COLOR SEXTET SCALAR PHENOMENOLOGY AT THE TEVATRON AND EARLY LHC

Qing-Hong Cao

HEP Division, Argonne National Lab
Enrico Fermi Institute, University of Chicago

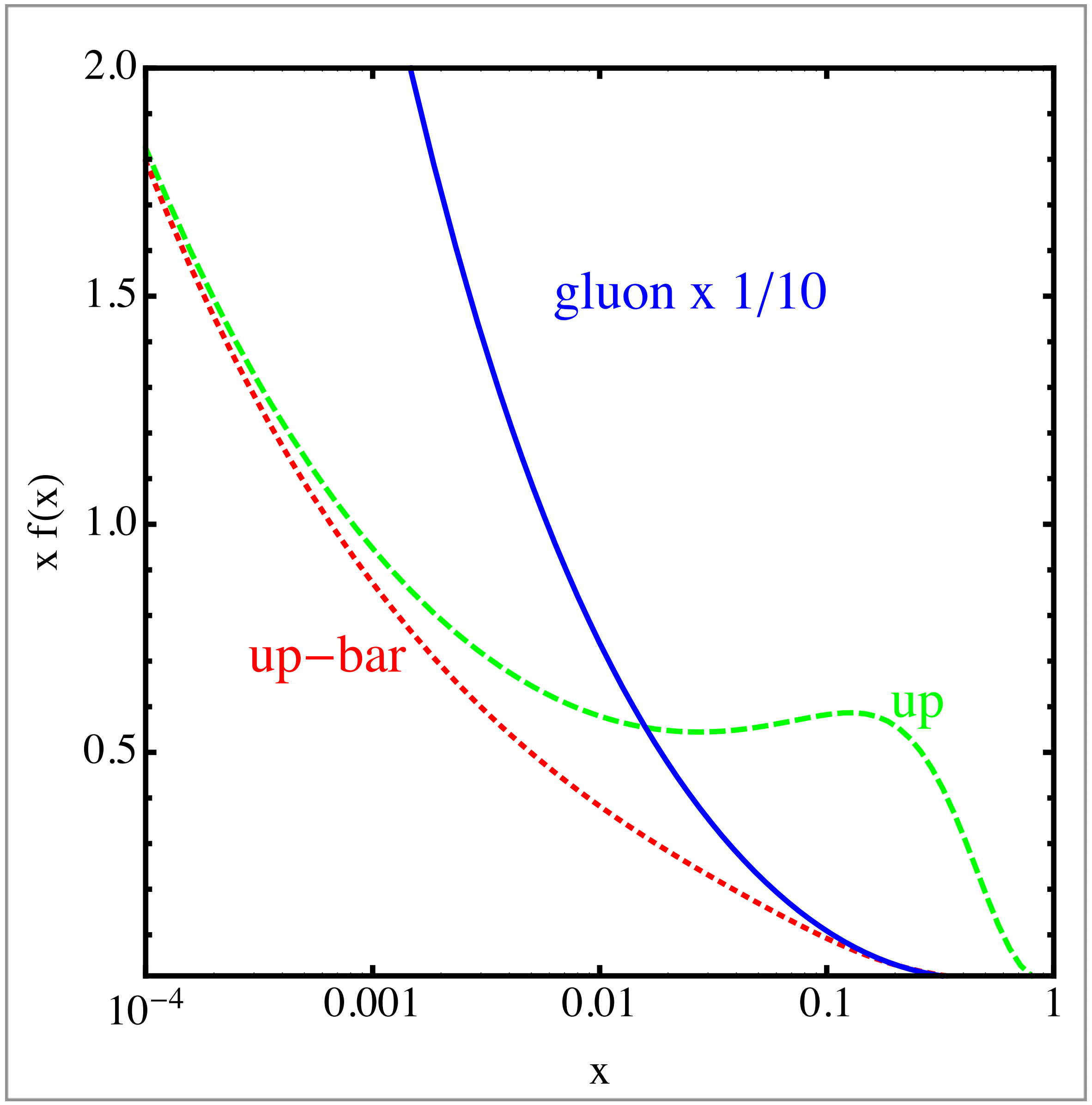
In collaboration with:

Edmond L. Berger, Chuan-Ren Chen, Gabe Shaughnessy, Hao Zhang
arXiv:1005.xxxx

LHC DECADE!

★ First years of the LHC decade will probe a new frontier of physics at the Terascale

DM, SUSY, UED, Exotics, etc.



$$\langle x \rangle \approx m_{\mathrm{NP}} / E_{cm}$$

★ New heavy resonance peaks at the large x region where valence-quarks dominate.

★ To be discovered at early LHC (7TeV and ~1 inverse fb luminosity), the NP needs to be **exotic**:

- ✳ ***Colored*** - large production rate
- ✳ ***Novel, easy detectable collider signature***
  charged leptons, heavy flavor jets, MET, etc
- ✳ ***Small SM backgrounds***

SEXTET SCALAR AND SAME-SIGN TOP PAIR PRODUCTION

★ Quark initial states can produce sextet and anti-triplet representation resonance

$$3 \times 3 = 6 + \bar{3}$$

$$3 \times \bar{3} = 1 + 8$$

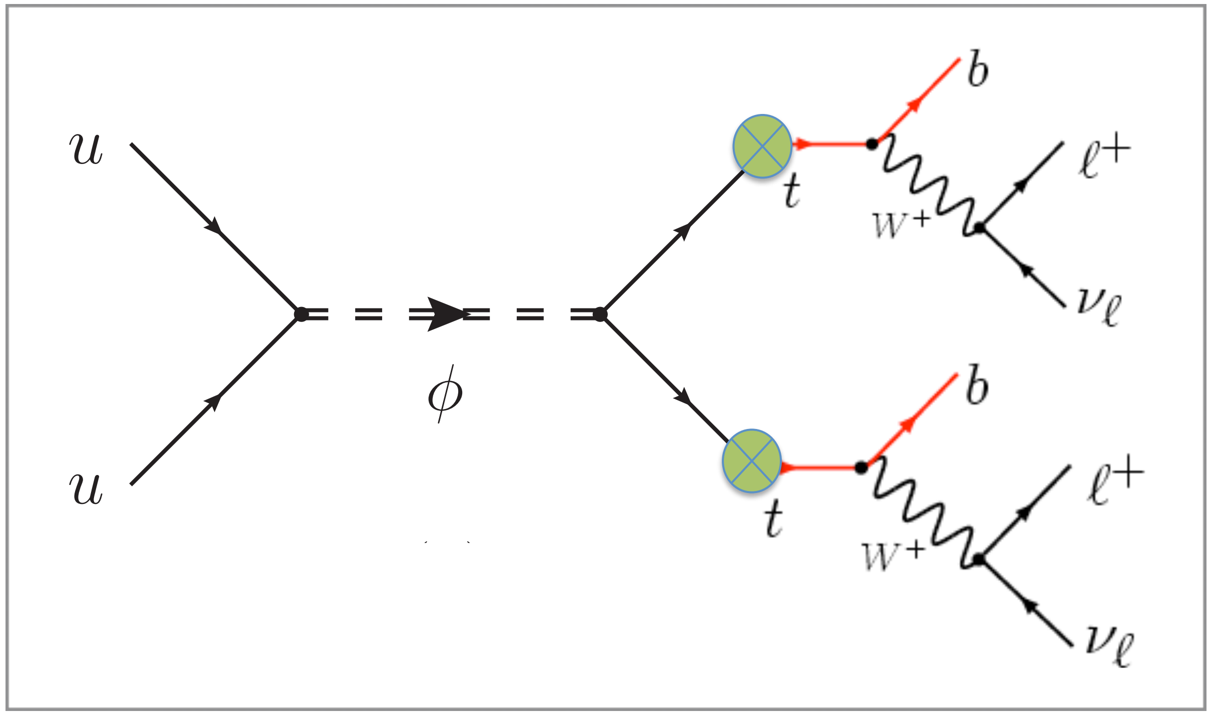
★ Observation of sextet scalar (ϕ) would imply non-standard unification

★ Couplings are not proportional to quark mass

$$\mathcal{L} \sim \phi_j^* K_{ab}^j q_a^T C^\dagger \lambda_R^{ab} P_R q_b + h.c.$$

★ PDF of initial quarks peaked for heavier resonance production

★ Same-sign top pair production



✳ large cross section

✳ same-sign charged lepton pair b-jets and large MET

✳ top quark polarization is crucial

We implement full spin correlation in our Monte Carlo simulation

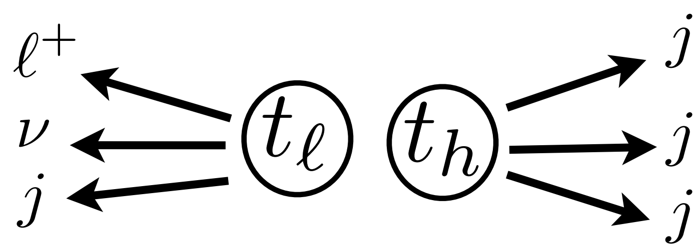
CONSTRAINTS FROM THE TEVATRON

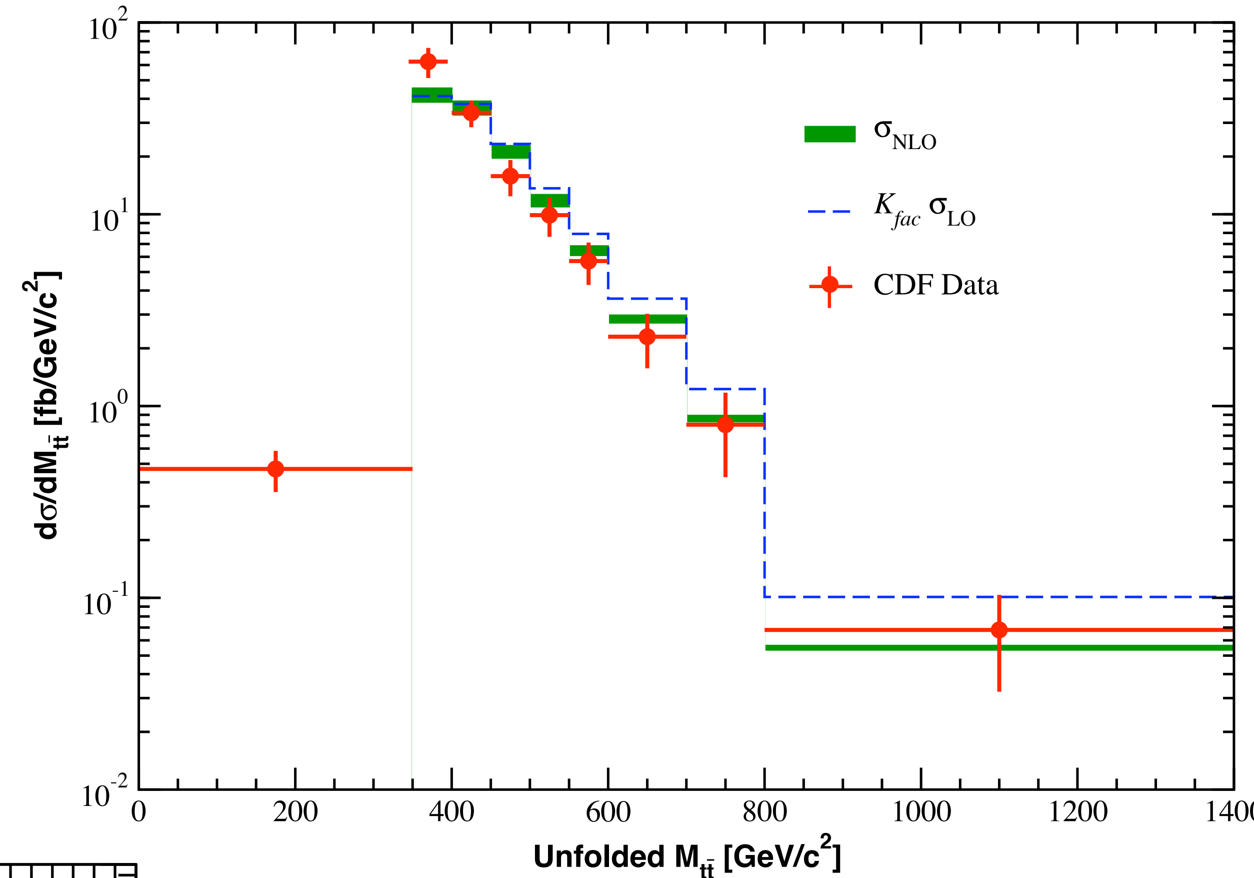
★ Top pair cross section constrained by CDF measurement of

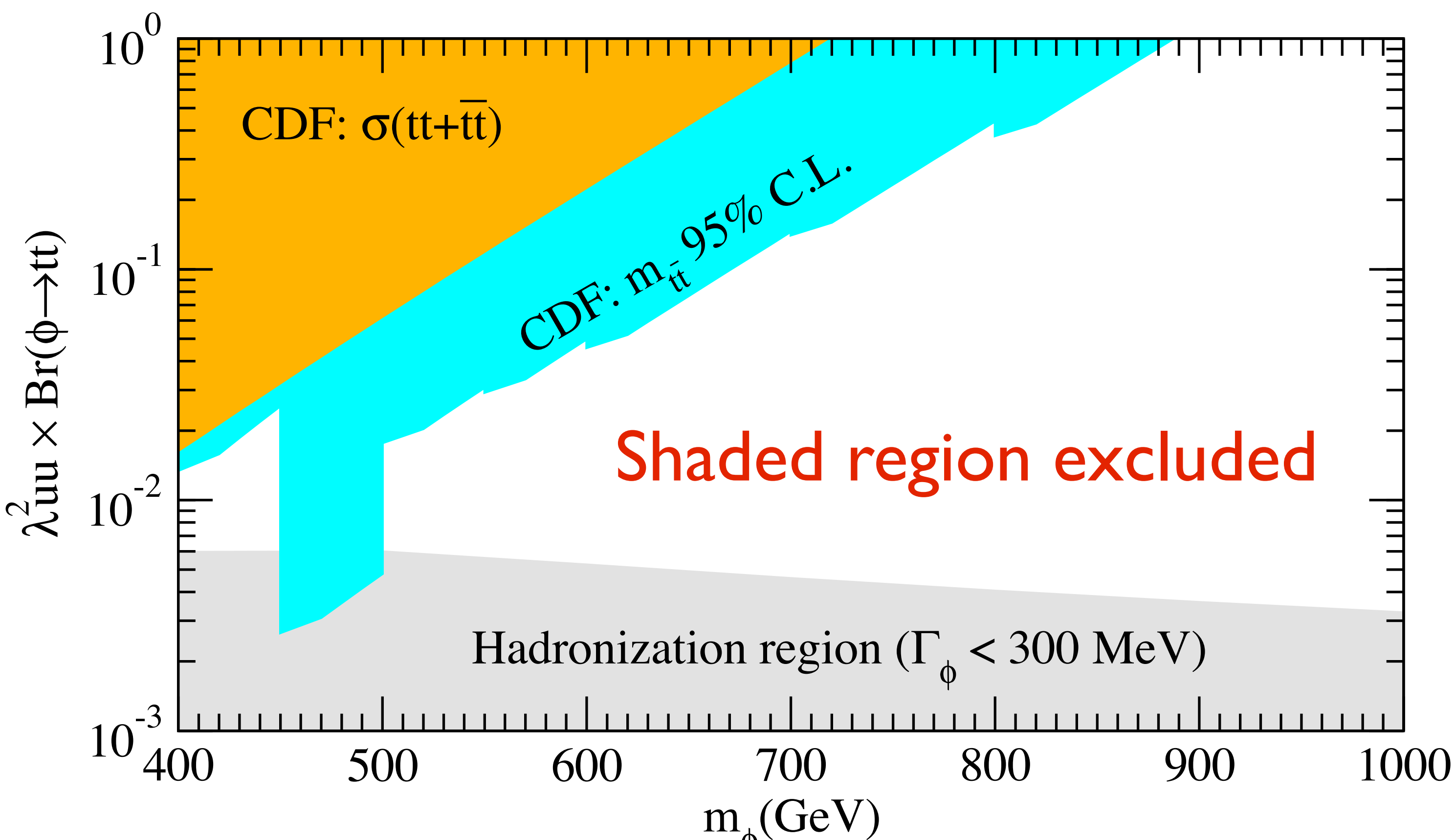
- ✳ Same-sign top production

$$\sigma_{tt+\bar{t}\bar{t}} < 0.7 \text{ pb}$$

- ✳ Distribution of $M_{t_\ell t_h}$



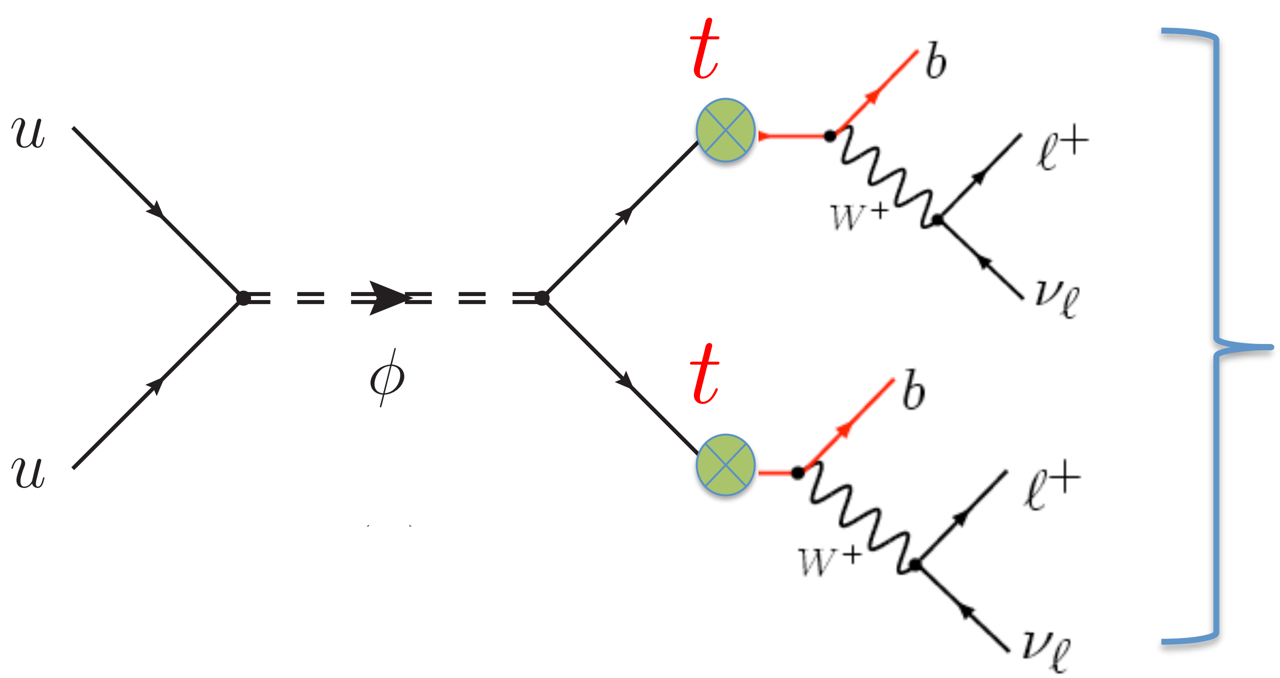




$$\begin{aligned} & \sigma(uu \to \phi \to tt) \\ \propto \quad & \sigma(uu \to \phi) \times Br(\phi \to tt) \\ \propto \quad & [\sigma(uu \to \phi)|_{\lambda=1}] \\ & \times \lambda^2_{uu} Br(\phi \to tt) \end{aligned}$$

SIGNAL AND BACKGROUNDS

★ Signal topology



same sign di-muons,
2 b-jets and MET

Much better reconstruction than electron

★ Prominent Backgrounds (ALPGEN)

$$pp \to t\bar{t} \to b\bar{b}W^+W^-,\ W^+ \to \ell^+\nu,\ W^- \to jj,\ \bar{b} \to \ell^+$$
$$pp \to W_1^+W_2^+jj,\ W^+ \to \ell^+\nu$$

} Dominant

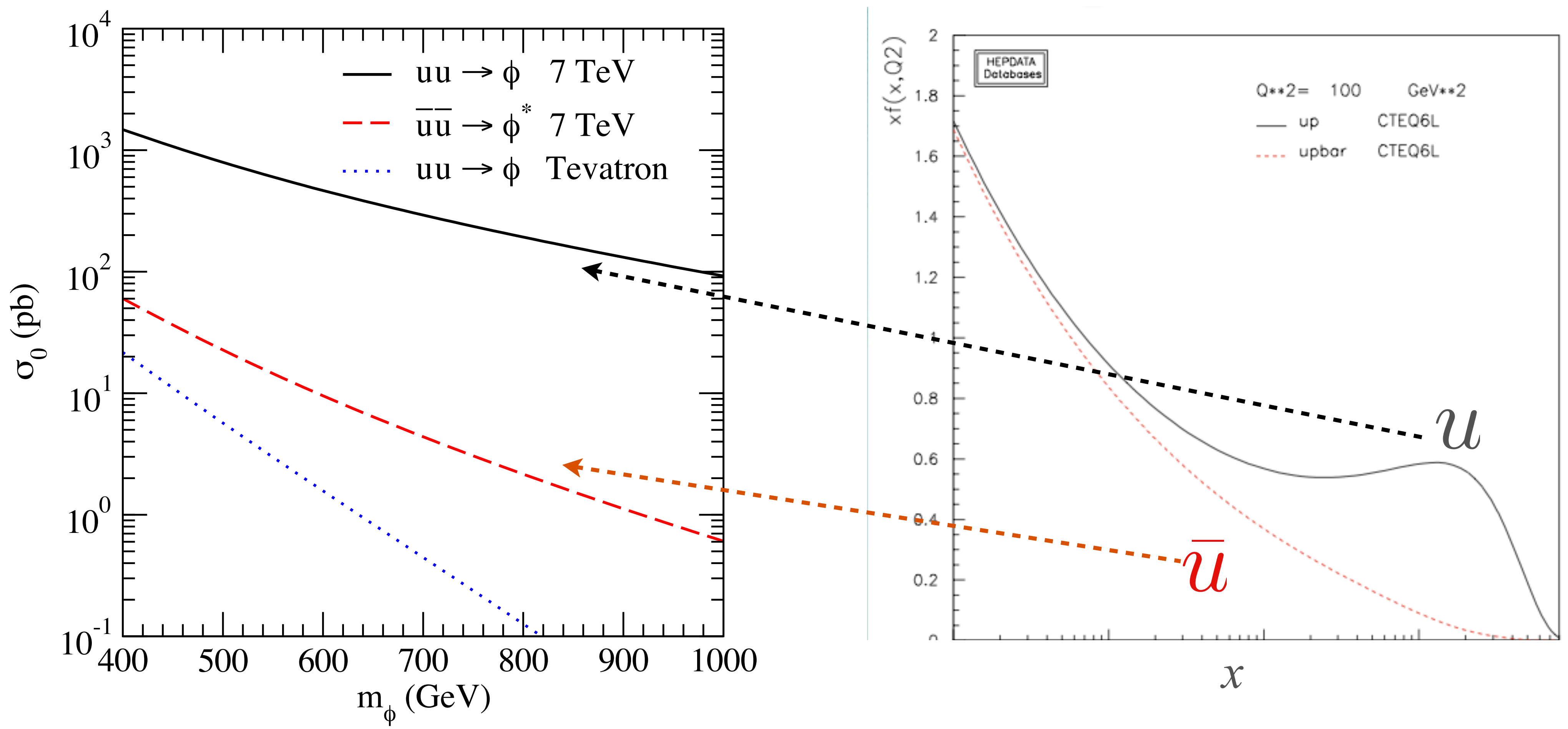
$$pp \to W^+W^+W^-,\ W^+ \to \ell^+\nu,\ W^- \to jj$$
$$pp \to ZW^+W^-,\ Z \to \ell^+\ell^-,\ W^+ \to \ell^+\nu,\ W^- \to jj$$

FIRST HINT AT EARLY LHC

★ More positive di-muons

✳ same-sign top pairs contribute an asymmetry in charge multiplicity

✳ Strong dependent on sextet scalar mass due to large PDF dependence



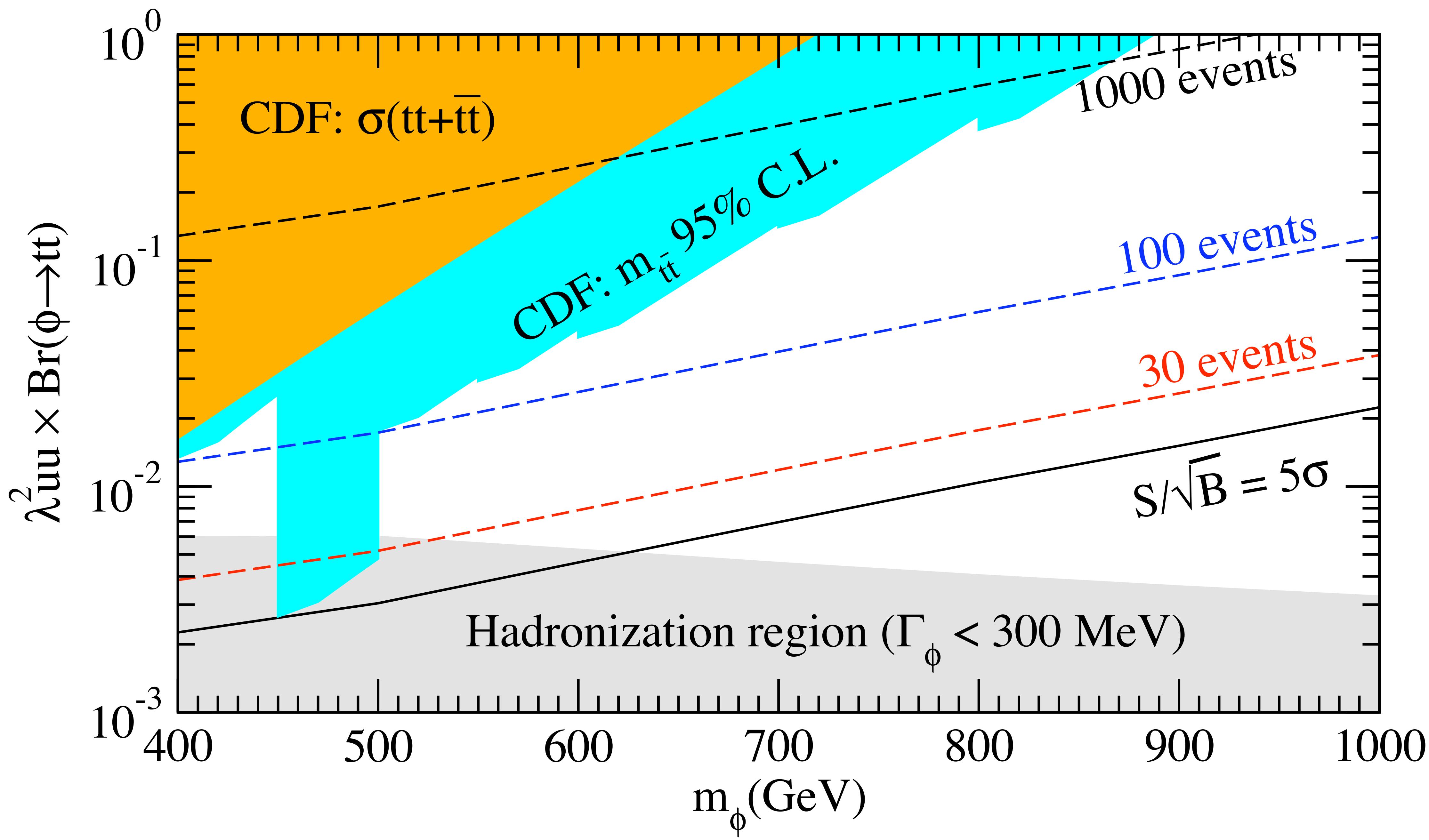
✳ Same-sign charge ratio gives independent verification of scalar mass

DISCOVERY POTENTIAL

★ Simple cuts to extract signal:

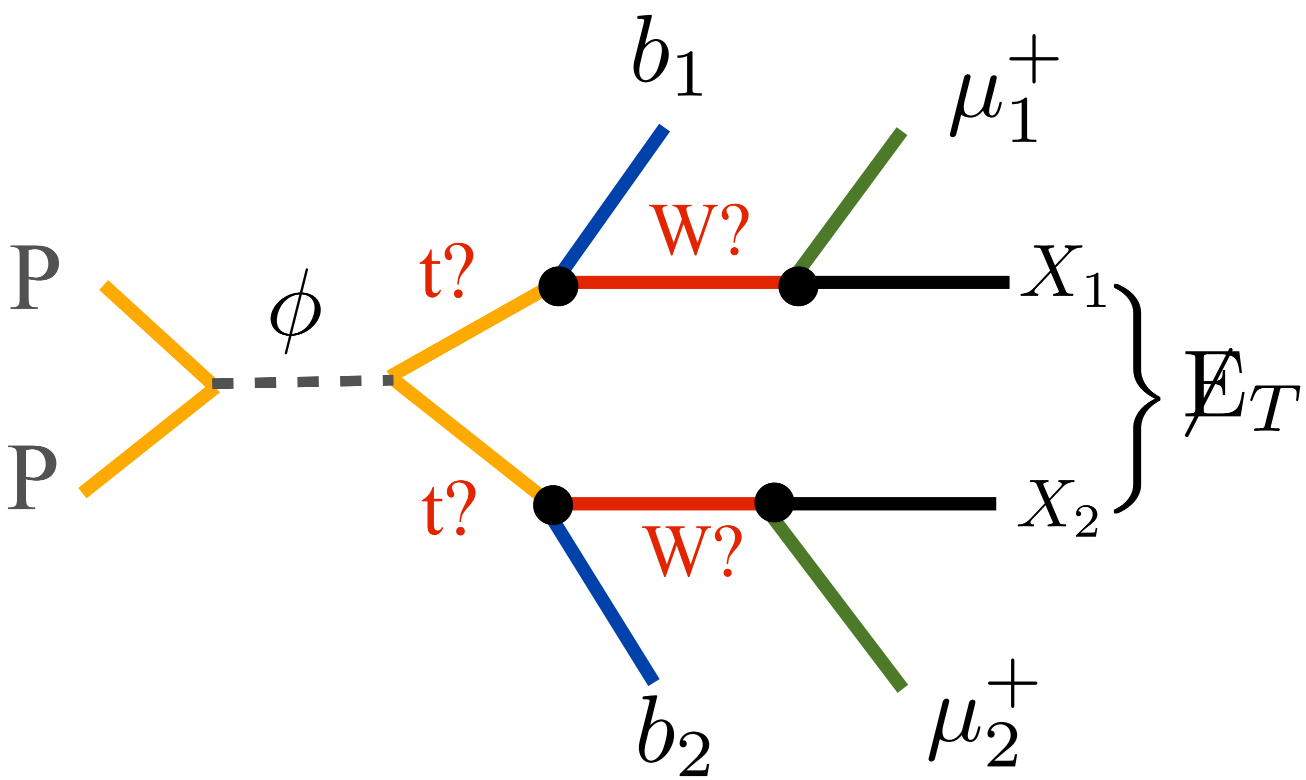
- ✳ Same sign di-muons
- ✳ Two jets with pT>50GeV
- ✳ About 12 background events

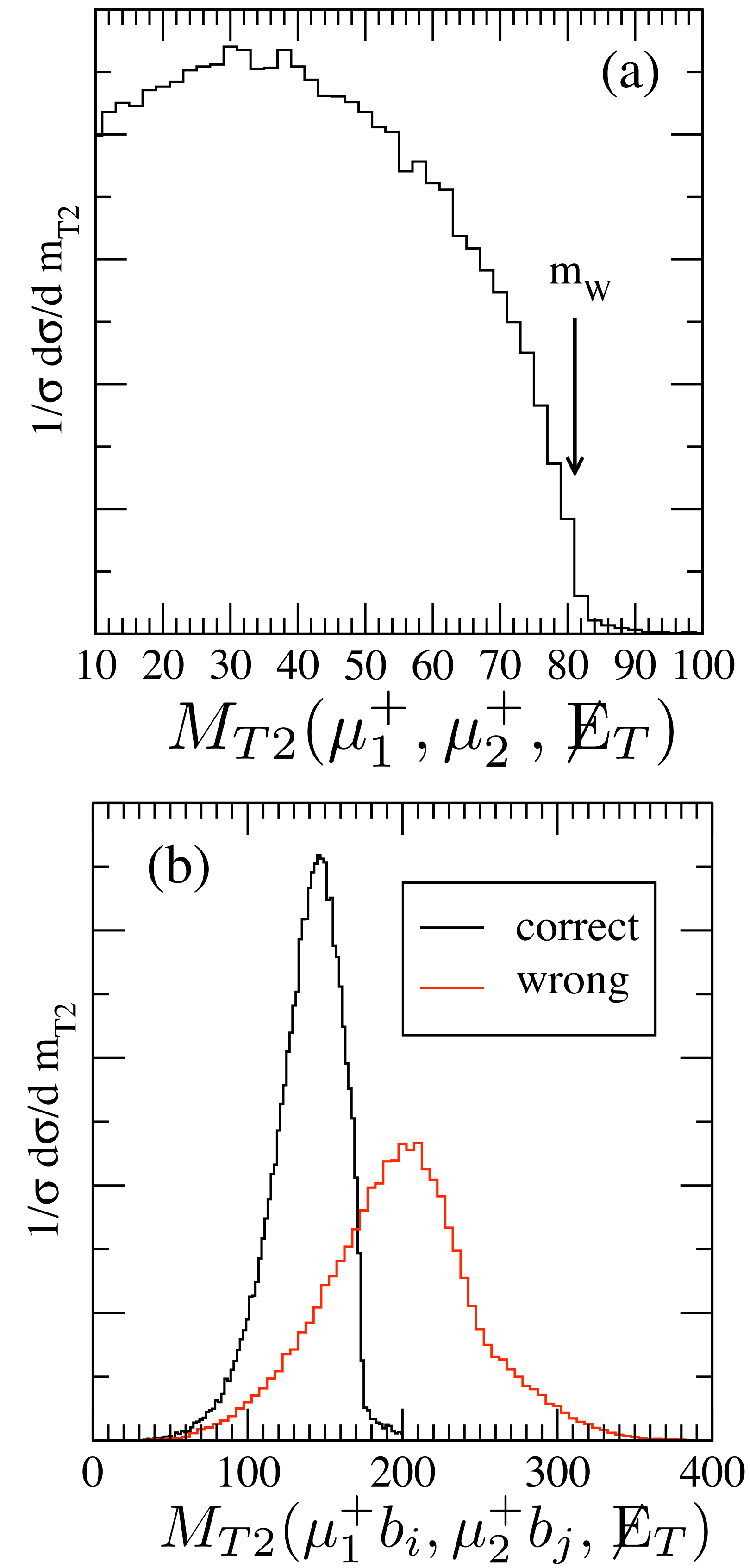
$$\mathcal{L} = 1\ \text{fb}^{-1}$$



TRANSVERSE MASS AND MT2

★ MT2 is similar to transverse mass of W-boson, but works for the case of two missing particles in the final state





$$M_{T2}^2(\mu_1^+, \mu_2^+, \not{E}_T) \leq m_W^2$$

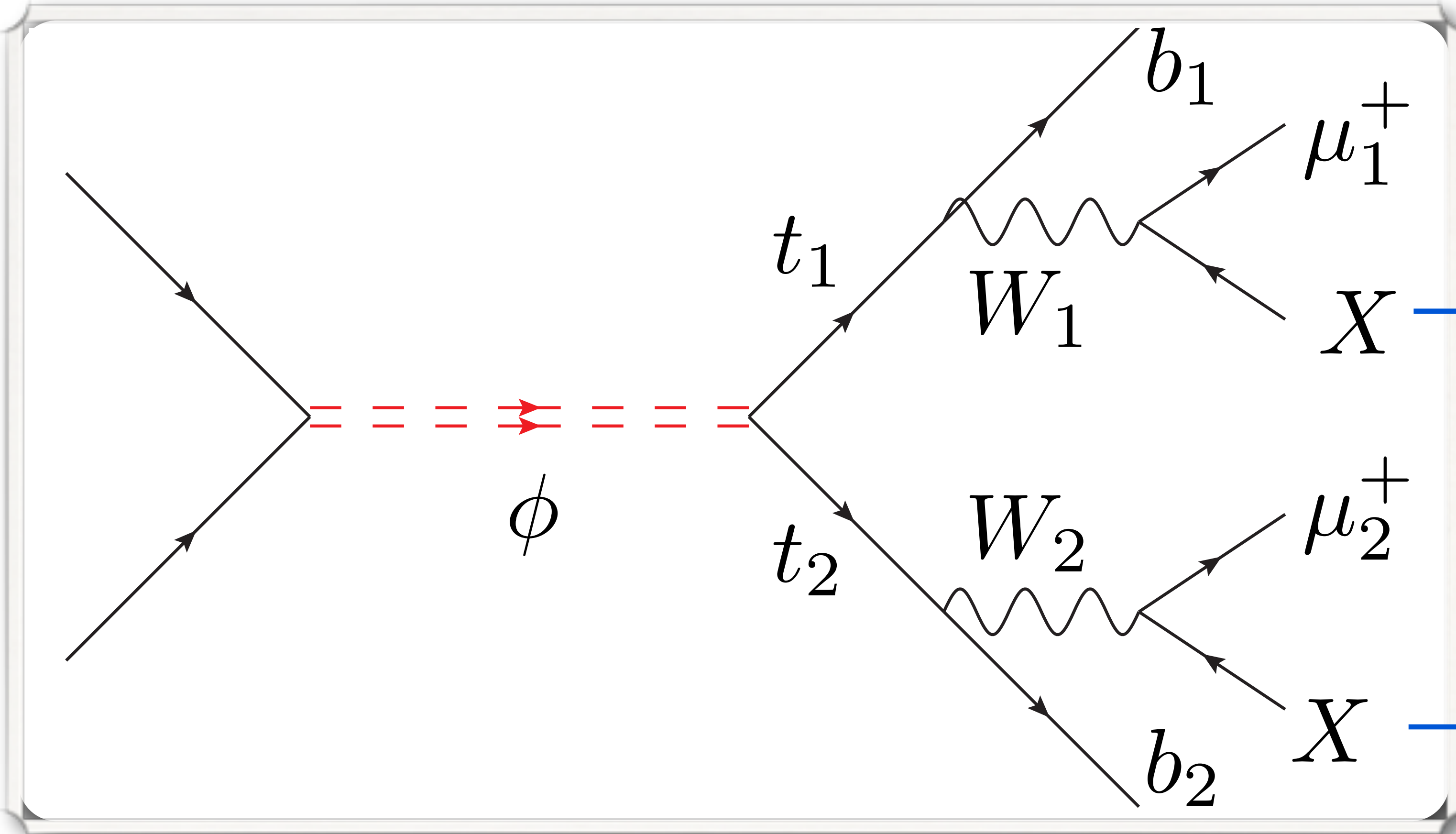
$$M_{T2}^2 \equiv \min_{\not{p}_{X_1}+\not{p}_{X_2}=\not{E}_T} \left[\max\left\{ m_T^2(\vec{p}_T^{\,\mu_1^+}, \not{\vec{p}}_{X_1}), m_T^2(\vec{p}_T^{\,\mu_2^+}, \not{\vec{p}}_{X_2}) \right\} \right]$$

C. G. Lester and D. J. Summers, hep-ph/9906349

Choosing smaller MT2 (correct combination found with 95% probability)

FULL EVENT RECONSTRUCTION

★ Four unknowns and four on-shell conditions



6 unknowns
-2 from MET

$$m_{W_1}^2 = (p_{\mu_1} + p_{\nu_1})^2$$
$$m_{W_2}^2 = (p_{\mu_2} + p_{\nu_2})^2$$
$$m_{t_1}^2 = (p_{W_1} + p_{b_1})^2$$
$$m_{t_2}^2 = (p_{W_2} + p_{b_2})^2$$

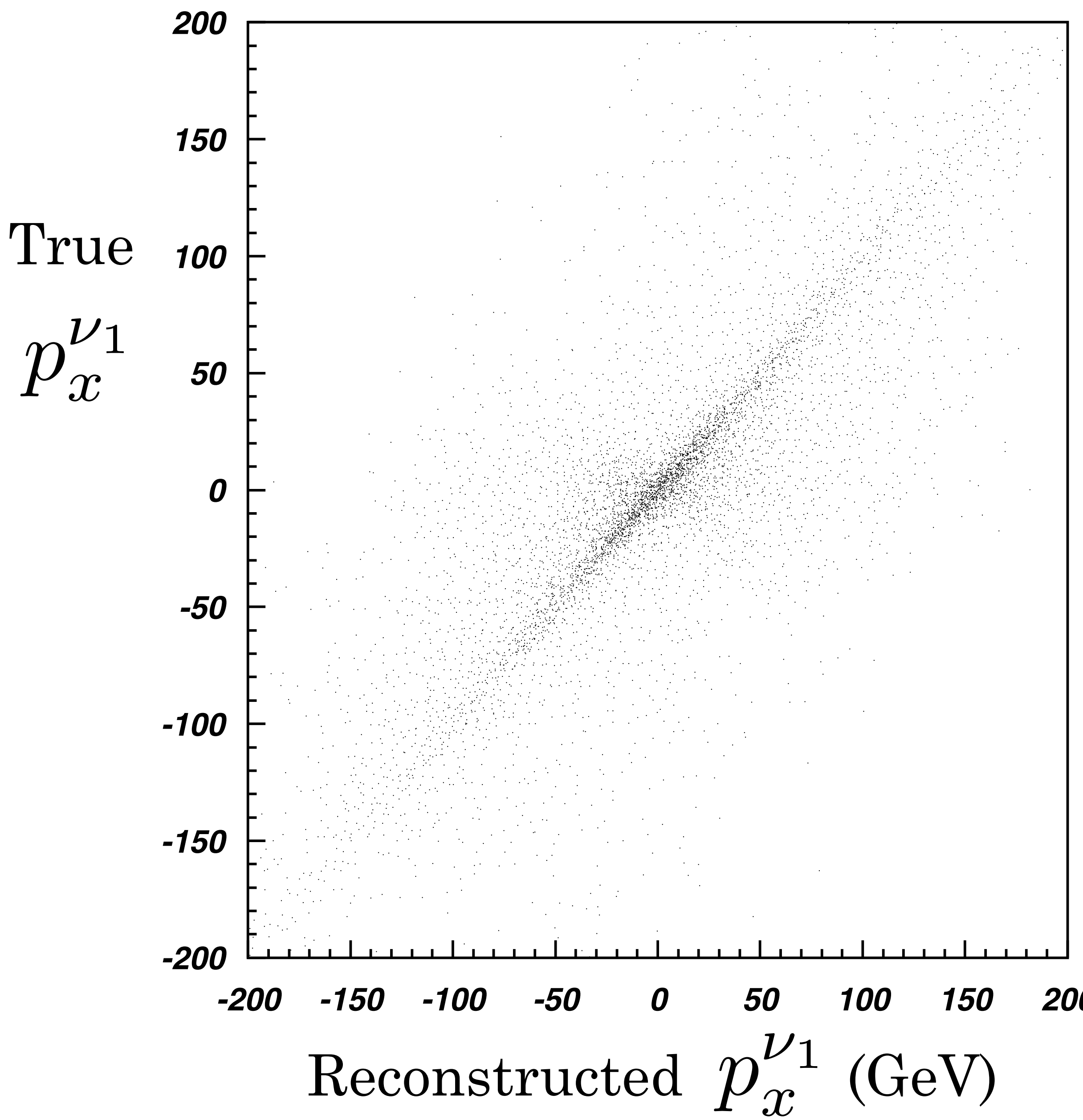
Quartic equation

$$p_x^4(\nu_1) + a\ p_x^3(\nu_1) + b\ p_x^2(\nu_1) + c\ p_x(\nu_1) + d = 0$$

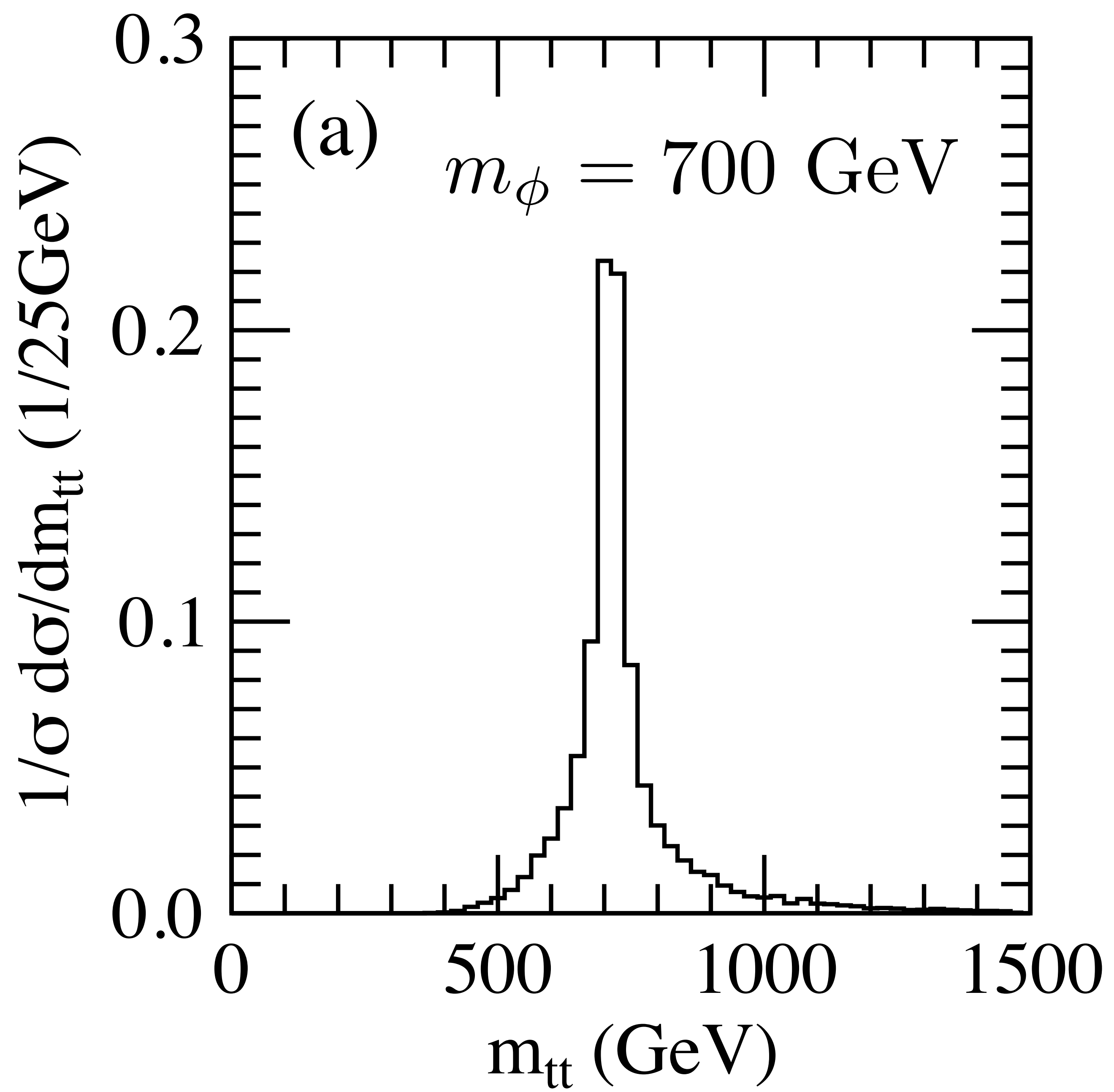
~~Two complex~~, two real solutions

RECONSTRUCTED EVENT DISTRIBUTION

★ Strong correlation between the true $p_x^{\nu_1}$ and reconstructed $p_x^{\nu_1}$



★ Can we determine the mass of the heavy resonance? Yes !



TOP QUARK POLARIZATION AND RESONANCE SPIN

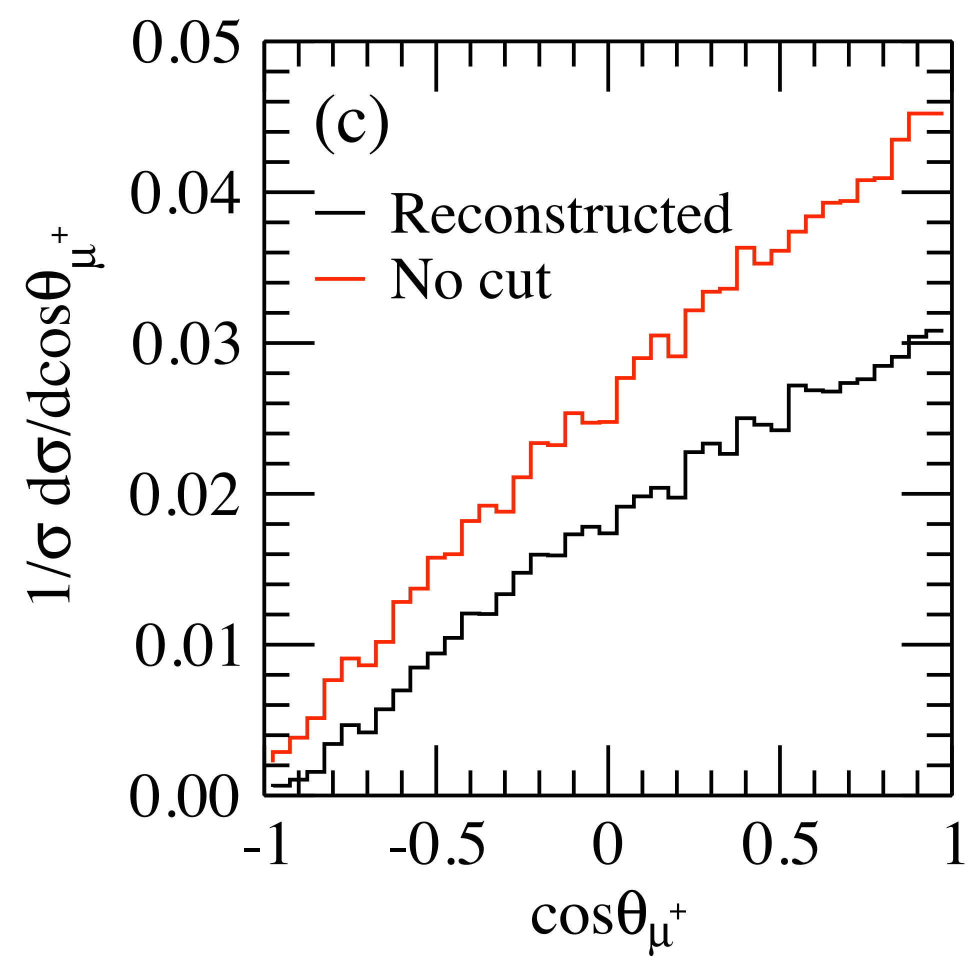
★ Polarization correlates with angle between top quark spin and charged lepton momenta

$$\frac{1}{\Gamma}\frac{d\Gamma(t\to b\ell\nu)}{d\cos\theta}=\frac{1}{2}\left(1+\frac{N_+-N_-}{N_++N_-}\cos\theta\right)$$

✳ Charged lepton typically follows top quark spin

✳ Right-handed top quark has $\frac{1}{2}(1+\cos\theta)$ dependence

✳ Roughly 30 events required to distinguish from unpolarized case



What is the polarization of the top quarks? Right-handed !

Are the top quarks from a scalar decay? Yes !

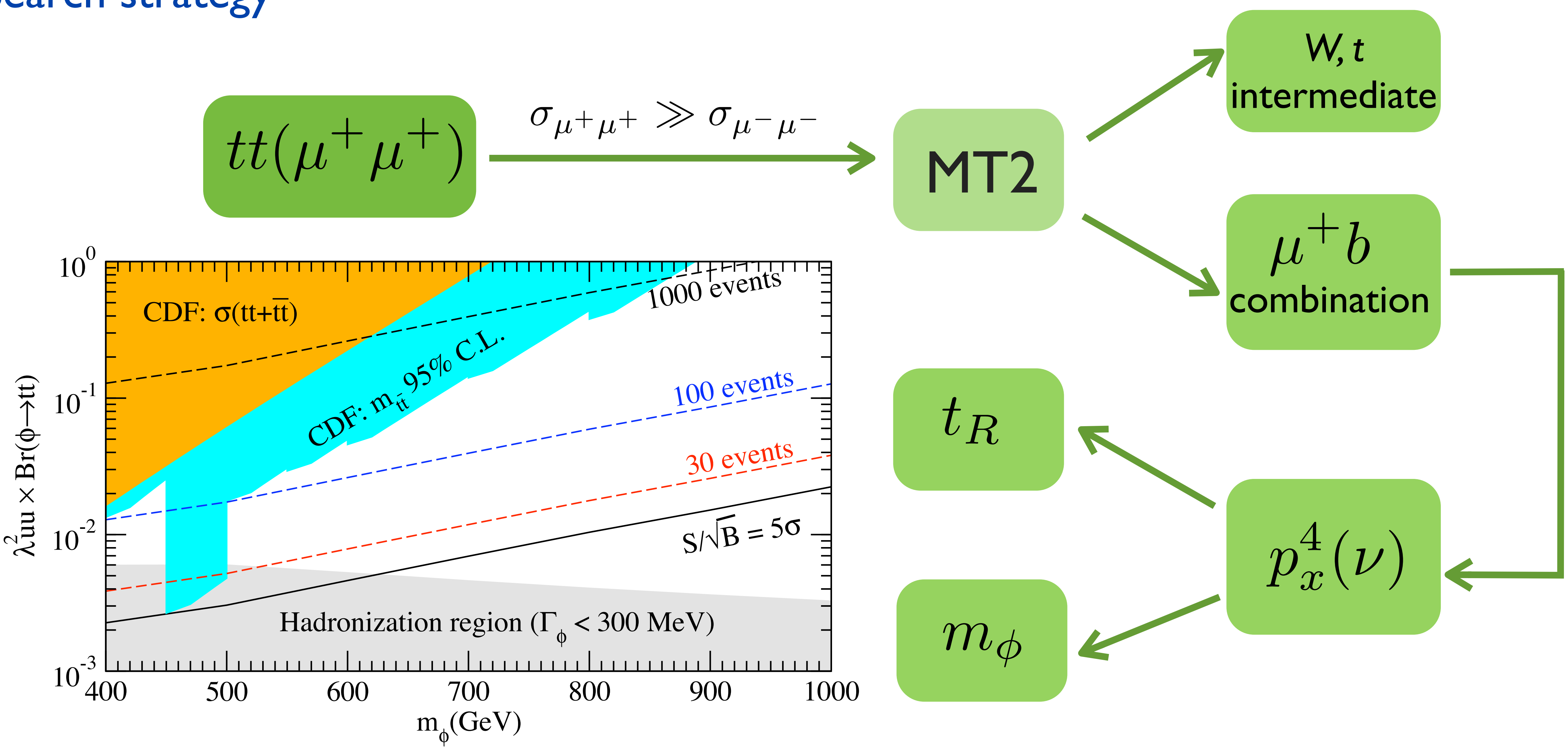
SUMMARY

★ Color sextet scalar has a great discovery potential at the early LHC

✳ Due to colored resonance, enhanced cross section relative to EW scale new physics

✳ Naturally large same-sign dilepton rates allow easy background rejection

★ Search strategy

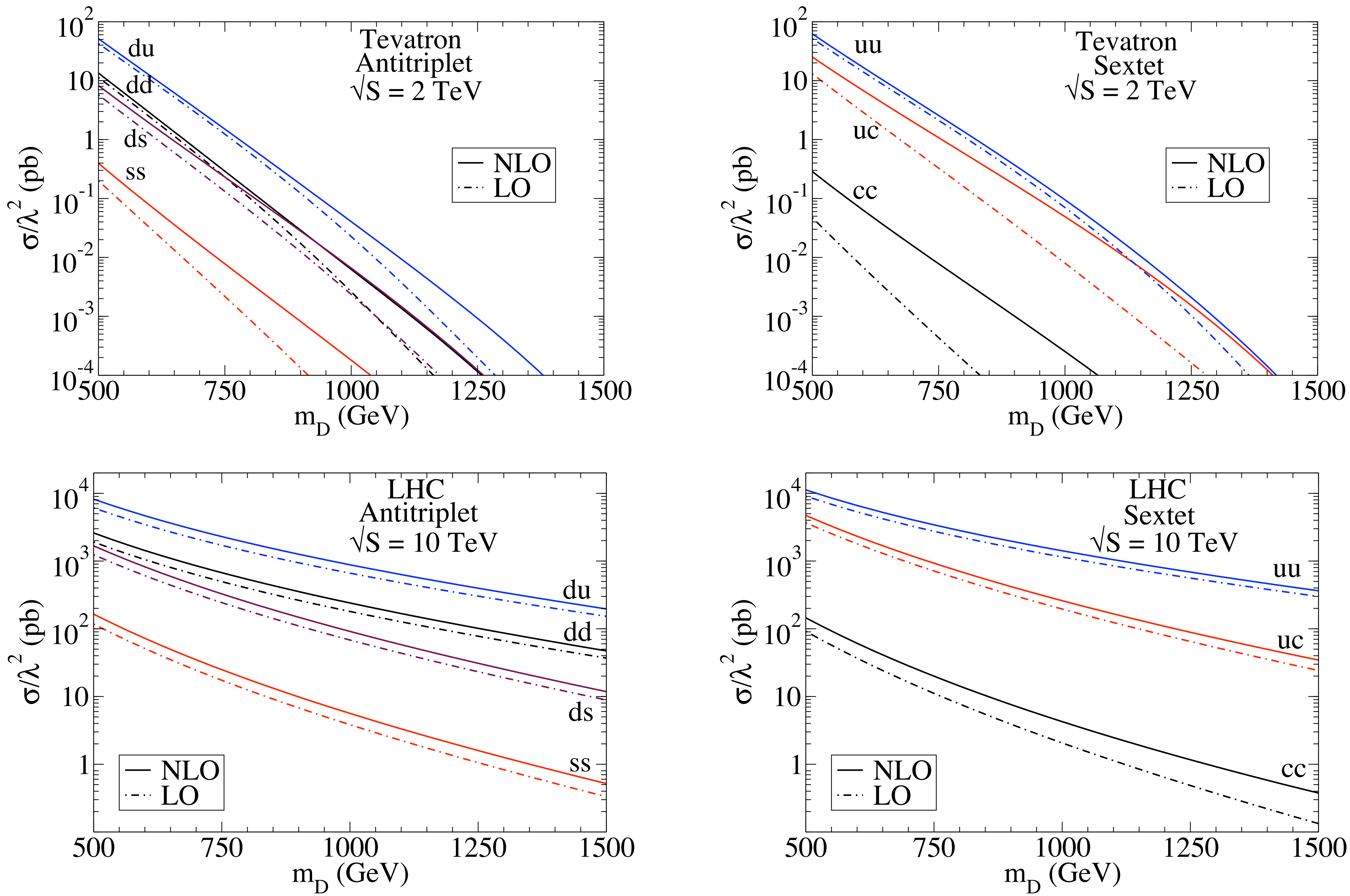


BACKUP SLIDES

PRODUCTION CROSS SECTION AT NLO

★ NLO QCD corrections to single color sextet scalar production is available

Han, Lewis, McElmurry, 0909.2666



SIMULATION'S GORY DETAILS

★ Acceptance cuts

- ✳ leptons $p_{T,\ell} \geq 20$ GeV $|\eta_\ell| < 2.0$
- ✳ jets: $p_{T,j} \geq 50$ GeV $|\eta_j| < 2.5$
- ✳ separation: $\Delta R_{\ell\ell,\ell j,jj} > 0.4$

★ Energy smearing $\frac{\delta E}{E} = \frac{a}{\sqrt{E/\mathrm{GeV}}} \oplus b$

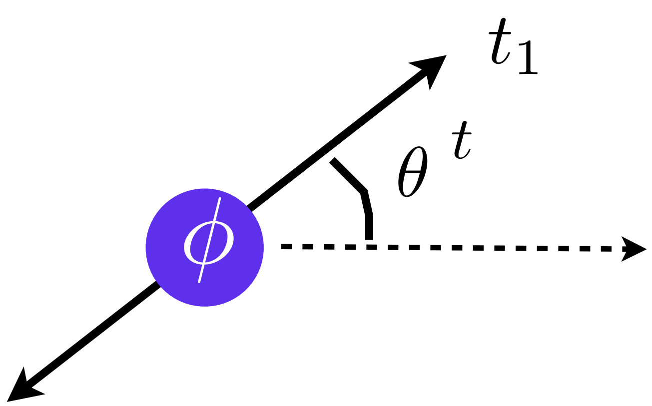
- ✳ leptons: $a = 10\%,$ $b = 0.7\%$
- ✳ jets: $a = 50\%,$ $b = 3\%$

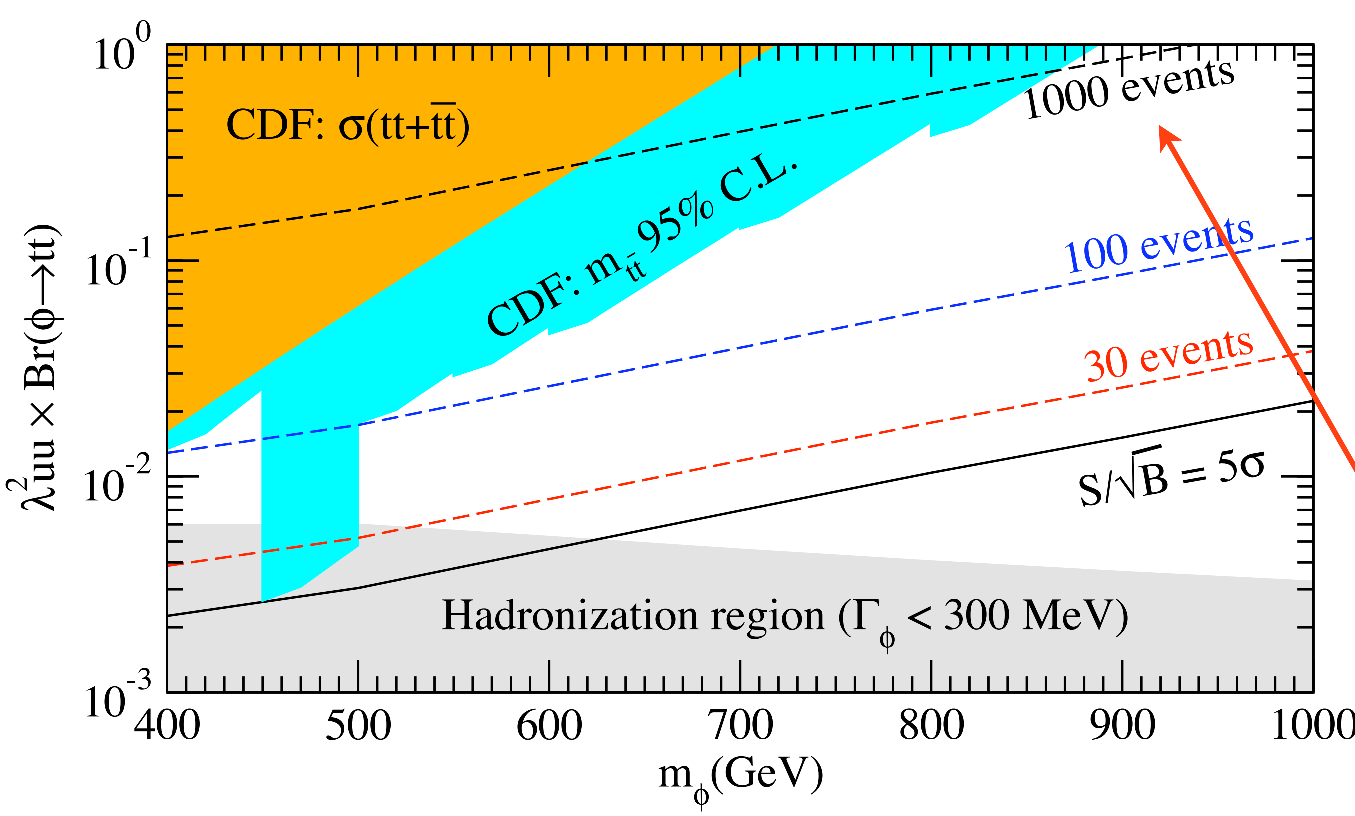
★ Tagging rates / Mistag rates

$$\epsilon_{c\to b} = 10\%, \quad \text{for } \mathrm{p_T(c)} > 50 \text{ GeV}$$

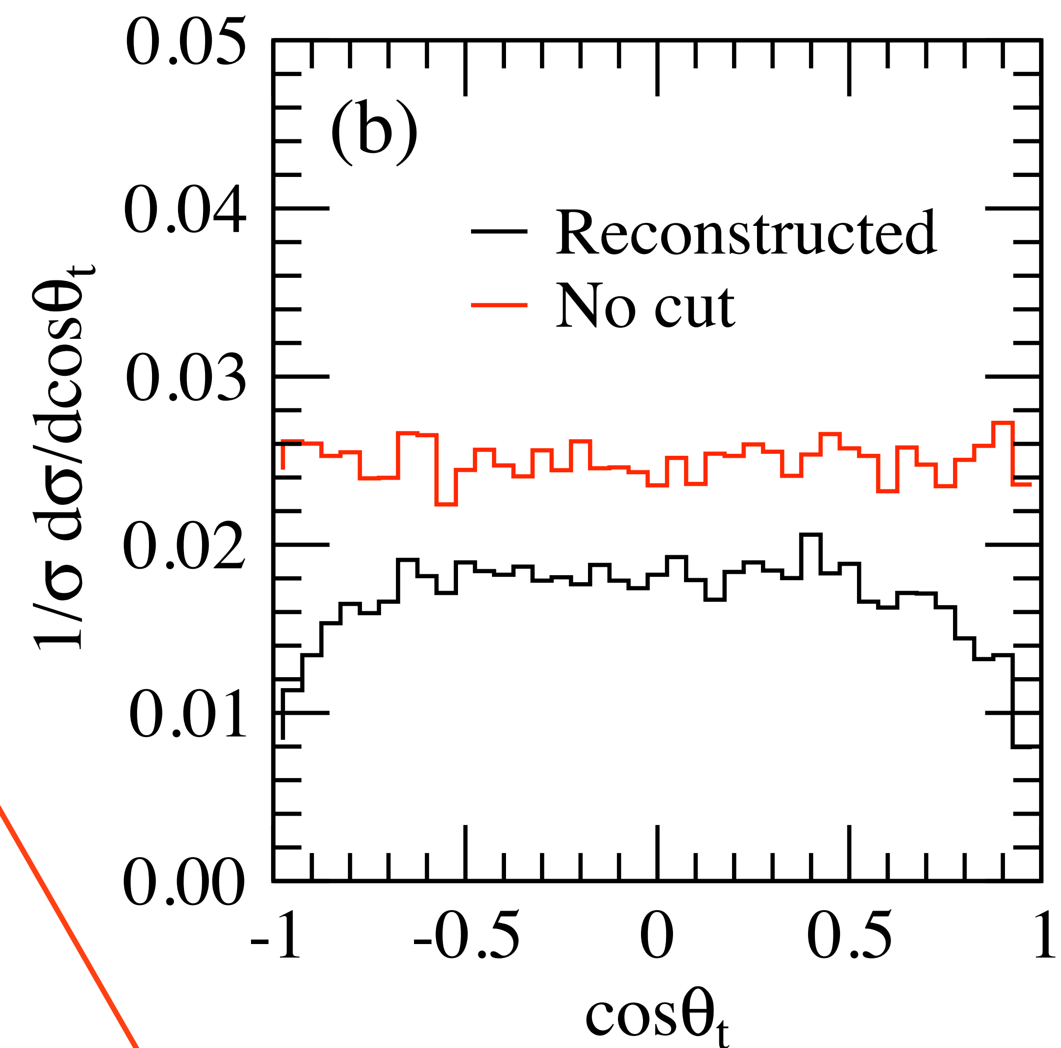
$$\epsilon_{u,d,s,g\to b} \approx 1\%$$

RECONSTRUCTED EVENT DISTRIBUTION





★ Can we determine the spin of the heavy resonance? Not trivial !



Not realistic for early LHC!

It requires ~ O(1000) events to verify the flat distribution.

TOP QUARK POLARIZATION

★ Among the top quark decay products, the charged lepton is maximally correlated with top quark spin.

$$\frac{1}{\Gamma}\frac{d\Gamma(t\to b\ell\nu)}{d\cos\theta}=\frac{1}{2}\left(1+\frac{N_+-N_-}{N_++N_-}\cos\theta\right)$$

★ θ is the angle, in the top quark rest frame, between the direction of the charged lepton and the spin of the top quark. In the helicity basis, top quark spin along its moving direction.

(a) left-handed top $(1-\cos\theta)$ (b) right-handed top $(1+\cos\theta)$