Outcome of BSM Theme

Jae Hyeok Yoo (Korea University)

07/19/2019

KAIST-KAIX Workshop for Future Particle Accelerators

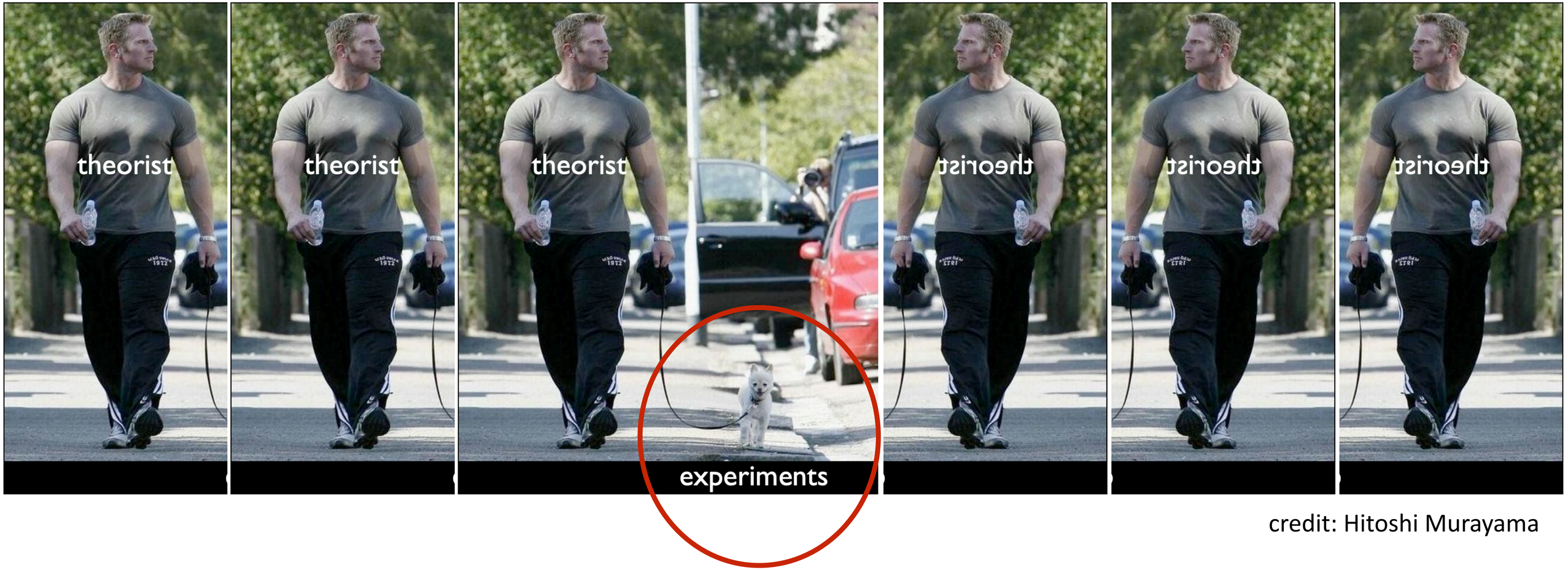
BSM session

- 7/16 Tue: 6 talks

Title	Speaker
Exploring the Global Symmetry Structure of the Higgs Potential via Same-Sign Pair Production of Charged Higgs	Kentarou Mawatari (Osaka U)
Broad Composite Resonances and Their Signals at the LHC	Ke-Pan Xie (SNU)
Continuum Naturalness	Gabriel Lee (Cornell/KU)
Strong Hidden Fermion Production and Relaxation	Fang Ye (KAIST)
Composite Higgs Models and Exotic Decays of Vector-Like Quarks	Thomas Flacke (IBS CTPU)
Searches for New Physics with Jet Time Substructure	Matthew Klimek (Cornell/KU)

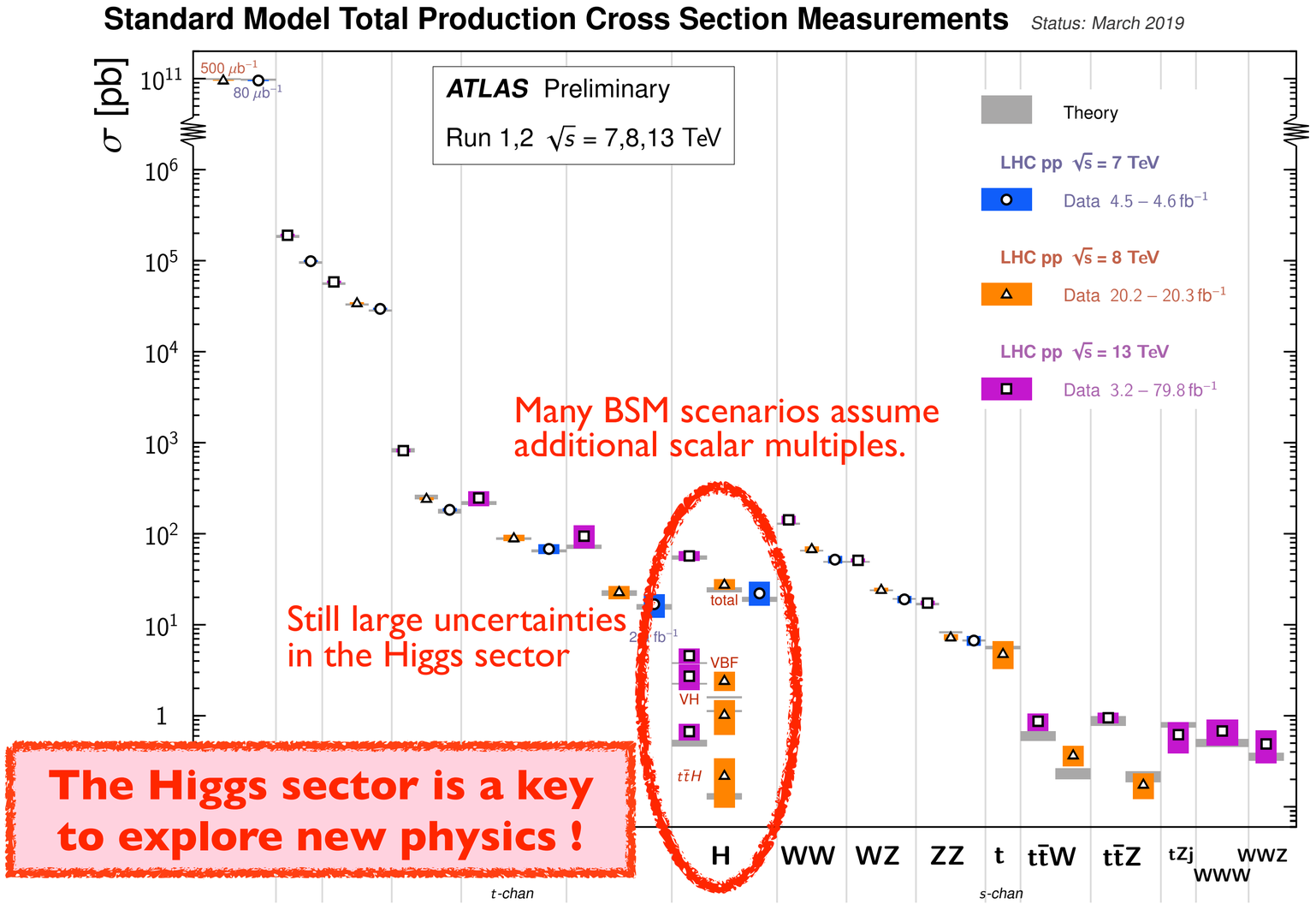
- Conveners: Michelangelo Mangano (CERN), Felix Yu (Mainz), Un-ki Yang (SNU), Jae Hyeok Yoo (KU)

An experimentalist summarizing 6 theory talks …



credit: Hitoshi Murayama

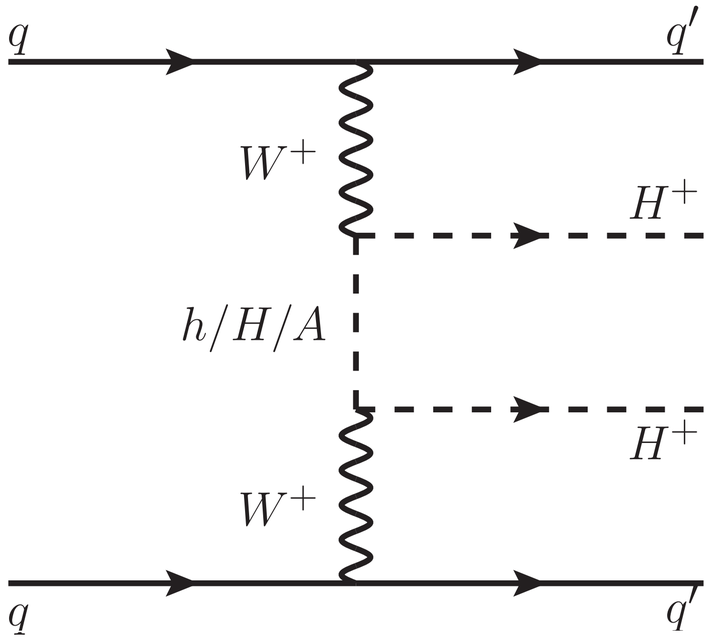
Exploring the Global Symmetry Structure of the Higgs Potential via Same-Sign Pair Production of Charged Higgs Bosons (Kentarou Mawatari)



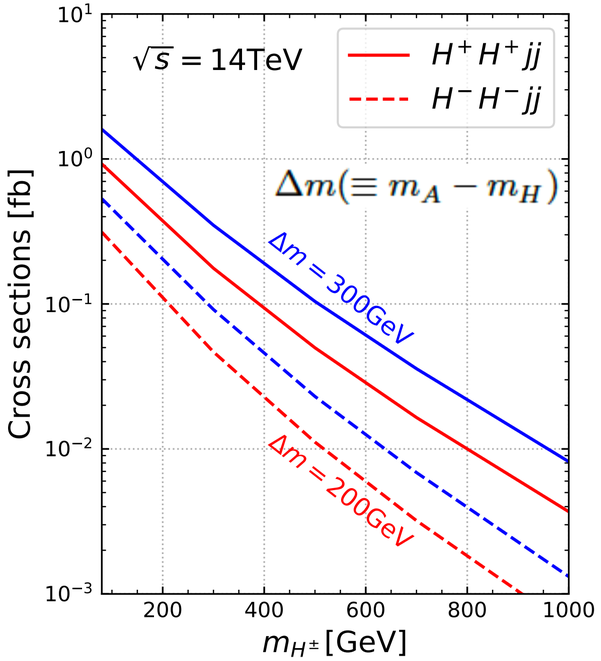
- Introduce non-minimal Higgs sector
  - HSM : Higgs Singlet Model
  - THDM: Two Higgs Doublet Model
- Additional Higgs bosons
  - H, A, $H^{\pm}$, …
- Charged Higgs bosons can provide striking signals

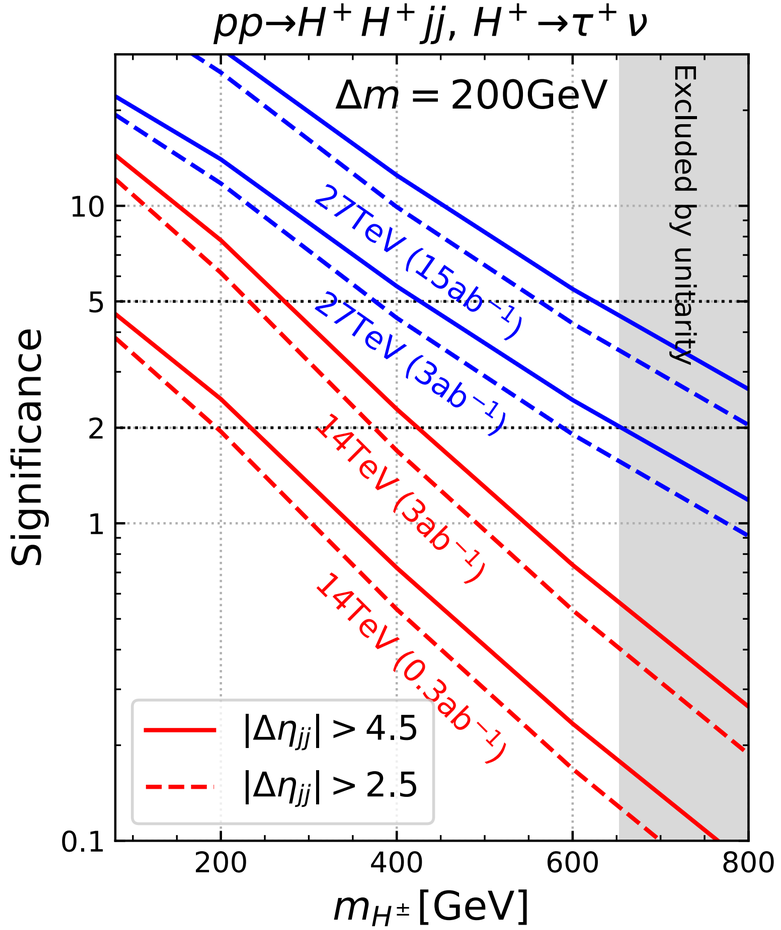
Exploring the Global Symmetry Structure of the Higgs Potential via Same-Sign Pair Production of Charged Higgs Bosons (Kentarou Mawatari)

Same-sign pair production



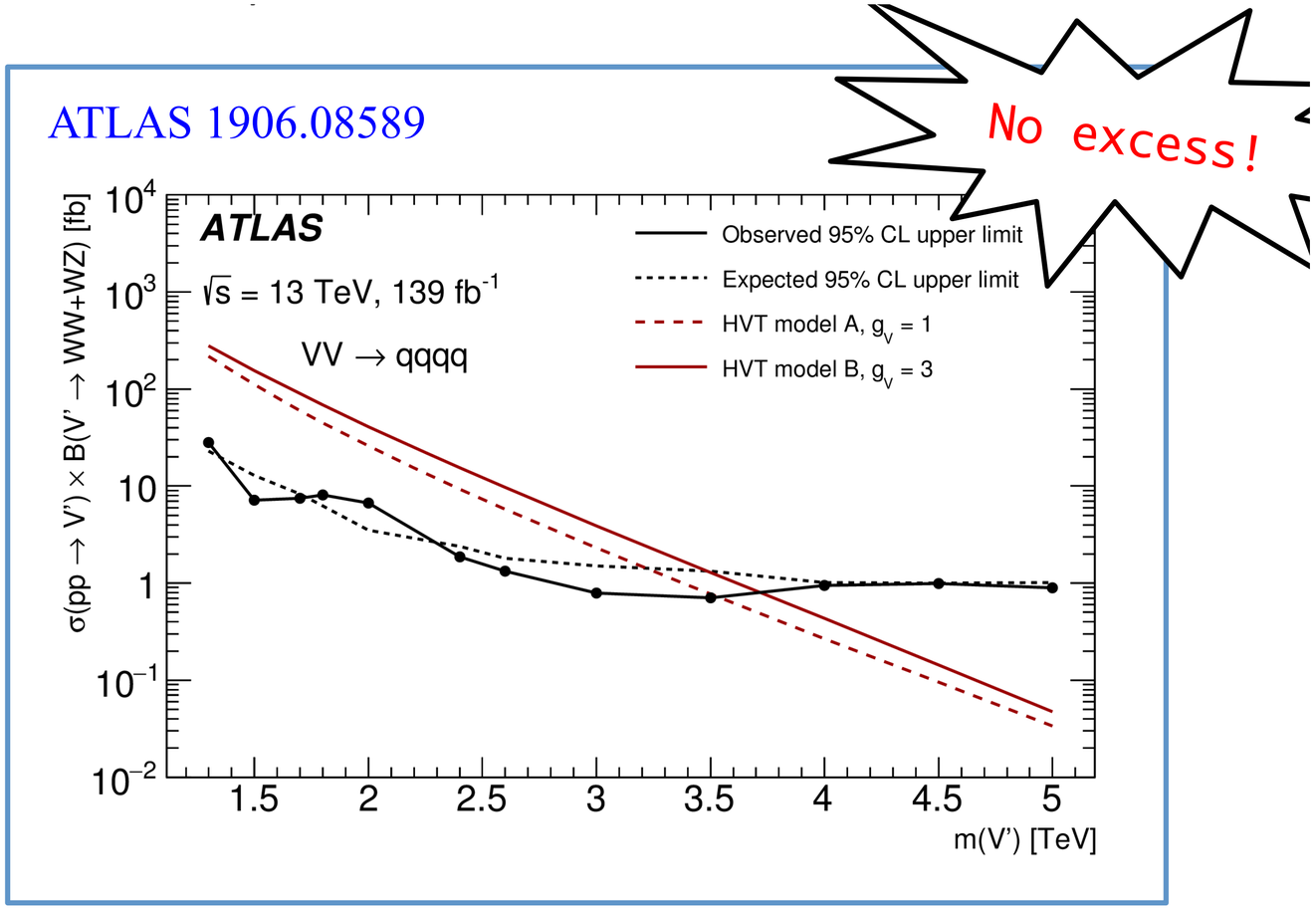
Aiko, Kanemura, Mawatari [1906.09101]





$$s = L\,\sigma^{\rm VBF}_{pp\to H^+H^+jj}(B_{H^+\to\tau\nu})^2\epsilon^\tau_{\rm sel}(\epsilon_\tau)^2$$
$$b = L\,\sigma^{\rm VBF}_{pp\to W^+W^+jj}(B_{W^+\to\tau\nu})^2\epsilon^\tau_{\rm sel}(\epsilon_\tau)^2$$

Broad Composite Resonances and Their Signals at the LHC (Ke-Pan Xie)

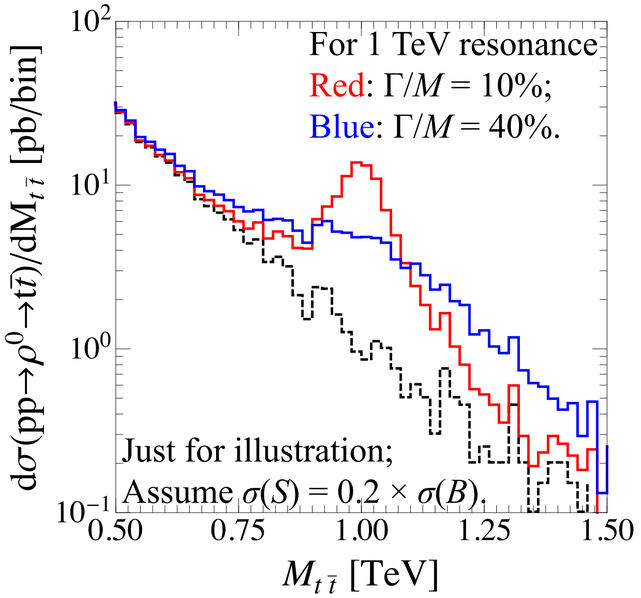


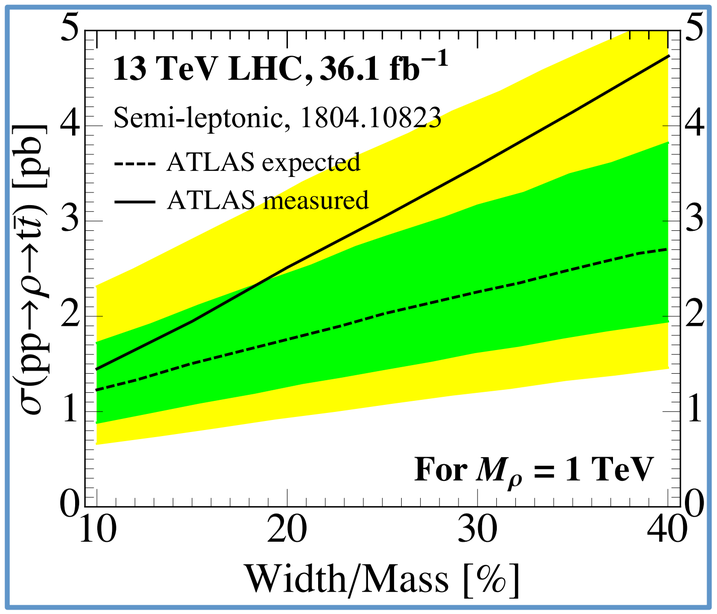
- Composite Higgs models
- $\rho^{\pm,0}$ resonances at colliders
  - decays to VV, but no evidence
- Two possibilities
  - heavier than expected
  - hidden in unexpected channels
- What if SM 3rd generation quark is strong dynamic bound state from new physics?
  - very broad decay width (tt or bb)

Broad Composite Resonances and Their Signals at the LHC (Ke-Pan Xie)

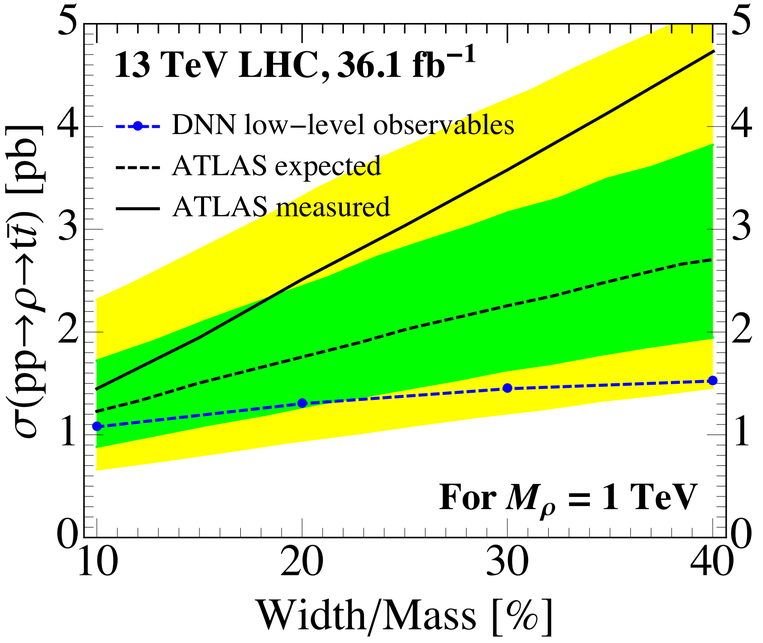
- Search for broad tt resonance

traditional search: fit M_{tt}



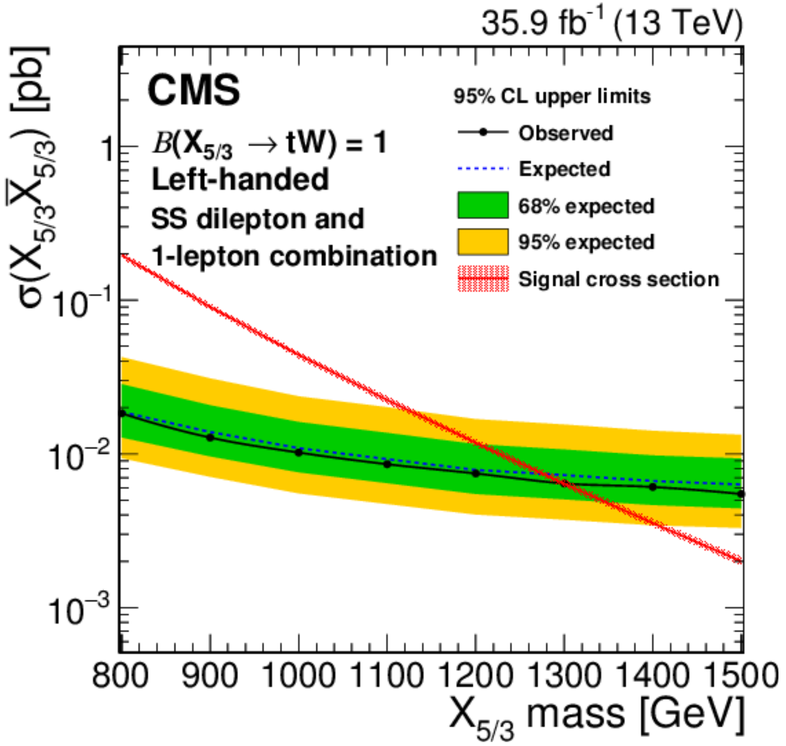


DNN

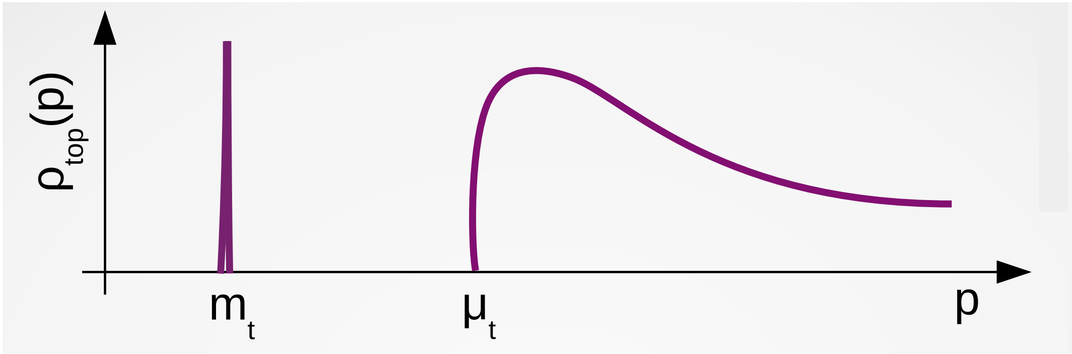


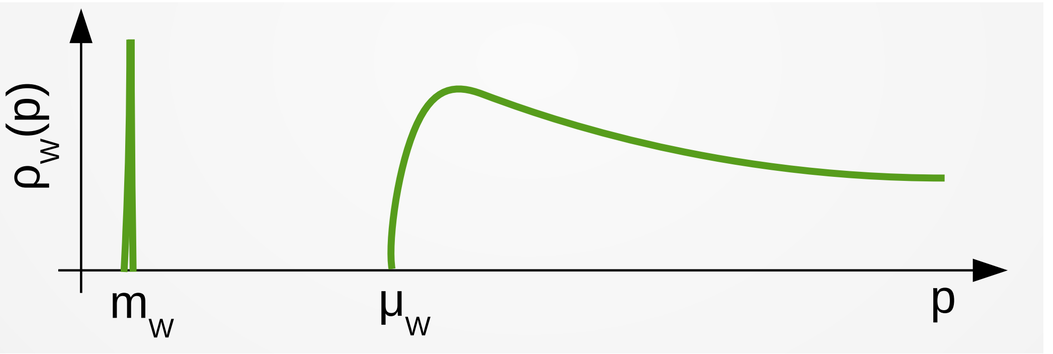
The DNN results are much insensitive to the width!

Continuum Naturalness (Gabriel Lee)

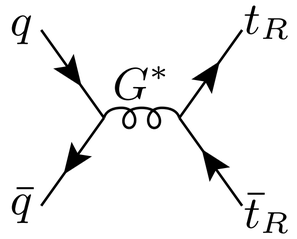


- Null results in LHC new physics searches
- Most LHC searches hunt for resonances
- What if new states are not particles?
- Build a model such that top and gauge boson partners form continua

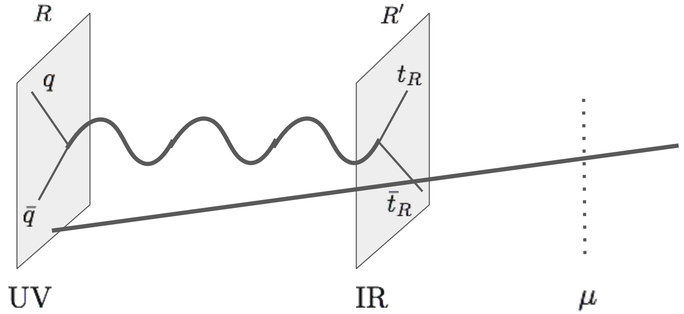


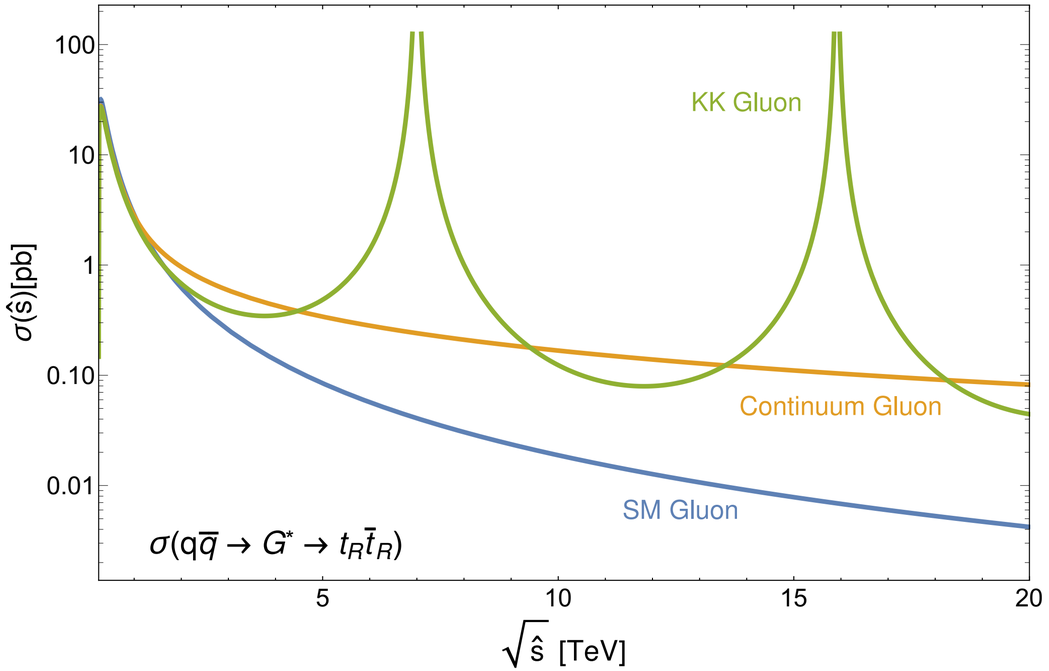


Continuum Naturalness (Gabriel Lee)



At the LHC, KK gluons are resonances in Drell-Yan processes, e.g., $q\bar{q} \to t_R\bar{t}_R$.





Instead, continuum gluons yield a smooth excess above the SM background, given by

$$\sigma(\hat{s}) \sim \sigma_{\rm SM}(\hat{s}) \times \hat{s}^2 |G(R, R'; \hat{s})|^2$$

Strong Hidden Fermion Production and Relaxation

(Fang Ye)

How to solve hierarchy problem? (naturalness)

- Solution (i): + symmetry, e.g. SUSY

  Higgs mass: sensitive to large UV corrections

  SUSY near EW scale solves hierarchy prob.

- Solutions (ii): via **dynamics**, e.g. **cosmological relaxation** of EW scale

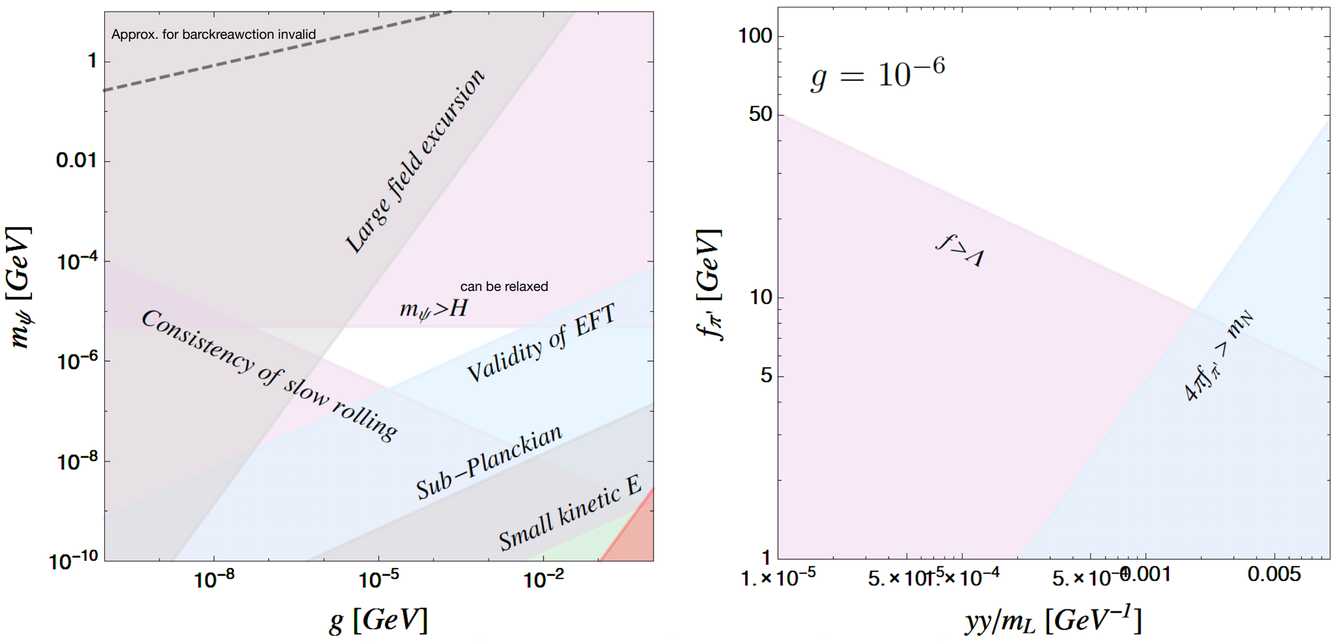
  Due to the null result @ LHC, this is an increasingly motivated scenario

Strong Hidden Fermion Production and Relaxation (Fang Ye)

- Relaxion: axion-like particle (ALP) whose periodic symmetry is **softly** and explicitly broken by a **small** coupling to Higgs (and also small self-coupling)

[Graham, Kaplan, Rajendran (GKR), 1504.07551]

A single non-QCD relaxion

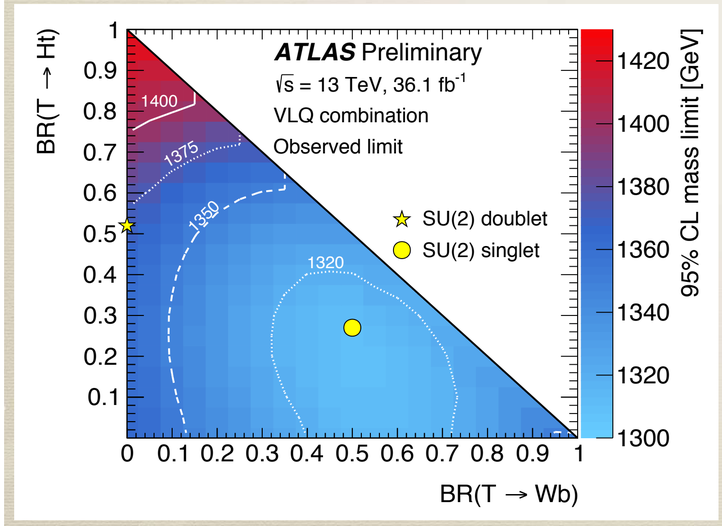


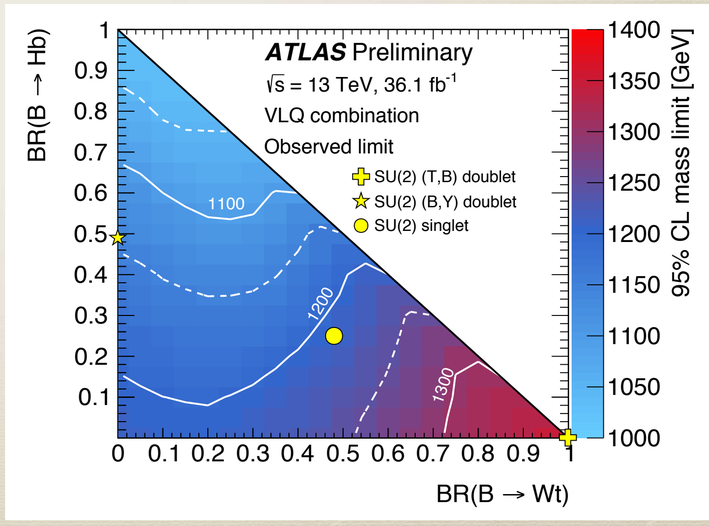
$\Lambda = 10^4$ GeV, $H = 5 \times 10^{-6}$ GeV, $f_\psi = 0.5$ GeV, and $N_e = 100$

Composite Higgs Models and Exotic Decays of Vector-Like Quarks (Thomas Flacke)

$X_{5/3}$ (with $X_{5/3} \rightarrow tW^+$): $M_X \gtrsim 1.3$ TeV, [CMS PAS B2G-16-019, ATLAS: 1806.01762]

T & B: Combined bounds on pair-produced top partners



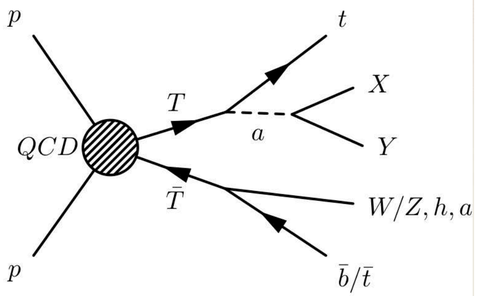


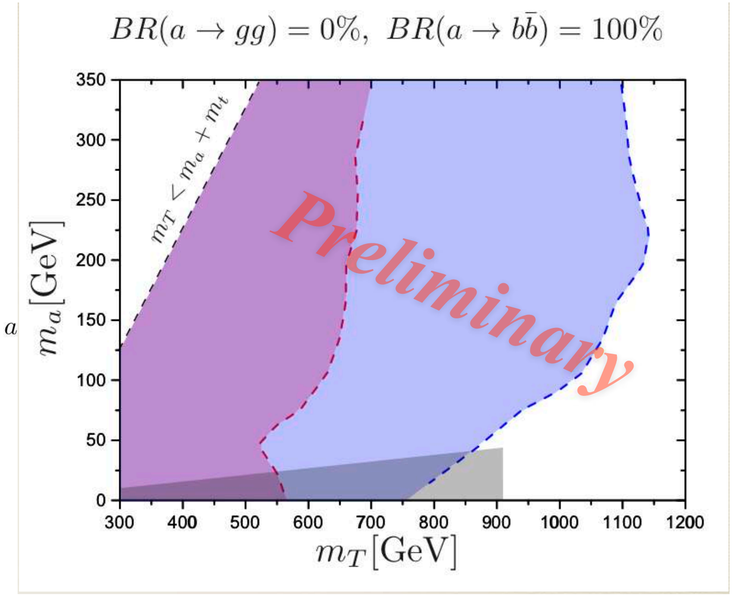
[ATLAS-CONF-2018-032]

- Future colliders will greatly improve the sensitivity to composite Higgs models via Higgs precision measurements, electroweak precision measurements, top pair production precision measurements, and (100 TeV collider) high-mass VLQ searches
- "Exotic" decays of top partners to t/b + pNGBs rather than to t/b + W/Z/h occur commonly in CH UV embeddings
  - These decays lead to many final states which are not explicitly targeted by current LHC searches

Composite Higgs Models and Exotic Decays of Vector-Like Quarks (Thomas Flacke)

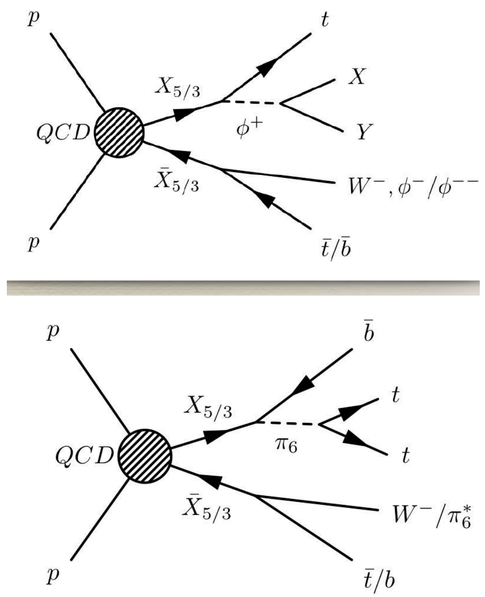
T->ta

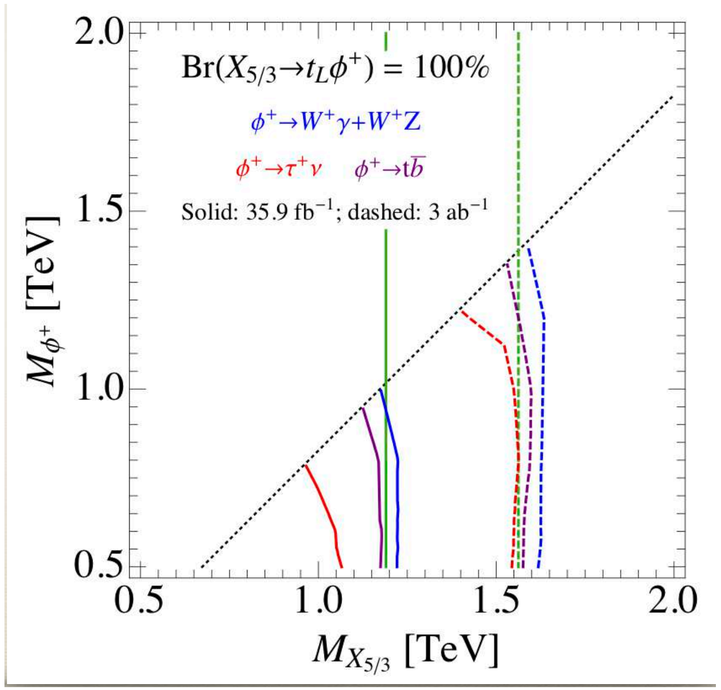




Red: RPV-SUSY (hadronic)	Recast searches Blue: VLQ search	Gray: Excited top search
CERN-EP-2015-020 (ATLAS) CERN-EP-2017-298 (ATLAS)	CERN-EP-2018-031 (ATLAS)	CERN-EP-2017-272 (CMS)

$X_{5/3}$ -> $b\pi_6$ or $t\phi^+$





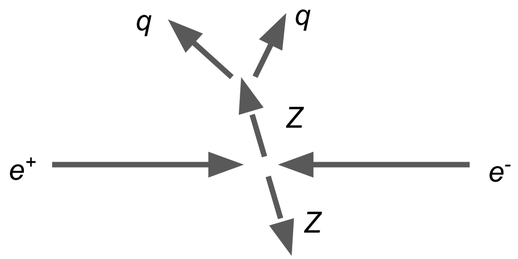
Recasting the most recent CMS $X_{5/3}$ same-sign lepton search JHEP 1903, 082

Searches for New Physics with Jet Time Substructure (Matthew Klimek)

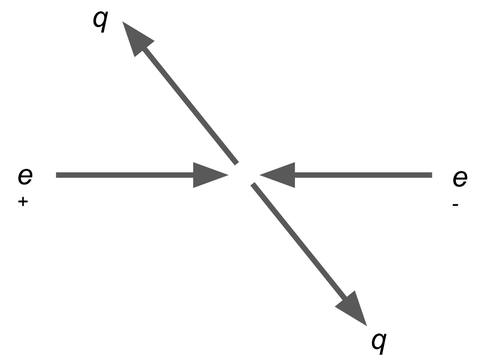
For meter-scale detectors, $n \sim 10$, $E \sim 100$ GeV, typical time-of-flight differences among jet hadrons:

$$\Delta t \sim R\Delta v \sim 10^{-8} \left(\frac{10 \times 1 \text{ GeV}}{100 \text{ GeV}} \right)^2 \text{ s} \sim 100 \text{ ps}$$

Signal:
ZZ to quarks

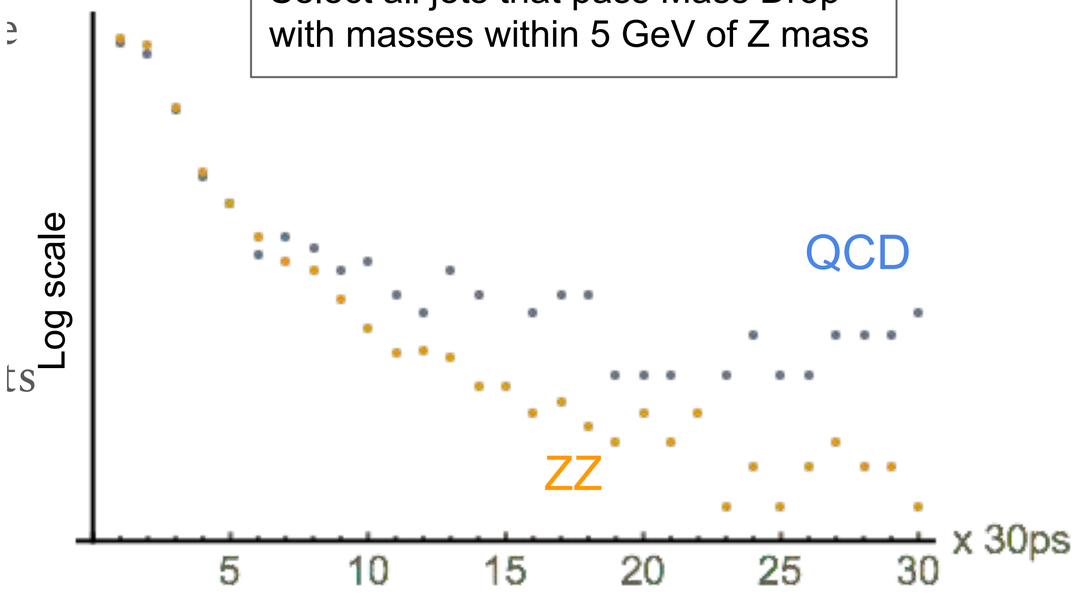


Background:
≤4 jets



ZZ jet hadrons have narrower arrival time distribution because they are more boosted

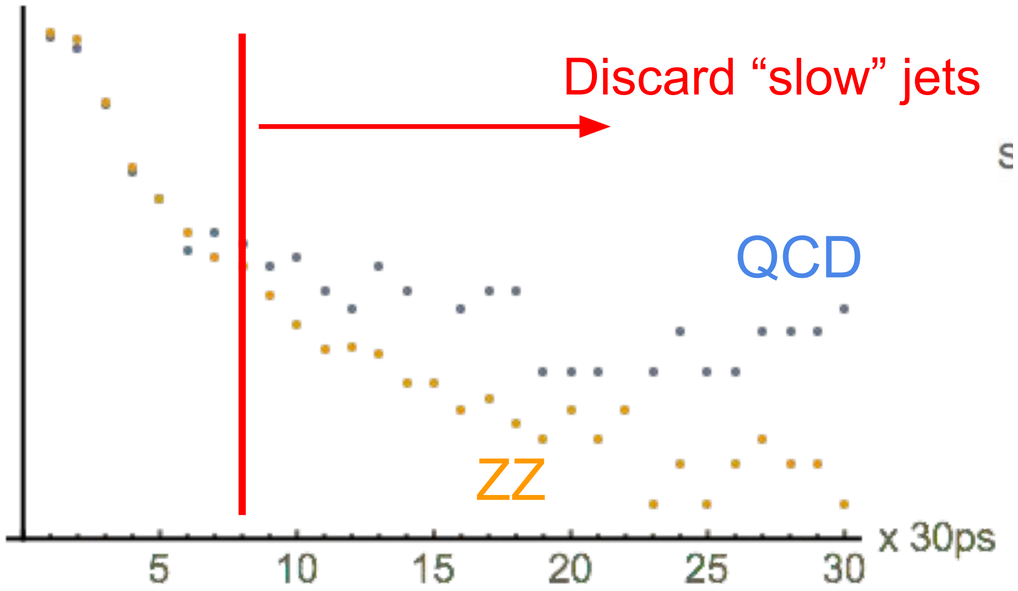
Select all jets that pass Mass Drop with masses within 5 GeV of Z mass



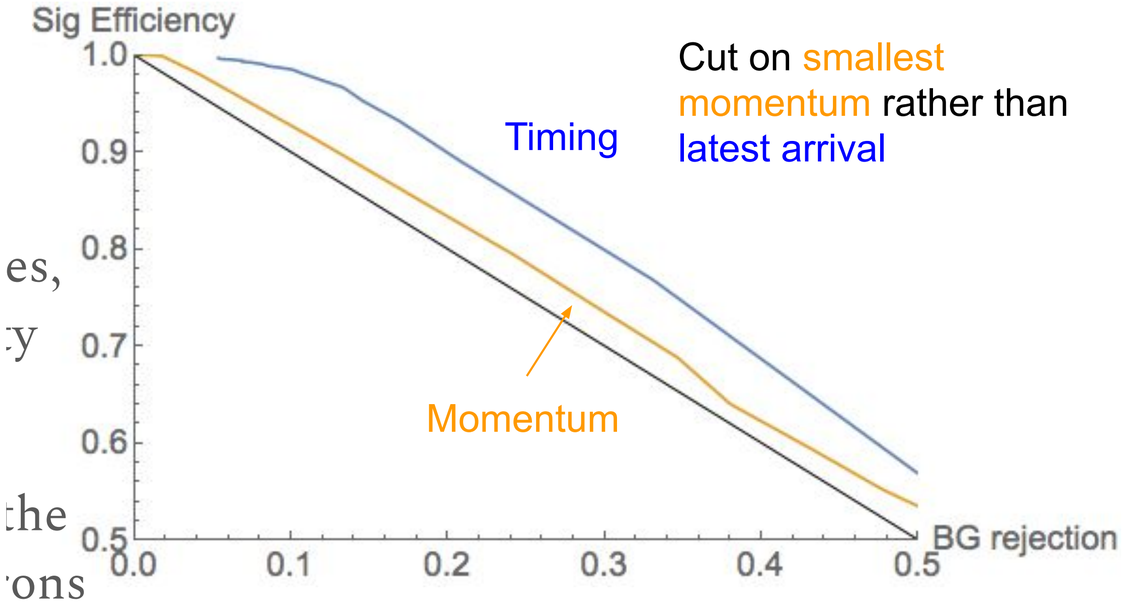
Arrival delay of latest (detectable) charged hadron

Searches for New Physics with Jet Time Substructure

(Matthew Klimek)



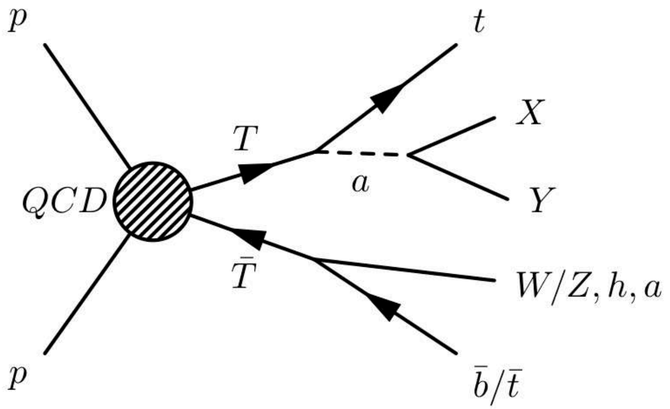
Arrival delay of latest (detectable) charged hadron

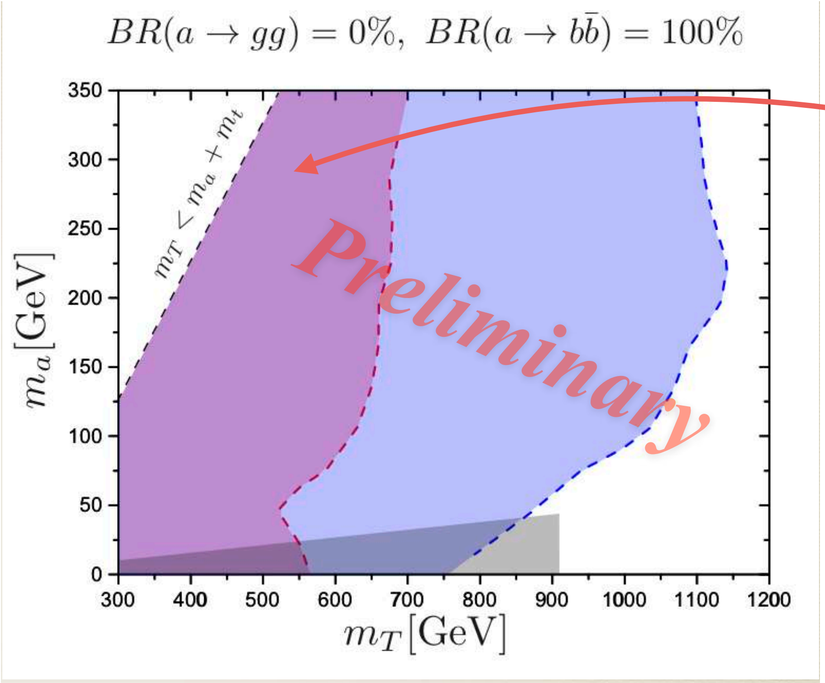


Future timing detector technology has capability
e.g., CMS time layer has ~30 ps resolution

Activities during the workshop

- Interesting ideas delivered by the speakers during the BSM sessions
- They initiated some followup discussions, e.g.,





Red:
RPV-SUSY (hadronic)
CERN-EP-2015-020 (ATLAS)
CERN-EP-2017-298 (ATLAS)

CMS 1L RPV SUSY search can be sensitive to this model if selection is adjusted

Conclusion and future direction

- A few very interesting ideas were presented (models and techniques)
- Phenomenology is mostly focused on hadron colliders
  - Understandable for direct searches
  - Is any of the ideas applicable in lepton colliders?
- This workshop is just the beginning
  - Hope there are more collaborations even after the workshop