Dimuon physics with CMS

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Outline

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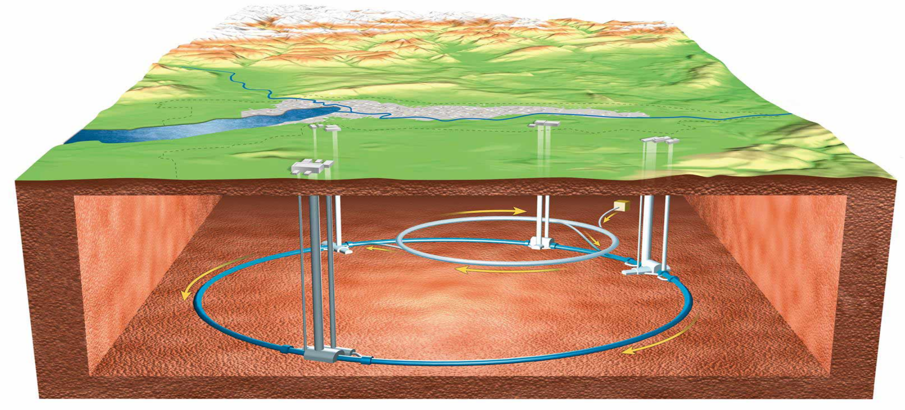
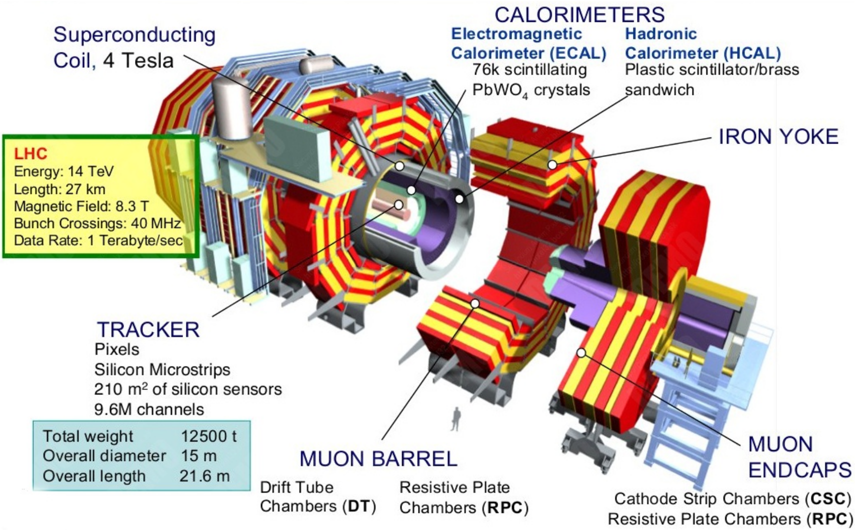
3. Physics at LHC and detector requirements
4. Muon reconstruction at CMS
5. (New) physics to probe with dimuons
6. CMS performance: chalendges of high mass dimuons, trigger, reconstruction
7. Experimental and theoretical unsertaities, backgrounds
8. CMS dimuon physics perspectives: discovery limits, spin discrimination
9. Conclusions

LHC the discovery machine



- Beam energy: 2x7(5)x10^{12}eV
- (High) luminosity: 10^{34}cm^{-2}s^{-1}
- 2835 bunches per beam
- 10^{11} protons per bunch
- Superconducting magnets
- 1232 dipole magnets (bending)
- 500 quadrupole magnets (focus)
- Energy stored (per beam): 360 MJ


CALORIMETERS
Electromagnetic Calorimeter (ECAL)
76k scintillating PbWO$_4$ crystals
Hadronic Calorimeter (HCAL)
Plastic scintillator/brass sandwich
Superconducting Coil, 4 Tesla
IRON YOKE
LHC
Energy: 14 TeV
Length: 27 km
Magnetic Field: 8.3 T
Bunch Crossings: 40 MHz
Data Rate: 1 Terabyte/sec
TRACKER
Pixels
Silicon Microstrips
210 m^2 of silicon sensors
9.6M channels
Total weight 12500 t
Overall diameter 15 m
Overall length 21.6 m
MUON BARREL
Drift Tube Chambers (**DT**)
Resistive Plate Chambers (**RPC**)
MUON ENDCAPS
Cathode Strip Chambers (**CSC**)
Resistive Plate Chambers (**RPC**)

Physics at LHC and detector requirements

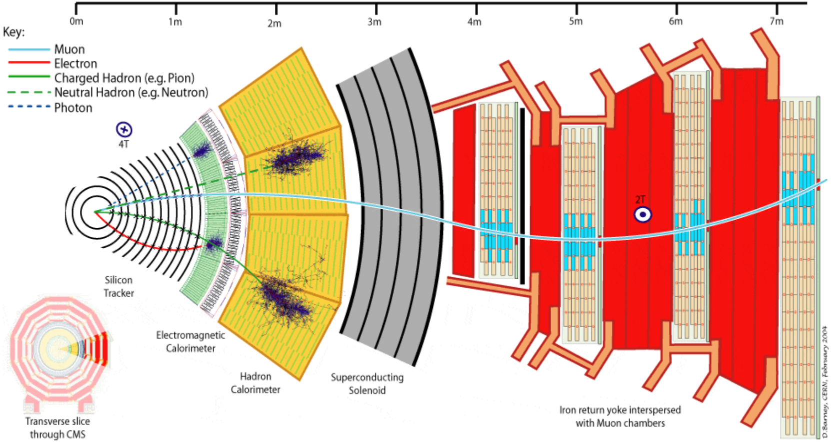
Key items of CMS physics program

- Higgs boson
- Supersymmetric particles
- New massive vector bosons
- Extra dimensions
- Standard model
- Heavy-ion physics

Summary of detector requirements

- Good muon identification and momentum resolution over a wide range of momenta in the region $|\eta| < 2.5$, good dimuon mass resolution ($\approx 1\%$ at 100 GeV/c^2) and the ability to determine unambiguously the charge of muons with p $<$ 1 TeV/c
- Good charged particle momentum resolution and reconstruction efficiency in the inner tracker. Efficient triggering and offline tagging of taus and b-jets
- Good electromagnetic energy resolution, good diphoton and dielectron mass resolution ($\approx 1\%$ at 100 GeV/c^2), wide geometric coverage ($|\eta| < 2.5$), measurement of the direction of photons and/or correct localization of the primary interaction vertex
- Good E_T^{miss} and dijet mass resolution, requiring hadron calorimeters with a large hermetic geometric coverage ($|\eta| < 5$) and with fine lateral segmentation

Muon reconstruction at CMS



Reconstruction makes use of the muon chambers and the silicon tracker by first finding a segment in the muon stations (StandAlone Muons), which is then matched to a compatible track in the silicon tracker (Tracker tracks). A combined fit of the muon segment and silicon tracks trajectory yields the final reconstructed muon track (Global Muons). The η-coverage for muon reconstruction in the CMS detector is $|\eta| < 2.4$.

Key parts of CMS tracking system

The CMS magnet:

- is the largest superconducting magnet ever built, weighs 12,000 tonnes,
- is cooled to -268.5^{o}C, a degree warmer than outer space,
- is 100,000 times stronger than the Earth's magnetic field,
- stores enough energy to melt 18 tonnes of gold (2.7GJ),
- uses almost twice much iron as the Eiffel Tower.

The muon system:

- contains 2 million cathode strip chamber wires. Though each is as thin as a human hair, not a single one has broken;
- formed the first and last slices of CMS to be lowered into the cavern with endcaps "YE+3" in November 2006 and "YE-1" in January 2008;
- will be aligned with the central tracker to within one sixth of a millimetre in order for the detectors to work together in reconstructing tracks;
- is made of components built in 15 countries.

The inner tracker:

- Strips: 9.3M channels, 200 m^2 total silicon, 10 layers (4 double sided stereo),
- Covers the region from 20cm to 120cm and up to $|\eta|<2.5$ (barrel $|\eta|<1.2$),
- Pixels: Read Out Chip bump bonded sensor pixels with $52 \;\; 80 = 4160$ pixels per ROC
- Total 15,840 ROCs for 66 million pixels,each pixel has a programmable threshold

(New) physics to probe with dimuons

Why dimuons? Because it is Compact MUON solenoid!

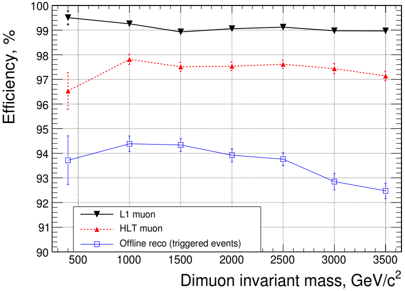
- Crossection of dijet signatures are higher, but muonic decays provide clear signatures with low and controlable backgrounds!
- Strong B-field and long lever arm (from IP and tracker to Muon system) for precise momentum estimation
- Redundant muon trigger
- High precision muon detectors

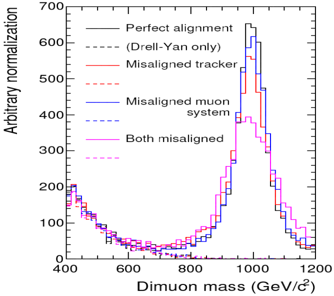
Search for deviations from Standard Model distributions High mass dilepton channel – low backgrounds, – distinctive experimental signature Nature of the deviations depends on the type of new physics.

- Drell-Yan process in TeV energy region: measure crossection, forward-backward asymmetry,
- Extended gauge models: Z' (spin 1)
- Extra dimentions: ADD (non resonance signal) and RS1 (spin 2 resonance) gravitons

The key point of these studies is precision high mass dimuon pairs crossection measurement → we need high efficiency of registration, triggering and reconstruction for muons as well as high precision of kinematic parameters estimation

CMS performance with dimuons: trigger efficiency, offline reconstruction





- High trigger efficiency for heavy dimuons
- CMS continues to improve trigger/offline reconstruction algorithms
- $\approx 4\%$ invariant mass resolution at 1 TeV
- CMS continues to improve trigger/offline reconstruction algorithms

Experimental unsertaities

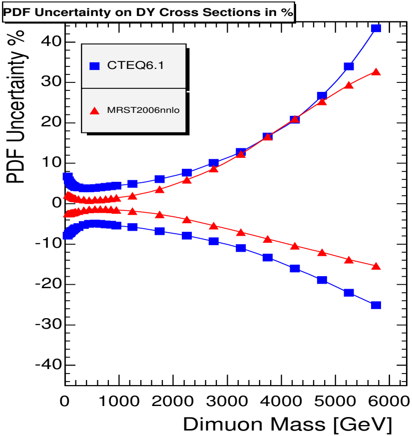
Difficulties measuring high-p_T muons

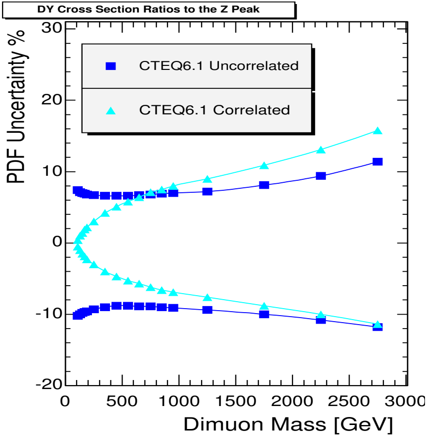
- Low trajectory curvature → limited p_T estimation precision
- Bremsstrahlung and EM showering → contaminated events
- Precision is extreamelly sensitive to detector misalignment

Experimental uncertainties:

- Misalignment effect increase of the mass residuals by around 30%
- Drift time and drift velocities
- Magnetic and gravitational field effects can cause a scale shift in a mass resolution by 5-10%
- Pile-up mass residuals increase by around 0.1–0.2 %
- Background uncertainties (variations of the bg. shape) a drop of about 10-15% in the significance values
- Trigger and reconstruction acceptance uncertainties

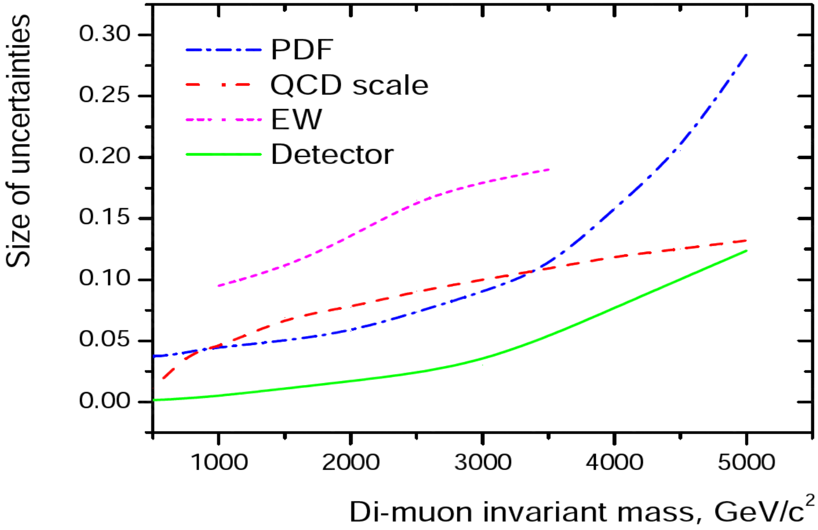
Theoretical unsertanties



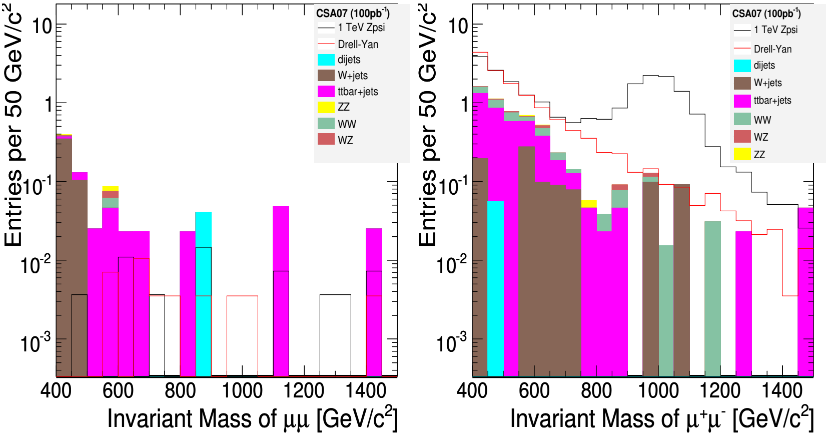


- QCD and EW high-order corrections (K factors)
- Parton Distribution Functions (PDF)
- Hard process scale (Q2)
- Cut efficiency, significance estimators

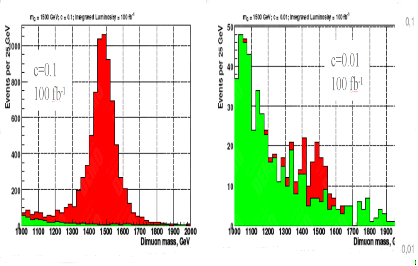
Uncertainties summary



Backgrounds



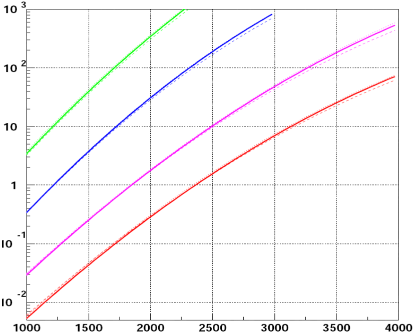
Invariant-mass distributions for opposite-sign (left) and same-sign (right) dimuons from 1 TeV/c2 Z_ψ and different background sources expected for Ldt = 100 pb1 after ap- plying all event-selection criteria. The spectrum is shown in the mass range $400 < M_{\mu\mu} < 1500 \mathrm{GeV}/c^2$



Virtual ADD graviton production:

- $\mu\mu$ in a final state
- Pythia+CTEQ6L, LO+K=1.3
- Full (GEANT4) simulation/reco +L1/HLT
- Misalignment, reco- and trigger inefficiency, etc

Discovery limit for RS1 graviton with $\mu\mu$ decay mode for different values of RS1 coupling constant $c = 0.01, 0.02, 0.05, 0.1$ (from top to bottom).

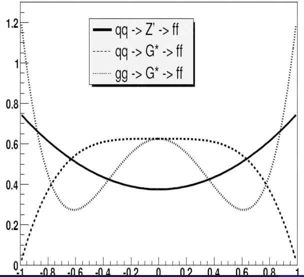


Spin discrimination

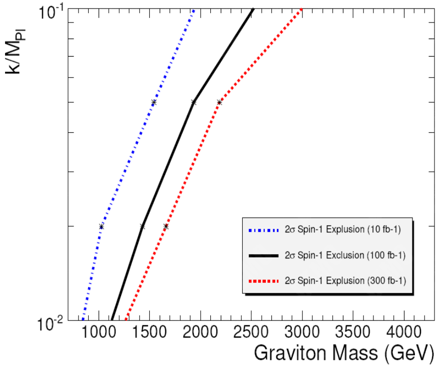
- Spin 1 states: Z' from extended gauge models, Z_{KK}
- Spin 2 states: RS1-graviton
- Method: unbinned likelihood ratio statistics incorporating angles of the decay product in the Colins-Sopher frame (R.Cousins et al JHEP 11 (2005) 046). The statistical technique has been applies to the fully simulated reconstructed events.

Angular distributions

- $qq \to G \to ff : 1 - 3\cos^2\theta + 4\cos^4\theta$
- $gg \to G \to ff : 1 - \cos^4\theta$
- $qq \to G \to VV : 1 - \cos^4\theta$
- $gg \to G \to VV : 1 + 6\cos^2\theta + \cos^4\theta$
- DY background: $1 + \cos^2\theta$



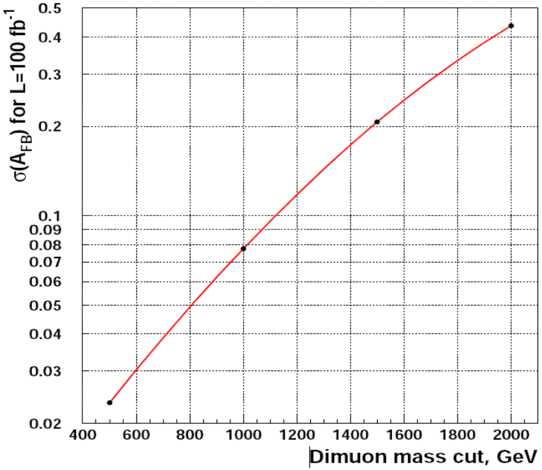
CMS reach for 2 discrimination between spin-1 and spin-2 hypotheses:



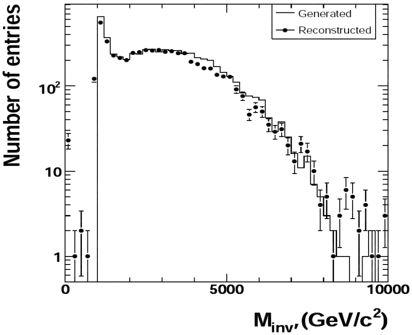
Forward backward asymmetry

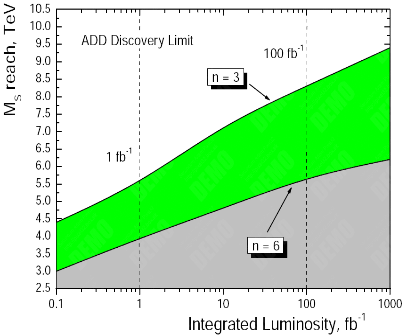
To test the helicity structure of the exchanged particles and discriminate between different new physics scenarios, the leptonic forward-backward asymmetry can be used:

$$\frac{d\sigma}{d\cos(\theta^*)} = c[\frac{3}{8}(1+b\cos^2\theta^*)+A_{FB}\cos\theta^*]$$



Discovery limits (ADD graviton)





Virtual ADD graviton production:

- $\mu\mu$ in a final state
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- Theoretical uncertanties

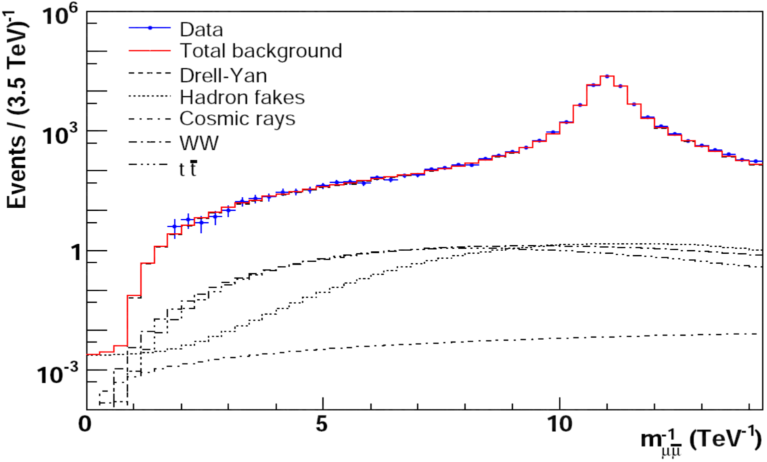
Confidence limits for:

- 1 fb^{-1} : 3.9-5.5 TeV for n=6..3
- 10 fb^{-1} : 4.8-7.2 TeV for n=6..3
- 100 fb^{-1} : 5.8-8.3 TeV for n=6..3
- 300 fb^{-1} : 5.9-8.8 TeV for n=6..3

LHC accelerator will provide an opportunity to test prediction of SM in a new energy region. Dimuon channel is clean, has low (and well understood) background. CMS detector is optimized for muonic studies.
The ability to identify and reconstruct muons with high efficiency over the whole kinematic range of the LHC is the key to the success of the CMS experiment. This requires algorithms that are robust and flexible and use all the available detector information over the full geometrical acceptance of the CMS detector.
The discovery potential of CMS experiments makes it possible to investigate different signals in TeV region of dimuon invariant masses:

- Drell Yan process
- Large Extra-Dimensions (ADD model)
- Randall-Sundrum (RS1)

Thank you!



The CDF analysis uses data corresponding to an integrated luminosity of 2.3 fb−1 of $p\bar{p}$. Dimuon invariant mass spectrum is consistent with the SM expectation for masses up to ≈ 1TeV