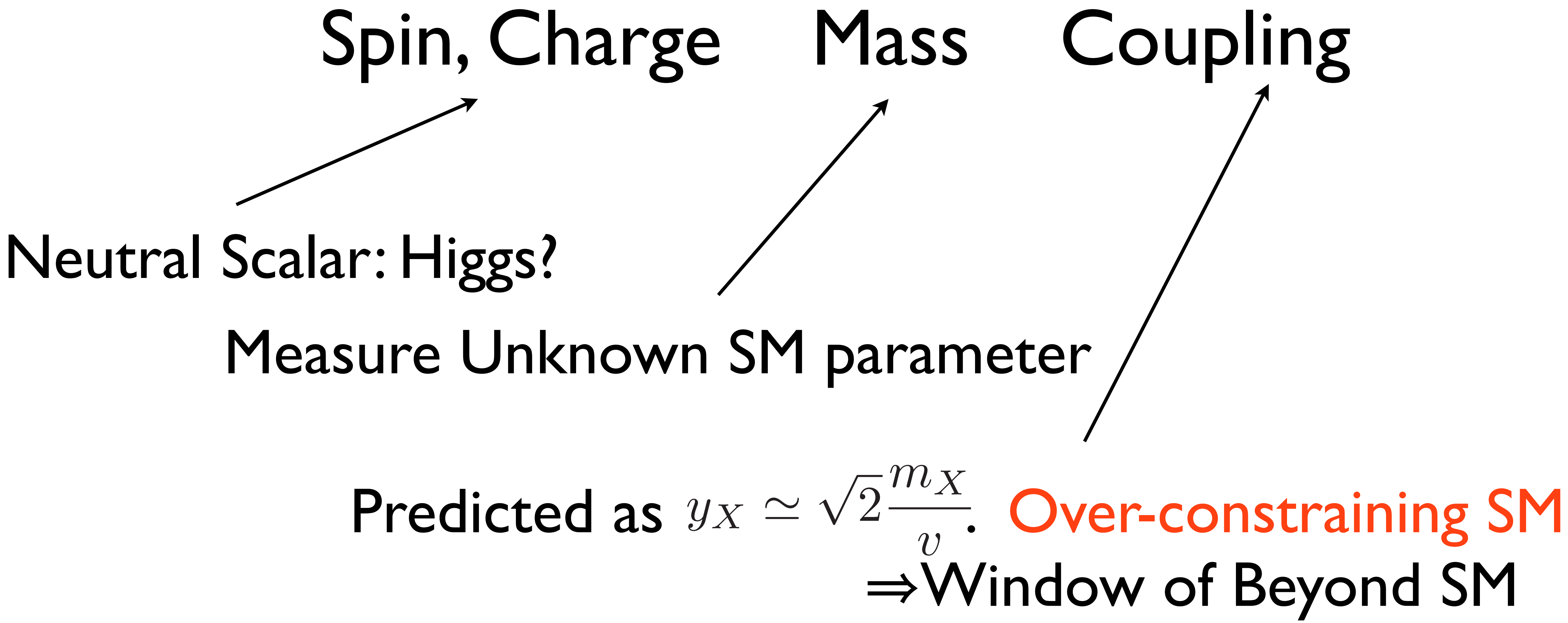
High Energy Flavour Physics

LHCP Conference, St Petersburg
Sept 4, 2015

Kohsaku Tobioka
KEK, Tel Aviv U, Weizmann Institute

Higgs in Standard Model



Spin, Charge   Mass   Coupling

Neutral Scalar: Higgs?

Measure Unknown SM parameter

Predicted as $y_X \simeq \sqrt{2}\frac{m_X}{v}$. Over-constraining SM

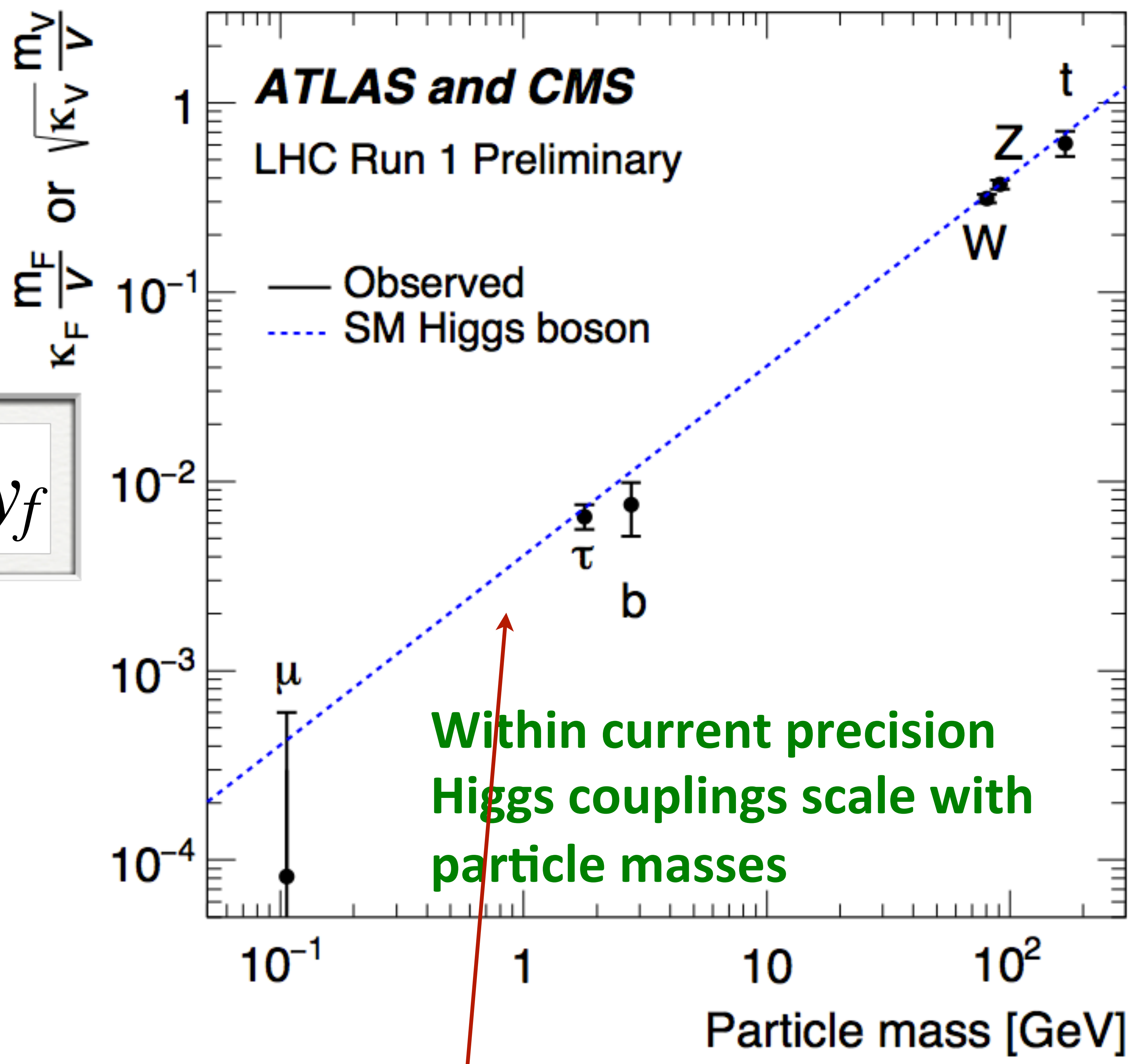
⇒Window of Beyond SM

$$y_u H Q u_R + \frac{|H|^2 H Q u_R}{\Lambda^2}$$

G. F. Giudice, O. Lebedev (08)
A. L. Kagan, G. Perez, T. Volansky, J. Zupan (09)
C. Delaunay, T. Golling, G. Perez, Y. Soreq (13)
and many

Talk by M. Pieri

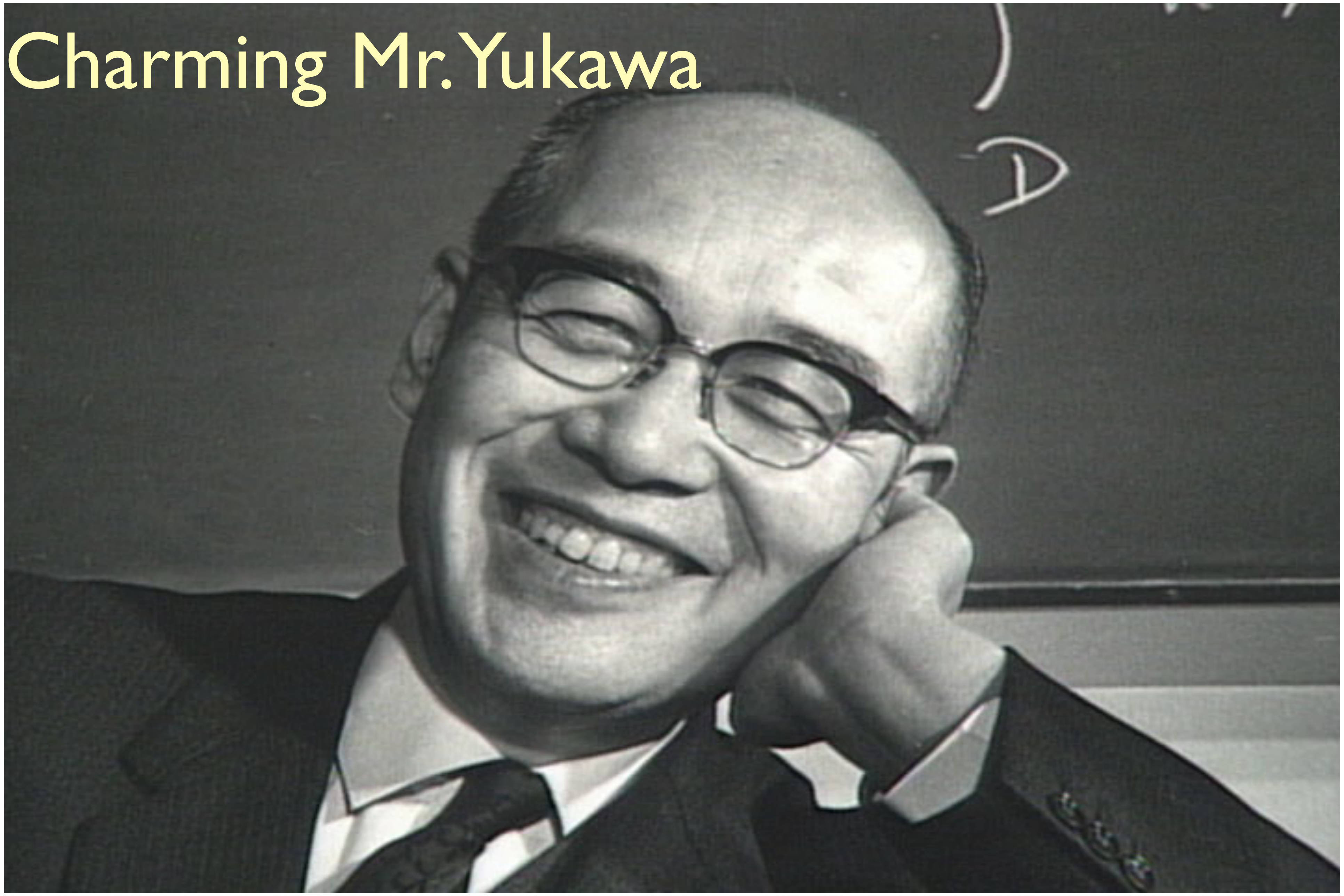
g_v, y_f



Within current precision Higgs couplings scale with particle masses

Next challenge is charm?

Charming Mr. Yukawa



Inclusive

$h\rightarrow \mathrm{cc}$

Exclusive

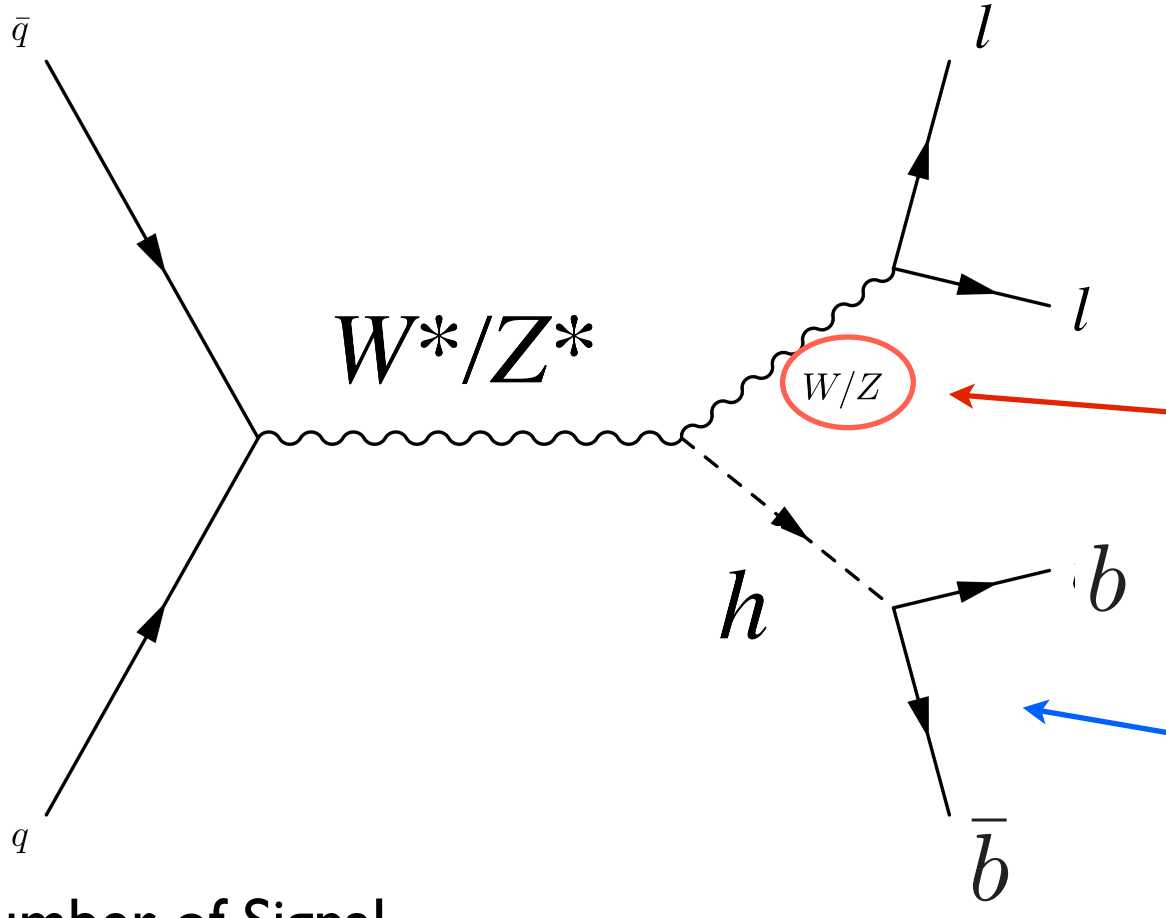
$h\rightarrow \mathrm{J}/\psi+\gamma$

Inclusive

$h \to cc$

Perez, Soreq, Stamou, KT
arXiv: 1503.00290 and 1505.06689

Vh (Associate) production



0,1, 2 lep

W/Z **reconstructed**

categorize by p_T^V

2 b-tags required

ATLAS	Med	Tight	CMS	Loose	Med1	Med2	Med3
ϵ_b	70%	50%	ϵ_b	88%	82%	78%	71%
ϵ_c	20%	3.8%	ϵ_c	47%	34%	27%	21%

Number of Signal

$$S^{VH} = \mathcal{L} \cdot \sigma \cdot \mathrm{Br}_b \cdot \epsilon_{b_1} \epsilon_{b_2} \cdot \epsilon$$

Tagging Efficiency of b-jet

Signal strength

$$\mu_b = \frac{S^{VH}_{obs}}{S^{VH}_{exp}} = \frac{\mathcal{L} \cdot \sigma \cdot \mathrm{Br}_b \cdot \epsilon_{b_1} \epsilon_{b_2} \cdot \epsilon}{\mathcal{L} \cdot \sigma_{SM} \cdot \mathrm{Br}_b^{SM} \cdot \epsilon_{b_1} \epsilon_{b_2} \cdot \epsilon} = \frac{\sigma \cdot \mathrm{Br}_b}{\sigma_{SM} \cdot \mathrm{Br}_b^{SM}}$$

$\mu_b^{\mathrm{ATLAS}} = 0.52 \pm 0.32 \pm 0.24 \quad \mu_b^{\mathrm{CMS}} = 1.0 \pm 0.5$ ⇒ **botom Yukawa**

ATLAS [arXiv:1409.6212] CMS [arXiv:1310.3687]

What if h→cc is enhanced?

$$\mu_b = \frac{S^{VH}_{obs}}{S^{VH}_{exp}} = \frac{\cancel{\mathcal{L}} \cdot \sigma \cdot \mathrm{Br}_b \cdot \epsilon_{b_1}\epsilon_{b_2} \cdot \cancel{\epsilon}}{\cancel{\mathcal{L}} \cdot \sigma_{SM} \cdot \mathrm{Br}_b^{SM} \cdot \epsilon_{b_1}\epsilon_{b_2} \cdot \cancel{\epsilon}}$$

➡ $$\frac{\sigma \cdot \mathrm{Br}_b \cdot \epsilon_{b_1}\epsilon_{b_2} + \sigma \cdot \mathrm{Br}_c \cdot \epsilon_{c_1}\epsilon_{c_2}}{\sigma_{SM} \cdot \mathrm{Br}_b^{SM} \cdot \epsilon_{b_1}\epsilon_{b_2}}$$

$$= \mu_b + \frac{\mathrm{Br}_c^{SM}}{\mathrm{Br}_b^{SM}} \frac{\epsilon_{c_1}\epsilon_{c_2}}{\epsilon_{b_1}\epsilon_{b_2}} \mu_c$$

$\mathrm{Br}^{SM}(h \to bb) = 0.57,$

$\mathrm{Br}^{SM}(h \to cc) = 0.028,$

$$\boxed{\mu_b + (0.05\,\epsilon_{c/b})\mu_c}$$

Large $\epsilon_{c/b}$, more sensitive to μ_c
but only constrain a combination (degeneracy)

⇨ Need very different working points $\epsilon_{c/b}$

Disentangle degeneracy

$\mu_b + (0.05\ \epsilon_{c/b})\mu_c$ ATLAS&CMS have different working points

	1st Tag	2nd Tag	$\epsilon_{c/b}$
(a)ATLAS	Med	Med	8.2×10^{-2}
(b)ATLAS	Tight	Tight	5.9×10^{-3}
(c)CMS	Med1	Med1	0.18
(d)CMS	Med2	Loose	0.19
(e)CMS	Med1	Loose	0.23
(f)CMS	Med3	Loose	0.16

$$L(\mu) = \prod_i P_{poiss}(k_i, N^{BG}_{SM,i} + \mu N^{signal}_{SM,i}).$$

Disentangle degeneracy

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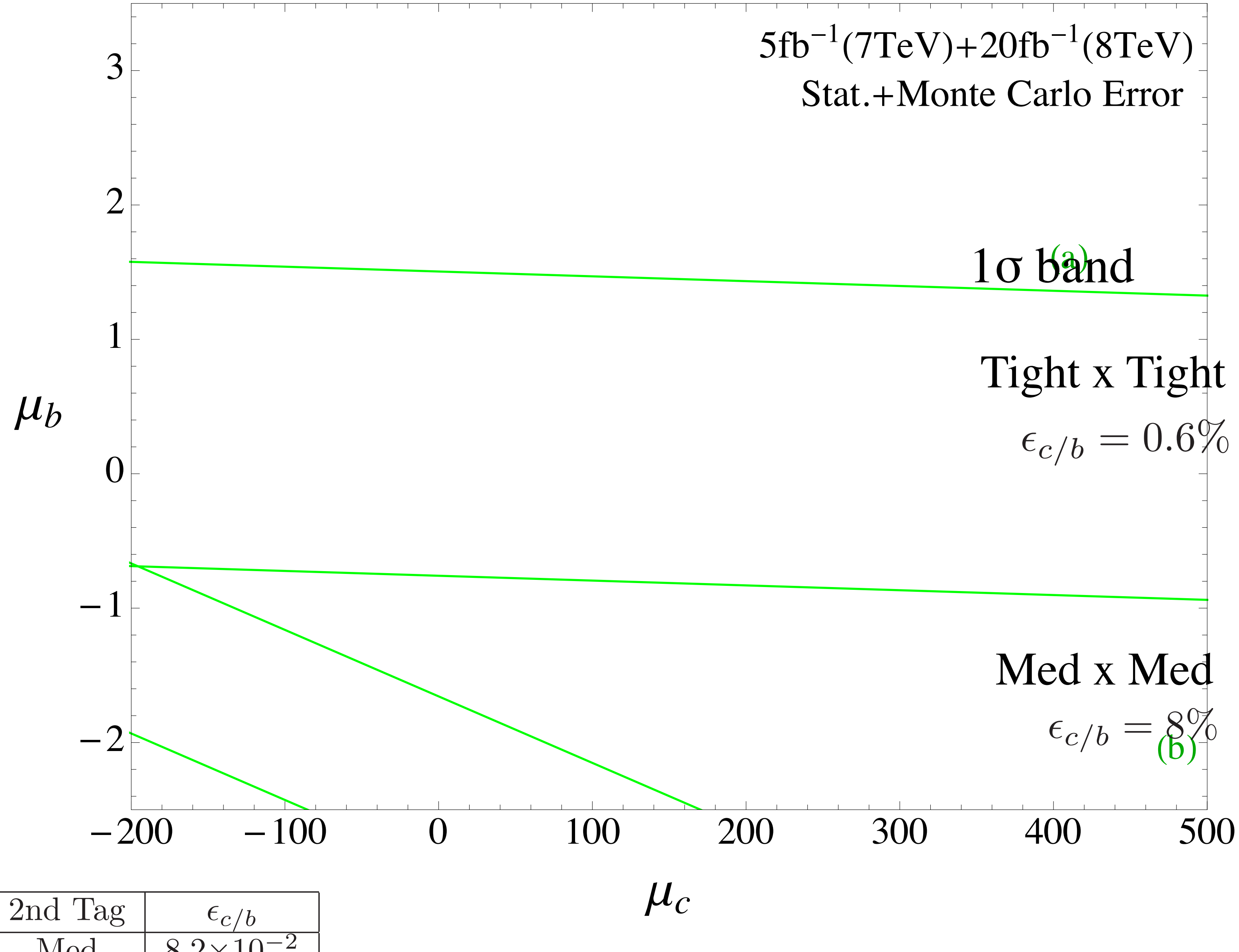

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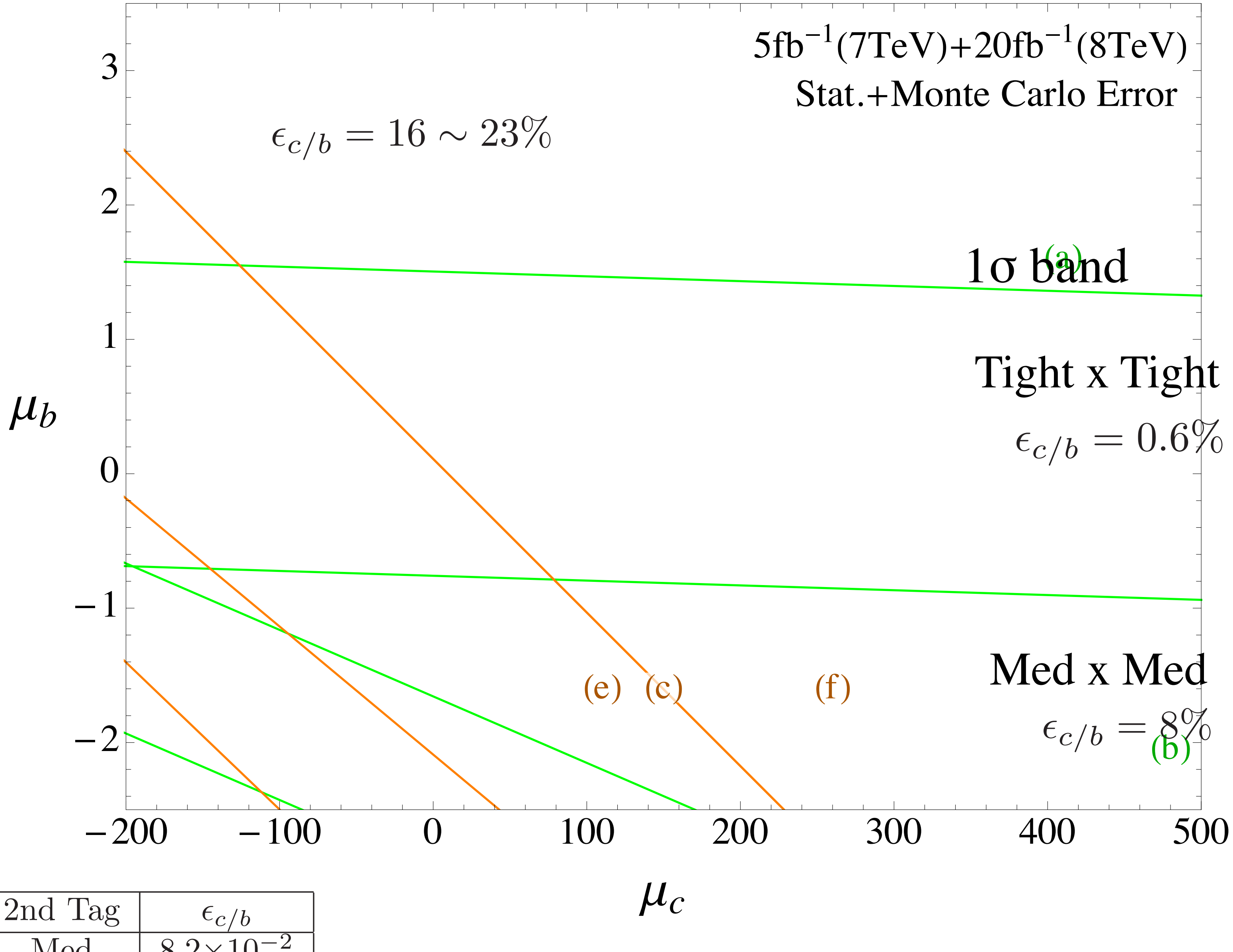

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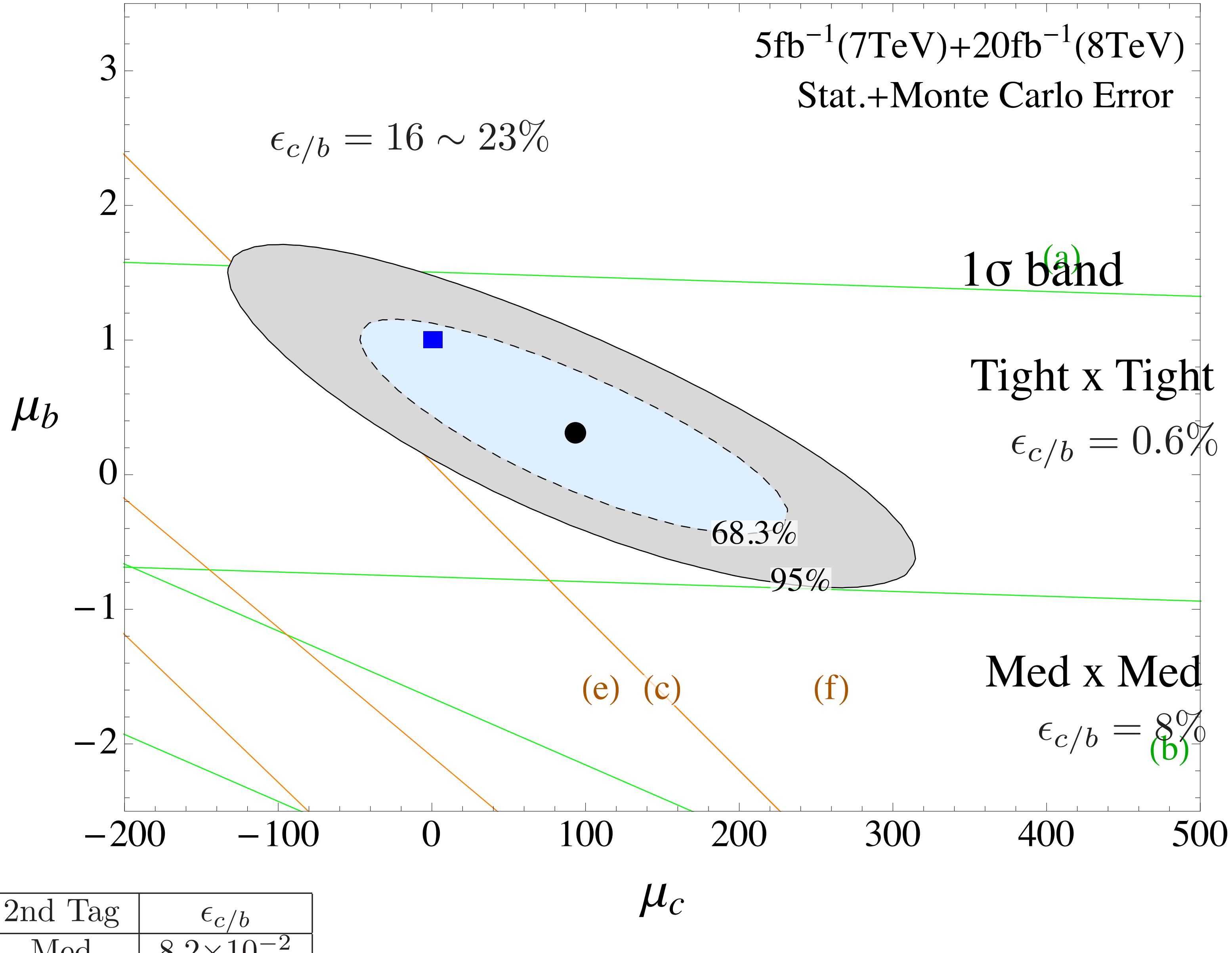

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Disentangle degeneracy

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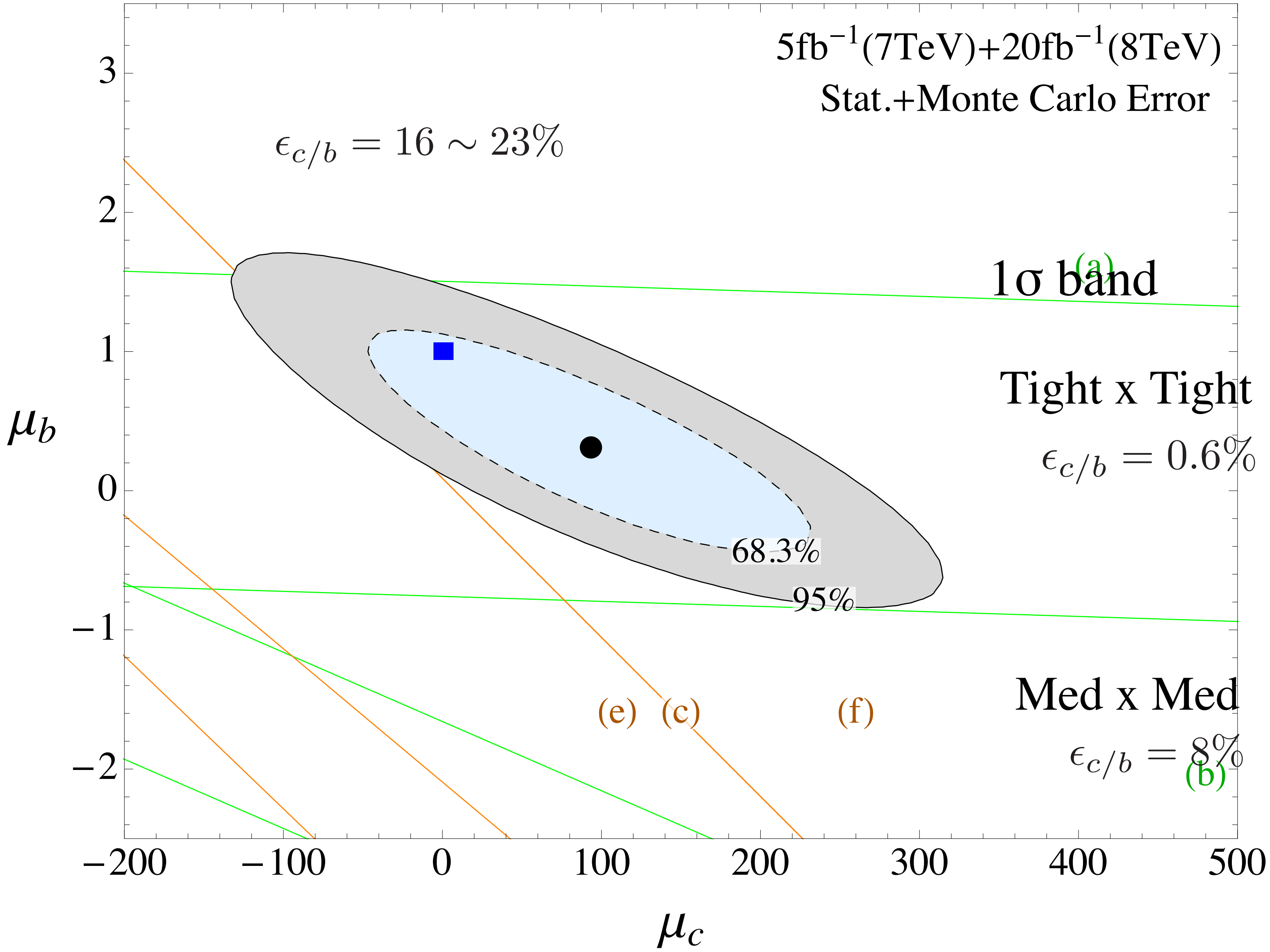


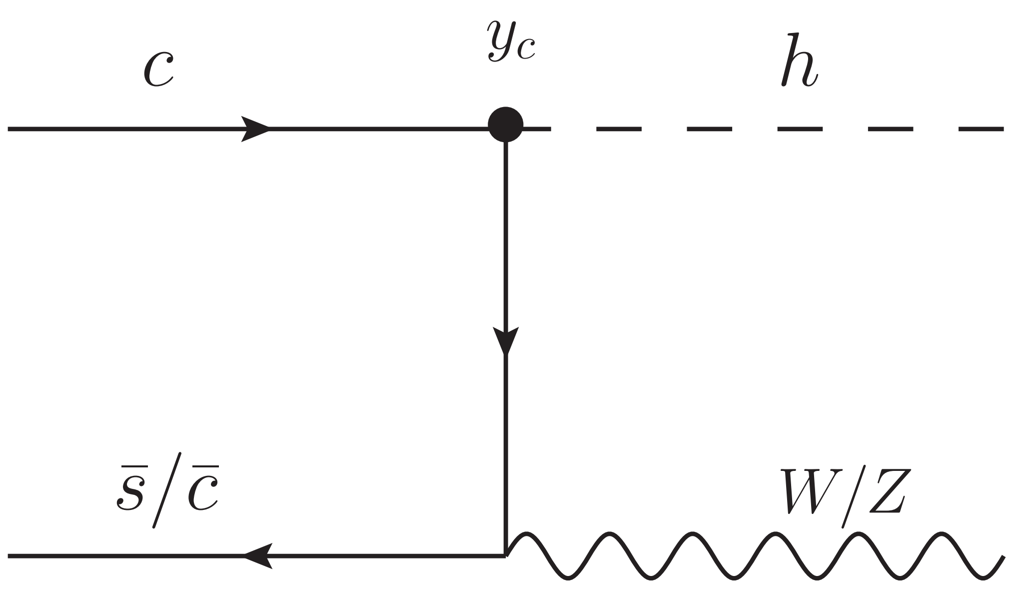
profiled μ_b

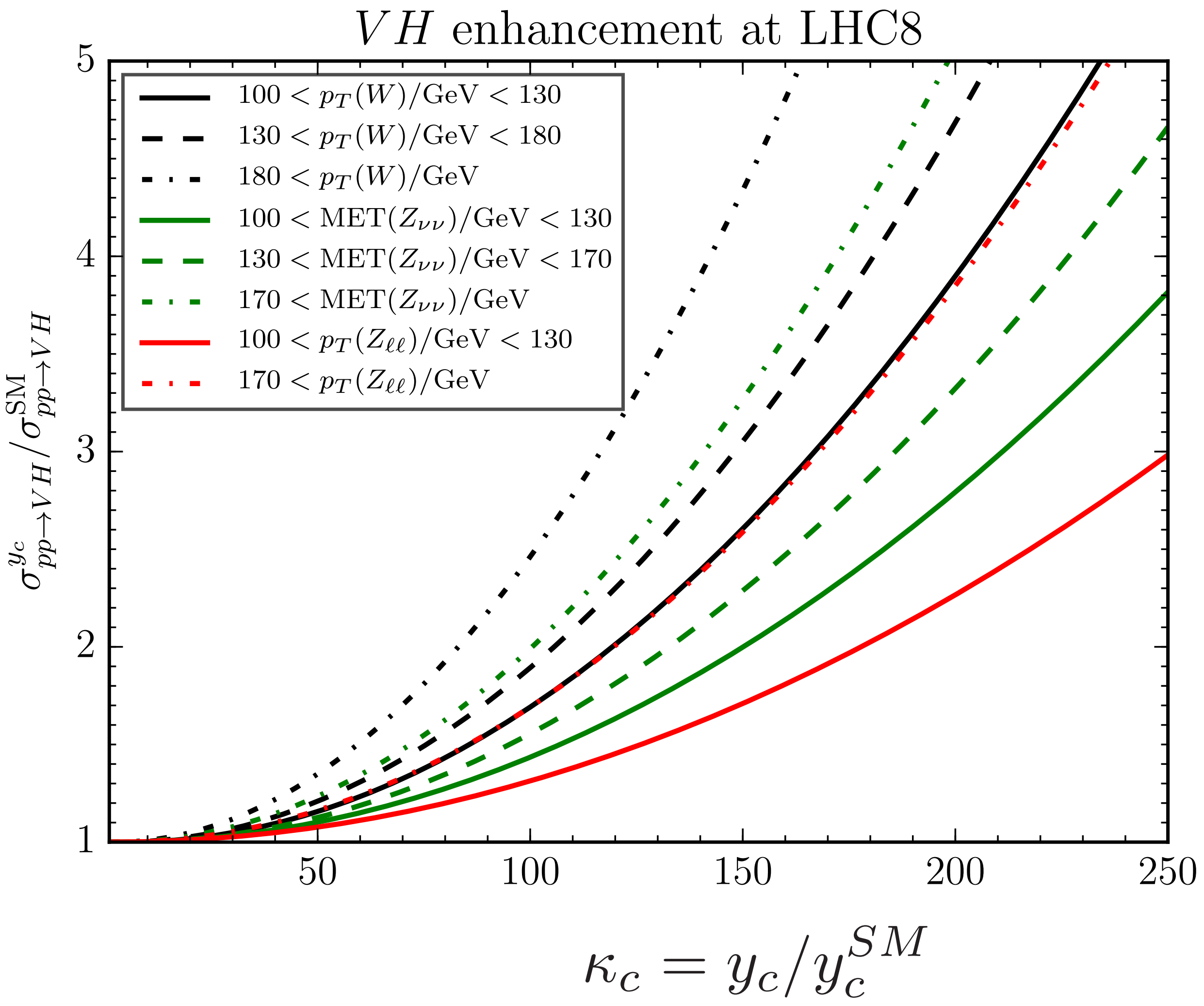
First bound on signal strength!

$$\mu_c = 95^{+90(175)}_{-95(180)} \text{ at } 68.3(95)\%\ \text{CL.}$$

New Production by large Yukawa

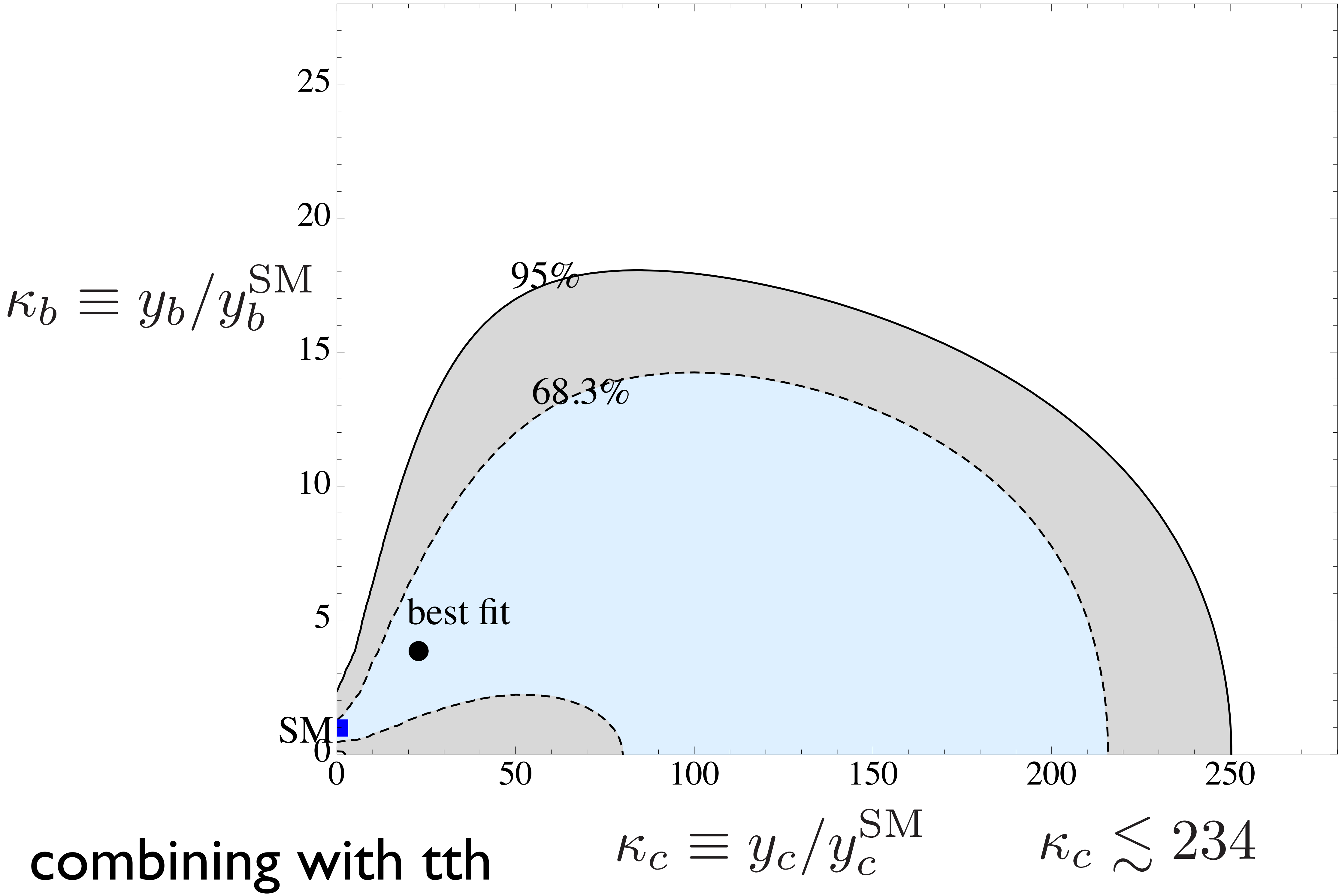
At large coupling $\kappa_c = y_c / y_c^{SM}$ ~100
switch on new production





some related work **[Brivio, Goertz, Isidori ('15)]**
pp→h+c is sensitive to κ_c

First Bound on Coupling



$\kappa_c \lesssim 234$

combining with tth

$y_t \neq y_c$ Exclude Higgs-quark coupling universality

Inclusive channel at Future LHC

I. Better sensitivity of Vh→bb at future LHC

$\Delta\mu_b \sim 0.5$ @ATLAS 8TeV

$\Delta\mu_b = 0.14$ @ATLAS Med (3000fb^{-1})

ATL-PHYS-PUB-2014-011

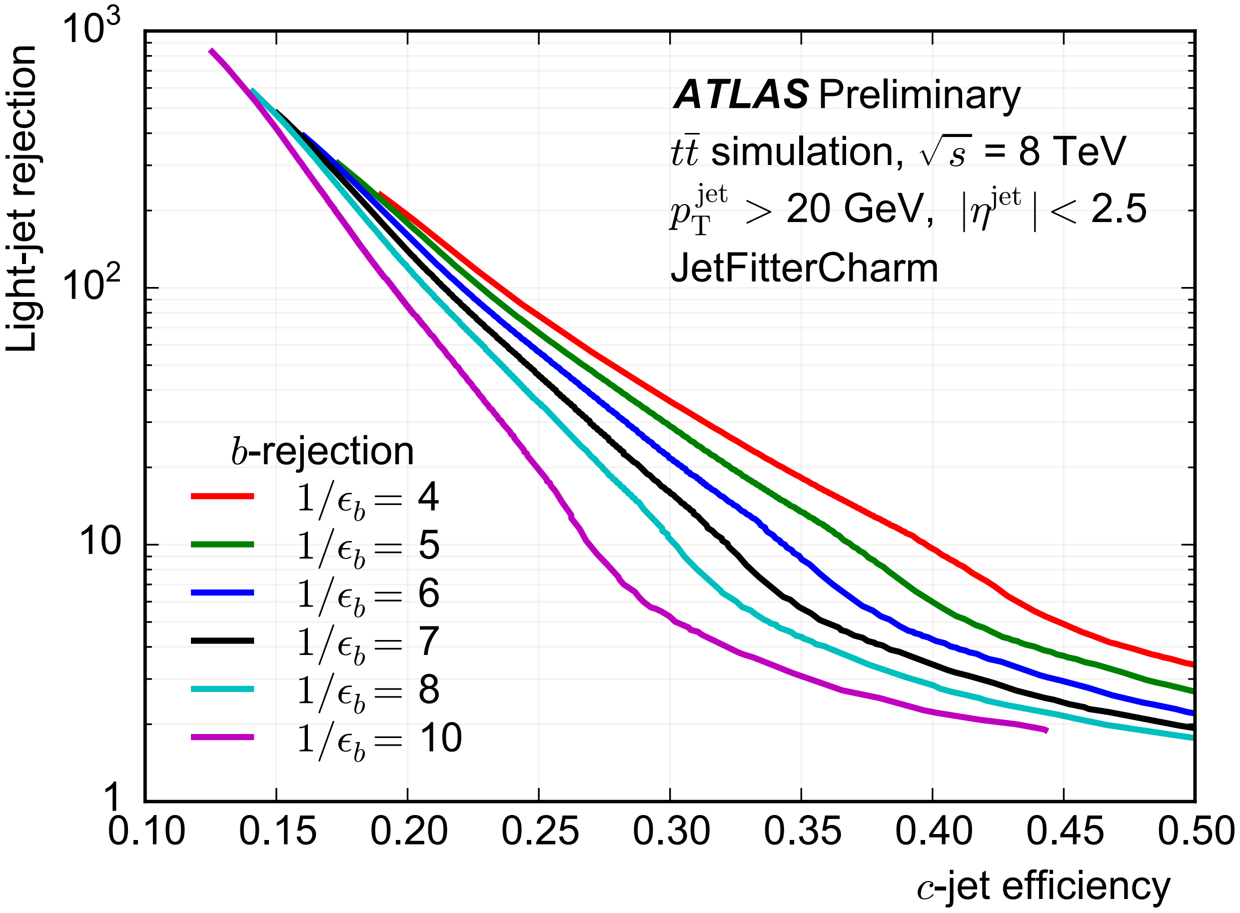
(1- and 2-lep channels)

Thanks ATLAS for providing tables!

II. New Technology: Charm tagging

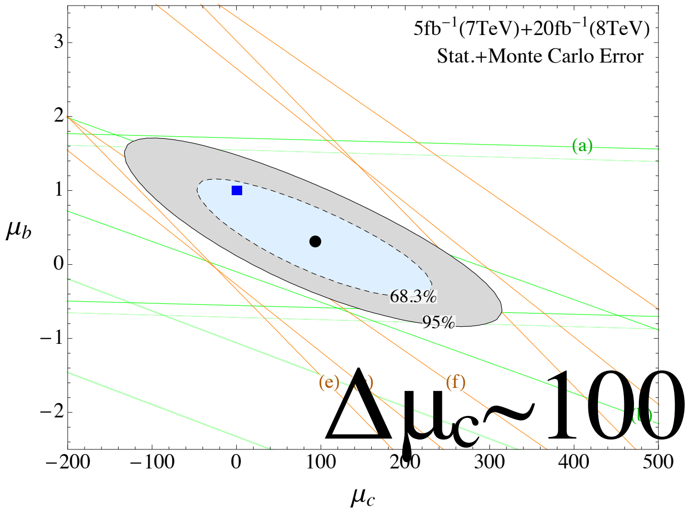
	ϵ_b	ϵ_c	ϵ_{light}	
Med:	70,	20,	1.25	(%)
	↓	↓	↓	
C-tag:	13,	19,	0.5	

Scharm study[arXiv:1501.01325]



Inclusive channel at Future LHC

Better $\Delta\mu_b$ and charm-tagging to disentangle μ_c



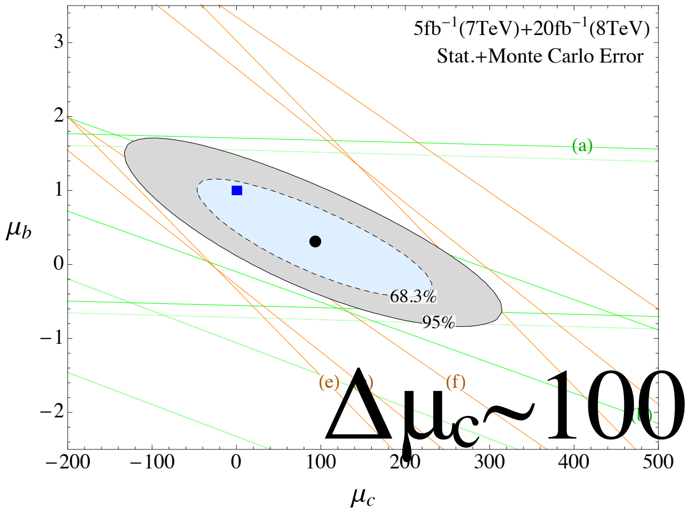
$\Delta\mu_c \sim 100$

	ϵ_b	ϵ_c	ϵ_{light}	
C-tag:	13,	19,	0.5	(%)

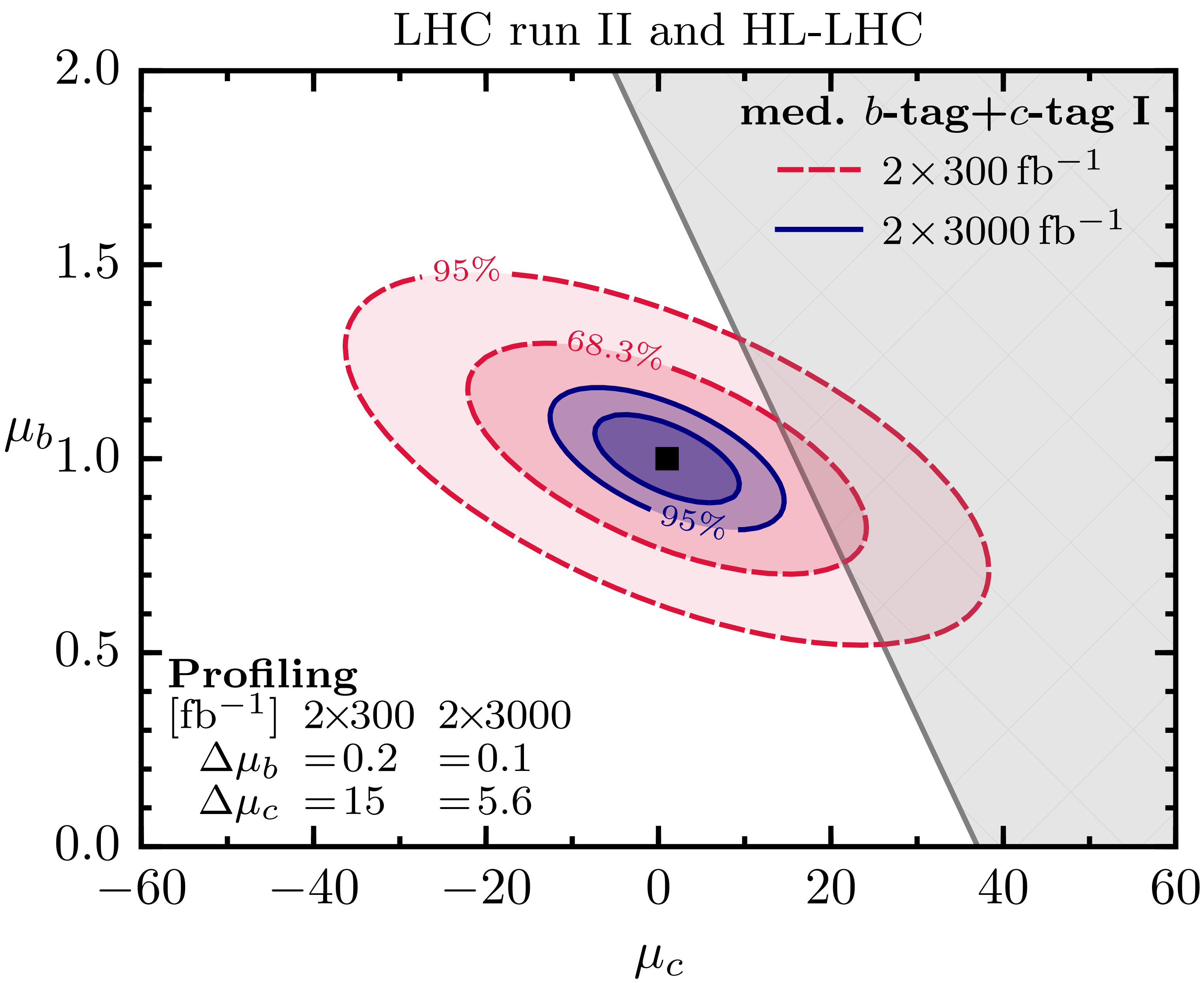
Inclusive channel at Future LHC

Better $\Delta\mu_b$ and charm-tagging to disentangle μ_c

	ϵ_b	ϵ_c	ϵ_{light}	
C-tag:	13,	19,	0.5	(%)



$\Delta\mu_c$~100

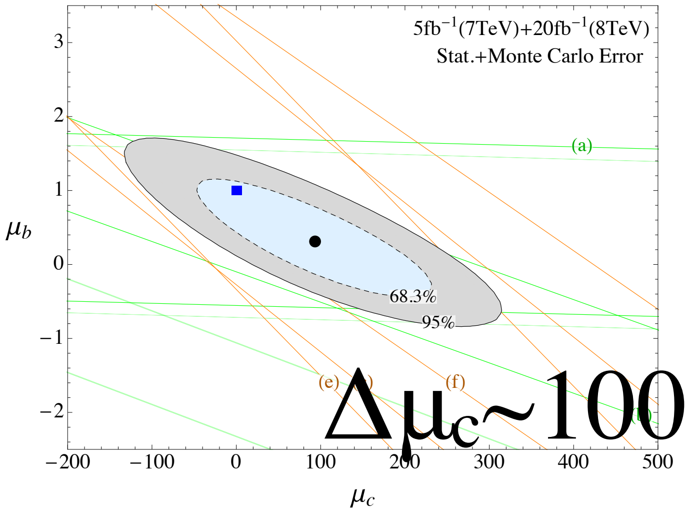


68%CL

$\Delta\mu_c$=15 (2x300fb^{-1})
=5.6 (2x3000fb^{-1})

Inclusive channel at Future LHC

Better $\Delta\mu_b$ and charm-tagging to disentangle μ_c

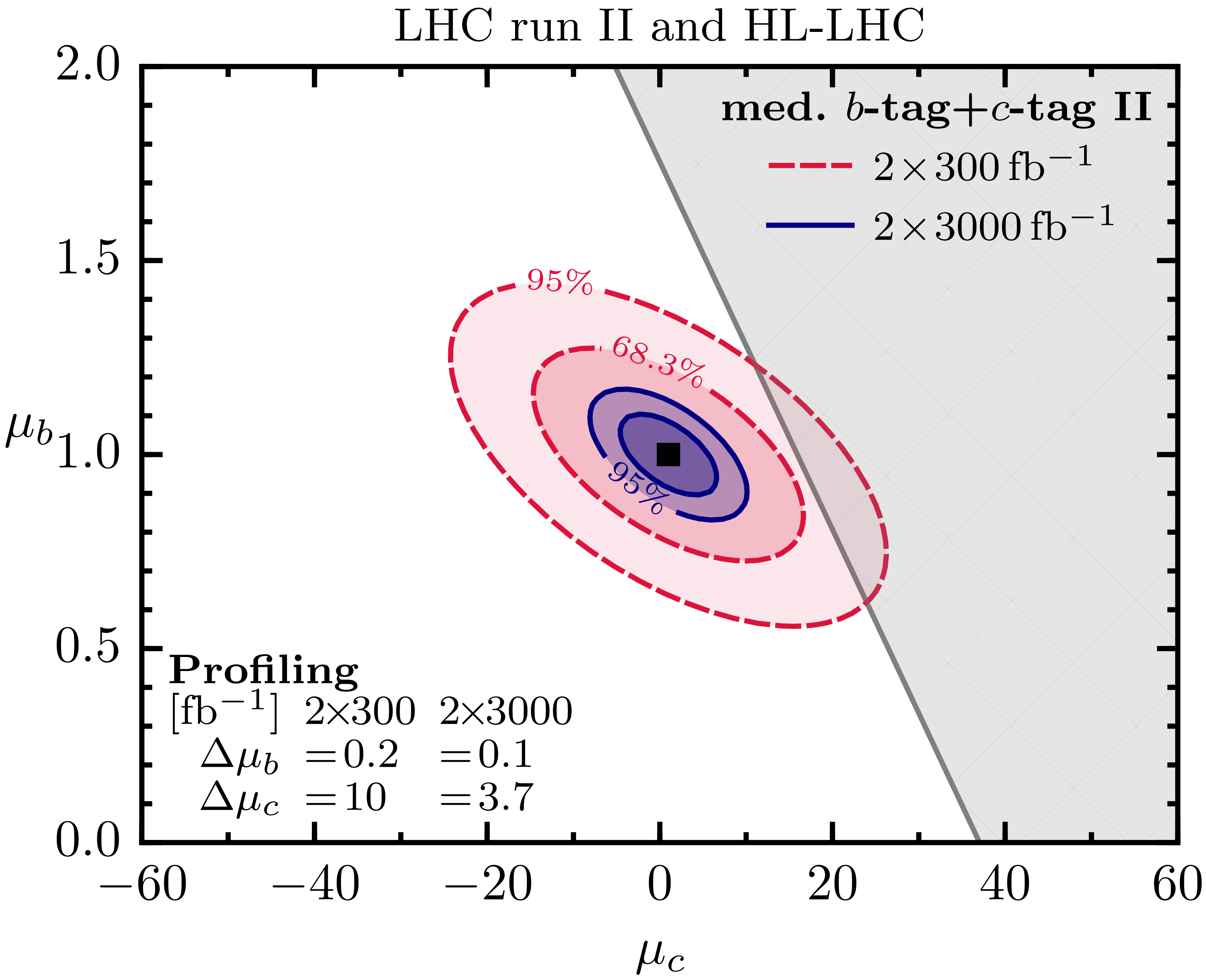


$\Delta\mu_c$~100

ϵ_b ϵ_c $\epsilon_{\rm light}$

C-tag: 20, 30, 0.5 (%)

Thanks to IBL



68%CL

$\Delta\mu_c$=10 (2x300fb^{-1})
=3.7 (2x3000fb^{-1})

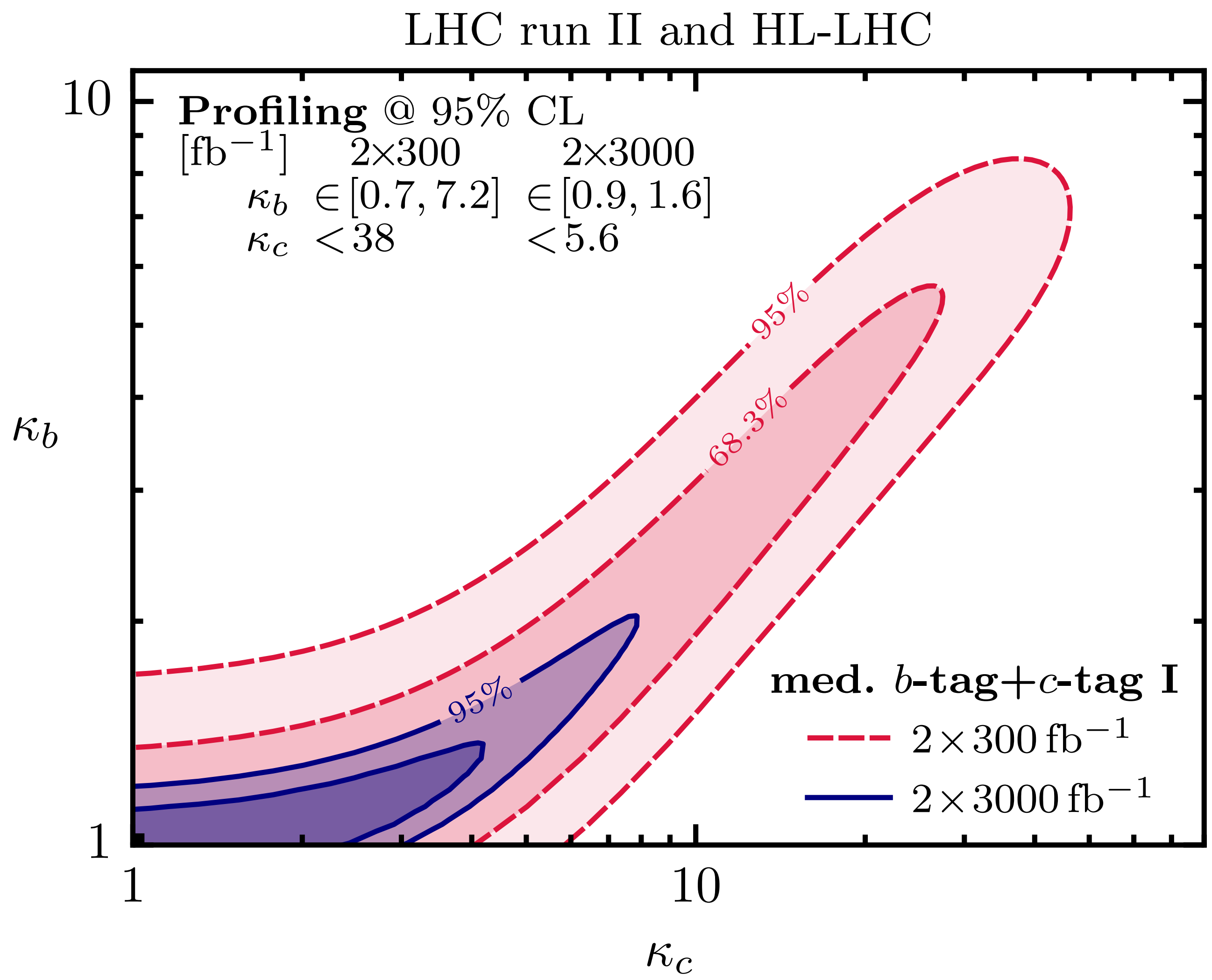
Inclusive channel at Future LHC

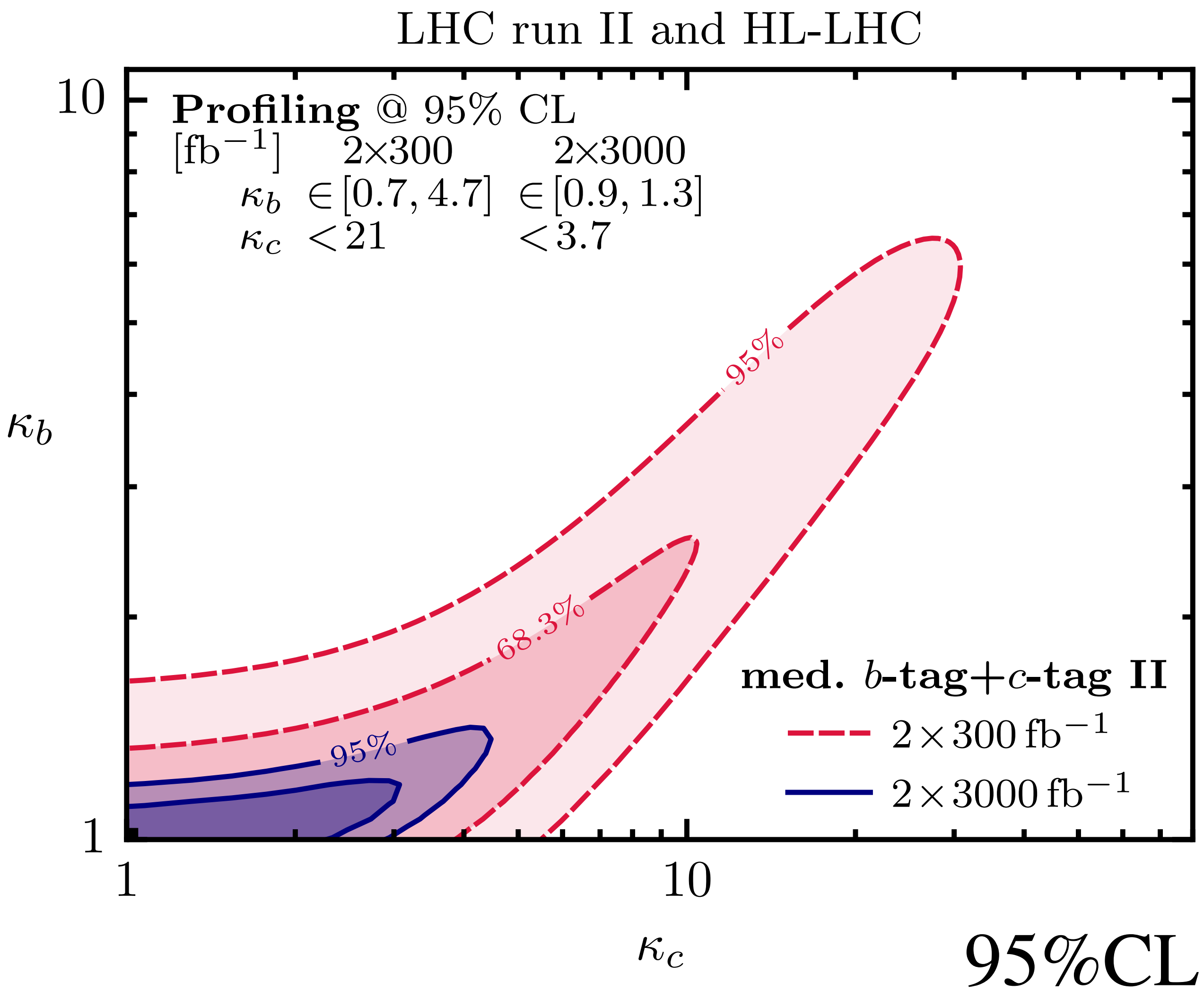
$\epsilon_b \quad \epsilon_c \quad \epsilon_{\rm light}$

C-tag: $13,\ 19,\ 0.5$ (%)

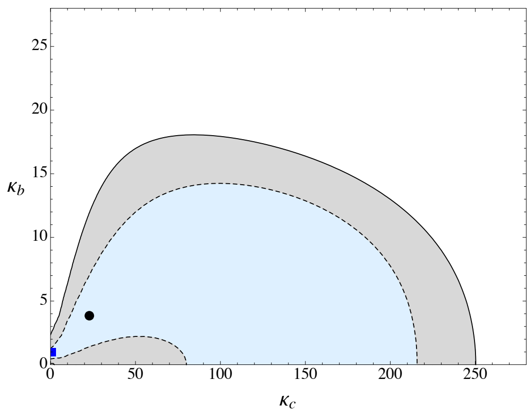
$\epsilon_b \quad \epsilon_c \quad \epsilon_{\rm light}$

$20,\ 30,\ 0.5$ (%)





95%CL



Run I

$\kappa_c \lesssim 234$

$\kappa_c < 21$ (2x300fb^{-1})

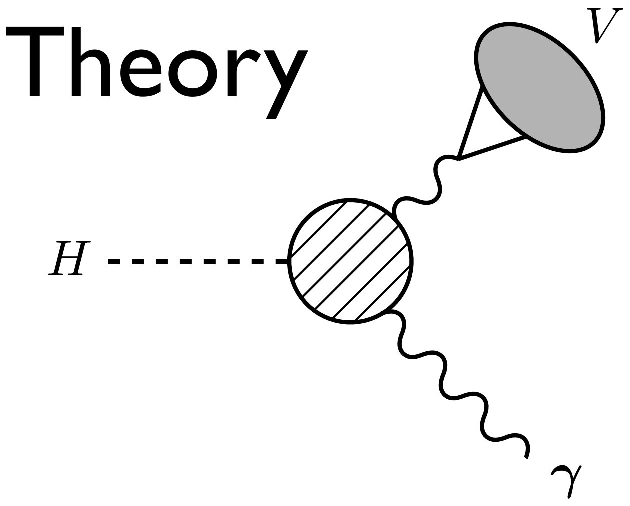
< 3.7 (2x3000fb^{-1})

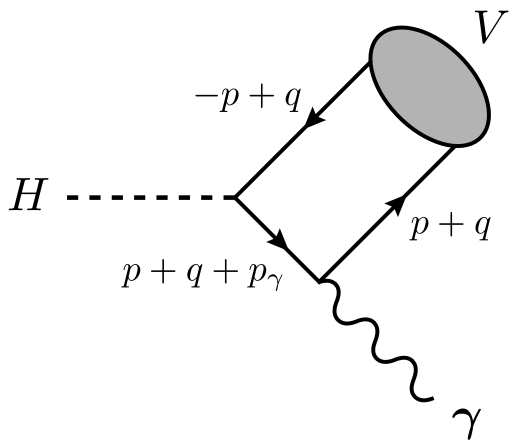
Exclusive

$h \to J/\psi + \gamma$

Exclusive J/ψ+γ channel

1.Theory





Bodwin, Petriello, Stoynev, Velasco ('13)

Bodwin, Chung, Ee, Lee, Petriello ('14)

Koenig, Neubert ('15)

Nice summary by Neubert's talk in SUSY2015

$$\Gamma(H \to J/\psi + \gamma) = \left|(11.9 \pm 0.2) - (1.04 \pm 0.14)\kappa_c\right|^2 \times 10^{-10}\ \mathrm{GeV}$$

2.Measurement

ATLAS [arXiv:1501.03276]
CMS [arXiv:1507.03031]

$$\boxed{\sigma \cdot \mathrm{Br}(H \to J/\psi\gamma) < 33\mathrm{fb}^{-1}}$$

[95%CL upper bound]

2.5 x10^{-6} [SM]

See talk by K.Tackmann

$$\mu^{95}_{J/\psi,8} = 515$$

3.Combine with *h*→*4l*, *γγ*

$$\frac{\sigma(pp \to h) \times \mathrm{BR}_{h\to J/\psi\gamma}}{\sigma(pp \to h) \times \mathrm{BR}_{h\to ZZ^*\to 4\ell}} = \frac{\Gamma_{h\to J/\psi\gamma}}{\Gamma_{h\to ZZ^*\to 4\ell}} = 2.79\frac{(\kappa_\gamma - 0.087\kappa_c)^2}{\kappa_V^2} \times 10^{-2} < 9.3$$

$$-210\kappa_V + 11\kappa_\gamma < \kappa_c < 210\kappa_V + 11\kappa_\gamma$$

Perez, Soreq, Stamou, KT ('15)

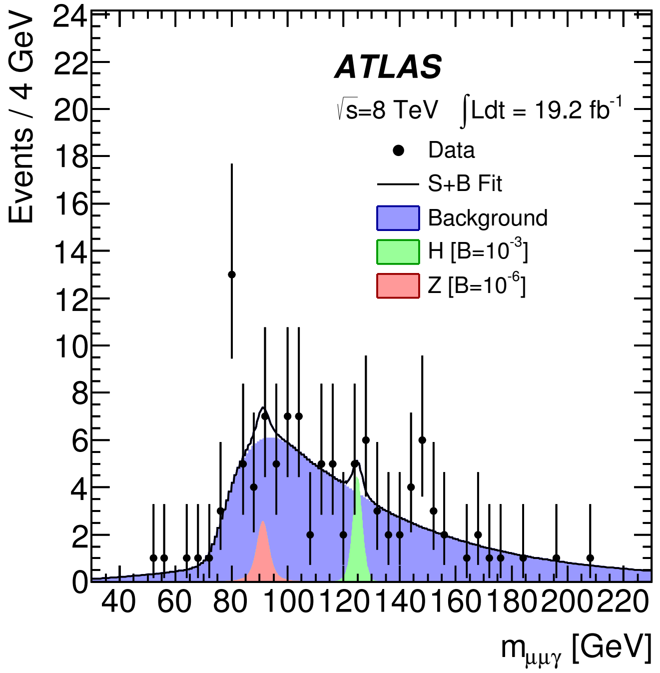
Calculation updated+*h*→*γ γ*

[arXiv: 1505.03870]
Koenig, Neubert

$$\kappa_c \lesssim 430$$

due to smaller κ$_c$ coefficient

J/ψ+γ Channel at Future LHC



We learn BG is important

Real J/ψ +real γ or fake j→γ

$$\frac{S^{95}_E}{\sqrt{B_E}} \approx \frac{S^{95}_8}{\sqrt{B_8}} \qquad (\sim 2\sigma)$$

Theorist's estimate of prospect

$$11\kappa_\gamma - 10\kappa_V \left(\frac{\mu^{95}_{J/\psi\gamma,E}}{\mu_{ZZ^*}}\right)^{1/2} < \kappa_c < 11\kappa_\gamma + 10\kappa_V \left(\frac{\mu^{95}_{J/\psi\gamma,E}}{\mu_{ZZ^*}}\right)^{1/2}$$

Perez, Soreq, Stamou, KT ('15)

$$R_E \equiv \frac{S^{SM}_E / B_E}{S^{SM}_8 \,/\, B_8}$$

E=14

$$\mu^{95}_{J/\psi\gamma,E} = \frac{S^{95}_E}{S^{SM}_E} \approx \left(\frac{B_E}{B_8}\frac{S^{SM}_8}{S^{SM}_E}\right)^{1/2}\left(\frac{S^{SM}_8}{S^{SM}_E}\right)^{1/2}\frac{S^{95}_8}{S^{SM}_8} = \underline{\frac{1}{R_E^{1/2}}\left(\frac{\sigma^{SM}_{h,8}\,\mathcal{L}_8}{\sigma^{SM}_{h,E}\,\mathcal{L}_E}\right)^{1/2}}\ \mu^{95}_{J/\psi\gamma,8}$$

⇨

$$11 - 45\left(\frac{1}{R_{14}}\,\frac{\sigma^{SM}_{h,8}}{\sigma^{SM}_{h,14}}\,\frac{2\times 3000\text{fb}^{-1}}{\mathcal{L}_{14}}\right)^{1/4} < \kappa_c < 11 + 45\left(\frac{1}{R_{14}}\,\frac{\sigma^{SM}_{h,8}}{\sigma^{SM}_{h,14}}\,\frac{2\times 3000\text{fb}^{-1}}{\mathcal{L}_{14}}\right)^{1/4}$$

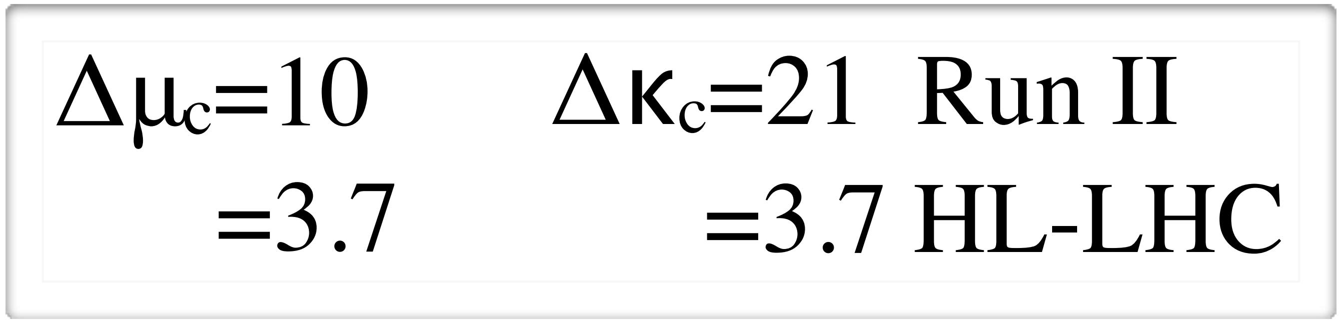
$(\kappa_V = \kappa_\gamma = \mu_{ZZ^*} = 1)$ S/B has to be improved significantly

Summary

- Recasting Vh (inclusive) study gives first bound on μ_c thanks to different tagging points of ATLAS&CMS

$$\mu_c = 95^{+90(175)}_{-95(180)} \text{ at } 68.3(95)\% \text{ CL.}$$

- Future LHC sensitivity [with charm-tagging]



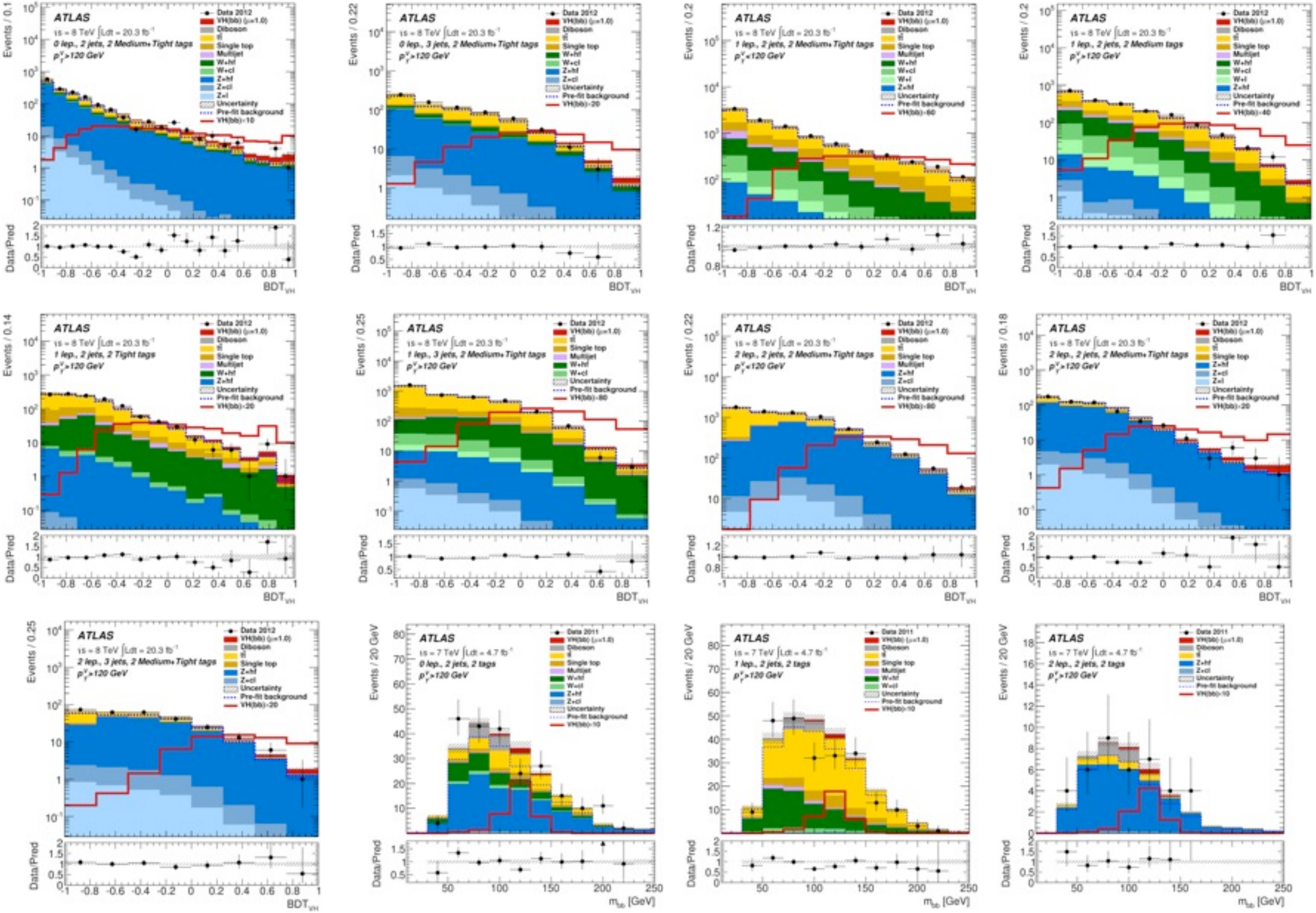
$\Delta\mu_c$=10	$\Delta\kappa_c$=21	Run II
=3.7	=3.7	HL-LHC

- Exclusive channel $h \to J/\psi\gamma$ needs significant improvement to have a comparable sensitivity
- Other modes, e.g. $h \to \phi\gamma$, also are challenging

Thank you

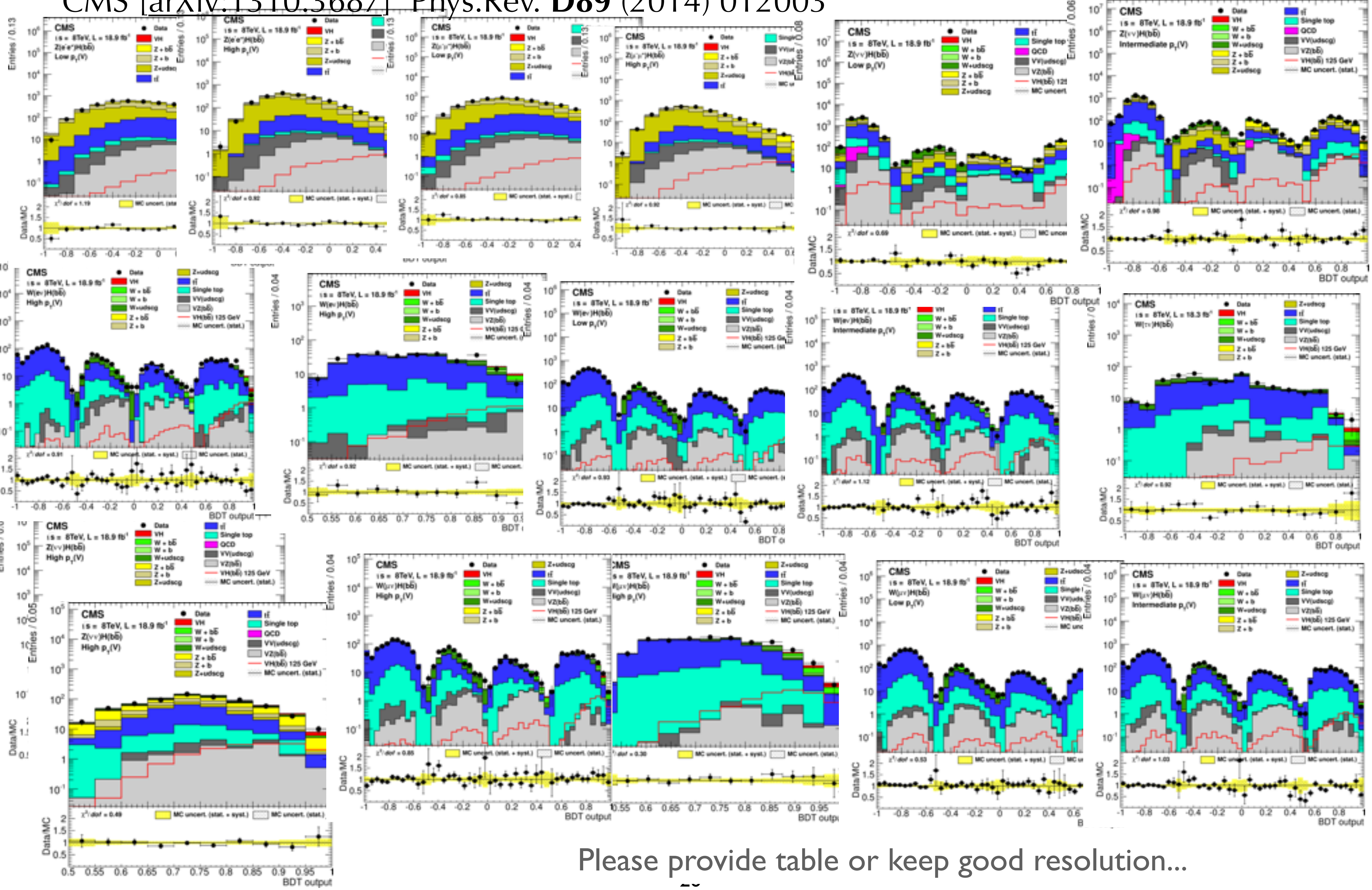
Collect info from ATLAS

ATLAS [arXiv:1409.6212]



Collect info from CMS

CMS [arXiv:1310.3687] Phys.Rev. **D89** (2014) 012003



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