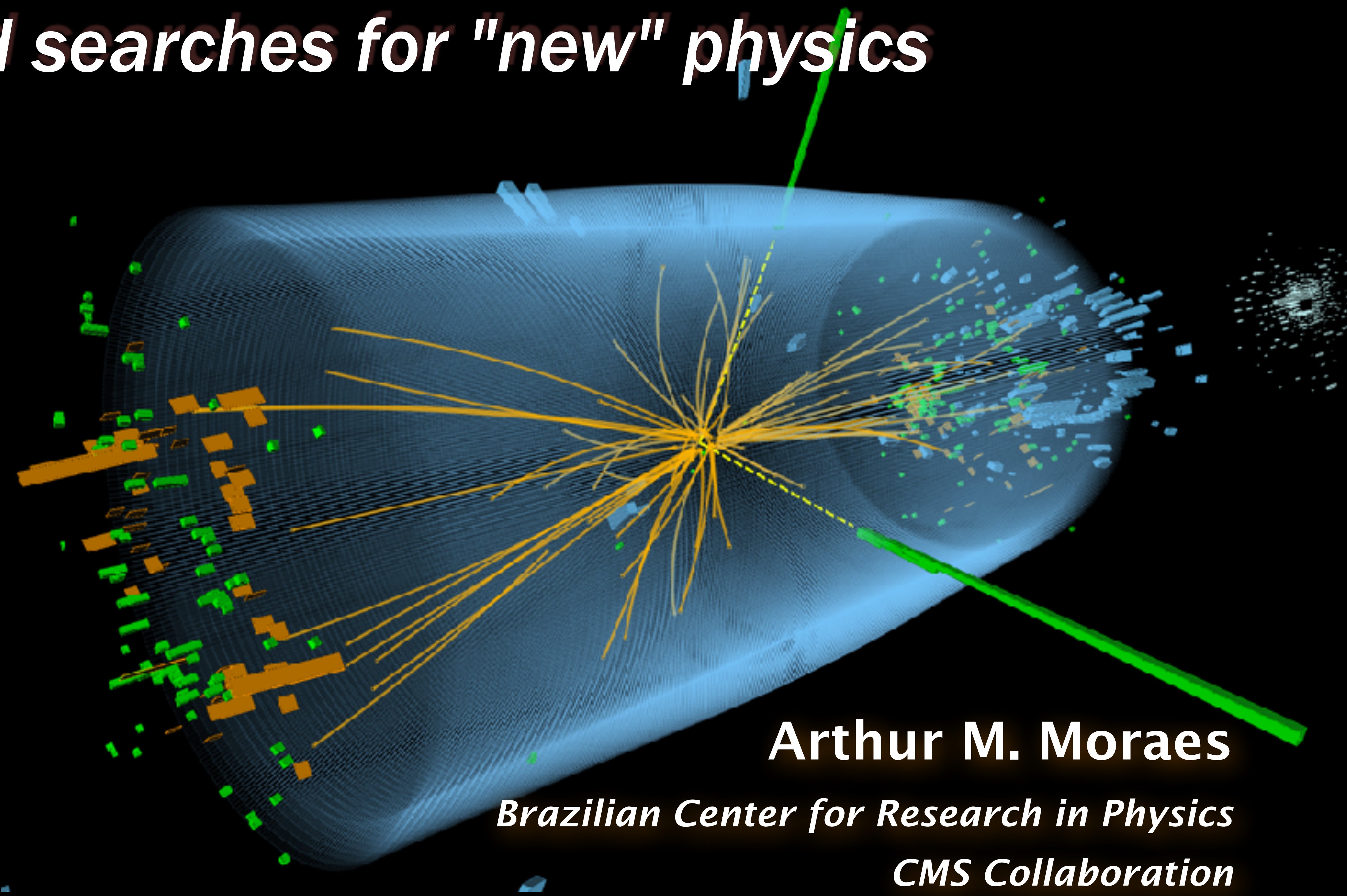
CMS highlights on precision measurements and searches for "new" physics



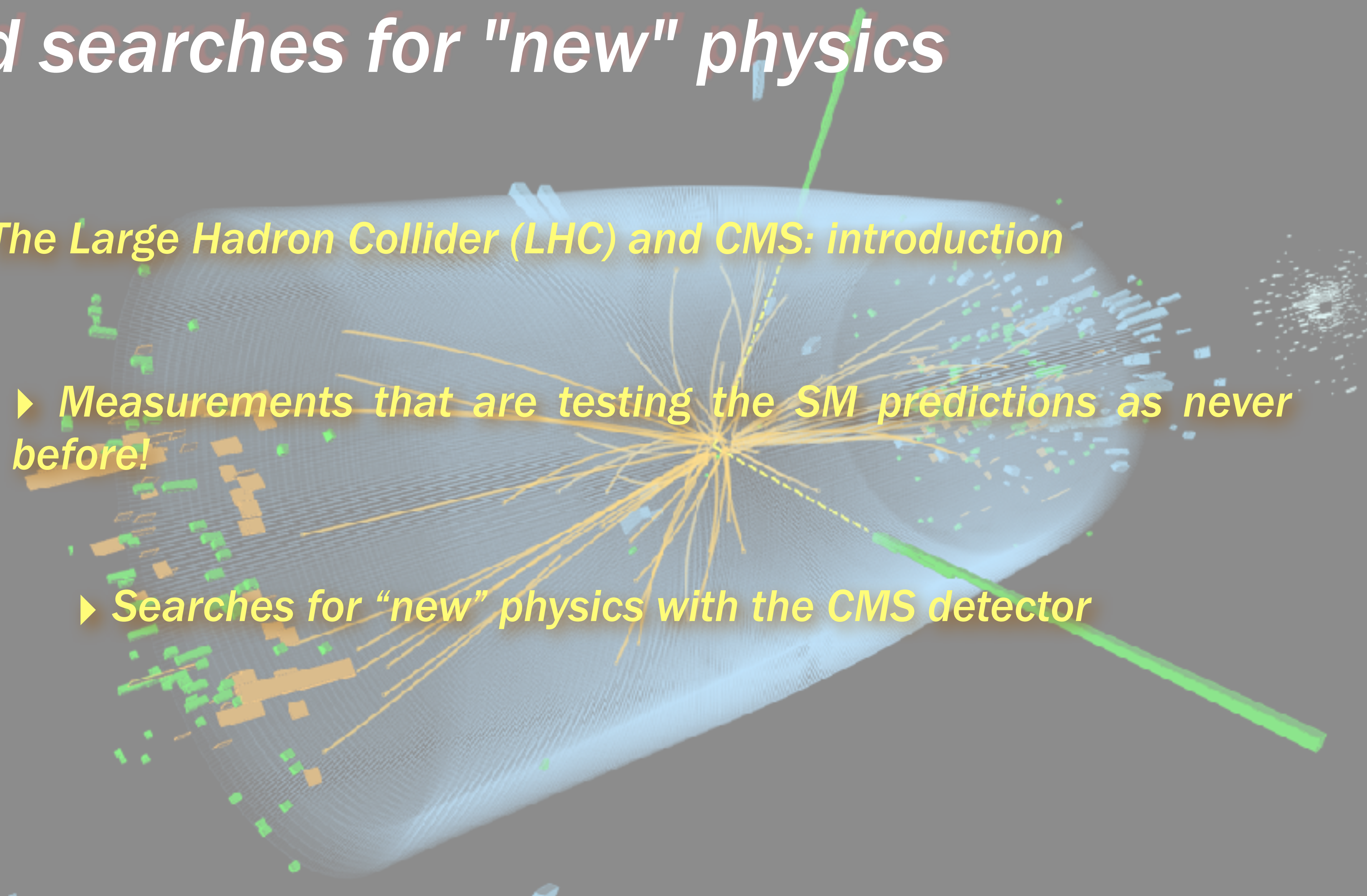
Arthur M. Moraes

Brazilian Center for Research in Physics

CMS Collaboration

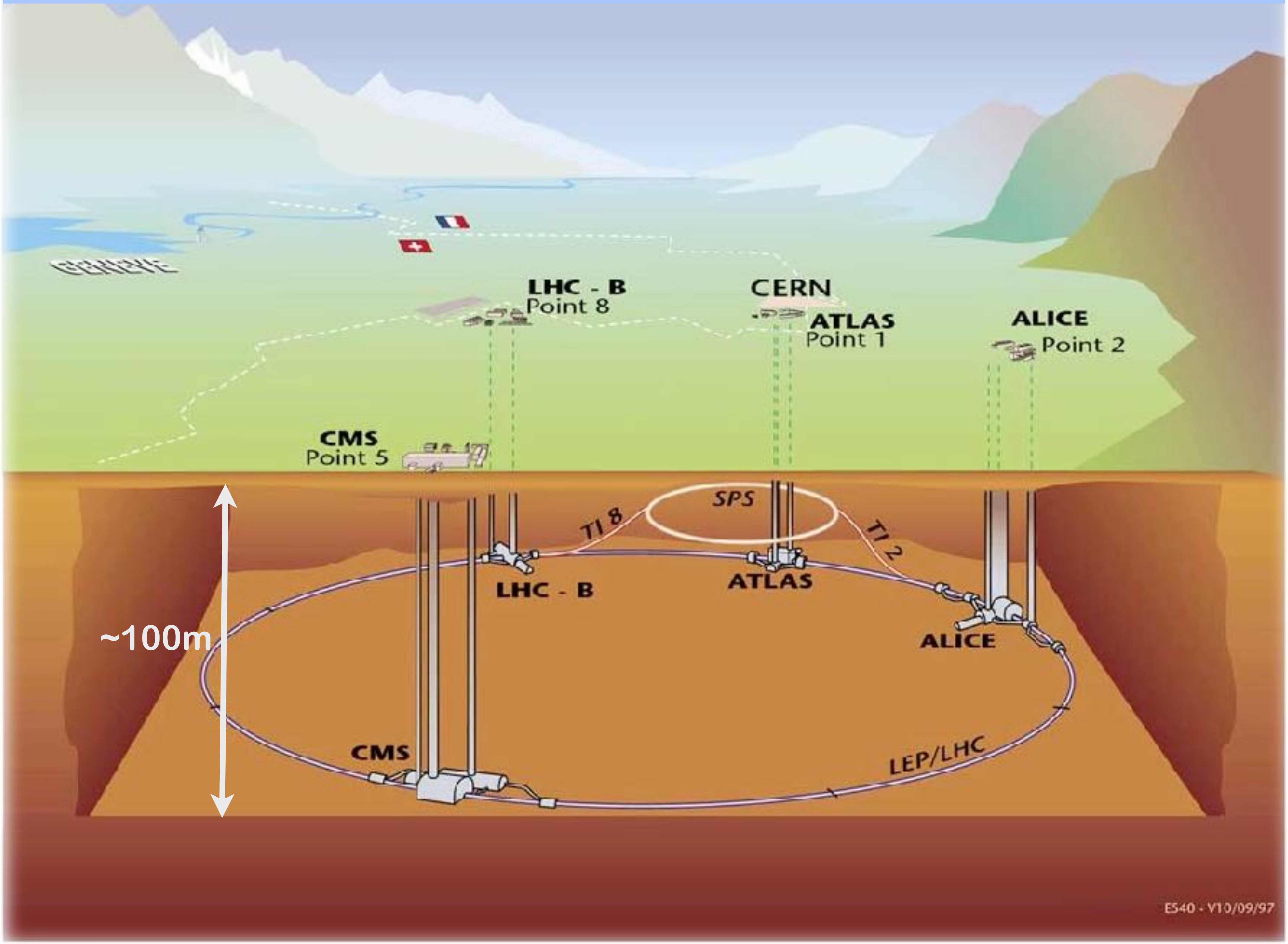
CBPF
Centro Brasileiro de Pesquisas Físicas

CMS highlights on precision measurements and searches for "new" physics

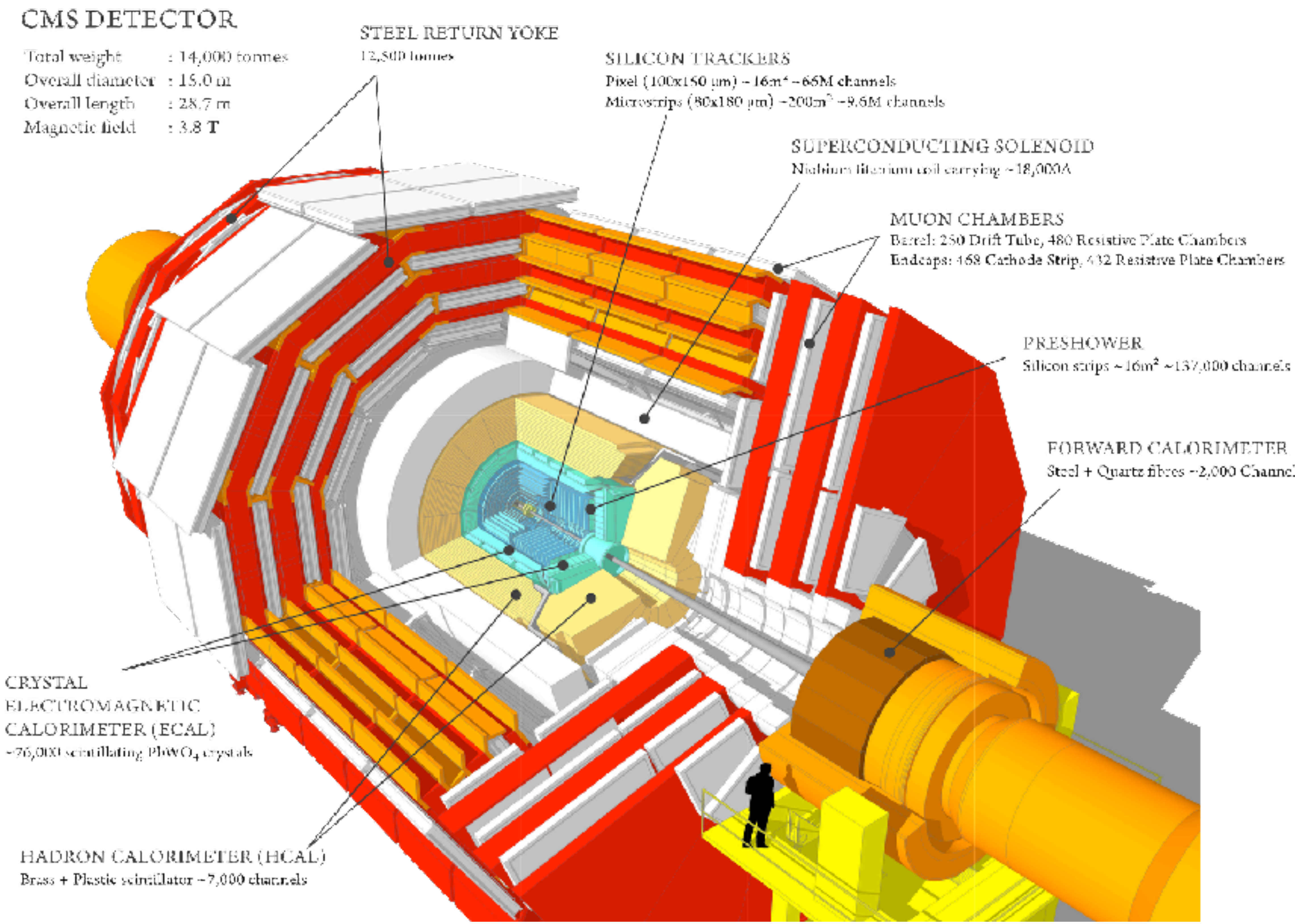


- The Large Hadron Collider (LHC) and CMS: introduction
- Measurements that are testing the SM predictions as never before!
- Searches for “new” physics with the CMS detector

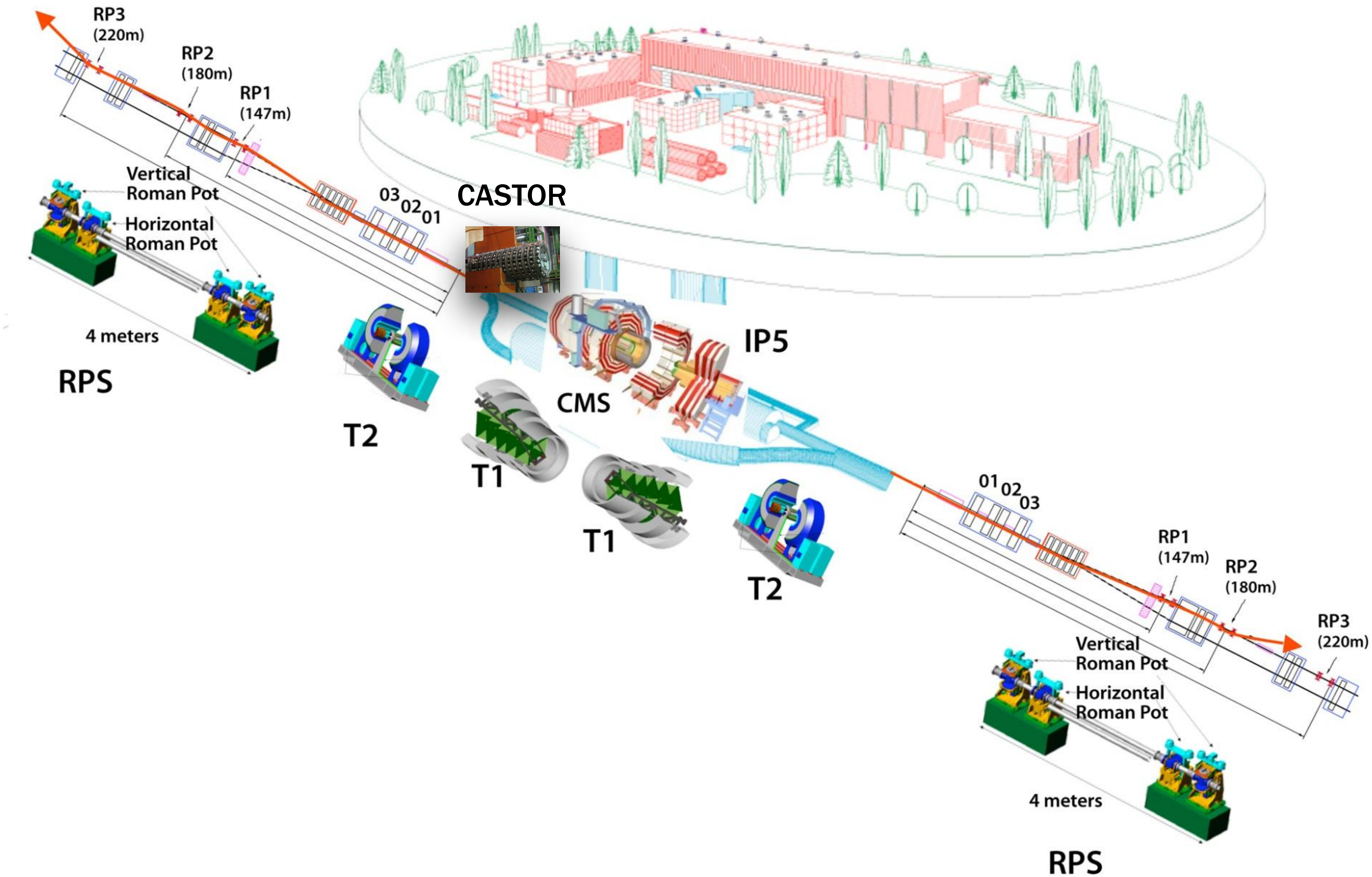
Four experiments are analyzing the collision products at the LHC: ATLAS, CMS, ALICE and LHCb



The Compact Muon Solenoid (CMS)



CMS & TOTEM: forward region coverage



The Compact Muon Solenoid (CMS)

2885
PHYSICISTS
(922 STUDENTS)

995
ENGINEERS

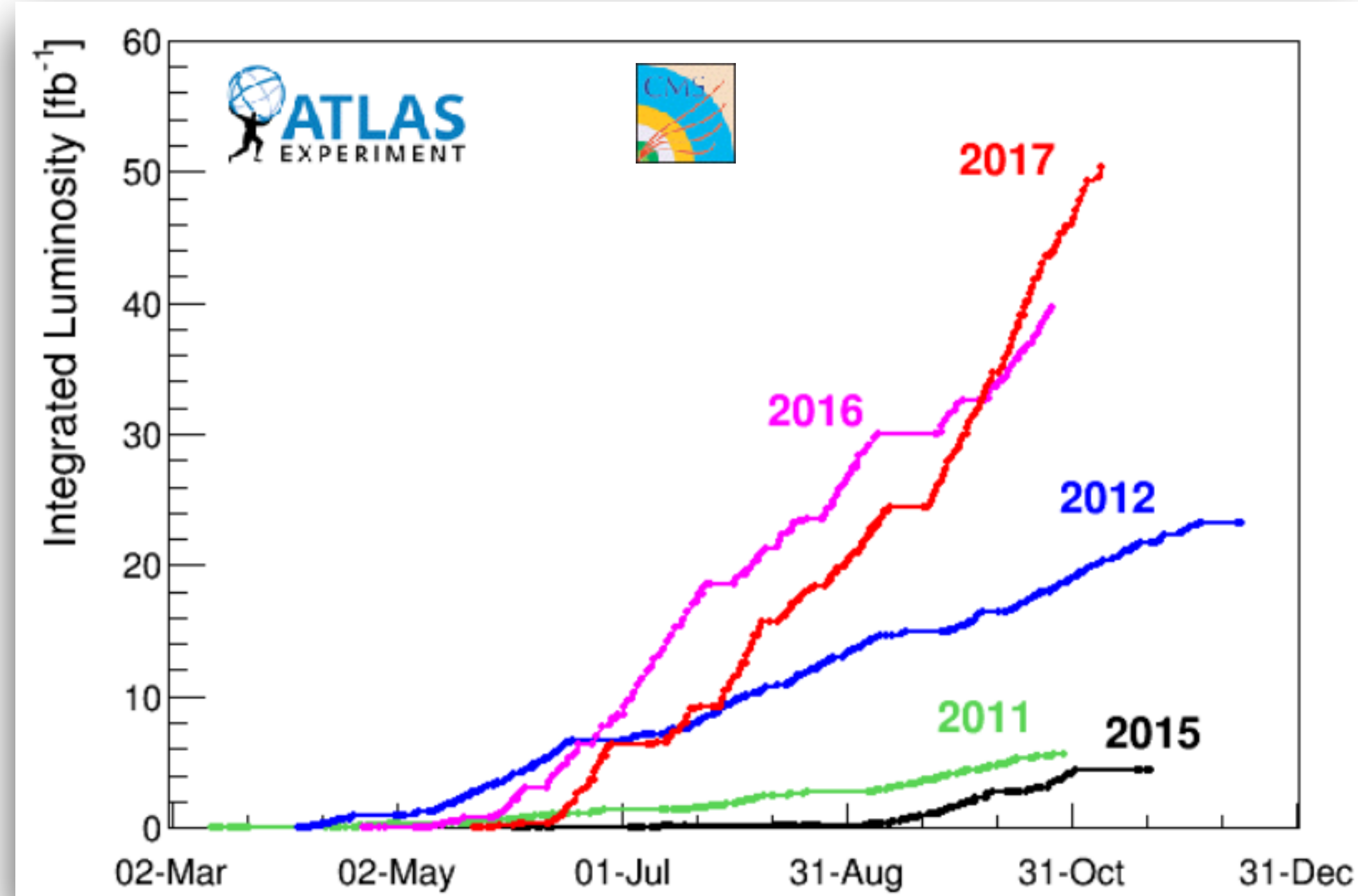
279
TECHNICIANS

198
INSTITUTES

45
COUNTRIES & REGIONS

The CMS Collaboration brings together members of the particle physics community from across the globe in a quest to advance humanity's knowledge of the very basic laws of our Universe. CMS has over 4000 particle physicists, engineers, computer scientists, technicians and students from around 200 institutes and universities from more than 40 countries.

The Large Hadron Collider: pp collisions



The LHC has also delivered several runs on pA and AA collisions.

https://lpc.web.cern.ch

$\sqrt{s}$=0.9 TeV

$\sqrt{s}$=7 TeV & 8 TeV

"Long Shutdown 1"

$\sqrt{s}$=13 TeV

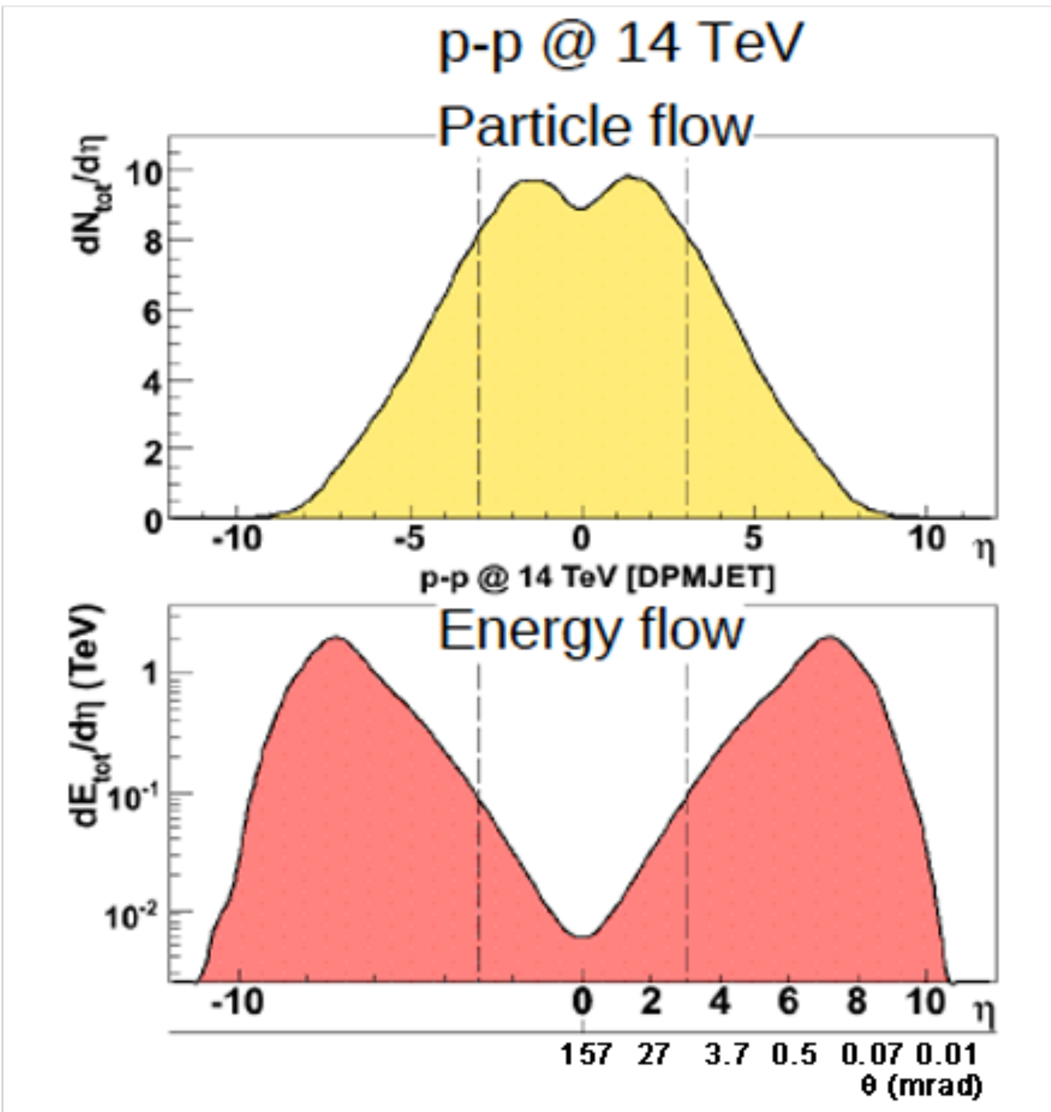
"Long Shutdown 2"

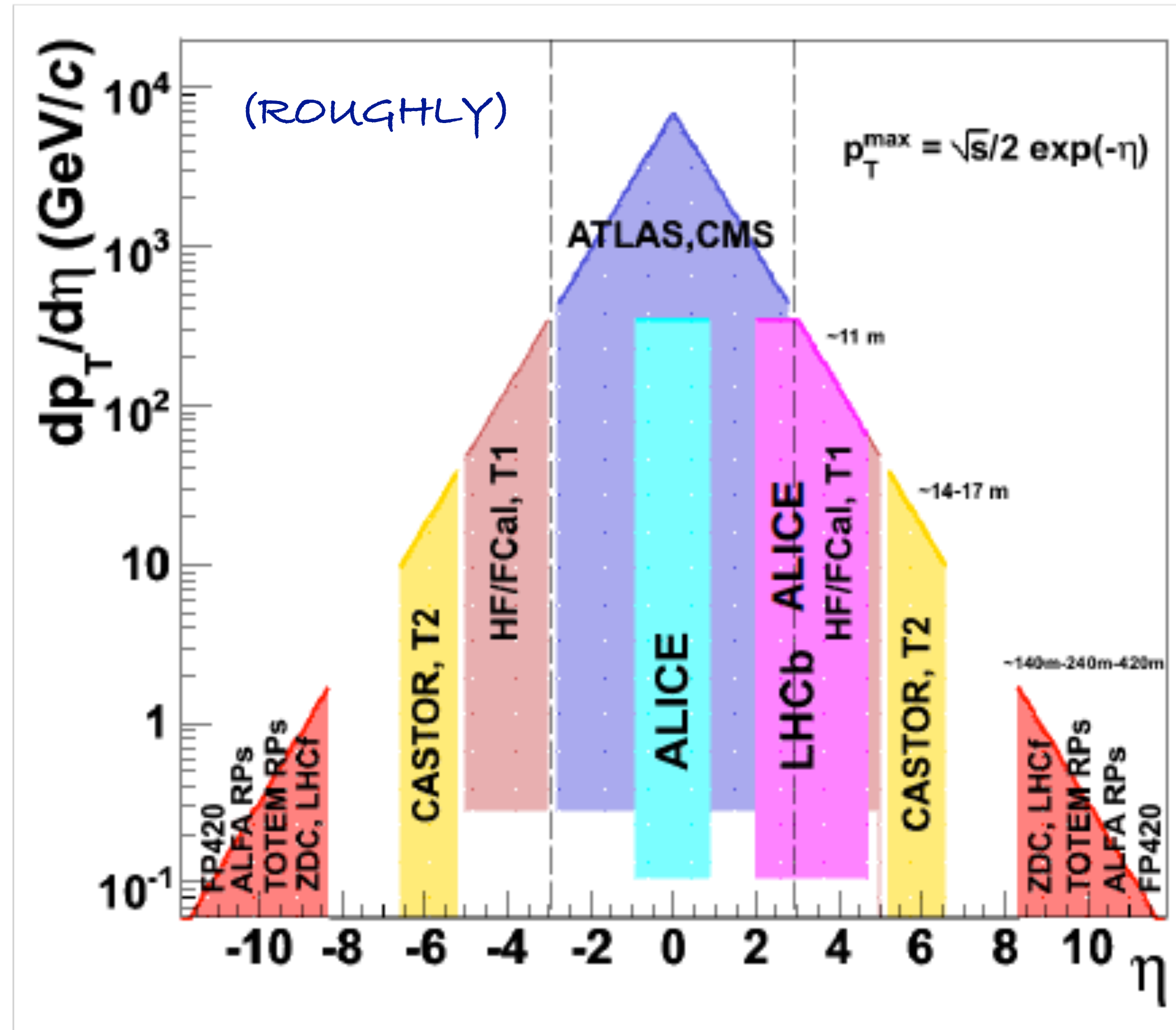
2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020

Run 1

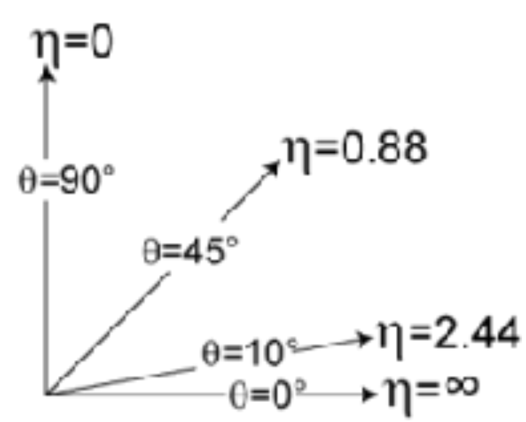
Run 2

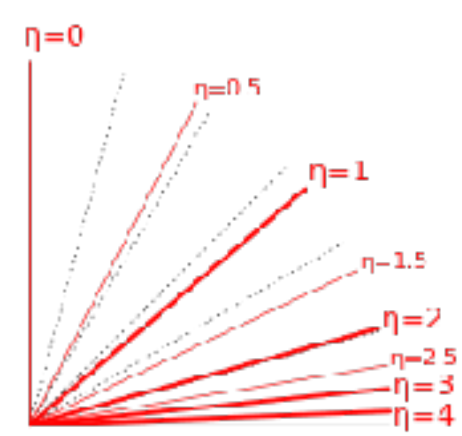
Detector Coverage



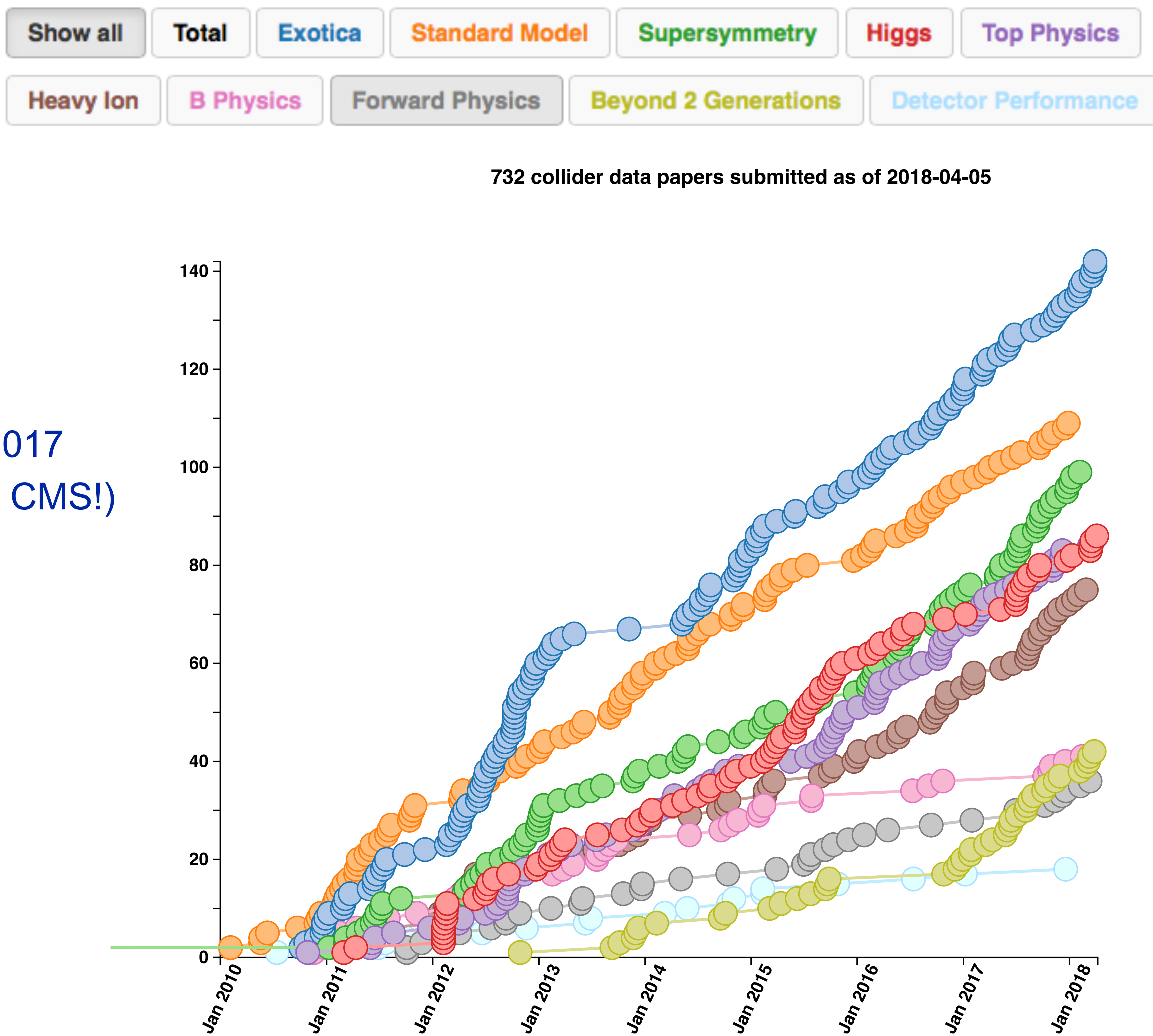


$$\eta = -\ln\left[\tan\left(\frac{\theta}{2}\right)\right]$$

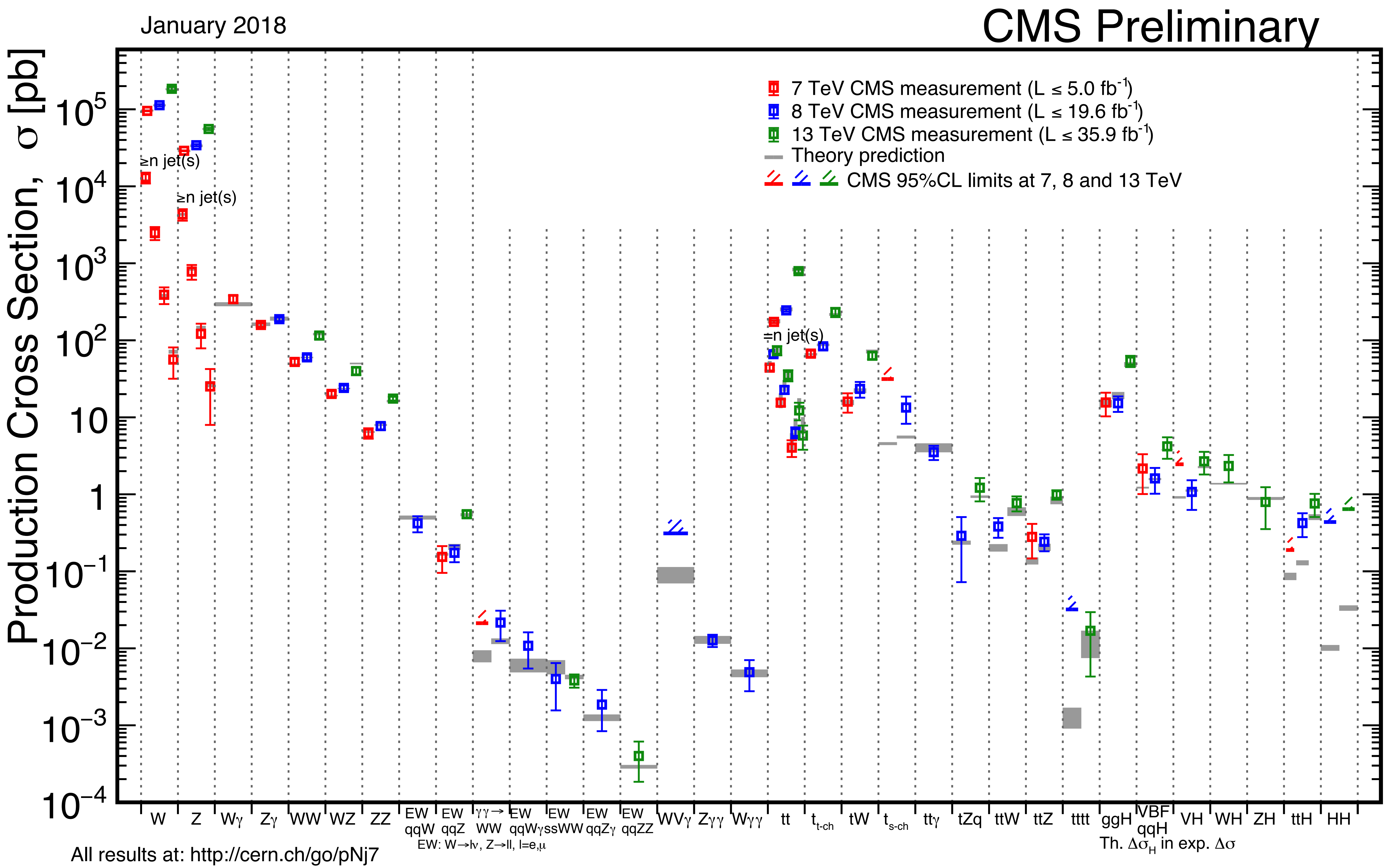


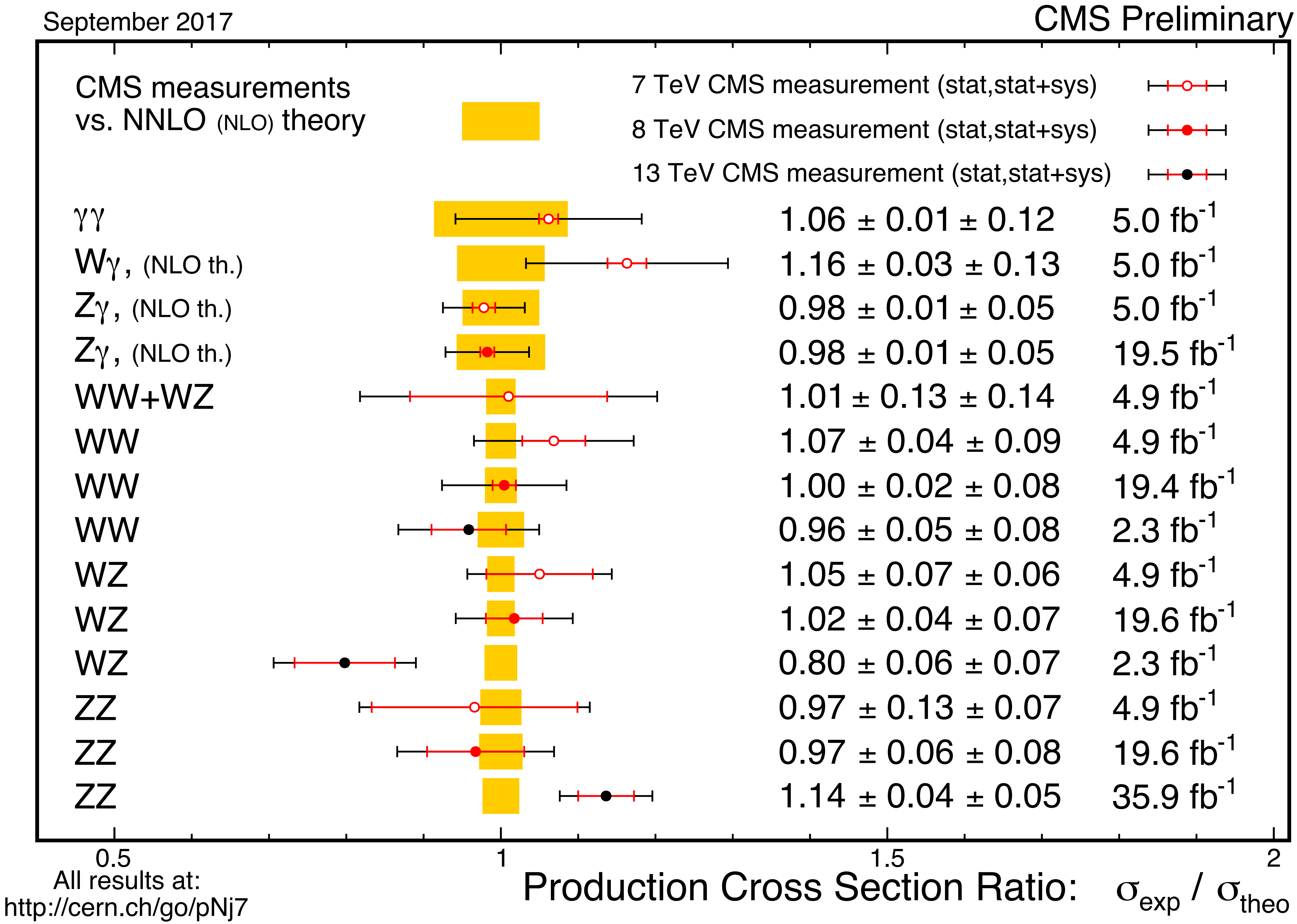


CMS publications versus time

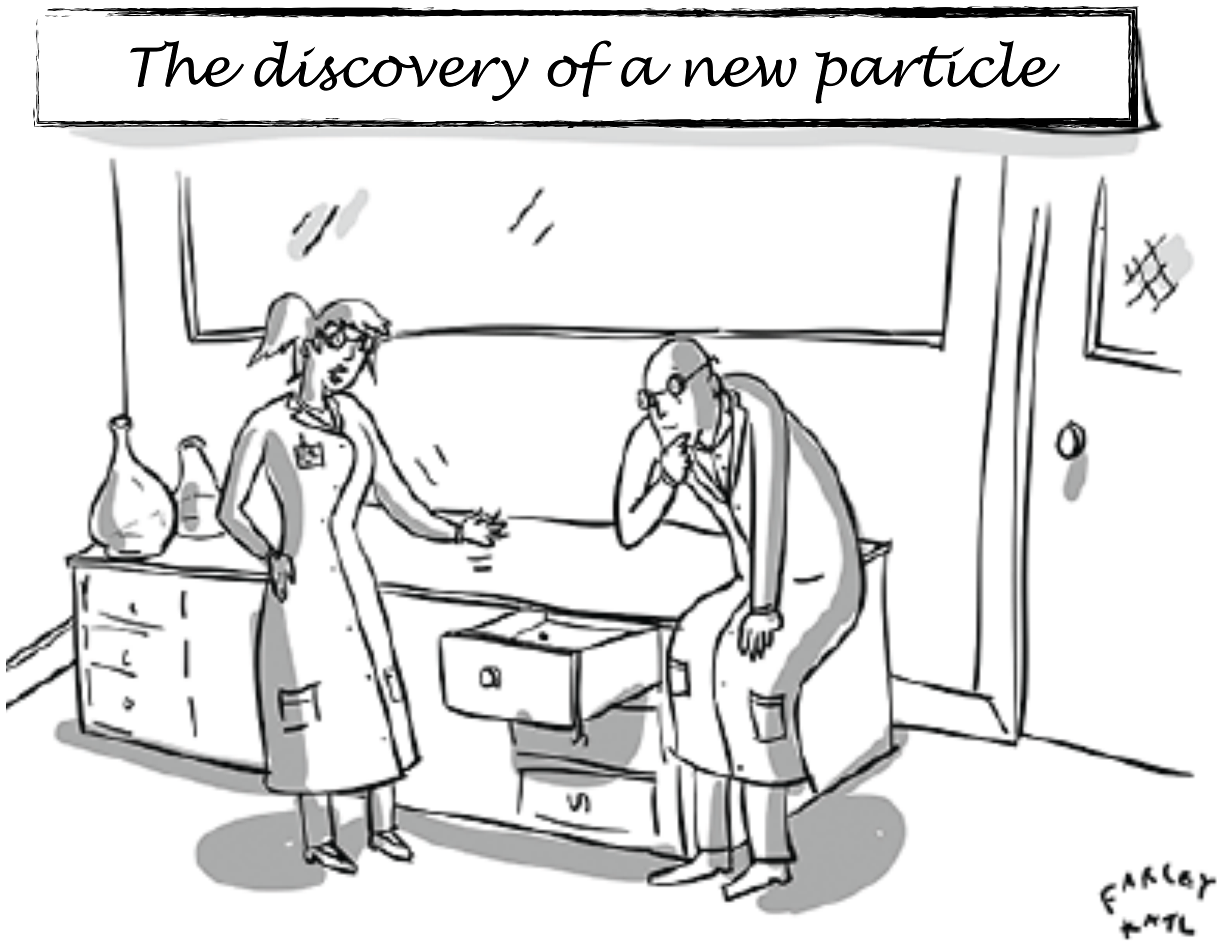


132 papers in 2017
(record year for CMS!)


January 2018
CMS Preliminary
Production Cross Section, σ [pb]
7 TeV CMS measurement (L ≤ 5.0 fb-1)
8 TeV CMS measurement (L ≤ 19.6 fb-1)
13 TeV CMS measurement (L ≤ 35.9 fb-1)
Theory prediction
CMS 95%CL limits at 7, 8 and 13 TeV
≥n jet(s)
≥n jet(s)
=n jet(s)
W Z Wγ Zγ WW WZ ZZ EW qqW EW qqZ γγ→WW EW qqWγ EW ssWW EW qqZγ EW qqZZ WVγ Zγγ Wγγ tt t-ch tW ts-ch ttγ tZq ttW ttZ tttt ggH VBF qqH VH WH ZH ttH HH
EW: W→lν, Z→ll, l=e,μ
Th. ΔσH in exp. Δσ
All results at: http://cern.ch/go/pNj7


September 2017
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
1.14 ± 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

How do we "find" rare physics in hadron colliders?



...funny how it is always in the last place we look for it...

Needle in a haystack problem!

p-p collisions are messy!

QCD background

Unprecedented pile up

Higgs boson (?)

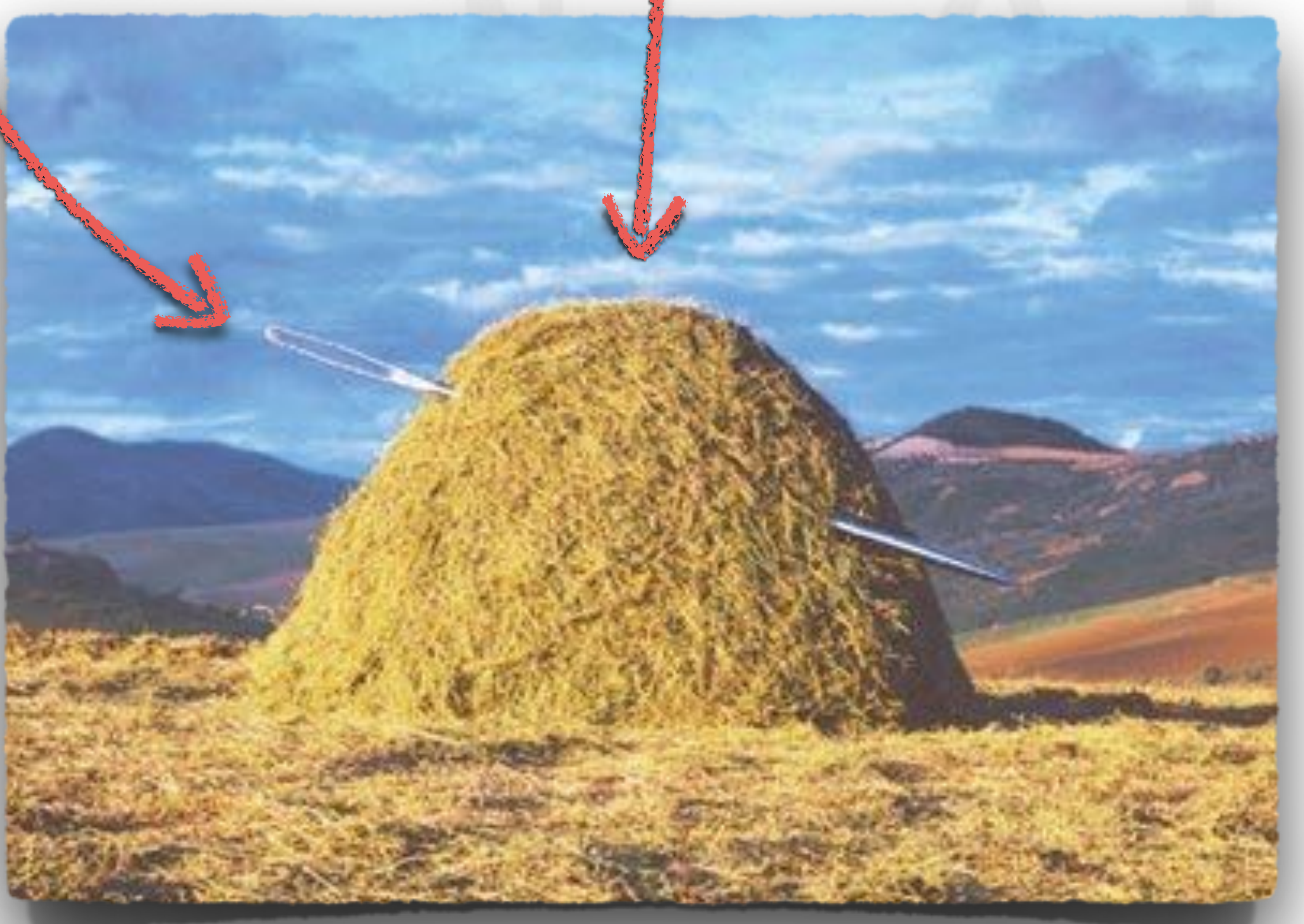
SUSY decay (?)

heavy resonance (?)

monojet (?)

4th generation (?)

...

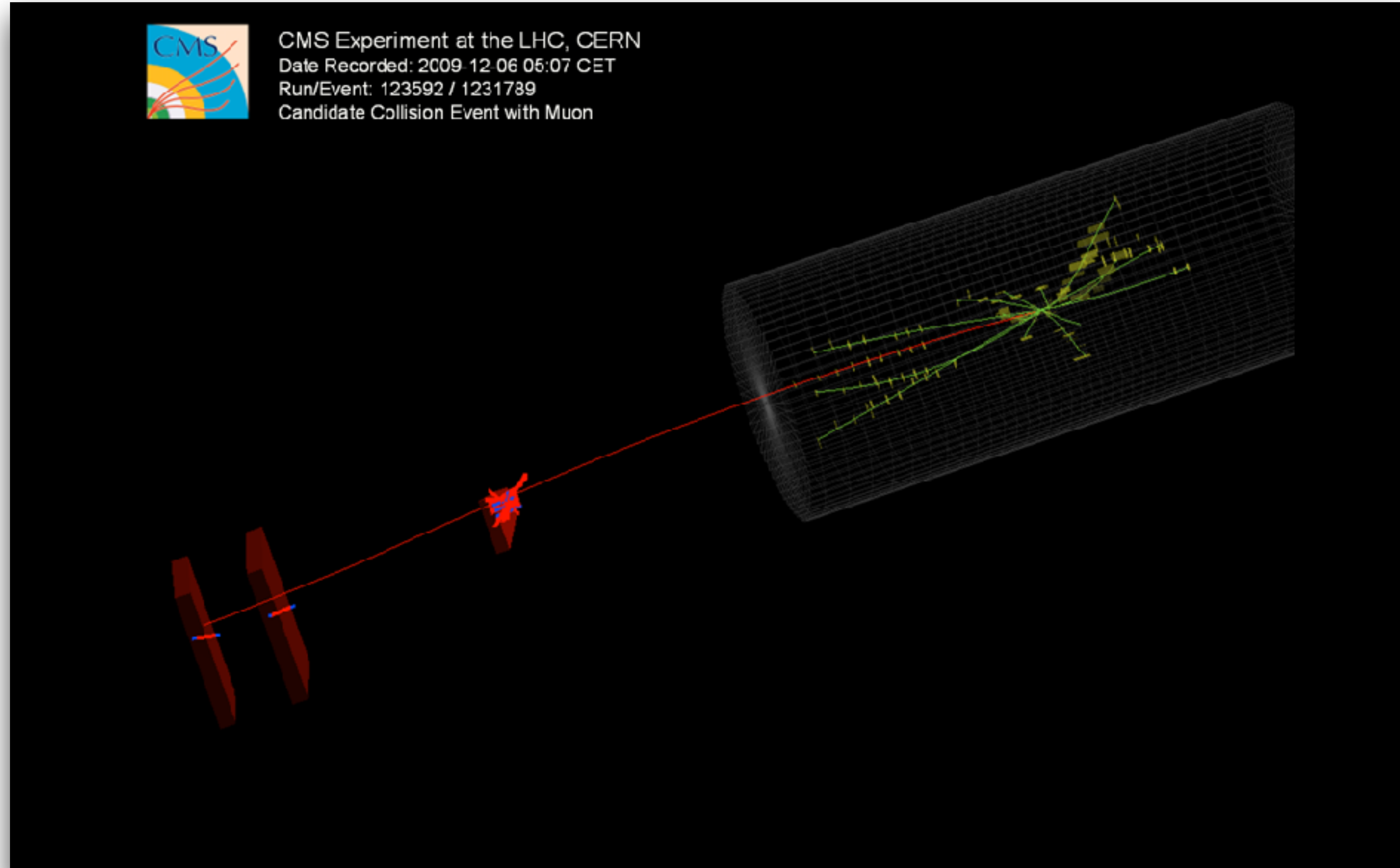


Understanding and modeling the QCD interactions has a direct impact on the potential for precision measurements and discovery.

- systematic uncertainties in physics calibration due to the non-perturbative QCD effects (e.g. the underlying event)
- model uncertainties in soft-QCD are propagated to the systematic uncertainties in many measurements (e.g. top-quark mass)
- largest systematics for Higgs cross-section is from $\sigma(ggF)$: 7% due to QCD scales and 7% due to knowledge of PDFs
- W/Z+jet is often one of the largest background to top-quark, SUSY, Higgs and exotic searches
- pile up

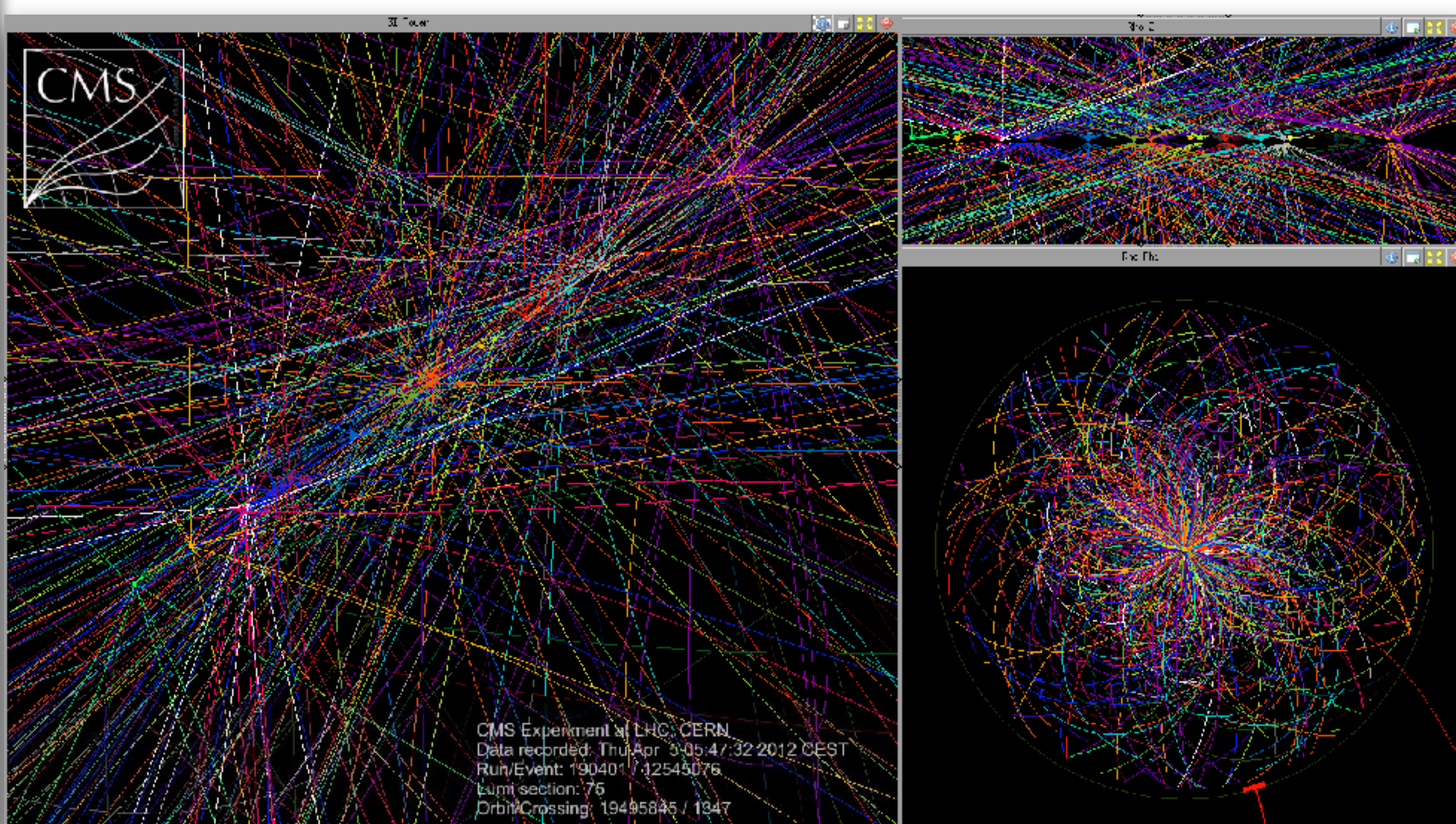
2009

Single vertex reconstructed!

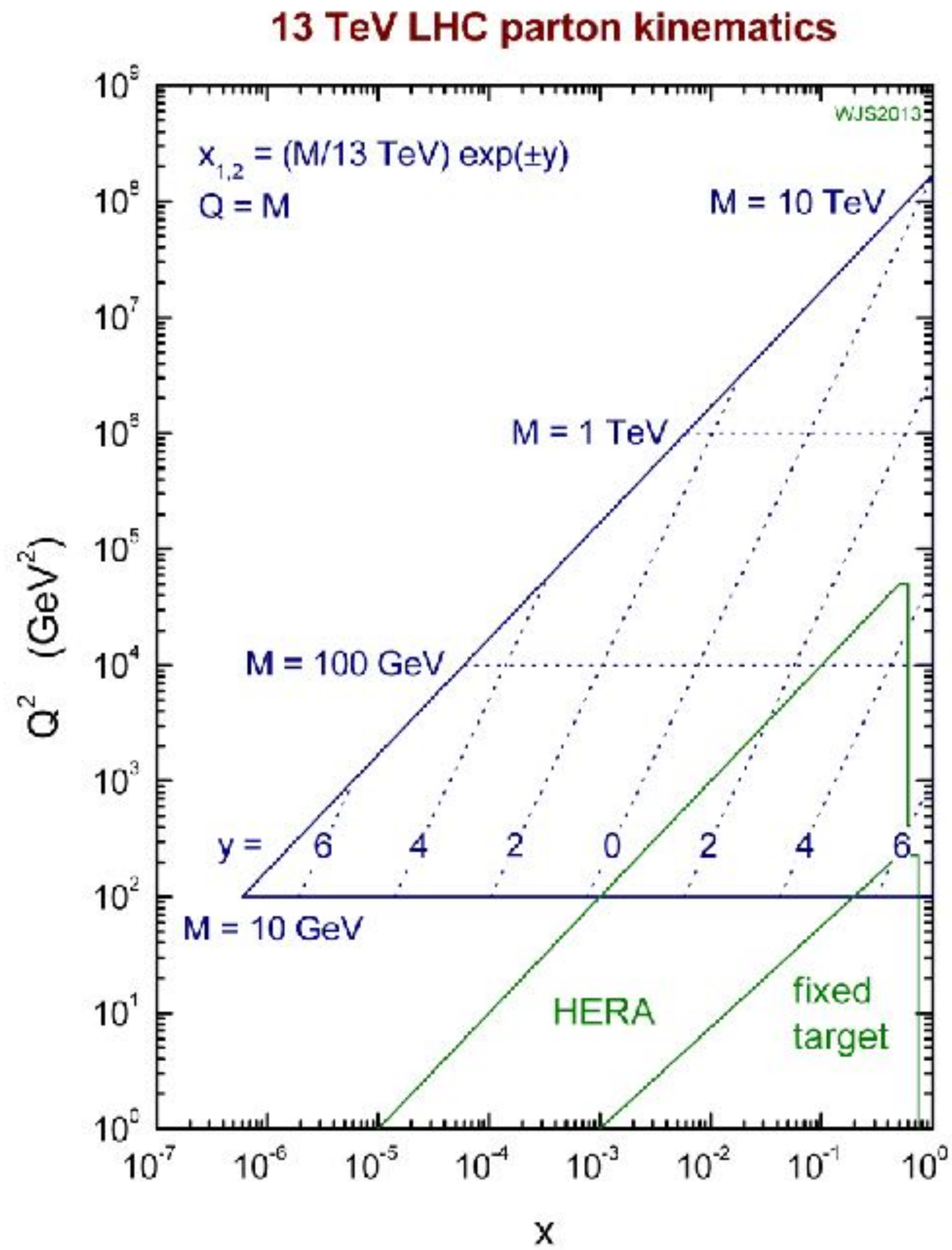


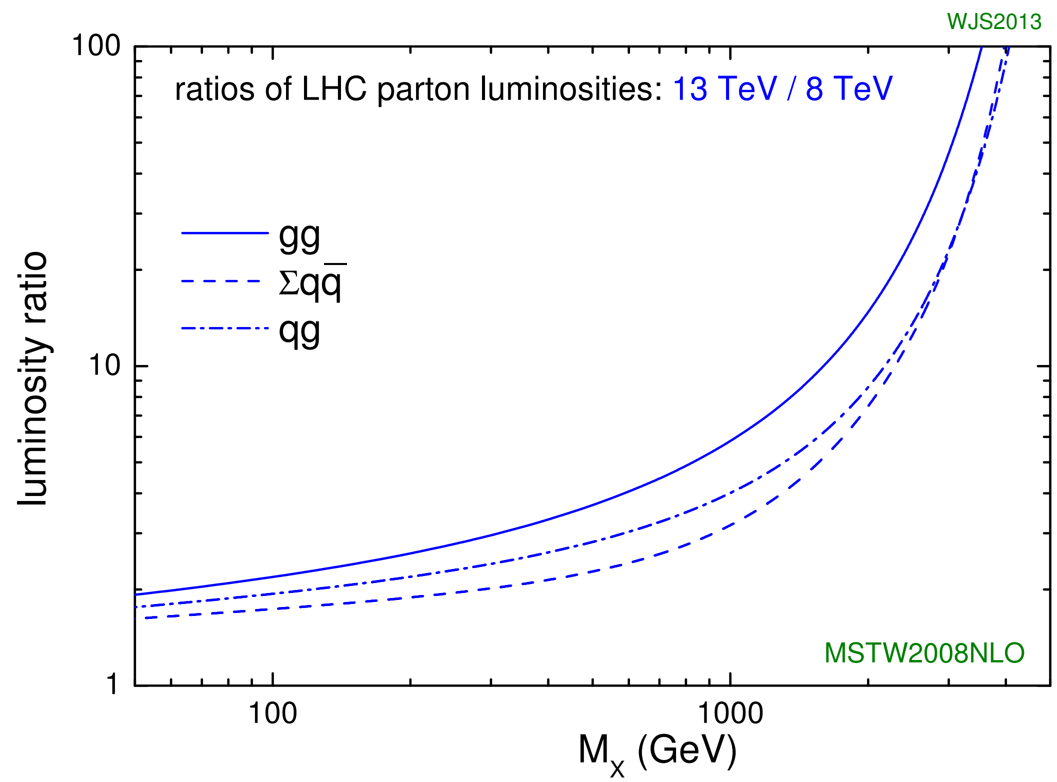
2012

29 pile up vertices!



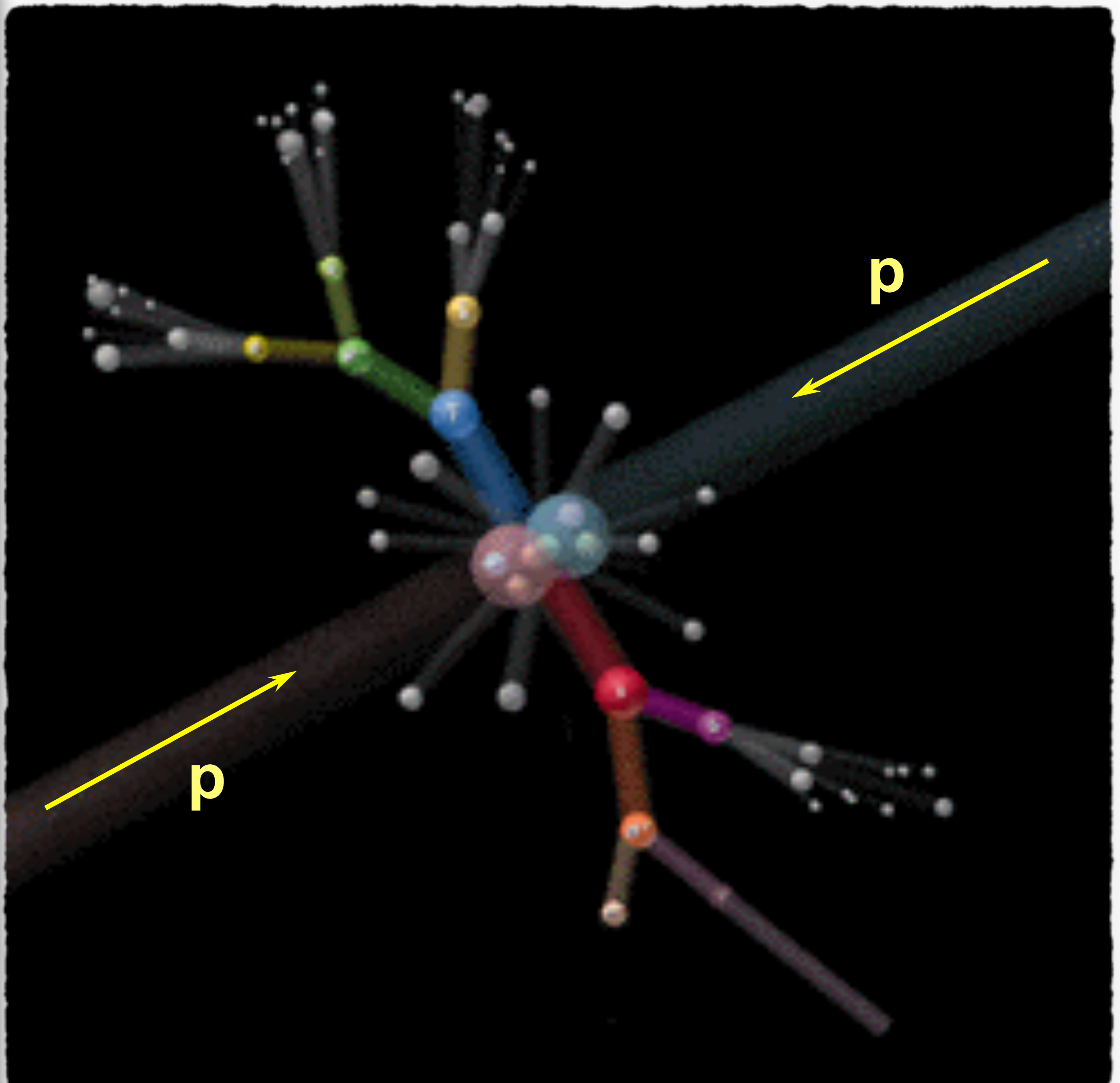
Parton kinematics at the LHC





News on QCD and Electroweak measurements

QCD at the LHC

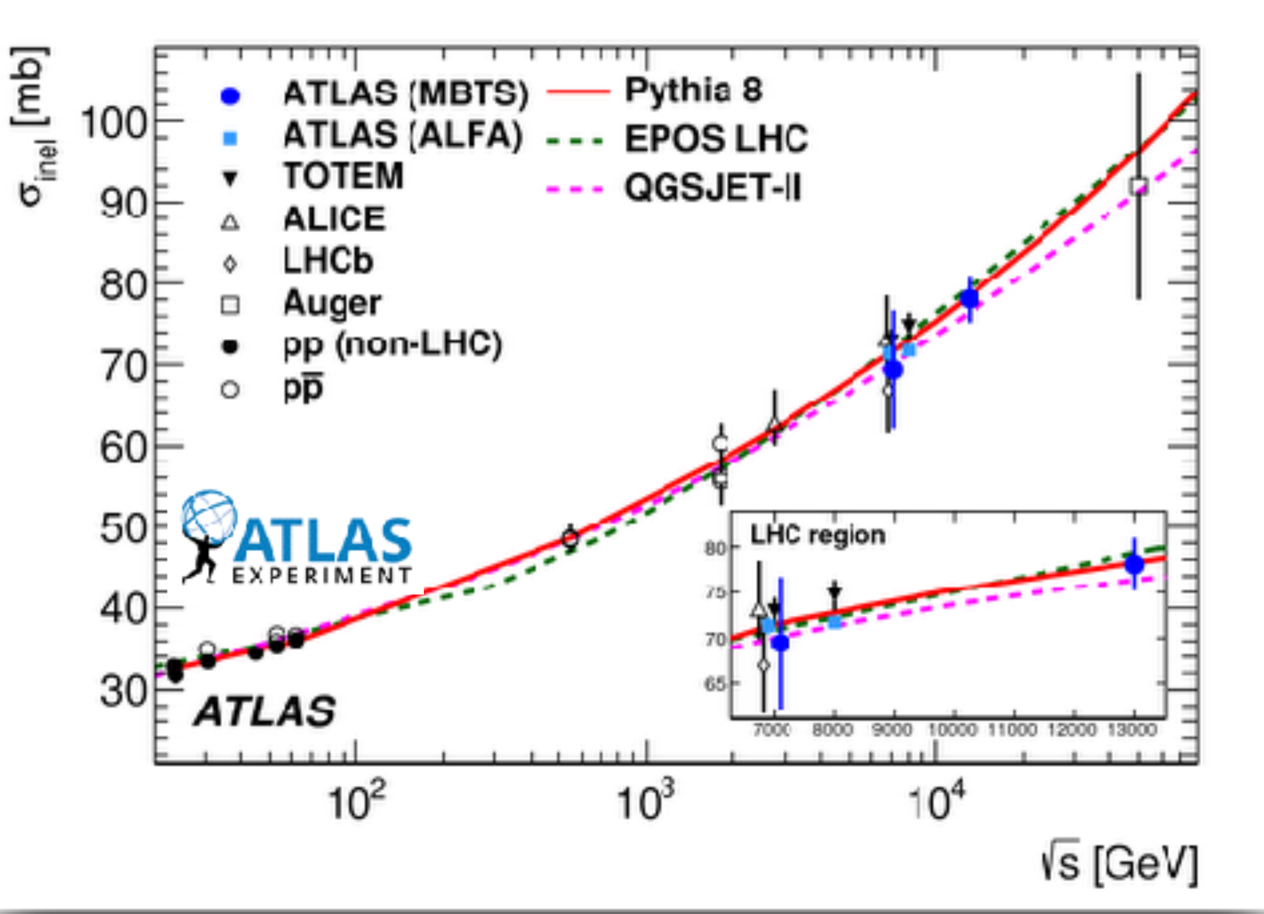


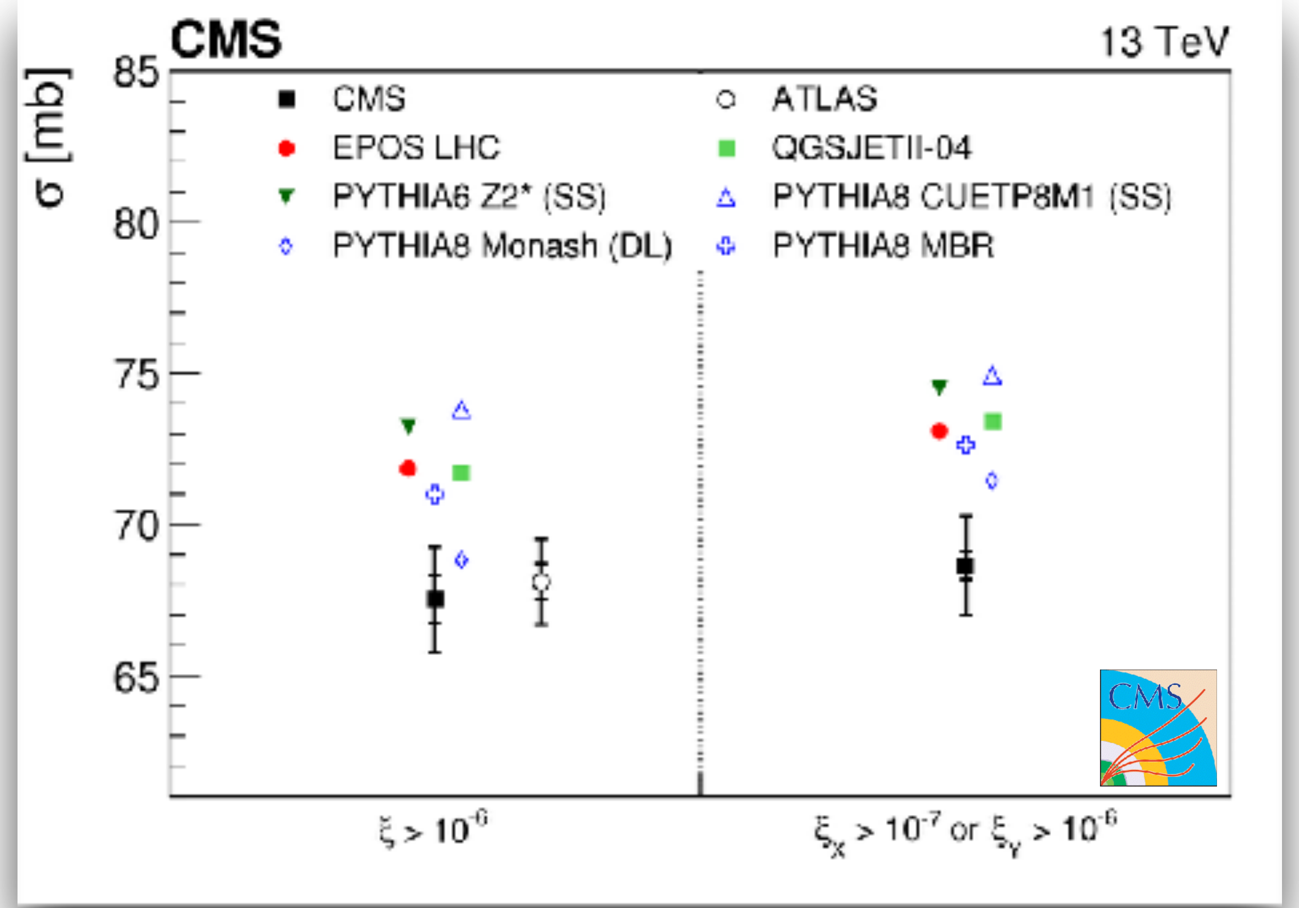
- Essentially all physics at high-energy hadron colliders are connected to the interactions of quarks and gluons (small & large transferred momentum).
  - Hard processes (high-p_T): well described by perturbative QCD
  - Soft interactions (low-p_T): require non-perturbative phenomenological models

Soft Interactions: Problems with strong coupling constant, $\alpha_s(Q^2)$, saturation effects,...

On average, inelastic hadron-hadron collisions have low transverse energy, low multiplicity.

Inelastic pp cross-section





The inelastic proton-proton cross section versus $\sqrt{s}$.

Inelastic interactions are selected using rings of plastic scintillators (MBTS) in the forward region ($2.07 < |\eta| < 3.86$)

A cross section of 68.1 ± 1.4 mb is measured in the fiducial region $\xi = M^2_X/s > 10^{-6}$

When extrapolated to the full phase space, a cross section of 78.1 ± 2.9 mb is measured.

Phys. Rev. Lett. 117 (2016) 182002

Proton-proton inelastic cross section at $\sqrt{s}$=13 TeV in two phase space regions, where $\xi = M^2/s$, compared to different models and to the ATLAS result.

The analysis is based on events with energy deposits in the forward calorimeters, which cover η of $-6.6 < \eta < -3.0$ and $+3.0 < \eta < +5.2$ (HF and CASTOR).

$\sigma(\xi > 10^{-6})$ = 67.5 ± 0.8 (syst) ± 1.6 (lumi) mb

$\sigma(\xi_X > 10^{-7}$ or $\xi_Y > 10^{-6})$ = 68.6 ± 0.5 (syst) ± 1.6 (lumi) mb

arXiv:1802.02613v1

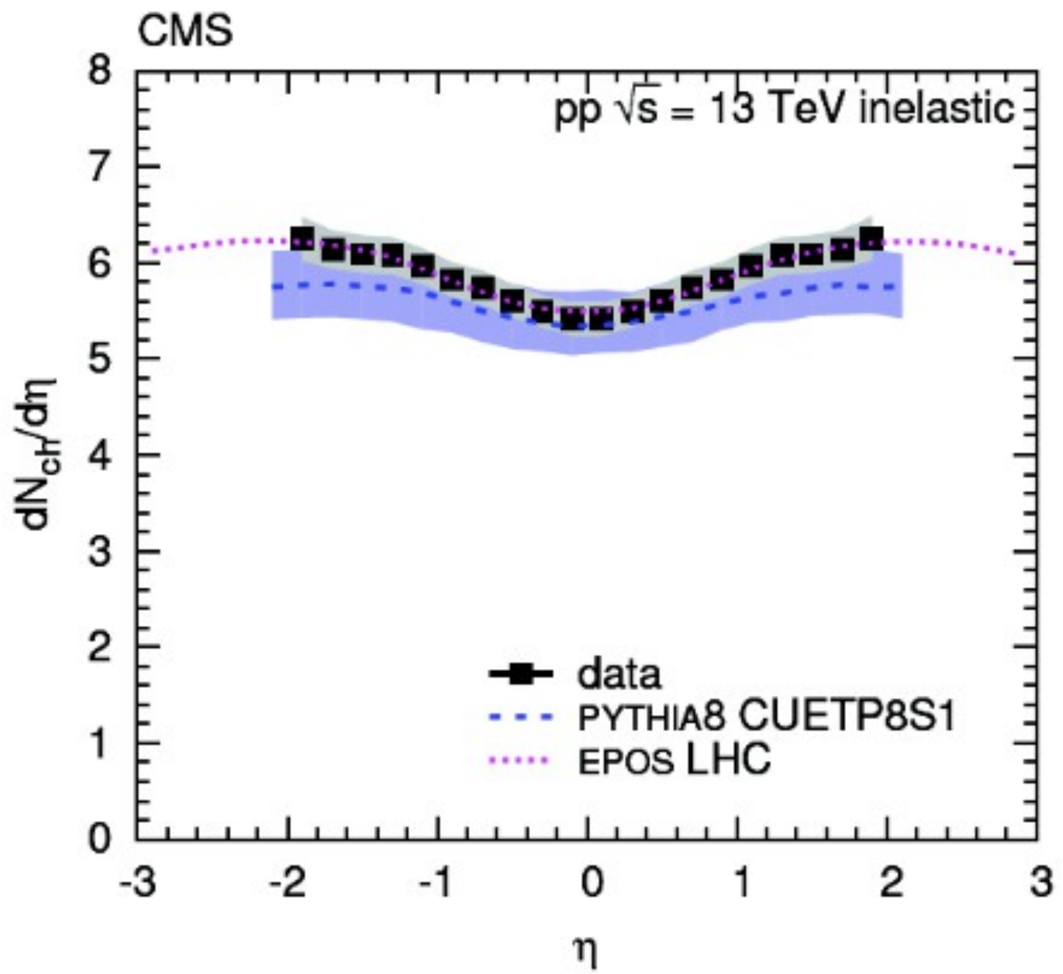
Submitted to J. High Energy Phys. (Feb 2018)

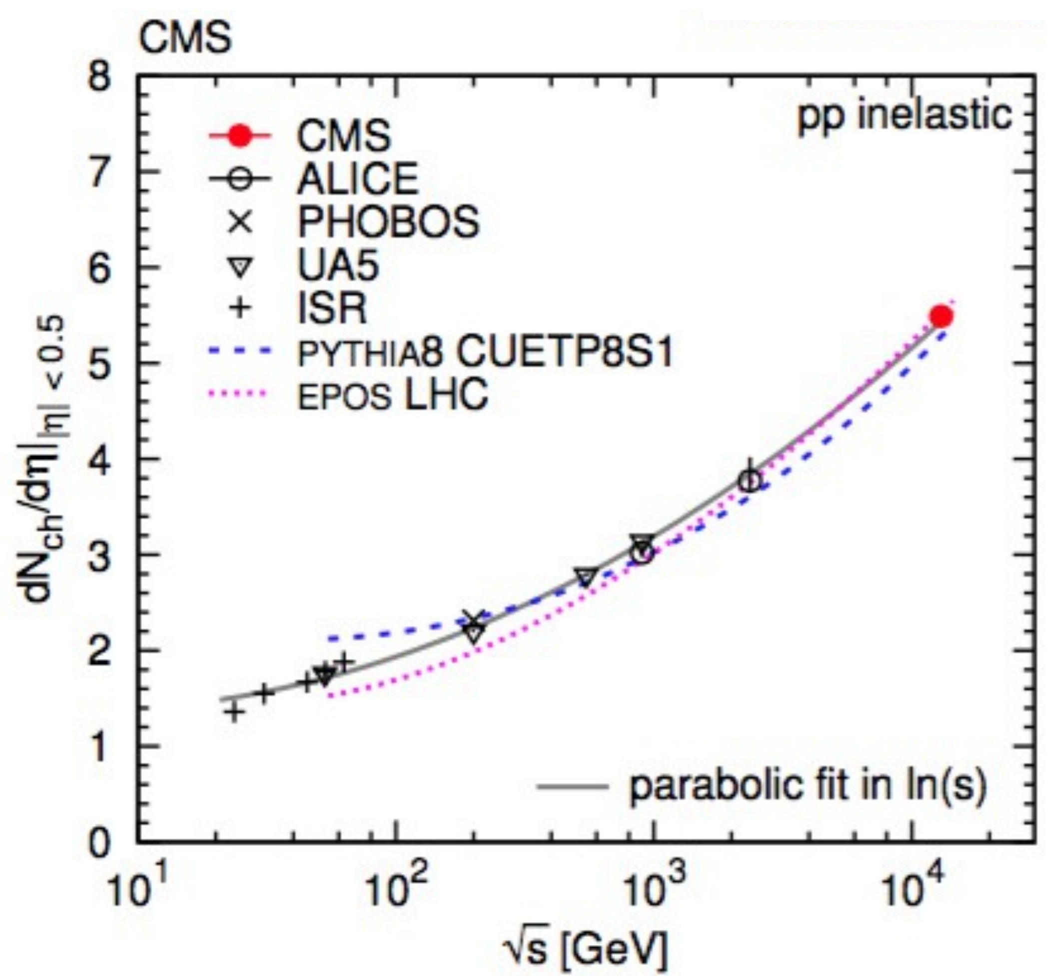
Charged Particle Density

Datasets:

- data taken June 7, 2015 -
- number of collisions per bunch crossing: ~0.05
- CMS tracker and pixel detectors ON
  CMS magnet off, B=0 (straight tracks)

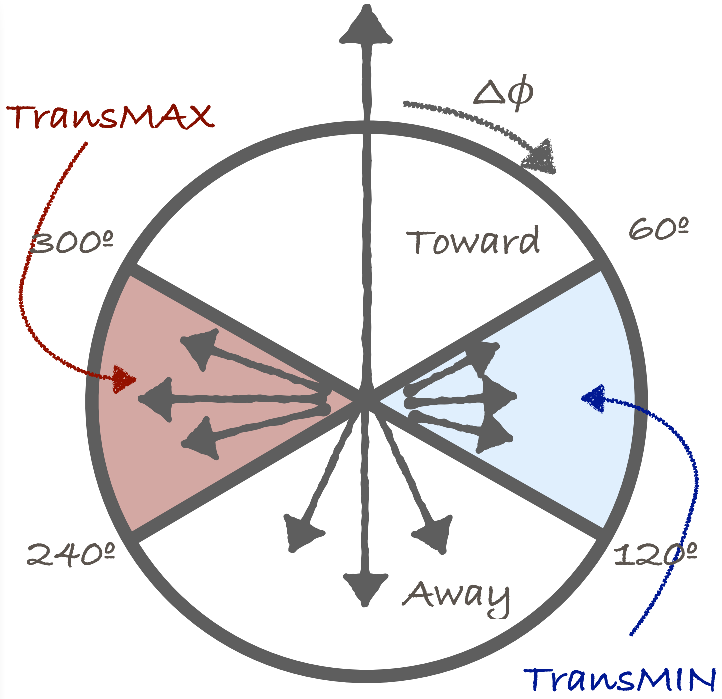
Particle multiplicity at different c.m. energies:
Important input to MC generator tuning!



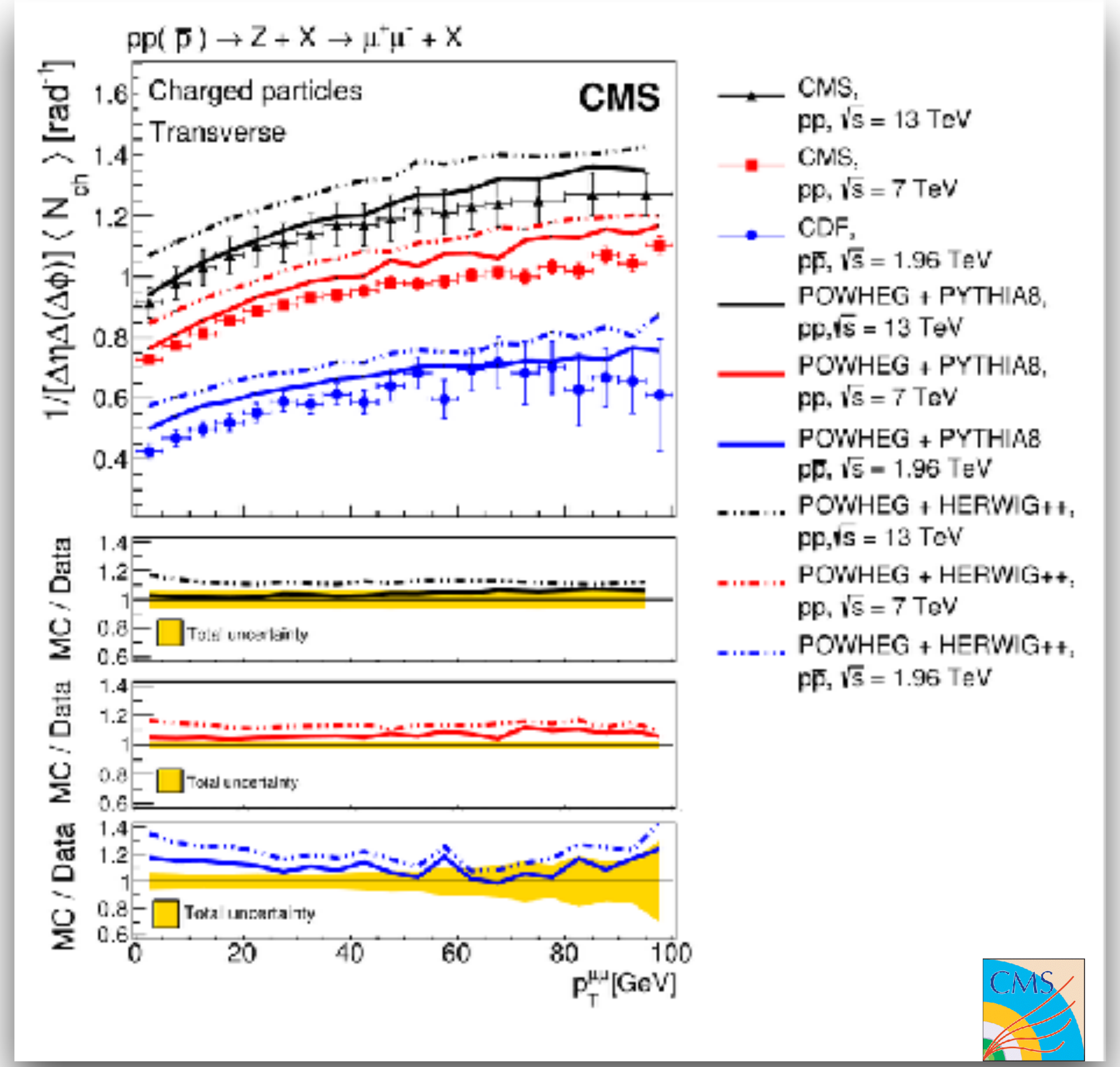


Phys. Lett. B 751 (2015) 143-165

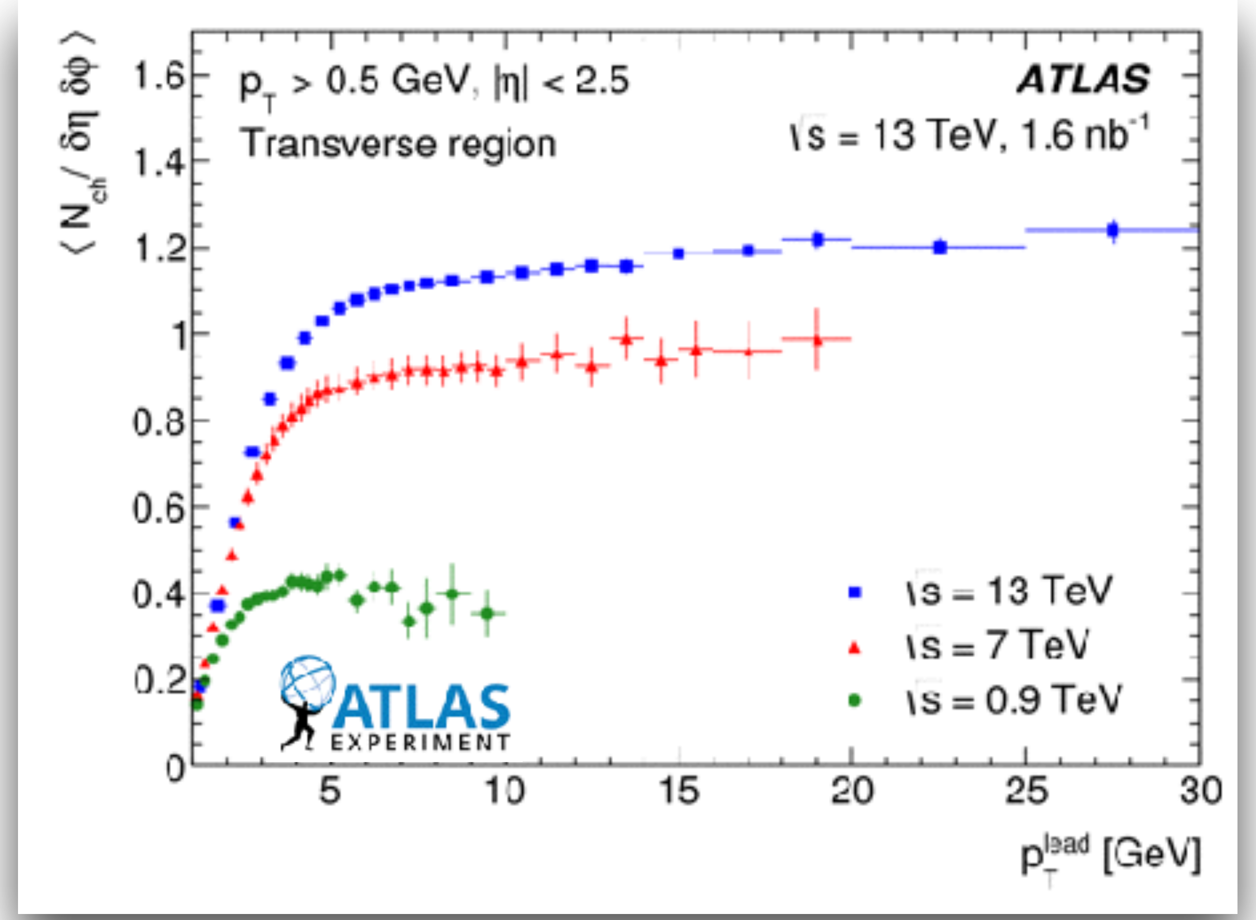
The underlying event



Measurement of the underlying event activity in pp collisions at 13 TeV, using inclusive Z boson production events (CMS).



Measurement of the underlying event activity in pp collisions at 13 TeV associated to the leading charged particle (ATLAS).



arXiv:1711.04299

Submitted to J. High Energy Phys. (Nov 2017)

JHEP03(2017)157

The strong coupling constant: $\alpha_S(Q)$

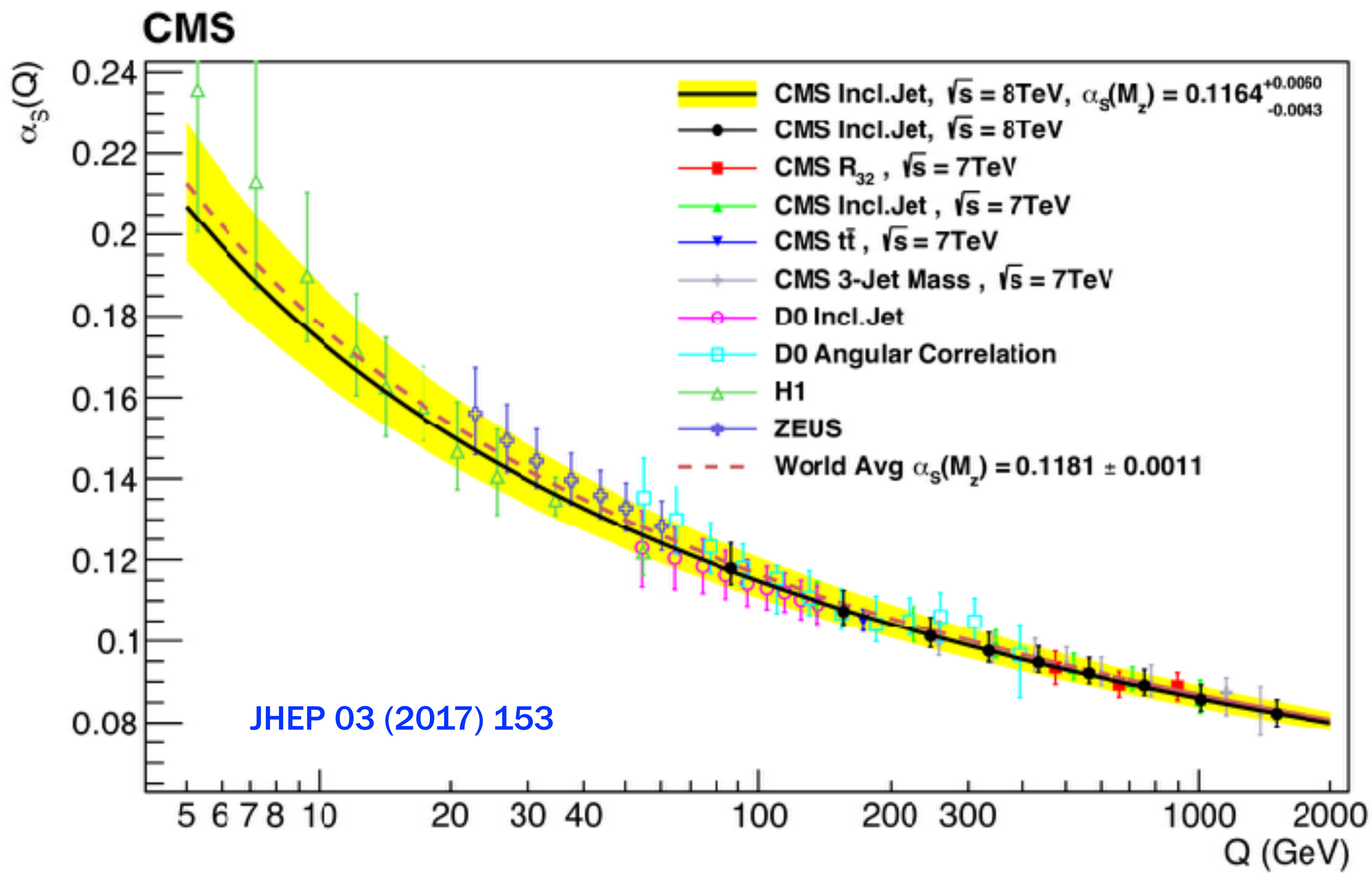
Least precisely known of all couplings

Impacts **"all"** LHC cross-sections.

Key for precise SM studies.

BSM physics (e.g. new coloured sectors).

Uncertainties: ±4% σ(ggH), ±7% H→cc, ±4% H→gg



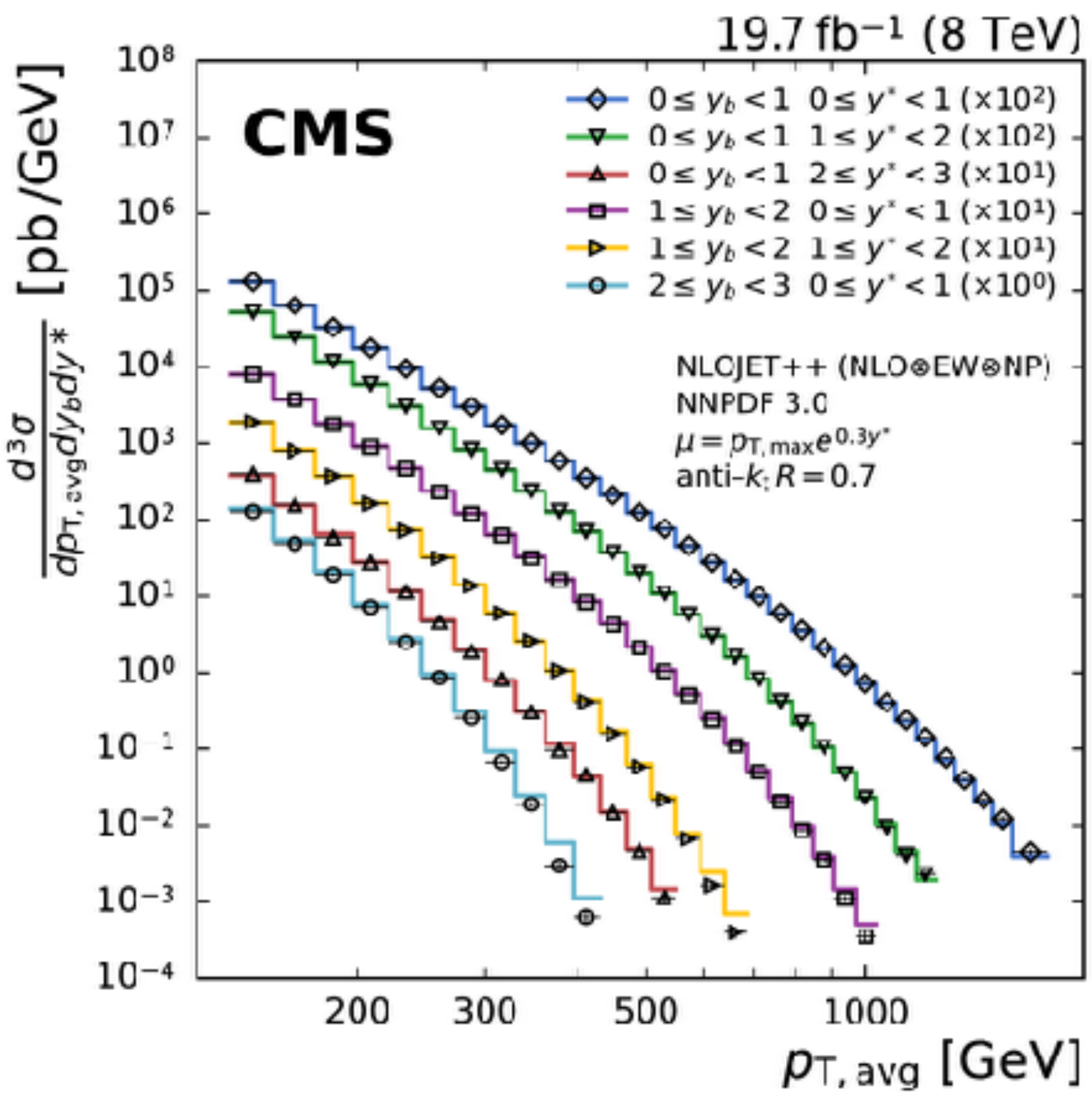
JHEP 03 (2017) 156

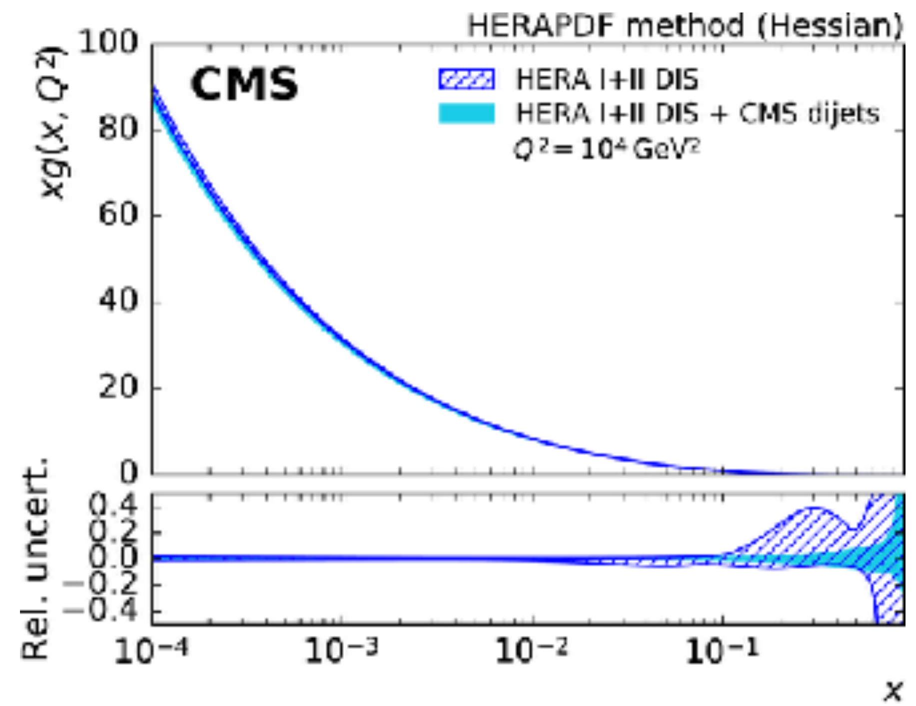
CMS PAS-SMP-16-008

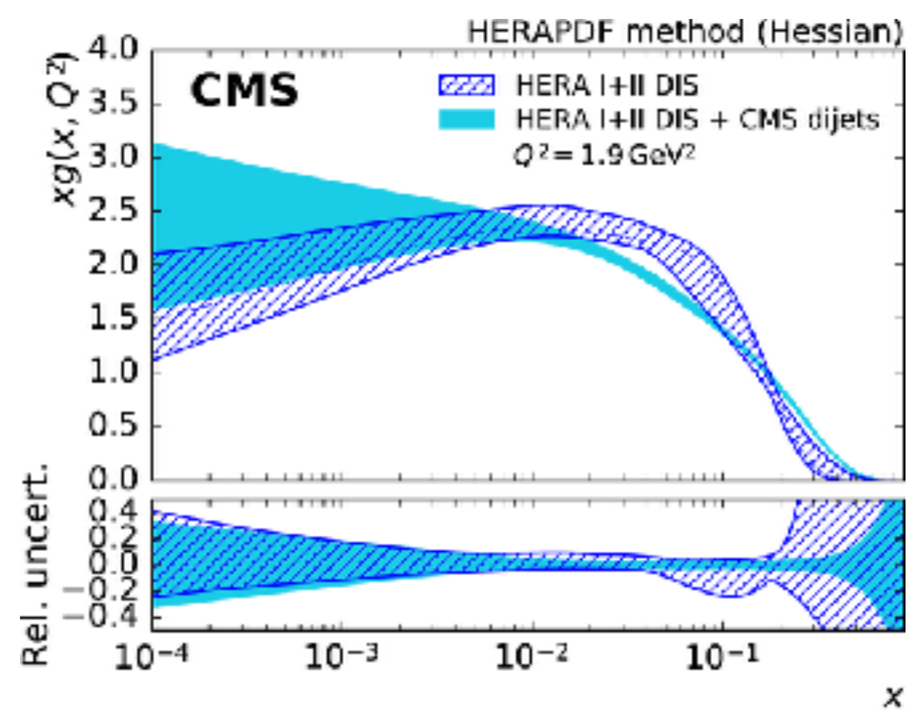
CMS PAS-SMP-16-011

method	$\alpha_S(m_Z)$	scale unc.	exp. unc.	PDF unc.
Inclusive jet	0.1164	+0.0053 -0.0028	+0.0015 -0.0016	+0.0025 -0.0029
multijet	0.1150	+0.0050 -0.0000	±0.0025	±0.0013
Triple diff. Xsection	0.1199	+0.0031 -0.0020	+0.0015 -0.0015	+0.0004 -0.0006

Triple differential jet cross-section and PDFs







Triple differential dijet cross section

$$\frac{d^3\sigma}{dp_{T,avg}dy^*dy_b} = \frac{1}{\epsilon\mathcal{L}_{int}^{eff}}\frac{N}{\Delta p_{T,avg}\Delta y^*\Delta y_b}$$

EPJC 77 (2017) 746

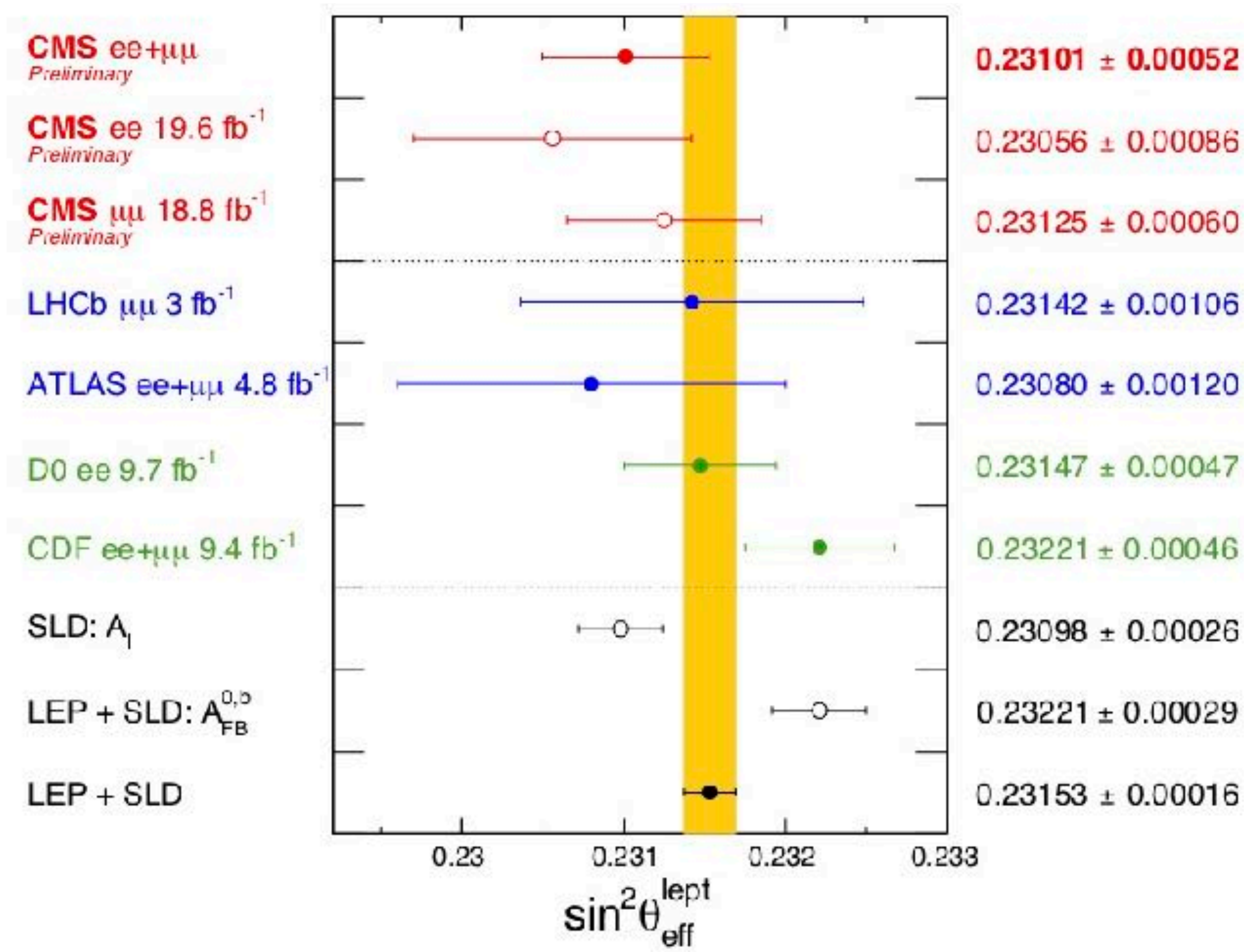
Measurement of the weak mixing angle with the forward-backward asymmetry of Drell-Yan events at 8 TeV

Measurement of the effective weak mixing angle using the forward-backward asymmetry of Drell-Yan (ee and μμ) events in pp collisions at √s = 8 TeV at CMS.

$$A_{FB} = \frac{\sigma_F - \sigma_B}{\sigma_F + \sigma_B},$$

$$\cos\theta^* = \frac{2(p_1^+ p_2^- - p_1^- p_2^+)}{\sqrt{M^2(M^2 + P_T^2)}} \times \frac{P_z}{|P_z|}$$

With new analysis techniques and a larger dataset, the statistical and systematic uncertainties are significantly reduced compared to our previous measurement.



The extracted value of the effective weak mixing angle from the combined ee and μμ data samples is:

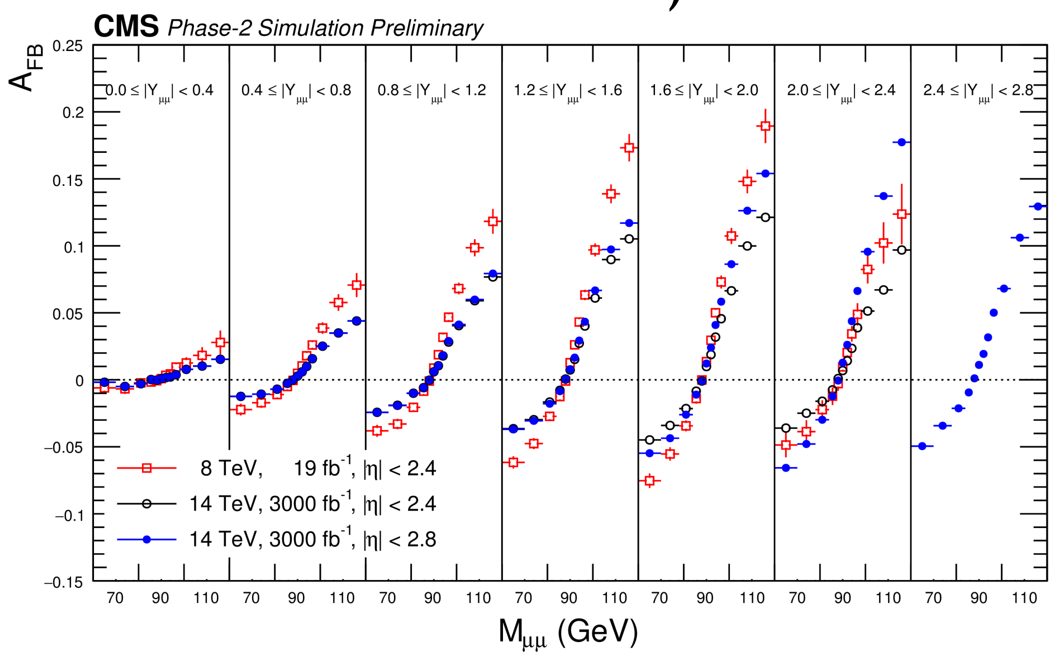
$$\sin^2\theta_{eff}^{lept} = 0.23101 \pm 0.00036(\mathrm{stat}) \pm 0.00018(\mathrm{syst}) \pm 0.00016(\mathrm{theory}) \pm 0.00030(\mathrm{pdf})$$

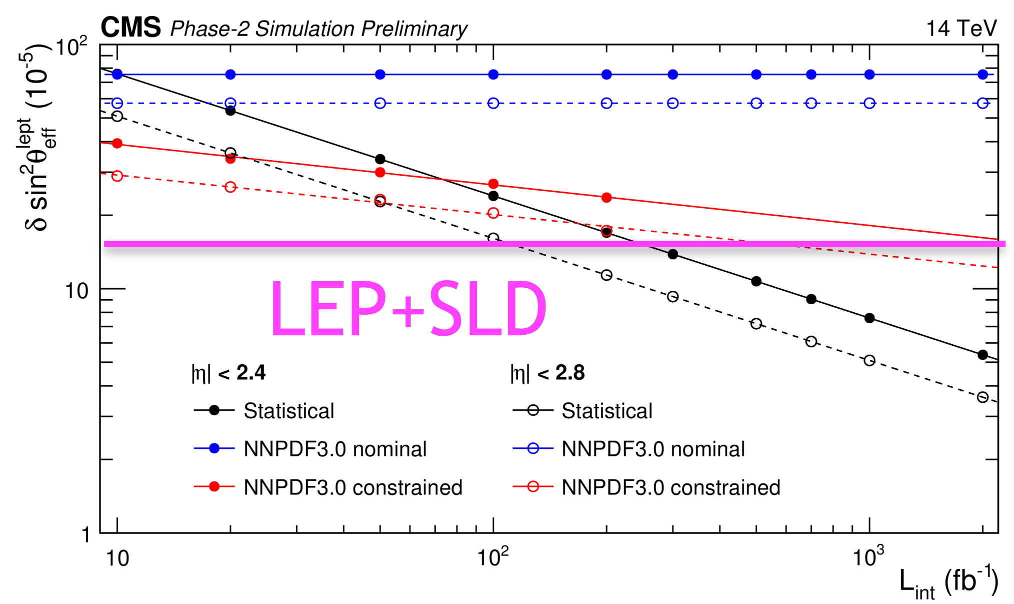
$$\sin^2\theta_{eff}^{lept} = 0.23101 \pm 0.00052.$$

The weak mixing angle with the forward-backward asymmetry of Drell-Yan events: **Future measurement!**

- What can we expect at the high-luminosity LHC **CMS-PAS-FTR-17-001**
  - Negligible statistical uncertainties
  - PDF uncertainties further constrained with profiling
  - Extended lepton acceptance with the upgraded CMS detector

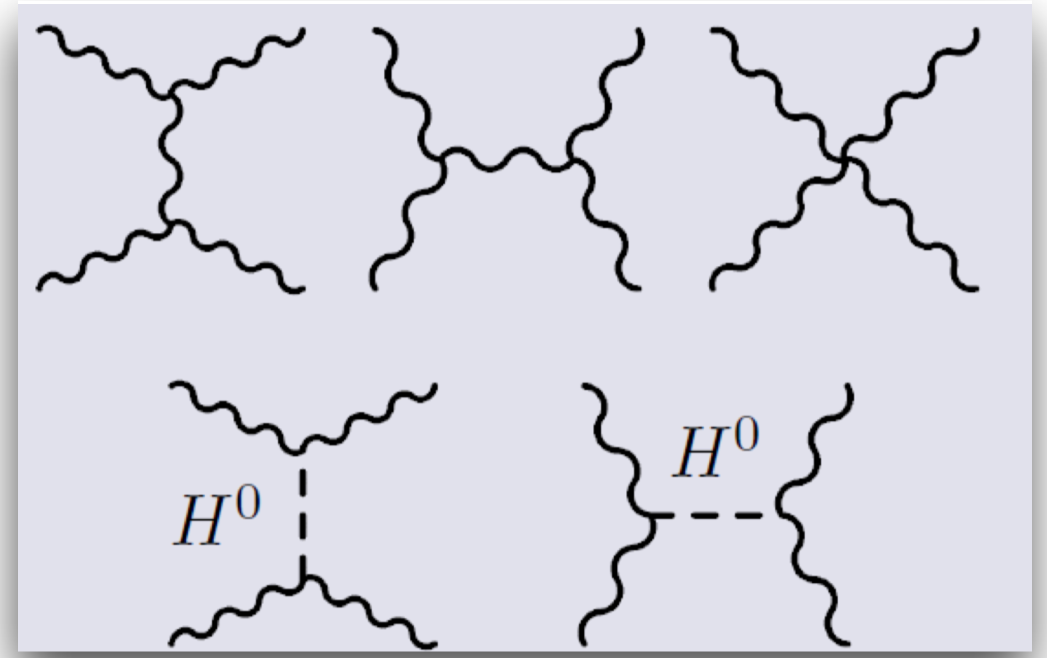
- Smaller A_{FB} at 14 TeV (less valence quark contribution)
- Larger lepton |η| acceptance





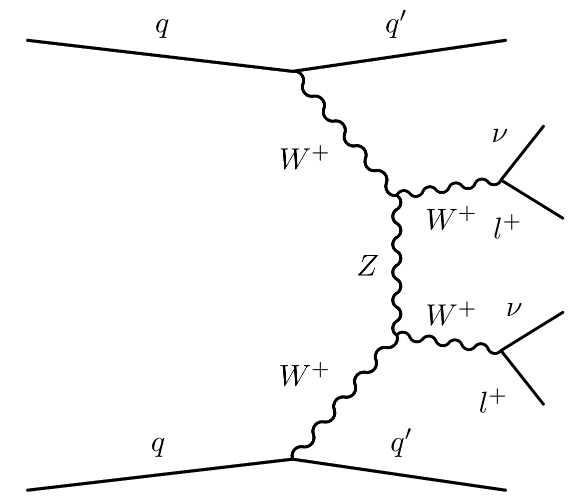
Gauge boson couplings

- Shift from precision observables to first measurements
- Probe the non-Abelian gauge structure of the EW interactions
- Vector boson scattering processes
    - What mechanism ensures the unitarity is respected?
    - Is the 125 GeV Higgs boson the only solution?
    - Characterized by VV and 2 jet final state



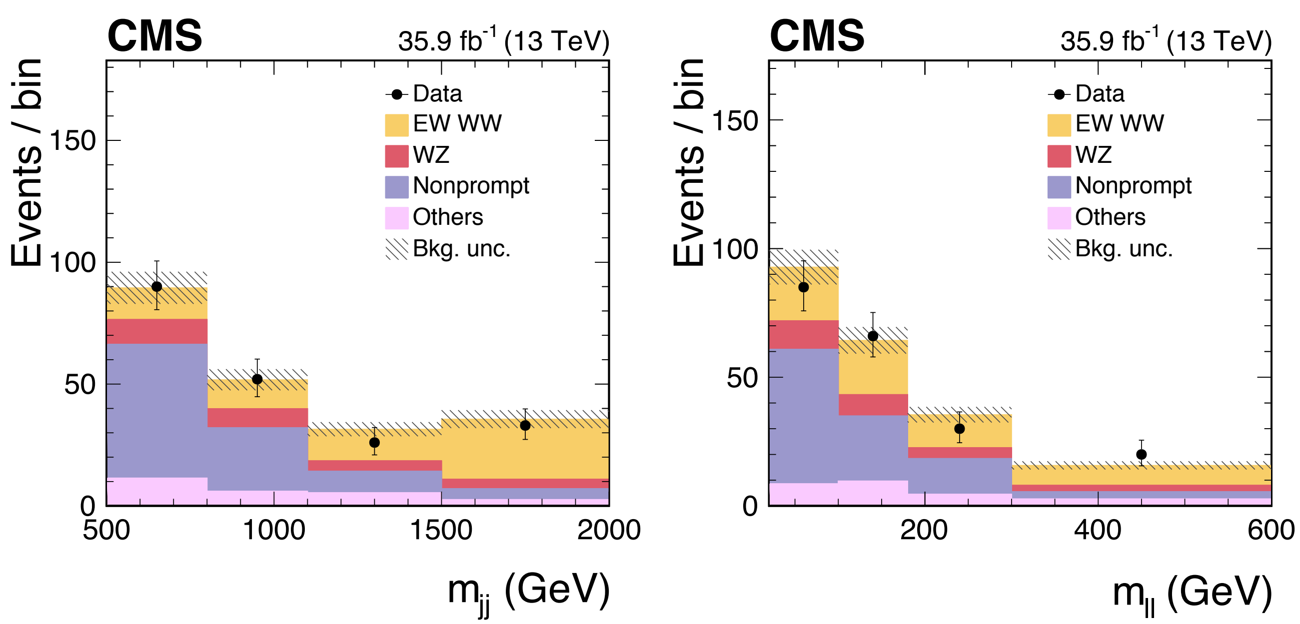
Observation of electroweak production of same-sign W boson pairs

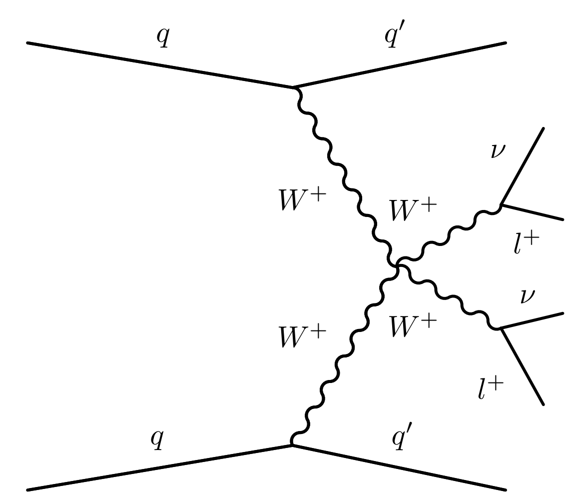
The first observation of electroweak production of same-sign W boson pairs in proton-proton collisions



pp collisions at 13TeV: the data sample corresponds to an integrated luminosity of 35.9 fb^{-1}

2 jet and 2 same-sign lepton final state





Observed (expected) significance is 5.5 (5.7) standard deviations

Observed signal is consistent with SM predictions

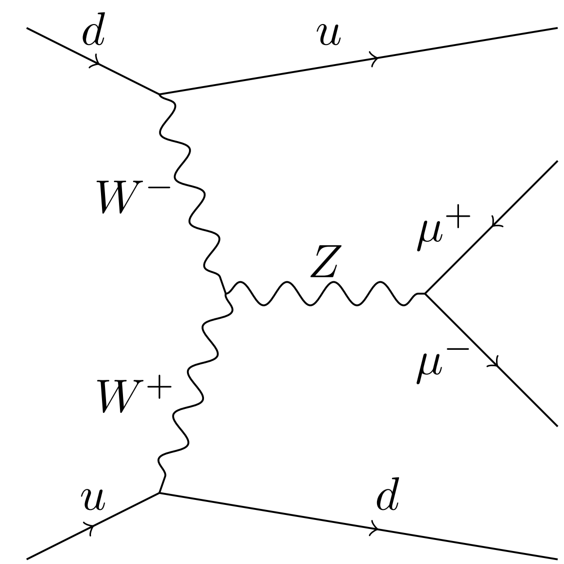
Evidence by ATLAS and CMS in Run 1

Phys. Rev. Lett. 120 (2018) 081801

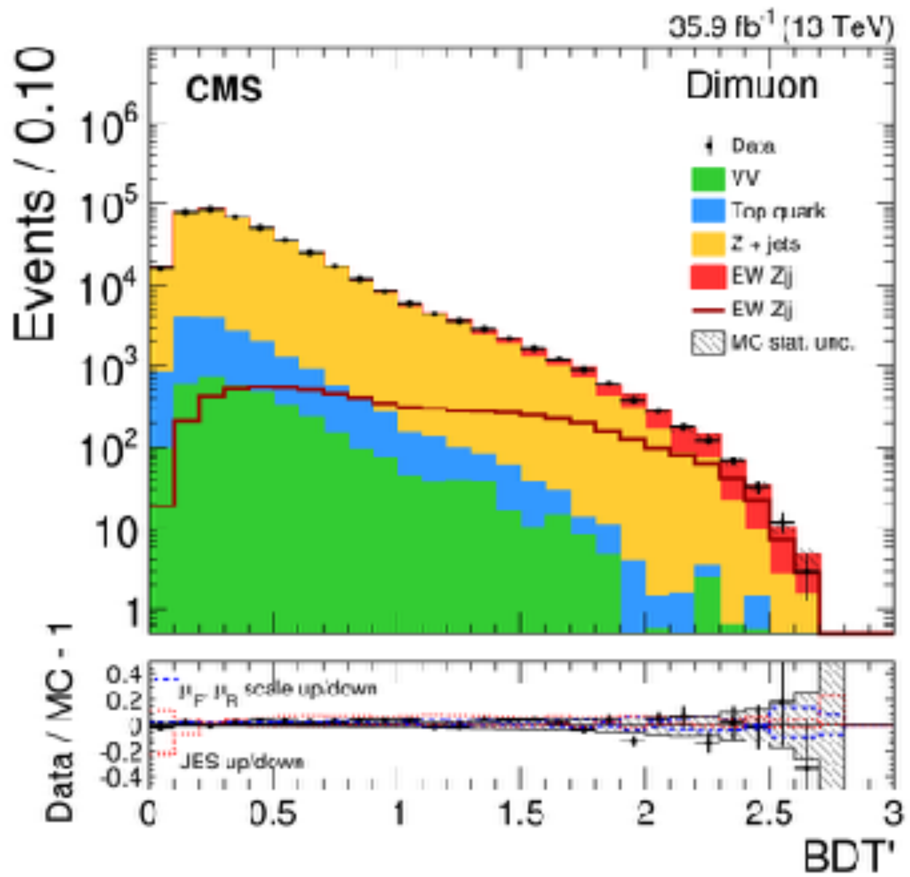
Electroweak Z + 2-jet production

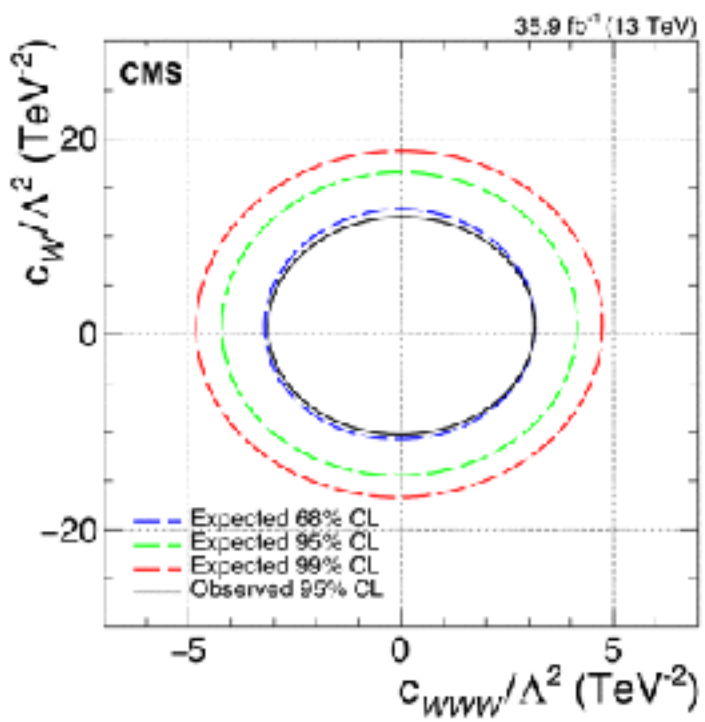
- Pure EW production of dileptons in association with two jets
- Measured cross section is in agreement with the leading order SM predictions

pp collisions at 13TeV: the data sample corresponds to an integrated luminosity of 35.9 fb^{-1}



$$\sigma(\text{EW } \ell\ell\text{jj}) = 552 \pm 19\,(\text{stat}) \pm 55\,(\text{syst})\,\text{fb},$$





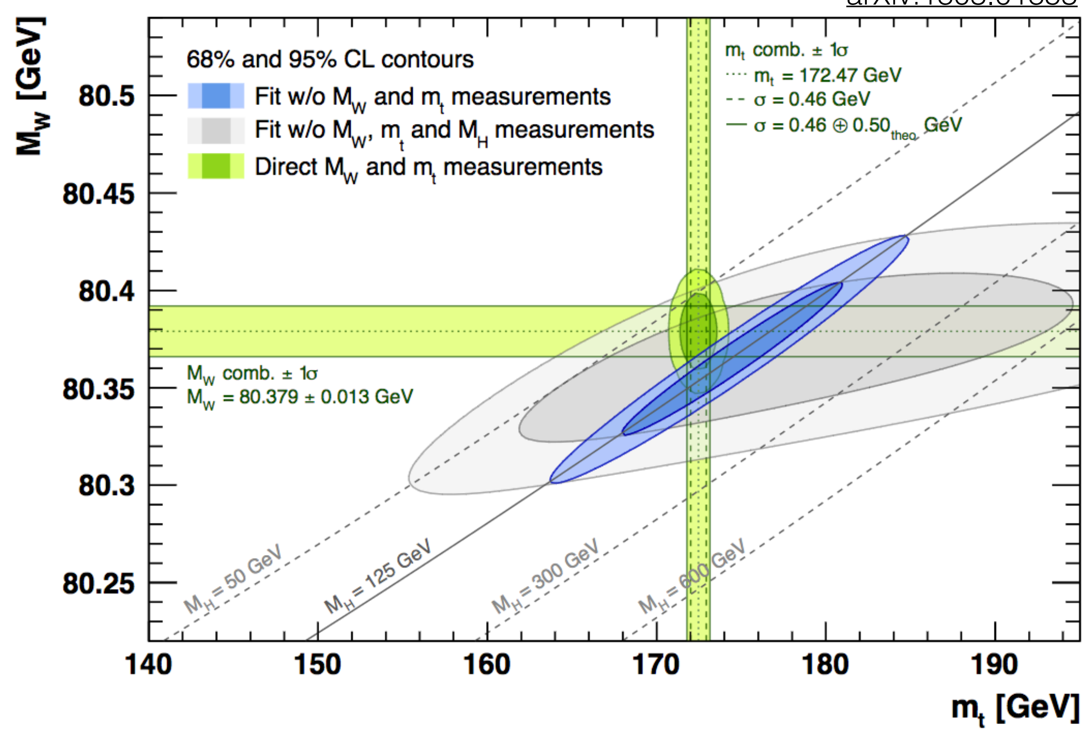
Best limits of anomalous triple gauge couplings!

Top quark measurements

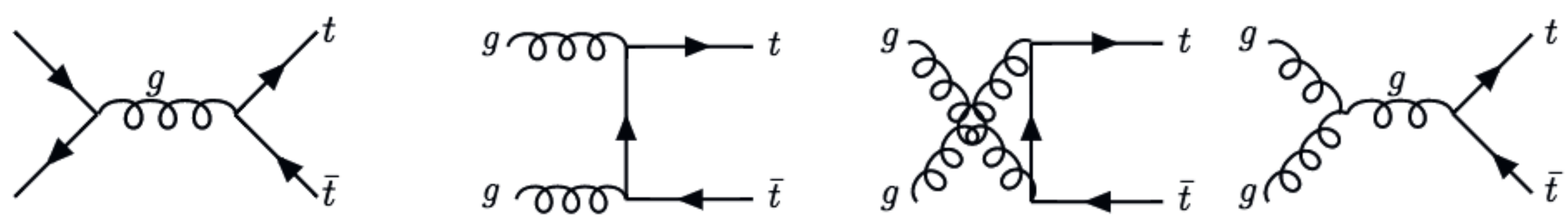
Every (top) precision measurement is a search

- The measurement of top properties is a test of the SM
  - The **top mass** is a **fundamental property**
    - Essential for probing the SM consistency via precision electroweak fits

arXiv:1803.01853

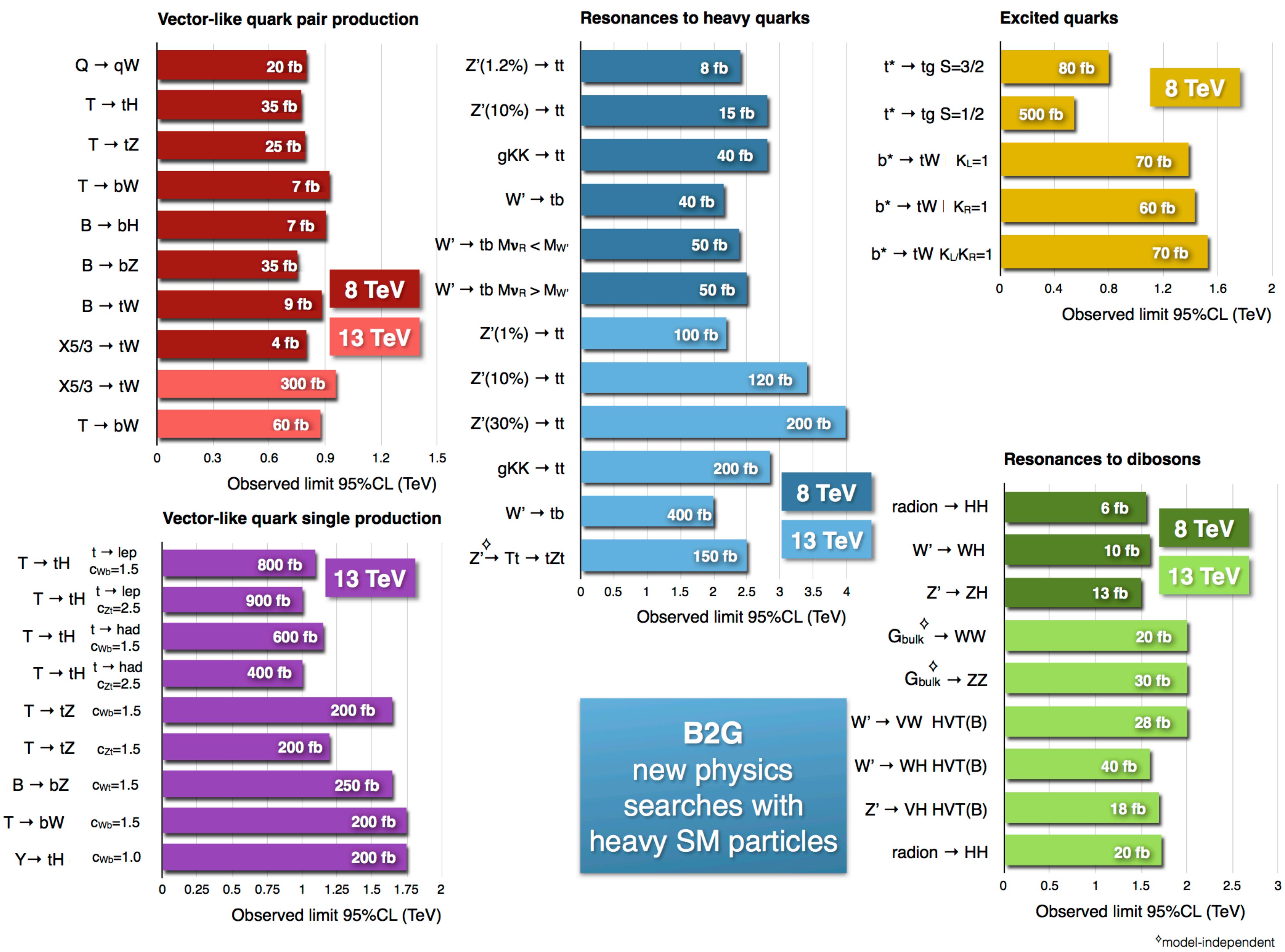


- But no matter if you like it or not: It is **unavoidable** at the LHC
  - Produced at a very high rate, mainly **via strong interaction** in **ttbar pairs**



  - and at a lower rate via **EWK interaction:** **single top quark** production

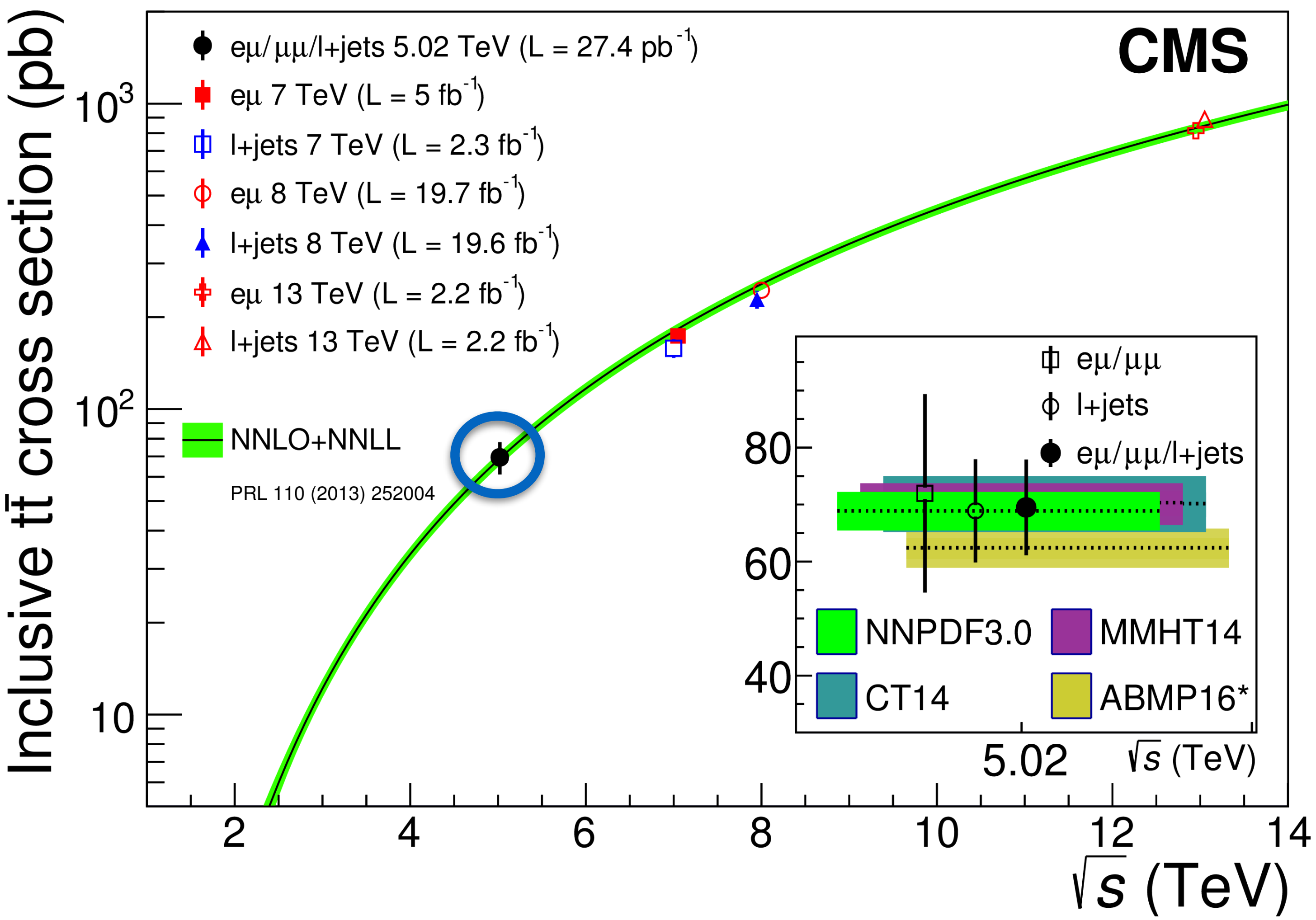
- The top quark is a main ingredient of many **new physics scenarios**
  - Exotic partners, rare decays, heavy new particles decaying to top, new particles produced together with top…



Top quark measurements

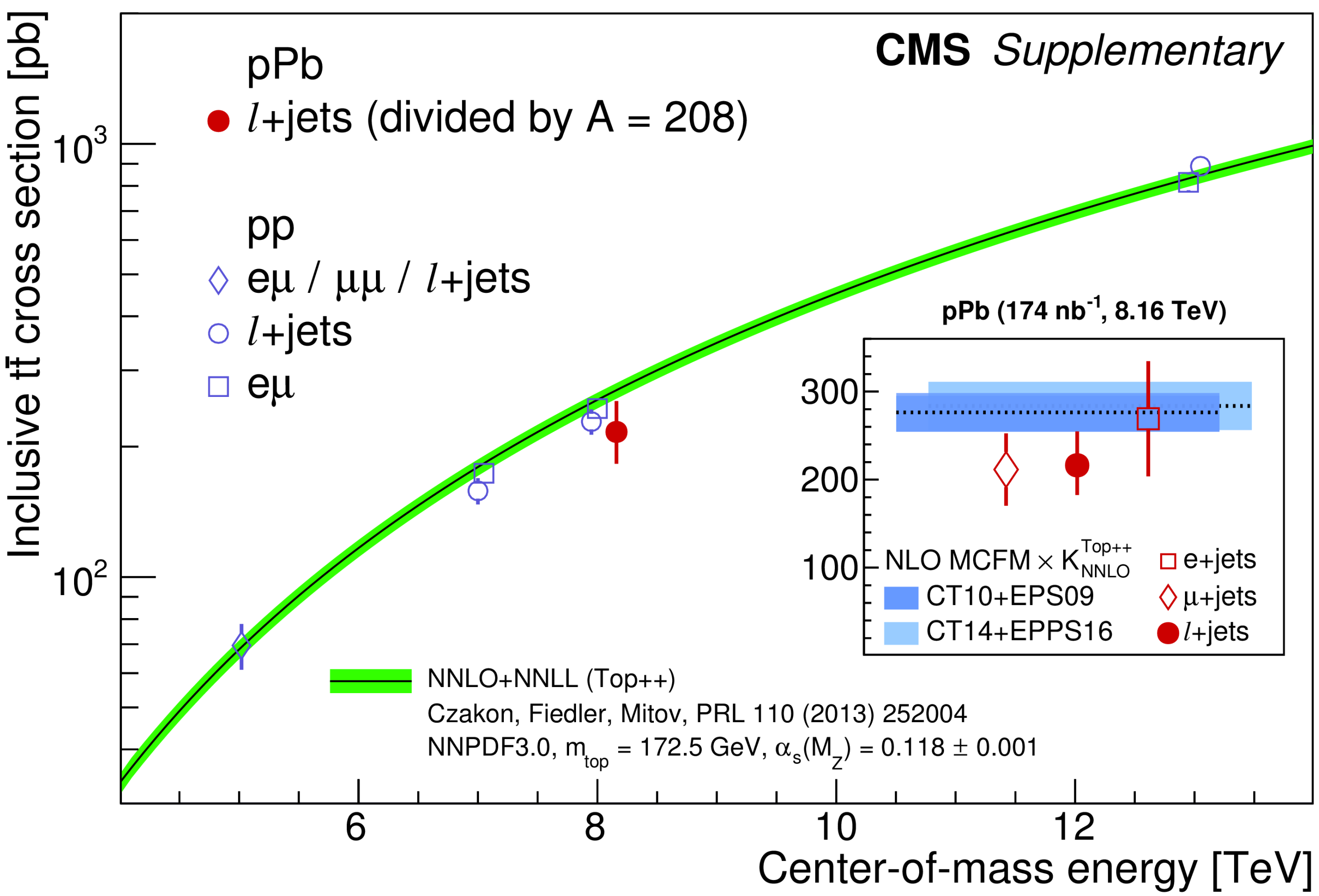
- In November 2015, the LHC delivered **pp collisions at 5.02 TeV**
  - Reference run for Heavy Ions collisions at that energy
- Measuring the inclusive tt cross section provides a **reference** for future measurements tt in nuclear collisions at that nucleon-nucleon collision energy
  - without the need to extrapolate from measurements at different √s

Surprise √s: 5TeV
1711.03143
Δσ/σ≈12%
Also useful to constrain PDFs



Top quark measurements

- Later, we did measure **tt production in actual Heavy Ions collisions**
  - proton-nucleus collisions, pPb data
  - center of mass energy of 8.16TeV
- **First observation** of the tt process using proton-nucleus collisions with > 5σ significance



Surprise collision type: pPb

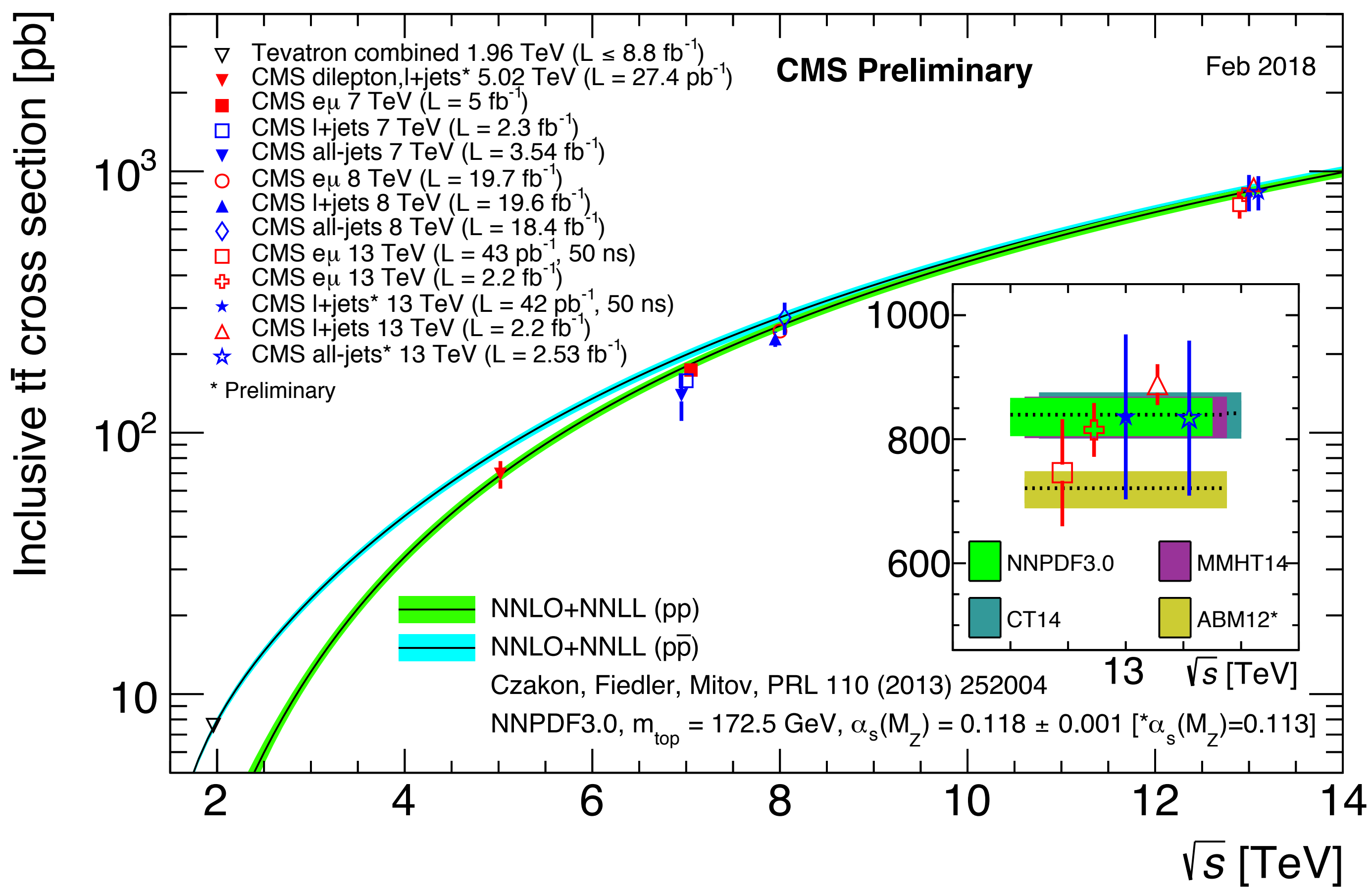
1709.07411

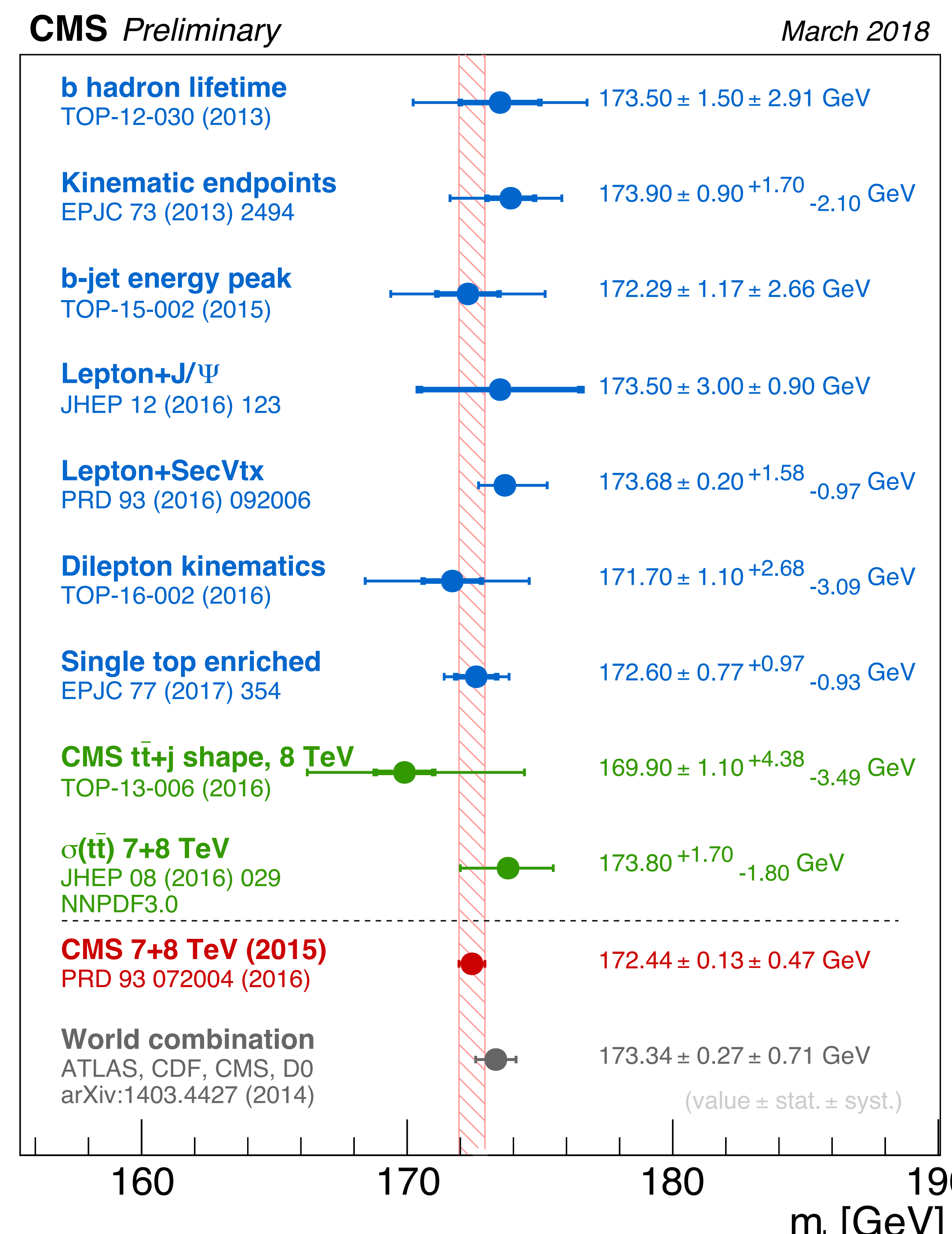
$\Delta\sigma/\sigma \approx 18\%$

Paves the way for future measurements in Heavy Ions

PRL 119 (2017) 242001

Top quark measurements: summary



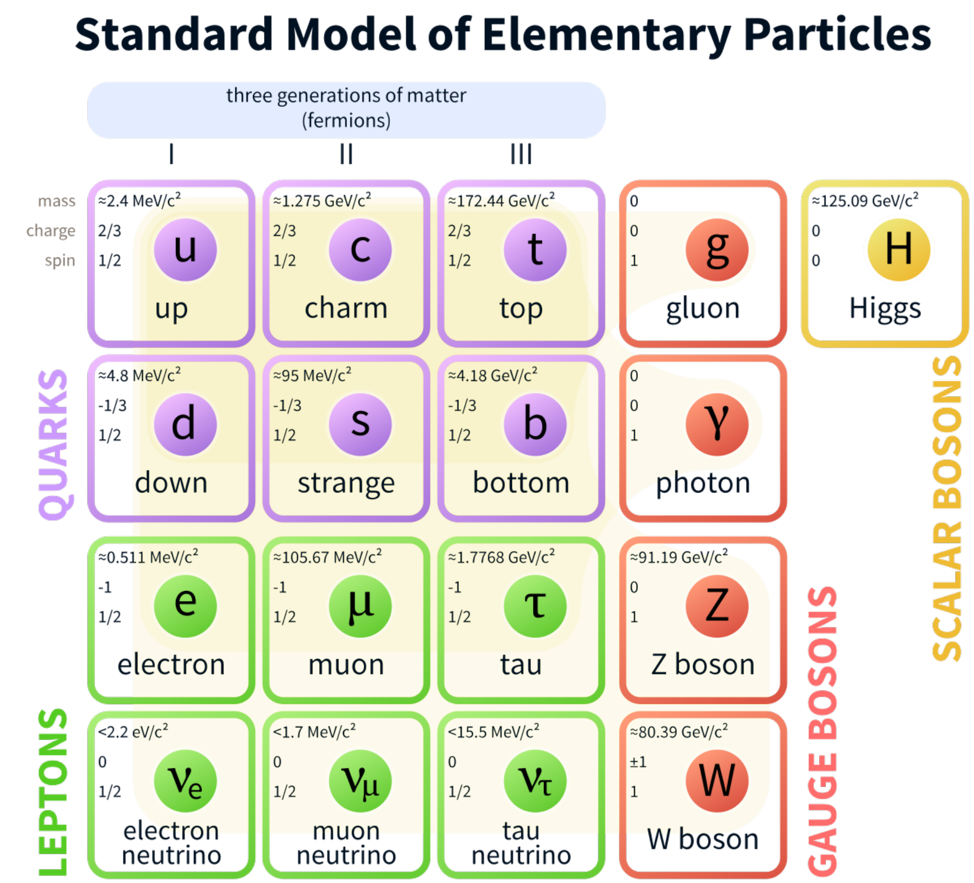


News on the Higgs sector

The Higgs boson: an introduction (I)

★ **The Standard model (SM)** of particle physics explains a wide variety of microscopic phenomena in a unified framework (Quantum Field Theory)

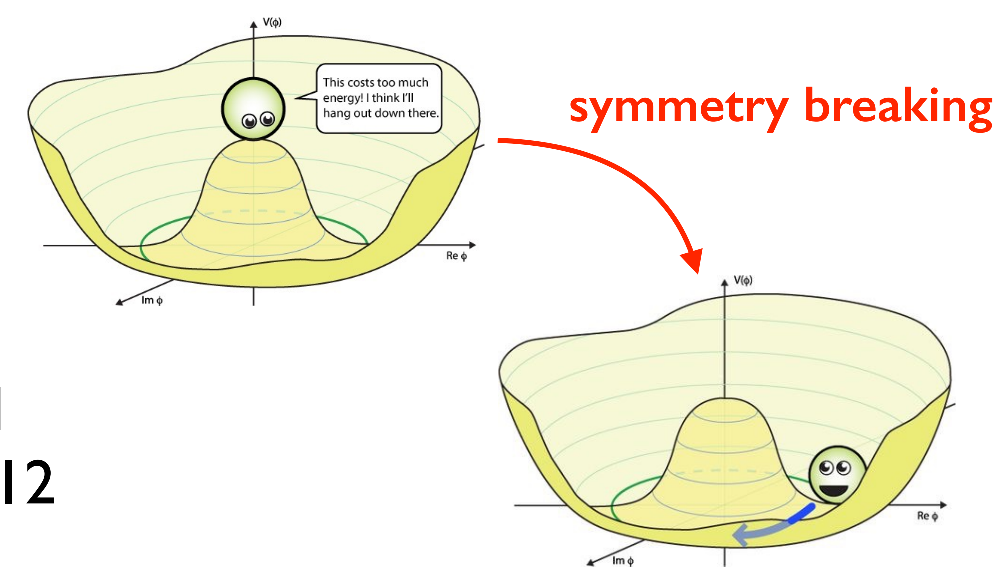
- ◉ matters consist of quarks and leptons
- ◉ interaction between particles governed by gauge bosons



★ **The Higgs mechanism** is responsible for assigning mass to particles

- ◉ Higgs boson is an evidence of the Higgs field

★ **A main goal of the LHC** is the in-depth investigation of electroweak symmetry breaking



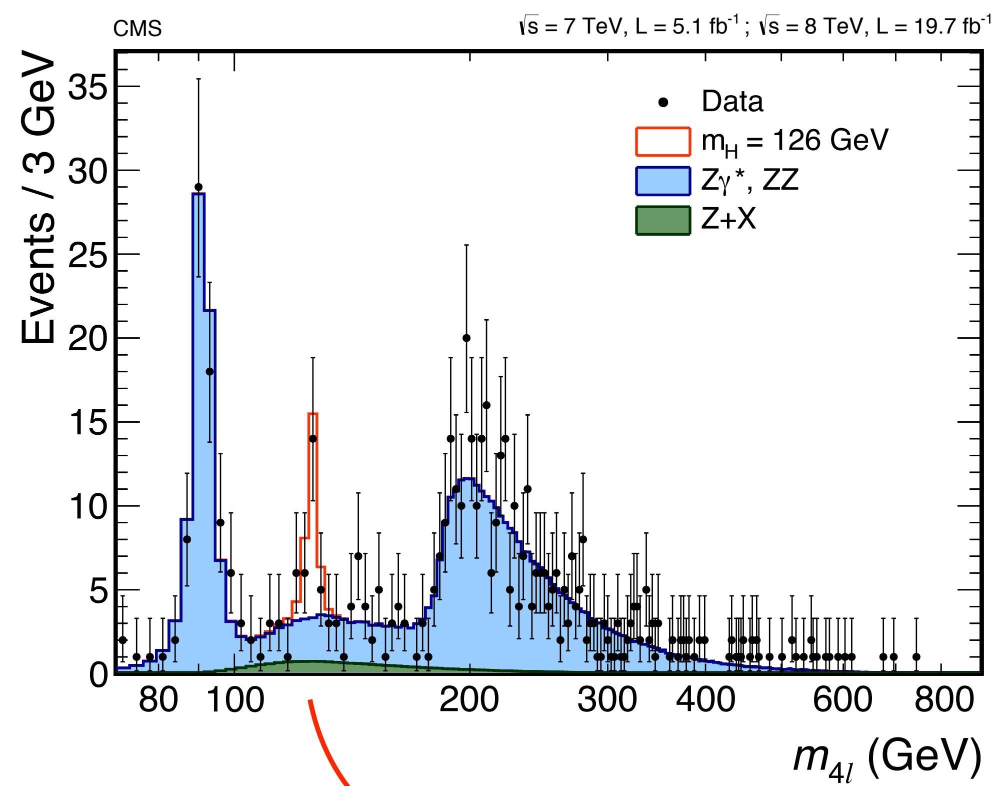
★ **A SM-like Higgs boson = H(125)** was discovered by ATLAS and CMS experiments of the LHC in 2012

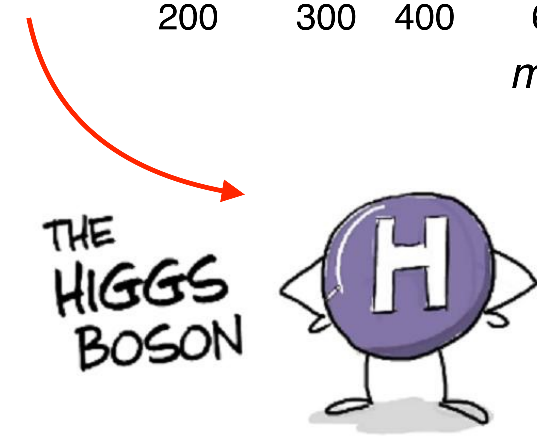
The Higgs boson: an introduction (II)

★ 6 years after the discovery, the story continues

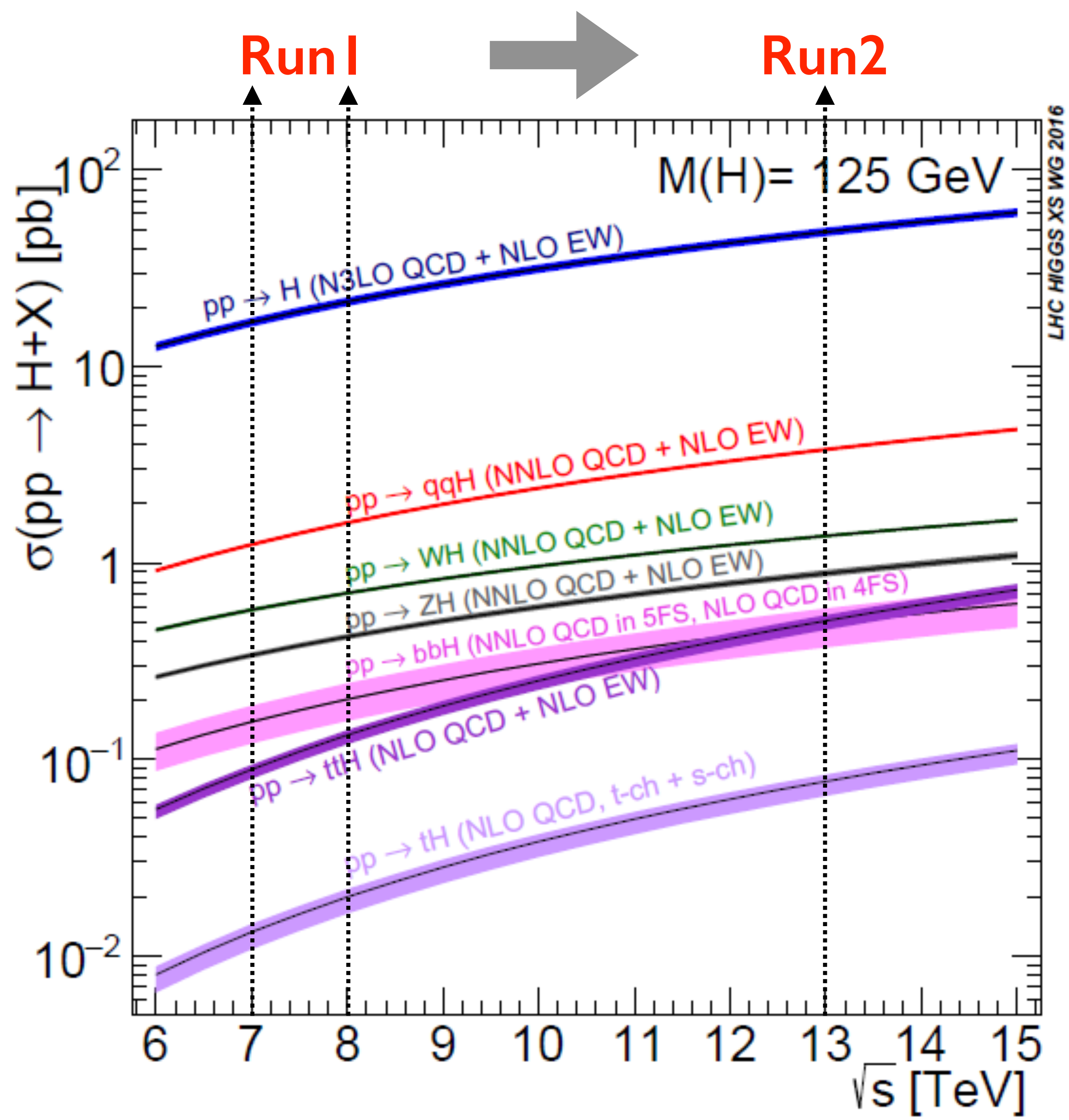
- **precise measurements** of properties
  - mass, couplings/cross-section
- **discover** other Higgs decay channels and production modes
  - $H \rightarrow \tau\tau$, $H \rightarrow bb$, ttH production
- **rare processes** : $H \rightarrow \mu\mu$, $H \rightarrow$ invisible
- **search for Higgs bosons beyond the SM**

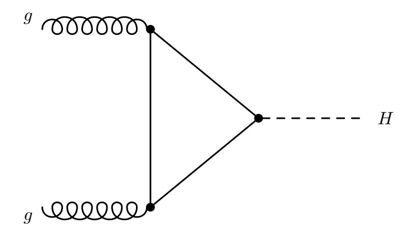
PRD 89 (2014) 092007



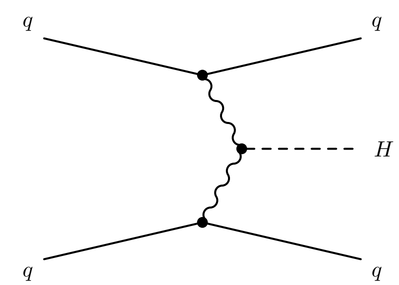


LHC: Higgs production

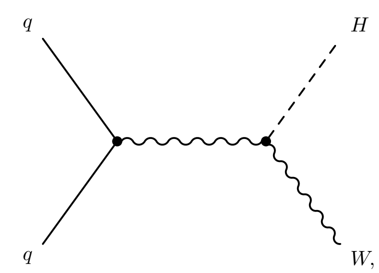




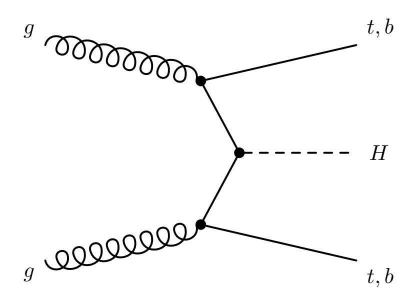
gluon fusion (ggH)
48.3 pb



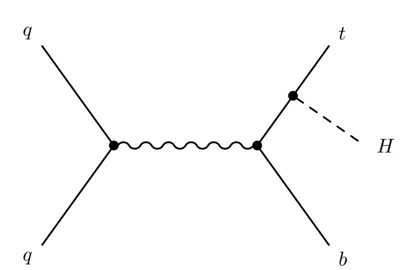
W/Z fusion (VBF)
3.77 pb



WH 1.36 pb
ZH 0.88 pb



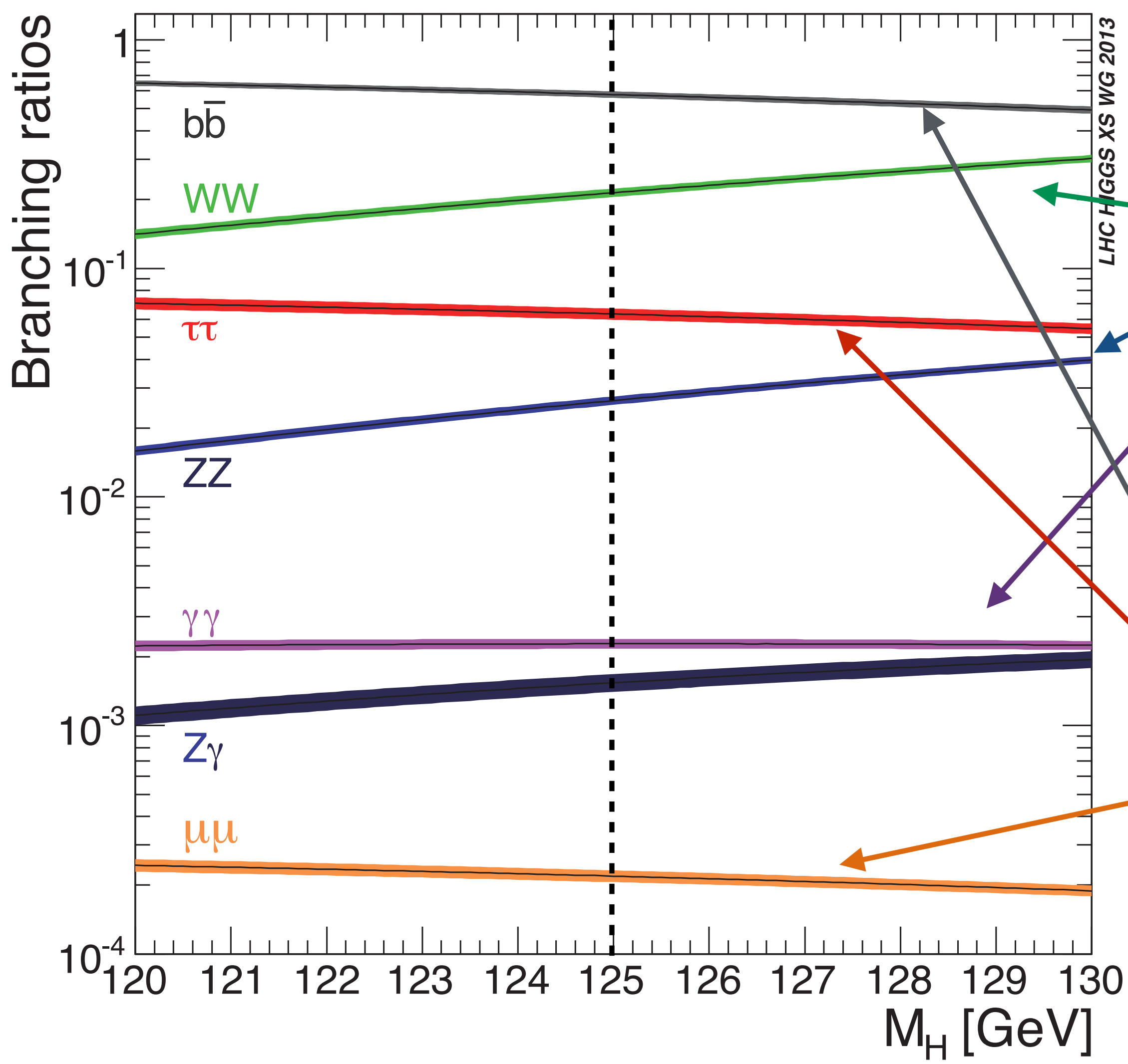
ttH
0.50 pb



tHq
0.074 pb

LHC: Higgs decays

★ Most of the H(125) decays accessible at the LHC



★ Bosonic decay : ZZ (3%), γγ (0.2%) as the discovery channels with clean final states, including WW (22%) for precise measurements

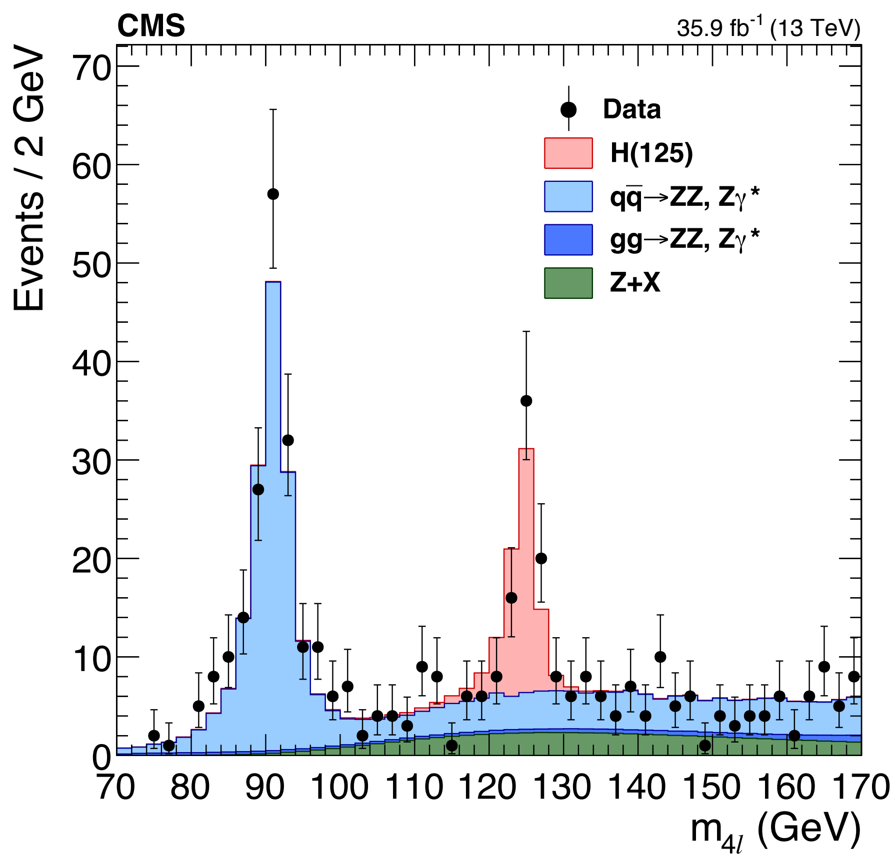
★ Fermionic decay : bb (58%) dominant channel, ττ (6%) and μμ (0.02%) as rare decay not discovered yet in Run1 → Highlights of Run2!

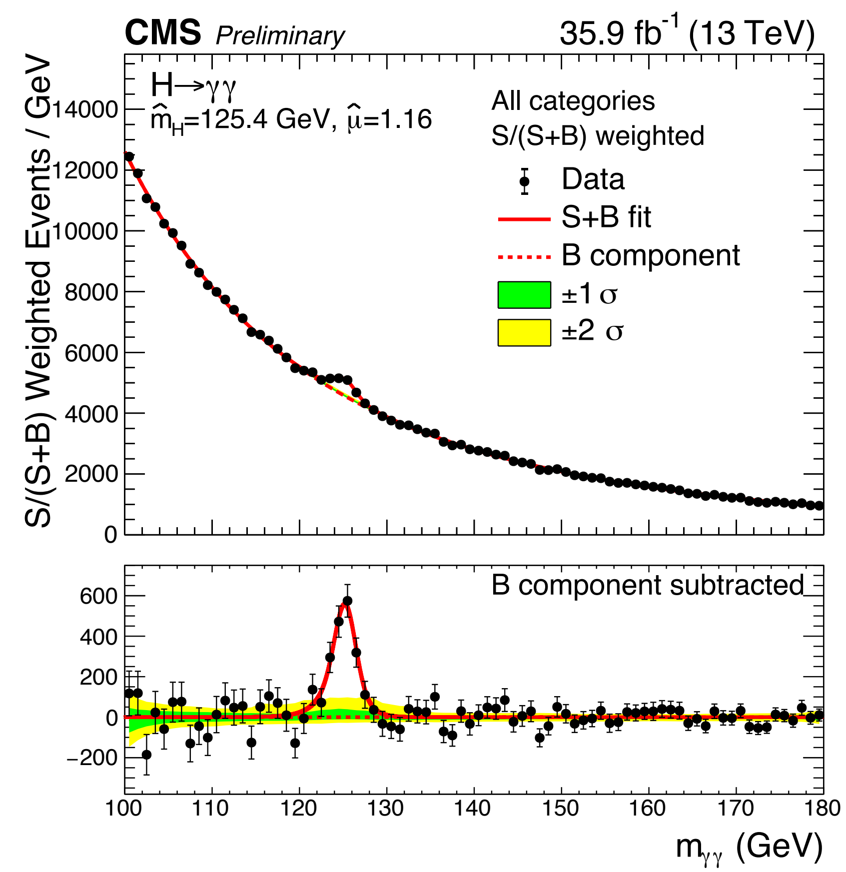
5 main production processes x 6 decay modes =30 exclusive final states contributed to H(125)

$H \rightarrow ZZ$ and $H \rightarrow \gamma\gamma$

JHEP 11 (2017) 047
CMS PAS HIG-16-040
CMS PAS HIG-17-015

★ Measurement of mass of H(125) decaying to 4 leptons and diphoton channels
- sensitivity enhanced by event categorizations





mass ($H \rightarrow ZZ$) : m_H = 125.26 ± 0.20 stat. ± 0.08 syst. GeV

12% more precise compared to Run1 ATLAS+CMS combination

H→ττ

PLB 779 (2018) 283

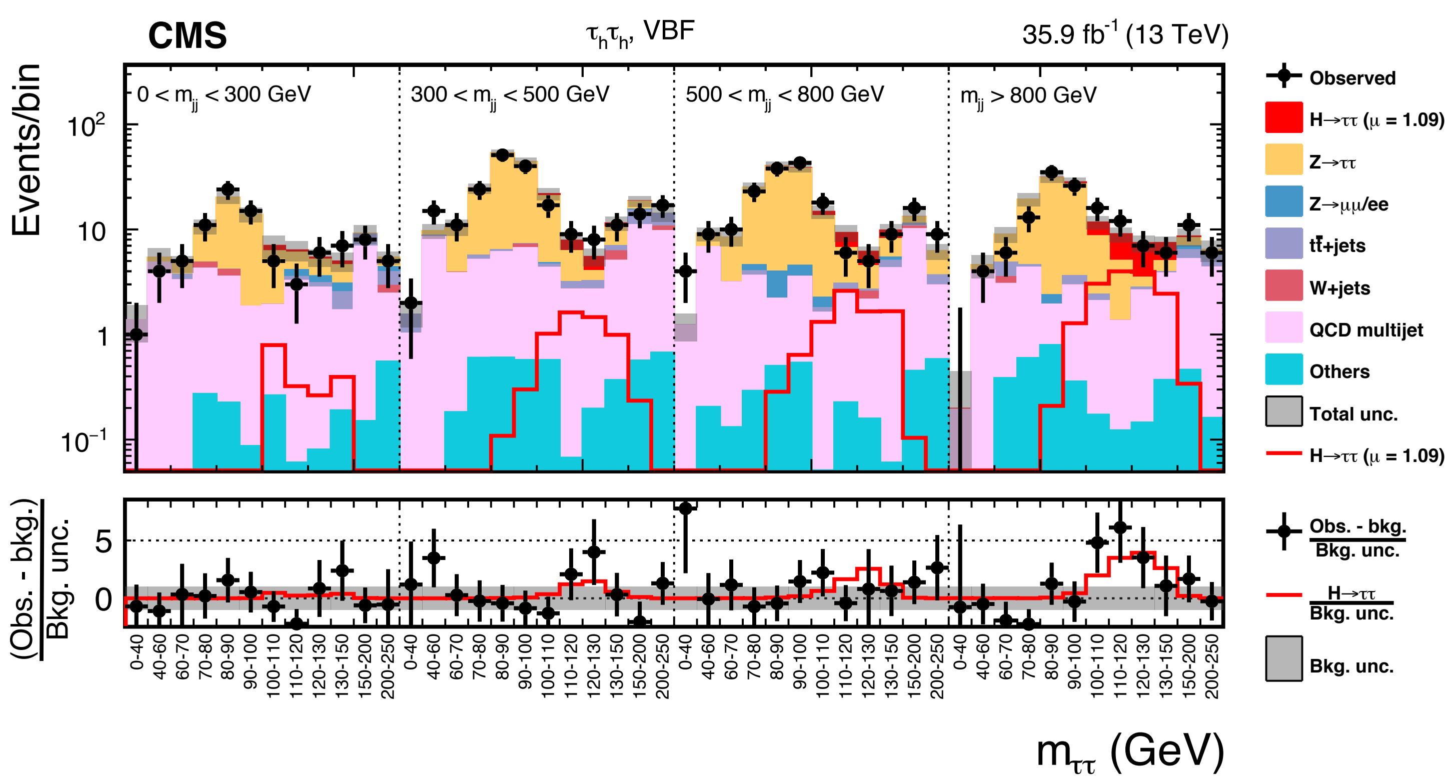
★ Second largest branching ratio (~6.3%) among fermionic decay channel
- lower background compare to bb

★ 4 most sensitive channels (eμ, $e\tau_h$, $\mu\tau_h$, $\tau_h\tau_h$) x 3 event categories (0-,1-,2-jets)
- targeting ggH and VBF processes

★ Clear excess at m_H=125 GeV

★ First observation of H→ττ from single experiment

4.9σ (4.7σ expected)
5.9σ combined with CMS Run1



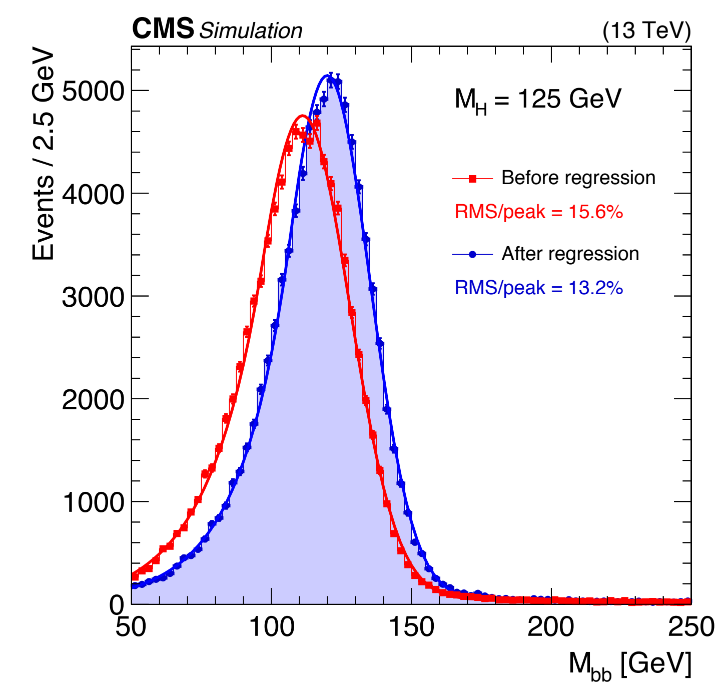
★ Signal strength μ (the ratio of the measured Higgs boson rate to its SM prediction) is compatible with SM

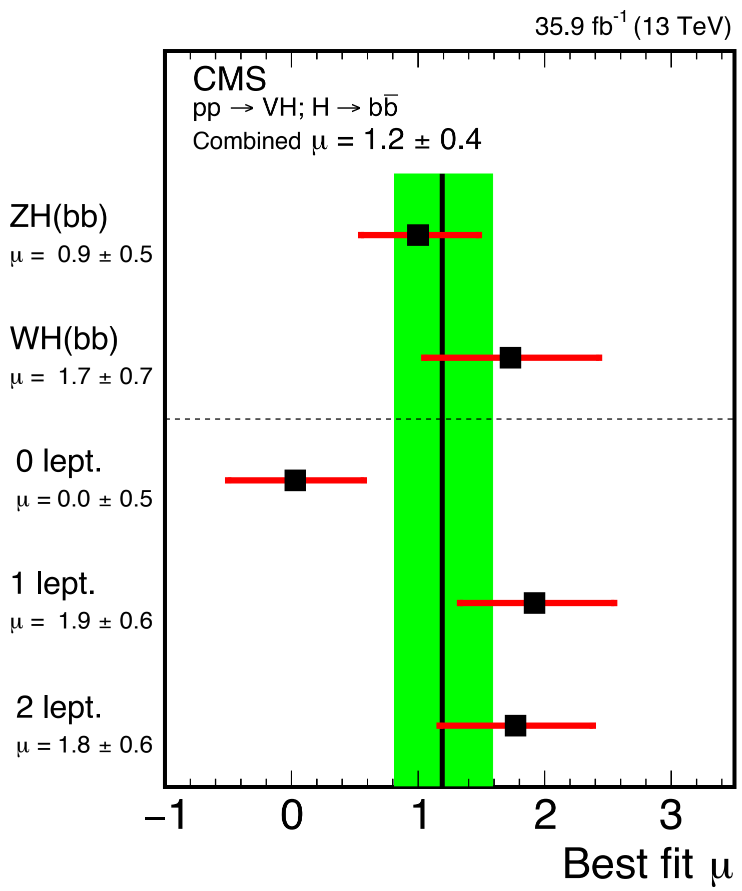
μ = 0.98 ± 0.18 (Run1+Run2)

VH H→bb

arXiv:1709.07497

- ★ Dominant decay mode (~58%) in SM, but not yet discovered due to large background
  - ◉ recoiling against W/Z boson is advantageous
- ★ 3 channels (0-, 1-, 2- leptons) from W/Z→$\ell\ell, \ell\nu, \nu\nu$
- ★ Multivariate regression to improve mass resolution
- ★ Signal extraction using multivariate analysis technique



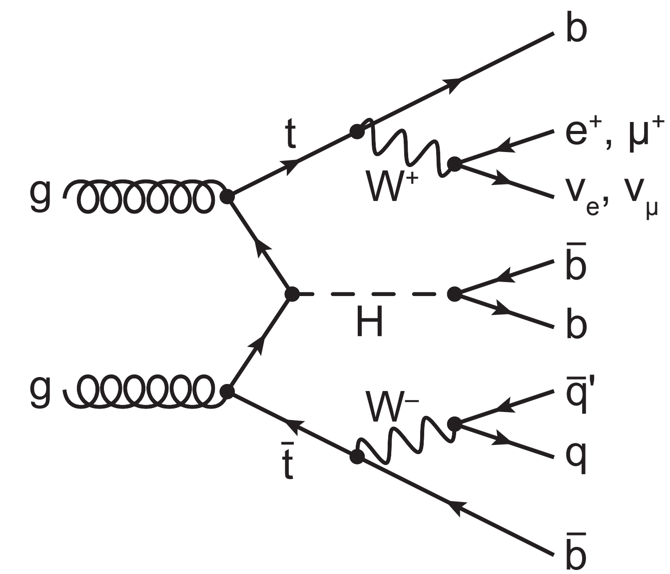


Evidence of H→bb which can lead to the discovery!

Data used	Significance expected	Significance observed	Signal strength observed
Run 1	2.5	2.1	$0.89^{+0.44}_{-0.42}$
Run 2	2.8	3.3	$1.19^{+0.40}_{-0.38}$
Combined	3.8	3.8	$1.06^{+0.31}_{-0.29}$

ttH H→bb (leptonic)

- ★ Direct probe of the top-Higgs Yukawa couplings
  - ◉ cross section increased by a factor of 3.9 in Run2
  - ◉ gain from largest BR(H→bb)
- ★ At least one lepton from top decay → higher purity
- ★ Complex final states require more sophisticated methods
  - ◉ 3 different multivariate analysis techniques
- ★ Limited by tt+HF and b-tagging uncertainties

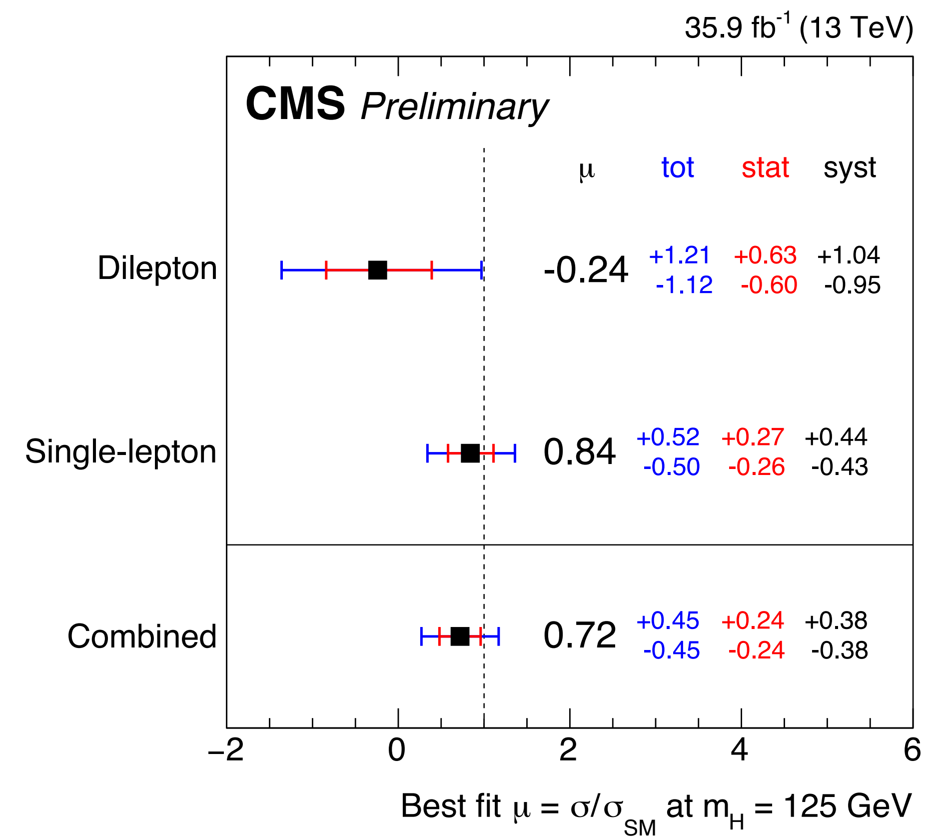


semileptonic ttH diagram

Best-fit μ = 0.72 ± 0.45

significance 1.6σ (2.2σ expected)

huge improvement in sensitivity than Run1



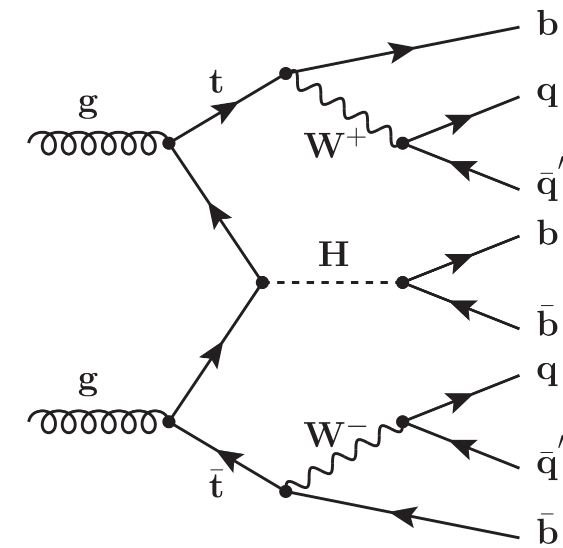
ttH H→bb (hadronic)

★ Hadronic top decay → higher rate (46%) but more challenging
  - ◉ ≥7 jets in an event requires dedicated all-jet triggers
  - ◉ fully reconstructed final state to the Higgs candidate

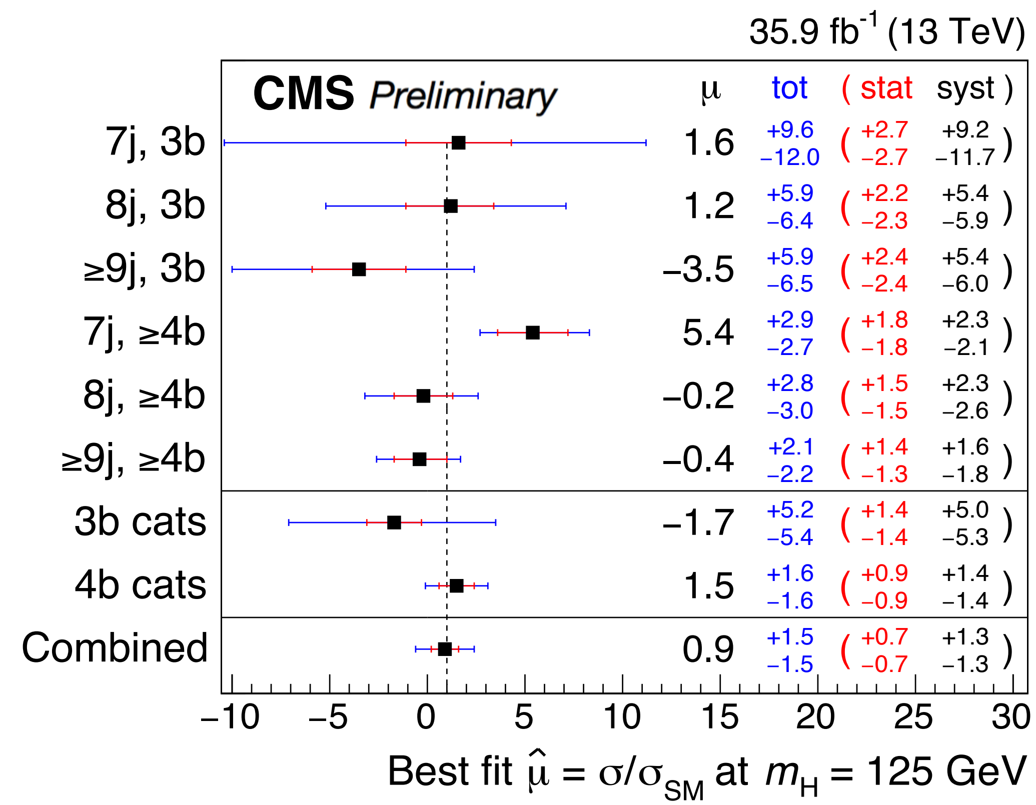
★ Enhanced quark-jet final states by quark-gluon jet discriminant
  - ◉ reduce QCD multijet background

★ Two levels of multivariate methods to separate signal and background

★ Provided supplementary sensitivity to the overall search for ttH production



fully hadronic ttH diagram



Best-fit μ = 0.9 ± 1.5,

upper observed limit μ < 3.8 at 95% CL

ttH Summary

- A variety of final states, studied with different experimental techniques:
  - tt + b-jets: large branching ratio, but complex multijet final state
  - tt + leptons ($H \rightarrow WW, ZZ, \tau\tau$): lower rate, low SM backgrounds
  - tt + $\gamma\gamma$, 4ℓ: small branching ratio, but very clean final state

decay mode	best fit μ	significance
$H \rightarrow \gamma\gamma$	2.2 (+0.9/-0.8)	3.3σ (1.6σ exp.)
$H \rightarrow WW, ZZ, \tau\tau$	1.23 (+0.45/-0.43)	3.2σ (2.8σ exp.)
$H \rightarrow bb$, 0ℓ	0.9 (+1.5/-1.5)	0.6σ (0.7σ exp.)
$H \rightarrow bb$, 1ℓ + 2ℓ	0.72 (+0.45/-0.45)	1.6σ (2.2σ exp.)

- The ttH combination is not yet available but all above channels enter the combination of couplings measurement

Rare H→μμ

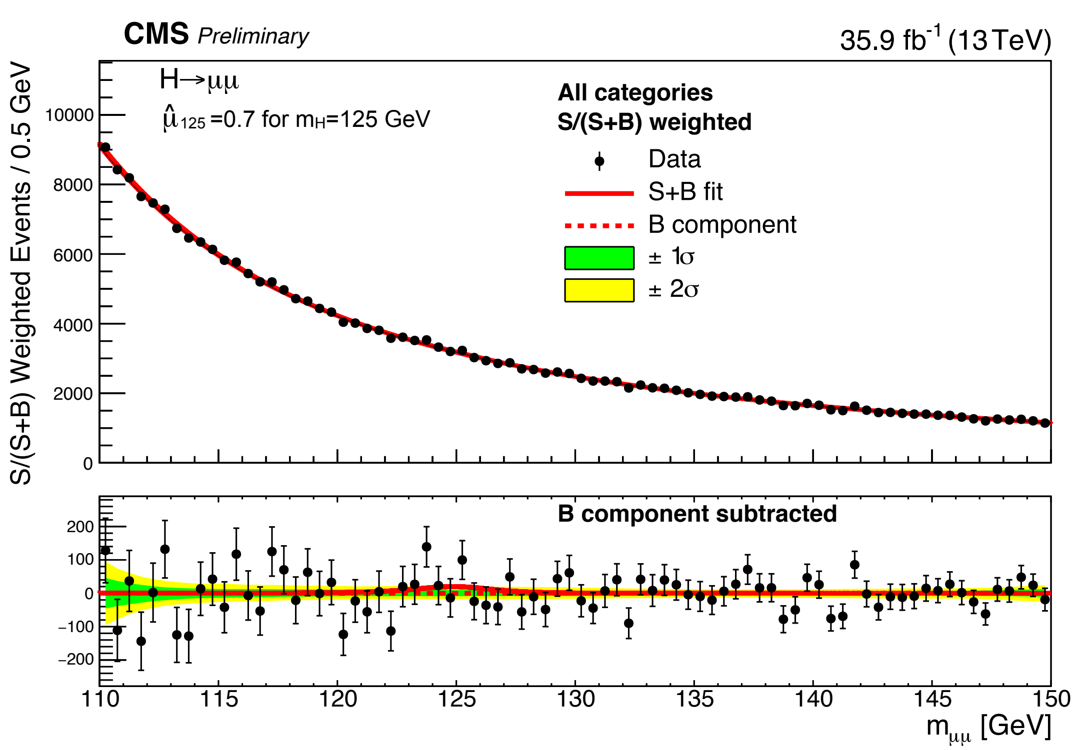
★ Probe of H(125) couplings to 2nd generation of leptons

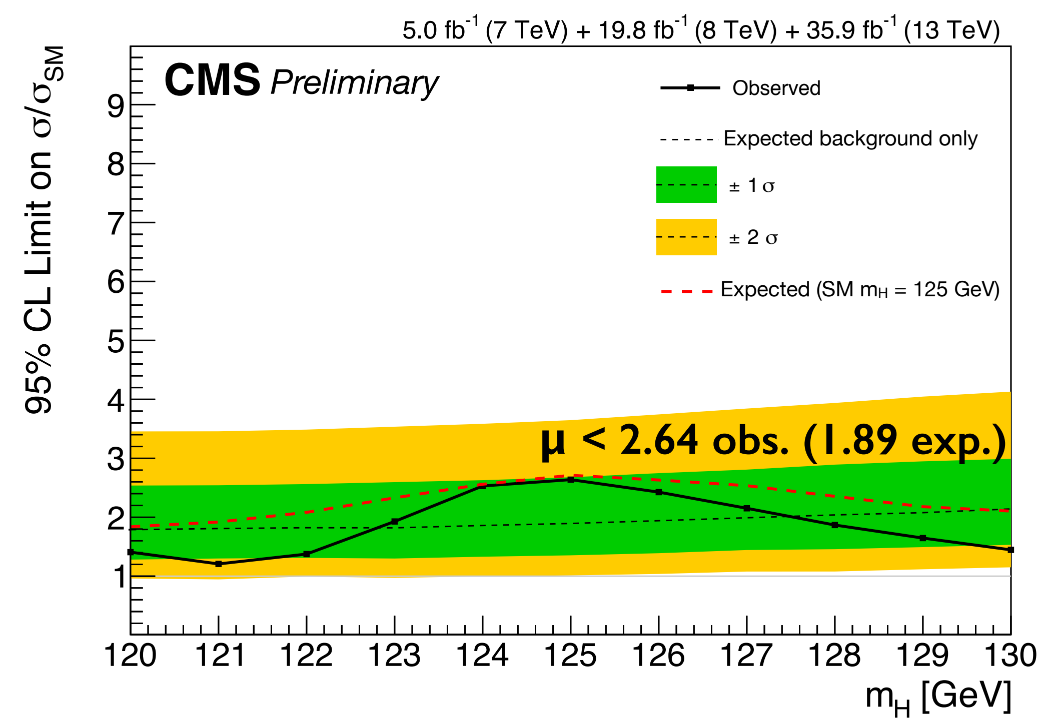
- very low BR (~0.02%)
- beneficial from excellent dimuon mass resolution

★ No significant excess is observed

- 95% CL upper limit on the signal strength

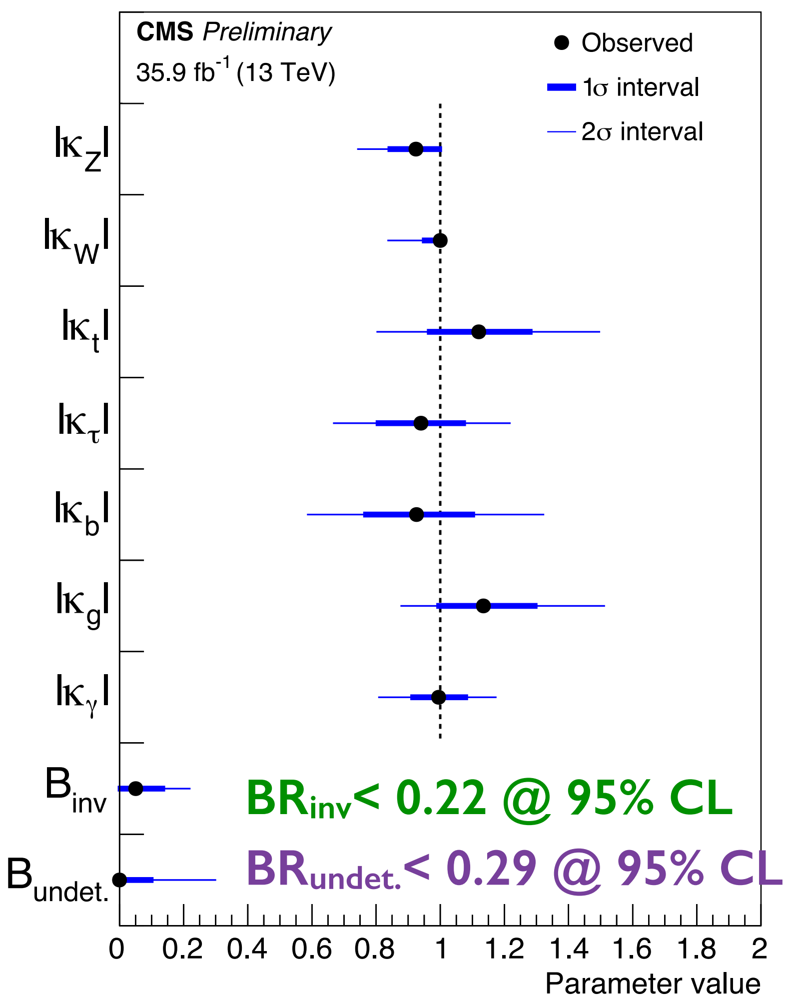
Run1+Run2 : best-fit μ = 0.9 ± 1.0 significance of 0.98σ (1.09σ expected)





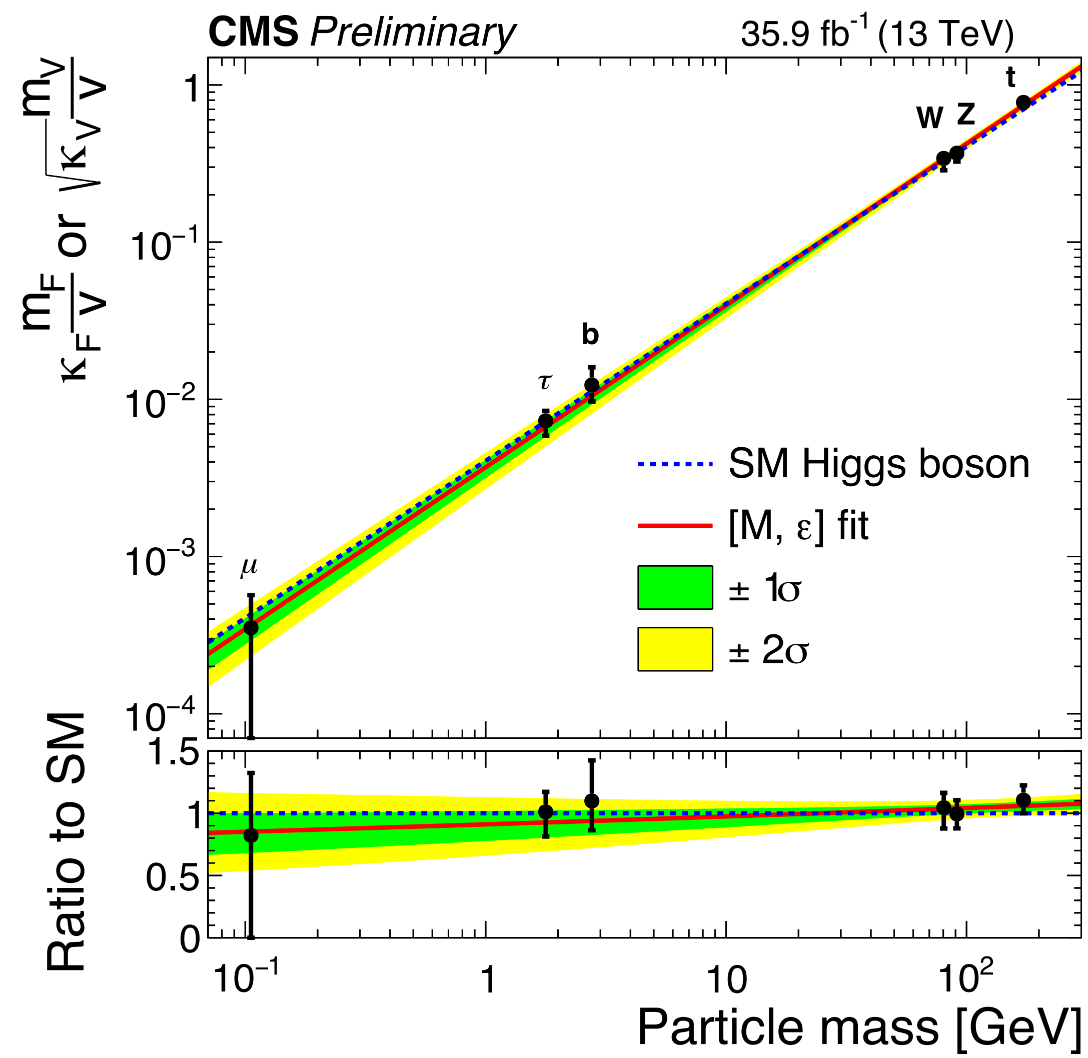
Couplings of H(125)

- ★ In κ-framework, κ represents the deviations from SM predictions of the Higgs boson couplings to SM bosons and fermions
- ★ By allowing BR(H→BSM) to vary in the fit, indirect constraints on Higgs couplings to invisible and undetected particles can be obtained
- ★ H(125) still looks SM-like up to now



$BR_{inv} < 0.22$ @ 95% CL

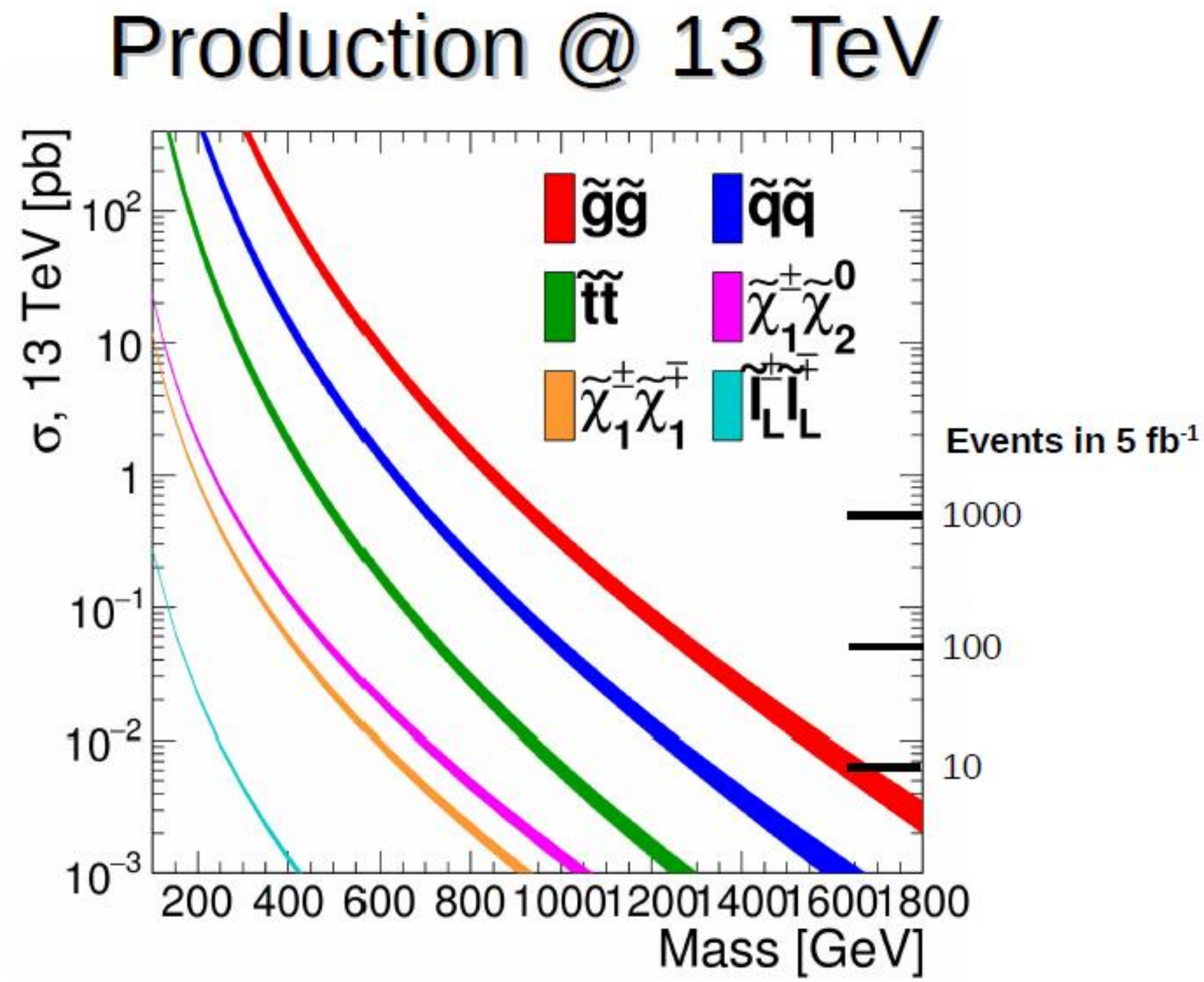
$BR_{undet.} < 0.29$ @ 95% CL



Physics Beyond the Standard Model (BSM)?

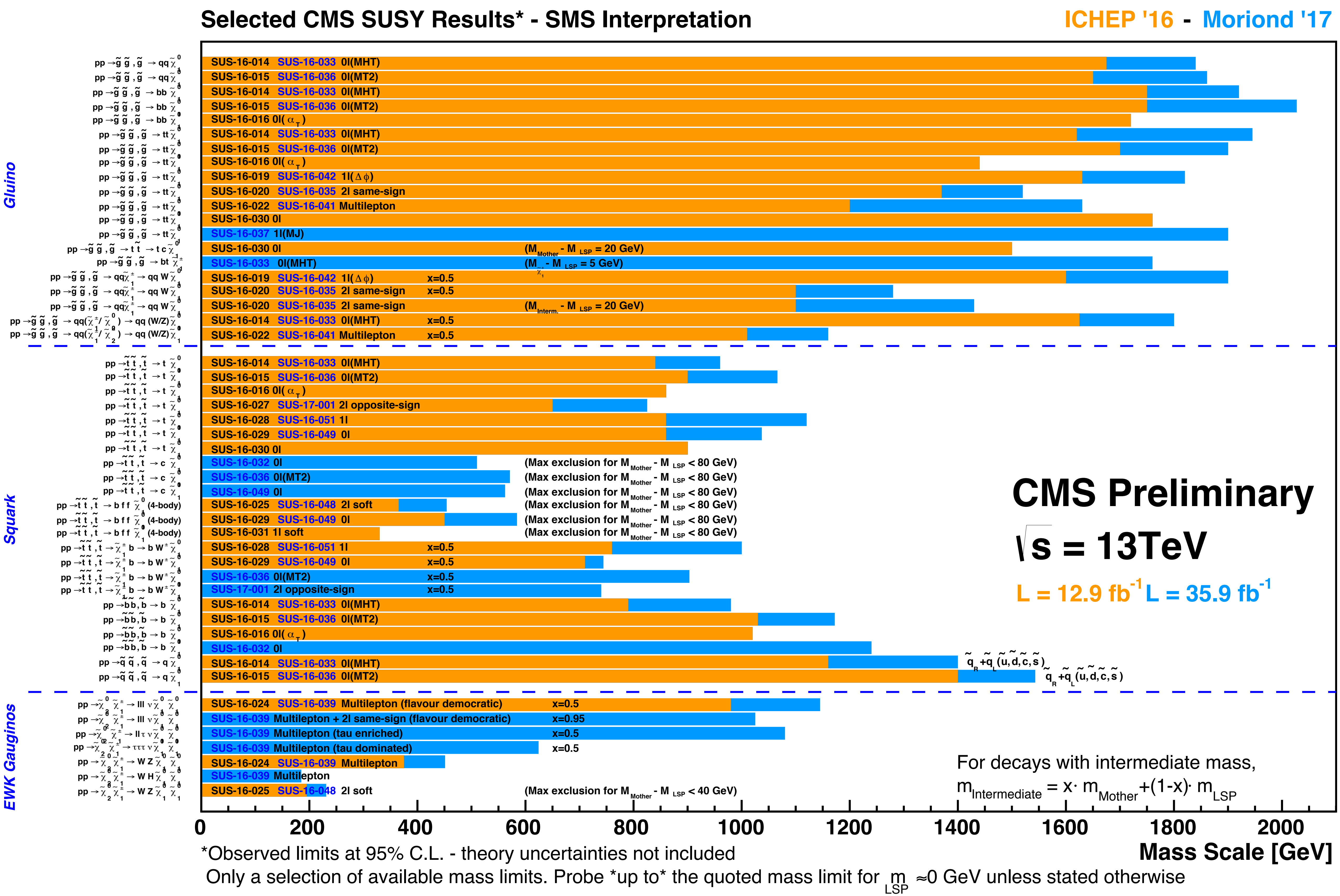
SUSY: where are we?

- This is just meant to give a hint of why we've done what we've done.
- Clearly if you want to look for the highest cross sections you start with gluinos and squarks.
- Where we are now, we're starting to eat into the space of the weak-inos.



https://twiki.cern.ch/twiki/bin/view/LHCPhysics/SUSYCrossSections

SUSY: where are we?



SUSY: where are we?

Having found no SUSY so far in "standard" channels (strong production, large mass splittings), the searches shifted in the following directions

- **Search for SUSY in compressed spectrum scenarios (e.g, stop nearly degenerate with top quark + neutralino masses)**
  Use ISR as an important tool to boost compressed system

- **Search for EW production of SUSY particles**
  First sensitivity for Higgsino pair production in Run 1; now rapidly increasing the reach

- **Search for SUSY via Higgs boson in decay chain**
  Just started to be sensitive

- **VBF SUSY production**
  Not yet sensitive - but a powerful tool for the future

SUSY: where are we?

- These new paradigms require new tools:
  - *Soft-lepton triggers*
  - *Jet substructure techniques*
  - *Ever increasing use of ISR as a tag*
  - *Charm tagging*
  - *Use of "designer" kinematic variables*
  - *Optimal top quark reconstruction*

- These tools are common between SUSY and many other searches, leading to significant cross- pollination spreading across the search fields and also now being used in precision measurements

Other scenarios (non-SUSY)

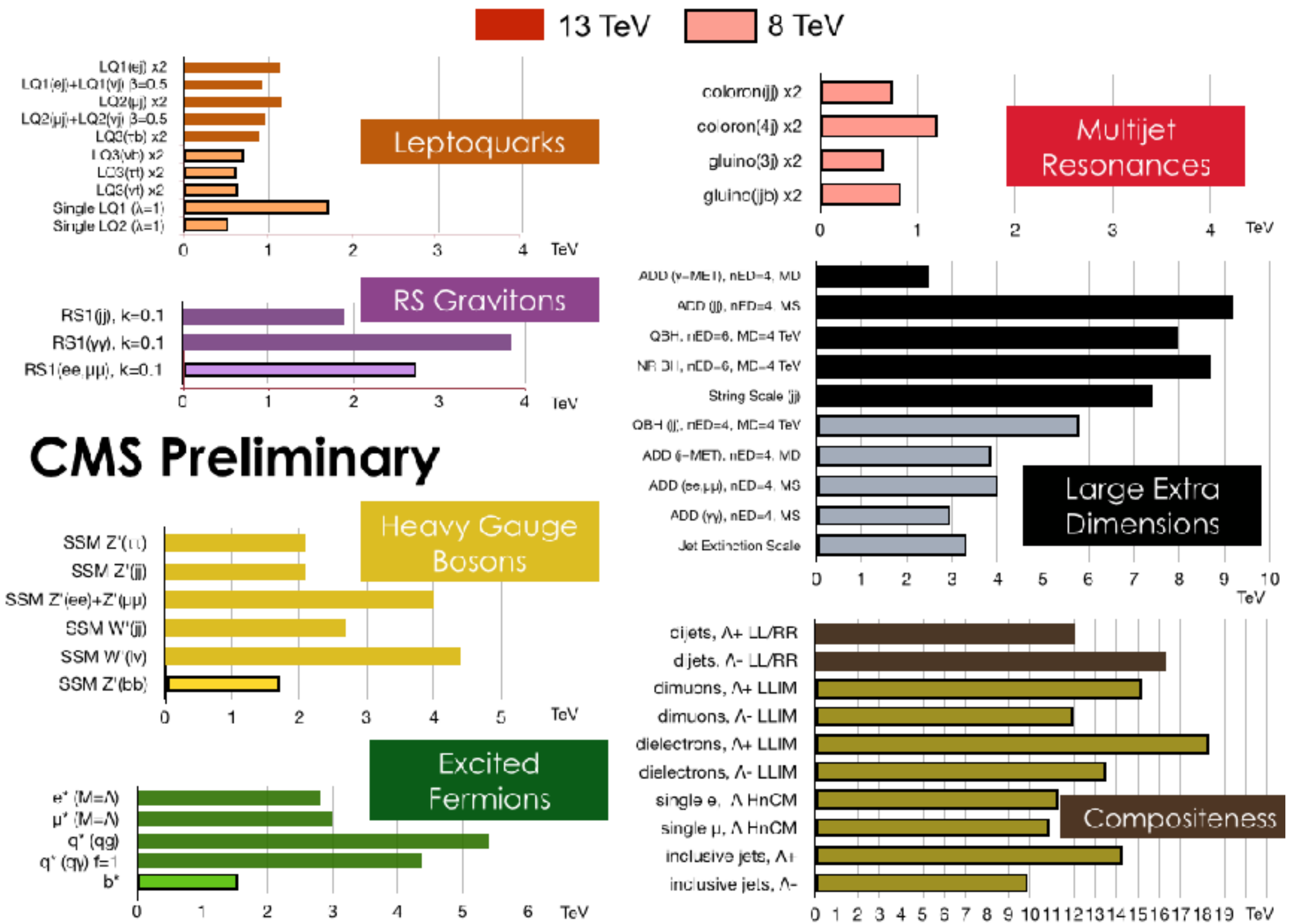
Search strategies

- Many handles to search for evidence of new phenomena
  - Multi-lepton final states
  - Lepton flavour violation
  - Exploit Higgs
  - Di-jet events

Physics models

- Heavy resonances
- Quantum black holes
- Extra dimensions
- Non-resonant effects
- Excited quarks
- ...

Other scenarios (non-SUSY)



LHC: the biggest, most complex scientific endeavour currently in activity. We're only on the 8th year of a program that will be active for (at least...) another 2 decades.

Data from the LHC provides a unique and rich environment to perform precision studies as well as searches for BSM signals.

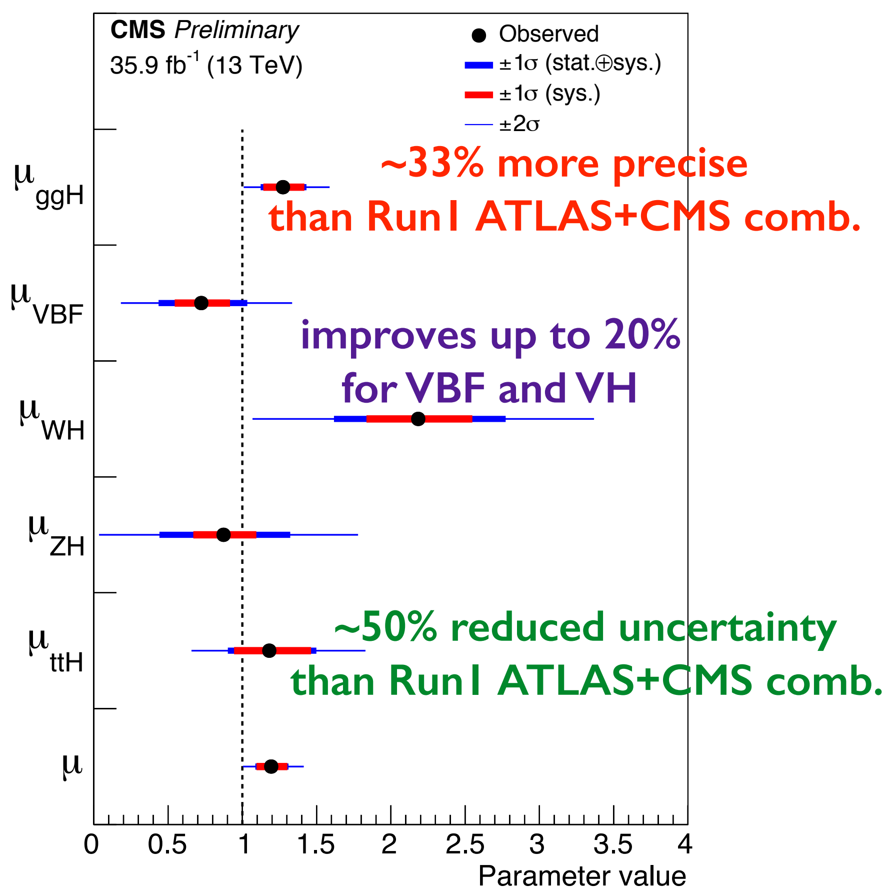
From common/abundant SM processes to rare events which "may" challenge our theory, LHC detectors are testing the SM predictions as never before!

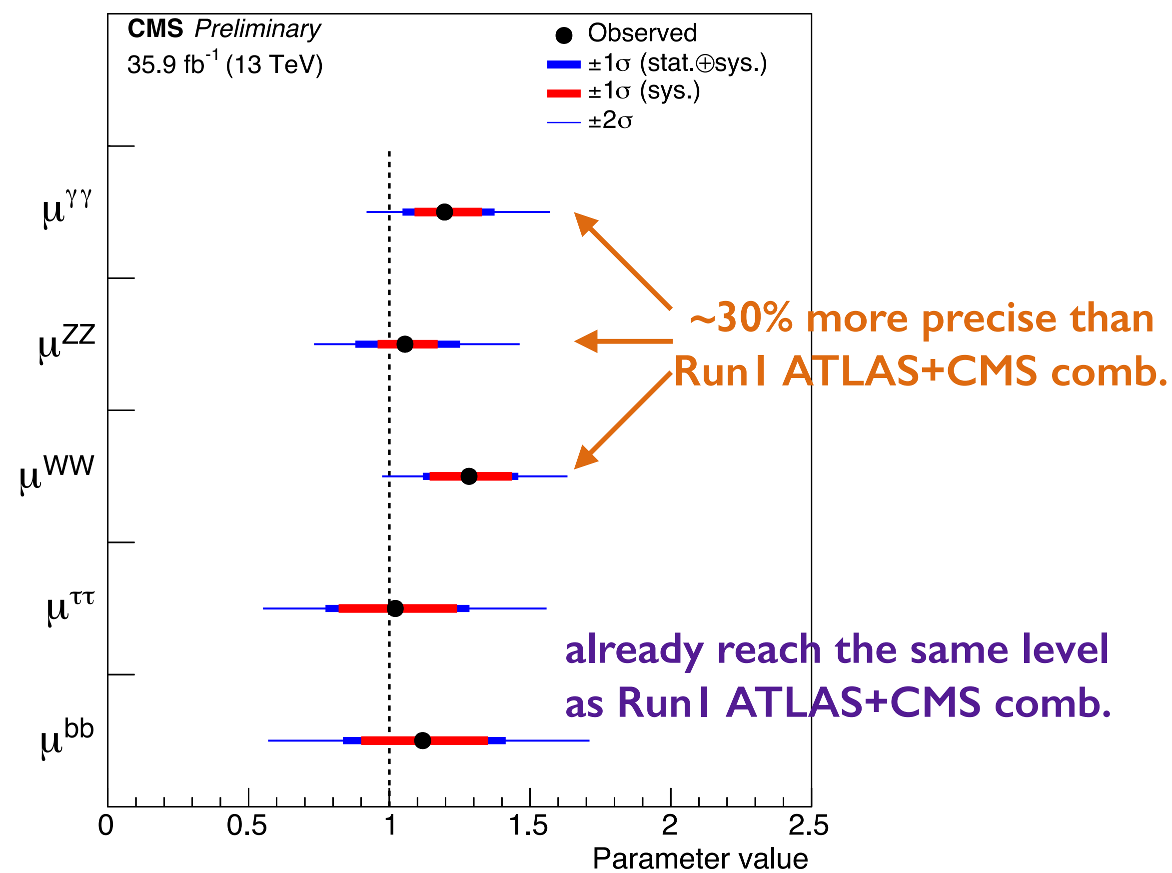
LHC upgrade: will bring new challenges and opportunities possible to achieve higher centre-of-mass energy (new type of hay), increased luminosity (bigger pile of hay).

Extras…

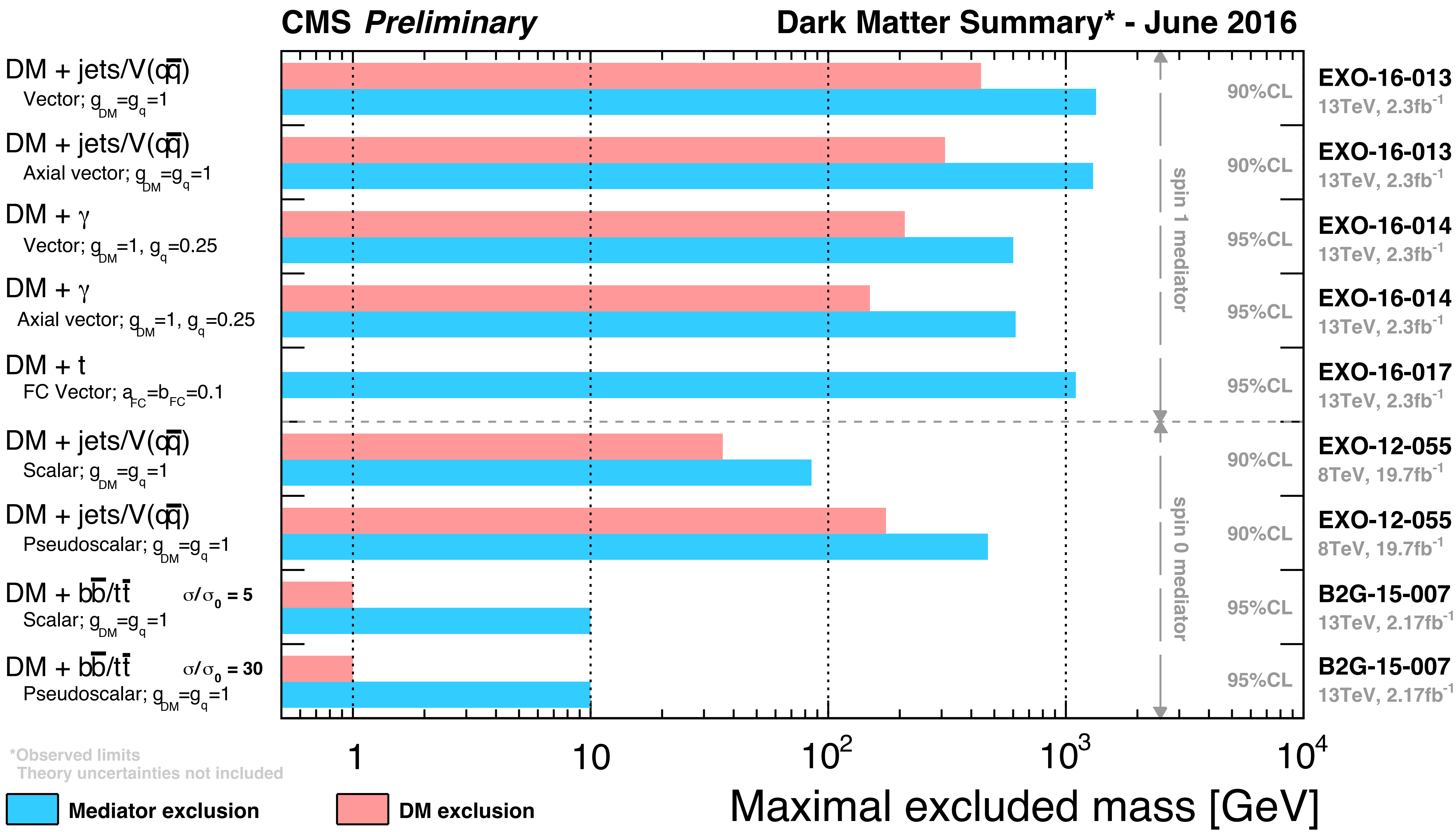
H(125) Combination

- ★ Cover a wide range of H(125) measurements using the full 2016 data
  - ◉ combined analysis sensitive to 22 out of 25 possible production x decay channels
- ★ Signal strengths for the production and decay are compatible with SM expectations





$$\mu = 1.17^{+0.10}_{-0.10} = 1.17^{+0.06}_{-0.06}\,(\text{stat.})\,^{+0.06}_{-0.05}\,(\text{sig. th.})\,^{+0.06}_{-0.06}\,(\text{other sys.})$$

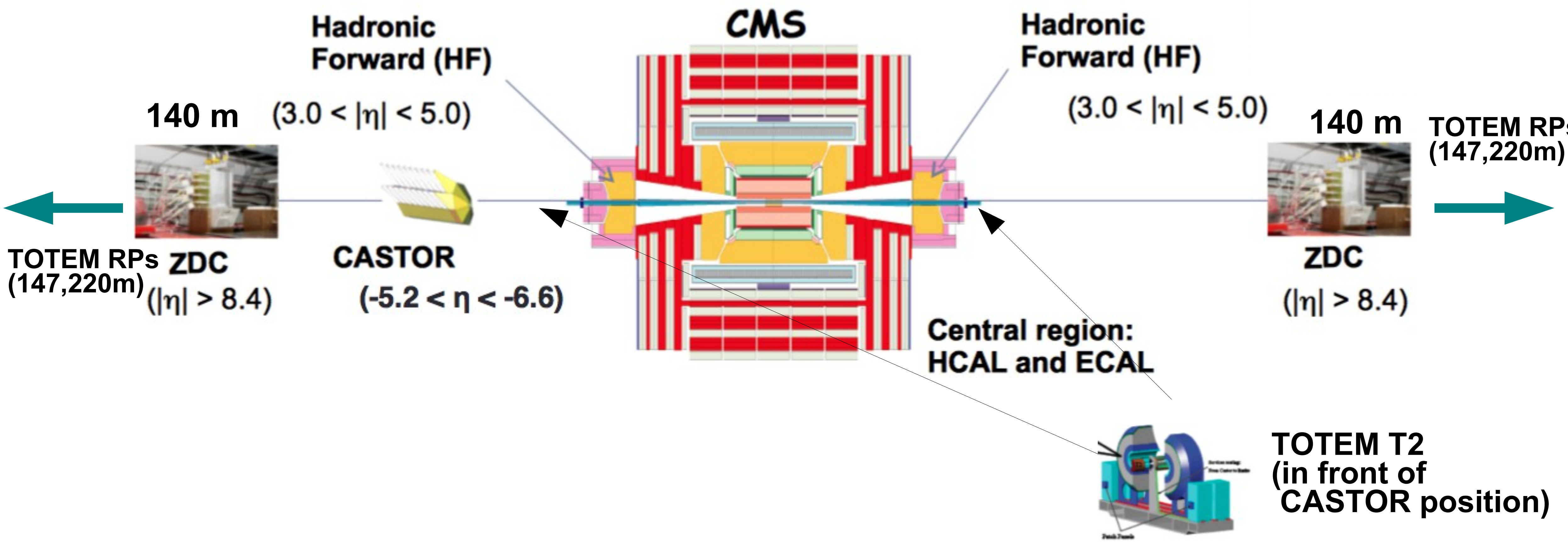

CMS Preliminary
Dark Matter Summary* - June 2016
DM + jets/V(qq̄)
Vector; g_DM=g_q=1
DM + jets/V(qq̄)
Axial vector; g_DM=g_q=1
DM + γ
Vector; g_DM=1, g_q=0.25
DM + γ
Axial vector; g_DM=1, g_q=0.25
DM + t
FC Vector; a_FC=b_FC=0.1
DM + jets/V(qq̄)
Scalar; g_DM=g_q=1
DM + jets/V(qq̄)
Pseudoscalar; g_DM=g_q=1
DM + bb̄/tt̄ σ/σ0 = 5
Scalar; g_DM=g_q=1
DM + bb̄/tt̄ σ/σ0 = 30
Pseudoscalar; g_DM=g_q=1
spin 1 mediator
spin 0 mediator
90%CL
90%CL
95%CL
95%CL
95%CL
90%CL
90%CL
95%CL
95%CL
EXO-16-013 13TeV, 2.3fb-1
EXO-16-013 13TeV, 2.3fb-1
EXO-16-014 13TeV, 2.3fb-1
EXO-16-014 13TeV, 2.3fb-1
EXO-16-017 13TeV, 2.3fb-1
EXO-12-055 8TeV, 19.7fb-1
EXO-12-055 8TeV, 19.7fb-1
B2G-15-007 13TeV, 2.17fb-1
B2G-15-007 13TeV, 2.17fb-1
1
10
10^2
10^3
10^4
Maximal excluded mass [GeV]
*Observed limits
Theory uncertainties not included
Mediator exclusion
DM exclusion

The Large Hadron Collider

QCD measurements at the LHC:

- test predictions of QCD phenomena at high(est) energies with large statistical samples of rare processes;
- detector allow measurements with unprecedented precision and fiducial coverage (wide x-coverage; unprecedented high-Q^2 interactions)

Forward Detectors at CMS

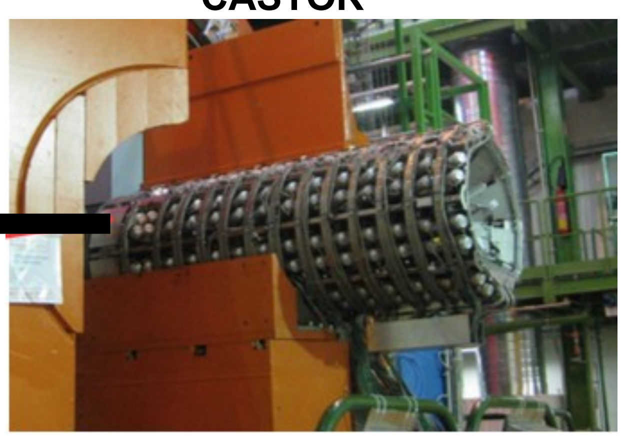


HF Detector

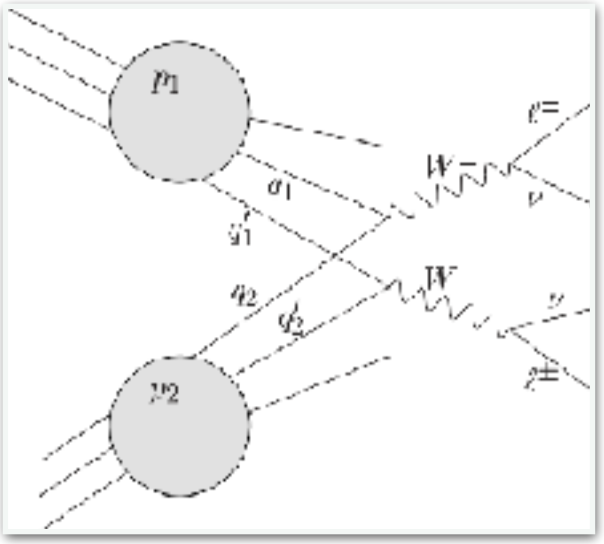
- @11.2 m from interaction point
- Rapidity coverage: **3 < |η| < 5**
- Steel absorbers/quartz fibers (Long+short fibers)
- 0.175x0.175 η/φ segmentation

- Tungsten-Quartz-Cherenkov sampling calorimeter
- Octagonal cylindrical shape
- Segmented in 16 sectors in φ and 14 modules in z
- Separated electromagnetic and hadronic sections
- Located at 14.4 m from IP in CMS

CASTOR



Constraints on the double parton scattering cross section from same-sign W boson pair production



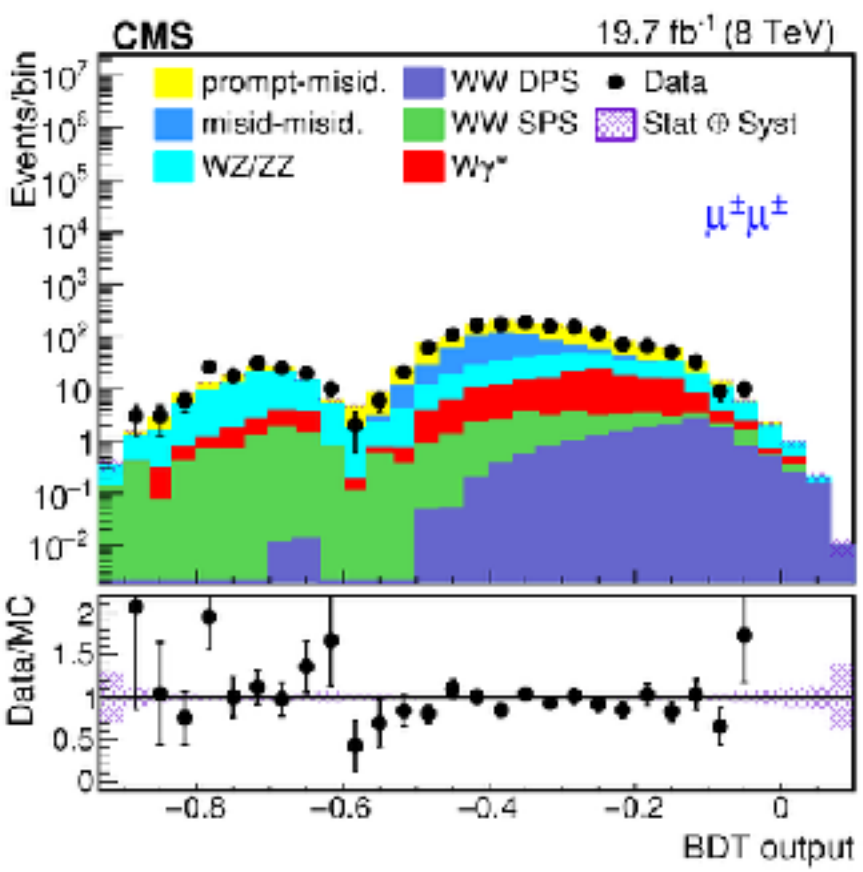
Schematic diagram corresponding to the production of a same-sign W boson pair via the DPS process.

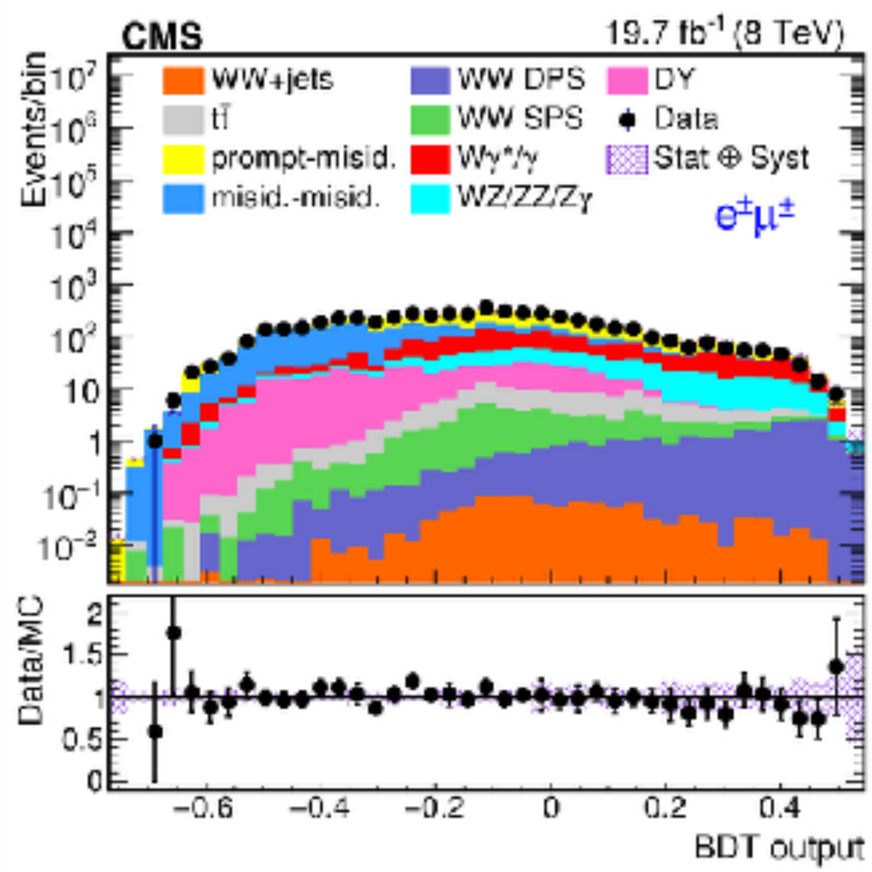
A first search for same-sign W boson pair production via double-parton scattering (DPS) in pp collisions at a center-of-mass energy of 8 TeV has been presented.

The analyzed data were collected by the CMS detector at the LHC during 2012 and correspond to an integrated luminosity of 19.7 fb−1.

The results presented here are based on the analysis of events containing two same-sign W bosons decaying into either same-sign muon-muon or electron-muon pairs.

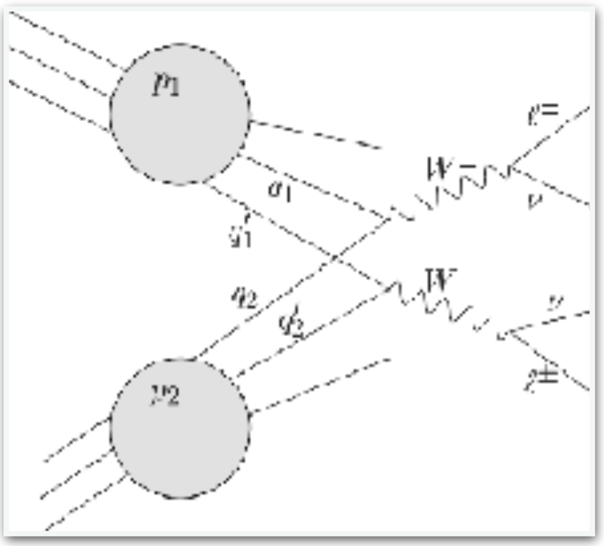
Several kinematic observables have been studied to identify those that can better discriminate between DPS and the single-parton scattering (SPS) backgrounds.



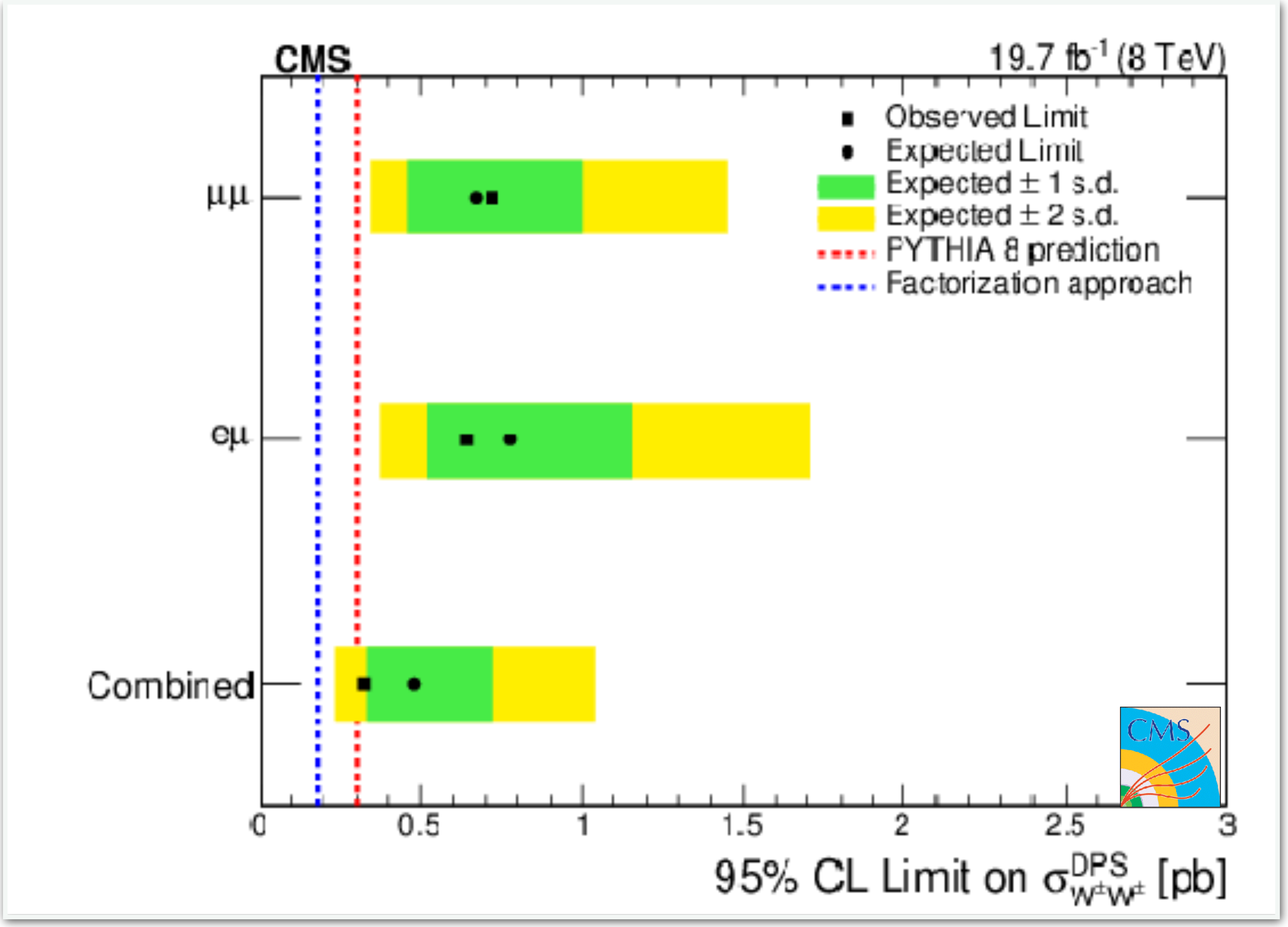


JHEP 02 (2018) 032

Constraints on the double parton scattering cross section from same-sign W boson pair production



Schematic diagram corresponding to the production of a same-sign W boson pair via the DPS process.



No excess over the expected contributions from SPS processes is observed.

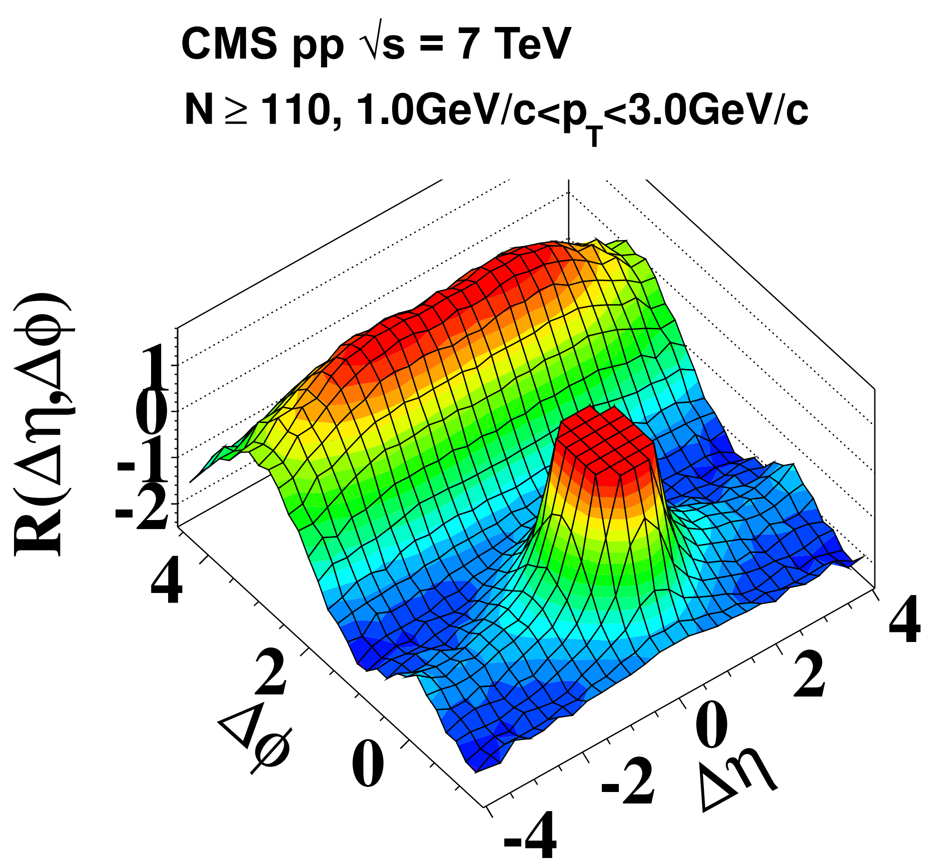
A 95% confidence level (CL) upper limit of 0.32 pb is placed on the inclusive cross section for same-sign WW production via DPS.

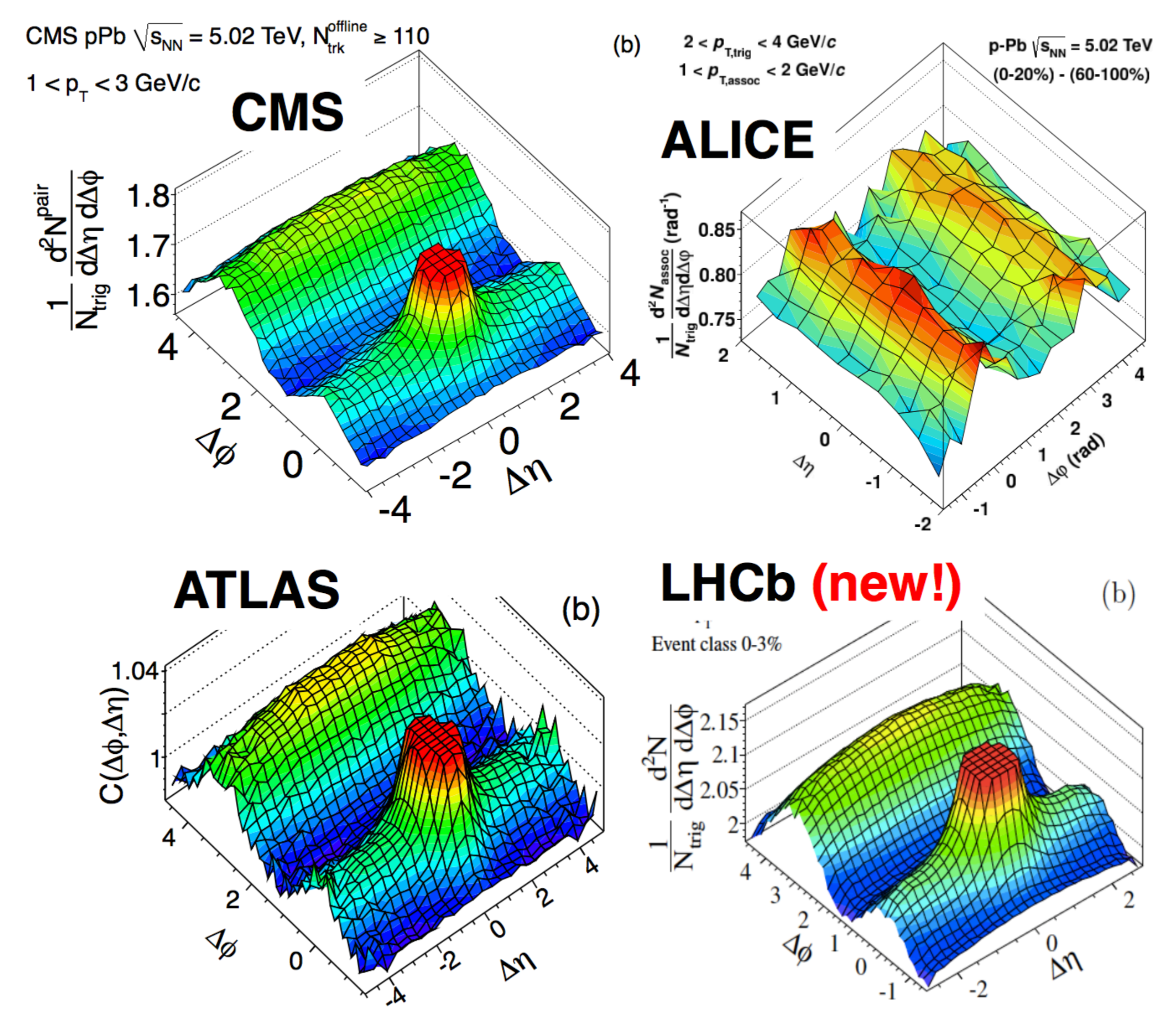
A corresponding 95% CL lower limit of 12.2 mb on the effective double-parton cross section is also derived, compatible with previous measurements as well as with Monte Carlo event generator expectations.

JHEP 02 (2018) 032

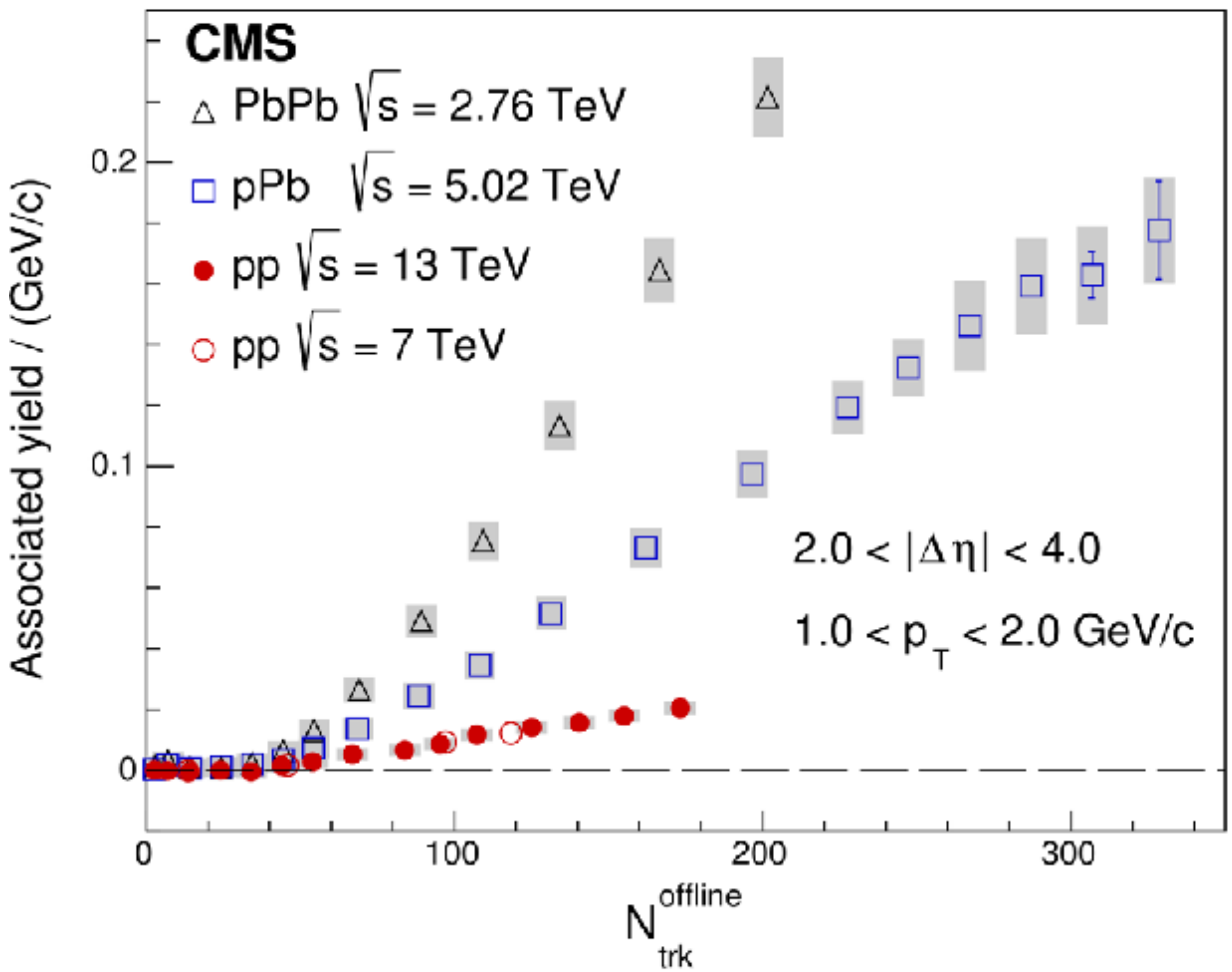
Two-particle angular correlations: the "ridge" effect

- Observation of near side long-range correlation in smaller system:
  - **Surprising!**
  - **CMS collaboration** was **the first** to discover it in small systems
  - **All LHC collaborations involved now!!!**





Comparison with different systems



Ridge yield starts to increase linearly for the three systems from N_{trk} ~ 40 (approximately)

Strong system-size dependence of the Associated Yield slope increase