RWTH

LEPTON+PHOTON 2017
Guangzhou, China

HIGHLIGHTS FROM CMS

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on behalf of the CMS collaboration

RWTH Aachen University,
Germany

CMS Compact Muon Solenoid

RWTH AACHEN UNIVERSITY
I. Physikalisches Institut B

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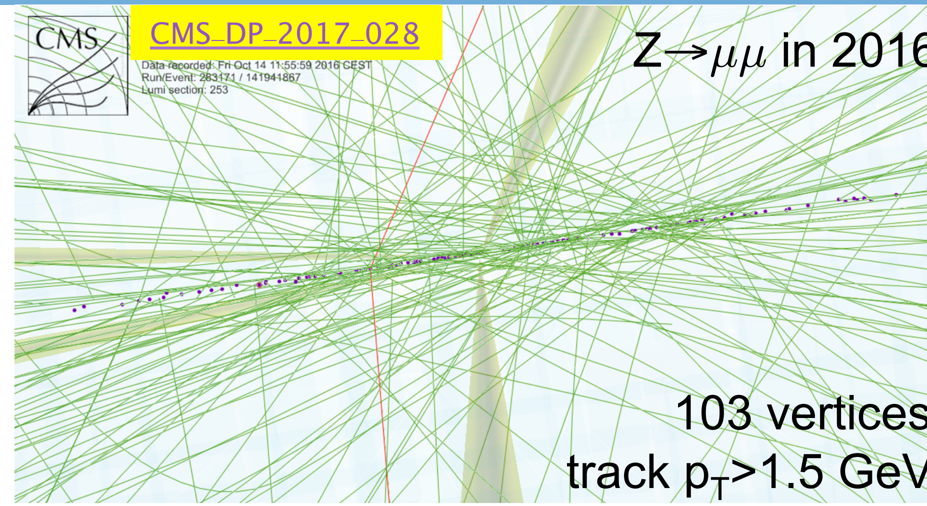
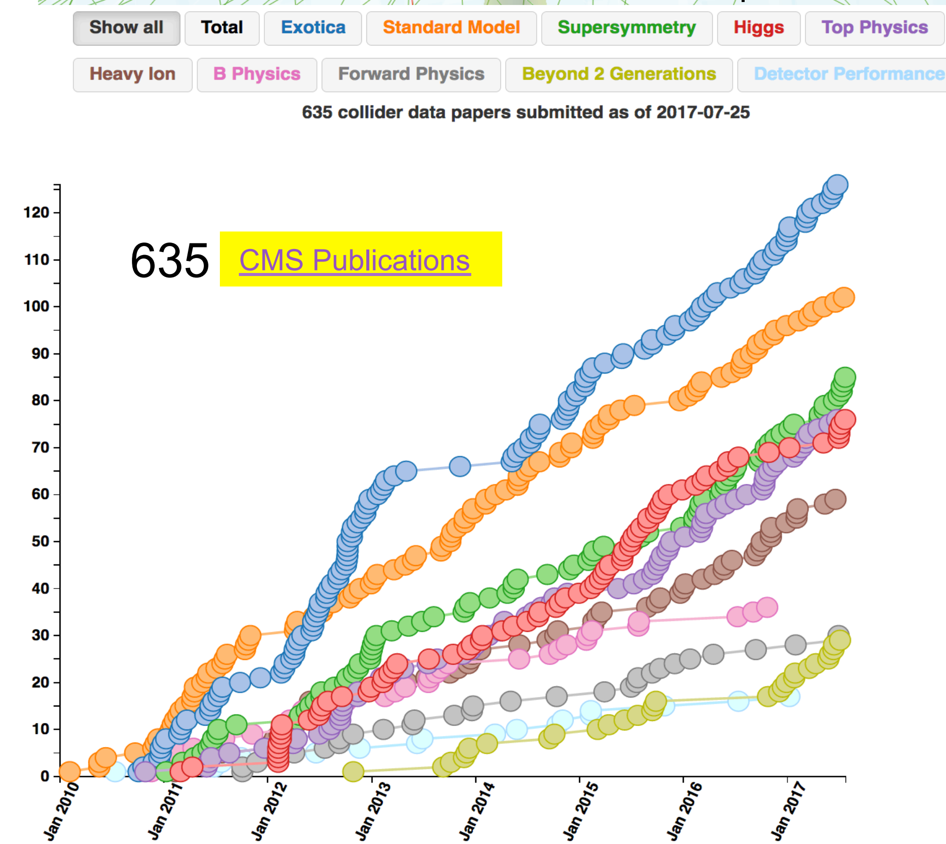
CMS collaboration

- 3500 scientists, engineers, and students
- 199 institutes
- 46 countries

Overview

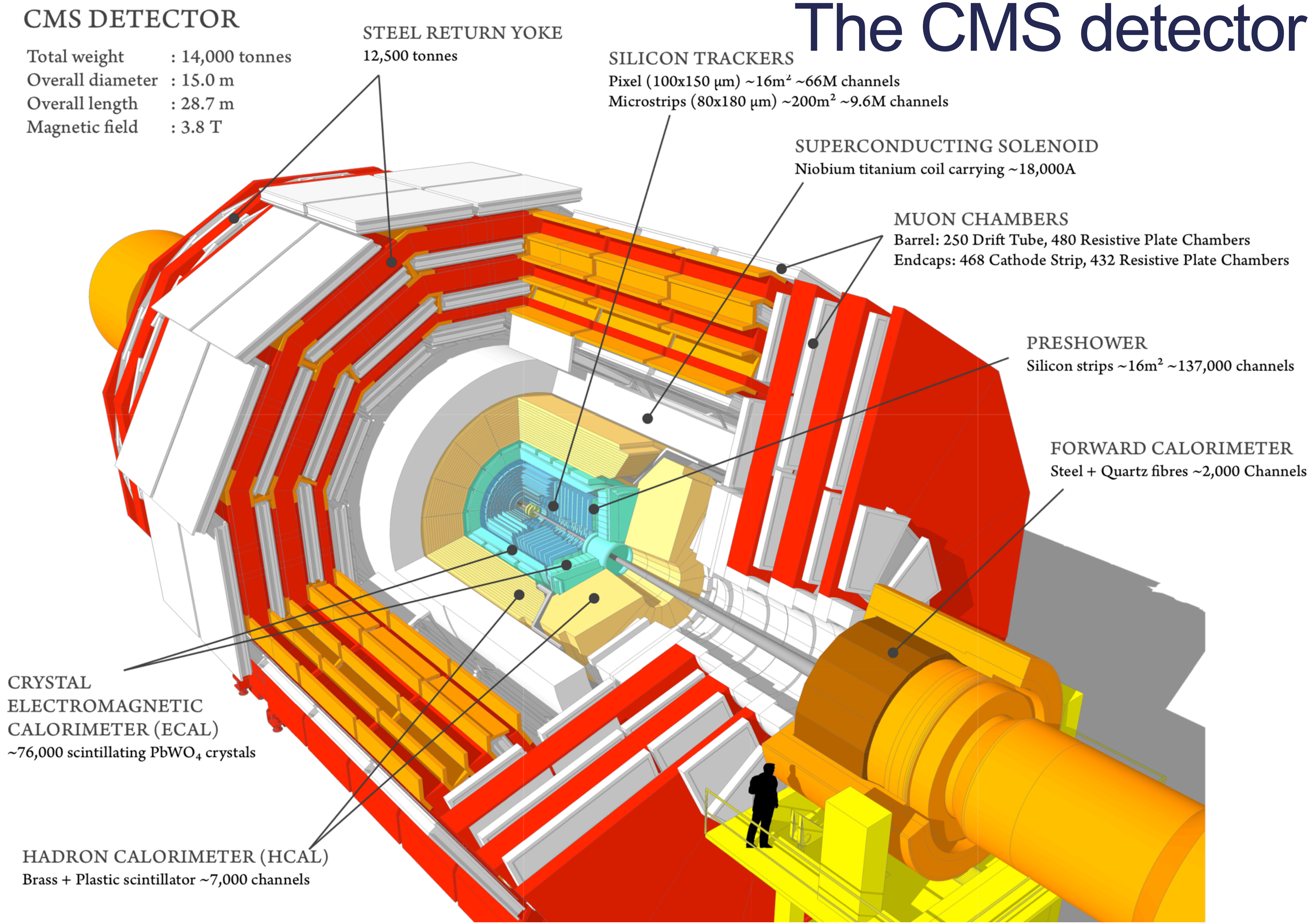
- <u>CMS Status</u>: Summer 2017
  - New Pixel detector
  - New HF calorimeter readout
  - Improved L1 Trigger
- <u>Physics Highlights</u>: 2016 data
  - using full 40 fb^{-1} 13 TeV data
  - 39 new results at Moriond 2017
  - 22 new results at LHCP 2017
  - 20 new results at EPS-HEP 2017
  - Here: selected new results





The Large Hadron Collider at CERN

The CMS detector



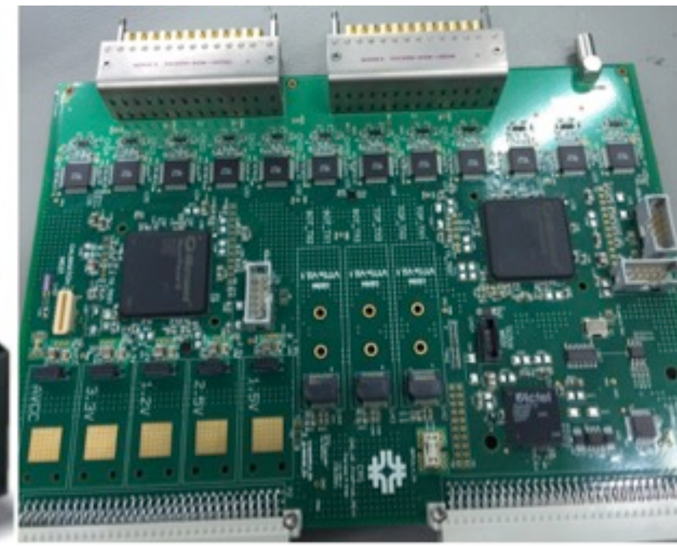
HF upgrade, Muon-endcap GEM prototype

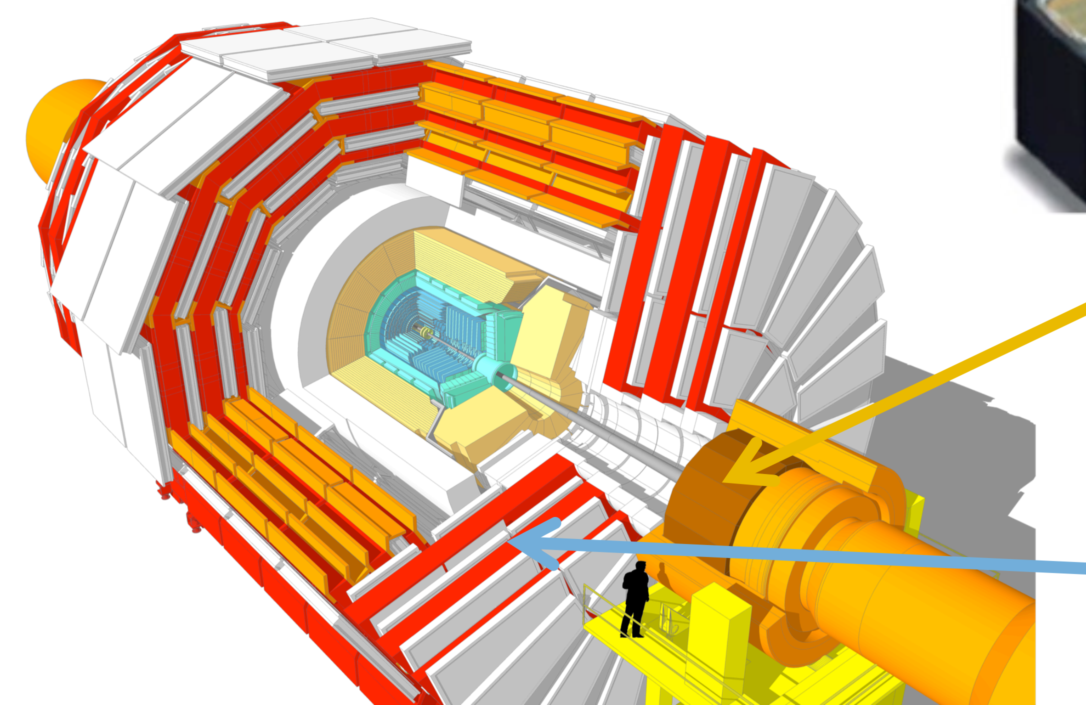
- HF readout upgraded

  replaced PMTs in LS1

  (2×QE, 2×Gain, dual readout,

  1/6 thick window/Cherenkov)

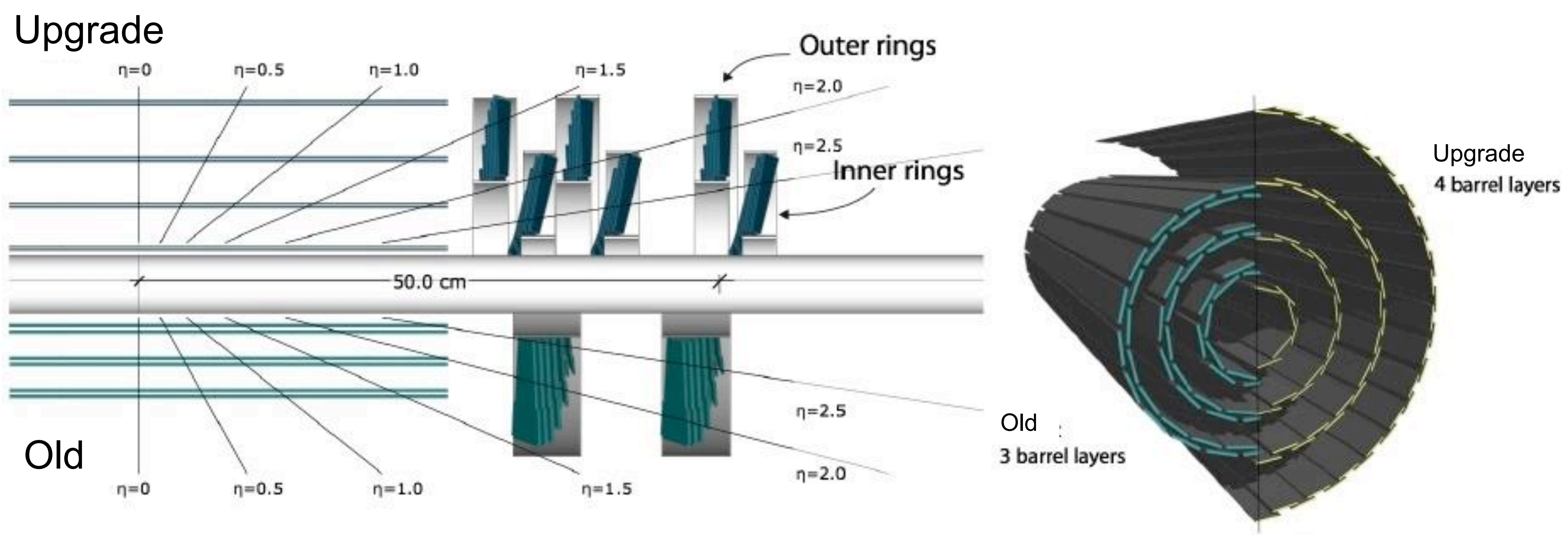




- GEM GE1/1 slice demonstrator installed

  (5 × 10^{o})

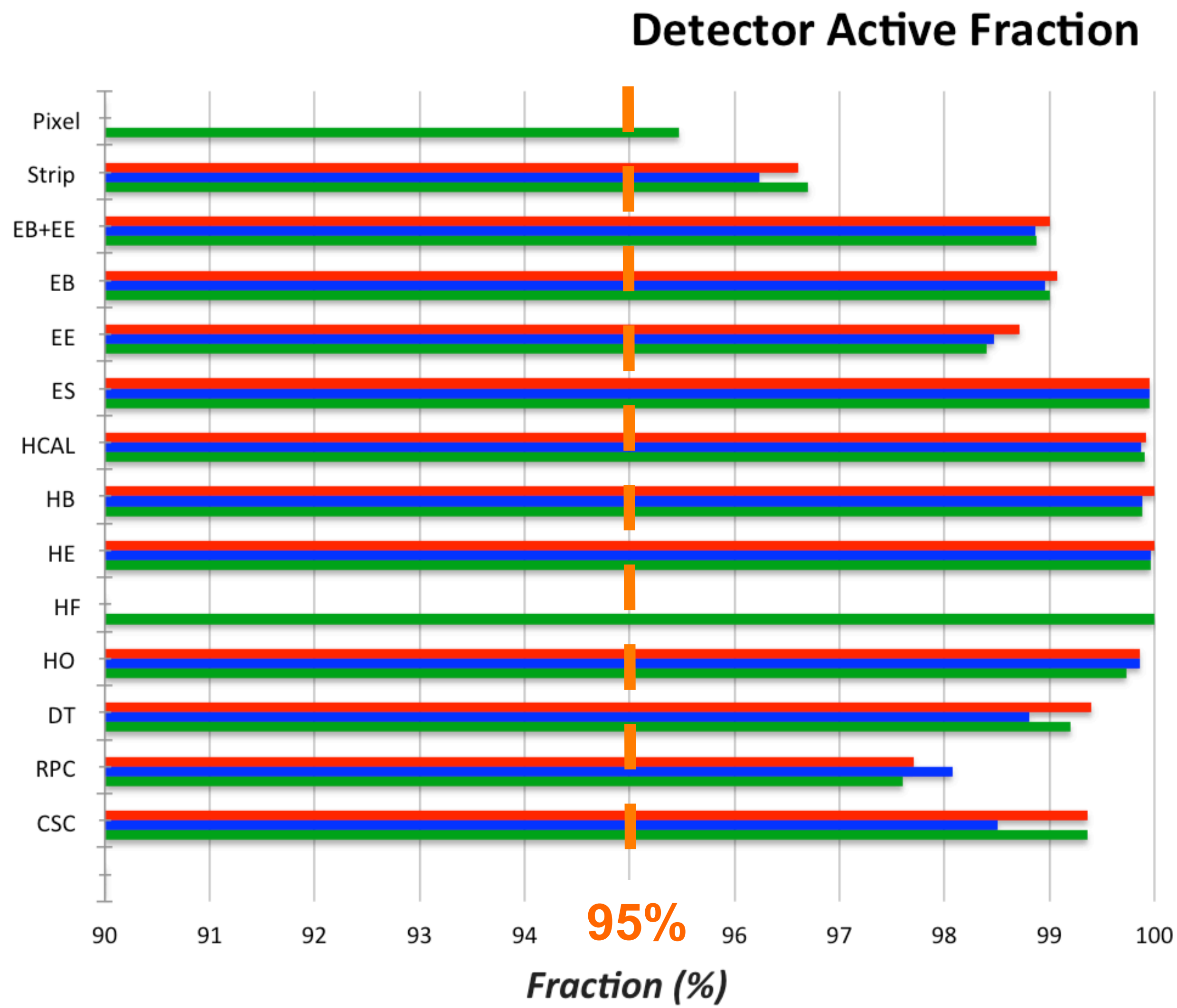
EYTS 2017: Pixel Detector Upgrade



- 4 layers, 3 disks
  - smaller radius inner layer (3cm)
- New readout chip
  - higher efficiency at high rate & high pile-up (up to 100 PU)
- CO_2 cooling and DC-DC powering
  - less material

CMS Performance

Active Channels



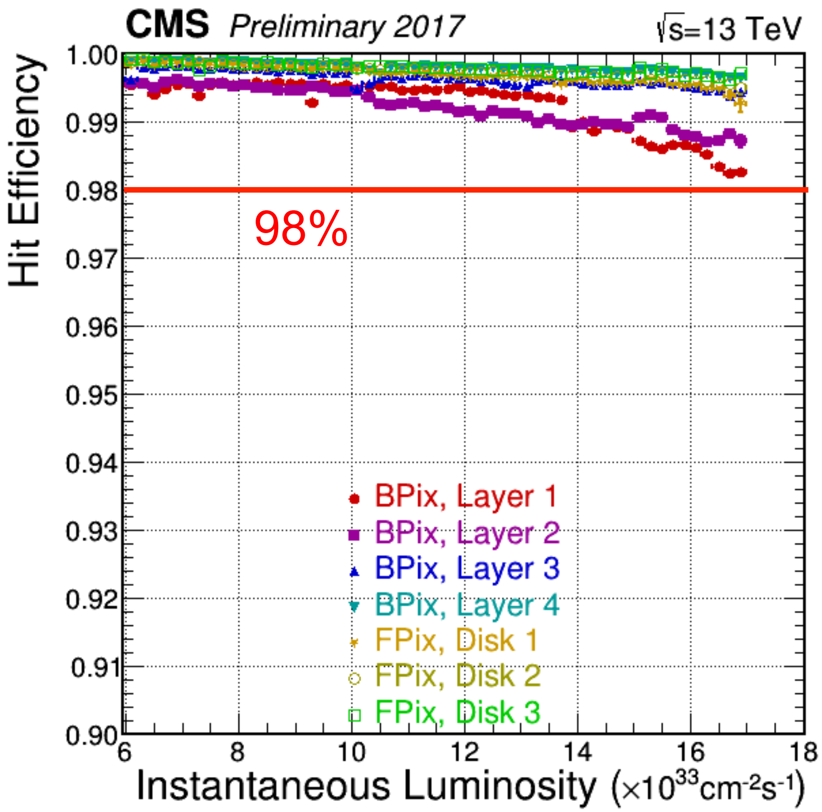
New Pixel detector

- Number of readout chips roughly doubled to 29696

New Hadronic Forward Calorimeter

CMS Public

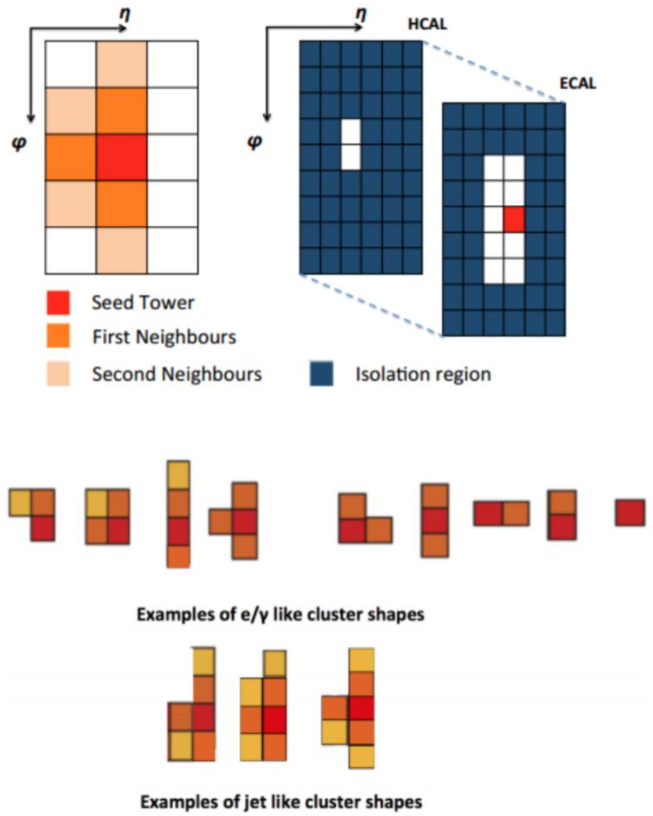
New Pixel detector performance



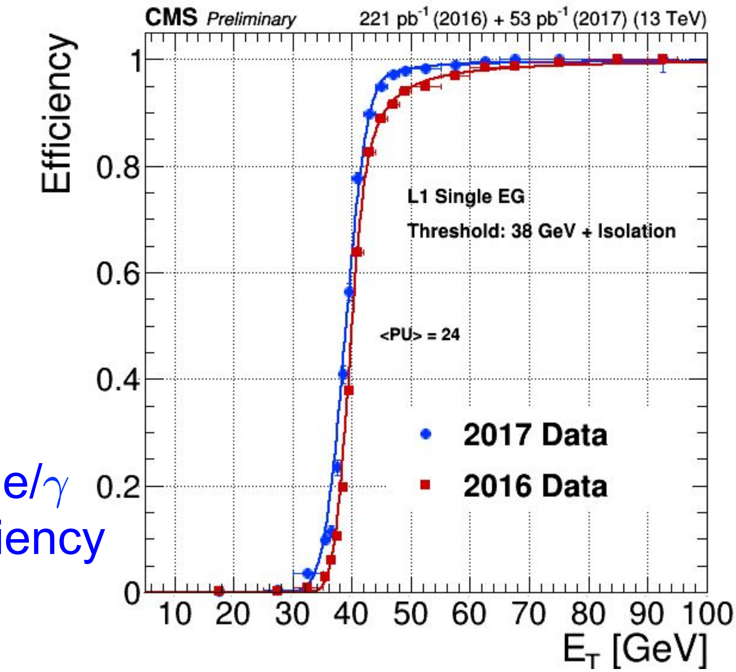
- Time alignment of Layer 1 and 2, which share a common programmable time delay, was difficult due a faster Layer 1 ROC.
  We succeeded in establishing an optimal common plateau of efficiency with values close to 99% for all pixel layers and disks at luminosities L=1.6E34cm^{-2} s^{-1}.
  - The timing is chosen to favour the Layer 1 performance.
- Although not yet at the ultimate detector performance, more complex functions like vertexing, b-tagging, and HLT electron reconstruction are significantly better than with the old detector, which would not have been able to cope with the rates in the first place.

Performance L1 e/γ trigger

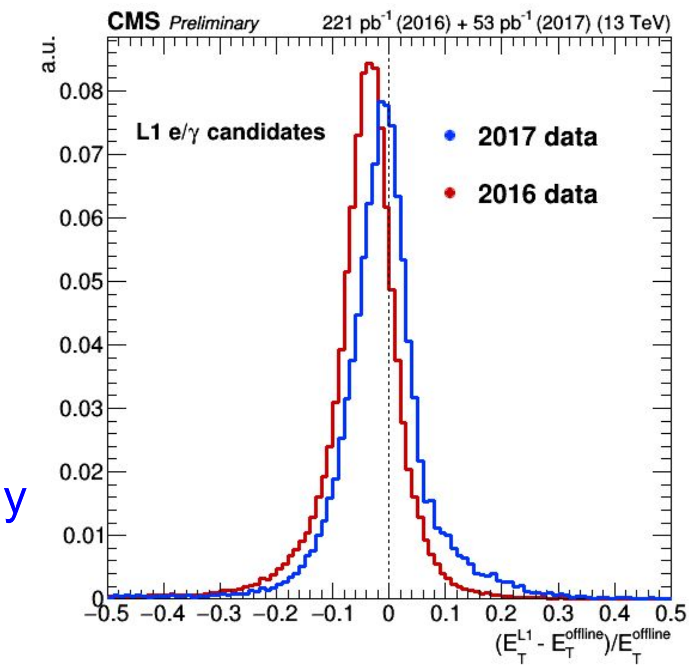
- Full upgrade of L1 trigger system during LS1
- cope with high inst. luminosity of 10^{34} $cm^{-2}s^{-1}$ and pileup



L1 isolated e/γ trigger efficiency



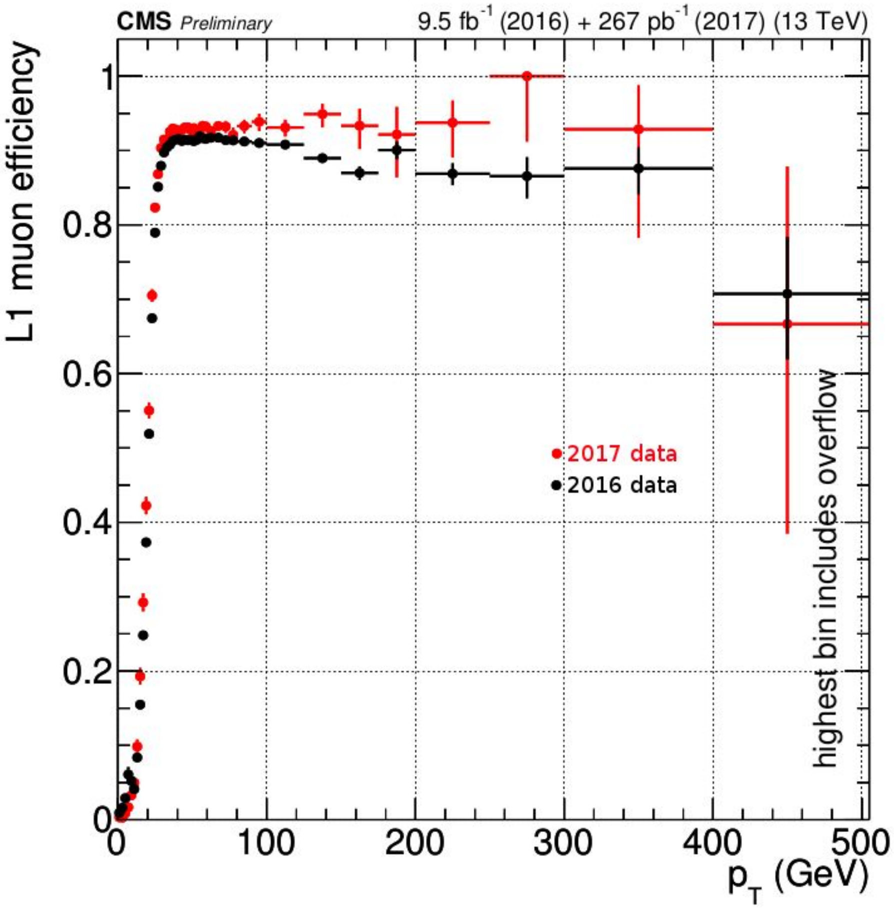
L1 e/γ energy resolution



CMS_DP_2017_024

CMS_DP_2017_024

Performance L1 muon trigger

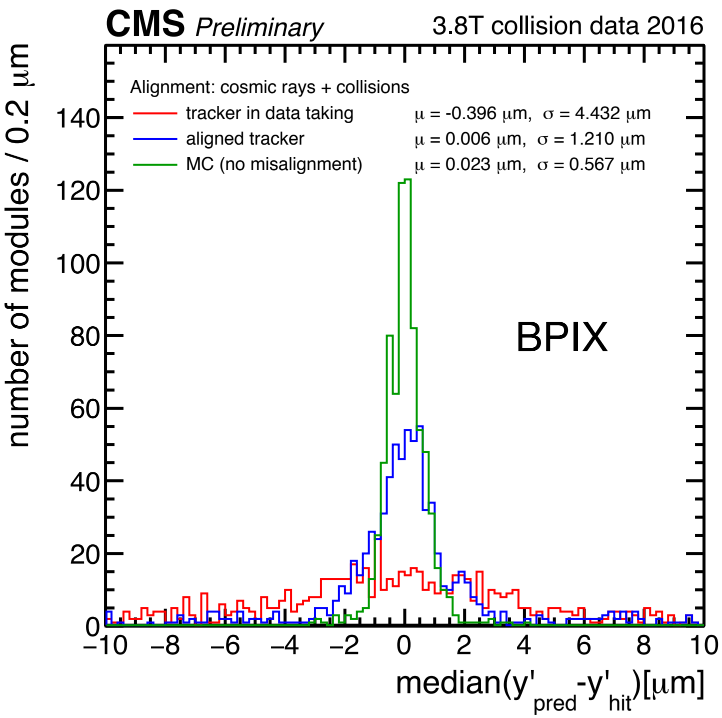


- Improved L1 muon track finding
- Improved L1 muon p_T resolution

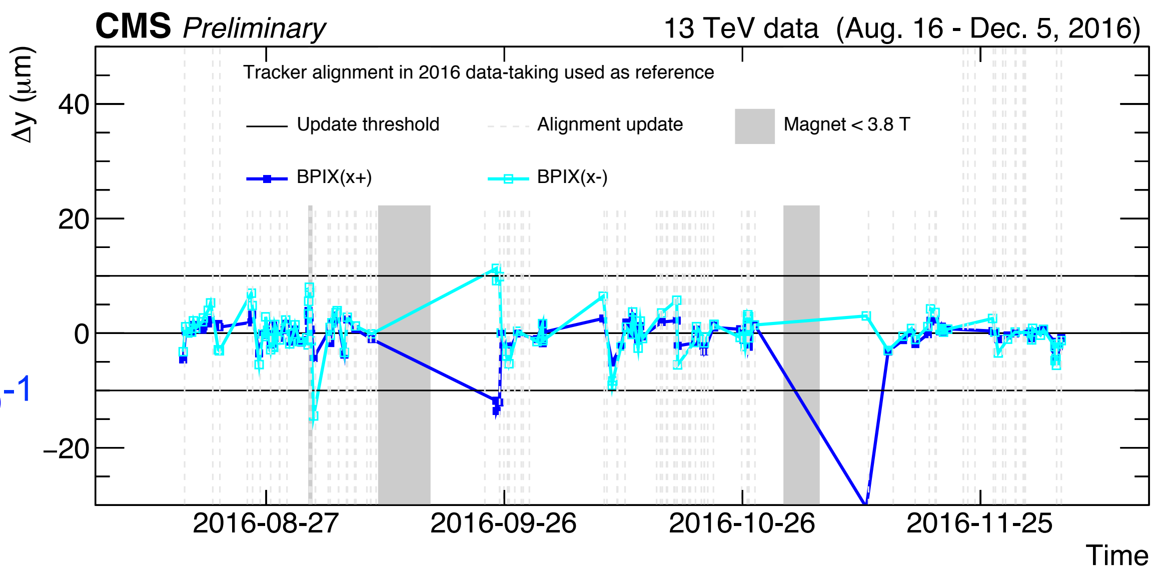
- L1 muon p_T>25 GeV efficiency vs. offline p_T
- L1 muon trigger with 25 GeV threshold expected to stay unprescaled in 2017 data taking

CMS_DP_2017_021

Performance Alignment



- Barrel pixel median residuals local y-positions
- Barrel pixel position is very sensitive to changes in temperature and magnetic field
- End-of-year alignment better than the alignment used in data taking by a factor 4

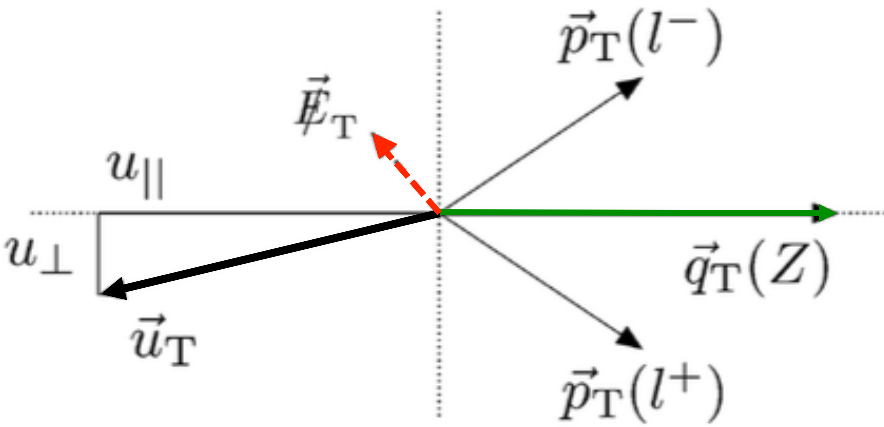


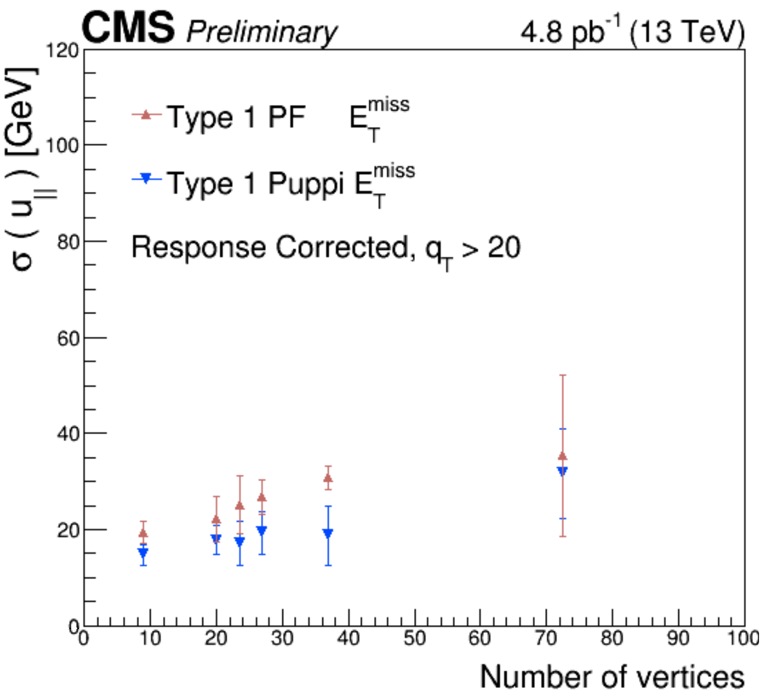
- Movements Barrel Pixel in global y-direction
- range corresponds to 16.4 fb^{-1}
- Gray bands: Magnet ramps

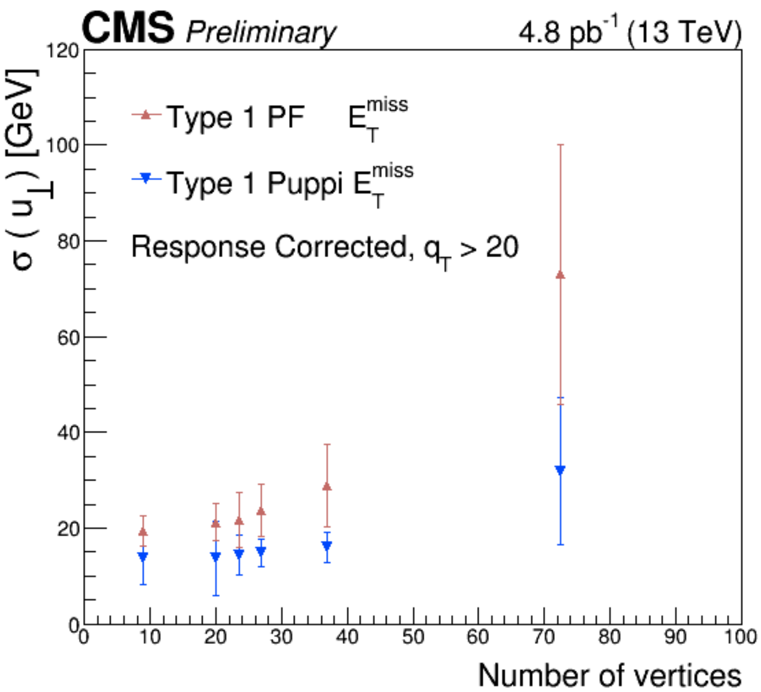
CMS_DP_2017_028

Performance MET in high pileup

- Compare the well measured Z→ ll to the recoiling hadronic system u_T
- Compare Particle Flow (PF) and PUPPI 10.1007/JHEP10(2014)059
- Resolution of parallel and perpendicular components of recoil:





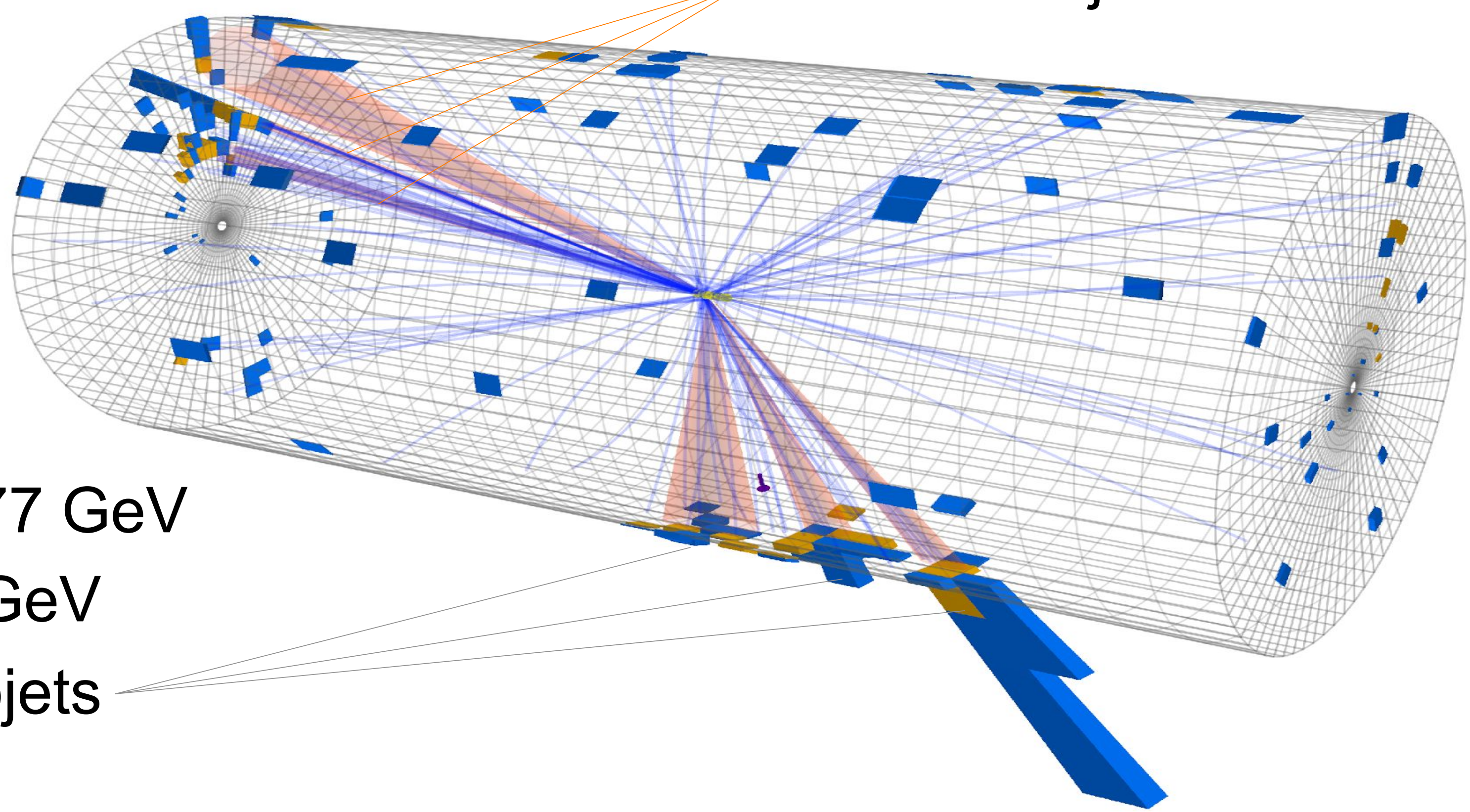


CMS_DP_2016_035

High energy event: $m(t\bar{t}) = 2.5$ TeV

CMS Experiment at LHC, CERN
Data recorded: Sun Jul 12 07:25:11 2015 CEST
Run/Event: 251562 / 111132974
Lumi section: 122
Orbit/Crossing: 31722792 / 2253

- m(t) = 176 GeV
- p_T = 488 GeV
- Three subjets

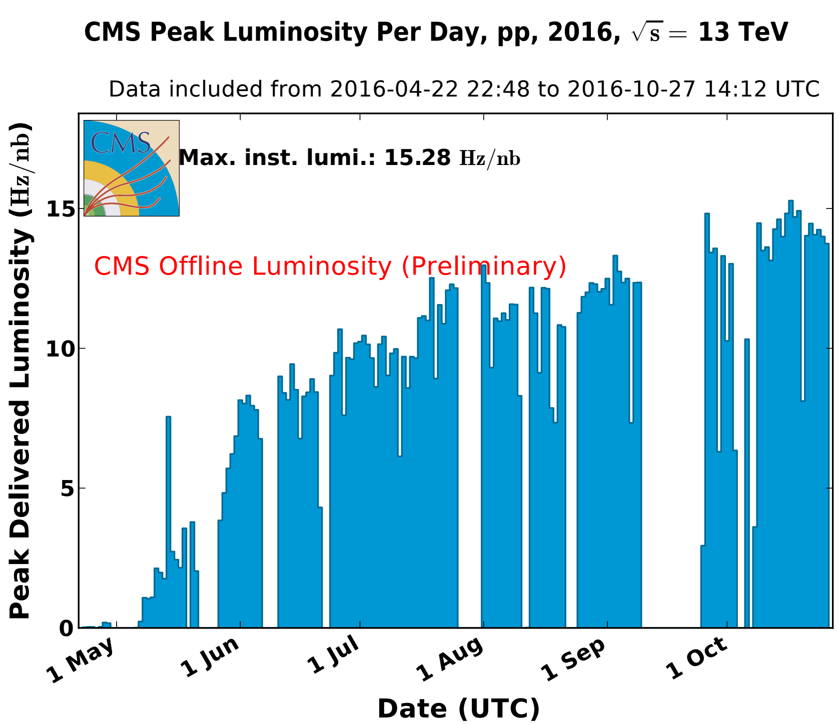


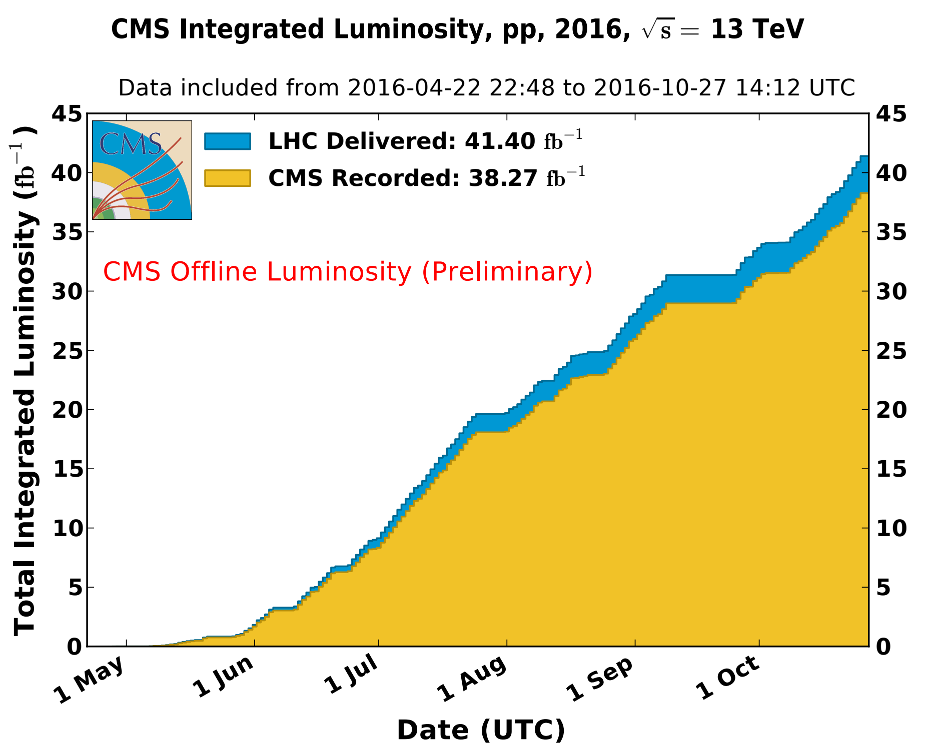
- m(t) = 177 GeV
- p_T = 613 GeV
- Three subjets

CMS Luminosity

Successful data-taking in 2016

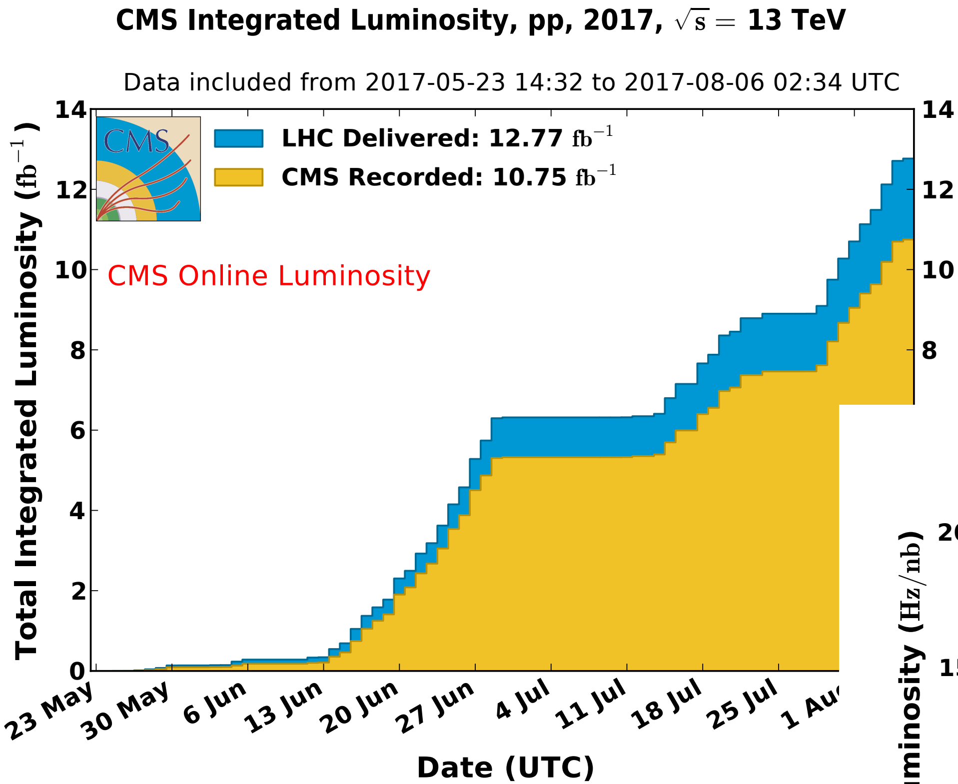
- second year of data at center-of-mass energy of 13 TeV
- 38 fb^{-1} recorded, exceeding goal of 25 fb^{-1}
- 92% of delivered luminosity was recorded
- dataset of presented physics results



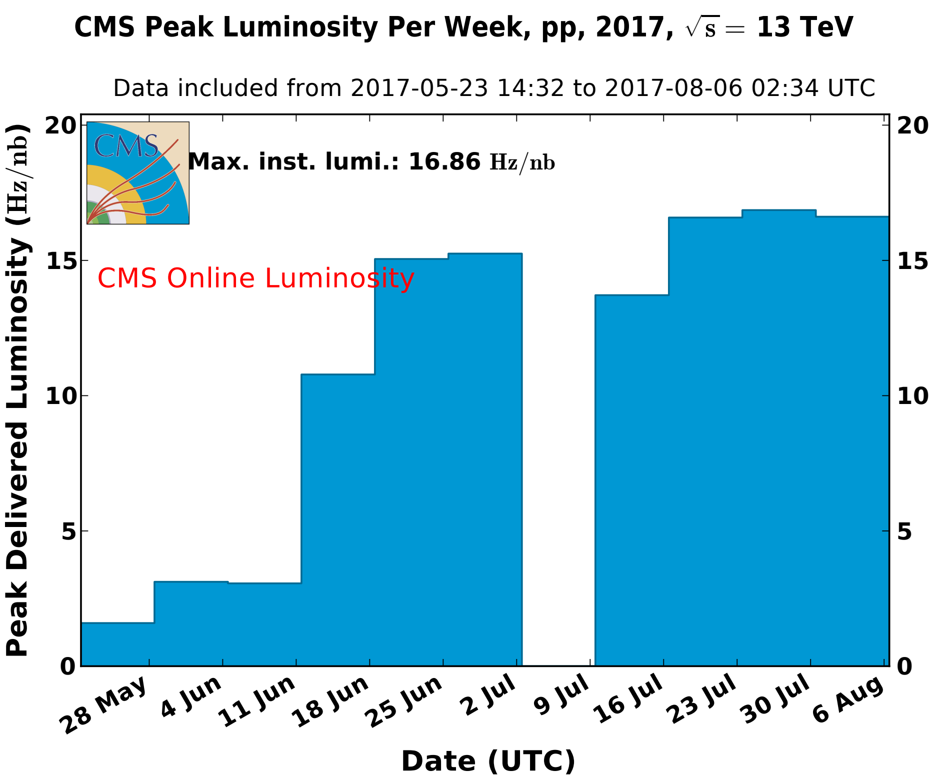


CMS Luminosity

Data-taking in 2017

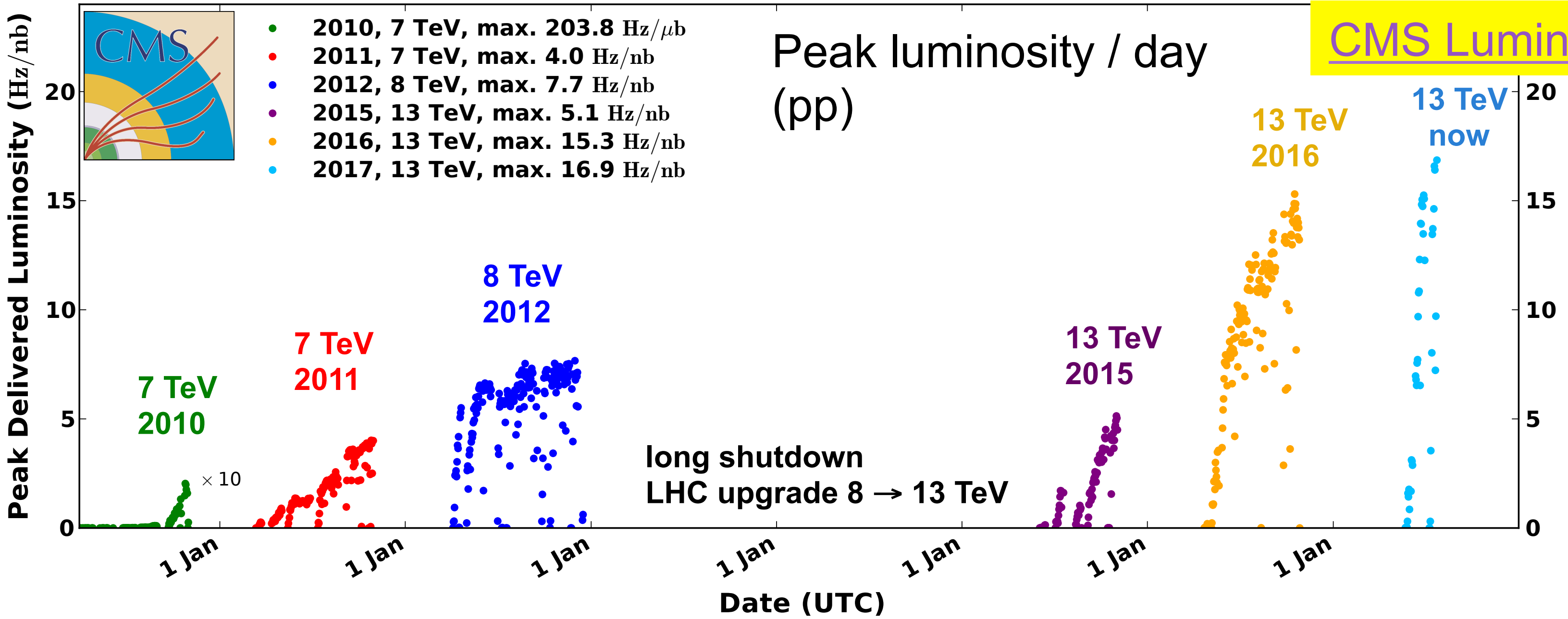


Very successful LHC start reaching 10^{34} $cm^{-2}s^{-1}$ fast!

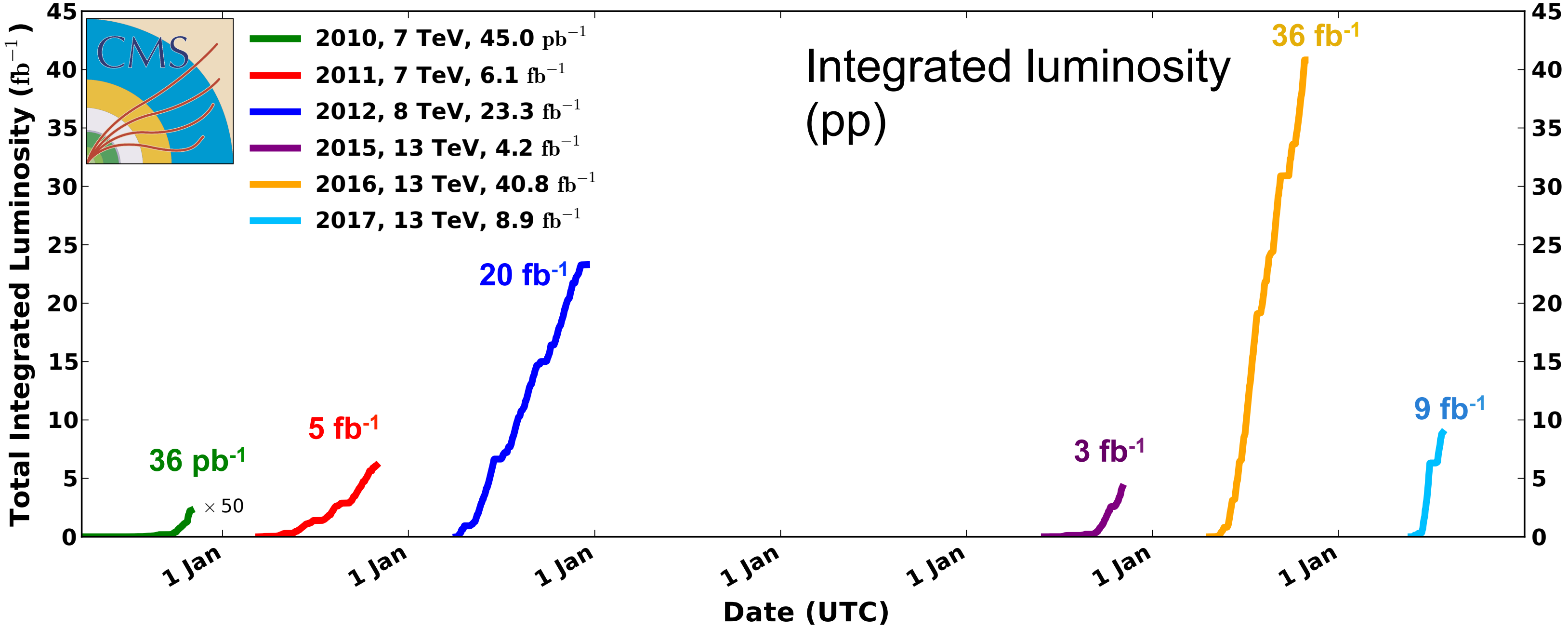


Overall 83.8% data collection efficiency

CMS Luminosity

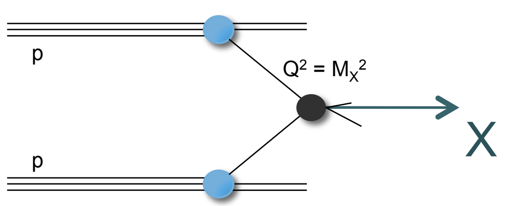


Data included from 2010-03-30 11:22 to 2017-07-24 03:55 UTC

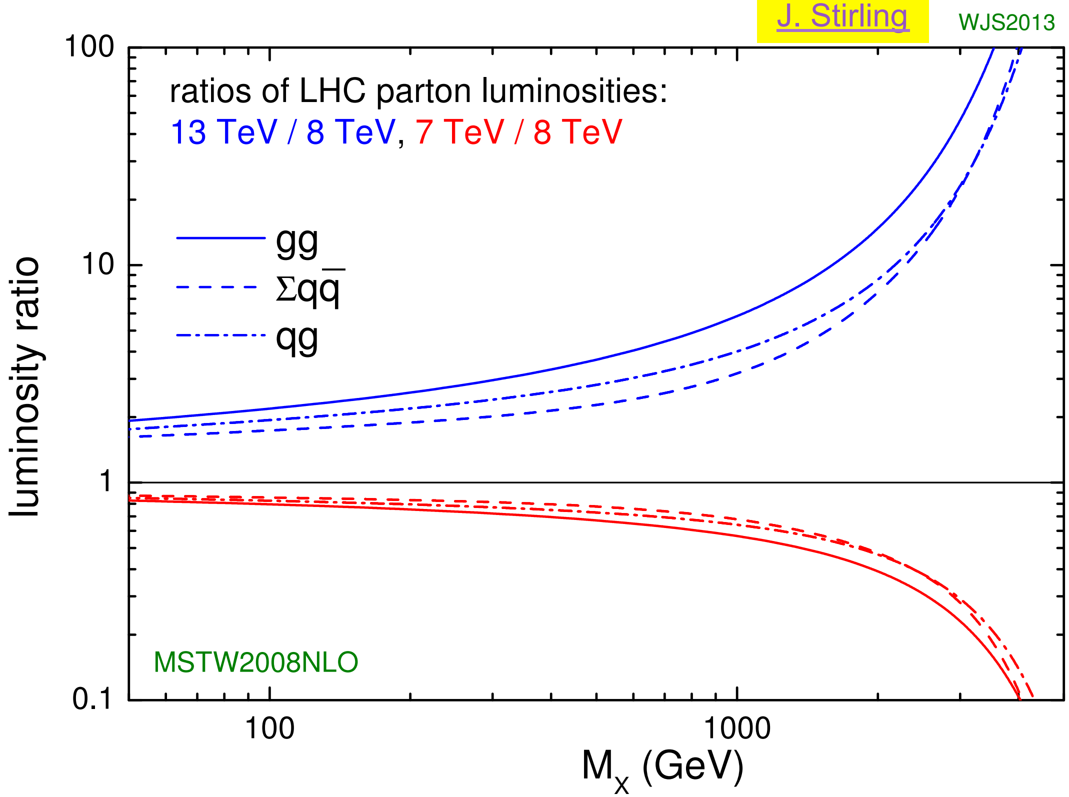


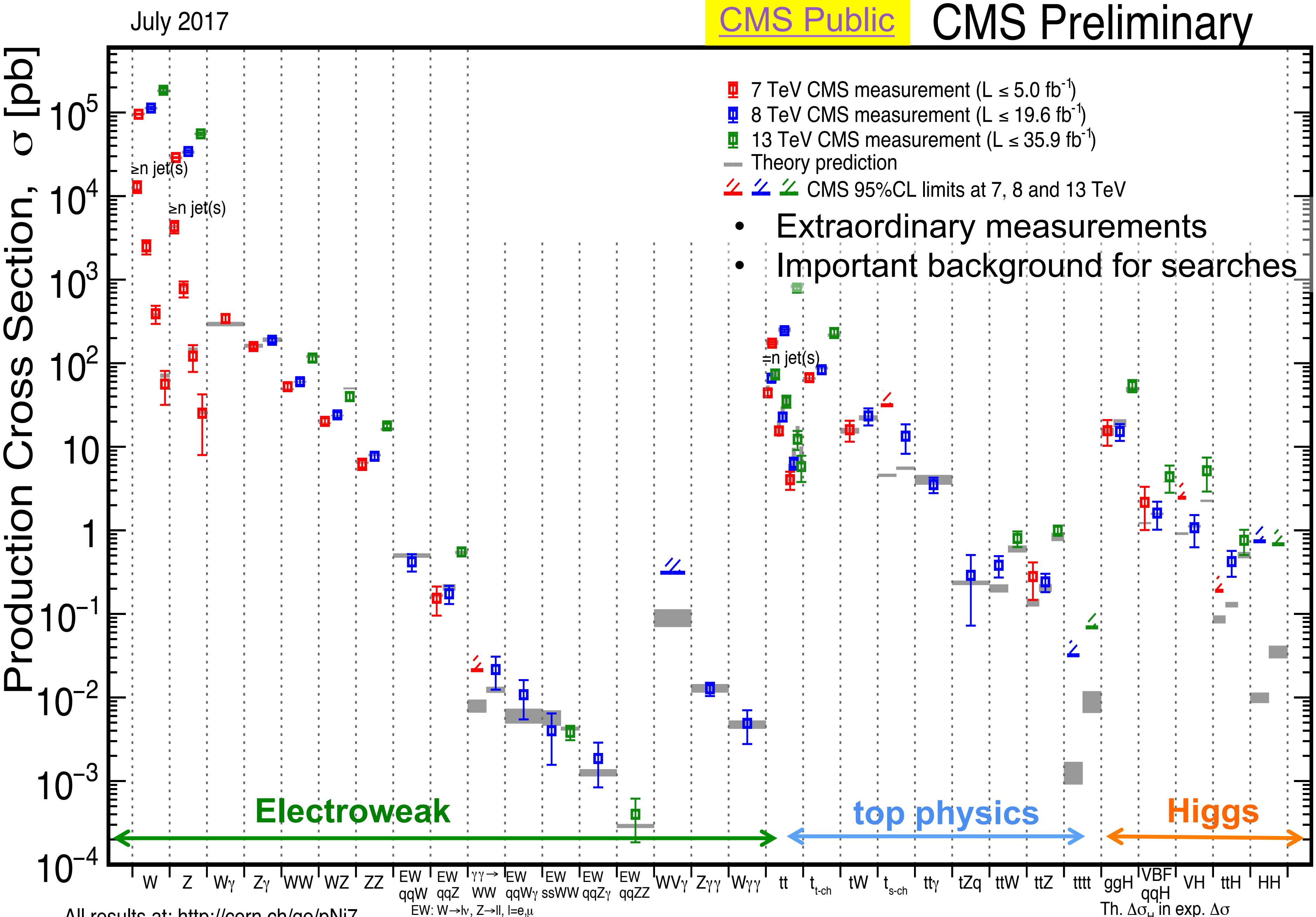
High expectations for the 13 TeV Run 2

- Cross section of processes increase with center-of-mass energy depending on the process mass scale
- Already twice the luminosity of the 8 TeV dataset
- Good for searches



J. Stirling





- Extraordinary measurements
- Important background for searches

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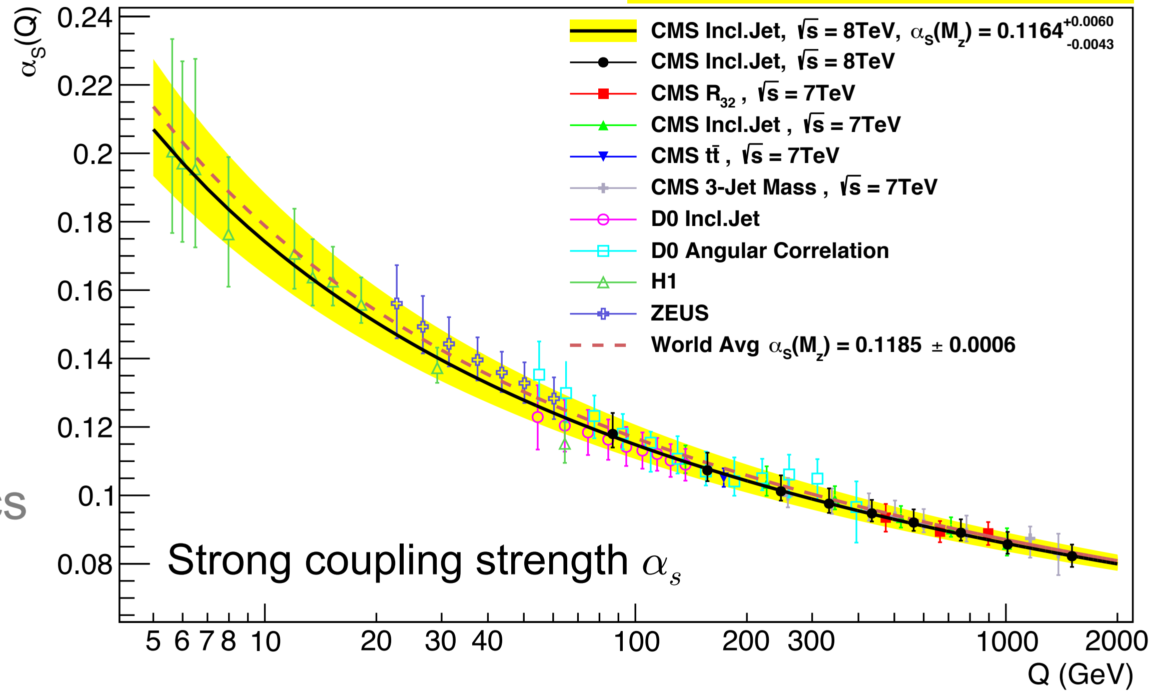
- CMS Status
- Physics Highlights
  - QCD multijet production
  - Electroweak production
  - Top physics
  - Higgs physics
  - Searches for New Physics
    - Exotica
    - Supersymmetry
- Conclusion

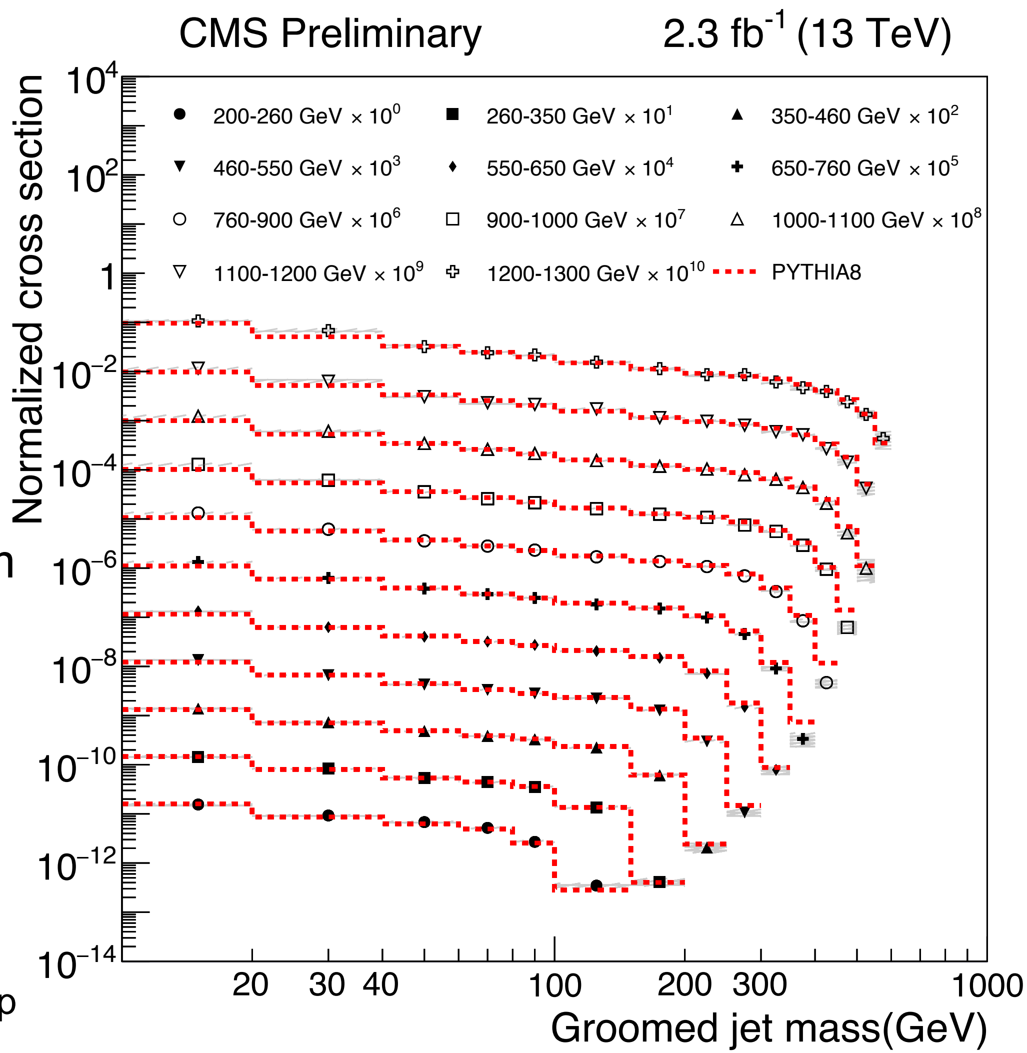
10.1007/JHEP03(2017)156



CMS-PAS-SMP-16-010

QCD: Differential jet production

- Dijet topology: unfolded as function of jet-mass and jet p_T
- jet mass sensitive to QCD parton showering and used in searches for new physics ("boosted" objects)
- With & without jet grooming algorithm to remove low energy portions from jet arising from soft radiation that are difficult to model.
- MC predictions of jet mass spectrum are found to be improved for groomed jets
- Jet grooming algorithm:
  - AK8 jet constituents reclustered by CA8
  - Hierarchical sequence of clustering reversed
  - soft drop (SD) algorithm removes low energetic constituents per declustering step



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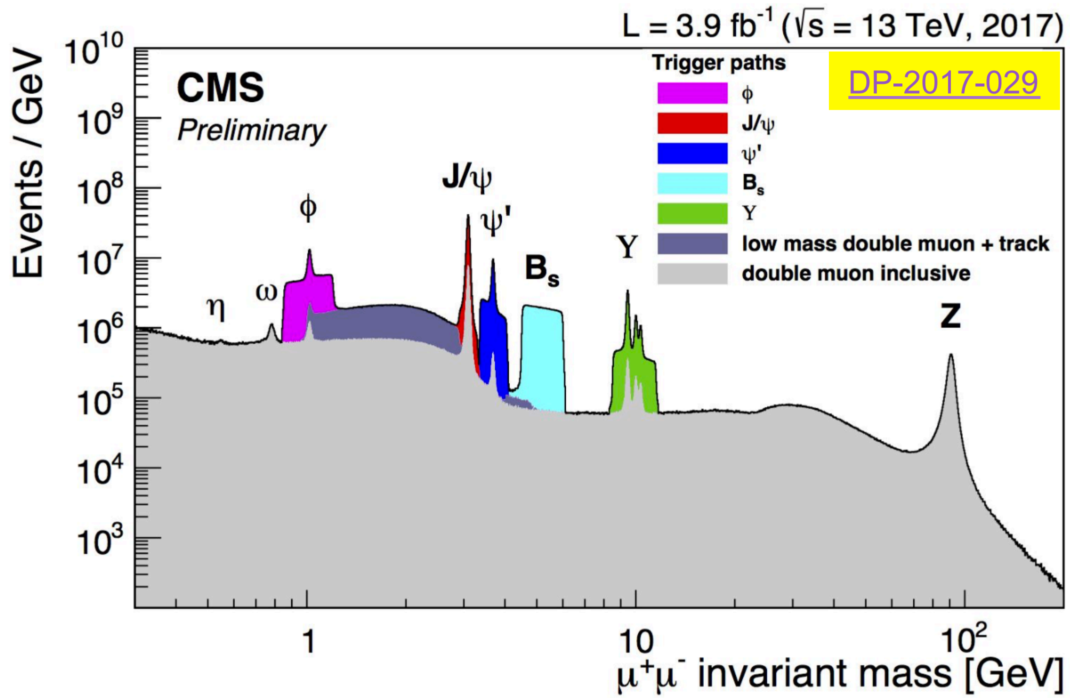
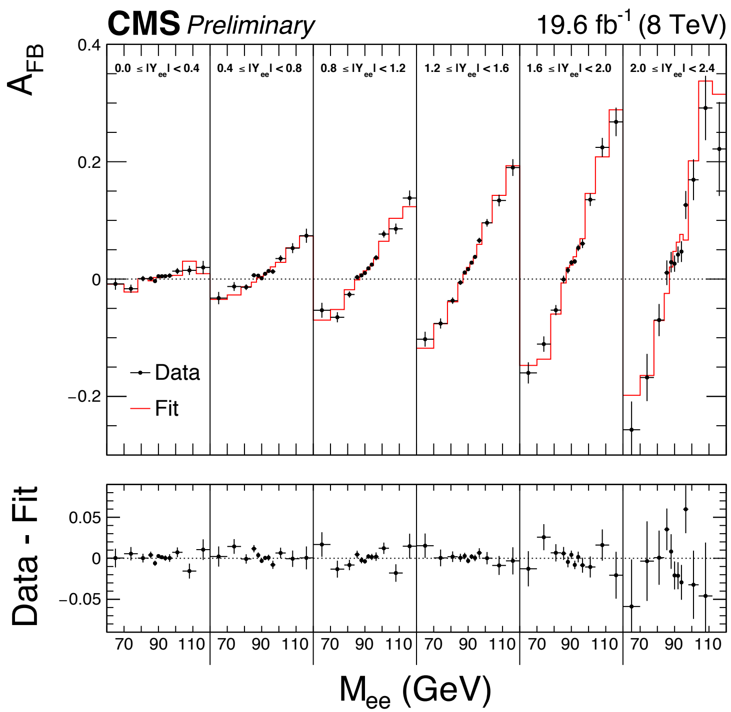


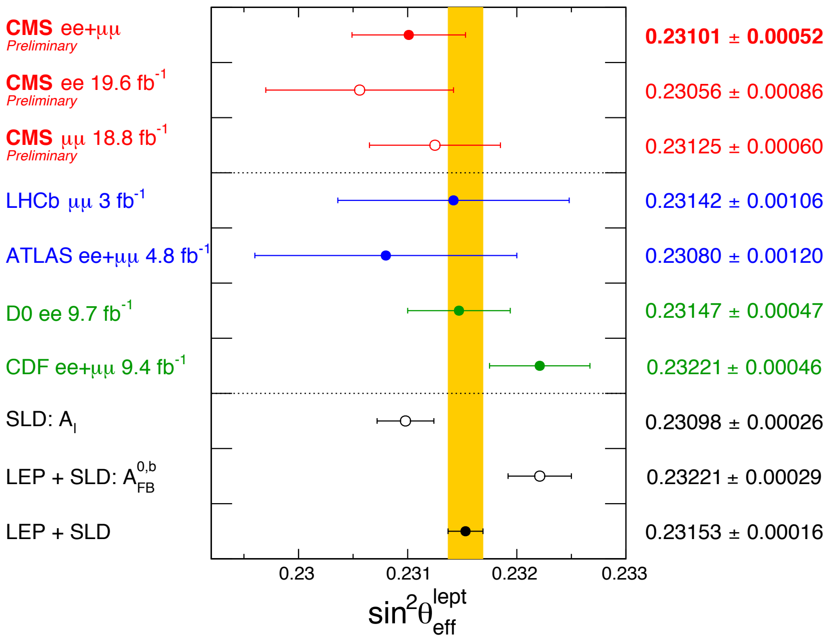
CMS-PAS-SMP-16-007

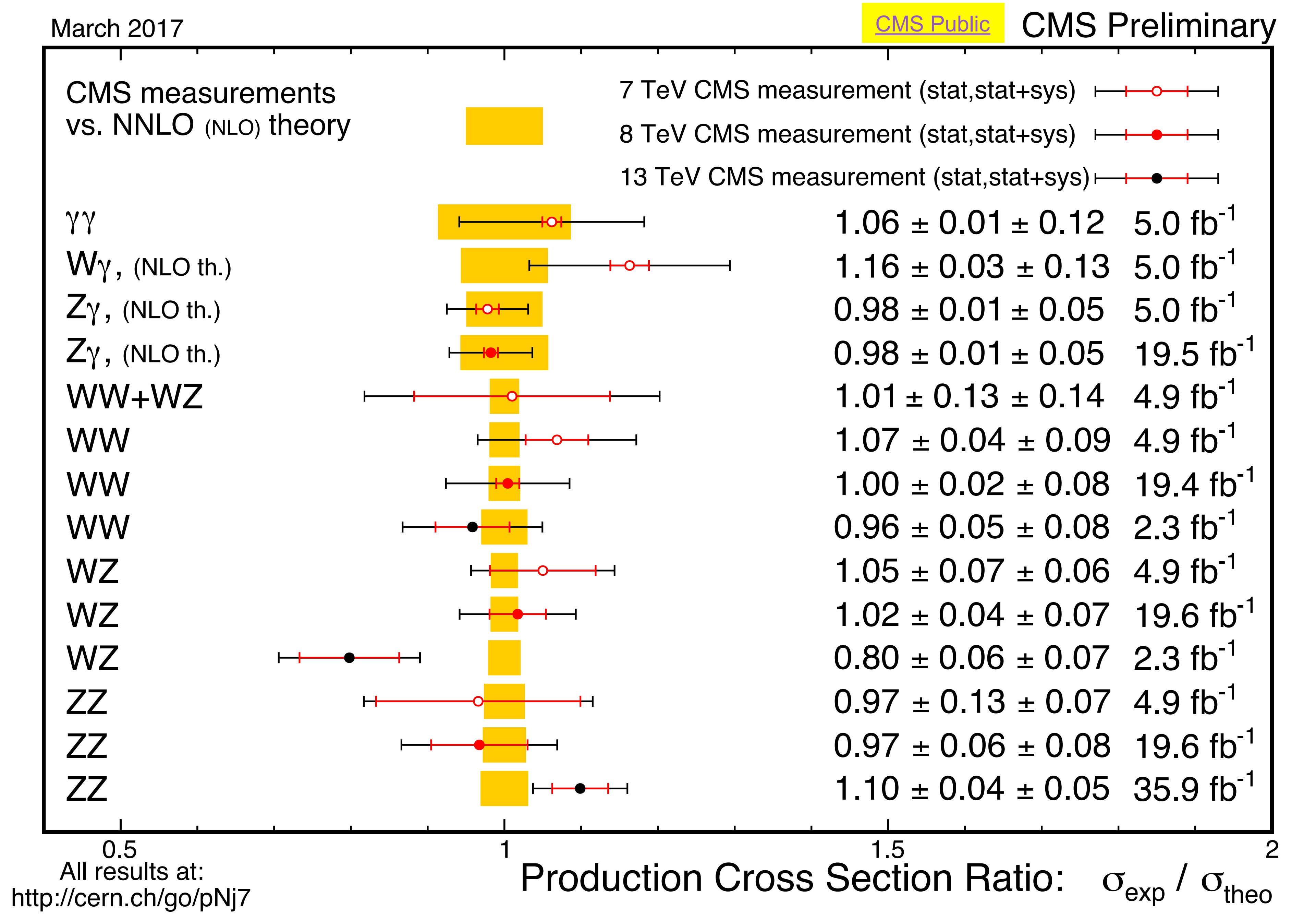
EWK: Measurement of the weak mixing angle

- using forward-backward asymmetry A_{FB} of DY (e^+e^-, $\mu^+\mu^-$) using the full 8 TeV data
- $\sin^2\theta$ extraction by fitting mass and rapidity dependence of A_{FB}, strong dependence on mass because of the axial – vector interference
- Most precise measurement of $\sin^2\theta$ at the LHC, similar to Tevatron experiments
- Allows also to constrain PDFs



$$\sin^2\theta^{\rm lept}_{\rm eff} = 0.23101 \pm 0.00036({\rm stat}) \pm 0.00018({\rm syst}) \pm 0.00016({\rm theory}) \pm 0.00030({\rm pdf})$$




March 2017
CMS Public
CMS Preliminary
CMS measurements
vs. NNLO (NLO) theory
7 TeV CMS measurement (stat,stat+sys)
8 TeV CMS measurement (stat,stat+sys)
13 TeV CMS measurement (stat,stat+sys)
γγ
Wγ, (NLO th.)
Zγ, (NLO th.)
Zγ, (NLO th.)
WW+WZ
WW
WW
WW
WZ
WZ
WZ
ZZ
ZZ
ZZ
1.06 ± 0.01 ± 0.12 5.0 fb-1
1.16 ± 0.03 ± 0.13 5.0 fb-1
0.98 ± 0.01 ± 0.05 5.0 fb-1
0.98 ± 0.01 ± 0.05 19.5 fb-1
1.01 ± 0.13 ± 0.14 4.9 fb-1
1.07 ± 0.04 ± 0.09 4.9 fb-1
1.00 ± 0.02 ± 0.08 19.4 fb-1
0.96 ± 0.05 ± 0.08 2.3 fb-1
1.05 ± 0.07 ± 0.06 4.9 fb-1
1.02 ± 0.04 ± 0.07 19.6 fb-1
0.80 ± 0.06 ± 0.07 2.3 fb-1
0.97 ± 0.13 ± 0.07 4.9 fb-1
0.97 ± 0.06 ± 0.08 19.6 fb-1
1.10 ± 0.04 ± 0.05 35.9 fb-1
0.5
1
1.5
2
All results at:
http://cern.ch/go/pNj7
Production Cross Section Ratio: σexp / σtheo

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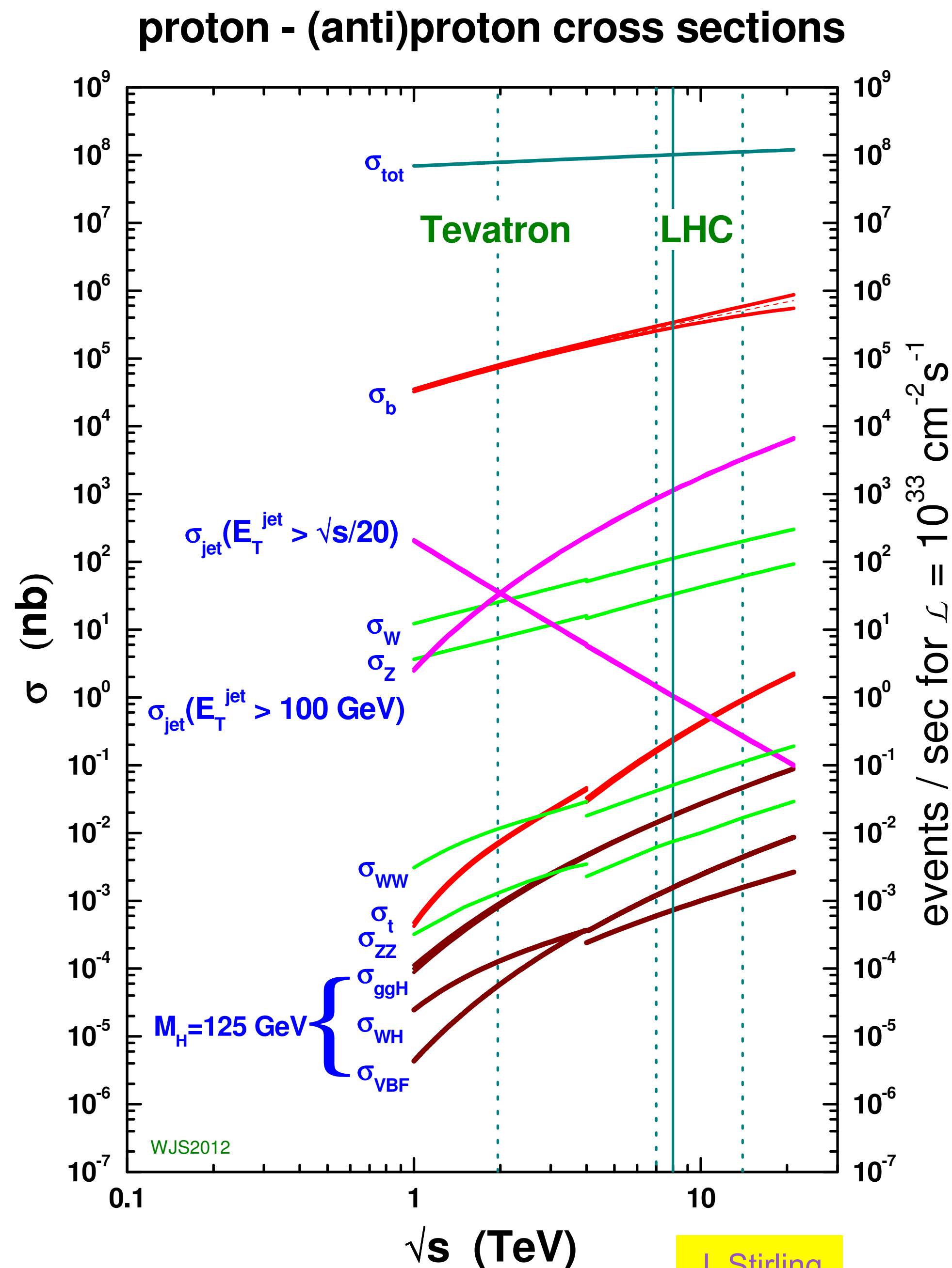
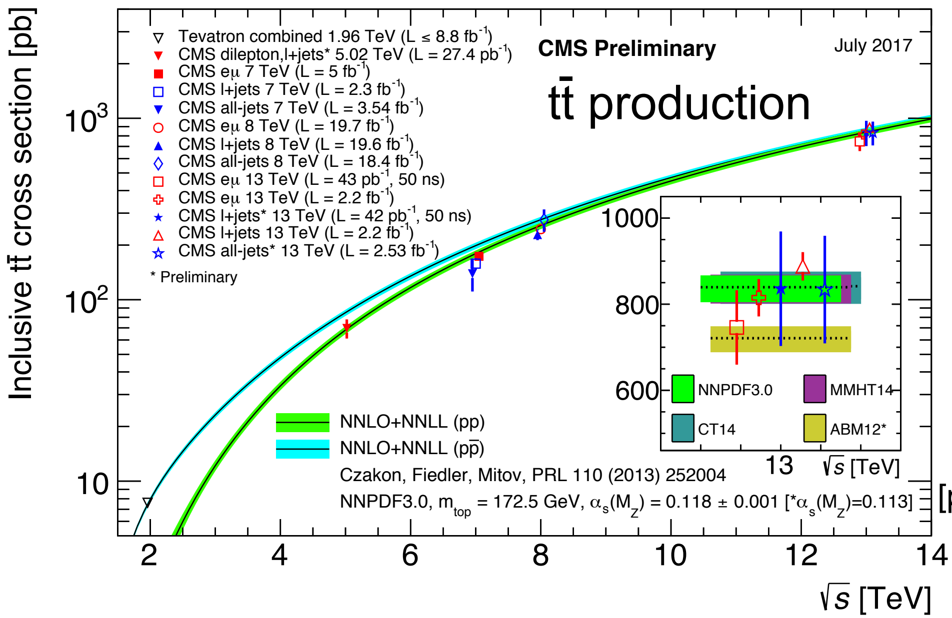


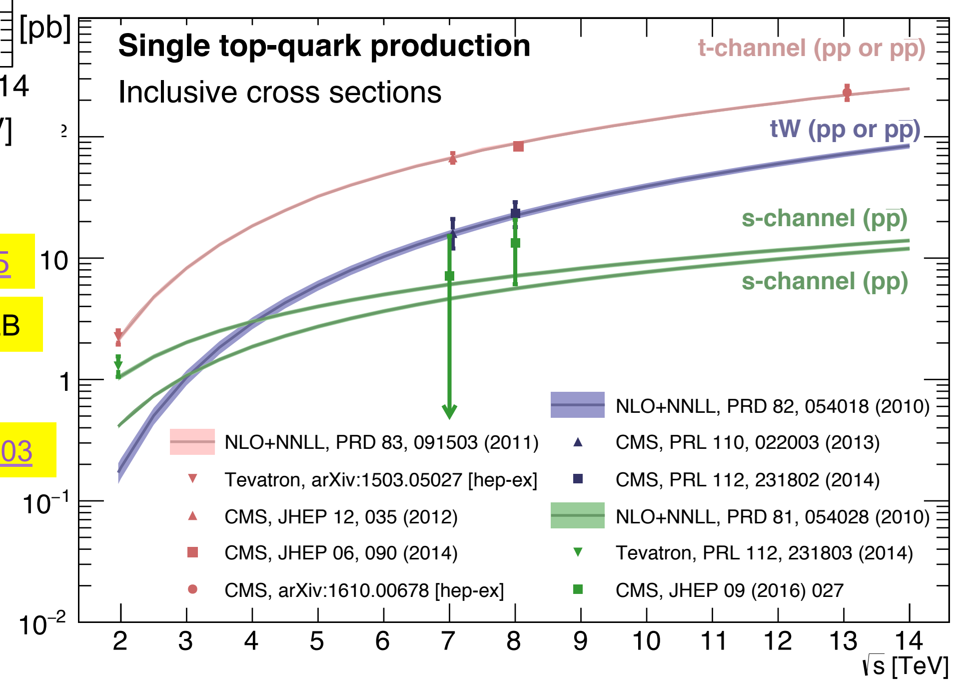
J. Stirling

CMS Public

LHC is a top quark factory



~50 top pairs every second at LHC!
(at 10^{34} $cm^{-2}s^{-1}$ instantaneous luminosity)



- Probing rare tt+X processes:
  - ttW @ 5.5σ, ttZ @ 9.9σ CMS_PAS_TOP_17_005
  - ttbb and ttbb/ttjj production 1705.10141, to PLB
  - ttγ production 1706.08128, subm. to JHEP
  - tZq production @ 2.4σ 10.1007/JHEP07(2017)003
- Measuring couplings
- Testing FCNC, BSM

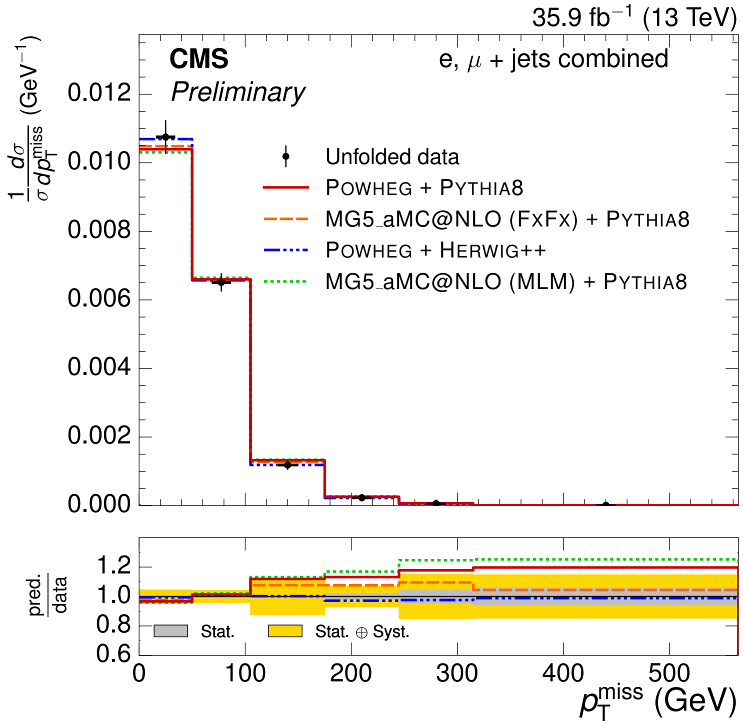
CMS_PAS_TOP_16_014

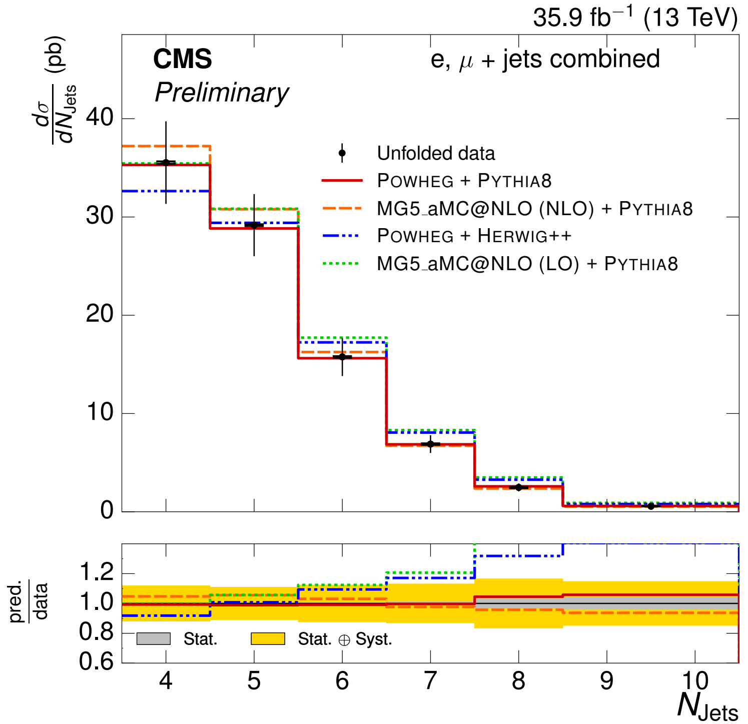
TOP: differential cross section

- semi-leptonic decay channel ($e^\pm$ or $\mu^\pm$)
- important verification of theoretical models, sensitive to rare SM processes like tt + (W, Z, or H), important SM background to searches
- σ(tt) differentially in variables, that don't need reconstruction of tt system
- unfolded to particle level, phase-space resembling fiducial volume of CMS

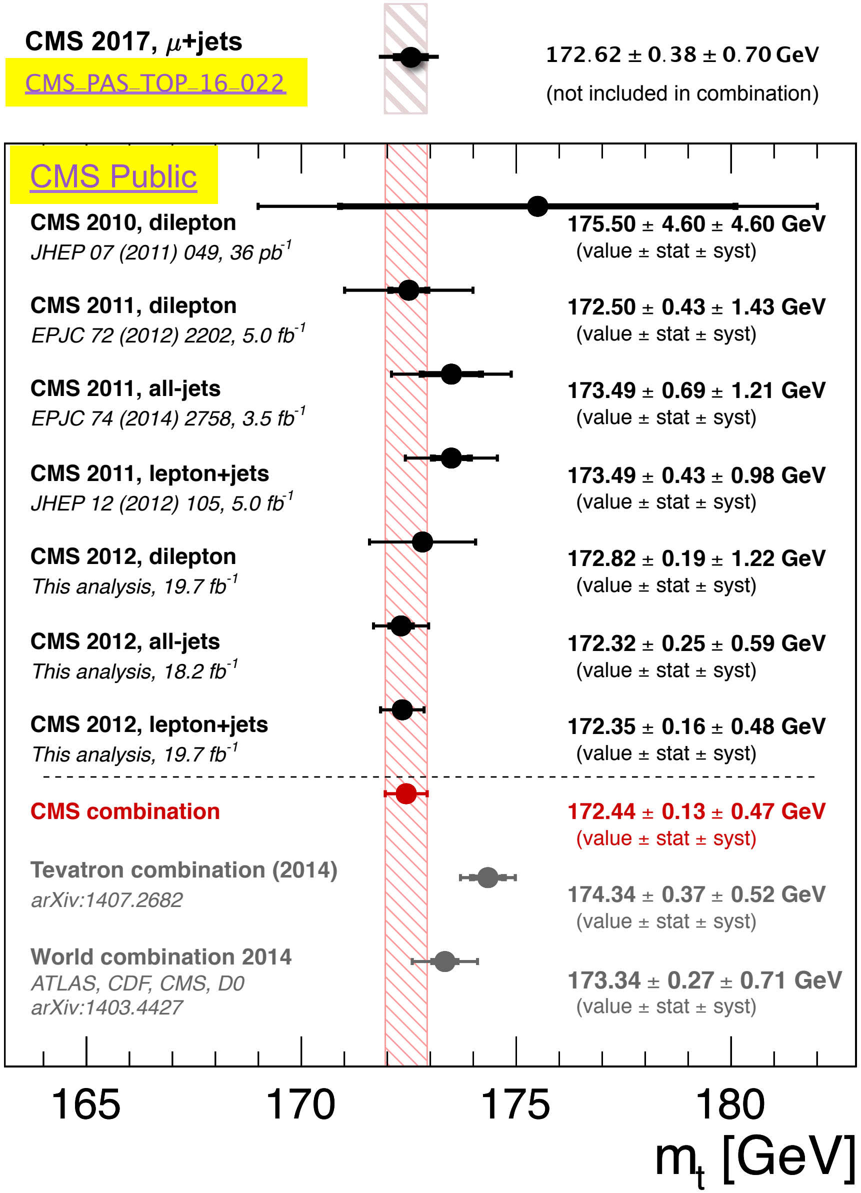
Latest of many similar results

- particle and parton level measurements;
- l+jets, dilepton, and all jets;
- boosted and resolved;
- based on global event variables and reconstructing the top system(s);
- double and simple differential

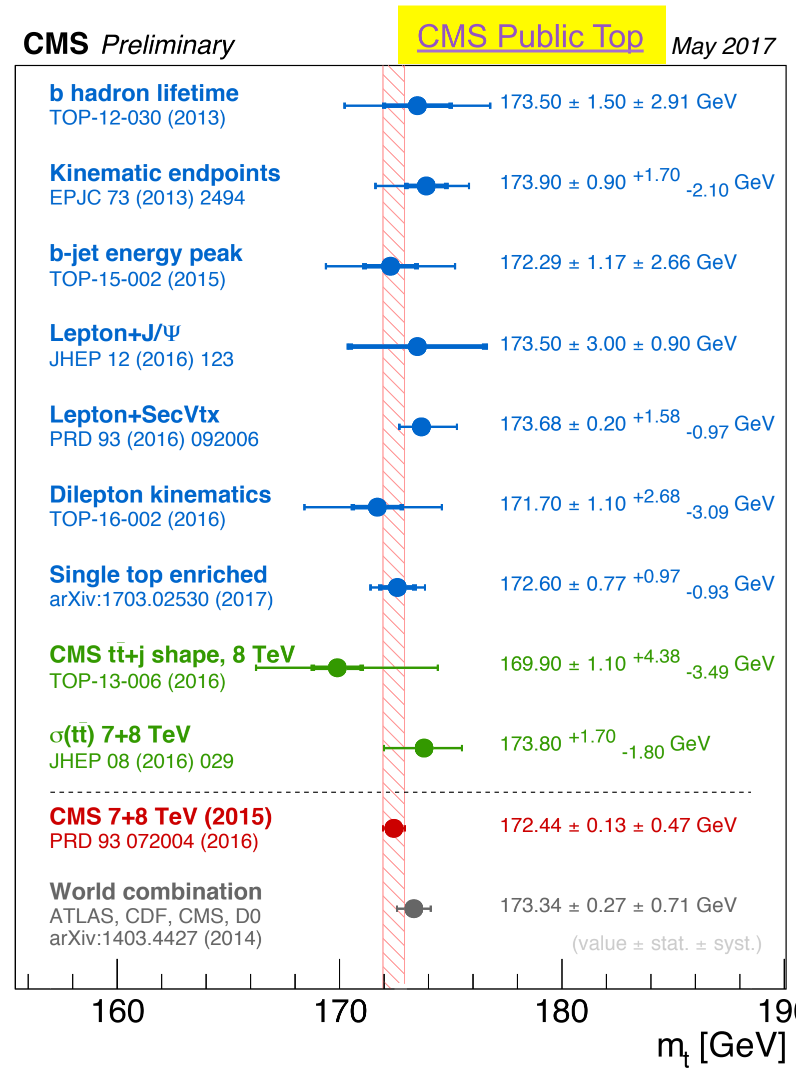




Top property measurements: Top mass



~0.3 %! precision



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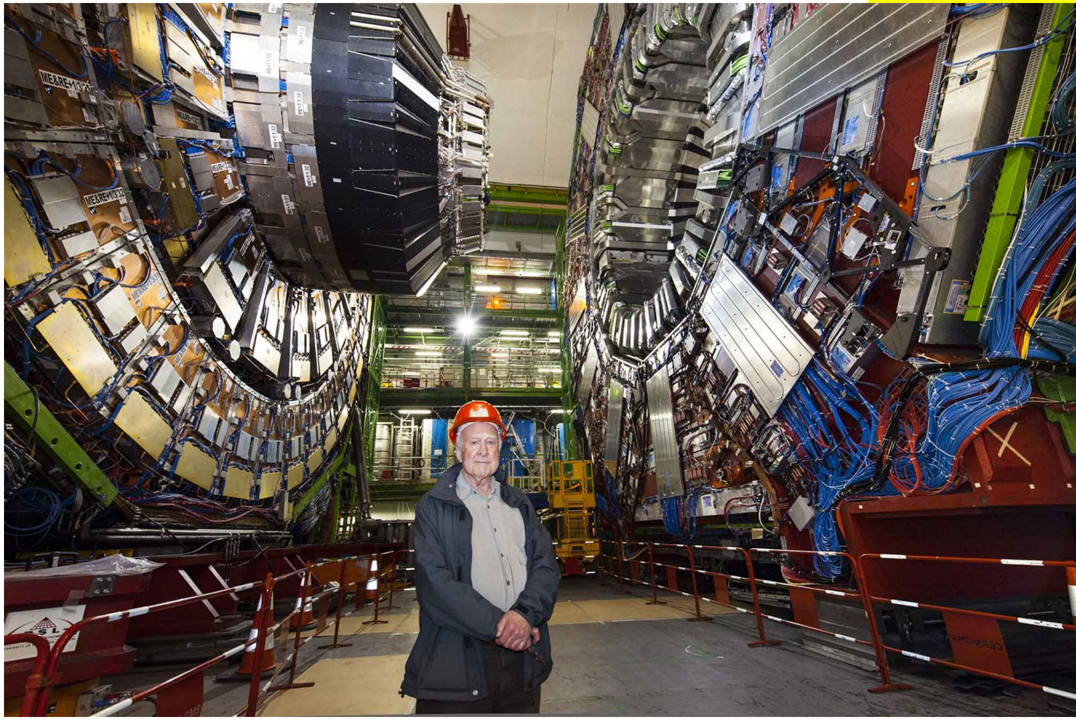
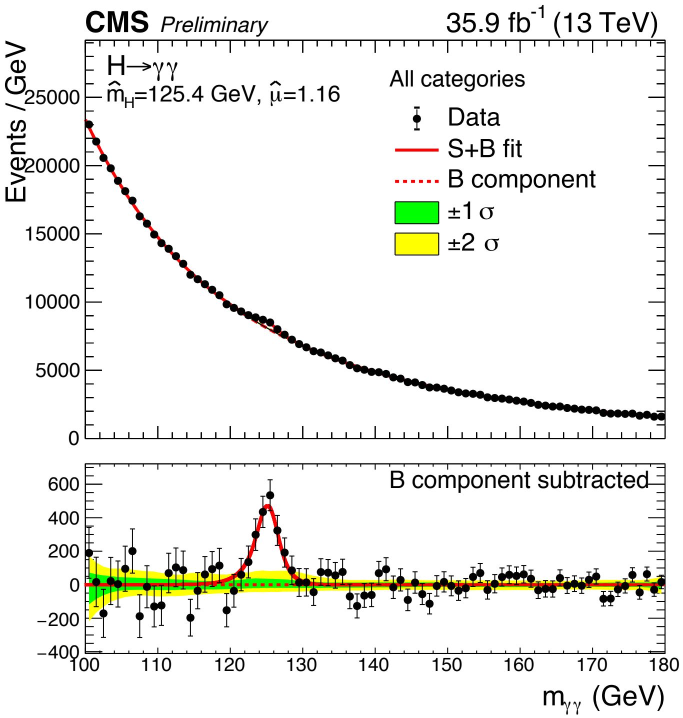
CMS Public

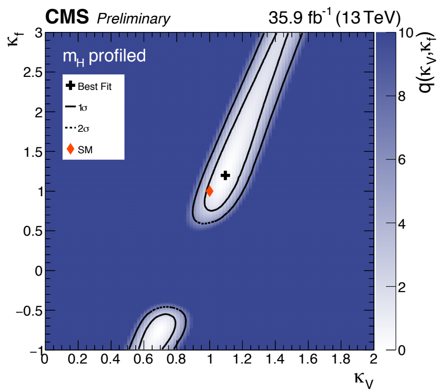


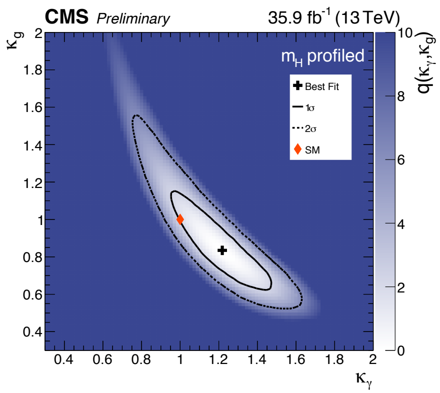
Discovery channels of the Higgs

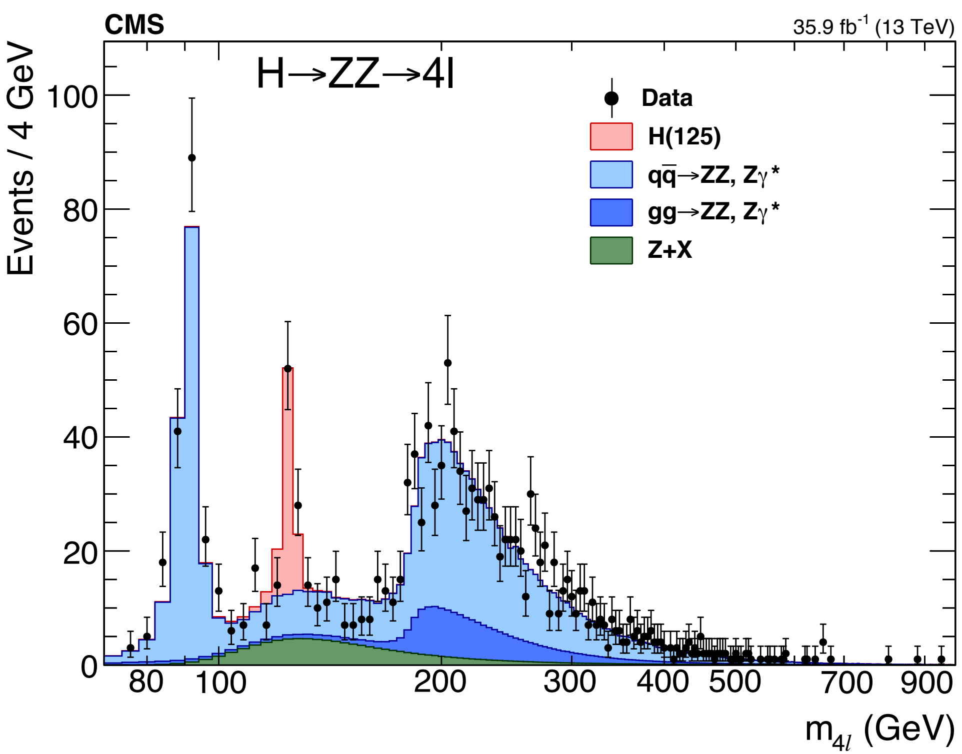
CMS_PAS_HIG_16_040,
1706.09936, subm. to JHEP



- Discovery channels despite small BF of ~0.23% ($\gamma\gamma$), ~0.013% (4l)
- clean signal, high precision, fully reconstructable
- consistent with SM

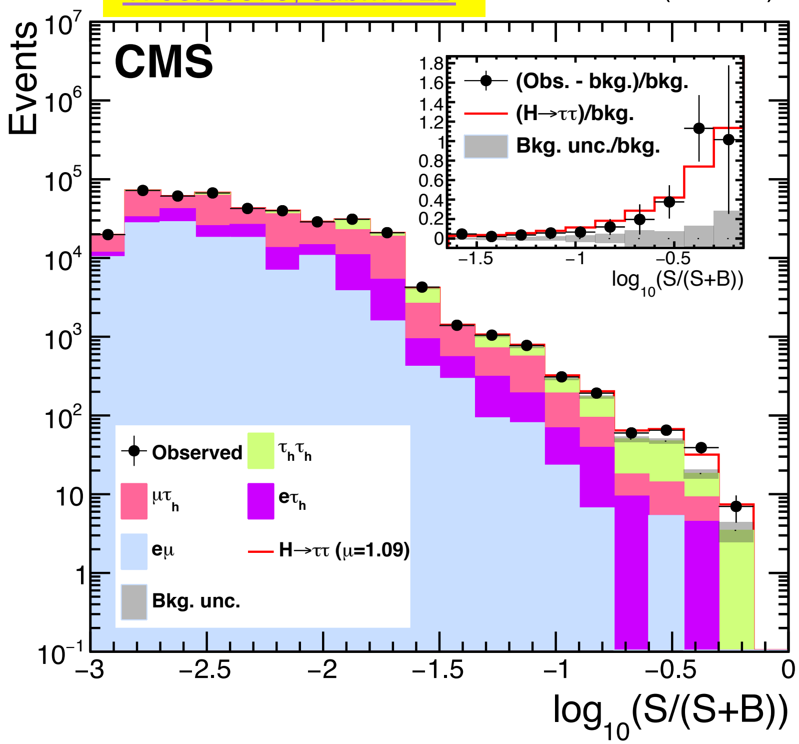




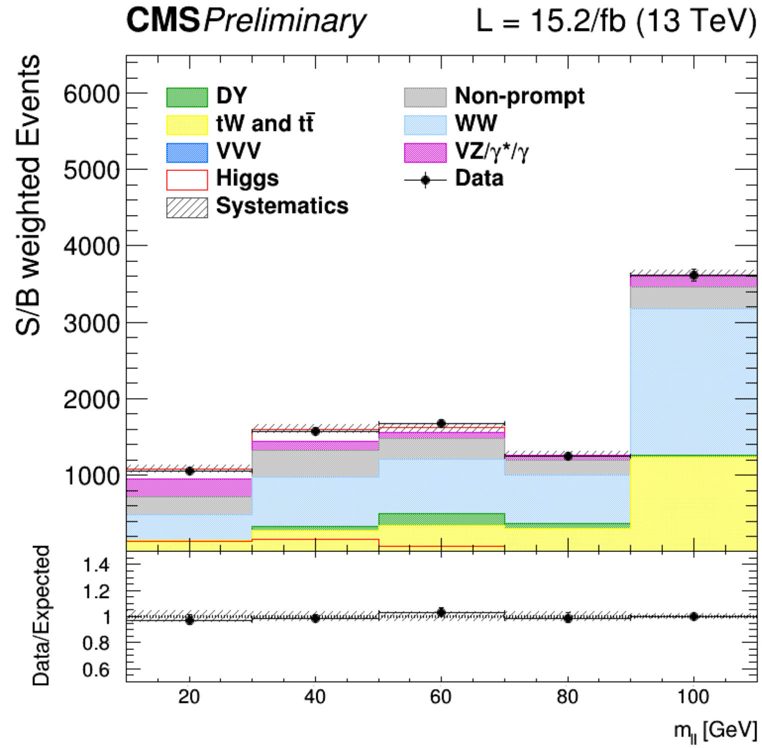


H→ττ and H→ W⁺W⁻ channels

1708.00373, subm PLB



CMS_PAS_HIG_16_021



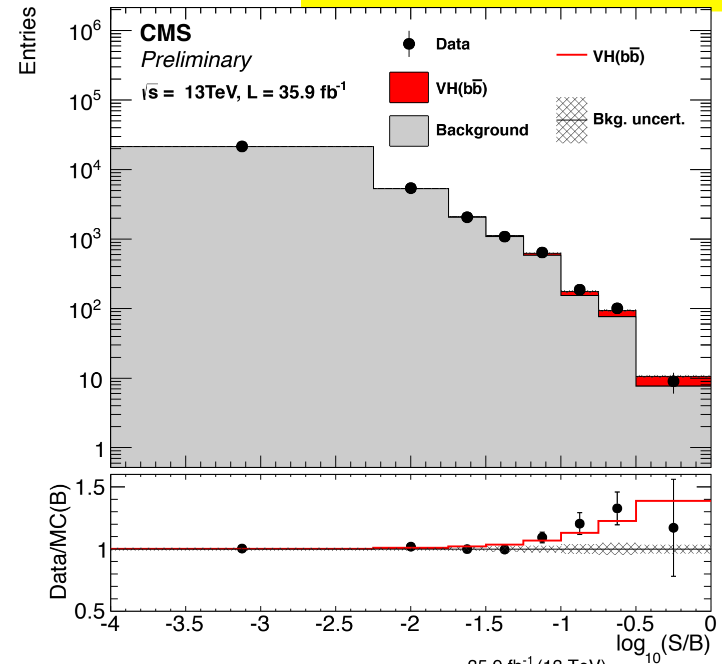
- Tau semi-hadronic & leptonic decay channels
  - Excellent CMS tau tagging
  - 4 final states (eμ, eτ_h, $\mu\tau_h$, $\tau_h\tau_h$)
  - 3 categories (0 jet, VBF, boosted)
- **4.9σ** (4.7σ expected) Run 1,2 combined:
  - $1.09^{+0.27}_{-0.26} \times \sigma_{SM}$ **5.9σ (5.9σ exp)**

- H→WW→$e\nu\mu\nu$
  - dilepton channel
  - ggH, VH, VBF production channels
- 4.3σ (4.1σ expected)
  - $1.05 \pm 0.26 \times \sigma_{SM}$

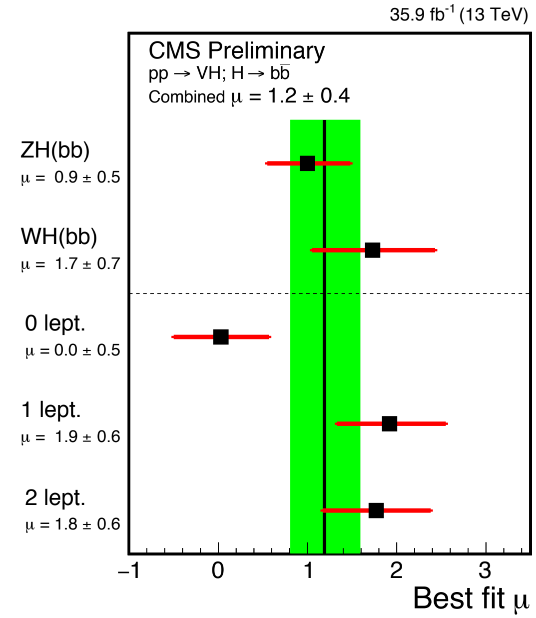
CMS_PAS_HIG_16_044

Strong evidence for V+ Higgs → $b\bar{b}$

- VH→ll'bb with V = (W, Z) & l = (e, μ, ν)
- Tevatron's most sensitive channel in reported evidence for Higgs 10.1103/PhysRevLett.109.071804
- 0,1,2 charged lepton channels; 21 control regions
- 7 BDT discriminator distributions
- Signal extraction by simultaneous binned likelihood fits of signal and backgrounds for all channels to the BDT distributions

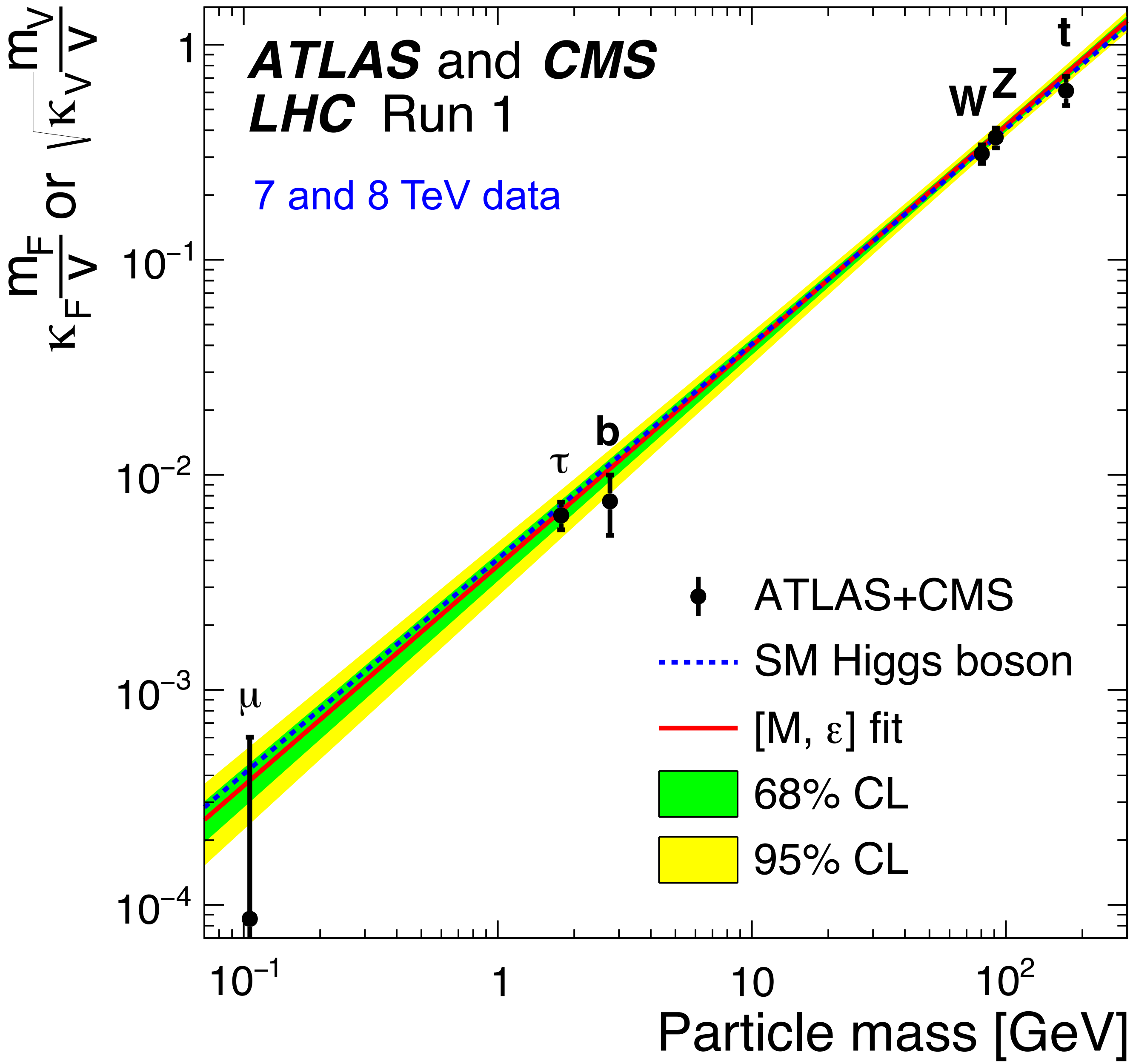


- Method validated on VZ with Z→ bb, observed with 4.96σ ($1.02^{+0.22}_{-0.23} \times \sigma_{SM}$)



- Combination with CMS Run I (7 & 8TeV): **3.8σ** (3.8σ expected)
  $1.06^{+0.31}_{-0.29} \times \sigma_{SM}$
- more details in talk by Keti Kaadze this afternoon

10.1007/JHEP08(2016)045

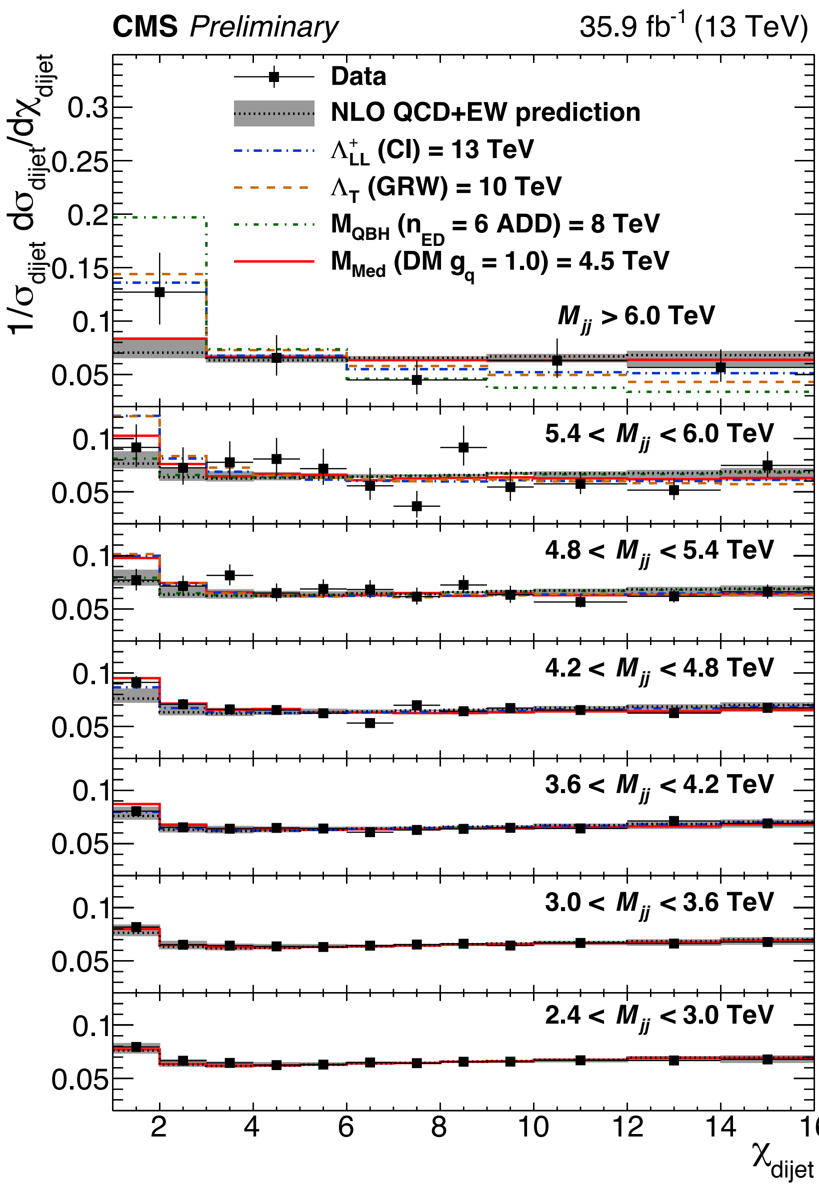


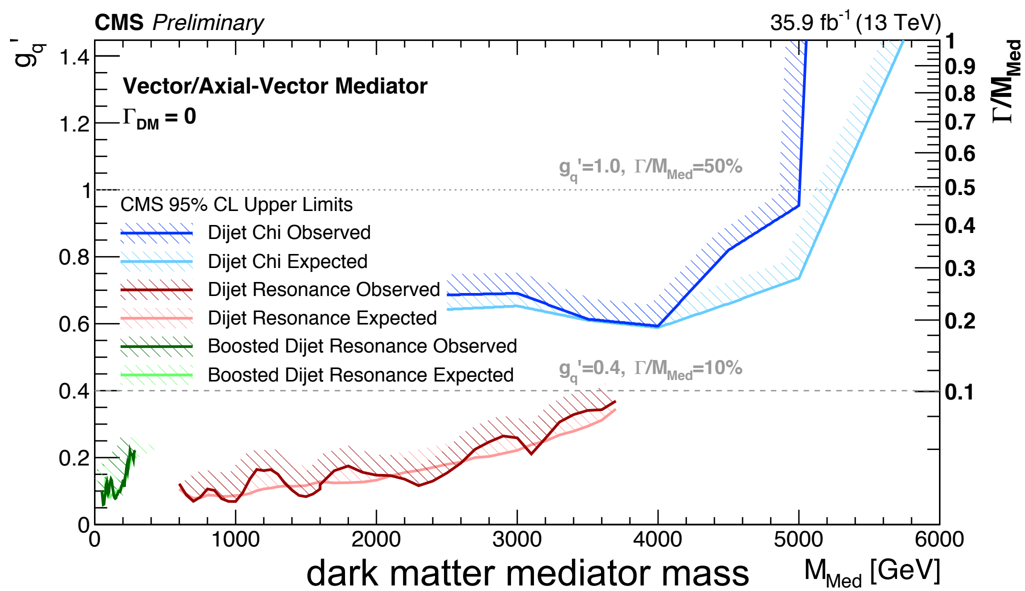
Contents

Map of Martin Waldseemüller labeling ‘terra incognita’ as America (1507).

CMS_EXO_16_046

Exotica – dijet angular correlations





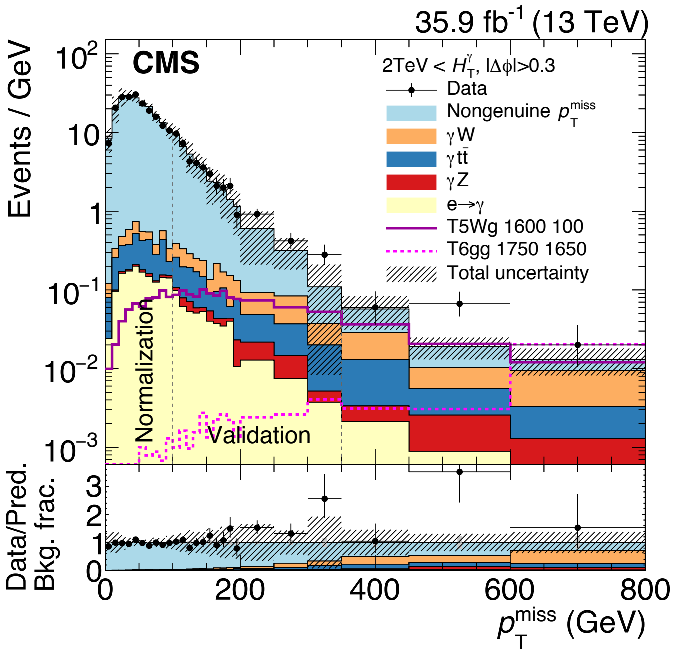
- qq CI, quantum BH, DM, extra dim.; constructive or destructive interference
- complementary to dijet narrow bump search
- QCD Rutherford scattering flat in χ_{dijet}
- First time limits on universal quark coupling to dark matter mediator 2.5 < M_{Med} < 5 TeV set, that is inaccessible through dijet resonances

$$\chi_{\text{dijet}} = e^{|y_1 - y_2|} \approx \frac{1+|\cos\theta^*|}{1-|\cos\theta^*|}$$

θ^*: jet angle to beam axis in dijet rest frame

1707.06193, subm. JHEP

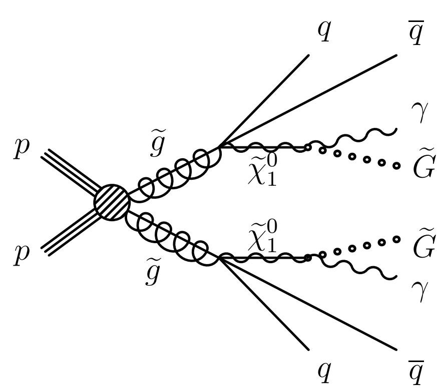
Supersymmetry – Gauge mediated breaking

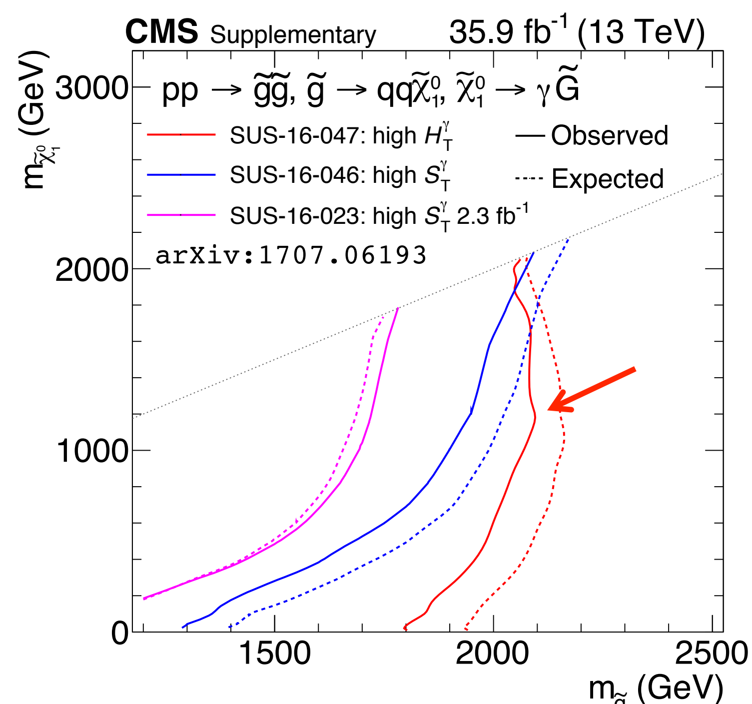


- At least one photon in final state
- Generic search for strongly produced GMSB SUSY with $\tilde{\chi}\rightarrow\gamma\ \tilde{G}$
- $m(\tilde{g})$ up to 2 TeV &
  $m(\tilde{q})$ up to 1.65 TeV excluded dep. on $m(\tilde{\chi}^0_1)$

- No excess observed
- Complementary channels
  - γ EWK, $\gamma\gamma$, γ+lepton, multi-lepton
  - Planning combination in model of General Gauge Mediation

    10.1007/JHEP01(2017)135,
    10.1007/JHEP03(2016)046

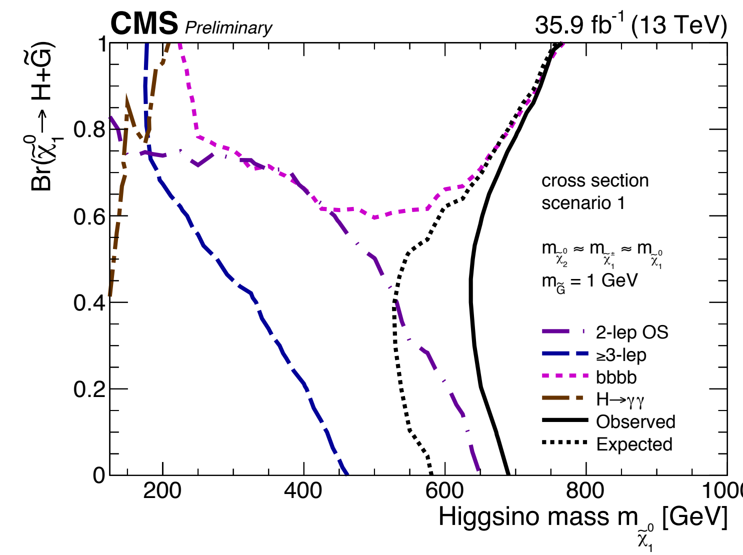


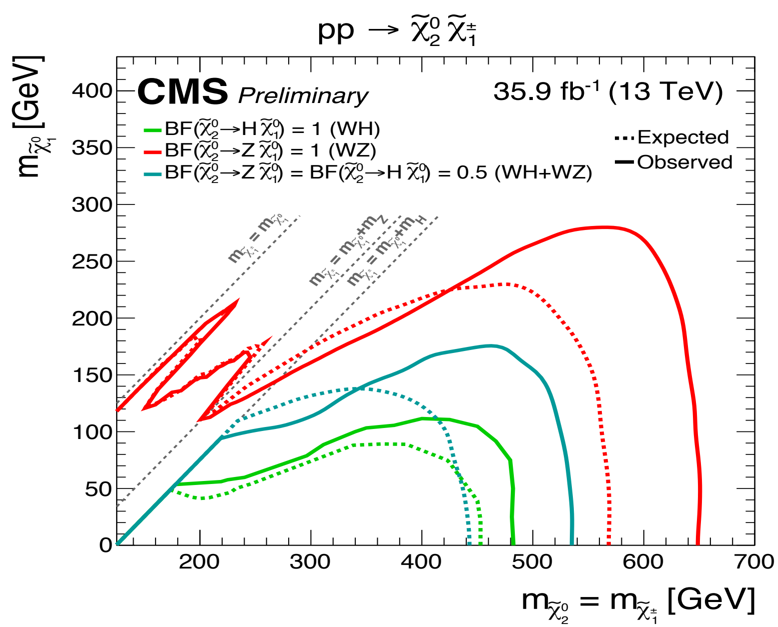


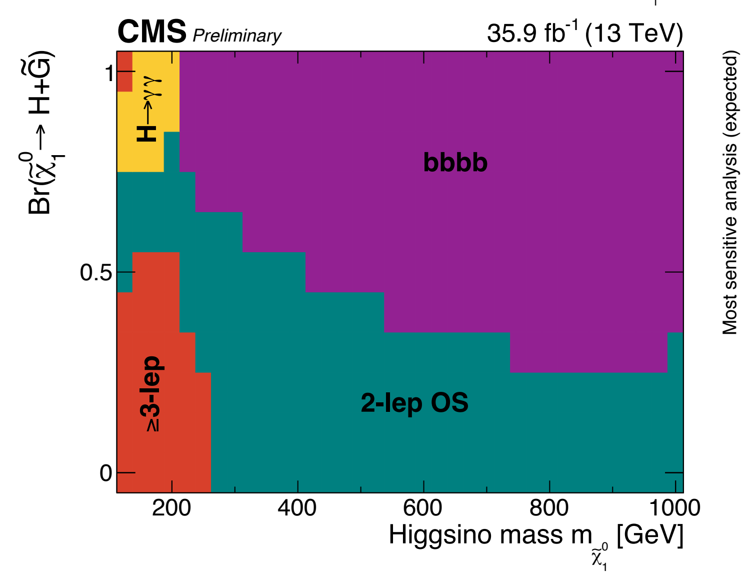
CMS_PAS_SUS_17_004

Supersymmetry – Electroweak searches combination

- Electroweak chargino & neutralino production
- Statistical combination of multiple analyses
  - multi-lepton, low p_T dileptons, OS&SF dilepton, WH, Razor $H\rightarrow\gamma\gamma$, H+MET
  - Optimized $\geq$3l search for $m(\chi_0{}^2) - m(\chi_0{}^1) = m(Z)$
- Model of $\chi^{\pm}{}_1 - \chi^0{}_2$ production
  - different $\chi^0{}_2$ decay scenarios



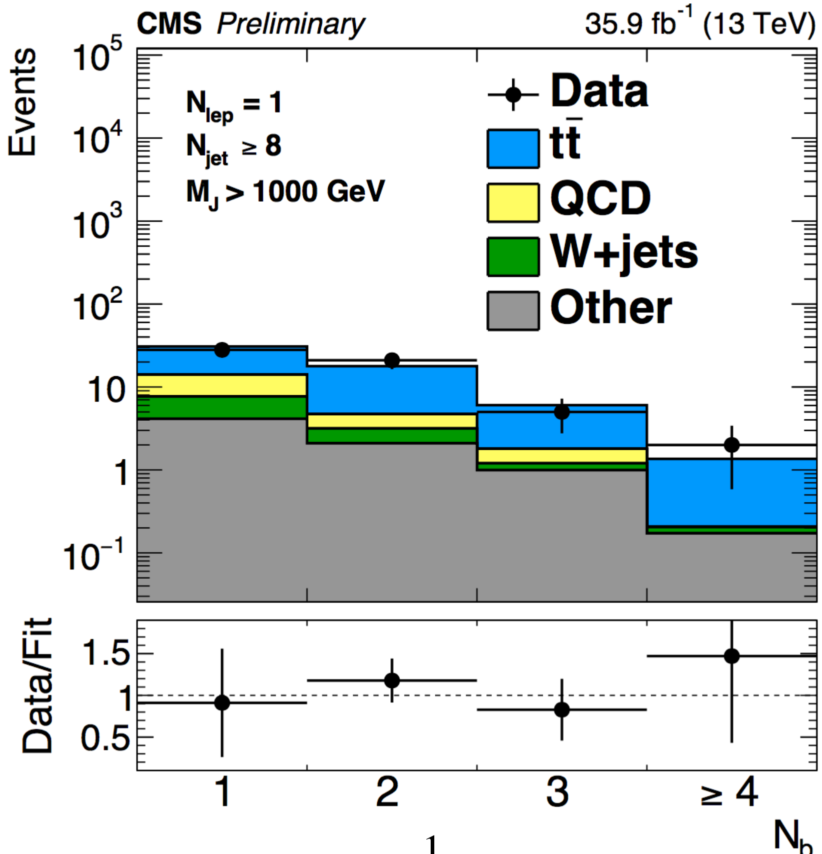


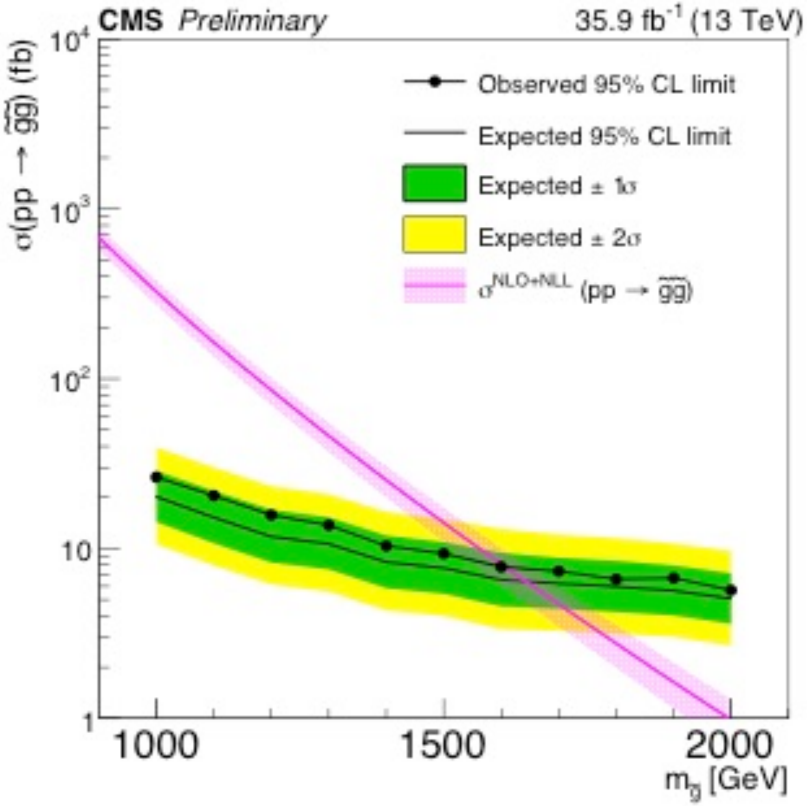


CMS_PAS-SUS_16_040

Supersymmetry: R-Parity violation

- No theoretical reason why R-parity must be conserved
- "Natural" RPV SUSY still largely unconstrained
- No MET requirement – also sensitivity to RPC SUSY with compressed mass spectra





$$W_{\not R_p} = \frac{1}{2}\lambda_{ijk}L_iL_jE_k^c + \lambda'_{ijk}L_iQ_jD_k^c + \frac{1}{2}\lambda''_{ijk}U_i^cD_j^cD_k^c + \mu_iH_mL_i$$

- Minimal Flavor violation: λ''_{tbs}
- $\tilde{g} \rightarrow t\,\tilde{t} \rightarrow t\,b\,s$, at least one iso. lepton (e, μ)
- signal extraction through shape fit to N_b in bins of N_{jet} and M_J

Conclusion

- Outstanding performance of LHC and the CMS detector
- Now results using up to 40 fb^{-1} of 13 TeV data are published
- Excellent performance of detectors Standard Model measurements make more complicated & specialized search analyses possible and worthwhile!
- SM precision measurements profit from increasing luminosity
- Naturalness arguments promises New Physics at the TeV scale, the TeV scale is now in reach!

References

All CMS public results: https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResults

Additional material

CMS_DP_2016_041

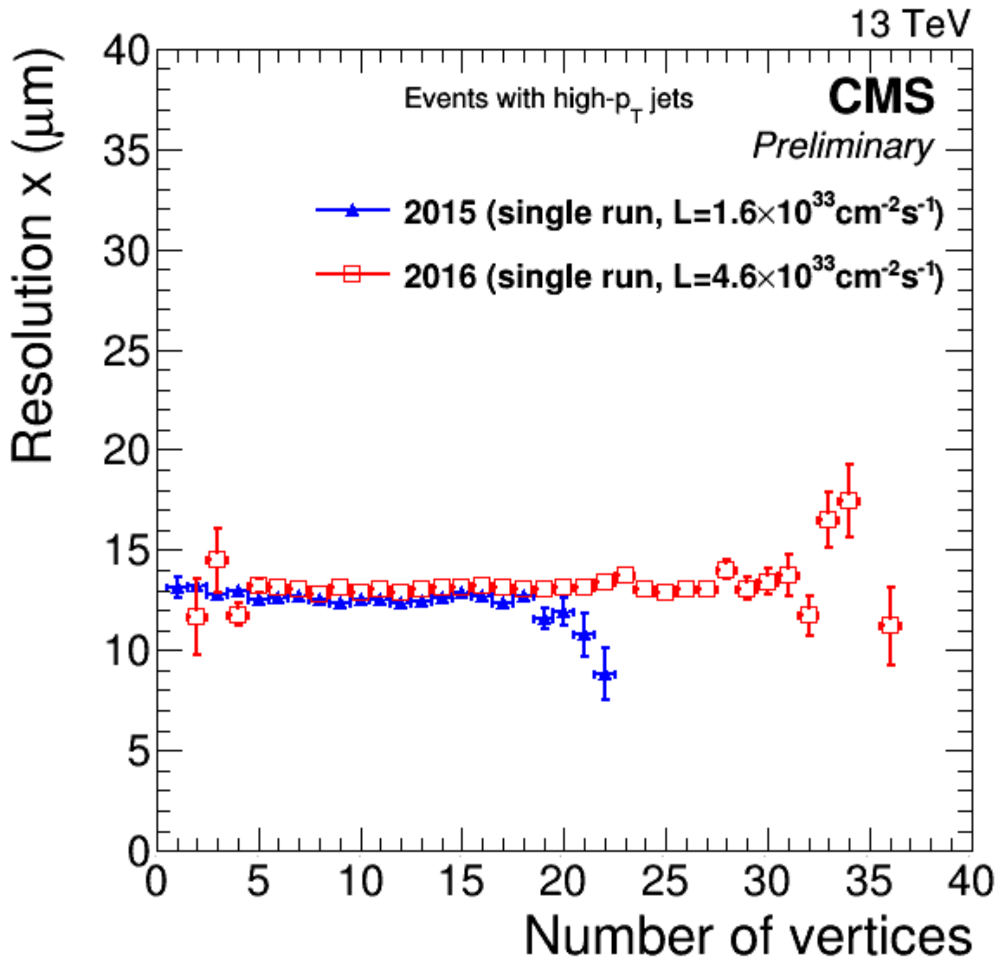
Performance Pixel: Vertex reconstruction

- Resolution vs pileup

- Better than 14 μm in x,y
- Better than 19 μm in z

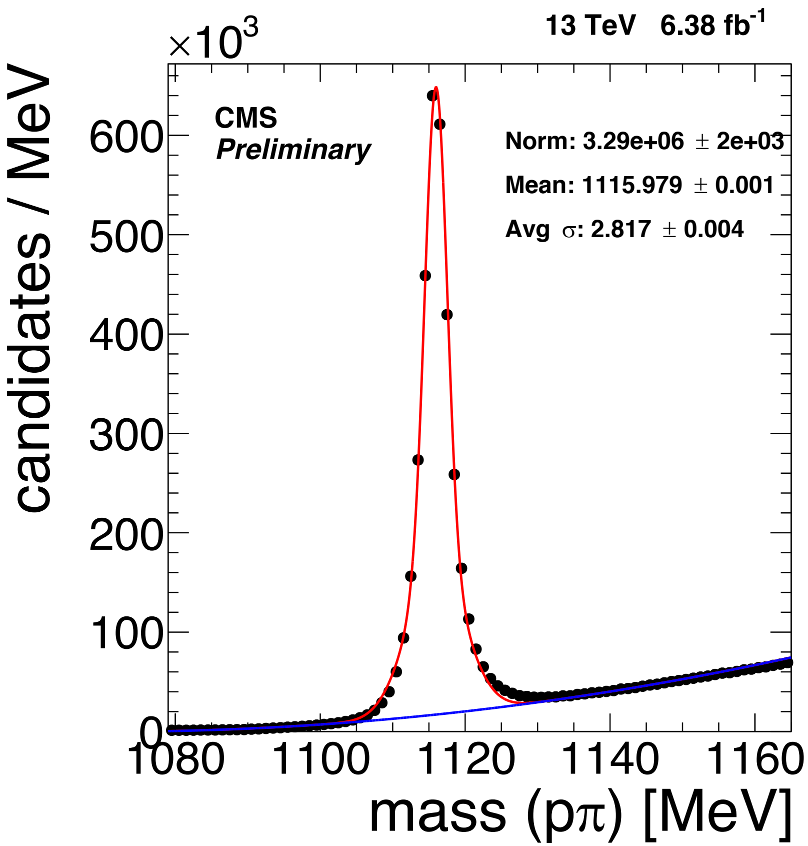
(for primary vertices with sum of track p_T > 100 GeV)

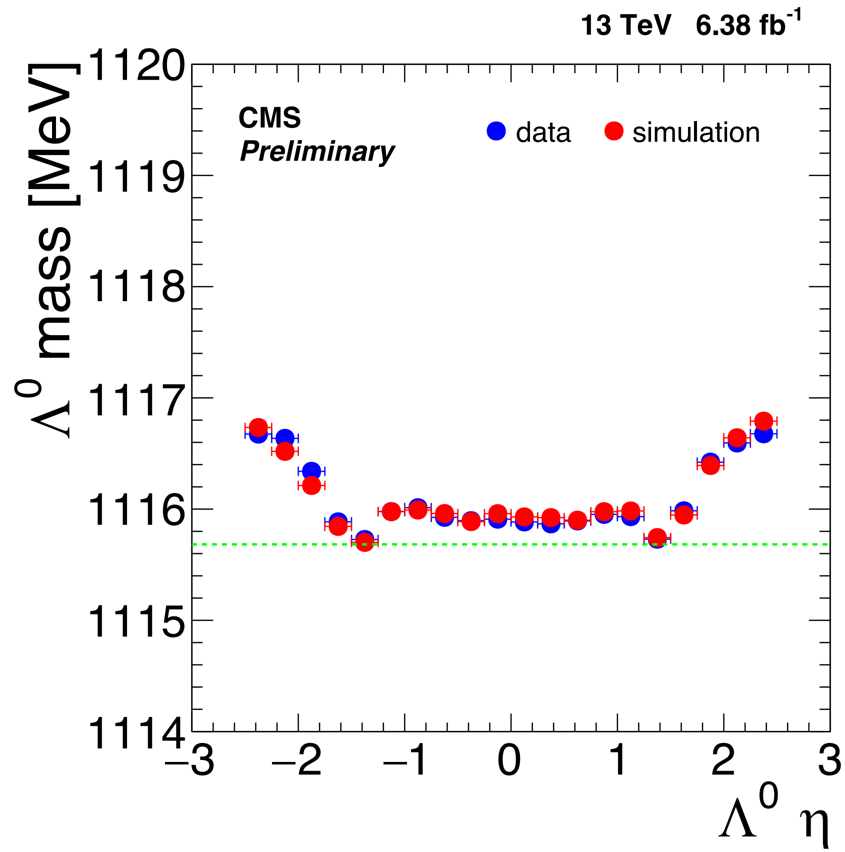
- Degradation of resolution by 10% caused by higher inst. luminosity causing larger pixel hit inefficiency



CMS_DP_2016_047

Performance tracking





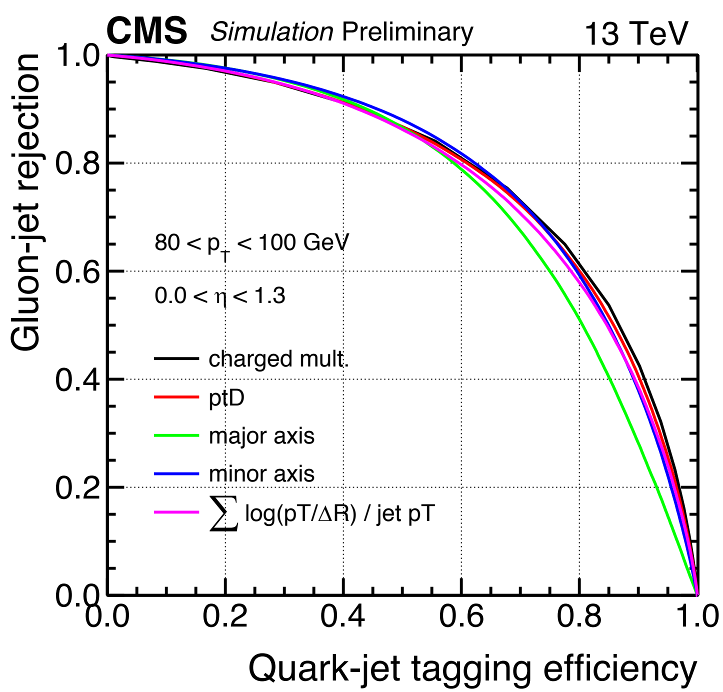
- Lambda invariant mass reconstructed from oppositely-charged pion/proton candidates in data.
- Fit with double-Gaussian with a common mean for the signal plus a quadratic polynomial for the background.

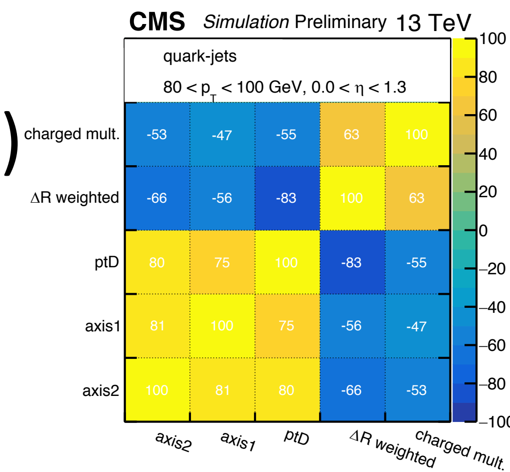
CMS_DP_2017_027

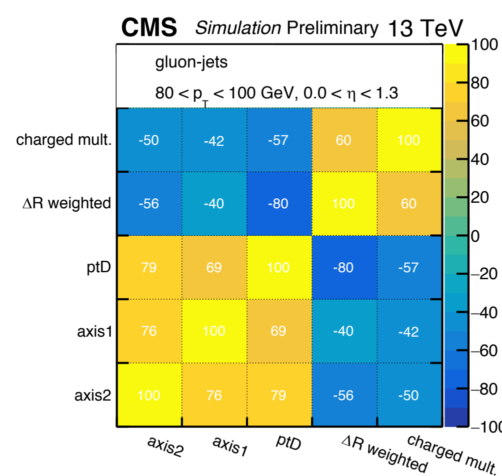
Performance: Jet substructure algorithms

- BDT quark / gluon jet discriminator

ROC curves and correlations (medium p_T)







Pythia QCD dijet simulation