MSSM $bb(H \rightarrow bb)$ semileptonic

Physics Approval

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ICHEP Approvals Marathon,
CERN, 25 June 2012

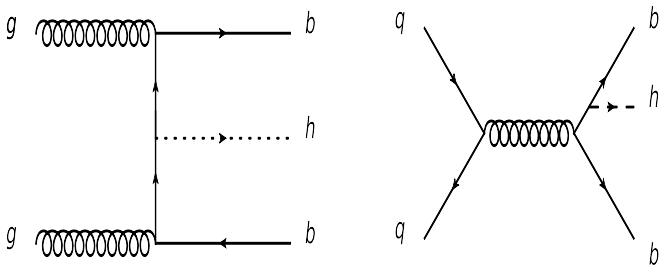
Outline

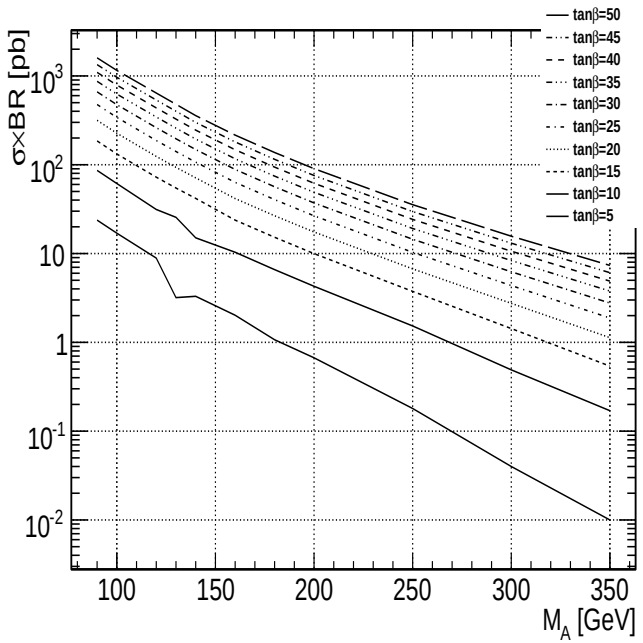
Analysis management

- New analysis, first time approval
- **ARC**
  - Amit Lath (chair)
  - Jacobo Konigsberg
  - Lars Sonnenschein
  - Maksym Titov
- Twiki CMS/HiggsBBbb
  - Q&A
- AN AN-11-428
- PAS HIG-12-027
- HN HIG-12-027

Intro: motivations

- Search for Neutral SUSY Higgs, $H \to b\bar{b}$;
- Large $BR(H \to b\bar{b}) \approx 90\%$
- huge multijet QCD background:
  - Use associate production to reject hadronic background
  - $pp \to b\bar{b}H \to b\bar{b}b\bar{b}$
  - Large σ for large $\tan\beta$
  - $A/H/h$ degeneration increases σ
  - *e.g.* $\sigma_{M=120} \times BR \approx 250\ pb$ for $\tan\beta = 30$
- Compete with $H \to \tau\tau$ channel:
  - larger yield,
  - larger background (QCD),
  - different channel.





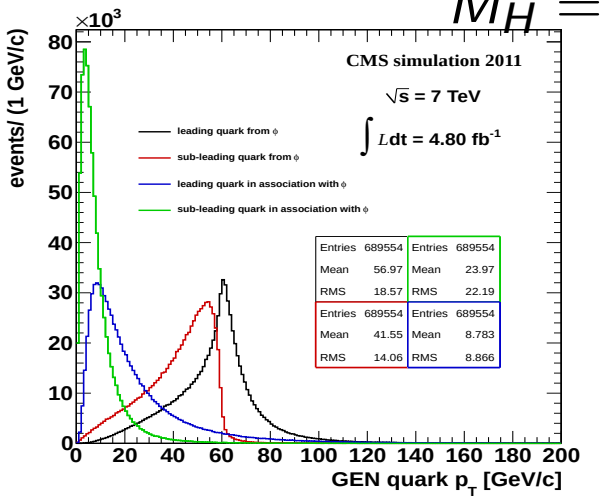
Analysis Strategy

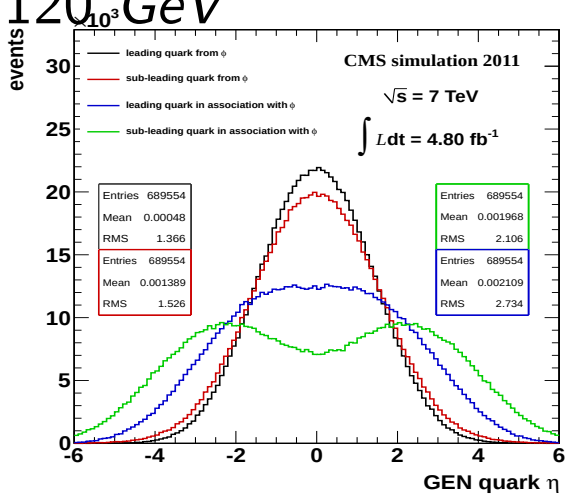
- 4 b final state: $H \rightarrow bb$ plus additional associated b's
- trigger is critical:
  - Use semi-leptonic (muon) b decay for trigger: muon+jets+b-tagging
- Major irreducible background source is multijet QCD
- Data driven background estimate from bbj sample
  - define signal-poor control sample;
  - B-tagging Matrix method:
    - ★ get b/c-fraction of 3rd jet from mass & lifetime fits
    - ★ combine with MC b-tagging efficiency to derive B-tag probability
    - ★ weight bbj events to estimate number of 3-b-tags in signal region
  - Second approach with nearest-neighbour method (hyperball)
    - ★ start from bjj
- Use reconstructed mass of leading jet pair as signal-sensitive variable in final fit
- Use only 2011 data: 4.8 fb^{-1}

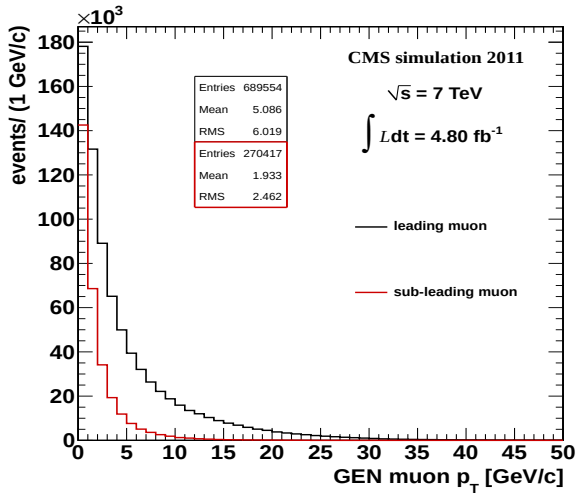
Trigger Strategy

- Use semi-leptonic b decay for trigger: **muon + jets + b-tagging**

$M_H = 120\,GeV$







Use different trigger Path in 2011 to cope with increasing $\mathcal{L}$

HLT paths	runs	triggers	$\int \mathcal{L}dt$ [pb^{-1}]
Mu12_CentralJet30_BtagIP	163738-165633	3 027 717	180.9
Mu12_DiCentralJet30_BtagIP3D	165970-166967	4 532 555	537.1
Mu12_DiCentralJet20_DiBtagIP3D1stTrack	167039-173198	2 244 550	1108.6
Mu12_eta2p1_DiCentralJet20_DiBtagIP3D1stTrack	173236-176469	1 237 147	652.2
Mu12_eta2p1_DiCentralJet20_DiBtagIP3D1stTrack*	176545-180252	5 690 304	2326.8
All		16 732 273	4805.7

Data Used

$H \to bb$ Signal selection samples	
Run2011A	/MuHad/Run2011A-May10ReReco-v1/AOD
Run2011A	/MuHad/Run2011A-PromptReco-v4/AOD
Run2011A	/MuHad/Run2011A-05Aug2011-v1/AOD
Run2011A	/MuHad/Run2011A-PromptReco-v6/AOD
Run2011B	/MuHad/Run2011B-PromptReco-v1/AOD

Trigger efficiency samples	
Run2011A	/SingleMu/Run2011A-May10ReReco-v1/AOD
Run2011A	/SingleMu/Run2011A-PromptReco-v4/AOD
Run2011A	/SingleMu/Run2011A-05Aug2011-v1/AOD
Run2011A	/SingleMu/Run2011A-PromptReco-v6/AOD
Run2011B	/SingleMu/Run2011B-PromptReco-v1/AOD

Table: Summary of data samples used in this analysis

Analysis selection

Selections

Baseline selections:

- Trigger
- Standard event cleaning filters
  - Scraping filter, good primary vertex filter, HBHE noise Filter
- at least 1 global muon $P_T^{\mu} > 15\ GeV$, no isolation required;
- at least 3 jets (PFak5, LooseId) $|\eta| < 2.6$, $P_T > (30, 30, 20)\ GeV$
  - $\Delta R_{ij} > 1$ for any pair $_{ij}$ of jets
  - the μ inside one of the two leading jets;

bjj the first jet must have b-tag $CSV > 0.8$

bbj the second jet must have b-tag $CSV > 0.8$

bbb last selection: third jet b-tag $CSV > 0.7$

- Processed with $\mathrm{CMSSW\_4\_2\_X}$

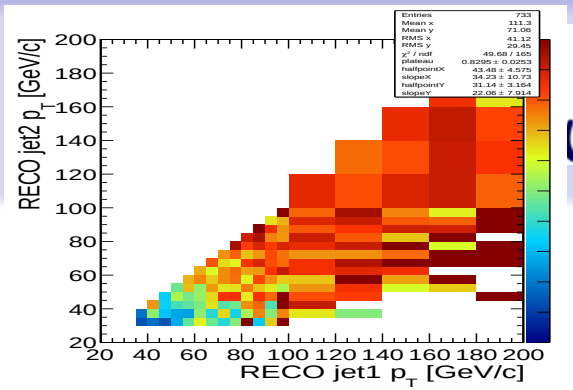
Data reduction

Table: Data reduction after each selection cut.

Cut	Events
All	16732273
$p_{\mathrm{T}}^{\mu} > 15\,\mathrm{GeV}/c$	9739139
$\#jets >= 3$	4511327
$\Delta R_{ij} >= 1$	3505584
$CSV(1^{st} - jet) > 0.8$	1932135
$CSV(2^{nd} - jet) > 0.8$	813685
μ in 1^{st} or 2^{nd} jet	785940
$CSV(3^{rd} - jet) > 0.7$	60195
$\int \mathcal{L} dt\ [\mathrm{pb}^{-1}]$	4805.7

PAS

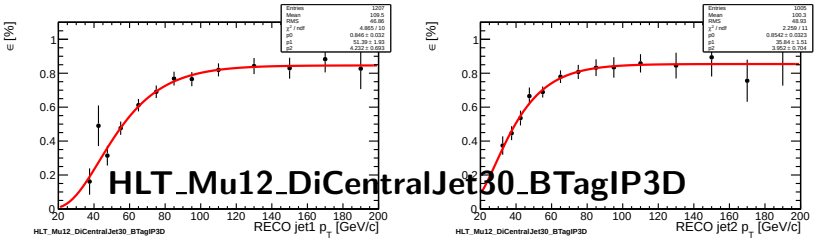
Trigger Efficiency vs Analysis

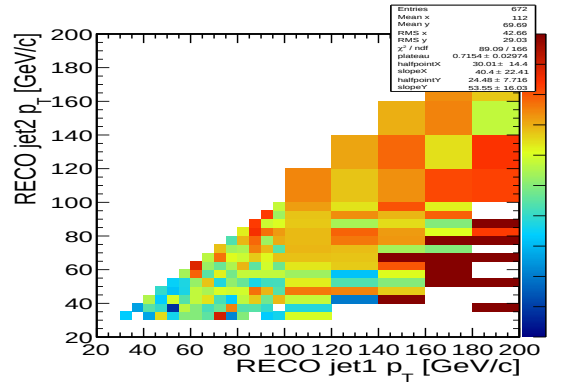


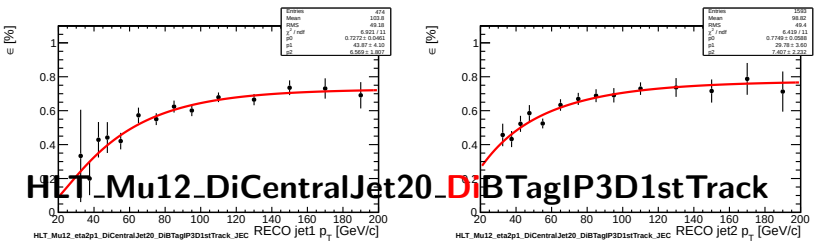
- $\epsilon_{trigger} = \epsilon(\mu) \times \epsilon(hadr)$
- **SingleMu PD**, select all events passing a single muon path.
- Apply selection
- Build Turn on curves vs first and second B-jets Pt:

$$\epsilon = \frac{\text{Hbb path \& sel \& SingleMuHLT}}{\text{sel \& SingleMuHLT}}$$

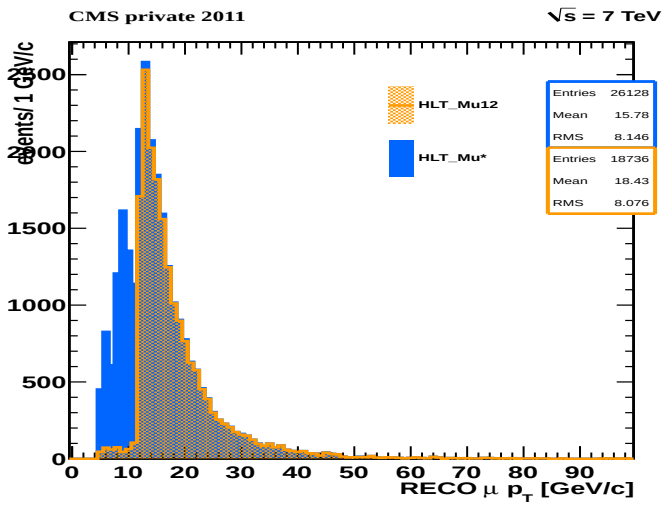
- Turn-on stable wrt SingleMu threshold
- shown for single and double online b-tag paths

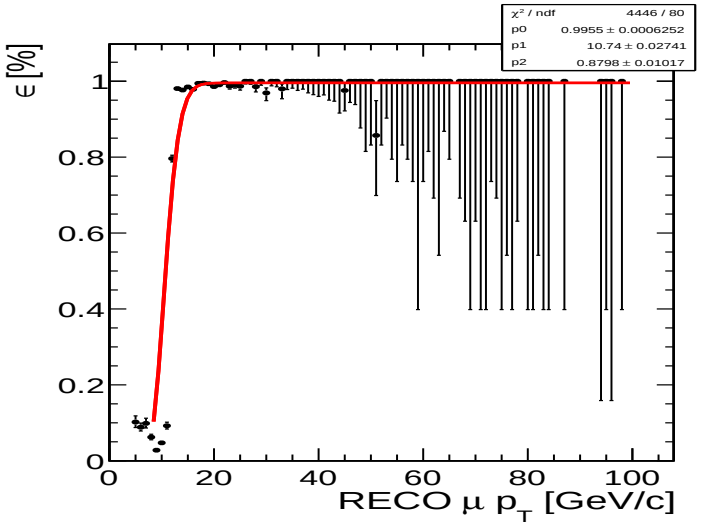






Muon "leg": $\epsilon(\mu)$



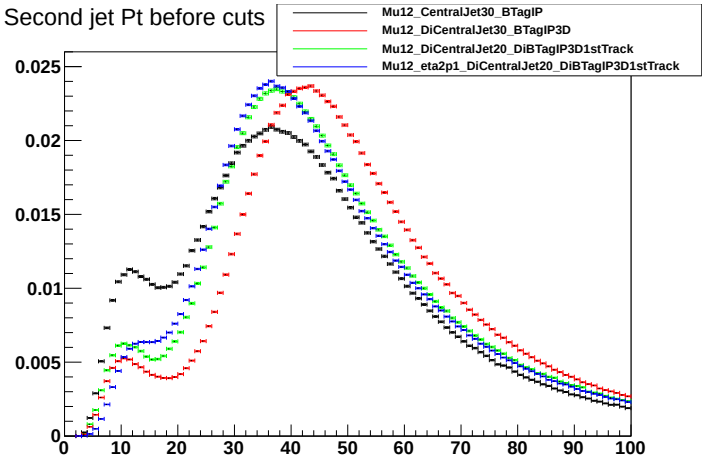


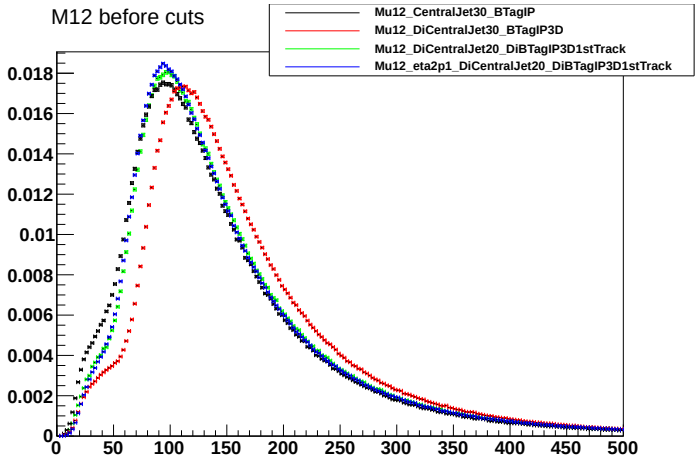
$\epsilon(\mu)$

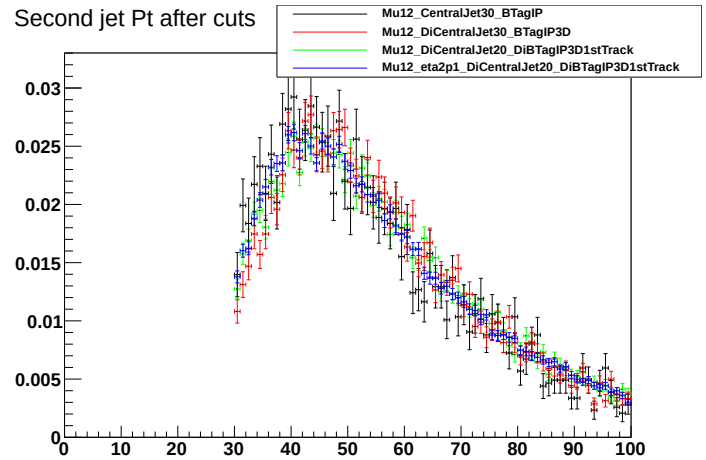
- consider `HLT_Mu12` path
- Computed on data using lower (pre-scaled) singleMu trigger path
- as a function of reconstructed muon p_{T}
- for $p_t > 15$ already in plateau $\gtrsim 99\%$.

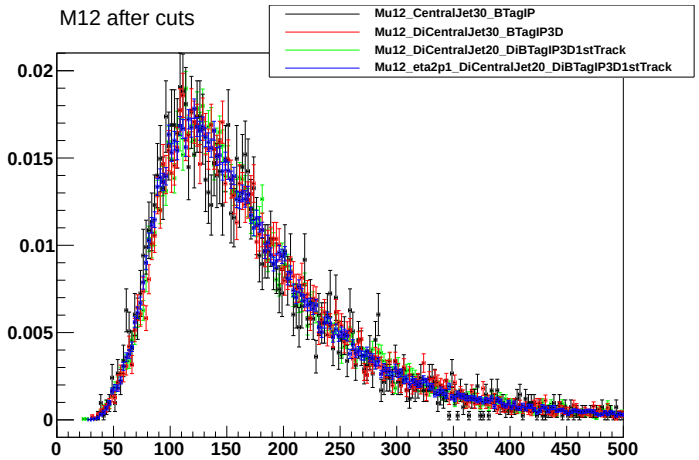
Trigger paths vs Analysis

Histograms with errorbars









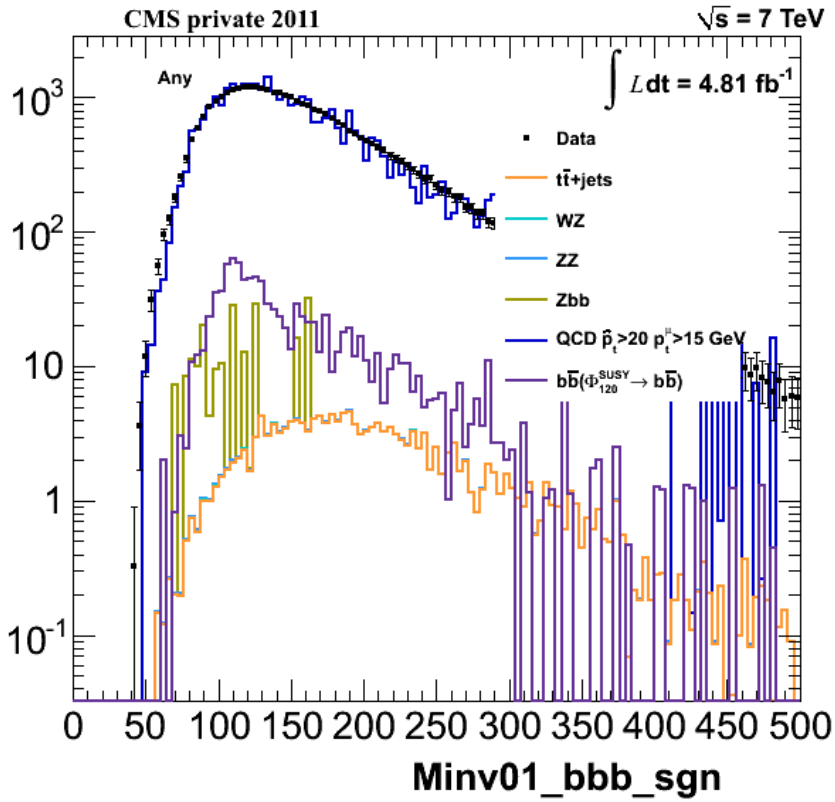
Principal background (from MC)

Table: Events passing all analysis cuts for MC simulated background samples. The quoted errors are statistical only.

Process	events
Multijet QCD	72043±747
$t\bar{t}$ + jets	303±5.8
$Z \to b\bar{b}$	540±70
ZZ	1.84±0.07
WZ	0.44±0.05
WW	0.03±0.03

PAS

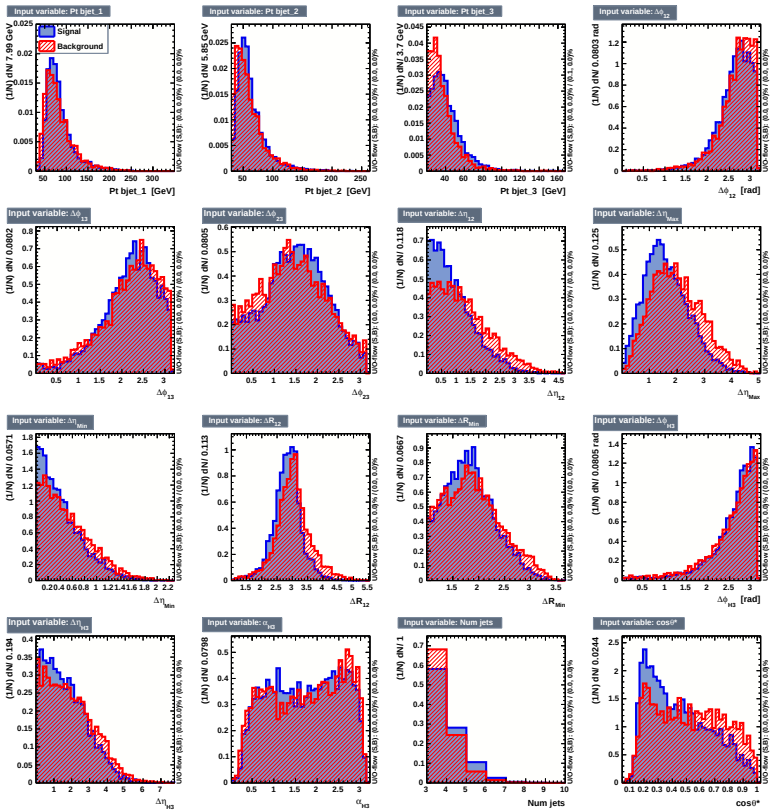
Two leading b-jets invariant mass:



Background is QCD, plus other at $\mathcal{O}(1\%)$ level or lower

Discriminator: Low Mass $M_H \leq 200$ GeV

Define a control region using a likelihood ratio discriminator using the most discriminating variables (depends on M_H)



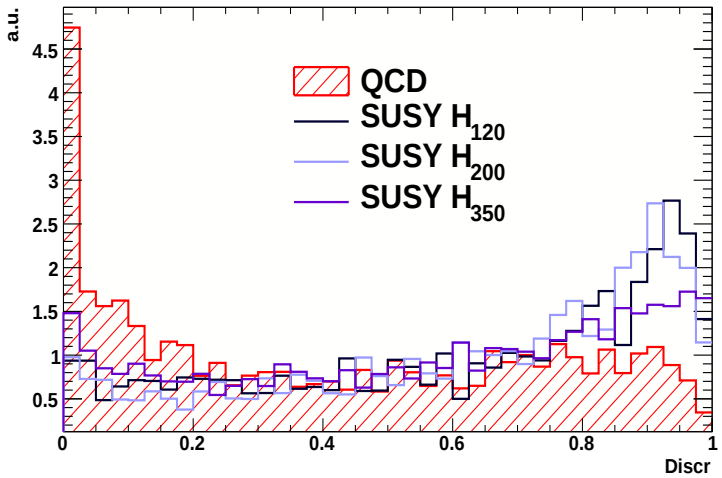
Likelihood ratio

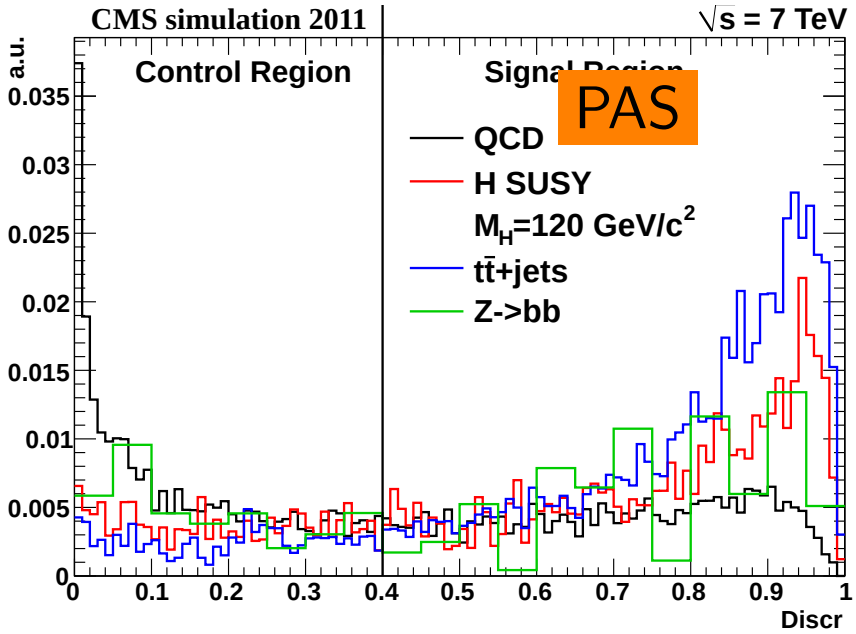
$$Discr = \frac{\Pi_i p_i^{(signal)(x_i)}}{\Pi_i p_i^{(signal)}(x_i) + \Pi_i p_i^{(QCD)}(x_i)}$$

Training $M_H = 120, 130, 140$

Used for test up to $M_H \leq 200$

Discriminator

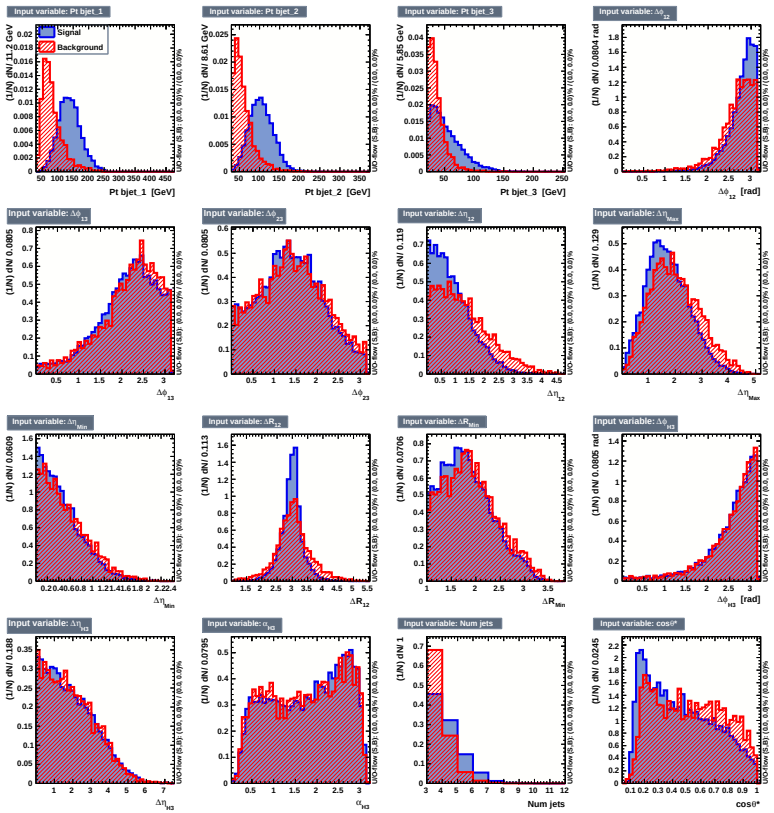




All distributions are normalized to unity.

In the analysis, the QCD is the largest background by far, and $t\bar{t}$ and $Z \to b\bar{b}$ are expected to be small, as shown in Table 3.

Discriminator: High Mass $M_H > 200$ GeV

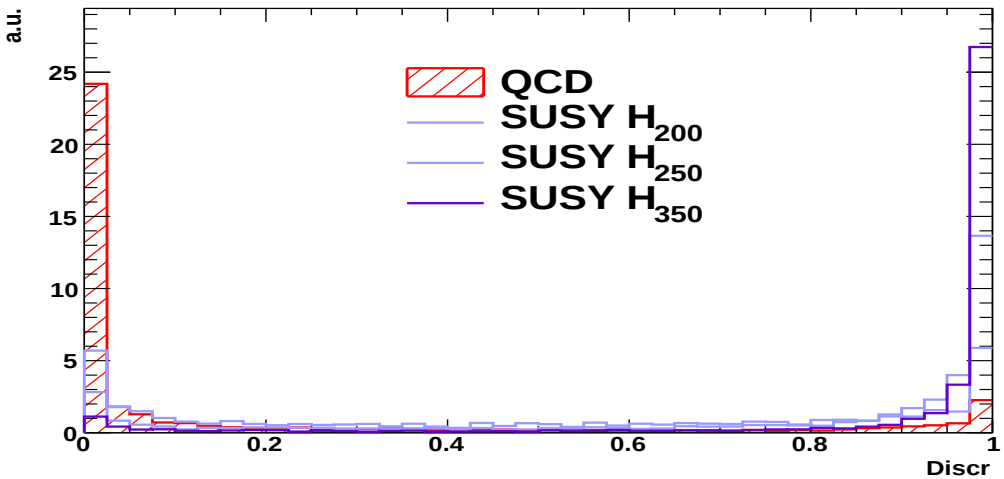


Likelihood ratio

$$Discr = \frac{\Pi_i p_i^{(signal)(x_i)}}{\Pi_i p_i^{(signal)}(x_i) + \Pi_i p_i^{(QCD)}(x_i)}$$

Training $M_H = 250, 300, 350$

Used for test from $M_H > 250$



Background determination: b-tag parametrization

- Build B-tagging probability matrices $P^{3^{rd}\,jet}_{b-tag}(\ldots)$ in control region for third jet, as a function of 3^{rd} jet and event parameters;

$$P^{3^{rd}\,jet}_{b-tag}(\ldots) = \epsilon_b \cdot f_b + \epsilon_c \cdot f_c + \epsilon_l \cdot 1 - f_b - f_c$$

  - b-tagging efficiencies $\epsilon' s$ from MC $\epsilon = \epsilon(E_T, |\eta|, N_{trk})$
  - flavour fractions $f_{b,c,l}$ from Data parametrization see next slides

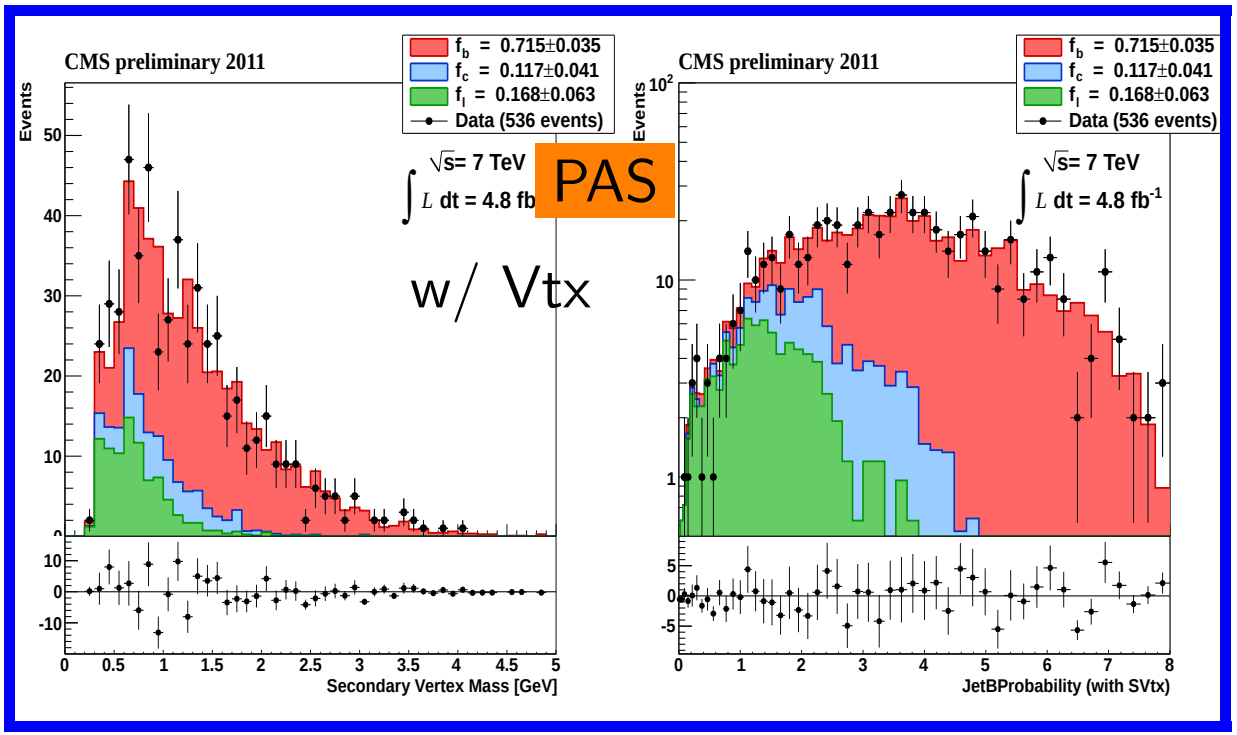
- Estimate any bbb distribution $F(x; bbb)$ for variable x in signal region starting from same distribution for bbj;

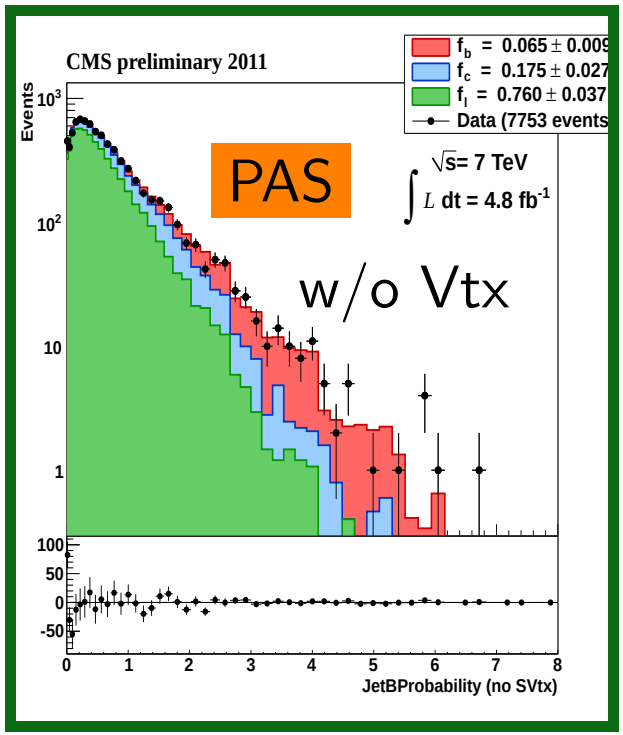
$$F(x; bbb) = F(x; bbj) \otimes P^{3^{rd}\,jet}_{b-tag}(\ldots)$$

Heavy quark fraction

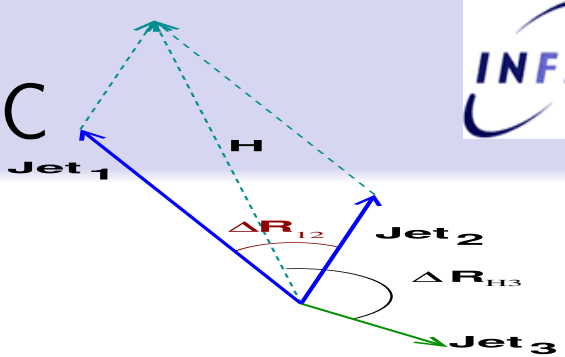
Consider Mass@Vertex and JetBProbability for third jet;

- build distribution templates from MC QCD, for B, C and Light;
- fit third jet distributions using templates and get $F_{b,c}$;
  - use only JetBProbabilty if Mass@Vertex not available.





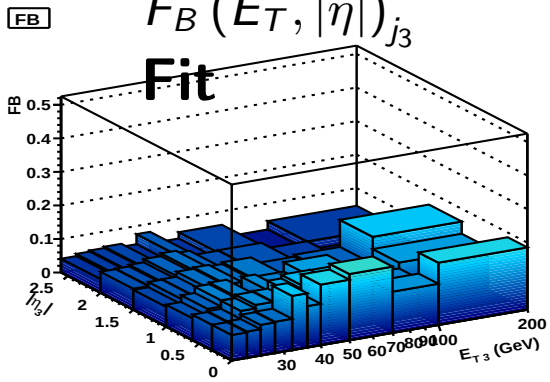
F_B parametrization & fit results in MC

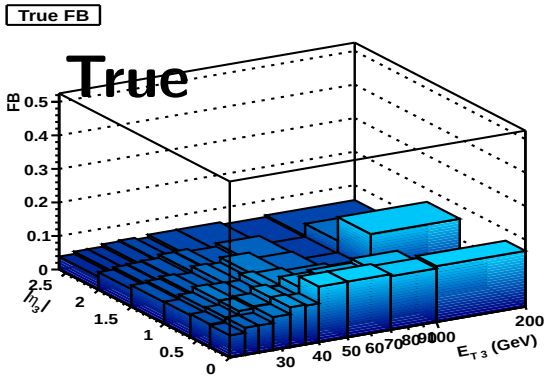


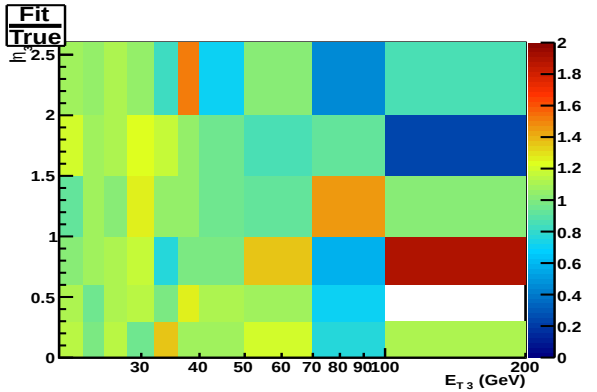
$$F_B = F_{B,C}\left(E_T^{(j_3)}, \left|\eta^{(j_3)}\right|\right) \times F_{B,C}\left(\Delta R_{H,j_3}, \Delta R_{j_1,j_2}\right)$$

assuming no correlation. Second factor only for shape.

$F_B\left(E_T, |\eta|\right)_{j_3}$

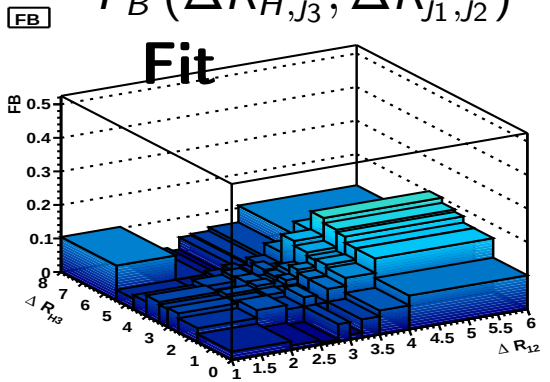


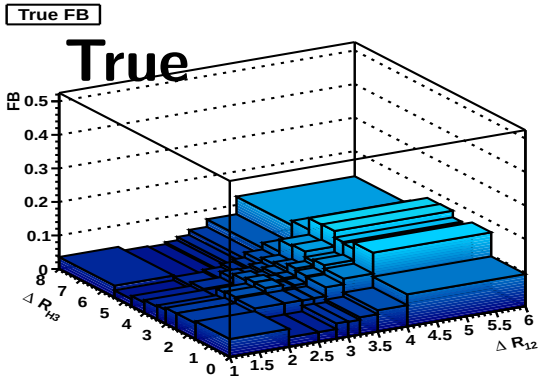


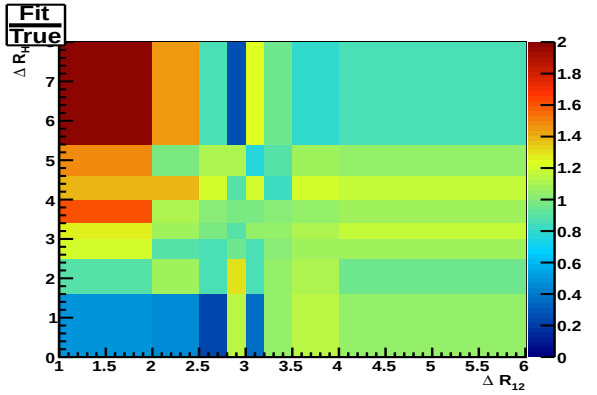


Overall bias for F_b around $\approx +6\%$

$F_B\left(\Delta R_{H,j_3}, \Delta R_{j_1,j_2}\right)$



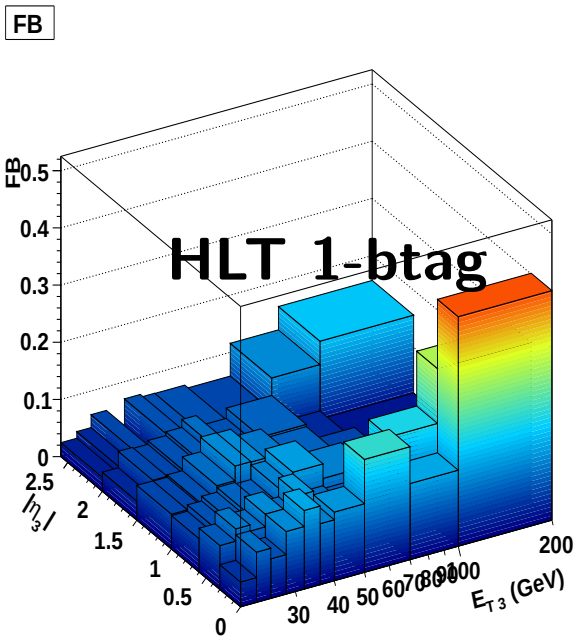


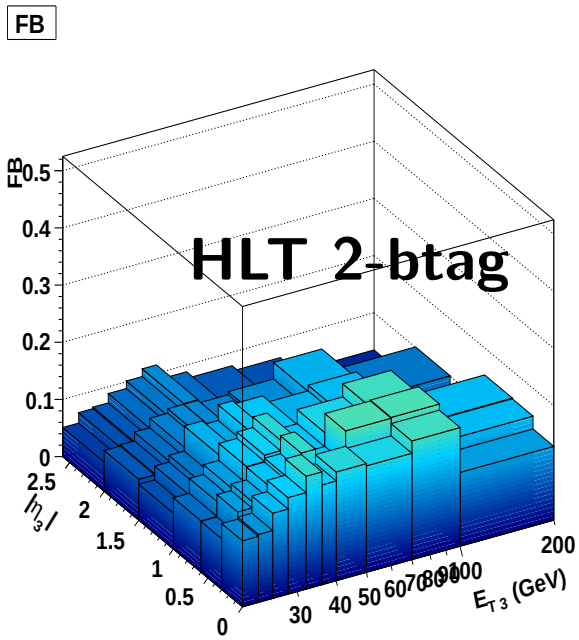


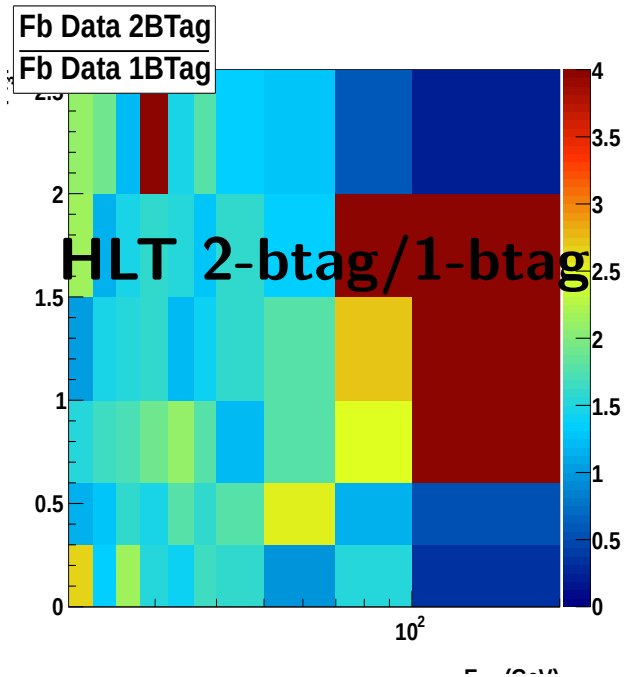
F_B Fit results Data (control region)

for Data, fit separately single B-tag and double B-Tag HLT paths.

$$F_B\left(E_T^{(j_3)}, \left|\eta^{(j_3)}\right|\right)$$



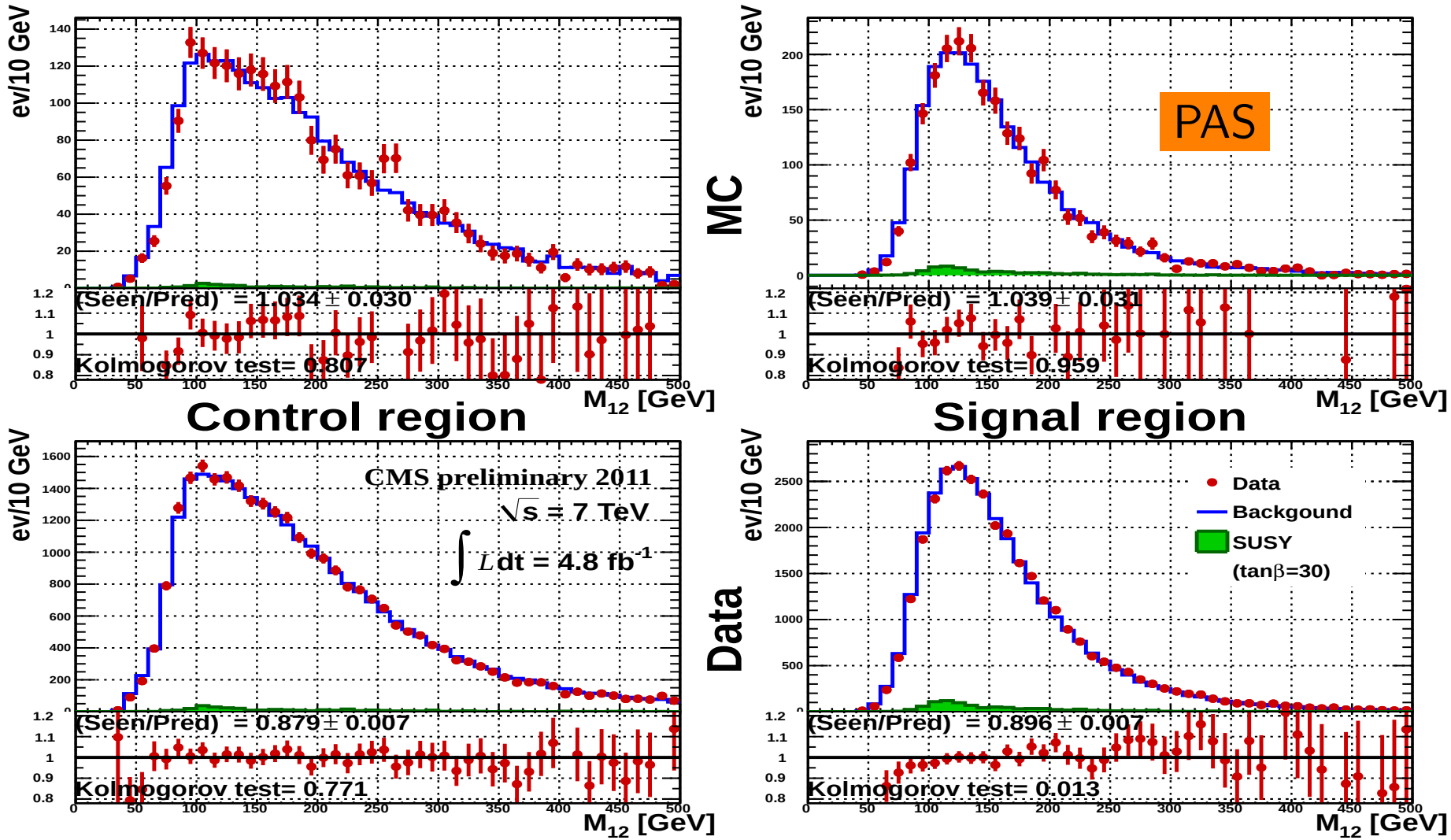




Enhancement of b in third jets, due to the online double b-tag trigger, is clearly visible.

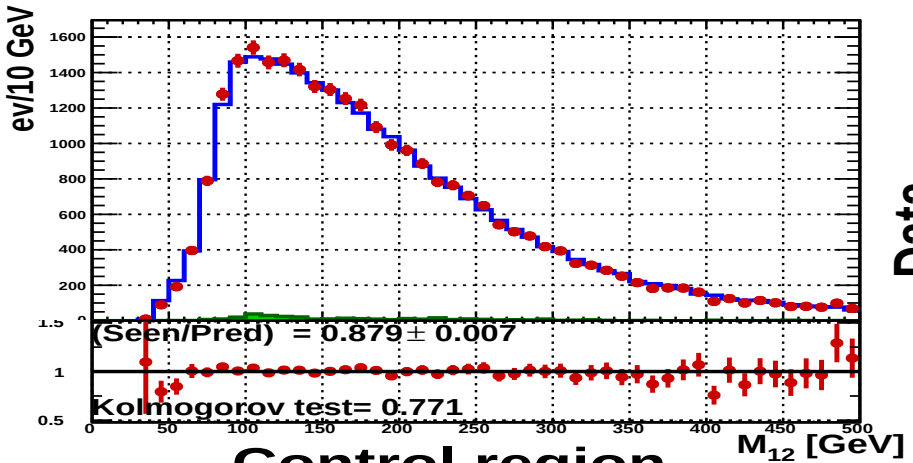
M_{jj} prediction vs *bbb* in MC and Data

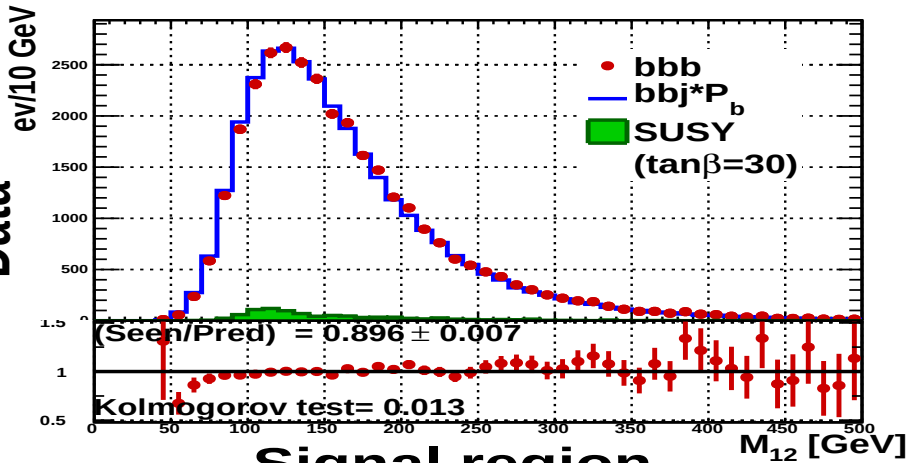
in control and signal region: Low Mass ($M_H \leq 200$) susy $M_H = 120$ *GeV*

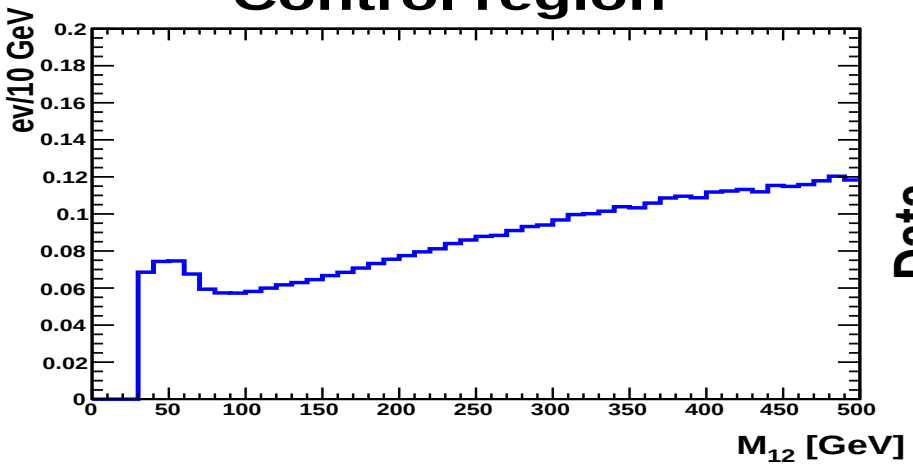


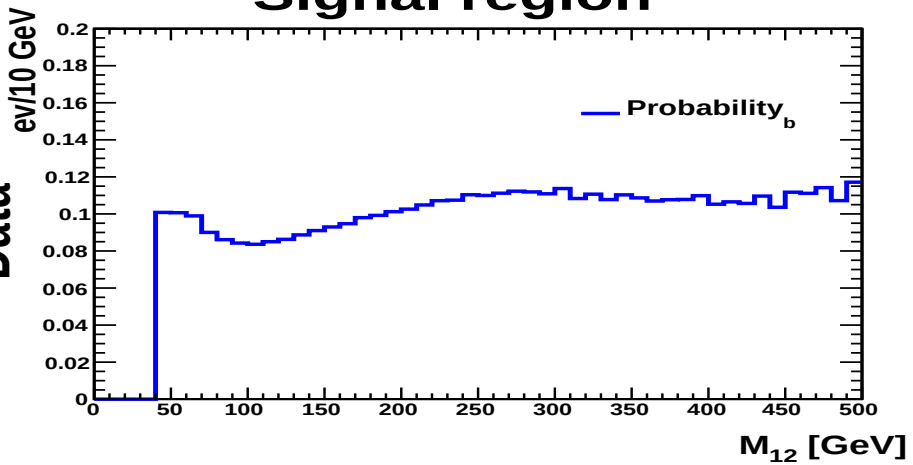
Background prediction is shown normalized to data: scale factor shown

Third jet B-tag probability: Data



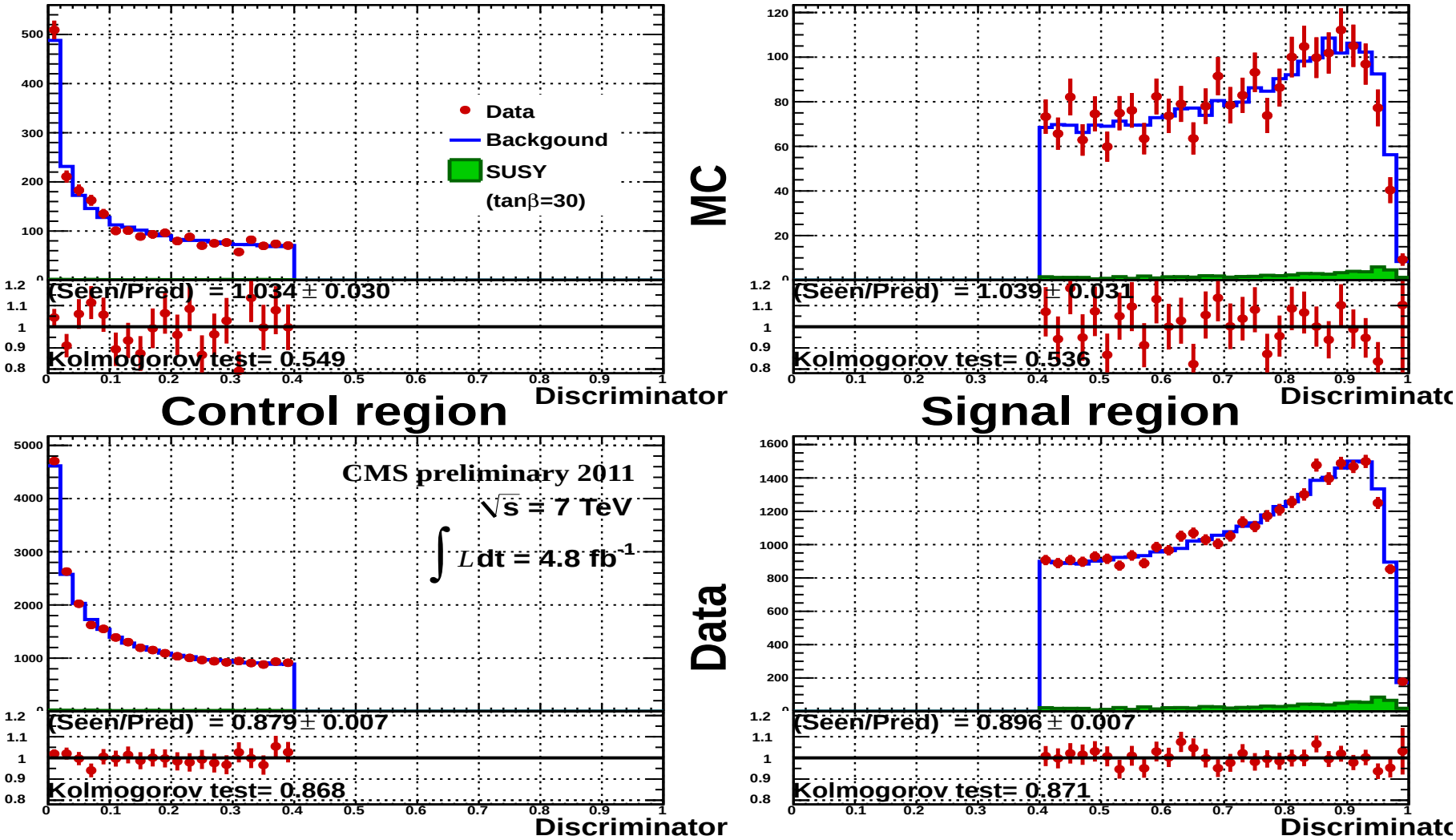






Discriminator prediction vs *bbb* in MC and Data

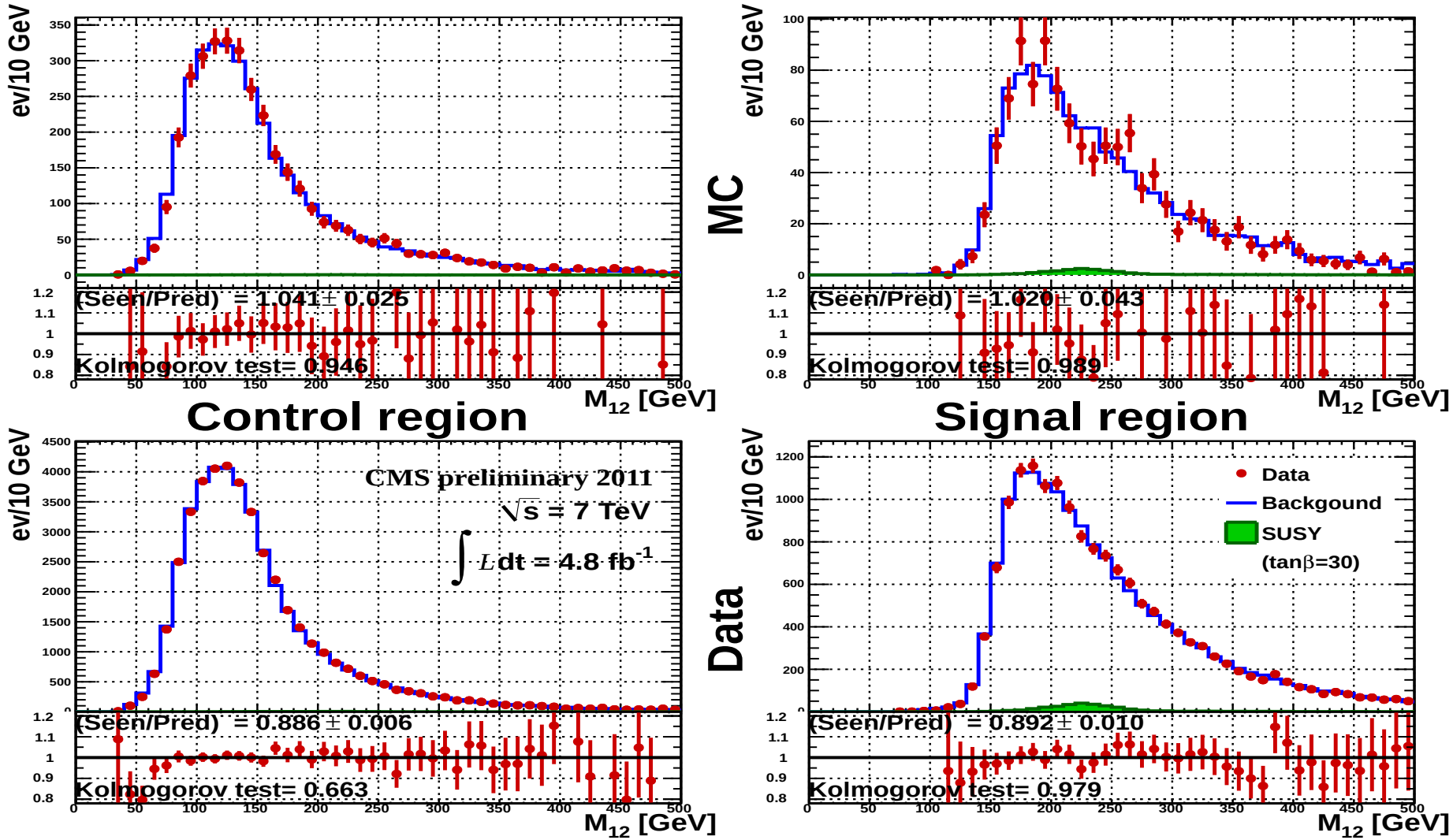
in control and signal region: Low Mass ($M_H \leq 200$) susy $M_H = 120$ *GeV*



Prediction stable wrt discriminator other variables in backup

M_{jj} prediction vs *bbb* in MC and Data

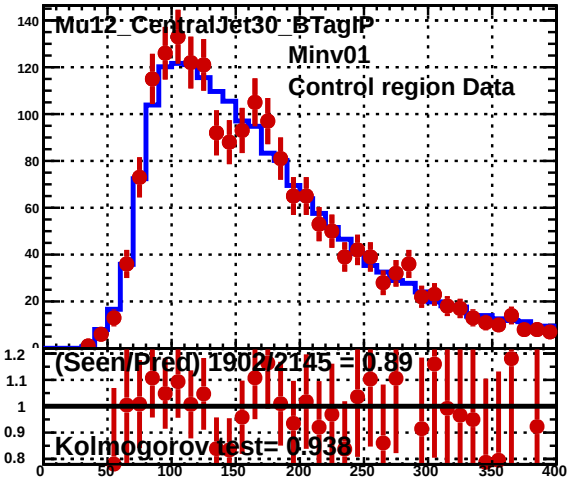
in control and signal region: High Mass ($M_H > 200$) susy $M_H = 250$ *GeV*

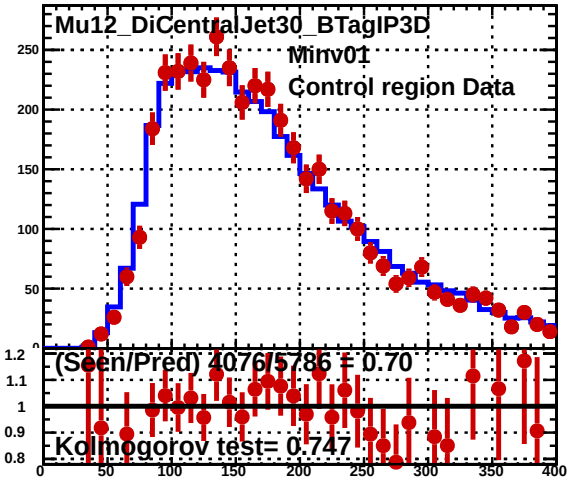


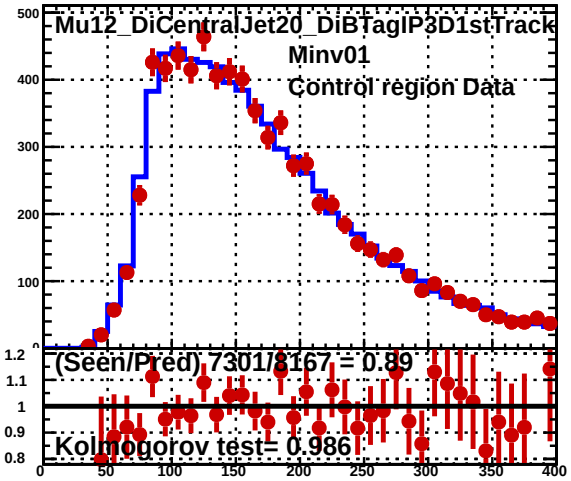
For Data (control region) shape fine, normalization $\sim 0.89\%$

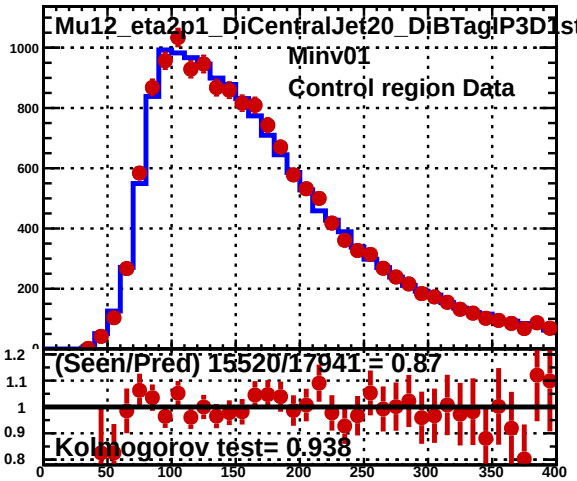
Data: M_{jj} prediction for different HLT paths

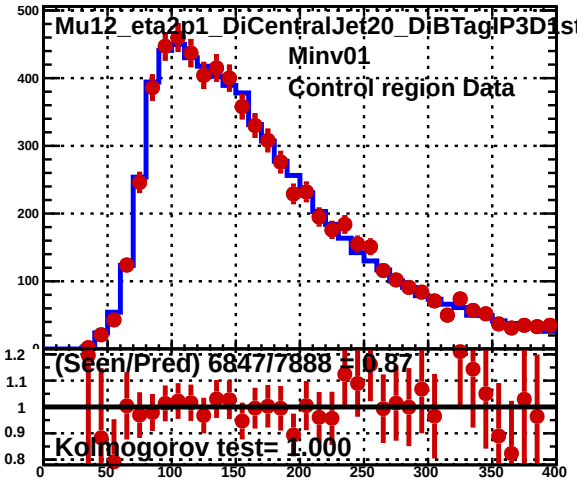
in control region: Low Mass ($M_H \leq 200$)











Shape fine for all HLT paths

Hyper Ball

Second approach, independent background estimation.

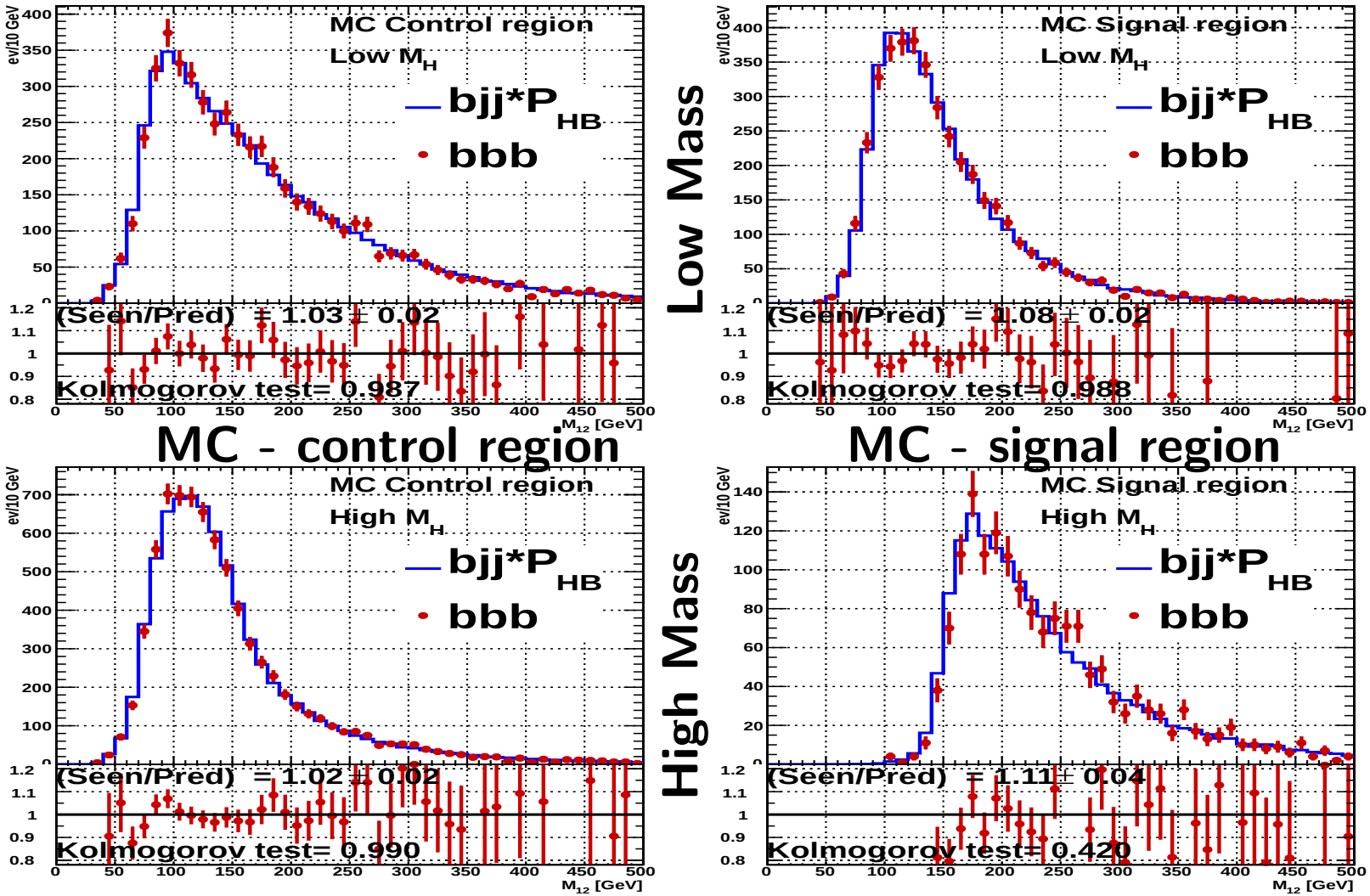
General idea

- Start from *bjj* sample, control region;
- For each event in $(bjj)_{CR}$ select a set of *similar* events $\mathcal{O}(100)$ from a large training sample $\mathcal{O}(500\,000)$
- Compute the fraction f of these events passing full selection (bbb) (weighted with distance);
- *similarity* is defined by *distance* between events in hyperspace
  $D^2 = \Sigma_i^n \left(w_i^2 \left(x_i - y_i\right)\right)^2$ (hence the name)
  - with x_i, y_i jets or event variables (p_T, η, $\Delta\phi_{ij}$, ...): total of 14 variables used;
  - w_i weight to account for different variable values and for variability of f vs a given variable;
  - subtleties: w_i tuning, which variables to consider, how many events in training sample, events near the boundary of variables domain, ...

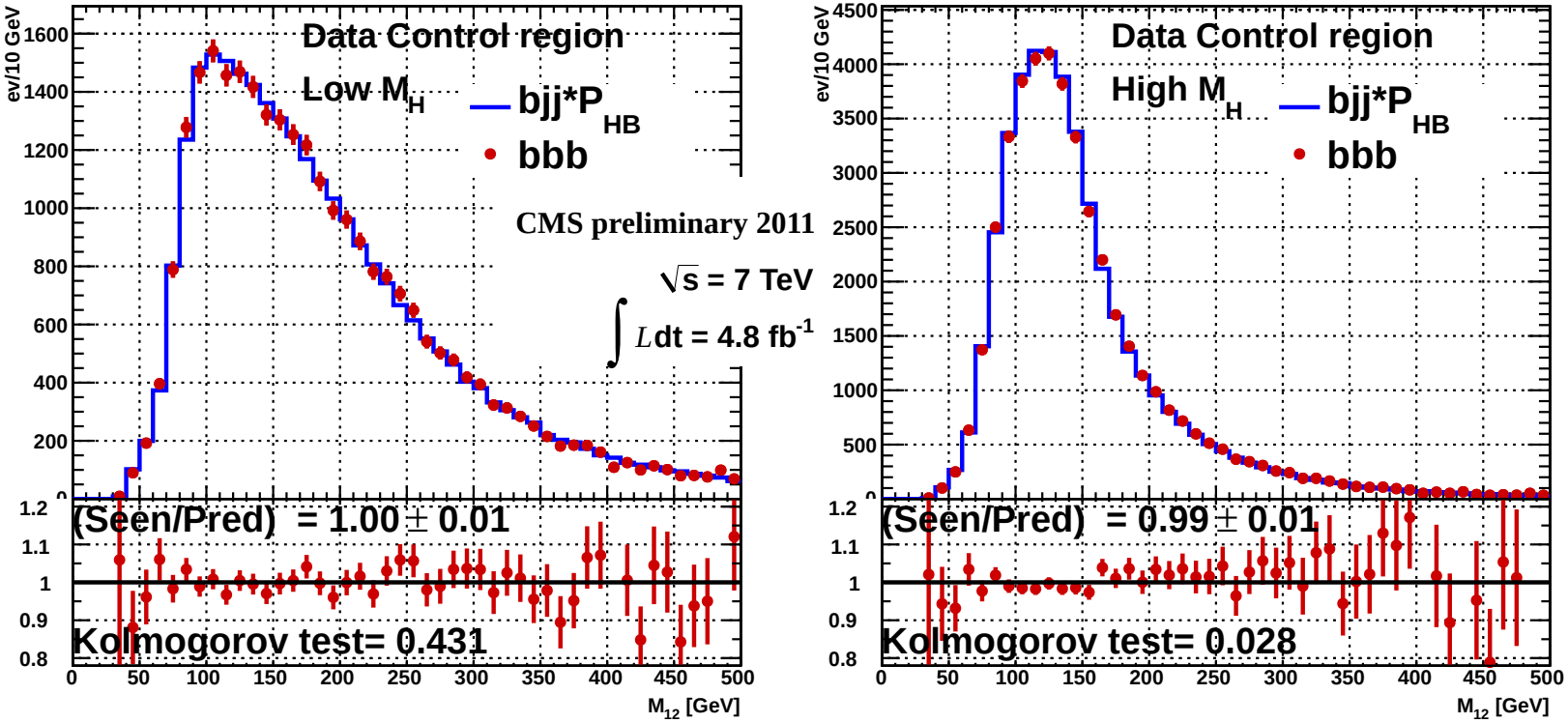
$F(x; bbb) = F(x; bjj) \otimes f$

Hyper Ball: results on QCD MC

Closure test



Hyper Ball: results on Data: Control region



Good closure for control region both in low and high mass range

B-Matrix vs HyperBall

B-Matrix

- starts from bbj;
- Efficiency and b,c templates from MC. $F_{b,c}$ from data fit;
- Control region is used to fit $F_{b,c}$;
- Binned parametrization with 4 parameters;

HyperBall

- start from bjj;
- Fully data driven: MC only as a closure test;
- 14 variables used, no binning issues;
- Control region is training sample: look at which events pass bbb selection;

()

Use B-Matrix prediction as a baseline, and Hyperball only to study systematics

B-Matrix vs HyperBall

B-Matrix

- starts from bbj;
- Efficiency and b,c templates from MC. $F_{b,c}$ from data fit;
- Control region is used to fit $F_{b,c}$;
- Binned parametrization with 4 parameters;

HyperBall

- start from bjj;
- Fully data driven: MC only as a closure test;
- 14 variables used, no binning issues;
- Control region is training sample: look at which events pass bbb selection;

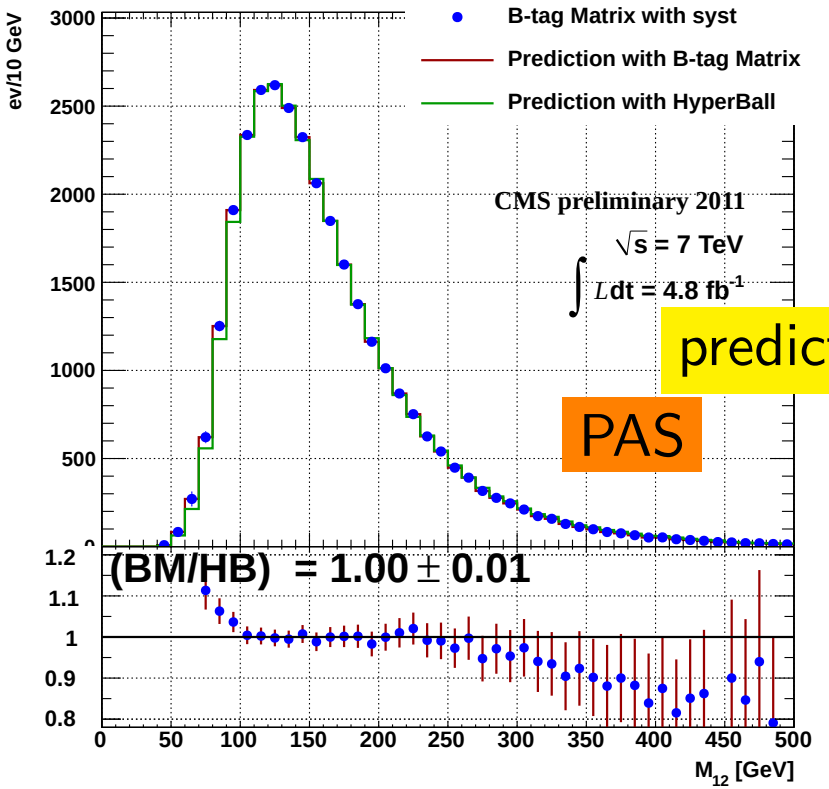
(As gently suggested during pre-approval)

Use B-Matrix prediction as a baseline, and Hyperball only to study systematics

Comparison of B-Matrix and HB prediction

In signal region

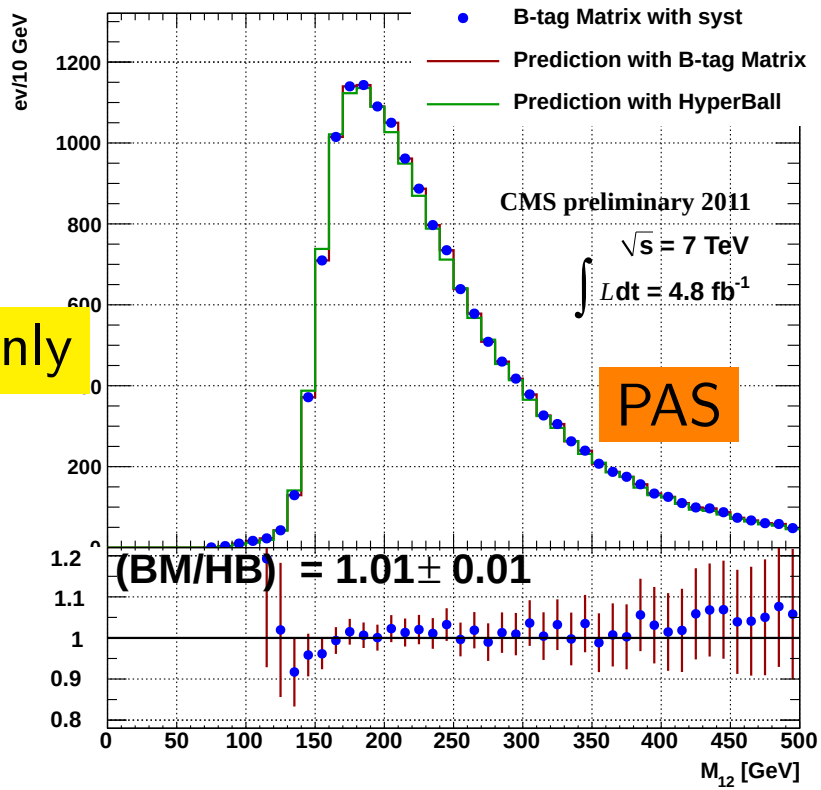
Low Mass $M_H < 200\ GeV$



PAS

prediction only

High Mass $M_H > 200\ GeV$



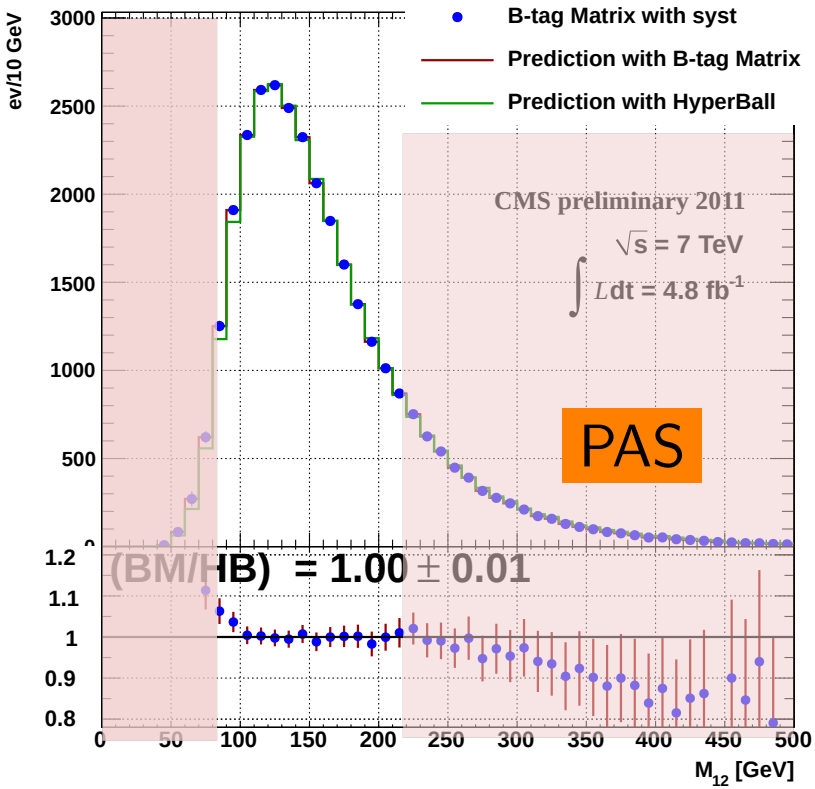
PAS

- Absolute prediction, **NOT** normalized to each other;
- use comparison as systematic error on shape, unfolding the statistical one (*pdg* recipe);

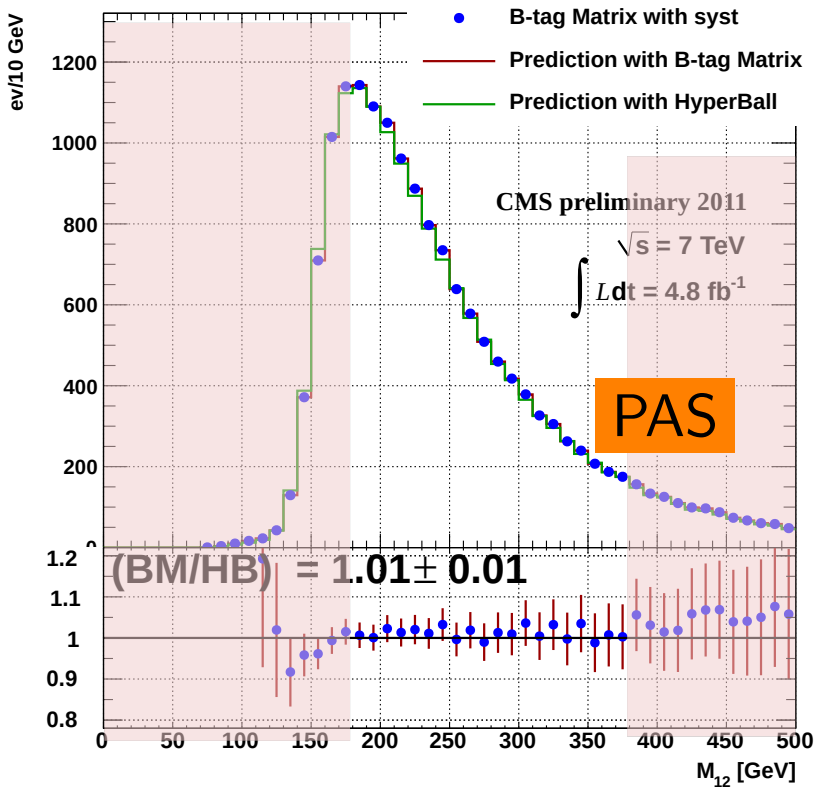
Comparison of B-Matrix and HB prediction

In signal region

Low Mass $M_H < 200$ *GeV*



High Mass $M_H > 200$ *GeV*



- Absolute prediction, **NOT** normalized to each other;
- use comparison as systematic error on shape, unfolding the statistical one (*pdg* recipe);

Systematics

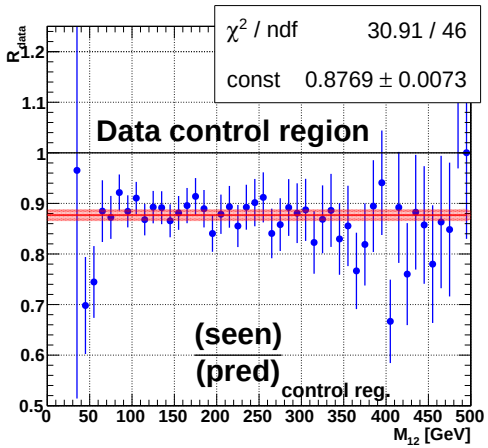
- Trigger syst: $\approx 3-5\%$ from data driven ϵ estimate;
- Physics object syst:
  - B-tagging eff. BTV-12-001 $\approx 4\%$ per BJet: $\approx 12\%$ for three jets.
  - JEScale $^{+2.5}_{-3.1}\%$
  - JEResolution $\pm 1.9\%$
  - Mu momentum scale $\approx 0.2\%$ and resolution $\approx 0.6\%$
- pdf For $M_H = 120\ GeV$: $^{+2.5}_{-2.7}\%$; for $M_H = 250\ GeV$: $^{+4.7}_{-4.4}\%$;
- Integrated Lumi syst: $\approx 2.2\%$
- Background normalization syst $\approx 5\%$ (see next slides):

Background Normalization and Systematics

Two major source of normalization systematics for the predicted *bbb* in signal region:

Systematics from *bbb* prediction from DATA control region

- compare *bbb* and prediction in DATA control region;
- use normalization in signal region;
- use fit error as systematics;

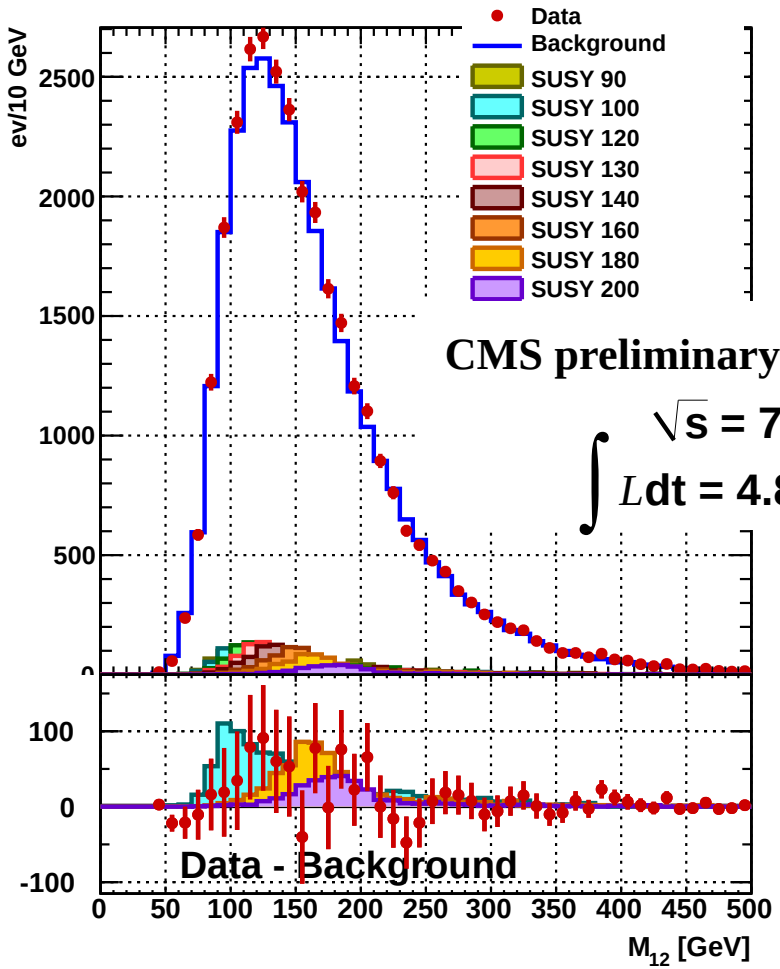


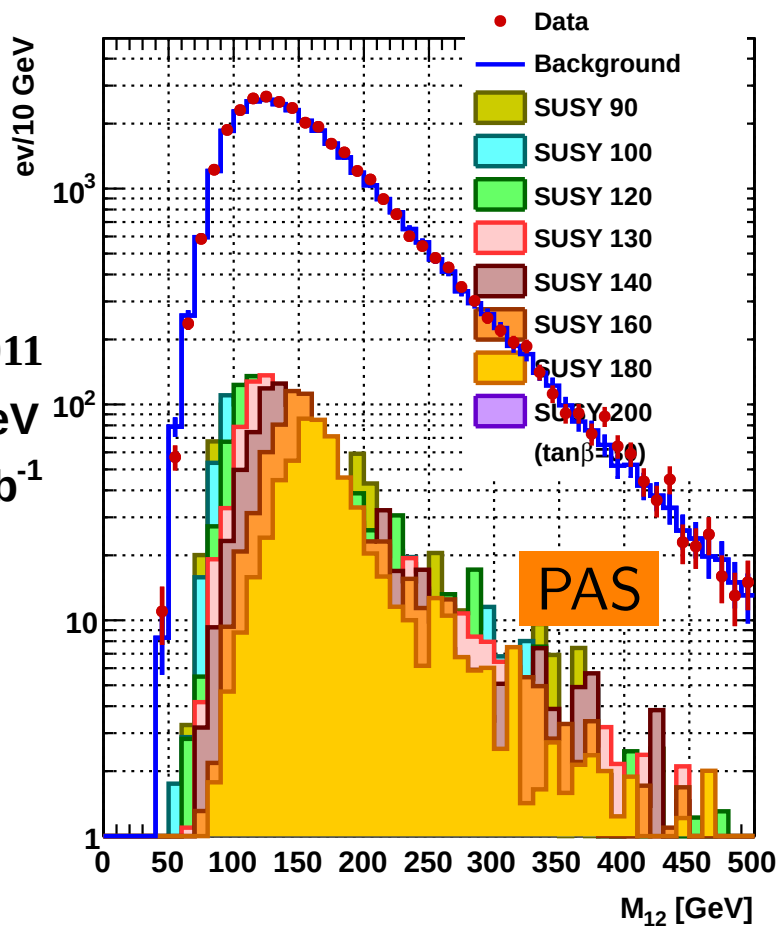
Systematics due to extrap. from control to signal region from MC

- shape is flat (within the stat) both in control and signal region;
- get a correction factor R_{extrap} obtained with *total number of events* division of the MC ratio plots on CR and SR
- plus systematics

Final prediction and signal ($\tan\beta = 30$)

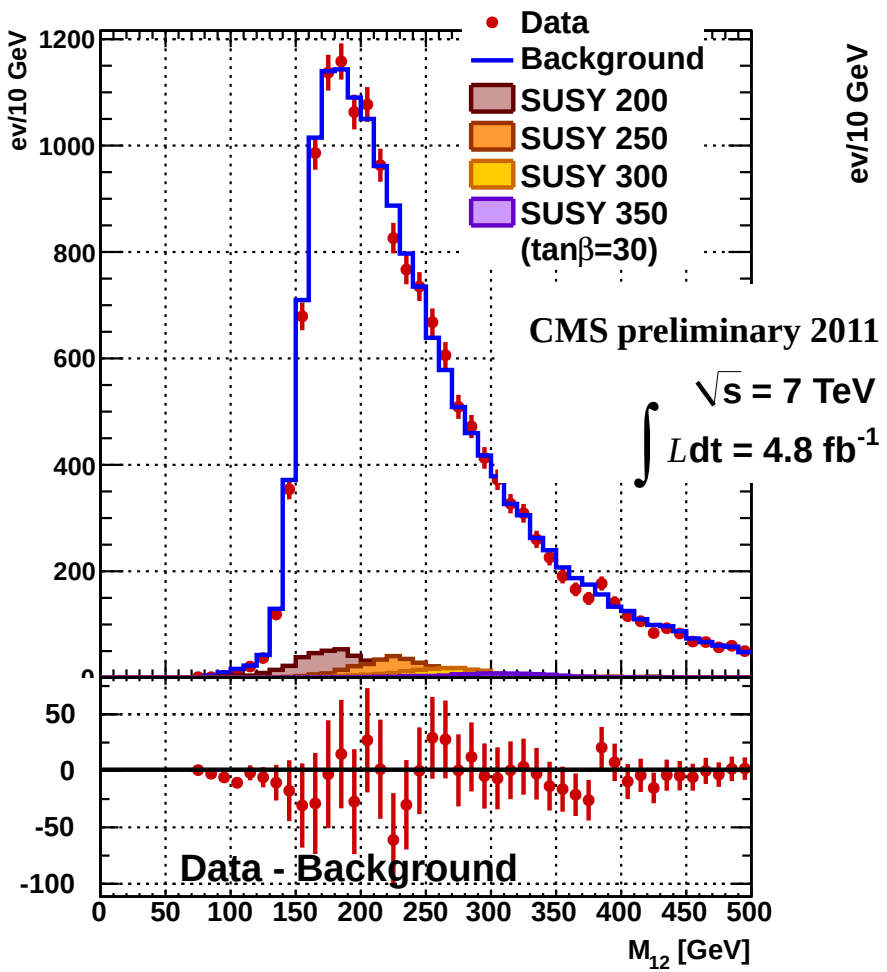
Low Mass

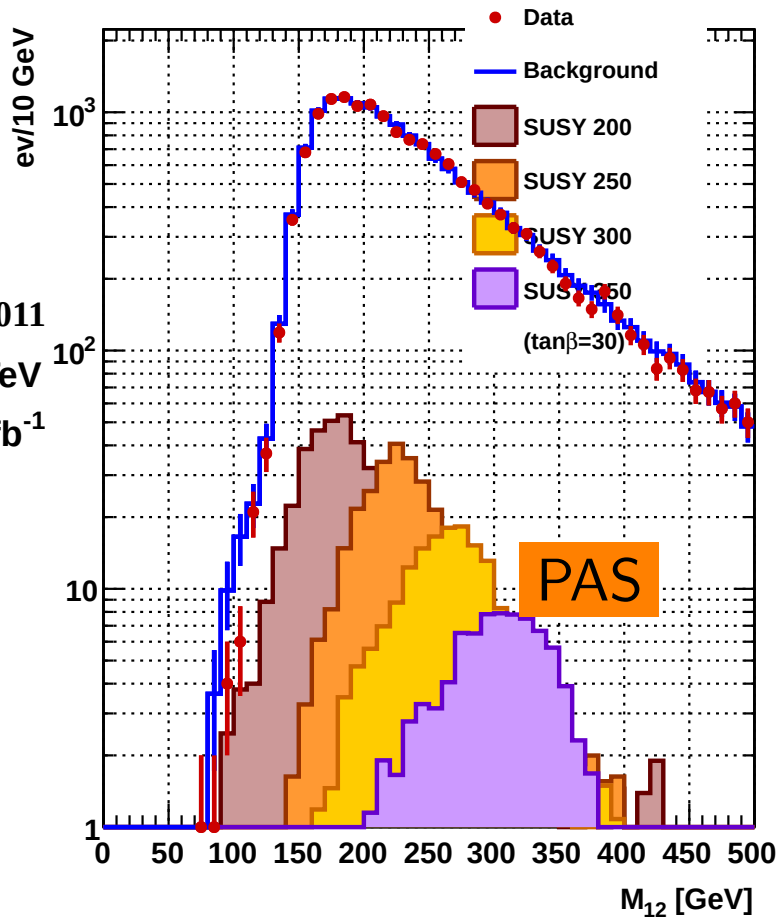




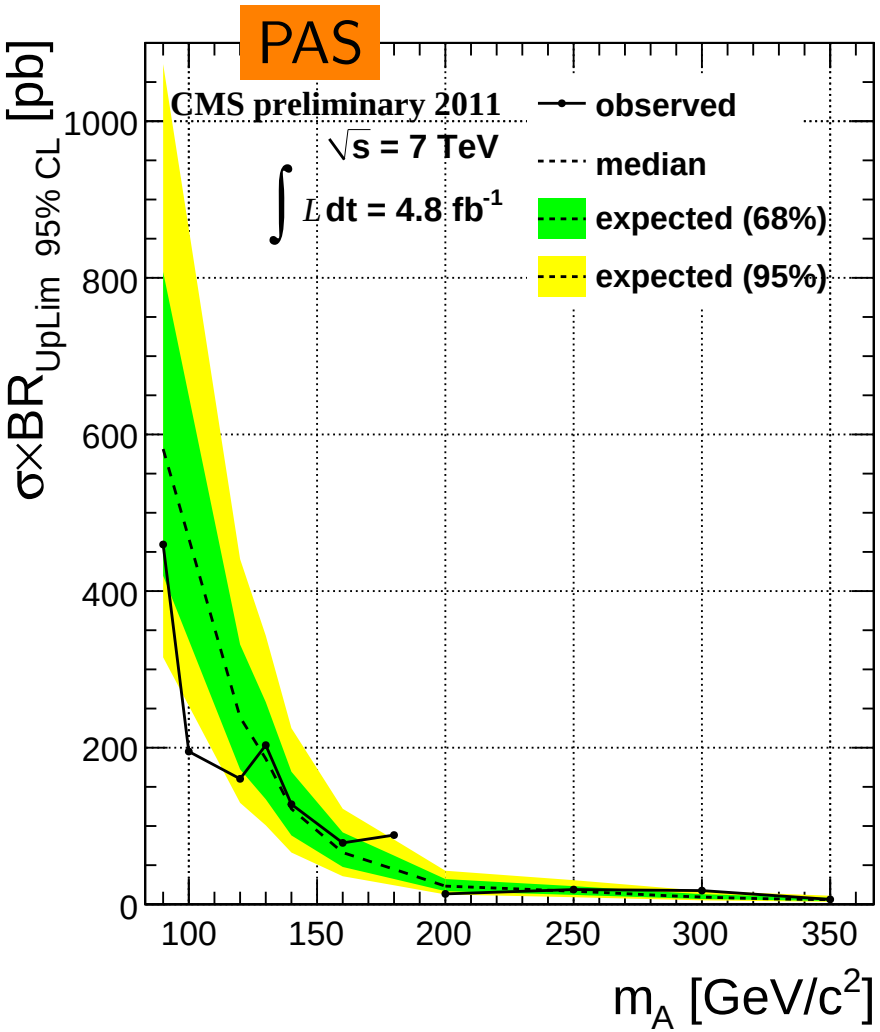
Final prediction and signal ($\tan\beta = 30$)

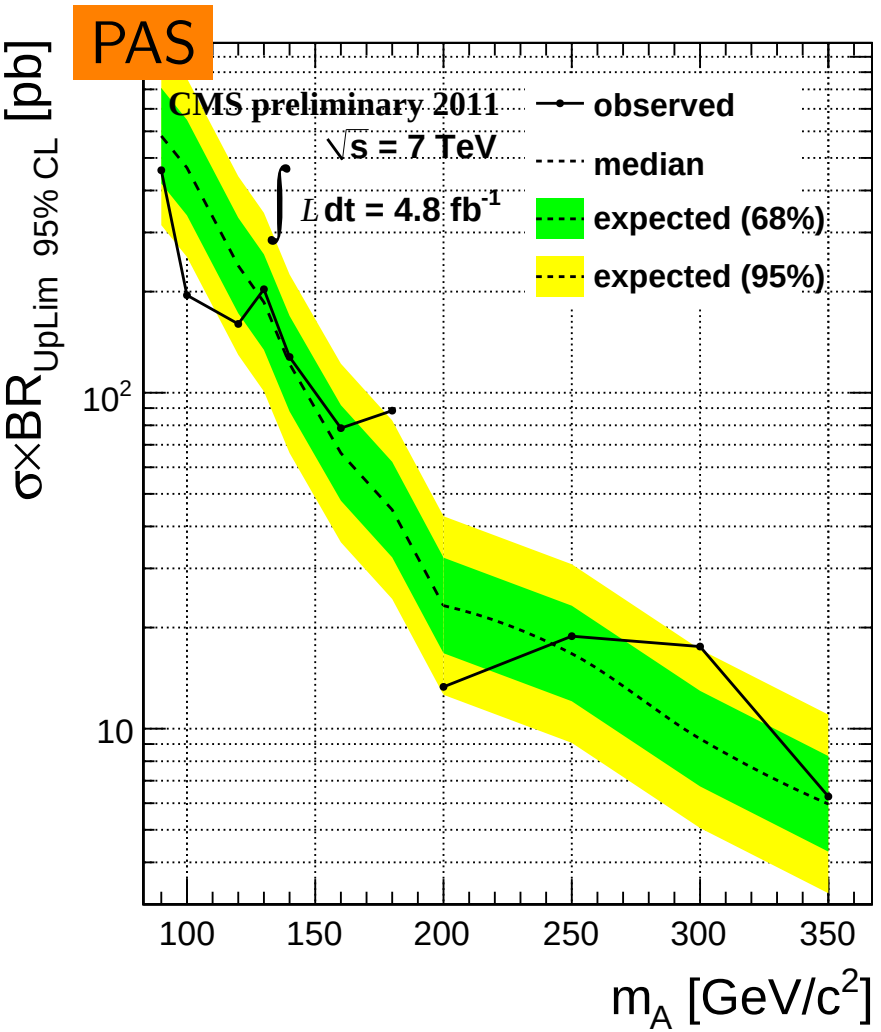
High Mass



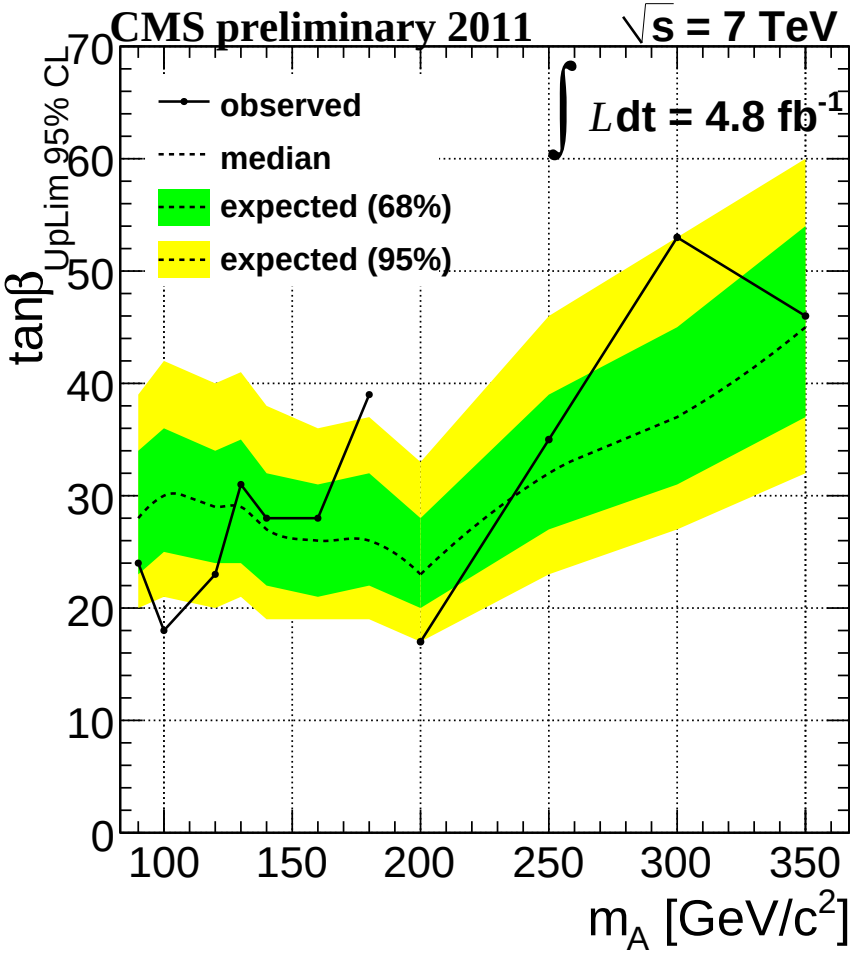


Sensitivity: stat + syst errors





Sensitivity: stat + syst errors

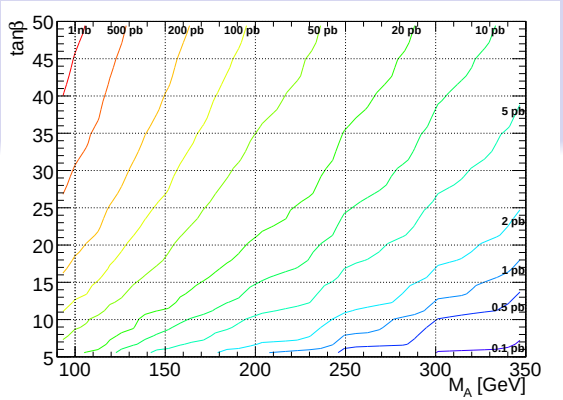


Summary

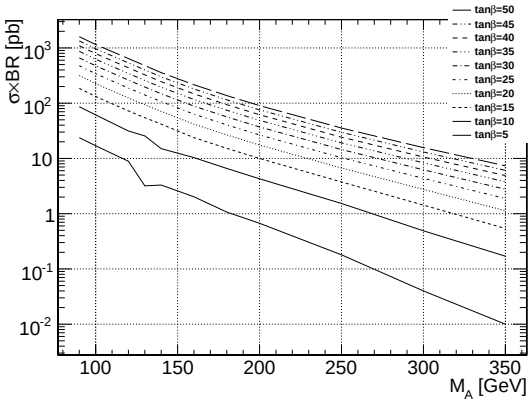
- Fow low mass, we do see a trend in the ratio data/prediction;
- maybe also for high mass, less evident;
- it results in over-stimate backgound in one region and under in an other.
- similar trend is not visible in control region, MC or comparing MB with HB
- trend is visible in no man's land $0.4 < D < 0.7$ for low mass;
- if correct signal region for what we see in NMI, less fluctuating results;
- results also shown using only $D > 0.7$ results also shown.

BACKUP

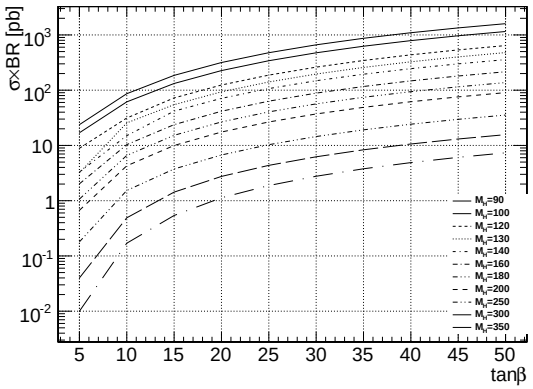
cross-section



(a) $\sigma \times BR$ vs $(M_A, \tan\beta)$



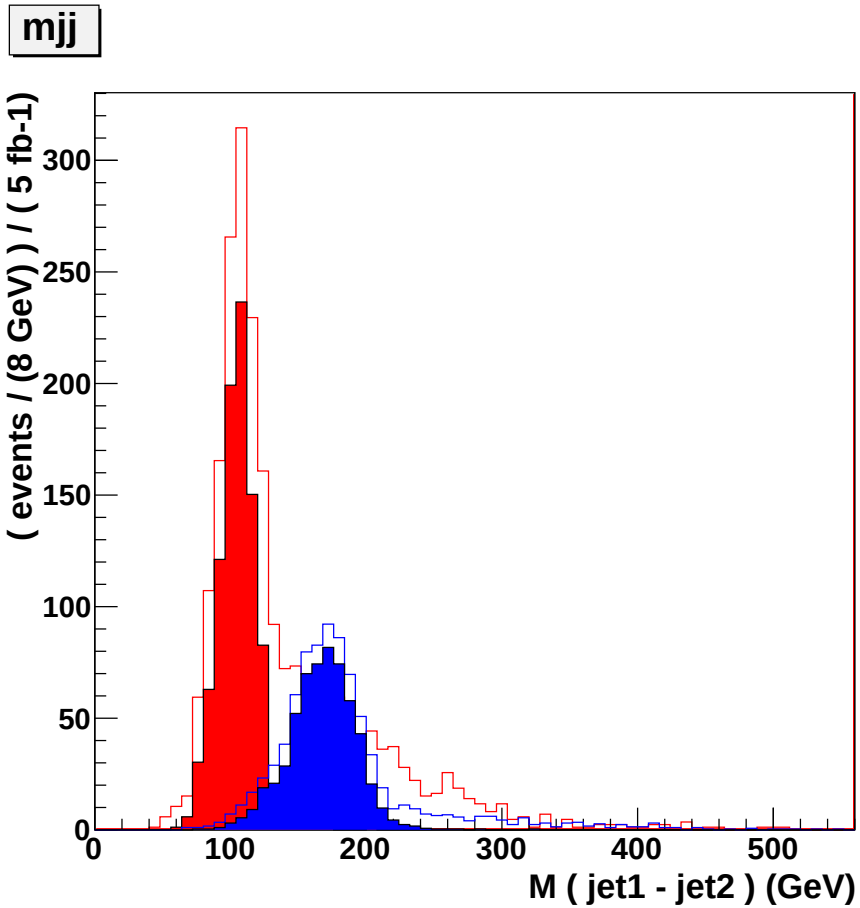
(b) $\sigma \times BR$ vs M_A



(c) $\sigma \times BR$ vs $\tan\beta$

Figure: (a) MSSM neutral higgs production cross section times branching ratio for $b\bar{b}H$ associated production at $\sqrt{s} = 7\ TeV$ and $H \to bb$ decay, as a function of M_A and $\tan\beta$, taking into account the mass degeneration. (b) Same as (a) as

Signal M_{12}


mjj
(events / (8 GeV)) / (5 fb-1)
300
250
200
150
100
50
0
0
100
200
300
400
500
M (jet1 - jet2) (GeV)

PU reweight

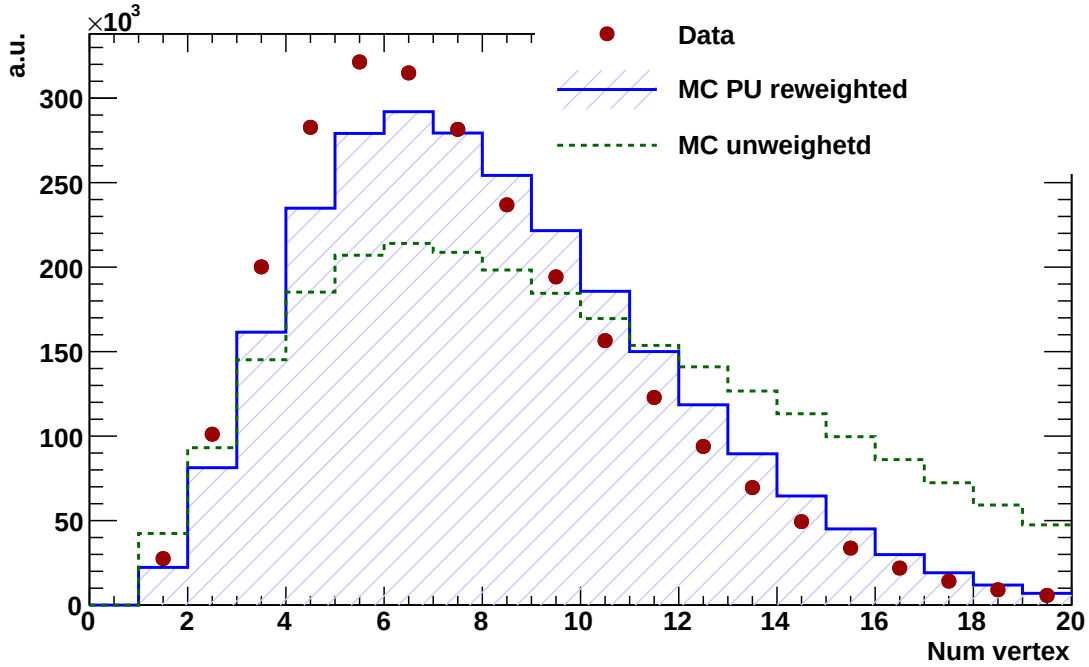


Figure: Reconstructed number of primary vertex in MC simulation with original and reweighted PileUp distribution compared to that found in 2011 Data.

MC samples

Background Processes		
Description	Dataset Name	$\int \mathcal{L} dt\ [fb^{-1}]$
QCD (μ enriched)	/QCD_Pt-20_MuEnrichedPt-15_TuneZ2_7TeV-pythia6	0.296
$t\bar{t} + jets$	/TTJets_TuneZ2_7TeV-madgraph-tauola	423
Signal Processes $bbH \rightarrow bbbb$		
$m_H = 90\ GeV$	/SUSYBBHToBB_M-90_7TeV-pythia6-tauola	1.64
$m_H = 100\ GeV$	/SUSYBBHToBB_M-100_7TeV-pythia6-tauola	2.29
$m_H = 120\ GeV$	/SUSYBBHToBB_M-120_7TeV-pythia6-tauola	4.29
$m_H = 130\ GeV$	/SUSYBBHToBB_M-130_7TeV-pythia6-tauola	5.41
$m_H = 140\ GeV$	/SUSYBBHToBB_M-140_7TeV-pythia6-tauola	3.98
$m_H = 160\ GeV$	/SUSYBBHToBB_M-160_7TeV-pythia6-tauola	6.22
$m_H = 180\ GeV$	/SUSYBBHToBB_M-180_7TeV-pythia6-tauola	9.73
$m_H = 200\ GeV$	/SUSYBBHToBB_M-200_7TeV-pythia6-tauola	14.80
$m_H = 250\ GeV$	/SUSYBBHToBB_M-250_7TeV-pythia6-tauola	37.96
$m_H = 300\ GeV$	/SUSYBBHToBB_M-300_7TeV-pythia6-tauola	87.52
$m_H = 350\ GeV$	/SUSYBBHToBB_M-350_7TeV-pythia6-tauola	198.56

HLT

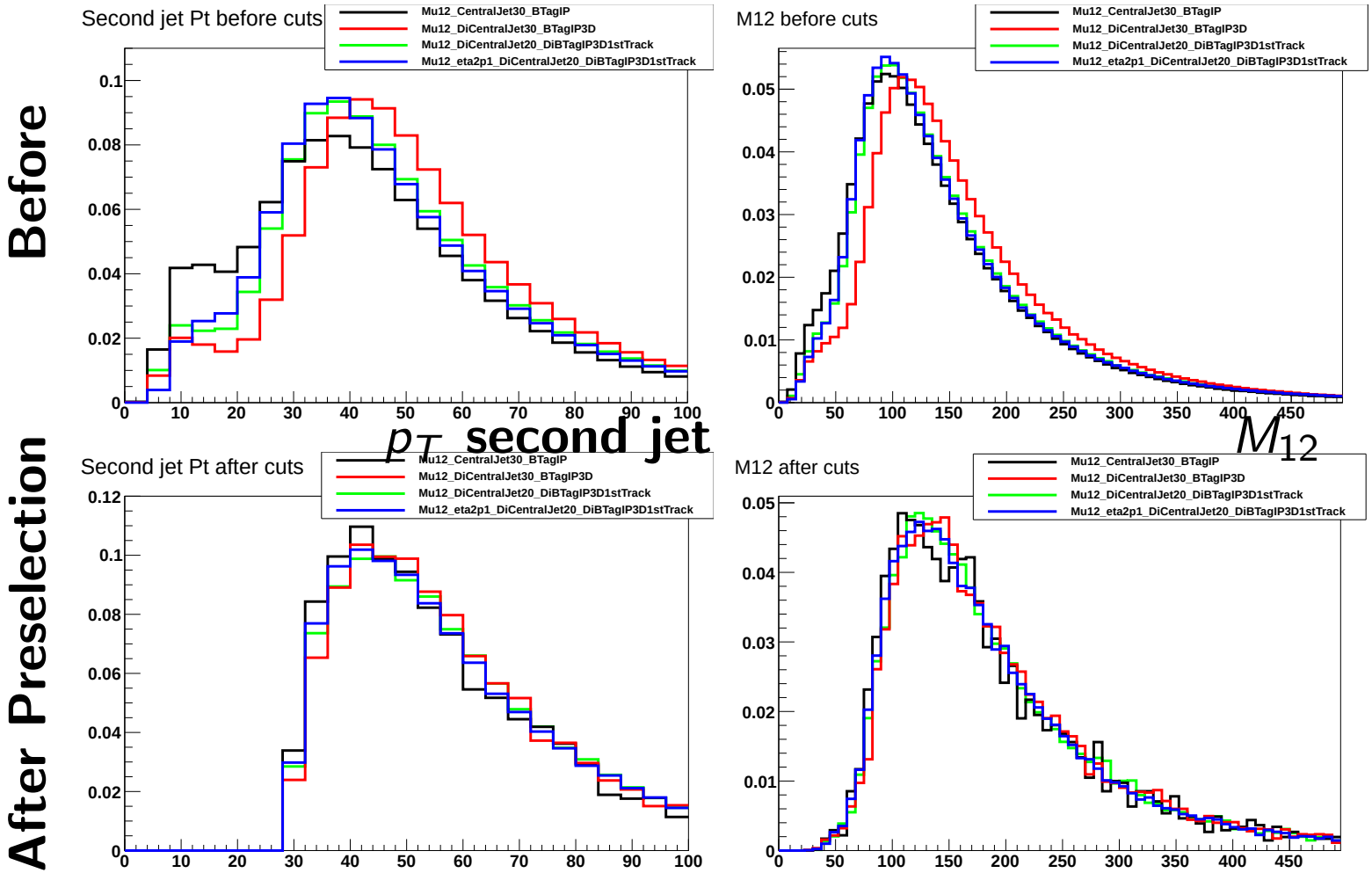
HLT paths *(L1 seed)*	run range	triggered events	$\int \mathcal{L} dt$ $[\mathrm{pb}^{-1}]$
HLT_Mu12_CentralJet30_BtagIP *L1_SingleMu7*	163738-165633	3 027 717	180.9
HLT_Mu12_DiCentralJet30_BtagIP3D *L1_SingleMu10*	165970-166967	4 532 555	537.1
HLT_Mu12_DiCentralJet20_DiBtagIP3D1stTrack *L1_SingleMu10*	167039-173198	2 244 550	1108.6
HLT_Mu12_eta2p1_DiCentralJet20_DiBtagIP3D1stTrack *L1_Mu10_Eta2p1_DoubleJet_16_8*	173236-176469	1 237 147	652.2
HLT_Mu12_eta2p1_DiCentralJet20_DiBtagIP3D1stTrack* *L1_Mu10_Eta2p1_DoubleJet_16_8**	176545-180252	5 690 304	2326.8
All		16 732 273	4805.7

Trigger eff

HLT Path	signal efficiency [%]
HLT_Mu12_CentralJet30_BtagIP	3.64 ± 0.19
HLT_Mu12_DiCentralJet30_BtagIP3D	2.28 ± 0.11
HLT_Mu12_DiCentralJet20_DiBtagIP3D1stTrack	1.66 ± 0.07
HLT_Mu12_eta2p1_DiCentralJet20_DiBtagIP3D1stTrack	1.65 ± 0.06

Table: Signal efficiency for the different HLT paths. The reported signal efficiency is estimated only for the Higgs mass point $m_H = 120 GeV/c^2$ and it does not take into account the offline selection.

Trigger paths vs Analysis

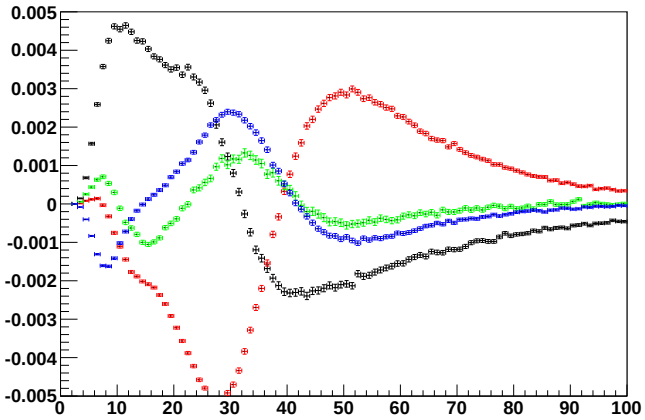


After pre-selection cut, distributions for different paths are similar

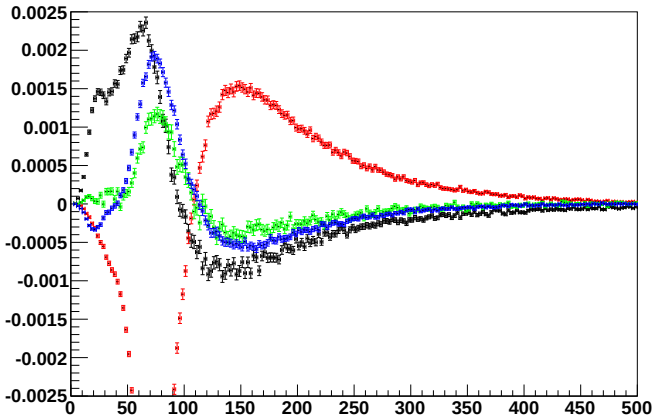
Trigger paths vs Analysis

Deviations from the averaged over all triggers

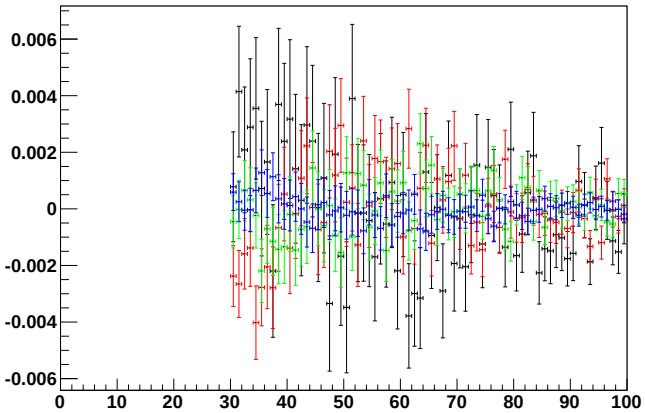
Second Pt before cuts



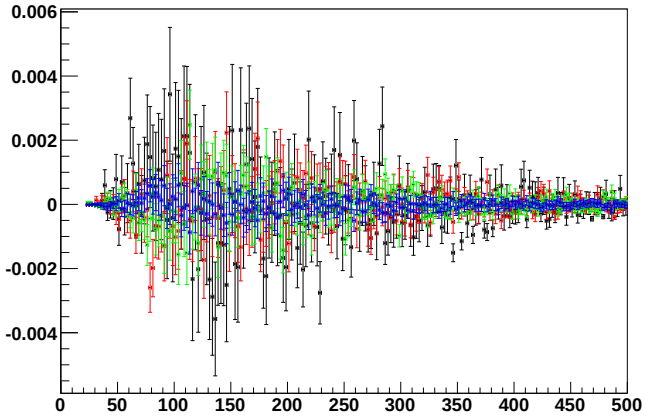
M12 before cuts



Second Pt after cuts



M12 after cuts



Physics Objects

- CMSSW 4_2_7 including JetMet suggested tags.
- AK5 ParticleFlow Jets, JEC applied:
  - L1FastJet, L2Relative, L3Absolute, L2L3Residual (only for Data)
  - Global Tag: `FT_R_42_V20A` and `START42_V17` for Data and MC
  - PU treatment: PF Charged Hadron Subtraction and Area Method;
  - Loose JetId selections;
- Jet b-tagging used is Combined Secondary Vertex (CSV);
- Standard Global Muon (no isolation requirements)

- JES and JER from POG (CERN-PH-2011/102 and update JetMET presentation 9/1/12);
- BTag efficiency studies on top samples (BTV-12-001);
- Muon (non isolated) efficiency on J/ψ MUO-10-004;

Data reduction

Cut	Mu12 CentralJet30 BTagIP	Mu12 DiCentralJet30 BTagIP3D	Mu12 DiCentralJet20 DiBTagIP3D1stTrack	Mu12_eta2p1 DiCentralJet20 DiBTagIP3D1stTrack	Mu12_eta2p1 DiCentralJet20_NewJEC DiBTagIP3D1stTrack	All
All	3027717	4532555	2244550	1237147	5690304	16732273
$p_{\mathrm{T}}^{\mu} > 15\ GeV$	1757902	2678935	1337394	742231	3222677	9739139
$\#jets >= 3$	665962	1245655	639616	404082	1556012	4511327
$\Delta R_{ij} >= 1$	513981	957884	498996	315284	1219439	3505584
$CSV(1^{st} - jet) > 0.8$	242982	492734	297838	184075	714506	1932135
$CSV(2^{nd} - jet) > 0.8$	52345	112428	162029	99175	387708	813685
μ in 1^{st} or 2^{nd} jet	50708	108551	156147	95760	374774	785940
$CSV(3^{rd} - jet) > 0.7$	3245	7323	12796	7623	29208	60195
$\int \mathcal{L} dt\ [pb^{-1}]$	180.9	537.1	1108.6	652.2	2326.816	4805.7

Table: Data reduction after each selection cut for the various trigger paths

Signal reduction

Background Processes		
Description	Dataset Name	$\int \mathcal{L}dt$ $[fb^{-1}]$
QCD (μ enriched)	/QCD_Pt-20_MuEnrichedPt-15_TuneZ2_7TeV-pythia6	0.296
$t\bar{t} + jets$	/TTJets_TuneZ2_7TeV-madgraph-tauola	423
$Z \to bb$	/DYToBB_M_50_TuneZ2_7TeV_pythia6	0.98
$Z \to \mu\mu + jets$	/DYJetsToLL_TuneZ2_M-50_7TeV-madgraph-tauola	11 322
ZZ	/ZZ_TuneZ2_7TeV_pythia6_tauola	977
WZ	/WZ_TuneZ2_7TeV_pythia6_tauola	407
WW	/WW_TuneZ2_7TeV_pythia6_tauola	145
Signal Processes $bbH \to bbbb$		
$m_H = 90$ GeV	/SUSYBBHToBB_M-90_7TeV-pythia6-tauola	1.64
$m_H = 100$ GeV	/SUSYBBHToBB_M-100_7TeV-pythia6-tauola	2.29
$m_H = 120$ GeV	/SUSYBBHToBB_M-120_7TeV-pythia6-tauola	4.29
$m_H = 130$ GeV	/SUSYBBHToBB_M-130_7TeV-pythia6-tauola	5.41
$m_H = 140$ GeV	/SUSYBBHToBB_M-140_7TeV-pythia6-tauola	3.98
$m_H = 160$ GeV	/SUSYBBHToBB_M-160_7TeV-pythia6-tauola	6.22
$m_H = 180$ GeV	/SUSYBBHToBB_M-180_7TeV-pythia6-tauola	9.73
$m_H = 200$ GeV	/SUSYBBHToBB_M-200_7TeV-pythia6-tauola	14.80
$m_H = 250$ GeV	/SUSYBBHToBB_M-250_7TeV-pythia6-tauola	37.96
$m_H = 300$ GeV	/SUSYBBHToBB_M-300_7TeV-pythia6-tauola	87.52
$m_H = 350$ GeV	/SUSYBBHToBB_M-350_7TeV-pythia6-tauola	198.56

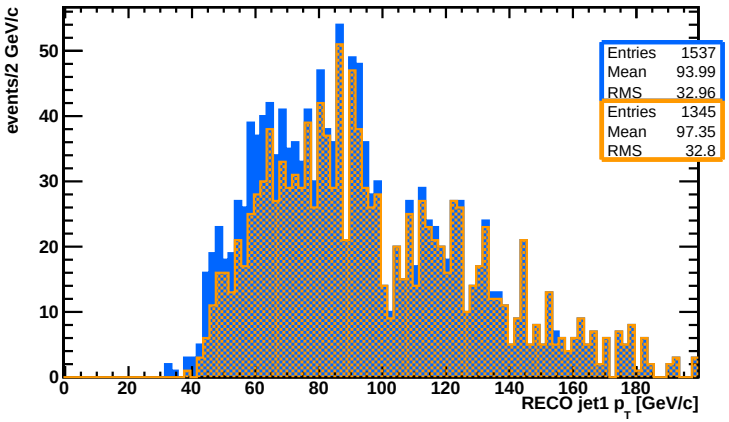
Table: Summary of MonteCarlo samples used in this analysis. For all sample, the full datasetpath is completed with `/Fall11-PU_S6_START42_V14B-v1/AODSIM`. For SUSY samples, the equivalent integrated luminosity refers to a cross section for $\tan\beta = 30$.

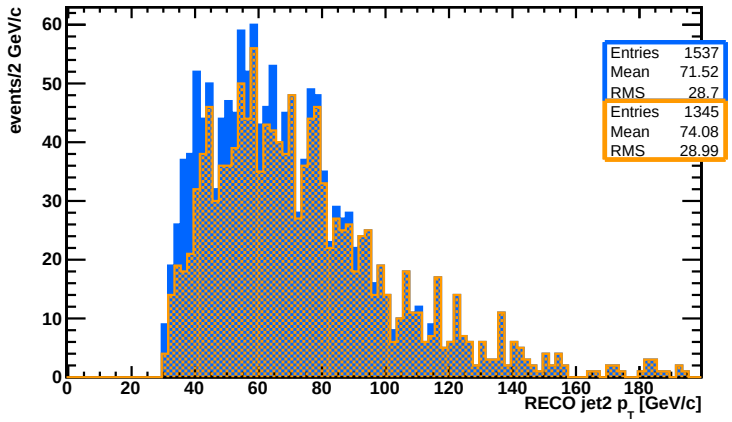
Signal reduction

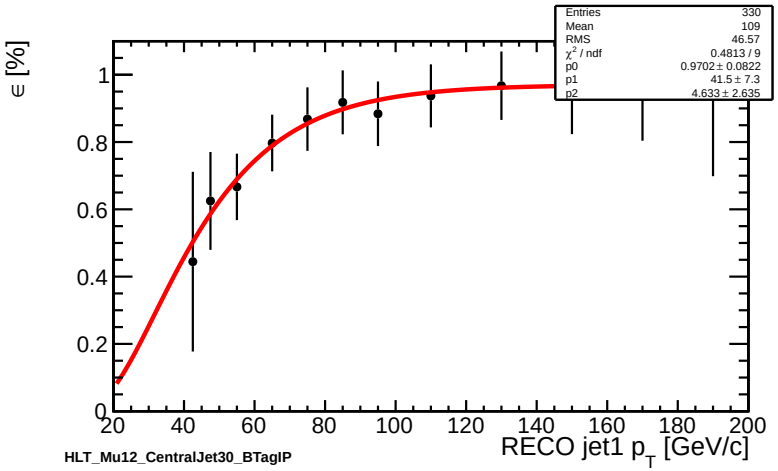
Cut	M_H [GeV] 250	300	350
All	69624	29935	13310
$p_T^{\mu} > 15$ GeV	8040	4014	1999
$\#jets >= 3$	3012	1686	901
$\Delta R_{ij} >= 1$	2381	1303	685
$CSV(1^{st} - jet) > 0.8$	1584	850	441
$CSV(2^{nd} - jet) > 0.8$	986	531	271
μ in 1^{st} or 2^{nd} jet	860	465	239
$CSV(3^{rd} - jet) > 0.7$	340	181	92
ϵ [%]	0.488	0.605	0.691

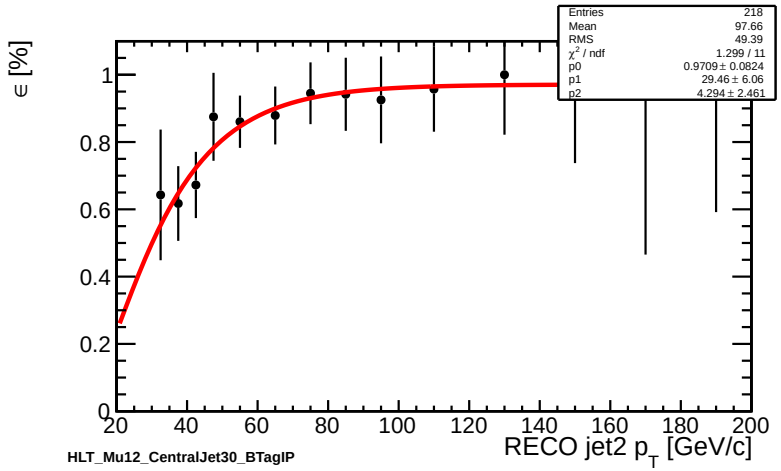
Table: Events reduction for selection cuts for SUSY simulated signal samples, normalized to a cross section for $\tan\beta = 30$, for mass point in the high mass range $M_H > 200$ GeV. The trigger efficiency is included only starting from the cut $\#jets >= 3$ by applying the data driven turn-on curves.

HLT_Mu12_CentralJet30_BTagIP

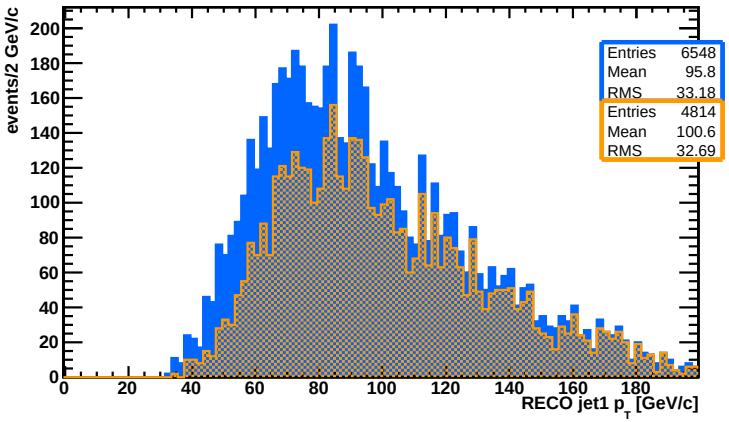


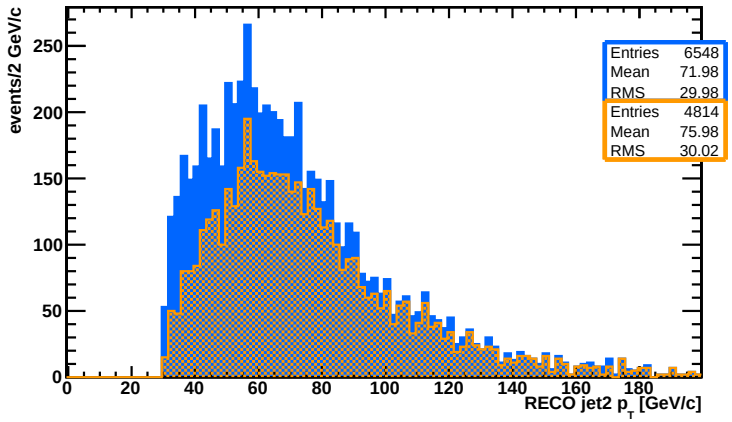


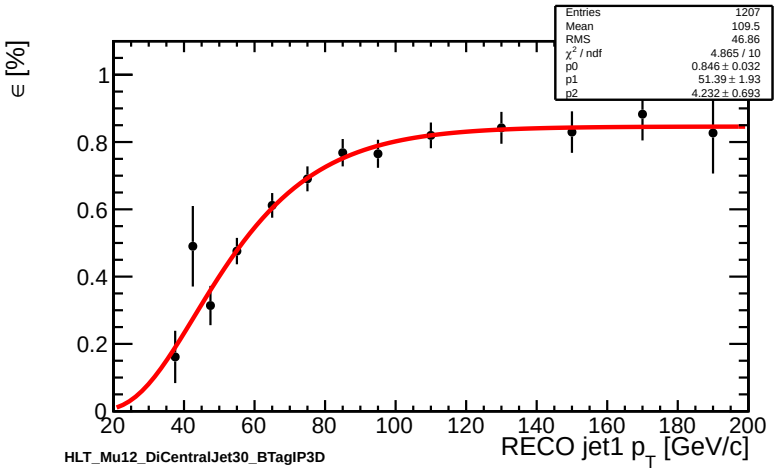


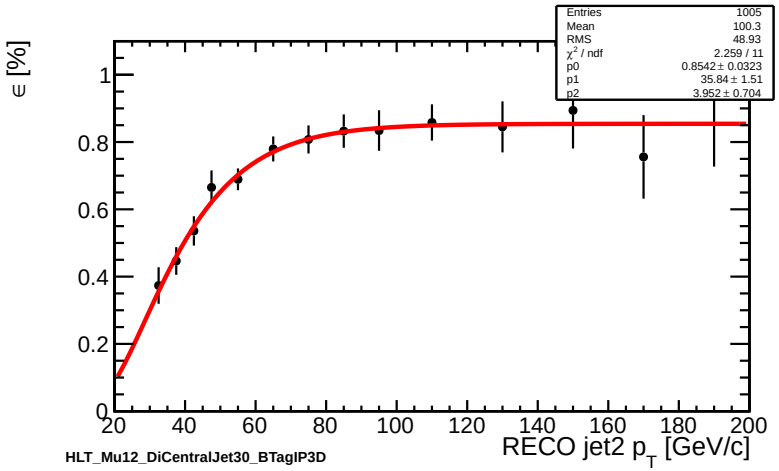


HLT_Mu12_DiCentralJet30_BTagIP3D

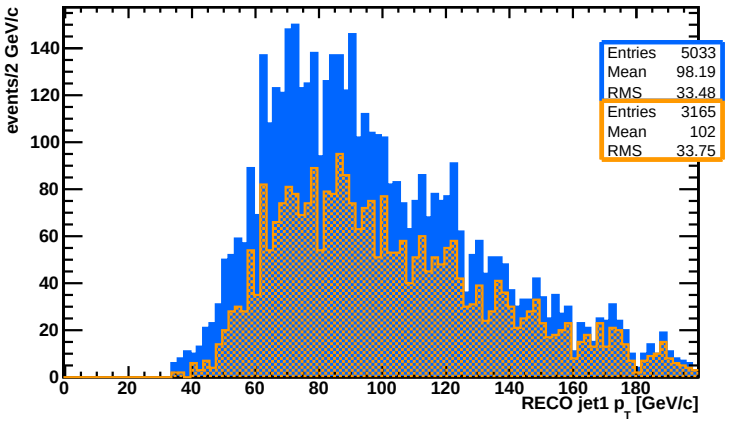


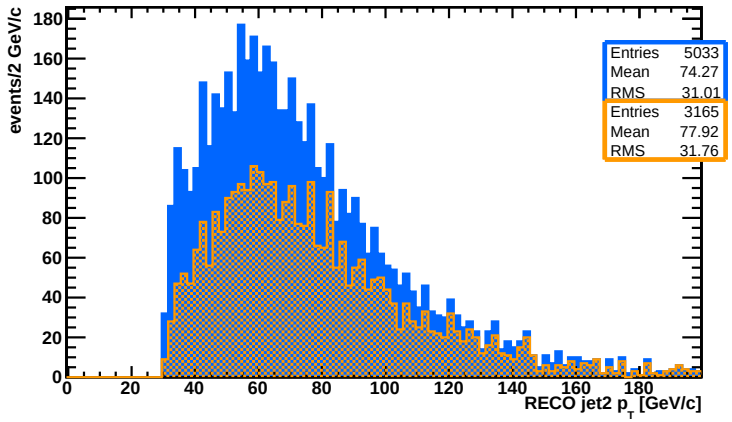


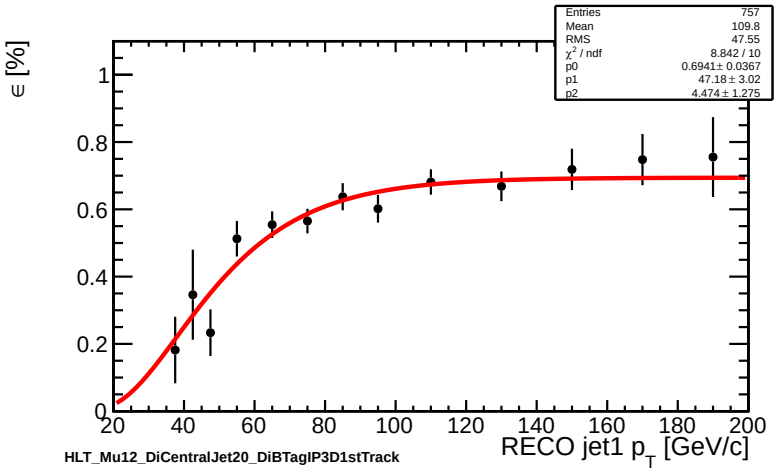


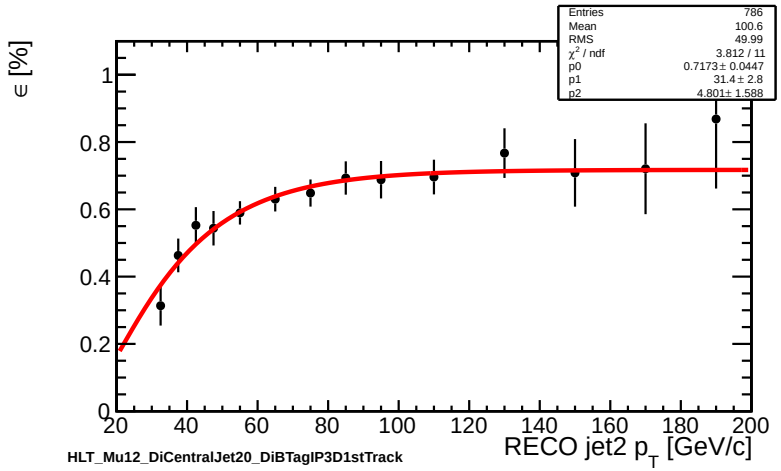


HLT_Mu12_DiCentralJet20_DiBTagIP3D1stTrack

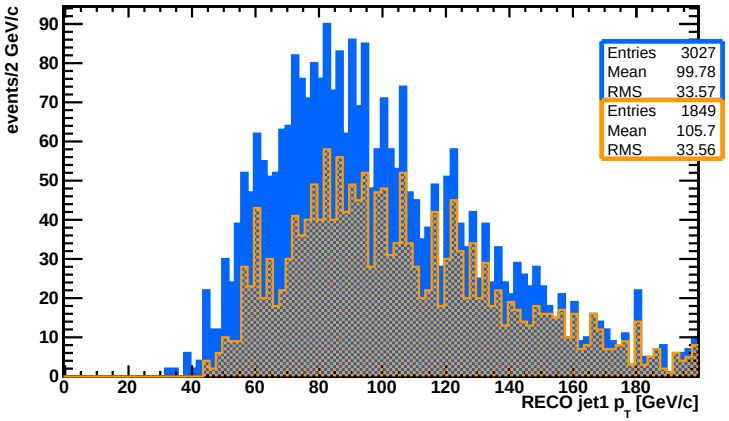


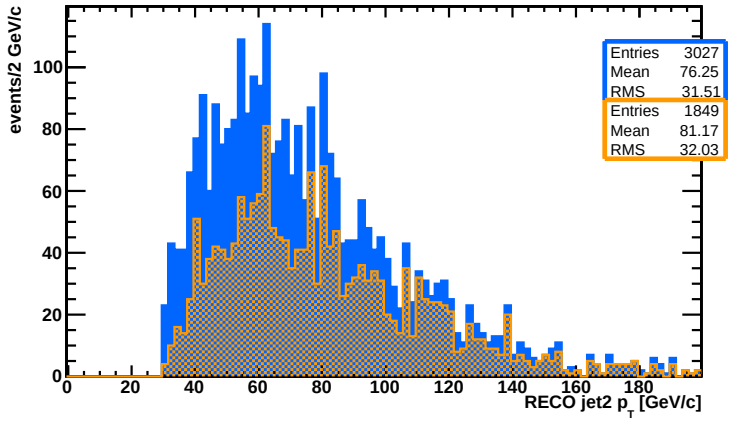


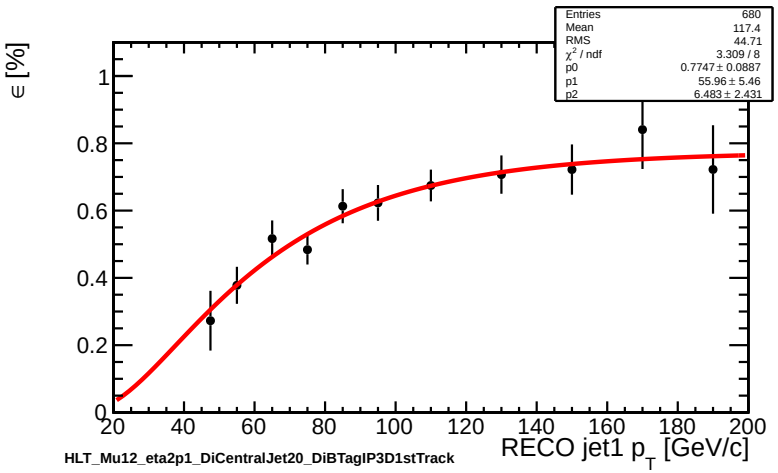


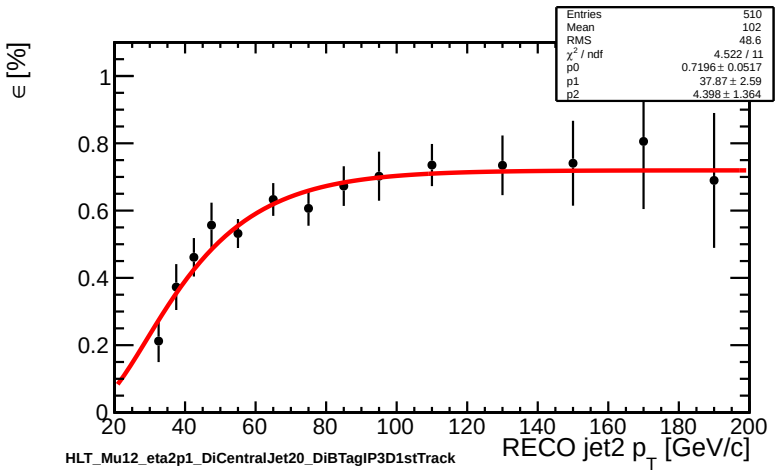


HLT_Mu12_eta2p1_DiCentralJet20_DiBTagIP3D1stTrack

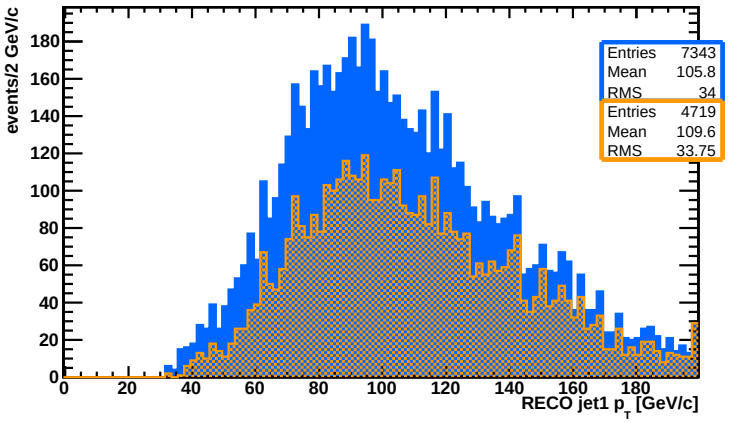


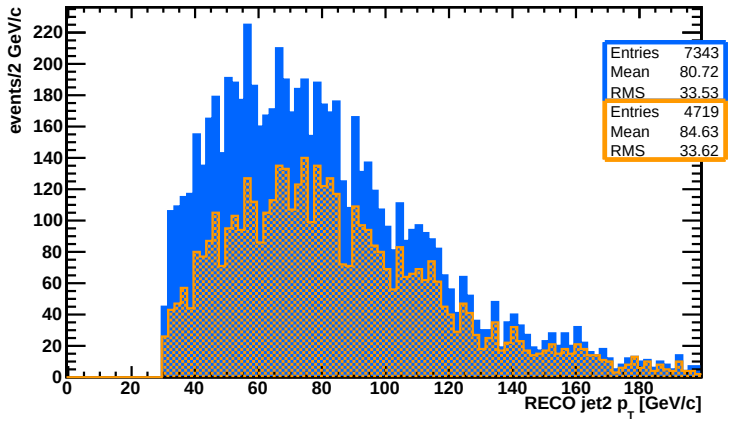


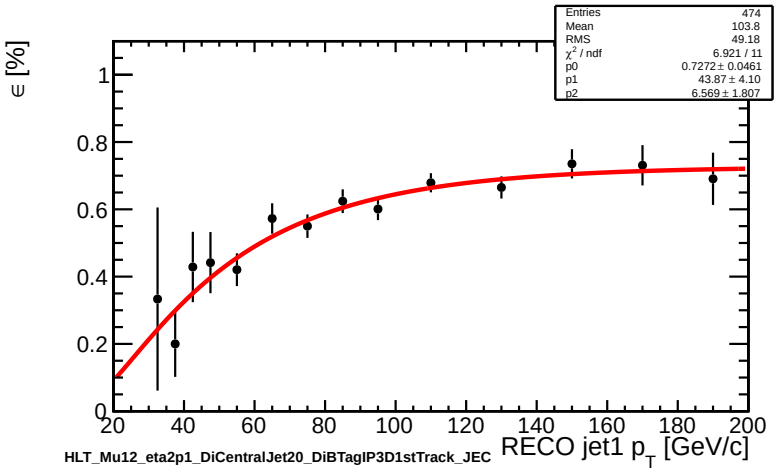


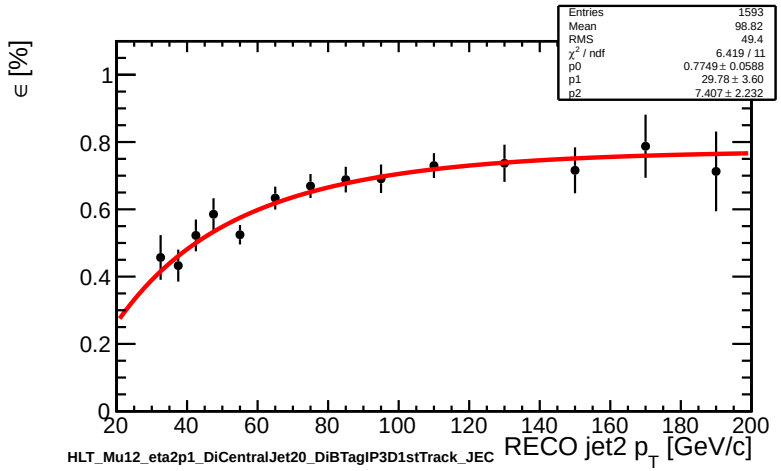


HLT_Mu12_eta2p1_DiCentralJet20_DiBTagIP3D1st



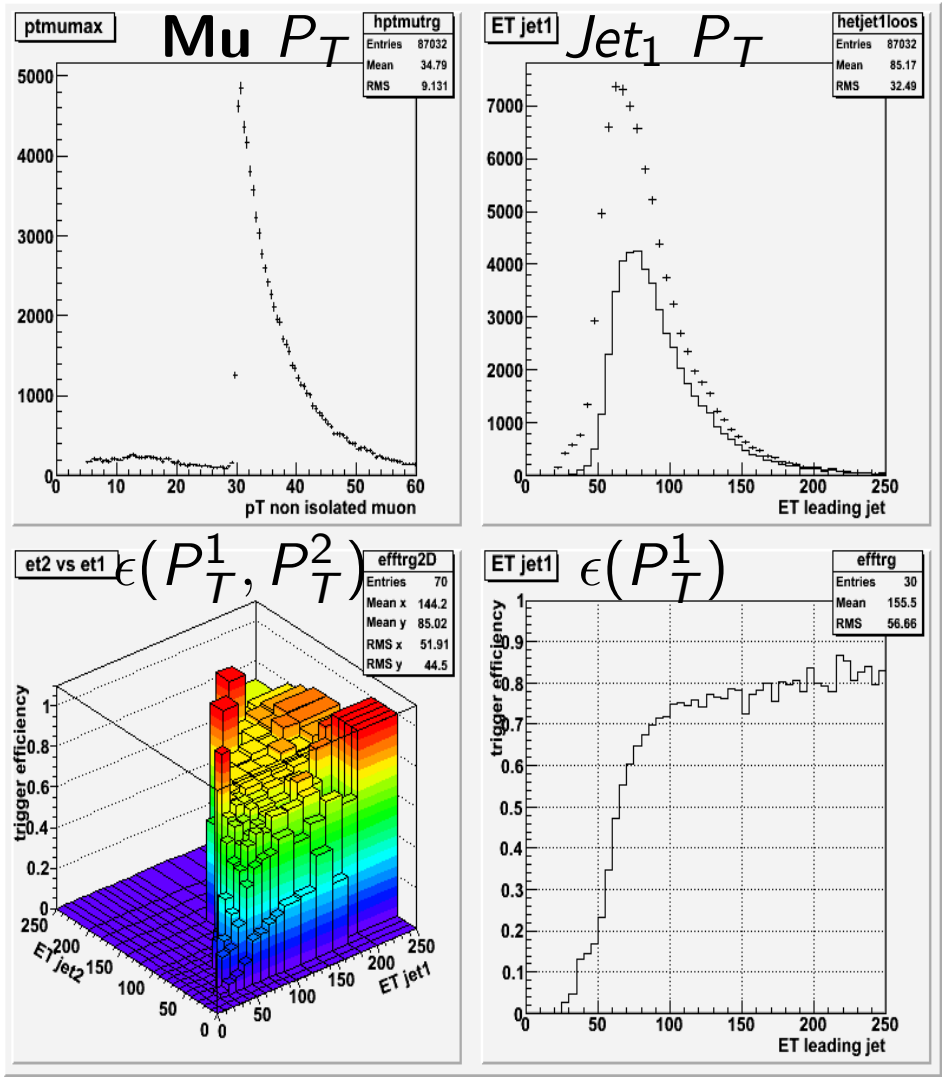




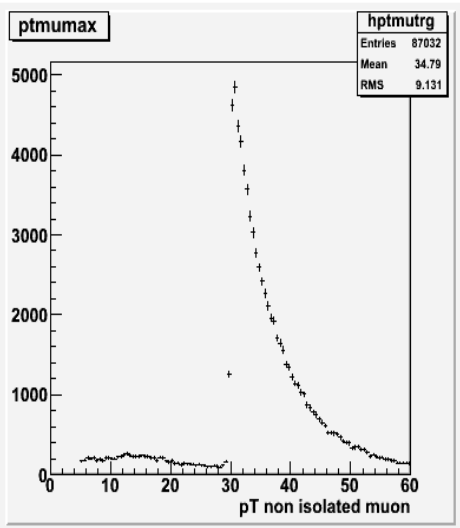


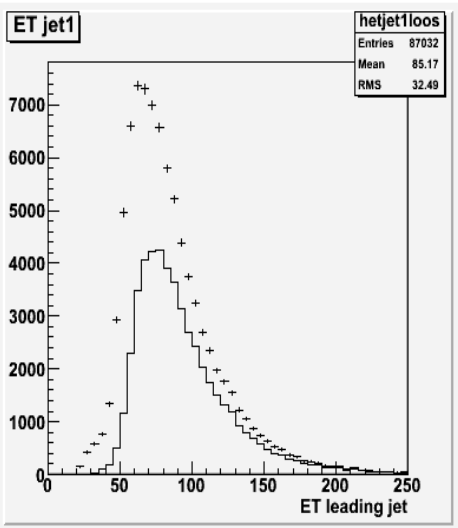
Trigger Efficiency vs Analysis

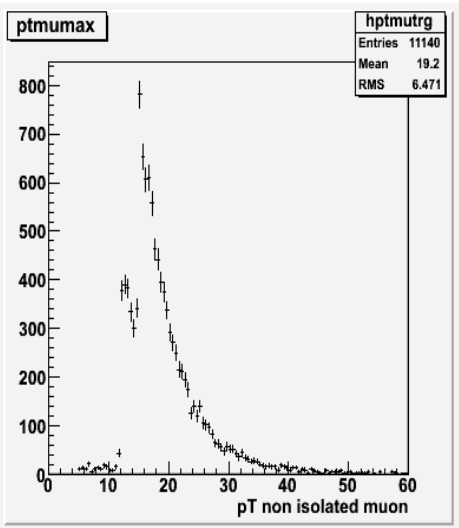
- Use **SingleMuon PD**, select all events passing a single muon path.
- Apply preselection (2 bjets)
- Build Turn on curves vs first and second B-jets Pt:
  $\epsilon = \frac{\text{Hbb path \& presel \& SingleMuHLT}}{\text{presel \& SingleMuHLT}}$
- Here for `HLT_Mu12_DiCentralJet30_BtagIP3D` and `SingleMu30`
- Turn-on stable wrt SingleMu threshold

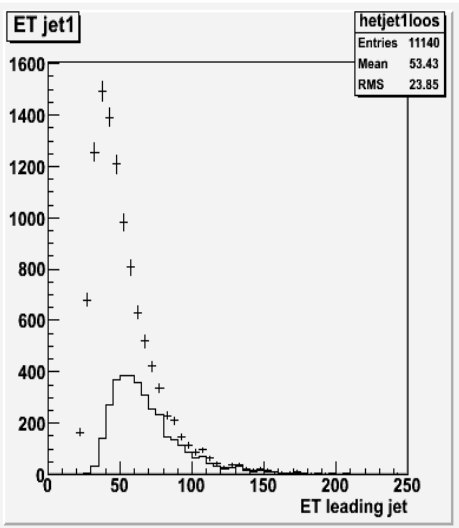


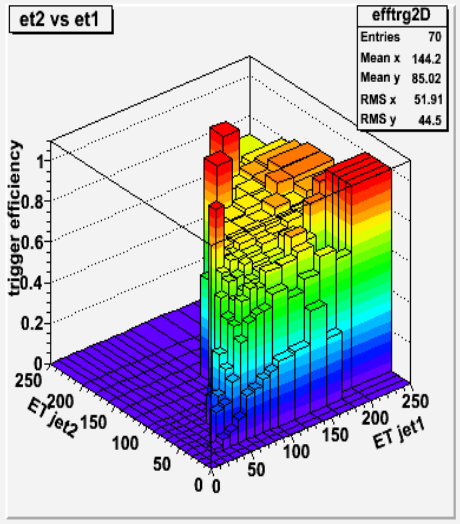
Trigger Efficiency (I)

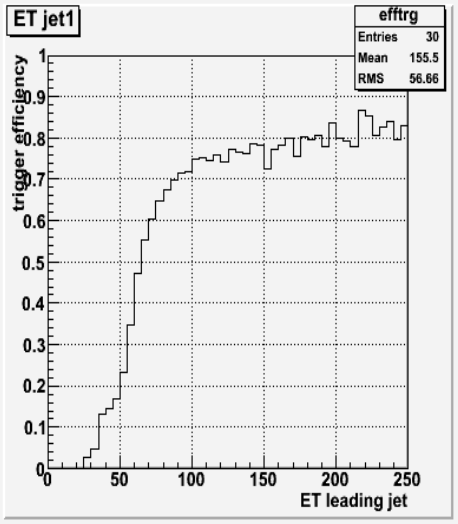


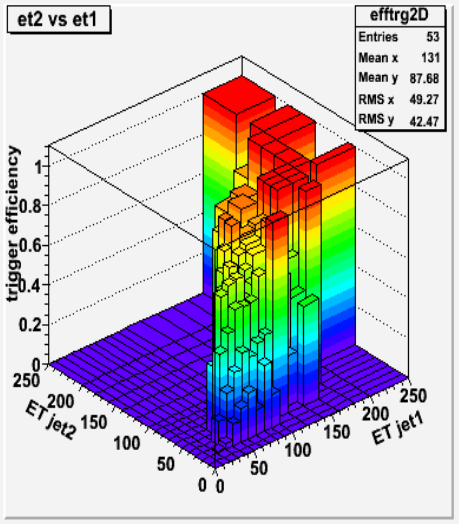


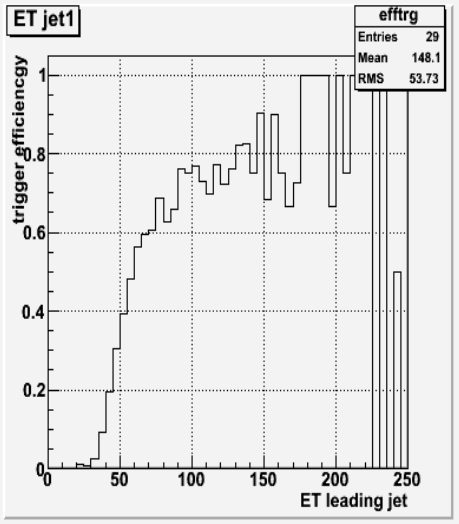








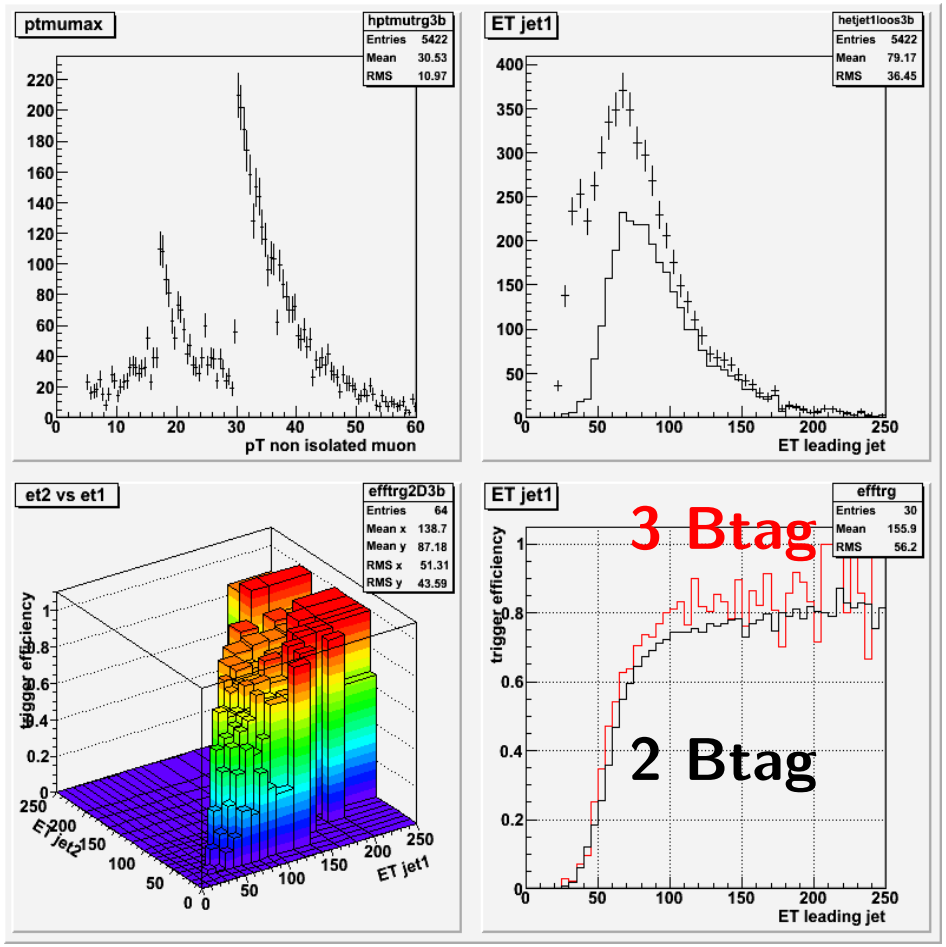




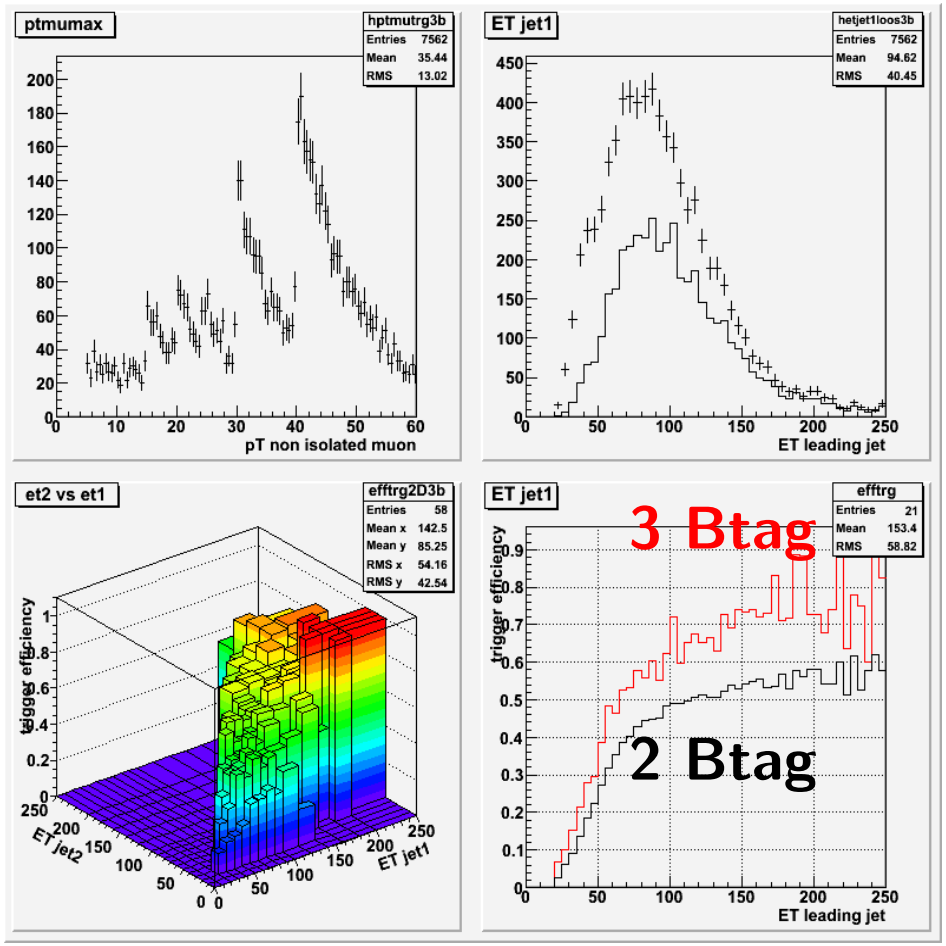
Turn-on stable for different SingleMu threshold (left Mu30, right Mu12 &

Trigger Efficiency (II) 2 btags vs 3 btags

HLT_Mu12_DiCentralJet30_BtagIP3D



HLT_Mu12_DiCentralJet20_DiBtagIP3D1stTrack



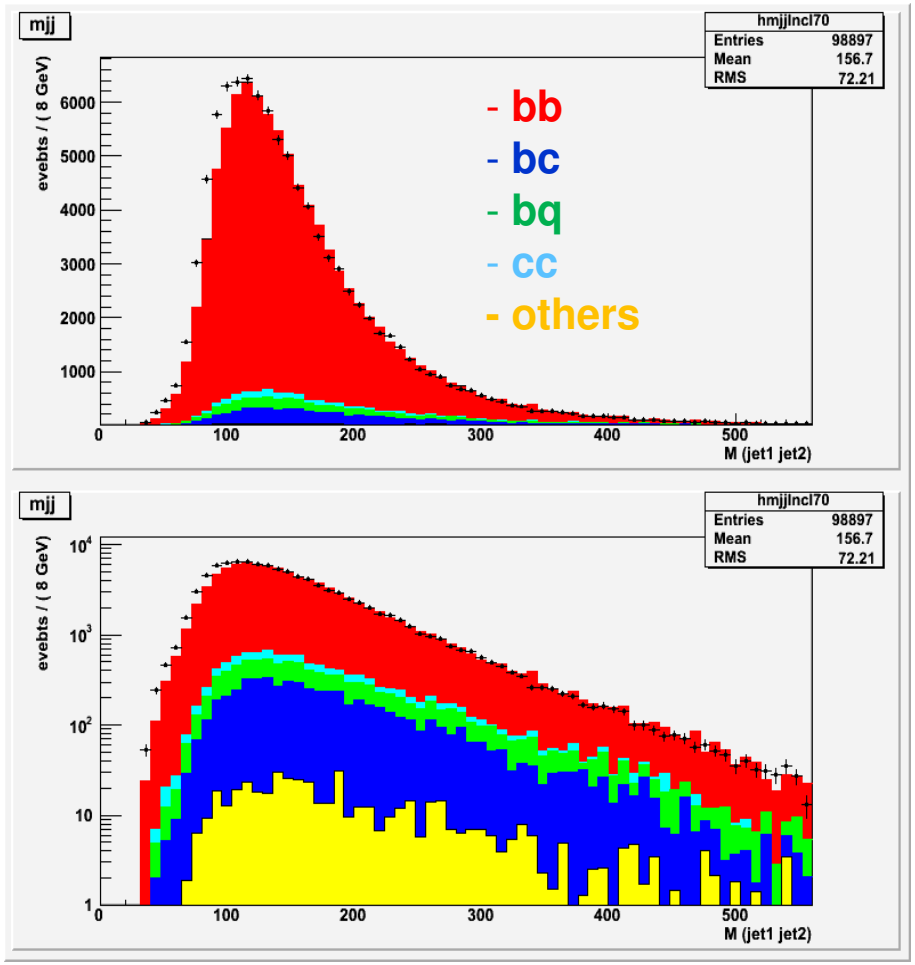
Statistics bit low but still affordable

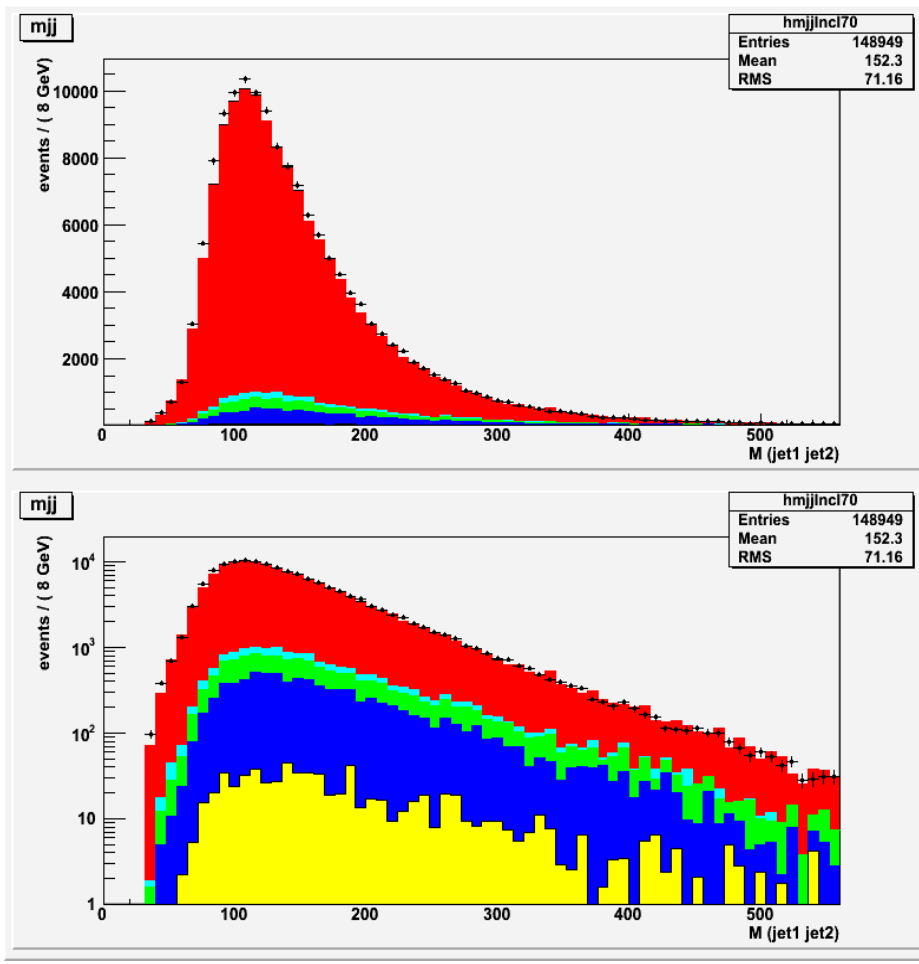
Mass spectra, trigger corrected

HLTMu12_DicentralJet30_BtagIP3D — **L = 525 pb-1**

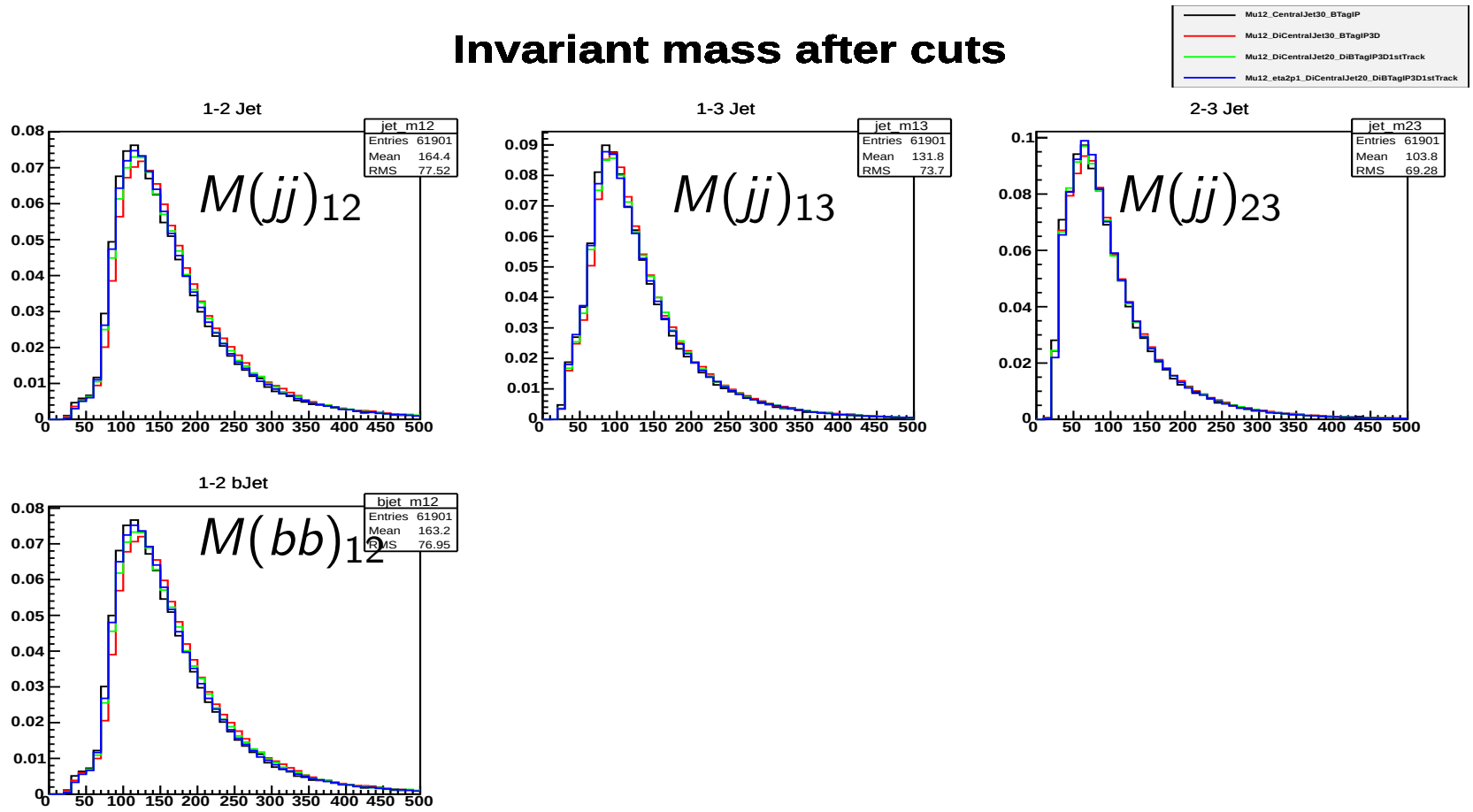
2 btags

HLTMu12_DicentralJet20_DiBtagIP3D1stTk — **L = 1002 pb-1**



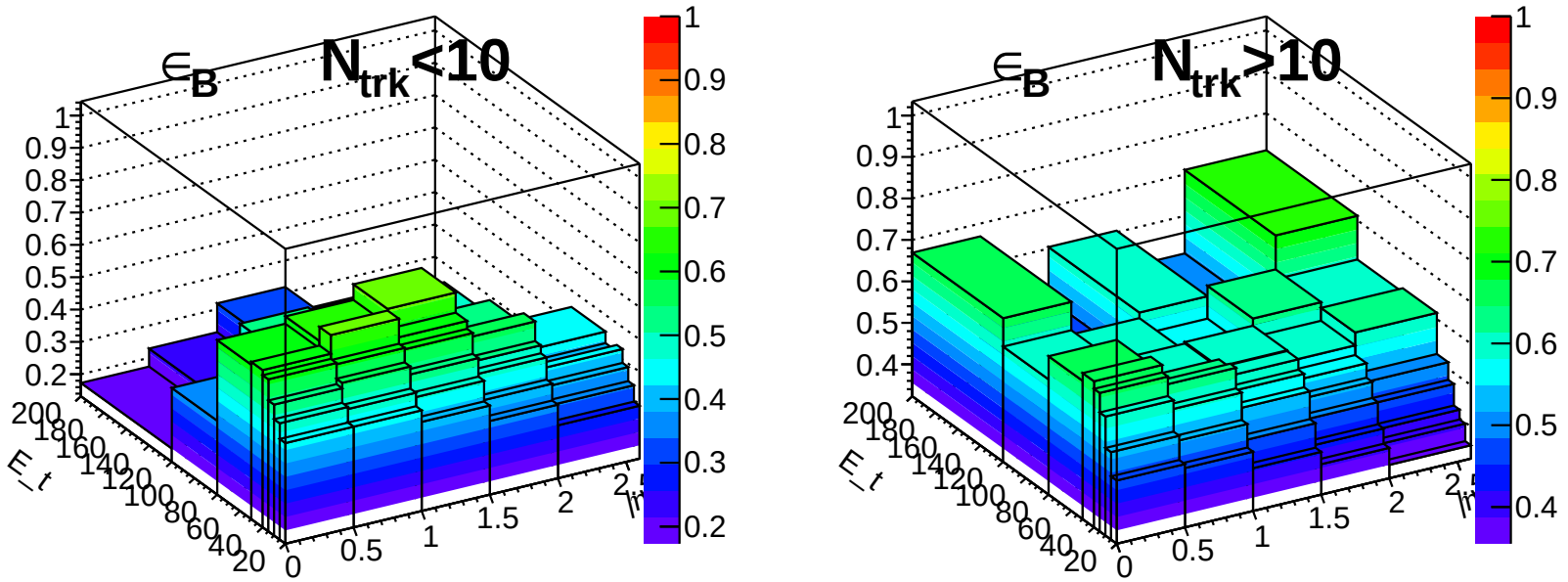


M_{jj} and M_{bb} for different HLT paths



Applying pre-selections (2 b-tag) only: no bias in M_{jj} nor M_{bb}

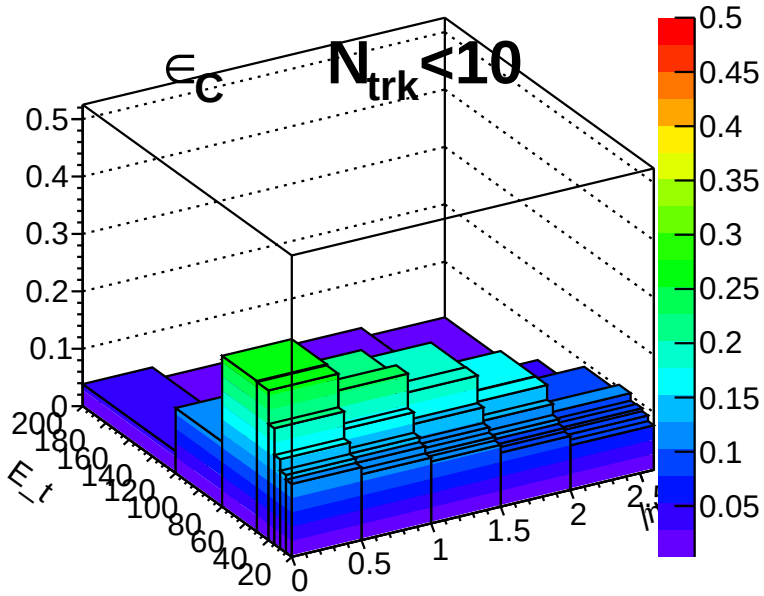
ϵ_b for bbj vs $|\eta|$, E_t vs N_{trk}

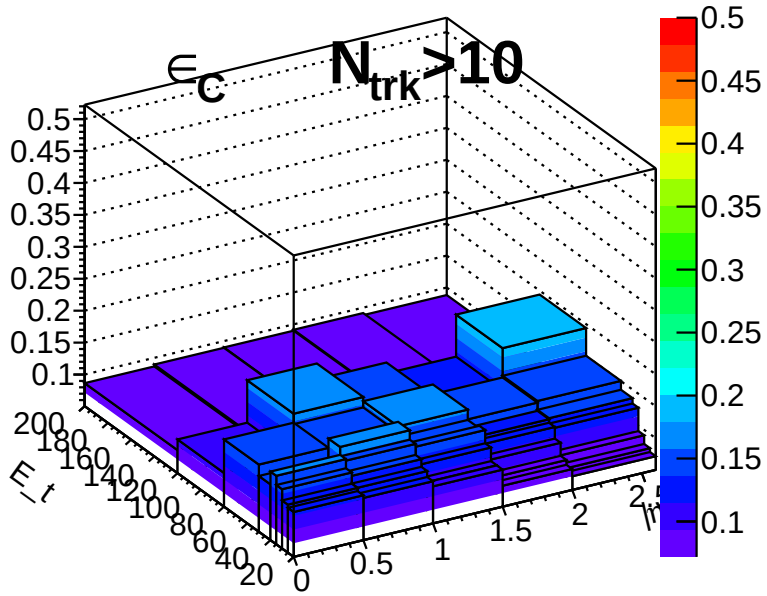


Left to Right:

ϵ_B All, $N_{trk} < 10$, $N_{Trk} \geq 10$

ϵ_c for bbj vs $|\eta|$, E_t vs N_{trk}

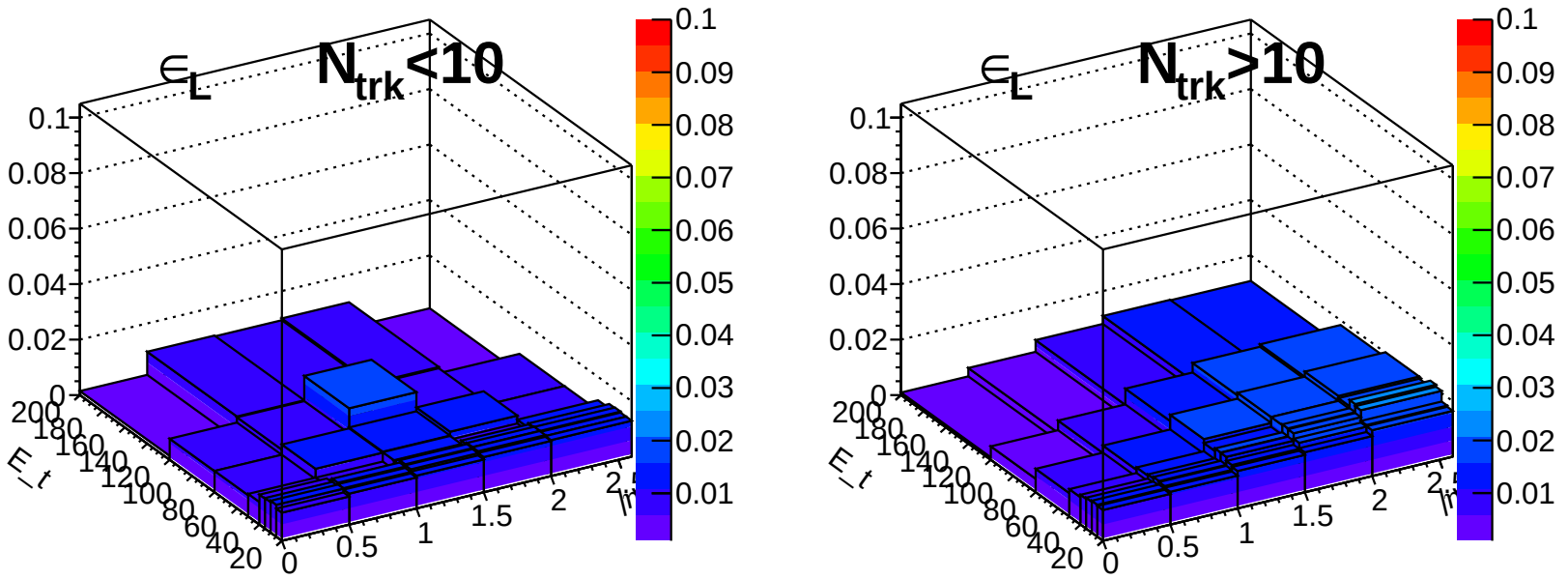




Left to Right:

ϵ_C All, $N_{trk} < 10$, $N_{Trk} \geq 10$

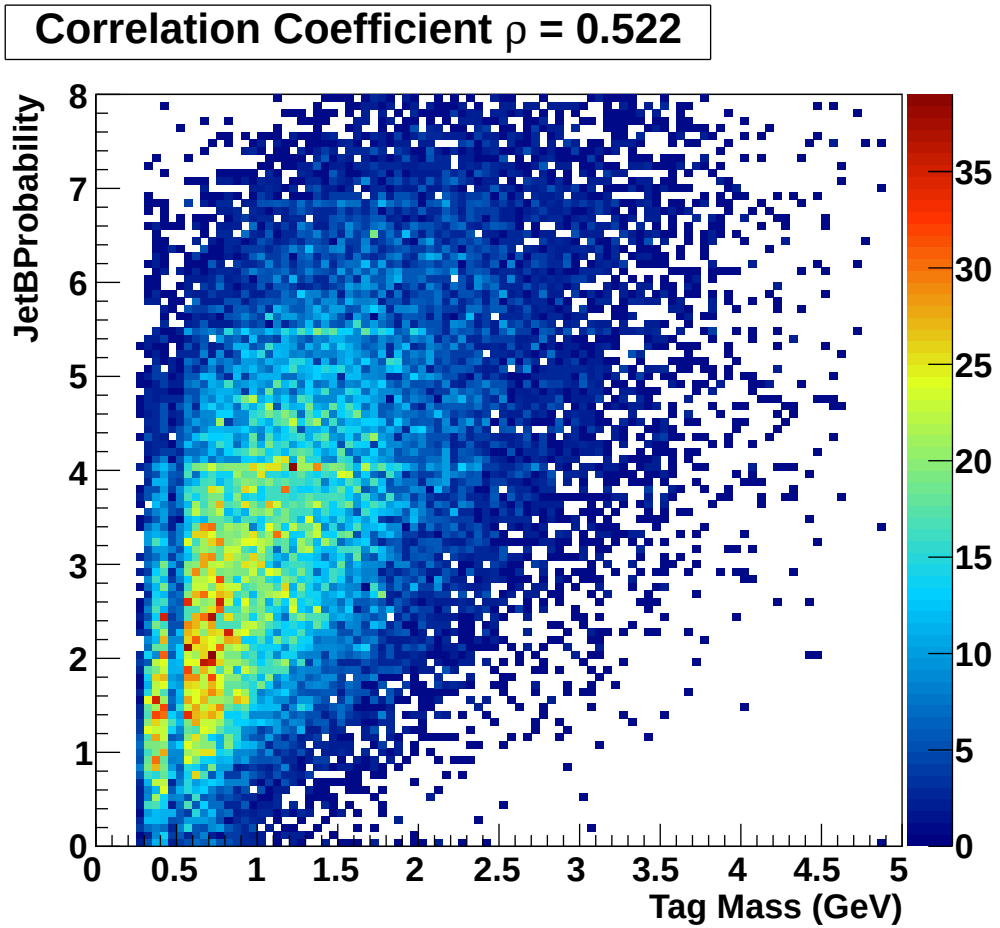
ϵ_{light} for bbj vs $|\eta|$, E_t vs N_{trk}



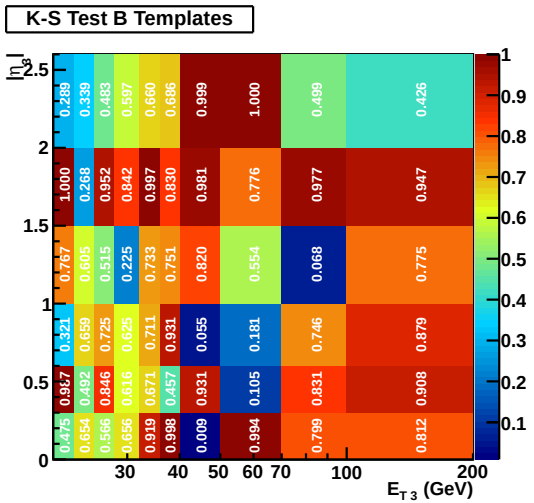
Left to Right:

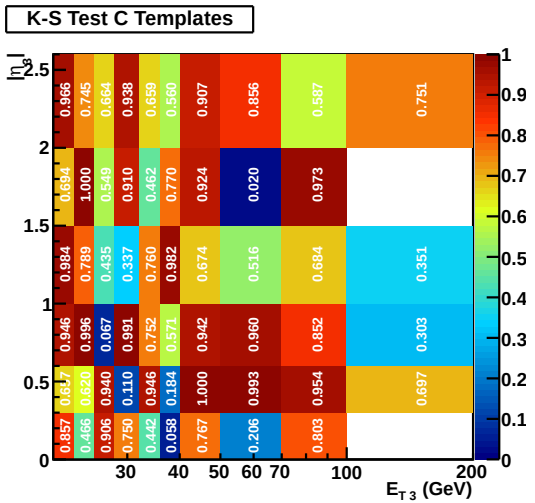
ϵ_{Light} All, $N_{trk} < 10$, $N_{Trk} \geq 10$

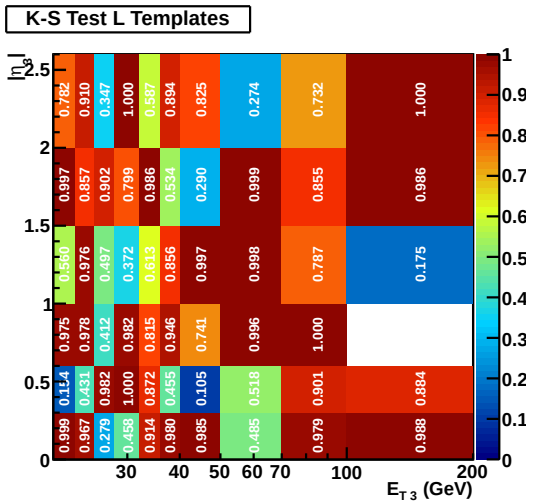
Mass@Vertex and JetBProbabiliy correlation



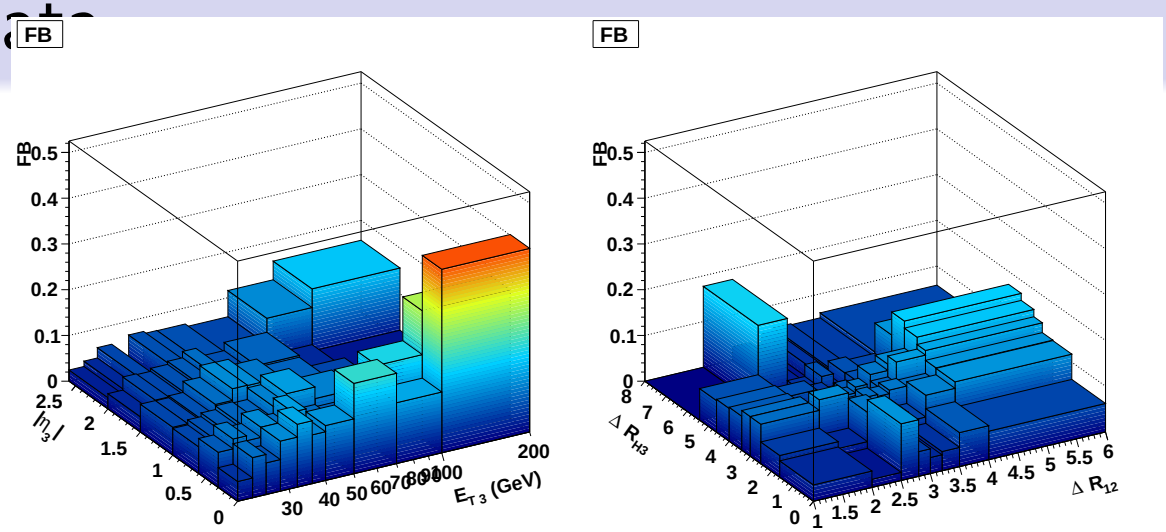
Template jjj vs bbj



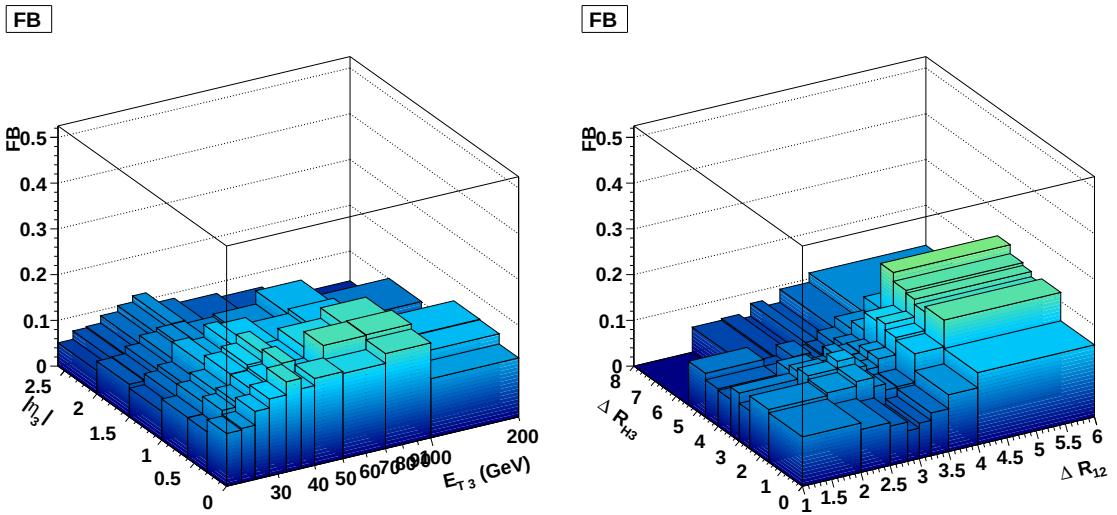




Fb in Data



(a) Single Btag triggered sample



$F_{b,c}$ parametrization

$$F_{B,C}\left(E_T^{(j_3)}, \left|\eta^{(j_3)}\right|\right) \times F_{B,C}\left(\Delta R_{H,j_3}, |\Delta R_{j_1,j_2}|\right)$$

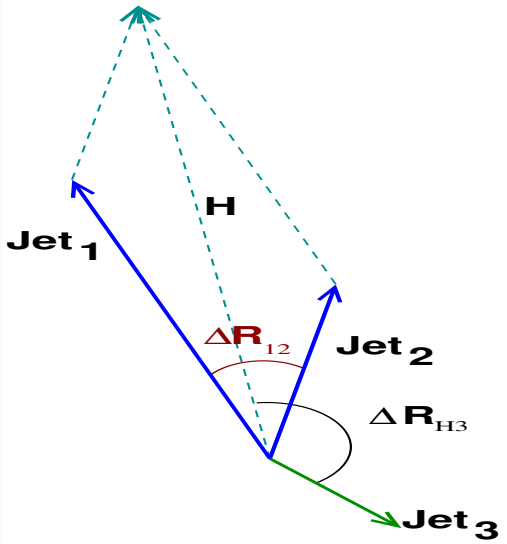
assuming no correlation.

One factor for the third jet features, one for the event topologies.

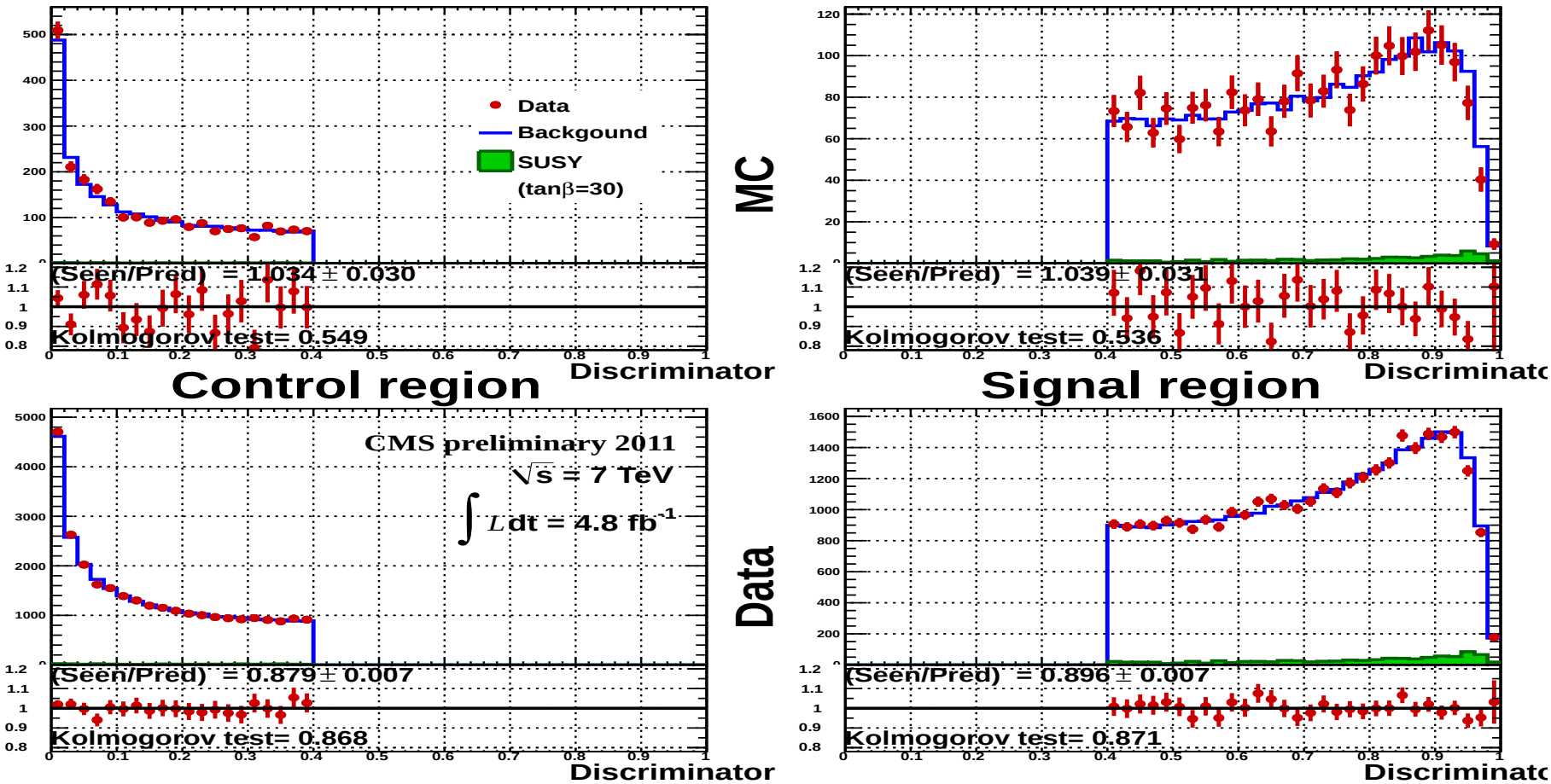
Use $F_{B,C}(\Delta R_{H,j_3}, |\Delta R_{j_1,j_2}|)$ only for shape:

$F_{B,C}$ average, weighted to *bbj* distribution, is normalized to unity.

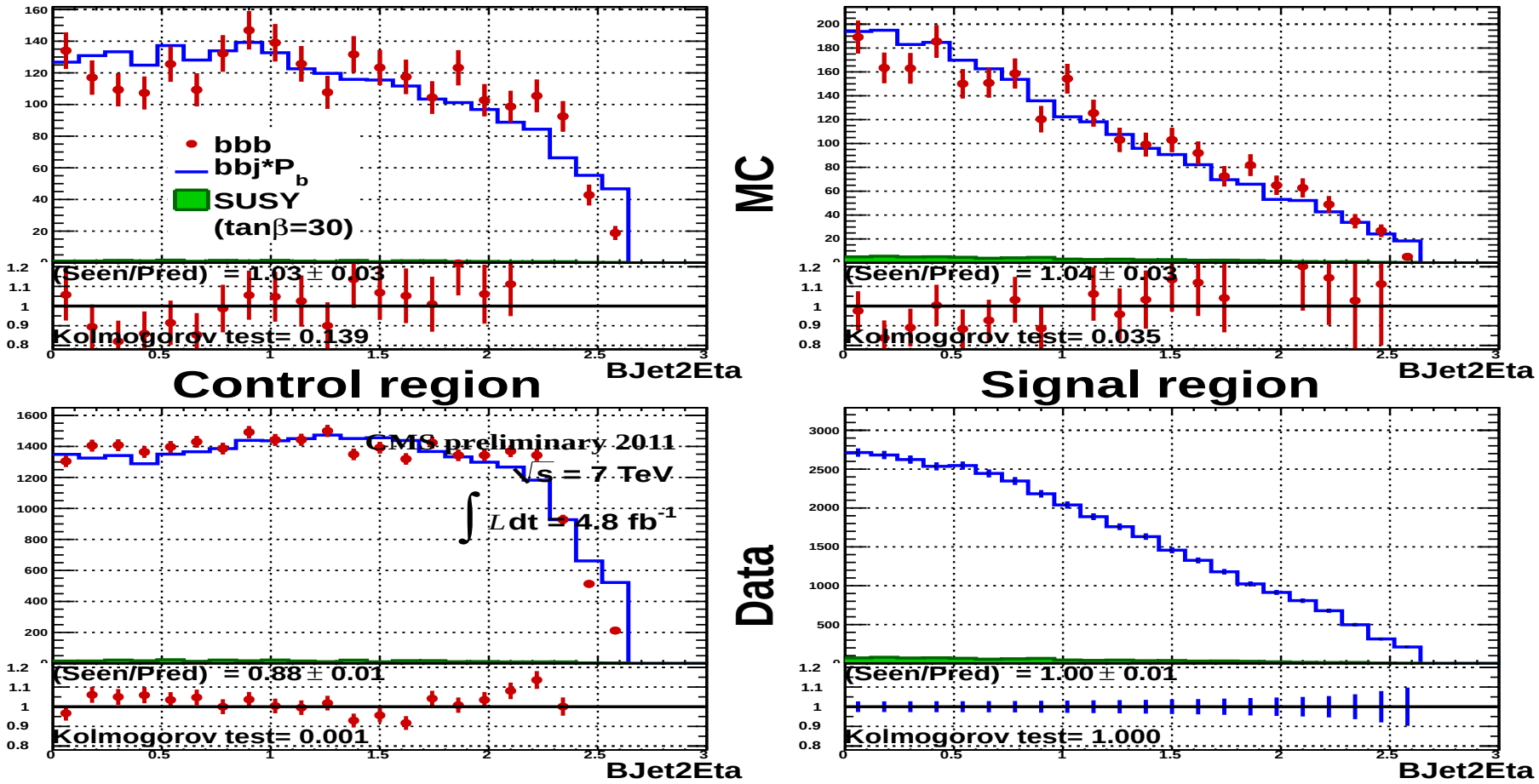
$$\int_{C\ reg.} \frac{dN}{d\Delta R_{12} d\Delta R_{H,j3}} \cdot F_{B,C}\left(\Delta R_{H,j3}, \Delta R_{12}\right) d\Delta R_{12} d\Delta R_{H,j3} = \int_{C\ reg.} \frac{dN}{d\Delta R_{12} d\Delta R_{H,j3}} d\Delta R_{12} d\Delta R_{H,j3}$$



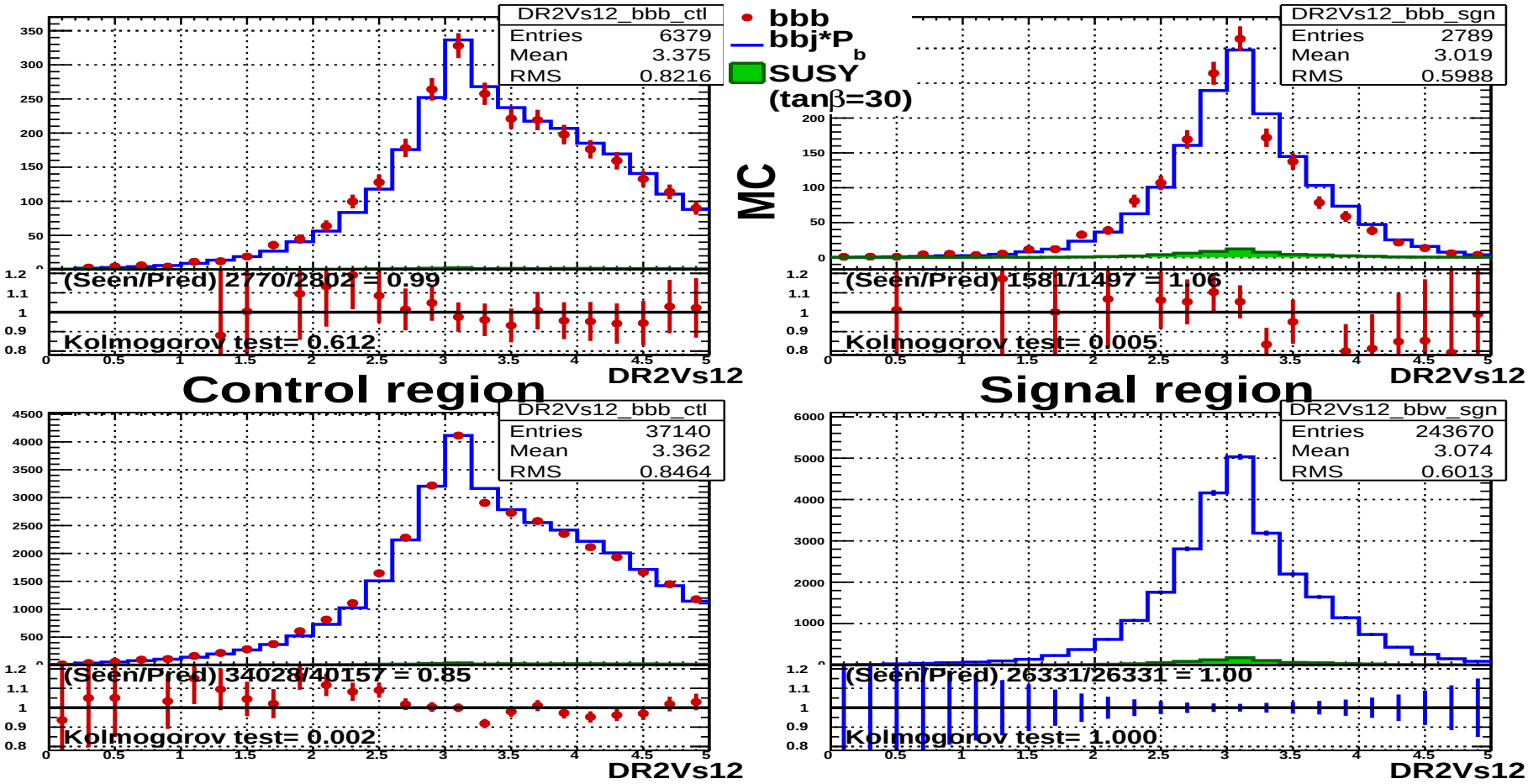
Prediction vs *bbb* in MC and Data



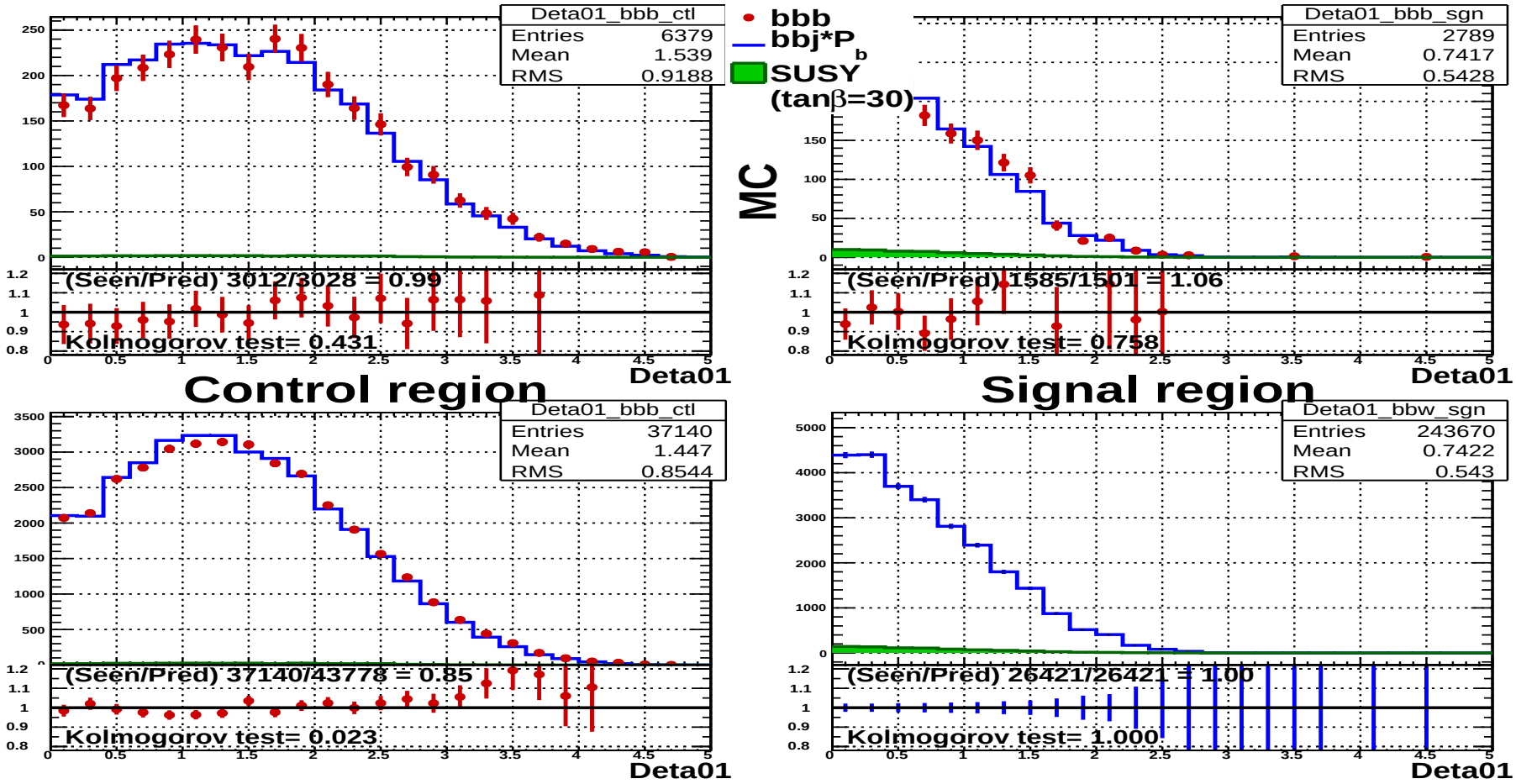
Prediction vs *bbb* in MC and Data



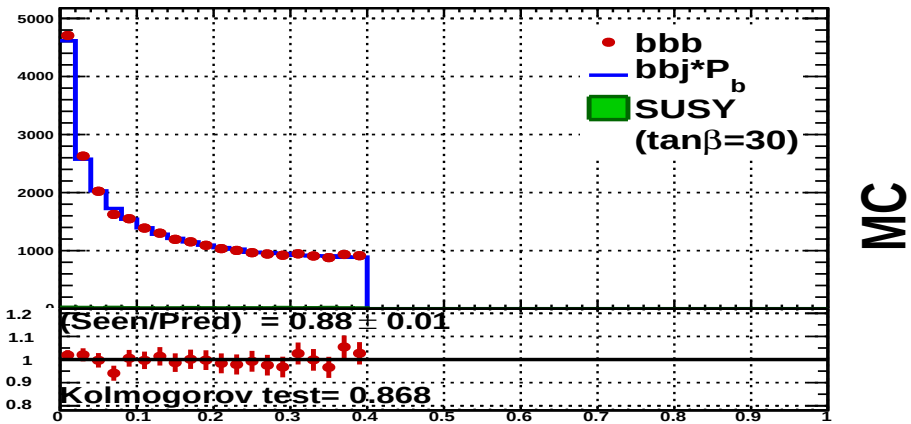
Prediction vs *bbb* in MC and Data



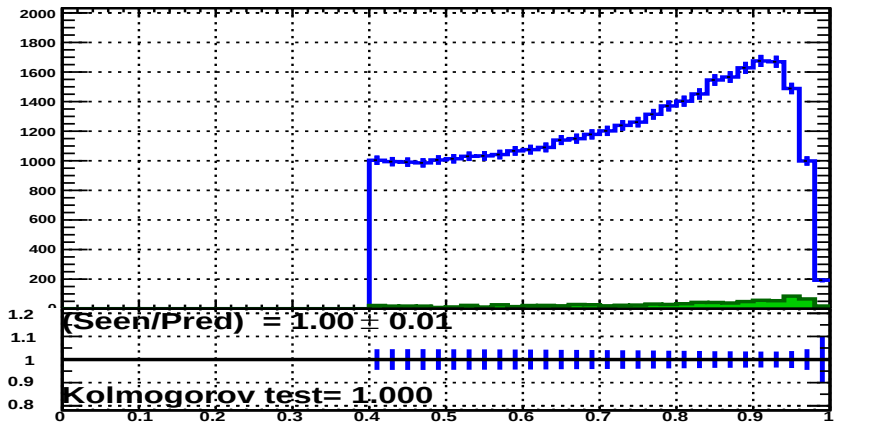
Prediction vs *bbb* in MC and Data



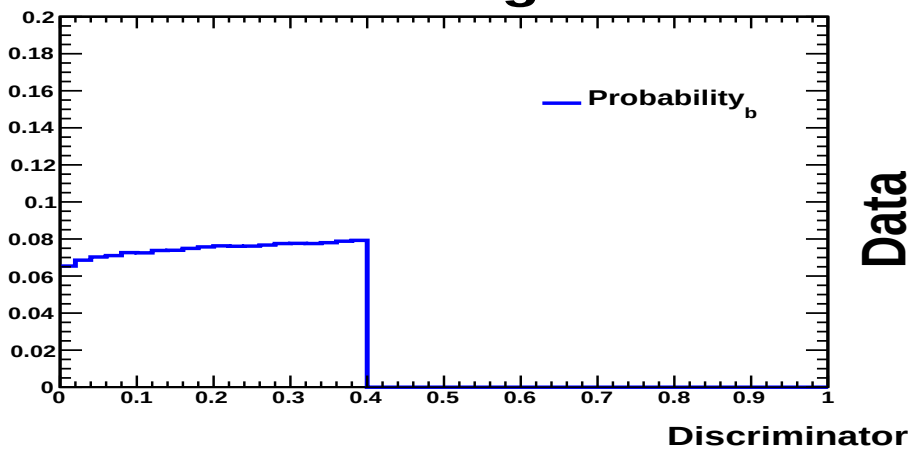
Prediction vs *bbb* and Data



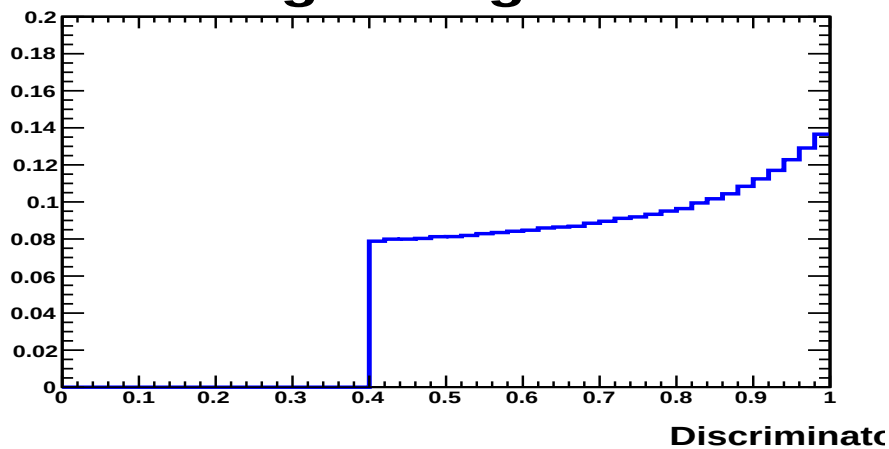
MC



Control region **Signal region**

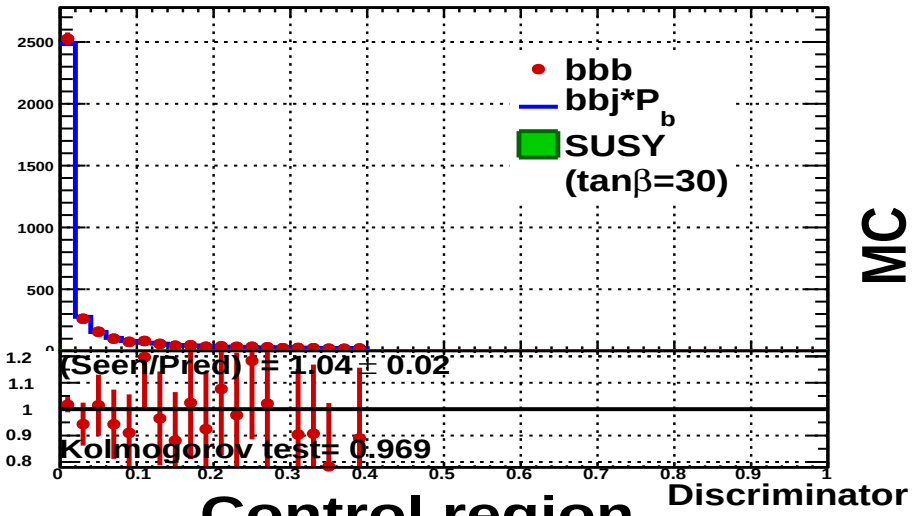


Data

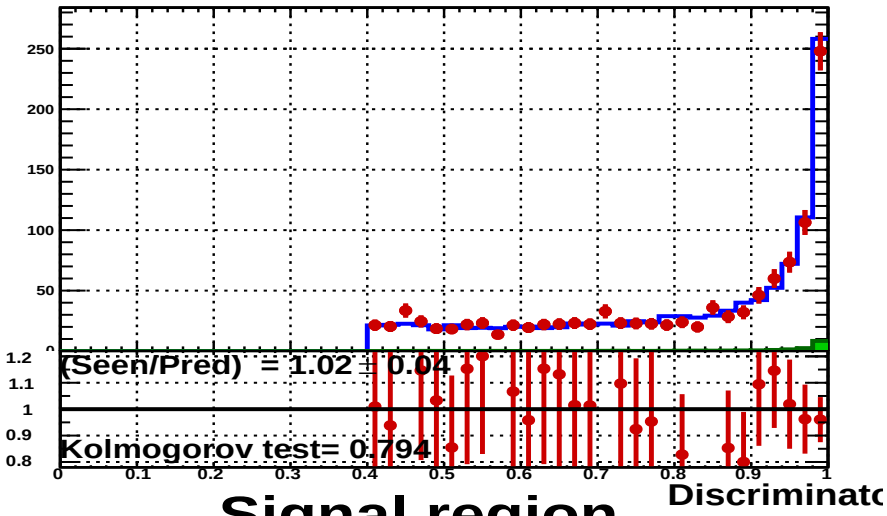


Discriminator prediction vs *bbb* in MC and Data

in control and signal region: High Mass ($M_H > 200$) susy $M_H = 250$ *GeV*

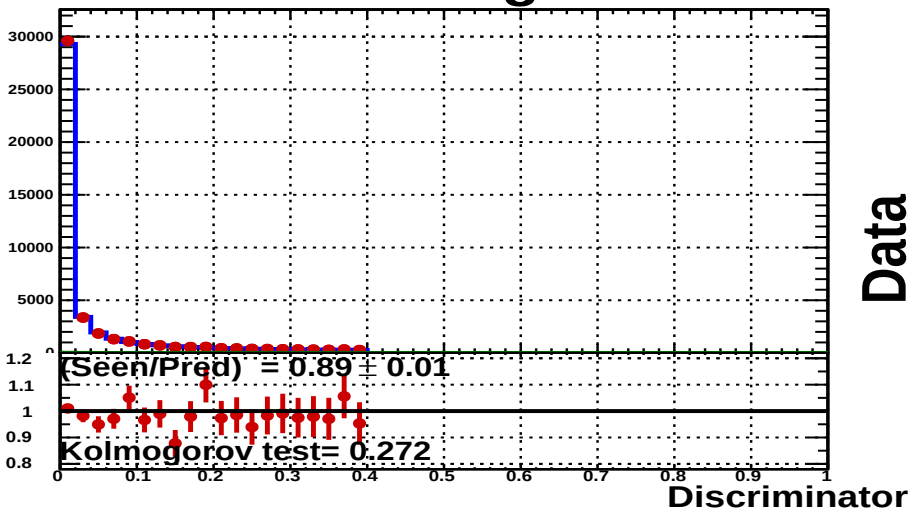


MC

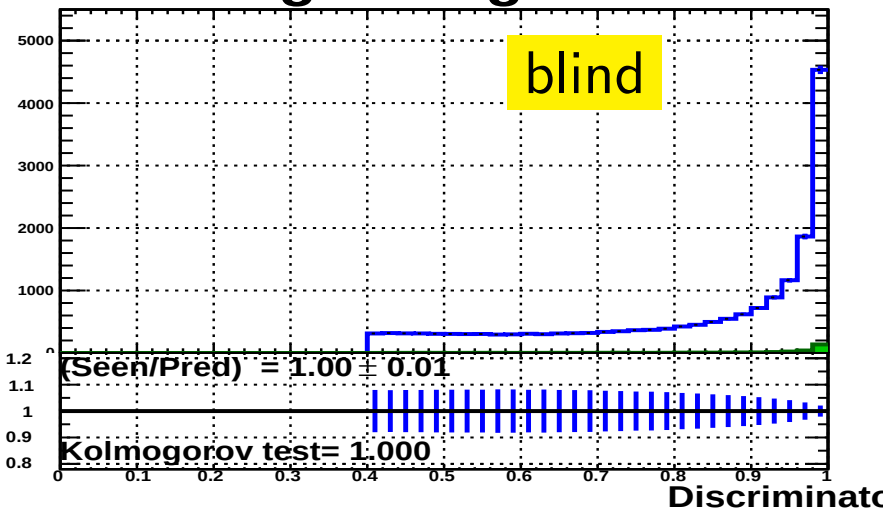


Control region

Signal region



Data

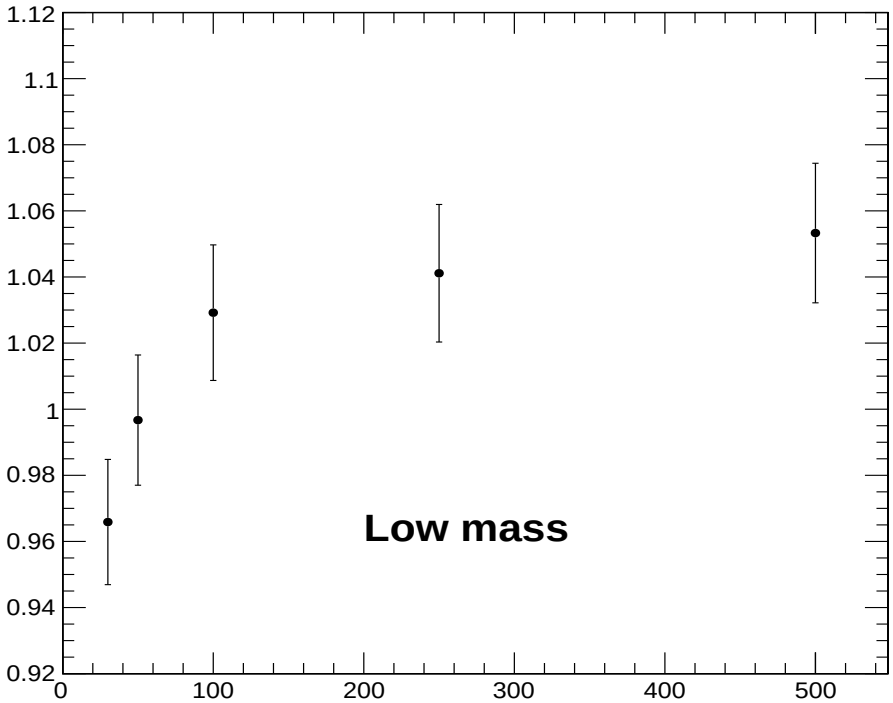


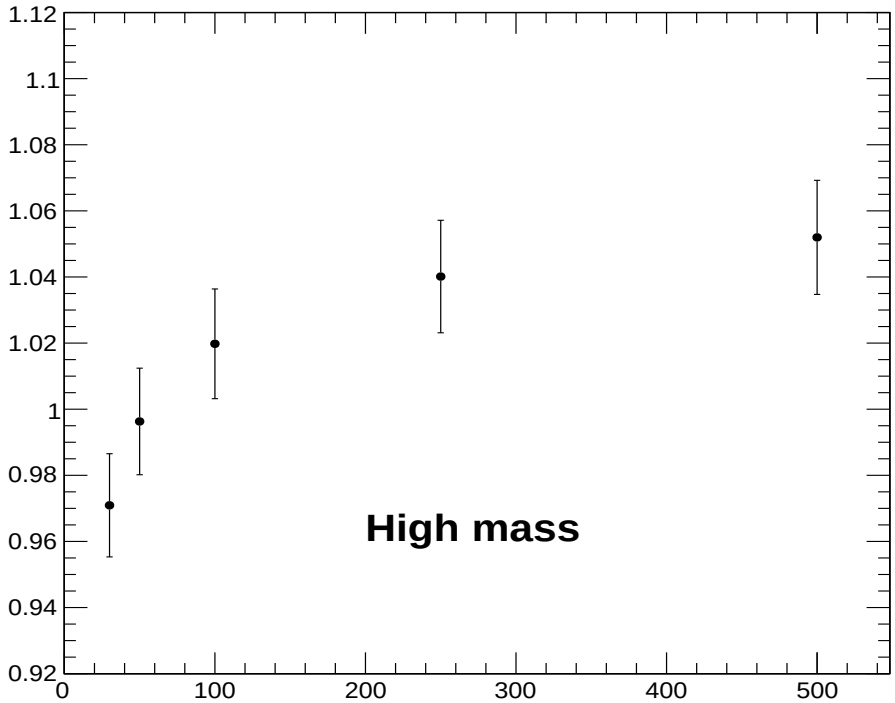
Variable used in HB

E_{T1}	1^{st} jet transverse energy
η_1	1^{st} jet pseudorapidity
E_{T2}	2^{nd} jet transverse energy
η_2	2^{nd} jet pseudorapidity
$n_{\mathrm{tk}2}$	2^{nd} jet track multiplicity
E_{T3}	3^{rd} jet transverse energy
η_3	3^{rd} jet pseudorapidity
$n_{\mathrm{tk}3}$	3^{nd} jet track multiplicity
$\Delta\varphi_{12}$	1^{st} and 2^{nd} jet azimut difference
ΔR_{23}	2^{nd} and 3^{rd} jet R distance
M_{12}	1^{st} and 2^{nd} jet invariant mass
p_{T12}	1^{st} and 2^{nd} jet combined transverse momentum
p_{T23}	2^{nd} and 3^{rd} jet combined transverse momentum
p_{T123}	1^{st}, 2^{nd} and 3^{rd} jet combined transverse momentum

Table: List of variables used to build the "distance" as defined in eq.**??**

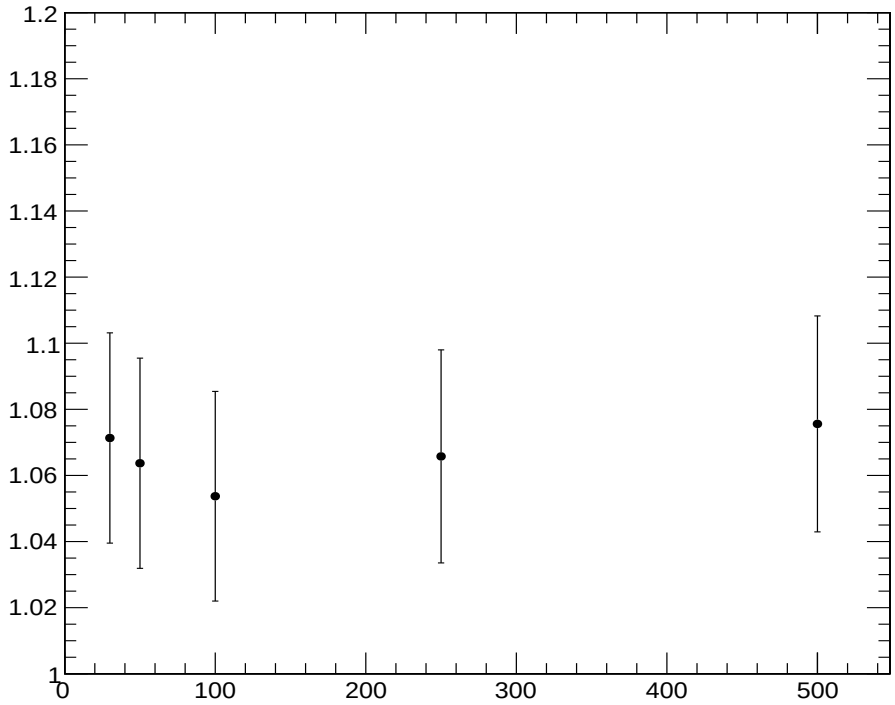
Hyper Ball: results HB size

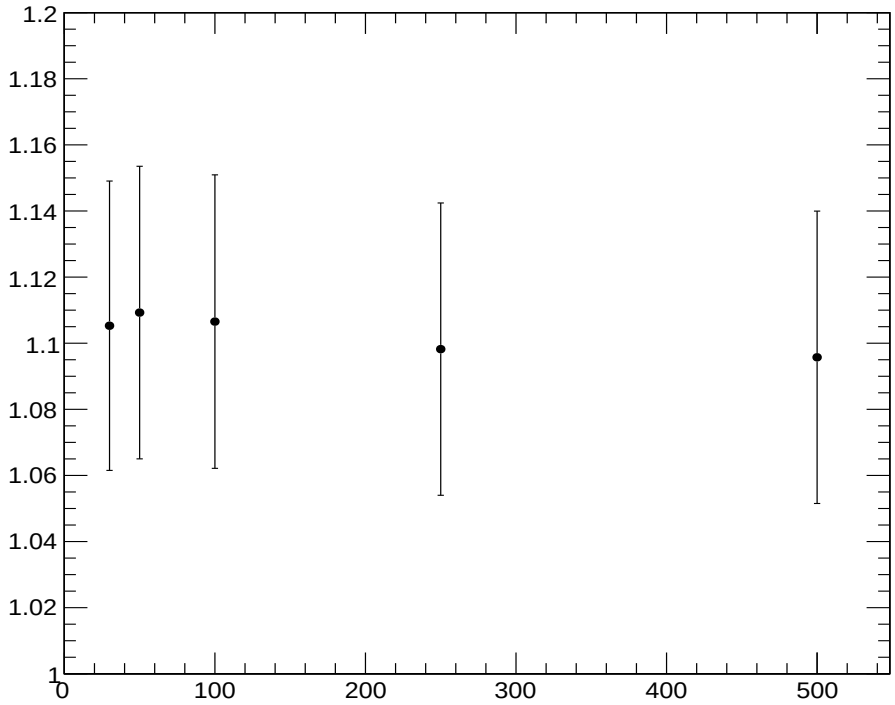




Stability of Seen/Pred in Control Region for Data vs HB size

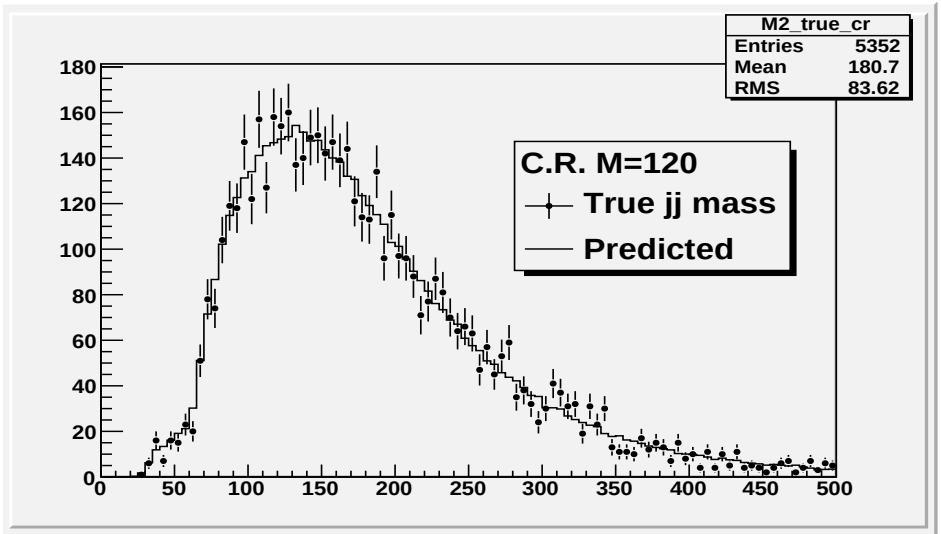
Hyper Ball: results HB size

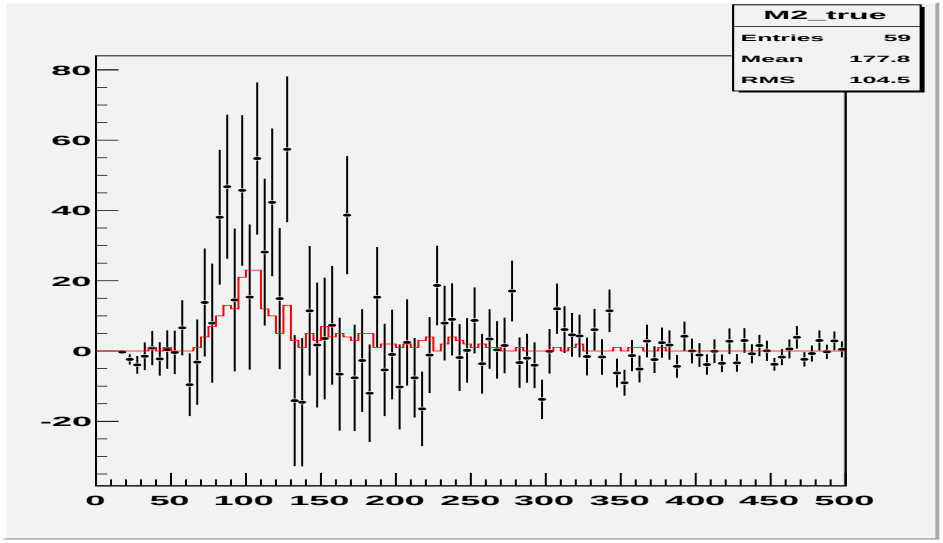




Stability of Seen/Pred in Signal over Control Region (R_{extrap}) for MC vs HB size

Hyper Ball: results on QCD MC



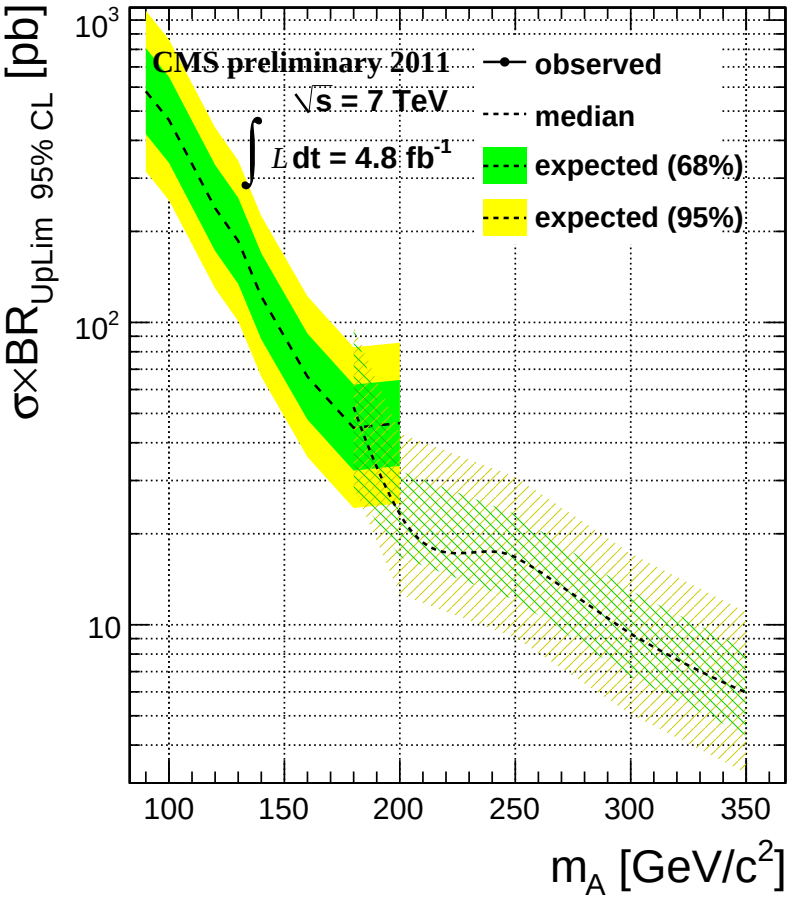


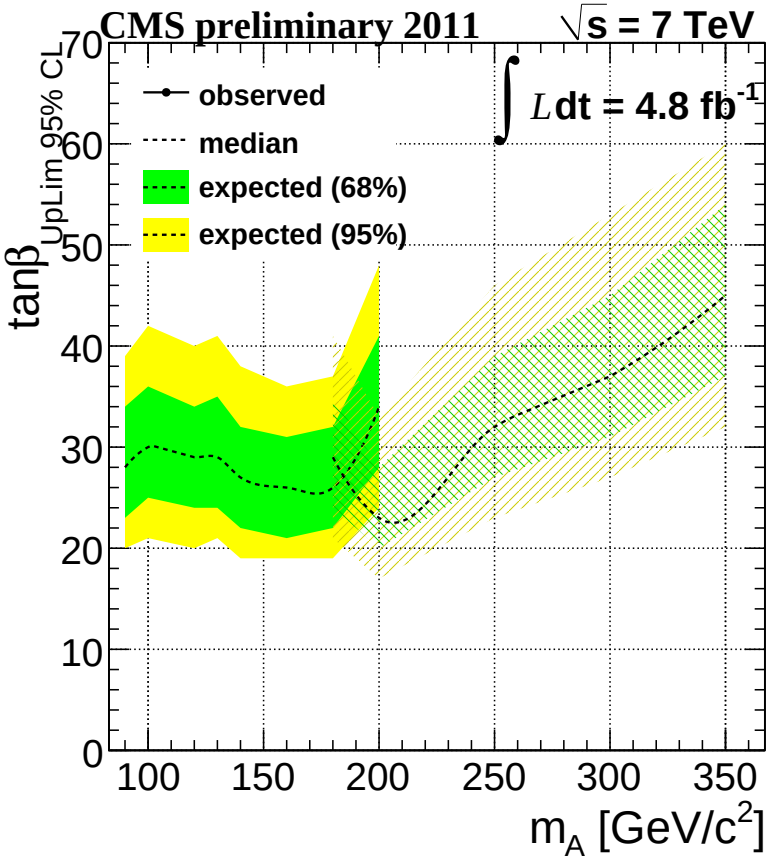
Example of signal injection and extraction $M_H = 120\ GeV$

Issues

- Values at 180 and 200 GeV are $+2\sigma$ and -2σ off.
- between 180 and 200 we change discriminator
  - low Mass$\rightarrow$high Mass
  - do not expect *a priori* a smooth transition
  - Try to switch region for 180 and 200 (next slides)

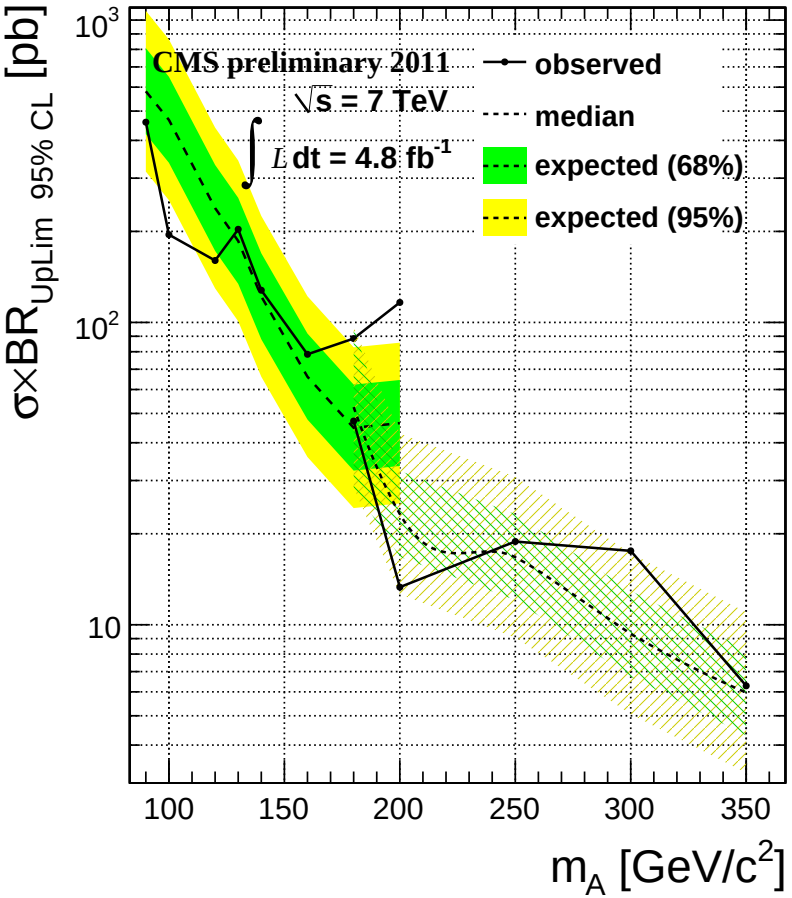
Switching 180 & 200 between low & high mass

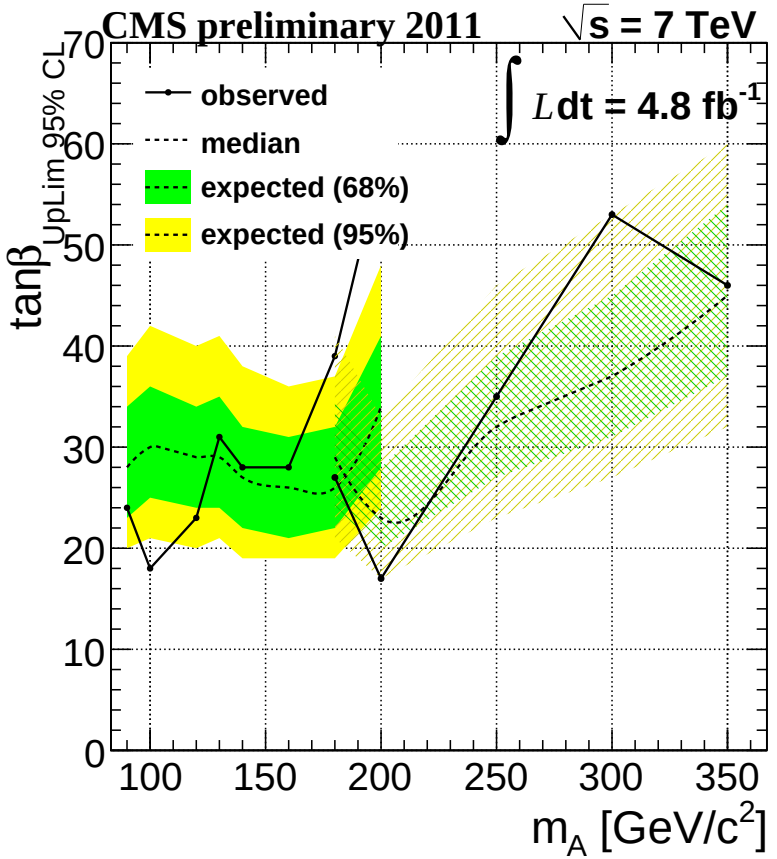




Predictions crosses at ≈ 180

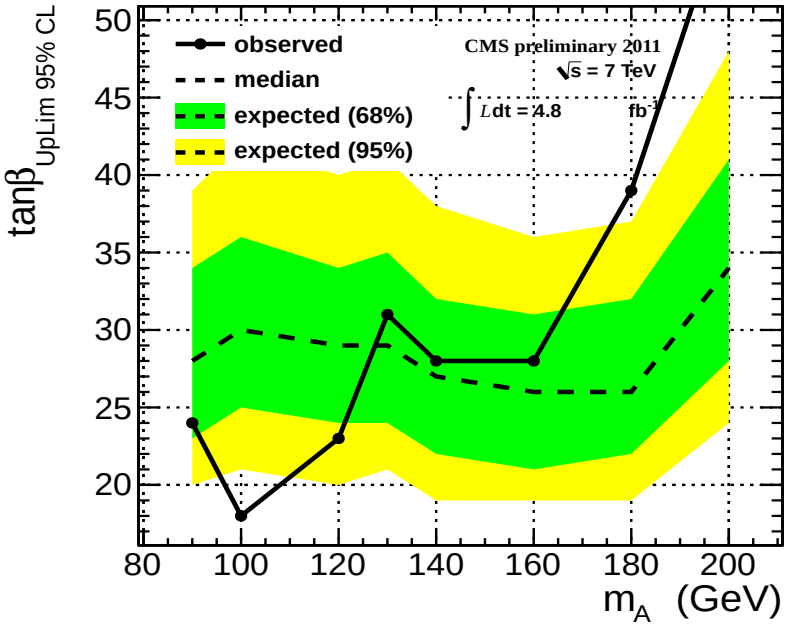
Switching 180 & 200 between low & high mass

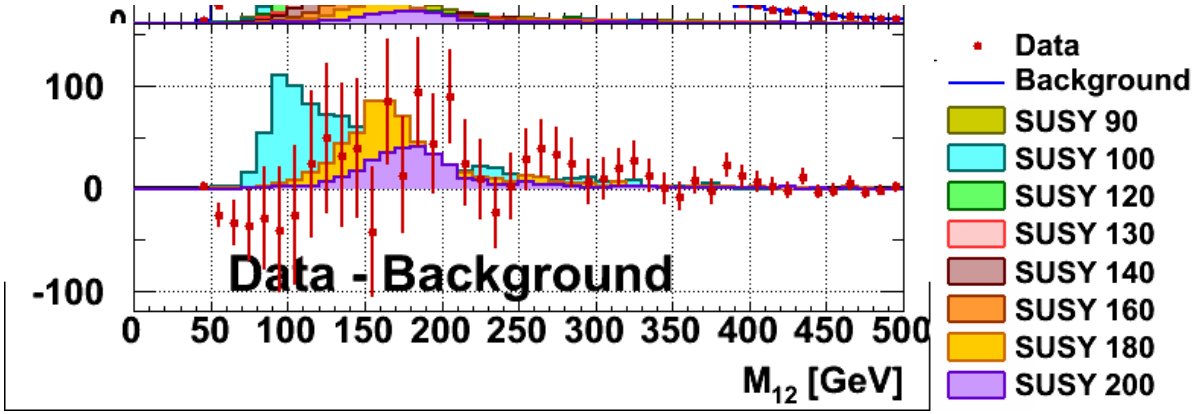




Predictions crosses at ≈ 180 For high Mass, 180 and 200 are fine

For Low Mass, 180 and 200 are quite off the expected: why?





Look like data-background has sinusoidal-like shape

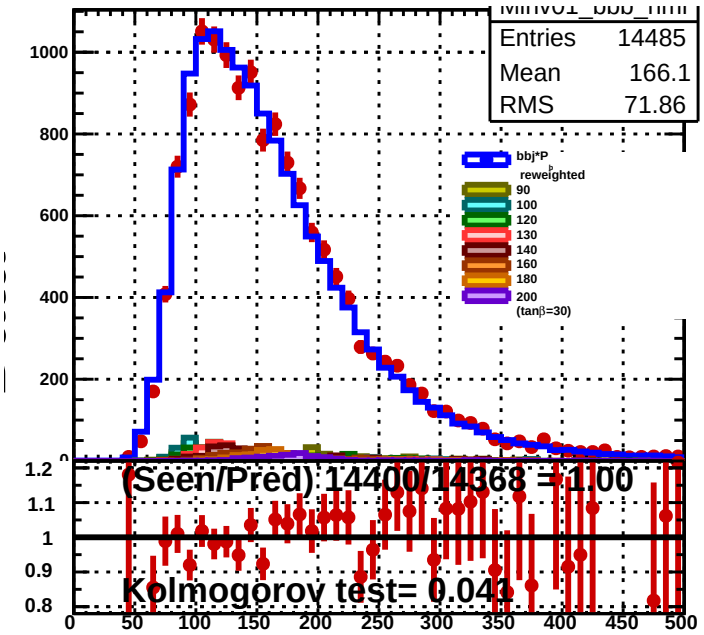
Possible origin

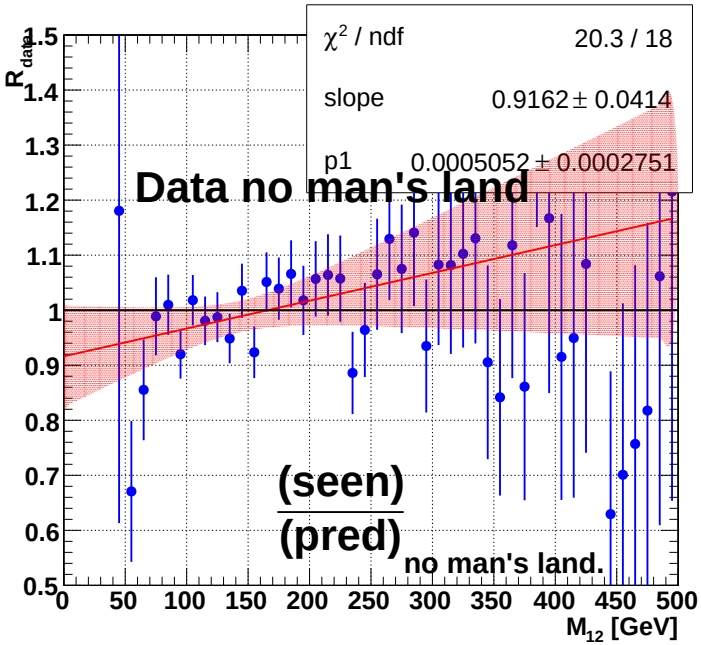
Could it be a M_{12} scale problem?

- Prediction is from data, not from MC.
  - Background is predicted from *bbj* sample, and M_{12} is the same by costruction in *bbj* and *bbb*;
  - Difficult to think that a $b-tag$ in the third jet could change the scale of the first two.
- Not seen in the MC (comparing control and signal region), but MC statistics is low.
- Should be visible also in the data control region, which is not
  - Could be a problem related to the parametrization used, but
- The hyperball shows a very compatible prediction in the interesting mass range;
- Do we see it in all signal region?
  - Look at no man's land ($0.4 < Discr < 0.7$).

No man's land Data vs prediction (low mass)

No Man's Land: a trend is visible KS=4.1%



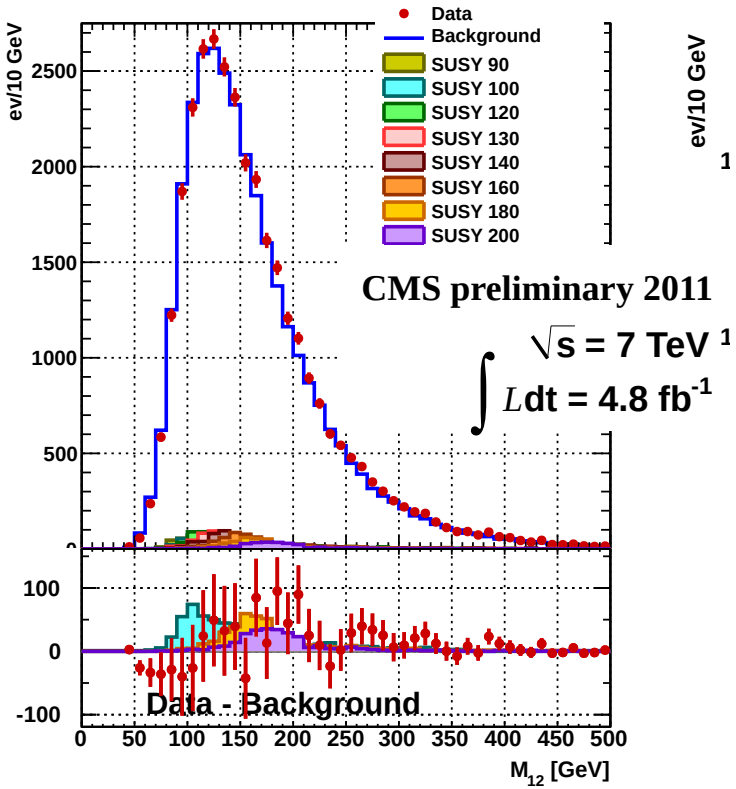


Additional correction

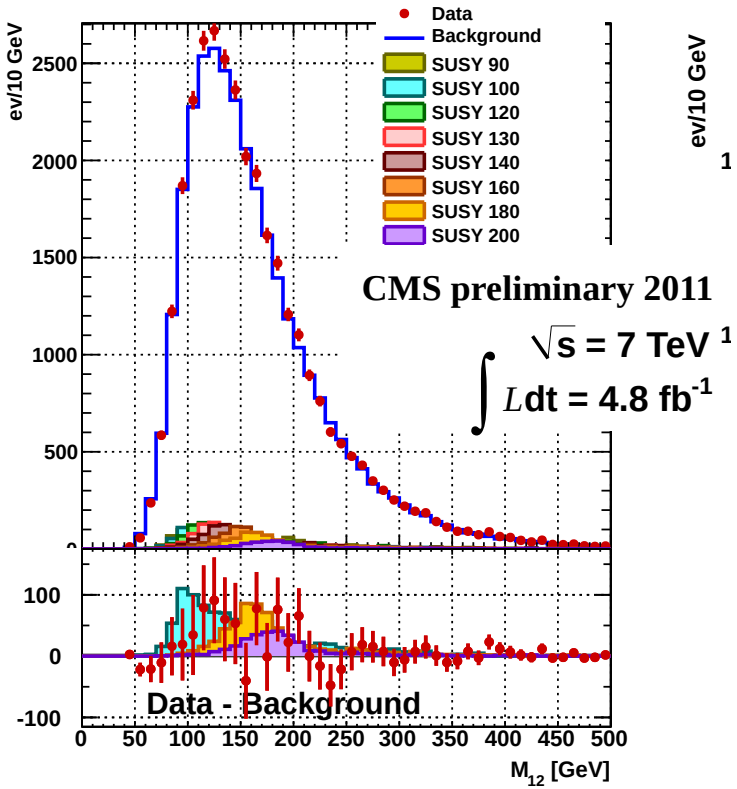
Use the *pol1* fit seen in the no man's land $0.4 < Discr < 0.7$ to correct for the prediction in the signal region

Application of correction in *Discr* > 0.4

Before correction

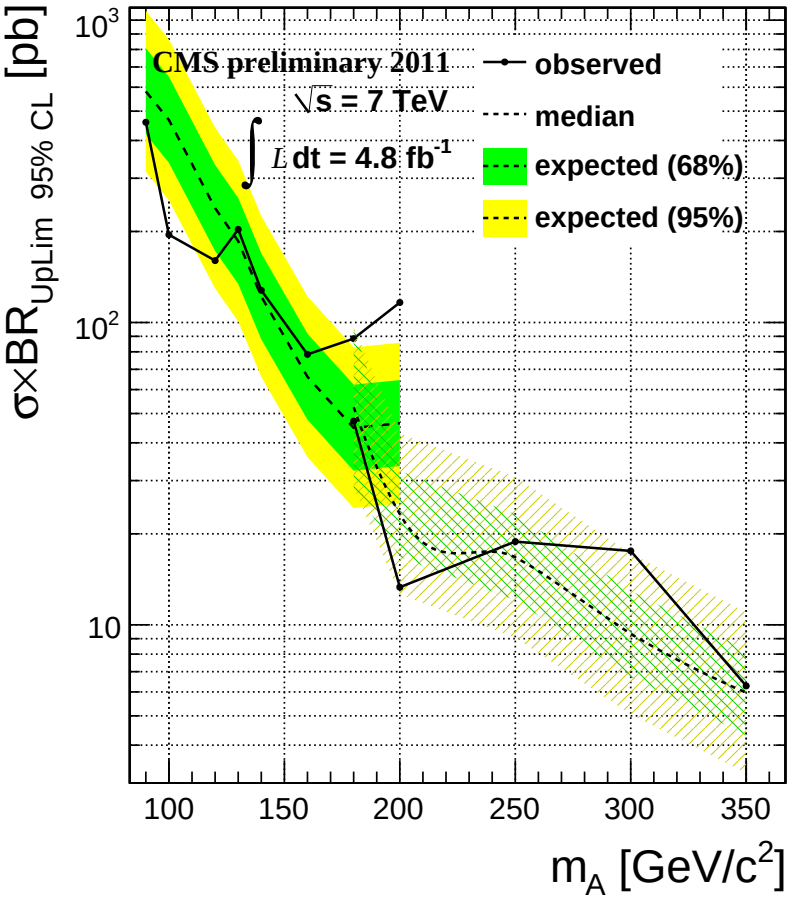


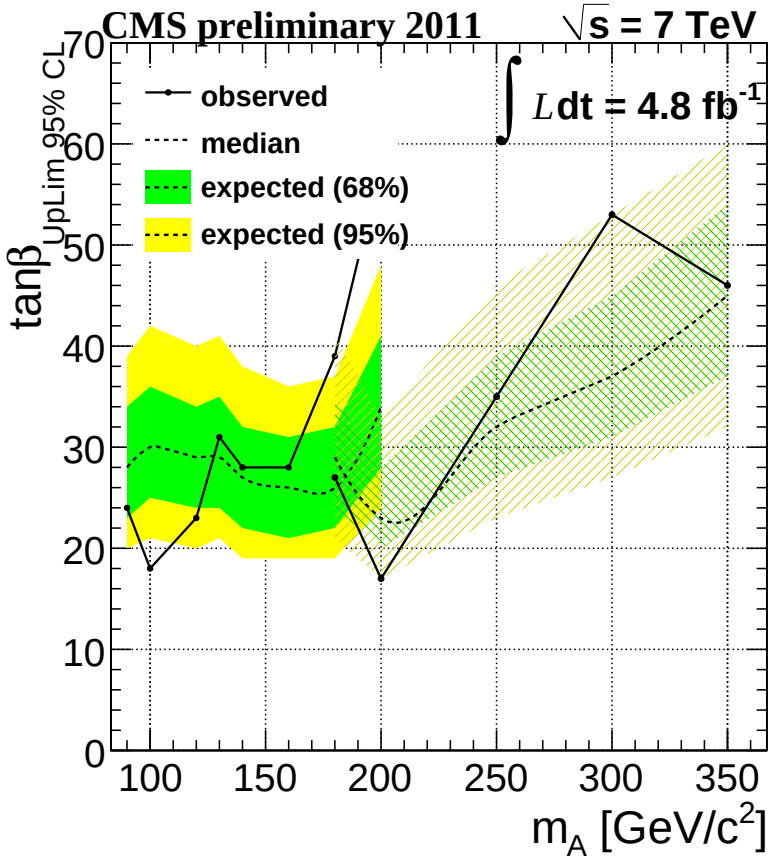
After correction



Try to use this correction, with additional systematics from fit errors, to get a x-section results

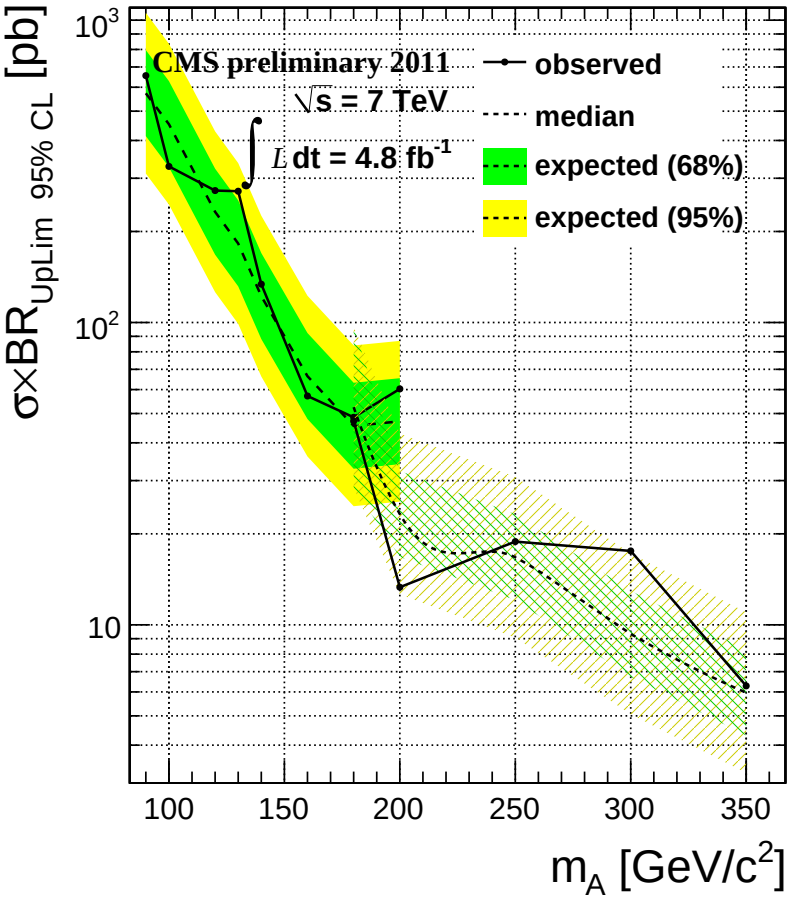
Original results (no correction from no man's land)

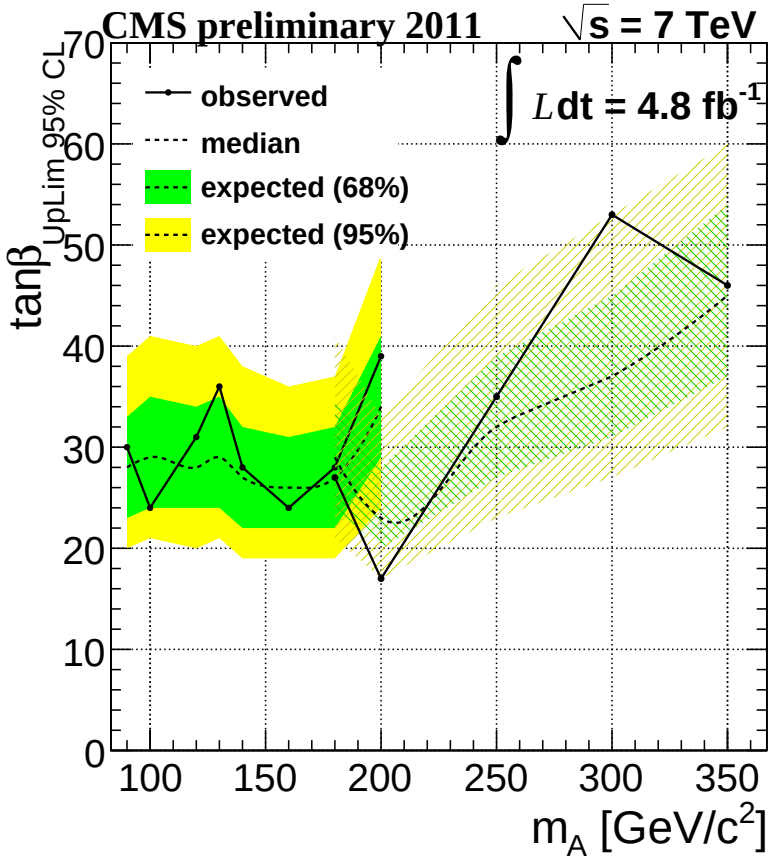




[]

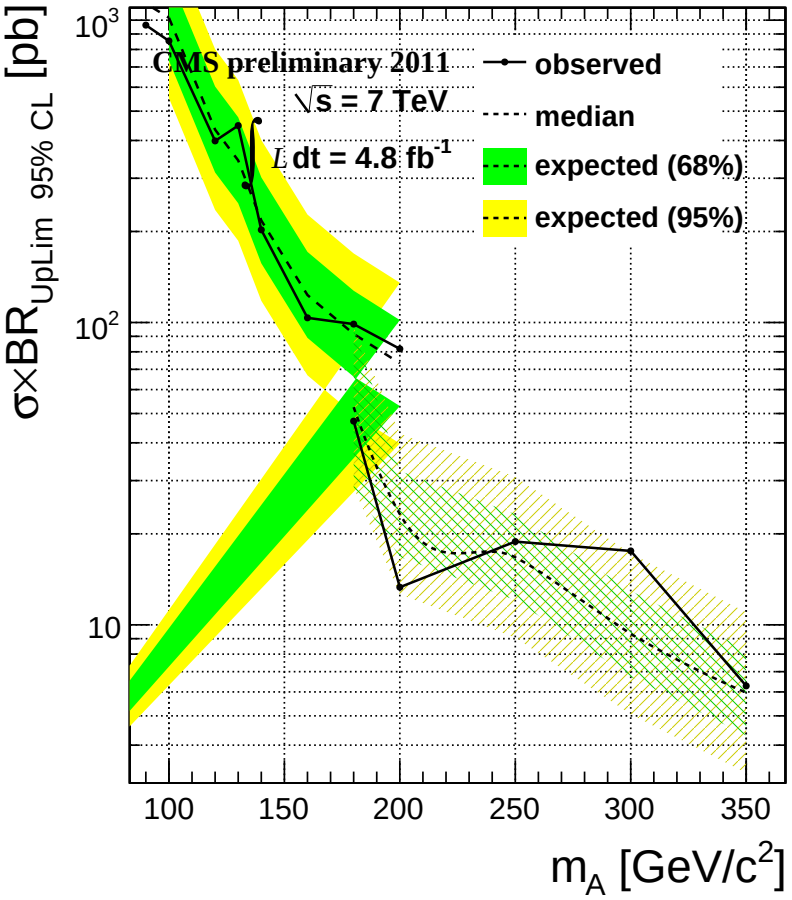
new results (with correction from no man's land)

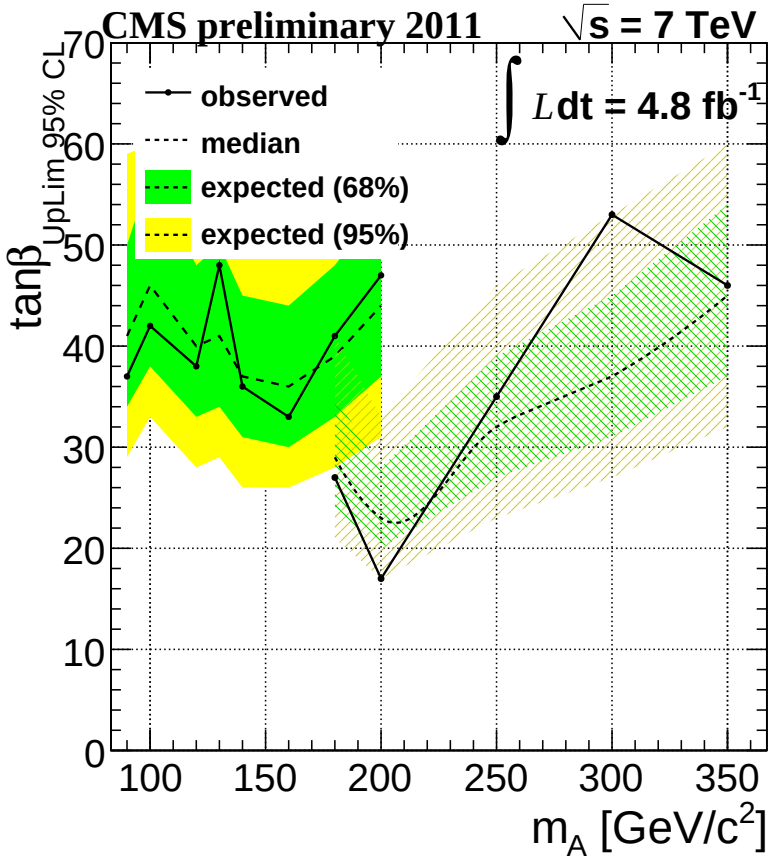




As expected, better agreement, (no syst yet)

new results (with correction and syst from no man's land)

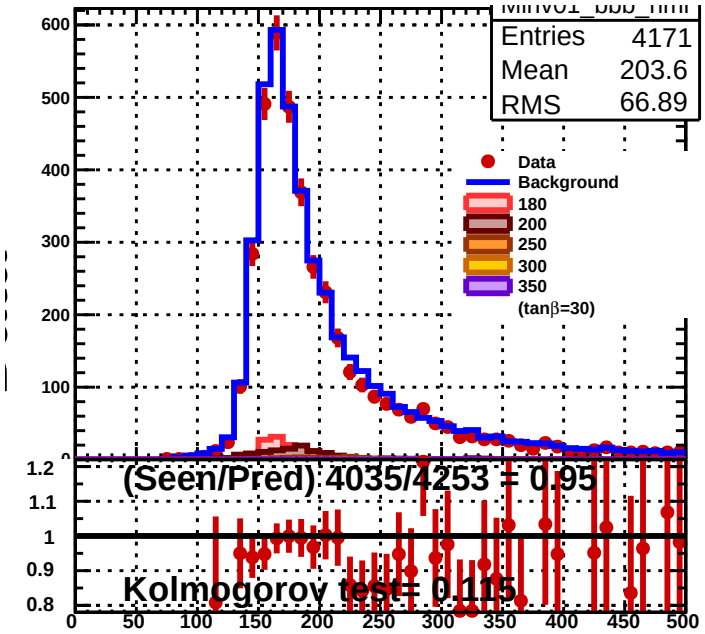


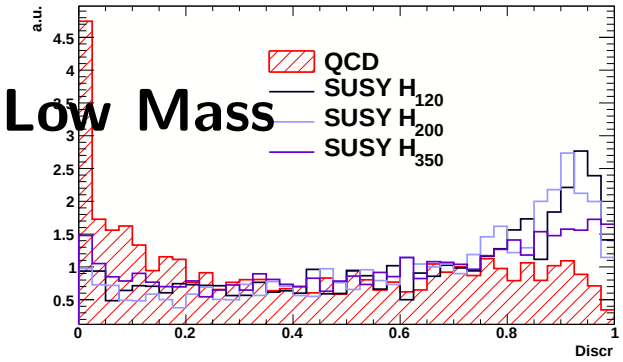


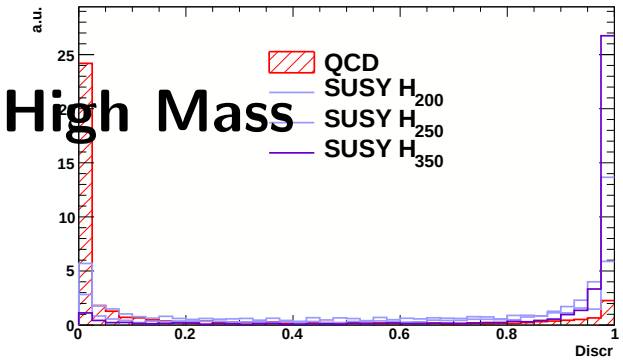
with 5% syst worst limits, but ok (only for low mass)

What about high mass?

No Man's Land. KS=11.5%







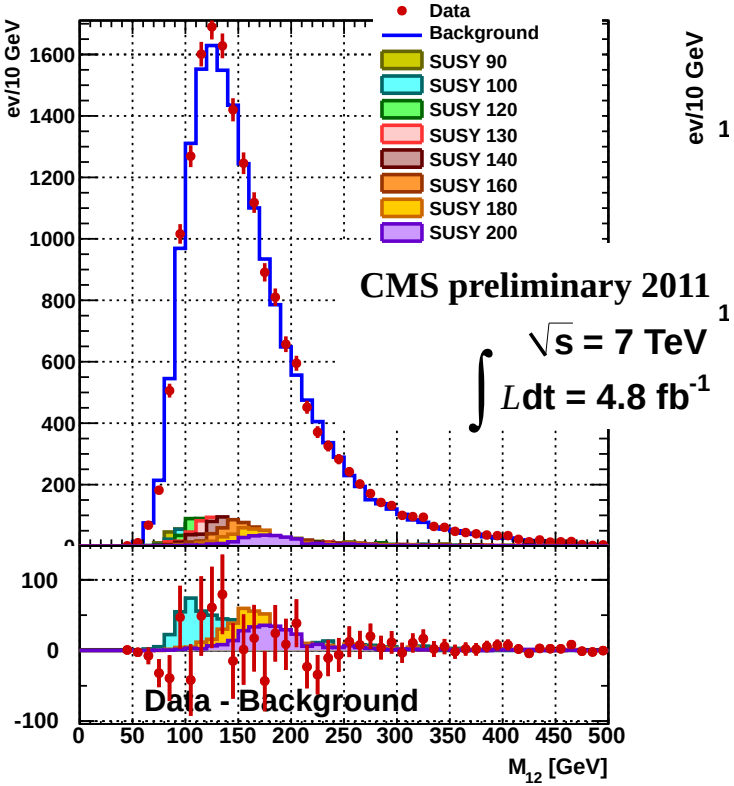
For high Mass the no man's land ($0.4 < Discr < 0.7$) is very poorly populated. . . no correction applied

Thou shalt not use data to correct prediction!

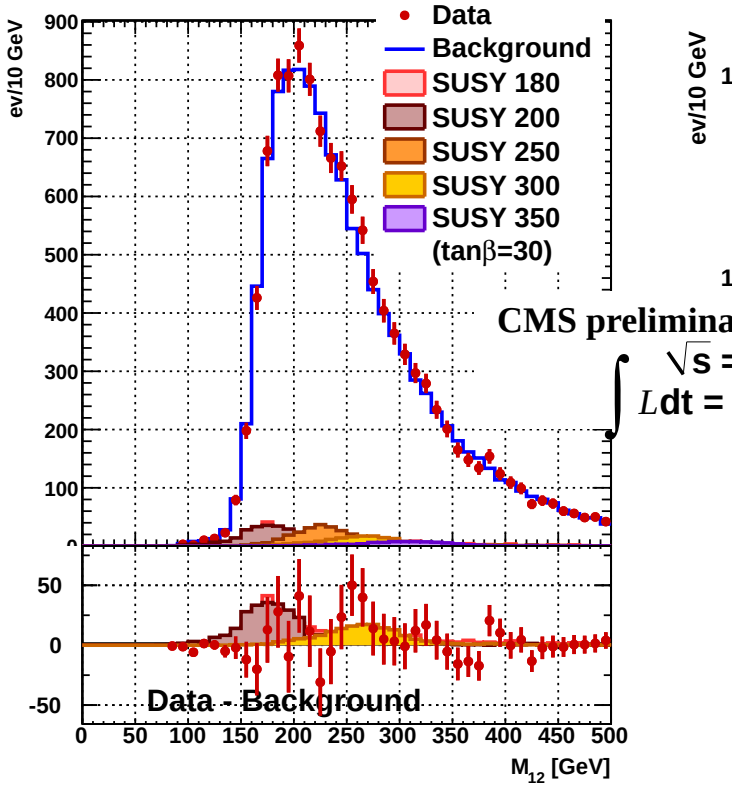
At least not the same data you are looking to.

Let's redefine signal region *Discr* > 0.7 (excluding no man's land)

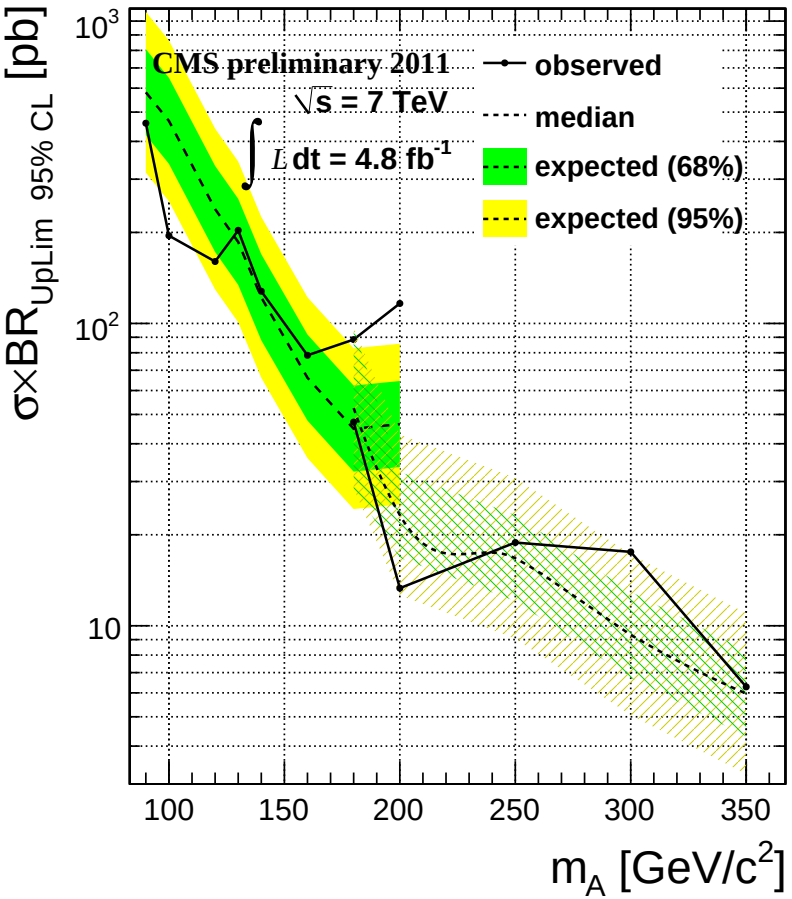
Low Mass

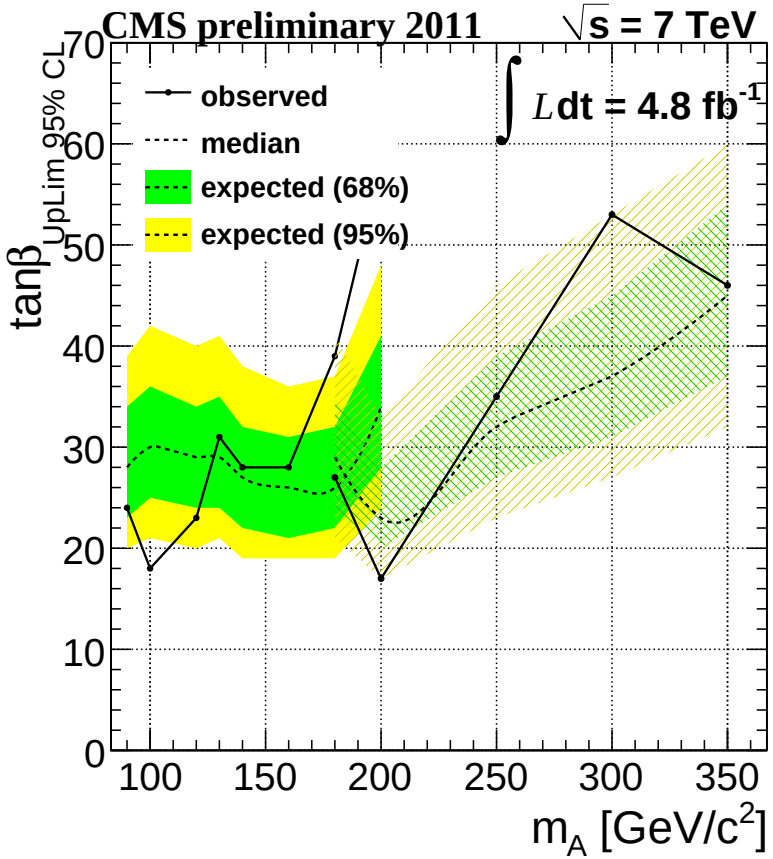


High Mass



Results using only *Discr* > 0.7





As expected, better agreement, and less fluctuating results

BACKUP