CMS Results from Run 2

Luca Malgeri on behalf of the CMS Collaboration

LP2015: XXVII International Symposium on
Lepton Photon Interactions at High Energies
17-22 Aug 2015, Ljubljana (Slovenia)

First things first

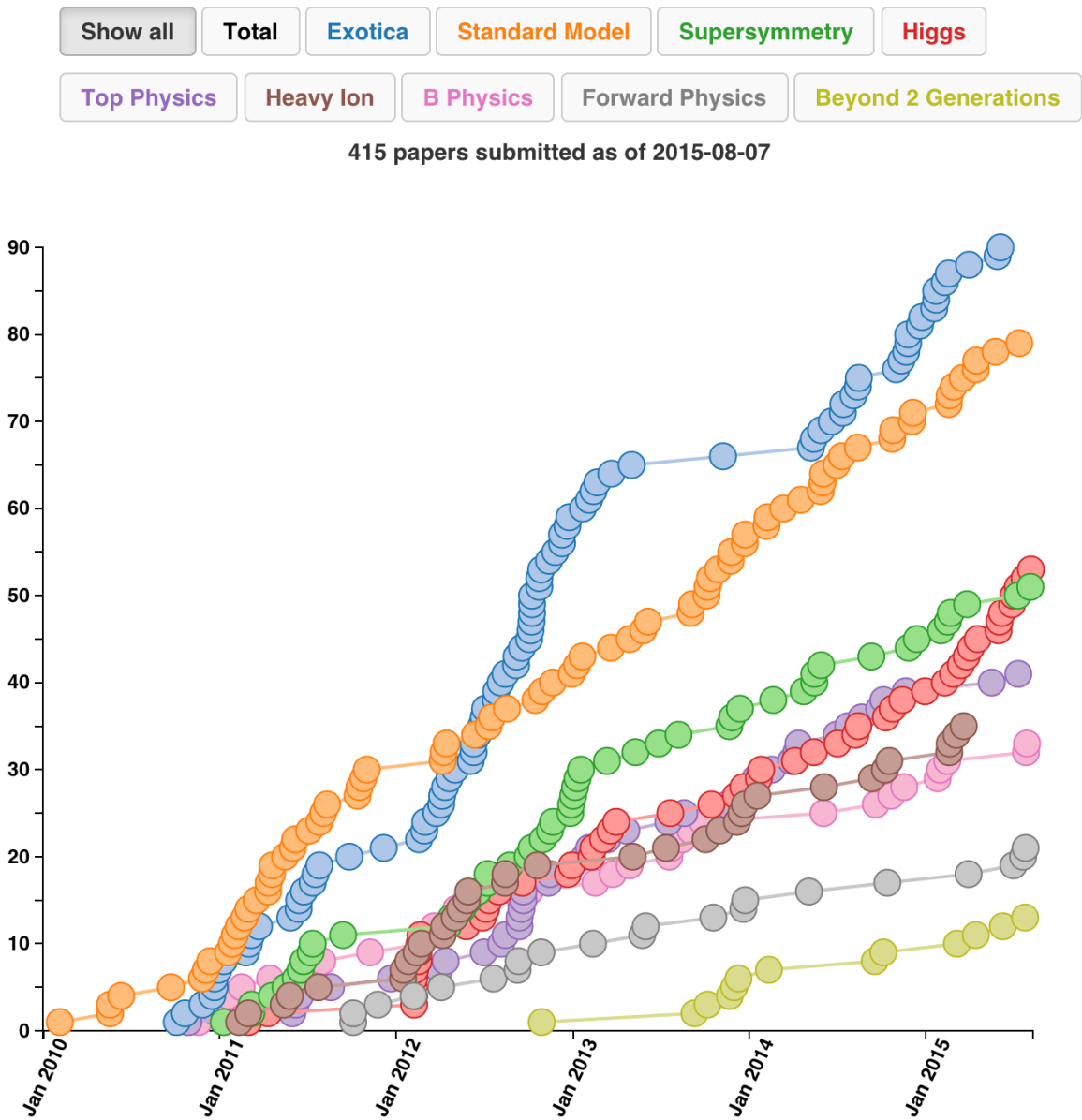
Thanks to the LHC team!

No results shown here would have been possible without their work!

Outline

- Where we started from
- Preparation for Run2
  - changes/improvements
  - pre-beam commissioning
- First collisions
  - Commissioning of physics objects
- First Physics results @13TeV
  - di-jet bump search analysis
  - particle multiplicity results
  - top pair cross section
- Outlook

Run I legacy



415 publication on collisions data submitted

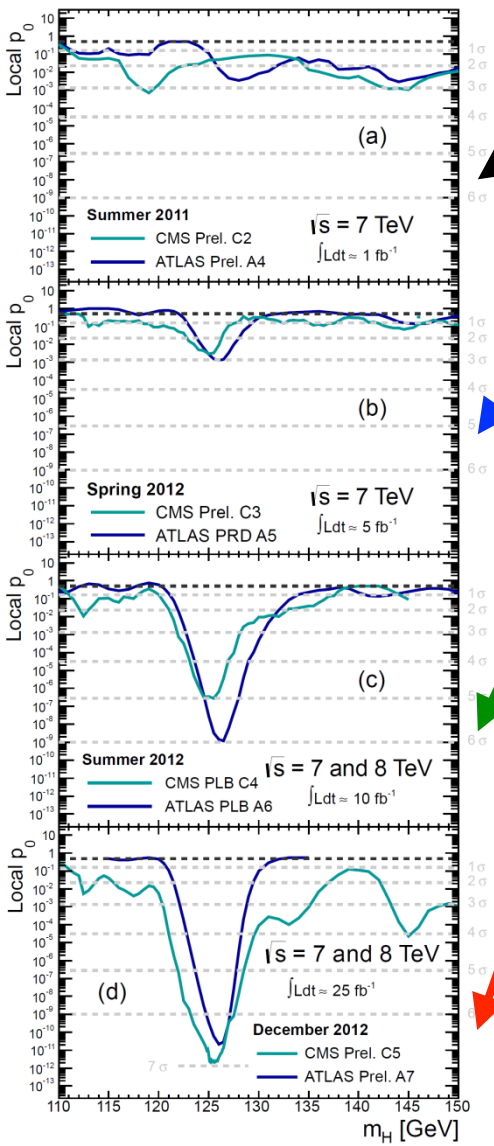
+23 performance papers based on cosmics data taking

And several more precision physics results still to come (SM, Top, B physics)

Run I legacy: Higgs

PRD 89 (2014) 092007,EPJC 74 (2014) 3076, EPJC 75 (2015) 212

From PDG

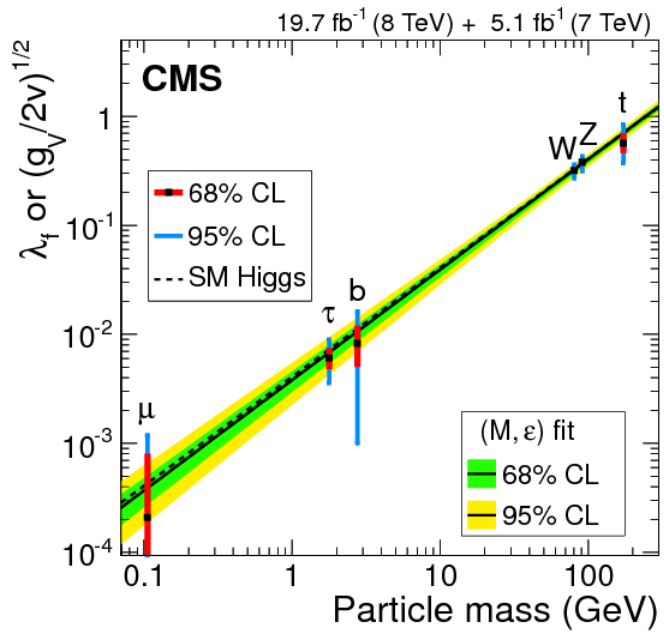


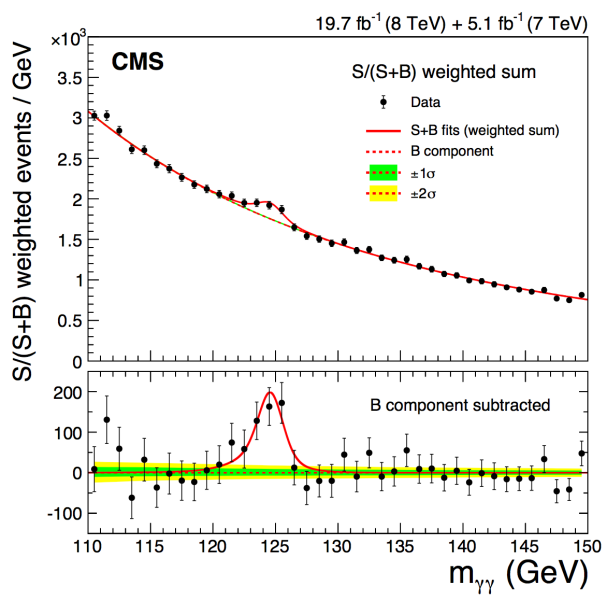
Summer 2011: nothing yet

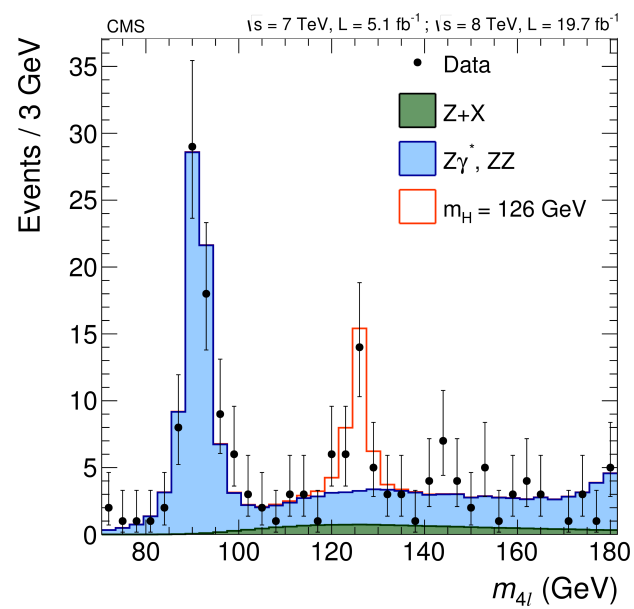
End of 2011: some hint

Summer 2012: discovery!

End of 2012: confirmation!

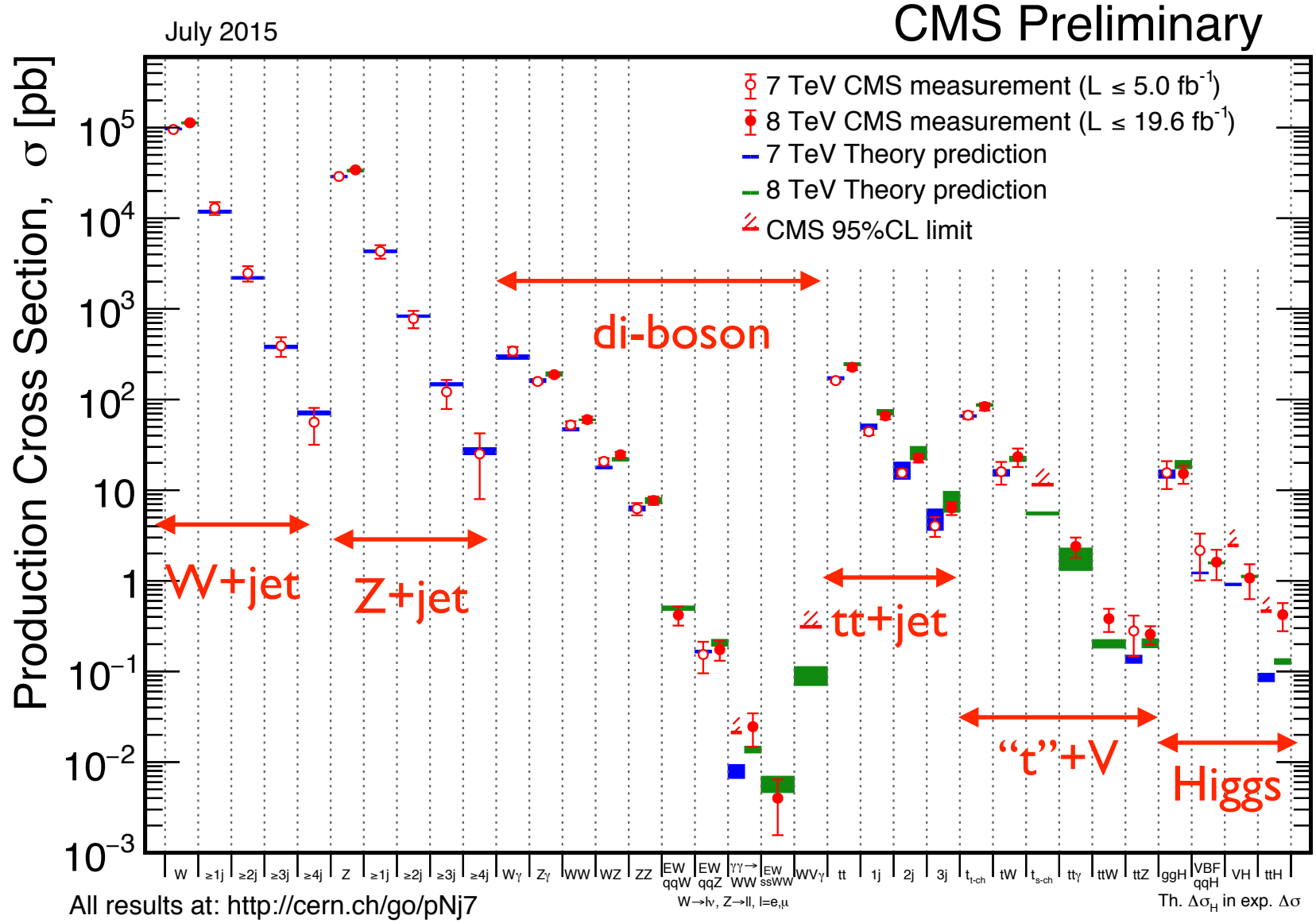






Run I legacy: SM cross sections

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsCombined



Run I legacy: searches

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsCombined

All NP searches were unfortunately null

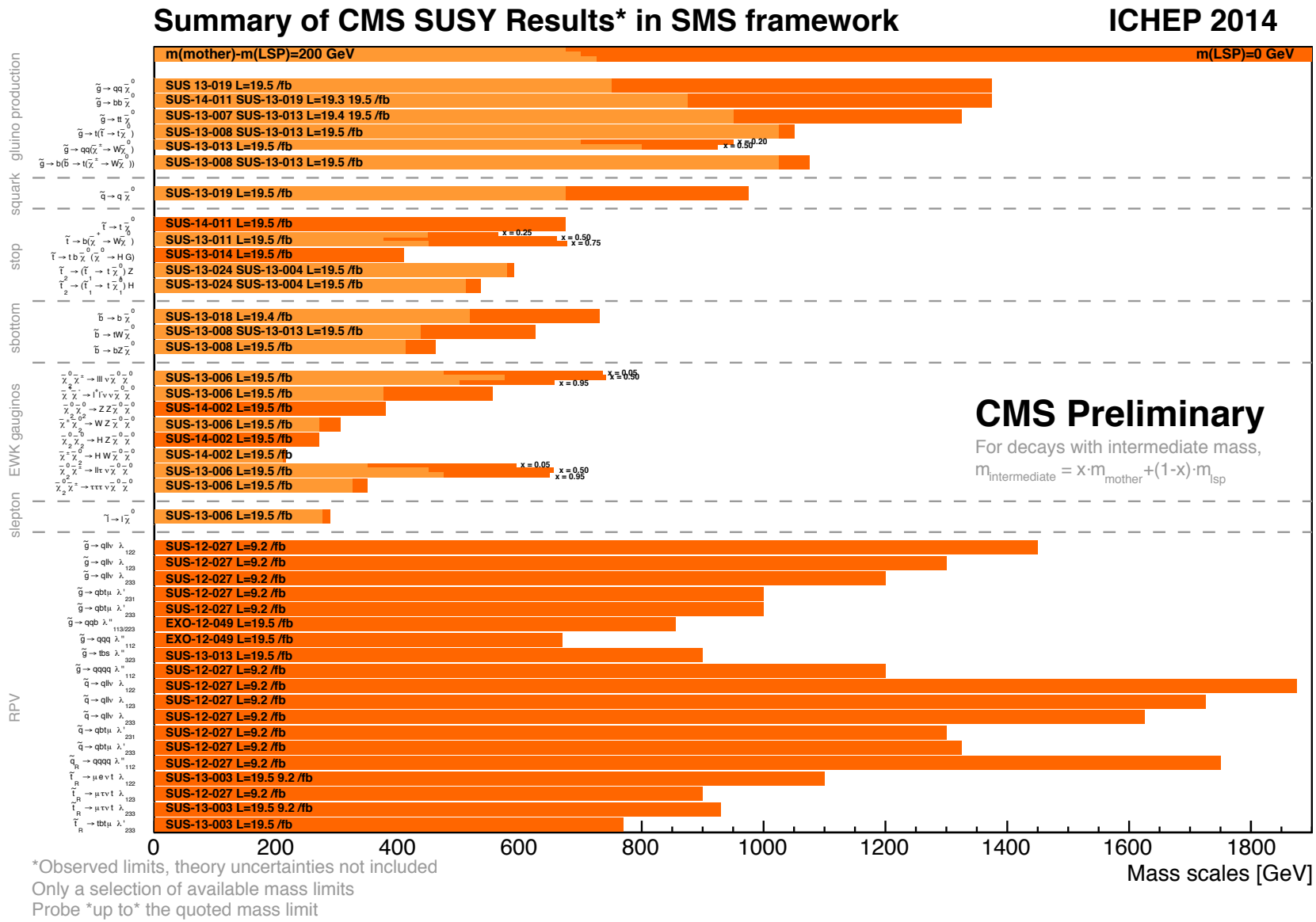
SuSy

gluino exclusions ~1.3 TeV

stop/sbottom ~700 GeV

EWKino ~300 GeV

CAVEAT: several assumptions behind these limits



Run I legacy: searches

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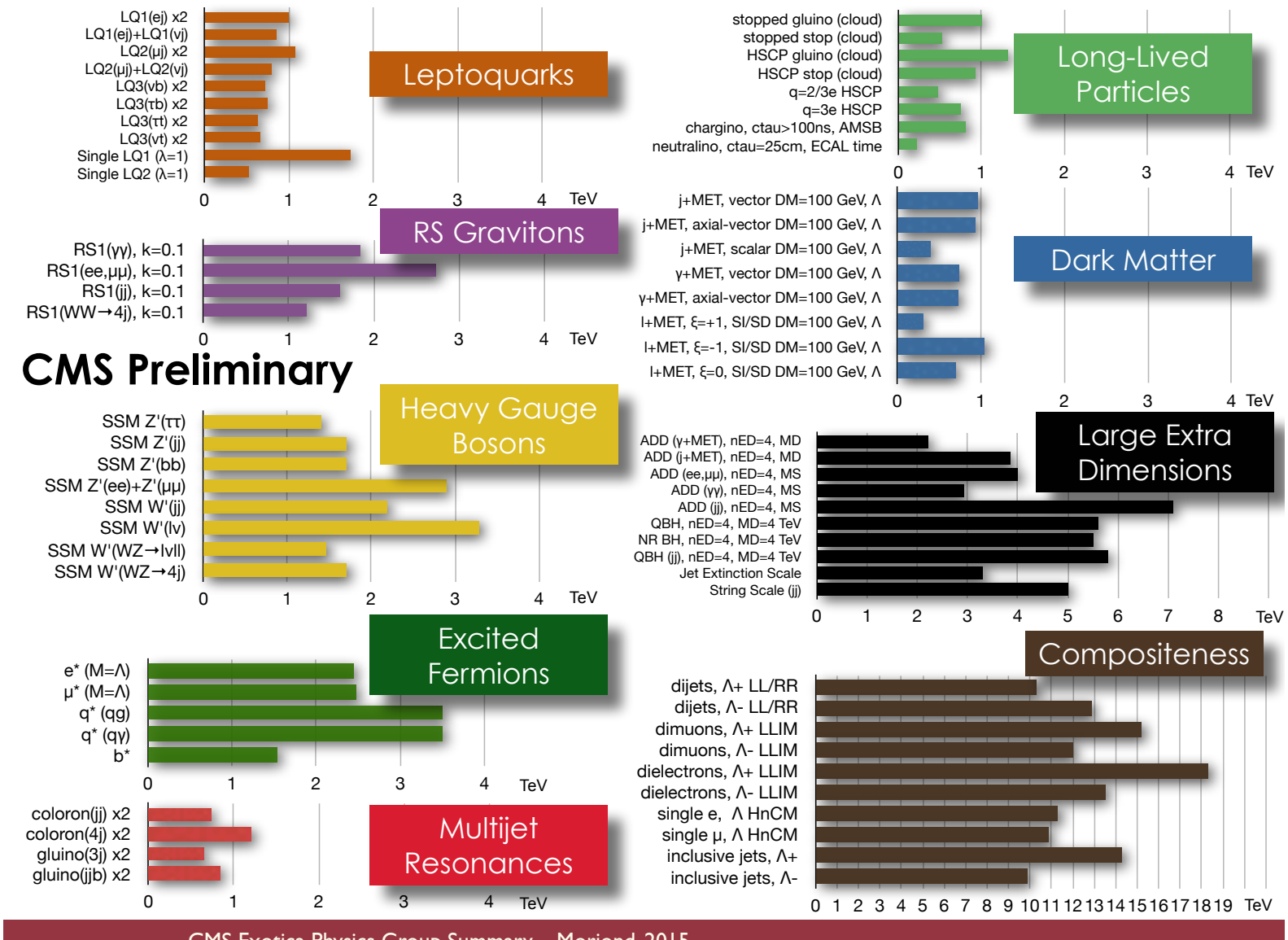
All NP searches were unfortunately null

Exotica searches

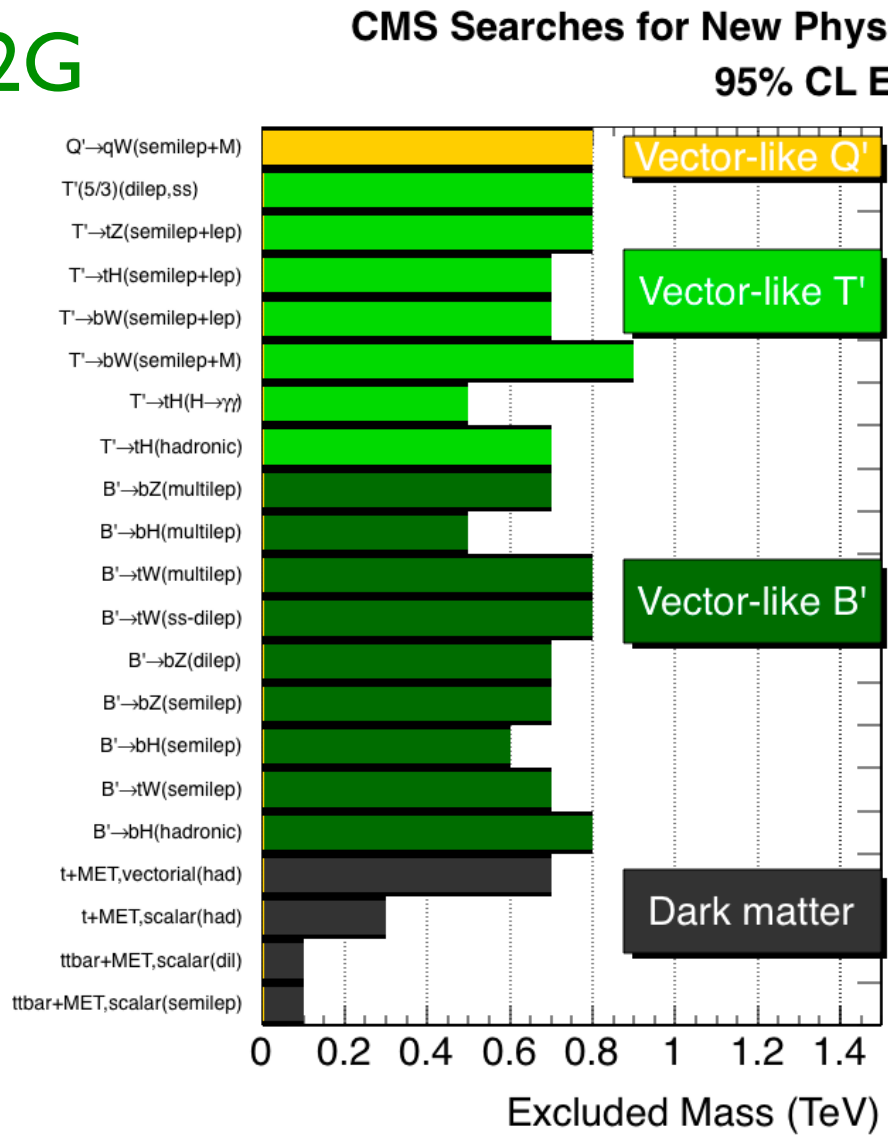


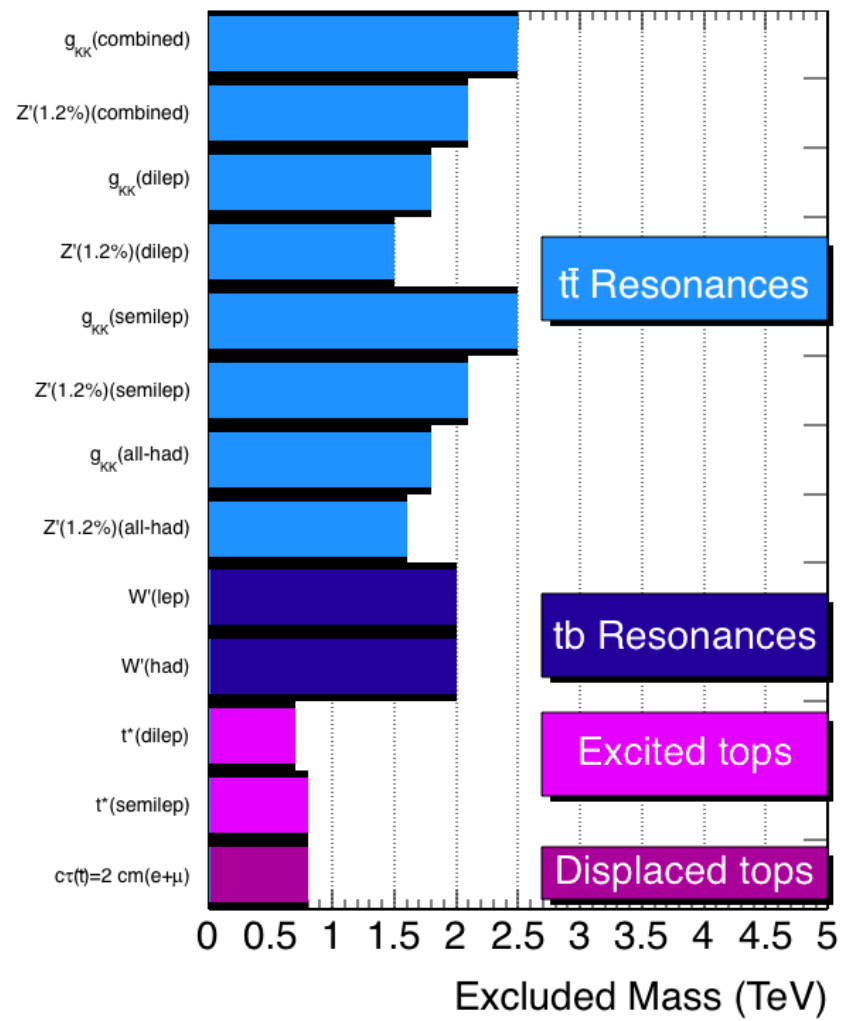
Run I legacy: searches

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsCombined

All NP searches were unfortunately null

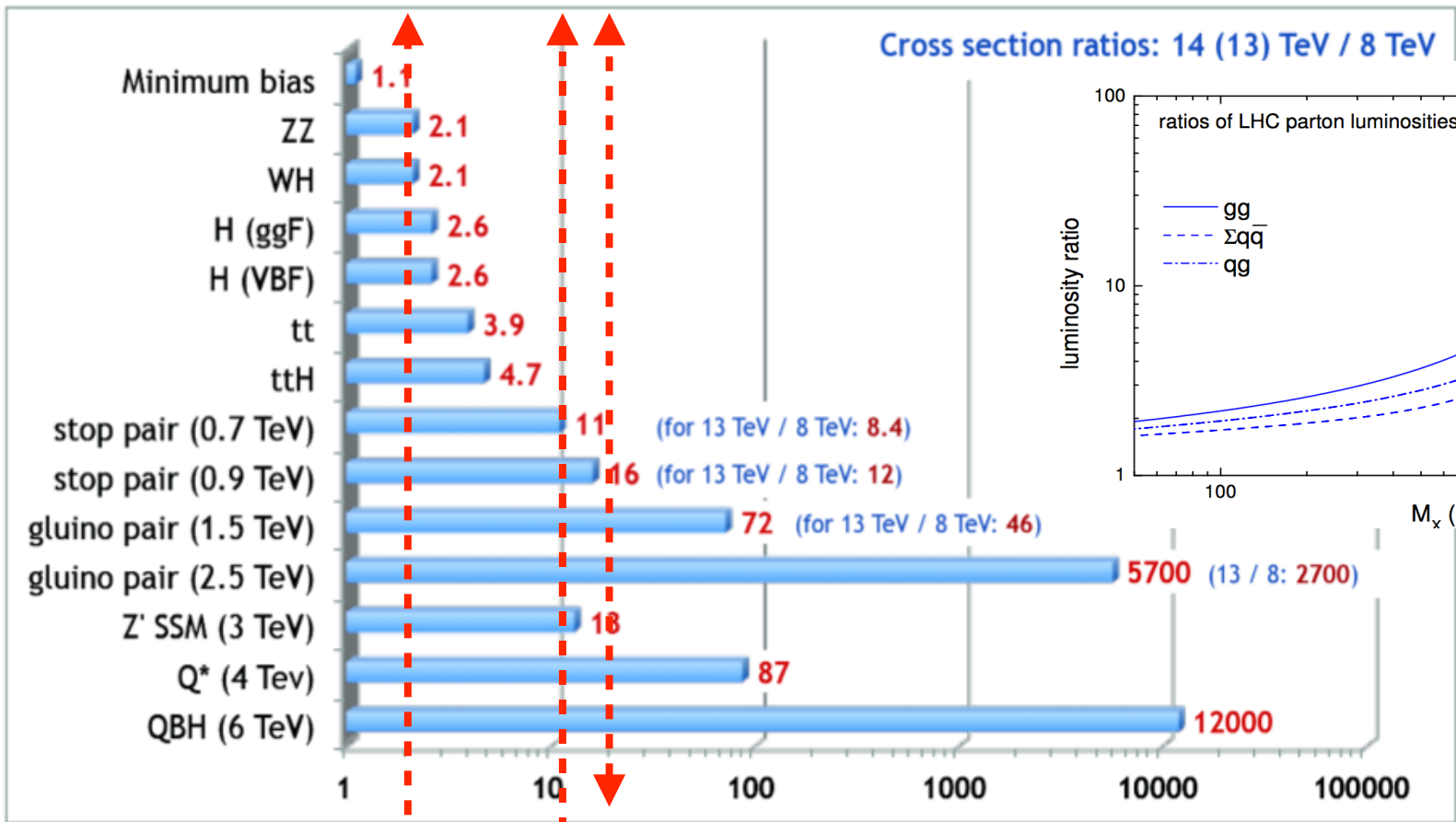
B2G





Run 2 physics guiding principle

The cross section boost @13 TeV enhances the discovery potential for massive objects by several factors → first 100's pb^{-1} might be a discovery dataset.



1 fb^{-1} equivalent reach to Run1

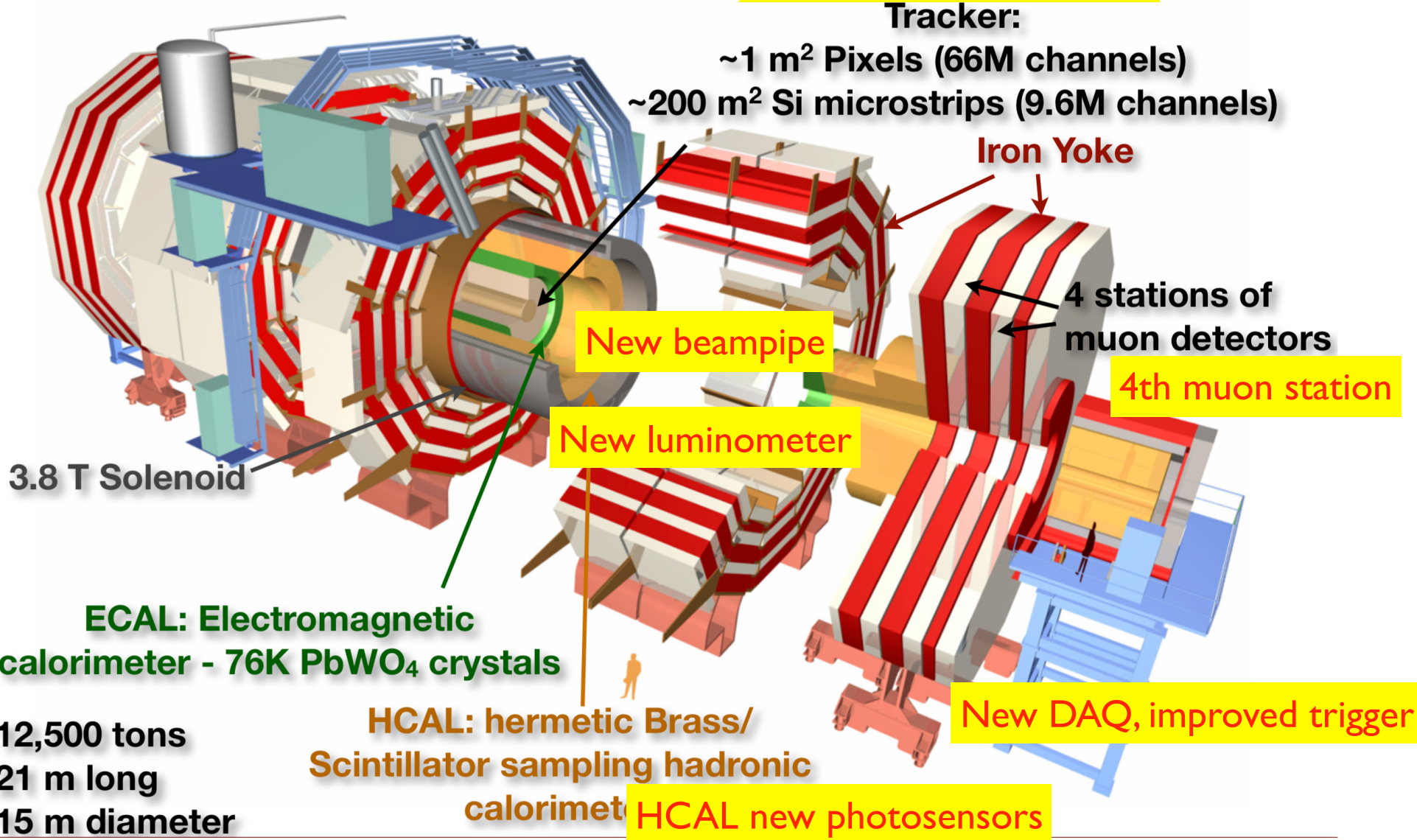
2 fb^{-1} equivalent reach to Run1

10 fb^{-1} equivalent reach to Run1

CMS activities during Long Shutdown

Interventions during shutdown

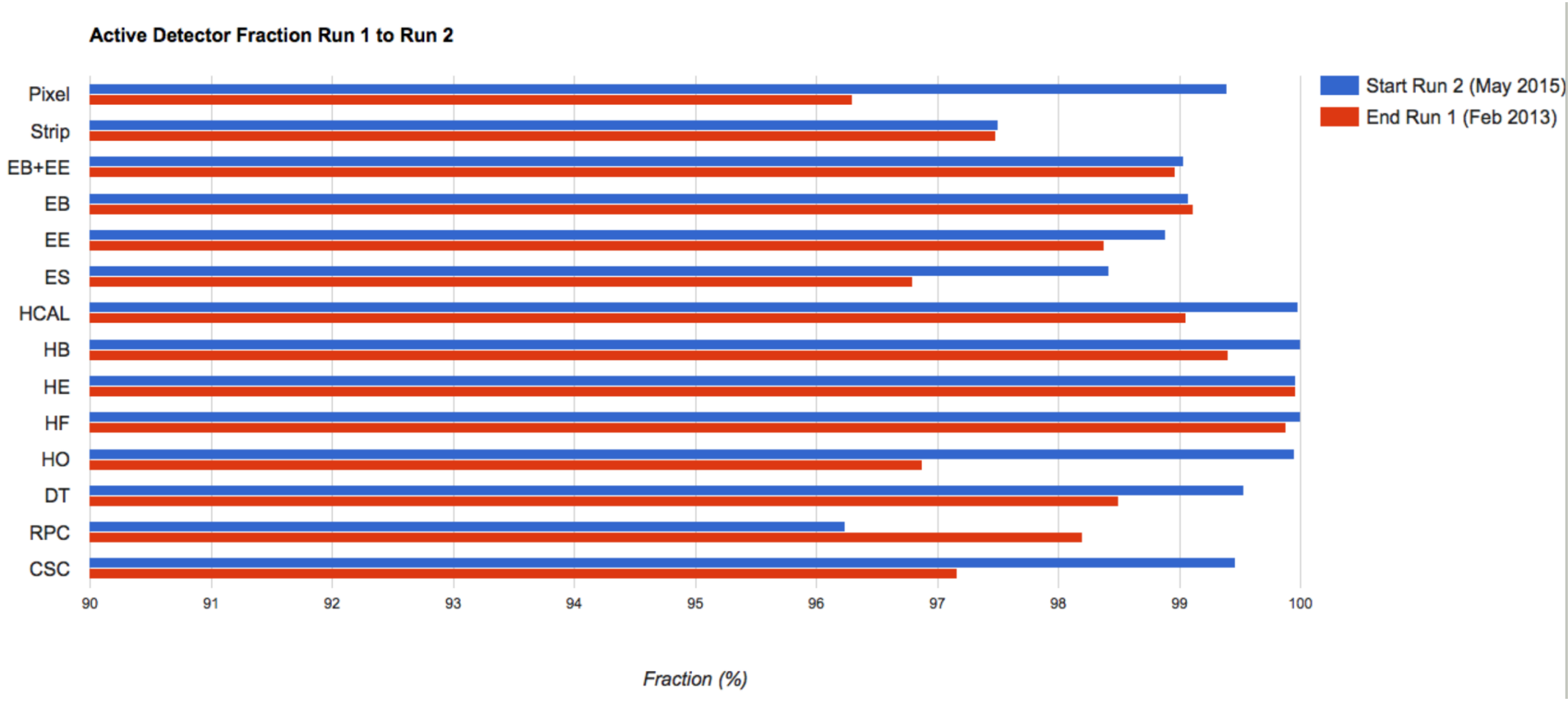
Pixel channels recovery
Tracker new dry air plant



Detector status

Several recovery campaigns have re-established an almost perfect status.

➡Please note that the scale starts at 90%!



Current machine plan

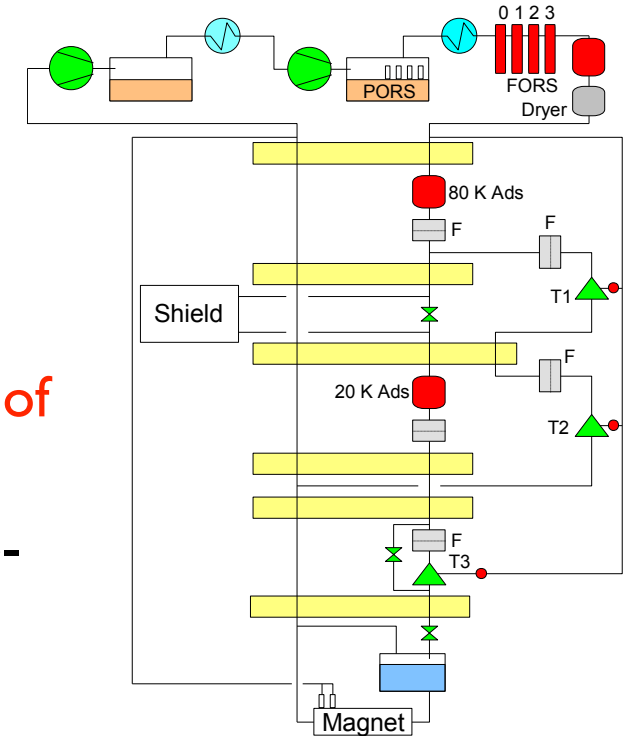
- Started beginning of June
- ramp-up @50ns bunch separation (collected up to 100pb^{-1})
- first period @25ns bunch separation (just started)
- second period of lumi production @25ns with possibly reduced β*
- ~ 1 month of Heavy Ion running at the end of the year

we are here

Then, collisions data arrived….

Magnet cryogenics issues

- The restart of the CMS magnet after LS1 was more complicated than anticipated due to problems with the cryogenic system in providing liquid Helium.
- Inefficiencies of the oil separation system of the compressors for the warm Helium required several interventions and delayed the start of routine operation of the cryogenic system.
- The data delivered during the first two weeks of LHC re-commissioning with beams at low luminosity have been collected with B=0



- Currently the magnet can be operated, but the continuous up-time is still limited by the performance of the cryogenic system requiring more frequent maintenance than usual.
- A comprehensive program to re-establish its nominal performance is underway. These recovery activities for the cryogenic system will be synchronized with the accelerator schedule in order to run for adequately long periods.
- A consolidation and repair program is being organized for the next short technical stops and the long TS at the end of the year.

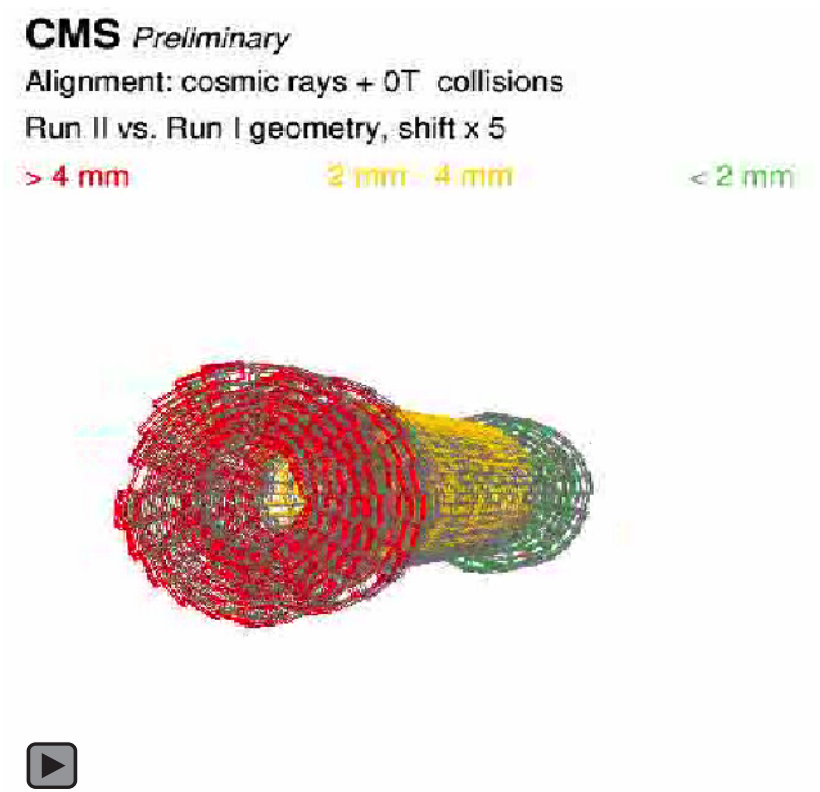
Physics Commissioning: alignment

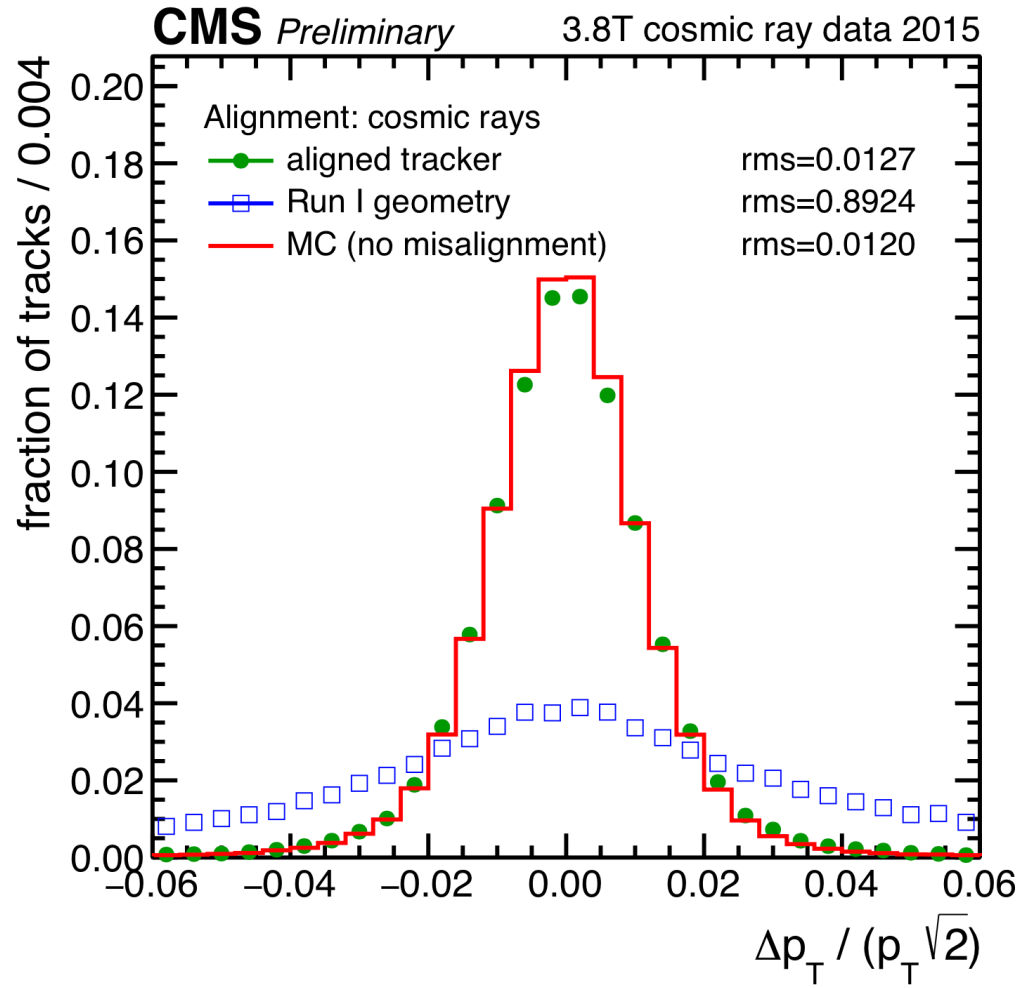
The alignment campaign started with cosmics data taking with and without magnetic field. It continued with first collisions.

It reached almost asymptotic performance (tested with split tracks technique)

CMS-DP-2015-029/CDS:2041841

Note: the pixel was re-centered after Run1 (-1.3, +3.4)mm.



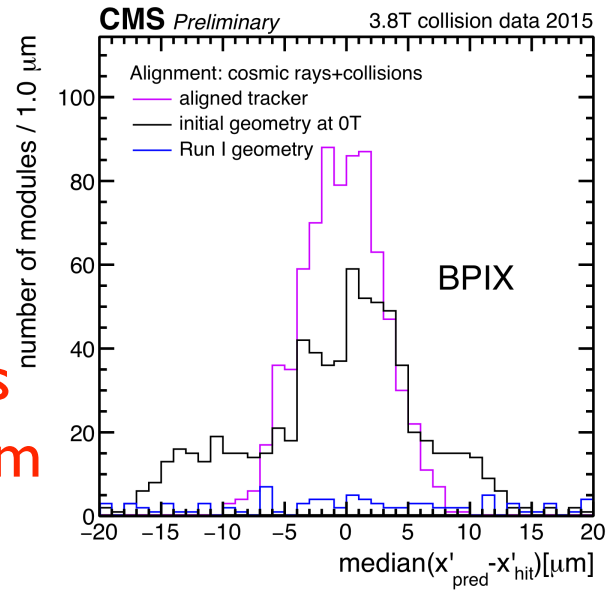


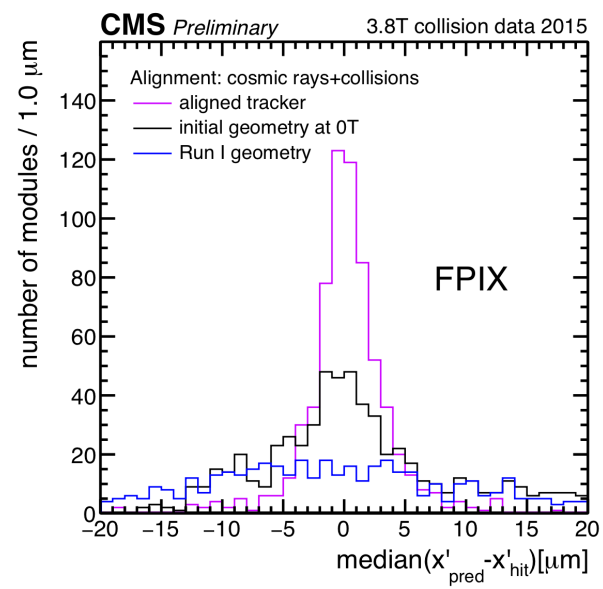
Physics Commissioning: alignment

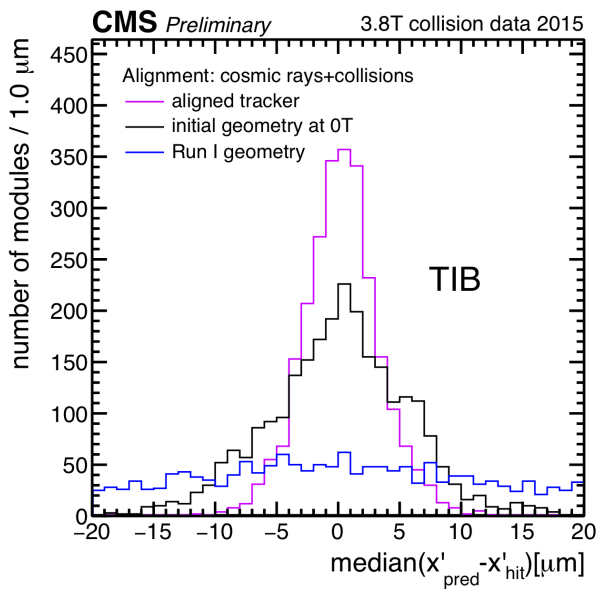
CMS-DP-2015-029/CDS:2041841

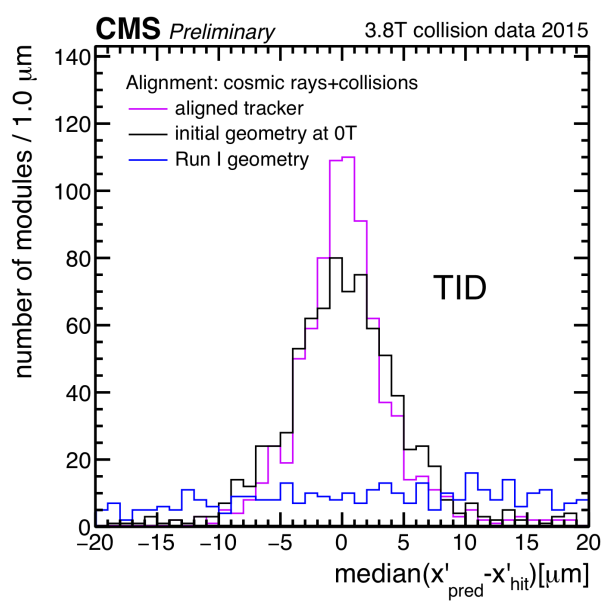
- 20M collisions tracks
- Run I geometry
- Initial geometry
- Aligned geometry

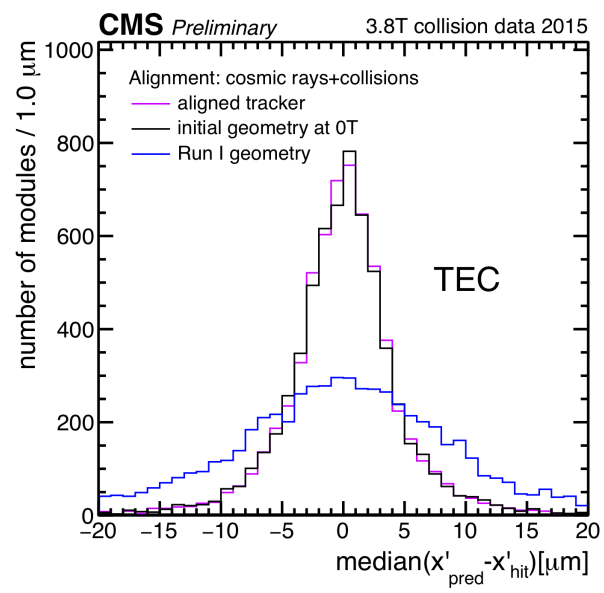
RMS of median of residuals after alignment ranging from 3 to 10μm









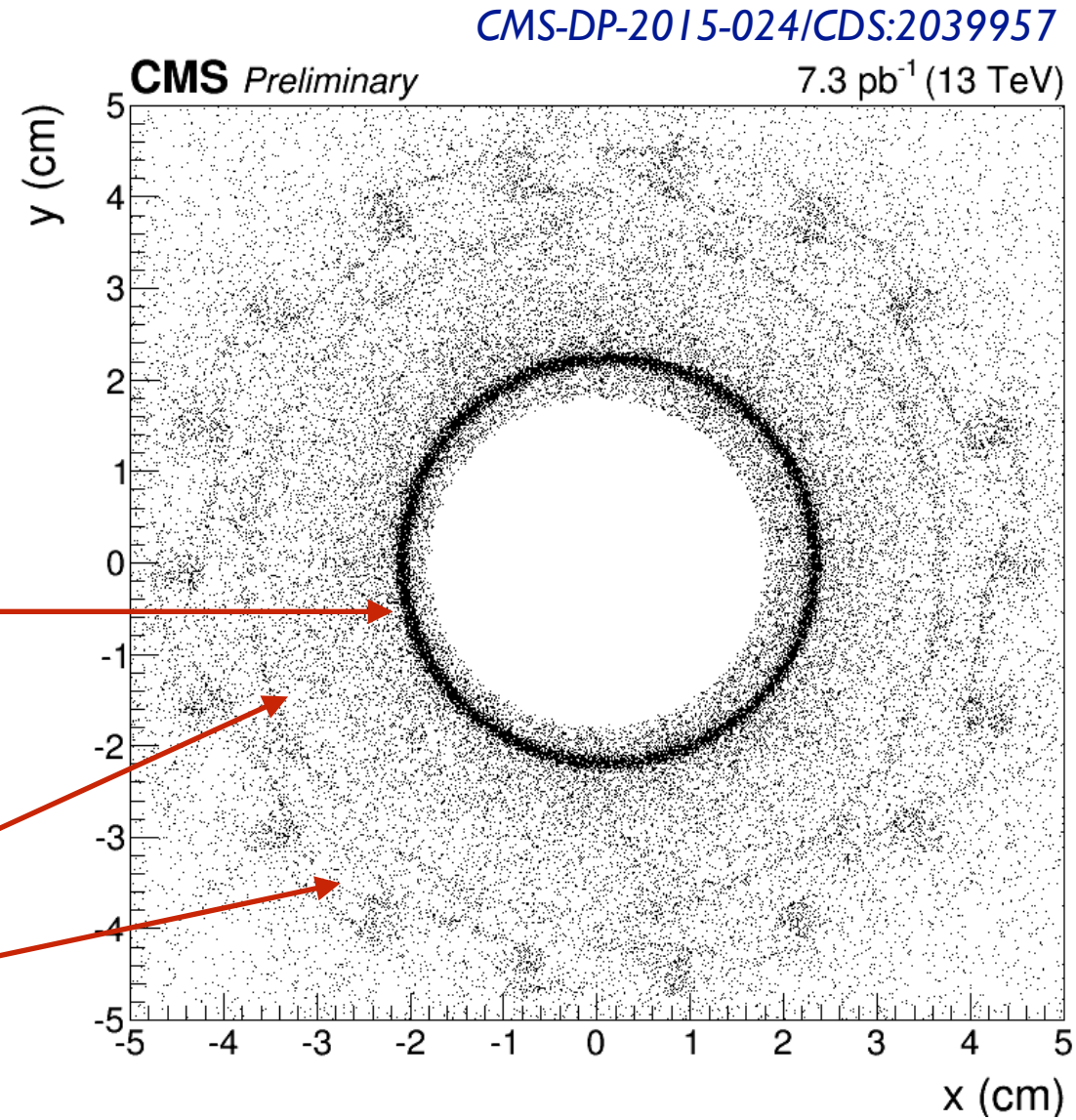


Physics Commissioning: speaking of geometry

Nuclear Interaction with 13 TeV Data

Nuclear interaction (0 or1 incoming tracks and ≥ 2 outgoing tracks) are used to build a "radiography". Known V0's and photon conversions are vetoed.

- The circle with radius around 2.25 cm corresponds to the beam pipe. This method allow to precisely measure its shift w.r.t. nominal position.
- The circle with radius around 3.7 cm corresponds to the Pixel Shield.
- The structure with radius around 4.2-4.7 cm corresponds to the 1st layer of the Pixel.

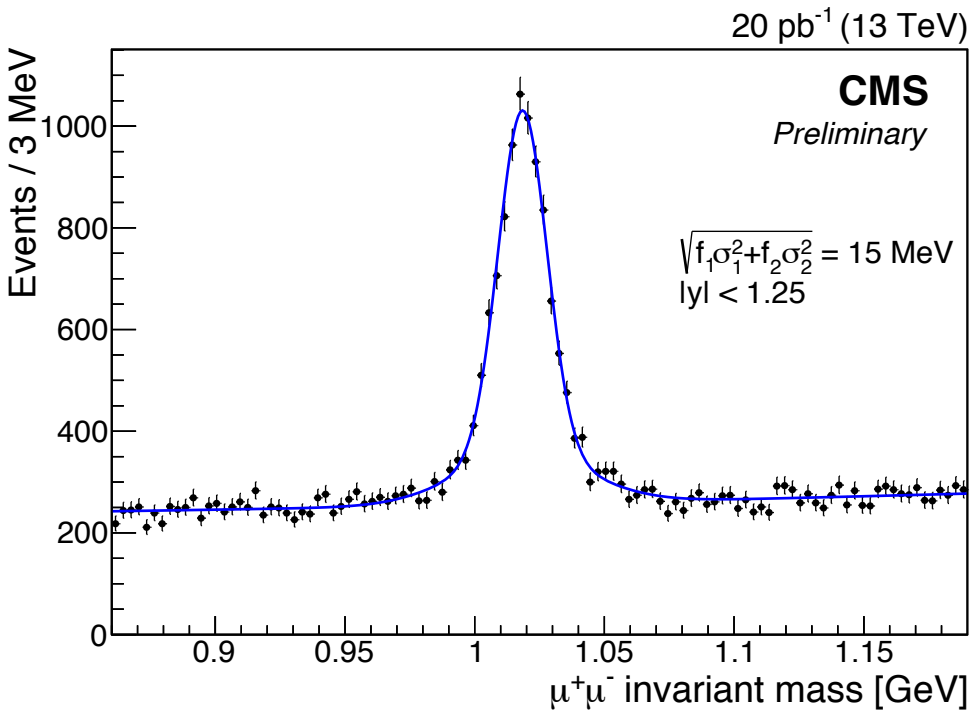


…….then standard candles

CMS-DP-2015-018/CDS:2037379

Φ(1020) from dedicated trigger path:

- opposite sign di-muon
- M_{inv}=0.85-1.2 GeV
- Signal PDF: double Gaussian with common mean
- Background PDF: Chebychev polynomial 2nd order



.....then standard candles

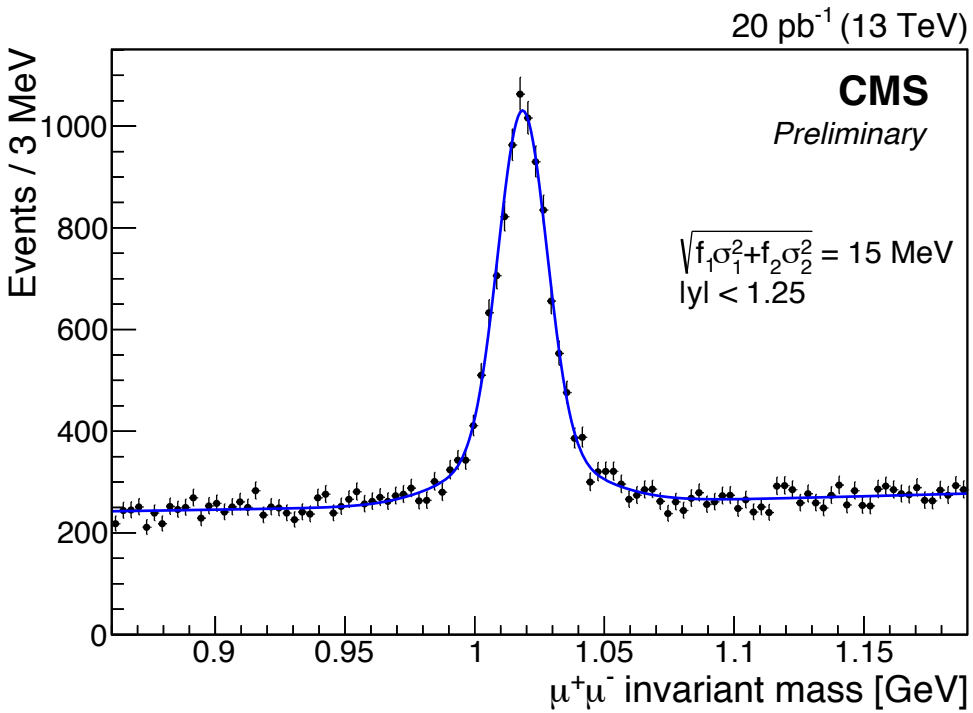
CMS-DP-2015-018/CDS:2037379

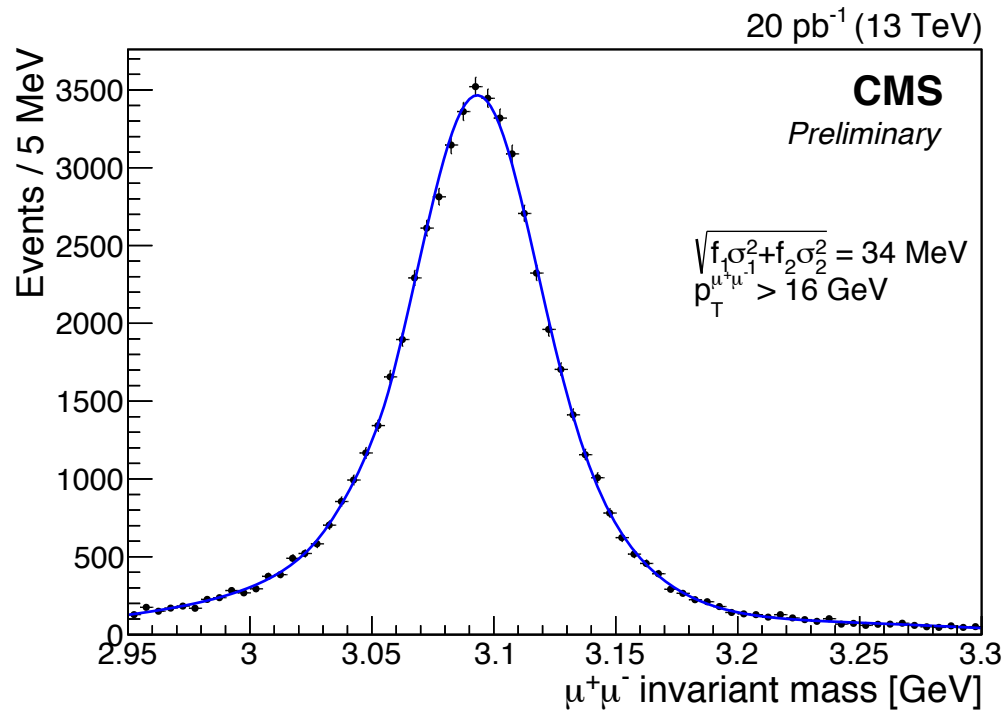
Φ(1020) from dedicated trigger path:

- opposite sign di-muon
- M_{inv}=0.85-1.2 GeV
- Signal PDF: double Gaussian with common mean
- Background PDF: Chebychev polynomial 2nd order

J/ψ from dedicated trigger path:

- opposite signe di-muon
- Minv=1.95-3.3 GeV
- Signal PDF: double Crystal Ball, common mean, n and α parameters
- Background PDF: Chebychev polynomial 2nd order





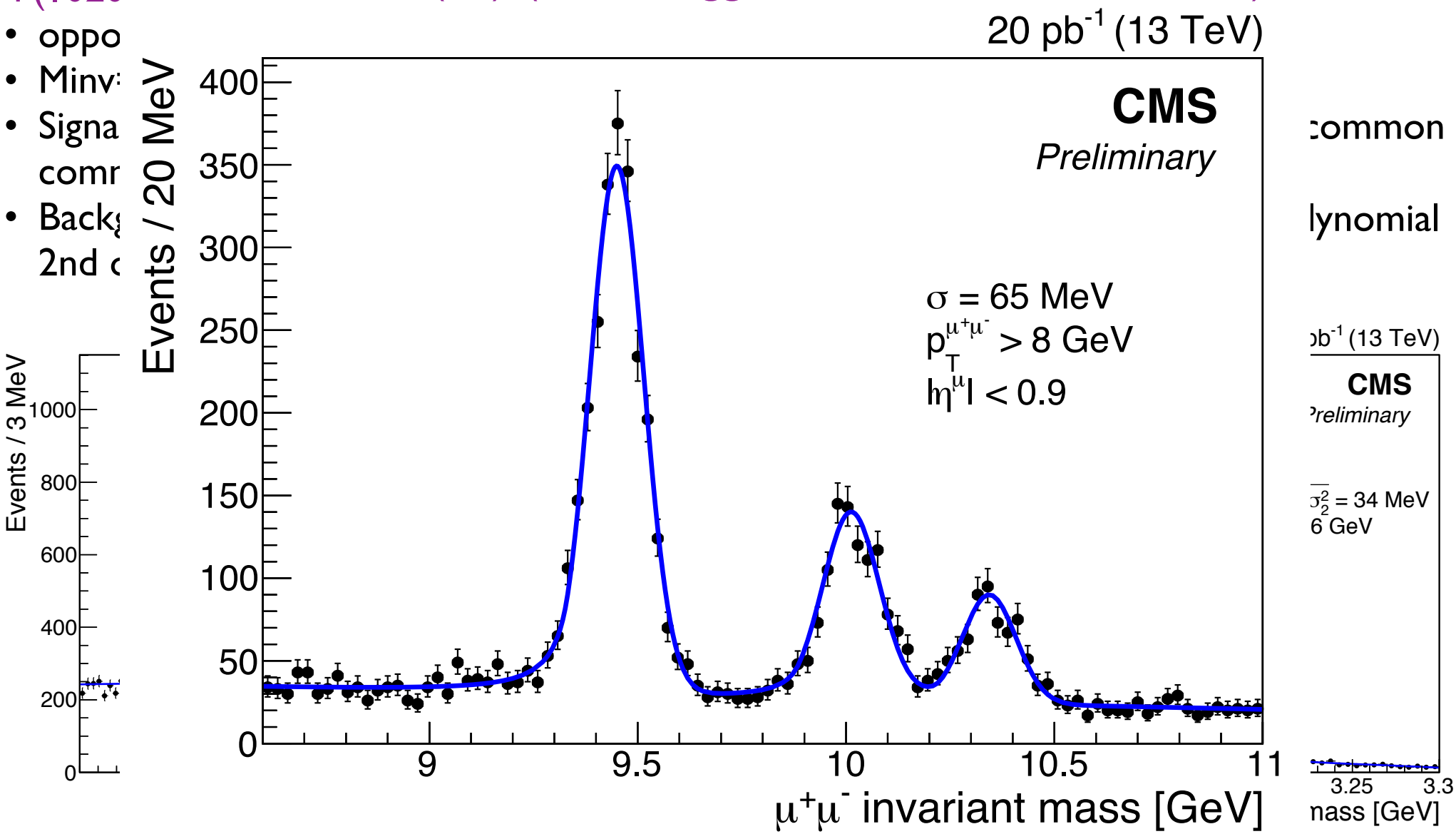
.....then standard candles

CMS-DP-2015-018/CDS:2037379

and also Υ(nS) (same trigger, different mass window)

Φ(1020)

- oppo
- Minv
- Signa
  comr
- Back
  2nd c



common

lynomial

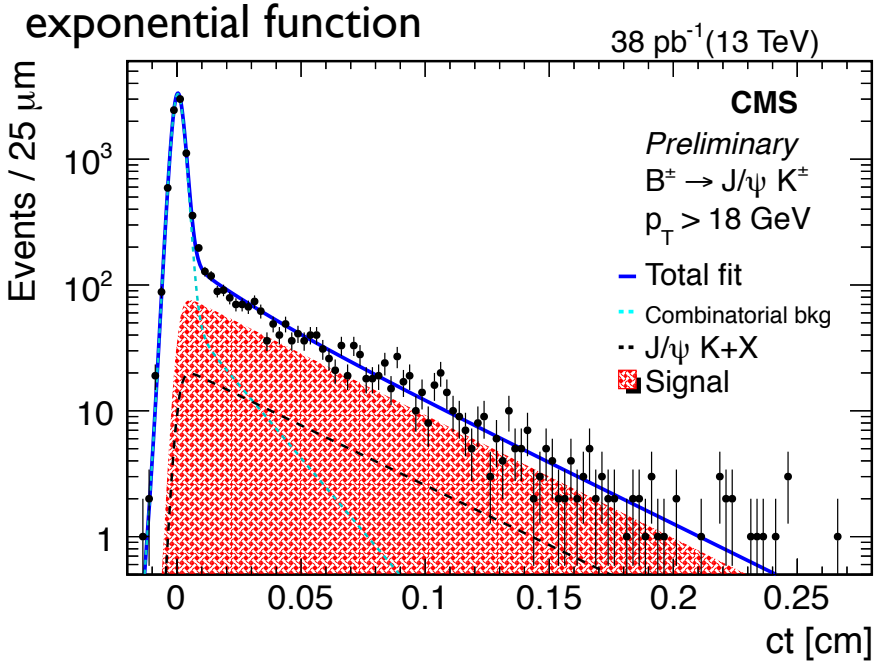
Spectroscopy with J/Ψ tag

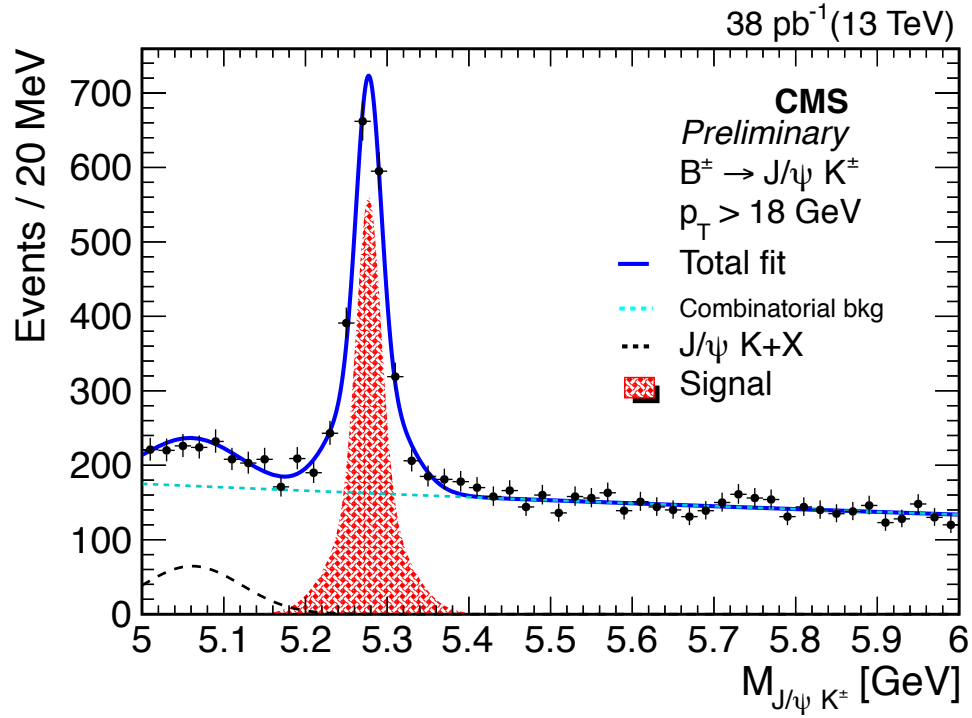
CMS-DP-2015-018/CDS:2037379

Trigger selection:

- J/ψ mass constraint (150MeV window)
- $p_T^{\mu} > 4$ GeV
- $|\eta^{\mu}| < 2.4$
- p_T (J/ψ) > 8 GeV

Fitting method:2D (mass, proper time)
mass and proper time projections shown here.
Decaying exponential terms: $e^{-ct/\lambda} \otimes$ Gaussian
background: prompt Gaussian + decaying exponential function





Mass: 5.277 ± 0.001(stat.) GeV
PDG= 5.279 GeV

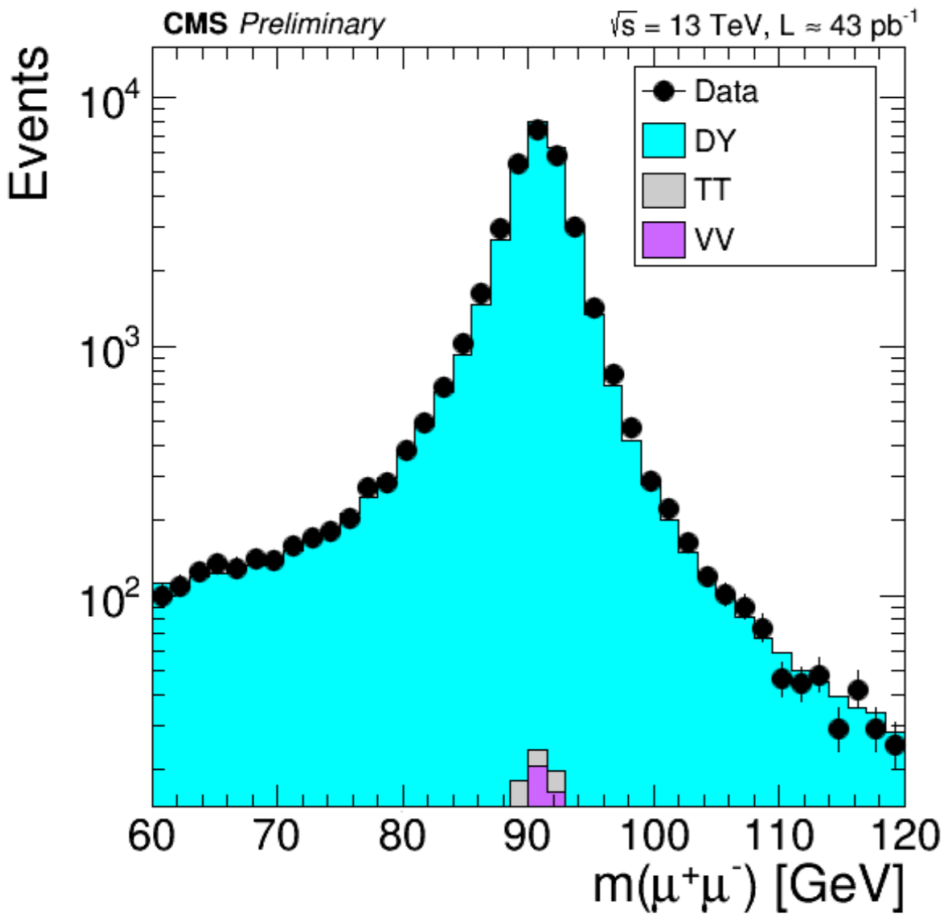
Signal: double Gaussian
Combinatorial background: exponential
J/ψ K+X: Gaussian

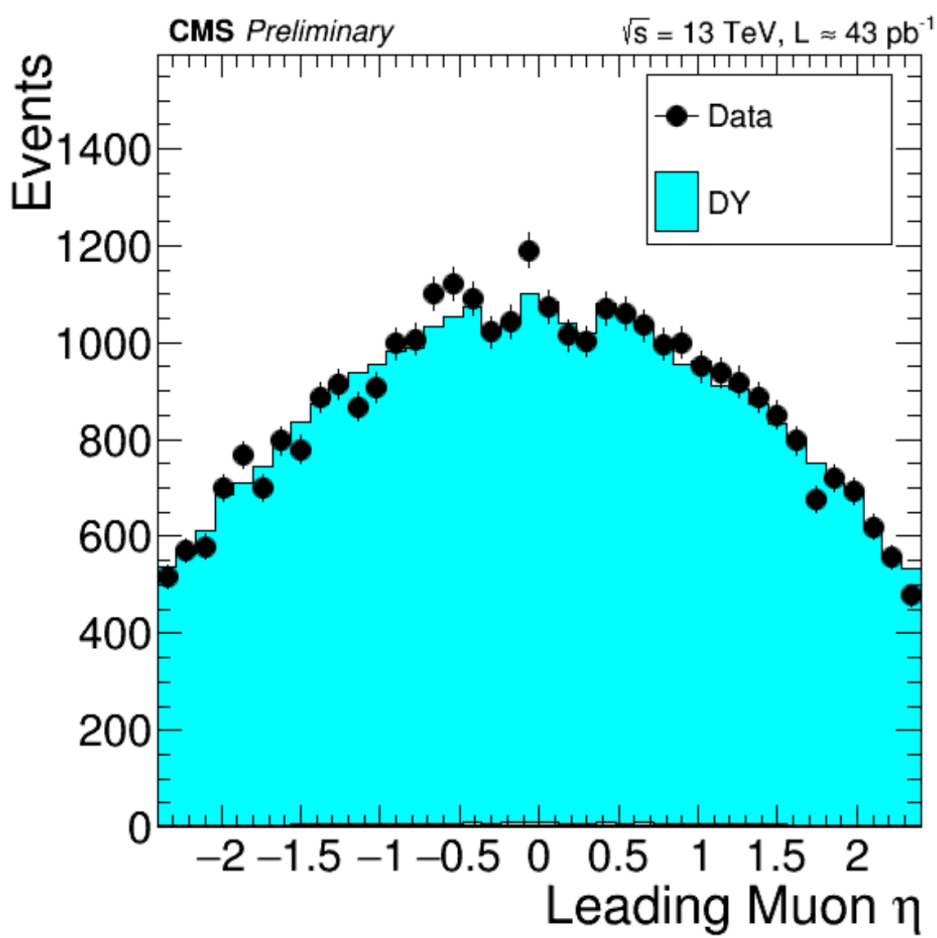
…….up to the Z.

CMS-DP-2015-015/CDS:2037372

Di-muon triggered events are compared with Drell-Yan MC simulations:

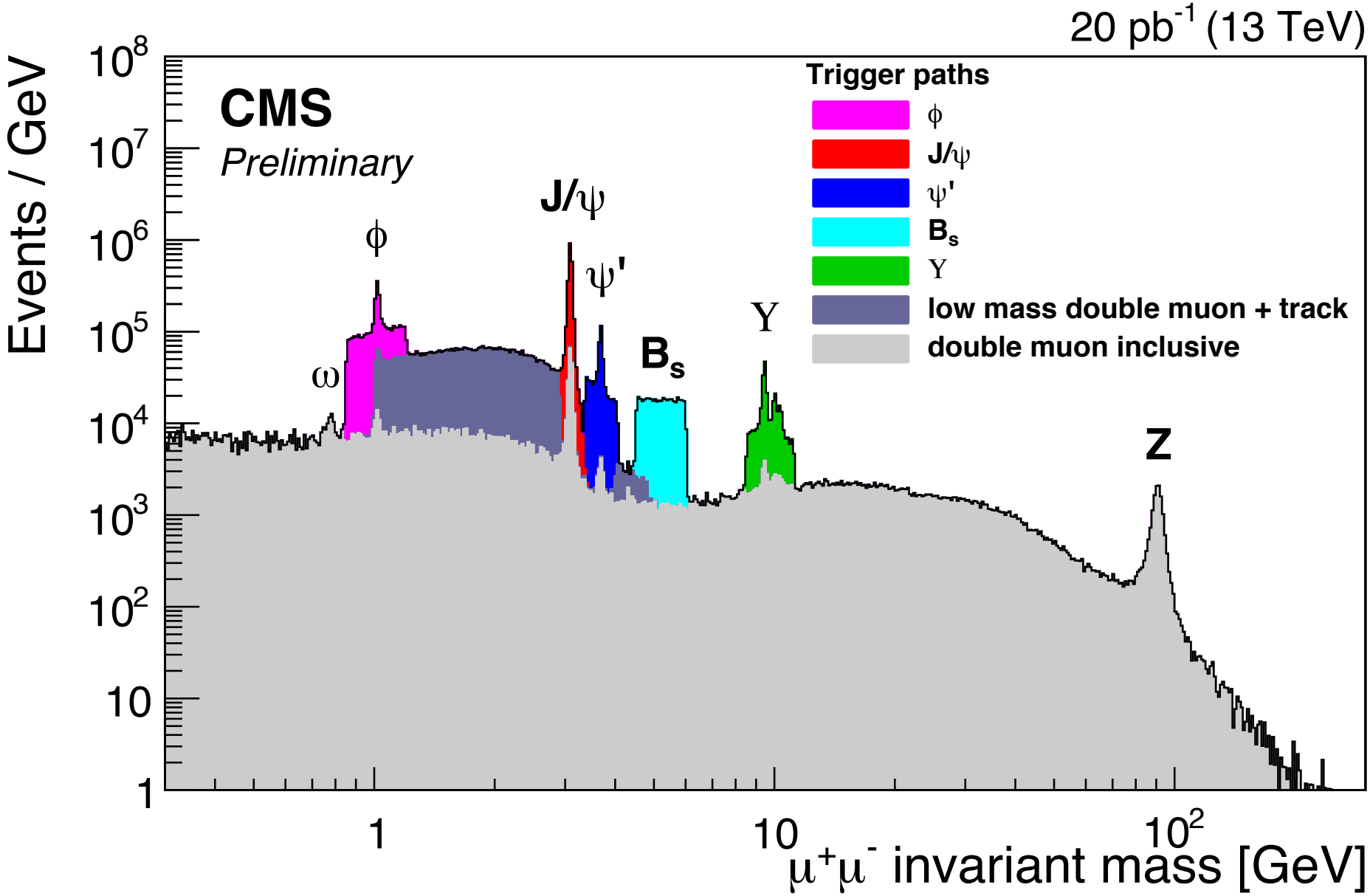
- at least two opposite-sign muons
- loose identification and isolation criterium
- p_T > 20 and 10 GeV, $|\eta| < 2.4$





A complete physics programs with two muons

CMS-DP-2015-018/CDS:2037379

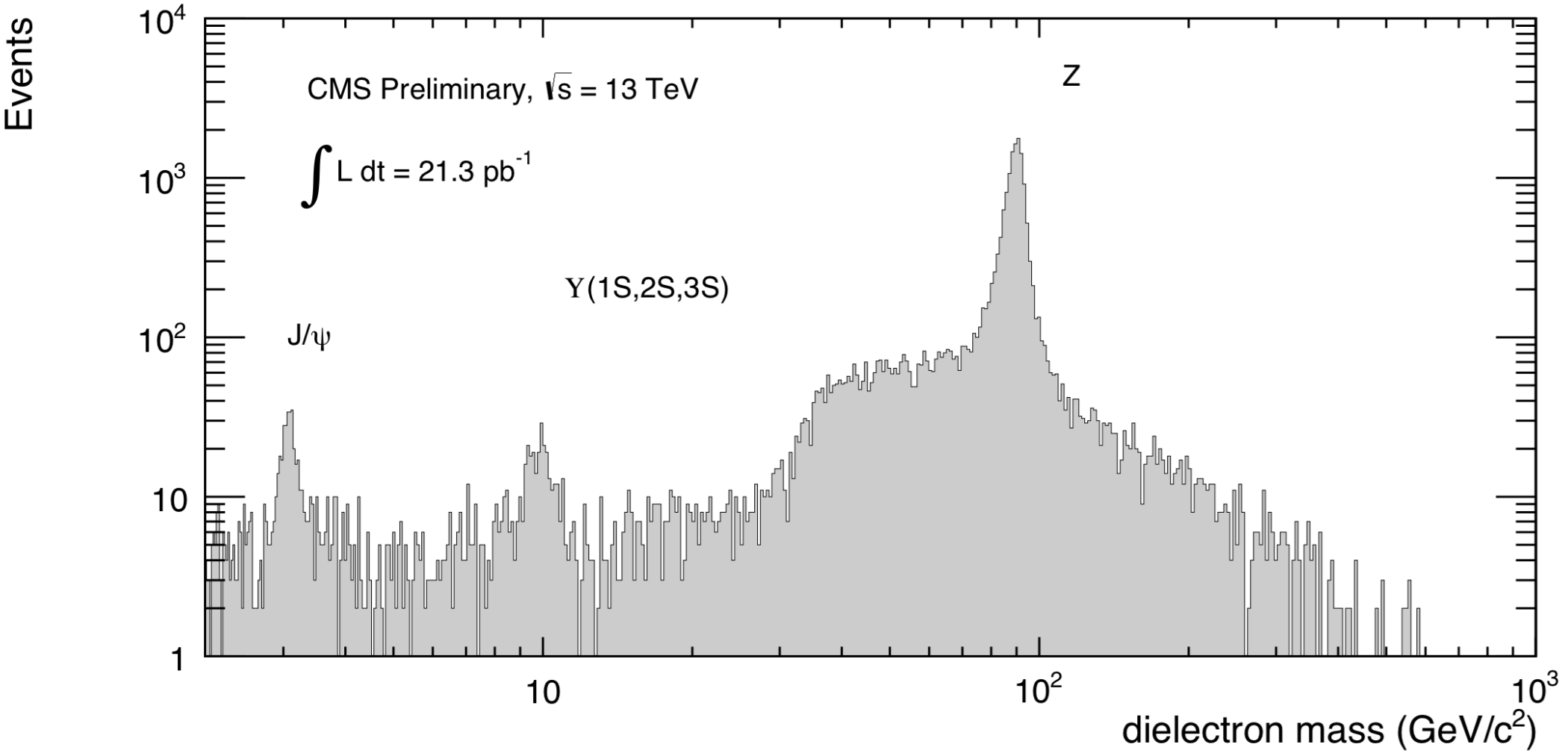


and also with di-electrons.

CMS-DP-2015-013/CDS:2037370

trigger selection: double electron photon path

- p_T>10 GeV, |η|<2.5

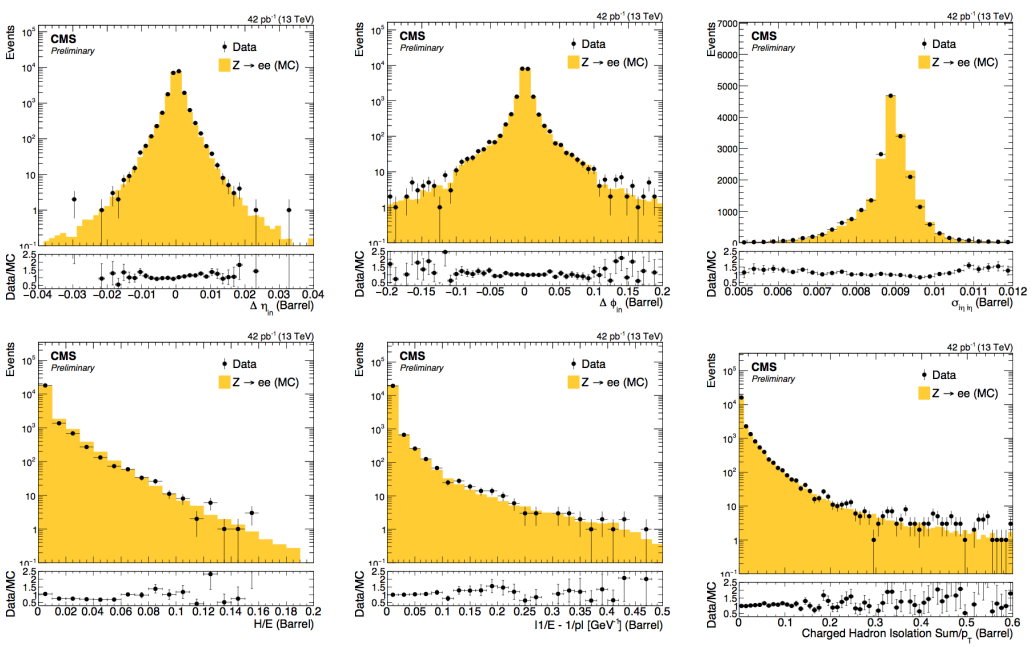


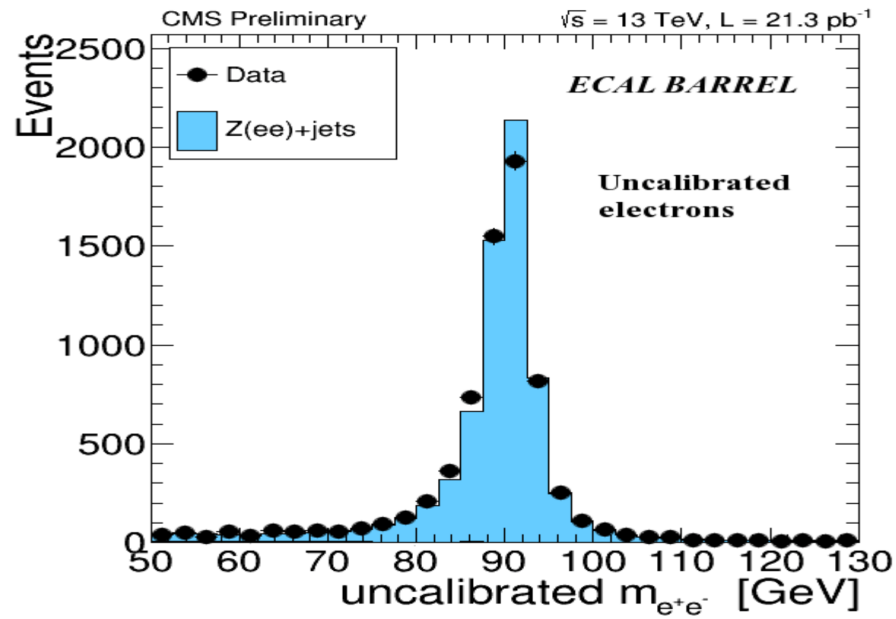
Electrons commissioning

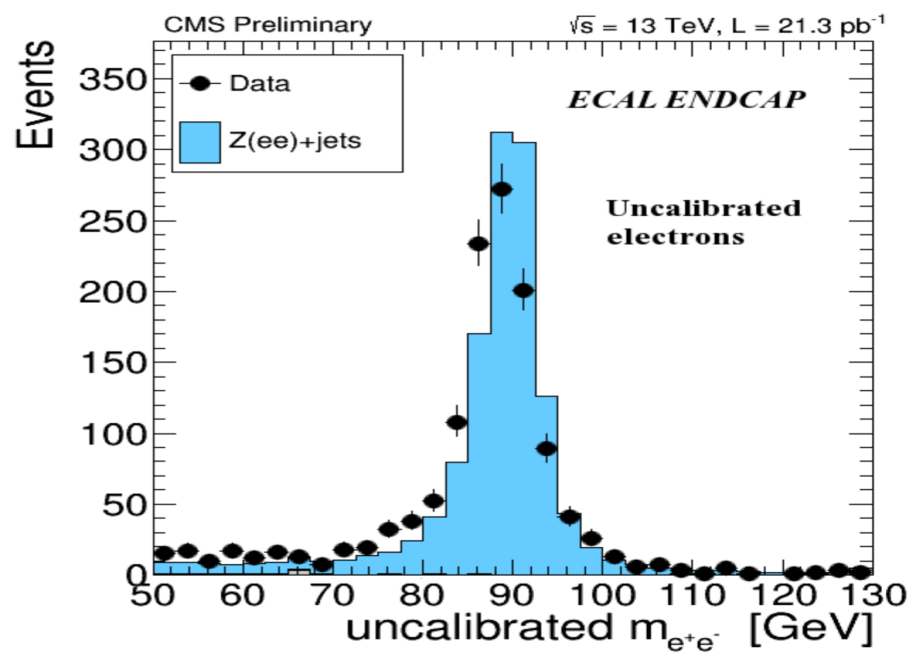
CMS-DP-2015-013/CDS:2037370

- All variables entering the electron id/MVA have been fully validated.
- Uncalibrated energy scale (from run1) already quite good.

➡Ready for physics.







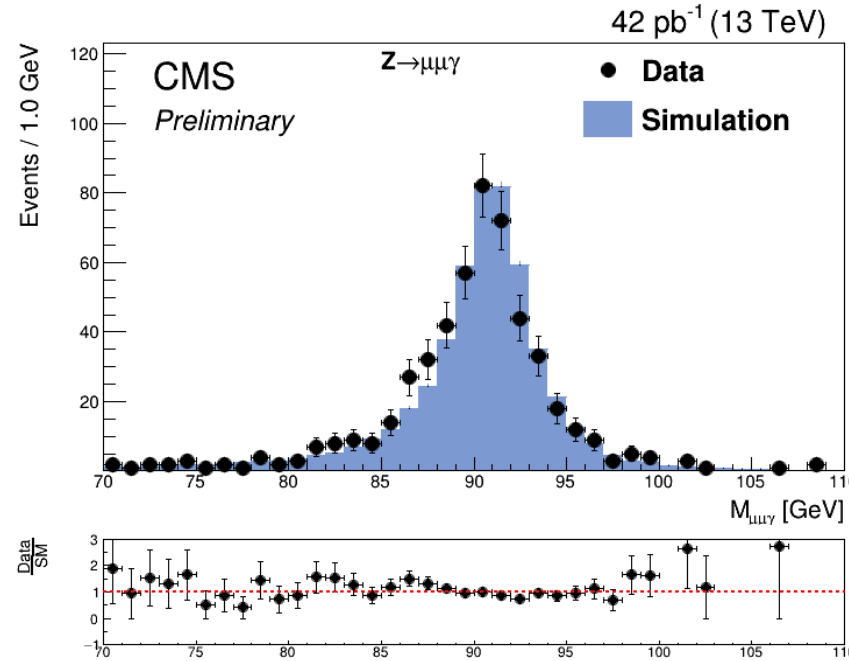
Photons commissioning

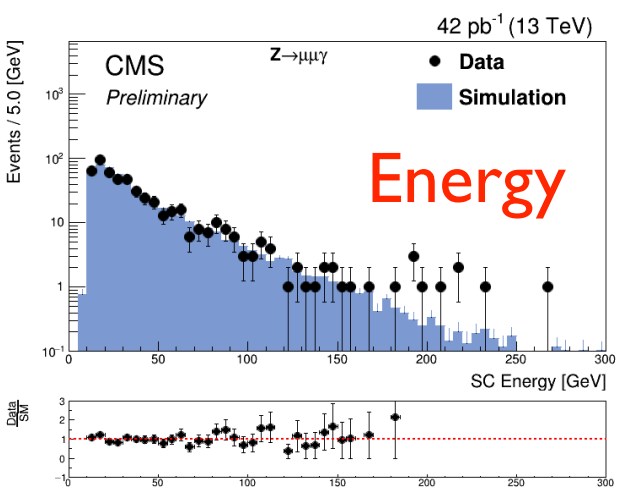
CMS-DP-2015-013/CDS:2037370

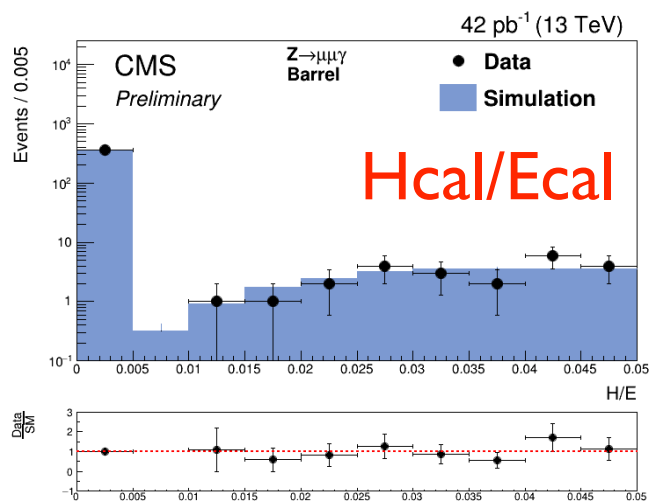
Using a clean sample of Z→μμγ:

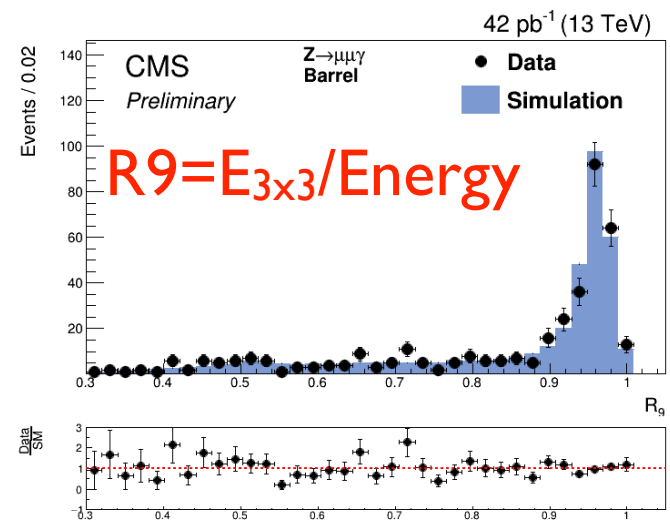
Muon P_T > 10 GeV (20 GeV for farthest)
Photon P_T > 10 GeV
- Isolated
- Hcal/Ecal < 0.05
- $\sigma_{i\eta i\eta}$< 0.011 (0.031) for Barrel(Endcap)

$\Delta R(\mu,\gamma)^{min}$ < 0.8





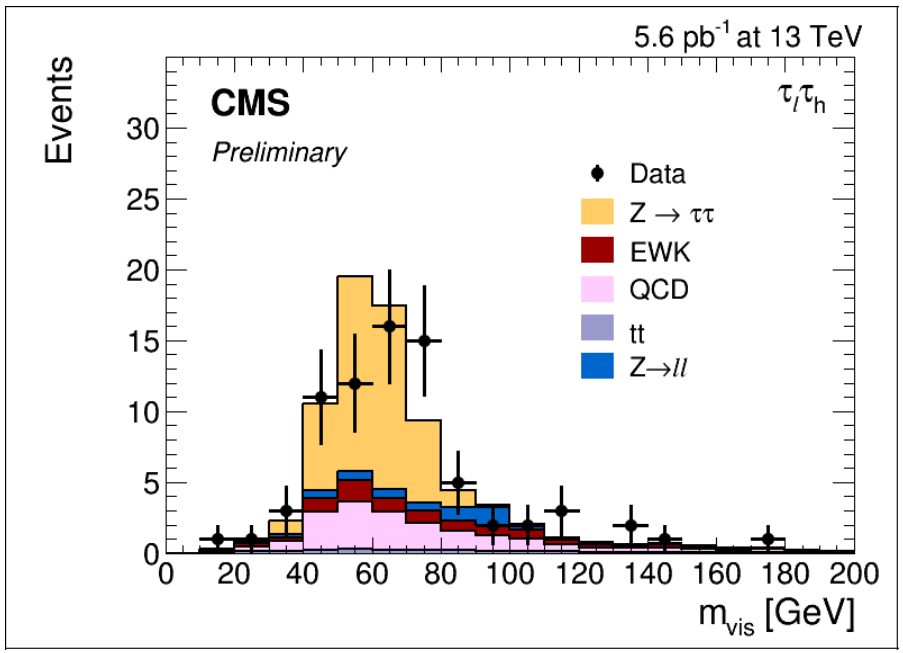


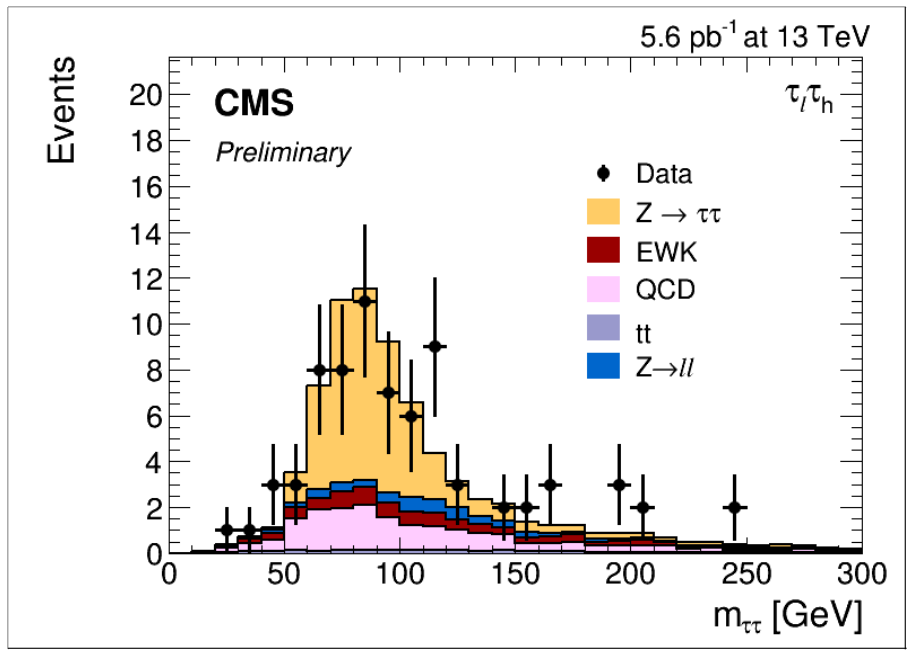


Tau commissioning

CMS-DP-2015-016/CDS:2037373

Reconstruction of Z → ττ in 13 TeV data





Visible mass distribution (left) and fully reconstructed mass using the SVFit algorithm (right) for leptonically and hadronically decaying taus at 13 TeV

Muons: p_T>18 GeV, η<2.1
Electrons: p_T>20 GeV η<2.1
Taus: p_T>20, η<2.3

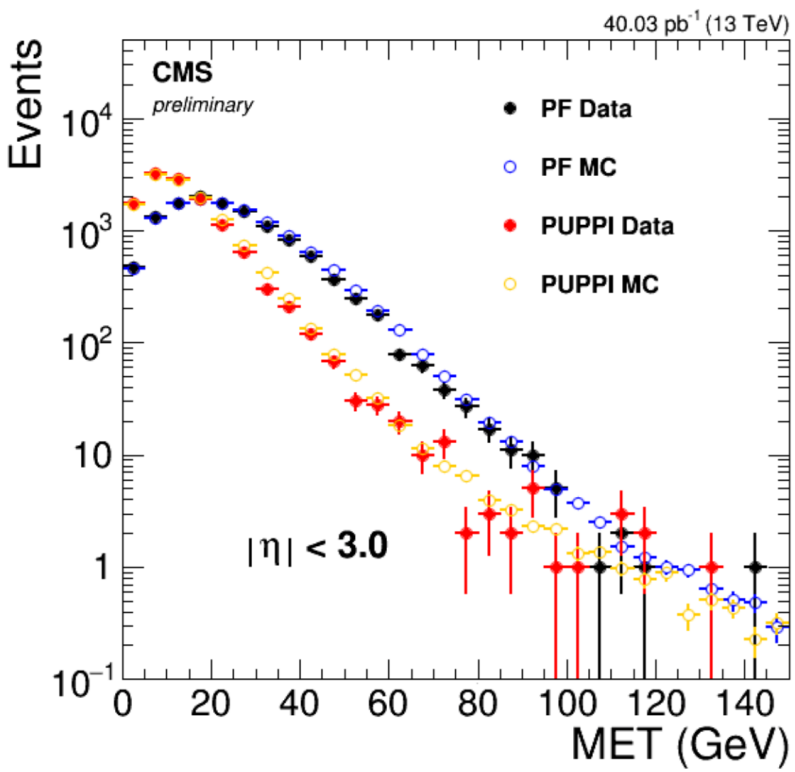
SVFit description: JHEP05(2014)104

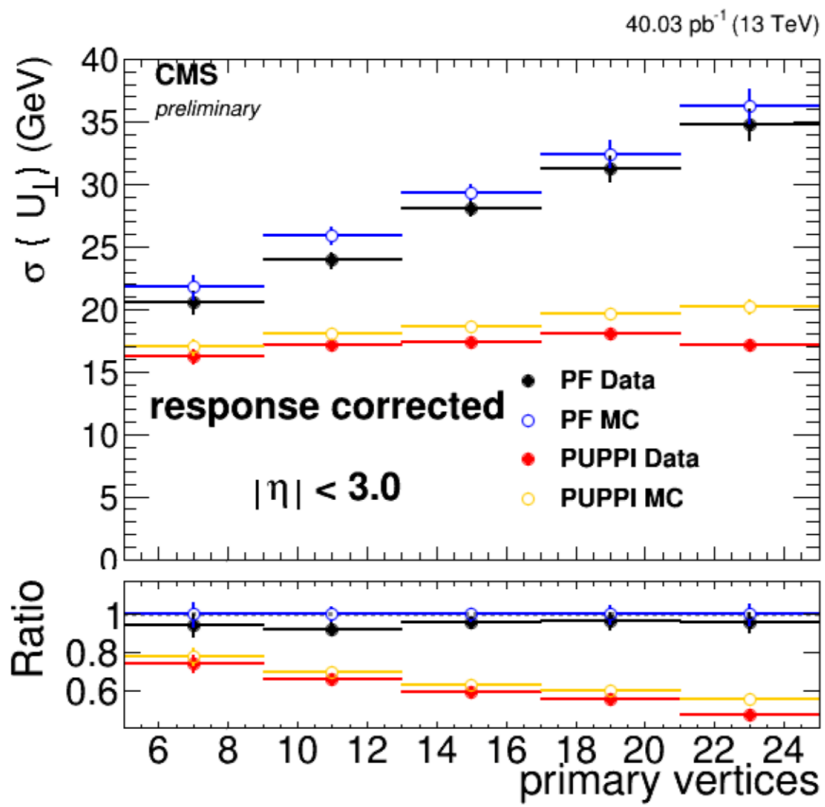
Missing Et performance

PF: standard Particle Flow reconstruction

PUPPI: Pile Up Per Particle Identification (http://arxiv.org/abs/1407.6013, CMS-PAS-JME-14-001)

- any particle flow candidate is weighted according to the surrounding activity
- the weights are optimized to discriminate particles from hard scattering vs particle from pile-up.



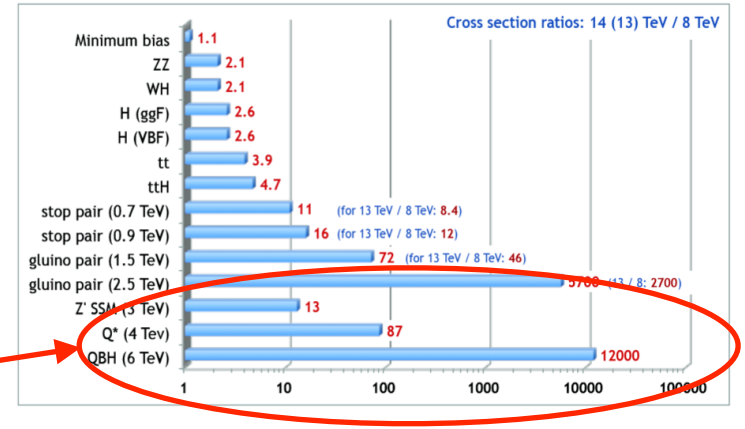


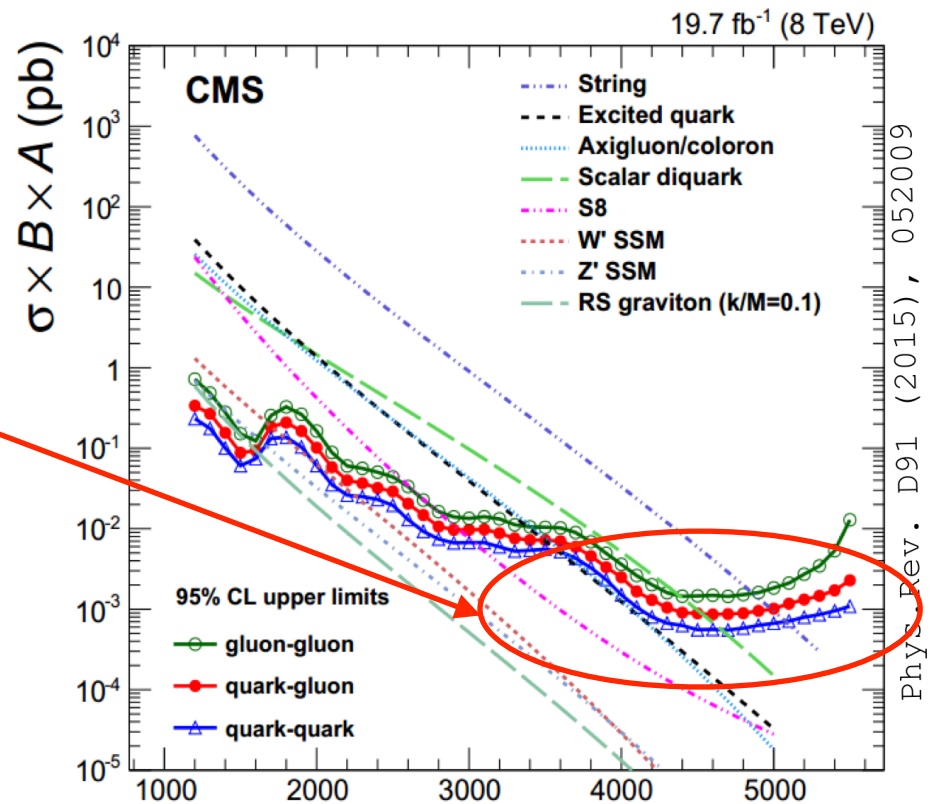
First Physics Analyses @13TeV

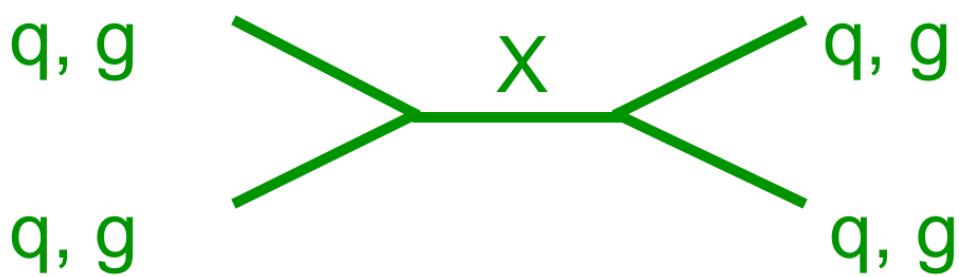
Di-jet resonance search

A classical bump search on top of a falling spectrum.

- Test directly s-channel production of a heavy resonance.
- Expect better limits w.r.t. Run1 already with few 100's pb^{-1} for masses above 4 TeV.







Di-jet resonance search

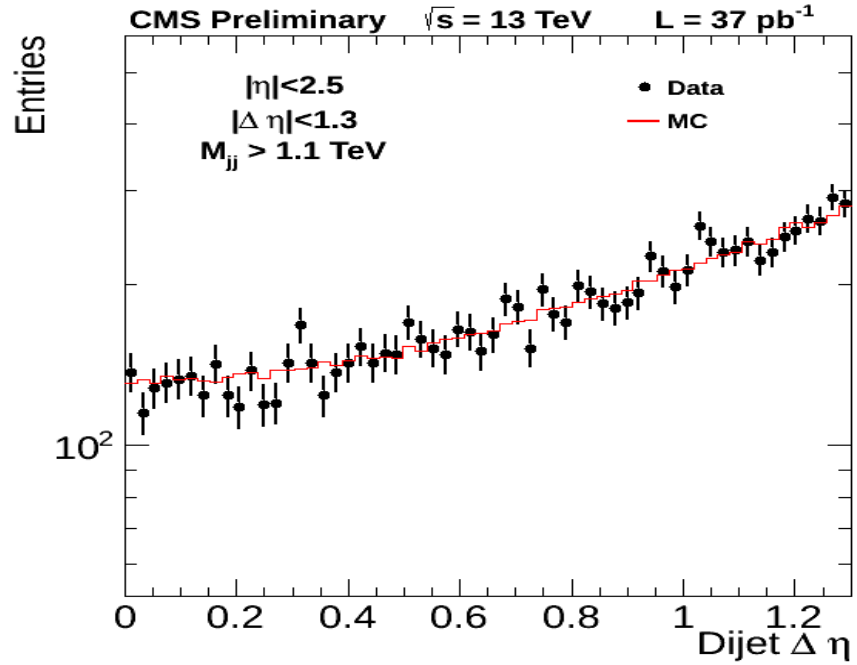
CMS-DP-2015-017/CDS:2037378

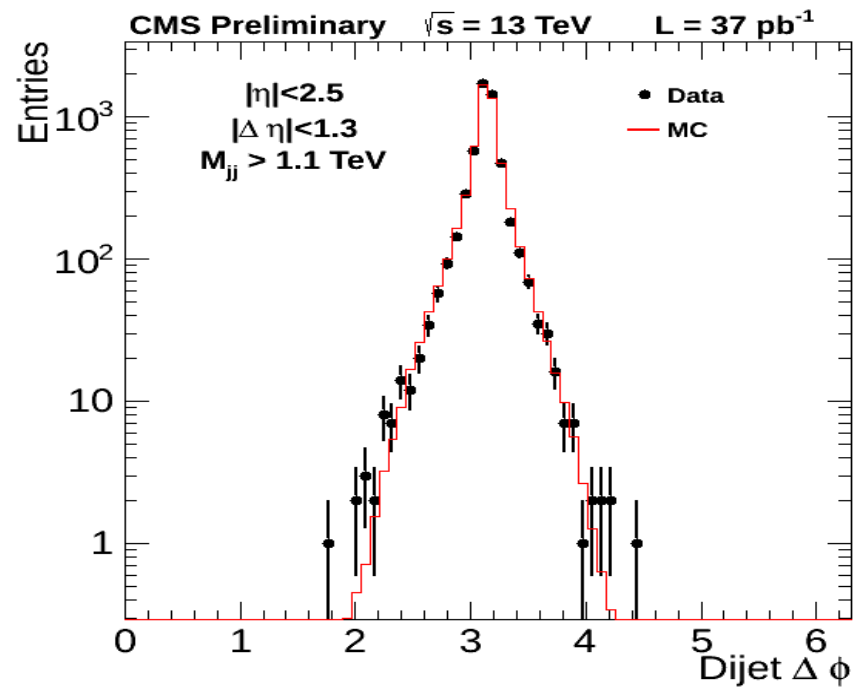
Di-jet event selection:

- Jet1: p_T > 60 GeV , $|\eta|$ < 2.5
- Jet2: p_T > 30 GeV , $|\eta|$ < 2.5
- $|\Delta\eta_{jj}|$<1.3

Geometrically close jets are combined into "wide jets", which are used to measure the dijet mass spectrum (M_{jj})

- M_{jj} > 1.1 TeV





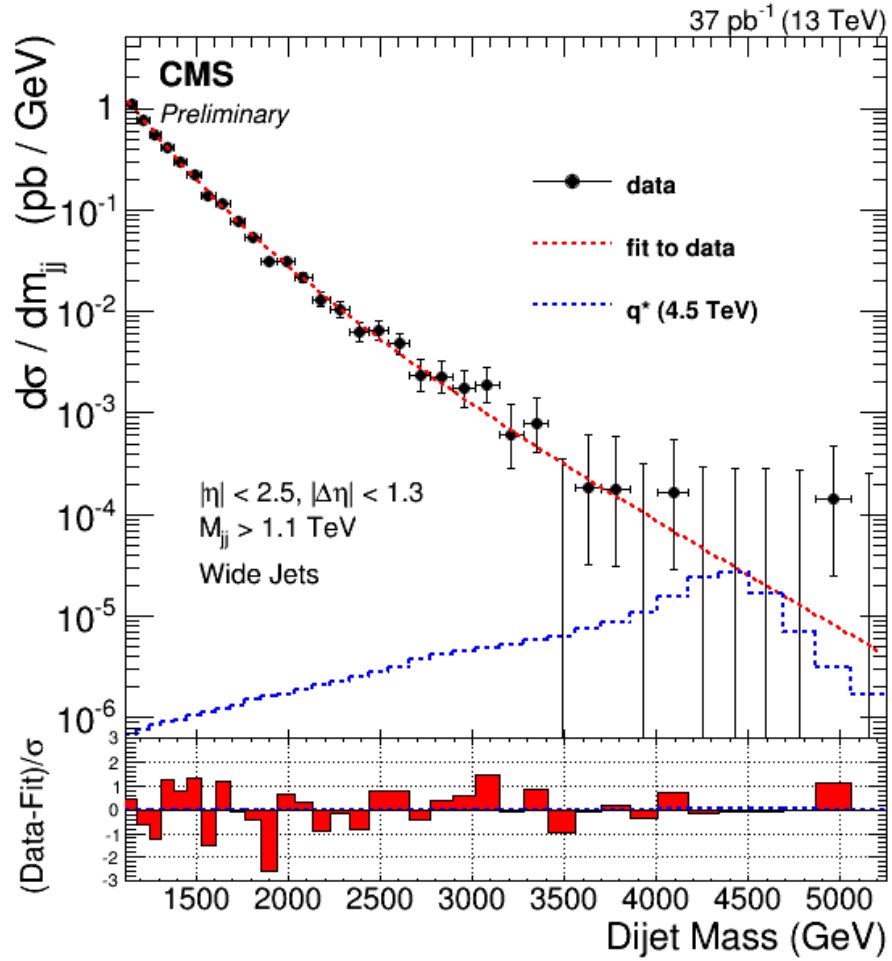
Di-jet resonance search

Fitting function unchanged since Run I

CMS-DP-2015-017/CDS:2037378

$$\frac{d\sigma}{dm_{jj}} = \frac{p_0(1-\frac{m_{jj}}{13000})^{p_1}}{(\frac{m_{jj}}{13000})^{p_2+p_3\ln(\frac{m_{jj}}{13000})}}$$

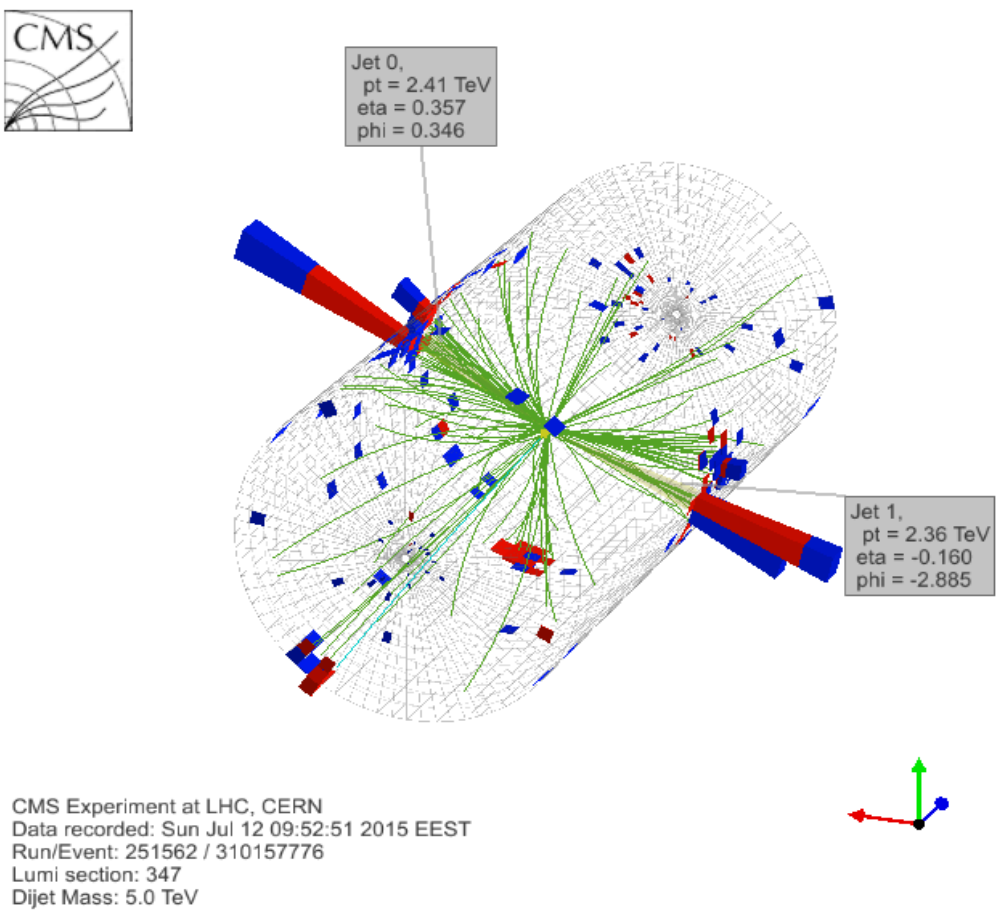
- Above 3.5 TeV
  - ➡~4.6 background events are expected (from fit to data) and
  - ➡~0.8 events of signal from the considered q* model (4.5 TeV).
  - ➡4 events are observed in data.
- With the current integrated luminosity we expect to exceed the sensitivity of the 8 TeV analyses only for narrow resonances with masses greater than about 5 TeV.

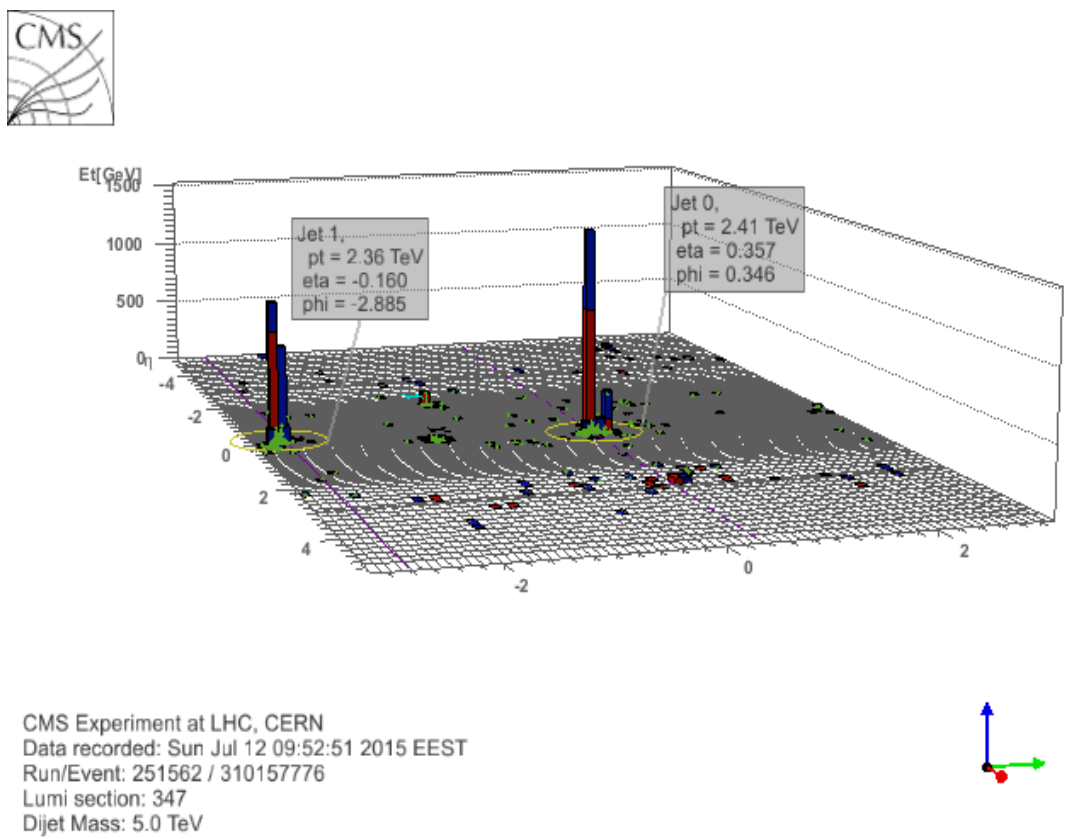


Stay tuned.

Di-jet Highest mass event (Mjj=5 TeV)

CMS-DP-2015-017/CDS:2037378

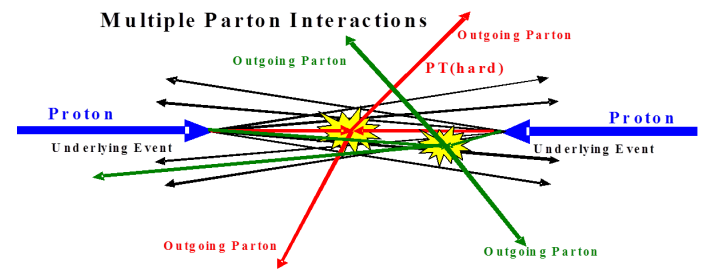




dN/dη: first publication!

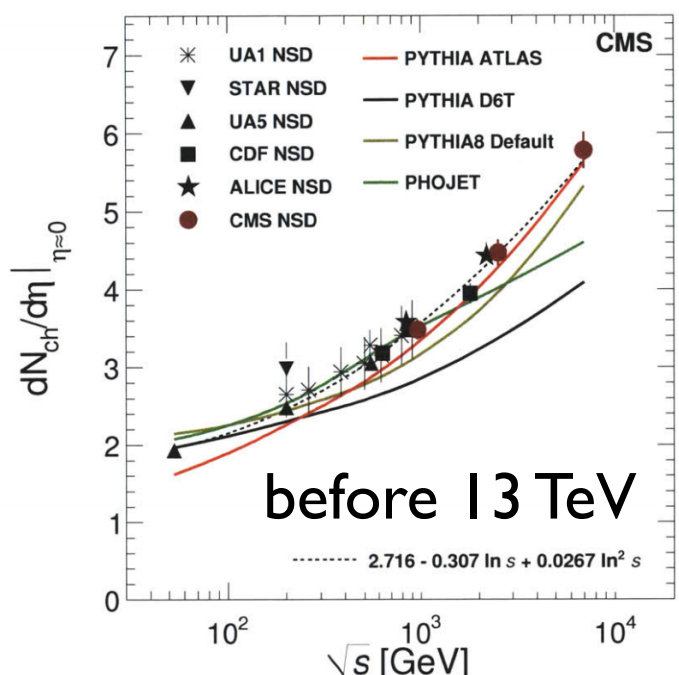
Pseudorapidity distribution of charged hadrons in proton-proton collisions at $\sqrt{s}$ = 13 TeV

arXiv: http://arxiv.org/abs/1507.05915
Submitted to PLB



The multiplicity measurement is a crucial measurement:

- the dependence of dN/dη on $\sqrt{s}$ gives an handle on the relative weight of soft and hard scattering contribution.
- The soft scattering is modelled phenomenologically and hard to predict (non-perturbative QCD).
- A precise measurement is crucial to tune all theory/MC predictions at a new energy



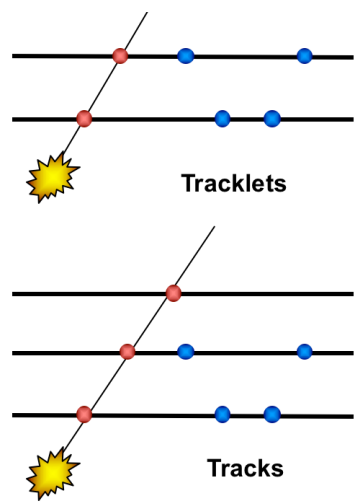
dN/dη: first publication!

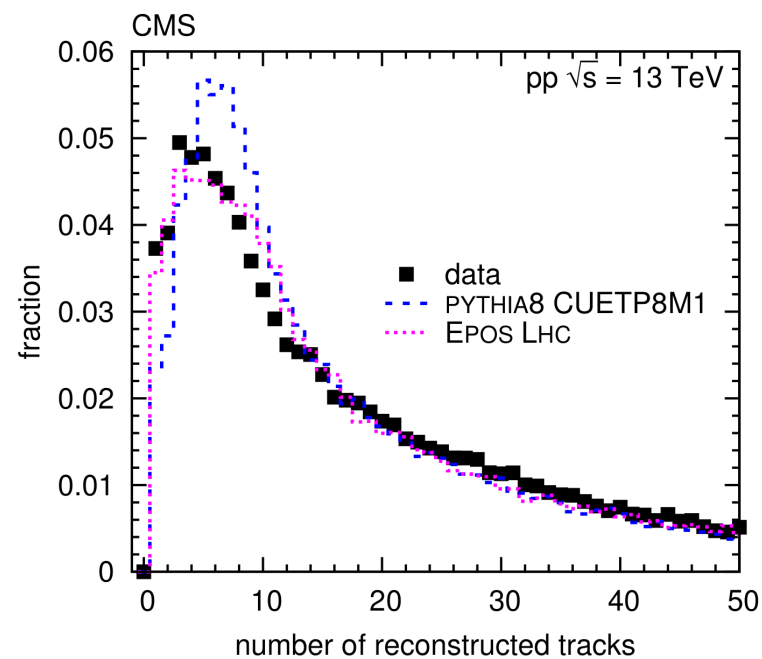
The $dN_{ch}/d\eta$ was measured in CMS in a special early run @13 TeV taken on June 7th (~1h30'):

- 11.5M events with no magnetic field
- 0.2% - 5% PU (separated beam)
- N_{ch} defined as:
  - all charged particles with $|\eta|<2$
  - decay products with $c\tau<1$cm included
  - secondary interactions excluded as well as prompt leptons

Two main analyses with several cross check:

- tracklet-based
- track based

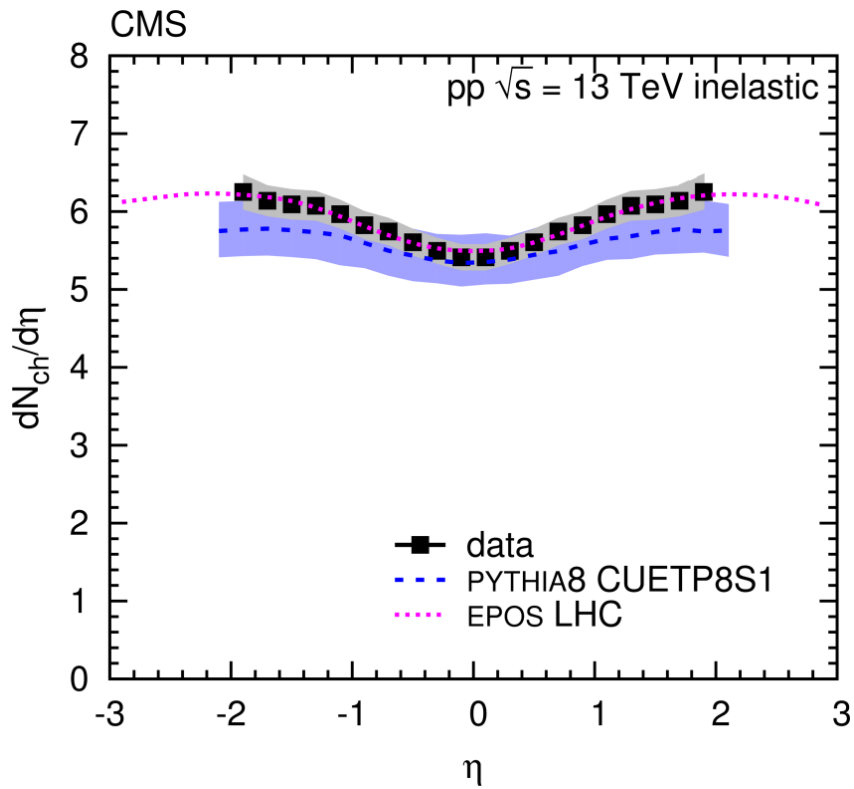


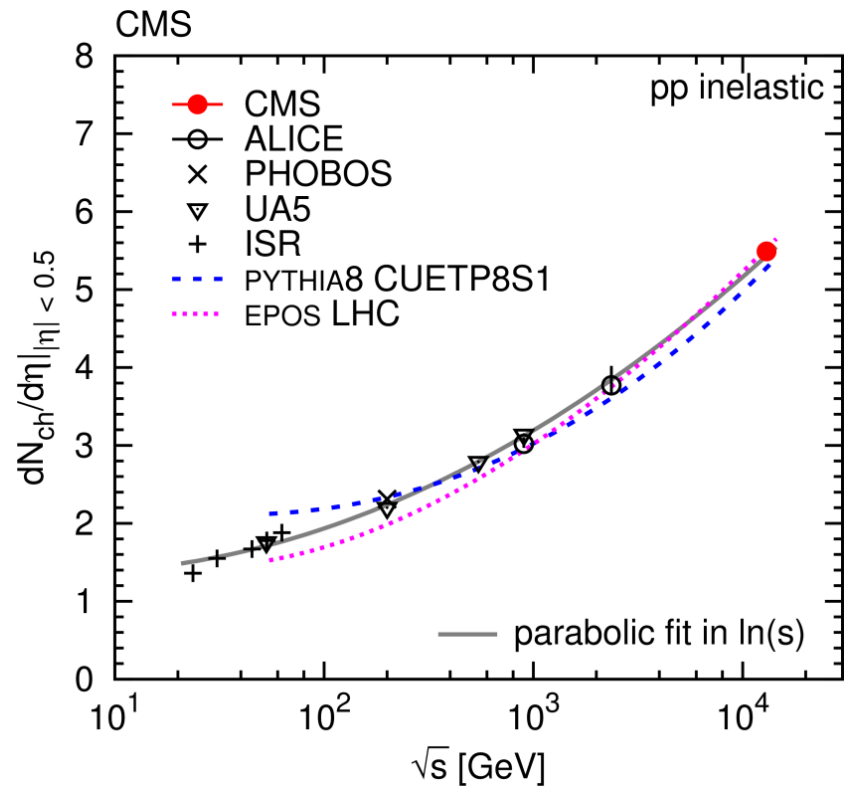


dN/dη: first publication!

The two analyses methods are fully consistent and are combined for the final results:

$dN_{ch}/d\eta|_{|\eta|<0.5} = 5.49 \pm 0.01\ (stat) \pm 0.17\ (syst)$





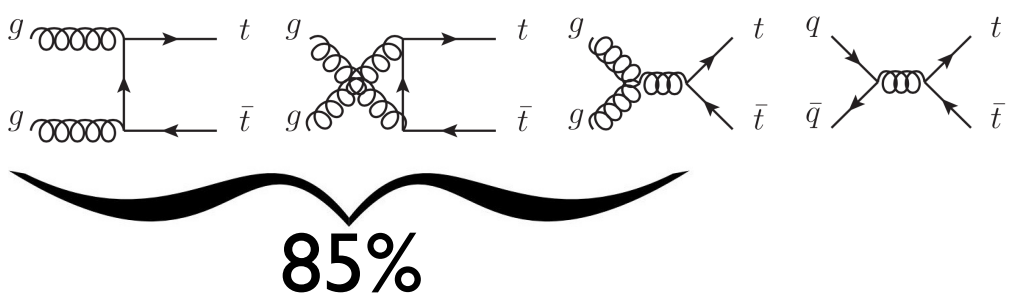
Mid-rapidity: EPOS LHC and PYTHIA8 CUETP8S1 consistent with data.
Rapidity dependence better described by EPOS LHC

Top pair cross section

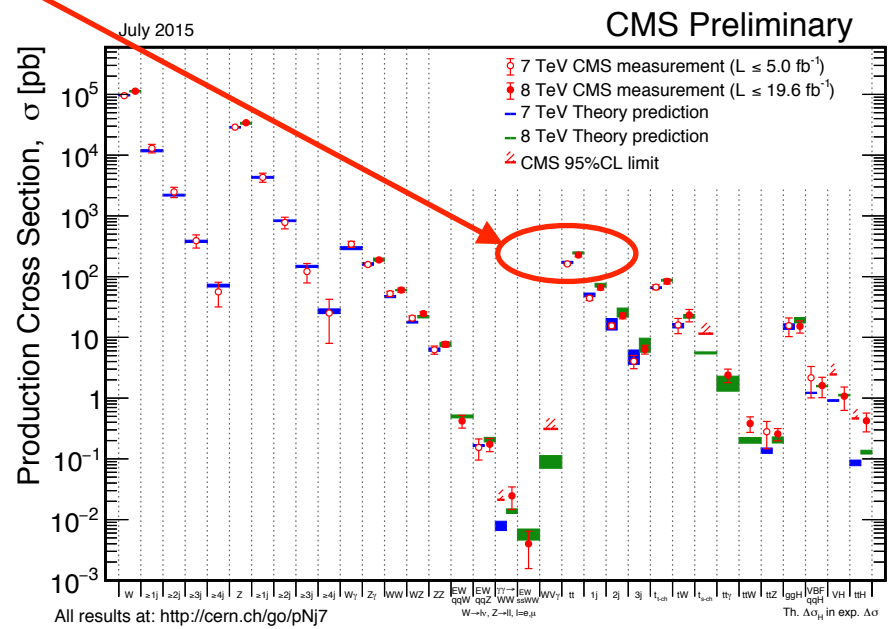
NEW

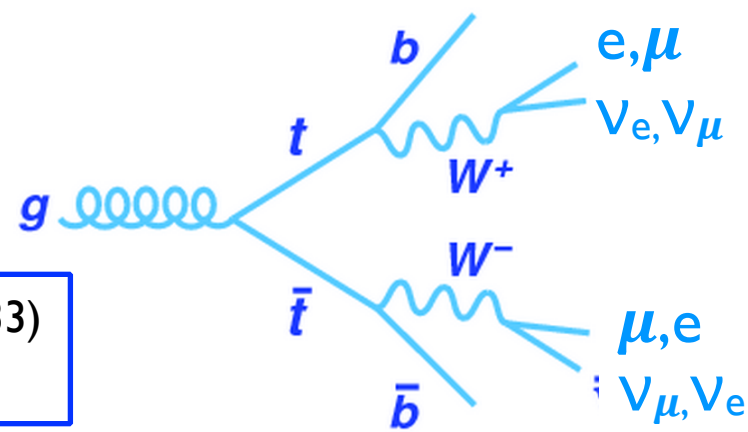
Why:

- it is a fundamental measurement of the SM (any deviation is sign of NP)
- its understanding is crucial for almost all NP searches
- accessible already with few pb-1
- relatively low systematics in the di-lepton channel



CMS-PAS-TOP-15-003





ATLAS inclusive result shown are EPS (ATLAS-CONF-2015-033)
σ_{tt}(13TeV)= 825 ± 49 (stat) ± 60 (syst) ± 83 (lumi) pb

Top pair cross section

CMS-PAS-TOP-15-003

Integrated lumi= 42 pb^{-1}

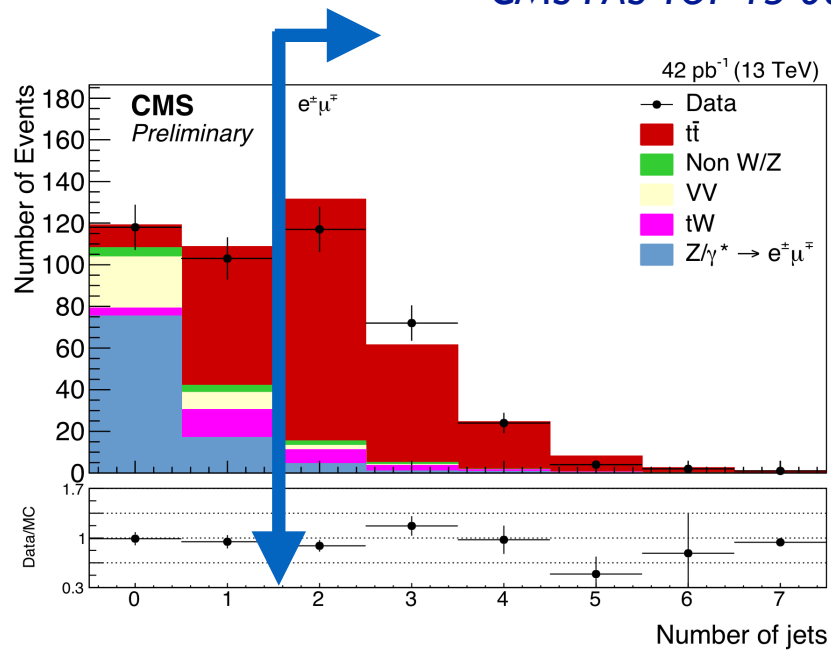
- all validated data from 50ns run

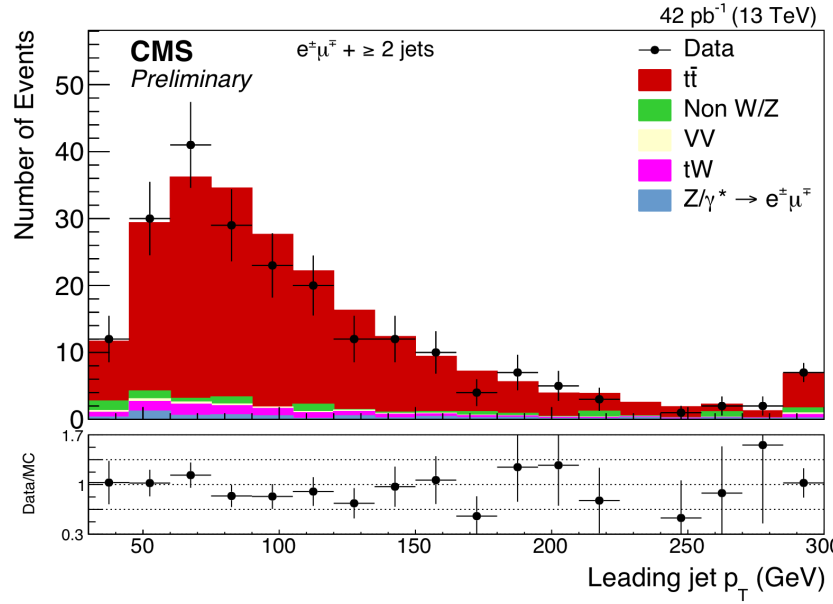
Signal tt MC reference sample:

- PowhegV2+Pythia8, normalized to NNLO+NNLL
- Other tt samples for systematics: MG5_aMC@NLO(FxFx)+Pythia8, Powheg + Herwig++, PowhegV2+Pythia8 Scale Up (Down)

Selection

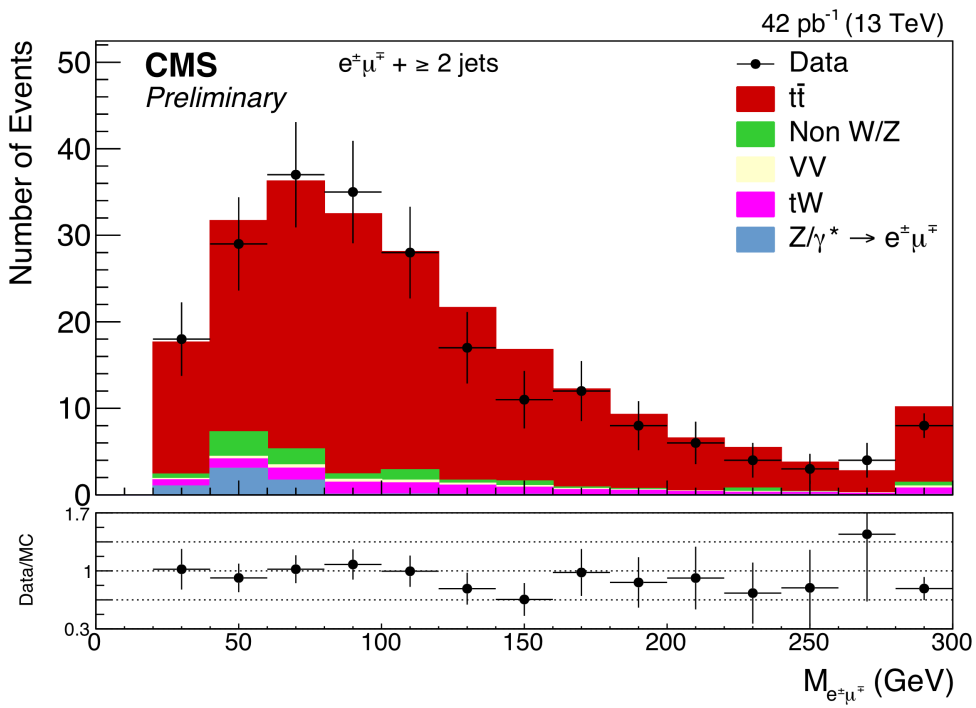
- At least 2 good (OS) leptons (1e and 1μ)
- pt(lept)> 20 GeV and |η|< 2.4
- If more than 2 good leptons, the two with highest pt are retained
- Di-lepton invariant mass > 20 GeV
- At least 2 jets (anti-kT R = 0.4)
- pt(jets)> 30 GeV and |η|< 2.4

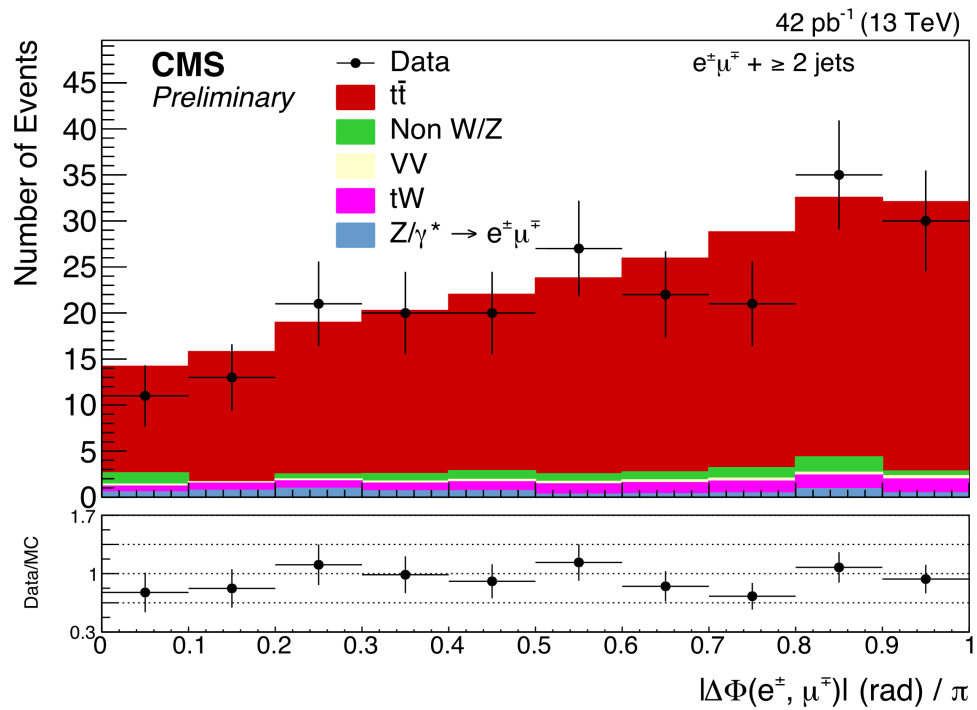




Top pair cross section

- The invariant mass distribution between the two lepton is a place where NP might hide.
- The Δφ distribution explores the spin correlation in the top ant-top pair.





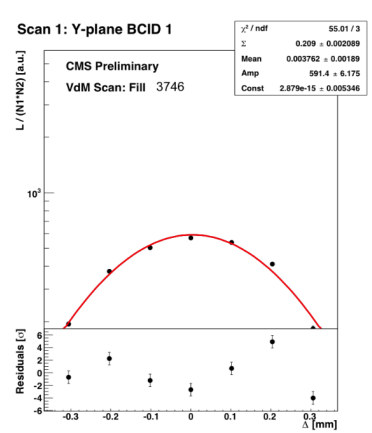
No statistically relevant deviation is observed

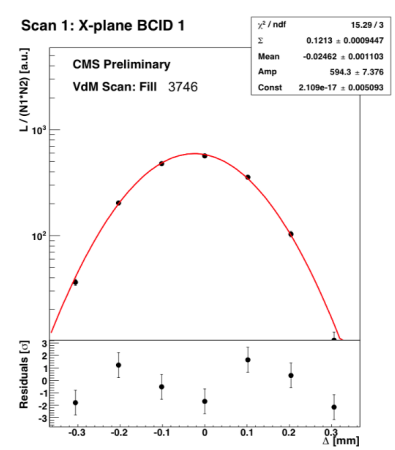
Top pair cross section

Systematics dominated by:

- Trigger efficiency:
  - affected by low stats in the monitoring trigger paths (3% stat. uncertainty)
- Lepton efficiency:
  - data driven based on standard tag and probe technique
  - fully dominated by data statistics
- Jet Energy Scale:
  - derived by propagating the current JES uncertainty (4%)
- Luminosity:
  - a preliminary calibration has been obtained from "mini" VdM scans, not optimized for a precision measurement
  - It is expected to go down substantially after a proper VdM scan foreseen for Aug 24th

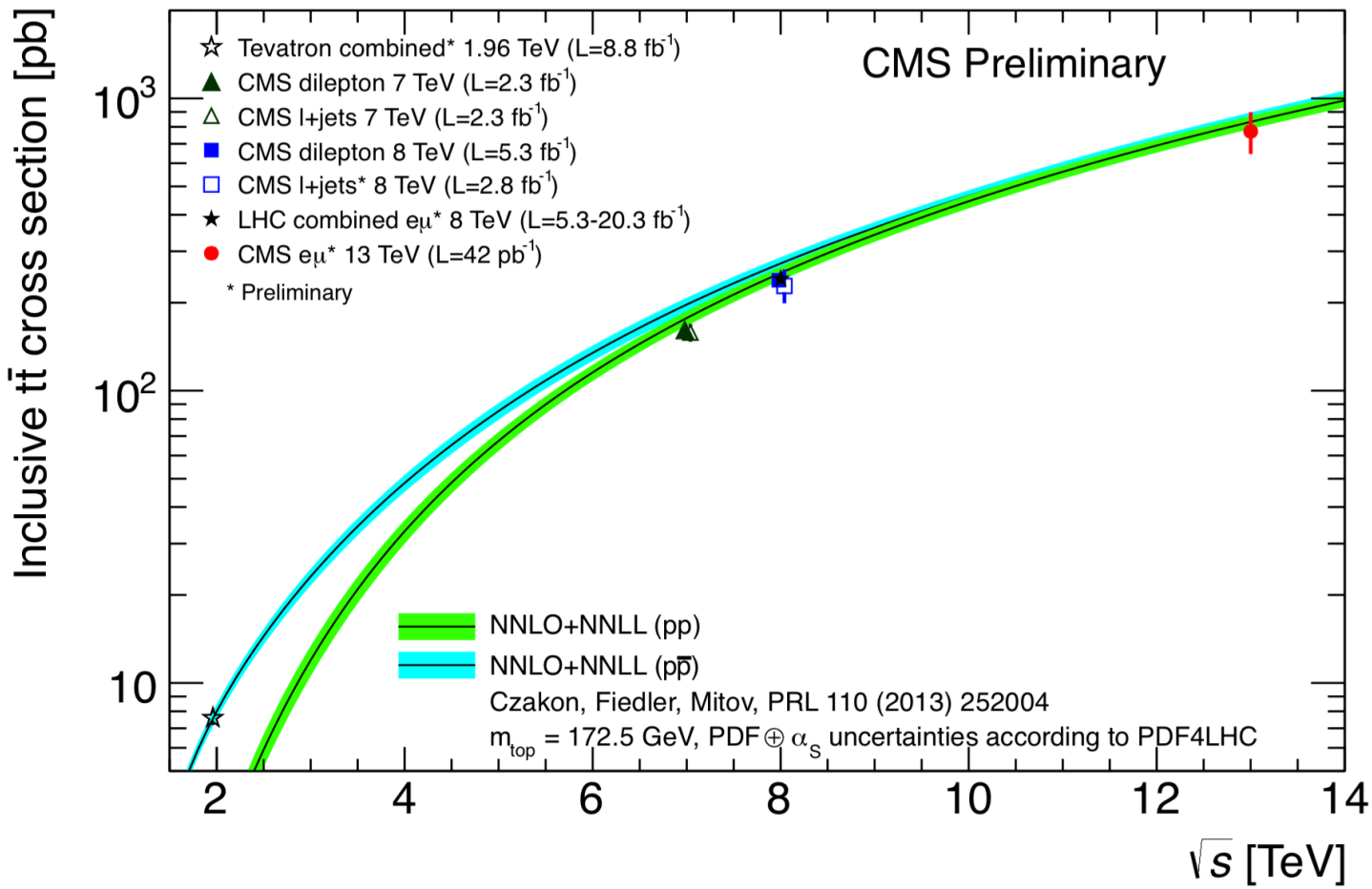
Source	$\Delta\sigma_{t\bar{t}}$ (pb)	$\Delta\sigma_{t\bar{t}}/\sigma_{t\bar{t}}$ (%)
Data statistics	60	7.7
Trigger efficiencies	39	5.0
Lepton efficiencies	33	4.3
Lepton energy scale	< 1	< 0.1
Jet energy scale	20	2.6
Jet energy resolution	< 1	≤ 0.1
Pileup	2.8	0.4
Scale (μ_F and μ_R)	1.5	0.2
$t\bar{t}$ NLO generator	15	1.9
$t\bar{t}$ hadronization	14	1.8
PDF	12	1.5
Single top quark	14	1.8
VV	3.5	0.5
Drell–Yan	3.9	0.5
Non-W/Z leptons	8	1.0
Total systematic (no integrated luminosity)	62	8.0
Integrated luminosity	93	12
Total	126	16.4





Top pair cross section

inclusive σ_{tt}(13TeV)= 772 ± 60 (sta) ± 62 (sys) ± 93 (lum) pb

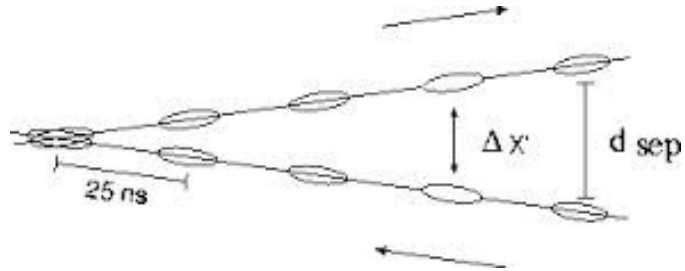


Results derived also in a fiducial volume: both leptons p_T > 20 GeV, $|\eta|$<2.4

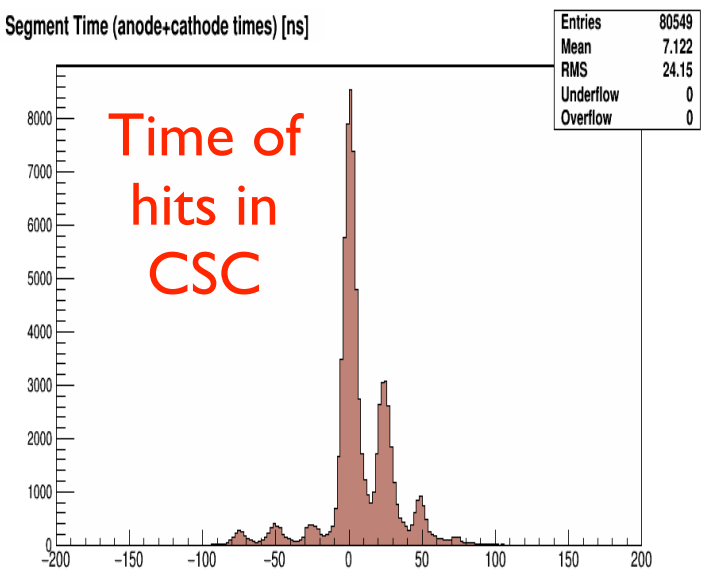
fiducial σ_{tt} =12.9±1.0(stat)±1.1(syst)±1.5(lumi)pb

Fresh out of the press

Since Aug 13th @ 01:11 UTC
we are running with 25ns bunch spacing!

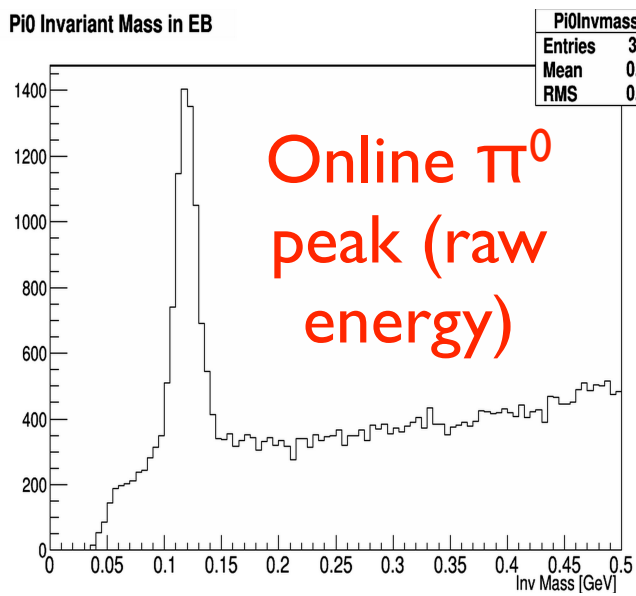


No time to have physics results to present here, but out-of-the-box online data quality plots look encouraging!

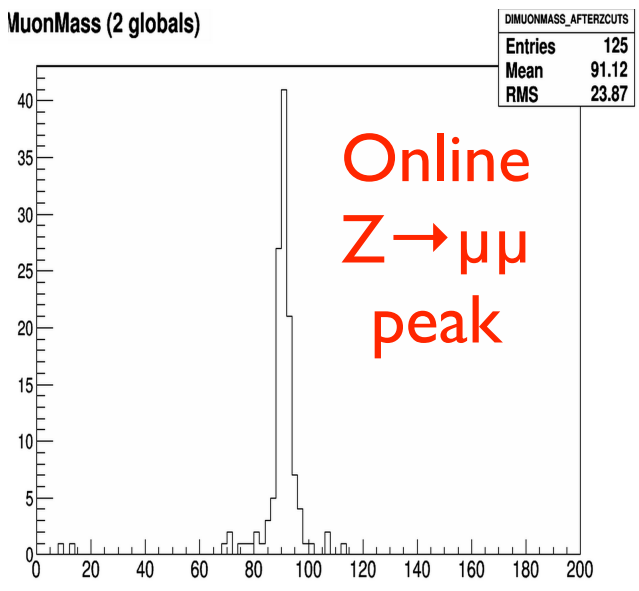


Time of hits in CSC

Note: structure depends on LHC beam/Trigger/readout



Online π^0 peak (raw energy)



Online $Z \rightarrow \mu\mu$ peak

from a single 200 nb^{-1} run

Summary

Many changes/improvements during the long shutdown:

- detectors
- trigger/DAQ
- Offline/computing

A fantastic work accomplished in time !

CMS is more than ready for first physics results:

- continuing a systematic commissioning of all physics objects
- dN/dη analysis (**submitted!**)
- top pair cross section (**first preliminary result** here!)
- di-jet resonance search (fully commissioned)

The search season is starting.
Next to come:

- more SM xsec measurements
- di-jet and di-lepton resonances
- multijet, black holes
- di-photon

Expected to exceed Run 1 limits for massive NP even with few 100's pb^{-1}

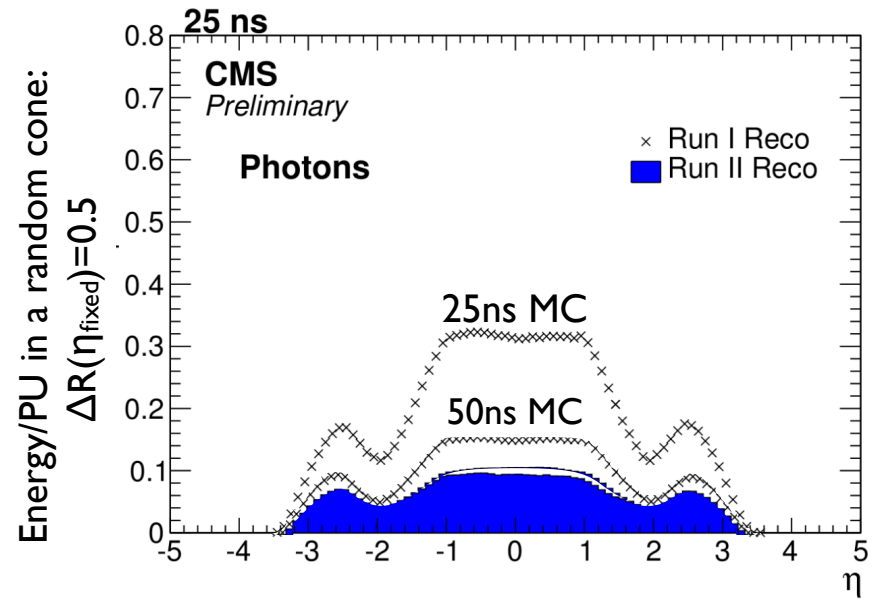
BACKUP

For a complete set of results on Run2 please have a look at:
http://cms-results.web.cern.ch/cms-results/public-results/publications/

Preparation activities

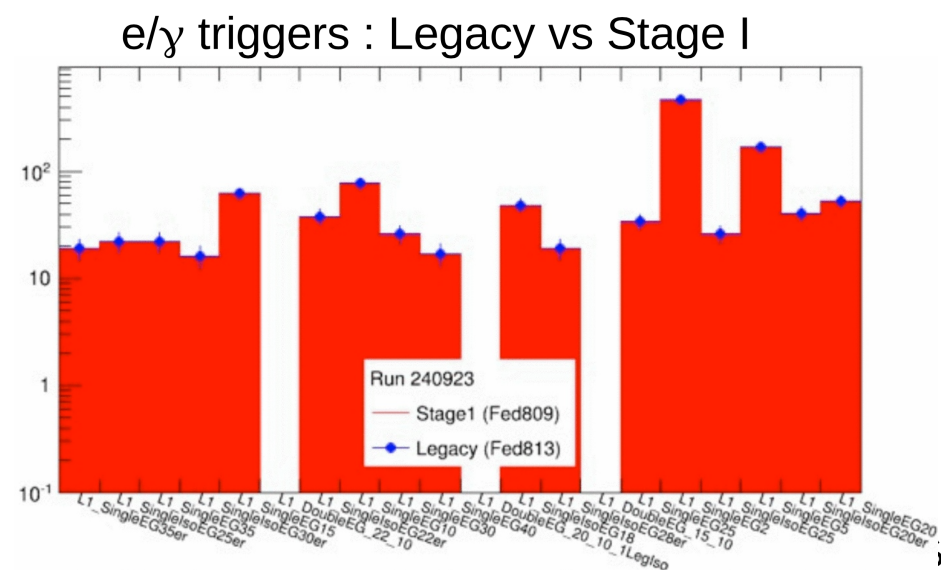
Significant effort on algorithm improvements with emphasis on pile-up mitigation to cope with 25ns bunch separation.

- Improvement on track reconstruction
- Out of time PU mitigation in the calorimeters



Run I (legacy) trigger system operational for 50ns running.
Stage I upgrade is being deployed for 25ns and HI running

- PU subtraction for all trigger objects
  Improved e/γ isolation and τ-trigger.



Preparation activities

High Level Trigger:

- Major improvements in the algorithms to cope with new conditions
- Including HLT specific OOT PU mitigation similar to offline

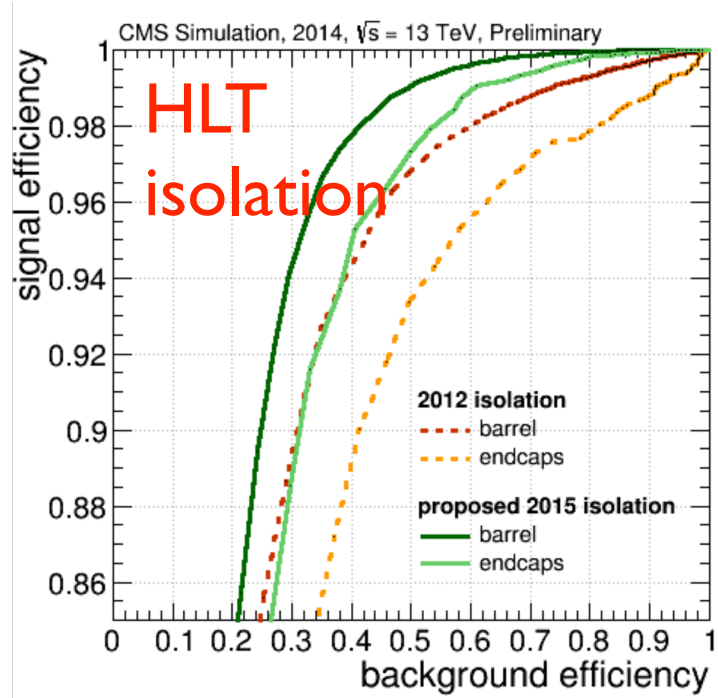
Offline and computing:

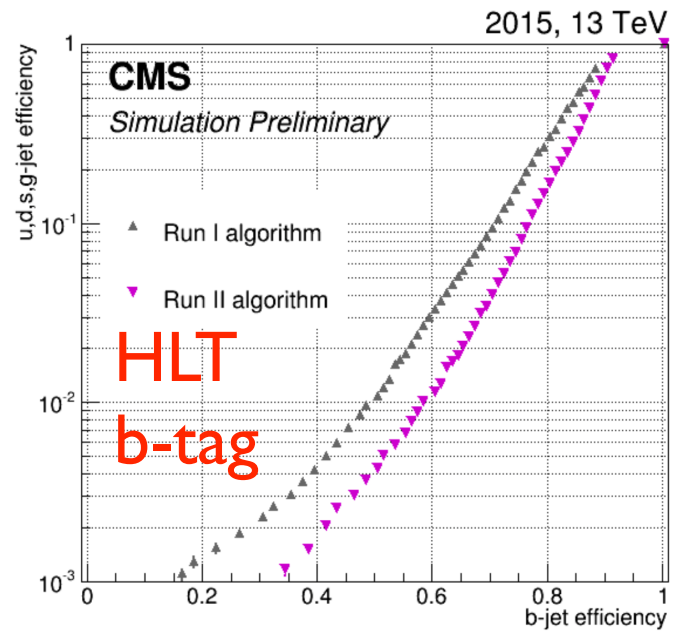
- Multithreading in simulation/reconstruction
- Rework of computing facilities (GRID and HLT) towards increased flexibility
- New Mini AOD format in production:

  compact high level data objects (30-50 kb/ event, i.e. /10 w.r.t. Run 1)

Physics Analyses:

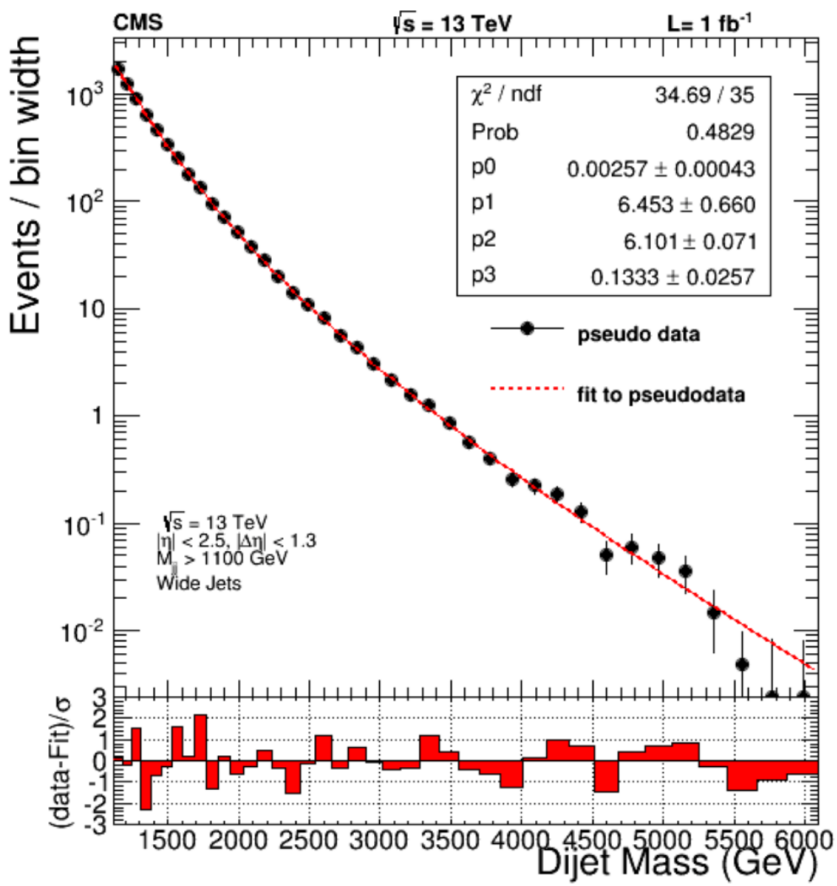
- several MC challenges simulating current data taking and defining Early Analyses procedures and milestones.

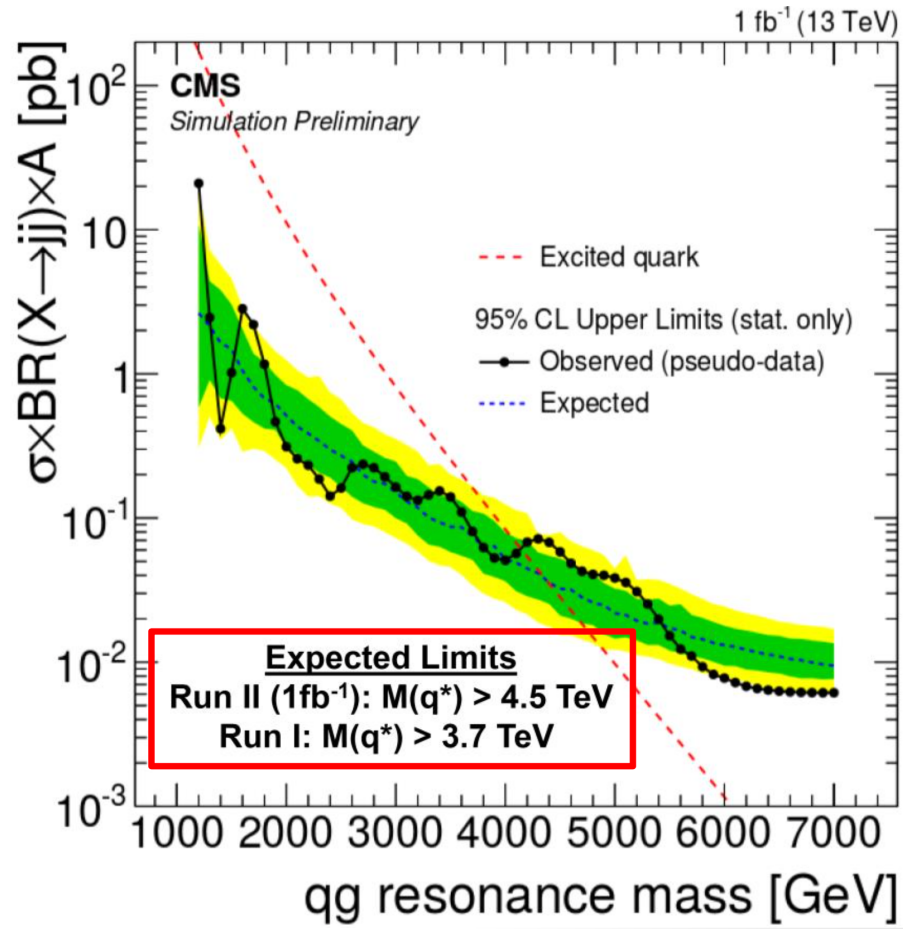




MC exercises

Dijet: background and shape fit from a MC exercise
Simulated data corresponding to 1fb^{-1}

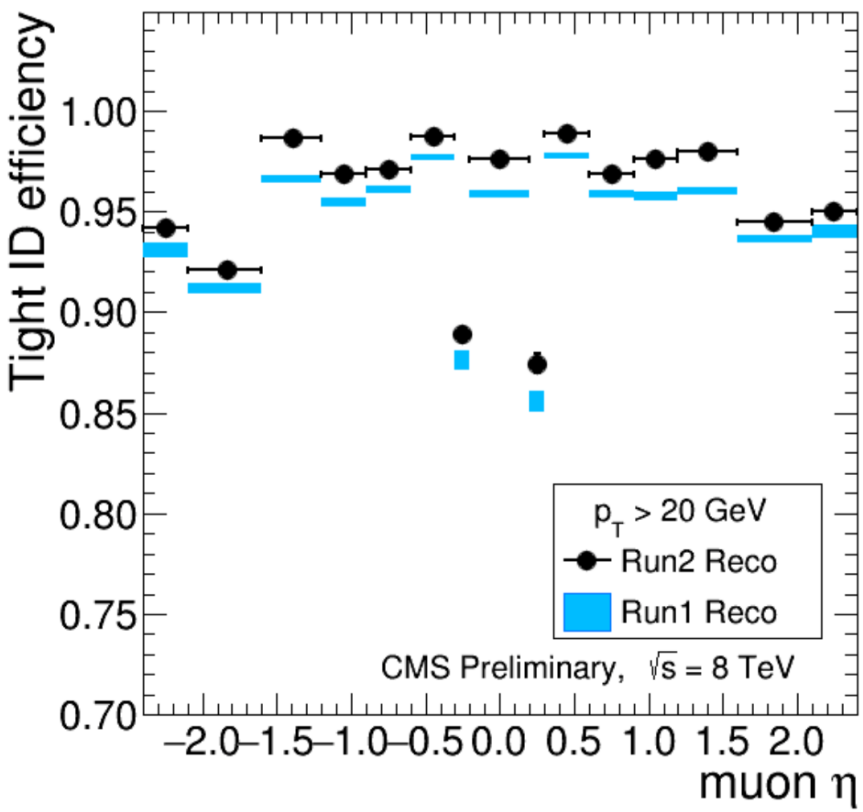


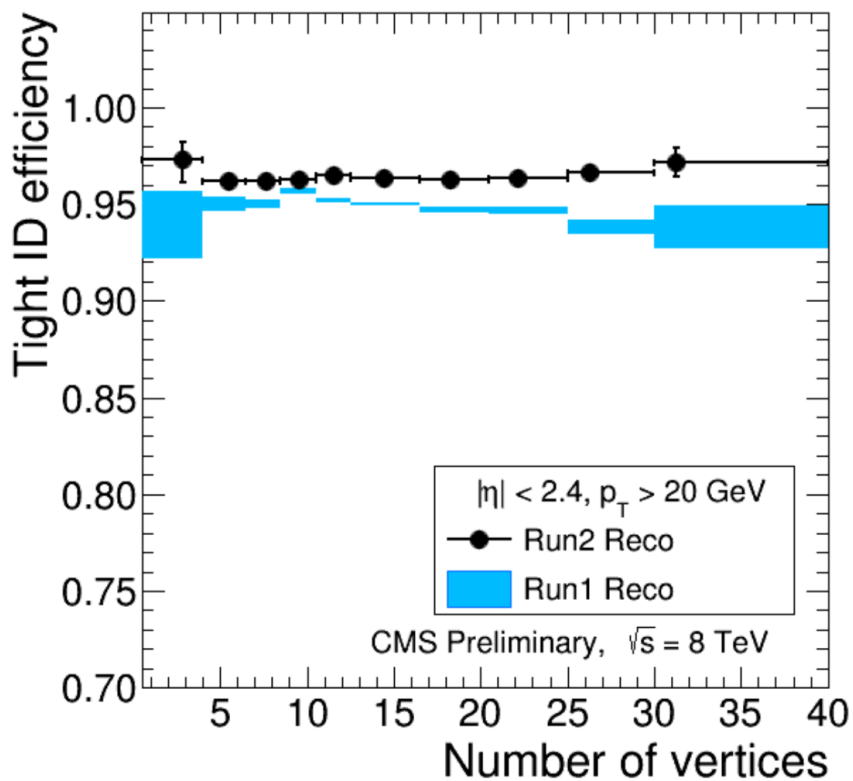


Muon performances

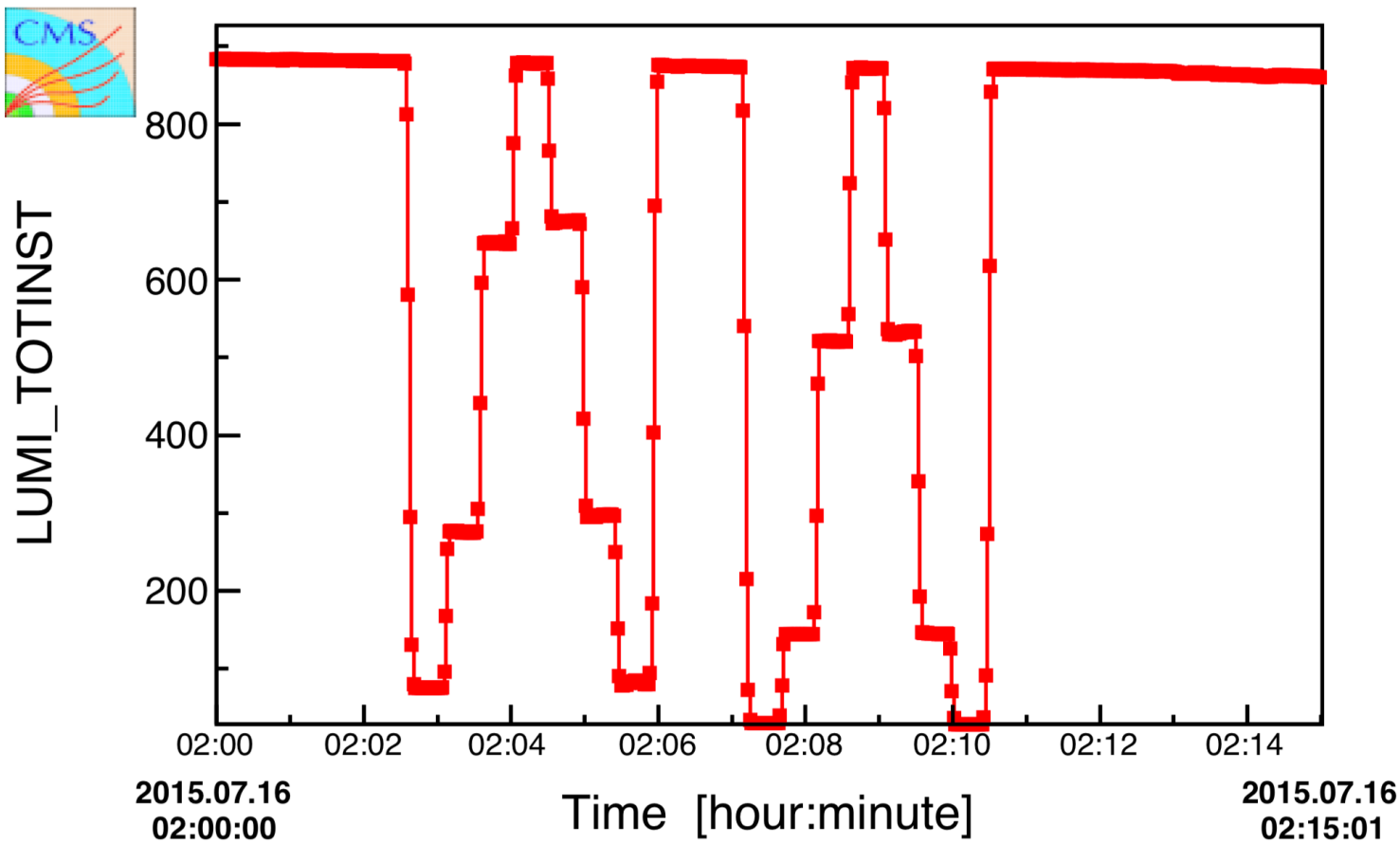
Muon tracking efficiency improved in Run2, especially in high PU environment, due to additional tracking iterations:

- Outside-in iteration designed to recover the missing tracks in the tracker
- Inside-Out iteration designed to improve the hit-collection efficiency (looser requirements)





Mini VdM scan



ECAL crystal response recovery