Search for rare processes with a Z+bb signature at the LHC using the Matrix Element Method

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Strategy

Discovery of Higgs boson only one missing part of the puzzle → need to search for Beyond Standard Model signals

Search for rare processes → restriction to processes with **2 leptons + 2 *b* jets** and not missing transverse energy in final state: ***llbb*** phase space:

Rarity ↓

Zbb
Top pair production with fully leptonic decay
ZZ
} Well known processes

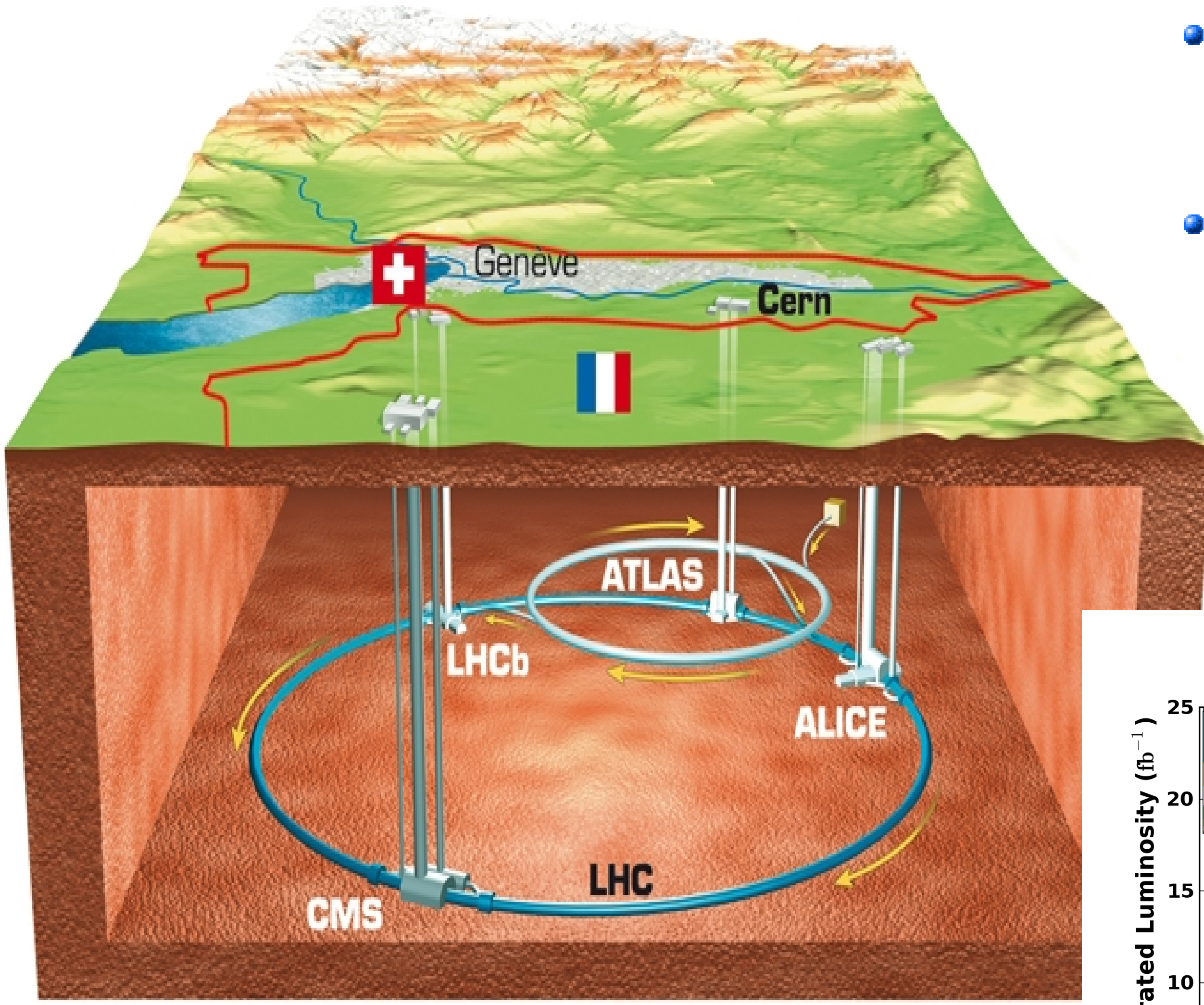
ZH
BSM ?

1) Identification of ***b* jets**
Tools → **b-tagging**

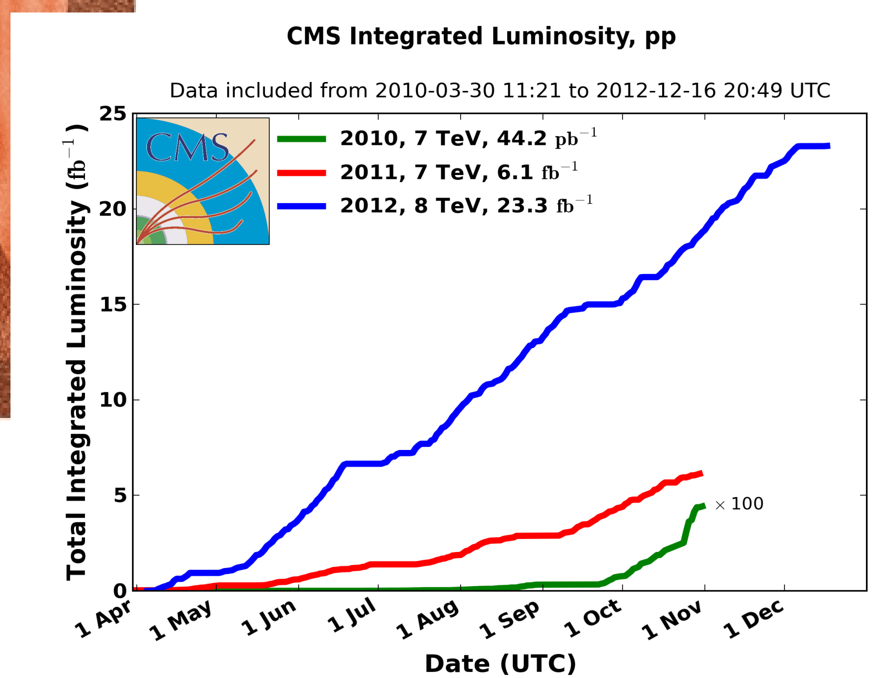
2) Discrimination between **SM processes** to extract rare processes (ZH)
Tool → **Matrix Element Method**

3) Very good discrimination between SM processes → excess of data
→ hint for BSM processes

The LHC

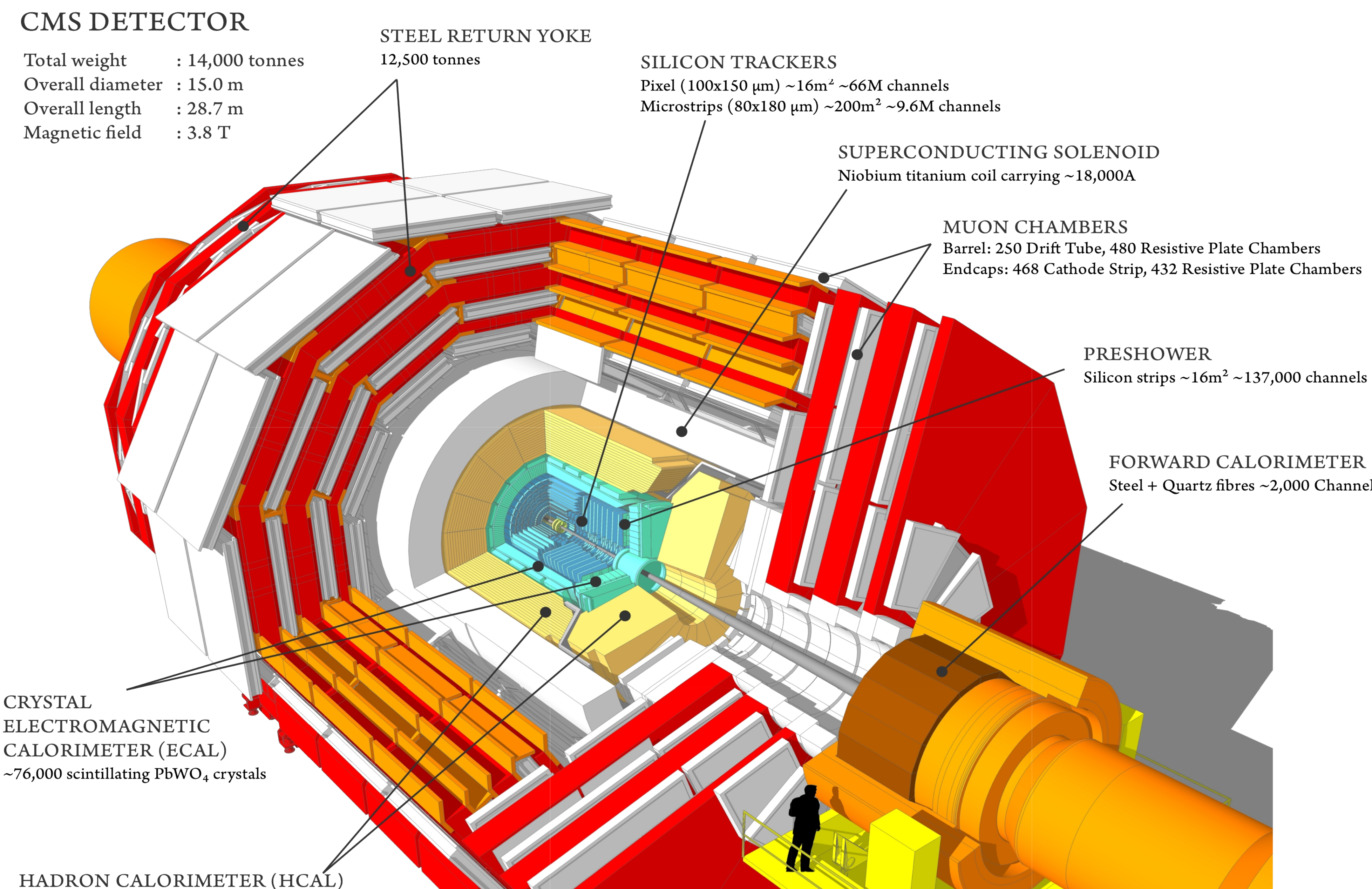


- Collisions at **7 TeV and 8 TeV** in 2012. Since Spring, **13 TeV**
- **Integrated delivered luminosity of 23.3 fb-1 in 2012 for CMS (recorded: 19.7 fb-1)**
- 4 experiments: ALICE, ATLAS, **CMS** et LHC-*b*.

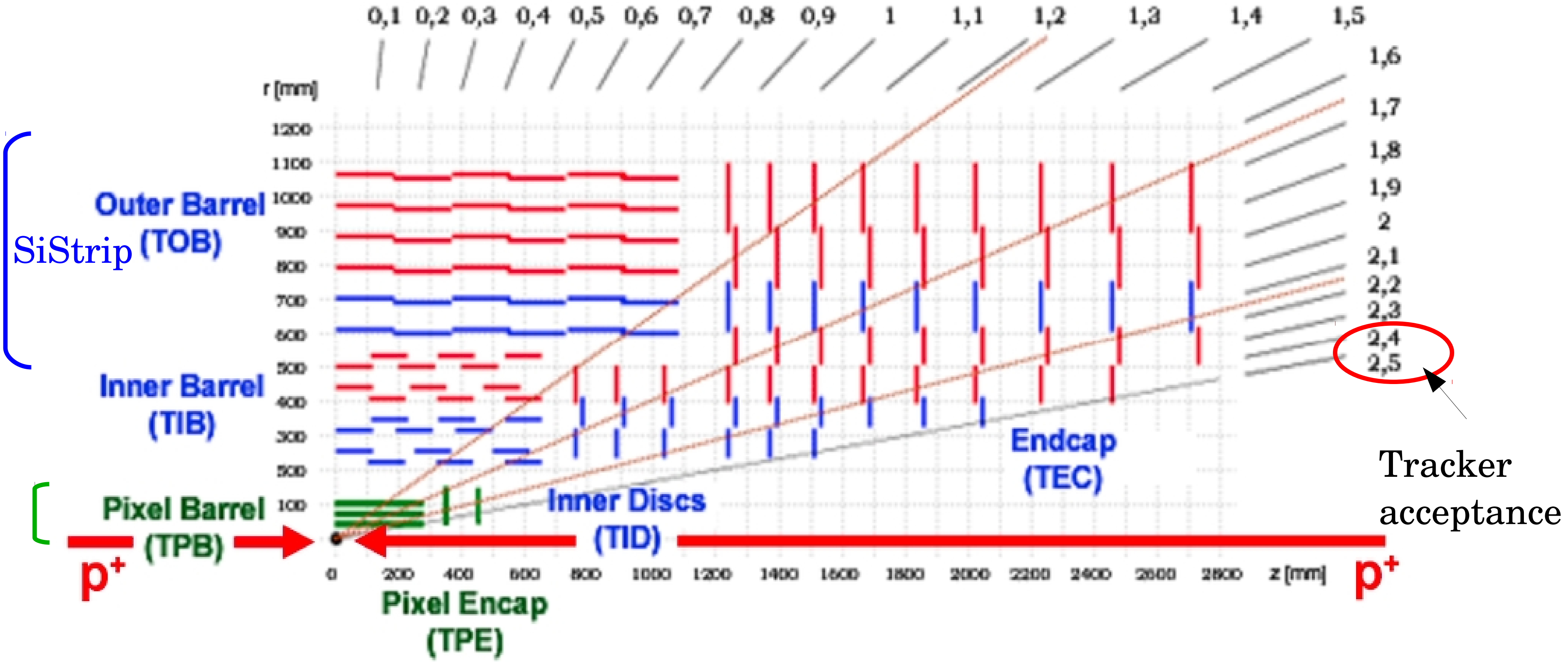


CMS

Detector divided in **sub-detectors** for **identification** of particles and **measuring** their **properties**.
4 Tesla magnet bend charged particles tracks



CMS tracker



- Largest silicon detector ever built
- Composed of pixel square-shaped: 100x150 µm²
- Close to **point of interaction** (4 cm)
- Resolution track IP: **30-100 µm**

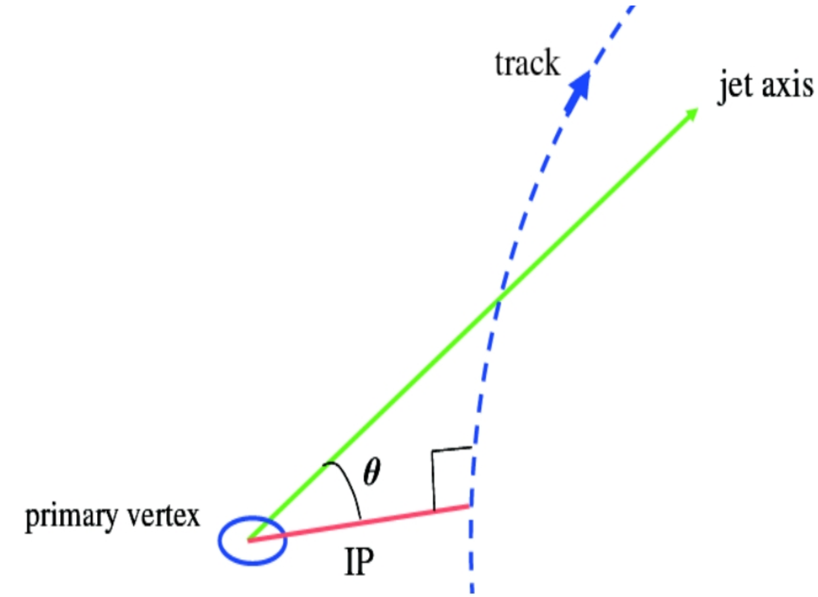
b-tagging within CMS

What is the b-tagging ?

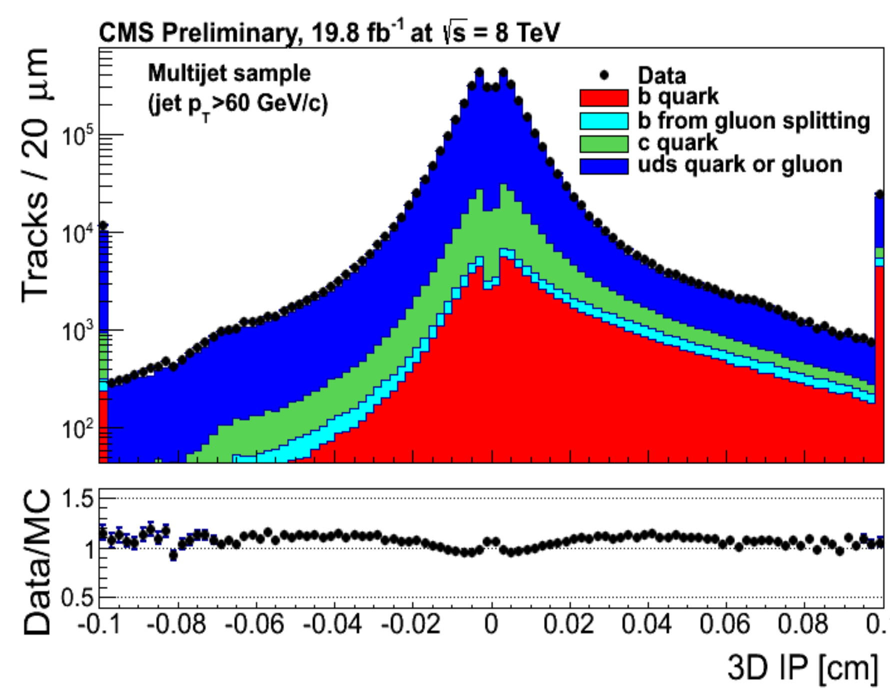
Looking for jets containing a B hadron

b jet → contains **B hadron → special properties**

- B hadron → flies into the beam pipe before it decays → **flying distance higher than its resolution**
  → **detect displaced secondary vertex**



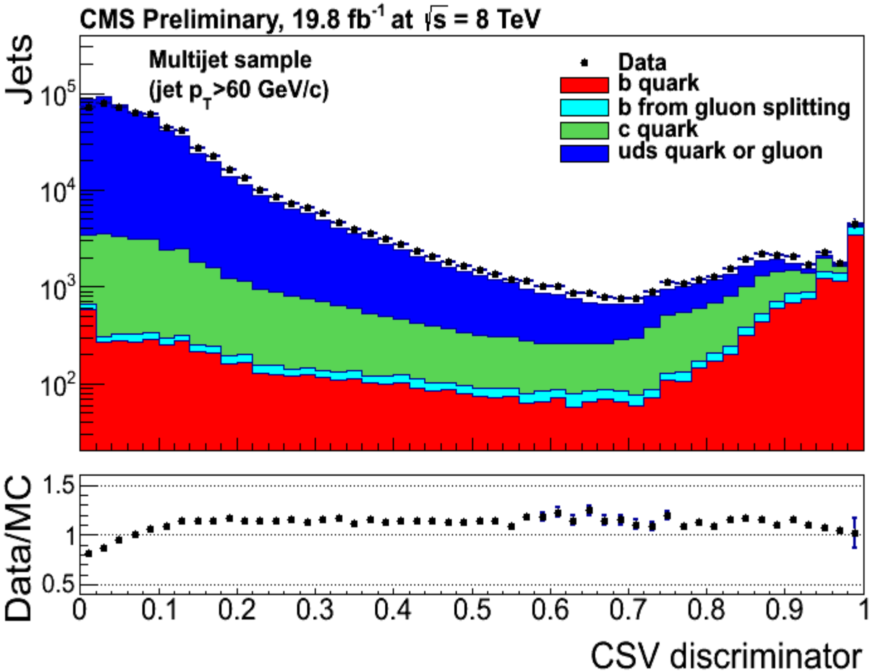
- Tracks coming from secondary vertex → **large impact parameter (IP)**
  → **use IP/σ** less sensitive to resolution effects



CSV vs JP

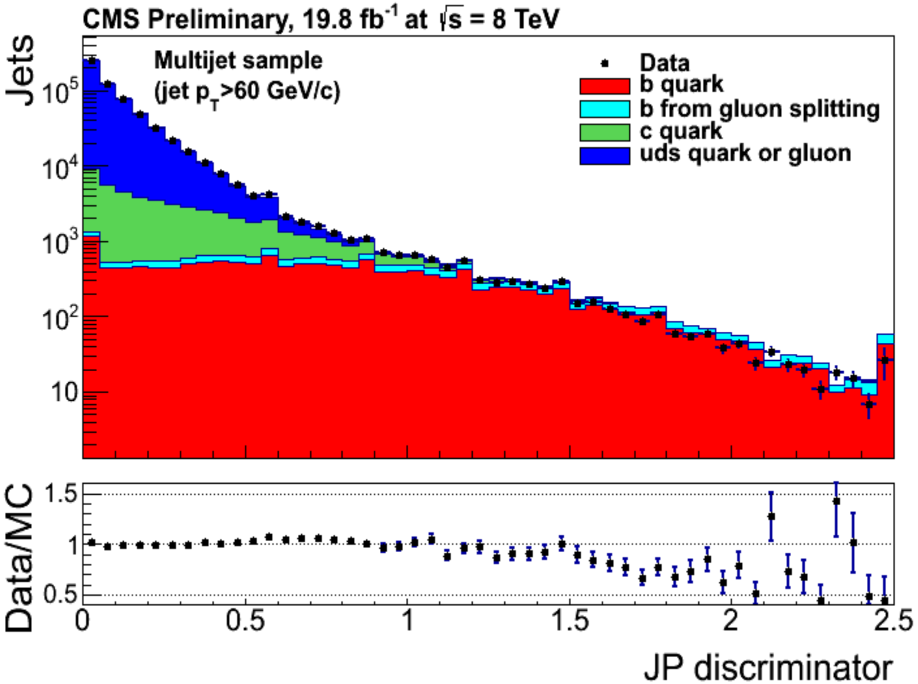
CSV

- Tagger giving the **best performance**
- Use **SV related variables** such as: SV mass, SV track multiplicity, SV flight distance, fraction of energy carried by SV particles, SV track rapidity, track IP
- Combine them using a **Multi Variate Tool** (likelihood ratio)



JP

- Use the **negative part of the IP distribution** (mainly tracks from PV) → compute **resolution function** to extract probability that a track come from the PV
- For all tracks in the jet, probabilities combined → probability that **jet** to come from the PV

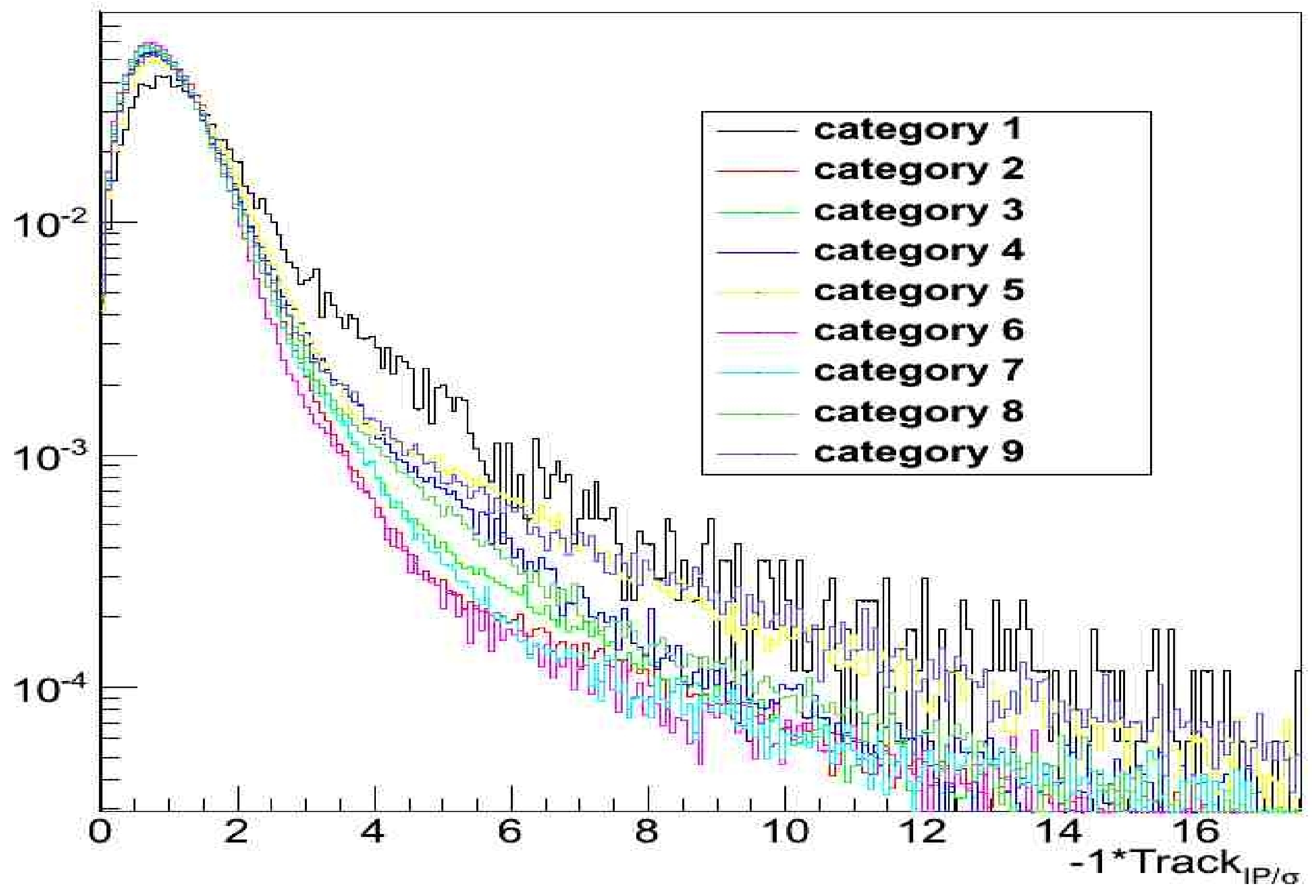


Calibration of Jet Probability

- Several tracks **categories** to build different resolution function → depend on the track quality → improve the calibration
- **Calibration** done with **data** events
- New code created two years ago: possibility to add new categories very easily

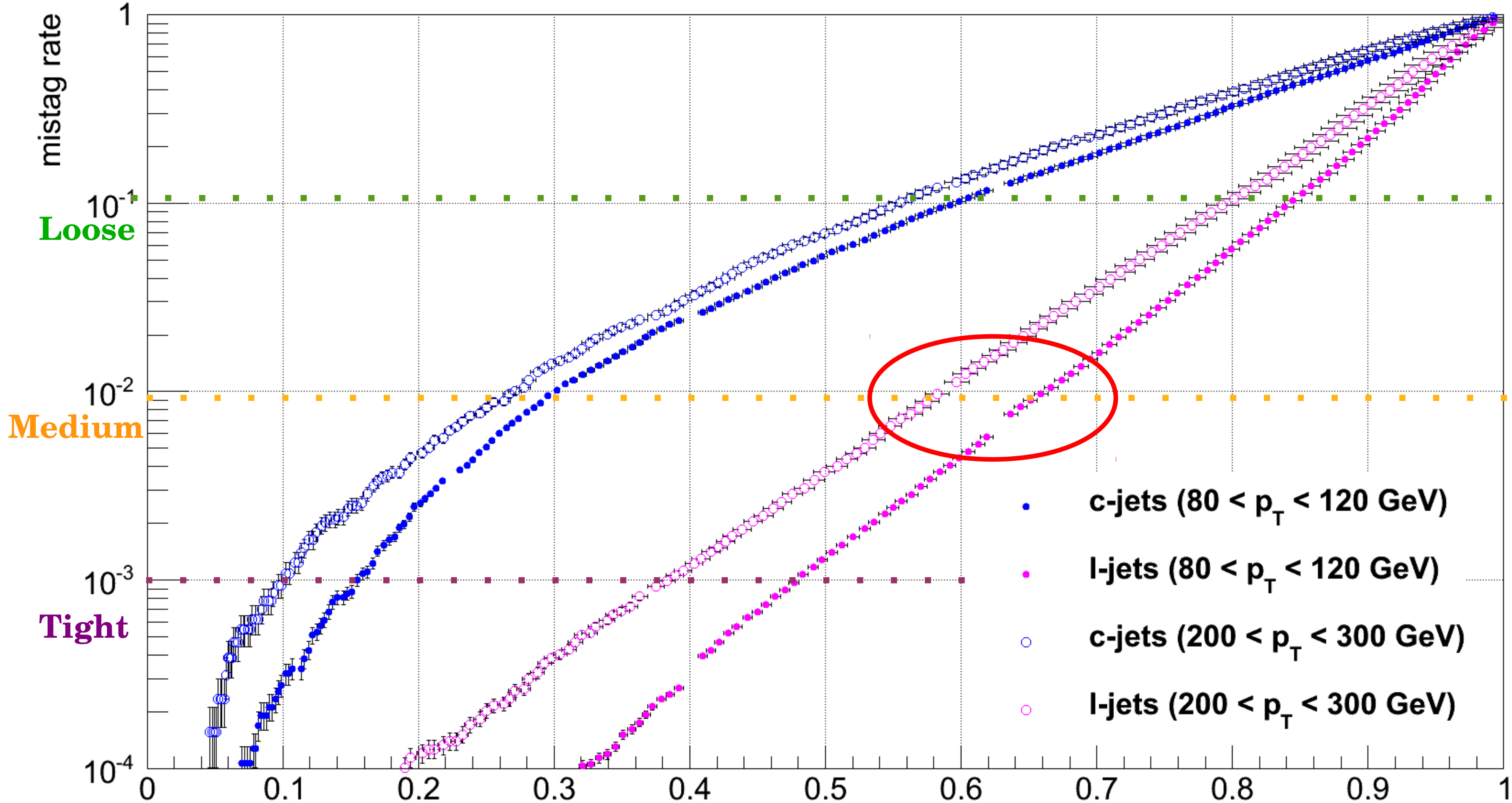
Variables defining tracks categories:

- Number of hits in the Pixel detector;
- Number of hits in tracker (Pixel+SiStrip);
- Momentum p of the track;
- η of the track;
- Normalized X^2 of the track



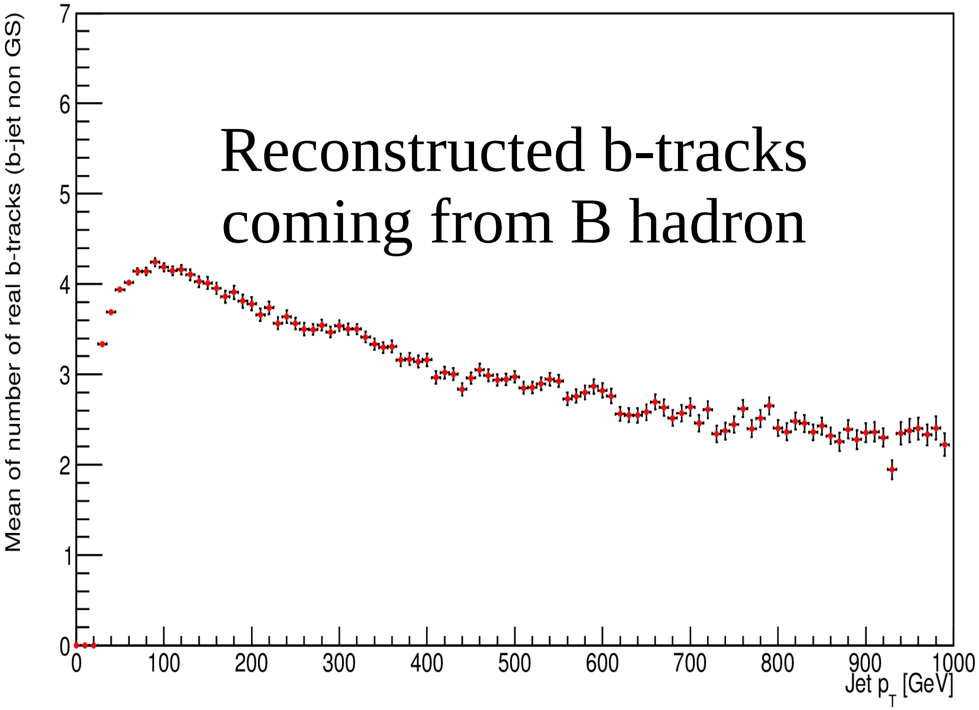
Performance at high p_T

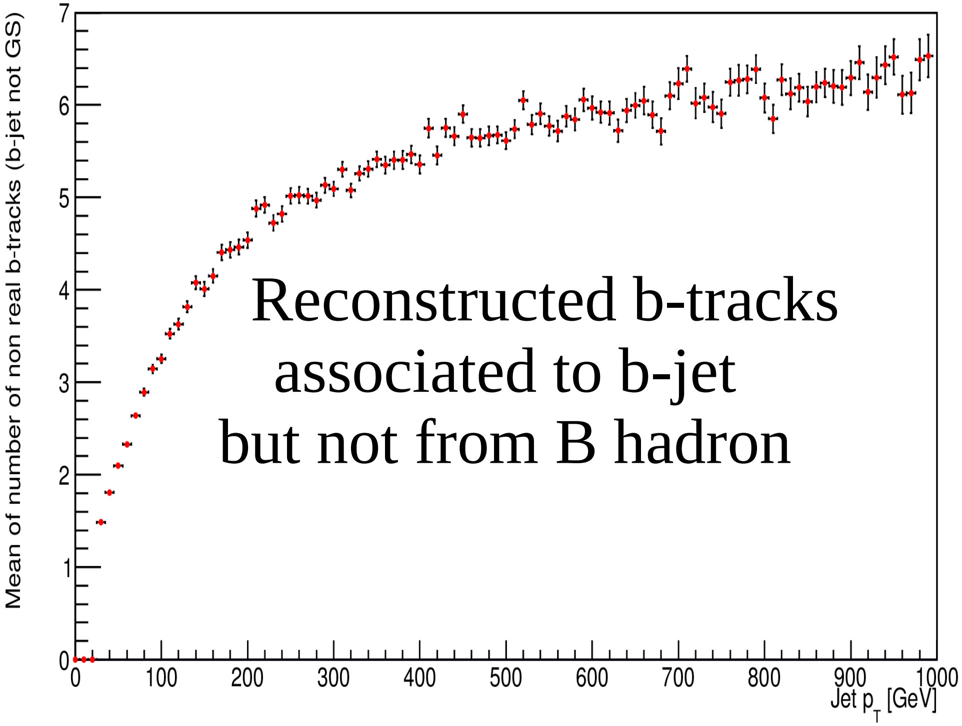
- At high p_T (> 200 GeV), all b-tagging algorithm show **loss** of performance
- For Jet probability, for a mistag rate of 1% → loss of b-tagging efficiency of ~ 7%
- Why ? Possible to recover from this loss ?



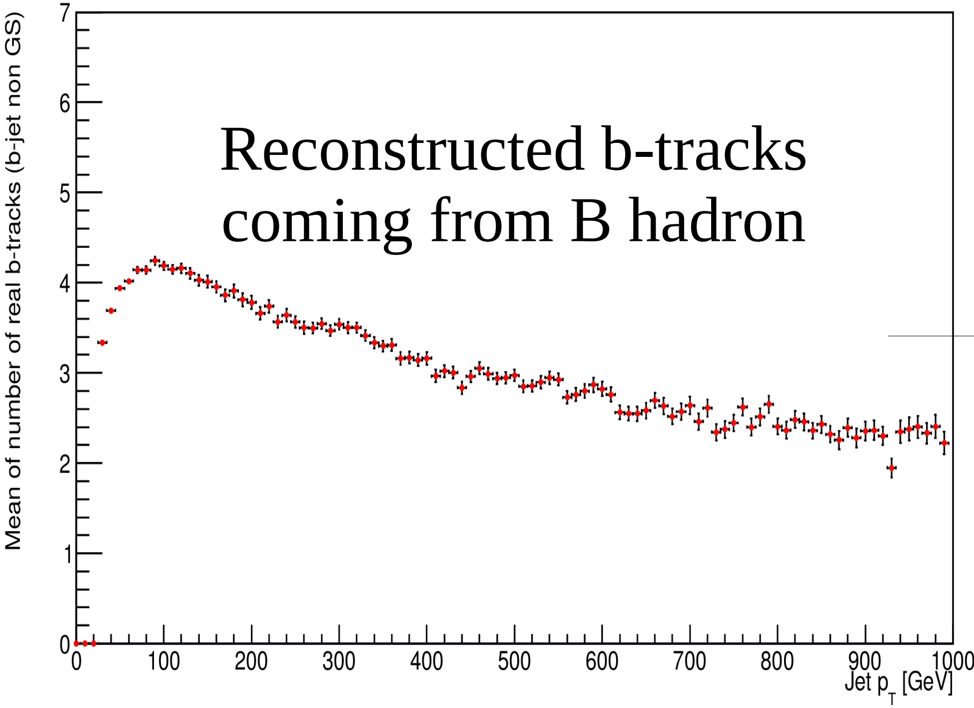
QCD multi-jets events

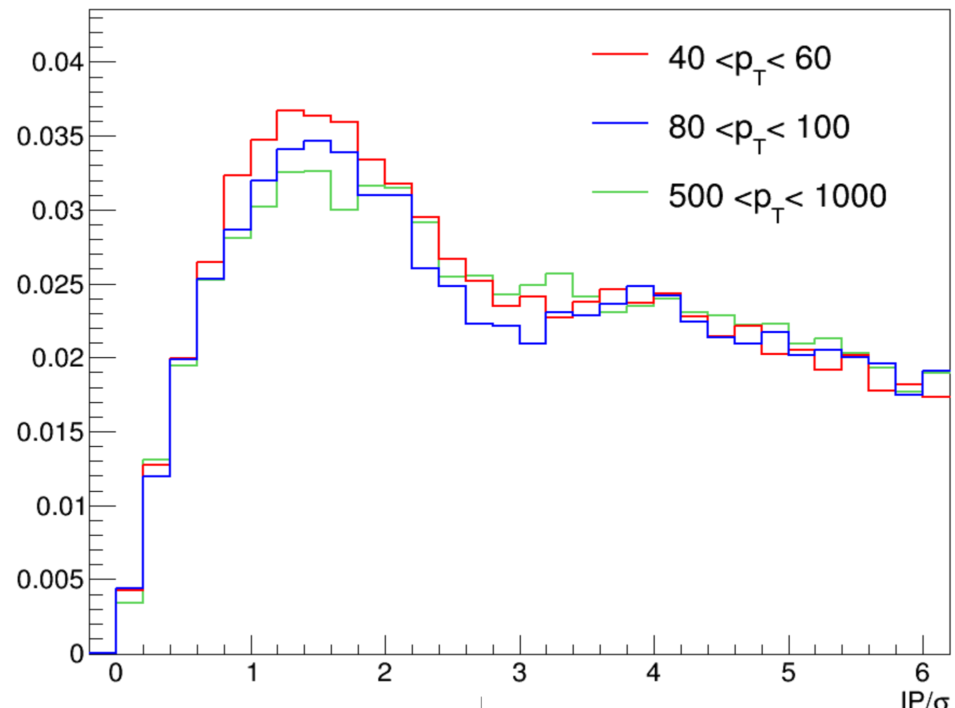
Loss of B tracks





Loss of B tracks

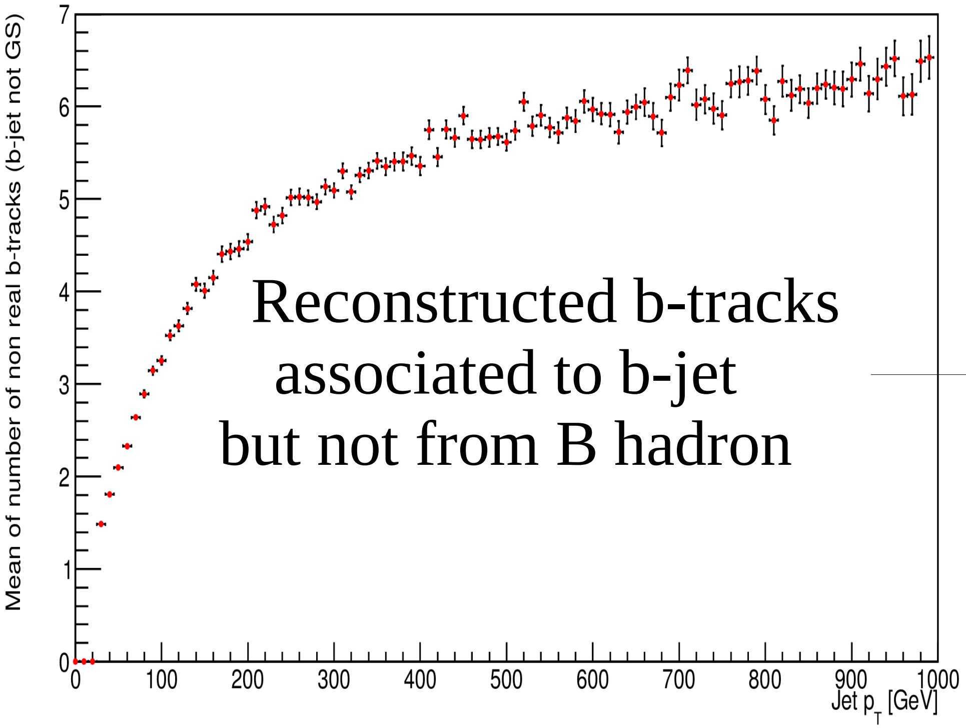


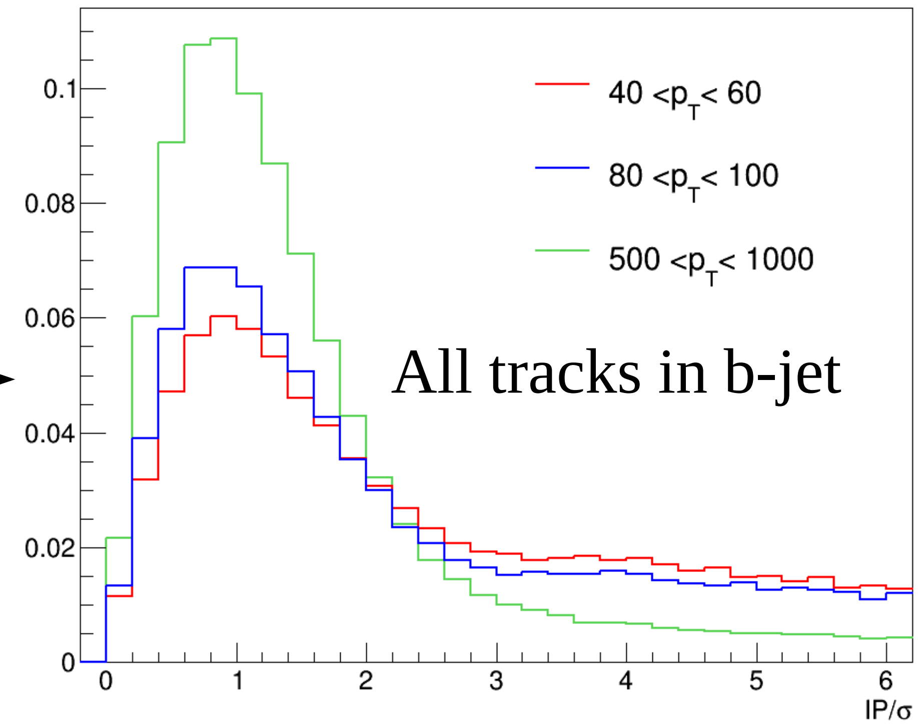


Loss of tracks from B →
tracking inefficiency

Expect behavior → IP/σ
Lorentz invariant

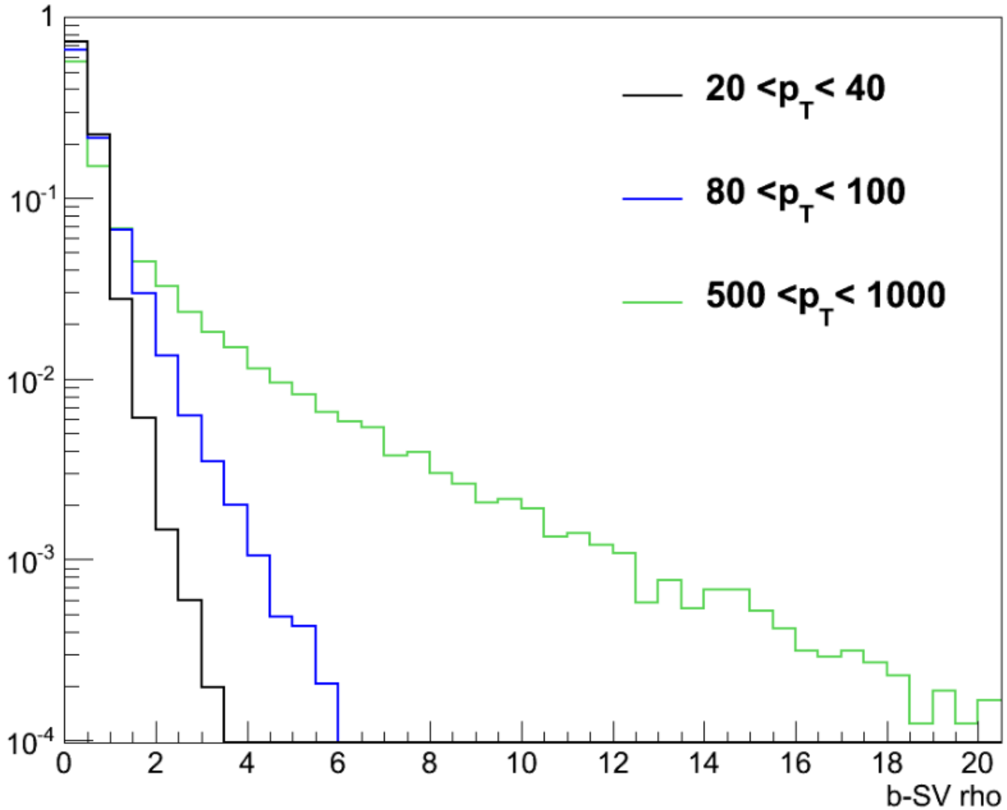
Impact on Jet Probability

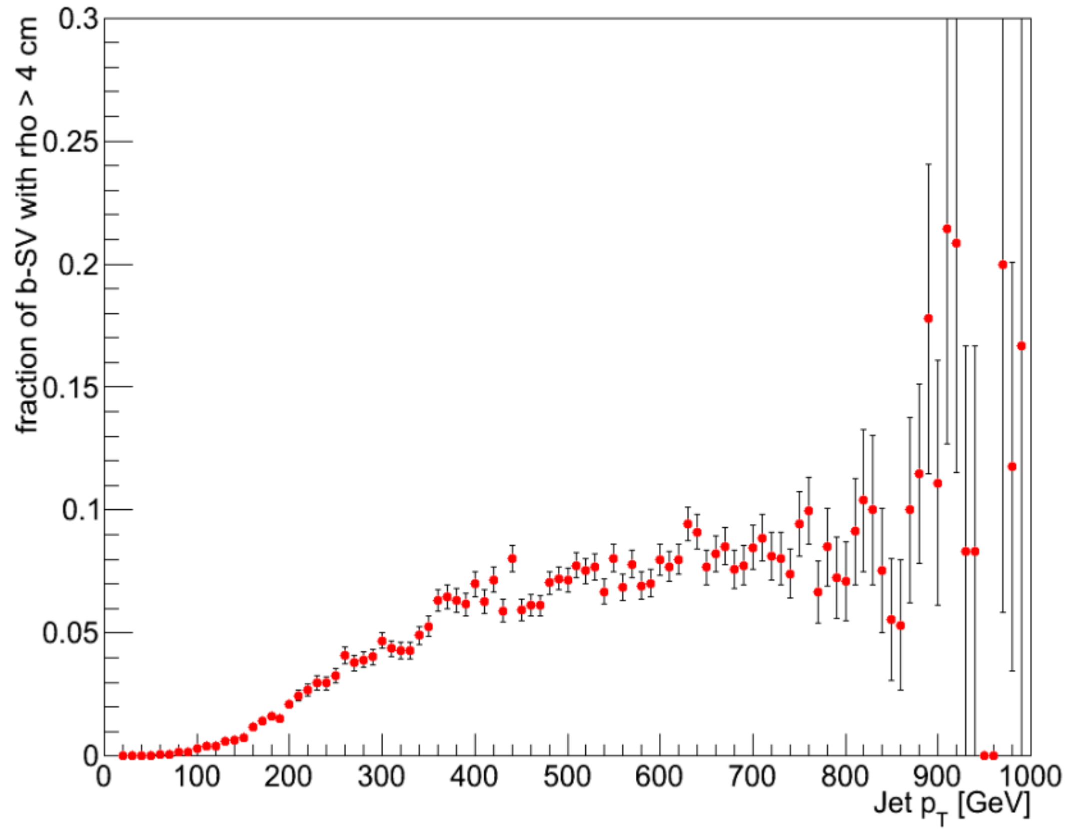




Non real b-tracks degrade resolution functions used in JP

Loss of B tracks

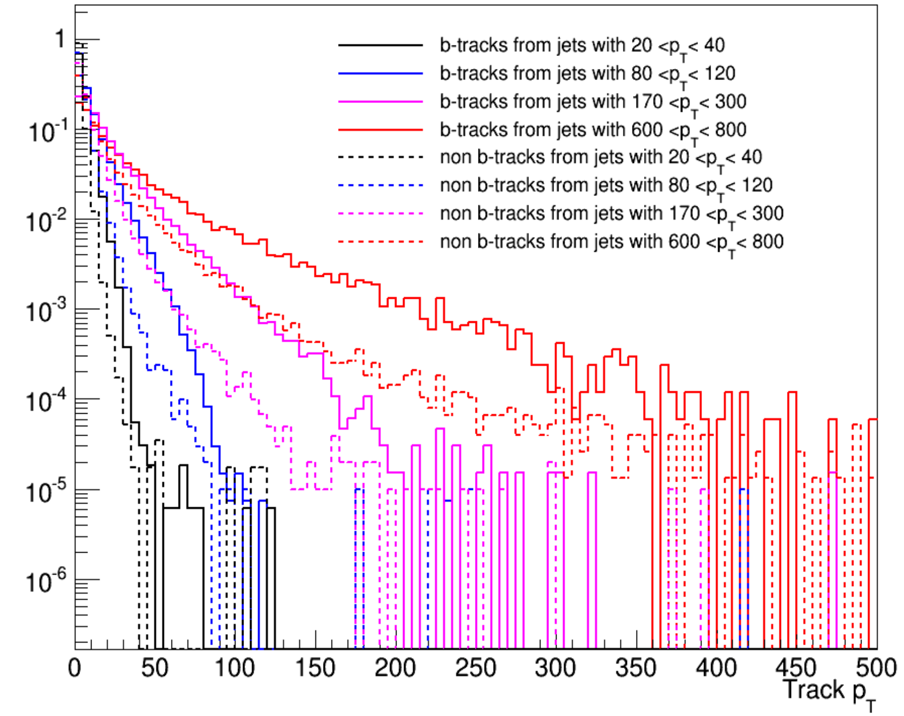




- B hadron flying distance in (x-y) plan **increases** with the jet p_T
- 4 cm = first pixel layer → fraction of SV decay after **first pixel layer**
- At 300 GeV ~ 5% SV decay after first pixel layer
- High p_T tracks collimated, hit the same pixel → do not pass standard **track selection** anymore (# hits in Pixel ≥2)

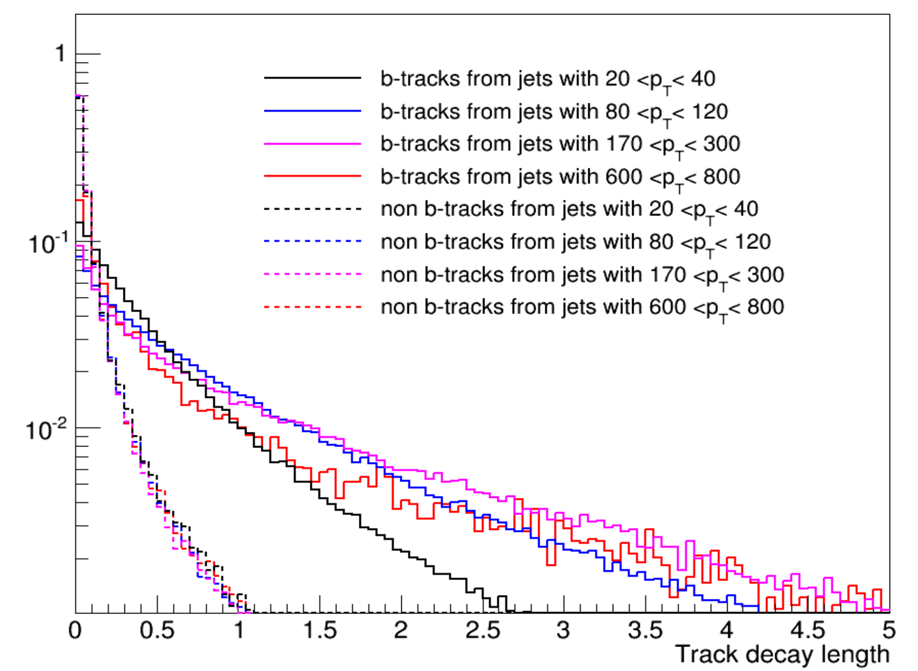
BDT

Idea: use a **BDT** to **discriminate** **real B tracks**/**non real B tracks**
→ apply **additional cut** to remove these tracks from JP algorithm

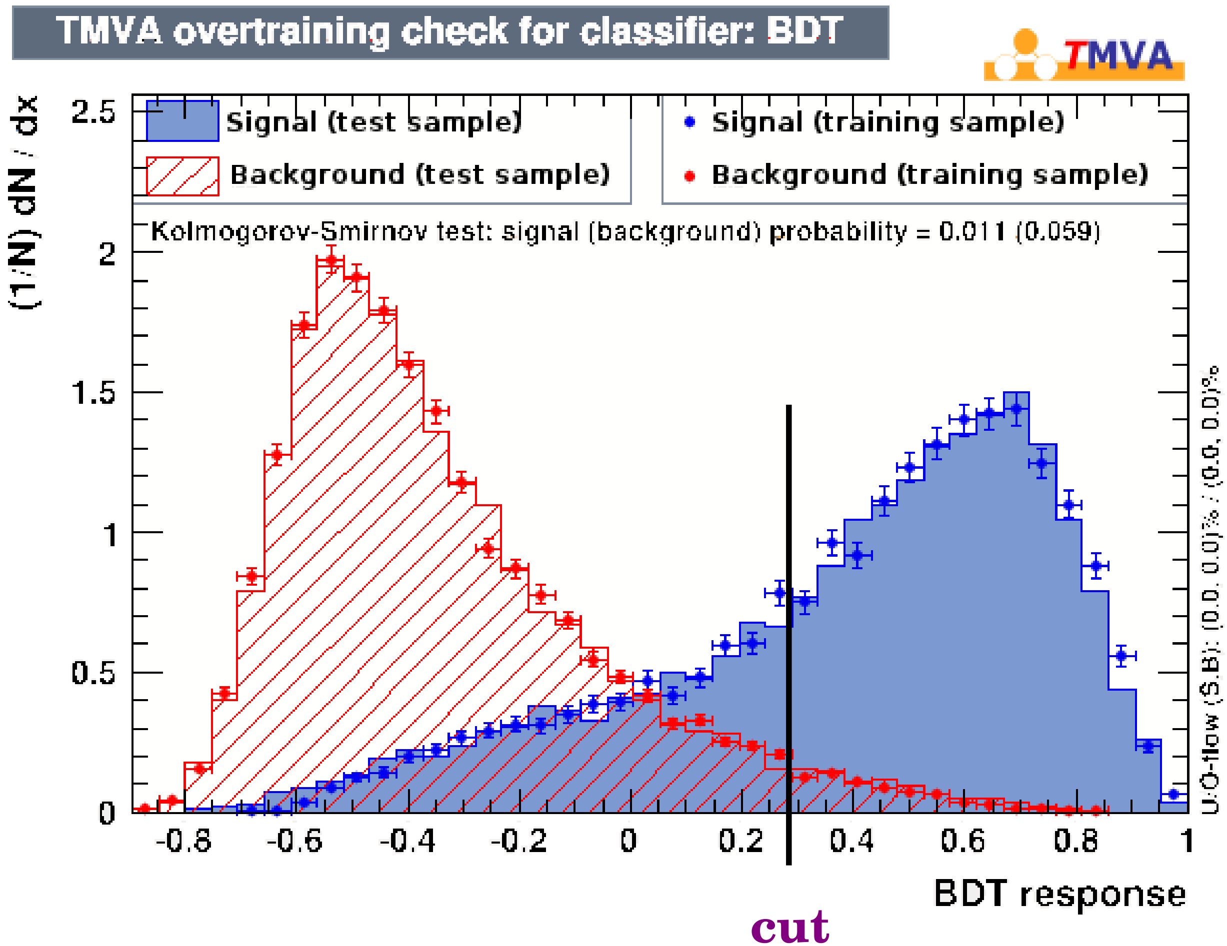


BDT variables:

- Track p_T
- ΔR between the track and the jet
- Number of hits in the pixel detector
- Number of hits in the SiStrip detector
- Relative p_T between the track and the jet axis (p_T^{rel})
- Normalized χ^2;
- Distance of the track to the (x,y) plane, d_{xy};
- Distance of the track to the z plane, d_z;
- Track decay length
- Track distance to jet axis
- Track-pair invariant mass



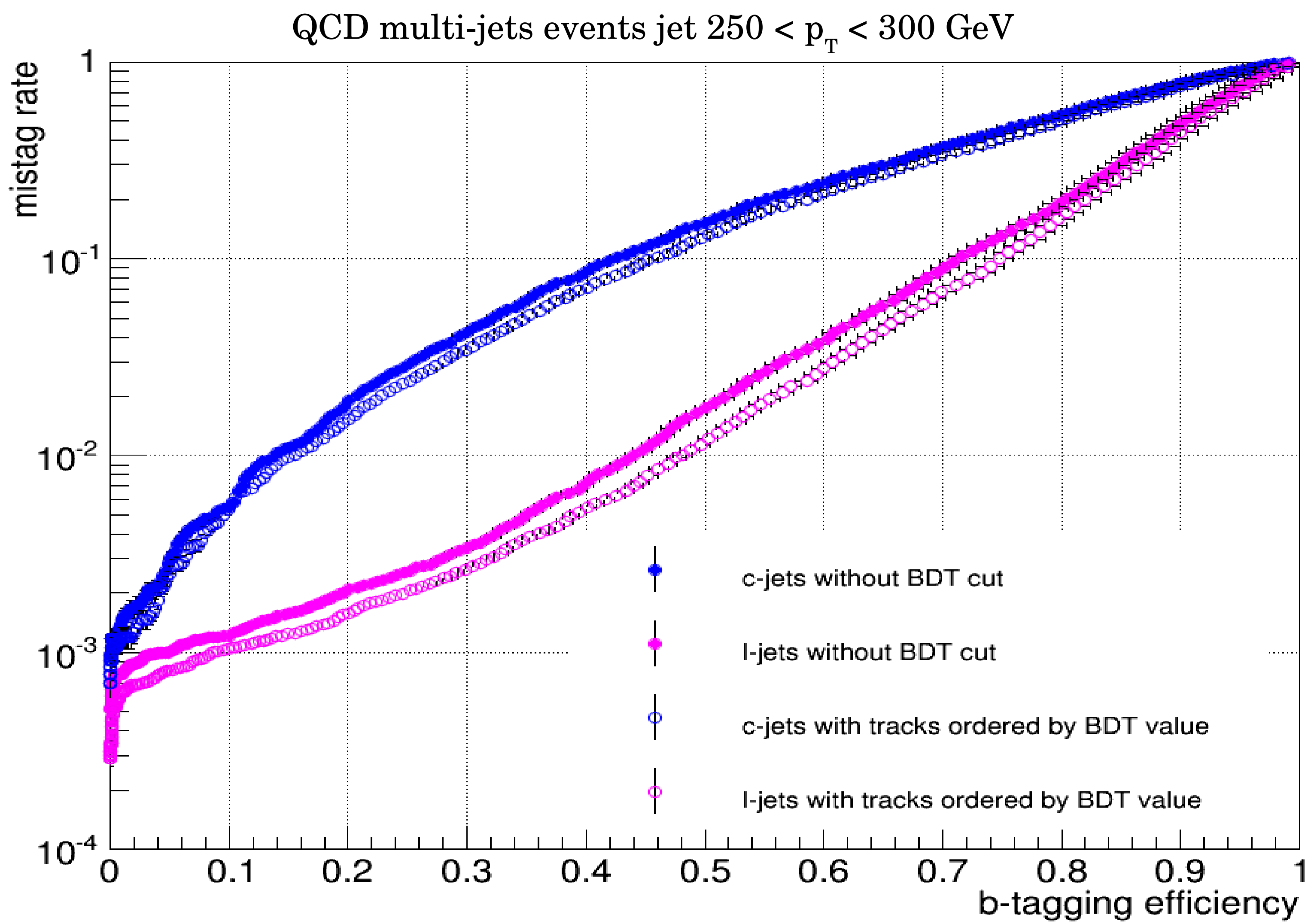
BDT



For JP, BDT cut of **0.3** → **improvement** of b-tagging efficiency of **~ 4%**

New Jet B Probability

Jet B Probability: JP in which 4 tracks with highest IP/σ have more weight in algorithm
→ Test: instead, 4 tracks with **highest BDT** output values



New calibration

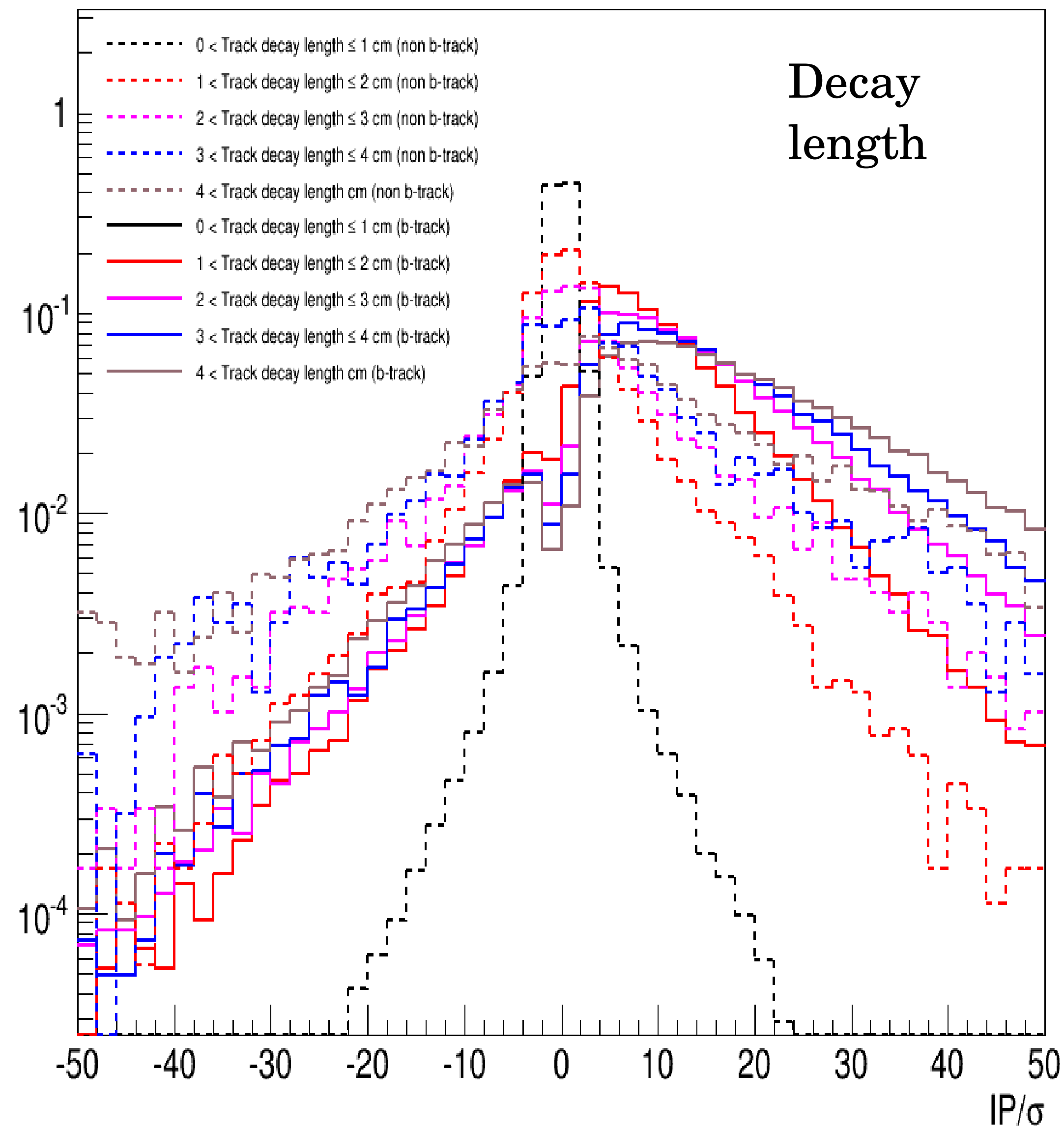
Some variables found to be **sensitive to IP/σ** → impact on the calibration

1) New calibration done with
- Add **decay length** in category definition
- Refinement: add more intervals in track **p**

→ No real improvement seen

2) Other test: calibration performed with **high p_T jets** ($300 < p_T < 470$ GeV)

→ No real improvement seen



Conclusion

- JP **robust** tagger calibrated with **data**
- At high p_T → loss of b-tagging efficiency
- Coming from a **loss of B tracks** in the b-jet and **contamination of non B tracks**
- **New calibrations** tested with new categories → no real improvement
- **BDT use to discriminate real from non real B tracks** and remove contamination in JP → visible improvement for high BDT cut
- Not implemented for 8 TeV analyses but hints for 13 TeV

Search for the associated production of Higgs and Z bosons with the Matrix Element Method using different algorithms for b-jets identification

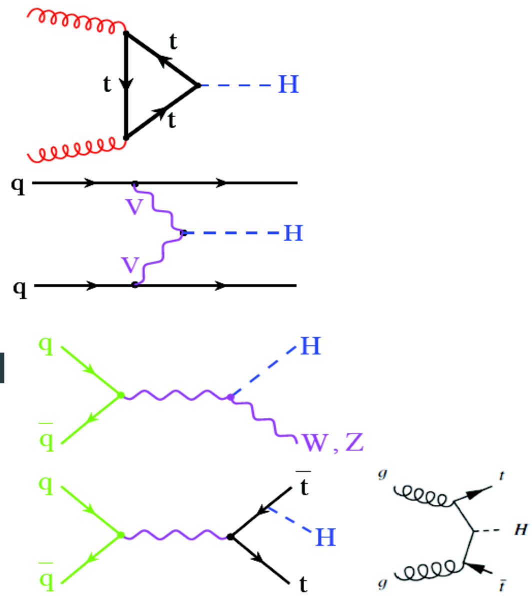
Higgs boson search: state of the art

July the 4th 2012 **discovery** of new particle compatible with the SM Higgs boson:

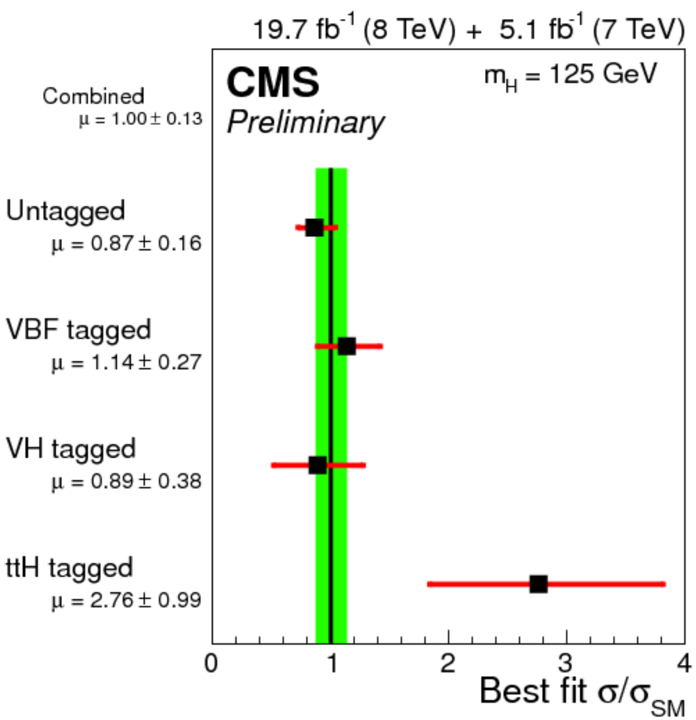
- $\mu = \sigma/\sigma_{SM}$=1.00 ±0.13 (at 125 GeV)
- mass = 125.03 ±0.3 GeV.
- Coupling established in channels $\gamma\gamma$, ZZ, WW

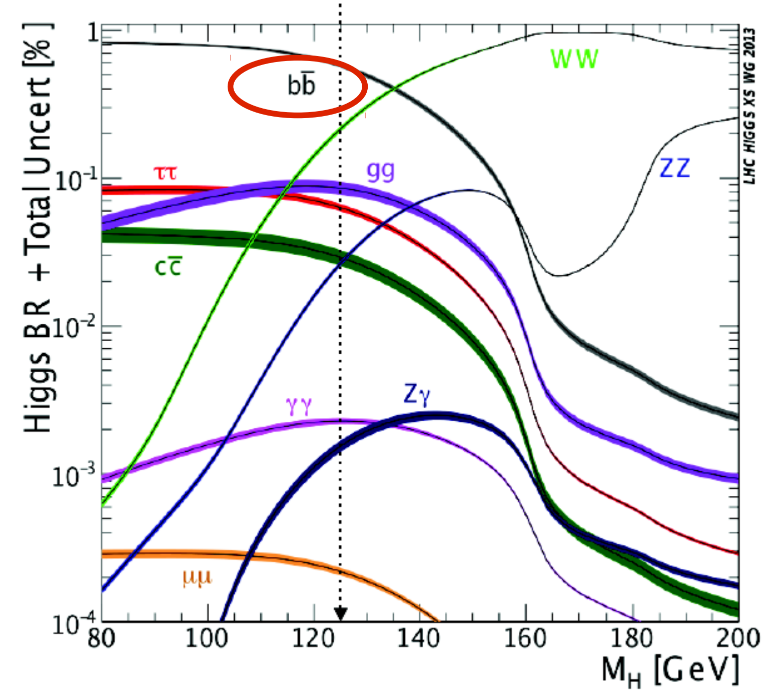
CMS official Twiki

- Gluon fusion
- VBF
- WH, ZH
- bbH, ttH



Coupling to ***b* quarks** → essential to state it is the **SM Higgs**, but more **challenging.**





Goal

- Z(ll)H(bb) channel → advantage: very **clean** signature, disadvantage: very **small cross** section → Z(ee/μμ/ττ)H(bb): 0.0249 pb (NNLO)

→ for 8 TeV sample ~ 500 events produced → detector acceptance + reconstruction effects + selection efficiency (SR) → **only 3.6% events selected**
→ if it is SM Higgs, difficult to see a 3σ excess in this channel

- Matrix Element Method shows an interesting potential

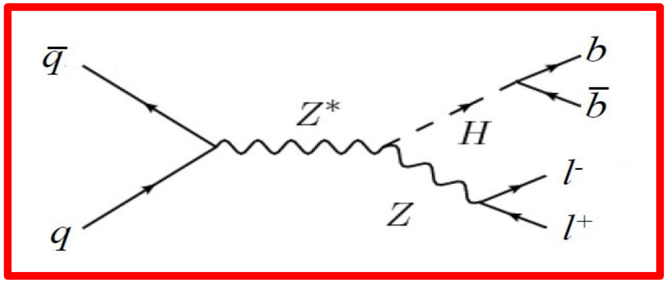
- Redo ME-based analysis using:

- Brand new **reprocessed data**

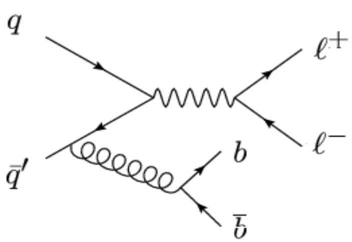
- Comparing **two b-tagging algorithm**: CSV and JP

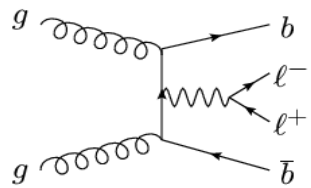
→ Paves the way to a **Model Independent search** using the same MEM approach

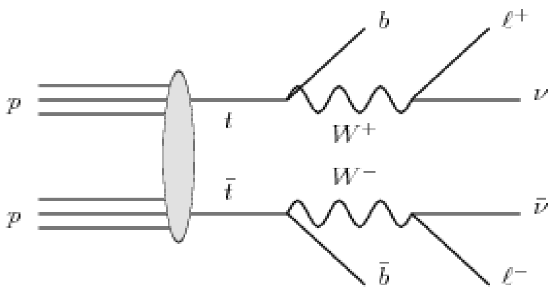
Events with llbb topology

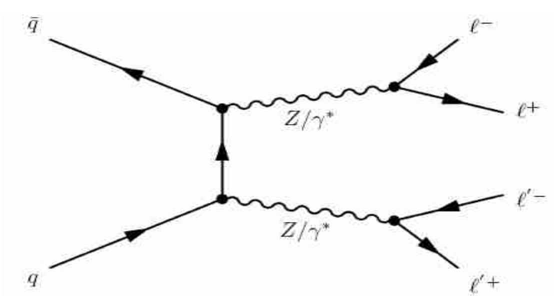


Signal: Z(ee/μμ/ττ)H(bb) (**ZH**) (0.0249 pb unc. ~4%)









Contribution

- DY events (3531.9 pb unc. 3%):
  Z(ee/μμ/ττ) + 2b, classified:
  Zbb, **Zbx**, **Zxx**
  → b: b-tagged jet correspond to b parton,
  x: b-tagged jet corresponds to c/l parton
- tt fully leptonic (**tt**) (26.6 pb unc. ~4%)
- Z(ee/μμ/ττ)Z(bb) (**ZZ**) (0.168 pb unc. ~15%)

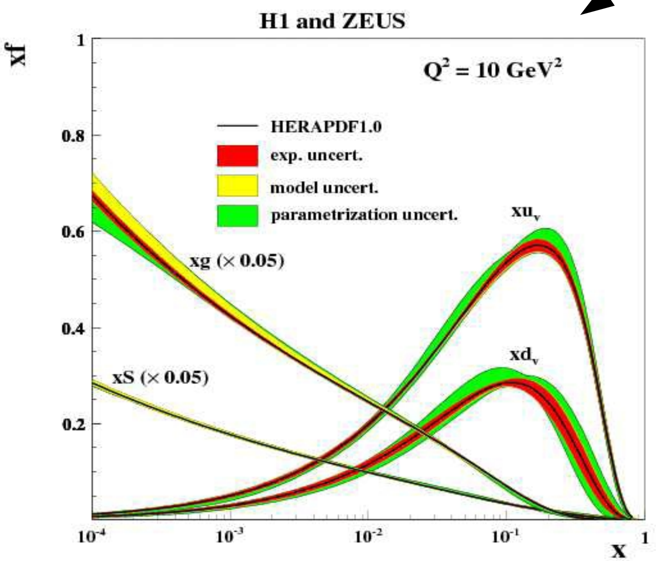
+ other negligible processes (WW, WZ, tW)

Data: sample collected at 8 TeV with L = 19.7 fb^{-1}

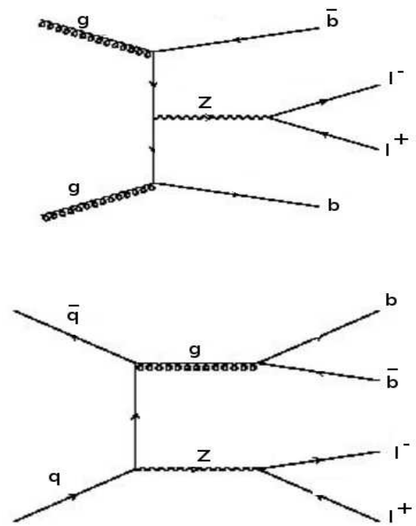
Matrix Element Method

Probability reconstructed event p^{vis} matches hypothesis α characterized by M(p):

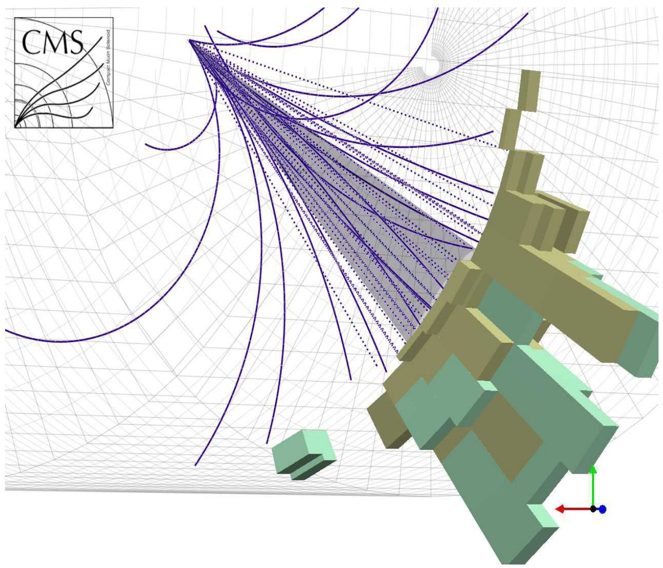
$$P(p^{vis}|\alpha) = \frac{1}{\sigma_\alpha} \int \underline{dx_1 dx_2 f(x_1) f(x_2)} \int \underline{d\phi |M(p)_\alpha|^2} \underline{W(p^{vis}, p)}$$



Proton density functions



Matrix Element at **LO** of the hypothesis



Transfer functions extracted from simulation

σ_α: total cross section, p: parton level event, p^{vis}: generator level event

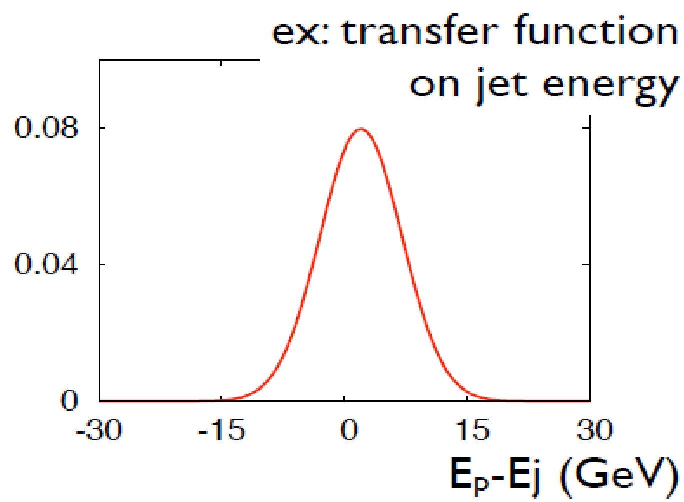
Weight = -log(P.σ_α) → computed with MadWeight

The Transfer Functions

- Transfer function: probability to go from final state generator level → detector level → take account for **showering/hadronization** effects + experimental **resolution/reconstruction** → M(p) convoluted with a TF $W(p^{vis},p)$.

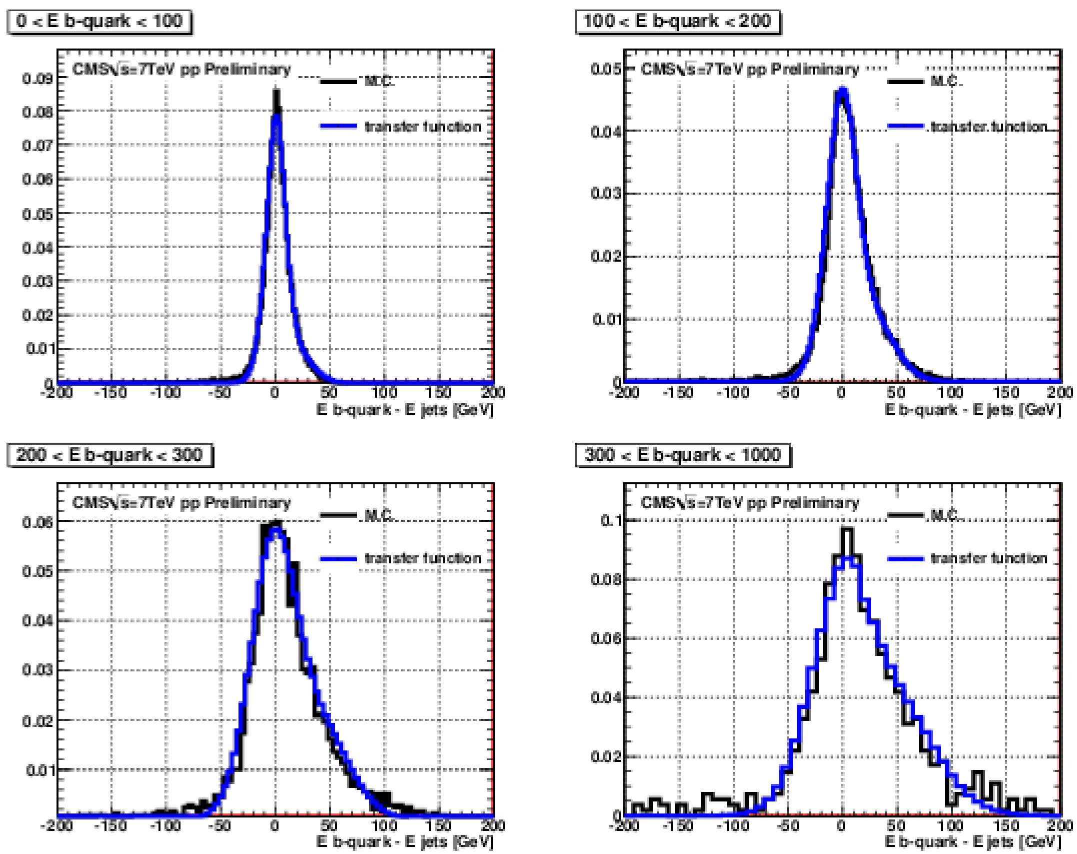
  Hypothesis:
  - lepton/jets direction well reconstructed → TF in **energy**
  - W= πWi → object TF not correlated;
  - No TF for **neutrinos.**

- Two sets of TF created: **parametrized** TF and **binned** TF



Parametrized TF

- Difference in energy (partonic/ reconstructed particle, ΔE) represented by a **double Gaussian function**
- **15** parameters fitted with un-binned likelihood function
- Use significant number of pair partonic-reconstructed particle (DY+tt dileptonic)
- For muon → parametrization in $1/p_T$
- For electrons and jets → distinction central-forward/backward



Central jets TF parametrized in ΔE, for different partonic energy ranges

Advantage:
reproduce very well tails

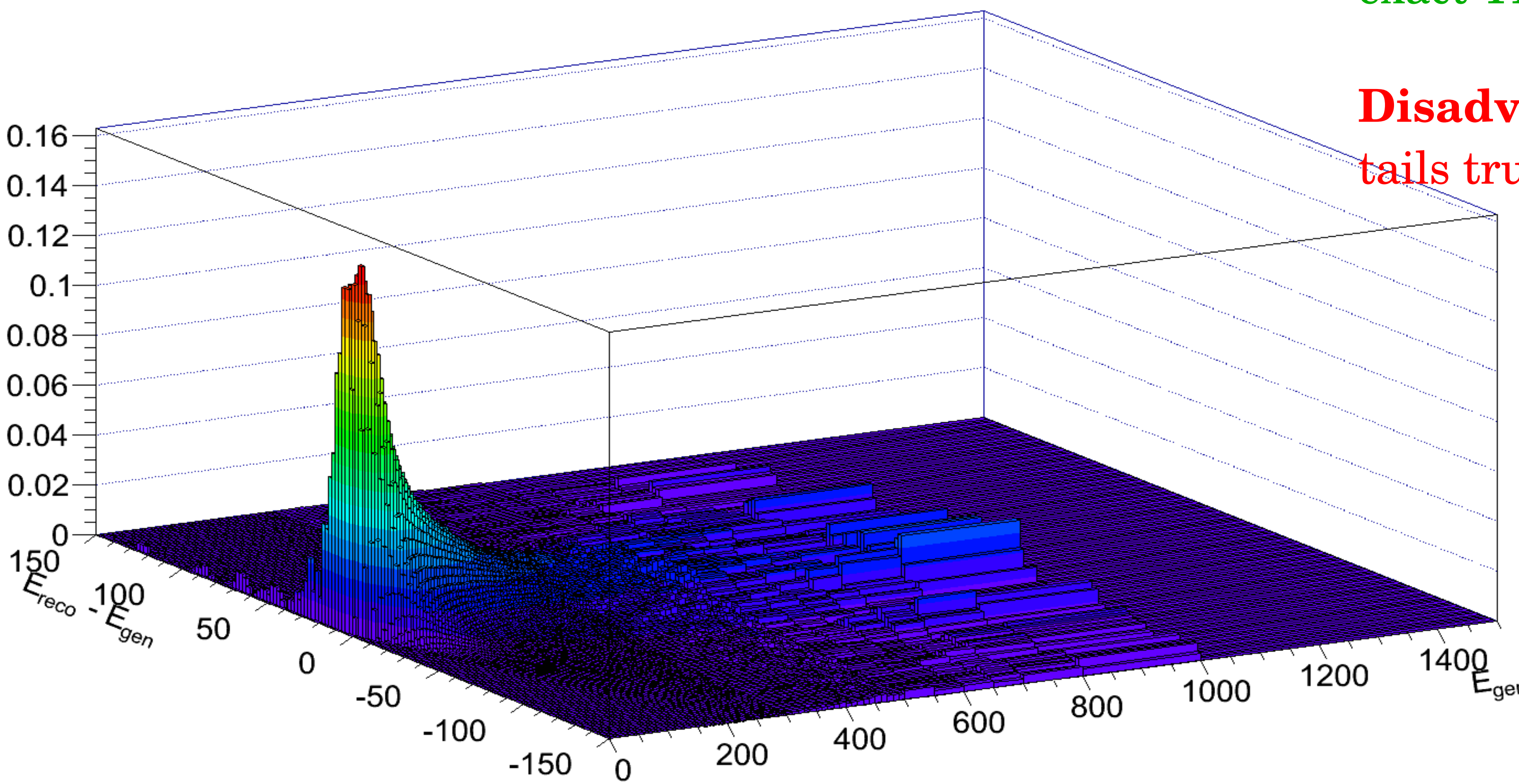
Disadvantage:
difficult to build

Binned TF

- **2D-histograms** ($\Delta E = E_{gen} - E_{reco}$ vs E_{gen}) → filled using high statistic sample (tt dileptonic)
- Histograms **smoothed** than **renormalized** to 1
- Electrons and jets TF → two η windows (central-forward/backward)
- Muon parametrized in E as well

Advantage:
exact TF

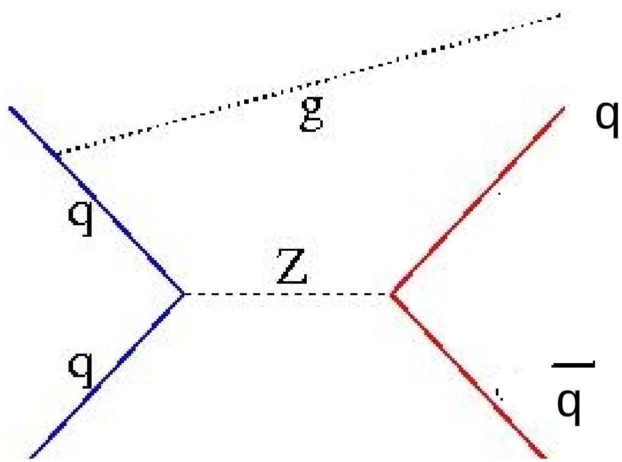
Disadvantage:
tails truncated



2D histogram: ΔE as a function of E, where E is the energy of a **central jets** (0.0 < |η|<1.6).

Corrections for NLO effects

LO ME : Initial State Radiation correction



ISR: very common

The Z produced is not at rest in transverse plan
→ induce a transverse **boost** of the system
→ Matrix Element at rest

➢ Correct for the boost

ISR correction

Two cases for ISR correction:

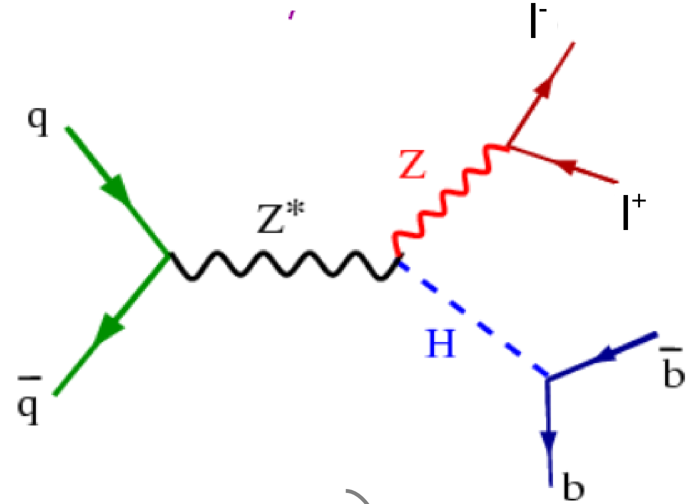
1) ISR correction used for **tt hypothesis**.: undetected particles in the final state
→ compute the ISR using the p_T of all the particles in the final state **+ info about the reconstructed E_t^{miss}**

$$\vec{P}_{T\,boost} = -\sum_{extra-jets} \vec{P_T} = \sum_{LO-Particles} \vec{P_T} + \vec{E}_T^{miss}$$

2) ISR correction used for **Zbb, ZZ and ZH hypotheses**: here, no undetected particles
→ compute the ISR using only the p_T of all the particles in the final state.

$$\vec{P}_{T\,boost} = -\sum_{extra-jets} \vec{P_T} = \sum_{LO-Particles} \vec{P_T}$$

Over-constrained systems: ZZ and ZH



Degrees of freedom:

- 2 PDF
- 4 particles in final state defined with (p_T, η, φ)

  → **14** degrees of freedom

Constraints:

- 2 Breit-Wigner
- 4 particles visible in final state defined with (p_T, η, φ)
- 4 (E-p conservation)

  → **18** constraints

System **over-contrained**:

→ Integral might not converge

2 Solutions:

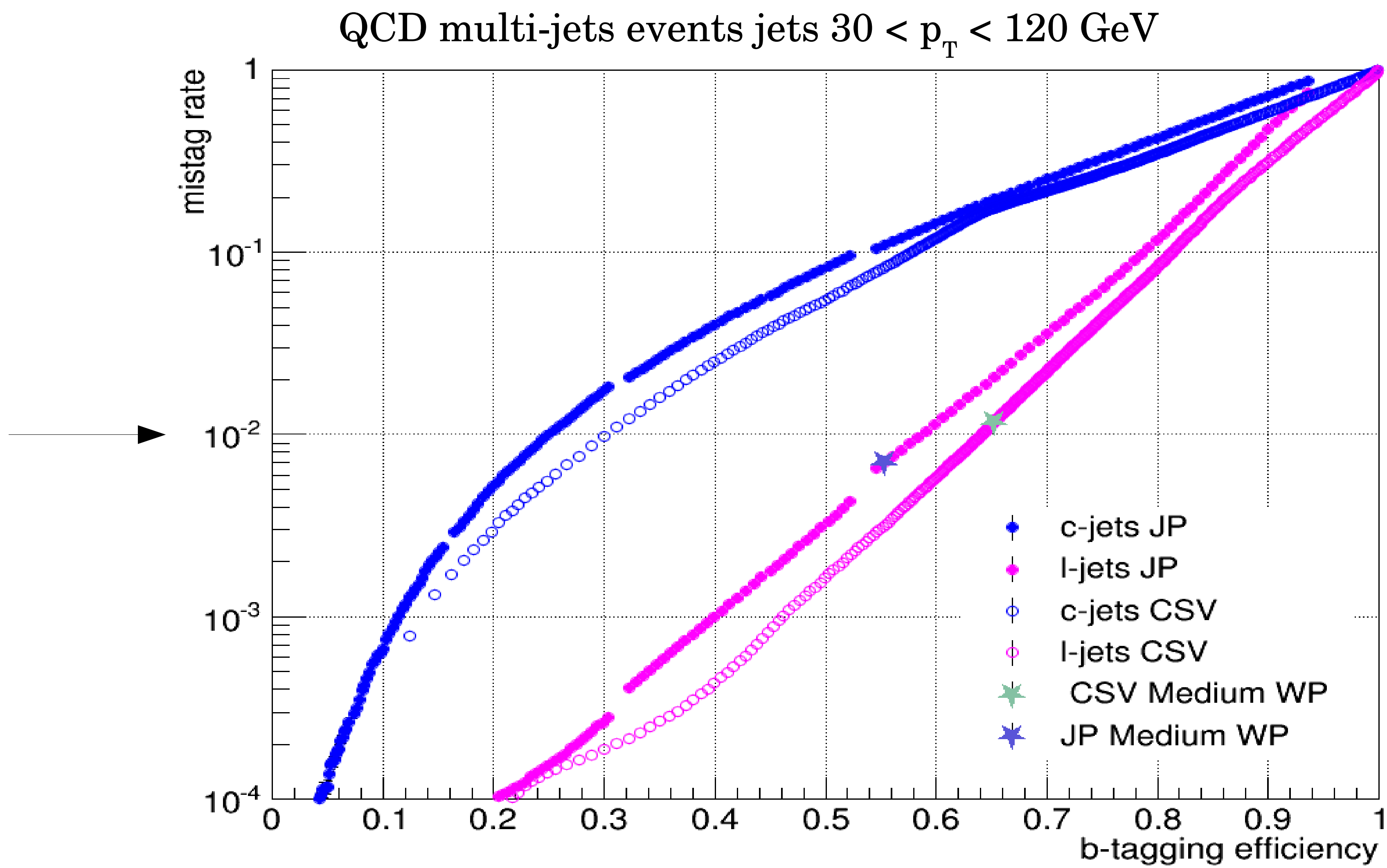
- Relax the E-p conservation constraint
- Enlarge BW width

Event selection

Trigger	DoubleMuon/DoubleElectron
Leptons	• p_T > 20 GeV • $\lvert\eta\rvert < 2.4$ for muons (2.5 electrons) • Veto $1.442 < \eta < 1.566$ for electrons • Isolated
Jets	• Leading jet: p_T > 30 GeV • Sub-leading jet: p_T > 30 GeV • Extra jet: p_T > 20 GeV • $\lvert\eta\rvert < 2.4$ • b-tagging: two **CSV/JP Medium** tagged b-jets • 2 event categories: **2j** and **3j**
Missing transverse energy	**MET significance < 10**

	Full region	Control Region	Signal Region
M_{ll}	60 – 120 GeV	76 - 106 GeV	76 – 106 GeV
M_{bb}	No cut	**2j:** < 90 or > 150 GeV **3j:** < 70 or > 150 GeV	**2j:** 90 – 150 GeV **3j:** 70 – 150 GeV

b-tagging



With Medium WP: JP → better purity

Yields in Full region

JP	Zbb	Zbx	Zxx	tt	ZZ	Total MC	Data
Z(μμ)	1135.1 ± 33.7	102.4 ± 10.1	170.6 ± 13.1	1030.9 ± 32.1	47.6 ± 6.9	2486.6 ± 49.9	3001
Z(ee)	821.4 ± 28.7	100.6 ± 10.0	121.2 ± 11.0	773.6 ± 27.8	36.2 ± 6.0	1853.0 ± 43.0	2082
Total	1956.5 ± 44.2	203.0 ± 14.2	211.8 ± 14.6	1804.5 ± 42.5	83.8 ± 9.2	4339.6 ± 65.9	5083

CSV	Zbb	Zbx	Zxx	tt	ZZ	Total MC	Data
Z(μμ)	1540.5 ± 39.2	220.0 ± 14.8	373.1 ± 19.3	1340.4 ± 36.6	67.8 ± 8.2	3541.8 ± 59.5	4214
Z(ee)	1133.0 ± 33.7	163.2 ± 12.8	254.3 ± 15.9	1005.5 ± 31.7	49.7 ± 7.0	2605.7 ± 51.0	2880
Total	2673.5 ± 51.7	383.2 ± 19.6	627.4 ± 25.0	2345.9 ± 48.4	117.5 ± 10.8	6147.5 ± 78.4	7094

Only statistical errors shown

Yields in Full region

JP	Zbb	Zbx	Zxx	tt	ZZ	Total MC	Data
Z(μμ)	1135.1 ± 33.7	102.4 ± 10.1	170.6 ± 13.1	1030.9 ± 32.1	47.6 ± 6.9	2486.6 ± 49.9	3001
Z(ee)	821.4 ± 28.7	100.6 ± 10.0	121.2 ± 11.0	773.6 ± 27.8	36.2 ± 6.0	1853.0 ± 43.0	2082
Total	1956.5 ± 44.2	203.0 ± 14.2	211.8 ± 14.6	1804.5 ± 42.5	83.8 ± 9.2	4339.6 ± 65.9	5083

x 1.36 (Zbb) **x 1.30** (tt) **x 1.40** (ZZ)

CSV	Zbb	Zbx	Zxx	tt	ZZ	Total MC	Data
Z(μμ)	1540.5 ± 39.2	220.0 ± 14.8	373.1 ± 19.3	1340.4 ± 36.6	67.8 ± 8.2	3541.8 ± 59.5	4214
Z(ee)	1133.0 ± 33.7	163.2 ± 12.8	254.3 ± 15.9	1005.5 ± 31.7	49.7 ± 7.0	2605.7 ± 51.0	2880
Total	2673.5 ± 51.7	383.2 ± 19.6	627.4 ± 25.0	2345.9 ± 48.4	117.5 ± 10.8	6147.5 ± 78.4	7094

Only statistical errors shown

Yields in Full region

JP	Zbb	Zbx	Zxx	tt	ZZ	Total MC	Data
Z(μμ)	1135.1 ± 33.7	102.4 ± 10.1	170.6 ± 13.1	1030.9 ± 32.1	47.6 ± 6.9	2486.6 ± 49.9	3001
Z(ee)	821.4 ± 28.7	100.6 ± 10.0	121.2 ± 11.0	773.6 ± 27.8	36.2 ± 6.0	1853.0 ± 43.0	2082
Total	1956.5 ± 44.2	203.0 ± 14.2	211.8 ± 14.6	1804.5 ± 42.5	83.8 ± 9.2	4339.6 ± 65.9	5083

x 1.88 **x 3**

CSV	Zbb	Zbx	Zxx	tt	ZZ	Total MC	Data
Z(μμ)	1540.5 ± 39.2	220.0 ± 14.8	373.1 ± 19.3	1340.4 ± 36.6	67.8 ± 8.2	3541.8 ± 59.5	4214
Z(ee)	1133.0 ± 33.7	163.2 ± 12.8	254.3 ± 15.9	1005.5 ± 31.7	49.7 ± 7.0	2605.7 ± 51.0	2880
Total	2673.5 ± 51.7	383.2 ± 19.6	627.4 ± 25.0	2345.9 ± 48.4	117.5 ± 10.8	6147.5 ± 78.4	7094

Only statistical errors shown

Yields in Full region

JP	Zbb	Zbx	Zxx	tt	ZZ	Total MC	Data
Z(μμ)	1135.1 ± 33.7	102.4 ± 10.1	170.6 ± 13.1	1030.9 ± 32.1	47.6 ± 6.9	2486.6 ± 49.9	3001
Z(ee)	821.4 ± 28.7	100.6 ± 10.0	121.2 ± 11.0	773.6 ± 27.8	36.2 ± 6.0	1853.0 ± 43.0	2082
Total	1956.5 ± 44.2	203.0 ± 14.2	211.8 ± 14.6	1804.5 ± 42.5	83.8 ± 9.2	4339.6 ± 65.9	5083

Data/MC = 1.17

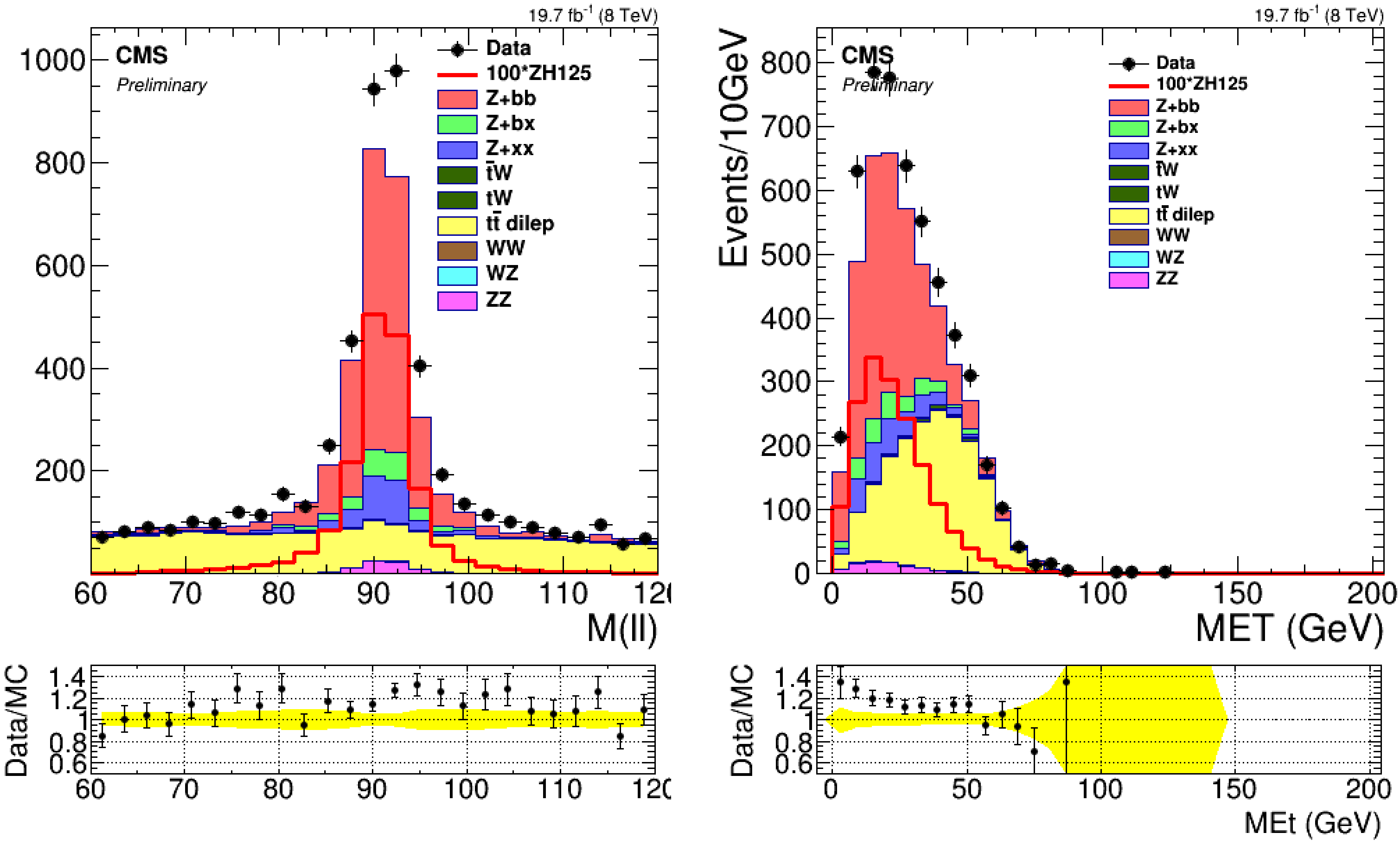
CSV	Zbb	Zbx	Zxx	tt	ZZ	Total MC	Data
Z(μμ)	1540.5 ± 39.2	220.0 ± 14.8	373.1 ± 19.3	1340.4 ± 36.6	67.8 ± 8.2	3541.8 ± 59.5	4214
Z(ee)	1133.0 ± 33.7	163.2 ± 12.8	254.3 ± 15.9	1005.5 ± 31.7	49.7 ± 7.0	2605.7 ± 51.0	2880
Total	2673.5 ± 51.7	383.2 ± 19.6	627.4 ± 25.0	2345.9 ± 48.4	117.5 ± 10.8	6147.5 ± 78.4	7094

Data/MC = 1.15

Only statistical errors shown

→ **Overall excess of data of 16%**

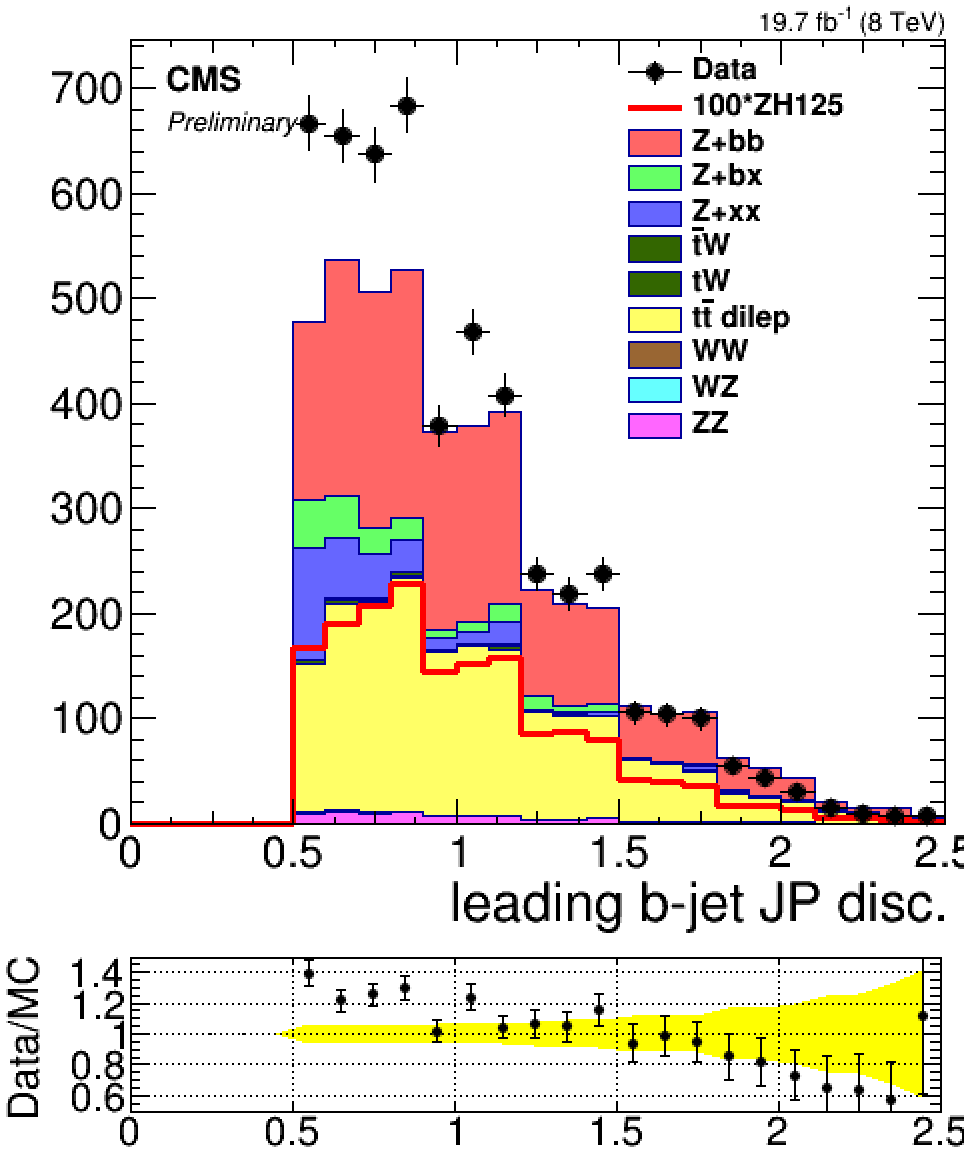
Excess in Full region

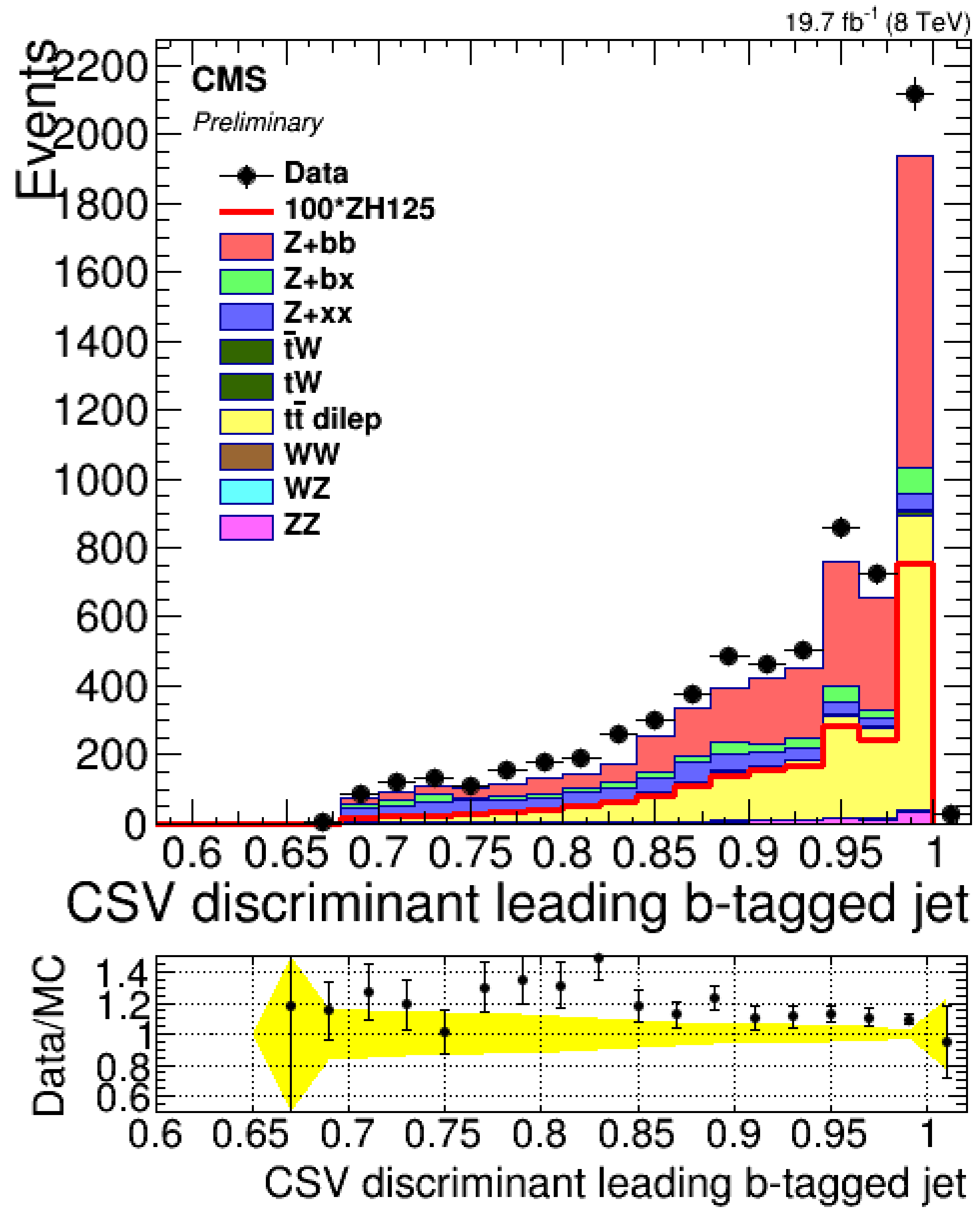


→ Full region for CSV discriminant

→ Excess seems located in ***Z* peak** and at **low MET**

Excess in Full region



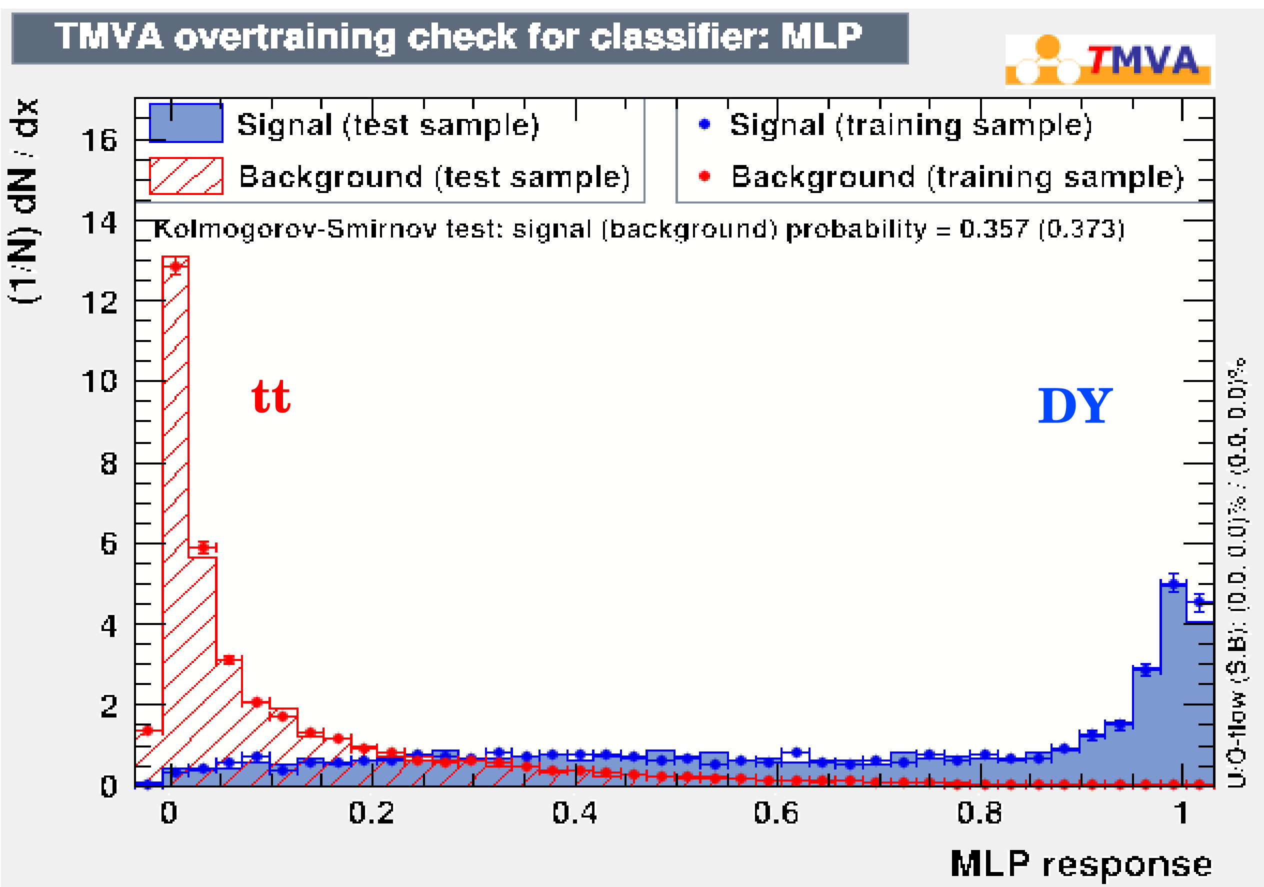


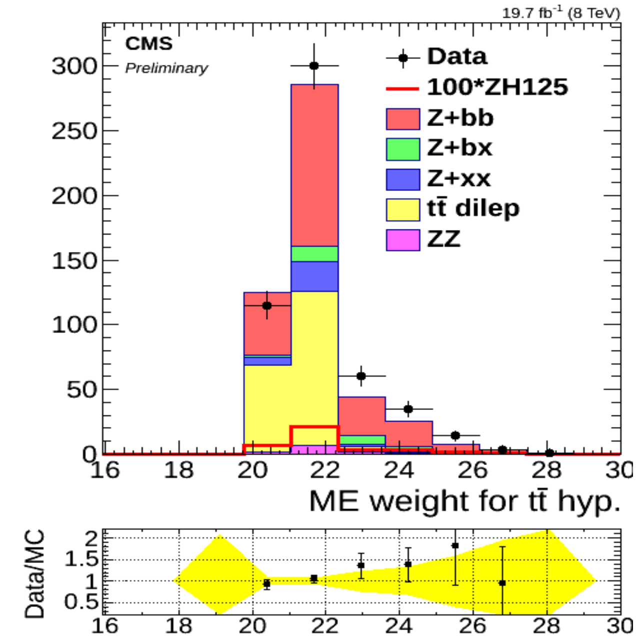
→ Seems also located at **low b-tag discriminator** values

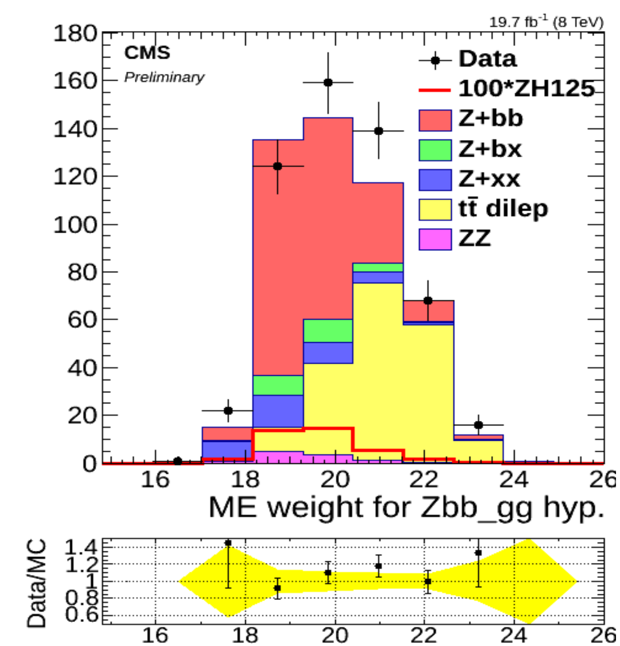
Background reweighting in Control Region

Reweight tt and DY events (Zbb, Zbx, Zxx)

- **tt** VS DY → **use NN taking as input ME weights**



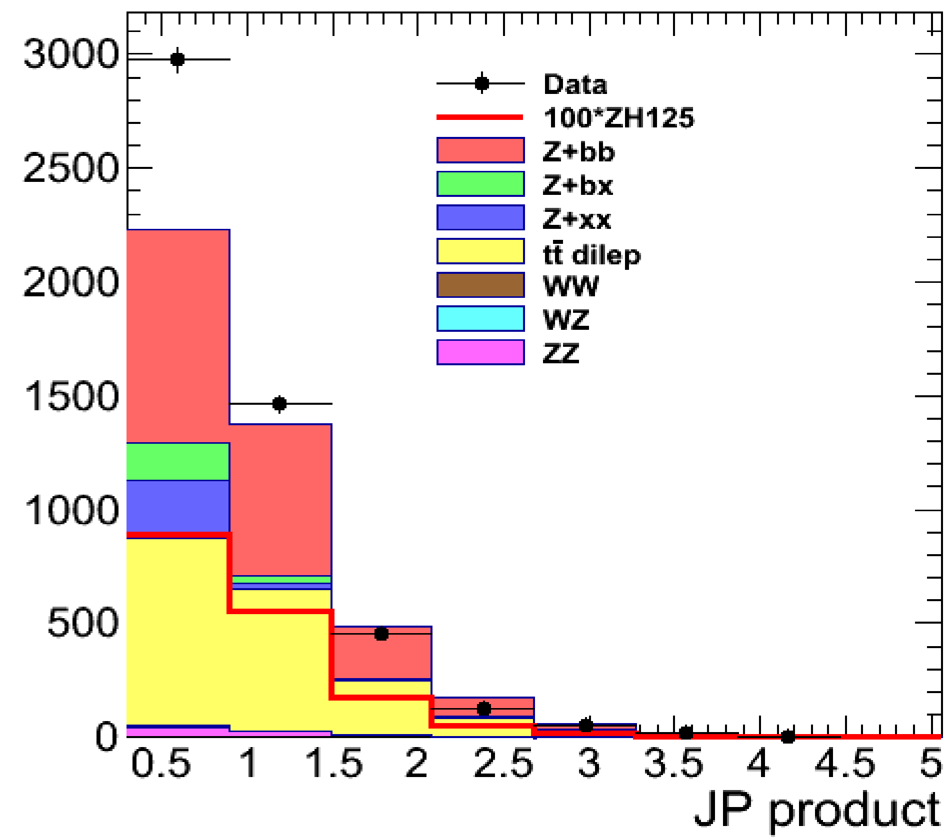




Background reweighting in Control Region

Reweight tt and DY events (Zbb, Zbx, Zxx)

- **tt** VS DY → **use NN**
- **Zbb** vs **Zbx**/**Zxx** → product of **b-tagging discriminator**



Background reweighting in Control Region

Reweight tt and DY events (Zbb, Zbx, Zxx)

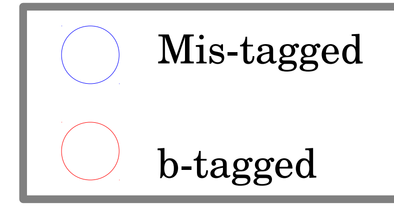
- **tt** VS DY → **use NN**
- **Zbb** vs **Zbx**/**Zxx** → product of **b-tagging discriminator**

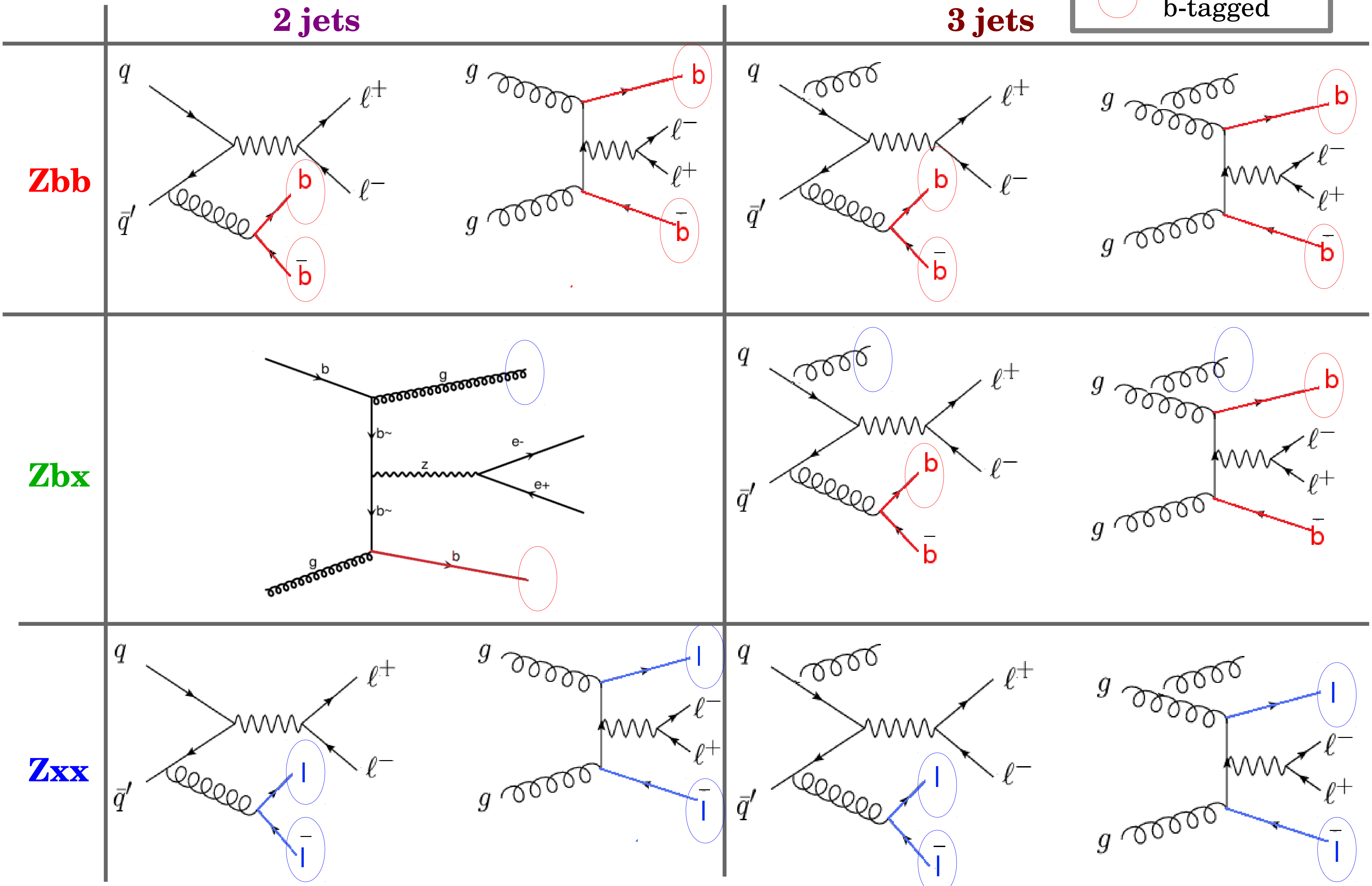
- Reweighting done simultaneously in **electron** and **muon** channels
- In **2 jets** and **3 jets** category → NLO effects

→ **8 SF**

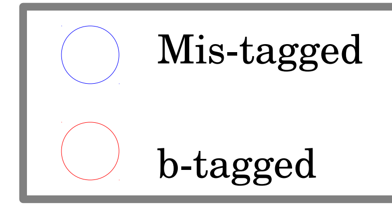
→ simplification → **only 4 to fit**

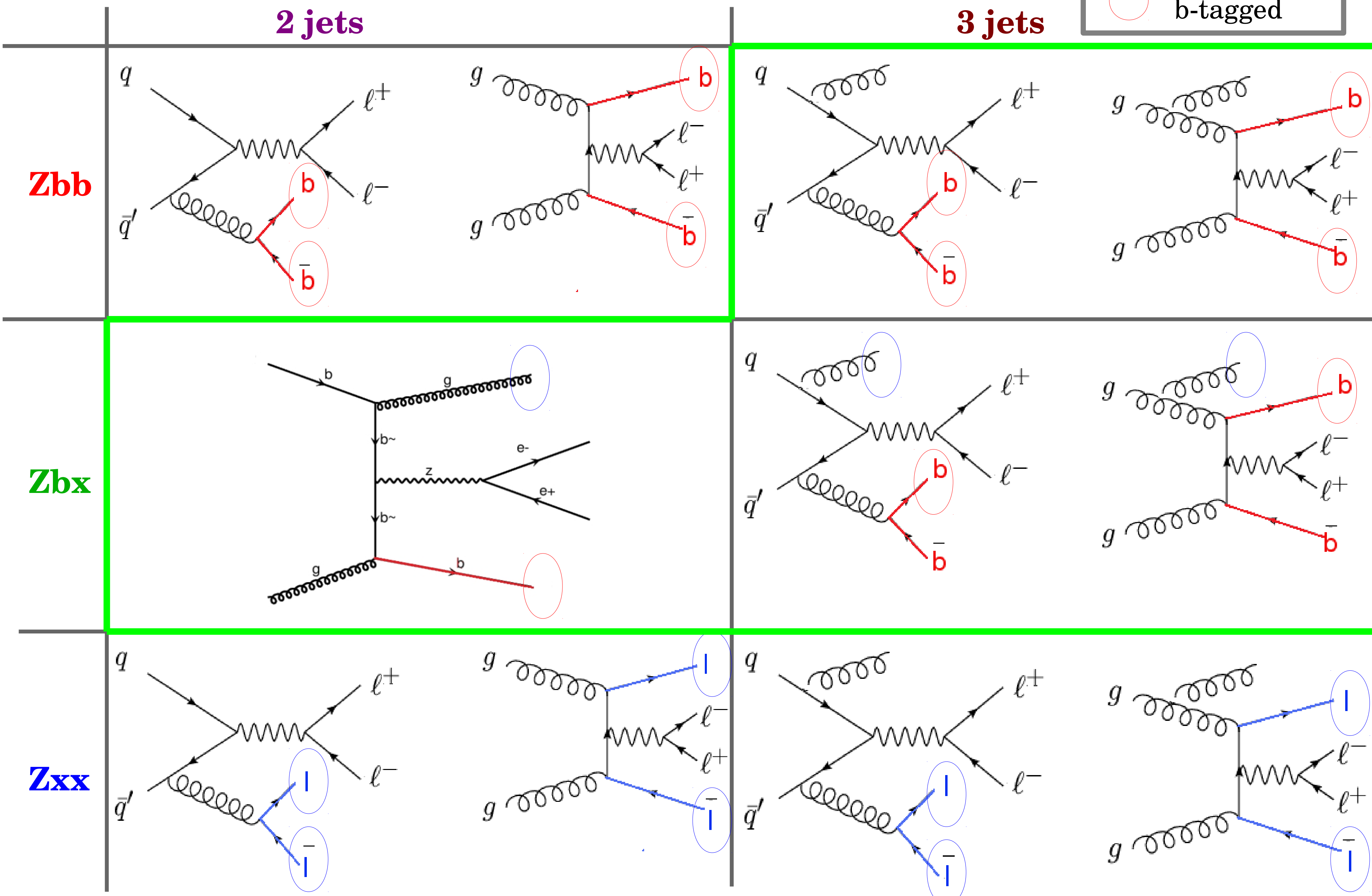
DY events categorization



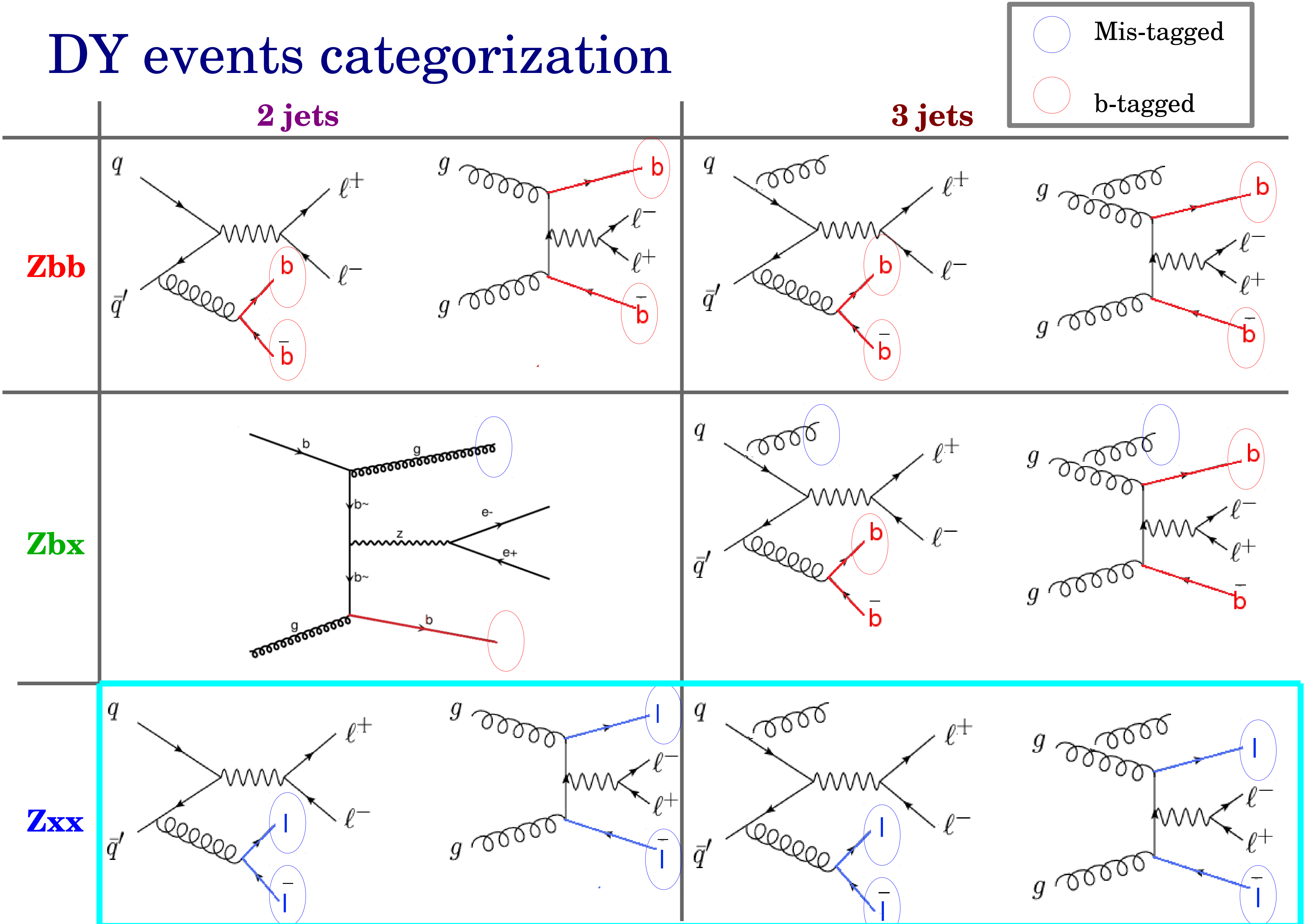


DY events categorization

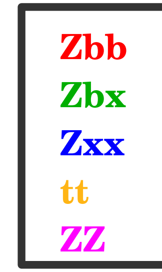




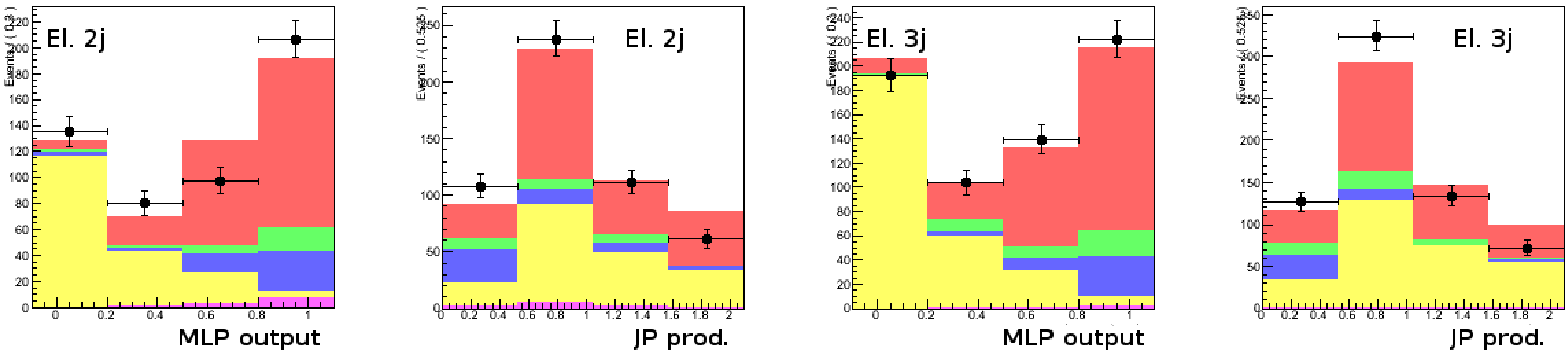
DY events categorization



Background reweighting



Simultaneous 2D-fit in electron/muon channel in 2j/3j categories:



For JP:

SF_{Zbb}	SF_{Zbx}	SF_{Zxx}	SF_{tt}
1.04 ± 0.06	1.27 ± 0.06	1.64 ± 0.24	1.03 ± 0.04

For CSV:

SF_{Zbb}	SF_{Zbx}	SF_{Zxx}	SF_{tt}
1.14 ± 0.06	1.35 ± 0.06	1.36 ± 0.14	1.01 ± 0.04

Error stat only

Yields Signal region post fit

JP	Zbb	Zbx	Zxx	tt	ZZ	Signal	Total MC (no signal)	Data
Z(ee/μμ)	942.1 ± 30.7	96.5 ± 9.8	208.2 ± 14.4	362.3 ± 19.0	50.5 ± 7.1	14.8 ± 3.8	1659.6 ± 40.7	1703

Data/MC=1.03

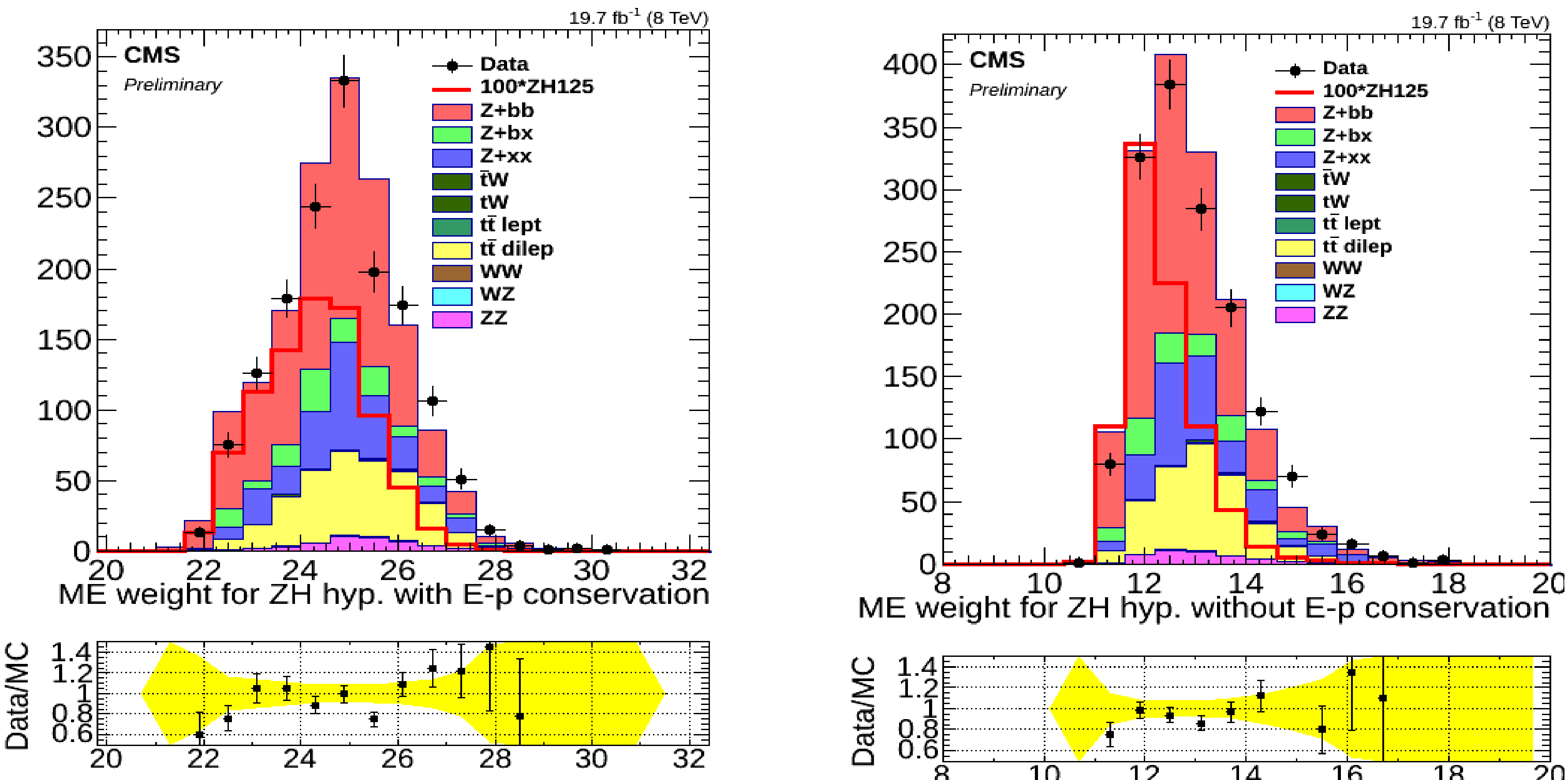
CSV	Zbb	Zbx	Zxx	tt	ZZ	Signal	Total MC (no signal)	Data
Z(ee/μμ)	1392.7 ± 37.3	197.6 ± 14.1	359.9 ± 19.0	463.0 ± 21.5	70.8 ± 8.4	19.7 ± 4.4	2484.0 ± 49.8	2394

Data/MC=0.96

	JP	CSV
S/√B	0.36	0.40

ME weights

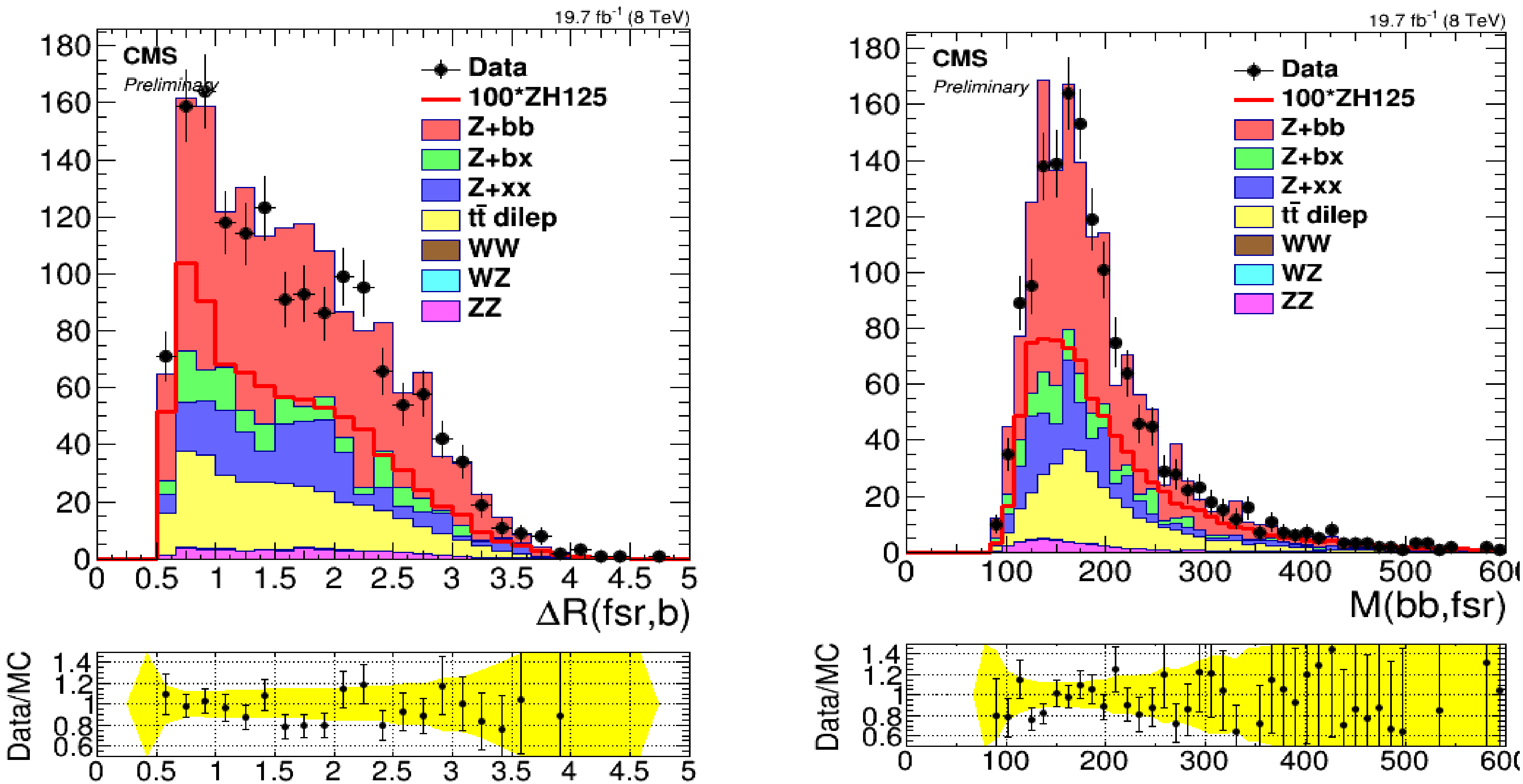
- 2 Zbb hypothesis: Zbb induced by qq (Zbb$_{qq}$) + Zbb induced by gg (Zbb$_{gg}$)
  → Approximation: same weight for Zbx and Zxx events
- 1 weight for tt di-leptonic hypothesis
- 2 weights for ZZ hypothesis, **with (without)** imposing **E-p conservation**: ZZ$_{cor0}$ (ZZ$_{cor3}$)
- 2 weights for ZH hypothesis, with (without) imposing E-p conservation: ZH$_{cor0}$ (ZH$_{cor3}$)



SR CSV 3j e+μ

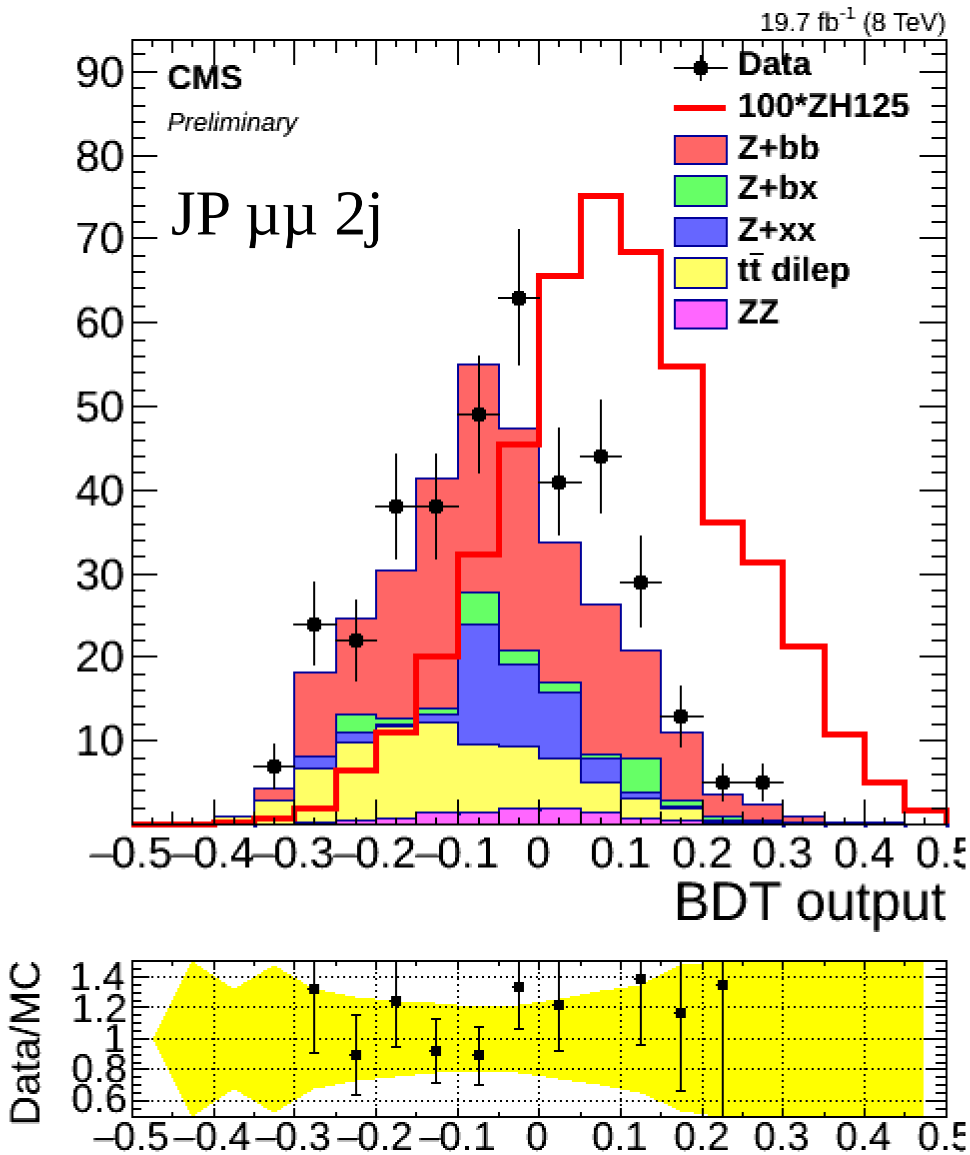
Background rejection

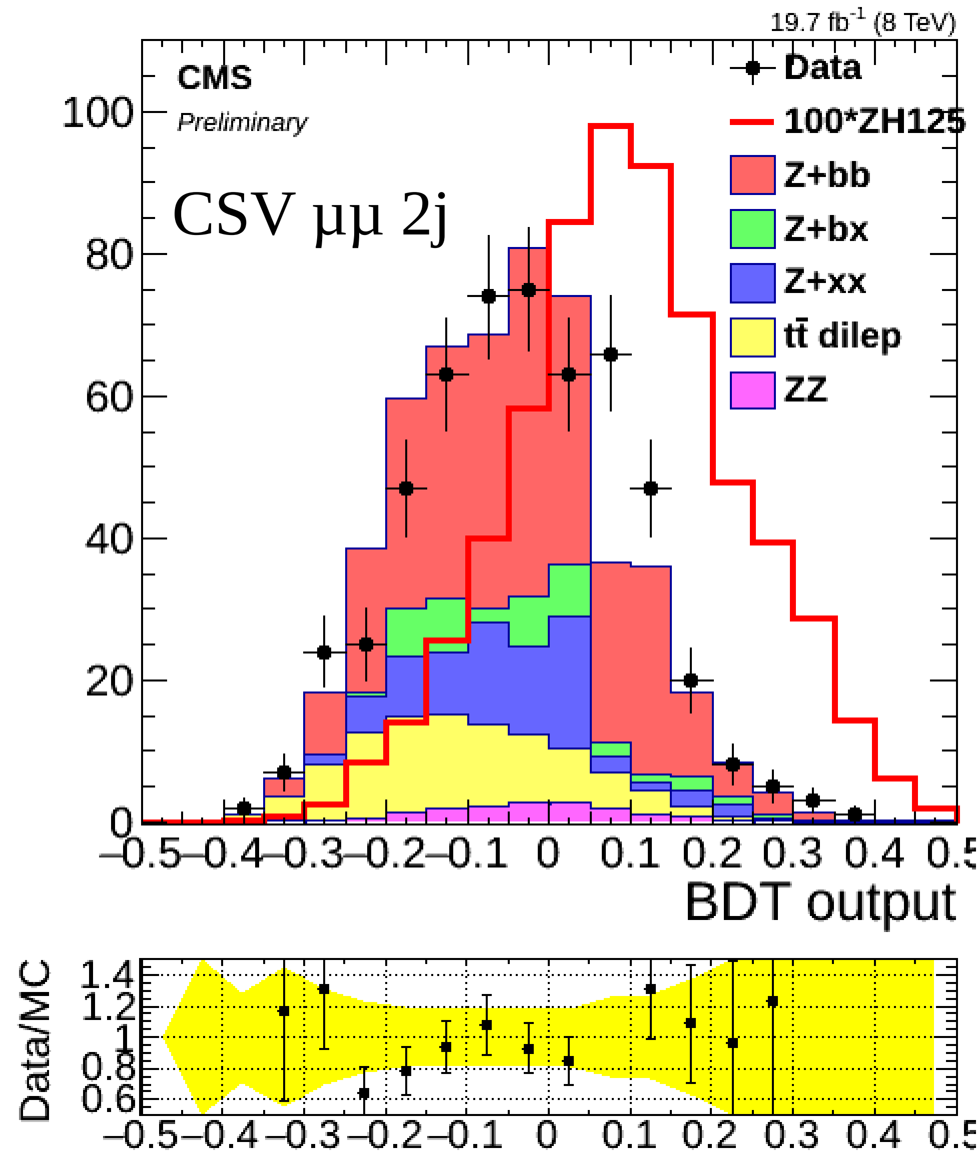
- Combine all the weights in a BDT to discriminate signal/background
- Trained electron/muon together, 2j/3j separately
- In 3 jets category, add 3 variables: ΔR(bb), ΔR(bj) (j: FSR j, b closest *b* jet) and M(bbj)



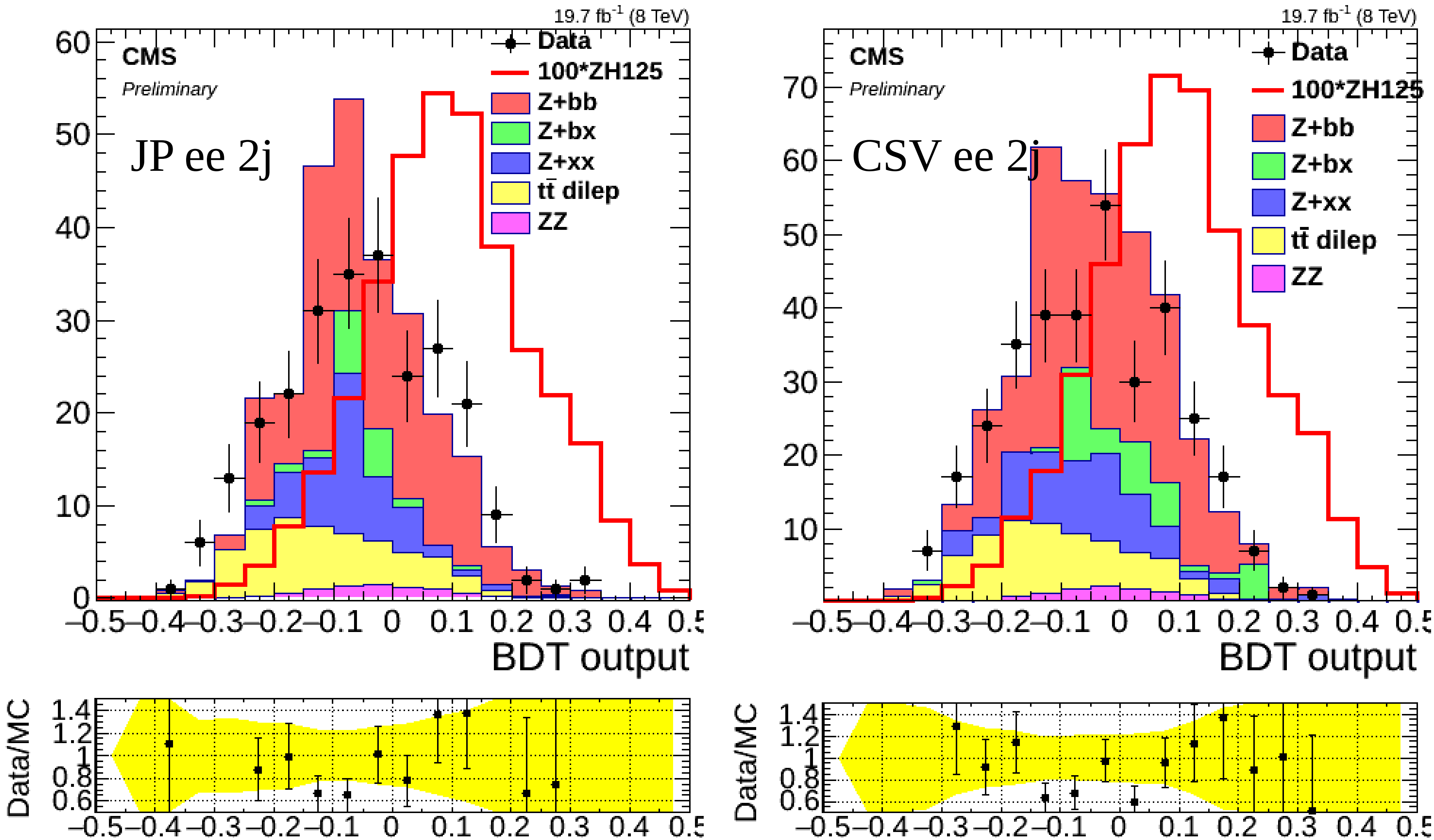
SR 3j e+μ

Background rejection





Background rejection



Systematics

Uncertainties on the global shape of the final discriminant applied directly

- **Luminosity**: 4.4% → for ZZ and ZH since other background reweighted
- **Signal cross section**: 4% → only on ZH
- **ZZ normalization** measured by CMS: 15% → only on ZZ
- **Lepton** reconstruction and trigger efficiencies (for signal only), from Tag and Probe method: 2% → only for ZH (taken into account in ZZ cross section measurement)

Systematics

Uncertainties on the global shape of the final discriminant for which **background fit redone**

- **b-tagging/mis-tag SF**: variated up and down, separately for heavy flavor jets (b-tagging), and for light jets (mis-tag) → give new event weight

- **JES/JER**: JES → apply jet-energy corrections (~3 %) = one standard deviation variations from default correction. JER → increasing/decreasing default smearing. Two effects measured:

  - Effect on the **event selection** → analysis redone with events affected by the change in JES/JER

  - **ME weights** recomputed with events JES/JER.

Systematics

Other systematics:

- **Background Fit**: statistical uncertainties associated SF extracted from the background fit → procedure to obtain uncorrelated SF
- **MC statistics**: alternative shapes

→ vary **exclusively content of one bin** of discriminator for **each process**

→ multiplied by factors representing one standard deviation of Poisson distribution

→ Only for the last 10 bins: more sensitivity

→ **Main systematic**

Systematics break-down JP

Table 4.18: Breakdown of the systematics on the final limits, for the **JP** tagger.

Systematic	Value	Degradation
No syst.	2.73	-
All syst.	3.52	28.9 %
-lumi.	3.52	-
-lepton SF	3.52	-
-ZH cross section + ZZ normalization	3.52	-
-JES	3.52	-
-JER	3.52	-
-b-tag. SF bc	3.48	0.9 %
-b-tag. SF light	3.52	-
-Background fit	3.39	3.7 %
MC statistics		
-All	3.20	9.8 %
-Zbb	3.27	7.7 %
-Zbx	3.52	-
-Zxx	3.48	0.9 %
-$t\bar{t}$	3.52	-
-ZZ	3.52	-
-ZH	3.52	-
MadWeight		
-JES	3.48	0.9 %
-JER	3.52	-

Results: 95% CL exclusion limit on μ

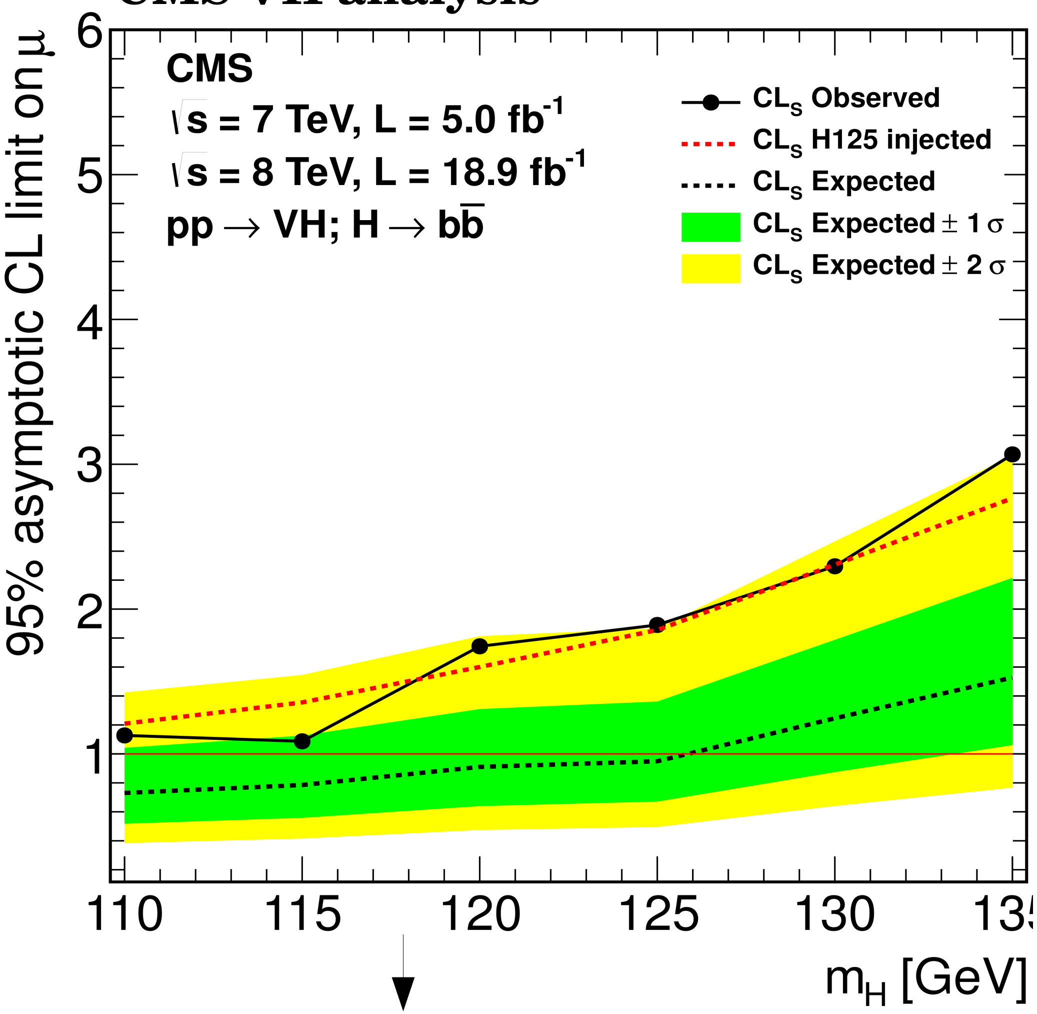
Unblind (using data)	Median (expected)	**Observed**	+1σ band
JP	4.82	**4.89**	**6.64**
CSV	3.73	**5.46**	**5.33**

→ Slightly better performance using CSV
→ Small excess for CSV

Z(ll)H(bb) channel

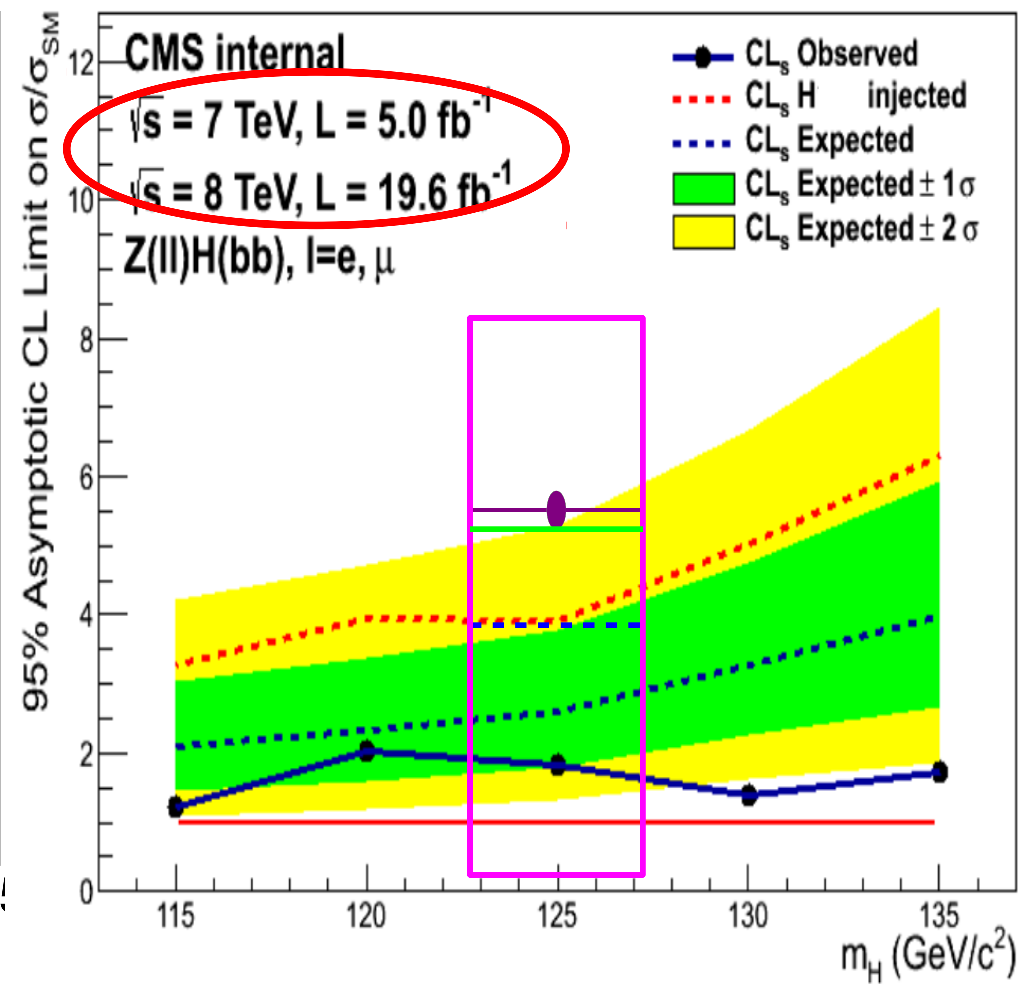
New results with CSV

CMS VH analysis



- Small excess
- Most of sensitivity coming from WH and Z(νν)

Previous ME-based analysis (CSV)



- Previous analysis → deficit, new: excess
- Expected limit slightly worse → lack of statistics for BDT training

Conclusion

- **Similar performance** for JP and CSV but CSV gives best limits
- Previous ME-based analysis: CSV tagger, not reprocessed data
- Exclusion limits on μ obtained **close** to limits found with previous analysis
- Many tools ready tuned, many ME weights computed

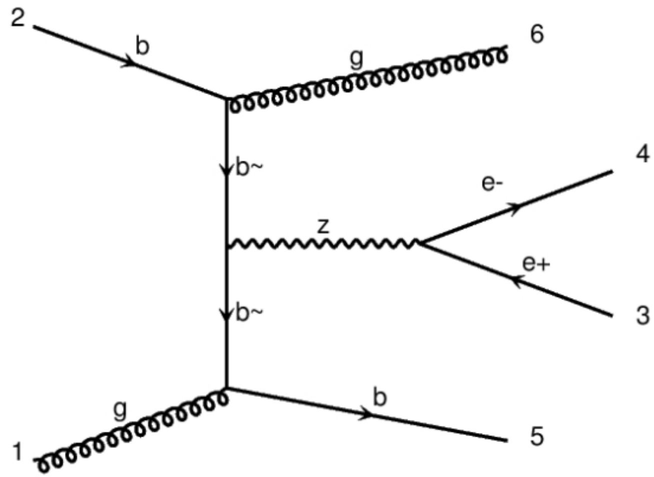
  $\rightarrow$ start to design Model Independent search

Model Independent search of new physics phenomena with a Z boson and two b jets in the final state

Zbb final state

- DY
  - Zbb
  - Zbx
  - Zxx
- **tt fully leptonic**
- **ZZ**
- ZH
- **WW**
- **WZ**

New weight: **Zbj$_{bg}$** hypothesis



- New inputs
- For WW, **ME weight**
- but very small contributions

Data: sample collected at 8 TeV with L = 19.7 fb^{-1}

Event selection

- Corresponds to the **Full Region** selection of previous analysis
- Use the SF obtained with **background reweighting** procedure for previous analysis, using CSV tagger

Trigger	DoubleMuon/DoubleElectron
Leptons	• $p_T > 20$ GeV • $\lvert\eta\rvert < 2.4$ for muons (2.5 electrons) • Veto $1.442 < \eta < 1.566$ for electrons • Isolated • **$60 < M_{ll} < 120$**
Jets	• Leading jet: $p_T > 30$ GeV • Sub-leading jet: $p_T > 30$ GeV • Extra jet: $p_T > 20$ GeV • $\lvert\eta\rvert < 2.4$ • b-tagging: two **CSV Medium** tagged b-jets
Missing transverse energy	MET significance < 10

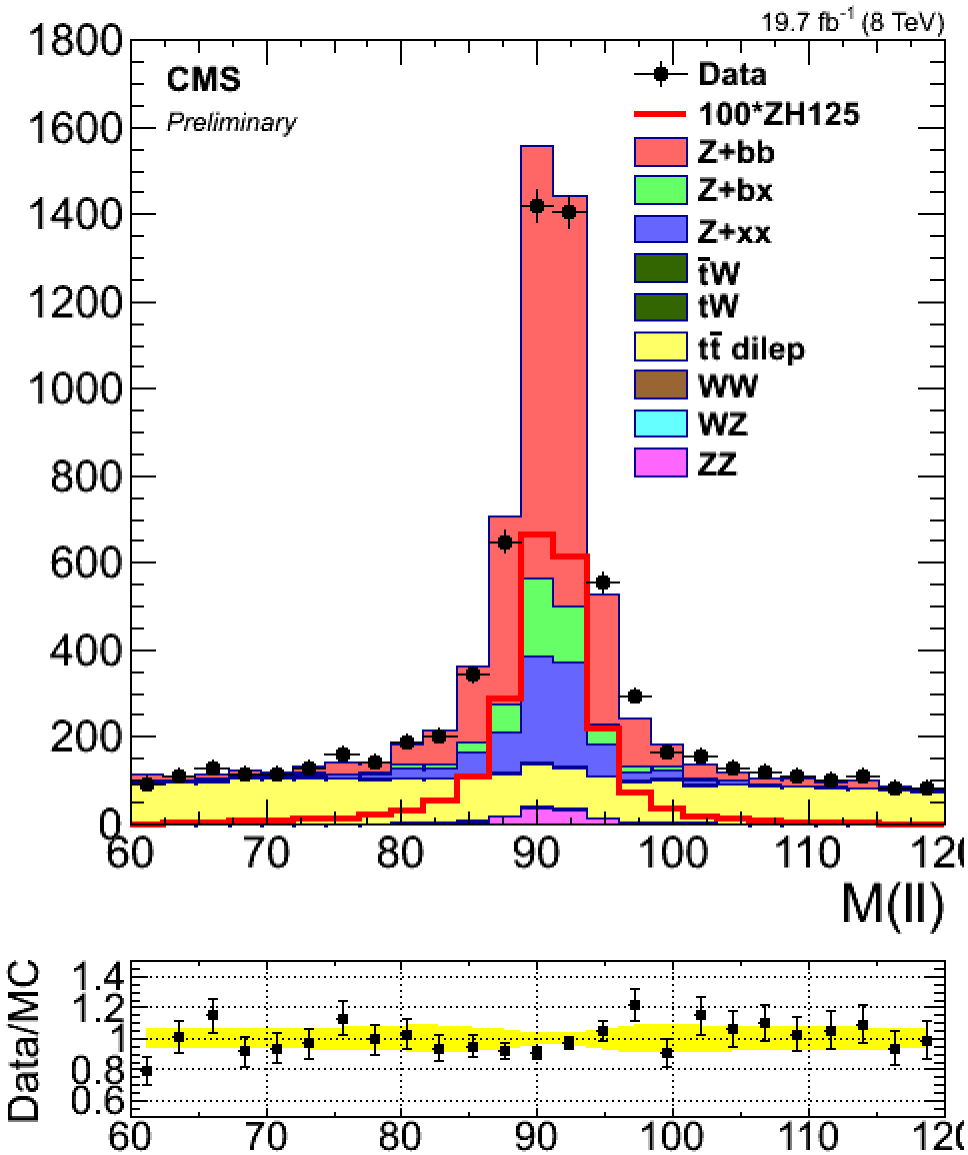
SF_{Zbb}	SF_{Zbx}	SF_{Zxx}	SF_{tt}
1.14 ± 0.06	1.35 ± 0.06	1.36 ± 0.14	1.01 ± 0.04

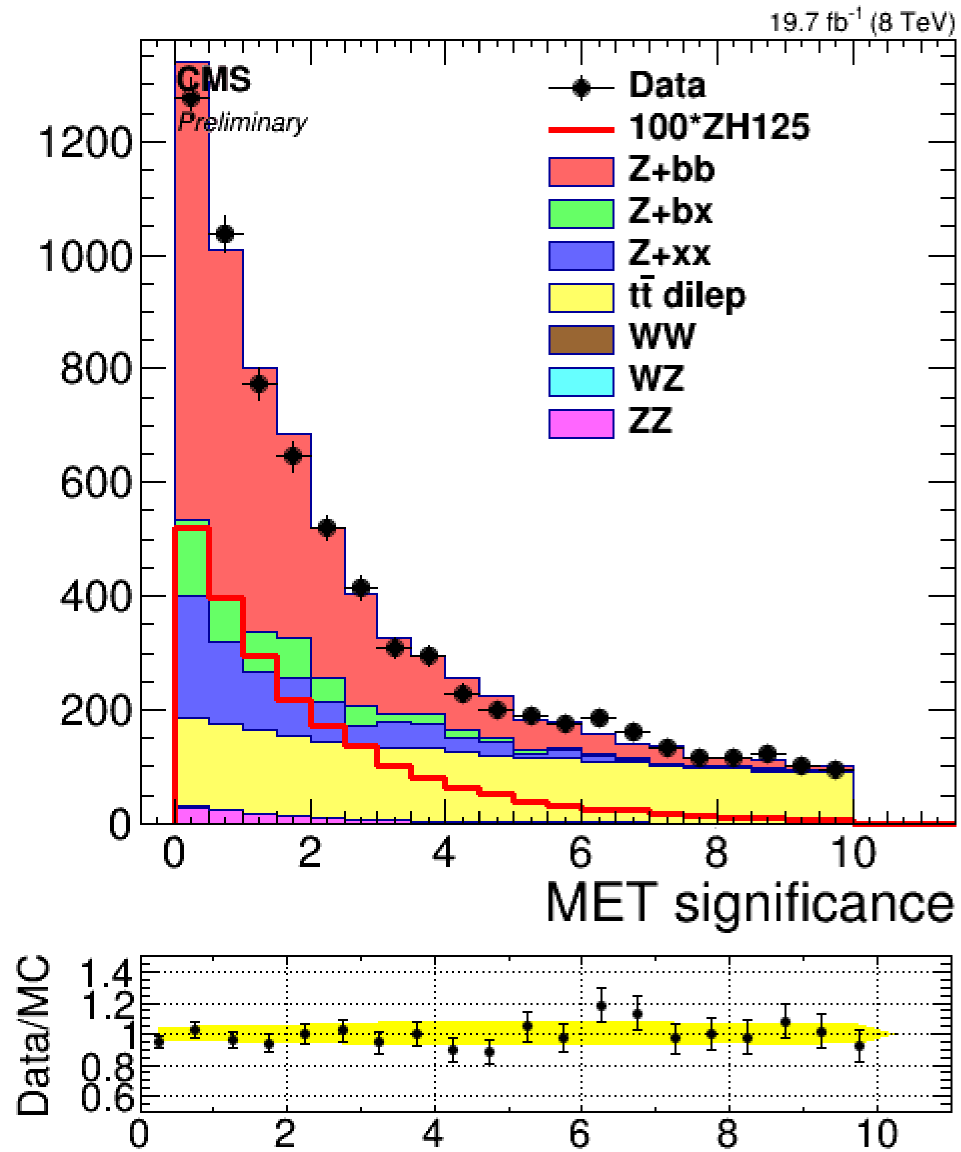
Yields

	Zbb	Zbx	Zxx	tt	ZZ	ZH	WW	WZ	Tot. MC	Data
Z → μμ	1930.0 ± 43.9	296.6 ± 17.2	507.0 ± 22.5	1348.4 ± 36.7	67.8 ± 8.2	12.6 ± 3.5	0.5 ± 0.7	7.8 ± 2.8	4170.7 ± 64.6	4214
Z → ee	1415.5 ± 37.6	220.0 ± 14.8	345.6 ± 18.6	1011.6 ± 31.8	49.7 ± 7.0	9.6 ± 3.1	0.3 ± 0.5	4.5 ± 2.1	3056.8 ± 55.3	2880
Total	3345.5 ± 57.8	516.6 ± 22.7	852.6 ± 29.2	2360.0 ± 48.6	117.5 ± 10.8	22.2 ± 4.7	0.8 ± 0.9	12.3 ± 3.5	7227.5 ± 85.0	7094

→ Overall Data/MC = 0.98

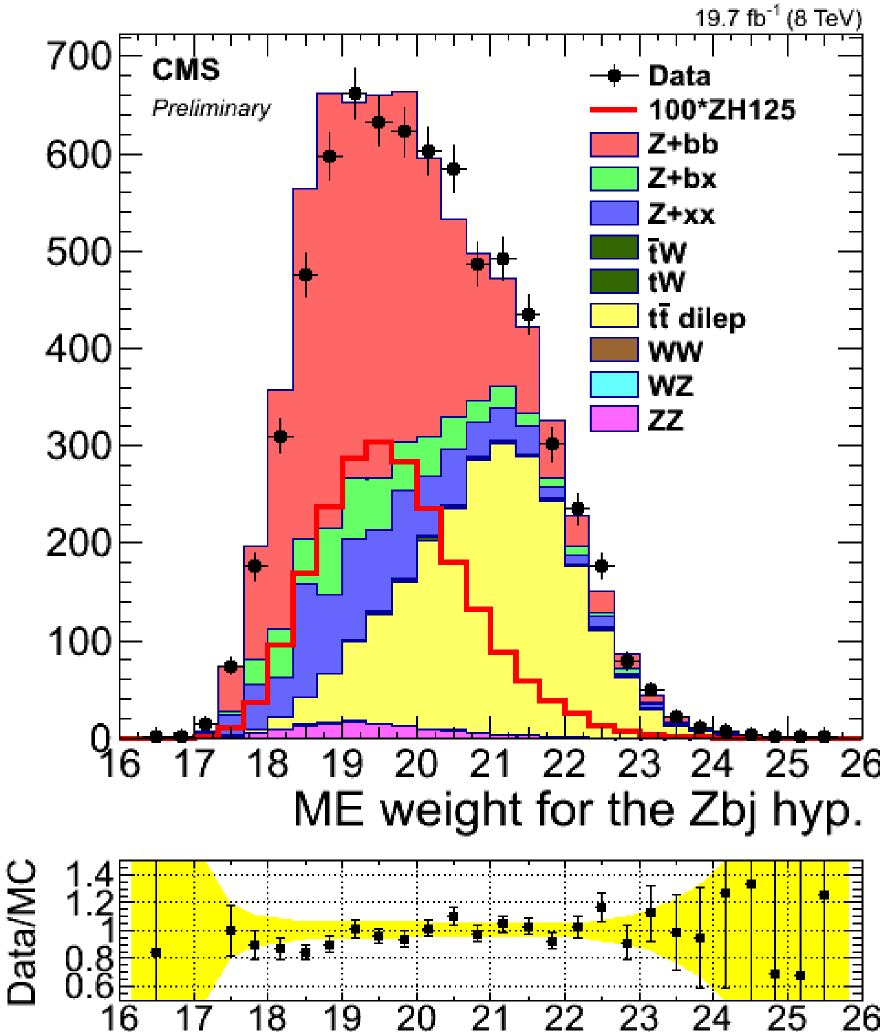
Control Plots

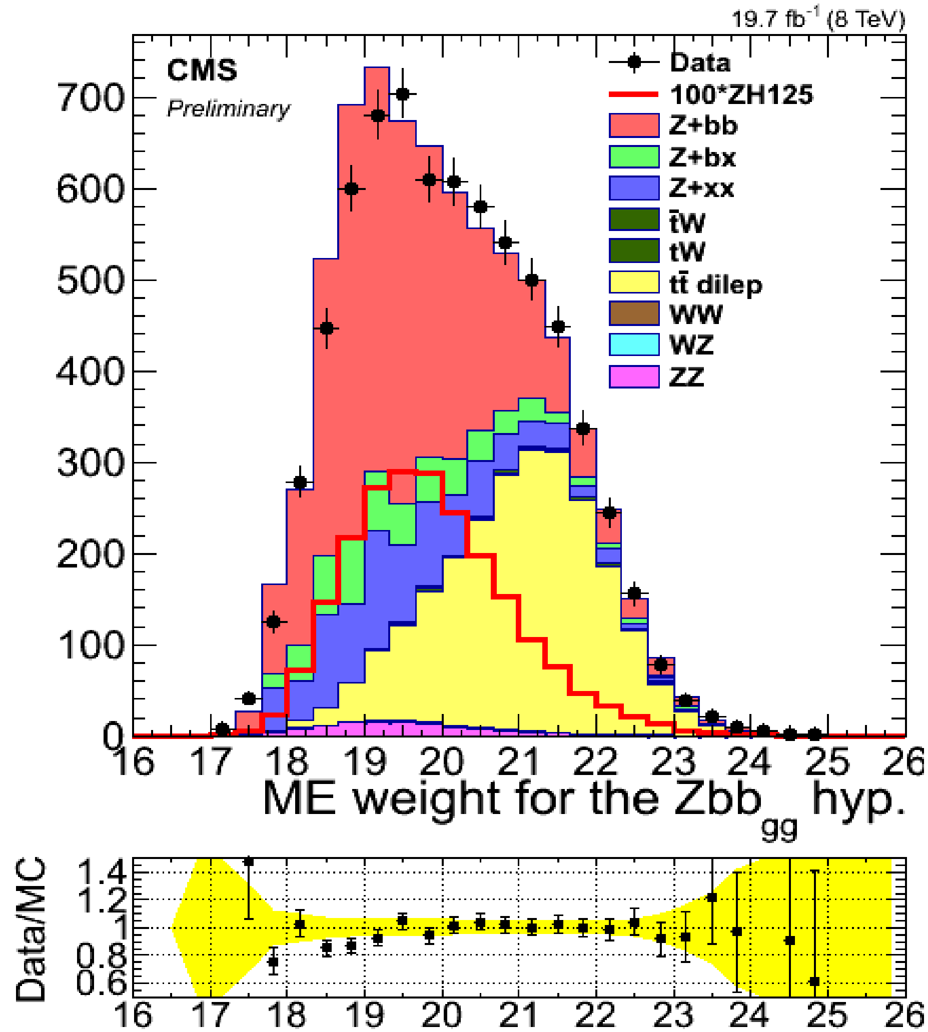




e+μ

Weights

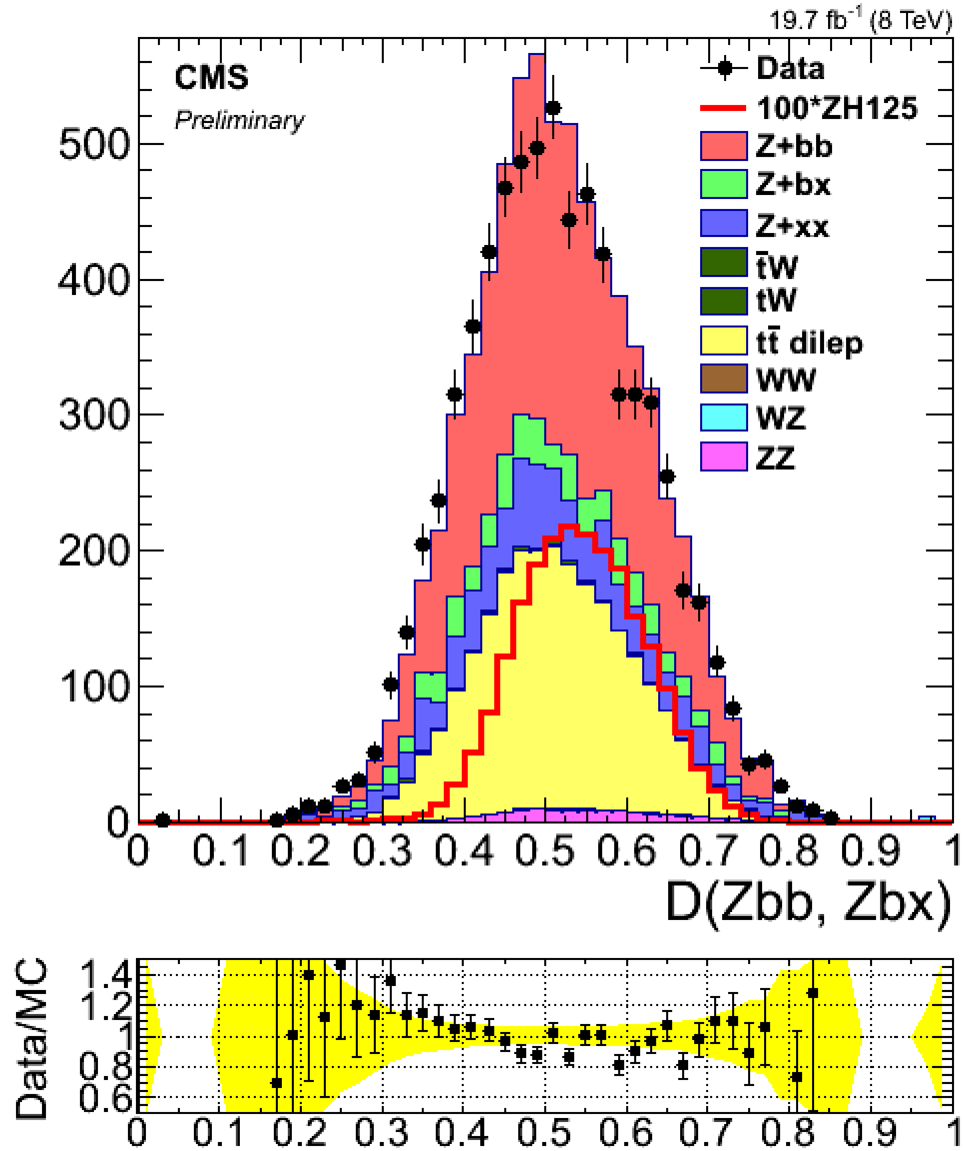




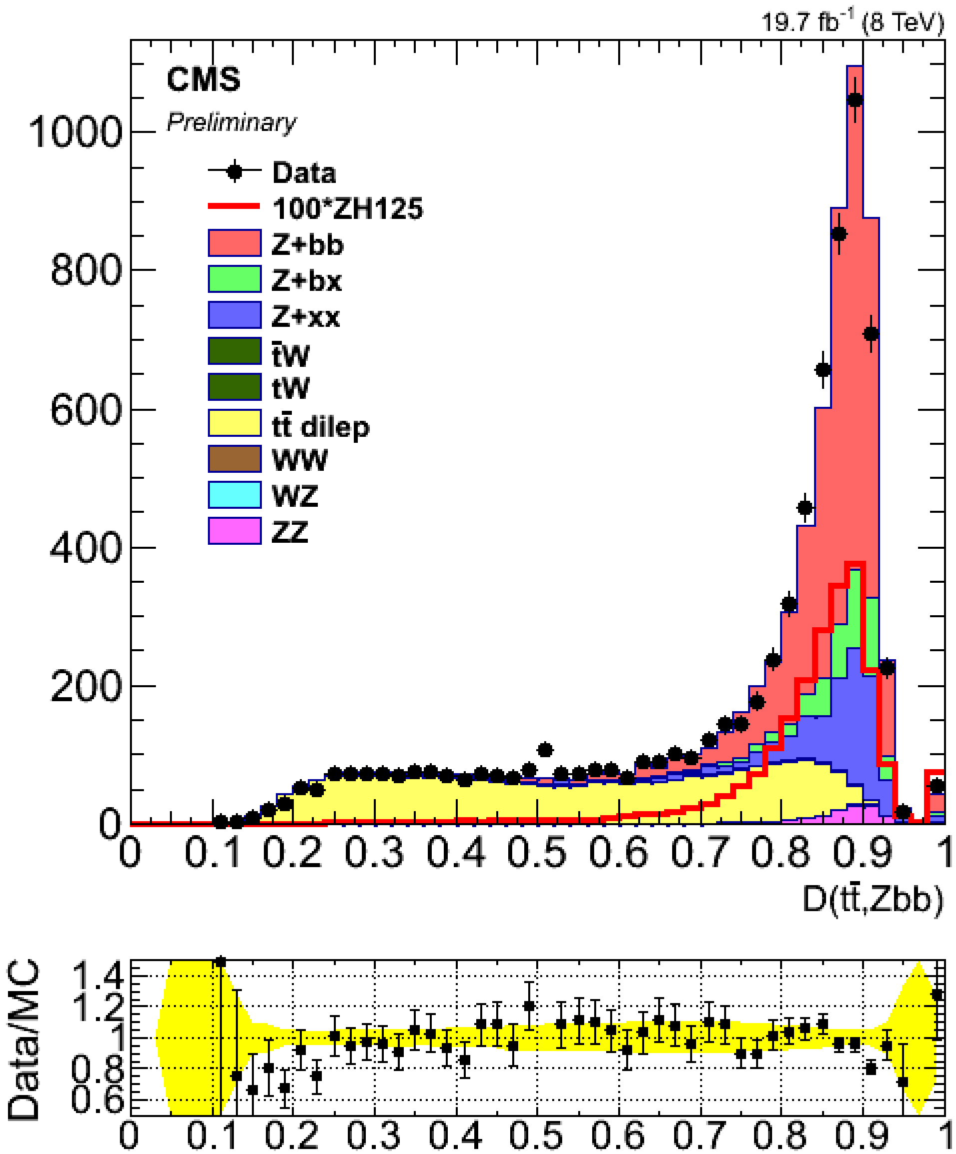
→ From these weights → creation of discriminating variable between process a and b:

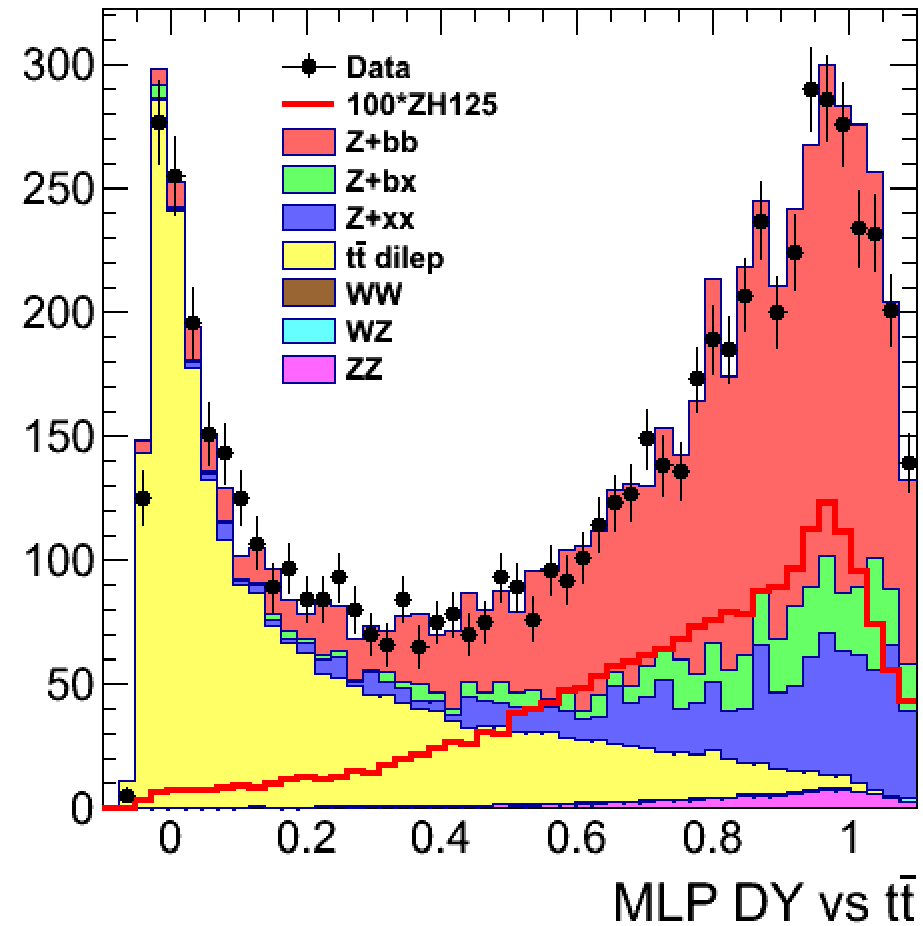
$$D = \frac{\arctan(W_a - W_b) + \pi/2}{\pi}$$

Discriminating variable



Discriminating variable





Here 2 Zbb weights taken into account

Recursive approach

Goal: discriminate **all the processes** between them: Zbb, Zbx, Zxx, ZZ, ZH and tt
→ based on a **recursive** approach

Example: 3 processes ordered by increasing yields: *a*, *b* and *c* → will start by discriminating *a* and *b; a* **smallest** yields → "signal"

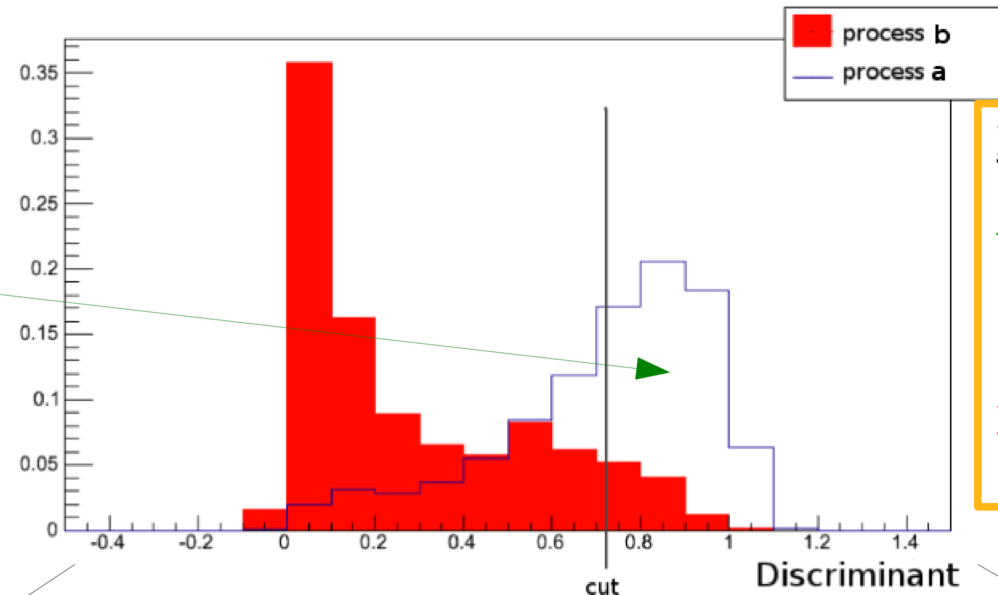
- Distributions of W_a and W_b renormalized to unity → $n_a = a.N_a = 1$ and $n_b = b.N_b = 1$;
- Build discriminating variable *D*
- Purity criteria fulfilled ? Yes → creation of two daughter "boxes", repeat the procedure
- **Purity criteria** defined as: $\frac{P_2 - P_1}{P_1} > \mathbf{cut_{Pur}} \rightarrow 2 * P_2 - 1 > \mathbf{cut_{Pur}}$

$$P_1 = \frac{n_{a(1)}}{n_{a(1)} + n_{b(1)}}$$ in mother box, $$P_2 = \frac{n_{a(2)}}{n_{a(2)} + n_{b(2)}}$$ In daughter "signal"-like box

- Additional criteria: N_a and N_b > $\mathbf{N_{MC}}$ in mother and daughter boxes.

Recursive approach

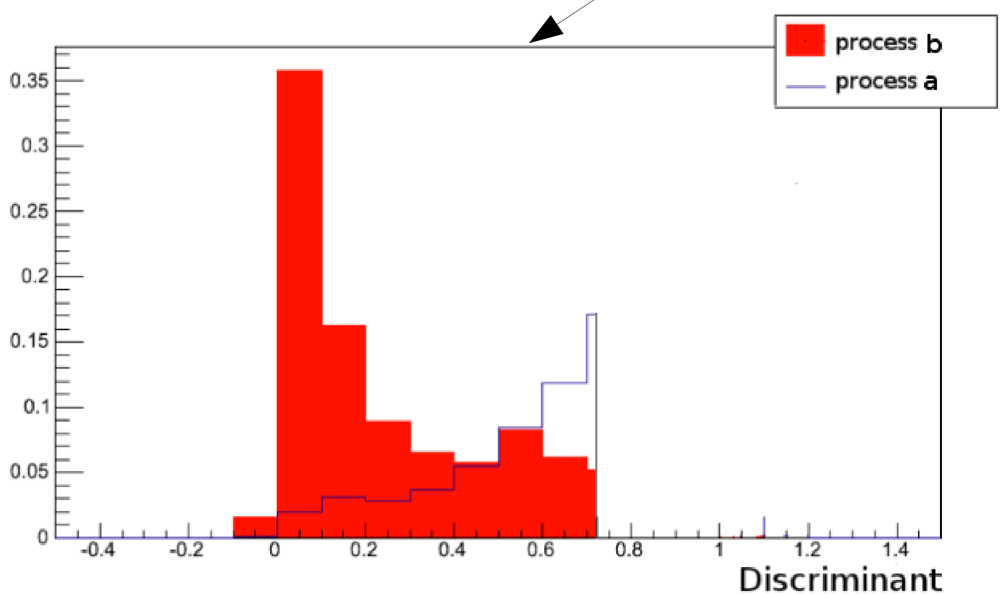
$$P_1 = \frac{n_{a(1)}}{n_{a(1)} + n_{b(1)}}$$

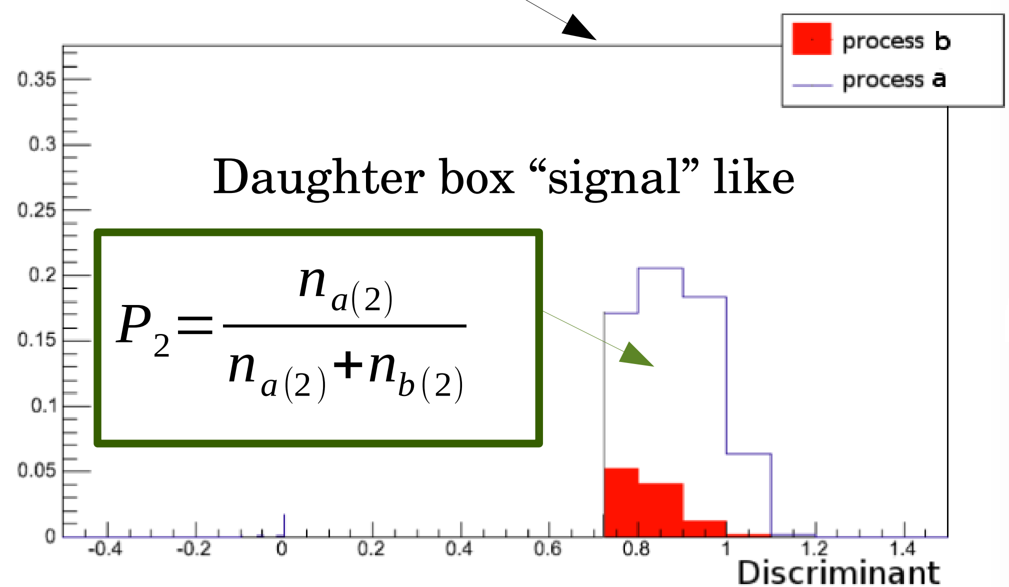


Purity criteria fulfilled ?

Yes → apply **cut** so that daughter box “signal” contains $\mathbf{f}_{\mathbf{sig}}$% of signal

No → try to discriminate *a* and *c*, then *b* and *c*





$$P_2 = \frac{n_{a(2)}}{n_{a(2)} + n_{b(2)}}$$

Free parameters

3 free parameters have to be optimized:

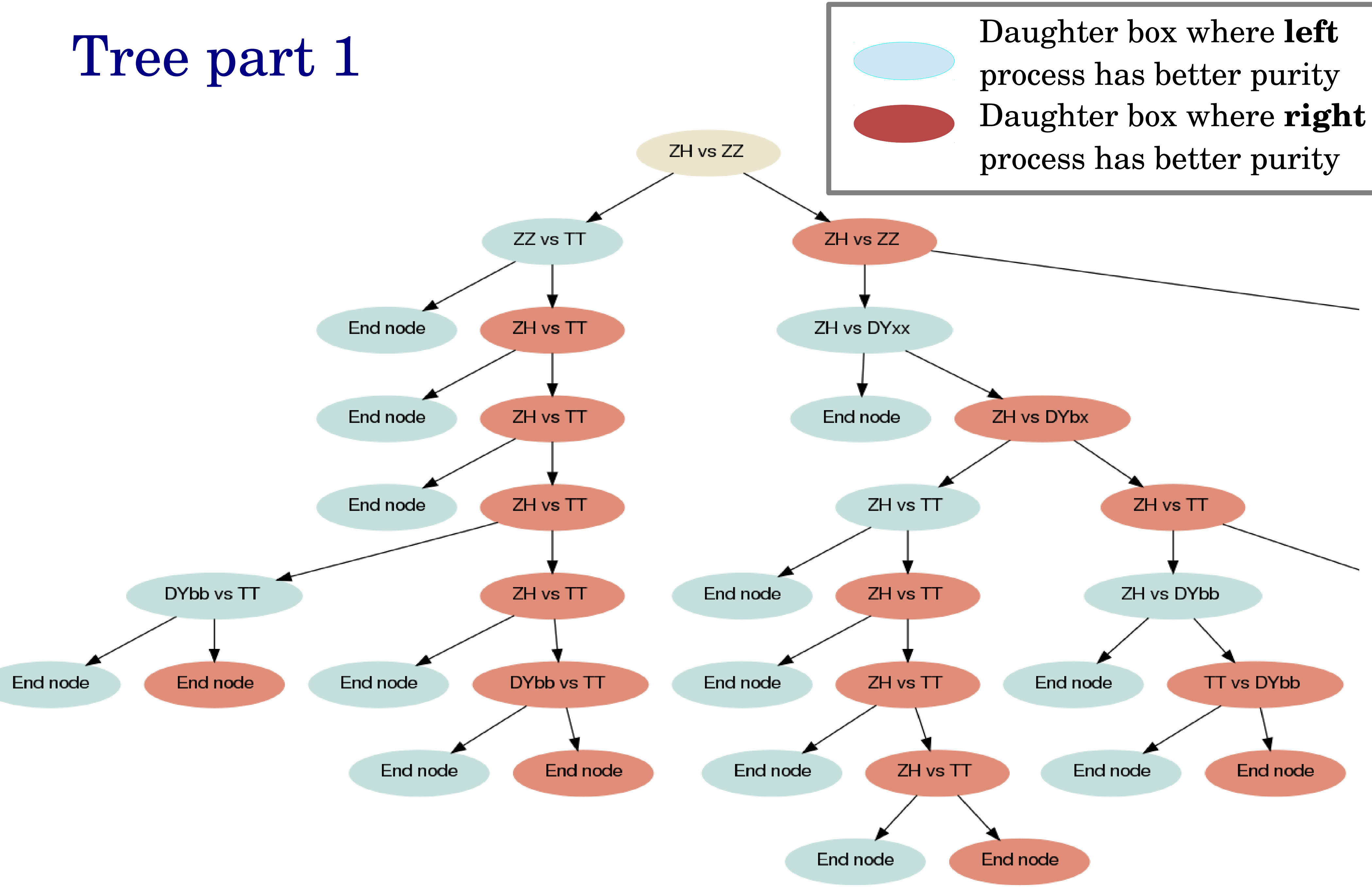
- Fraction of signal $\mathbf{f_{sig}}$ going to the ”signal“-like daughter box
- Improvement on the purity criteria $\mathbf{cut_{Pur}}$
- Minimum number of generated MC events $\mathbf{N_{MC}}$ mother and daughter boxes should contain

Nominal values:

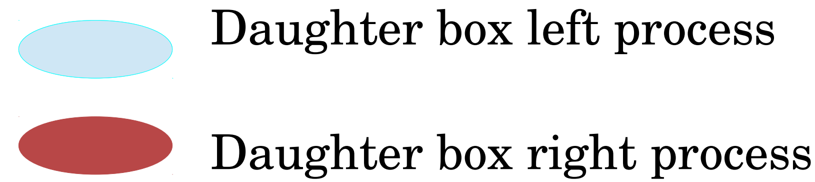
- f_{sig}=50%
- Cut_{Pur} = 0.4
- N_{MC}=100

→ **Tuned** taking as reference the 95% CL exclusion limit on the ZH signal strength

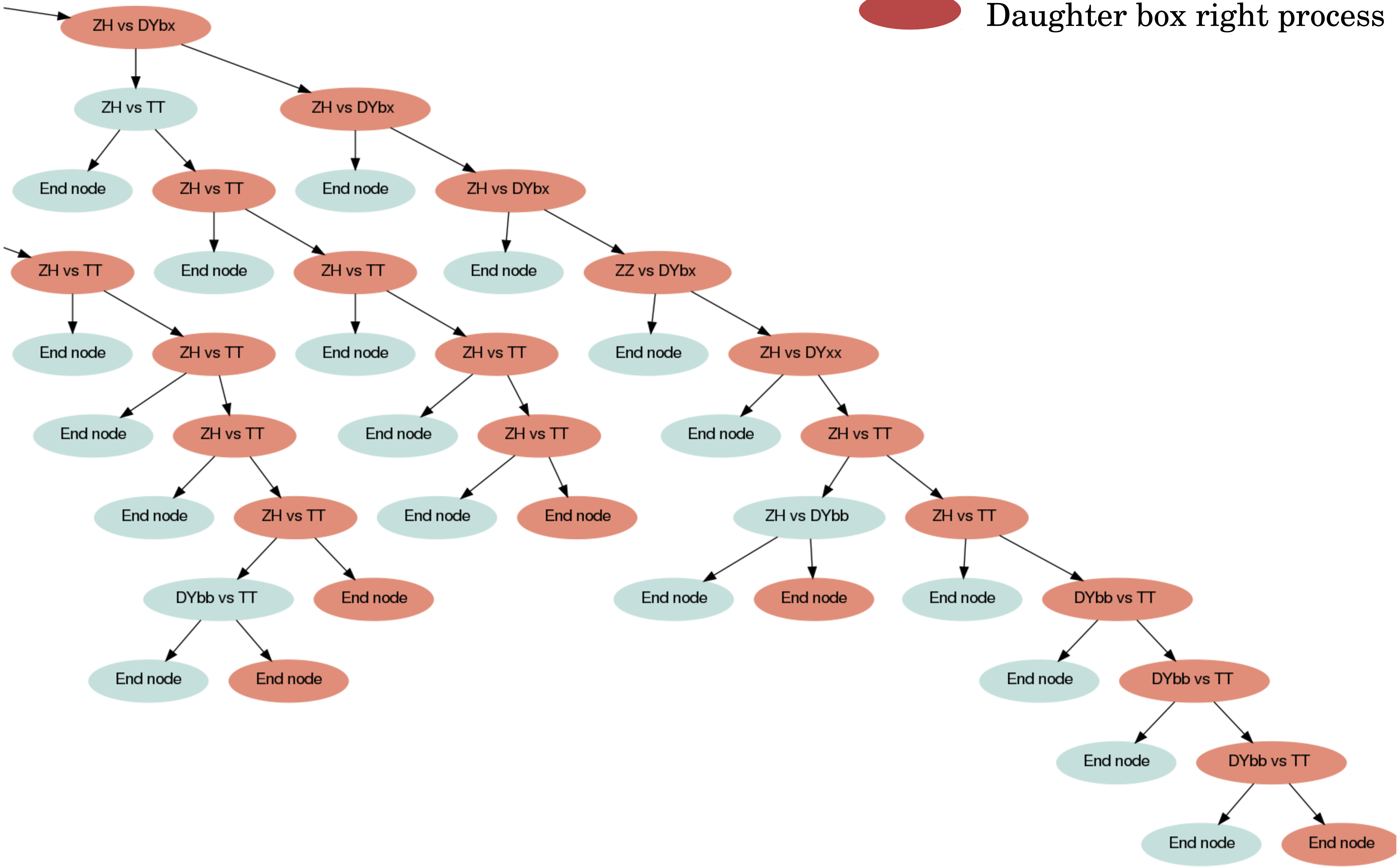
Tree part 1


Daughter box where **left** process has better purity
Daughter box where **right** process has better purity
ZH vs ZZ
ZZ vs TT
ZH vs ZZ
End node
ZH vs TT
ZH vs DYxx
End node
ZH vs TT
End node
ZH vs DYbx
End node
ZH vs TT
ZH vs TT
ZH vs TT
DYbb vs TT
ZH vs TT
End node
ZH vs TT
ZH vs DYbb
End node
End node
End node
DYbb vs TT
End node
ZH vs TT
End node
TT vs DYbb
End node
End node
End node
ZH vs TT
End node
End node
End node
End node

Tree part 2



Daughter box left process
Daughter box right process

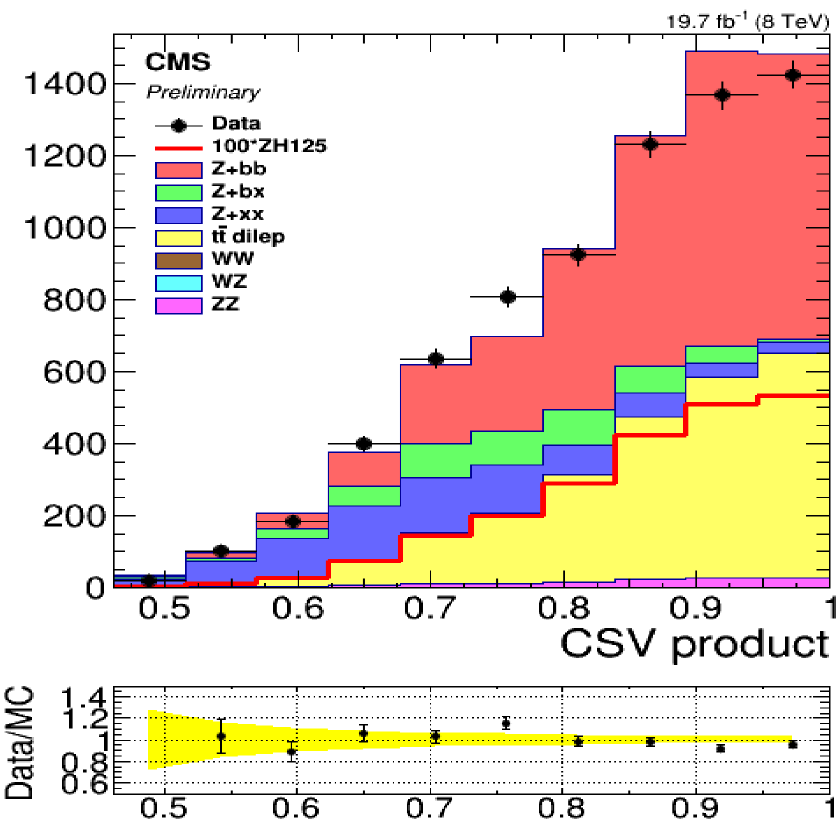


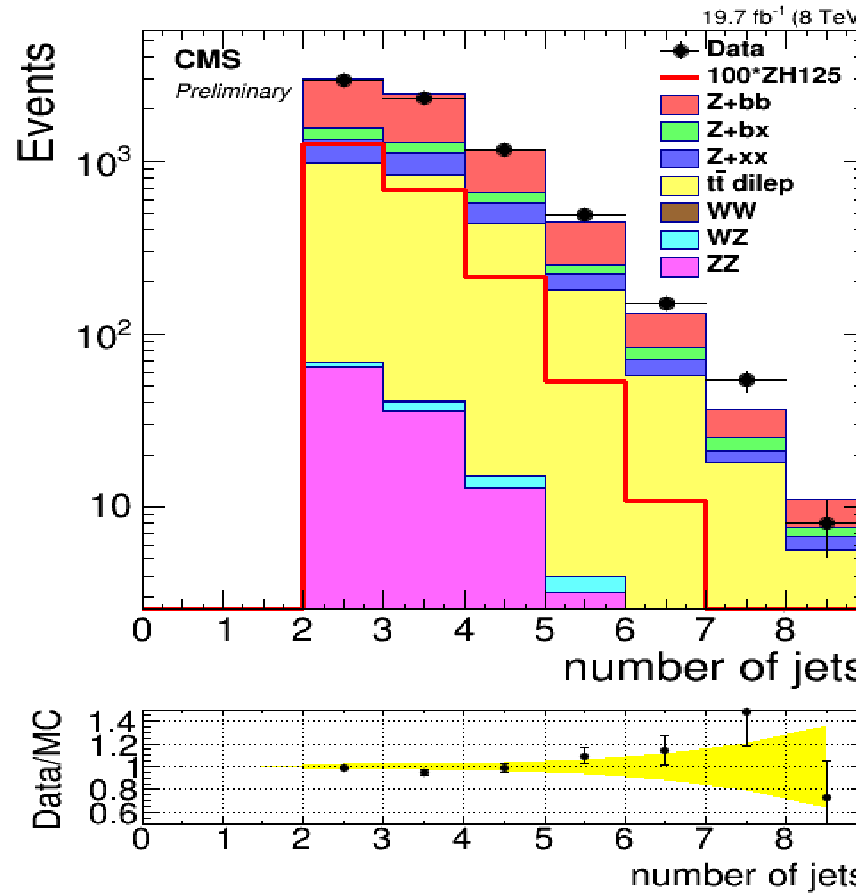
ZH vs DYbx
ZH vs TT
ZH vs DYbx
End node
ZH vs TT
End node
ZH vs DYbx
ZH vs TT
End node
ZH vs TT
End node
ZZ vs DYbx
End node
ZH vs TT
End node
ZH vs TT
End node
ZH vs DYxx
End node
ZH vs TT
End node
ZH vs TT
End node
ZH vs TT
End node
ZH vs TT
End node
End node
ZH vs DYbb
ZH vs TT
DYbb vs TT
End node
End node
End node
End node
DYbb vs TT
End node
End node
End node
DYbb vs TT
End node
DYbb vs TT
End node
End node

Additional event categorization

Final daughter boxes further sub-divided with respect to:

- **b-tagging**: distribution of CSV product of the 2 b jets → cut in half
  →1 box **b-like**, 1 box **light-like**





- **Extra jets**: events daughter boxes sorted depending on number of extra jets
  → no extra jet = **2-jet** box, at least 1 extra jet = **3-jet** box

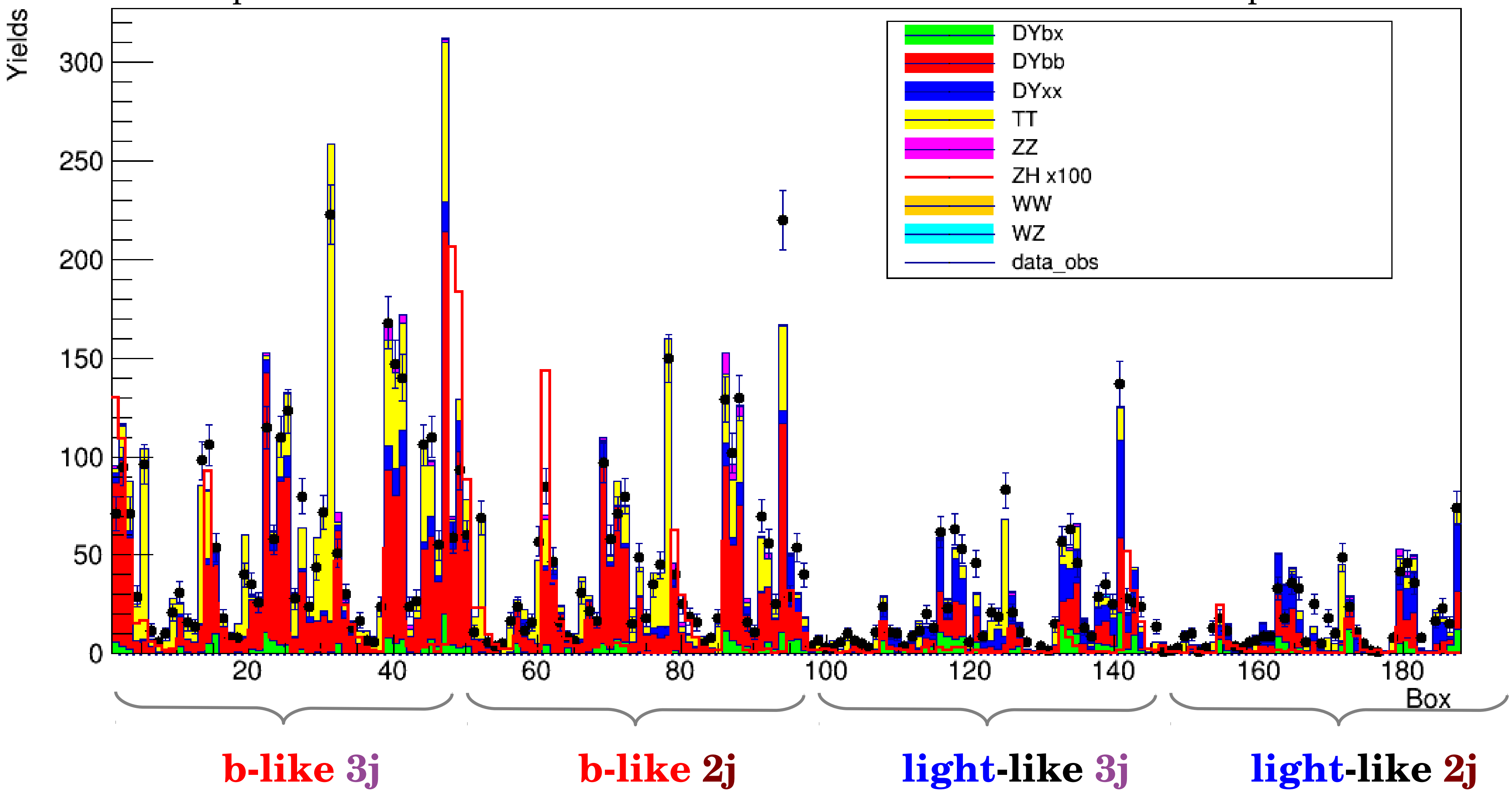
→ In the end, number of boxes **multiplied by 4**

Distribution of final discriminant

In the end → X boxes created → now **N = X.4** boxes

→ Creation of **final histogram** of N bins regrouping the four histograms b/light-like in 2 jets/3 jets category: bin i filled with expected yield for the i^{th} box

Example of final discriminator distribution for **nominal** values of the free parameters



Sensitivity of the method

Toy MC used to test the sensitivity of the method:

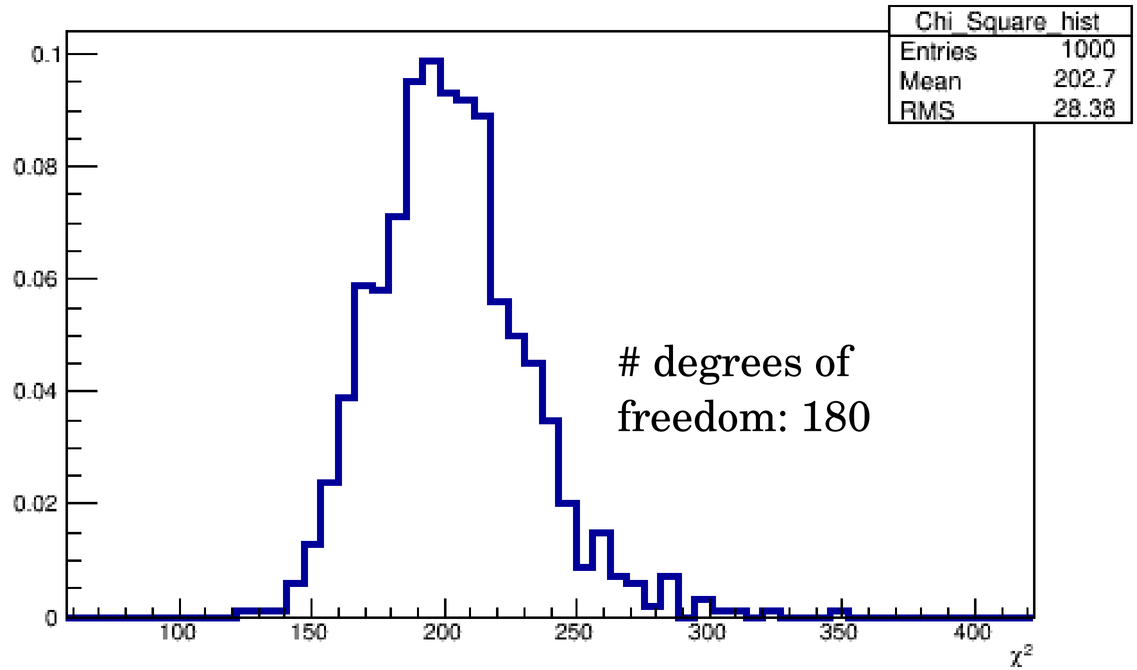
From final discriminator histogram (previous slide):

- Pseudo-data events **generated** from the distribution of the total MC (reweighted to expected yields

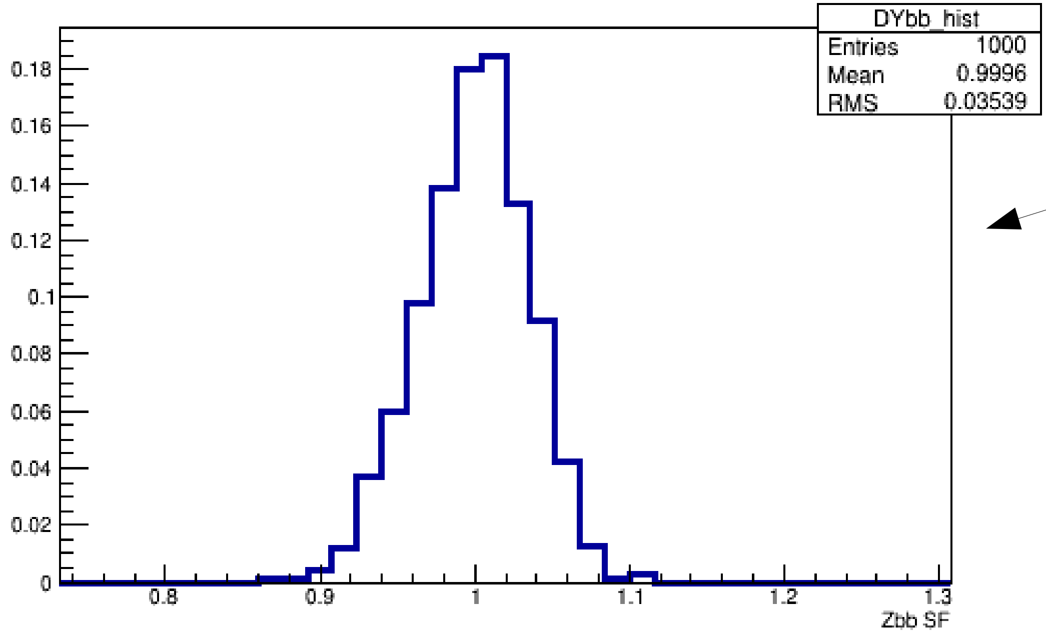
  Each bin of the distribution, “data” point **within the statistical MC error**

- Experiment repeated **1000** times
- For each experiment → **fit** to evaluate the data/MC agreement
- **SF** for each process contribution derived

Sensitivity of the method



degrees of freedom: 180



Expected relative error on extracted SF:

Zbb : 3.5%.
Zbx: 18.8%
Zxx: 9.1 %
tt: 2.9%
ZZ: 53.4%
ZH: 253.2%

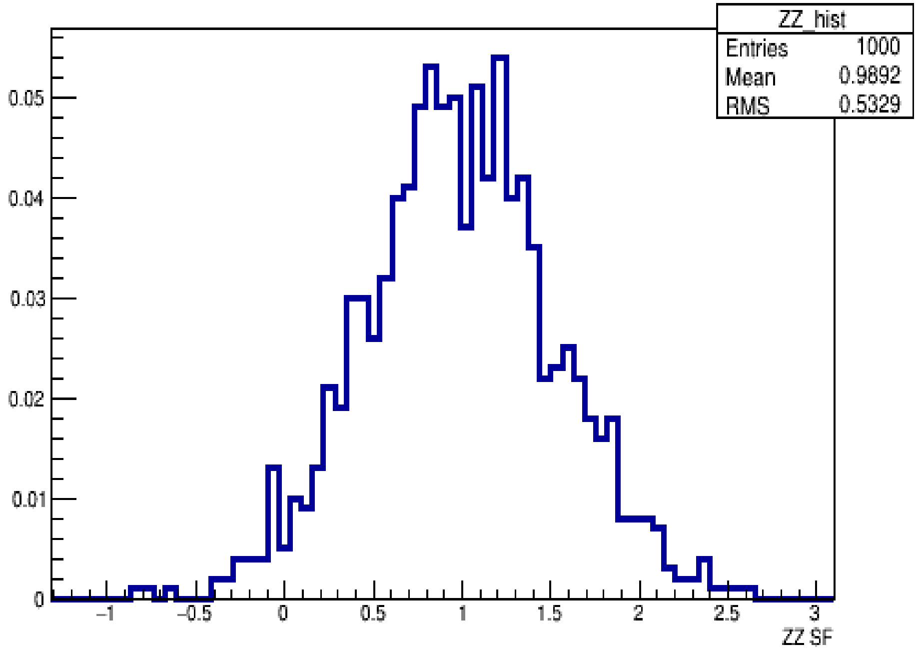
Fit to the data

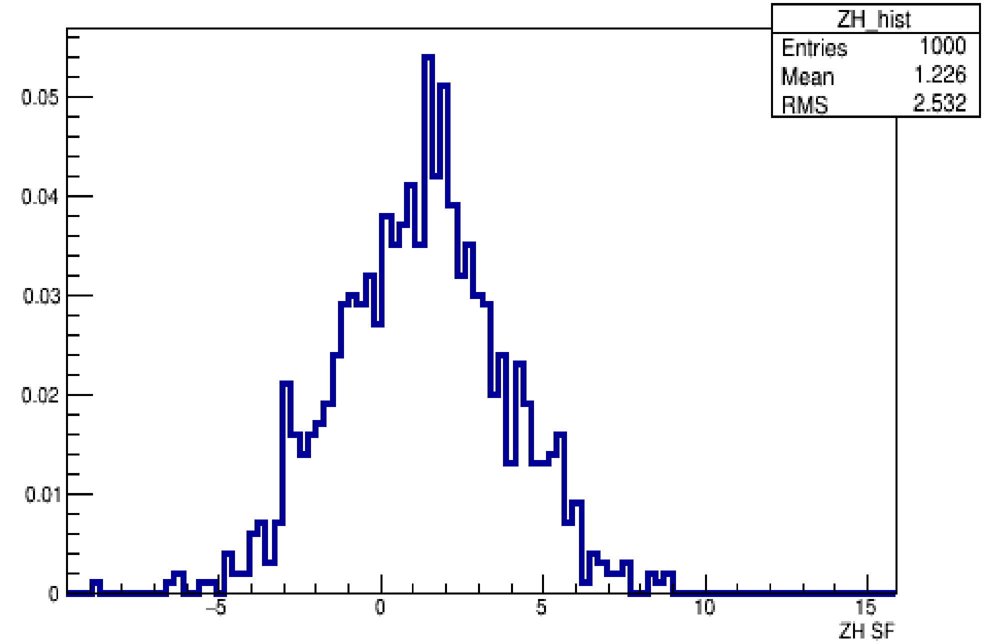
Same fit performed with the **real** data → value χ^2: 435.9

SF extracted:

- Zbb: 0.90 ± 0.04→ *1.14 = 1.03 ± 0.05
- Zbx: 1.48 ± 0.76→ *1.35 = **2.00 ± 1.03**
- Zxx: 0.76 ± 0.09→ *1.36 = 1.03 ± 0.12
- tt: 1.05 ± 0.03 → *1.01 = 1.06 ± 0.03
- ZZ: 1.39 ± 0.51
- ZH: -0.99 ± 2.37

None of them highly correlated





Exclusion limits for the ZH search

- Tune free parameters → arbitrary choice: best 95% CL on ZH μ → best discrimination of process with **smallest yield** → comparison **previous analysis**

- Several tests performed with different values for:

- cut_{Pur}: 0.1, 0.2, 0.3, **0.4**, 0.5, 0.6, 0.7, 0.8, 0.9
- f_{sig}: **50**, 60, 70
- N_{MC}: 50, 75, **100**

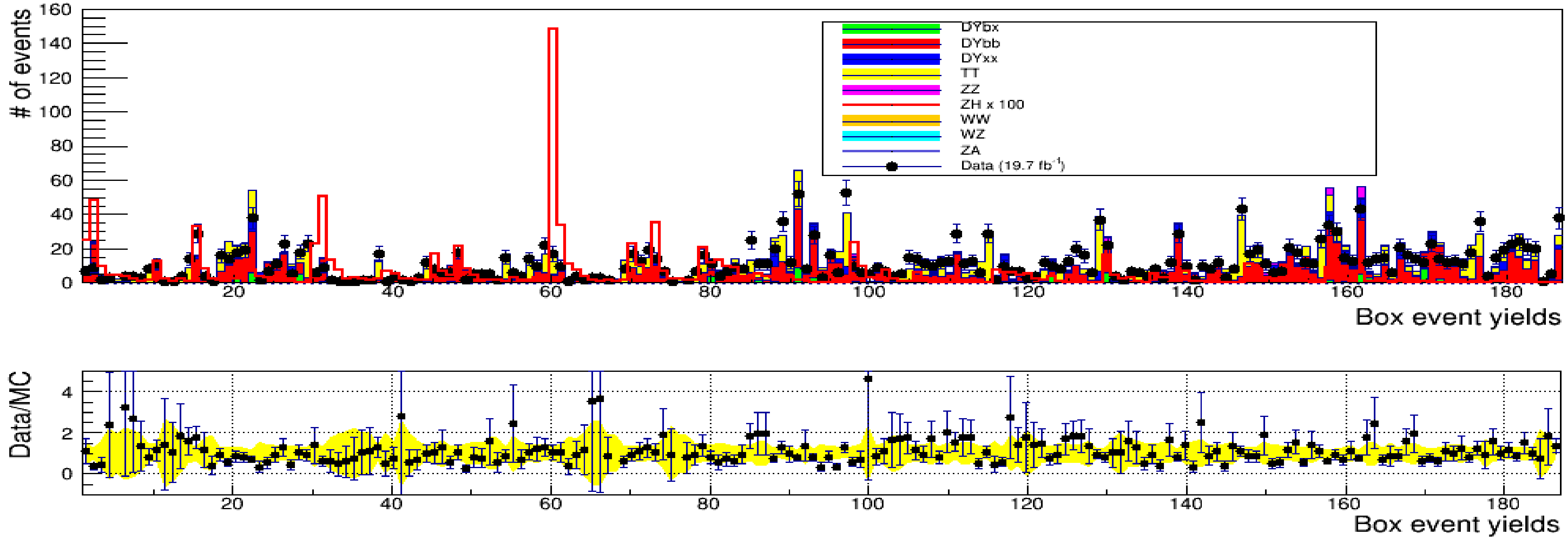
Using nominal parameters values, also testing:

- No use of Zbj_{bg} weight (same weight than for Zbb and Zxx) → see impact of this weight
- Use ZH/ZZ hypothesis without E-p conservation (correction 3 instead of correction 0)

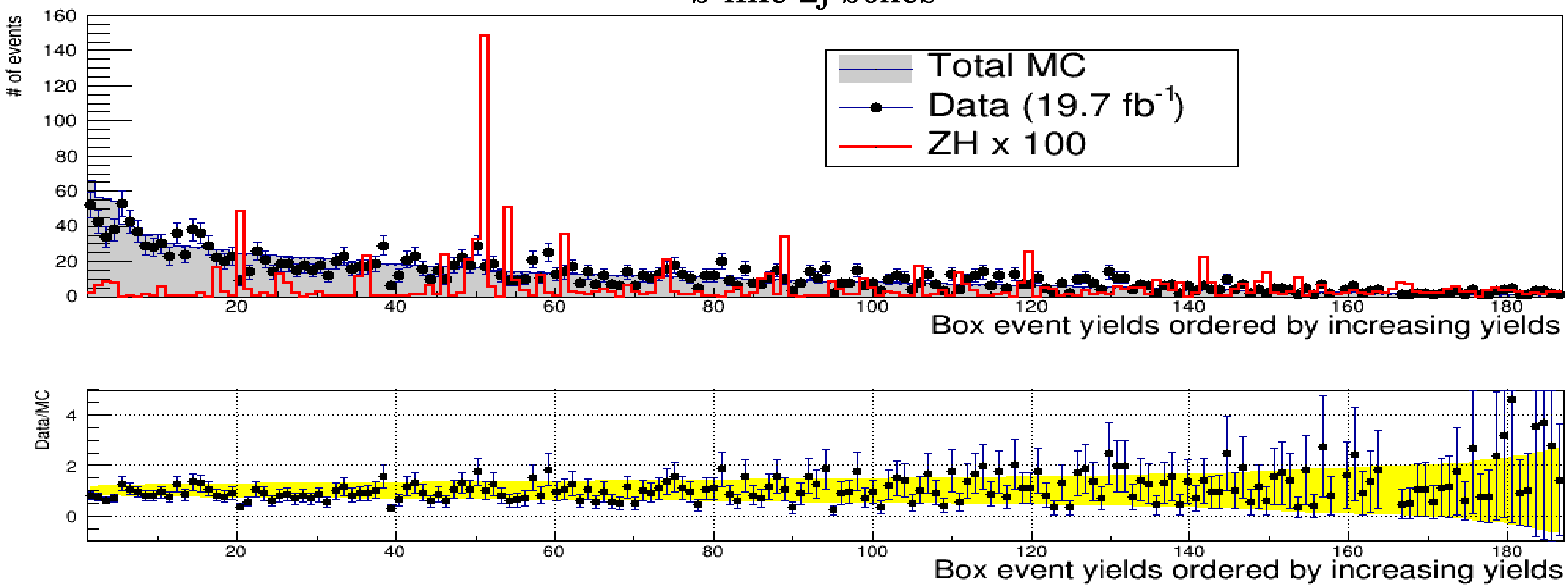
→

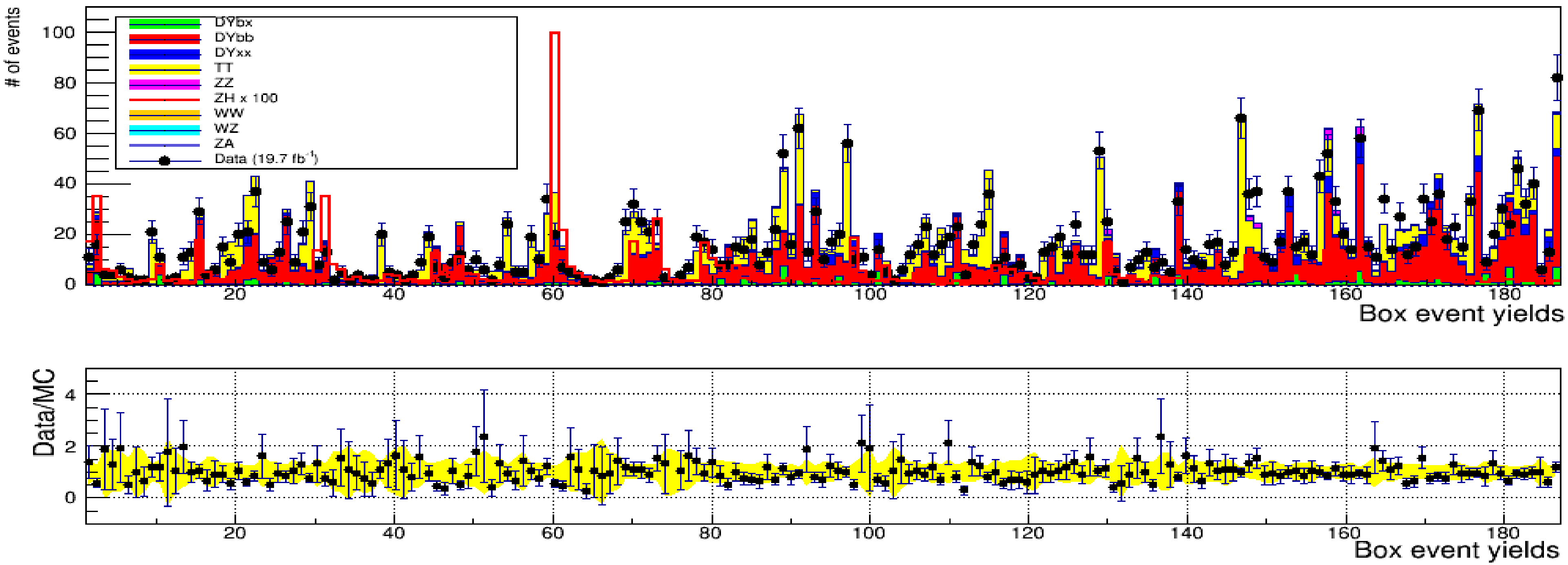
Best limit obtained with:

- $cut_{Pur} = 0.1$
- $N_{MC} = 50$
- $f_{sig} = 60$
- Use of Zbj_{bg} weight
- Use of correction 3

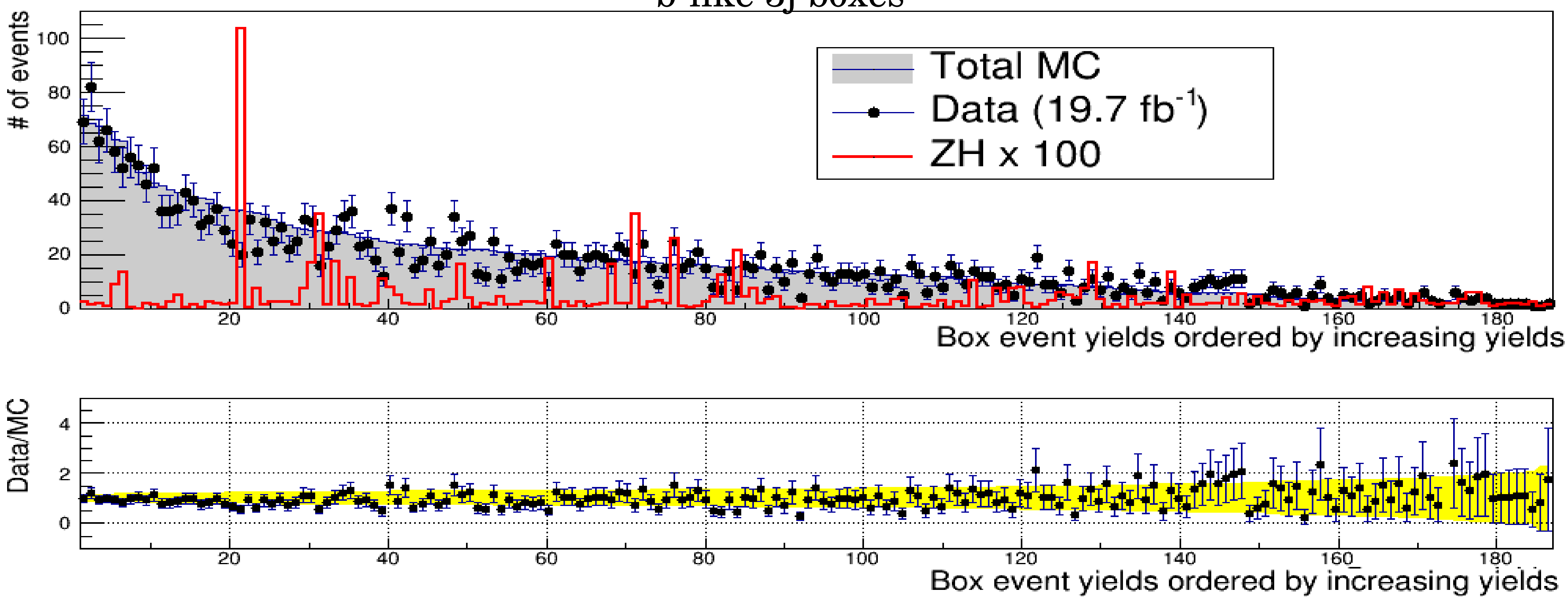


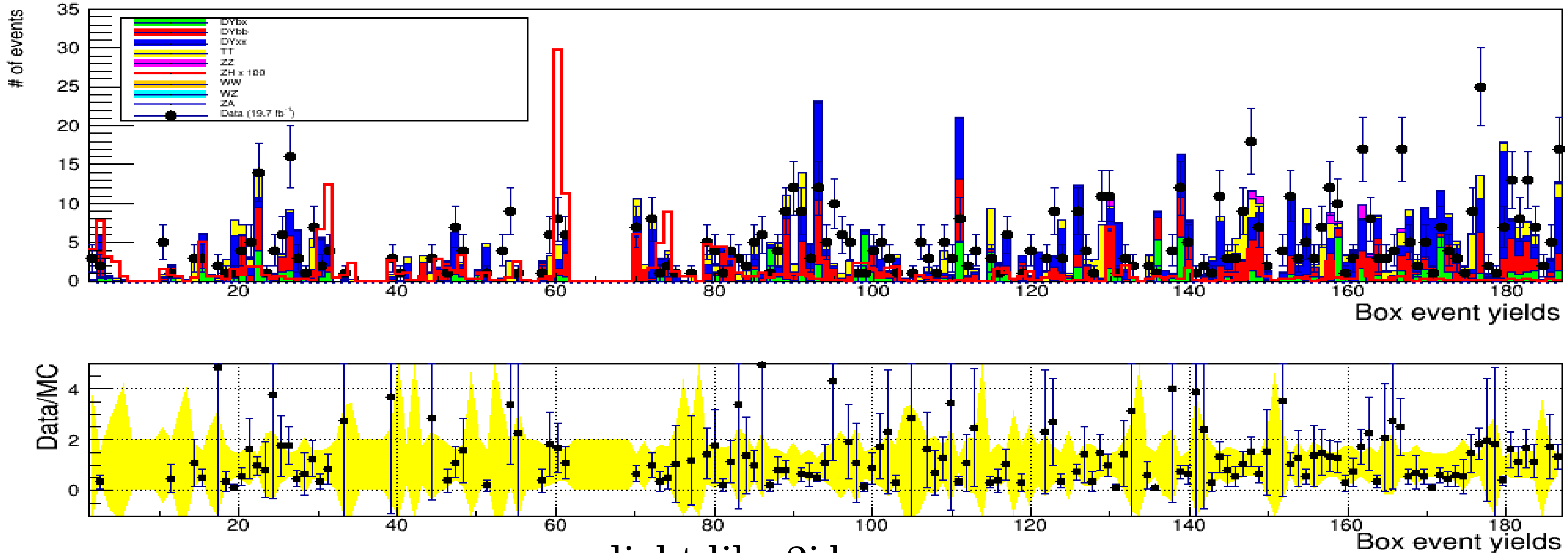
b-like 2j boxes



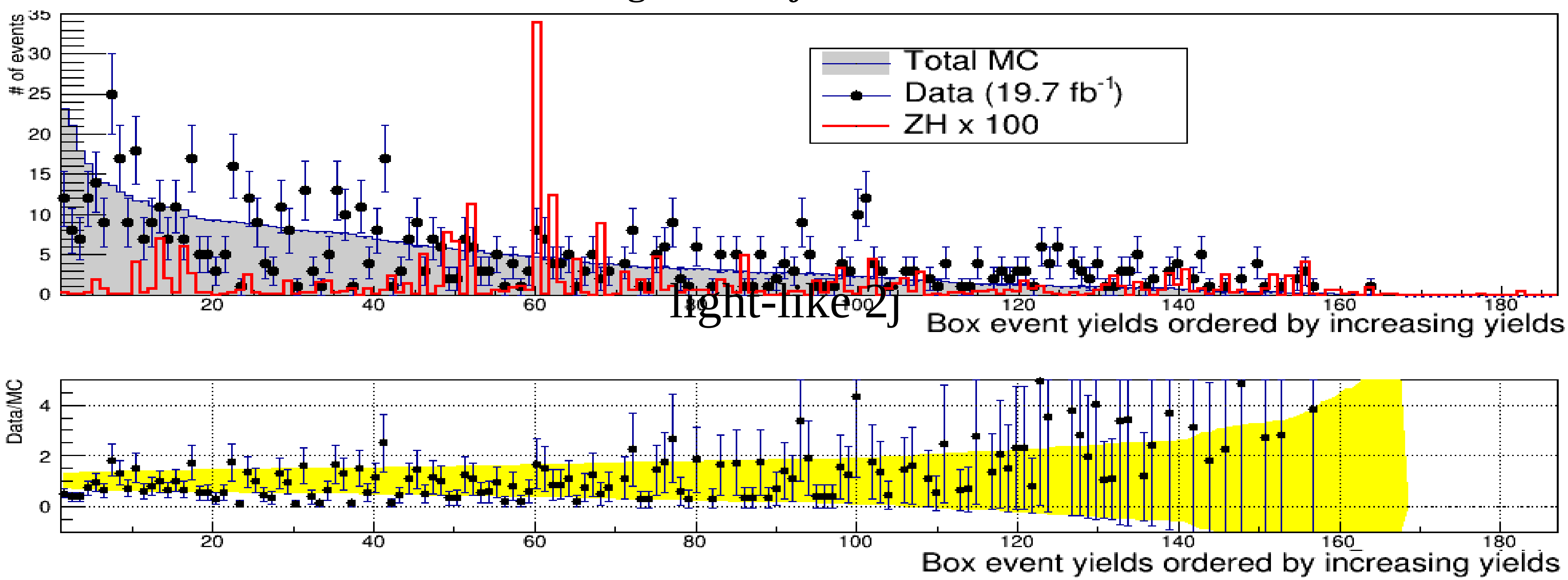


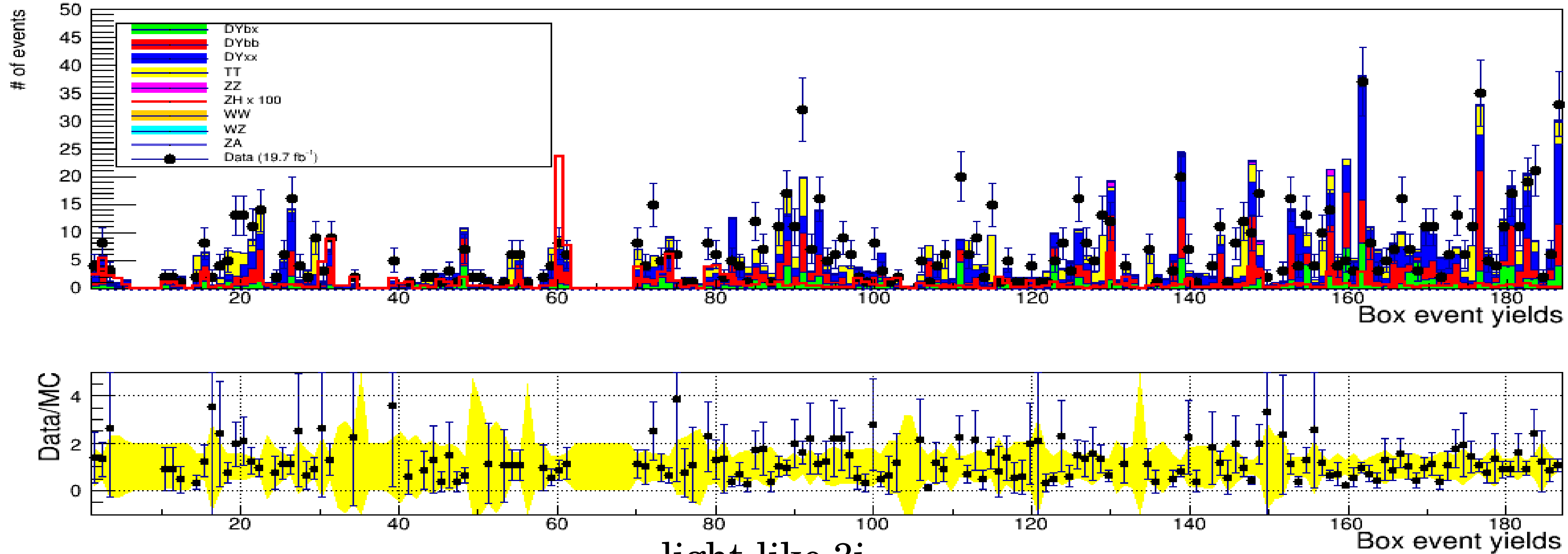
b-like 3j boxes



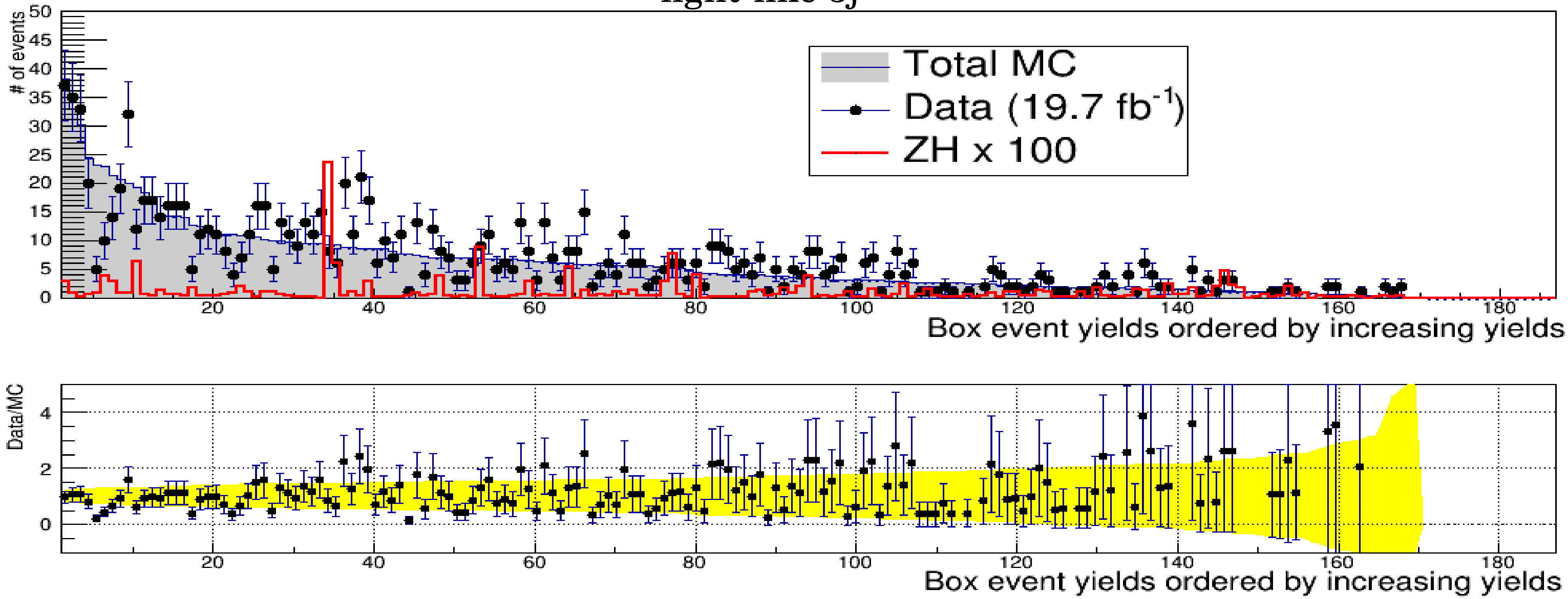


light-like 2j boxes





light-like 3j



Systematics

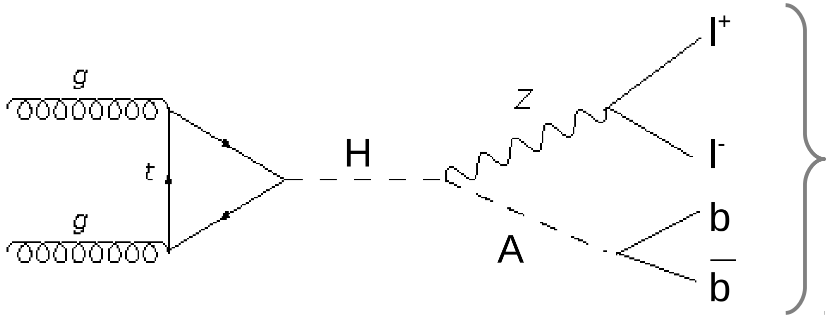
Same systematics than for previous analysis:

- Luminosity
- ZH normalization
- ZZ cross section
- Lepton uncertainty
- Background reweighting
- JES
- JER
- b-tag SF
- MadWeight
- MC statistics: each bin of final discriminator histogram → contains N MC generated events
  → $N_{UP} = N + \sqrt{N}$, $N_{DOWN} = N - \sqrt{N}$

<u>95% CL exclusion limit on signal strength:</u>

With all systematics, limit **3.05** → **3.58** (17.4% degradation)
With only MC stat. systematic, **3.05** → **3.20** (4.9 % degradation)

Exclusion limits on μ for the ZA search for one mass point



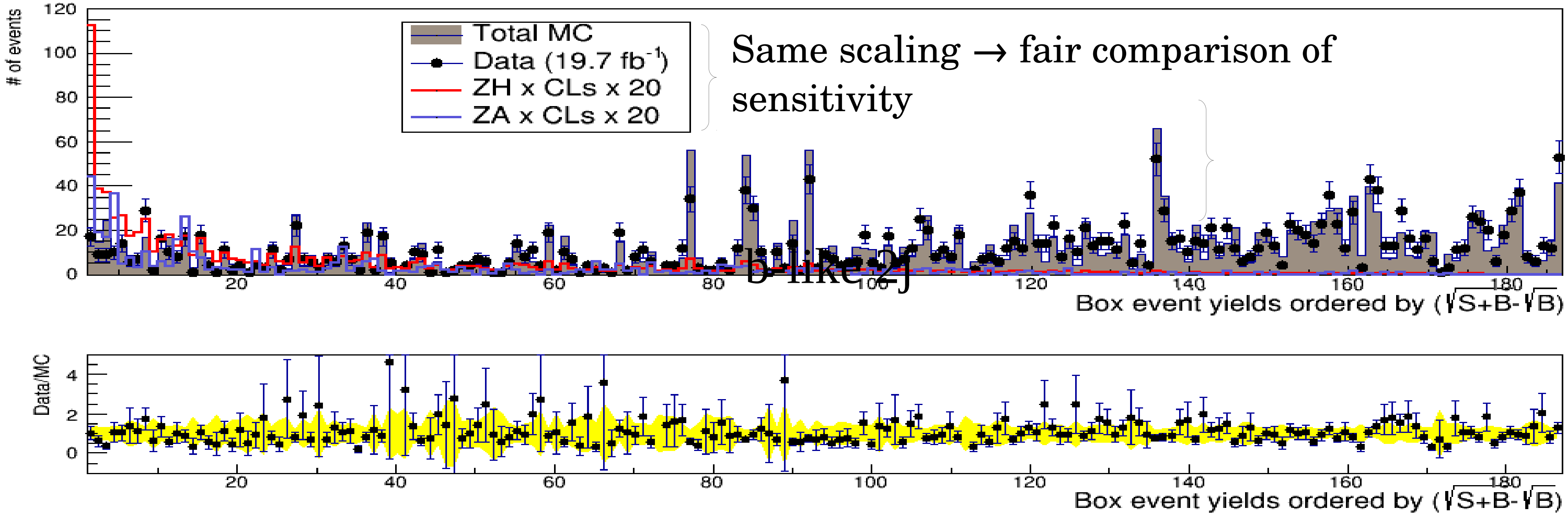
2HDM model
H: heavy Higgs (329 GeV)
A: pseudo-scalar light Higgs (142 GeV)
Cross section*BR: 0.076 pb

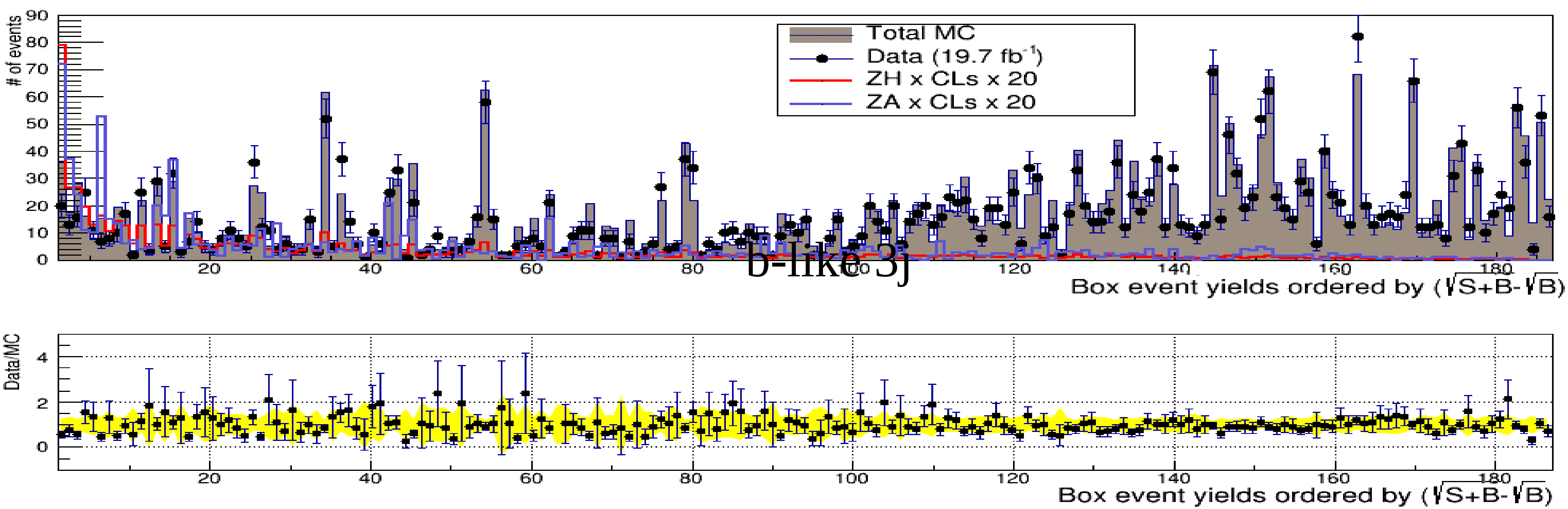
Goal: not exhaustive analysis, just compare results for one mass point with another analysis
Using the **same configuration** than for ZH → compute CLs for exclusion **limit on the ZA cross section:**

- Without systematics: **0.36**
- With only MC related systematic: **0.38**
- Hypothesis: same degradation expected for all the systematics than for the ZH case → limit with all systematics: **0.42**

→ Exclusion limit on signal strength with the dedicated analysis (CMS PAS HIG-15-001) for this mass point (with all systematics): **0.83**
→ **Same order**

Exclusion limits for the ZA search





Conclusion

- Based on ZH ME-based dedicated search, design Model Independent search
- Leads to the creation of **several boxes**, with very different **contributions of various SM processes**
- **Few** free parameters (3) to tune
- Exclusion limit on ZH signal strength **close** to the one found with **previous analysis**
- Exclusion limit on ZA signal strength **same order** than for dedicated search
- Only **prospect** → improvements to be done

General Conclusion

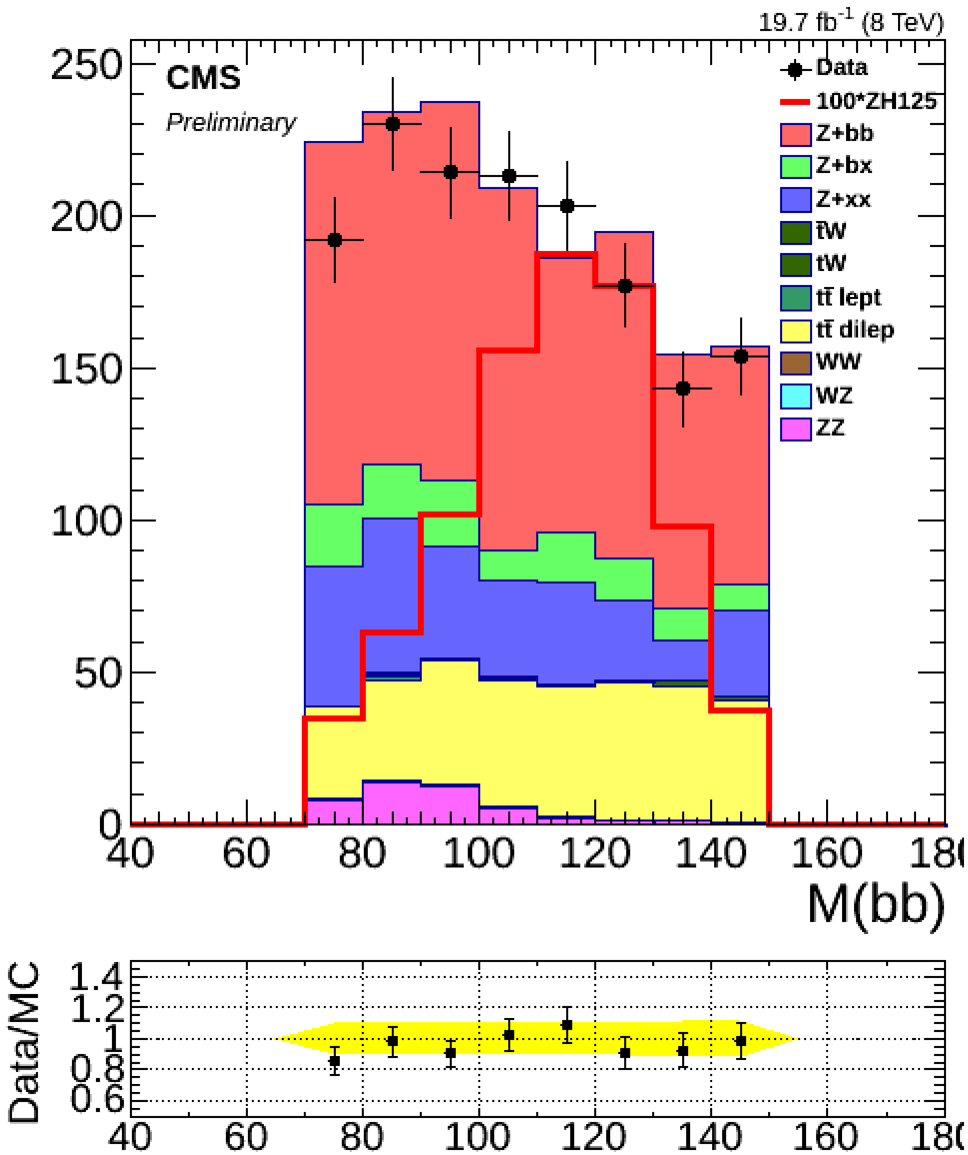
- Study of b-tagging at high p_T performed → it is possible to recover a few % from the loss of performance observed for JP thanks to BDT

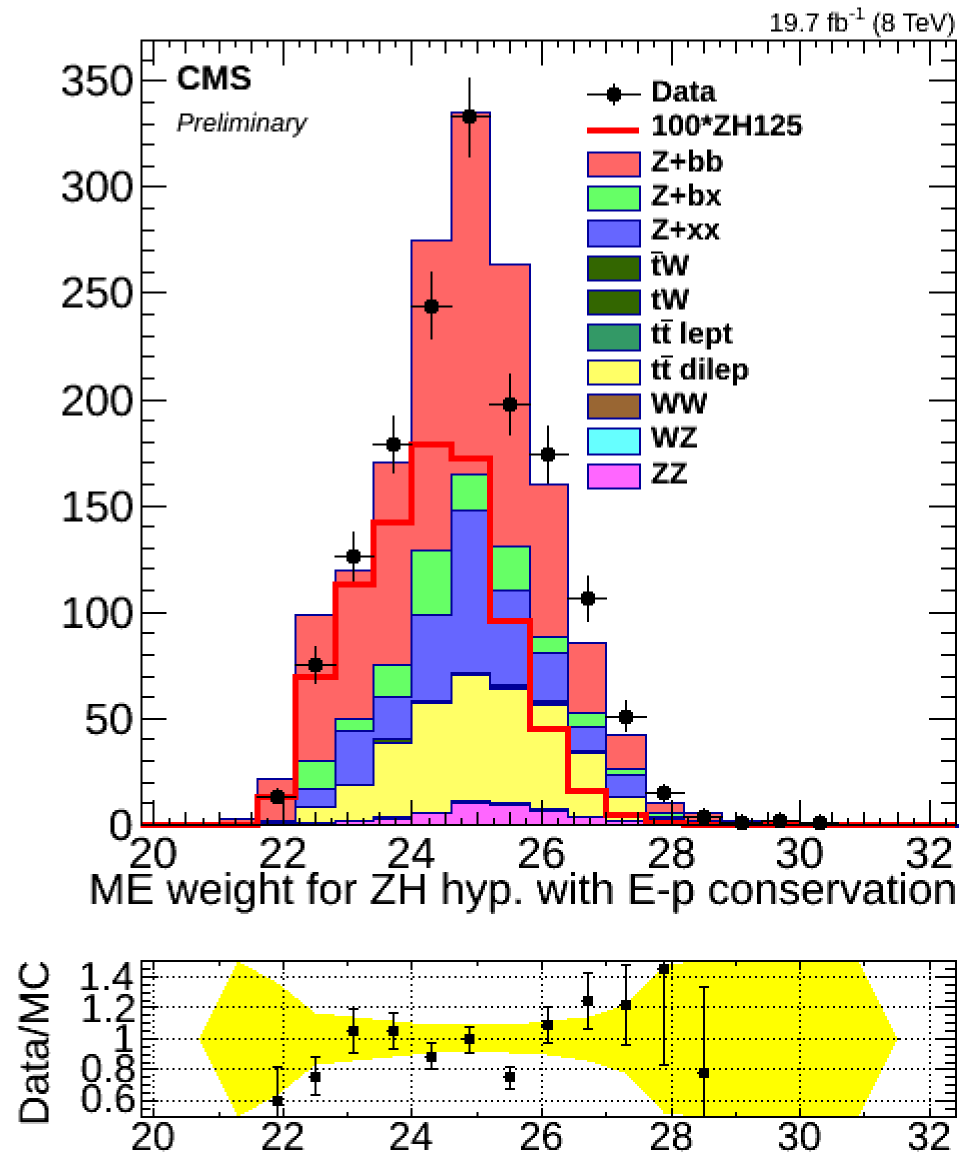
- ZH search performed using ME method and 2 b-tagging algorithms
→ similar exclusion limits found for both algorithm, better results using CSV

- Based on ZH search → design Model Independent search → sensitivity on rare processed with *llbb* final state

Extra material

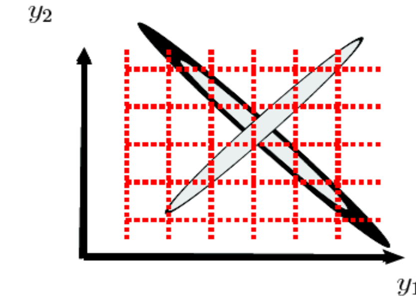
A powerfull tool





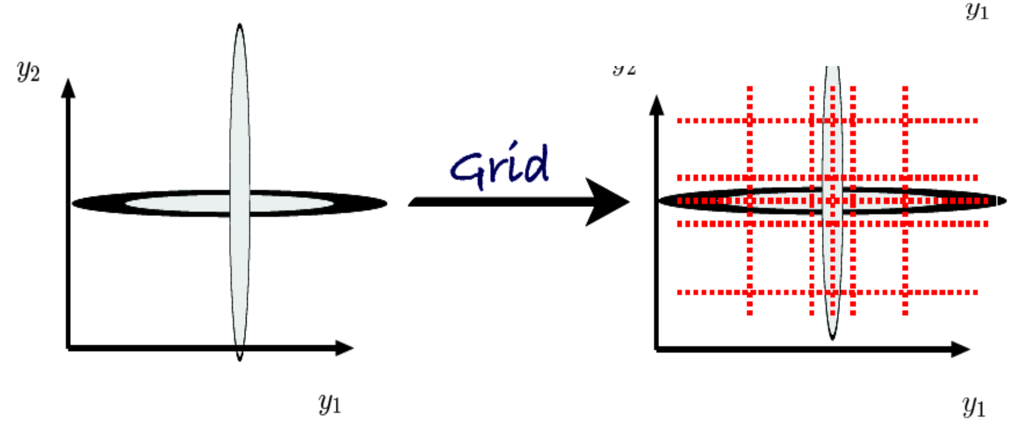
→ Weight = final discriminating variable

MadWeight



- Integral computation → **not trivial** ! Presence of sharp functions:
  - Breit-Wigner
  - Transfer functions

  Degrees of freedom/constrains of system
  → if same number peaks aligned
  → if not, weighted average of several wei



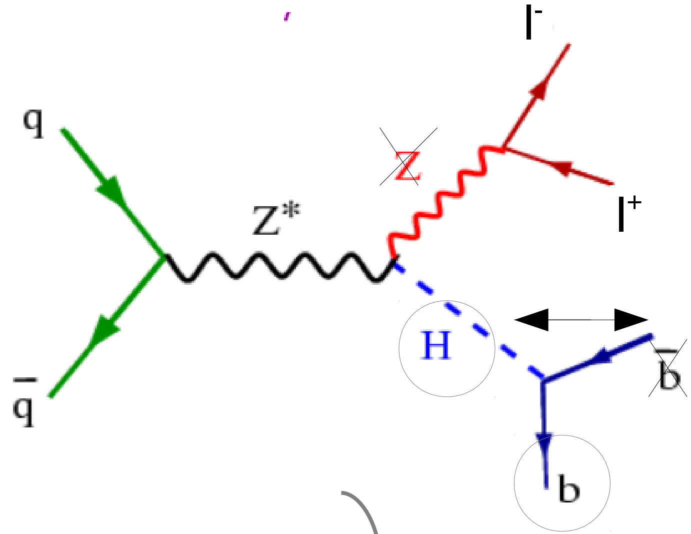
- The adaptive Monte-Carlo Technique picks points in interesting areas, make the integral **converge**

- This is model dependent → need to be **automatic**, model independent, **fast** and smart

- Real experiment: a reconstructed event cannot be weighted by a **unique** ME → average between several weights (parton-jet matching combination)

→ Use **MadWeight** (based on MadGraph) to compute the integral

Over-constrained systems



Degrees of freedom:

- 2 PDF
- 4 particles in final state defined with (p_T, η, φ)

  → **14** degrees of freedom

Constraints:

- 2 Breit-Wigner
- 4 particles visible in final state defined with (p_T, η, φ)
- 4 (E-p conservation)

  → **18** constrains

System **over-contrained**:

→ Madweight will not converge

Solutions:

- Relax the E-p conservation constraint on p_x p_y
- Enlarge BW width

Fitted TF parameters

$$W(E, E^{vis}) = \frac{1}{2\pi(a_2 + a_3 \times a_5)}[\exp(-\frac{(E - E^{vis} - a_1)^2)}{2 \times a_2^2}) + a_3 \times \exp(\frac{(E - E^{vis} - a_4)^2)}{2 \times a_5^2})]$$

$$a_i = a_{i,0}E + a_{i,1} \times E + a_{i,2} \times \sqrt{E}$$

	Independent term	$\frac{1}{p_T}$ **term**	$\sqrt{\frac{1}{p_T}}$ **term**
a_1	$a_{10} = -1,89.10^{-04} \pm 1,00.10^{-06}$	$a_{11} = 1,87.10^{-06} \pm 8,30.10^{-07}$	$a_{12} = 0{,}00$
a_2	$a_{20} = 0{,}00$	$a_{21} = 0{,}00$	$a_{22} = -2,99.10^{-03} \pm 7,52.10^{-08}$
a_3	$a_{30} = 0{,}00$	$a_{31} = 4,90.10^{-02} \pm 1,38.10^{-03}$	$a_{32} = 0{,}00$
a_4	$a_{40} = -1,09.10^{-03} \pm 1,49.10^{-04}$	$a_{41} = 0{,}00$	$a_{42} = 4,98.10^{-01} \pm 1,02.10^{-04}$
a_5	$a_{50} = 1,69.10^{-03} \pm 1,49.10^{-04}$	$a_{51} = 0{,}00$	$a_{52} = 0{,}00$

b-tagging in CMS

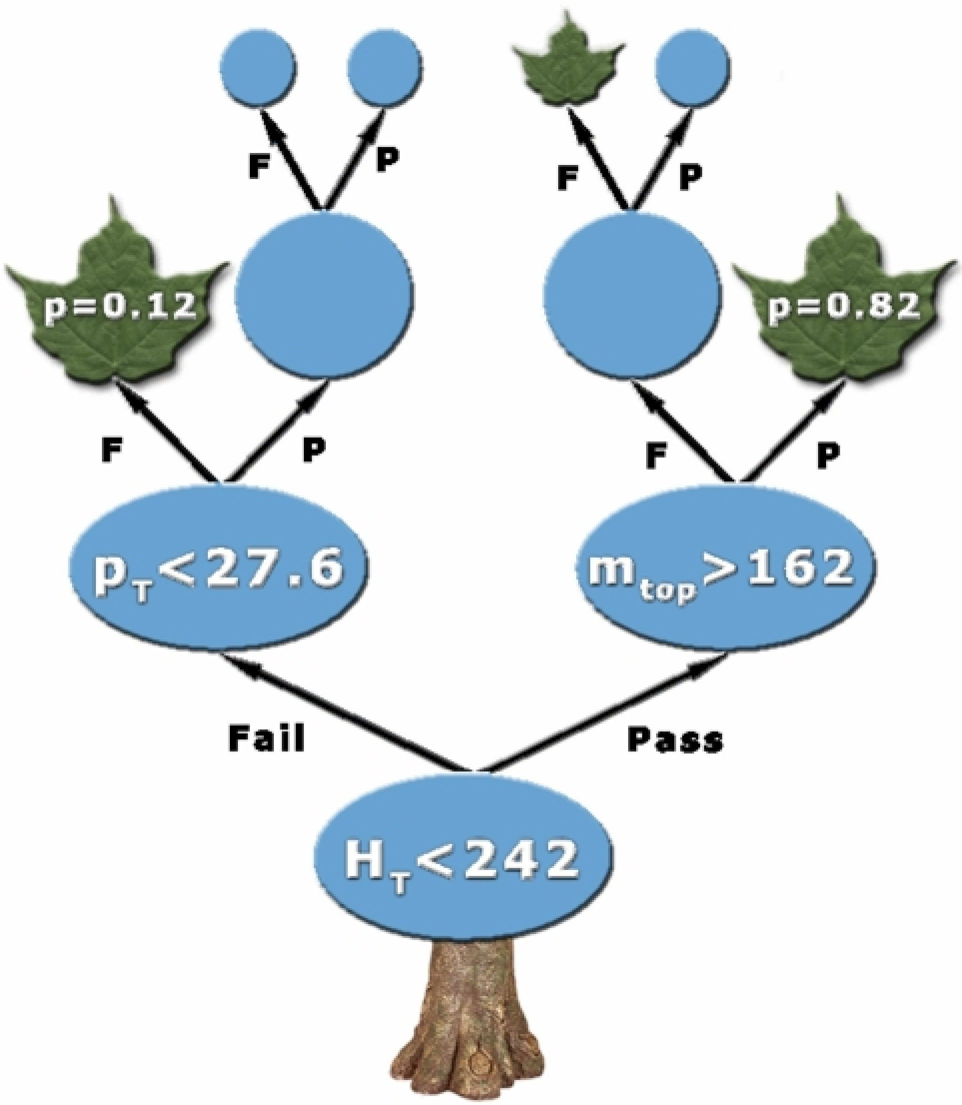
Why is it important to have a strong track selection ?

To avoid:
- secondary interactions with tracker material → **fake SV;**
- other **long lived particles** (K°s, Λ°);
- tracks coming from **PU events;**

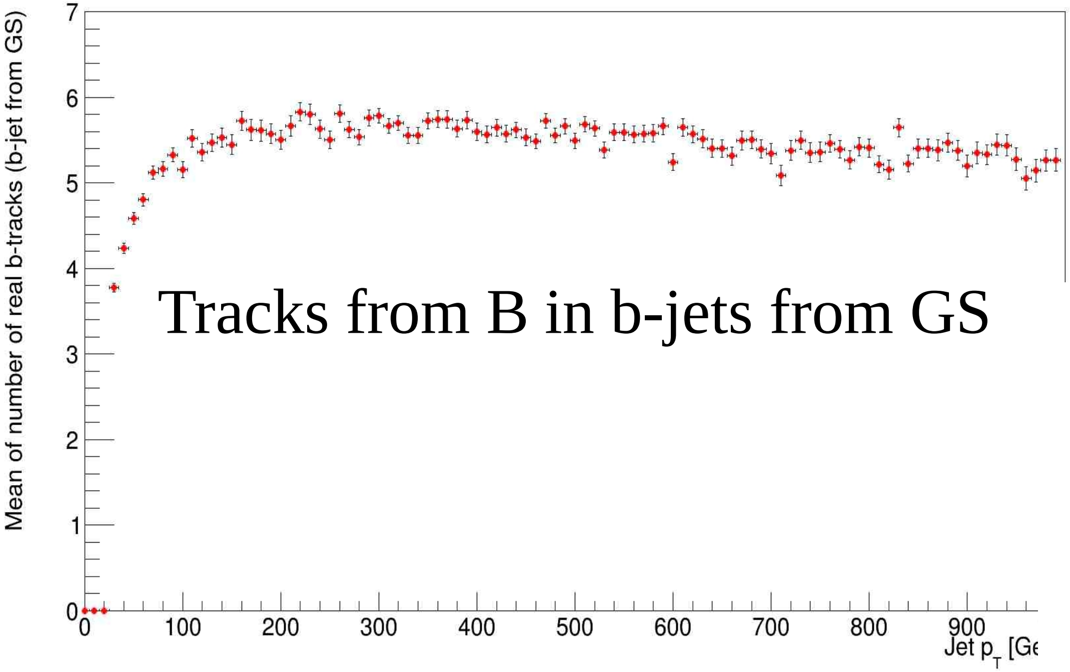
b-tagging official track quality cut selection:

- $p_T > 1$ GeV;
- Decay length < 10cm;
- Transverse impact parameter < 2 mm;
- Number of pixel hits >=2;
- Number of pixel+ silicon tracker >=8;
- Normalized $chi^2 < 10$;
- Track to jet axis distance < 0.7 mm;

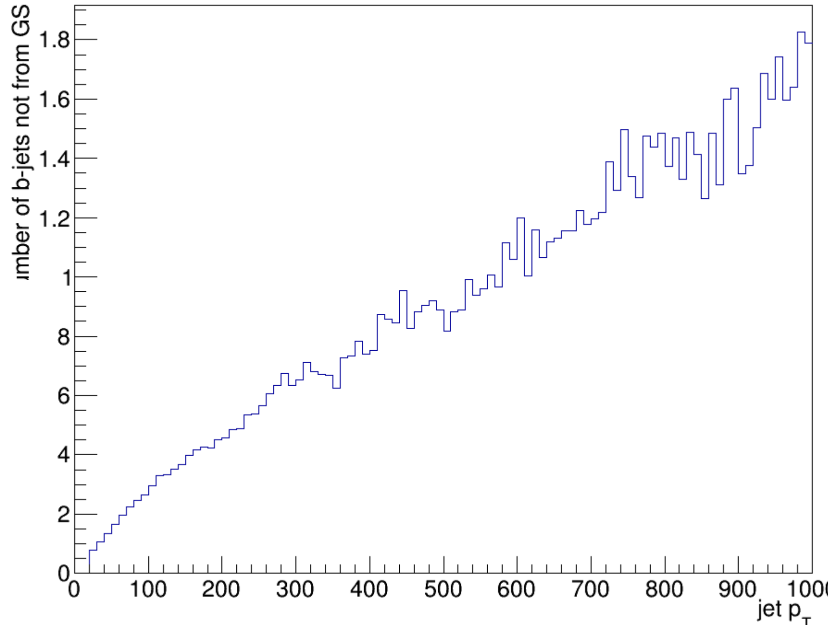
BDT

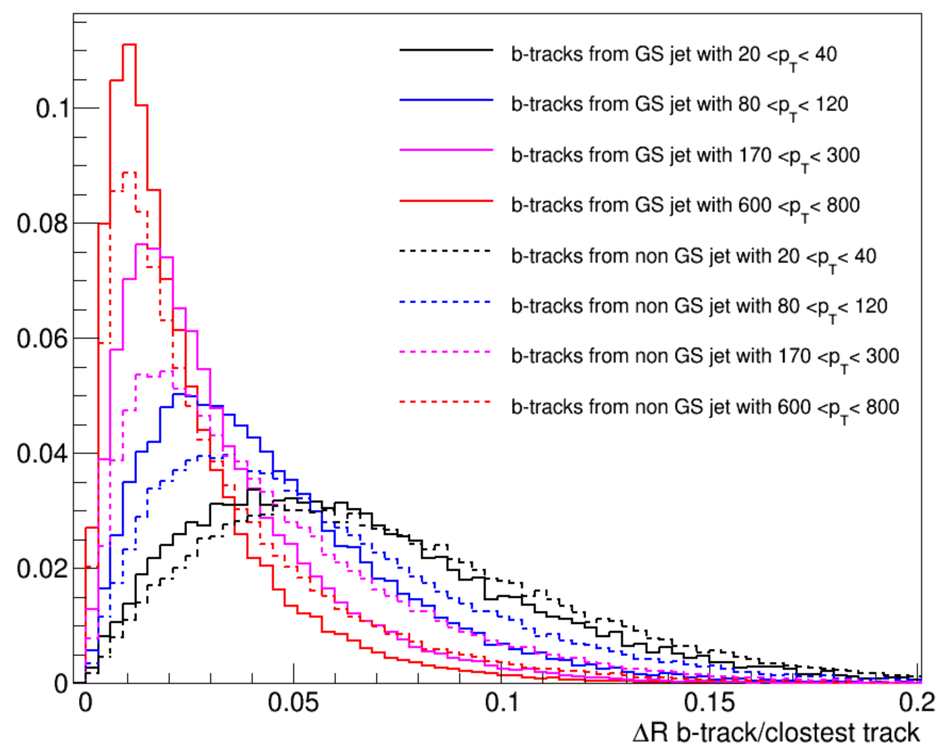


Gluon splitting

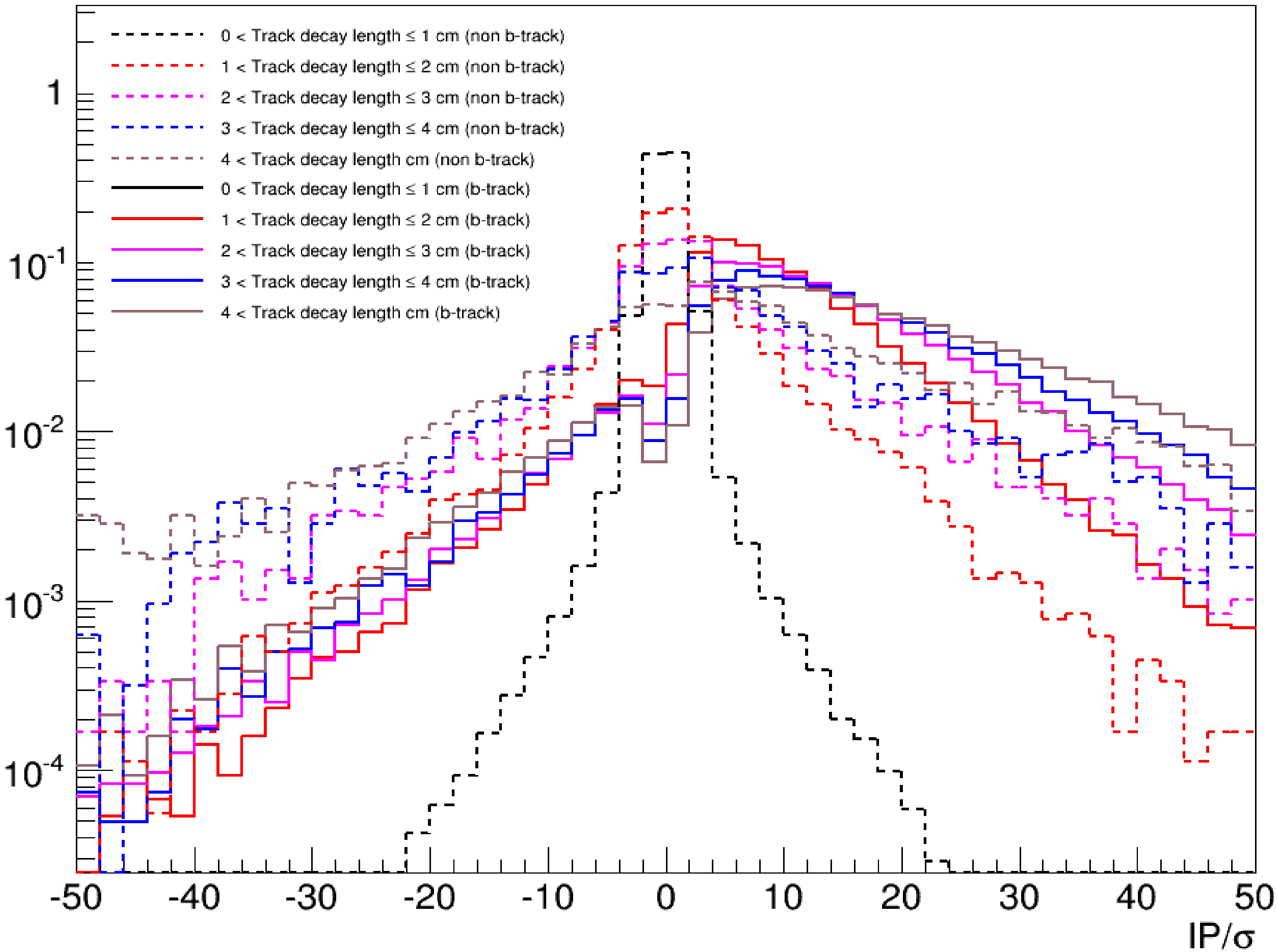


Tracks from B in b-jets from GS

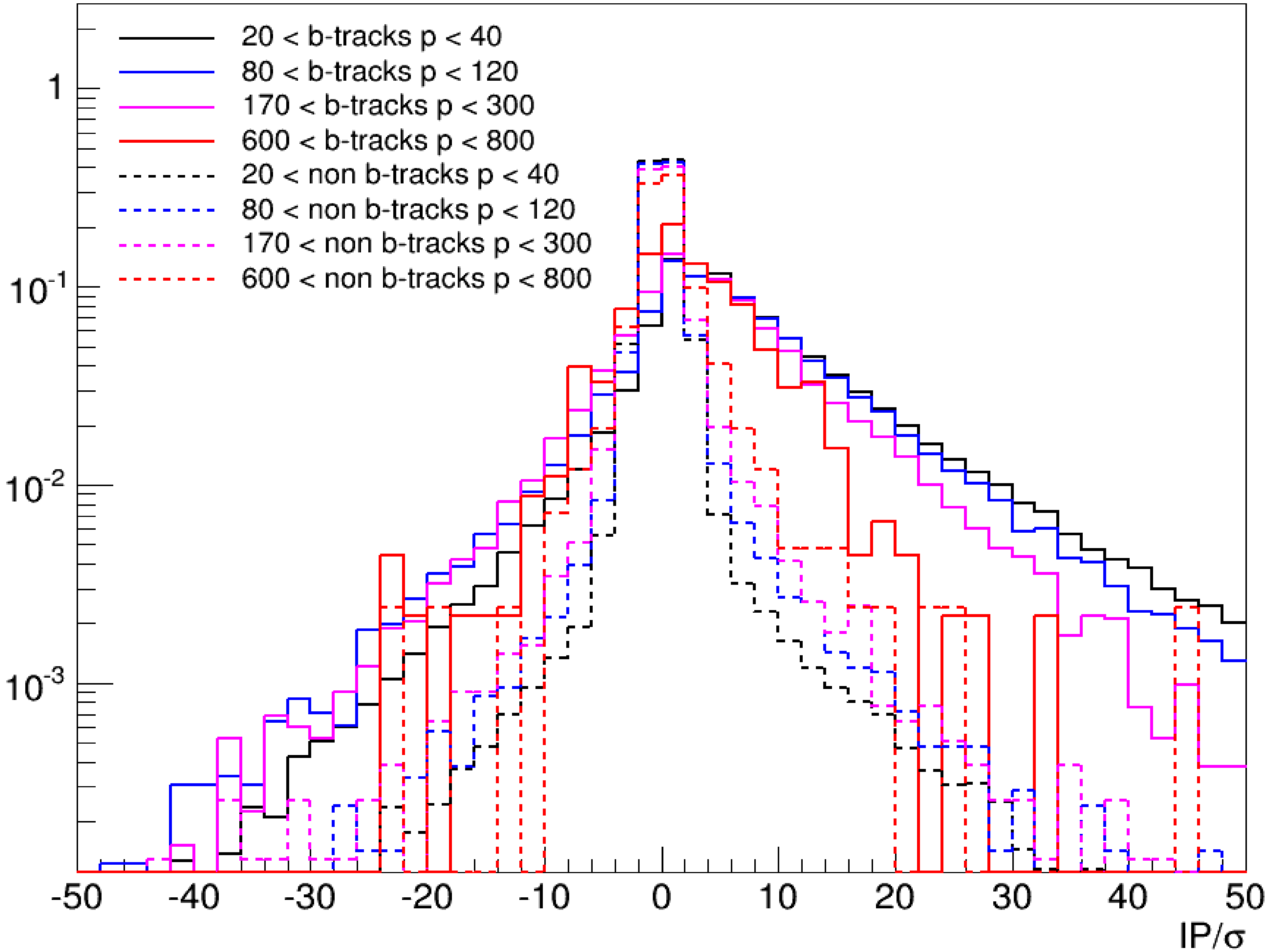




Discriminating variables



Discriminating variables

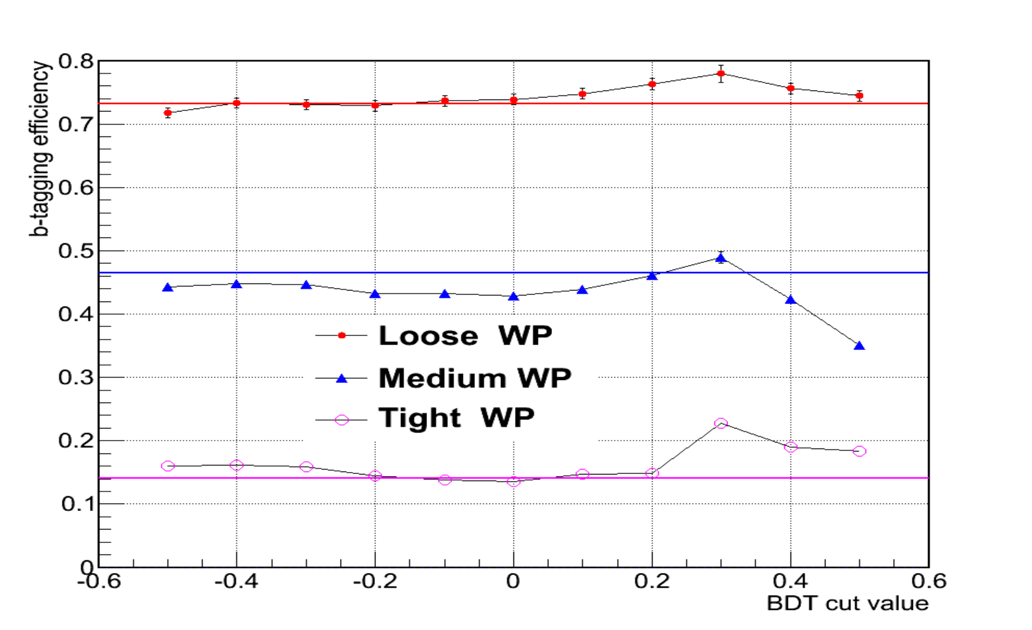


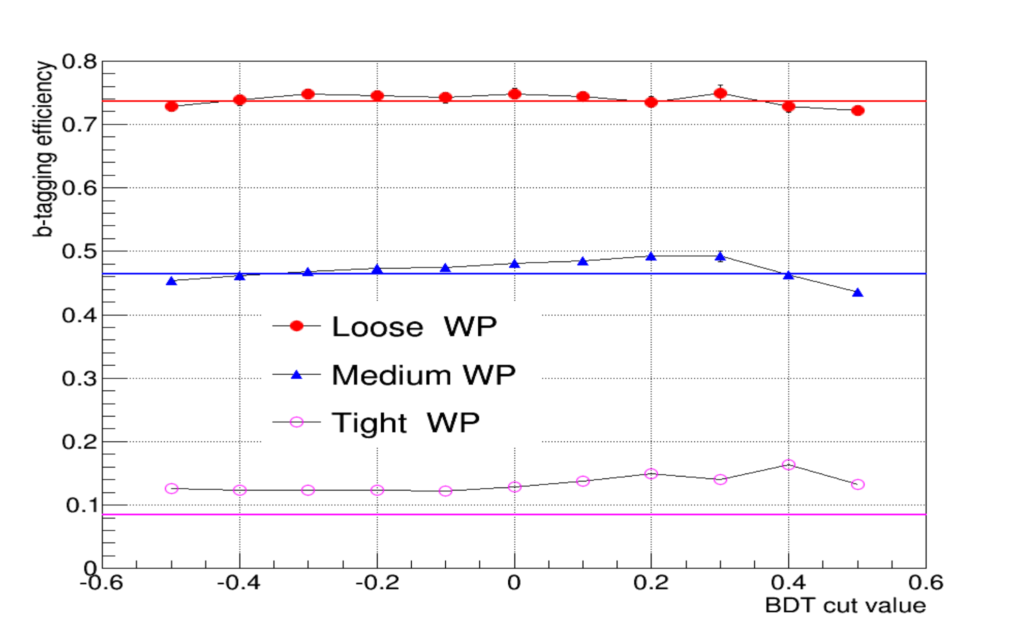
BDT results for jets 250 < p_T < 300 GeV

For JP:

→ gain of ~ 4% of b-tagging efficiency for all WP for a cut at 0.3

(reference: cut at -1)





For JBP:

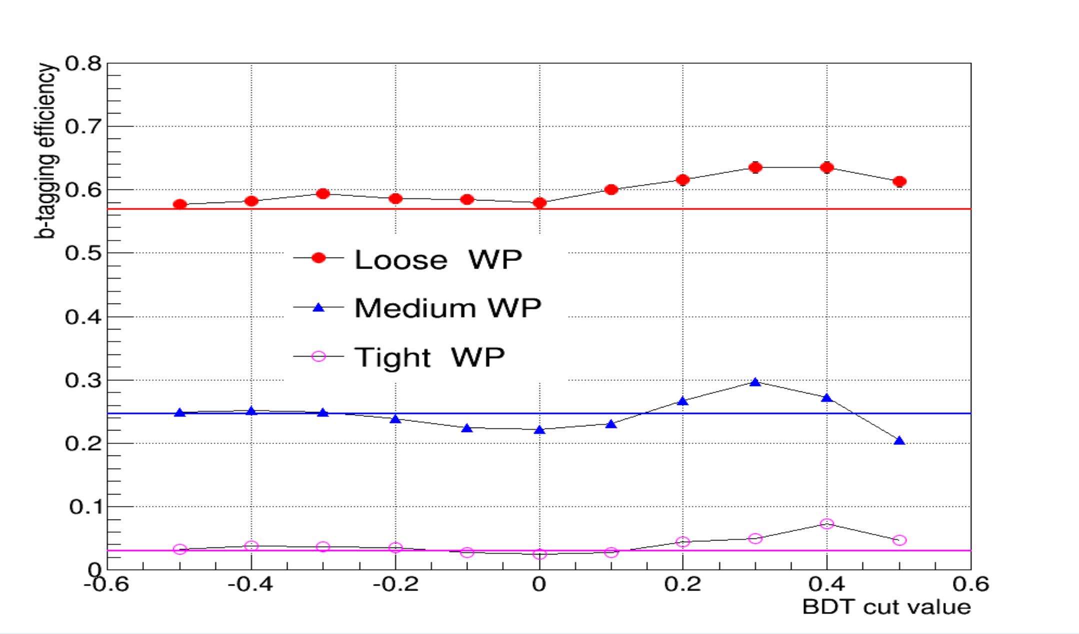
→ gain of a few % for a cut at 0.2/0.3

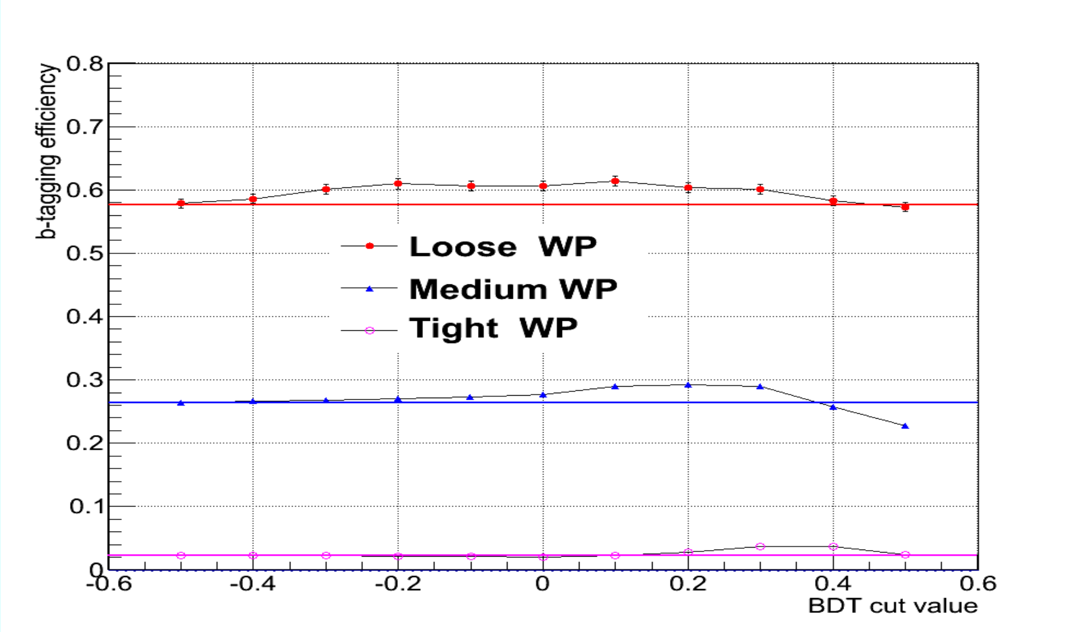
(reference: cut at -1)

BDT results for jets 450 < p_T < 550 GeV

For JP:

→ gain of ~ 4% of b-tagging efficiency for all WP for a cut at 0.3

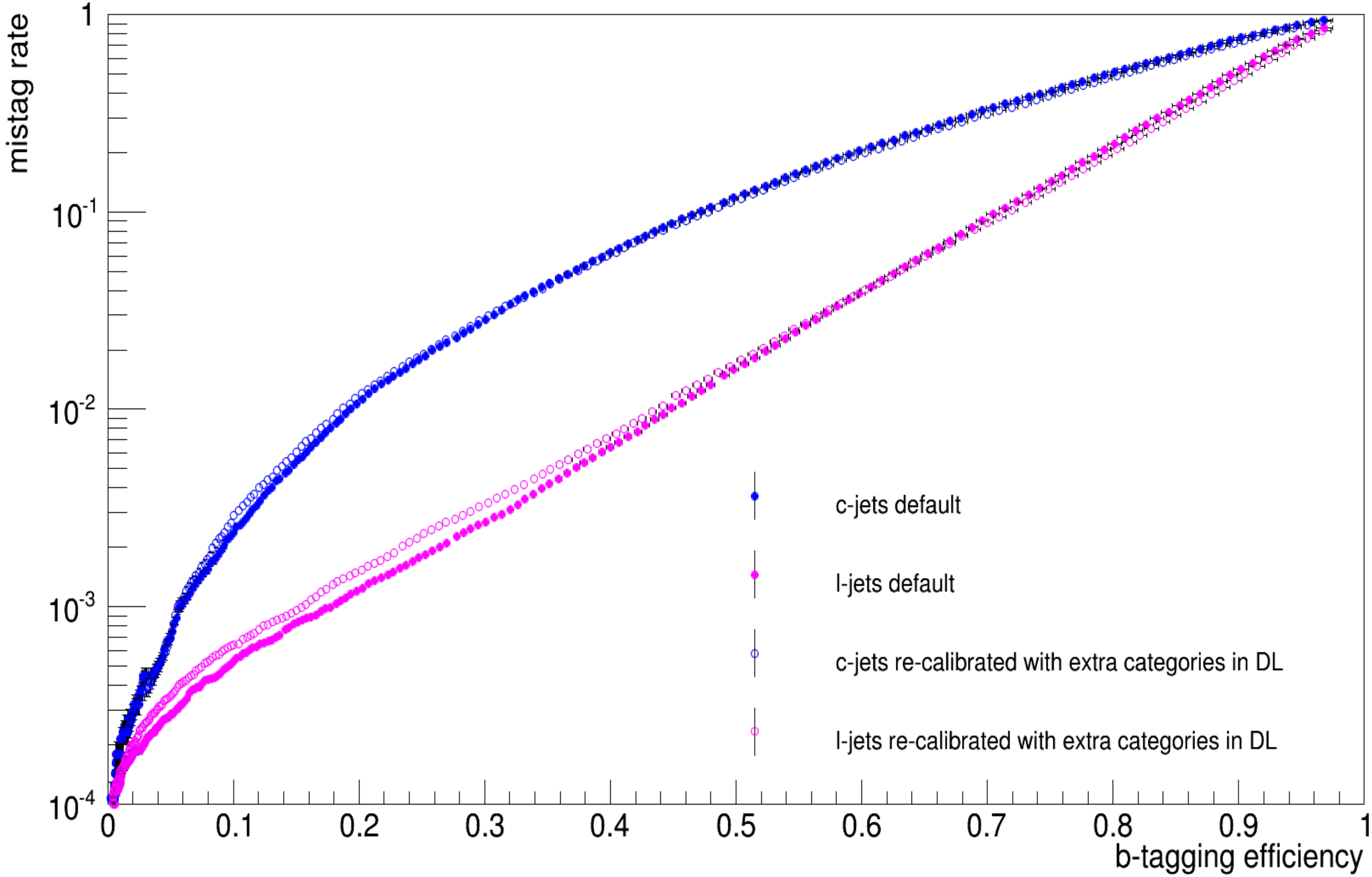




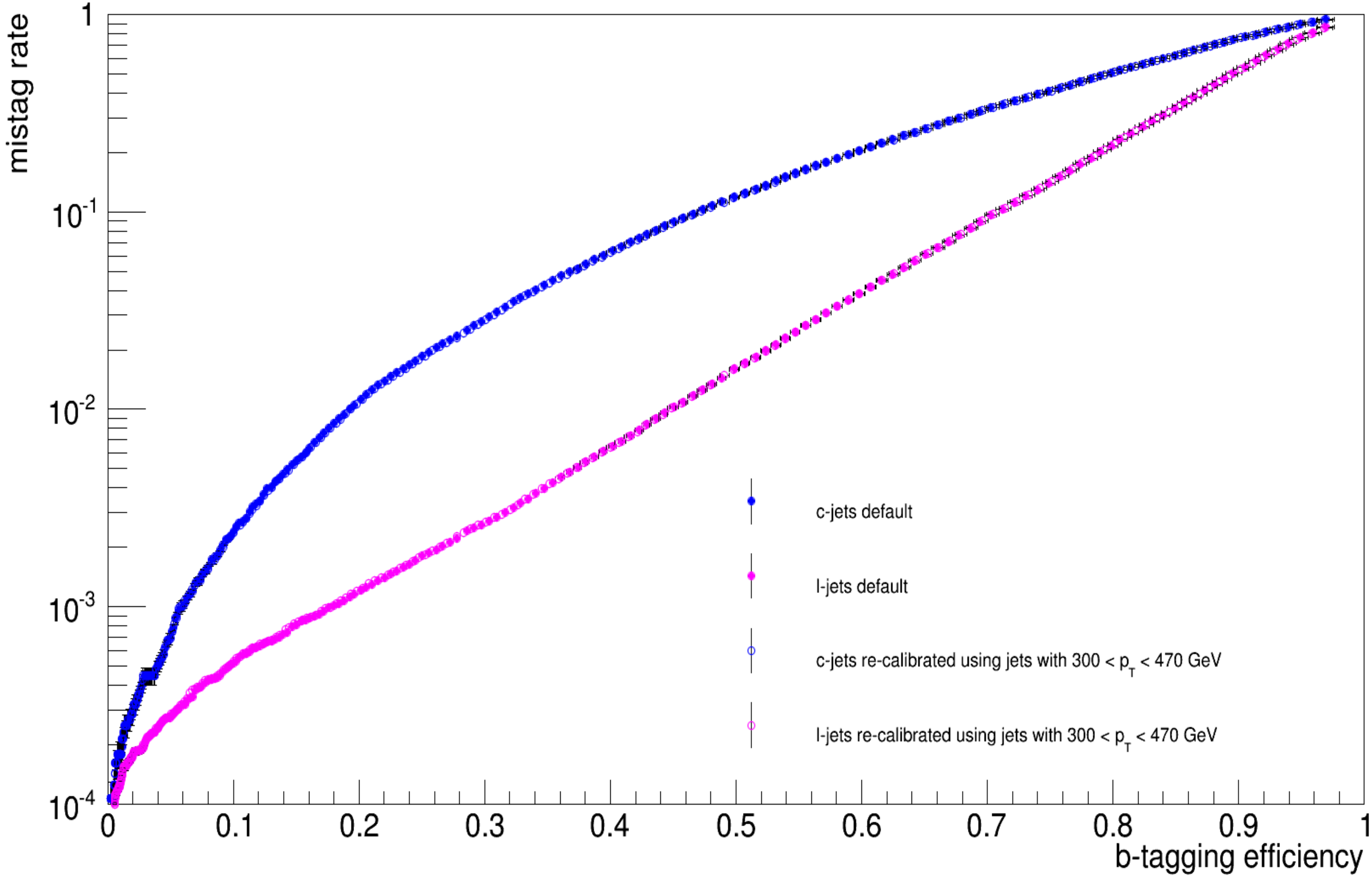
For JBP:

→ gain of a few % for a cut at 0.2/0.3

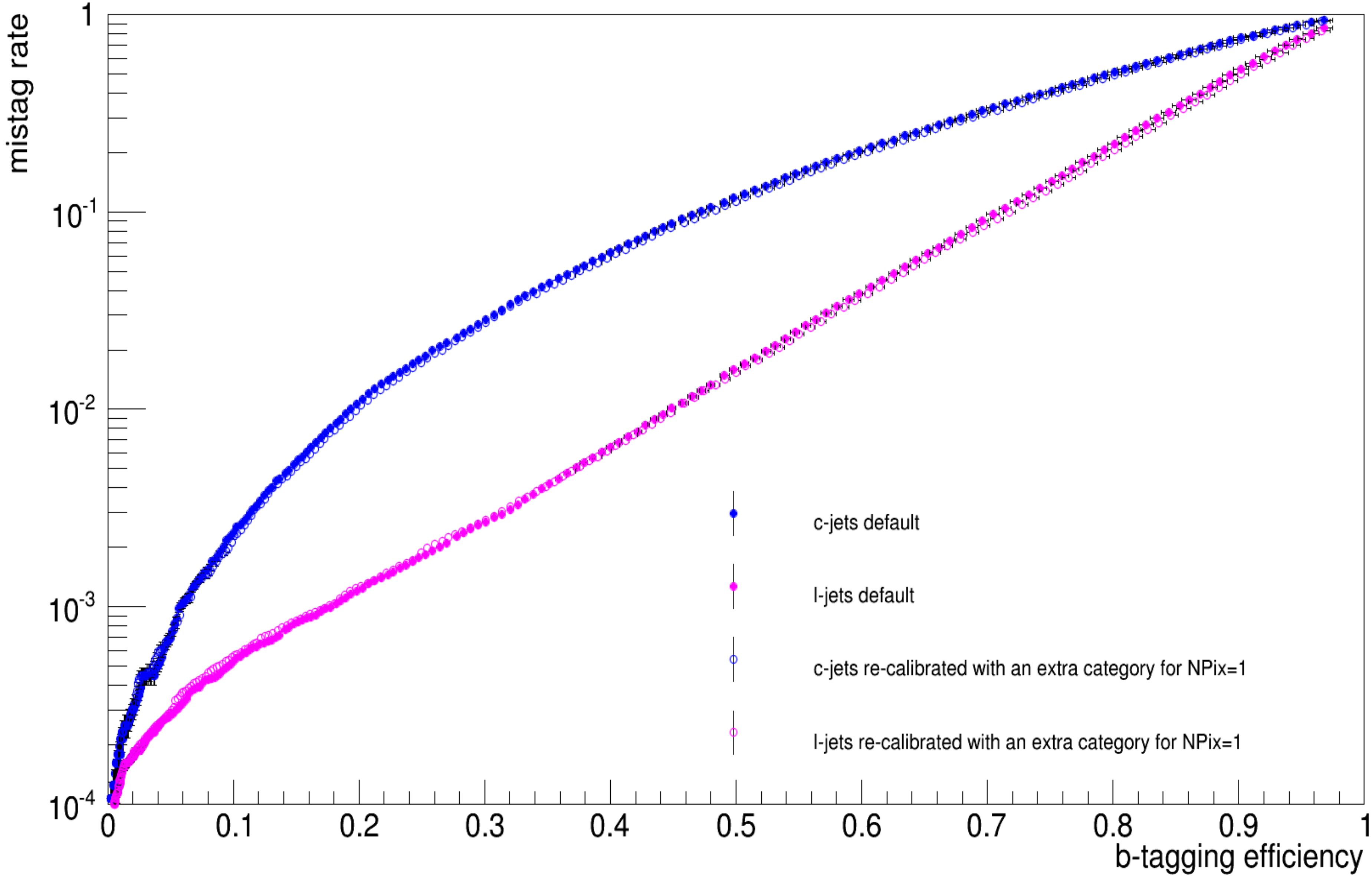
New calibrations



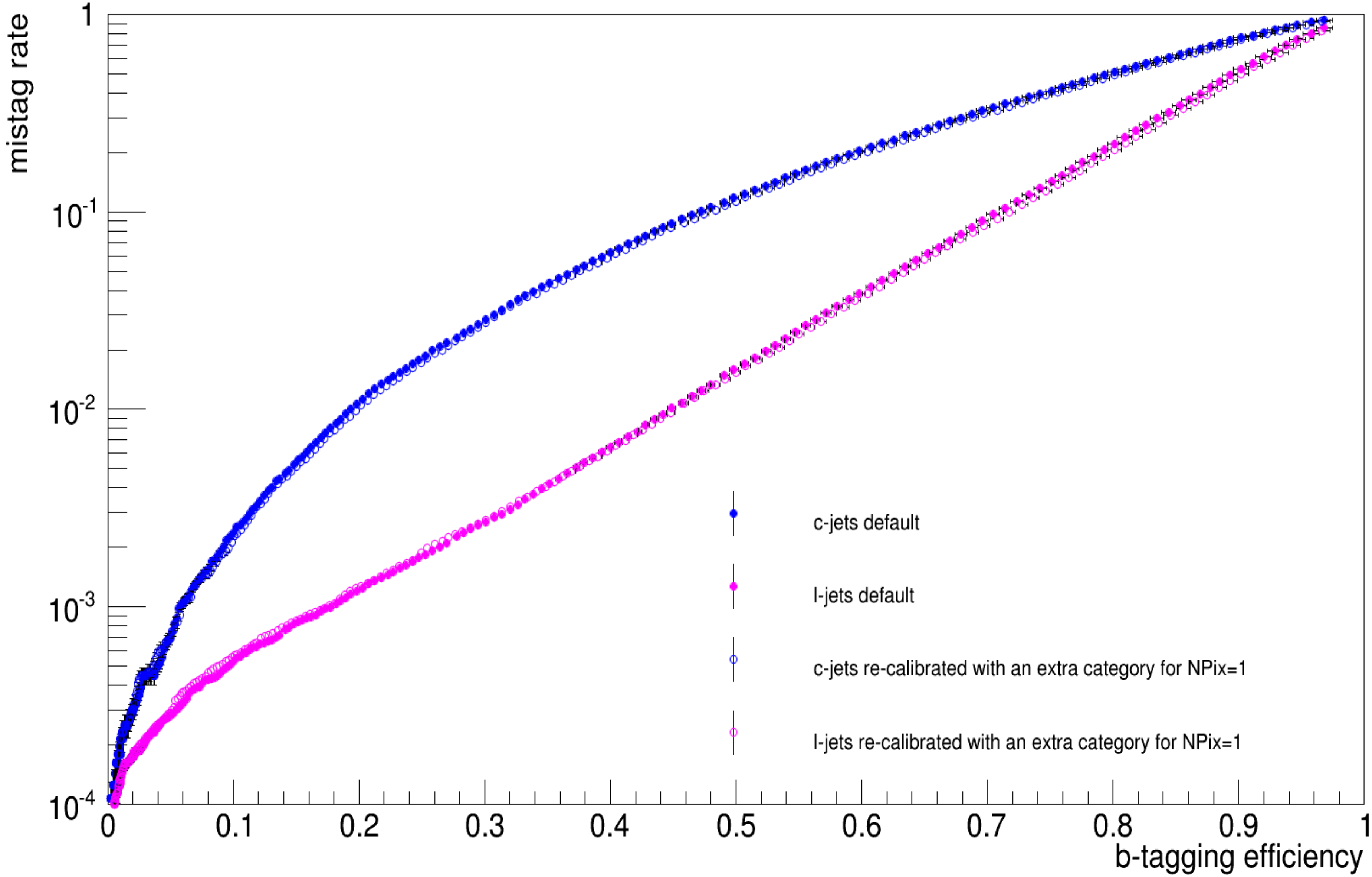
New calibrations



New calibrations



New calibrations



ZH search

CMS VH analysis

Table 10: The expected and observed 95% CL upper limits on the product of the VH production cross section times the $H \rightarrow b\bar{b}$ branching fraction, with respect to the expectations for the standard model Higgs boson, for partial combinations of channels and for all channels combined, for $m_H = 125$ GeV. Also shown are the expected and observed local significances.

$m_H = 125$ GeV	σ/σ_{SM} (95% CL) median expected	σ/σ_{SM} (95% CL) observed	Significance expected	Significance observed
$W(\ell\nu, \tau\nu)H$	1.6	2.3	1.3	1.4
$Z(\ell\ell)H$	1.9	2.8	1.1	0.8
$Z(\nu\nu)H$	1.6	2.6	1.3	1.3
All channels	0.95	1.89	2.1	2.1

Merging DY samples

- Use exclusive DY samples with different ranges $p_T(Z)$ and H_T ($p_T(Z)$: 50-70, 70-100, >100 and >180 GeV, H_T: 200-400 and > 400 GeV)
- Combined according to a reweighting procedure → accounts for the different cross section + effective number of events processed for each exclusive sample. First, $p_T(Z)$ samples combined:

$$w_i^{pt} = \frac{\sigma_i}{\sigma_{incl}} \times \frac{N_{tot}^{pt}}{N_i^{pt}}$$

$\sigma_{i:}$ absolute cross section for each of the processes
N_i^{pt} :number of events generated for exclusive sample
σ_{incl}: total cross section for the DY inclusive sample
N_{tot}^{pt}: sum of events inclusive DY sample + all $p_T(Z)$ events

- H_T DY samples reweighted similarly but accounts for previous $p_T(Z)$ reweighting:

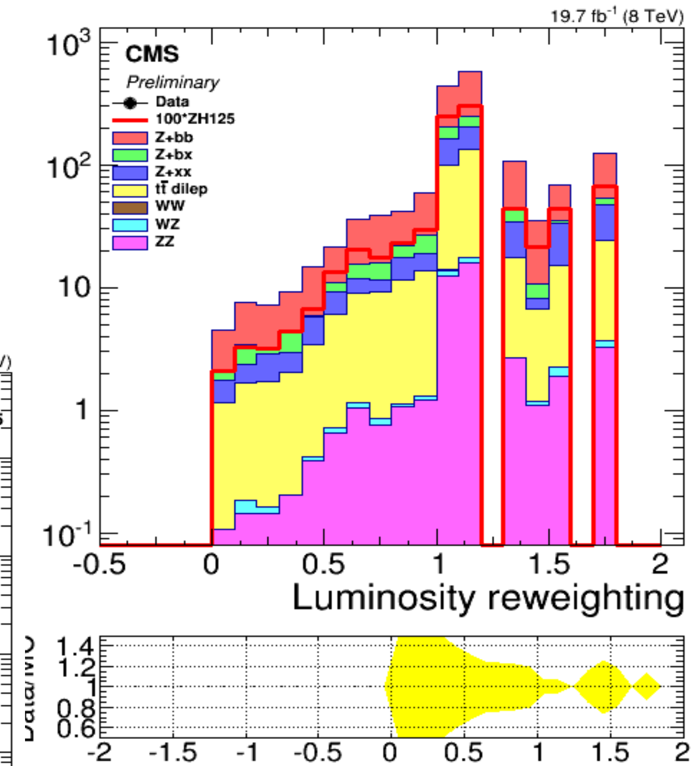
$$w_j^{HT} = \frac{\sigma_j}{\sigma_{incl}} \times \frac{N_{tot}^{HT}}{N_j^{HT-pt}}$$

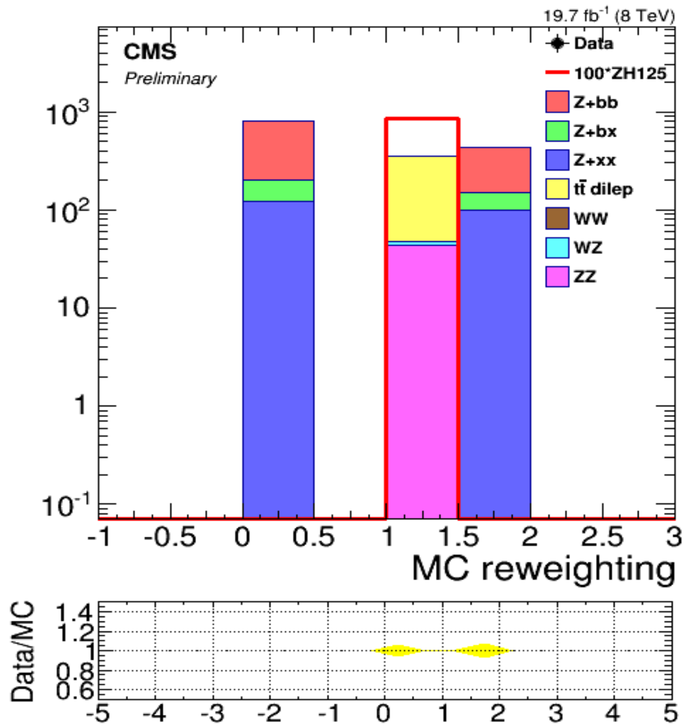
$N_j^{HT\text{-}pt} = N_j^{HT} + \Sigma_i \, w_i^{pt} * N_{ij}^{pt}$ → accounts for the numbers of events from the i^th^ p_T sample going in the j^th^ H_T bin
N_{tot}^{HT} : total number of events from all H_T samples

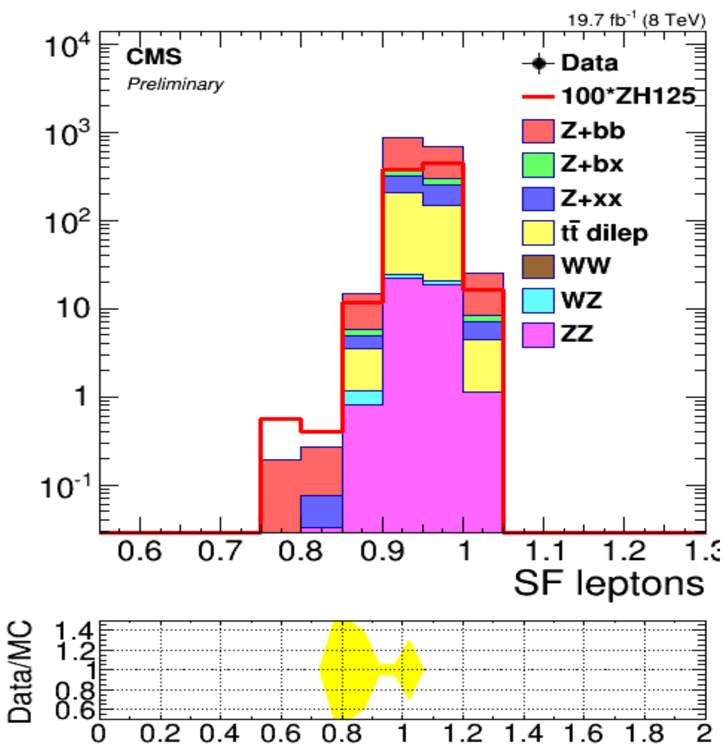
- Final weight for each event extracted → ratio between events falling simultaneously into two-dimensional i^th^ p_T -j^th^ H_T bin and total number of generated events in that bin:

$$w_{ij} = \frac{(N_{ij}^{pt} \cdot w_i^{pt} + N_j^{HT}) \cdot w_j^{HT}}{N_{ij}^{gen}}$$

Monte Carlo reweighting: SF







b-tagging SF

b tagger	misidentification probability	SF_{light}
JPL	0.0944 ± 0.0004	$1.03 \pm 0.01 \pm 0.07$
CSVL	0.0990 ± 0.0004	$1.10 \pm 0.01 \pm 0.05$
JPM	0.0105 ± 0.0002	$1.10 \pm 0.02 \pm 0.20$
CSVM	0.0142 ± 0.0002	$1.17 \pm 0.02 \pm 0.15$
TCHPT	0.0026 ± 0.0001	$1.27 \pm 0.06 \pm 0.27$
JPT	0.0013 ± 0.0001	$1.11 \pm 0.07 \pm 0.31$
CSVT	0.0016 ± 0.0001	$1.26 \pm 0.07 \pm 0.28$

For SF_b, at most 5% of uncertainty

Background reweighting: correlation matrix

For JP:

tt	1.000	-0.135	-0.191	-0.018
Zbb	-0.135	1.000	0.093	**-0.324**
Zbx	-0.191	0.093	1.000	**-0.438**
Zxx	-0.018	-0.324	-0.438	1.000

For CSV:

tt	1.000	-**0.316**	**-0.424**	0.055
Zbb	-0.316	1.000	0.194	**-0.320**
Zbx	-0.424	0.194	1.000	**-0.461**
Zxx	0.055	-0.320	-0.461	1.000

Systematics break down

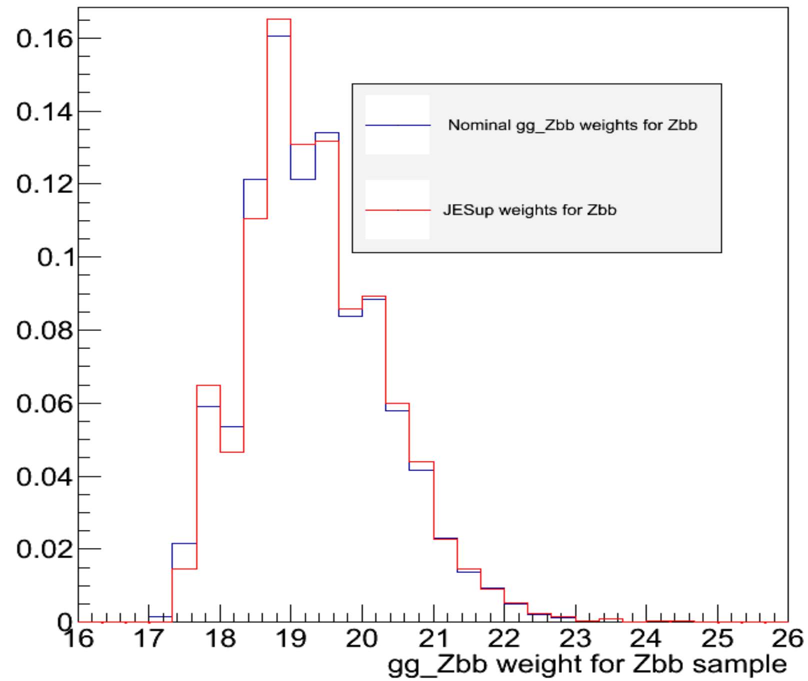
Table 4.19: Breakdown of the systematics on the final limits, for the **CSV** tagger.

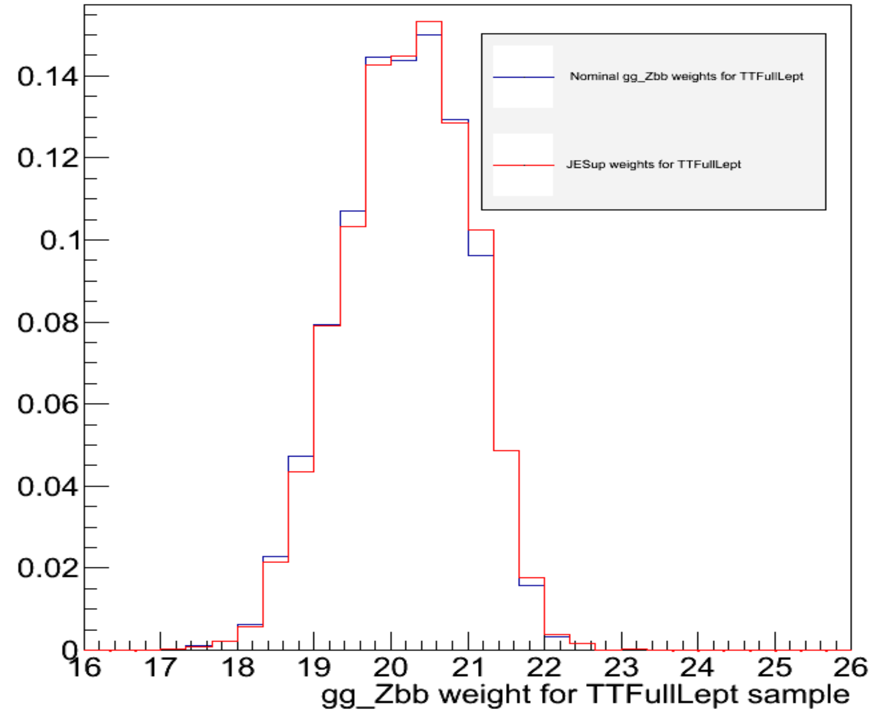
Systematic	Value	Degradation
No syst.	2.59	-
All syst.	3.39	30.9 %
-lumi.	3.39	-
-lepton SF	3.39	-
-ZH cross section + ZZ normalization	3.39	-
-JES	3.39	-
-JER	3.39	-
-b-tag. SF bc	3.39	-
-b-tag. SF light	3.39	-
-Background fit	3.27	3.7 %
MC statistics		
-All	2.93	15.7 %
-Zbb	3.10	9.4 %
-Zbx	3.33	1.8 %
-Zxx	3.33	1.8 %
-$t\bar{t}$	3.39	-
-ZZ	3.39	-
-ZH	3.39	-

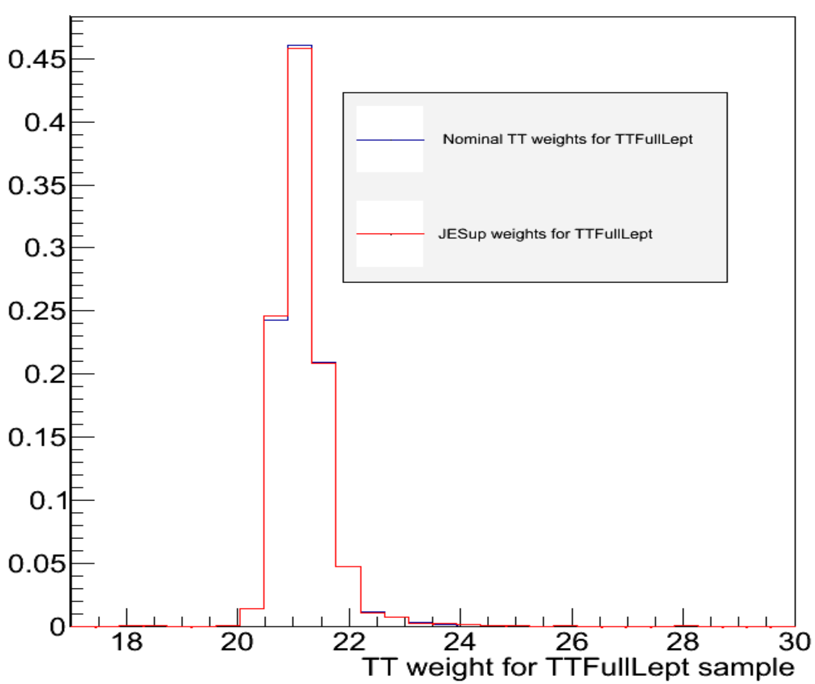
Table 4.18: Breakdown of the systematics on the final limits, for the **JP** tagger.

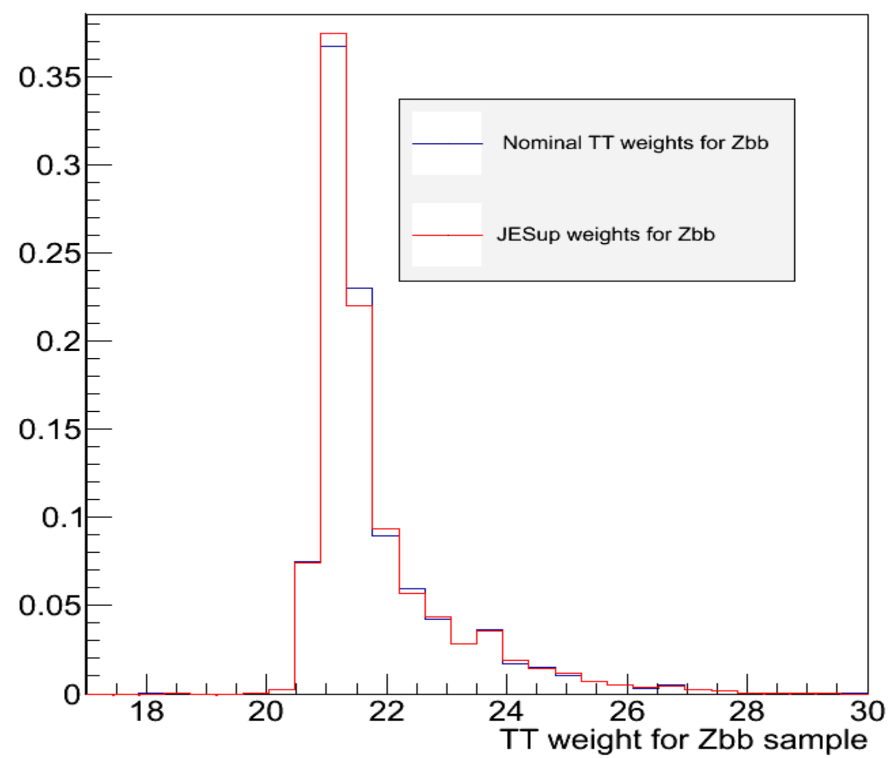
Systematic	Value	Degradation
No syst.	2.73	-
All syst.	3.52	28.9 %
-lumi.	3.52	-
-lepton SF	3.52	-
-ZH cross section + ZZ normalization	3.52	-
-JES	3.52	-
-JER	3.52	-
-b-tag. SF bc	3.48	0.9 %
-b-tag. SF light	3.52	-
-Background fit	3.39	3.7 %
MC statistics		
-All	3.20	9.8 %
-Zbb	3.27	7.7 %
-Zbx	3.52	-
-Zxx	3.48	0.9 %
-$t\bar{t}$	3.52	-
-ZZ	3.52	-
-ZH	3.52	-
MadWeight		
-JES	3.48	0.9 %
-JER	3.52	-

MadWeight effect

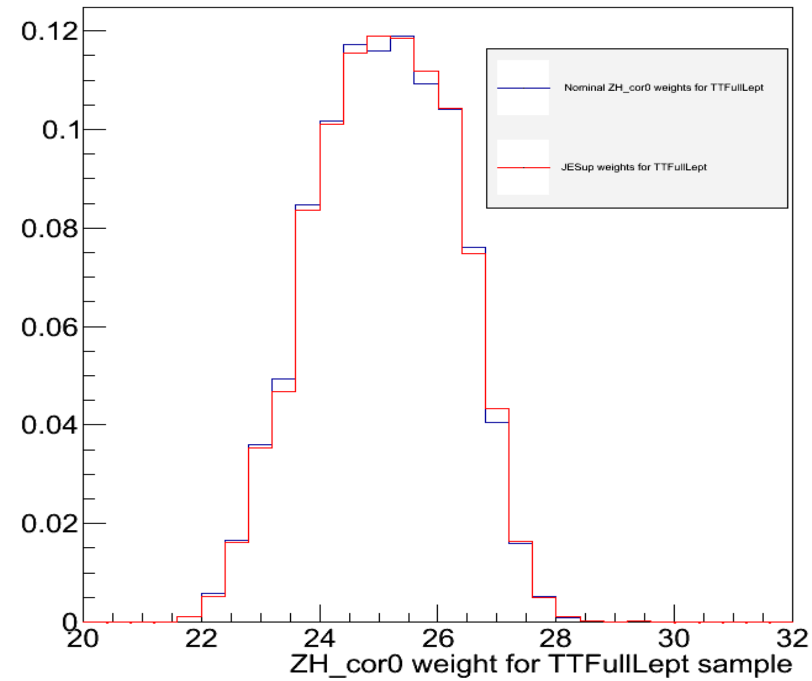


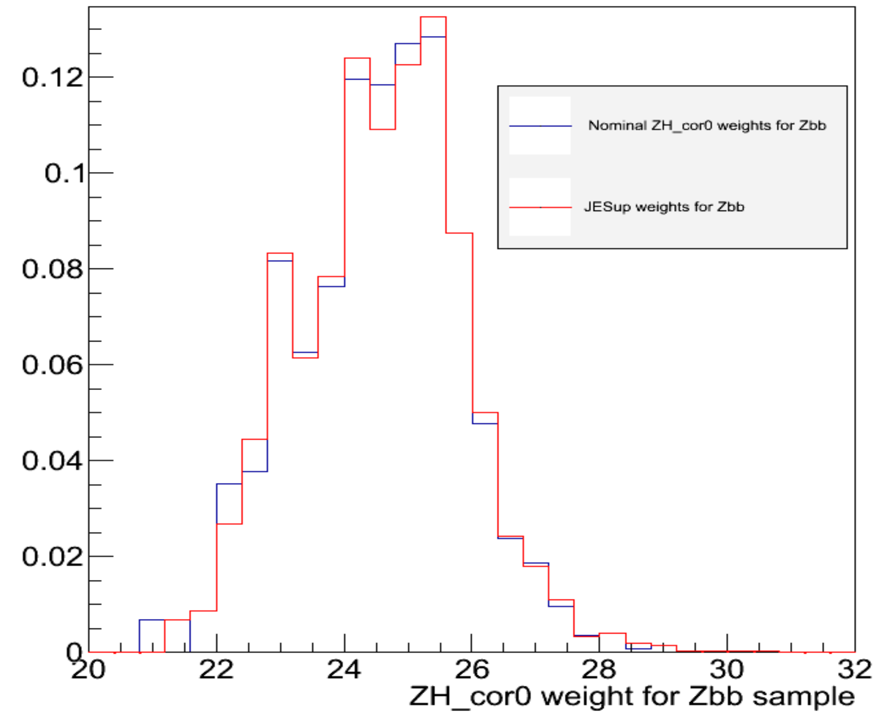


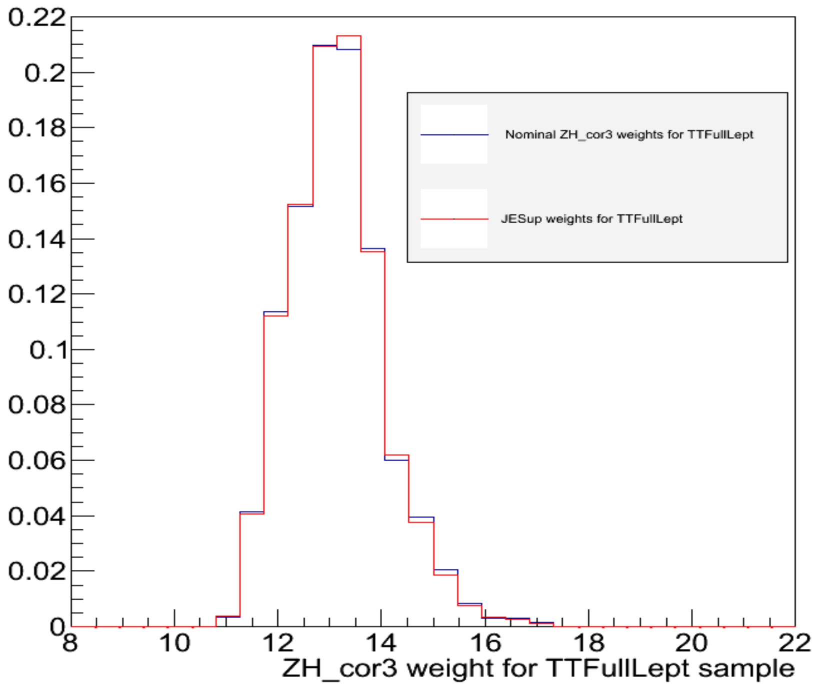


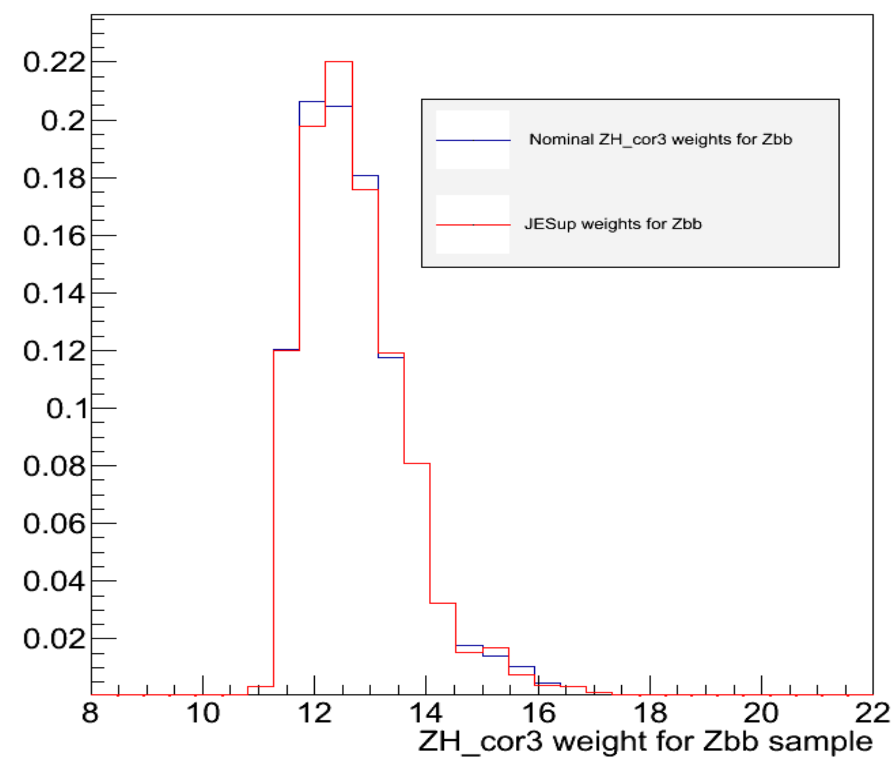


MadWeight effect

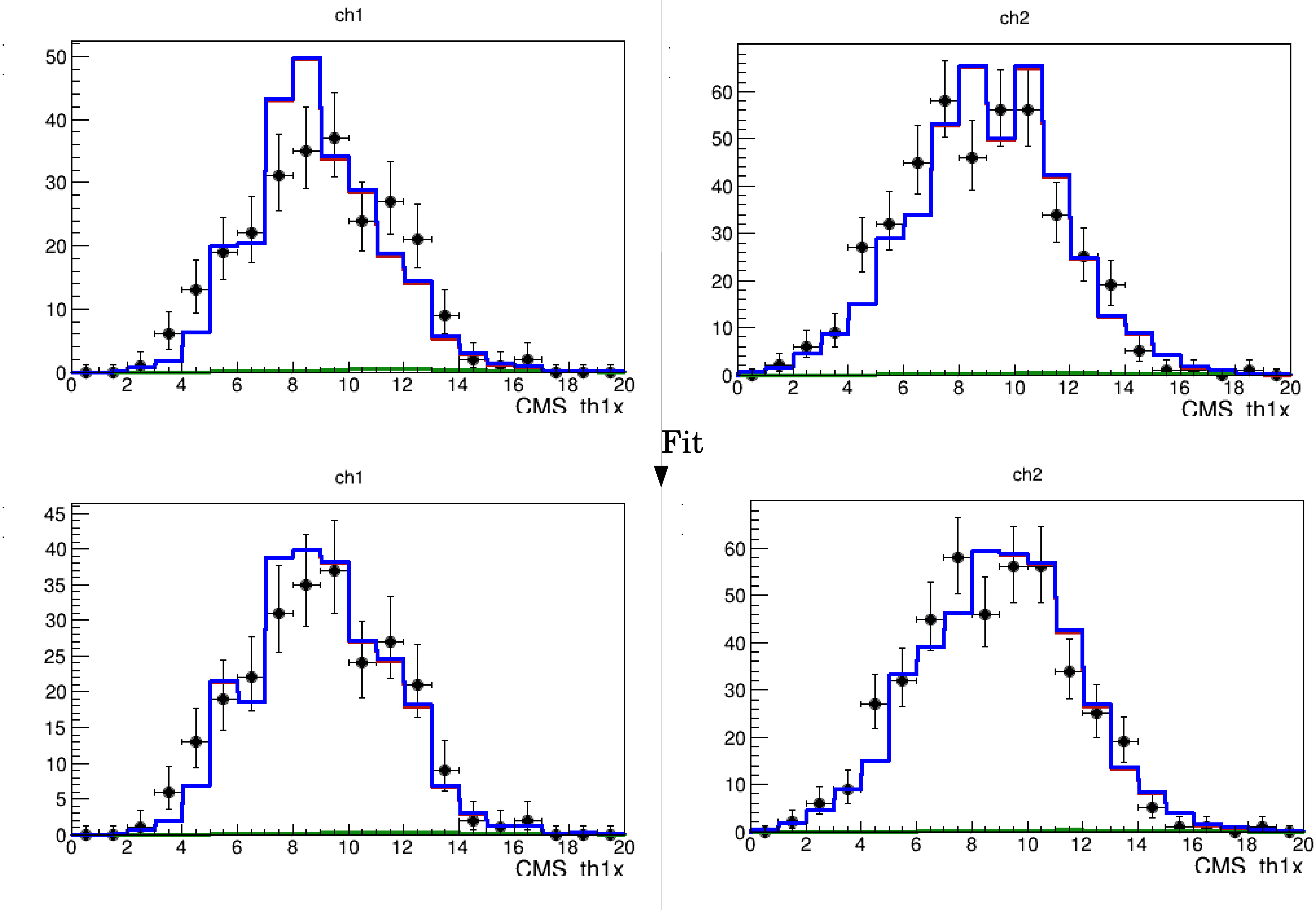




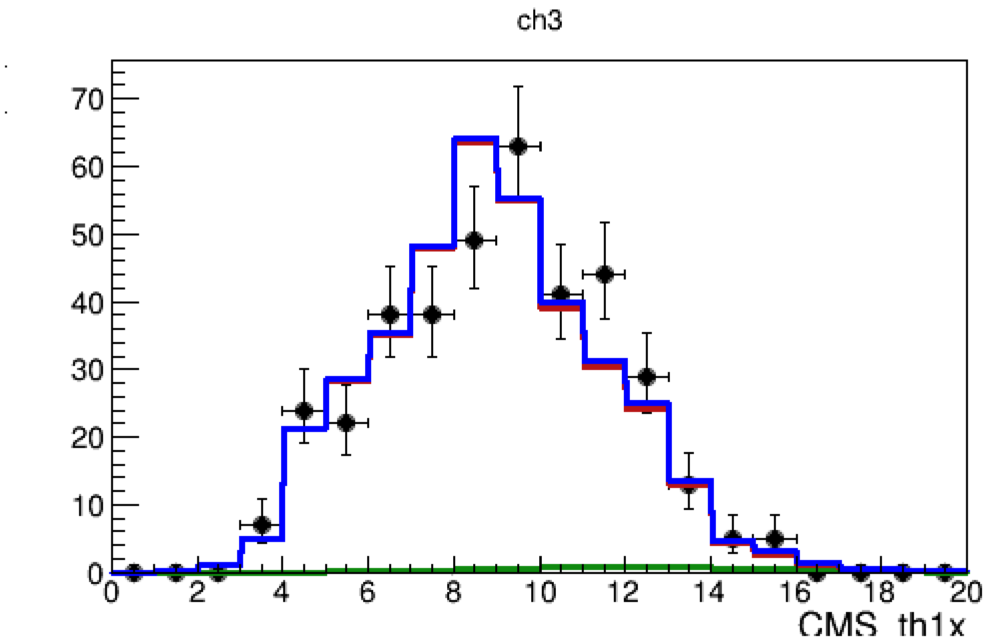


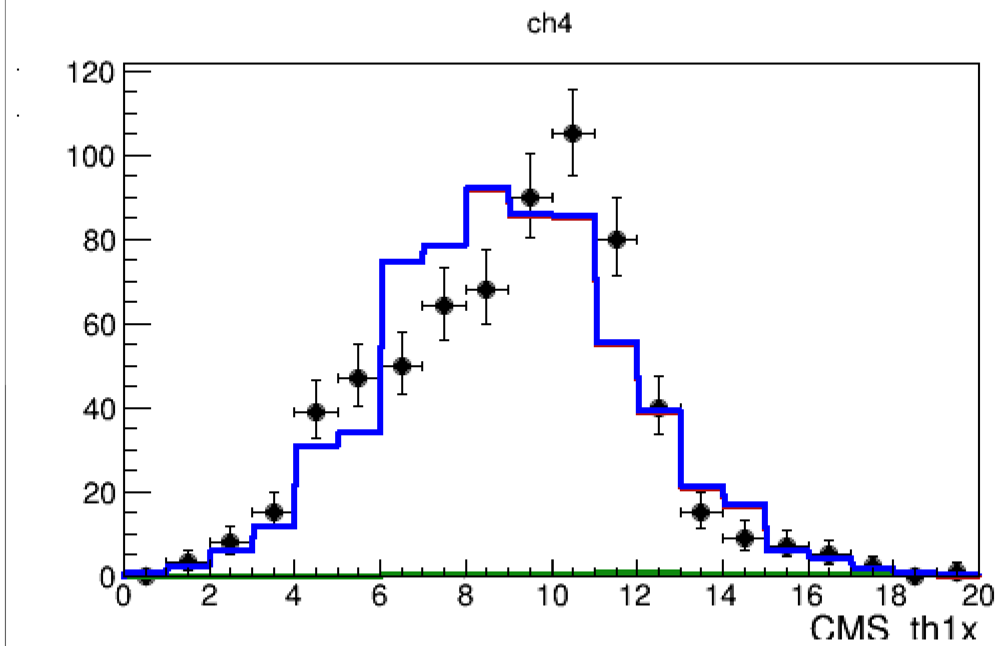


Unblinding (JP)

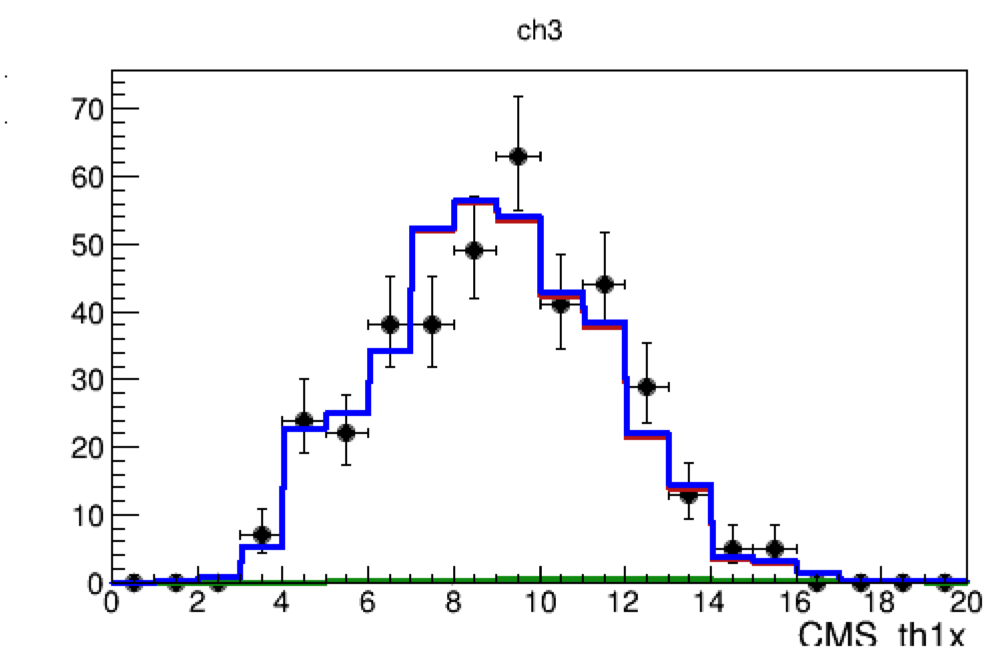


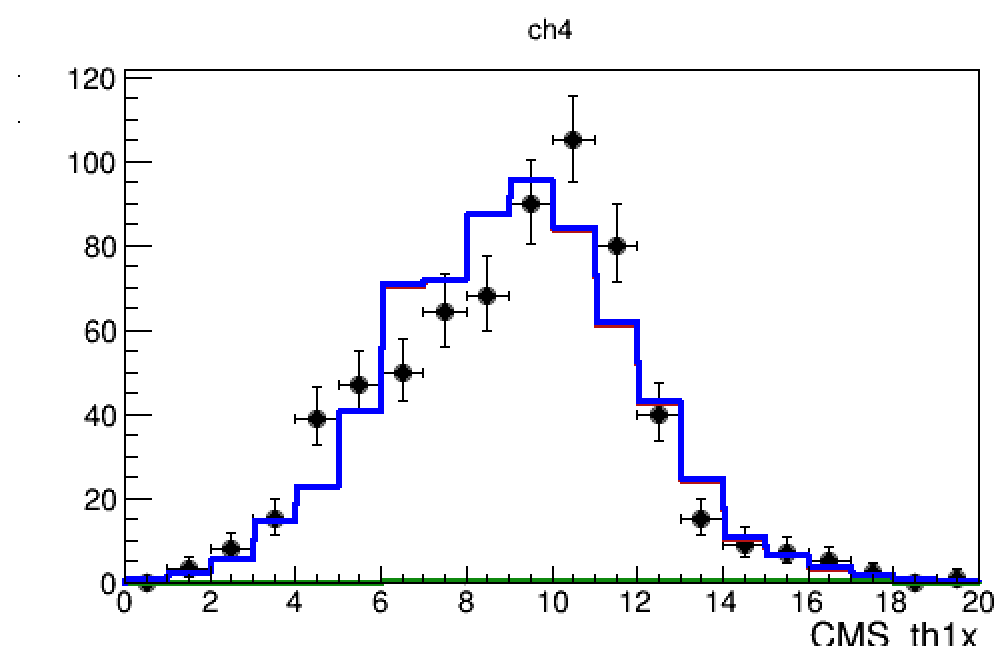
Unblinding (JP)



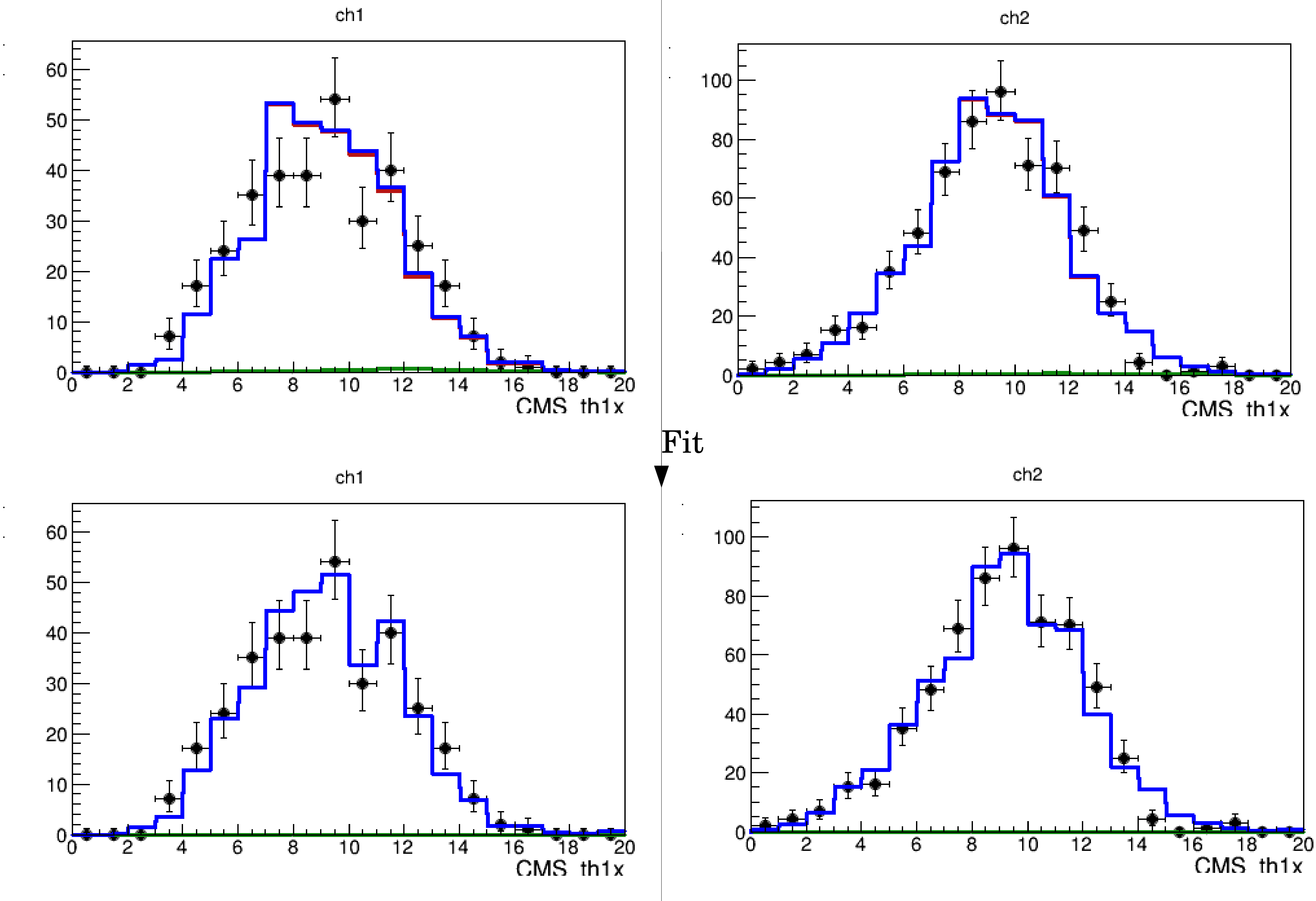


Fit

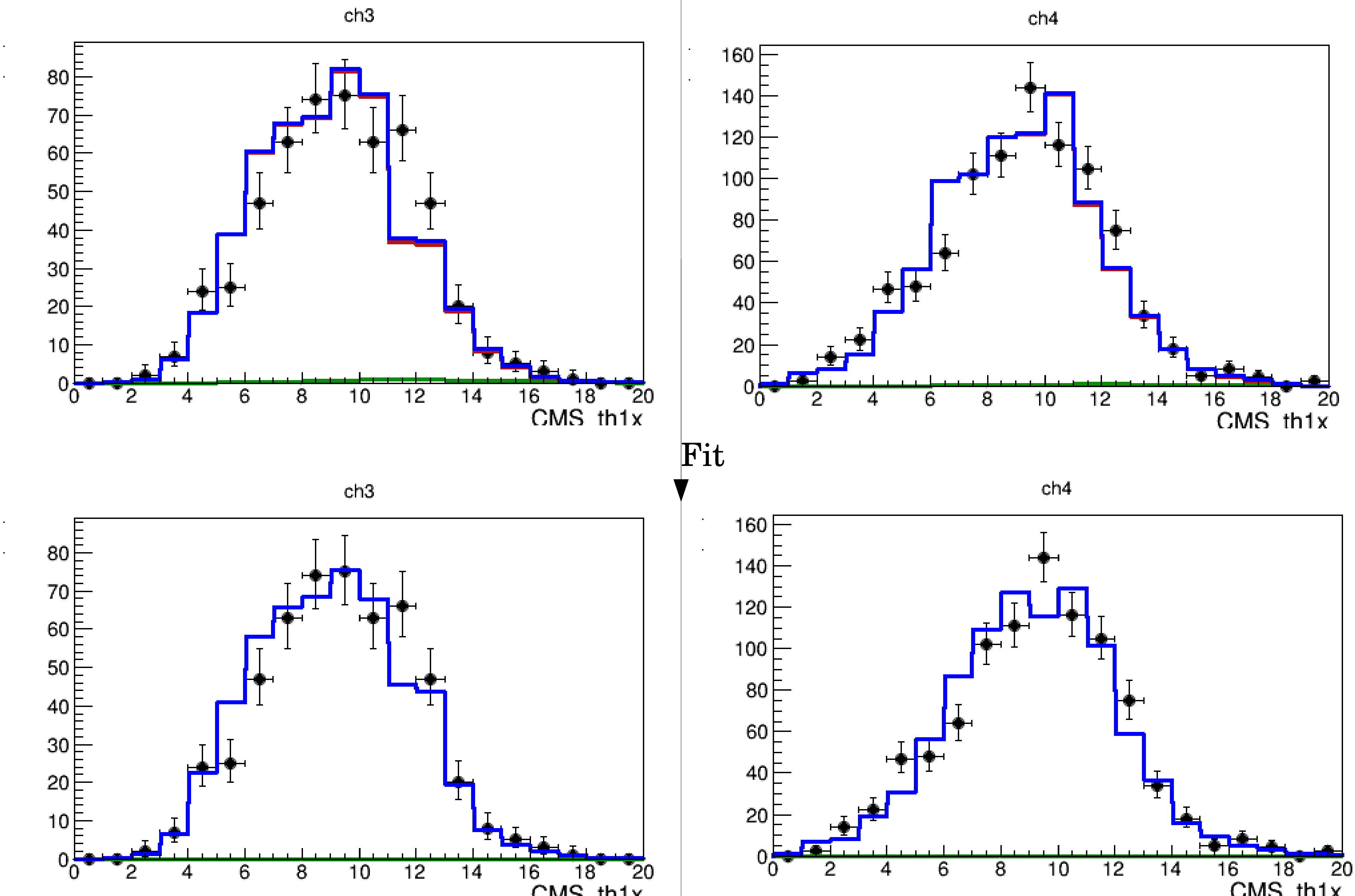




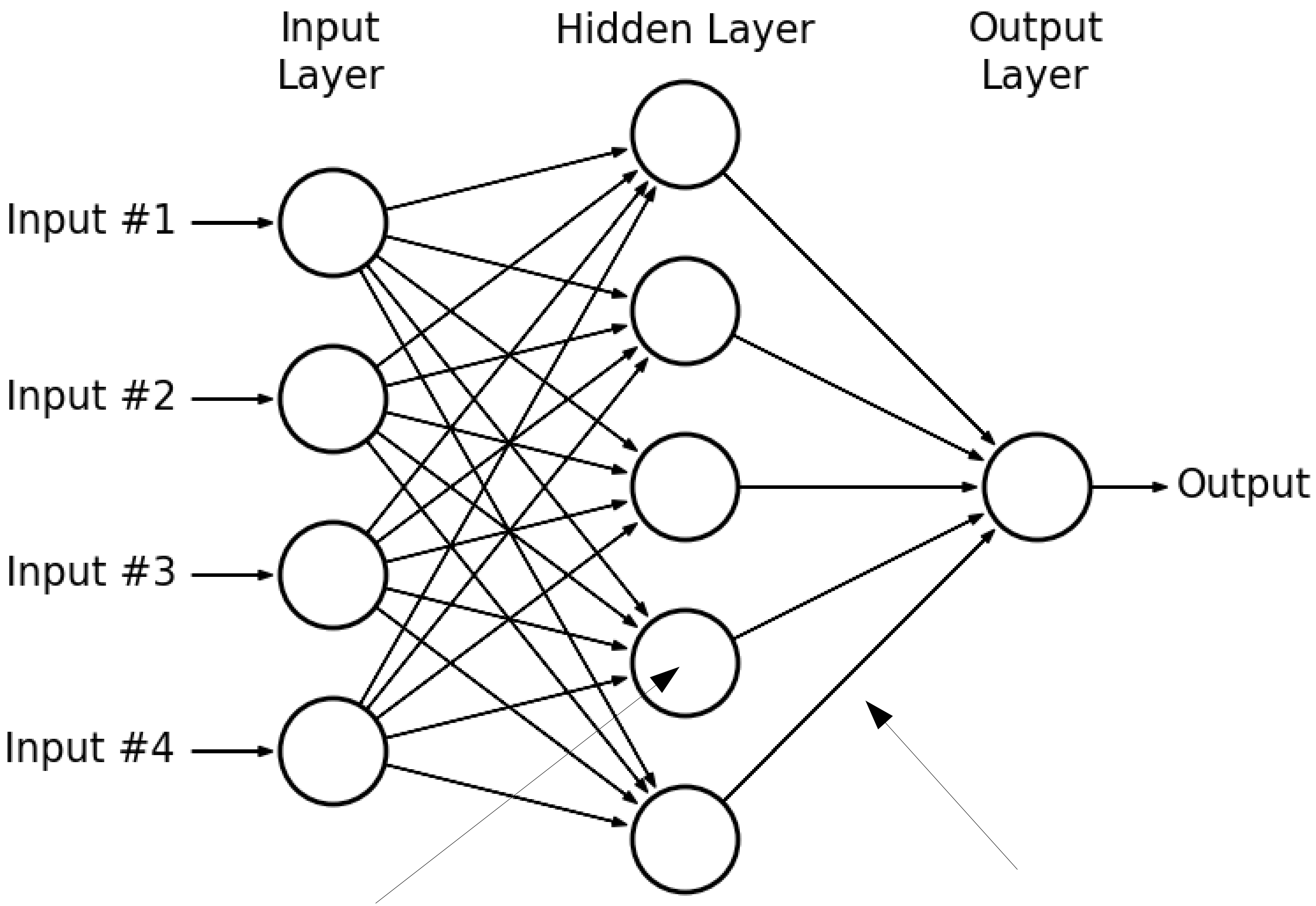
Unblinding (CSV)



Unblinding (CSV)



Neural Network

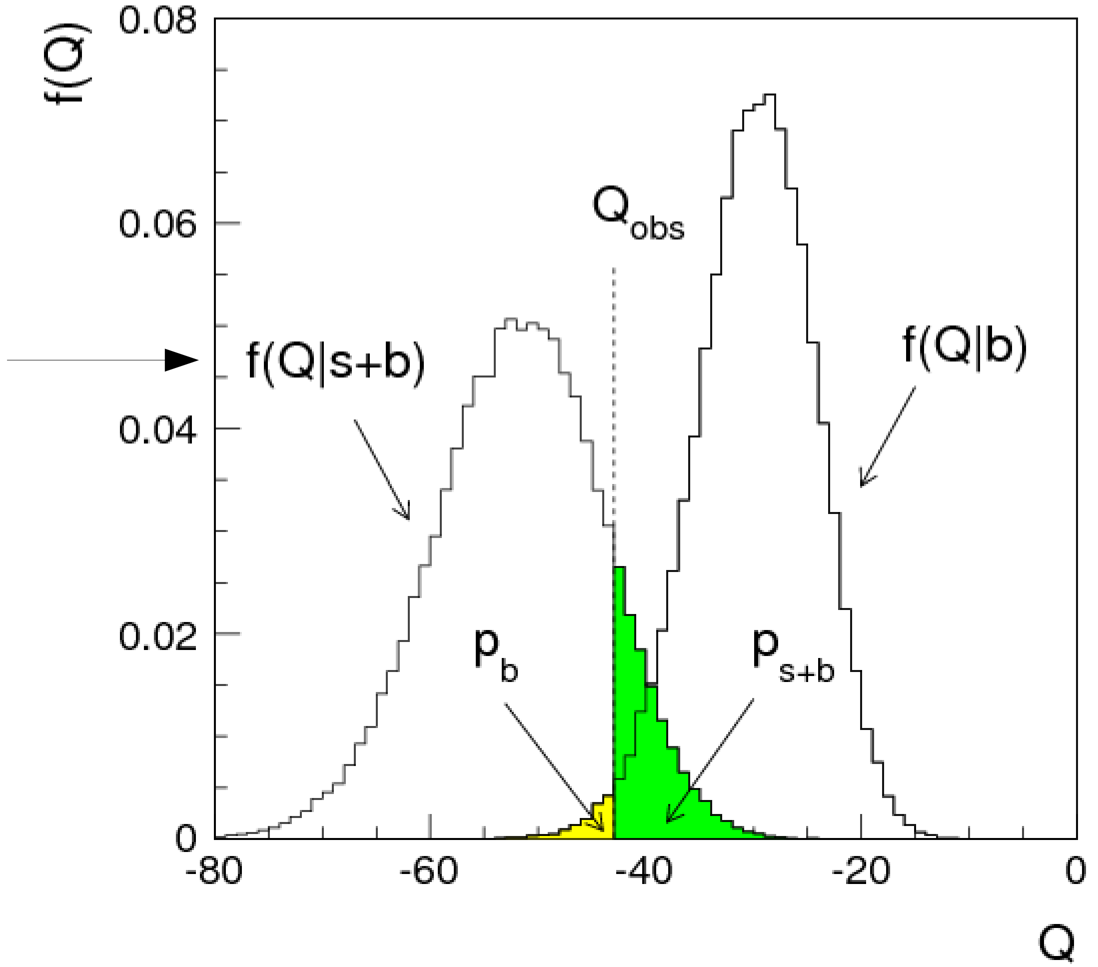


Each neuron represents a weighted sum of the neurons from the previous layer

Synapse: represents a sigmoid function

CLs

How much likely data correspond to hypothesis s+b



Tag and Probe

The Tag and Probe Tool is a generic tool developed to measure any user defined object efficiency from data at CMS by exploiting di-object resonances like Z or J/Psi.

- Resonances are reconstructed as pairs with one leg passing a tight identification (tag) and one passing a loose identification (probe)
- "Passing probes" are defined according to whatever is the efficiency to measure
- (tag + passing probe) and (tag + failing probe) distributions are fit separately with a signal + background model
- The efficiency is computed from the ratio of the signal yields in the two distributions above
- The procedure is repeated in bins of the probe variables (e.g. pT, η ...) to compute efficiency histograms as a function of those variables

MI search

Tunning of free parameters

cut_{Pur} value	# of boxes	Limit CSV	Limit CSV with MC stat.	Limit CSV+ # jets	Limit CSV+ # jets with MC stat.
0.1	90	3.61	3.80	3.23	3.42
0.2	72	4.23	4.51	3.89	4.23
0.3	73	4.02	4.36	3.77	4.20
0.4	47	4.23	4.61	4.02	4.52
0.5	40	4.27	4.61	4.05	4.52
0.6	28	4.33	4.73	4.11	4.66
0.7	18	4.61	5.02	4.39	4.92
0.8	11	4.92	5.30	4.64	5.14
0.9	4	5.30	5.70	5.02	5.55

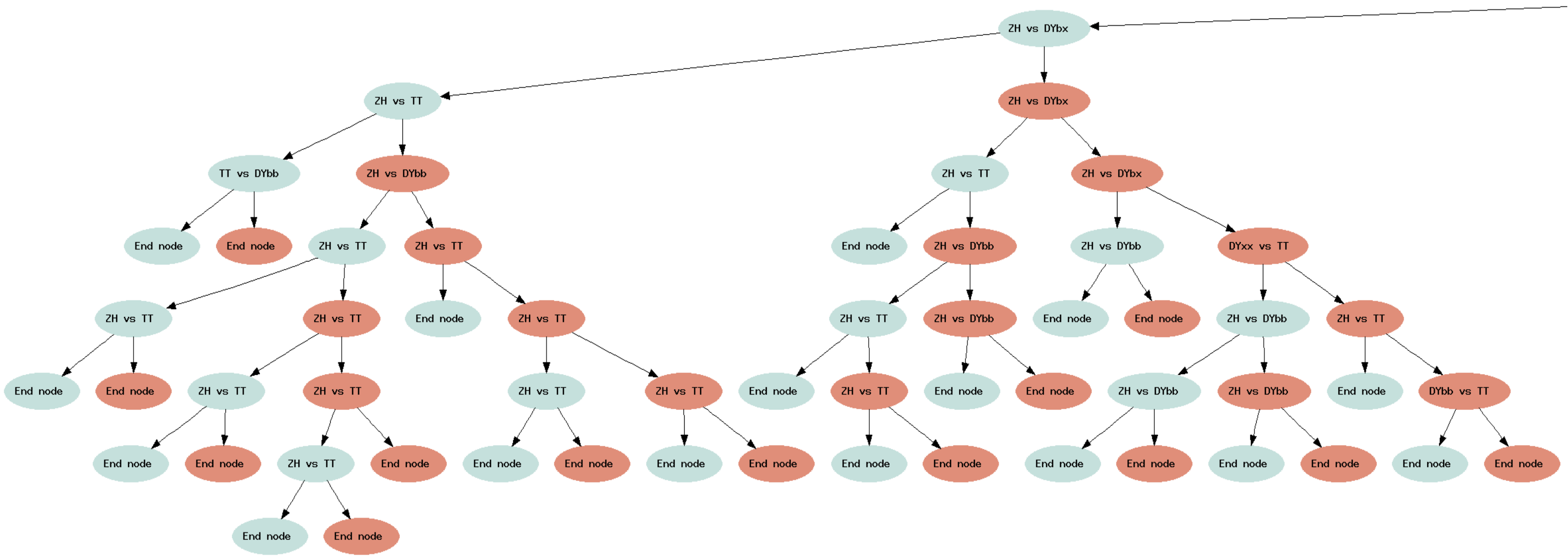
N_{MC} value	# of boxes	Limit CSV	Limit CSV with MC stat.	Limit CSV+ # jets	Limit CSV+ # jets with MC stat.
50	87	4.14	4.45	3.86	4.30
75	75	4.14	4.45	3.89	4.36

f_{signal} value	# of boxes	Limit CSV	Limit CSV with MC stat.	Limit CSV+ # jets	Limit CSV+ # jets with MC stat.
60%	57	4.05	4.39	3.80	4.33
70%	46	4.20	4.61	3.95	4.48

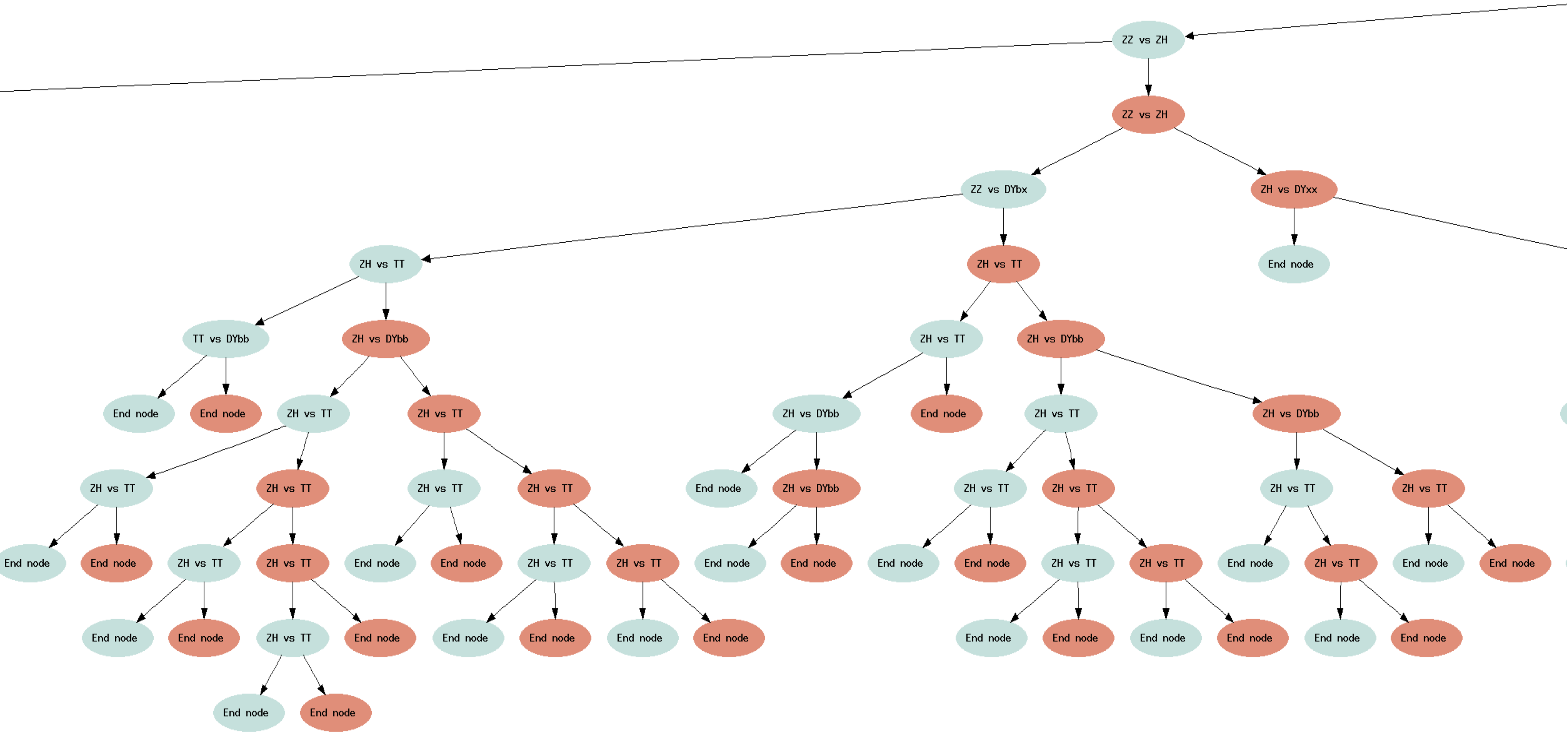
	# of boxes	Limit CSV	Limit CSV with MC stat.	Limit CSV+ # jets	Limit CSV+ # jets with MC stat.
cor3	58	3.83	4.05	3.58	3.86
no Zbj	37	4.30	4.64	4.08	4.55

Correlation matrix fit to data

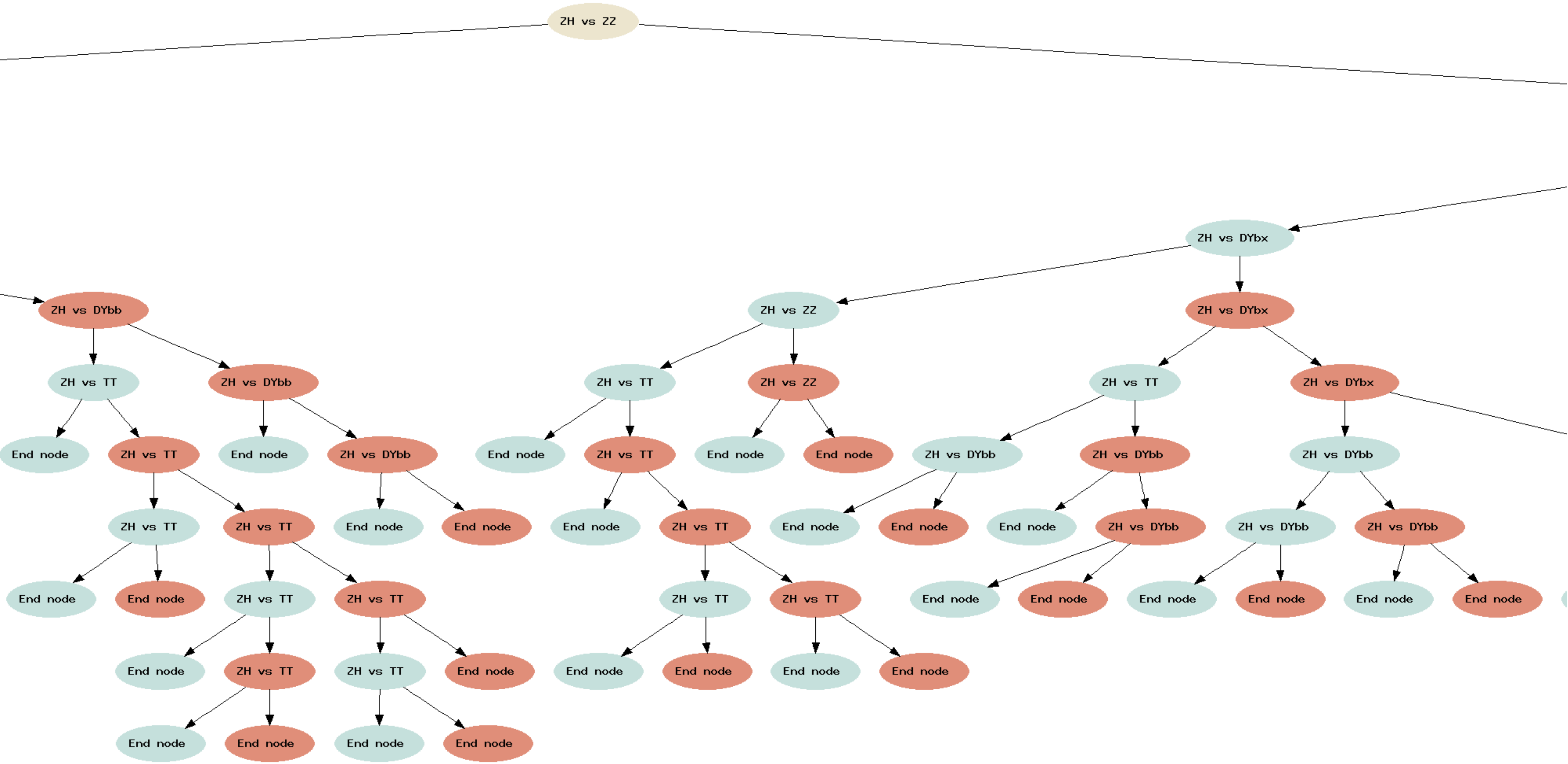
Tree for best configuration



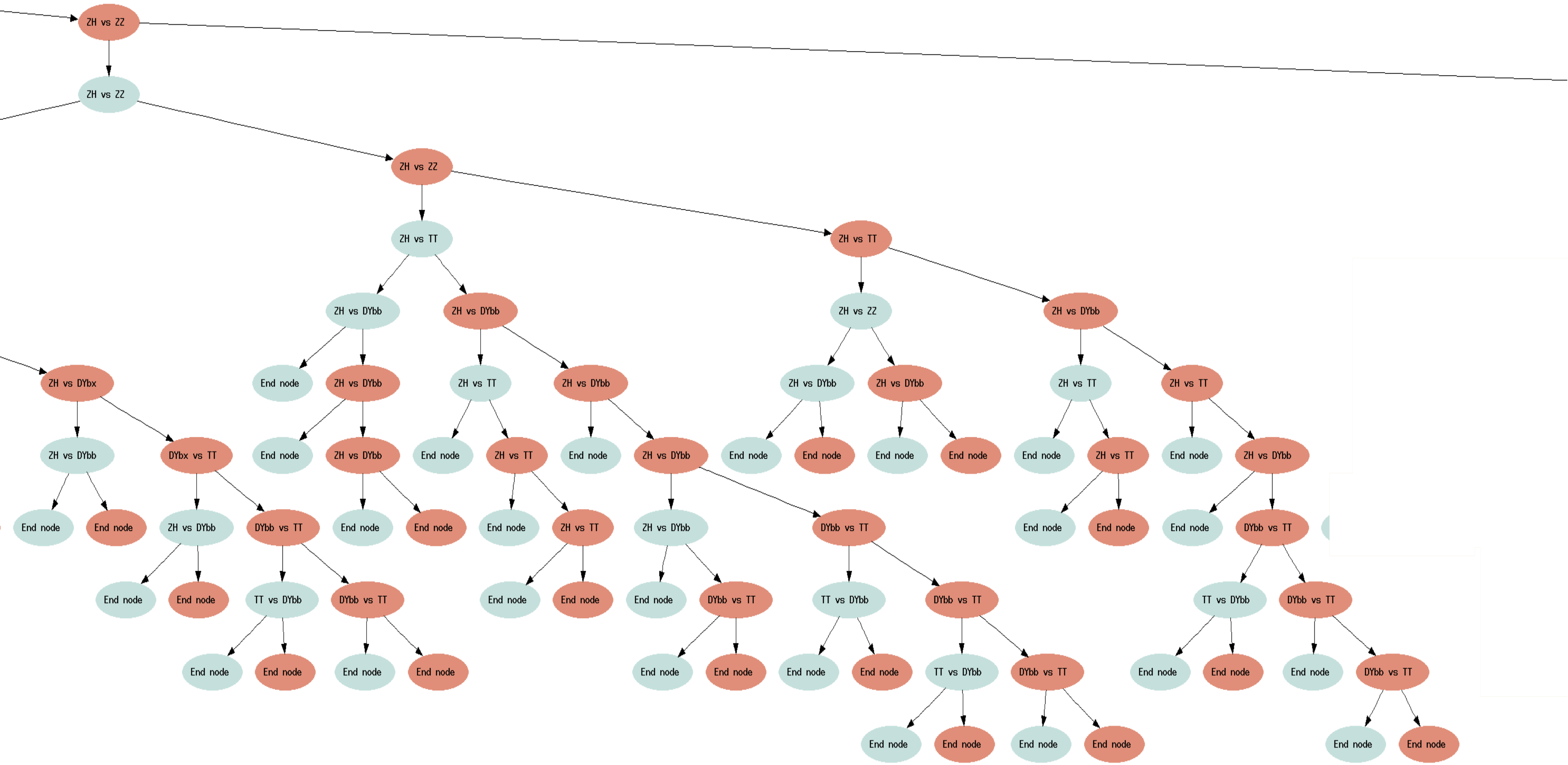
Tree for best configuration



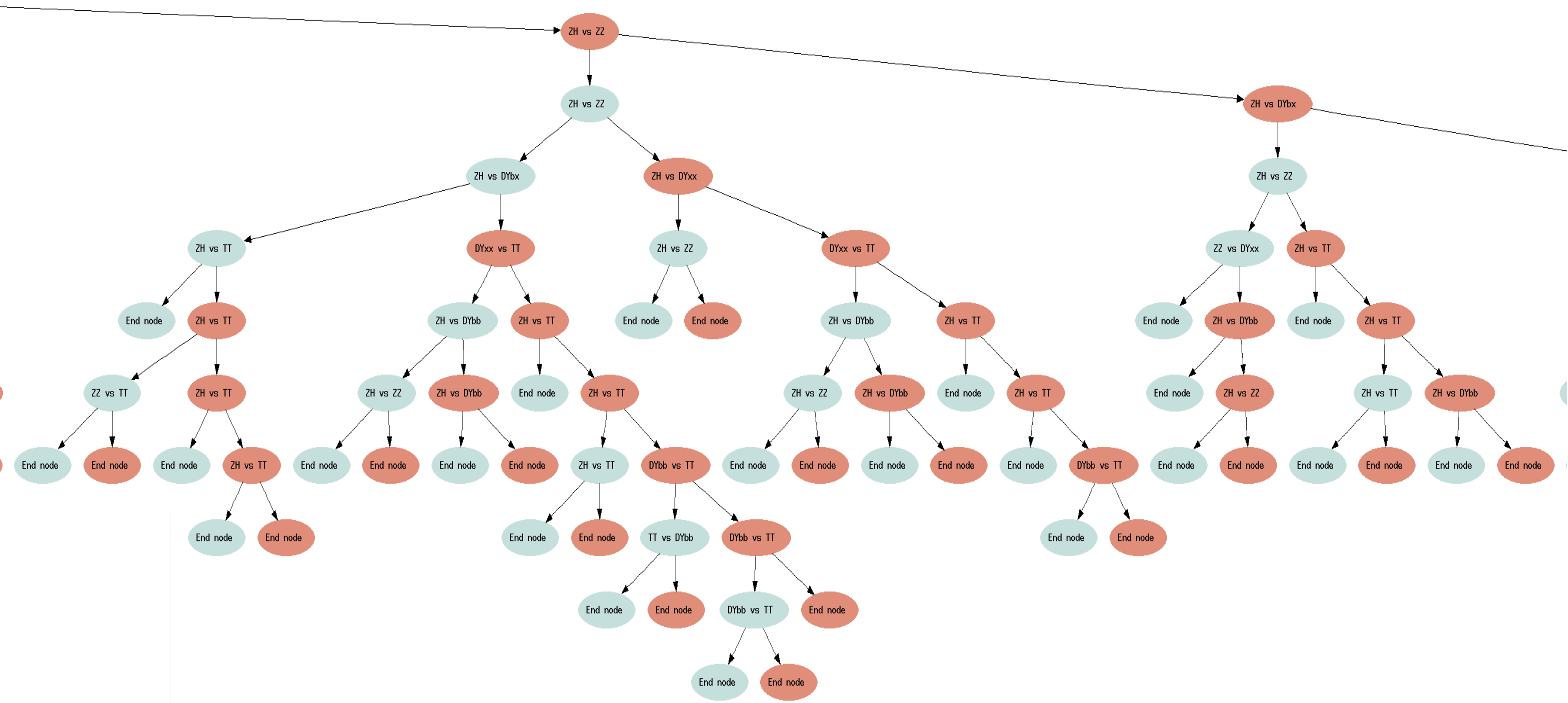
Tree for best configuration



Tree for best configuration



Tree for best configuration



Tree for best configuration