A Measurement of $\mathcal{R} = \sigma(\mu\mu + b)/\sigma(\mu\mu + \text{jets})$ with 2010 ATLAS data

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Introduction

The Quark Parton Model

total cross-section of hard scattering by two hadrons P_1, P_2

$$\sigma(P_1,P_2) = \sum_{i,j}^{N_q} \int dx_1 dx_2 f_i(x_1,\mu^2) f_j(x_2,\mu^2) \hat{\sigma}_{ij}(p_1,p_2,\alpha_s(\mu^2),Q^2/\mu^2)$$

- P_i ... momentum of incoming hadron i
- x_i ... momentum fraction of parton i extracted from hadron i
- N_q ... number of quark flavors to be considered
- μ^2... factorisation scale
- $\hat{\sigma}_{ij}$ .. total cross-section of parton-parton interaction
- p_i ... momentum of initial state parton i
- $\alpha_s(\mu^2)$ ... strong coupling constant
- Q^2 ... energy scale of the interaction (momentum transfer during hard scattering)

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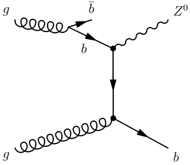
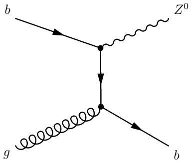
Fixed Flavor Number Scheme (FNS)

- N_q is fixed (e.g. $N_q = 4$)
- for $i < N_q$: $m_Q = 0$
- for $i = N_q$: $m_Q > 0$
- for $i > N_q$: flavor generated only through gluon splitting



Variable Flavor Number Scheme (VNS)

- N_q varies depending on $Q^2 \sim m_q$
- series of Fixed Flavor Number Scheme
- **requires heavy flavor PDF in the proton**



Heavy Quarks in Initial and Final states

Theoretical Observations

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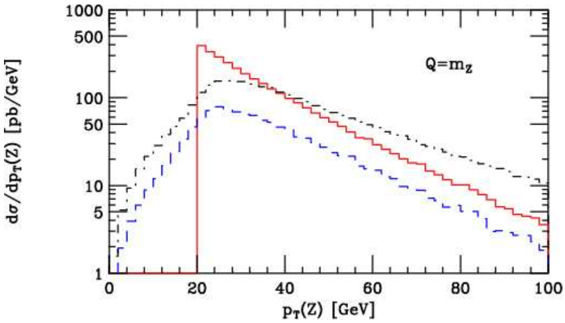

Figure 1: p_{t,Z^0} distribution in $Z + b$ final states at NLO, calculated in the VFS and FFS, from [5]. The **black dashed** curve shows the contribution of $q\bar{q} \to Z^0 b\bar{b}$.

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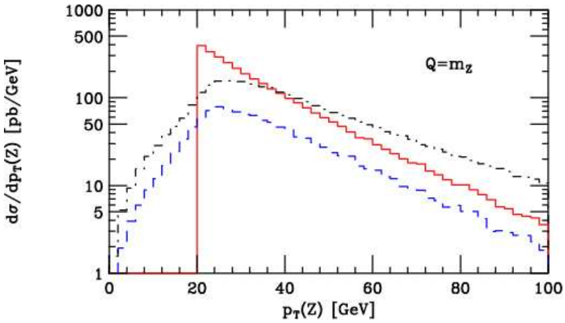

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- **measure bPDF** at LHC to validate these schemes
- impact on **Higgs predictions** at LHC

Getting ready to find the Higgs

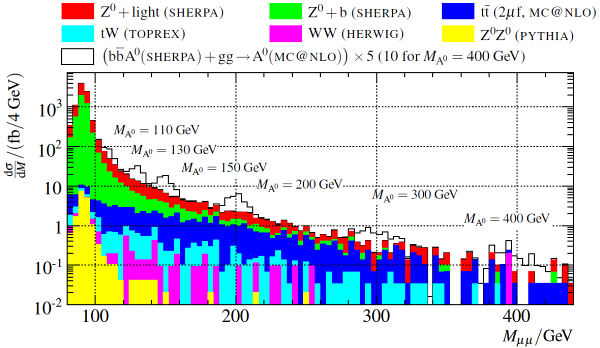

Figure 2: Invariant muon-muon mass distribution of b-associated MSSM neutral Higgs boson events including background in proton-proton collisions at $\sqrt{s} = 14\,\mathrm{TeV}$ from [6].

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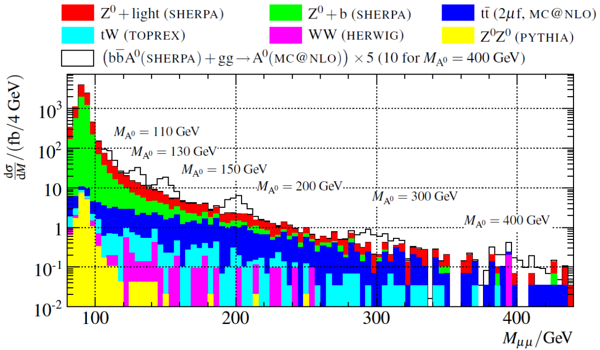

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- $Z^0 + b$ is irreducible background to neutral MSSM Higgs bosons produced in association with b quarks
- worthwhile to measure this background with high precision before looking for the Higgs

Published Measurments

results

$$\mathcal{R} = \frac{\sigma(\mu\mu+b)}{\sigma(\mu\mu+\text{jets})}$$

D0[3]	$0.023 \pm 0.004(\text{stat})^{+0.002}_{0.003}(\text{syst})$
CDF[4]	$0.0236 \pm 0.0074(\text{stat}) \pm 0.0053(\text{sys})$

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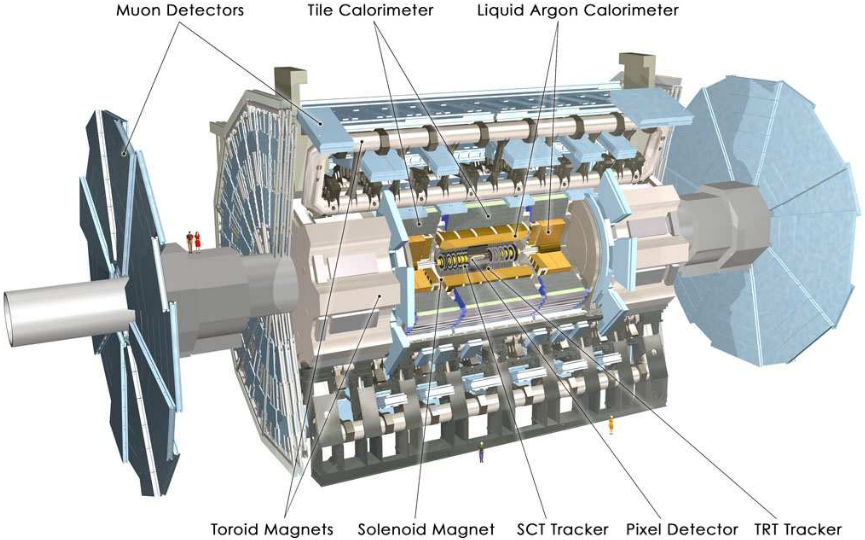
observed events

	$N(Z+b)$	$\mathcal{L}_{int}/1\,\mathrm{pb}^-1$
$D0[3]$	$27(ee)+22(\mu\mu)$	180
$CDF[4]$	45 ± 14[a]	330

[a] after background and mistag subtraction

Experiment

ATLAS


Muon Detectors
Tile Calorimeter
Liquid Argon Calorimeter
Toroid Magnets
Solenoid Magnet
SCT Tracker
Pixel Detector
TRT Tracker

Heavy Flavor Tagging

From theory we learn, [5]

On the experimental side, ... the [Z + b] final state is relatively easy to identify.

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Heavy Flavor Tagging

- tagging algorithms provide a weight w_{tag} (which is not necessarily a probability)
- tagging algorithms can be complicated, I opted for the simple ones to start with
- data-driven estimation of (mis-)tagging efficiencies is non-trivial
- it's tagging, not identification!

SV0 as an Example for Secondary Vertex Taggers

The Algorithm

1. use high quality tracks associated to calorimeter jet
2. discard displaced vertices attributed to V^0 decays
3. discard displaced vertices attributed to material interactions
4. with $L = |\vec{x}_{pv} - \vec{x}_{sv}|$, use $S_L = sign(L)\frac{L}{\sigma(L)}$ as discriminating variable

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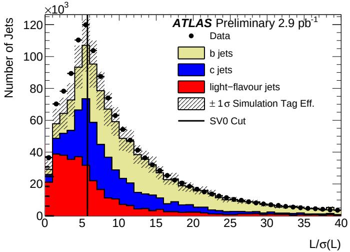
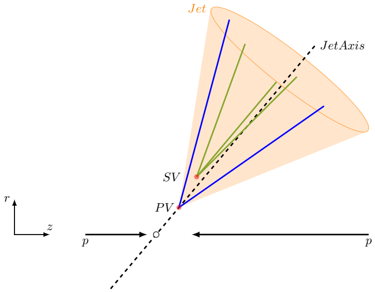


Figure 3: The signed decay length significance for the SV0 *b*-tagging algorithm in 2010 data, [1].

definition of longitudinal impact parameter



TrackCounting2D as an example of Impact Parameter Based Taggers

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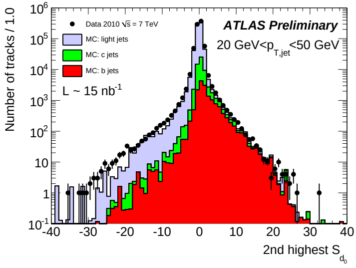
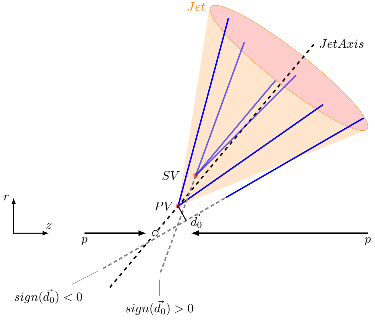


Figure 4: Distribution of the second highest impact parameter significance S_{d0} for data (black points) and Monte Carlo (plain histograms) from [2].

definition of transverse impact parameter



Analysis

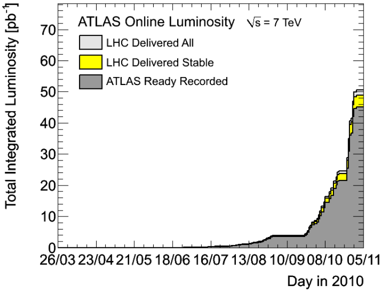
Goal of Our Measurement

Want to measure ...

$$\mathcal{R} = \frac{\sigma(\mu\mu + b + (N_{\text{jets}} - 1))}{\sigma(\mu\mu + N_{\text{jets}})}\Big|_{m_{\mu\mu} \approx m_{Z^0}} \text{ vs. } N_{\text{jets}}$$

- ratio measurement cancels systematic uncertainties
  - need to check correlations to prove which do and which don't cancel
- luminosity uncertainty cancels as well

Event Selection



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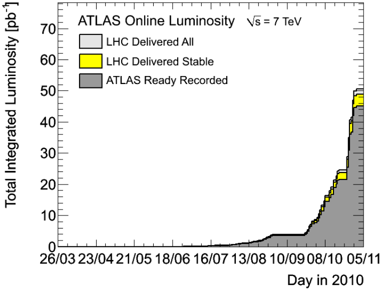

trigger	**data periods**	$\mathcal{L}_{int}/1\,\mathrm{pb}^{-1}$
L1_MU10	A-E3	0.698
EF_mu10_MG	E4-G1	3.024
EF_mu13_MG[a]	G2- I1	15.829
EF_mu13_MG_tight	I1 - I2	15.572

[a] used in MC as well

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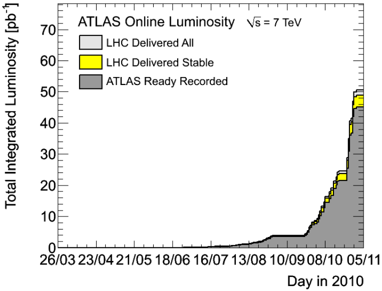

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Runs chosen

runs E4-I2
(160899 − 167844)
$\mathcal{L}_{int} = 34.426\,\mathrm{pb}^{-1}$

Muon Candidate Cuts

reconstructed muon candidate cuts

- $p_{t,\mu} > 20\,\mathrm{GeV}$
- $|\eta_\mu| < 2.5$
- $(\Sigma p_{t,Cone|\Delta R(\mu,track)<0.2})/p_{t,\mu} < .1$
- all simulated muons have been smeared to data-driven performance estimates

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muon pairs

- opposite charge required for both muon candidates
- $|m_{\mu,\mu} - 91.2\,\mathrm{GeV}| < 25\,\mathrm{GeV}$
- select Z^0 with highest $\Sigma_i p_{t,\mu i}$

(For more Information see backup slide on Detailed Cut List.)

Jet Cuts

- algorithm: Anti-Kt with $D = 0.4$
- input: globally calibrated topo clusters (H1 style)
- rescaled to electro-magnetic energy scale

(For more Information see backup slide on SV0 rescaling.)

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- jet quality criteria

- used TrackCounting2D tagger: $w_{TC2D} > 2.6$ ($\epsilon_b|_{t\bar{t}} = 0.45$)
- used SV0 tagger: $w_{SV0} > 5.72$ ($\epsilon_b|_{t\bar{t}} = 0.498$, MC-Data rescaling applied)

(For more Information see backup slide on SV0 rescaling.)

Invariant Mass without b-tagging requirement

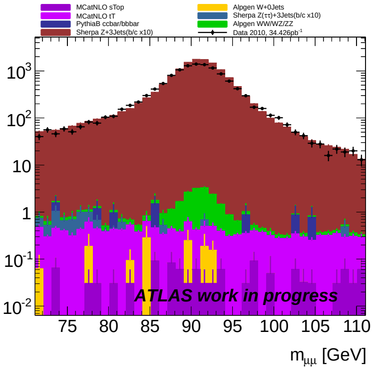


Figure 5: Invariant Muon-Muon mass

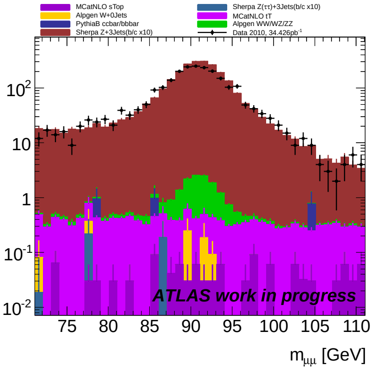


Figure 6: Invariant Muon-Muon mass **requiring at least 1 reconstructed jet**

Invariant Mass requiring at least one b-tagged jet per event

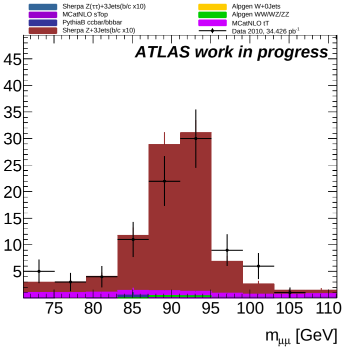


Figure 7: Invariant Muon-Muon mass requiring **at least 1 b-tagged jet by TrackCounting2D**

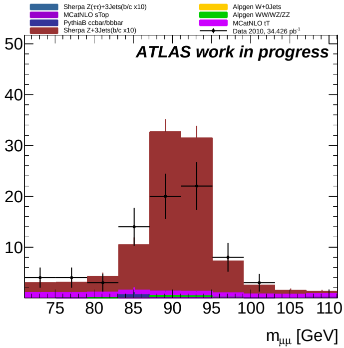


Figure 8: Invariant Muon-Muon mass requiring **at least 1 b-tagged jet by SV0 with MC-Data scaling applied**.

total MC	(89.8 ± 9.5)
total Data	(91.0 ± 9.5)

total MC	(92.9 ± 9.6)
total Data	(78.0 ± 8.8)

b-tagged Jet Multiplicity

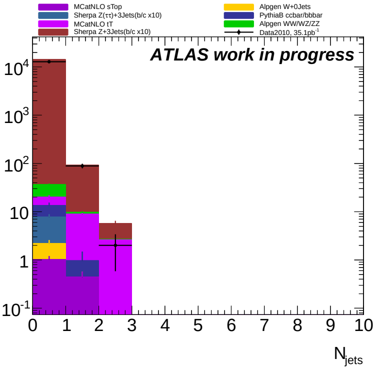


Figure 9: number of **TrackCounting2D b-tagged jets** requiring a Z^0 candidate in the event

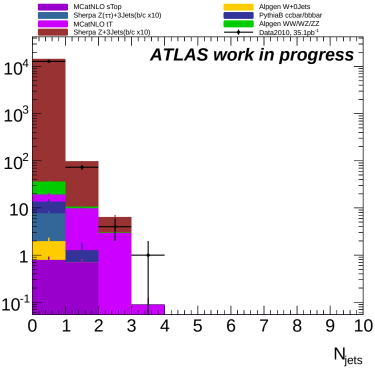


Figure 10: number of **SV0 b-tagged jets** requiring a Z^0 candidate in the event with MC-Data scaling applied.

Current Status

Physical Background (not shown today)

- migrating to new data taking software release
- studies on QCD background contributions ongoing
- studies on $t\bar{t}$ background contributions ongoing

Non-Physical Background

- evaluate methods to correct for b-tagging inefficiencies
- choose an advanced tagger

Summary

- A measurement of $Z + b$ is worthwhile to cross-check SM predictions as well as enable Higgs discoveries
- the measurement depends crucially on b-tagging
- $Z + b$ final states have been reconstructed in $\mu\mu$ channel with 2 competing simple taggers in 2010 ATLAS data
- the event yields promise a competing analysis with publications by CDF and D0

BACKUP

Detailed Muon Cuts

- `MuID` algorithm used for reasons of robustness from rel15 to rel16
- $p_{t,\mu} > 20\,\mathrm{GeV}$
- $|\eta_\mu| < 2.5$
- author $= 12|13$ (for staco: author $= 6|5$)
- `IsCombined`[1]
- `Combined+MuGirl` (to resolve inefficiencies)
- $N_{PIX} > 0 \cap N_{SCT} > 6 \cap f_{TRT}^{outliers} < 0.9$
- $|z_0(trk, PV)| < 10\,\mathrm{mm} \cap |d_0(trk, PV)| < 0.1\,\mathrm{mm}$
- $(\Sigma p_{t,Cone|\Delta R(\mu,track)<0.2})/p_{t,\mu} < 0.1$
- for staco: $\chi^2 < 150$, $\frac{p_{MS}-p_{ID}}{p_{ID}} > -0.4$
- all MC muons have been rescaled according to MCP recommendations

[1] contradicting cut to author $= 12|13$ (was part of skimming) – will be dropped

Scaling MC to Data

method used in $t\bar{t}$ observation

ATL-COM-PHYS-2010-331

for selected and tagged jets

$$w = \text{ScaleFactor}^{MC-Data}_{flavour}(p_t, \eta)$$

for selected and un-tagged jets

$$w = \frac{1-\text{ScaleFactor}^{MC-Data}_{flavour}(p_t,\eta)\cdot\epsilon_{flavour}(p_t,\eta)}{1-\epsilon_{flavour}(p_t,\eta)}$$

event weight

a product of jet weights $W = \prod_{\text{all jets}} w_i$

SV0 Performance from Dijet data

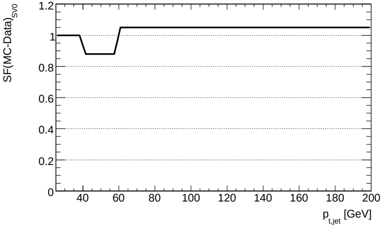


Figure 11: scale factors for MC-Data reweighting from Dijet Data.

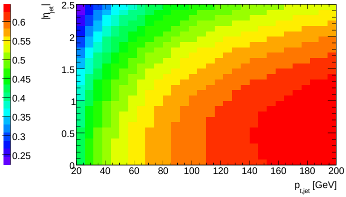


Figure 12: Bottom flavor tagging efficiency from Dijet Data.

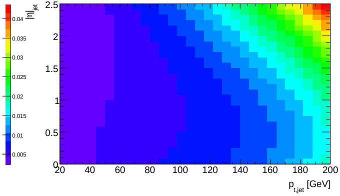


Figure 13: Light flavor (mis-)tagging efficiency from Dijet Data.

Alpgen $Z^0 + jets$ final states

Alpgen MC datasets

- Alpgen samples 10766[0 − 5] have only $Z^0 + N[g, u, d, s, c]$jets final states
- the only source of b quarks is the parton shower (Fig. 14,15)
- there are Alpgen samples with filtered $Z^0 + g$ final states (Fig. 16), but they are difficult to merge with standard ones mentioned above

Figure 14: Alpgen ZmumuNpX initial state $b\bar{b}$ generation

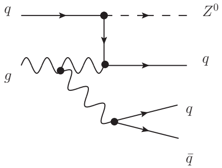


Figure 15: Alpgen ZmumuNpX final state $b\bar{b}$ generation

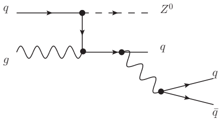
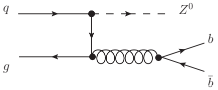


Figure 16: Alpgen Zmumubb samples



Data Samples

background

- 10769[0-5].AlpgenJimmyWmunu
- 105200.T1_McAtNlo_Jimmy
- 10710[0-3].AlpgenJimmyWWlnulnuNp[0-3]
- 1071[08-11].AlpgenJimmyZZincllNp[0-3]
- 10710[4-7].AlpgenJimmyWZincllNp[0-3]
- 109276.J0_pythia_jetjet_1muon
- 109277.J1_pythia_jetjet_1muon
- 109278.J2_pythia_jetjet_1muon
- 109279.J3_pythia_jetjet_1muon
- 109280.J4_pythia_jetjet_1muon
- 109281.J5_pythia_jetjet_1muon
- 108405.PythiaB_bbmu15X
- 106059.PythiaB_ccmu15X
- 108341.st_tchan_munu_McAtNlo_Jimmy.merge
- 108344.st_schan_munu_McAtNlo_Jimmy.merge
- 108346.st_Wt_McAtNlo_Jimmy

signal

- mc09*Alpgen*Z* samples not feasible (see backup slide)
- mc09_7TeV.109526.SherpaZ3jetstomumu

[1] Calibrating the *b*-tag and mistag efficiencies of the sv0 *b*-tagging algorithm in 3 pb^{-1} of data with the atlas detector.
Technical Report ATLAS-CONF-2010-099, CERN, Geneva, Dec 2010.

[2] Performance of impact parameter-based b-tagging algorithms with the atlas detector using proton-proton collisions at $\sqrt{s} = 7$ tev.
Technical Report ATLAS-CONF-2010-091, CERN, Geneva, Oct 2010.

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A Measurement of the ratio of inclusive cross sections sigma (p anti-p -¿ Z + b-jet) / sigma (p anti-p -¿ Z + jet) at s**(1/2) = 1.96-TeV.
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Measurement of the b jet cross-section in events with a Z boson in p anti-p collisions at s**(1/2) = 1.96-TeV.
Phys.Rev., D74:032008, 2006.

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Overview of the theory of W/Z + jets and heavy flavor.
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[6] Markus Warsinsky, M Kobel, M Schumacher, and F Krauss.
Studies of b-associated production and muonic decays of neutral Higgs bosons at the ATLAS experiment within the Minimal Supersymmetric Standard Model. oai:cds.cern.ch:1312682.
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