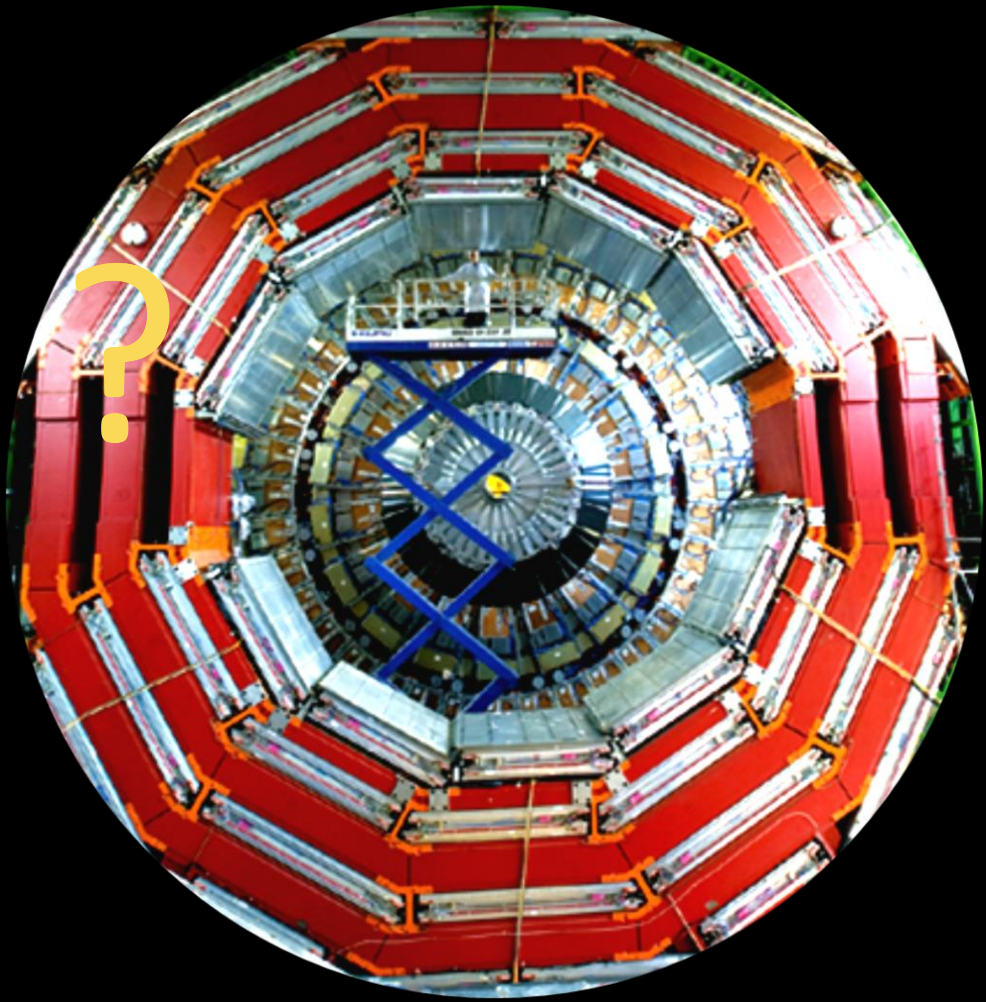
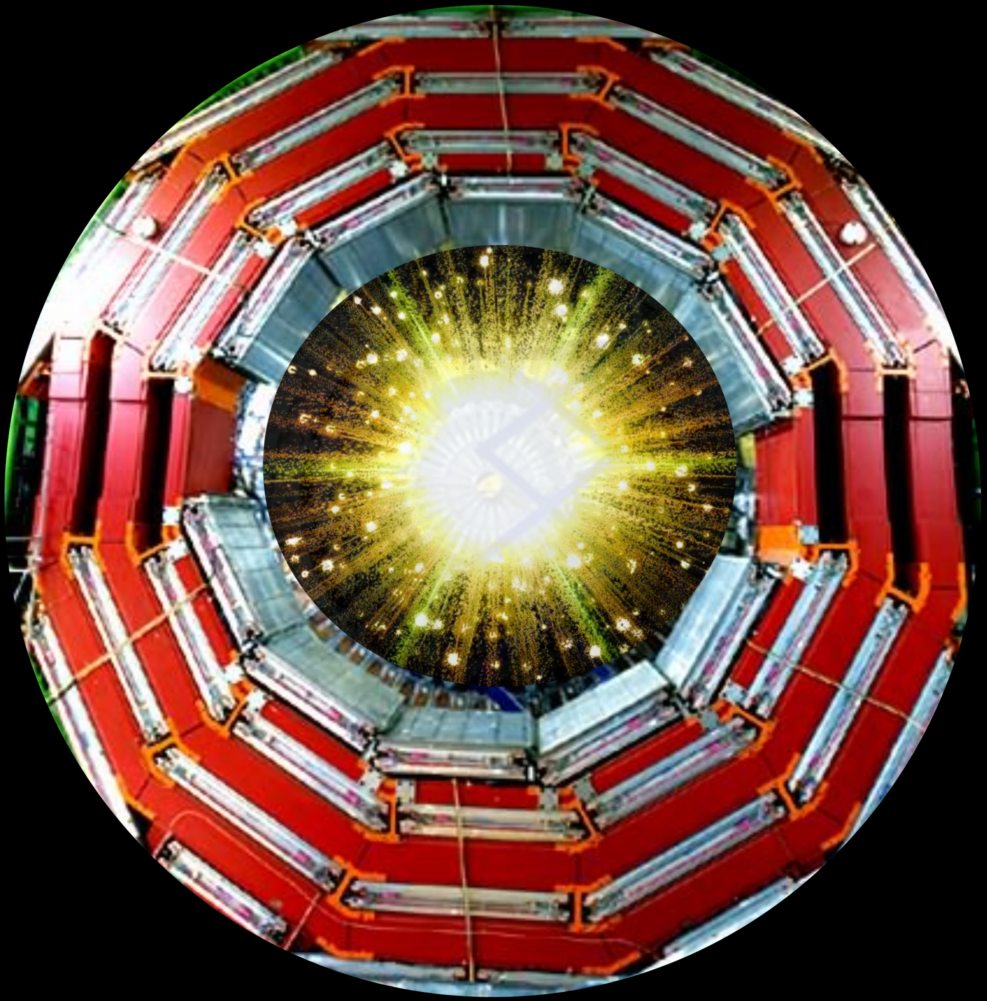
This here is a view from the CMS detector:



For a loooooooooong time we had this:



Now at last, we are blessed with this!

In the end, what we'd like to see is this.
But we need to work on it.

? CMSMC for New Physics: Status & Requirements

Sezen Sekmen (Florida State University)
on behalf of CMS Collaboration

TOOLS 2010, Winchester, 29/06 – 02/07/2010

IN THIS TALK:

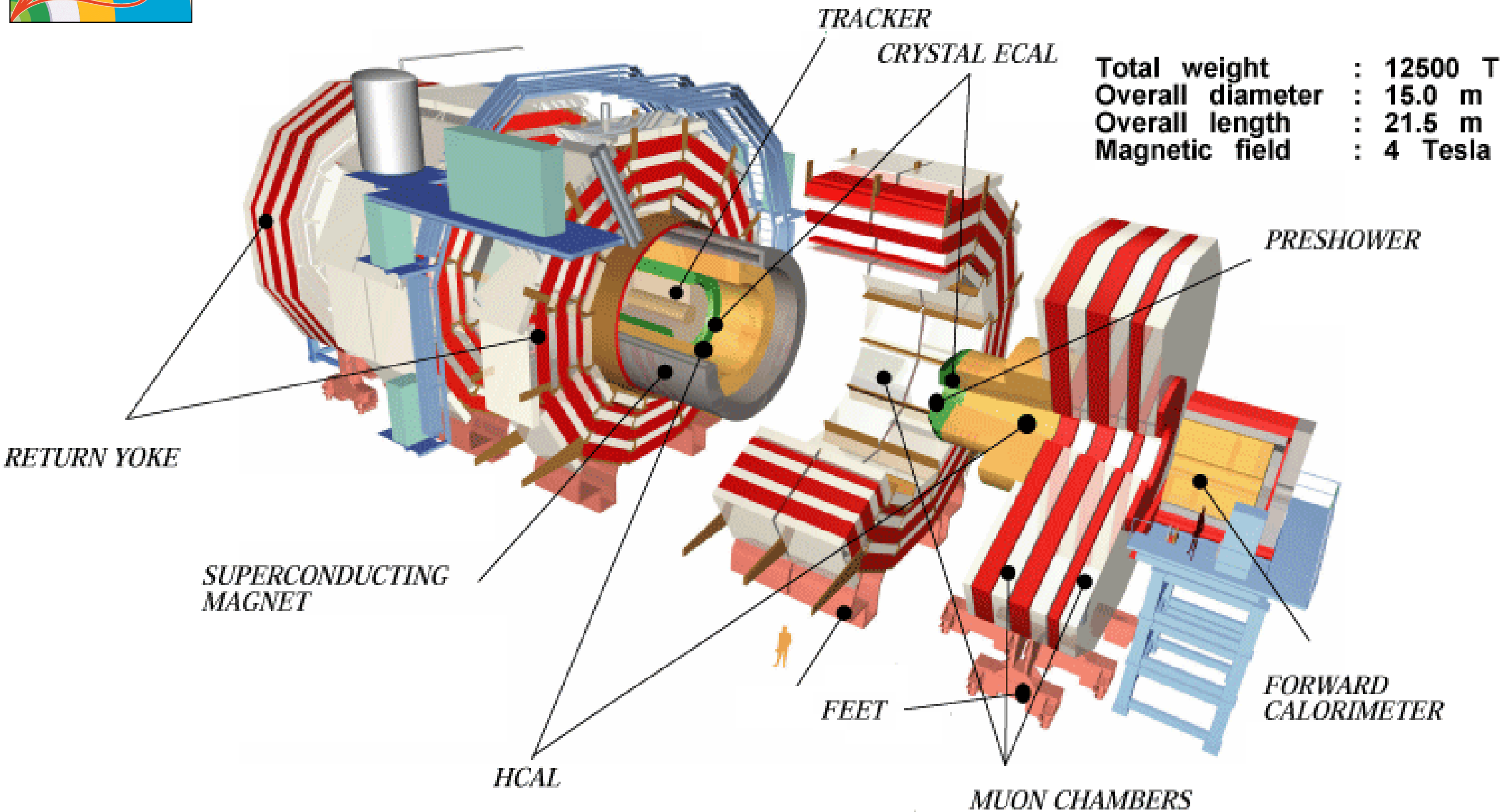
The CMS detector

The first data

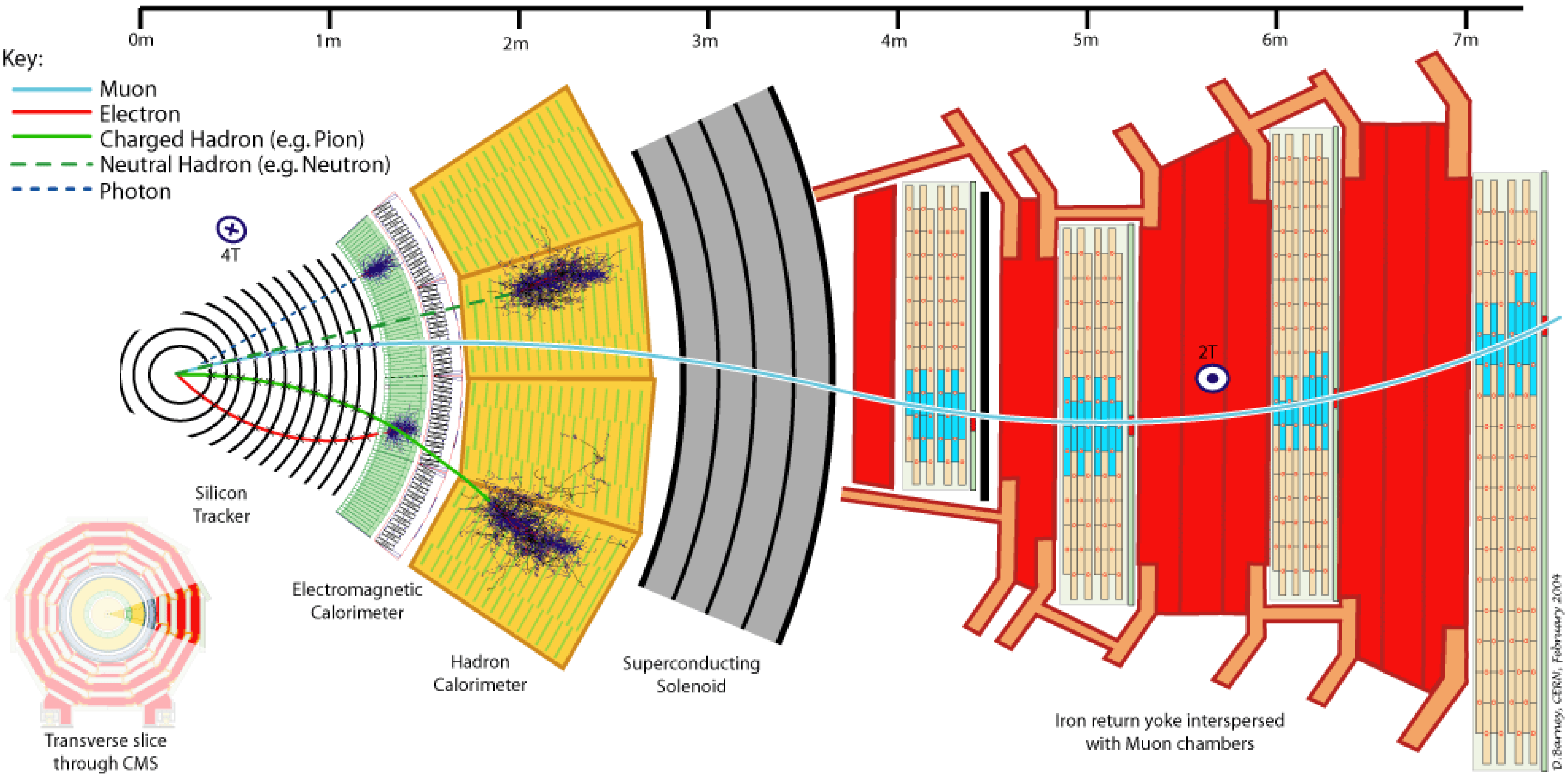
MC at work in CMS: with and without data

Implementing the MC in CMS: situation, comments and questions

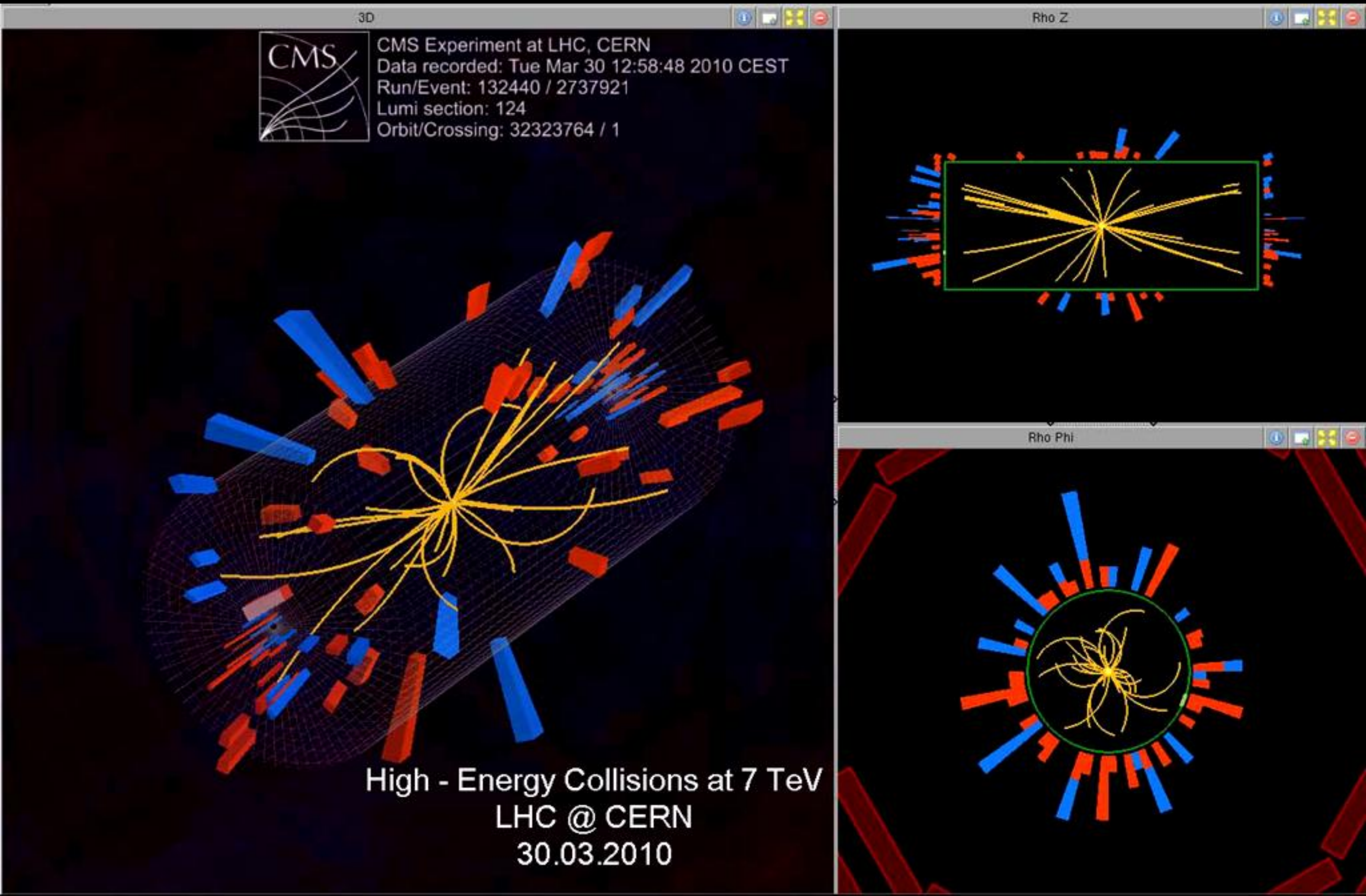
The Detector



Particles in The Detector



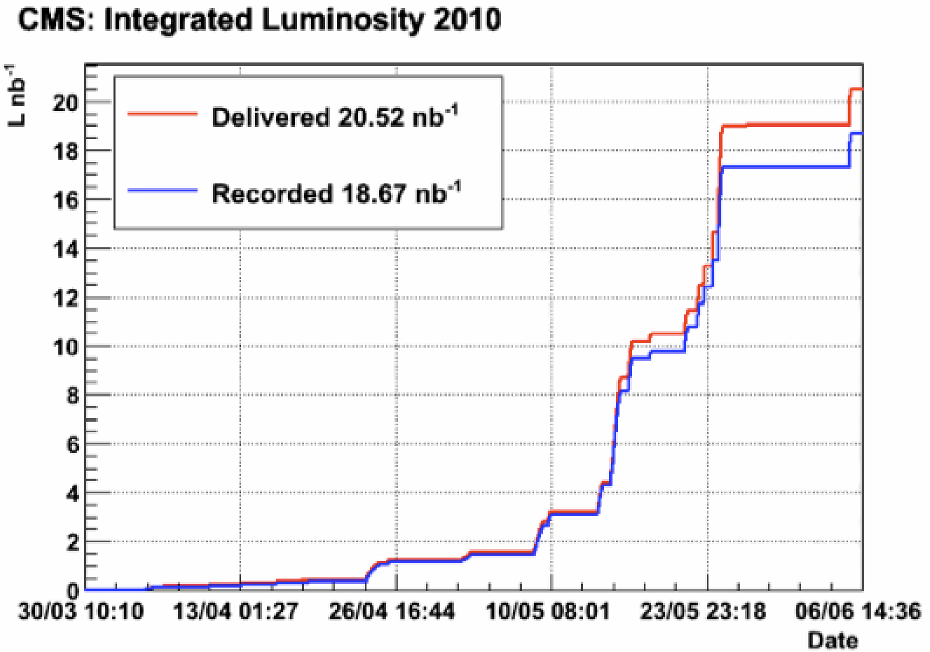

The first data...
WUNDERPhoto.net


3D
Rho Z
Rho Phi
CMS
CMS Experiment at LHC, CERN
Data recorded: Tue Mar 30 12:58:48 2010 CEST
Run/Event: 132440 / 2737921
Lumi section: 124
Orbit/Crossing: 32323764 / 1
High - Energy Collisions at 7 TeV
LHC @ CERN
30.03.2010

30 March 2010 – CMS control room

CMS current status

Collecting data

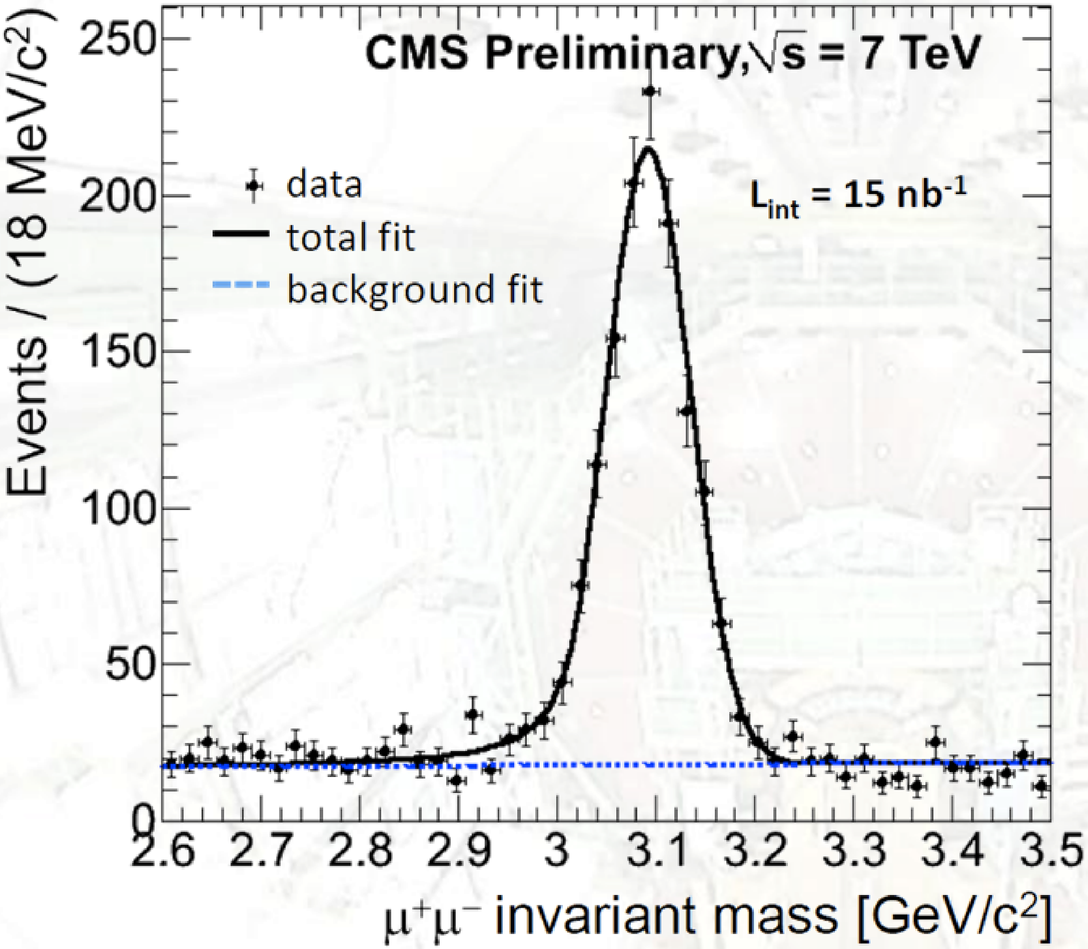


...plus another ~15nb^{-1} on the weekend!

Luminosity	Physics reach
1 mb-1	UE, MB
1 µb-1	Jets, heavy flavor
1 nb-1	W, Z
1 pb-1	ttbar
10 pb-1	Dijets, HCSP, …
100 pb-1	W', Z', low mass SUSY
1 fb-1	SUSY, MSSM Higgs

The plan is to reach 100nb^{-1} at the end of July, and 1fb^{-1} in 2011.

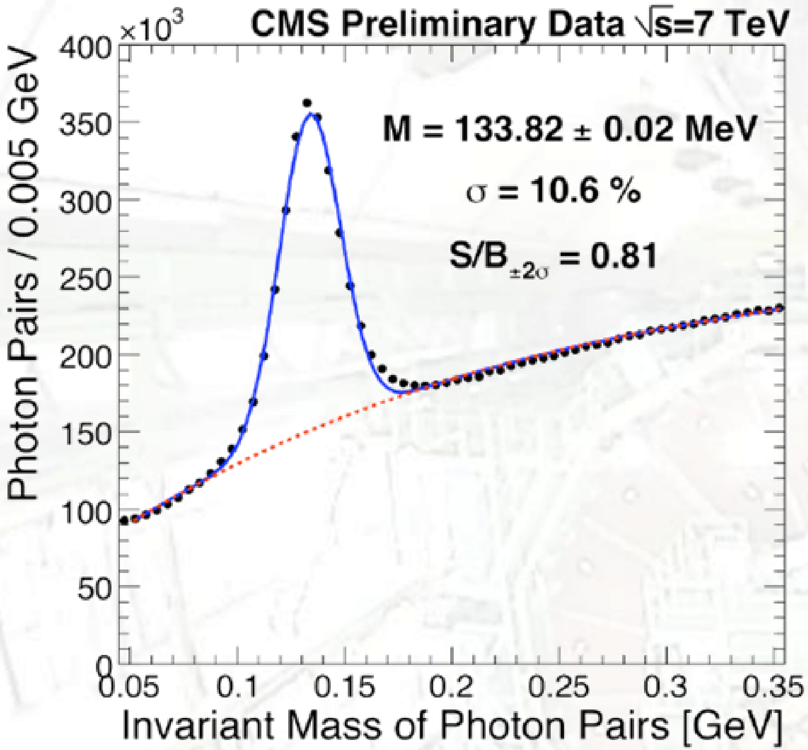
Dimuon resonances: J/ψ

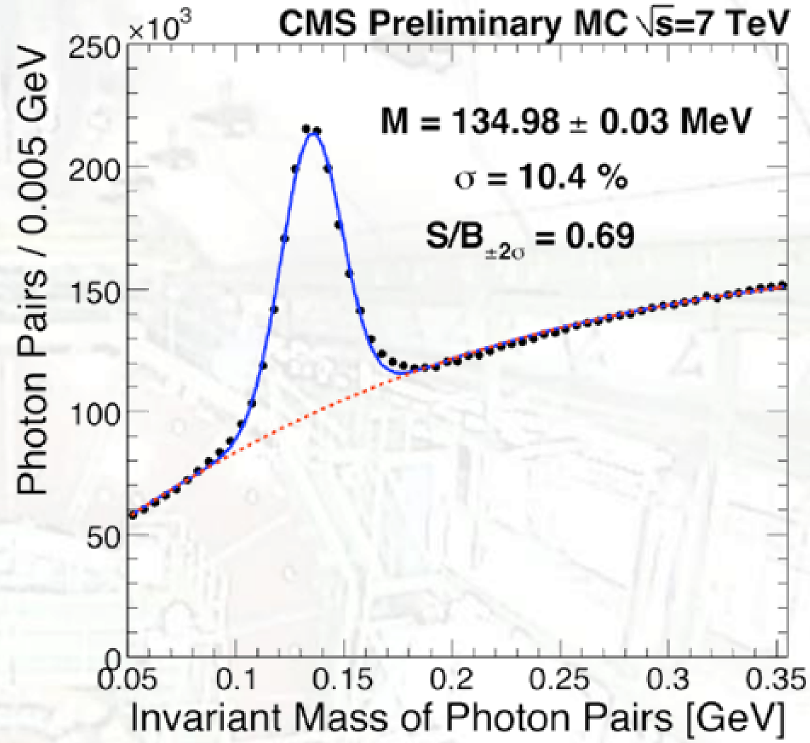


Signal events: 1230 ± 47
Sigma: (42.7 ± 1.9) MeV
M_0: 3.092 ± 0.001 GeV
S/B = 5.4 (M_0 ± 2.5σ)
χ^2/ndof = 1.1

Fit: polynomial for the background and Crystal-Ball for the signal.

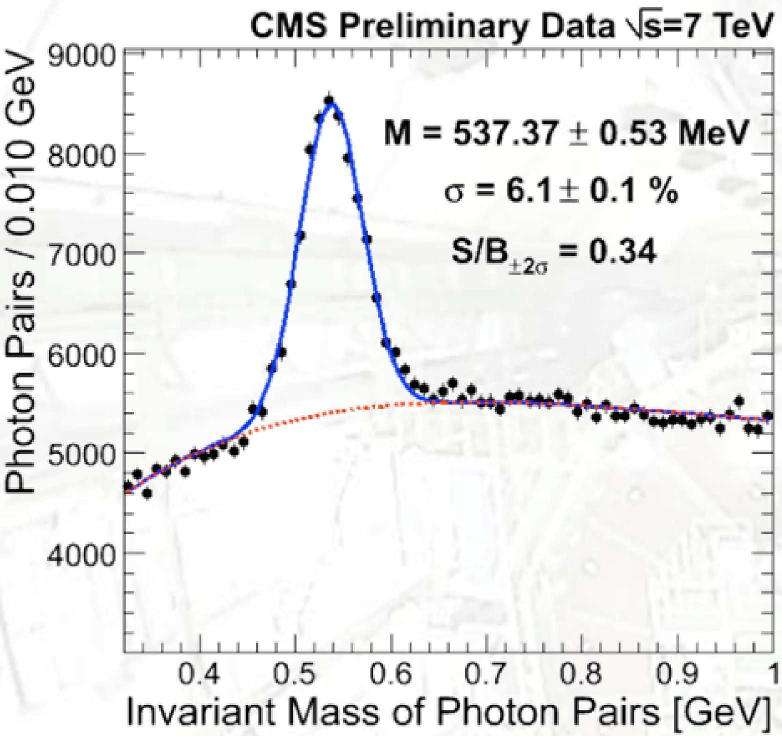
Diphoton resonances: π^0

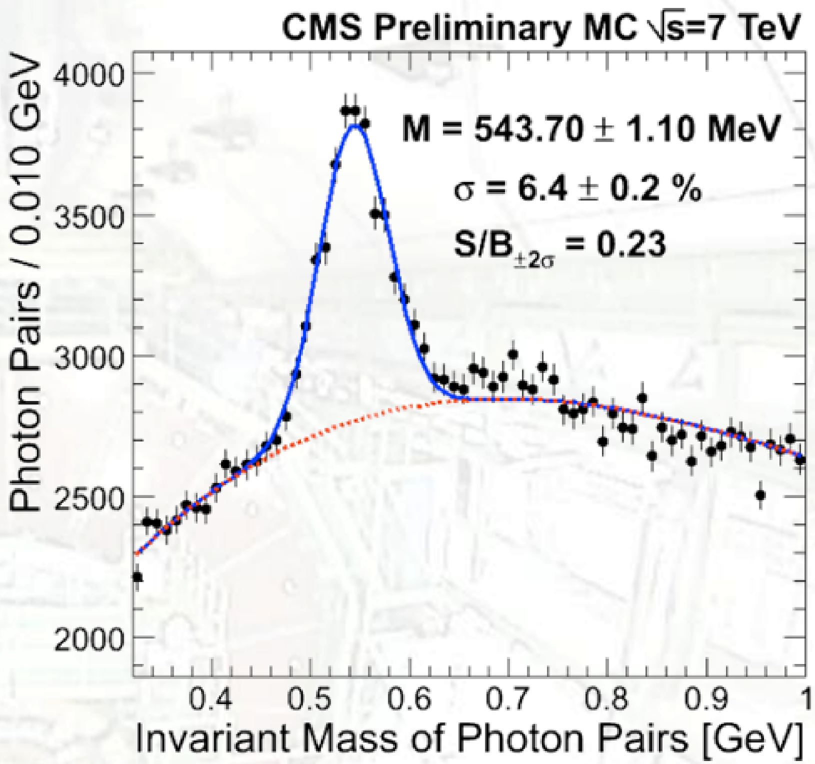




Using 0.43 nb^{-1} of data.
Fit to Gaussian on top of 2nd order polynomial background.
Good agreement with MC. 1441K γγ pairs within the peak.

Diphoton resonances: η





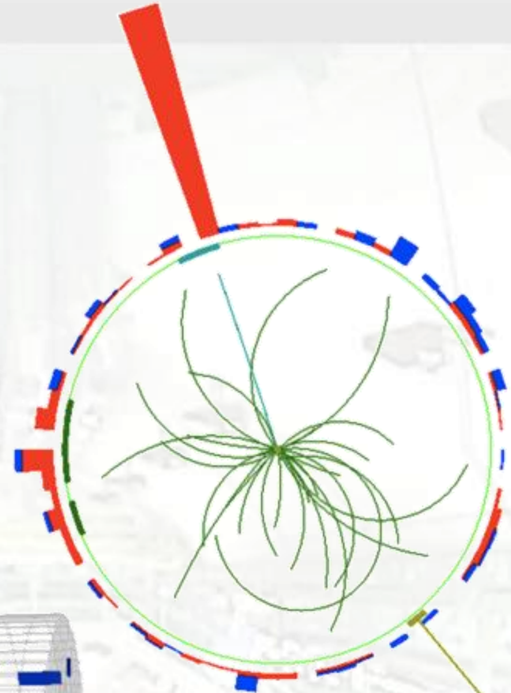
Using 0.43 nb^{-1} of data.

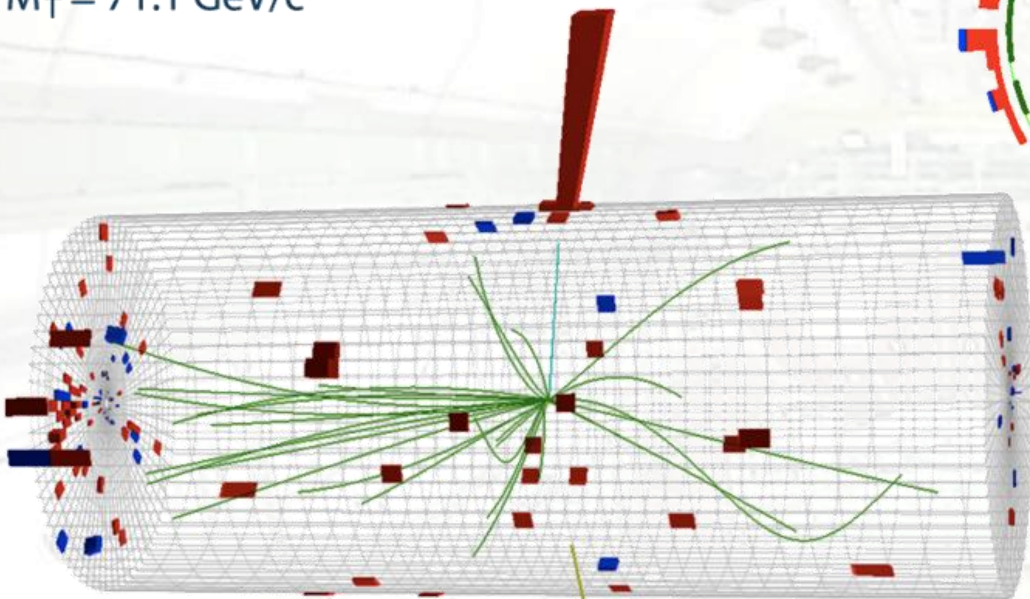
Fit to Gaussian on top of 2^{nd} order polynomial background.

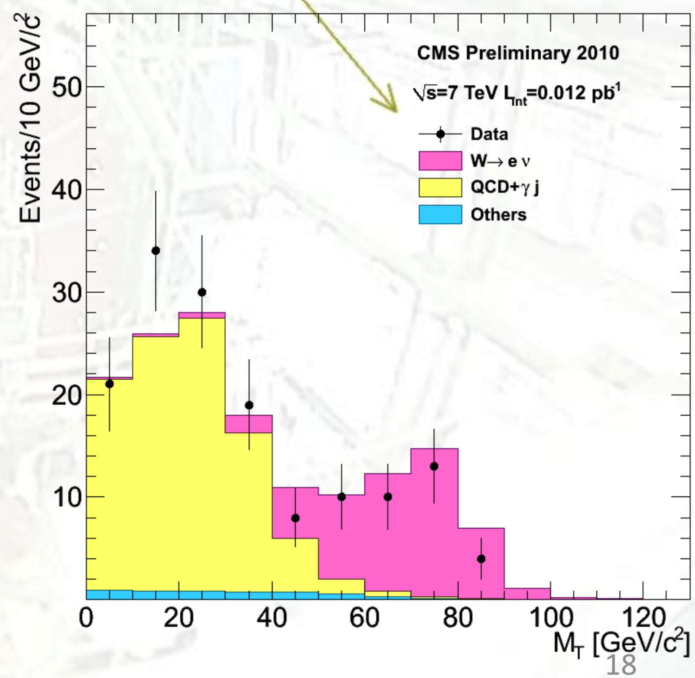
Good agreement with MC. 25.5K γγ pairs within the peak.

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



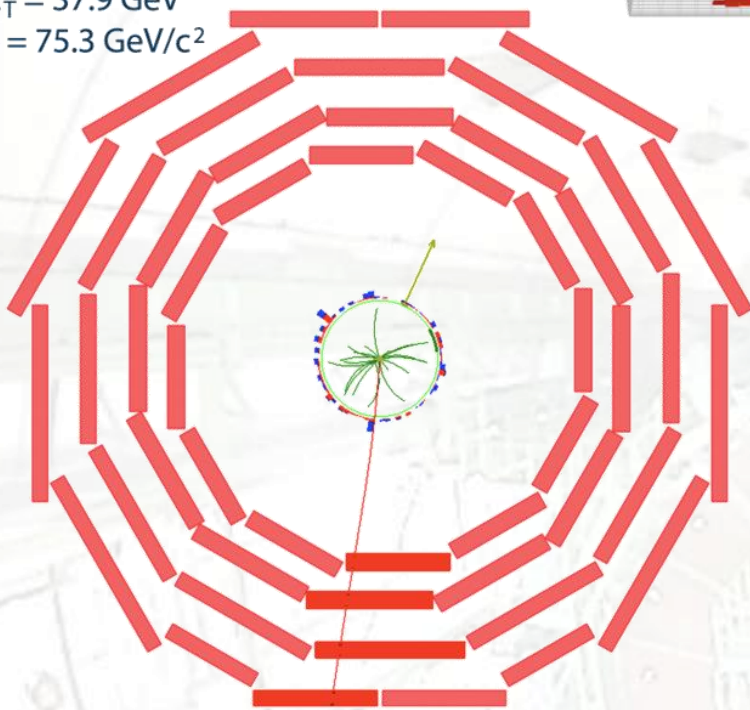


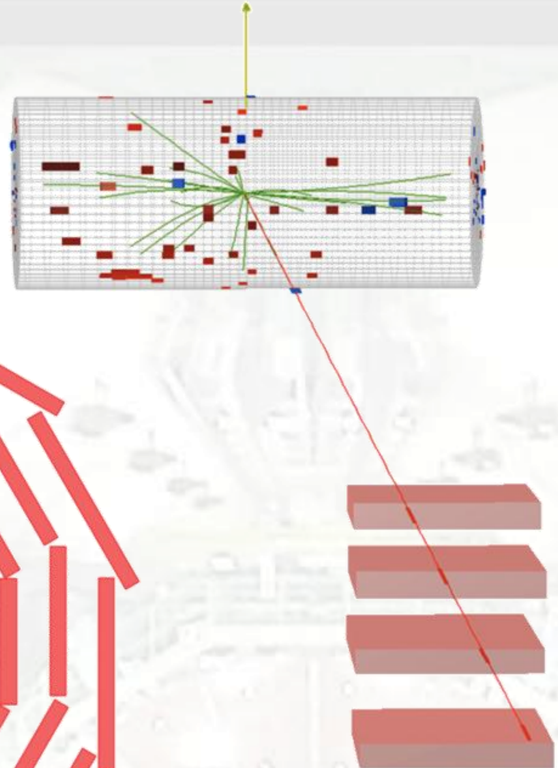


W -> eν candidate

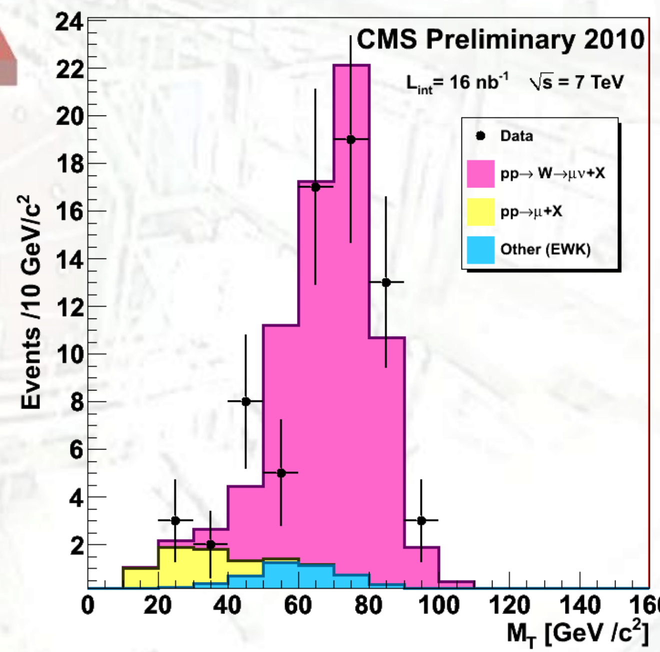
CMS Experiment at LHC, CERN
Run 133875, Event 1228182
Lumi section: 16
Sat Apr 24 2010, 09:08:46 CEST

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





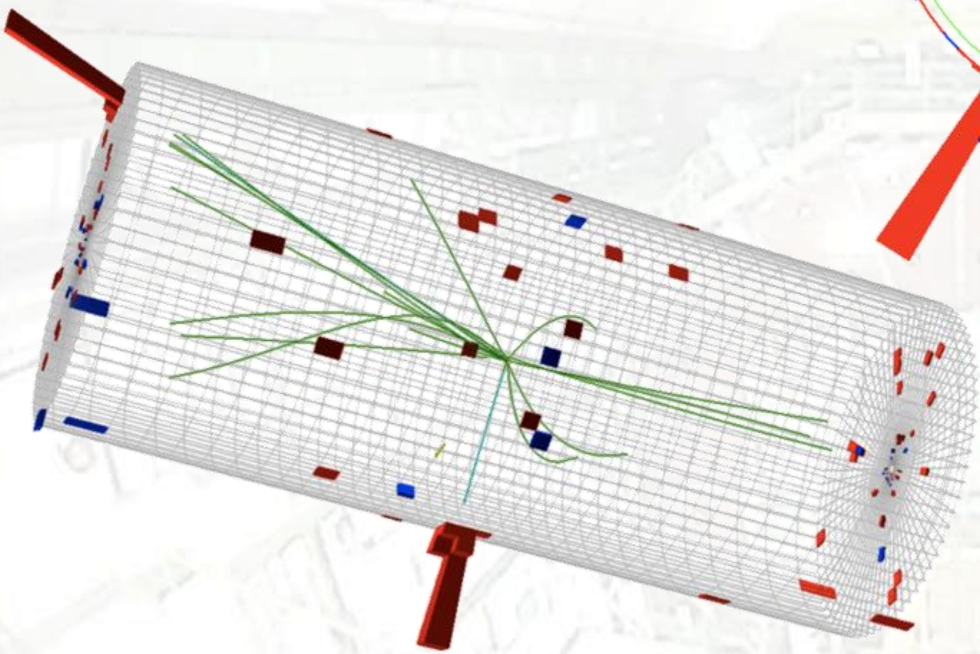
W -> μν candidate

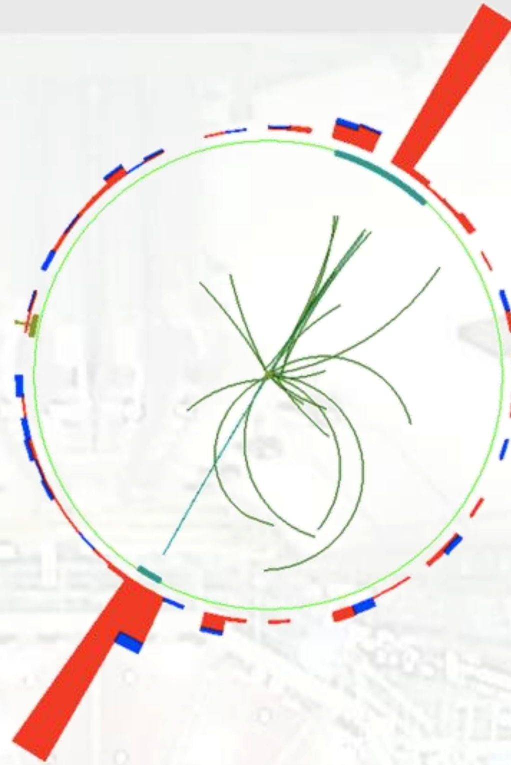


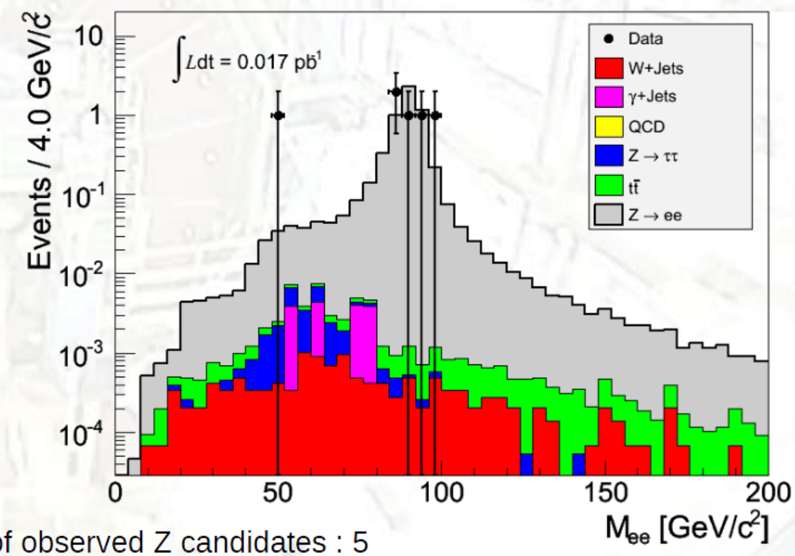
CMS Experiment at LHC, CERN
Run 133877, Event 28405693
Lumi section: 387
Sat Apr 24 2010, 14:00:54 CEST

Electrons p_T = 34.0, 31.9 GeV/c
Inv. mass = 91.2 GeV/c^2

Z -> e+e- candidate



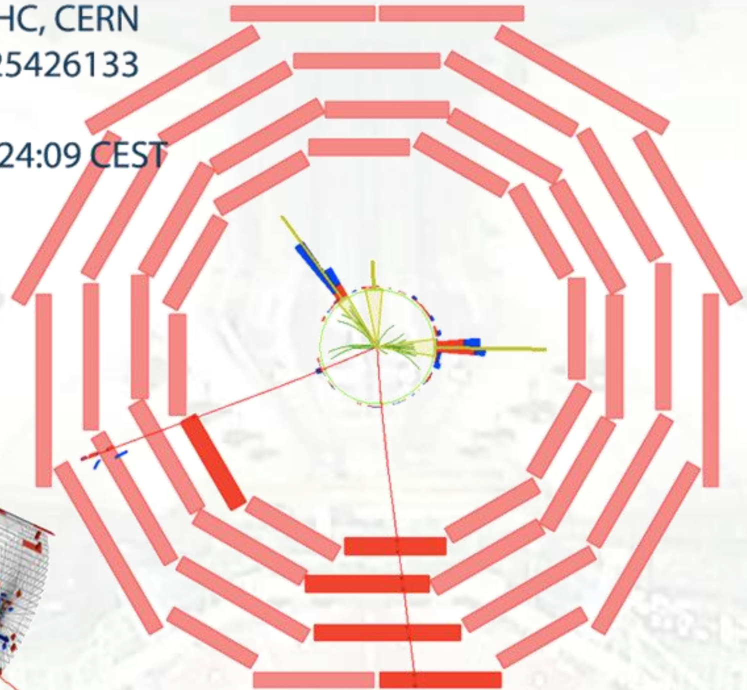




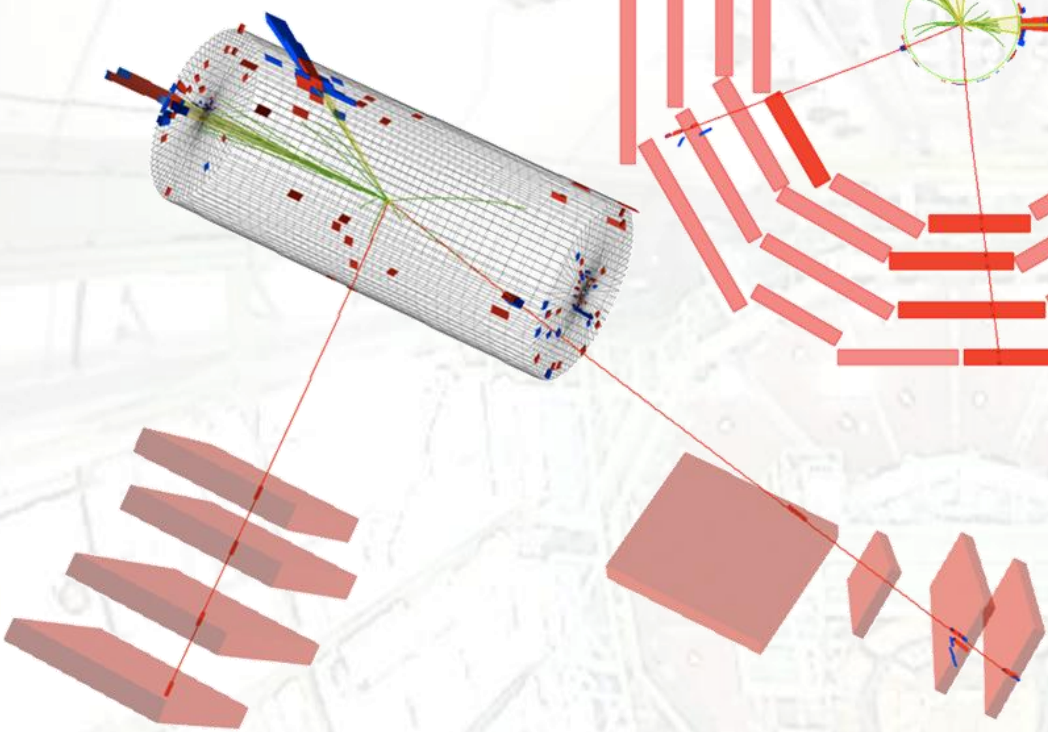
- Number of observed Z candidates : 5

cmseye07 2010-06-02 15:25:12

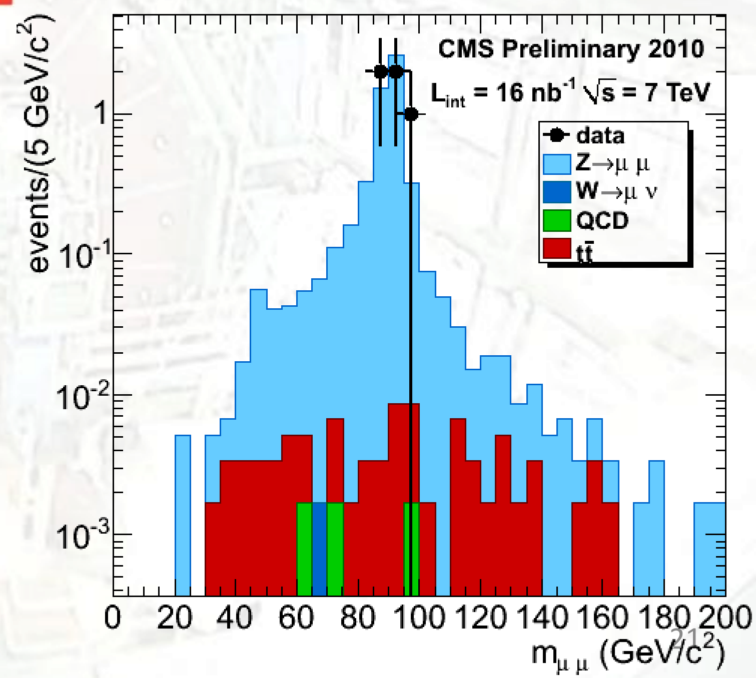
CMS Experiment at LHC, CERN
Run 135149, Event 125426133
Lumi section: 1345
Sun May 09 2010, 05:24:09 CEST



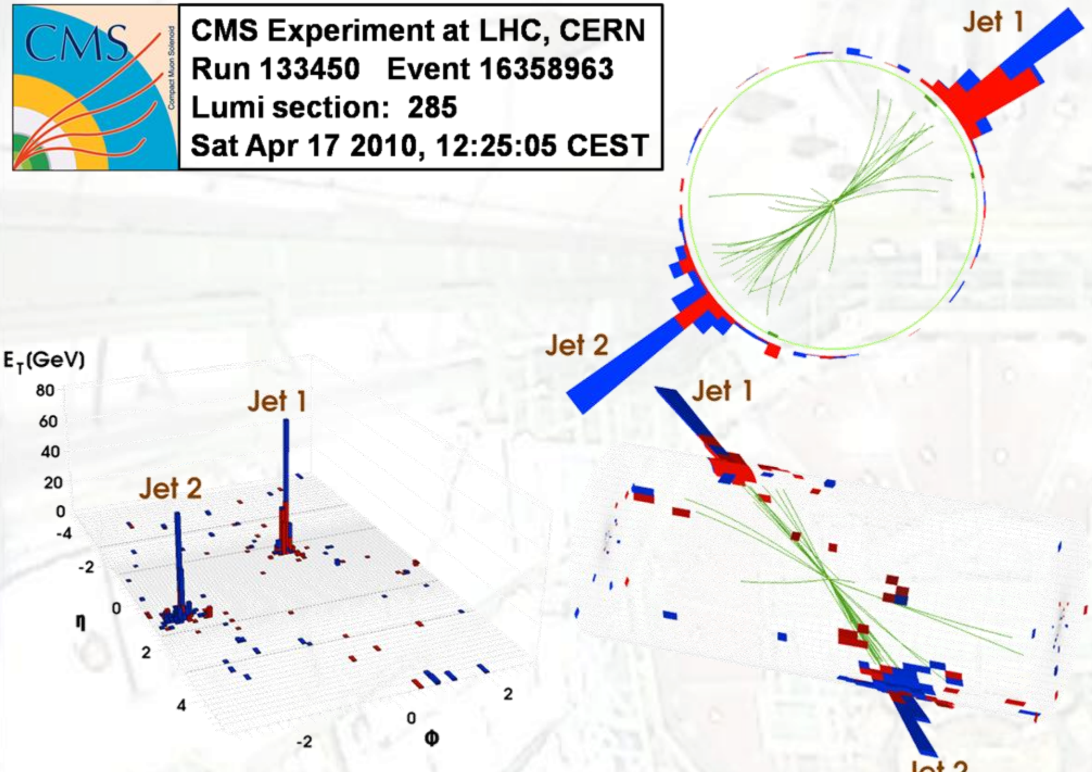
Muon p_T = 67.3, 50.6 GeV/c
Inv. mass = 93.2 GeV/c^2



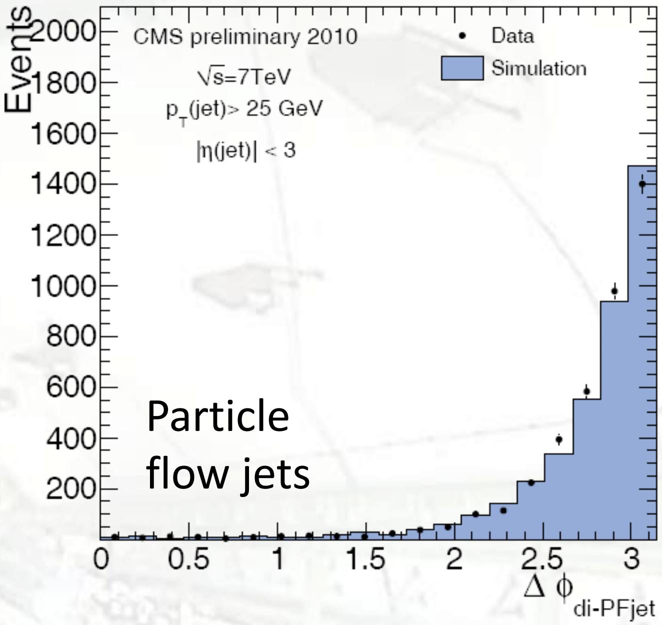
Z -> μ+μ- candidate

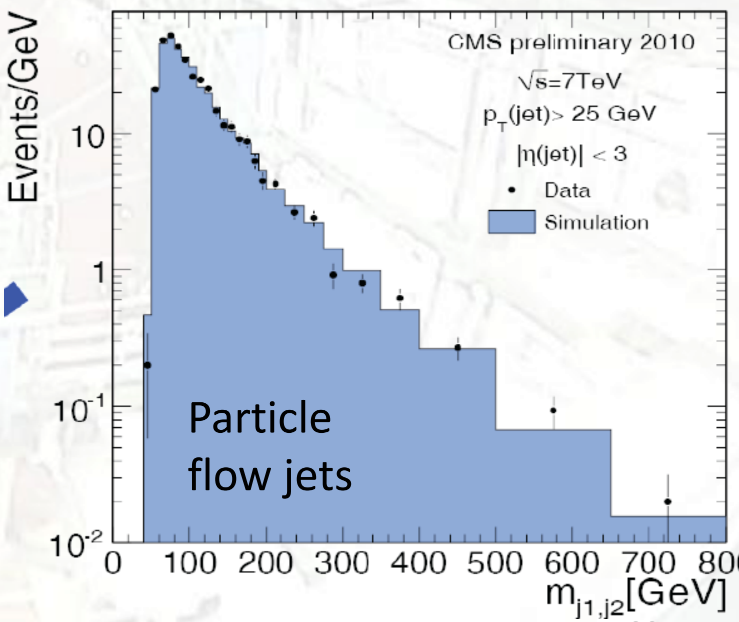


Jets

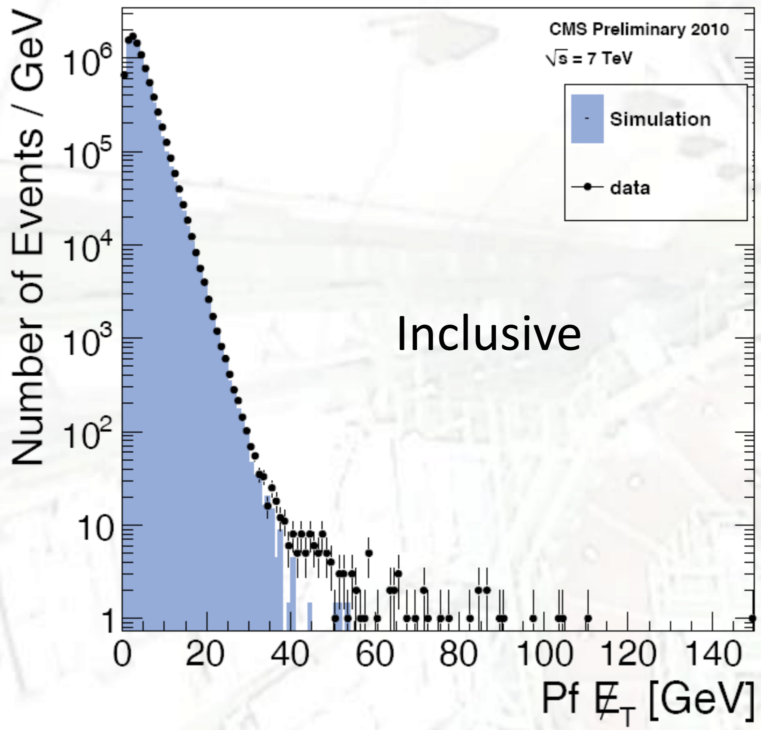


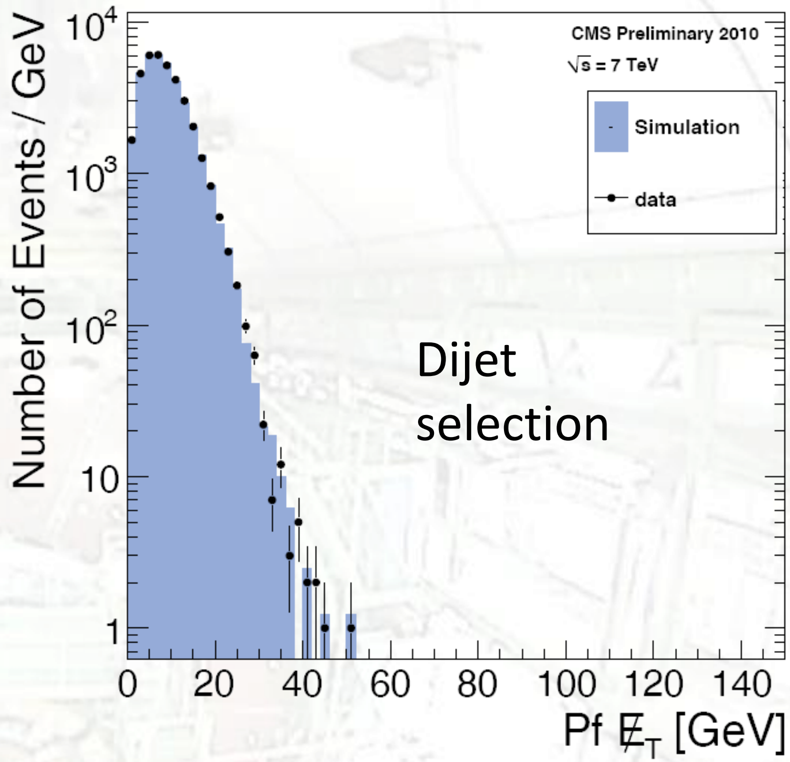
Dijet event



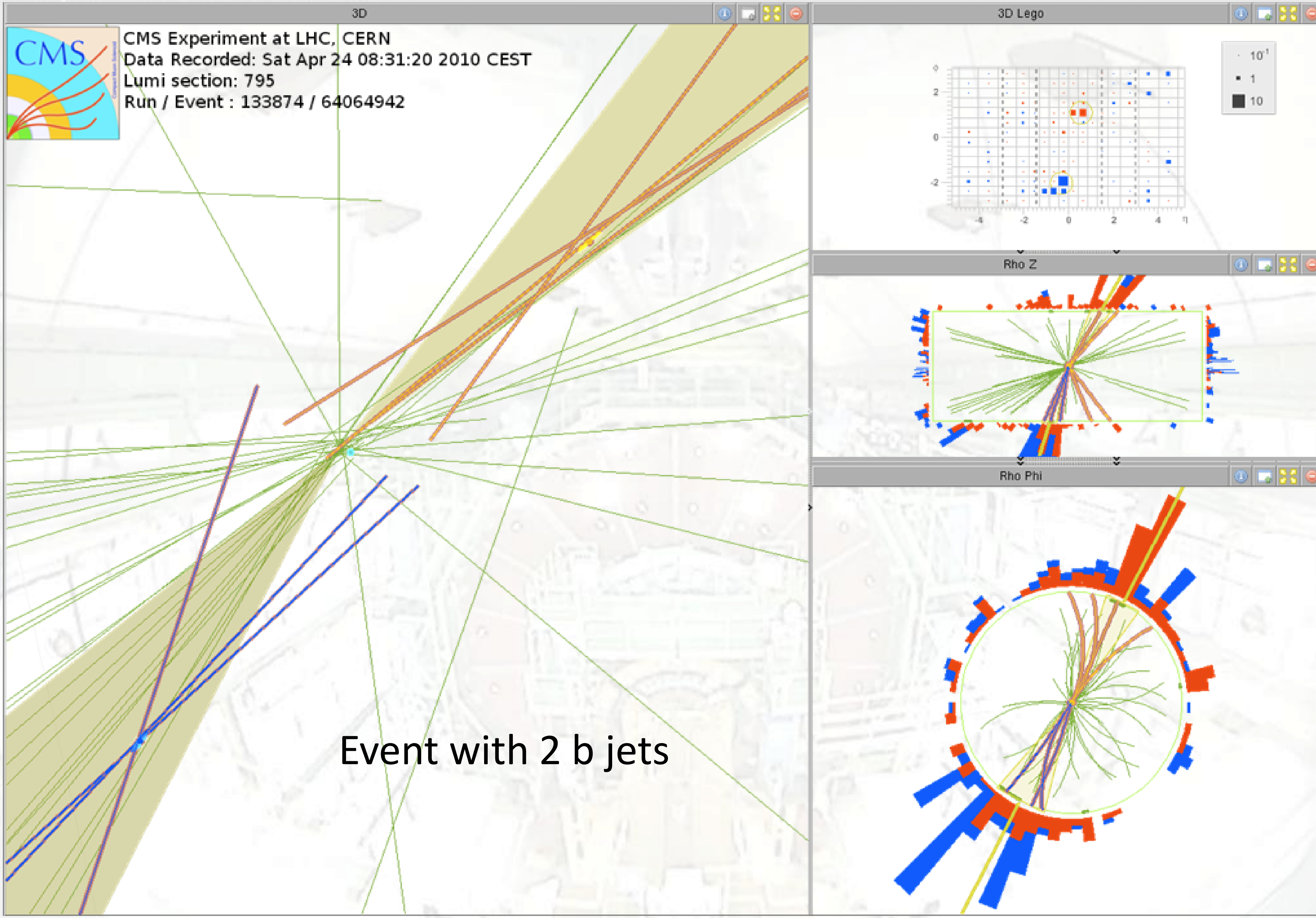


Missing energy





MET overall well described. More tails in data. New methods being investigated for cleaning noise.



Event with 2 b jets


CMS
At CMS, can’t do without MC… addicted…

Extensive usage of physics simulation tools at every stage

Before data taking:

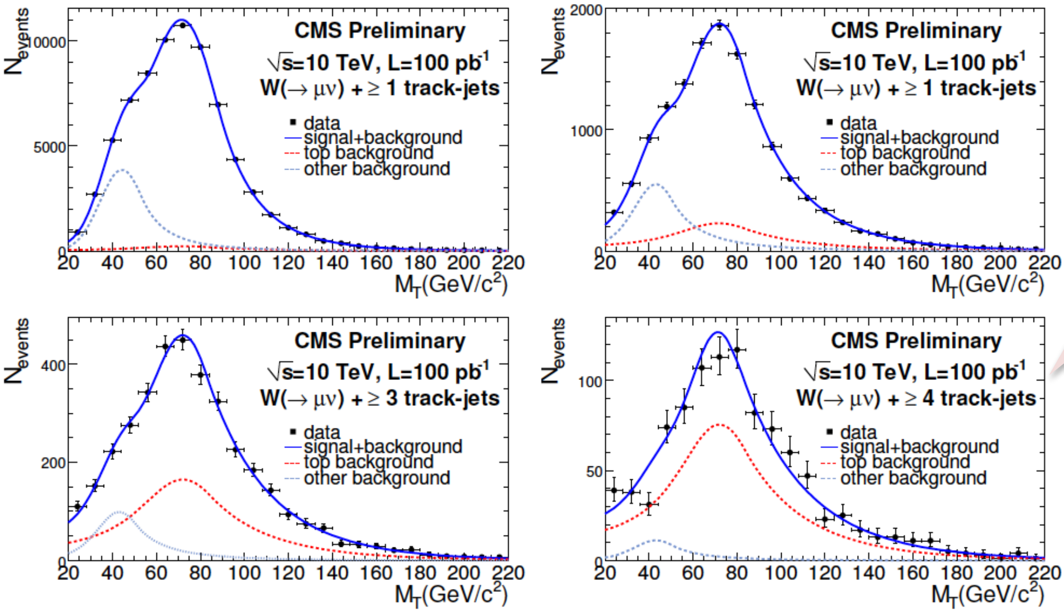
- Test the physics discovery potential/reach of the collider + detector.
- Devise/exercise various measurement methods for observables such as masses, cross sections, BRs, etc.
- Develop data-driven SM background estimation methods
- …

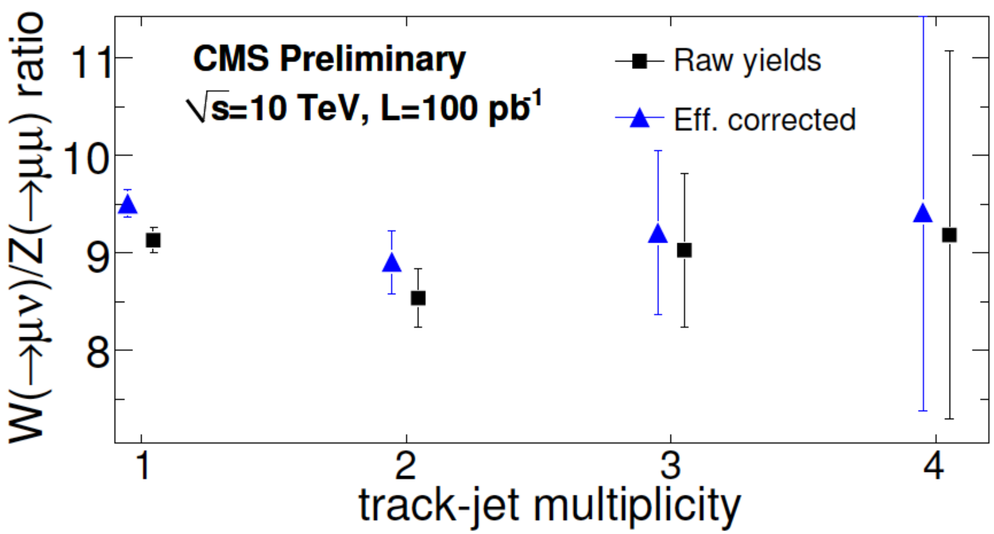
After data taking:

- Extensive MC-data comparisons in all possible parts of the phase space → tuning of MC parameters.
- (Hopefully!) "limited" MC input to data analysis: MC predictions for distributions, cross sections, efficiencies, can be used for well-confirmed cases
- …


without data…

EW physics



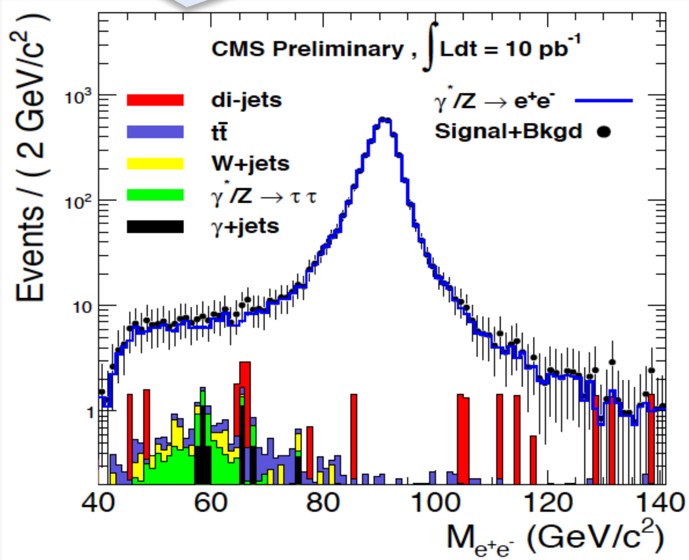


Measure W->njets/Z->njets ratio to test the SM.

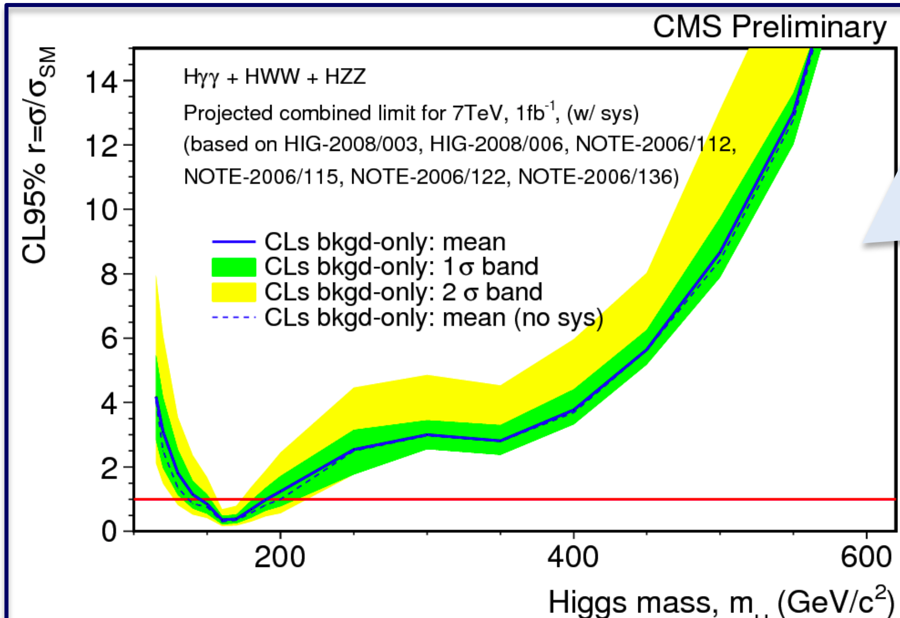
- Number of W+jets events are estimated from an ML fit to the full set of events.
- MadGraph+Pythia6

Z -> ee cross section measurement: the Z(ee) mass

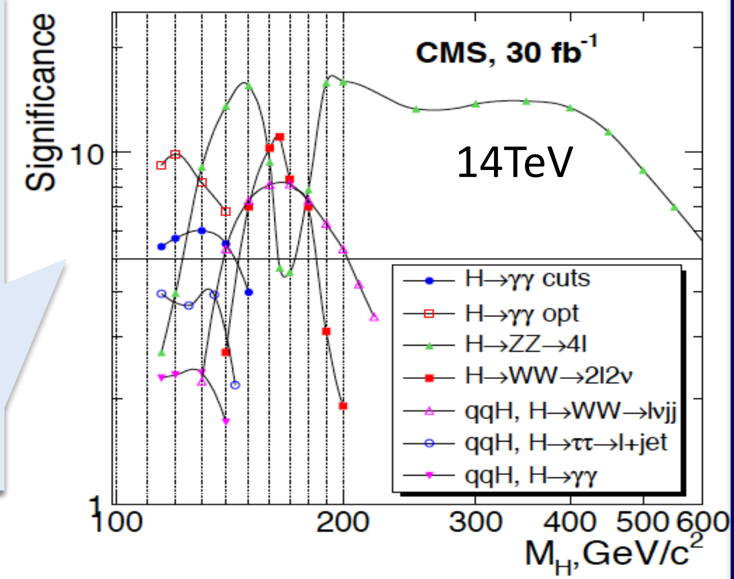
- Pythia6

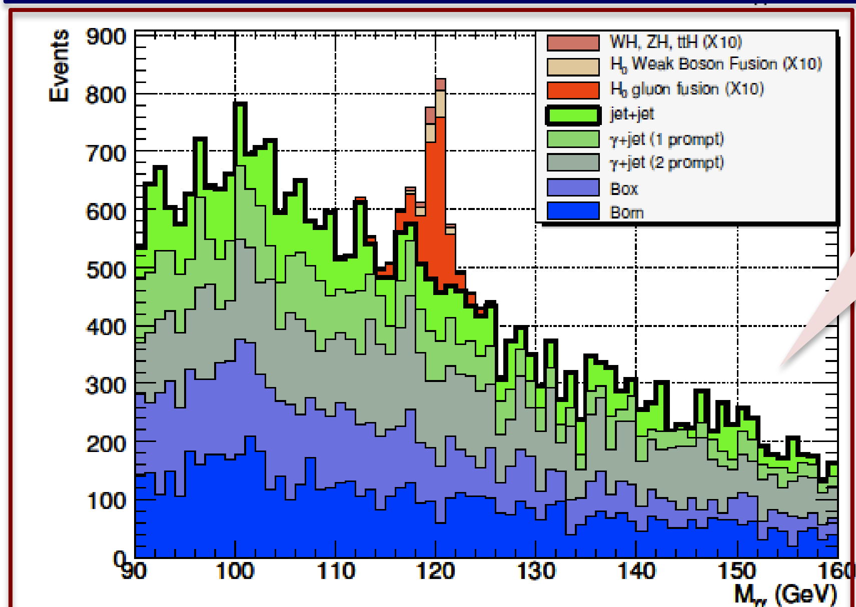


SM Higgs



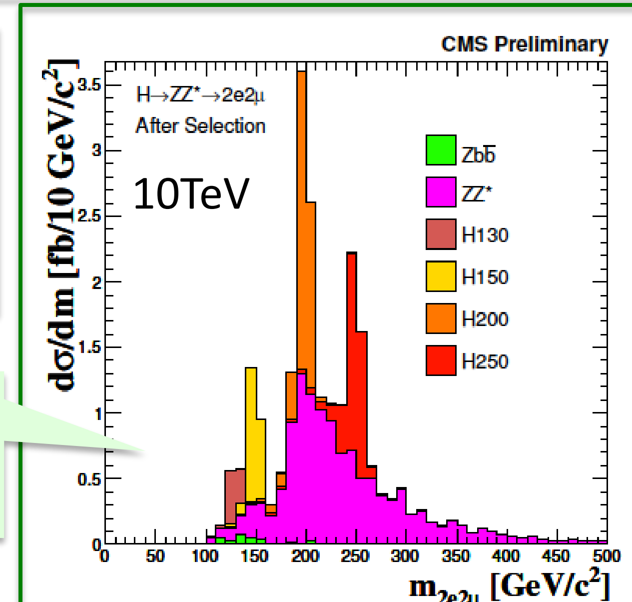
Sensitivity to SM Higgs now and later. Pythia6 (recent work with MC@NLO)





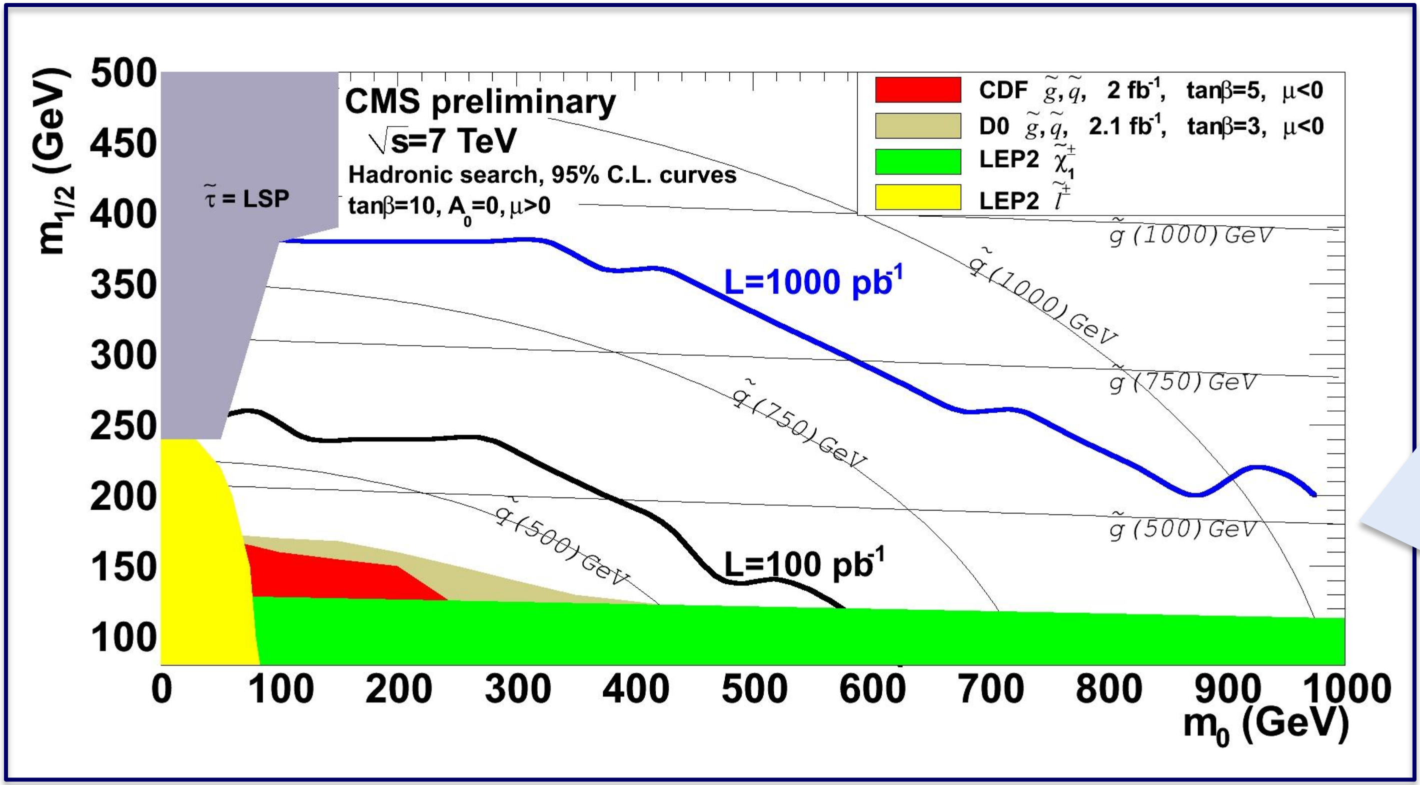
H -> YY searches. Signal magnified by x10 for better visuality! Pythia6

H -> ZZ -> 2e2μ. Pythia6



SUSY: mSUGRA reach@7TeV+multijets+MET

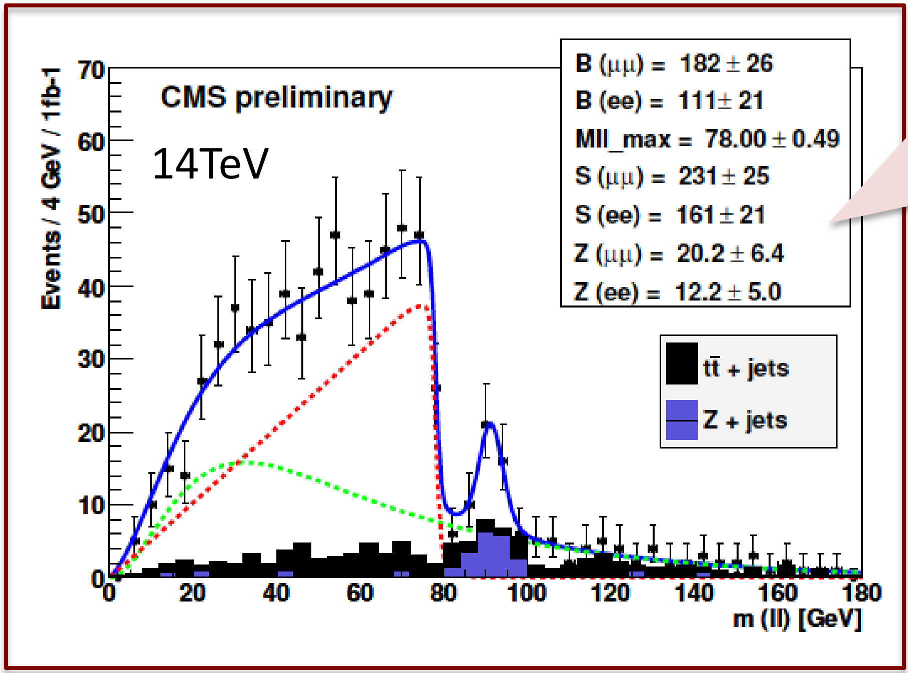
- Currently CMS SUSY generation is done as follows:
  SOFTSUSY (spectra) -> SUSYHIT (decays) -> Pythia6 (generation)
- Past searches used ISAJET (spectra / decays / generation).
- Comparison of SUSY spectrum calculators studied: discrepancies still exist in high m0, A0 and tanβ regions.
- Prospino is used for NLO calculations.



mSUGRA reach:
jets+MET inclusive
(lepton veto)
SoftSUSY + SUSYHIT+ Pythia6

High signal efficiency, but significant BG contamination

SUSY: measurements



Dilepton edge reconstruction –> input to SUSY mass measurements

LM1: m0, mhf, A0, tb, μ = 60, 250, 0, 10, +

SOFTSUSY + SUSYHIT + PYTHIA6

- OSSF dileptons + jets + MET channel
  - M(ll) TH: 78.15 GeV
  - M(ll) measured: 78.00 + 0.49 GeV

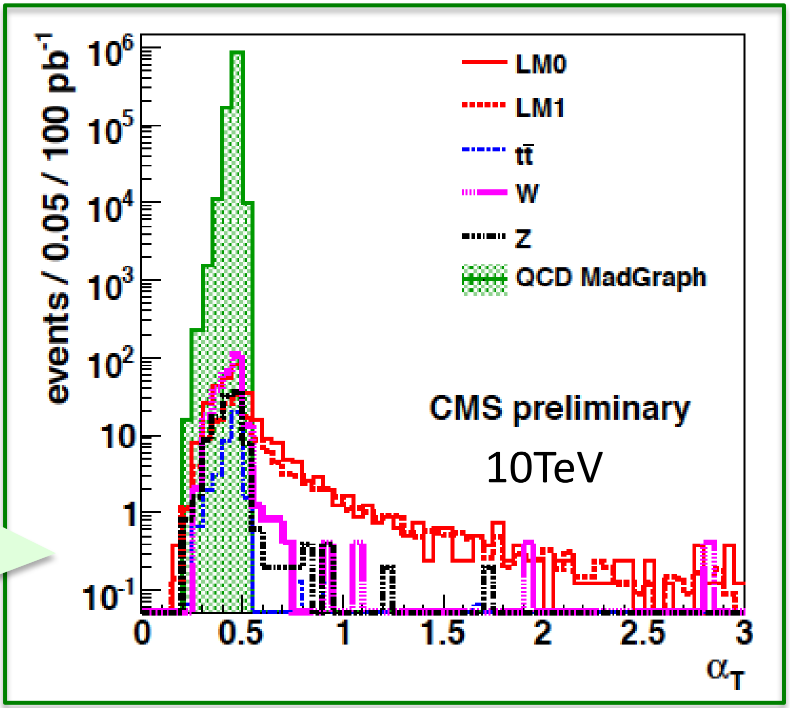
Testing Randall & Tucker-Smith αT:

αT = ET(j2) / MT

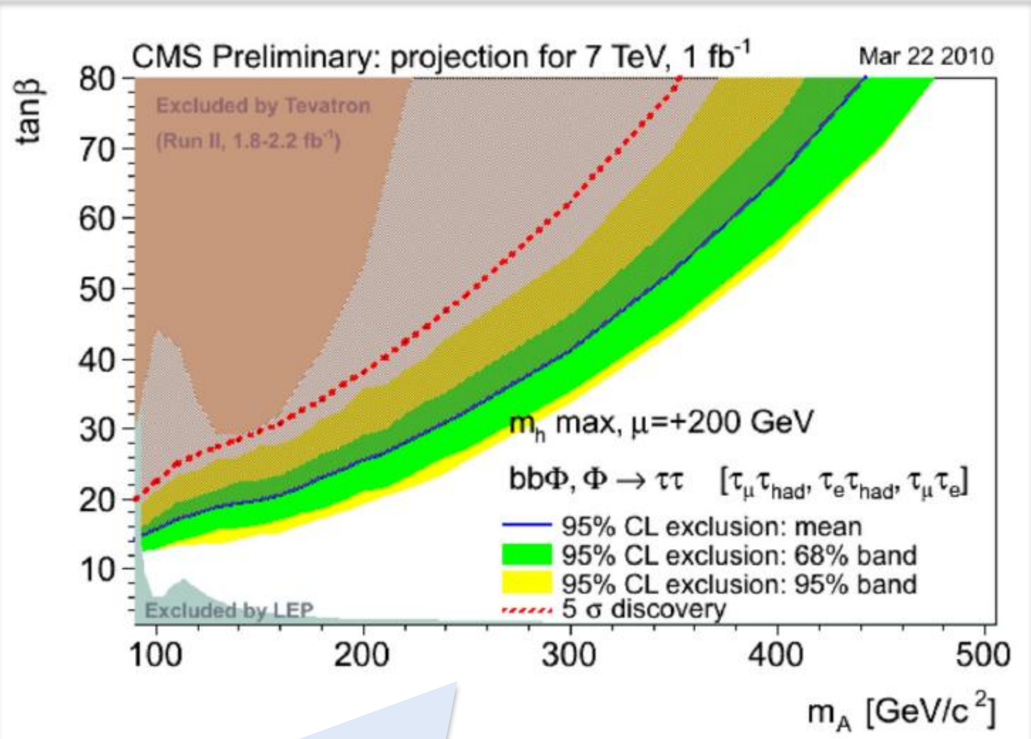
The ratio cancels detector resolution effects

Very useful variable in QCD background discrimination and estimation – **can't ever rely on MC for QCD!!!**

SOFTSUSY + SUSYHIT + Pythia



SUSY Higgs

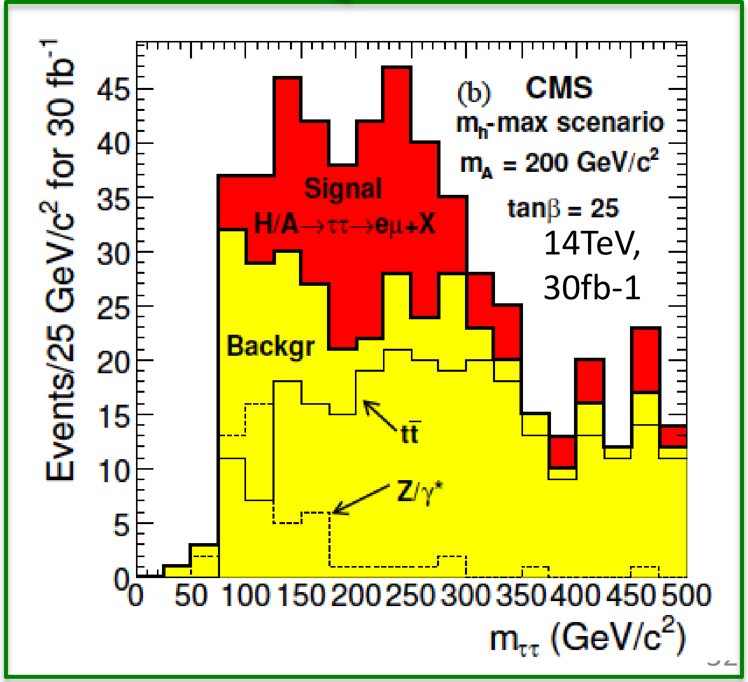


MSSM neutral Higgs discovery reach:

- Associated production with b jets with τ decays: pp -> bbΦ(-> ττ) , where Φ = h, H, A
    - Signal events: Pythia6 -> TAUOLA
    - NLO cross sections: MCFM
    - Branching ratios: FeynHiggs

Pseudoscalar Higgs (m_A) peak

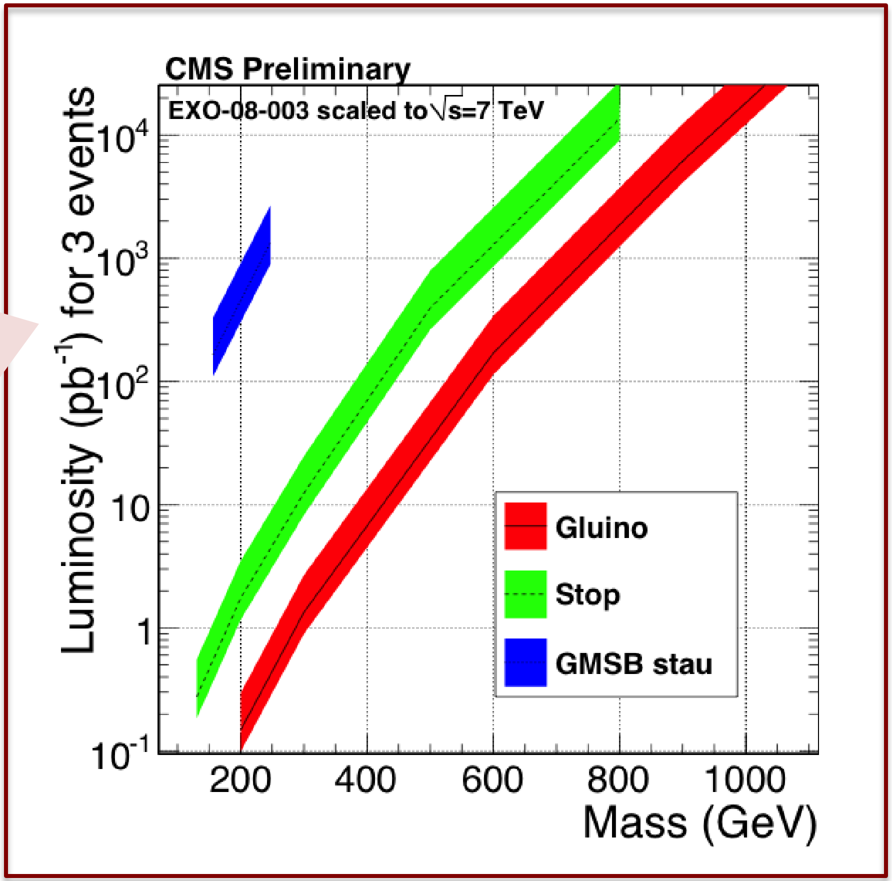
- pp -> bbA(-> ττ)
- m_A = 140 GeV, tanβ = 20
    - Signal events: Pythia6 ->TAUOLA
    - NLO cross sections: MCFM
    - Branching ratios: FeynHiggs

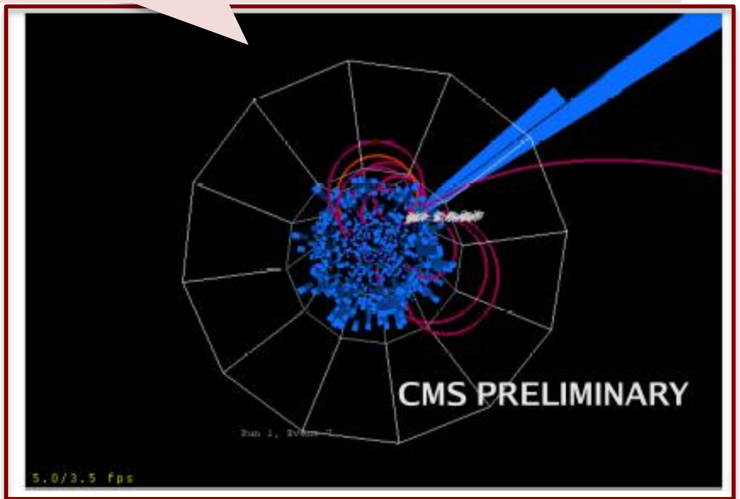


Heavy stable charged particles

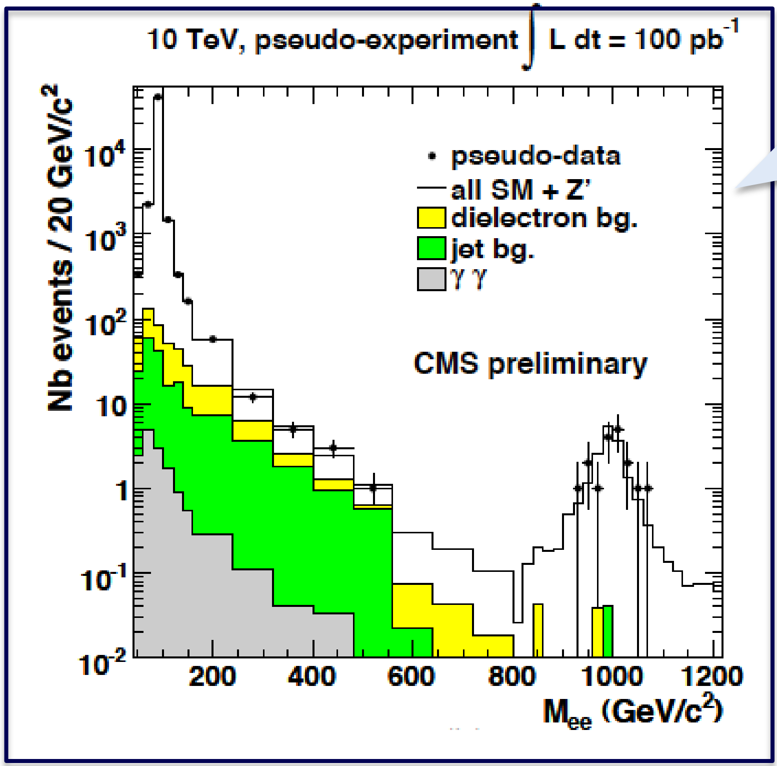
Reach for heavy charged "stable" particles (HCSP) – Pythia6

- HCSP arise in different models, e.g.: SUSY with gravitino LSP, SUSY with stop LSP, split SUSY, some UED models, etc.
- HCSP have **muon-like signature** – but they have low velocity - **non-relativistic**
- Measure β using tracker dE/dx and muon time of flight and calculate the mass.
- Negligible backgrounds



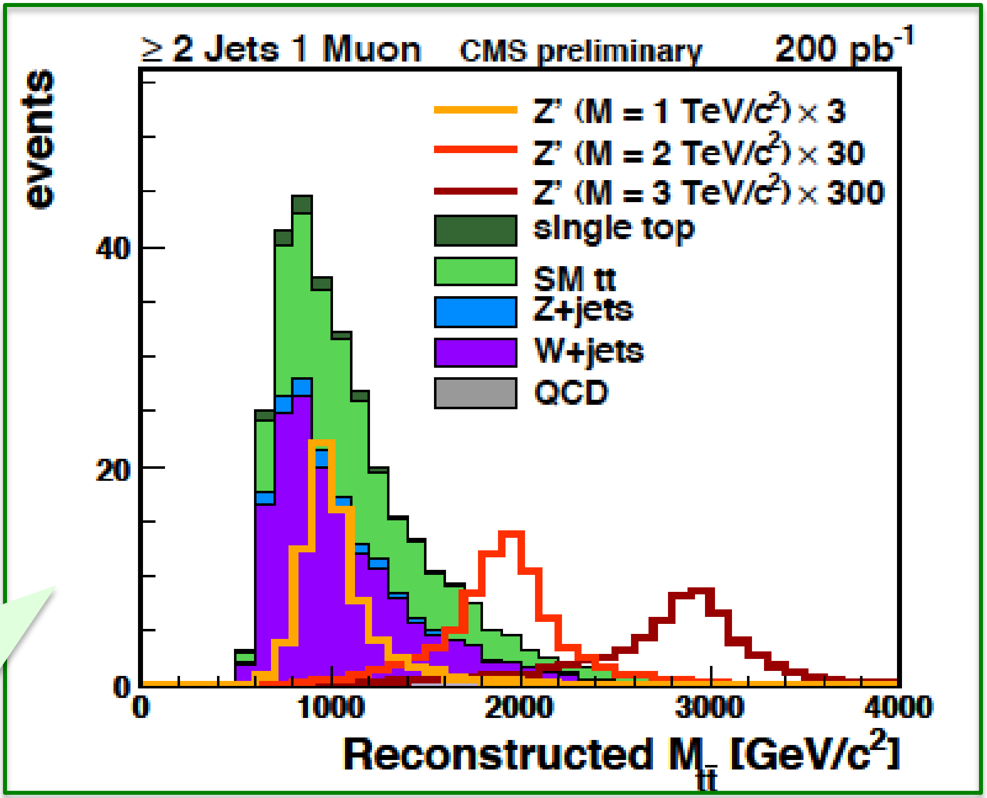


Z prime



Z' mass reconstruction in the dielectron channel: m(Z') = 1 TeV – PYTHIA8

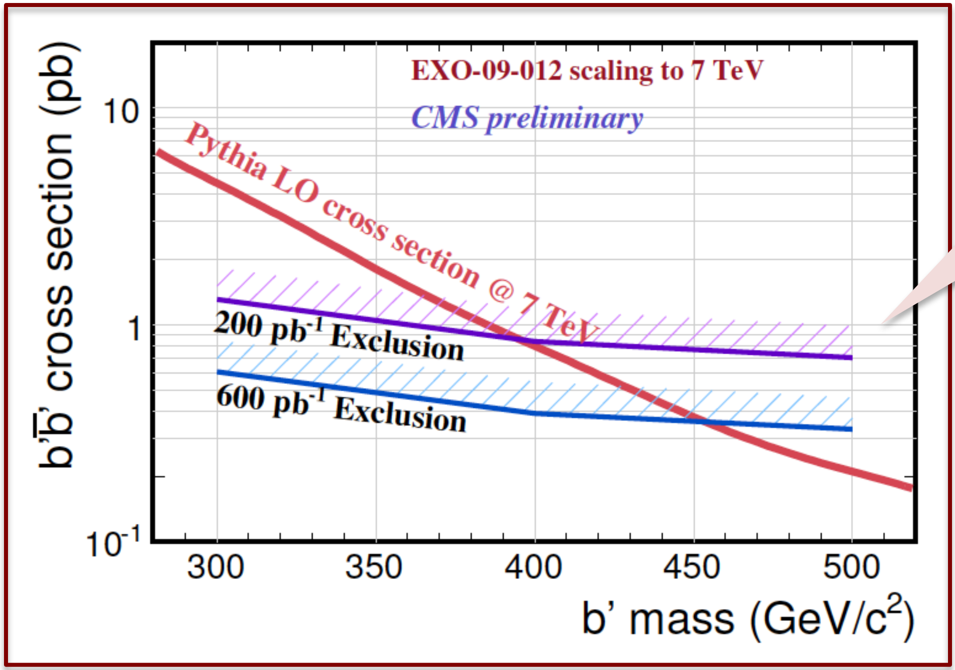
Pseudo-data: Set of events taken randomly from MC such that number of events exactly correspond to the L of interest – can model expected statistical errors.



Z' mass reconstruction for Z' -> tt.

- Used boosted tops, with one top decaying to bμν, other hadronically
- Signals are magnified – good modeling of BG necessary
- MADGRAPH+PYTHIA6 for both signal and majority of backgrounds.

Fourth generation



Sensitivity to b' -> tW for high mass b':

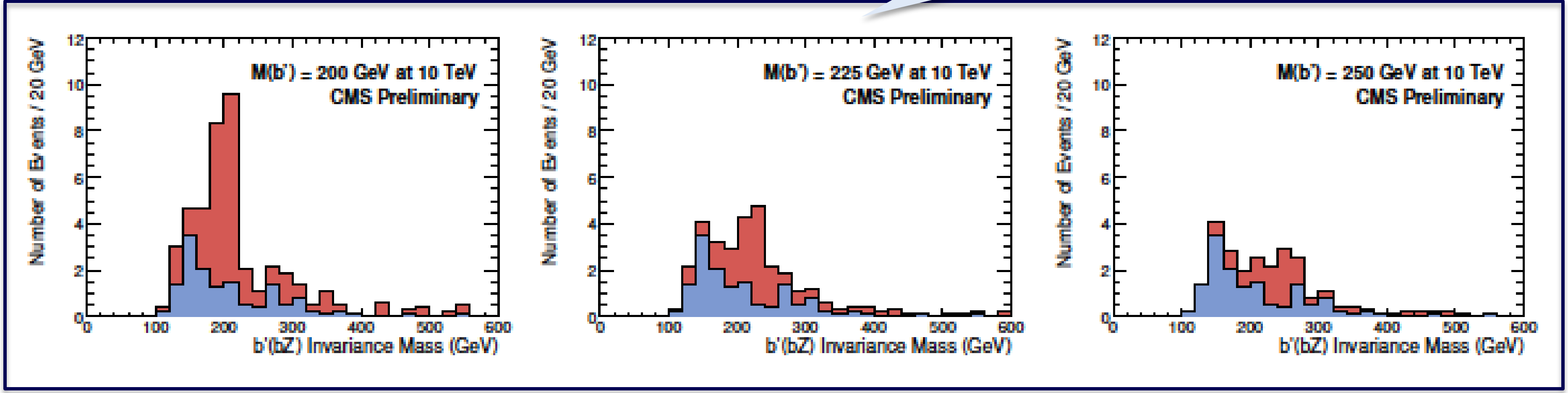
Same sign dilepton or trileptons +jets

PYTHIA6

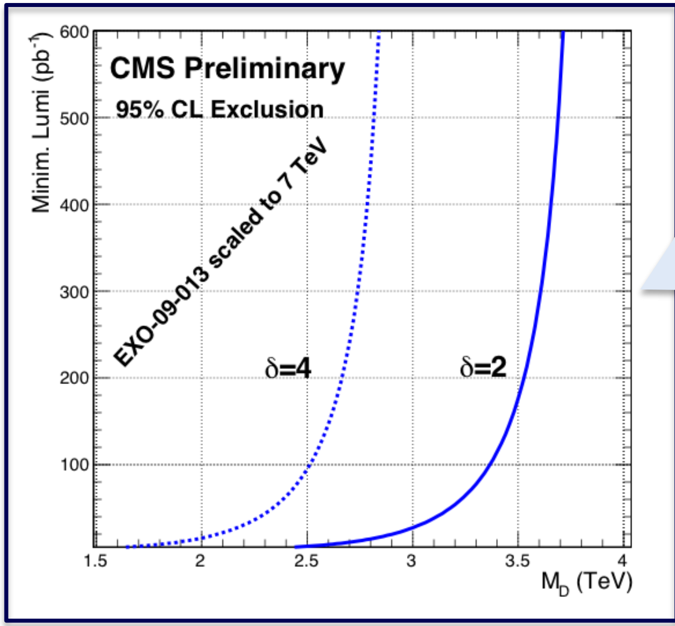
b' mass for low mass b': from b' -> bZ

Multilepton final state

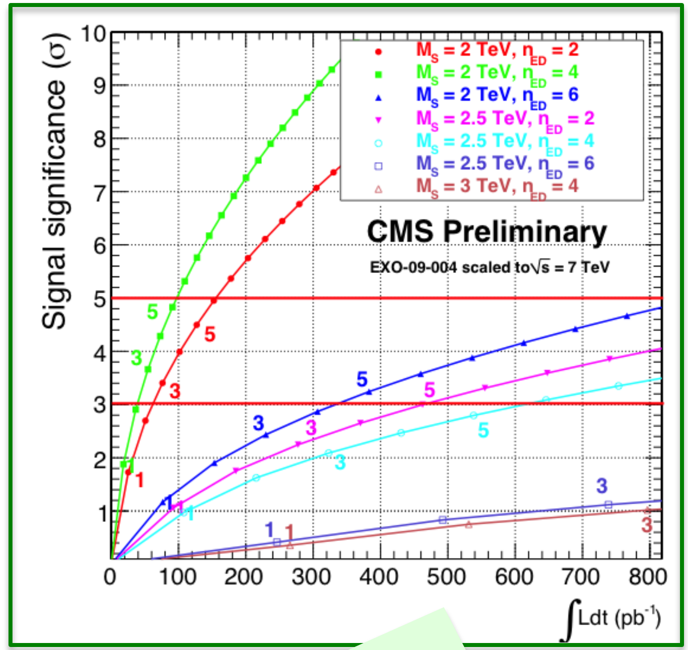
PYTHIA6



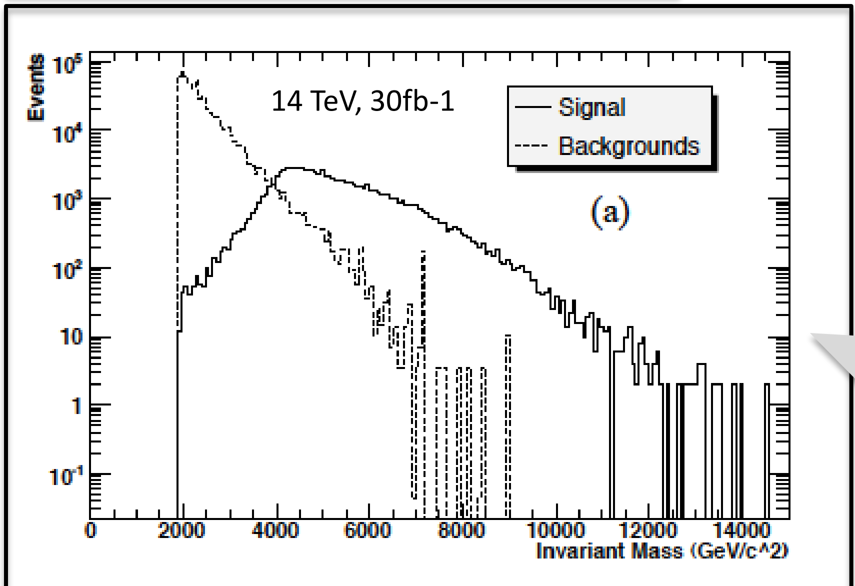
Large Extra Dimensions



ADD graviton reach for monojet
pp -> qG/gG
Single jet+MET channel
SHERPA

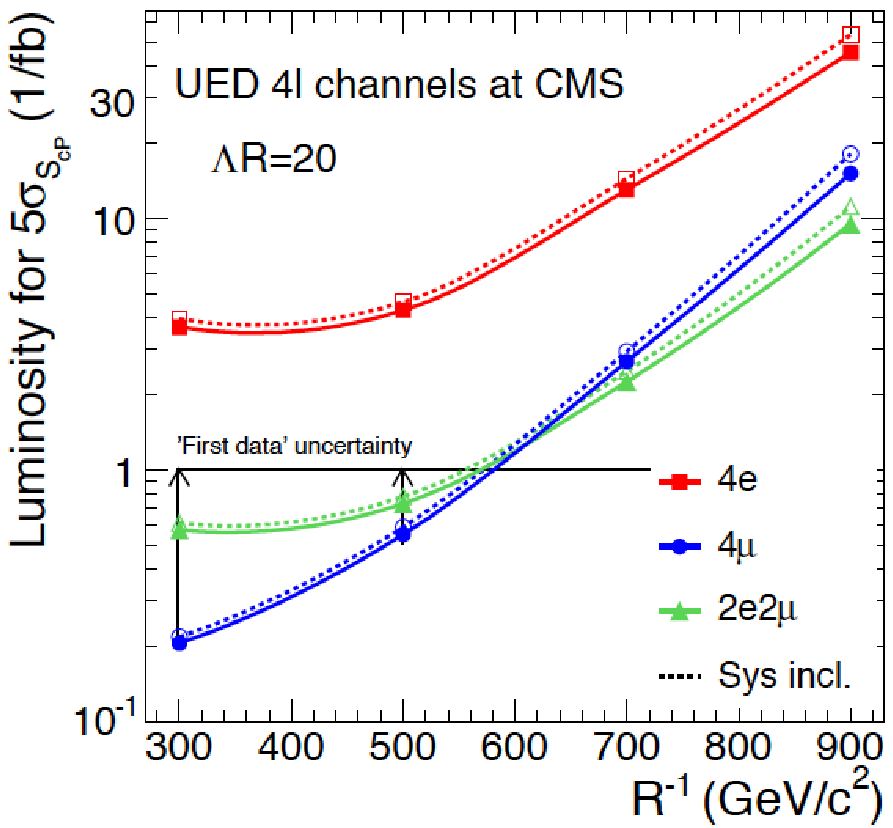


ADD graviton reach for diphotons
Pp -> (virtual ADD G) -> γγ
SHERPA



ADD black holes:
M_D = 2, δ = 3, BH mass = 3-14TeV
Mutijet + multilepton search
CHARYBDIS

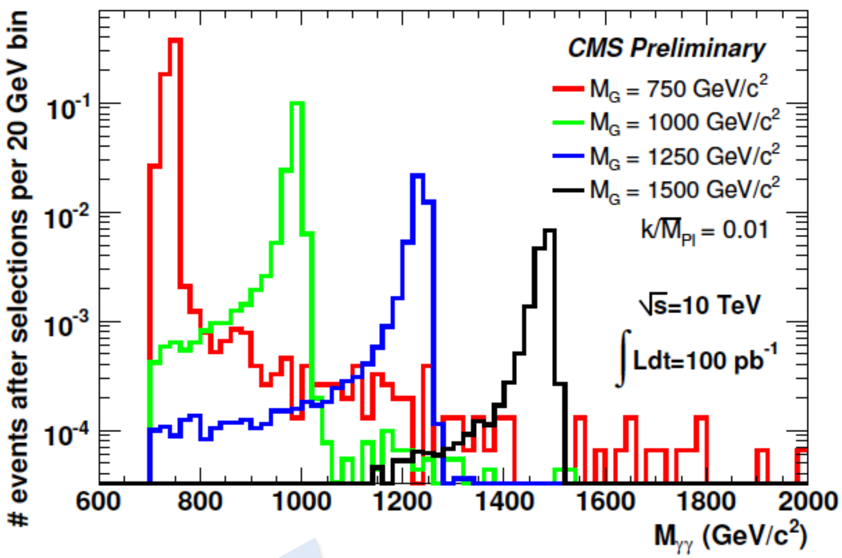
Universal Extra Dimensions

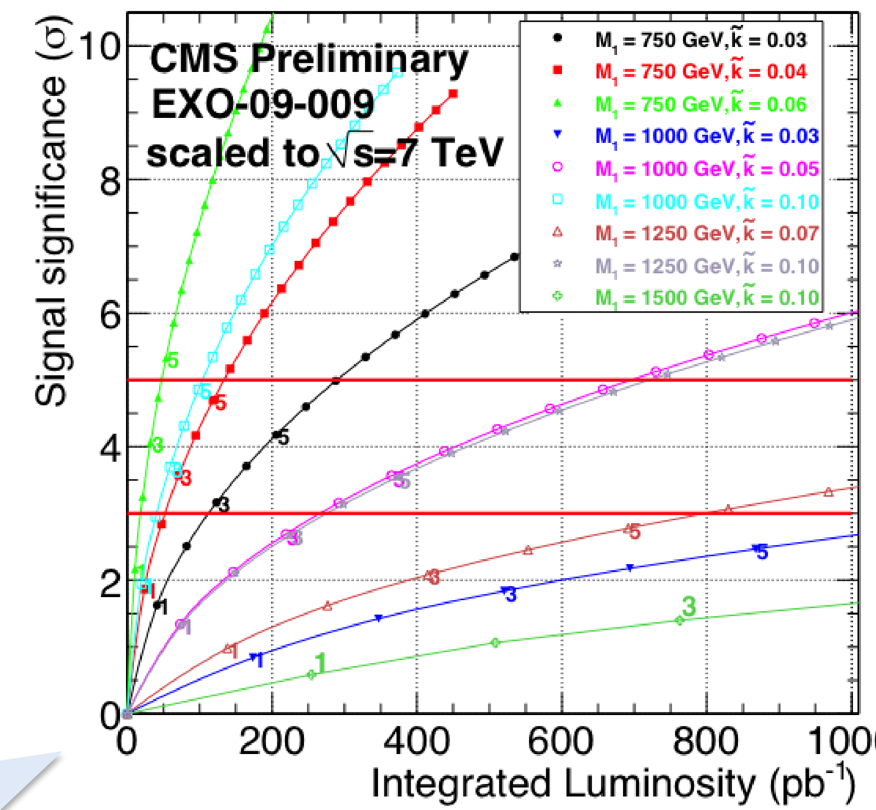


Minimal UED reach.

- Very **compressed spectra**: Mass difference between the heaviest and the lightest mode is O(100 GeV), which leads to **soft SM decay products**.
- 2 pairs of OSSF leptons + MET + b/Z veto
- CompHEP (production) + UUDECAY (KK mode decays)

Randall-Sundrum gravitons



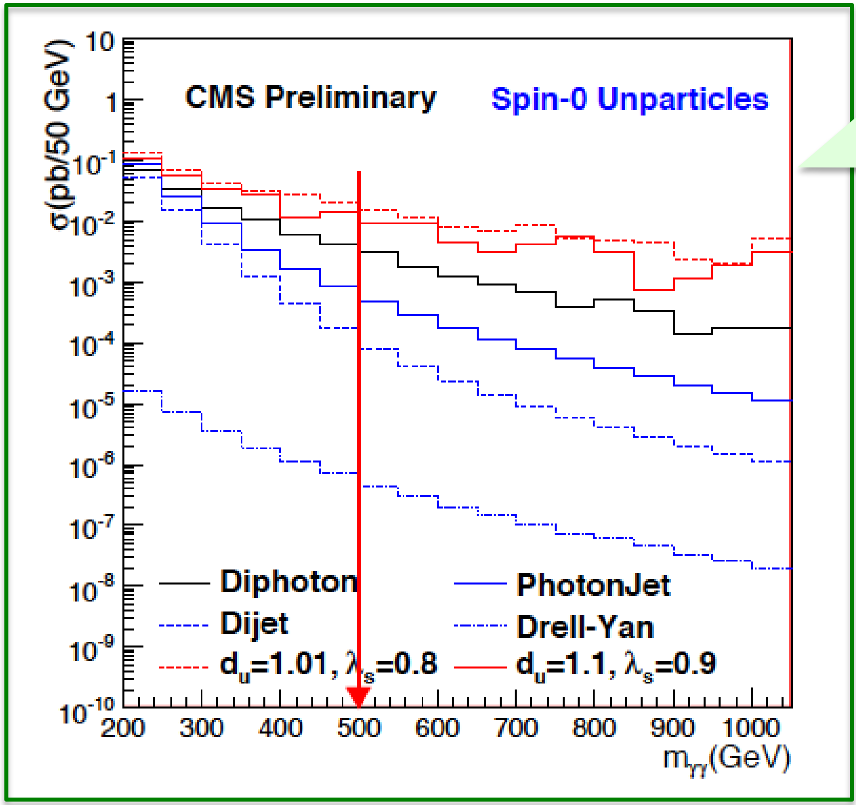


RS gravitons in the diphoton channel:

- Diphoton invariant mass distribution after selection for various graviton masses
- CMS discovery reach

PYTHIA6

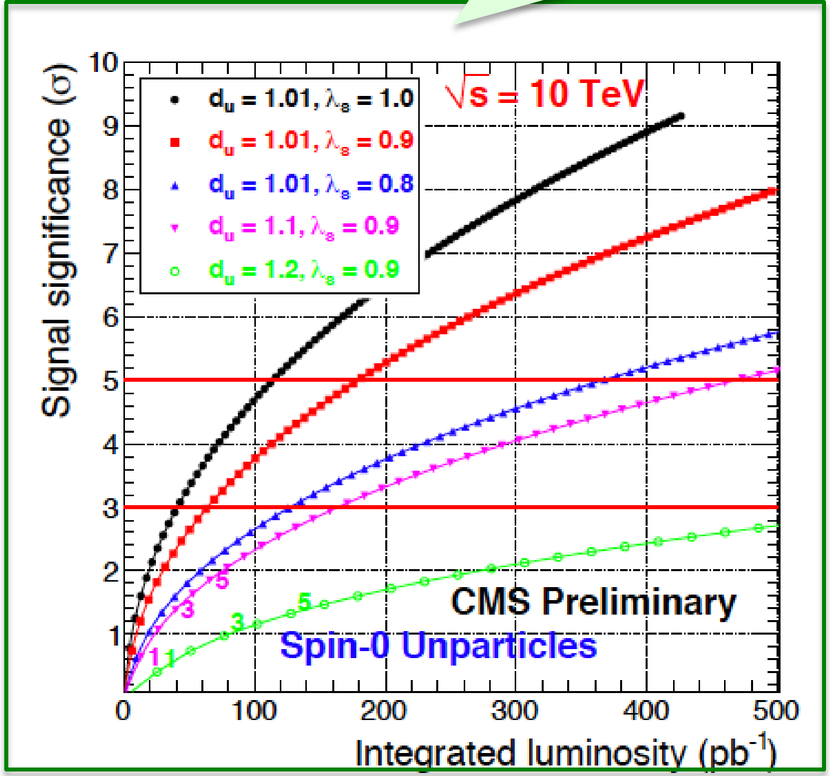
Unparticles



Search for virtual unparticle production with subsequent decay to diphotons

PYTHIA8

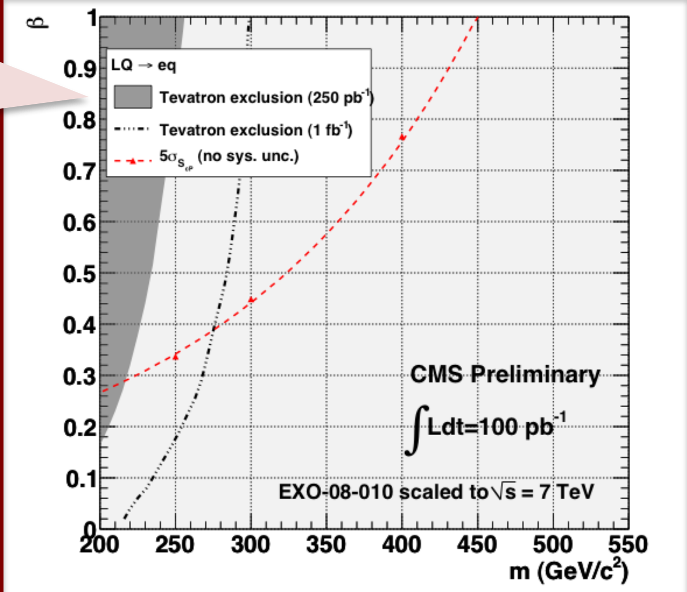
- Diphoton invariant mass
- Unparticle discovery reach



Leptoquarks

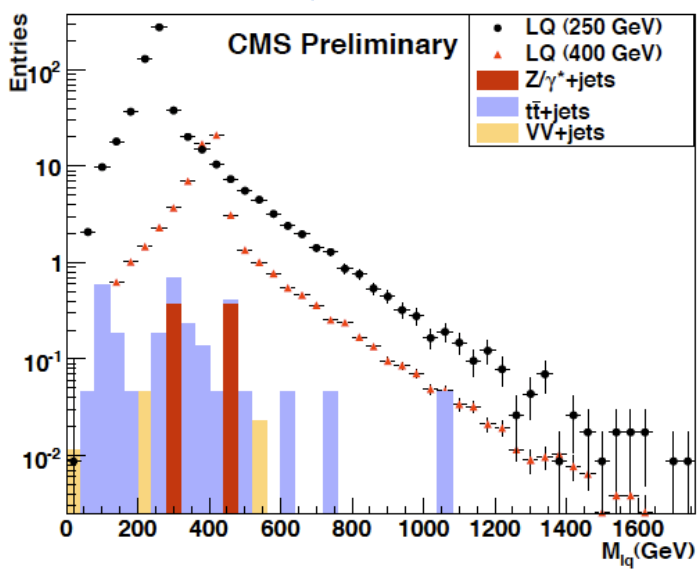
Search for 1st generation scalar LQ pair production:
pp -> LQLQ, LQ -> eν : PYTHIA6

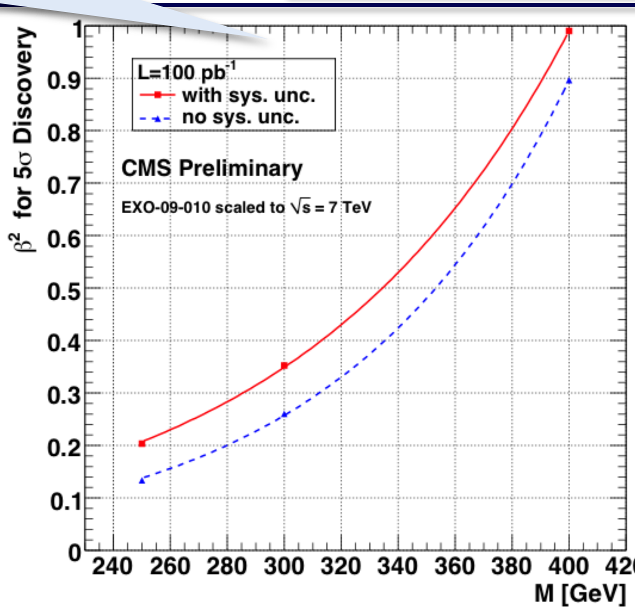
- 2e + ≥2j + high hadronic transverse momentum
- Discovery reach shown



Search for 2nd generation scalar LQ pair production

- Pp -> LQLQ, LQ -> μν : PYTHIA6
- 2μ + ≥2jets + high hadronic transverse momentum
- Reach and reconstruction of LQ mass from μj

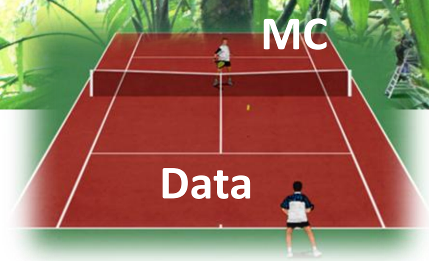





with data...

Tuning the MC: principles

Delicate and *iterative* business

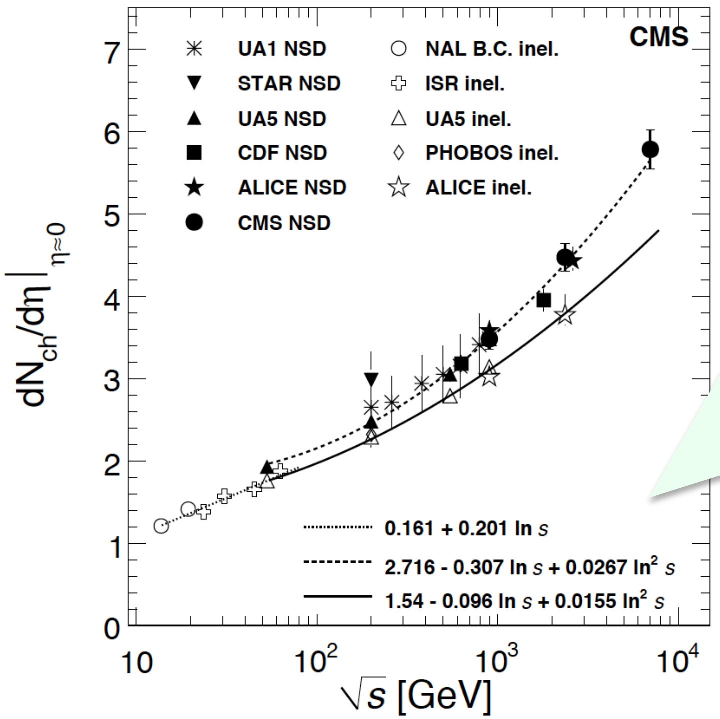


- MC parameters need to be tuned with data
- Starting from the first data, i.e.: measurements on minimum bias and underlying event, all measurements on various processes, energy ranges and various parts of kinematical phase space will contribute iteratively
    - A set of tunable MC parameters x and a set of distributions that are only sensitive to x are selected
    - Several sets of MC events corresponding to real data are generated with various MC parameter sets
    - Distributions from MC and data are compared.
    - The MC parameter set leading to MC distributions that describe the data best is selected as the new tune.

Tuning the MC: How to tune better

- **Majority of tunings done "by-hand".** Recently automated approaches that feature systematic parameter sampling and fits to data are being devised.
  - There are dedicated tools for automated tuning, e.g.: PIVET, PROFESSOR (CMS integration has started)
- **Majority of tunings done based on a single process.** The universal tunes, consistent with all processes can be best found by working with distributions composed of a full set of processes. But, for this we need the closest estimates of cross sections and relative proportions of final states! Theorist friends, help!
- **Majority of tunings do not take into account detector effects.**
  - Work with distributions that are independent of detector effects,
  - Combine detector parameters with MC parameters, and tune the whole set together

Tuning the MC with charged hadron distributions



Charged particle density in central pseudo-rapidity region for non-single-diffractive (NSD) events, for pp collisions at 7TeV at CMS:

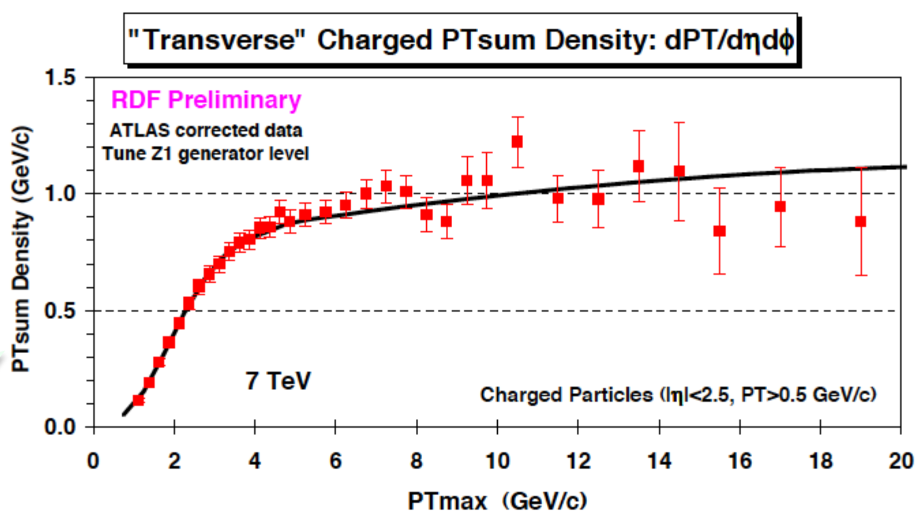
$dN_{ch}/d\eta_{|\eta|<0.5}$ = 5.78 ± 0.01 (stat) ± 0.23 (syst)

This + measurements from other experiments exceed predictions from existing MC parameter sets.
-> a new tune needs to be defined.

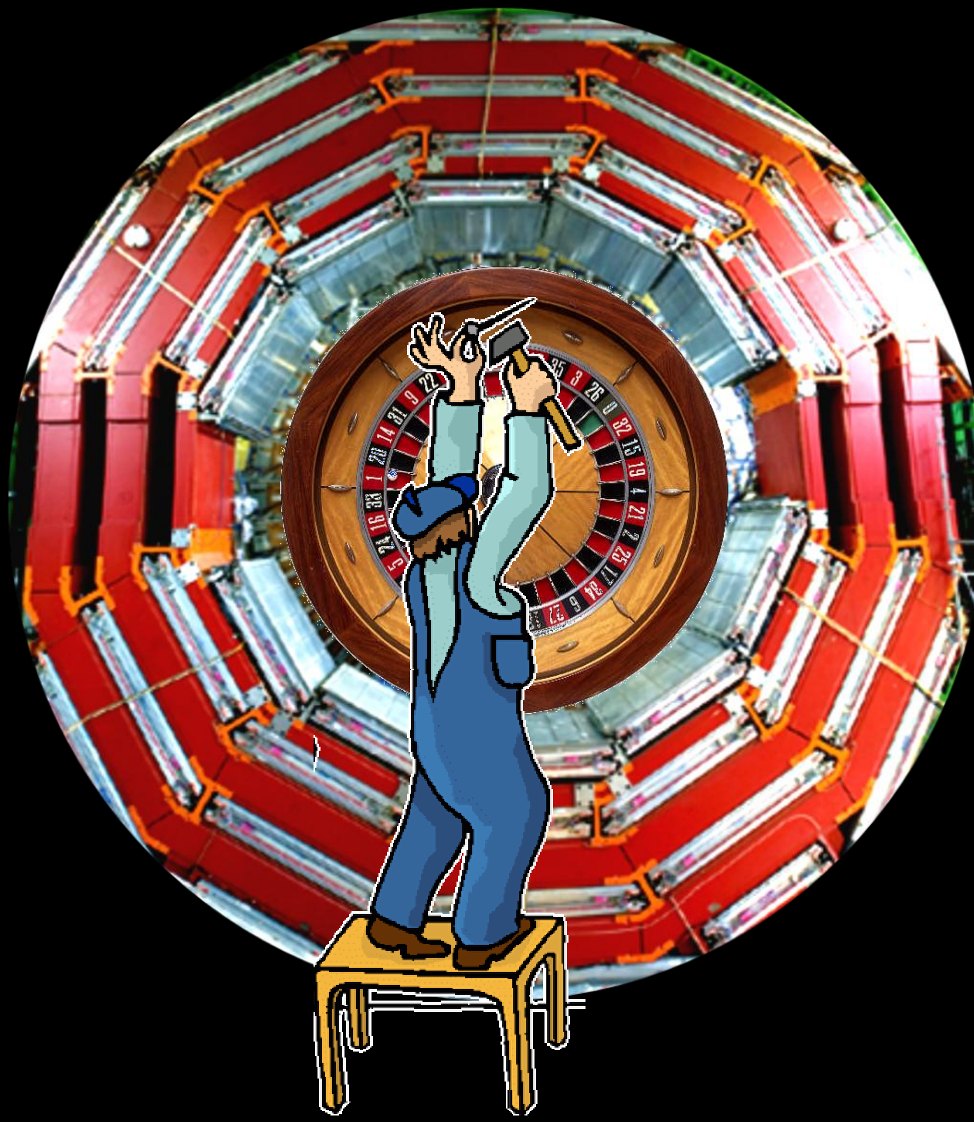
Figure shows a combination of $dN_{ch}/d\eta$ results from various experiments, for various sqrt(s).

A new PYTHIA tune, "**Z1**", by Rick Field was shown to describe NSD data very well (results not public yet).

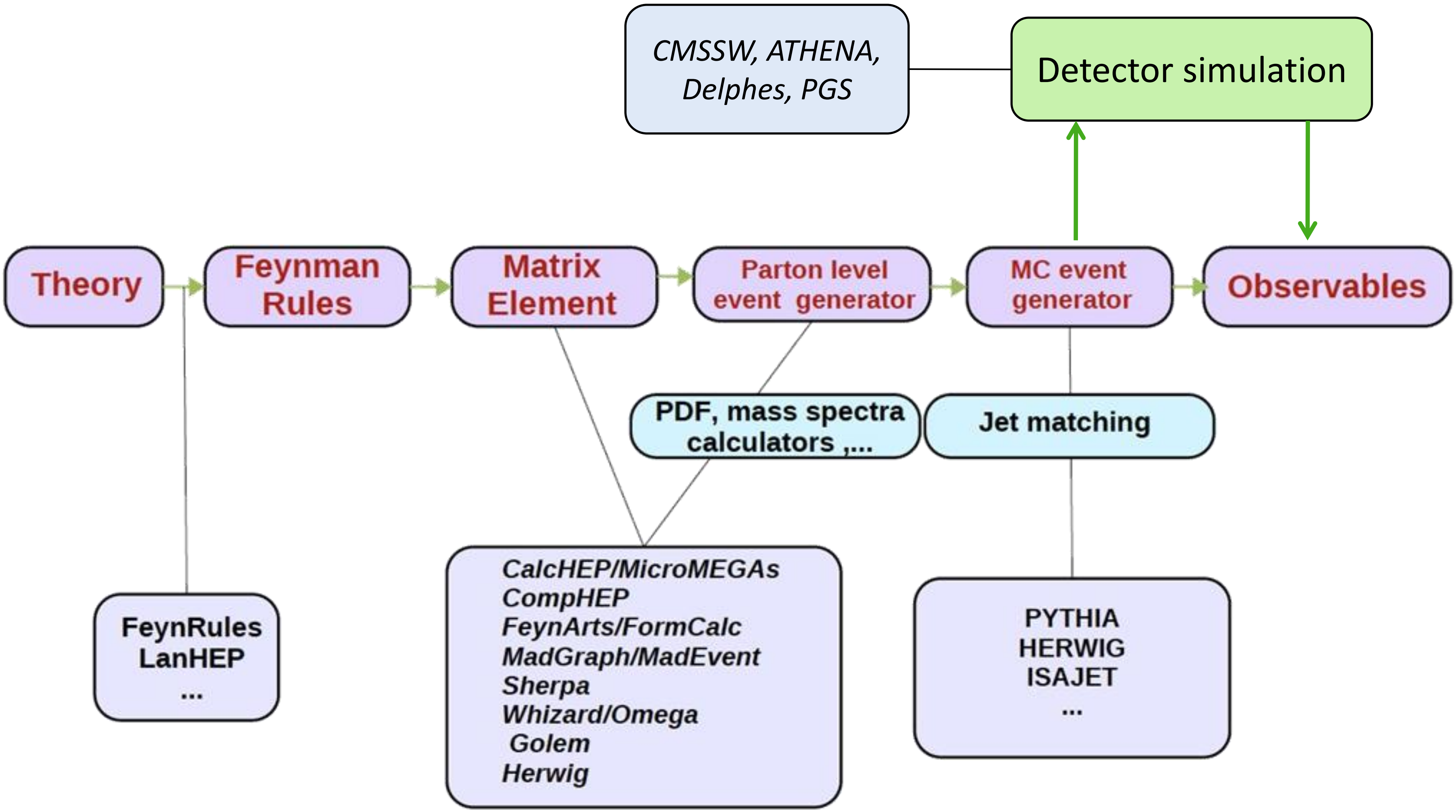
Plot shows that the **Z1** tune also describes ATLAS underlying event (UE) data very well.



Implementing the MC in CMS



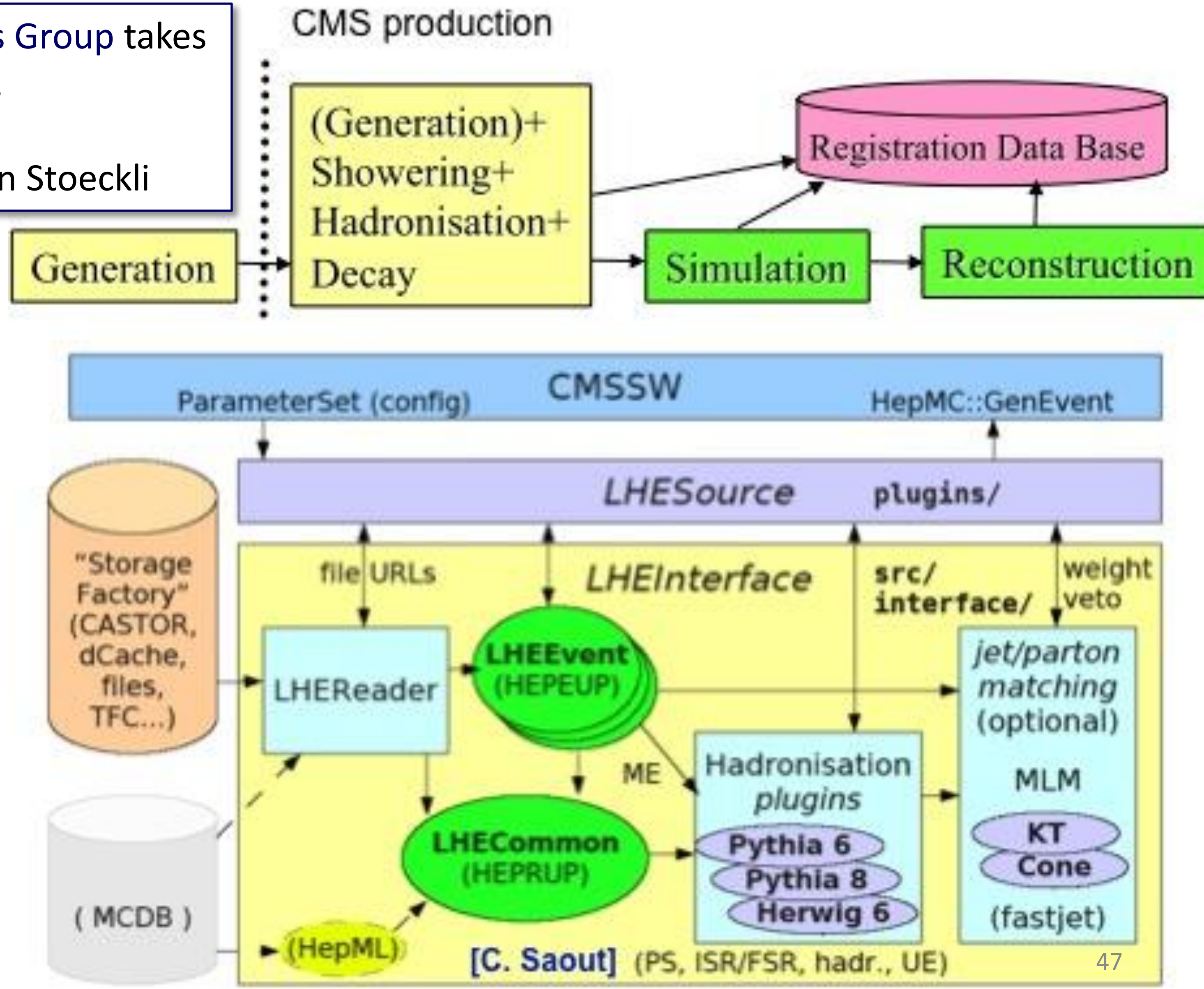
Making events: The TH point of view



from A. Belyaev

Making events: The CMS point of view

CMS Generator Tools Group takes care of all MC issues.
Current conveners:
Fabio Cossutti, Fabian Stoeckli



[C. Saout]

CMS & event generators: Multi-purpose

PYTHIA6:

- Main multi-purpose generator: used for generating ~400M fully simulated 7TeV events past half year
- Used for various processes: EWK, QCD, Higgs, SUSY, Exotics, ..
- Standard tune/shower: D62 with Q2 shower; transition to pT planned

PYTHIA8:

- Extensive usage for MinBias and QCD. Also used for unparticle generation (only tool known to provide unparticle processes)

HERWIG:

- Used almost exclusively for QCD studies (comparison to PY6)
- Shower/hadronizer for MC@NLO
- Used together with JIMMY

HERWIG++:

- Used almost exclusively for QCD studies (comparison to HW6/PY6)

SHERPA:

- Almost exclusive usage in EWK studies,
- Also in EXOTICA: e.g.: models with extra dimensions

CMS & event generators: multi-leg matrix element

MADGRAPH:

- Main CMS multi-leg generator
- Used a lot for QCD, VB(-pairs)+jets, HQ(-pairs)+jets, γγ(+VB)+jets, Z'
- Interfaced to PY6 for shower/hadronization

ALPGEN:

- Used mainly for top pair, VB(+HQ)+jets, QCD high jet multiplicity
- Used for systematic comparisons with MADGRAPH
- Used when many legs (more than what MADGRAPH can do in a reasonable amount of time!) are needed

CalcHEP:

- Used for BSM models: 3-site model (Higgsless extra-dimensional model), long-lived particle studies for Littlest Higgs model with broken T-parity, boosted Z-boson within the model with excited quarks
- Also for SM: VB-fusion processes as background

CompHEP:

- Single top with anomalous Wtb, FCNC, W' and charged Higgs
- MSSM Higgs at large tanβ

CMS & event generators: NLO; special tools

NLO generators:

MC@NLO

- Used for top pair, single top, gluon fusion, Higgs, DY, W pairs

POWHEG

- Used for DY, Higgs

Other specialized generators:

- Forward physics
  - POMWIG, EXHUME, HARDCOL
  - In preparation: CASCADE, POMPYT, RAPGAP
- Heavy ion physics
  - PYQUEN, HYDJET
  - In preparation/discussion: AMPT, EPOS
- Generators used in the past
  - ISAJET (SUSY), Charybdis (Black holes)

CMS & event generators: Generation strategies

- Most multi-purpose generators are completely integrated in CMS software framework (CMSSW) by linking to external shared object libraries -> users can generate full events with CMSSW run commands, and configure generators from CMSSW configuration files.
- Production with LHE:
  - Generation of LHE files are decoupled from CMSSW – done independently and stored in MCDB.
  - LHE files needing shower/hadronization are processed via LHEInterface of CMSSW, that again allows manipulation of shower/hadr. Parameters via CMSSW configs.
  - Special case: ALPGEN: Has its own format. AlpgenInterface can convert ALPGEN format to LHE back and forth
- Tools that can't be interfaced as above are interfaced in specialized ways, but this results in additional effort from the Generators Group and non-standard workflows for the computing group -> these tools are less popular among the users. E.g.: SHERPA

CMS & event generators: Comments, questions, plans (1)

- Generation in CMS has been PYTHIA6-centric: well-tested tool; used in many analyses in previous experiments; comes with most-sophisticated, tested tunes; well-documented.
  - Adapting stepwise enhancement of the usage of new C++ tools. Considerable increase in PYTHIA8 usage after LHC startup. Would benefit also from clear comparisons with HERWIG and HERWIG++ to understand pros and cons.
- SHERPA: A very powerful tool, however very complicated generation procedure. No LHE interface, which makes life difficult. We desire a SHERPA LHE interface which would make interface with e.g. MADGRAPH possible.

CMS & event generators: Comments, questions, plans (2)

Tools that fulfill one or more of the following technical requirements are very easy to interface to the CMSSW framework

- package available as shared object library, providing interfaces in C++ to (at least) the main routines
- package ideally provides output (allows input) in HepMC format
- package provides as output/accepts as input standard LHE format
- all relevant parameters can be set via input files, i.e. no compilation step is needed
- memory consumption of the tool should be under control

Clear and detailed documentation is extremely important!!!

CMS & (N)NLO codes, cross sections

Inclusive cross sections:

- Higher order cross sections are computed ad. hoc. by each physics group, using the following tools:
  - NLO: MCFM (generic); HDECAY, HIGLU (Higgs); PROSPINO (SUSY)
  - NNLO: HggTotal (gg->H); HNNLO, Fehip (Higgs); FEWZ (DY)
- Calculation totally decoupled from CMSSW framework – cross sections do not correspond to generated events
- There are efforts within CMS (an organized group to compile SM cross sections), and also in wider community (Higgs@LHC - ATLAS+CMS+TH) to synchronize the numbers

Exclusive cross sections:

- In cases where higher order QCD corrections have impact on shapes of distributions, differential reweighting is used.
- An example for this is Higgs production in gluon-fusion, where Higgs pt-dependent K-factors are used to re-weight the PYTHIA6 events to the MC@NLO Higgs pt spectrum.

CMS & (N)NLO codes, cross sections

Errors on Cross-Sections are usually evaluated by

- varying the renormalization & factorization scales in a range [μ/2, 2 μ] around some default central, process dependent scale μ,
- varying the PDF sets (usually within the error sets of a default set).

The total error is then computed as the square-root of the sum of the squares of the individual errors.

CMS & (N)NLO codes, cross sections: Questions, Comments

- It is necessary to be able to access and change some parameters, such as PDF, center-of mass energy, etc.
- Need to find a standardized way to compute theoretical uncertainties
  - A general desire is that tools to compute cross-sections (e.g. MCFM) would provide a possibility to compute errors (e.g. from PDF error sets) in a standard format (i.e. Without the need of re-running the code for all error PDF sets).

CMS & decay packages

TAUOLA

- Used for where emphasis lies on spin-correlations in τ decays.

EVTGEN

- Used for samples where decays of B-hadrons are of special interest.

PHOTOS

- Planned to be used for leptonic decays of vector bosons

BR tool: SUSYHIT

- Calculation of BRs for supersymmetric particle decays

CMS & (N)NLO codes, cross sections: Questions, Comments

Main question is to find a way to sensibly combine TAUOLA and EVTGEN.

CMS & MC - Further comments: Generic

- Cross sections for multijets: Can we extrapolate the multijet cross section from the N jets bin to the N+1 jets bin?
- Need to understand heavy flavor content, e.g.: in QCD or in Wqq + jets: best possible simulation of heavy flavor is crucial for a reliable discovery of BSM signals
- Understanding of the sensitivity of W charge asymmetry to jet multiplicity
- Treatment of ISR/FSR matching uncertainties – can matching scale be understood as a tunable parameter?
- A better understanding of PDFs – pros and cons of different PDF sets
- Combining and synchronizing efforts among different experiments and TH:
    - Synchronization of MC parameters, higher order cross-sections, etc.
    - Definition/generation of common ME samples in LHE format for storage in MCDB?

CMS & MC - Further comments: BSM

- Models & FeynRules: FeynRules has not been used so far, however it is much welcome, since it is easily combined with ME generators. Would be great help if new models should come with a FeynRules calculation available.
- SUSY spectra: Differences still exist among various codes computing SUSY spectra in e.g.: in high m_0, high tanβ, high A_0 regions.
- Generation of inclusive samples: For models that come with a multitude of new particles, it is difficult to compose pp -> inclusive samples with hard radiation (e.g.: SUSY + jets) – problem of double counting.
  - Availability of automated procedures for making inclusive BSM+jets samples would allow experimentalists to exercise more realistic simulation studies.

SUMMARY

- CMS successfully performing: collected ~30nb^{-1} so far.
- Various physics simulation tools have been used to explore physics opportunities with CMS for SM and diverse BSM models
- With the present minimum bias and underlying event data, tuning of MCs already started – but we need to implement more systematic approaches
- CMS has incorporated a majority of existing tools into its framework. Implementation becomes easier when the tools have uncomplicated workflows, follow standards such as LHE, SLHA, and allow easy access to input parameters.
- We also welcome a common act towards understanding MC parameters, higher-order cross sections and theoretical uncertainties.