DITTO ERC Project: comprehensive search for new phenomena in the dilepton spectrum at the LHC

Tetiana Hryn'ova (LAPP, CNRS)

LHC Job Matching Event - 3/05/2023

DITTO Project

Based in LAPP, Annecy, France (<50 km south of CERN, 40’ drive)

Project will start on 1st of October 2023 for 5 years

2 postdoctoral researcher and 1 software engineer positions are open initially for 2 years with extensions expected

Job announcements [detailed in the next slides] to be posted shortly to the CNRS Job Portal https://emploi.cnrs.fr/Offres.aspx and LAPP website https://lapp.in2p3.fr/

Detailed DITTO project description starts on page 6

2 postdocs, Jared Little and Daniel Lewis, and 1 PhD student, Tom Cavaliere, are currently working at LAPP on related Run 2 analysis subjects. More people will join the team in coming years

DITTO Software Engineer position overview

Main Responsibilities:

- Software development in the ATLAS software framework Athena [https://atlassoftwaredocs.web.cern.ch/athena/athena-intro/], based on inter-experiment framework Gaudi Hive.
- Implementation of improvements to the ATLAS electron and tau-lepton reconstruction and identification in both trigger and offline environment using the cutting-edge machine-learning techniques.
- Ensure portability of the developed software into the High Luminosity LHC ATLAS trigger environment (2029+), which will be based on a hybrid architecture (the exact technology to be chosen in mid-2025).

Qualifications:

- Master, DEA, DESS or engineering degree (BAC+5) in computer science or particle physics.

Expertise:

- Experience with machine learning techniques and tools.
- Experience with software development for high energy or nuclear physics experiments would be appreciated.
- Experience programming of heterogeneous devices, GPUs, FPGAs, or HPC machines would be appreciated (possibility to training in these areas)
- Skills in development, deployment and unit tests
- Skills in Continuous integration and deployment on GitLab
- Working in Linux environment

Know-how:

- Ability to work within a multidisciplinary team (engineers and physicists) and in a large international collaboration
- Ability to present technical work in English: Fluency in English, speaking and writing (B2 minimum).
- Basic knowledge of French could be useful.
- Interest to learn and ability to manage the project

DITTO postdoctoral researcher positions overview

Main Responsibilities

Position 1

- ATLAS HMDY measurements based on the combined LHC Run 2 (2015-2018) and Run 3 (2022-2025) data sets in the tau-lepton channels ($\tau\tau/\tau\nu$)
- Work on ATLAS tau-lepton reconstruction, identification and calibration improvements

Position 2

- ATLAS HMDY measurements based on the combined LHC Run 2 (2015-2018) and Run 3 (2022-2025) data sets in the light lepton channels (ee/ev/$\mu\mu/\mu\nu$)
- Work on ATLAS electron reconstruction, identification and calibration improvements

Common

- The performance improvements will be implemented in ATLAS software framework Athena [https://atlassoftwaredocs.web.cern.ch/athena/athena-intro/], in a way to facilitate their application in the HL-LHC ATLAS trigger environment, based on a hybrid architecture (CPU/GPU/FPGA).
- Develop in the ATLAS git environment [https://gitlab.cern.ch/] a common framework for the complete analysis chain for the HMDY channels (selection/background estimation/unfolding/etc) usable in the Open Data environment.

Qualifications

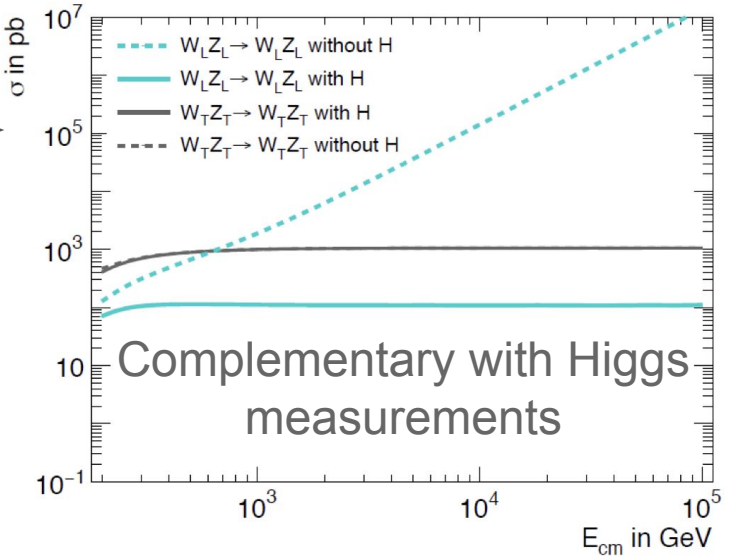
Candidates should hold a Ph.D. degree, obtained less than 7 years before the starting date of the position.
A strong experience in software development, data analysis and knowledge of statistical techniques for data analysis for high energy physics experiments is required. Experience with analysis of LHC data based on C/C++ and Python, machine learning techniques and tools, expertise programming accelerators (GPUs etc) would be appreciated.
Ability to work in a large international collaboration is a must.
Fluency in English, speaking and writing (B2 minimum).
Basic knowledge of French could be useful.

Another position currently offered at LAPP in ATLAS:

EW measurements & extensions for the Phase-II detector

Two-year (extendable) position at LAPP (Annecy) with frequent trips to CERN (<50 km).

Polarization effects in diboson events produced at LHC are a crucial topic!



Probing the 'closure' of the EW sector

Measurements in VBS diboson events are challenging (background, not so high cross-section,...)

Future ATLAS Phase-II detector (future tracker with extended coverage, new high granularity timing detector,...)

→ possibility for a larger acceptance

The position: working with a PhD student (and senior physicists in a team dedicated to diboson measurements) developing machine learning tools for the WZ VBS measurements with Run-III data & exploration of performance improvements (e.g. forward electrons) using the Phase-2 detector.

Possibility to contribute to operations of the electromagnetic calorimeter and the preparation of the online software architecture for Phase-II (expertise of the group also involved in upgrade of the electronics)

Contact: Olivier.Arnaez@cern.ch

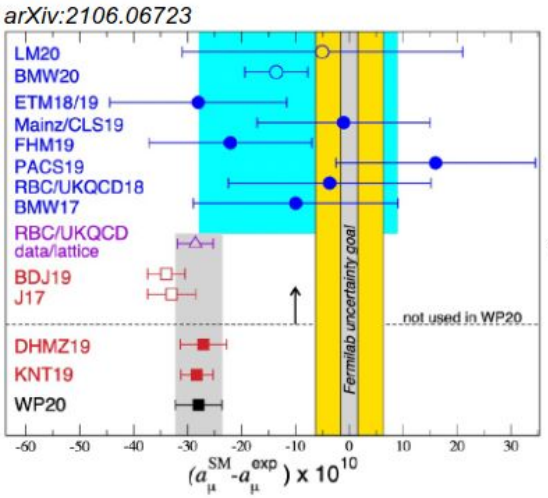
https://lapp.in2p3.fr/spip.php?article3313

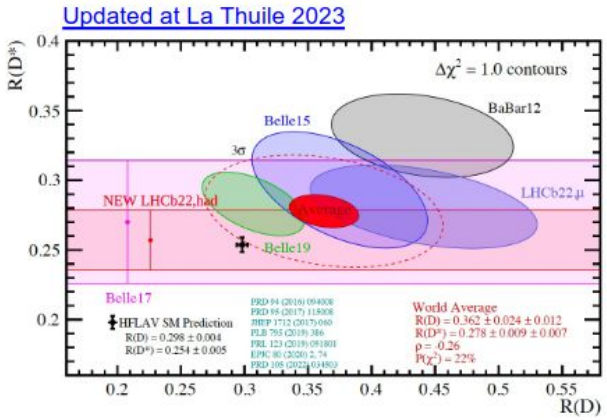
DITTO Project

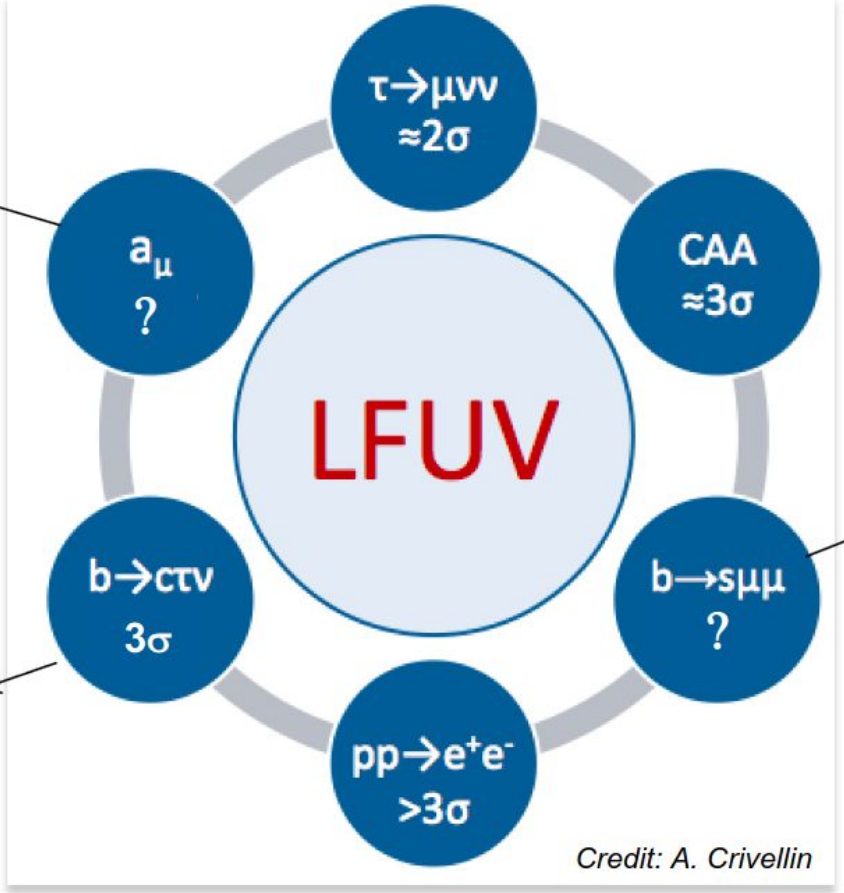
Open questions in Particle Physics

Following a discovery of Higgs boson in 2012,
Standard Model (SM) of particle physics is complete and self-consistent

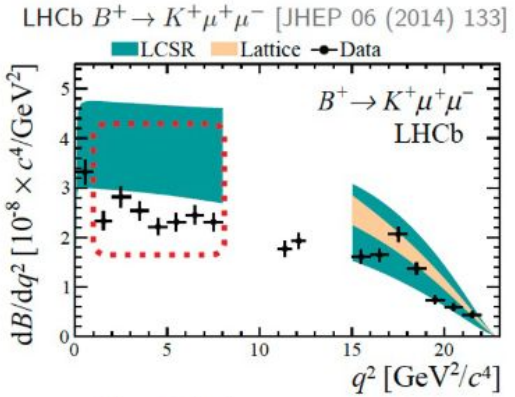
BUT: no gravity, unclear origin of dark matter, why 3 lepton generations,
and hints of lepton flavor universality violation (LFUV):

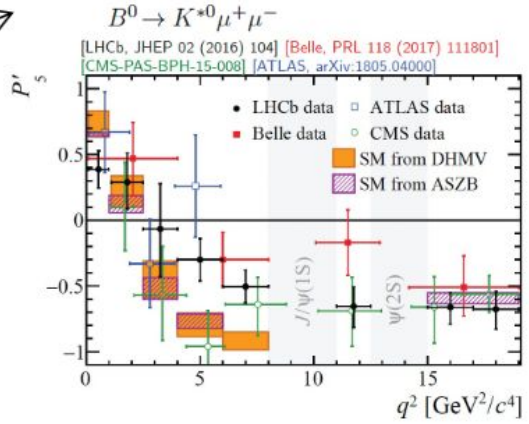






However, the other b→sμμ anomalies are still there!

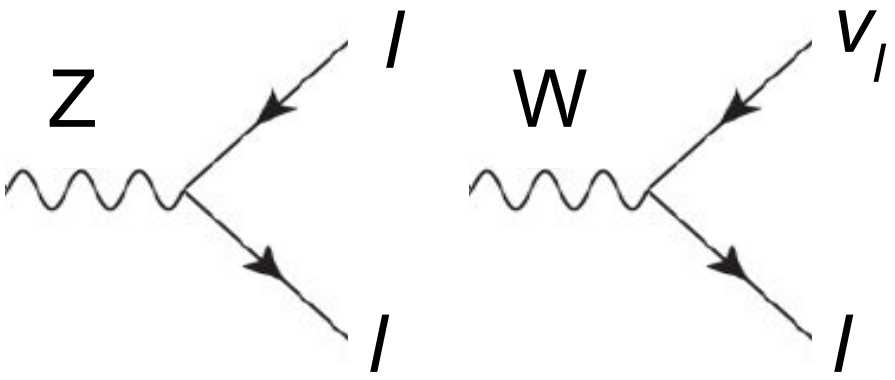




Figures from the talk of A. Juste @ Moriond EW 2023

Motivation for DITTO Project

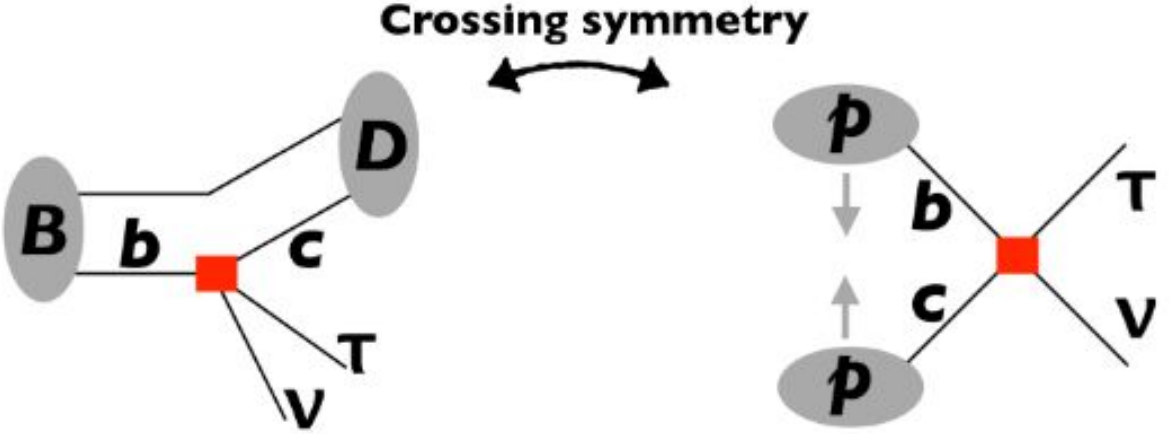
Lepton Flavor Universality (LFU):
in Standard Model
leptons (l=electrons, muons and τ) have
the same interaction strength
with the electroweak-force.
Differences => New Phenomena



Similar pattern of deviations in B-meson decays is seen by multiple experiments

From Phys. Rev. Lett.122 131803 (2019)

B-meson decays



Drell-Yan scattering at high dilepton mass (HMDY)

sensitive to the same new phenomena

Signature: excess or deficit of events with ll/lν => DITTO Project

DITTO Main Goals and Deliverables

Use the unprecedented dataset & world's highest-energy collisions of 13.6 TeV at the LHC

Measure HMDY for the first time together in all flavor combinations: (ee/ν, μμ/ν, ττ/ν…) in m_{ll}, rapidity,.. to search for deviations from SM predictions

$$pp \rightarrow \ell^+\ell^-/\ell\nu(+b)$$

Excellent lepton performance crucial to achieve measurement precision

Probe additional b-quark jets to increase sensitivity to new phenomena

DITTO Timeline: 1 Oct 2023 - 30 Sept 2028

Experimental Equipment: ATLAS detector @ LHC

Proton-proton data sets to be used in DITTO project:

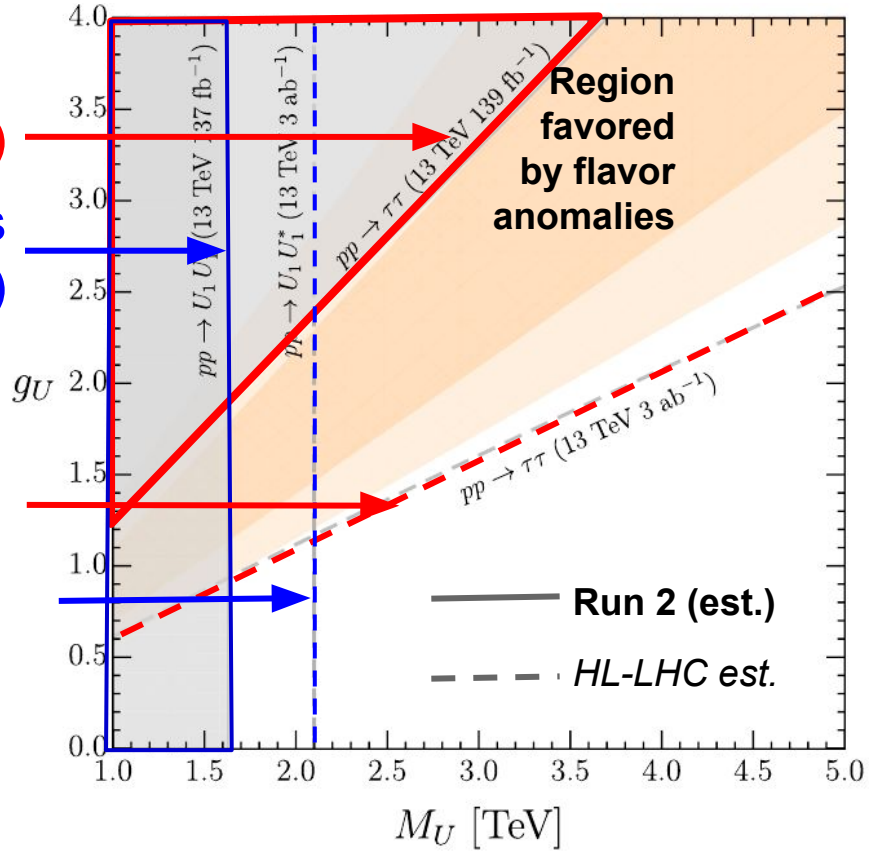
Run 2 (2015-2018)	**Run 3 (2022-2025)**	***HL-LHC** (2029+)*
139fb^{-1} @ 13TeV & 2x10^{34} cm^{-2}s^{-1}	**~290fb^{-1}** @ 13.6TeV & 2x10^{34} cm^{-2}s^{-1}	***~3ab^{-1}*** *@ 14TeV & 5-7x10^{34} cm^{-2}s^{-1}*

Run 2 HMDY $\tau\tau$ ("DITTO")

Run 2 direct searches for lepto-quarks (U)

HL-LHC HMDY $\tau\tau$

HL-LHC direct search



From JHEP 08 (2021) 050

HMDY measurements much more powerful than direct searches

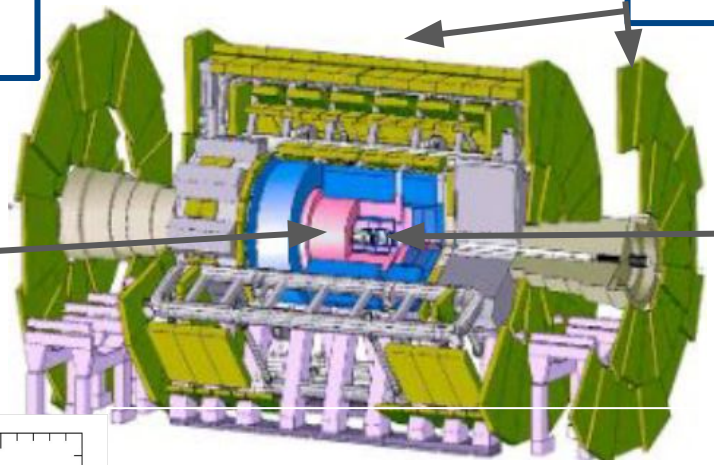
Analysis of Run 2 + Run 3 data, preparation for HL-LHC data taking.

ATLAS Run 3 & HL-LHC Detector Improvements

Trigger/DAQ
Run 3: improved granularity of hardware calorimeter & muon trigger
Recorded events rate increase: x 3
HL-LHC: Trigger recorded rate x 10
New trigger architecture

High Granularity Timing Detector: new for HL-LHC

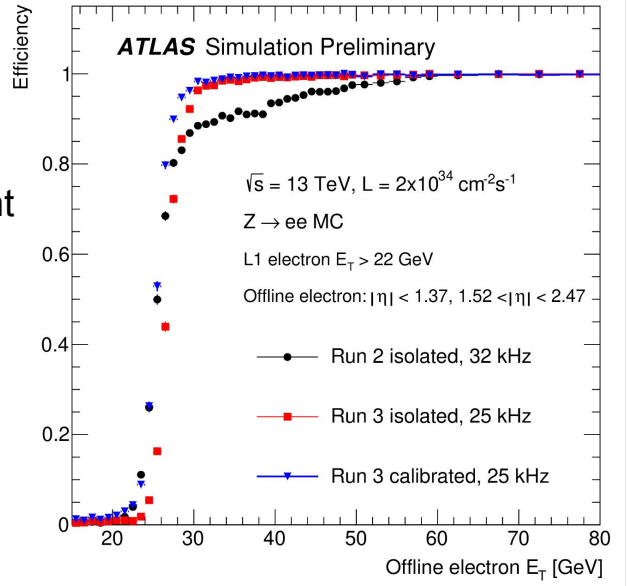
Muon System (MS)
Run 3: New Small Wheel detector
HL-LHC: Minor detector upgrades + replacement of the readout electronics



Calorimeters (Calo)
HL-LHC: replacement of the readout electronics

Inner Detector (InDet)
HL-LHC: Detector replacement
Increased coverage from $|\eta|<2.5$ to $|\eta|<4.0$

Run 3 Electron Trigger Efficiency Improvement

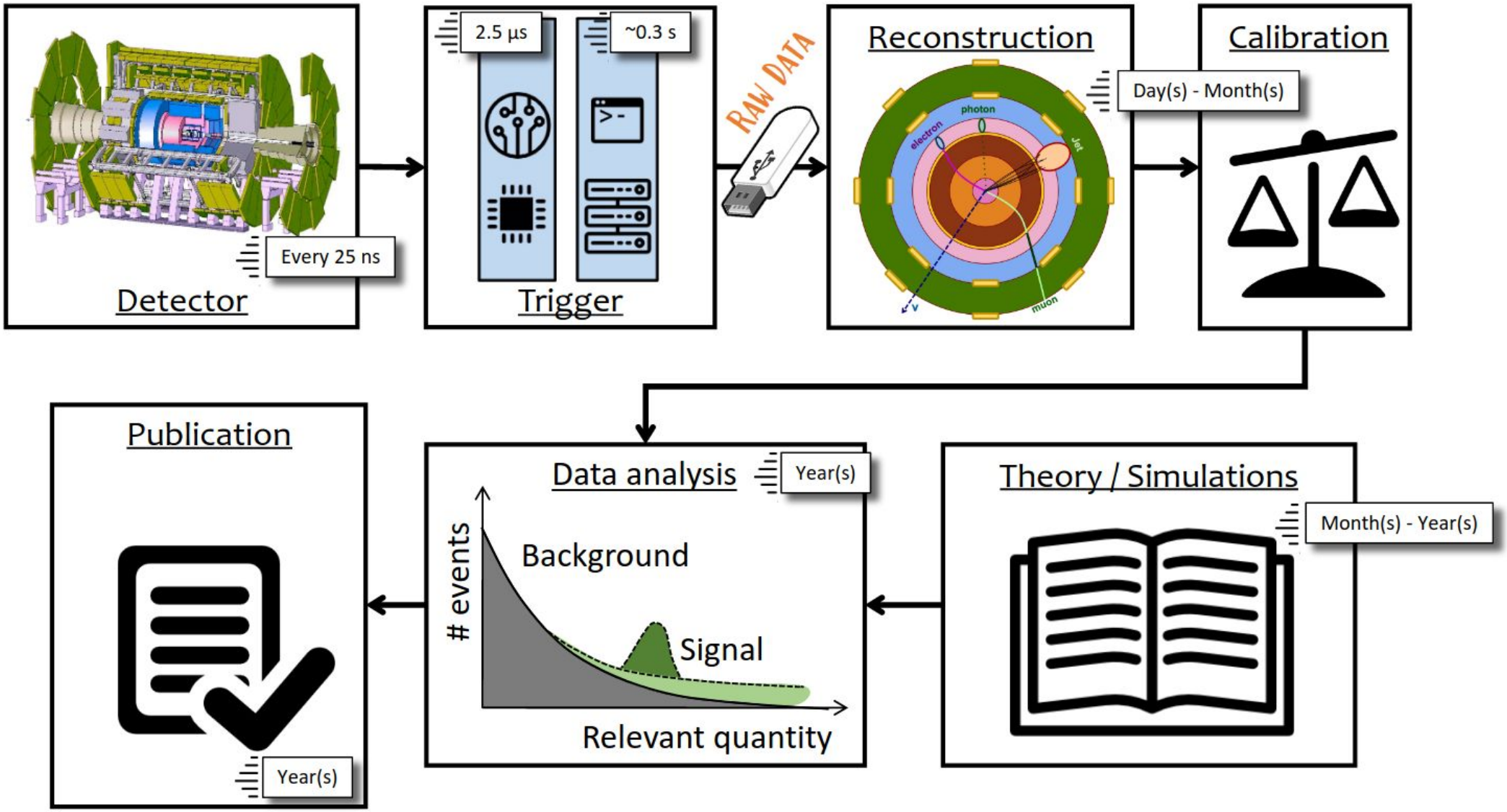


Main objects of interest for HMDY measurements:

- **electrons (Calo+InDet)** - *this project*
- muons (MS + InDet) - *common project with Weizmann (Joint PhD program)*
- **tau-leptons (Calo + InDet)** - *this project*
- bjets (Calo + InDet)
- neutrinos : missing transverse energy (Calo)

From https://twiki.cern.ch/twiki/bin/view/AtlasPublic/L1CaloTriggerPublicResults

ATLAS analysis chain

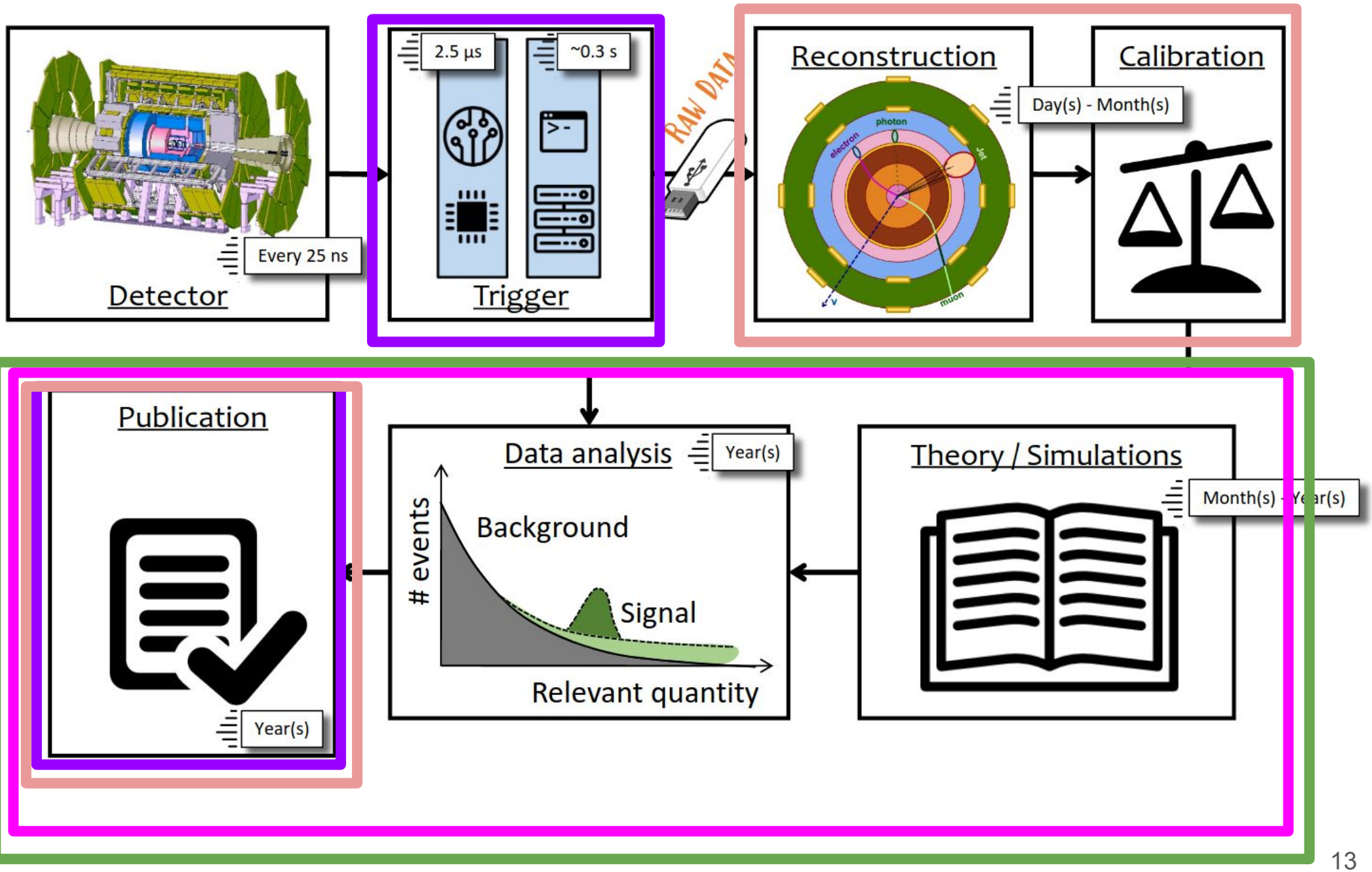


DITTO team will bring innovative ideas to each step of the ATLAS analysis chain

Schema from A. Sfyrla

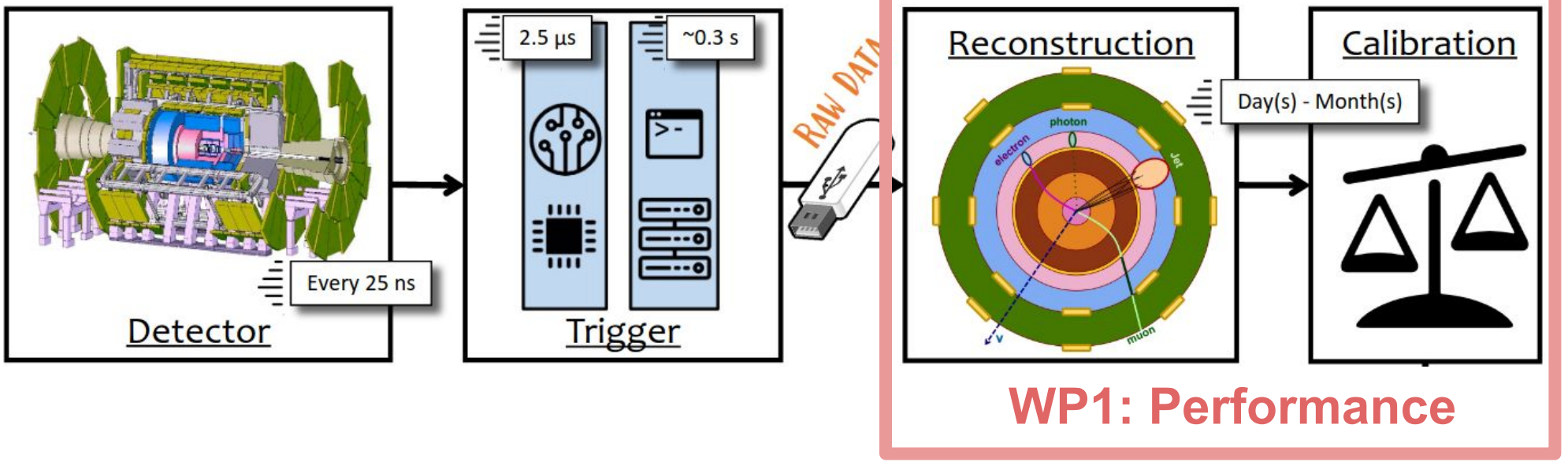
DITTO Project Organisation

WP1 WP2 WP3 WP4



DITTO Project Organisation (WP1)

Max signal efficiency - min systematic uncertainties - all channels together



Main responsibilities:
Postdoc 1 - tau performance improvement studies
Postdoc 2 - electron performance improvement studies
Software Engineer - implementation into ATLAS software

Novel identification based on calorimeter cells and tracks for electrons and τ-leptons

$W \rightarrow l\nu$ and $tt \rightarrow WWbb \rightarrow e\nu\mu\nu bb$ events to reduce uncertainties @ high p_T

ATLAS electron reconstruction & identification

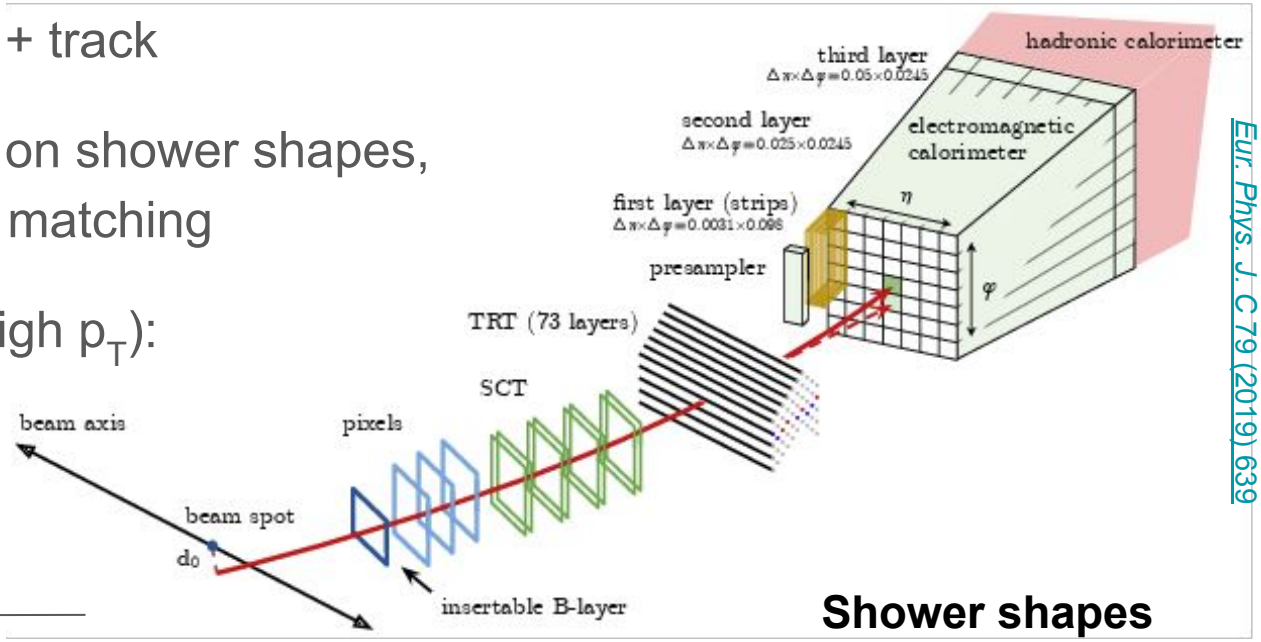
Reconstructed from energy cluster + track

Identification (ID): likelihood based on shower shapes, track information, and track-cluster matching

Data/MC corrections, calibration (high p_T):

extrapolate Z→ee tag&probe

studies



Eur. Phys. J. C 79 (2019) 639

Shower shapes

Under development (DNN/CNN):

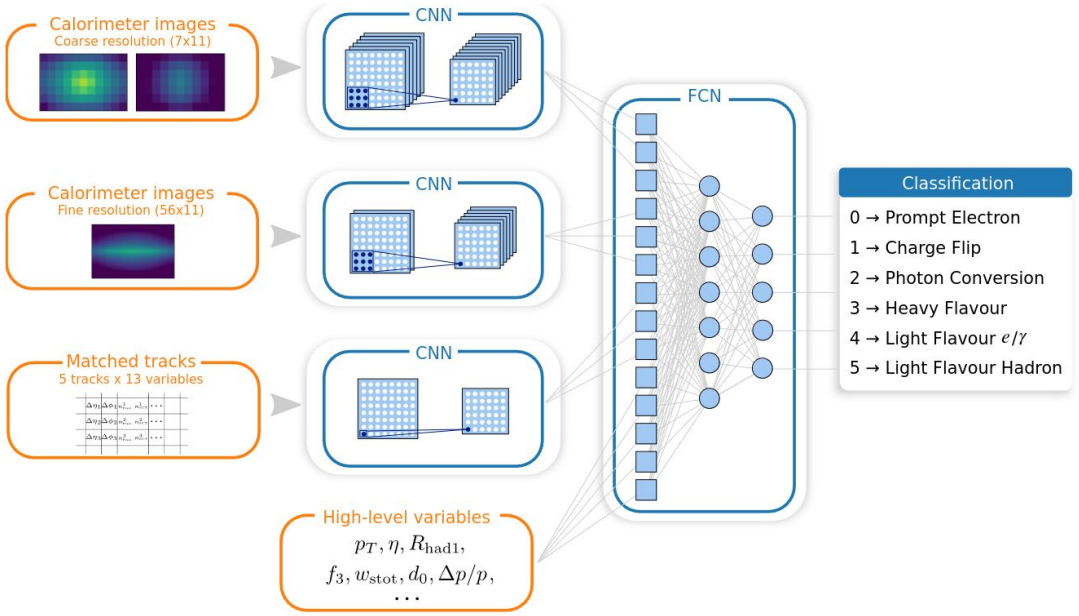
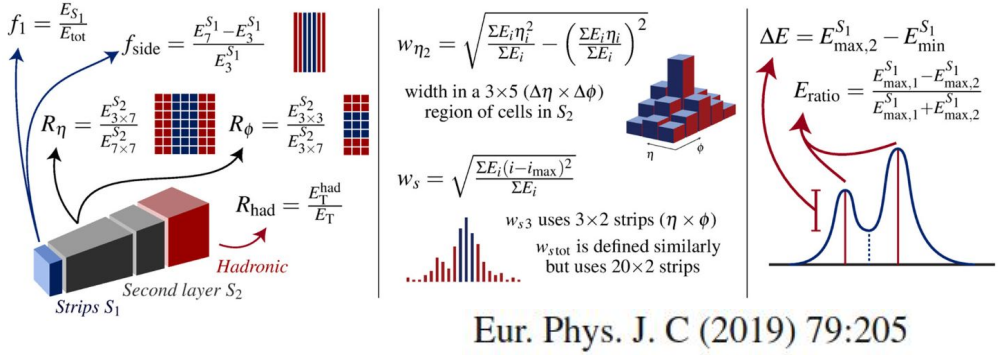


Figure 4: Global neural network architecture.



Eur. Phys. J. C (2019) 79:205

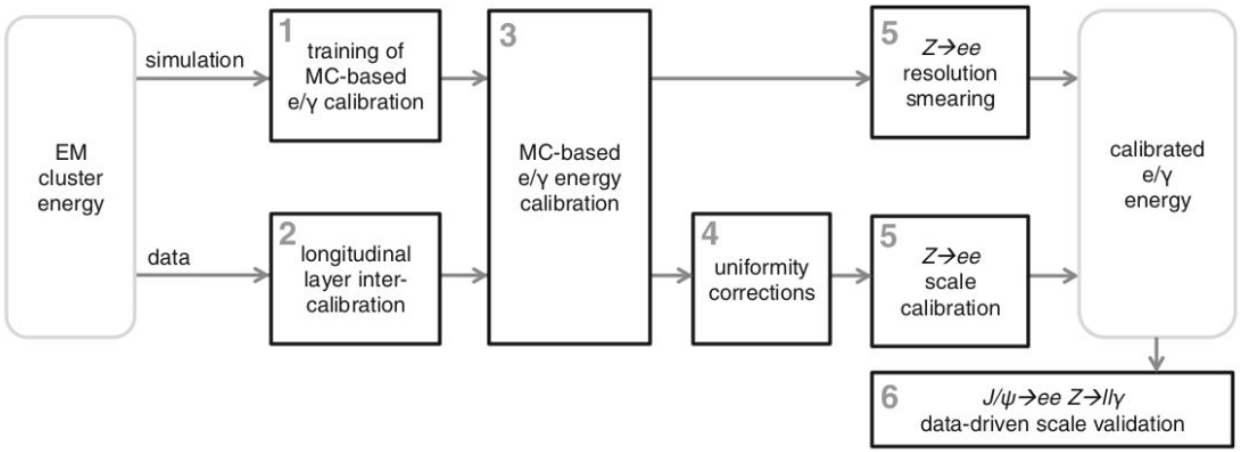
New identification algorithm, CNN, uses lower level (cell information)
Challenge: find data-driven training samples, in particular at high p_T

WP1: electron performance improvements

Goal: maximize statistics, minimize uncertainties (e.g. calibration is expected to be second largest contribution in dielectron channel)

Tasks:

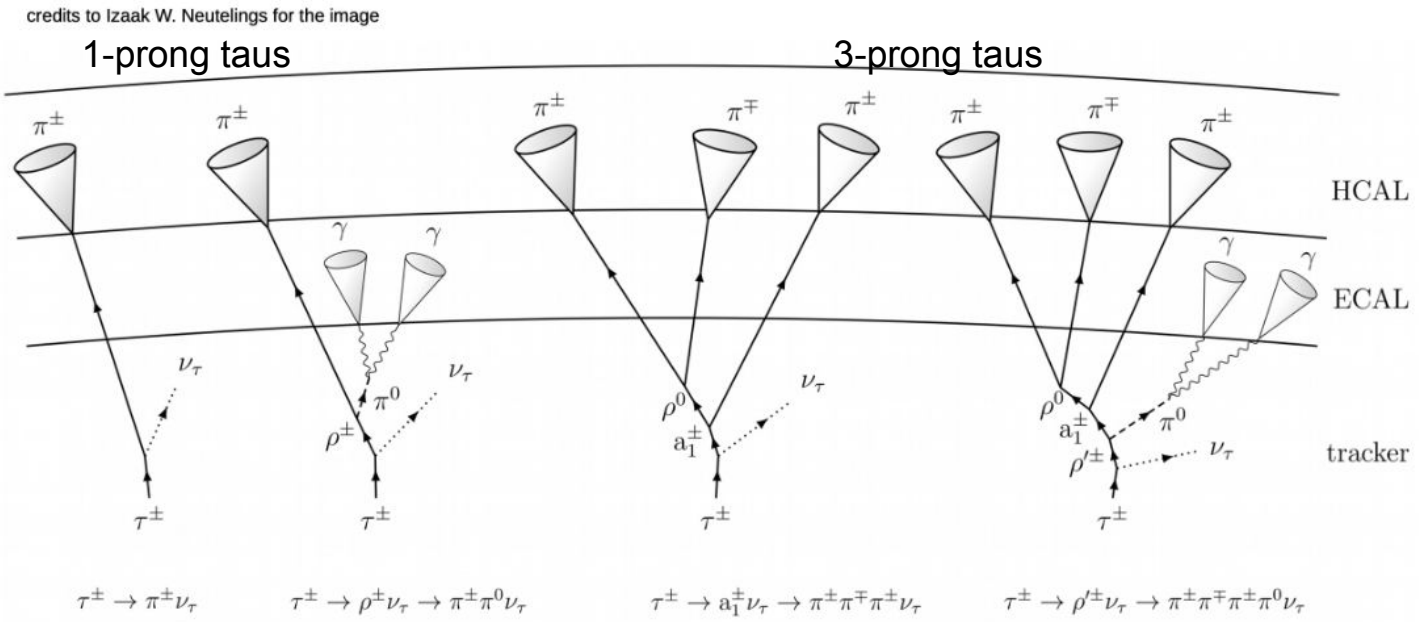
- Explore usage of additional electron signal samples ($W \rightarrow l\nu$ and $tt \rightarrow WWbb \rightarrow e\nu\mu\nu bb$) for efficiency measurements to reduce uncertainties @ high p_T
- ATLAS calibration procedure is already very complex, but at high p_T uncertainties can be further improved, for example with medium/low gain intercalibration procedure similar to that for high/medium gain described in PhD of L. Franco (Ch. 4)

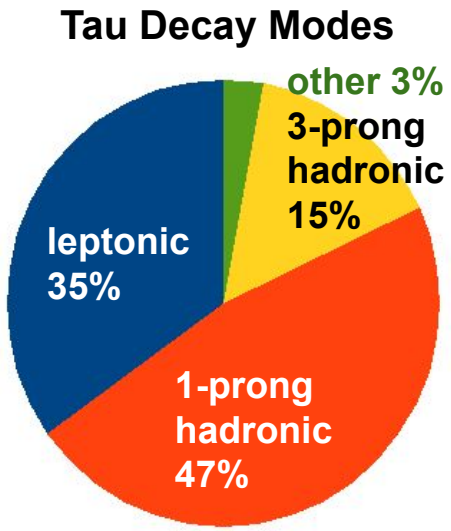


- Investigate improvement of HMDY analysis uncertainties with new electron identification methods (DNN/CNN/GNN), and ensure their full implementation into the ATLAS analysis framework AthenaMT if beneficial

ATLAS tau performance improvements

Hadronic taus reconstructed from tracks and clusters





ATLAS Main reco/ID steps:

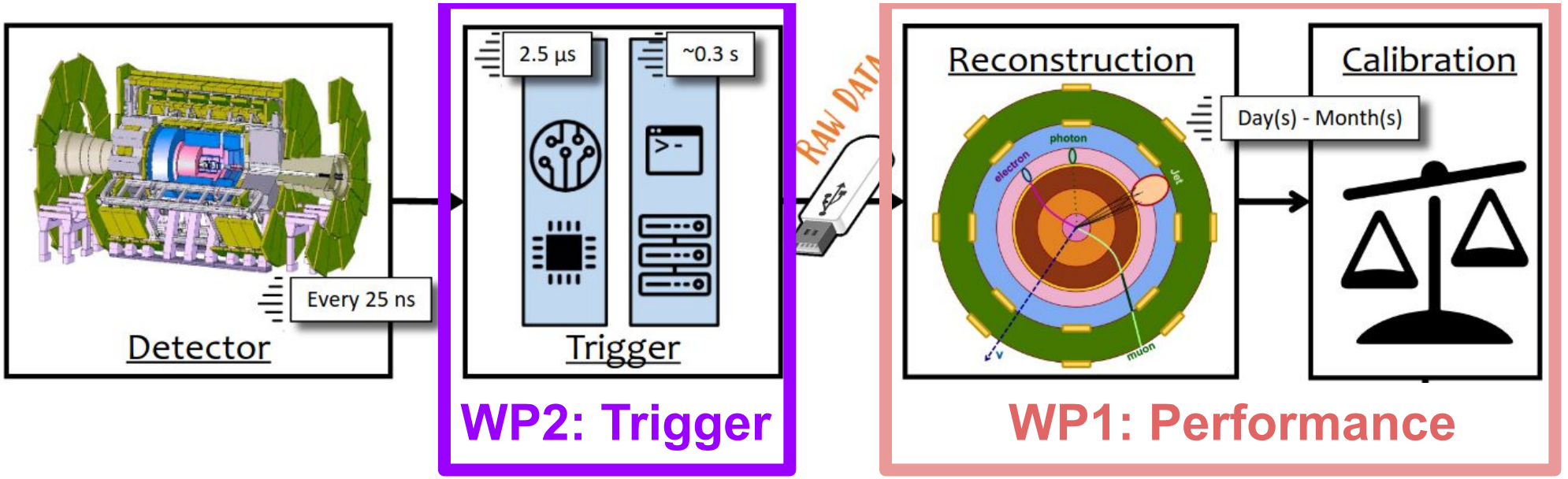
- use jets as seeds,
- identify tau vertex & use RNN to classify tracks associated to taus (tau/isolation/conversion/fake);
- calibrate tau energy using information from tracks and clusters;
- Identification: use RNN to discriminate against jets; run decay mode classifier; apply electron veto

DITTO Focus:

- evaluate benefits from unified identification step (GNN)
- Investigate improvements for high p_T calibration/identification

DITTO Project Organisation (WP2)

Max signal efficiency - min systematic uncertainties - all channels together



Main responsibilities:
Postdoc 1 - tau trigger studies
Postdoc 2 - electron trigger studies
Software Engineer - implementation into ATLAS software for Run 3 and HL-LHC

Port improvements to trigger consistent with new hybrid architecture for HL-LHC (CPU, GPU, FPGA - decision expected in 2025).

Focus on ATLAS High Level Trigger, which uses offline-like algorithms.

Only events accepted by trigger are saved for future analyses: need to ensure consistent selection of events between trigger and offline for Run 3.

This development is done in the ATLAS analysis framework AthenaMT

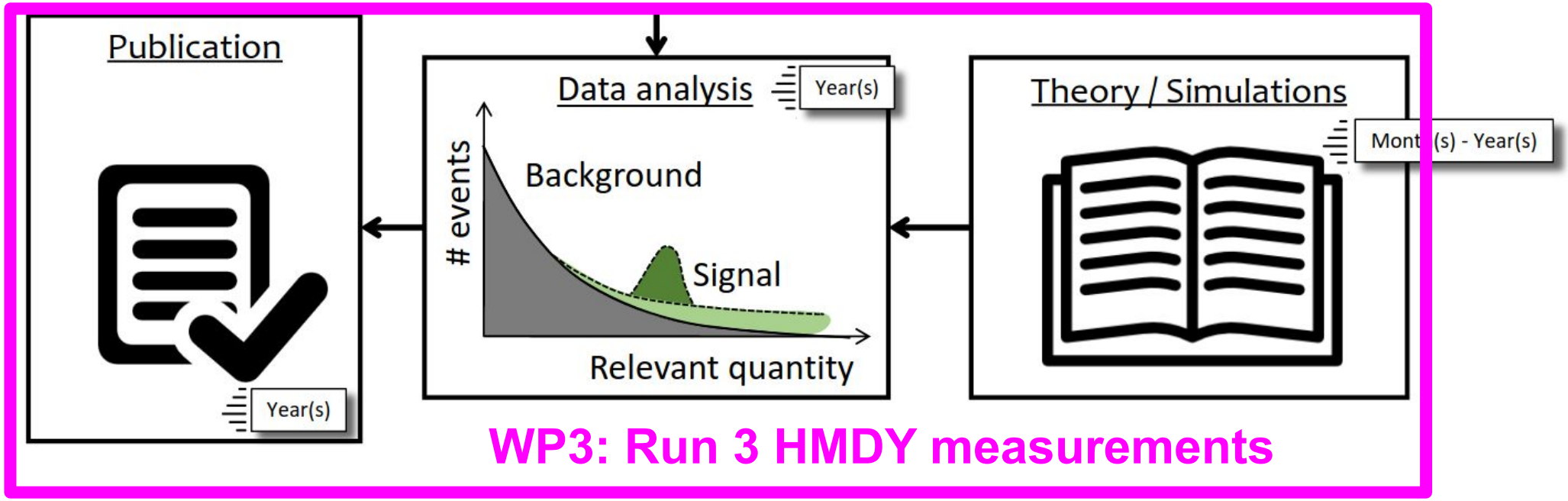
DITTO Project Organisation (WP3)

Max signal efficiency - min systematic uncertainties - all channels together

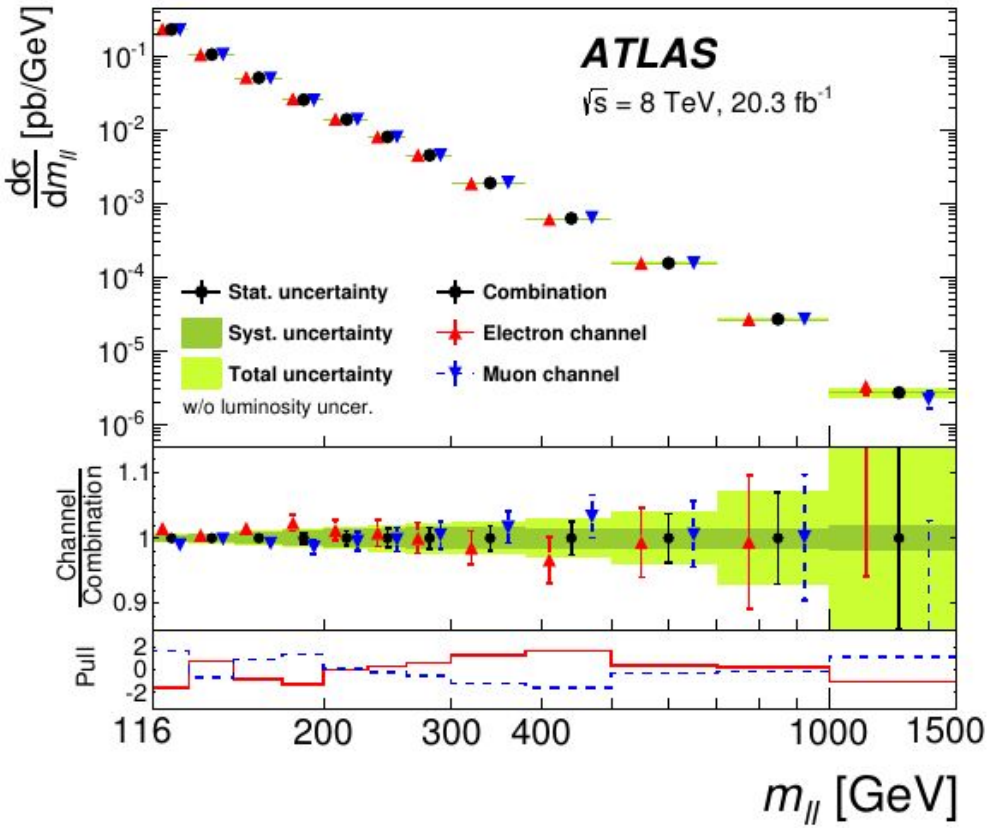
Main responsibilities:
Postdoc 1 - channels with taus (tautau/taunu)
Postdoc 2 - channels with light leptons (ee/enu/mumu/munu)

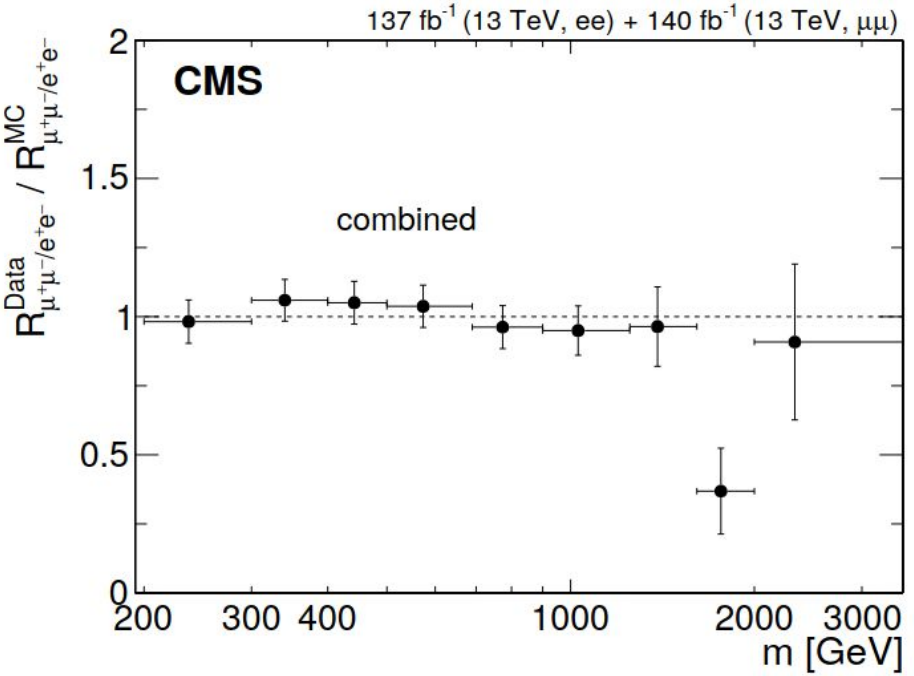
Measure all channels coherently: minimize background uncertainties

Adapt to Open data environment to facilitate reinterpretations and outreach use.



State of Art: HMDY @ LHC





JHEP 08 (2016) 009

JHEP 07 (2021) 208

At √s=8 TeV in the ee/μμ uncertainties of ~2 (11)% for masses of 200 (1000) GeV

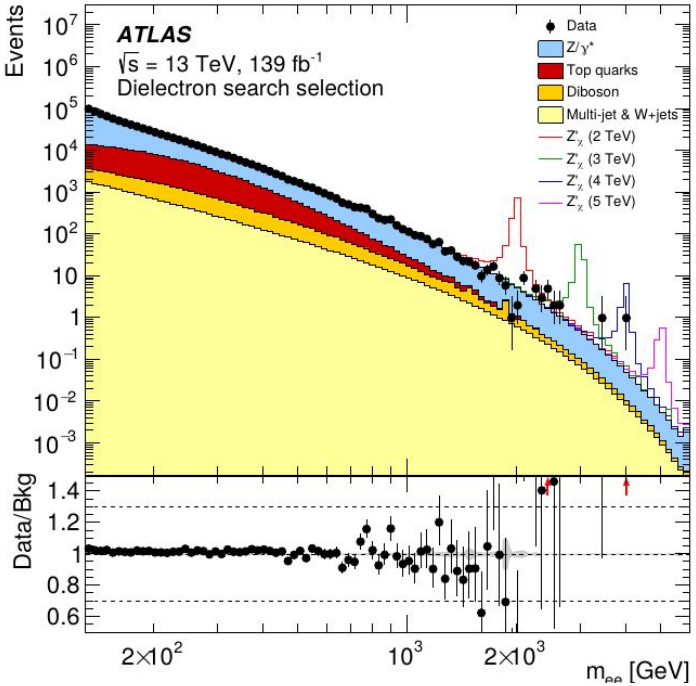
The Run 2+3 data set will allow

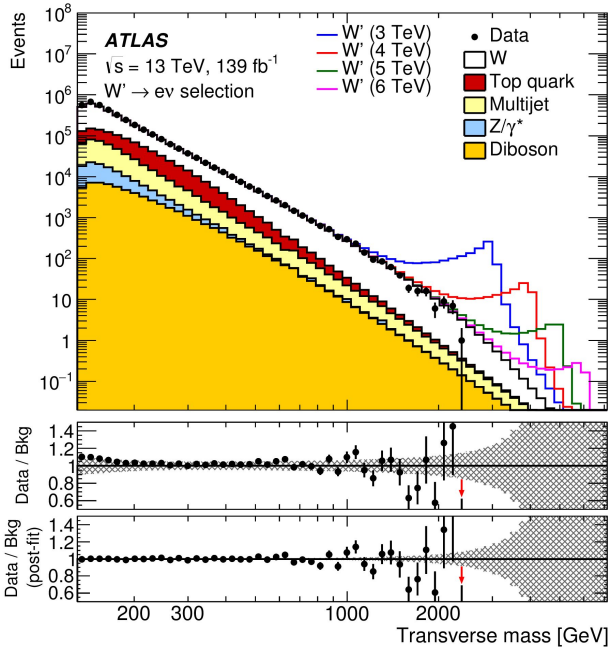
- achieve similar uncertainties for tau-lepton channels
- reduction of stat uncertainties by a factor 6, to 2% up to ~1TeV

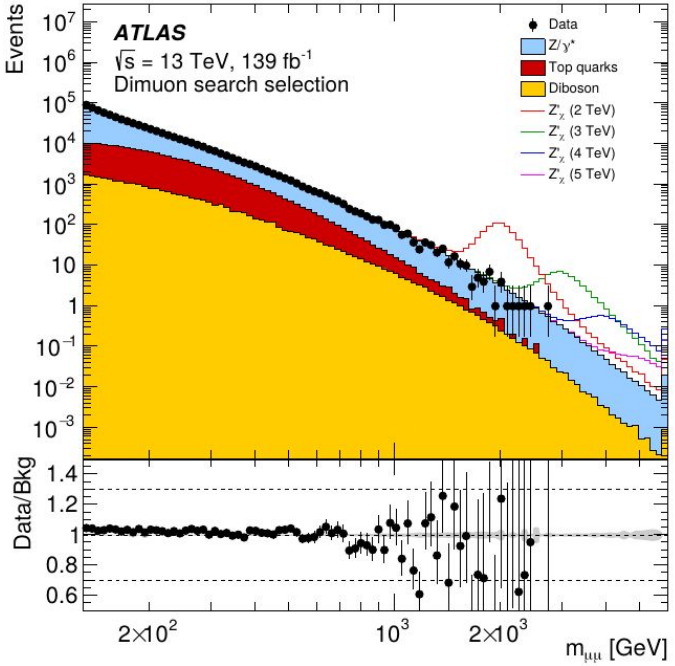
for light lepton channels; hope to contain systematic uncertainties at the same level

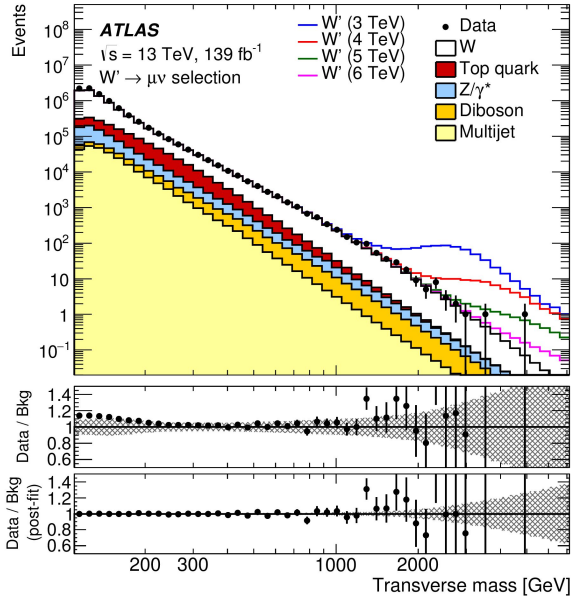
Maintain at LAPP full analysis chain for all HMDY channels: selection (optimized for SM Effective Field Theory reinterpretation, see bonus slides), background estimation (following slides), unfolding and SMEFT reinterpretation (bonus slides)

HMDY light lepton channels









Run 2 light lepton search results give an idea for expected backgrounds for the HMDY measurements

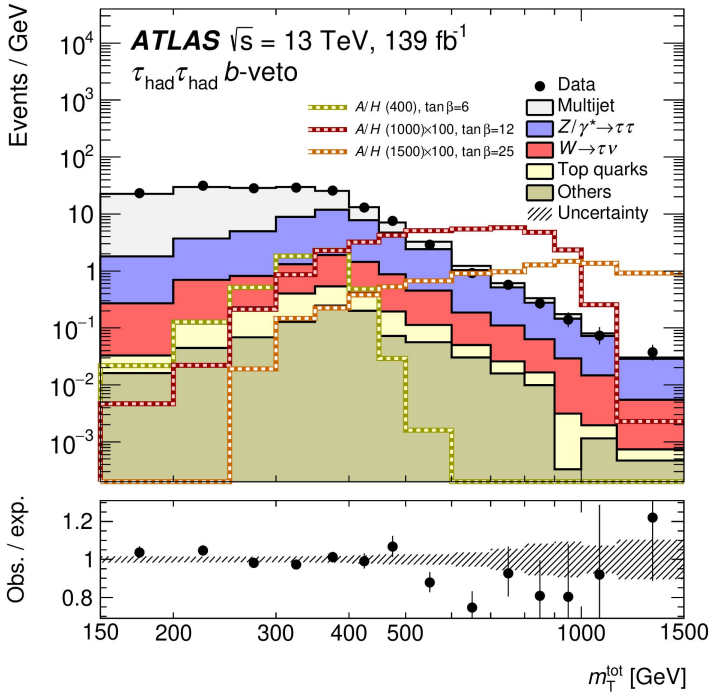
Major source of systematics is expected to be ttbar background estimation.

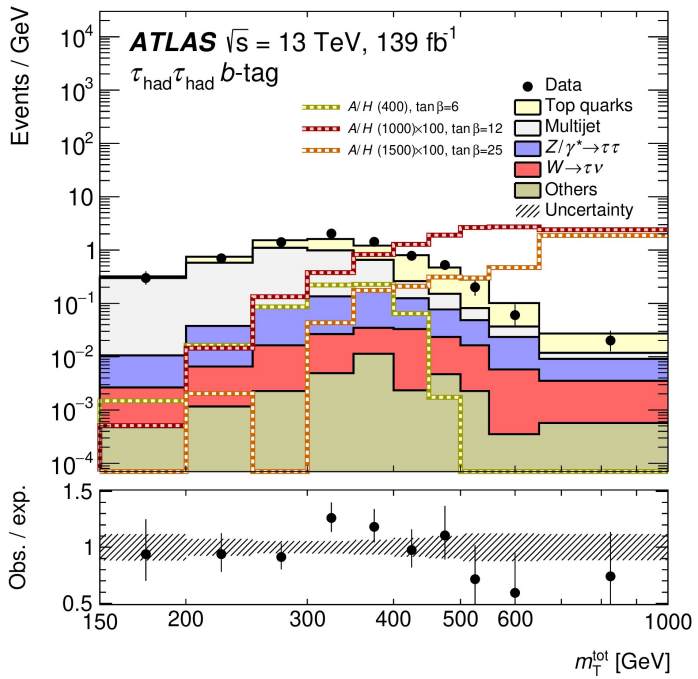
Use muon performance improvements done in other ATLAS groups.

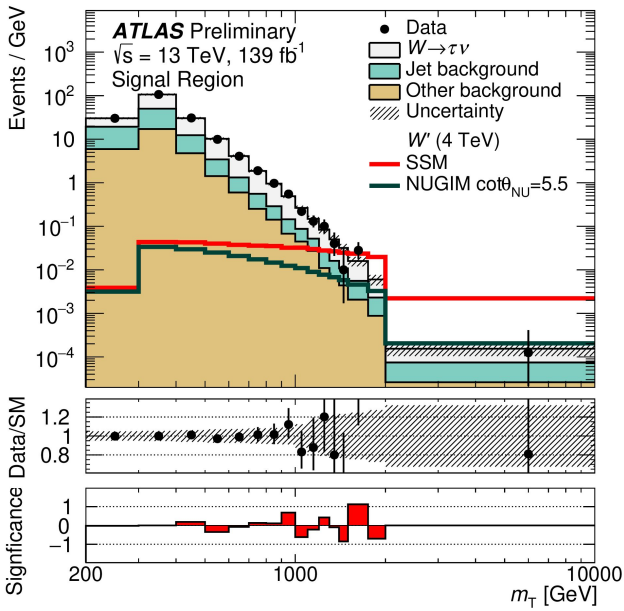
Benefit from LAPP team expertise on Run 2 dilepton resonance searches & HMDY+bjet measurements in the light dilepton channels
=> Extend existing frameworks to include charged HMDY and tau-lepton channels

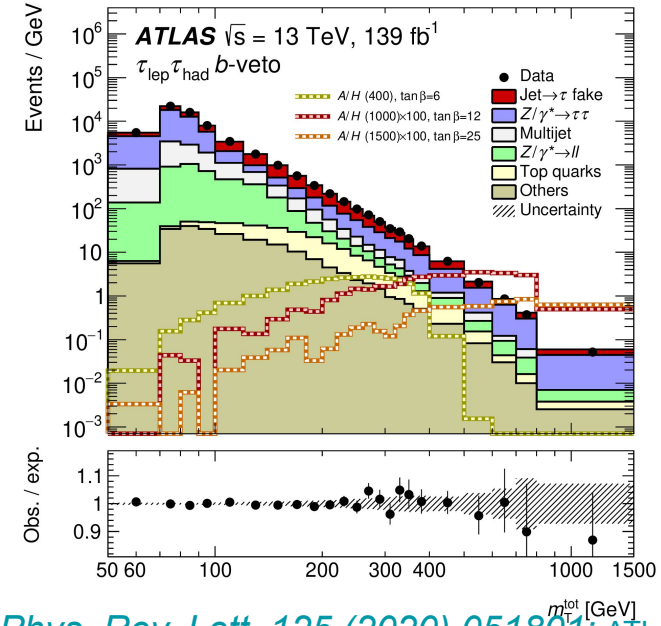
Phys. Lett. B 796 (2019) 68; *Phys. Rev. D 100 (2019) 052013*

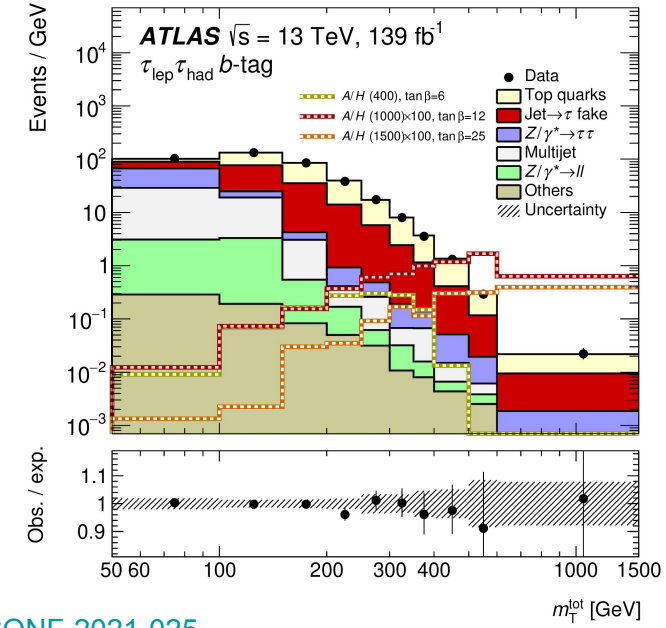
HMDY - tau channels











Run 2 resonance searches with taus give an idea for expected backgrounds for the HMDY measurements

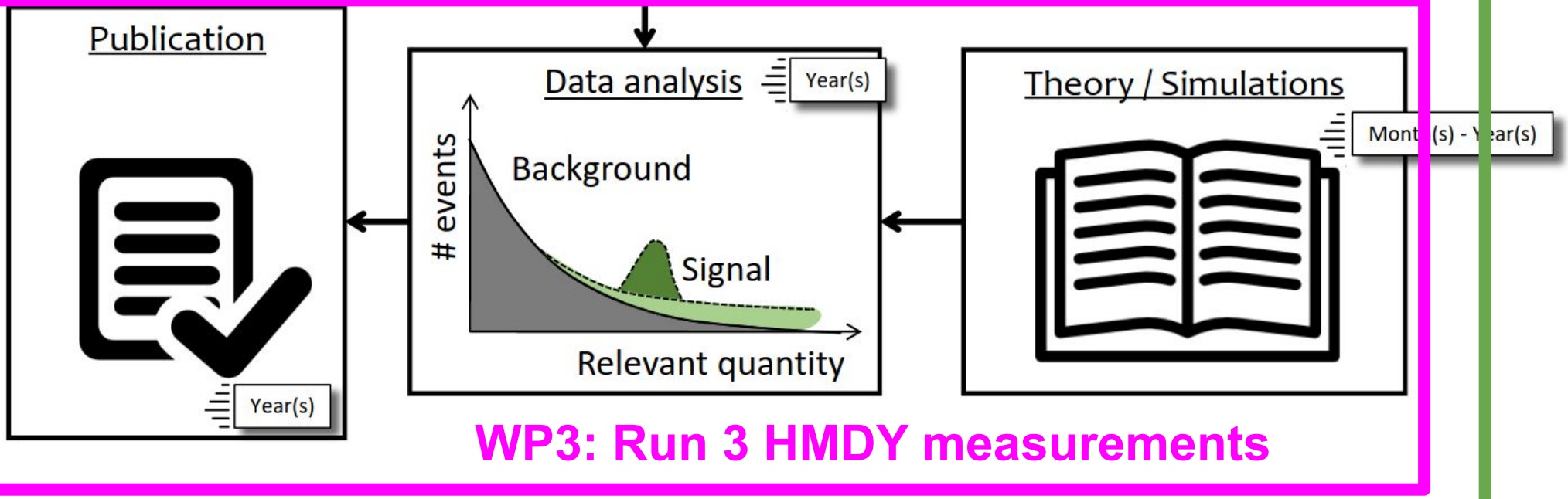
Consider separately channels with 2 hadronic taus and one hadronic and 1 leptonic tau

Major source of systematics is expected to be fake background estimation.

Phys. Rev. Lett. 125 (2020) 051801; ATLAS-CONF-2021-025

Bonus slides

DITTO Project Organisation (WP4)



WP3: Run 3 HMDY measurements

WP4: HL-LHC expectations & SMEFT interpretation

(not covered in current job offers expected to start later, see bonus slides for details)

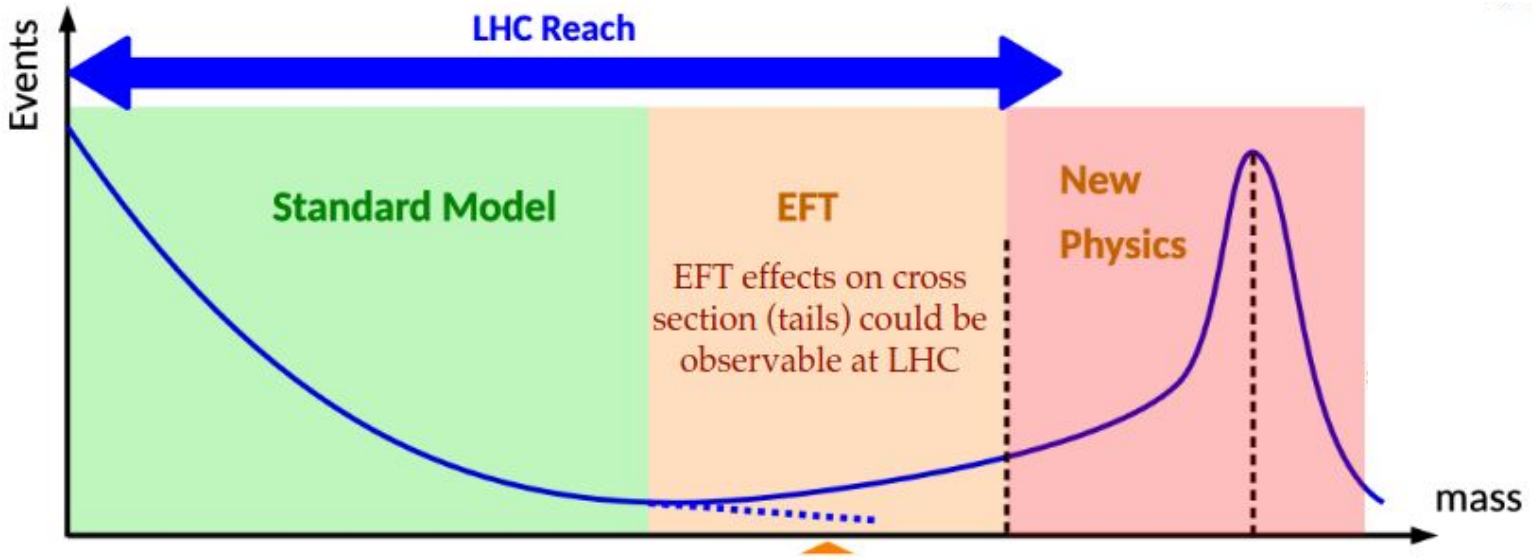
SMEFT: probing beyond LHC reach (WP4)

SM Effective Field Theory (SMEFT) approach: contributions of new phenomena parametrized as effective operators (O_i) added to the SM Lagrangian ($\mathcal{L}_{SM}$)

$$\mathcal{L}_{SMEFT} = \mathcal{L}_{SM} + \sum O_i^{(6)} c_i / \Lambda^2 + \ldots$$

c_i coupling coefficients

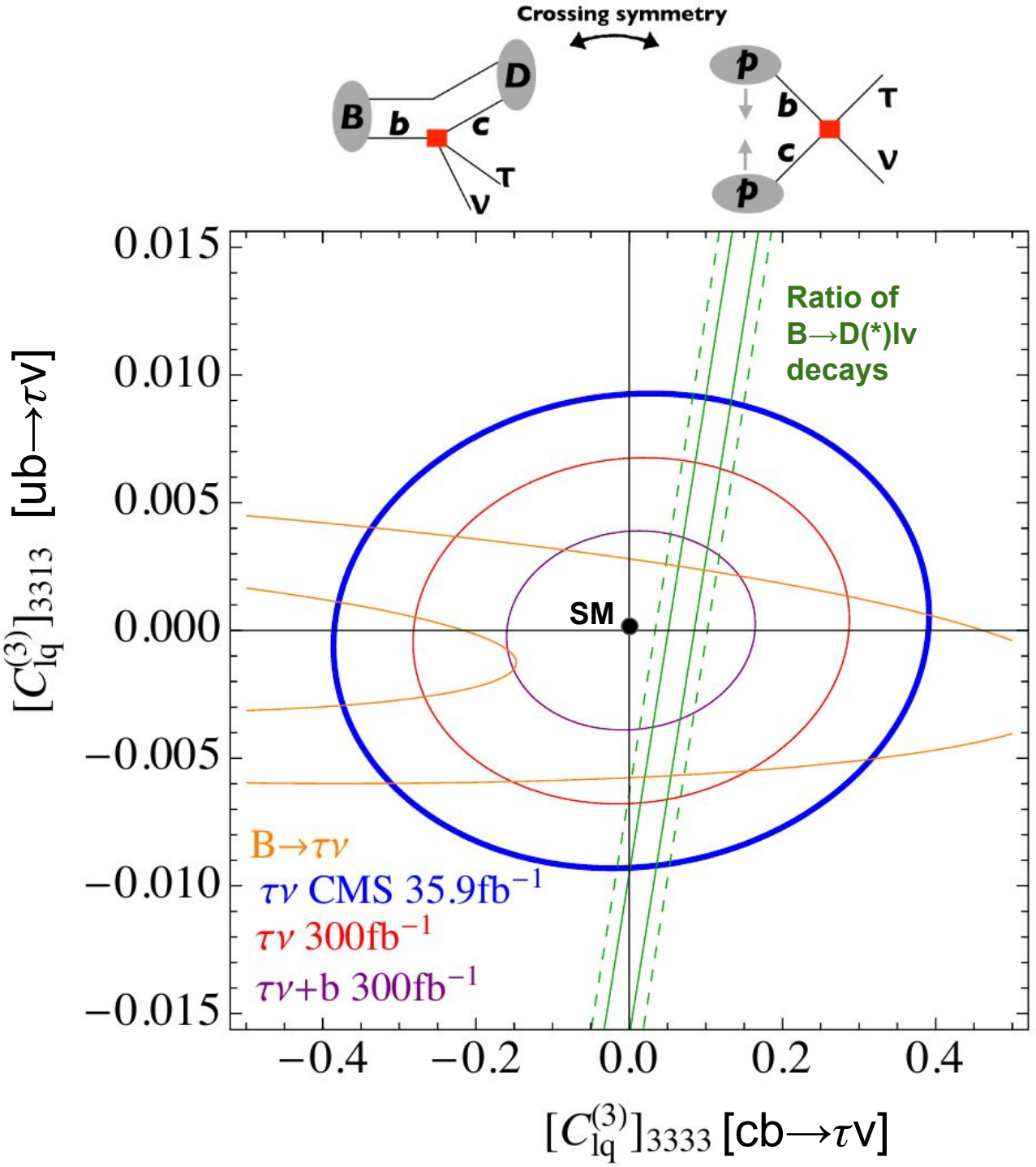
Λ scale of new phenomena



Probing the highest available energy regimes provides the largest sensitivity to new phenomena that are not directly accessible at LHC

SMEFT interpretation of HMDY measurements will benefit from framework developed for EFT@LHC ANR grant (2022-25) @ LAPP

SMEFT interpretation of the results (WP4)

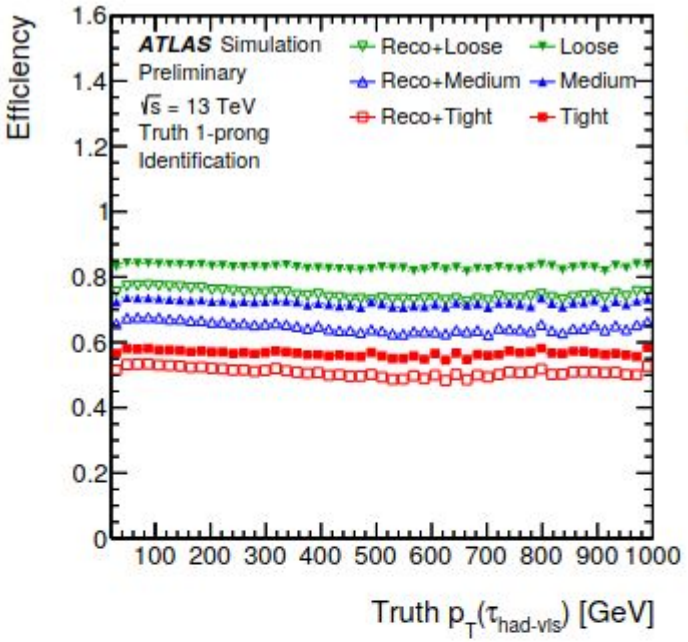


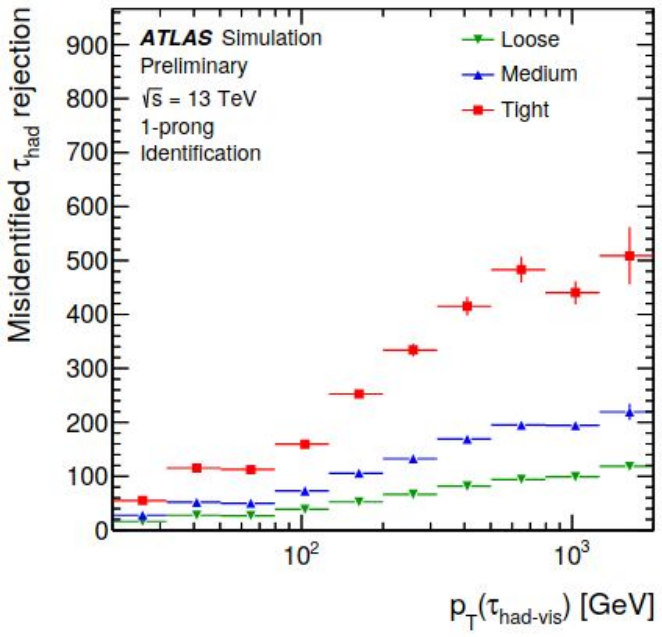
Use SMEFT global fit framework developed at LAPP:

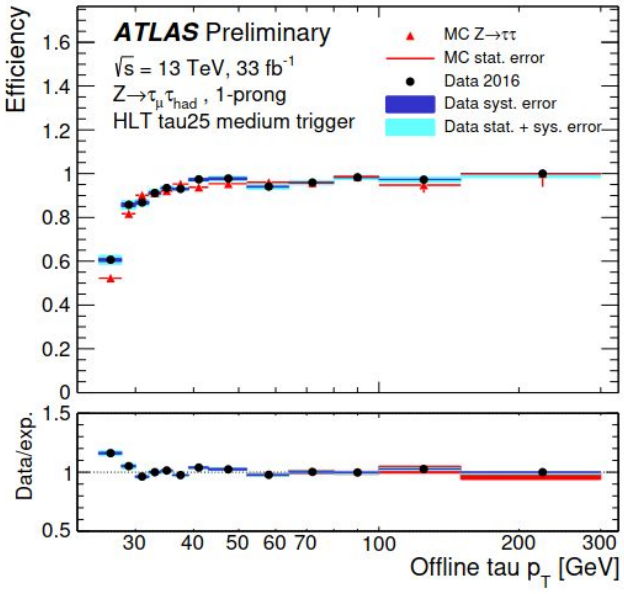
- Flavor dependent effects of new phenomena **ττ/τν > μμ/μν > ee/eν** (LFU-violating scenario)
- **10-fold increase in data set** increases **sensitivity by ~30%**
- Addition of **b-quark jets increase sensitivity** to new phenomena **by 30%**

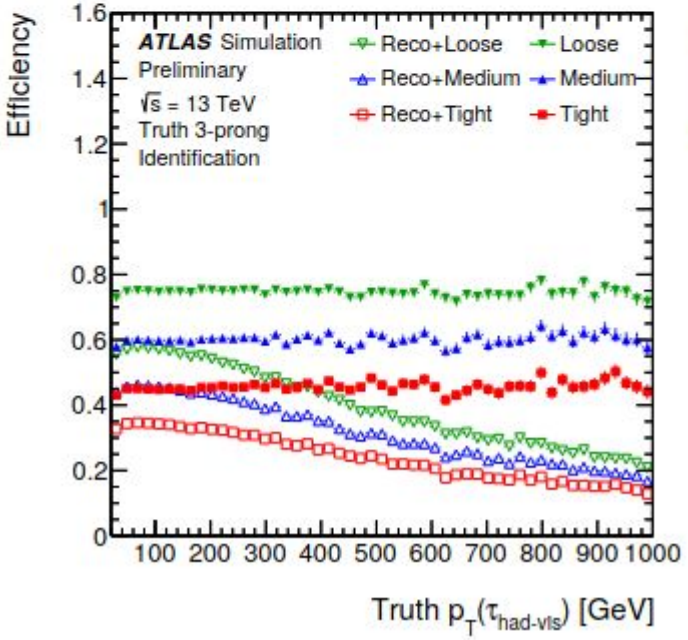
Pattern of deviations will point to the nature of new phenomena

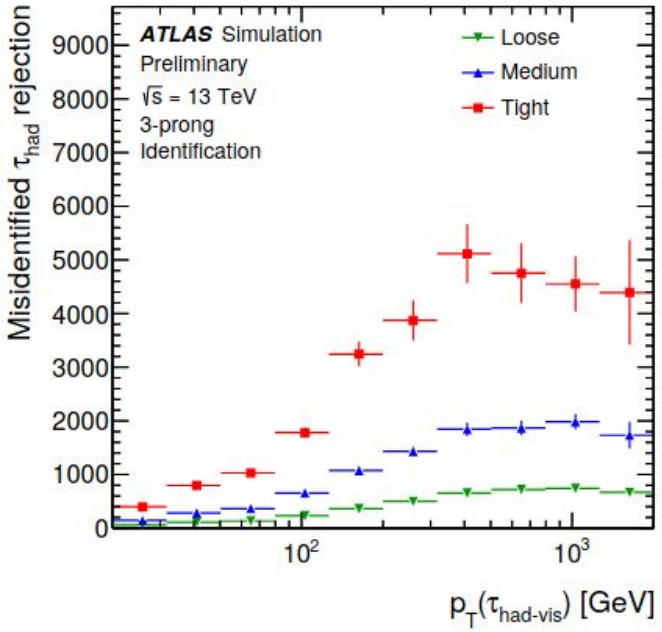
Tau performance: offline(WP1)+trigger(WP2)

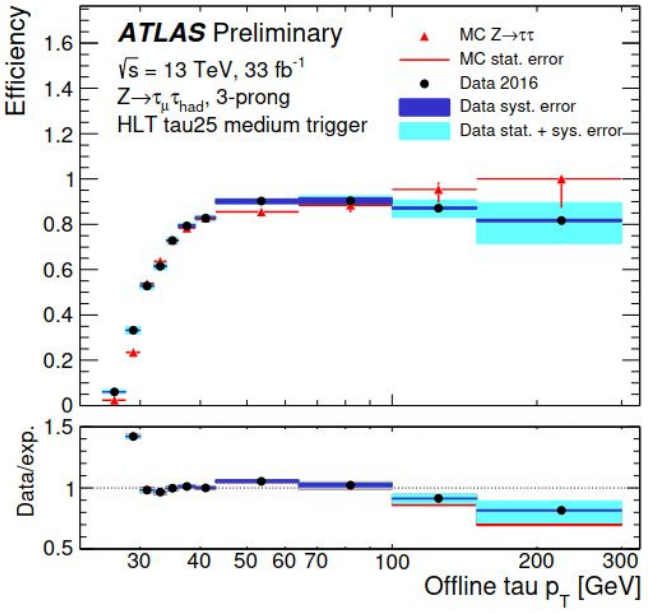












https://cds.cern.ch/record/2827111/files/ATL-PHYS-PUB-2022-044.pdf
https://cds.cern.ch/record/2274201/files/ATLAS-CONF-2017-061.pdf

Performance work: offline(WP1)+trigger(WP2)