Les Houches PhysTeV2015
BSM WG Summary
Part I

Cedric Delaunay
LAPTh-CNRS
Annecy-le-Vieux

June 19, 2015

Personal impression

- Higgs is the star of the workshop
  - fine, it's the only new particle discovered (thus far!)

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- which attracted (distracted?) a lot BSMers
  - fine, BSM is the naturalness partner of Higgs

- But too early to surrender to EFT!!
  - Colored BSM right around the corner at LHC run II?
  - Uncolored BSM down to 200-300GeV still allowed

Topics discussed

New Physics Working Group

Session 2

- Dijet Resonances
- Composite Higgs and Top Partners
- Diboson Resonances
- LFV and B Meson Decays
- Compressed Spectra, Stops and EWinos
- Dark Matter and Higgs (Crosslist)

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Relaxation

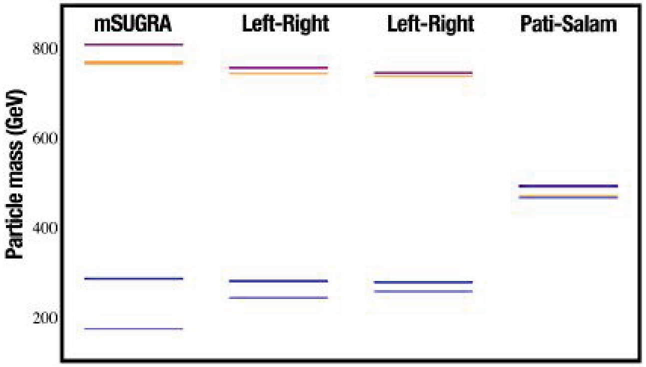
BSM phenomenologists: take a break?

Compressed spectra (aka SUSY)

Compressed spectra

M. Krauß, S. Kulkarni, U. Laa, W. Porod, B. Sanjoy, J. Tattersall

Idea: Pati-Salam inspired scenarios lead to compressed spectra for sfermions at the elektroweak scale



V. De Romeri, M. Hirsch, M. Malinsky, arXiv:1107.3412 [hep-ph]

features:

- $\tilde{\nu}_R$ LSP with mass ordering $m_{\tilde{q}} > m_{\tilde{\nu}}$
- extra heavy gauge bosons/gauginos
- extended Higgs sector
- typical mass splitting in the sfermion sector 20-100 GeV $\Rightarrow$ 3-body decays of $\tilde{f}$

Compressed spectra

questions to be addressed

- to which extent do 8 TeV data constrain such a model using `CheckMATE` for SUSY + evaluation of updated Z' constraints
- constraints due to dark matter
- depending on the $\tilde{f}$ masses and their mass splitting:
  what is the reach of LHC 13/14 TeV

status: testing the corresponding `SPheno` version and the interfaces to the other programs, first parameter scans, in particular for the branching ratios of

$$
\begin{aligned}
\tilde{q} &\to q l^{\pm} \tilde{l}^{\mp} \;,\; q' \nu \tilde{l} \\
&\to q' l \tilde{\nu} \;,\; q \nu \tilde{\nu} \\
\tilde{l} &\to l \nu \tilde{\nu}
\end{aligned}
$$

in some corners of parameters with sufficient mass splitting

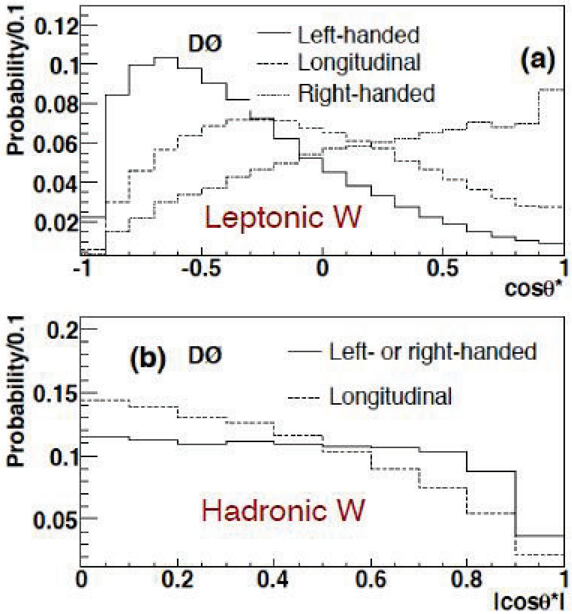
$$
\begin{aligned}
\tilde{t}_2 &\to Z\tilde{t}_1, W\tilde{b}_1 \\
\tilde{b}_2 &\to Z\tilde{b}_1, W\tilde{t}_1
\end{aligned}
$$

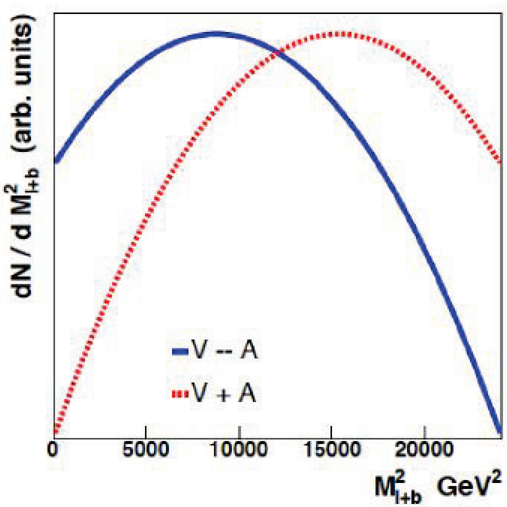
Composite partners
VLQs, VLLs

Measuring VLQ Properties

- Chirality of couplings crucial info
  - Done for t→Wb, established mostly longitudinal W's
  - For VLQs, depends on couplings to Higgs
    - By construction, no Yukawas
    - ➡ Can yield precious info on underlying physics

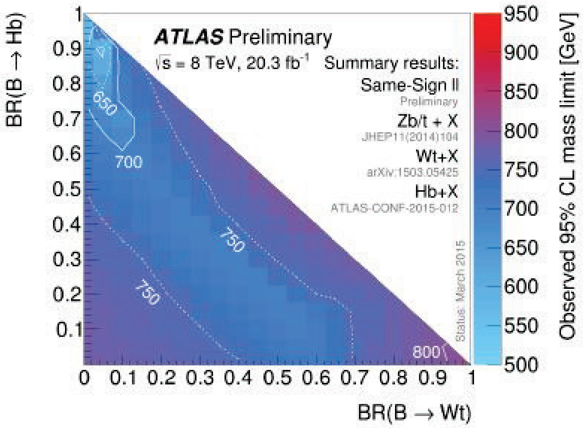
Barducci, Boos, Santiago, Juste, Parolini, Majumder, …



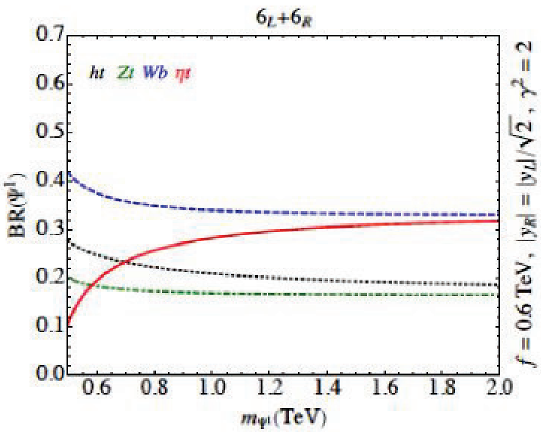


More VLQ Signals

- Diboson production via t-channel VLQ exchange Boos, Santiago, Juste, Cacciapaglia
  - Modifications of diboson kinematics
- Other VLQ decays Brooijmans, Cacciapaglia, …
  - Experiments have been presenting results in "simplified models", assuming e.g. $BR(T\to Wb)+BR(T\to ht)+BR(T\to Zt)=1$
  - UV completions have more new particles VLQs can decay to



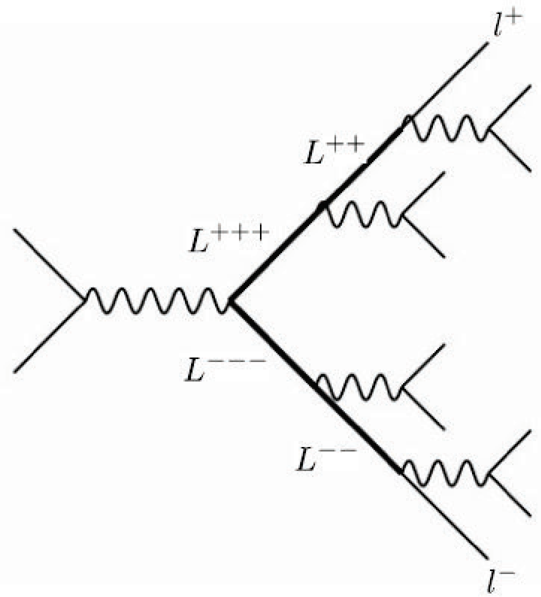
Anandakrishnan, Colins, Farina, Kuflik, Perelstein, arXiv:1506.05130, Serra, arXiv:1506.05110

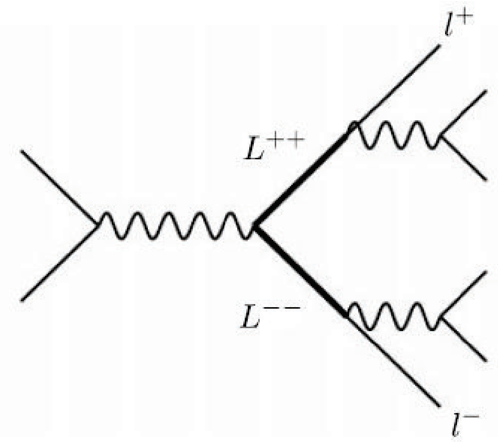


- Produce "coverage matrix" to see if some channels have no/poor coverage

Search for doubly/triply charged leptons

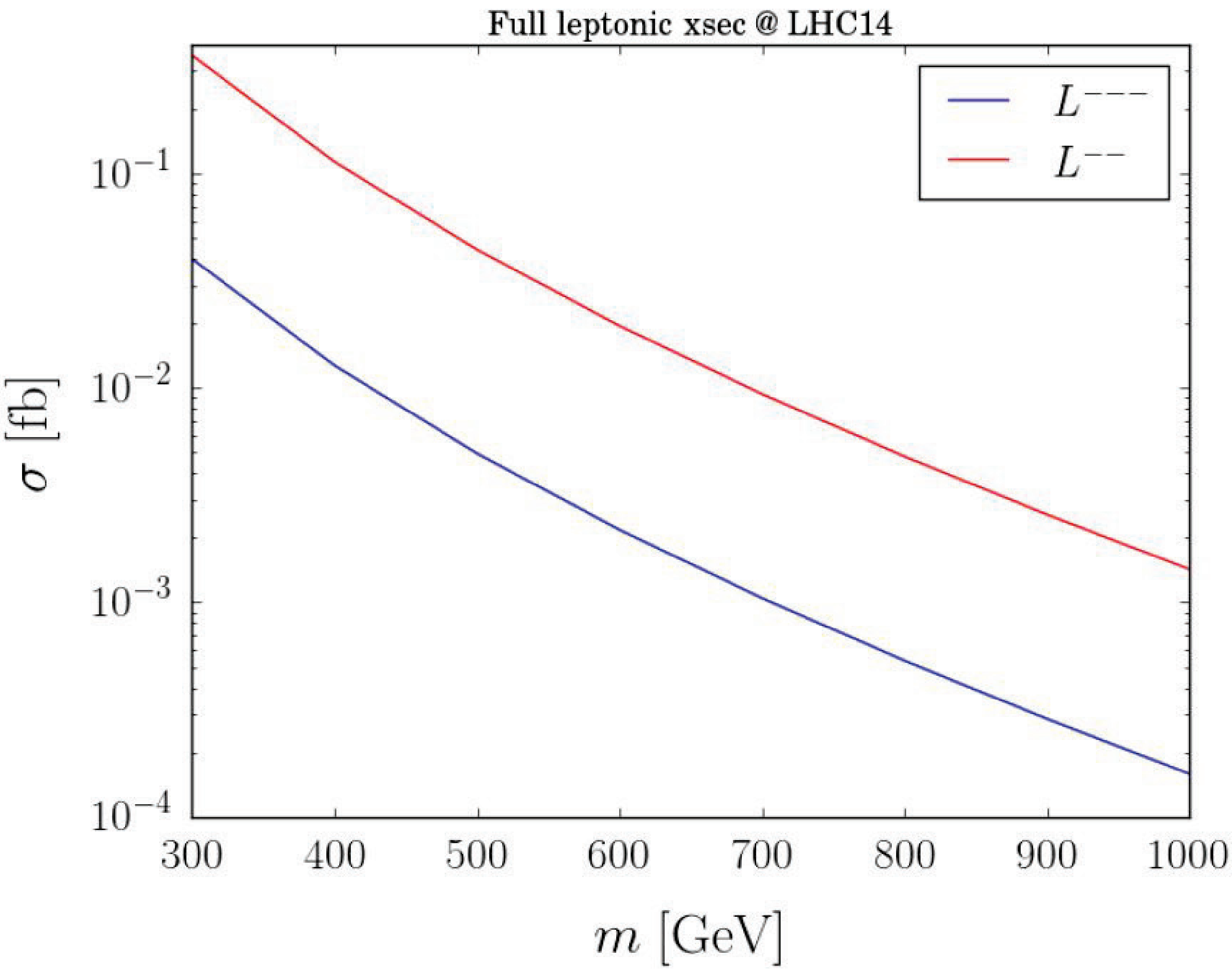
- General prediction in CHMs
- Pair production (more 'model independent')





Adrian Carmona, Florian Goertz, Alberto Parolini

Search for doubly/triply charged leptons



Adrian Carmona, Florian Goertz, Alberto Parolini

Search for doubly/triply charged leptons

- Backgrounds: multi Z/W production

L^{+++}

4Z	0.02 fb
2Z 2W	0.4 fb
3Z (+ some E_{miss})	[10 fb]

L^{++}

3Z	10 fb
Z 2W	90 fb
4 W	0.6 fb
2Z (+ some E_{miss})	[10 pb]

14 TeV LHC

- Before branching
- Can be efficiently rejected by vetoing Z-mass window
- Very clean measurement, very small backgrounds (L^{+++})

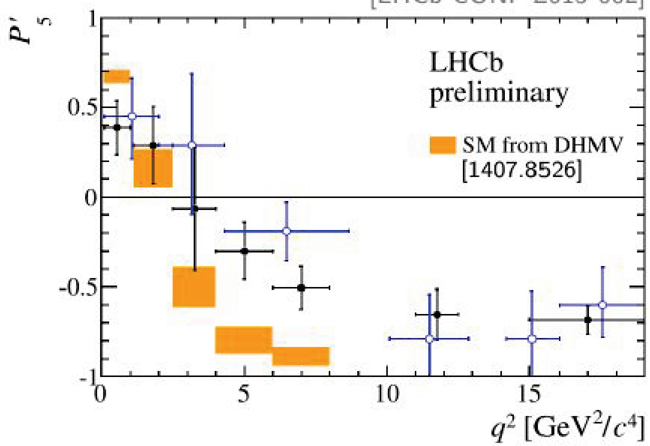
B meson LFV decays

LFV in B Meson decays

- Anomalies in lepton flavour conserving transitions $b \longrightarrow s\ell\ell$

LCHb, 1406.6482, PRL

[LHCb-CONF-2015-002]



$$P'_5 = \frac{S_5}{\sqrt{F_L(1-F_L)}}$$

$$R_K = \frac{\int_{q^2_{\min}}^{q^2_{\max}} \frac{d\Gamma[B^+ \to K^+\mu^+\mu^-]}{dq^2} dq^2}{\int_{q^2_{\min}}^{q^2_{\max}} \frac{d\Gamma[B^+ \to K^+e^+e^-]}{dq^2} dq^2}$$

$$R_K = 0.745^{+0.090}_{-0.074}\,(\mathrm{stat}) \pm 0.036\,(\mathrm{syst})$$

$$R_K^{SM} \simeq 1.00$$

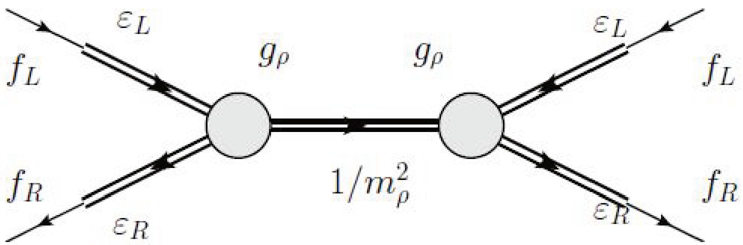
2.9σ in [4,6] GeV^2 bin (+2.9σ in [6,8] GeV^2 bin)

- What about Lepton Flavour Violation (LFV)? $b \longrightarrow s\ell\ell'$

- Working group: Bharucha, Carmona, Delaunay, Frigerio, Goertz, Nardecchia, Parolini

LFV in B Meson decays

- Connection between $b \to s\ell\ell$ and $b \to s\ell\ell'$ is *model dependent*
- We focus on the framework of partial compositeness
- Flavour violation is regulated by mixing between elementary and composite states



$$\sim \frac{g_\rho^2}{m_\rho^2} \epsilon_L^i \epsilon_R^i \epsilon_L^j \epsilon_R^j$$

- Mixing parameters are related to values of fermion masses and mixing

$$(Y_u)_{ij} \sim g_\rho \epsilon_i^q \epsilon_j^u \qquad (Y_d)_{ij} \sim g_\rho \epsilon_i^q \epsilon_j^d \qquad (Y_e)_{ij} \sim g_\rho \epsilon_i^\ell \epsilon_j^e,$$

- In the lepton sector parameters cannot be univocally connected to physical inputs, due to our ignorance on neutrino masses
- Our questions: range of LFV allowed by the mass constraints? prediction for the LHCb? super-B factories? what are the typical values of the mixing parameters? ….

Les Houches PhysTeV2015
BSM WG Summary
Part II

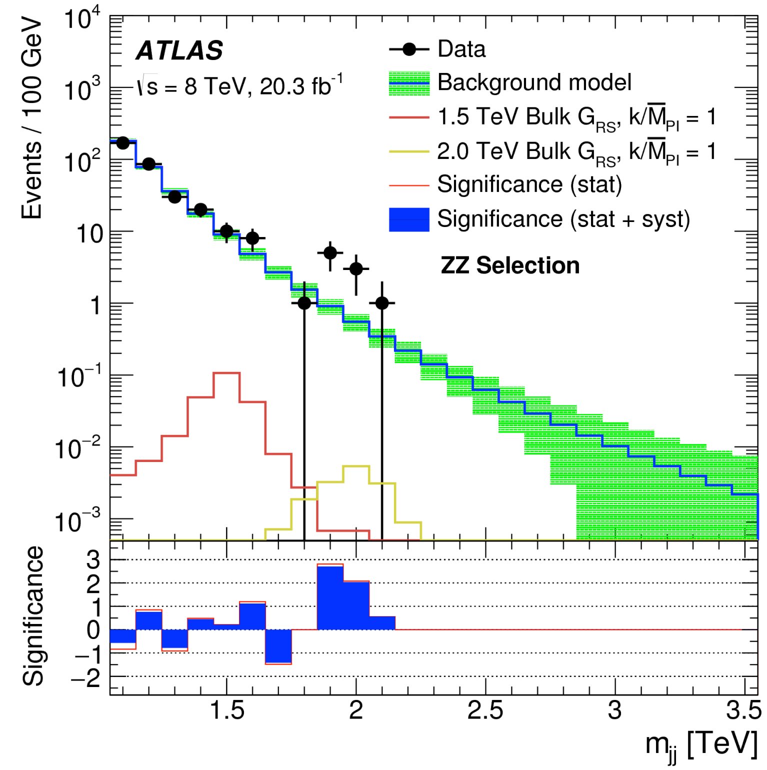
Gustaaf Brooijmans
Columbia University
New York

June 19, 2015

Diboson Resonances

Brooijmans, Morse, Pollard, Tattersall, Lane, Martin, Sanz, Hewett, Rizzo, Nardecchia, Katz, Chivukula, Simmons, Carvalho, Santiago, Delgado …

- Recent ATLAS paper with 2+ sigma excess has stirred the pot (again)
  - Not the only excess close to 2 TeV
- Plan of action agreed on
  - Produce summary of pp→ X → YY results (currently a table with expected and observed limits), quantify
  - Model builders have until July 15 to post models on arXiv
  - August 1 **joint** "pre-proceeding" with presentation of experimental results and summary of models
  - In proceedings, results from simulation showing power of (**TBD**) discriminating variables

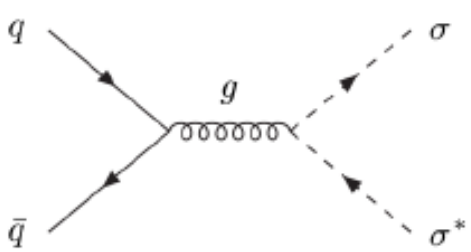


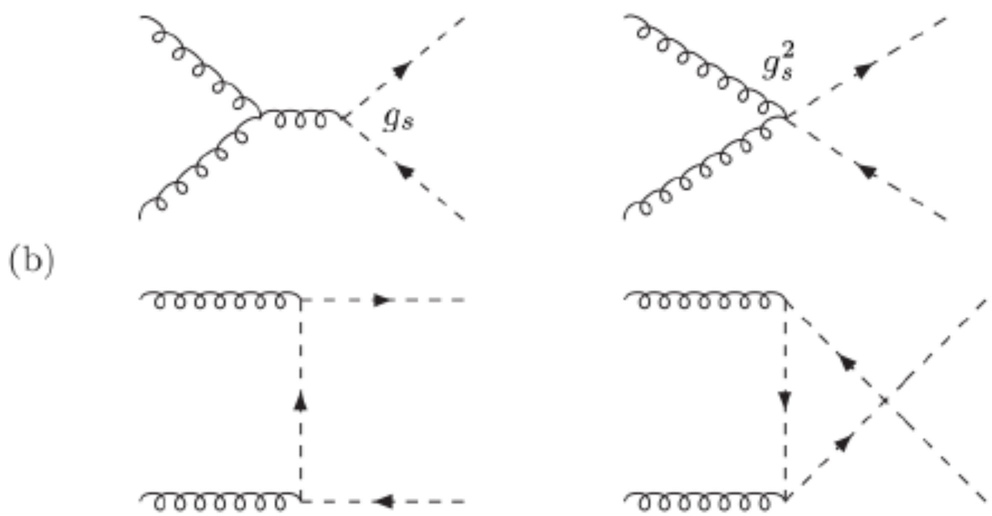
		1.8 TeV				1.9 TeV				2.0 TeV			
Channel	Reference	Exp.	Obs.	Significance	σ	Exp.	Obs.	Sig.	σ	Exp.	Obs.	Sig.	Signal σ
ATLAS All-Hadronic WZ	[1]	15 fb	30 fb	1.5 σ	-	13 fb	35 fb	2 σ	-	12 fb	36 fb	2.2 σ	3 fb (8 evts)
ATLAS All-Hadronic WW	[1]	18 fb	18 fb	0 σ	-	16 fb	29 fb	1.3 σ	-	15 fb	30 fb	1.6 σ	3.5 fb
ATLAS All-Hadronic ZZ	[1]	13 fb	30 fb	1.7 σ	-	11 fb	29 fb	2.0 σ	3.3 fb	10 fb	29 fb	2.2 σ	-
CMS All-Hadronic WZ	[2]	12 fb	17 fb	0.8 σ	-	10 fb	18 fb	1.5 σ	-	8 fb	13 fb	1.2 σ	-
CMS All-Hadronic WW	[2]	27 fb	40 fb	1 σ	-	22 fb	40 fb	1.5 σ	-	18 fb	27 fb	1 σ	-
CMS All-Hadronic ZZ	[2]	22 fb	29 fb	0.7 σ	-	18 fb	33 fb	1.5 σ	-	14 fb	24 fb	1.2 σ	-
ATLAS $\ell\nu jj$	[3]	13 fb	12 fb	0 σ	-	12 fb	12 fb	0 σ	-	10 fb	9 fb	0 σ	-
CMS $\ell\nu J$	[4]	4.3 fb	6 fb	1 σ	-	3.4 fb	3.7 fb	0 σ	-	3.3 fb	3.3 fb	0 σ	-
ATLAS $\ell\ell jj$ (ZZ)	[5]	6 fb	6 fb	0 σ	-	6 fb	7 fb	0.3σ	-	6 fb	7 fb	0.5σ	-
ATLAS $\ell\ell jj$ (WZ)	[5]	16 fb	14 fb	0 σ	-	17 fb	20 fb	0.5σ	0.5 fb (2.5 evts)	14 fb	20 fb	0.5σ	-
CMS $\ell\ell J$ (ZZ)	[4]	7 fb	13 fb	1.9 σ	-	7 fb	12 fb	1.7 σ	-	6.3 fb	8.3 fb	1 σ	-
ATLAS $\ell\ell,\nu\nu bb$ (ZH)	[6]	15 fb	14 fb	0 σ	-	17 fb	16 fb	0σ	-	20 fb	20 fb	0 σ	-
ATLAS $\ell\nu bb$ (WH)	[6]	33 fb	30 fb	0 σ	-	42 fb	35 fb	0σ	-	48 fb	40 fb	0 σ	-
CMS All-Hadronic (ZH)	[7]	8 fb	13 fb	1 σ	1? fb	7 fb	9 fb	0.5 σ	-	7 fb	7 fb	0 σ	-
CMS All-Hadronic (WH)	[7]	9 fb	13 fb	1 σ	1? fb	8 fb	9 fb	0.3 σ	-	7 fb	7 fb	0 σ	-
CMS $\ell\nu bb$ (WH)	[8]	22 fb	42 fb	2 σ	-	20 fb	40 fb	2 σ	-	18 fb	32 fb	2 σ	-
CMS $\tau\tau J$ (ZH)	[9]	24 fb	29 fb	0.8 σ	-	22 fb	27 fb	1 σ	-	20 fb	24 fb	1 σ	-
CMS $\ell\ell jj$ (W_R)	[10]	18 fb	20 fb	0.2 σ	-	4 fb	14 fb	1.6 σ	-	2 fb	13 fb	2 σ	-
CMS All-Hadronic qZ	[2]	50 fb	80 fb	1 σ	-	43 fb	80 fb	1.8 σ	-	35 fb	62 fb	1.7 σ	-

Dijet Resonance Pairs

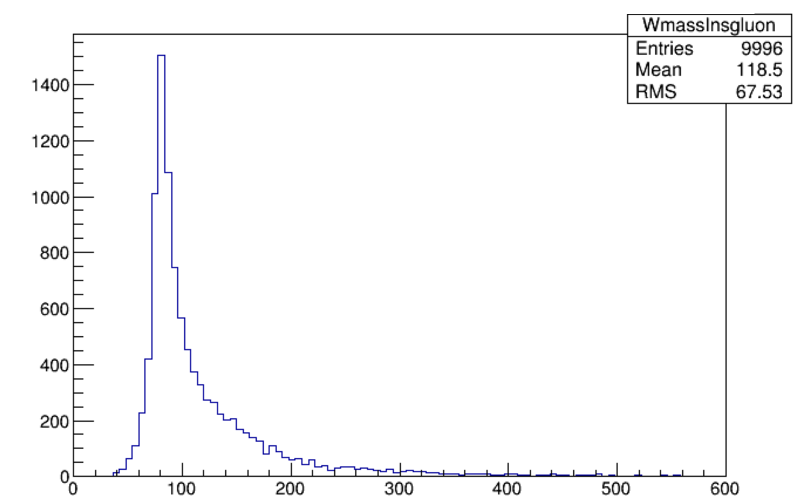
Searching for sgluons at the LHC 13TeV

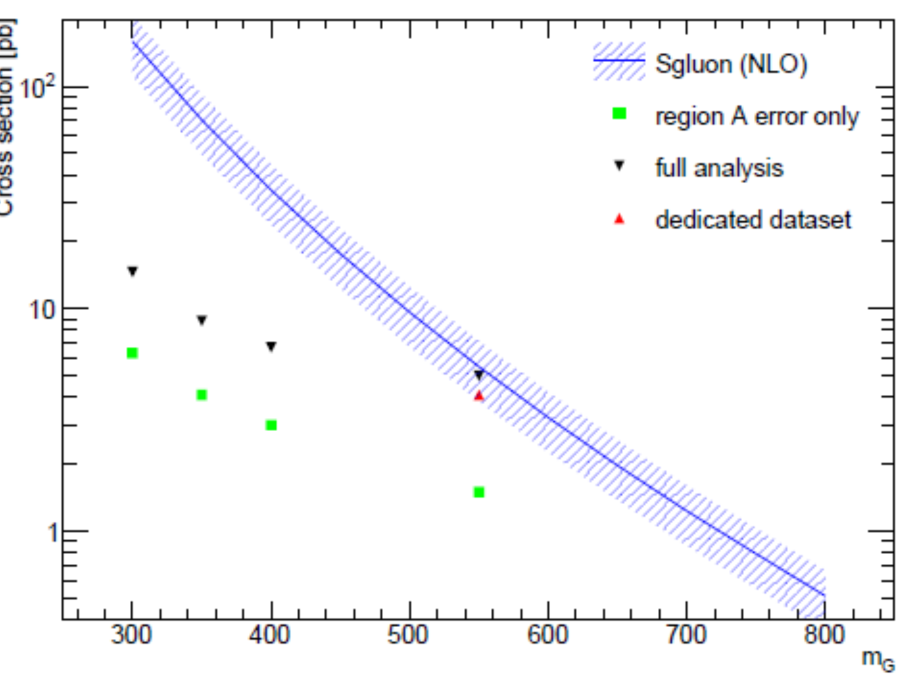
Thomas Spieker, Sophie Henrot-Versillé, Dirk Zerwas (LAL)





Reconstructed W mass

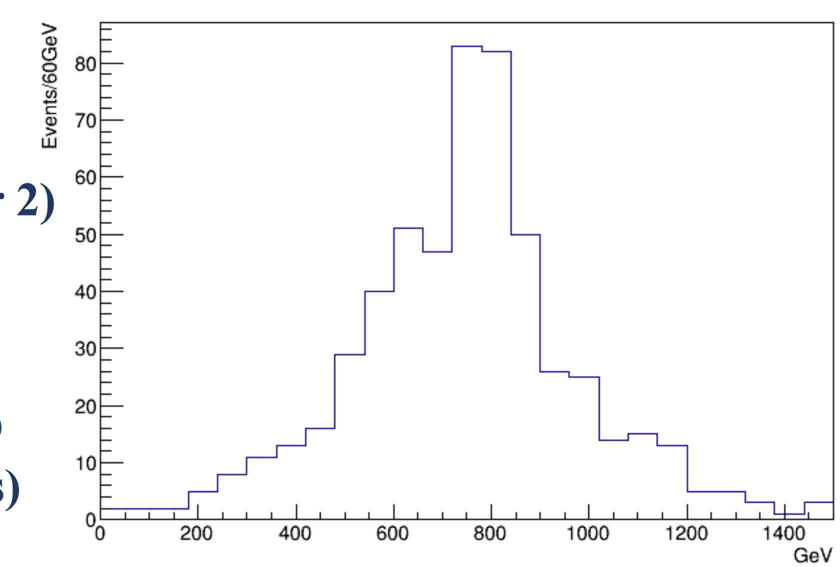




Color octet scalars
Pair produced
Final state: 4 gluon jets
Expectation 13TeV 10fb-1: 550GeV (factor 2)

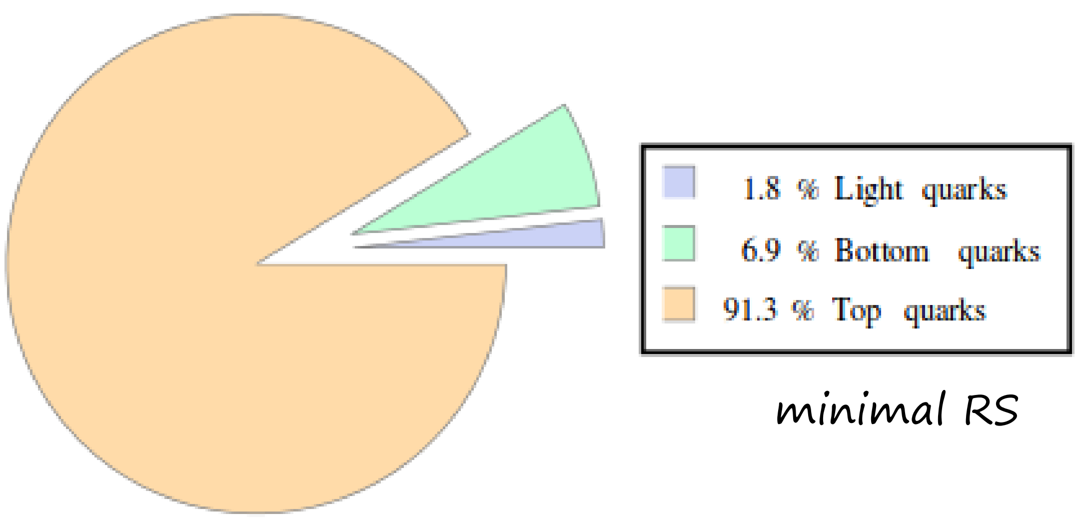
Final state: 2tops+2gluons
Simplified analysis (multi-jets, btag)
Show (biased) invariant masses as proof ☺
Sgl→gg (all events), Sgl→gg (after all cuts)

Reconstructed sgluon mass

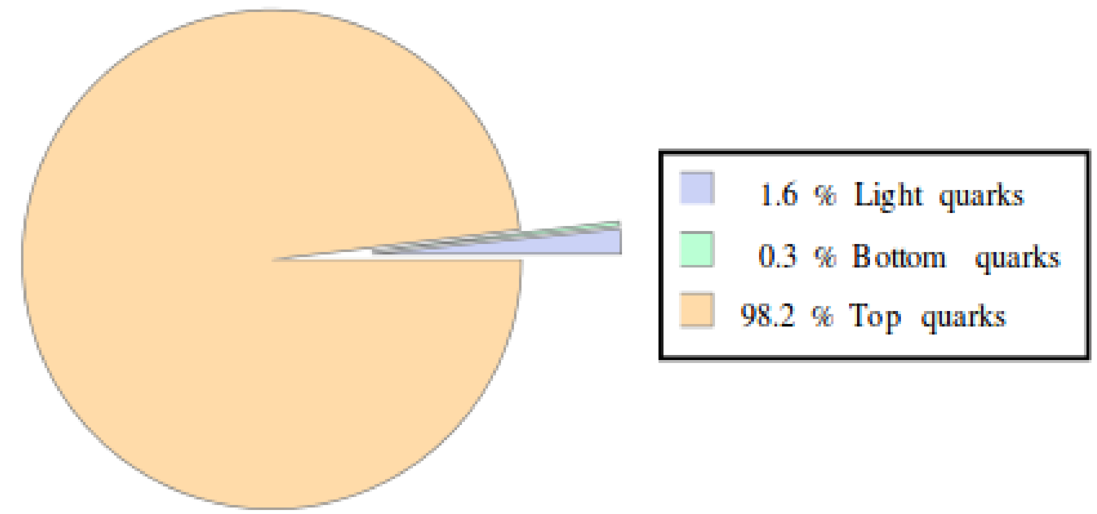


Discrimination between models: jj vs $t\bar{t}$,...

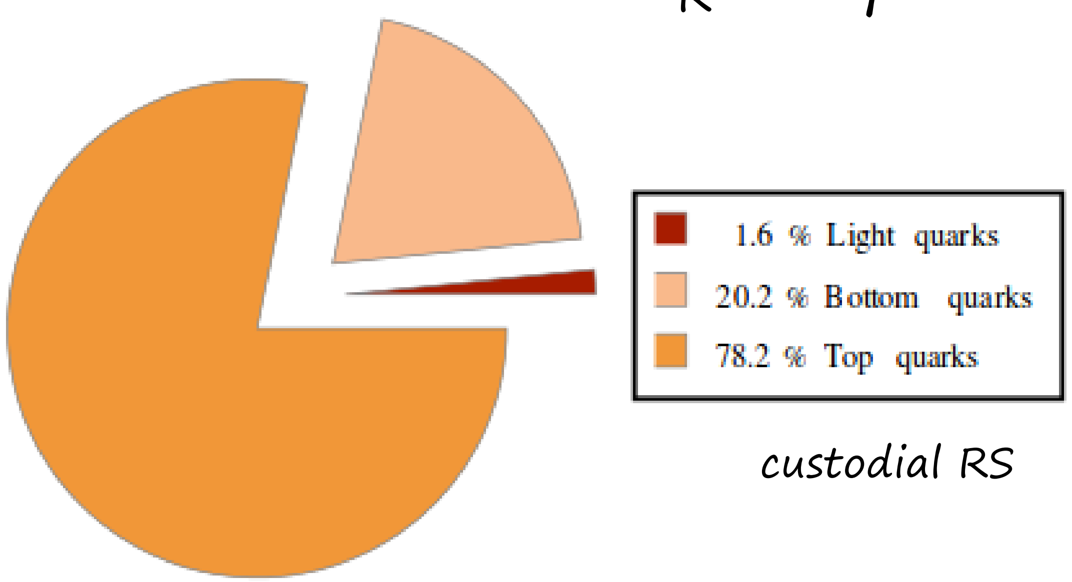
- BR of first KK gluon (warped XD, partial compositeness)



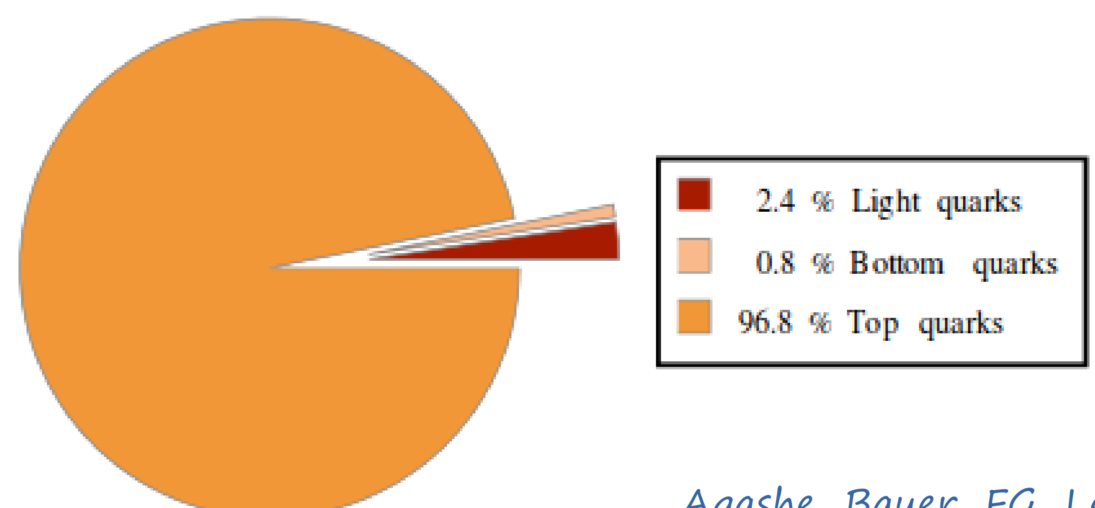
minimal RS



→ t_R compositeness →



custodial RS



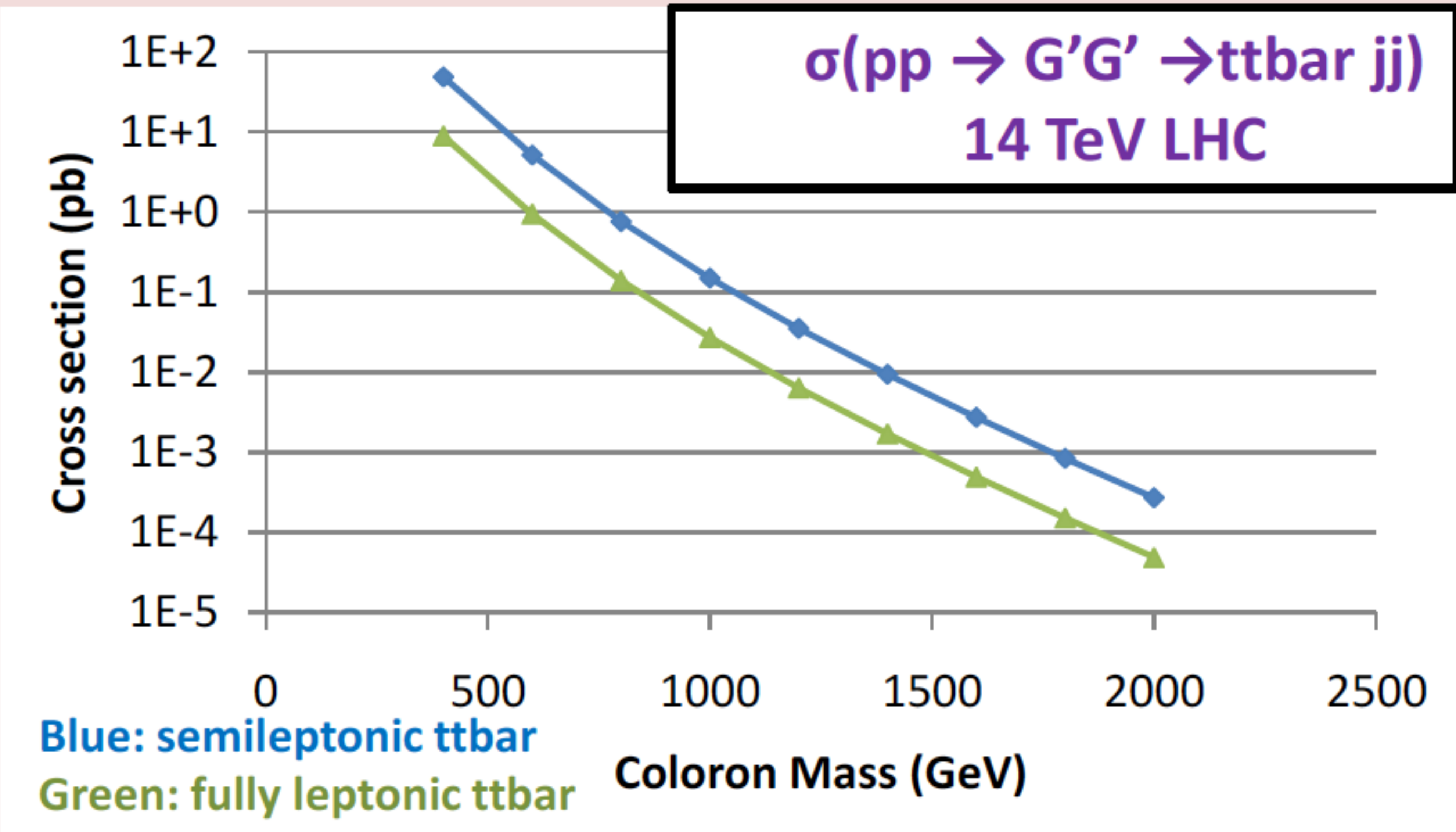
Agashe, Bauer, FG, Lee, Vecchi, Wang, Yu 1310.1070

Paired (tt)(jj) resonance search

Felix Yu

- Pair production via **gluon fusion guaranteed** for new colored states – searches in 4j, 4t final states
  - Single dijet resonance xsecs are **model dependent**
- Decay to **(tt)(jj)** has been **overlooked**

(tt)(jj) provides important and complementary information about flavor structure



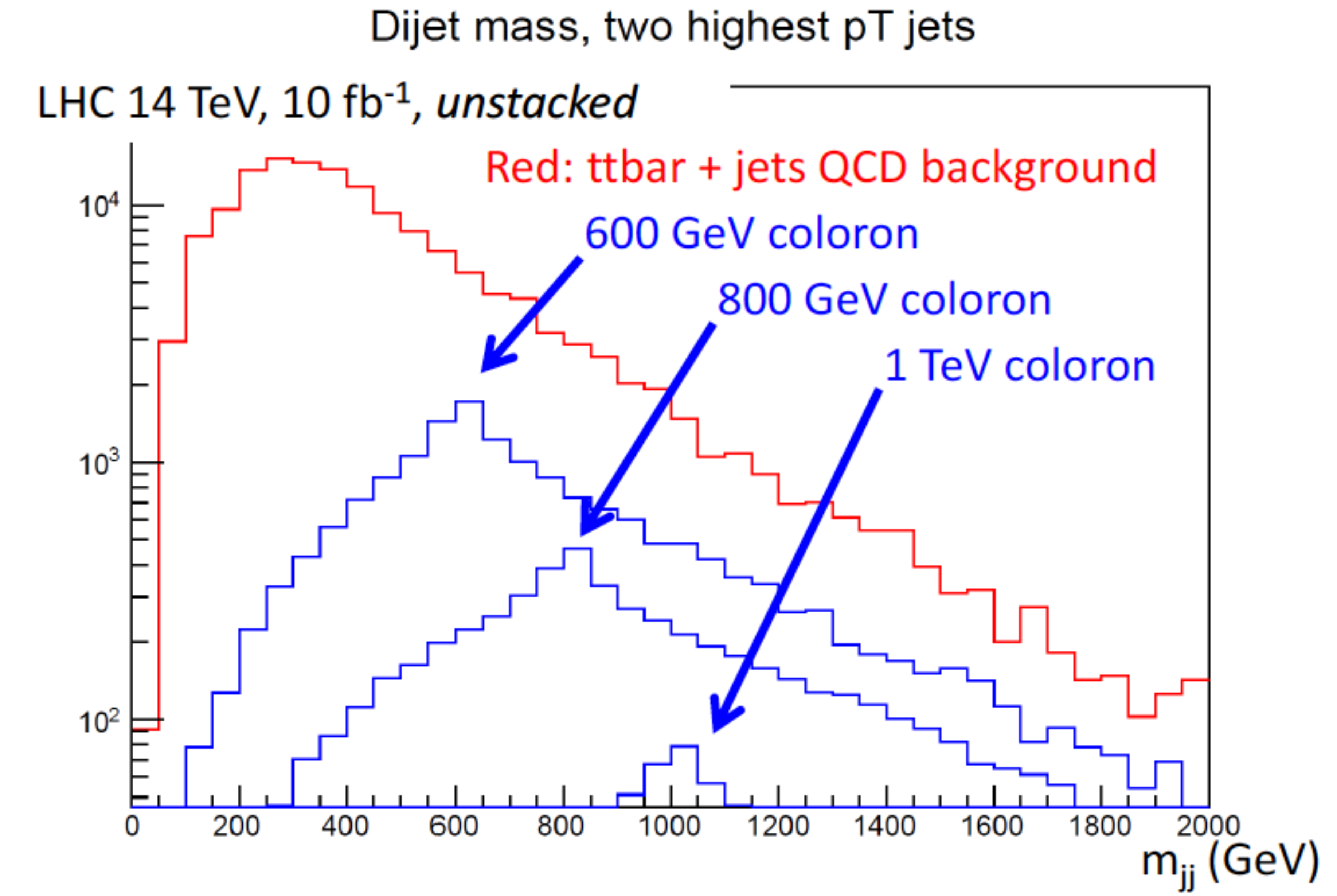
Paired (tt)(jj) resonance search

Felix Yu

- Main (irreducible) background is **ttbar + jets**
  - Semileptonic: **106 pb**
  - Fully leptonic: **46 pb**

Semileptonic channel:
Cut on lepton
Two b tags
Look at m_{jj} of leading and subleading p_T jets

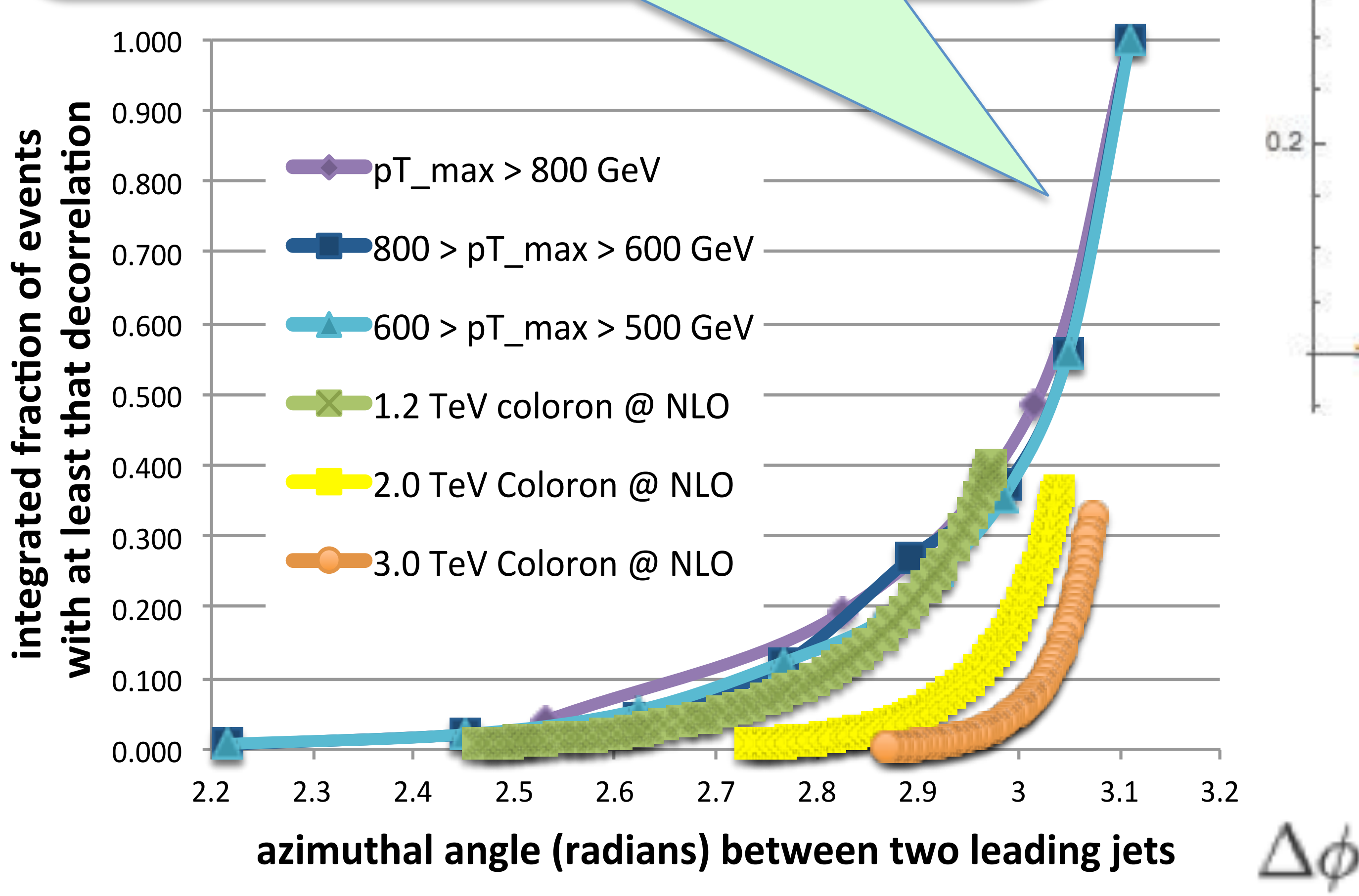
Many kinematic handles, optimization underway



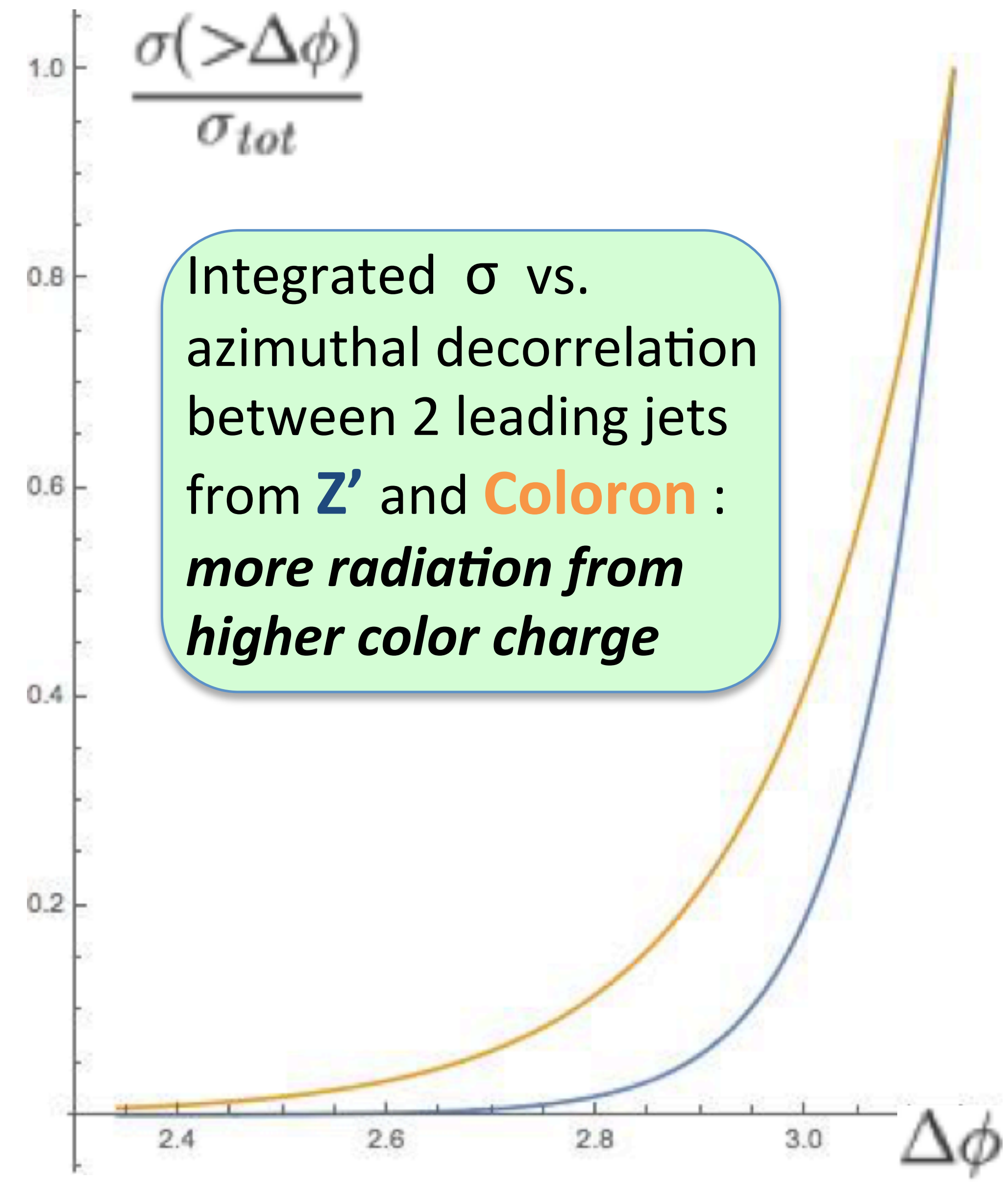
Dijet Resonances

Dijet Azimuthal Decorrelation Reveals Resonance's Color Charge [Preliminary]
RS Chivukula & EH Simmons

Integrated fraction of events vs. azimuthal angle between 2 leading jets; ATLAS 7 TeV data (thin curves), NLO colorons prediction (thick curves); ***colorons yield decorrelation of observable magnitude***



Integrated σ vs. azimuthal decorrelation between 2 leading jets from **Z'** and **Coloron** : ***more radiation from higher color charge***



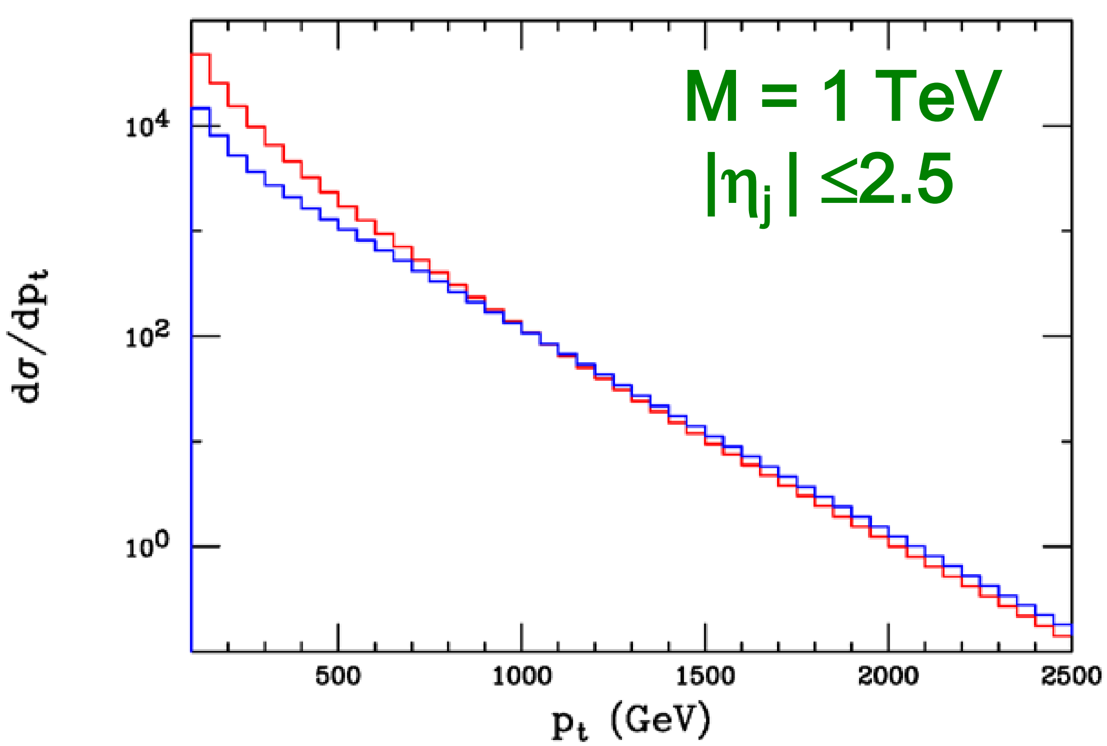
References:

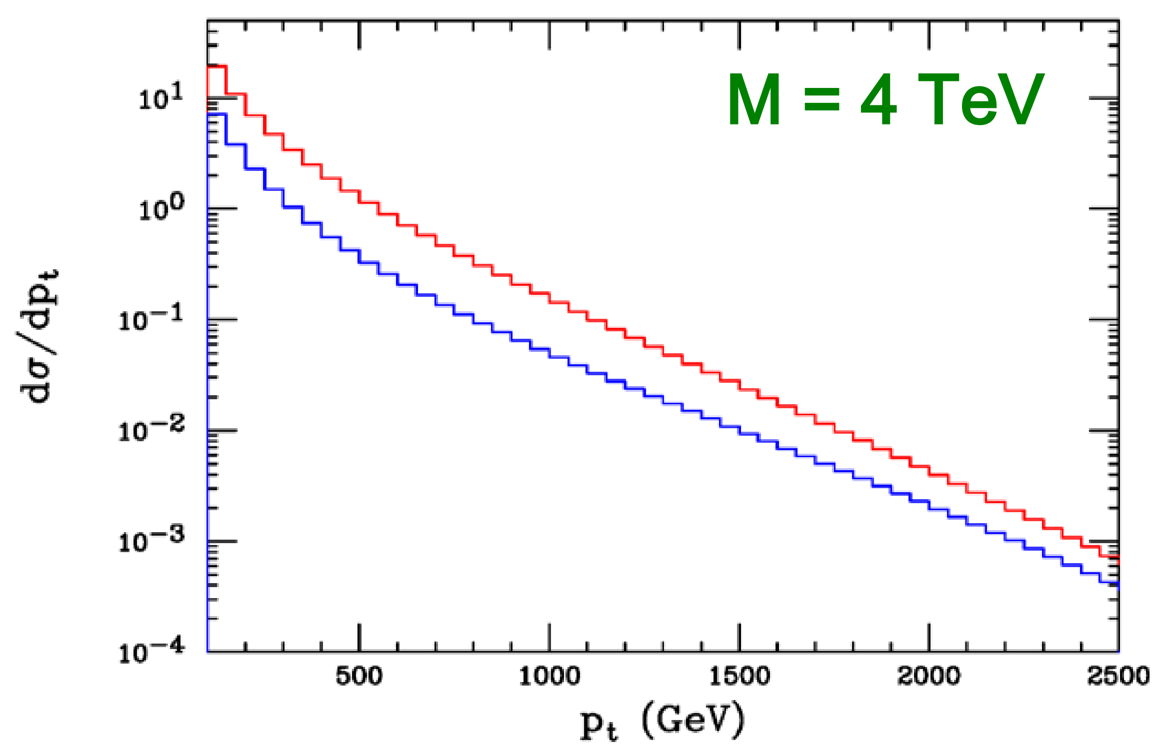
- Z' simulation*: Open J.Microphys*. 3 (2013) 34-42.
- Colorons @ NLO: *Phys. Rev*. D85 (2012) 054005
- ATLAS on azimuthal decorrelation: *Phys.Rev.Lett* 106 (2011) 172002

Color Singlet vs Octet Via Additional Jet p_T ? - Hewett & Rizzo+…

- LO parton-level comparison of associated jet production w/ a spin-1 state X : color singlet vs. octet. First step of a more detailed study…
- Expect: Color octets radiate more so expect harder jet p_t distribution
- Expect: As X gets heavier it radiates less so any differences vanish

→ Easily separable @ 1 TeV but resolving power lost at large masses
→ NLO…. More power with 2j ?





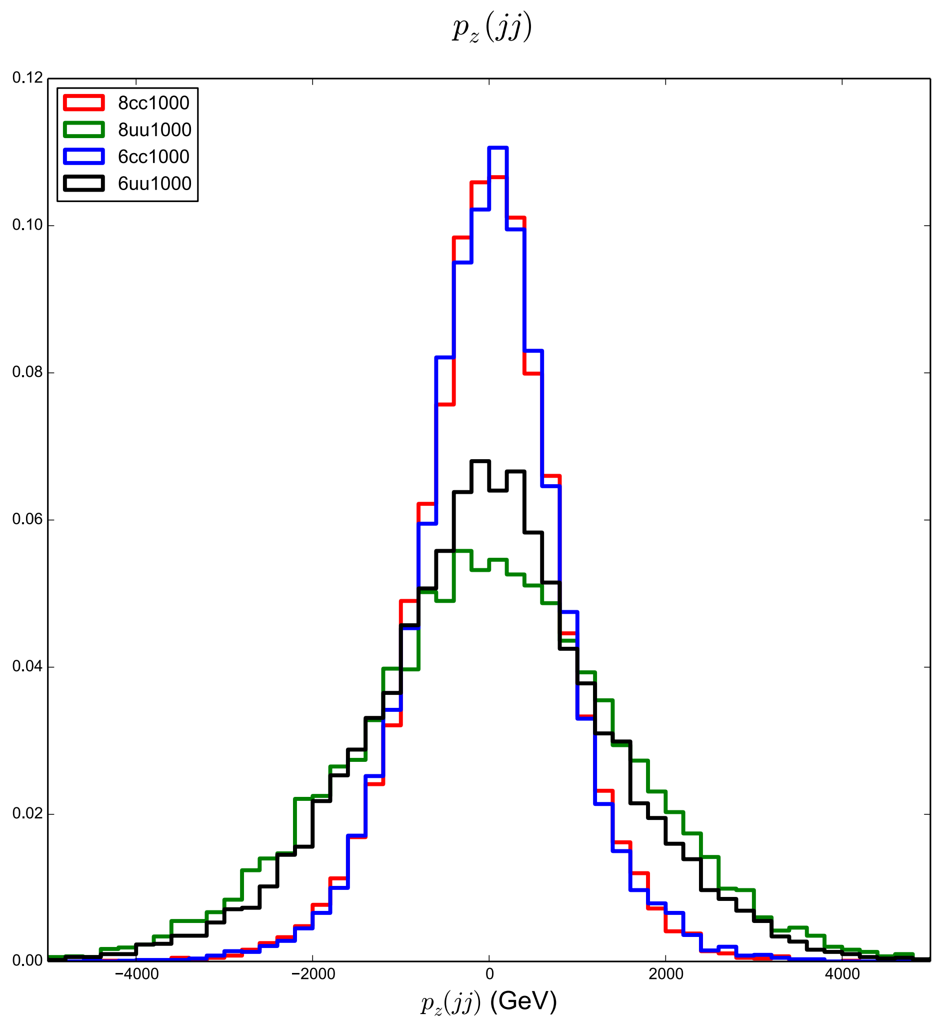
red = singlet, blue = octet

Jose Santiago
Tom Flacke
Florian Goertz
Adrian Carmona

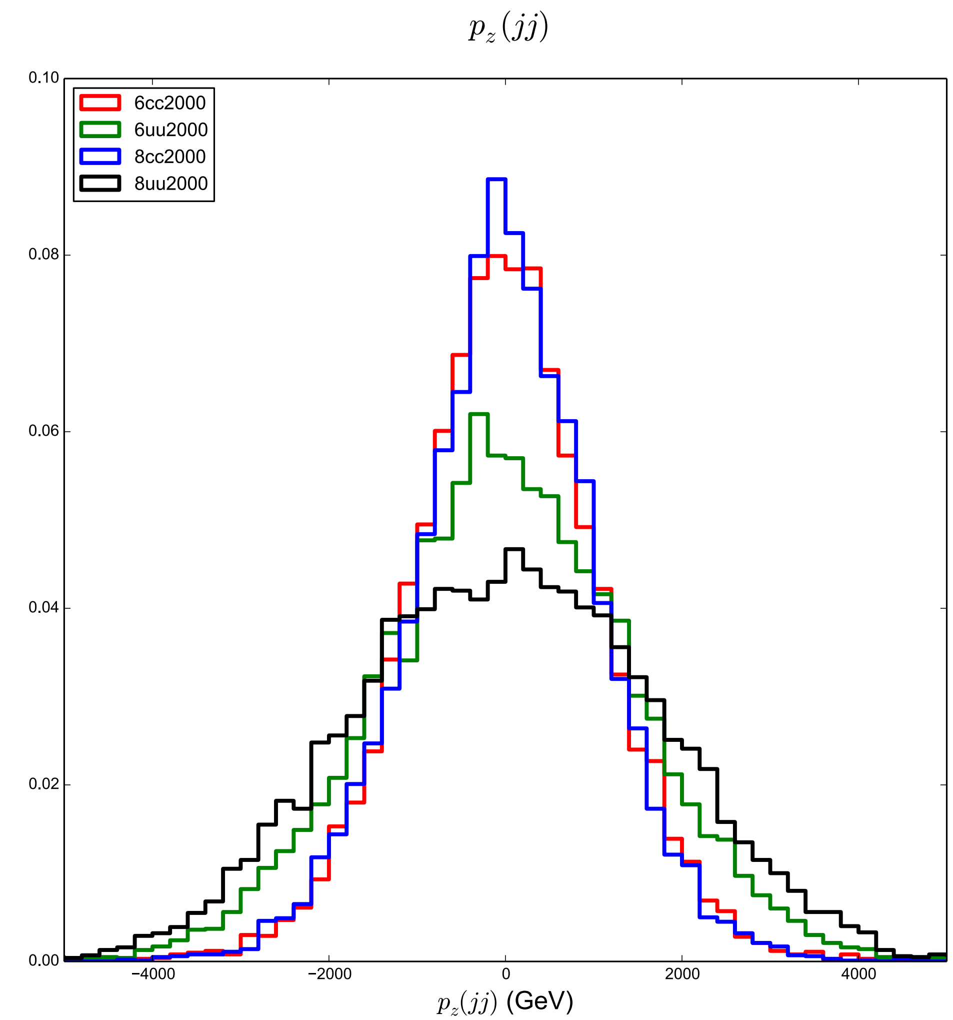
Suppose in a few months we find a dijet resonance.

Scalar/Vector? (color-neutral? triplet? sextet? octet?)

- Triplets and Sextets couple to qq (e.g. uu or cc)
- Singlets and octets couple to $q\bar{q}$ (or gg)
- Differing PDFs for quarks (esp. u vs. $\bar{u}$) lead to differing p_z distributions in dijet signals.



1 TeV resonance

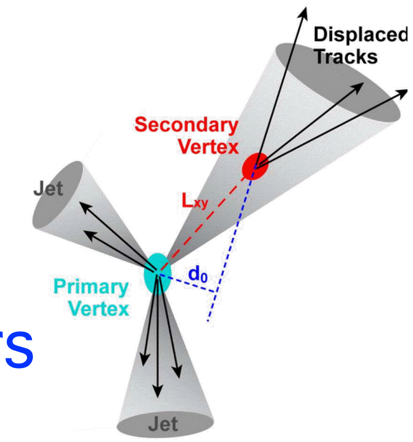


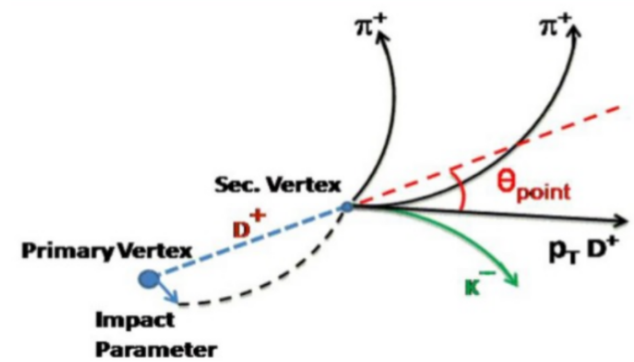
2 TeV resonance

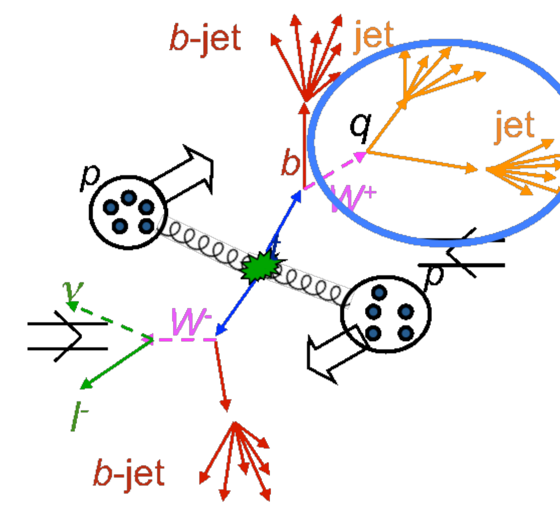
Can we use this for discrimination?

DiJet Flavor Determination

- Can we convincingly determine dijet flavor at the LHC?
  - gg vs. uu/dd/ss vs. cc vs. bb vs. tt
- Tools exist, including:
  - Quark/Gluon discriminator for light flavor (LF=u,d,s)
  - Dedicated b,c, and t-taggers







- Some overlap between taggers, study needed for combination possibilities
  - Example working points which prioritize low fake rate over efficiency
  - These numbers are for single objects, not the two jet system

8 TeV LHC CMS+ATLAS	200+GeV efficiency (%)	200+GeV misid (%)	1+TeV efficiency (%)	1+TeV misid (%)
t	30	1	30	0.2
b	70	~20% c 1.5% LF	50-60	~15% c 4% LF
c	20	20% b 1 % LF	??	??
quark/gluon (jets>30)	40% uds	6	??	??