Search for New Physics with Leptons in the Final State

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RWTH Aachen, III. Phys. Inst. A

On behalf of the CMS collaboration

Terascale 13th Annual Meeting 26 – 27 November 2019

Analyses
Potpurri of Aachen results

Emphasis on BSM with muon's and tau's in final state

- Excited lepton ℓ^* via CI to $\ell\ell$jj

- New heavy boson W´ to $\ell\nu$

- BSM with 3rd generation X to $\tau\nu$

- Model-unspecific search MUSIC

Run-2 data
Taken with CMS detector

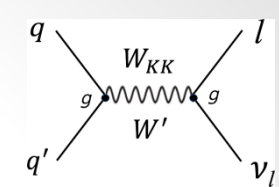# Single Lepton Searches

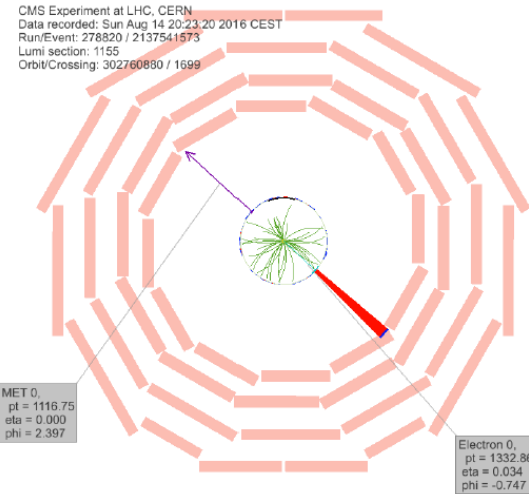III. Physikalisches Institut A

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W´ to e, μ + MET

New heavy charged vector boson (W´) predicted by many models.

Benchmark = SM-like (sequential SM-like W´).

Leptonic channels ($\ell\nu$) exhibit max. sensitivity due to high signal eff. and low bkgr (signal at high masses).

Experimental signature

- Single, isolated high p_T lepton (e,μ)
- Balanced with MET (p_T/MET ≈ 1)
- $\Delta\phi(\ell$, MET) from two-body decay

CMS Experiment at LHC, CERN
Data recorded: Sun Aug 14 20:23:20 2016 CEST
Run/Event: 278820 / 2137541573
Lumi section: 1155
Orbit/Crossing: 302760880 / 1699

MET 0,
pt = 1116.75
eta = 0.000
phi = 2.397

Electron 0,
pt = 1332.86
eta = 0.034
phi = -0.747
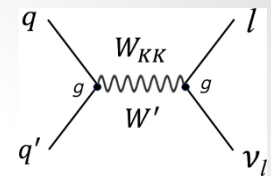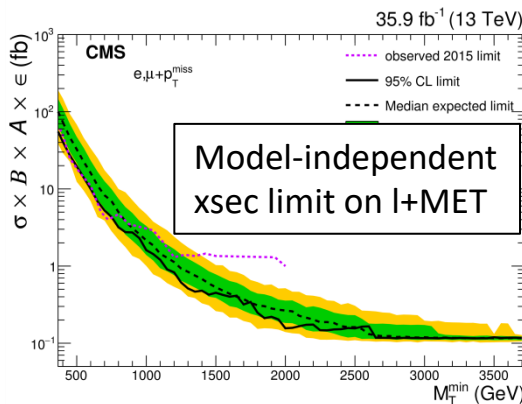
Signal selection

- Single lepton trigger, with thresholds ele≈240 GeV, μ≈50 GeV
- Kinematic selection $\Delta\phi$ > 2.5, 0.4 < p_T/MET < 1.5
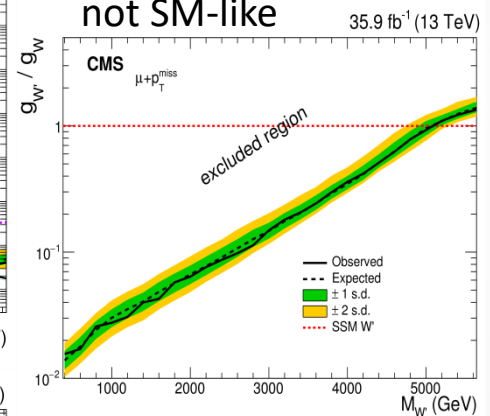
W′ to e, μ + MET

- Dominant, irreducible bkgr = W off-shell. Other: ttbar, DY, VV, QCD
- and wrongly reconstructed high-p_T leptons. Reconstruction of e, μ with p_T = O(TeV). Standard candle for performance, alignment, calibration.

M(W′) > 5.2 TeV
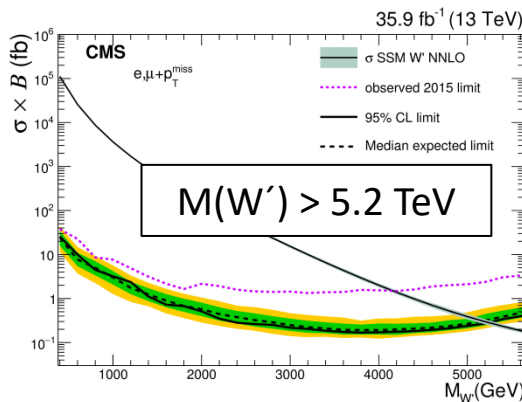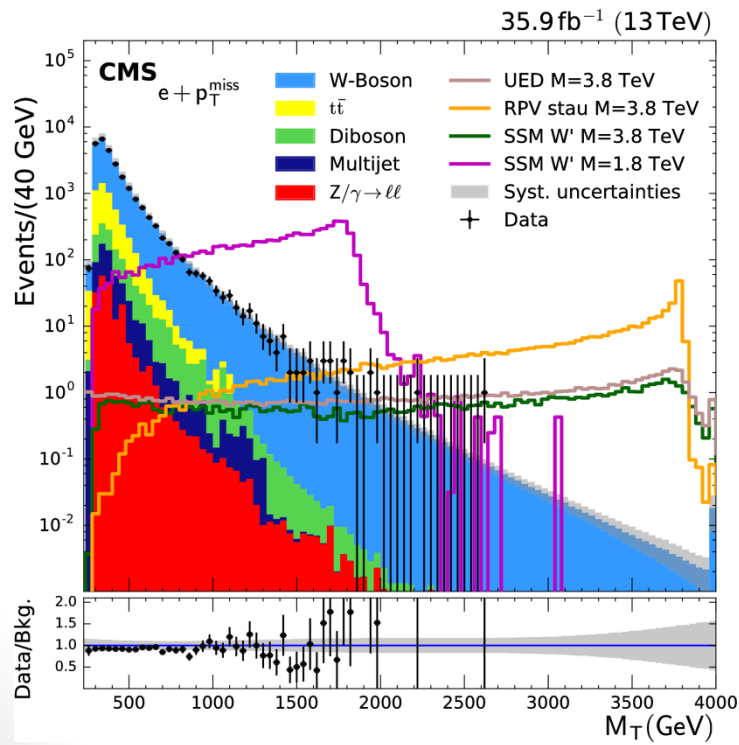
Weaker couplings, not SM-like

Model-independent xsec limit on l+MET

+ other interpretations

Discriminating variable:

$$M_T = \sqrt{2 p_T^l E_T^{miss}(1 - \cos[\Delta\phi(\vec{p}_T^{\,l}, \vec{p}_T^{\,miss})])}$$

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Single Tau

In principle, similar to single lepton channels but tau's

- **Decay:** Tau short lifetime (3 x 10^{-13} s) → 50 GeV τ travels in detector ~3 mm.
- **Reconstructed as jets:** use hadronic decays to distinguish from leptons.

Decay mode	Meson resonance	$\mathcal{B}$ [%]
$\tau^- \to e^- \bar{\nu}_e \nu_\tau$		17.8
$\tau^- \to \mu^- \bar{\nu}_\mu \nu_\tau$		17.4
$\tau^- \to h^- \nu_\tau$		11.5
$\tau^- \to h^- \pi^0 \nu_\tau$	$\rho(770)$	26.0
$\tau^- \to h^- \pi^0 \pi^0 \nu_\tau$	$a_1(1260)$	9.5
$\tau^- \to h^- h^+ h^- \nu_\tau$	$a_1(1260)$	9.8
$\tau^- \to h^- h^+ h^- \pi^0 \nu_\tau$		4.8
Other modes with hadrons		3.2
All modes containing hadrons		64.8

Single e, μ often undistinguishable from prompt e, μ signatures

Hadronic decays (1 or 3 charged hadrons) and several neutral hadrons = jet
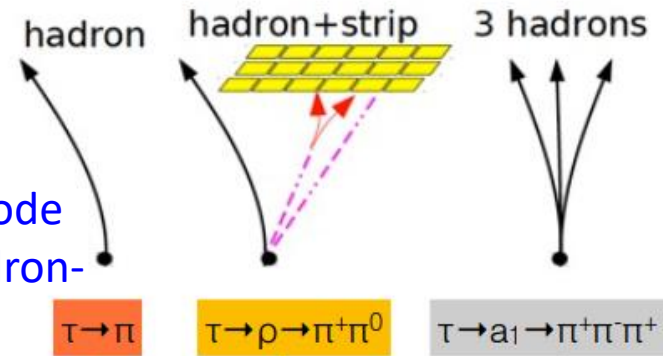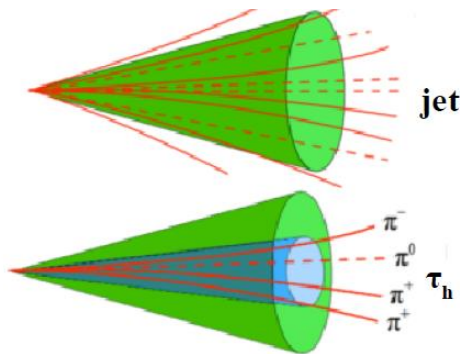
Up to now: Decay mode identification via hadron-plus-strip algorithm. Presently developing a NN-based ID.
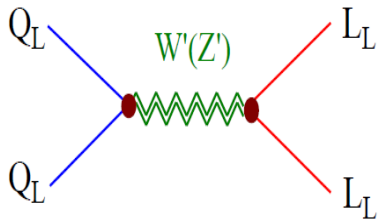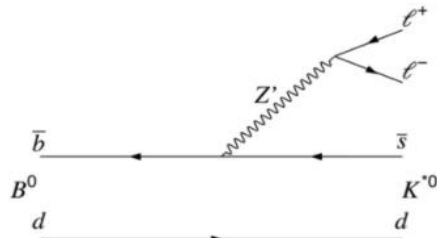
Why Tau's ?

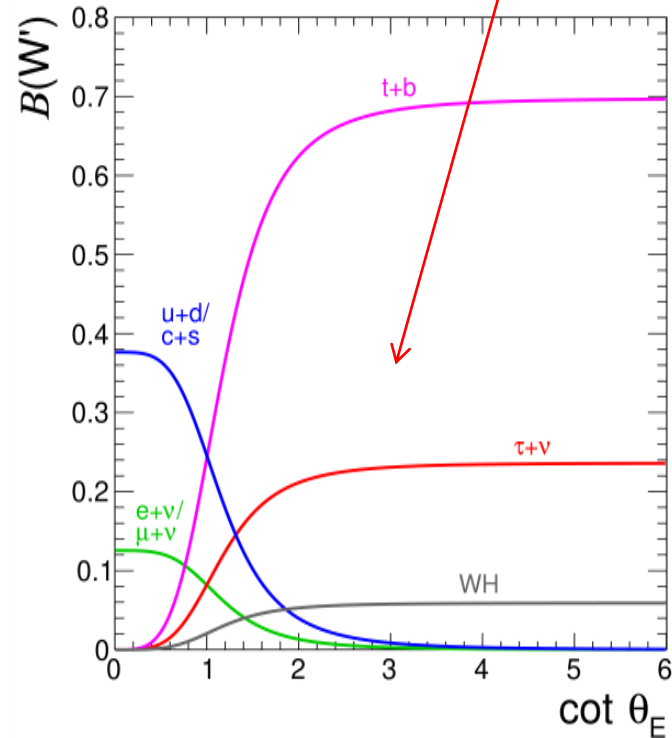Interest from observed anomalies in B-physics

Interesting for models with enhanced couplings to 3rd gen.

Possible explanation are leptoquark (LQ)-like or Z′/W′ mediators. TeV scale and 3rd generation favored.

Possible new contribution in the
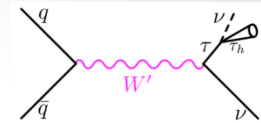$b \to s\ell\ell$ transition
in BSM scenarios involving Z'
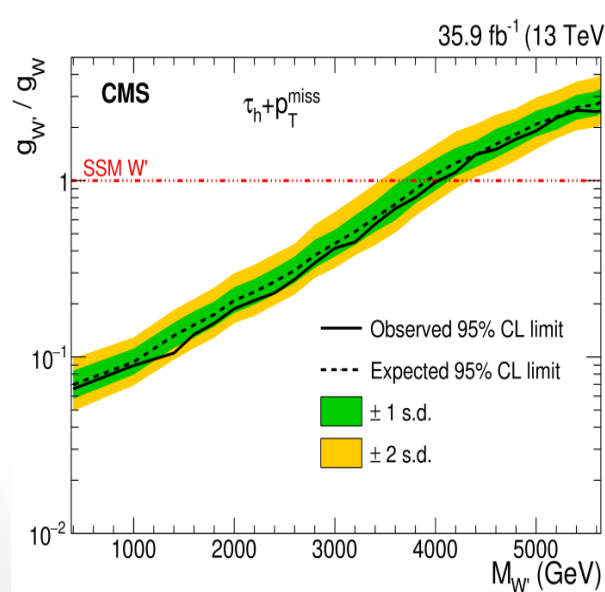
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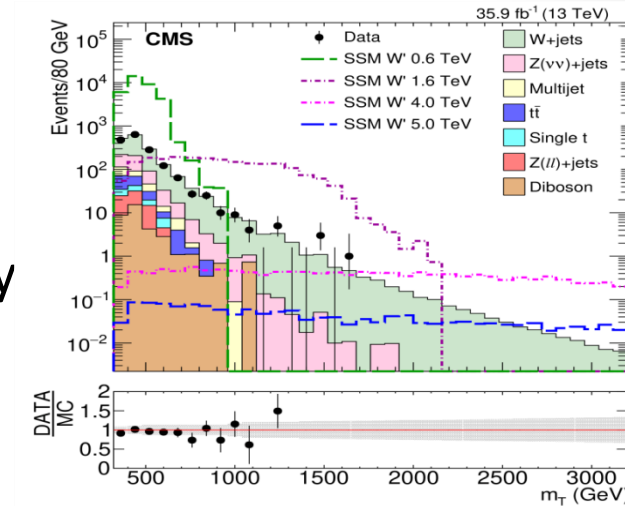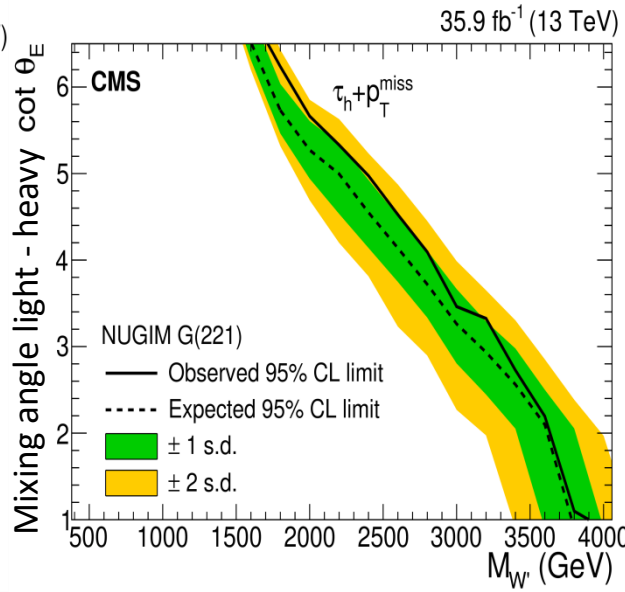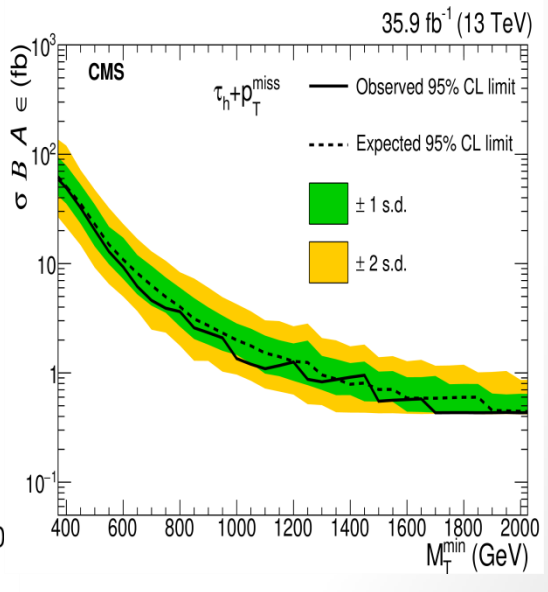# Single Tau @ Run-2

Signal selection

- τ+MET cross trigger

- Select single τ-jet from hadronic τ decay

- Kinematic selection on back-to-back

SSM interpretation: excluded up to 4 TeV

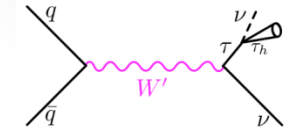Non-universal couplings: excluded 2D plane of mixing angle cot θ_E and mass

Cross-section limit

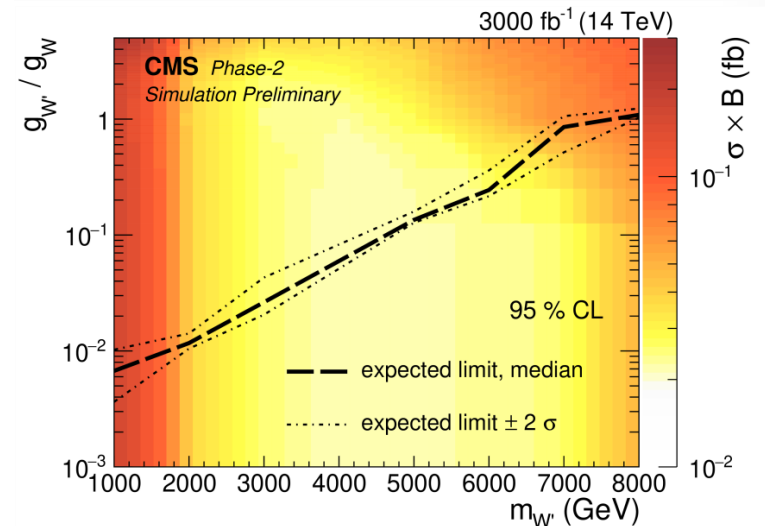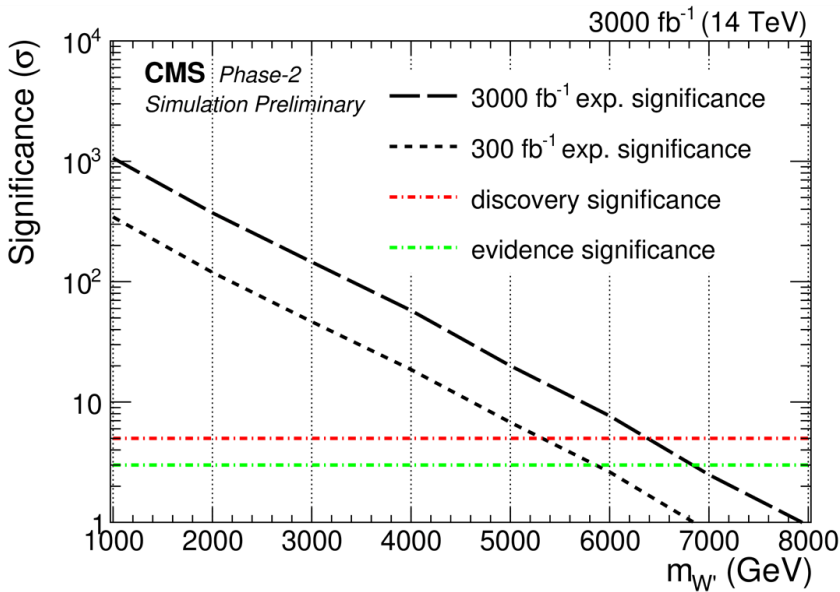III. Physikalisches Institut A
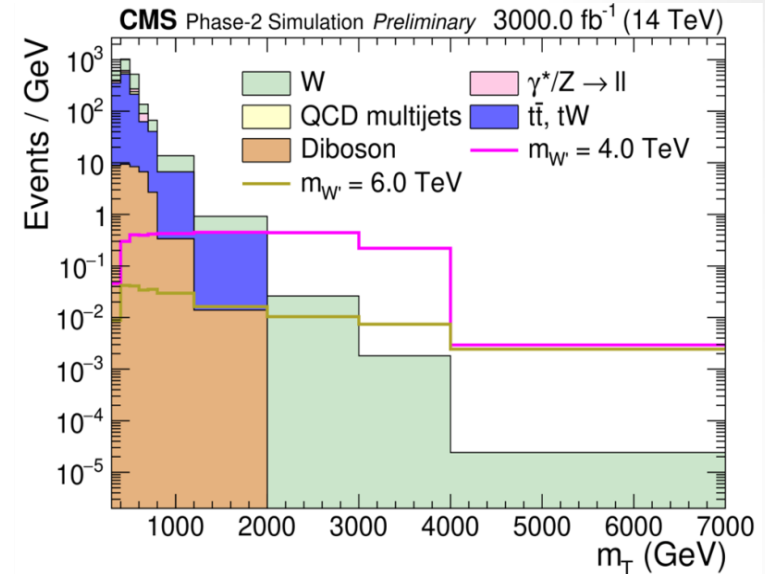
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Single Tau @ HL-LHC

At HL-LHC challenging conditions: e.g. up to 200 PU evts

Profit from 10x higher luminosity (3000/fb Phase-2 w.r.t. 300/fb for Phase-1)

Projection with DELPHES based on 2016

With 3000/fb for SSM $W' \rightarrow \tau\nu$
Discovery significance up to 6.5 TeV
Exclusion up to 7 TeV

Compositeness and Excited Leptons

Compositeness

Fermions may not be fundamental but composite objects bound below an energy scale Λ.

Would yield excited leptons (ℓ^*) or quarks (q*) produced via contact interaction (CI).

- Model parameters: Mass M(ℓ^*), compositeness scale Λ

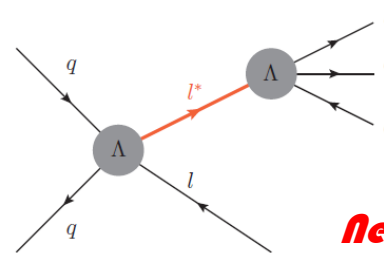- Concentrating on high masses. Cross sections scale with Λ

Excited lepton decay via gauge interaction (emission of γ, Z, W) or via contact interaction (2ℓ2j).
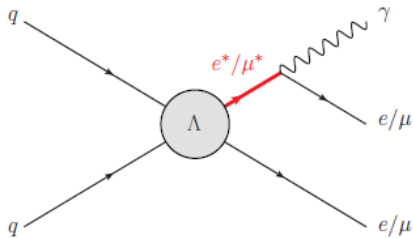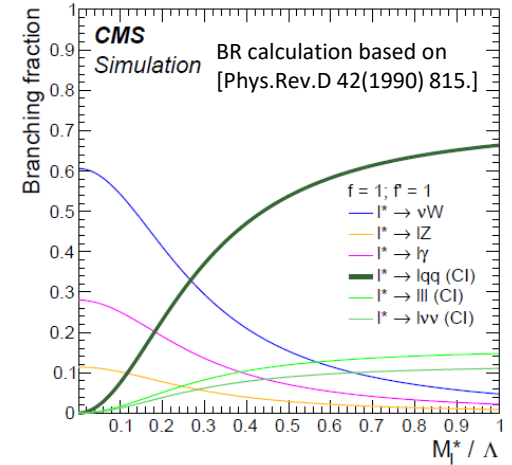
New in Run-2

Photon emission (eeγ/$\mu\mu\gamma$) most sensitive for high Λ at low masses

Run-2 exclusion with 36/fb = 3.8 TeV

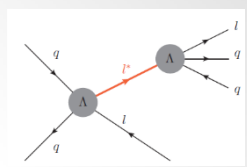Decay via CI to hadronic channels (eejj/$\mu\mu$jj) most sensitive for high masses
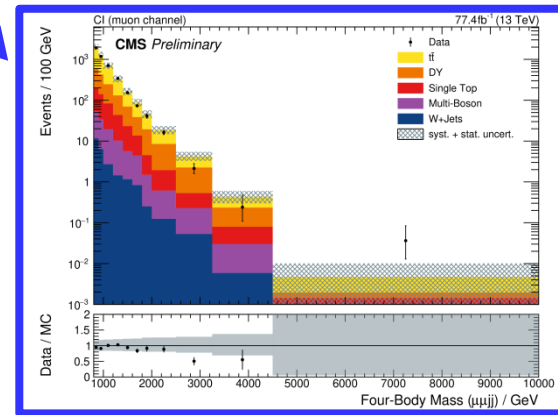
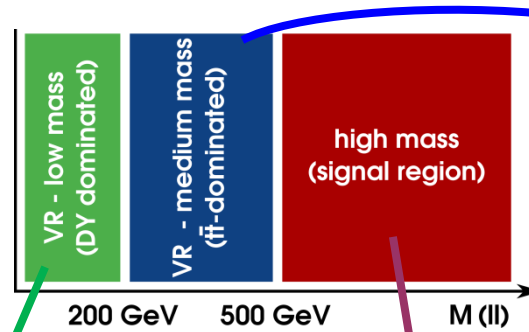Run-2 exclusion with 77/fb = 5 TeV
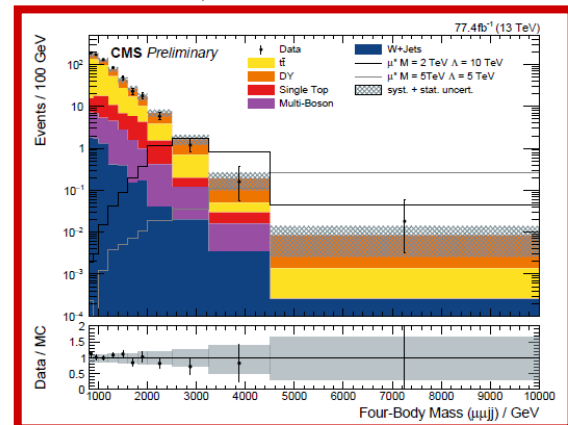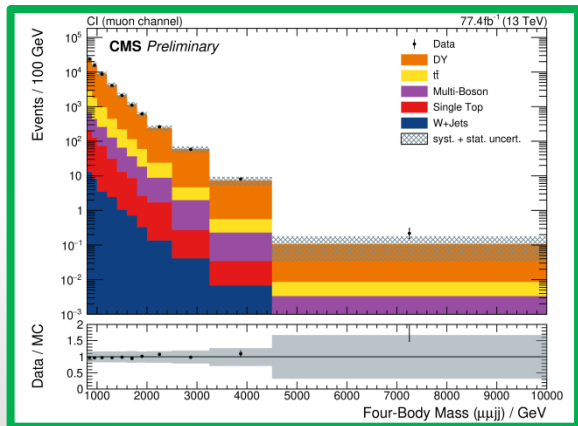
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Excited Lepton via $\ell\ell jj$ CI

Signal selection

- Selection of two same flavour leptons and two AK4 jets
- Discriminating variable: 4-body mass $M(\ell\ell jj)$
- Background composition function of $M(\ell\ell)$. Two CRs and high mass SR. Mostly DY and ttbar, estimated with simulation.
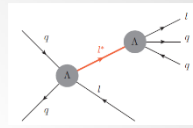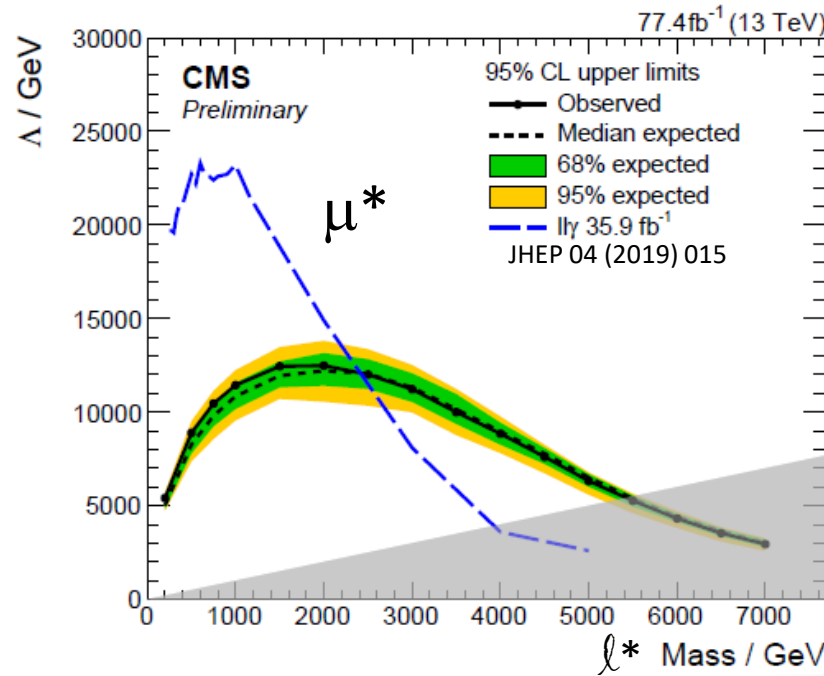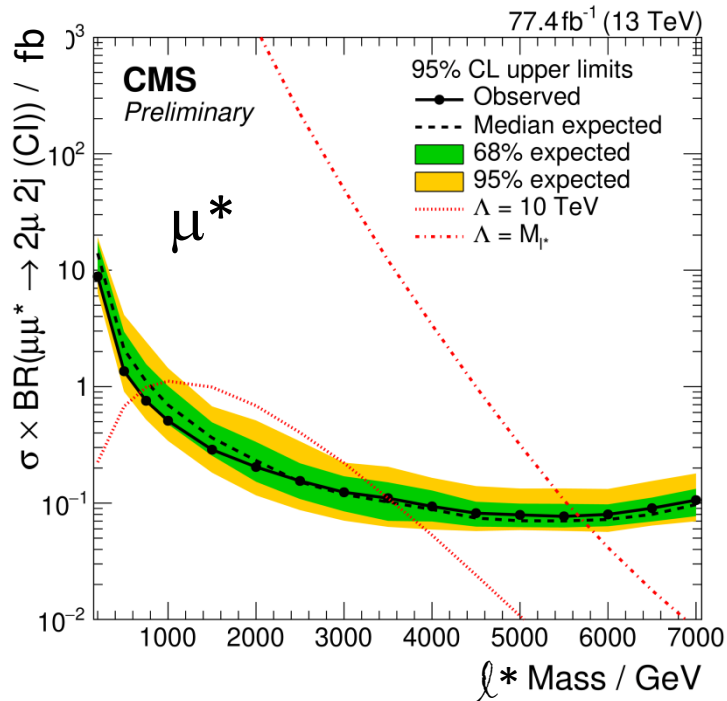

Example muon channel

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Excited Lepton via $\ell\ell$jj CI

No indication of a signal.

Results: excluding Λ < 13 TeV for M(l*) around 2 TeV.

Extend M(ℓ*) limits to 5.6 TeV (e*)/5.7 TeV (μ*).

Scenario f=f'=1 where $\ell\ell\gamma$ contributes.

Without a Model
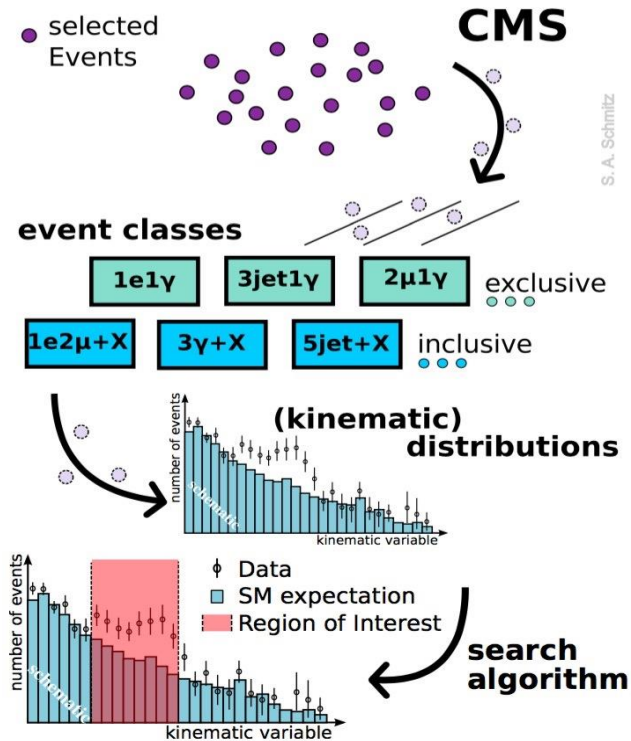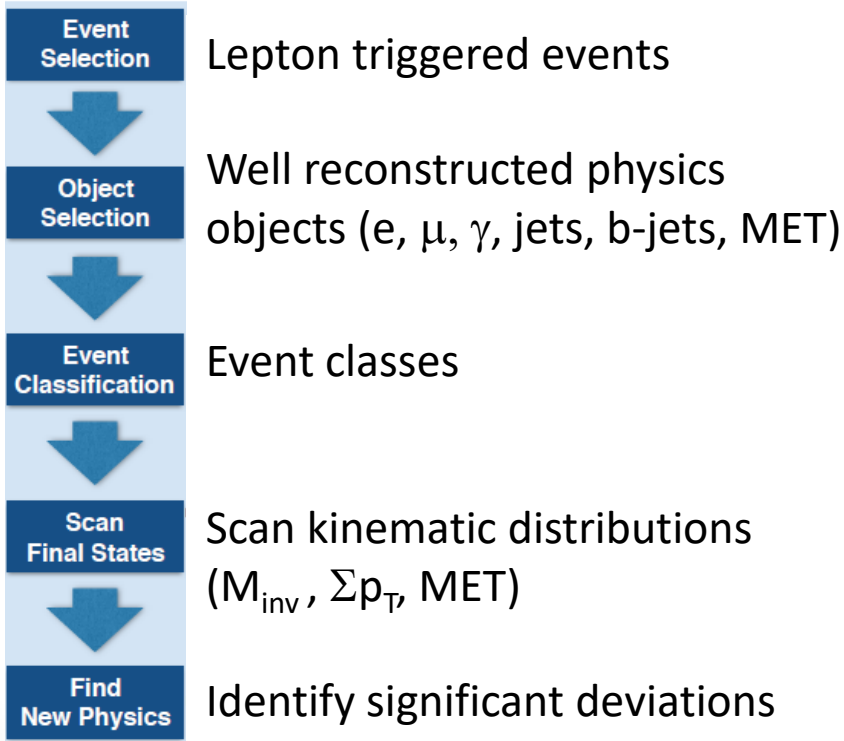
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MUSIC - Concept

Generalised <u>M</u>odel-<u>U</u>nspecific <u>S</u>earch <u>i</u>n <u>C</u>MS

Complementary to dedicated analyses

\+ Sensitive to unconsidered scenarios and „not yet thought of"

\- Large number of final states, reduced sensitivity w.r.t. Dedicated analyses

Event Selection — Lepton triggered events

Object Selection — Well reconstructed physics objects (e, μ, γ, jets, b-jets, MET)

Event Classification — Event classes

Scan Final States — Scan kinematic distributions (M_{inv}, Σp_T, MET)

Find New Physics — Identify significant deviations

MUSIC - Event Classification

- Scan kinematic distributions (M_{inv}, Σp_T, MET) for discrepancies between data and simulated SM expectation

- Correct for look-elsewhere-effect with several toy experiments

- Challenging to draw conclusions based on scans of hundreds of final states
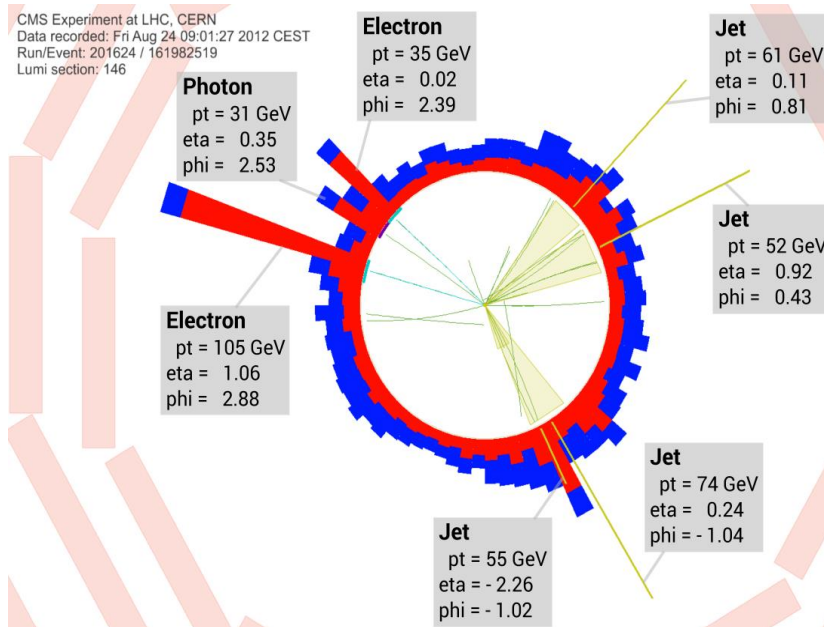 → Global description as graph of #evt classes vs deviation (-log(p))

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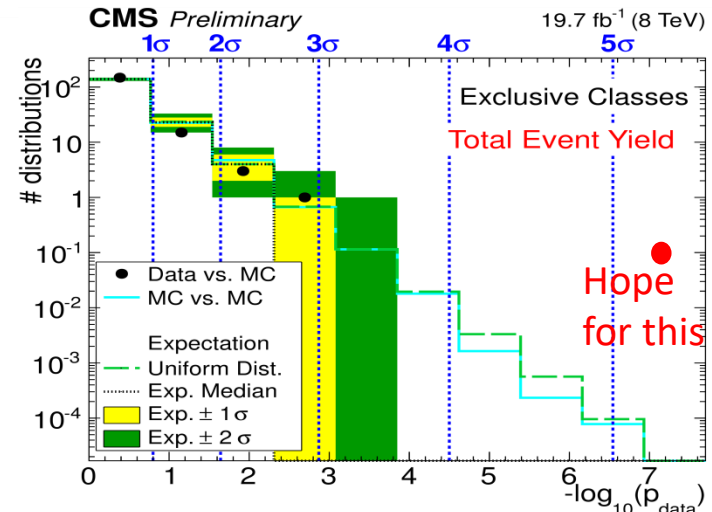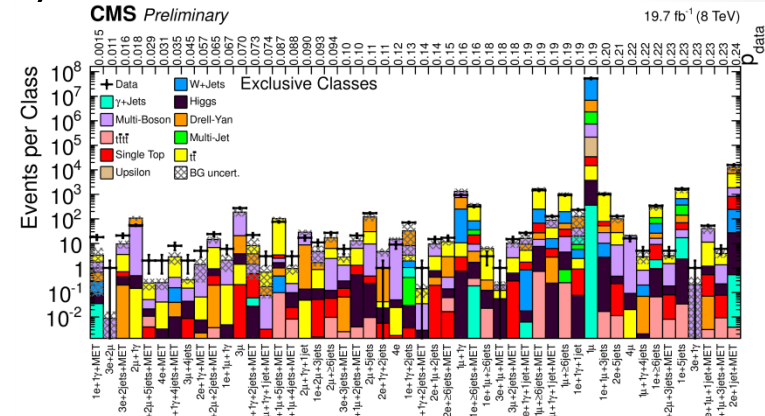
MUSIC – Proof of Concept
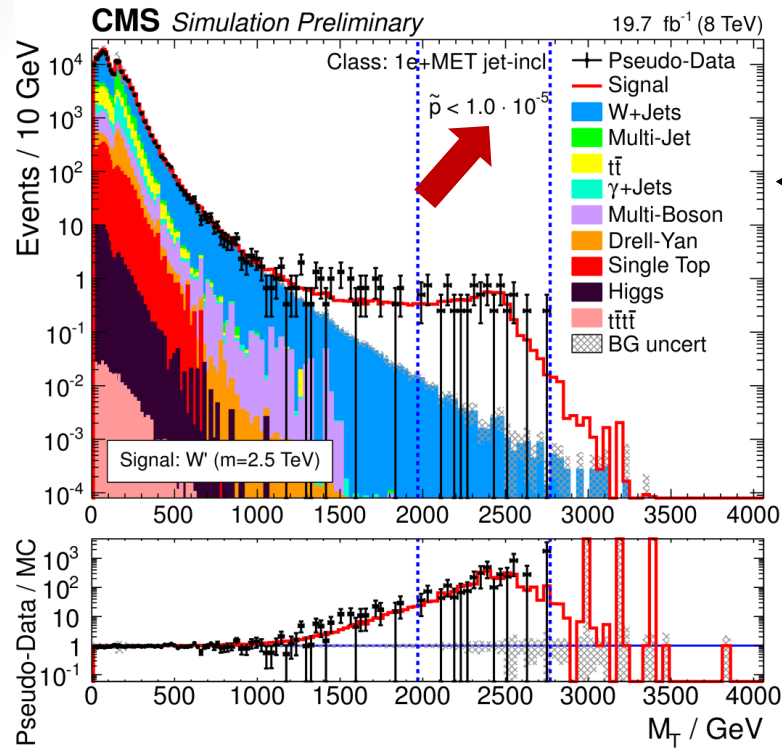
Add pseudo-data from W´ BSM model

Run MUSIC workflow to determine sensitivity

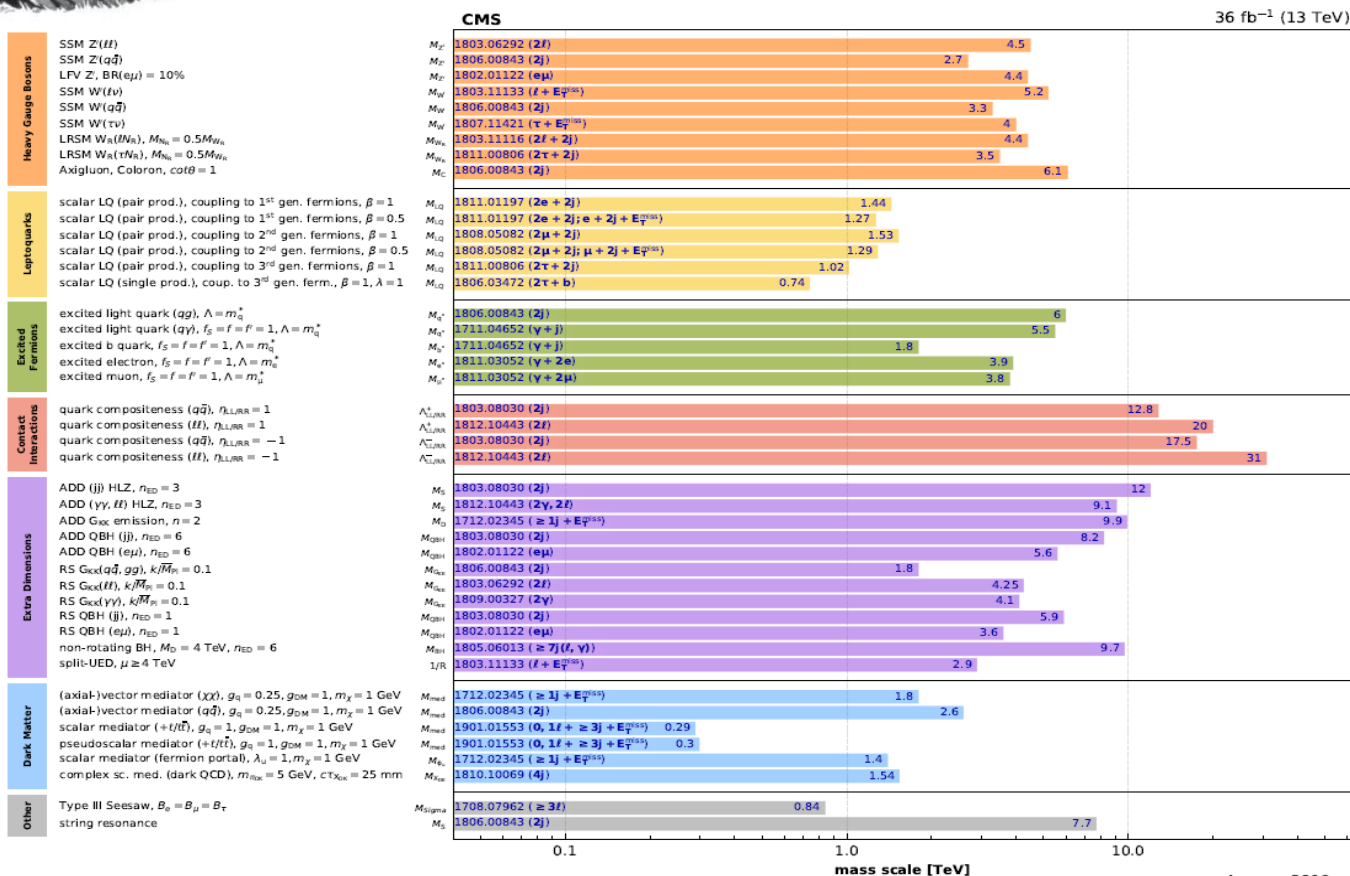Find unusual event which otherwise may have been overlooked

Outlook: Keep searching... Stay tuned

Many more CMS results on

http://cms-results.web.cern.ch/cms-results/public-results/publications/EXO/index.html

Overview of CMS EXO results

CMS — 36 fb^{-1} (13 TeV)

Selection of observed exclusion limits at 95% C.L. (theory uncertainties are not included). January 2019

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BACKUP

Searches are performed with the CMS detector

SUPERCONDUCTING COIL

CALORIMETERS

ECAL
Scintillating PbWO4 crystals

HCAL
Plastic scintillator/brass sandwich
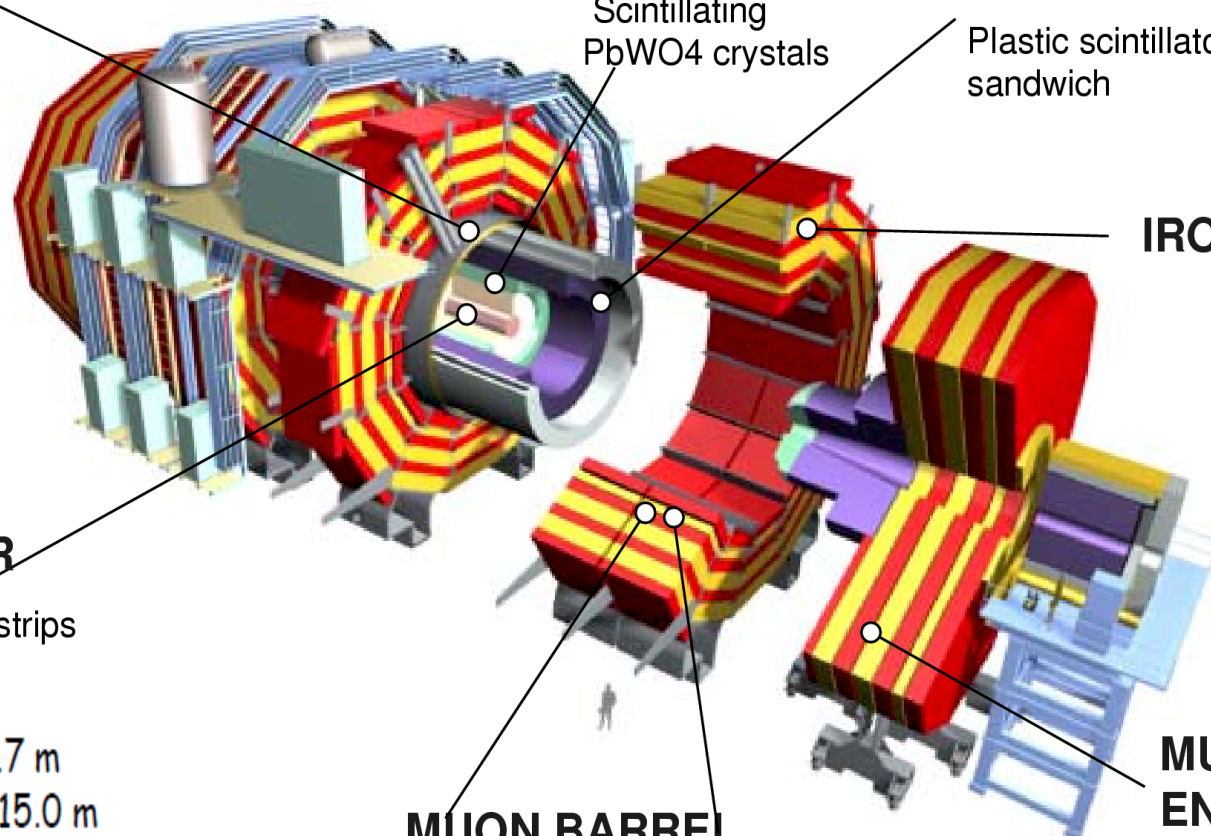
IRON YOKE

TRACKER
Silicon Microstrips
Pixels

Overall length : 28.7 m
Overall diameter : 15.0 m
Total weight : 14000 tons
Magnetic field : 3.8 T

MUON BARREL
Drift Tube Chambers (**DT**)
Resistive Plate Chambers (**RPC**)

MUON ENDCAPS
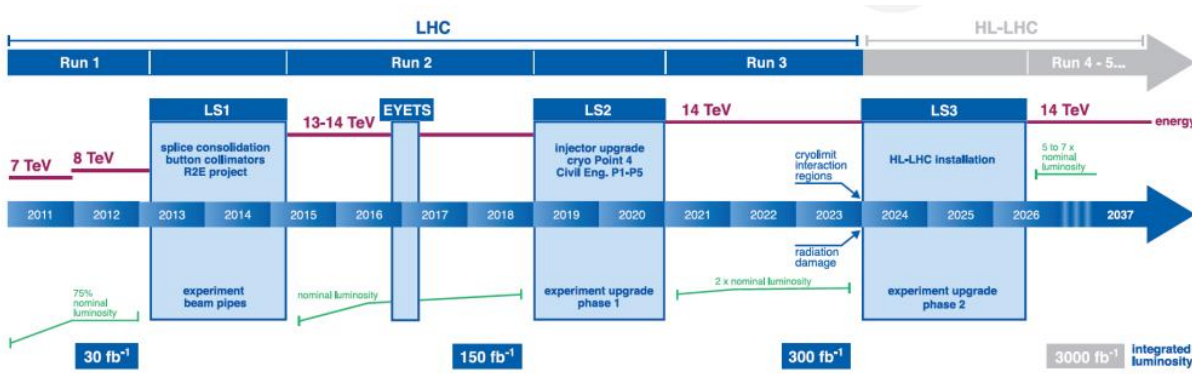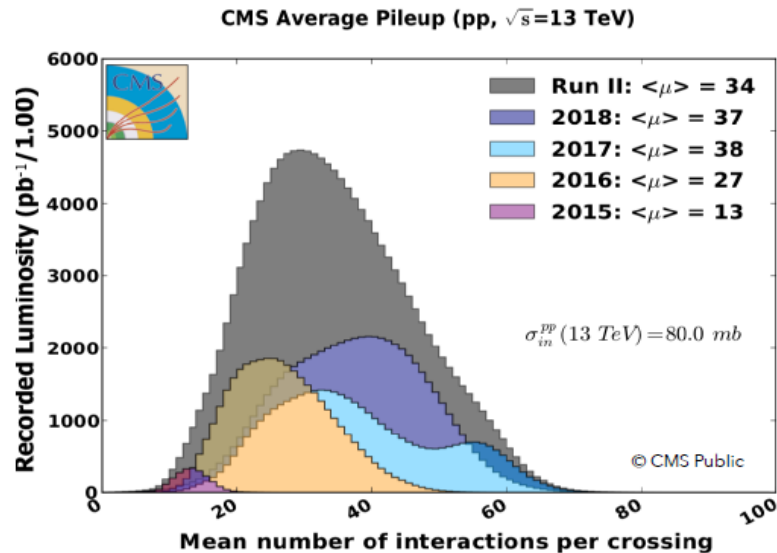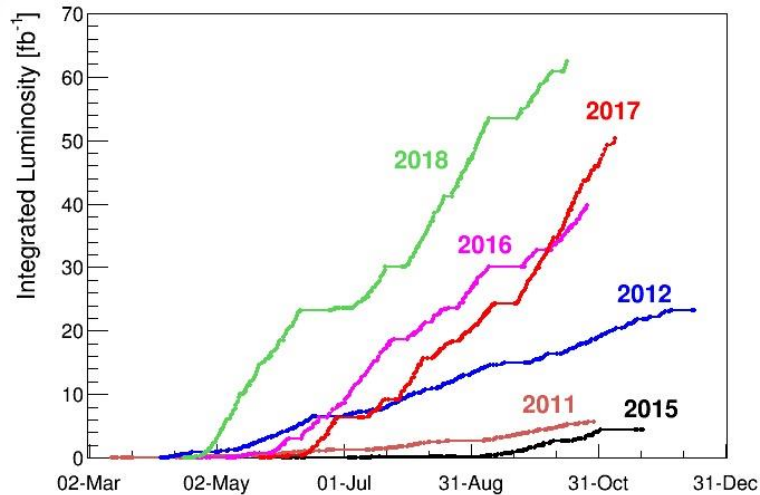Cathode Strip Chambers (**CSC**)
Resistive Plate Chambers (**RPC**)

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LHC Performance

CMS Average Pileup (pp, $\sqrt{s}$=13 TeV)

Run II: $\langle\mu\rangle = 34$
2018: $\langle\mu\rangle = 37$
2017: $\langle\mu\rangle = 38$
2016: $\langle\mu\rangle = 27$
2015: $\langle\mu\rangle = 13$

$\sigma_{in}^{pp}(13\ TeV) = 80.0\ mb$

LHC very successful !

Run-2 with ≈140 fb^{-1} of high quality data

~900 CMS publications since LHC started

- **140 fb^{-1}** by 2018 Run 2
- 300 fb^{-1}: by 2023 Run 3
- 3000 fb^{-1}: by 2037 High-lumi LHC (HL-LHC)