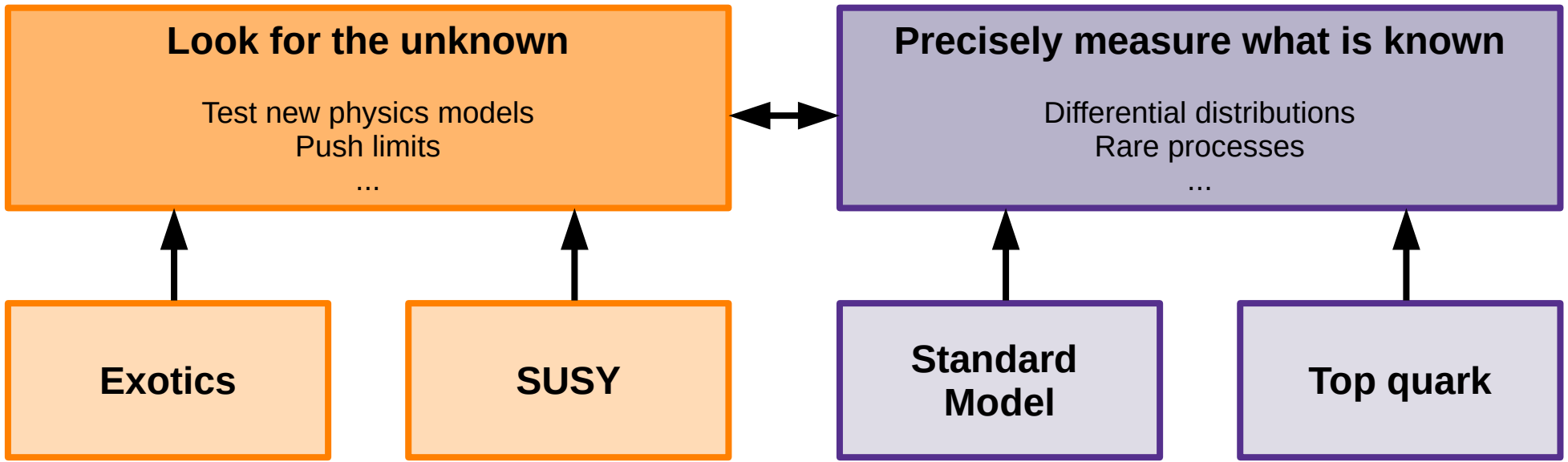
Physics analysis activities in ATLAS-Bologna

Matteo Negrini
for the ATLAS-BO group

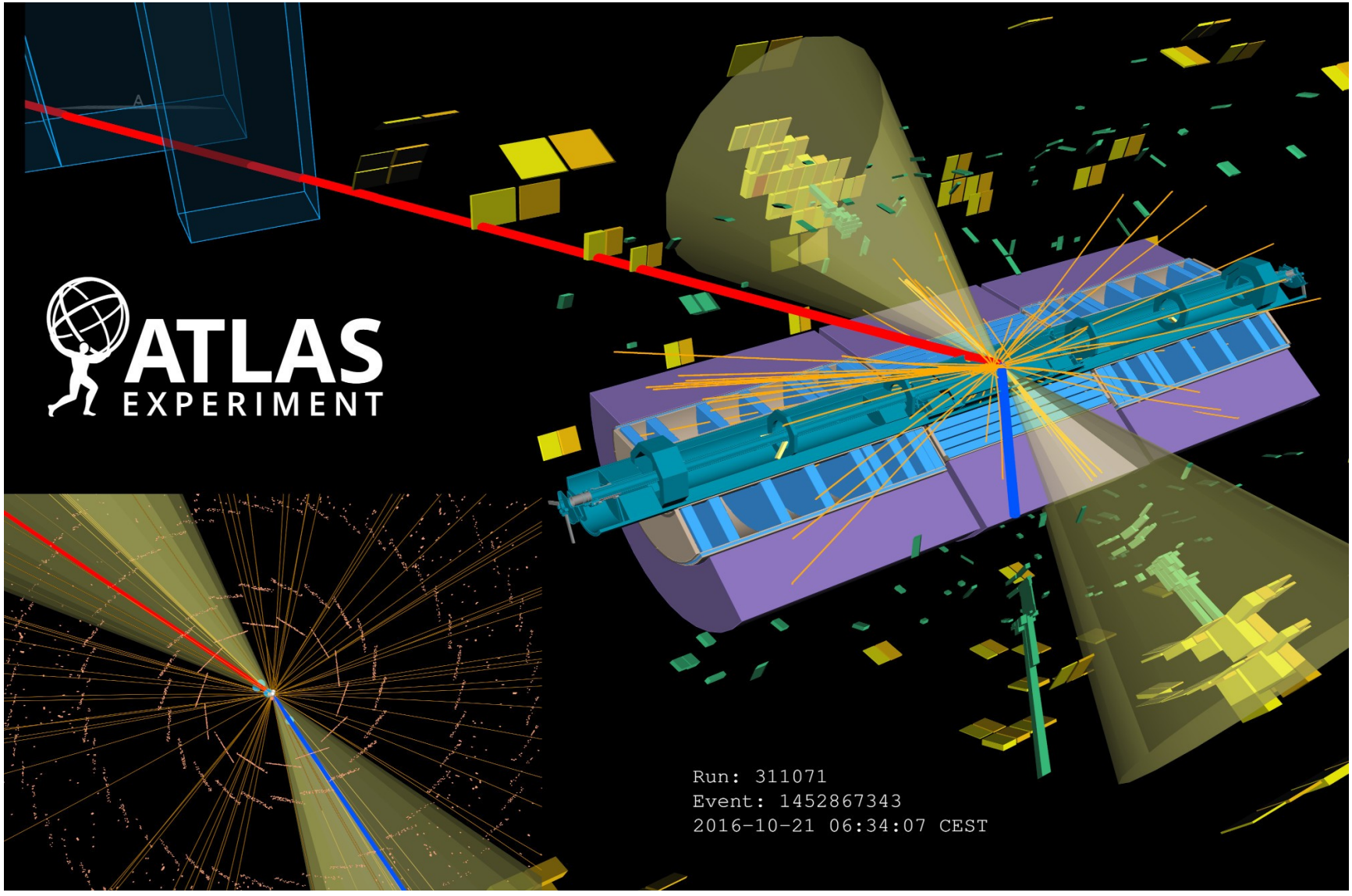
Assemblea di Sezione INFN-BO - 28/03/2022

Bologna in the ATLAS Physics program



Muon Combined Performance

Common Fake Factor Project


ATLAS
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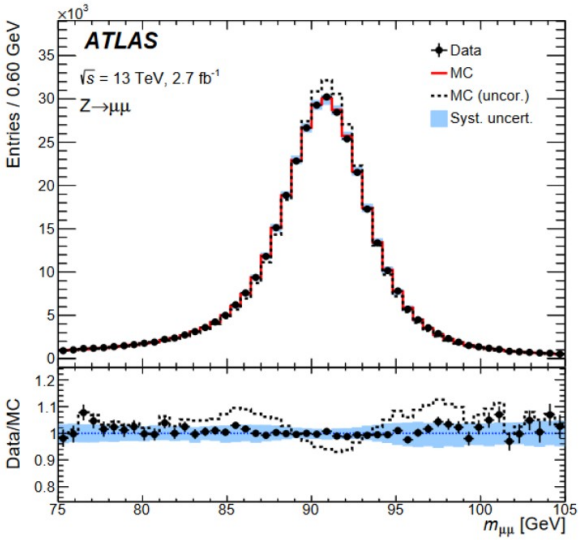
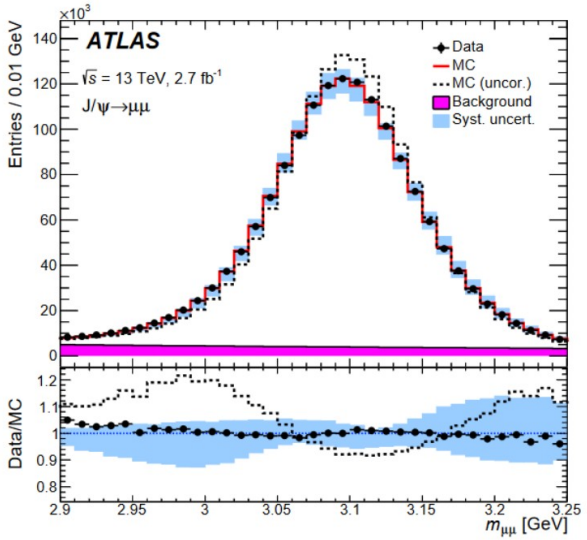
Muon Combined Performance



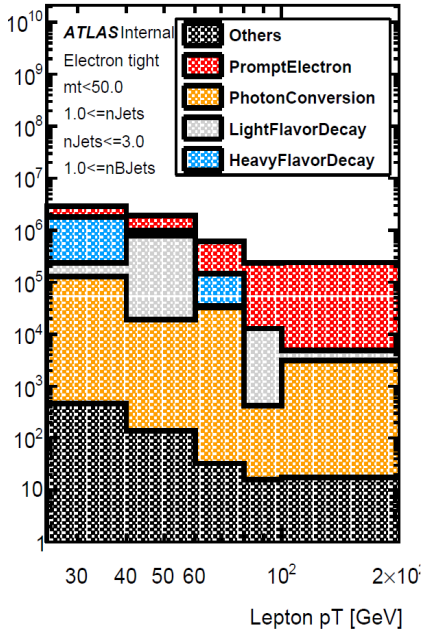


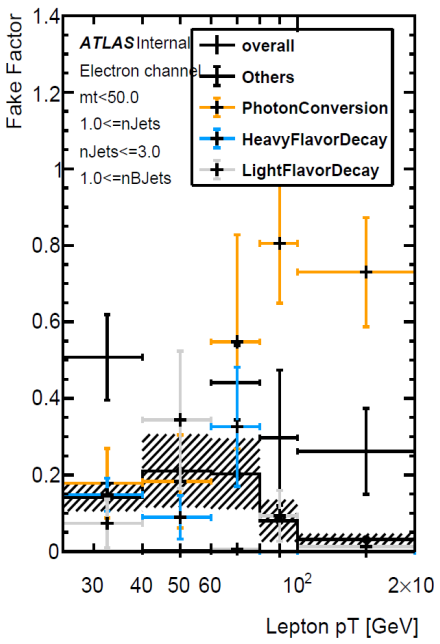
Muon momentum calibration corrections

- To be applied to MC samples in physics analyses
- Based on: Z, J/ψ di-muon events
- Corrections provided in η and p_T regions

- **People:** Noemi Cavalli, Max Sioli
- **Responsibilities:**
  - N Cavalli: Liaison between Top and Muon Combined Performance groups
  - N Cavalli: Editor of the muon momentum calibration note

Common Fake Factor project





Project to distribute "Fake Factor" (FF), which is used for fake lepton estimation

FF is important parameter for most of the analysis handling lepton object, but currently, each analysis group needs to evaluate it by themselves

By providing common FF available for various analyses:

- avoid a large amount of duplicated work
- reduce the risk of bias in the fake lepton estimation
- solve uncovered dependence and correspondingly reduce uncertainty

Status:

- Survey of the FF estimation in physics analyses: **Done**
- Study of physics behind the FF using MC with truth information: **Ongoing**

- **People:** Kazuki Todome, Giuseppe Carratta
- **Responsibilities:**
  - K Todome: project leader

Standard Model

- Aim at precision measurement of SM processes
- Focus on Z production in association with jets
- Differential cross-section measurements and comparisons with state-of-the-art MC calculations

- **People:** Camilla Vittori, Laura Fabbri, Benedetto Giacobbe
- **Responsibilities:**
  - C Vittori: Convener of the W/Z physics sub-group (end March 2023)
  - C Vittori: MC contact for the SM physics group
- **Ongoing physics analyses:**
  - Z + high-p_T jets → Recently approved by ATLAS, submitted to JHEP.
  - Z + b-jets e c-jets → In progress
- **Future perspectives:** W/Z cross-section with first Run 3 data; Full Run 2 differential W+bb analysis

Z + high-p_T jets

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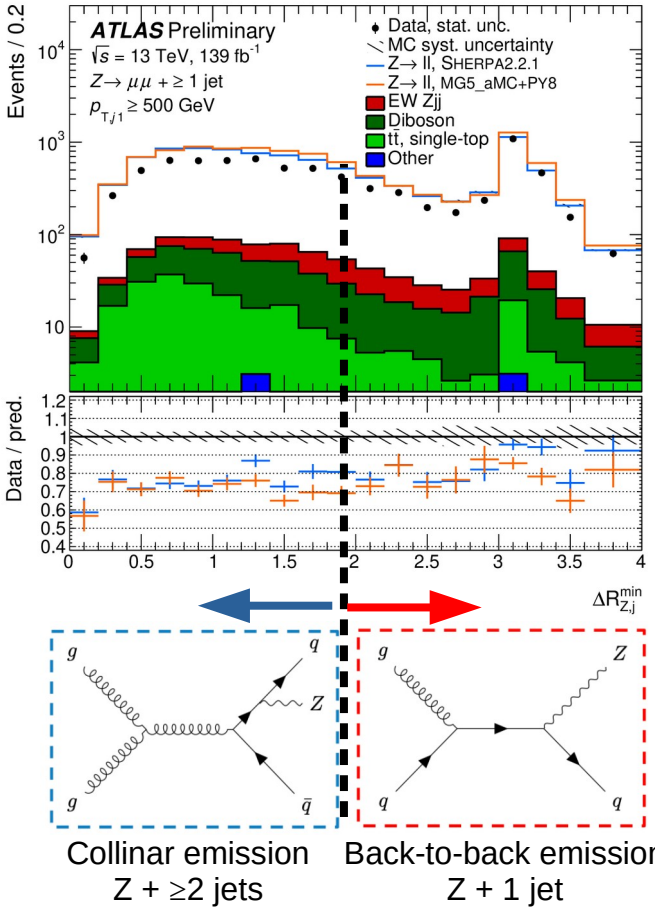
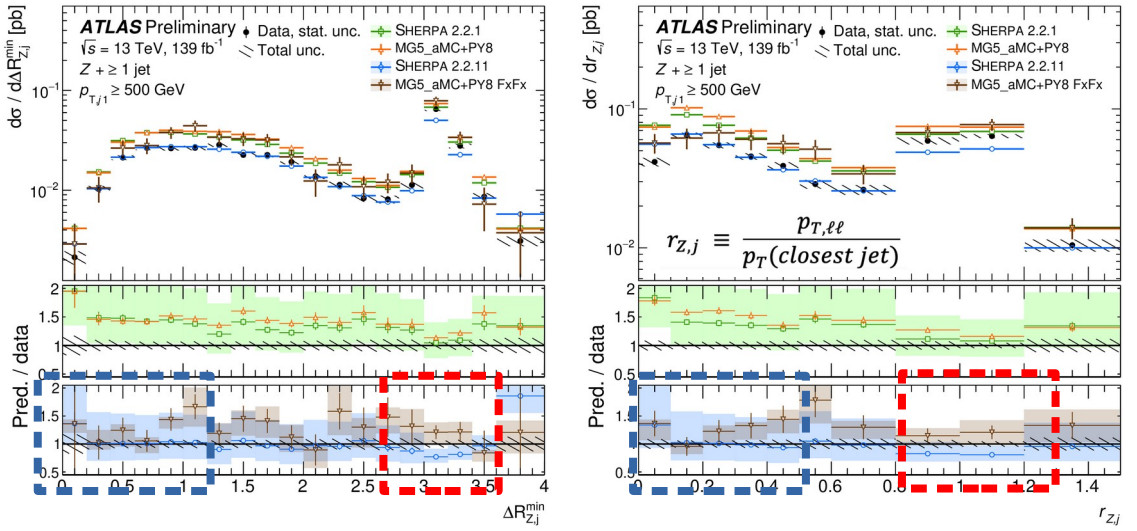


- Data poorly described by legacy MC generators in high-p_T regions
- First measurement in ATLAS of Z+jets separating the collinear and back-to-back (high-p_T) processes
- 15 observables compared with modern MC generators



- Significant improvement obtained with state-of-the-art Sherpa 2.2.11 and Madgraph FxFx
- Best agreement with NNLOJET predictions

Z + b-jets and c-jets

WORK IN PROGRESS

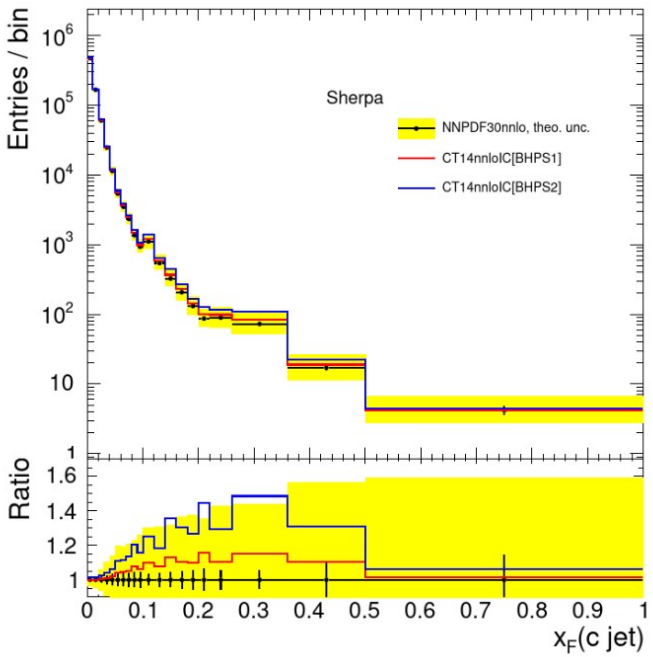
- Differential cross-section measurement of Z+≥1 b-jet, Z+≥2 b-jets e Z+≥1 c-jet
- Cross-section ratio Z+b/Z+c at high rapidity to enhance the sensitivity to Intrinsic Charm (IC)

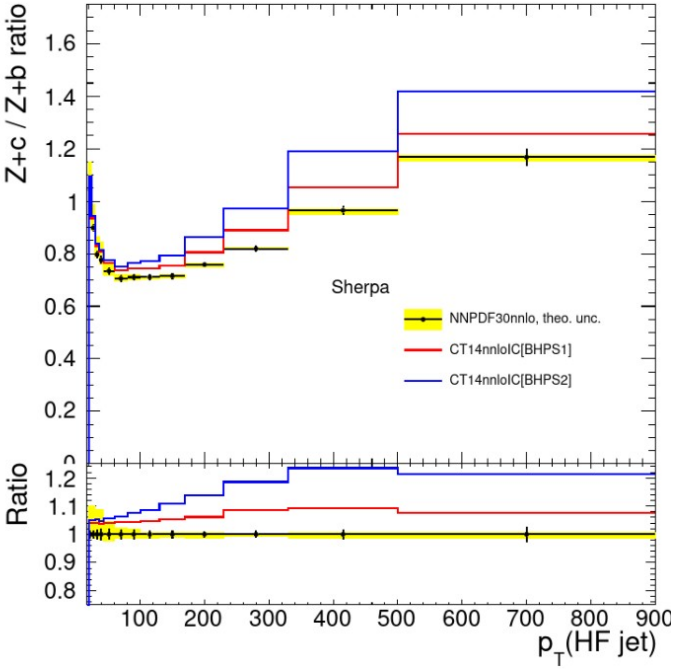
Testing PDFs with different IC content to determine sensitivity to IC

Sensitivity increases with x_F but large theoretical uncertainties

Theoretical uncertainties small in Z+c/Z+b ratios

$$x_F = \frac{2p_T \sinh(y)}{\sqrt{s}}$$





Top quark

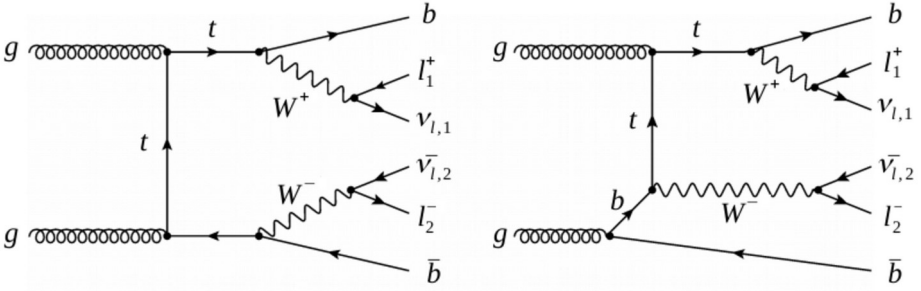
- The heaviest elementary particle in the SM (~mass of Au atom).
  It decays before to hadronise → Study properties of a bare quark
- Main focus on top-pair production
- Precision measurements, comparisons with state-of-the-art calculations, search for BSM production in the EFT interpretation

- **People:** Lorenzo Bellagamba, Gianluca Bianco, Noemi Cavalli, Matteo Negrini, Marino Romano, Max Sioli
- **Responsibilities:**
  - M Romano: Convener of the top cross-section physics sub-group (end March 2022)
  - N Cavalli: Coordinator of top-antitop samples production for EFT analyses
- **Ongoing physics analyses:**
  - WWbb differential cross-section → In progress
  - Top quark mass from differential cross-sections → In progress (M Negrini contact editor)
  - Search for same-sign top production → In progress (N Cavalli analysis contact)

WWbb

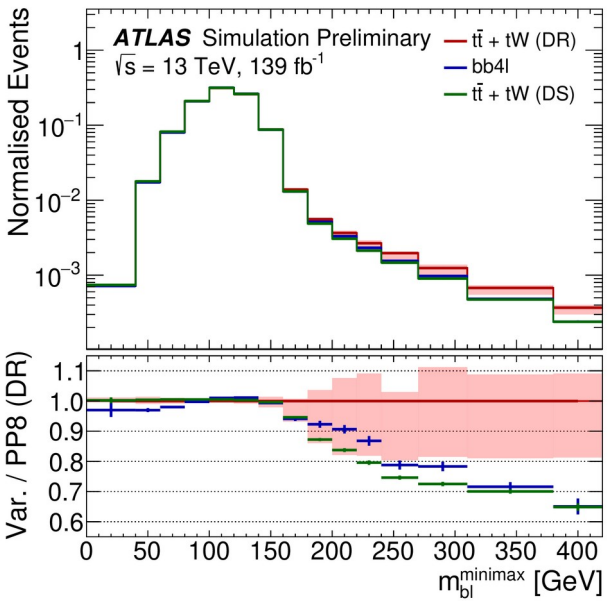
ATL-PHYS-PUB-2021-042

- Top-antitop pair production interfere with other SM processes (mainly single-top+W).
- Until today this was modeled with two approximate approaches of “diagram removal” or “diagram subtraction”, yielding different results (e.g. $m_{bl}^{minimax}$ distribution)
- “bb4l” is a state-of-the-art MC generator implemented in Powheg that computes the process at NLO with complete treatment of the interference
- Aim to improve precision on $t\bar{t}$ production differential cross-sections using state-of-the art MC



$$m_{b\ell}^{\text{minimax}} = \min\{\max(m_{b_1,\ell_1}, m_{b_2,\ell_2}), \max(m_{b_2,\ell_1}, m_{b_1,\ell_2})\}$$

WORK IN PROGRESS



Top quark mass

WORK IN PROGRESS

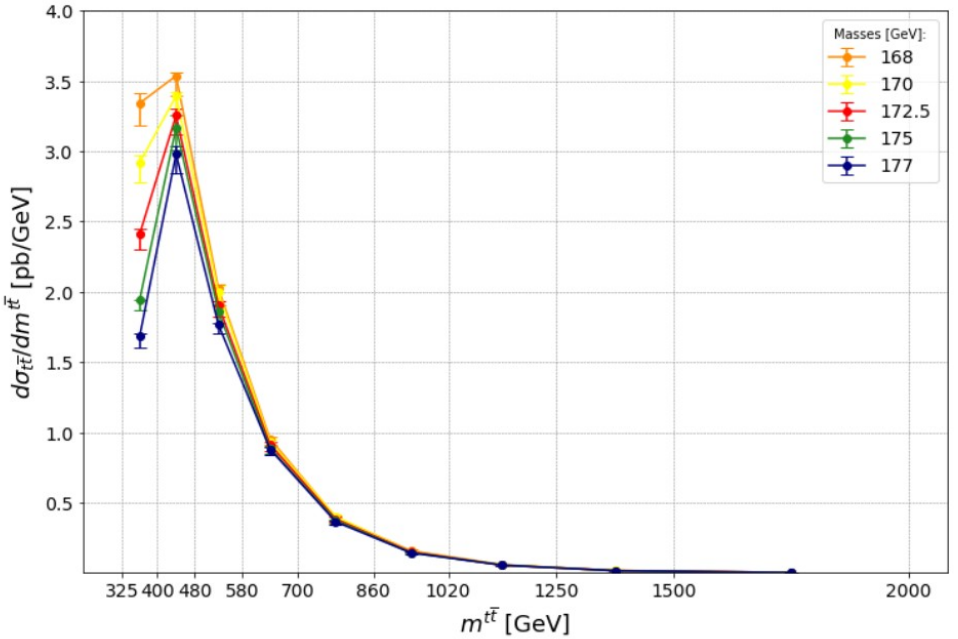
The $t\bar{t}$ differential cross-section is sensitive to the top quark mass.

Measurements can be compared with fixed-order theoretical calculations (pole m_t measurement)

Exploiting NNLO differential cross-section calculations
Contacts with the developers of the MATRIX code (M. Grazzini)

Theoretical calculation done in Bologna using the available multi-core resources:
- theophys02
- Matrix HPC cluster (Open Physic Hub)

Expected uncertainty on $\mathbf{m_t^{POLE}}$ comparable with "standard" $\mathbf{m_t}$ measurements using MC predictions (>1 GeV)



$t\bar{t}$ differential cross-section as a function of the invariant mass of the $t\bar{t}$ system (master thesis E. Cuppini)

Same-sign top quark pair

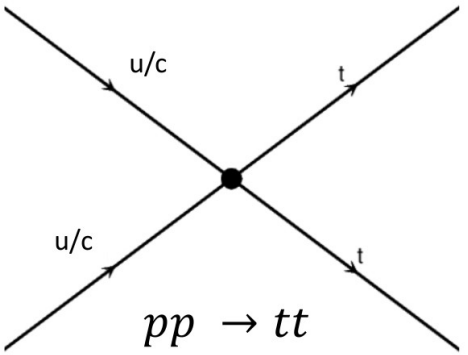
WORK IN PROGRESS

Same-sign top quark pair production has a tiny cross-section in the SM
$\sigma(pp \rightarrow tt)_{SM} = 4 \cdot 10^{-15}$ pb

The cross-section could be enhanced by non-SM processes.

EFT approach in the generation of MC samples.
Fruitful collaboration with EFT experts in Bologna (F. Maltoni)

EFT pointlike interaction

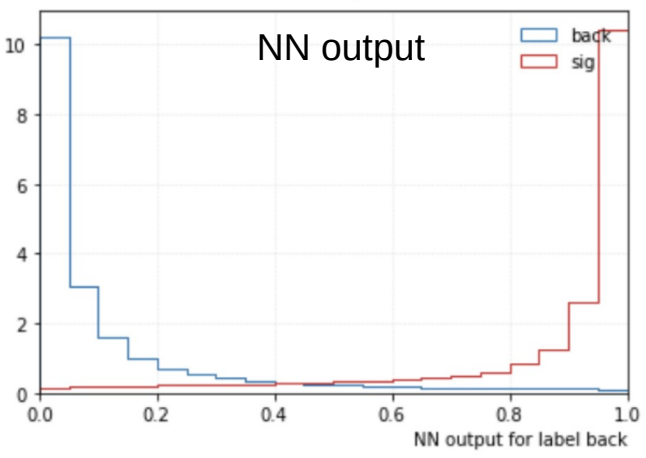


dim6 operators (Warsaw basis)

$$\mathcal{O}_{RR} = [\bar{t}_R \gamma^\mu u_R]\,[\bar{t}_R \gamma_\mu u_R]$$
$$\mathcal{O}_{LR}^{(1)} = [\bar{Q}_L \gamma^\mu q_L]\,[\bar{t}_R \gamma_\mu\, u_R]$$
$$\mathcal{O}_{LR}^{(8)} = [\bar{Q}_L \gamma^\mu T^A q_L]\,[\bar{t}_R \gamma_\mu\, T^A u_R]$$

Analysis strategy:

- Lepton isolation working point based on BDT to better suppress background from lepton fakes
- Data driven electron charge mis-id estimation
- Dedicated CRs to constrain main backgrounds (ttW, ttZ, VV)
- DNN to discriminate S vs B (cross-validation)
- Limits on EFT operators



Exotics

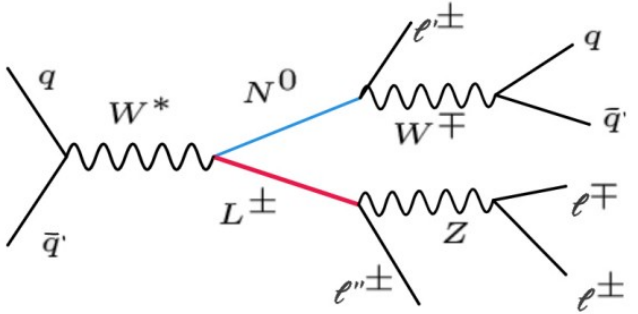
- BSM searches with focus on multi-lepton final states (small SM backgrounds)
- Flavour anomalies → Leptoquarks
- Muon g-2 → Vector-Like Leptons (VLL)
- Neutrino mass → Heavy leptons (neutral or charged): Seesaw mechanism

- **People:** Giuseppe Carratta, Matteo Franchini, Antonio Sidoti
- **Responsibilities:**
  - A Sidoti: Convener of the Lepton+X physics sub-group (end October 2021)
- **Physics analyses:**
  - Vector-Like Leptons → In progress (M Franchini analysis contact)
  - Double charged Higgs → In progress (A Sidoti contact editor)
  - Type III Seesaw → Submitted (M Franchini analysis contact, A Sidoti contact editor)

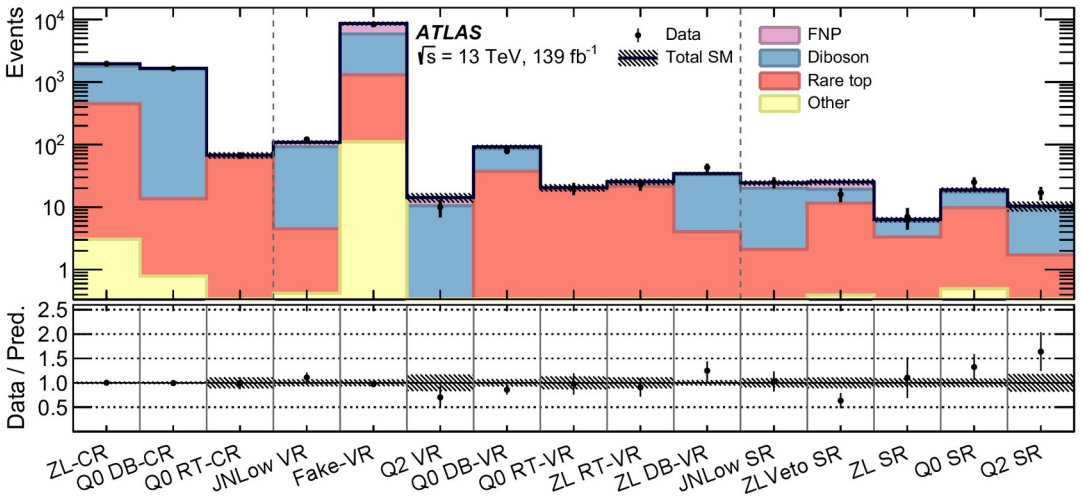
Type III Seesaw heavy leptons

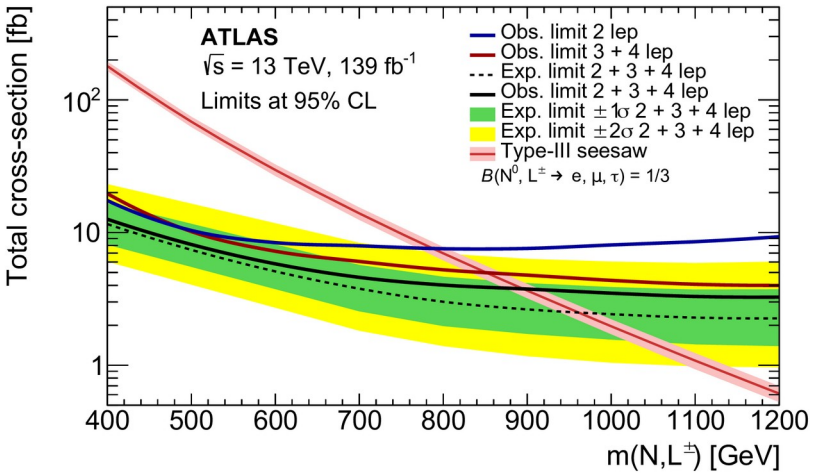
arXiv:2202.02039

- Seesaw mechanism proposed to explain the small ν mass by introducing an heavy Majorana neutrino
- Type III seesaw models includes a new fermionic triplet coupled to EW bosons
- Lower mass limit pushed at **910 GeV (95% CL)** combining all 2-3-4 leptons final states



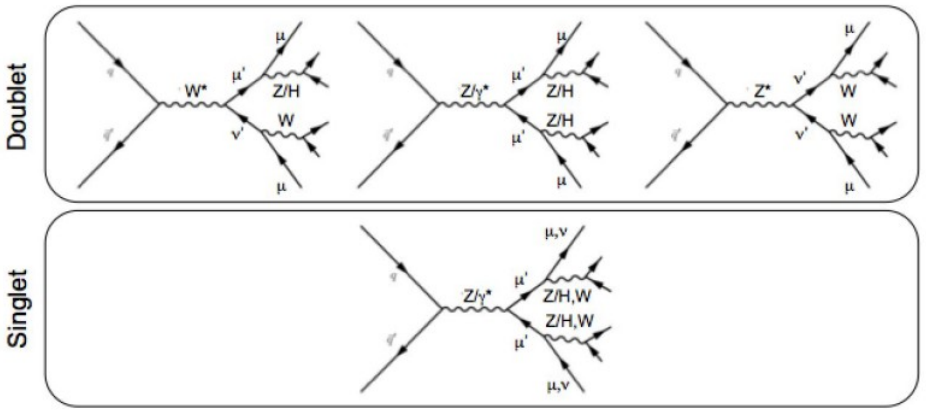
Final states with 2-3-4 leptons



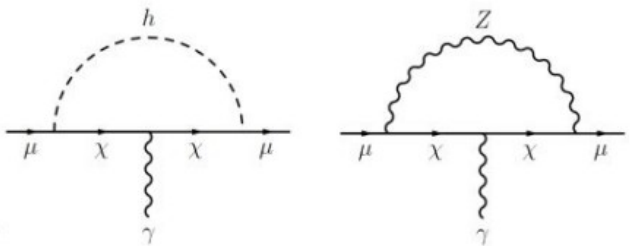


Vector-like Leptons

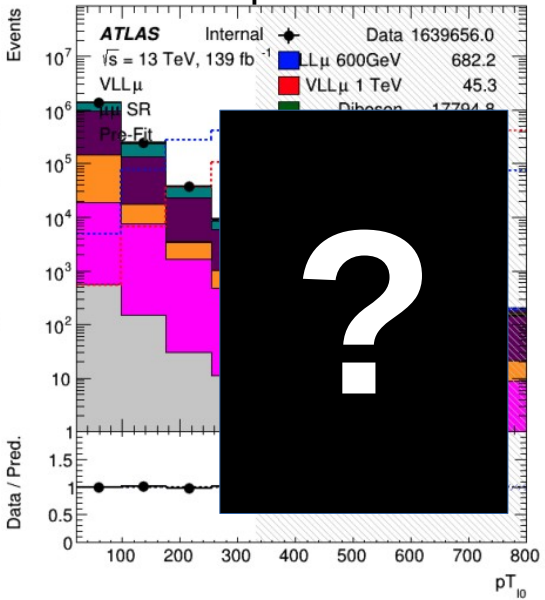
WORK IN PROGRESS



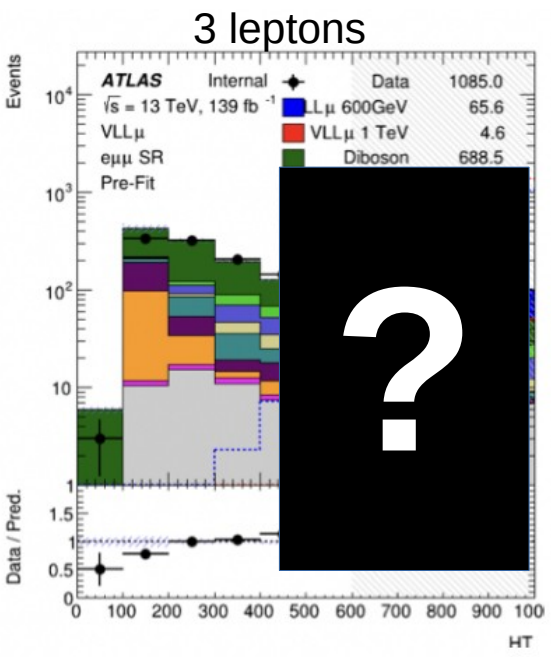
- Multi-lepton final states (2-3-4 leptons)
- Can contribute to the muon g-2



2 leptons



3 leptons

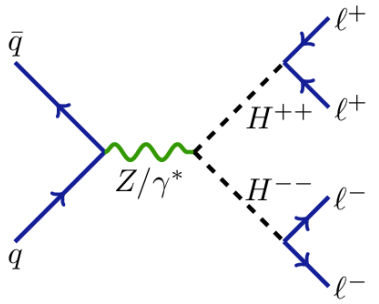


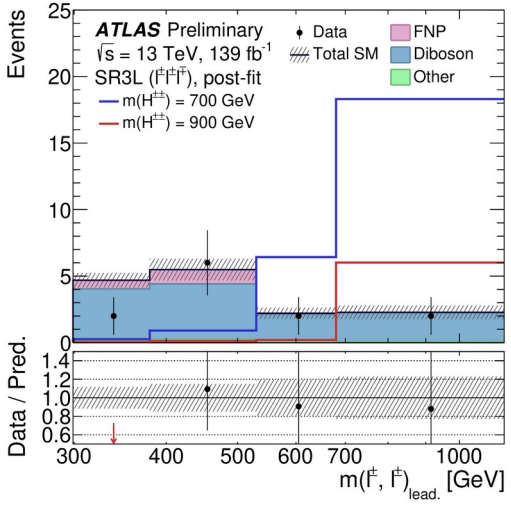
Some discriminating variables (scalar sun of the p_T of the leptons or all the objects in the final state)

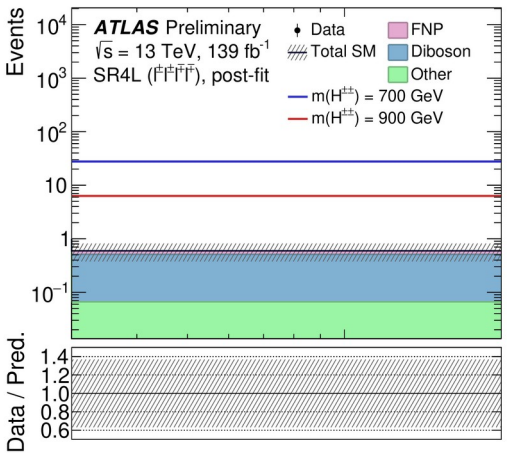
Doubly charged Higgs

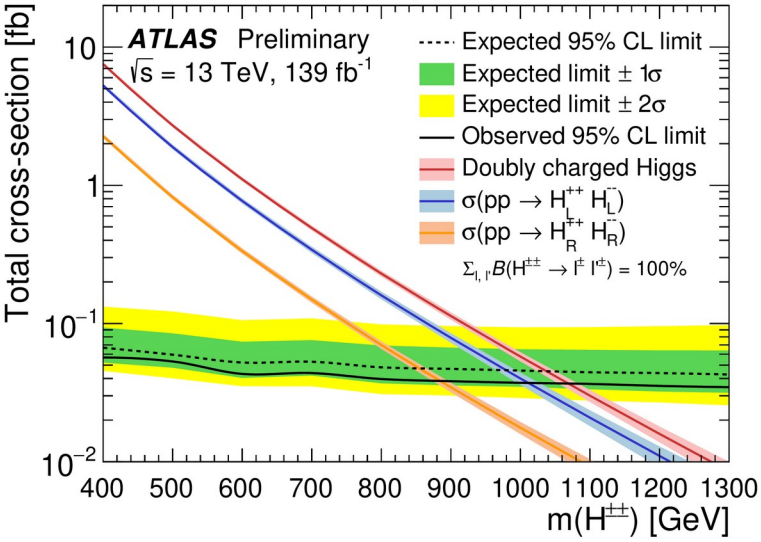
ATLAS-CONF-2022-010

- $H^{\pm\pm}$ do not exist in the SM but predicted by some BSM theories
- Multi-lepton signatures
- Observable: invariant mass of same-sign leptons
- Lower mass limit pushed at **1080 GeV (95% CL)**









3-3-1 model implemented in collaboration with Costantini, Corcella (arXiv:1806.04536)

SUSY

EW

strong

Two main line of research

1 Lepton final states (three papers)

-Chargino neutralino production through Wh

-Chargino neutralino production through WZ

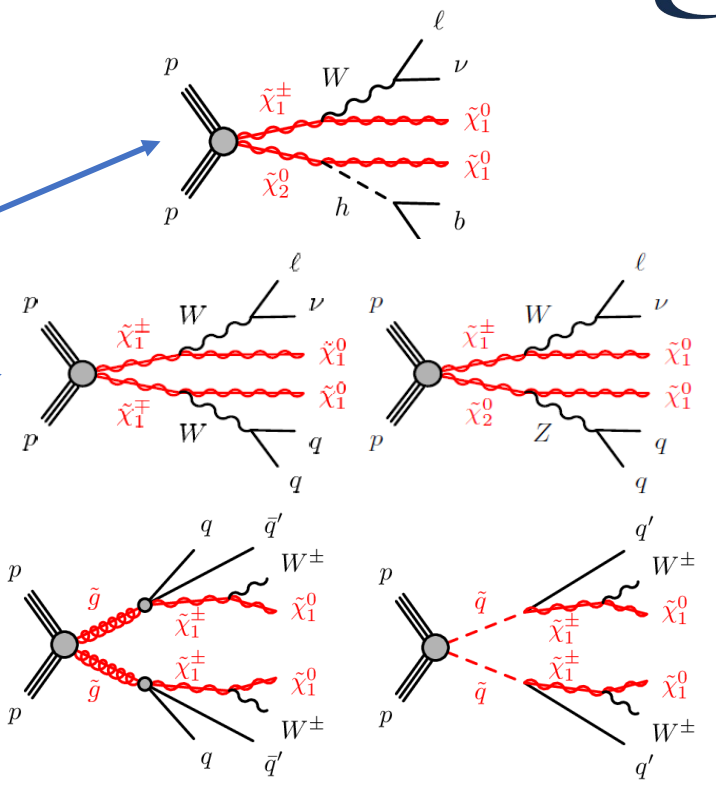
Chargino chargino production through WW

-Strong production of light squarks and gluinos

Electroweak end-of-run combinations:

Statistical combinations of results and

reinterpretations in new models



- **People:** Alberto Cervelli (former: Silvia Biondi, Kazuki Todome)
- **Responsibilities:**
  - A Cervelli: analysis contact of these analyses

Published SUSY results

Direct production of electroweakinos

Strongly relies on b-jet reconstruction

Three different signal regions targeting different mass hypotheses

Ongoing: new development using ML expected at ICHEP

Main backgrounds come from top pair production and W+jets

Limit improved by **150 GeV** w.r.t run 1 results

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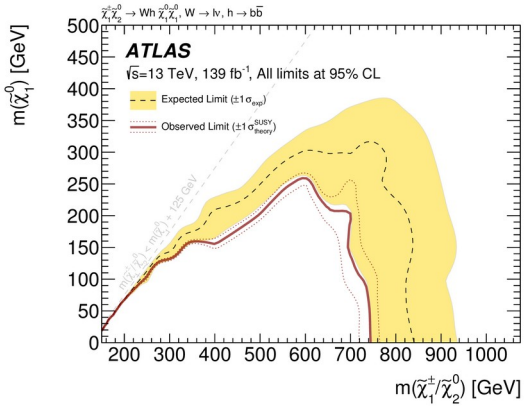
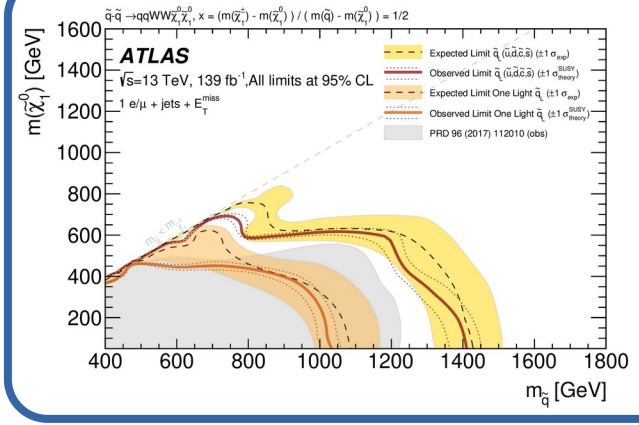
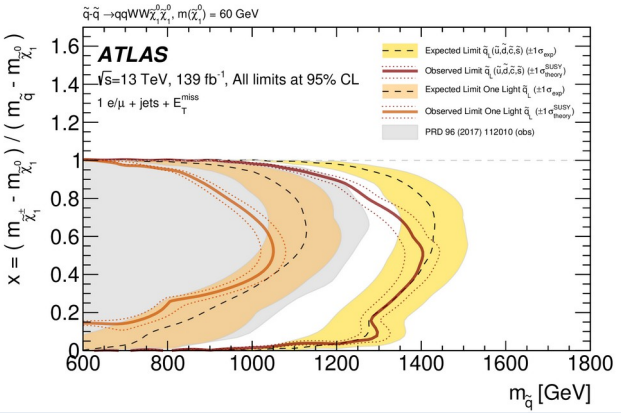






Targets high jet multiplicity events (up to 6)

Results interpreted in **direct gluino/squark decay**, and in one-step decays (two susy decays in the chain)

Main backgrounds coming from W+jet, diboson

Eur. Phys. J. C 81 (2021) 600

SUSY ongoing effort

WORK IN PROGRESS

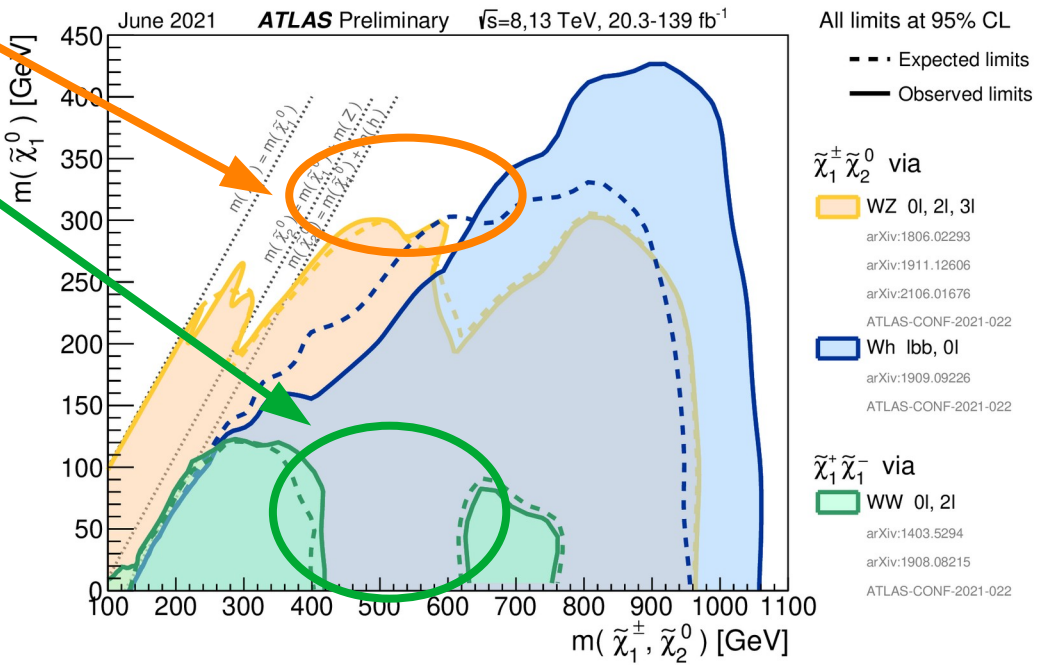
New results expected for ICHEP

Chargino neutralino pair production in WZ final states
Sensitive in the highlighted region, complimentary to other searches

Chargino Chargino pair production in WW final states
Sensitive in the highlighted region, complimentary to other searches

Statistical combination of all Run2 results. Analyses were grouped by final state signature → searches orthogonal and complimentary

Combinations will be a summary paper with complete summary of results, statistical combinations and reinterpretation in not-simplified models



Summary and outlook

- ATLAS-Bologna analysis activities covering many aspects of the ATLAS physics program
  - Combined Performance (Muon momentum corrections, common fake-factors)
  - SM and Top quark physics
  - BSM searches (Exotics, SUSY, Top)
- Fruitful contacts with theorists → New models, improve precision
- Next steps: finalization of Run 2 data analyses, preparation for Run 3