Przegląd wyników eksperymentu CMS z ostatniego roku

(ze szczególnym naciskiem na wyniki z konferencji ICHEP2010)

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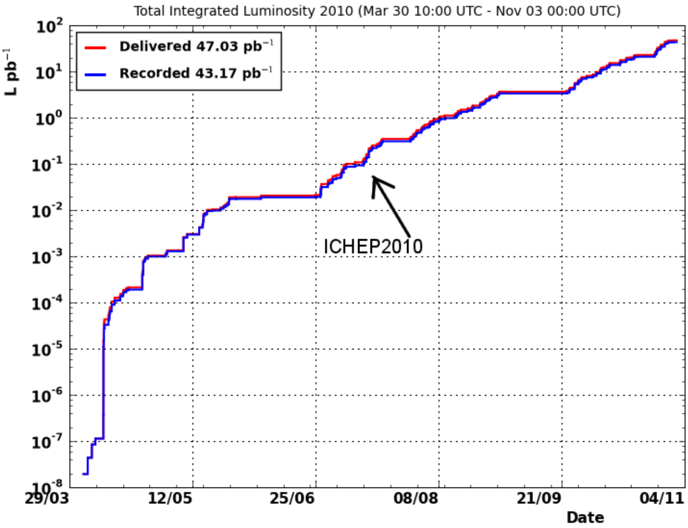
The Andrzej Soltan Institute for Nuclear Studies

17 grudnia 2010


Total Integrated Luminosity 2010 (Mar 30 10:00 UTC - Nov 03 00:00 UTC)
Delivered 47.03 pb^{-1}
Recorded 43.17 pb^{-1}
L pb^{-1}
10^{2}
10^{1}
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
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ICHEP2010
29/03
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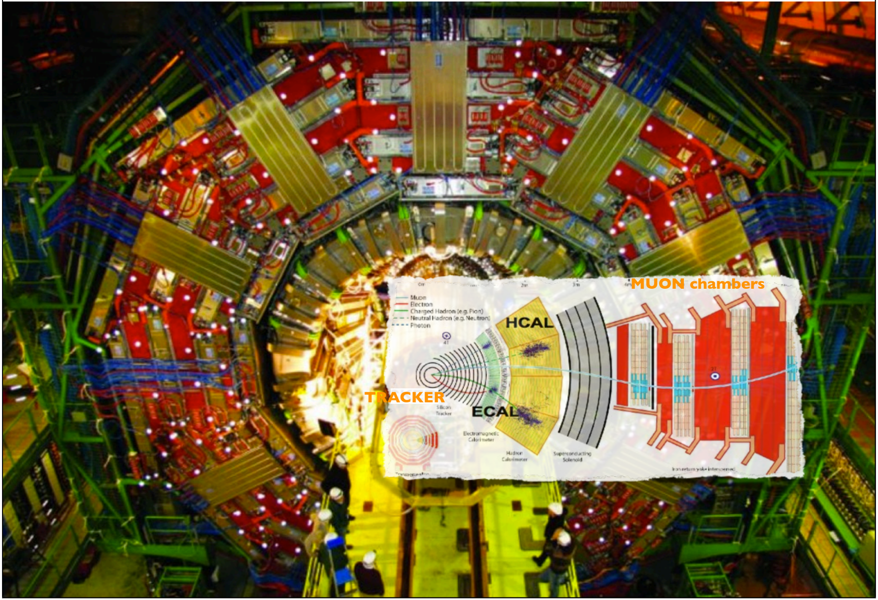
Date

the CMS detector

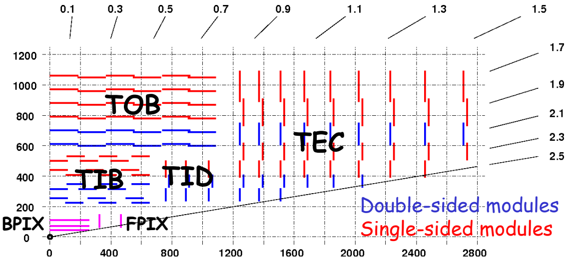


Outline

1. Detektor śladowy
2. Rekonstrukcja śladów i wierzchołków, oznaczanie b
3. Kalorymetry
4. Fotony i elektrony
5. Miony
6. Algorytm rekonstrukcji ”Particle Flow”
7. Fizyka kwarku top
8. Zamiast podsumowania

The largest silicon tracking detector ever built!

- must provide low occupancy for LHC high luminosity
- high-precision tracking for heavy flavour identification
- coverage up to $|\eta| < 2.5$



Strips

- 9.3M channels
- ~ 200 m^2 sensor area
- 10 barrel layers
- 9 (+3) endcap disks

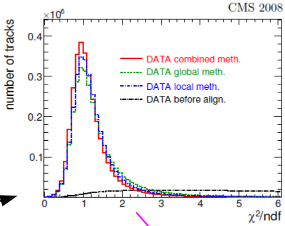
Pixels

- 66M channels
- ~ 1.1 m^2 sensor area
- 3 barrel layers
- 2 endcap disks
- innermost layer at r = 4.3 cm

Operational fractions
strips: 98.1%
pixels: 98.3%

Track-based alignment algorithms

- global method "Millipede II"
  - real module positions from residual minimization
  - matrix size reduction without loss of correlations or precision -> O(10^5) global parameters
  - only a few iterations necessary
- local method "Hit and Impact Point (HIP)"
  - local solution for each module, so no correlations
  - large number of iterations for large misalignment
- final results from running both in sequence
- first alignment campaign with cosmics
  - tracks mostly vertical, best results in barrel
  - results already close to ideal geometry
- alignment update with collisions
  - using high-quality tracks from minimum bias collisions
  - further improvement, most pronounced in forward region



input to MC

Subdetector	Data 7TeV [μm]	MC startup [μm]	MC no misal. [μm]
Pixel Barrel u	1.6	3.1	0.9
Pixel Barrel v	5.5	8.9	1.8
Pixel Forward u	5.7	10.7	2.5
Pixel Forward v	7.3	14.4	6.1
TIB	5.1	10.1	3.2
TOB	7.5	11.1	7.5
TID	4	10.4	2.4
TEC	10.1	22.1	2.9

RMS of median of residuals

Alignment outlook

- inclusion of beam halo, isolated muons, laser alignment data
- use mass constraints from resonances

See poster by Jula Draeger
The Alignment of the CMS Silicon Tracker

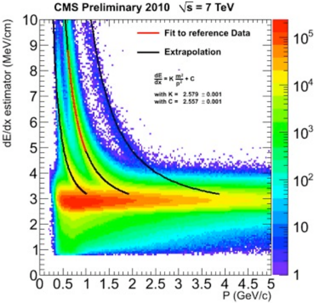
Search for Heavy Stable Charged Particles

- Attempt to identify the HSCP as it moves through the detector
  - Looking for an excess of tracks with **high p_t, high dE/dx**
- HSCP will be highly penetrating and identified as a muon
  - R-hadrons undergo nuclear interactions, and may change charge/flavour
  - Some models of R-hadron interactions **predict they become neutral and remain so**

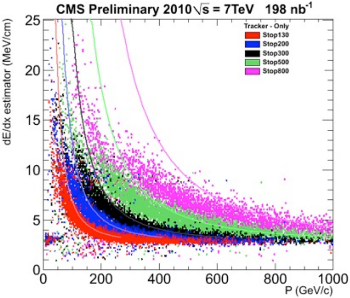
referred to later as "Neutral R-baryon" model

- Perform two analyses
  - Track+muon - for muon-like HSCP
  - Track-only - for non muon-like HSCP
- Benchmark signals
  - Track+muon => mGMSB stau (100-300 GeV)
  - Track only => stop & gluino R-hadron (130-900 GeV), with "Cloud model" of R-hadron interactions
- Triggers
  - For muon-like HSCP, use muon triggers (muon > 3 GeV, double muon > 0 GeV)
  - For non muon-like HSCP, trigger on other products of the event (jet > 50 GeV, E_t^{miss} > 45 GeV)

Mass Reconstruction

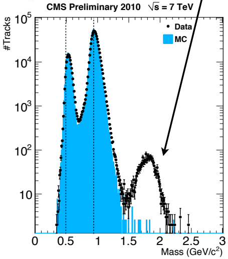


min-bias data



...and stop MC

Discovery of the deuteron!



- Mass reconstruction
  - Approximate Bethe-Bloch formula before minimum

$$I_h = K\frac{m^2}{p^2} + C$$

  - Extract parameters K, C by fitting to the proton line
  - Reverse to compute higher masses

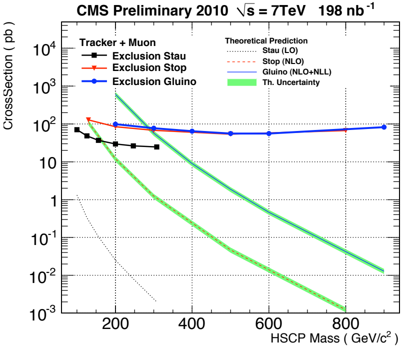
Jim Brooke (Univ. of Bristol) - ICHEP 2010, Paris 5

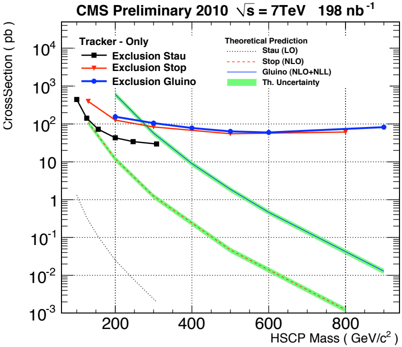
Search Results

- Null result in signal region and full mass spectrum

TIGHT	Exp.	Obs.	Exp. in full spectrum	Obs. in full spectrum
Muon-like	0.153 ± 0.061	0	0.249 ± 0.050	0
Tk-only	0.060 ± 0.021	0	0.060 ± 0.011	0

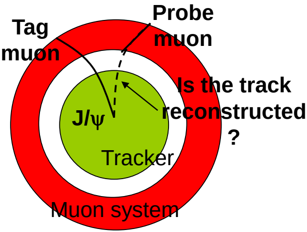
- 95% CL limits on the production cross-section for stau, stop and gluino
  - Track-only analysis => **exclude $m_{\tilde{g}}$ < 271 GeV/c^2**
  - Track+muon analysis => **exclude $m_{\tilde{g}}$ < 284 GeV/c^2**

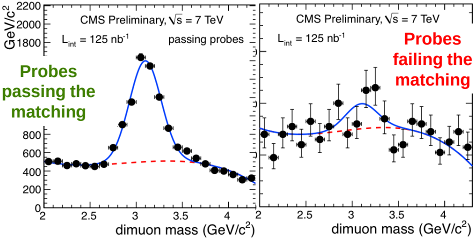




Outline

Tracking Efficiency for muons (from J/ψ)





Reconstruction efficiency in the Tracker is estimated from the ratio of the yields of probes that either pass or fail the matching with a Tracker track.

$$\epsilon_T \epsilon_M = \frac{\epsilon - \epsilon_F}{1 - \epsilon_F}$$

Tracking efficiency (ϵ_T); random matching (ϵ_F)

Region	Data Eff. (%)	Sim Eff. (%)	Data/Sim
$0.0 \leq \lvert\eta\rvert < 1.1$	$100.0^{+0.0}_{-0.3}$	$100.0^{+0.0}_{-0.1}$	$1.000^{+0.001}_{-0.003}$
$1.1 \leq \lvert\eta\rvert < 1.6$	$99.2^{+0.8}_{-1.0}$	$99.8^{+0.1}_{-0.1}$	$0.994^{+0.009}_{-0.010}$
$1.6 \leq \lvert\eta\rvert < 2.1$	$97.6^{+0.9}_{-1.0}$	$99.3^{+0.1}_{-0.1}$	$0.983^{+0.009}_{-0.010}$
$2.1 \leq \lvert\eta\rvert < 2.4$	$98.5^{+1.5}_{-1.6}$	$97.6^{+0.2}_{-0.2}$	$1.010^{+0.015}_{-0.016}$
Combined	$98.8^{+0.5}_{-0.5}$	$99.2^{+0.1}_{-0.1}$	$0.996^{+0.005}_{-0.005}$

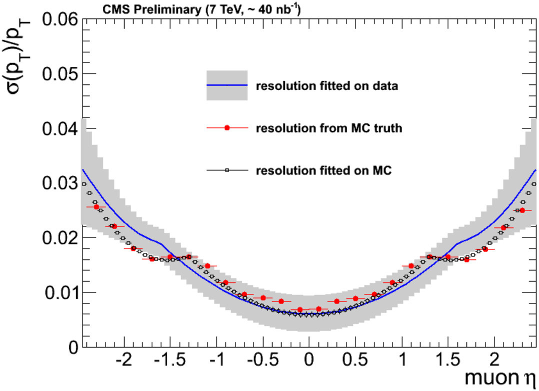
Measured tracking efficiency close to 99% and compatible with simulation

Estimate of Transverse Momentum resolution from J/ψ width

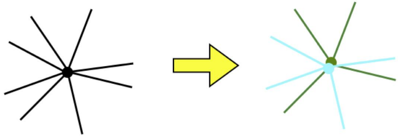
A set of functions describes the expected dependence of the p_T resolution on track kinematics.

J/Ψ width expressed as a function of the kinematics of the 2 tracks.

The best estimate of the p_T resolution is then determined through an unbinned likelihood fit of data.

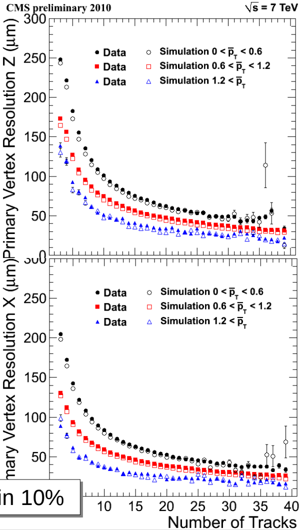


Primary Vertex: Position Resolution



Single vertex reconstructed using “all” the tracks

Same collision point reconstructed **twice** using **half of the tracks**



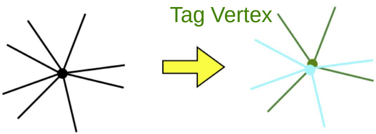
The position of one vertex is compared to the position of the other.

Repeating for many events, the intrinsic resolution of the primary vertex fitter is estimated directly from data.

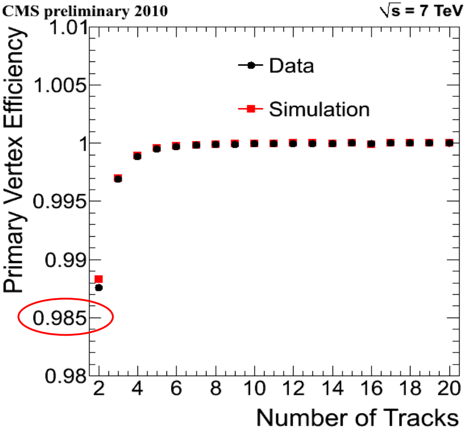
Not shown: Pull distributions have widths equal to 1 within 10%

Primary Vertex (II) Reconstruction Efficiency

Same technique also used to estimate, from DATA, the PV reconstruction ***efficiency***.



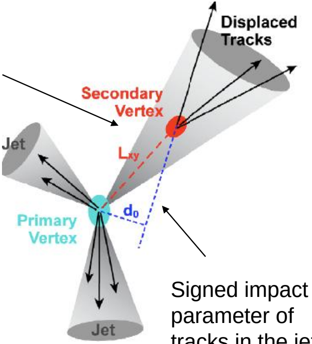
Is there a probe vertex ?



PV efficiency = #probes / #tags

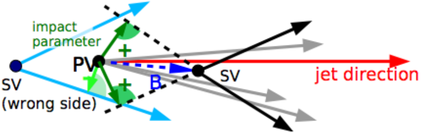
Main Observables used by B-tagging algorithms

Signed decay length of secondary vertexes

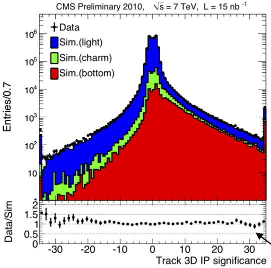


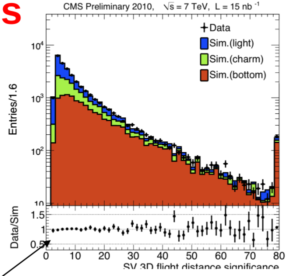
Signed impact parameter of tracks in the jet

Signs of Impact parameter and of vertex decay length are defined according to jet direction

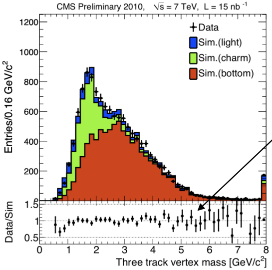


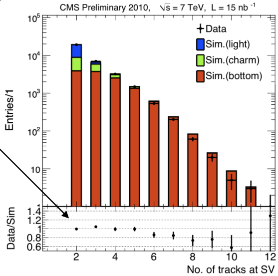
Data/MC comparison for B-Tagging observables





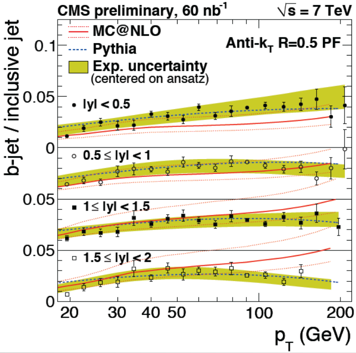
DATA/MC ratio is close to 1 for all observables (including those not shown)

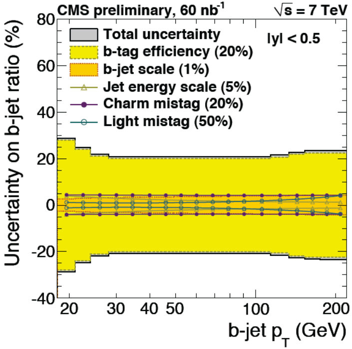




Ratio to Inclusive Jet Cross Section

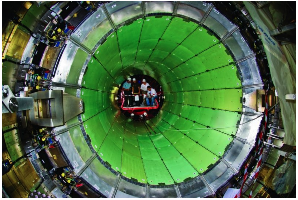
- Inclusive jet cross section measurement → Talk by M. Voutilainen [CMS PAS QCD-10-011]
- Measurement of ratio reduces experimental uncertainty from jet energy reconstruction and luminosity
- Fit of measured ratio of data and PYTHIA for 30 < p_T < 150 GeV and |y| < 2 yields scale factor of $0.99 \pm 0.02(\text{stat}) \pm 0.21(\text{syst})$





Outline

The CMS calorimeters

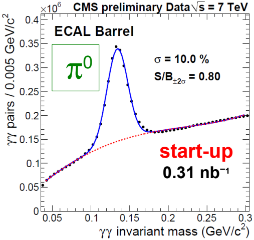


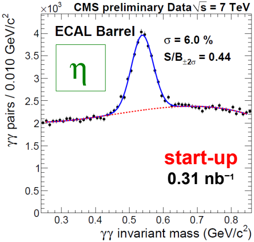
- Electromagnetic calorimeter, ECAL: Homogeneous $PbWO_4$ crystal calorimeter
  - Barrel (EB): $PbWO_4$
    - $26X_0$. $\Delta\eta x\Delta\varphi$ = 0.0174x0.0174
  - Endcap (EE): $PbWO_4$
    - $25X_0$. $\Delta\eta x\Delta\varphi$ = 0.021x0.021~0.050x0.050
  - Preshower in endcap (ES): $3X_0$ lead with 2 planes of 61mm x 1.9mm Si strips
  - Target resolution: 0.5% at high energy
  - > 99% working channels (EB: 99.3, EE: 98.94, ES: 99.8)
  - stable conditions: temp. RMS 0.003°C (EE: 0.015°C). Laser response stability < 0.02%.

- Hadronic calorimeter, HCAL:
  - Barrel (HB): Brass + Scintillators
    - $\Delta\eta x\Delta\varphi$ = 0.087x0.087
  - Barrel tail catcher (HO): Scintillators
  - Endcap (HE): Brass + Scintillators
    - $\Delta\eta x\Delta\varphi$ = 0.087x0.087...0.35x0.087
  - Forward (HF): Steel + quartz fibre (Čerenkov)
    - $\Delta\eta x\Delta\varphi$ = 0.349x(0.175 or 0.35)
  - > 99.75% working channels (100% in HB/HE/HF)

ECAL start-up conditions

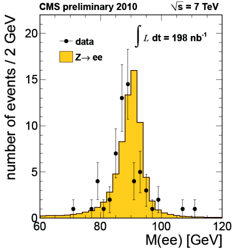
- Synchronization
  - All channels synchronized.
  - Providing a time measurement precision better than 1ns.
- Calibration
  - Start-up calibration uses results from a 10-year campaign of test-beam and cosmics rays precalibration, in-situ “splash” events and π^0 calibration.
  - Precision of start-up calibration:
    - EB: 0.5% ~ 2.2% *(1.2% in central region with first 120 nb^{-1})*
    - EE: 5%
    - ES: 2.2% *(better than design goal)*
  - Target with 10 pb^{-1}: 0.5% in EB; 1%~2% in EE
- Alignment
  - ES vs EE:
    - misalignment < 0.5mm (+/- 0.2mm)
  - Tracker vs ES/EE:
    - Δy = 7~8mm for + and – side
    - Δx ~ 5mm for + side
  - Possible small displacement in EB. Will be measured with the increased integrated luminosity



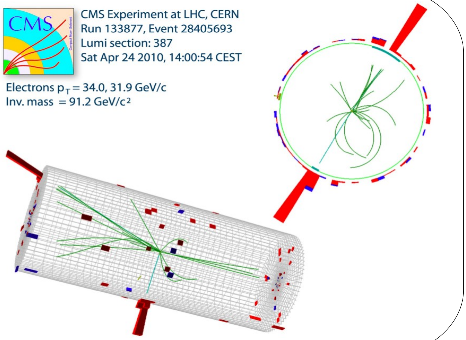


More details in posters #824 (Y. Yang), #507 (Z.-K. Liu), #477 (Y.-M. Tzeng)

$Z \rightarrow e^+e^-$

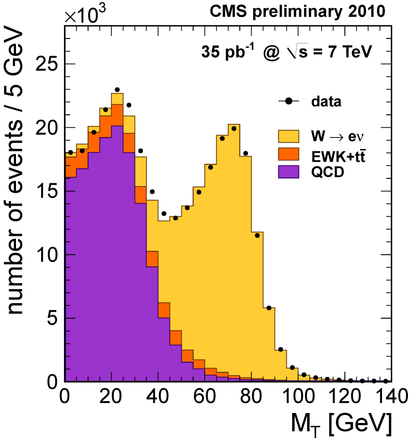


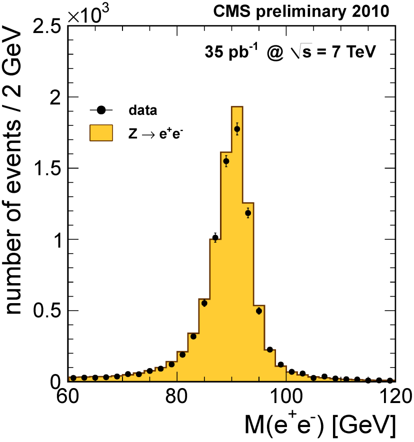
Distribution of M_{ee} of selected $Z \rightarrow e+e-$ candidates



See J. Mans' talk and M. Cepeda's talk

$W \rightarrow e\nu$ and $Z \rightarrow ee$ - 35pb^{-1}



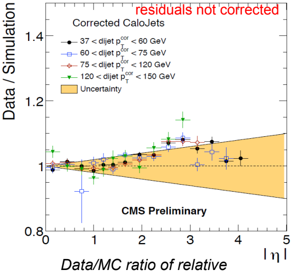


HCAL start-up conditions

- All channels synchronized
  - Providing a time measurement precision in HB and HE better than 2ns.
- Precalibration
  - Absolute scale set in test beam
  - Intercalibration made in-situ with Co^{60} source
  - Cosmic rays and “splash” events *(beam dumped on a collimator 150 m from IP)*
- Data-driven calibrations
  - Target: 5% on absolute scale, 0.5% (2%) on relative scale for barrel (endcap)
  - Requires ~10 pb^{-1}. With available data, set limit on systematic uncertainties.
  - Single particle response: E_{calo}/p_{track}
    - barrel: agreement with Monte Carlo within 3%
    - endcap: response ≤ 8% higher than Monte Carlo. It will be adjusted with more data when performing the actual calibration.
  - Jet energy scale: from dijet balance
    - Uncertainties currently used in analyses,

      $$10\% + 2\% \, |\eta|$$

      is confirmed within the statistics errors (71 nb^{-1}, but with trigger prescale)

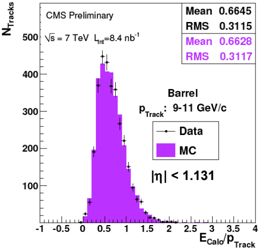


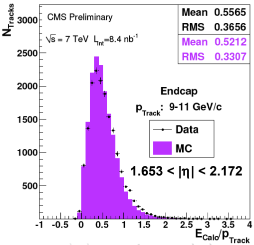
Data/MC ratio of relative response from dijet balance

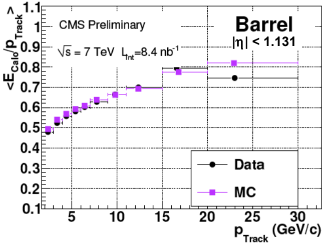
More details in P. De Barbaro's poster #854

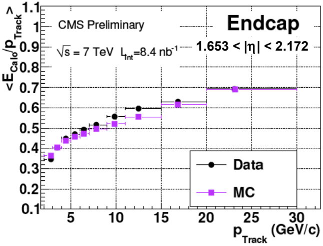
Detector response comprehension, HCAL

- Single particle response measurement as function of the track momentum. Selecting isolated charged particles with low deposit in ECAL (< 500MeV).





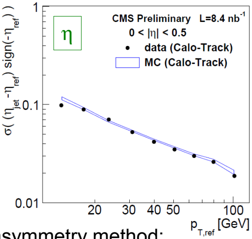


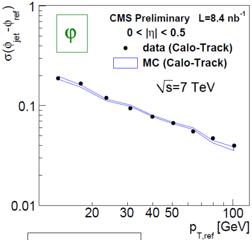


Jet measurement resolution

- Position resolution estimated by comparing tracker and calorimeter based measurements

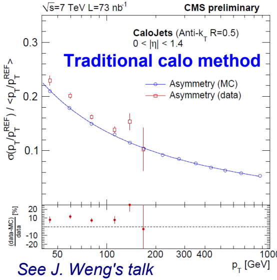
"out-of-the-box" Monte Carlo

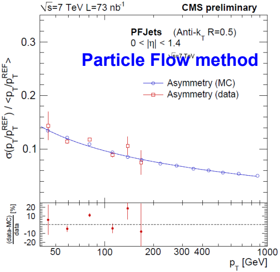




anti-k_t algo

- P_T resolution estimated with dijet asymmetry method:





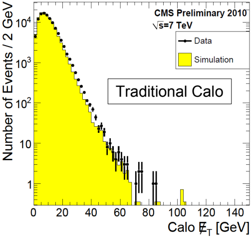
See J. Weng's talk

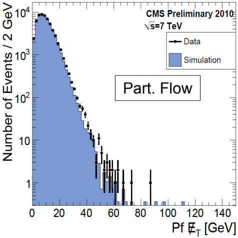
Particle flow technique strongly improves resolution in low P_T range

Already better than design resolution ($100\%/\sqrt{E} \oplus 5\%$)

Missing Et measurement performance

Missing E_T for Dijet events measured with two methods.
$p_T > 25$ GeV/c

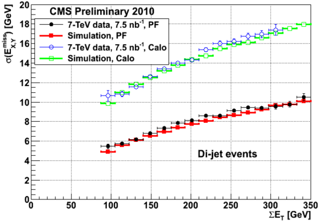




Monte Carlo describes the data well over 3 orders of magnitude without tuning.

Missing Et Gaussian core resolution:

- < 10 GeV on whole ΣE_T range up to 350GeV.
- Factor 2 improvement from Particle Flow technique.

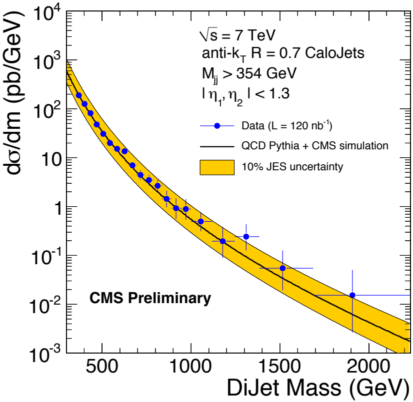


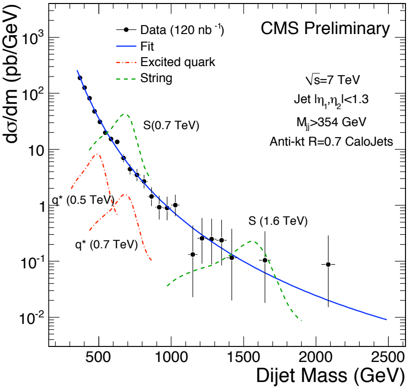
See particle flow algorithm F. Beaudette's talk this afternoon

Philippe Gras CEA/IRFU - ICHEP 2010 11

Dijet mass

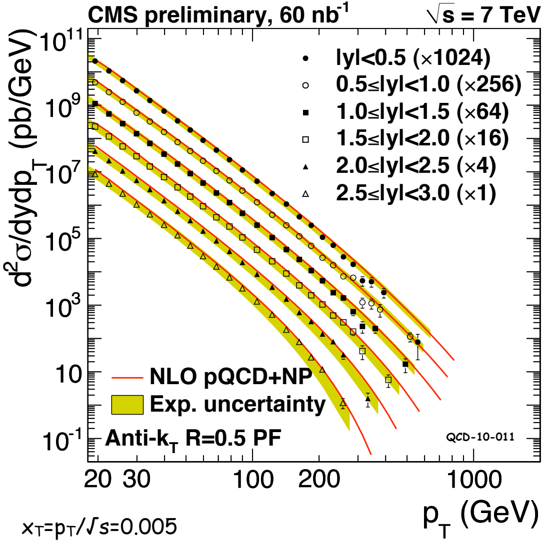
- Dijet mass measurement is sensitive to JEC and luminosity, but doubles as a bump-hunt for new physics **(talk by K. Kousouris)**
- Theory sensitivity to PDFs and scale similar to inclusive jets





Inclusive jet cross section

- Inclusive jet p_T spectra are in good agreement with NLO theory for all reconstruction types
- Past Tevatron published (0.7 fb^{-1}) record of 624 GeV jet at high p_T
- Extending below TeV's 50 GeV at low p_T thanks to novel reconstruction methods (Particle Flow)
- Extending up to |y|<3.0 **(P. Bartalini: 3<|y|<4.7)**
- Low p_T reach limited from theory side by non-perturbative corrections
- Systematic uncertainty is centered around PF ansatz

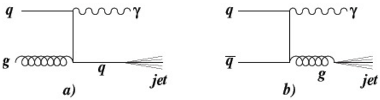


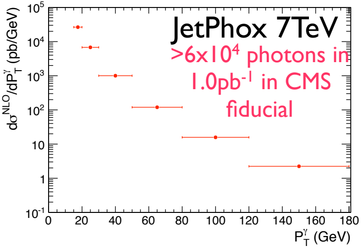
$x_T = p_T/\sqrt{s} = 0.005$

Outline

Introduction

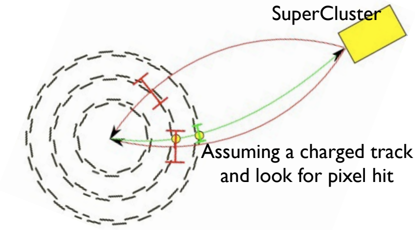
- Study of single isolated photon production gives a good test and information on pQCD as well as PDFs.
- Provide basic understanding of photons in CMS
- Foundation of photon+X analyses, such as photon +jet or Higgs to 2 photons.

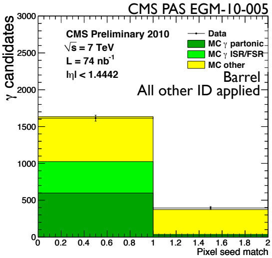


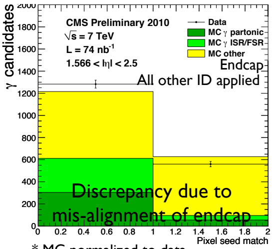


Photon ID Variables

- MC sample compositions based on PYTHIA cross sections.
- Use 74 nb^{-1} data for the following results, MC distributions are normalized to data observed.
- Require not to match pixel hit consistent with a track from interaction point.





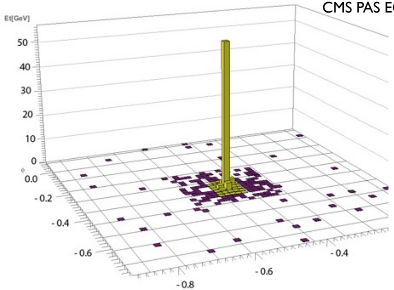


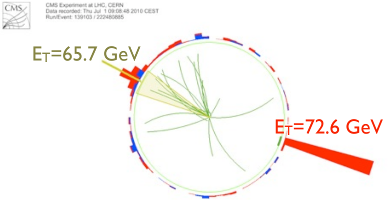
* MC normalized to data

Event Display

- This event shows a photon+jet event with good balance on E_T and ϕ.
- Photon is isolated with energy spread (shower shape) match expectation of a photon.

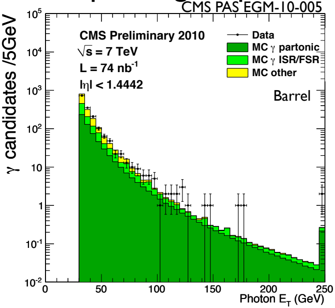
CMS PAS EGM-10-005

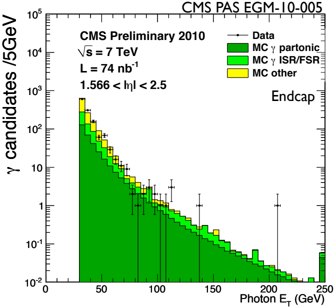




Isolated Photons

- With photon ID applied, clear component from prompt isolated photons can be seen.
- Purity is estimated between 40 to 100% depending on photon E_T

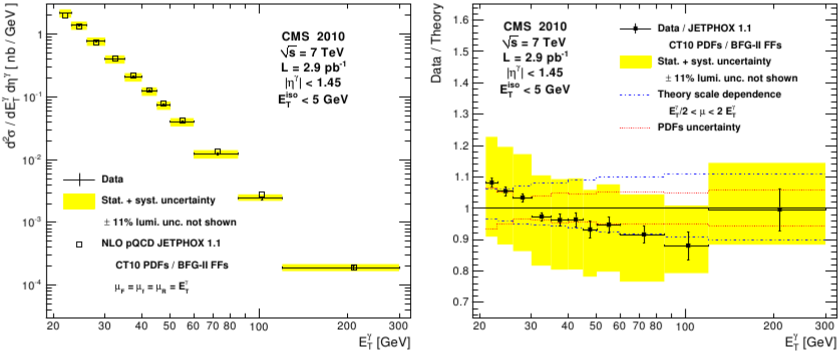




* MC normalized to data

* MC normalized to data

“Measurement of the Isolated Prompt Photon Production Cross Section in pp Collisions at sqrt(s) = 7 TeV”



arXiv:1012.0799v1

Electron reconstruction

Energy clustering to recover bremsstrahlung

- **Superclusters** are built by collecting clusters of crystals within in φ window

Electron seeding two complementary algorithms

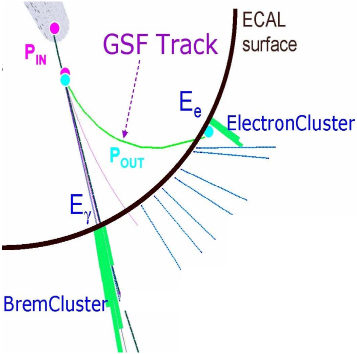
- Start from ECAL superclusters and search for compatible hits in the tracker inner layers (ECAL driven)
- Start from tracks (Tracker driven)

Electrons tracking

- Bremsstrahlung energy loss modeled with a mixture of Gaussians (Gaussian Sum Filter)

Electrons preselection

- Track Supercluster position matching cuts
- Multivariate analysis



Roberto Salerno, ICHEP July 22-28, 2010, Paris 6

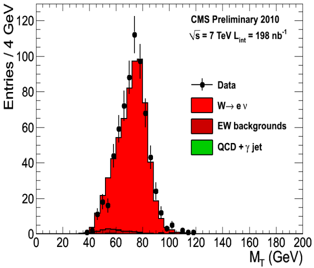
Electron commissioning at high pT

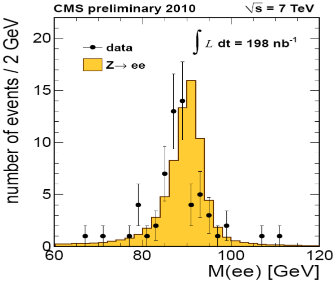
with more statistics use electrons from W/Z

W and Z selections are used to commission reconstruction and measure efficiencies

W Selection:
- high MET
- 1 high energy ECAL supercluster
- little hadronic activity

Z Selection:
- Tag: identified/isolated electron
- Probe: 1 ECAL supercluster
- Invariant mass

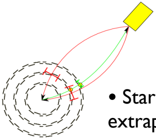




Z peak out of the box shift within 1%

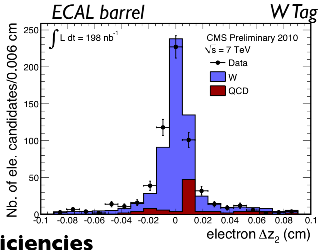
Figures are for selected electrons

Electron reconstruction

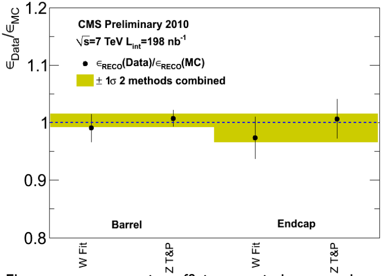


ECAL driven seeding

- Start by high ET ECAL supercluster and extrapolate toward innermost tracker layers
- Pair of hits are selected within a window around the expected position (r-phi and r-z planes)



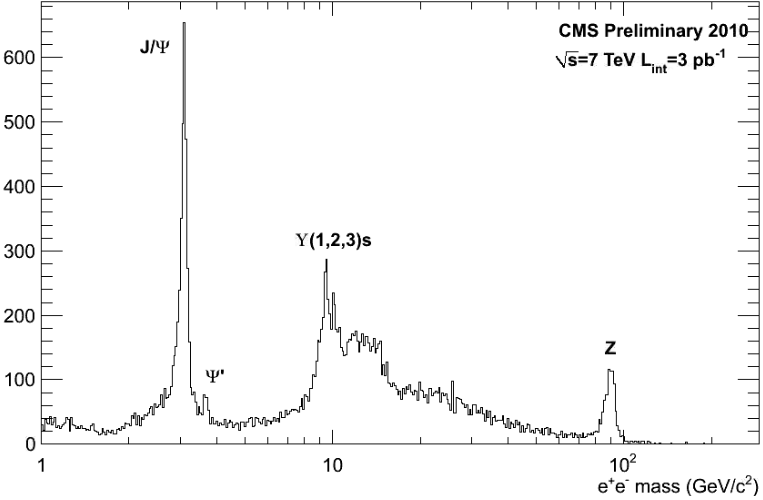
Electron reconstruction efficiencies



Electron reconstruction efficiency ratio between data and MC
The shaded region is the combined efficiency data/MC ratio

Detector	Method	Data	MC
Barrel	*Z Tag&Probe*	0.993 ± 0.014	0.985
Endcap	*Z Tag&Probe*	0.968 ± 0.034	0.961

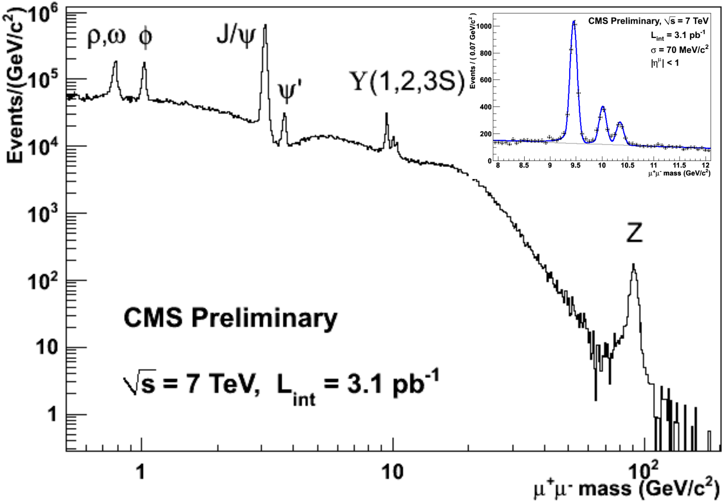
Recent progress: invariant mass in e^+e^-



G. TONELLI, CERN/INFN/UNIPISA RRB_31 OCTOBER 12, 2010

Outline

Here is the Compact Muon Solenoid



Invariant mass resolution at the Z peak ~ 1%

CMS Muon System and Tracker

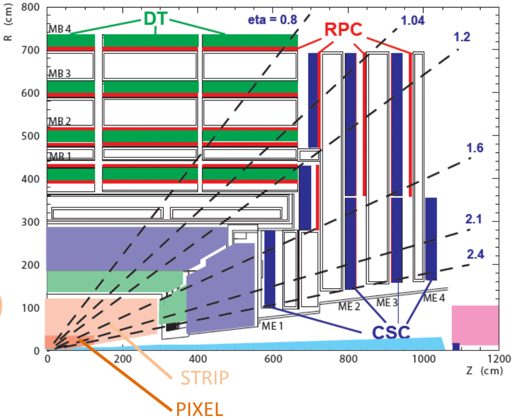
Muon system:

- Drift Tubes (DT)
- Cathode Strip Chambers (CSC)
- Resistive Plate Chambers (RPC)

Silicon Tracker:

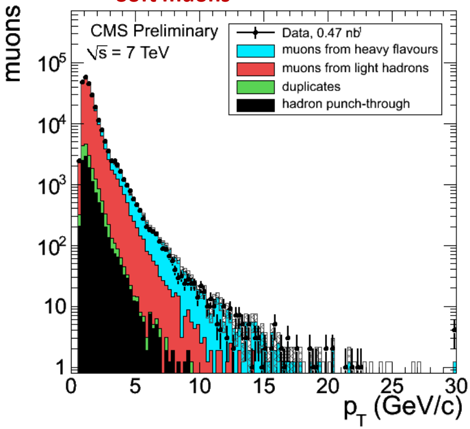
- Pixels (3 layers)
- Strips (10-12 layers)

Magnet: B = 3.8 T



Soft muons: kinematics

Soft muons



Data collected with a minimum bias trigger

compared to

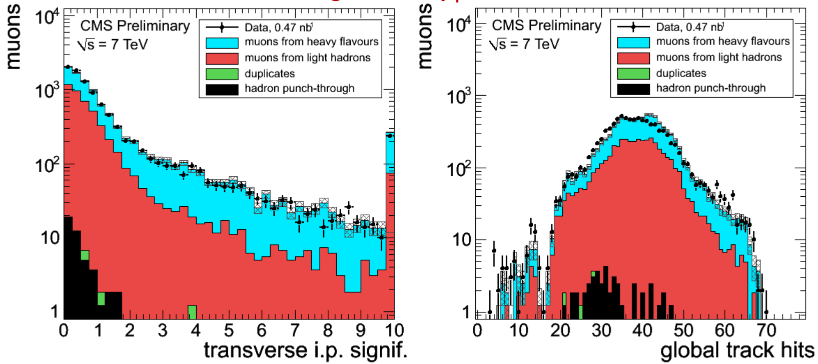
Simulation of min. bias events; muons separated according to their origin:

- **84% from π/K decays**
- **9% from b/c decays**
- **4.4% from hadron punch-through**
- **2.8% duplicates (1 sim. particle giving >1 reco. muons)**

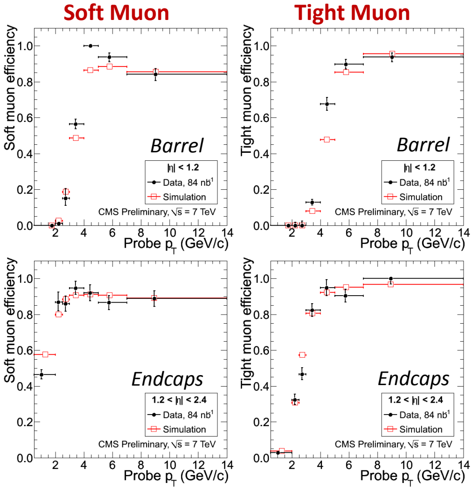
Other muon observables

Other data/sim. comparisons, with different sensitivities to the performance of the identification algorithms, the modelling of the detector, and to the sample composition.

Tight Muon, $p_T > 3$ GeV



Identification efficiency from J/Ψ



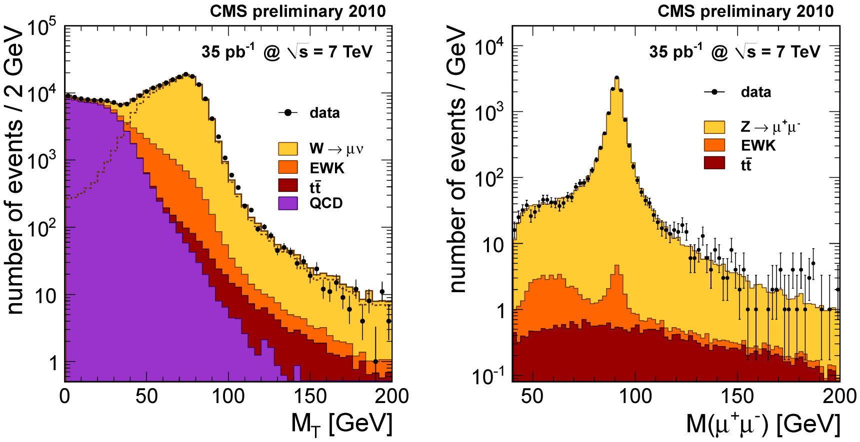
Results from data in agreement with expectations from simulation at the 5-10% level almost everywhere

... just a few months after the startup!

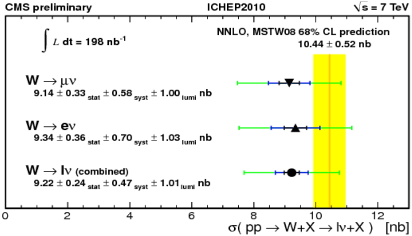
Momentum scale and resolution

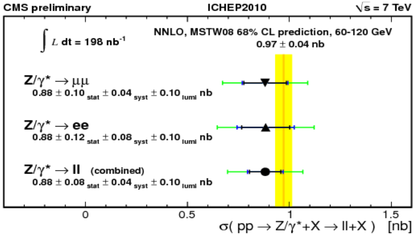
- The momentum measurement for muons is dominated by the silicon tracker for $p_T < 200$ GeV/c
- Measurement on data using muons from J/Ψ
  - momentum scale bias: $(2\pm1) \times 10^{-3}$
  - momentum resolution agrees with expectations from simulation within 5%
- More details in the CMS tracking performance talk by B. Mangano in this morning's session, or in the CMS Physics Analysis Summary TRK-10-004

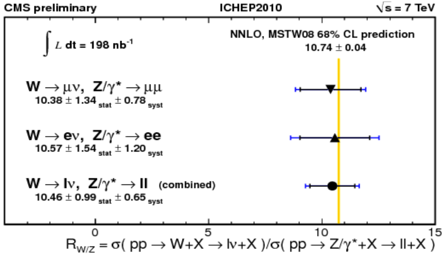
$W \to \mu\nu$ and $Z \to \mu\mu$ - 35pb^{-1}



Full Results

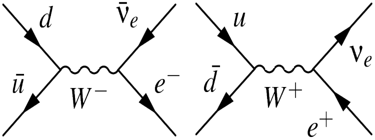


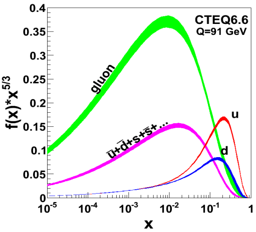


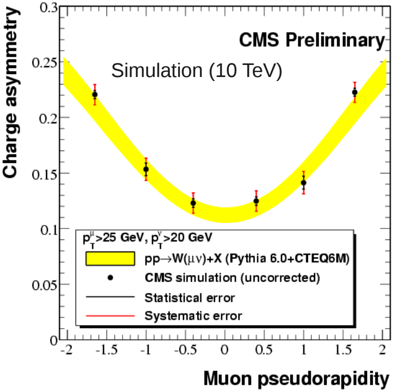


W charge Asymmetry

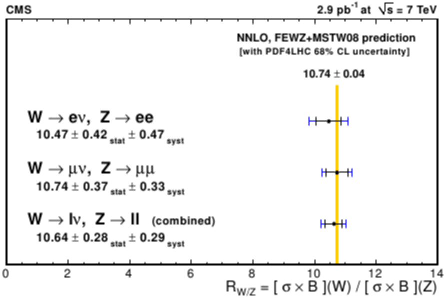
$$A(\eta) = \frac{\frac{d\sigma}{d\eta}(W^+ \to \mu^+\nu) - \frac{d\sigma}{d\eta}(W^- \to \mu^-\nu)}{\frac{d\sigma}{d\eta}(W^+ \to \mu^+\nu) + \frac{d\sigma}{d\eta}(W^- \to \mu^-\nu)}.$$

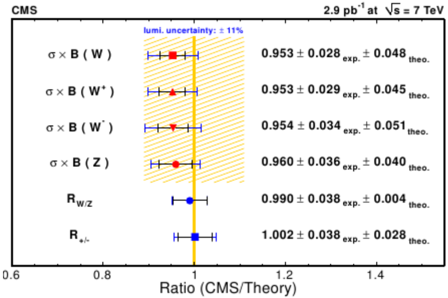






"Measurements of Inclusive W and Z Cross Sections in pp Collisions at $\sqrt{s} = 7\text{TeV}$"

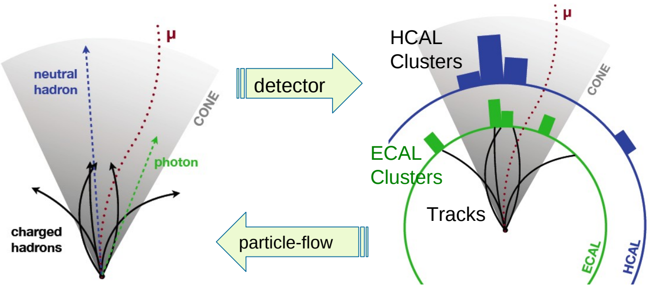




arXiv:1012.2466, submitted to the Journal of High Energy Physics

Outline

Overview: the Particle Flow algorithm

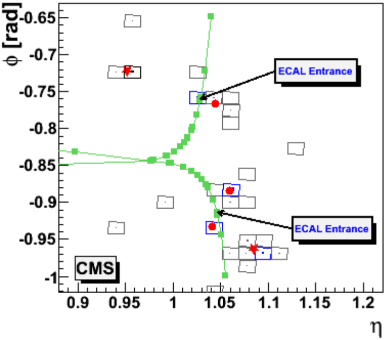


The list of individual particles is then used to build jets, to determine the missing transverse energy, to reconstruct and identify taus from their decay products, to tag b jets …

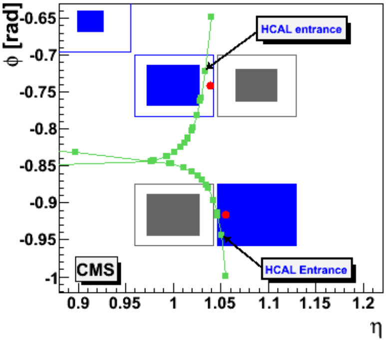
Florian Beaudette – CERN/LLR

Track-cluster link

ECAL surface

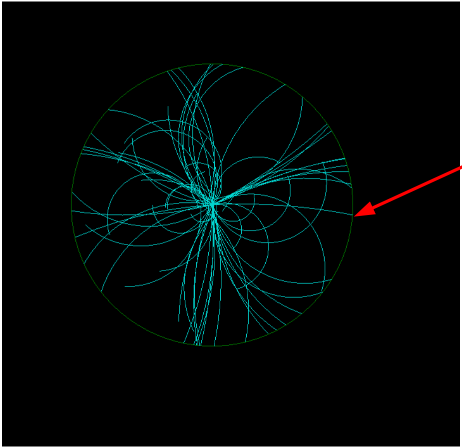


HCAL surface



- Two photons (ECAL clusters not linked to any track) plus a $\pi-$ and a $\pi+$

Event Display, transverse view (2.36 TeV data)



Charged hadron

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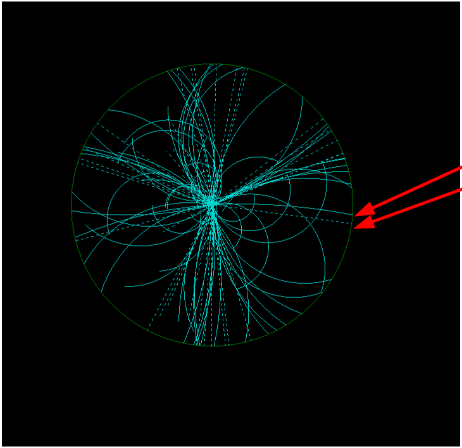
4/21

Event Display, transverse view (2.36 TeV data)



Charged hadron
Photon (dashed line)

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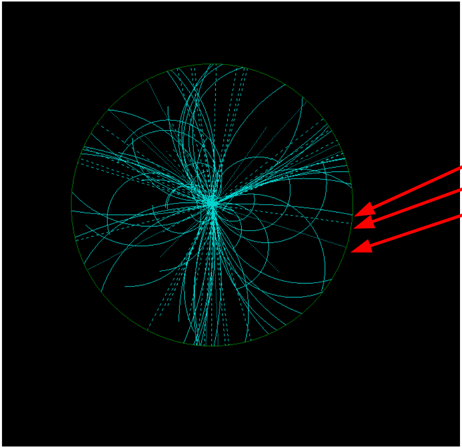
5/21

Event Display, transverse view (2.36 TeV data)



Charged hadron
Photon (dashed line)
Neutral hadron (dotted line)

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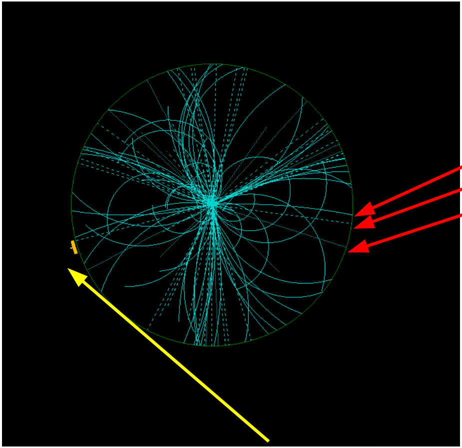
6/21

Event Display, transverse view (2.36 TeV data)

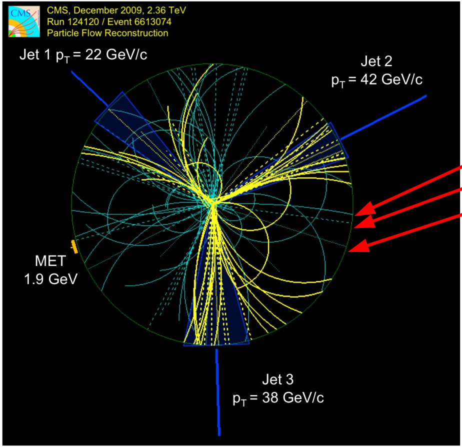


Charged hadron
Photon (dashed line)
Neutral hadron (dotted line)

$\text{Sum}E_T$: 178 GeV
MET : 1.9 GeV

$$\overrightarrow{\text{MET}} = -\sum_{i=0}^{N_{particles}} \vec{E}_T^i$$

Event Display, transverse view (2.36 TeV data)



Particles clustered in jets

Jet

Charged hadron
Photon (dashed line)
Neutral hadron (dotted line)

SumE_T : 178 GeV
MET : 1.9 GeV
Jet Algo: anti-Kt R=0.5
Three jets with p_T> 20GeV/c

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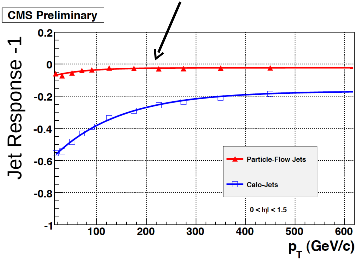
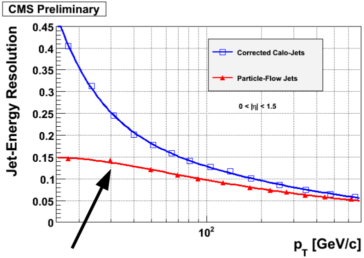
8/21

Jet energy response & resolution

simulated QCD-multijets events
barrel: $|\eta| < 1.5$

95-97% of the p_T reconstructed, over the whole range





Very large improvement at low pT, thanks to the tracks

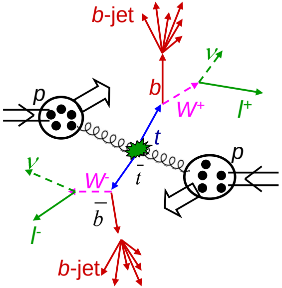
Outline

Dilepton+X Selection

- Dilepton channels: *ee, μμ, eμ*
  - Triggers: μ+X (p_T > 9 GeV/c) or e/γ+X (E_T > 15 GeV)
  - 2 isolated, prompt, oppositely charged leptons (l = e,μ) of good quality
    - $p_T(l)$ > 20 GeV/c
    - $|\eta_\mu| < 2.5$, $|\eta_e| < 2.4$
    - Relative isolation:

$$\text{Rel.isol.} = \frac{\overbrace{\sum_{R<0.3} p_T^{\text{track}} + \sum_{R<0.3} p_T^{\text{ECAL}} + \sum_{R<0.3} p_T^{\text{HCAL}}}^{\text{Detected energy around lepton}}}{p_T(\text{lepton})} < 15\ \%$$

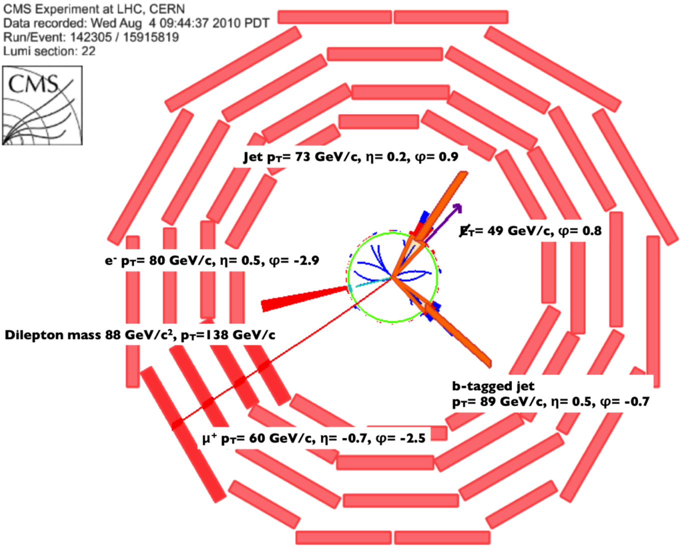
  - Missing transverse energy (MET)
    - using calorimeter⊕tracking
    - MET > 30 (20) GeV (in $e\mu$+X)



- *Z*-boson veto:
  - $76 < M_{ee,\mu\mu} < 106$ GeV/c^2
- Count additional jets:
  - anti-k_T jets, R = 0.5
  - using calorimeter⊕tracking info
  - $|\eta| < 2.4$, p_T > 30 GeV/c

≥ 2 jets typical for ttbar

Top physics - candiate event



"First Measurement of the Cross Section for Top-Quark Pair Production in Proton-Proton Collisions at $\sqrt{s} = 7\mathrm{TeV}$"

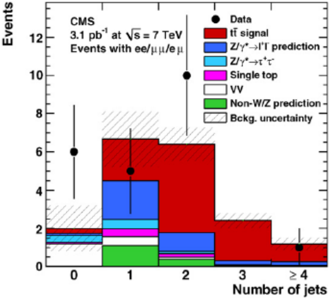


Fig. 1. Number of jets in events passing all dilepton selection criteria before the ⩾2-jet requirement for all three dilepton modes combined, compared to signal and background predictions. The hatched bands reflect the uncertainties on the background predictions.

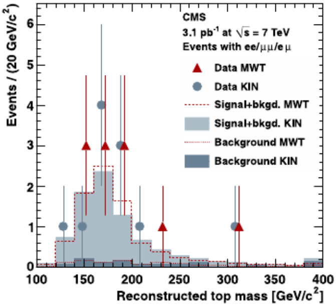


Fig. 2. Distribution of the top-quark mass using two different reconstruction methods [35,36], compared with the expected yields from simulated signal-plus-background and background-only hypotheses. The points in each bin for the two methods are slightly offset in reconstructed mass to allow coincident points to be visible. The last bin contains the overflow.

$$\sigma(\mathrm{pp} \rightarrow \mathrm{tt} + \mathrm{X}) = 194 \pm 72(\mathrm{stat.}) \pm 24(\mathrm{syst.}) \pm 21(\mathrm{lumi.})\mathrm{pb}$$

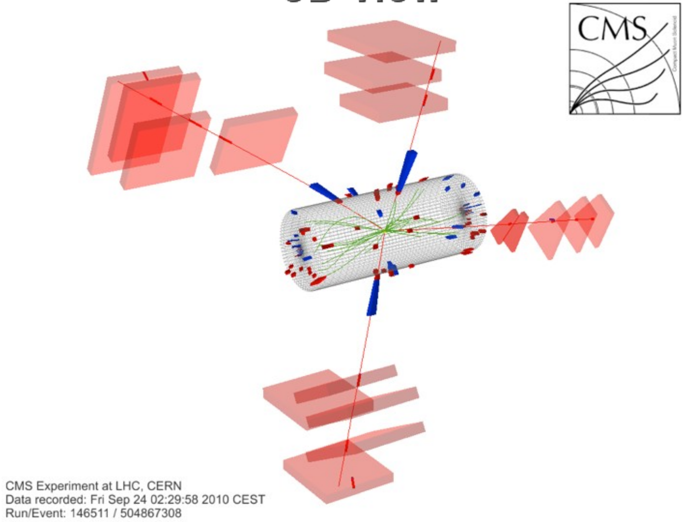
3.1 pb-1 of data, 11 candidate events.

arXiv:1010.5994

Submitted to the Physics Letters B

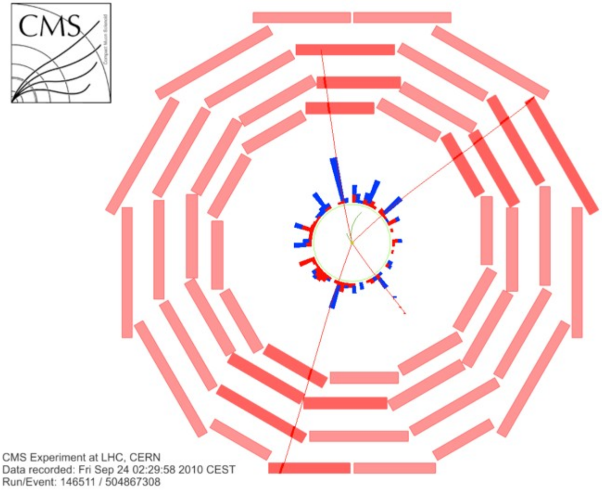
Outline

3D view



No explicit cut on tracks p_T

ρ-φ view



Only tracks with p_T>1 GeV are displayed

Event Details

CMS Experiment at LHC, CERN
Data recorded: Fri Sep 24 02:29:58 2010 CEST
Run/Event 146511/504867308

Muons (p_T [GeV], η, φ [rad])

μ_0^-(48.1422, -0.412532,-1.92555)
μ_1^+(43.4421, 0.204654, 1.79493)
μ_2^+(25.8769, -0.782084, 0.774588)
μ_3^-(19.5646, 2.01112, -0.980597)

Invariant Masses

$\mu_0 + \mu_1$: 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

19