FRAGMENTATION UNCERTAINTIES ON HADRONIC TOP QUARK MASS MEASUREMENTS AND *IN-SITU* CALIBRATION OF FRAGMENTATION MODELS

1712.05801

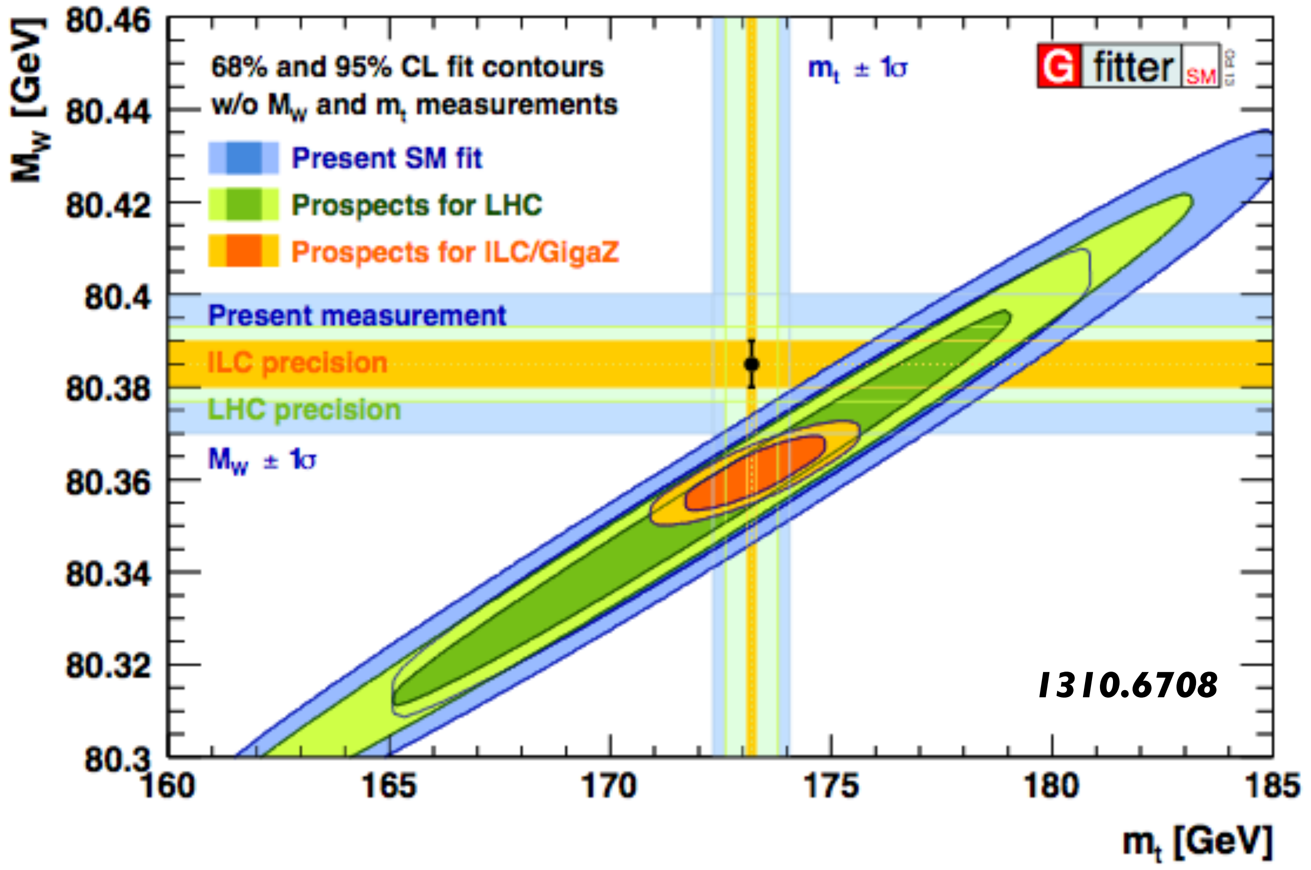
Roberto Franceschini (Rome 3 U.)
with G. Corcella (Frascati) and D. Kim (CERN)

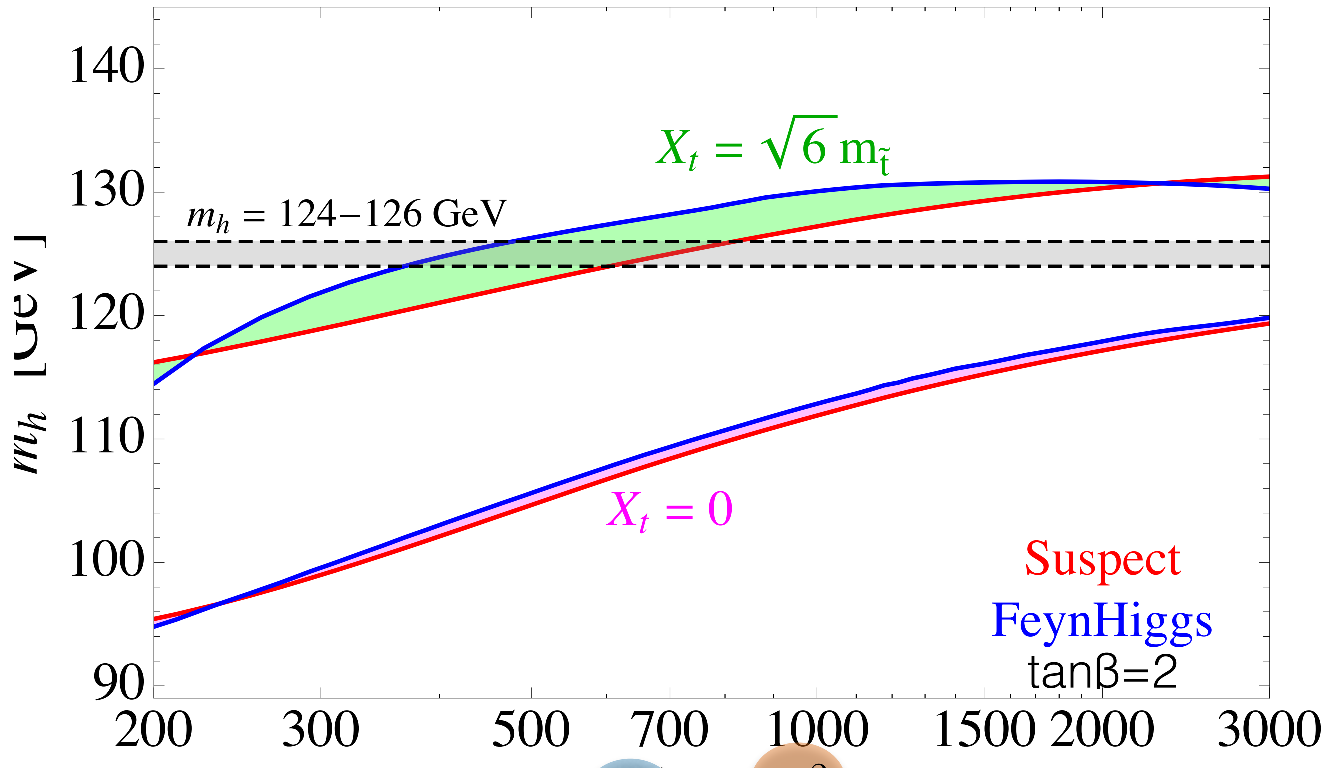
Universität Wien, April 10th 2018 - Teilchenphysikseminar

ROMA TRE UNIVERSITÀ DEGLI STUDI

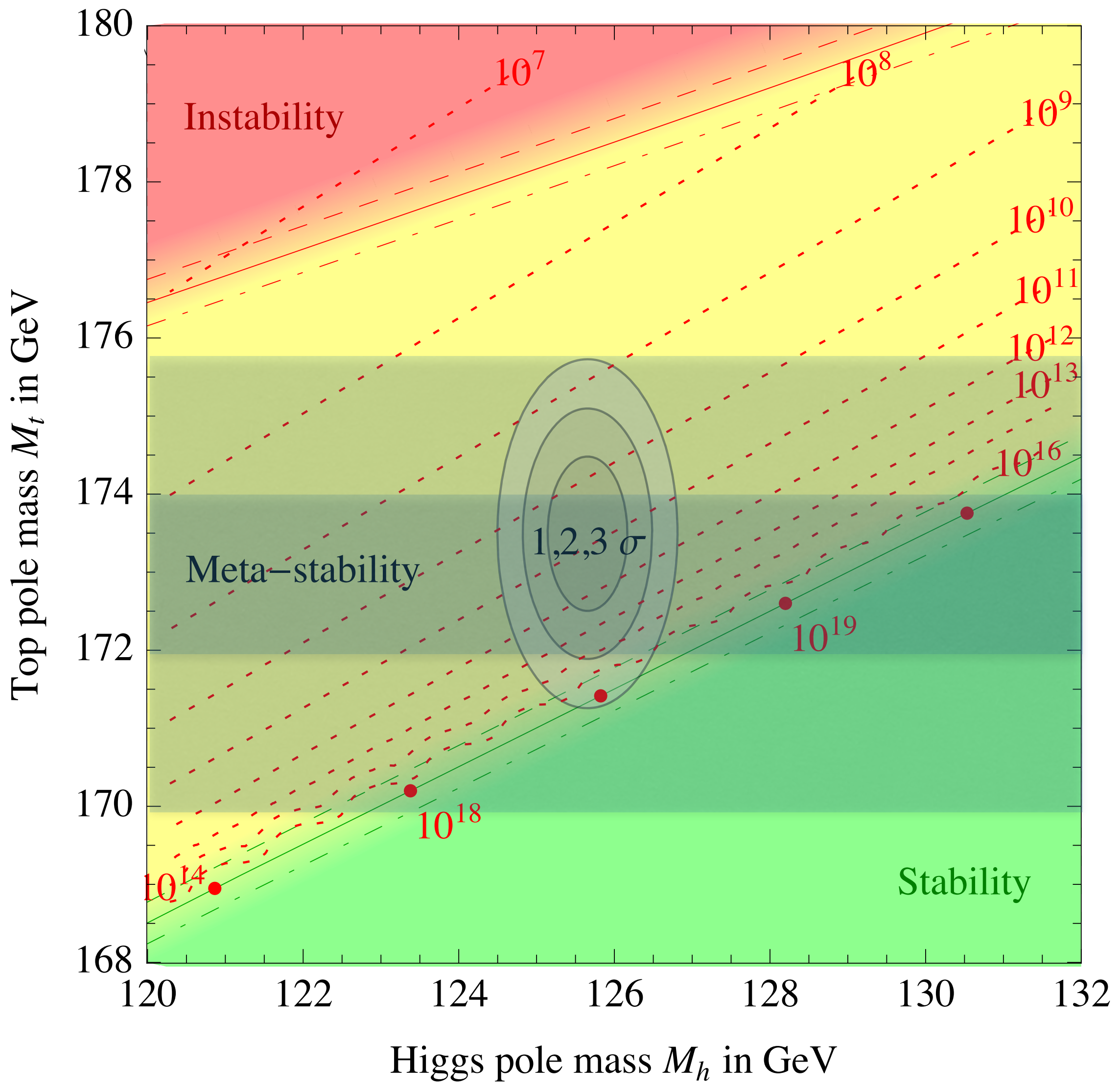
Rita Levi Montalcini

MOTIVATION TO STUDY TOP MASS

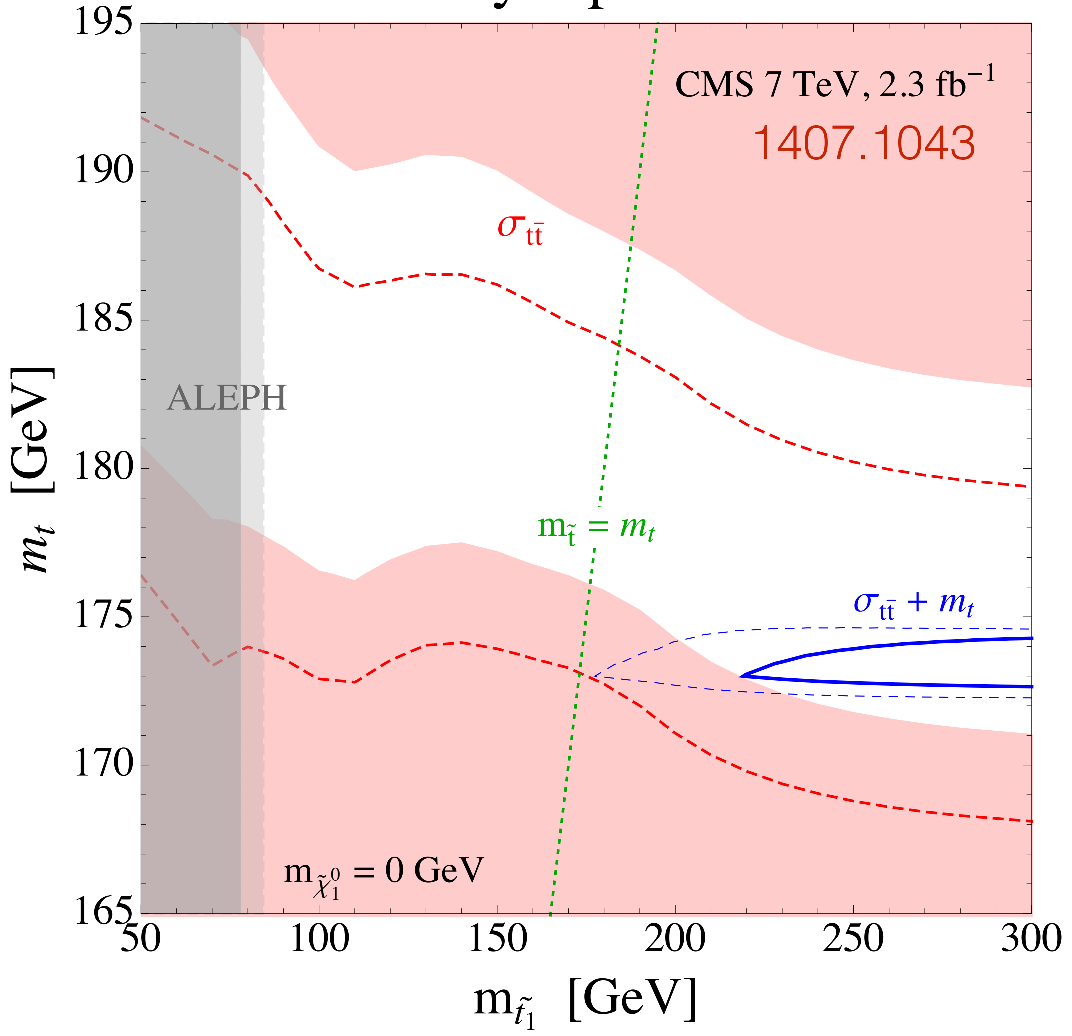




$$m_h^2 \approx m_Z^2 \cos^2 2\beta + \frac{3}{(4\pi)^2}\frac{m_t^4}{v^2}\left[\ln\frac{m_{\tilde{t}}^2}{m_t^2} + \frac{X_t^2}{m_{\tilde{t}}^2}\left(1 - \frac{X_t^2}{12 m_{\tilde{t}}^2}\right)\right]$$



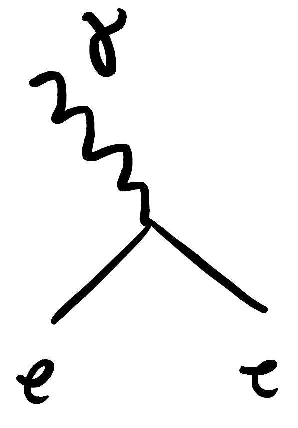
vary top mass



- Top is key to SM validity
- top-Higgs is the cornerstone of BSM!

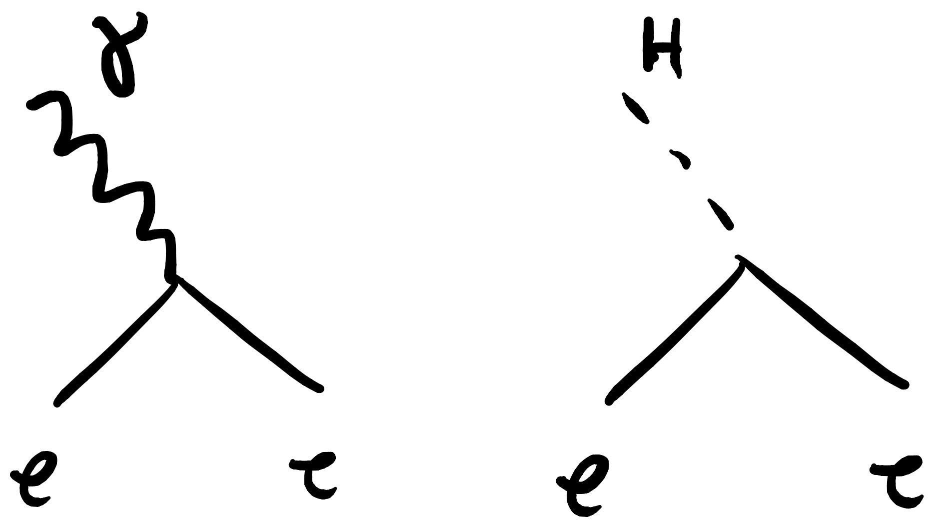
MOTIVATION TO STUDY TOP MASS

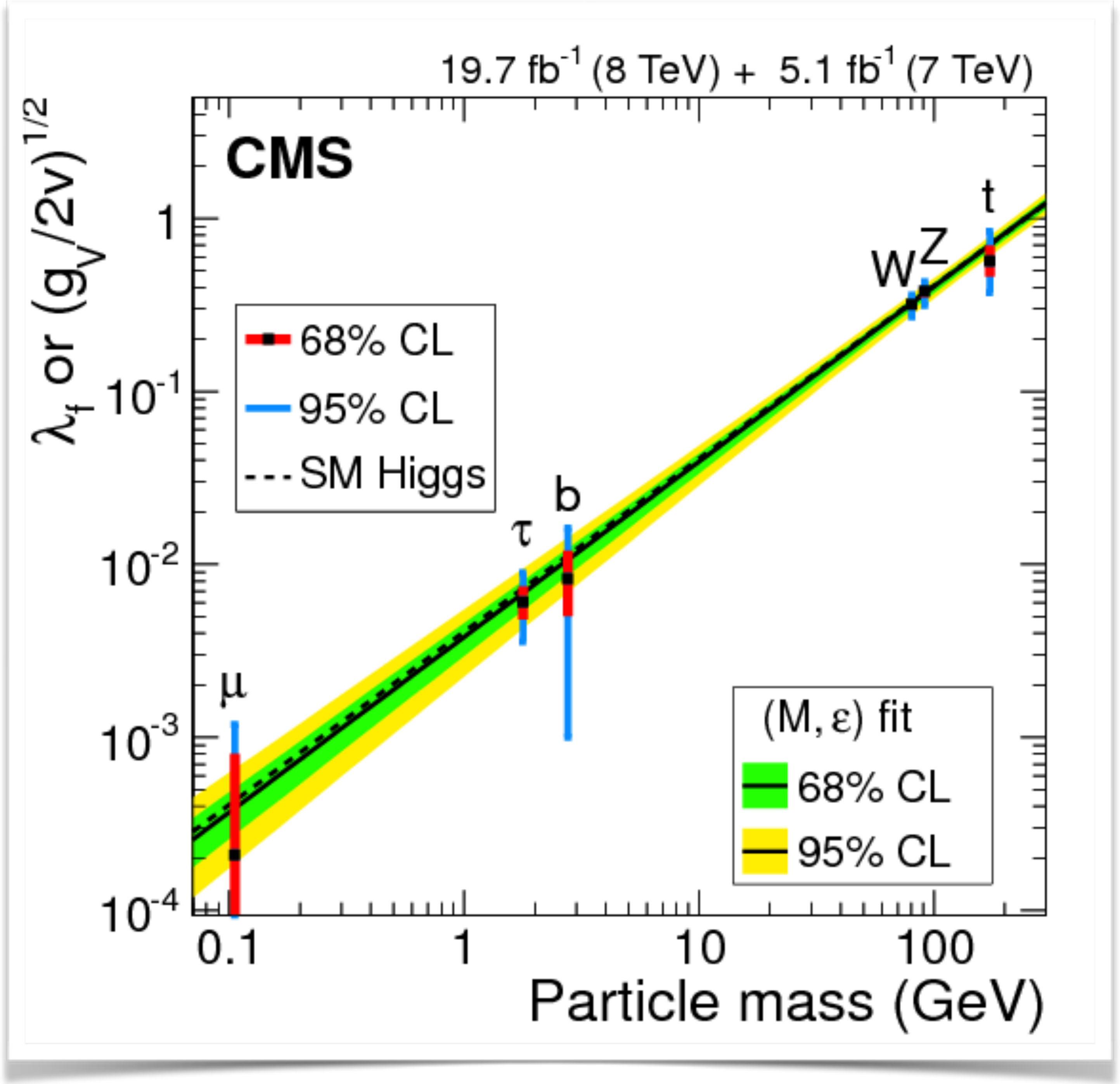
1930 - 2012



- A new fundamental interaction!

2012 -

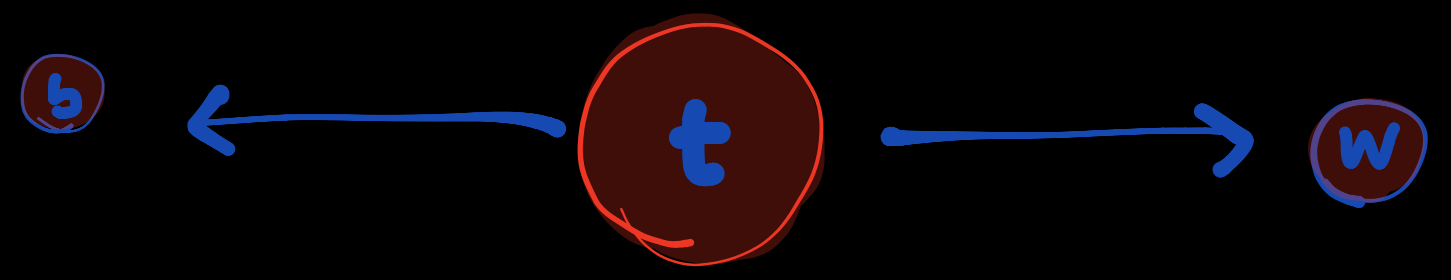




- Fundamental (?) Yukawas are the discovery of 21st century
- "Mass is an interaction with the Higgs" is the result of LHC Higgs discovery and measurements

INTERACTIONS ARE NOT 4-VECTORS

$$M = P_0$$



conservation of 4-momentum

$P(top) = \Sigma_i\ p_i$ $\quad$ i={leptons & hadrons}

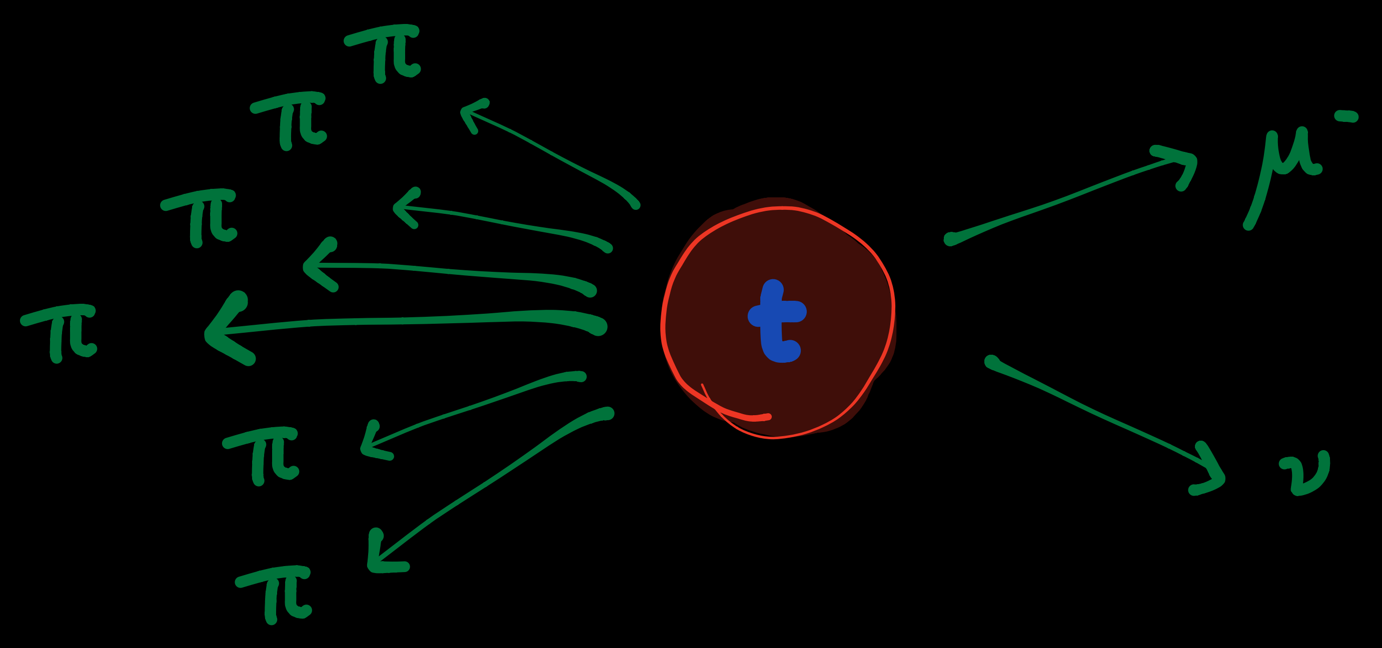
Power-corrections:

- hadronization
- interactions of the colliding protons
- Interaction with the underlying color field

Possible size of corrections around Λ_{QCD}

INTERACTIONS ARE NOT 4-VECTORS

$$M = P_0$$



conservation of 4-momentum

$P(top) = \Sigma_i\, p_i$ i={leptons & hadrons}

Power-corrections:

- hadronization
- interactions of the colliding protons
- Interaction with the underlying color field

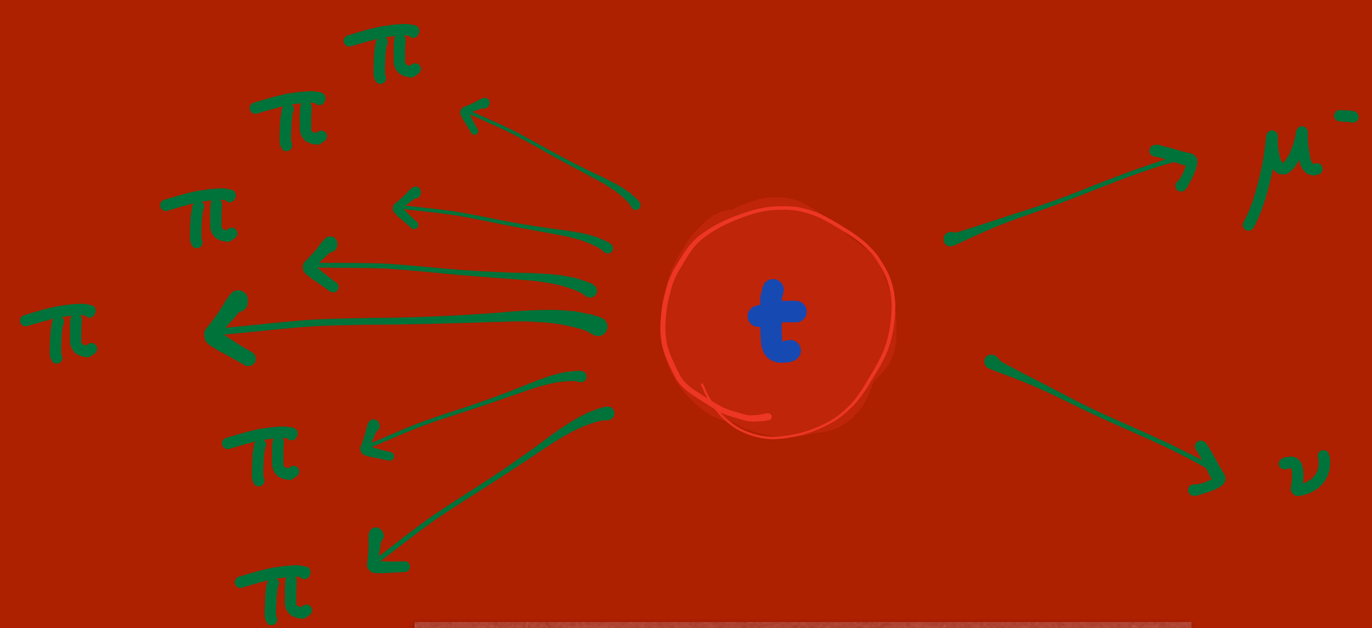
Possible size of corrections around Λ_{QCD}

INTERACTIONS ARE NOT 4-VECTORS

$$M = P_0$$

P=(M,0,0,0)

top → leptons and hadrons



- isolated colored particle

The truth is that the mass of particle exceeds this intuition.
It is like the **measurement of a coupling** in the Lagrangian

conservation of 4-momentum

$P(top) = \Sigma_i\, p_i$ i={leptons & hadrons}

$\Sigma\,(|p|, \overline{p}) \rightarrow (M,0,0,0)$

Power-corrections:

- hadronization
- interactions of the colliding protons
- Interaction with the underlying color field

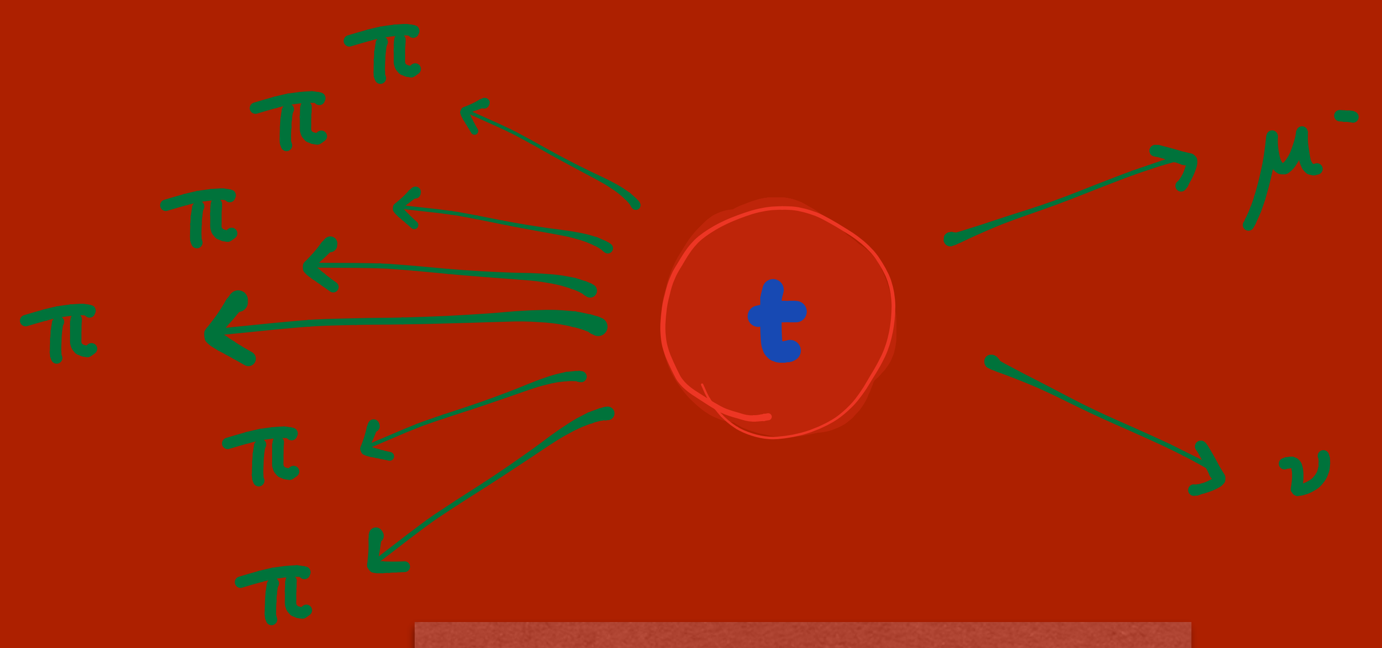
Possible size of corrections around Λ_{QCD}

INTERACTIONS ARE NOT 4-VECTORS

$$M = P_0$$

P=(M,0,0,0)

top → leptons and hadrons



- isolated colored particle

The truth is that the mass of particle exceeds this intuition.
It is like the **measurement of a coupling** in the Lagrangian

$Obs(m_{top}, g_3, \ldots)$

Power-corrections:

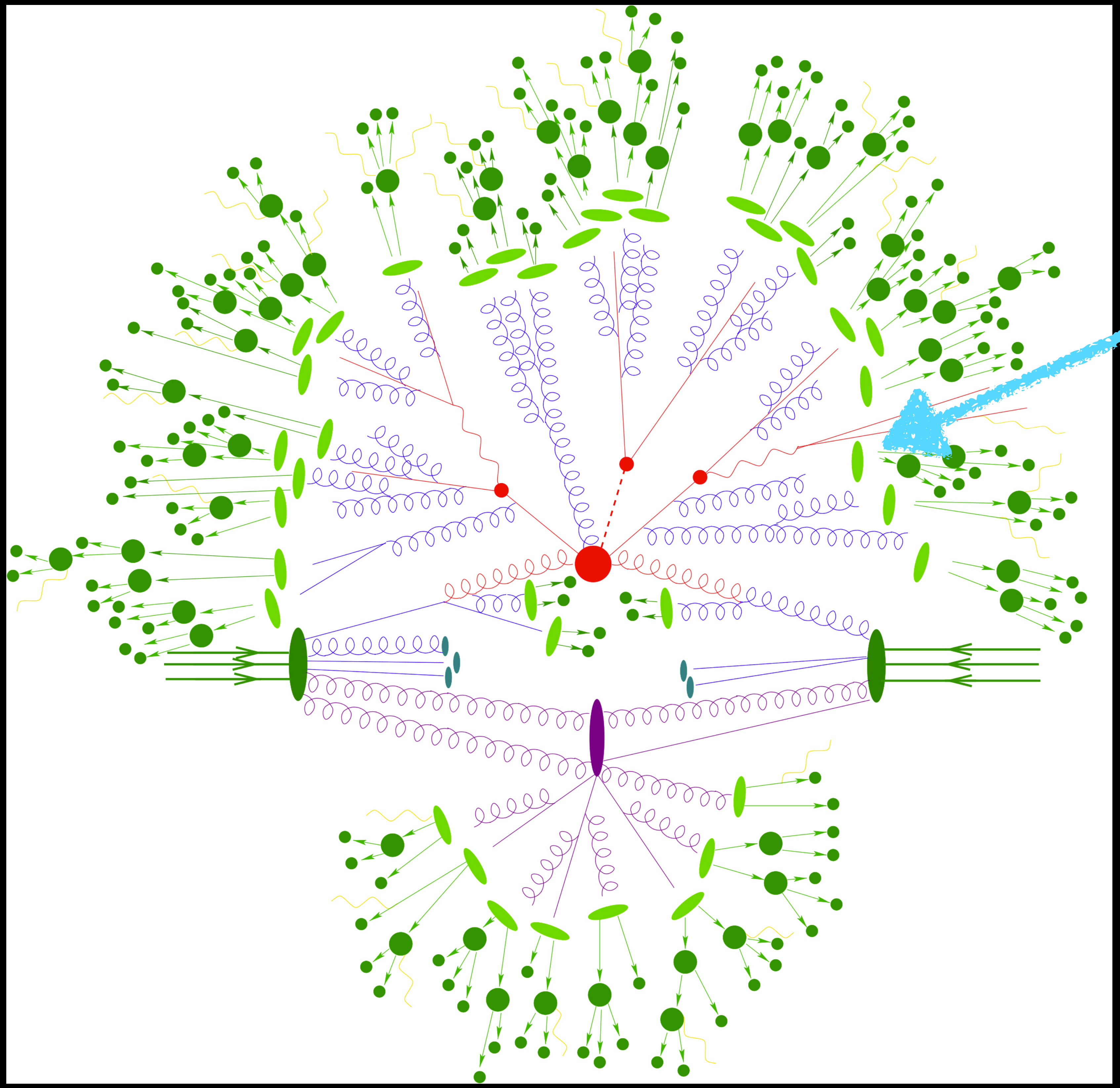
- hadronization
- interactions of the colliding protons
- Interaction with the underlying color field

Possible size of corrections around Λ_{QCD}

STATUS

MEASUREMENT AT $\lesssim$0.5%! ⇒ *PRECISION* QCD

EXPERIMENTAL PRECISION IS SYSTEMATICS LIMITED (JES, ..., HADRONIZATION)



Today's talk

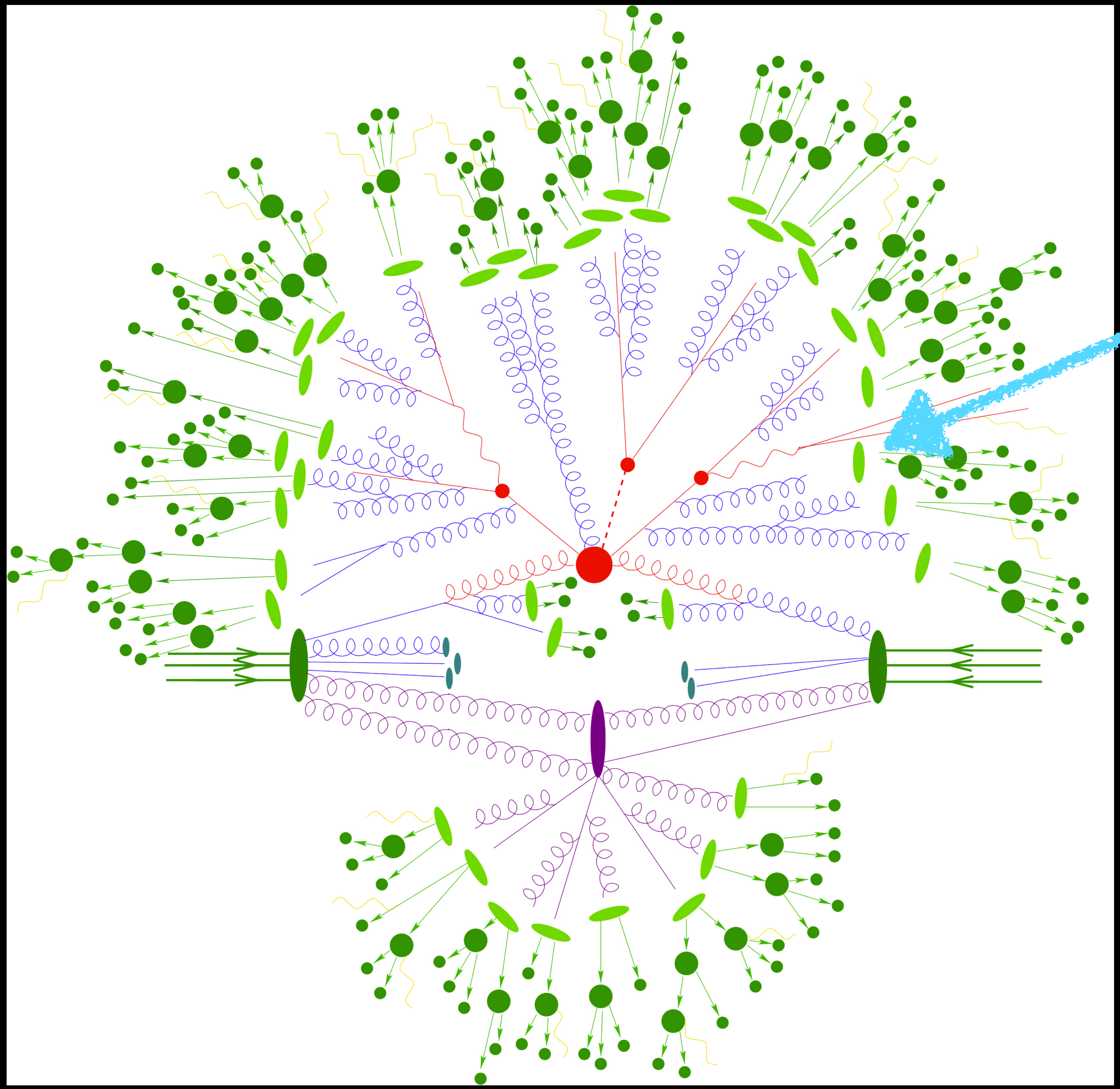
HOW WELL DO WE KNOW THESE NON-PERTURBATIVE EFFECTS

THE STRENGTH OF THE FUTURE LHC TOP MASS MEASUREMENT WILL BUILD ON THE **DIVERSITY OF METHODS** ⇒ NOT VERY USEFUL TO TALK ABOUT "*SINGLE BEST MEASUREMENT*"

STATUS

MEASUREMENT AT ≲0.5%! ⇒ *PRECISION* QCD

EXPERIMENTAL PRECISION IS SYSTEMATICS LIMITED (JES, …, HADRONIZATION)



Today's talk

WHAT IS THE CURRENT UNCERTAINTY FROM <u>HADRONIZATION MODELING</u>?

HOW PRECISELY WE NEED TO TUNE THE MODELS ON (TOP QUARK SPECIFIC) DATA?

CAN WE TUNE THE MODELS FROM DATA PRECISELY ENOUGH?

THE STRENGTH OF THE FUTURE LHC TOP MASS MEASUREMENT WILL BUILD ON THE **DIVERSITY OF METHODS** ⇒ NOT VERY USEFUL TO TALK ABOUT "*SINGLE BEST MEASUREMENT*"

BEYOND JETS

- Mass measurement methods using jets ⇒ Jet Energy Scale uncertainty

- Useful to look at mass measurement that do not have Jet Energy Scale uncertainty

PLENTY OF B-HADRON EVENTS AT LHC

$$N_{\mathrm{ev}} \sim 10^5 \frac{\mathcal{L}}{1/\mathrm{ab}} \frac{\epsilon_{\mathrm{tagging}}}{10^{-4}} \cdot \epsilon_{\mathrm{cuts}} \cdot BR(t\bar{t})$$

$\varepsilon_{\mathrm{tagging}}$

$B \to$ tracks + neutral

1603.06536

$B \to \ell + X$

0906.5371

L_{xy}

CMS-PAS-TOP-12-030

O(1)

$B \to$ tracks

$B \to J/\psi + X$

CMS-PAS-TOP-15-014

O(10^{-4})

BEYOND JETS

- Mass measurement methods using jets ⇒ Jet Energy Scale uncertainty
- Useful to look at mass measurement that do not have Jet Energy Scale uncertainty

PLENTY OF B-HADRON EVENTS AT LHC

$$N_{\rm ev} \sim 10^5 \frac{\mathcal{L}}{1/\text{ab}} \frac{\epsilon_{\rm tagging}}{10^{-4}} \cdot \epsilon_{\rm cuts} \cdot BR(t\bar{t})$$

$t \to \ell + X$ $\quad \varepsilon_{\text{tagging}} \sim O(1)$

$tt \to \ell^+ \ell^- + X$

$\varepsilon_{\text{tagging}}$

$B \to$ tracks + neutral

1603.06536

$B \to \ell + X$

0906.5371

L_{xy}

CMS-PAS-TOP-12-030

O(1)

$B \to$ tracks

$B \to J/\psi + X$

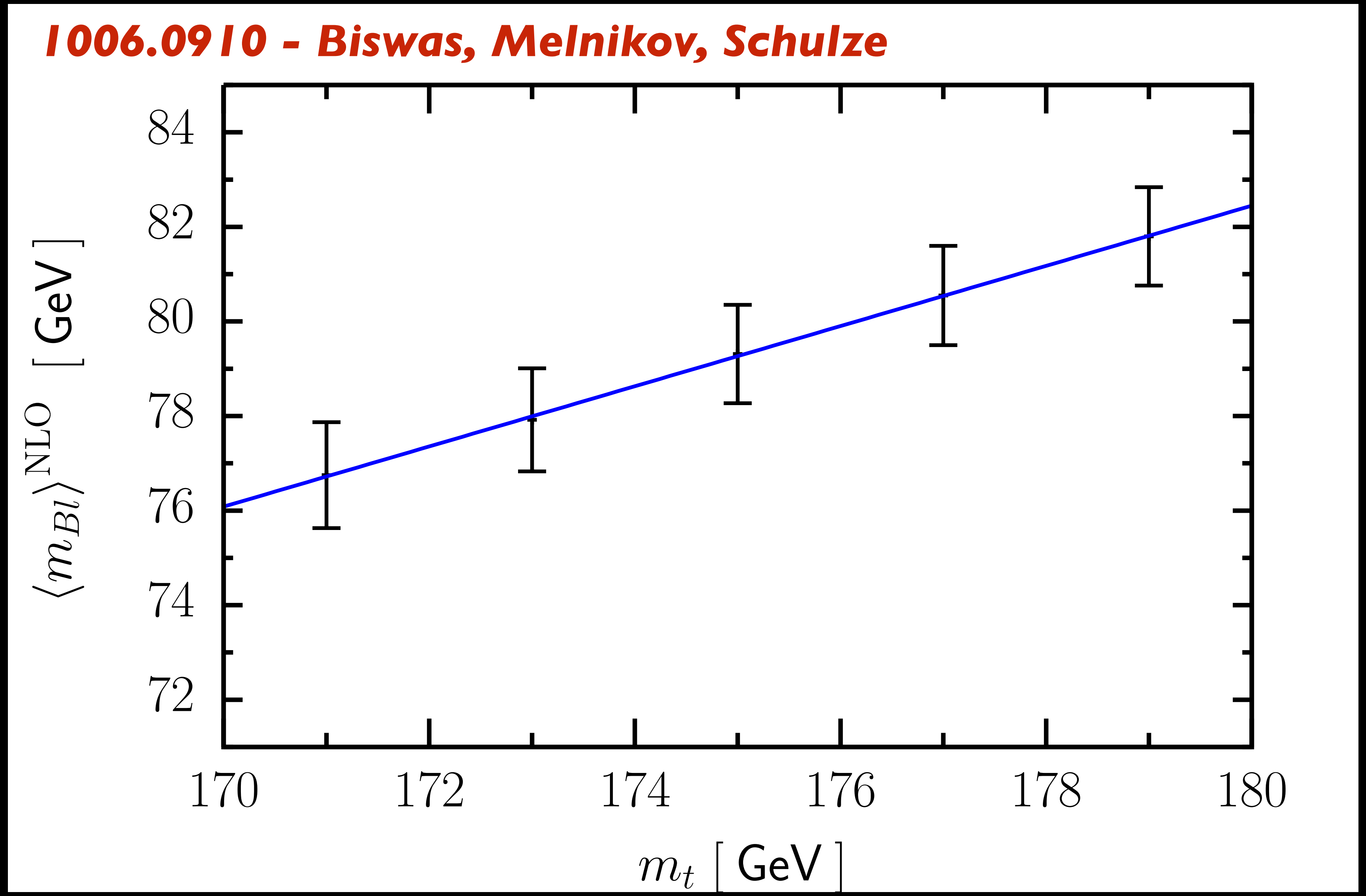
CMS-PAS-TOP-15-014

$O(10^{-4})$

HADRON SPECTRUM

FROM FRAGMENTATION FUNCTIONS

pp → $t\bar{t}$ ⊗ NLO fragmentation function



Maybe NNLO ⊗ fragmentation functions

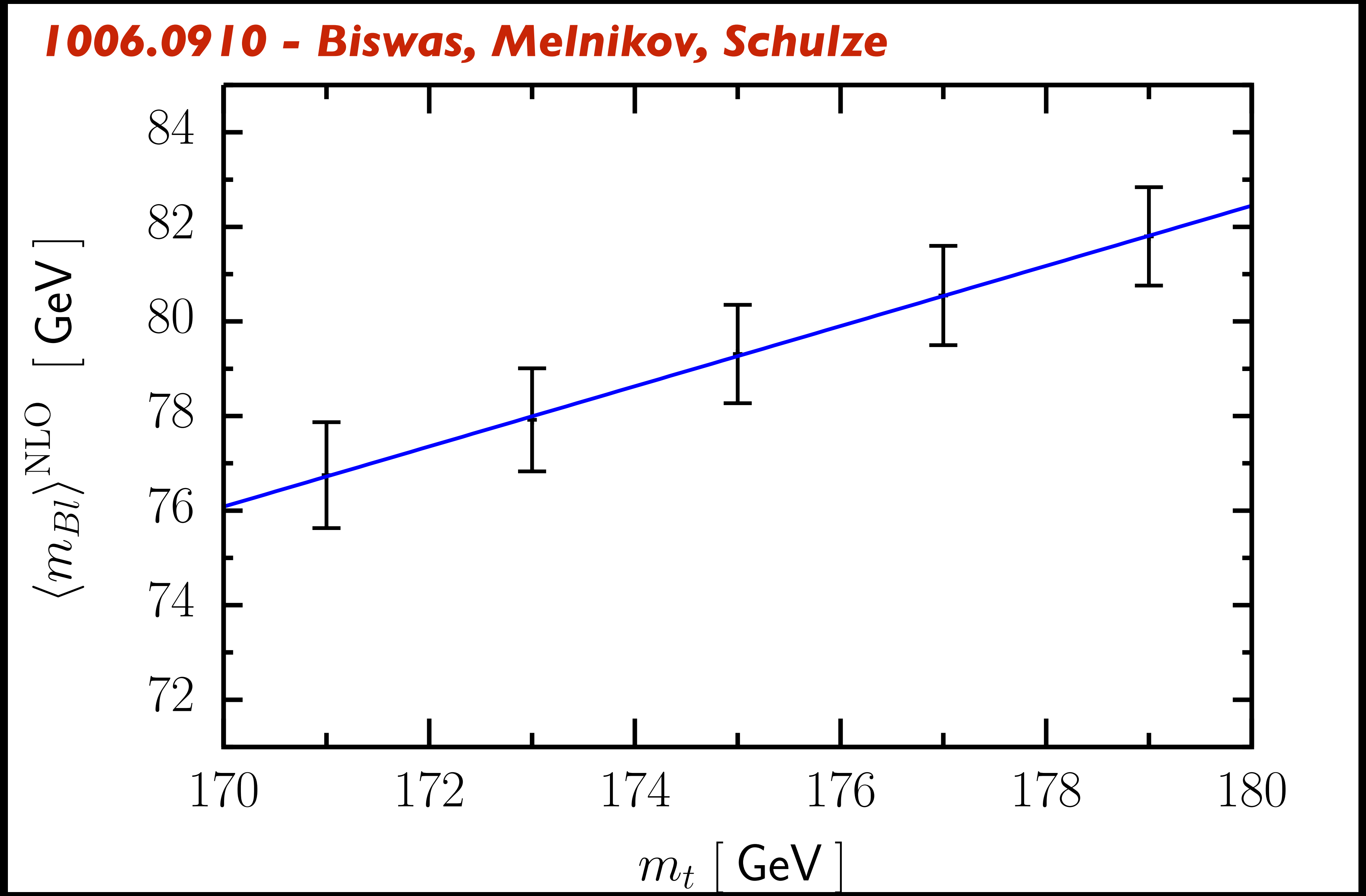
1606.07737

Most likely N^{3}LO ⊗ fragmentation functions

HADRON SPECTRUM

FROM FRAGMENTATION FUNCTIONS

pp → $t\bar{t}$ ⊗ NLO fragmentation function



NLO sensitive to the scale choice: ±1.8 GeV on m_{top}

Maybe NNLO ⊗ fragmentation functions

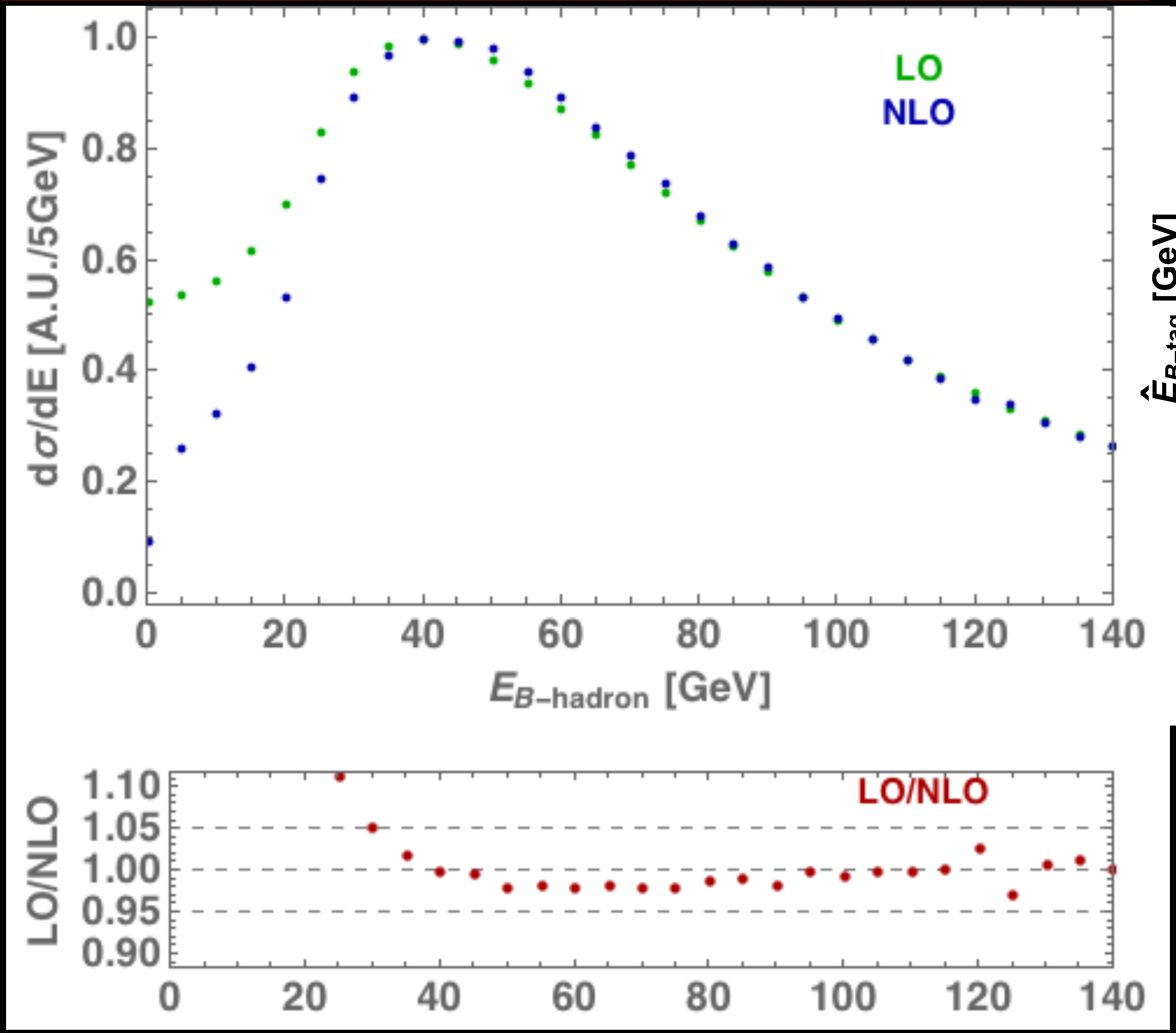
1606.07737

Most likely N^{3}LO ⊗ fragmentation functions

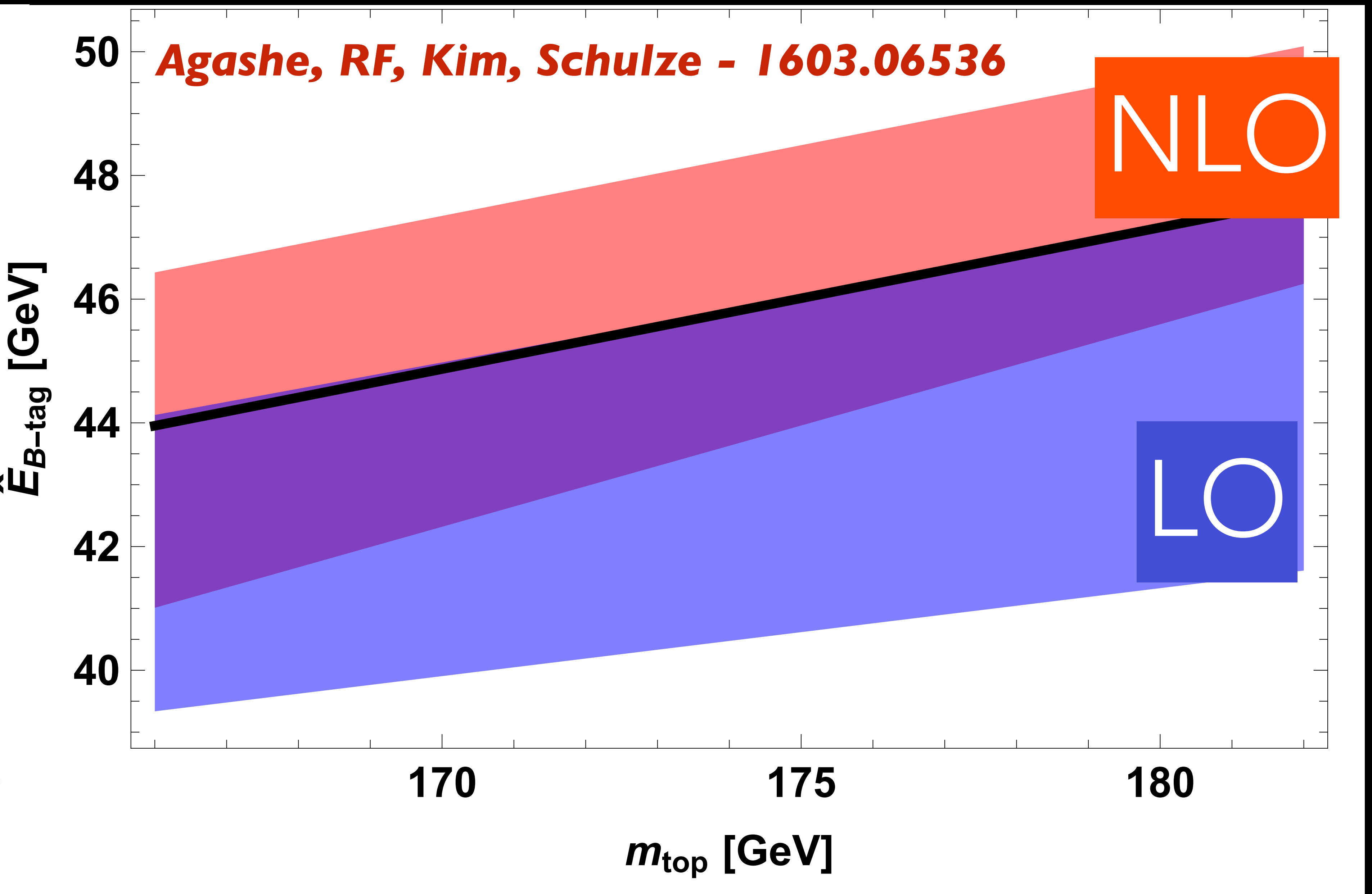
HADRON SPECTRUM

FROM FRAGMENTATION FUNCTIONS

pp → $t\bar{t}$ ⊗ NLO fragmentation function



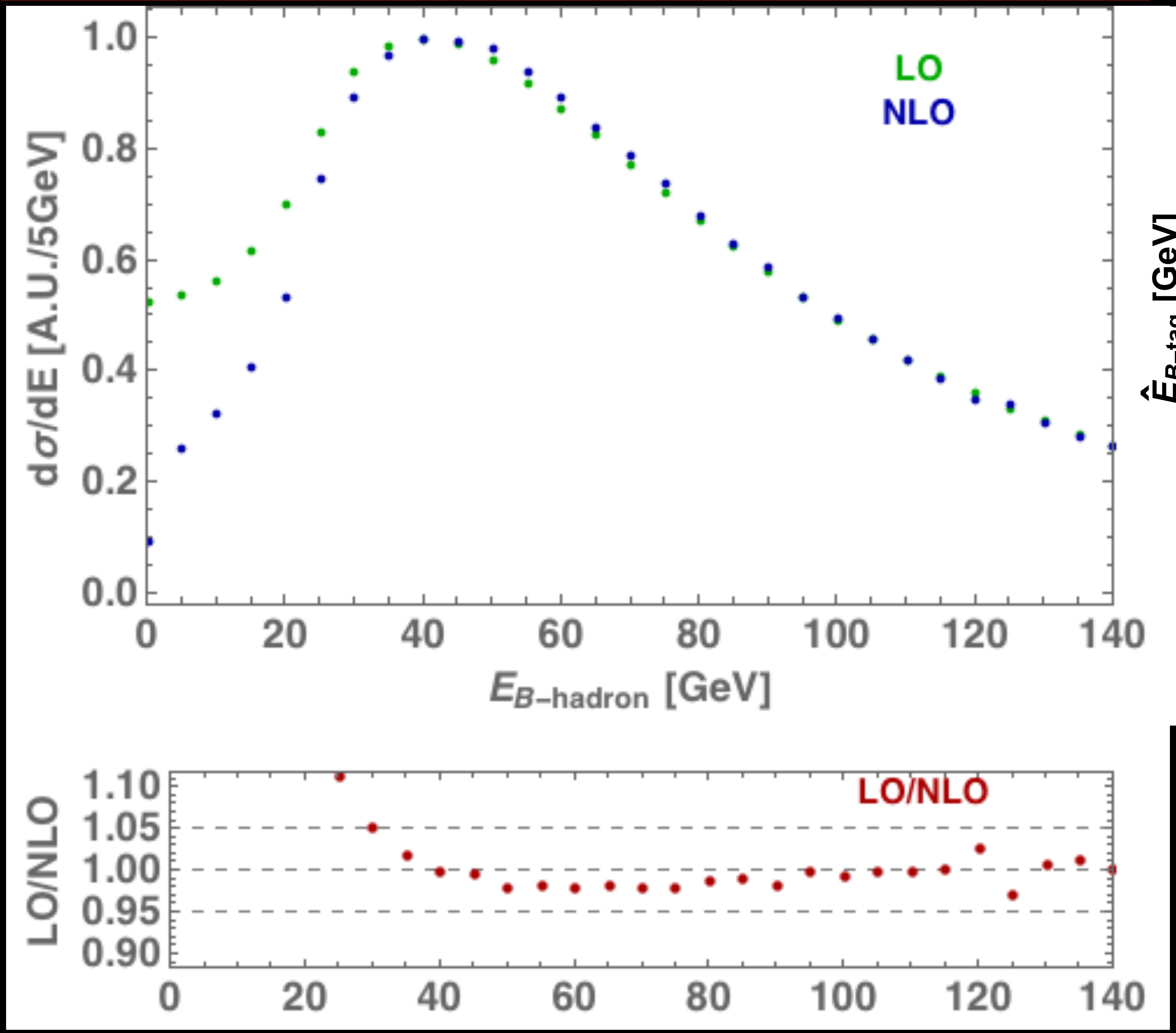
dominated by fragmentation scale



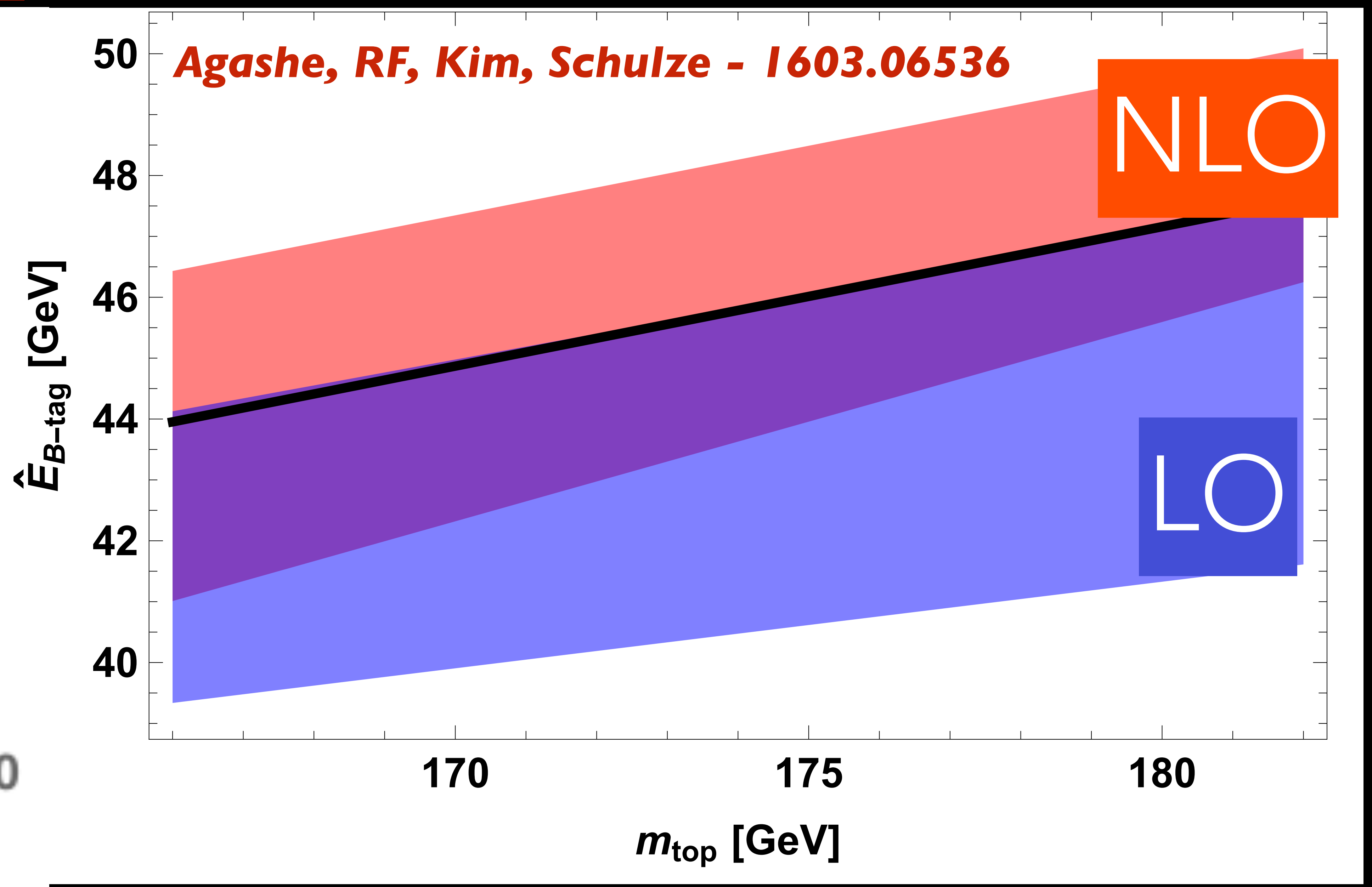
HADRON SPECTRUM

FROM FRAGMENTATION FUNCTIONS

pp → $t\bar{t}$ ⊗ NLO fragmentation function



dominated by fragmentation scale

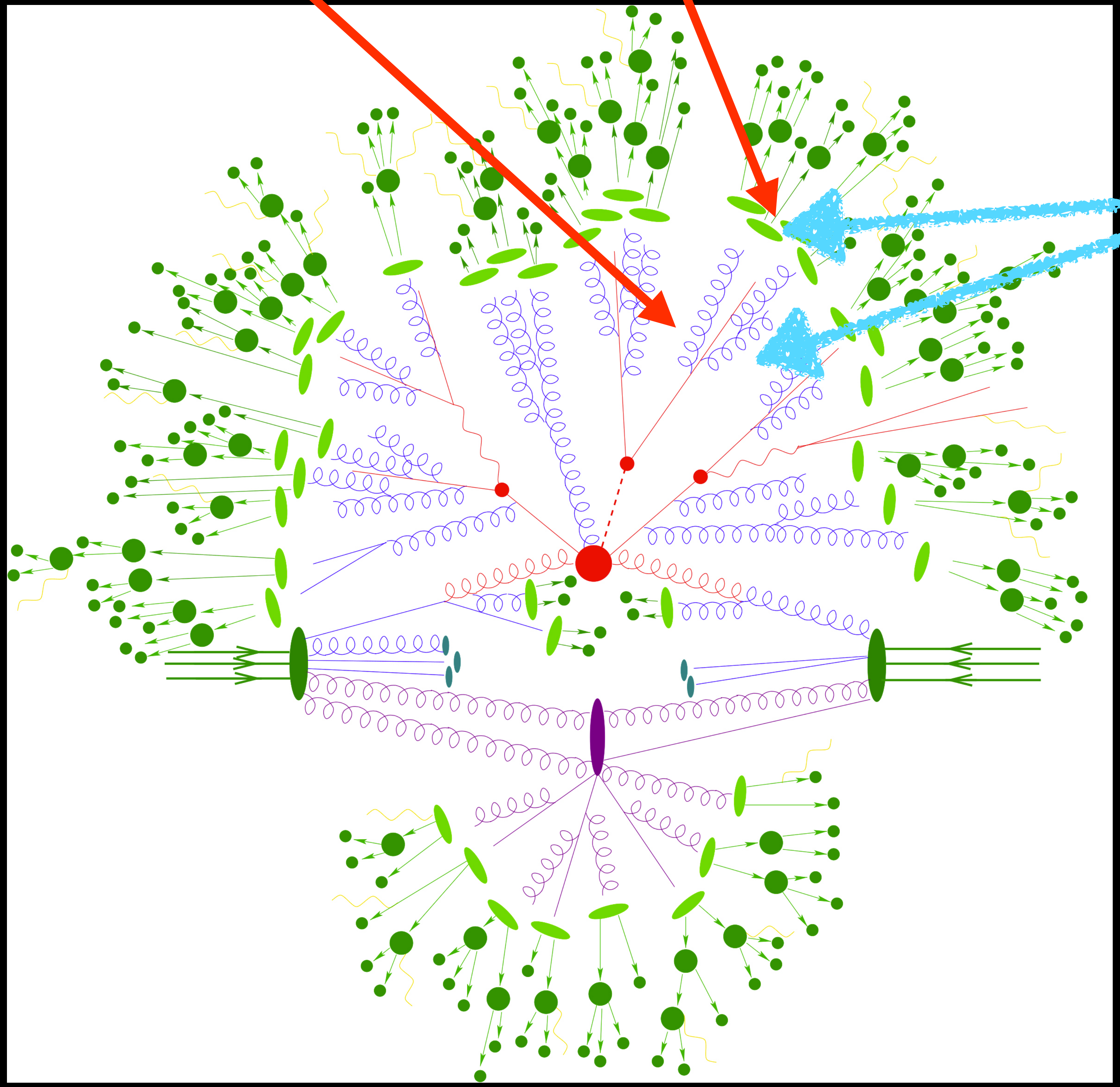


NLO sensitive to the scale choice: ±3.5 GeV on m_{top}

HADRON SPECTRUM

FROM MONTE CARLO EVENT GENERATORS

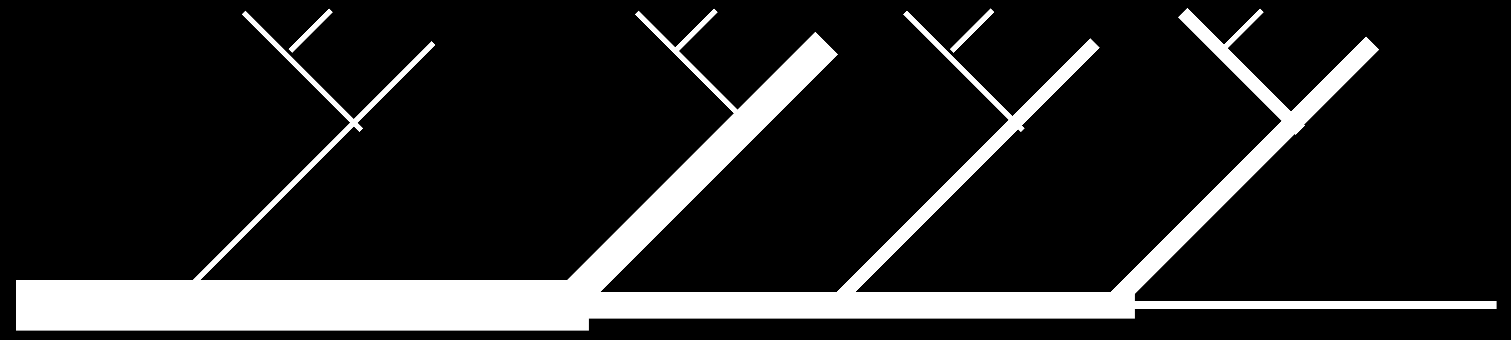
pp → $t\bar{t}$ @ NLO ⊗ Parton Shower + Non-Perturabtive Models



Today's talk

EVENT GENERATORS

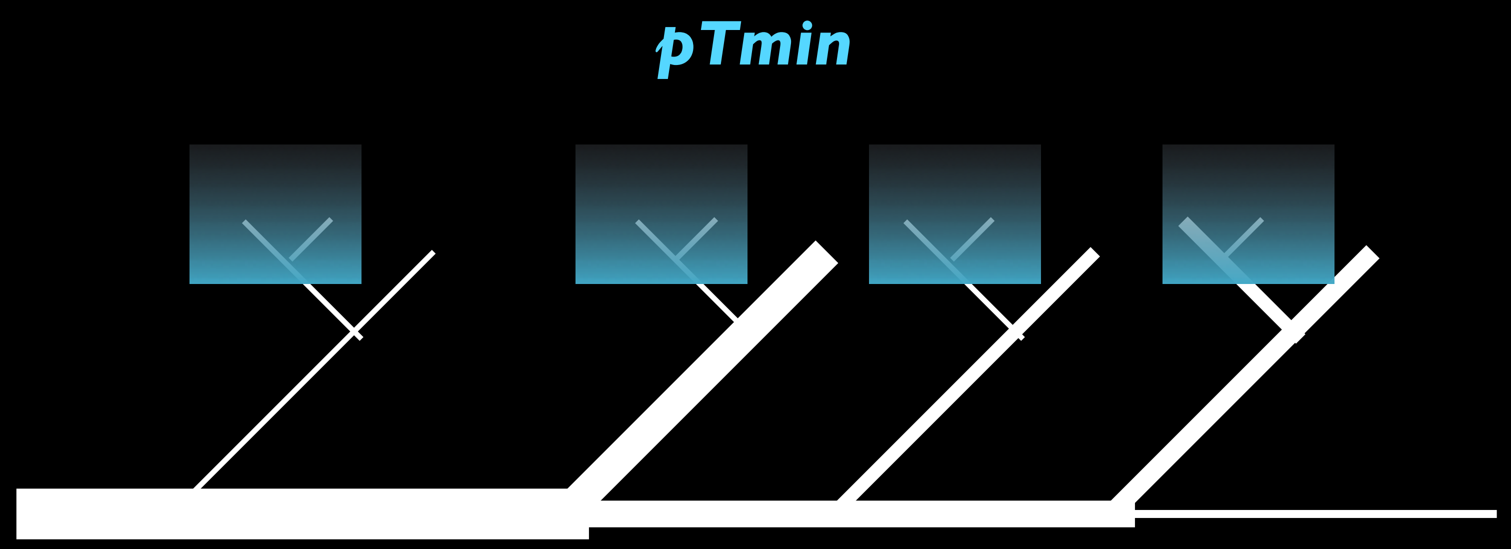
PYTHIA PARAMETERS



	Pythia8 parameter	range	Monash default
$p_{T,\mathrm{min}}$	TimeShower:pTmin	0.25-1.00 GeV	0.5
$\alpha_{s,\mathrm{FSR}}$	TimeShower:alphaSvalue	0.1092 - 0.1638	0.1365
recoil	TimeShower:recoilToColoured	*on* and *off*	*on*
b quark mass	5:m0	3.8-5.8 GeV	4.8 GeV
Bowler's r_B	StringZ:rFactB	0.713-0.813	0.855
string model a	StringZ:aNonstandardB	0.54-0.82	0.68
string model b	StringZ:bNonstandardB	0.78-1.18	0.98

EVENT GENERATORS

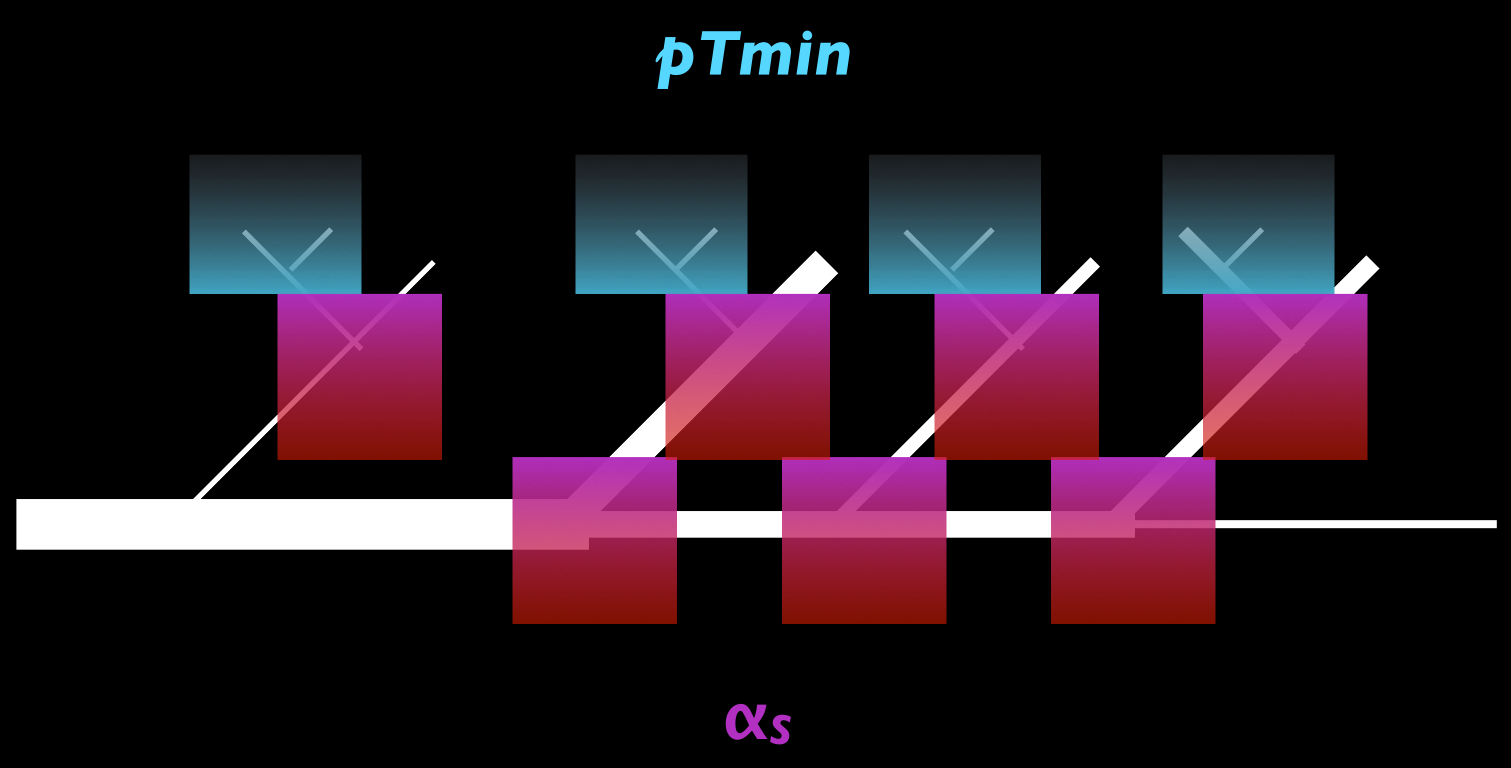
PYTHIA PARAMETERS



	PYTHIA8 parameter	range	Monash default
$p_{T,\mathrm{min}}$	TimeShower:pTmin	0.25-1.00 GeV	0.5
$\alpha_{s,\mathrm{FSR}}$	TimeShower:alphaSvalue	0.1092 - 0.1638	0.1365
recoil	TimeShower:recoilToColoured	*on* and *off*	*on*
b quark mass	5:m0	3.8-5.8 GeV	4.8 GeV
Bowler's r_B	StringZ:rFactB	0.713-0.813	0.855
string model a	StringZ:aNonstandardB	0.54-0.82	0.68
string model b	StringZ:bNonstandardB	0.78-1.18	0.98

EVENT GENERATORS

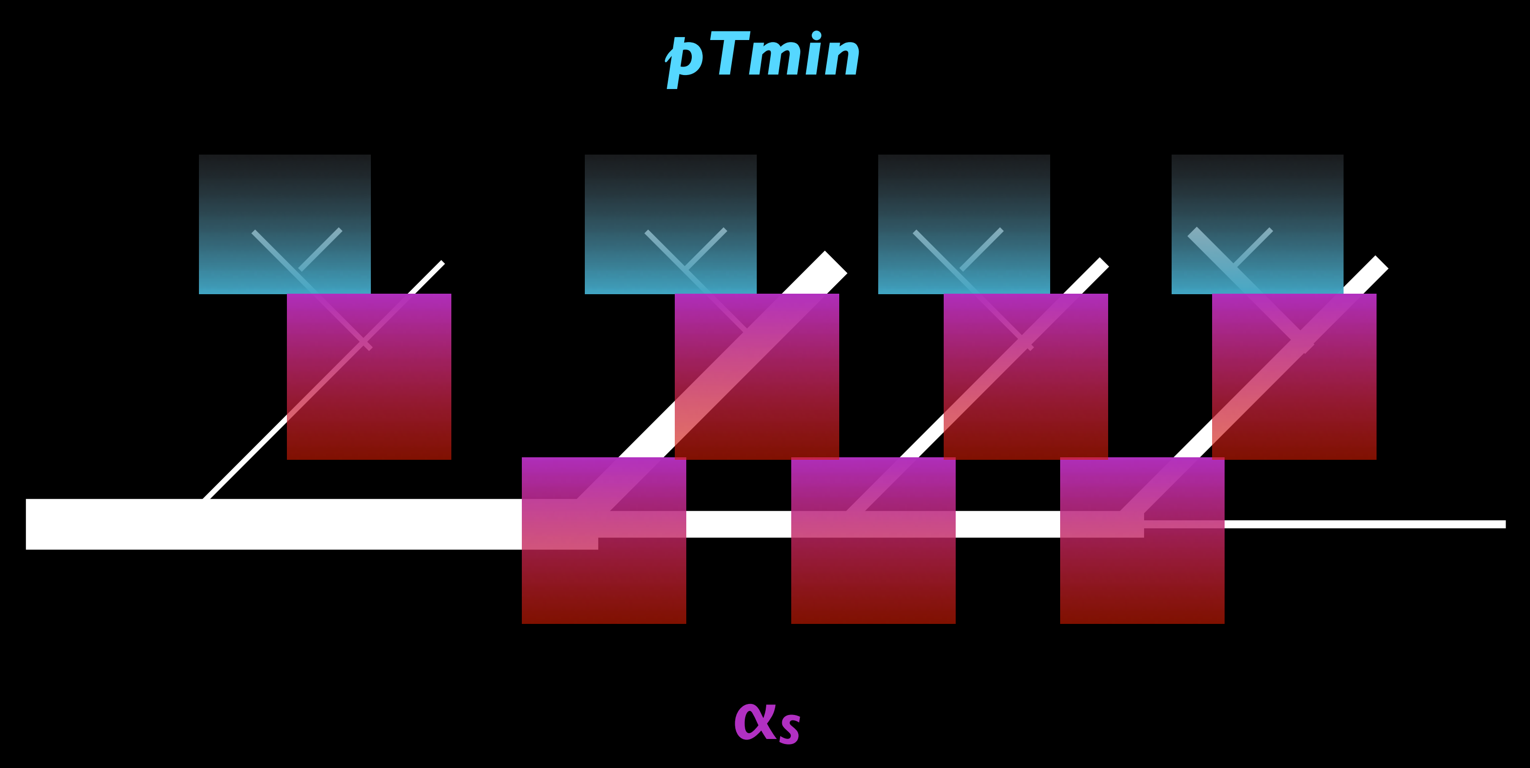
PYTHIA PARAMETERS



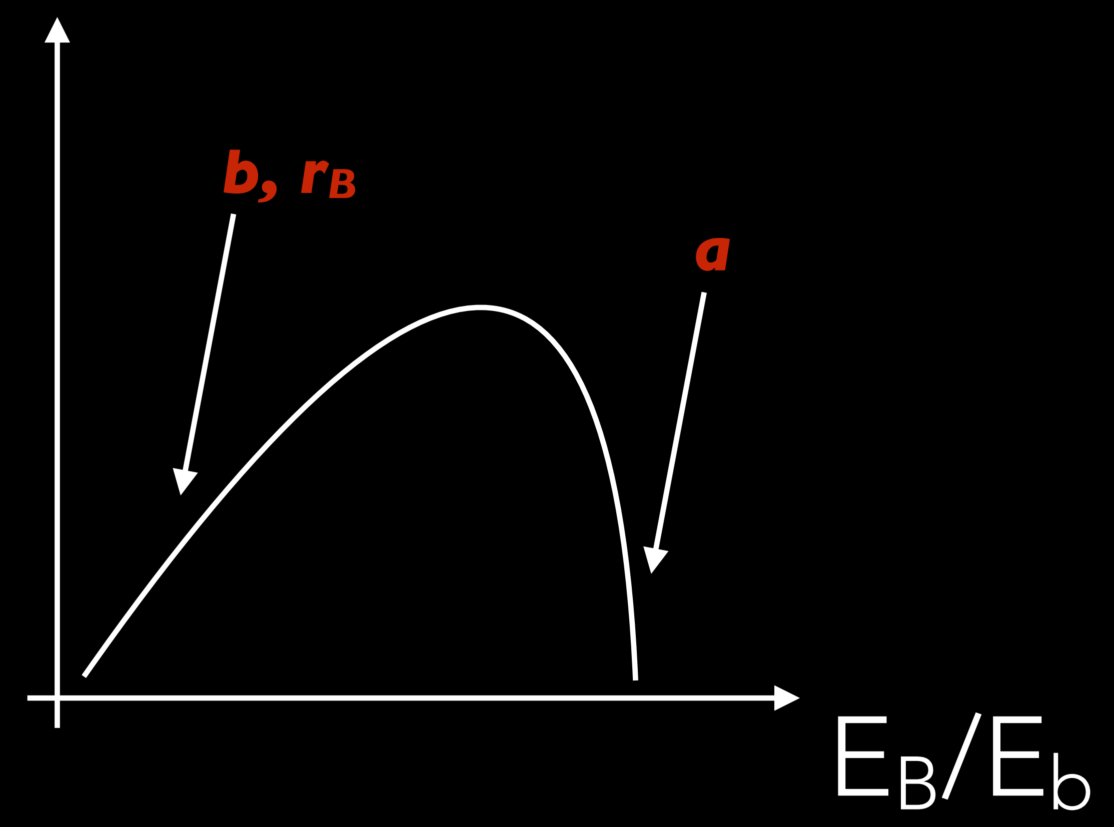
	PYTHIA8 parameter	range	Monash default
$p_{T,\min}$	TimeShower:pTmin	0.25-1.00 GeV	0.5
$\alpha_{s,\mathrm{FSR}}$	TimeShower:alphaSvalue	0.1092 - 0.1638	0.1365
recoil	TimeShower:recoilToColoured	*on* and *off*	*on*
b quark mass	5:m0	3.8-5.8 GeV	4.8 GeV
Bowler's r_B	StringZ:rFactB	0.713-0.813	0.855
string model a	StringZ:aNonstandardB	0.54-0.82	0.68
string model b	StringZ:bNonstandardB	0.78-1.18	0.98

EVENT GENERATORS

PYTHIA PARAMETERS

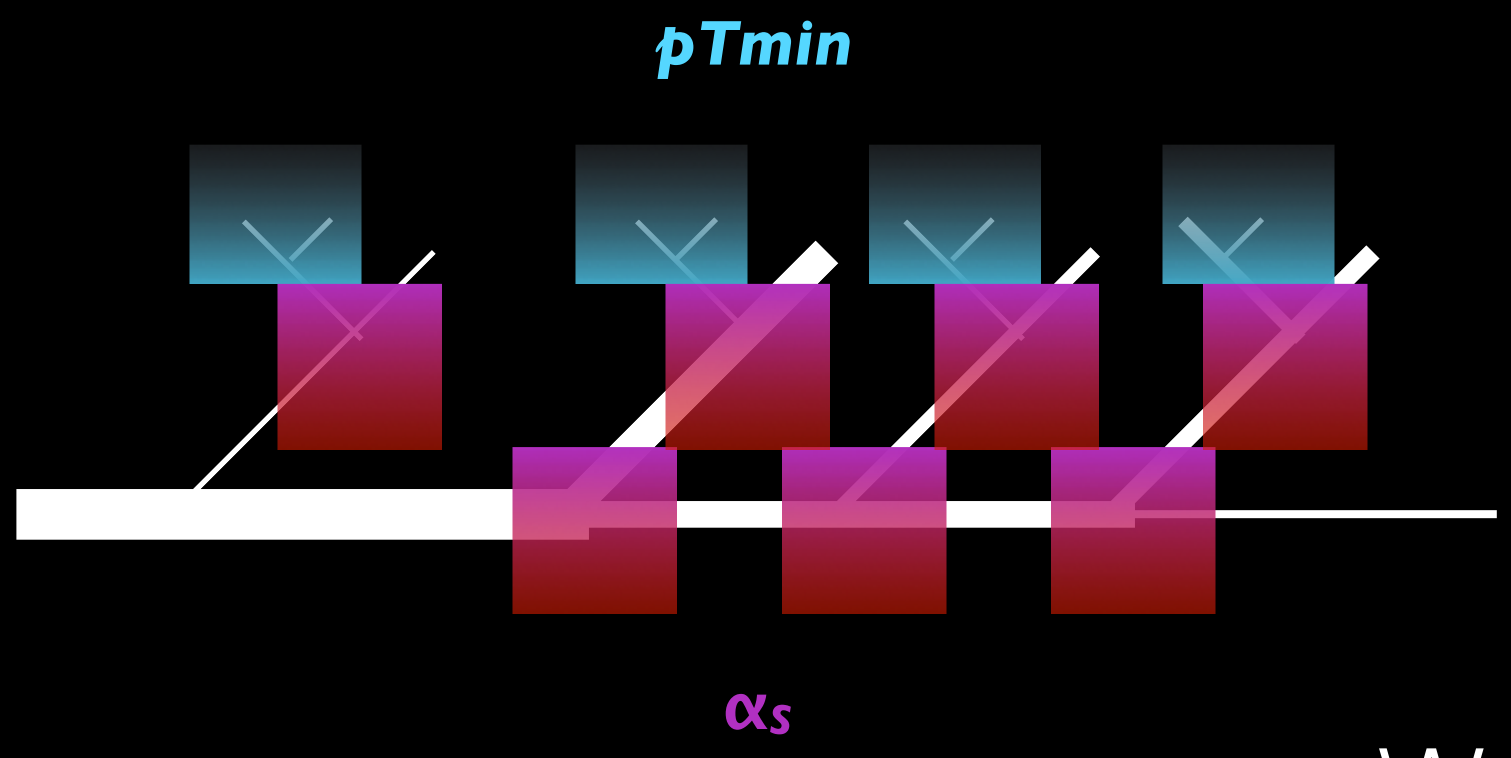


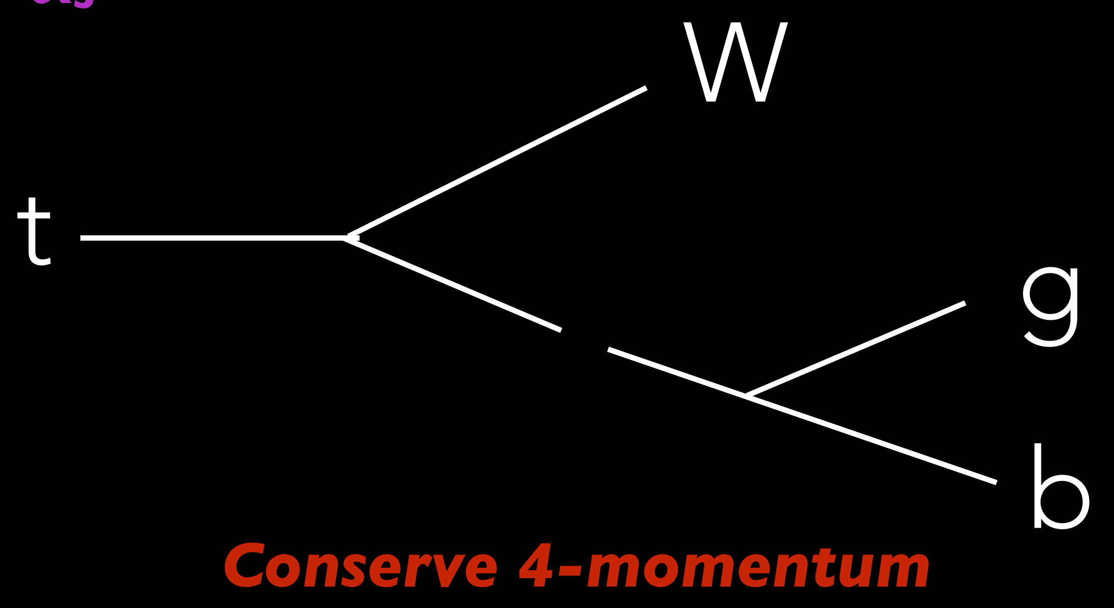
	PYTHIA8 parameter	range	Monash default
$p_{T,\mathrm{min}}$	TIMESHOWER:PTMIN	0.25-1.00 GeV	0.5
$\alpha_{s,\mathrm{FSR}}$	TIMESHOWER:ALPHASVALUE	0.1092 - 0.1638	0.1365
recoil	TIMESHOWER:RECOILTOCOLOURED	*on* and *off*	*on*
b quark mass	5:M0	3.8-5.8 GeV	4.8 GeV
Bowler's r_B	STRINGZ:RFACTB	0.713-0.813	0.855
string model a	STRINGZ:ANONSTANDARDB	0.54-0.82	0.68
string model b	STRINGZ:BNONSTANDARDB	0.78-1.18	0.98

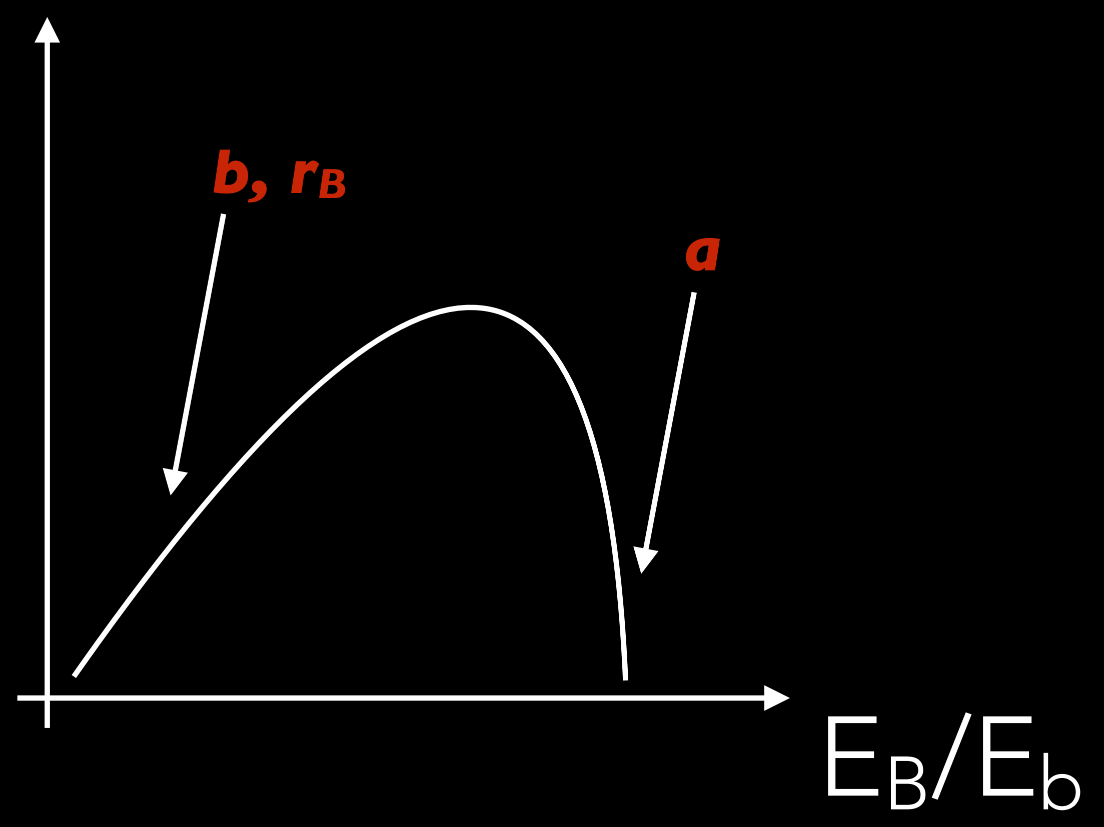


EVENT GENERATORS

PYTHIA PARAMETERS



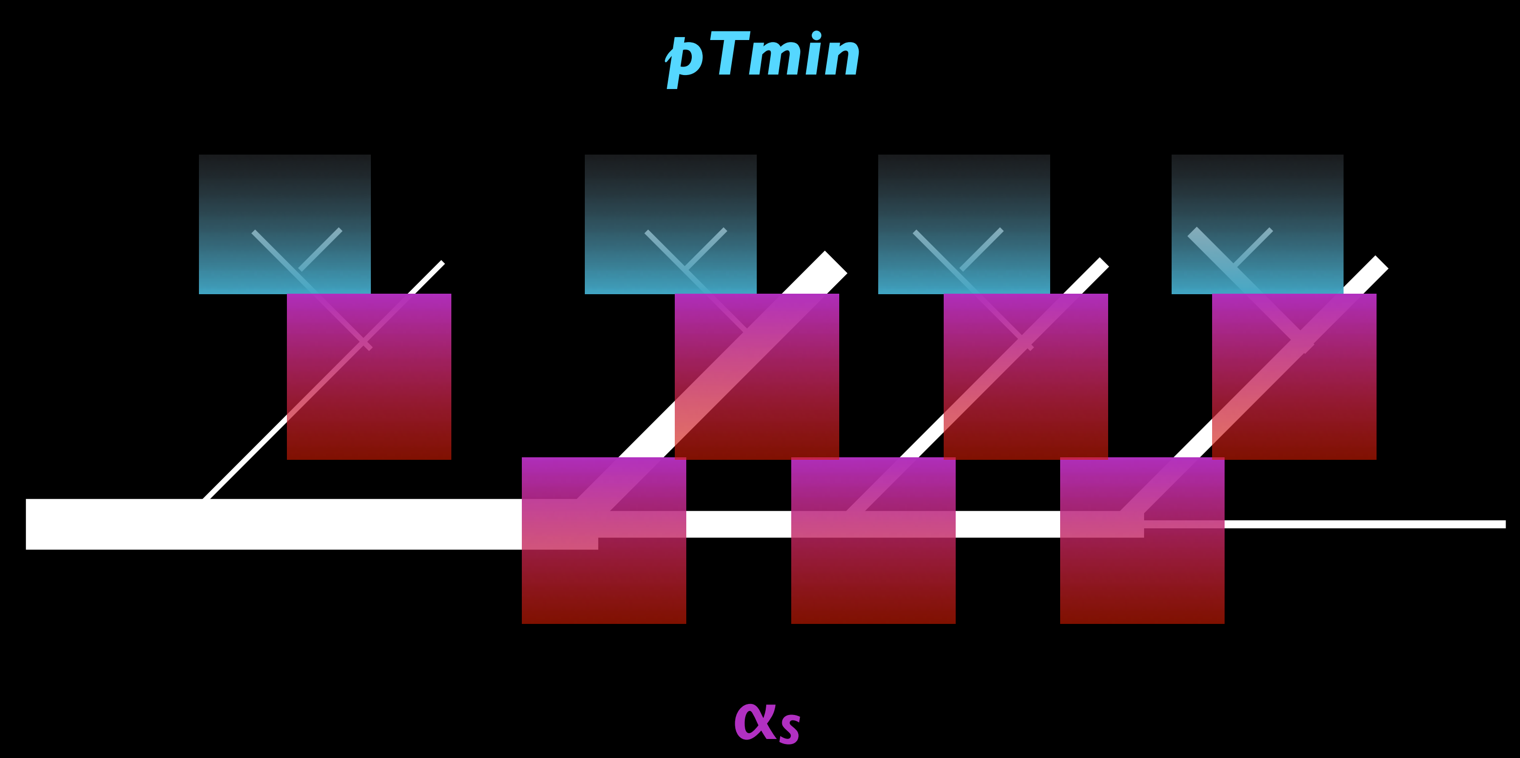


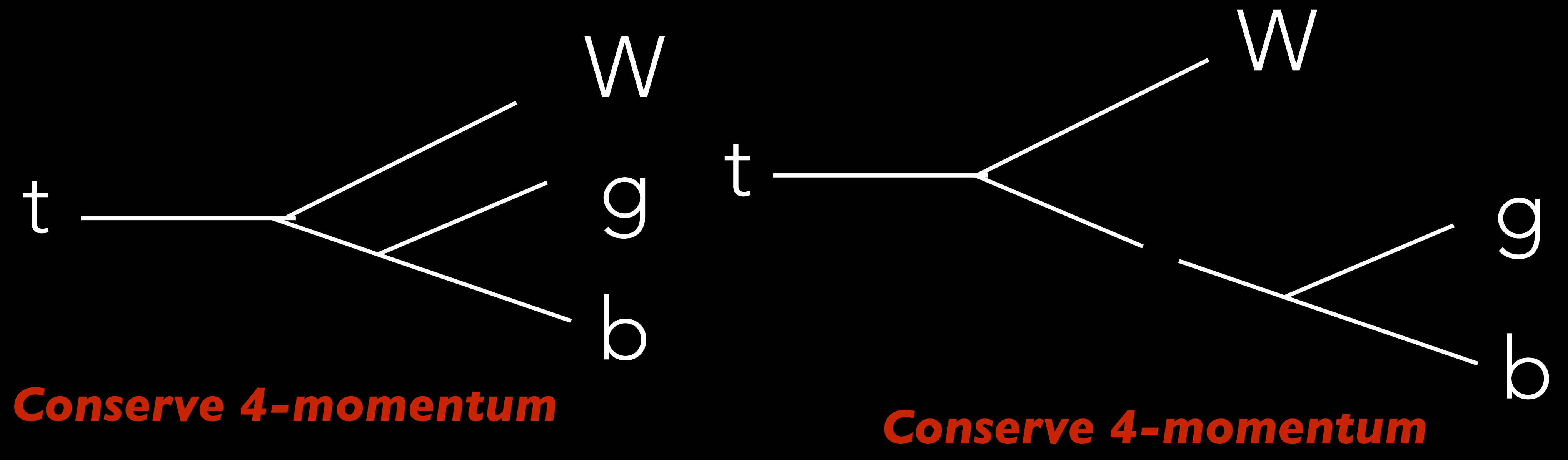


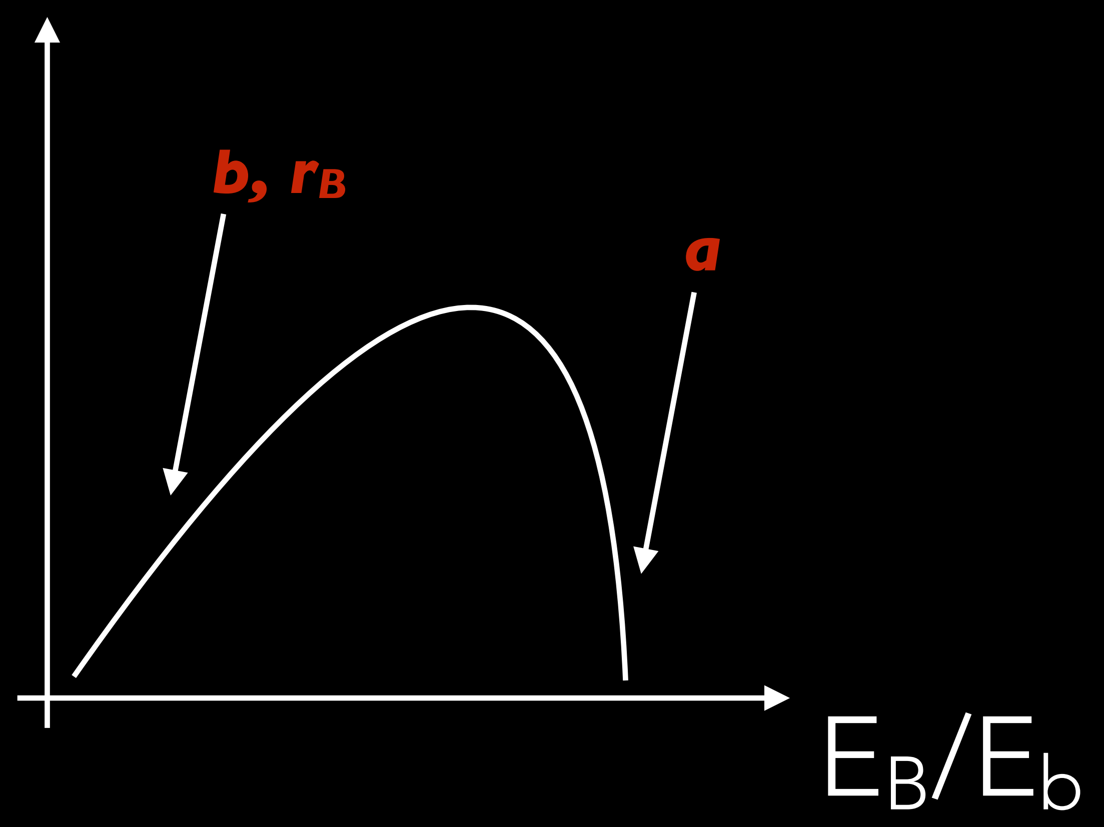
	Pythia8 parameter	range	Monash default
$p_{T,\min}$	TimeShower:pTmin	0.25-1.00 GeV	0.5
$\alpha_{s,\mathrm{FSR}}$	TimeShower:alphaSvalue	0.1092 - 0.1638	0.1365
recoil	TimeShower:recoilToColoured	*on* and *off*	*on*
b quark mass	5:m0	3.8-5.8 GeV	4.8 GeV
Bowler's r_B	StringZ:rFactB	0.713-0.813	0.855
string model a	StringZ:aNonstandardB	0.54-0.82	0.68
string model b	StringZ:bNonstandardB	0.78-1.18	0.98

EVENT GENERATORS

PYTHIA PARAMETERS

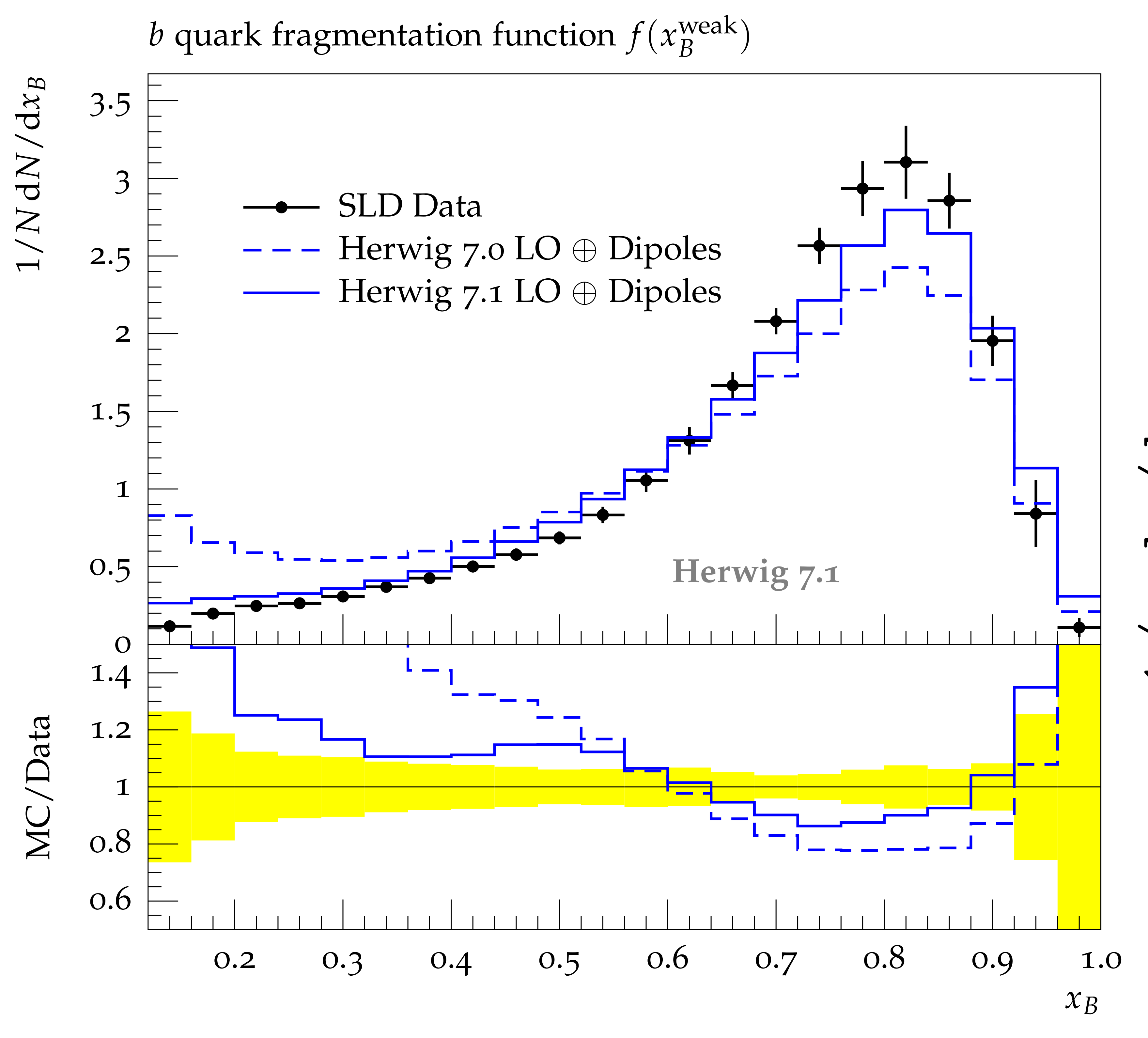


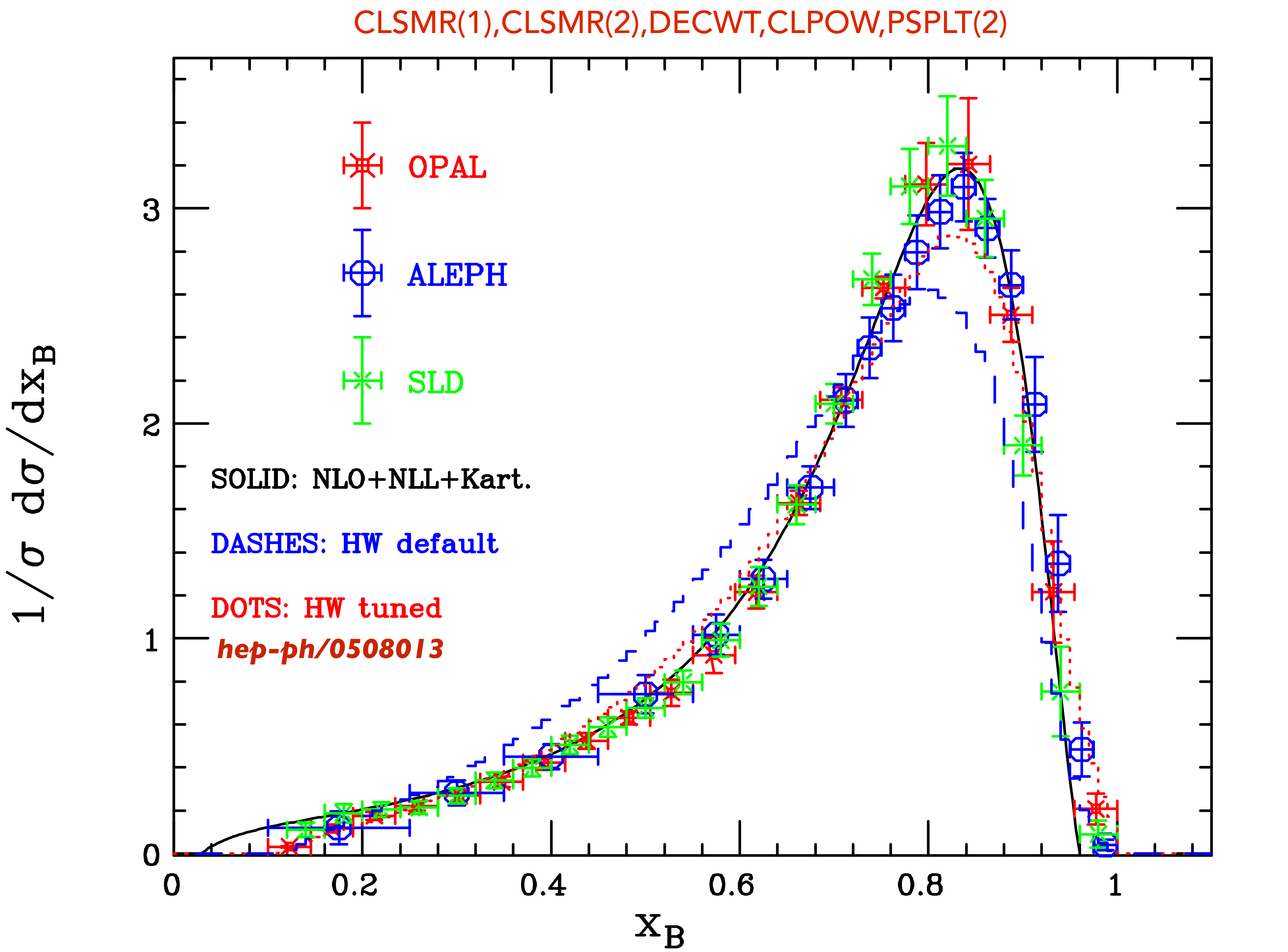




	Pythia8 parameter	range	Monash default
$p_{T,\mathrm{min}}$	TimeShower:pTmin	0.25-1.00 GeV	0.5
$\alpha_{s,\mathrm{FSR}}$	TimeShower:alphaSvalue	0.1092 - 0.1638	0.1365
recoil	TimeShower:recoilToColoured	*on* and *off*	*on*
b quark mass	5:m0	3.8-5.8 GeV	4.8 GeV
Bowler's r_B	StringZ:rFactB	0.713-0.813	0.855
string model a	StringZ:aNonstandardB	0.54-0.82	0.68
string model b	StringZ:bNonstandardB	0.78-1.18	0.98

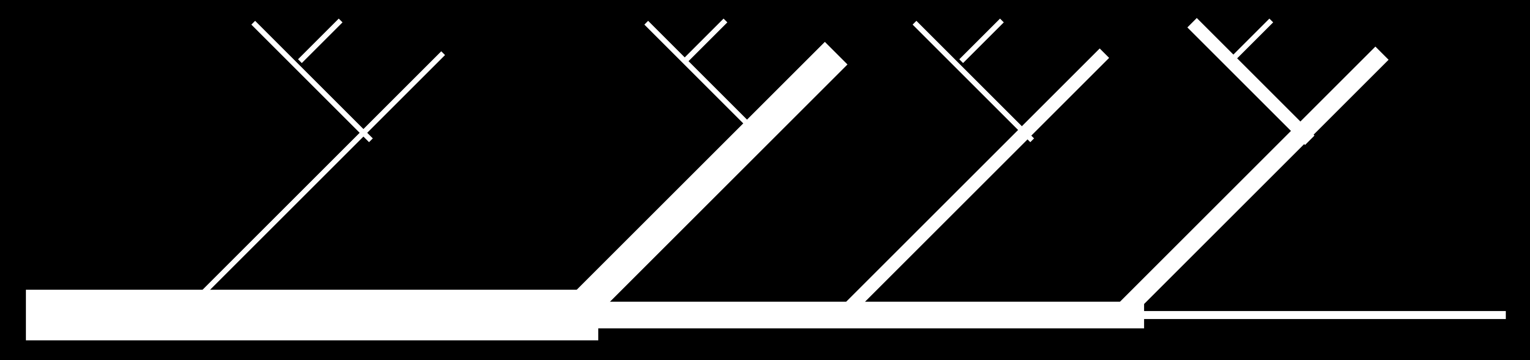
HERWIG 7 HERWIG 6





EVENT GENERATORS

HERWIG PARAMETERS

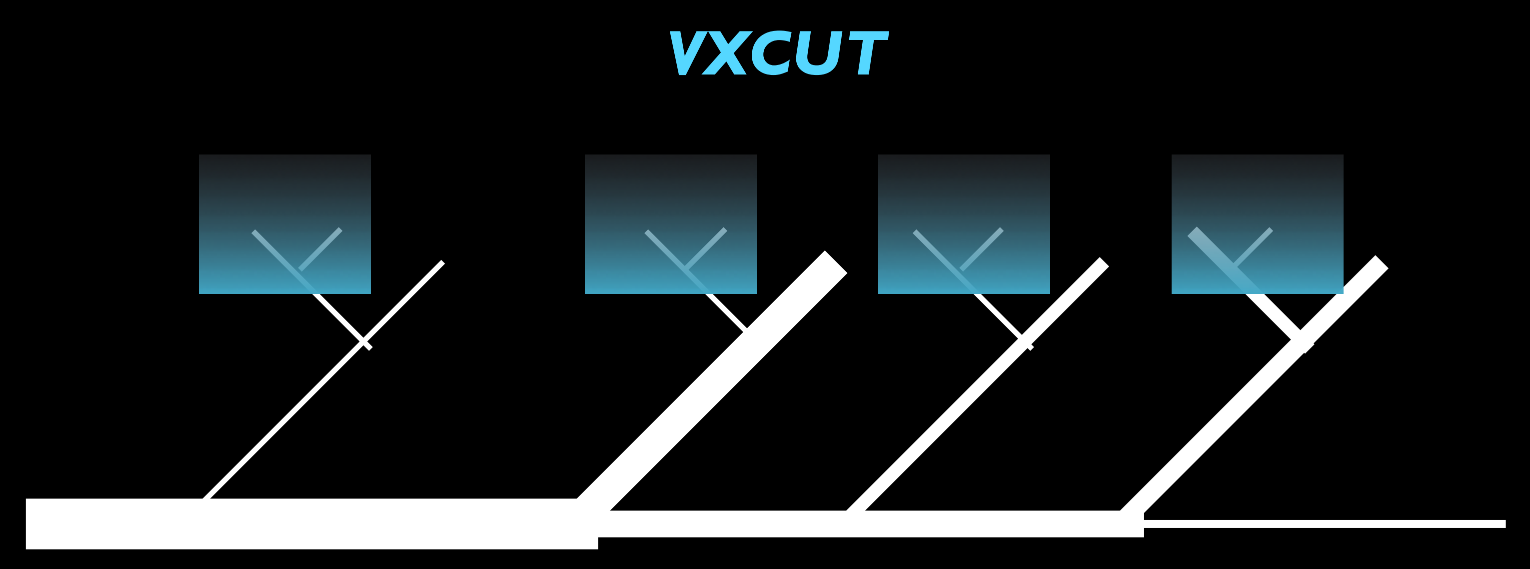


	parameter	range	default
Cluster spectrum parameter	PSPLT(2)	0.9 - 1	1
Power in maximum cluster mass	CLPOW	1.8 - 2.2	2
Maximum cluster mass	CLMAX	3.0 - 3.7	3.35
CMW Λ_{QCD}	QCDLAM	0.16 - 2	0.18
Smearing width of B-hadron direction	CLMSR(2)	0.1 - 0.2	0
Quark shower cutoff	VQCUT	0.4 - 0.55	0.48
Gluon shower cutoff	VGCUT	0.05 - 0.15	0.1
Gluon effective mass	RMASS(13)	0.65 - 0.85	0.75
Bottom-quark mass	RMASS(5)	4.6 - 5.3	4.95

MASS OF DAUGHTER CLUSTERS UNIFORMLY DISTRIBUTED IN M^{PSPLT}

EVENT GENERATORS

HERWIG PARAMETERS

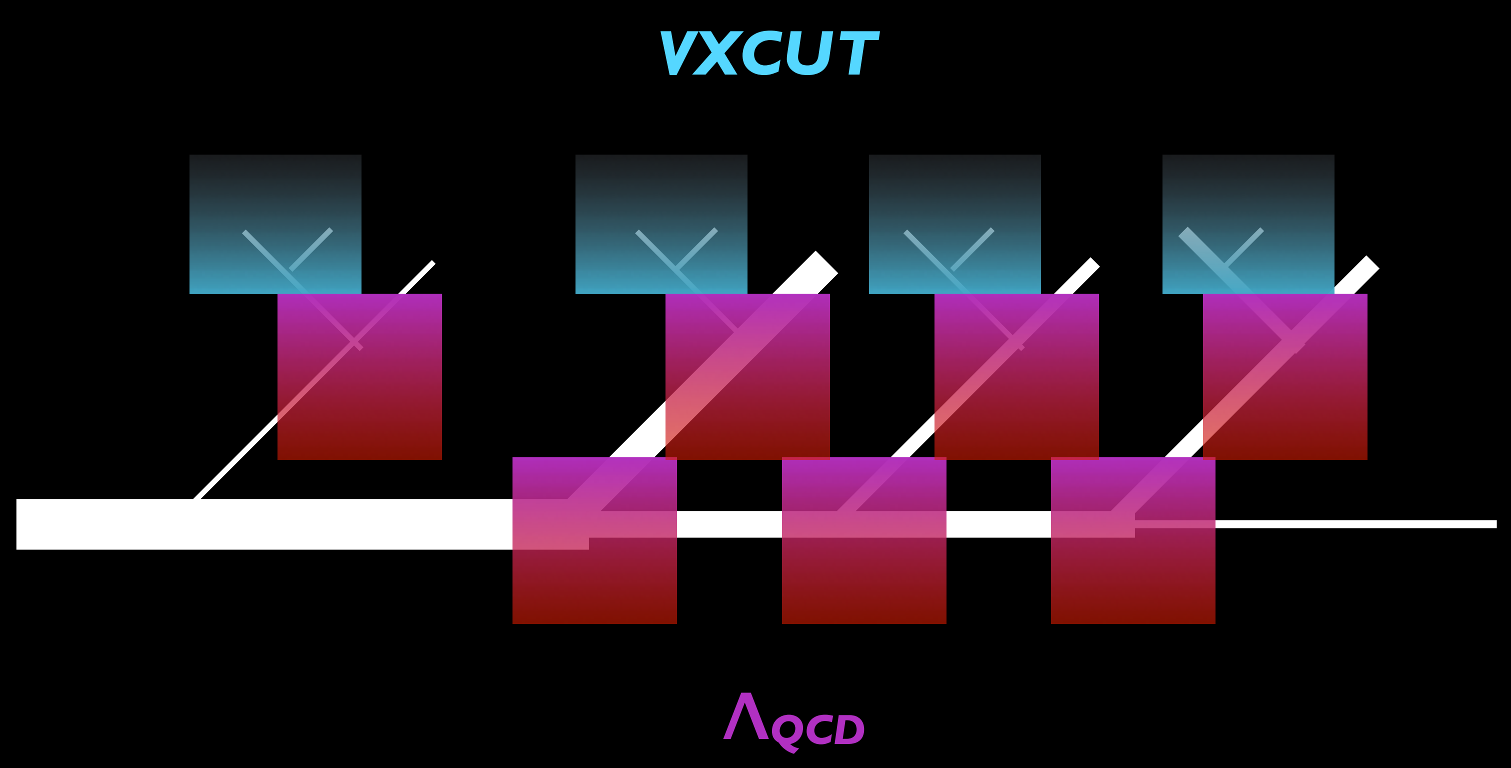


	parameter	range	default
Cluster spectrum parameter	PSPLT(2)	0.9 - 1	1
Power in maximum cluster mass	CLPOW	1.8 - 2.2	2
Maximum cluster mass	CLMAX	3.0 - 3.7	3.35
CMW Λ_{QCD}	QCDLAM	0.16 - 2	0.18
Smearing width of B-hadron direction	CLMSR(2)	0.1 - 0.2	0
Quark shower cutoff	VQCUT	0.4 - 0.55	0.48
Gluon shower cutoff	VGCUT	0.05 - 0.15	0.1
Gluon effective mass	RMASS(13)	0.65 - 0.85	0.75
Bottom-quark mass	RMASS(5)	4.6 - 5.3	4.95

MASS OF DAUGHTER CLUSTERS UNIFORMLY DISTRIBUTED IN M^{PSPLT}

EVENT GENERATORS

HERWIG PARAMETERS

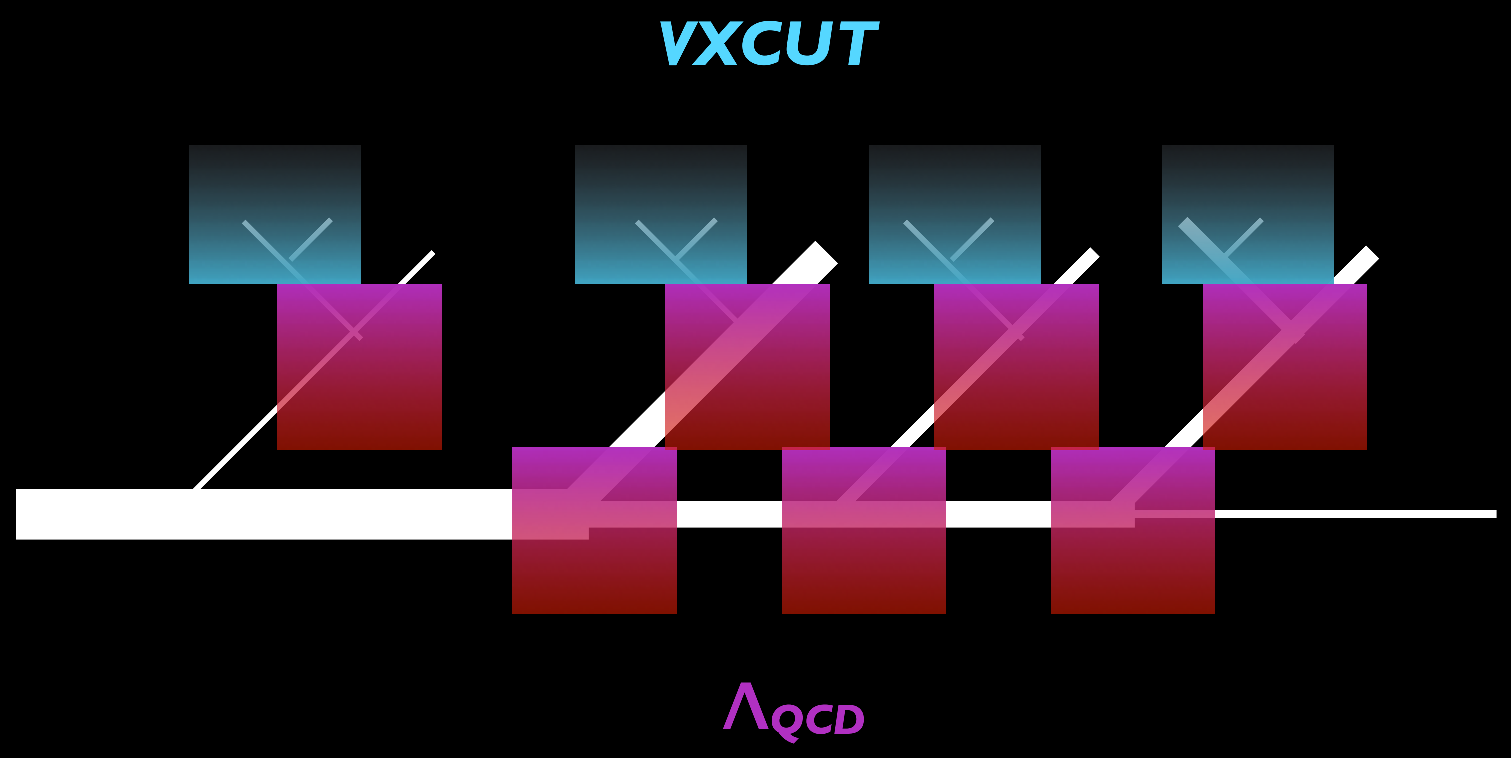


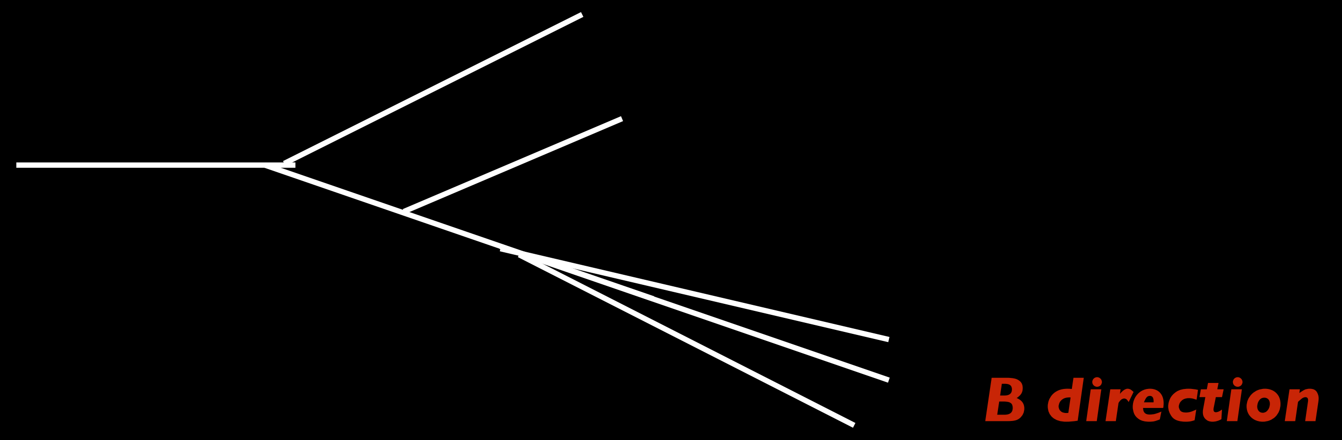
	parameter	range	default
Cluster spectrum parameter	PSPLT(2)	0.9 - 1	1
Power in maximum cluster mass	CLPOW	1.8 - 2.2	2
Maximum cluster mass	CLMAX	3.0 - 3.7	3.35
CMW Λ_{QCD}	QCDLAM	0.16 - 2	0.18
Smearing width of B-hadron direction	CLMSR(2)	0.1 - 0.2	0
Quark shower cutoff	VQCUT	0.4 - 0.55	0.48
Gluon shower cutoff	VGCUT	0.05 - 0.15	0.1
Gluon effective mass	RMASS(13)	0.65 - 0.85	0.75
Bottom-quark mass	RMASS(5)	4.6 - 5.3	4.95

MASS OF DAUGHTER CLUSTERS UNIFORMLY DISTRIBUTED IN M^{PSPLT}

EVENT GENERATORS

HERWIG PARAMETERS



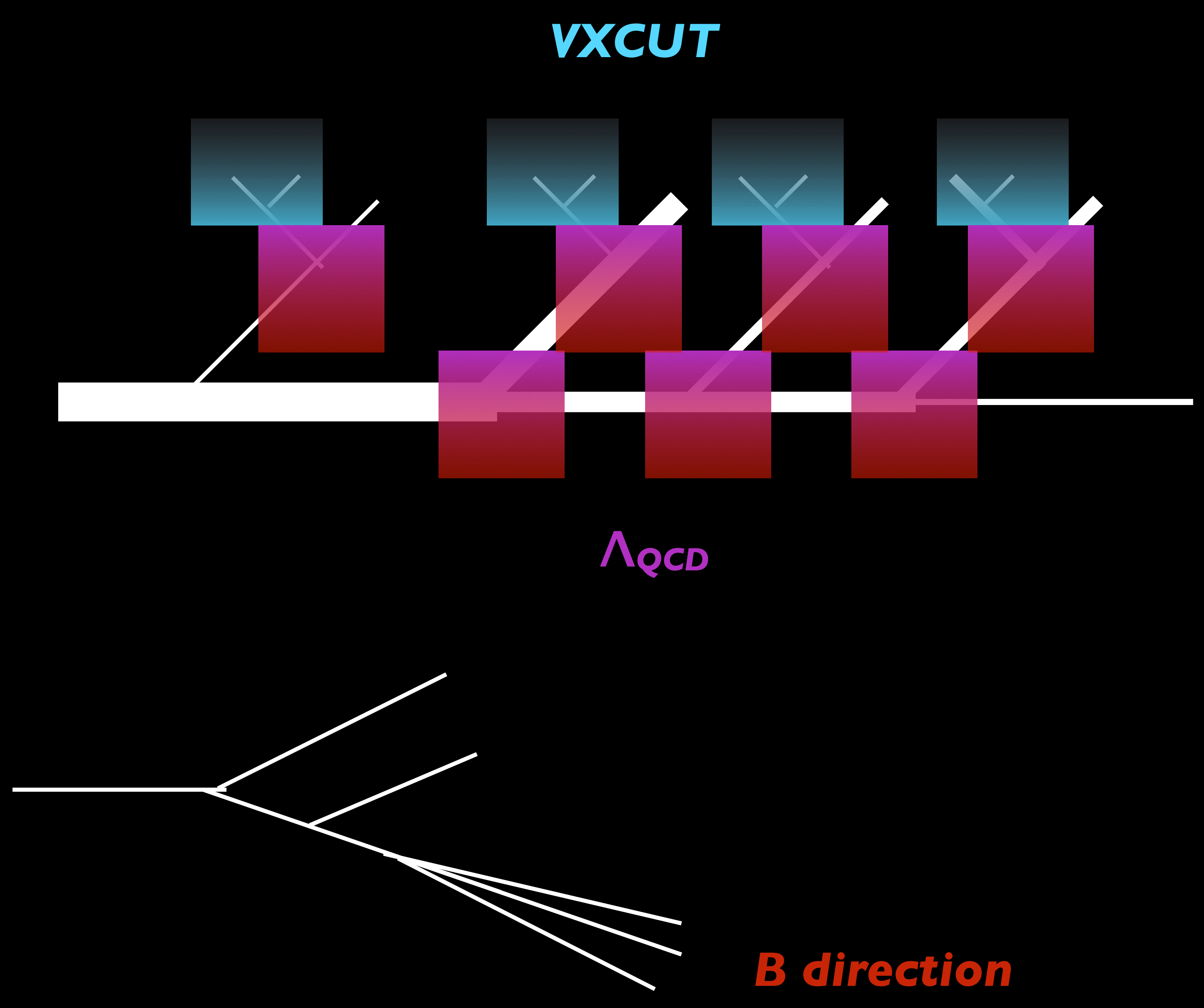


	parameter	range	default
Cluster spectrum parameter	PSPLT(2)	0.9 - 1	1
Power in maximum cluster mass	CLPOW	1.8 - 2.2	2
Maximum cluster mass	CLMAX	3.0 - 3.7	3.35
CMW Λ_{QCD}	QCDLAM	0.16 - 2	0.18
Smearing width of B-hadron direction	CLMSR(2)	0.1 - 0.2	0
Quark shower cutoff	VQCUT	0.4 - 0.55	0.48
Gluon shower cutoff	VGCUT	0.05 - 0.15	0.1
Gluon effective mass	RMASS(13)	0.65 - 0.85	0.75
Bottom-quark mass	RMASS(5)	4.6 - 5.3	4.95

MASS OF DAUGHTER CLUSTERS UNIFORMLY DISTRIBUTED IN M^{PSPLT}

EVENT GENERATORS

HERWIG PARAMETERS



	parameter	range	default
Cluster spectrum parameter	PSPLT(2)	0.9 - 1	1
Power in maximum cluster mass	CLPOW	1.8 - 2.2	2
Maximum cluster mass	CLMAX	3.0 - 3.7	3.35
CMW Λ_{QCD}	QCDLAM	0.16 - 2	0.18
Smearing width of B-hadron direction	CLMSR(2)	0.1 - 0.2	0
Quark shower cutoff	VQCUT	0.4 - 0.55	0.48
Gluon shower cutoff	VGCUT	0.05 - 0.15	0.1
Gluon effective mass	RMASS(13)	0.65 - 0.85	0.75
Bottom-quark mass	RMASS(5)	4.6 - 5.3	4.95

$$M^{\mathtt{CLPOW}} < \mathtt{CLMAX}^{\mathtt{CLPOW}} + (\mathtt{RMASS}(i) + \mathtt{RMASS}(j))^{\mathtt{CLPOW}}$$

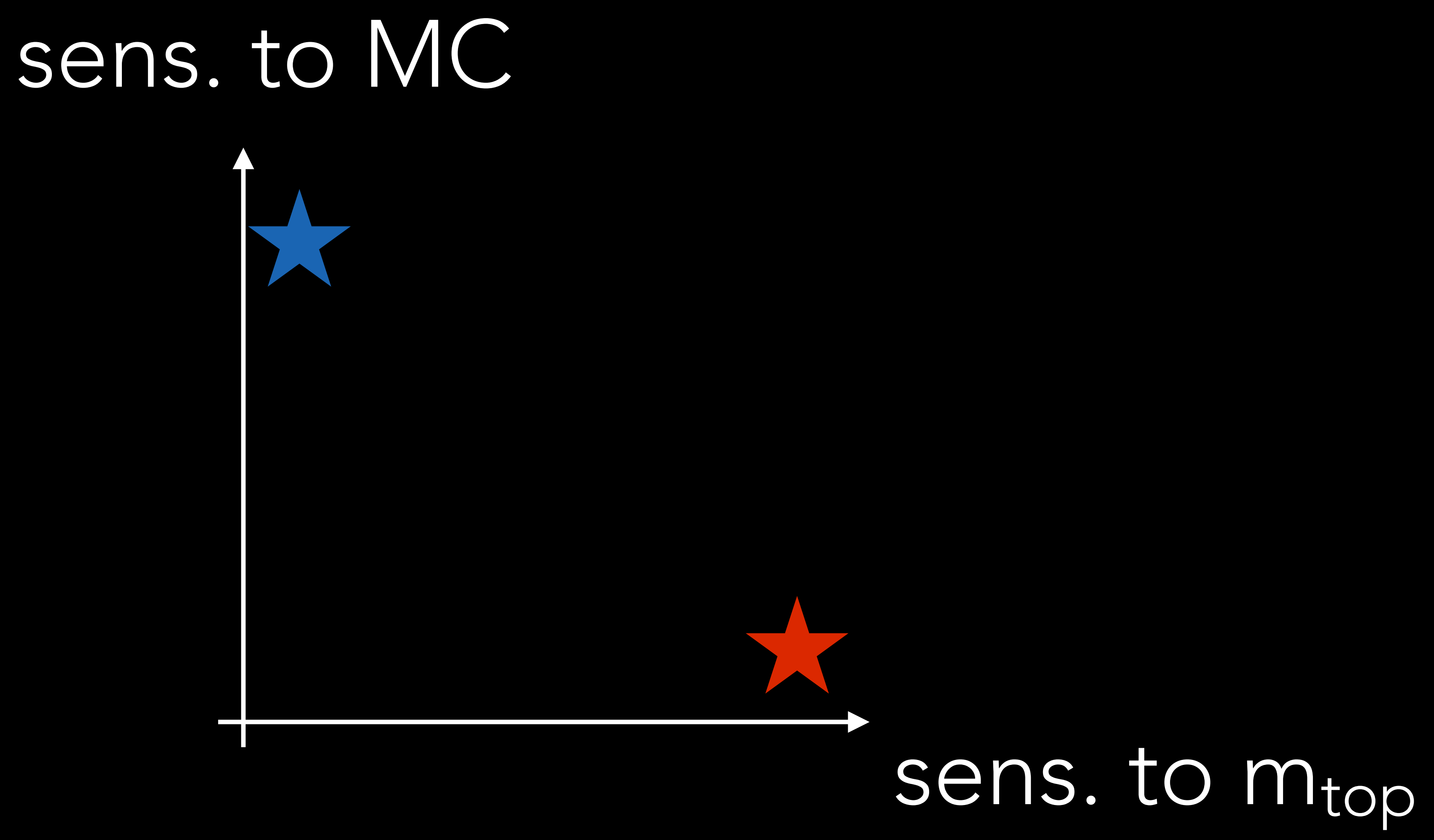
MASS OF DAUGHTER CLUSTERS UNIFORMLY DISTRIBUTED IN M^{PSPLT}

EVENT GENERATORS

PREDICTIONS

Observable that are sensitive to m_{top}

Observable that are not sensitive to m_{top}

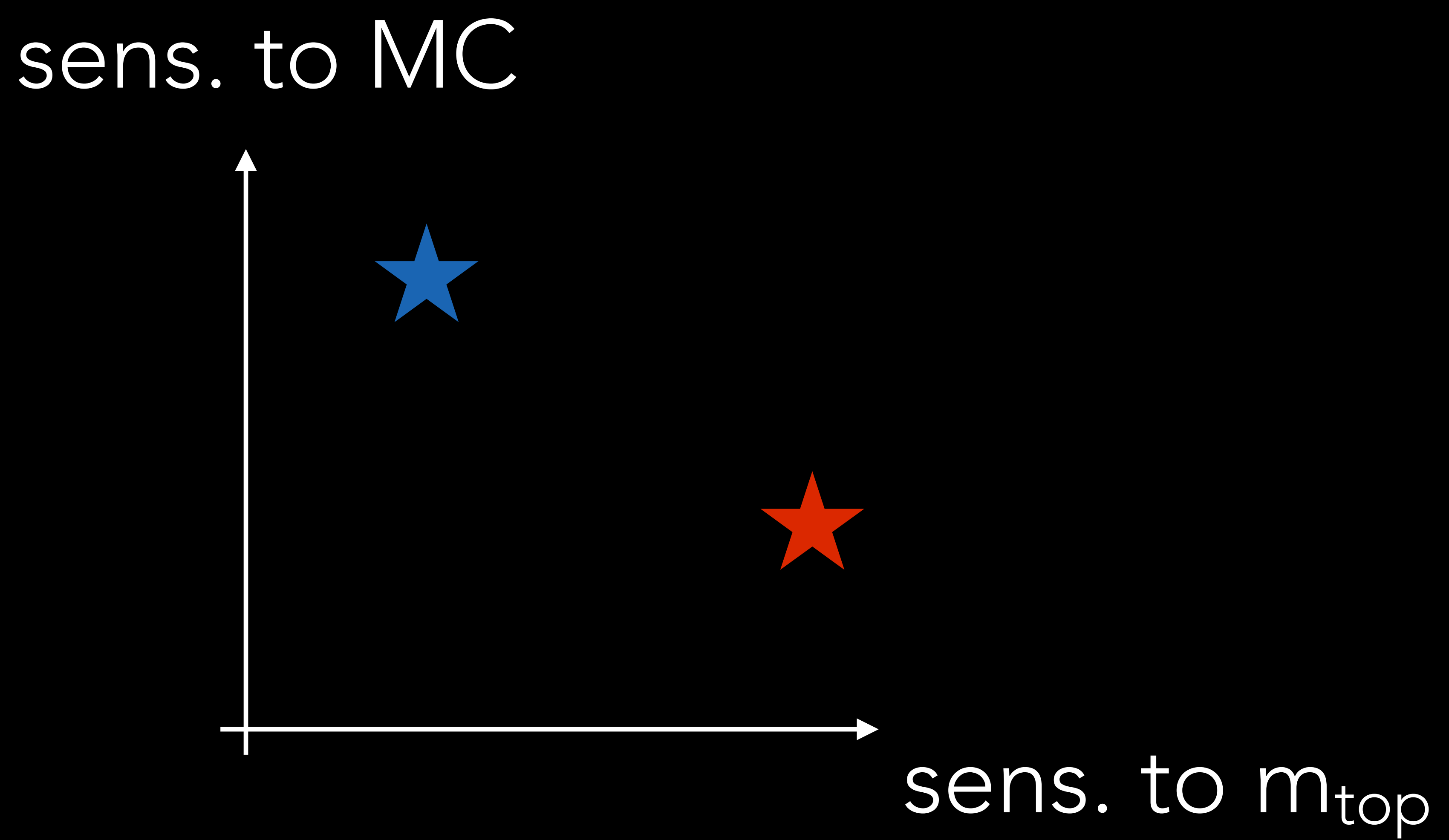


EVENT GENERATORS

PREDICTIONS

Observable that are sensitive to m_{top}

Observable that are not sensitive to m_{top}



SENSITIVITY TO THEORY PARAMETERS

SENSITIVITY= RATIO

$$\frac{\text{(RELATIVE VARIATION OF THE OBSERVABLE)}}{\text{(RELATIVE VARIATION OF THE PARAMETER)}}$$

$$\Delta_\theta^{(O)} = \frac{\delta O/O}{\delta\theta/\theta}$$

$\Delta^{(mtop)}{}_\theta < 0.003$

m(Bl), p_{Tmin} : $\Delta^{(mt)}{}_{mBl} \cdot \Delta^{(mBl)}{}_{pTmin} < 0.003$

SENSITIVITY TO THEORY PARAMETERS

SENSITIVITY= RATIO

$$\frac{\text{(RELATIVE VARIATION OF THE OBSERVABLE)}}{\text{(RELATIVE VARIATION OF THE PARAMETER)}}$$

RELATIVE RATIO: NOT STRONGLY DEPENDENT ON THE RANGE OR CENTRAL VALUE OF THE PARAMETER

$$\Delta_{\theta}^{(O)} = \frac{\delta O/O}{\delta\theta/\theta}$$

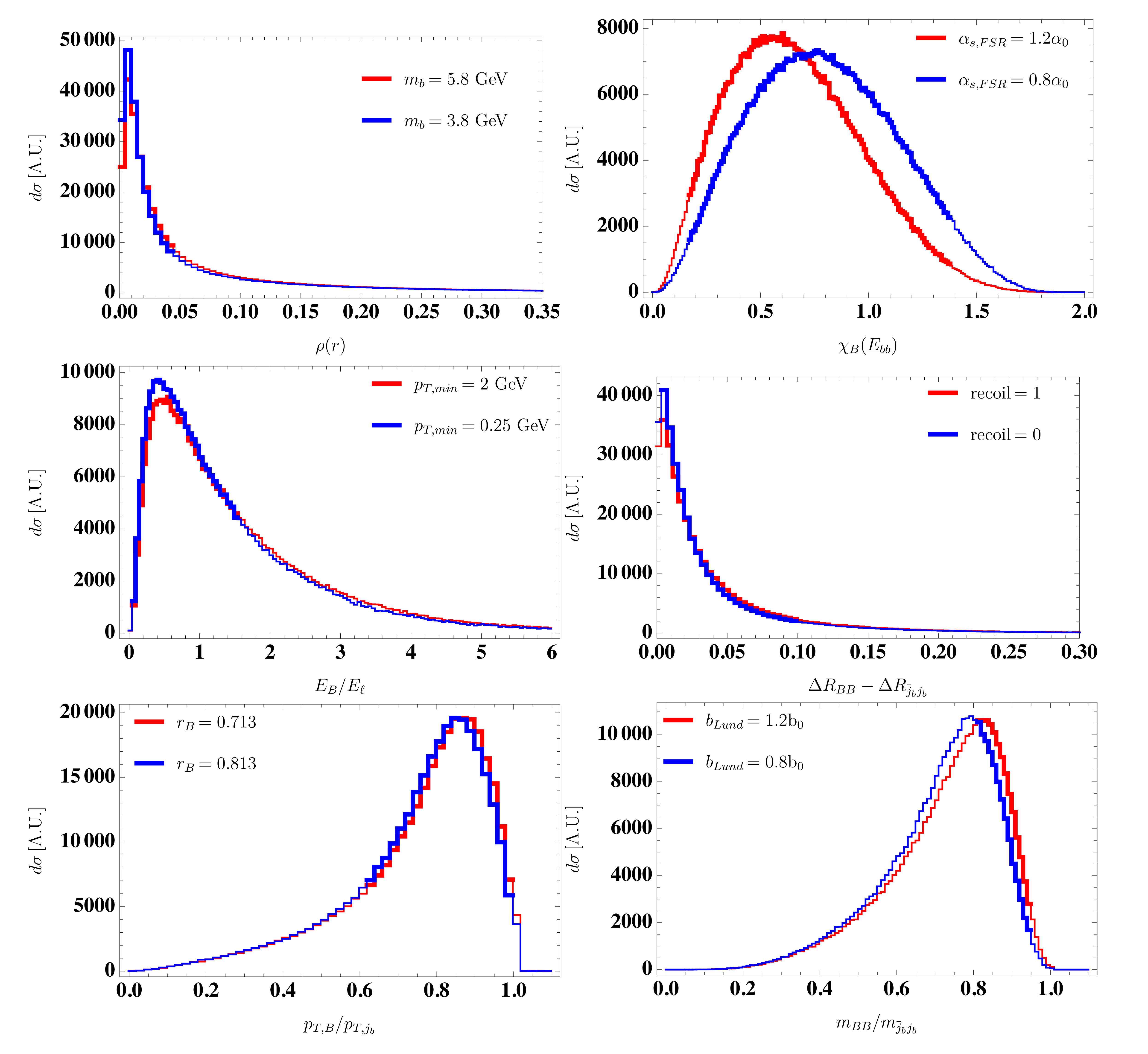
O(1) FOR MOST CASES

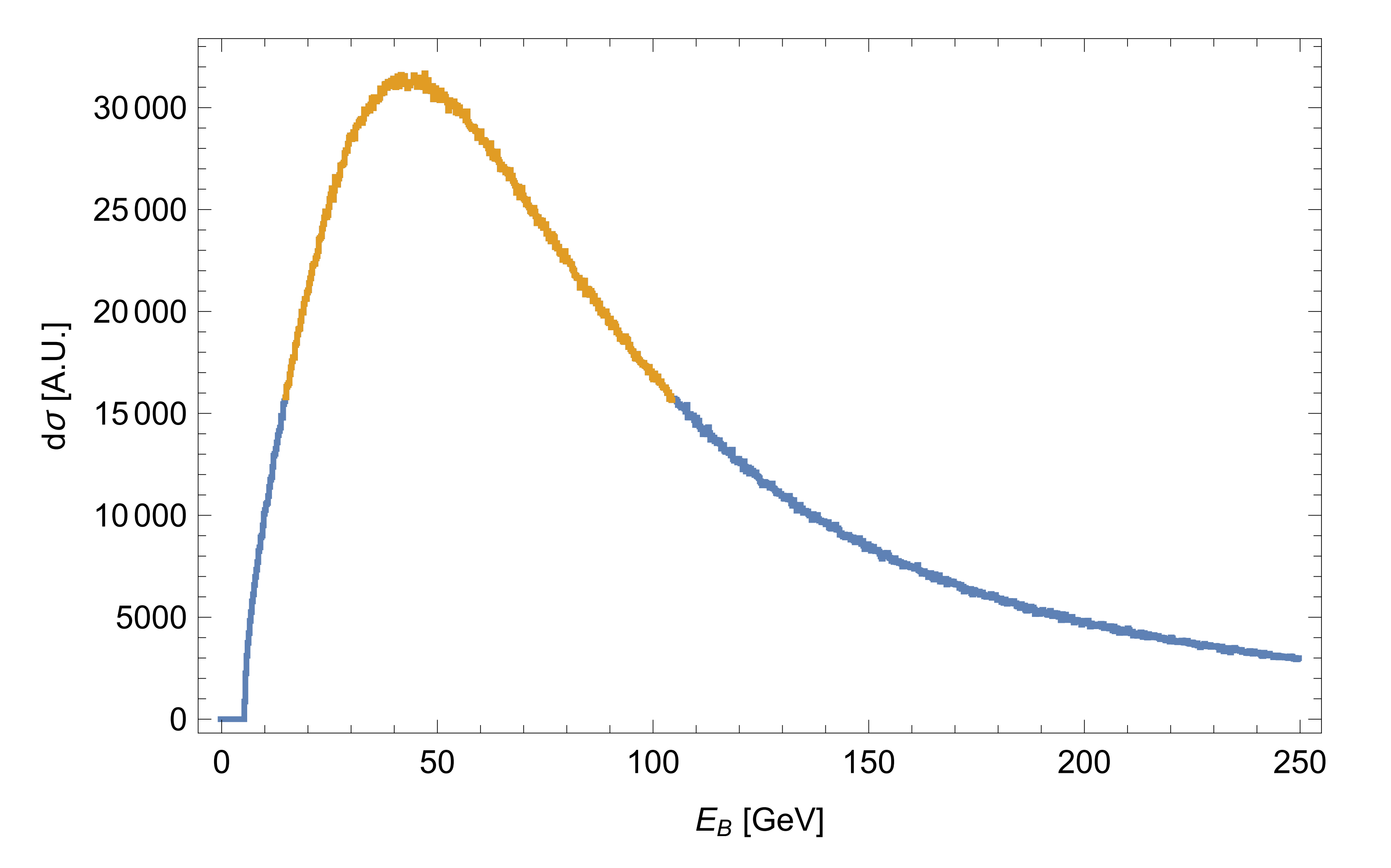
$\Delta^{(mtop)}{}_{\theta}<0.003$

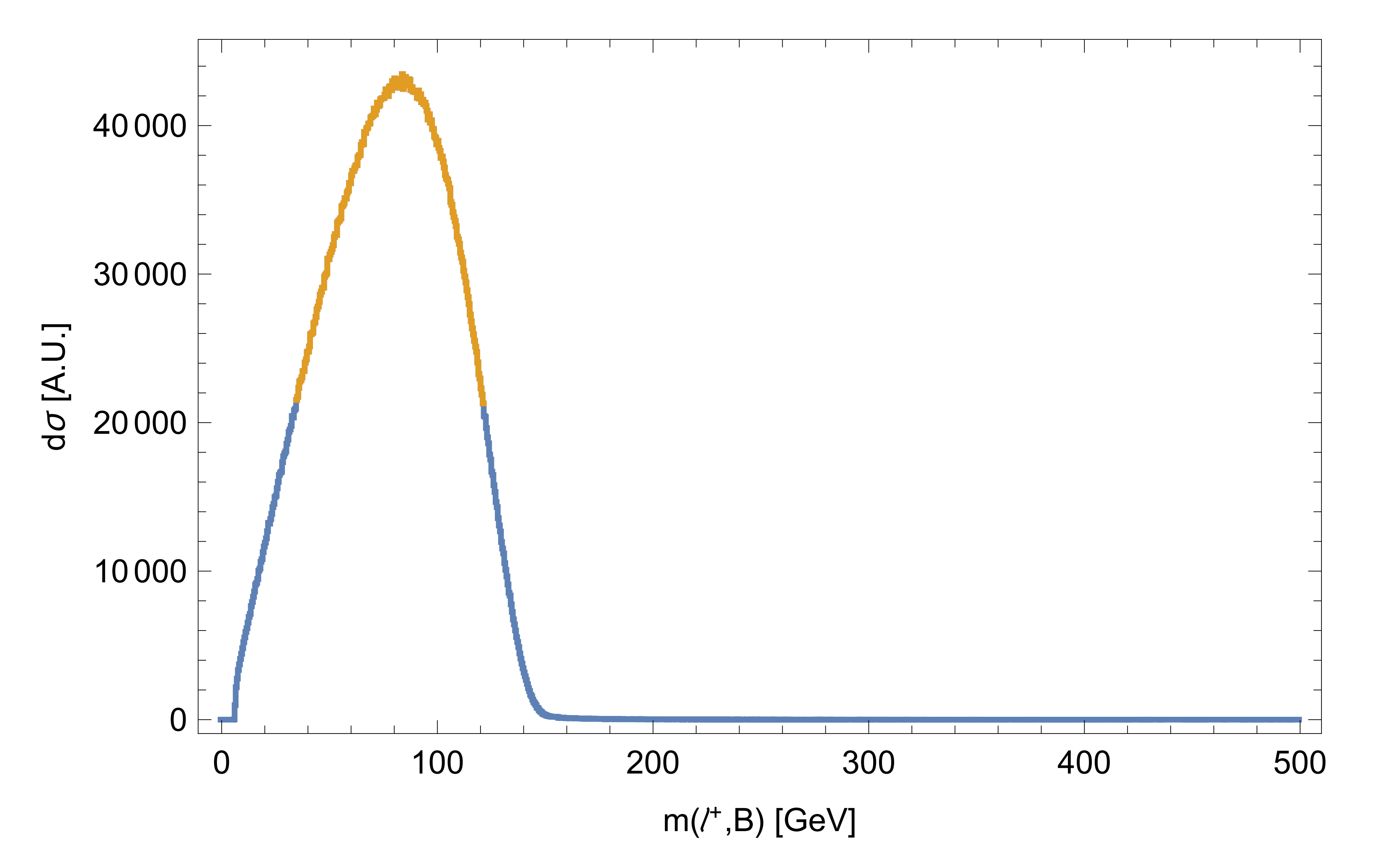
m(Bl), p_{Tmin} : $\Delta^{(mt)}{}_{mBl}\cdot\Delta^{(mBl)}{}_{pTmin}<0.003$

RESULTS

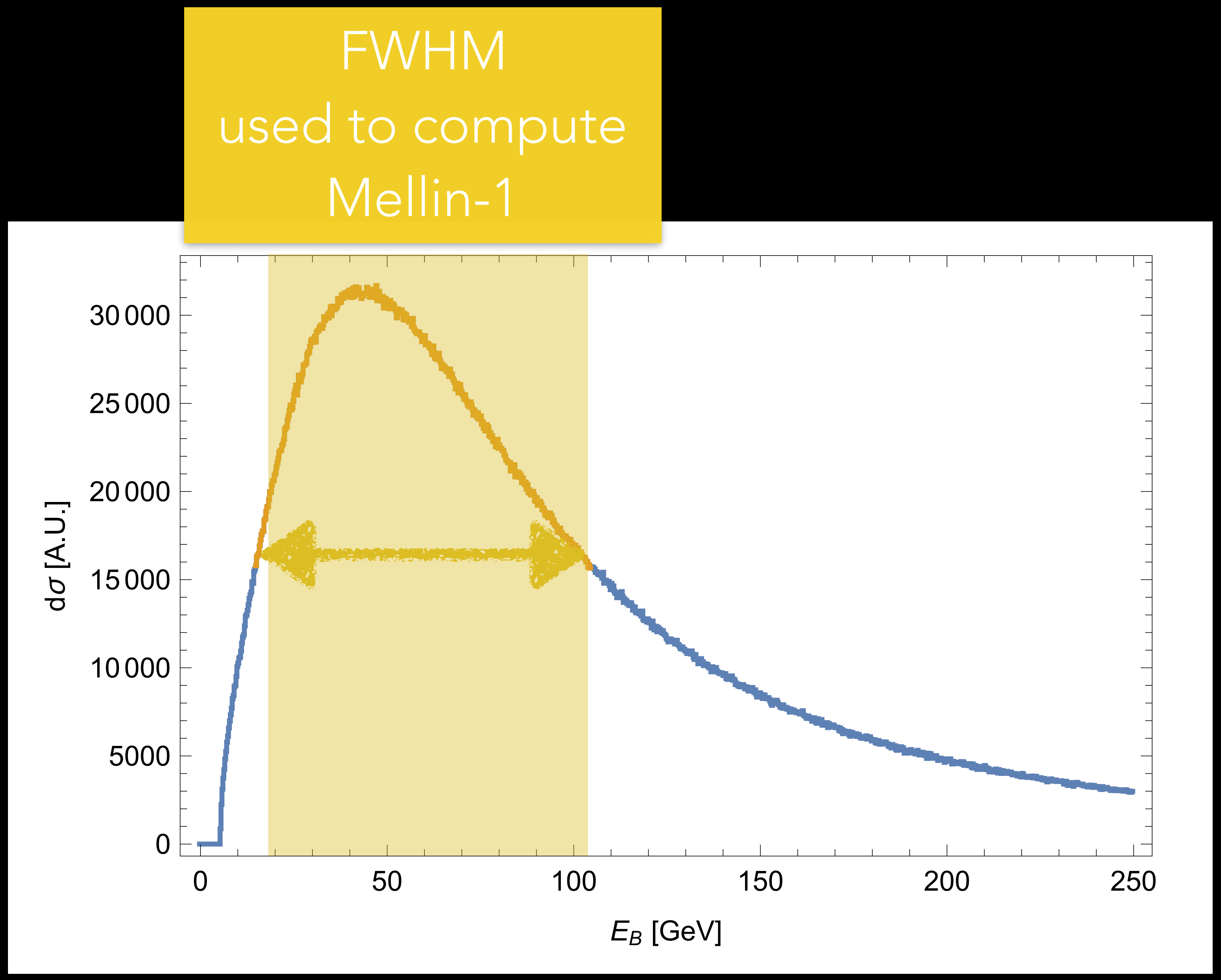
PYTHIA

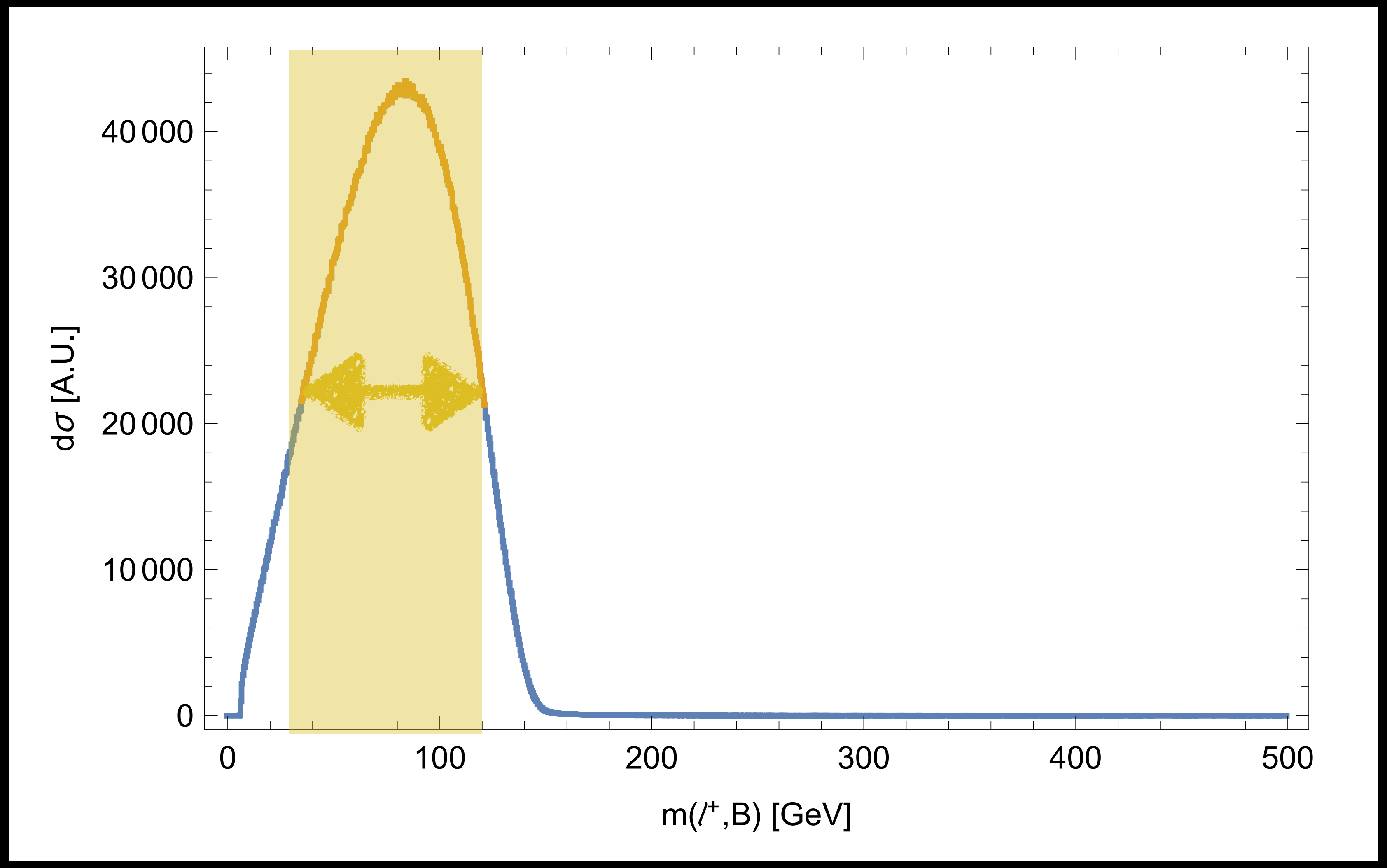






- Homogeneous recipe for all observables
- Tails might bring in sensitivity to unknown unknowns
- Bulk of the events, large data sample





- Homogeneous recipe for all observables
- Tails might bring in sensitivity to unknown unknowns
- Bulk of the events, large data sample

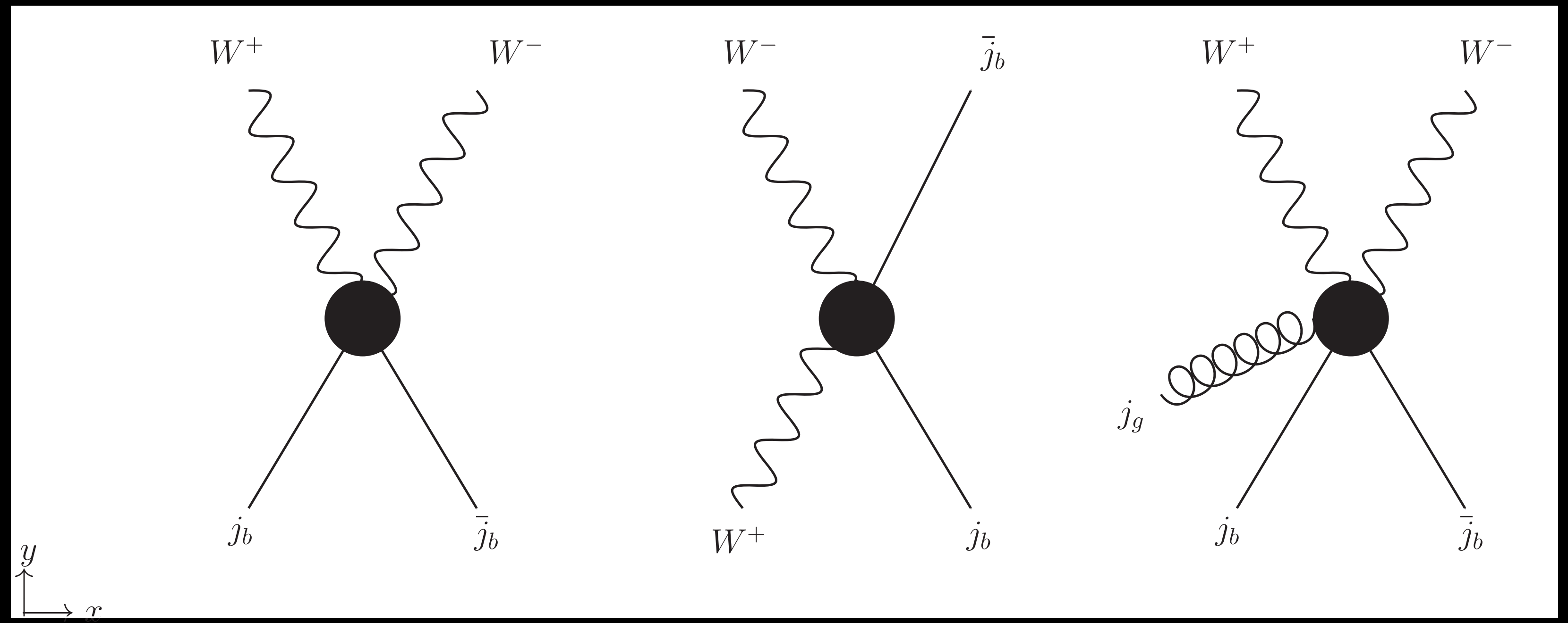
RESULTS

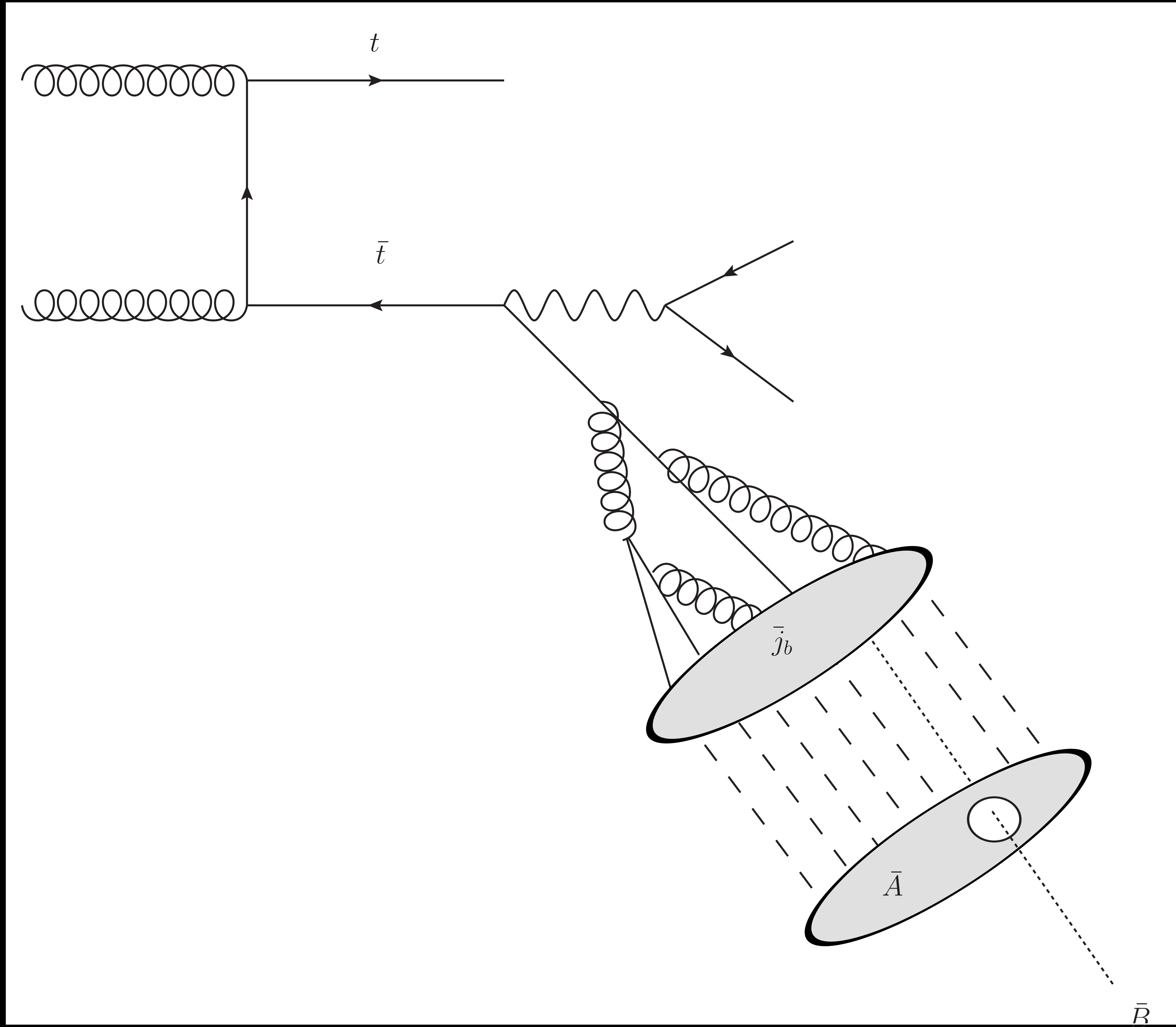
PYTHIA

$\mathcal{O}$
$\rho(r)$
$p_{T,B}/p_{T,j_b}$
E_B/E_{j_b}
E_B/E_ℓ
$E_B/(E_\ell + E_{\bar{\ell}})$
$m(j_{\bar{b}})/\mathrm{GeV}$
$\chi_B(\sqrt{s_{\min,bb}})$
$\chi_B\left(E_{j_b} + E_{\bar{j}_b}\right)$
$\chi_B(m_{j_b j_{\bar{b}}})$
$\chi_B\left(\lvert p_{T,j_b}\rvert + \lvert p_{T,\bar{j}_b}\rvert\right)$
$m_{BB}/m_{j_b j_{\bar{b}}}$
$\Delta\phi(j_b j_{\bar{b}})$
$\Delta R(j_b j_{\bar{b}})$
$\Delta\phi(BB)$
$\Delta R(BB)$
$\lvert\Delta\phi(BB) - \Delta\phi(j_b j_{\bar{b}})\rvert$
$\lvert\Delta R(BB) - \Delta R(j_b j_{\bar{b}})\rvert$

$$\rho(r) = \frac{1}{\Delta r}\frac{1}{E_j}\sum\nolimits_{\text{track}} E(\text{track})\theta\left(\lvert r - \Delta R_{j,\text{track}}\rvert < \delta r\right):$$

$$\chi_B = 2E_B/X_B \qquad X_B = m_{j_b j_{\bar{b}}},\ \sqrt{s_{\min}},\ \lvert p_{T,j_b}\rvert + \lvert p_{T,j_{\bar{b}}}\rvert \text{ and } E_{j_b} + E_{\bar{j}_b}.$$





RESULTS

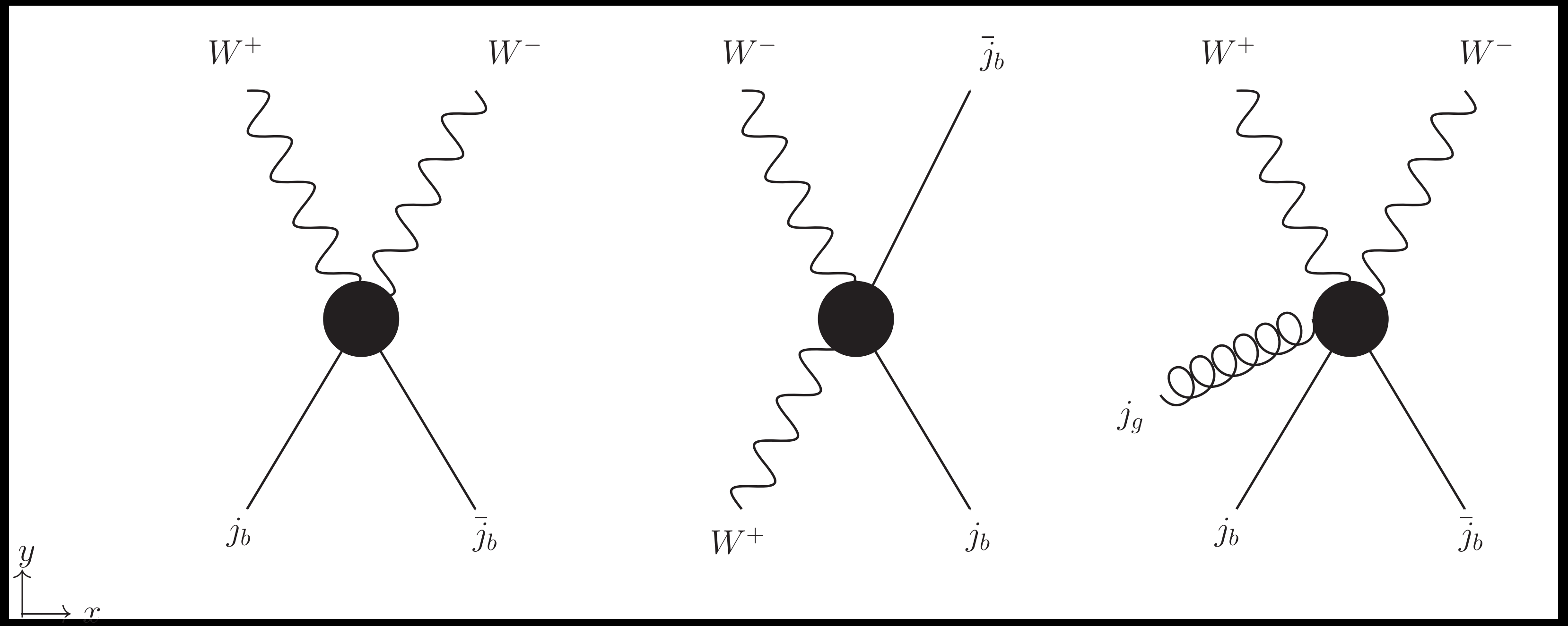
PYTHIA

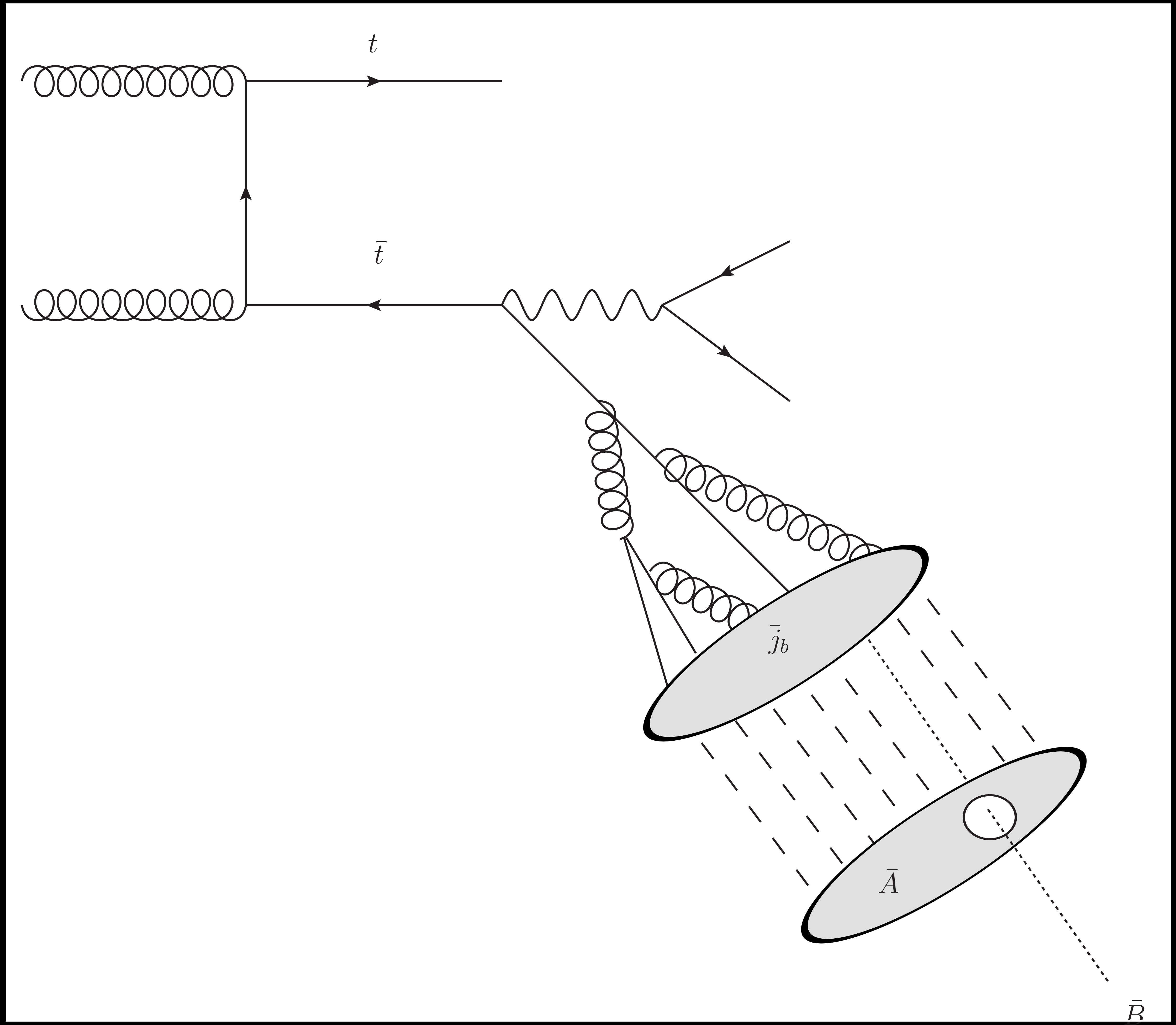
$\mathcal{O}$
$\rho(r)$
$p_{T,B}/p_{T,j_b}$
E_B/E_{j_b}
E_B/E_ℓ
$E_B/(E_\ell + E_{\bar\ell})$
$m(j_{\bar b})/\mathrm{GeV}$
$\chi_B(\sqrt{s_{\min,b\bar b}})$
$\chi_B\left(E_{j_b} + E_{\bar j_b}\right)$
$\chi_B(m_{j_b j_{\bar b}})$
$\chi_B\left(\lvert p_{T,j_b}\rvert + \lvert p_{T,\bar j_b}\rvert\right)$
$m_{BB}/m_{j_b j_{\bar b}}$
$\Delta\phi(j_b j_{\bar b})$
$\Delta R(j_b j_{\bar b})$
$\Delta\phi(BB)$
$\Delta R(BB)$
$\lvert\Delta\phi(BB) - \Delta\phi(j_b j_{\bar b})\rvert$
$\lvert\Delta R(BB) - \Delta R(j_b j_{\bar b})\rvert$

$$\rho(r) = \frac{1}{\Delta r}\frac{1}{E_j}\sum_{\text{track}} E(\text{track})\theta\left(|r - \Delta R_{j,\text{track}}| < \delta r\right);$$

PURE TRACKER

$$\chi_B = 2E_B/X_B \qquad X_B = m_{j_b j_{\bar b}},\ \sqrt{s_{\min}},\ |p_{T,j_b}| + |p_{T,j_{\bar b}}| \text{ and } E_{j_b} + E_{j_{\bar b}}.$$





RESULTS

PYTHIA

$\mathcal{O}$	Range	$\Delta_{m_t}^{(\mathcal{M}_\mathcal{O})}$	$\Delta_\theta^{(\mathcal{M}_\mathcal{O})}$						
			$\alpha_{s,FSR}$	m_b	$p_{T,\min}$	a	b	r_B	recoil
$\rho(r)$	0-0.04	-0.007(7)	0.78(1)	0.204(4)	-0.1286(8)	0.029(3)	-0.043(4)	0.056(7)	0.020(1)
$p_{T,B}/p_{T,j_b}$	0.6-0.998	-0.053(1)	-0.220(3)	-0.1397(8)	0.0353(5)	-0.0187(4)	0.0451(6)	-0.0518(9)	-0.0108(3)
E_B/E_{j_b}	0.6-0.998	-0.049(1)	-0.220(3)	-0.1381(8)	0.0360(5)	-0.0186(4)	0.0447(6)	-0.052(1)	-0.0107(3)
E_B/E_ℓ	0.05-1.5	-0.155(7)	-0.156(3)	-0.053(3)	0.0149(7)	-0.007(2)	0.016(2)	-0.016(10)	-0.0087(7)
$E_B/(E_\ell + E_{\bar{\ell}})$	0.05-1.0	0.021(5)	-0.231(2)	-0.082(4)	0.0228(4)	-0.011(2)	0.026(2)	-0.028(6)	-0.0113(3)
$m(j_{\bar{b}})/\mathrm{GeV}$	8-20	0.229(3)	0.218(1)	0.022(1)	-0.0219(7)	0.000(1)	-0.001(1)	0.001(3)	0.0050(3)
$\chi_B(\sqrt{s_{\min,bb}})$	0.075-0.875	-0.177(4)	-0.262(4)	-0.086(1)	0.0255(3)	-0.0105(10)	0.027(1)	-0.031(3)	-0.0137(2)
$\chi_B\left(E_{j_b} + E_{j_{\bar{b}}}\right)$	0.175-1.375	-0.109(2)	-0.357(4)	-0.134(1)	0.0373(3)	-0.016(1)	0.040(1)	-0.045(4)	-0.0175(3)
$\chi_B(m_{j_b j_{\bar{b}}})$	0.175-1.375	-0.089(3)	-0.252(3)	-0.080(1)	0.0248(3)	-0.010(1)	0.024(1)	-0.028(5)	-0.0126(2)
$\chi_B\left(\lvert p_{T,j_b}\rvert + \lvert p_{T,j_{\bar{b}}}\rvert\right)$	0.46-1.38	-0.15(2)	-0.47(1)	-0.189(10)	0.054(3)	-0.023(10)	0.06(1)	-0.07(4)	-0.022(2)
$m_{BB}/m_{j_b j_{\bar{b}}}$	0.8-0.95	-0.0191(8)	-0.0623(7)	-0.0464(5)	0.0146(2)	-0.0093(3)	0.0180(4)	-0.0212(9)	-0.00296(10)
$\Delta\phi(j_b j_{\bar{b}})$	0.28-3.	-0.210(7)	0.027(3)	0.001(2)	-0.0014(5)	-0.000(3)	-0.000(1)	-0.003(9)	0.0003(5)
$\Delta R(j_b j_{\bar{b}})$	1.4-3.3	-0.071(3)	0.010(1)	0.0005(10)	-0.0004(2)	-0.000(1)	0.0004(9)	0.001(3)	0.0001(2)
$\Delta\phi(BB)$	0.28-3.	-0.207(7)	0.026(2)	0.001(1)	-0.0008(4)	0.000(4)	0.000(2)	-0.000(8)	0.0002(5)
$\Delta R(BB)$	1.4-3.3	-0.070(3)	0.009(1)	0.000(1)	-0.0003(2)	-0.0003(10)	0.0002(9)	-0.000(4)	0.0001(2)
$\lvert\Delta\phi(BB) - \Delta\phi(j_b j_{\bar{b}})\rvert$	0-0.0488	0.06(1)	0.734(6)	0.099(5)	-0.088(2)	0.006(5)	-0.004(5)	0.01(2)	0.026(2)
$\lvert\Delta R(BB) - \Delta R(j_b j_{\bar{b}})\rvert$	0-0.0992	0.10(1)	0.920(3)	0.079(5)	-0.075(1)	-0.000(4)	0.005(4)	-0.00(2)	0.0418(8)

THIS MATRIX CAPTURES THE MONTE CARLO MODELING AS A LINEAR SYSTEM

RESULTS

PYTHIA

EACH LINE IS A VECTOR OF GRADIENTS OF THE OBSERVABLE W.R.T. A PARAMETER Θ

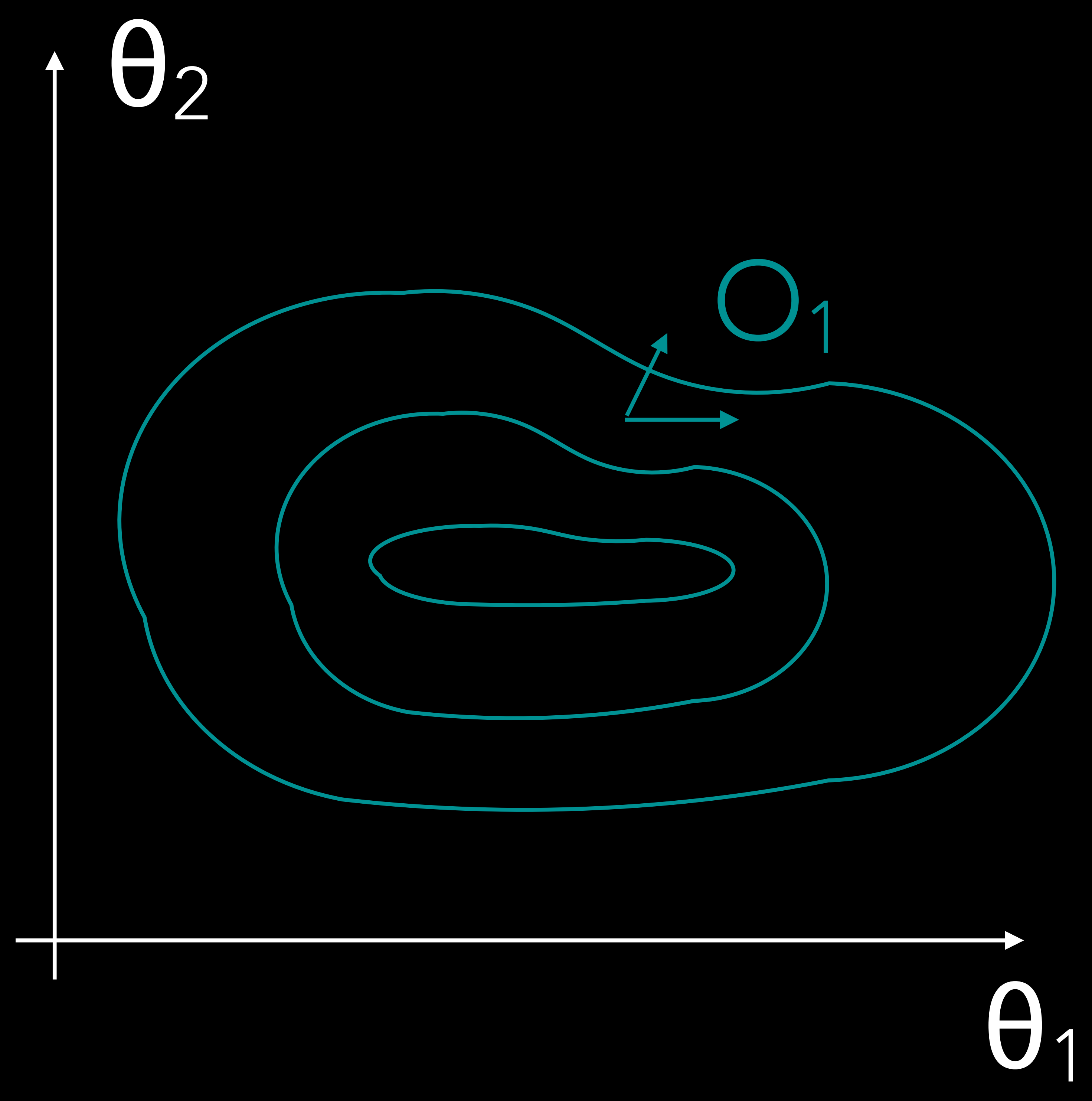
$\mathcal{O}$	Range	$\Delta_{m_t}^{(\mathcal{M}_\mathcal{O})}$	$\Delta_\theta^{(\mathcal{M}_\mathcal{O})}$						
			$\alpha_{s,FSR}$	m_b	$p_{T,\min}$	a	b	r_B	recoil
$\rho(r)$	0-0.04	-0.007(7)	0.78(1)	0.204(4)	-0.1286(8)	0.029(3)	-0.043(4)	0.056(7)	0.020(1)
$p_{T,B}/p_{T,j_b}$	0.6-0.998	-0.053(1)	-0.220(3)	-0.1397(8)	0.0353(5)	-0.0187(4)	0.0451(6)	-0.0518(9)	-0.0108(3)
E_B/E_{j_b}	0.6-0.998	-0.049(1)	-0.220(3)	-0.1381(8)	0.0360(5)	-0.0186(4)	0.0447(6)	-0.052(1)	-0.0107(3)
E_B/E_ℓ	0.05-1.5	-0.155(7)	-0.156(3)	-0.053(3)	0.0149(7)	-0.007(2)	0.016(2)	-0.016(10)	-0.0087(7)
$E_B/(E_\ell + E_{\bar{\ell}})$	0.05-1.0	0.021(5)	-0.231(2)	-0.082(4)	0.0228(4)	-0.011(2)	0.026(2)	-0.028(6)	-0.0113(3)
$m(j_{\bar{b}})/\text{GeV}$	8-20	0.229(3)	0.218(1)	0.022(1)	-0.0219(7)	0.000(1)	-0.001(1)	0.001(3)	0.0050(3)
$\chi_B(\sqrt{s_{\min,b\bar{b}}})$	0.075-0.875	-0.177(4)	-0.262(4)	-0.086(1)	0.0255(3)	-0.0105(10)	0.027(1)	-0.031(3)	-0.0137(2)
$\chi_B\left(E_{j_b} + E_{j_{\bar{b}}}\right)$	0.175-1.375	-0.109(2)	-0.357(4)	-0.134(1)	0.0373(3)	-0.016(1)	0.040(1)	-0.045(4)	-0.0175(3)
$\chi_B(m_{j_b j_{\bar{b}}})$	0.175-1.375	-0.089(3)	-0.252(3)	-0.080(1)	0.0248(3)	-0.010(1)	0.024(1)	-0.028(5)	-0.0126(2)
$\chi_B\left(\lvert p_{T,j_b}\rvert + \lvert p_{T,j_{\bar{b}}}\rvert\right)$	0.46-1.38	-0.15(2)	-0.47(1)	-0.189(10)	0.054(3)	-0.023(10)	0.06(1)	-0.07(4)	-0.022(2)
$m_{BB}/m_{j_b j_{\bar{b}}}$	0.8-0.95	-0.0191(8)	-0.0623(7)	-0.0464(5)	0.0146(2)	-0.0093(3)	0.0180(4)	-0.0212(9)	-0.00296(10)
$\Delta\phi(j_b j_{\bar{b}})$	0.28-3.	-0.210(7)	0.027(3)	0.001(2)	-0.0014(5)	-0.000(3)	-0.000(1)	-0.003(9)	0.0003(5)
$\Delta R(j_b j_{\bar{b}})$	1.4-3.3	-0.071(3)	0.010(1)	0.0005(10)	-0.0004(2)	-0.000(1)	0.0004(9)	0.001(3)	0.0001(2)
$\Delta\phi(BB)$	0.28-3.	-0.207(7)	0.026(2)	0.001(1)	-0.0008(4)	0.000(4)	0.000(2)	-0.000(8)	0.0002(5)
$\Delta R(BB)$	1.4-3.3	-0.070(3)	0.009(1)	0.000(1)	-0.0003(2)	-0.0003(10)	0.0002(9)	-0.000(4)	0.0001(2)
$\lvert\Delta\phi(BB) - \Delta\phi(j_b j_{\bar{b}})\rvert$	0-0.0488	0.06(1)	0.734(6)	0.099(5)	-0.088(2)	0.006(5)	-0.004(5)	0.01(2)	0.026(2)
$\lvert\Delta R(BB) - \Delta R(j_b j_{\bar{b}})\rvert$	0-0.0992	0.10(1)	0.920(3)	0.079(5)	-0.075(1)	-0.000(4)	0.005(4)	-0.00(2)	0.0418(8)

THIS MATRIX CAPTURES THE MONTE CARLO MODELING AS A LINEAR SYSTEM

RESULTS

PYTHIA

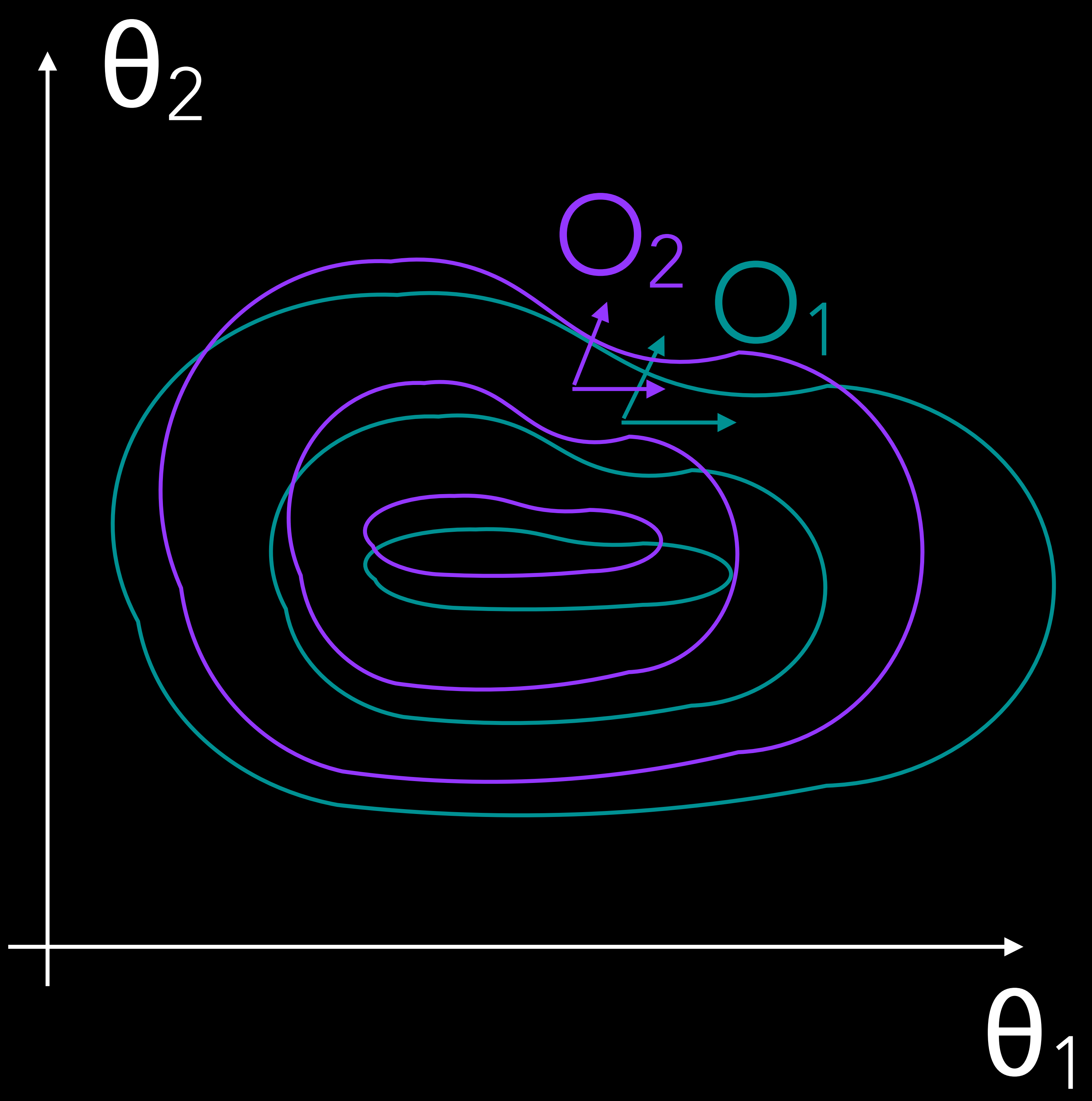
$\mathcal{O}$	Range	$\Delta_{m_t}^{(\mathcal{M}_\mathcal{O})}$	$\Delta_\theta^{(\mathcal{M}_\mathcal{O})}$						
			$\alpha_{s,FSR}$	m_b	$p_{T,\min}$	a	b	r_B	recoil
$\rho(r)$	0-0.04	-0.007(7)	0.78(1)	0.204(4)	-0.1286(8)	0.029(3)	-0.043(4)	0.056(7)	0.020(1)
$p_{T,B}/p_{T,j_b}$	0.6-0.998	-0.053(1)	-0.220(3)	-0.1397(8)	0.0353(5)	-0.0187(4)	0.0451(6)	-0.0518(9)	-0.0108(3)
E_B/E_{j_b}	0.6-0.998	-0.049(1)	-0.220(3)	-0.1381(8)	0.0360(5)	-0.0186(4)	0.0447(6)	-0.052(1)	-0.0107(3)
E_B/E_ℓ	0.05-1.5	-0.155(7)	-0.156(3)	-0.053(3)	0.0149(7)	-0.007(2)	0.016(2)	-0.016(10)	-0.0087(7)
$E_B/(E_\ell + E_{\bar{\ell}})$	0.05-1.0	0.021(5)	-0.231(2)	-0.082(4)	0.0228(4)	-0.011(2)	0.026(2)	-0.028(6)	-0.0113(3)
$m(j_{\bar{b}})/\mathrm{GeV}$	8-20	0.229(3)	0.218(1)	0.022(1)	-0.0219(7)	0.000(1)	-0.001(1)	0.001(3)	0.0050(3)
$\chi_B(\sqrt{s_{\min,bb}})$	0.075-0.875	-0.177(4)	-0.262(4)	-0.086(1)	0.0255(3)	-0.0105(10)	0.027(1)	-0.031(3)	-0.0137(2)
$\chi_B\left(E_{j_b} + E_{\bar{j}_b}\right)$	0.175-1.375	-0.109(2)	-0.357(4)	-0.134(1)	0.0373(3)	-0.016(1)	0.040(1)	-0.045(4)	-0.0175(3)
$\chi_B(m_{j_b j_{\bar{b}}})$	0.175-1.375	-0.089(3)	-0.252(3)	-0.080(1)	0.0248(3)	-0.010(1)	0.024(1)	-0.028(5)	-0.0126(2)
$\chi_B\left(\lvert p_{T,j_b}\rvert + \lvert p_{T,\bar{j}_b}\rvert\right)$	0.46-1.38	-0.15(2)	-0.47(1)	-0.189(10)	0.054(3)	-0.023(10)	0.06(1)	-0.07(4)	-0.022(2)
$m_{BB}/m_{j_b j_{\bar{b}}}$	0.8-0.95	-0.0191(8)	-0.0623(7)	-0.0464(5)	0.0146(2)	-0.0093(3)	0.0180(4)	-0.0212(9)	-0.00296(10)
$\Delta\phi(j_b j_{\bar{b}})$	0.28-3.	-0.210(7)	0.027(3)	0.001(2)	-0.0014(5)	-0.000(3)	-0.000(1)	-0.003(9)	0.0003(5)
$\Delta R(j_b j_{\bar{b}})$	1.4-3.3	-0.071(3)	0.010(1)	0.0005(10)	-0.0004(2)	-0.000(1)	0.0004(9)	0.001(3)	0.0001(2)
$\Delta\phi(BB)$	0.28-3.	-0.207(7)	0.026(2)	0.001(1)	-0.0008(4)	0.000(4)	0.000(2)	-0.000(8)	0.0002(5)
$\Delta R(BB)$	1.4-3.3	-0.070(3)	0.009(1)	0.000(1)	-0.0003(2)	-0.0003(10)	0.0002(9)	-0.000(4)	0.0001(2)
$\lvert\Delta\phi(BB) - \Delta\phi(j_b j_{\bar{b}})\rvert$	0-0.0488	0.06(1)	0.734(6)	0.099(5)	-0.088(2)	0.006(5)	-0.004(5)	0.01(2)	0.026(2)
$\lvert\Delta R(BB) - \Delta R(j_b j_{\bar{b}})\rvert$	0-0.0992	0.10(1)	0.920(3)	0.079(5)	-0.075(1)	-0.000(4)	0.005(4)	-0.00(2)	0.0418(8)



RESULTS

PYTHIA

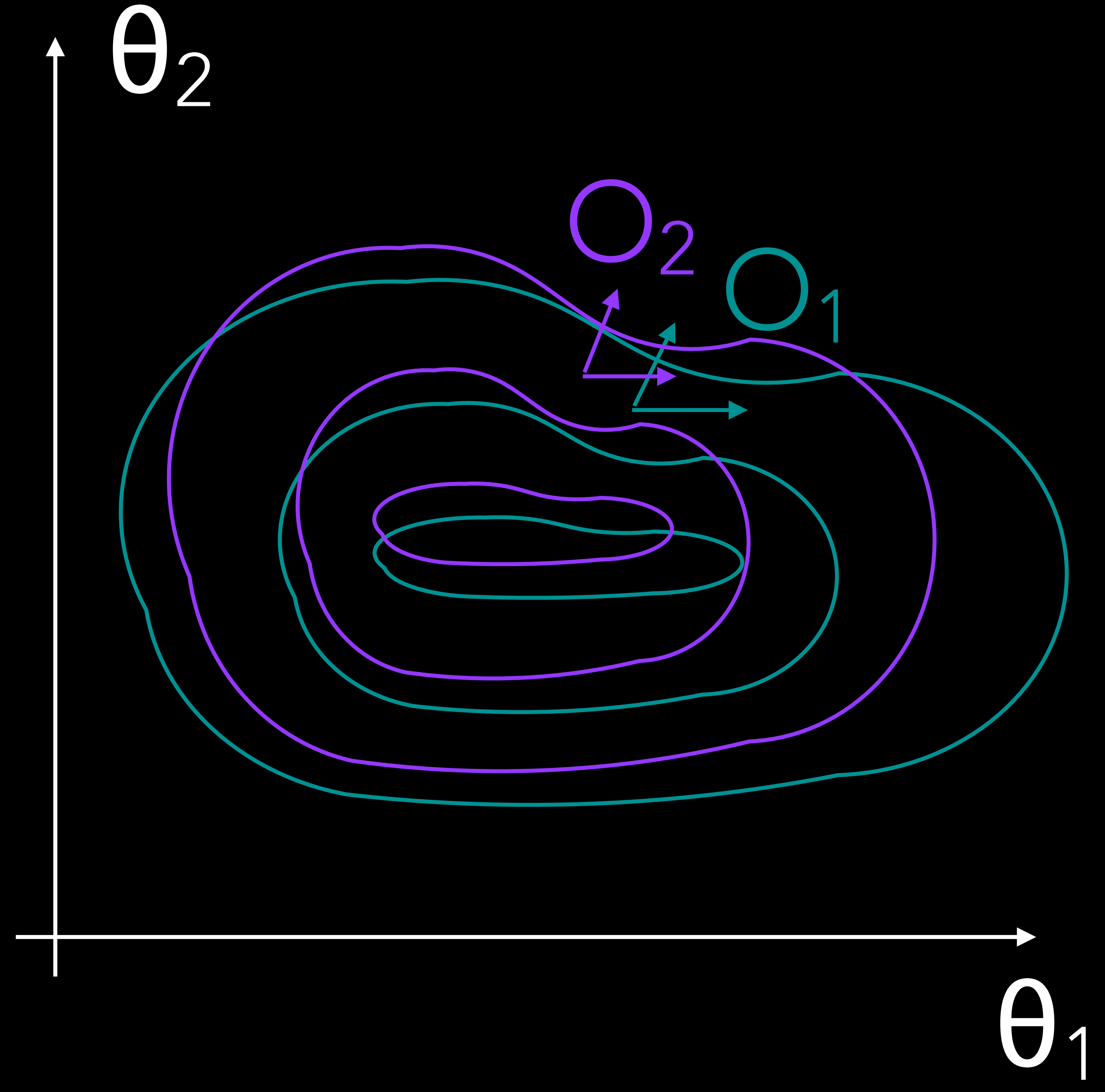
$\mathcal{O}$	Range	$\Delta_{m_t}^{(\mathcal{M}_\mathcal{O})}$	$\Delta_\theta^{(\mathcal{M}_\mathcal{O})}$						
			$\alpha_{s,FSR}$	m_b	$p_{T,\min}$	a	b	r_B	recoil
$\rho(r)$	0-0.04	-0.007(7)	0.78(1)	0.204(4)	-0.1286(8)	0.029(3)	-0.043(4)	0.056(7)	0.020(1)
$p_{T,B}/p_{T,j_b}$	0.6-0.998	-0.053(1)	-0.220(3)	-0.1397(8)	0.0353(5)	-0.0187(4)	0.0451(6)	-0.0518(9)	-0.0108(3)
E_B/E_{j_b}	0.6-0.998	-0.049(1)	-0.220(3)	-0.1381(8)	0.0360(5)	-0.0186(4)	0.0447(6)	-0.052(1)	-0.0107(3)
E_B/E_ℓ	0.05-1.5	-0.155(7)	-0.156(3)	-0.053(3)	0.0149(7)	-0.007(2)	0.016(2)	-0.016(10)	-0.0087(7)
$E_B/(E_\ell + E_{\bar{\ell}})$	0.05-1.0	0.021(5)	-0.231(2)	-0.082(4)	0.0228(4)	-0.011(2)	0.026(2)	-0.028(6)	-0.0113(3)
$m(j_{\bar{b}})/\mathrm{GeV}$	8-20	0.229(3)	0.218(1)	0.022(1)	-0.0219(7)	0.000(1)	-0.001(1)	0.001(3)	0.0050(3)
$\chi_B(\sqrt{s_{\min,bb}})$	0.075-0.875	-0.177(4)	-0.262(4)	-0.086(1)	0.0255(3)	-0.0105(10)	0.027(1)	-0.031(3)	-0.0137(2)
$\chi_B\left(E_{j_b} + E_{\bar{j}_b}\right)$	0.175-1.375	-0.109(2)	-0.357(4)	-0.134(1)	0.0373(3)	-0.016(1)	0.040(1)	-0.045(4)	-0.0175(3)
$\chi_B(m_{j_b j_{\bar{b}}})$	0.175-1.375	-0.089(3)	-0.252(3)	-0.080(1)	0.0248(3)	-0.010(1)	0.024(1)	-0.028(5)	-0.0126(2)
$\chi_B\left(\lvert p_{T,j_b}\rvert + \lvert p_{T,\bar{j}_b}\rvert\right)$	0.46-1.38	-0.15(2)	-0.47(1)	-0.189(10)	0.054(3)	-0.023(10)	0.06(1)	-0.07(4)	-0.022(2)
$m_{BB}/m_{j_b j_{\bar{b}}}$	0.8-0.95	-0.0191(8)	-0.0623(7)	-0.0464(5)	0.0146(2)	-0.0093(3)	0.0180(4)	-0.0212(9)	-0.00296(10)
$\Delta\phi(j_b j_{\bar{b}})$	0.28-3.	-0.210(7)	0.027(3)	0.001(2)	-0.0014(5)	-0.000(3)	-0.000(1)	-0.003(9)	0.0003(5)
$\Delta R(j_b j_{\bar{b}})$	1.4-3.3	-0.071(3)	0.010(1)	0.0005(10)	-0.0004(2)	-0.000(1)	0.0004(9)	0.001(3)	0.0001(2)
$\Delta\phi(BB)$	0.28-3.	-0.207(7)	0.026(2)	0.001(1)	-0.0008(4)	0.000(4)	0.000(2)	-0.000(8)	0.0002(5)
$\Delta R(BB)$	1.4-3.3	-0.070(3)	0.009(1)	0.000(1)	-0.0003(2)	-0.0003(10)	0.0002(9)	-0.000(4)	0.0001(2)
$\lvert\Delta\phi(BB) - \Delta\phi(j_b j_{\bar{b}})\rvert$	0-0.0488	0.06(1)	0.734(6)	0.099(5)	-0.088(2)	0.006(5)	-0.004(5)	0.01(2)	0.026(2)
$\lvert\Delta R(BB) - \Delta R(j_b j_{\bar{b}})\rvert$	0-0.0992	0.10(1)	0.920(3)	0.079(5)	-0.075(1)	-0.000(4)	0.005(4)	-0.00(2)	0.0418(8)

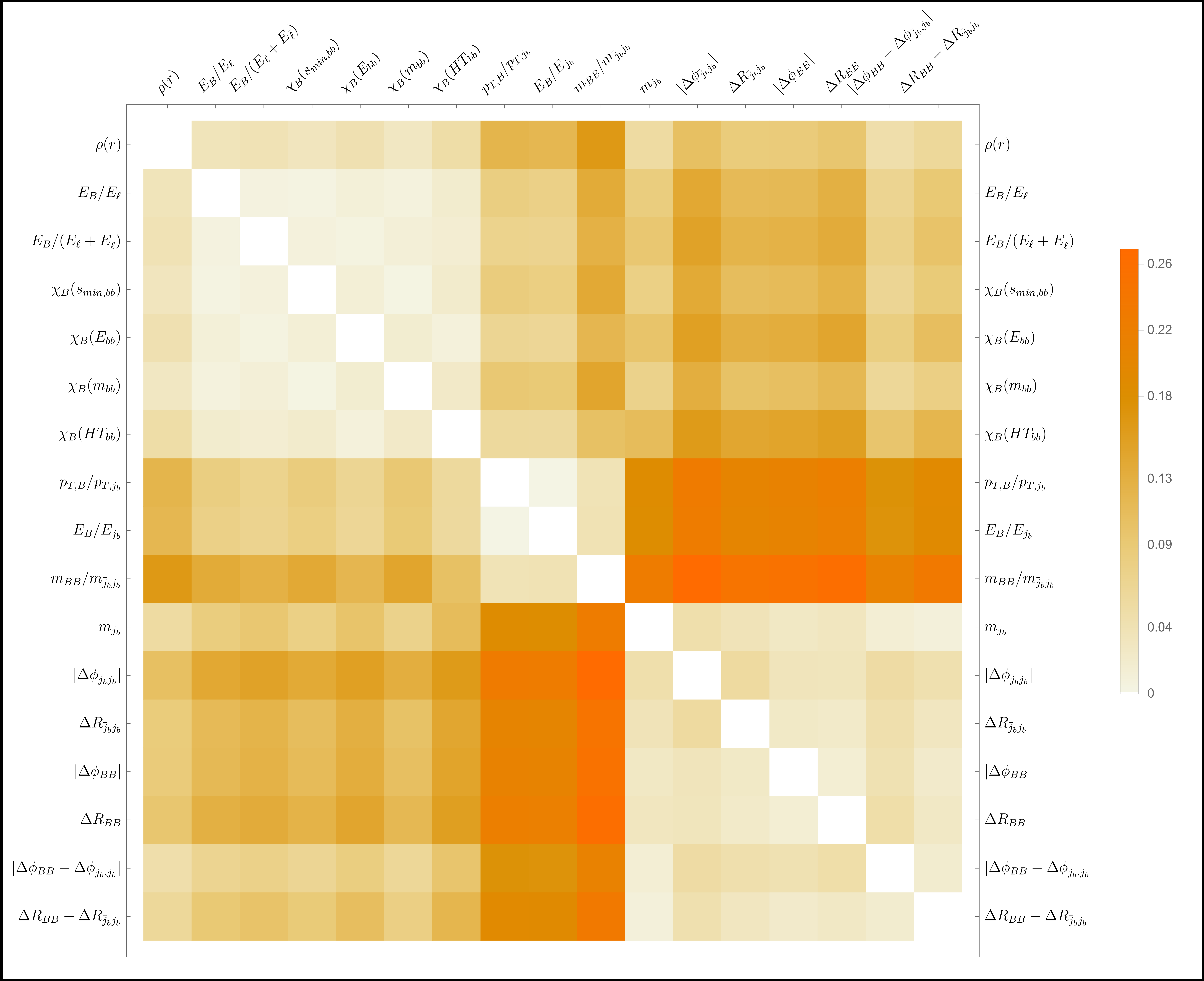


RESULTS

PYTHIA

$\mathcal{O}$	Range	$\Delta_{m_t}^{(\mathcal{M}_\mathcal{O})}$	$\Delta_\theta^{(\mathcal{M}_\mathcal{O})}$						
			$\alpha_{s,FSR}$	m_b	$p_{T,\min}$	a	b	r_B	recoil
$\rho(r)$	0-0.04	-0.007(7)	0.78(1)	0.204(4)	-0.1286(8)	0.029(3)	-0.043(4)	0.056(7)	0.020(1)
$p_{T,B}/p_{T,j_b}$	0.6-0.998	-0.053(1)	-0.220(3)	-0.1397(8)	0.0353(5)	-0.0187(4)	0.0451(6)	-0.0518(9)	-0.0108(3)
E_B/E_{j_b}	0.6-0.998	-0.049(1)	-0.220(3)	-0.1381(8)	0.0360(5)	-0.0186(4)	0.0447(6)	-0.052(1)	-0.0107(3)
E_B/E_ℓ	0.05-1.5	-0.155(7)	-0.156(3)	-0.053(3)	0.0149(7)	-0.007(2)	0.016(2)	-0.016(10)	-0.0087(7)
$E_B/(E_\ell + E_{\bar{\ell}})$	0.05-1.0	0.021(5)	-0.231(2)	-0.082(4)	0.0228(4)	-0.011(2)	0.026(2)	-0.028(6)	-0.0113(3)
$m(j_{\bar{b}})$/GeV	8-20	0.229(3)	0.218(1)	0.022(1)	-0.0219(7)	0.000(1)	-0.001(1)	0.001(3)	0.0050(3)
$\chi_B(\sqrt{s_{\min,bb}})$	0.075-0.875	-0.177(4)	-0.262(4)	-0.086(1)	0.0255(3)	-0.0105(10)	0.027(1)	-0.031(3)	-0.0137(2)
$\chi_B\left(E_{j_b} + E_{\bar{j}_b}\right)$	0.175-1.375	-0.109(2)	-0.357(4)	-0.134(1)	0.0373(3)	-0.016(1)	0.040(1)	-0.045(4)	-0.0175(3)
$\chi_B(m_{j_b j_{\bar{b}}})$	0.175-1.375	-0.089(3)	-0.252(3)	-0.080(1)	0.0248(3)	-0.010(1)	0.024(1)	-0.028(5)	-0.0126(2)
$\chi_B\left(\lvert p_{T,j_b}\rvert + \lvert p_{T,\bar{j}_b}\rvert\right)$	0.46-1.38	-0.15(2)	-0.47(1)	-0.189(10)	0.054(3)	-0.023(10)	0.06(1)	-0.07(4)	-0.022(2)
$m_{BB}/m_{j_b j_{\bar{b}}}$	0.8-0.95	-0.0191(8)	-0.0623(7)	-0.0464(5)	0.0146(2)	-0.0093(3)	0.0180(4)	-0.0212(9)	-0.00296(10)
$\Delta\phi(j_b j_{\bar{b}})$	0.28-3.	-0.210(7)	0.027(3)	0.001(2)	-0.0014(5)	-0.000(3)	-0.000(1)	-0.003(9)	0.0003(5)
$\Delta R(j_b j_{\bar{b}})$	1.4-3.3	-0.071(3)	0.010(1)	0.0005(10)	-0.0004(2)	-0.000(1)	0.0004(9)	0.001(3)	0.0001(2)
$\Delta\phi(BB)$	0.28-3.	-0.207(7)	0.026(2)	0.001(1)	-0.0008(4)	0.000(4)	0.000(2)	-0.000(8)	0.0002(5)
$\Delta R(BB)$	1.4-3.3	-0.070(3)	0.009(1)	0.000(1)	-0.0003(2)	-0.0003(10)	0.0002(9)	-0.000(4)	0.0001(2)
$\lvert\Delta\phi(BB) - \Delta\phi(j_b j_{\bar{b}})\rvert$	0-0.0488	0.06(1)	0.734(6)	0.099(5)	-0.088(2)	0.006(5)	-0.004(5)	0.01(2)	0.026(2)
$\lvert\Delta R(BB) - \Delta R(j_b j_{\bar{b}})\rvert$	0-0.0992	0.10(1)	0.920(3)	0.079(5)	-0.075(1)	-0.000(4)	0.005(4)	-0.00(2)	0.0418(8)





CONSTRAINING POWER

- Singular Value Decomposition to find combination of observable (O_i) that are sensitive to combinations of parameters (p_i)

$$\frac{\partial O}{O} = \Delta_g^{(0)} \frac{\partial g}{g}$$

	α_s	m_b	pT_{min}	a	b	r_B	recoil
Sensitivity	1.7	0.26	0.48	0.0075	0.0055	0.0033	0.0013

NOT EVEN A 10^{-3} ACCURATE MEASUREMENT OF THE MELLIN MOMENTS CAN FIX HADRONIZATION PARAMETERS BETTER THAN O(1)

CONSTRAINING POWER

- Singular Value Decomposition to find combination of observable (O_i) that are sensitive to combinations of parameters (p_i)

$$\frac{\partial O_i}{O_i} = \Delta_{ij} \frac{\partial p_j}{p_j}$$

	α_s	m_b	pT_{min}	a	b	r_B	recoil
Sensitivity	1.7	0.26	0.48	0.0075	0.0055	0.0033	0.0013

NOT EVEN A 10^{-3} ACCURATE MEASUREMENT OF THE MELLIN MOMENTS CAN FIX HADRONIZATION PARAMETERS BETTER THAN O(1)

CONSTRAINING POWER

- Singular Value Decomposition to find combination of observable (O_i) that are sensitive to combinations of parameters (p_i)

	α_s	m_b	pT_{min}	a	b	r_B	recoil
Sensitivity	1.7	0.26	0.48	0.0075	0.0055	0.0033	0.0013

NOT EVEN A 10^{-3} ACCURATE MEASUREMENT OF THE MELLIN MOMENTS CAN FIX HADRONIZATION PARAMETERS BETTER THAN O(1)

CONSTRAINING POWER

$$\begin{pmatrix} O_1 \\ \vdots \\ O_n \end{pmatrix} = \underbrace{\Delta}_{L \cdot \mathrm{diag} \cdot R} \begin{pmatrix} p_1 \\ \vdots \\ p_n \end{pmatrix}$$

- Singular Value Decomposition to find combination of observable (O_i) that are sensitive to combinations of parameters (p_i)

	α_s	m_b	pT_{min}	a	b	r_B	recoil
Sensitivity	1.7	0.26	0.48	0.0075	0.0055	0.0033	0.0013

NOT EVEN A 10^{-3} ACCURATE MEASUREMENT OF THE MELLIN MOMENTS CAN FIX HADRONIZATION PARAMETERS BETTER THAN O(1)

CONSTRAINING POWER

$$\begin{pmatrix} O_1 \\ \vdots \\ O_n \end{pmatrix} = \underbrace{\Delta}_{L \cdot \mathrm{diag} \cdot R} \begin{pmatrix} p_1 \\ \vdots \\ p_n \end{pmatrix}$$

- Singular Value Decomposition to find combination of observable (O_i) that are sensitive to combinations of parameters (p_i)

$$O' = L' O \qquad p' = R p$$

	α_s	m_b	pT_{min}	a	b	r_B	recoil
Sensitivity	1.7	0.26	0.48	0.0075	0.0055	0.0033	0.0013

NOT EVEN A 10^{-3} ACCURATE MEASUREMENT OF THE MELLIN MOMENTS CAN FIX HADRONIZATION PARAMETERS BETTER THAN O(1)

CONSTRAINING POWER

$$\begin{pmatrix} O_1 \\ \vdots \\ O_n \end{pmatrix} = \underbrace{\Delta}_{L \cdot \mathrm{diag} \cdot R} \begin{pmatrix} \theta_1 \\ \vdots \\ \theta_n \end{pmatrix}$$

- Singular Value Decomposition to find combination of observable (O_i) that are sensitive to combinations of parameters (p_i)

$$O' = L' O \qquad \theta' = R\theta$$

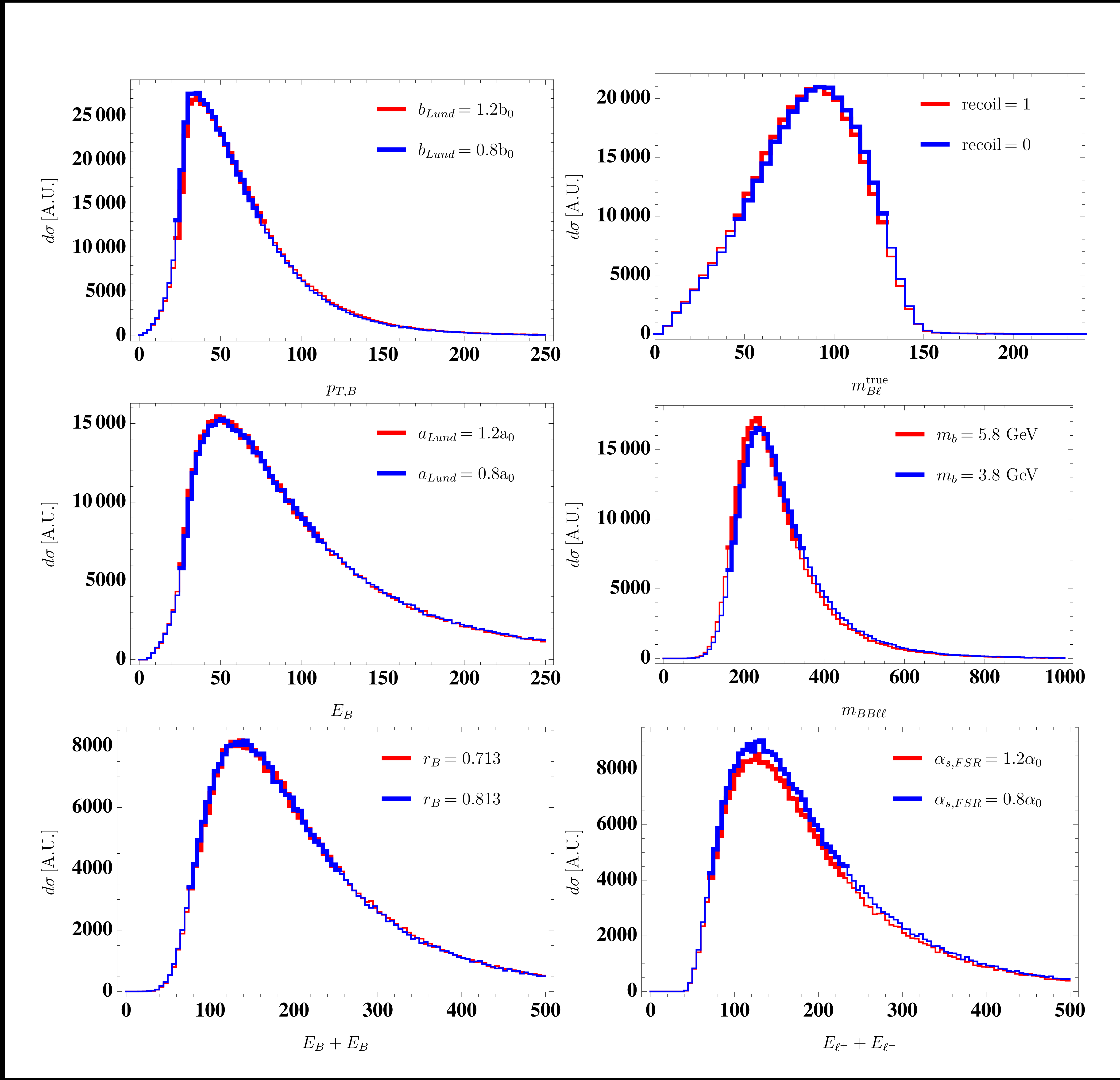
$$\mathbf{cov}_{\frac{d\theta}{\theta}} = \tilde{\Delta}_{\theta}^{(\mathcal{M}_{\mathcal{O}})} \cdot \mathbf{cov}_{\frac{d\mathcal{O}}{\mathcal{O}}} \cdot \tilde{\Delta}_{\theta}^{(\mathcal{M}_{\mathcal{O}})^t} .$$

	α_s	m_b	pT_{min}	a	b	r_B	recoil
Sensitivity	1.7	0.26	0.48	0.0075	0.0055	0.0033	0.0013

NOT EVEN A 10^{-3} ACCURATE MEASUREMENT OF THE MELLIN MOMENTS CAN FIX HADRONIZATION PARAMETERS BETTER THAN O(1)

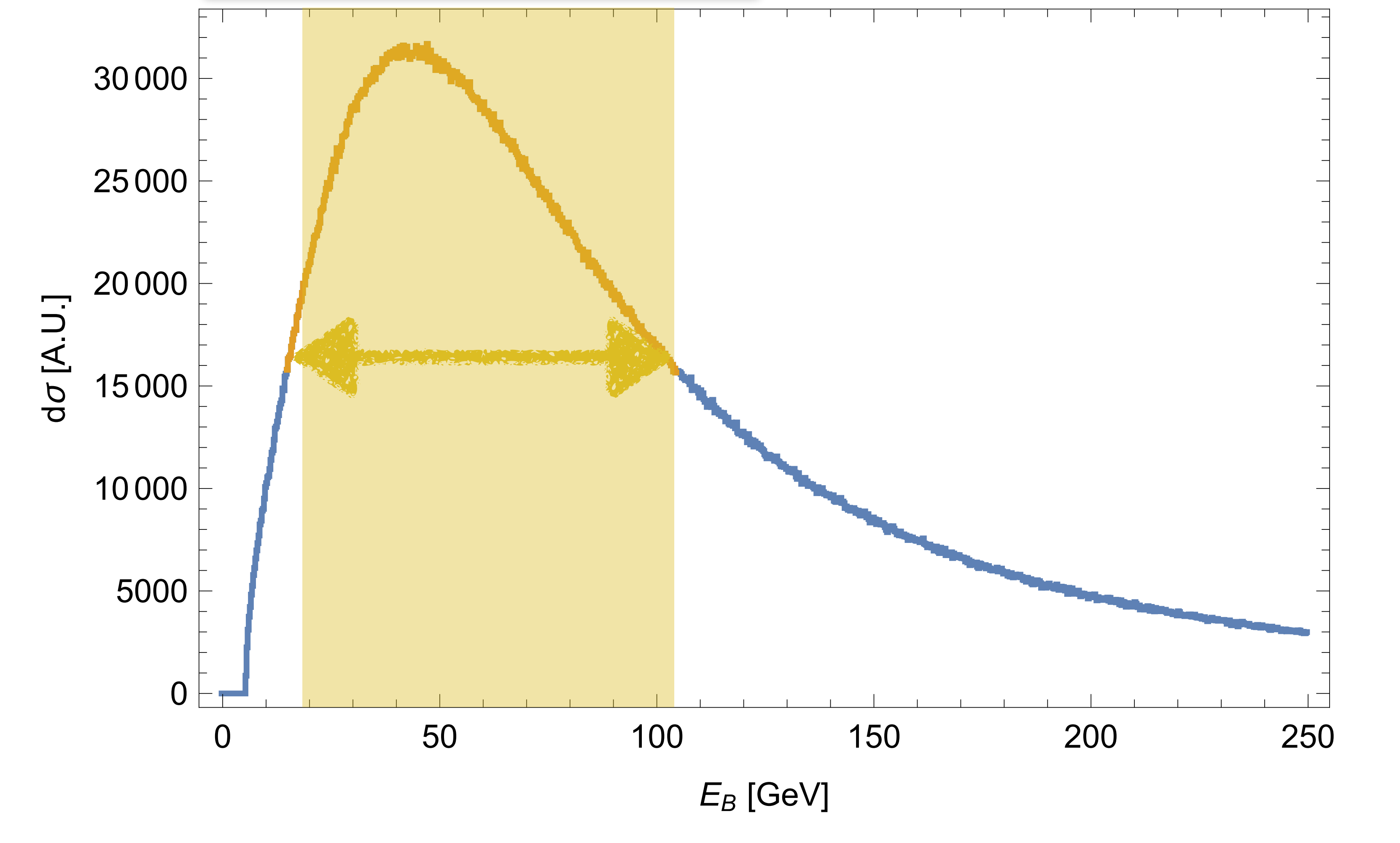
CAN TOP MASS BE MEASURED PRECISELY ENOUGH ?

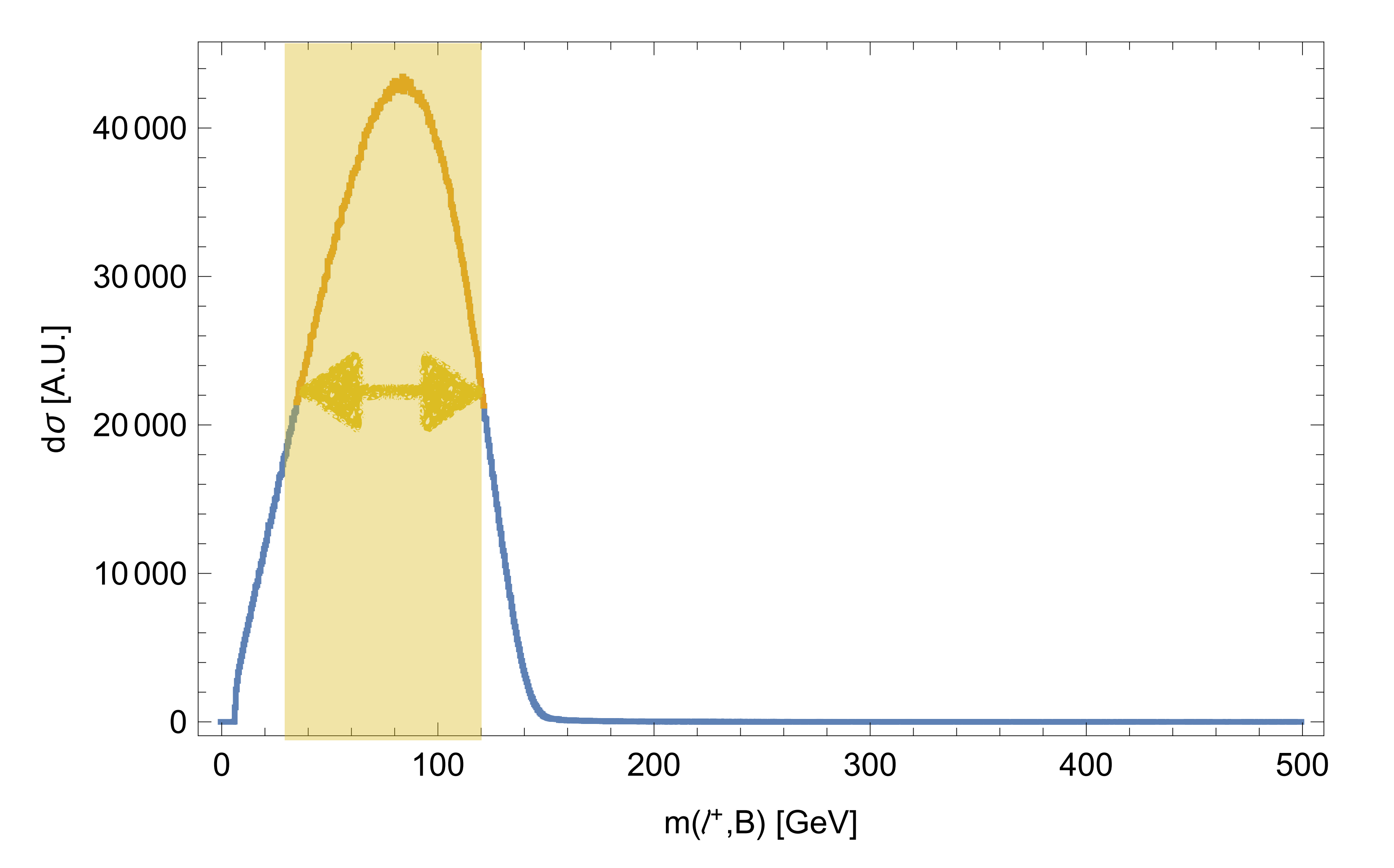
CAN TOP MASS BE MEASURED PRECISELY ENOUGH ?



CAN TOP MASS BE MEASURED PRECISELY ENOUGH ?

FWHM
used to compute
Mellin-1





CAN TOP MASS BE MEASURED PRECISELY ENOUGH ?

PYTHIA

CAN TOP MASS BE MEASURED PRECISELY ENOUGH ?

$\mathcal{O}$	Range	$\Delta_{m_t}^{(\mathcal{M}_\mathcal{O})}$	$\Delta_\theta^{(m_t)}$						
			$\alpha_{s,FSR}$	m_b	$p_{T,\min}$	a	b	r_B	recoil
E_B	28-110	0.92(5)	-0.52(2)	-0.21(3)	0.057(4)	-0.02(2)	0.06(2)	-0.10(5)	-0.022(5)
$p_{T,B}$	24-72	0.92(3)	-0.54(2)	-0.21(2)	0.056(4)	-0.03(2)	0.07(1)	-0.09(4)	-0.023(2)
$m_{B\ell,\text{true}}$	47-125	1.30(2)	-0.241(8)	-0.072(6)	0.022(2)	-0.007(5)	0.023(6)	-0.02(2)	-0.008(2)
$m_{B\ell^+,\min}$	30-115	1.16(2)	-0.282(5)	-0.078(7)	0.024(2)	-0.011(7)	0.021(7)	-0.04(2)	-0.010(1)
$E_B + E_B$	83-244	0.92(4)	-0.50(2)	-0.21(2)	0.056(6)	-0.02(2)	0.07(3)	-0.08(6)	-0.020(4)
$m_{BB\ell\ell}$	172-329	0.96(2)	-0.25(1)	-0.10(1)	0.028(3)	-0.01(1)	0.026(7)	-0.03(3)	-0.008(2)
$m_{T2,B\ell,\text{true}}^{(\text{mET})}$	73-148	0.95(3)	-0.27(1)	-0.09(1)	0.029(3)	-0.009(9)	0.03(1)	-0.03(4)	-0.010(3)
$m_{T2,B\ell,\min}^{(\text{mET})}$	73-148	0.95(3)	-0.27(1)	-0.09(1)	0.029(3)	-0.009(9)	0.03(1)	-0.03(4)	-0.010(3)
$m_{T2}^{(\ell\nu)}$	0.5-80	-0.118(7)	-0.03(2)	0.00(2)	0.002(8)	0.00(2)	-0.01(2)	0.00(7)	0.004(5)
$m_{\ell\ell}$	37.5-145	0.40(5)	-0.03(5)	-0.01(4)	0.00(1)	0.01(5)	0.01(4)	0.0(1)	0.00(1)
$E_\ell + E_\ell$	75-230	0.54(5)	-0.03(3)	0.00(3)	0.003(9)	0.01(3)	-0.00(2)	0.06(9)	0.003(8)
E_ℓ	23-100	0.48(4)	-0.02(5)	0.00(5)	0.004(9)	0.01(4)	-0.01(4)	-0.06(9)	0.003(8)

PYTHIA

CAN TOP MASS BE MEASURED PRECISELY ENOUGH ?

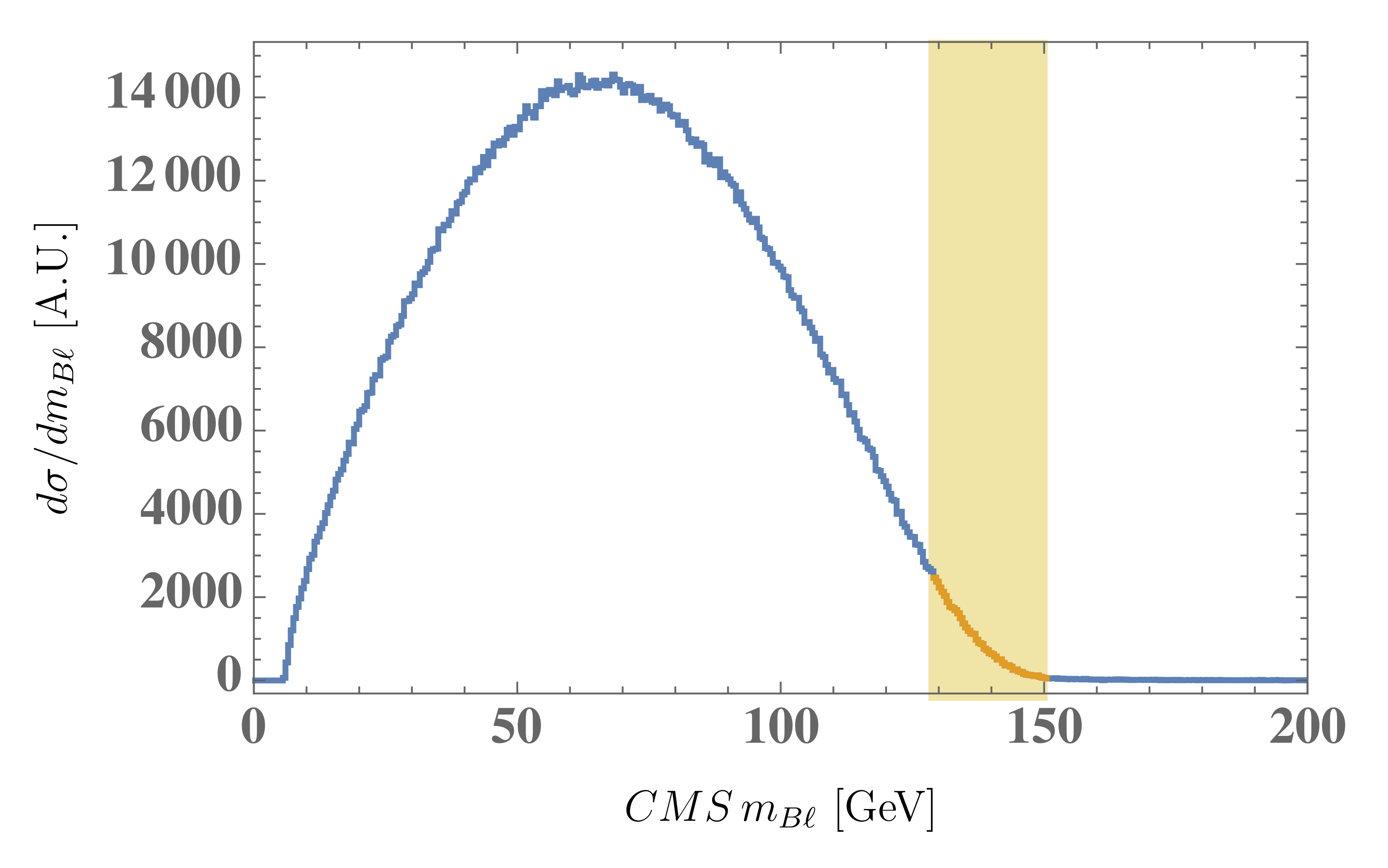
$\mathcal{O}$	Range	$\Delta_{m_t}^{(\mathcal{M}_{\mathcal{O}})}$	$\Delta_\theta^{(m_t)}$						
			$\alpha_{s,FSR}$	m_b	$p_{T,\min}$	a	b	r_B	recoil
E_B	28-110	0.92(5)	-0.52(2)	-0.21(3)	0.057(4)	-0.02(2)	0.06(2)	-0.10(5)	-0.022(5)
$p_{T,B}$	24-72	0.92(3)	-0.54(2)	-0.21(2)	0.056(4)	-0.03(2)	0.07(1)	-0.09(4)	-0.023(2)
$m_{B\ell,\text{true}}$	47-125	1.30(2)	-0.241(8)	-0.072(6)	0.022(2)	-0.007(5)	0.023(6)	-0.02(2)	-0.008(2)
$m_{B\ell^+,\min}$	30-115	1.16(2)	-0.282(5)	-0.078(7)	0.024(2)	-0.011(7)	0.021(7)	-0.04(2)	-0.010(1)
E_B+E_B	83-244	0.92(4)	-0.50(2)	-0.21(2)	0.056(6)	-0.02(2)	0.07(3)	-0.08(6)	-0.020(4)
$m_{BB\ell\ell}$	172-329	0.96(2)	-0.25(1)	-0.10(1)	0.028(3)	-0.01(1)	0.026(7)	-0.03(3)	-0.008(2)
$m_{T2,B\ell,\text{true}}^{(\text{mET})}$	73-148	0.95(3)	-0.27(1)	-0.09(1)	0.029(3)	-0.009(9)	0.03(1)	-0.03(4)	-0.010(3)
$m_{T2,B\ell,\min}^{(\text{mET})}$	73-148	0.95(3)	-0.27(1)	-0.09(1)	0.029(3)	-0.009(9)	0.03(1)	-0.03(4)	-0.010(3)
$m_{T2}^{(\ell\nu)}$	0.5-80	-0.118(7)	-0.03(2)	0.00(2)	0.002(8)	0.00(2)	-0.01(2)	0.00(7)	0.004(5)
$m_{\ell\ell}$	37.5-145	0.40(5)	-0.03(5)	-0.01(4)	0.00(1)	0.01(5)	0.01(4)	0.0(1)	0.00(1)
$E_\ell+E_\ell$	75-230	0.54(5)	-0.03(3)	0.00(3)	0.003(9)	0.01(3)	-0.00(2)	0.06(9)	0.003(8)
E_ℓ	23-100	0.48(4)	-0.02(5)	0.00(5)	0.004(9)	0.01(4)	-0.01(4)	-0.06(9)	0.003(8)

"SIMPLE" OBSERVABLES (MELLIN MOMENTS) REQUIRE GOOD KNOWLEDGE OF MONTE CARLO PARAMETERS

- α_s needed at 1%
- m_b needed at 3%
- all the rest needed at 10%

- All hadronic observables in the same ballpark (within factor 2)
- m_{T2} similar to m_{Bl}
- Fully Leptonic observables one order less sensitive (stat~0)

End-point



- 1% of the cross-section to go the end-point
- how much better does it get?

CAN TOP MASS BE MEASURED PRECISELY ENOUGH ?

SENSITIVIY ~ PERCENT OR BELOW

$\mathcal{O}$	Range	$\Delta_{m_t}^{(\mathcal{O})}$	$\Delta_\theta^{(m_t)}$						
			$\alpha_{s,FSR}$	m_b	$p_{T,\min}$	a	b	r_B	recoil
$E_{B,\text{peak}}$	35-85	0.8(1)	-0.74(9)	-0.26(4)	0.05(1)	-0.04(2)	0.08(3)	-0.07(9)	-0.031(7)
$\breve{m}_{B\ell,\text{true}}$	127-150	1.26(1)	0.017(6)	0.003(9)	-0.006(2)	-0.008(2)	0.008(7)	-0.016(6)	-0.00042(9)
$\breve{m}_{B\ell,\min}$	127-150	1.28(1)	-0.023(3)	-0.022(2)	0.006(3)	-0.008(3)	0.008(3)	-0.02(1)	-0.0001(6)
$\breve{m}^{(\text{mET})}_{T2,B\ell,\text{true}}$	150-170	0.98(2)	-0.01(2)	-0.023(3)	0.007(1)	-0.006(3)	0.010(4)	-0.011(9)	-0.0002(8)
$\breve{m}^{(\text{mET})}_{T2,B\ell,\min}$	150-170	0.97(2)	-0.02(1)	-0.021(5)	0.006(2)	-0.006(3)	0.009(4)	-0.01(1)	-0.0001(8)
$\breve{m}^{(\text{mET})}_{T2,B\ell,\min,\perp}$	138-170	0.89(2)	-0.071(5)	-0.046(7)	0.012(2)	-0.011(7)	0.010(8)	-0.01(2)	-0.002(1)
$\breve{m}^{(\text{mET})}_{T2,B}$	142-170	0.95(3)	-0.089(6)	-0.064(6)	0.018(1)	-0.017(4)	0.031(4)	-0.04(2)	-0.0028(8)
$\breve{m}^{(\text{mET})}_{T2,B,\perp}$	126-170	0.94(4)	-0.07(1)	-0.04(1)	0.011(3)	-0.009(9)	0.02(1)	-0.03(4)	-0.001(2)

- α_s needed at 10%
- m_b needed at 10%
- r_B needed at 10%
- all the rest needed at "100%"

"NOT SO SIMPLE" OBSERVABLES (END-POINTS) REQUIRE FAIR KNOWLEDGE OF MONTE CARLO PARAMETERS (MOSTLY SHOWERING)

CAN TOP MASS BE MEASURED PRECISELY ENOUGH ?

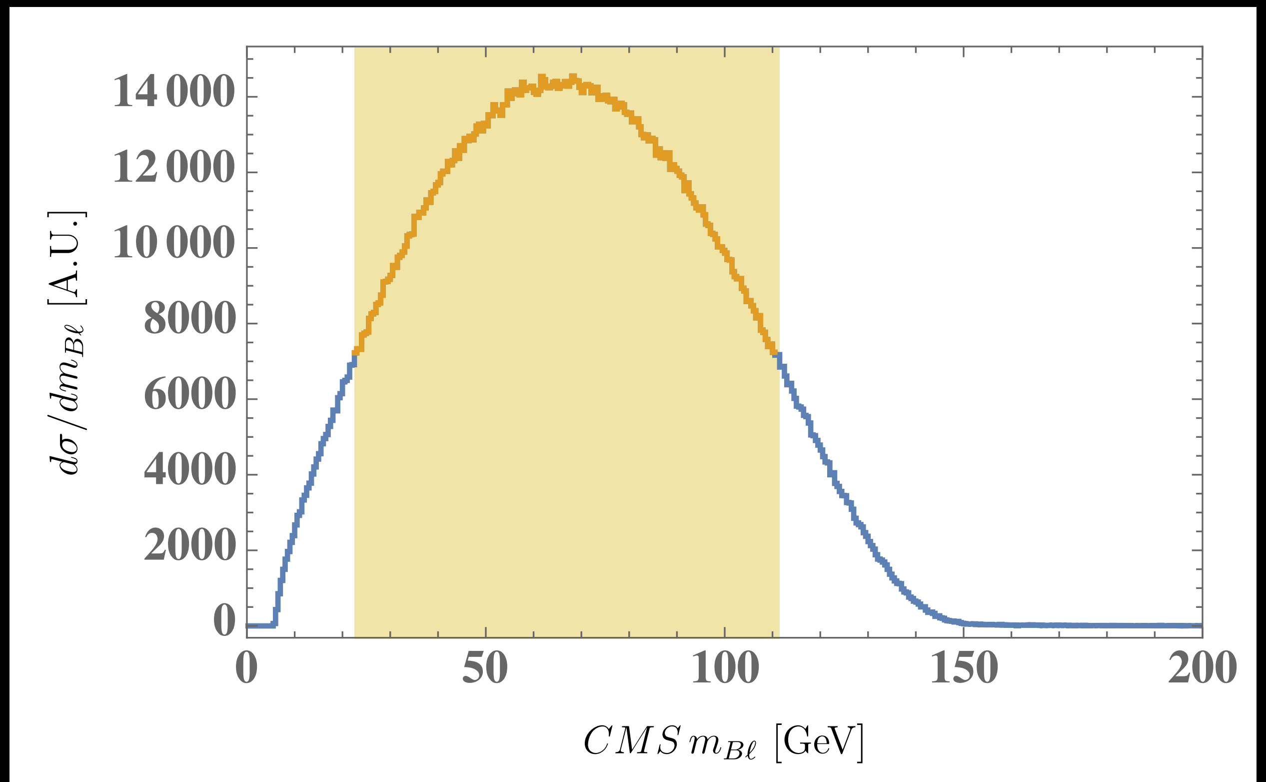
$\mathcal{O}$	$\Delta_{m_t}^{(\mathcal{M}_\mathcal{O})}$	$\Delta_\theta^{(m_t)}$								
		PSPLT	QCDLAM	CLPOW	CLSMR(2)	CLMAX	RMASS(5)	RMASS(13)	VGCUT	VQCUT
$m_{B\ell,\text{true}}$	0.52	0.036(4)	-0.008(2)	-0.007(5)	0.002(3)	-0.007(4)	0.058(1)	0.06(5)	0.003(1)	-0.003(3)
$p_{T,B}$	0.47	0.072(1)	-0.03(9)	-0.02(7)	0.0035(5)	-0.03(5)	0.11(9)	0.12(5)	0.0066(2)	-0.006(5)
E_B	0.43	0.069(7)	-0.026(7)	-0.017(5)	0.0038(9)	-0.01(2)	0.12(1)	0.12(2)	0.006(2)	-0.007(5)
E_ℓ	0.13	0.0005(5)	-0.04(3)	0.04(2)	-0.0002(2)	-0.004(4)	0.008(3)	0.008(2)	-0.002(5)	0.008(2)

"NOT SO SIMPLE" OBSERVABLES (END-POINTS) REQUIRE FAIR KNOWLEDGE OF MONTE CARLO PARAMETERS (MOSTLY SHOWERING)

- $\Lambda_{QCD} \Rightarrow \alpha_s$ needed at 1%
- $m_{b,g}$ needed at 1%
- cluster mass spectrum (PSPLT, CLPOW, CLMAX) needed at 10%
- all the rest needed at "100%"

- $\Lambda_{QCD} \Rightarrow \alpha_s$ needed at 3%
- $m_{b,g}$ needed at 2%
- cluster mass spectrum (PSPLT, CLPOW, CLMAX) needed at 20%
- all the rest needed at "100%"

MONTE CARLO CALIBRATION TARGETS

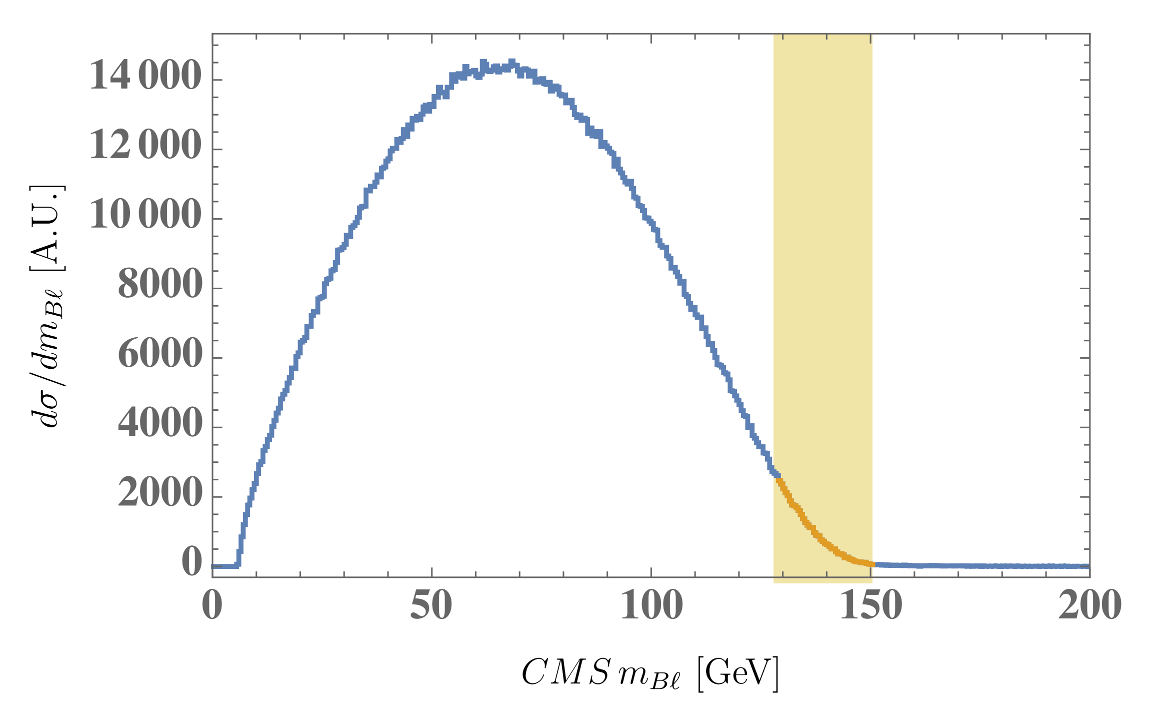


Pythia8

- α_s needed at 1%
- m_b needed at 3%
- all the rest needed at 10%

Herwig6

- $\Lambda_{QCD} \Rightarrow \alpha_s$ needed at 1%
- $m_{b,g}$ needed at 1%
- cluster mass spectrum (PSPLT, CLPOW, CLMAX) needed at 10%
- all the rest needed at "100%"



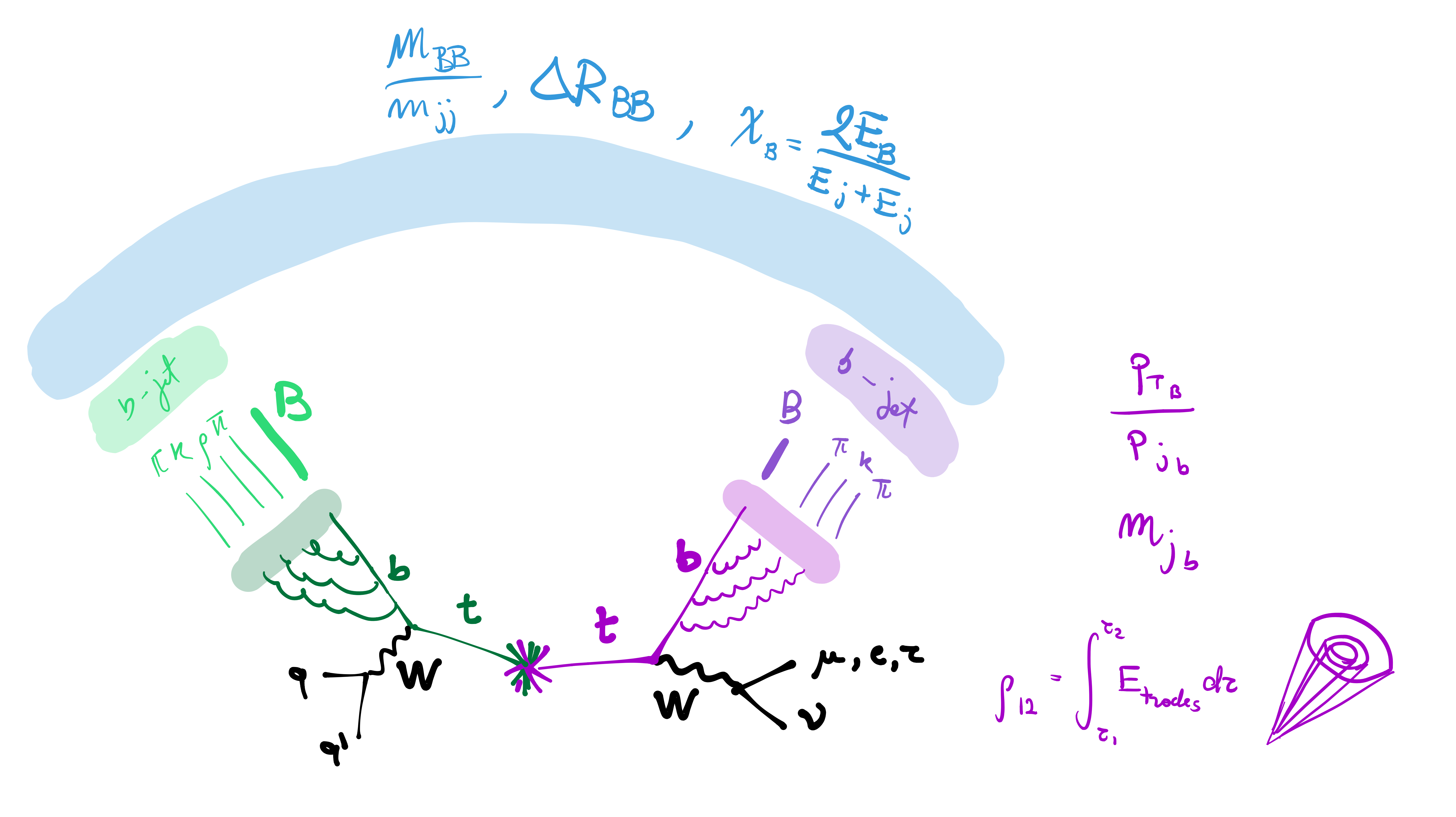
Pythia8

- α_s needed at 10%
- m_b needed at 10%
- r_B needed at 10%
- all the rest needed at "100%"

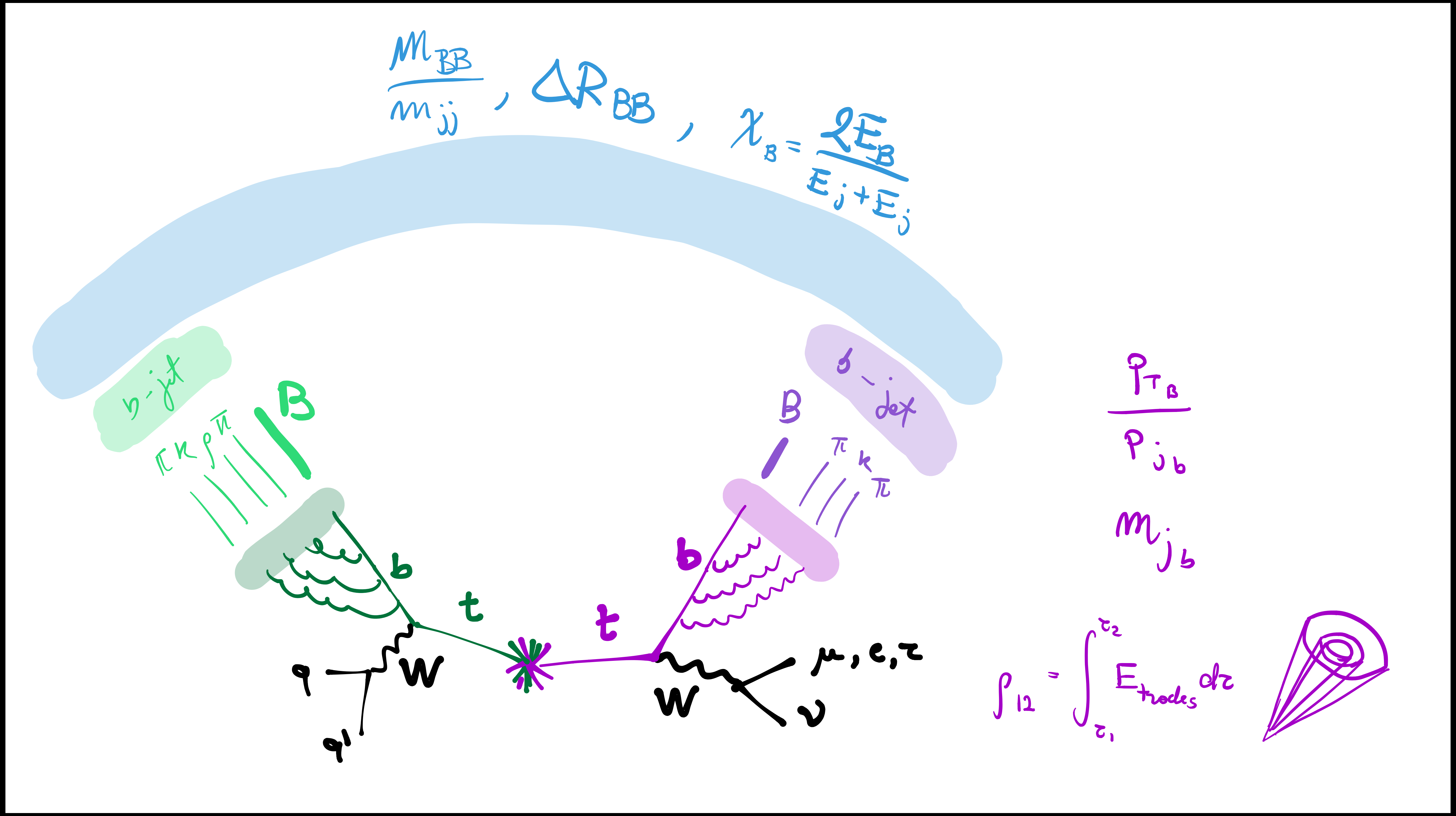
Herwig6

- $\Lambda_{QCD} \Rightarrow \alpha_s$ needed at 3%
- $m_{b,g}$ needed at 2%
- cluster mass spectrum (PSPLT, CLPOW, CLMAX) needed at 20%
- all the rest needed at "100%"

IN-SITU MONTE CARLO CALIBRATION



IN-SITU MONTE CARLO CALIBRATION

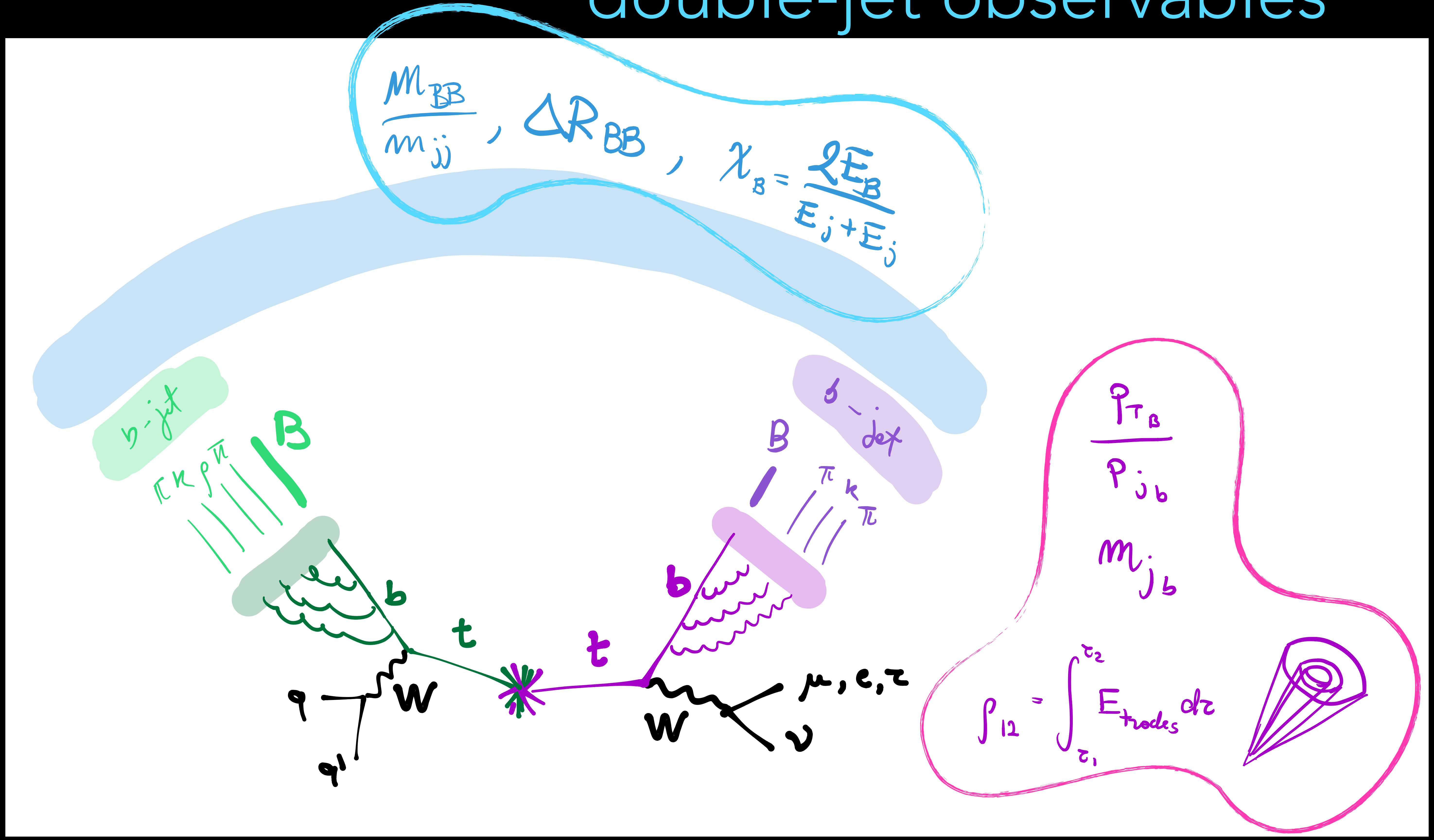


Measure ***n*** observables and simultaneously extract ***m*** theory parameters, one of which is m_{top}, the rest are MC parameters

IT IS NOT A TUNING: PERCENT DIFFERENCES IN THE MC PARAMETERS ARE BEYOND THE ACCURACY OF THE MC, IT CANNOT BE UNIVERSAL

IN-SITU MONTE CARLO CALIBRATION

double-jet observables

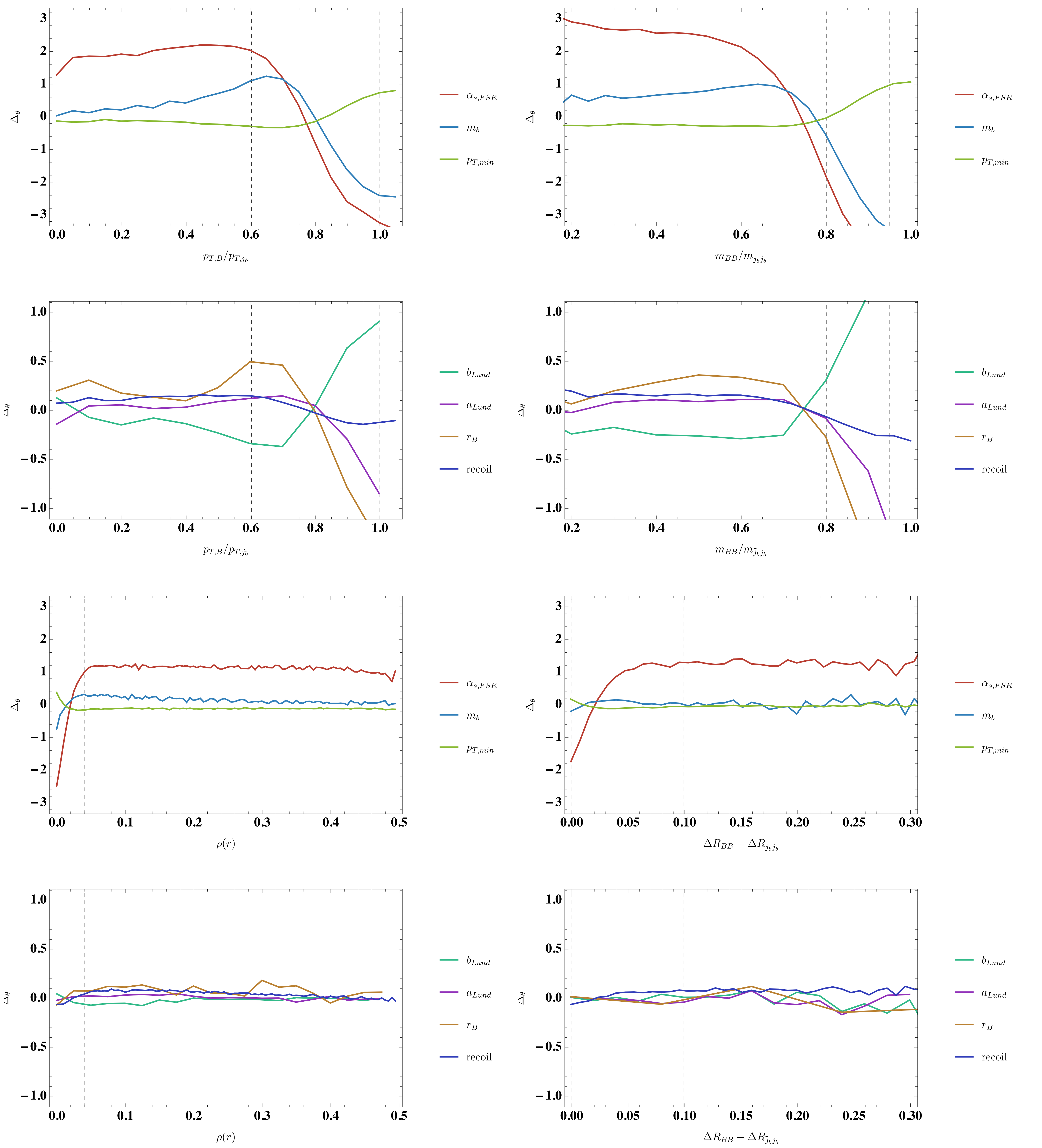


single-jet observables

- some involve jet-energy
- might be a limitation to the calibration
- explore tracker-only observables as well

EACH BIN IS AN OBSERVABLE

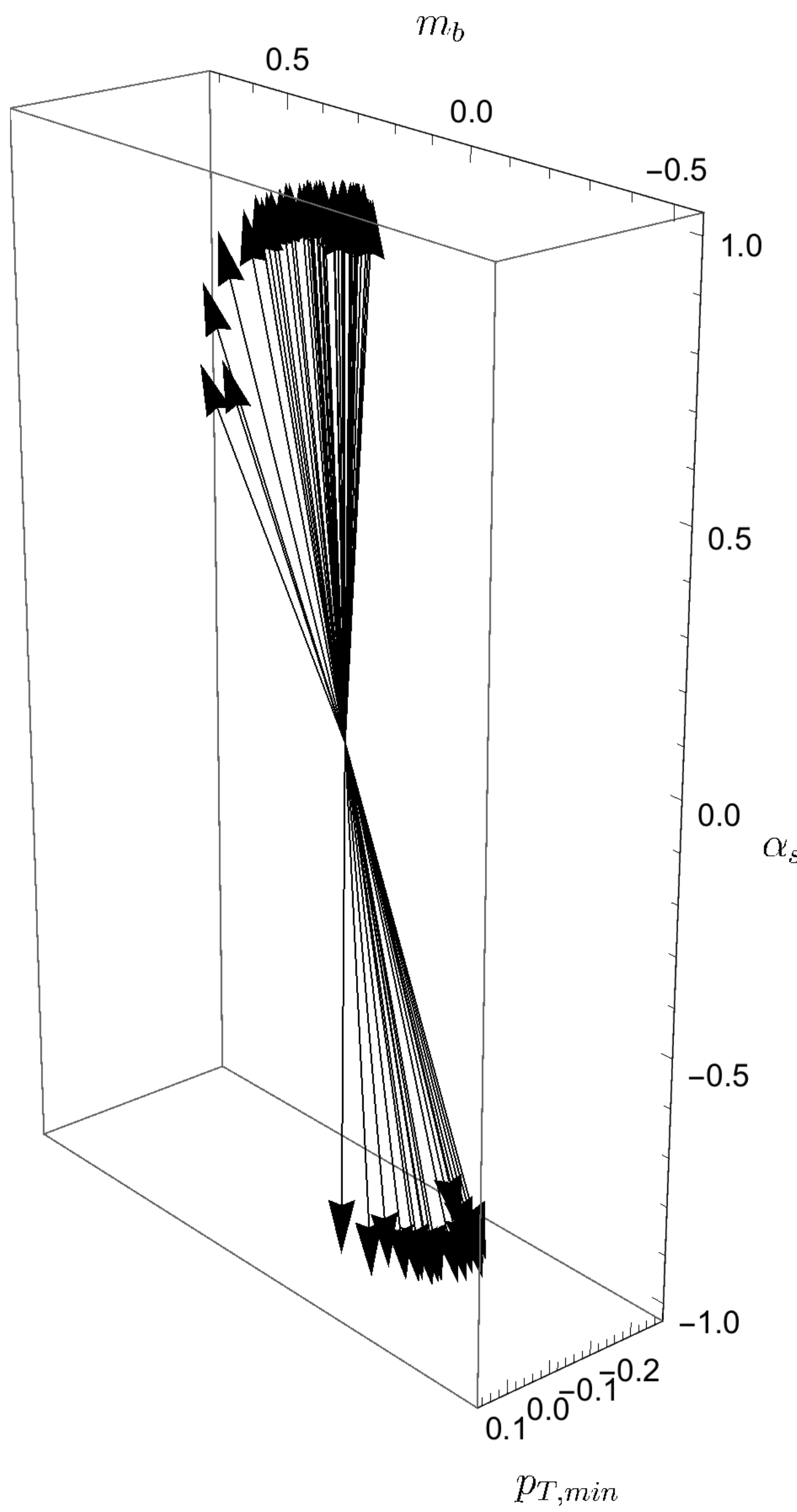
Full shape analysis:
Instead of Mellin moments,
use all bins

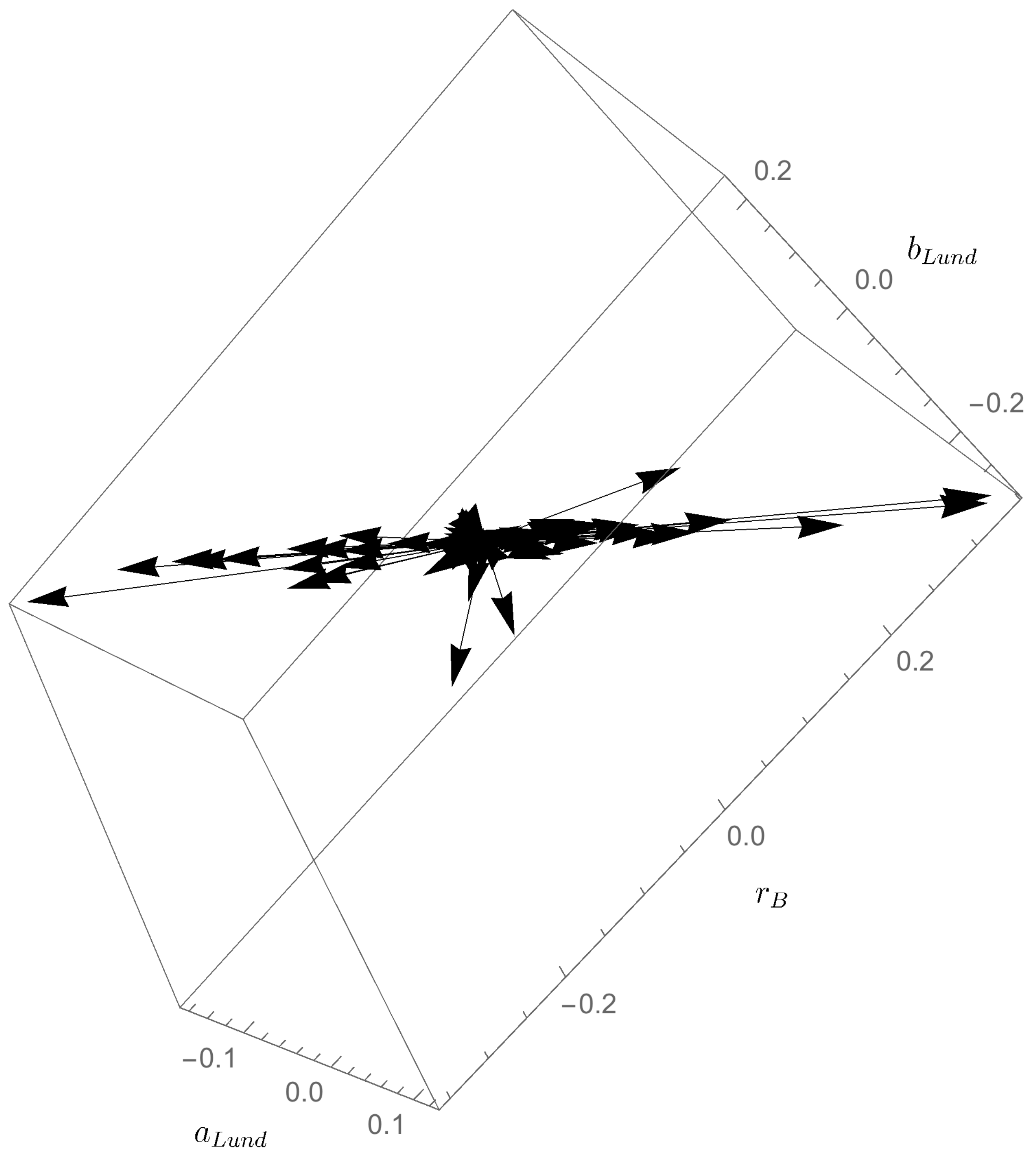


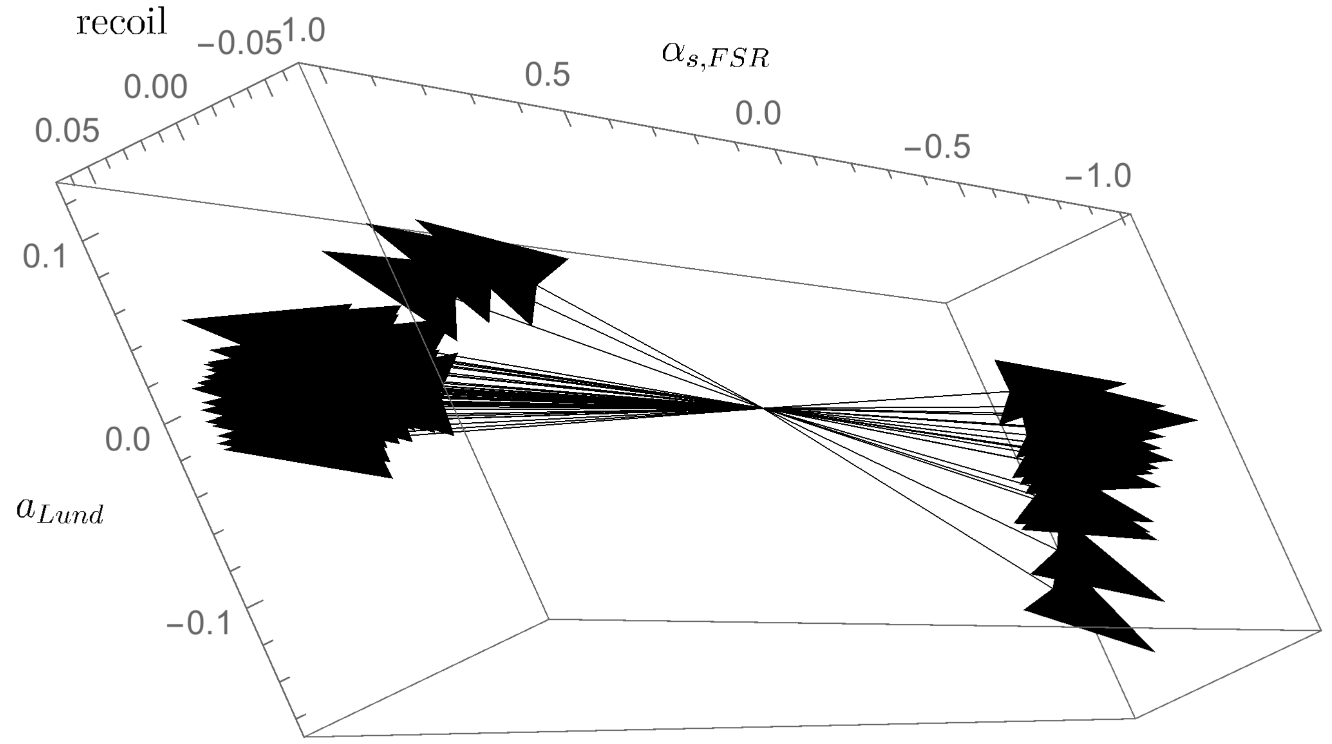
EACH BIN IS AN OBSERVABLE

$\mathcal{O}$	Range	N_{bins}
$\rho(r)$	0.-0.4	16
$p_{T,B}/p_{T,j_b}$	0.-0.99	11
E_B/E_ℓ	0.05-4.55	9
$\chi_B\left(E_{j_b}+E_{\bar{j}_b}\right)$	0.-2.	10
$m_{BB}/m_{j_b j_{\bar{b}}}$	0.-0.998	11
$\lvert\Delta R(BB)-\Delta R(j_b j_{\bar{b}})\rvert$	0.-0.288	9

Full shape analysis:
In principle each bin is sensitive to a different combination of parameters







EACH BIN IS AN OBSERVABLE

$\mathcal{O}$	Range	N_{bins}
$\rho(r)$	0.-0.4	16
$p_{T,B}/p_{T,j_b}$	0.-0.99	11
E_B/E_ℓ	0.05-4.55	9
$\chi_B\left(E_{j_b}+E_{\bar{j}_b}\right)$	0.-2.	10
$m_{BB}/m_{j_b j_{\bar{b}}}$	0.-0.998	11
$\lvert\Delta R(BB)-\Delta R(j_b j_{\bar{b}})\rvert$	0.-0.288	9

Full shape analysis:
In principle each bin is sensitive to a different combination of parameters

1% MEASUREMENT OF EACH BIN

IMPLIES RELATIVE ERRORS:

$\alpha_{s,FSR}$	m_b	$p_{T,\min}$	a	b	r_B	recoil
0.045	0.14	0.35	0.5	0.48	0.21	0.73

$$\begin{pmatrix} 1. & -0.13 & 0.48 & -0.37 & -0.24 & 0.38 & -0.85 \\ -0.13 & 1. & 0.01 & 0.62 & 0.81 & -0.46 & -0.06 \\ 0.48 & 0.01 & 1. & -0.09 & -0.13 & 0.53 & -0.08 \\ -0.37 & 0.62 & -0.09 & 1. & 0.8 & -0.47 & 0.31 \\ -0.24 & 0.81 & -0.13 & 0.8 & 1. & -0.23 & 0.15 \\ 0.38 & -0.46 & 0.53 & -0.47 & -0.23 & 1. & 0. \\ -0.85 & -0.06 & -0.08 & 0.31 & 0.15 & 0. & 1. \end{pmatrix}$$

SUMMARY

PROBED NON-PERTURBATIVE ASPECT OF MONTE CARLO: HADRONIZATION MODEL

PROBED m_{top}-SENSITIVE OBSERVABLES THAT DO NOT SUFFER JET UNCERTAINTIES

Hadron-level observables can lead to useful top mass measurements

UNCERTAINTY FROM HADRONIZATION MODELING CAN BE AS LARGE AS FEW % OF MODEL PARAMETER UNCERTAINTY (BOTH HW PSPLT AND PY r_B, b)

END-POINT OBSERVABLES CAN REDUCE DEPENDENCE OF HADRONIZATION (OTHER THEORY ISSUES STEP IN)

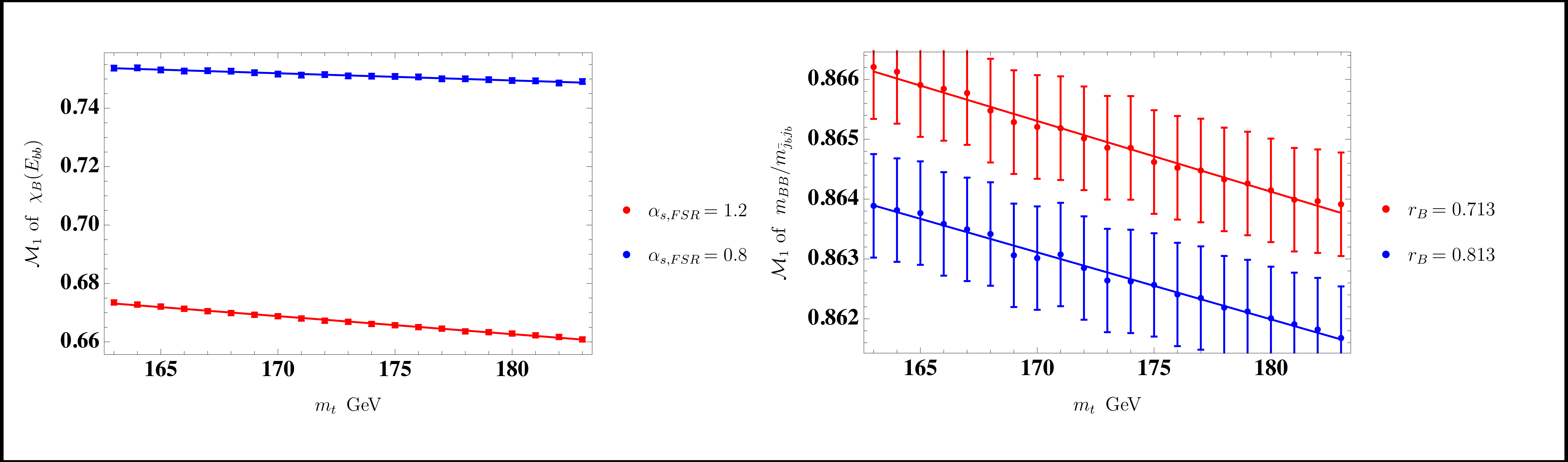
IN SITU CALIBRATION: MEASURING m_{top} & RELEVANT MC PARAMETERS IN THE SAME DATA CAN FIX MC BLURRINESS

$pp \to bb$ CAN ALSO BE USED TO CROSS-CHECK AND TO TEST UNIVERSALITY

SIMILAR STUDY CAN BE REPEATED FOR COLOR RECONNECTION

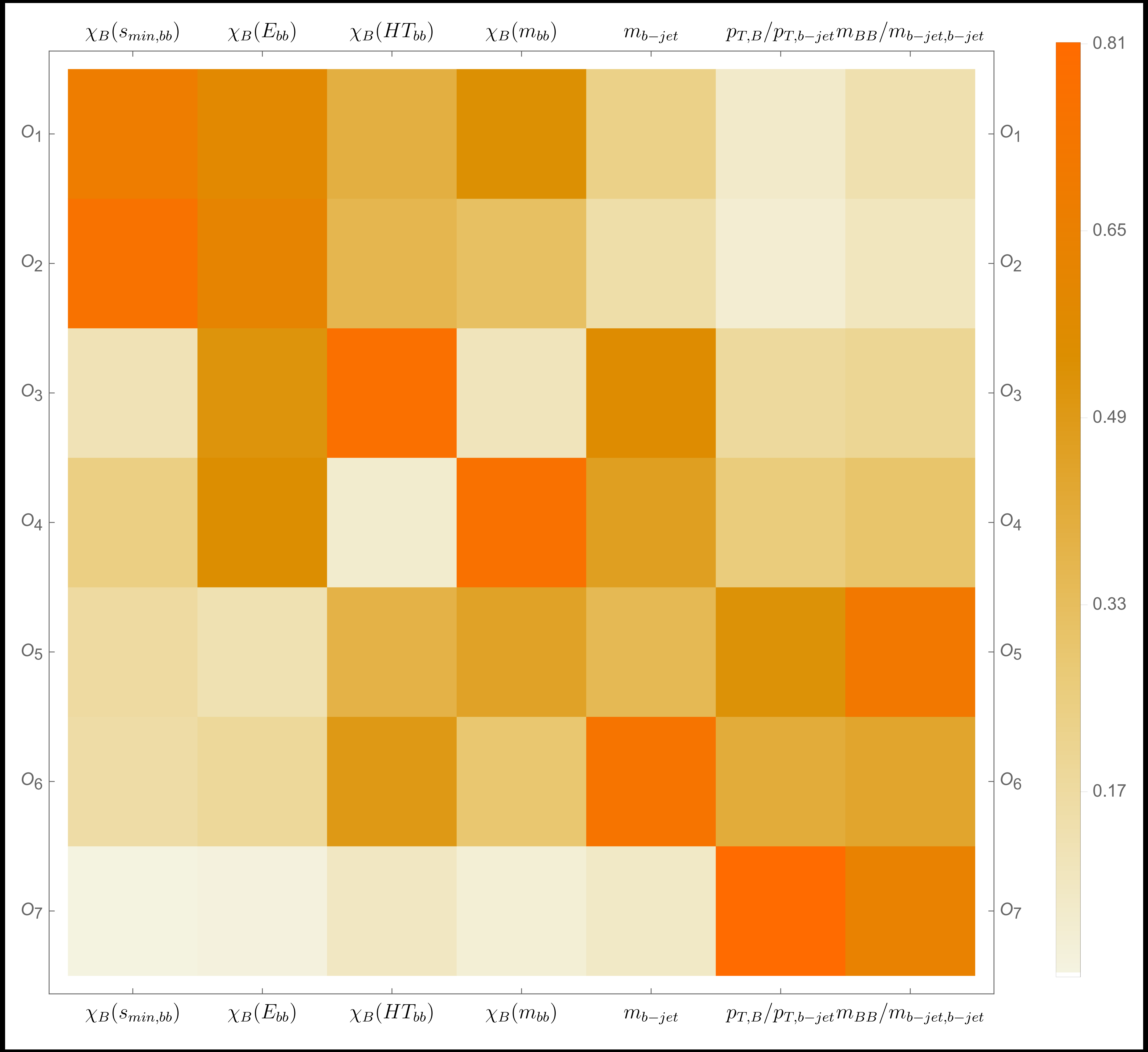
THANK YOU!

DEPENDENCE ON TOP MASS IN CALIBRATION



OBSERVABLES

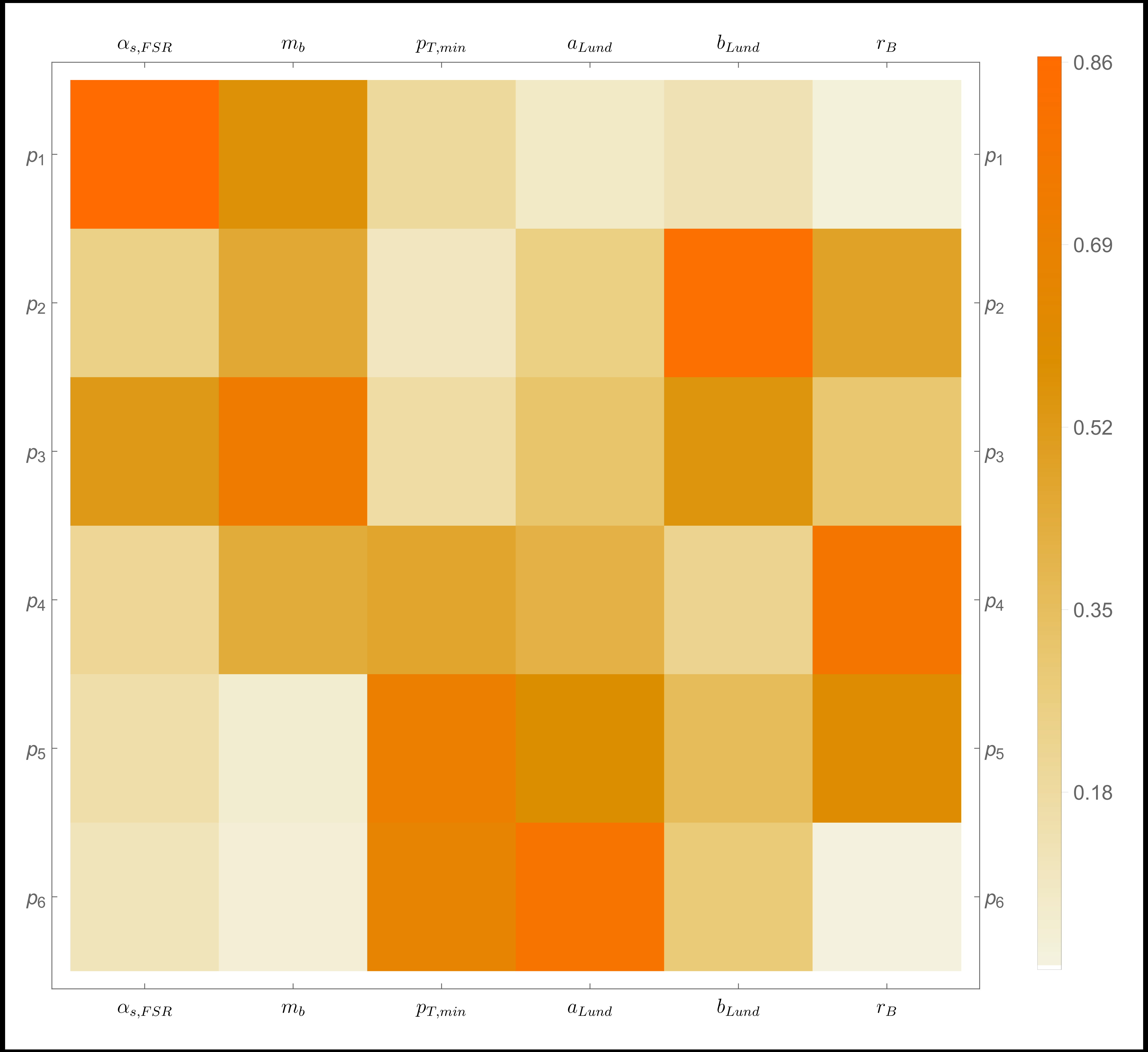
CALIBRATION



	$\chi_B(s_{min,bb})$	$\chi_B(E_{bb})$	$\chi_B(HT_{bb})$	$\chi_B(m_{bb})$	m_{b-jet}	$p_{T,B}/p_{T,b-jet}$	$m_{BB}/m_{b-jet,b-jet}$
O_1	-0.64	-0.51	-0.31	-0.46	0.12	-0.03	-0.05
O_2	0.75	-0.56	-0.27	-0.22	0.06	-0.03	-0.04
O_3	-0.05	-0.45	0.75	-0.04	-0.47	-0.07	-0.08
O_4	0.13	0.46	-0.03	-0.75	-0.39	-0.15	-0.19
O_5	0.07	0.05	0.29	-0.38	0.27	0.46	0.69
O_6	-0.06	-0.07	-0.43	0.19	-0.73	0.32	0.36
O_7	-0.01	-0.01	-0.04	0.03	-0.04	-0.81	0.58

PARAMETERS

CALIBRATION



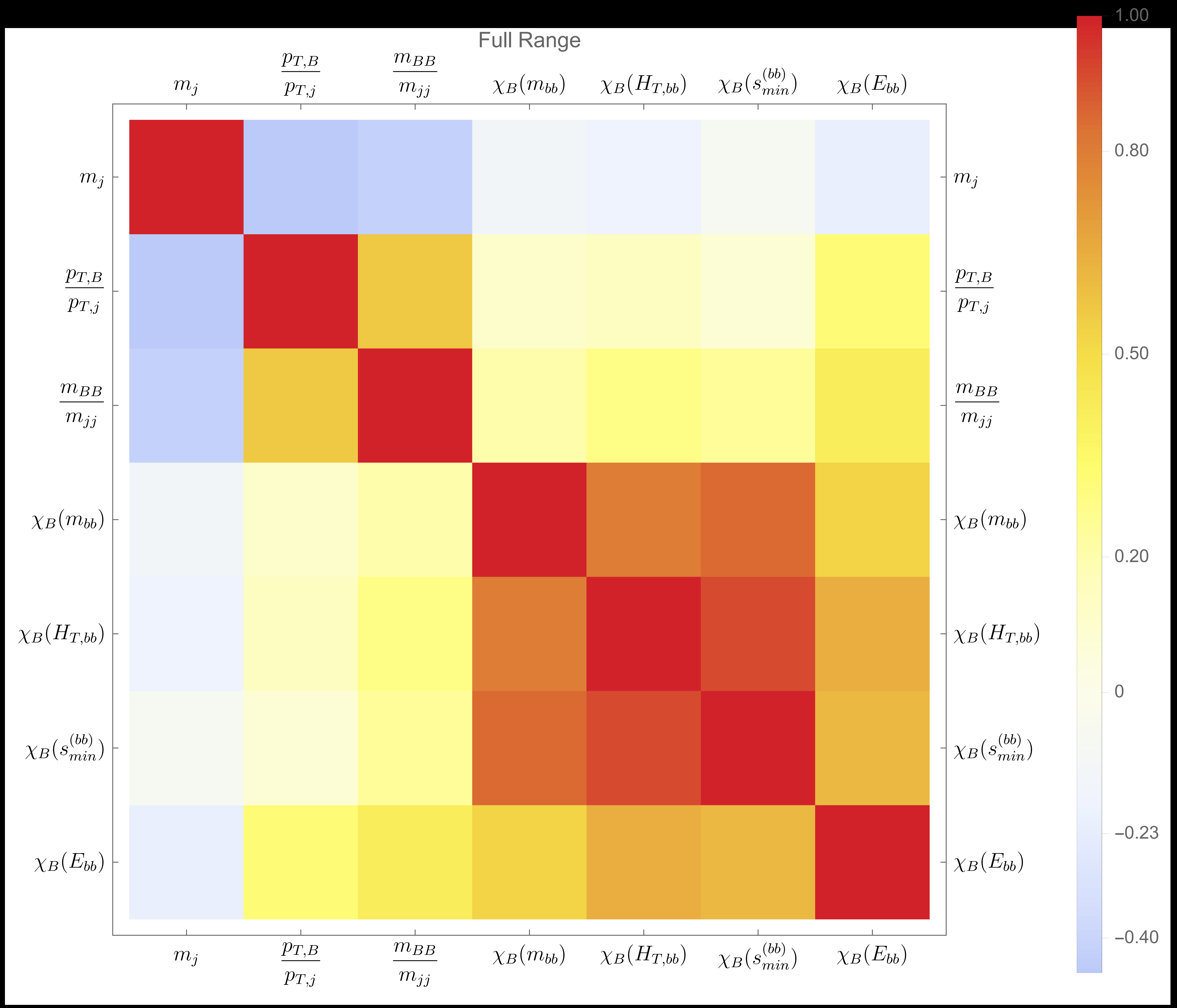
	$\alpha_{s,FSR}$	m_b	$p_{T,min}$	a_{Lund}	b_{Lund}	r_B
p_1	0.87	0.48	-0.11	0.04	-0.07	-0.01
p_2	0.15	-0.37	0.05	0.15	-0.81	0.39
p_3	-0.45	0.7	-0.1	0.2	-0.46	-0.19
p_4	-0.12	0.37	0.39	-0.33	0.14	0.75
p_5	0.09	-0.01	0.67	-0.48	-0.26	-0.49
p_6	0.06	0.01	0.61	0.77	0.18	-0.01

RESULTS & CORRELATION

CALIBRATION

ASSUMING THAT NO OBSERVABLE WILL BE KNOWN BETTER THAN 1% (JETS USED TO NORMALISE)

	$\alpha_{s,FSR}$	b_{Lund}	m_b	r_B	$p_{T,min}$	a_{Lund}
$\frac{\delta\theta}{\theta}$	0.0073	0.033	0.065	0.15	0.56	3.2

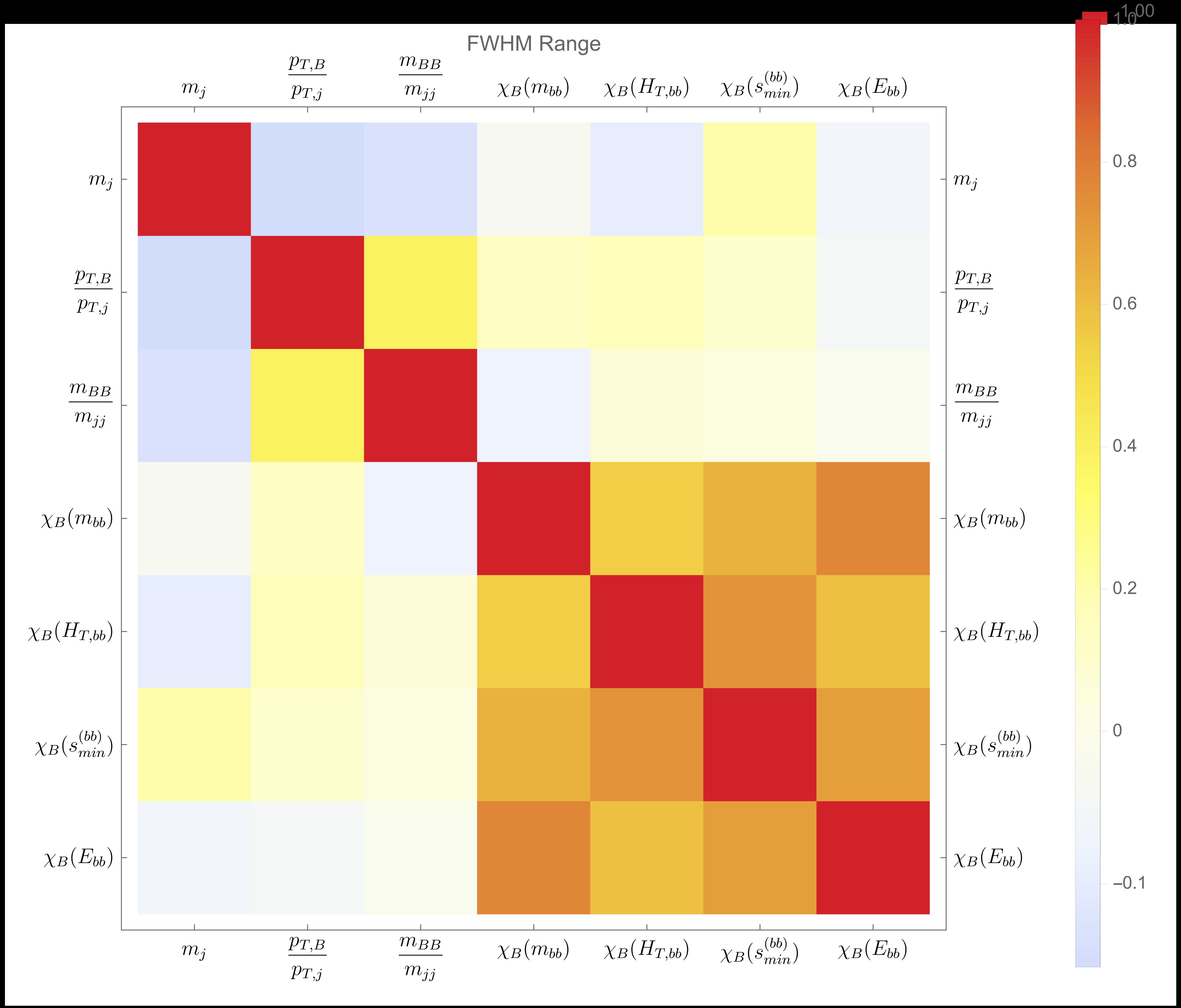


RESULTS & CORRELATION

CALIBRATION

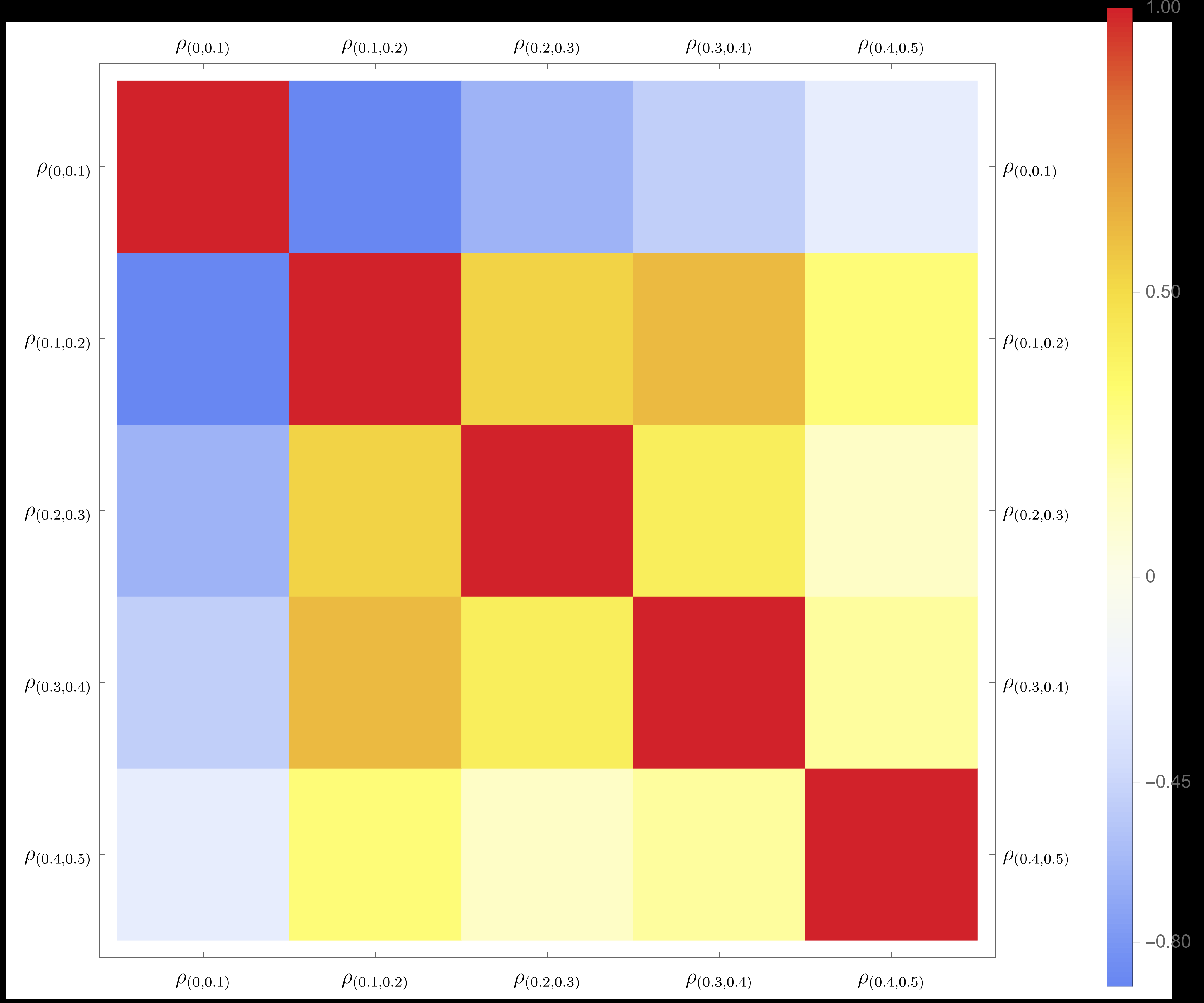
ASSUMING THAT NO OBSERVABLE WILL BE KNOWN BETTER THAN 1% (JETS USED TO NORMALISE)

	$\alpha_{s,FSR}$	b_{Lund}	m_b	r_B	$p_{T,min}$	a_{Lund}
$\frac{\delta\theta}{\theta}$	0.0073	0.033	0.065	0.15	0.56	3.2

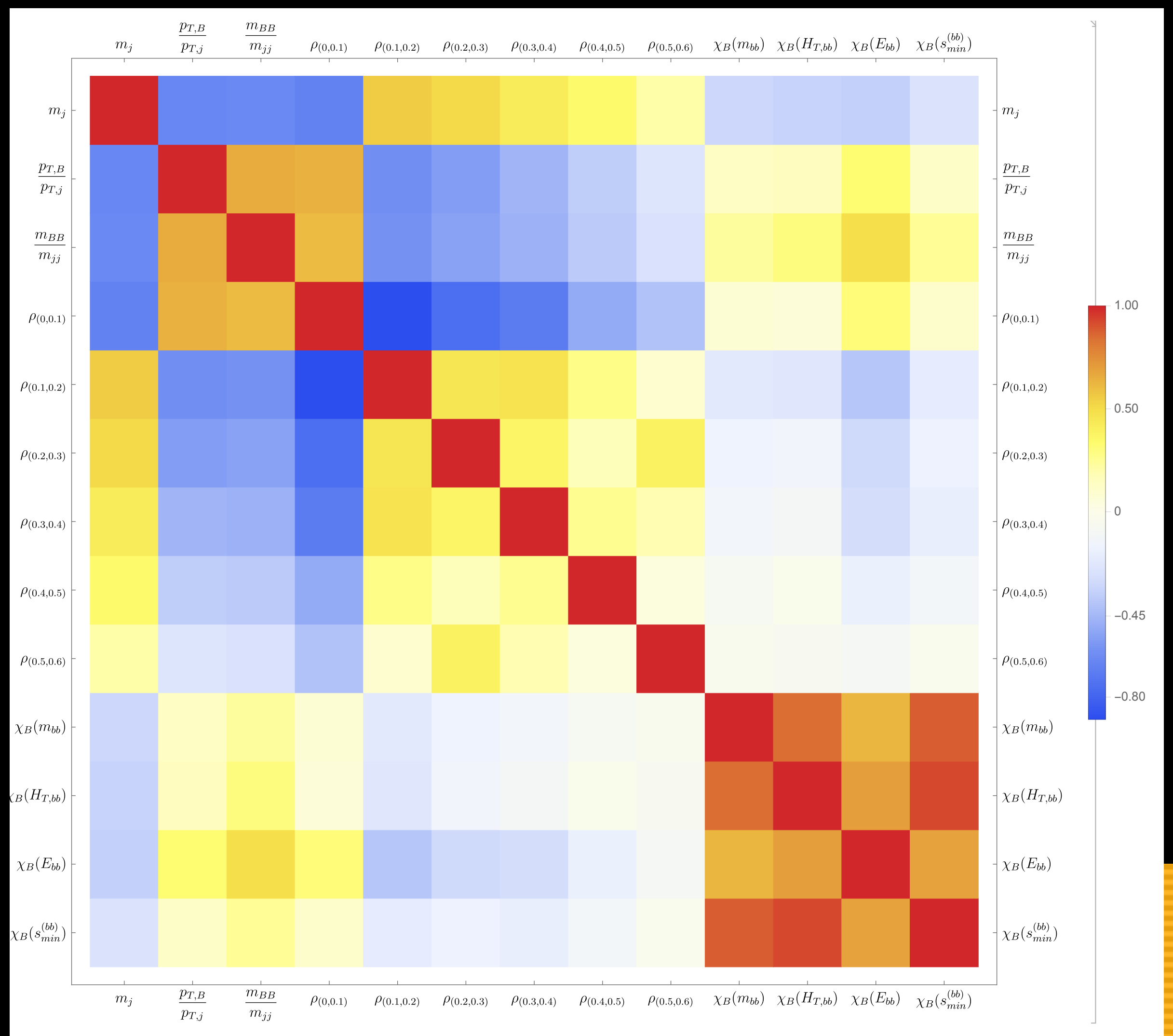


ENERGY DISTRIBUTION IN A JET ANNULUS

CALIBRATION

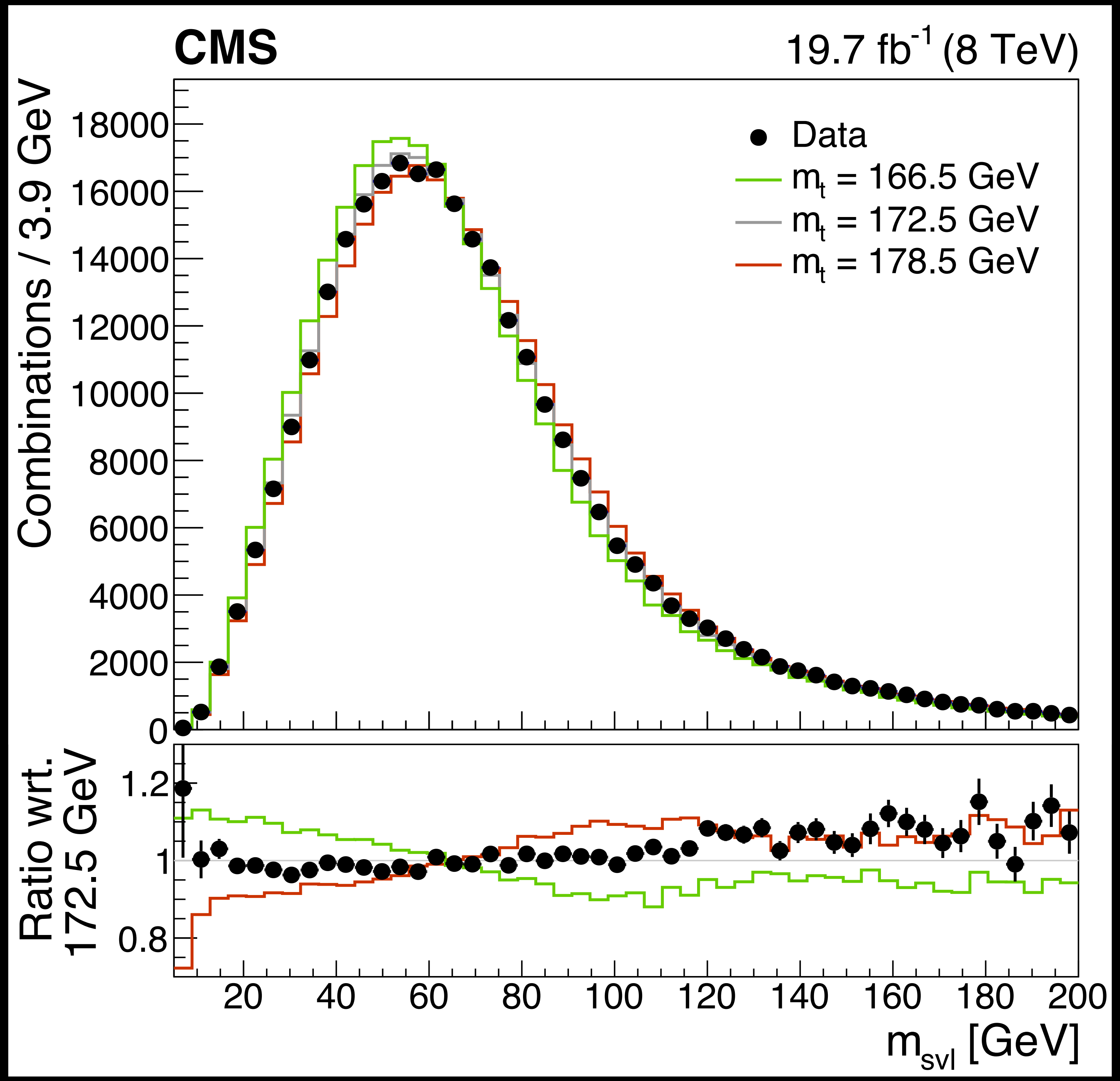


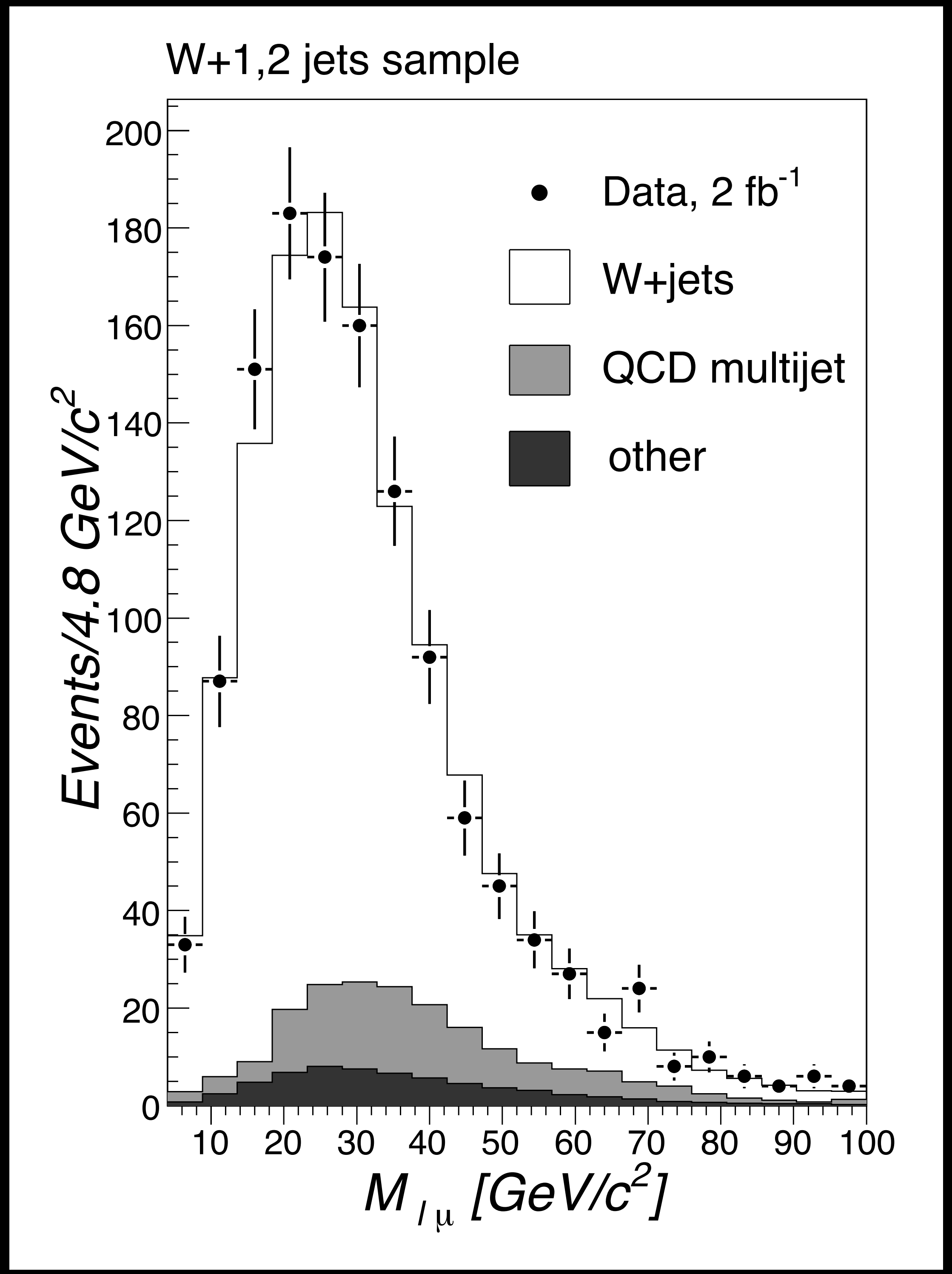
	$\alpha_{s,FSR}$	m_b	$p_{T,min}$	a_{Lund}	b_{Lund}	r_B
$\rho_{(0.,0.1)}$	−0.35±0.001	−0.057±0.002	0.029±0.0004	−0.0066±0.002	0.014±0.001	−0.018±0.004
$\rho_{(0.1,0.2)}$	1.3±0.008	0.27±0.008	−0.12±0.003	0.032±0.009	−0.07±0.007	0.09±0.02
$\rho_{(0.2,0.3)}$	1.3±0.007	0.2±0.007	−0.13±0.002	0.025±0.009	−0.049±0.006	0.065±0.02
$\rho_{(0.3,0.4)}$	1.3±0.007	0.16±0.005	−0.14±0.001	0.016±0.005	−0.035±0.005	0.044±0.02
$\rho_{(0.4,0.5)}$	1.2±0.007	0.1±0.007	−0.13±0.002	0.014±0.003	−0.018±0.007	0.01±0.02

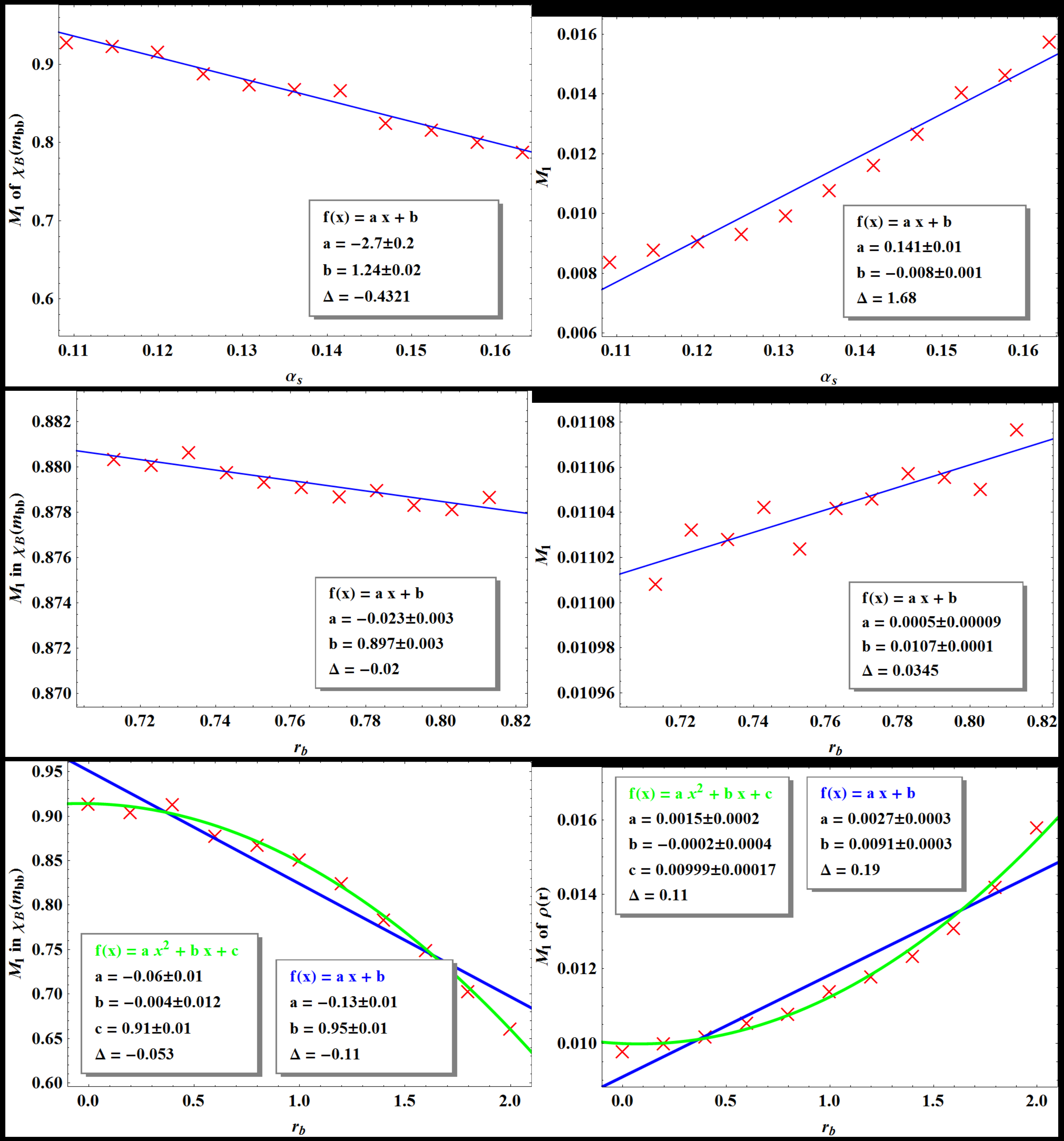


	m_j	$\frac{p_{T,B}}{p_{T,j}}$	$\frac{m_{BB}}{m_{jj}}$	$\rho_{(0,0.1)}$	$\rho_{(0.1,0.2)}$	$\rho_{(0.2,0.3)}$	$\rho_{(0.3,0.4)}$	$\rho_{(0.4,0.5)}$	$\rho_{(0.5,0.6)}$	$\chi_B(m_{bb})$	$\chi_B(H_{T,bb})$	$\chi_B(E_{bb})$	$\chi_B(s_{min}^{(bb)})$
m_j	1.	-0.46	-0.45	-0.48	0.4	0.34	0.27	0.18	0.12	-0.12	-0.13	-0.13	-0.07
$\frac{p_{T,B}}{p_{T,j}}$	-0.46	1.	0.5	0.5	-0.43	-0.35	-0.25	-0.14	-0.07	0.09	0.09	0.18	0.08
$\frac{m_{BB}}{m_{jj}}$	-0.45	0.5	1.	0.49	-0.42	-0.34	-0.25	-0.14	-0.08	0.14	0.18	0.32	0.15
$\rho_{(0,0.1)}$	-0.48	0.5	0.49	1.	-0.9	-0.63	-0.52	-0.3	-0.17	0.07	0.07	0.18	0.07
$\rho_{(0.1,0.2)}$	0.4	-0.43	-0.42	-0.9	1.	0.31	0.31	0.16	0.07	-0.06	-0.07	-0.15	-0.06
$\rho_{(0.2,0.3)}$	0.34	-0.35	-0.34	-0.63	0.31	1.	0.21	0.1	0.23	-0.04	-0.03	-0.12	-0.04
$\rho_{(0.3,0.4)}$	0.27	-0.25	-0.25	-0.52	0.31	0.21	1.	0.16	0.11	-0.03	-0.03	-0.1	-0.05
$\rho_{(0.4,0.5)}$	0.18	-0.14	-0.14	-0.3	0.16	0.1	0.16	1.	0.06	-0.02	-0.01	-0.05	-0.03
$\rho_{(0.5,0.6)}$	0.12	-0.07	-0.08	-0.17	0.07	0.23	0.11	0.06	1.	-0.01	-0.01	-0.03	-0.01
$\chi_B(m_{bb})$	-0.12	0.09	0.14	0.07	-0.06	-0.04	-0.03	-0.02	-0.01	1.	0.79	0.49	0.83
$\chi_B(H_{T,bb})$	-0.13	0.09	0.18	0.07	-0.07	-0.03	-0.03	-0.01	-0.01	0.79	1.	0.54	0.89
$\chi_B(E_{bb})$	-0.13	0.18	0.32	0.18	-0.15	-0.12	-0.1	-0.05	-0.03	0.49	0.54	1.	0.53
$\chi_B(s_{min}^{(bb)})$	-0.07	0.08	0.15	0.07	-0.06	-0.04	-0.05	-0.03	-0.01	0.83	0.89	0.53	1.

$$\Delta_{m_t}^{(\langle m_{\ell\mu}\rangle)} \simeq 0.3$$







M_1 of $\chi_B(m_{bb})$
α_s
f(x) = a x + b
a = −2.7±0.2
b = 1.24±0.02
Δ = −0.4321
M_1
α_s
f(x) = a x + b
a = 0.141±0.01
b = −0.008±0.001
Δ = 1.68
M_1 in $\chi_B(m_{bb})$
r_b
f(x) = a x + b
a = −0.023±0.003
b = 0.897±0.003
Δ = −0.02
M_1
r_b
f(x) = a x + b
a = 0.0005±0.00009
b = 0.0107±0.0001
Δ = 0.0345
M_1 in $\chi_B(m_{bb})$
r_b
f(x) = a x^2 + b x + c
a = −0.06±0.01
b = −0.004±0.012
c = 0.91±0.01
Δ = −0.053
f(x) = a x + b
a = −0.13±0.01
b = 0.95±0.01
Δ = −0.11
M_1 of $\rho(r)$
r_b
f(x) = a x^2 + b x + c
a = 0.0015±0.0002
b = −0.0002±0.0004
c = 0.00999±0.00017
Δ = 0.11
f(x) = a x + b
a = 0.0027±0.0003
b = 0.0091±0.0003
Δ = 0.19