CMS STATUS AND PROSPECTS

A brief chat on who and where we are, and where we are going to

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for the CMS Frascati group

Slides material courtesy of CMS Collaboration
many thanks in particular to
my colleagues Davide Piccolo and Luigi Benussi (Frascati)
and to
Mario Kadastik - KBFI Estonia
Karl M. Ecklund - Rice University
Mario Galanti - University of Cyprus
Michael Murray - Kansas University
Urs Langenegger - PSI

OUTLINE

- The Detector
- Performances
- Early Data Taking Runs
- First Physics
- Prospects

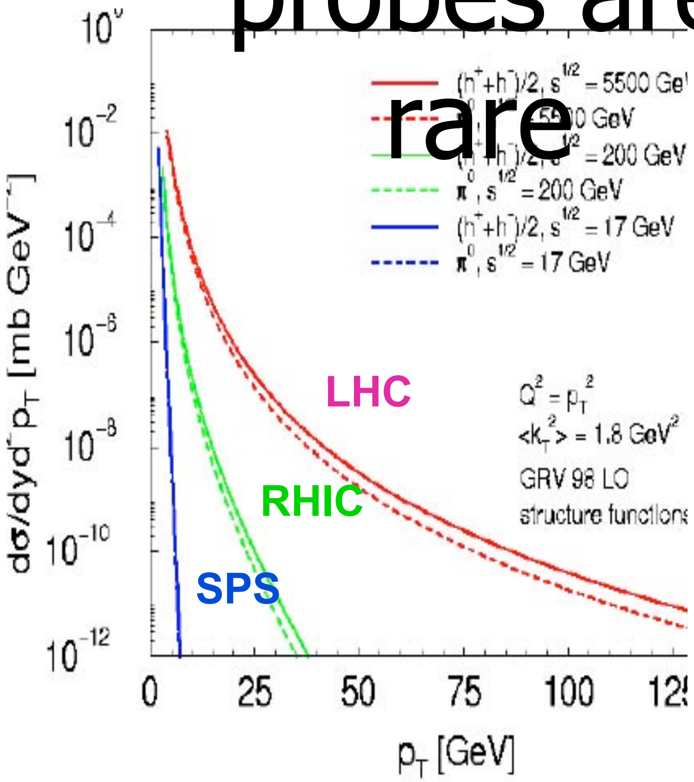
Compact Muon Solenoid
METHOD AND GOALS

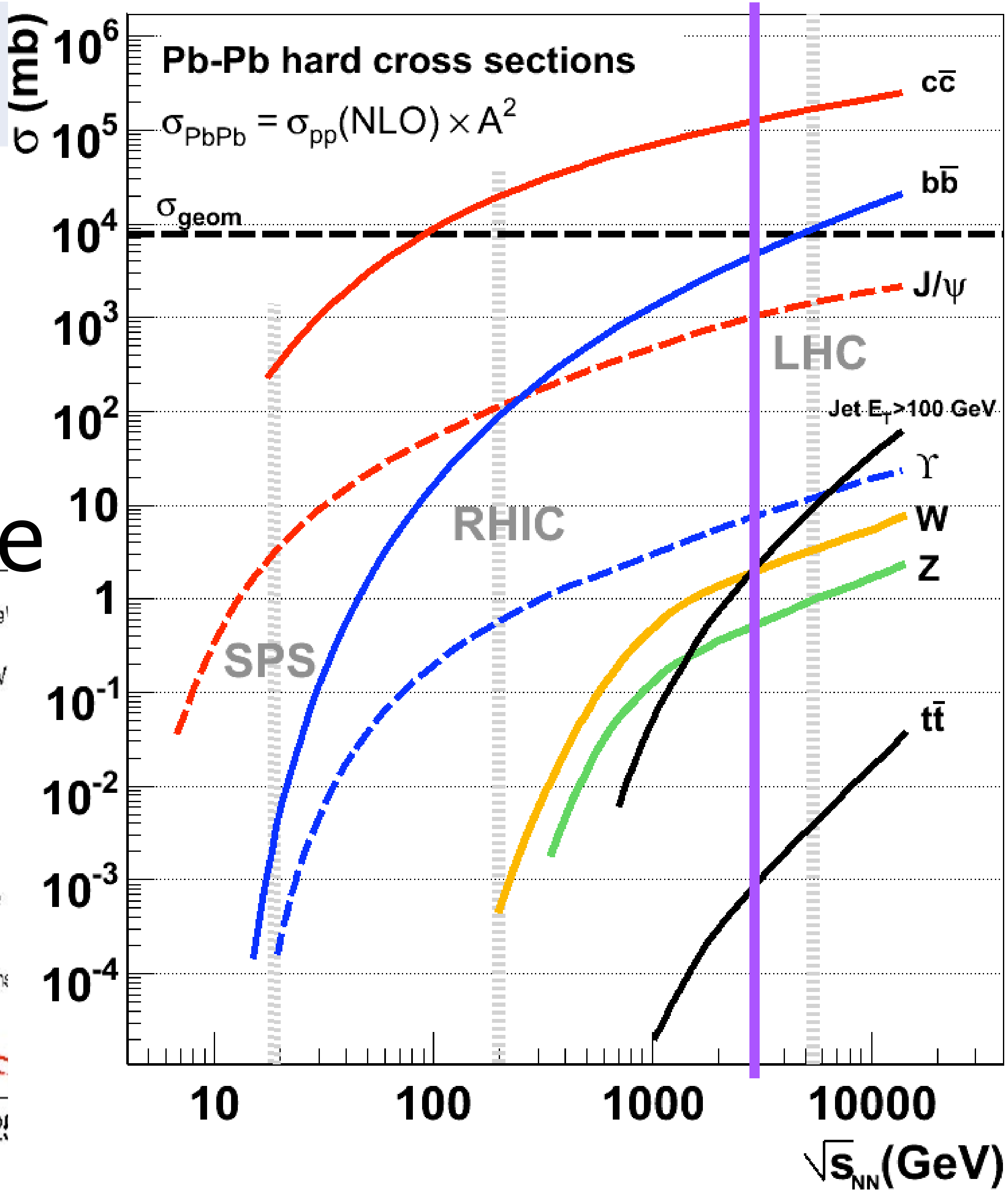
- Hermetic detector in a 4T solenoid
- Tracking
- Crystal calorimetry
- Muon detection

- Find the Higgs
- Find the New Physics
- High precision SM (W,Z,top) physics
- B physics
- Heavy ion programme   NOT COVERED IN THIS TALK :-)

NOT COVERED

Hard probes are rare

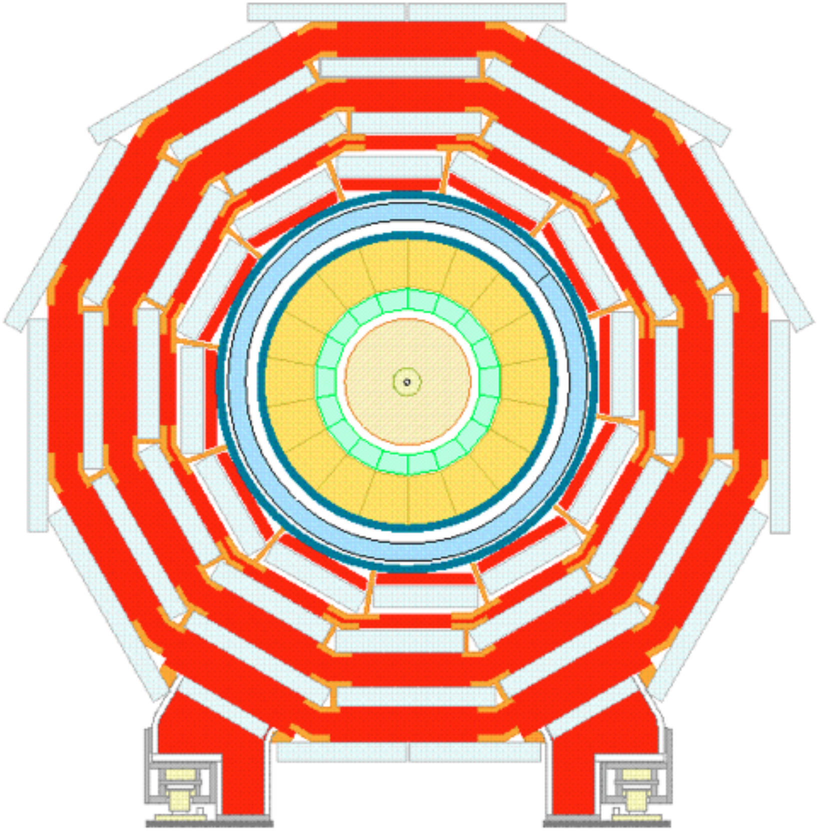




Compact Muon Solenoid

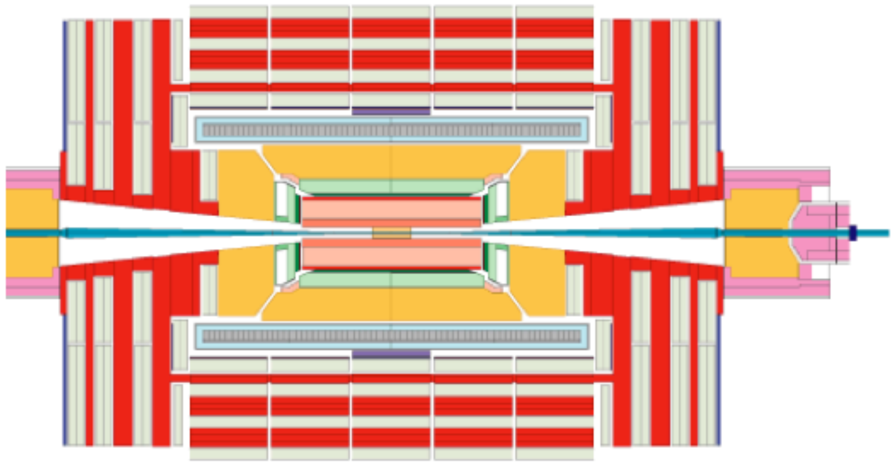
- Precision Silicon Tracking
- EM Calorimeter
- Hadron Calorimeter
- 3.8 T Magnetic Field
- Muon Detectors

JINST 3 08004 (2008)



Transverse Slice

Longitudinal Slice

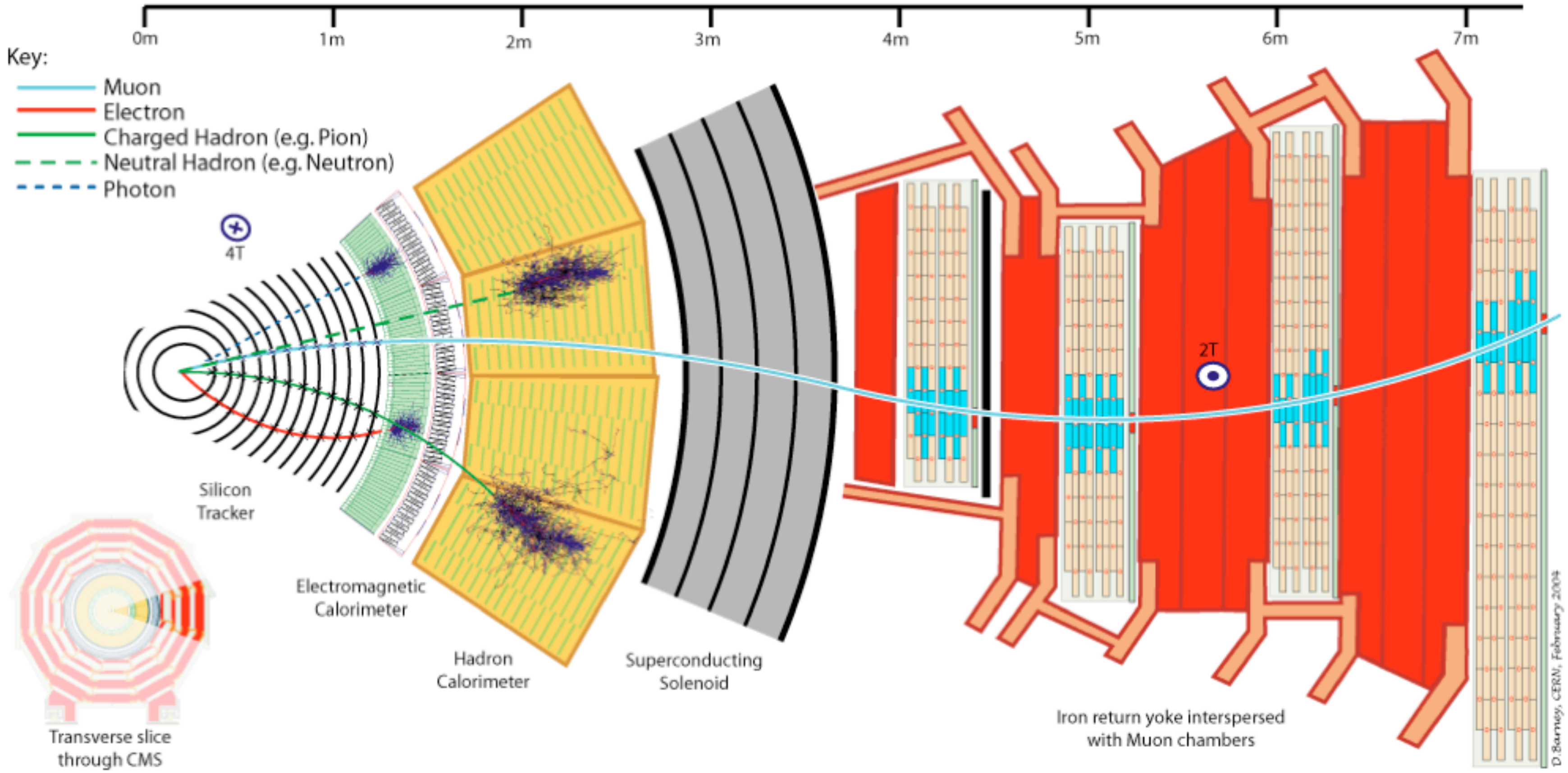


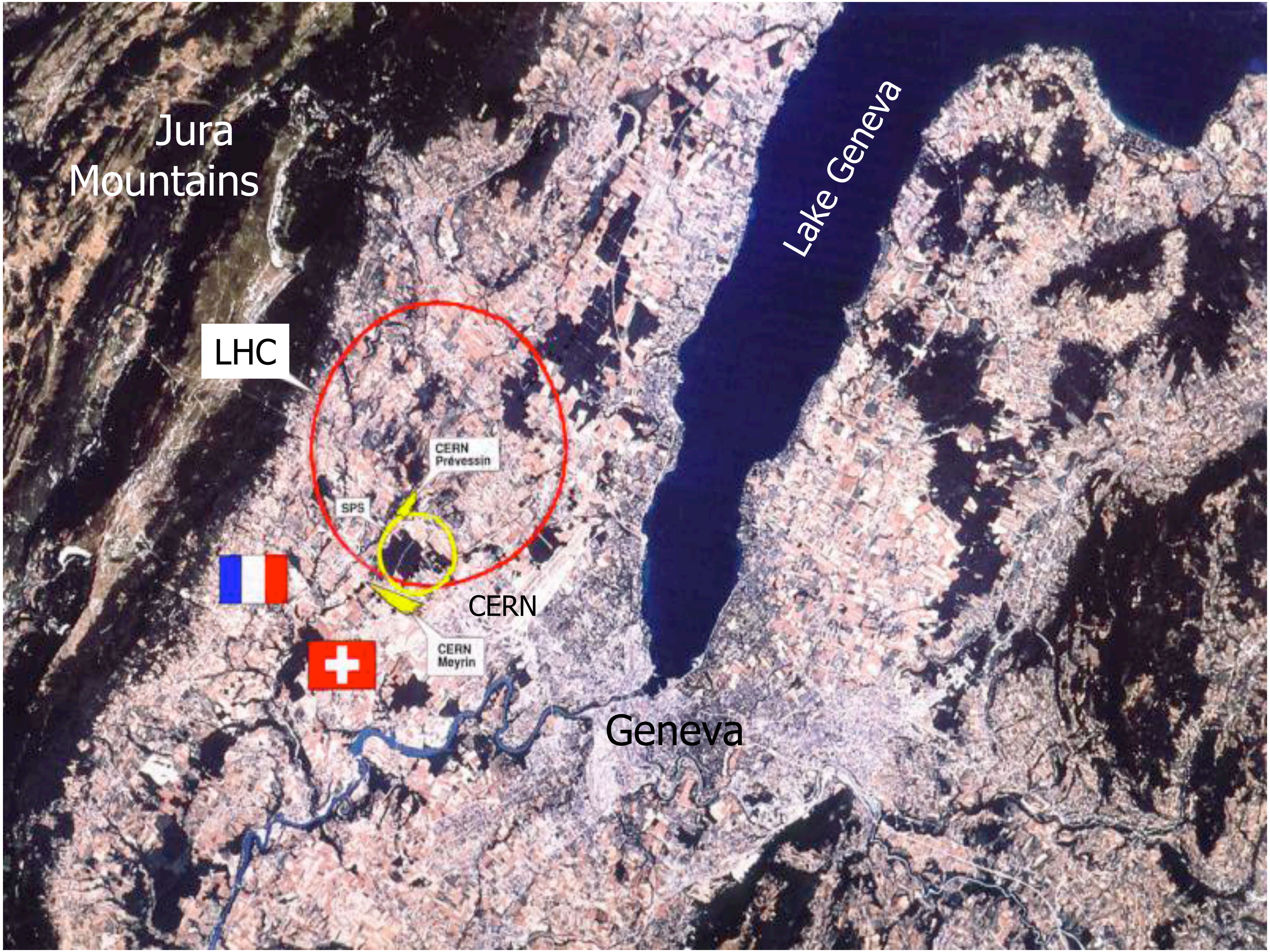
15 m

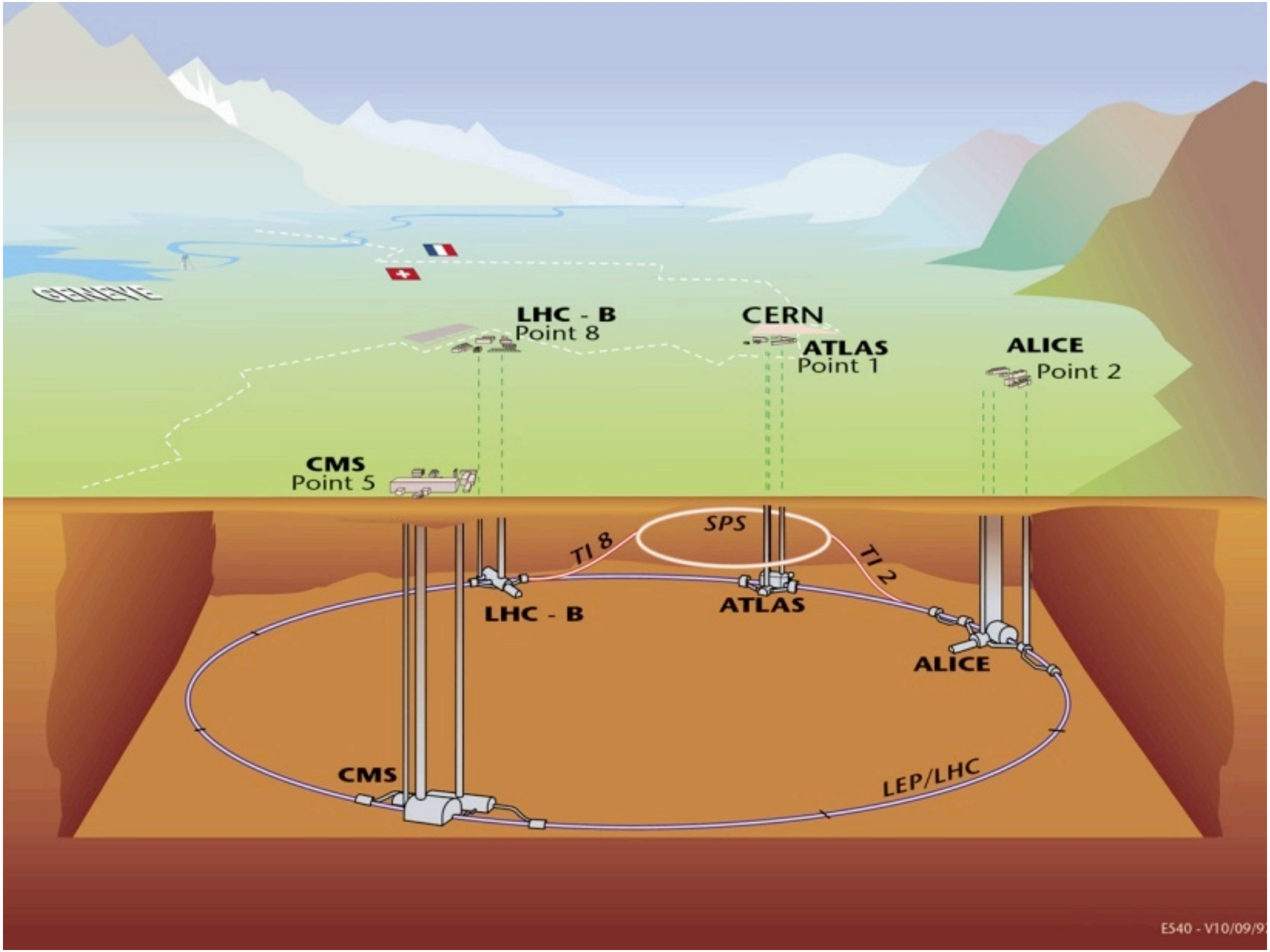
21 m

31 May 10 CMS Status - Karl.Ecklund@rice.edu 15

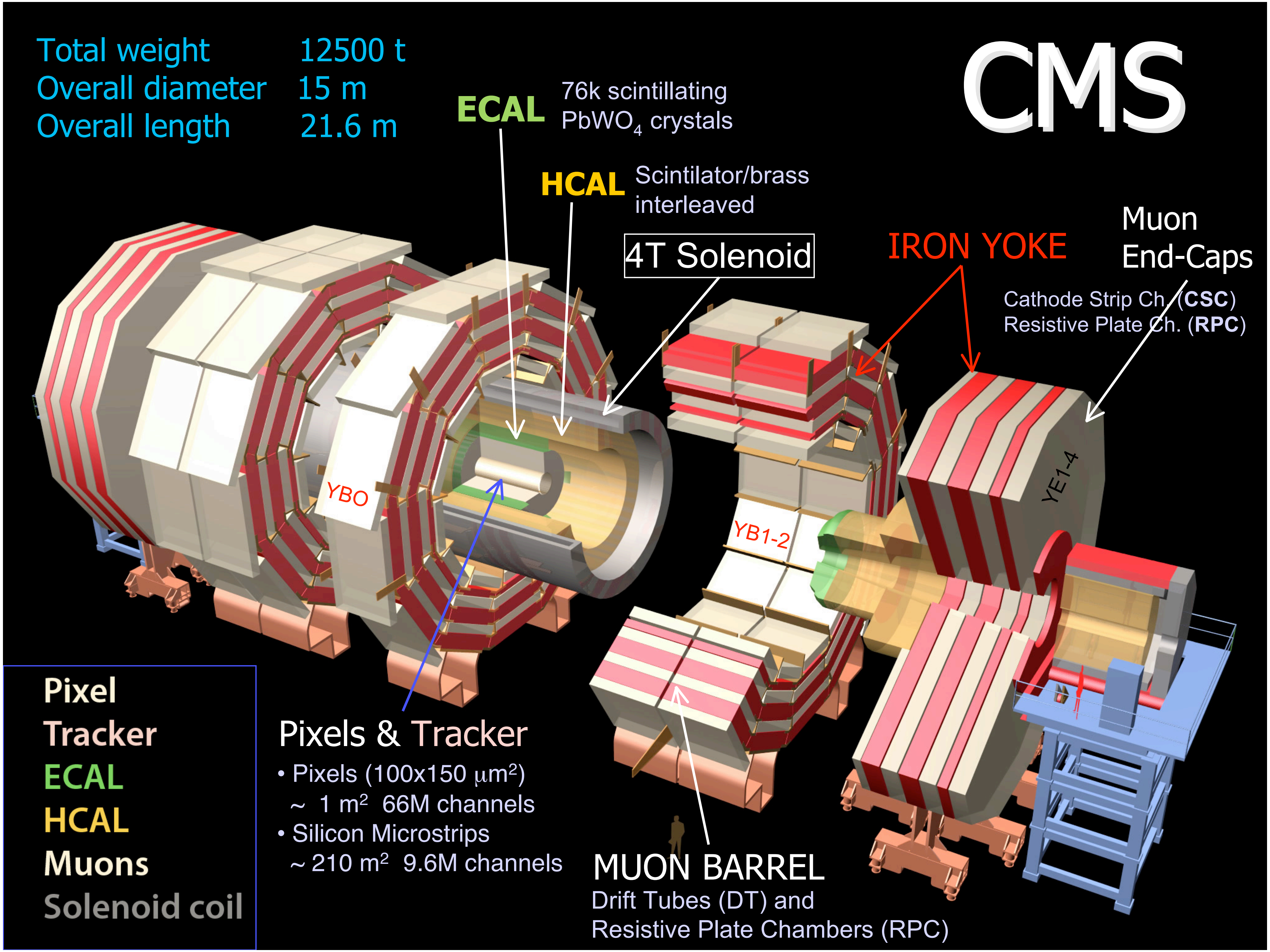
Particle Detection in CMS




Jura
Mountains
Lake Geneva
LHC
CERN
Prévessin
SPS
CERN
CERN
Meyrin
Geneva

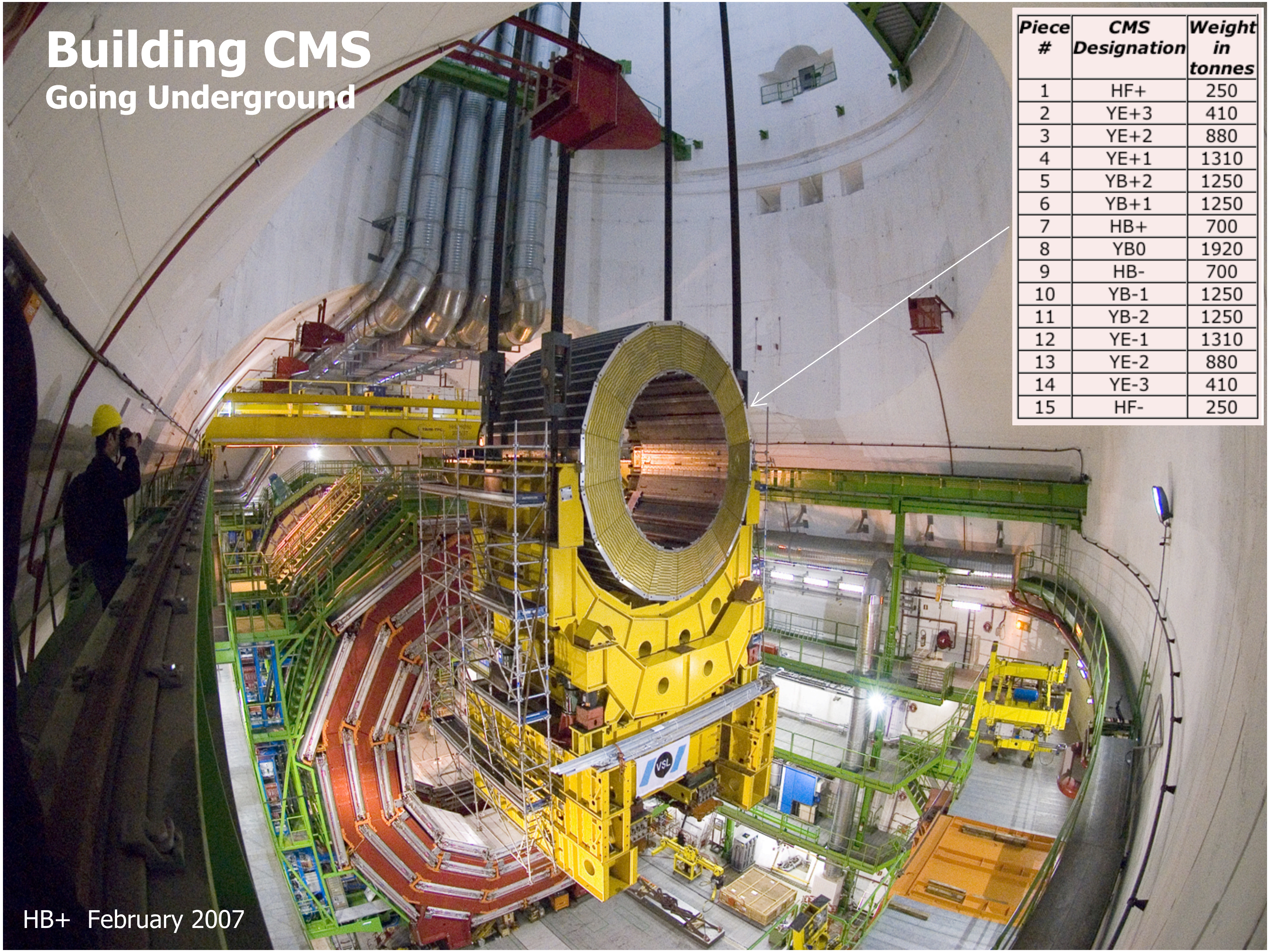


LHC - B
Point 8
CERN
ATLAS
Point 1
ALICE
Point 2
CMS
Point 5
SPS
TI 8
TI 2
LHC - B
ATLAS
ALICE
CMS
LEP/LHC
E540 - V10/09/9


Total weight 12500 t
Overall diameter 15 m
Overall length 21.6 m
CMS
ECAL
76k scintillating PbWO4 crystals
HCAL
Scintilator/brass interleaved
4T Solenoid
IRON YOKE
Muon End-Caps
Cathode Strip Ch. (CSC)
Resistive Plate Ch. (RPC)
YBO
YB1-2
YE1-4
Pixel
Tracker
ECAL
HCAL
Muons
Solenoid coil
Pixels & Tracker
• Pixels (100x150 μm2)
~ 1 m2 66M channels
• Silicon Microstrips
~ 210 m2 9.6M channels
MUON BARREL
Drift Tubes (DT) and
Resistive Plate Chambers (RPC)

Building CMS

Going Underground

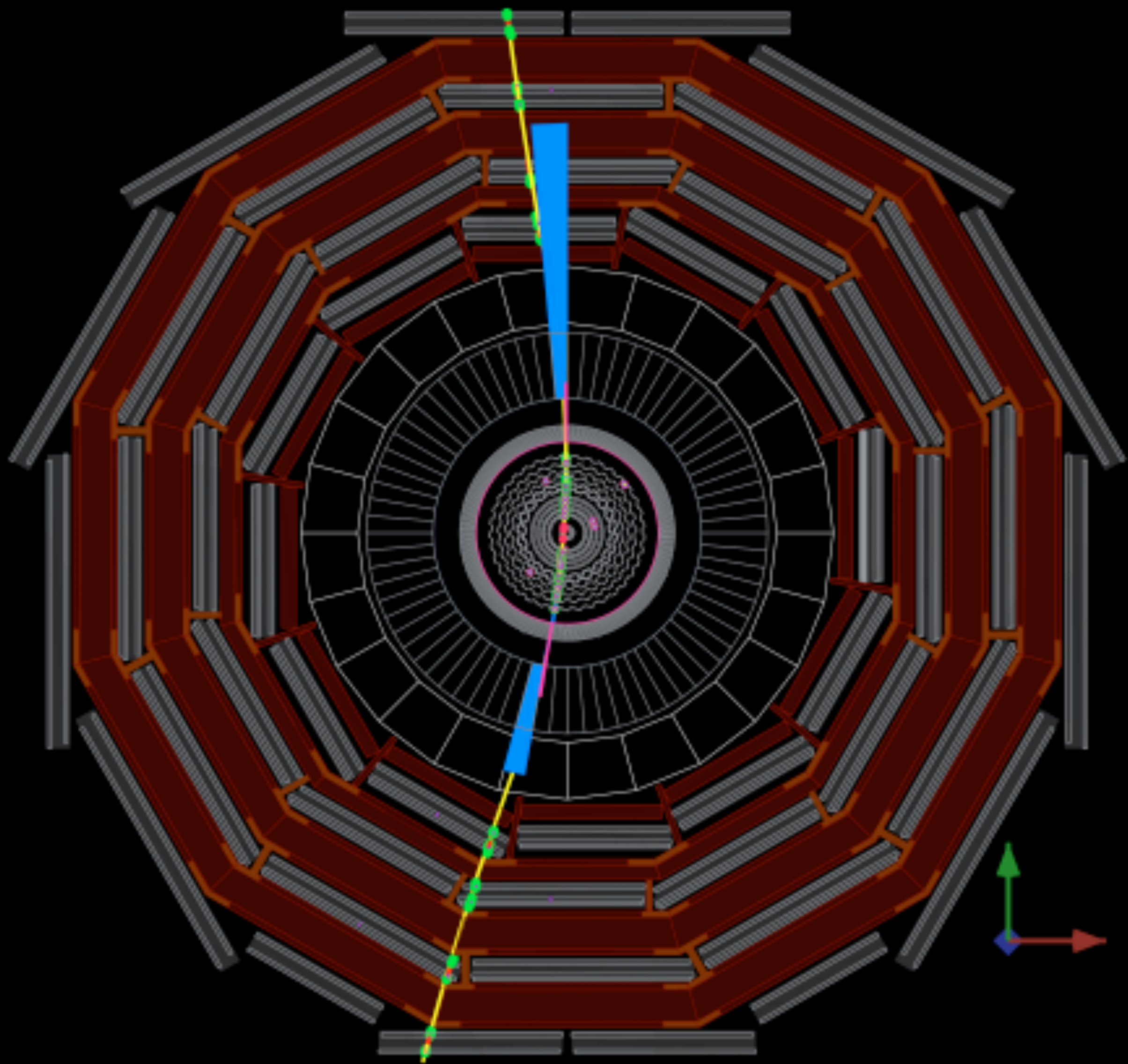


Piece #	CMS Designation	Weight in tonnes
1	HF+	250
2	YE+3	410
3	YE+2	880
4	YE+1	1310
5	YB+2	1250
6	YB+1	1250
7	HB+	700
8	YB0	1920
9	HB-	700
10	YB-1	1250
11	YB-2	1250
12	YE-1	1310
13	YE-2	880
14	YE-3	410
15	HF-	250

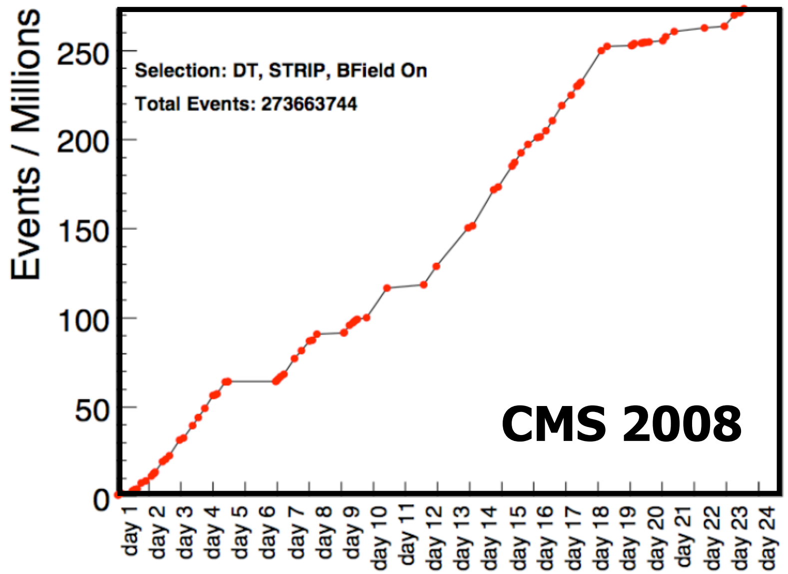
HB+ February 2007

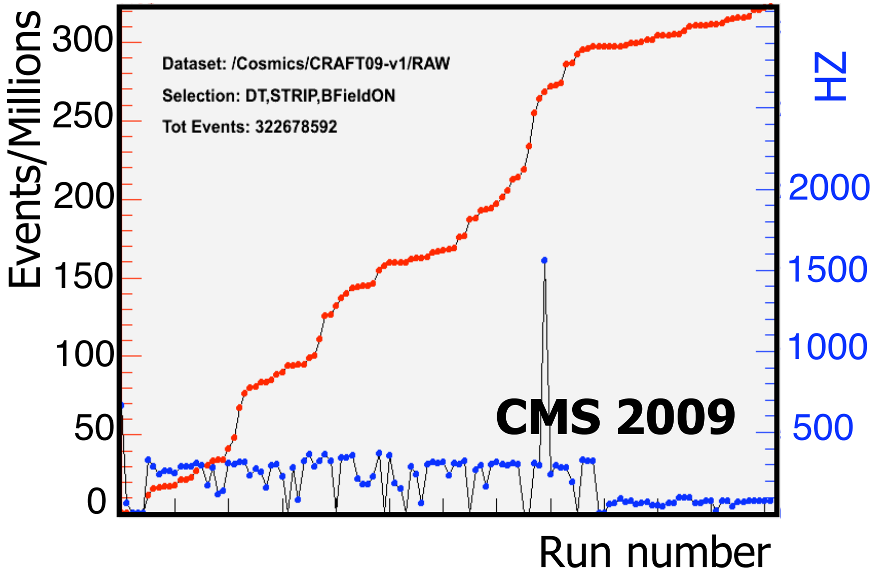
Commissioning with Cosmics

Cosmic
Runs
At
Four
Tesla



CRAFT 2008 & 2009
VERY LONG DATA TAKING WITH COSMICS USEFUL TO COMMISSION THE DETECTOR





B = 3.8 Tesla
Tracker & μDT "on"

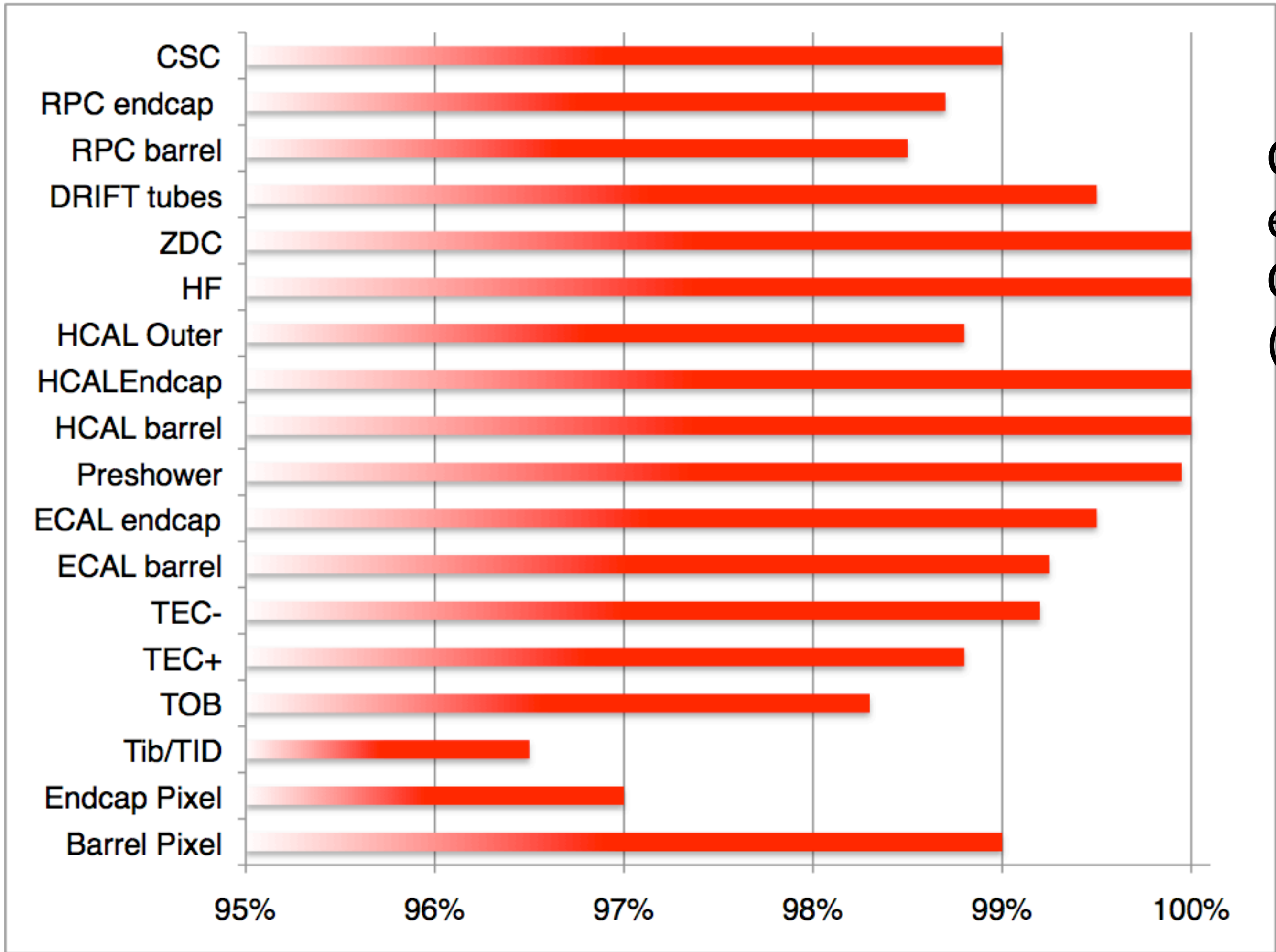
- Autumn '08
  - 275 M without pixels
  - 194 M with all detectors

- Summer '09
  - 320 M with all detectors

In total, > 1 billion cosmic trigger Logged between 2008 and 2009 !

CRAFT 2009 Operations

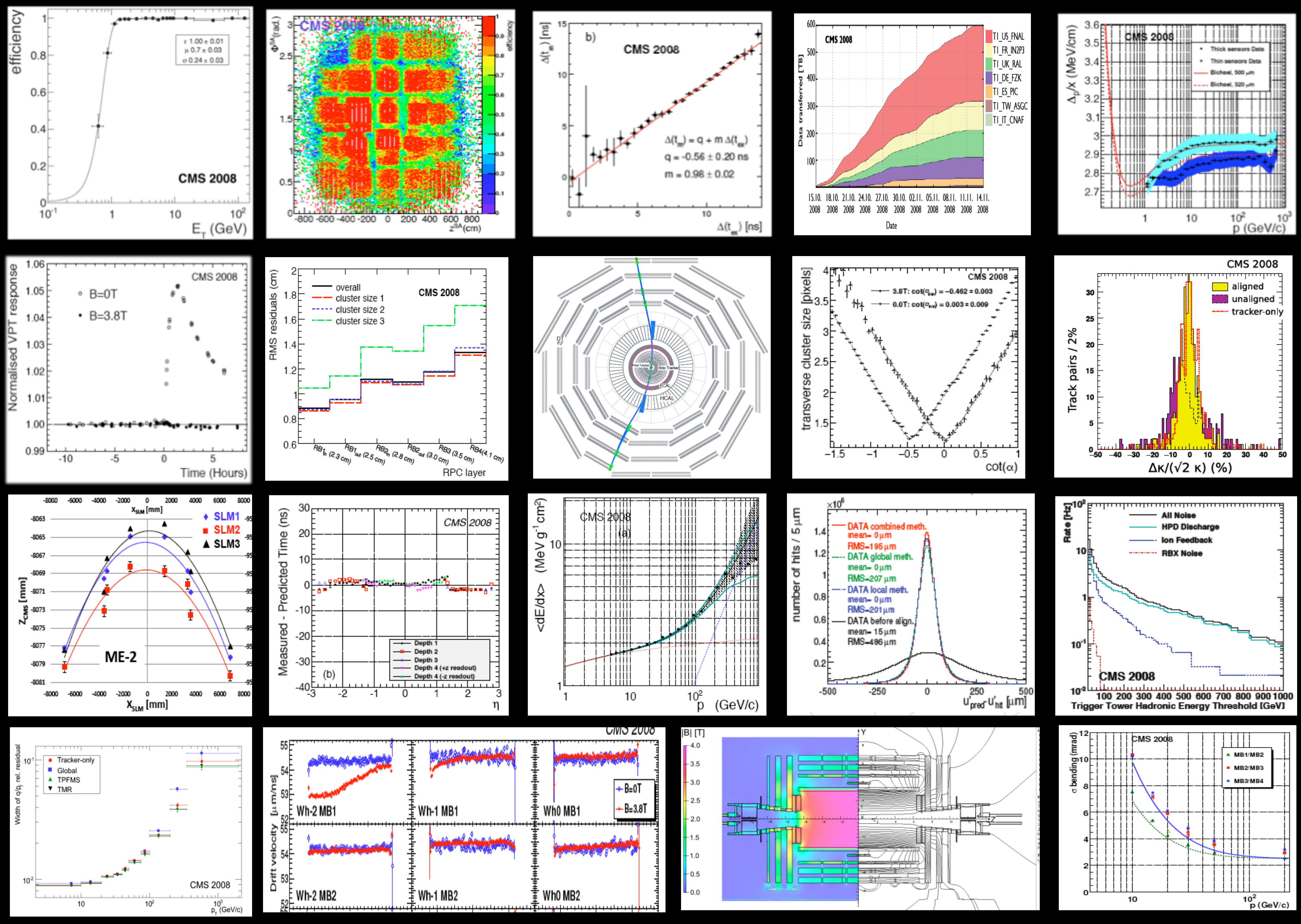
% of Detector Operational (August 2009)



Global operation efficiency during CRAFT 09 > 80% (>90 % in weekends)

Aim for > 90% during for LHC runs

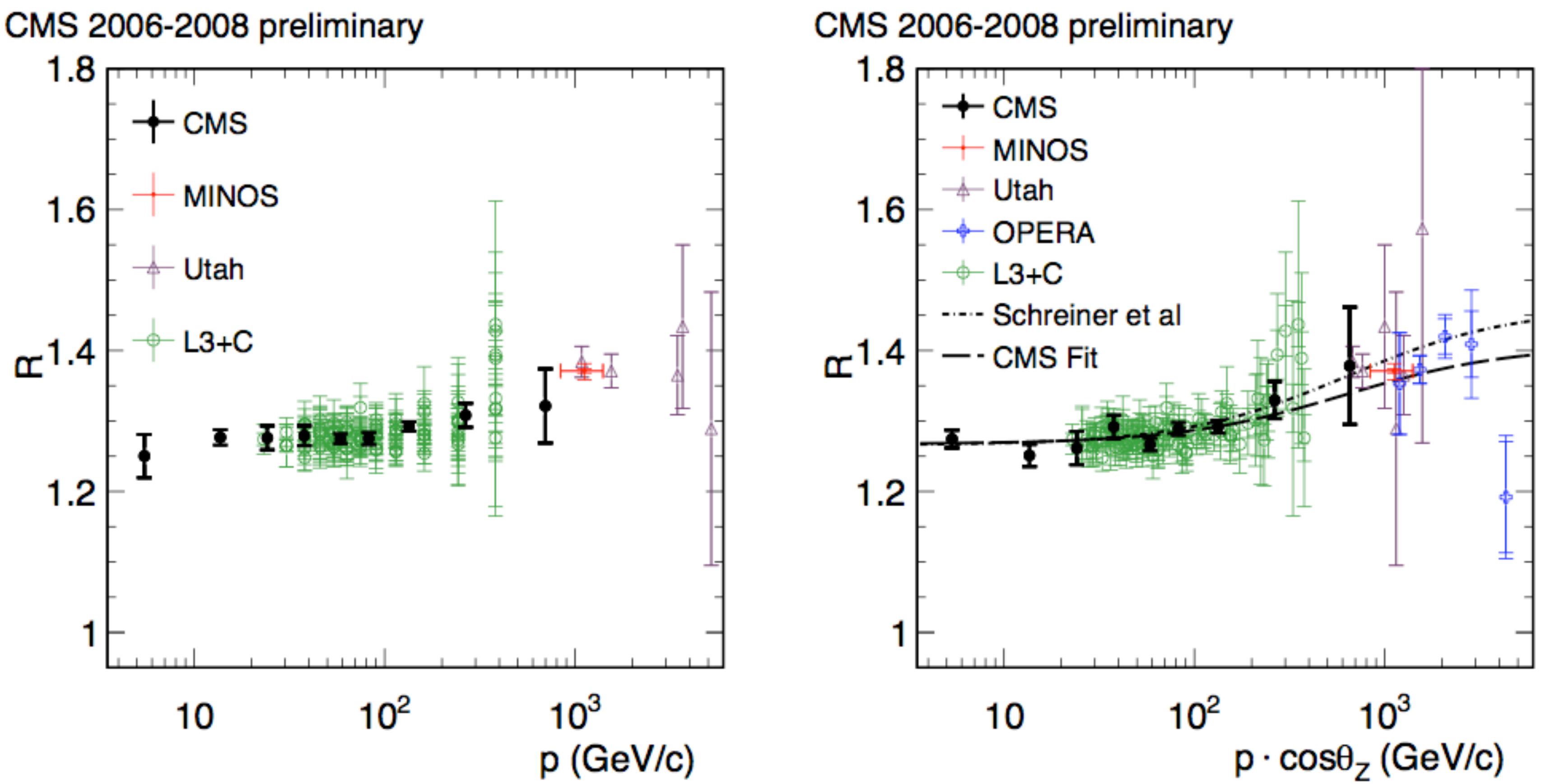
23 “CRAFT” Papers Published in JINST



Validation of subdetector performance (skipping, see backup slides)

Physics from cosmics

arXiv:1005.5332v1 [hep-ex] 28 May 2010



Measurement of the Charge Asymmetry of Atmospheric Muons with the CMS Detector - R=positive/negative.

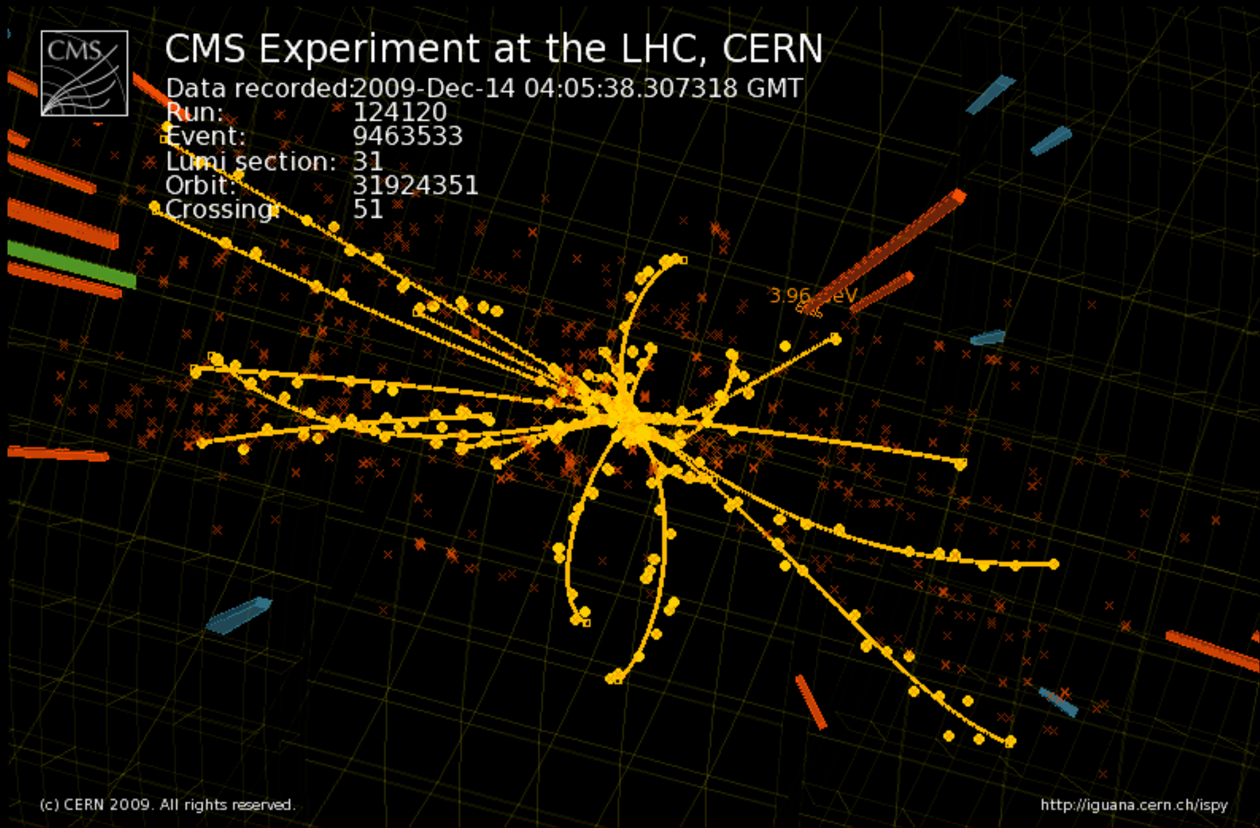
Commissioning with Collisions

LHC
Pilot Runs

$\sqrt{s}$ = 900 GeV
&
2.36 TeV

Physics Run
Start-up

$\sqrt{s}$ = 7 TeV



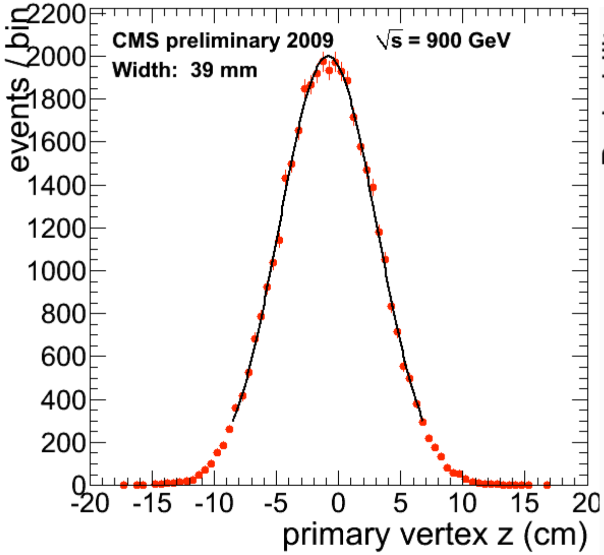
e.g. First collision at record $\sqrt{s}$ = 2.36 TeV

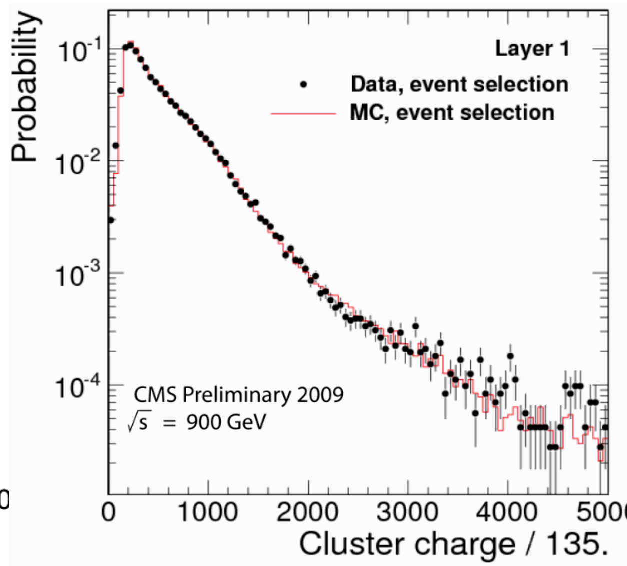
Si Tracker: Performance @LHC

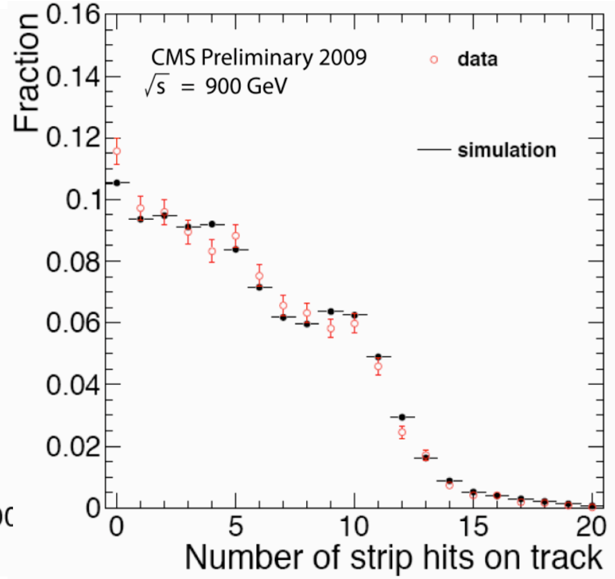
Primary Vertex

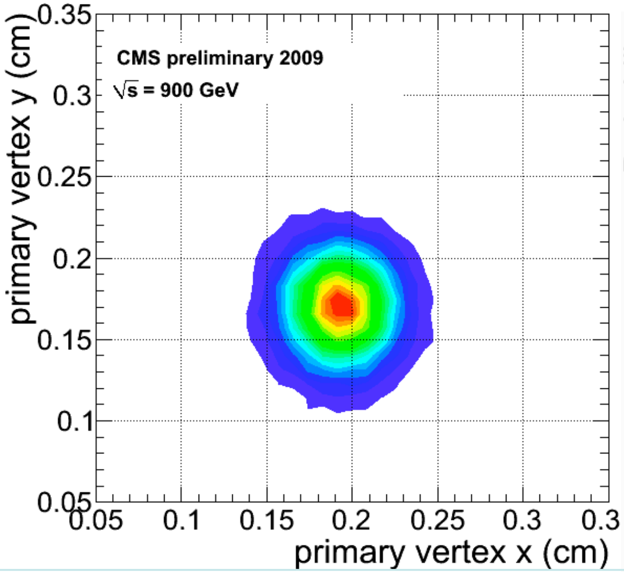
Pixels Clusters

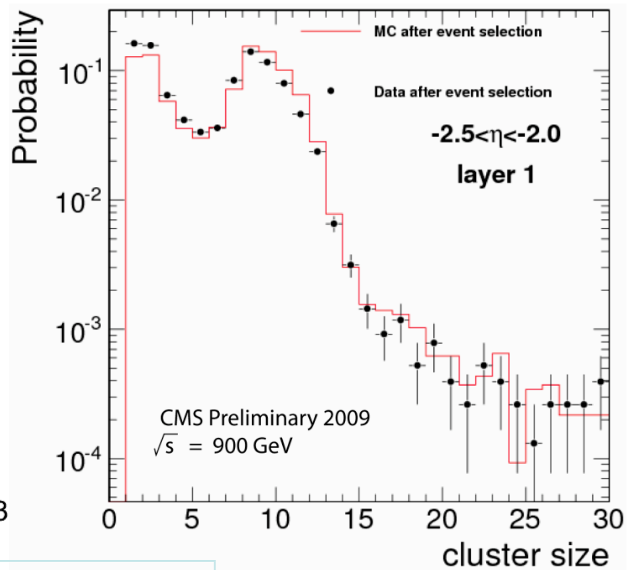
Strip Tracker

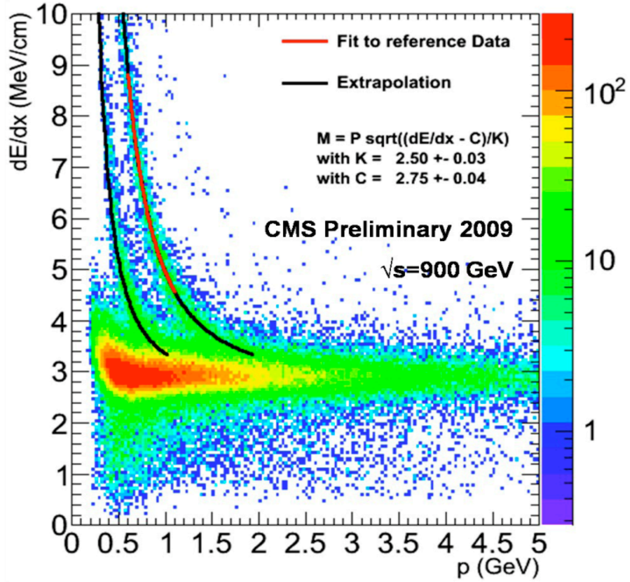






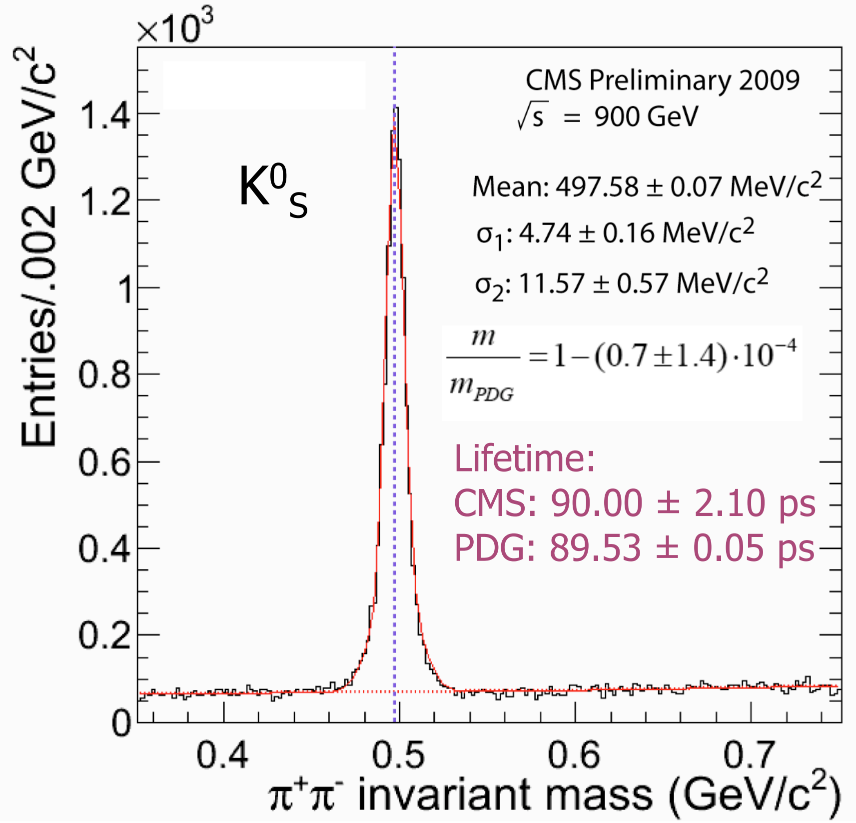


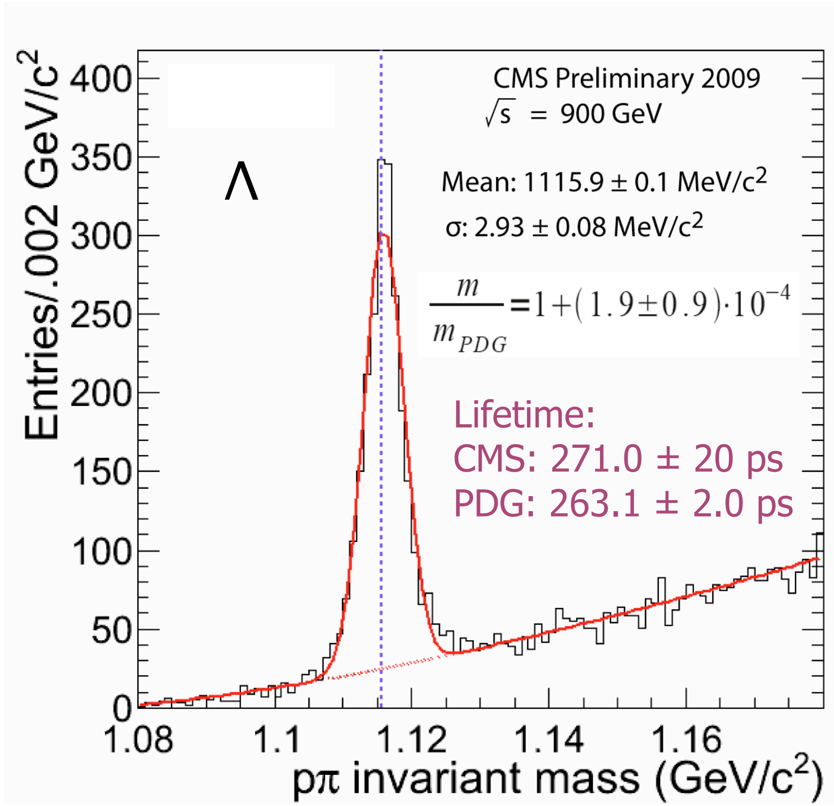




Low Mass Resonances

Tracker



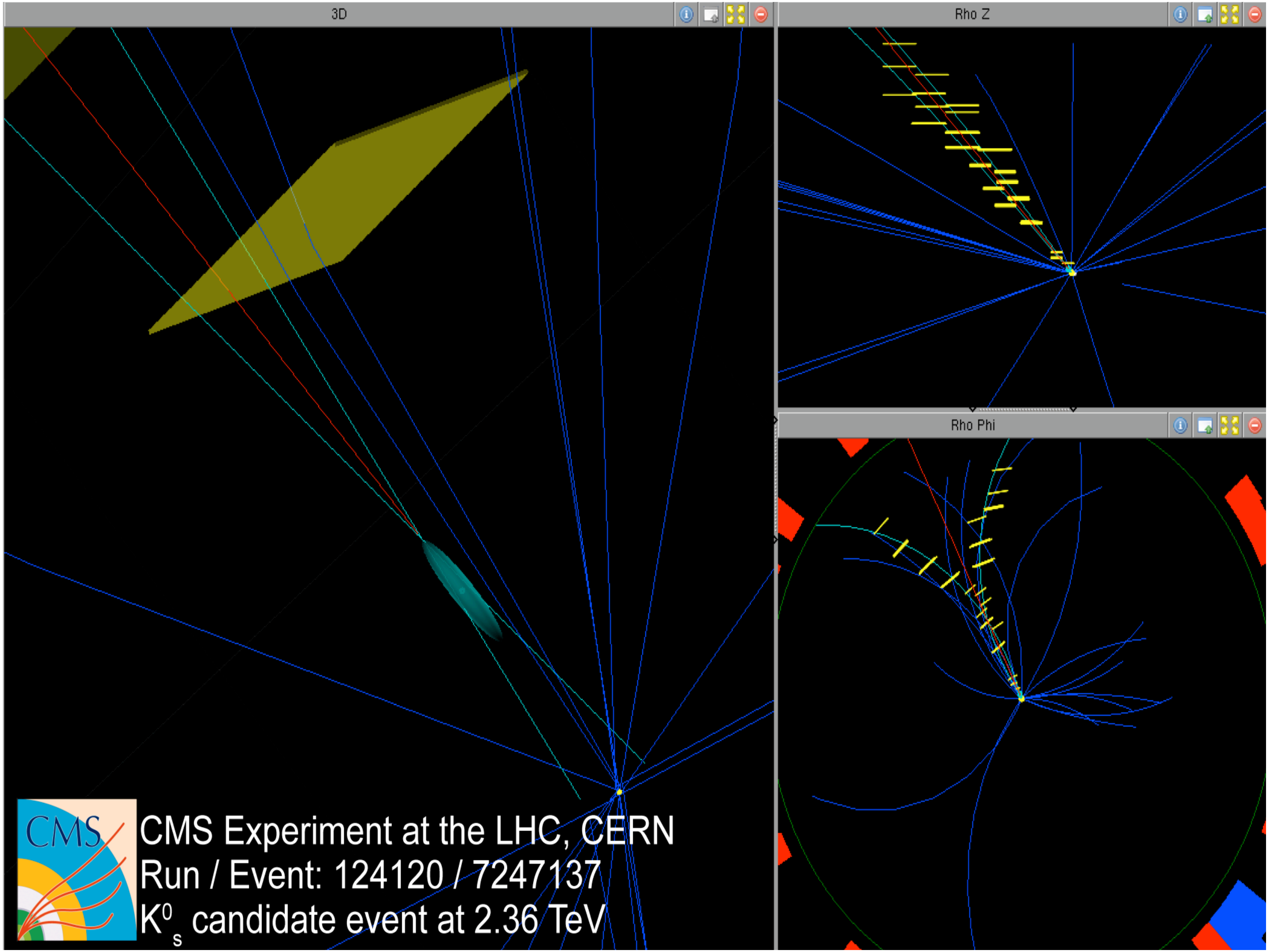


First stable beams with 4x4 bunches ~ $1\text{x}10^{10}$ protons on 6th of Dec. … K^0_S & Λ analyses completed 7th of Dec.

Excellent understanding of the momentum scale for low mass resonances

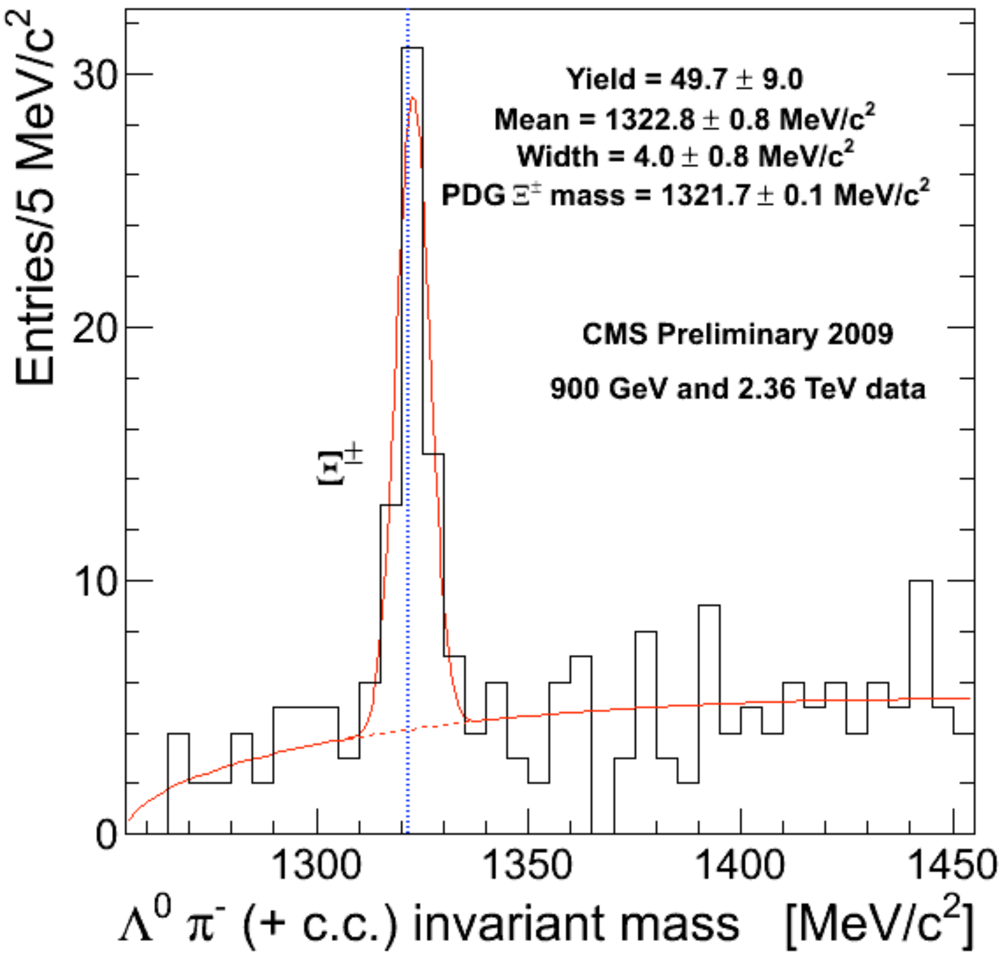
Accurate tracking, vertexing, alignment, magnetic field etc

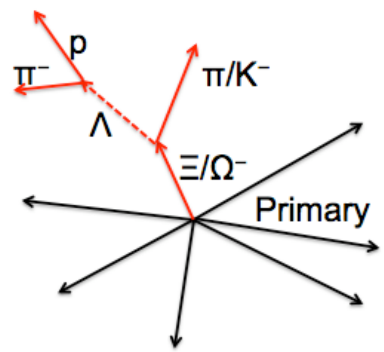
CMS DP 2010-001


3D
Rho Z
Rho Phi
CMS
CMS Experiment at the LHC, CERN
Run / Event: 124120 / 7247137
K0s candidate event at 2.36 TeV

… and even more

LHC Pilot Runs





$\Xi^{\pm} \longrightarrow \Lambda\pi^{\pm}$

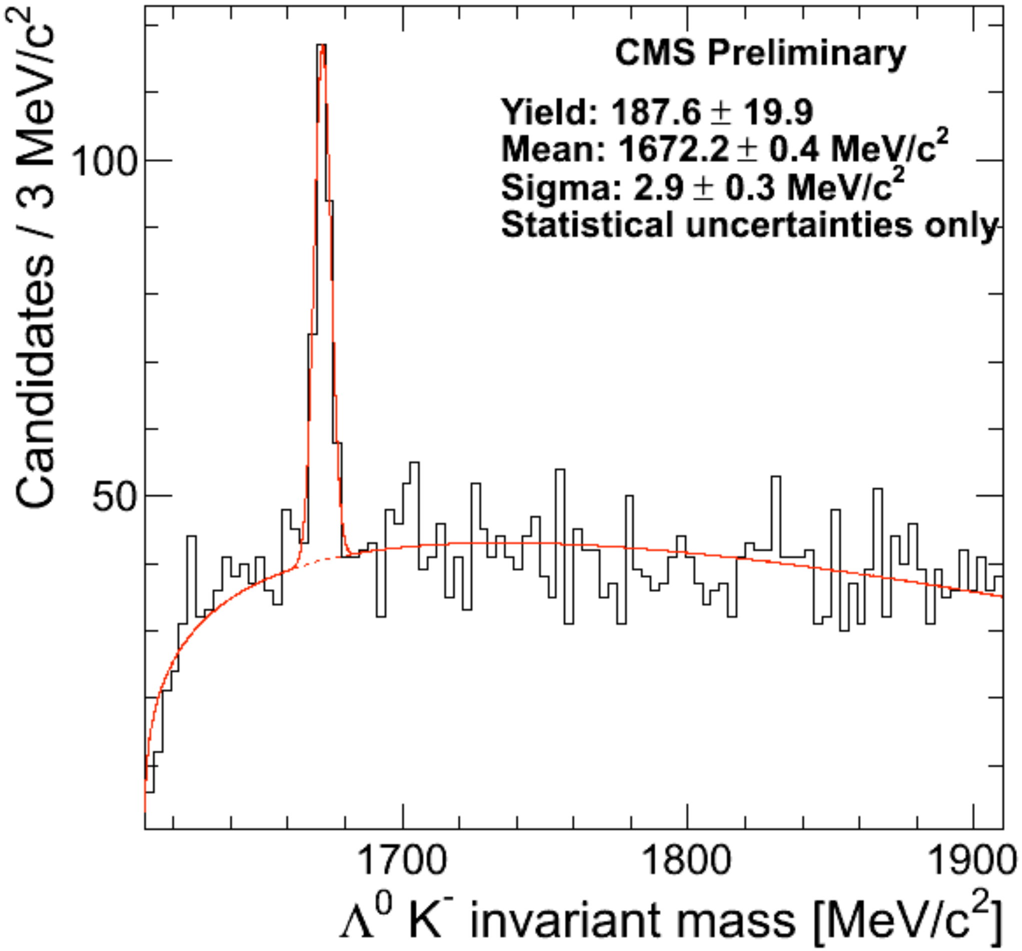
$\Lambda\pi$ Invariant mass

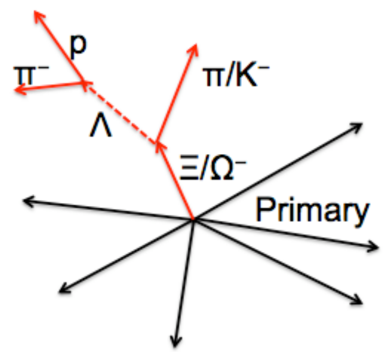
- tracks displaced from primary vertex ($d_{3D} > 3\sigma$)
- Common displaced vertex ($L_{3D} > 10\sigma$)

CMS DP 2010-004

… and even more

LHC $\sqrt{s}$ = 7 TeV





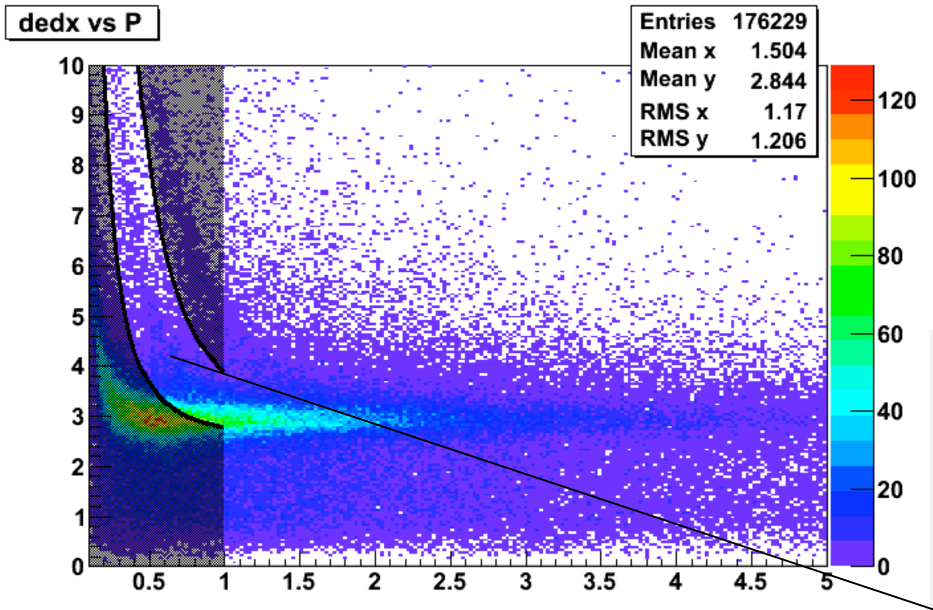
$\Omega^{\pm} \longrightarrow \Lambda k^{\mp}$

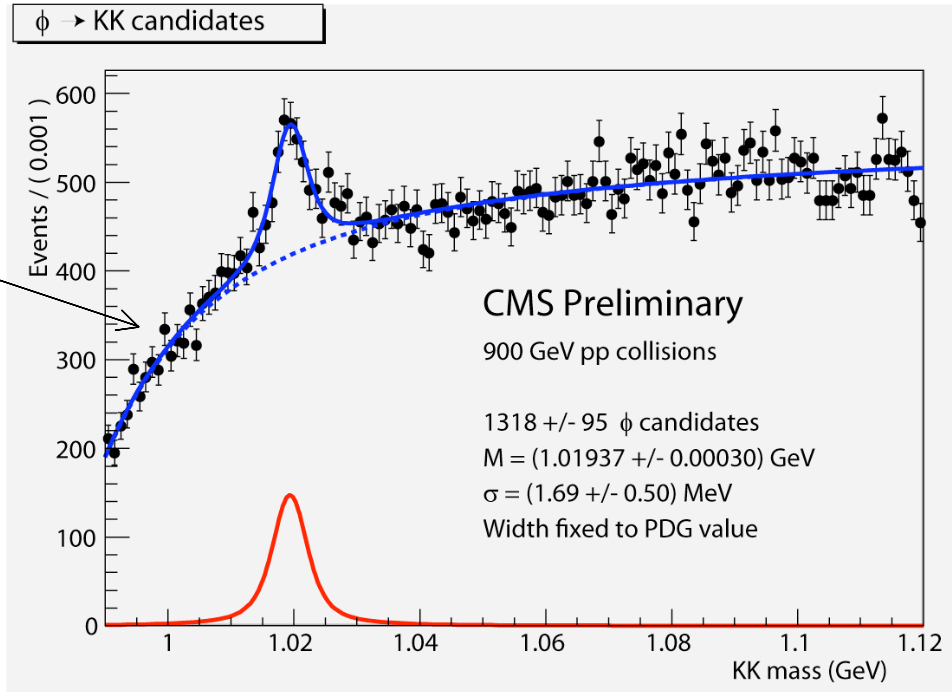
ΛK^{-} or anti-ΛK^{+} Invariant mass

- combinations fit to a common vertex

Φ → K^+K^- using dE/dX

Tracker





K^0_s, Λ, ϕ ...

- Validate Tracking
  - Reconstruction
  - Secondary Vertex Finding
  - Magnetic Field
  - Material
  - Momentum scale
- Validation of MC

CMS DP 2010-001

Inclusive Reconstruction of D^0

ž Dataset: 27 million minimum bias events

ž Decay mode reconstruction

D^0 ! K 3^+

ž Selection criteria

. transverse momentum cuts

$p_?(K)$	>	1:25 GeV
$p_?(^3)$	>	1:0 GeV
$p_?(D^0)$	>	3:0 GeV

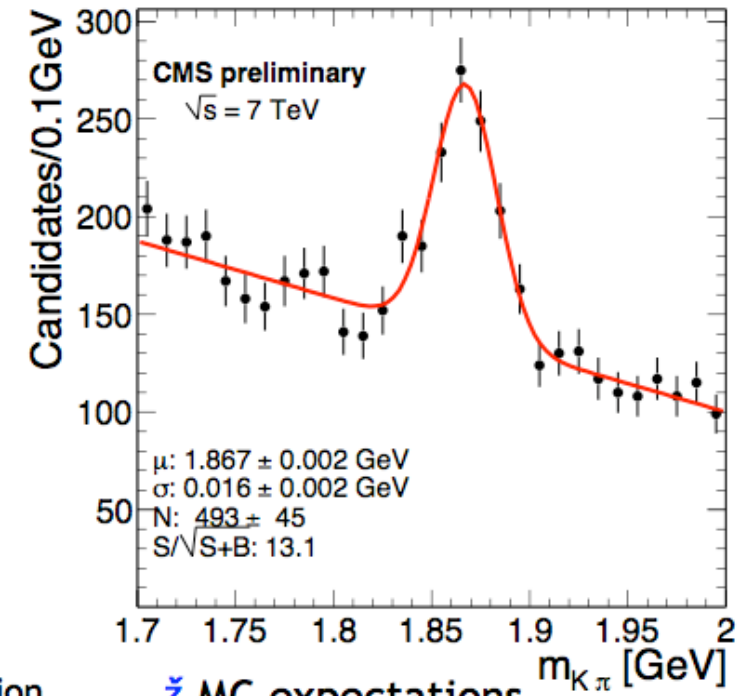
. Vertexing cuts

$d(K;\ ^3)$	<	0:025 cm
^{2}	<	4:5
$3 < l_{xy}=¡(l_{xy})$	<	20
$¡(l_{xy})$	<	0:03 cm

. D^0 momentum vs. PV-SV direction

$\backslash(p_{D^0}; \overline{PV:SV})$	<	0:1

. allow for multiple candidates



ž MC expectations

. Peak: 1:863 š 0:002 GeV

. Width: 0:014 š 0:002 GeV

More Open Charm: Dť+

- ž Data set: 37 million minimum bias events
- ž Decay mode reconstruction

$$D^{ť+} \; ! \; D^0 \, 3^+_s \; ! \; K \; 3^+ \, 3^+_s$$

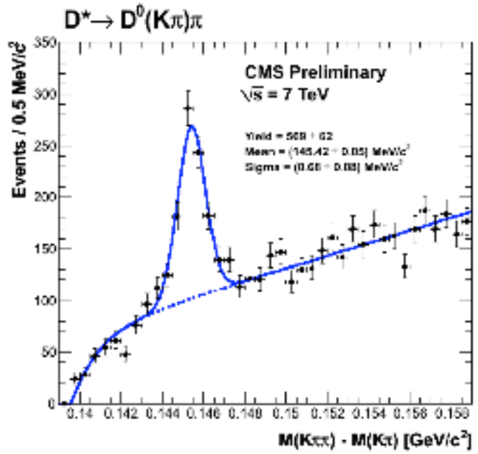
- ž Kinematic selection

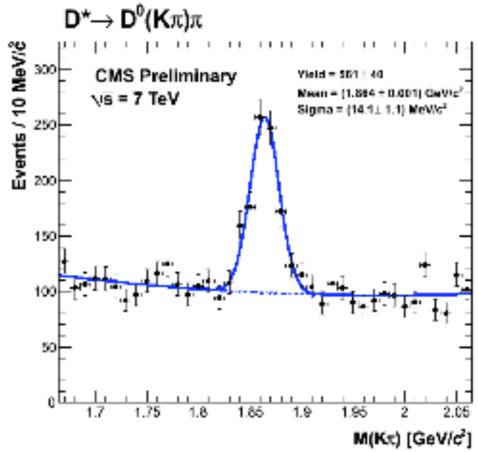
$$p_?^{\text{track}} > 0.6\,\text{GeV}$$
$$p_?^{3_s} > 0.25\,\text{GeV}$$
$$p_?^{D^{ť+}} > 5\,\text{GeV}$$

choose single $D^{ť+}$ candidate
(with highest transverse momentum)

- ž Mass windows (for other projections)

$$jm_{K3} \quad m^{D^0}_{\text{PDG}} j < 25\,\text{MeV}$$
$$jm_{K33_s} \quad m_{K3} \quad Žm_{\text{PDG}} j < 1.2\,\text{MeV}$$

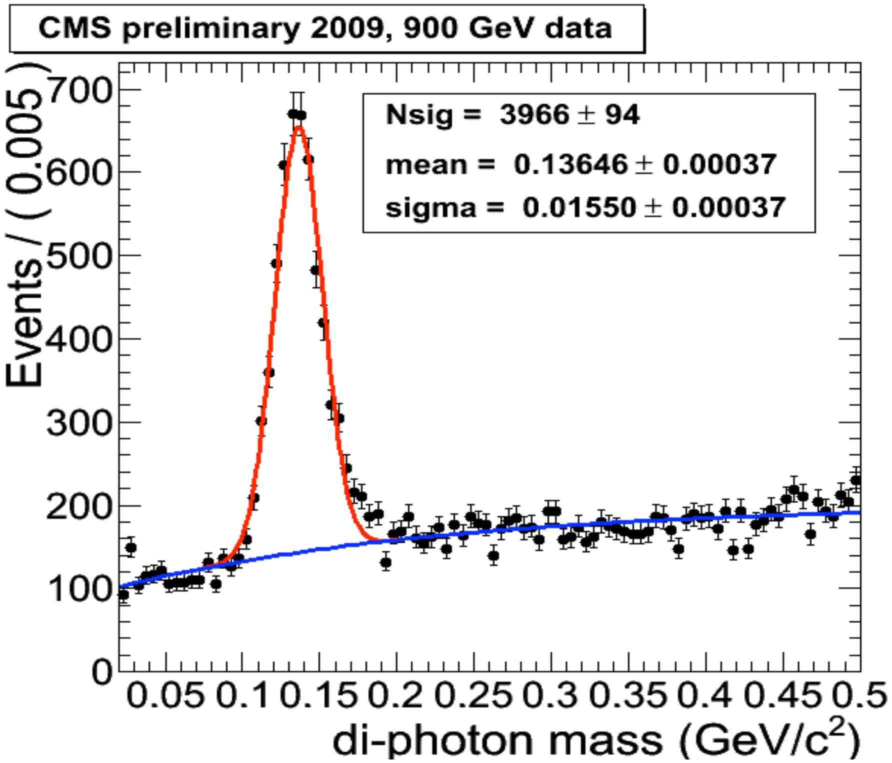


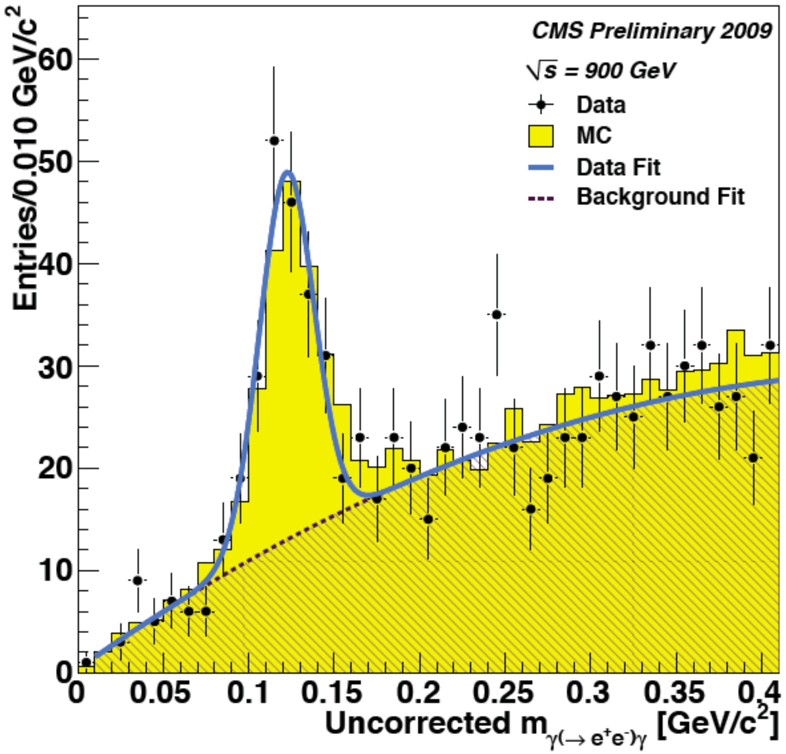


Urs Langenegger Flavor physics with CMS: Status and Perspectives (2010/05/25) 15

First γγ Resonance in CMS

ECAL



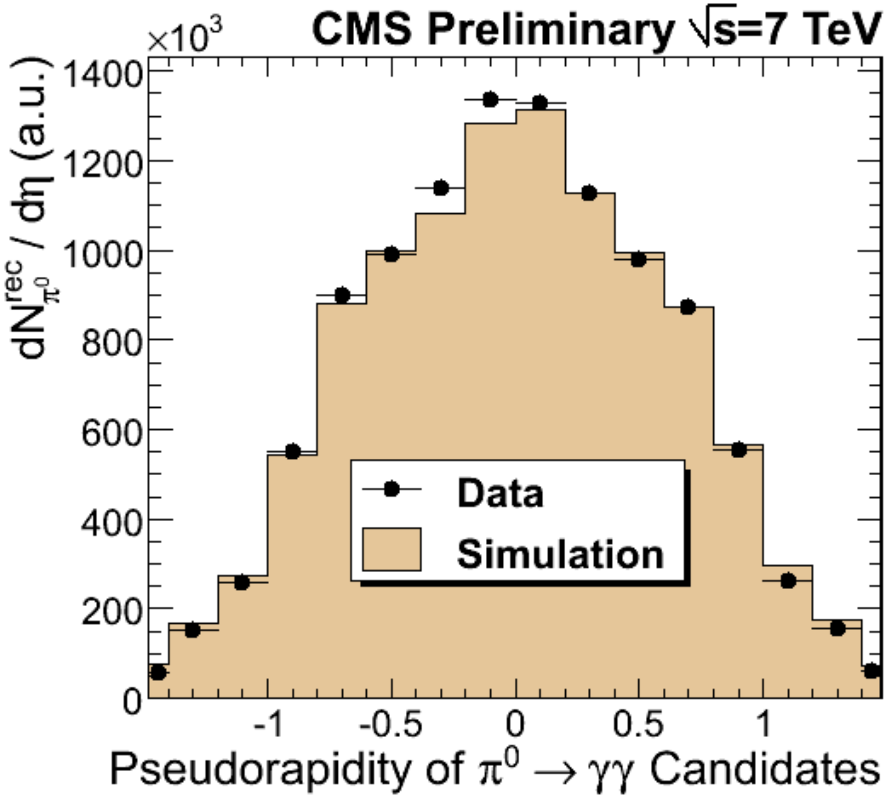


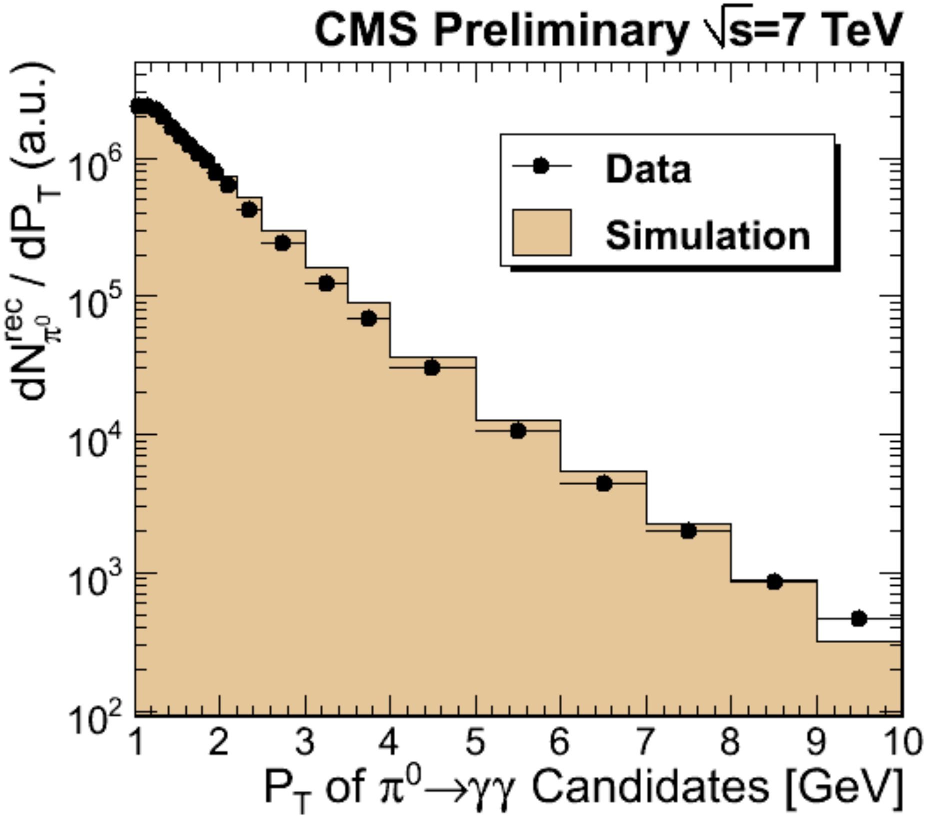
With "Out of the box" MC corrections: within 2% of PDG mass …

Π^0 with one leg reconstructed (track-driven) as conversion !

First π^0 peak shown already the 27th of November !

… and even more



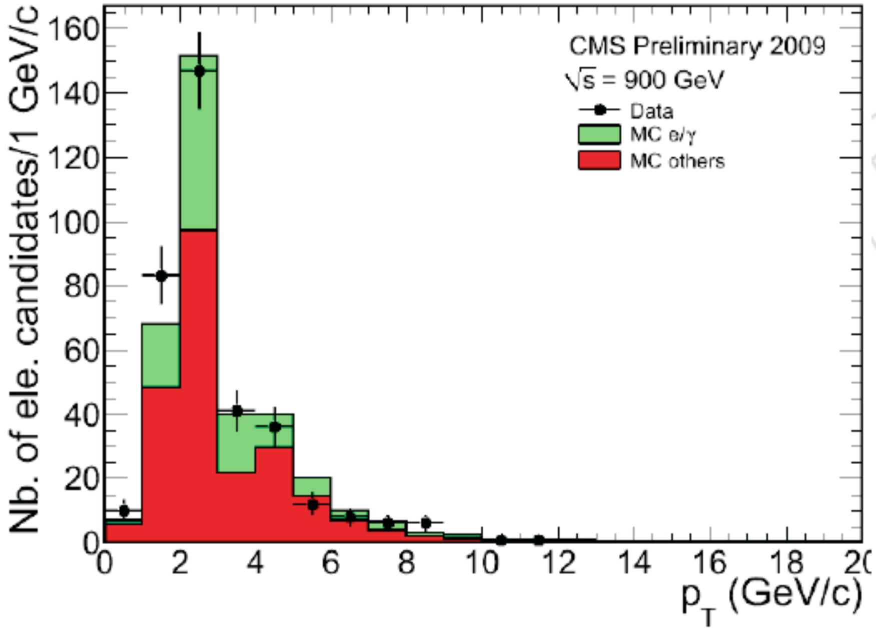


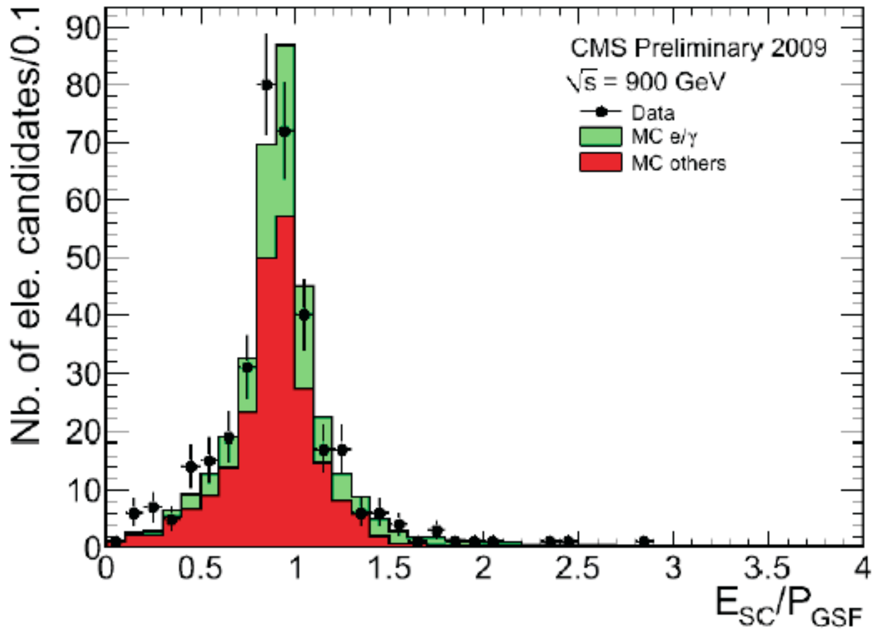
Measured by fitting the peak reconstructed in each η-bin (after selection). The MC is normalized to Data. No other corrections were applied (η = pseudorapidity of reconstructed $\pi^0 \rightarrow \gamma\gamma$ candidates).

Same ad for dN/dP_T (P_T refers to transverse momentum of the reconstructed $\pi^0 \rightarrow \gamma\gamma$ candidates).

Electrons

Commissioning with wildly opened pre-selection requirements





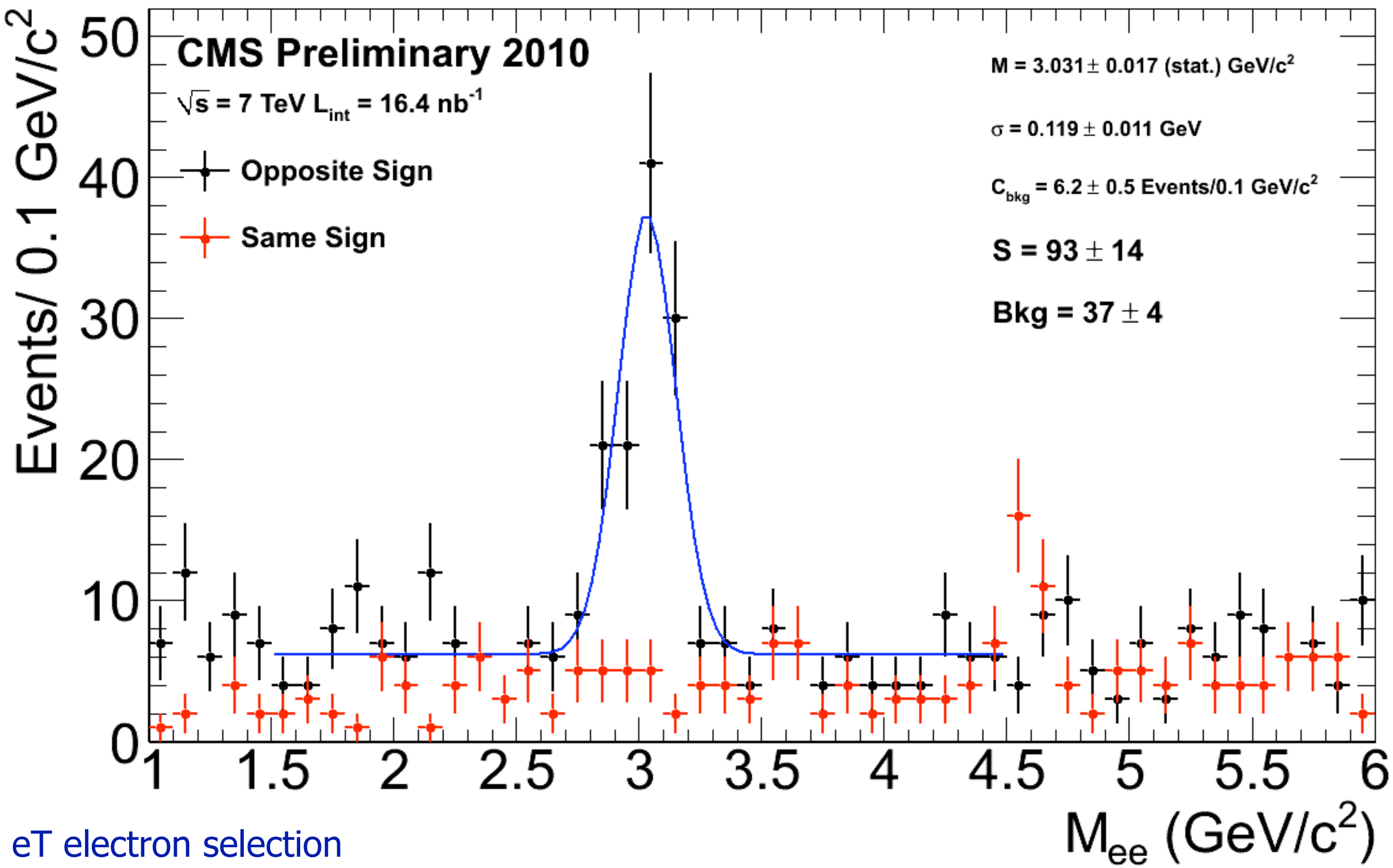
Low statistics for "signal" in these data …
mainly a commissioning exercise for electron reconstruction observables on "background fakes" (only ~ 1/3 e mostly from secondary conversions)

Agreement with MC is promising

Reconstructed e candidates combines two seeding algorithms

- "ecal driven" optimized for W/Z … H electrons (clusters of E_T > 4 GeV)
- "tracker driven" bringing more for electrons at low p_T or in jets

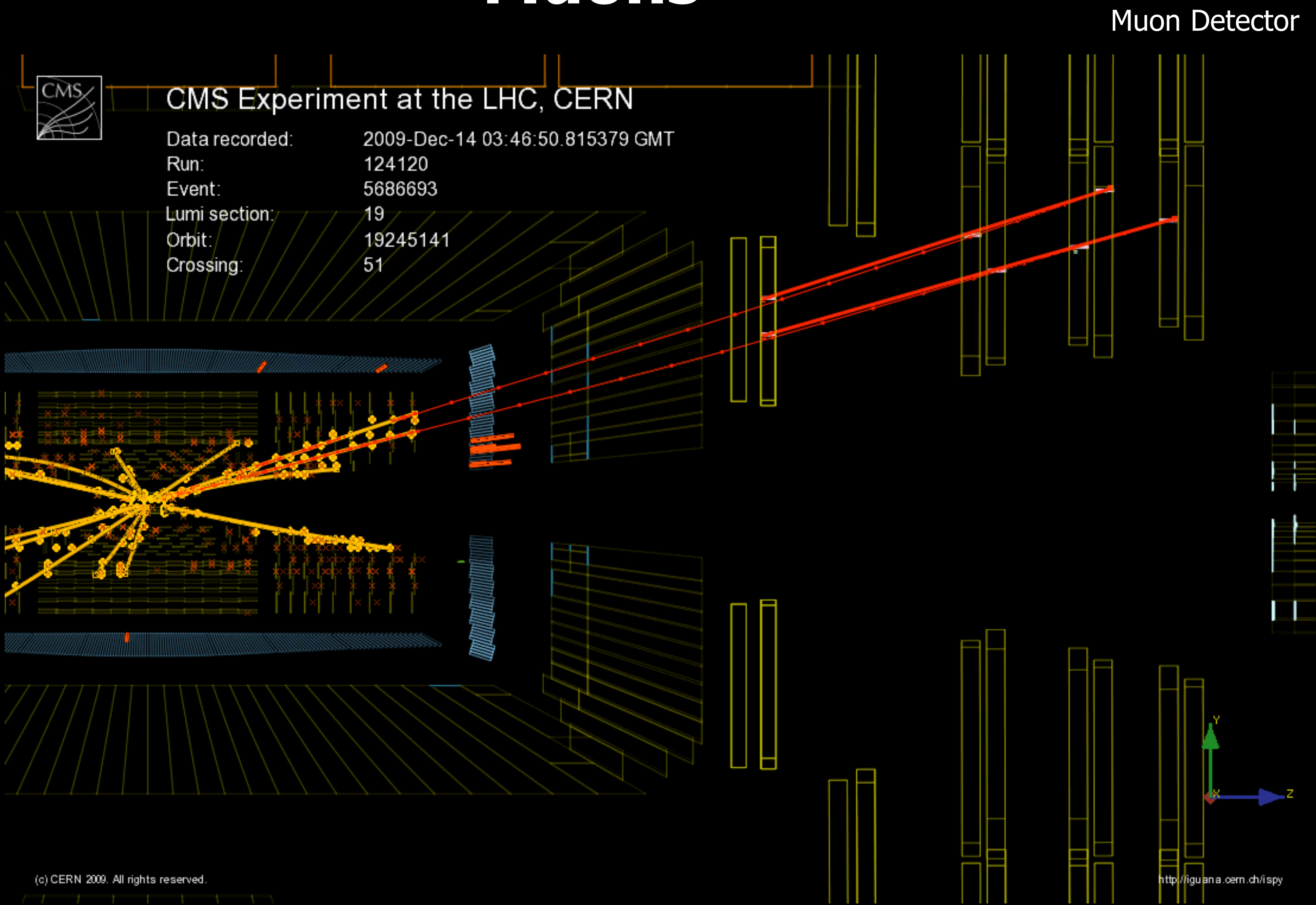
Electrons



- Low eT electron selection
- Look at same sign and opposite sign combinations separately
- Binned likelihood fit of a gaussian + constant in mass range 1.5 – 4.5 GeV
- Signal is the integral of the gaussian, BG quoted in ± 2.5 sigma around the mean

CMS@LHC

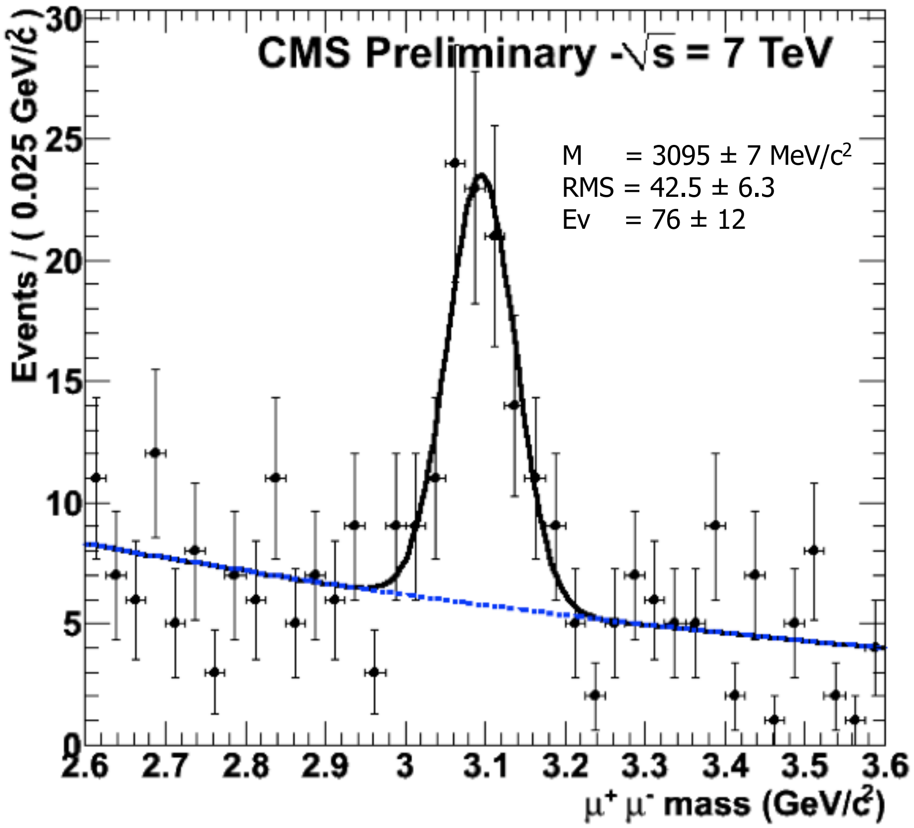
Muons



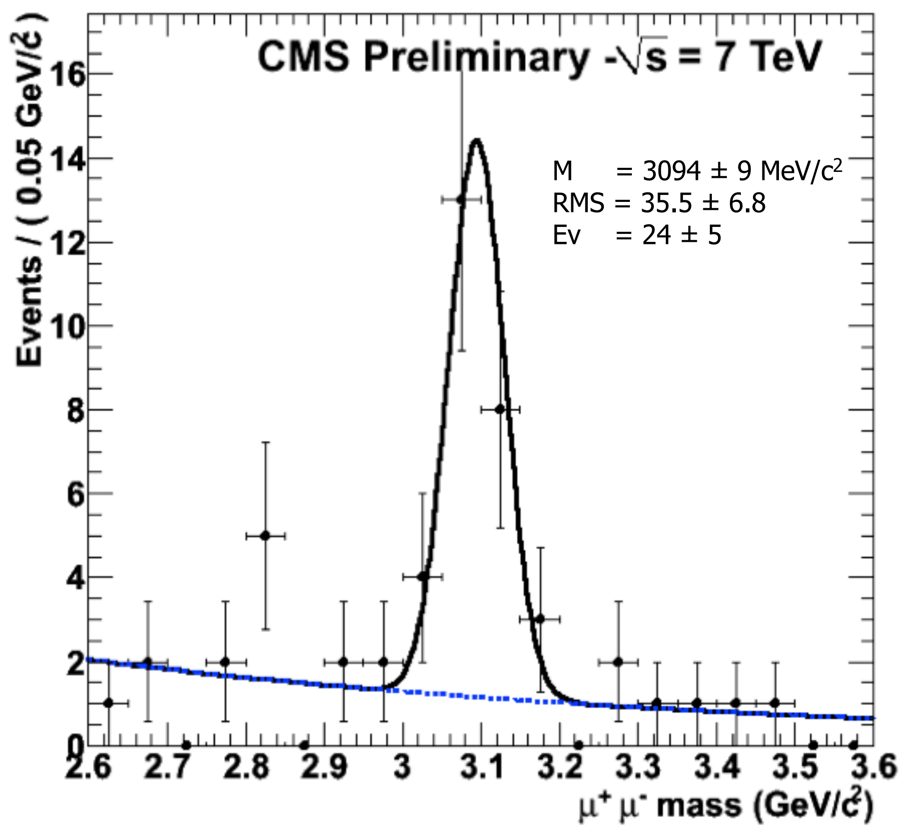
$p_T(\mu_1)$ = 3.6 GeV, $p_T(\mu_2)$ = 2.6 GeV, $m(\mu\mu)$= 3.03 GeV

Muons

J/ψ → $\mu^+\mu^-$ with ~1 nb^{-1} data



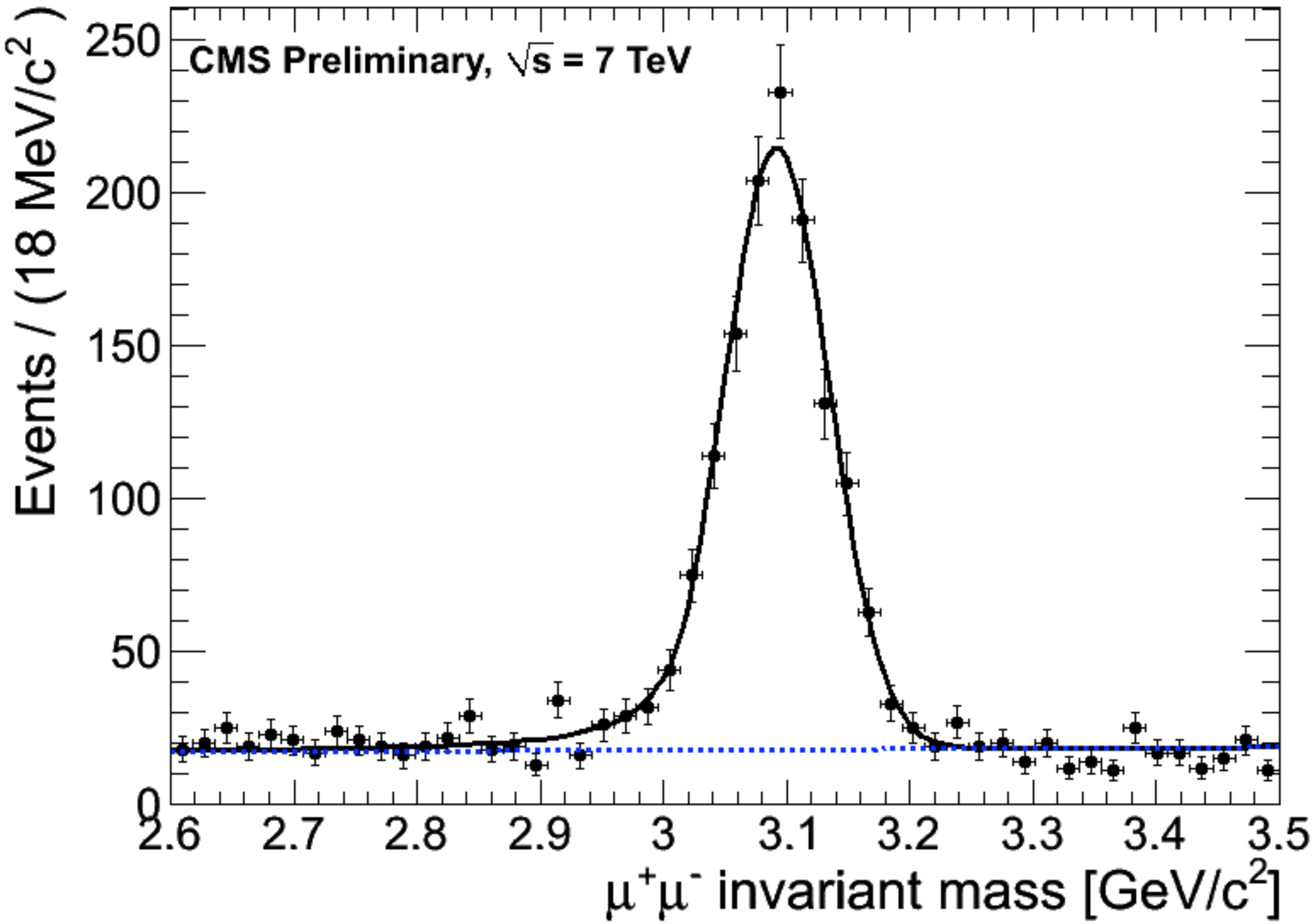
Loose selection cuts



Tight selection cuts

Muons

Result of J/ψ at L_{int} = 15 nb^{-1}



Signal events: 1230 ± 47

Sigma: 42.7 ± 1.5 (stat.) MeV

M_0: 3.092 ± 0.001 (stat.) GeV

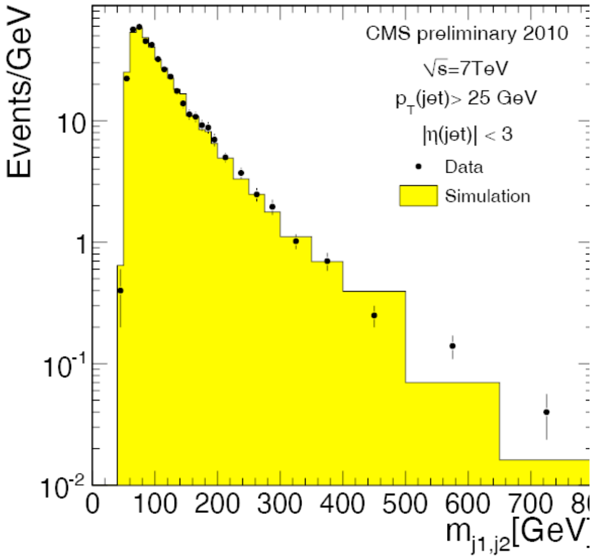
S/B = 5.4 (M_0 ± 2.5σ)

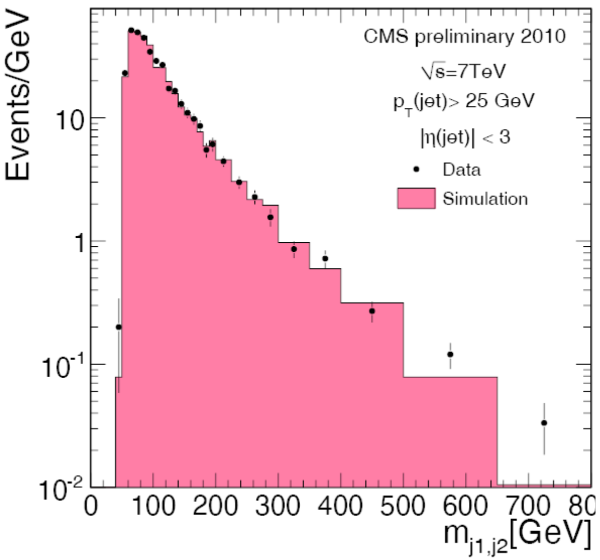
χ^2/ndof = 1.1

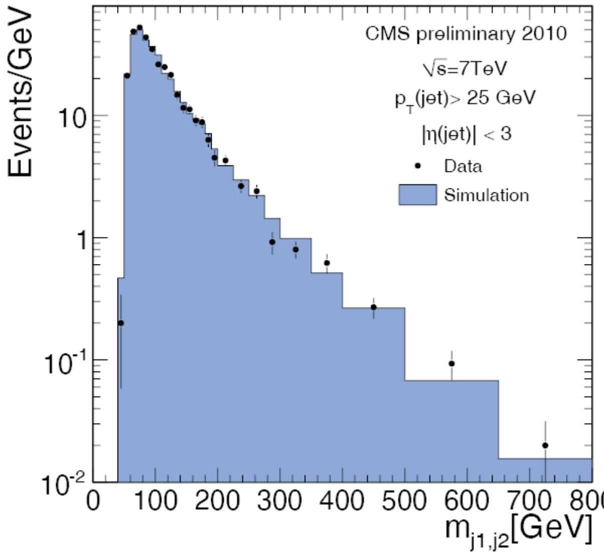
Di-Jets

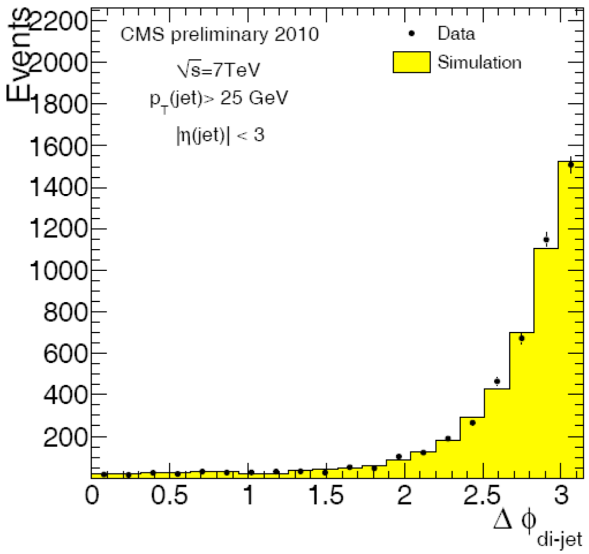
ECAL+HCAL+HF

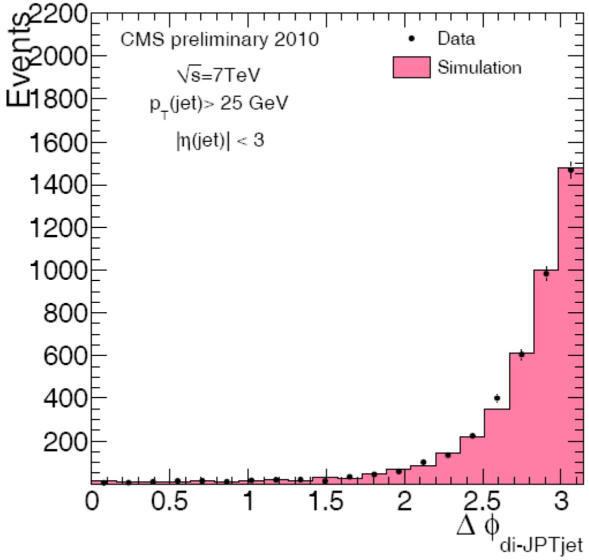
Calo jets | **JPT jets** | **PF jets**

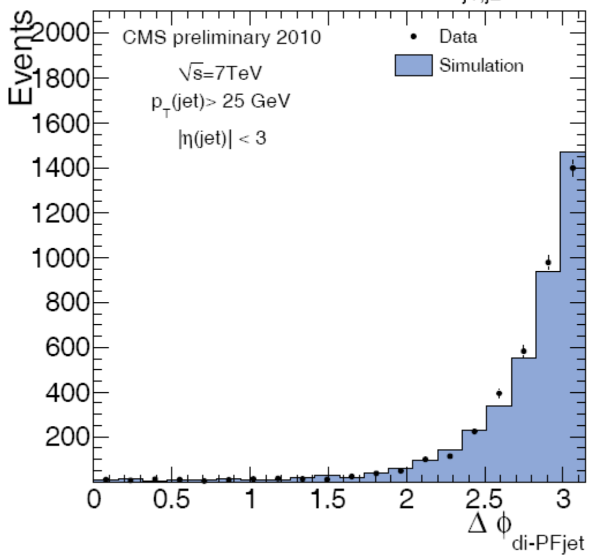




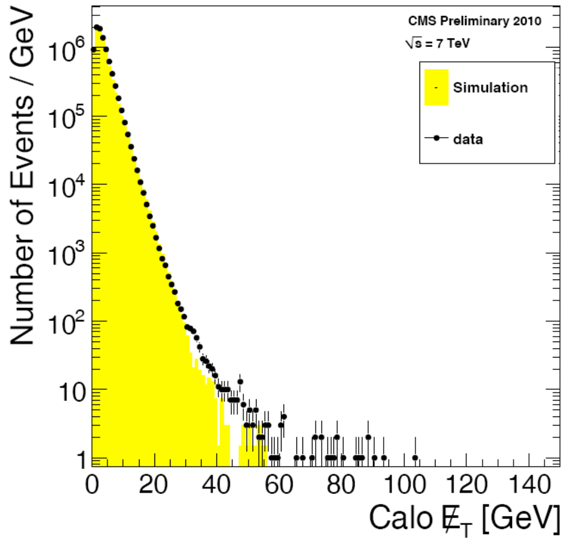


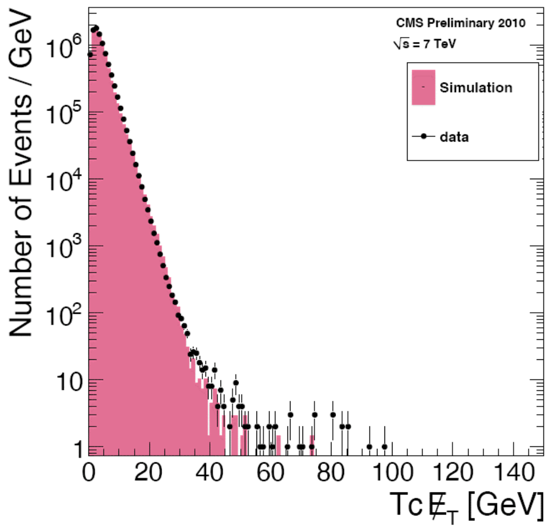


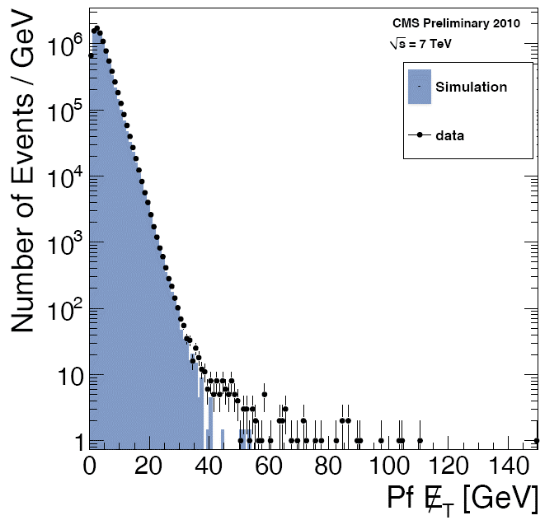


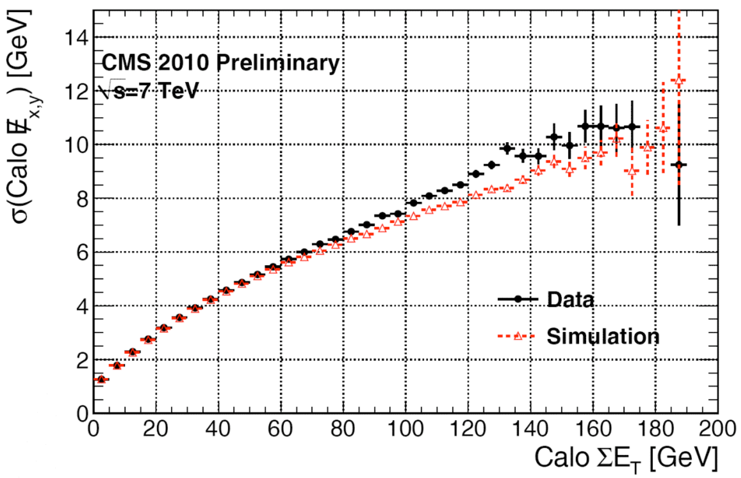


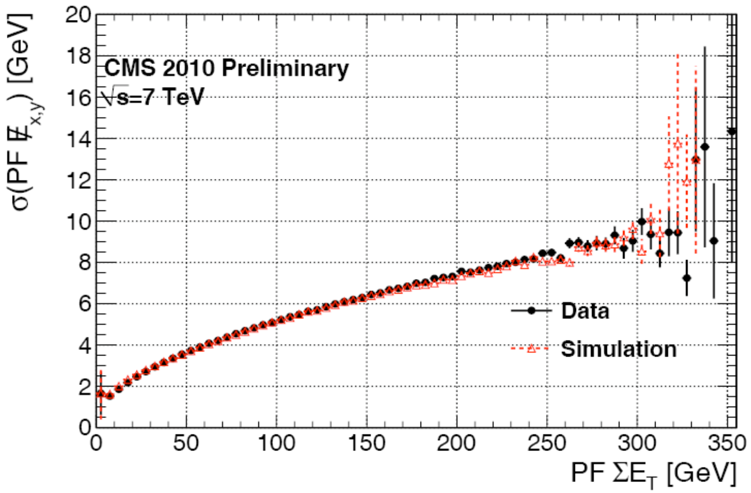
Missing E_T


CMS Preliminary 2010
√s = 7 TeV
Simulation
data
Number of Events / GeV
Calo E̸T [GeV]

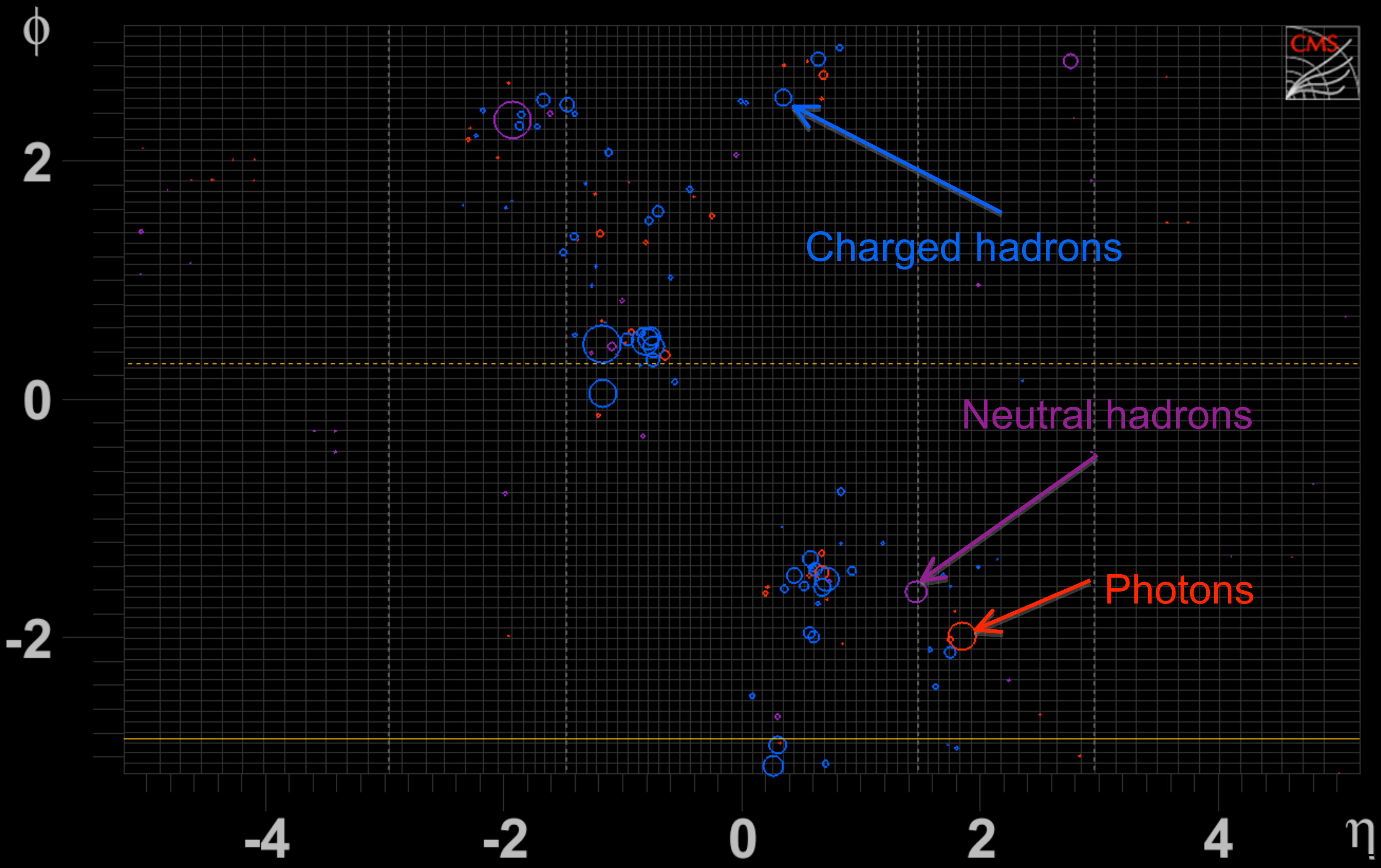

CMS Preliminary 2010
√s = 7 TeV
Simulation
data
Number of Events / GeV
Tc E̸T [GeV]


CMS Preliminary 2010
√s = 7 TeV
Simulation
data
Number of Events / GeV
Pf E̸T [GeV]

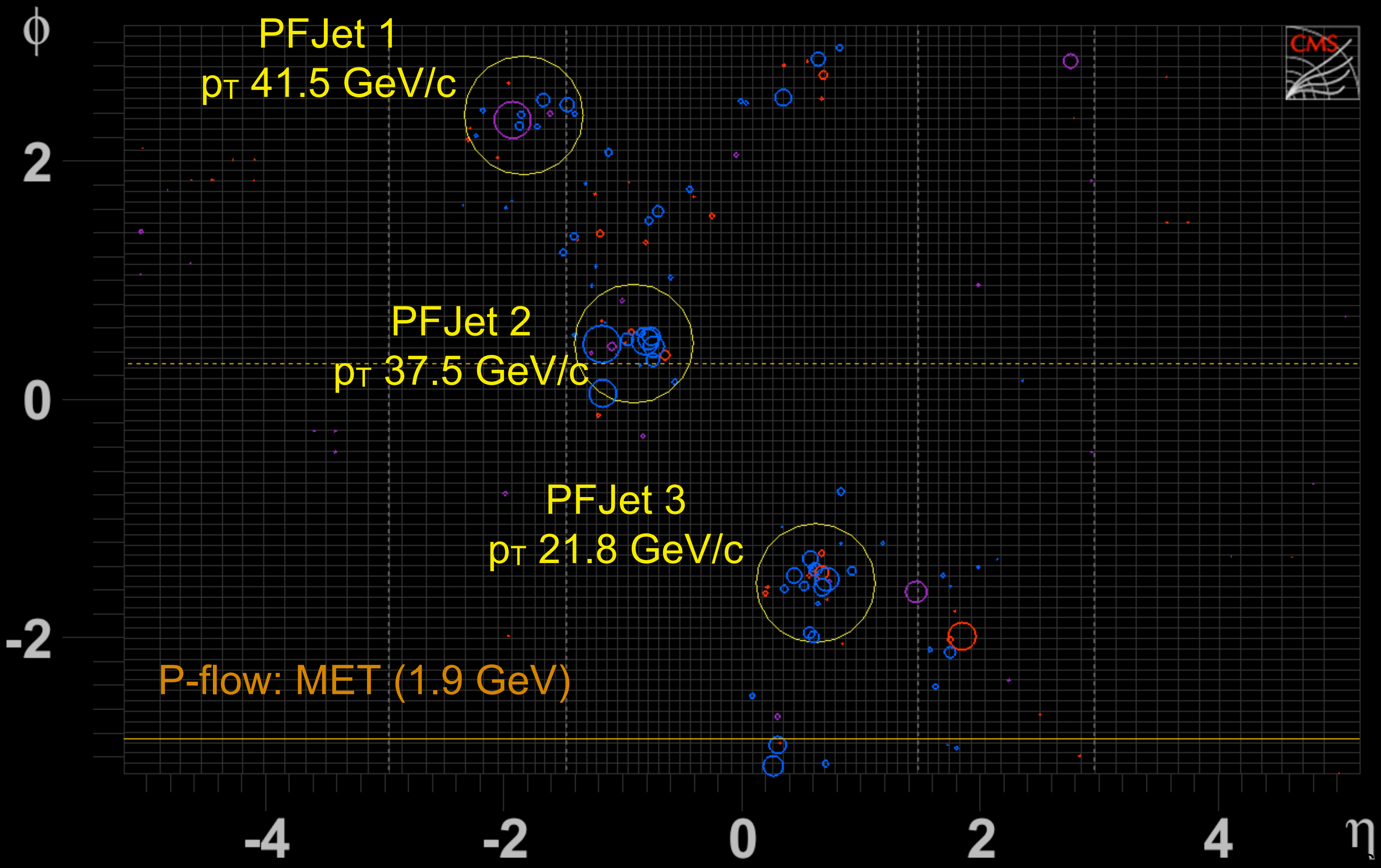

CMS 2010 Preliminary
√s=7 TeV
Data
Simulation
σ(Calo E̸x,y) [GeV]
Calo ΣET [GeV]


CMS 2010 Preliminary
√s=7 TeV
Data
Simulation
σ(PF E̸x,y) [GeV]
PF ΣET [GeV]

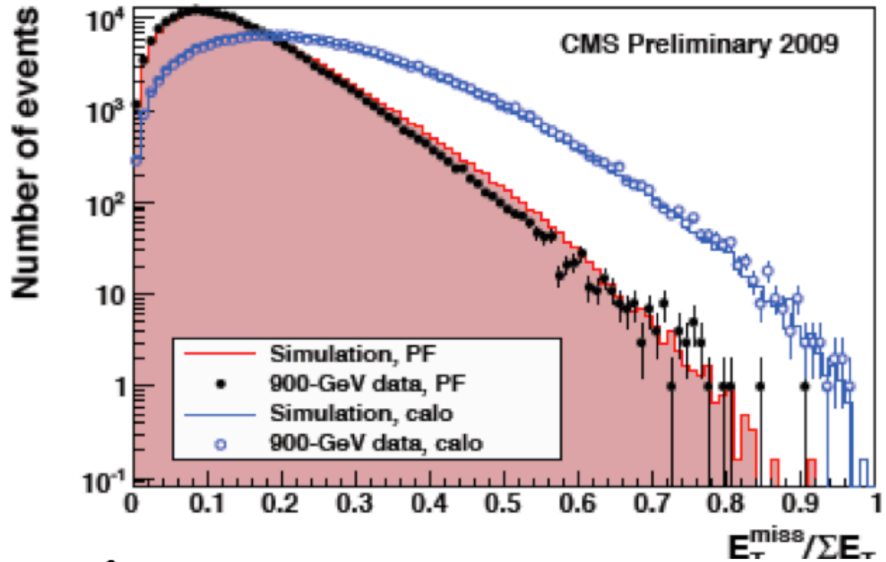
“Particle Flow”: reconstruct particle content



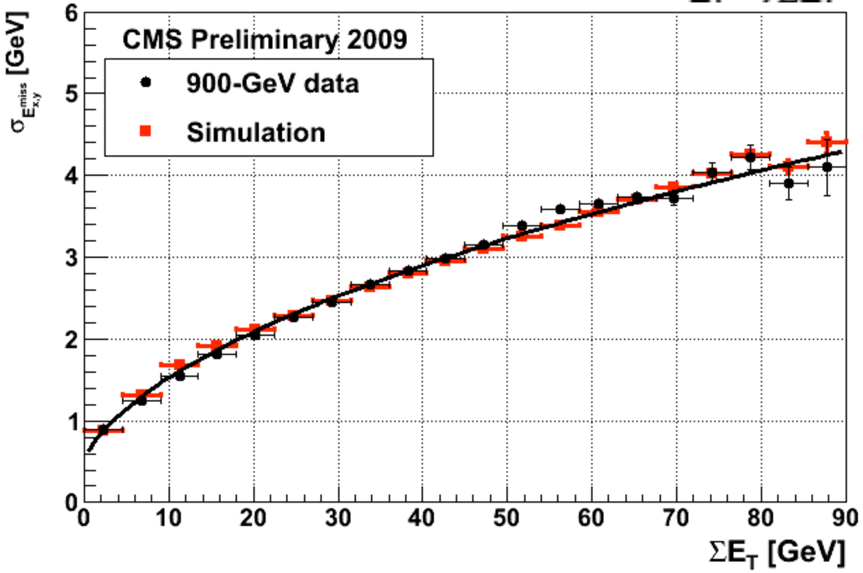
Pflow: Jet reconstruction follows naturally ... and so are global quantities like E_T^{miss}



Particle Flow



Accurate understanding of the calorimeter and optimal use of the granularity and of the excellent performance of our detectors



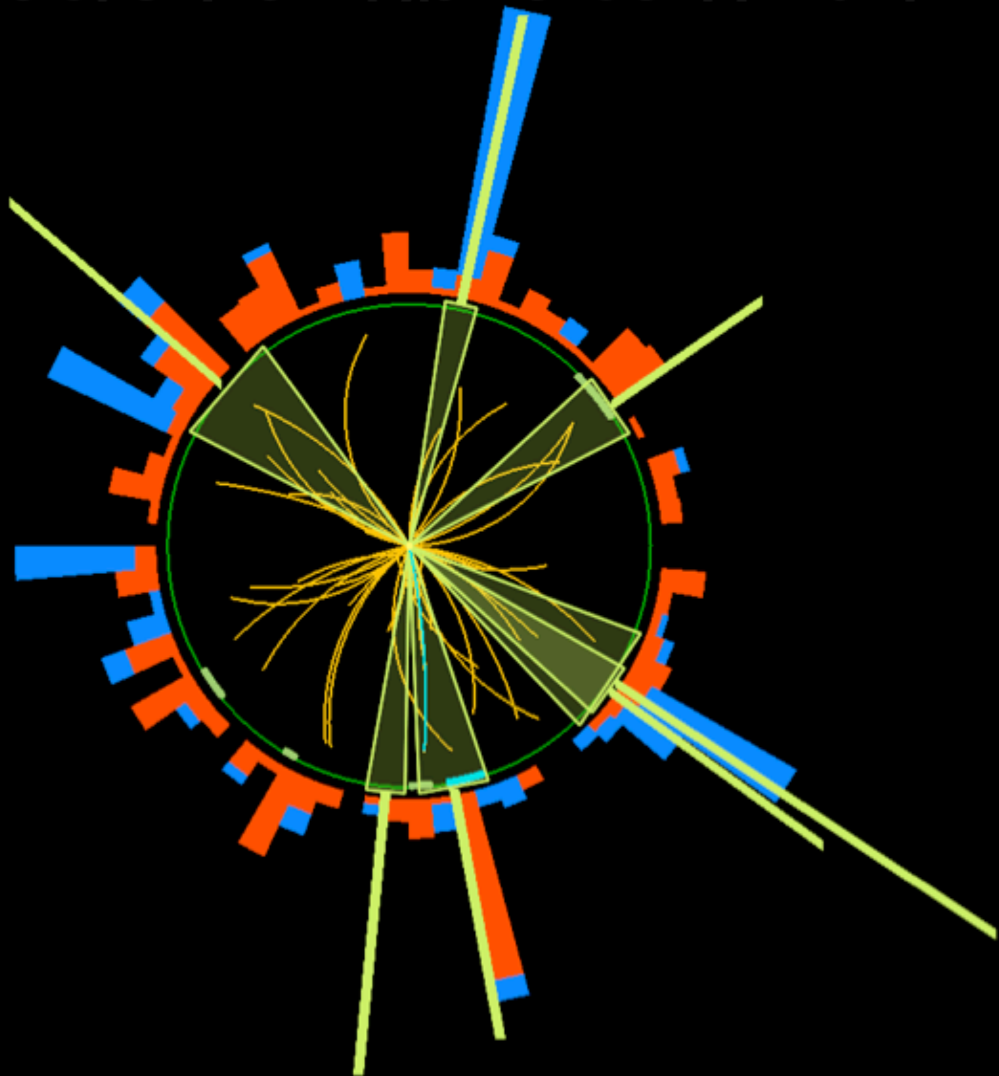
$$\sigma(E_{x,y}^{\text{miss}}) = a \oplus b\sqrt{\sum E_{\text{T}}}$$

a = 0.55 GeV
b = 45 % (PFlow)

Prospects For Physics Run I

LHC
Physics Run I

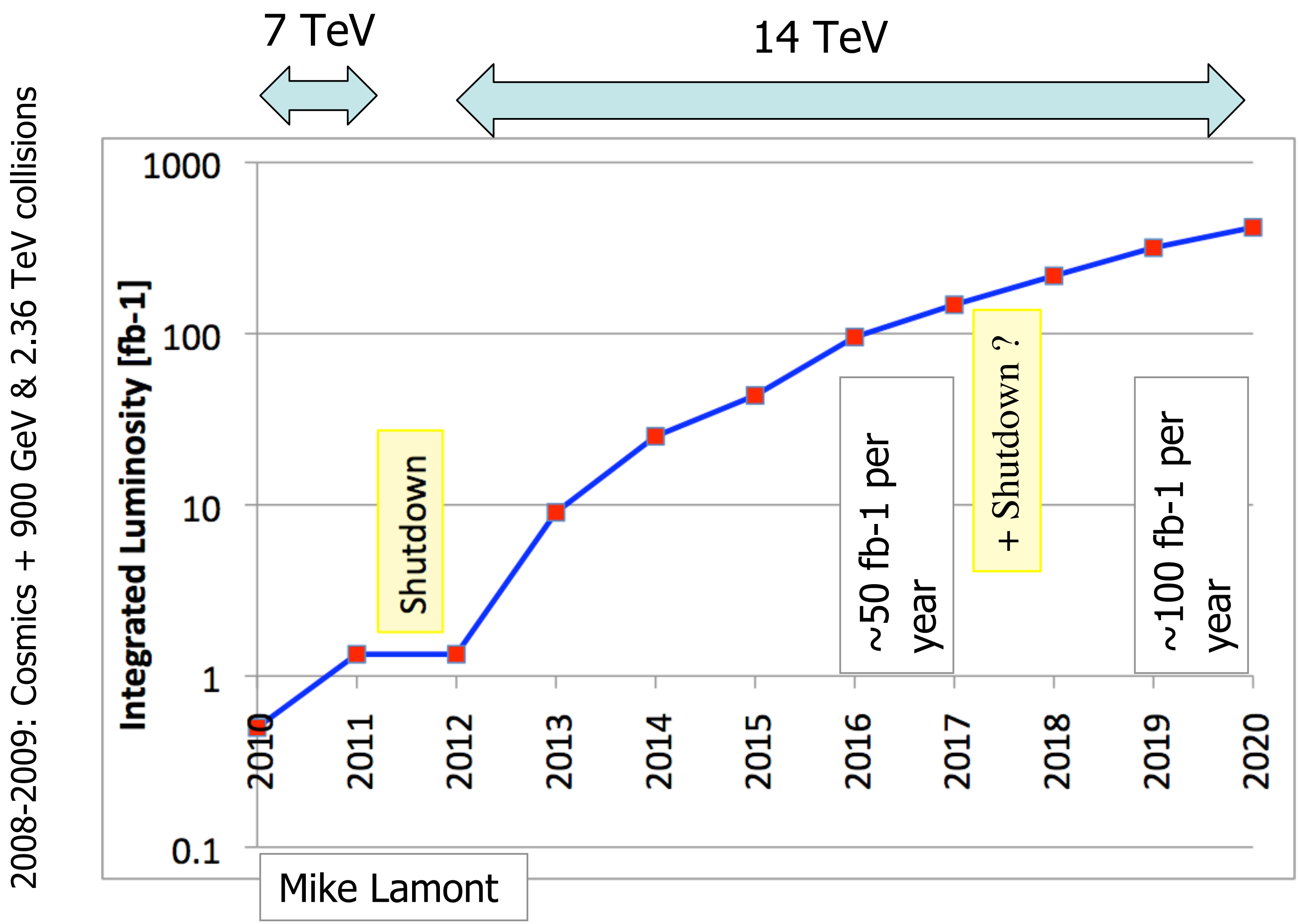
$\sqrt{s} = 7$ TeV
$\mathcal{L} = 1\ fb^{-1}$



Multi Jet Event at 7 TeV

LHC Expectations

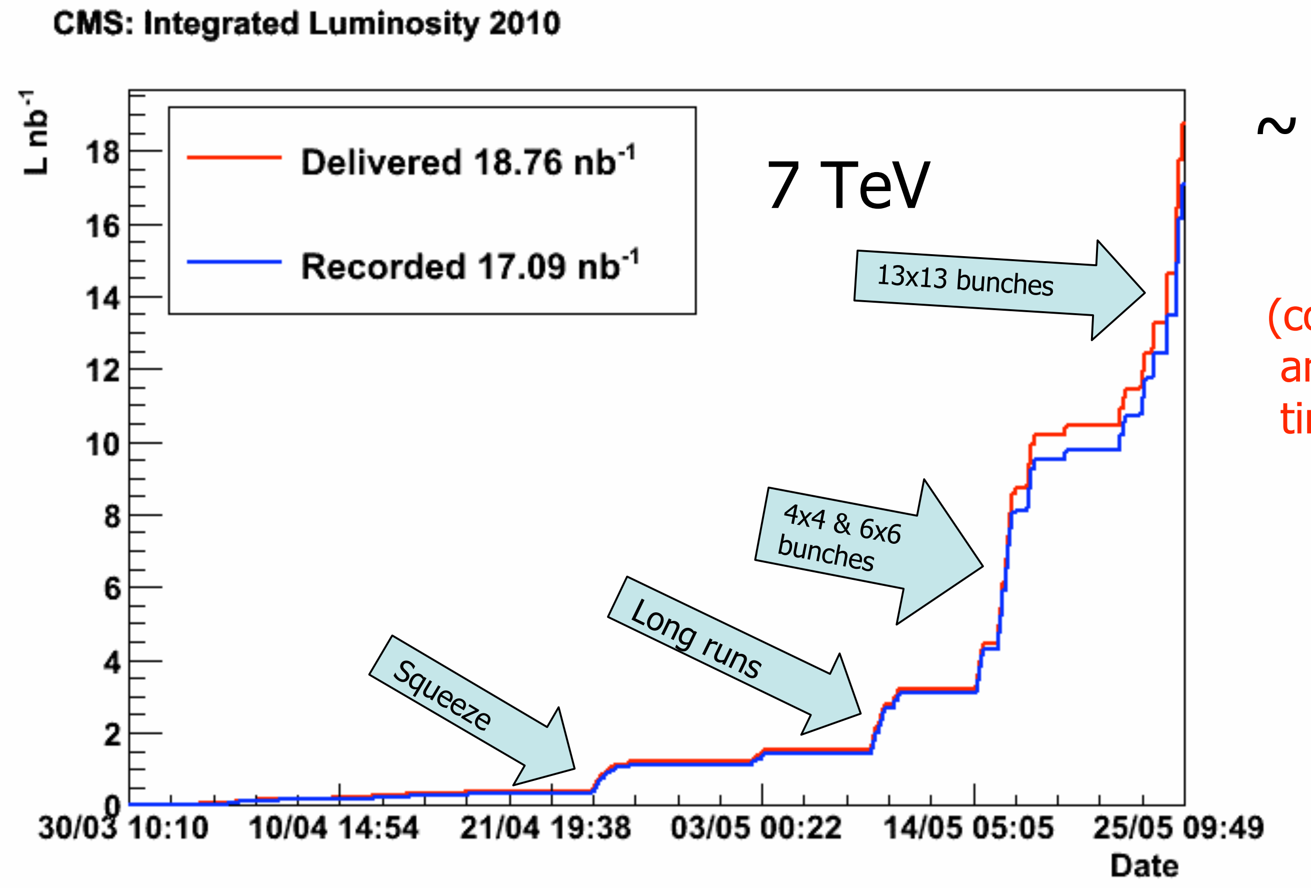
P. Jenni, Moriond 2010



Ultimate sLHC exploitation at 1000 fb-1/year

CMS PTDR Prospective (30 fb-1@14 TeV) relevant in ~2015

CMS Integrated Luminosity

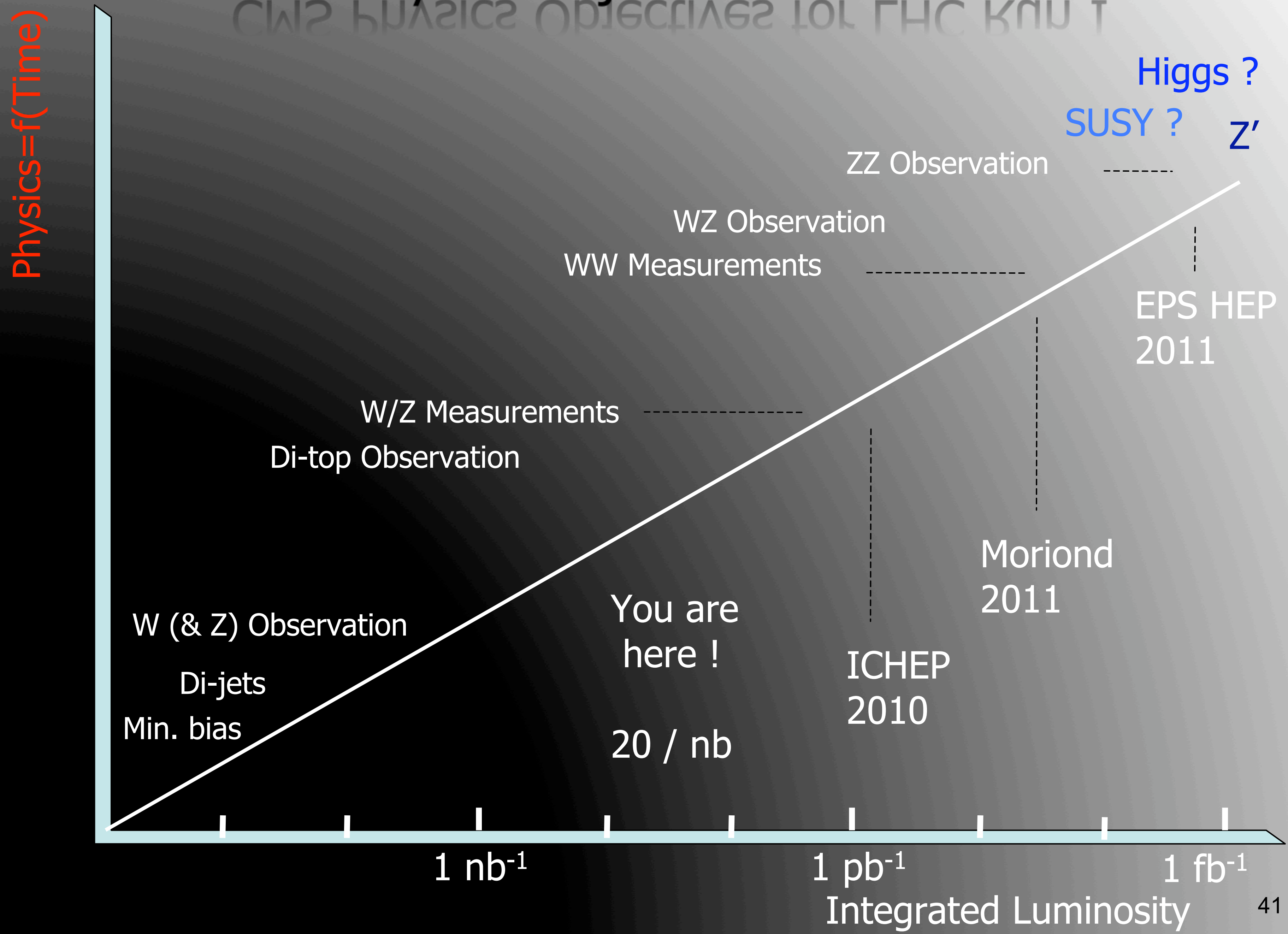


~ 91% data taking efficiency

(contains effects of "pause and resume" needed for timing & calibration scans)

- Detailed timing and calibration studies performed on all detectors
- Preliminary analysis on physics objects
- Reached 1.5 10^{29} Hz/cm^2 during 13x13 running end of May

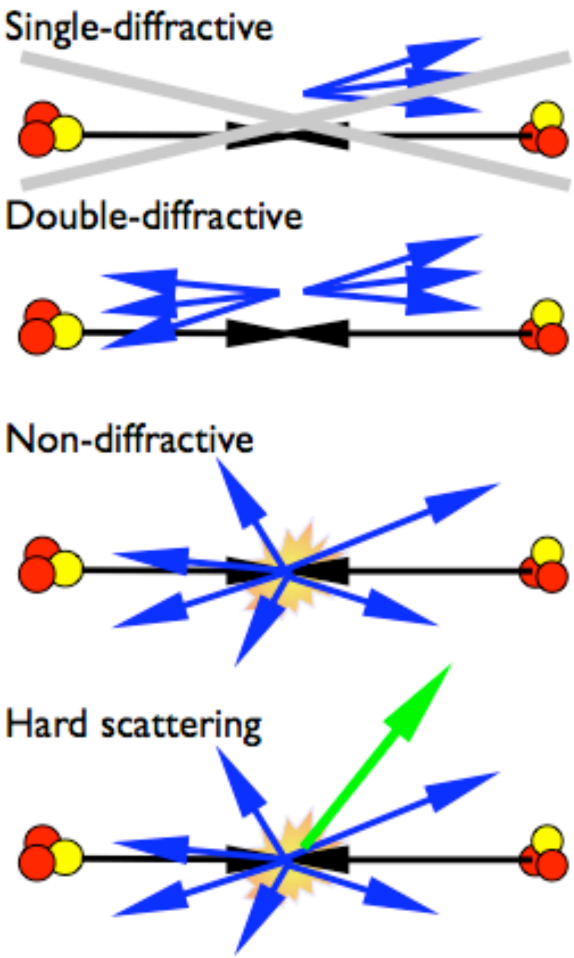
CMS Physics Objectives for LHC Run I



EARLY PHYSICS RESULTS

MINIMUM BIAS PHYSICS @ 7TeV
Trigger and selection

- "**Minimum bias**" collision events are selected using signals from
  - **BSC**
  - **Beam Pick-up Timing for Experiments (BPTX)**: two detectors at 175 m from interaction point that measure the presence of the beam
- **Requirements**:
  - Coincidence of BSC and BPTX on both sides
  - Request for a well reconstructed primary vertex
- Rejection of events induced by beam halo and beam background
- Some analyses use only **Non Single-Diffractive (NSD)** events
  - Selected requiring at least one tower with E > 3 GeV in **each** side of HF



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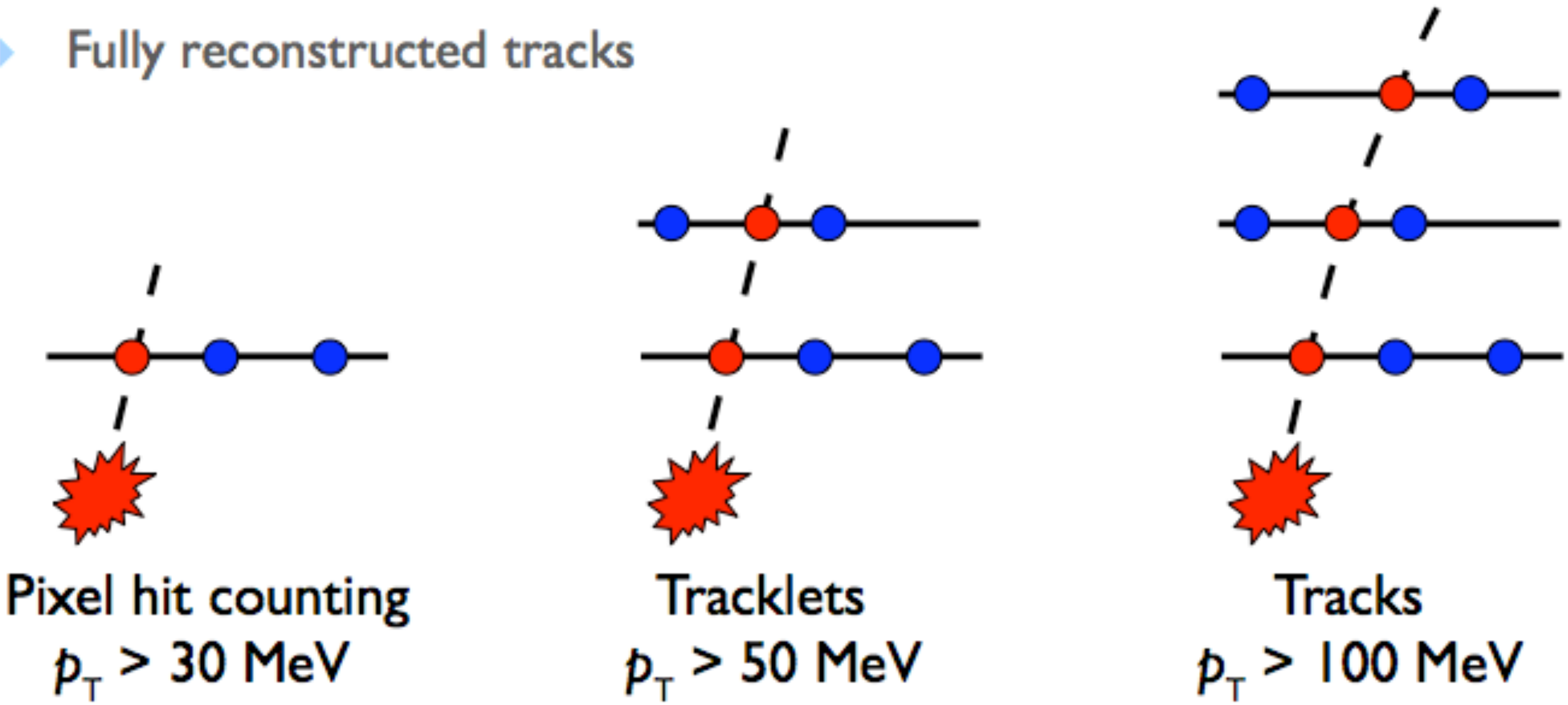
Transverse-momentum and pseudorapidity distributions of charged hadrons in pp collisions at sqrt(s) = 0.9 and 2.36 TeV
arXiv:1002.0621v2 [hep-ex] 8 Feb 2010

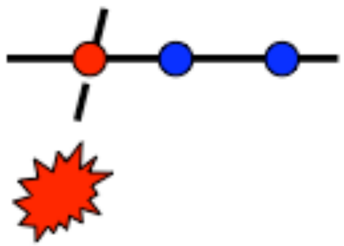
Transverse-momentum and pseudorapidity distributions of charged hadrons in pp collisions at sqrt(s) = 7 TeV
arXiv:1005.3299v1 [hep-ex] 18 May 2010

Measurement techniques

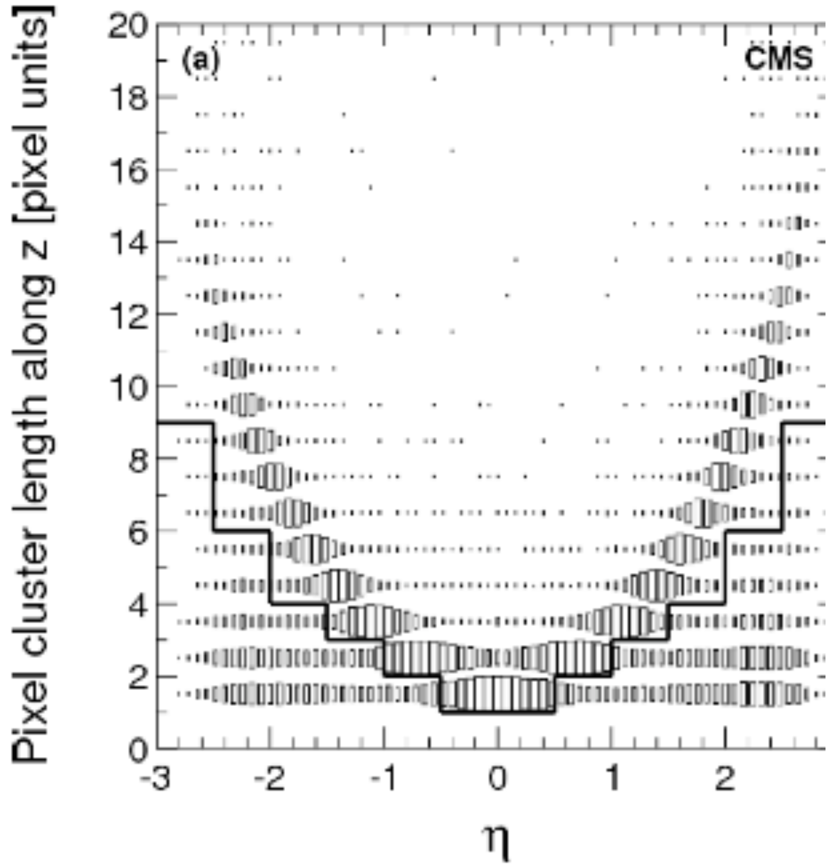
- Three different measurement techniques applied
  - Number of clusters (hits) in the pixel detector
  - Track fragments ("tracklets") obtained correlating two hits in the pixel detector, compatible with the vertex
  - Fully reconstructed tracks



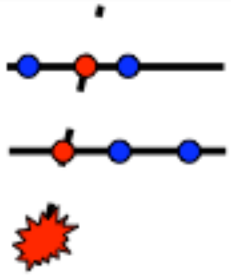
Pixel cluster counting



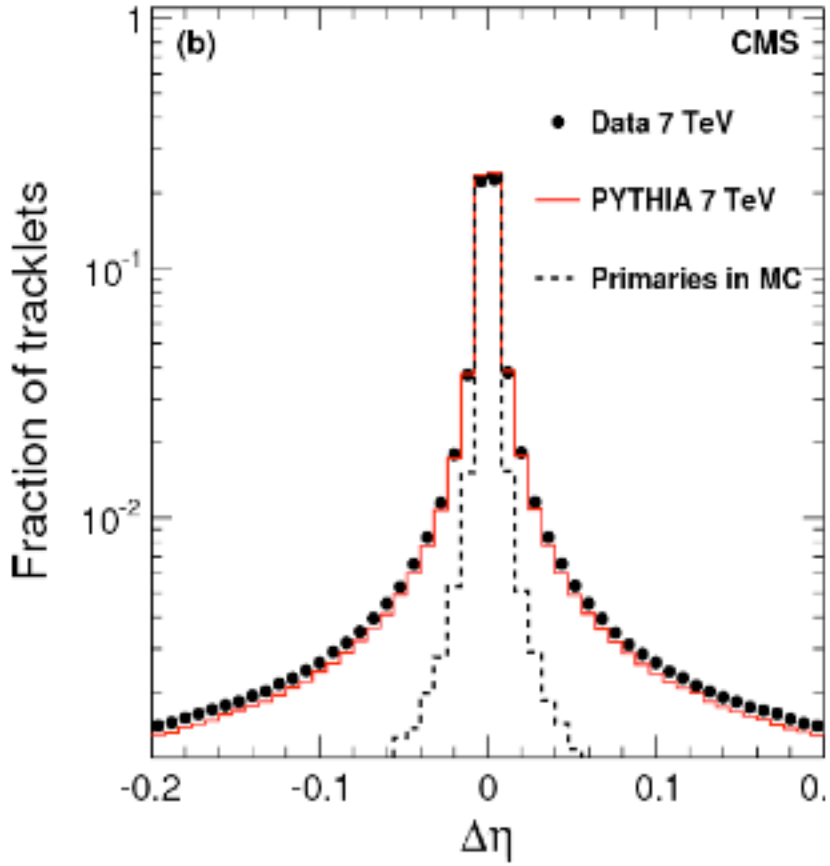
- Clusters belonging to tracks coming from the interaction point are selected cutting on their size along z
- Cluster length for tracks coming from primary vertex is ~|sinh(η)|
- Short clusters coming from loopers, displaced decays, secondaries are removed



Tracklets

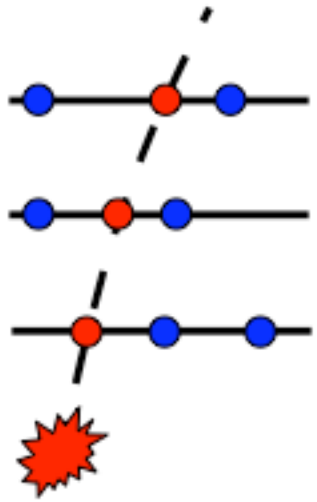


- Track fragments (tracklets) coming from interaction point are selected exploiting the strong correlation in η between their two hits
- Combinatorial background subtracted using sideband technique
  - Signal region |Δφ|<1, |Δη|<0.1
  - Sideband region 1<|Δφ|<2
  - Background flat in |Δφ|
- MC-based corrections for acceptance, weak decays, secondaries, pixel efficiency, splitting



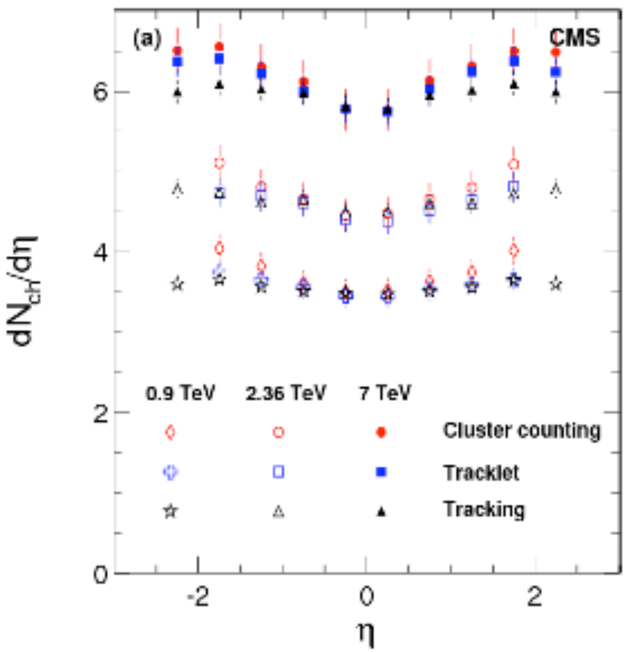
Tracks

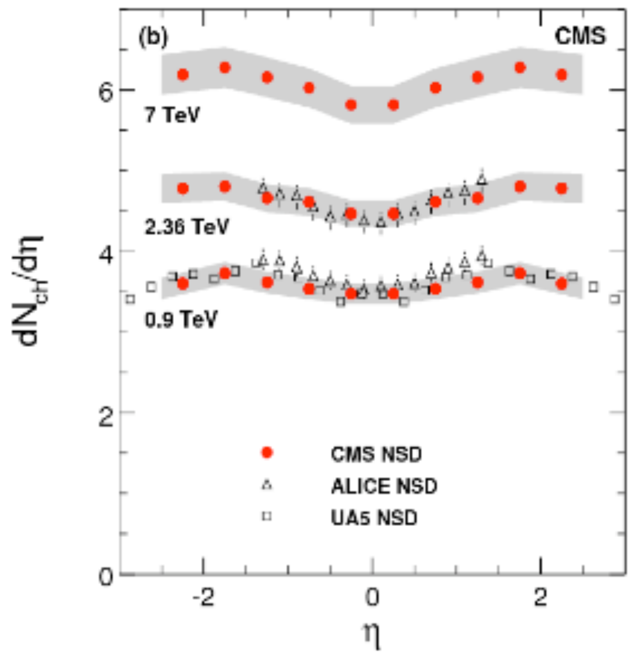
- The third method uses fully reconstructed tracks in pixel and strip detectors
- Tracking algorithm uses several iterative steps
- Background reduced by selecting tracks
  - with at least 3 hits in pixel + strips
  - compatible with primary vertex
- This method gives the cleanest results, but
  - Has the highest p_T threshold
  - Requires good knowledge of alignment and beam-spot



Results: $dN_{ch}/d\eta$

- **Left**: results obtained with the three methods for NSD events
  - Compatible within the errors
- **Right**: averaged results compared with ALICE and UA5
  - Systematic uncertainties mainly coming from trigger, event selection, reconstruction efficiencies (~5%)



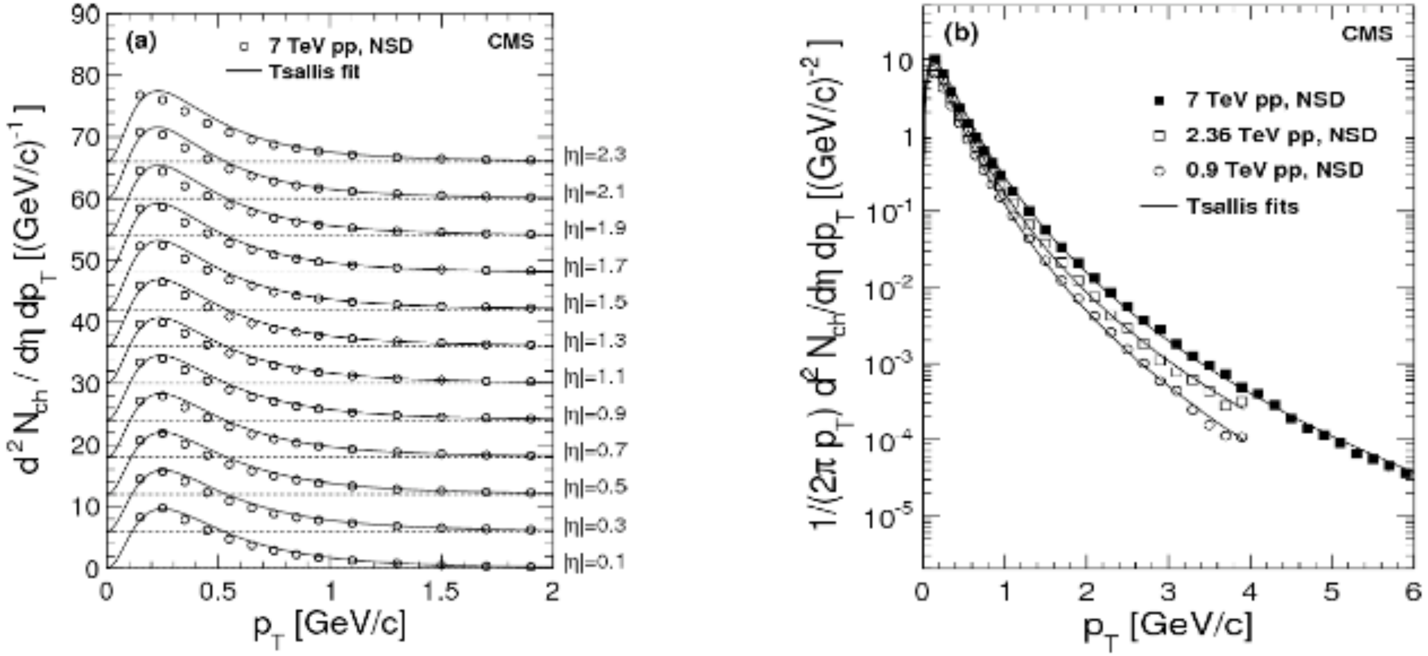


Results: p_T

- p_T distributions fitted with Tsallis function (exp + power law)

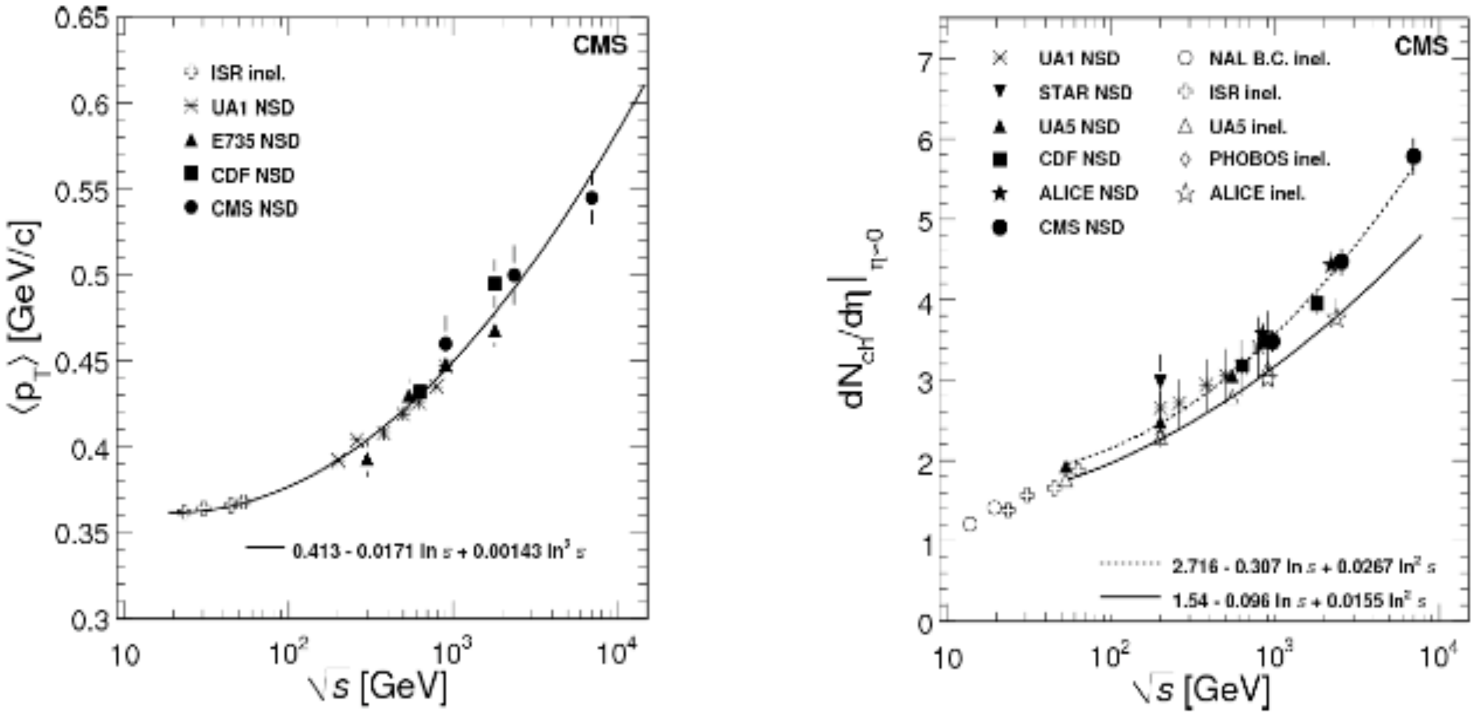
$$E\frac{d^3N_{ch}}{dp^3} = \frac{1}{2\pi p_T}\frac{E}{p}\frac{d^2N_{ch}}{d\eta dp_T} = C(n,T,m)\frac{dN_{ch}}{dy}\left(1+\frac{E_T}{nT}\right)^{-n}$$

Loose depencence on η, so fit in the whole range possible



Energy dependence

- Dependence ~ $\ln^2 s$
- Steep increase in $dN_{ch}/d\eta|_{|\eta|\approx 0}$ with energy
  - Similar to what is found by ALICE at the same energies
  - Significantly higher than most event generator predictions



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First Measurement of Bose-Einstein Correlations at sqrt(s)=0.9 and 2.36 TeV at the LHC

arXiv:1005.3294v1 [hep-ex] 18 May 2010

Bose-Einstein Correlation (BEC)

- Probability for identical bosons produced incoherently by a source to have similar momenta is enhanced with respect to uncorrelated case **(reference)**

$$R = \frac{P(b_1, b_2)}{P(b_1)\,P(b_2)}$$

$$R = \left(\frac{dN_{sig}/dQ}{dN_{ref}/dQ} \right)$$

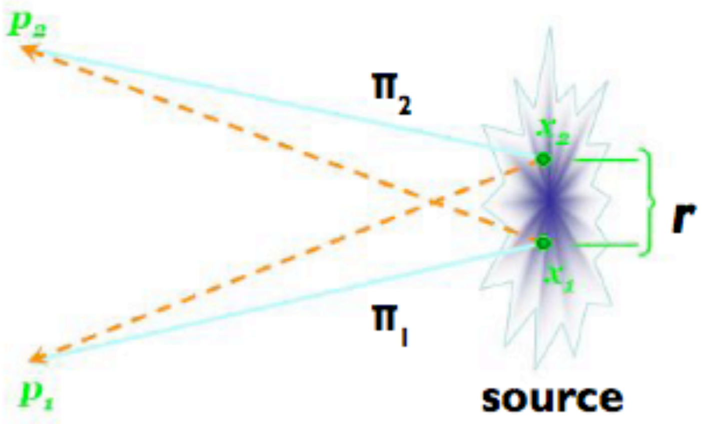
- BEC gives information on the **size and shape** of the primary source
- *R* is expressed as a function of the pair **Q-value**:

$$Q = \sqrt{-(p_1 - p_2)^2} = \sqrt{m_{inv}^2 - 4m_\pi^2}$$

- We parameterize *R*(*Q*) with a Lorentz-invariant form describing the emission from **a spherical region**:

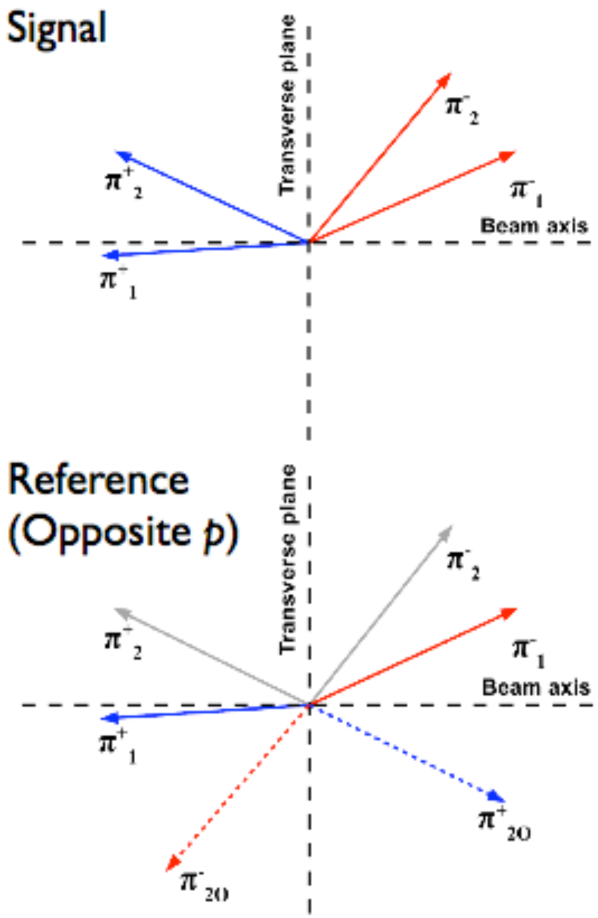
$$R(Q) = C\left[1 + \lambda\Omega(Qr)\right] \cdot (1 + \delta Q)$$

  - Ω is the **Fourier transform** of the space distribution of the emission region, whose **effective size** is given by *r*;
  - λ is a **strength parameter** and
  - δ allows for **long-range correlations**



BEC – Signal and reference samples

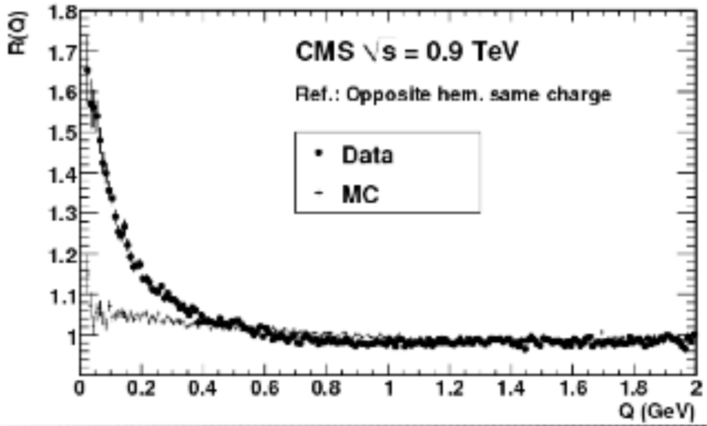
- In this study we considered **7 reference samples**, considering pairs made with:
  - **1.** Opposite-charge tracks
  - **2.** Opposite-charge tracks in which one has p inverted
  - **3.** Same-charge tracks in which one has the p inverted
  - **4.** Same-charge tracks in which one has p_T inverted
  - Same-charge tracks from different events
    - **5.** Random mixing
    - **6.** Event mixing based on similar $dN_{ch}/d\eta$ distribution
    - **7.** Event mixing based on similar total invariant mass
- **No golden reference. All are used and results are combined**

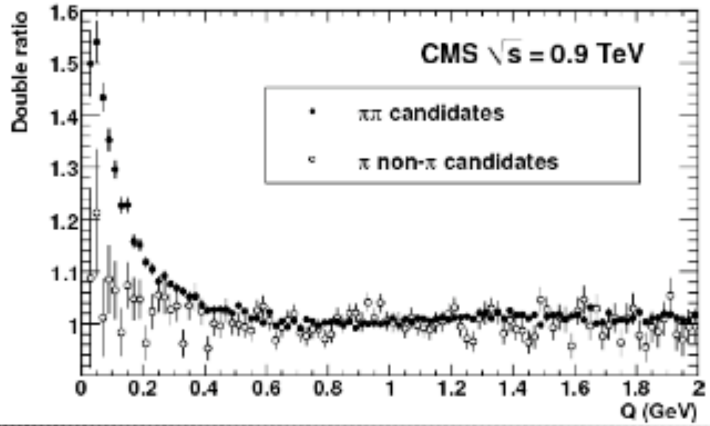


BEC – Double ratios

- The ratio *R* defined above shows a clear BEC signal at low *Q*
  - Monte Carlo simulates no BEC
- The distribution *R*(*Q*) is distorted by resonances and long-range correlations at high *Q*
  - These are generally well reproduced by simulation
- We use **double ratios** to remove these and other unwanted features from the *R*(*Q*) distribution
- **Cross-check**: if we form pairs with pion – non-pion candidates (identified with d*E*/dx in the tracker) the BEC effect disappears

$$\Re = \frac{R}{R_{MC}} = \frac{\left(\frac{dN_{sig}/dQ}{dN_{ref}/dQ}\right)}{\left(\frac{dN_{sig,MC}/dQ}{dN_{ref,MC}/dQ}\right)}$$





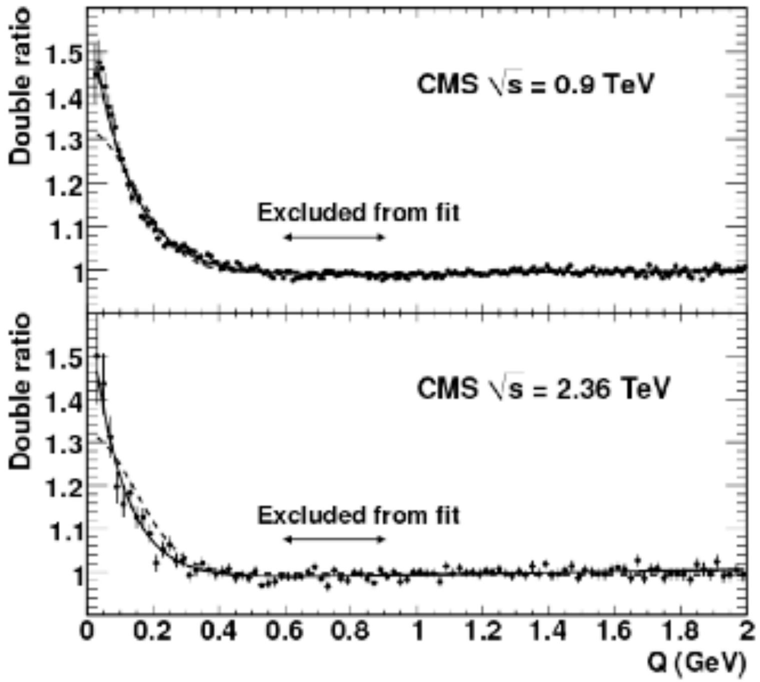
BEC – Results

- Fits are performed with an exponential and a Gaussian form for Ω:

$$\Omega = \exp(-Qr),\ \Omega = \exp(-Qr)^2$$

- Our data is well described by exponential fits, while **the Gaussian form is very disfavored** (bad fit *p*-value)
- A single value for the BEC parameters can be obtained by building a combined reference sample (*m*=7):

$$\Re_{comb} = \frac{dN_{sig}/dQ}{dN_{sig,MC}/dQ} \cdot \left(\frac{\sum_{i=1}^{m} dN_{i,MC}/dQ}{\sum_{i=1}^{m} dN_{i}/dQ} \right)$$



- Results of the fit (combined sample):

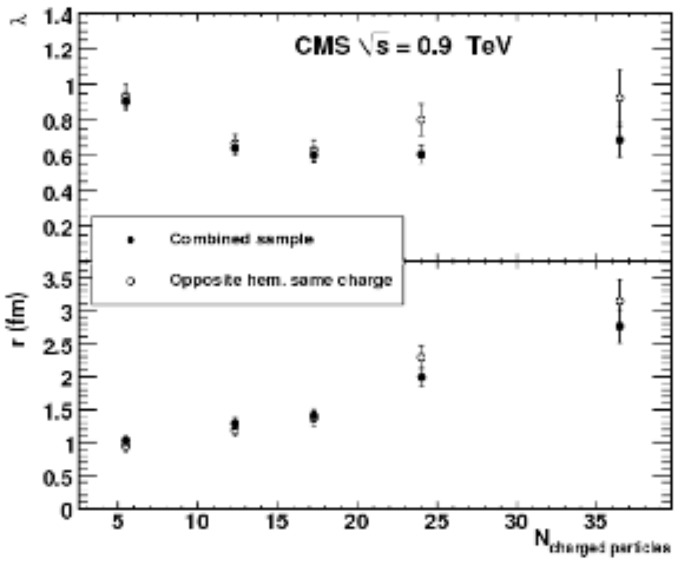
  λ = 0.625 ± 0.021 (stat.) ± 0.046 (syst.) and r = 1.59 ± 0.05 (stat.) ± 0.19 (syst.) fm at 0.9 TeV

  λ = 0.663 ± 0.073 (stat.) ± 0.048 (syst.) and r = 1.99 ± 0.18 (stat.) ± 0.24 (syst.) fm at 2.36 TeV

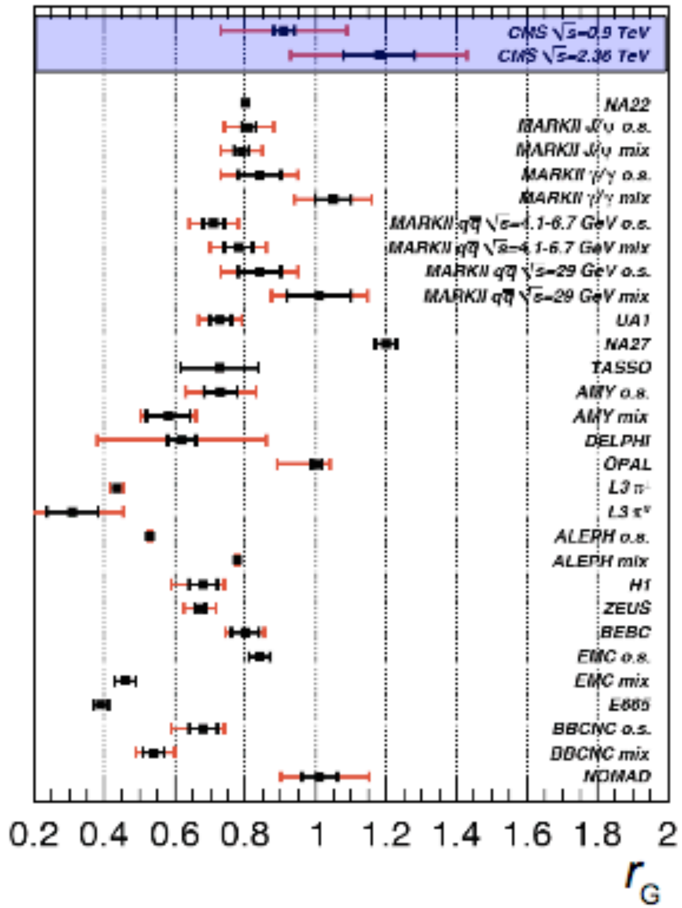
- Main systematics source is the choice of the reference sample

BEC – Results (2)

- The parameters of BEC depend on the **total charged multiplicity** in the event
  - The radius r **increases significantly** with N_{tracks}
  - The strenght λ **slightly decreases**
- This effect is present in 0.9 TeV and in 2.36 TeV data
- CMS results consistent with previous measurements

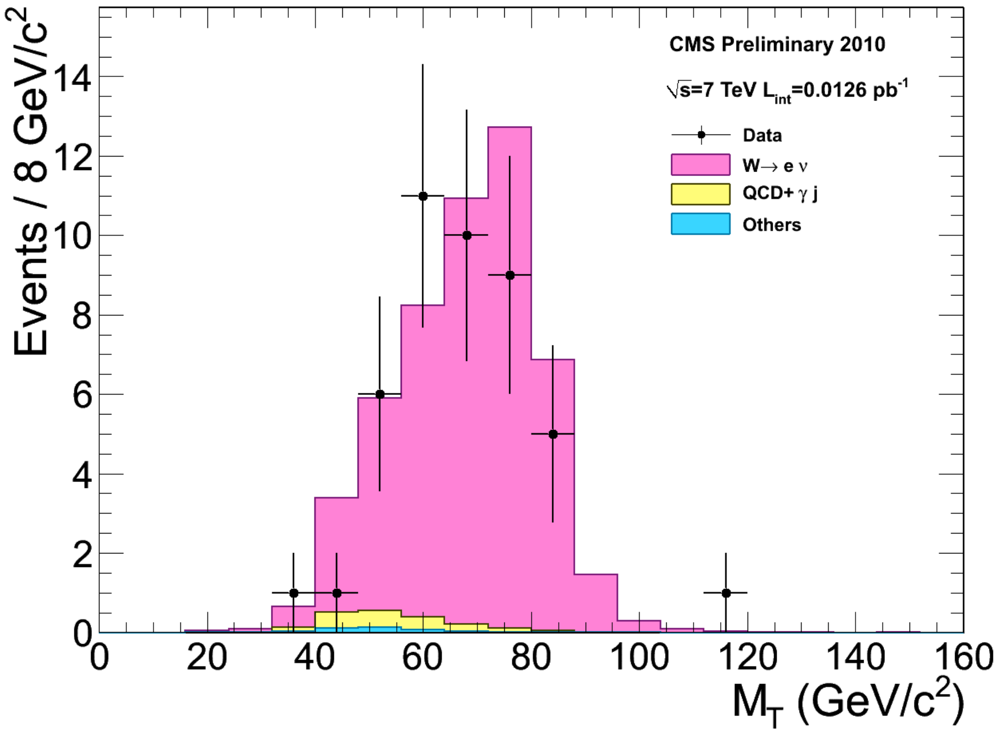


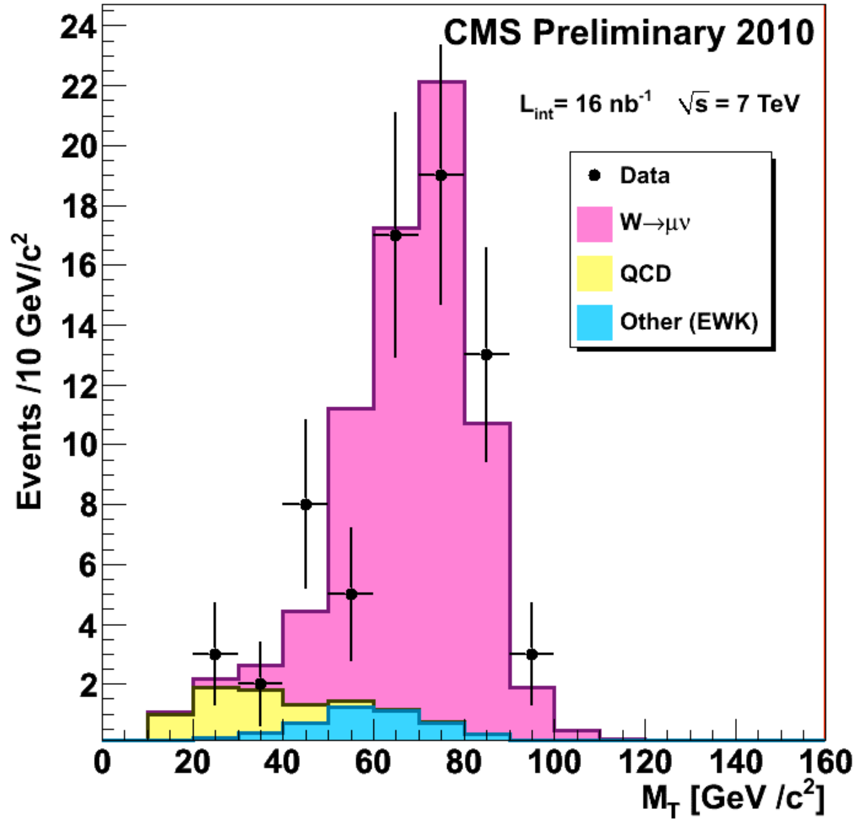
CMS results scaled ($r_G = r/\sqrt{\pi}$)



Rediscovering the SM

W boson



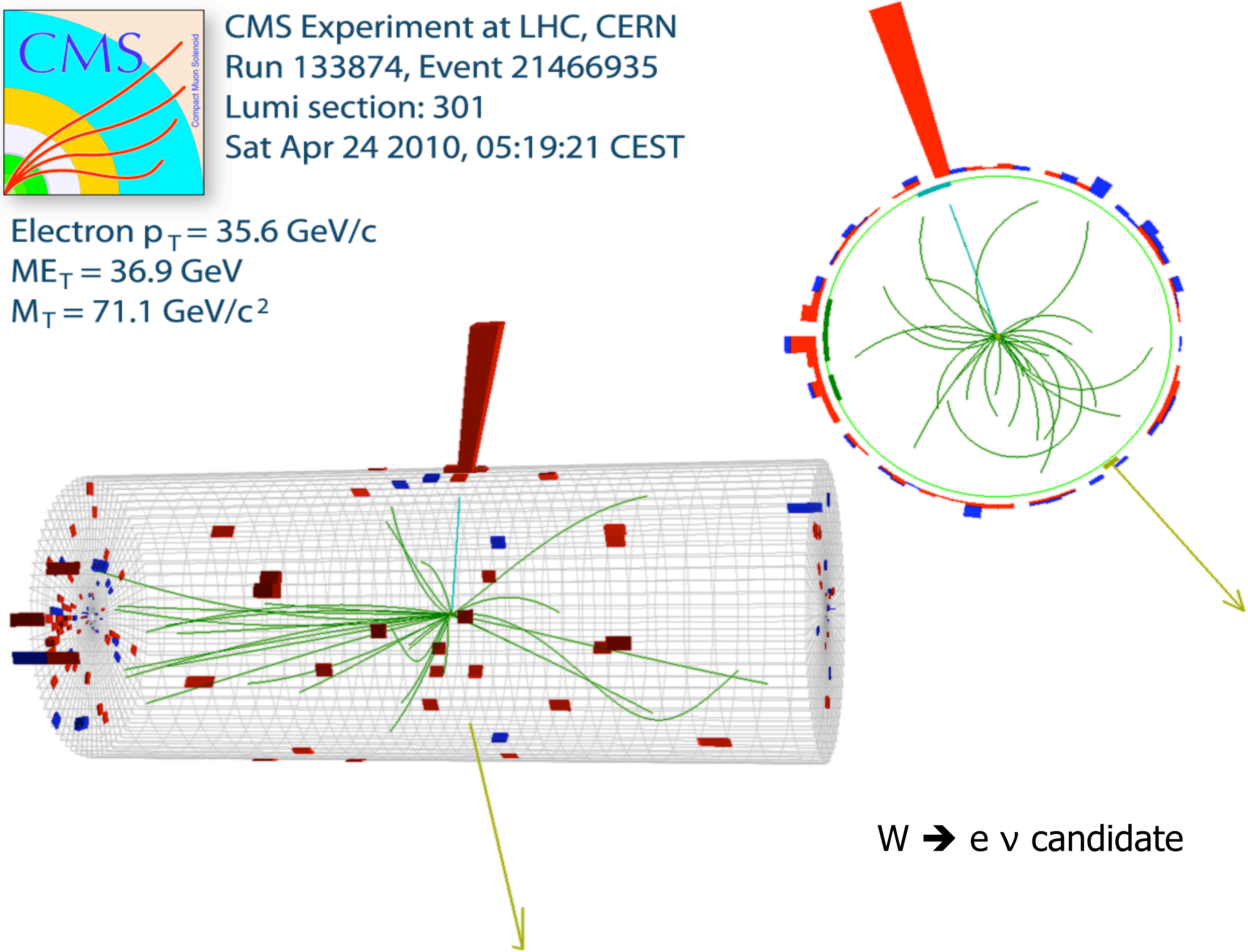


Electron channel:
Total: 44 candidates, expected BG ~ 2 events 40 candidates with M_T > 50 GeV

Muon channel:
With MT > 50 GeV: 57 events

CMS Experiment at LHC, CERN
Run 133874, Event 21466935
Lumi section: 301
Sat Apr 24 2010, 05:19:21 CEST

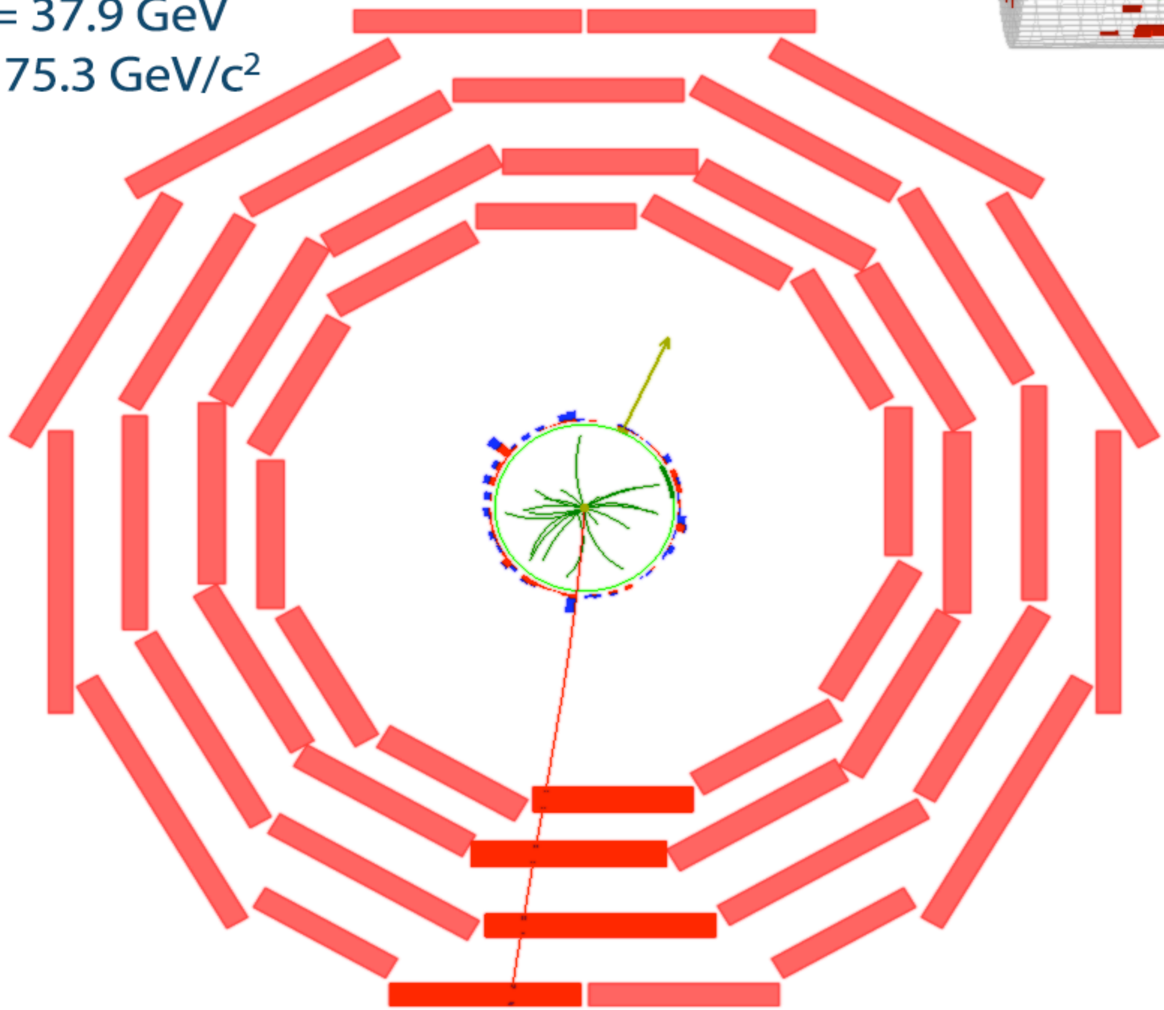
Electron $p_T = 35.6$ GeV/c
$ME_T = 36.9$ GeV
$M_T = 71.1$ GeV/c^2

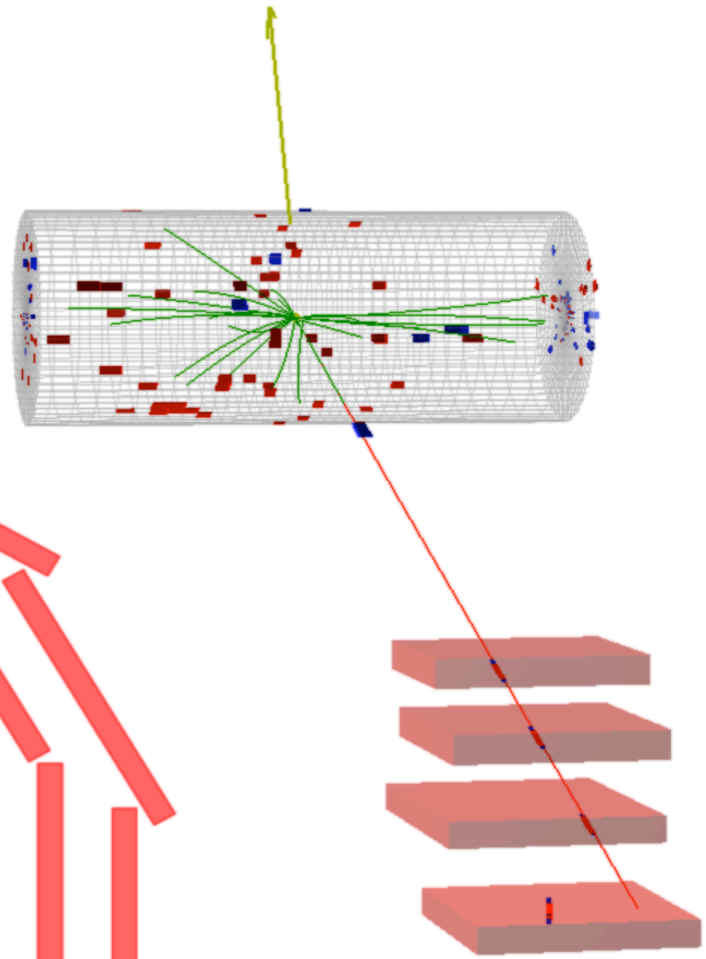


W → e ν candidate

CMS Experiment at LHC, CERN
Run 133875, Event 1228182
Lumi section: 16
Sat Apr 24 2010, 09:08:46 CEST

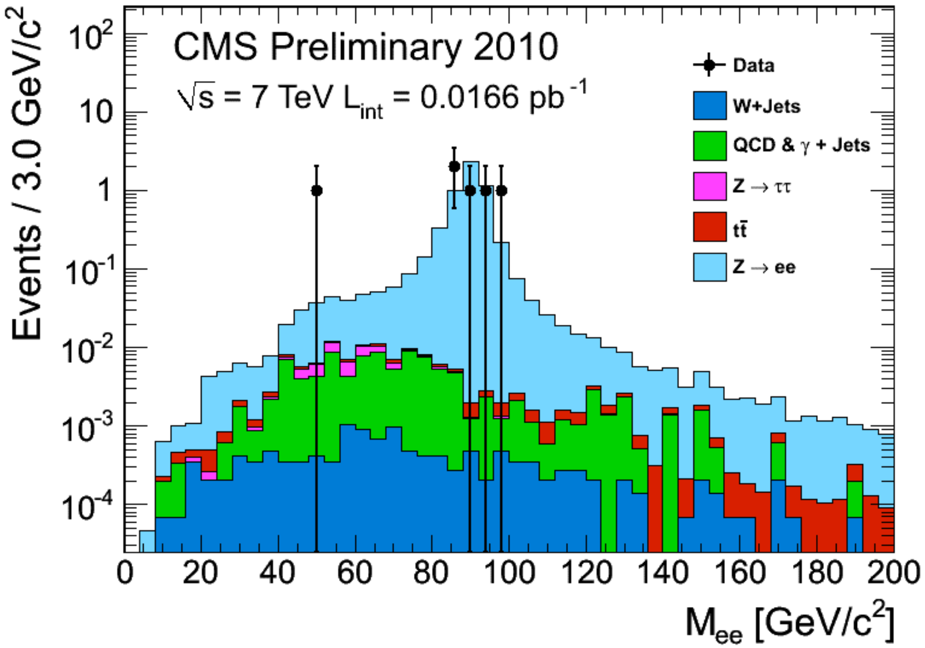
Muon p_T= 38.7 GeV/c
ME_T= 37.9 GeV
M_T= 75.3 GeV/c^2

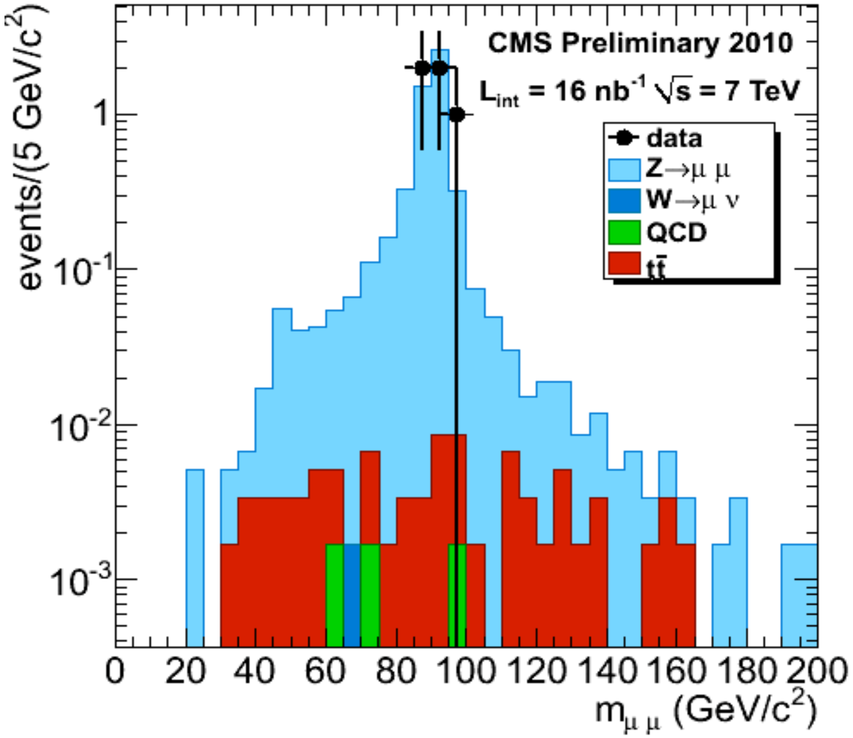




W → μ ν candidate

Z boson



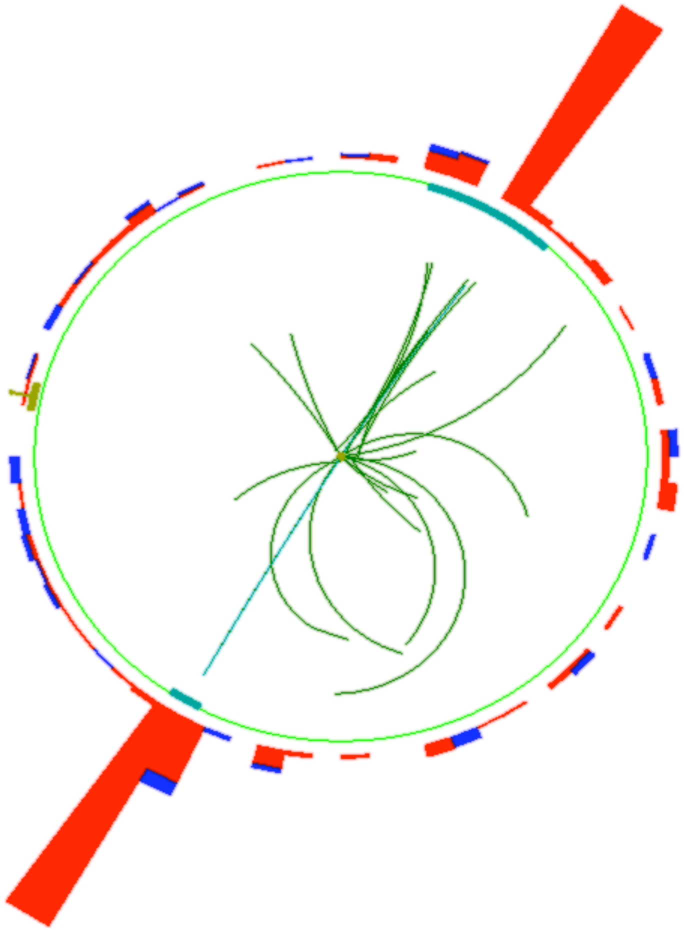


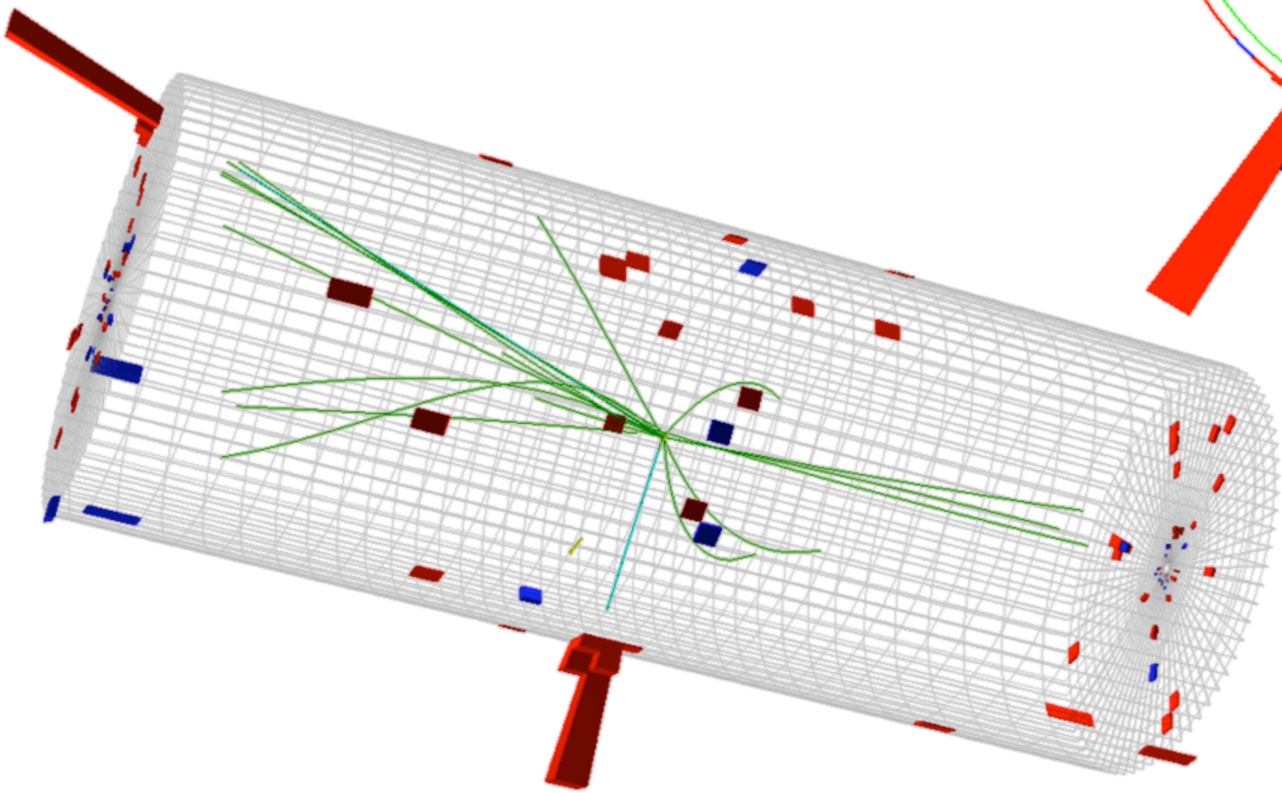
- 5 candidates in the peak region
- Photon10 HLT required (10 GeV E_t EM cluster)
- Both electrons required to pass a loose simple cut based electron Id and isolation selection
- BG from PYTHIA, signal POWHEG rescaled to NLO cross section
- Normalization to integrated luminosity

- Muon Id criteria (global and tracker muon, impact parameter, c2, number of hits, …).
- HLT pT single-muon threshold (L3): 9 GeV, |h| < 2.1 for at least one of the muons.
- Muon pT > 20 GeV.
- Loose muon isolation: track-pT sum in a DR < 0.3 cone must be less than 3 GeV.

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/c^2

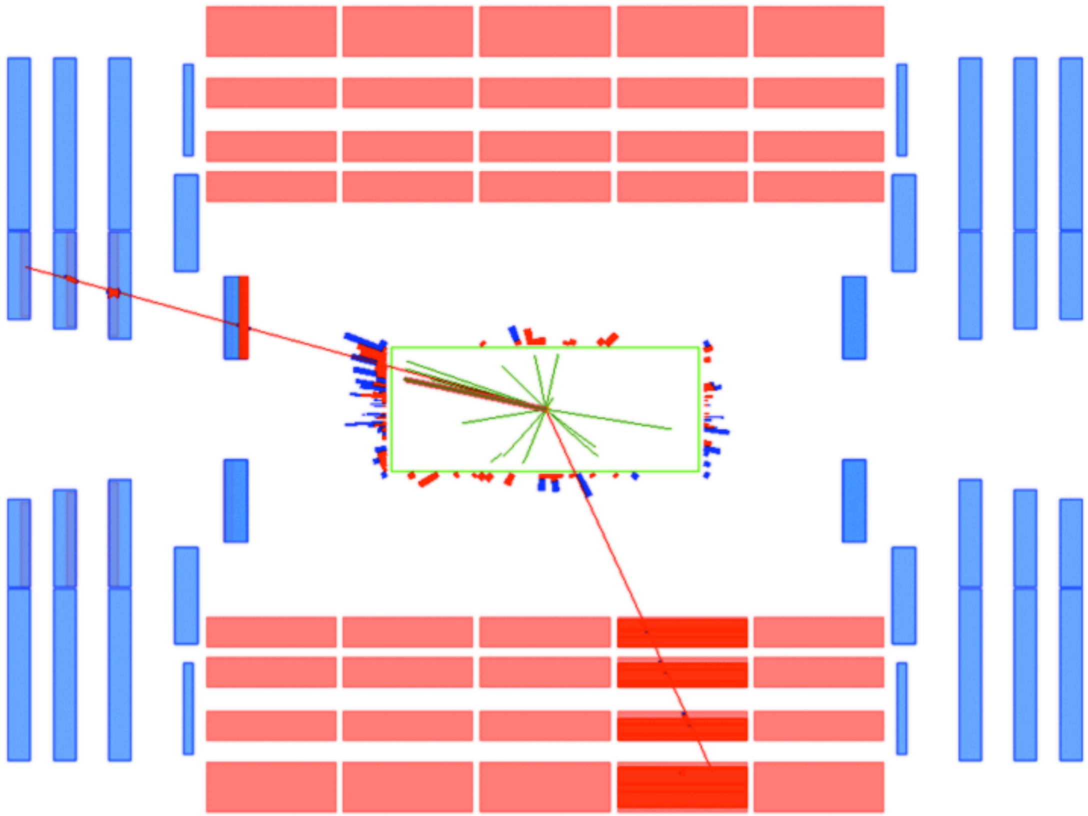


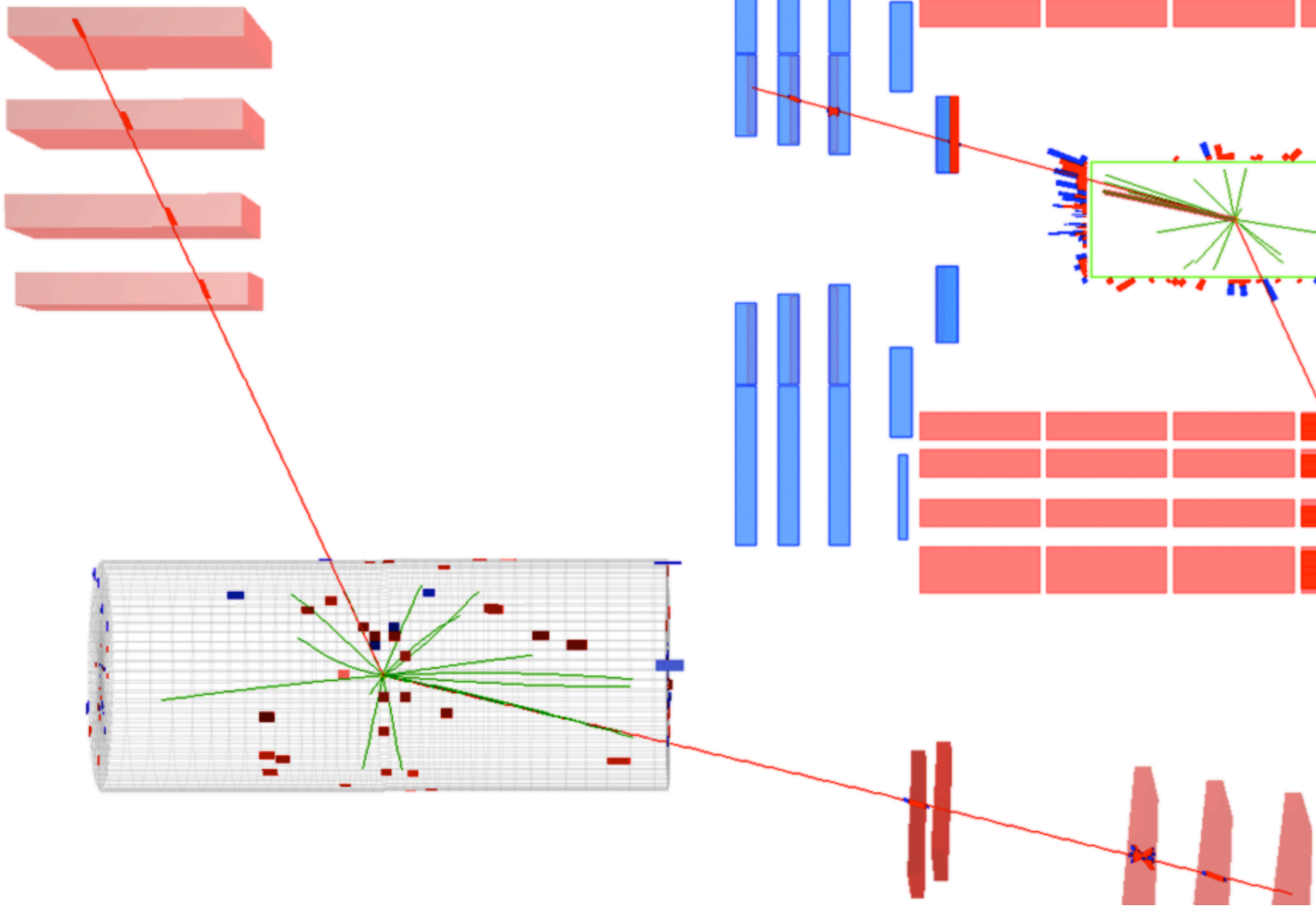


Z ➔ e e candidate

CMS Experiment at LHC, CERN
Run 136087 Event 39967482
Lumi section: 314
Mon May 24 2010, 15:31:58 CEST

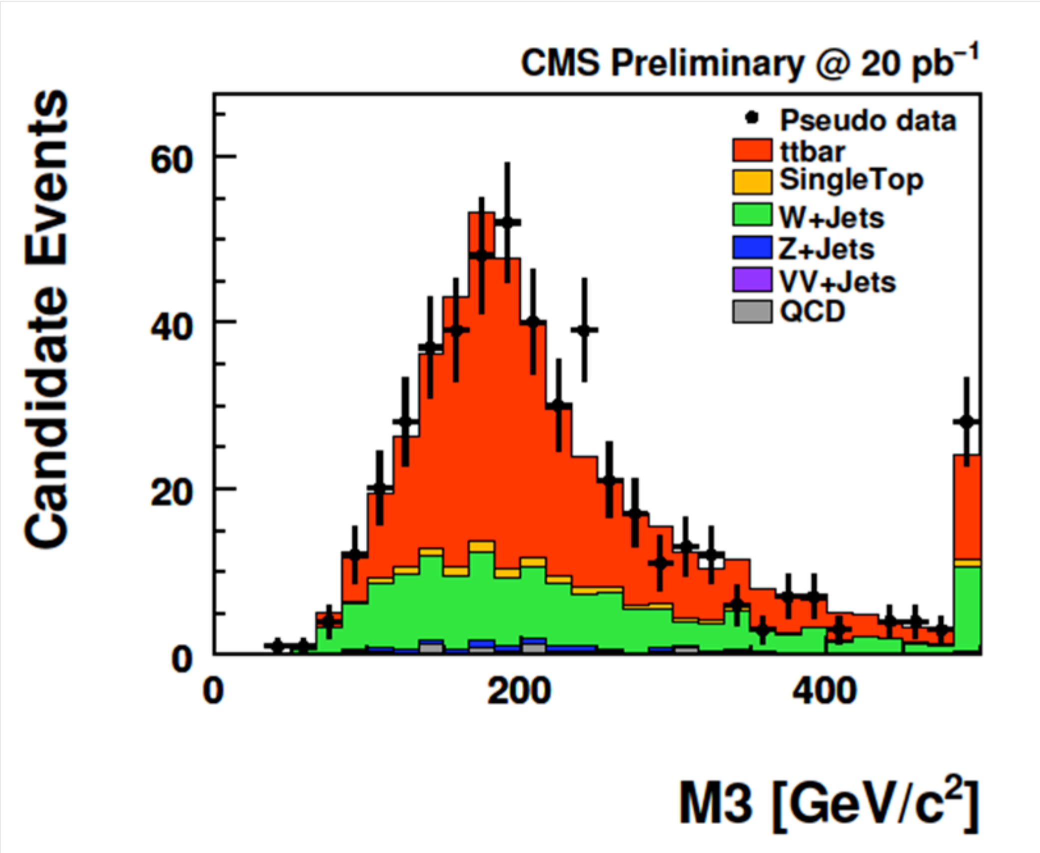
Muon p_T= 27.3, 20.5 GeV/c
Inv. mass = 85.5 GeV/c^2

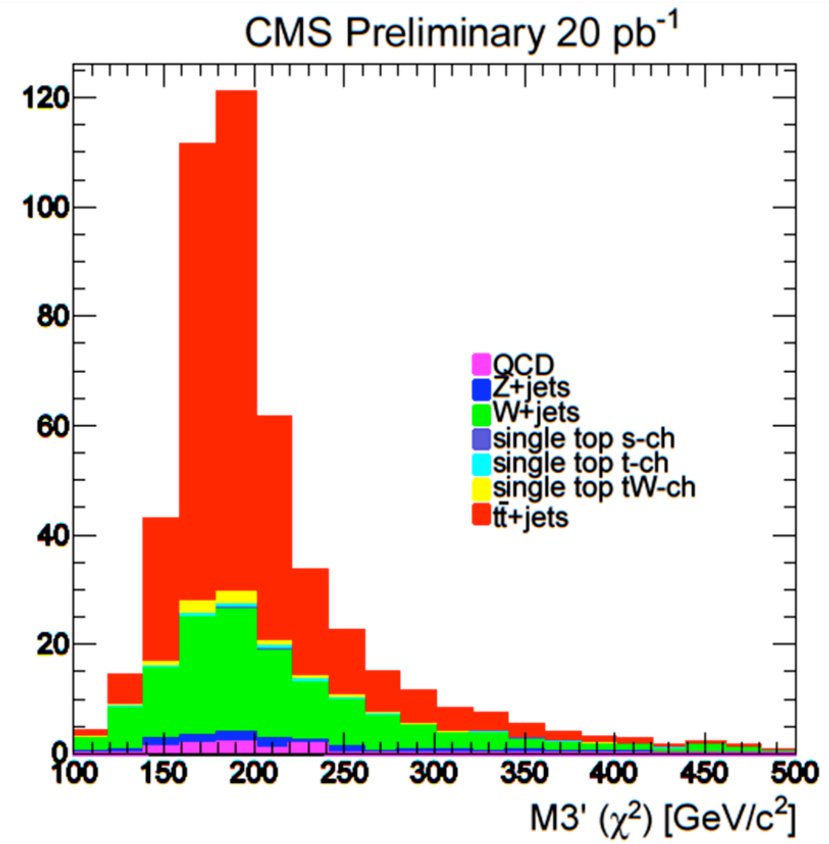




Z ➔ $\mu\ \mu$ candidate

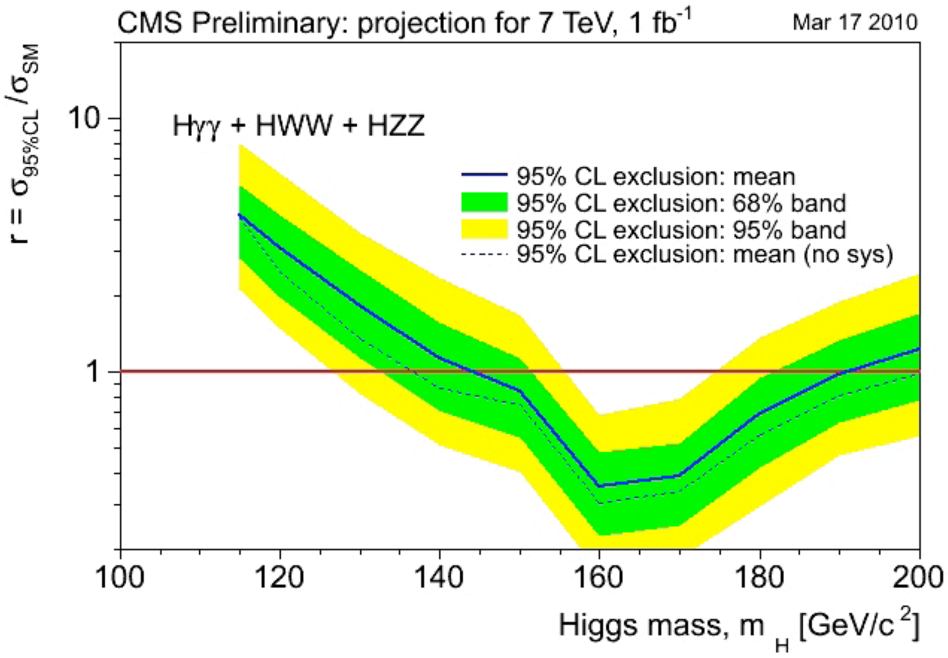
Top in the future

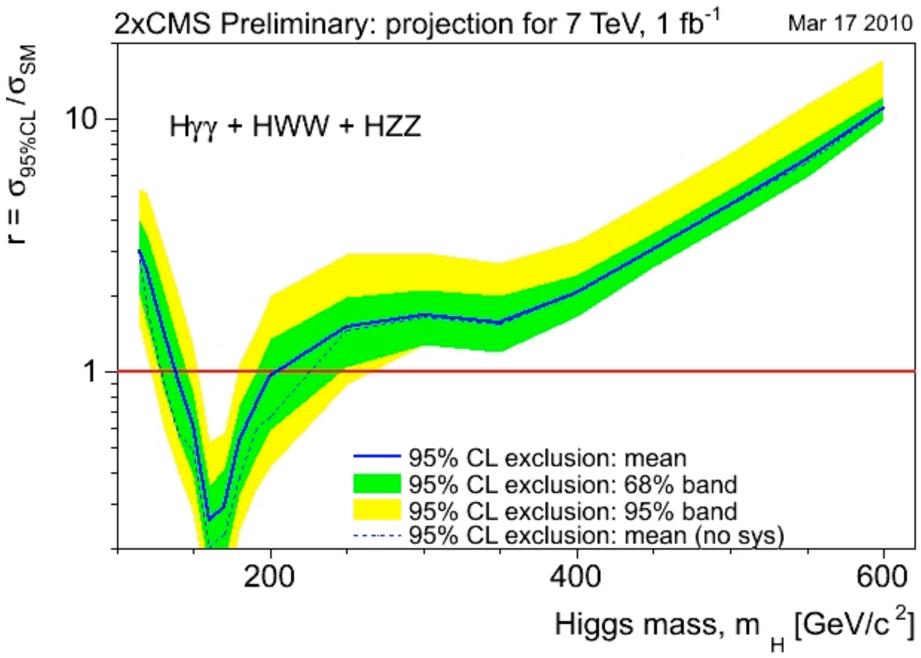




Predictions for the near future, for the M3 the invariant mass of the three jets is taken, which have the largest invariant transverse mass, for the M3' a χ^2 method is used to fit the event topology more precisely in the jets selection

SM Higgs Boson

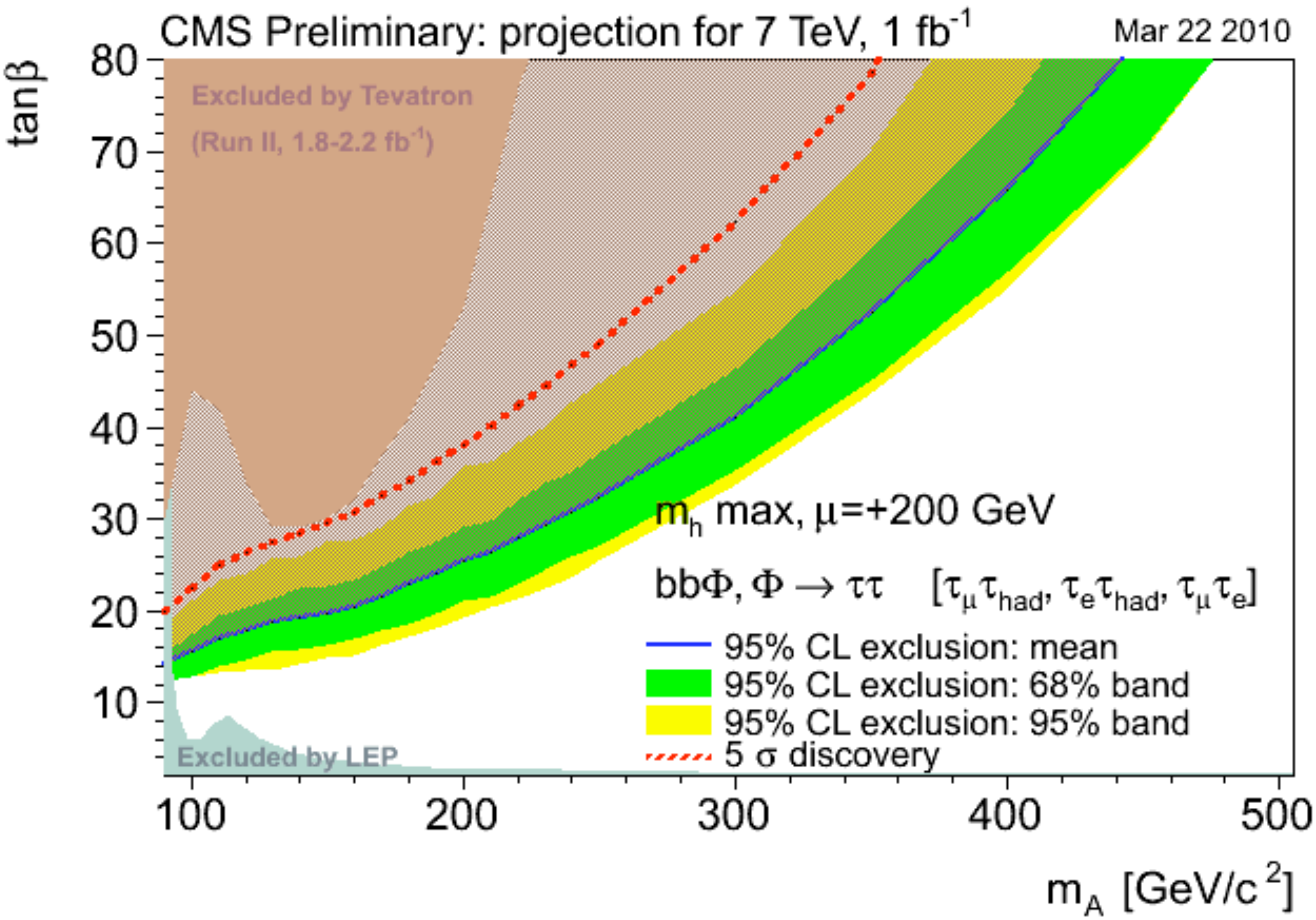




Exclusion regions that CMS can reach alone. The expected exclusion mass range is $145<m_H<190$ GeV

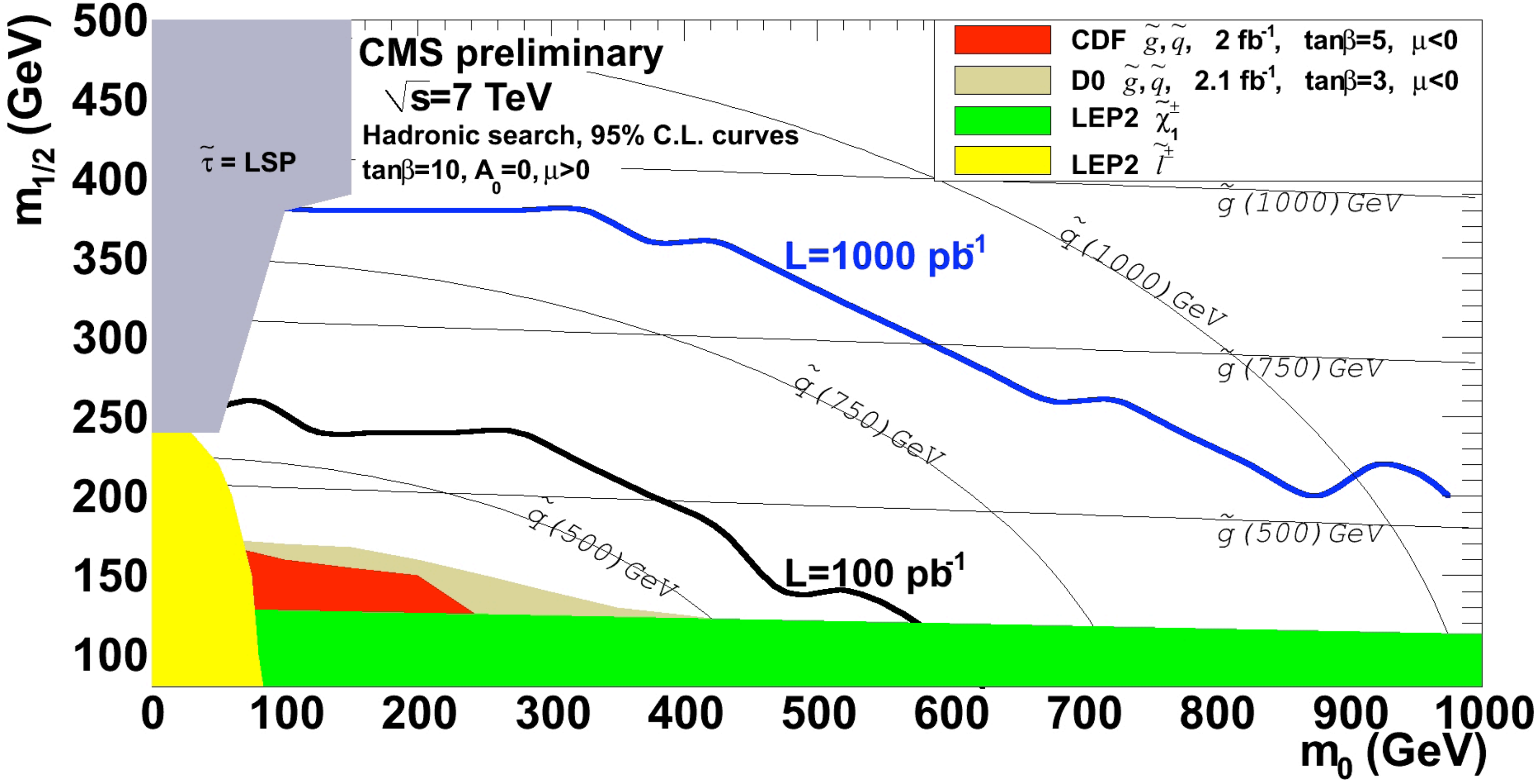
This plot is intended to *indicate* what ATLAS + CMS combined sensitivity might be at $1fb^{-1}$. The expected exclusion mass range for the SM Higgs is $140<m_H<200$ GeV

MSSM Higgs Boson

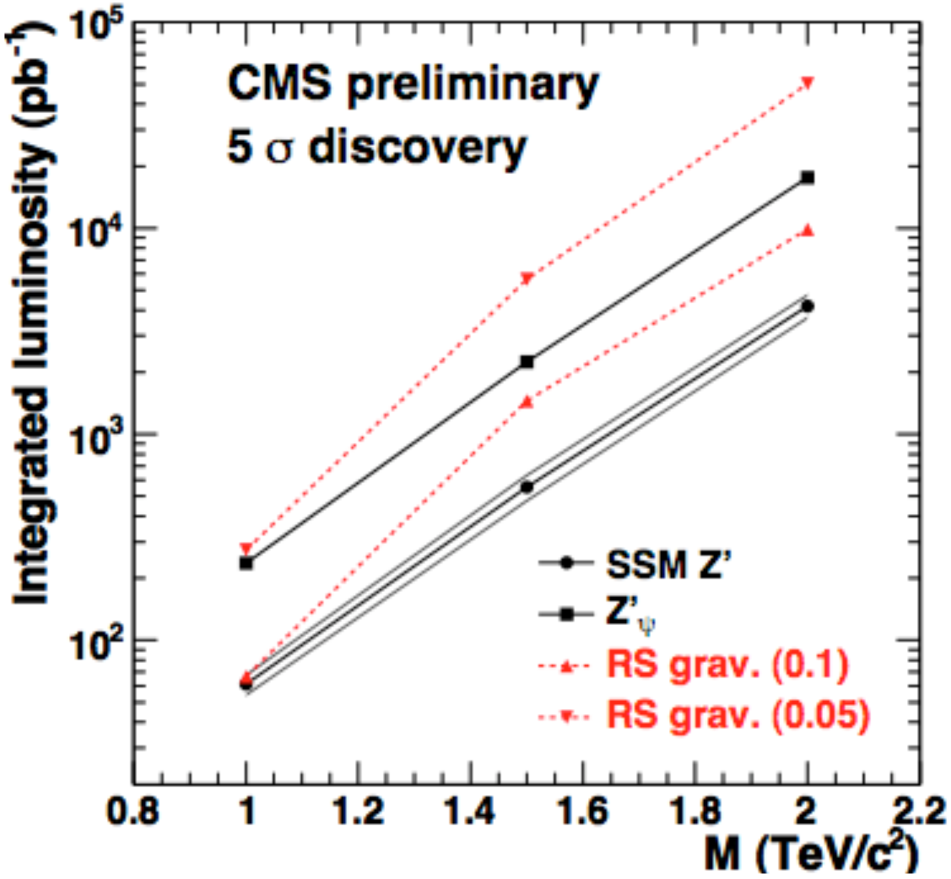


Supersymmetry

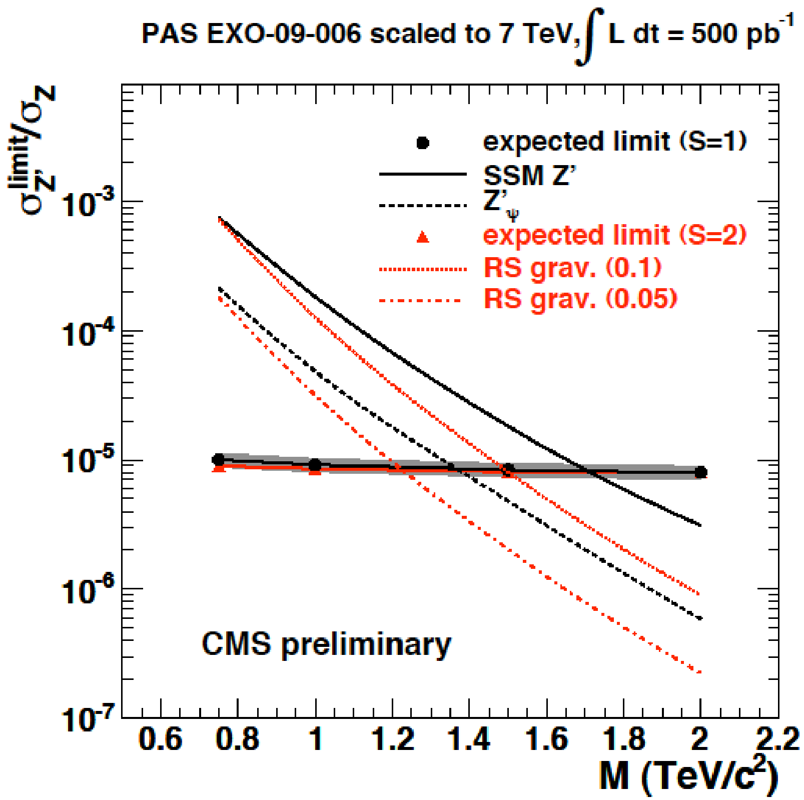
e.g. all-hadronic searches



TeV Resonances



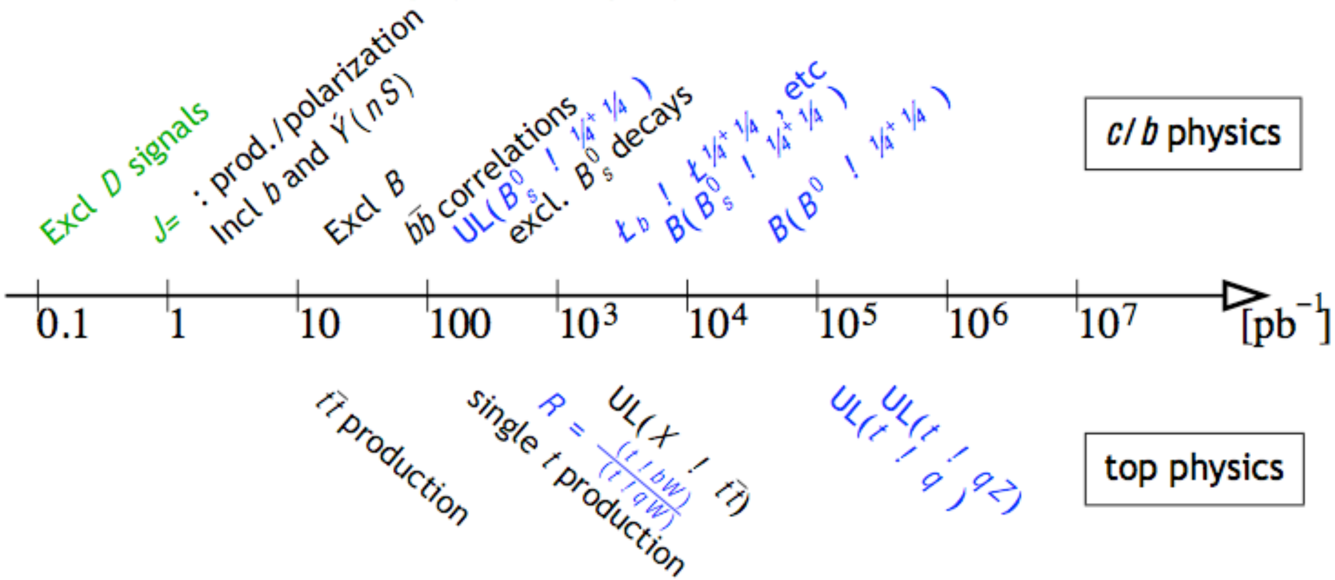
e.g. di-lepton channels



Background dominated by Drell-Yan

Continuous Evolving Program

- Reminder:
  - 2010: roughly $100\,\mathrm{pb}^{-1}$ of *delivered* integrated luminosity at $\sqrt{s} = 7\,\mathrm{TeV}$
  - 2011: roughly $1\,\mathrm{fb}^{-1}$ at $\sqrt{s} = 7\,\mathrm{TeV}$
  - $10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$: roughly $30\,\mathrm{fb}^{-1}$ per year (at $\sqrt{s} = 14\,\mathrm{TeV}$)



with many intermediate and/or improved results

Urs Langenegger | Flavor physics with CMS: Status and Perspectives (2010/05/25) | 3

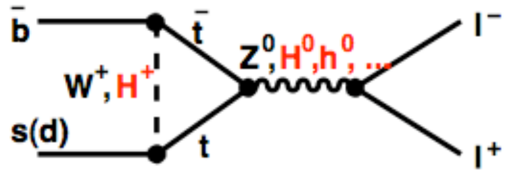
Bs --> mu+mu-

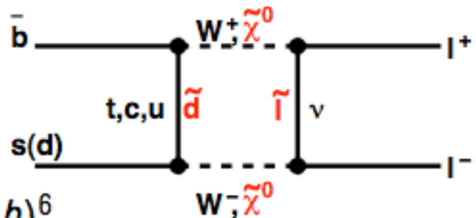
B_s^0 ! ¼+ ¼ : Search for New Physics

- ž Decays highly suppressed in Standard Model (Artuso et al, 2008)
  - . effective FCNC, helicity suppression
  - . SM expectation:

$B(B_s^0$! ¼+ ¼)	=	(3:86 š 0:15) ð 10 ^{9}
$B(B^0$! ¼+ ¼)	=	(1:06 š 0:04) ð 10 ^{10}

  - . Cabibbo-enhancement $(jV_{ts}j > jV_{td}j)$ of B_s^0 ! ¼+ ¼ over B^0 ! ¼+ ¼ only in MFV models





- ž Sensitivity to new physics
  - . 2HDM: B / $(\tan \beta)^4$; m_{H^+}; MSSM: B / $(\tan \beta)^6$
  - ! Constraints on parameter regions
  - ! 'Measurement' of tan β (Kane, *et al.* ph/0310042)
- ž Plus: 'time-dependent' physics program
  - . very early data: ³; K muon misid rates with b ! ¼D^0(K ³+) X
  - . early data: B^+ ! J= K^+, B_s^0 ! J= normalization/control sample
  - . some more data: $B(B_s^0$! ¼+ ¼) upper limit
  - . even more data: $B(B_s^0$! ¼+ ¼) measurement

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Bs --> mu+mu-

CMS-PAS-BPH-07-001

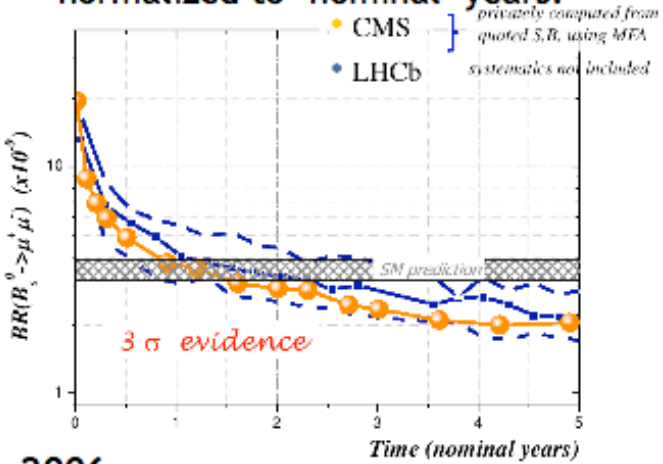
B_s^0 ! ¼+ ¼ : Expected Performance

ž With 1.0 fb 1 at $p\overline{s}$ = 14 TeV, expect to obtain at 90% C.L.

Signal yield	n_S	=	$2{:}36^{+0{:}076}_{\ \ 0{:}074}$(stat)
Signal efficiency	"$_S$	=	0:023 š 0:001 (stat)
BG rejection	"$_B$	=	(7:82 š 0:369) ð 10 ^{9}(stat)
BG: dimuons	$n_B^{¼¼}$	=	$2{:}54^{+0{:}719}_{\ \ 0{:}560}$(stat)
BG: muon+fake	$n_B^{¼h}$	=	$2{:}54^{+0{:}719}_{\ \ 0{:}560}$(stat)
$n_B^{non\ \ rare} = n_B^{¼¼} + n_B^{¼h}$		=	$5{:}07^{+1{:}44}_{\ \ 1{:}12}$(stat)
BG: rare	n_B^{rare}	=	$1{:}45^{+0{:}276}_{\ \ 0{:}276}$(total)
$n_B = n_B^{non\ \ rare} + n_B^{rare}$		=	$6{:}53^{+2{:}43}_{\ \ 2{:}43}$(total)

B(B_s^0 ! ¼+ ¼)   1:6 ð 10 ^{8}

normalized to 'nominal' years:



. Substantial improvement with respect to 2006

no pile-up, $p\overline{s}$ = 14 TeV

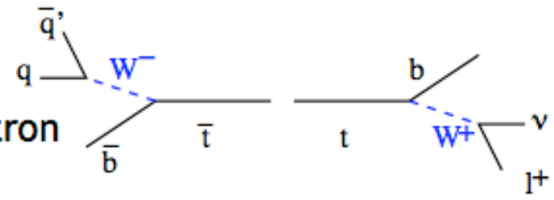
+ high-luminosity trigger, no tracker muons, cut-n-count analysis

CMS-PAS-TOP-08-002

LHC as a Top Factory

- The LHC at $\sqrt{s} = 14$ TeV is a top 'factory'

$$\sigma_{tot}(pp \to t\bar{t}) \approx 830 \text{ pb}$$

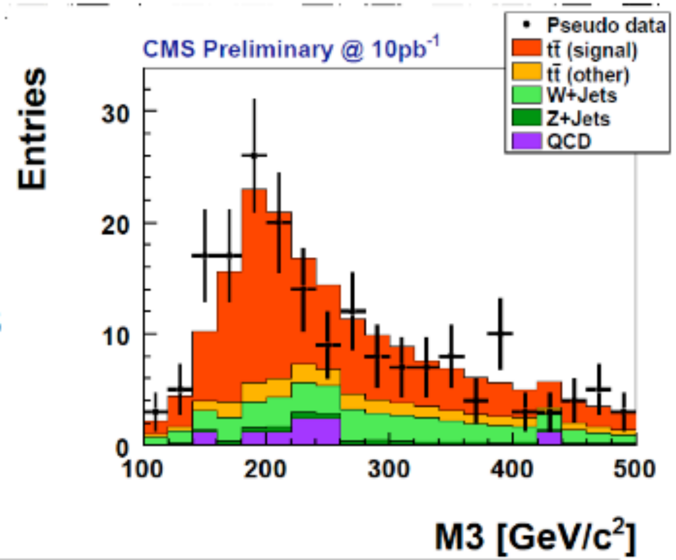


  - 100-fold increase of cross section wrt Tevatron (LHC at 10/7 TeV $\approx$ 50/20 $\times$ Tevatron)
  - 100-fold increase of (design) luminosity

(μ+ jets: 15%)

- Decays
  - 2/3: $t \to q q'$
  - 11%: $t \to \ell^+ \nu, \ell = e, \mu$
- Example analysis at $\sqrt{s} = 14$ TeV
  - isolated muon $p_\perp > 30$ GeV
  - jets with $E_T > 65, 40, 40, 40$ GeV
  - observable: hadronic top 3-jet mass

  $\to$ In 10 pb^{-1}
  128 signal events
  90 background events



$\Rightarrow$ or: 'recoil' physics . . .

CERN/LHCC 2006-021

Top Flavor Physics: Rare Decays

ž FCNC top decays are an excellent area for BSM searches

Decay	SM	two-Higgs	SUSY with R	Exotic Quarks	Exper. Limits(95% CL)
$t \to gq$	5×10^{-11}	$\sim 10^{-5}$	$\sim 10^{-3}$	$\sim 5 \times 10^{-4}$	< 0.29 (CDF+TH)
$t \to \gamma q$	5×10^{-13}	$\sim 10^{-7}$	$\sim 10^{-5}$	$\sim 10^{-5}$	< 0.0059 (HERA)
$t \to Zq$	$\sim 10^{-13}$	$\sim 10^{-6}$	$\sim 10^{-4}$	$\sim 10^{-2}$	< 0.14 (LEP-2)

ž Event selection

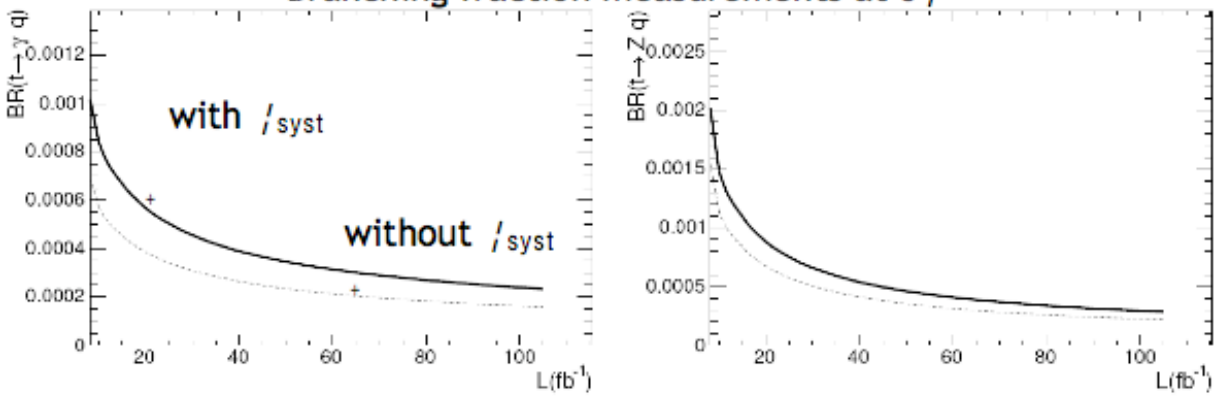
. 1 isolated high-$p_?$ lepton ($p_? > 20$ GeV) + 1 high-E_T photon ($E_T > 50$ GeV)

. exactly 1 b jet ($E_T > 40$ GeV) + 1 non-b jet ($E_T > 50$ GeV)

. $150 < m_q < 200$ GeV, $\cos(t_q; t_{SM}) < 0.95$

! efficiency " ³ 2%

Branching fraction measurements at 5 /



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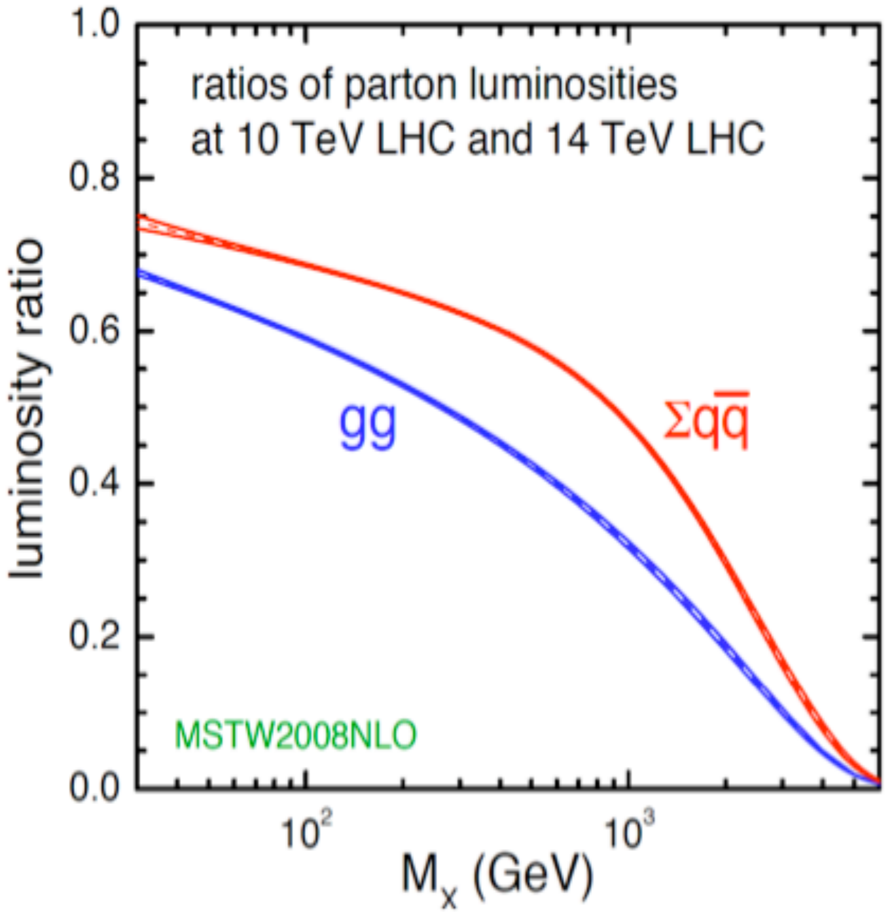
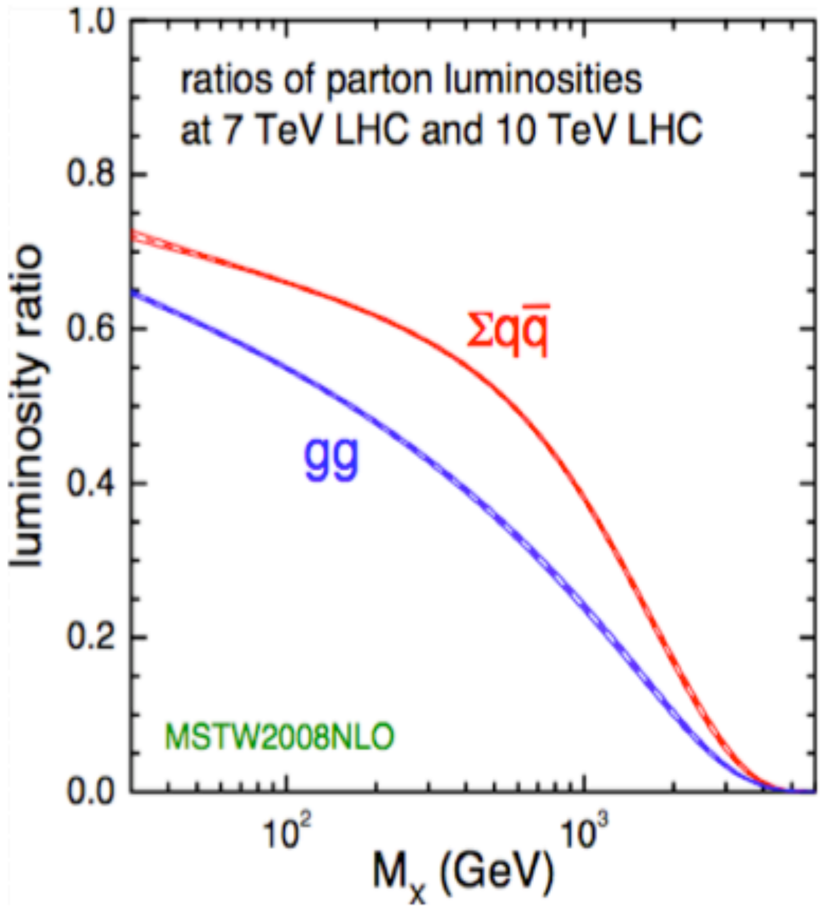
Conclusions: promises, promises …

- The full CMS Detector was operational for the first LHC beams in 2008
- CMS could profit from extensive Cosmic Data taking campaigns in 2008 and 2009 for commissioning
- Data taking with LHC Pilot runs in December 2009 was a great success, with performances validated to expectations within hours, and extensive analyses performed within O(day)'s !
- The experiment currently runs in a "minimum bias" mode with LHC collisions at $\sqrt{s}$ = 7 TeV … and first EWK Boson candidates observed !
- With O(1 to 10) pb-1 expected by ICHEP 2010, a first major production of physics results (EWK, top sector, QCD, …) are expected
- Di-boson observation and first significant constraints (or hints) on the SM Higgs boson are expected in 2010-2011
- The experiment has a some discovery reach beyond the SM already in 2010-2011 (e.g. scalar sector at high tan β, sparticles, TeV Resonances)
- The full analysis chain is in place and able to produce physics output as designed

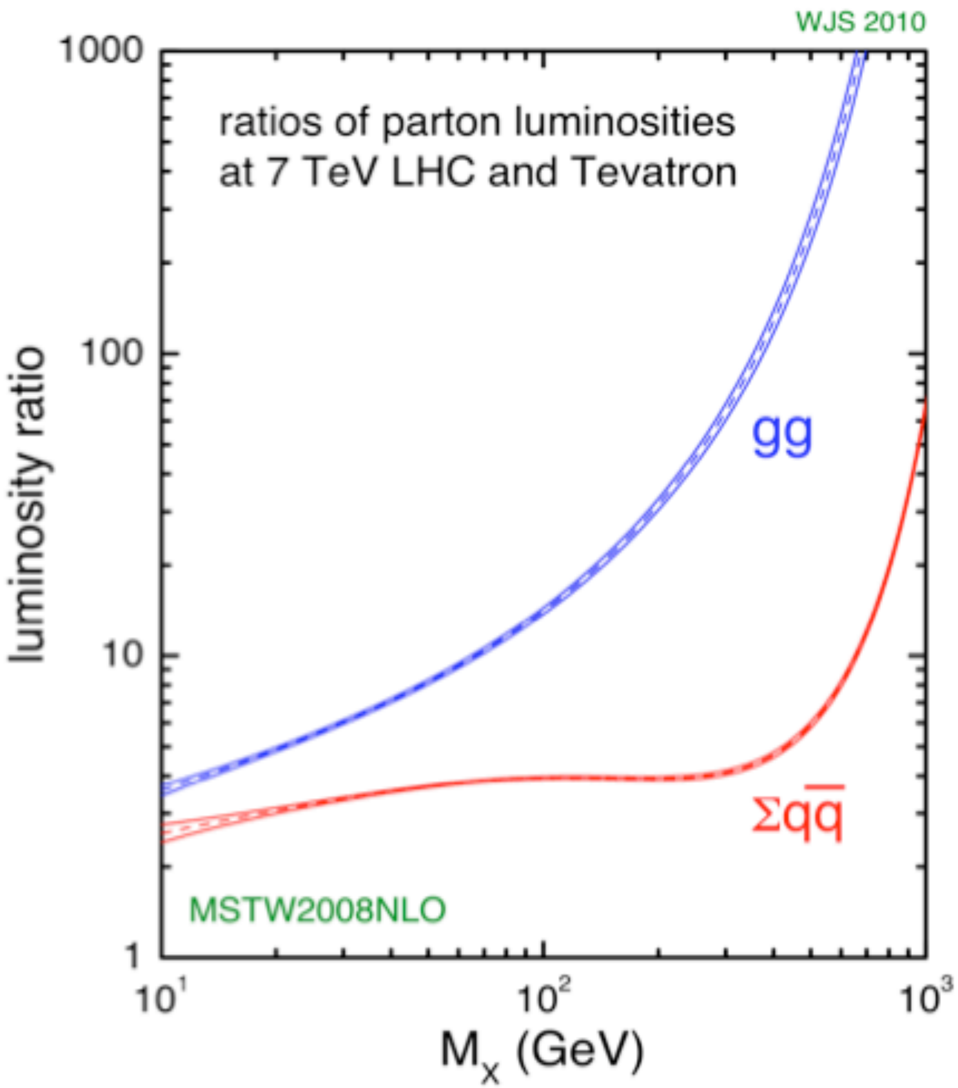
BACK-UP

Parton Luminosities

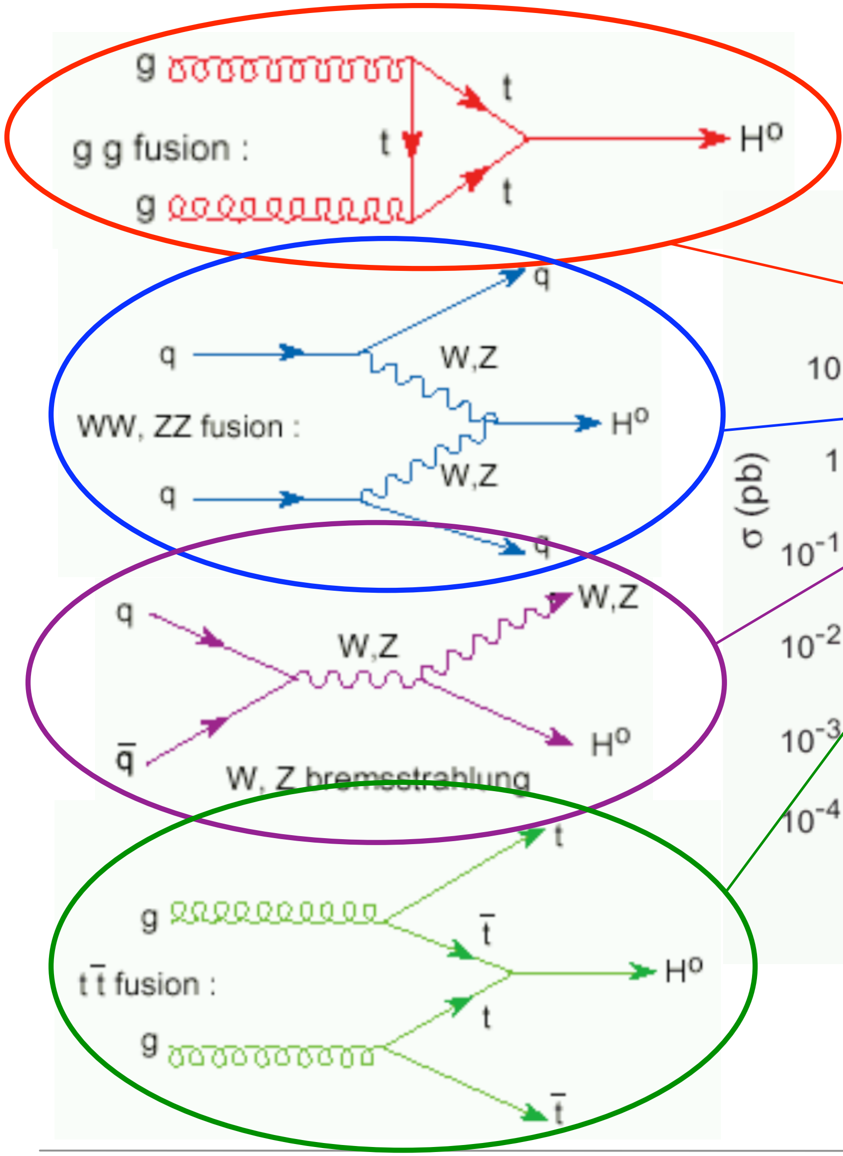




Parton Luminosities

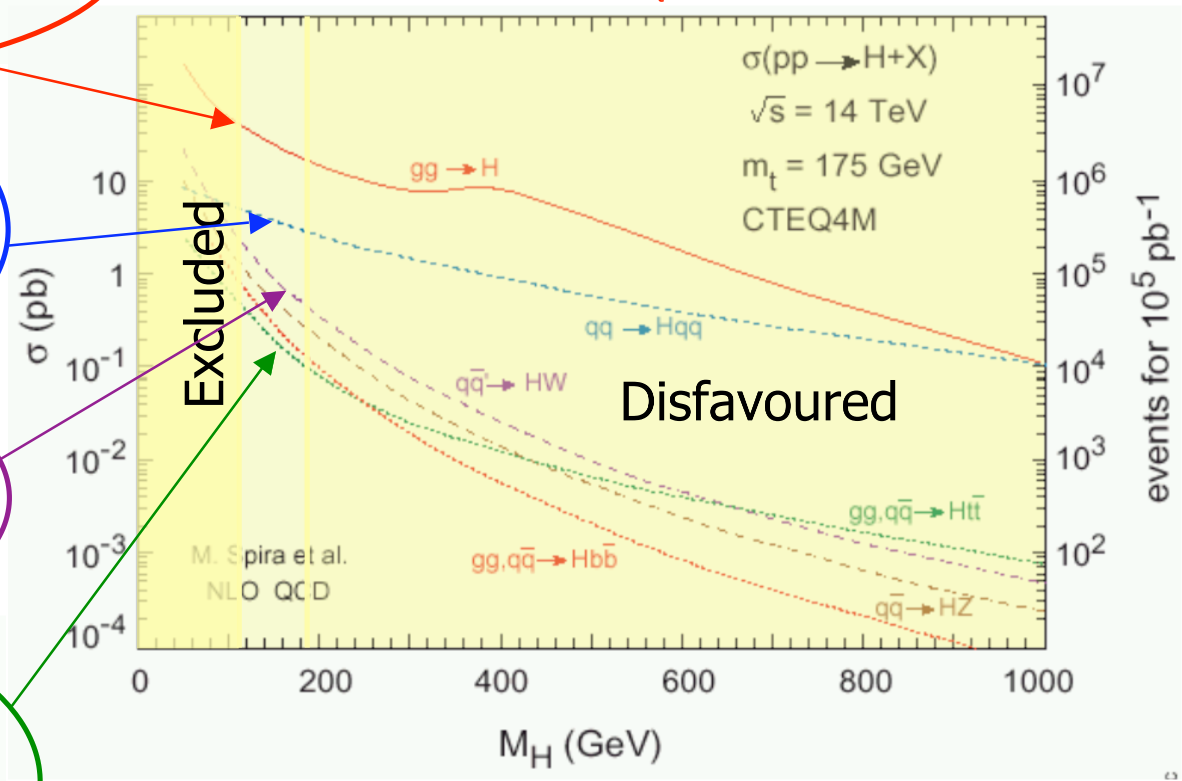


Production Modes and Cross-sections



H⁰ Production

CTEQ6M, M_t=175 GeV used for PTDR



BSM Physics can change these in a major way !!! (e.g. bbH in MSSM)

Observability

A. Djouadi, hep-ph/0503172

M_H < 140-150 GeV

H → bb

Dominant mode … but crippling QCD background … exploitable in ttH or VH associated modes ?

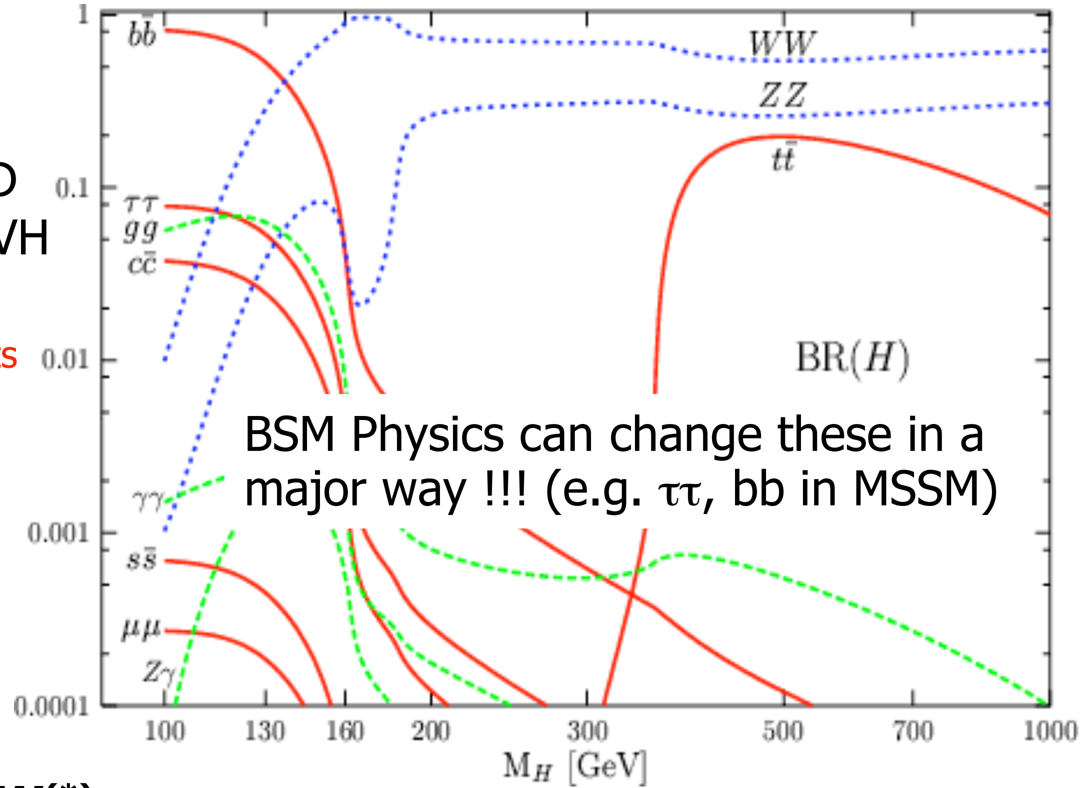
e.g. G. Salam et al. boosted H, "fat" jets

H → $\tau^+\tau^-$

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 γ/Jet (γ ID, γ Iso., $M_{\gamma\gamma}$) separation



BSM Physics can change these in a major way !!! (e.g. ττ, bb in MSSM)

M_H > 125-130 GeV

H → WW(*)

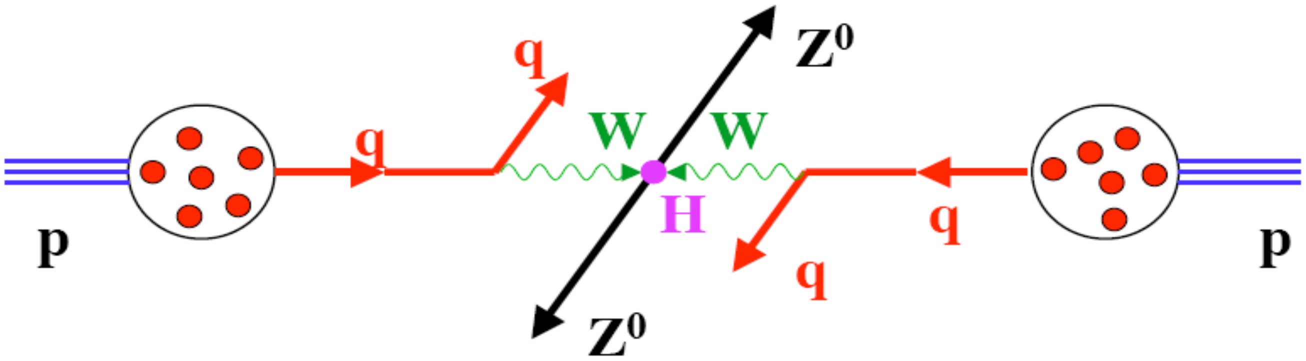
Dominant mode, $l^+\nu l^-\nu$ channel optimal for $M_H = 2\,M_W$; lνqq' channel exploitable at large MH or through VBF

H → ZZ(*)

Small *BR* but "golden mode" for a discovery $l^+l^-\,l^+\,l^-$

The Large Hadron Collider

- A broad band exploratory machine
- May need to study W_L-W_L scattering at c.m. energy of ~ 1 TeV



Need $E_W \sim 500$ GeV ⇒ q ~ 1 TeV ⇒ $\sqrt{s_{pp}} \sim 14$ TeV

- May need to study a Higgs boson physics at a $M_H \sim 0.8$ TeV

Event rate = $\mathcal{L}\,\sigma$ Br

e.g. H ~ 0.8 TeV; H → ZZ → 4l

Events/year ≥ 10 ⇒ $(10/10^7) \times 1/(10^{-37}\ 10^{-3})$ = L ~ $10^{34} cm^{-2} s^{-1}$

Physics & The LHC Detectors

The essential physics motivations back in 1989:

Electroweak Symmetry Breaking

e.g. SM Higgs ⇔ High Luminosity*, √s ~14 TeV

γ's or isolated leptons

* pile-up ! … more than 20 min. bias events superimposed

Hierarchy of Fundamental Interactions

e.g. SUSY to stabilize the Higgs mass vs GUT/Planck scales

⇔ multijets and missing P_T

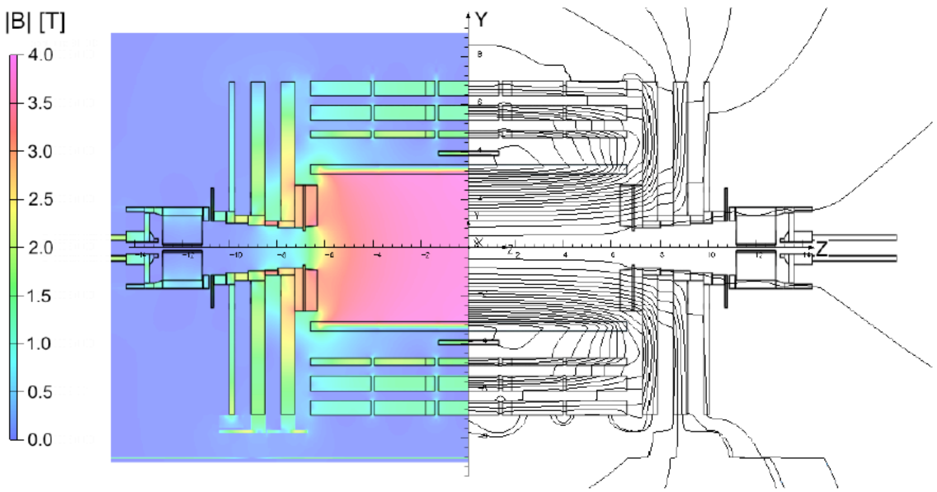
Unification and Extended Symmetries

e.g. Z'-like resonances at the TeV

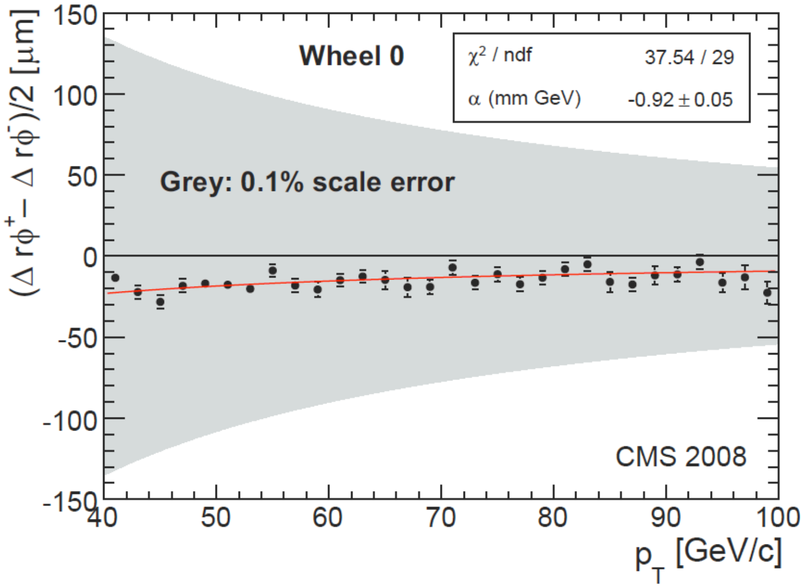
⇔ measurements at very high momentum

Solenoid Field MAP

2010 JINST 5 T03021



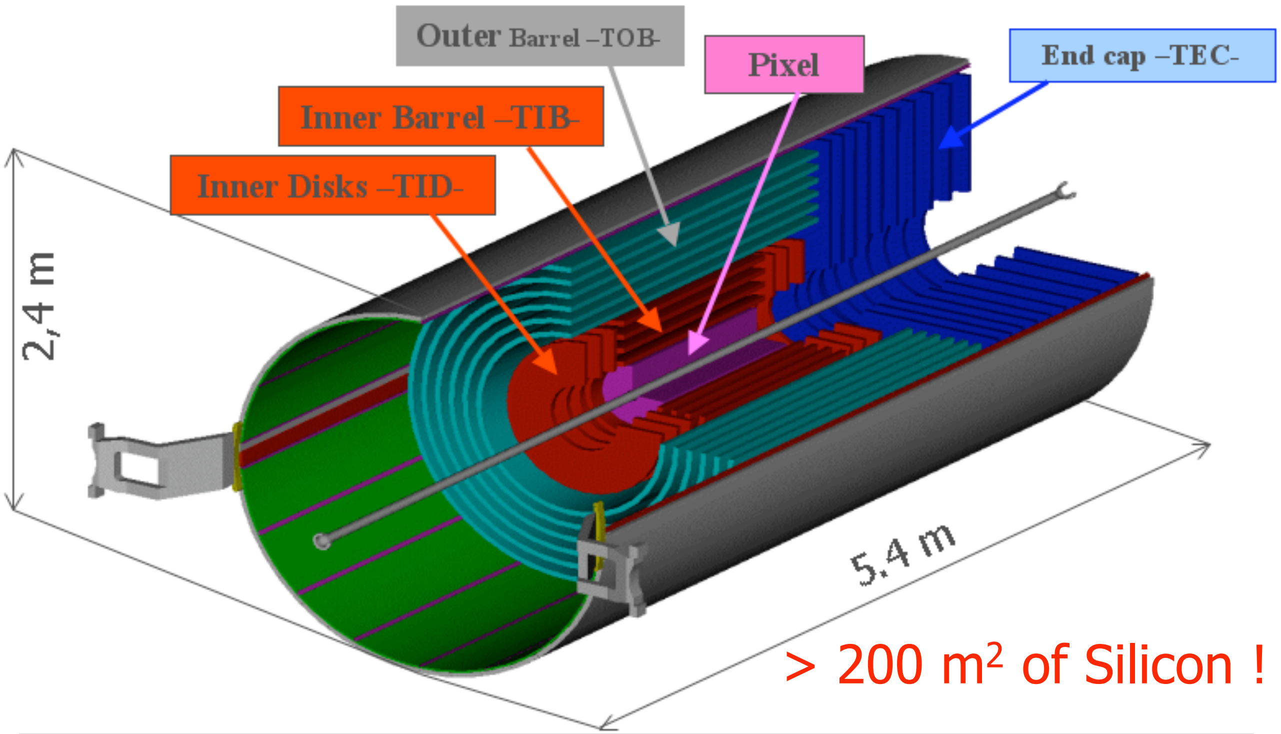
Precision modelling and measurement of the **B** field ⇔ Implemented in MC model



Extrapolation of track from inner tracker to first layer of barrel muon chamber ⇔ verity that **B** field inside solenoid known to < 1‰

The CMS Si Tracker

Pixel detector and a Silicon microstrip tracker:



> 200 m^2 of Silicon !

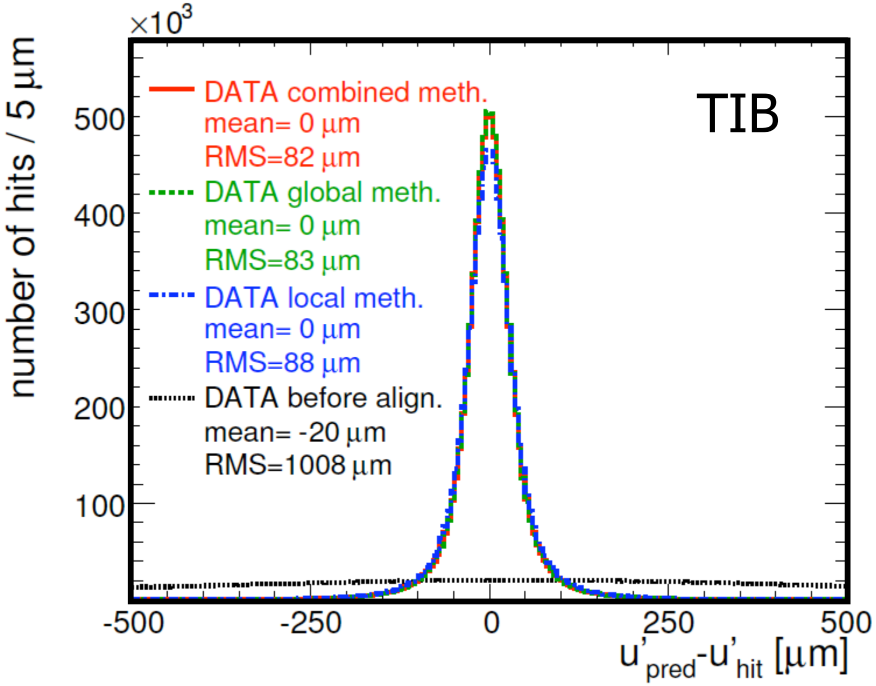
SILICON μ-STRIP
- Track measurement with best possible $\Delta P/P$ and high efficiency from P ~ GeV/c to TeV/c
- Fine granularity (low occupency) for track isolation

PIXEL DETECTOR
- Provides seeds for the particle tracks
  e.g. Kalman Filter reco.
- Responsible for good vertexing
  e.g. Impact parameter or DCA to interaction VTX
- Help determine Z coordinates of events
  suppresses pile-up; σ_{VTX} ~ 5 cm
- Event topology info. for High Level Trigger

Volume ≈ 24 m^3 T° ≈ –10 ^{0}C
Dry atmosphere … for years !

Si Tracker: Alignement

2010 JINST 5 T03009



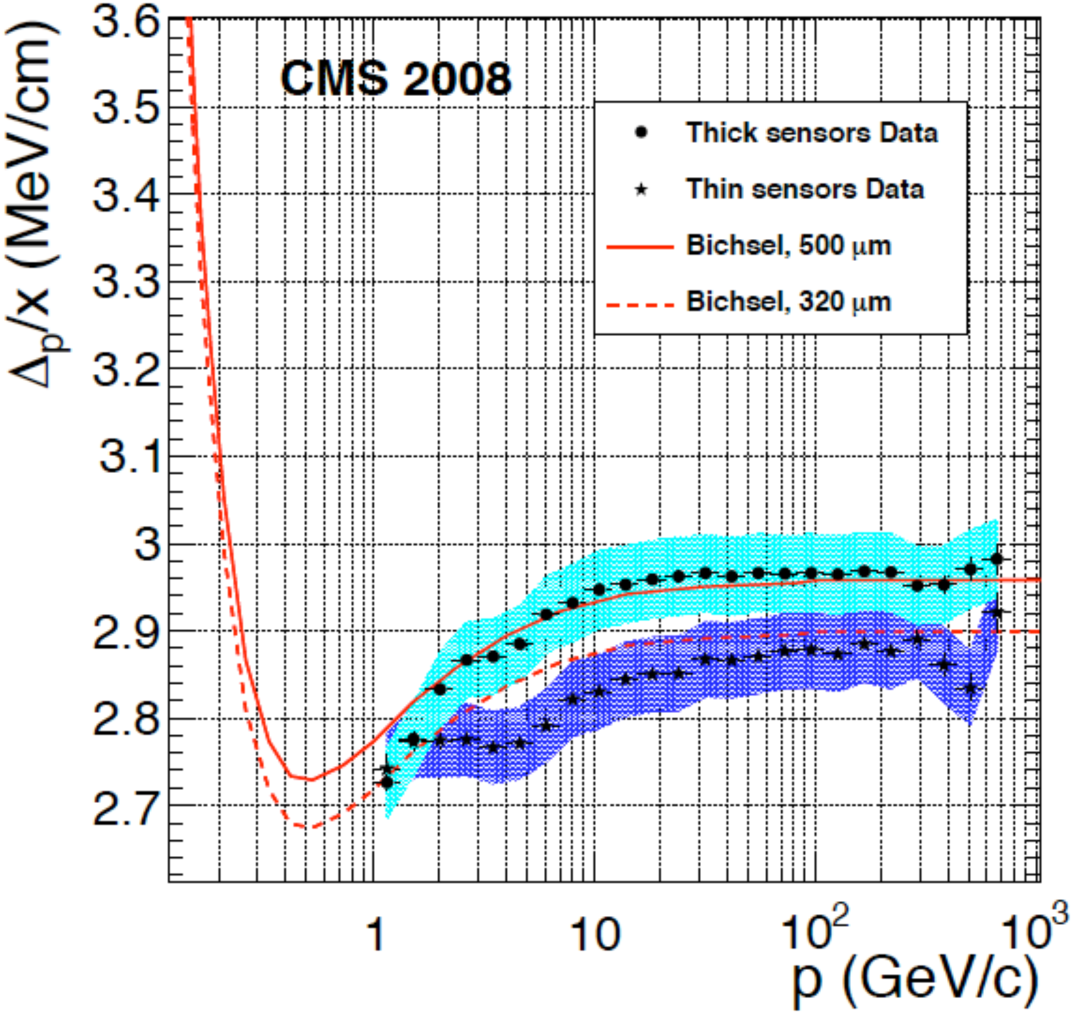
DMR RMS (µm)	CRAFT 2008	2009 prelim.	MC alignment	Ideal alignment	Modules >30 Hits
BPIX (x)	2.6	2.5	2.1	2.1	757/768
BPIX (y)	4.0	4.0	2.5	2.4	757/768
FPIX (x)	13.1	13	12.0	9.4	391/672
FPIX (y)	13.9	13	11.6	9.3	391/672
TIB (x)	2.5	3	1.2	1.1	2623/2724
TOB (x)	2.6	3	1.4	1.1	5129/5208
TID (x)	3.3	4	2.4	1.6	807/816
TEC (x)	7.4	8	4.6	2.5	6318/6400

Use RMS of distribution of mean of residuals as a “measure” of alignment quality (insensitive to multiple scattering)

Alignement measured in CRAFT08 and confirmed in CRAFT09(insensitive to multiple scattering)

Si Tracker: Calibration

2010 JINST 5 T03008



<u>Relative Calibration:</u>
most probable value of signal adjusted to expected MIP

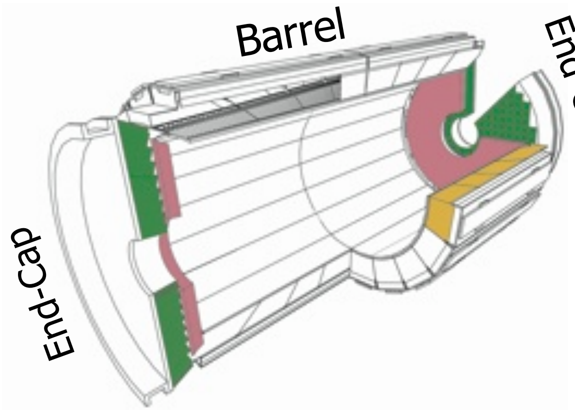
<u>Absolute calibration:</u>
extracted from ionization curve adjusted to *Landau-Vavilov-Bischel* function:
262 ± 3   e-/ADC count

Agrees with calibration pulse:
269 ± 13 e-/ADC count obtained with charge injection circuitry

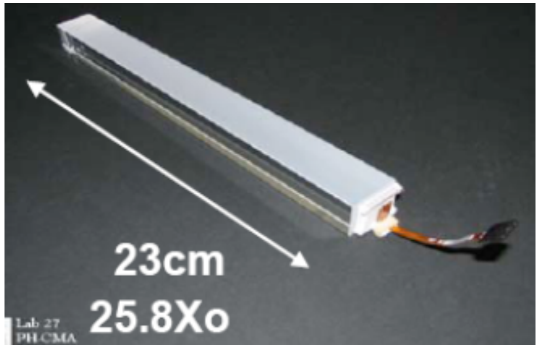
S/N (peak mode)

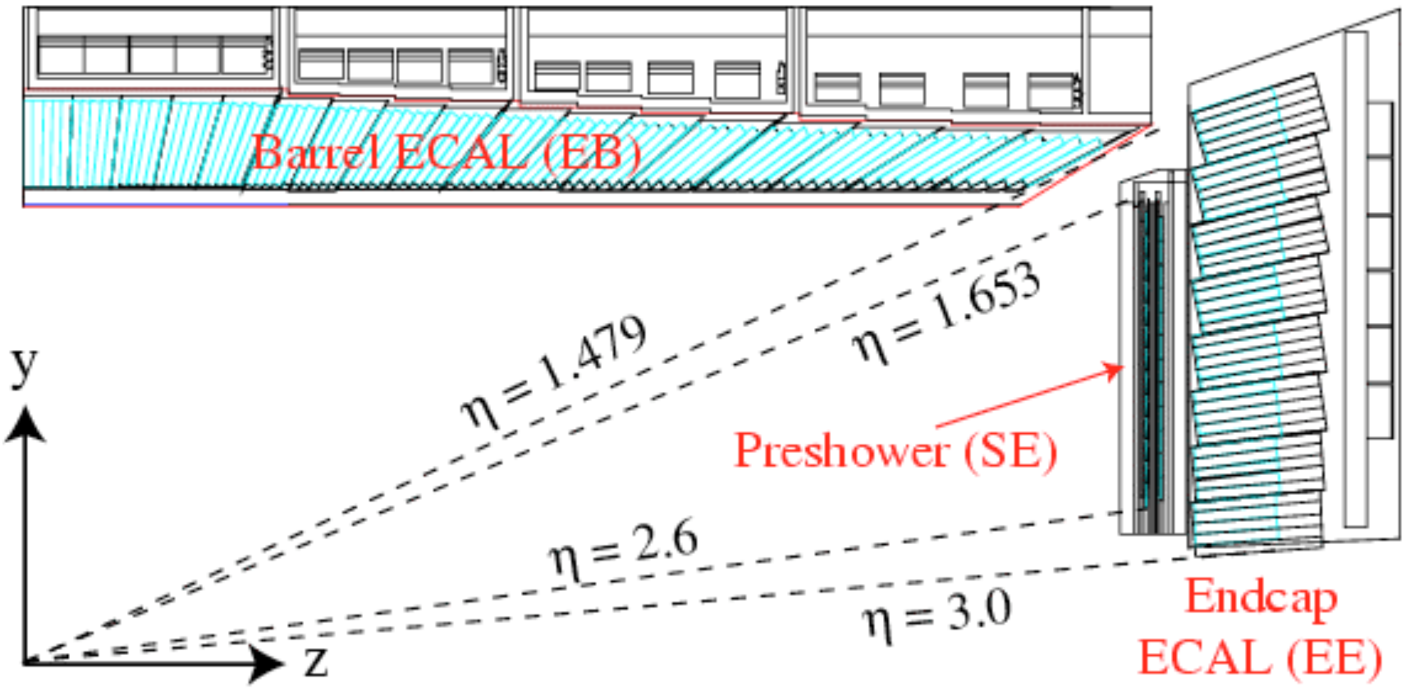
TIB	TID	TOB	TEC thin	TEC thick
25	28	32	27	32

The CMS ECAL



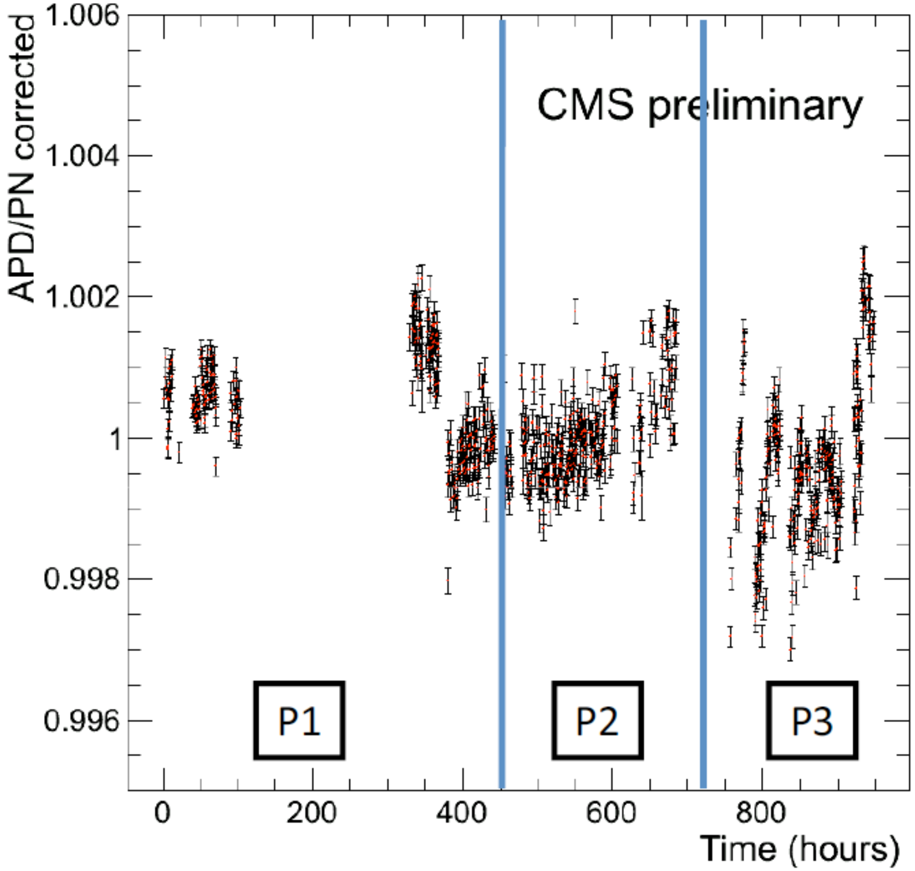
PbWO4 crystals
X_0 = 0.89 cm
R_M = 2.10 cm

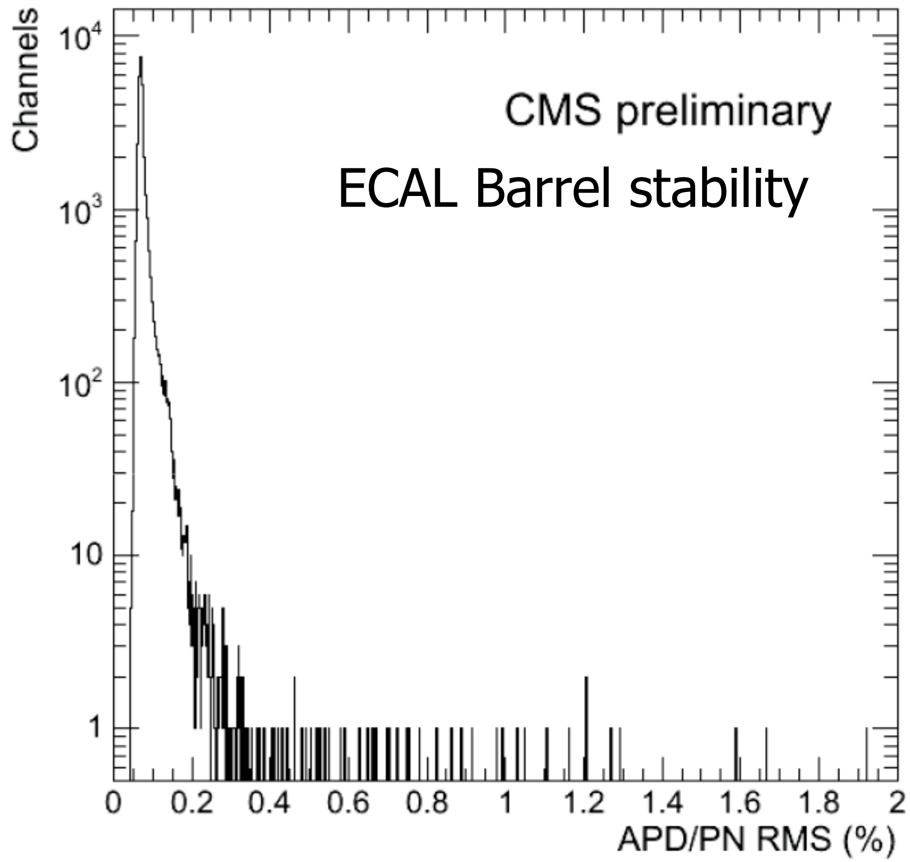




CRAFT

ECAL: Monitoring Response





Response of typical channel

APD response normalized to PN diode which monitors laser light

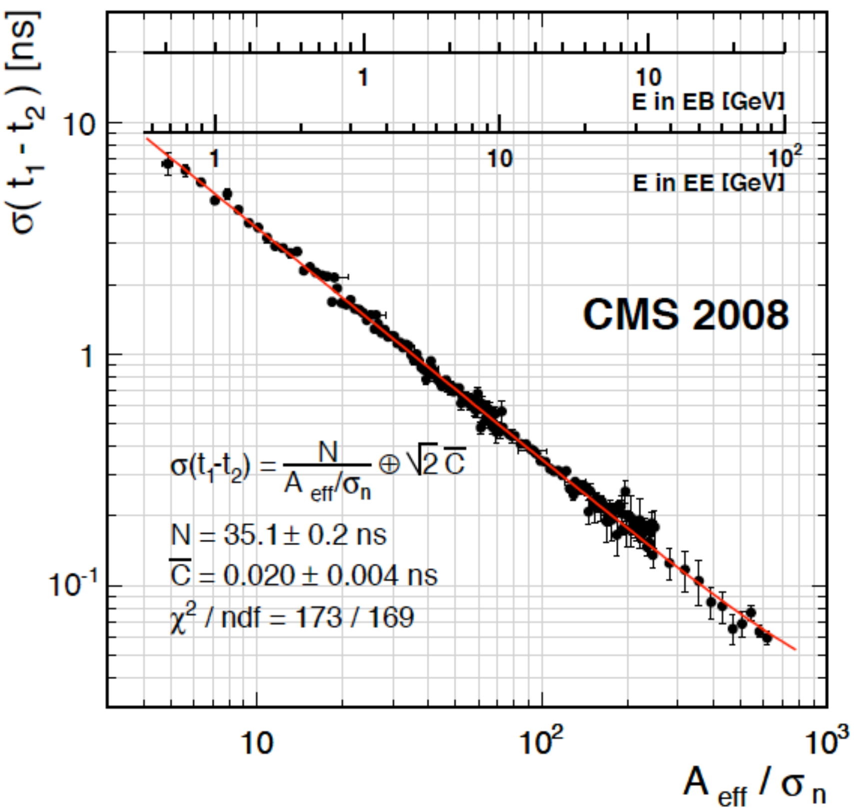
RMS of normalized response in P2

Spec. < 1 ‰ achieved

T. Camporesi
LHCC 23-09-2009

ECAL: Timing Performance

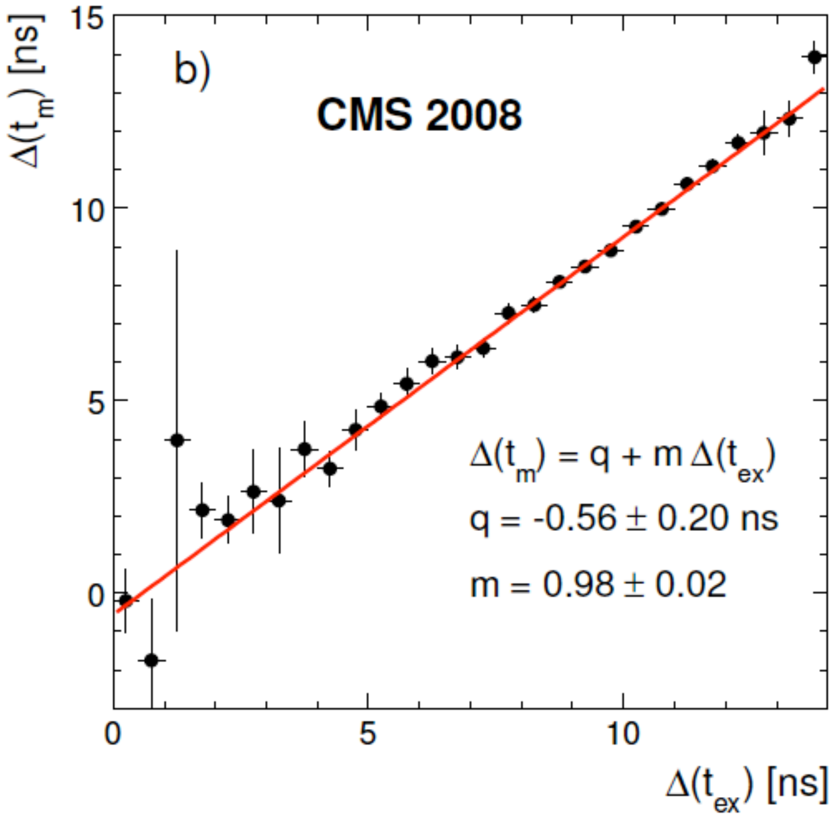
2010 JINST 5 T03011



Time resolution vs Amplitude

$$\sigma^2(t) = \left(\frac{N\sigma_n}{A}\right)^2 + \left(\frac{S}{\sqrt{A}}\right)^2 + C^2$$

$$A_{\mathrm{eff}} = A_1 A_2 / \sqrt{A_1^2 + A_2^2}$$



Time difference $\Delta(t_m)$ between up and down clusters vs expectation from time-of-flight

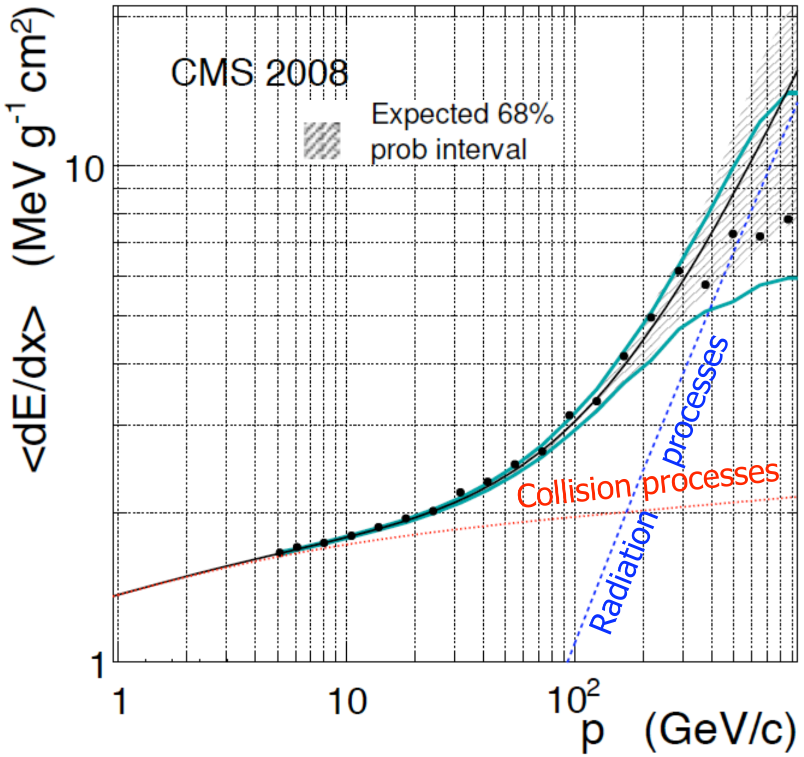
ECAL: μ Stopping Power

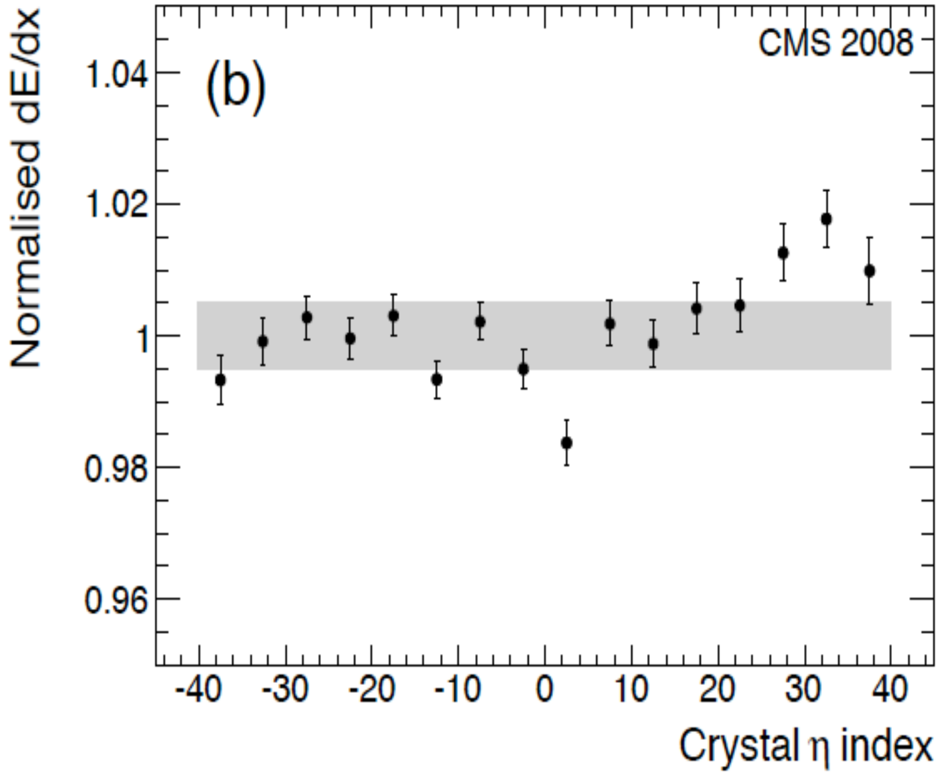
2010 JINST 5 T03010 2010 JINST 5 P03007

Reminder:

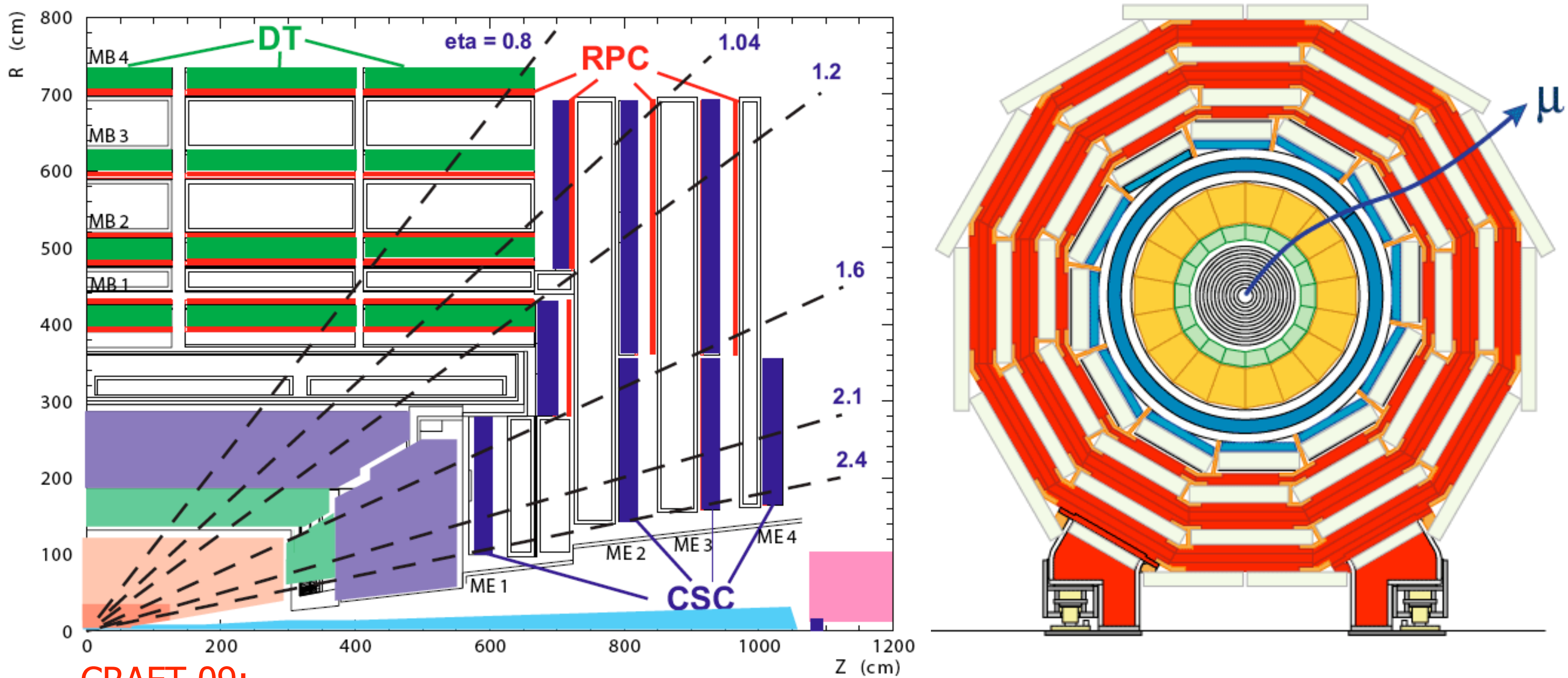
- 4 SM (1700 channels each) have been calibrated with electrons
- Transferred to all 36 barrel SM by means of cosmic ray inter-calibration

⇔Typical single channel uncertainty of 1.5%





The CMS Muon Detector



CRAFT 09:

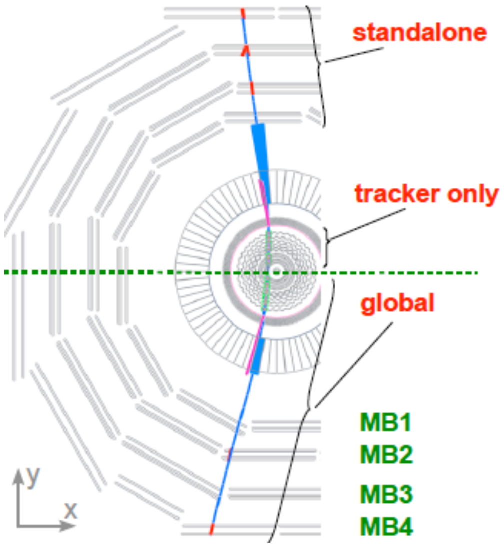
- 98.4% Drift Tubes (DT) cell efficiencies
- Barrel and Forward Resistive Plate Chambers (RPCs) fully functional
- 99% operational efficiency for CSC (MWPC with Cathode Strip Readout)

Hits precision with 50-220 μm resolution

CRAFT

Muon: Momentum Resolution

2010 JINST 5 T03022

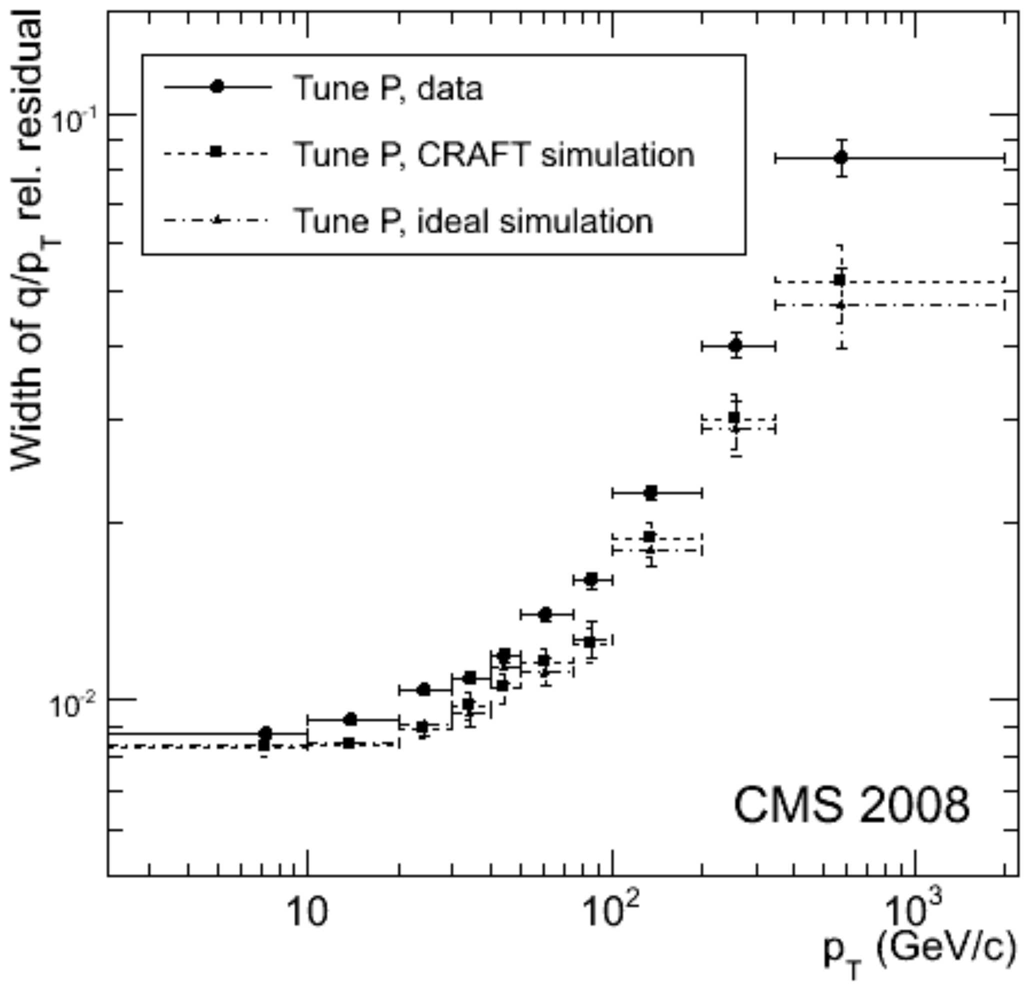


$$R(q/p_T) = \frac{(q/p_T)^{\text{upper}} - (q/p_T)^{\text{lower}}}{\sqrt{2}(q/p_T)^{\text{lower}}}$$

Resolution Performance:

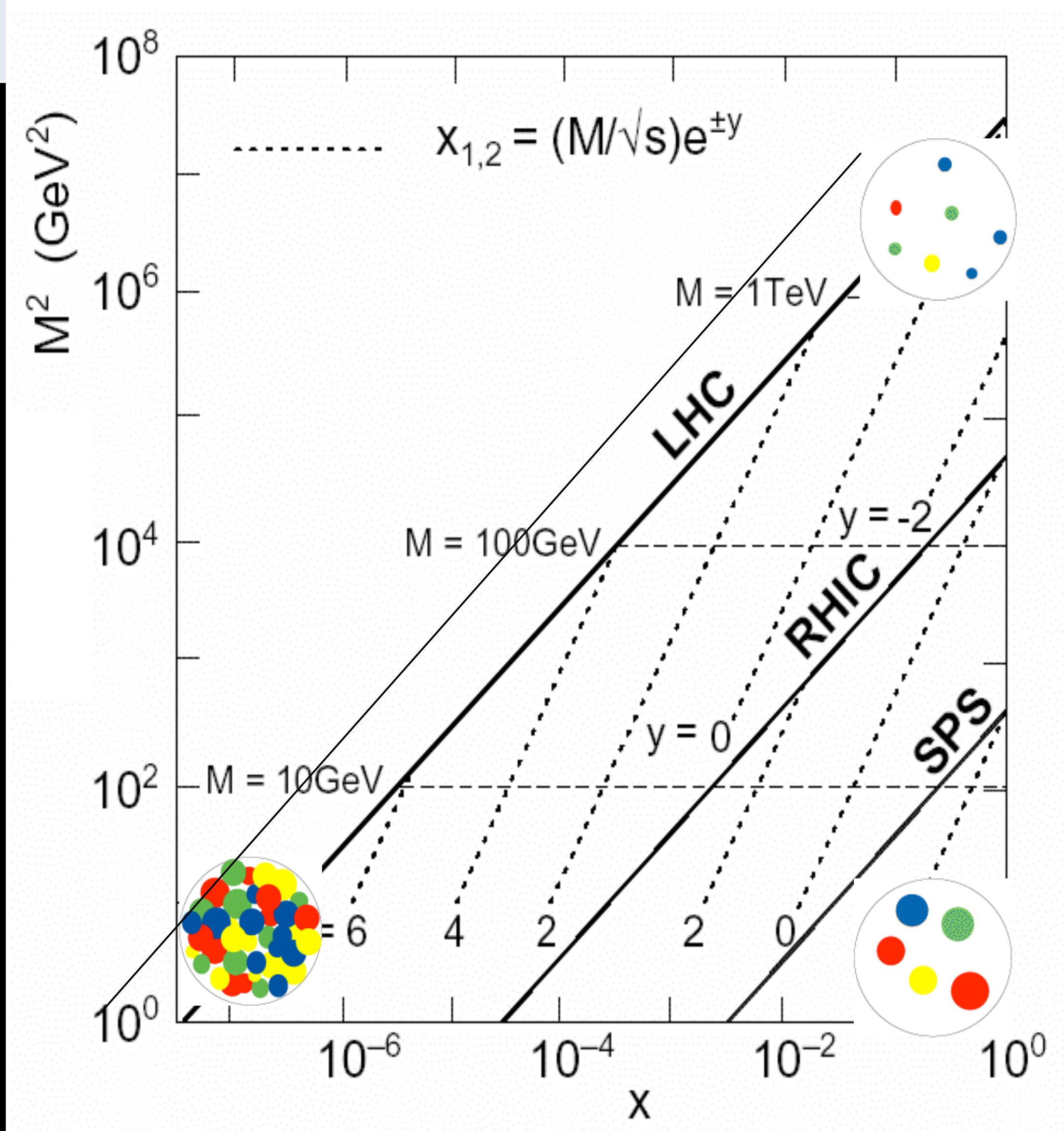
<1% @ <10 GeV/c

8% @ 500 GeV/c



NOT COVERED

High Rate, Trigger



Rapidity Range