Tagging new physics with charm

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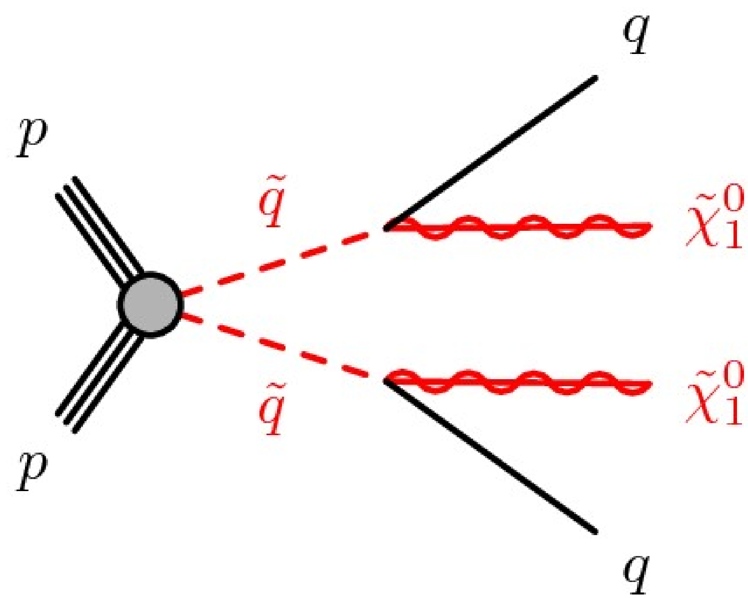
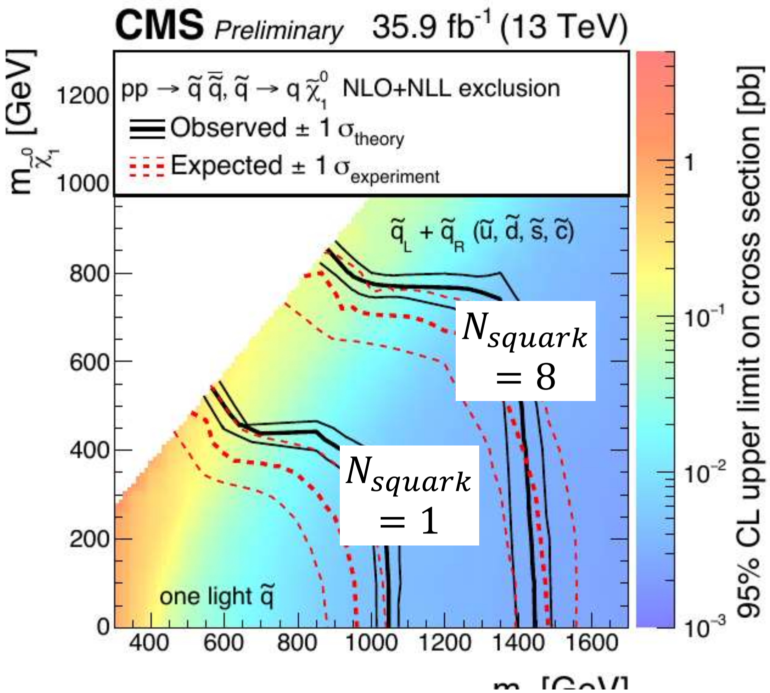
1703.05748

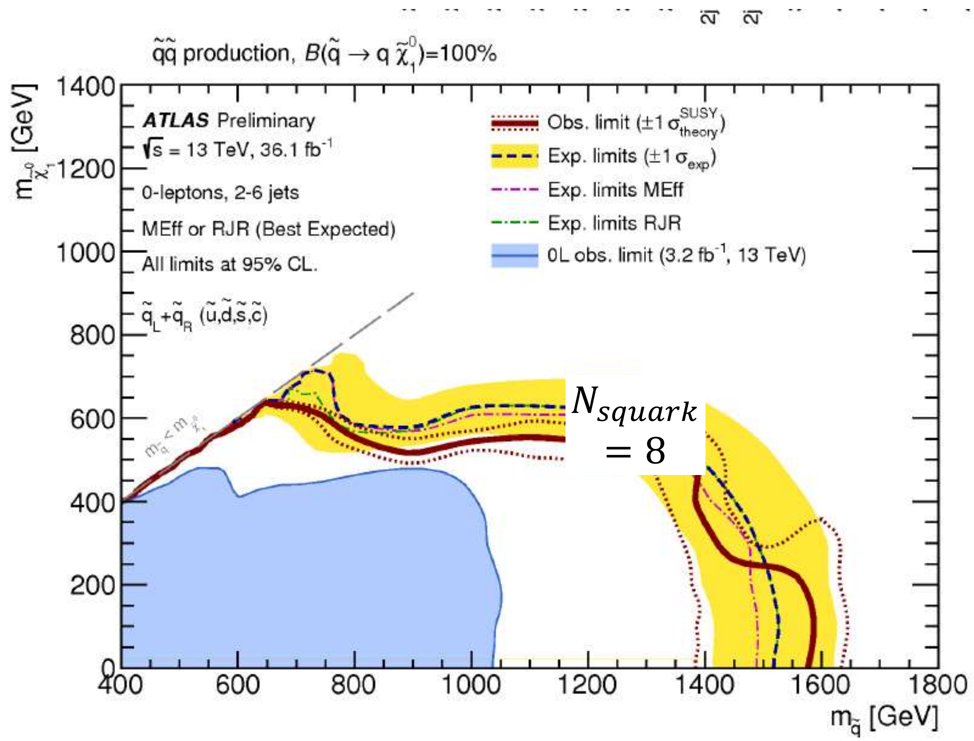
squark searches @ LHC, (HL)LHC



2*j*+MET

Moriond 2017: (decoupled gluino)





CMS excluded region: 13 TeV, 35.9 fb^{-1} :

for $m_{\tilde{g}} = \infty$ and $m_{\mathrm{LSP}} = 0$,

- $N_{\tilde{q}} = 1$: $m_{\tilde{q}}$ < 1.05 TeV
- $N_{\tilde{q}} = 8$: < 1.55 TeV
- $N_{\tilde{q}} = 2$: $\lesssim$ 1.2 TeV
- $N_{\tilde{q}} = 4$: $\lesssim$ 1.35 TeV

CMS excluded region:

$13\,\mathrm{TeV}, 35.9\,\mathrm{fb}^{-1}$:

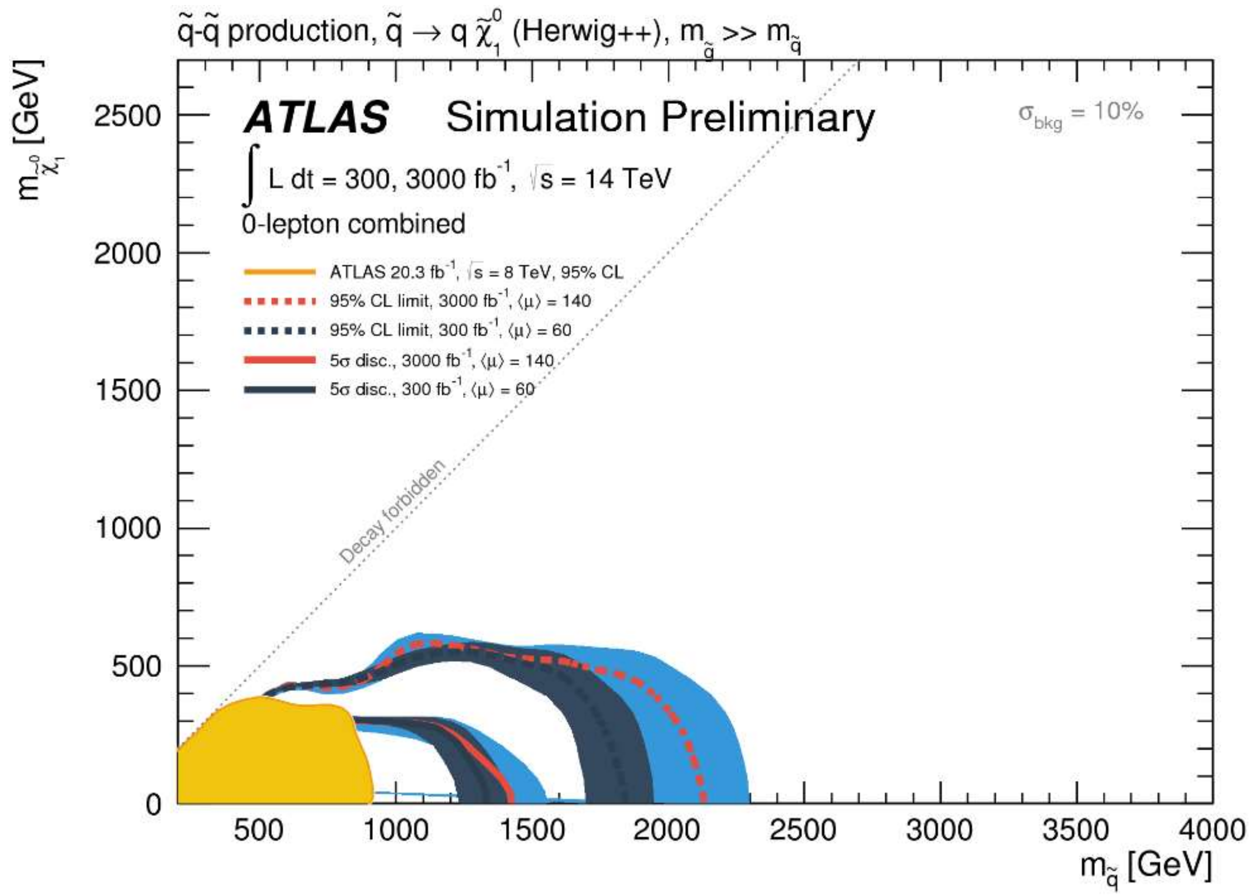
- $N_{\tilde{q}} = 8$: $< 1.55\,\mathrm{TeV}$

ATLAS projected reach:

$14\,\mathrm{TeV}, 3000\,\mathrm{fb}^{-1}$:

5σ disc. $m_{\tilde{q}} \lesssim 1.4\,\mathrm{TeV}$

2σ excl. $m_{\tilde{q}} \lesssim 2.2\,\mathrm{TeV}$



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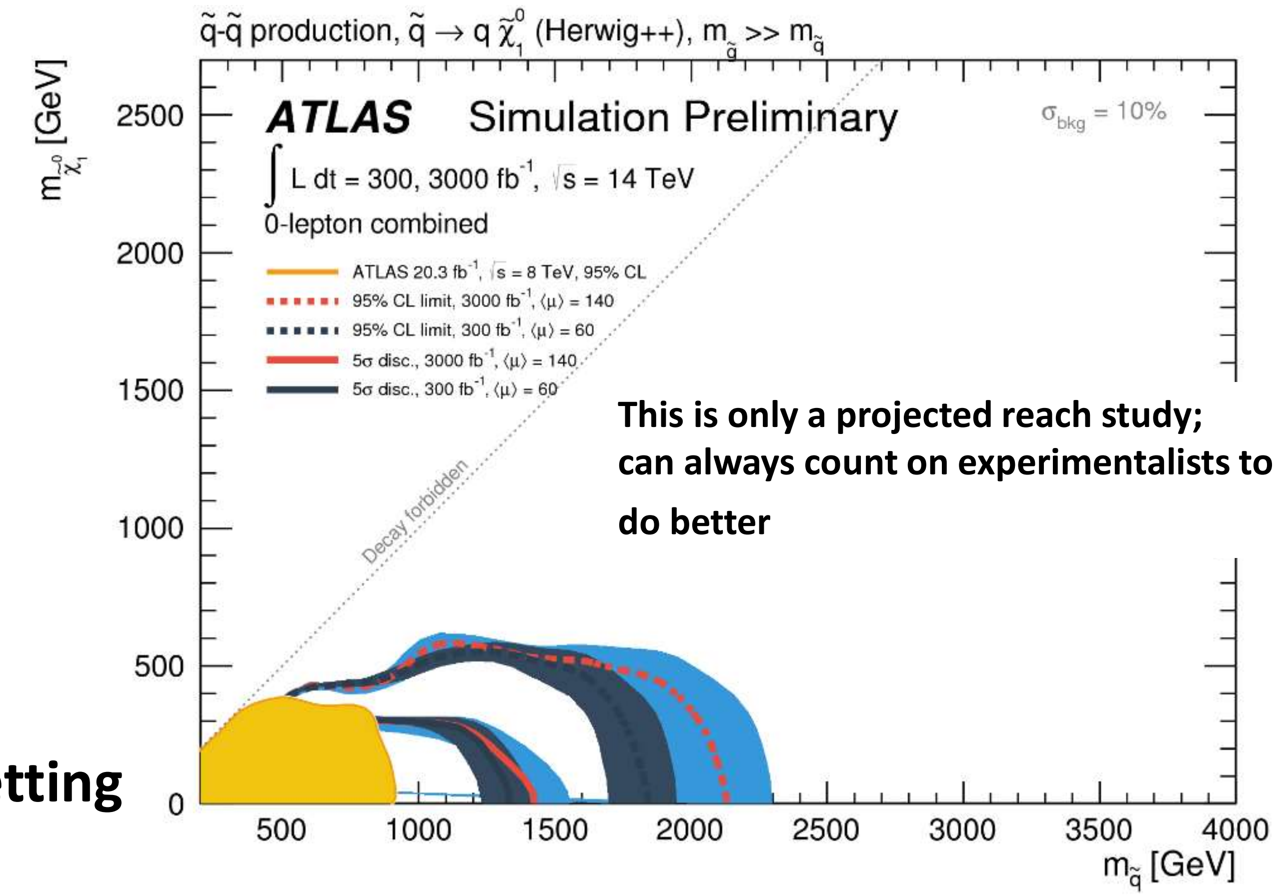


This is only a projected reach study; can always count on experimentalists to do better

discovery prospects getting super slim

charm tagging:

- can we use charm tagging to improve discovery prospects?
  - most challenging: heavy gluino – smallest production cross-section
  - not necessarily supersymmetry: any ``quark-partners” with decays to jets+MET

- beyond discovery: if 2j+MET excess: what is it?
  - is it supersymmetry?
  - if supersymmetry: how many squarks are we seeing?
  - gluino mass (future colliders)?

experimentally: charm tagging is more difficult than b tagging

theoretically: charm tagging, bottom tagging give different sorts of information

the 3^{rd} generation is special: stop, sbottom may have different mass from other squarks (more generally for top, bottom partners)

but squark masses may be 1^{st}-2^{nd} generation flavor blind (at least approximately)

charm tagging probes this 1-2 structure

a few words on charm tagging:

CMS

Identification of c-quark jets at the CMS experiment
PAS BTV-16-001

- MVA–based discriminator
  - displaced tracks
  - secondary vertices
  - soft leptons
- calibration on W+c, top quark pairs (13 TeV, first year of Run II, 2.6 fb^(-1))

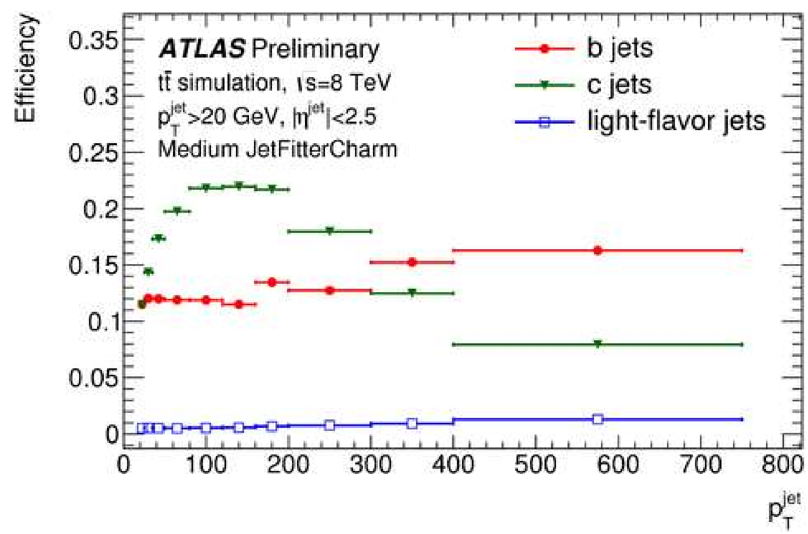
WP	ϵ^c	ϵ^b	ϵ^{light}	CvsL	CvsB
c-tagger L	0.9	0.45	0.99	$>$ -0.67	$>$-0.23
c-tagger M	0.39	0.26	0.19	$>$ 0.05	$>$ -0.16
c-tagger T	0.2	0.24	0.02	$>$ 0.45	$>$ -0.35

ATLAS Performance and Calibration of the JetFitterCharm Algorithm for c-Jet Identification

ATL-PHYS-PUB-2015-001

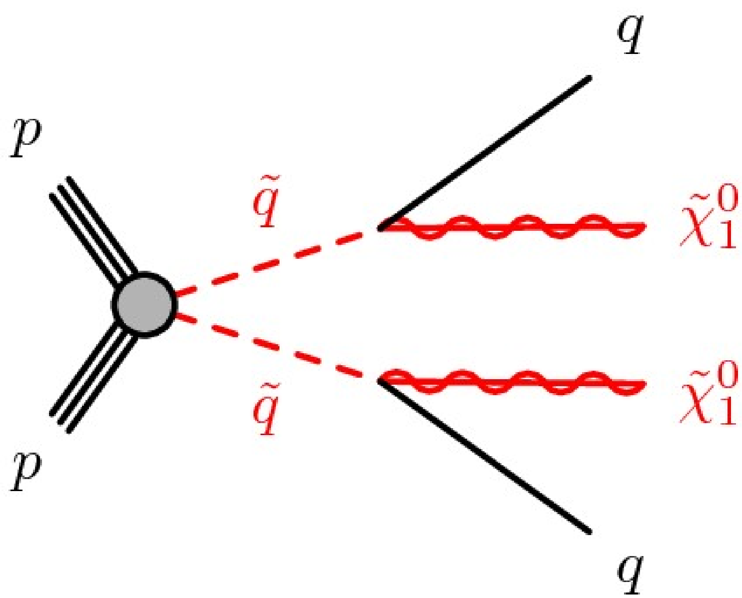
- impact parameter
- secondary-vertex (reconstruct b to c decay vtx: especially useful for b vs c)
- calibration multi-jet events with reconstructed D mesons, t-tbar pairs

working point: 19% 13% 0.5%



more work currently
ATLAS: IBL
+ **machine learning**

back to: squark production



simplified model with $1^{st}+2^{nd}$ generation squarks, gluino, bino LSP

assume:

- squarks of the same gauge quantum numbers are degenerate; but some hierarchies may exist between up/down, L/R
- only the **lightest** (degenerate) squarks can be produced at the LHC (requires only mild hierarchies)
- the gluino is very heavy: cannot be produced at LHC

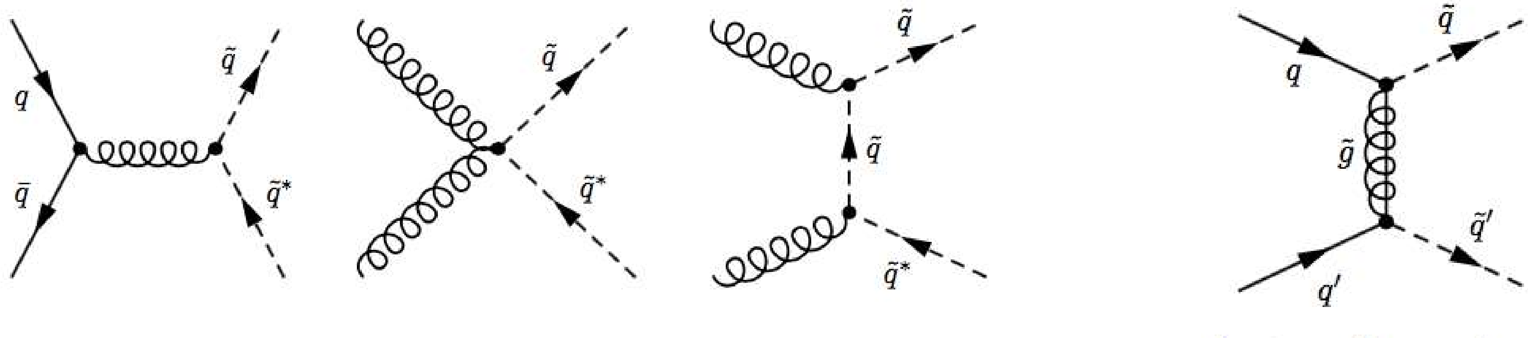
3 benchmark scenarios:

- $N_{\tilde{q}} = 2$: $\tilde{u}_R$, $\tilde{c}_R$ (degenerate)
- $N_{\tilde{q}} = 4$: $\tilde{u}_R$, $\tilde{c}_R$, $\tilde{d}_R$, $\tilde{s}_R$
- $N_{\tilde{q}} = 8$: all the 8 squarks

can be produced at the LHC

$$pp \to \widetilde{q}\widetilde{q}^* \to q\bar{q} + \not{E}_{\mathrm{T}};$$

$$\widetilde{q} = \text{ some of } \quad \widetilde{u}_{\mathrm{L,R}}, \widetilde{d}_{\mathrm{L,R}}, \widetilde{s}_{\mathrm{L,R}}, \widetilde{c}_{\mathrm{L,R}}.$$



standard searches:

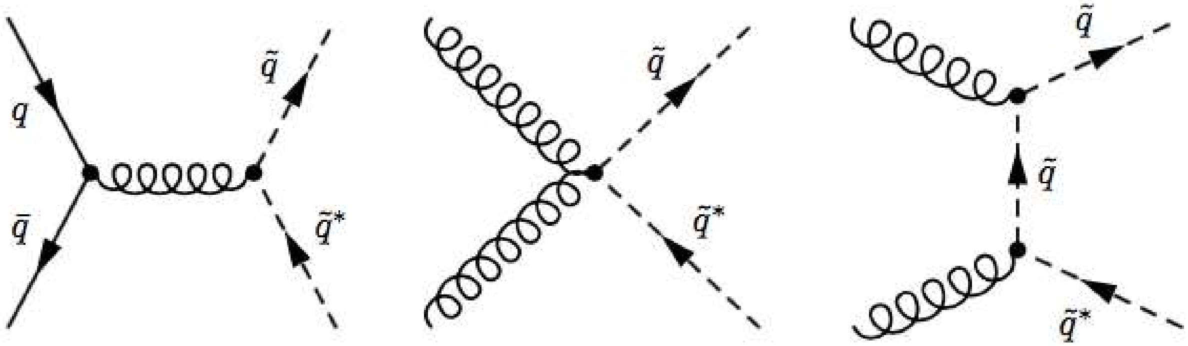
number of events passing 2j+MET selection:

$$\sigma = \sigma(m_{\widetilde{q}}, m_{\widetilde{g}}, N_{\widetilde{q}})$$

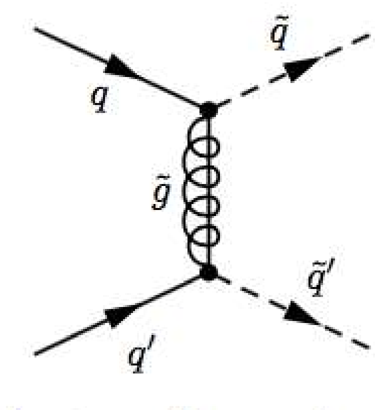
+ kinematic info, eg: $m_{\rm T2} \leq m_{\rm T2}^{\rm endpoint}(m_{\widetilde{q}}, m_{\rm LSP})$

$$\left(\approx \frac{m_{\widetilde{q}}^2 - m_{\rm LSP}^2}{m_{\widetilde{q}}}\right)$$

charm tagging: a handle on flavor (in 1st-2nd generation):



flavor universal



flavor dependent:
dominated by valence (s)quarks
and → large (decouples slowly with gluino mass)

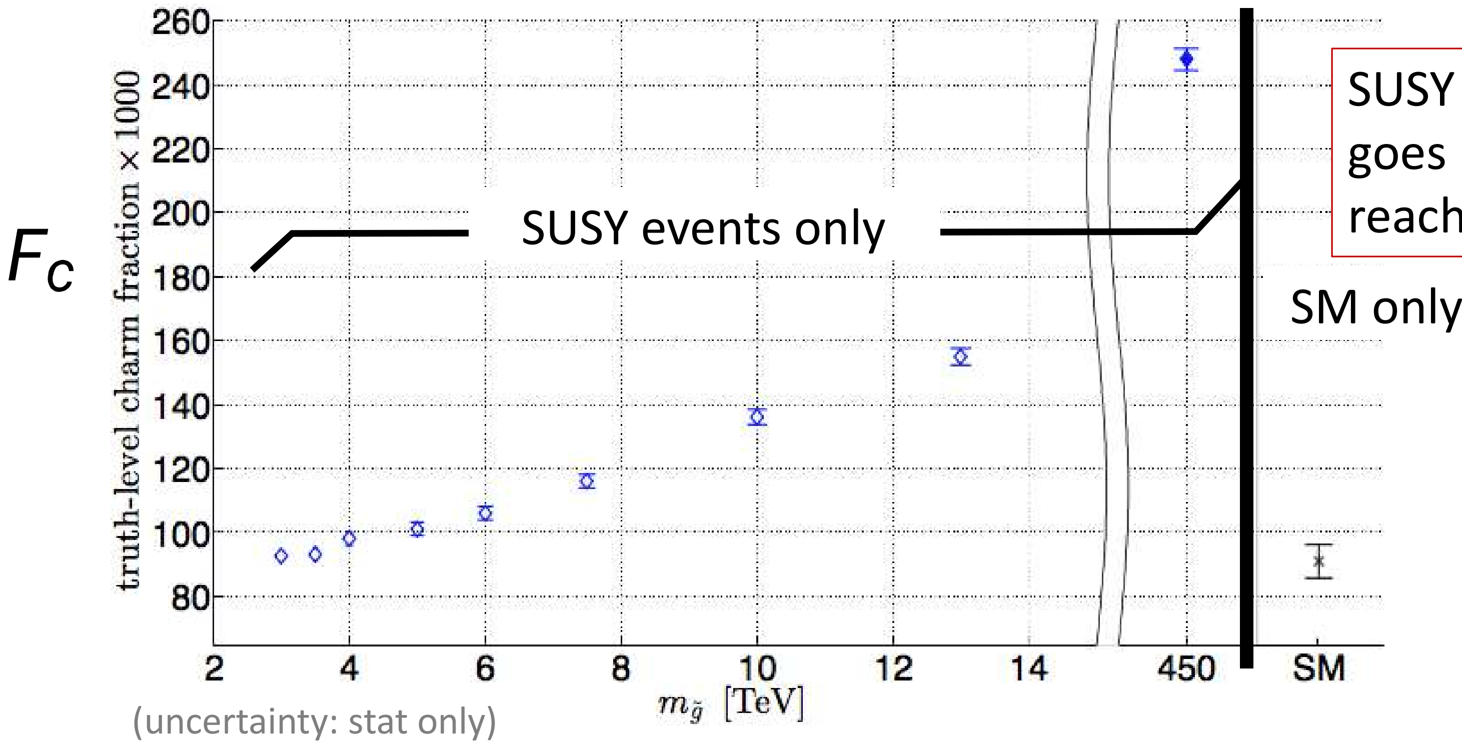
charm content of sample: sensitive to gluino mass
large for heavy gluino

CHARM FRACTION:

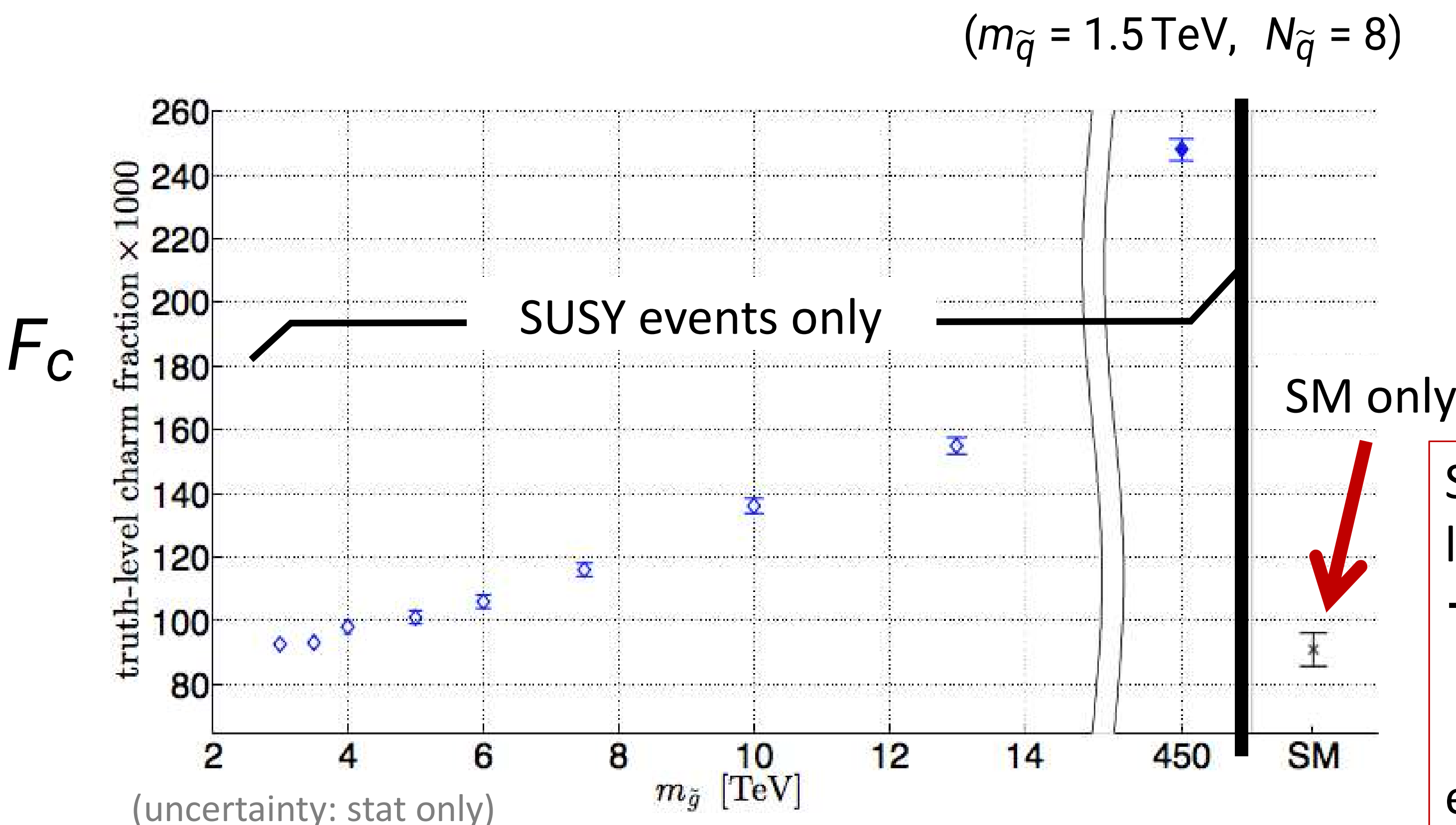
$$F_c := \frac{N(\text{c-tagged jet})}{N(\text{jet})}$$

with an ideal tagger (100% efficiency, no mistags):

($m_{\tilde{q}}$ = 1.5 TeV, $N_{\tilde{q}}$ = 8)



SUSY charm fraction:
goes up with gluino mass
reaches ¼ for decoupled gluino



SUSY charm fraction:
larger than SM
→ help discriminate
for discovery

especially for heavy gluino

analysis details:

simulate squark pair production + decay following ATLAS 2jet+MET analyses:

- (HL)LHC: ATLAS HL-LHC (PHYS-PUB-2014-010; Meff-2j-3100)
- current exclusions: ATL-CONF-2016-078 (Meff-2j-2000)

		Meff-2j-2000	Meff-2j-3100
Number of jets, electrons, muons		$\geq 2, = 0, = 0$	
$\not{E}_T$ [GeV]	$>$	250	160
$p_T(j_1), p_T(j_2)$ [GeV]	$>$	250, 250	160, 60
$\lvert\eta(j_1, j_2)\rvert$	$<$	1.2	—
$\Delta\phi(j_{1,2,(3)}, \not{E}_T)_{\min}$	$>$	0.8	0.4
$\Delta\phi(j_{i>3}, \not{E}_T)_{\min}$	$>$	0.4	0.2
$\not{E}_T/\sqrt{H_T}$ [GeV$^{1/2}$]	$>$	20	15
m_{eff}(incl.) [GeV]	$>$	2000	3100

- SUSY and SM by MG5+Pythia6/taoula+Delphes3.3.0
- SUSY: prospino NLO
- SM: rescaling wrt ATLAS simulation

SM background:

3100Meff: Z (invisible) + jets

[2100Meff: also W (hadronic tau, or lost lepton) + jets]

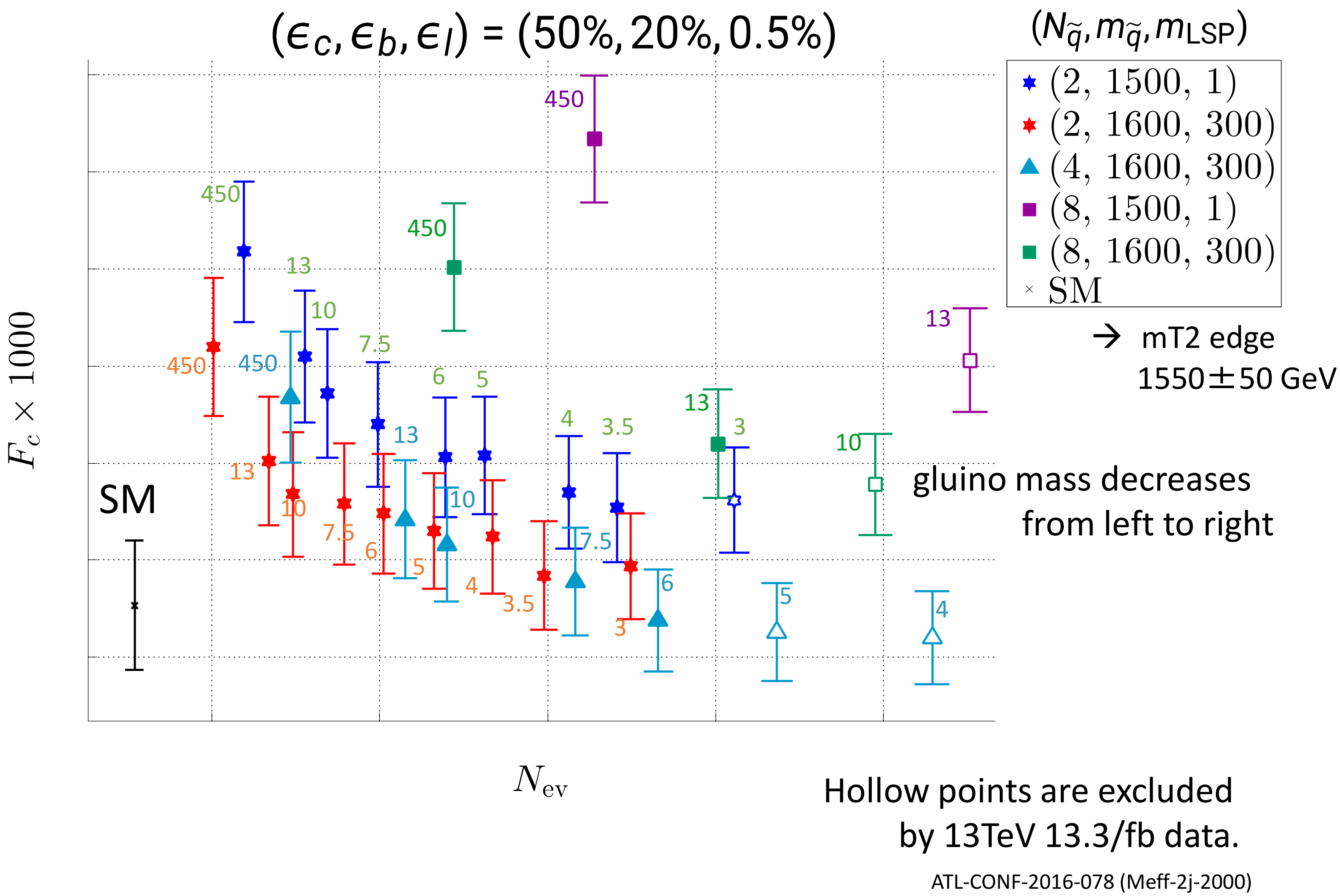
in principle: Z (invisible) + jets and its charm content can be measured via

Z (l+l-) + jets

gedunken charm-tagging:

take 2 hardest jets in each event:

- for each jet: go to truth-level Pythia output and check whether jet contains b, c → label jet as b, c, light accordingly
- multiply numbers by efficiency/mistag rate

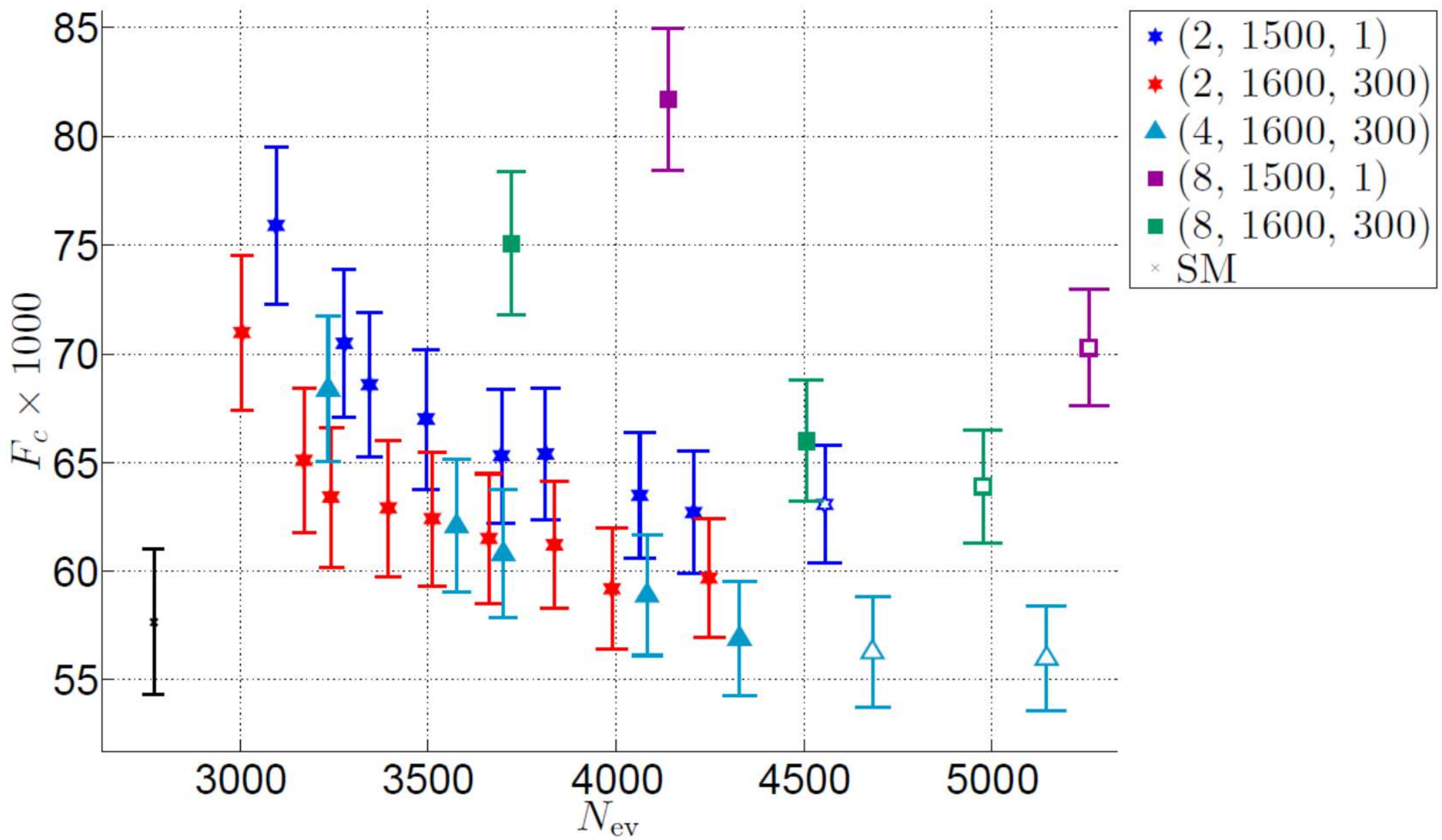


$(\epsilon_c, \epsilon_b, \epsilon_l)$ = (50%, 20%, 0.5%)
$(N_{\tilde{q}}, m_{\tilde{q}}, m_{\rm LSP})$
(2, 1500, 1)
(2, 1600, 300)
(4, 1600, 300)
(8, 1500, 1)
(8, 1600, 300)
SM
→ mT2 edge
1550±50 GeV
gluino mass decreases
from left to right
Hollow points are excluded
by 13TeV 13.3/fb data.
ATL-CONF-2016-078 (Meff-2j-2000)
$F_c \times 1000$
$N_{\rm ev}$

DISCOVERY

uncertainty:
stat only, ***y*-axis only**

$(\epsilon_c, \epsilon_b, \epsilon_l) = (50\%, 20\%, 0.5\%)$



DISCOVERY

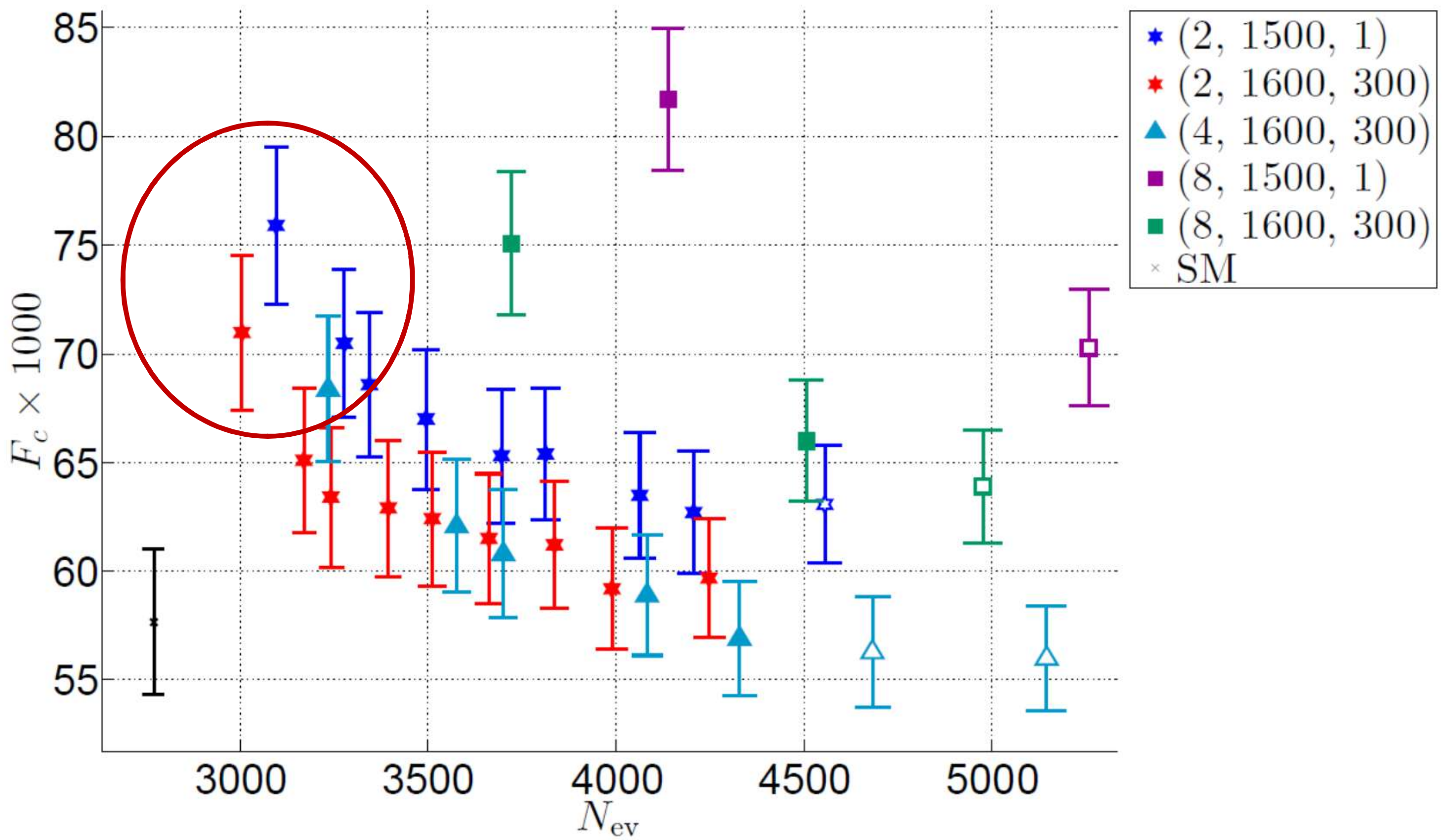
uncertainty:
stat only, ***y*-axis only**

standard analyses:
x-axis only:
with ~10% uncertainty:
discovery challenging

charm fraction increases
sensitivity

many systematic errors
cancel in ratio:
** systematic uncertainty on charm tagging; PDFs

$(\epsilon_c, \epsilon_b, \epsilon_l)$ = (50%, 20%, 0.5%)



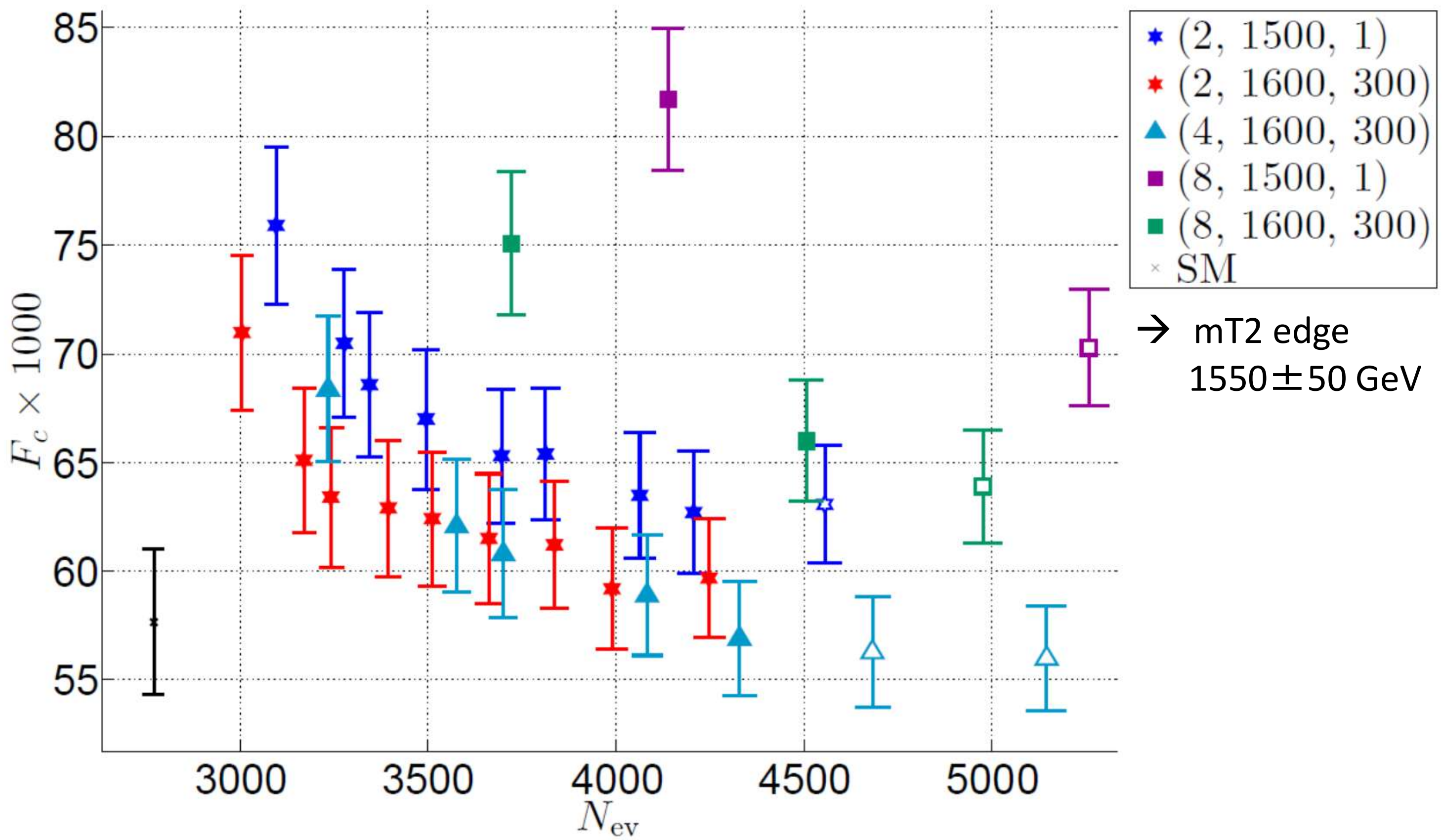
post-DISCOVERY

$(\epsilon_c, \epsilon_b, \epsilon_l)$ = (50%, 20%, 0.5%)

with x-axis only: can't discriminate between different models

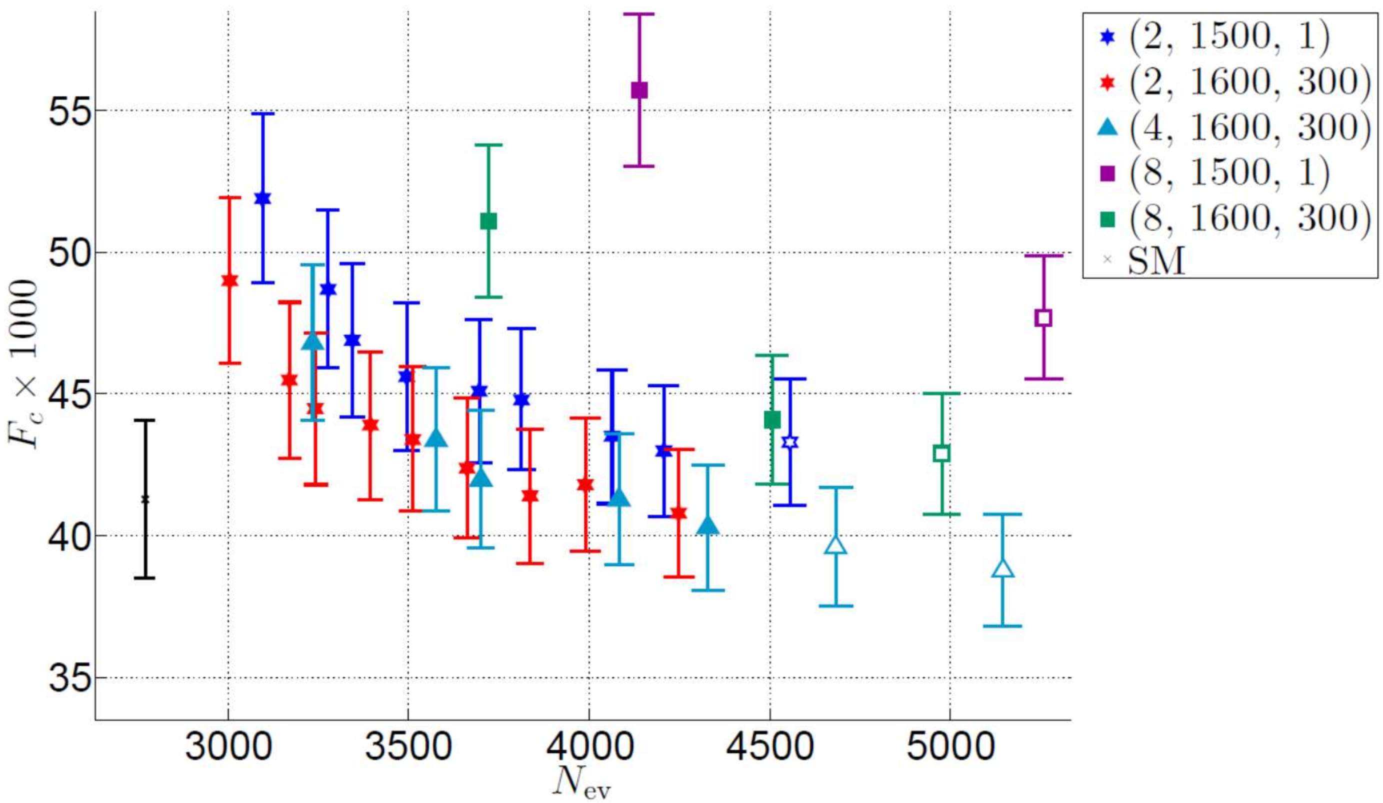
charm fraction: helps break degeneracy

discriminate between ``no gluino" and below 10TeV : syst uncertainties on c-tagging crucial



→ mT2 edge 1550±50 GeV

$(\epsilon_c, \epsilon_b, \epsilon_l) = (30\%, 20\%, 0.5\%)$



To conclude

what's going on at the weak scale?

charm tagging provides a novel handle

SM measurements and NP searches are both interesting

- Z+charm cross section CMS-PAS-SMP-15-009
- charm squark search $(pp \to \tilde{c}\tilde{c}^*)$ ATLAS [1501.01325]

○ Higgs charm Yukawa (Higgs to c cbar) Perez, Soreq, Stamou, Tobioka [1505.06689]

- compressed top squark $(pp \to \tilde{t}\tilde{t}^*, \quad \tilde{t} \to c + \not{E}_T)$ ATLAS [1407.0608], CMS [CMS-PAS-SUS-13-009]

○ flavored naturalness top-charm mixing Giudice, Paradisi, Perez, Zupan [1302.7232] here:

additional handle for squark searches

if discovered: what is it? are there additional particles beyond LHC?

- how many squarks?
- gluino mass?
- Dirac vs Majorana?
- flavor: if small mass splittings → mixings:

$$pp \to \tilde{u}\tilde{c}^* \to u\bar{c} + \not{E}_T$$

Thank you!