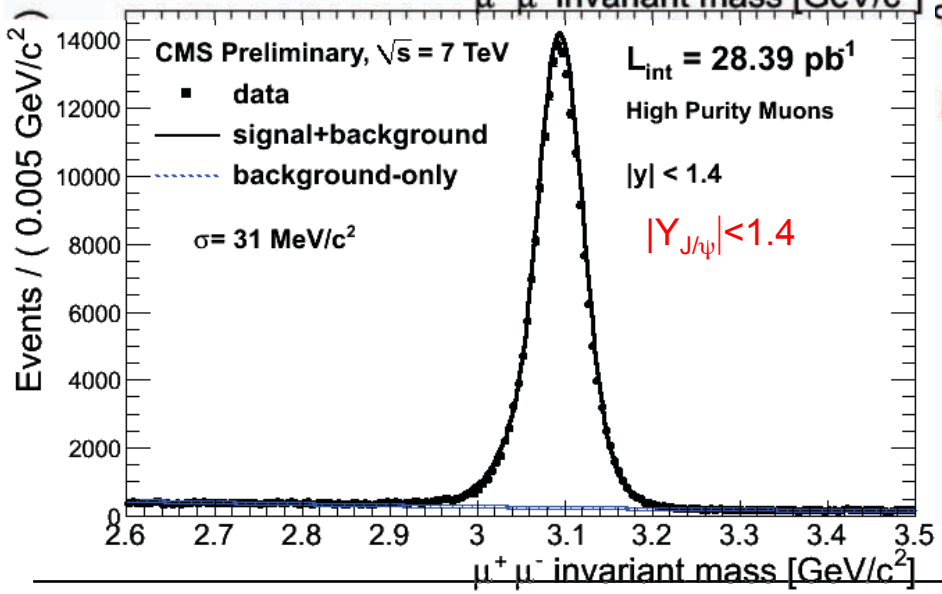
Comparison with theory

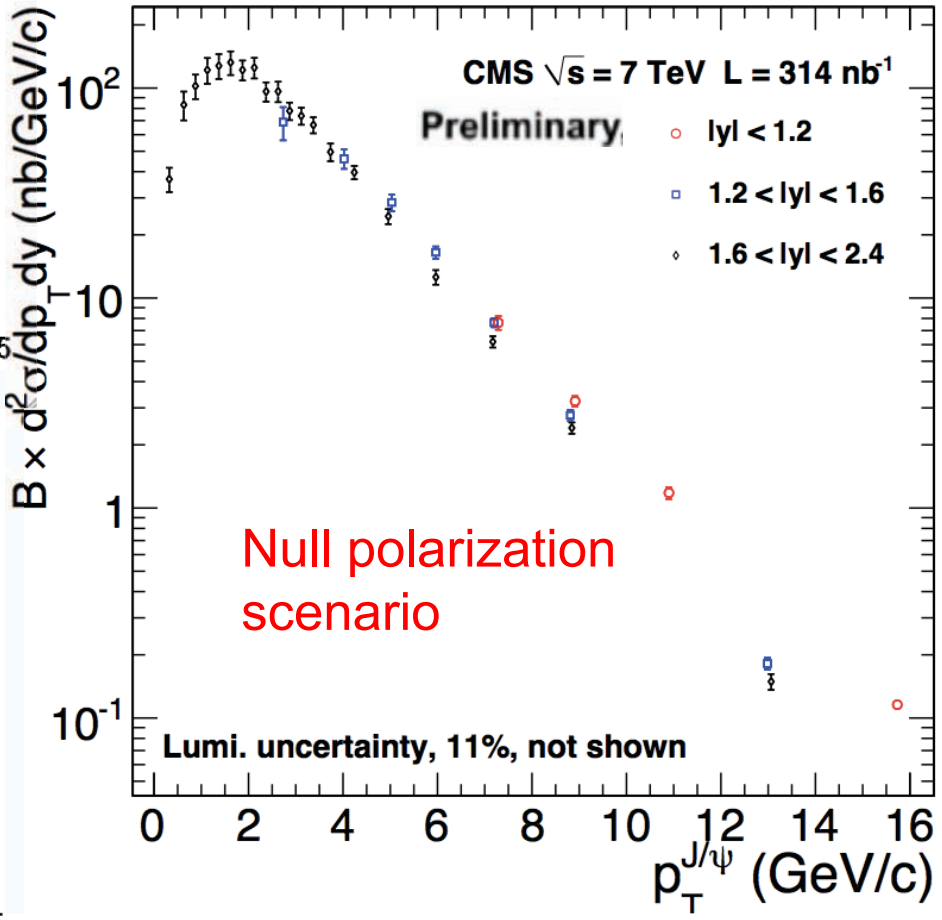


Measurement at higher Q^2 and lower $x_t = 2E_t/\sqrt{s}$ than Tevatron

J/ψ production cross sections



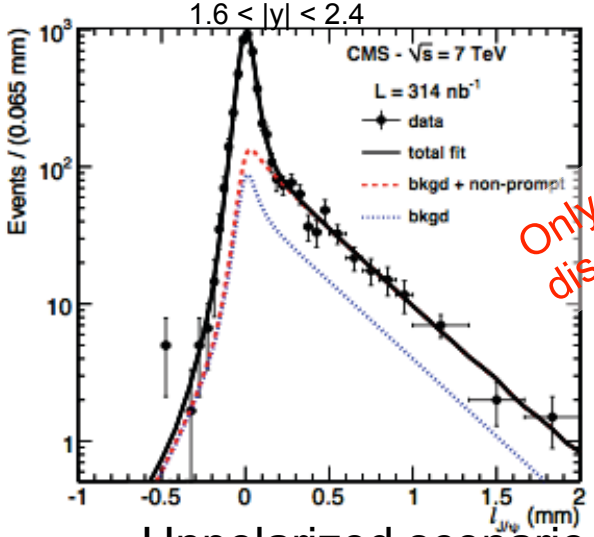




… and separating prompt/b decay

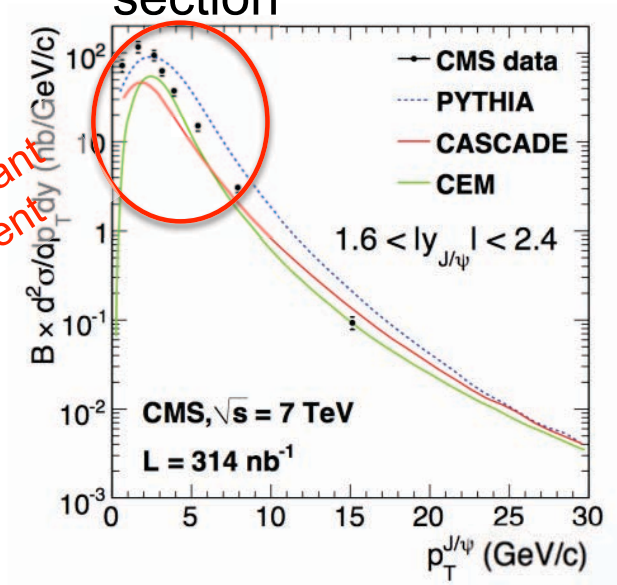
Transverse J/ψ flight distance in bins of p_t and η

$6.5 < p^{J/\psi} < 10$ GeV/c,
$1.6 < |y| < 2.4$

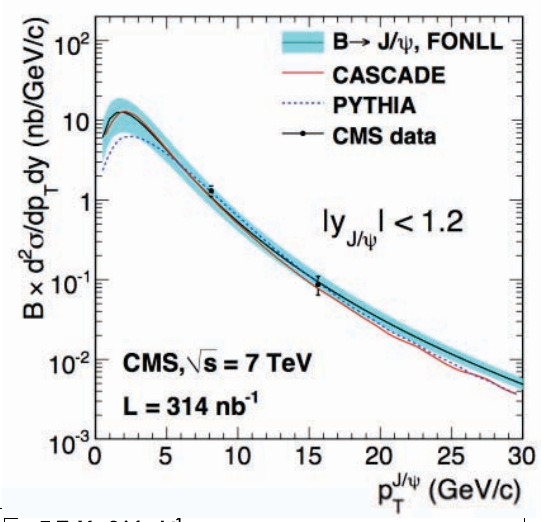


Only significant disagreement

Prompt diff. x-section



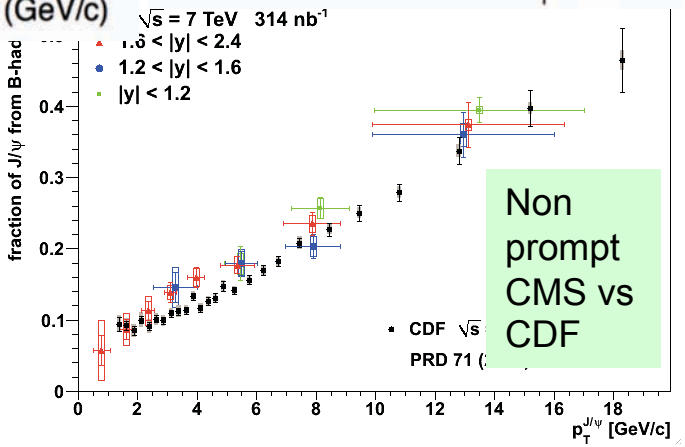
Non-Prompt diff. x-section



Unpolarized scenario :

$$BR(J/\psi \to \mu^+\mu^-) \cdot \sigma(\mathrm{pp} \to \text{prompt } J/\psi) = 196.7 \pm 3.8 \pm 10.7 \pm 21.6 \text{ nb}$$

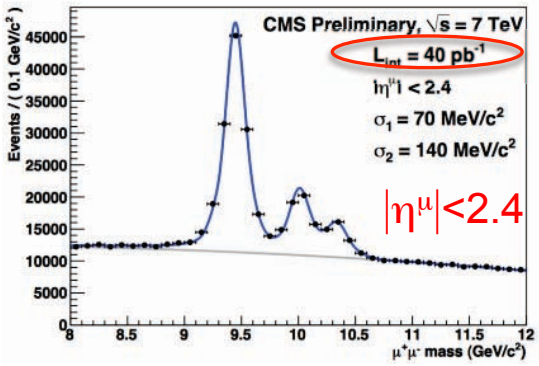
$$BR(J/\psi \to \mu^+\mu^-) \cdot \sigma(\mathrm{pp} \to bX \to J/\psi X) = 53.3 \pm 2.2 \pm 4.6 \pm 5.9 \text{ nb}$$



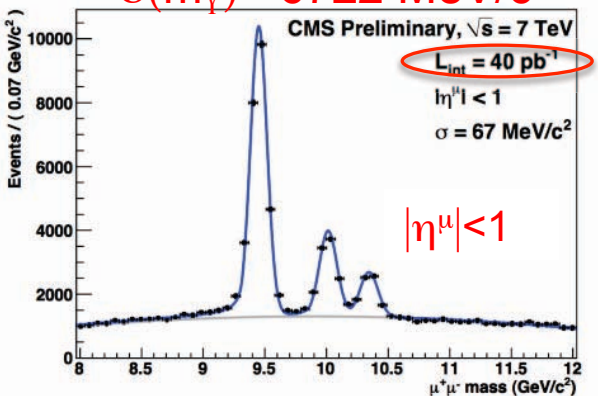
Non prompt CMS vs CDF

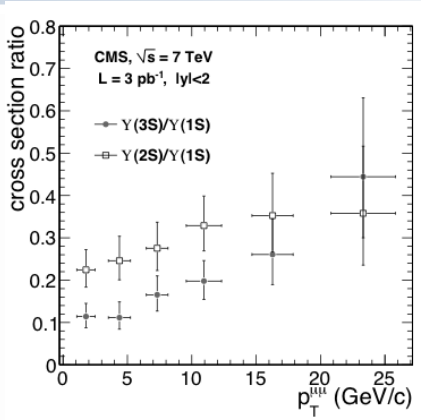
Υ production

$\sigma(m_\Upsilon)$= 70±2 MeV/c^2



$\sigma(m_\Upsilon)$= 67±2 MeV/c^2





σ Ratios
$|y^\Upsilon|$<2

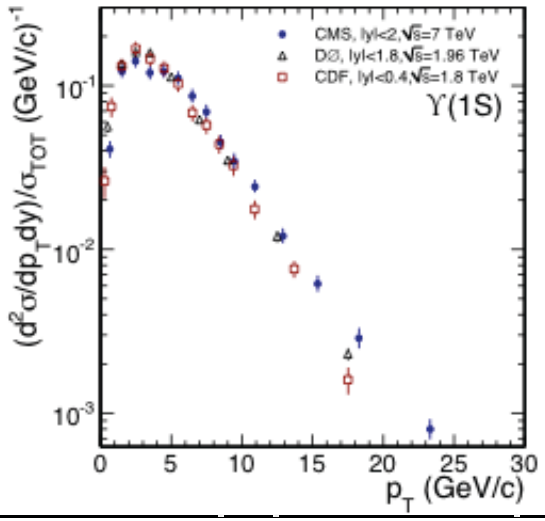
Unpolarized production assumption:

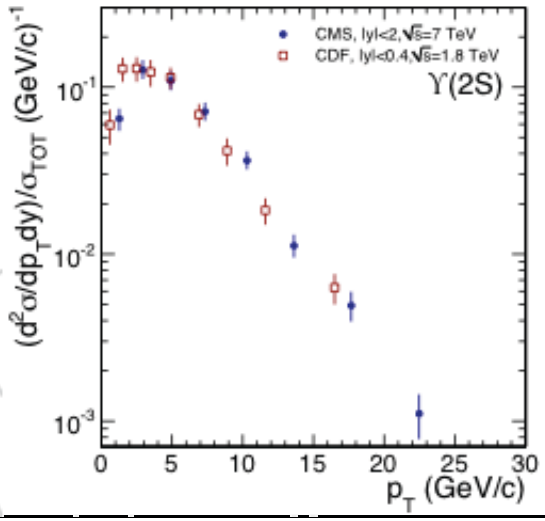
$$\sigma(pp \to \Upsilon(1S)X) \cdot \mathcal{B}(\Upsilon(1S) \to \mu^+\mu^-) = (7.49 \pm 0.13(\text{stat.})^{+0.67}_{-0.49}(\text{syst.}) \pm 0.82(\text{lumi.}))\ \text{nb},$$

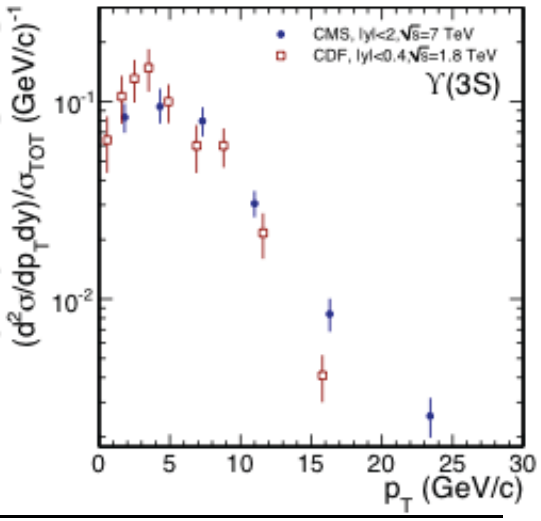
$$\sigma(pp \to \Upsilon(2S)X) \cdot \mathcal{B}(\Upsilon(2S) \to \mu^+\mu^-) = (1.93 \pm 0.08(\text{stat.})^{+0.19}_{-0.14}(\text{syst.}) \pm 0.21(\text{lumi.}))\ \text{nb},$$

$$\sigma(pp \to \Upsilon(3S)X) \cdot \mathcal{B}(\Upsilon(3S) \to \mu^+\mu^-) = (1.04 \pm 0.07(\text{stat.})^{+0.12}_{-0.09}(\text{syst.}) \pm 0.11(\text{lumi.}))\ \text{nb}.$$

CMS vs CDF & D0







$B_s \rightarrow J/\psi\,\phi$

Fit results:

$\mu_{gauss} = 5.3670 \pm 0.0012$ GeV/c^2

$\sigma_{gauss} = 16.4 \pm 1.2$ MeV/c^2

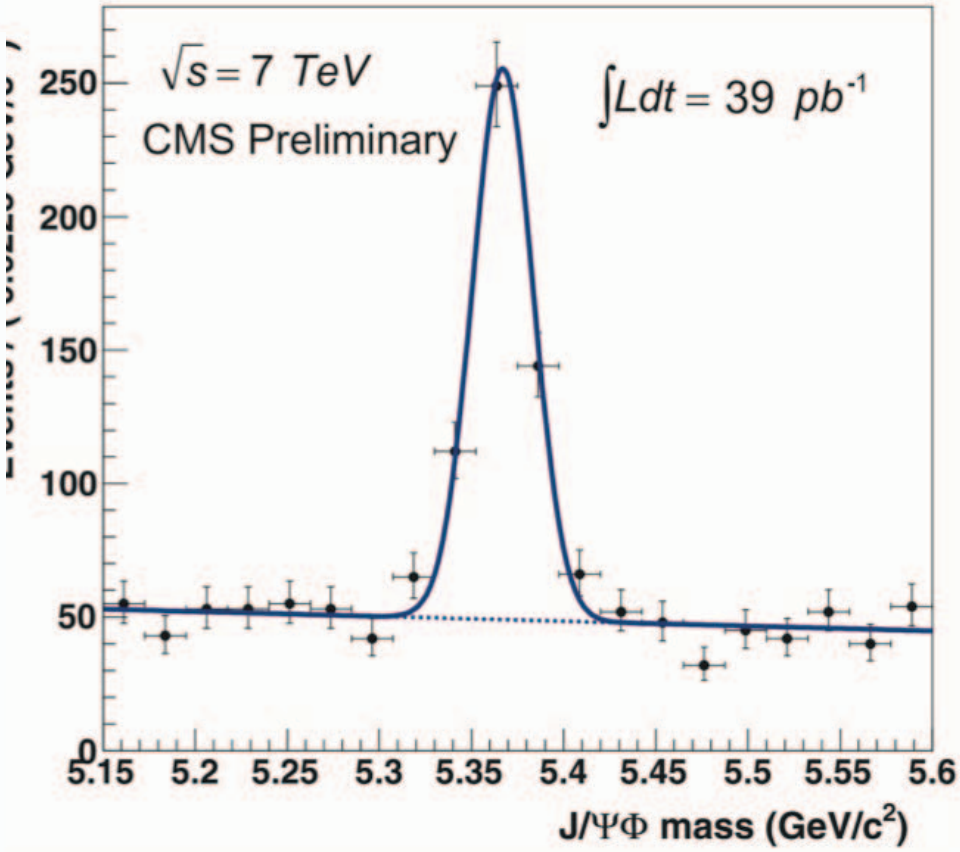
$N_{signal} = 377 \pm 26$

$N_{BG} = 978 \pm 36$

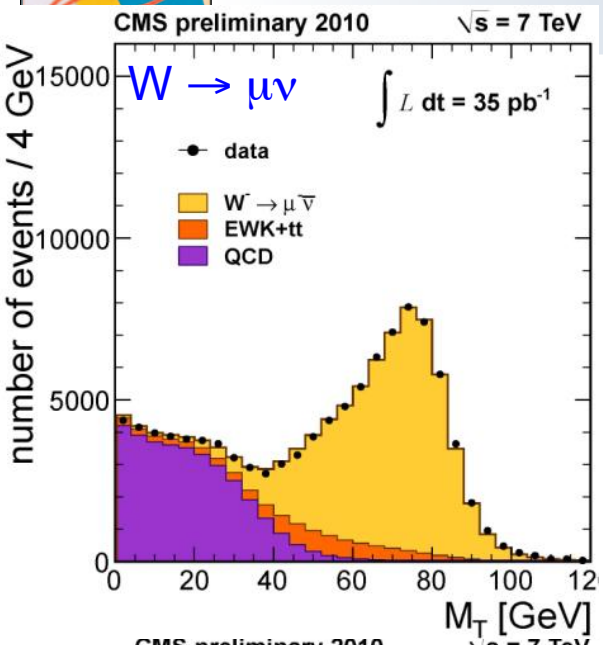
$\chi^2/ndof = 0.91$

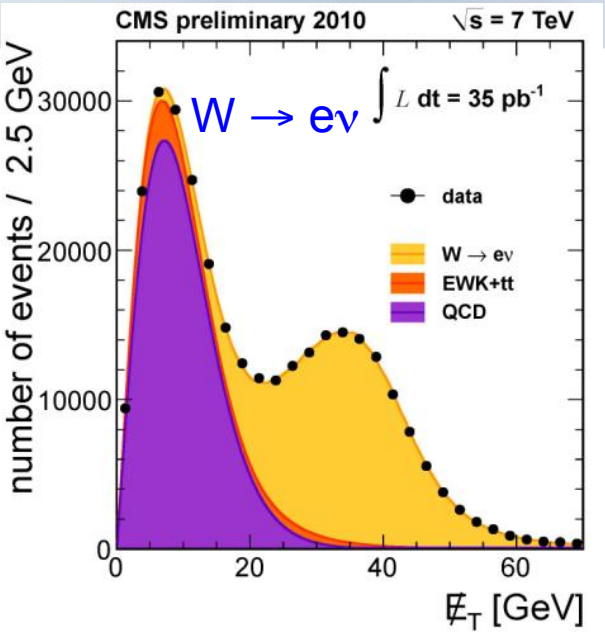
$S/\sqrt{(S+B)} \approx 10$

$S/B \approx 0.4$



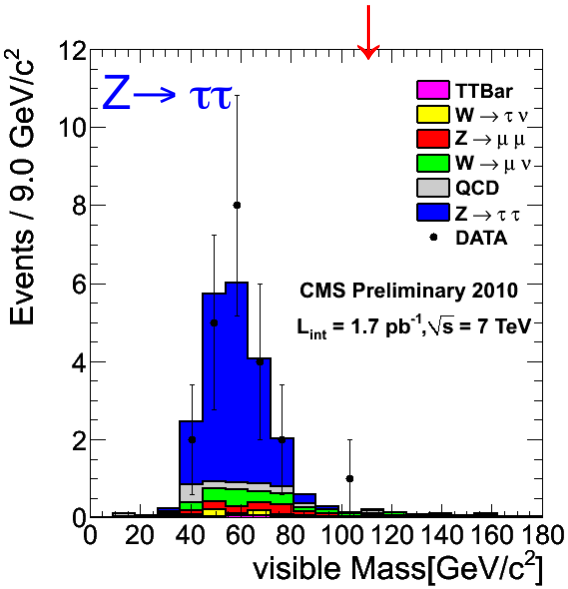
W and Z

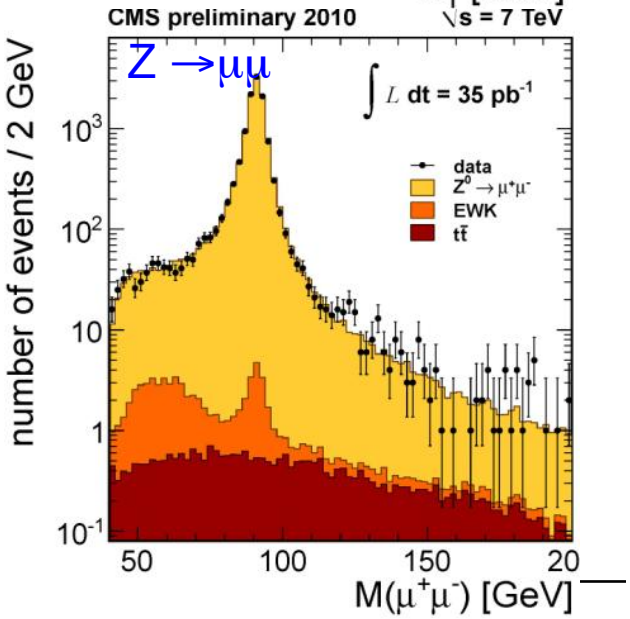


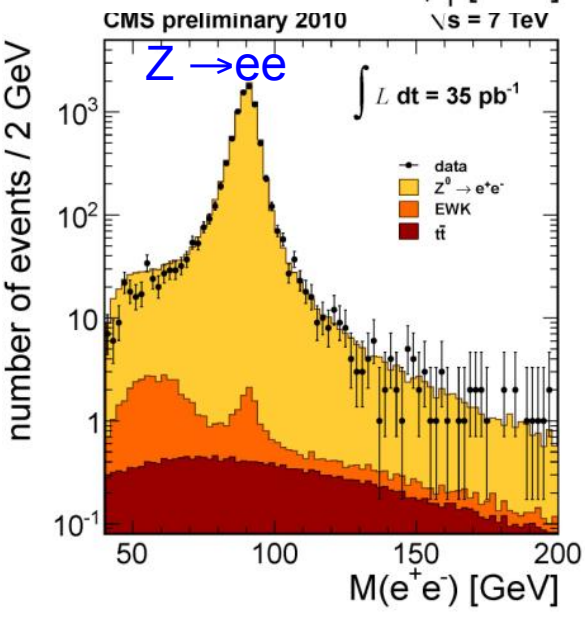


← W (35pb^{-1})

Z→ ττ



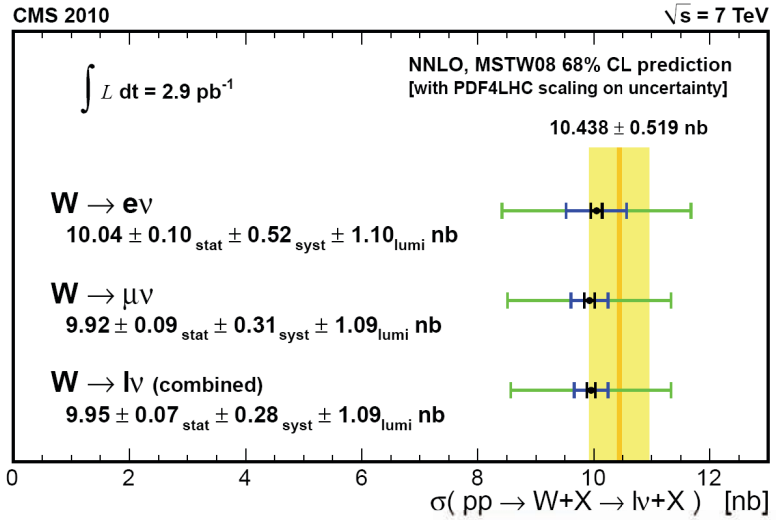


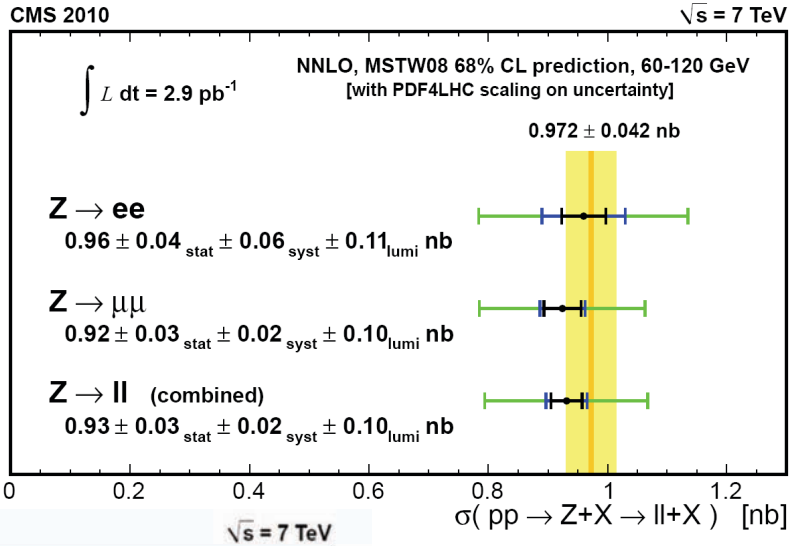


← Z (35 pb^{-1})

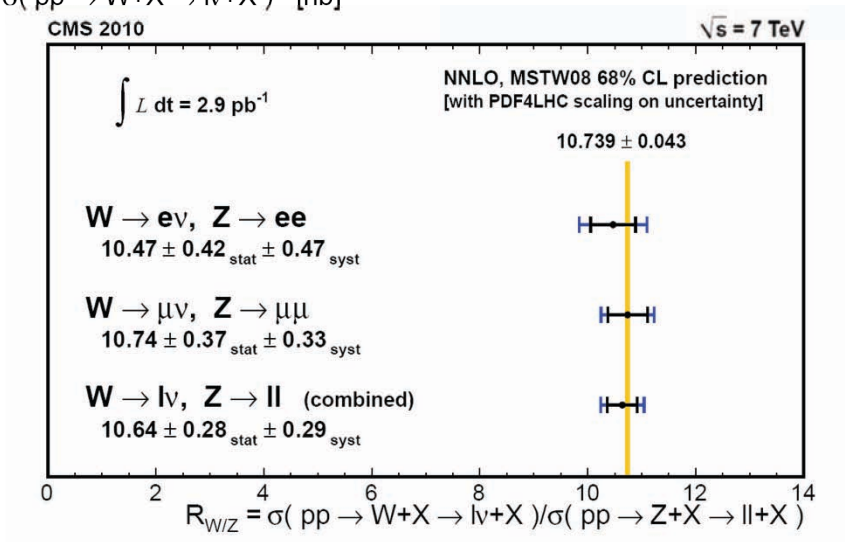
Electroweak: Z & W cross sections

W and Z cross sections:

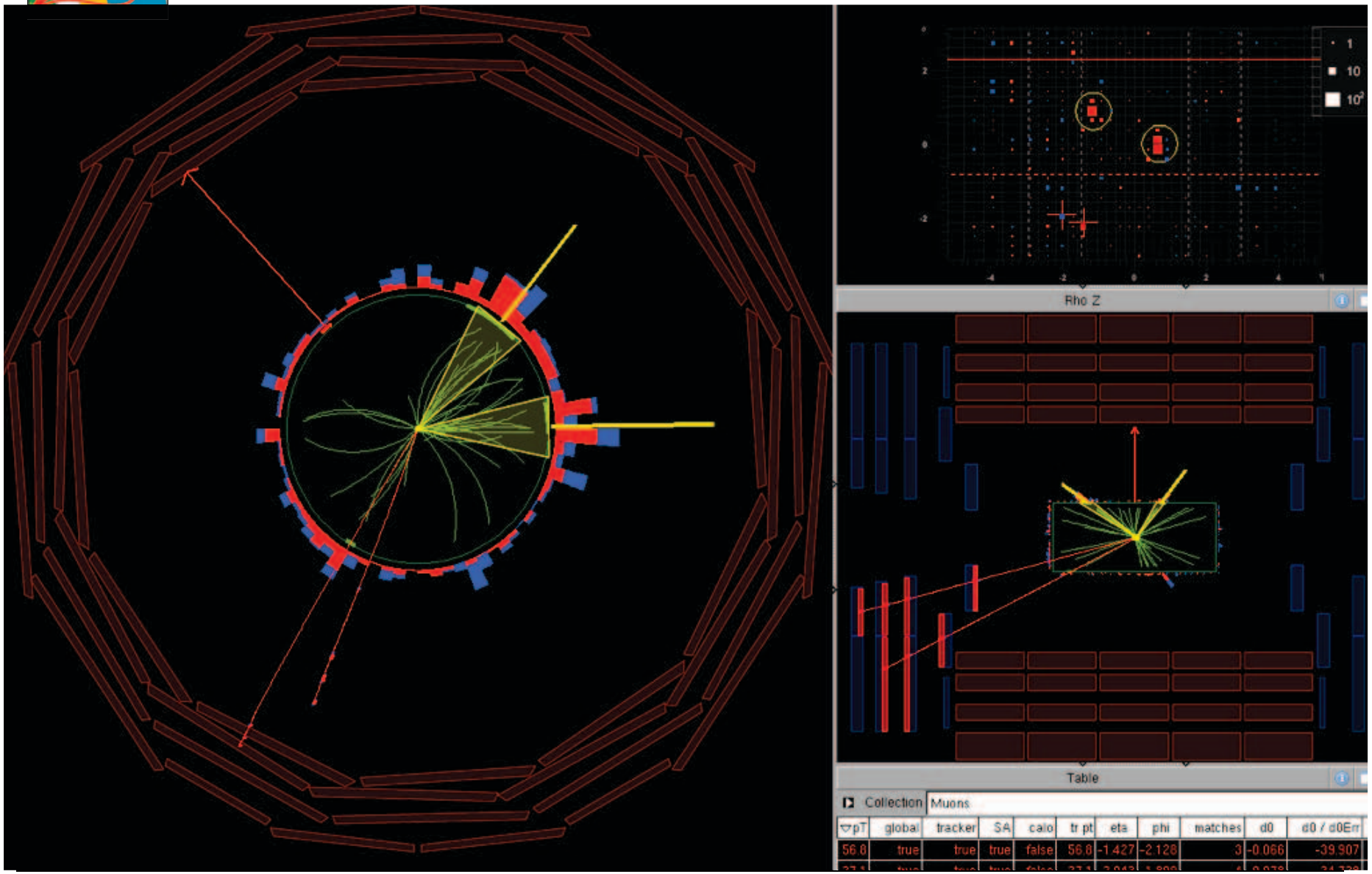




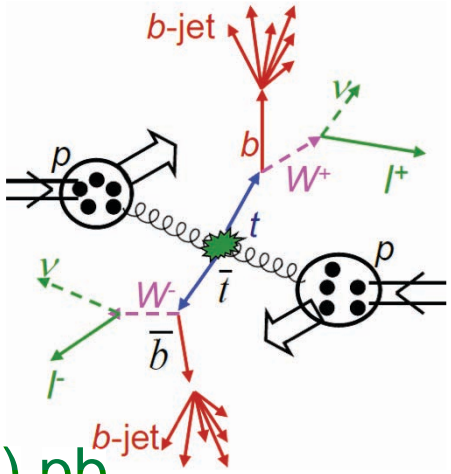
Ratio of W to Z cross sections:



The most challenging quark: the top

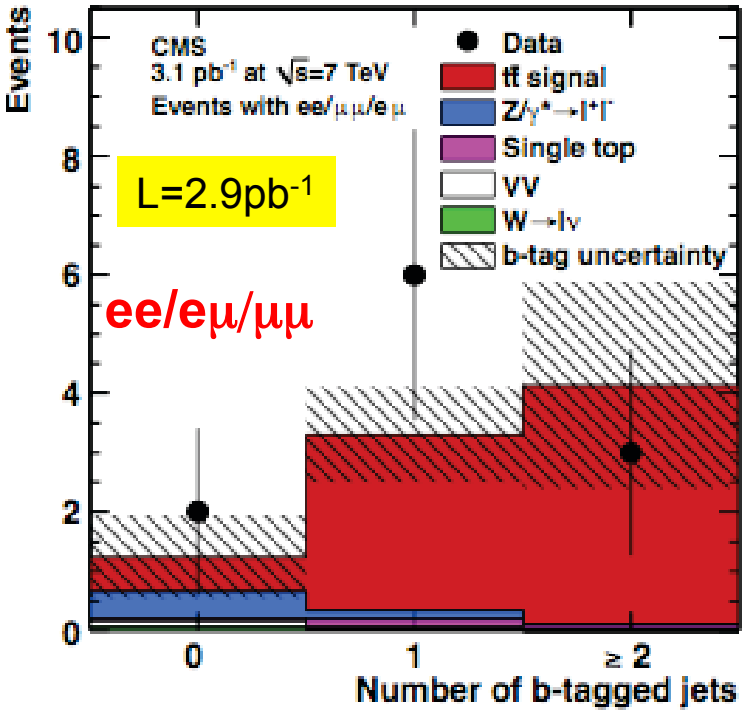


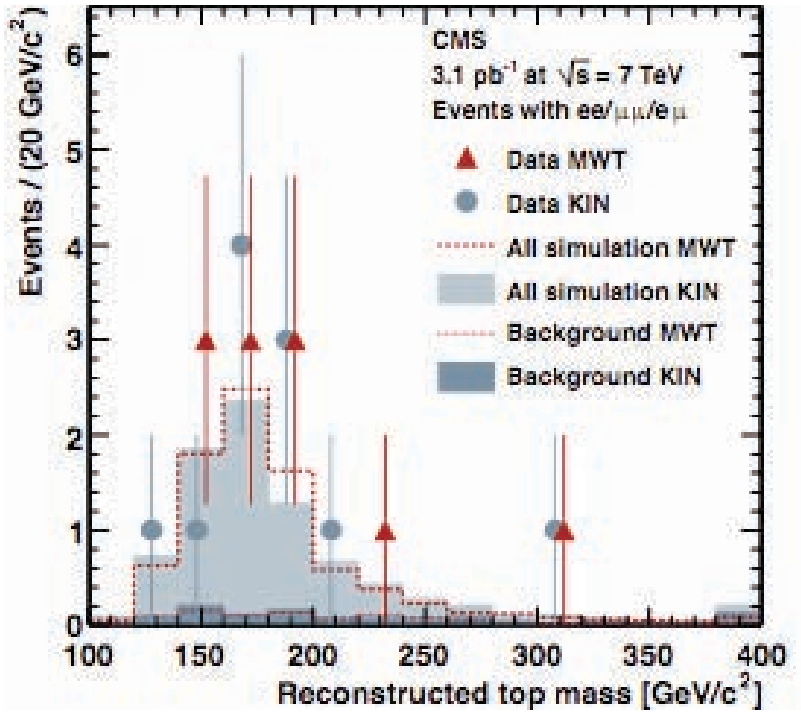
Top



Full selection applied: Z-Veto, |M(ll)-M(Z)|>15 GeV
MET >30 (20) GeV in ee,μμ, (eμ); N(jets)≥2

$\sigma(pp \rightarrow t\bar{t}) = 194 \pm 72(stat.) \pm 24(syst.) \pm 21(lumi.)$ pb

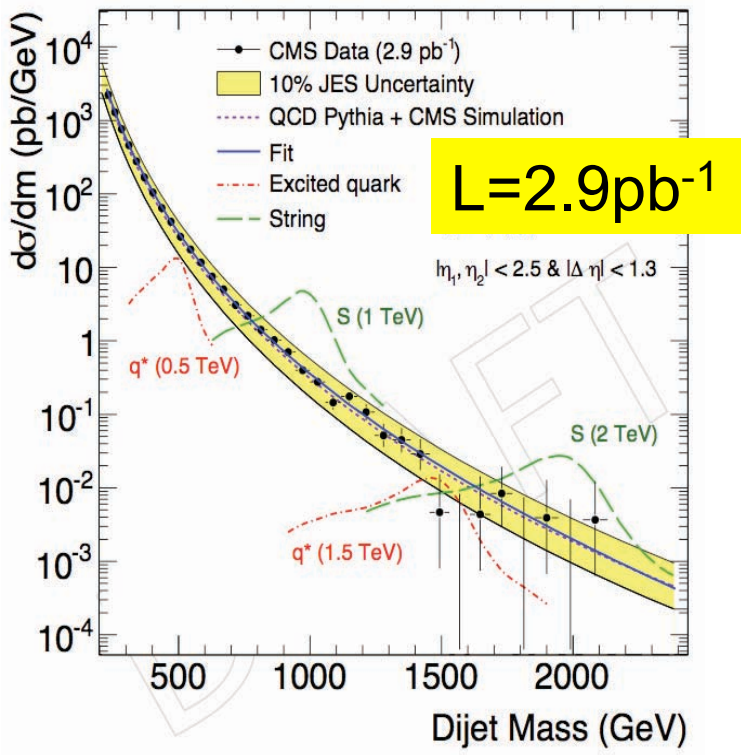


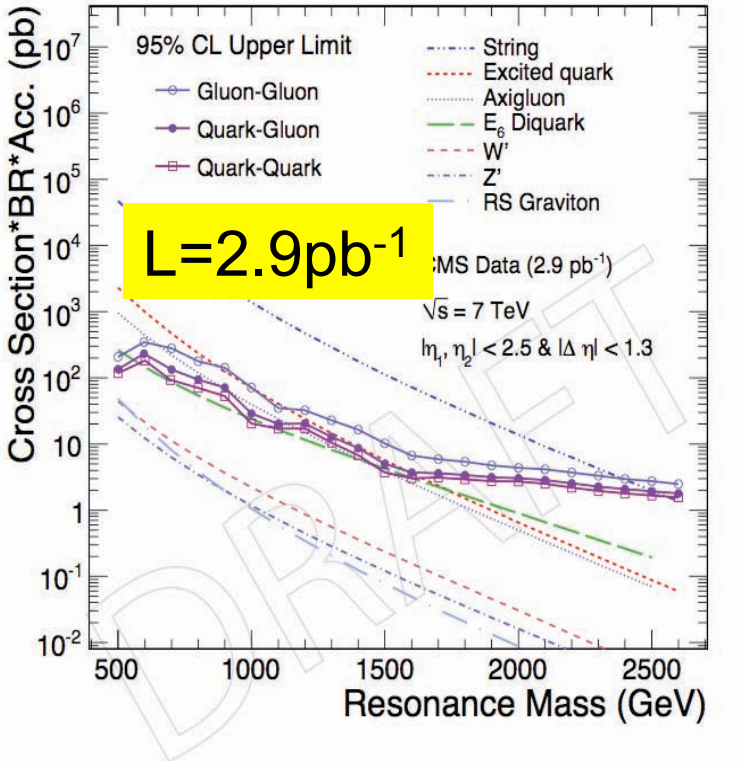


Submitted to PL-B arXiv:1010.5994

Search for narrow resonances in di-jet final states

Measured, in 2.9pb^{-1} of data, dijet mass differential cross section for $|\eta_1,\eta_2|<2.5$ and $|\Delta\eta_2|<1.3$. The distribution is sensitive to coupling of any new massive object to quarks & gluons.



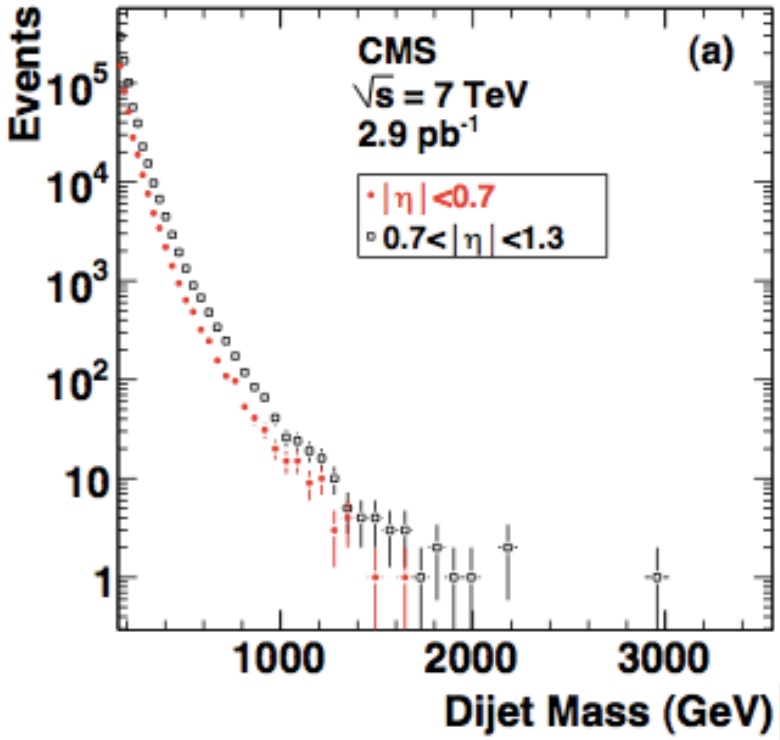


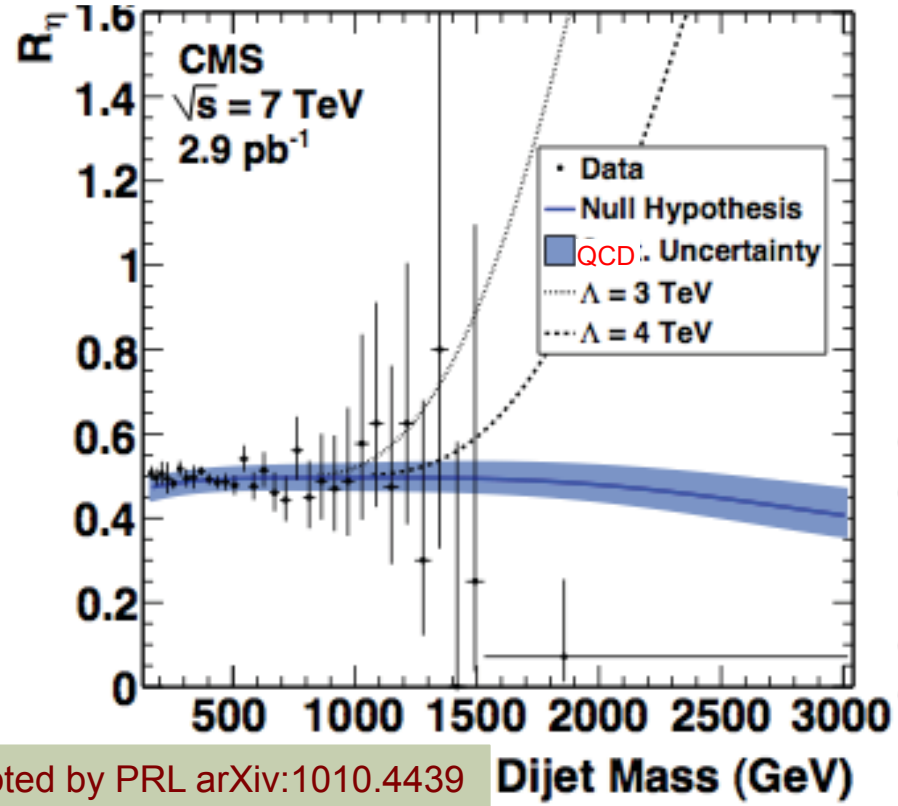
95% CL mass limits for new particles decaying to parton pairs: String resonances >2.5TeV; Excited quarks >1.58TeV….

Quark compositeness/QCD

Centrality ratio

Contact interaction: excluded for Λ<4 TeV (higher than expected -2.9 TeV- due to fewer-than-expected events at high Dijet mass)

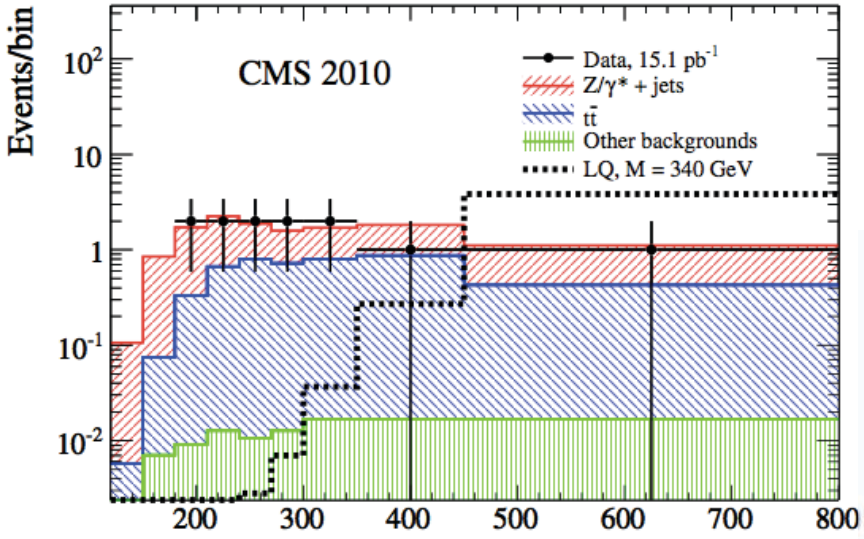




Accepted by PRL arXiv:1010.4439

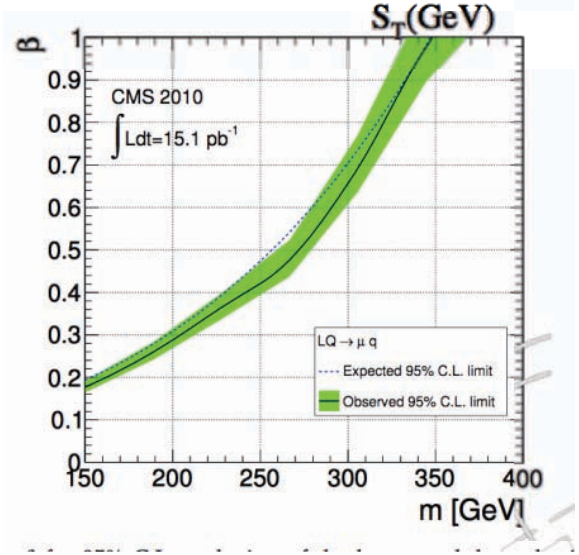
Leptoquark search

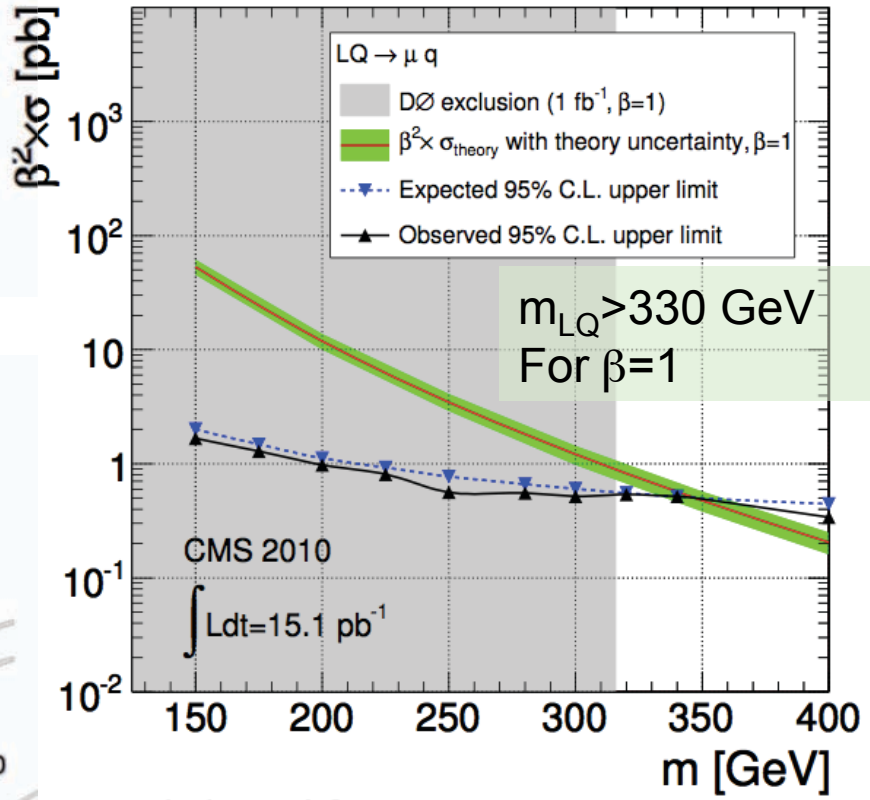
Search for pair produced LQ decaying β % in μ+jet



Final discri variable

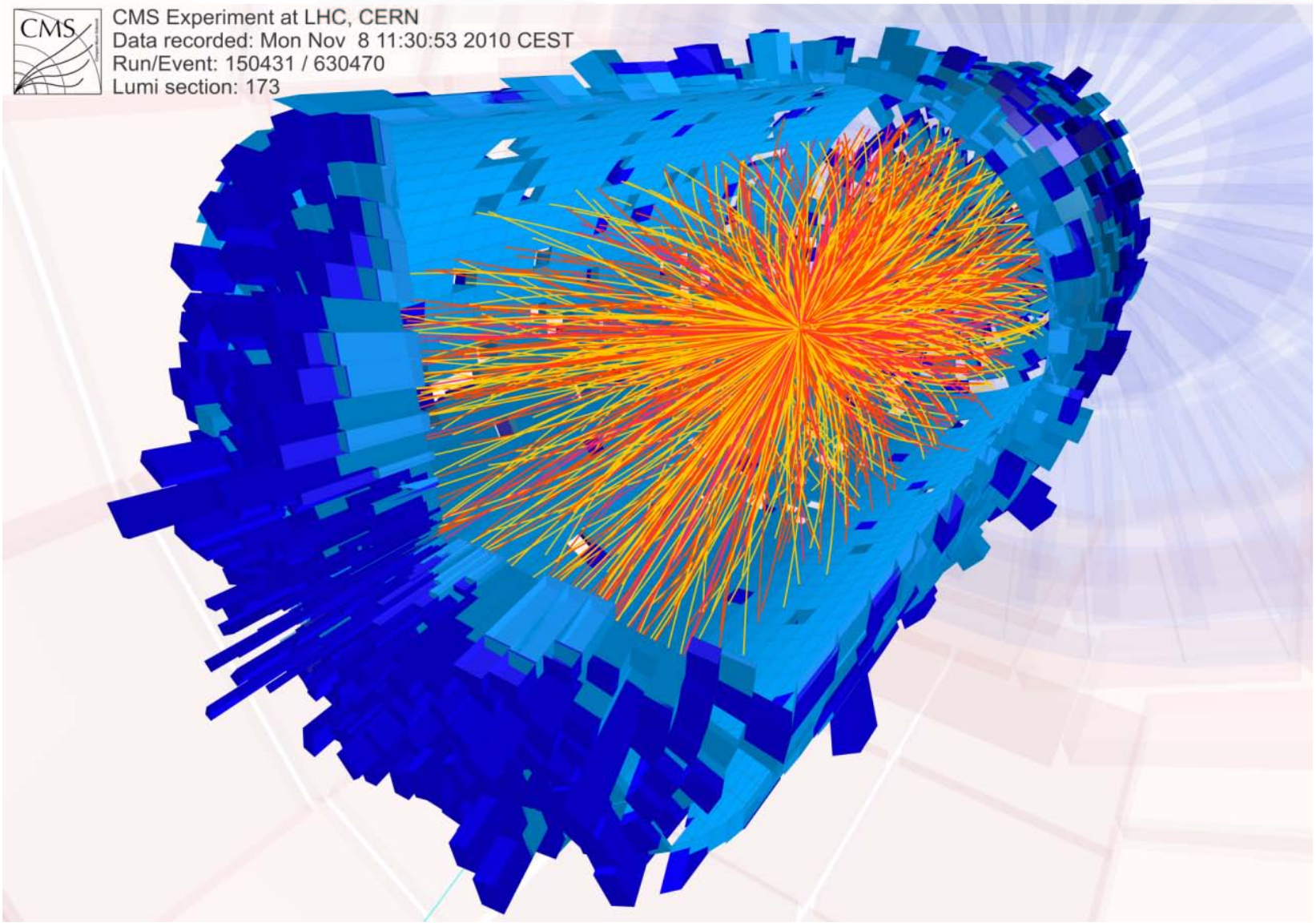
As a function of β



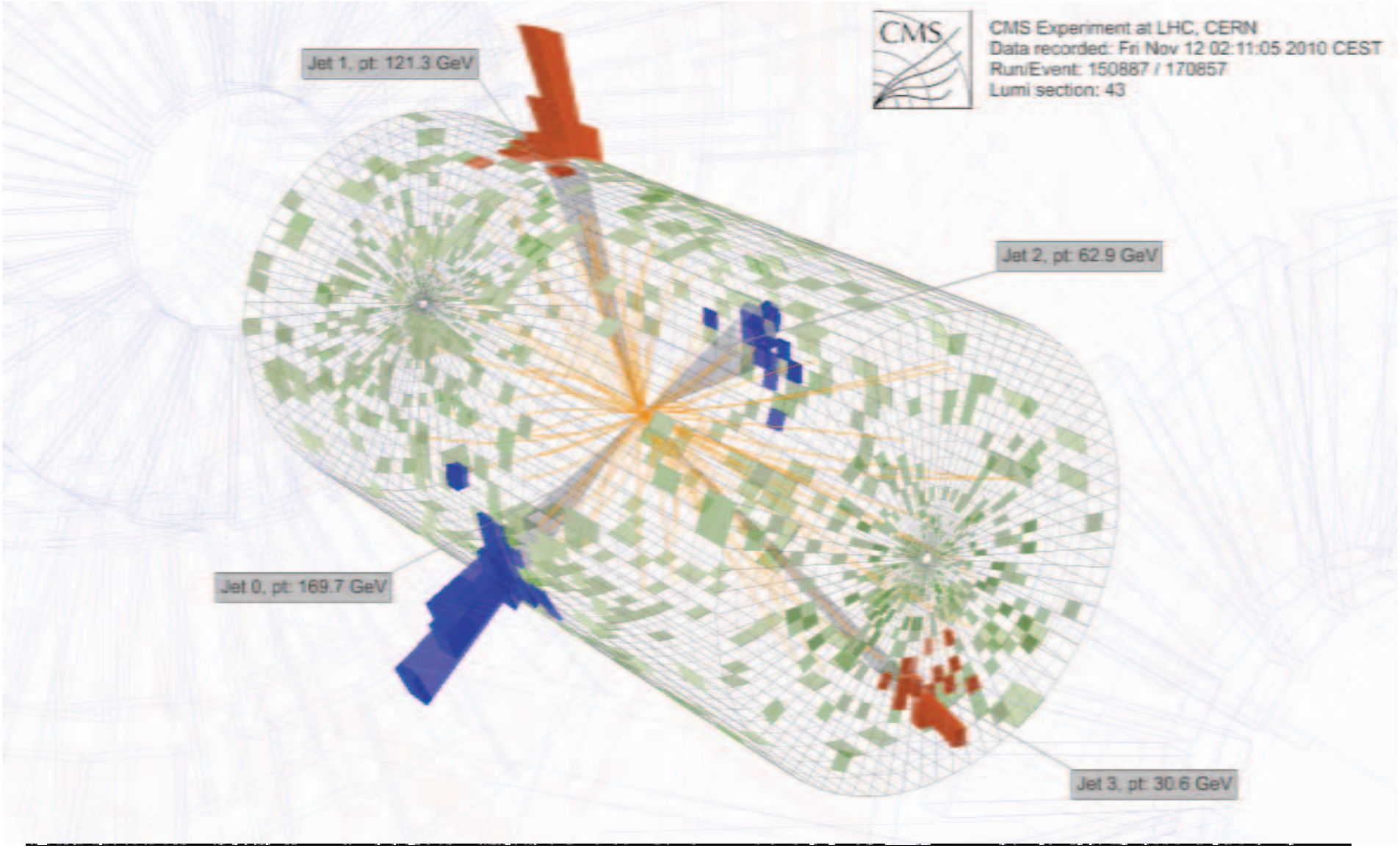


m_{LQ}>330 GeV
For β=1

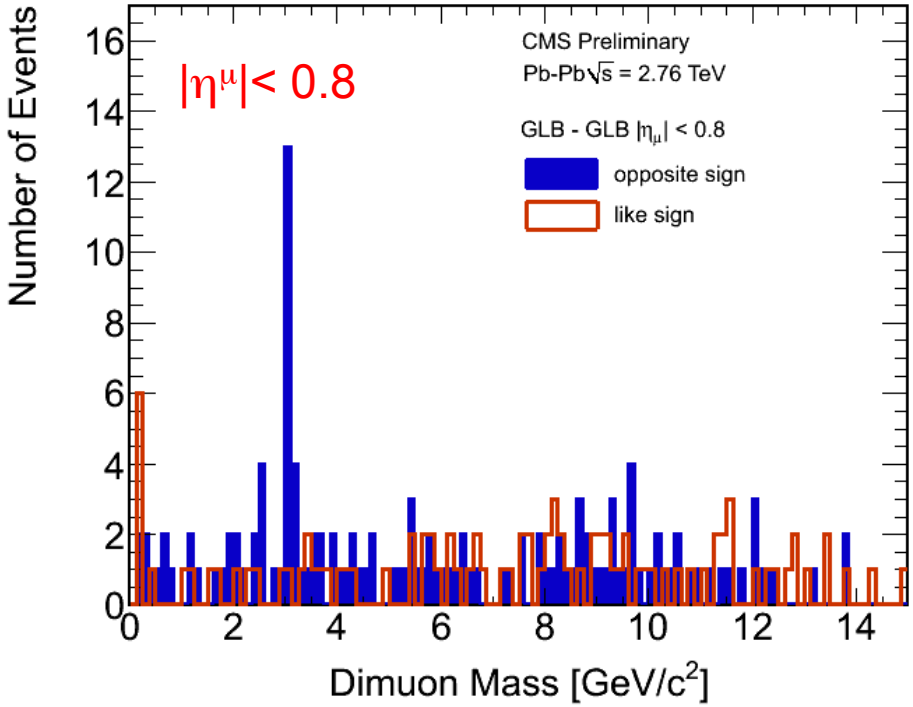
Heavy Ion Collisions in CMS Since Nov. 8

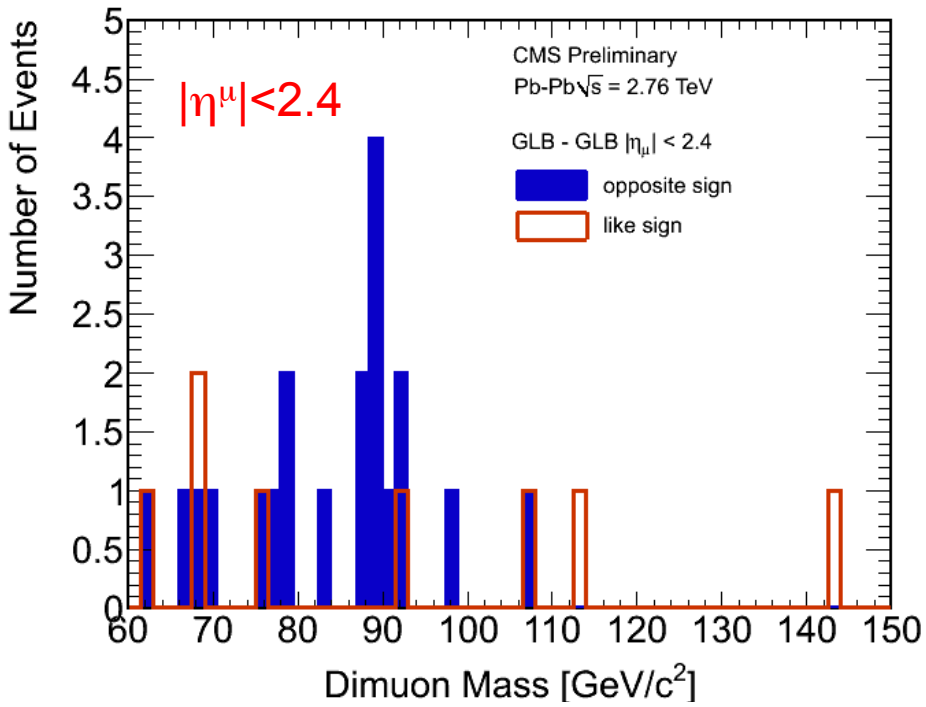


Heavy Ions: 4 jet event



HI: Di-μ mass distrib (1.6 μb^{-1})

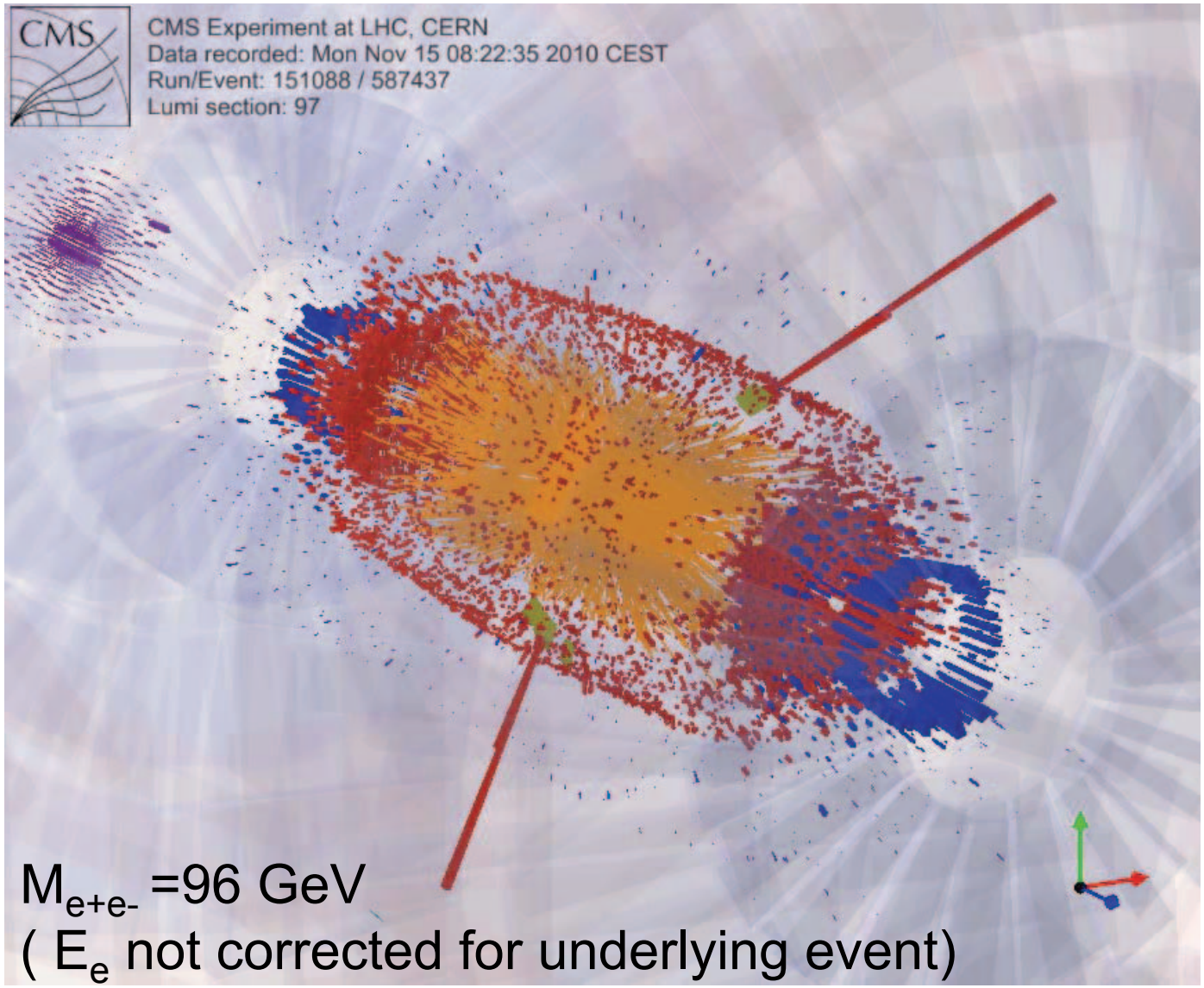




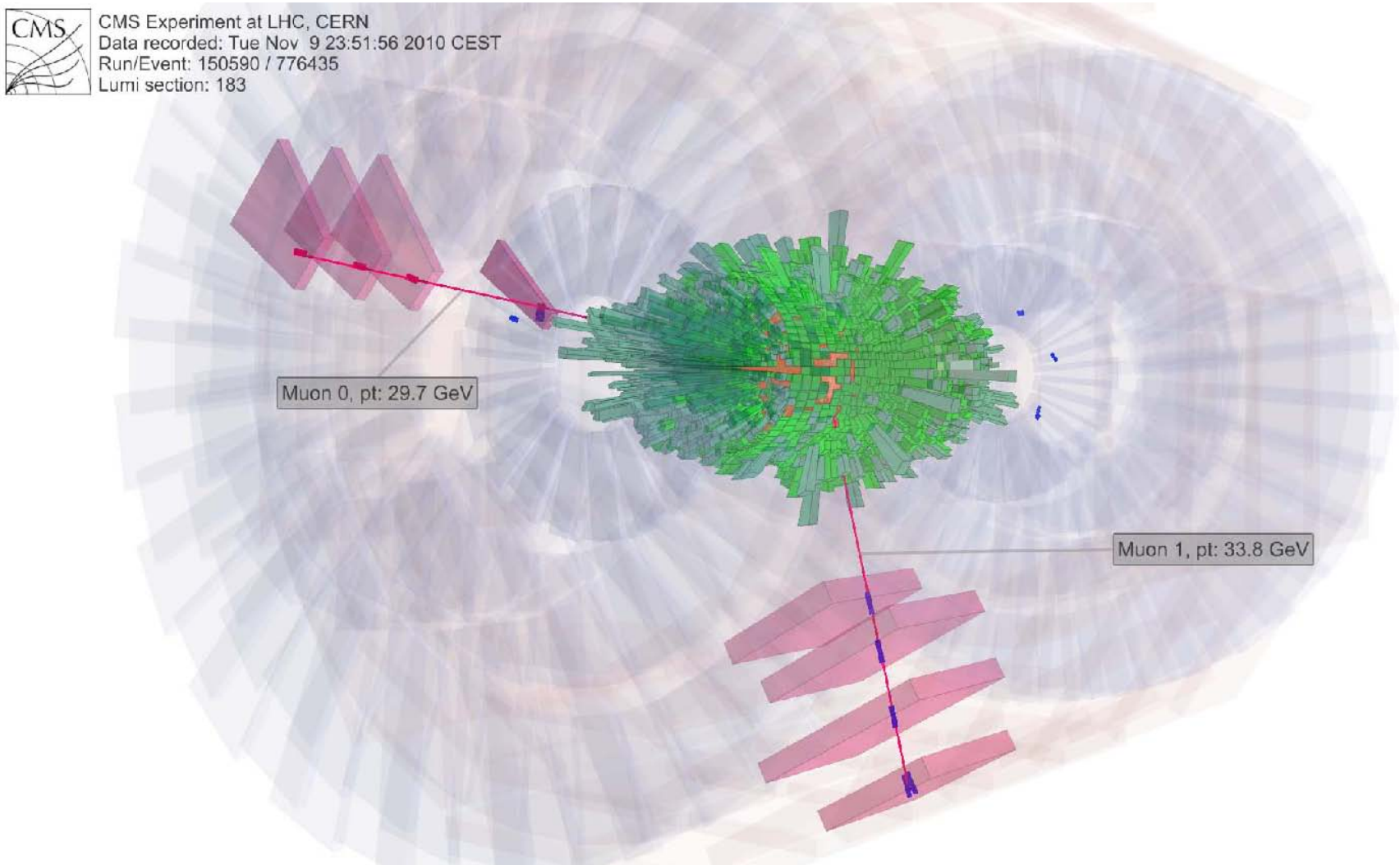
blue= opposite sign

red= like-sign

Heavy Ion Z → ee Candidate



Heavy Ion Z → μμ Candidate



$M_{\mu+\mu-}$ = 93 GeV : possibly the first Z ever seen in HI

LHC in 2011 & 2012: the dream

Energy 8 TeV; bunch spacing 50-75ns depending on electron cloud effects; running time: 2011 and 2012.

$$L = \frac{N^2 k_b f}{4\pi\sigma_x\sigma_y} F = \frac{N^2 k_b f \gamma}{4\pi\varepsilon_n \beta^*} F$$

- Nearly all the parameters are variable (and not independent)
  - Number of bunches per beam — k_b — **350→1400 4**
  - Number of particles per bunch — N — **1×10^{11}→1.6×10^{11} 2.5**
  - Normalised emittance — ε_n — **2.5→1.8 ~1.3**
  - Relativistic factor (E/m_0) — γ — **7TeV→8TeV 1.14**

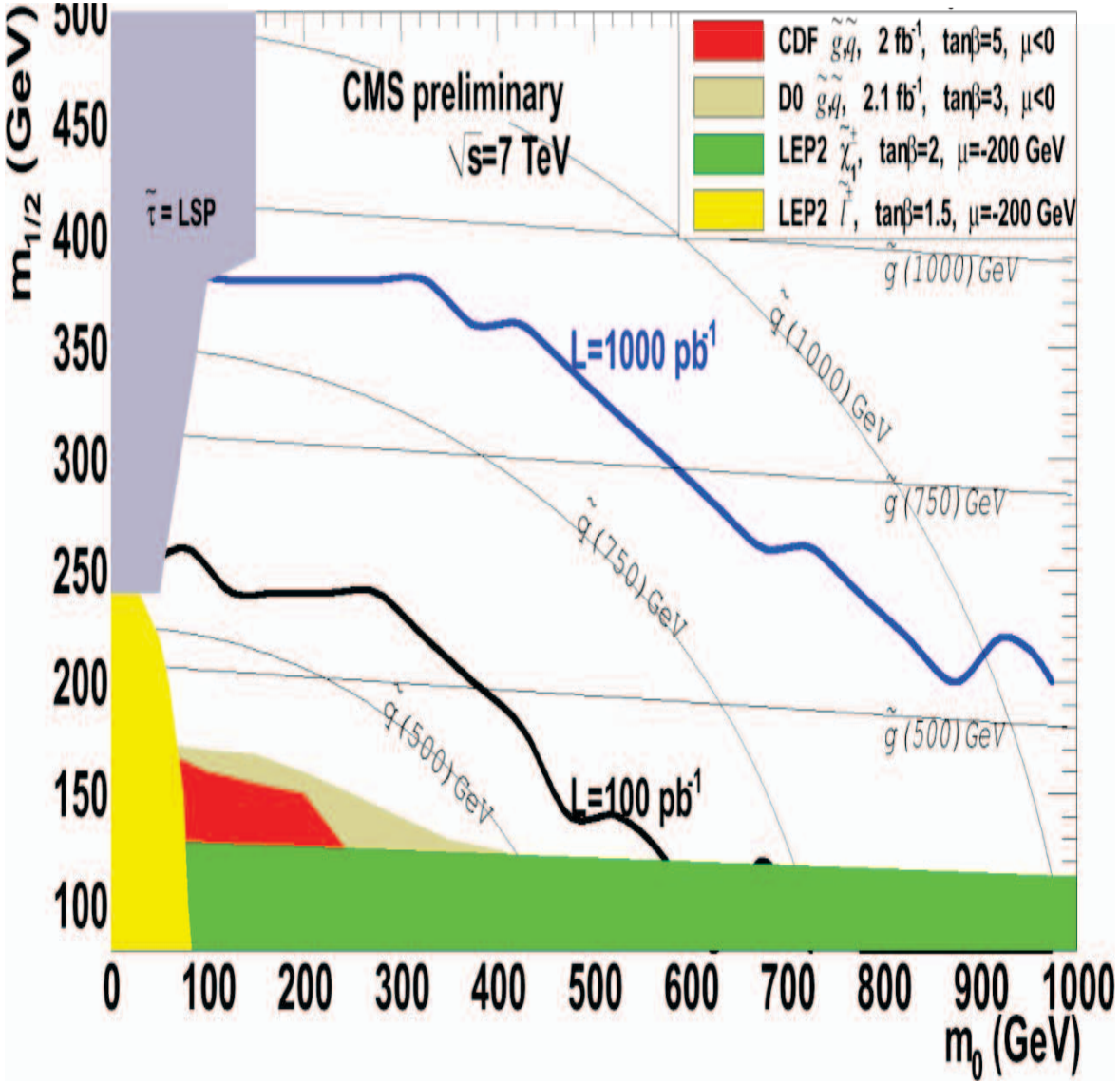
  - Beta function at the IP — β^* — **3.5m→2m→1m 3.5**
  - Crossing angle factor — F —
    - Full crossing angle — θ_c
    - Bunch length — σ_z
    - Transverse beam size at the IP — σ^*

~ FACTOR 15-50

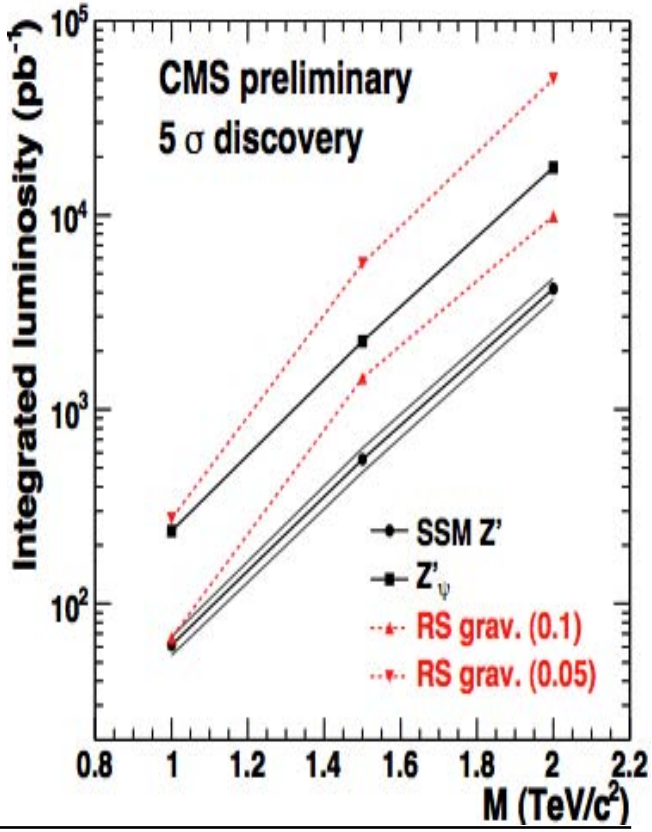
$$F = 1/\sqrt{1+\left(\frac{\theta_c\sigma_z}{2\sigma^*}\right)^2}$$

BUT life will be harder and not everything will work perfectly… however….

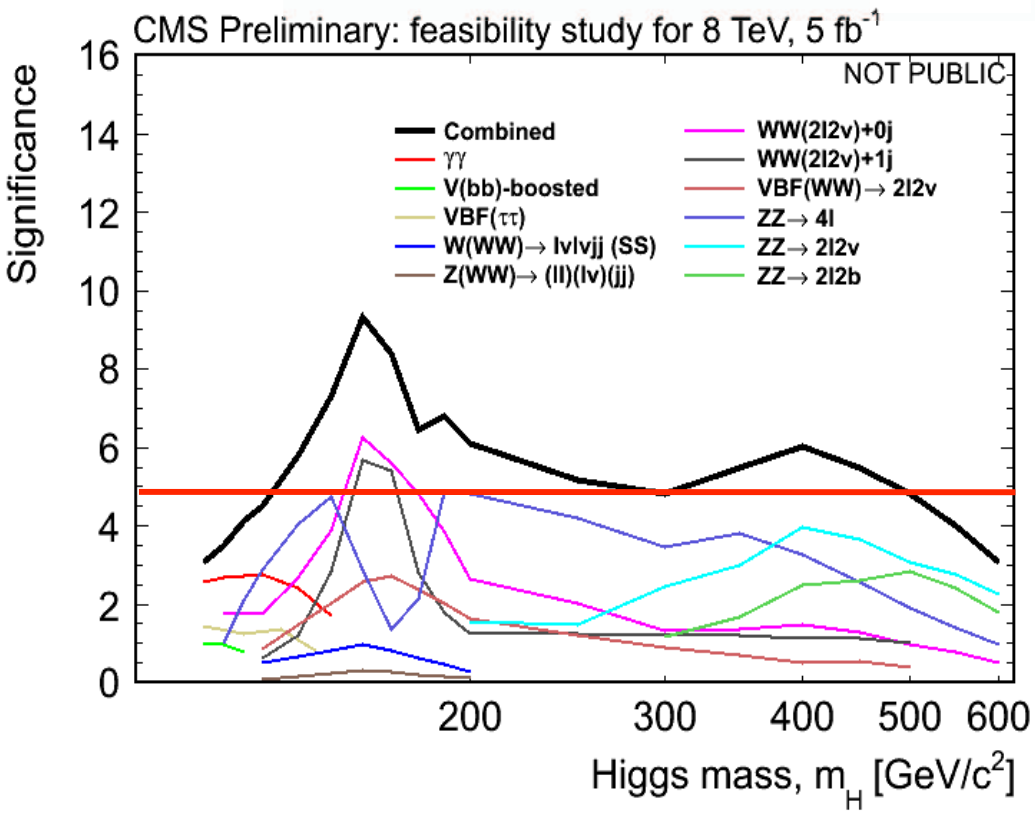
The reward: Physics Prospects for the 2011-12 Run

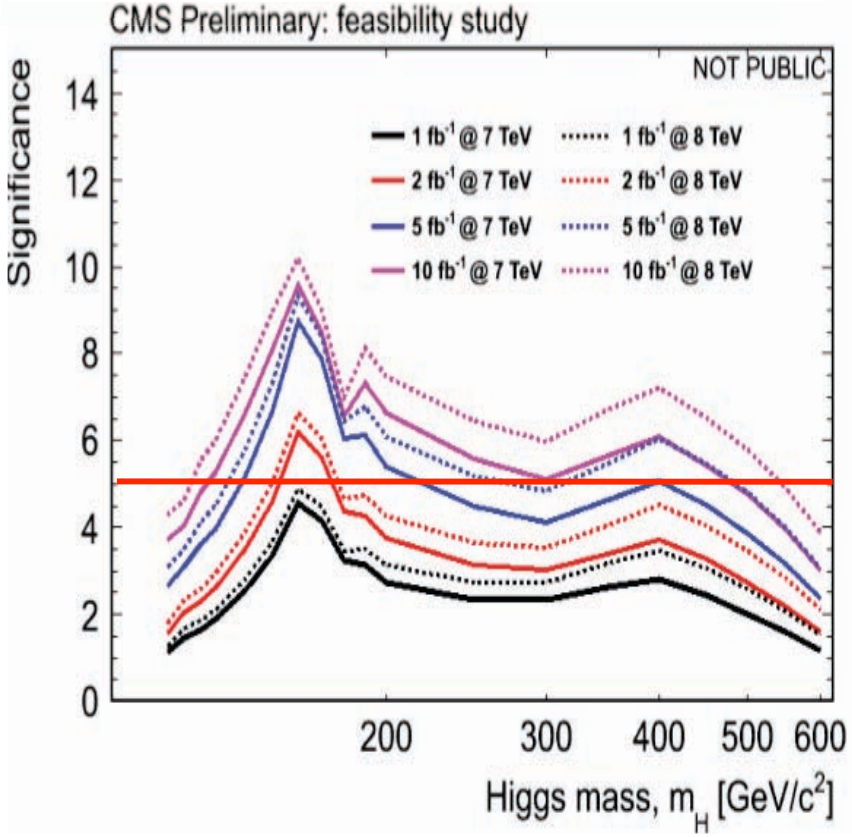


W' and Z' up to the MultiTeV region. SUSY ~ m squarks and gluinos >1 TeV



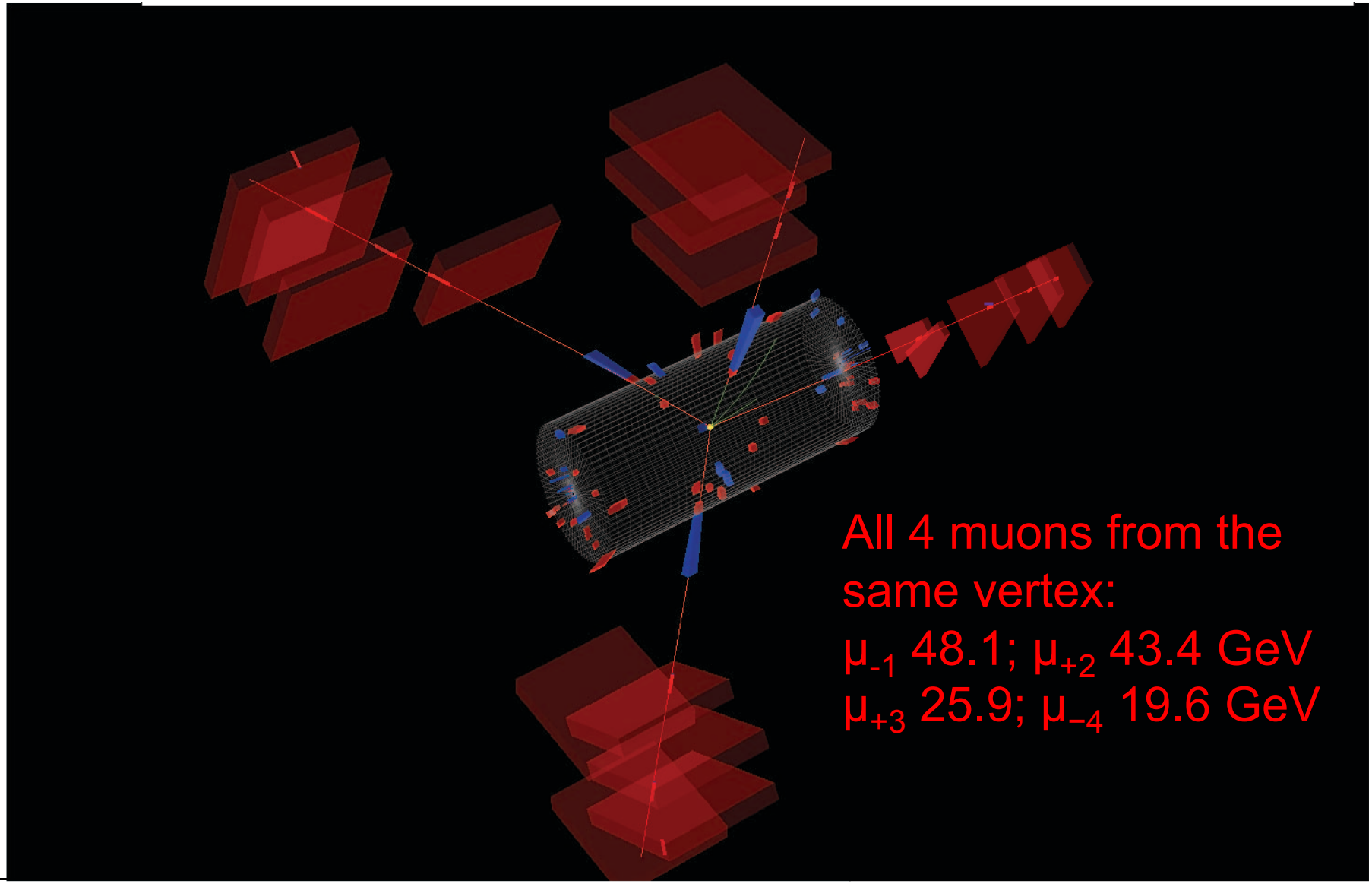
Prospects for the Higgs search in 2011-12





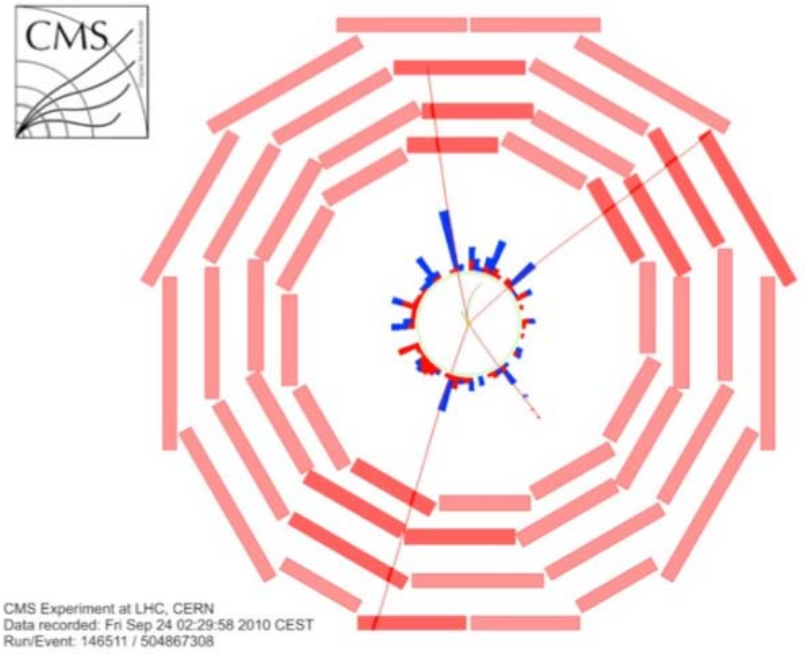
Given the excellent performance of LHC in 2010 and the prospects of getting more integrated luminosity in 2011-12 we have recently re-evaluated the reach of CMS 2011; preliminary studies done, considering for the moment only the most promising channels: **with 10fb^{-} at 8 TeV we can discover the Higgs over the mass range between ~115 and ~600GeV.**

The first ZZ→4μ event



More about first ZZ→4μ event

ρ-φ view



Only tracks with p_T>1 GeV are displayed

$\mu_0 + \mu_1$: 92.15 GeV (total(Z) p_T 26.5 GeV, ϕ -3.03),
$\mu_2 + \mu_3$: 92.24 GeV (total(Z) p_T 29.4 GeV, ϕ +.06),
$\mu_0 + \mu_2$: 70.12 GeV (total p_T 27 GeV),
$\mu_3 + \mu_1$: 83.1 GeV (total p_T 26.1 GeV).

Invariant Mass of 4μ: 201 GeV

Probability to find such an event in the first 22pb^{-1} of data: 16%.

Just a reminder…

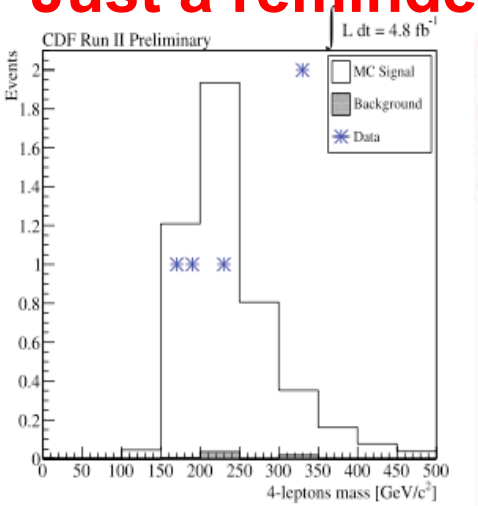


Figure 4: CDF ZZ result.

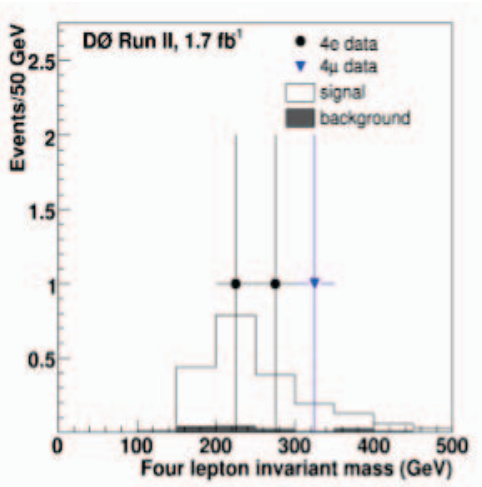


Figure 5: D0 ZZ result.

Conclusions & Outlook

Very Good Year for CMS & the LHC

- 42 pb^{-1} of pp data
- Heavy Ions
- CMS Detector performing well

Good Physics Results

- "Rediscovered" the Standard Model
- Electroweak & top cross sections agree with SM
- Starting to set new limits on new physics
- First Glimpse at Heavy Ions

Prospects for 2011-12

- Maybe 5 – 10 fb^{-1} of pp data
- Good chance to find new physics