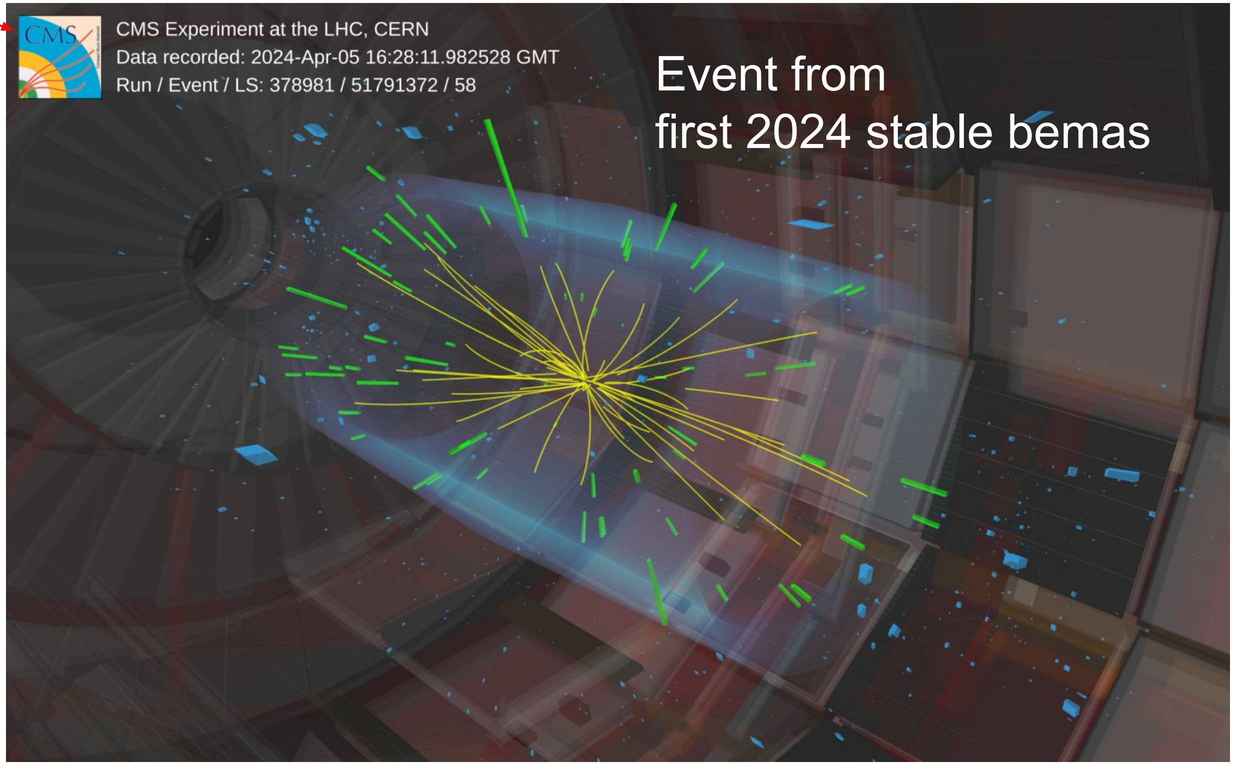
CMS NA Status in 202~~4~~5

Alberto Orso Maria Iorio
For the CMS Naples group

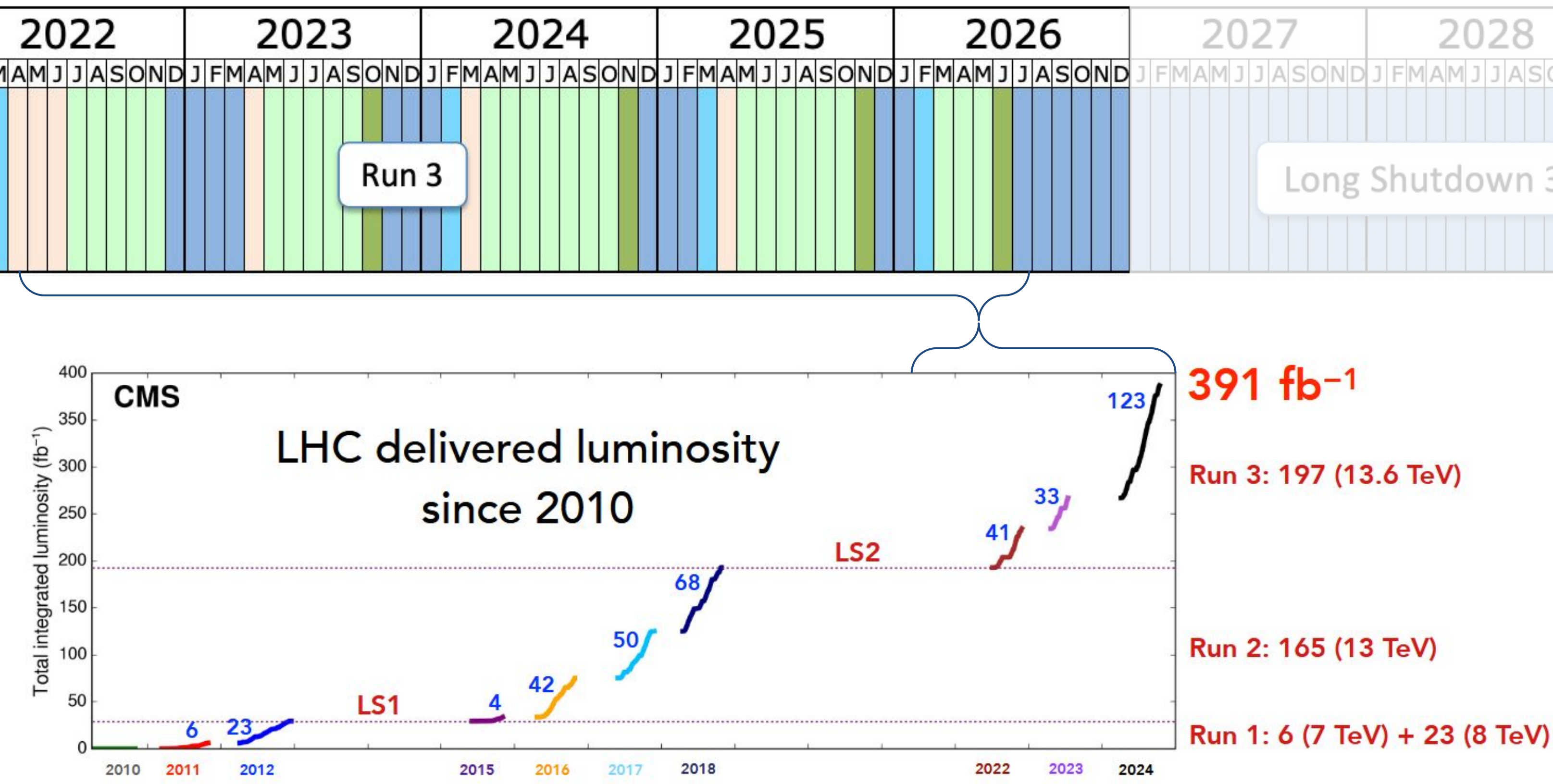
The LHC taking off with the luminosity!

LHC data taking in full swing!

- **13.6 TeV** center-of-mass energy
- Inst. luminosity up to $2 \cdot 10^{34}$ cm^{-2} s^{-1}
- A total of **123 fb delivered**
- this year alone comparable with Run 2!



Where are we with Run 3?



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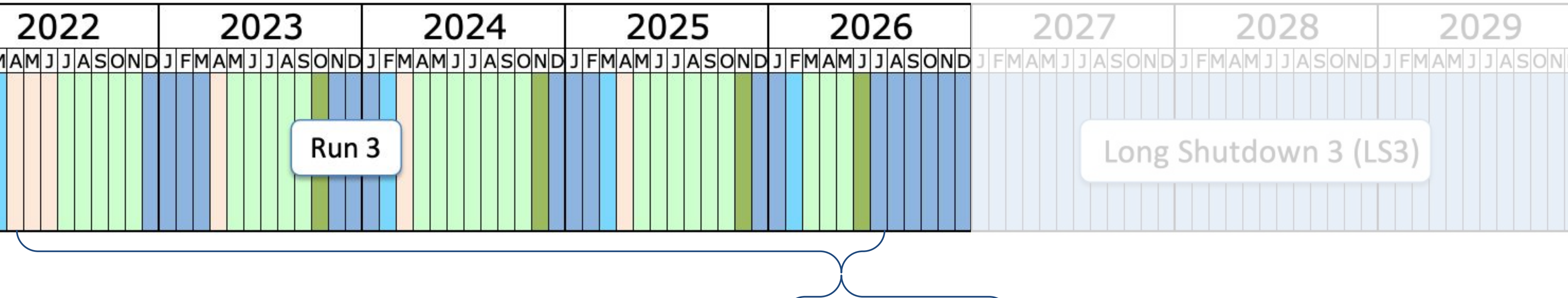
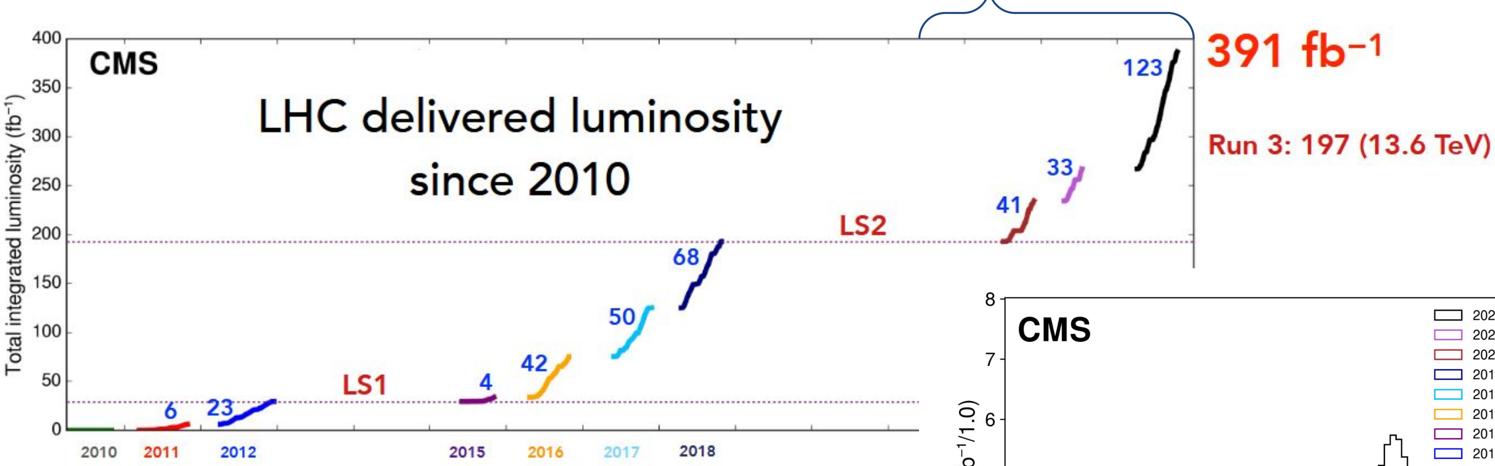
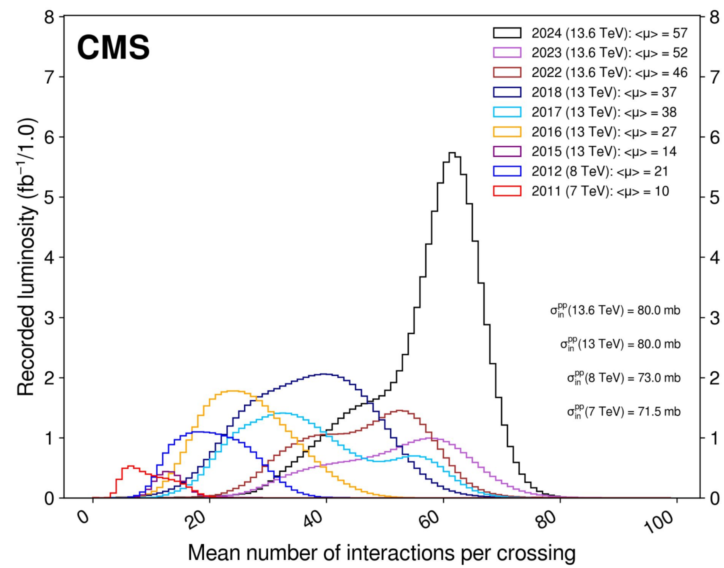
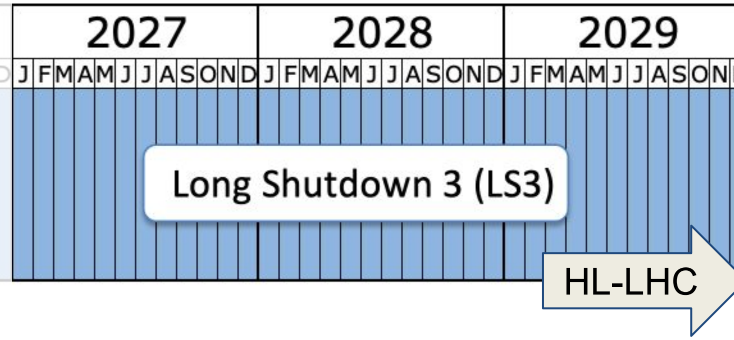






Record luminosity…
…but also record #pileup events!

Looking forward

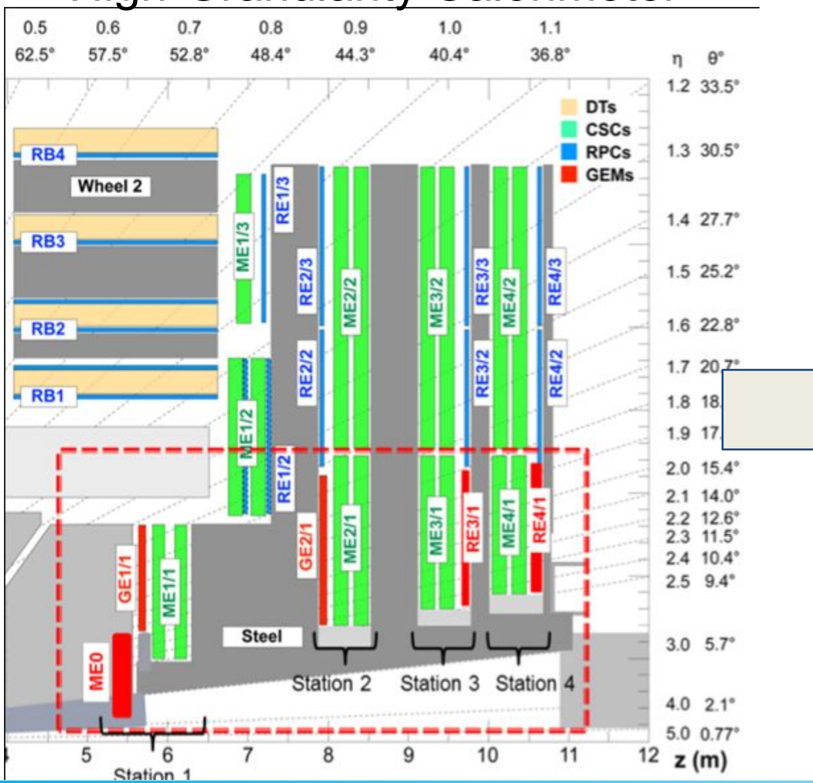


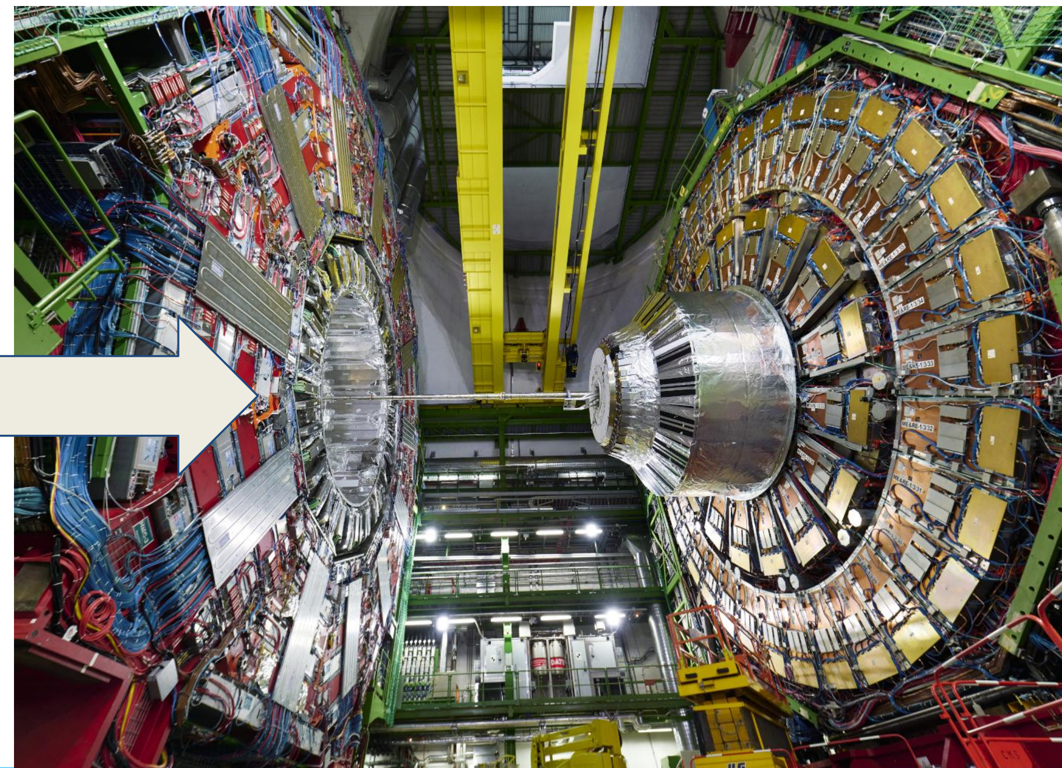
Phase 2 upgrade:

- additional low angle, high-rate muon detectors
  ⇒ GEM, iRPC

And also:

- Additional silicon tracker layers, trigger input
- High-Granularity Calorimeter



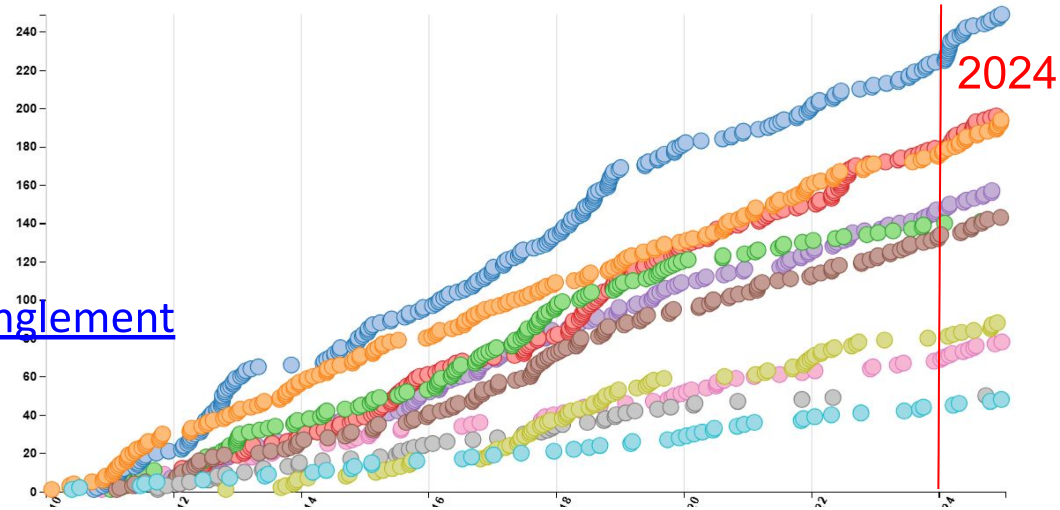


2024 CMS physics results: numbers and highlights

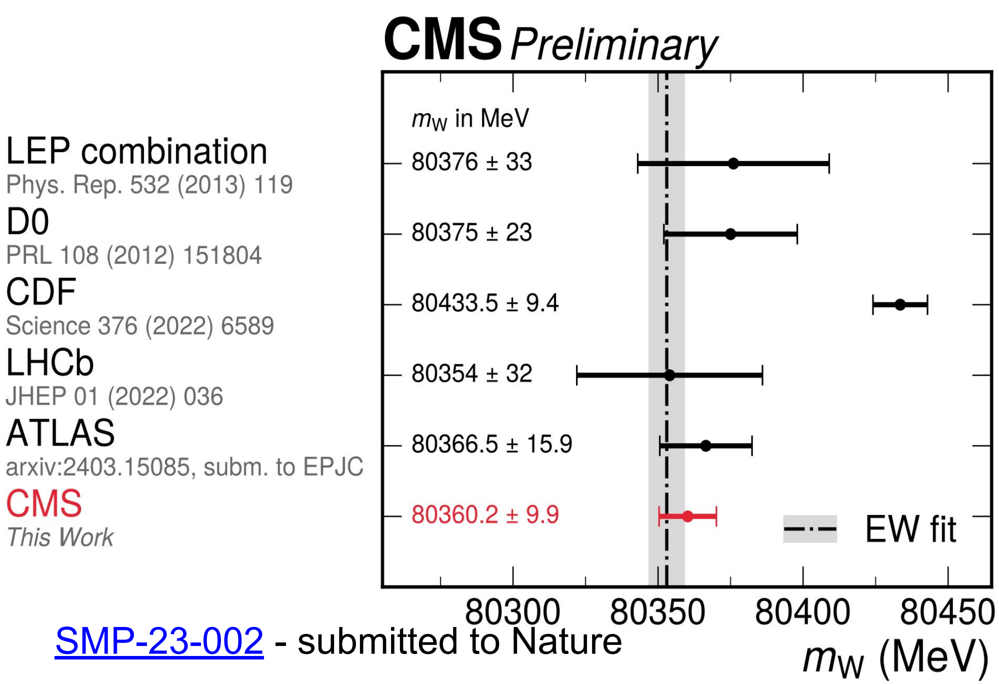
110 results approved
100 papers published

Among which:

- 3 CERN press releases: [sin2θ](), [mW](), [entanglement]()
- 8 CERN [News]()
- 54 Physics briefings, see also [here]()

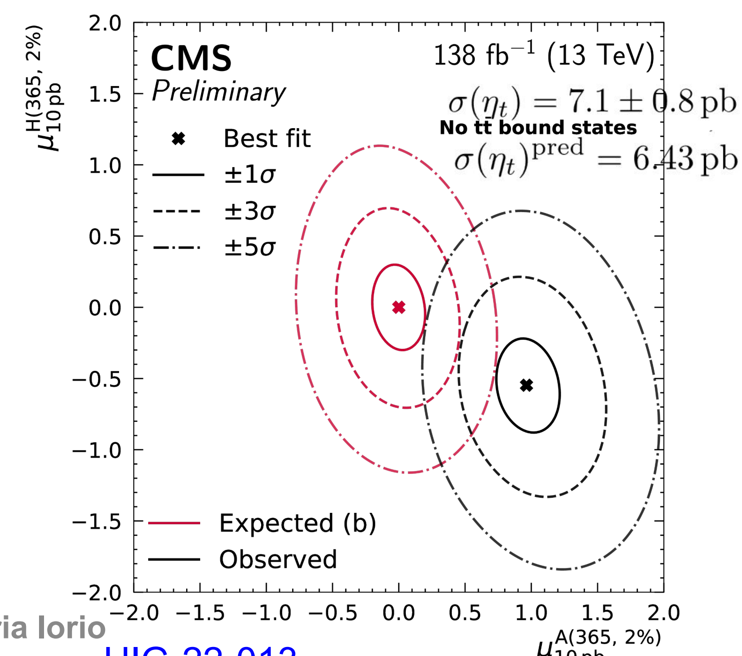


W boson mass measurement:



[SMP-23-002]() - submitted to Nature

Top quark-antiquark bound state



[HIG-22-013]()

CMS@NA people

Staff:

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L. Lista (PO UniNA)

P. Paolucci (DR INFN)

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Antonio Vanzanella

Antonio Pandalone

Francesco Cassese

Giuseppe Passeggio

PhD students:

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Francesco Confortini (PhD UniNA I year)

Carlo Di Fraia (PhD UniNA II year)

Leonardo Favilla (PhD SSM II year)

CMS Master theses in 2024:

Benedetta Argiento

Fabrizio Salerno

CMS PhD theses defended in 2024:

Francesco Carnevali

Responsibilities in 2024:

RPC Project manager (L2): S. Buontempo

HV GEM manager (L3): Antimo Cagnotta, A.O.M. Iorio

Very Heavy Fermion convener (L3): F. Fabozzi

CMS@NA detector activities

Activity

GEM (Gas Electron Multiplier)

- **Power system** responsibility
- GEM Operation at CERN
- Study of discharges
- Background studies

RPC(Resistive Plate Chambers)

- Background studies
- Project Management

CMS@NA detector activities

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With the collaboration

- HV system maintenance
- realization of HV for the new chambers
- on site testing
- Detector commissioning

- Muon chambers background studies
- Physics components splitting
- Relation with Luminosity and monitored current

- Governance of the RPC group

Involvement in operation and upgrade

CMS@NA detector activities

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- Governance of the RPC group

Involvement in operation and upgrade

In Naples

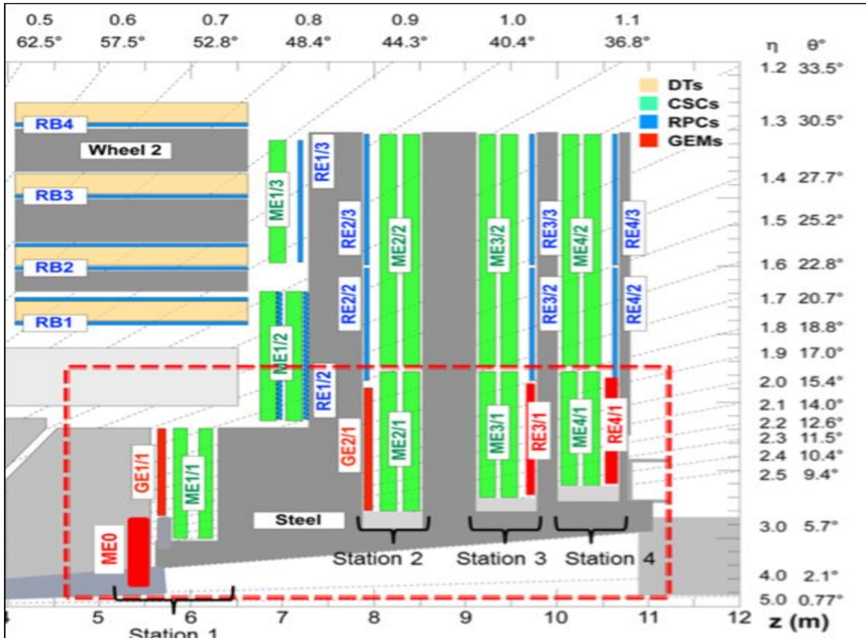
- Local setup for studies of GEM behavior and HV commissioning
- Assembly and testing of HV components
- Special PICOAmmeter to study current flow in GEM

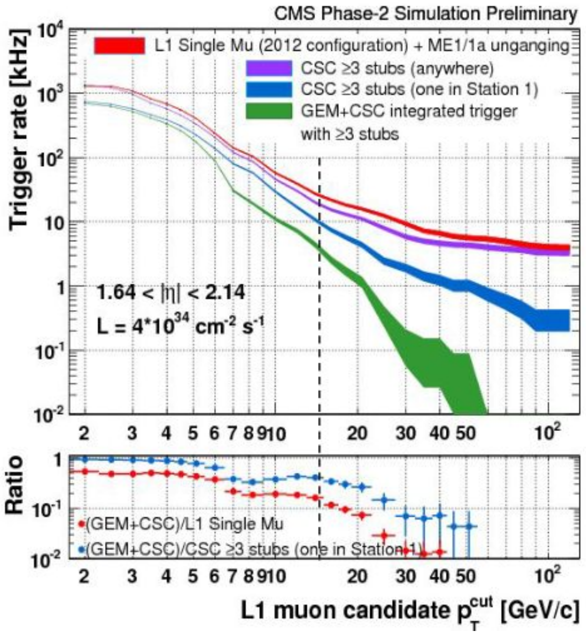
The muon system upgrade

HL-LHC upgrade:

- Increase in **instantaneous luminosity** :
  $2\ 10^{34} \rightarrow 5\ 10^{34}\ cm^{-2}\ s^{-1}$
- Increase in **pileup events**
  From an average of **~50** to an average of **140**

⇒Increased overall background: issues for **trigger rate, reconstruction, detector aging**





New GEM chambers :

- aim to **significantly reduce** the background-induced trigger rate in the low-angle (high-eta) region, $|\eta| > 1.6$

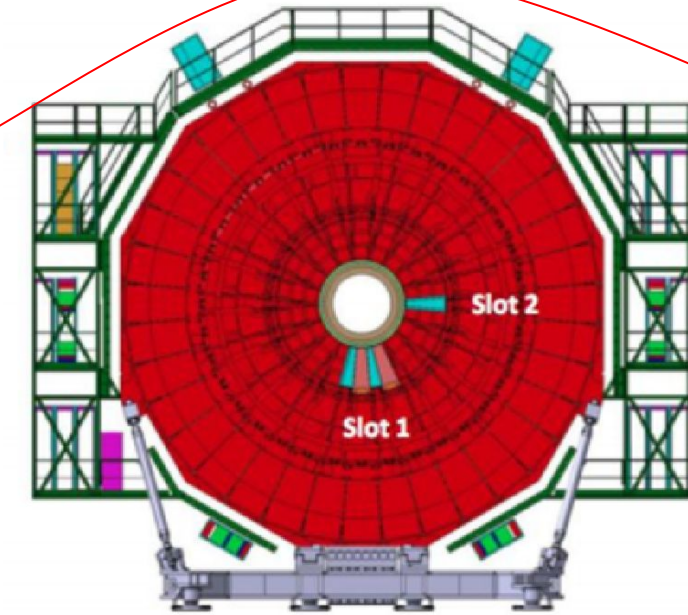
An in depth description of a GEM's workings in Leonardo's talk!

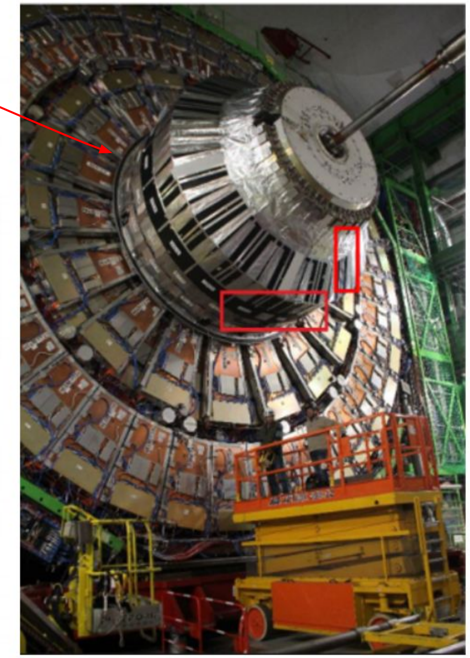
The GEM upgrade challenge

3 stations to be installed

- **GE1/1** : installed before Run 3
→**144 chambers**

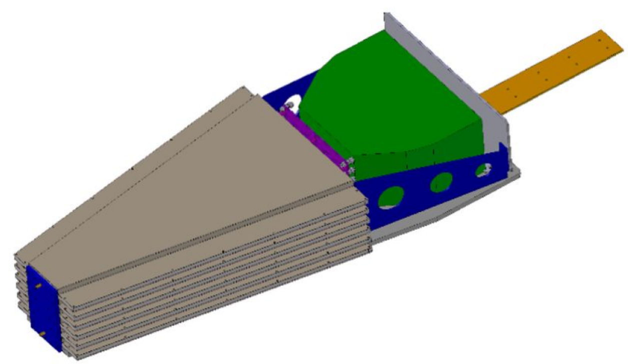
- **GE2/1** and **ME0**: to be installed after Run 3 - during LS2
→**216 chambers each**



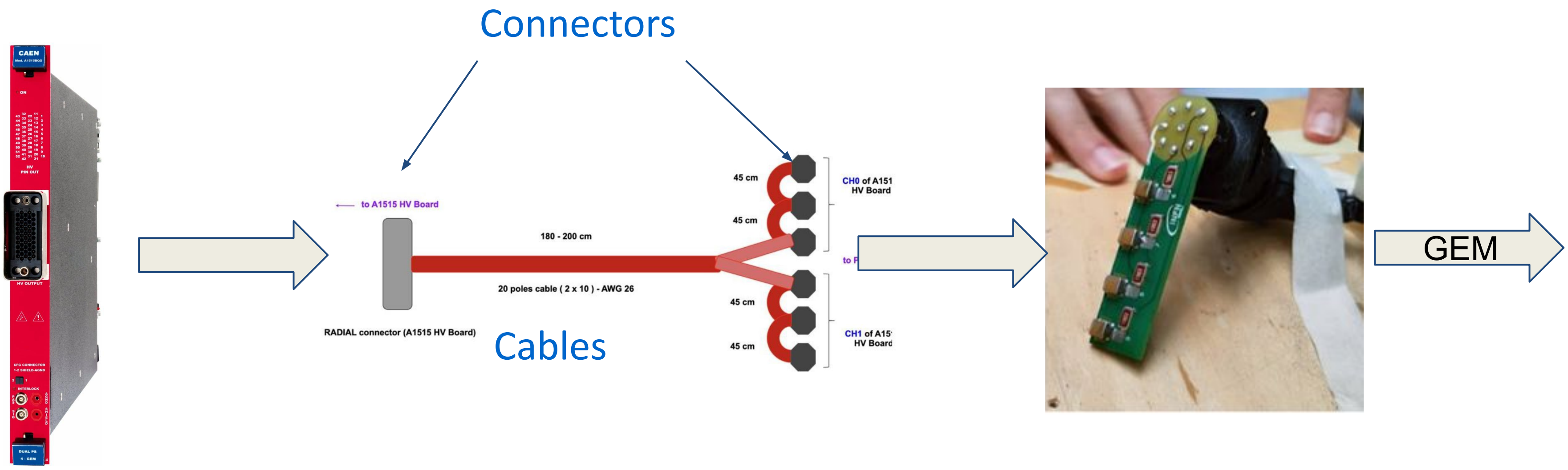


Some key features:

- **Triple-GEM**, with multiple multiplication stages
- 70/30 mixture of **Ar/C0_2**
- Very **large chambers** for GE2/1 (~2m^2 each)
- Stacks of **6 chambers** for ME0



Power System for ME0: schematic “flow” and main components



HV board:
CAEN A1515TGHP
- Can provide HV to 6 chambers
- Tested by CMSNA at CERN
- power needs to be distributed

Distribution
- Cable split the output
- Connectors at multiple junctions
- Need to be prepared ad hoc at CERN

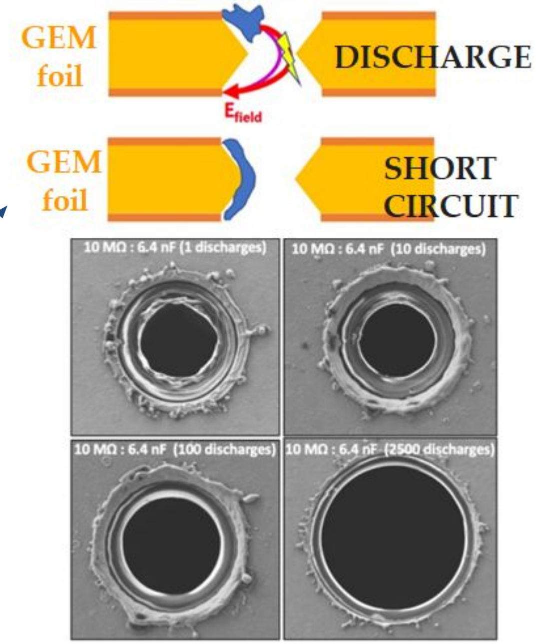
HV filters
- Necessary for noise reduction
- Designed by CMSNA
- Preparation by the NA team in Naples and at CERN

GEM operation

Large contribution to GEM operation and studies

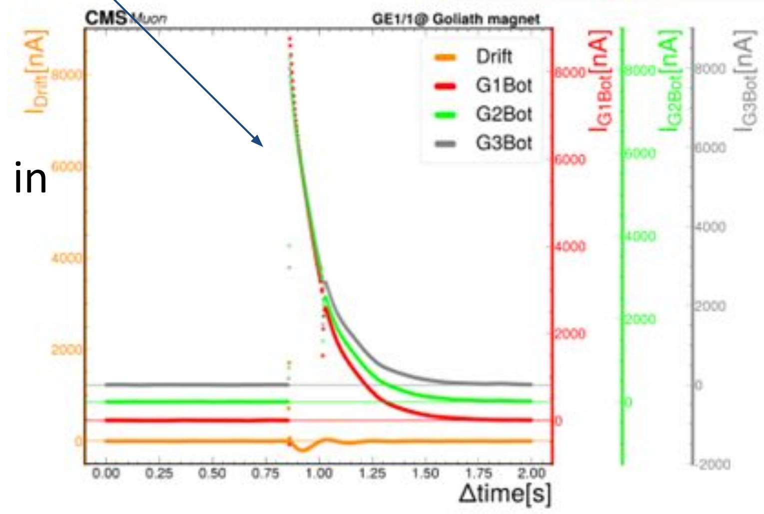
- **GE1/1** : installed before Run 3 ⇒ chance to monitor the chambers' behavior!

- Main threat to detector workings: **presence of discharges**



Studies and counter-measures

- Previous work by **A.Cagnotta** et al. : [2023 JINST 18] [P11029] (discharge study with magnetic field before Run-II) → allowed to decide operational protocol



- During last year further studies of **mitigation strategies** in case of excessive discharges leading to short circuits, exploiting **distribution of HV**

- Particularly important for **GE2/1** and **ME0** chambers, which are more tricky due to size/position

GEM @ Naples

Triple-GEM prototype at Naples

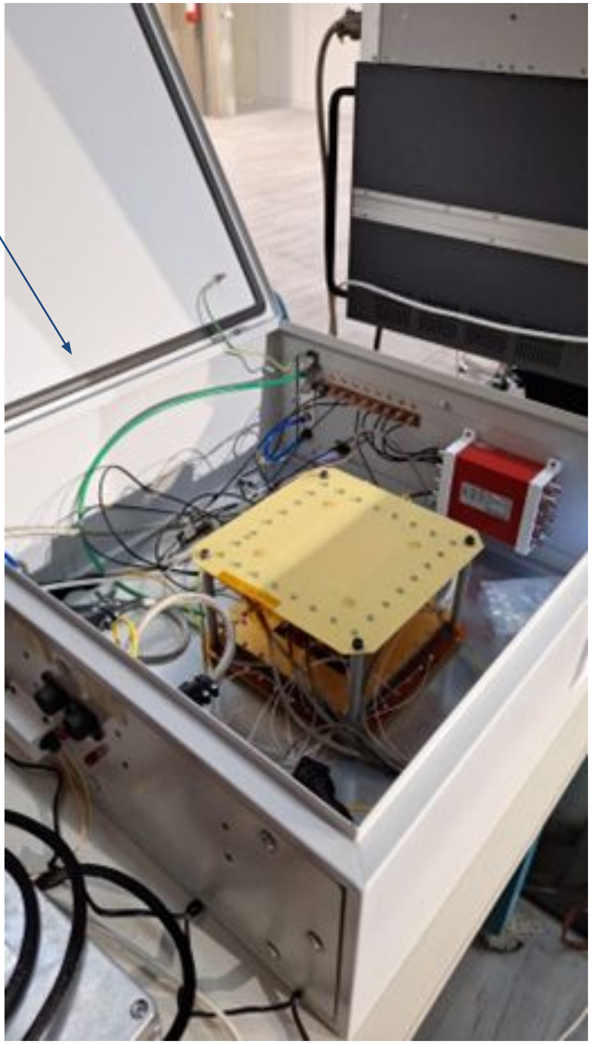
- Same gas mixture as CMS GEM, but much smaller scale

- **Test-bench** for some of chamber's features

- Allows to study the **full HV chain** in a realistic scenario

- Use of an "homemade" **PICOAmmeter**

- More in Leonardo's talk!



Contributions from:
A. Cagnotta, F. Confortini, C. Di Fraia, L.Favilla

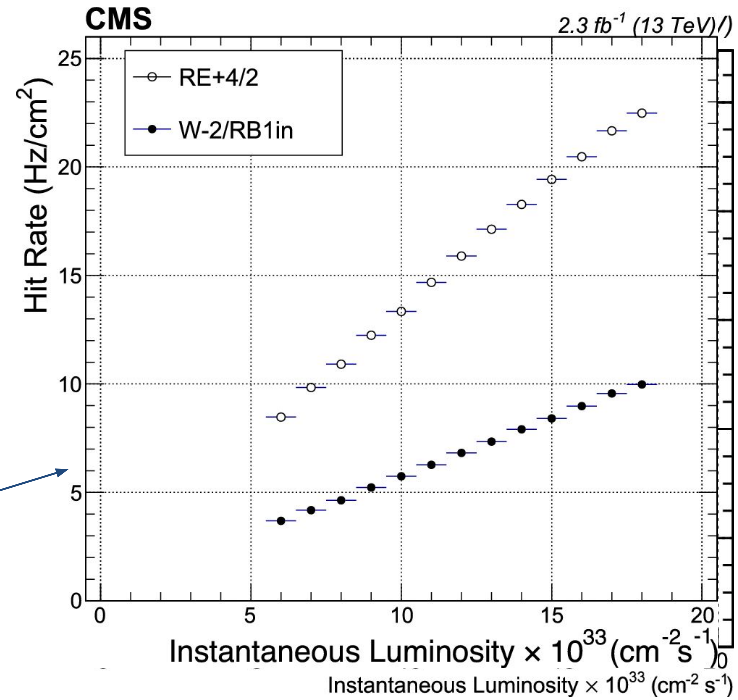
Muon background studies: a cross-detector effort

Study of muon background in RPC and GEM

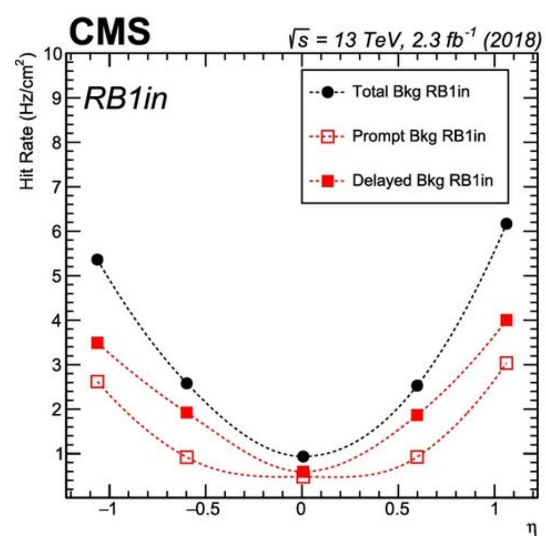
- Study of the hit-rate per unit surface of the detectors

- can be associated to different **physics contributions** that are not prompt muons.

- Depends on the overall activity in the detector → **correlated to luminosity**



- allows also to highlight the **more exposed parts of the detector** to radiation (typically the most forwa ones)



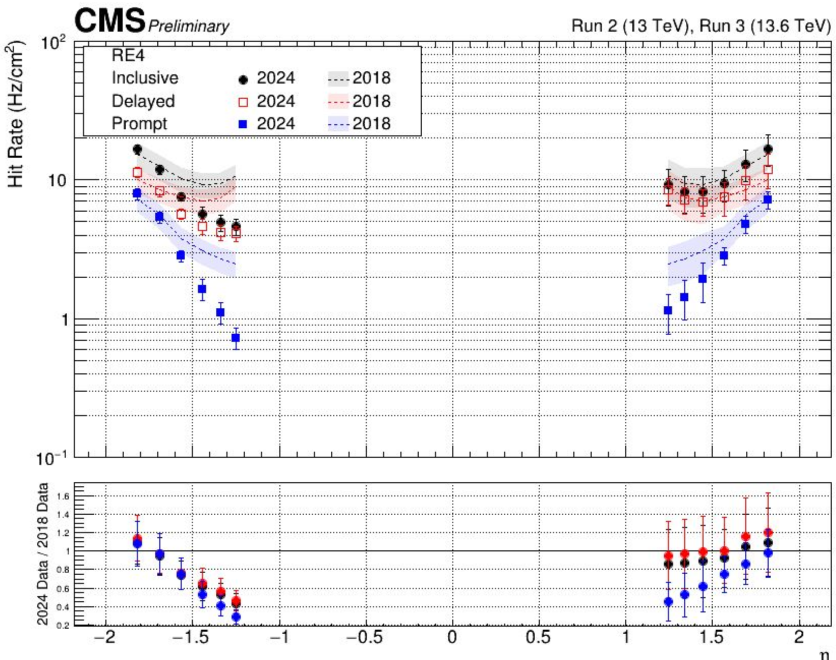
Large effort on Run-2 for a paper with these studies fo all the muon system (**F. Carnevali** et al):

[Eur. Phys. J. C (2024) 84:955]

Muon background studies in Run 3

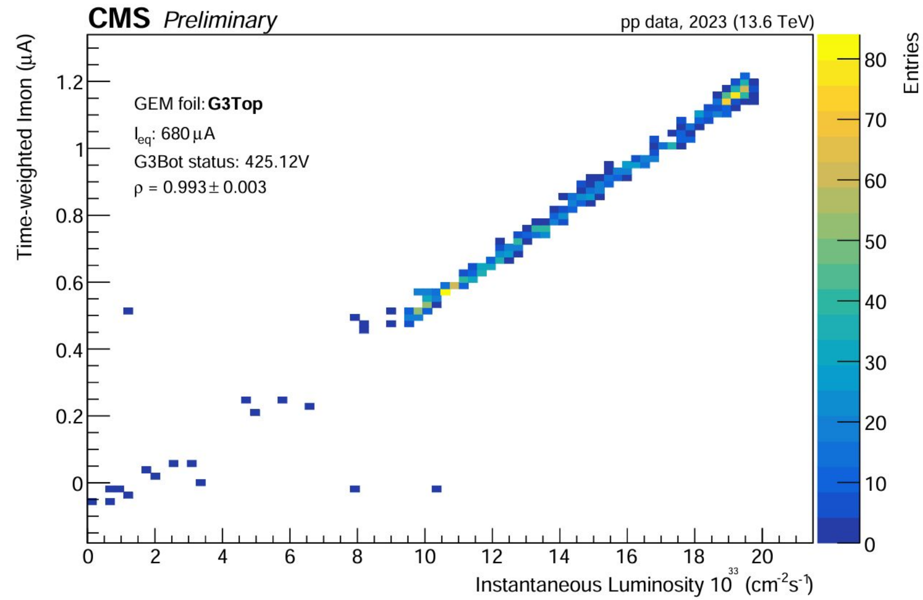
With Run 3 studied went on - now with the addition of GEM:

- RPC: refining techniques and studying the effect of the different detector conditions



RPC: hit rate in the forward region (chambers RE4). One can appreciate the difference on the left due to the installation of a shielding in Run 3

- GEM: also in correlation to the measured current in the chambers



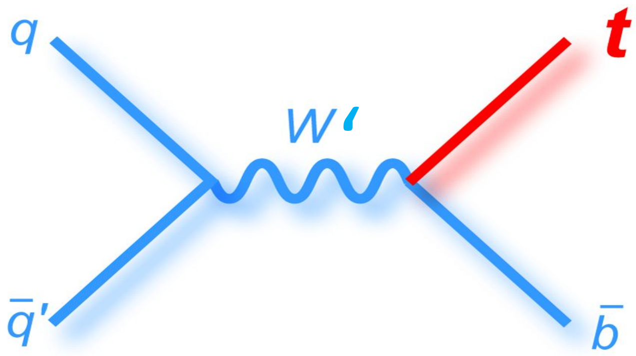
GEM: Correlation of the baseline current flowing through a GEM foil

L. Favilla et al.
CMS-DP-2024-108

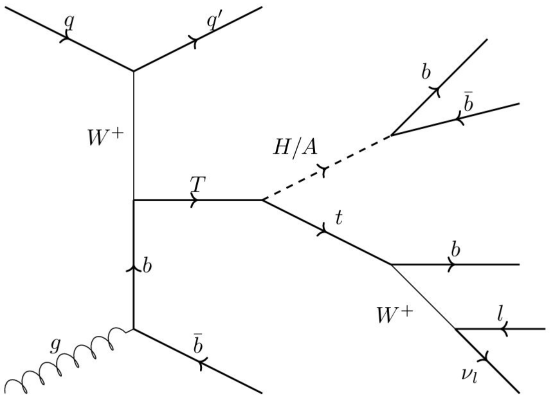
C. Di Fraia et al.
CMS-DP-2024-117

CMS@NA analysis activities

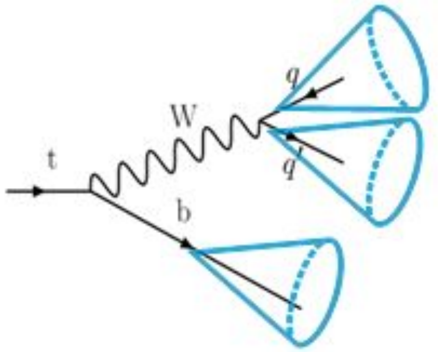
New bosons searches



New fermions searches



Top-tagging studies



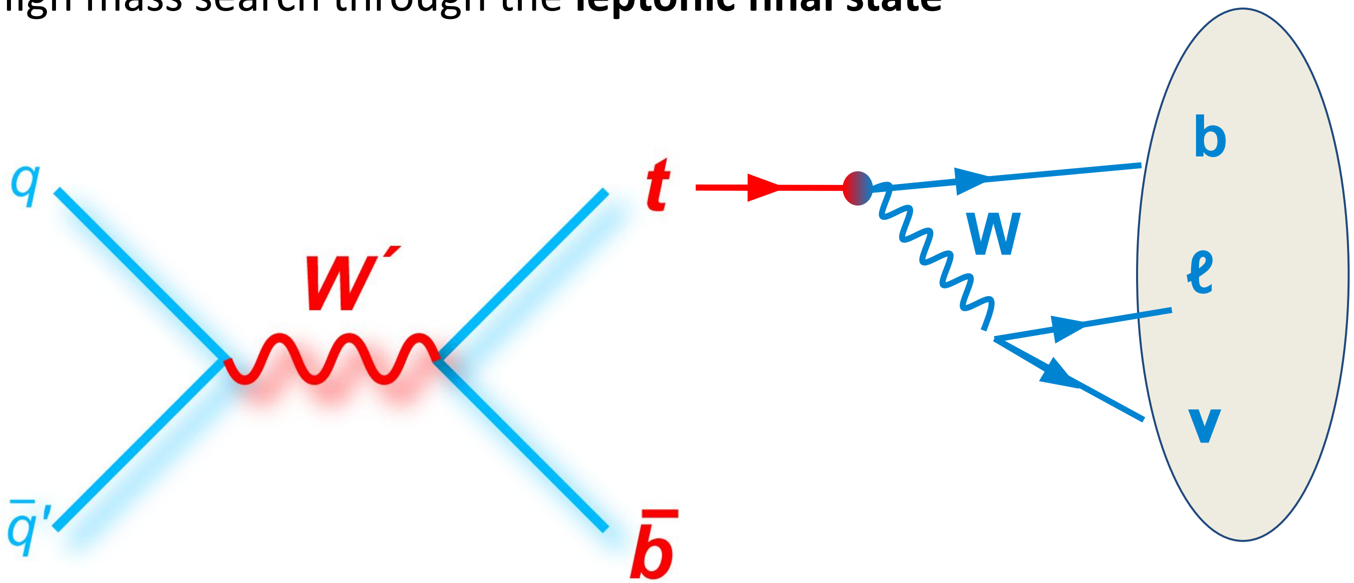
Quasi-interactive analysis

Legacy Run II analysis: W' search

Search for a new resonance decaying to a **top-bottom** quark pair

JHEP 05 (2024) 046

High mass search through the **leptonic final state**



b- quark producing a Jet that can be **b-tagged**

Lepton: muon or electron

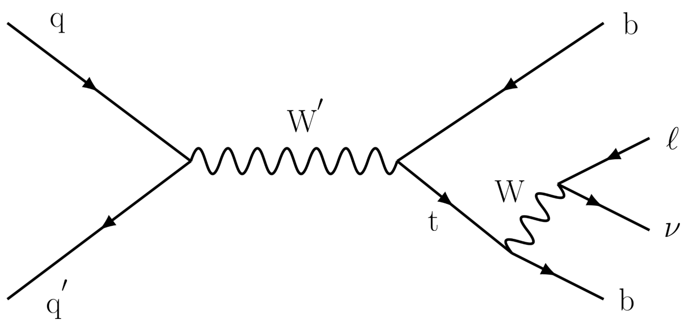
Neutrino → **momentum Is missing** to kinematic closure

Study as function of the right or left, couplings as well as the particle width to allow for a wide range of interpretations

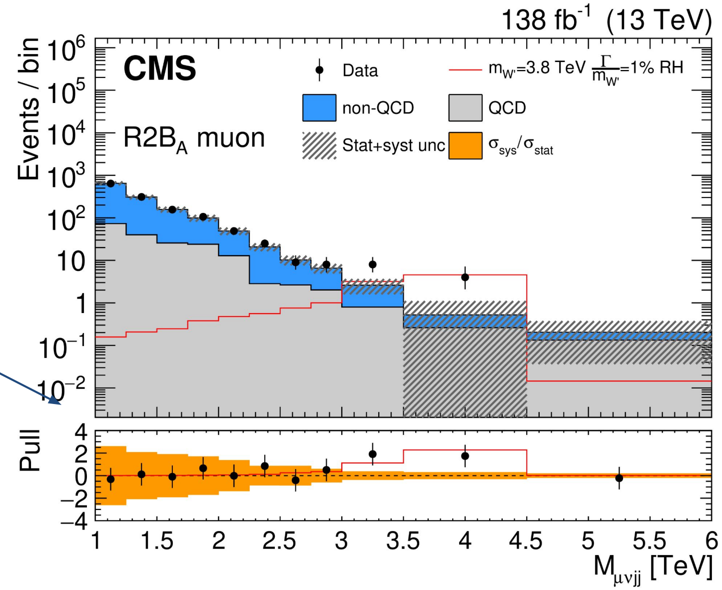
$$\mathcal{L}^{eff.} = \frac{V^{f_i f_j}}{2\sqrt{2}} g_w \bar{f}_i \gamma_\mu \left[\alpha_R^{f_i f_j} (1+\gamma^5) + \alpha_L^{f_i f_j} (1-\gamma^5) \right] W'^\mu f_j + h.c.$$

W’ search results

W’ ⟶ tb: resonance in mW’ reconstructed from 1 top + 1 jet b



mW’



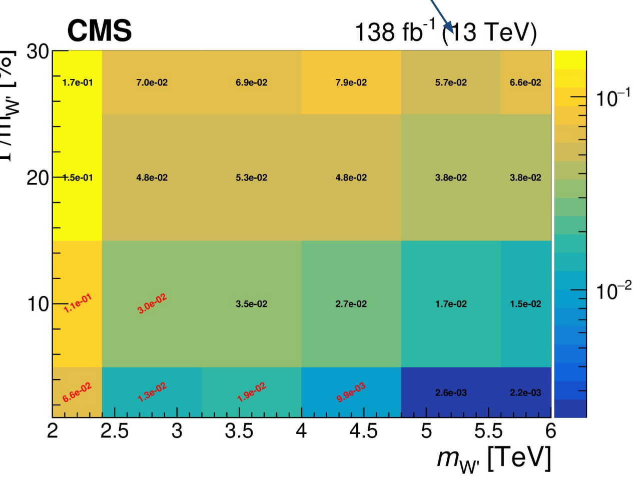
Largest excess: 2.6 standard deviations a mW=3.8 TeV

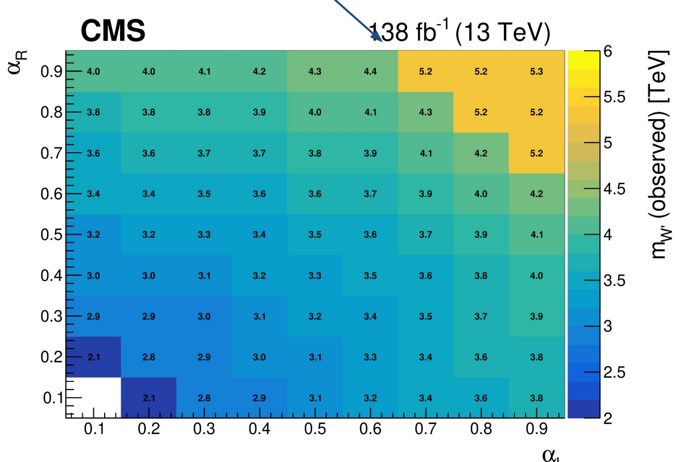
Measured vs:

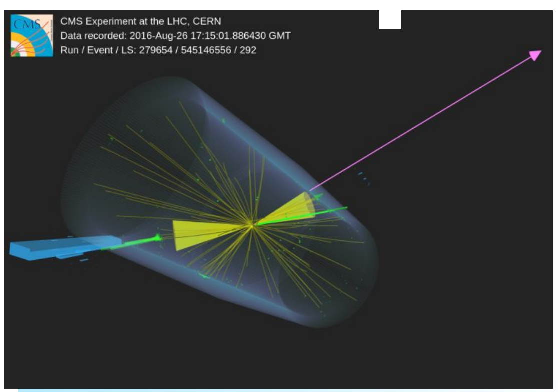
- Left- or right-handed components of the current
- Particle width

Physics briefing :

[The beauty, the top, and the mighty](#)







Analyses in progress: VLQ searches

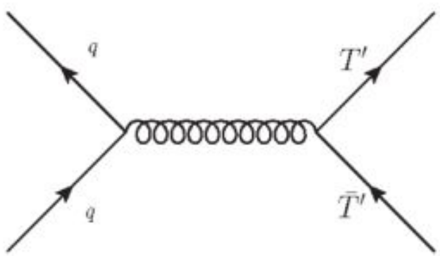
Vector-like quarks: new colored fermions common to several BSM models

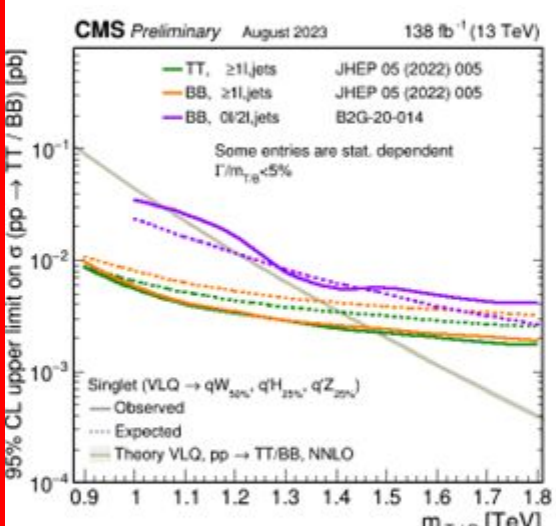
Both left- and right-handed currents

$$J^{\mu +} = J^{\mu +}_{L} + J^{\mu +}_{R} = \bar{u}_L \gamma^\mu d_L + \bar{u}_R \gamma^\mu d_R = \bar{u} \gamma^\mu d$$

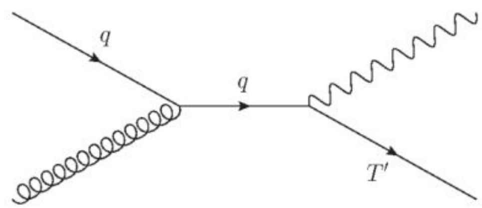
Most common VLQ hypotheses

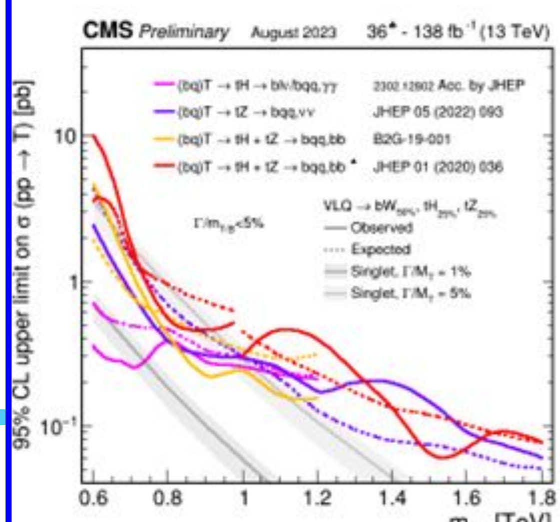
Pair production



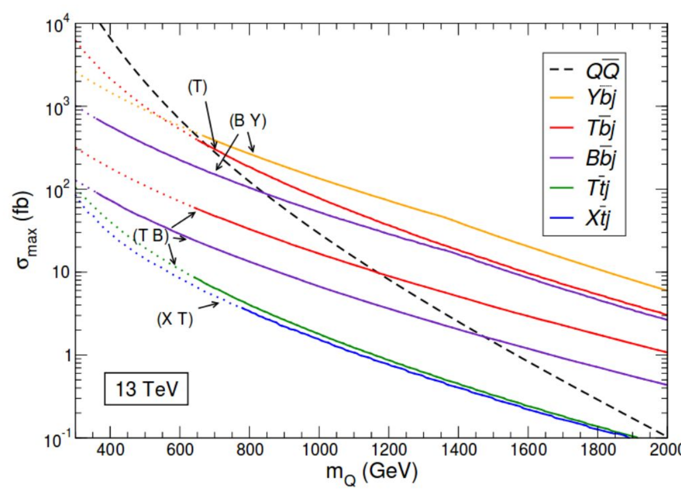


Single production



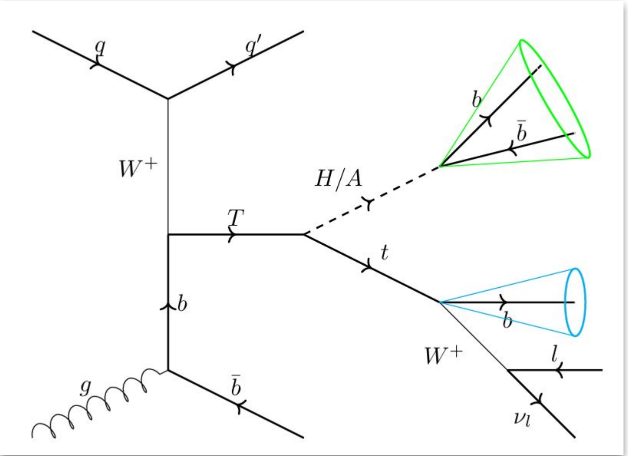


VLQ	Electric charge
X	+5/3
T	+2/3
B	-1/3
Y	-4/3



VLQ@NA

WIP for Moriond 25'



T→ tA

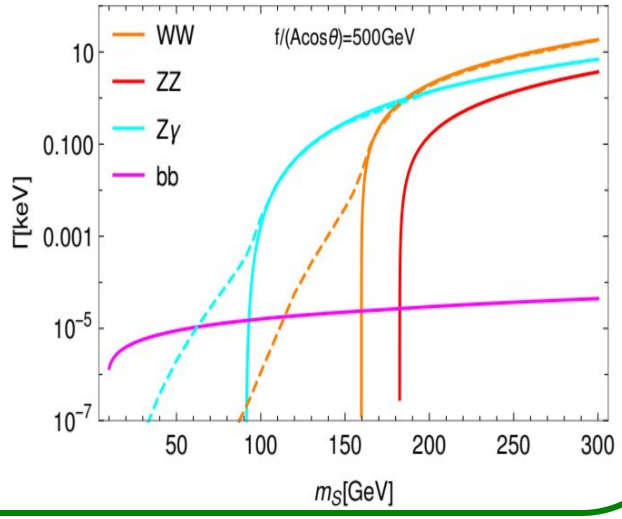
Top + 1 new boson A

- non-minimal models: Could have escaped searches so far!

- Run 2 legacy analysis

- uses XGBoost tagger for leptonic top quarks

F. Carnevali, C. Di Fraia



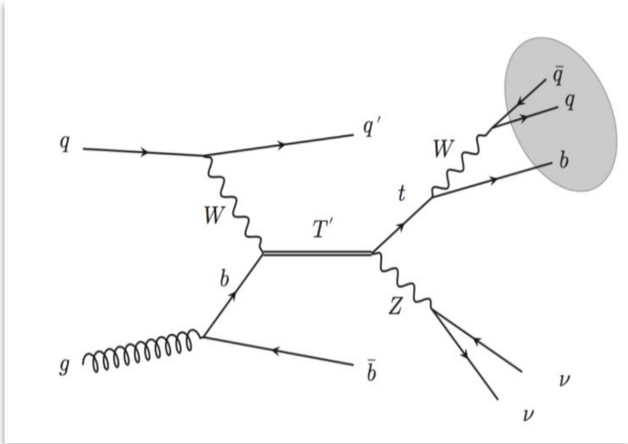
T → tZ

Top + missing energy

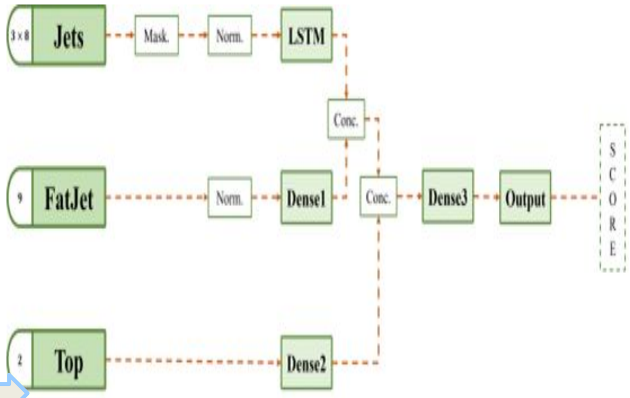
- state common to many BSM interpretations

- Run 3 analysis

- Uses special hadronic top quark tagger



A. Cagnotta, L. Favilla



B.Argiento, F.Salerno

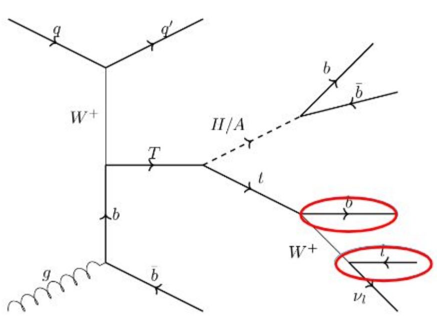
Top quark identification via Machine Learning: XGBTop

Multiclass BDT (MBDT) algorithm to discriminate between leptonically decaying top quark and combinatorial background

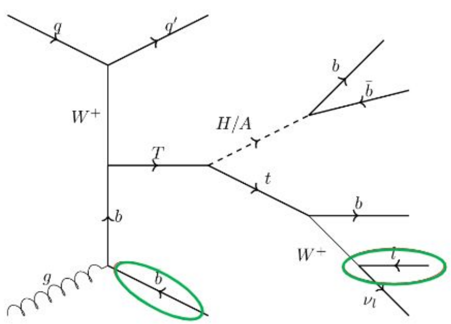
8 different trainings, taking into account the top quark p_T (threshold 500 GeV), the lepton, and the Merged or Resolved topology.

Top Lepton	Electron				Muon			
Top Configuration	Resolved		Merged		Resolved		Merged	
Top p_T	Low p_T	High p_T	Low p_T	High p_T	Low p_T	High p_T	Low p_T	High p_T
Jet_Mass	✓	✓	✓	✓	✓	✓	✓	✓
Jet_p_T	✓	✓	✓		✓			
Jet_DeepFlavB	✓	✓	✓	✓	✓	✓	✓	✓
Lepton_p_T	✓							
Lepton_Dxy	✓	✓	✓	✓	✓	✓	✓	✓
Lepton_DxyErr	✓				✓			
Lepton_ Dz	✓	✓	✓	✓	✓		✓	✓
Lepton_DzErr	✓				✓			
Lepton_Iso	✓	✓	✓	✓	✓	✓	✓	✓
Lepton_MiniIso	✓	✓	✓	✓	✓	✓	✓	✓
$\frac{Lepton\_p_T}{Jet\_p_T}$	✓		✓	✓			✓	
Top_Mass	✓	✓	✓	✓	✓	✓	✓	✓
Top_p_T	✓		✓		✓		✓	✓
Top_Mass (No MET)	✓	✓			✓	✓		
Top_p_T (No MET)	✓							
Top_m_T	✓	✓	✓	✓		✓		✓
Top_Rel_p_T	✓	✓	✓	✓		✓	✓	✓
Top_cosθ	✓		✓		✓			✓
$\Delta R(l_{top}, jet_{top})$	✓		✓	✓	✓	✓		

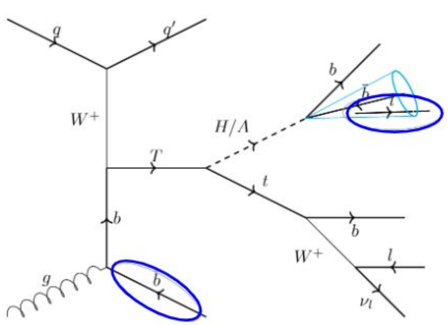
Top True



Top Other



Top QCD



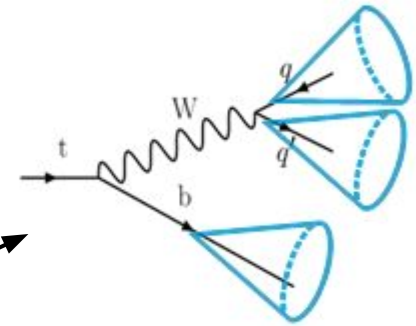
Top quark identification via Machine Learning: TROTA

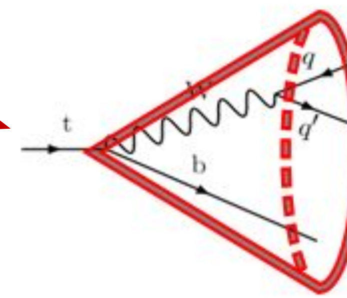
TROTA

Top Reconstruction: an Object Tagger Algorithm

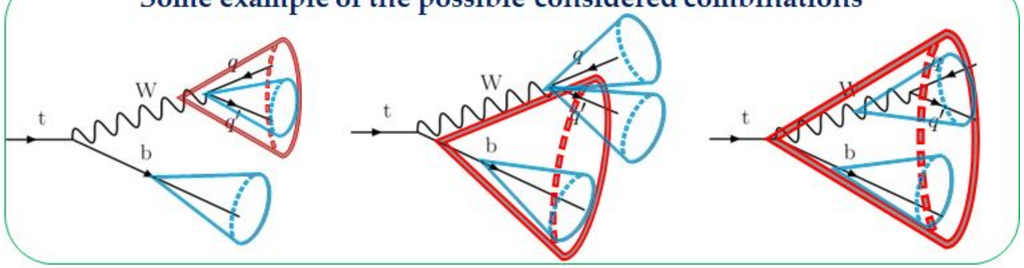
Three main topologies are defined to optimize the reconstruction:

- **Top Resolved** → 3 narrow (AK4) jets → Specific for low pt
- **Top Mixed** → combination of AK4 and AK8
- **Top Merged** → 1 large (AK8) jet → ParticleNet Top tagger





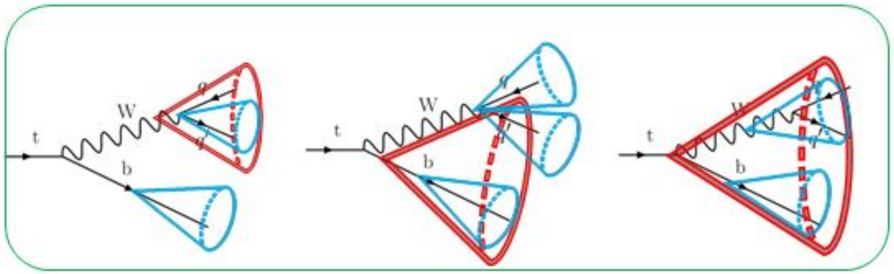
Some example of the possible considered combinations

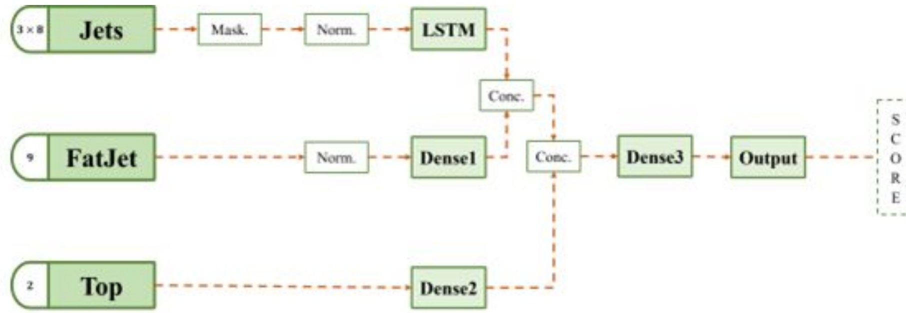


Mixed top quark case

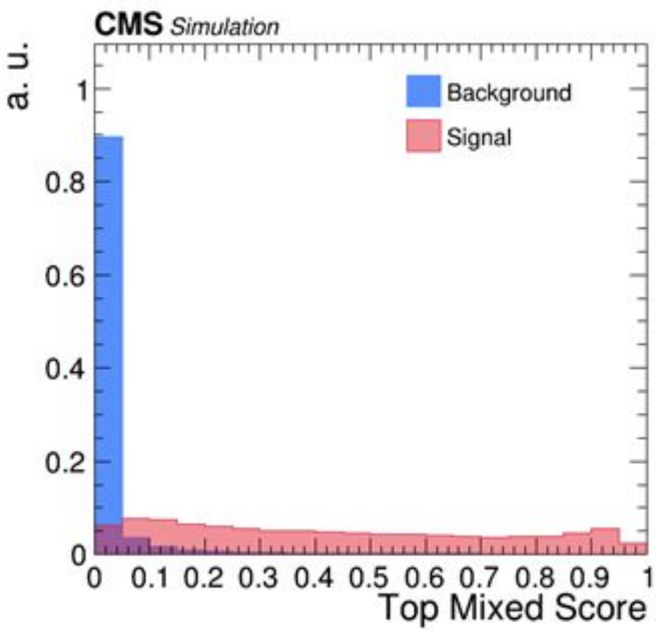
Mixed case:

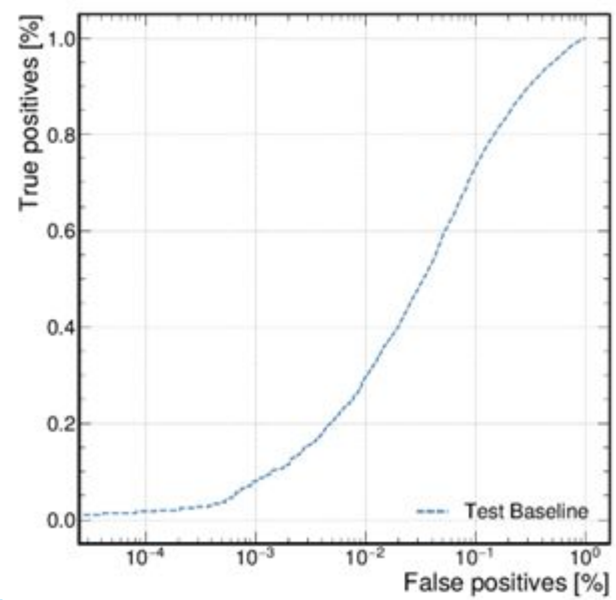
→2-3 AK4 jets + 0-1 AK8 jet plus overall top quark features (sum of 4 momenta)





Strong discrimination against QCD backgrounds





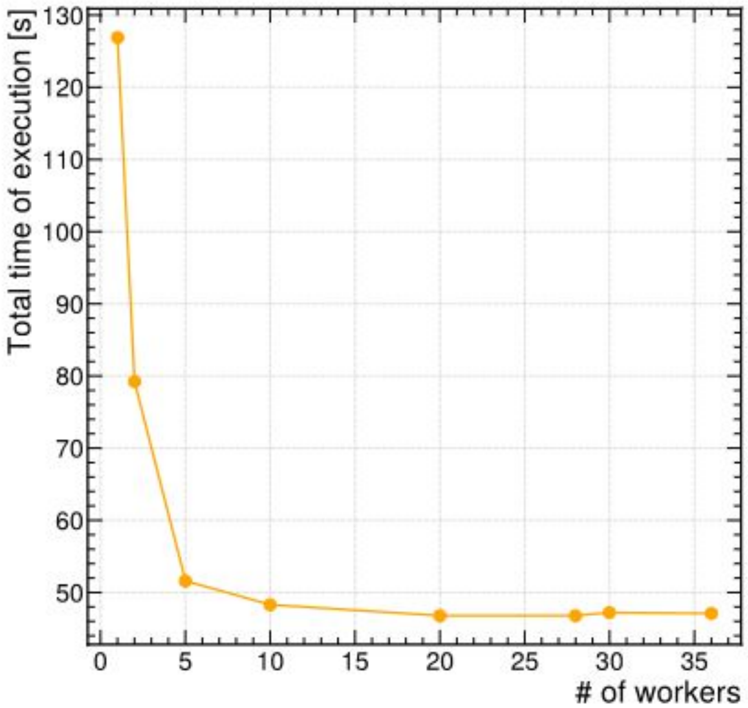
Technological advancements: Quasi-interactive analysis

Run 3 analysis: working to best exploit the new national-scale High-Rate platform underwork by INFN

→ real time allocation of resources for distributed computation

→ user-customized environment via container-based technologies

Below: example of the execution time of the analysis on the new platforma s function of the # workers.



A. Cagnotta

see also:

- Talk by Antimo on 8/1/25 at the topical INFN workshop https://agenda.infn.it/event/44199/contributions/251828/

- Collaborating with the ICSC project: https://www.supercomputing-icsc.it/en/icsc-home/

Conferences and presentations

Talks at conferences: 2 national, 4 international
IFAE 2024, C. Di Fraia, Ricerca di Vector-Like quark ad LHC con l'esperimento CMS
SUSY 2024, Antimo Cagnotta, *Searches for dark matter with CMS*
ICHEP 2024, S. Buontempo, *Improved RPC (iRPC) detector for CMS data taking in HL-LHC*
BOOST 2024, A.O.M. Iorio, *Search for heavy BSM particles in final states with boosted top quarks or W bosons at CMS*
SIF 2024, Benedetta Argiento: *Ricerche di nuova fisica con oggetti pesanti ad alto boost di Lorentz in eventi con jet*
TWEPP 2024, Carlo Di Fraia, *High-Voltage studies for the new GE1/1 GEM Station in the CMS Experiment*

Posters: 1 national, 2 international
TWEPP 2024, Carlo Di Fraia, *High-Voltage studies for the new GE1/1 GEM Station in the CMS Experiment*
RPC 2024, Leonardo Favilla, *CMS RPC Background studies in LHC Run 2 and Run 3*
IFAE 2024, Leonardo Favilla, Ricerche di nuova fisica con di oggetti pesanti ad alto boost di Lorentz in eventi con jet

What does the future bring? Well… a lot!

Data taking: last 2 years of data taking, 2025: lots of data to collect, calibrate physics objects with, analyze!

Upgrade: ME0 chambers will have to be ready by 2026, then installation starts!

Detector studies: pursue the study of backgrounds and use our knowledge and tools for the study of discharges in ad hoc tests foreseen for March, use of PICOAmmeter for monitoring of GEM chambers already installed in CMS

BSM searches:
- $T \longrightarrow tA$: work in progress to publish this year - would be the first of its kind and the best analysis in most of the phase space.
- $T \longrightarrow tZ$: adding Run 3 data, possible further extensions to other models, very promising the use of new technologies!

New taggers: plan to document the new taggers with the collaboration of the CMS dedicated working group

HPC: move the analyses to exploit the HPC paradigm

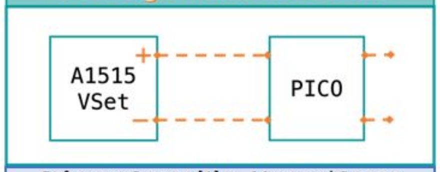
Top quark physics: plan to reinstate the CKM measurements in the top quark sectors over the next year

Backup

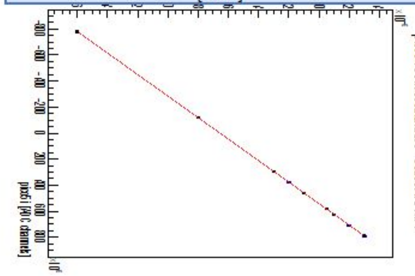
PICO@INFN – Sezione di Napoli

- Pico:
  - High-Voltage monitoring instrument for triple-GEMs
  - capable of measuring currents and voltages
  - current resolution: $\sim 10pA$
  - voltage resolution: $\sim 10mV$
  - sampling rate: up to **400Hz** (1Hz for HV board)
- Performed:
  - current and voltage calibrations
  - resolution estimation

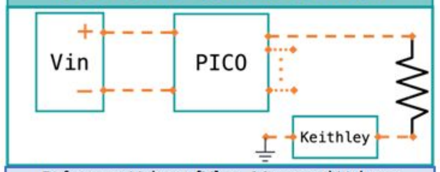
Voltage Calibration



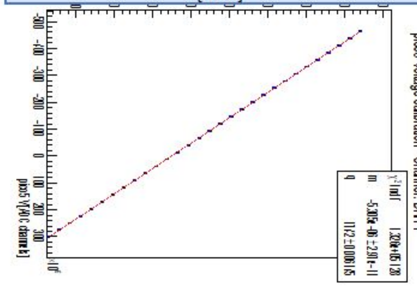
Reference Current [A] vs. Measured Current [ADC]



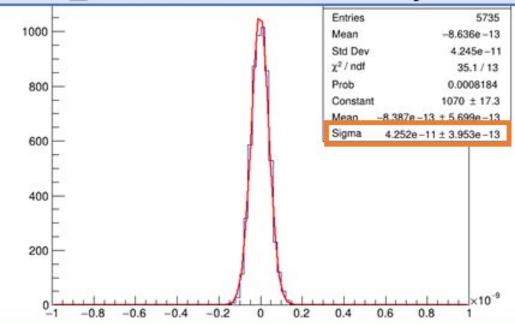
Current Calibration



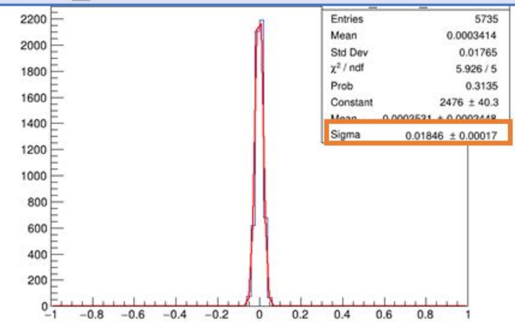
Reference Voltage [V] vs. Measured Voltage [ADC]



I_DRIFT resolution $\sim 40pA$



V_DRIFT resolution $\sim 20mV$



The importance for the SM: the CKM matrix

Matrix of fundamental parameters regulating the “mixing” between quark families

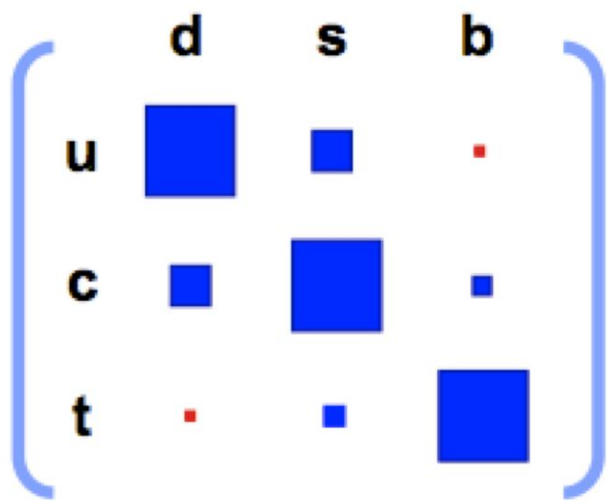
→ **No hypothesis on unitarity needed** (possible presence of other families).

→ Can be seen as a transformation between the **free particle** vs **interacting lagrangian** eigenstates

→ **Cannot be measured directly anywhere else**

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

Pictorically representing the couplings

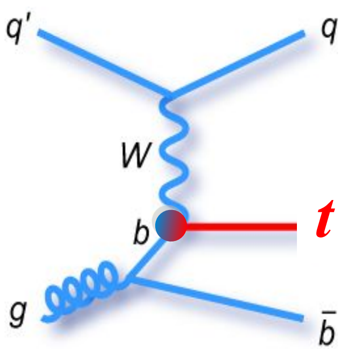


The CKM matrix in single top

Appears in the **electroweak interactions of top quarks:**

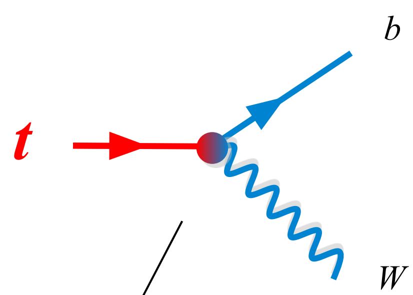
1 - Production mechanism:

$\sigma \propto |V_{tb}|^2$



2 - Decay mechanism**:**

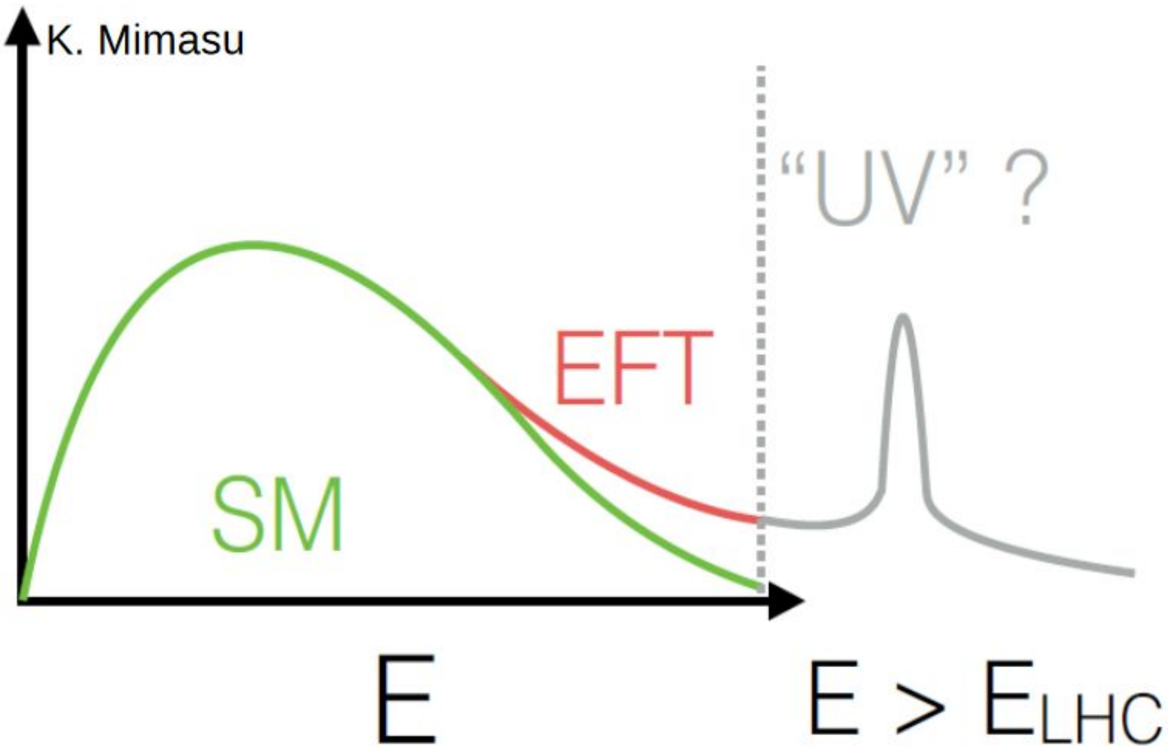
$BR(t \rightarrow Wb) \propto |V_{tb}|^2/(|V_{tb}|^2 + |V_{td}|^2 + |V_{ts}|^2)$



$$\frac{-ig}{2\sqrt{2}}\bar{t}\gamma^{\mu}(1-\gamma^{5})V_{tb}bW_{\mu}$$

→ for single top **it appears twice!**

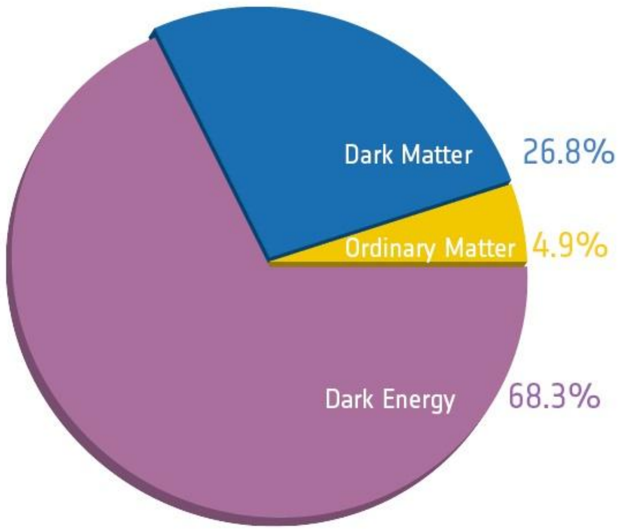
New physics with top quark: indirect search



◦ **Precision measurements:**

- Portal to new physics for non-reachable energies with strong effect
- Need to find sensitive observables

The Dark Matter issue



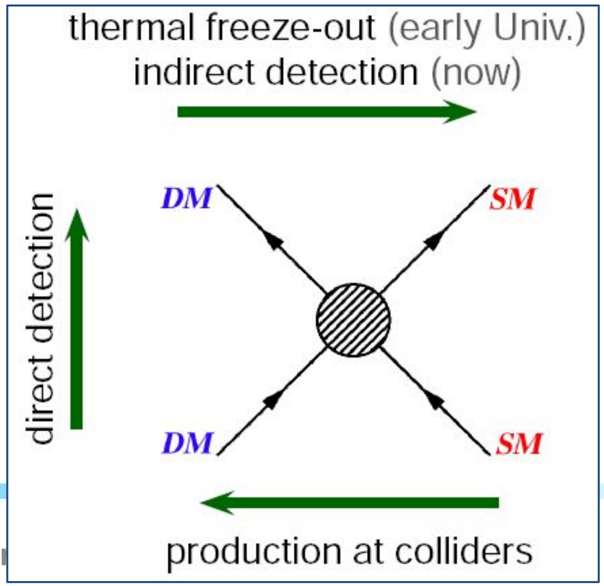
◦ Evidence of matter not interacting via EW force: **Dark Matter**

- **Rotational speed** of galaxies
- Pattern of **anisotropies in the Cosmic Microwave Background**

◦ **5 times more than ordinary matter!**

- Must be **invisible** and very **abundant.**

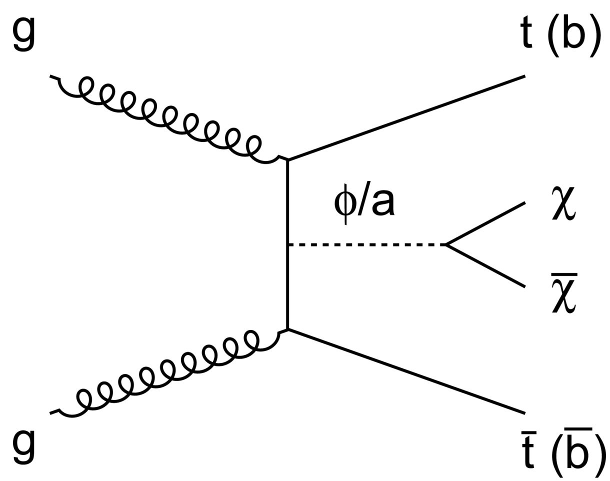
→ Possible **findings at LHC**! Complementary to direct detection experiments

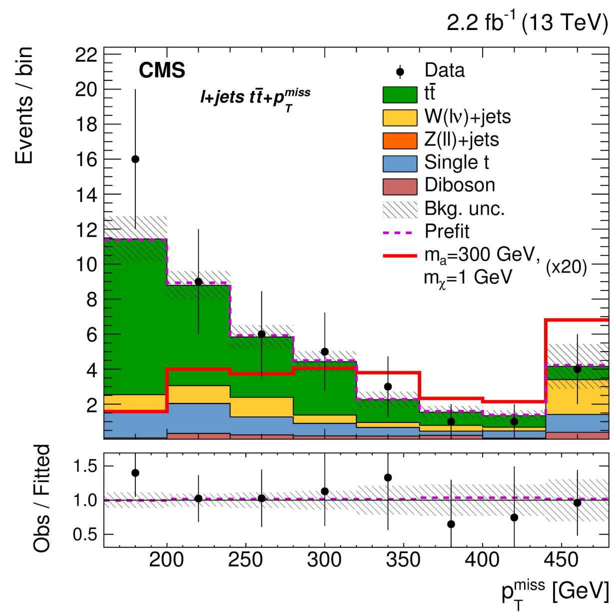


◦ **LHC DM forum:**

- to have a common ground to discuss and compare with direct detection experiments
- set of **Simplified Models** to have an easy interpretation!

The Dark Matter at LHC : top quarks

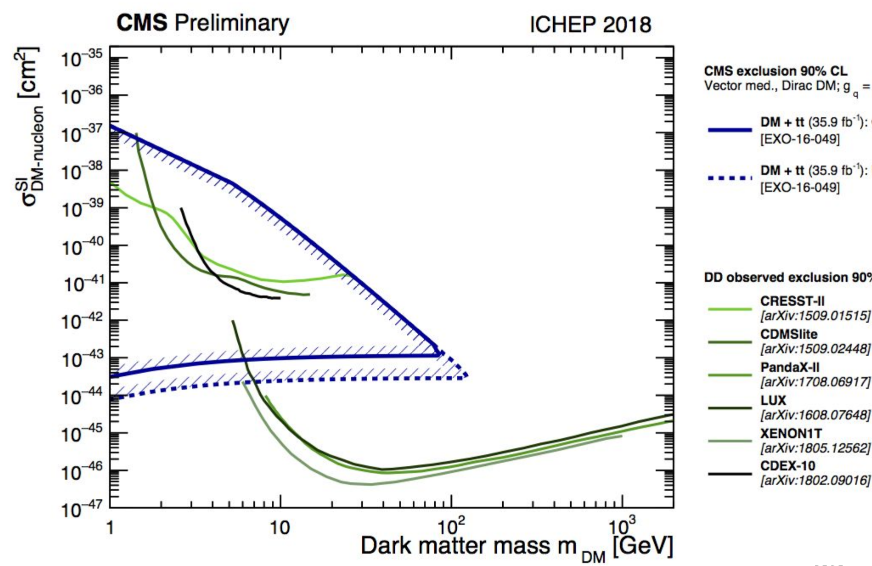




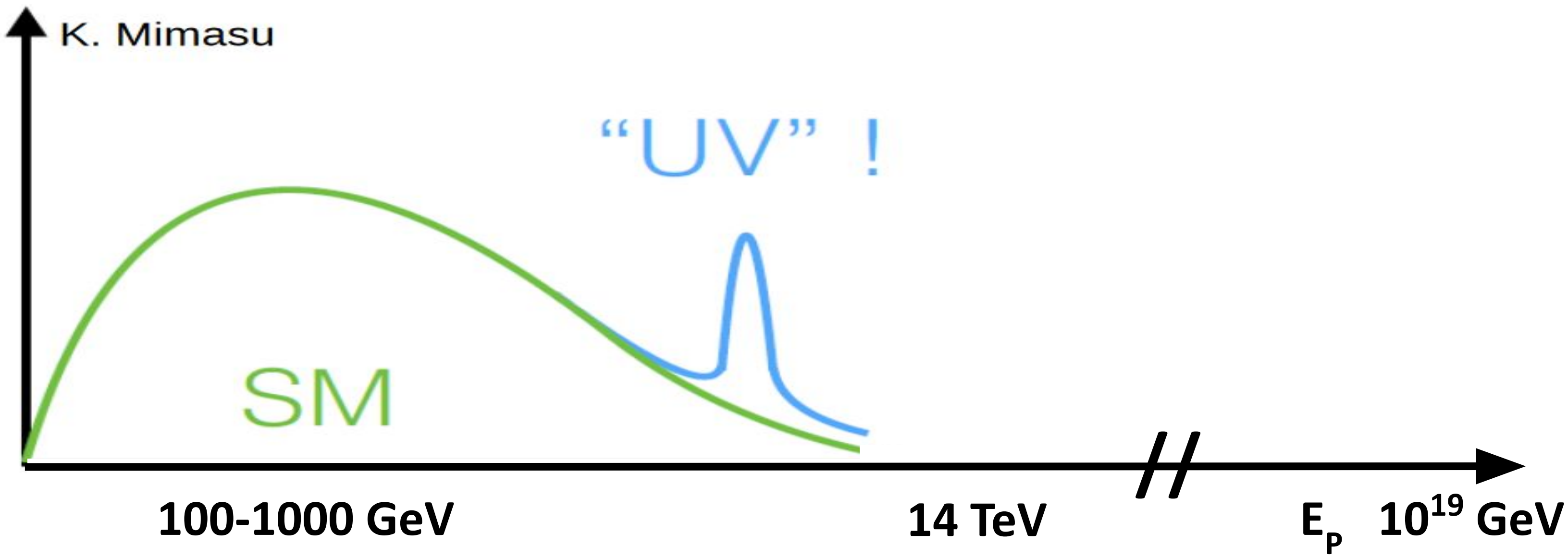
◦ Coupling with scalar or pseudo-scalar mediator ϕ/a: depends on the **mass of the quark it couples with!**

◦ Interesting perspectives by adding searches with **single-top quark production**.

→ Limits expressed in terms of cross-section, can be compared with direct detection like XENON, LUX e

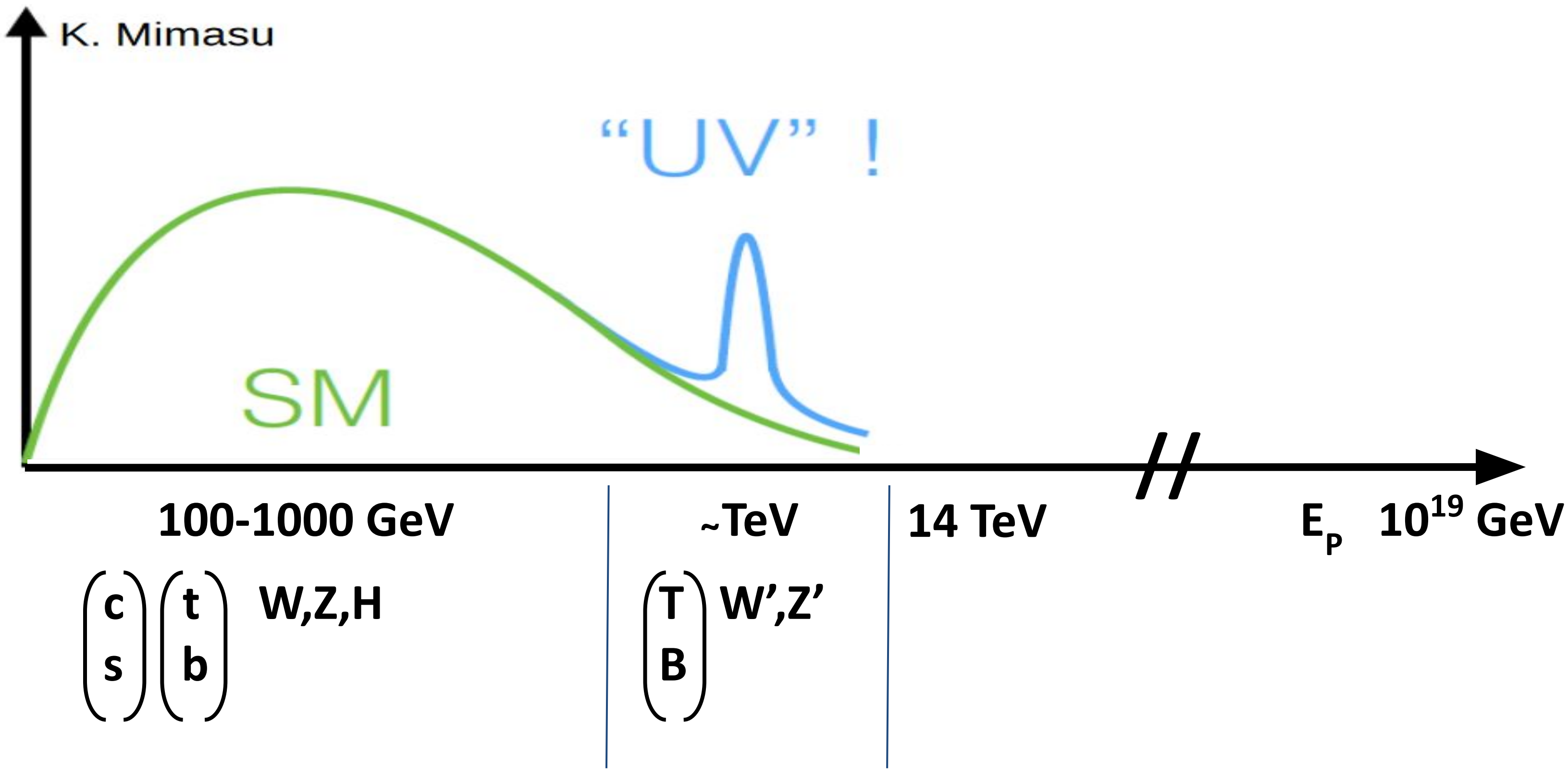


Heavy final states:
new sector of physics at LHC



$\begin{pmatrix} c \\ s \end{pmatrix} \begin{pmatrix} t \\ b \end{pmatrix}$ **W,Z,H**

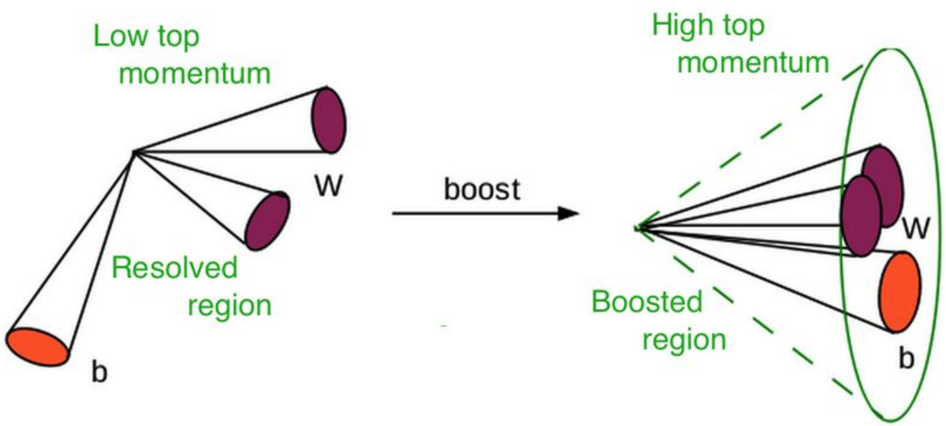
Heavy final states: new sector of physics at LHC



◦ Models addressing **hierarchy** problems (for **higgs** or quark masses, or **planck scale**) foresee a new sector of physics: Compositeness, GUT models, 2HDM, Extra Dimensions.
◦ New **bosons** (Z',W',H+,H-) or **quarks** (T,B...) with similar quantum numbers as SM ones, but different masses and couplings.

Probing the high-energy regime: boosted topologies

New particle mass **at the scale of TeV** → relativistic boost for heavy SM particles!



→ Decay particles in the radius : **$\Delta R \sim 2M/P_T$**

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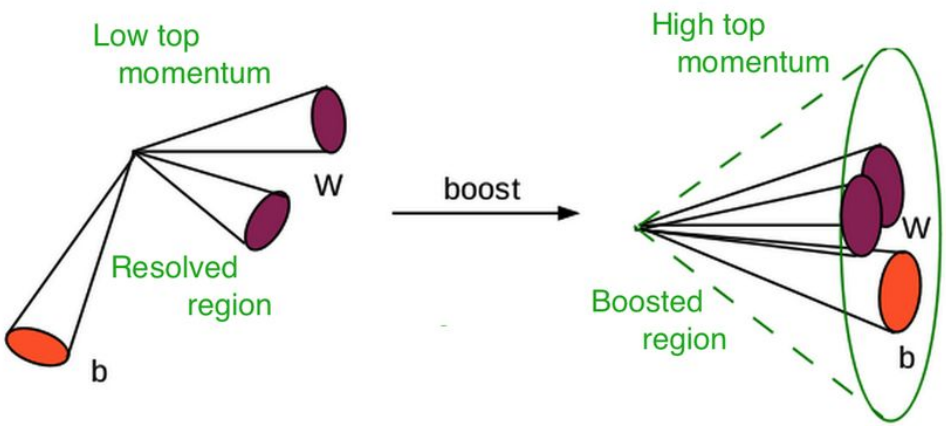
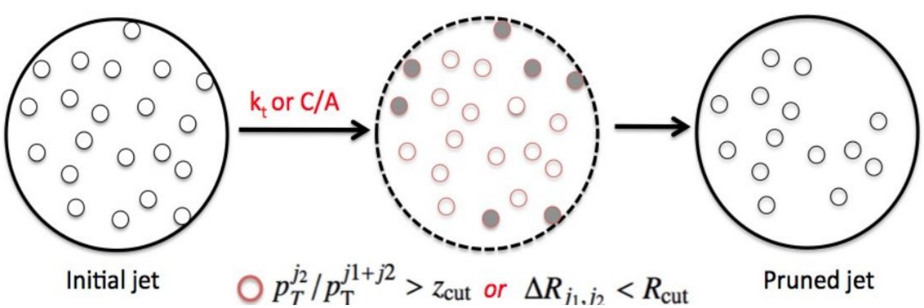
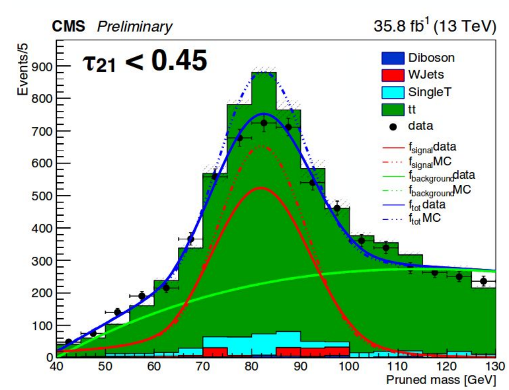


→ Decay particles in the radius : **$\Delta R \sim 2M/P_T$**

→ **Cleaning the jet** of the extra soft radiation necessary, e.g.:

Pruning, Filtering, Soft drop



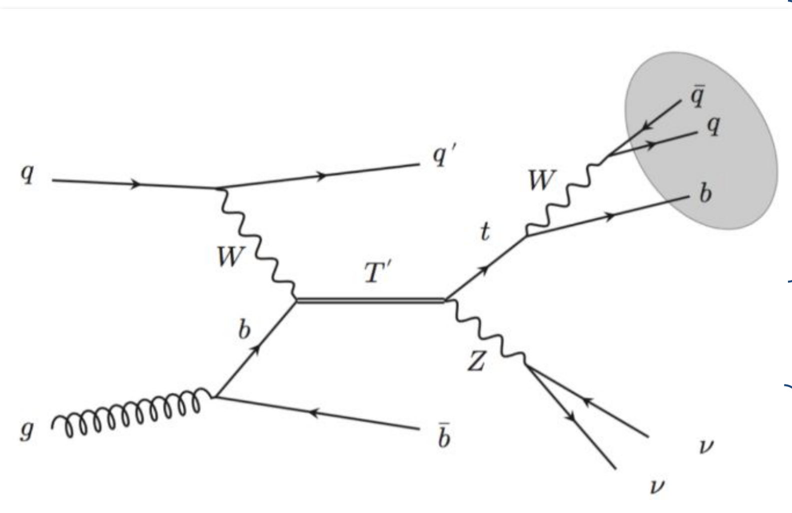


Heavy searches: Vector Like Quarks example

Resonance of T' quarks

→ Appears in composite Higgs, Extra dimensions, ea al.

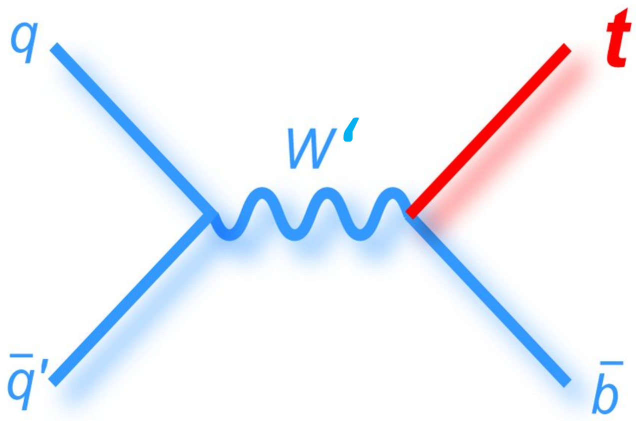
Possible re-interpretation: single t + DM



- Hadronic top-leg reconstruction:
  1 **merged top quark "jet" with substructure**

- Z-leg reconstruction:
  Energy missing in the detector

An example of resonances probing b-flavor anomalies: W' → tb



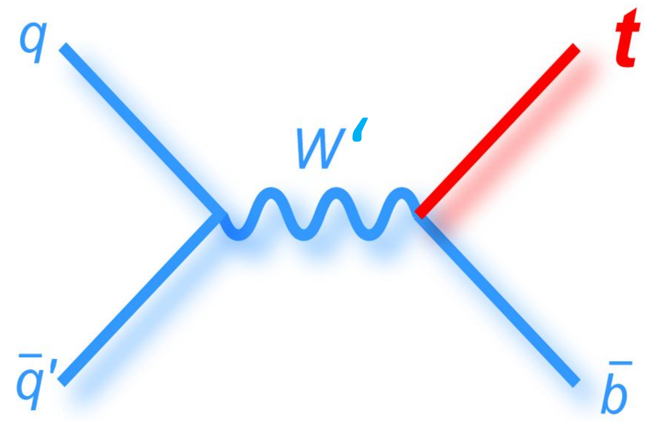
Resonance of W' to top quark + b quarks

→ Can be right handed or left handed (with interference with the standard model production)

Possible involvement in b-flavor anomalies:

Additional contributions to B^0 decays to $\mathbf{D^{*+}\,\tau\nu}$

An example of resonances probing b-flavor anomalies: W' → tb



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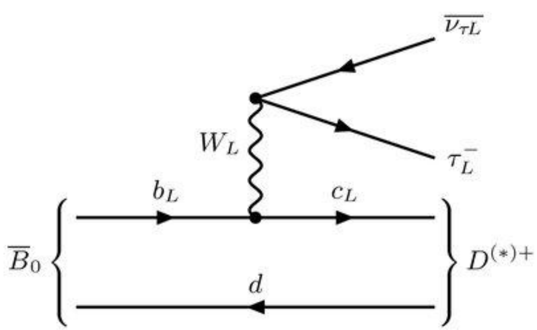
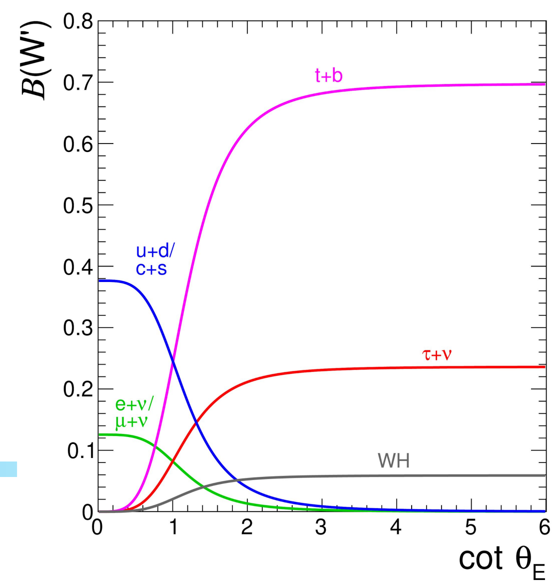
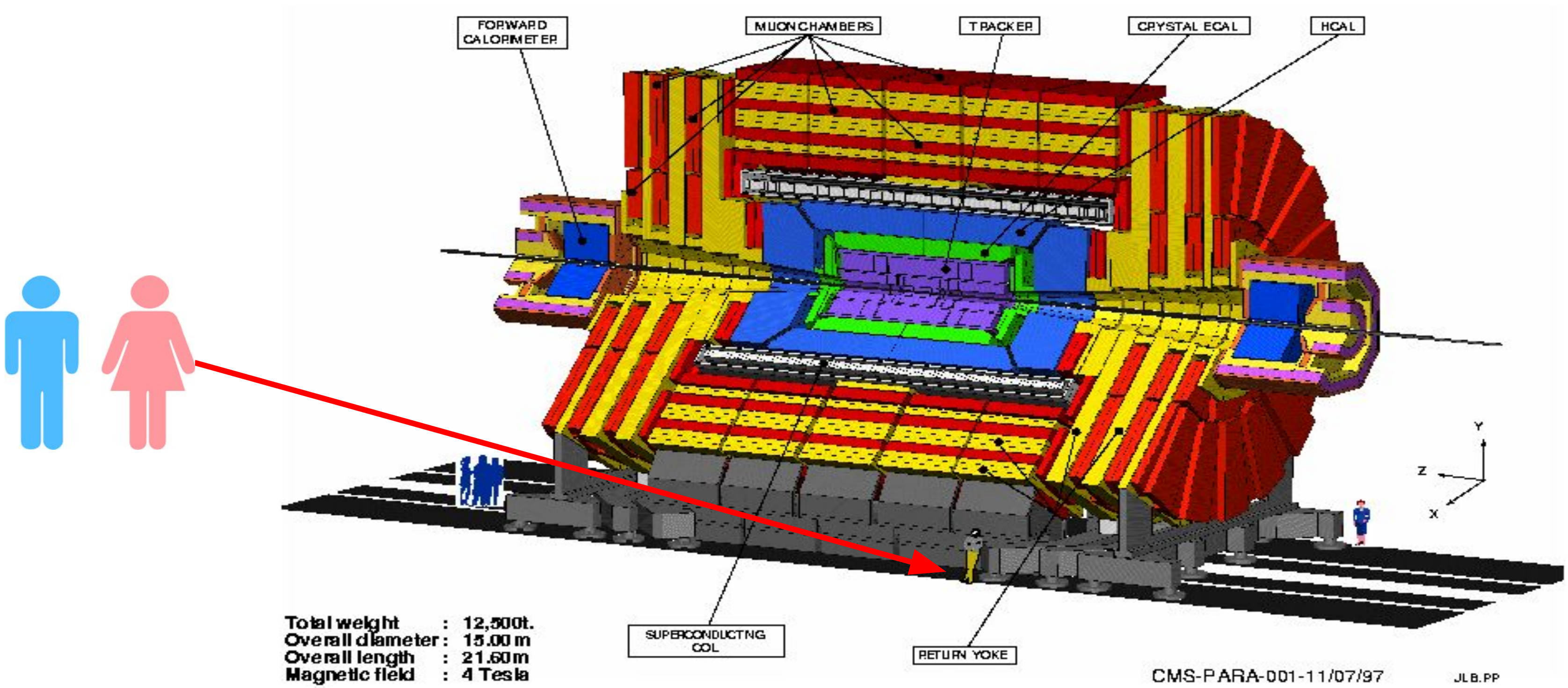
$$R(D^*) = \frac{BR(B \rightarrow D^* \tau \nu)}{BR(\bar{B} \rightarrow D^* l \nu)}$$



(a)



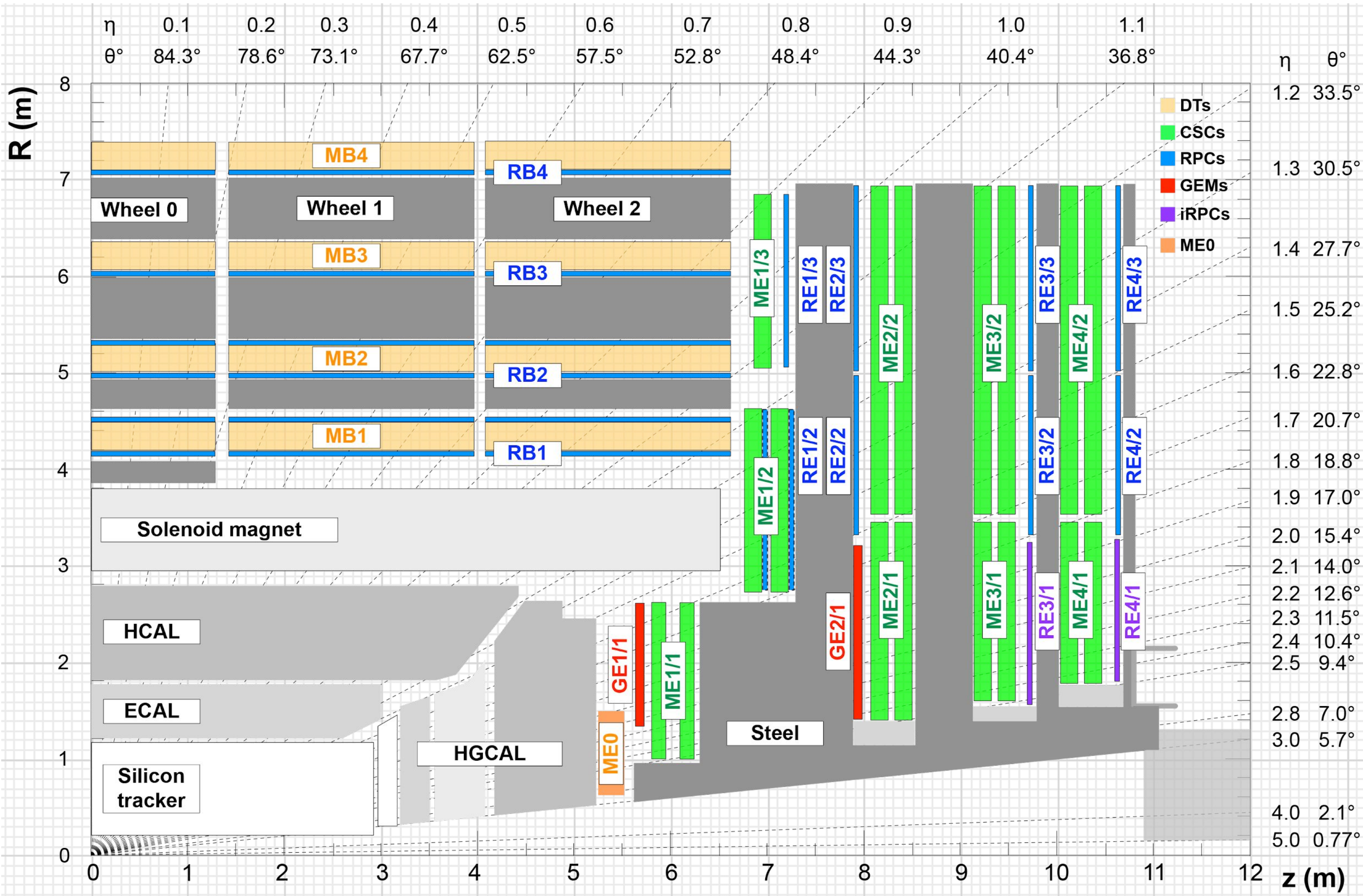
The CMS detector



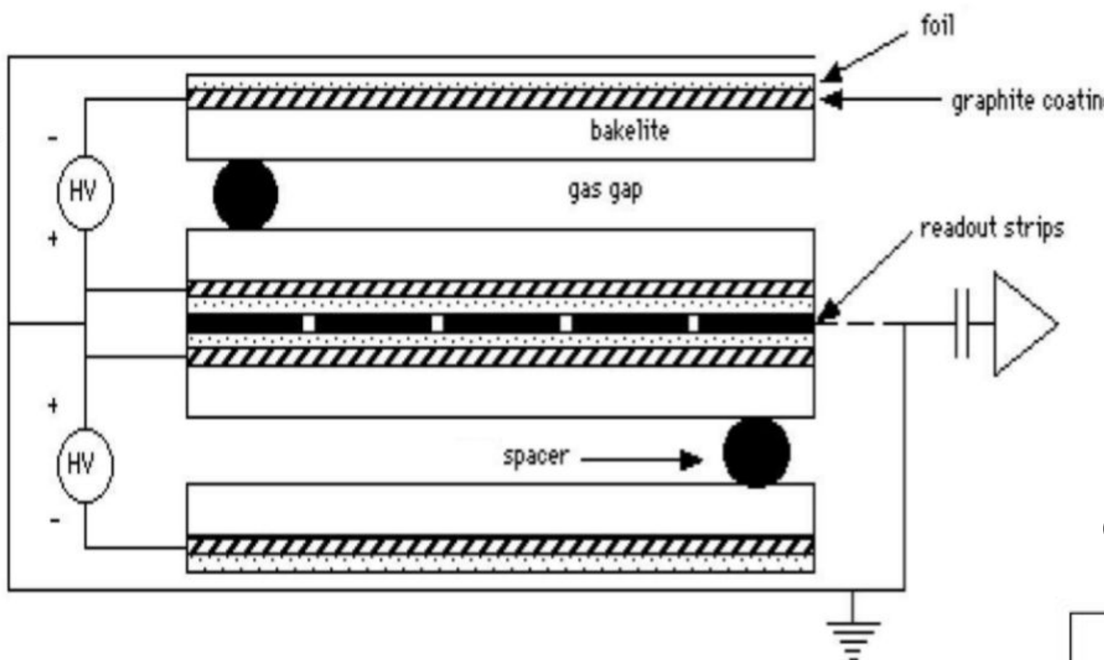
Detectors → Onion Structures:

- ❑ Inner Detector
- ❑ E.M. and Hadronic Calorimeters
- ❑ Muon Spectrometers
- ❑ Magnet System: → superconducting solenoid magnet (coils of wire)

CMS side-view for Run-III



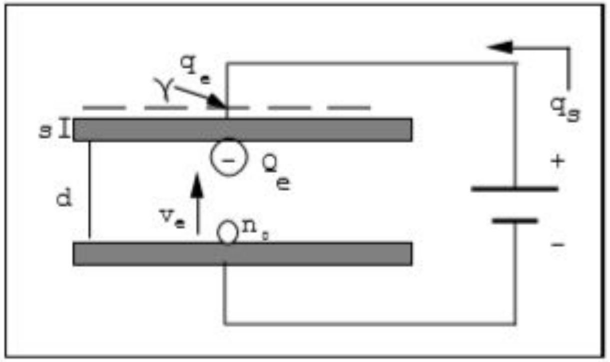
Resistive Plate Chambers at CMS



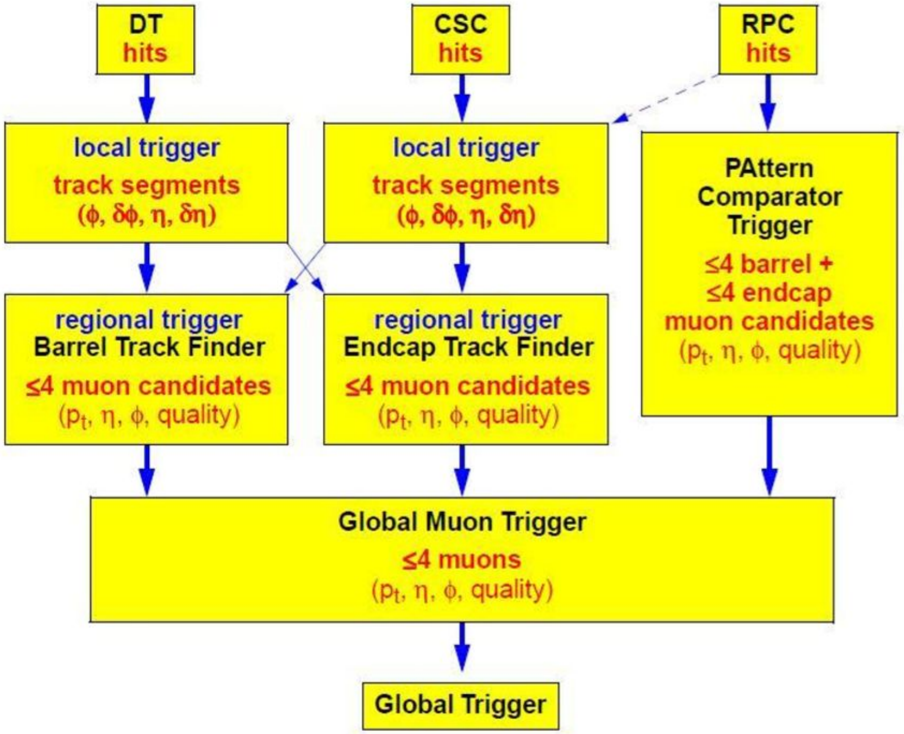
CMS requirements for RPCs

Efficiency	> 95%
Time resolution	≤ 3 ns (98% within 20 ns)
Average cluster size	≤ 2 strips
Rate capability	≥ 1 kHz/cm^2
Power consumption	< 2-3 W/m^2
Operation plateau	> 300 V
# Streamers	< 10%

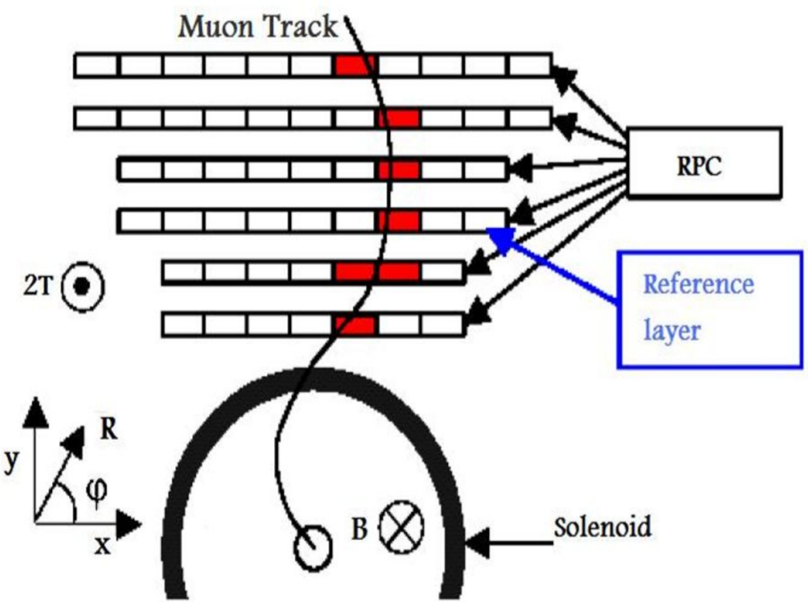
Charge formation model:



Muon System and RPC trigger:



RPC: PAttern Comparator Trigger PACT



Muon System specifications:

Muon subsystem	Drift Tubes (DT)	Cathode Strip Chambers (CSC)	Resistive Plate Chambers (RPC)
Function	Tracking, p_T trigger, BX ID	Tracking, p_T trigger, BX ID	p_T trigger, BX ID
$\|\eta\|$ range	0.0–1.2	0.9–2.4	0.0–1.6
No. of stations	4	4 (no ME4/2 ring)	Barrel 4; Endcap 3
No. of layers	r-ϕ: 8, z: 4	6	2 in RB1 and RB2; 1 elsewhere
No. of chambers	250	468	Barrel 480; Endcap 432
No. of channels	172 000	Strips 220 000; Wire groups 183 000	Barrel 68 000; Endcap 41 000
Design position resolution (σ) for perpendicular tracks	per wire 250 μm; r-ϕ (6/8 pts) 100 μm; z (3/4 pts) 150 μm	per chamber r-ϕ (6 pts) ME1/1, ME1/2 75 μm other CSCs 150 μm; r (6 pts) 1.9–6.0 mm	Strip size (on the order of a centimeter)
Design time resolution	5 ns	6 ns	3 ns

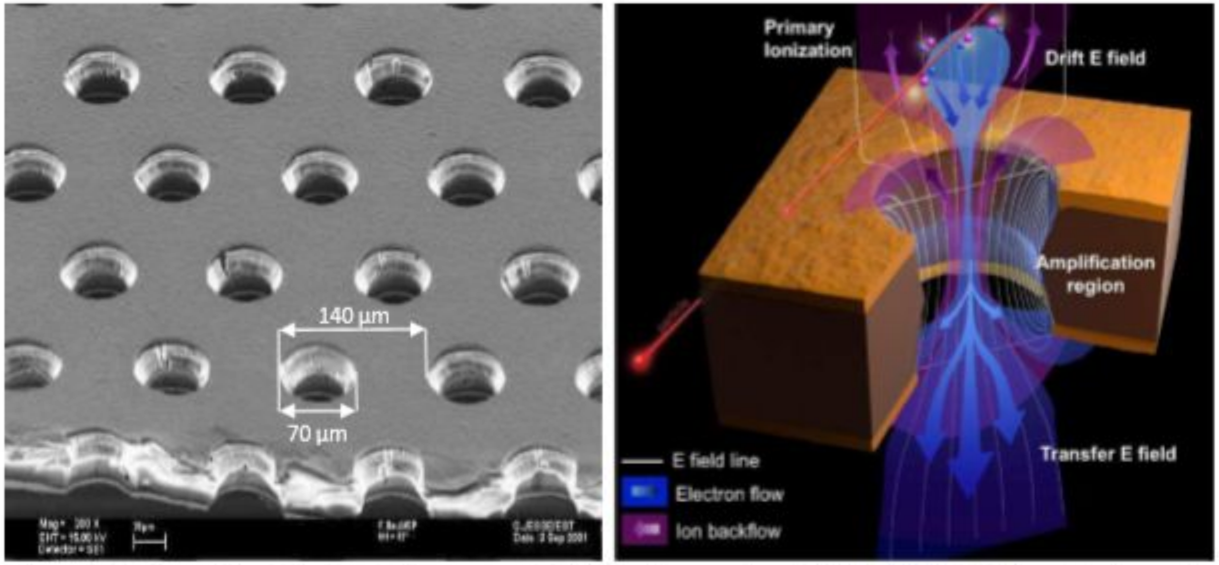
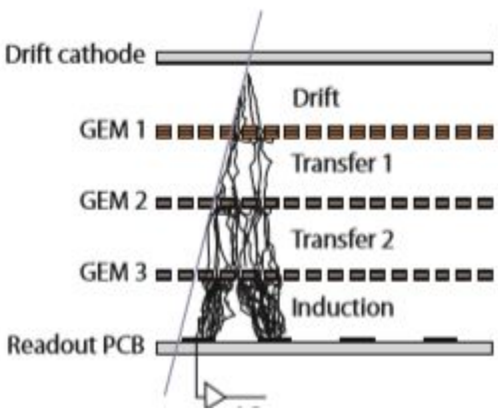


Figure 2.1: Scanning Electron Microscope (SEM) picture of a GEM foil (left) [10] and schematic view of the electric field lines (white), electron flow (blue), and ion flow (purple) through a bi-conical GEM hole (right). The outer diameters of the hole are 70 μm and the inner diameter is 50 μm; the hole pitch is 140 μm.



CMS Requirements for GEM:

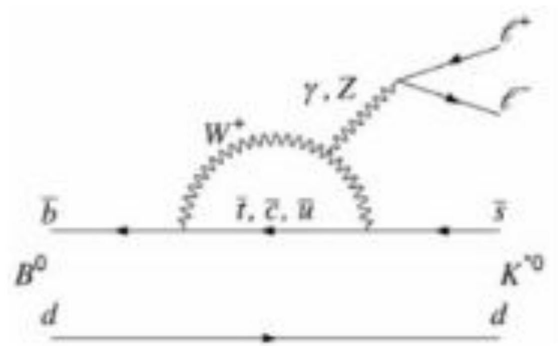
- Maximum geometric acceptance within the given CMS envelope.
- Rate capability of 10 kHz/cm^2 or better.
- Single-chamber efficiency of 97% or better for detecting minimum ionizing particles.
- Angular resolution of 300 μrad or better on $\Delta\phi = \phi_{GE1/1} - \phi_{ME1/1}$
- Timing resolution of 10 ns or better for a single chamber.
- Gain uniformity of 15% or better across a chamber and between chambers.

B-flavor anomalies

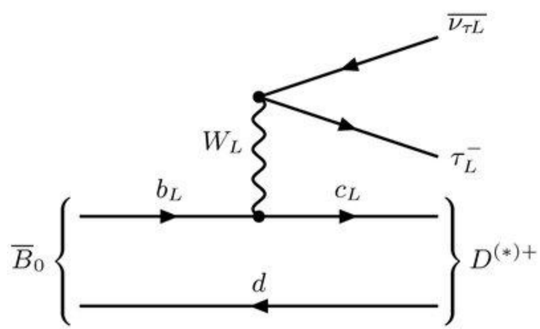
Anomalous measurement

Possible bsm contribution

$$R(K^*) = \frac{BR(B^0 \rightarrow K^* \mu\mu)}{BR(B^0 \rightarrow K^* ee)}$$



$$R(D^*) = \frac{BR(B \rightarrow D^* \tau\nu)}{BR(\bar{B} \rightarrow D^* l \nu)}$$



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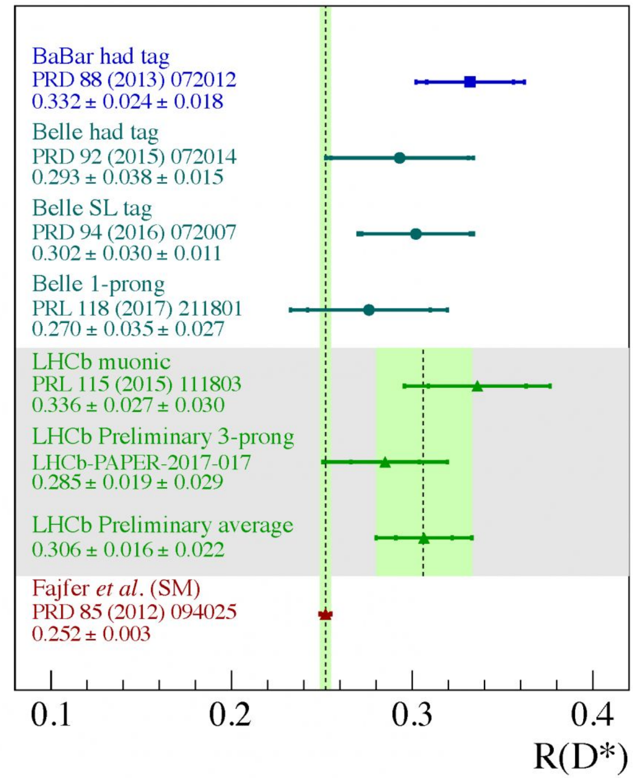
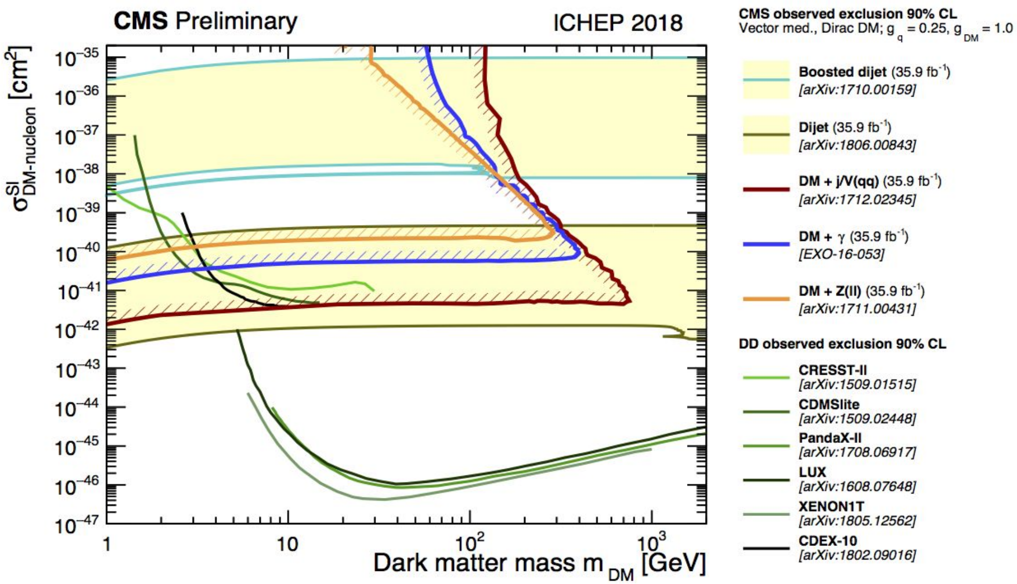
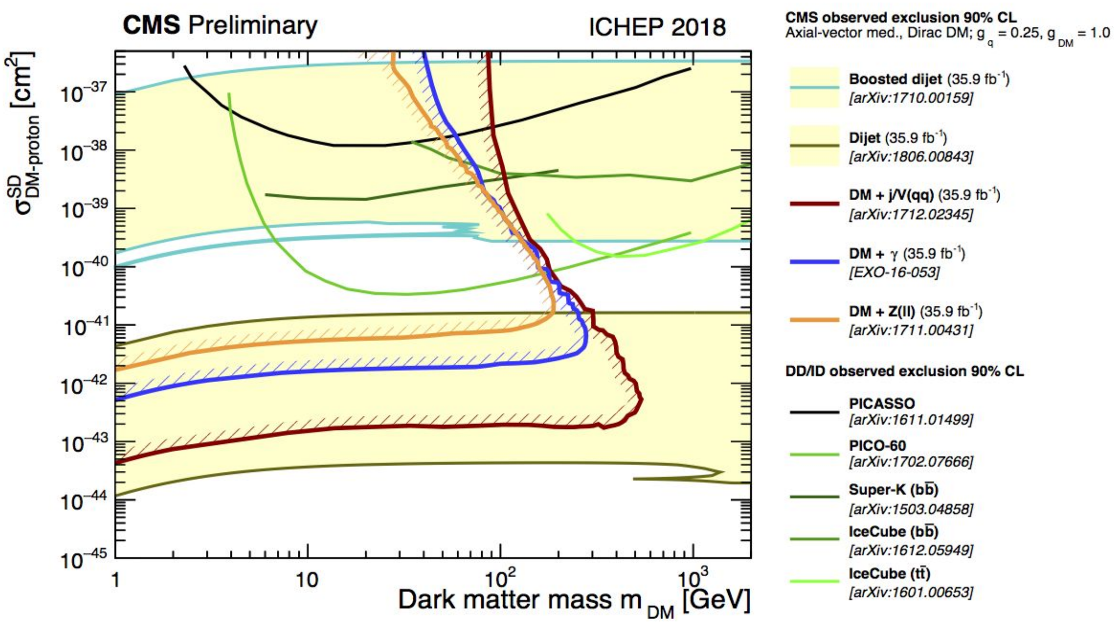


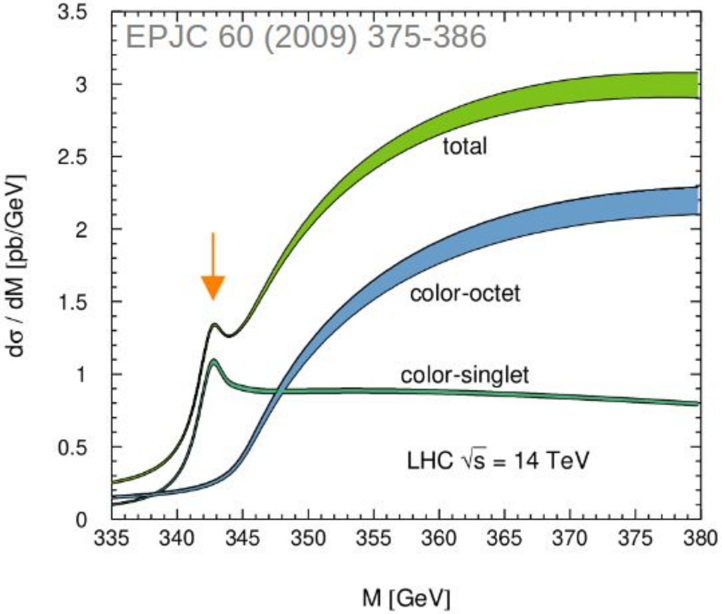
Dark Matter summary plots

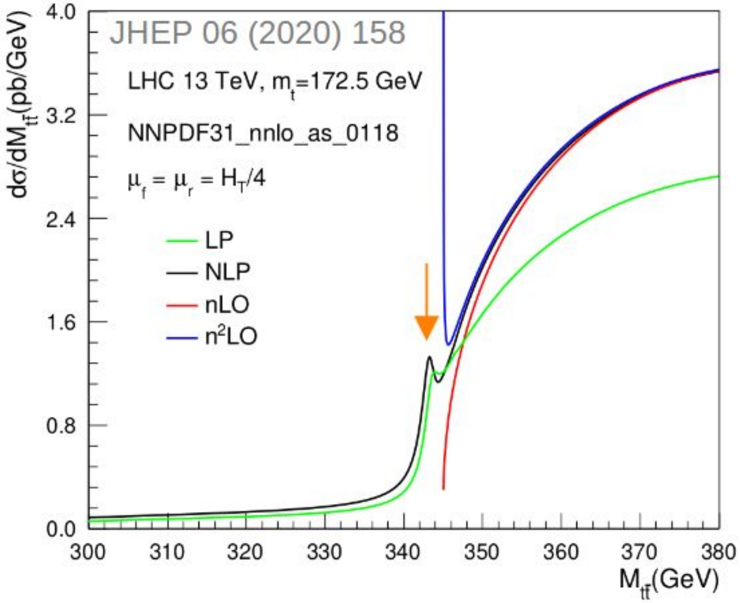




$t\bar{t}$ bound states

- SM predicts $t\bar{t}$ (quasi-)bound states below the $t\bar{t}$ threshold





- So far not observed!
- Dominant component: pseudoscalar – can we search for it?

Bins : cut in an helicity variable specific feature of a pseudoscalar resonance