Recasting LHC analyses with MADANALYSIS 5

Problems & solutions

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Mini-workshop on recasting ATLAS and CMS new physics searches

LPSC Grenoble - September 8-12, 2014

Outline

1. The MA5-tune of DELPHES 3

2. Selected items on the implementation and the validation of LHC analyses

3. Summary

The MA5-tune of DELPHES 3: technicalities

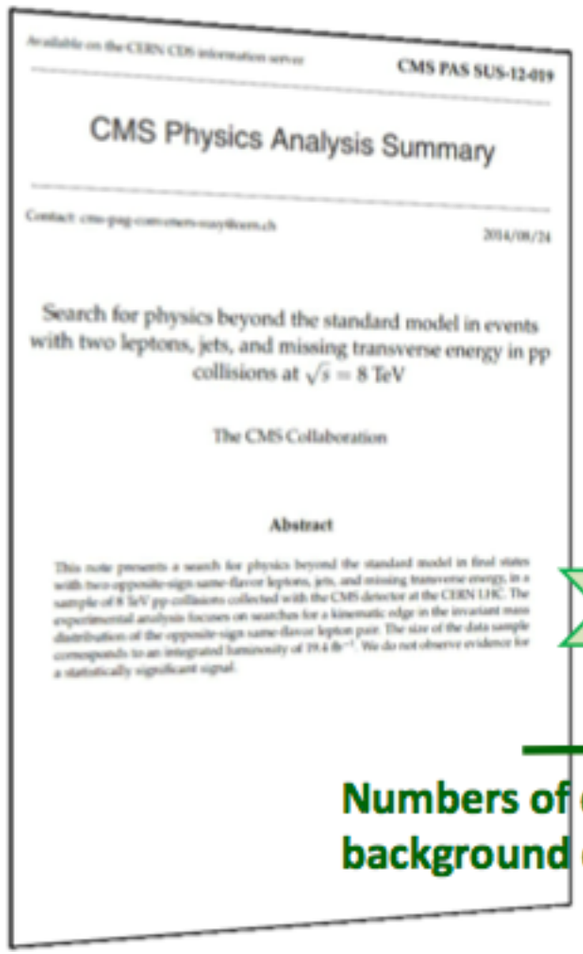
Recasting and designing LHC physics analyses

- Determining the sensitivity of the LHC to a new physics model by analyzing specific signatures
  - Recasting an existing LHC analysis
    - ★ Generation of signal Monte Carlo event samples
    - ★ Event generation: LHE (parton level) - STDHEP/HEPMC (hadron level) - ROOT (reconstructed level)
    - ★ Analysis by mimicking as much as possible the experimental cuts
  - Designing a novel LHC analysis
    - ★ Generation of background and signal Monte Carlo event samples
    - ★ Event generation: LHE (parton level) - STDHEP/HEPMC (hadron level) - ROOT (reconstructed level)
    - ★ Analysis by tuning the thresholds to increase a factor of merit of choice

- Monte Carlo production: time and disk space consuming
  - In order to only do it once:
    - ★ Inclusion in the output ROOT file all information needed for all foreseen works
    - ★ Analysis-dependent issues (like lepton isolation) to be achieved at the analysis level
  - The size of the ROOT file must be kept reasonable

A compromise must be found

The MADANALYSIS 5 strategy for recasting an LHC analysis



✦ Why a tune of DELPHES?

- ✤ The output ROOT file must be flexible and general enough to address any LHC analysis
  - ★ Optimal choice: one ROOT file for any (ATLAS or CMS) analysis
  - ★ Likely option: one CMS and one ATLAS ROOT file
  - ★ Current option: one CMS and many ATLAS ROOT files
- ✤ The standard DELPHES output cannot be used for that purpose

One of the goals of this workshop

Cleaning the ROOT output file

✦ Generated particles at all levels (parton, hadron, reconstructed)
- ✤ Useful
- ✤ Heavy (disk space consuming)

✦ The MA5-tune solution
- ✤ All reconstructed objects are stored, including track information
- ✤ Keeping all initial-state and hard-process particles
- ✤ The particle history for beauty and charm hadrons (starting from the hard process)
- ✤ Final-state electrons and muons are linked to their mother, …, grand-grand-mother
  - ★ Useful to determine whether the lepton is prompt, issued from a tau, *etc.*
- ✤ All other particles are discarded

✦ Linking reconstructed and generated objects
- ✤ Leptons: reconstructed leptons are smeared generated leptons
  - ★ Easy to link without any mismatch (included in the output file)
- ✤ Jets: reconstructed jets can be matched to generated partons (via a standard ΔR method)
  - ★ To be implemented at the analysis level by the user
  - ★ Private methods exist for the moment (to be public one day?)
  - ★ Limitations: light partons arising from the showering are not stored in the output file
  - ★ Could be included at the DELPHES level

Lepton isolation

✦ Lepton isolation is analysis-dependent

- ✤ The output ROOT file must contain the necessary information
- ✤ Storing track, calorimeter, *etc.*, information is too heavy

✦ The MA5-tune solution

- ✤ Storing isolation variables that are computed at the DELPHES level
- ✤ Sum of the p_T of all tracks and of all calorimetric deposits in a given cone around the lepton
- ✤ Number of tracks in this cone
- ✤ Particle flow isolation information is also retained (currently under study)

	DR=0.2	DR=0.3	DR=0.4	DR=0.5
Tracker isolation				
Calorimeter isolation				
ParticleFlow isolation				

- ✤ The p_T threshold is fixed at the level of DELPHES

✦ Cleaning of the jet collection

- ✤ In standard DELPHES, isolated leptons are removed from the jet collection (the UNIQUEOBJECTFINDER method)
- ✤ By-passed in the MA5-tune
- ✤ Jet cleaning must be done at the analysis level (e.g., a ΔR method)
- ✤ The H_T variable must be recalculated

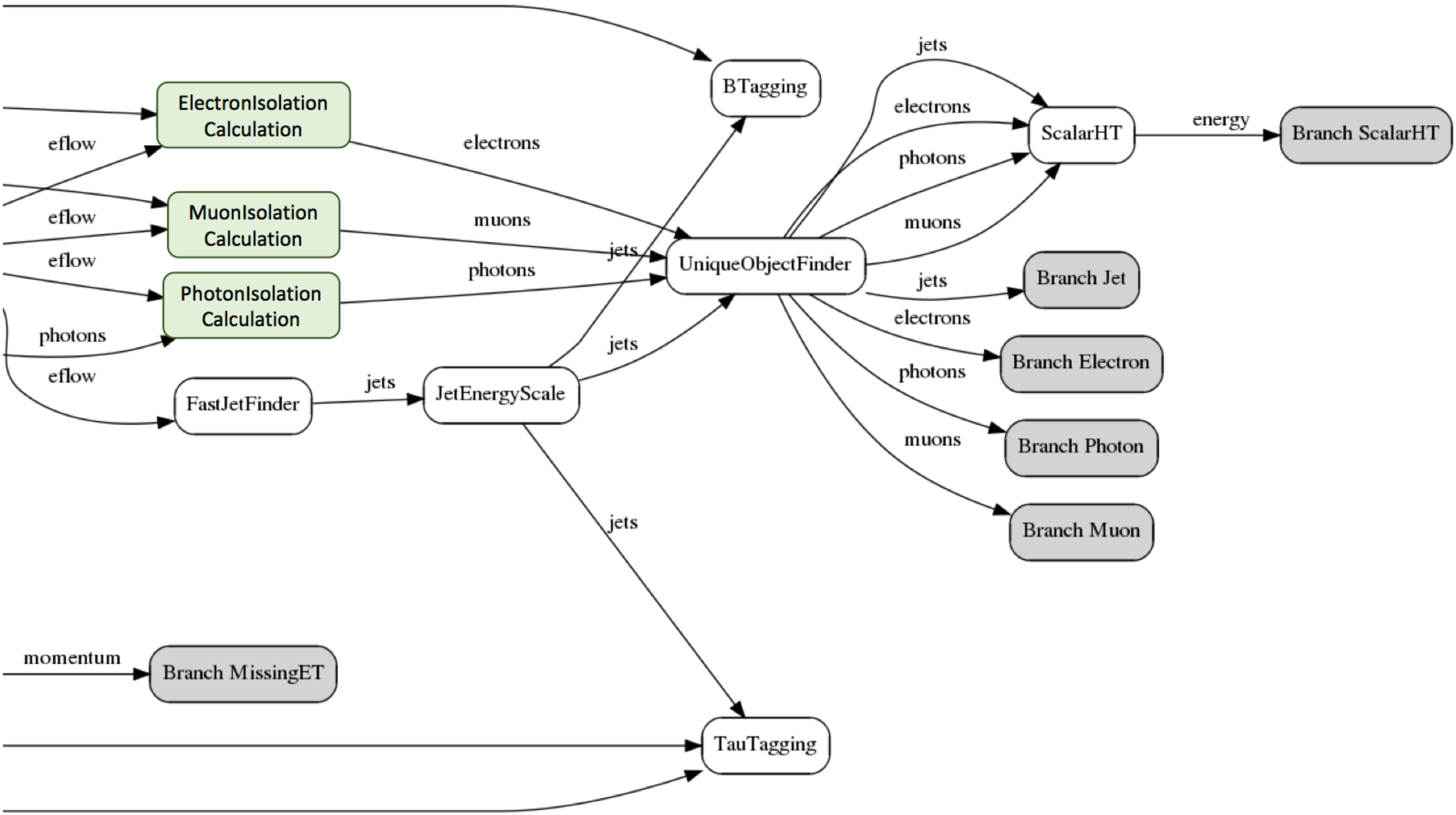
B-tagging

- Two strategies are implemented in DELPHES
  - Parameterization (in the detector card): several benchmark (or cards) are thus required
  - Track-counting algorithm

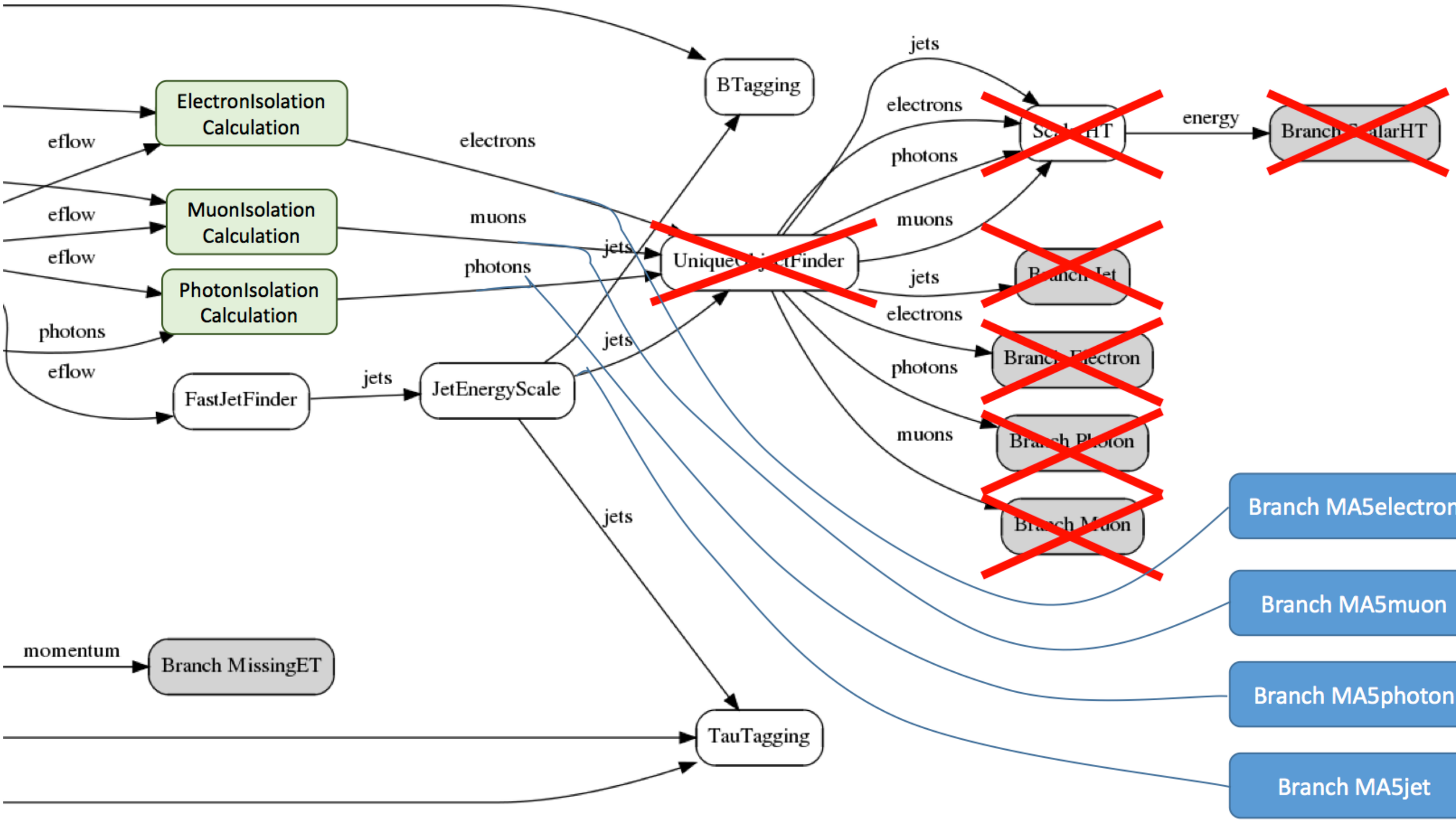
- The (old) MA5-tune solution
  - A parametric approach included in the detector card

- The (new) MA5-tune solution
  - A parametric approach to be performed at the analysis level
  - A matching between jets and partons is required
    - ★ CMS: currently developed by CMS b-taggging experts themselves in Strasbourg
    - ★ ATLAS: nothing is done at the moment

Inside the code: isolation



Inside the code: output



Future developments

- **c-tagging**
  - On-going studies
  - Status: no implementation so far

- **Displaced vertices**
  - Account for particle lifetimes
  - Efficiency for track reconstruction depending on its impact parameters and pseudorapidity
  - Status: existing old private DELPHES 2 code

- **Muon electric charge mis-identification**
  - Important for analysis based on same-sign dileptons
  - Status: existing old private DELPHES 2 code

- **Identification of hadronically decaying tau**
  - Current strategy: a tau is a jet identified as a tau
  - Improvement strategy 1: dedicated algorithm like in DELPHES 2
  - Improvement strategy 2: efficiency and resolution effects applied on the generated taus
  - Status: really needed soon

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Implementation and validation of ATLAS analyses

Published or to-be published | Problems with the validation | Starting validation

1. ATLAS-SUS-2013-04 (1308.1841): multijet + missing energy
   [Blanke, Fuks, Galon]
2. ATLAS-SUS-2013-05 (1308.2631): two b-jets + missing energy
   [Chalons]
3. ATLAS-SUS-2013-11 (1403.5294): two leptons + missing energy
   [Dumont]
4. ATLAS-SUS-2013-12 (1402.7029): three leptons + missing energy
   [de Causmaecker, Fuks, Mawatari]
5. ATLAS-SUS-2013-13 (1405.5086): at least four leptons + missing energy
   [Mawatari]
6. ATLAS-SUS-2013-14 (1407.0350): two hadronic taus + missing energy
   [de Causmaecker, Fuks]
7. ATLAS-SUS-2013-18 (1403.4853): at least three b-jets + missing energy
   [Mitzka, Fuks]
8. ATLAS-SUS-2013-19 (1407.0600): two leptons + b-jet(s) + missing energy
   [Chalons]

Implementation and validation of CMS analyses

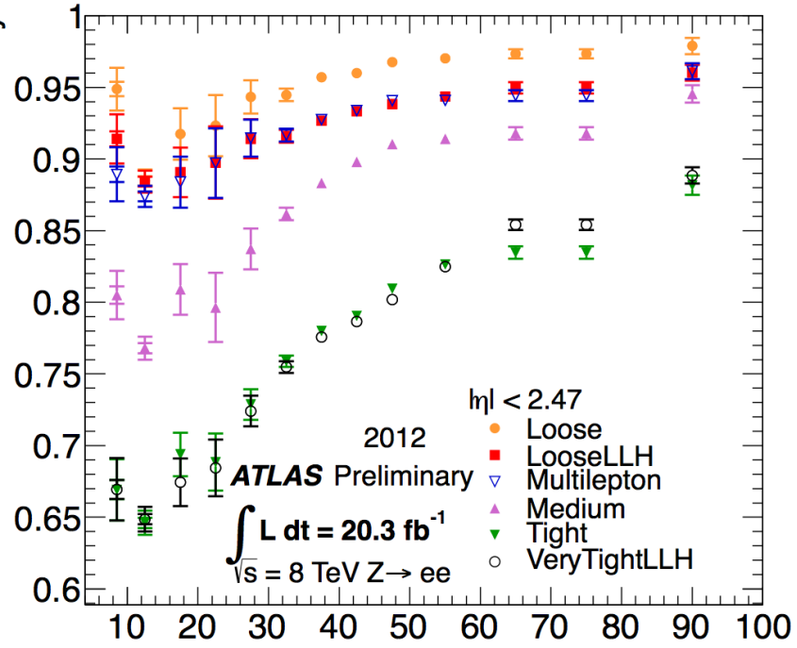
Published or to-be published | Problems with the validation | Starting validation

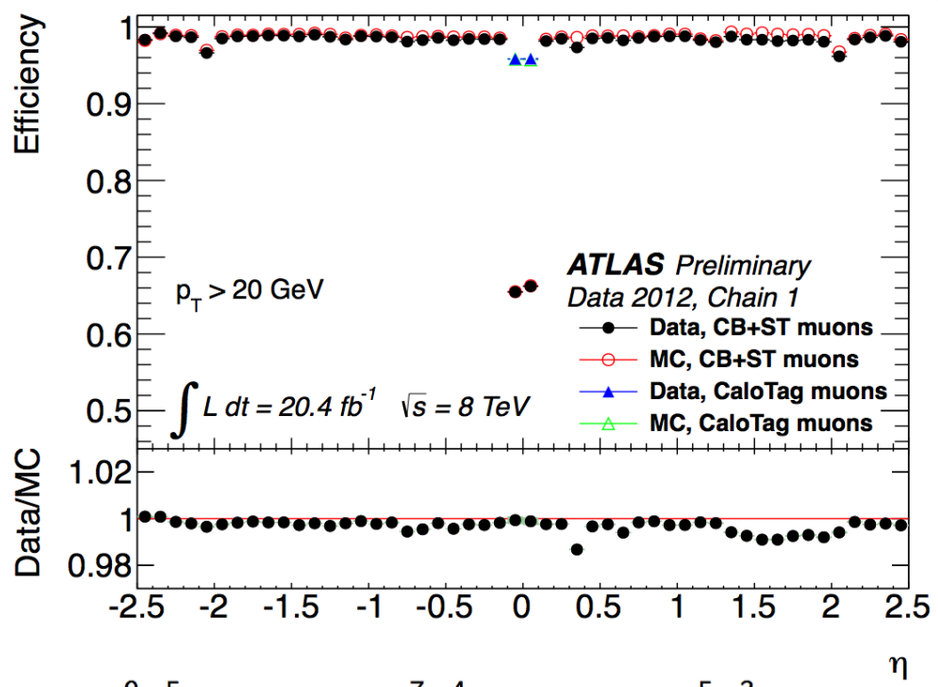
1. CMS-B2G-13-003: vector-like quarks in multileptonic events
   [Alloul, Basso, Fuks]
2. CMS-SUS-12-028 (1303.2985): α_T
   [Blanke, Fuks, Galon]
3. CMS-SUS-13-002 (1404.5801): three or more lepton + missing energy
   [Alloul, Basso, Fuks]
4. CMS-SUS-13-007 (1311.4937): single lepton + b-jets + missing energy
   [Kraml, Laa, Sengupta]
5. CMS-SUS-13-008: three leptons + 1 b-jet + missing energy
   [Alloul, Basso, Fuks]
6. CMS-SUS-13-011 (1308.1586): stops in the single lepton mode
   [Dumont, Fuks, Wymant]
7. CMS-SUS-13-012 (1402.4770): multijets and missing energy
   [Bein, Sengupta]
8. CMS-SUS-13-013 (1311.6736): same-sign dilepton + jets
   [Alloul, Basso, Fuks]
9. CMS-SUS-13-015: stops in multijet + missing energy
   [Bein, Kraml]
10. CMS-SUS-13-016: opposite sign dilepton, b-jets and missing energy
    [Sengupta, Kulkarni]

Lepton identification in ATLAS analyses

[Chalons]

- Original implementation of ATLAS-SUS-2013-05: large differences with ATLAS results
  - Discussions with ATLAS people
  - Update of the lepton efficiencies (from ATLAS-CONF-2014-032)
  - Update of the b-tagging identification and misidentification rates (see next slides too)





$$\varepsilon_e^{\text{med.}} = \begin{cases} p_T < 90 : 1.66.10^{-11} p_T^6 - 5.71.10^{-9} p_T^5 + 8.09.10^{-7} p_T^4 - 5.88.10^{-5} p_T^3 \\ \qquad + 2.2.10^{-3} p_T^2 - 3.46.10^{-2} p_T + 0.96 \\ p_T > 90 : 0.95 \end{cases}$$

$$\varepsilon_e^{\text{med.}} / \varepsilon_e^{\text{tight}} = \begin{cases} p_T < 90 : 2.34.10^{-7} p_T^3 - 4.09.10^{-5} p_T^2 + 3.15.10^{-3} p_T + 0.81 \\ p_T > 90 : 0.93 \end{cases}$$

$$\varepsilon_\mu = \begin{cases} |\eta| \leq 0.1 \ \& \ p_T > 6 : 0.65 \\ 0.1 < |\eta| \leq 2.5 \ \& \ p_T > 6 : 0.99 \\ |\eta| > 2.5 : 0 \end{cases}$$

Description of ATLAS-SUS-2013-05 (I)

[Chalons]

Description	Signal Regions	
	SRA	SRB
Event cleaning	Common to all SR	
Lepton veto	No e/μ after overlap removal with $p_{\rm T} > 7(6)$ GeV for $e(\mu)$	
$E_{\rm T}^{\rm miss}$	> 150 GeV	> 250 GeV
Leading jet $p_{\rm T}(j_1)$	> 130 GeV	> 150 GeV
Second jet $p_{\rm T}(j_2)$	> 50 GeV,	> 30 GeV
Third jet $p_{\rm T}(j_3)$	veto if > 50 GeV	> 30 GeV
$\Delta\phi(\boldsymbol{p}_{\rm T}^{\rm miss}, j_1)$	-	> 2.5
b-tagging	leading 2 jets ($p_{\rm T} > 50$ GeV, $\lvert\eta\rvert < 2.5$)	2nd- and 3rd-leading jets ($p_{\rm T} > 30$ GeV, $\lvert\eta\rvert < 2.5$)
	$n_{b\text{-jets}} = 2$	
$\Delta\phi_{\rm min}$	> 0.4	> 0.4
$E_{\rm T}^{\rm miss}/m_{\rm eff}(k)$	$E_{\rm T}^{\rm miss}/m_{\rm eff}(2) > 0.25$	$E_{\rm T}^{\rm miss}/m_{\rm eff}(3) > 0.25$
$m_{\rm CT}$	$> 150, 200, 250, 300, 350$ GeV	-
$H_{\rm T,3}$	-	< 50 GeV
m_{bb}	> 200 GeV	-

Table 1. Summary of the event selection in each signal region.

$$\Delta\phi_{min} = \min(|\phi_1 - \phi_{\not p_T}|, |\phi_2 - \phi_{\not p_T}|, |\phi_3 - \phi_{\not p_T}|)$$

$$m_{eff}(k) = \sum_{i=1}^{k} (p_T^{jets})_i + \not E_T$$

$$H_{T,3} = \sum_{i=4}^{n} (p_T^{jets})_i$$

Description of ATLAS-SUS-2013-05 (2)

[Chalons]

- No LHE input files were provided by the ATLAS collab.
- Simulate the signal sample through MadGraph5_v1.4.8+PYTHIA6 then passed to DELPHESMA5TUNE using generic official SLHA files provided by the ATLAS SUSY conveners

- For SRA four benchmark point are given for validation
  - Two for the cutflows
    - $(m_{\tilde{b}_1}, m_{\tilde{\chi}_1^0}) = (500, 1)$ GeV
    - $(m_{\tilde{t}_1}, m_{\tilde{\chi}_1^\pm}, m_{\tilde{\chi}_1^0}) = (500, 120, 100)$ GeV
  - Two for the distributions
    - $(m_{\tilde{b}_1}, m_{\tilde{\chi}_1^0}) = (500, 1)$ GeV
    - $(m_{\tilde{t}_1}, m_{\tilde{\chi}_1^\pm}, m_{\tilde{\chi}_1^0}) = (500, 105, 100)$ GeV

- For SRB four benchmark point are given for validation
  - Two for the cutflows
    - $(m_{\tilde{b}_1}, m_{\tilde{\chi}_1^0}) = (350, 320)$ GeV
    - $(m_{\tilde{t}_1}, m_{\tilde{\chi}_1^\pm}, m_{\tilde{\chi}_1^0}) = (500, 420, 400)$ GeV
  - Two for the distributions
    - $(m_{\tilde{b}_1}, m_{\tilde{\chi}_1^0}) = (300, 200)$ GeV
    - $(m_{\tilde{t}_1}, m_{\tilde{\chi}_1^\pm}, m_{\tilde{\chi}_1^0}) = (250, 155, 150)$ GeV

Some results for ATLAS-SUS-2013-05

[Chalons]

✦Exemplary cut-flow tables

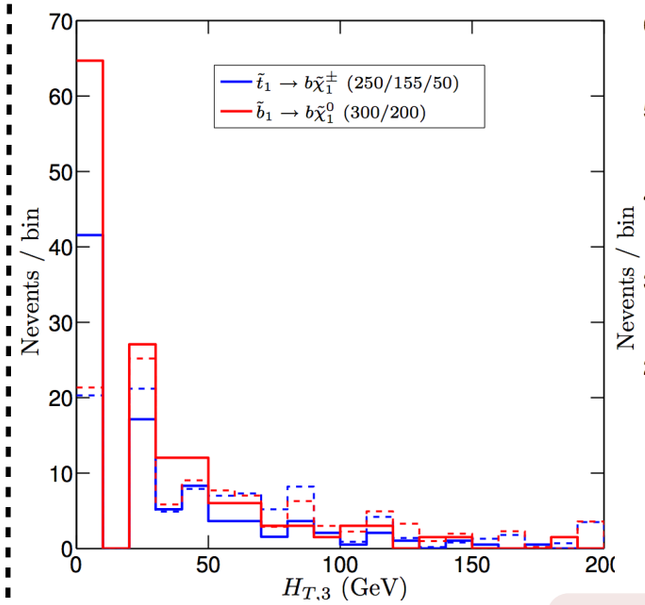
cut	$m_{\tilde{b}_1} = 500$ GeV ATLAS	MA 5	rel.	$m_{\tilde{t}_1} = 500$ GeV ATLAS	MA5	rel.
$E_T^{\rm miss} > 80$ GeV filter	1606.0	1628.2	+1.38%	1632.0	1585.2	−2.87%
+ Lepton veto	1505.0	1223.5	−18.7%	1061.0	863.2	−18.6%
+ $E_T^{\rm miss} > 150$ GeV	1323.0	1052.2	−20.5%	859.0	696.3	−18.9%
+ Jet Selection	119.0	142.3	+19.6%	39.0	47.6	+22.0%
+ $M_{bb} > 200$ GeV	96.0	116.5	+21.4%	32.0	38.8	+21.5%
+ $M_{CT} > 150$ GeV	82.0	97.5	+18.9%	26.8	31.7	+18.3%
+ $M_{CT} > 200$ GeV	67.0	80.7	+20.4%	20.2	24.5	+21.3%
+ $M_{CT} > 250$ GeV	51.0	60.8	+19.0%	13.2	16.6	+25.8%
+ $M_{CT} > 300$ GeV	35.0	42.3	+20.9%	7.7	9.2	+19.5%

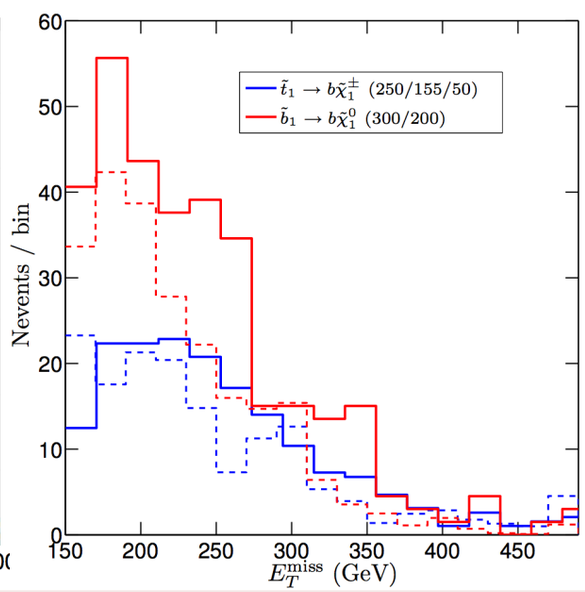
cut	$m_{\tilde{b}_1} = 350$ GeV ATLAS	MA 5	rel.	$m_{\tilde{t}_1} = 500$ GeV ATLAS	MA5	rel.
$E_T^{\rm miss} > 80$ GeV filter	6221.0	5963.7	−4.13%	1329.0	1117.9	−15.9%
+ Lepton veto	4069.0	4450.4	+9.37%	669.0	702.9	+5.07%
+ $E_T^{\rm miss} > 250$ GeV	757.0	724.5	−4.29%	93.0	86.8	−6.67%
+ Jet Selection	7.9	7.5	−5.06%	6.2	5.7	−8.06%
+ $H_{T,3} < 50$ GeV	5.2	6.6	+26.9%	3.0	4.6	+53.3%

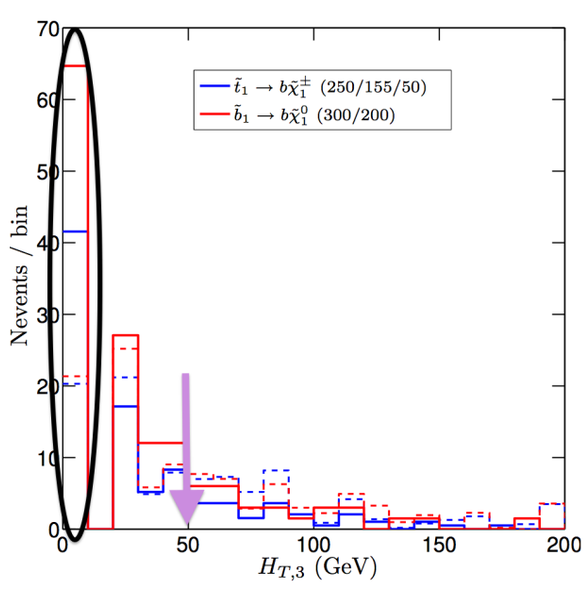
Lepton veto issues:

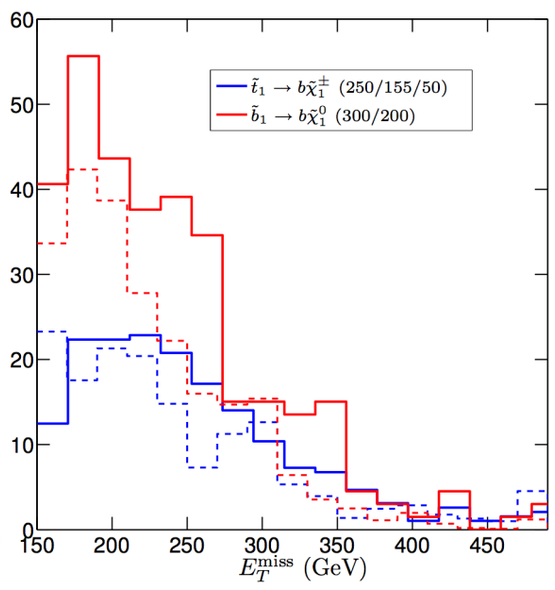
★ Might be related to lepton isolation (see next slides too)

✦Exemplary figures









Not enough jet activity for SRB

★ Might be related to JES (see next slides)

Limit settings for ATLAS-SUS-2013-05

[Chalons]

benchmark	σ_{95} MA5	σ_{95} ATLAS	bestSR MA5	bestSR ATLAS
b300_n200	0.75 pb	1.17 pb	SRB	SRB
b350_n320	3.31 pb	4.24 pb	SRB	SRB
b500_n1	0.0166 pb	0.0298 pb	SRA MCT_{300}	SRA MCT_{300}
t250_c155_n150	1.30 pb	3.65 pb	SRB	SRB
t500_c105_n100	0.0253 pb	0.0284 pb	SRA MCT_{300}	SRA MCT_{200}
t500_c120_n100	0.0503 pb	0.117 pb	SRA MCT_{250}	SRA MCT_{300}
t500_c420_n400	0.51 pb	2.56 pb	SRB	SRB

benchmark	(1-CLs)% MA5	(1-CLs)% ATLAS
b300_n200	100.0%	99.8%
b350_n320	35.9%	32.5%
b500_n1	100.0%	99.7%
t250_c155_n150	100.0%	99.1%
t500_c105_n100	100.0%	98.8%
t500_c120_n100	99.8%	90.2%
t500_c420_n400	24.8%	14.9%

Overall our recasted analysis is more constraining than the ATLAS one.

B-tagging in ATLAS analyses: ATLAS-SUS-2103-19

[Chalons]

✦ Improved description of the b-taggging with the implementation of ATLAS-SUS-2013-19

- ✤ Update of the b-tagging efficiency from ATLAS-CONF-2014-004
- ✤ Foreseen update with the b-jet misidentification rates from ATLAS-CONF-2014-046

✦ Description of ATLAS-SUS-2013-19

<table>
<tr><td colspan="5">Two OS 10 GeV preselected leptons</td></tr>
<tr><td colspan="5">lepton isolation</td></tr>
<tr><td colspan="5">$m_{\ell\ell} > 20$ GeV</td></tr>
<tr><td colspan="5">p_T leading lepton > 25 GeV</td></tr>
<tr><td colspan="4">Leptonic M_{T2}</td><td>Hadronic M_{T2}</td></tr>
<tr><td colspan="4">Z veto
$\Delta\phi > 1$
$\Delta\phi_b < 1.5$</td><td># b-jets $= 2$
$M_{T2}^{\mathrm{b-jet}} > 160$
$M_{T2} < 90$
$1^{st}\ell$ $p_T < 60$</td></tr>
<tr><td>$M_{T2} > 90$</td><td>$M_{T2} > 100$</td><td>$M_{T2} > 110$</td><td>$M_{T2} > 120$</td><td></td></tr>
<tr><td>-</td><td>1^{st} jet $p_T > 100$</td><td>1^{st} jet $p_T > 20$</td><td>-</td><td>-</td></tr>
<tr><td>-</td><td>2^{nd} jet $p_T > 50$</td><td>2^{nd} jet $p_T > 20$</td><td>-</td><td>-</td></tr>
</table>

✦Exemplary cut-flow table

cut	# events (scaled to 100000.0)	rel.	# events (official)
Initial number of events	100000.0	100000.0	
Two 10 GeV SF preselected ℓ	2893.0	−97.1%	2212.9
lepton isolation	657.3	−77.3%	1646.1
opposite sign leptons	657.3	−0.0%	1594.0
$m_{ll} > 20$ GeV	607.5	−7.6%	1506.0
Trigger lepton p_T requirement	507.5	−16.5%	1319.0
2 b-jets	209.3	−58.8%	529.9
$m_{T2}^{\mathrm{b-jet}} > 160$ GeV	28.1	−86.6%	42.3
$m_{T2} < 90$ GeV	28.1	−0.0%	42.3
leading lepton $p_T < 60$ GeV	22.3	−20.6%	29.9

Lepton isolation issues

Jet energy scale in the ATLAS card

✦ Original implementation of ATLAS-SUS-2013-04: large differences with ATLAS

✤ Discussions with ATLAS people

✤ Design of JES correction functions based on the Monte Carlo truth and DELPHES-MA5TUNE

$$\begin{cases} p_T > 100.0 : 1.00/(1.00 - 0.015874205774624516 - 1.5596526607501018 * \ln(p_T)/p_T) \\ p_T \leq 100.0 : 1.00/(1.00 - 0.28148029547368\text{:}\ \ 0.019155389997112204 * \ln(95.6961580995732 * p_T)) \end{cases}$$

✦ Exemplary cut-flow table [ATLAS-SUS-2013-14: Blanke, Fuks, Galon]

Cut	# events MADANALYSIS 5	# events (official)
Initial number of events	206.3	206.3
6 jets with $E_T > 45$ GeV	150.3	168
lepton veto	89.4	78
8 jets ($p_T > 50$ GeV)	15.0	16.3
$E_T/\sqrt{H_T} > 4$ GeV$^{1/2}$	12.4	14.1
→ without b-tags	0.51	0.85
→ with 1 b-tag	2.1	3
→ with 2 b-tags	9.7	11
7 jets ($p_T > 80$ GeV)	7.44	7.53
$E_T/\sqrt{H_T} > 4$ GeV$^{1/2}$	6.08	6.25
→ without b-tags	0.14	0.31
→ with 1 b-tag	1.0	1.3
→ with 2 b-tags	4.9	5.1
≥ 8 jets ($p_T > 80$ GeV)	2.6	3.2
$E_T/\sqrt{H_T} > 4$ GeV$^{1/2}$	2.0	2.6
→ without b-tags	0.02	0.13
→ with 1 b-tag	0.23	0.55
→ with 2 b-tags	1.7	2.1

Good agreement for many signal regions

✦ Not working for some ATLAS analyses; improvements for some other

✤ Further studies are on-going, based on well-controlled Monte Carlo samples

Lepton isolation and overlap removal in ATLAS analyses

Most of the analyses dealing with leptons have problems

cut	our nev	exp events
Initial number of events	55.0	55.0
4 leptons	28.1	36.7
0 tau	25.6	21.4
trigger	25.6	21.3
Z-veto SFOS	15.9	11.6
etmiss $>$ 50	13.4	10.0

[ATLAS-SUS-2013-13: Mawatari]

cut	our nev	exp events
Initial number of events	28033.7	28033.7
triggers	15759.1	-
dR(leptons) $>$ 0.3	15742.3	-
3 signal leptons	1823.6	-
1 electron or muon	1823.6	-
no taus	583.1	-
0 sfos	176.6	19.0
b jet veto	175.2	18.0
etmiss $>$ 50	91.1	12.0
3rd lepton pt $>$ 20	32.2	7.0
min dphi(llp) $<=$ 1.0	15.4	5.0

[ATLAS-SUS-2013-12: de Causmaecker, Fuks, Mawatari]

cut	# events (scaled to 80000.0)	# events (official)
Initial number of events	80000.0	
Two 10 GeV SF preselected ℓ	1881.2	3811.0
lepton isolation	1031.8	3197.0
opposite sign leptons	1031.8	3167.0
$m_{ll} > 20$ GeV	1013.9	3144.0
Trigger lepton p_T requirement	1005.0	3253.5
Z veto	777.3	2463.6
$\Delta\phi > 1$	654.5	1834.9
$\Delta\phi_b < 1.5$	479.8	1402.8
$m_{T2} > 90$ GeV	155.1	396.5

[ATLAS-SUS-2013-19: Chalons]

Lepton identification is a problem

- On-going discussions with ATLAS people
- Status: object overlap removal might be the issue

Hadronic taus

Some of our recasted analyses employ hadronically-decaying tau

cut	our nev	exp events
Initial number of events	4384.8	4384.8
triggers	1187.8	-
dR(leptons) $>$ 0.3	1186.7	-
3 signal leptons	114.4	-
1 electron or muon	114.4	-
two taus	32.2	48.0
b jet veto	31.8	46.0
etmiss $>$ 50	23.7	35.0
mt2 max $>$ 100	7.7	14.0

[ATLAS-SUS-2013-12: de Causmaecker, Fuks, Mawatari]

cut	sim events	exp events
Initial number of events	30000.0	29500.0
at least two leptons	4630.0	1499.1
at least two taus and e/mu veto	806.0	352.5
ditau trigger	576.0	175.6
exactly 2 os taus, jet/z-veto	34.0	22.4
mt2 $>$ 30 gev	14.0	16.1
mttau1 + mttau2 $>$ 250 gev	8.0	8.5

[ATLAS-SUS-2013-14: de Causmaecker, Fuks]

Electron and muon isolation might be the problem

- Further investigations are necessary
- Status: object overlap removal might be the issue

Outline

1. The MA5-tune of DELPHES 3

2. Selected items on the implementation and the validation of LHC analyses

3. Summary

Summary

✦ The MA5-tune of MADANALYSIS 5

- ✤ New lepton and photon isolation module
- ✤ Cleaning of the output file
- ✤ Future novel b-tagging startegy
- ✤ Developments in the pipeline: lepton charge misidentification, c and tau tagging, displaced vertices

✦ Applications to several ATLAS and CMS analyses

- ✤ Good agreement for CMS analyses
  - ★ Current problems with SUS-13-013 under investigation
- ✤ Lots of troubles with ATLAS analyses
  - ★ JES issues under investigation
  - ★ Lepton identification and object overlap removal issues under investigation
  - ★ Maybe tau issues under investigation