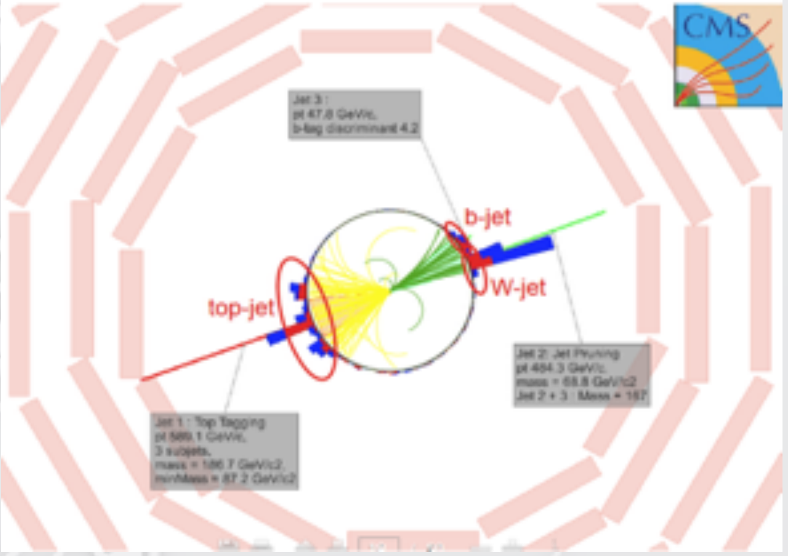
Boosted Objects (BSM) &…

2016 June 23

Seung J. Lee

Outline

- Introduction
- Boosted Objects from BSM
  - SUSY, XD, Composite Higgs Models, etc
- Jet-substructure with Artificial Neural Network
- Summary



Jets & New Physics

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- Looking for new physics in “energetic” jets has a long tradition:

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No. 4077 December 20, 1947 NATURE

EVIDENCE FOR THE EXISTENCE OF NEW UNSTABLE ELEMENTARY PARTICLES

By Dr. G. D. ROCHESTER
AND
Dr. C. C. BUTLER
Physical Laboratories, University, Manchester

AMONG some fifty counter-controlled cloud-chamber photographs of penetrating showers which we have obtained during the past year as part of an investigation of the nature of penetrating particles occurring in cosmic ray showers under lead, there are two photographs containing forked tracks of a very striking character. These photographs have been selected from five thousand photographs taken in an effective time of operation of 1,500 hours. On the basis of the analysis given below we believe that one of the forked tracks, shown in Fig. 1 (tracks *a* and *b*), represents the spontaneous transformation in the gas of the chamber of a new type of uncharged elementary particle into lighter charged particles, and that the other, shown in Fig. 2 (tracks *a* and *b*), represents similarly the transformation of a new type of charged particle into two light particles, one of which is charged and the other uncharged.

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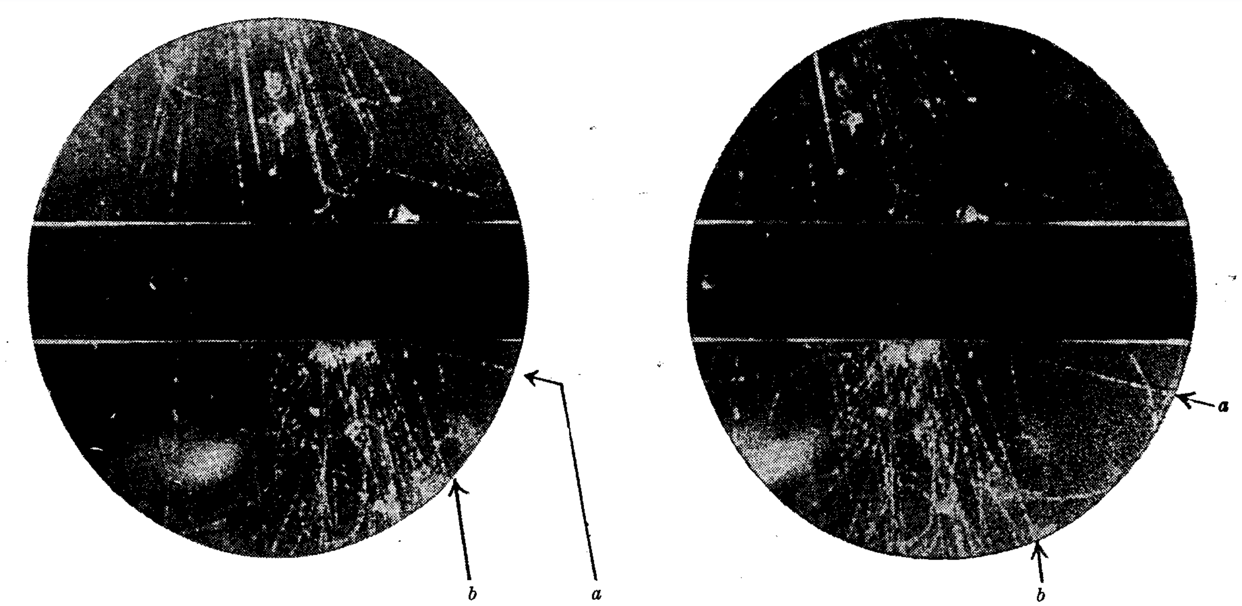

Fig. 1. STEREOSCOPIC PHOTOGRAPHS SHOWING AN UNUSUAL FORK (*a b*) IN THE GAS. THE DIRECTION OF THE MAGNETIC FIELD IS SUCH THAT A POSITIVE PARTICLE COMING DOWNWARDS IS DEVIATED IN AN ANTICLOCKWISE DIRECTION

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THE NEW UNSTABLE COSMIC-RAY PARTICLES

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1953 Rep. Prog. Phys. 16 364

CONTENTS

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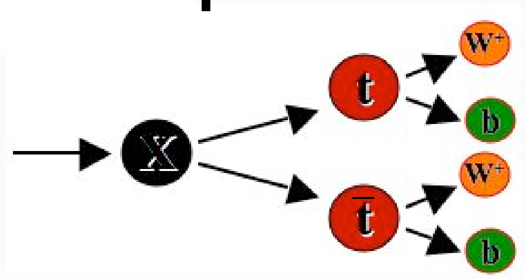
Top jets @ LHC

- NP @ EWSB scale => New states decay quickly into top + X



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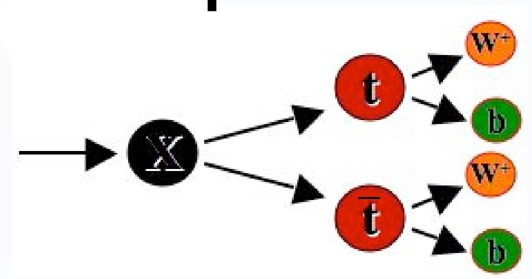

♦ If $m_X >> m_t$, the outgoing tops are ultra-relativistic, their products collimate => top jets.

$$\Delta R \approx 2\, m / p_T$$

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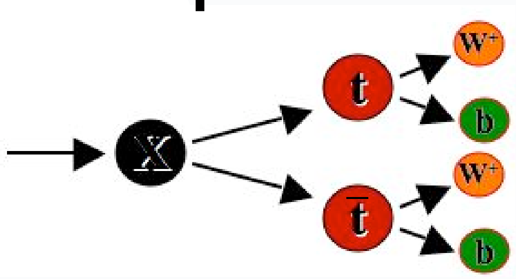

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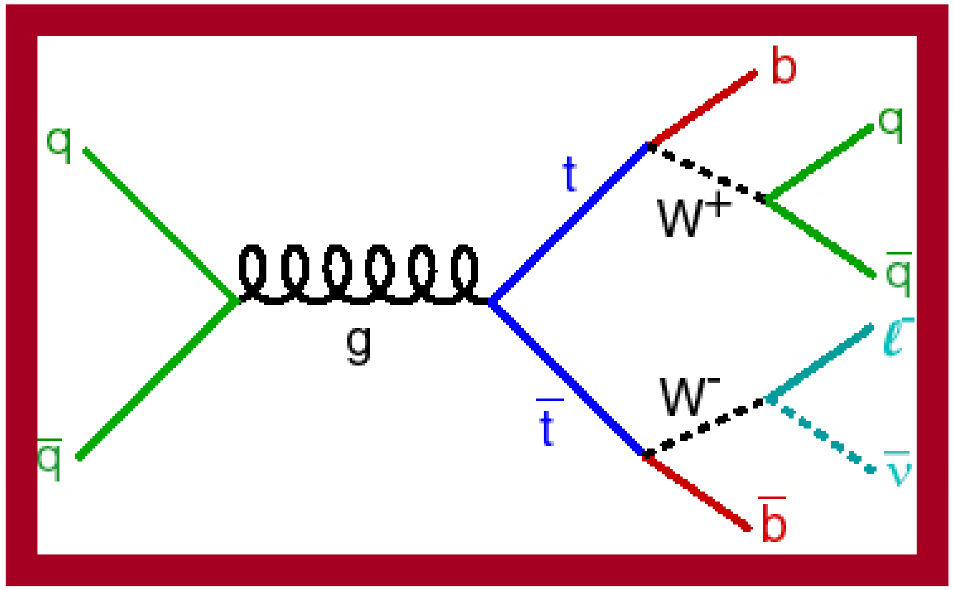

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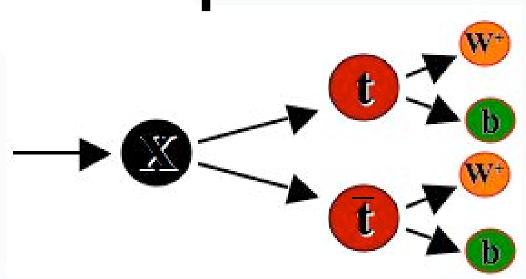

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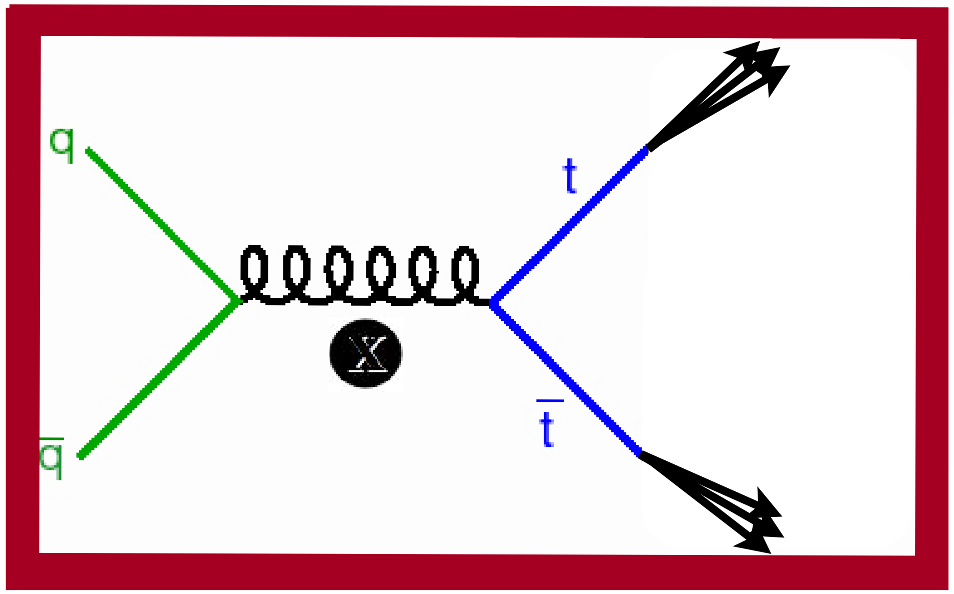

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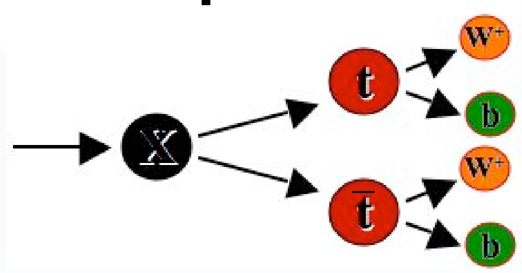

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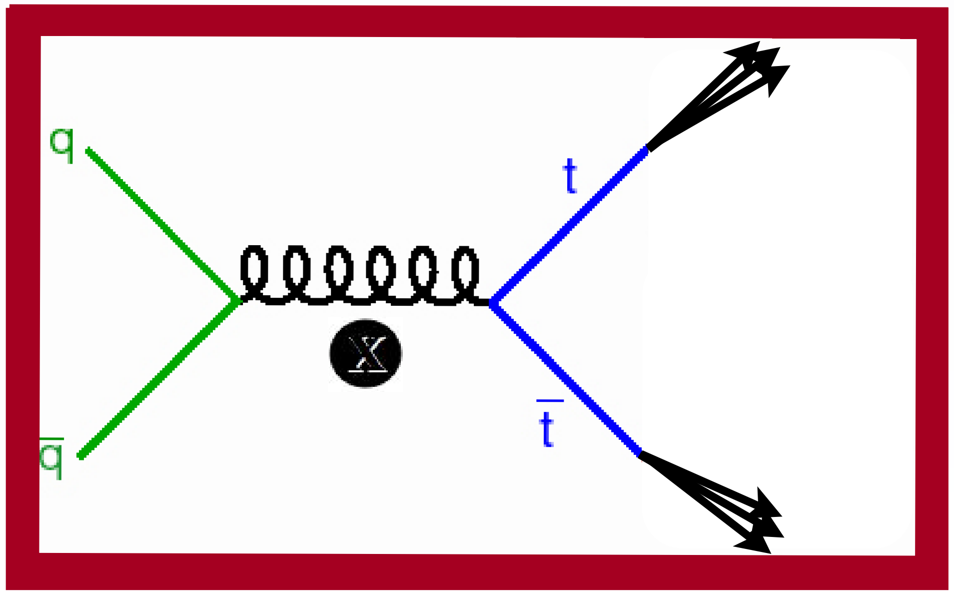

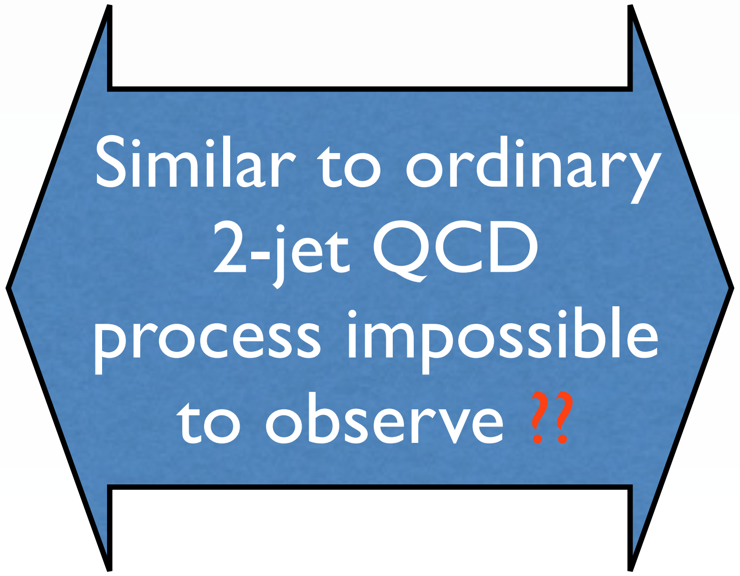

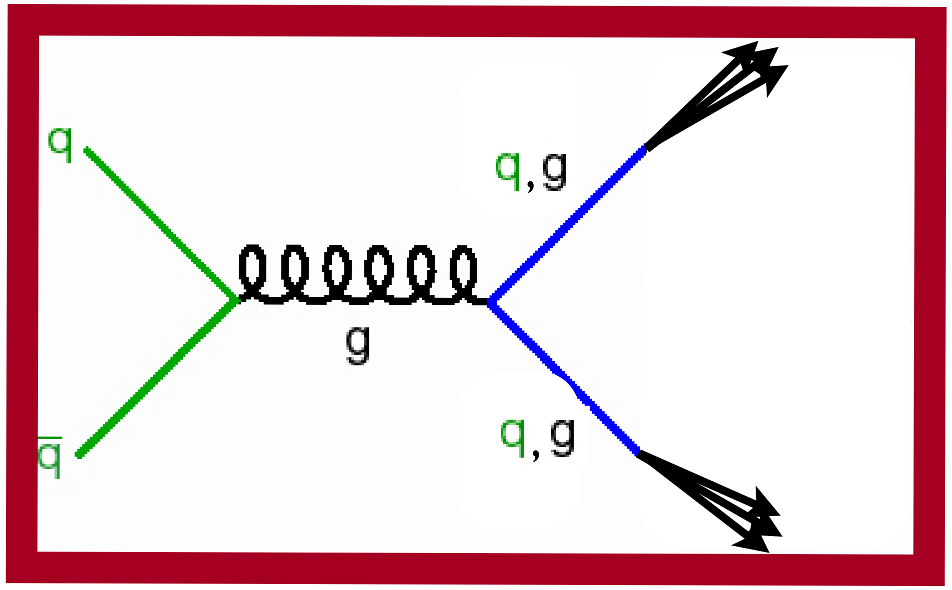

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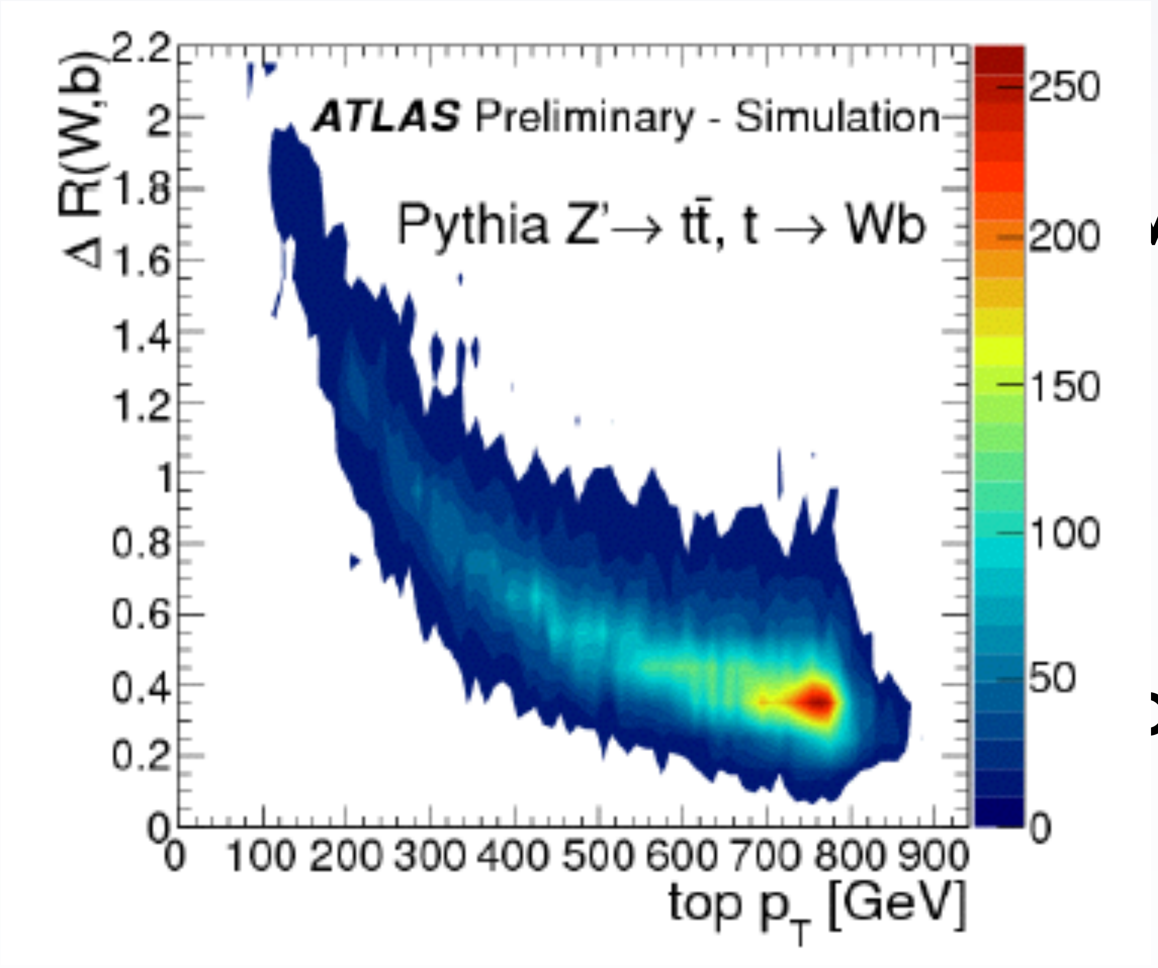

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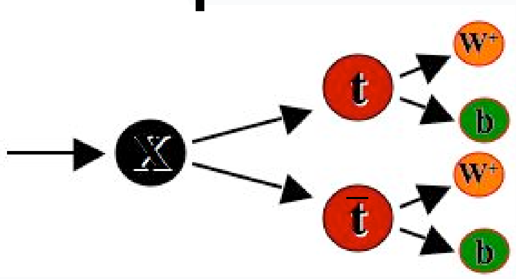

ps are ultra-relativistic, their products

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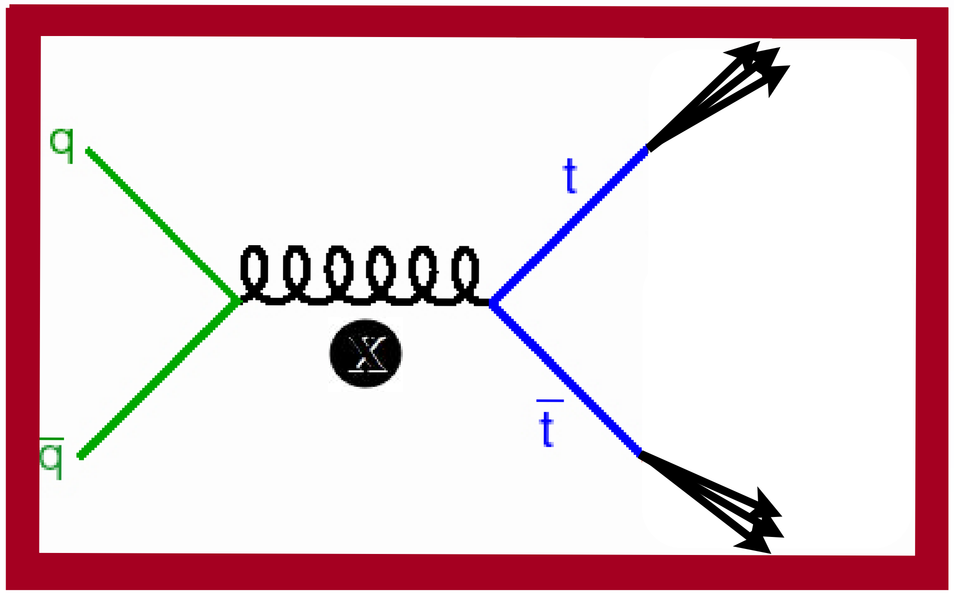
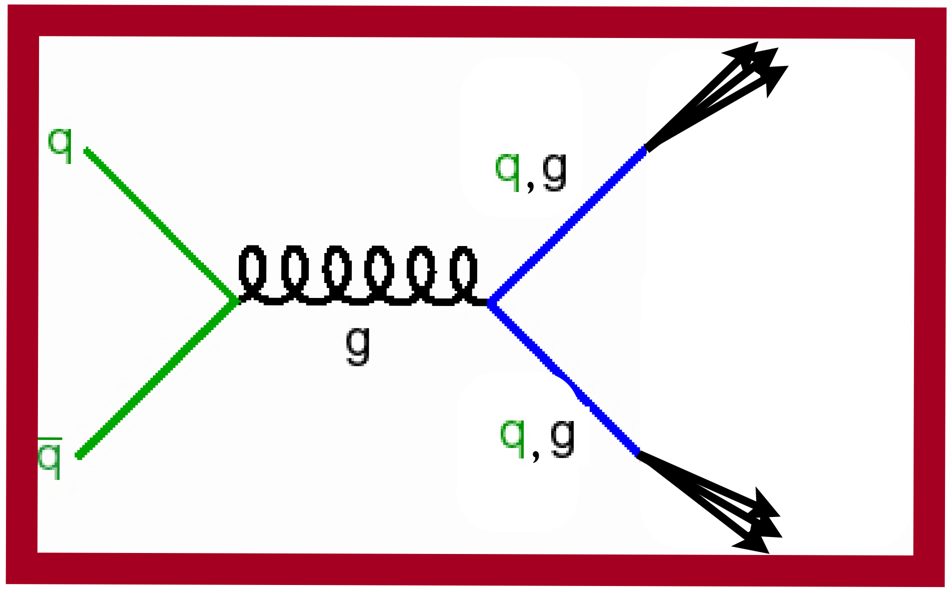
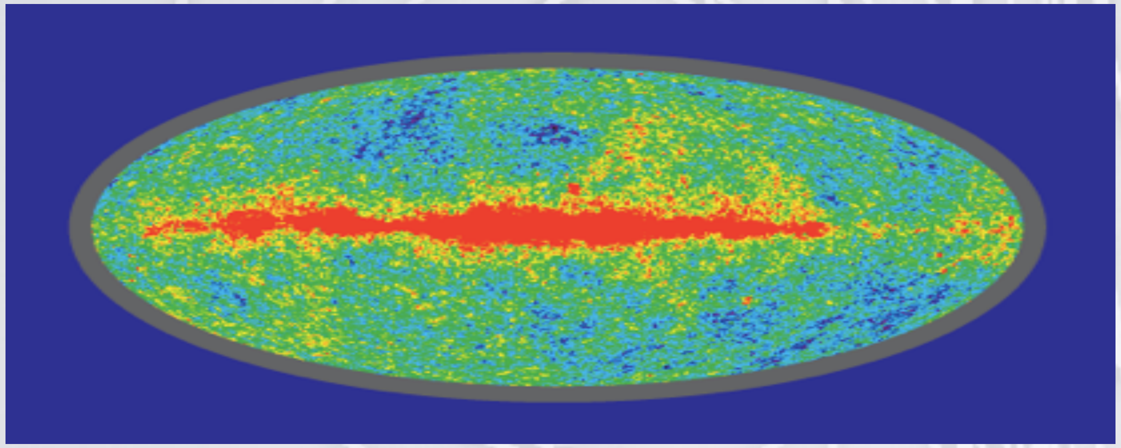
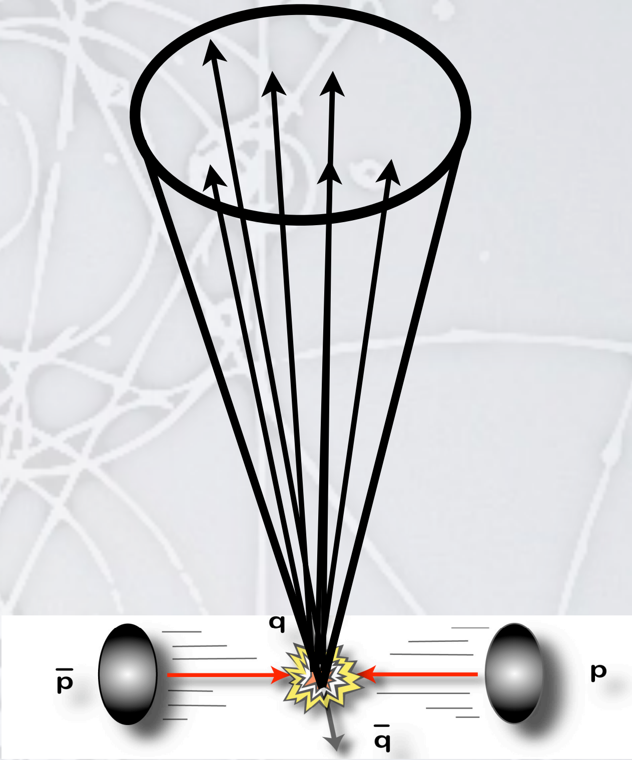


Similar to ordinary 2-jet QCD process impossible to observe ⁇



Need to understand the energy flow inside jet





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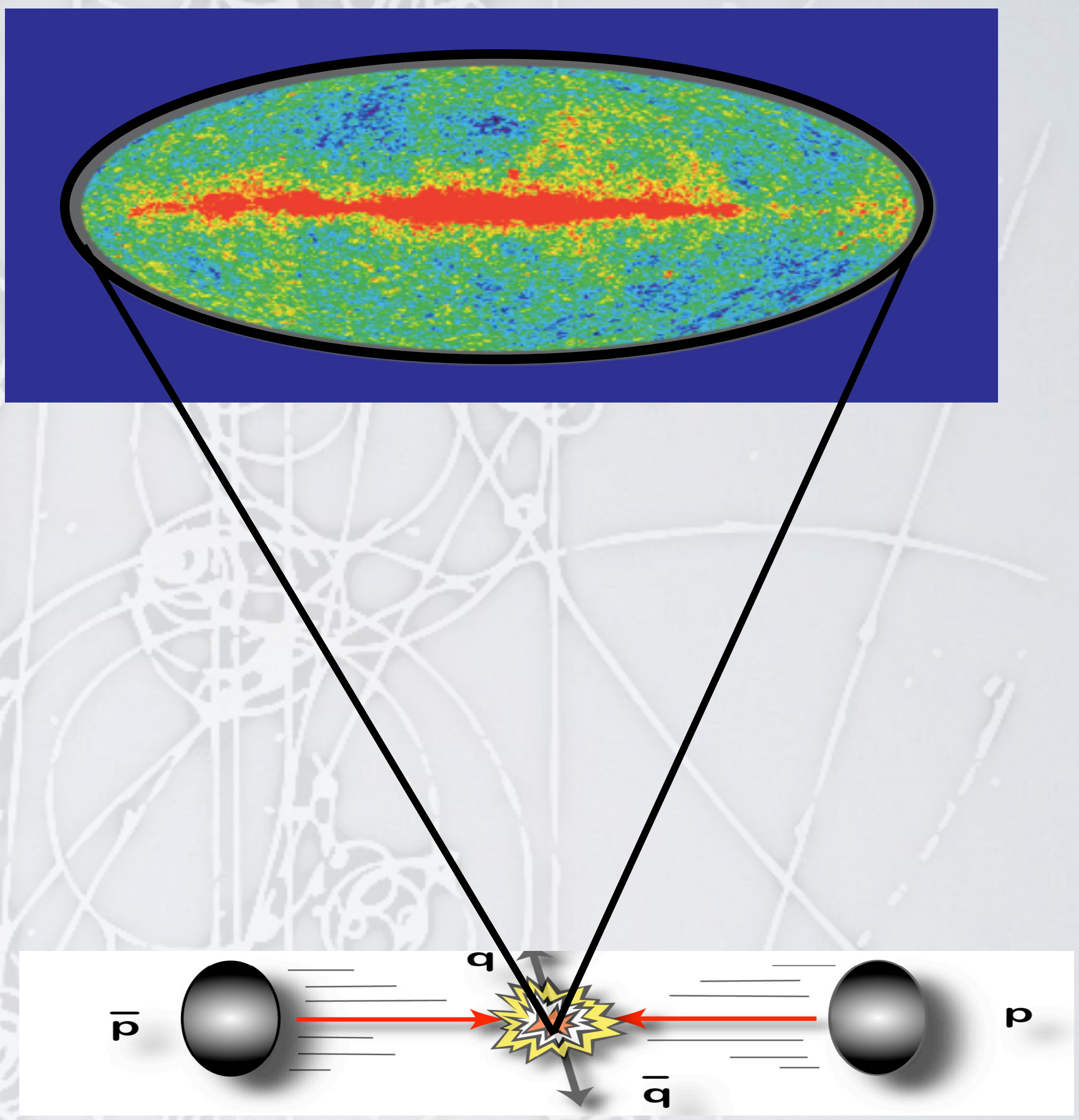
Jet Substructure



i)Algorithmic…
(Jet declustering)

ii)Jet Shape (calculable)

iii)Matrix-element (shower deconstruction)

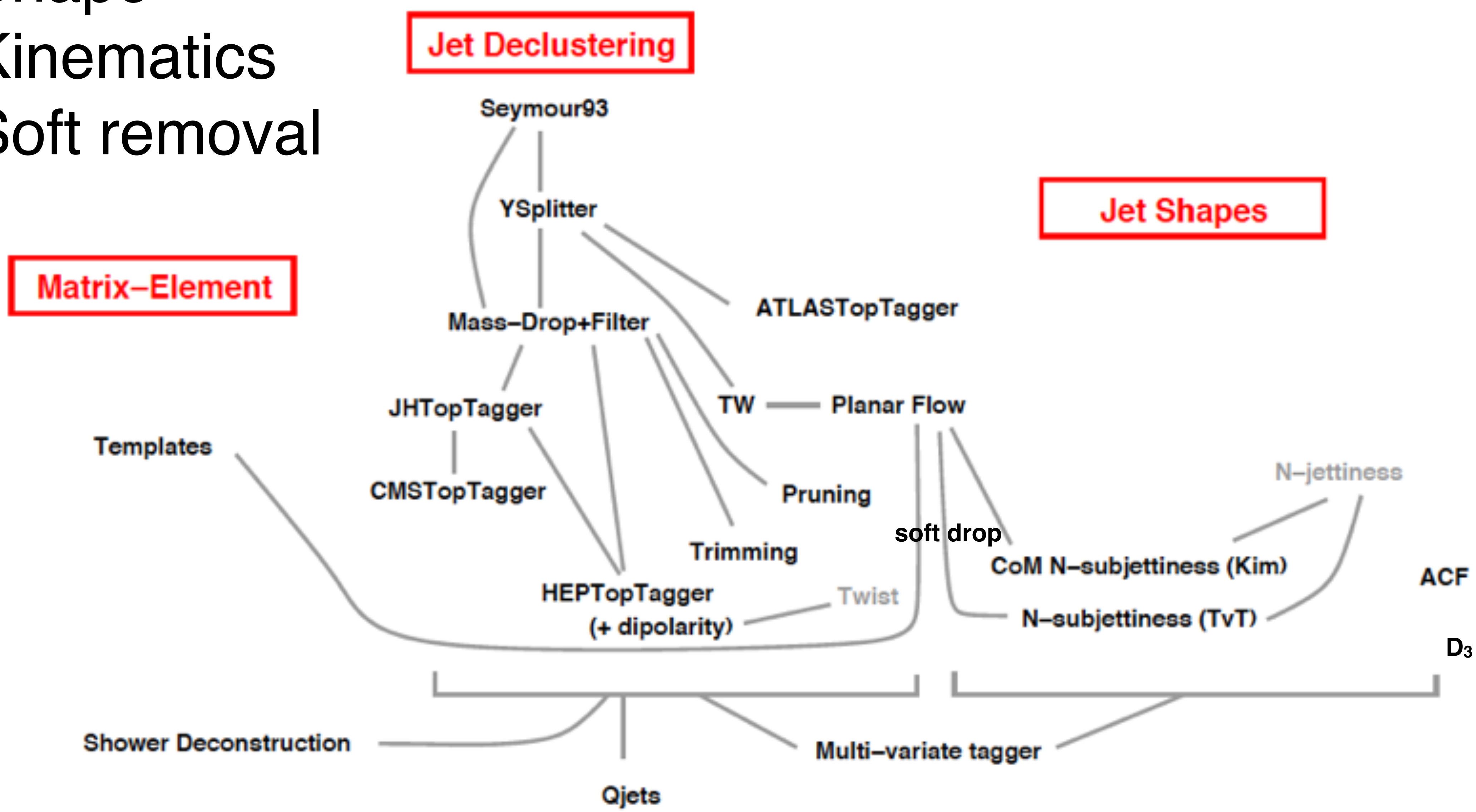
iv)Template

…

How do we know it's top jet?
Jet substructure

Very active research field

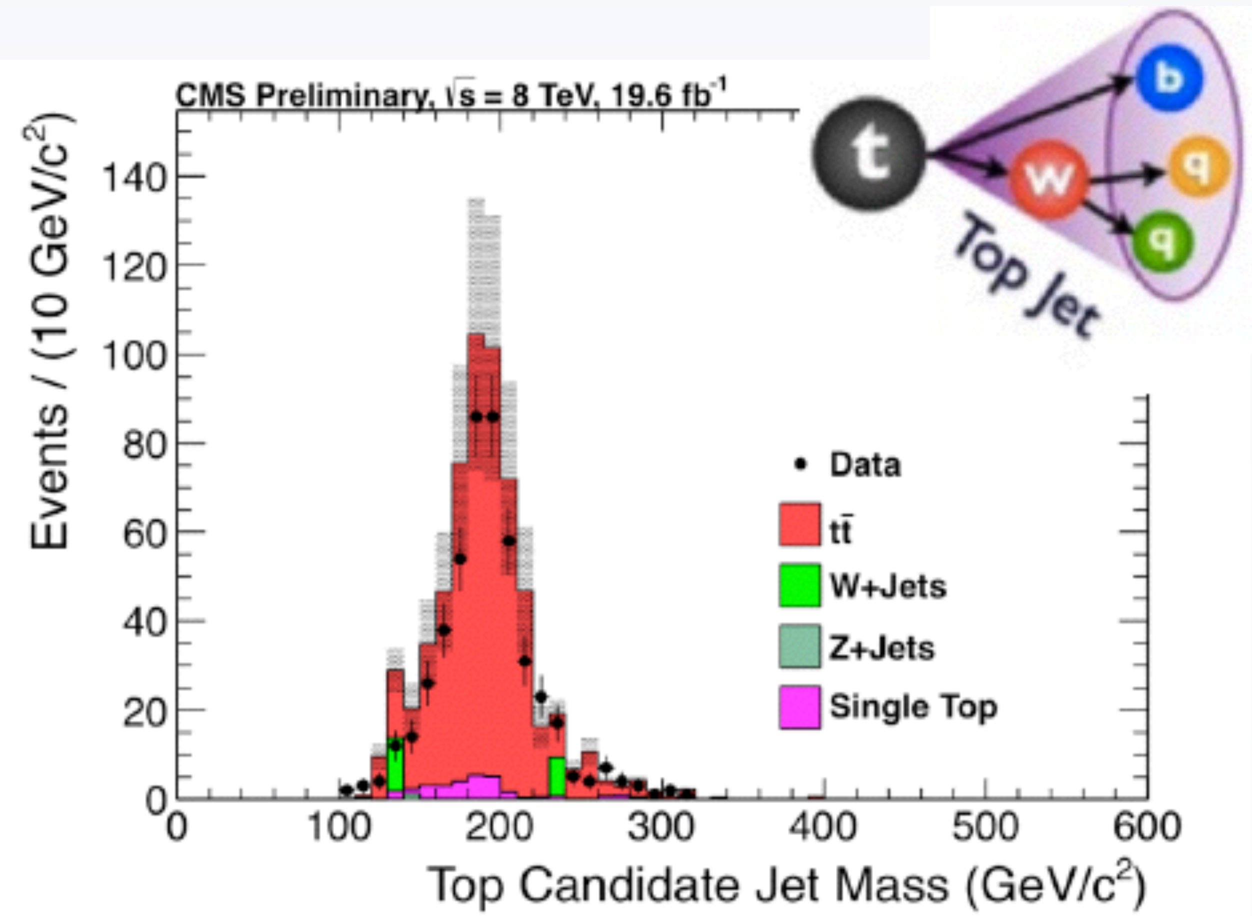
.Shape
.Kinematics
.Soft removal



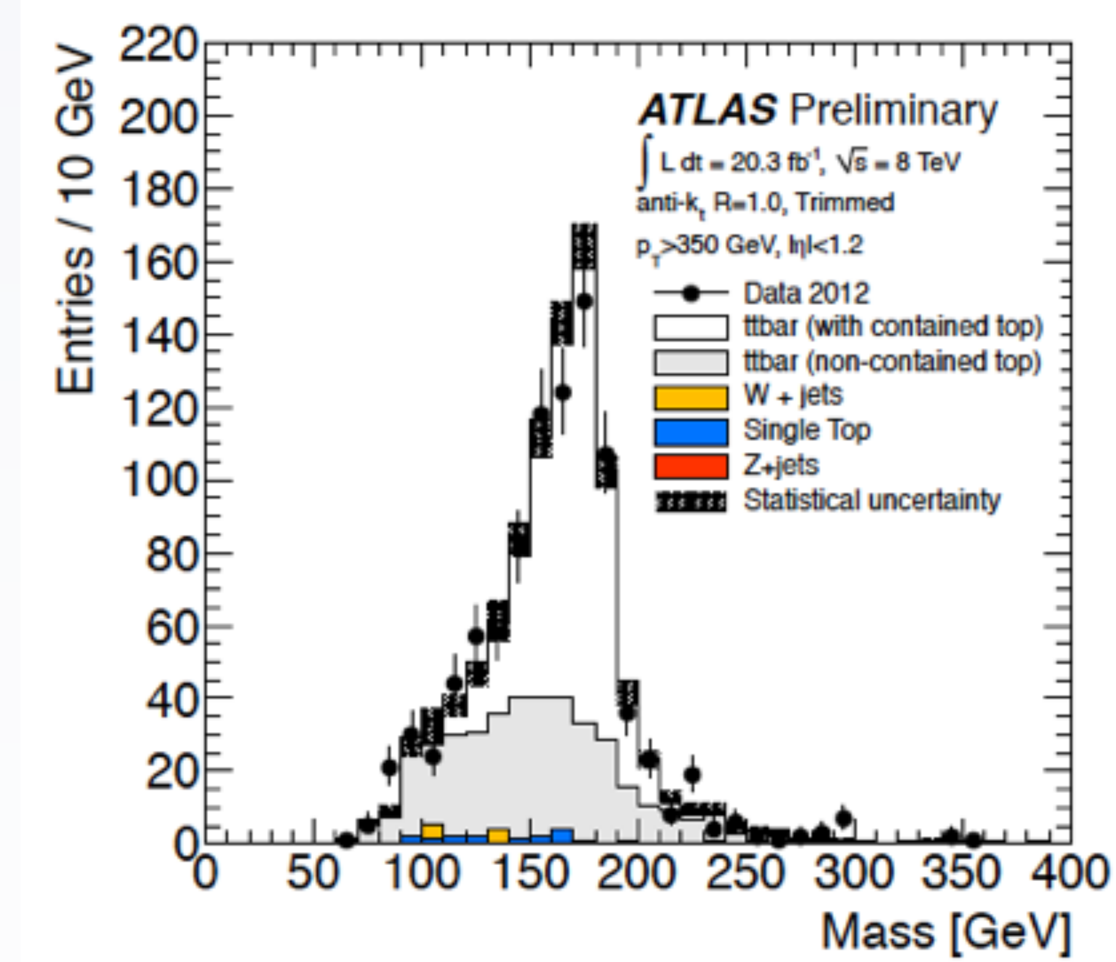
apologies for omitted taggers, arguable links, etc.

Gavin Salam

Lesson from Run I & early Run 2: it works!



$p_T > 400$ GeV



Jet p_T > 350 GeV and 3 k_t subjets

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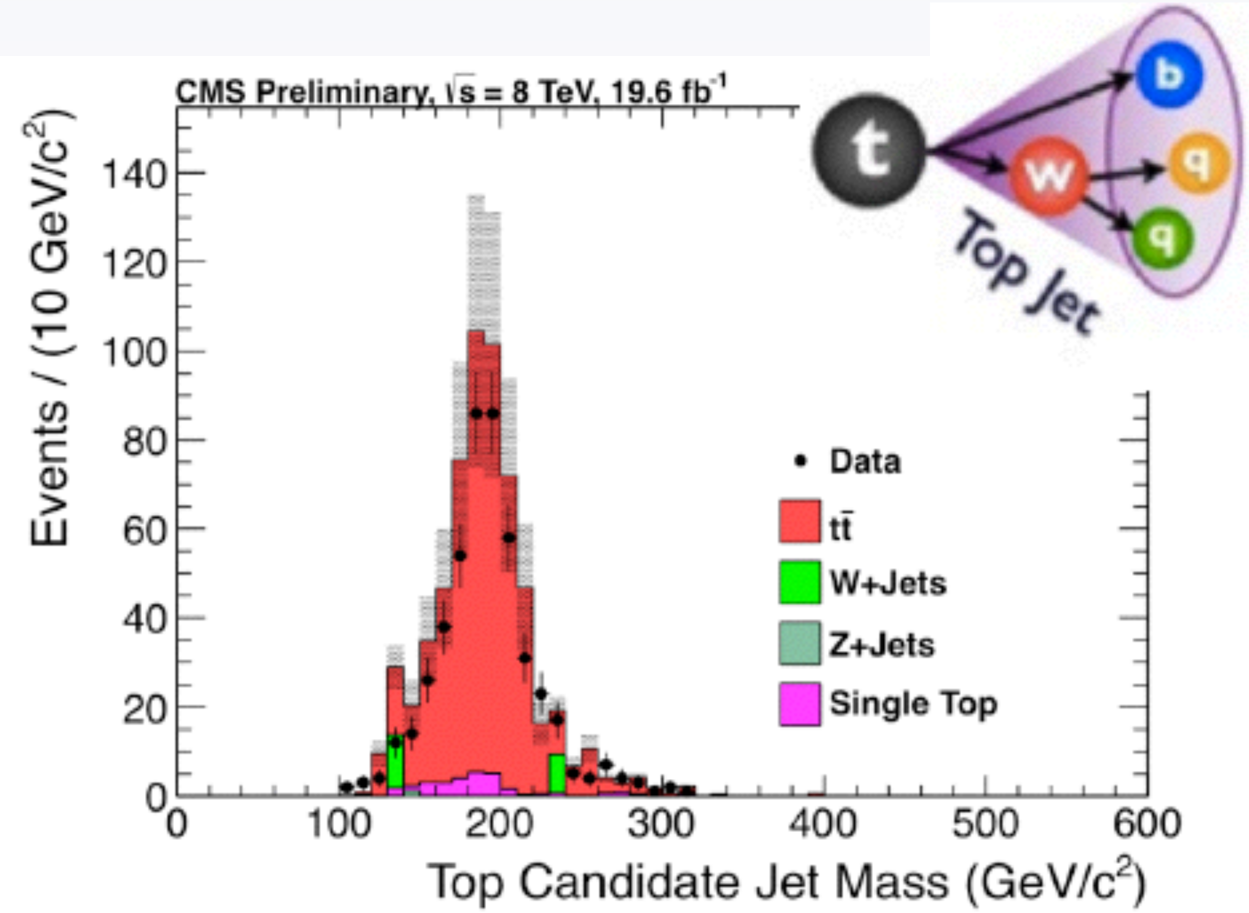

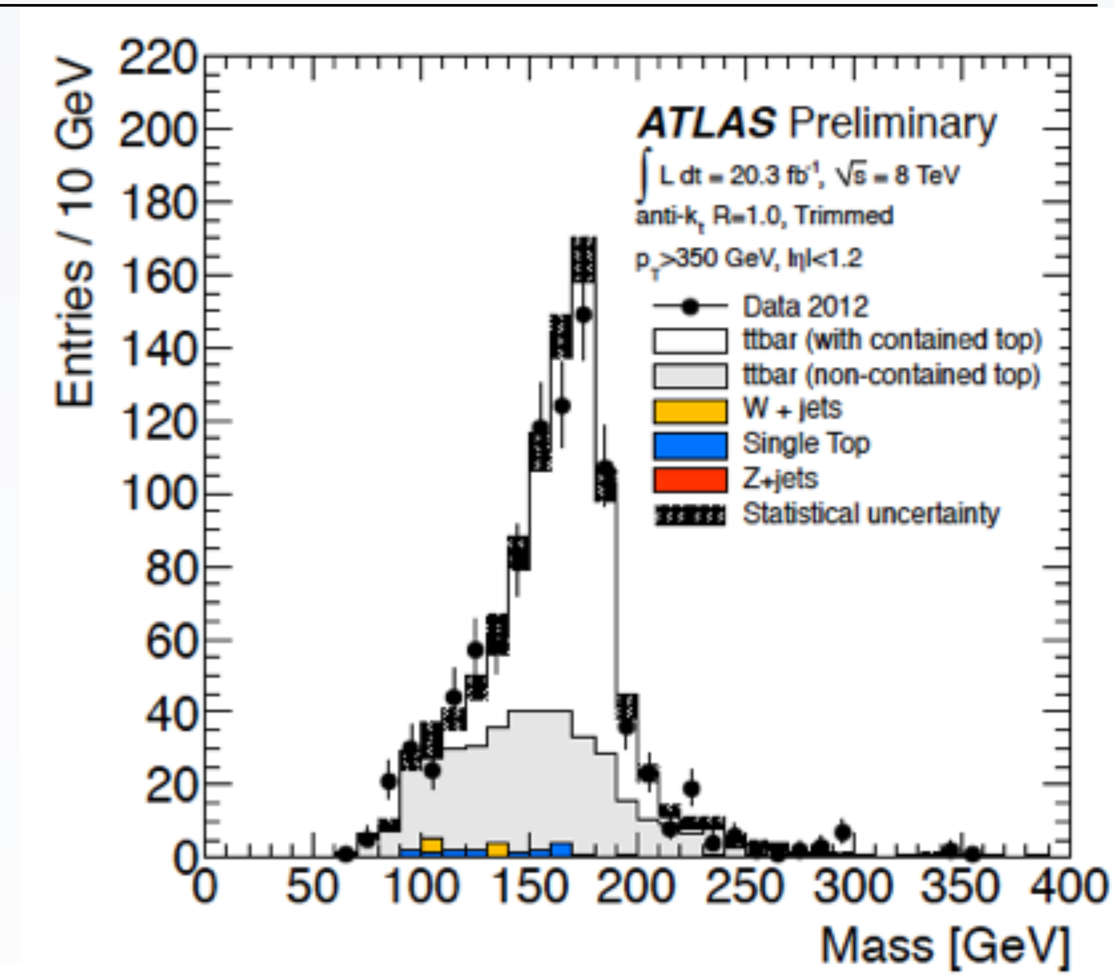

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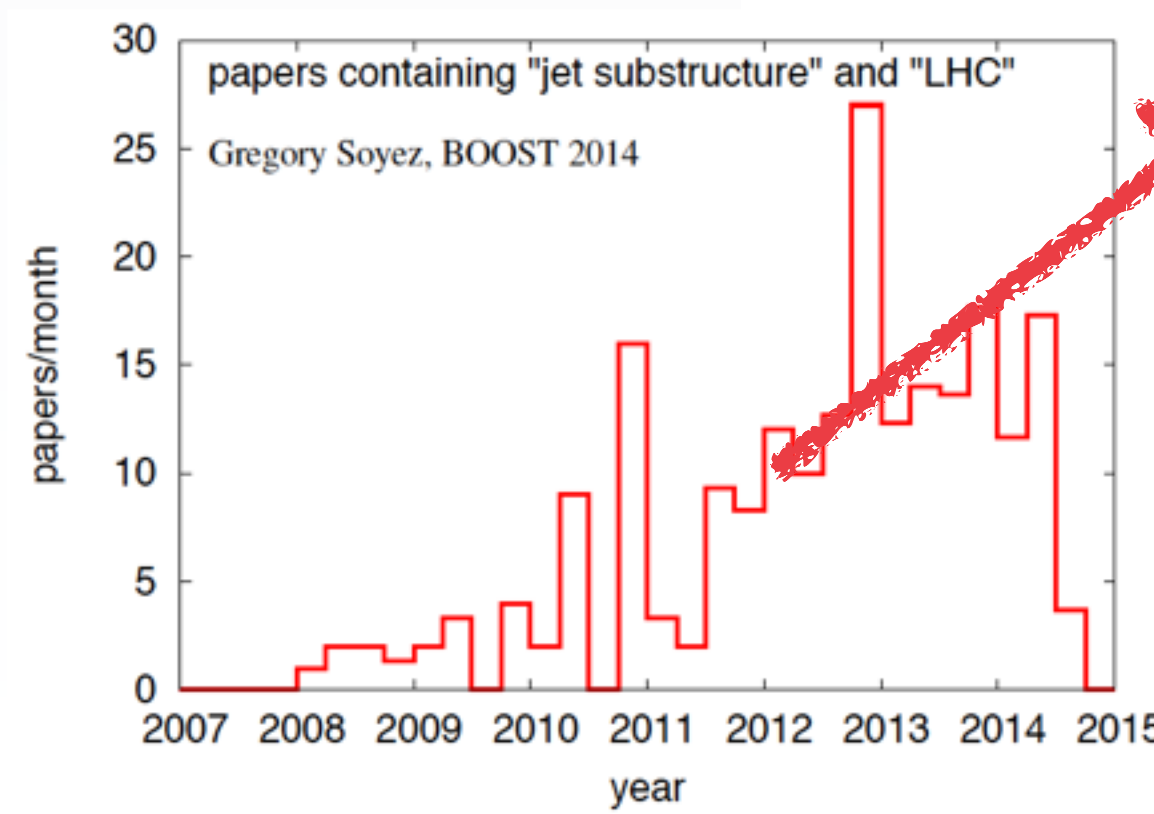

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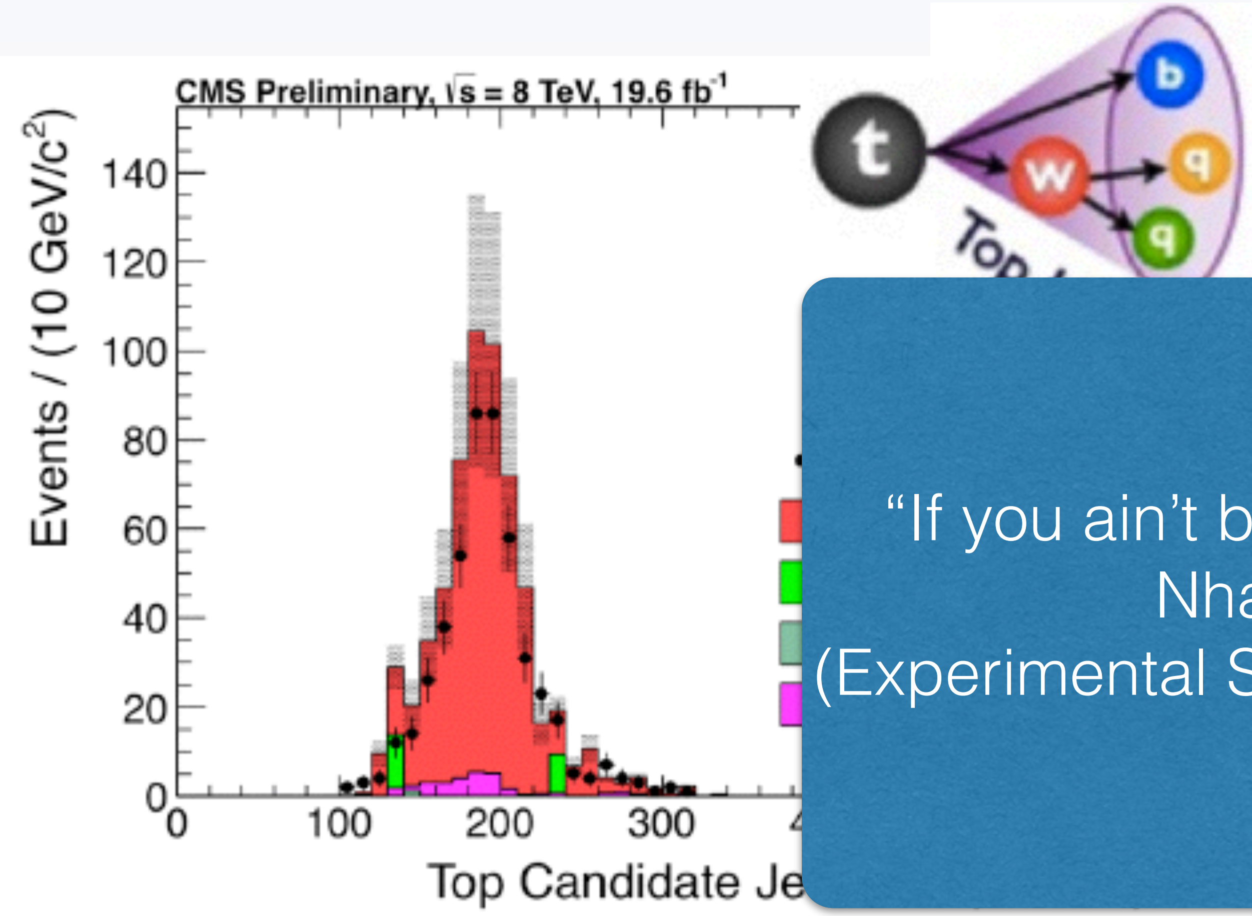

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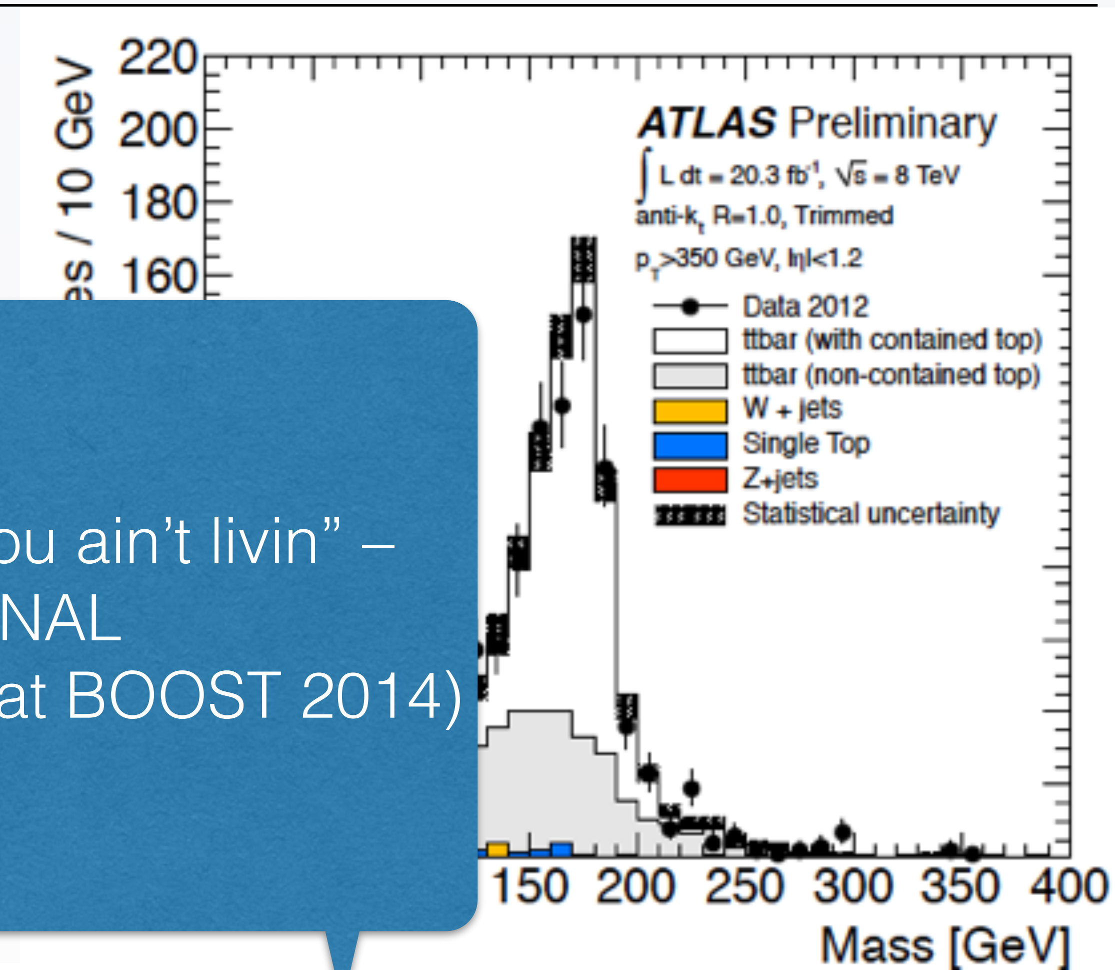
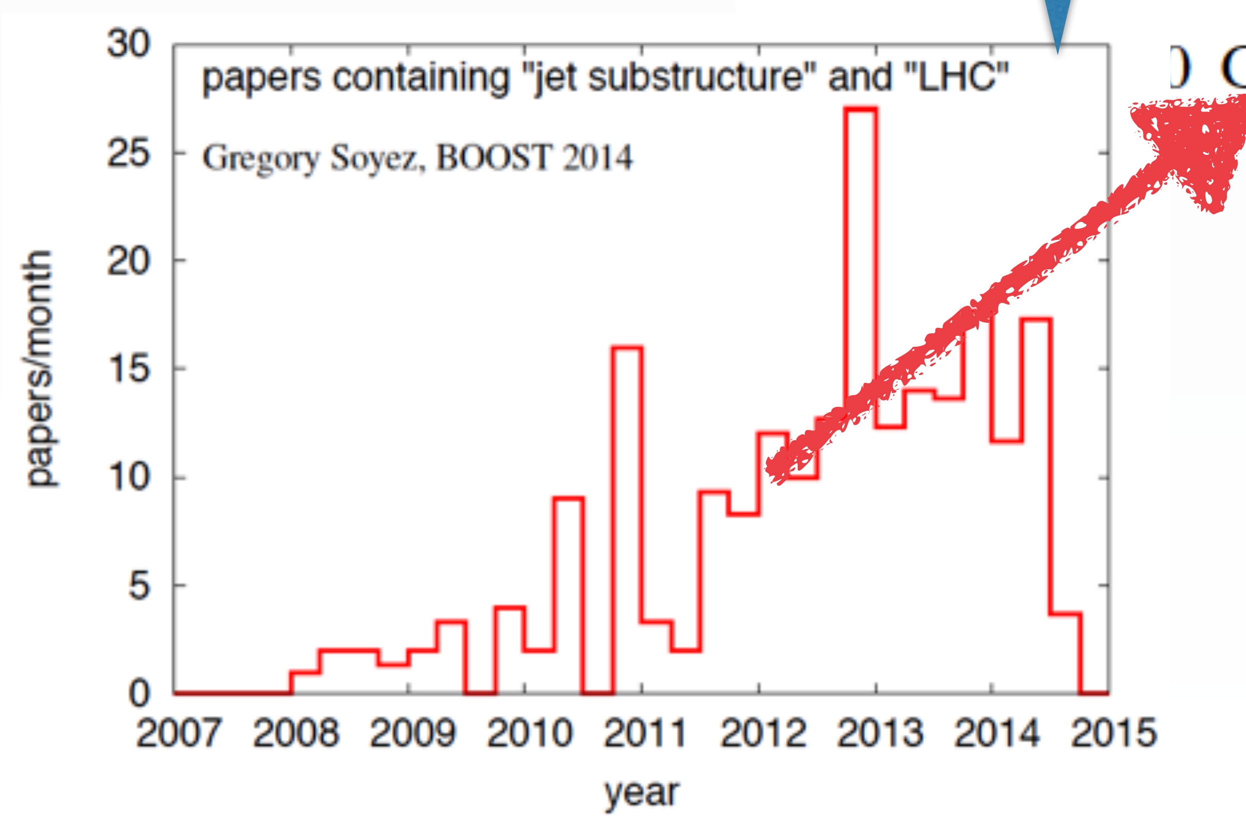


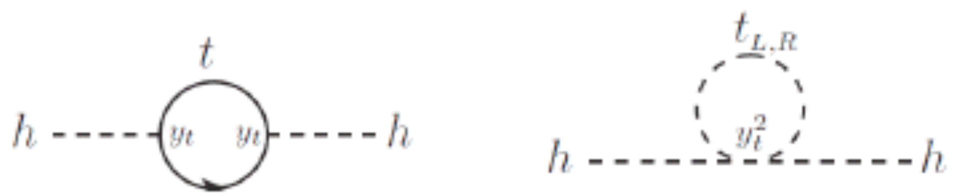
) GeV and 3 k_t subjets

"If you ain't boostin', you ain't livin" – Nhan Tran, FNAL
(Experimental Summary at BOOST 2014)



Boosted Objects (BSM)

Naturalness => new colored partners, potentially within the LHC reach.



$$\frac{\delta m_h^2}{m_h^2} \sim \left(\frac{\tilde{m}_t}{400\,\mathrm{GeV}}\right)^2$$

2 leading frameworks
of naturalness

AdS/CFT
warped extra dimension

Supersymmetry
top partners=stops

Composite Higgs
top partners = "T"

Well, Higgs is just another fundamental scalar bosons, and more is coming…!
$m_{stop} \gtrsim 700$ GeV

No, Higgs is just another composite resonance we are familiar with …!

Boosted Objects (BSM)

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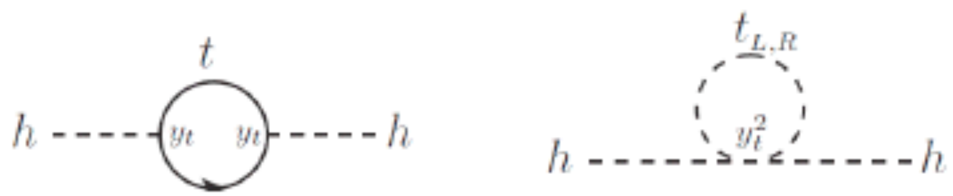
*Neutral Naturalness (~ a last resort…) is not discussed in this talk



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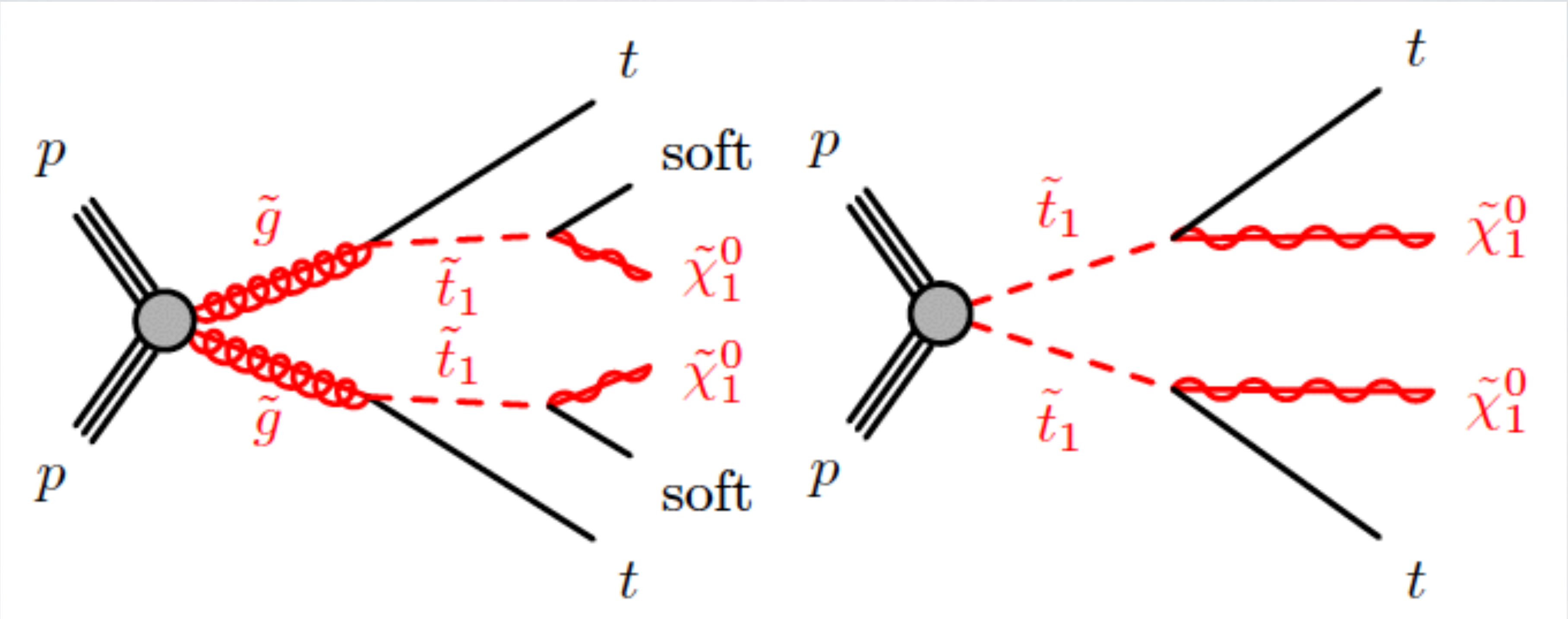
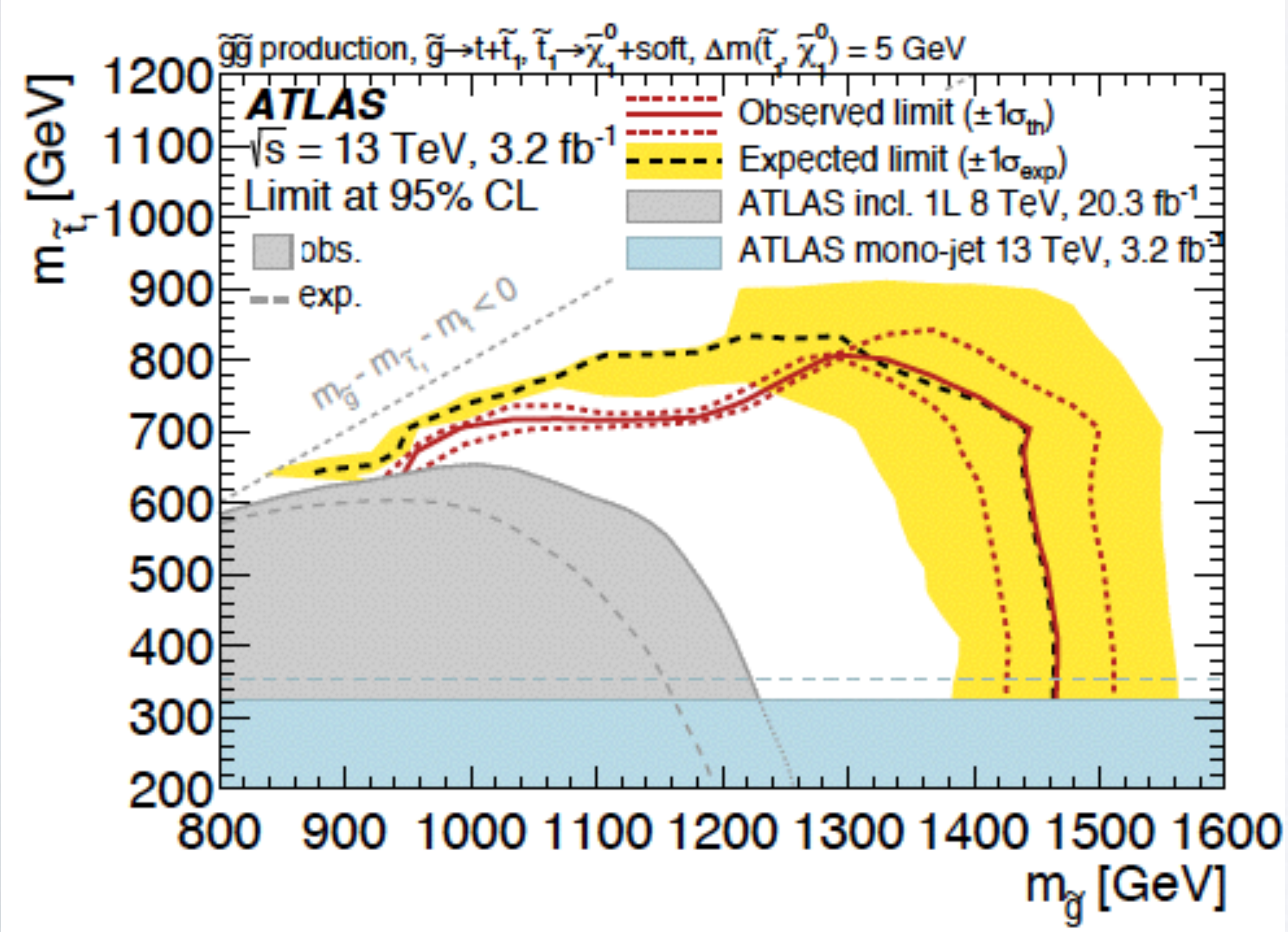
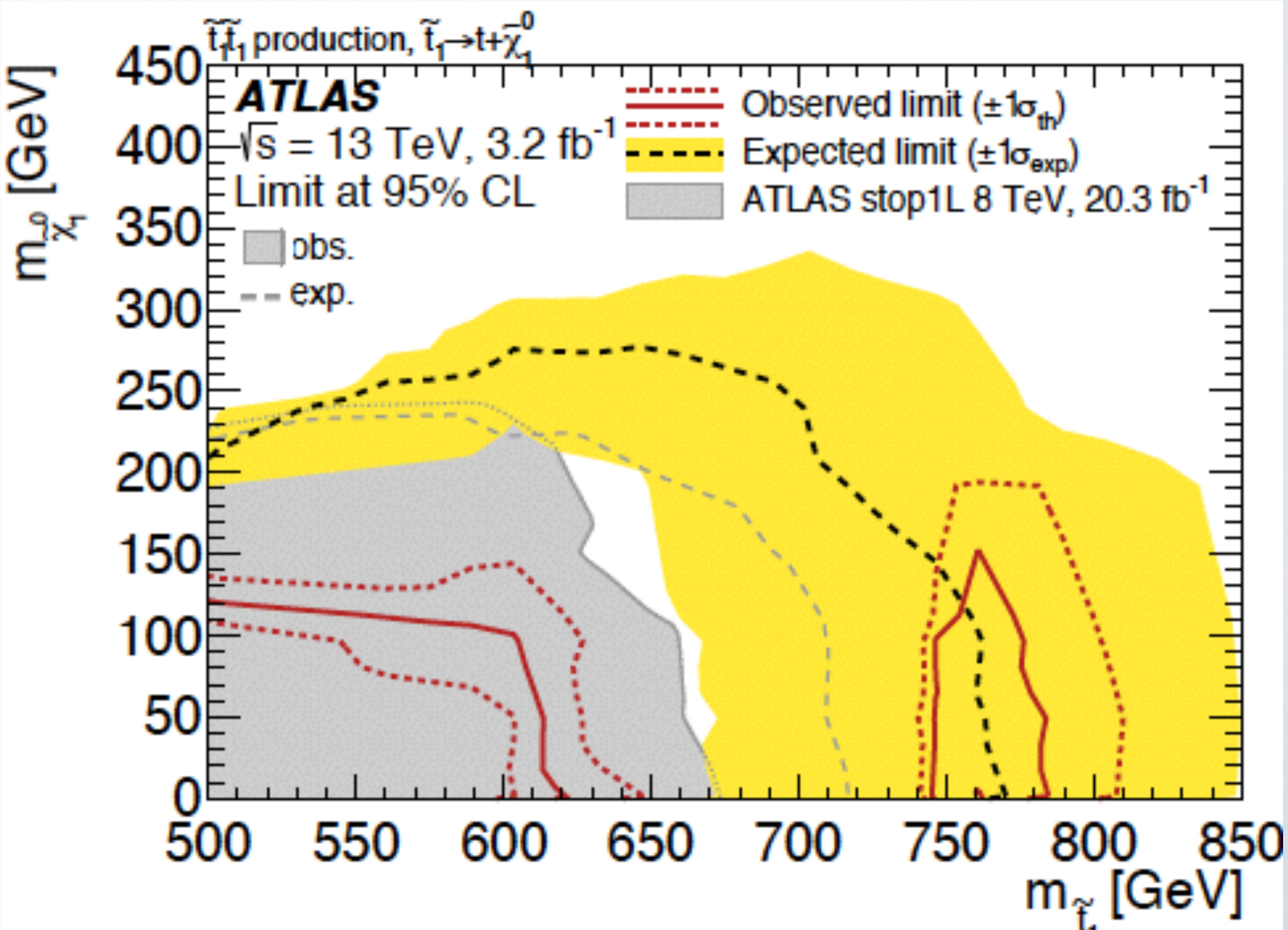
Boosted Objects (BSM): SUSY examples



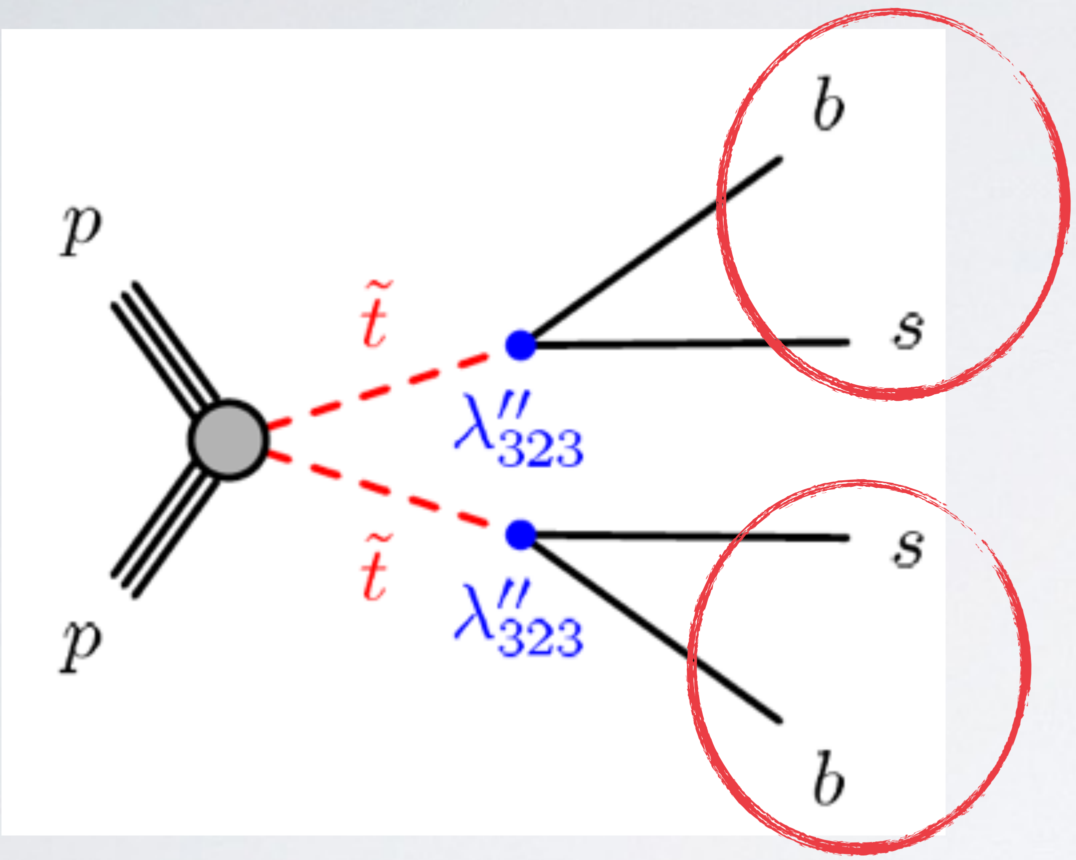


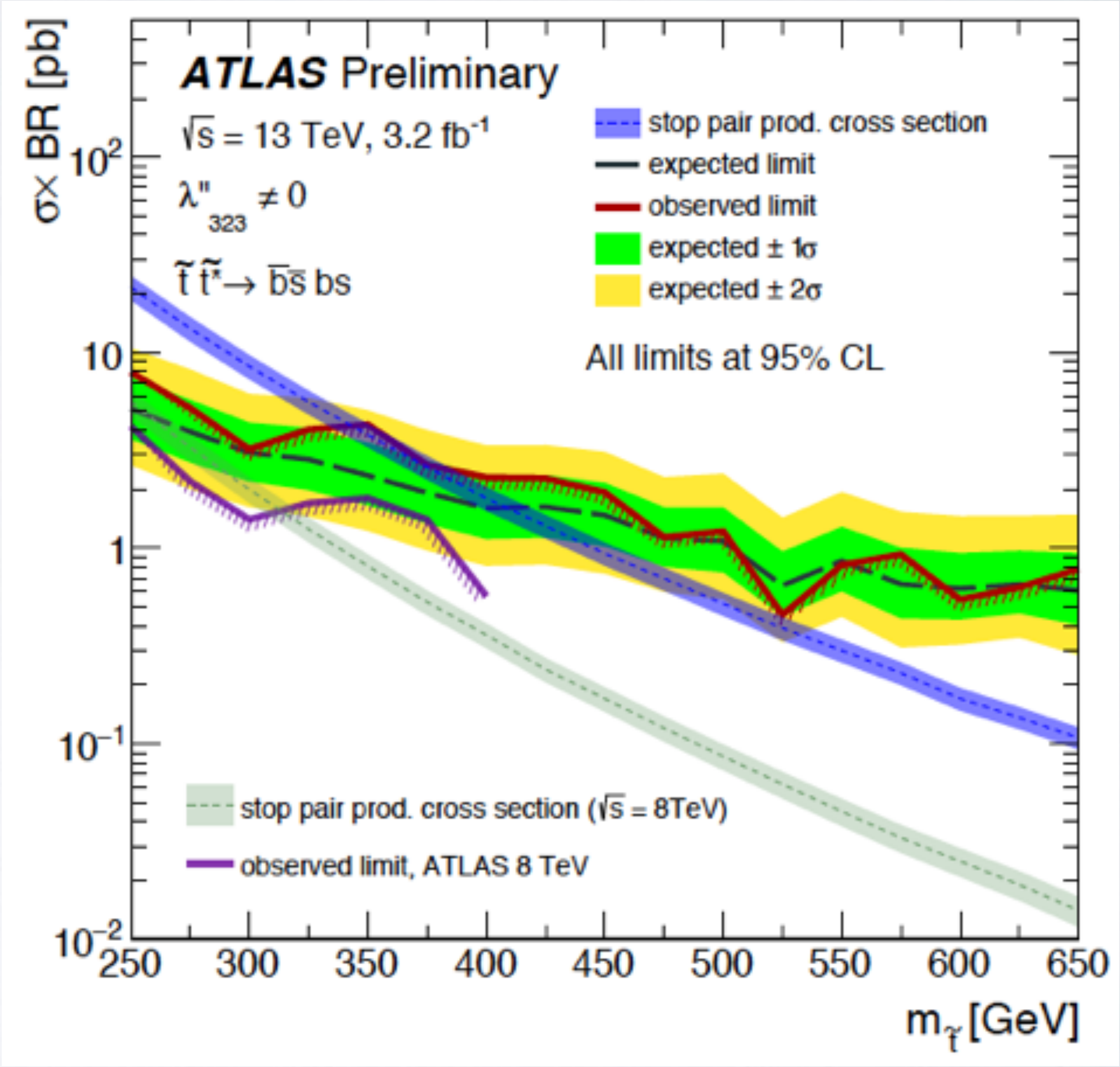


Boosted Objects (BSM): SUSY examples

- **RPV SUSY**

e.g. Fat jet with BDRS substructure algorithm Han, Katz, Son, Tweedie 12'





c.f. RPV SUSY w/ gluino decays to three quarks.

Eshel, Gedalia, Perez, Soreq 11'

Boosted Objects (BSM):Composite Higgs Models

$\mathcal{L}^{UV}_{comp} + \mathcal{L}^{UV}_{el,mix}$

Λ_{UV}

strong
dynamics

Higgs mass term is
irrelevant above Λ_{IR}

$\mathcal{L}^{IR}_{comp} + \mathcal{L}^{IR}_{el,mix}$

$\Lambda_{IR} \sim g_\rho f$

IR scale is dynamically generated
f ⇔ a symmetry breaking scale

heavy
resonances

$g_\psi f$

PNGB model often requires $g_\psi f \neq g_\rho f$ for less fine-tuning to get ~125 GeV higgs

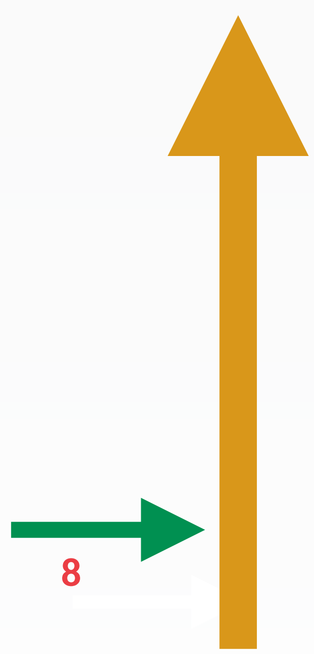
Λ_{EW}

weak
dynamics

$$m_h^2 \sim \frac{N_c}{2\pi^2} \frac{v^2}{f^2} M_T$$

$$\xi \equiv \frac{v^2}{f^2}$$

Composite Higgs Models: EWPT



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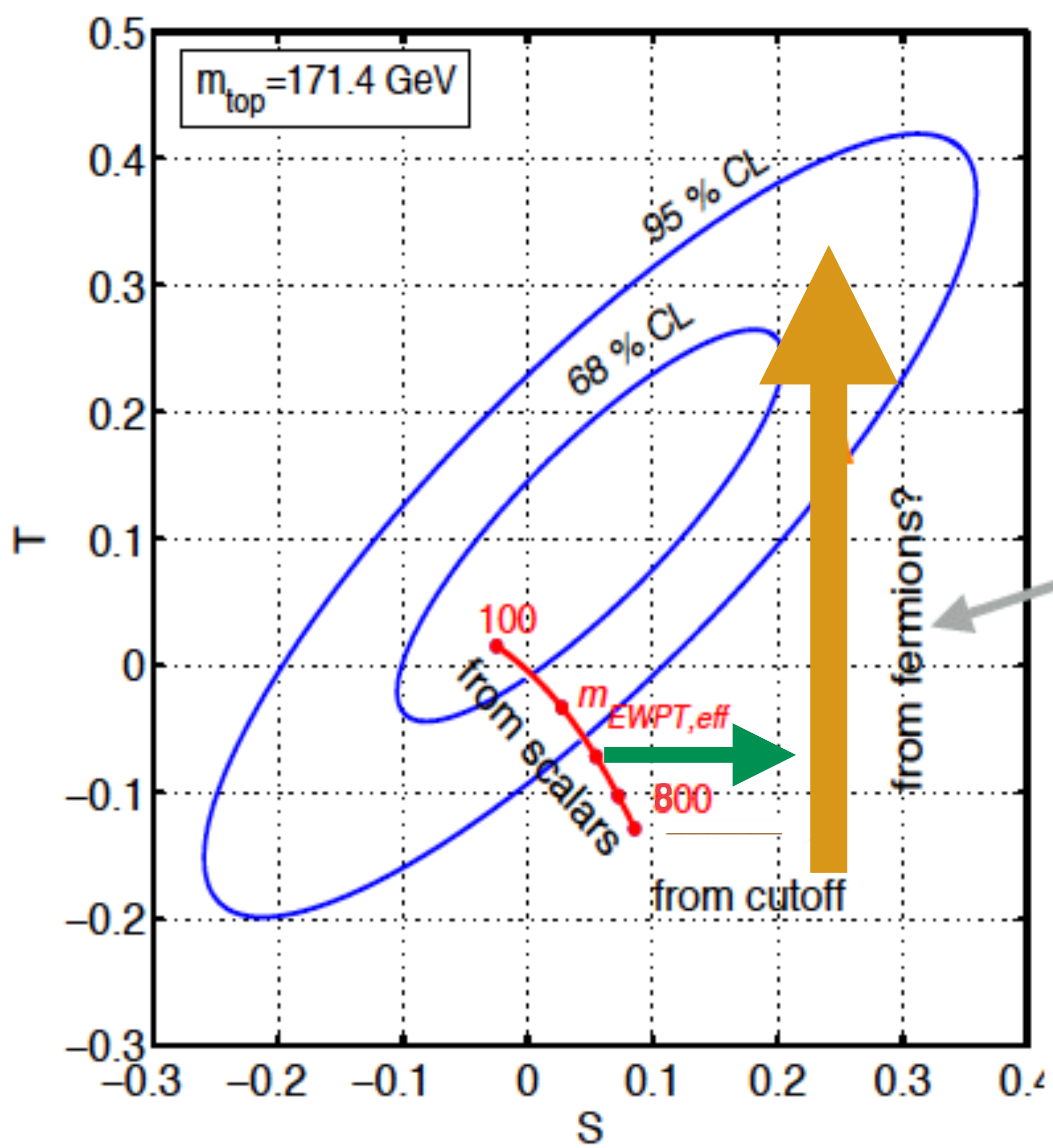


[Barbieri, Bellazzini, Rychkov, Varagnolo, 2007]

$$\Delta\hat{S} = \frac{g^2}{96\pi^2}\xi \log\left(\frac{8\pi m_W}{g m_h \sqrt{\xi}}\right) + \frac{m_W^2}{m_\rho^2} + \alpha\frac{g^2}{16\pi^2}\xi\,,$$

$$\Delta\hat{T} = -\frac{3g'^2}{32\pi^2}\xi \log\left(\frac{8\pi m_W}{g m_h \sqrt{\xi}}\right) + \beta\frac{3y_t}{16\pi^2}\xi\,,$$

Modified Higgs couplings go in bad direction.

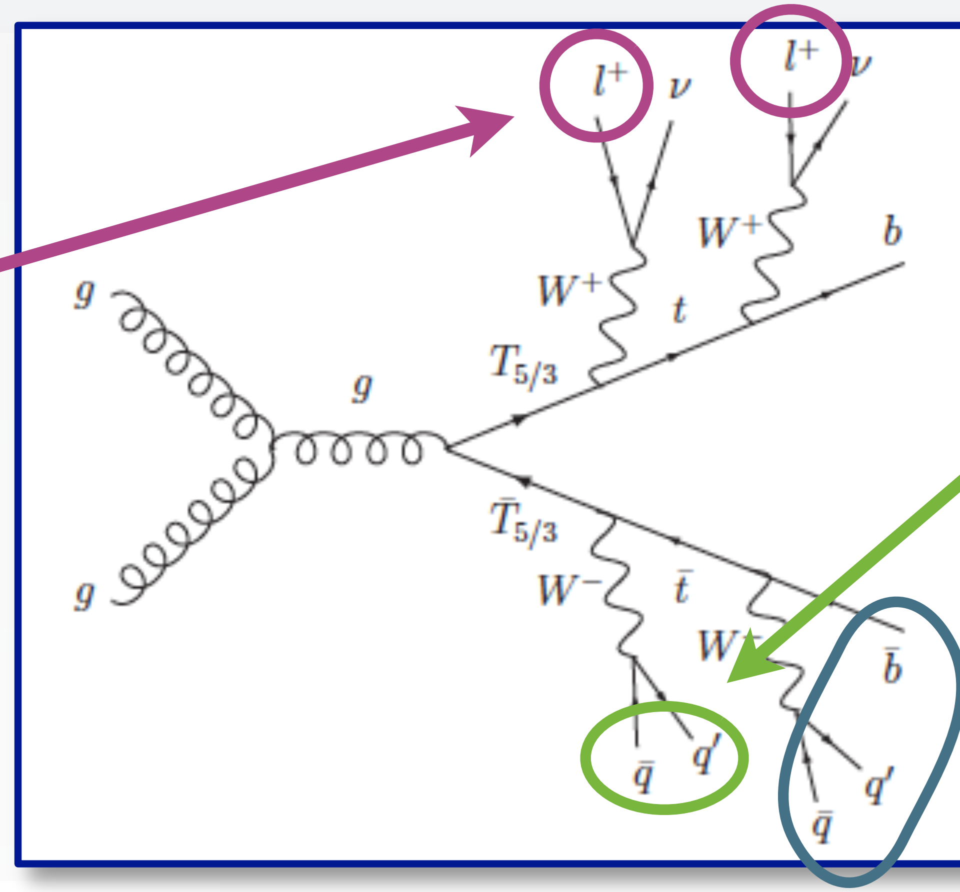
Resonance exchange as well

Light Top Partners come to rescue.

Top Partner Searches at Run 1 & early Run2

Simone, Matsedonski, Rattazzi, Wulzer `12
Azatov, Son, Spannowsky `13
Matsedonski, Panico, Wulzer `14

same-sign dileptons



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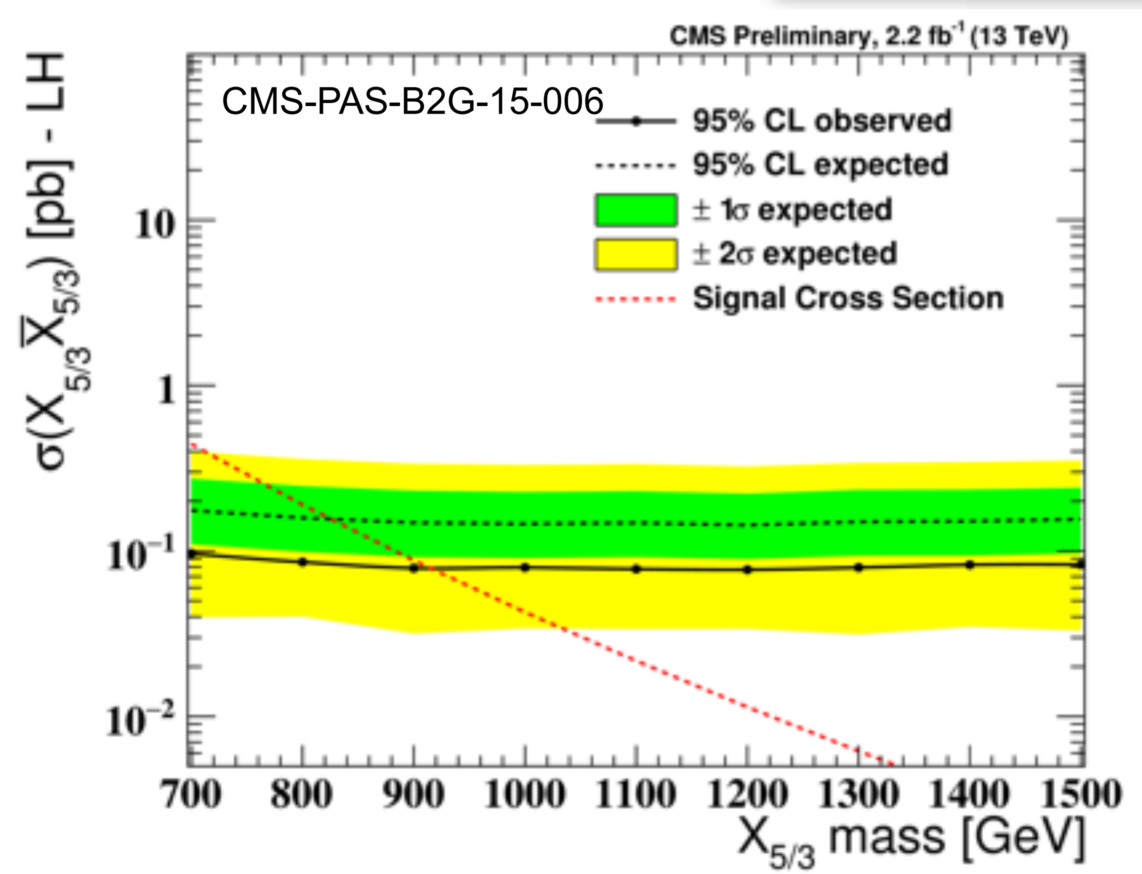
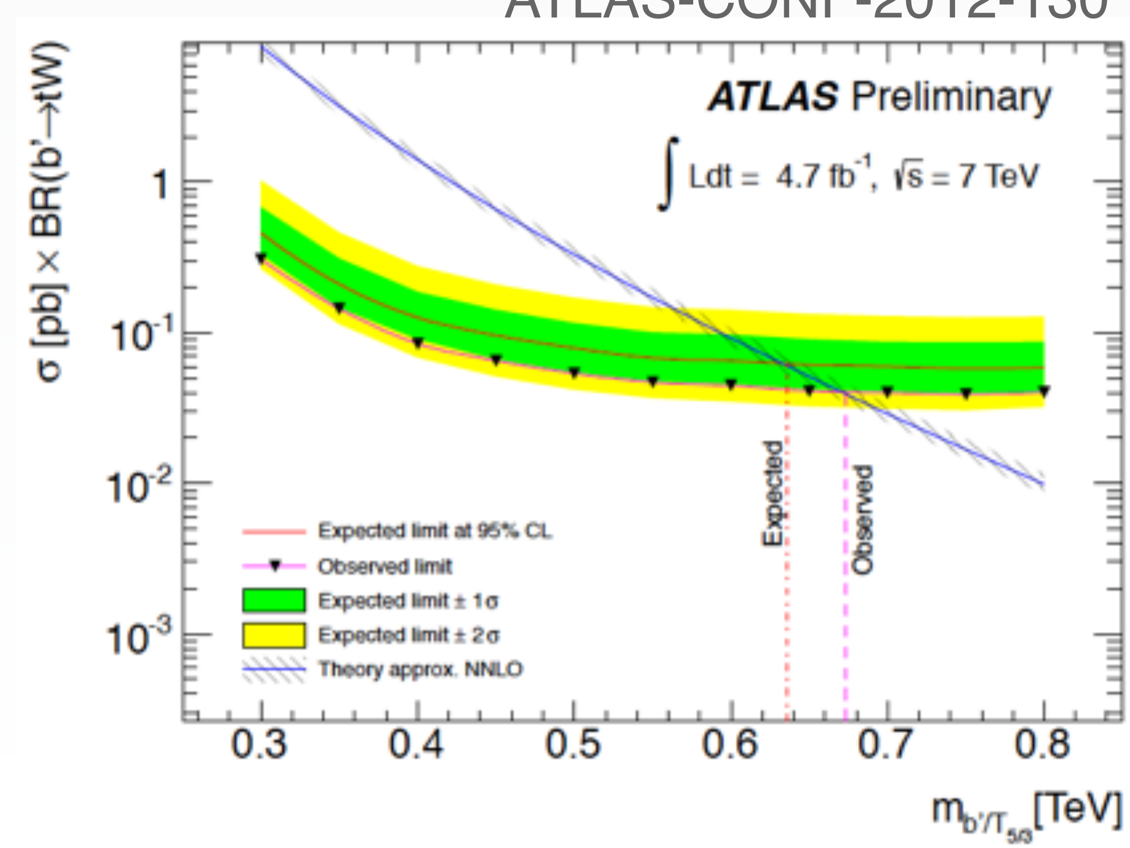
2 subjets,
M_j[60,130]

CMS top tag

10.1103/PhysRevLett.112.171801



ATLAS-CONF-2012-130



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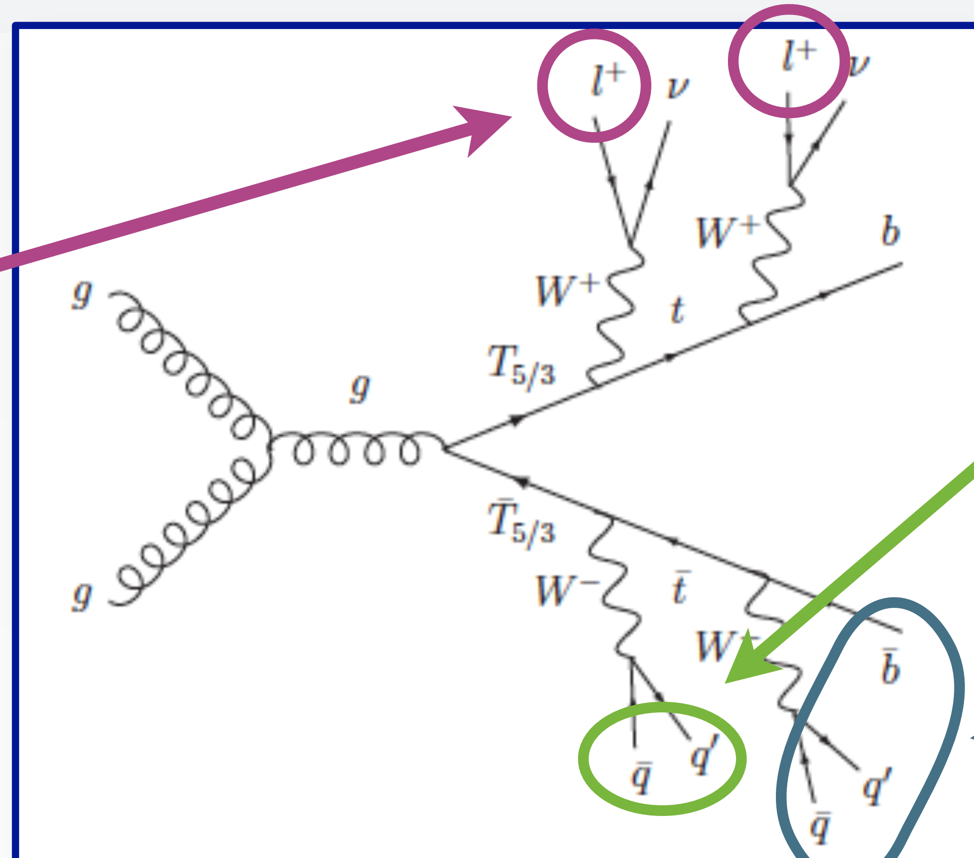

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Oblique parameter fits of LEP & Tevatron data gave
f ≳ 800GeV

Grojean, Matsedonskyi, Panico `13

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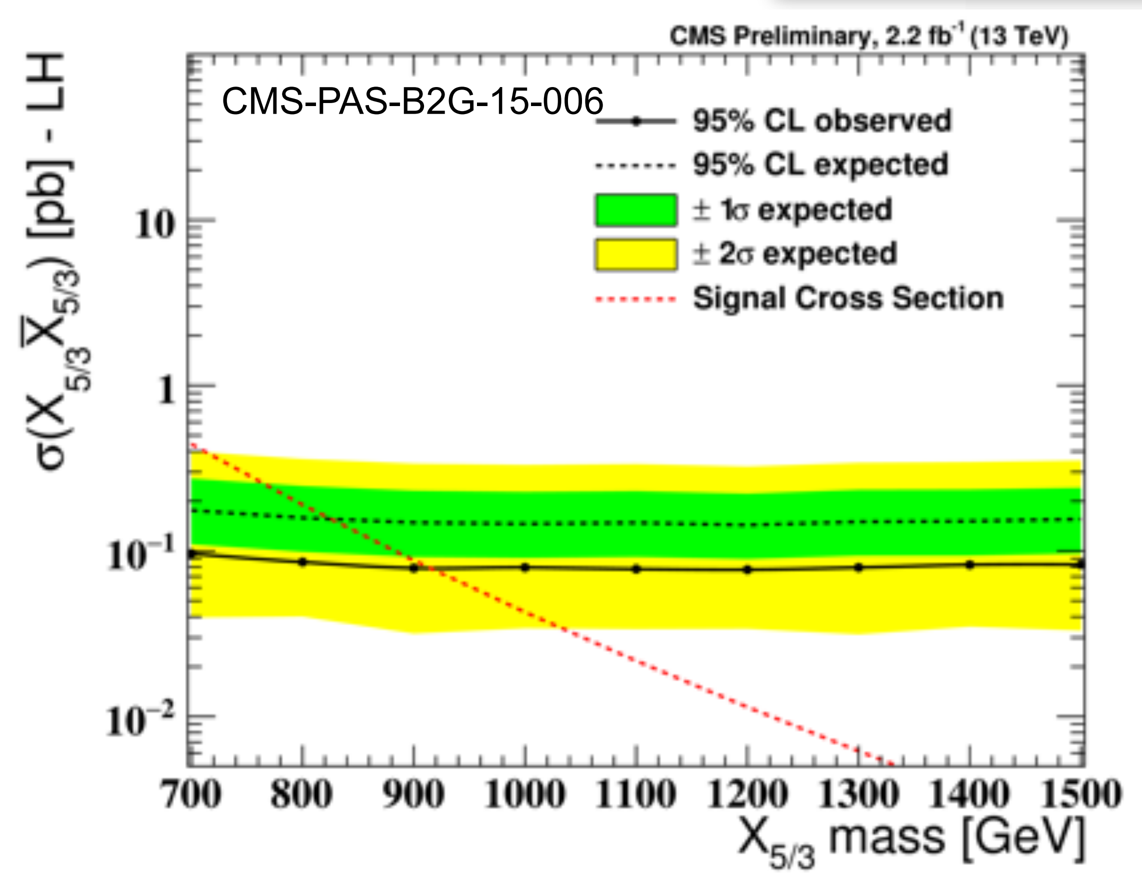

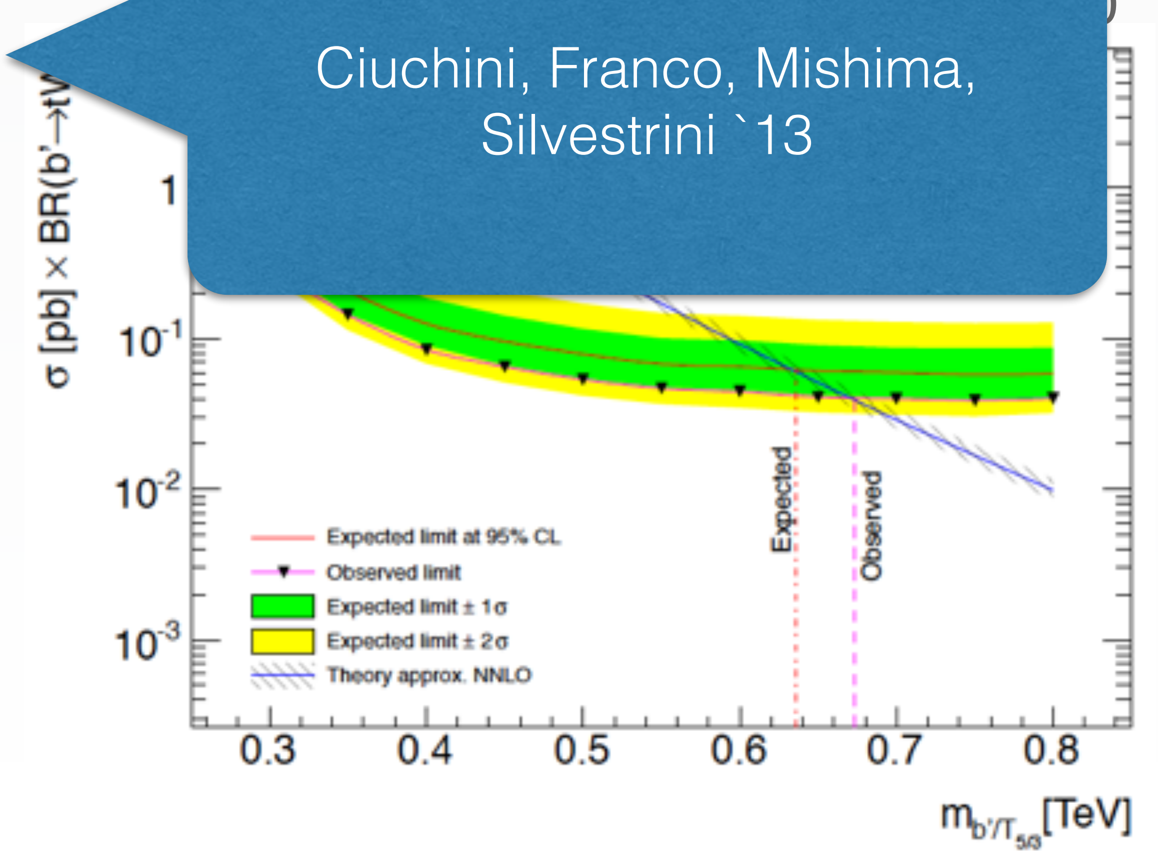

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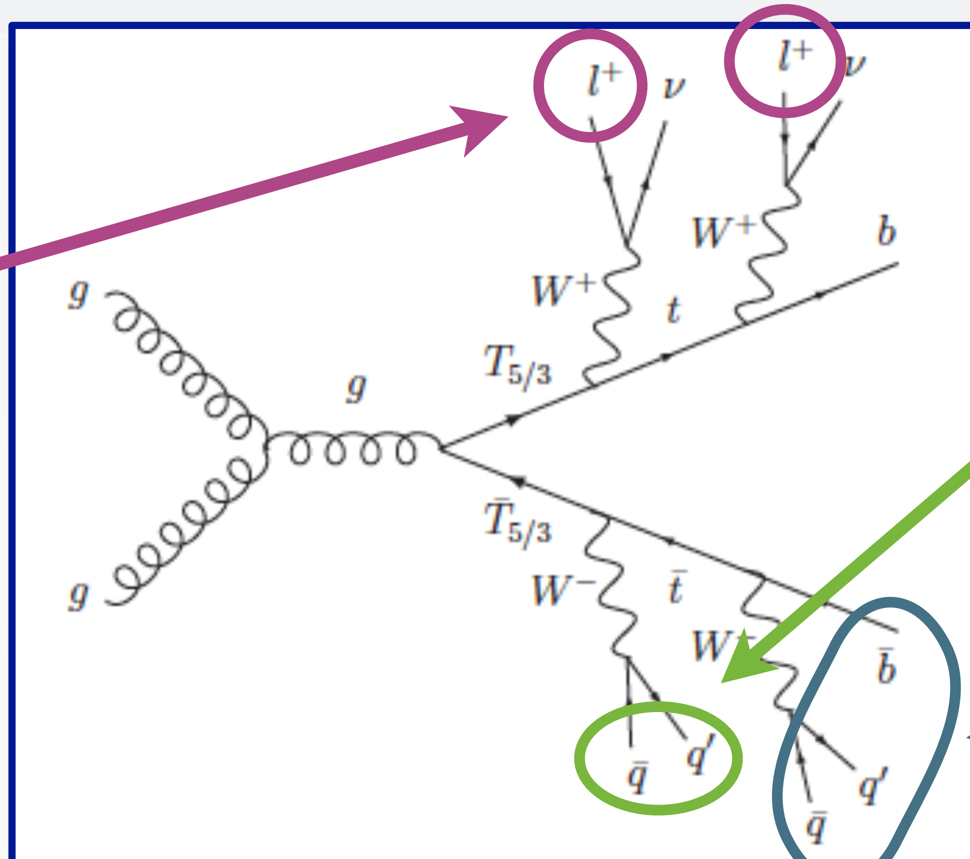

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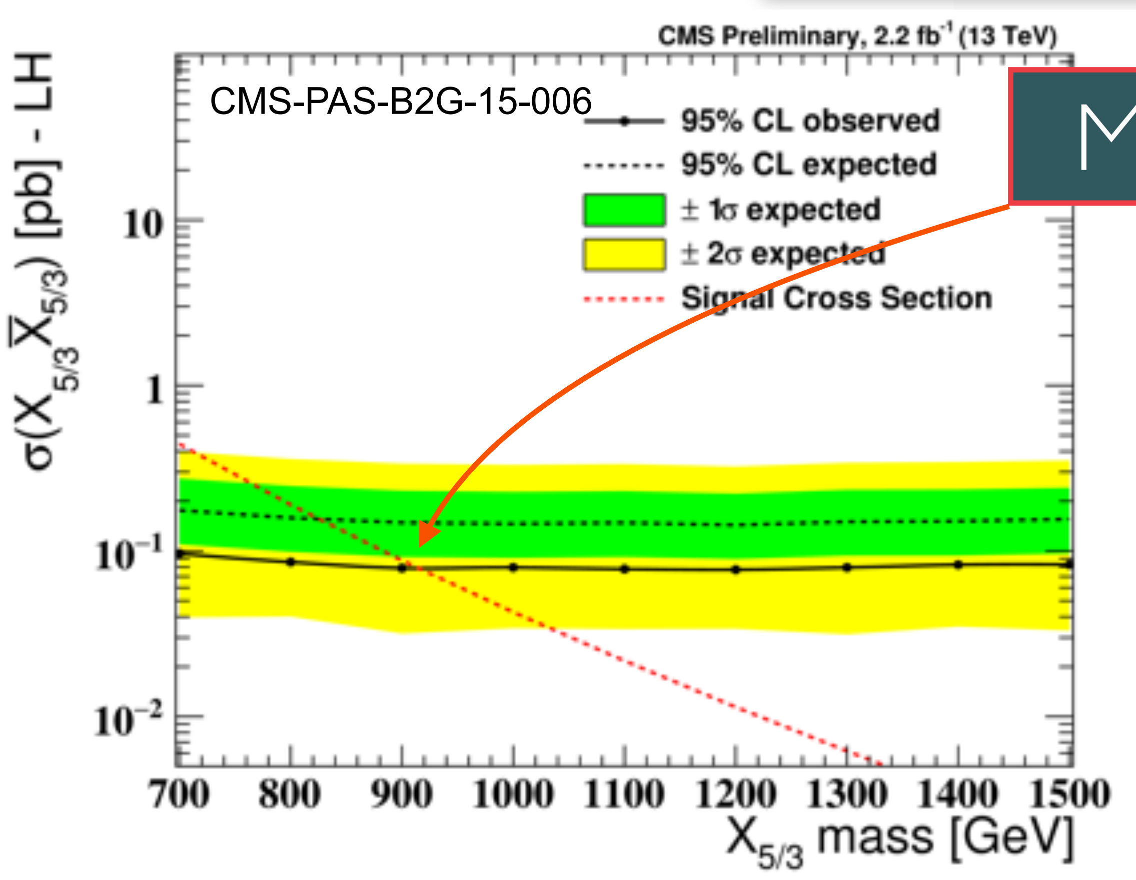
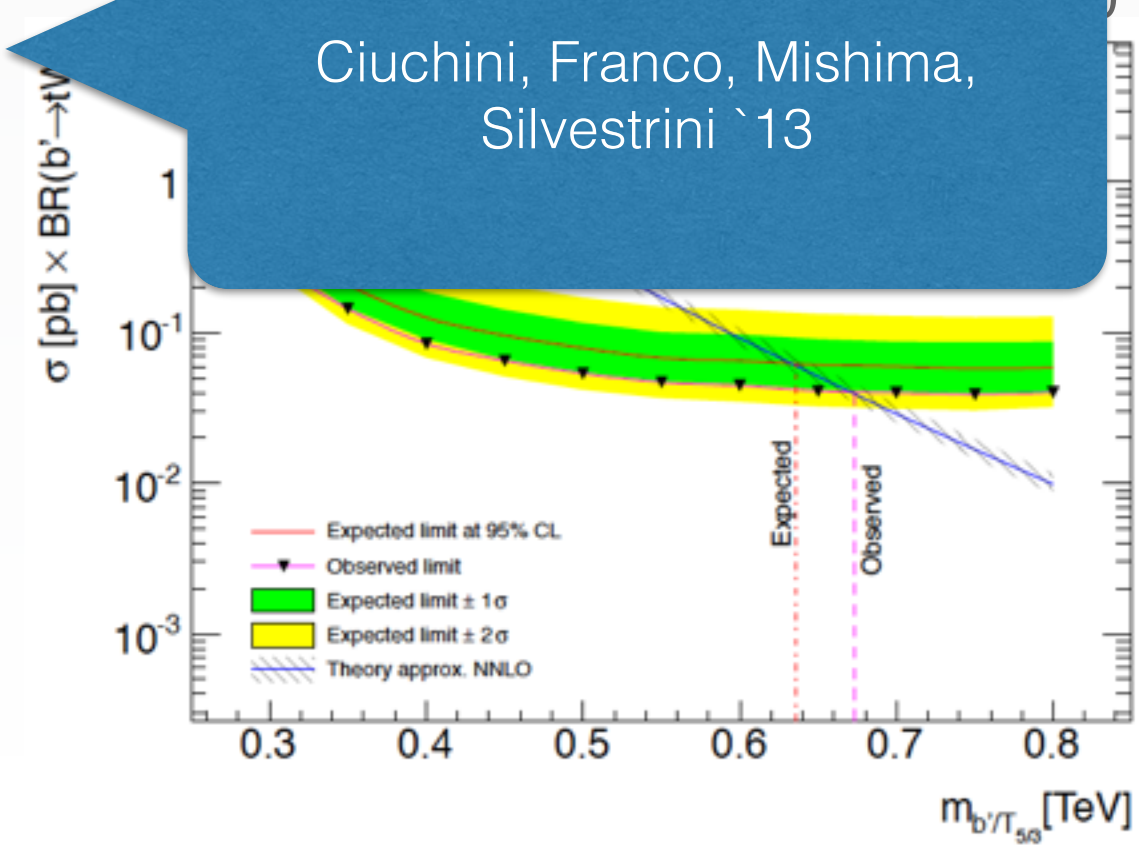


$M_{5/3} \gtrsim 900$



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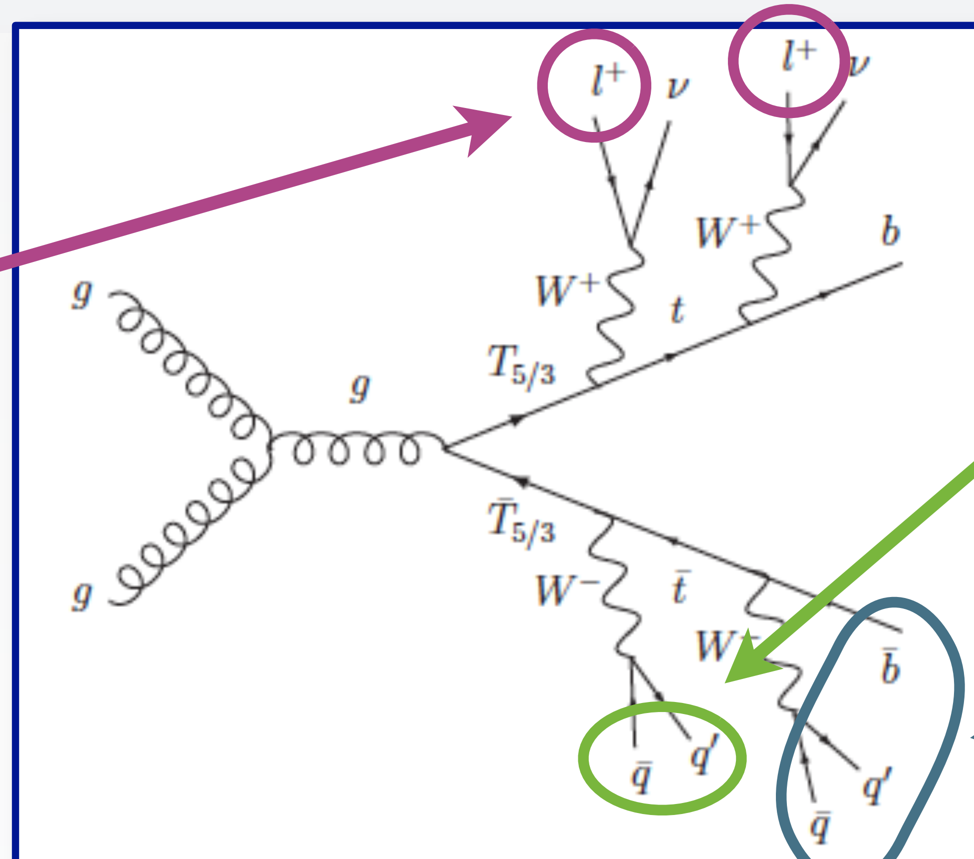

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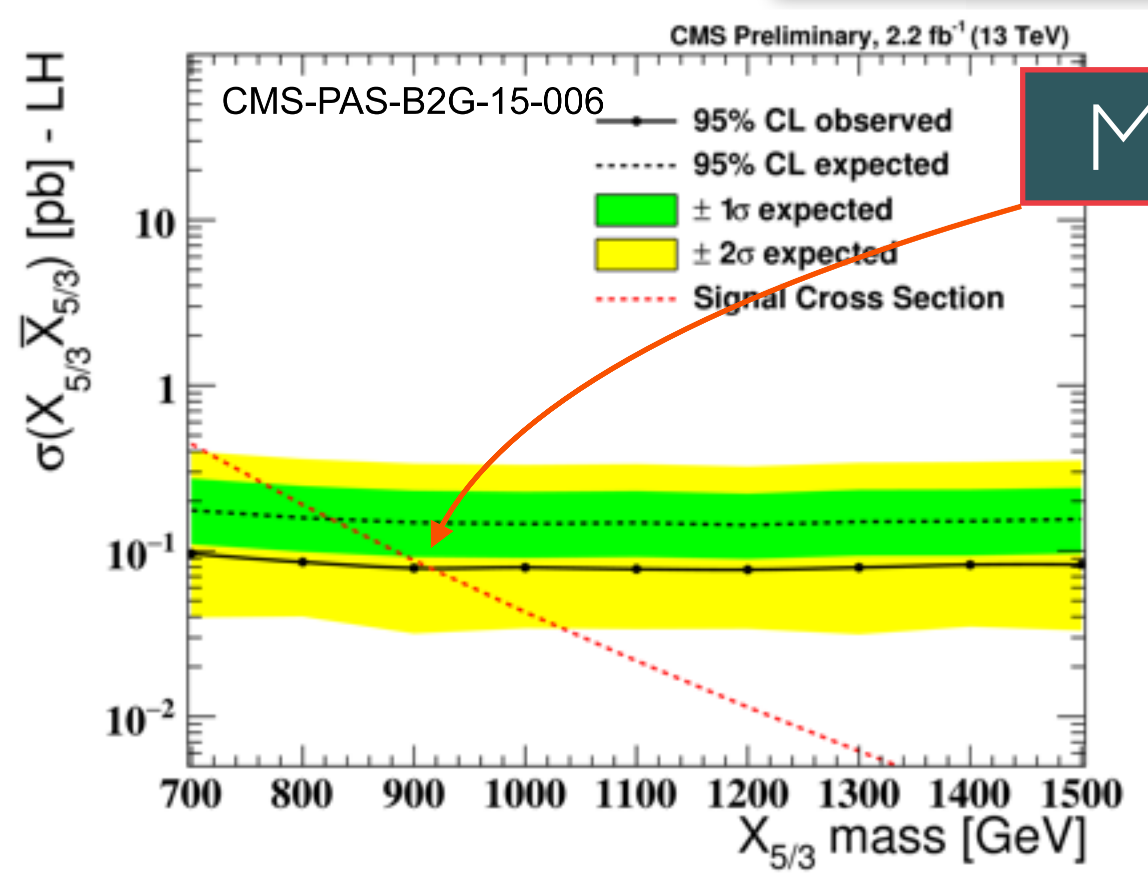
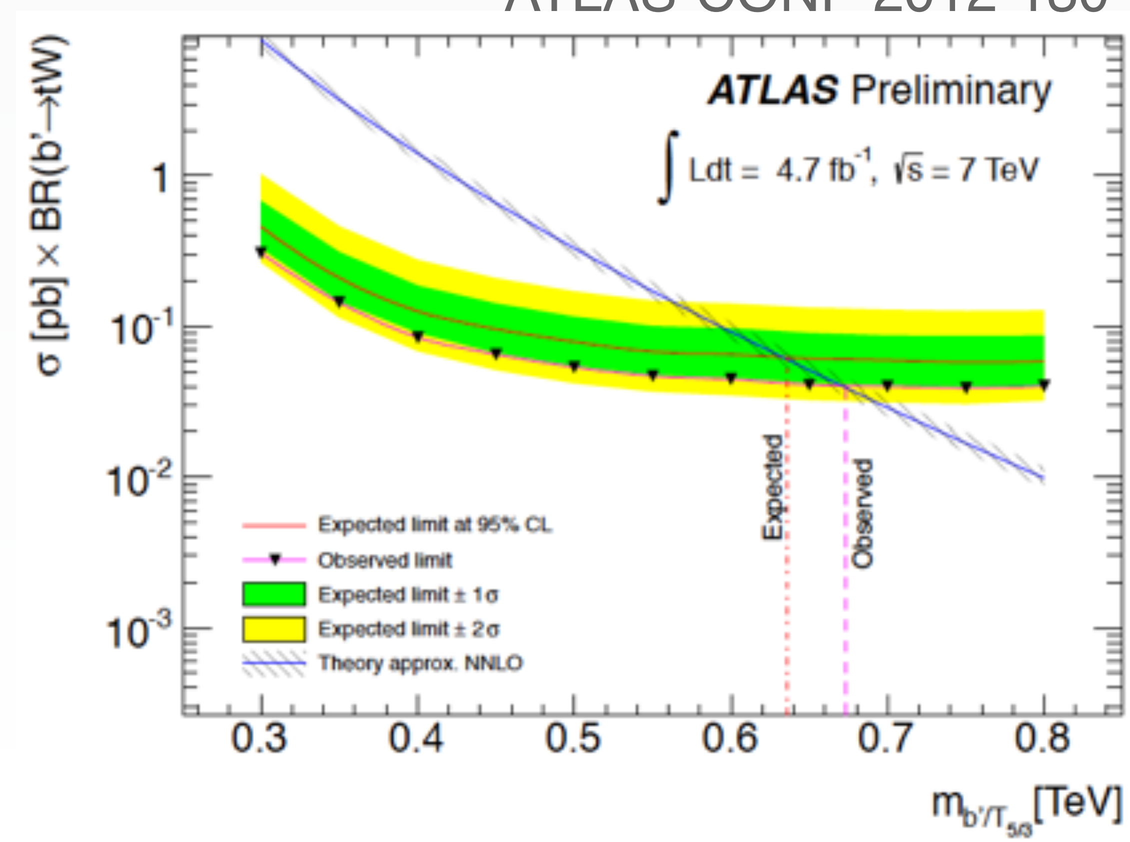


$M_{5/3} \gtrsim 900$

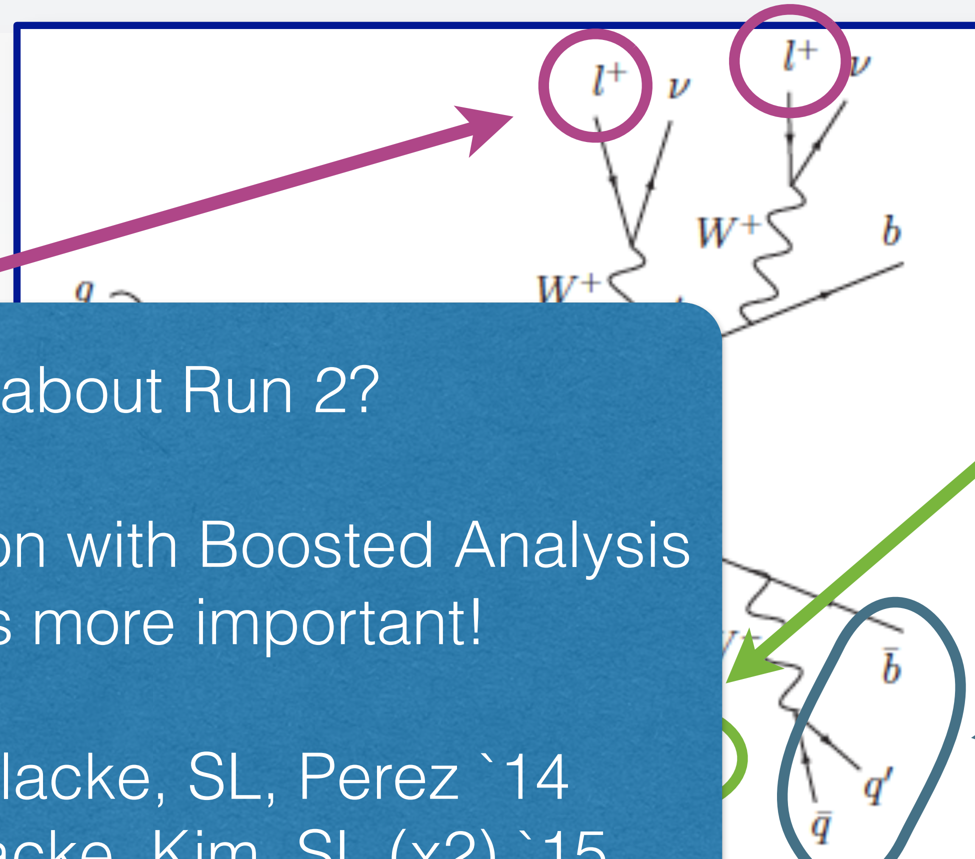
ATLAS-CONF-2012-130



Top Partner Searches at Run 1 & early Run2

Simone, Matsedonski, Rattazzi, Wulzer `12
Azatov, Son, Spannowsky `13
Matsedonski, Panico, Wulzer `14

same-sign
di



W tag:
2 subjets,
M_j[60,130]

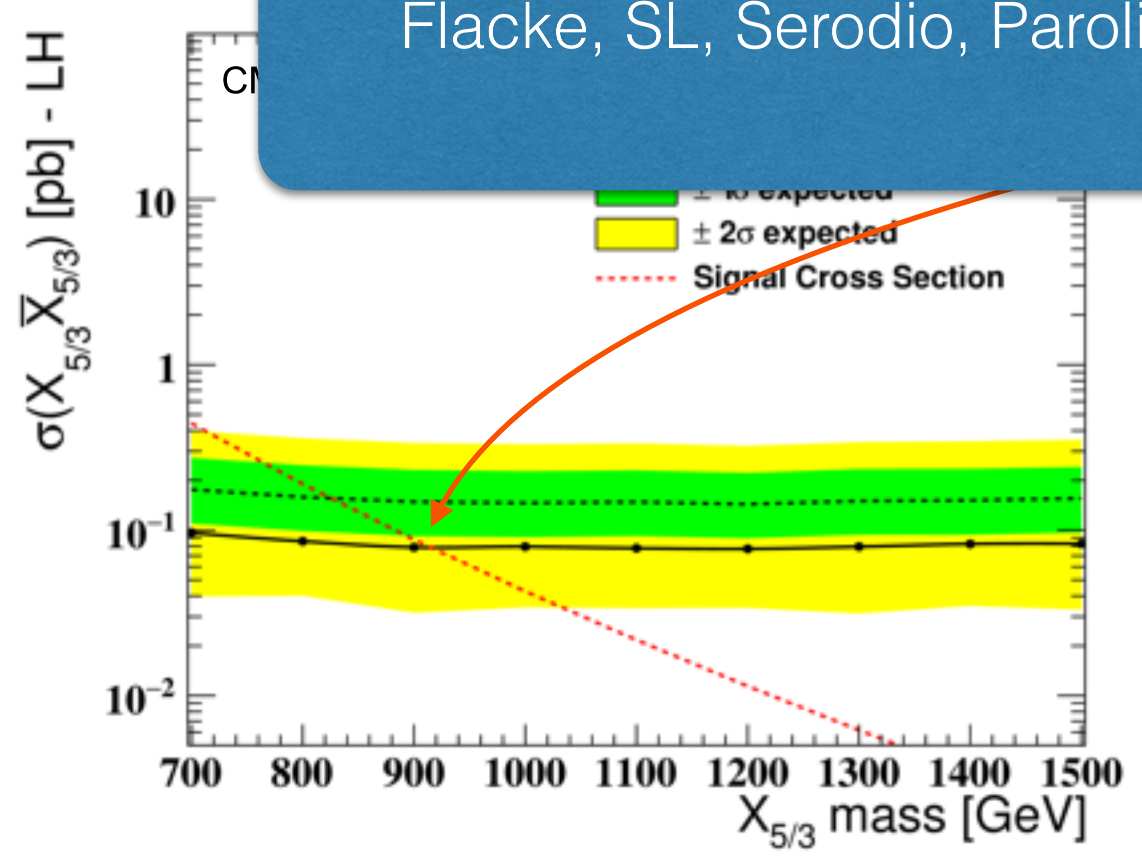
CMS top tag

How about Run 2?

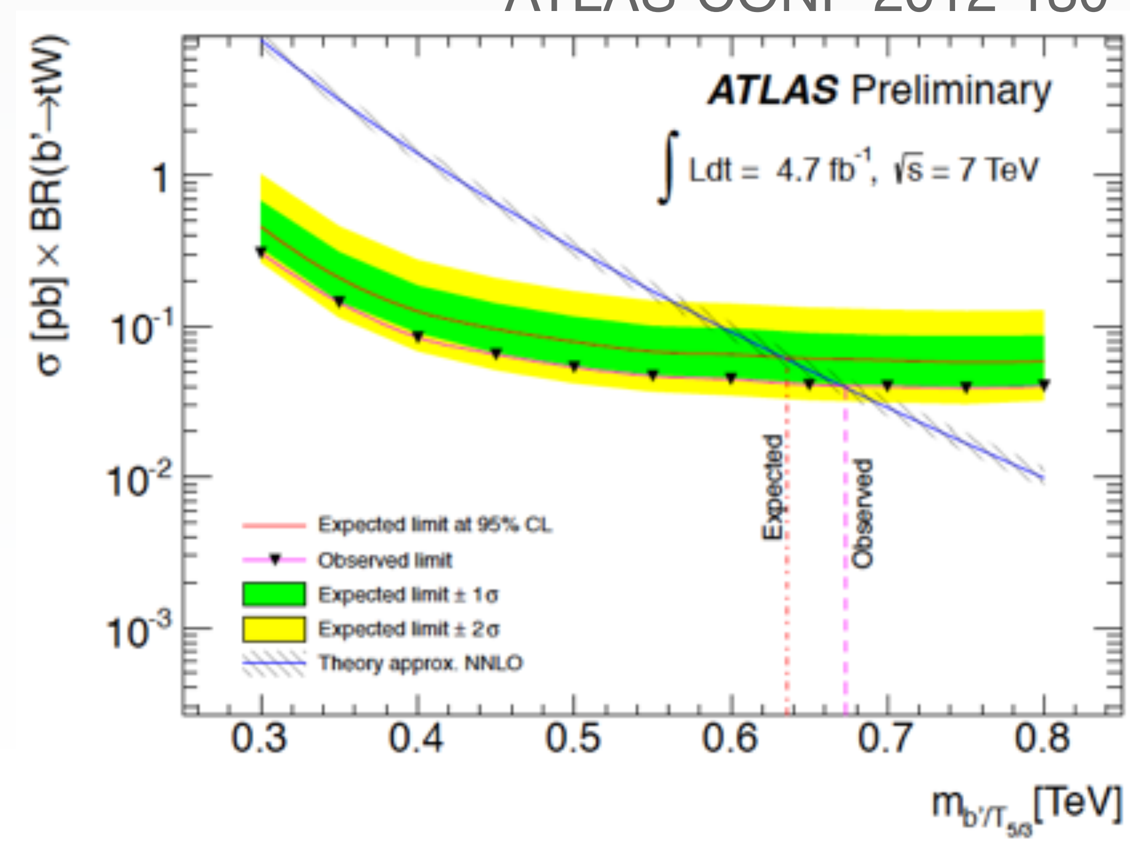
Single production with Boosted Analysis becomes more important!

Backovic, Flacke, SL, Perez `14
Backovic, Flacke, Kim, SL (x2),`15
Flacke, SL, Serodio, Parolini, `16

10.1103/Phy

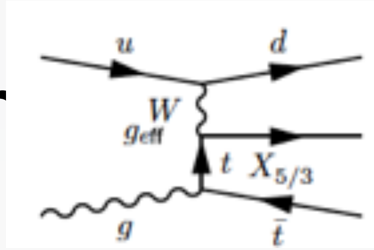


ATLAS-CONF-2012-130



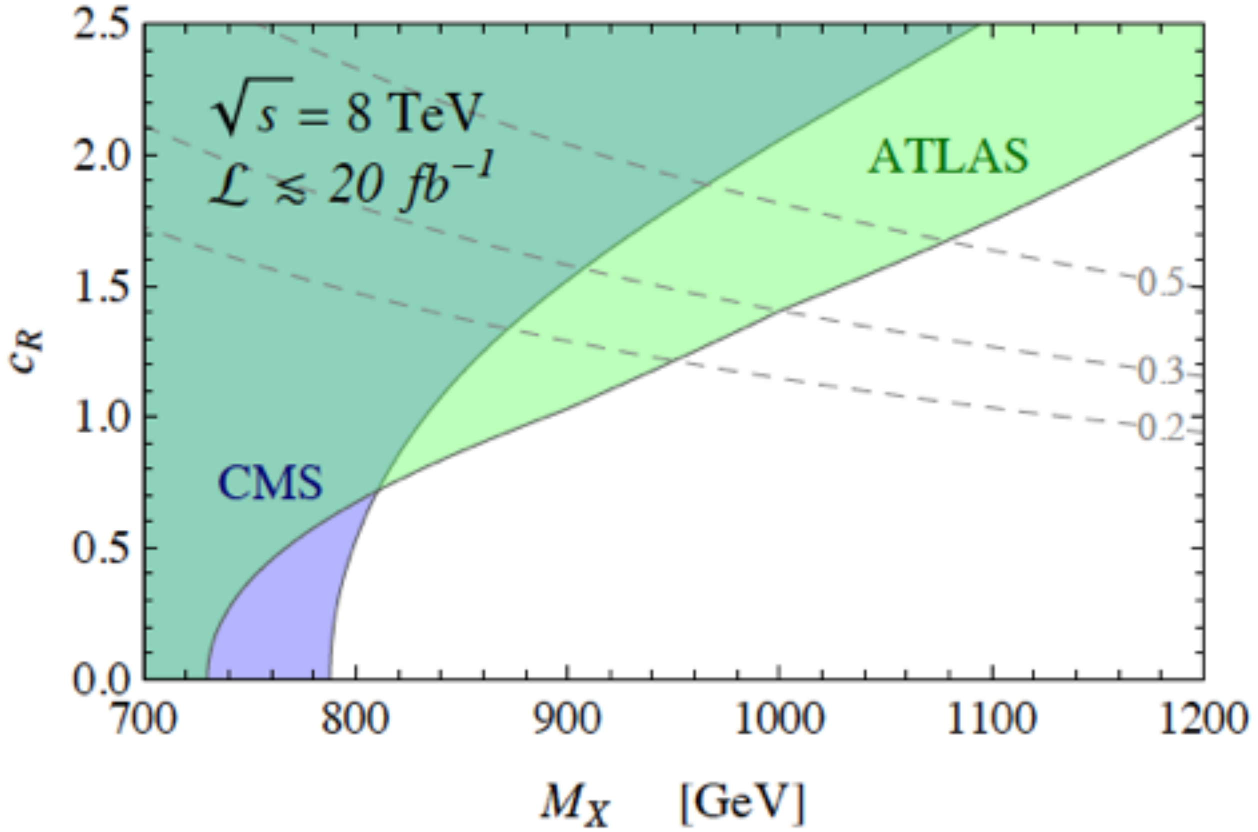
Top partners @ Run 2 of the LHC

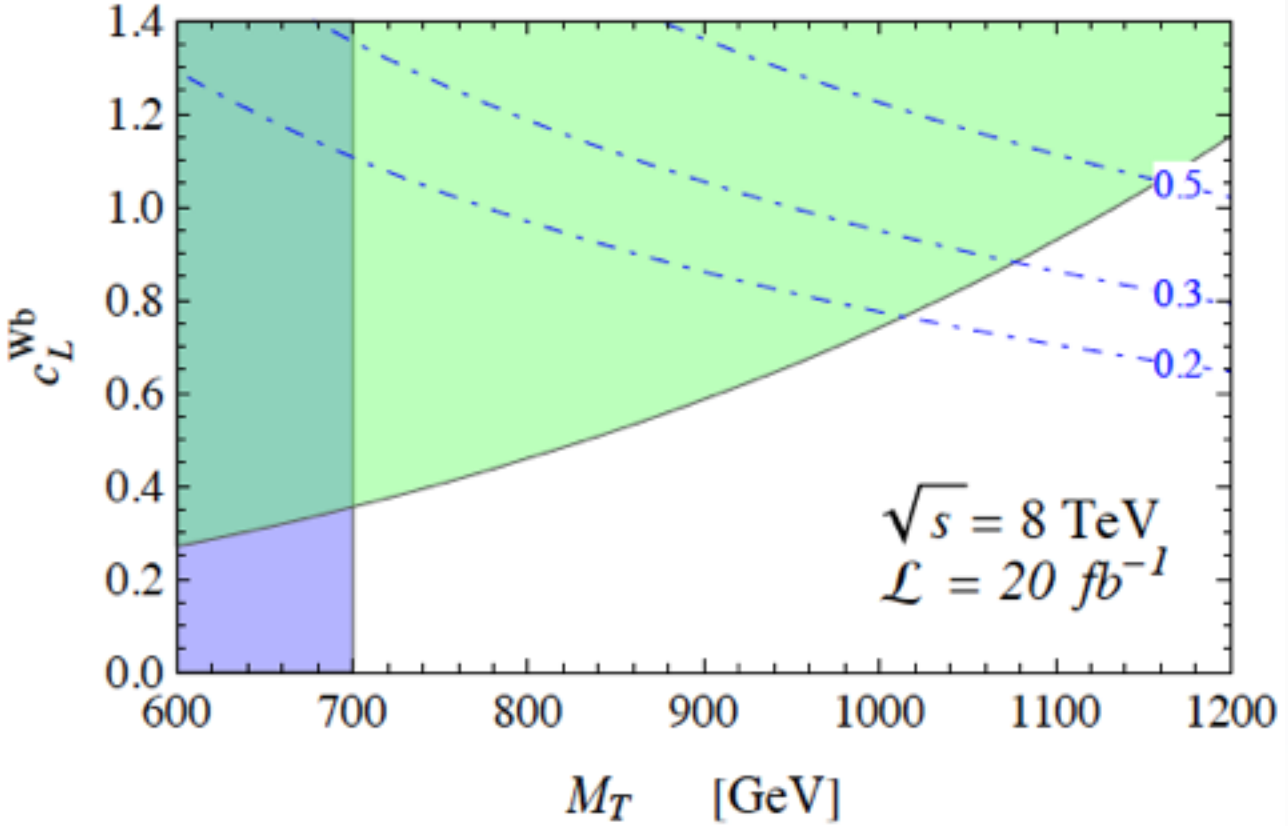
- Run1 bounds including single-production char from same sign lepton searches:



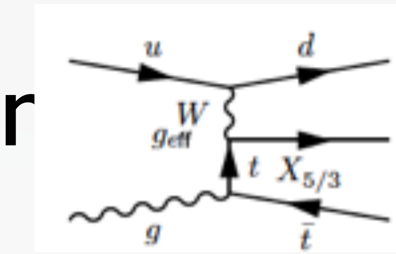
Matsedonski, Panico, Wulzer `14

Azatov, Son, Spannowsky `13 (for boosted analysis for run I)





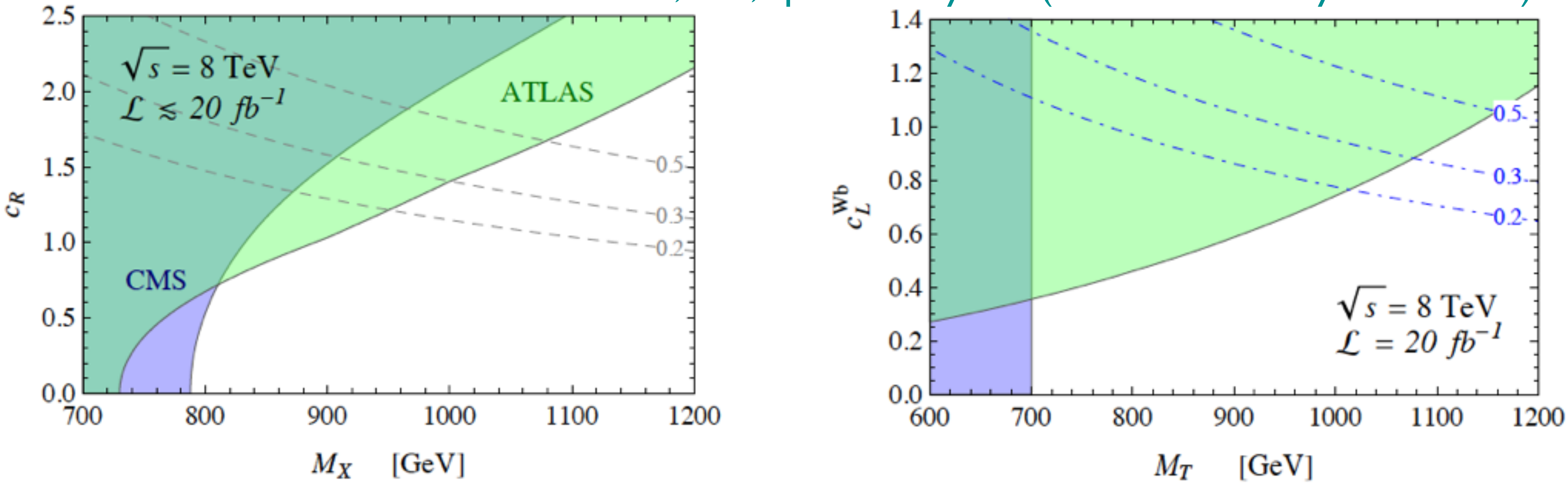
Top partners @ Run 2 of the LHC

- Run1 bounds including single-production char 

  from same sign lepton searches:

Matsedonski, Panico, Wulzer `14

Azatov, Son, Spannowsky `13 (for boosted analysis for run I)



- Game changer for run II: boosted analysis for single production

Backovic, Flacke, SL, Perez `14

Backovic, Flacke, Kim, SL (x2),`15

Flacke, SL, Serodio, Parolini, `16

General Set-up

* As a setup we choose the minimal composite Higgs model based on SO(5)/SO(4). We use the CCWZ construction in order to write down $\mathcal{L}_{eff}$ in a nonlinearly invariant way under SO(5)   Coleman, Wess, Zumino '69,   Callan, Coleman '69

* The lightest composite top quark partner resonances are assumed to be in the 5 of SO(5)

$$\psi = \begin{pmatrix} Q \\ \tilde{U} \end{pmatrix} = \frac{1}{\sqrt{2}} \begin{pmatrix} iD - iX_{5/3} \\ D + X_{5/3} \\ iU + iX_{2/3} \\ -U + X_{2/3} \\ \sqrt{2}\tilde{U} \end{pmatrix} = \begin{bmatrix} \tilde{\psi}_4 \\ \tilde{\psi}_1 \end{bmatrix}_{\frac{2}{3}}$$

elementary quarks: $q_L^5 \equiv \frac{1}{\sqrt{2}}(id_L\,, d_L\,, iu_L\,, -u_L\,, 0)^T$ $u_R^5 \equiv (0\,,0\,,0\,,0\,,u_R)^T$

* BSM particle content: 5 = 4 + 1 $Y = T_R^3 + X$

	U	$X_{2/3}$	D	$X_{5/3}$	$\tilde{U}$
$SO(4)$	**4**	**4**	**4**	**4**	**1**
$SU(3)_c$	**3**	**3**	**3**	**3**	**3**
EM charge	$2/3$	$2/3$	$-1/3$	$5/3$	$2/3$

the strong sector resonances are classified in terms of irreducible representations of the unbroken global *SO*(4)

General Set-up

* BSM particle content: 5 = 4 + 1 $\qquad Y = T^3_R + X$

	U	$X_{2/3}$	D	$X_{5/3}$	$\tilde{U}$
$SO(4)$	**4**	**4**	**4**	**4**	**1**
$SU(3)_c$	**3**	**3**	**3**	**3**	**3**
EM charge	$2/3$	$2/3$	$-1/3$	$5/3$	$2/3$

* Two principal ways to embed the right-handed up-type quarks:
  - In the elementary sector, which mix with their partners, (→ "partially composite quarks")
    Matsedonski, Panico, Wulzer `14
    Backovic, Flacke, SL, Perez `14
  - or as chiral composite states. (→ "fully composite quarks")
    Simone, Matsedonski, Rattazzi, Wulzer `12

General Set-up

* BSM particle content: 5 = 4 + 1

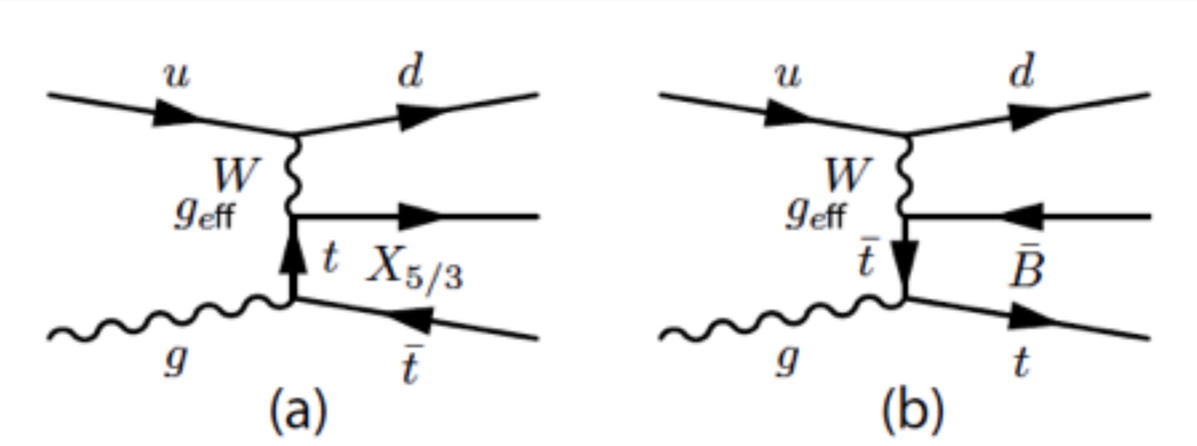
$$Y = T_R^3 + X$$

	U	X
$SO(4)$	**4**	
$SU(3)_c$	**3**	
EM charge	2/3	2

In this talk, I will focus on partially composite quarks scenario

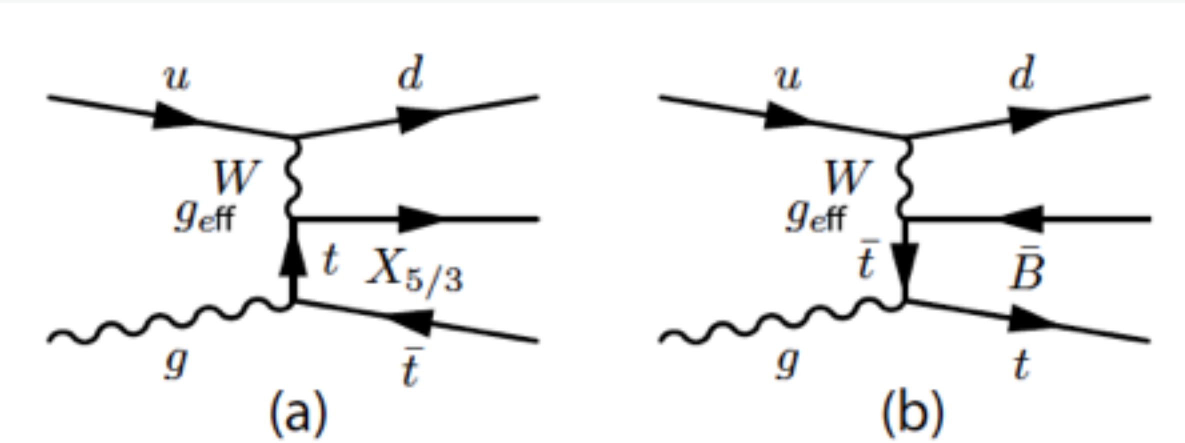
* Two principal ways to embed the right-handed up-type quarks:
  - In the elementary sector, which mix with their partners, (→ "partially composite quarks")
    Matsedonski, Panico, Wulzer `14
    Backovic, Flacke, SL, Perez `14
  - or as chiral composite states. (→ "fully composite quarks")
    Simone, Matsedonski, Rattazzi, Wulzer `12

Top partners @ Run 2 of the LHC

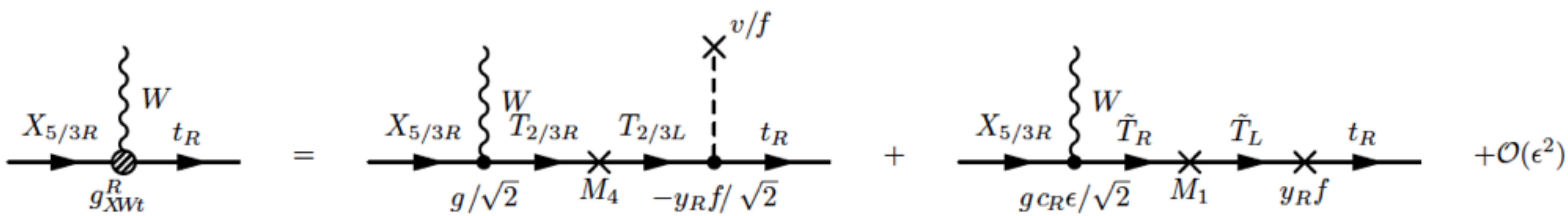


$$
\begin{aligned}
\mathcal{L} = & + i\bar{q}'_L \not{D} q'_L + i\bar{t}'_R \not{D} t'_R + i\bar{b}'_R \not{D} b'_R \\
& + i\bar{\tilde{\psi}}_4 \not{D} \tilde{\psi}_4 + i\bar{\tilde{\psi}}_1 \not{D} \tilde{\psi}_1 - M_4 \bar{\tilde{\psi}}_4 \tilde{\psi}_4 - M_1 e^{i\phi} \bar{\tilde{\psi}}_1 \tilde{\psi}_1 \\
& + \left(i c_L \bar{\tilde{\psi}}^i_{L4} \gamma^\mu d_{\mu i} \tilde{\psi}_{L1} + i c_R \bar{\tilde{\psi}}^i_{R4} \gamma^\mu d_{\mu i} \tilde{\psi}_{R1} + h.c. \right) \\
& - \left(y_L f \bar{q}^{t5}_L U \tilde{\psi}_R + y_R f \bar{t}^5_R U \tilde{\psi}_L + h.c. \right) .
\end{aligned}
$$

Top partners @ Run 2 of the LHC

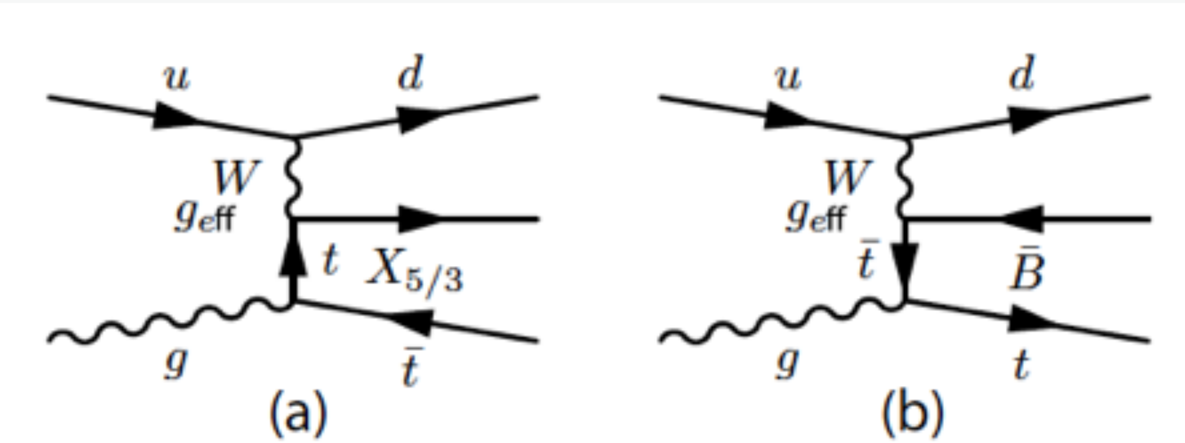


$$
\begin{aligned}
\mathcal{L} = &+ i\bar{q}'_L \not{D} q'_L + i\bar{t}'_R \not{D} t'_R + i\bar{b}'_R \not{D} b'_R \\
&+ i\bar{\tilde{\psi}}_4 \not{D} \tilde{\psi}_4 + i\bar{\tilde{\psi}}_1 \not{D} \tilde{\psi}_1 - M_4 \bar{\tilde{\psi}}_4 \tilde{\psi}_4 - M_1 e^{i\phi} \bar{\tilde{\psi}}_1 \tilde{\psi}_1 \\
&+ \left(i c_L \bar{\tilde{\psi}}^i_{L4} \gamma^\mu d_{\mu i} \tilde{\psi}_{L1} + i c_R \bar{\tilde{\psi}}^i_{R4} \gamma^\mu d_{\mu i} \tilde{\psi}_{R1} + h.c. \right) \\
&- \left(y_L f \bar{q}^{t5}_L U \tilde{\psi}_R + y_R f \bar{t}^5_R U \tilde{\psi}_L + h.c. \right).
\end{aligned}
$$



$$
\begin{aligned}
g^L_{XWt} &= G^X_{L\,i} \left(U^t_L\right)^\dagger_{i1} = \mathcal{O}(\epsilon^2), \\
g^R_{XWt} &= G^X_{R\,i} \left(U^t_R\right)^\dagger_{i1} = \frac{g}{\sqrt{2}} \left(U^{*t}_{R\,13} + c_R \epsilon U^{*t}_{R\,14}\right) + \mathcal{O}(\epsilon^2), \\
&= -\frac{g e^{-i\tilde{\phi}}}{\sqrt{2}} \frac{\epsilon}{\sqrt{2}} \left(\frac{y_R f M_1}{M_4 M_{Ts}} - \sqrt{2} c_R \frac{e^{-i\phi} y_R f}{M_{Ts}} \right) + \mathcal{O}(\epsilon^2).
\end{aligned}
$$

Top partners @ Run 2 of the LHC



$$m_t = \frac{v}{\sqrt{2}} \frac{|M_1 - e^{-i\phi} M_4|}{f} \frac{y_L f}{\sqrt{M_4 + y_L^2 f^2}} \frac{y_R f}{\sqrt{|M_1|^2 + y_R^2 f^2}} + \mathcal{O}(\epsilon^3),$$

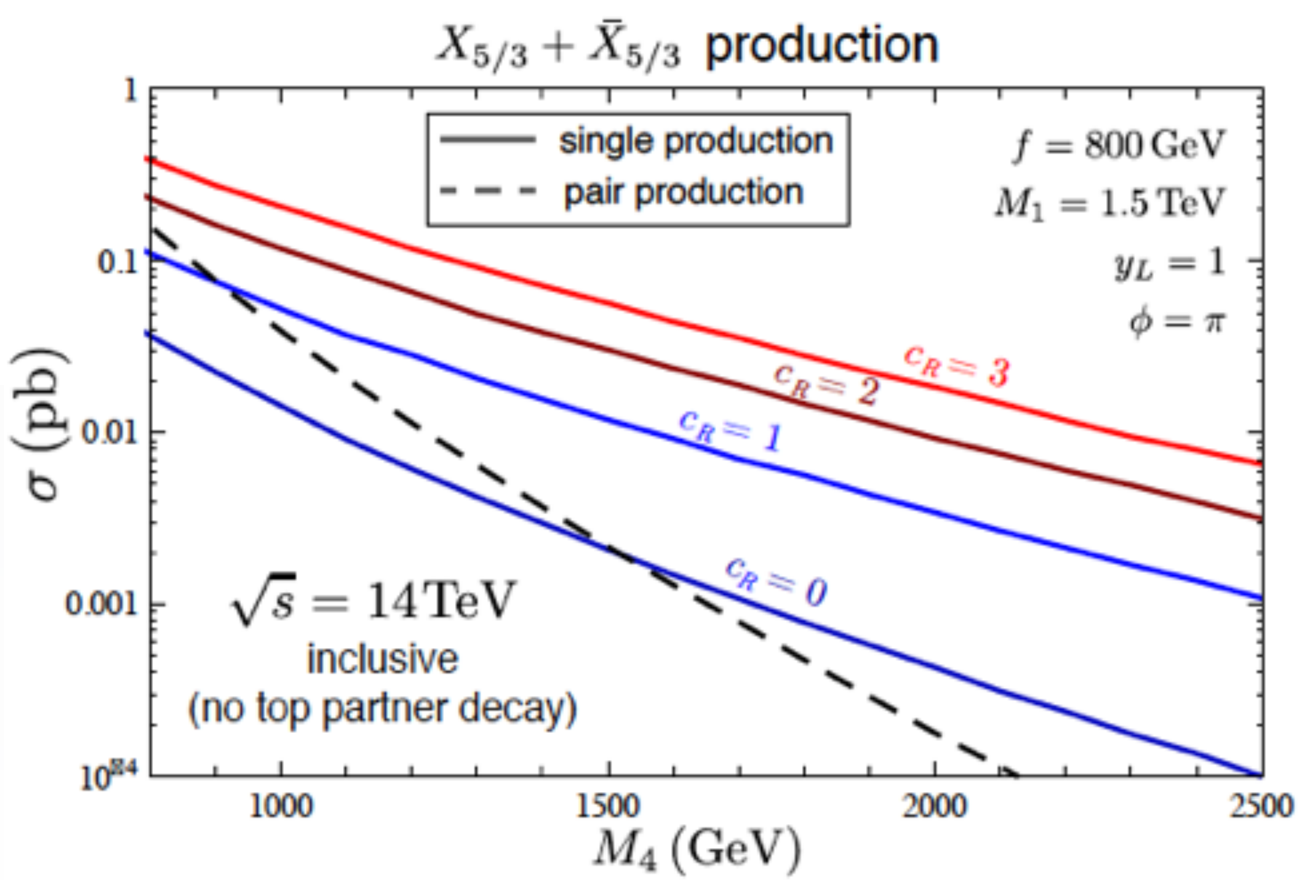
$$M_B = \sqrt{M_4^2 + y_L^2 f^2},$$

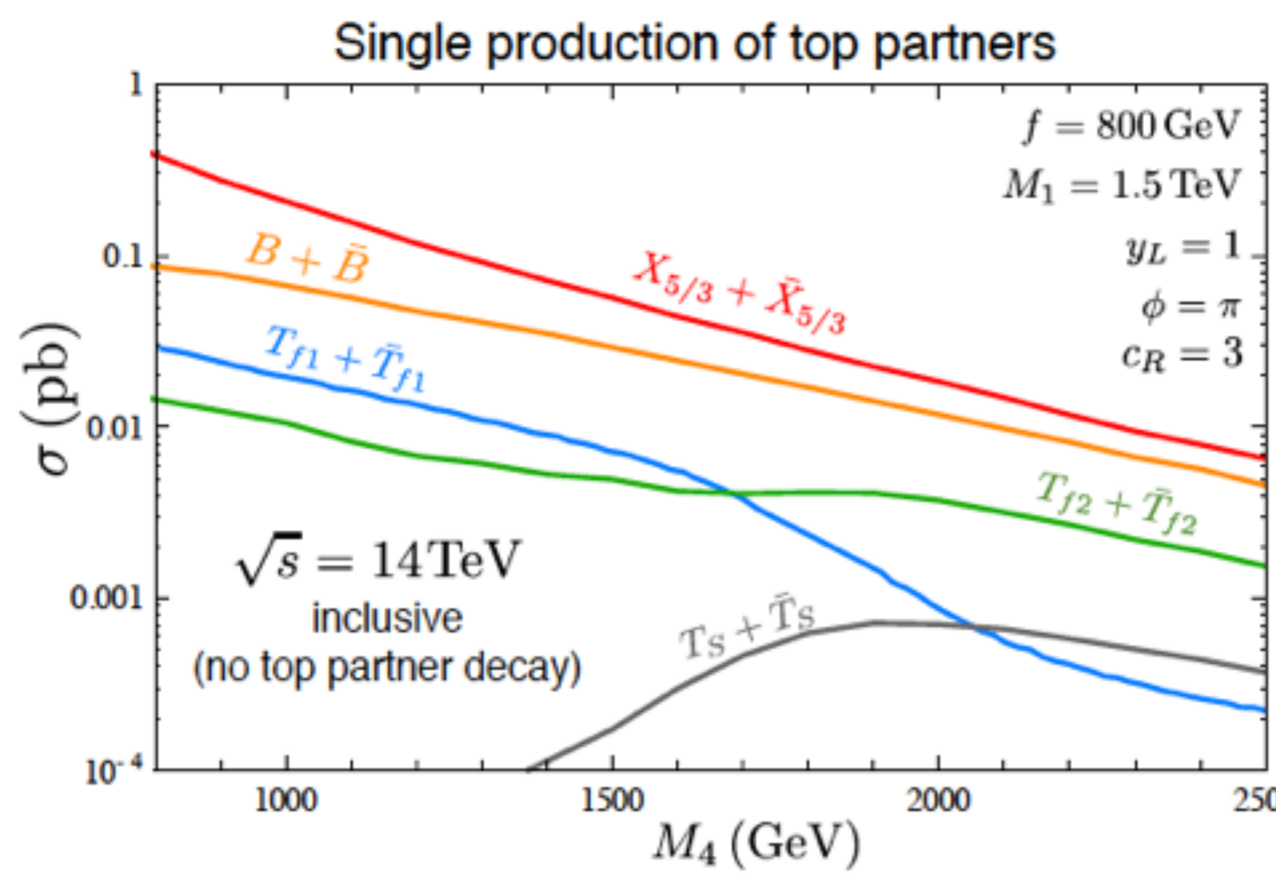
$$M_{X_{5/3}} = M_4,$$

$$M_{Tf1} = M_4 + \mathcal{O}(\epsilon^2),$$

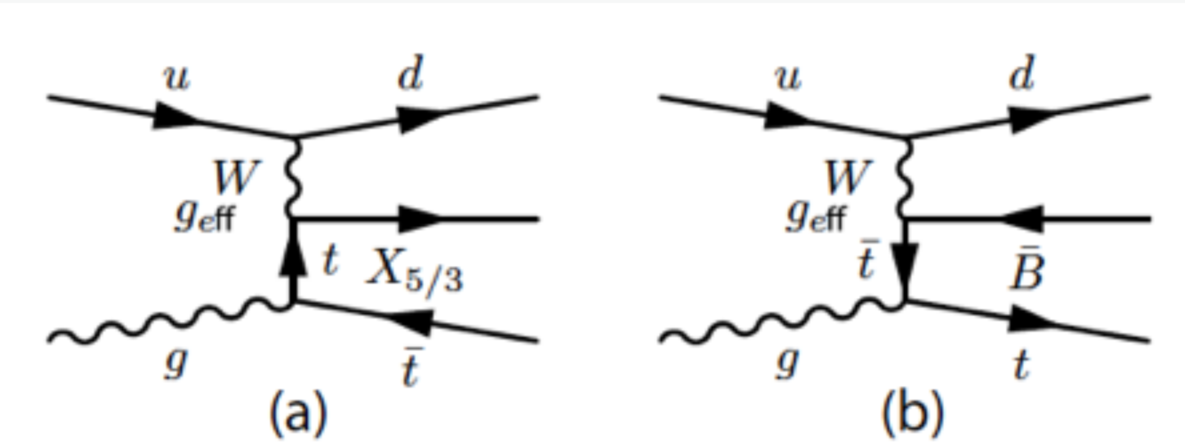
$$M_{Tf2} = \sqrt{M_4^2 + y_L^2 f^2} + \mathcal{O}(\epsilon^2),$$

$$M_{Ts} = \sqrt{|M_1|^2 + y_R^2 f^2} + \mathcal{O}(\epsilon^2),$$





Top partners @ Run 2 of the LHC



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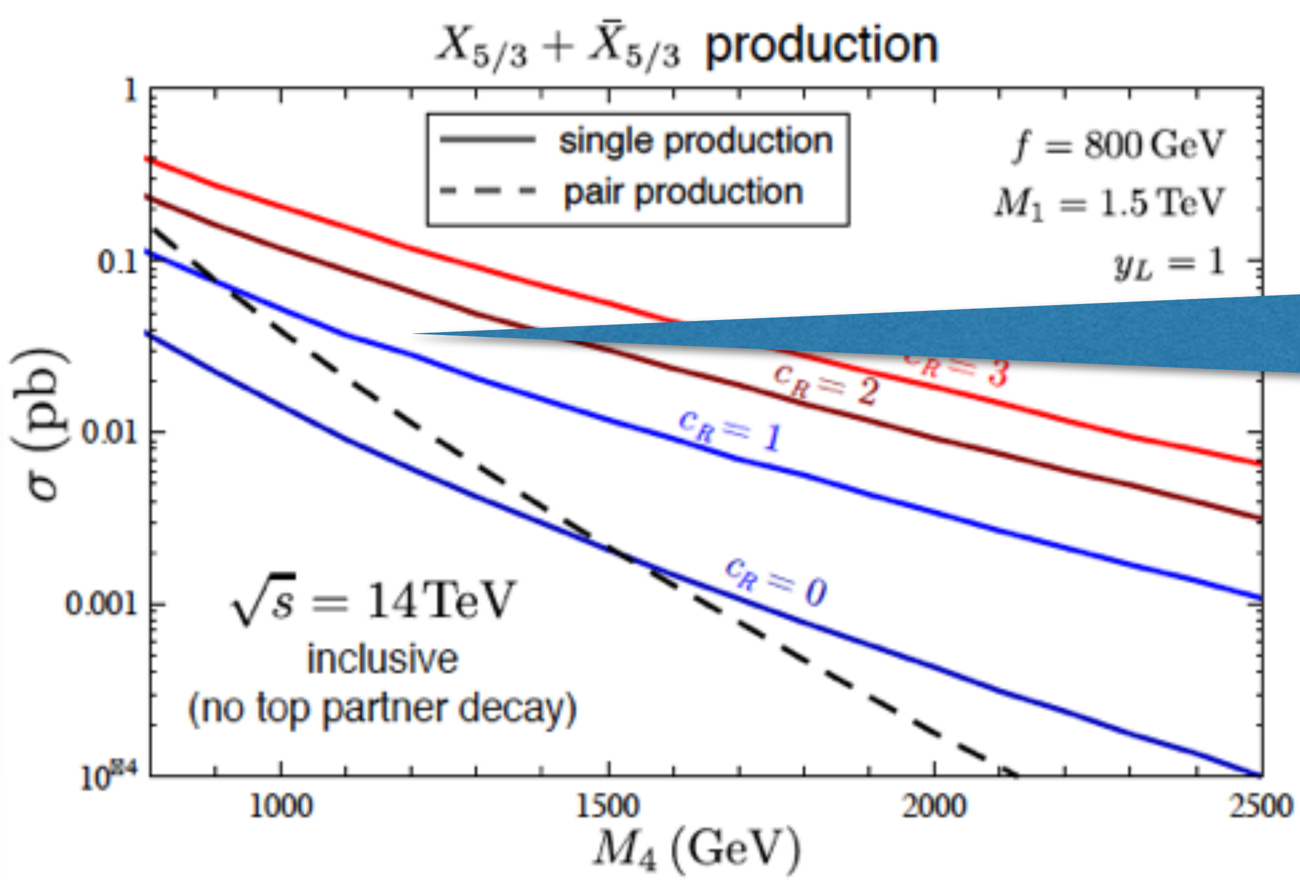
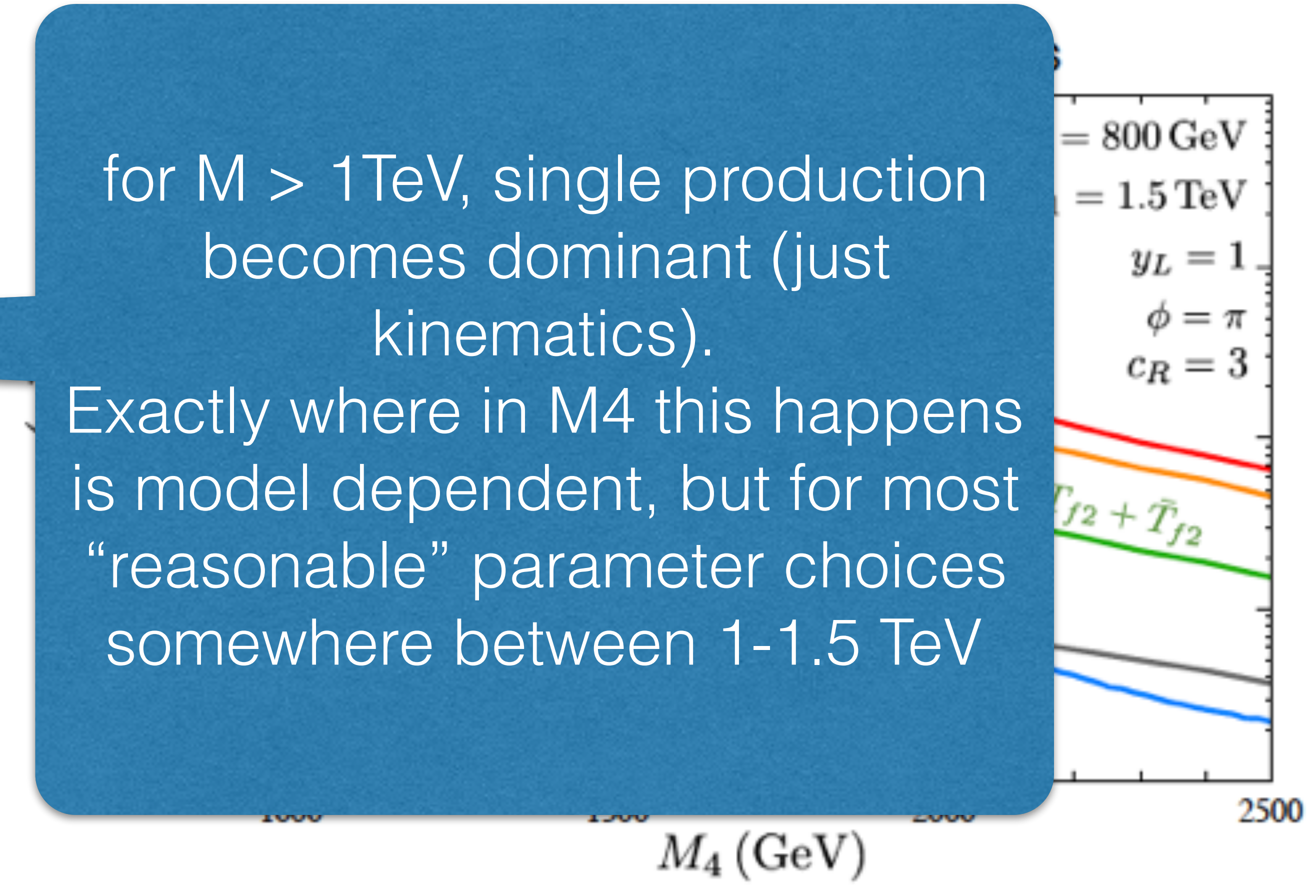
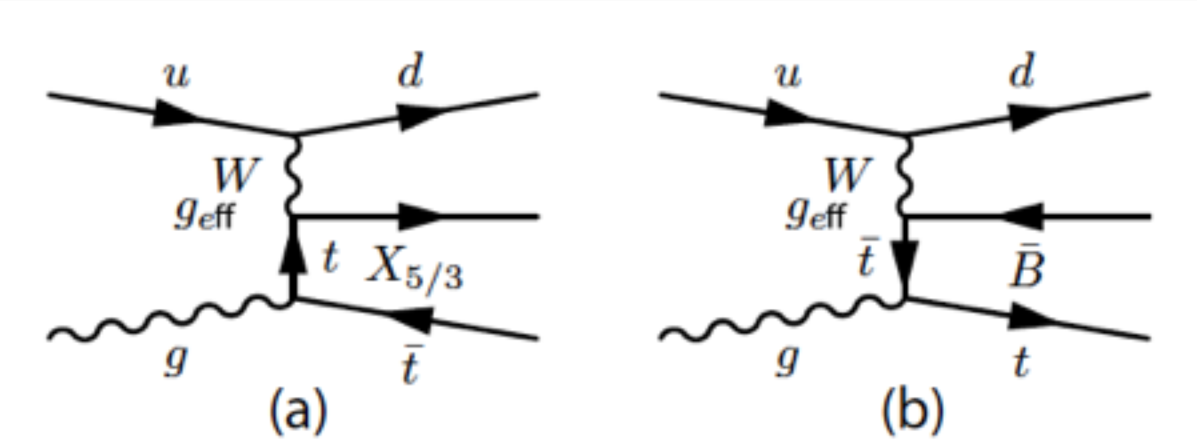




for M > 1TeV, single production becomes dominant (just kinematics).
Exactly where in M4 this happens is model dependent, but for most “reasonable” parameter choices somewhere between 1-1.5 TeV

Top partners @ Run 2 of the LHC



$$m_t = \frac{v}{\sqrt{2}} \frac{|M_1 - e^{-i\phi} M_4|}{f} \frac{y_L f}{\sqrt{M_4 + y_L^2 f^2}} \frac{y_R f}{\sqrt{|M_1|^2 + y_R^2 f^2}} + \mathcal{O}(\epsilon^3),$$

$$M_B = \sqrt{M_4^2 + y_L^2 f^2},$$

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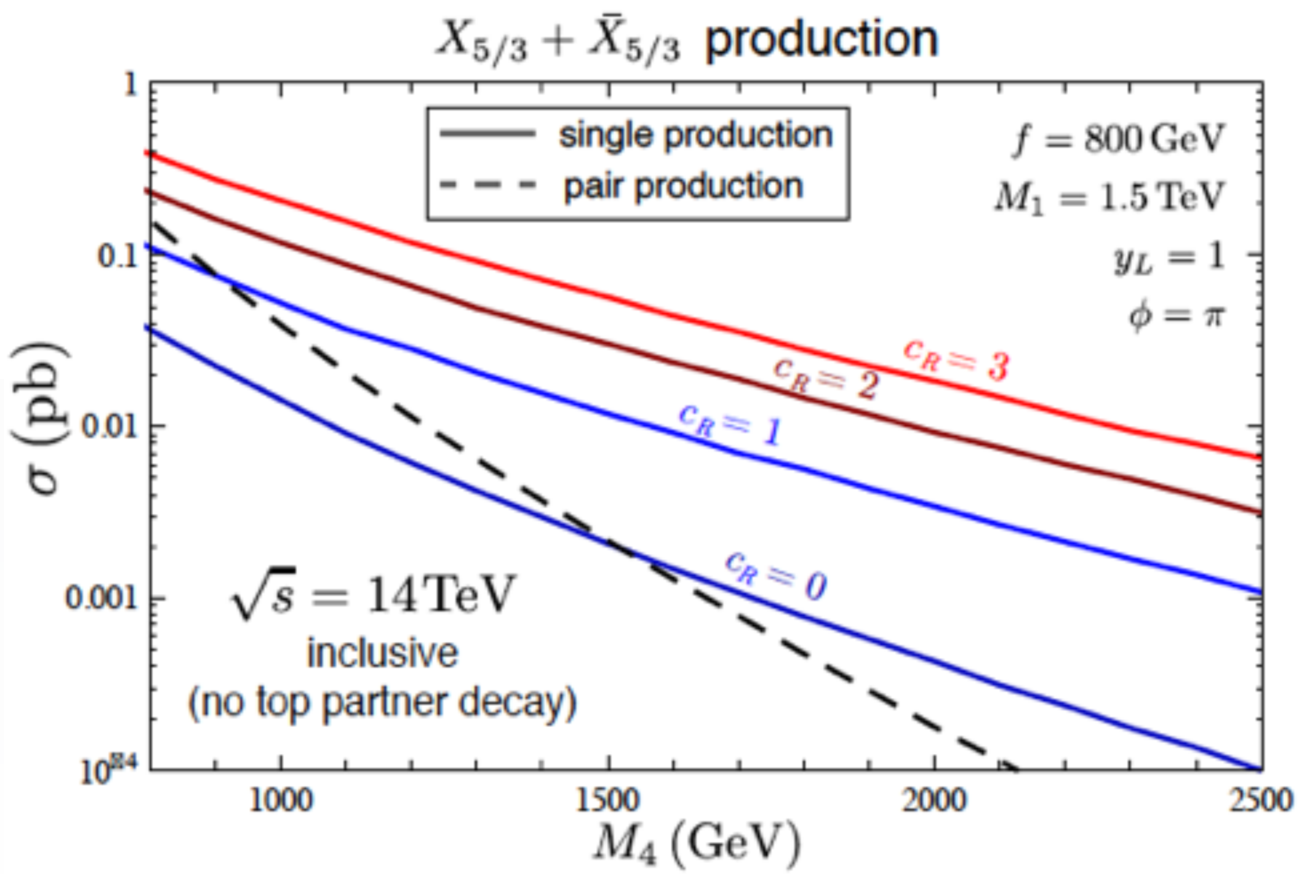
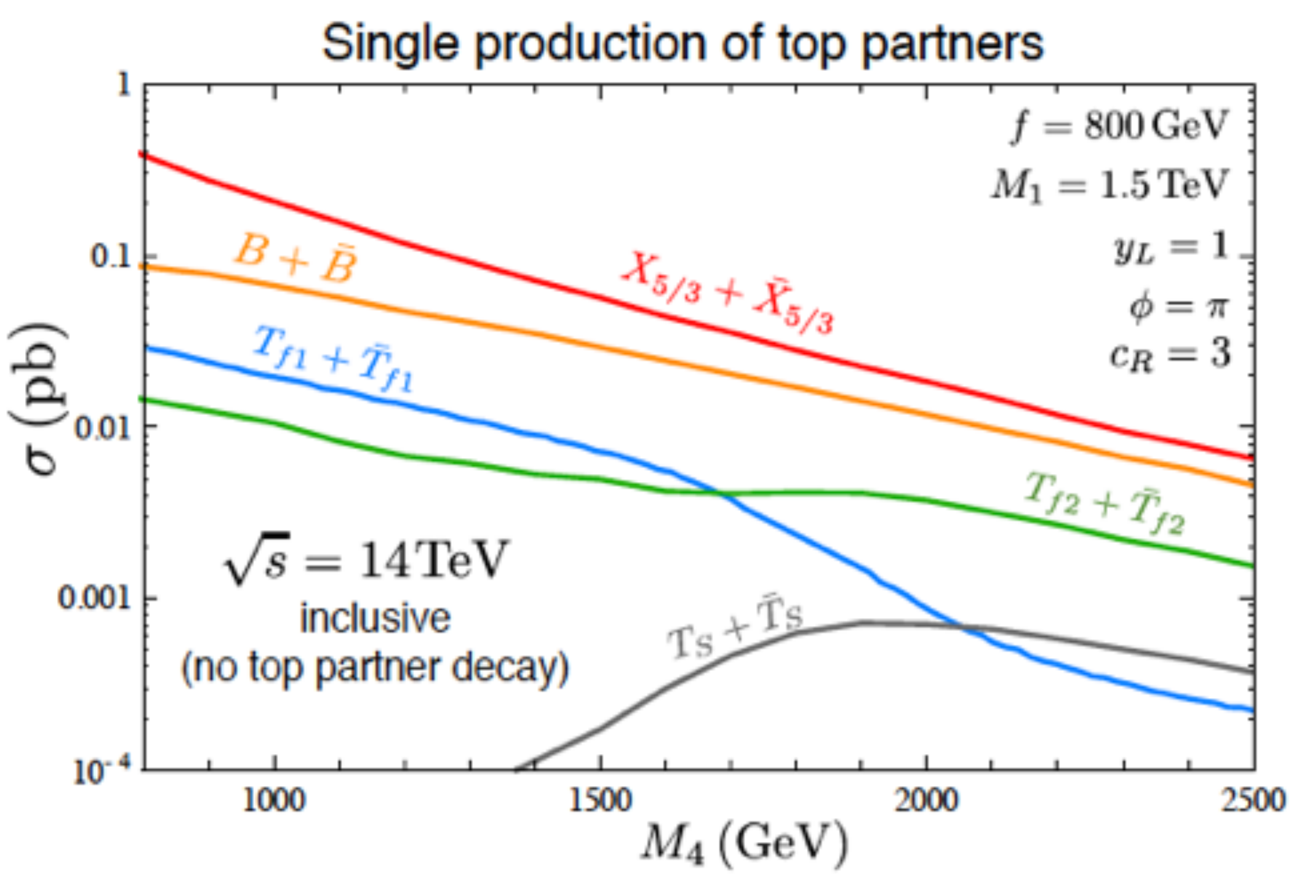
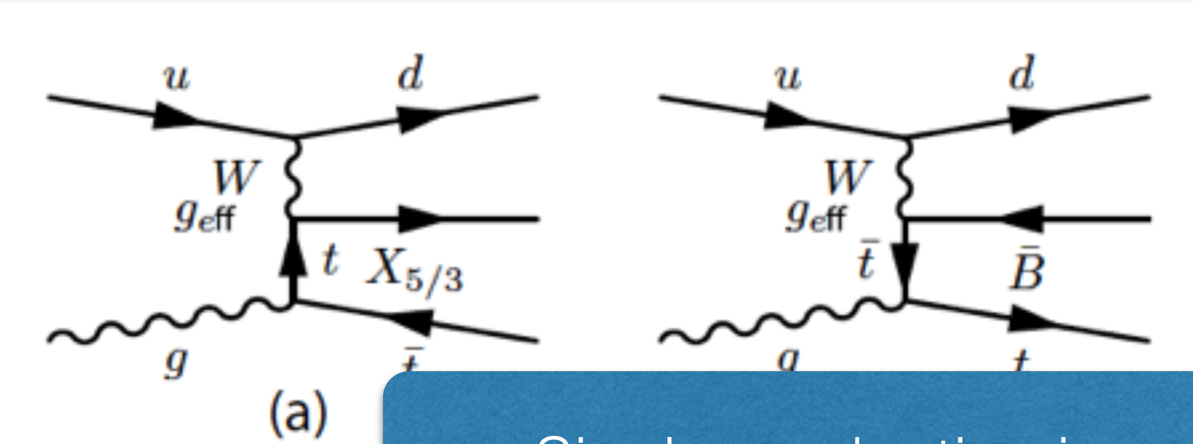
$$M_{Ts} = \sqrt{|M_1|^2 + y_R^2 f^2} + \mathcal{O}(\epsilon^2),$$





Top partners @ Run 2 of the LHC



$$
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M_B &= \sqrt{M_4^2 + y_L^2 f^2}, \\
M_{X_{5/3}} &= M_4, \\
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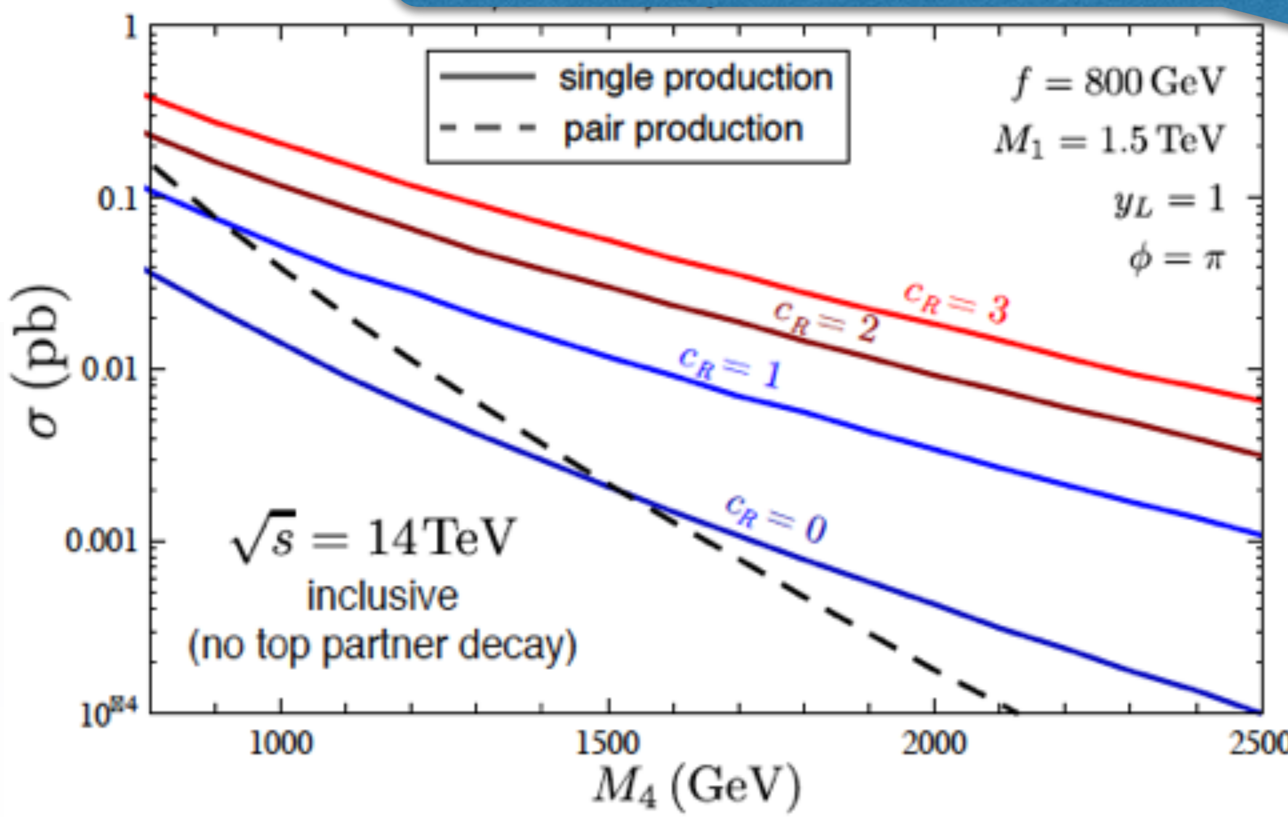
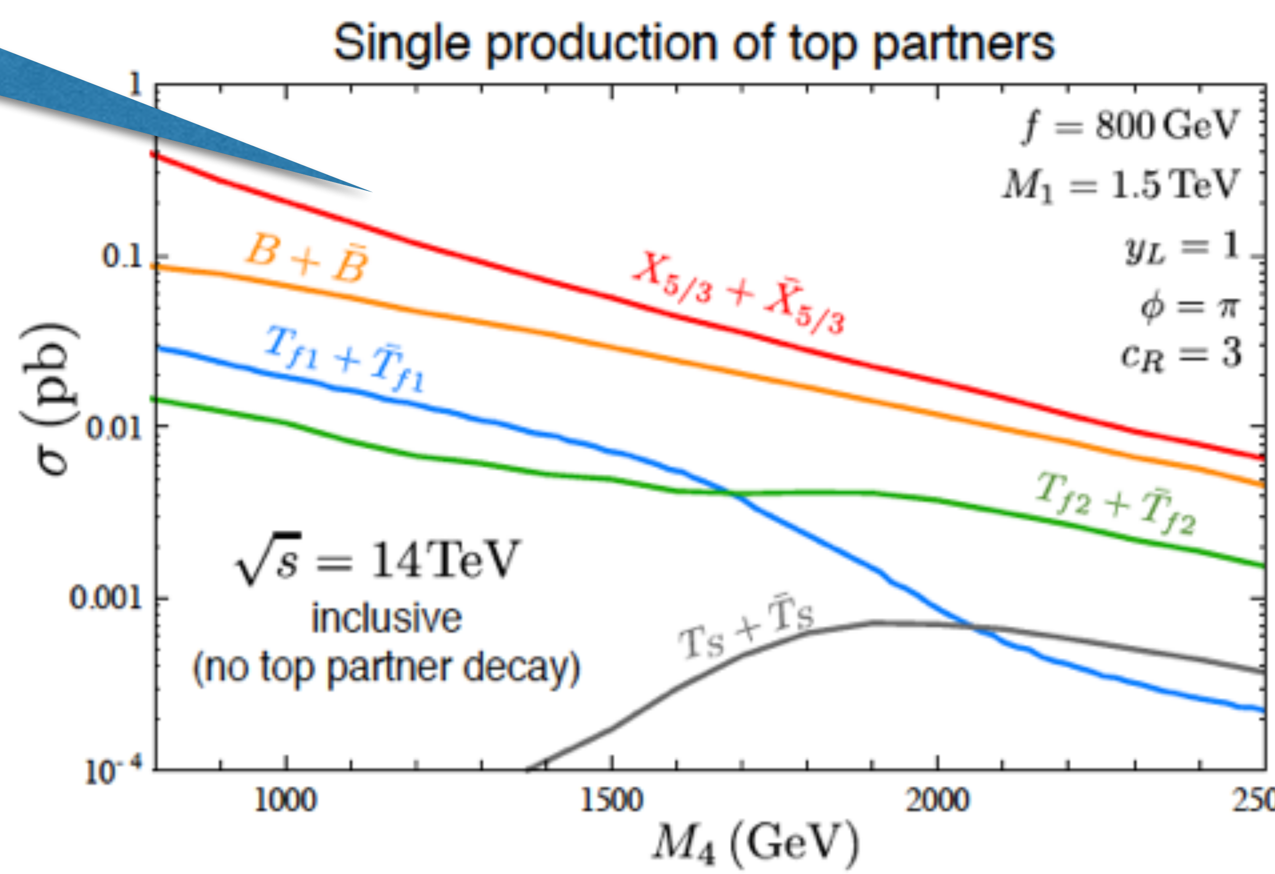
M_{Ts} &= \sqrt{|M_1|^2 + y_R^2 f^2 + \mathcal{O}(\epsilon^2)},
\end{aligned}
$$

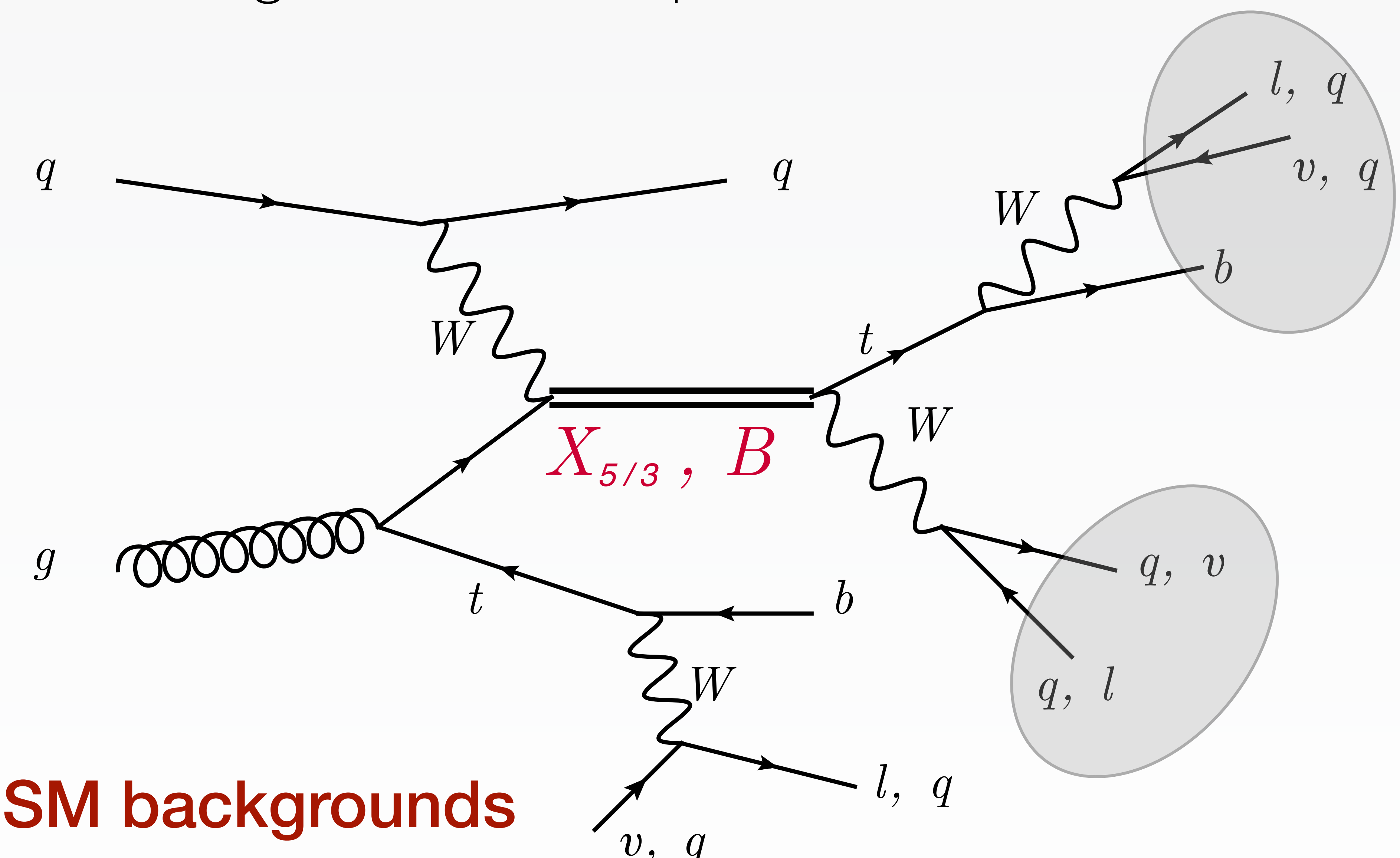
Single production is dominated by X5/3 and B partners.





Top partners @ Run 2 of the LHC

- Single production of top partners might looks complicated

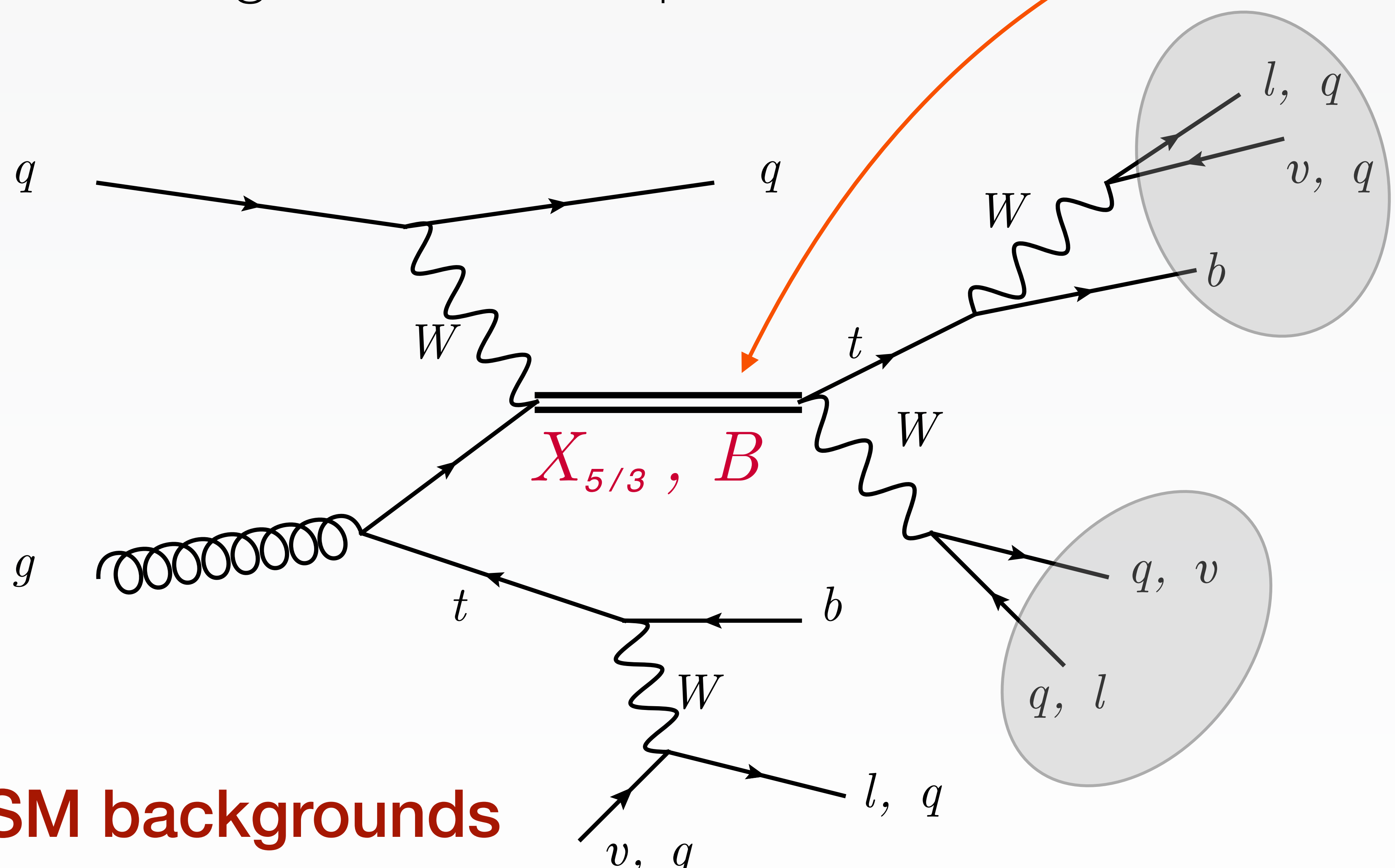


Large **SM backgrounds**
(di-tops, **W**+jets, …)

Top partners @ Run 2 of the LHC

- Single production of top partners might looks complicated

$M \sim O(1\,\text{TeV})$

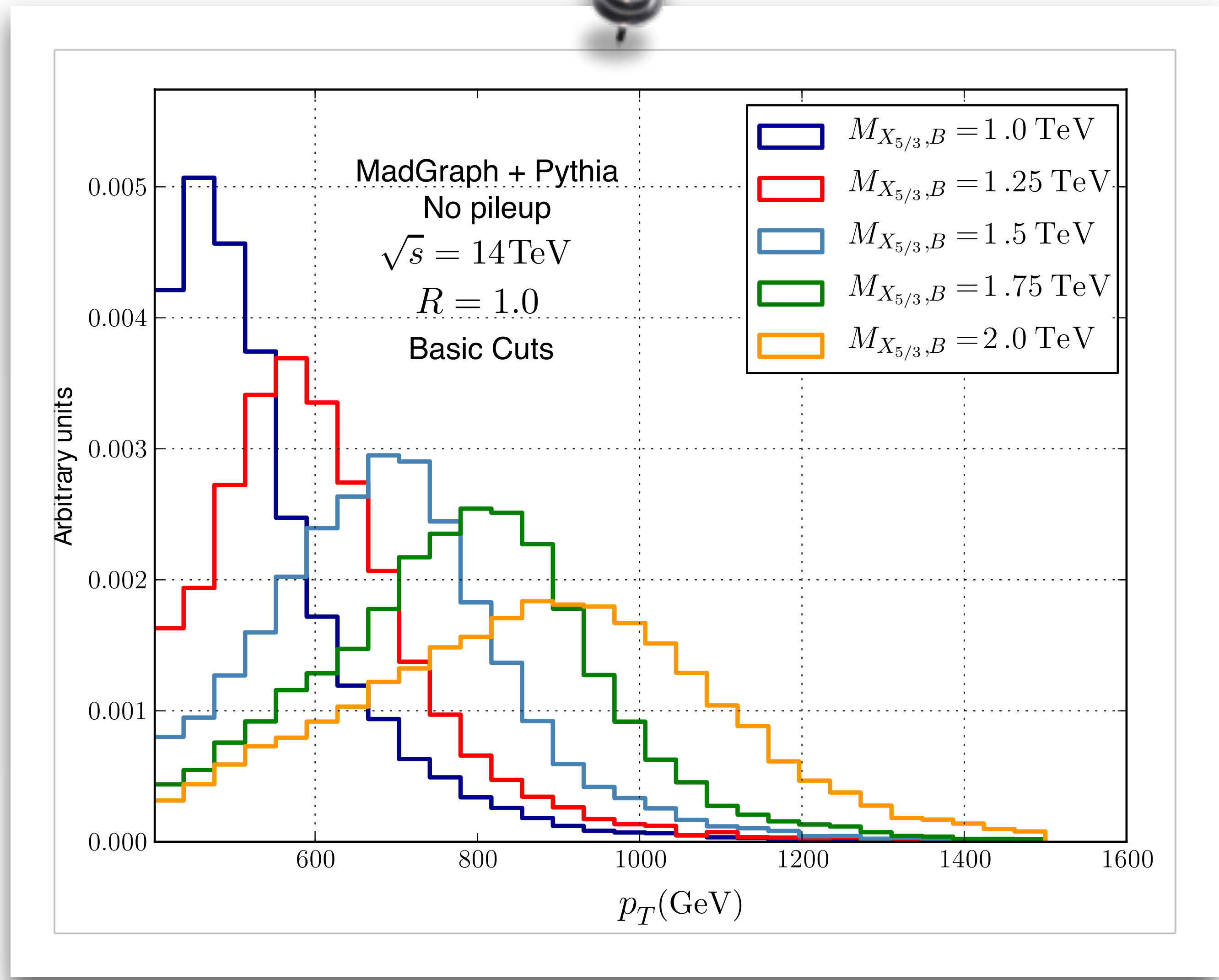


Large **SM backgrounds**
(di-tops, **W**+jets, …)

Top partners @ Run 2 of the LHC

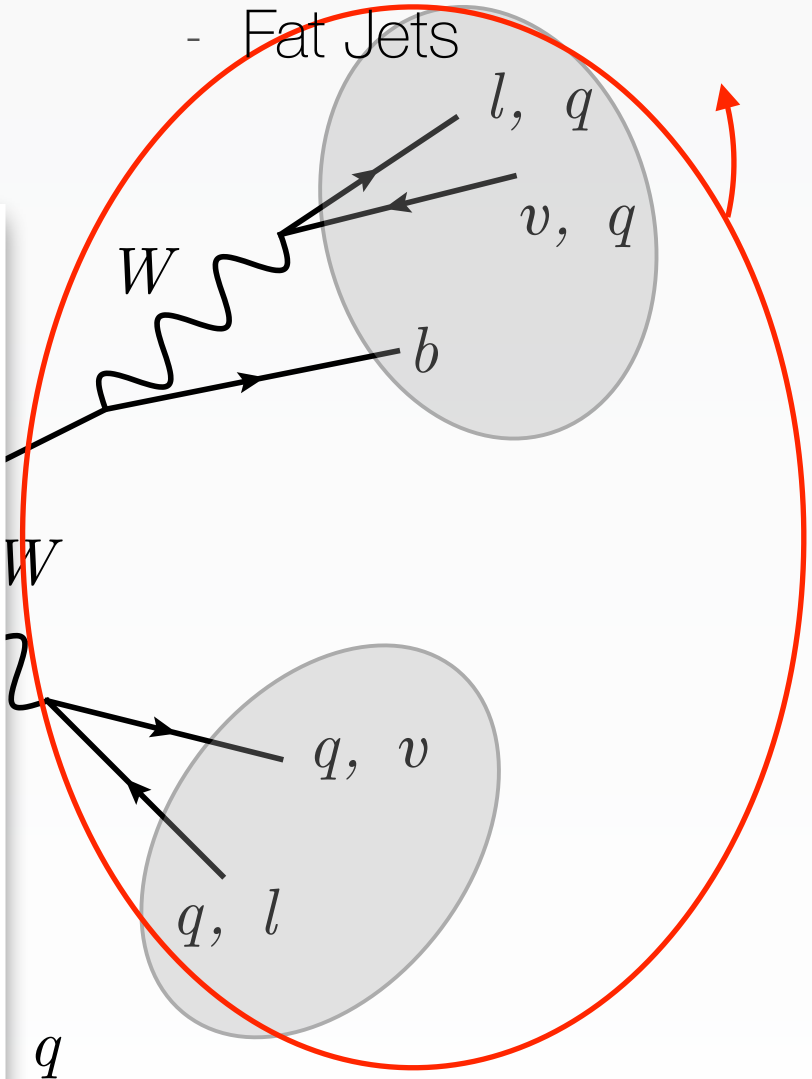
Unique event topology!

At least **three interesting handles** on the SM backgrounds



Boosted t / W

- Hard Lepton
- Missing Energy
- Fat Jets



Top partners @ Run 2 of the LHC

Boosted t / W

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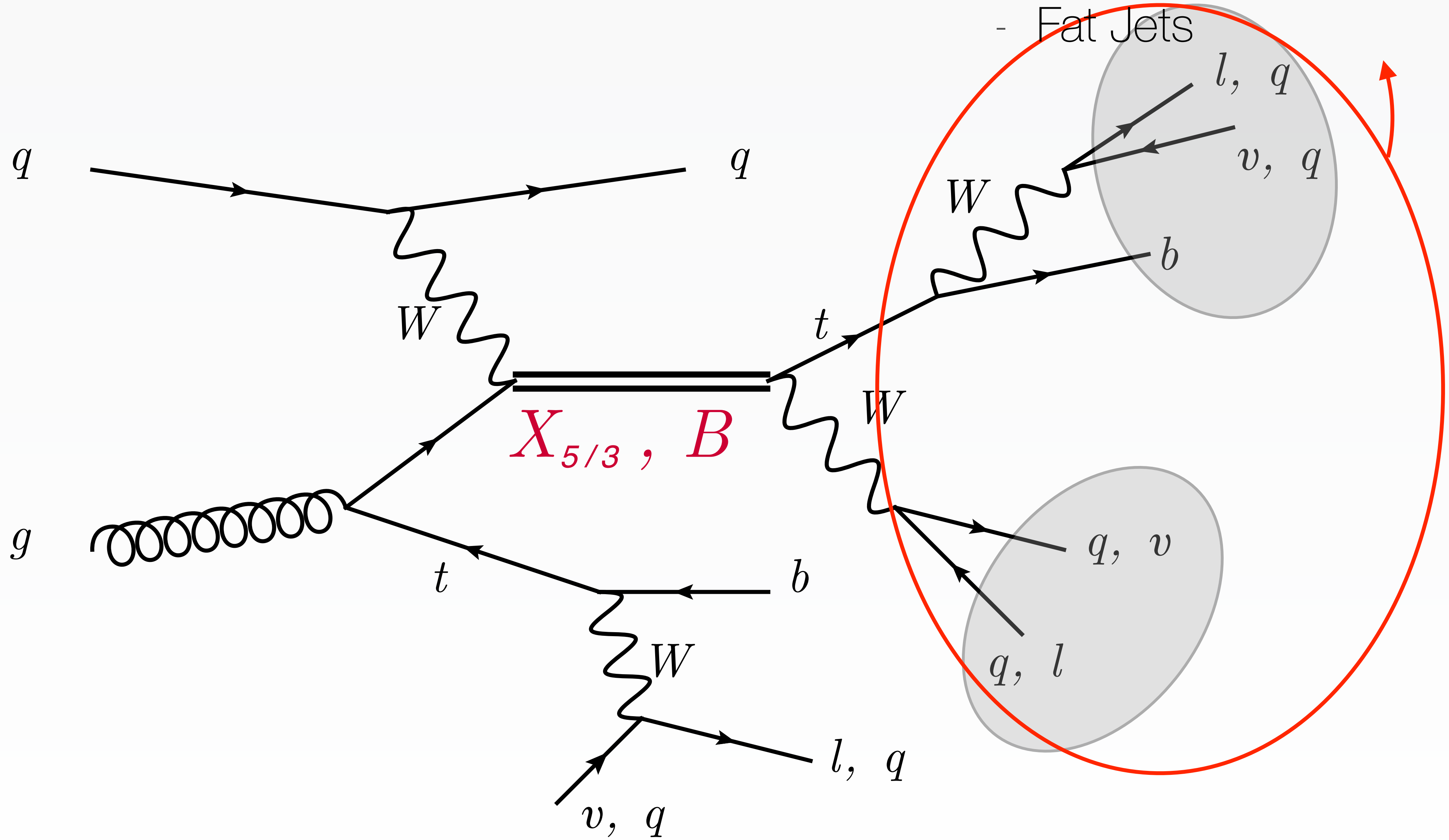
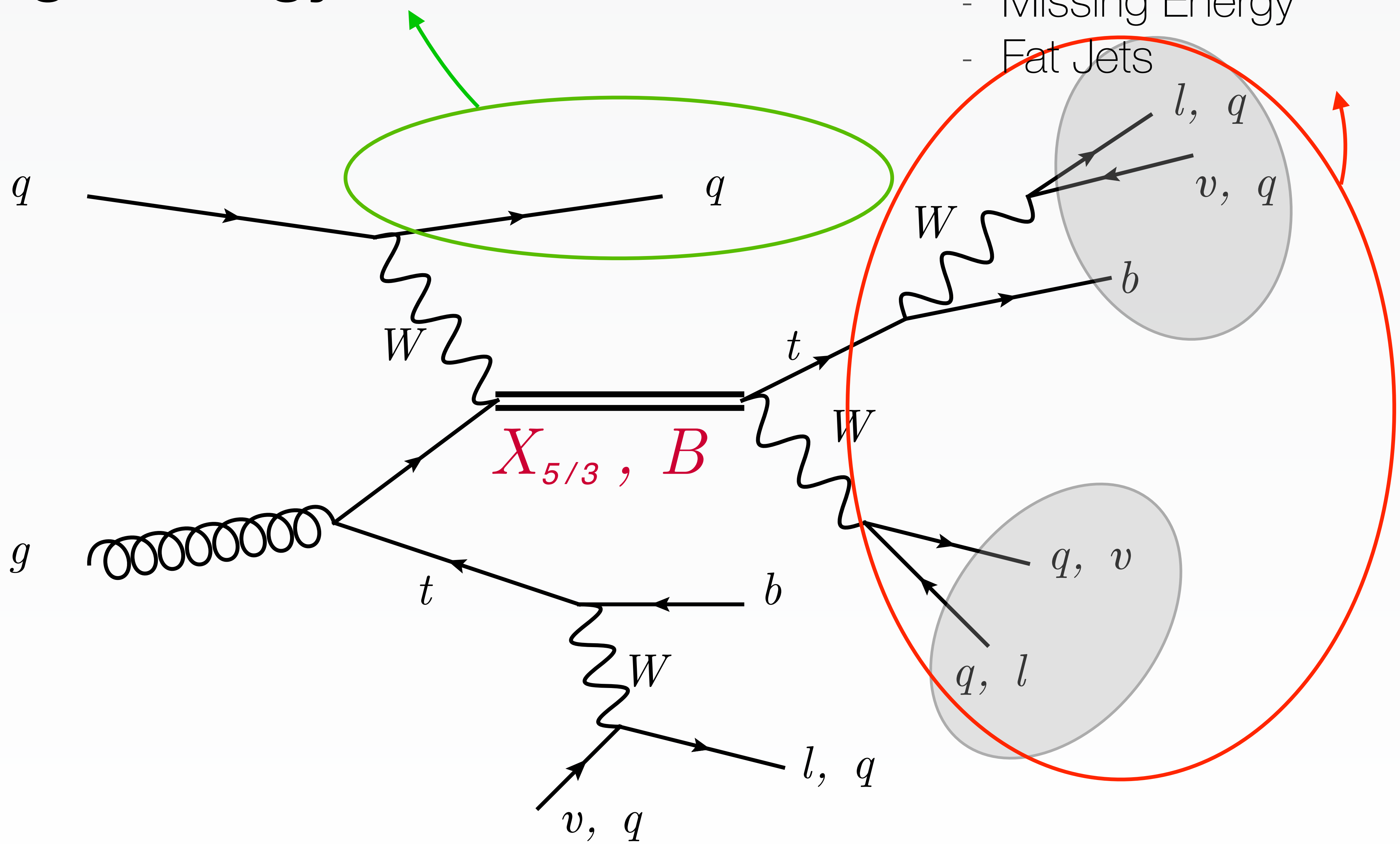


Top partners @ Run 2 of the LHC

Boosted t / W

- Hard Lepton
- Missing Energy
- Fat Jets

High Energy Forward Jet



Top partners @ Run 2 of the LHC

Boosted t / W

- Hard Lepton
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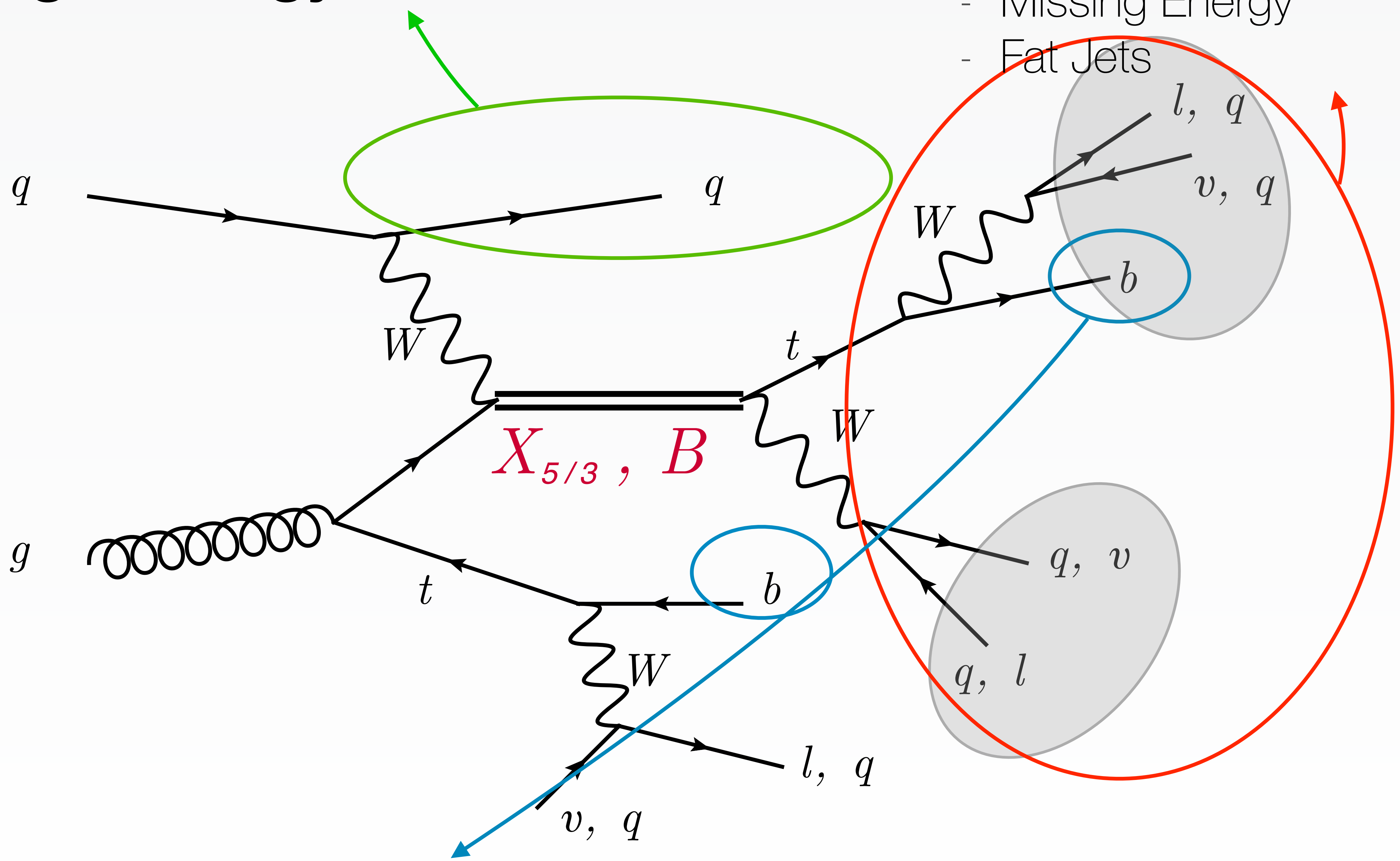
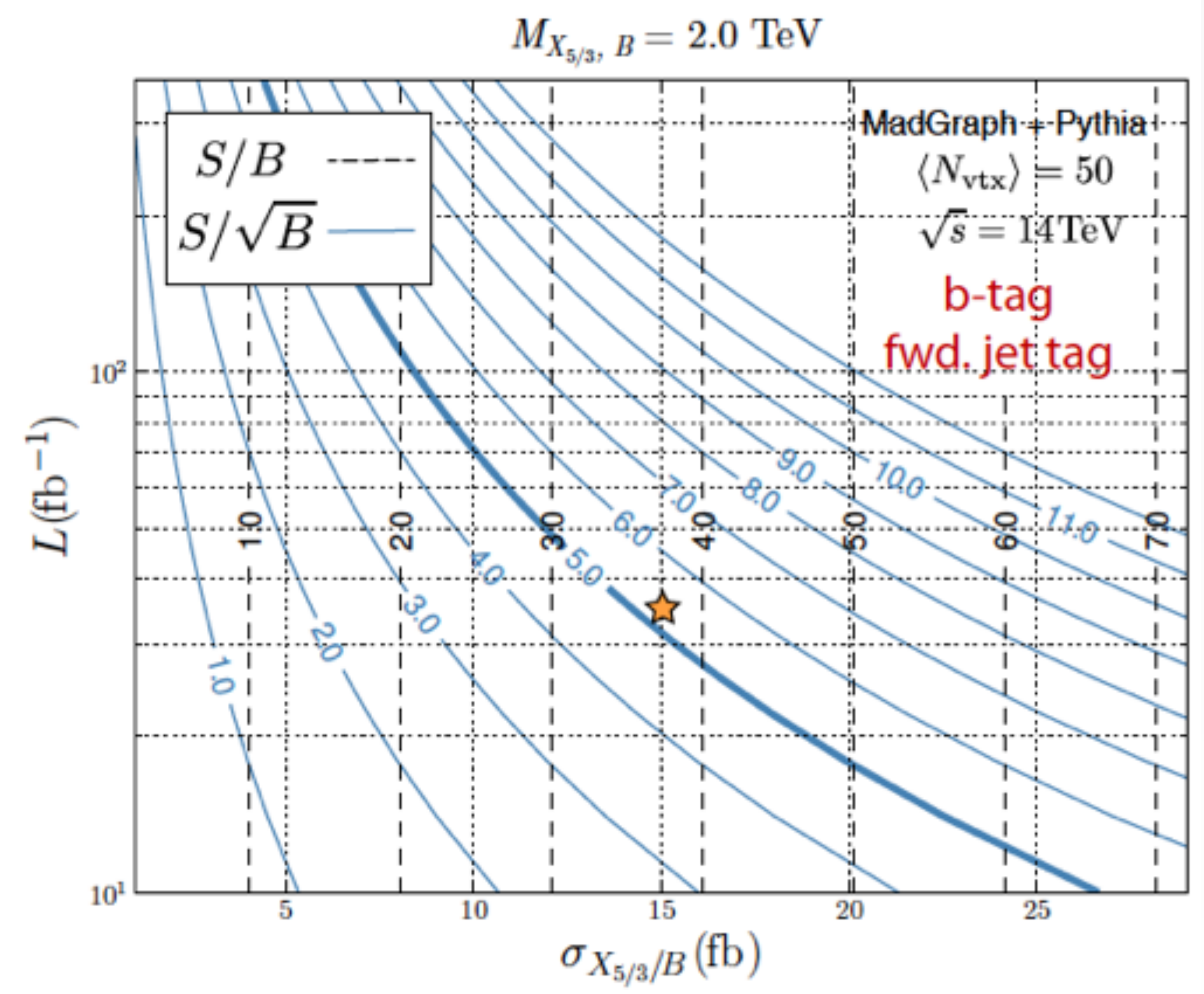
High Energy Forward Jet



Two b-tags

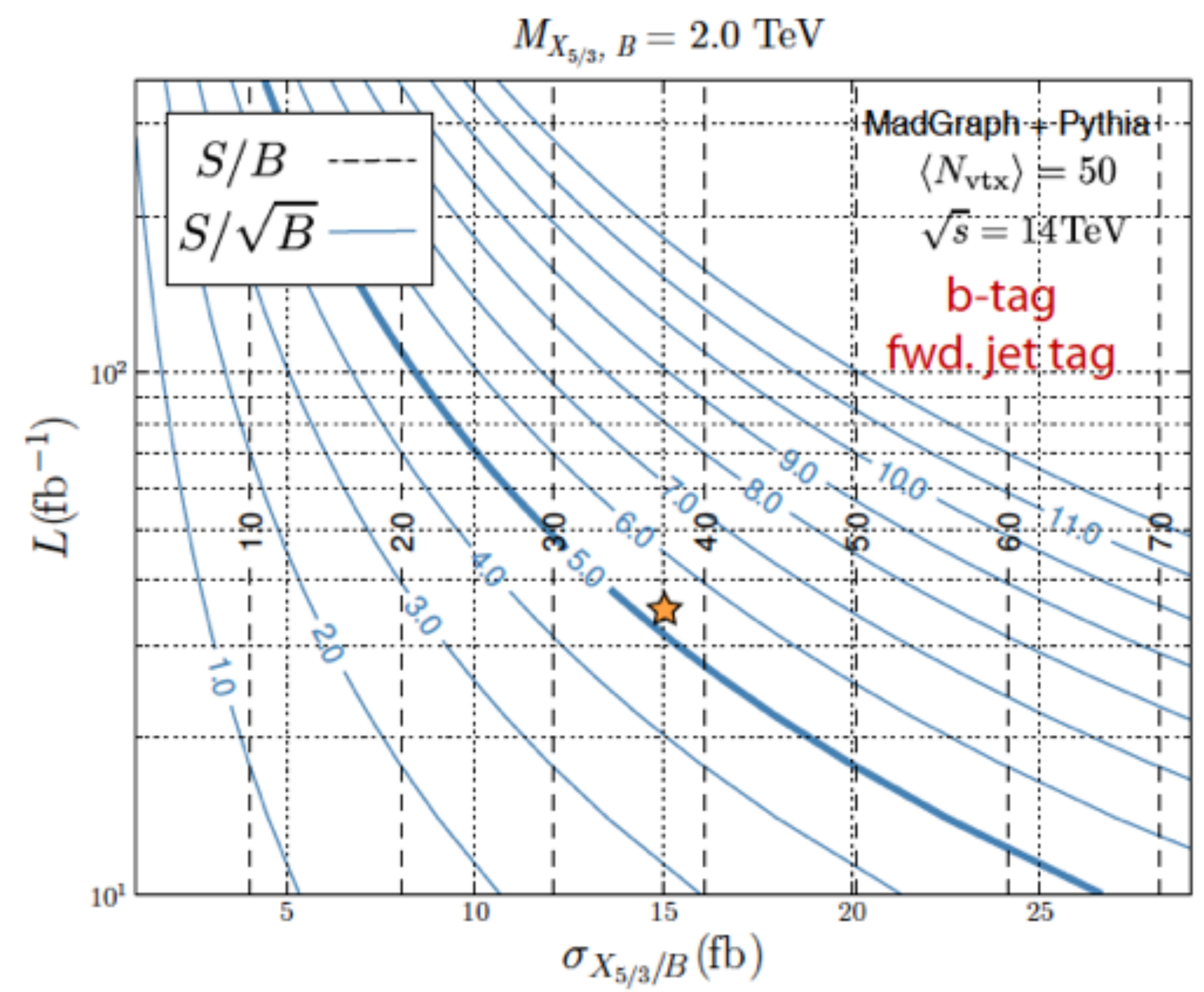
♦ Template Overlap Method w/ forward jet tagging & b-tagging



Backovic, Flacke, SL, Perez `14

♦ Template Overlap Method w/ forward jet tagging & b-tagging

- We showed that Run 2 of the LHC at 14 TeV can detect and measure 2 TeV top partners in a lepton-jet final state, with almost 5 sigma signal significance and S/B > 1 at 35 fb^{-1}
- A sizeable part of the model parameter space parts which result in a 2 TeV top partner can be ruled at 2 sigma with as little as 10 fb^{-1}



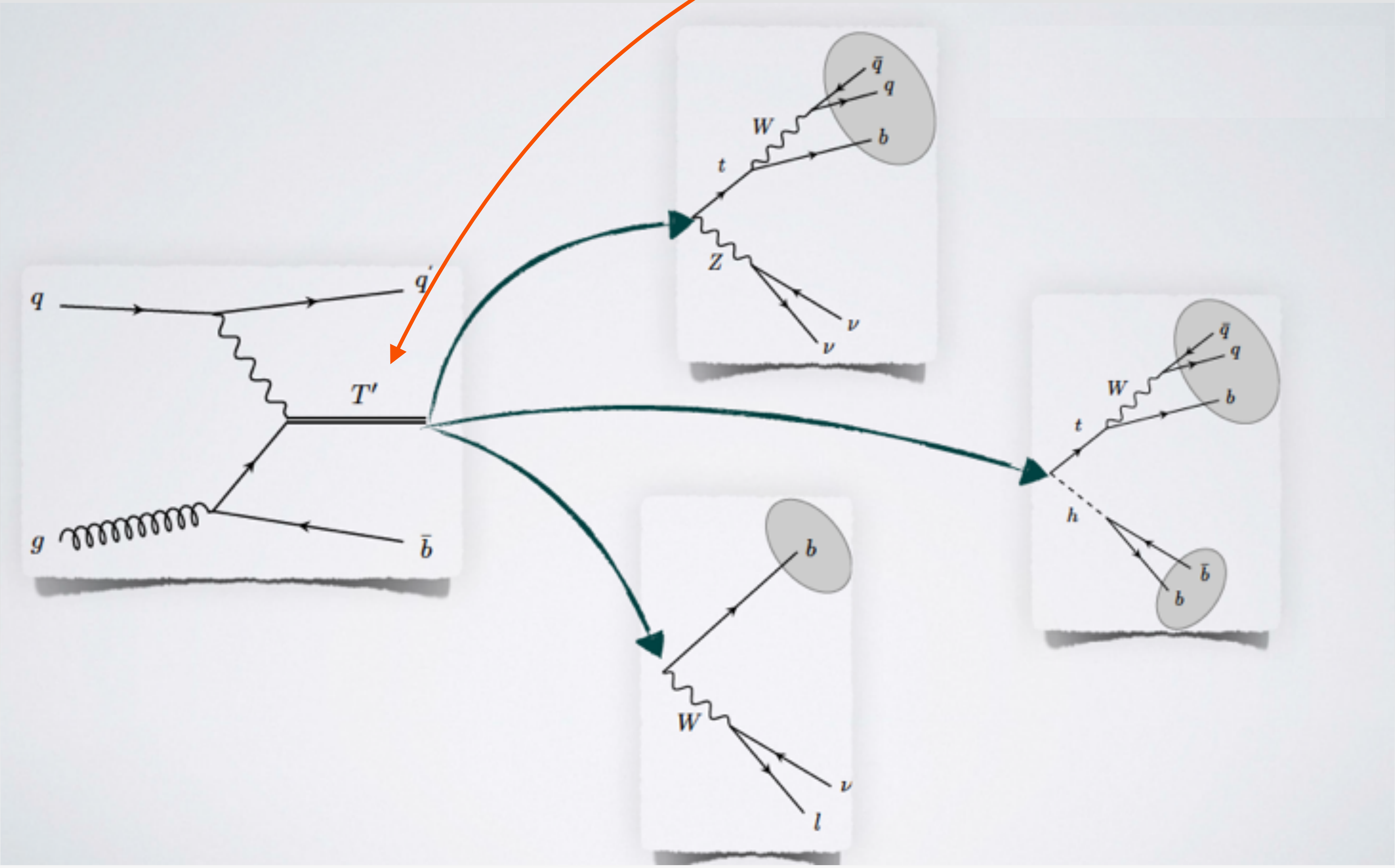
Backovic, Flacke, SL, Perez `14

Top partners @ Run 2 of the LHC

Single production of top partners

Backovic, Flacke, Kim, SL (x2), `15
Flacke, SL, Serodio, Parolini, `16

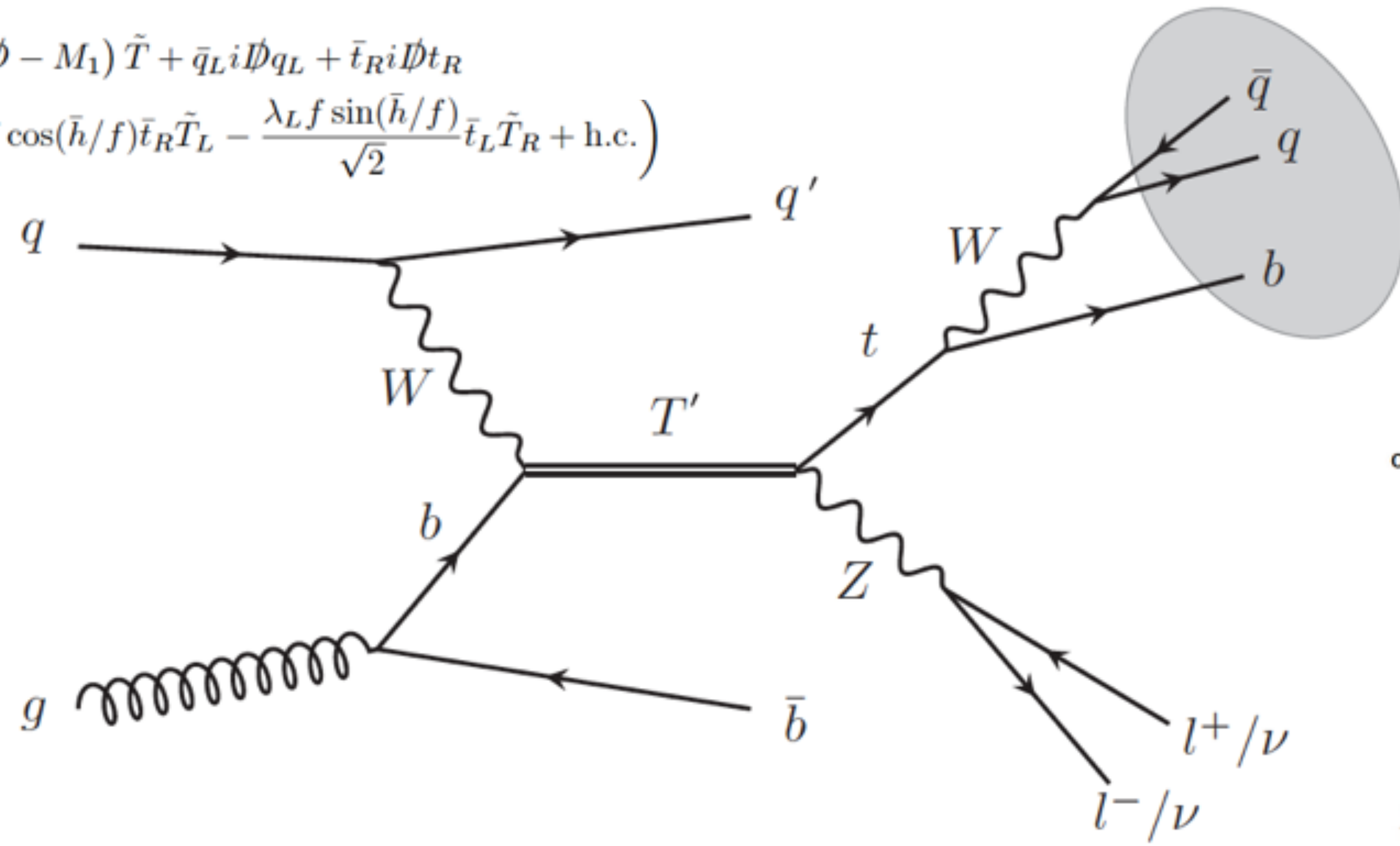
$M \sim O(1\,\mathrm{TeV})$

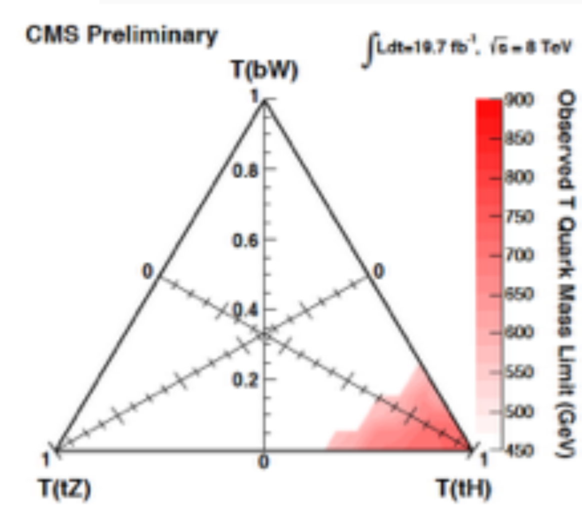


Top partners @ Run 2 of the LHC

- For simple study we chose $SU(2)_L$ singlet top partners (with charge 2/3) **(BR(t+h)~25%, BR(t+Z)~25%, BR(b+W)~50%)**

$$\mathcal{L} \supset \bar{\tilde{T}}' \left(i\not{D} - M_1\right)\tilde{T} + \bar{q}_L i\not{D} q_L + \bar{t}_R i\not{D} t_R - \left(\lambda_R f \cos(\bar{h}/f)\bar{t}_R \tilde{T}_L - \frac{\lambda_L f \sin(\bar{h}/f)}{\sqrt{2}}\bar{t}_L \tilde{T}_R + \text{h.c.}\right)$$

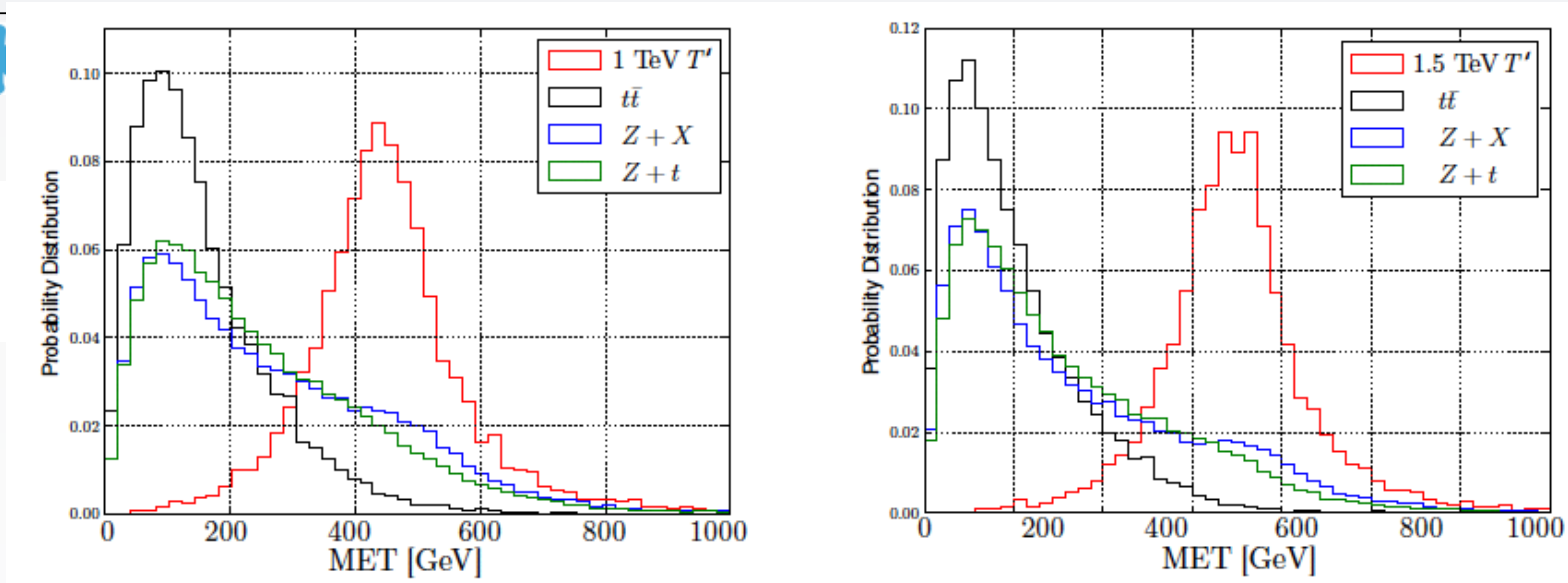




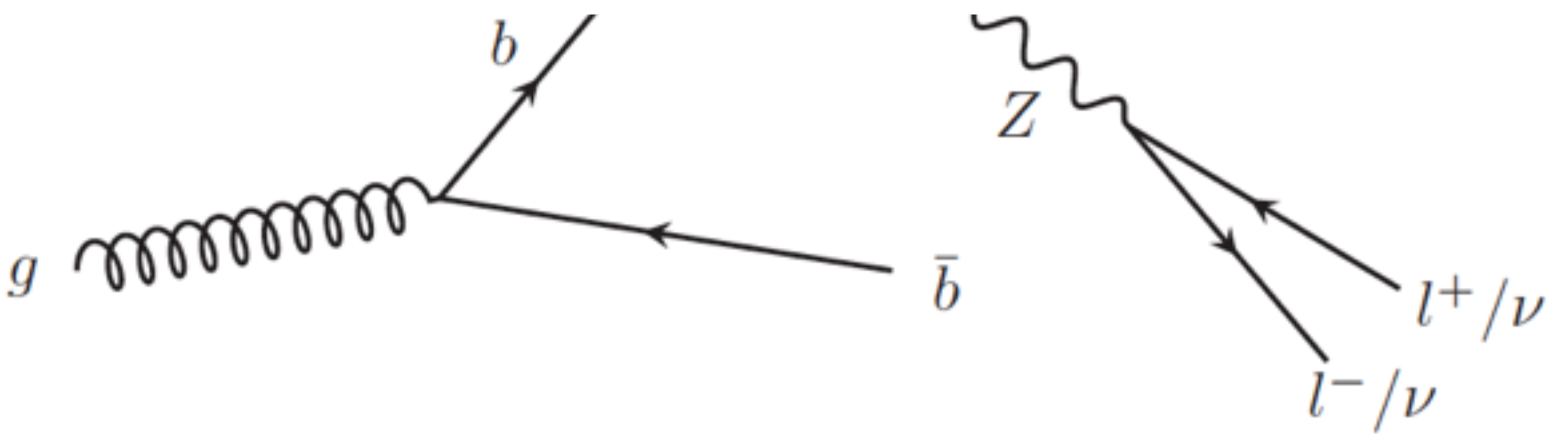
- For **Run I**, **(Z → MET)+hadronic** channel was not utilized due to large SM background (e.g. t+MET): **(Z → dilepton)+hadronic channel** has been the golden channel

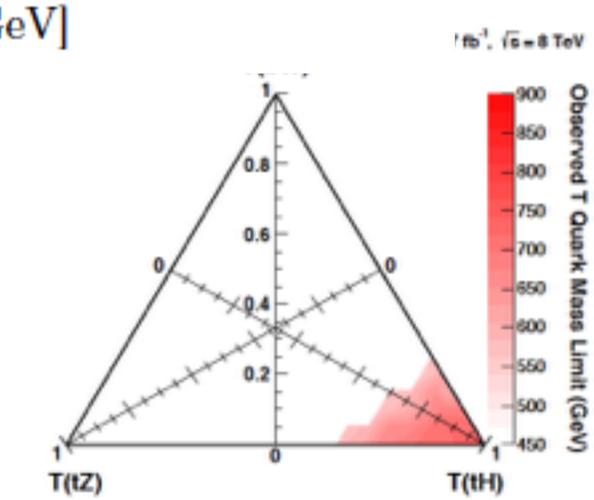
Backovic, Flacke, Kim,SL `15 (x2)

Top partners @ Run 2 of the LHC



0%)





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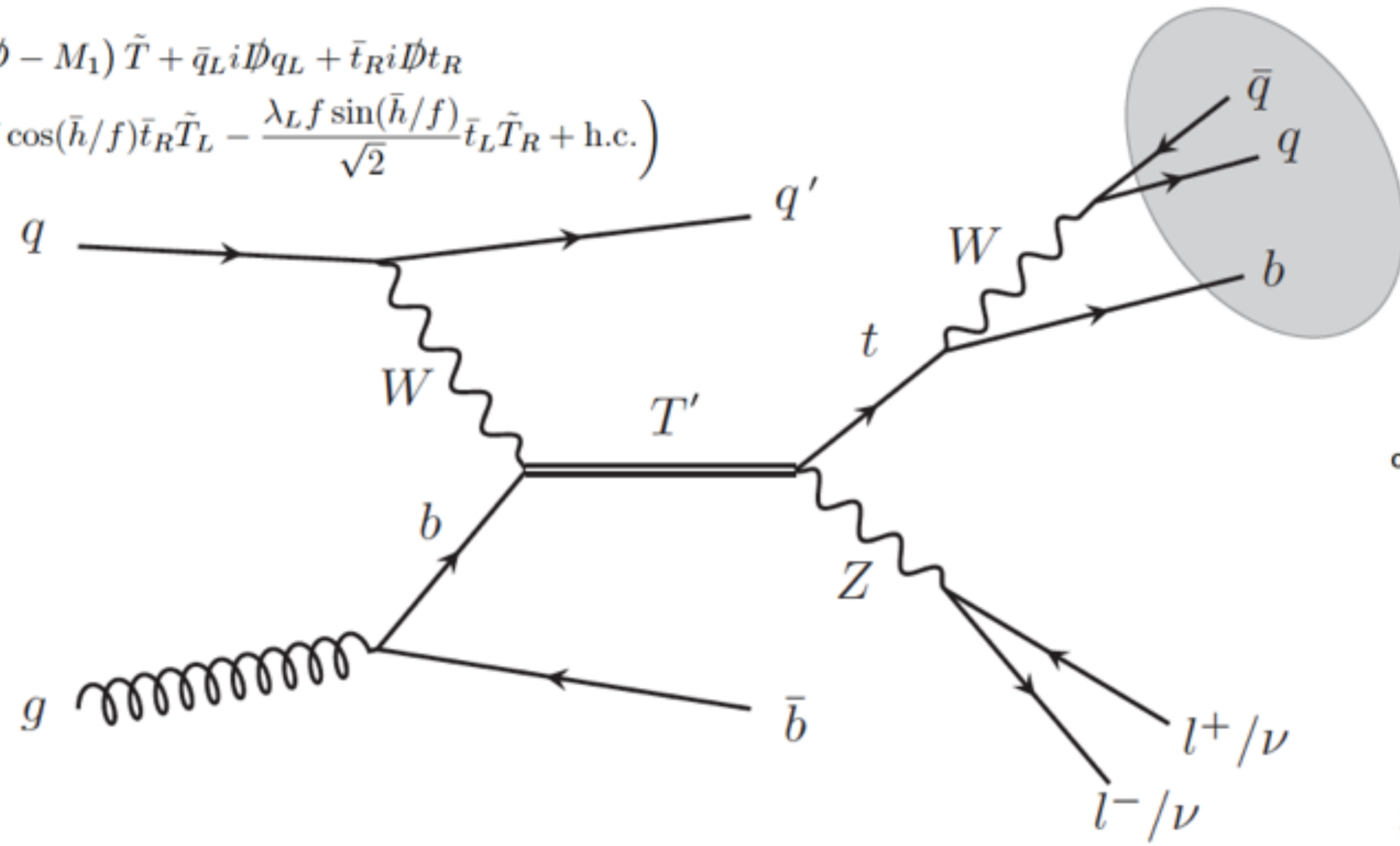
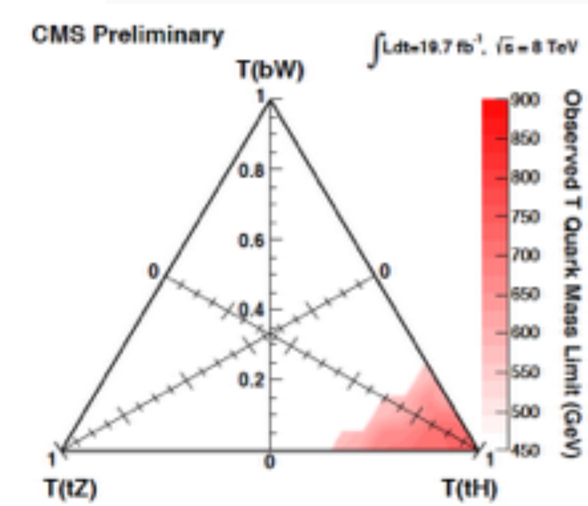
Backovic, Flacke, Kim,SL `15 (x2)

Top partners @ Run 2 of the LHC

- For simple study we chose $SU(2)_L$ singlet top partners (with charge 2/3) **(BR(t+h)~25%, BR(t+Z)~25%, BR(b+W)~50%)**

$$\mathcal{L} \supset \bar{\tilde{T}}' \left(i\not{D} - M_1\right)\tilde{T} + \bar{q}_L i\not{D} q_L + \bar{t}_R i\not{D} t_R - \left(\lambda_R f \cos(\bar{h}/f)\bar{t}_R \tilde{T}_L - \frac{\lambda_L f \sin(\bar{h}/f)}{\sqrt{2}}\bar{t}_L \tilde{T}_R + \text{h.c.}\right)$$





- For **Run I**, **(Z → MET)+hadronic** channel was not utilized due to large SM background (e.g. t+MET): **(Z → dilepton)+hadronic channel** has been the golden channel

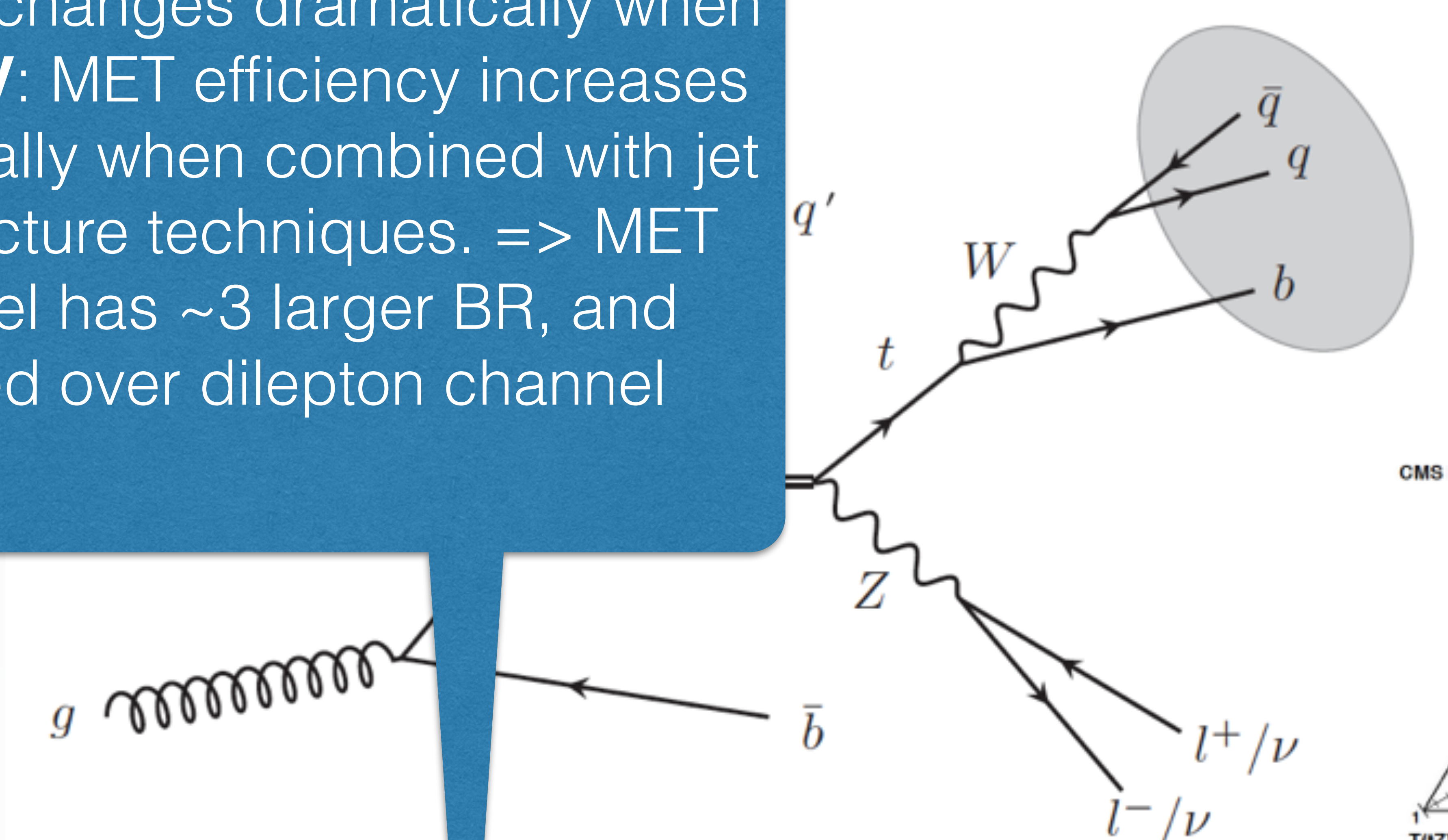
Backovic, Flacke, Kim,SL `15 (x2)

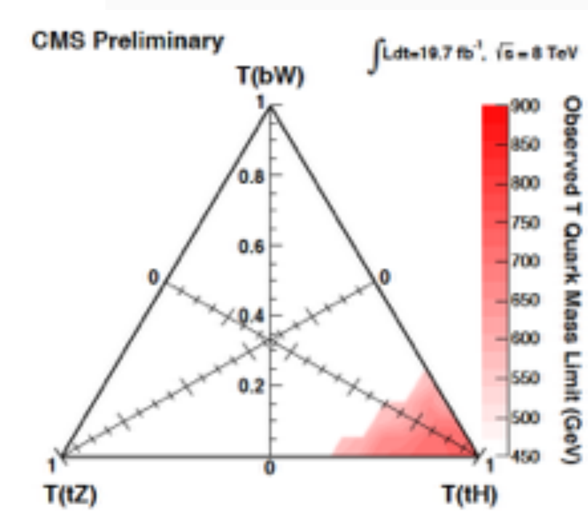
Top partners @ Run 2 of the LHC

se $SU(2)_L$ singlet top

(BR(t+h)~25%, BR(t+Z)~25%, BR(b+W)~50%)

Situation changes dramatically when **M > 1TeV**: MET efficiency increases dramatically when combined with jet substructure techniques. => MET channel has ~3 larger BR, and favored over dilepton channel





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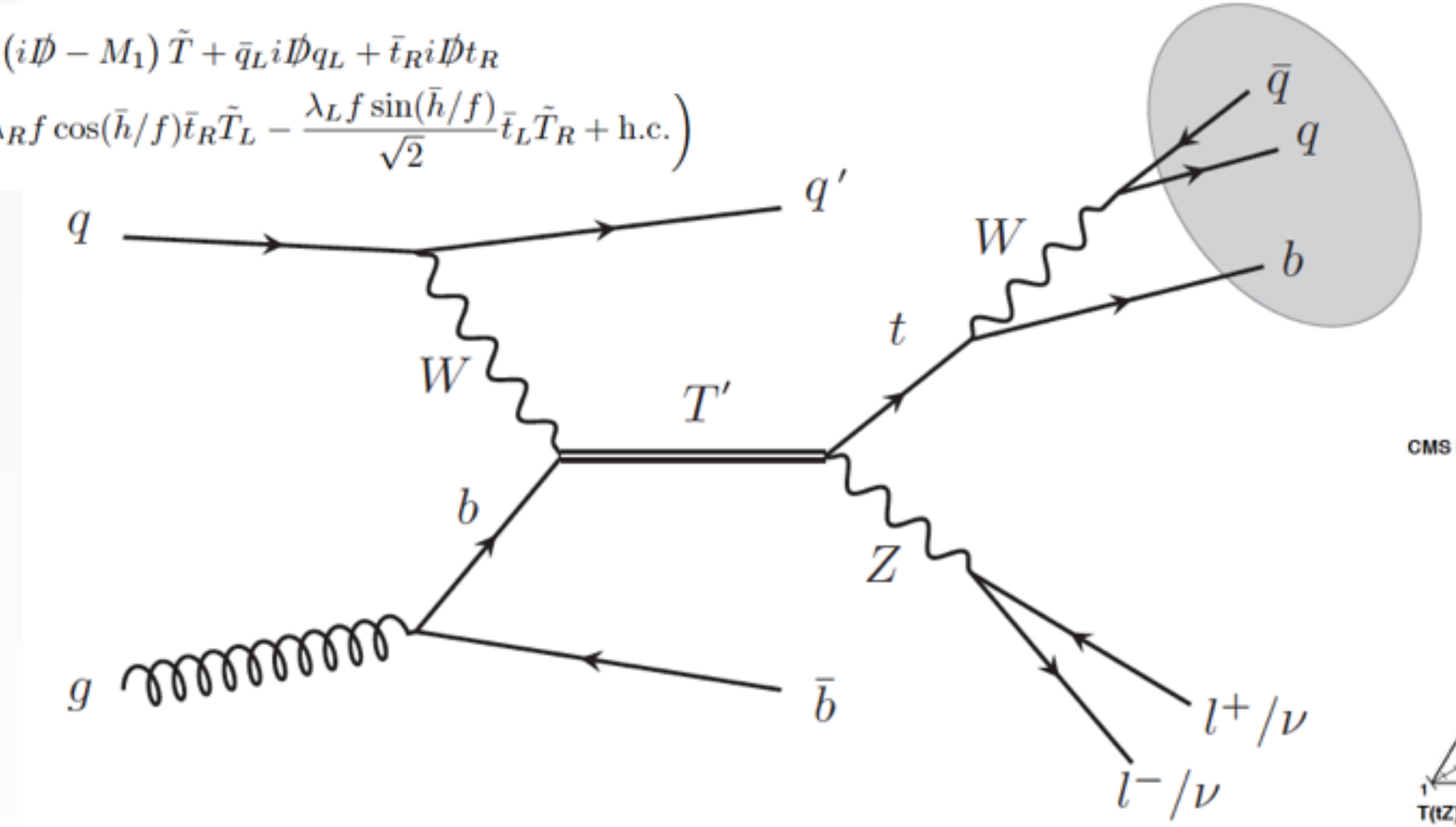

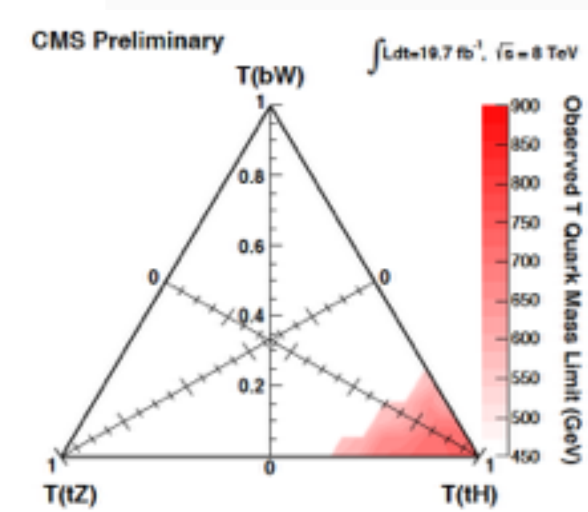

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Backovic, Flacke, Kim,SL `15 (x2)

Top partners @ Run 2 of the LHC

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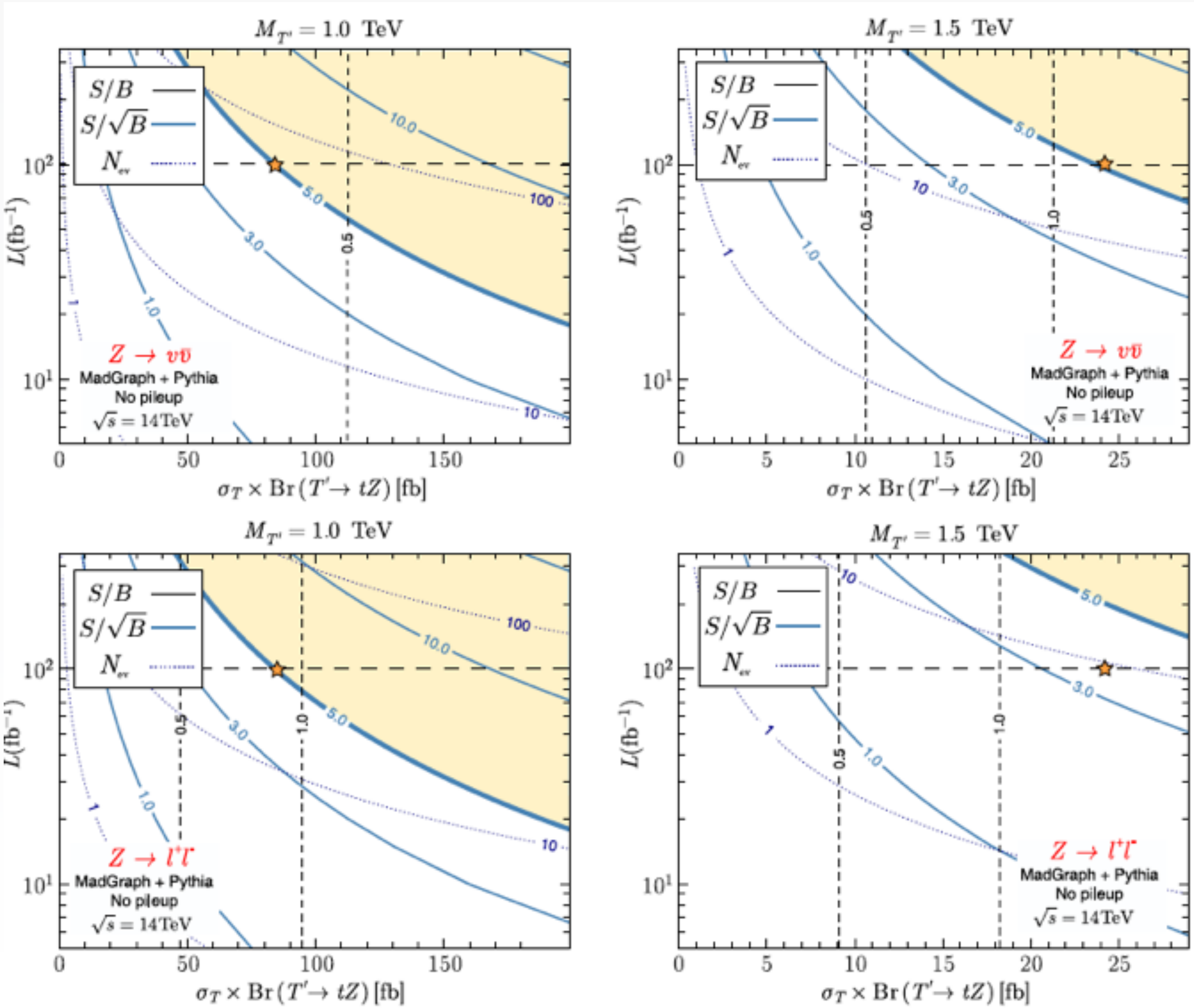
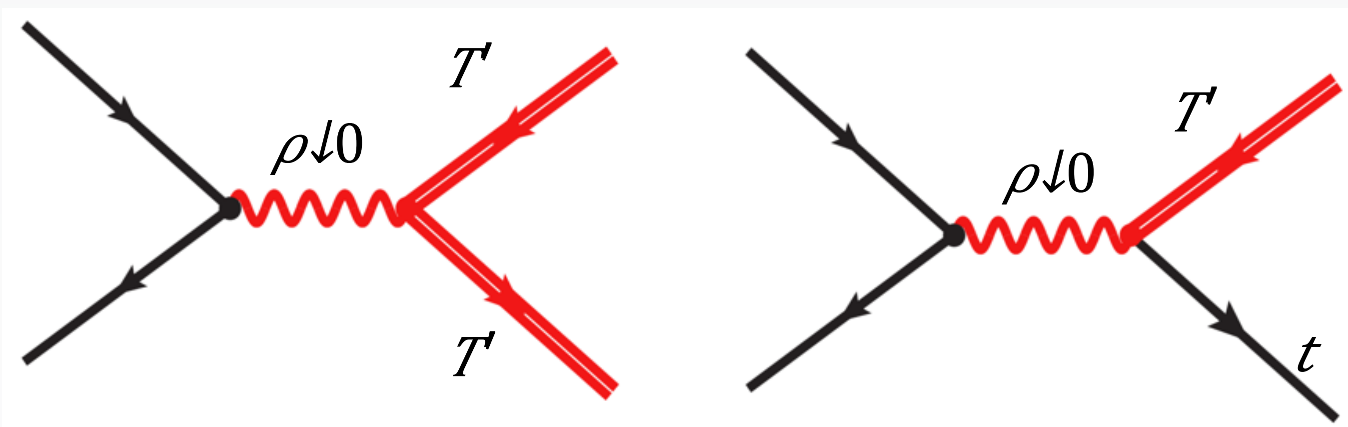
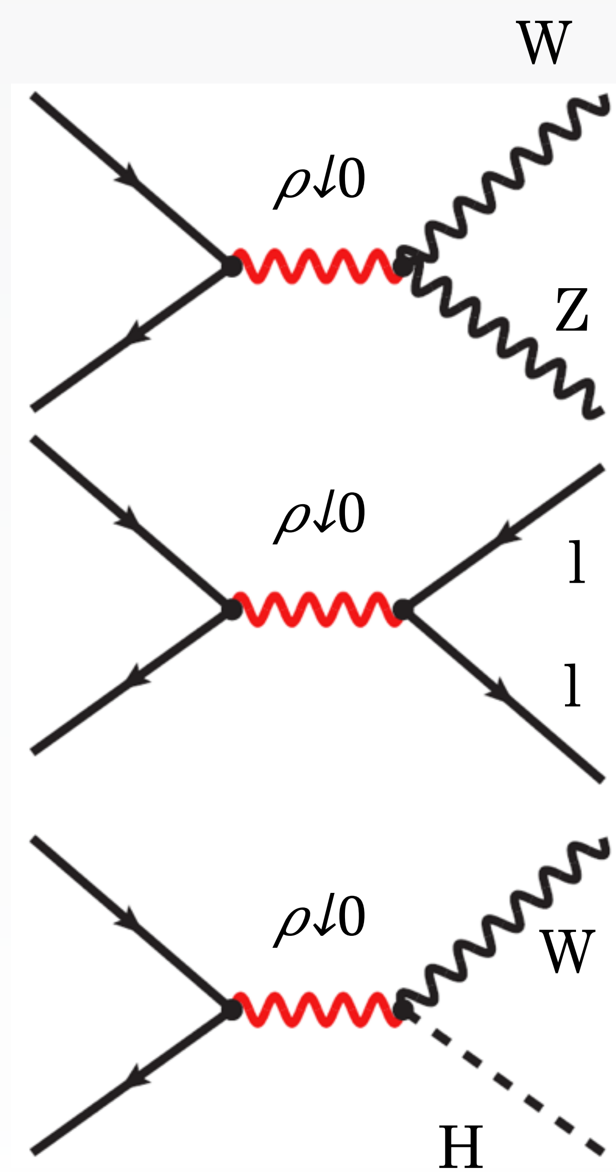
Backovic, Flacke, Kim,SL `15



Composite Vector Resonances

ρ decay channels: SM (di-quark, di-lepton, di-boson) and
Exotics (t T, TT) – Top partner production channels





- Current searches - ONLY SM final states for ρ decays
- Additional signatures to be added to support the **"no lose" strategy for Z'** (neutral heavy resonances)
- Can be combined with di-lepton, VV, VH
- resonance searches **if some excess is observed**
- Bounds on $\rho{\downarrow}\pm$ – using $X_{5/3}$'s

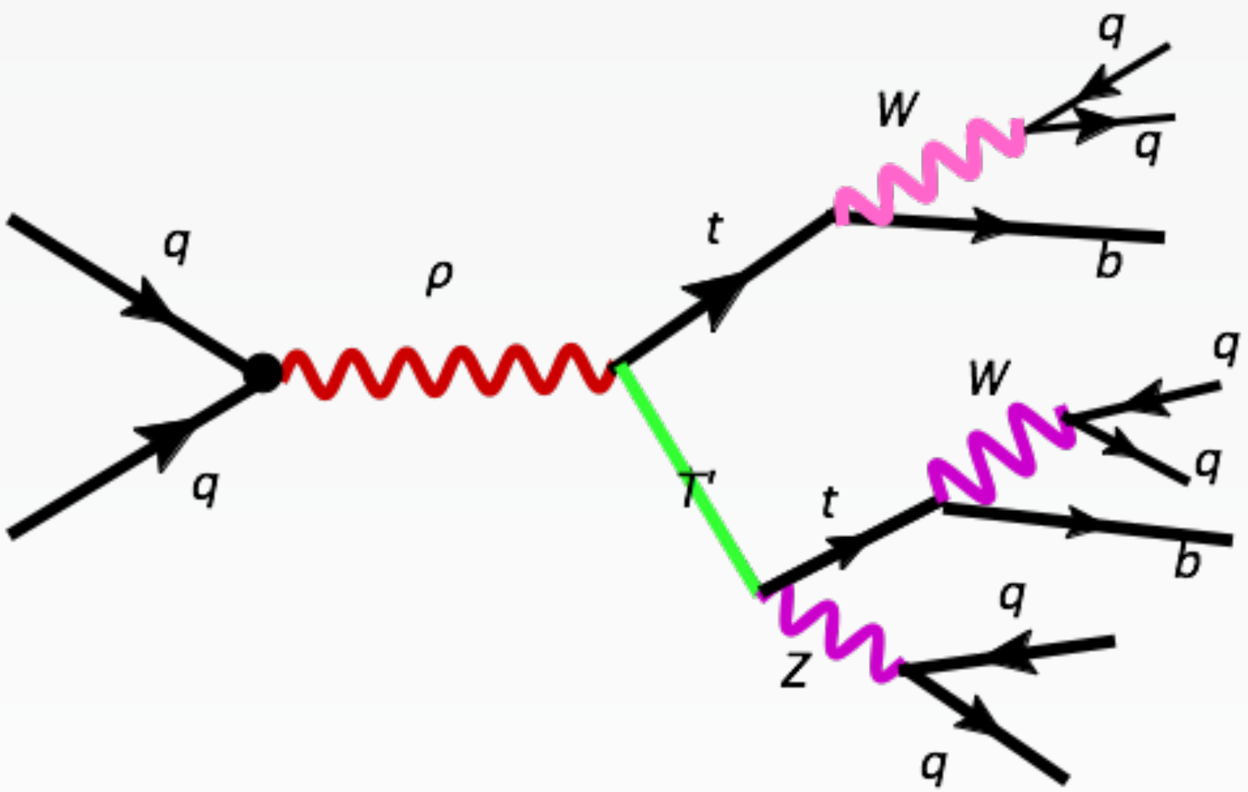
[Barducci, Delauney – 1511.01101]

Composite Vector Resonances

Backovic, Jain, Flacke, SL in progress `16

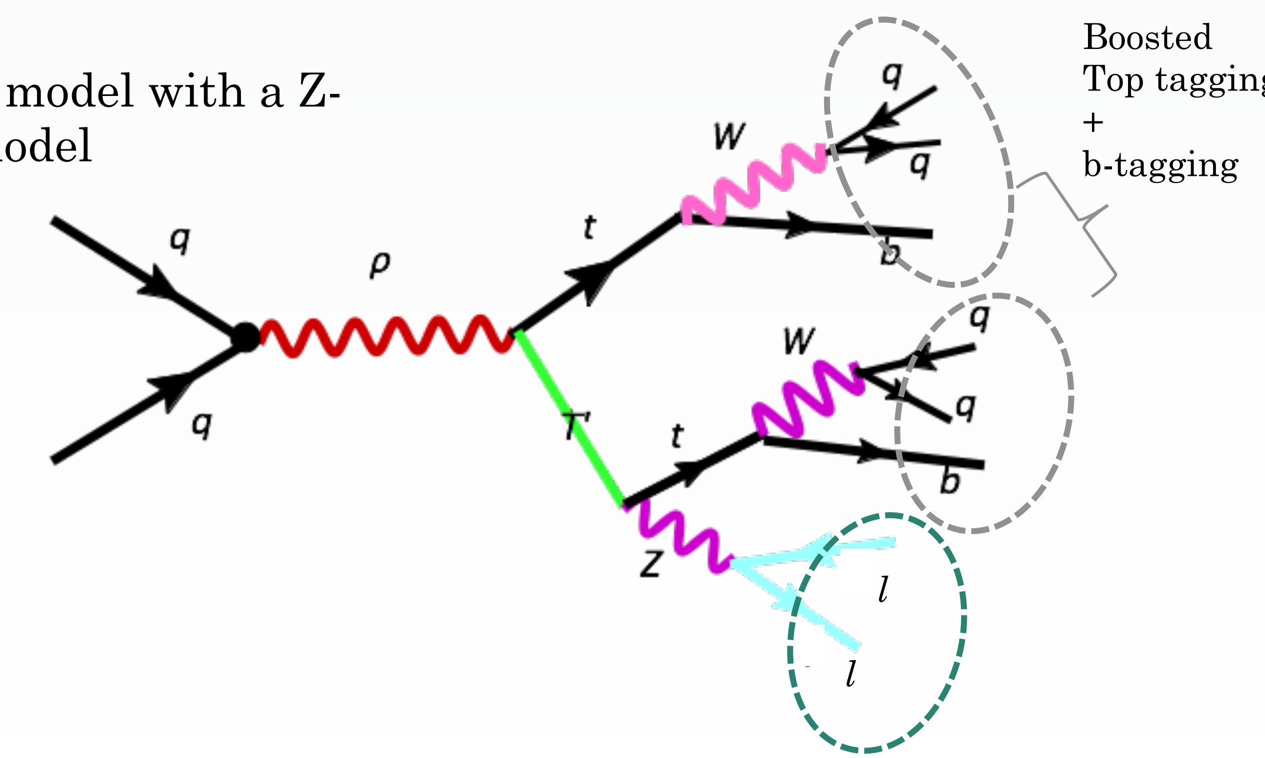
Production of T' from ρ_0 ~ **40 fb @ 14TeV ***

3 Fat jets in an event



Boosted
Top tagging
+
b-tagging

Madgraph 5 with Feynrules model implementation of a toy model with a Z-prime , interfaced with VLQ model and an effective Higgs model



Composite Vector Resonances

Backovic, Jain, Flacke, SL in progress `16

Production of T' from ρ^0 ~ **40 fb @ 14TeV ***

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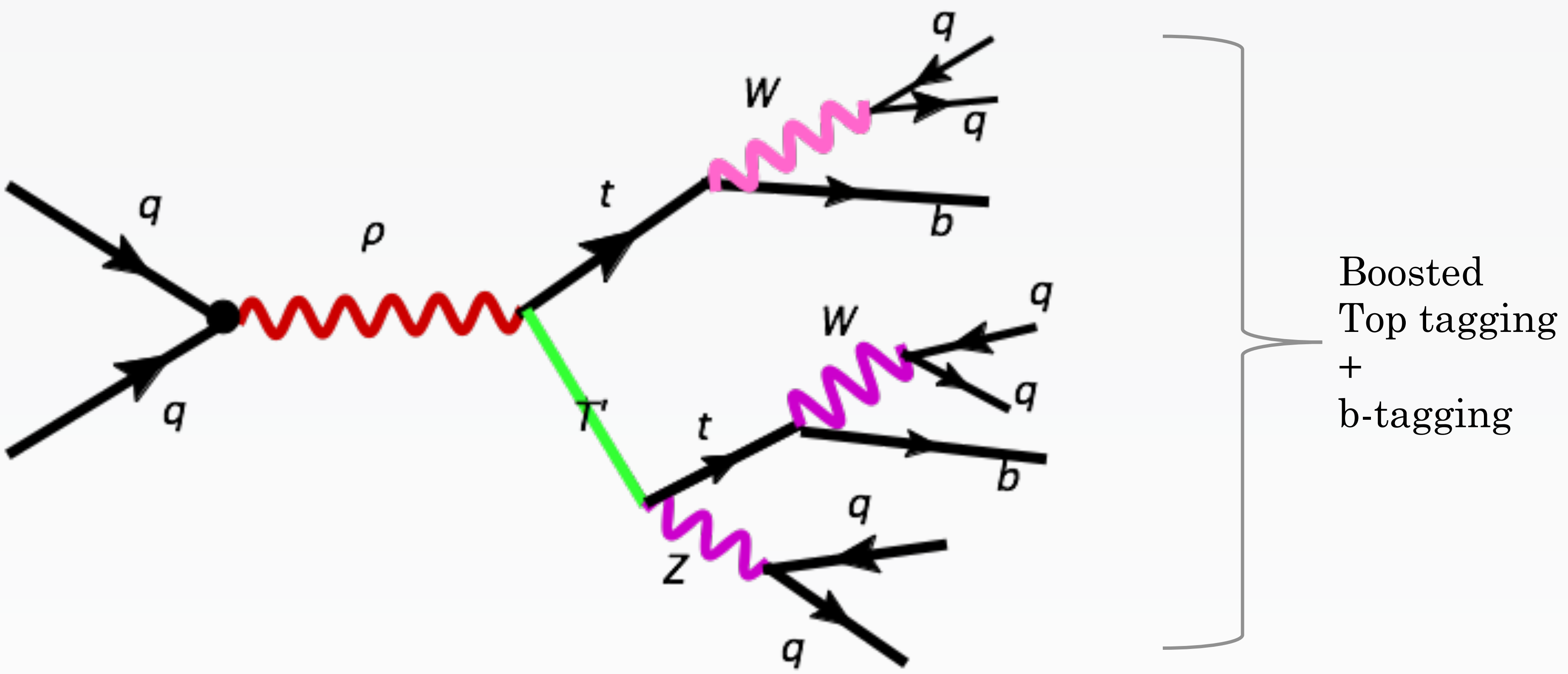
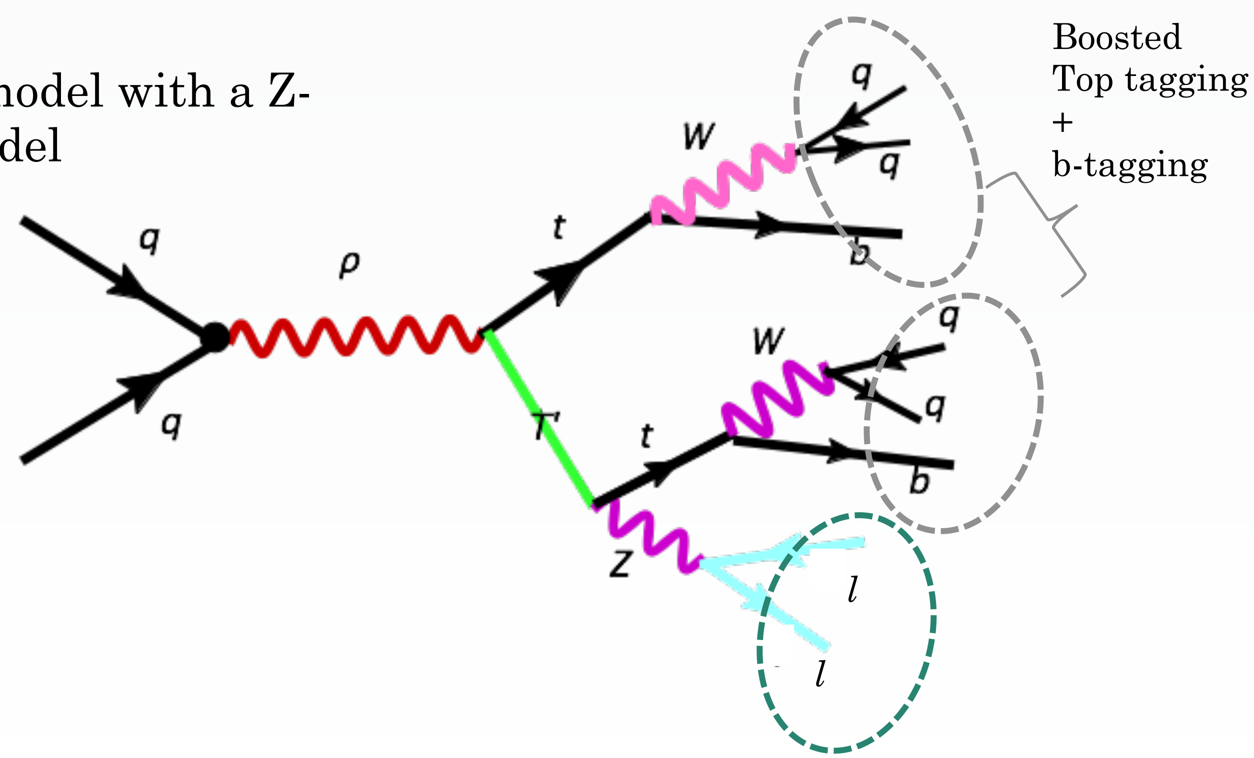


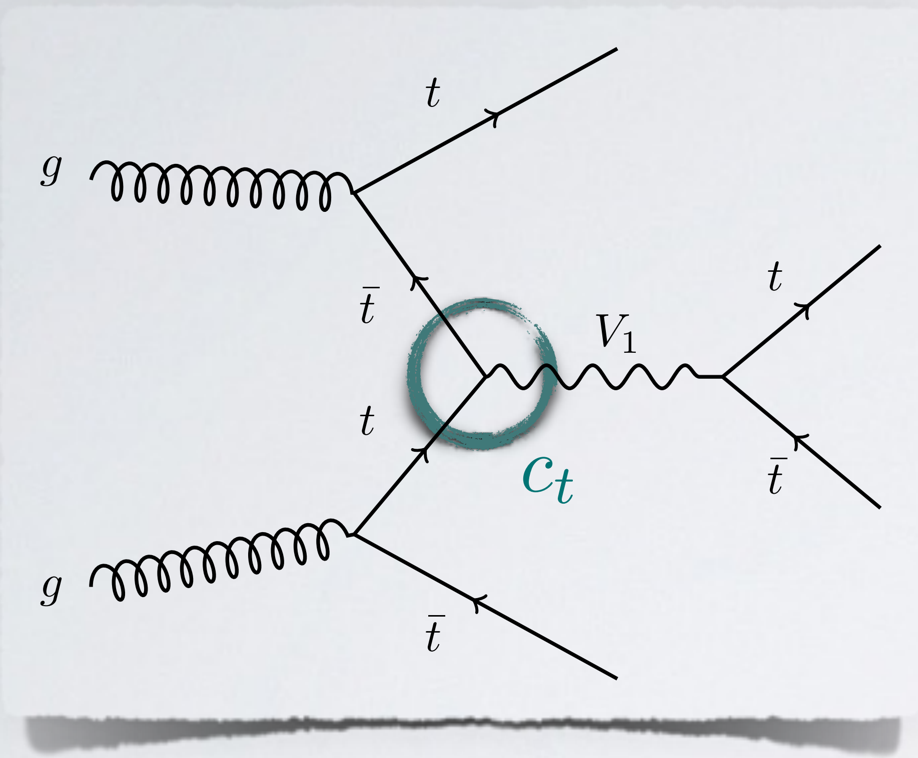
Madgraph 5 with Feynrules model implementation of a toy model with a Z-prime , interfaced with VLQ model and an effective Higgs model

Need to consider top partners in the final state of vector resonance!



Top-philic Vector Resonance

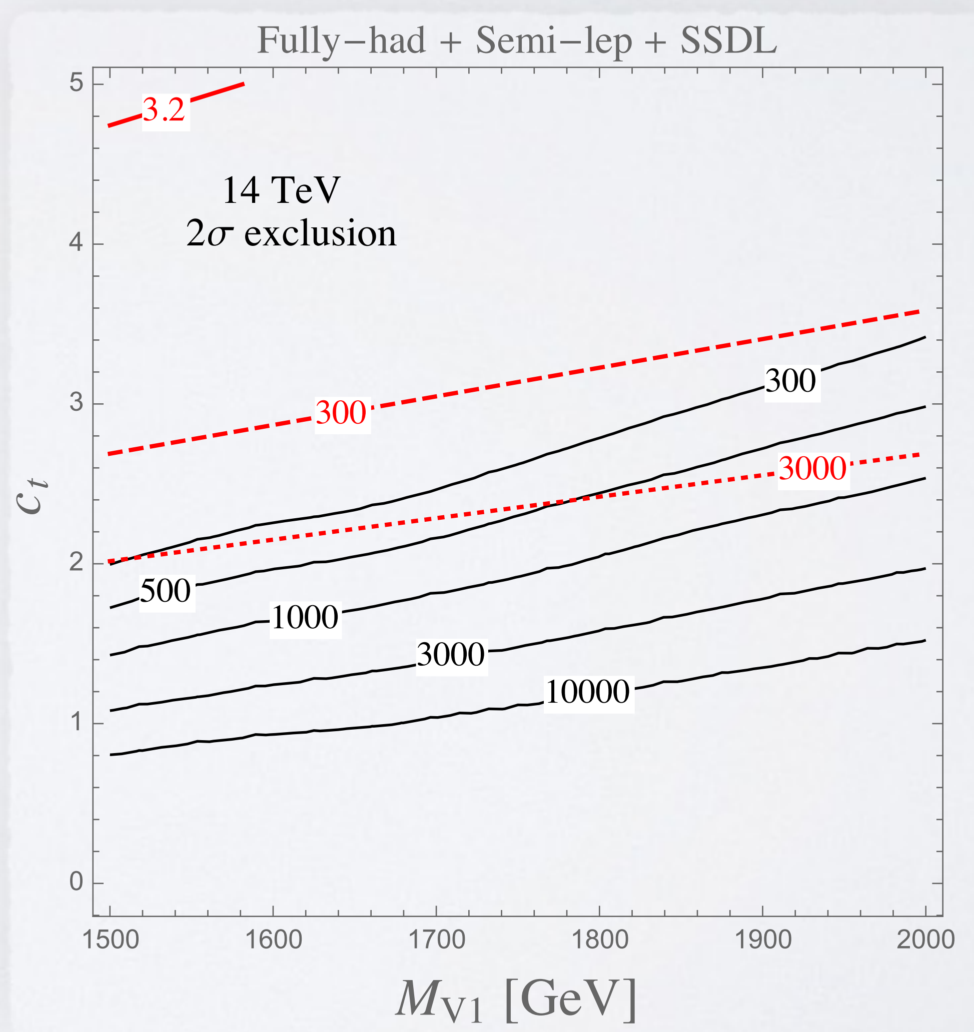
SSDL: Liu & Mahbubani '15
Kim, Kong, SL, Mohlabeng '16



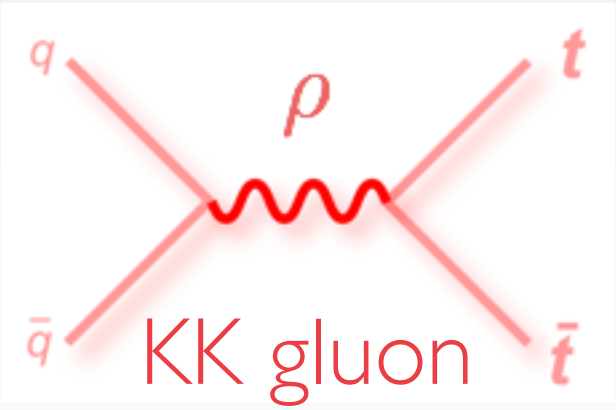
$$\mathcal{L}_{int} = c_t\,\bar{t}\,\gamma_\mu(\cos\theta P_L + \sin\theta P_R)\,t\,V_1^\mu$$

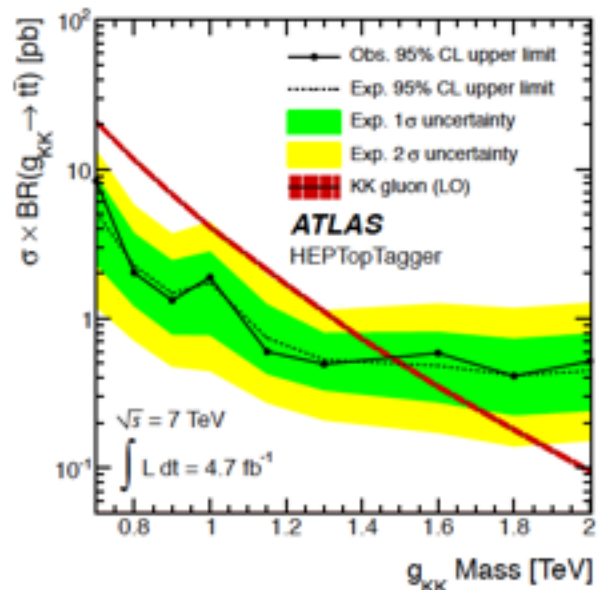
- Single production in $t\bar{t}t\bar{t}$ final state.
- Single production depends only on c_t and M_{V_1}

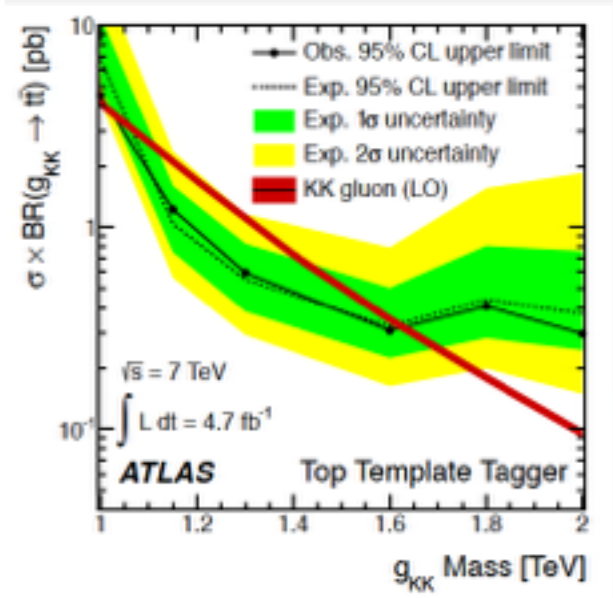
- Two boosted tops from a resonance decay, and two non-boosted spectator tops.

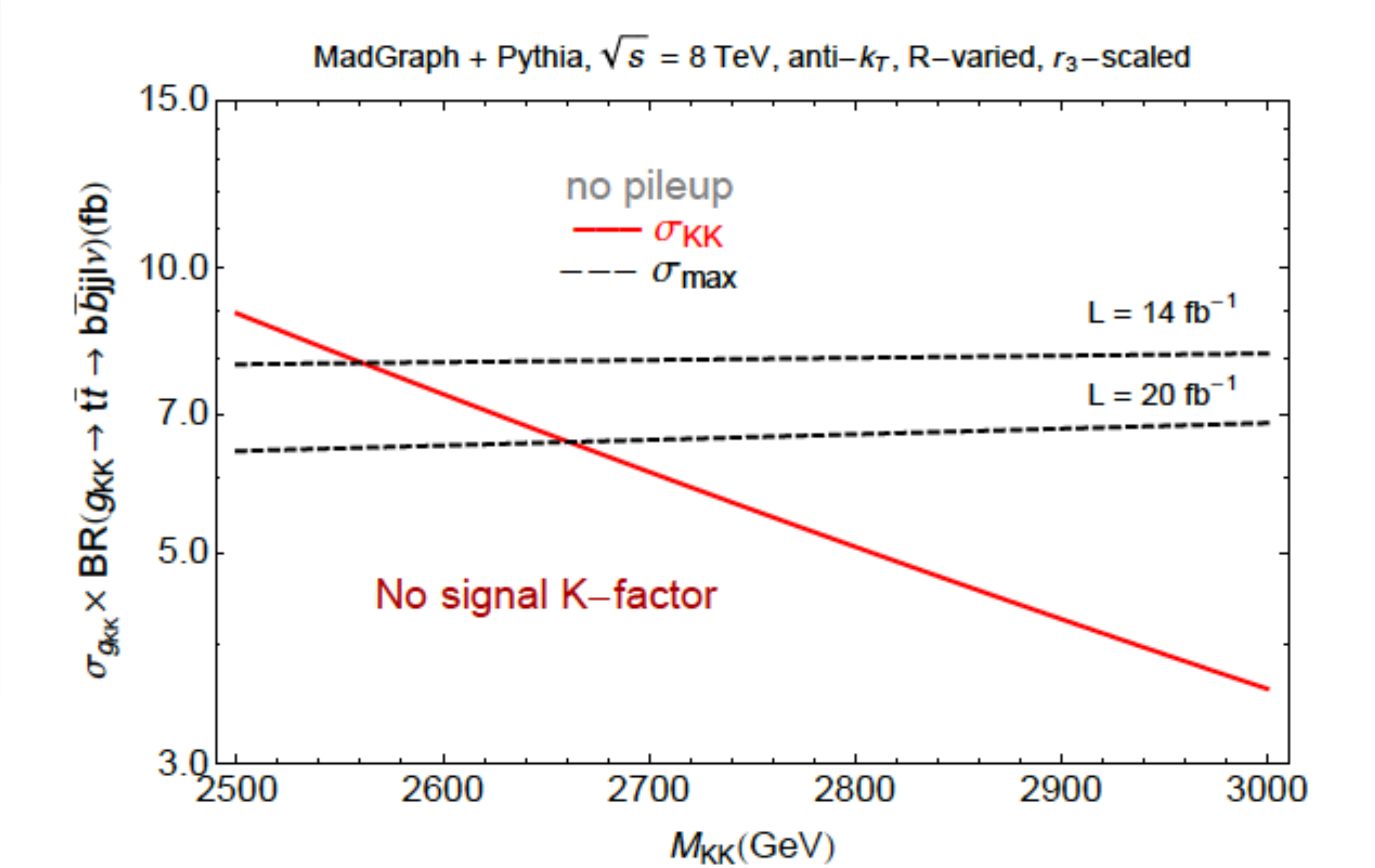


Composite Vector Resonances

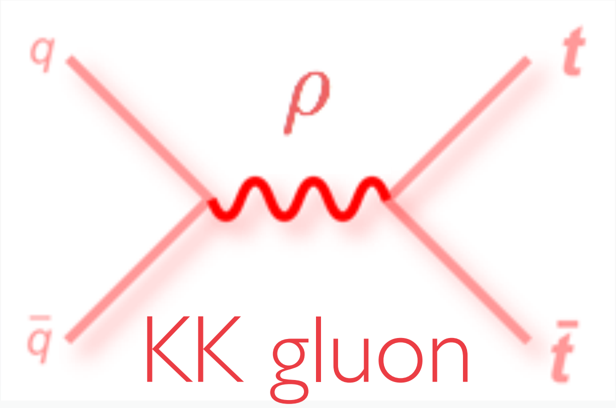


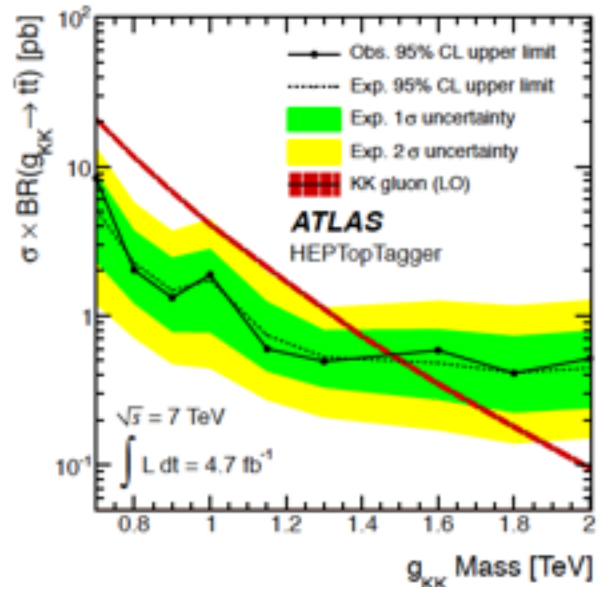


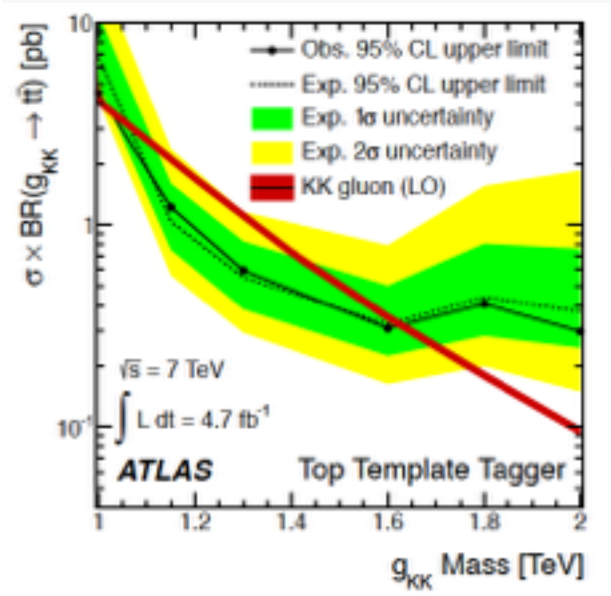




Composite Vector Resonances







Snowmass top quark working group report `13
Warped Extra Dimensional Benchmarks for Snowmass `13

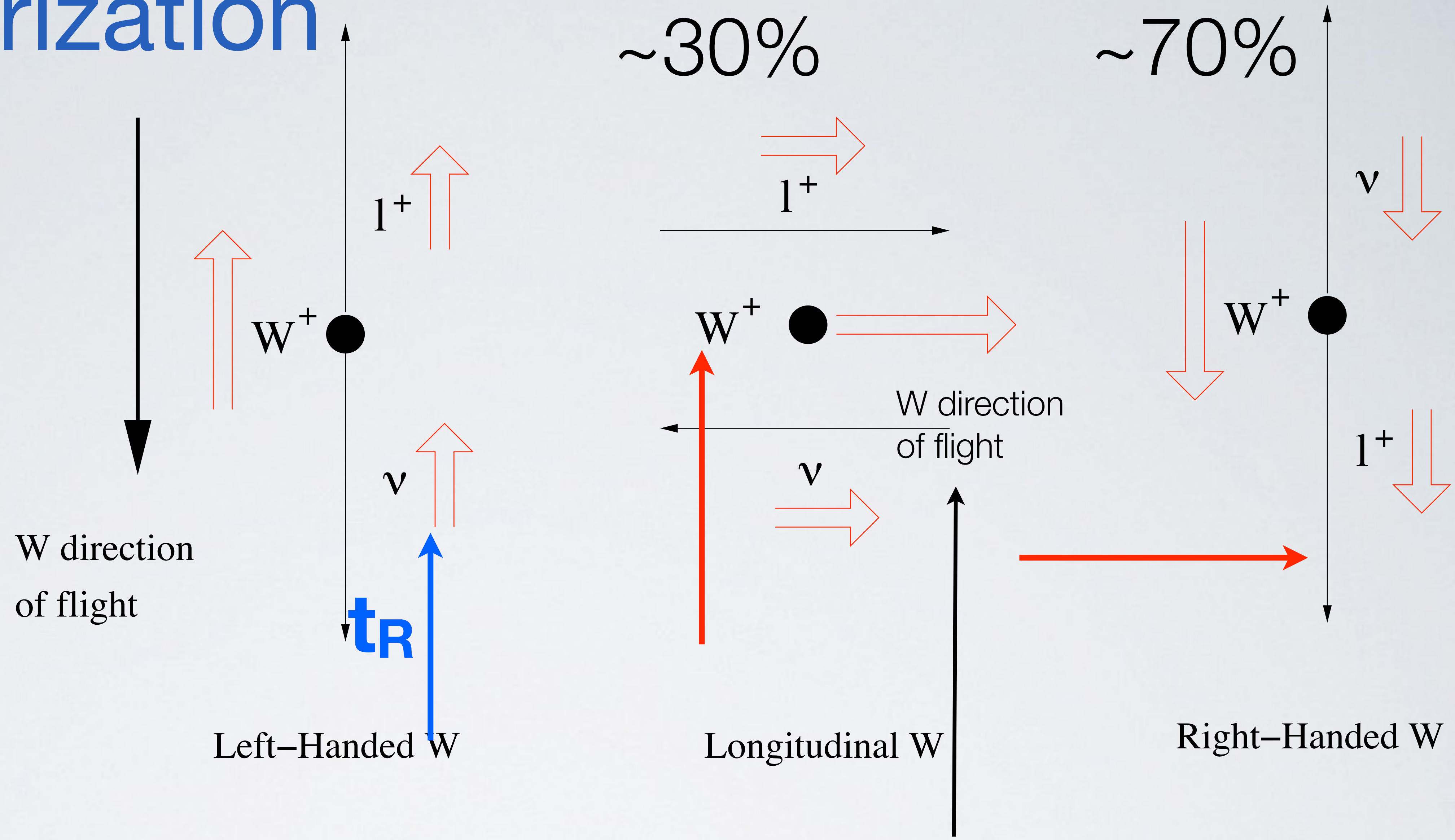
Collider	Luminosity	Pileup	95 % exclusion for Z'	95 % exclusion for KK gluon
LHC 14 TeV	300 fb^{-1}	50	3.3 TeV	4.3 TeV
LHC 14 TeV	3 ab^{-1}	140	5.5 TeV	6.7 TeV

Table 1-18. *Expected mass sensitivity for a leptophobic Z' and KK gluon decaying into semileptonic $t\bar{t}$ [140].*

Collider	Luminosity	Pileup	3 σ evidence	5 σ discovery
LHC 14 TeV	300 fb^{-1}	50	3.8 TeV	3.2 TeV
LHC 14 TeV	3 ab^{-1}	50	4.4 TeV	3.5 TeV

Table 1-19. *Expected mass sensitivity for a KK gluon decaying into semileptonic $t\bar{t}$, based on a study for the Snowmass process using the template overlap method.*

Top Polarization

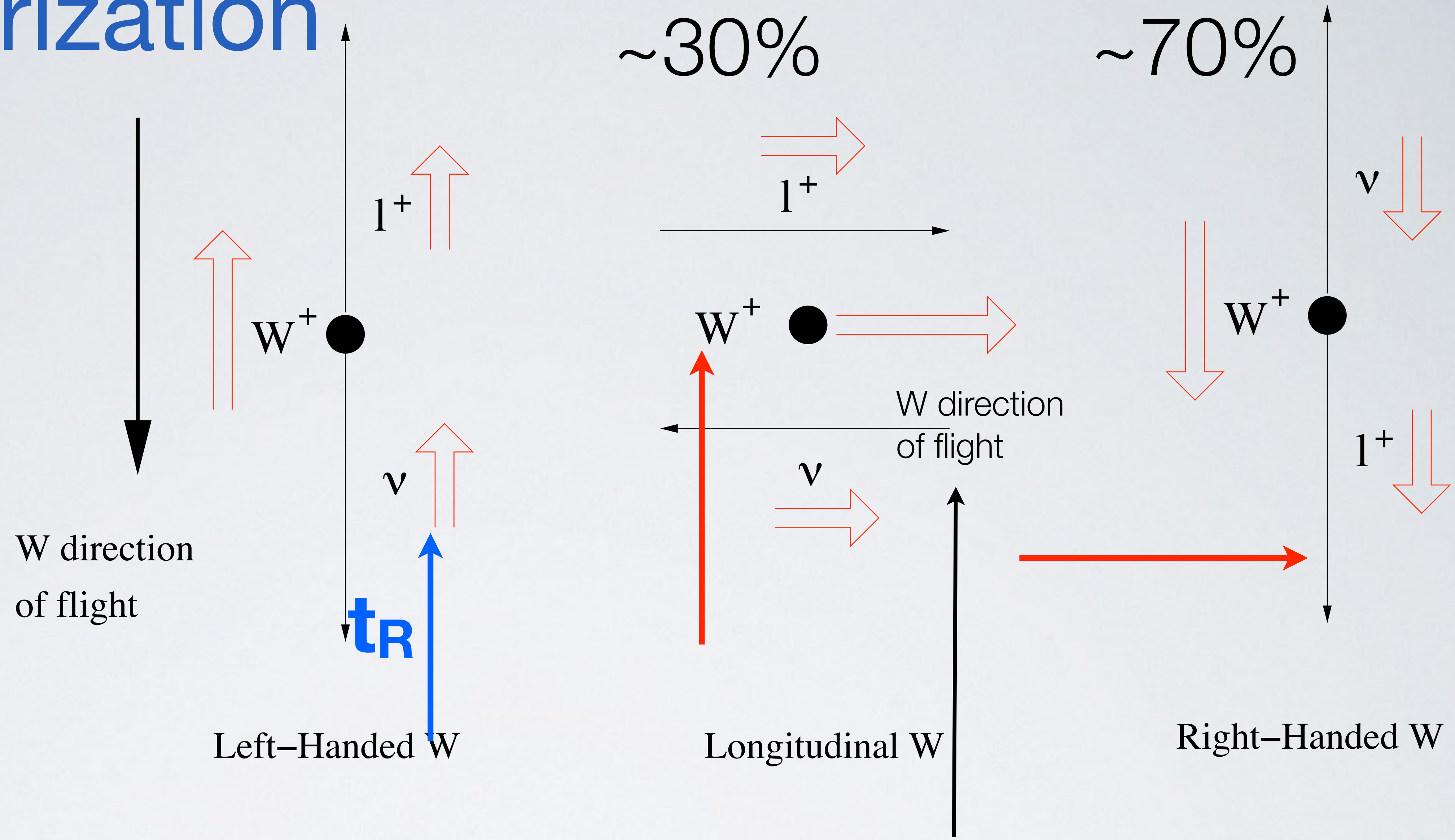


- lepton:forwarded for t_R

  back-warded for t_L

Allmeida, SL, Sung, Perez, '08
Shelton '08
Perelstein, Weiler '08
Bhattacherjee, Mandal, Nojiri '12

Top Polarization



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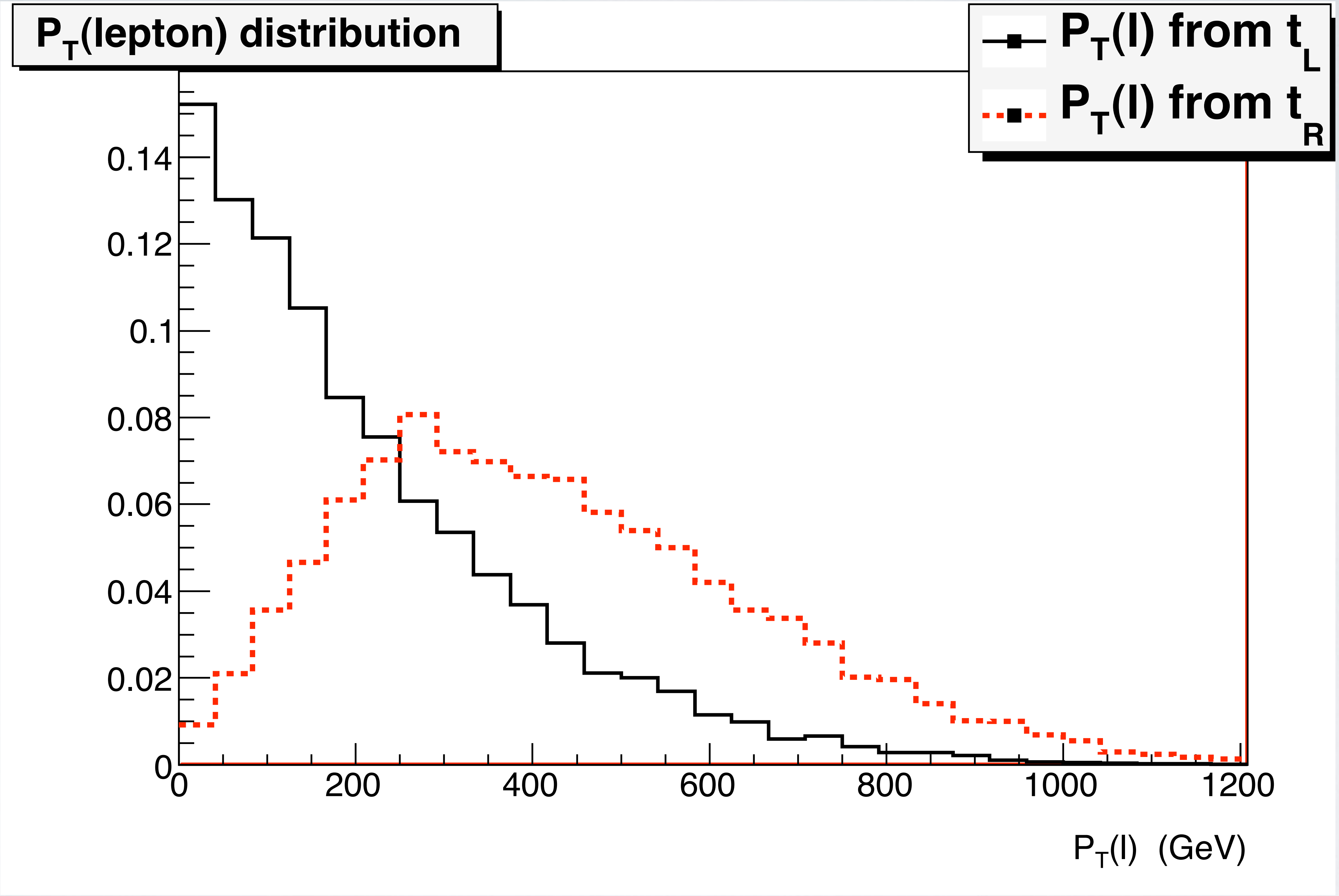
  back-warded for t_L

Allmeida, SL, Sung, Perez, ’08
Shelton ’08
Perelstein, Weiler ’08
Bhattacherjee, Mandal, Nojiri ’12

For Boosted Longitudinal W: letpon is forwarded

$p_T(top) > 1TeV$

MG/ME

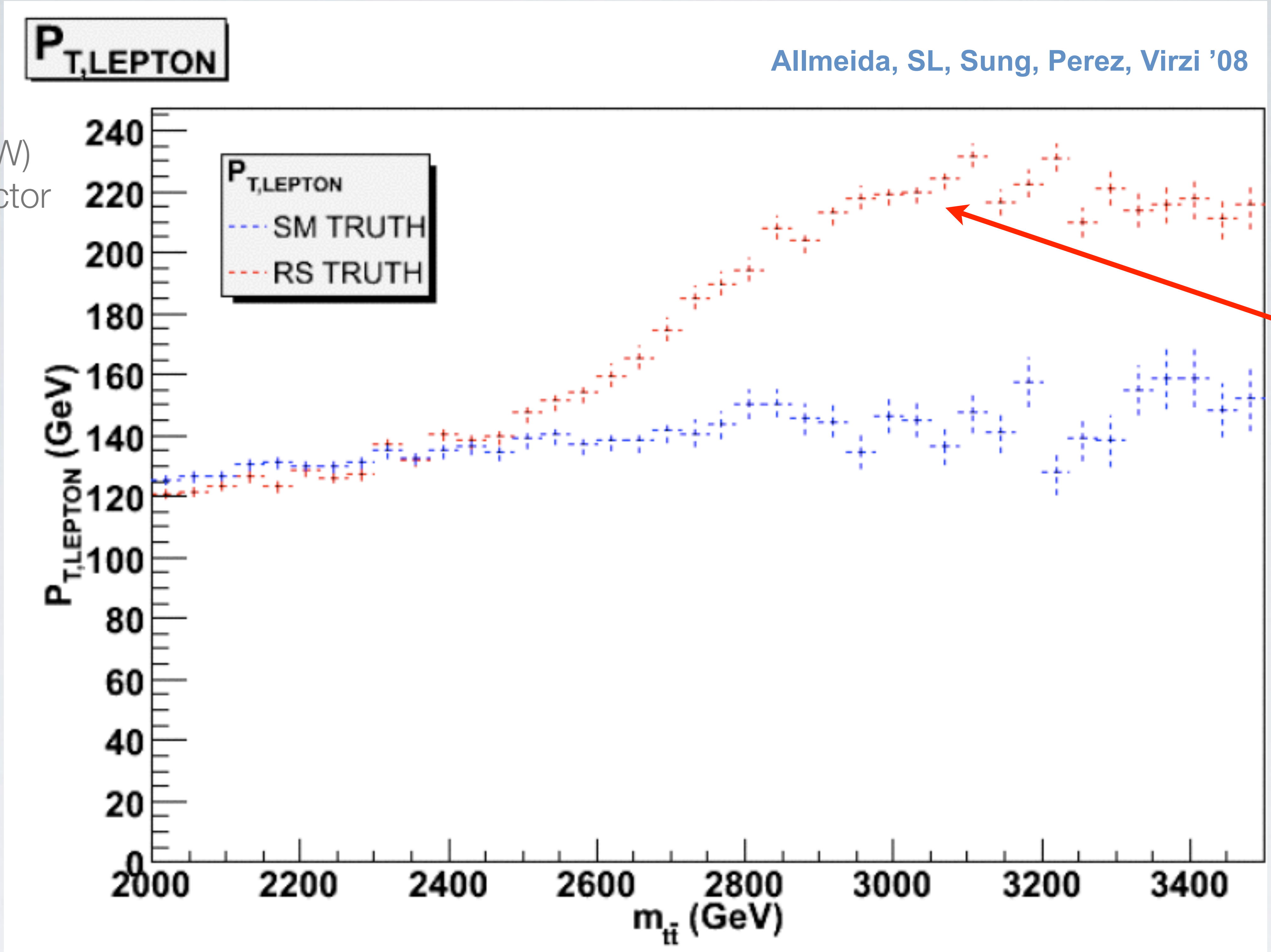


- for example with the KK gluon, you'll see suddenly only leptons/bs that follows the RH curves

Leptonic Top

- charged lepton as a spin analyzer

Sherpa (CKKW)
Without Detector
Simulation

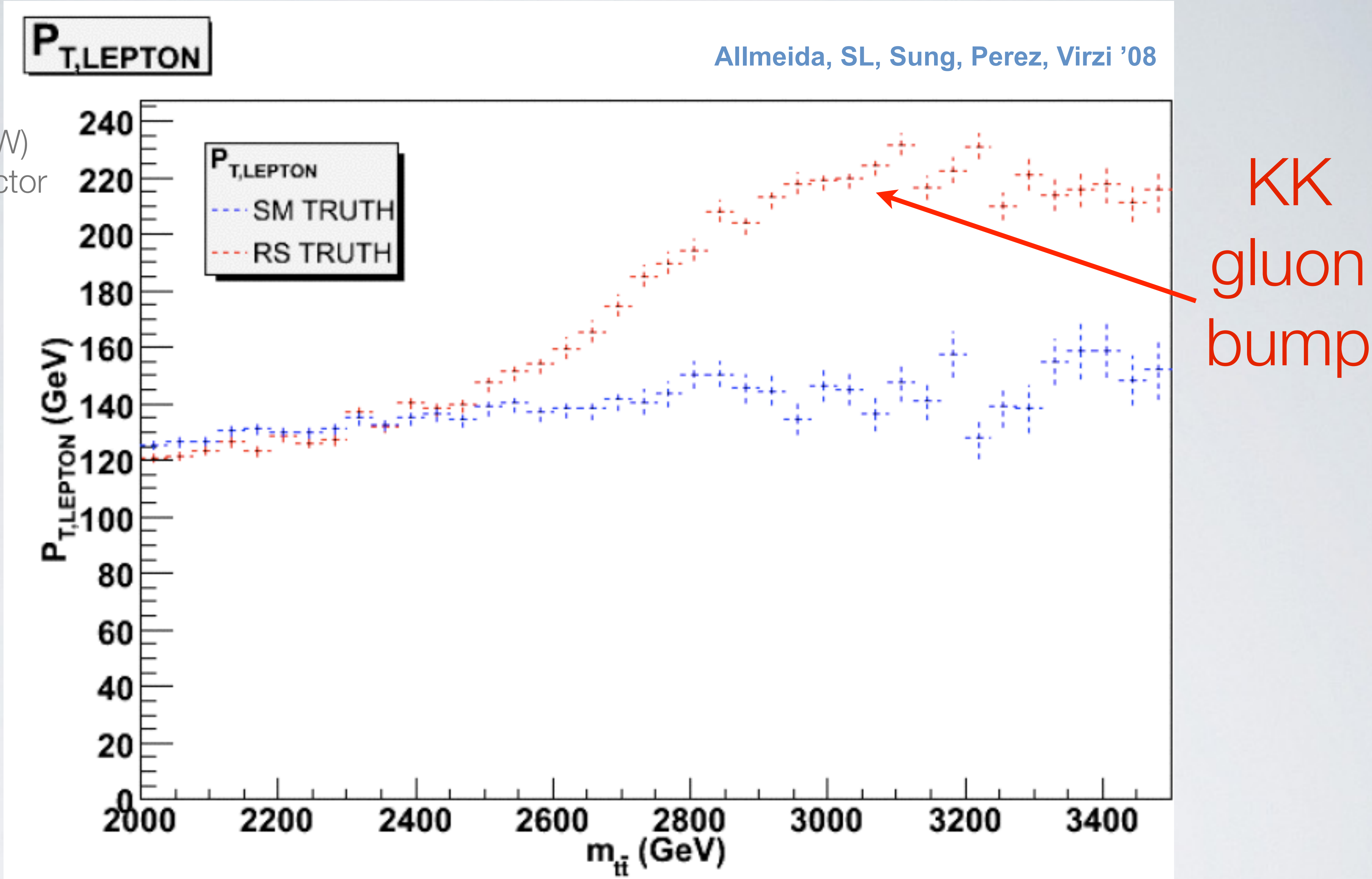


KK
gluon
bump

Example: KK gluon

- lepton PT is harder near the KK gluon plateau

Sherpa (CKKW)
Without Detector
Simulation



SUSY: stop mixing (heavy stop decaying into top and neutralino, e.g. Perelstein Weiler '08)

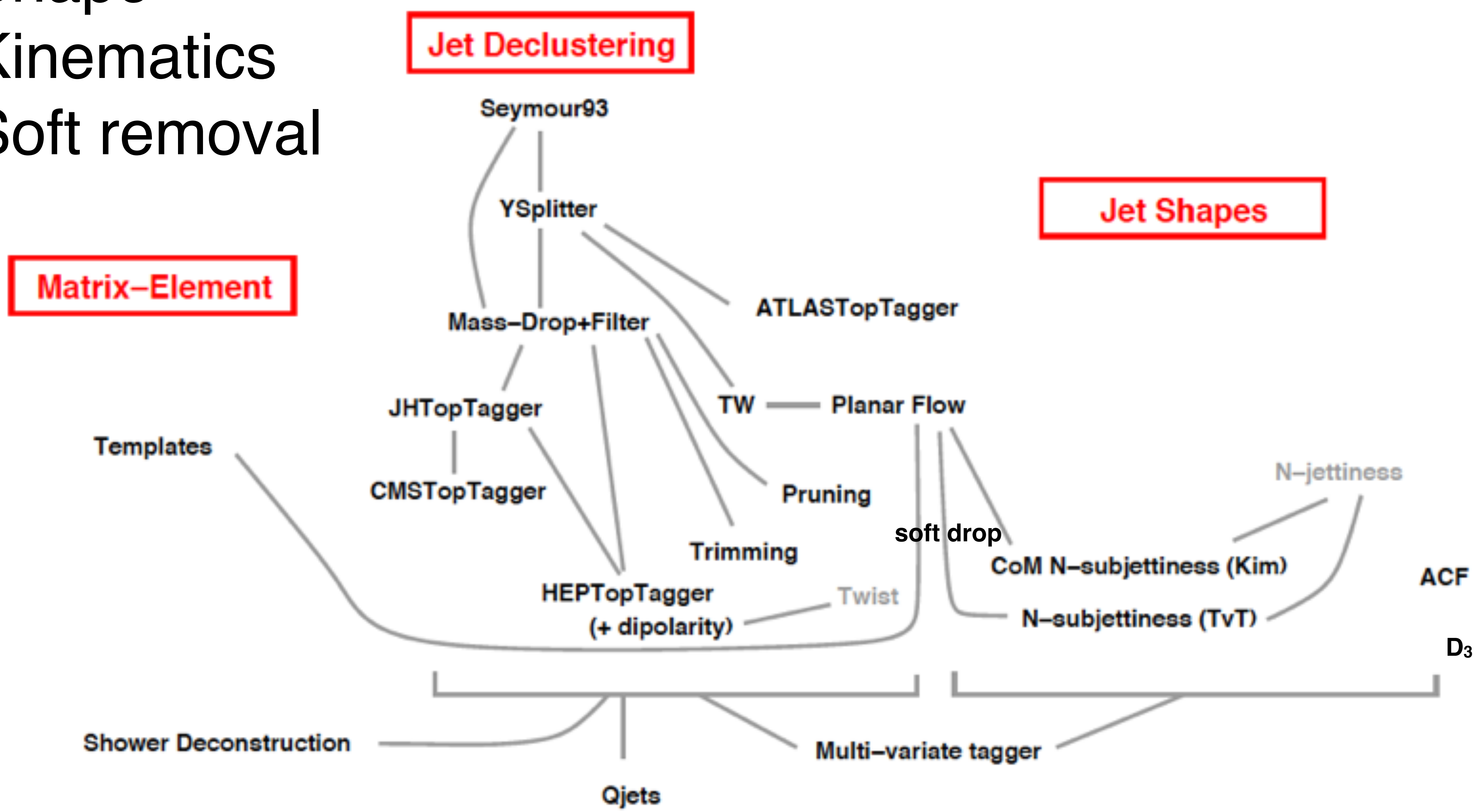
Example: KK gluon

- lepton PT is harder near the KK gluon plateau

How do we know it's top jet?
Jet substructure

Very active research field

.Shape
.Kinematics
.Soft removal

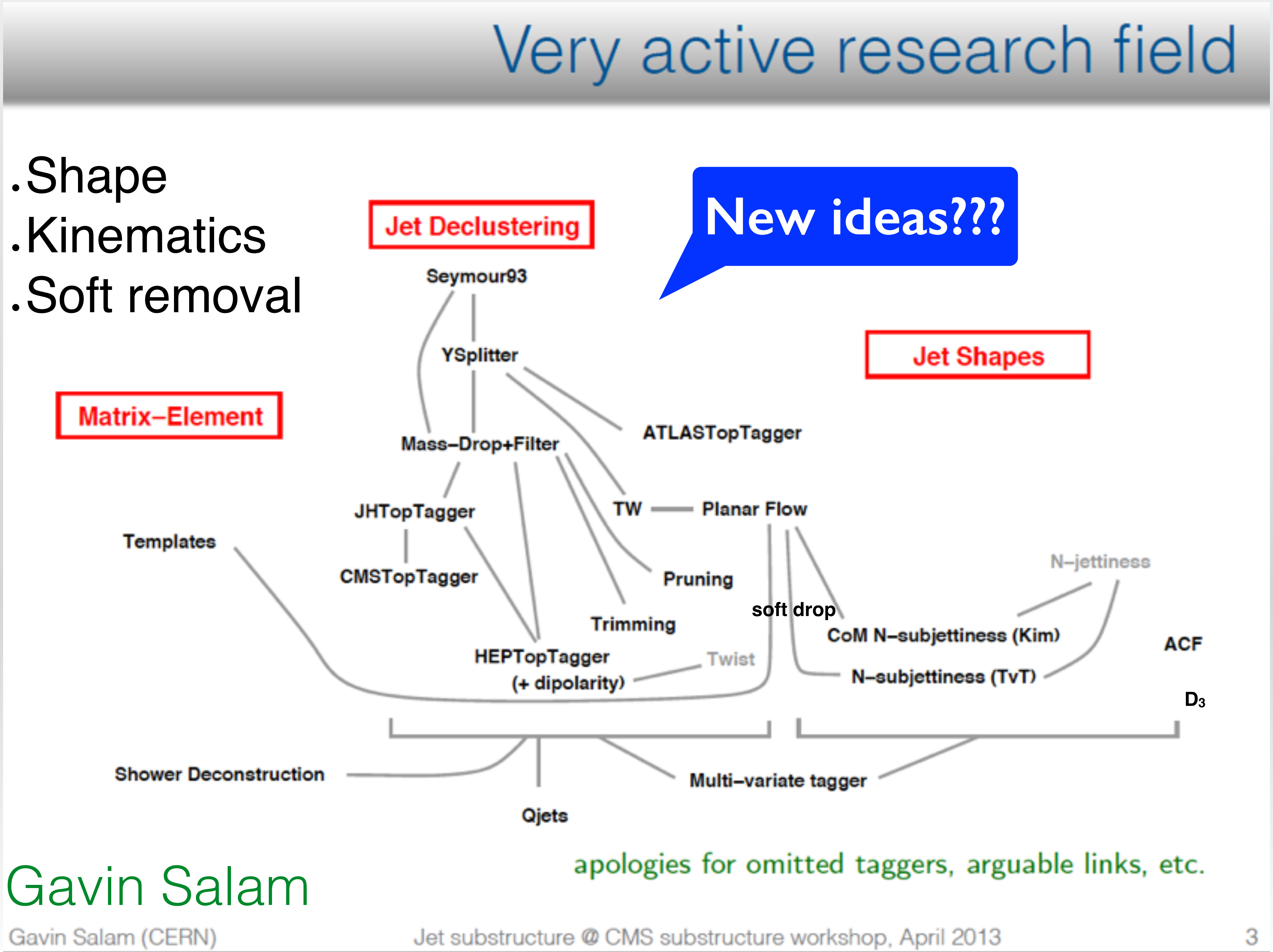


apologies for omitted taggers, arguable links, etc.

Gavin Salam

How do we know it's top jet?
Jet substructure

- .Shape
- .Kinematics
- .Soft removal



Ideas from theory community is saturated so far,
and experimentalists took over the job,
except for some theory calculation for
resummation effect for jet-shape observables…

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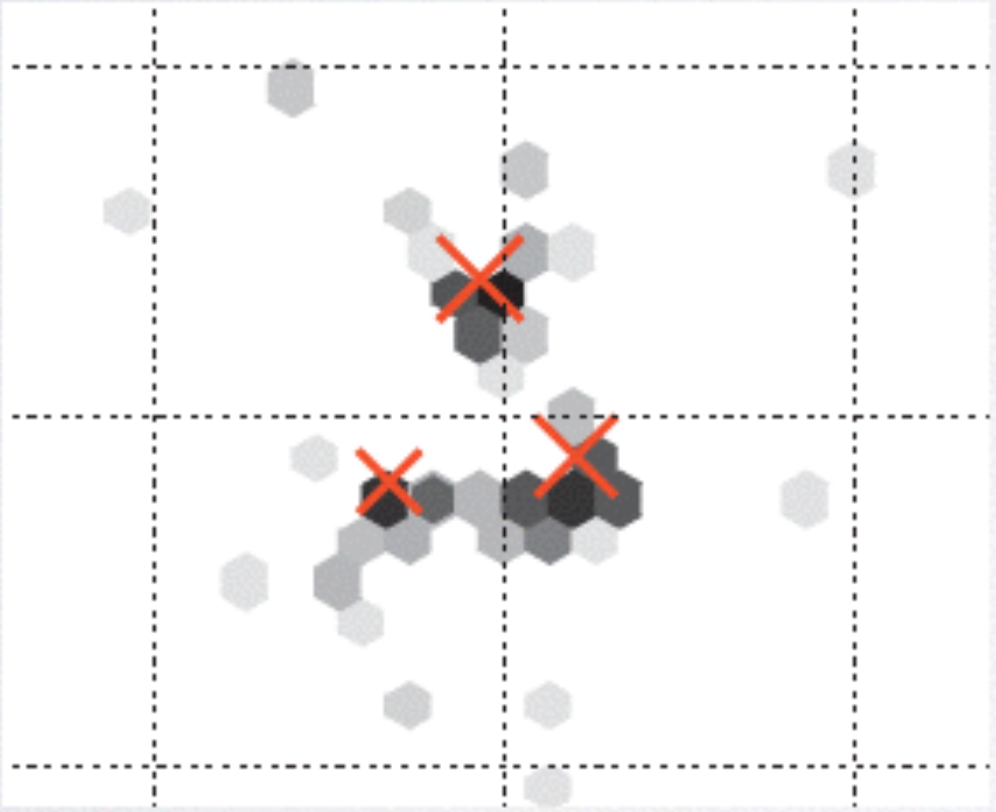
Jet Substructure with Artificial Neural Network (NN)

Almeida, Backovic, Cliche, SL, Perelstein `15

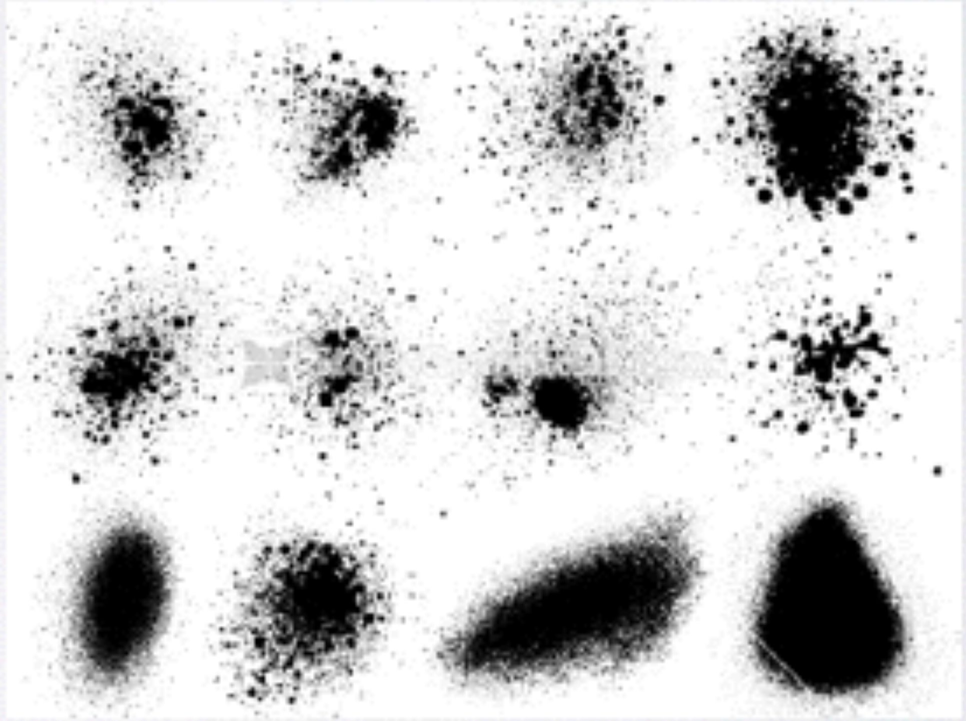
Basic Idea: Treat a jet as a **"splash pattern"** or image.

⇩

Use **image/pattern recognition** technology to classify "splash patterns".



=



jet "splash patterns" contain all of calo. information.

Jet Substructure with Artificial Neural Network (NN)

Almeida, Backovic, Cliche, SL, Perelstein `15

✱ Network Training (based on feed-forward neural network)

- The weights W are determined through a "training" procedure:
  - Generate large MC samples of top-jets (SM ttbar) and QCD jets (dijet)
  - "Feed" these samples to ANN, record output Y_i for each jet
  - Compute the "error function" (desired outputs: y_i=1 for top, y_i=0 for QCD):

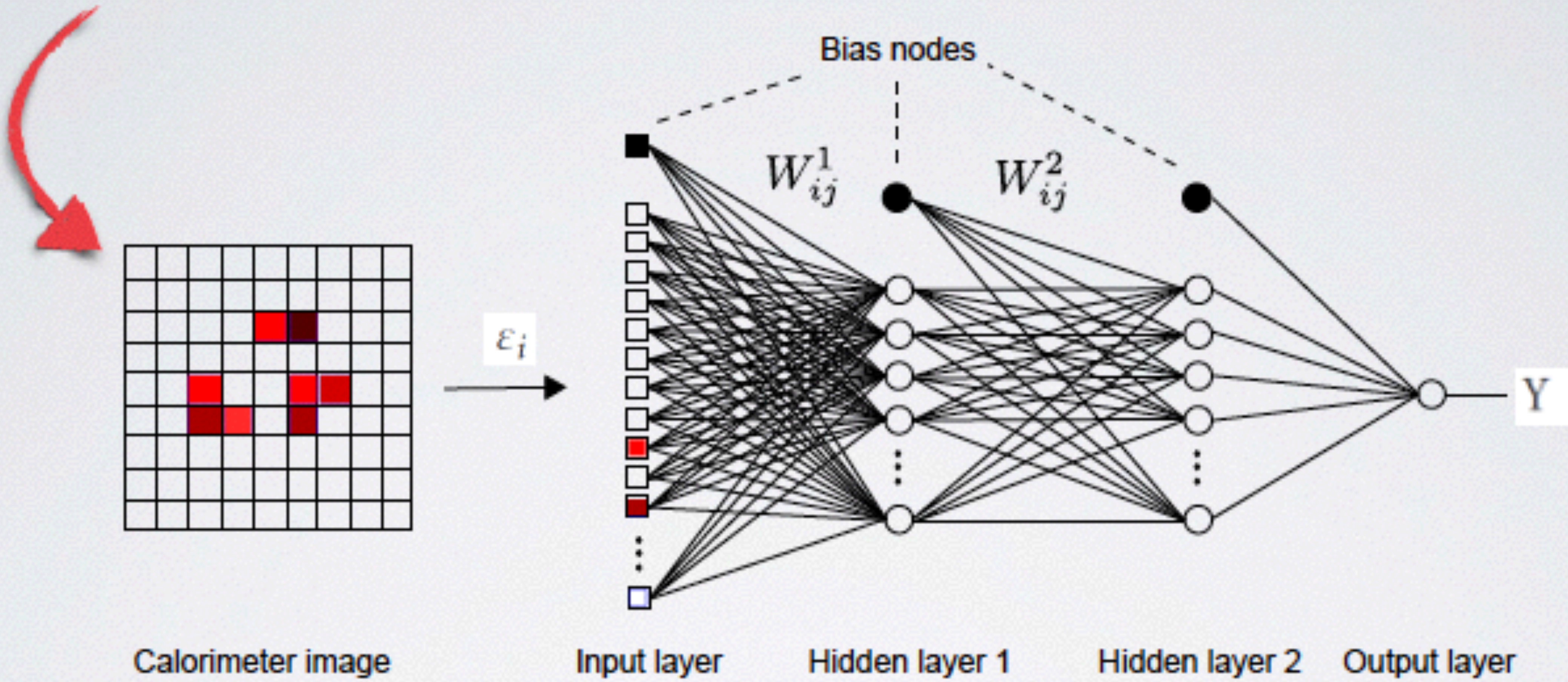
$$\text{Log-loss} = -\frac{1}{N}\sum_{i=1}^{N}\left[y_i \log(Y_i) + (1-y_i)\log(1-Y_i)\right].$$

  - Adjust weights iteratively to minimize the error function
  - Minimizing a function of 100,000 variables is not trivial, but there are well-know numerical techniques for this; we use the back-propagation algorithm, with "batch gradient descent with momentum" minimization
- Outcome: a set of weights such that Y_i close to 1 for top jets, close to 0 for QCD jets
- ANN "learns" how to tell them apart, using all available info! (or: it just constructed a complicated but optimal - in some sense - observable)

Classifying splash pattern with Artificial NN

Almeida, Backovic, Cliche, SL, Perelstein `15

Feed the entire jet **(splash pattern)** as an **array of pixels**.



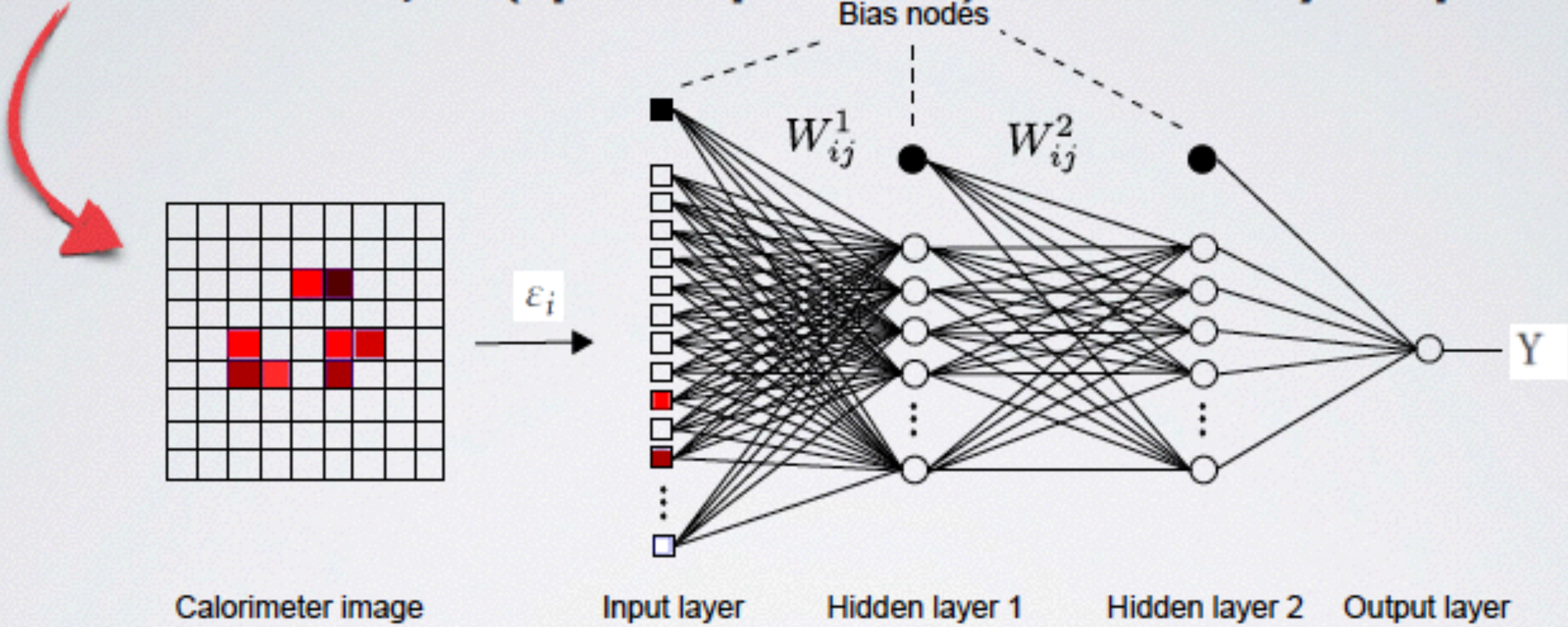
At each layer compute a weighted sum:

$$\epsilon_i \rightarrow h_i^{(1)} = f(W_{ij}^{(1)}\epsilon_j + b_i^{(1)}) \rightarrow \cdots \rightarrow h_i^{(l)} = f(W_{ij}^{(l)}h_j^{(l-1)} + b_i^{(l)}) \rightarrow Y = f(W_j^{(O)}h_j^{(l)} + b^{(O)})$$

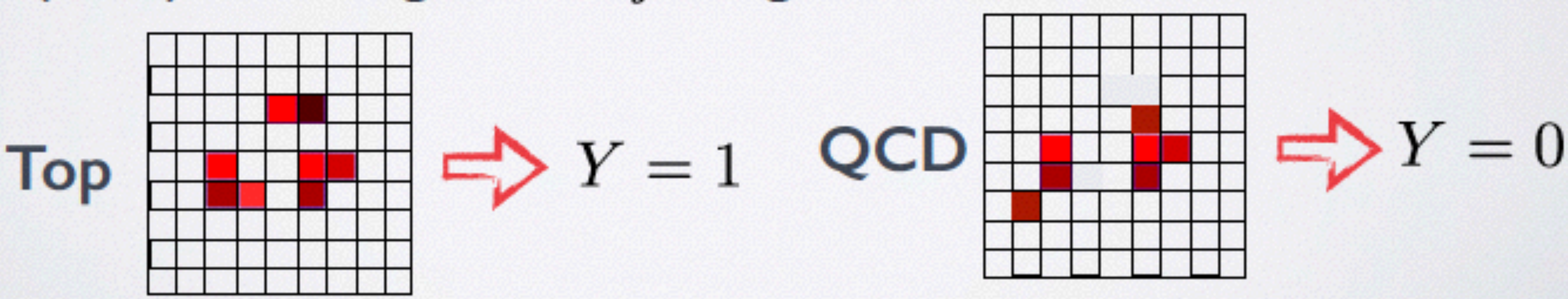
$$f(z) = \frac{1}{1+e^{-z}}$$

Classifying splash pattern with Artificial NN

Feed the entire jet **(splash pattern)** as an **array of pixels**.



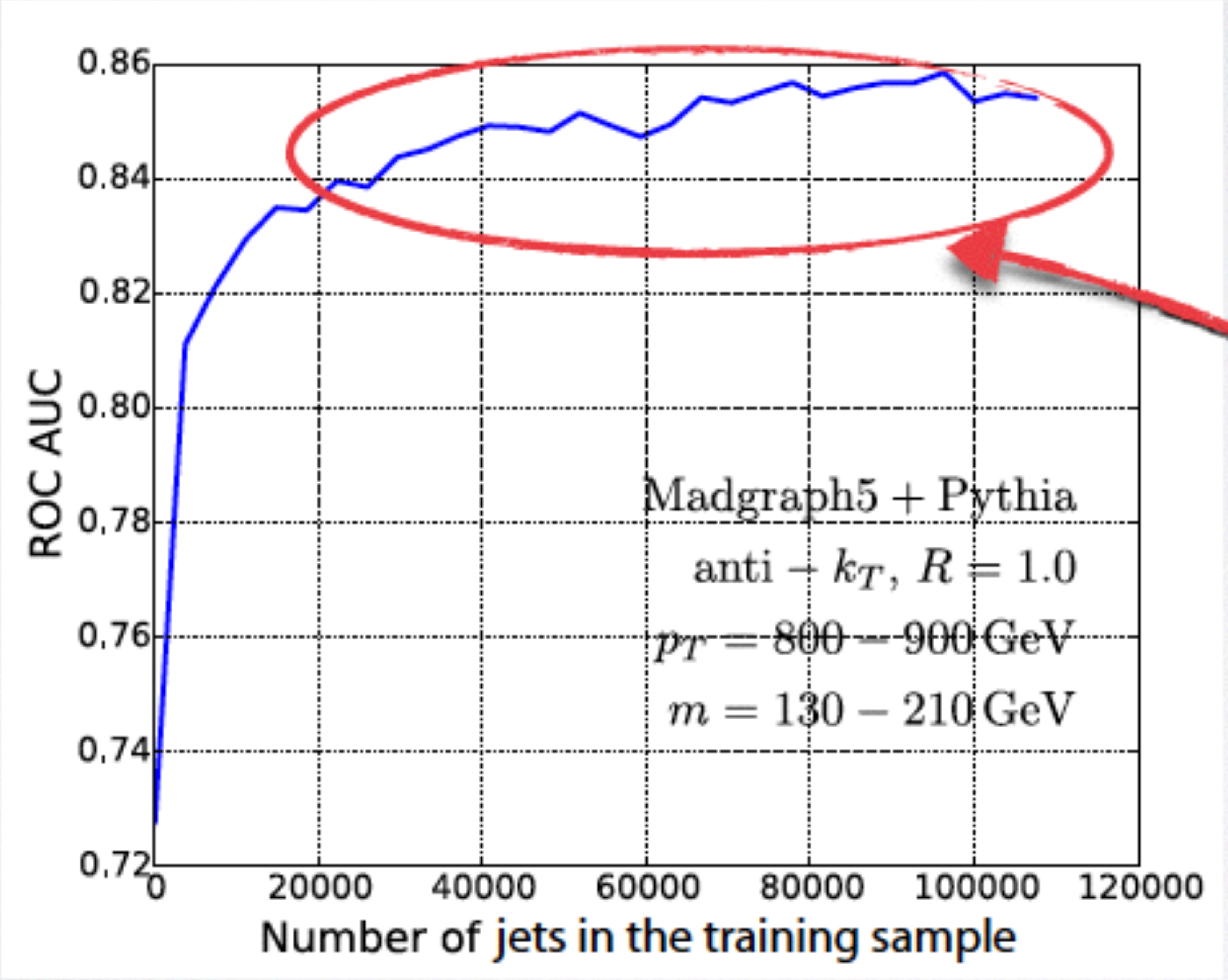
Adjust (train) the weights W_{ij} to give:



*** We use the standard back-propagation algorithm with gradient descent

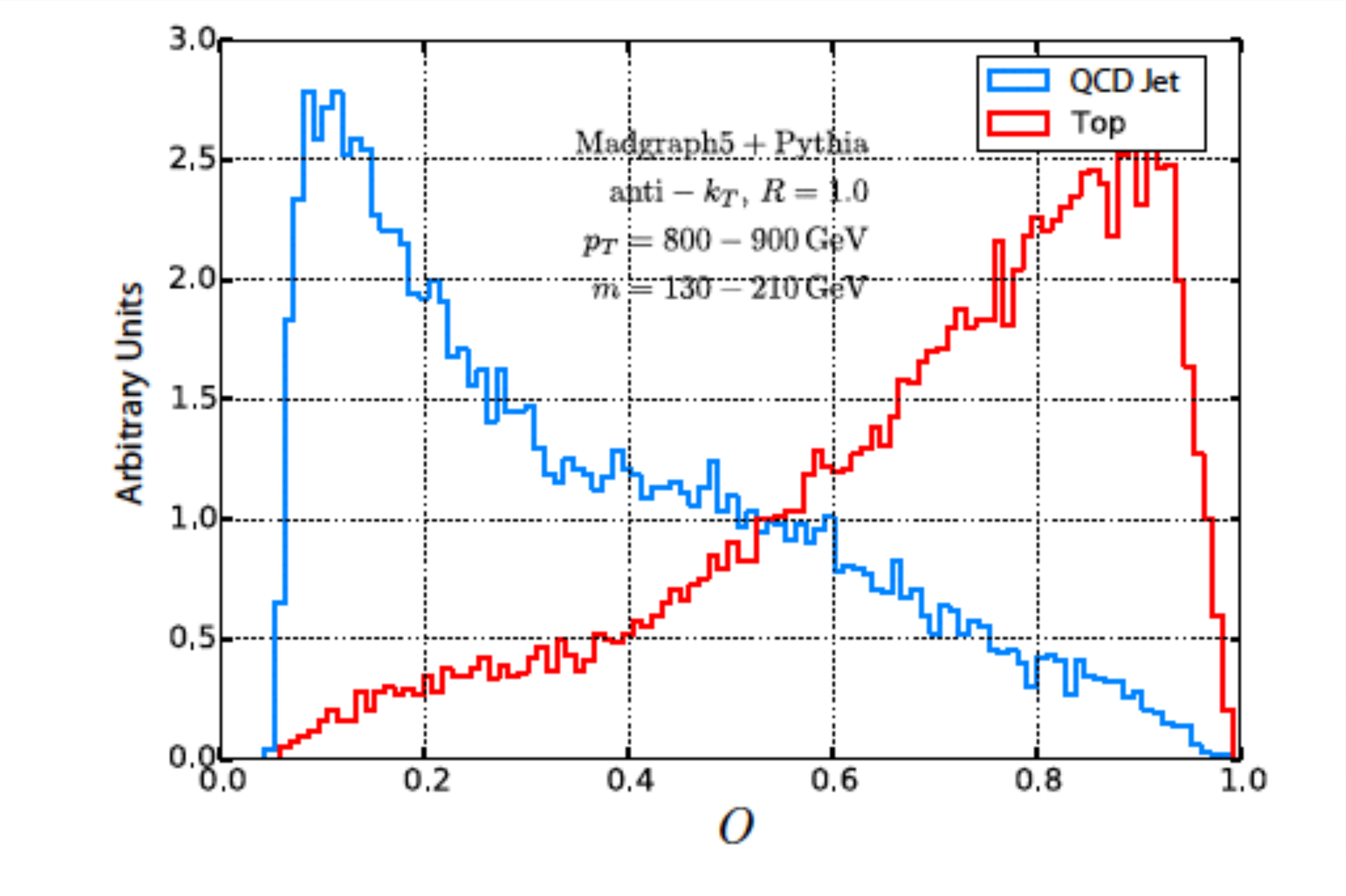
Artificial NN: Size of training sample

test sample of 50000 pre-processed top jets



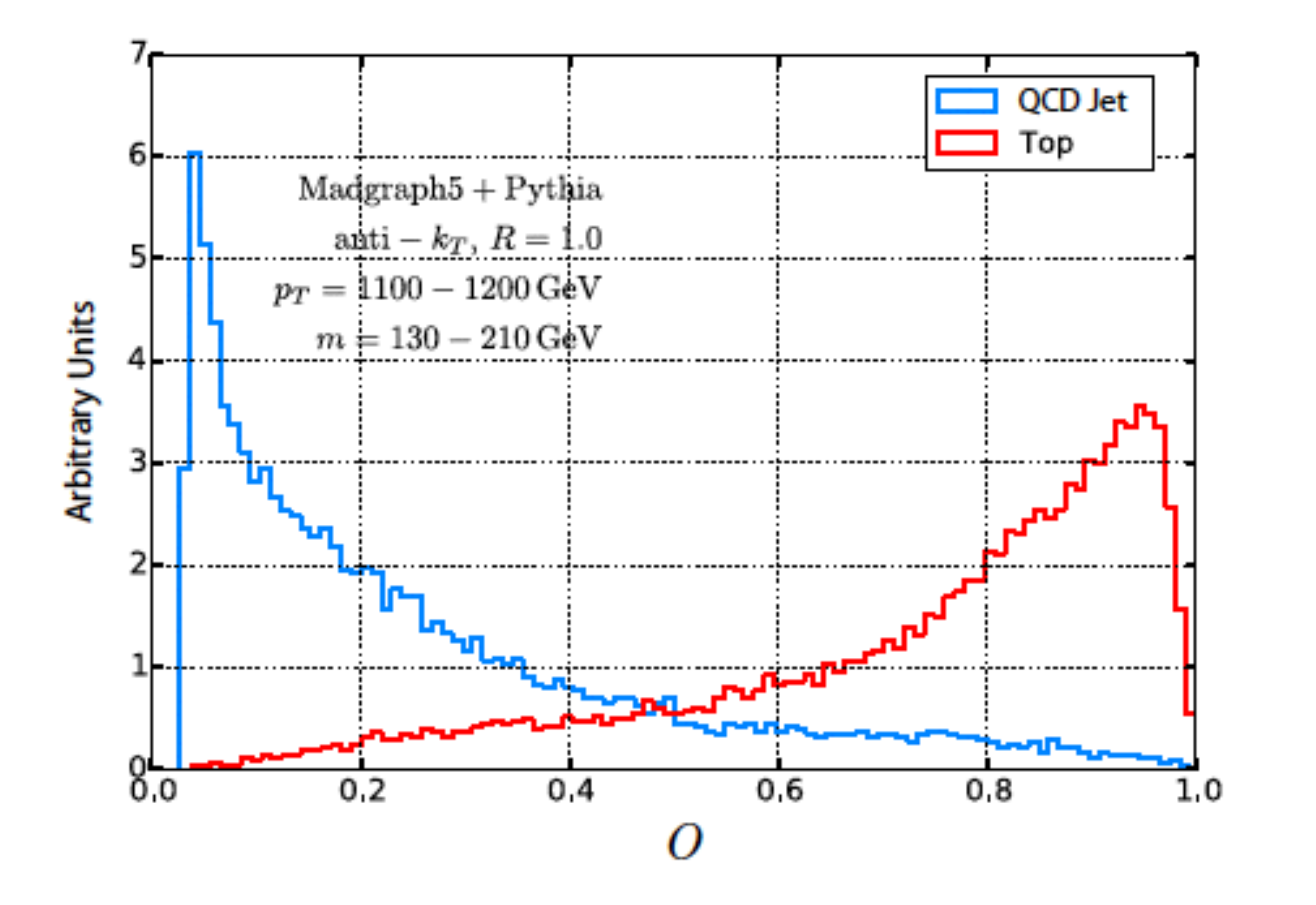
Only about 20000 events needed to train the NN

Artificial NN: A few examples



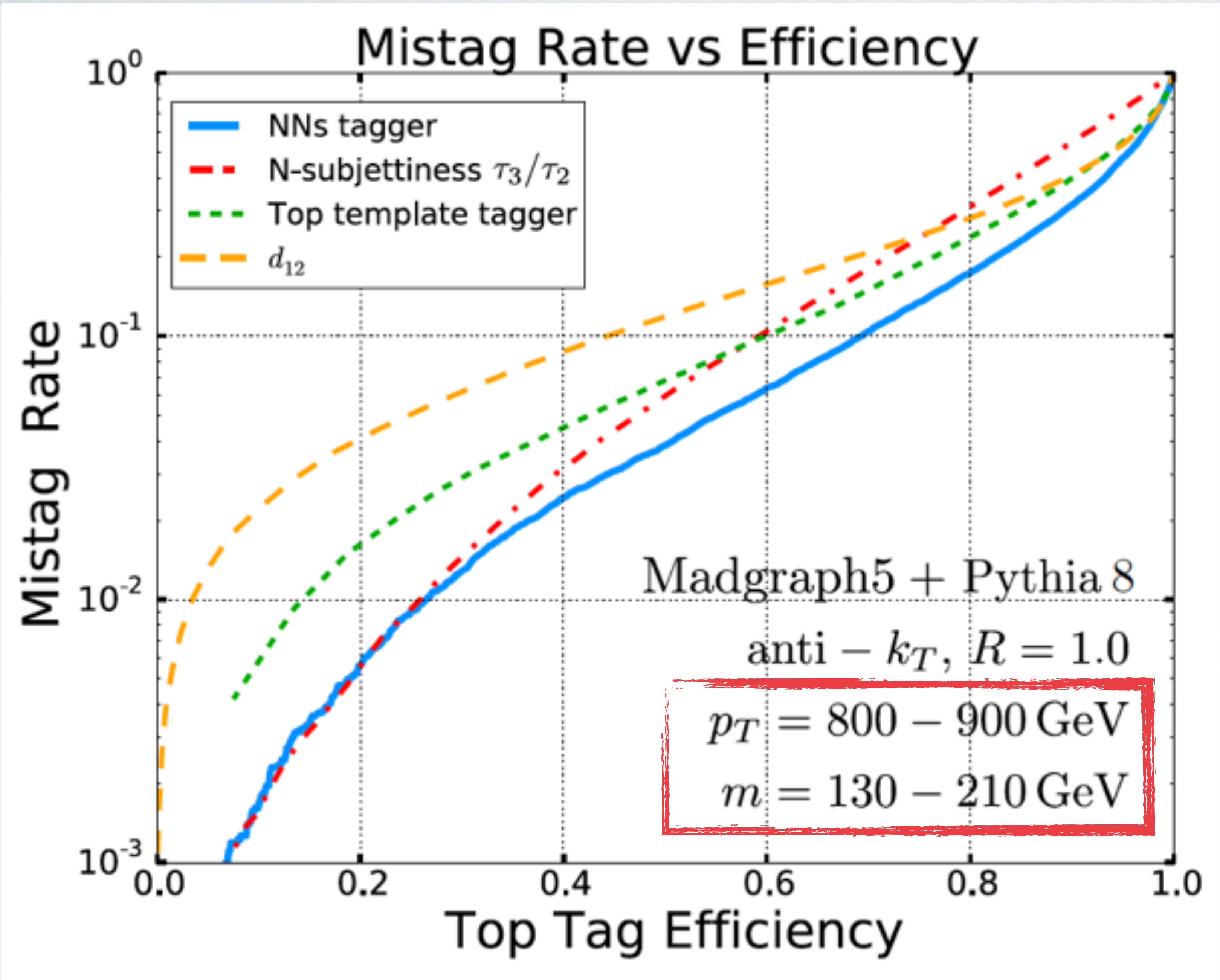
Good Signal / Background separation

Artificial NN: A few examples



Even better at higher P_T

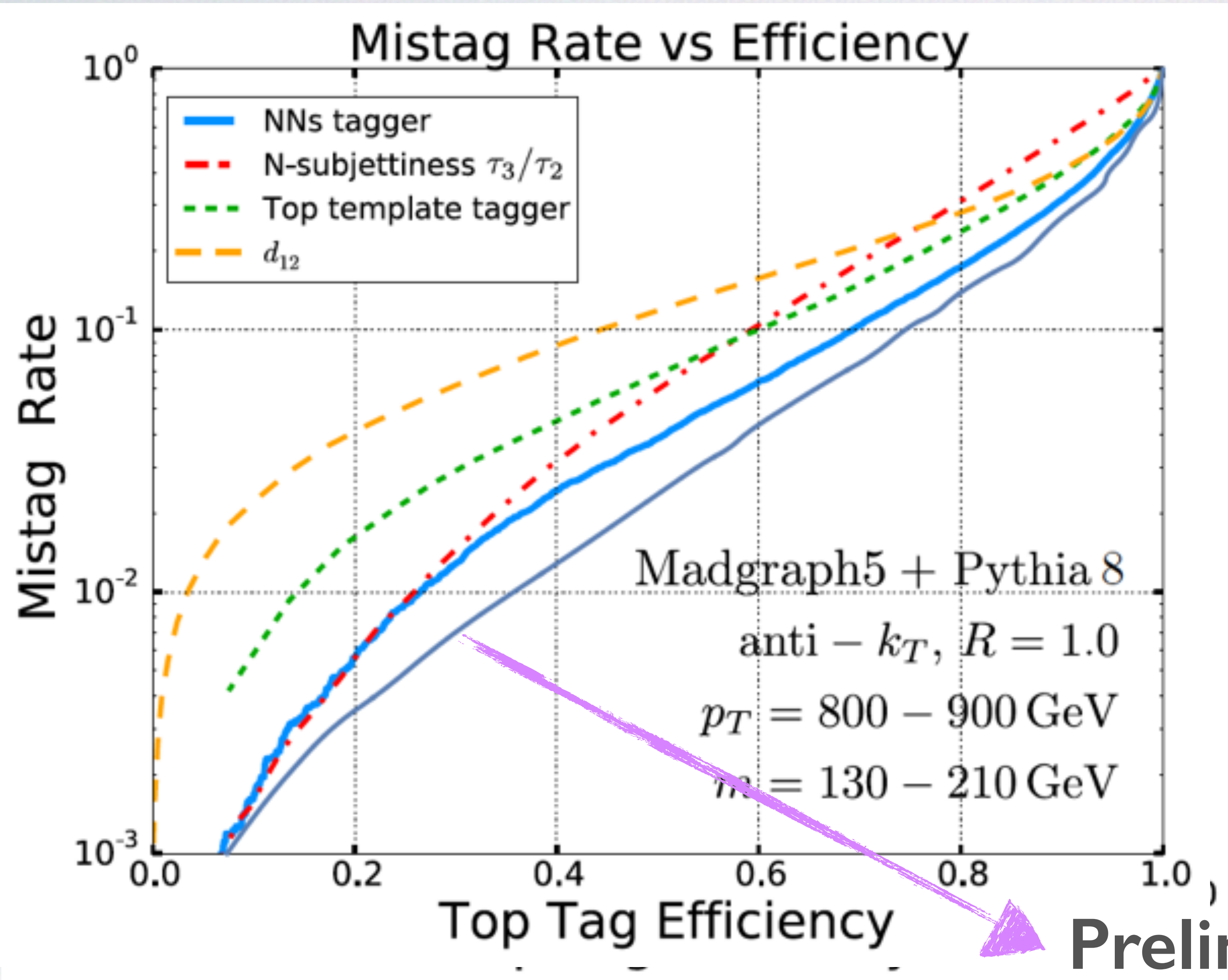
Artificial NN: Comparison with other top taggers



$$\mathrm{Eff} = \frac{N^{\mathrm{top}}_{\mathrm{top}}}{N_{\mathrm{top}}}, \quad \mathrm{Mistag} = \frac{N^{\mathrm{top}}_{\mathrm{QCD}}}{N_{\mathrm{QCD}}}$$

NN top tagger performance better or comparable to some existing techniques!

Artificial NN: Comparison with other top taggers



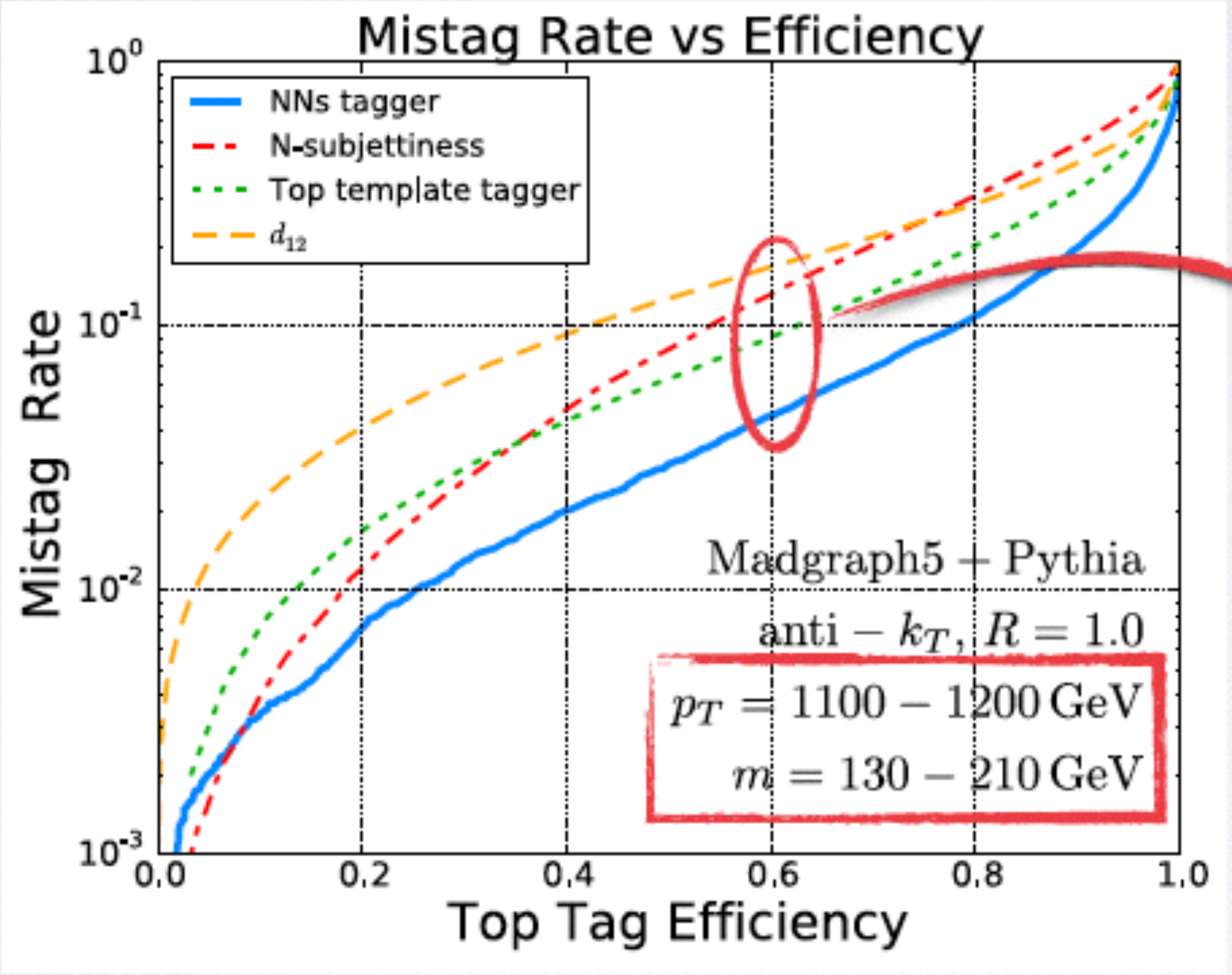
$$\mathrm{Eff} = \frac{N_{\mathrm{top}}^{\mathrm{top}}}{N_{\mathrm{top}}}, \quad \mathrm{Mistag} = \frac{N_{\mathrm{QCD}}^{\mathrm{top}}}{N_{\mathrm{QCD}}}$$

NN top tagger performance better or comparable to some existing techniques!

Preliminary: improving ANN further!

Almeida, Backovic, SL, Perelstein, and CMS group @ Korea University

Artificial NN: Comparison with other top taggers



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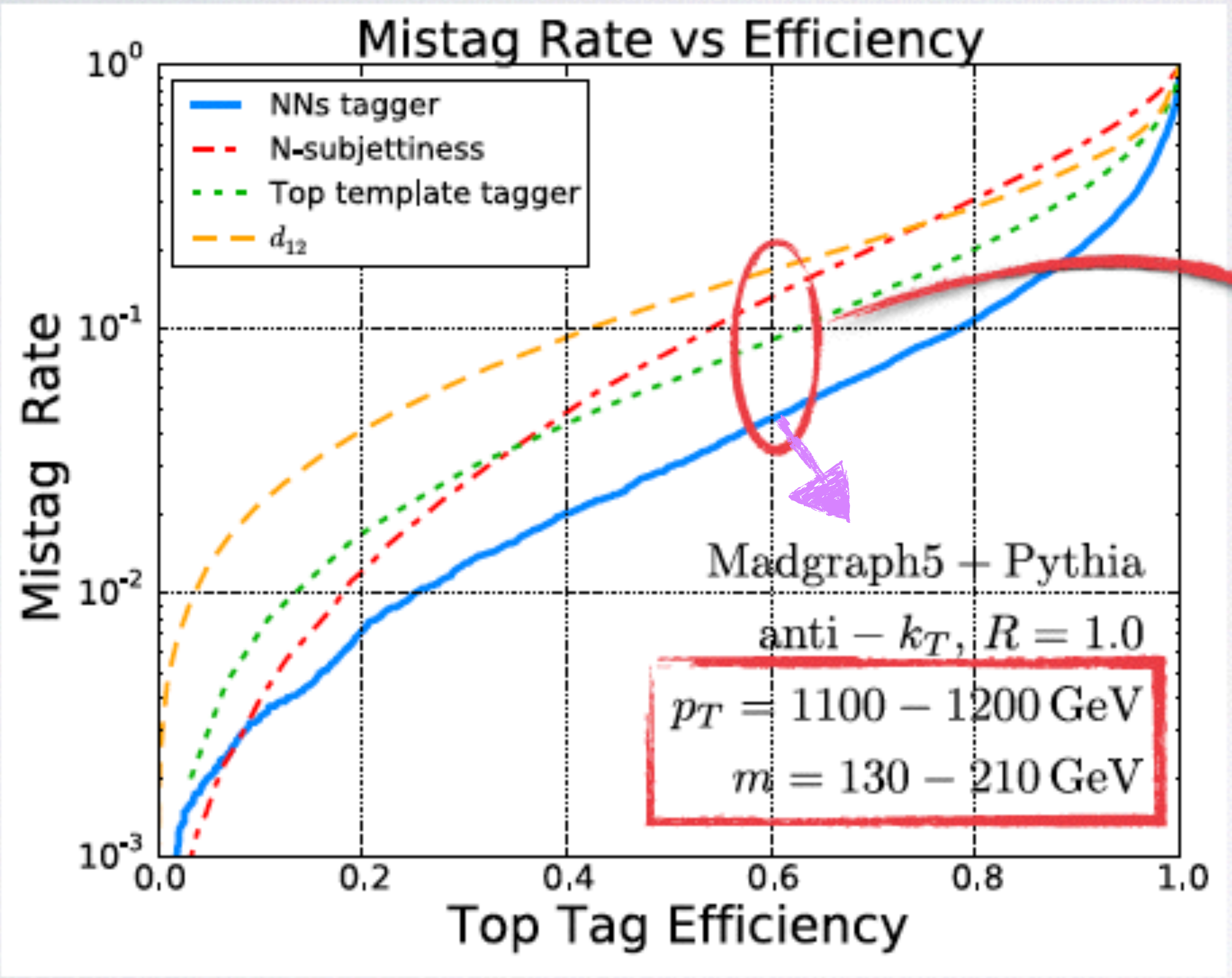
~ factor of 2 -3 improvement over existing methods!

Artificial NN: Comparison with other top taggers



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~ factor of 2 -3 improvement over existing methods!

Almeida,Backovic, SL,
Perelstein, and
CMS group @ Korea
University

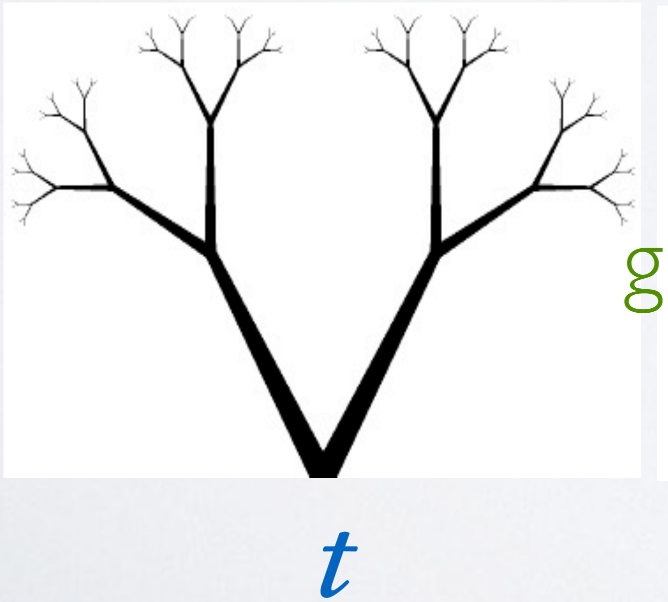
INFRARED SAFETY

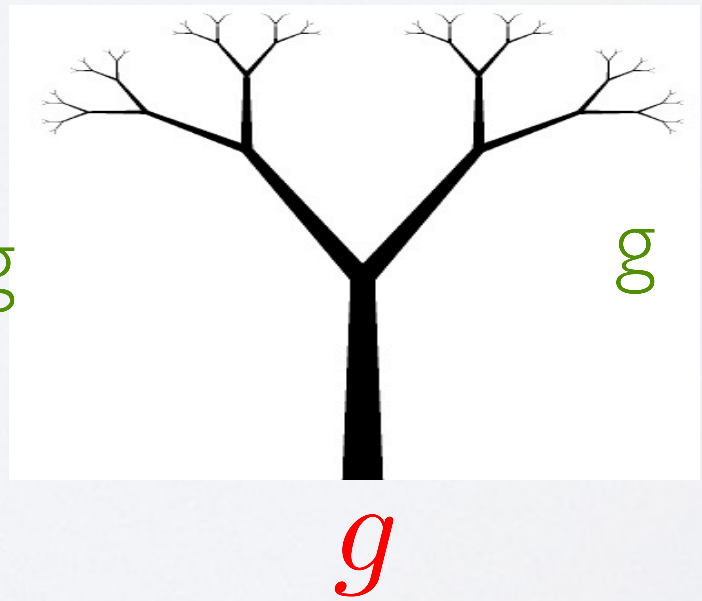
An observable *O* is infrared and collinear safe if

$$\mathcal{O}_{n+1}(k_1, k_2, \ldots, k_i, k_j, \ldots k_n) \rightarrow \mathcal{O}_n(k_1, k_2, \ldots k_i + k_j, \ldots k_n)$$

whenever one of the k_i/k_j becomes soft or k_i and k_j are collinear

i.e. the observable is insensitive to emission of soft particles or to collinear splittings





Almeida,Backovic, SL,
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CMS group @ Korea
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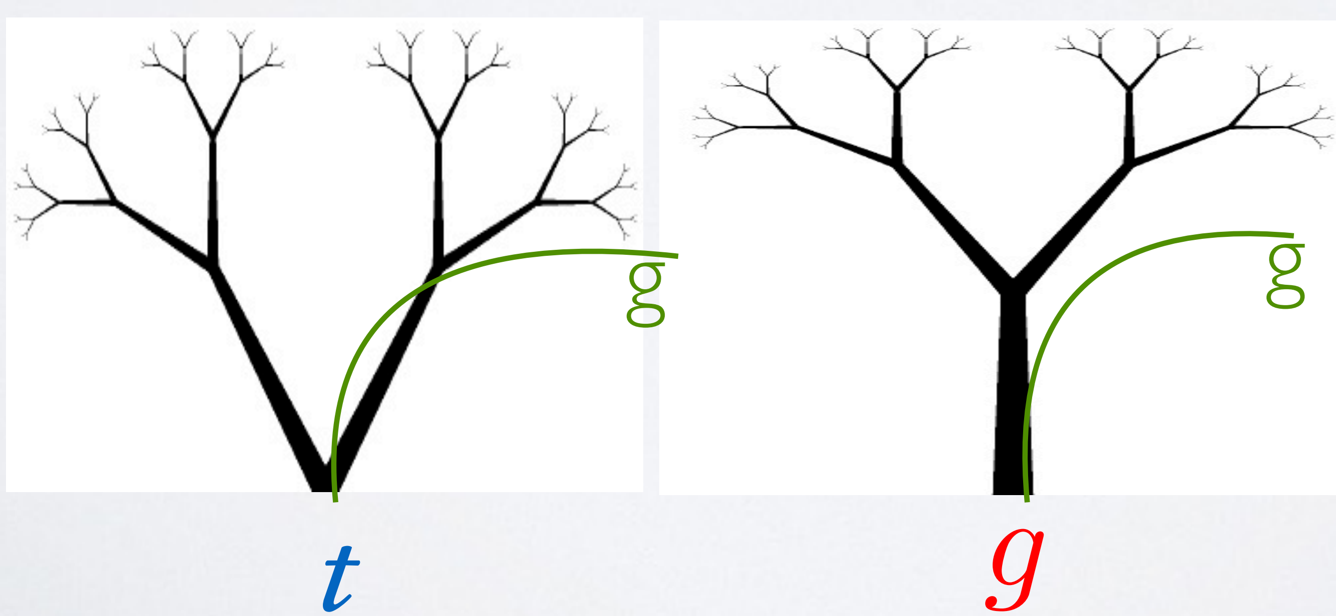


Work in Progress:
Test t vs q+g
and t+g vs q+g+g

ANN is IR SAFE

Top partners @ Run II

Boosted jet-substructure is a must tool for RUN II physics!

Maybe more rooms left for new ideas!

Naturalness @ Run 2: will be pushed further
e.g. Composite Top Partners will be probed beyond 2 TeV!

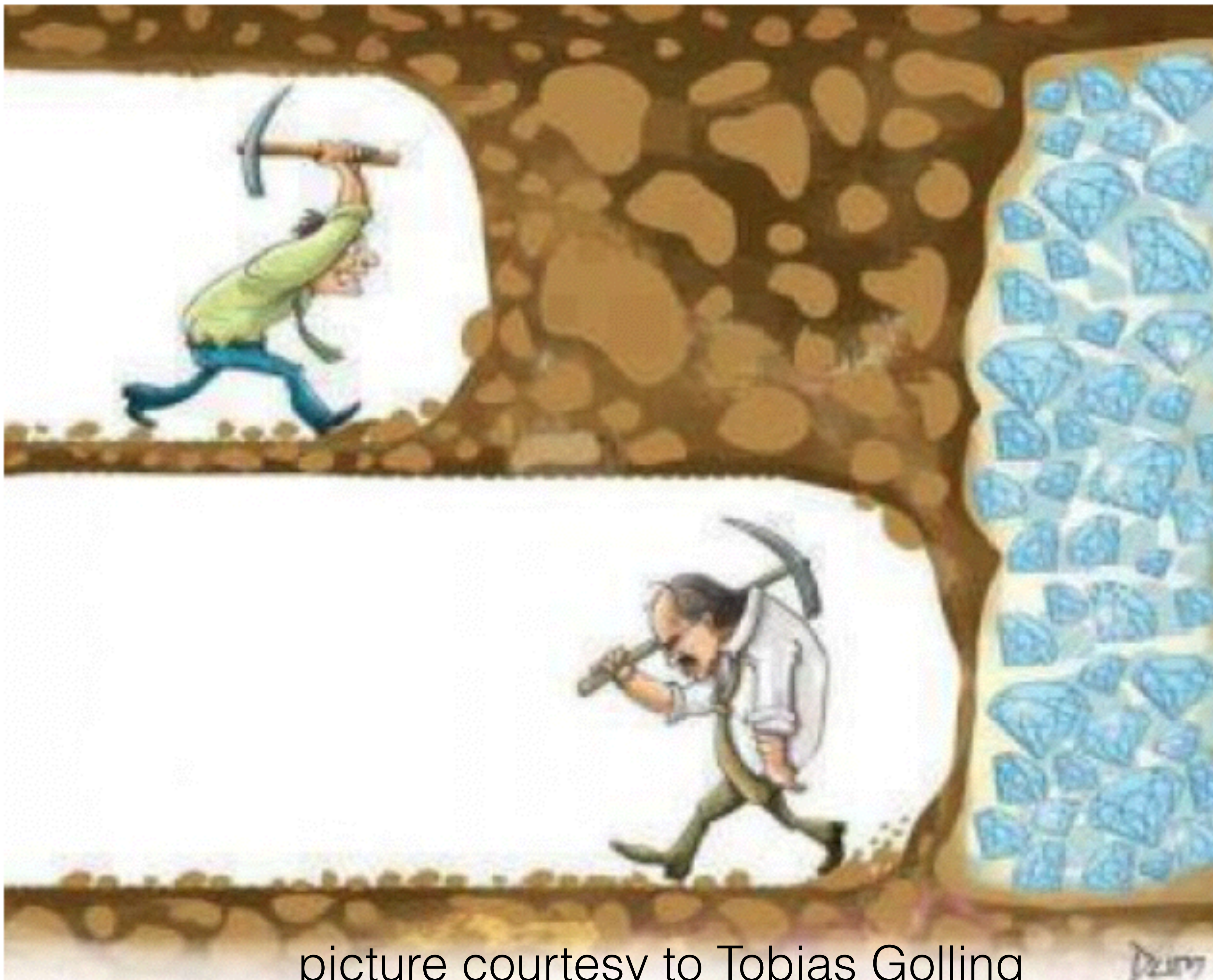
Top partners @ Run II

Be

Na er

e.g d

We Might be this Close!



picture courtesy to Tobias Golling

Thank You

Partial Composite light quarks

Delaunay, Fraille, Flacke, SL, Panico, Perez `13
Flacke, Kim, SL, Lim `13

* Fermion Lagrangian:

$$\mathcal{L}_{comp} = i\,\overline{Q}(D_\mu + ie_\mu)\gamma^\mu Q + i\overline{\tilde{U}}\not{D}\tilde{U} - M_4\overline{Q}Q - M_1\overline{\tilde{U}}\tilde{U} + \left(ic\overline{Q}^i\gamma^\mu d^i_\mu \tilde{U} + \text{h.c.}\right)$$

$$\mathcal{L}_{el,mix} = i\,\overline{q}_L\not{D}q_L + i\,\overline{u}_R\not{D}u_R - y_L f\overline{q}^5_L U_{gs}\psi_R - y_R f\overline{u}^5_R U_{gs}\psi_L + \text{h.c.},$$

where d^i_μ, e_μ are the CCWZ "connections", and U_{gs} is the Goldstone matrix

$$U_{gs} = \begin{pmatrix} 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & \cos\overline{h}/f & \sin\overline{h}/f \\ 0 & 0 & 0 & -\sin\overline{h}/f & \cos\overline{h}/f \end{pmatrix},$$

with $\overline{h} = \langle h \rangle + h$.

* Derivation of Feynman rules:
  - expand d_μ, e_μ, U_{gs} around $\langle h \rangle$,
  - diagonalize the mass matrices,
  - match the lightest up-type mass with the SM quark mass (m_u or m_c) $\rightarrow$ this fixes y_L in terms of the other parameters ($y_R \sim 1 \Rightarrow y_L \ll 1$)
  - calculate the couplings in the mass eigenbasis.

$$m_u \simeq \frac{v}{\sqrt{2}f} \times |M_1 - M_4| \times \frac{y_L f}{\sqrt{(M_4^2 + y_L^2 f^2)}} \times \frac{y_R f}{\sqrt{(M_1^2 + y_R^2 f^2)}}$$