IN2P3-COPIN Workshop
21-22 November 2023, Warsaw

Your signal is my background and vice versa. Use of electrons in jets with Atlas data.

(IN2P3-COPIN 10-140)

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LPNHE, Paris

Our collaboration

- **We have been collaborating since 2002, with the support of IN2P3-COPIN since 2003**
- Currently small team
  - French side: Frederic Derue
  - Polish side : Anna Kaczmarska, Marcin Wolter, Bartłomiej Żabinski
  - Hoping to have PhD students involved
- Our current collaboration is for …
  - long-term effort to fight against common backgrounds
  - Not really designed for an analysis in common – even if it would be easier
  - Share of experience, software tips & tricks can be done in an easier way in person
  - Can it be done at CERN? Not really …. We go there for meetings, shifts etc…

- **Current activities**
  - M(top) measurements using b→J/ψ→μμ
    - Identification of leptons inside jets
    - Fake leptons estimate
  - Searches for Beyond SM physics in final states with taus
    - H^+->tau nu, hh-> multileptons
    - Fake leptons estimate
    - Fake tau estimate is dependent also on the identification of leptons inside jets
    - Top production is the major or one of the major backgrounds
  - Systematics connected to the modeling of top production processes
  - Towards High Luminosity-LHC
    - Prospects for m(top) measurements
    - Tau reconstruction and identification

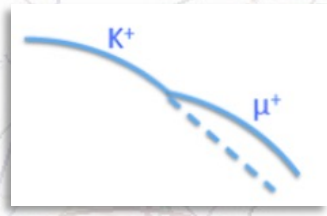
Common to our analyses: fake electrons and muons estimate

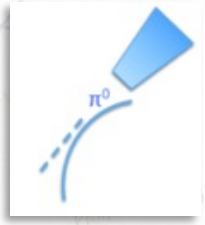
- One of the common backgrounds in all our studies are low density jets
  - including electrons/muons from heavy flavours, electrons from Dalitz decays, muons from kaons decays, or photon conversions originating from neutral pion decays and jets in general
  - They can mimic signal, isolated leptons

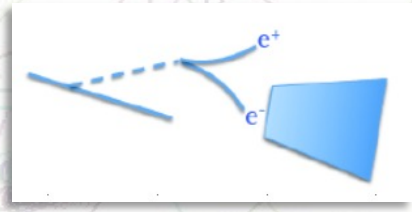
- Fake electrons and muons are badly modelled by Monte Carlo
  - We need to use **data-driven methods**
    - fake factors, matrix method
    - based on the measurement of efficiencies of leptons in data with relaxed identification criteria in regions enriched in « real leptons » and « fake leptons »
    - highly rely on our previous experience on the performance of isolated electrons and electrons in jets

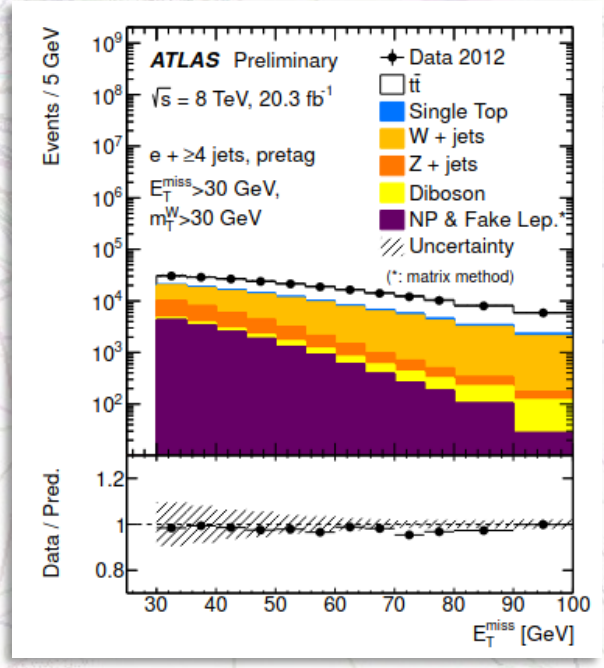
- Those methods are used in many analyses with electrons or muons in final states, including all top quark studies

- This is a small background in general, but it is difficult to estimate





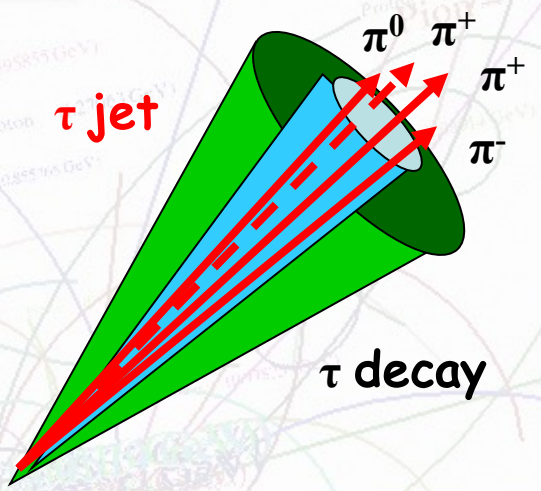




ATLAS-CONF-2014-058

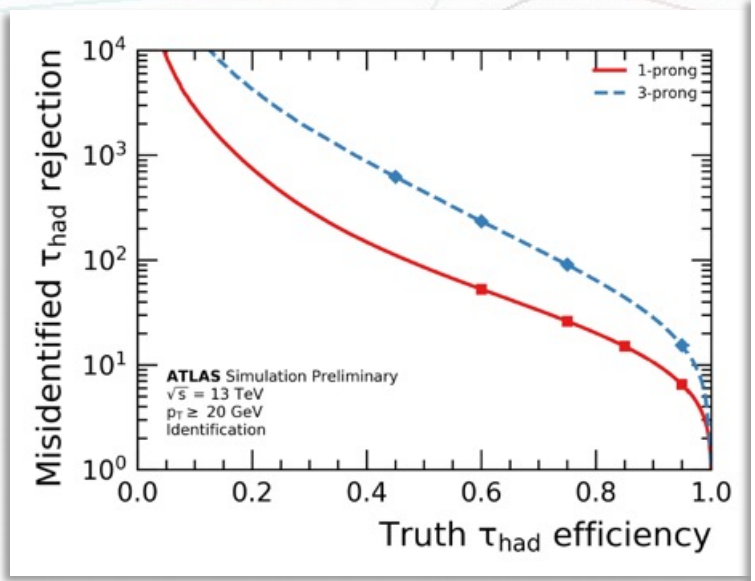
Common to our analyses: fake tau leptons

Decay modes	Branching ratio
leptonic	35.2%
1-prong ($\tau \to n\pi^0\pi^\pm\nu$)	49.5%
3-prong ($\tau \to n\pi^0\pi^\pm\pi^\mp\pi^\pm\nu$)	14.6%

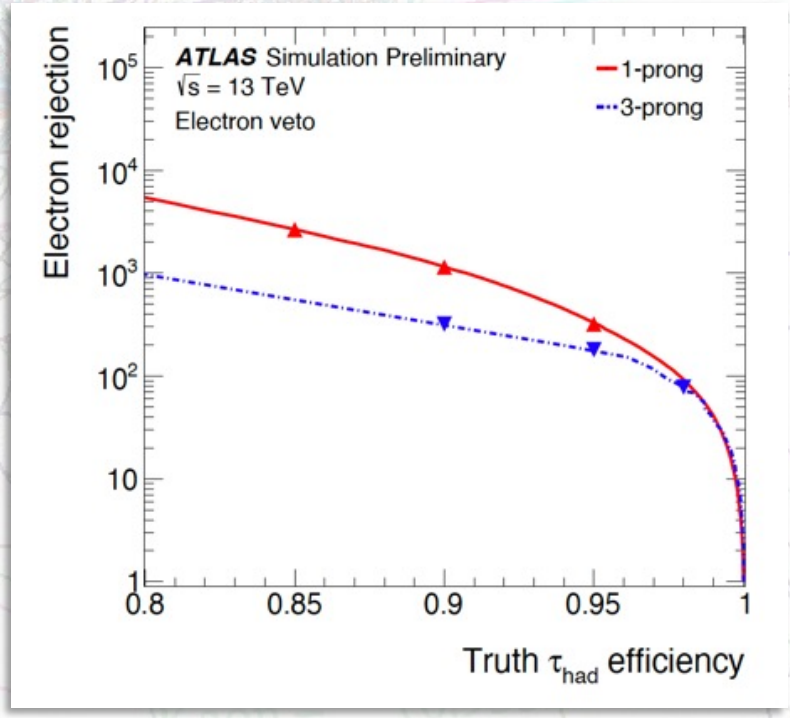


Tau hadronic decays in detector:

- Decay products very collimated
- Low track multiplicity
- Displased secondary vertex
- Main sources of fake taus:
  - QCD jets, **electrons, muons**



- Rejection of isolated electrons from Z->ee!
- Rejection of tau candidates built from electrons in jets is much more difficult and it requires knowledge of how to identify such electrons



ATL-PHYS-PUB-2022-044

Common to our analyses: top production modelling

- Monte Carlo modelling of top quarks is crucial for top analysis and analyses where top quark is an important background
- It is a limiting factor in many precision measurements and major systematics in searches
- **Dealing with top modeling systematics is now an important part of our collaboration**

Hadronisation
Pythia 8 vs Herwig 7
impact on jet energy response

b-fragmentation
variation of Bowler-Lund rb
parameter of fragmentation function

This modelling will be studied/tuned using same events as for m(top) study

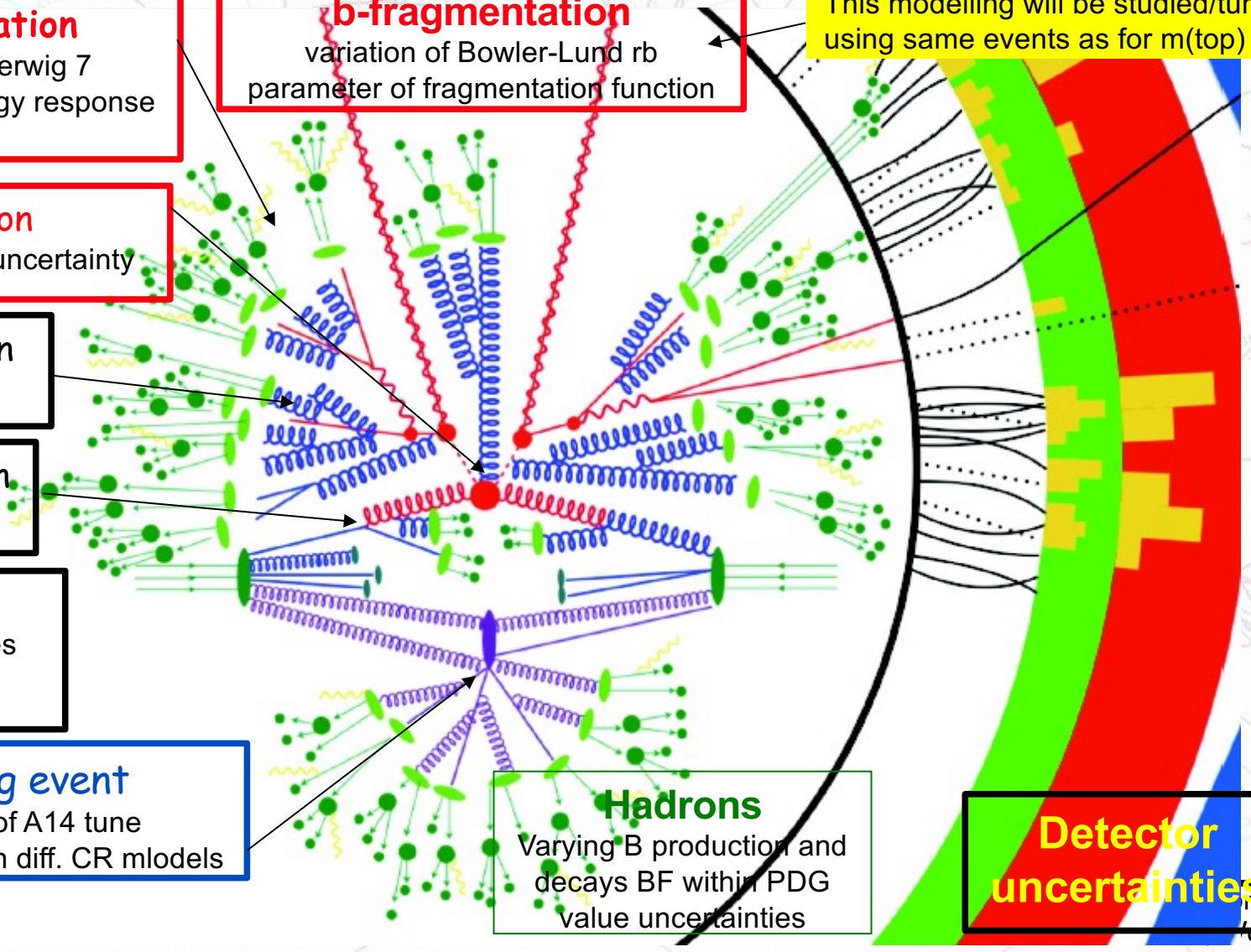
Hard interaction
Powheg vs MC@NLO as uncertainty

Final State Radiation
m (from 0.5 to 2)

Initial State Radiation
α, m, m (from 0.5 to 2)

ME-PS matching
variation of **h** that regulates
first high-p emission

Underlying event
UE : variation of A14 tune
CR : retuning UE with diff. CR mlodels



Hadrons
Varying B production and decays BF within PDG value uncertainties

Detector uncertainties

m(top) measurements using b→J/ψ→μμ

Studies of ttbar pairs in the final state with B-hadron decaying in J/ψ (b→J/ψ →μμ) offers alternative methods to measure m(top) using the sensitivity of m(l J/ψ) to m(top)

Motivations

- purely leptonic observable less sensitive to jet energy calibration than from m(lb)
- will help to reduce the uncertainties in combination of all measurements

Challenges

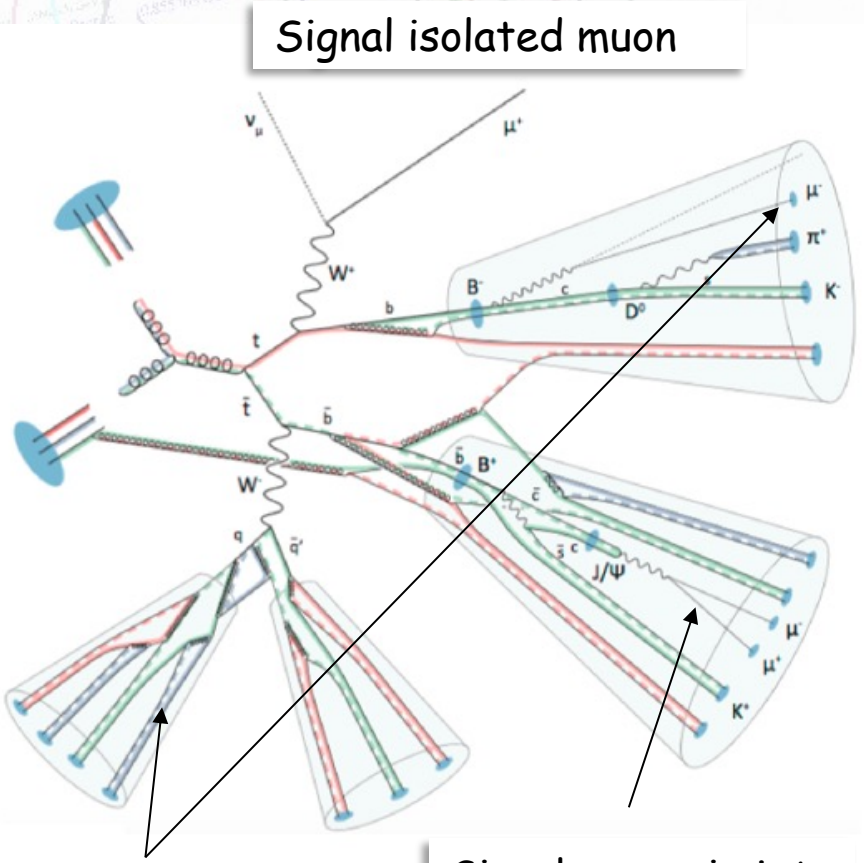
- sensitivity to parton shower & hadronization, b-quark production/fragmentation/decay
- low BR(b→J/ψ →μμ) ~ 6.8×10^{-4} ⇒ low statistics

Leptons in jets

- Signal muons in jets (identification)
- Also, sources of fake isolated leptons

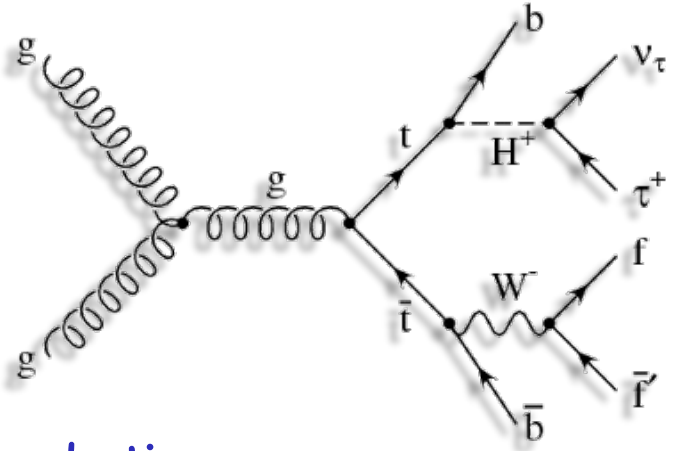
Progress during last year

- **Run 2 legacy paper in preparation** (expected in 2024)
- Estimation and understanding of top modeling systematics
- truth-level analysis for better parameter tunes for (FSR, b-fragmentation rb) variations
- more MC events produced using filtered samples to reduce statistical component of systematics
- background mitigation by cut optimization



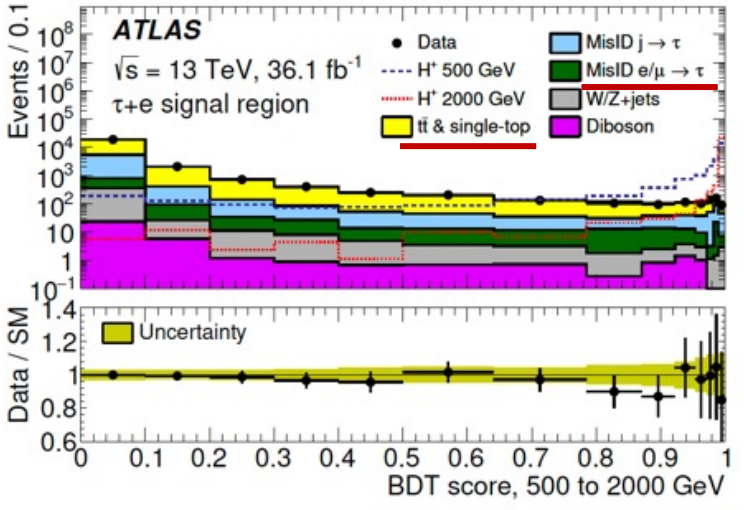
Searches for charged Higgs

- An extended Higgs sector proposed in various BSM models (like Two-Higgs Doublet Model)
- If realized by nature, it results in the existence of additional Higgs bosons
- Finding direct evidence for an extended Higgs sector would make an outstanding discovery
- Search for a charged member of the extended Higgs sector ($H^{\pm}$) in its decays to a τ lepton and its neutrino
  - τ_{had}+jets: $pp \rightarrow bbWH^{\pm} \rightarrow bb(jj)(\tau_{had}\nu)$
  - τ_{had}+lepton: $pp \rightarrow bbWH^{\pm} \rightarrow bb(e/mu\ \nu)(\tau_{had}\nu)$
  - $m(H^{\pm})$ = 80 GeV – 3 TeV



- Leptons in jets
  - Sources of fake isolated leptons in τ_{had}+lepton channel
  - Sources of fake taus in both channels

- In both channels, the main background is due to **top quark production**



Progress during last year

- **Finalizing works on Run2 Legacy paper** (expected in 2024)
- Final tunes of ttbar Monte Carlo reweighting
- Estimation and understanding of top modeling systematics
- Continuation of statistical analysis

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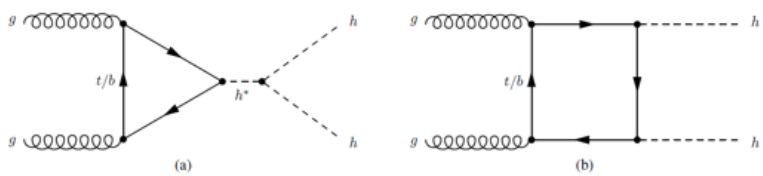
JHEP 09 (2018) 139

Searches for hh production

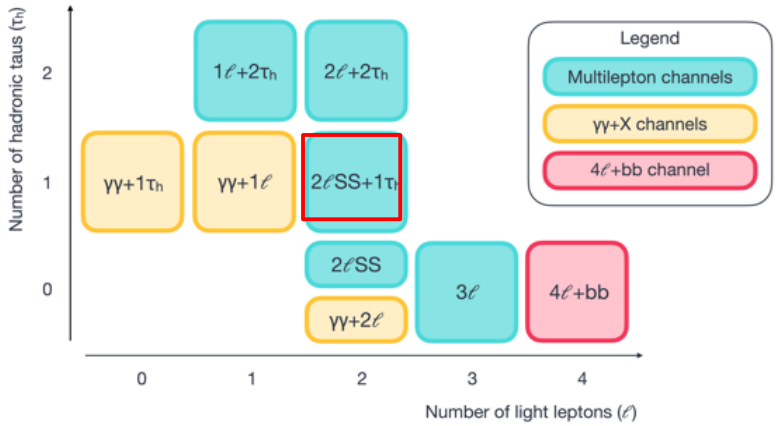
- Measurements of double Higgs production lead to a better understanding of the electroweak symmetry-breaking mechanism
- Higgs self-coupling is a good probe for BSM processes



The measurements of di-Higgs production in the channels with leptons in the final state have never been performed by ATLAS previously.
A combination of all multileptons channels can bring interesting results.

HH decay mode	bb	WW	ττ	ZZ	γγ
bb	33%				
WW	25%	4.6%			
ττ	7.4%	2.5%	0.39%		
ZZ	3.1%	1.2%	0.34%	0.076%	
γγ	0.26%	0.10%	0.029%	0.013%	0.0005%

- 9 channels with leptons in the final state investigated
- The top quark production processes are:
  - One of the main backgrounds in all channels
  - The source of fake leptons



Progress during last year
- **Finalizing works on full Run2 paper** (expected in 2024)
- In 2lSS+1tau channel
  - Fake leptons background modelling
  - Estimation and understanding of fake leptons systematics

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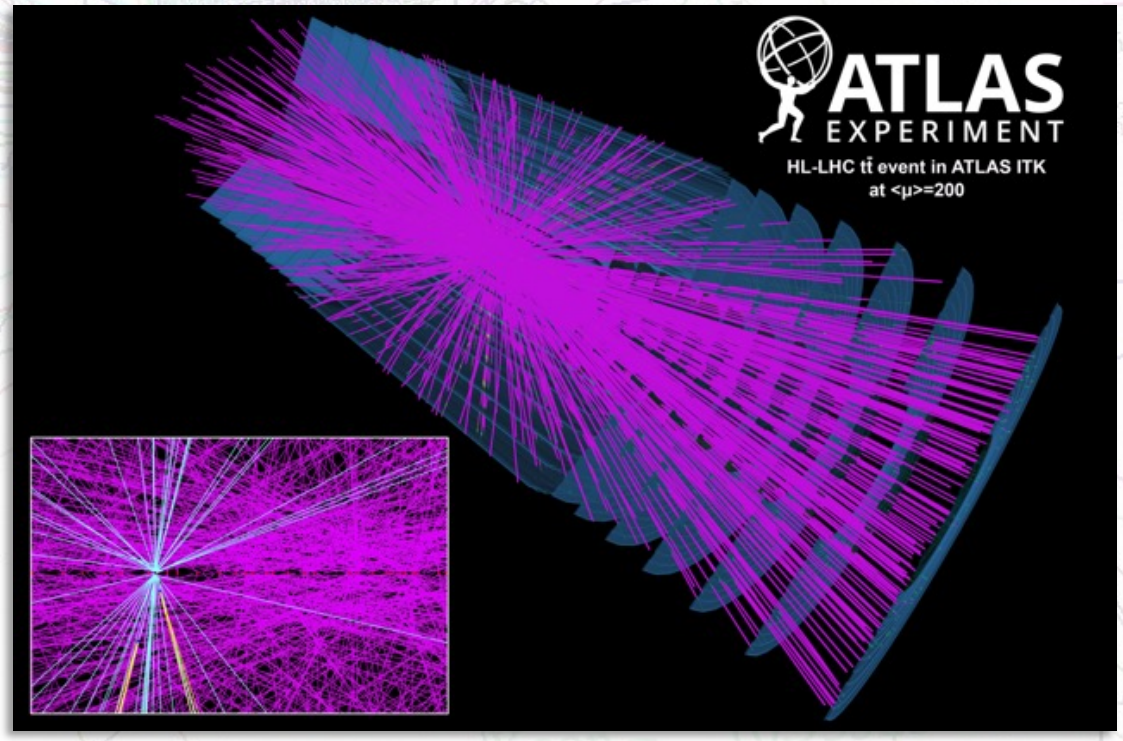
Toward High Luminosity LHC

- **High Luminosity-LHC**
  - ultimate evolution of LHC machine performance operation at 14 TeV
  - instantaneous nominal luminosity x 5-7.5 up to $L=7.5\times10^{34}cm^{-2}s^{-1}$
  - integrated luminosity x 10 to collect up to 3000-4000 fb^{-1}
    - increased radiation damage
  - challenging experimental conditions
    - up to 140-200 p-p collisions per bunch crossing
    - mitigated by extensive upgrades of the experiment

- **Top @ High Luminosity-LHC**
  - huge yield increase :
    - 3B ttbar events
    - 300 M tW
    - 30 M s-channel
    - 30k 4-top



simulated ttbar event at average pile-up of 200 collisions per bunch crossing

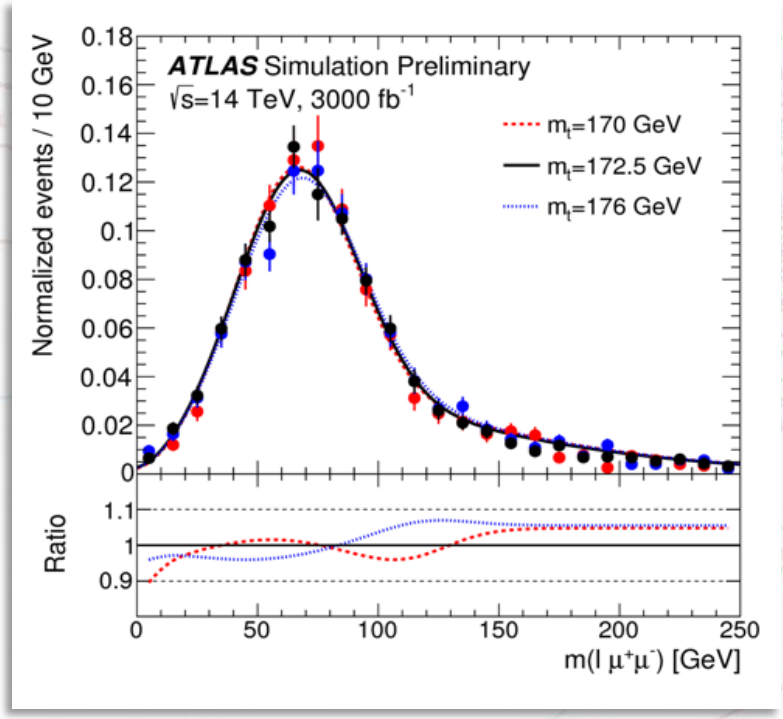
[Upgraded Event displays]

m(top) measurements using b→J/ψ→μμ @ HL-LHC

CERN Yellow Report arXiv:1902.04070

ATL-PHYS-PUB-2018-042

- Prospective study based on HL-LHC simulated data
- Number of expected events at the end of HL-LHC: 2×10^5 candidates wrt ~10^4 at the end of Run 2
  - 18% additional events thanks to the higher cross-section
  - 10% additional events thanks to large coverage in $|\eta|<4$ with detector upgrade



Statistical uncertainty	0.14
Method uncertainty	0.11
Signal modelling uncertainties	
$t\bar{t}$ NLO modelling	0.06
$t\bar{t}$ PS and hadronisation	0.05
$t\bar{t}$ b-production	0.24
$t\bar{t}$ b-fragmentation	0.11
Initial- and final-state radiation	0.04
Underlying event	0.02
Colour reconnection	0.02
Background modelling uncertainties	0.10
Experimental uncertainties	
Jet energy scale (JES)	0.31
b-jet energy scale (b-JES)	0.06
Jet energy resolution (JER)	0.13
Jet vertex fraction	0.02
Electrons	0.03
Muons	0.09
Pile-up	0.04
Total Systematic uncertainty	0.48
Total	0.50

Our collaboration is originally about this background.
But now modelling issues become more important.

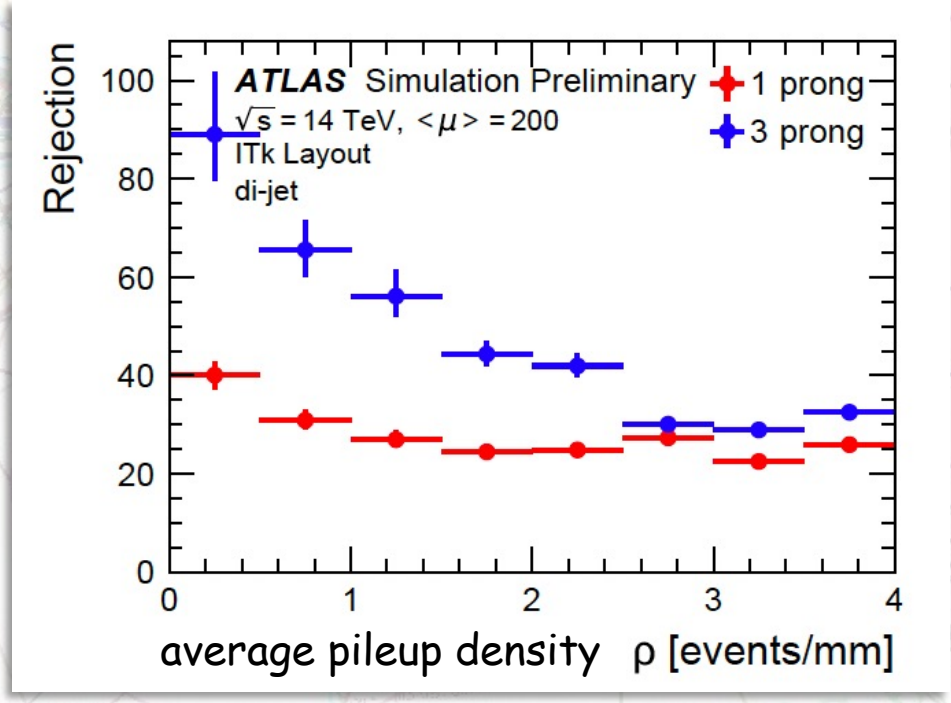
$\sigma(m_{top}) = 0.14\ (stat) \pm 0.48\ (syst)\ GeV \sim 0.50\ GeV$

HL-LHC key parameters

- **High Luminosity-LHC**
  - ultimate evolution of LHC machine performance operation at 14 TeV
  - instantaneous nominal luminosity x 5-7.5 up to $L=7.5\times10^{34}cm^{-2}s^{-1}$
  - integrated luminosity x 10 to collect up to 3000-4000 fb^{-1}
    - increased radiation damage
  - challenging experimental conditions
    - up to 140-200 p-p collisions per bunch crossing
    - mitigated by extensive upgrades of the experiment

- **Tau leptons @ HL-LHC**
  - Reconstruction will be difficult due to a huge increase in the pileup rate
  - Need to associate particles with the correct vertex
  - High particle densities – high occupancy in calorimeters. Worse fake rejection

  - We have started to work on those issues this year



ATL-PHYS-PUB-2021-023

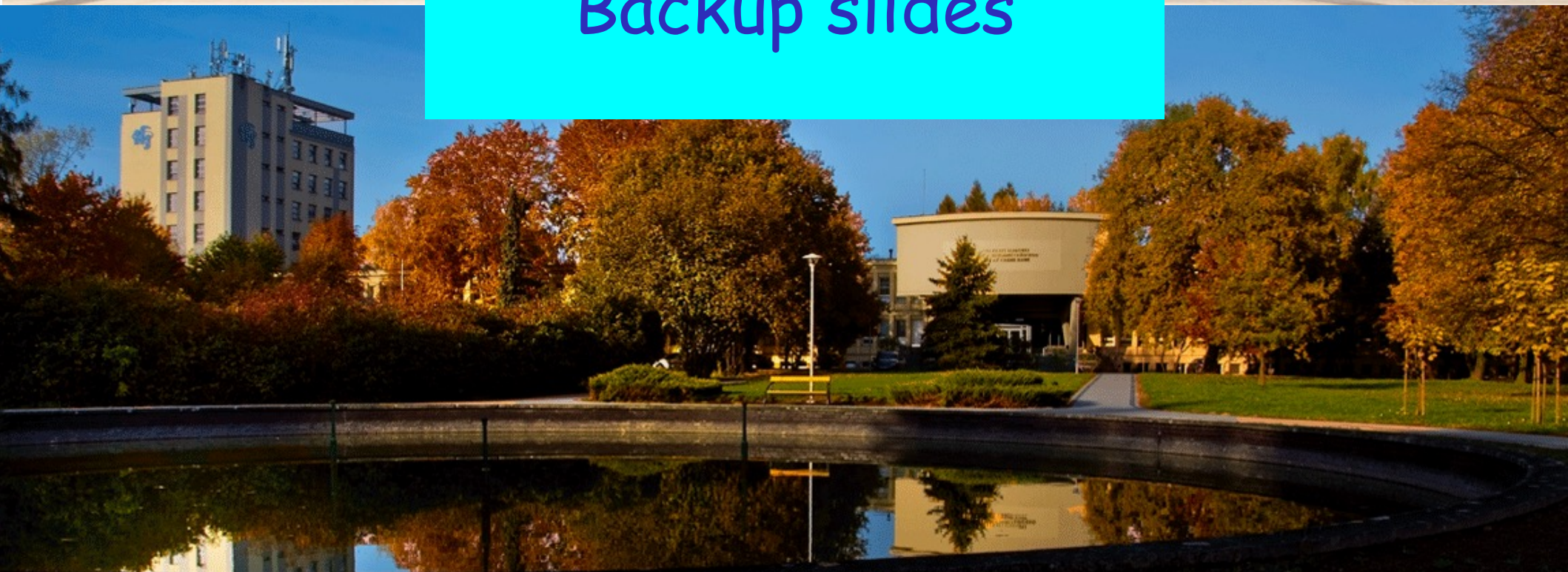
Summary

- **Continuation of collaboration lasting for more than 20 years**
- **It is now mainly based on estimation and systematics for common backgrounds (being sometimes the other side signal)**
- During last year the main work was performed toward Run 2 Legacy papers
- Activities for HL-LHC have already started and slowly speeding up…
- **We plan to continue those activities in 2024 (finalizing papers) + start to work on Run3 data**

- **Areas of interest to be (more) developed**
  - Frederic Derue and Bartłomiej Zabinski represent their funding agencies in the Internation Computing Board
    - sharing of knowledge
  - Machine Learning tools: we heavily used it in the 2000's for electrons in jets and soft-electron b-tagging. Big evolution of tools since then….
    - Used in our BSM searches => port this experience to the performance field
  - Both ATLAS groups are working on HH – but not LPNHE member of our project, and not on the same final state (bb vs multileptons)
    - Sharing the experience and analysis tools

- **Recent "side effects" of our collaboration**
  - Participation in the Visiting teacher/researcher program
    - A. Kaczmarska got a 1-month invitation from Université Paris Cité in 2024
  - F. Derue invited by International PhD School IFJ-PAN (KISD) to give lectures on Detector Physics in January 2023
  - Exchange of ideas/gadgets for our outreach activities!

Backup slides

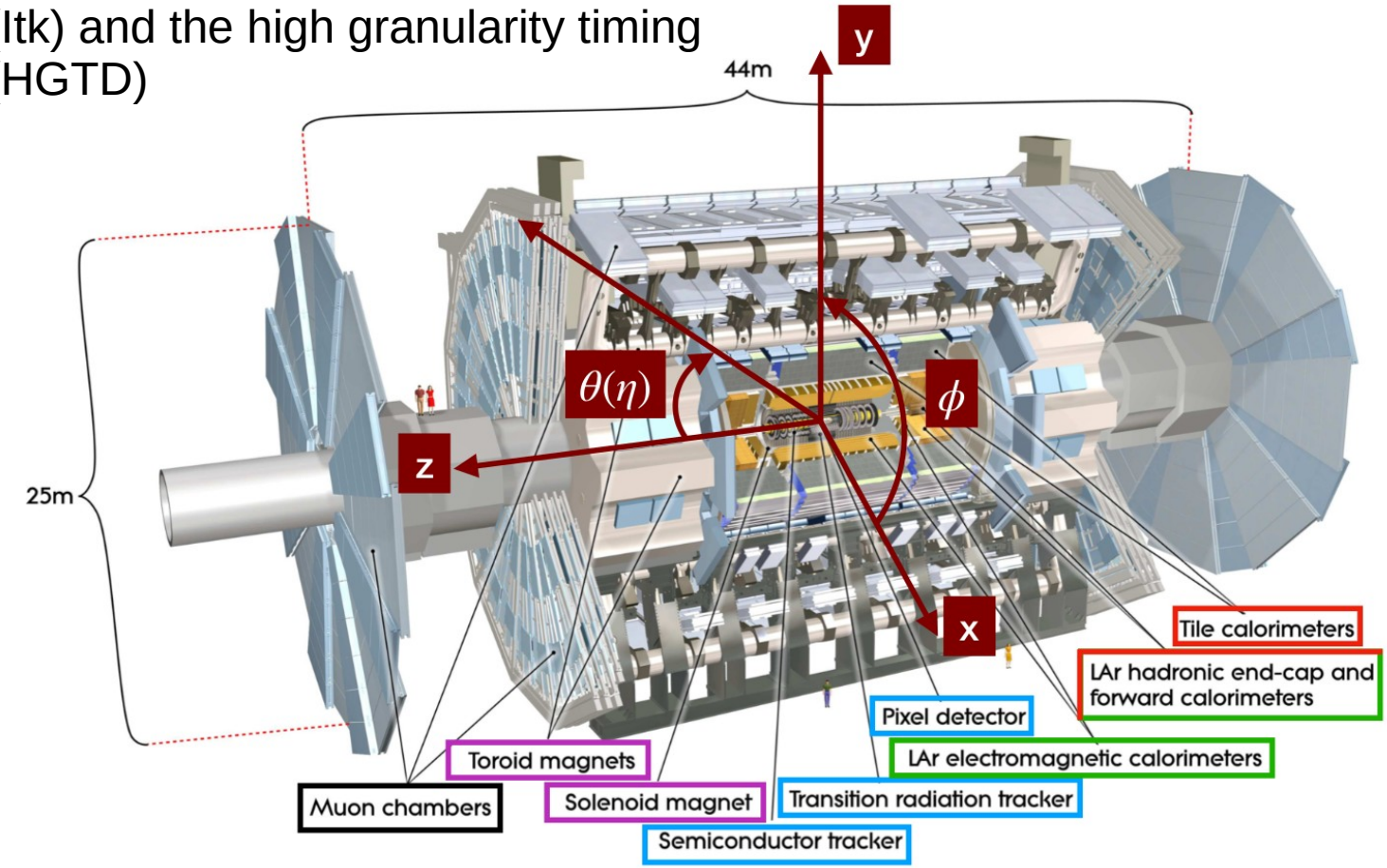


Prospectives for Run 3 and HL-LHC

LHC / HL-LHC plan

Build on group hardware experience

- LPNHE Paris has participated to the building, characterization and running of the electromagnetic calorimeter. It is now involved in the upgrade of the detector for the high-luminosity phase HL-LHC (>2028) with the full silicon tracker inner detector (Itk) and the high granularity timing detector (HGTD)



- IFJ-PAN Cracow has participated to the building, characterization and running of the Semiconductor tracker (SCT) and the Transition Radiation Tracker (TRT).
  It is now involved in the upgrade of the detector for the high-luminosity phase HL-LHC (>2028) with the full silicon tracker inner detector (Itk)

Build on software and combined performance expertise

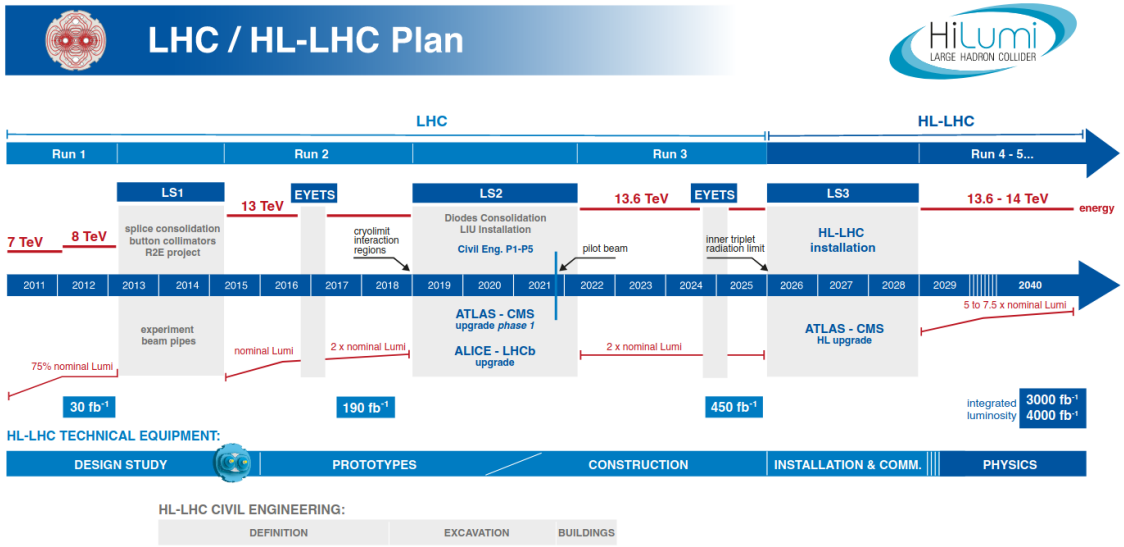
- **electron-photon Working group (2003-2010)**
  - PhD thesis of A. Kaczmarska on soft-electrons, 2000
  - development of soft-electron reconstruction/identification algorithm. Introduced the track-based algorithm to complement the existing calorimeter-based. Full integration into a single, robust and effective package/algorithm.
    → F. Derue e/gamma software manager 2008-2009
  - study of test beam data (2006-2008)
  - first electron reconstruction with commisionning/early data (2009-2010)

- **τ–lepton Working Group (2006-2015)**
  - development of τ-lepton reconstruction/identification algorithm Introduced the track-based algorithm to complement the existing calorimeter-based. Full integration into a single, robust and effective package/algorithm.
    → A. Kaczmarska software manager 2008-2009
  - applied to commissioning/early data (2009-2010)

- **flavour tagging Working group (2003-2010)**
  - development of soft-electron b-tagging algorithm
  - applied to early data (2009-2010) then stop of this acticity

Physics studies era

- **Since start of data taking (2010 → present)**



- LPNHE group analyses (relevant for the project):
  physics with (soft) electrons $J/\psi \rightarrow ee$: 2010-2012
  Fake electrons and muons estimate : 2011 → 2017
  top quark physics : cross-section in dilepton channel : 2010-2012
  m(top) in dilepton channel : 2012-2015
  m(top) with $b \rightarrow J/\psi \rightarrow \mu\mu$: 2015 → present
- IFJ-PAN analyses : SM studies $W \rightarrow \tau\nu_\tau$, $Z \rightarrow \tau\tau$ + τ reconstruction : 2010-2015
  τ polarisation : 2013-2016
  $H \rightarrow \tau\tau$: 2015 → present
  BSM searches :
  $H^{\pm} \rightarrow \tau\nu_\tau$: 2012 → present
  $HH \rightarrow$ multilepton: 2019 → present

Research projects

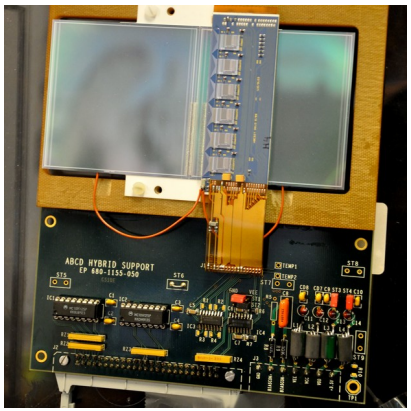
- **IN2P3-COPIN 10-140 since 2006 (actually autumn 2002)**
  - French side : F. Derue (each years), T. Theveneaux-Pelzer (2011), S. Pires (2014)
  - Polish side : A. Kaczmarska (almost each years), P. Bruckman de Renstrom (2013), P. Malecki (2011, 2012, 2013, 2014), M. Wolter (2011, 2012, 2019), A. Zemła (2010, 2013, 2014, 2015), B. Żabinski (2016, 2018, 2021, 2022)

- **European project**
  - A. Kaczmarska got Marie Curie Intra-European-Fellowship MEIF-CT-2003-501408, 2004-2006 at LPNHE Paris
  - Marie Curie Reintegration Grant (ERG) MERG-CT-2005-030760, 2006-2007, grant holder, Towards observation of hadronic tau decays in the ATLAS experiment with the first LHC collisions: key for observability of the New Physics and Higgs boson(s)

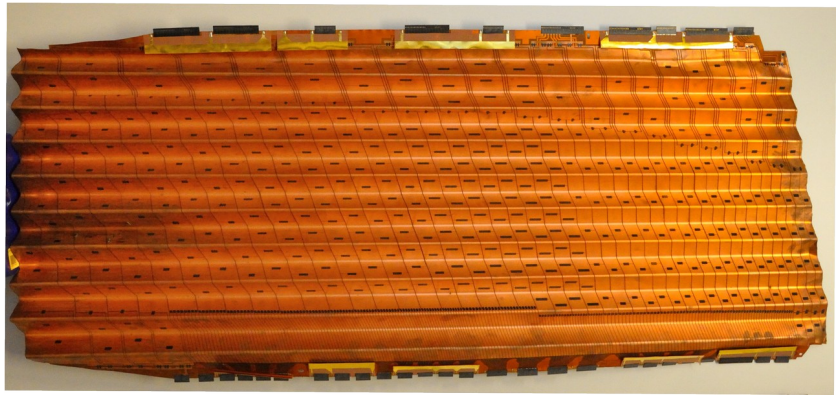
- **Visiting teacher / researcher program**
  - A. Kaczmarska got a 1 month invitation from Université Paris Cité in 2010, 2011, 2012, 2013, 2014, 2015, 2017, 2018, 2019 (cancelled), 2020 cancelled), and two weeks in 2021, 2022
  - F. Derue invited by International PhD School IFJ-PAN to give lectures on Detector Physics in January 2023

Outreach activities

- exchange / gifts of some hardware/photos for our Festival of Sciences



ATLAS SiliCon Tracker module
from IFJ-PAN now in LPNHE



Electrode from ATLAS electromagnetic calorimeter
from LPNHE now in IFJ-PAN

- private visit of Museum Sciences-ACO in Orsay in 2019

Video « Witam w Paryżu » for IFJ-PAN for Festival of Science in september 2022

Tatoos on HEP/Cosmo for younger public taken from IFJ-PAN to LPNHE

- ….

Related ATLAS publications

- **Physics analyses publications**
  - Search for heavy Higgs bosons decaying into two tau leptons, (2020) Phys. Rev. Lett. 125, 051801
  - Report on the Physics at the HL-LHC and Perspectives for the HE-LHC, arXiv:1902.10229, CERN-LPCC-2019-01
  - HL-LHC prospect for top mass using J/Psi, ATLAS Coll. ATL-PHYS-PUB-2018-042
  - Measurement of τ polarisation in $Z/\gamma^* \rightarrow \tau\tau$ decays in pp collisions at $\sqrt{s}$=8 TeV with the ATLAS detector, ATLAS Coll, EPJC 78(2018)163
  - Search for charged Higgs boson decaying via H+->tau nu in the tau+jets and tau+lepton final states with 36.1 fb-1 of pp collision data recorded at sqrt(s) = 13 TeV with the ATLAS experiment, JHEP 1809 (2018) 139
  - Reconstruction of J/ψ mesons in $t\bar{t}$ final states in proton-proton collisions at $\sqrt{s}$=8 TeV with the ATLAS detector, ATLAS Coll., ATLAS-CONF-2015-040
  - HL-LHC prospect for top mass using J/Psi, ATLAS Coll. ATL-PHYS-PUB-2018-042
  - Search for charged Higgs bosons produced in association with a top quark and decaying via H+- -> tau nu using pp collision data recorded at $\sqrt{s}$=13 TeV by the ATLAS detector, ATLAS Coll, Phys. Lett. B 759 (2016) 555-574
  - Search for charged Higgs bosons in the +jets final state with 14.7 fb-1 of pp collision data recorded at $\sqrt{s}$=13 TeV with the ATLAS experiment, ATLAS-CONF-2016-088
  - Search for charged Higgs bosons decaying via $H^{+-} \rightarrow \tau\nu_\tau$ in fully hadronic final states using pp collision data at $\sqrt{s}$=8 TeV with the ATLAS detector, JHEP03 (2015) 088
  - Search for charged Higgs bosons decaying via $H^+ \rightarrow \tau\nu_\tau$ in hadronic final states using pp collision data at $\sqrt{s}$=8 TeV with the ATLAS detector, ATLAS-CONF-2014-050
  - Search for charged Higgs bosons in the tau+jets final state, ATLAS Coll, ATLAS-CONF-2013-090
  - Application of TauSpinner for studies on tau-lepton polarization and spin correlations in Z, W and H decays at LHC, A. Kaczmarska et al, arXiv:1402.2068, 2014
  - Measurement of the Z to tau tau cross section with the ATLAS detector, ATLAS Coll., Phys. Rev. D84 (2011) 112006

Related ATLAS publications

- **Combined performance publications**
  - Reconstruction, Identification, and Calibration of hadronically decaying tau leptons with the ATLAS detector for the LHC Run 3 and reprocessed Run 2 data, ATLAS Coll., ATL-PHYS-PUB-2022-044
  - Measurement of the tau lepton reconstruction and identification performance in the ATLAS experiment using pp collisions at √s=13 TeV, ATLAS-CONF-2017-029
  - Reconstruction of hadronic decay products of tau leptons with the ATLAS experiment, ATLAS Coll., Eur. Phys. J C 76(5), 1-26 (2016)
  - Identification and energy calibration of hadronically decaying tau leptons with the ATLAS experiment at √s=8 TeV, Eur. Phys. J. C75 (2015) 303
  - Commissioning of the reconstruction of hadronic tau lepton decays in ATLAS using pp collisions at √s=13 TeV, ATL-PHYS-PUB-2015-025
  - Estimation of non-prompt and fake lepton backgrounds in final states with top quarks produced in proton-proton collisions at √s=8 TeV with the ATLAS detector, ATLAS Coll., ATLAS-CONF-2014-058
  - Identification and energy calibration of hadronically decaying tau leptons with the ATLAS experiment in pp collisions at √s=8 TeV, ATLAS Coll., Eur. Phys. J. C75 (2015) 303
  - Expected electron performance in the ATLAS experiment, ATLAS Coll., ATLAS-PHYS-PUB-2011-006
  - Tau reconstruction with 7 TeV collisions in ATLAS, talk the 11th International, A. Kaczmarska, Workshop on Tau Lepton Physics Manchester, UK, 13-17 September 2010
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