Post-doctoral research associate candidate for the project:

CLUSTER OF EXCELLENCE
"QUANTUM UNIVERSE"

Riccardo Salvatico
PhD student at University of Torino

Introducing myself and my research activities

Introducing myself

@ University of Torino, Italy

My career in physics, so far:

- **Bachelor thesis (2015):** study of criticality and sub-criticality conditions of the experimental fission reactor VENUS-F
  - → Result of a three-months internship at KIT, Karlsruhe
- **Master thesis (2017):** search for the rare decay of $W \to \pi\gamma$ in pp collisions at 13 TeV at CMS
  - → An analysis started from zero – as was my knowledge of CMS and its procedures and techniques
- **PhD (2017-now):** search for the rare decay of $W \to \pi\gamma$ in pp collisions at 13 TeV at CMS
  - → Improving the search, trying to make the best out of the full Run2 dataset, and targeting the publication
  - → In addition, working on the upgrade and the operation of the CMS ECAL
  - → Physics analysis and detector activities benefited from the year (2019) I have spent at CERN after winning a fellowship from INFN
  - → Conducting teaching and tutoring activities for Bachelor students

The search for $W \to \pi\gamma$

No exclusive hadronic decay of the W boson has ever been observed

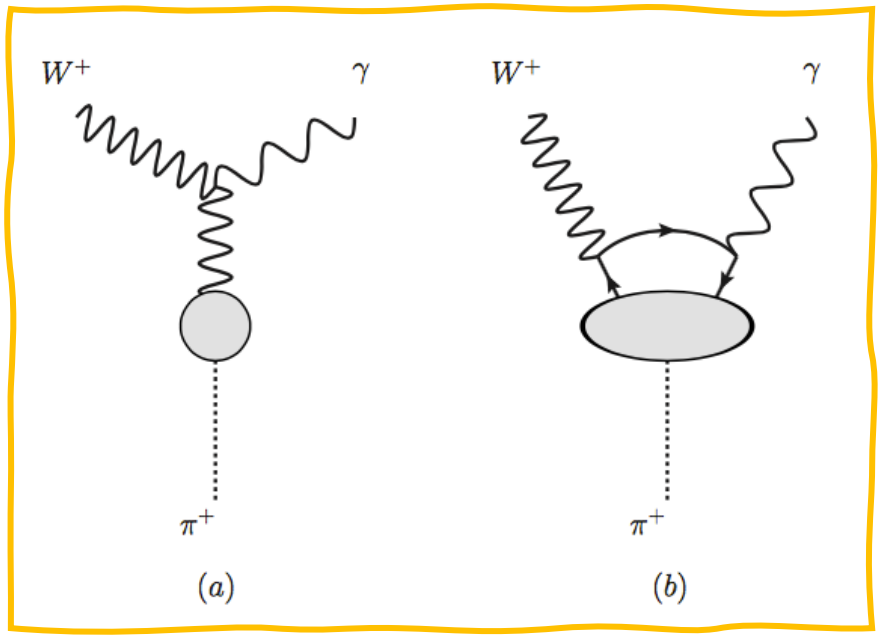
95% CL upper limits measured before:

$\mathfrak{B}(W^{\pm} \to \pi^{\pm}\gamma) < 7.0 \times 10^{-6}$ [CDF]

$\mathfrak{B}(W^{\pm} \to D_s^{\pm}\gamma) < 1.3 \times 10^{-3}$ [CDF]

$\mathfrak{B}(W^{\pm} \to \pi^{\pm}\pi^{\pm}\pi^{\mp}) < 1.01 \times 10^{-6}$ [CMS]

To be compared with many more results on exclusive hadronic decays of the Z boson



Theoretical predictions have rather large uncertainties

e. g. $10^{-9} \lesssim \mathfrak{B}(W^{\pm} \to \pi^{\pm}\gamma) \lesssim 10^{-6}$

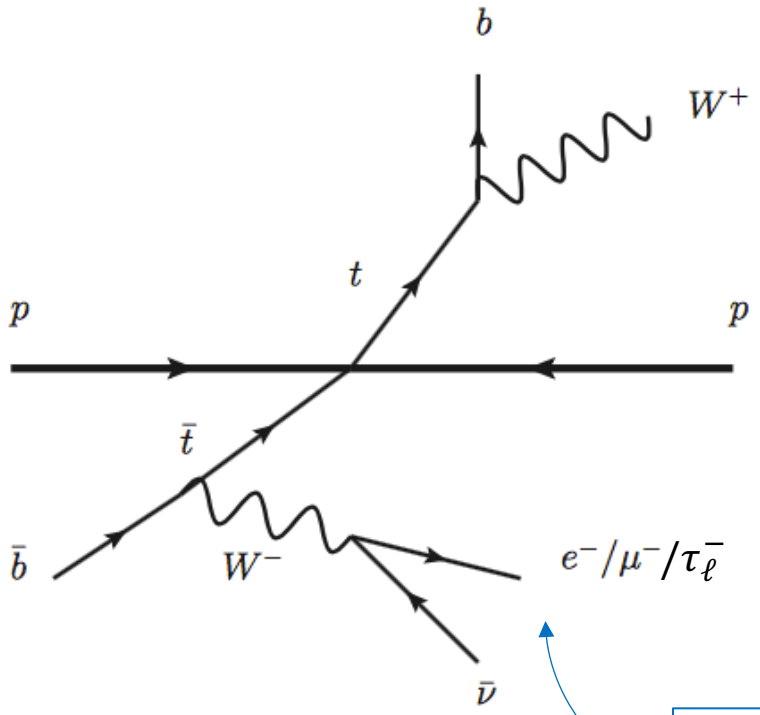
- Observation would provide a good probe of the SM
- Could provide insights into QCD (e.g. factorization and meson form factors at high energy scales)
- Opportunity to measure m_W through visible decay products only → interesting scenario at future hadron colliders

Strategy

* M. Mangano, T. Melia
Rare exclusive hadronic W decays in a $t\bar{t}$ environment

Hard to perform this search at CMS by triggering on the photon

Isolate $t\bar{t}$ events*



Leptonic decay of one W for trigger and event ID

CMS-PAS-SMP-20-008 EPJC 75, 258 (2015)

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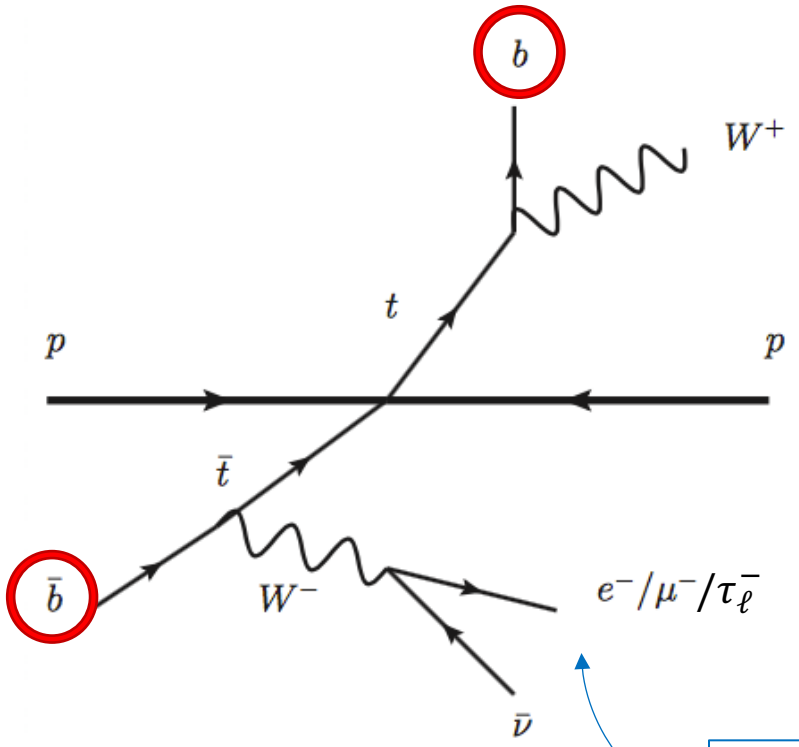

The presence of two b-jets is a specific trait of the $t\bar{t}$ topology
→ reduce contribution from non- $t\bar{t}$ backgrounds

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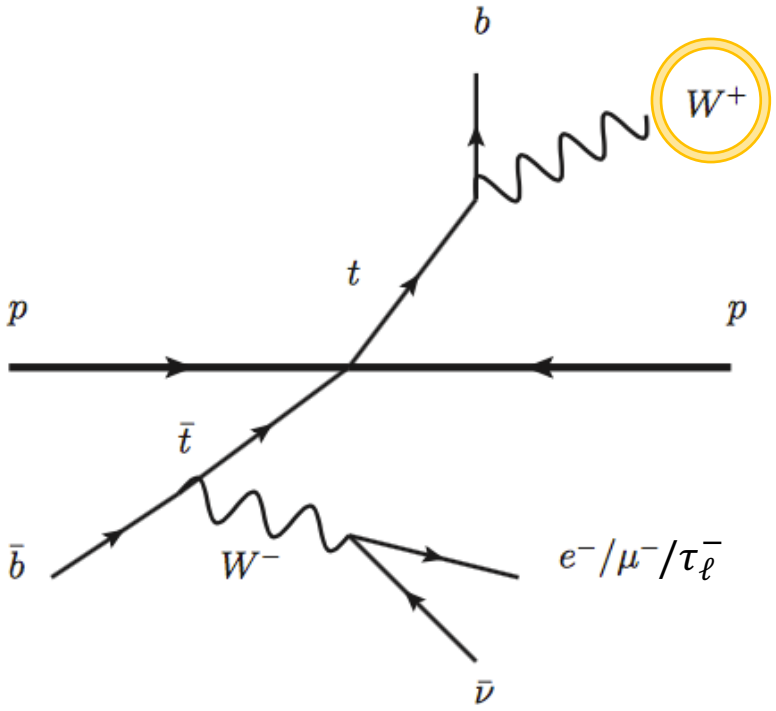


W^+ (W^-) analyzed to find the rare decay

γ Isolated high-E_T photon

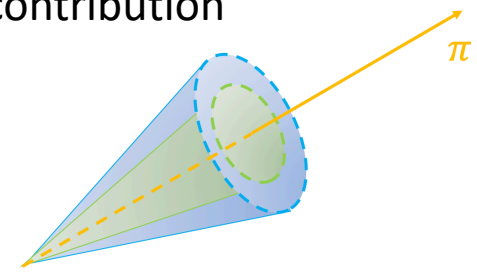
π Isolated high-p_T pion

Measure $\mathfrak{B}(W \to \pi\gamma)$
with a fit on the reconstructed $m_{\pi\gamma}$ distribution

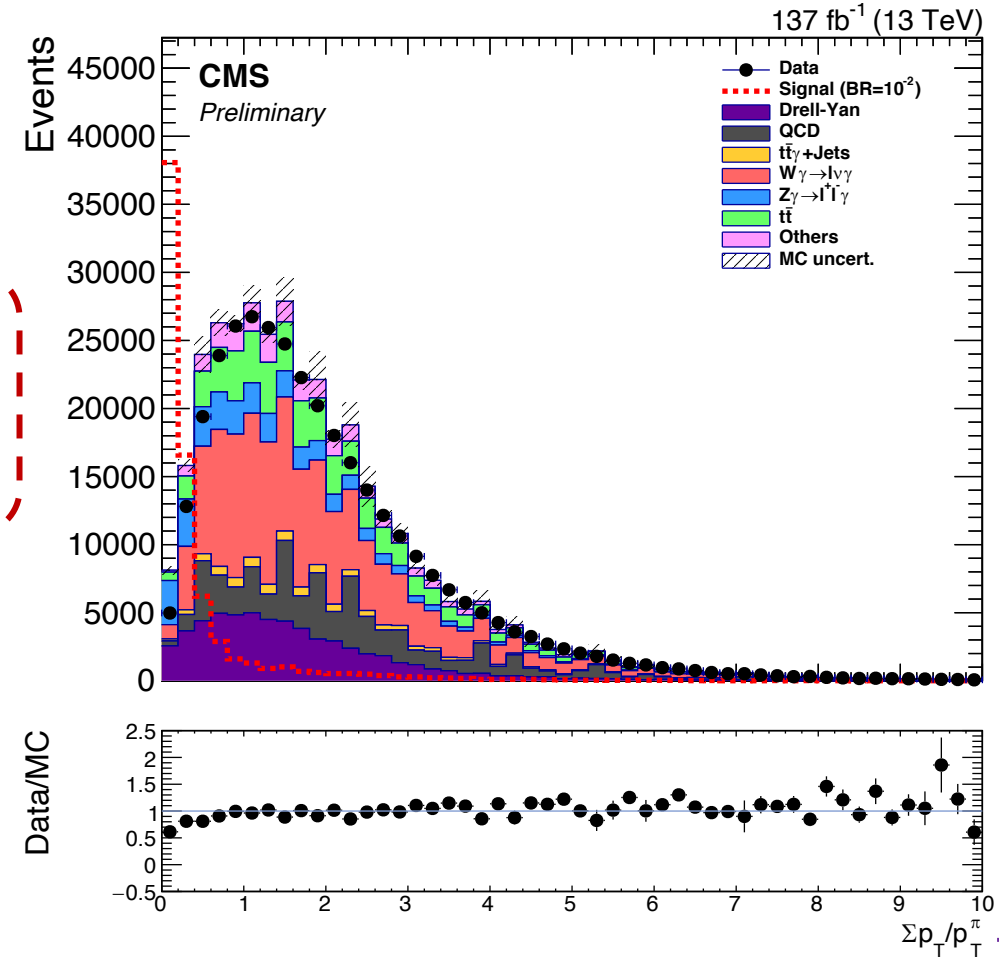
CMS-PAS-SMP-20-008 EPJC 75, 258 (2015)

Pion isolation

$\sum p_T$ of all the particles contained in a cone of $0.02 \leq \Delta R \leq 0.5$ around the pion, excluding contribution from pile up (charged particles are requested to come from primary vertex)



The pion from W $\rightarrow \pi\gamma$ decay originates from an EW process → hadronic activity in its vicinity is expected to be low



Pion **relative isolation** $\sum p_T / p_T^{\pi}$

CMS-PAS-SMP-20-008

Event selection

Trigger

- Single muon or single electron

Collision dataset corresponding to $137\ \mathrm{fb}^{-1}$ at $13\ \mathrm{TeV}$

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- Single muon or single electron

Event preselection

- **ONE** isolated muon **OR** electron **ONLY** ($p_{\mathrm{T}} > 25\ \mathrm{GeV}$)
- One pion ($p_{\mathrm{T}} > 20\ \mathrm{GeV}$) with charge ≠ lepton charge
- One isolated photon ($E_{\mathrm{T}} > 20\ \mathrm{GeV}$)

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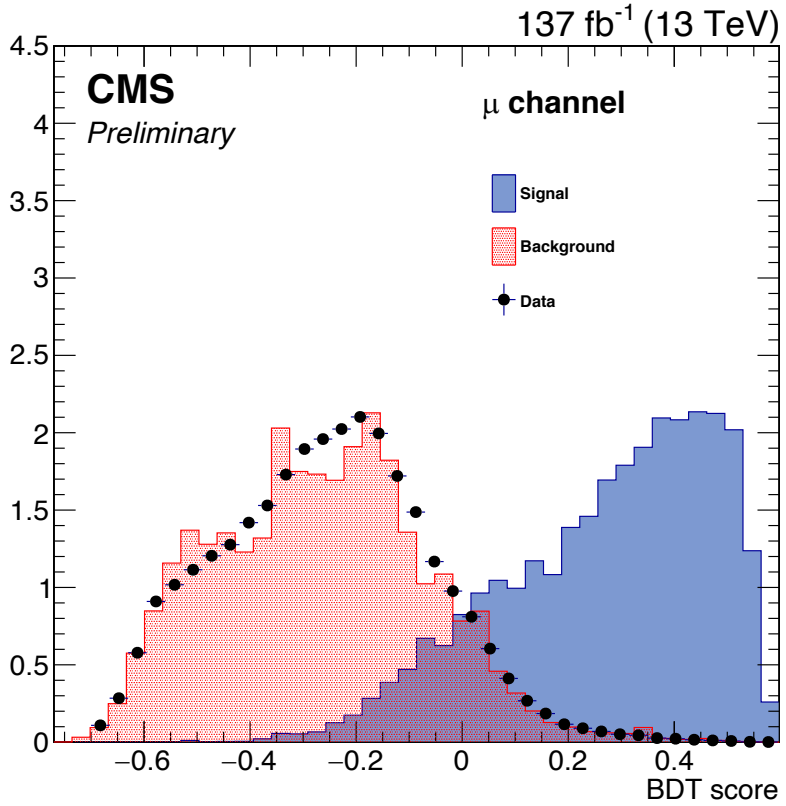
Collision dataset corresponding to 137 fb^{-1} at 13 TeV

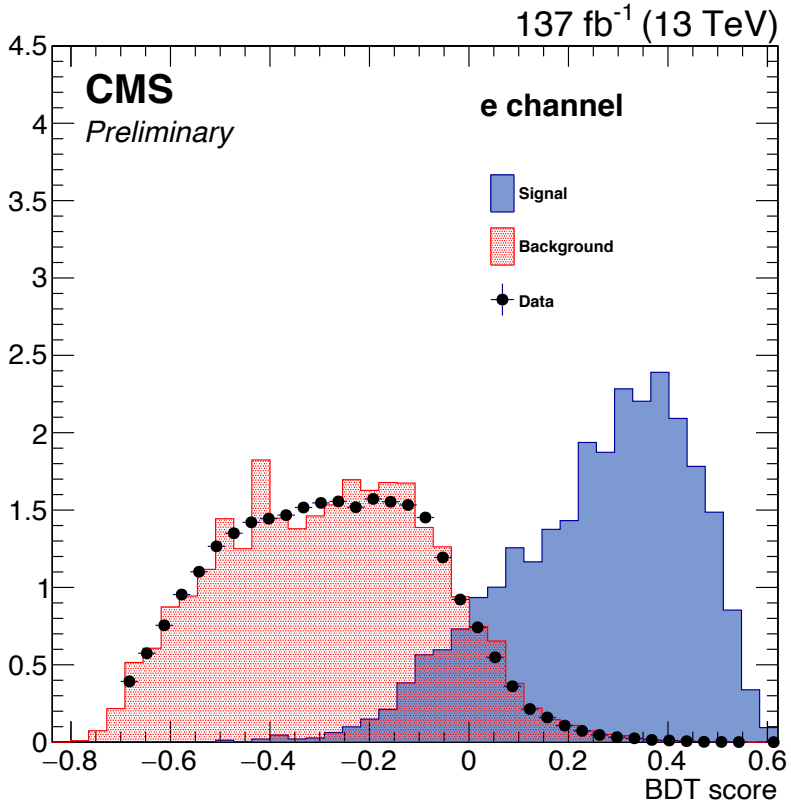
BDT (trained on MC simulation), exploiting:

- Relatively high p_{T} of the particles involved
- Moderate amount of E_{T}^{miss}
- Number of b-tagged jets (supposed to be 2 for signal)
- Pion isolation

Event classification



Control region ⟷ Signal region

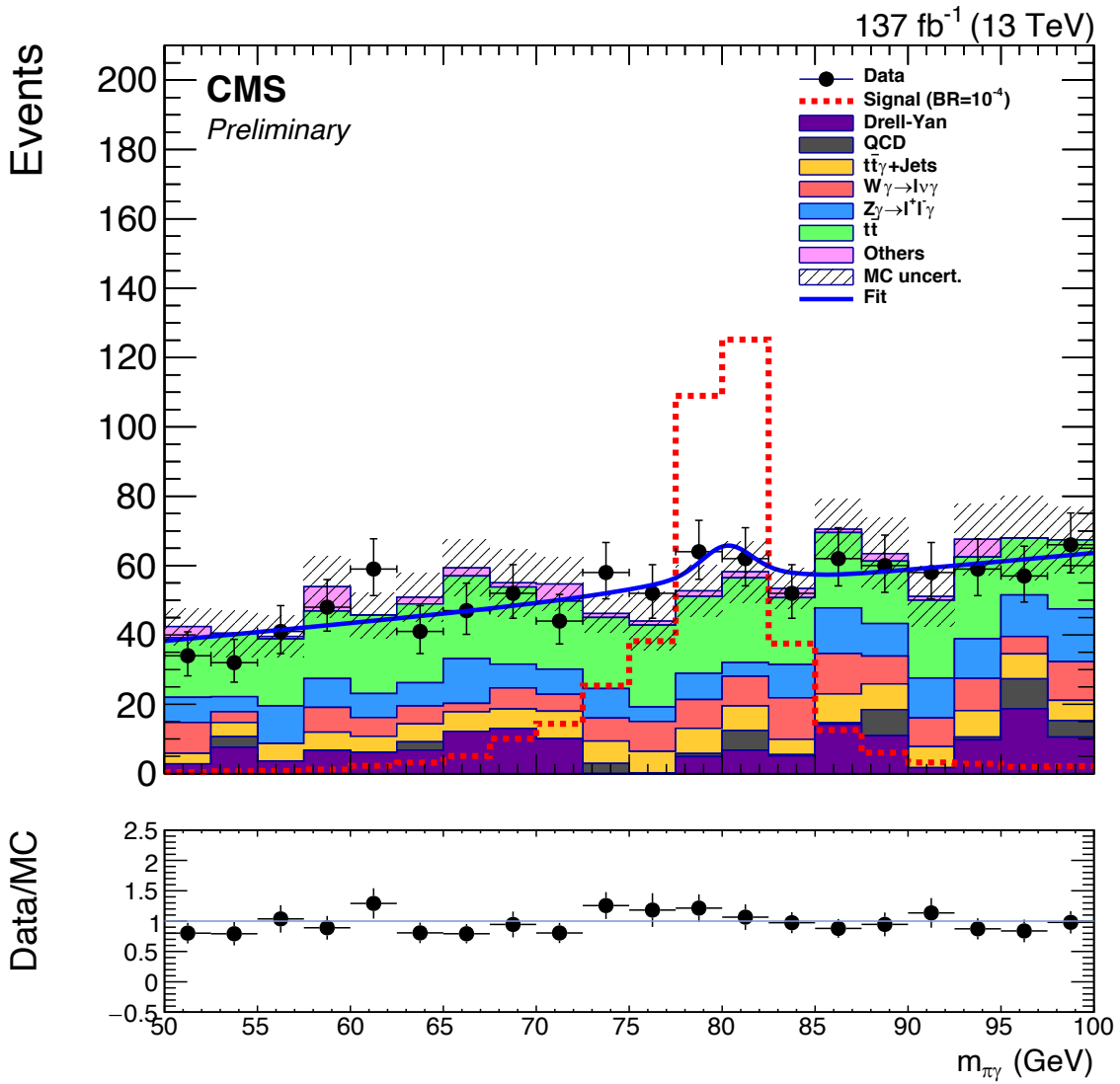


Control region ⟷ Signal region

Then, the $m_{\pi\gamma}$ distribution is observed

- *Control regions (merged)*→ estimate the background functional form directly from data → independent from MC description
- *Signal regions (merged)* → fit to extract $\mathfrak{B}(\mathrm{W} \to \pi\gamma)$. Signal functional form derived from MC simulation

Results



Unbinned ML fit to $m_{\pi\gamma}$ in the sum of the muon and electron SR

No significant excess above the expected background is observed

$$\mathrm{UL}\left(\mathfrak{B}_{W\to\pi\gamma}\right) = 1.51 \times 10^{-5} \qquad \mathrm{CL} = 95\%$$

- **Statistical uncertainty is dominant**
  - It represents ~80% of the total uncertainty

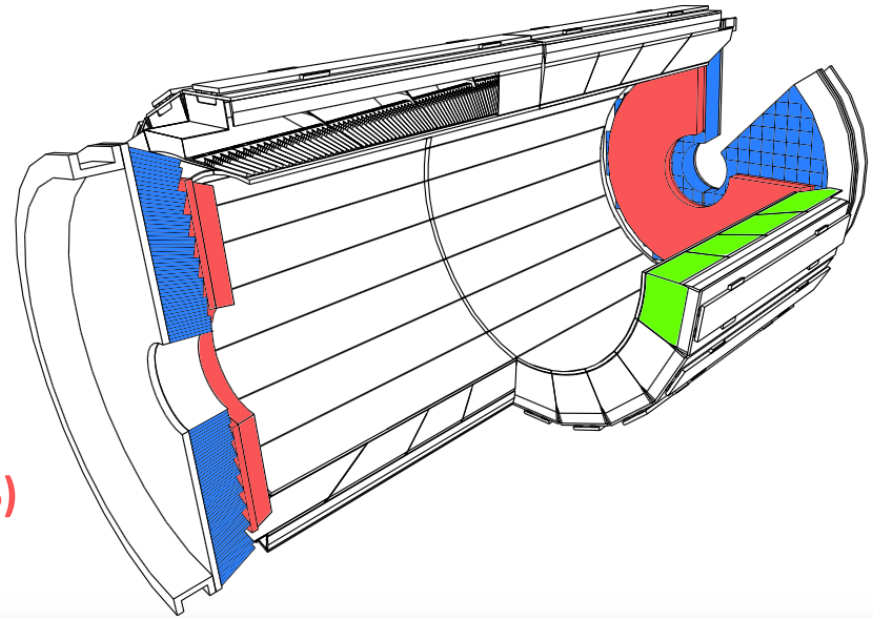
- **Systematic uncertainties**
  - Integrated luminosity
  - $t\bar{t}$ production cross section, measured by CMS
  - Background parametrization
  - Signal parametrization
  - Efficiency/Acceptance:
    - BDT modeling
    - Signal modeling (PYTHIA 8)
    - Lepton and photon scale corrections
    - Charge misidentification

CMS-PAS-SMP-20-008

On the detector side…

I have been working on the **CMS ECAL** since my master

- Beam tests on new calorimeter prototypes and electronics for Phase2
- Deployment and monitoring of the Prompt Calibration Loop (electronic pedestals measurement)
- Simulation of the Phase2 ECAL Barrel electronics
- Serving as ECAL Detector expert On Call during data taking and MWGR



ECAL Barrel (EB)

ECAL Endcap (EE)

ECAL Preshower (ES)

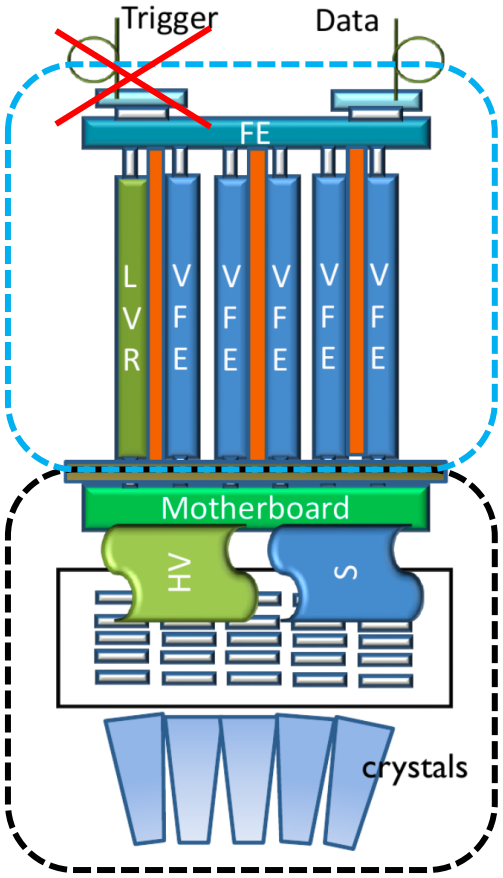
ECAL in Phase2

https://cds.cern.ch/record/2283187/files/CMS-TDR-015.pdf

❑ **Complete redesign of EB electronics from the avalanche photodiode (APD) up**

- Cope with increased CMS-wide L1 trigger latency ($4.5\ \mu s \rightarrow 12.5\ \mu s$) and rates (100 kHz → 750 kHz)
- Upgrade trigger capabilities

➡ L1 trigger logic moved off-detector and evaluated by powerful and flexible FPGA processors



- Improve time resolution ($30\ ps$ at $50\ GeV$) → better primary vertex ID
- Improve discrimination between scintillation light from EM showers and direct hits in the APD

➡ Faster analog electronics and sampling frequency increased to 160 MHz

❑ **EE will not be able to sustain the high radiation levels and will be replaced by HGCAL**

My work on the Phase2 upgrade

Changes in the electronics:

- Shorter pulse shaping
- Higher sampling frequency
- Different APD gain number and values
- Different number of samples

Substantial modifications in CMSSW:

- ❑ Sampling frequency
- ❑ Number of samples
- ❑ Number of APD gains – gain scheme – gain switch
- ❑ Pedestals
- ❑ Removal of EE and ES

Needed both in the event simulation
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Great effort to:

- Keep Phase1 and Phase2 codes working in parallel
- Avoid massive duplication of Phase1 classes → *templating*

A Pull Request to merge the new code in CMSSW is currently being reviewed

Needed both in the event simulation and reconstruction frameworks

What I have learned

The search for $W \to \pi\gamma$, of which I am the main author, taught me how to **carry out a research project independently**.

It also taught me how to:

- Use the CMS analysis framework
- Look for useful documentation
- Be patient with problems which seem unsolvable
- Ask for support to relevant experts
- Keep my supervisors and the PAG/POG conveners up-to-date with the ongoing work

From my involvement in detector upgrade and operations, I have learned how to **work in a team productively,** even when the only option is to cooperate remotely.

Thanks to the weeks spent as Detector expert On Call, I now know I can **handle stressful situations** in which it is important to make quick decisions.

I am used to **present the results of my research** and I am able to adapt to different kinds of audience. Thanks to my involvement in outreach (such as being a CMS guide), I have also learned how to deliver information to a general public.

Future projects: thrilling questions, exciting solutions

The Physics landscape of this century is still studded with open questions. Among these:

What is the nature of Dark Matter? Can we investigate it at hadron colliders?

Astrophysical and cosmological data, so far, can only tell us how much DM there is in the universe, and not what it is

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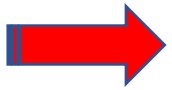
Several DM production models tested at the LHC



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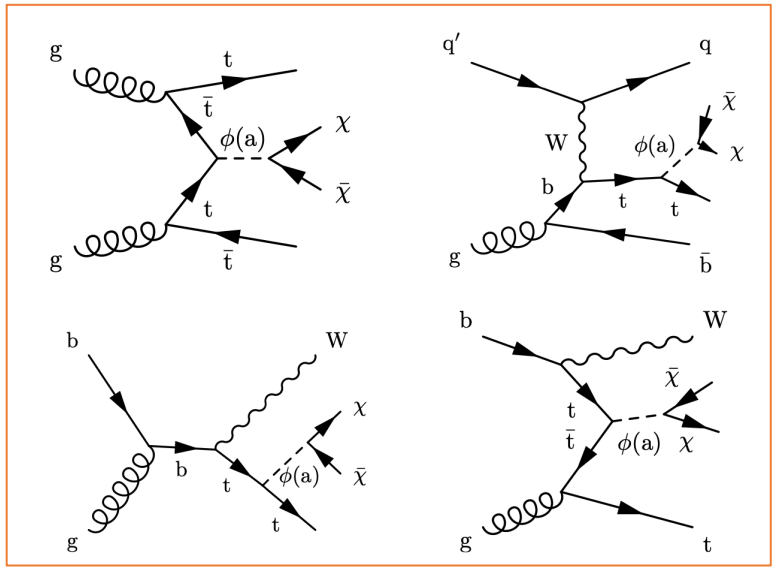

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Some very promising searches at CMS do not make use of the full Run2 luminosity yet !

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Example: search for DM in events with $t\bar{t} \rightarrow$ leptonic + scalar mediator

For signal, $p_{\mathrm{T}}^{\mathrm{miss}}$ arising from: neutrinos & invisible mediator

New variable: $\boldsymbol{p_{\mathrm{T}}^{\mathrm{Dark}}}$ → Algorithm that reconstructs the kinematic of the event under the hypothesis of $p_{\mathrm{T}}^{\mathrm{miss}}$ only arising from top quark decay. When solution not found, $p_{\mathrm{T}}^{\mathrm{Dark}}$ defined as residual contribution to $p_{\mathrm{T}}^{\mathrm{miss}}$

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This is what I would like, and I am committed to do

What I envisage in the near future

I am now ready to take on new research projects and face the challenges that come with them

- ✓ I have acquired a fair amount of skills that are useful in HEP, and I have developed creativity and problem solving

- ❑ There are fields in which I want to expand my knowledge (e.g. machine learning techniques)
- ❑ I am thrilled by the opportunity to explore new topics with respect to my background in HEP (SM measurements)
- ❑ Chance to assume more responsibilities
- ❑ Happy about the supervising opportunity – I deem teaching and more in general being able to pass on the knowledge to be essential for a researcher

I believe this position would give me the opportunity to grow and to achieve my career targets for the near future

I would be eager to contribute to the efforts of the CMS group in DESY!

BACKUP

Theoretical calculations of $W \to \pi\gamma$

Arnellos, Marciano, Parsa → Assume the Brodsky-Lepage (BL) asymptotic formula for the off-shell photon-photon-pion vertex, $\gamma^*\gamma\pi$, for both the vector and axial form factors.
Estimated order of magnitude: $\mathfrak{B}(W \to \pi\gamma) \sim 10^{-9}$

Kneum, Pham → One-loop calculation leading to the estimate: $\mathfrak{B}(W \to \pi\gamma) \sim 10^{-8} - 10^{-6}$

M. Mangano, T. Melia → Adapt Manohar's calculation of $Z \to \pi^0\gamma$, which uses an operator product expansion (OPE) at leading order in α_S, retaining only the leading terms in a tower of twist two operators.
Estimated order of magnitude: $\mathfrak{B}(W \to \pi\gamma) \sim 10^{-9}$, although the expansion is not convergent and will be modified by important higher order corrections