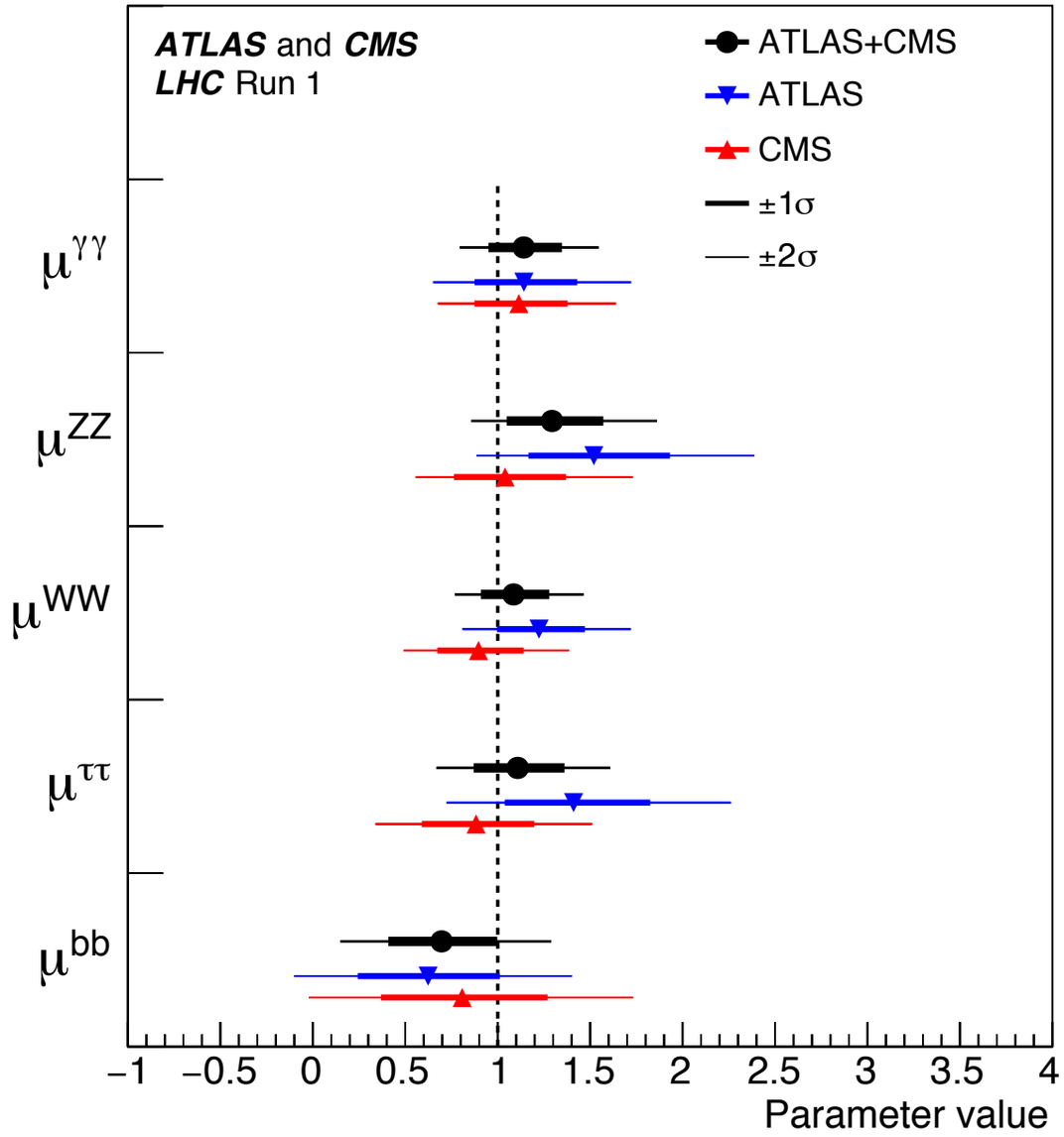
LIGHT QUARK YUKAWA COUPLINGS FROM HIGGS KINEMATICS

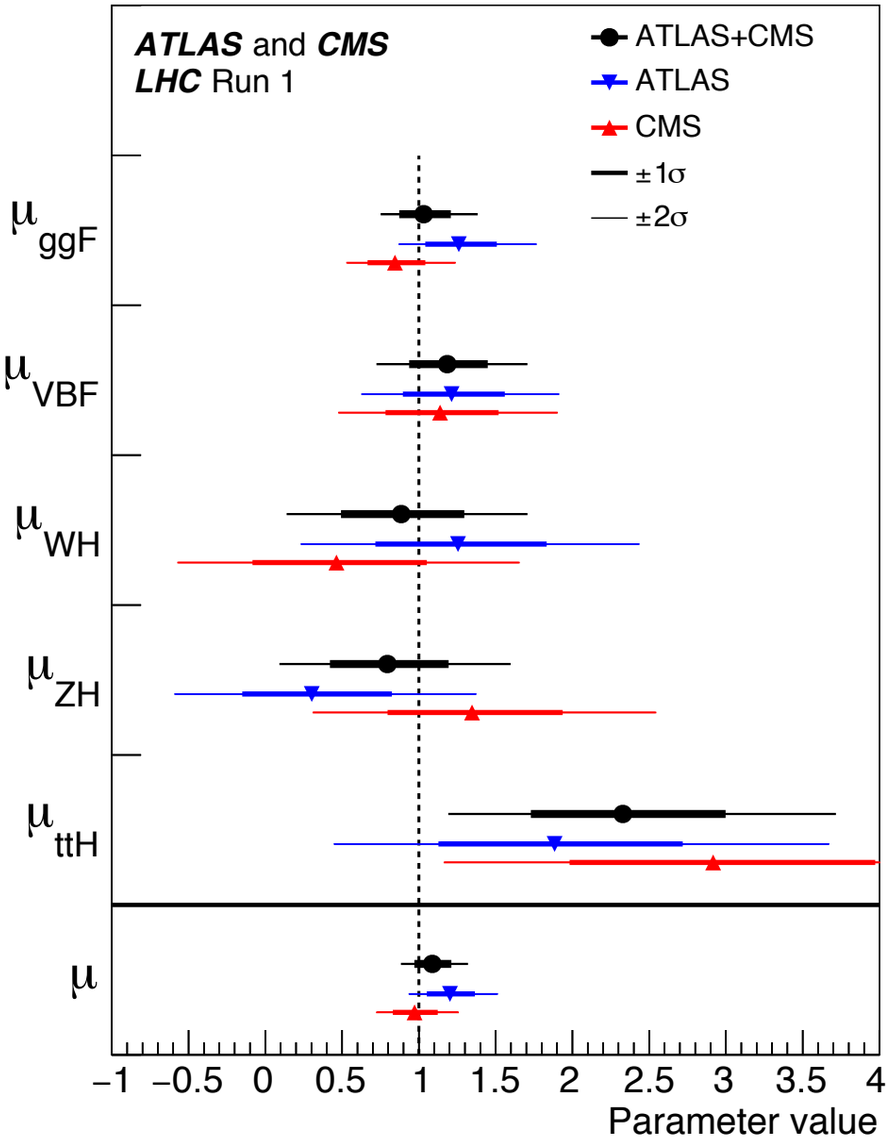
Yotam Soreq

YS, Hua Xing Zhu, Jure Zupan - 1606.09621

Exotic Higgs decays workshop, SLAC, Nov 8, 2016

HIGGS RESULTS





$\mu^f = BR^f / (BR^f)_{SM}$ $\mu_i = \sigma_i / (\sigma_i)_{SM}$

$m_h = (125.09 \pm 0.24)$ GeV

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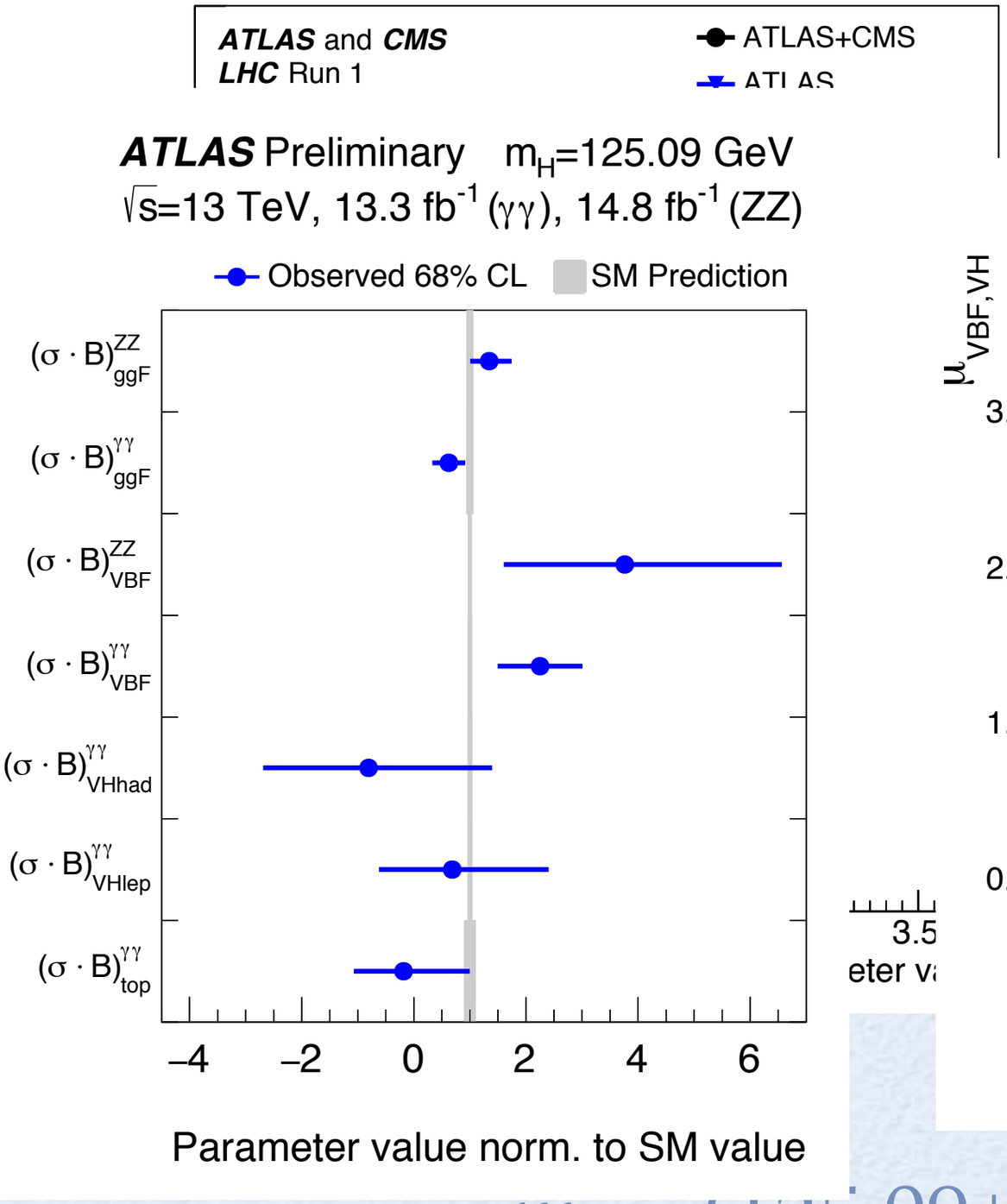

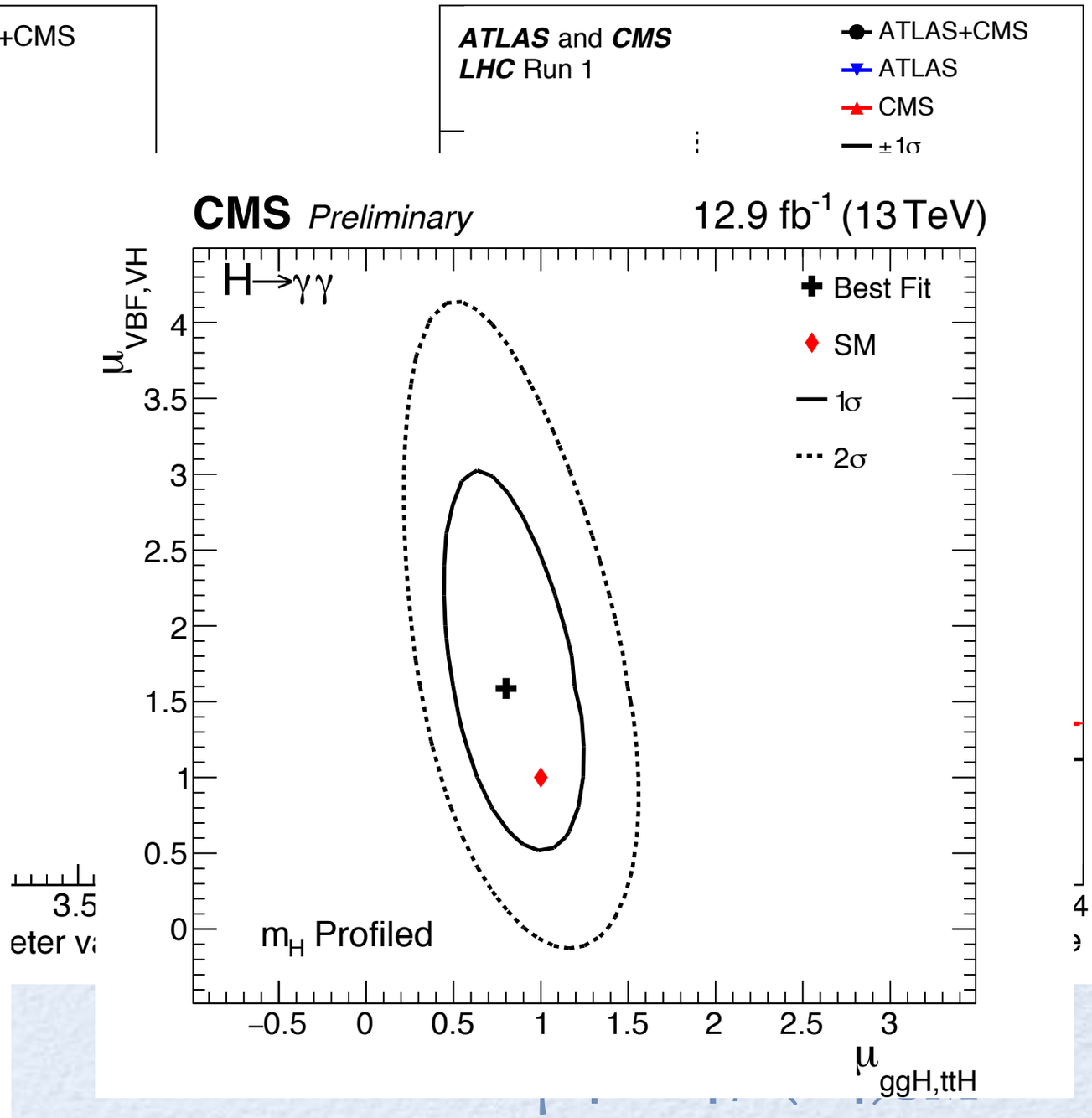

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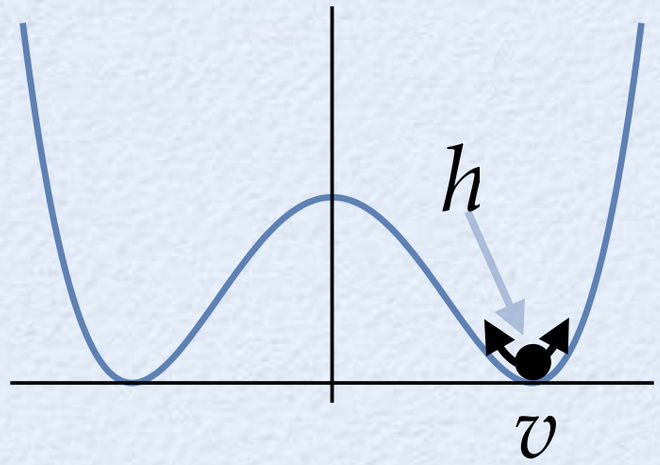
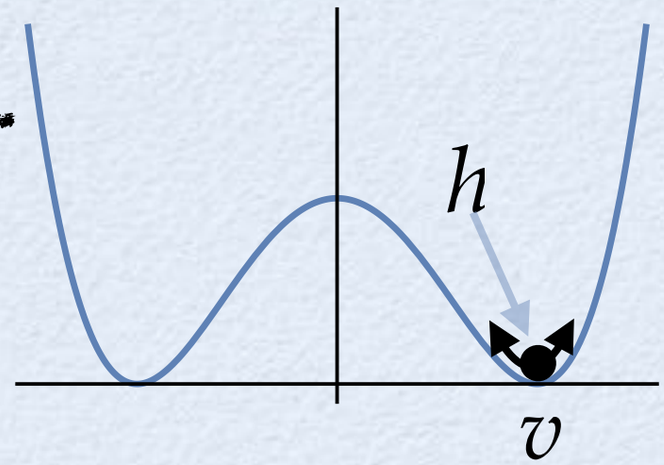
HIGGS IN THE STANDARD MODEL



HIGGS IN THE STANDARD MODEL

unitarize: $V_L V_L \rightarrow V_L V_L$

$m_{W,Z} \neq 0$



tested by:

direct - $h \rightarrow WW^*, ZZ^*$

indirect - Electroweak precision

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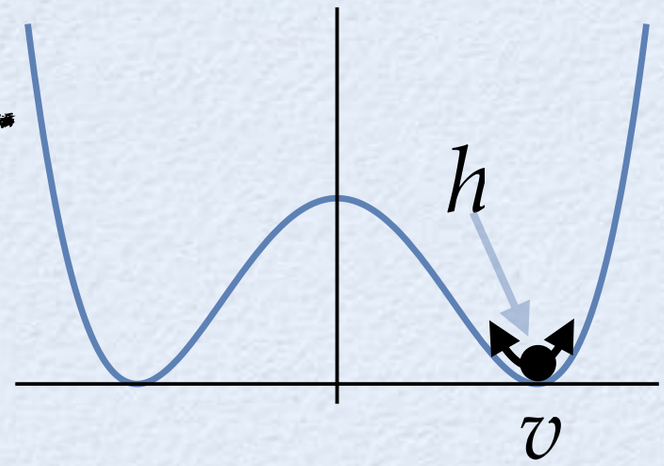

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indirect - Electroweak precision

the Higgs is the main source of Electroweak symmetry breaking

HIGGS IN THE STANDARD MODEL

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unitarize: $f\bar{f} \to V_L V_L$

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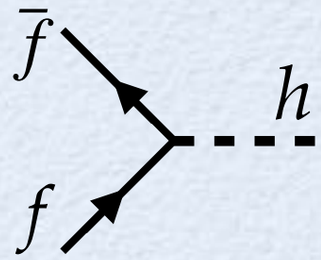

$y_f \propto m_f$

much less is known

INTRODUCTION

Yukawa interaction

$$\mathcal{L}_Y = Y^u_{ij} \bar{u}^i_L u^j_R h + Y^d_{ij} \bar{d}^i_L d^j_R h + Y^\ell_{ij} \bar{\ell}^i_L \ell^j_R h + h.c.$$

flavor **dependent** interaction

(unlike gauge interactions which are flavor blind)

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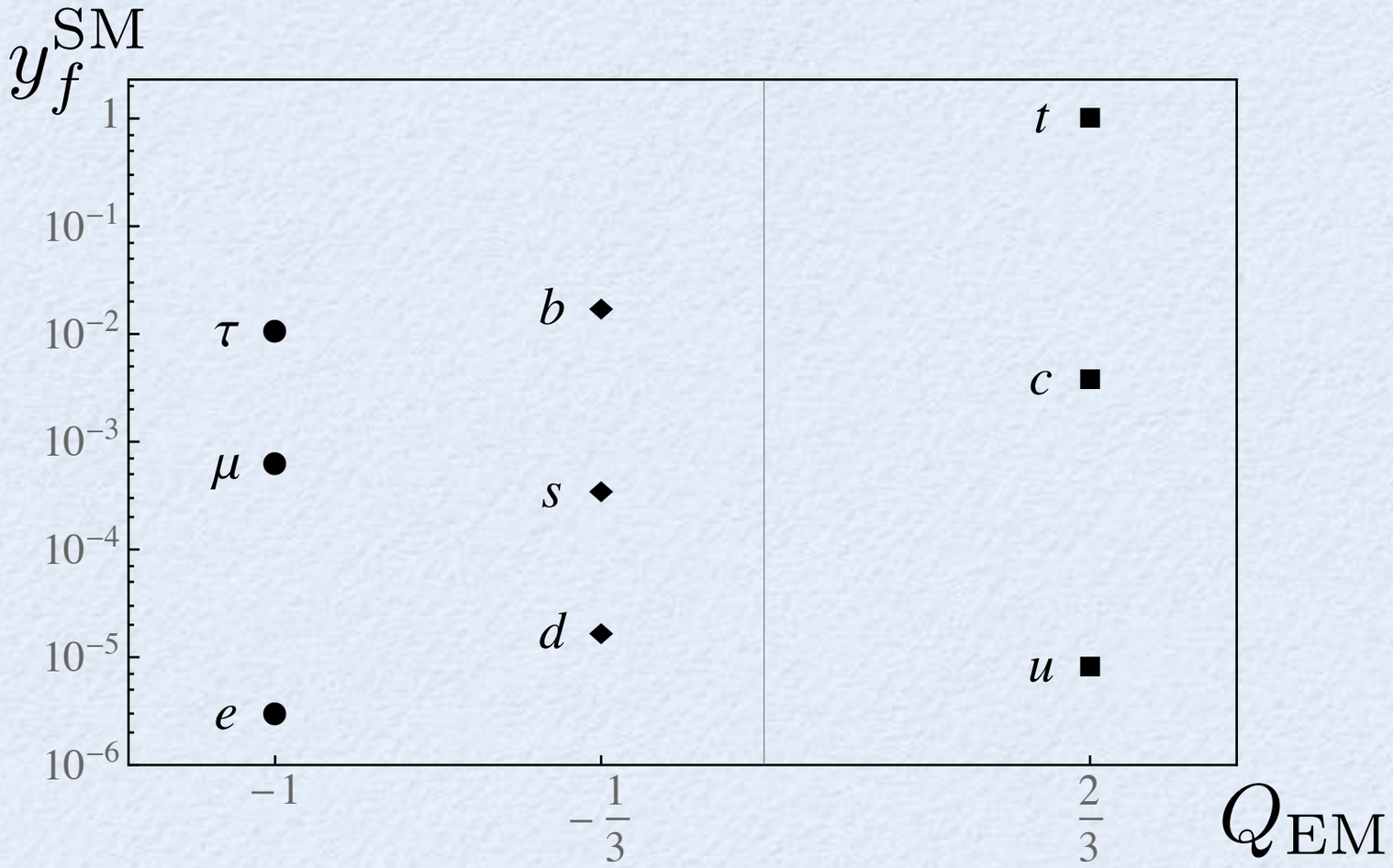
flavor **dependent** interaction

(unlike gauge interactions which are flavor blind)

$$y_f^{\rm SM} = \frac{m_f}{v}$$

- non-universal and hierarchical
- diagonal

INTRODUCTION



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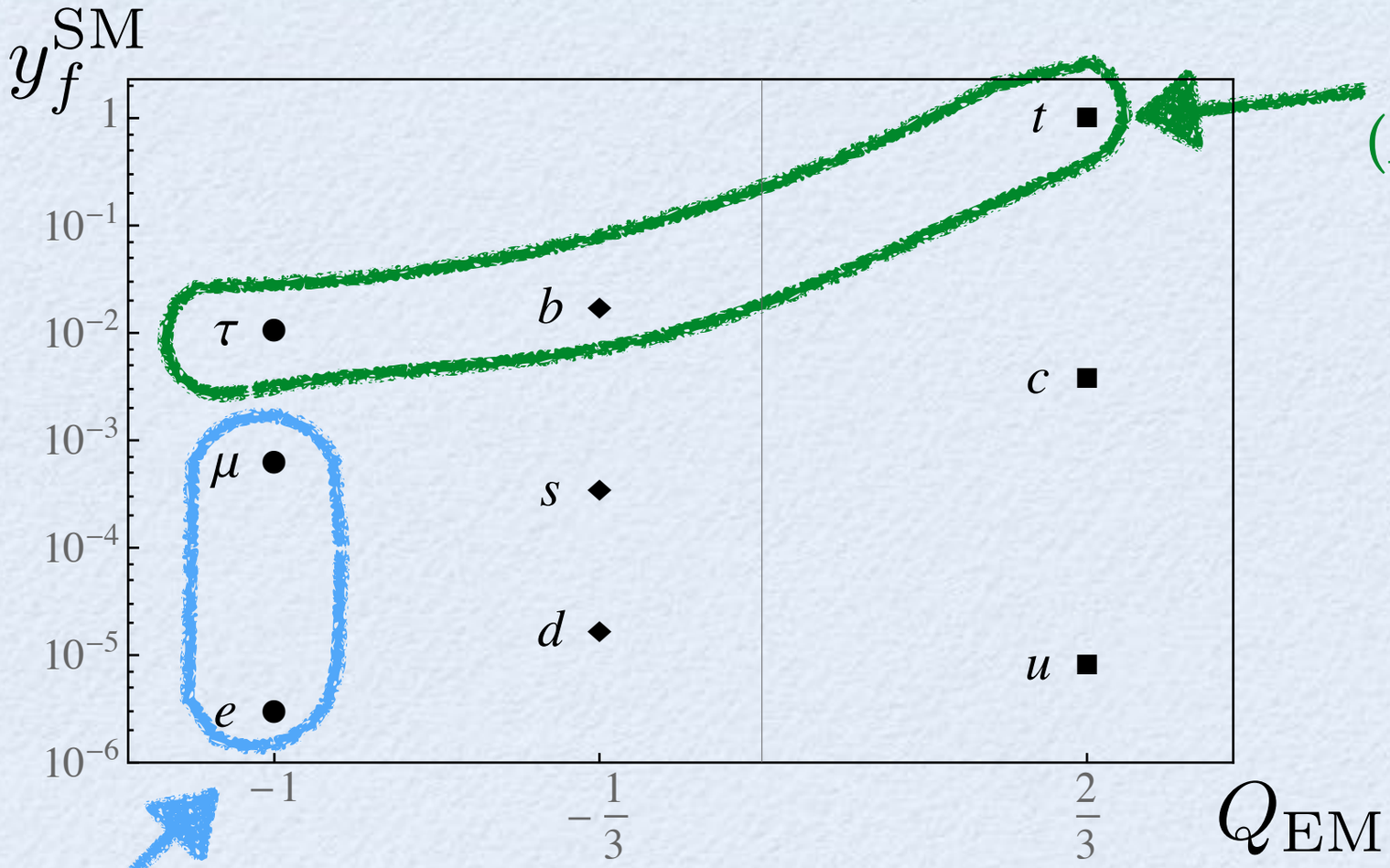

current measurements
(ATLAS+CMS - run 1+2 naive)

$$\mu^{\tau\tau} = 1.12^{+0.24}_{-0.22}$$

$$\mu^{bb} = 0.58 \pm 0.25$$

$$\mu_{t\bar{t}h} = 2.06 \pm 0.38$$

upper bounds
(ATLAS+CMS)

$$\mu^{\mu\mu} < 3.5$$

$$\mu^{ee} < 4 \times 10^5$$

discussion about Y_e

W. Altmannshofer, J. Brod, and M. Schmaltz, 1503.04830

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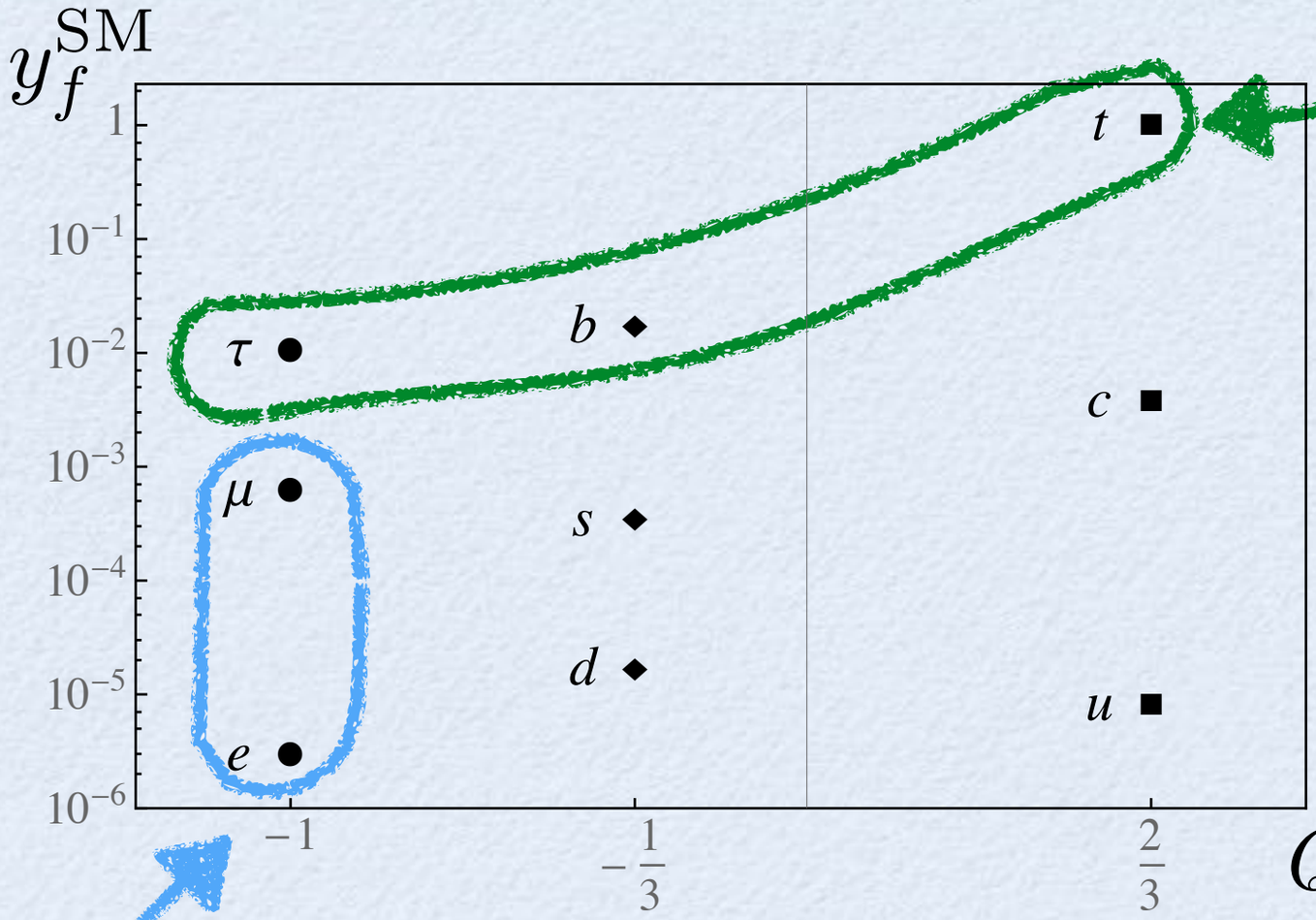

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discussion about Y_e

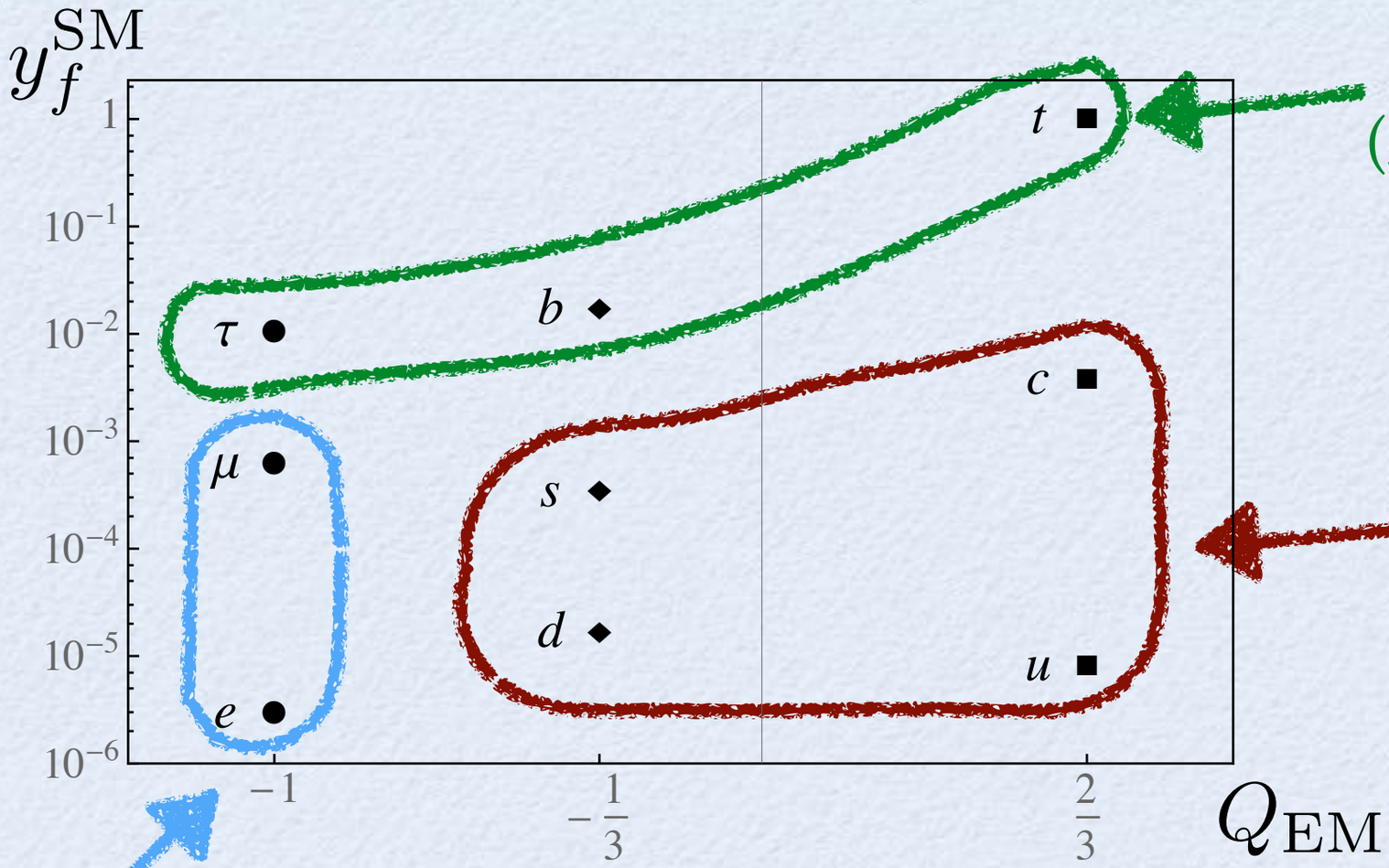
$$\frac{\mu^{\mu\mu}}{\mu^{\tau\tau}} < 6$$

$$y_\mu < y_\tau$$

$$\left.\frac{\mu^{\mu\mu}}{\mu^{\tau\tau}}\right|_{y_\tau = y_\mu} \approx 280$$

W. Altmannshofer, J. Brod, and M. Schmaltz, 1503.04830

INTRODUCTION



current measurements
(ATLAS+CMS - run 1+2 naive)

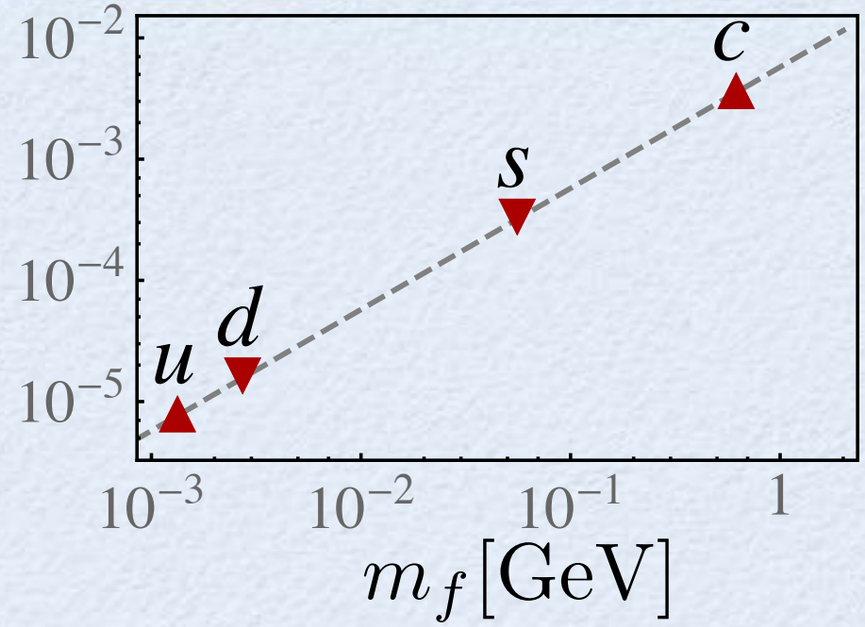
??

upper bounds
(ATLAS+CMS)

Do light quark masses arise via couplings to the Higgs?

PROBING LIGHT QUARK YUKAWAS

$$y_f^{\rm SM} = \frac{m_f}{v}$$



challenges

- SM-Higgs rates are tiny
- QCD background
- flavor tagging

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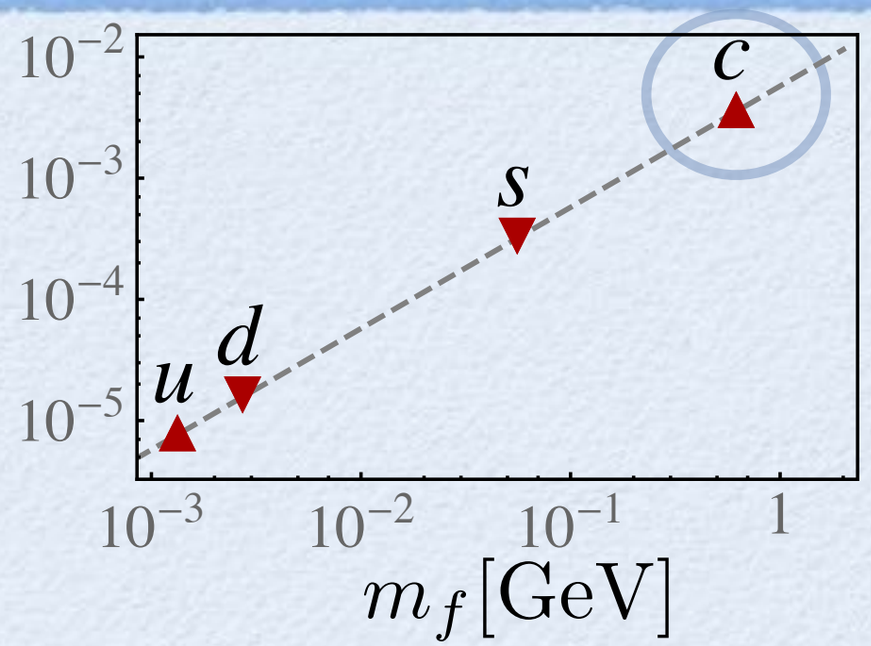

inclusive rates

Delaunay, Golling, Perez, YS, 1310.7029
Perez, YS, Stamou, Tobioka, 1505.06689, 1503.00290
Brivio, Goertz, Isidori, 1507.02916
ATLAS, 1407.0608
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ATL-PHYS-PUB-2015-001

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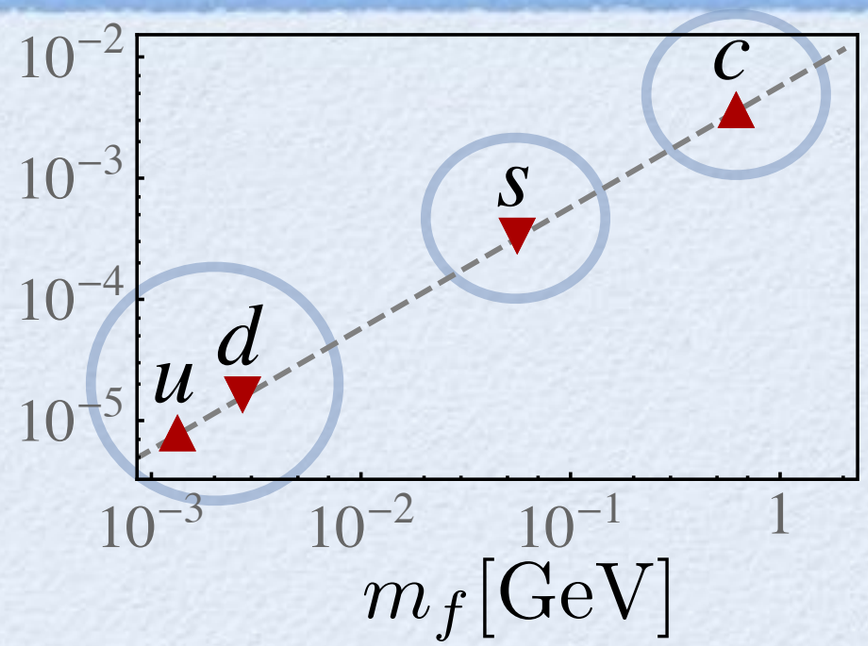

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exclusive rates ($h \to \gamma V$)

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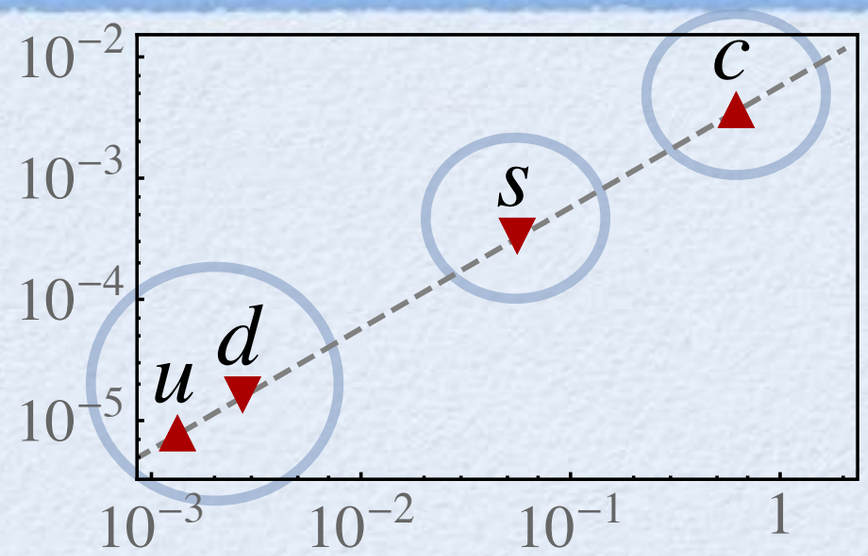

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Higgs kinematics

Bishara, Haisch, Monni, Re 1606.09253
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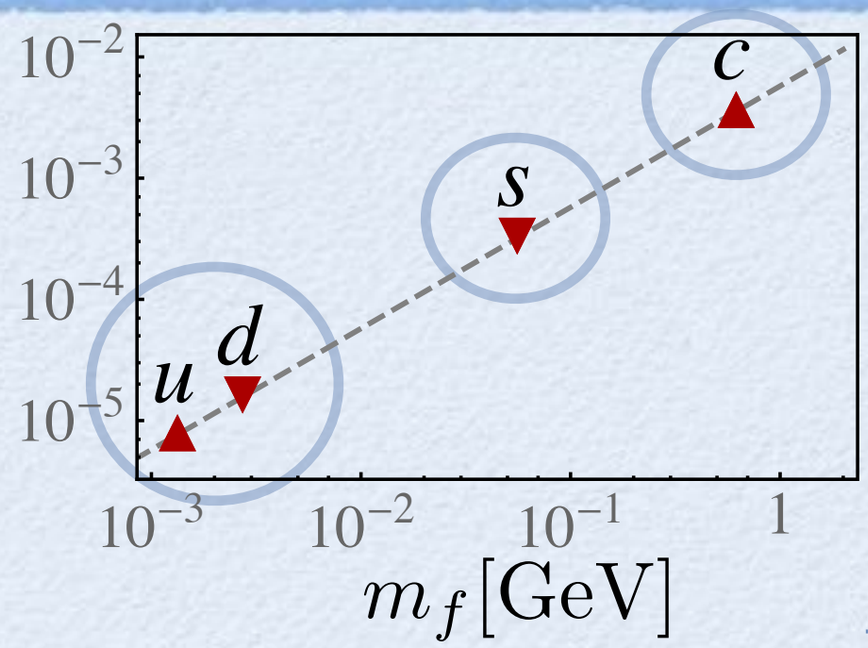

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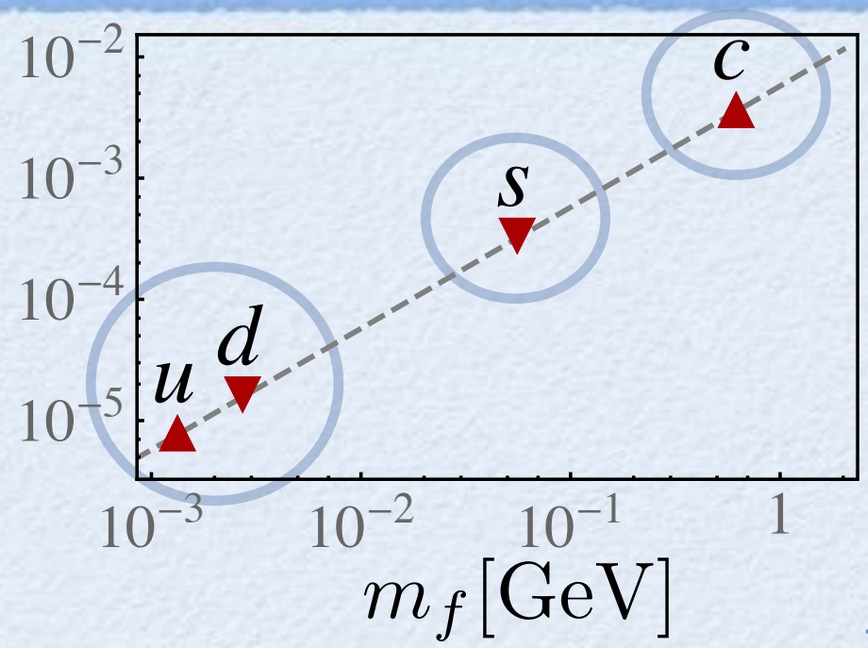

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Stamou's talk

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Alte's talk

Higgs kinematics

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YS, Zhu, Zupan 1606.09621

this talk

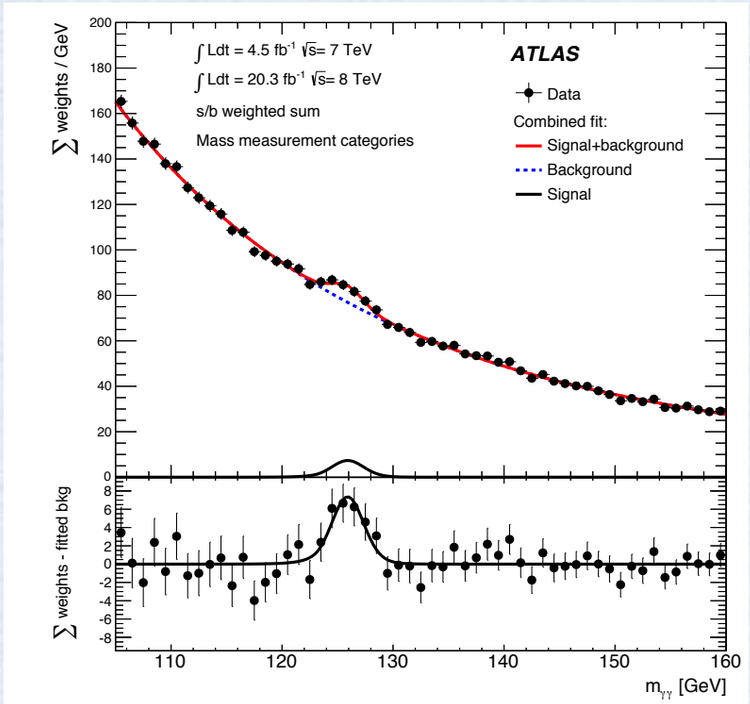
Higgs production

Zhou, 1505.06369
Yu 1609.06592

INDIRECT CONSTRAINTS

Higgs width

$$\Gamma_{\text{total}} < 1.7\,,\,2.6\,\text{GeV}$$ CMS, ATLAS



$$\Gamma^{\text{SM}}_{\text{total}} \simeq 4\,\text{MeV}$$

Perez, YS, Stamou, Tobioka, 1503.00290
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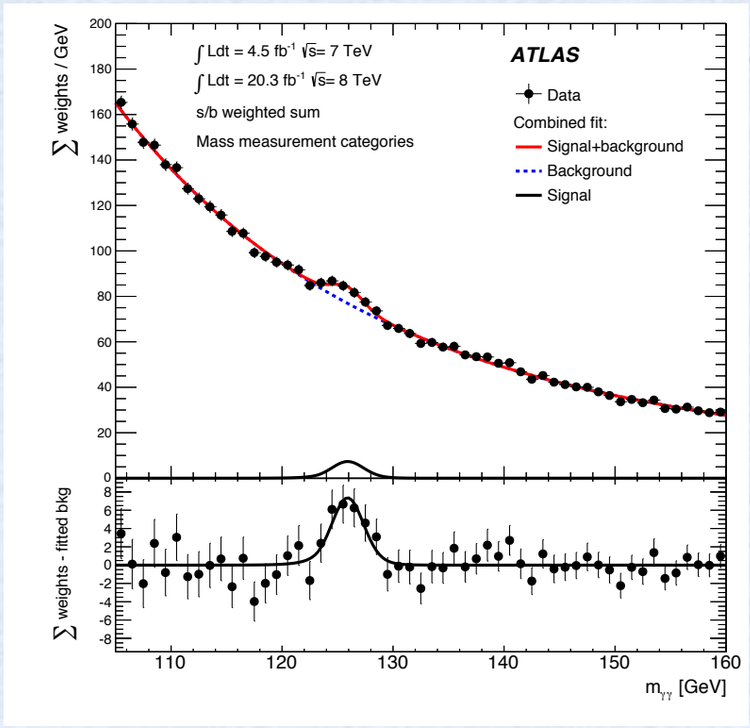

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assume saturation by $h \to qq$

$$\bar{\kappa}_q \equiv \frac{y_q^{\rm exp}}{y_b^{\rm SM}} < 26\,, 33$$

$$\Gamma_{\rm total}^{\rm SM} \simeq 4\,{\rm MeV}$$

normalized to the SM bottom Yukawa

Perez, YS, Stamou, Tobioka, 1503.00290
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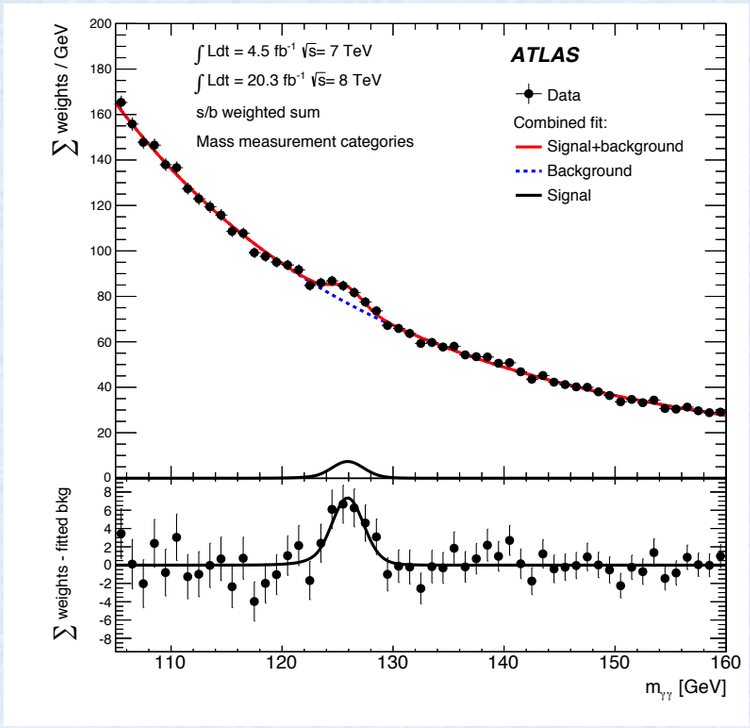

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$$\Gamma_{\rm total}^{\rm SM} \simeq 4\,{\rm MeV}$$

global fit

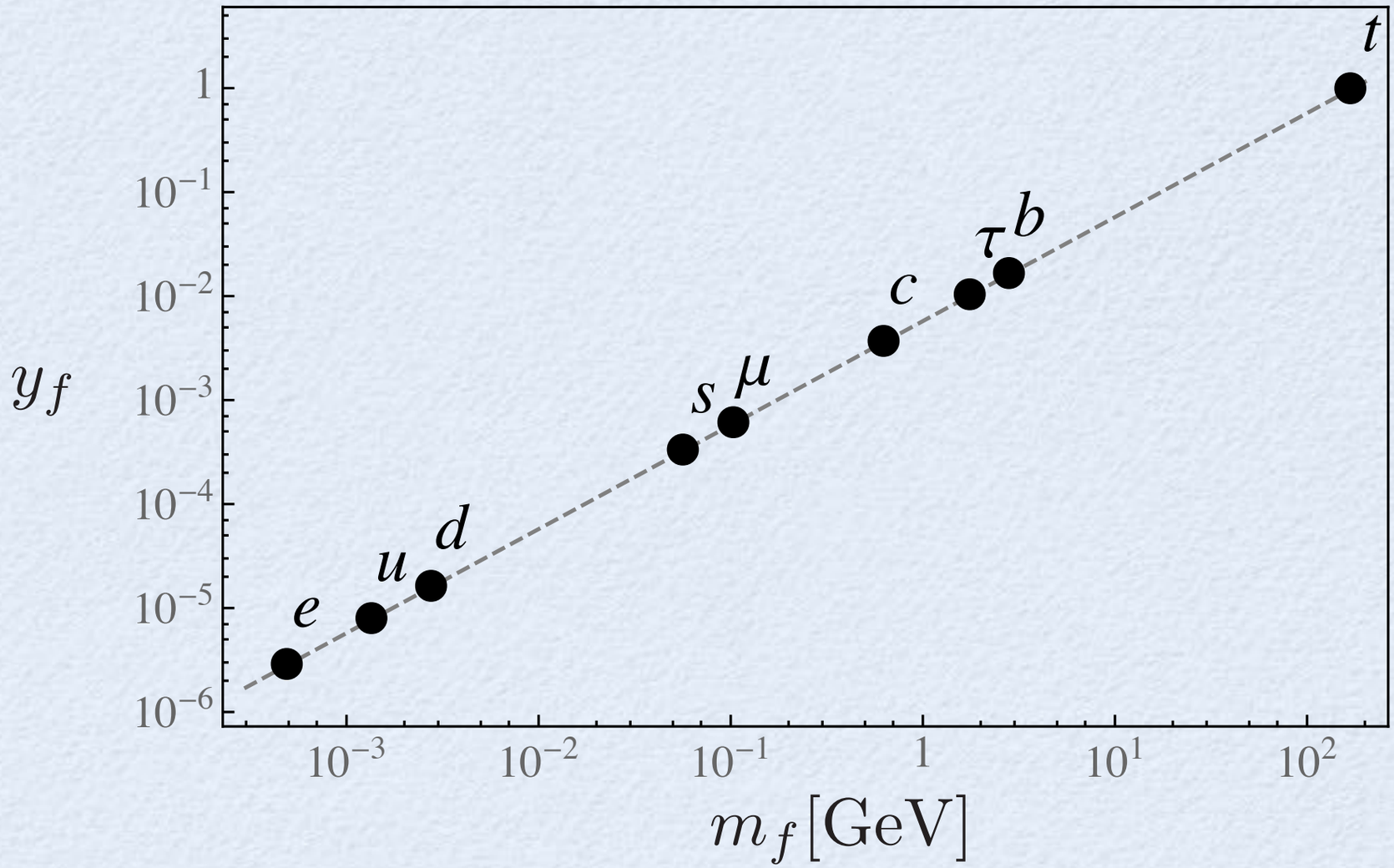
$$\bar{\kappa}_q \equiv \frac{y_q^{\rm exp}}{y_b^{\rm SM}} \lesssim 1.3$$

normalized to the SM
bottom Yukawa

(includes electroweak precision)

Perez, YS, Stamou, Tobioka, 1503.00290
Zhou, 1505.06369

CURRENT BOUNDS SUMMARY



direct searches (ATLAS+CMS)

Γ_h<1.7 GeV (CMS)

global analysis

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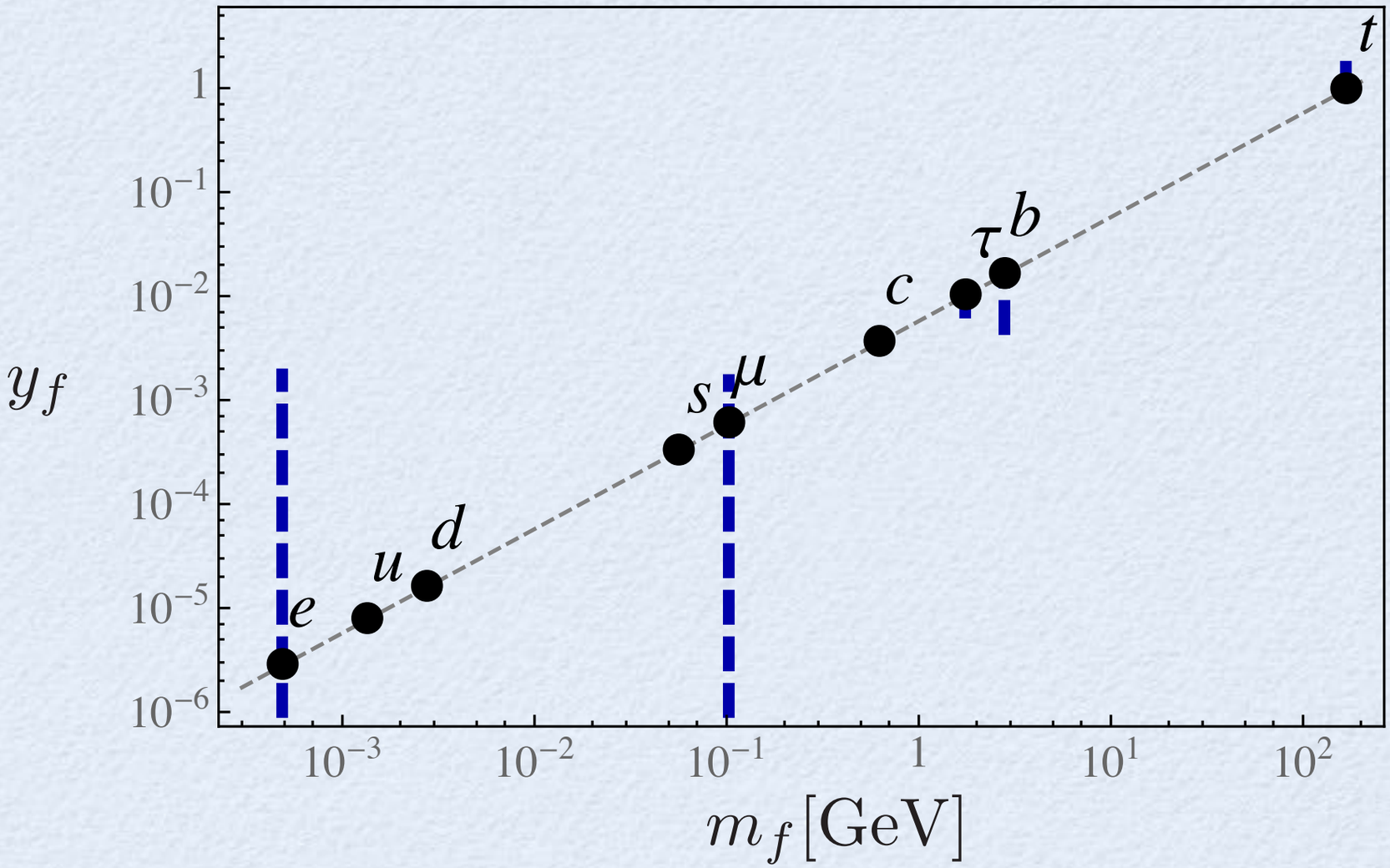

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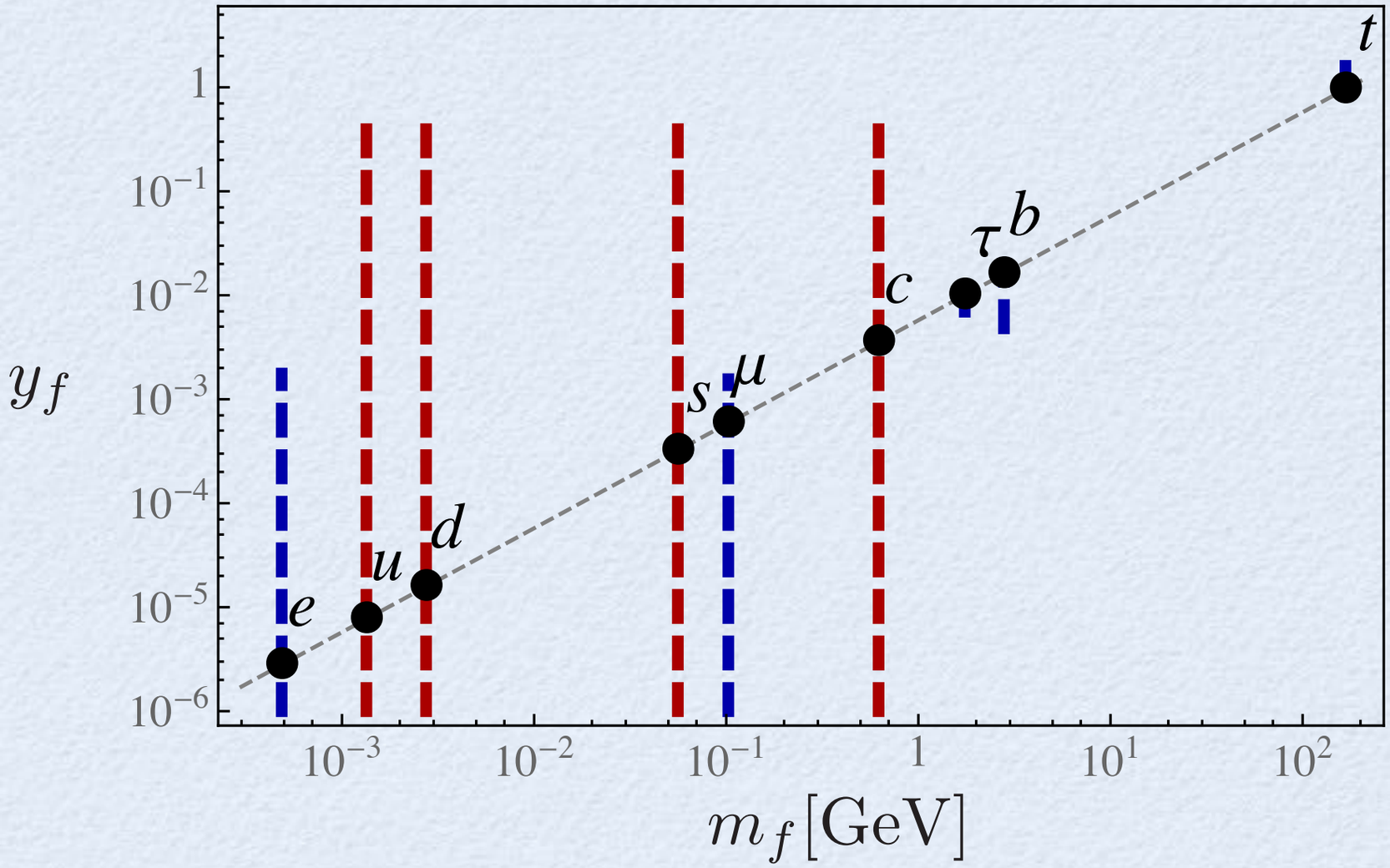

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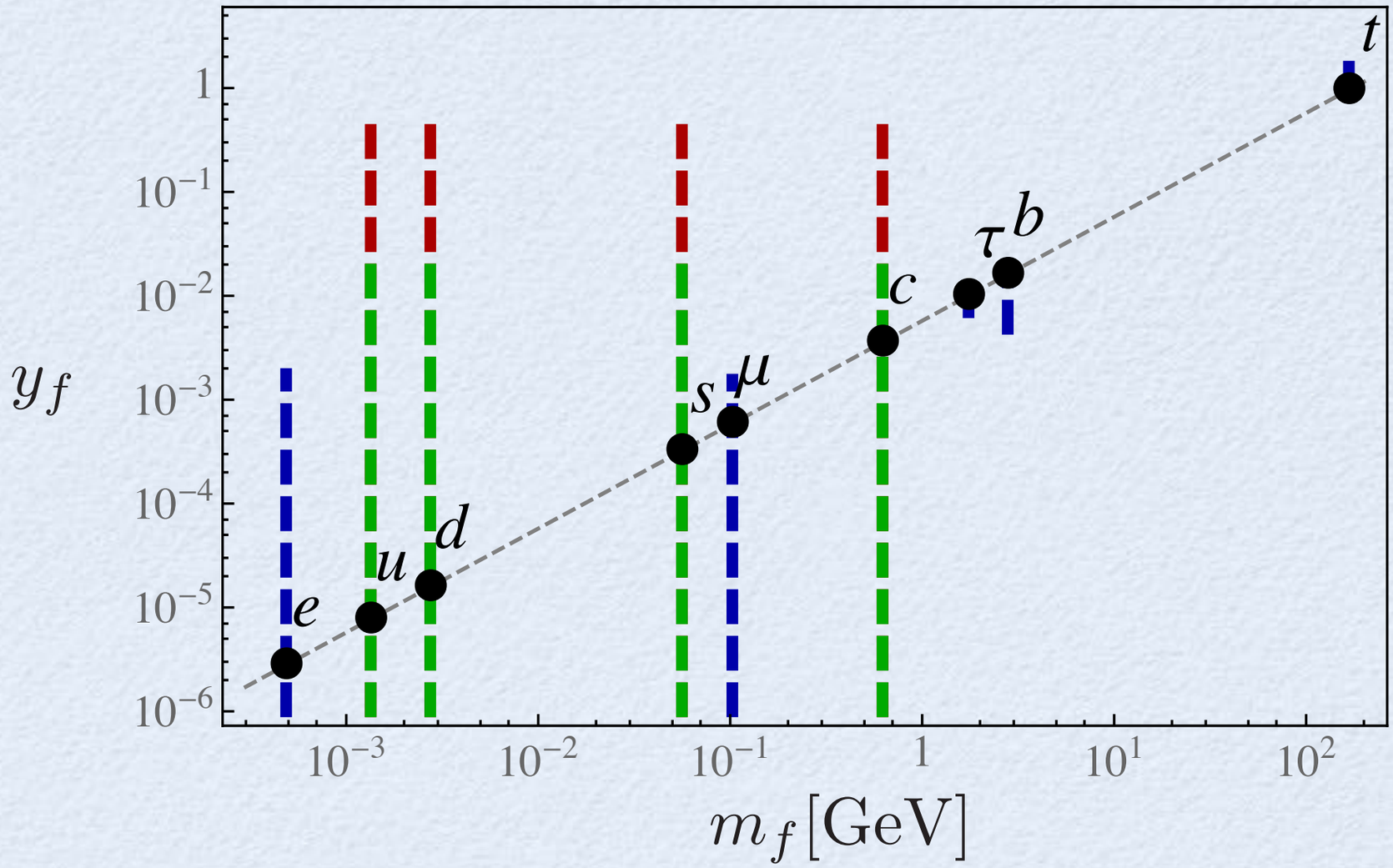

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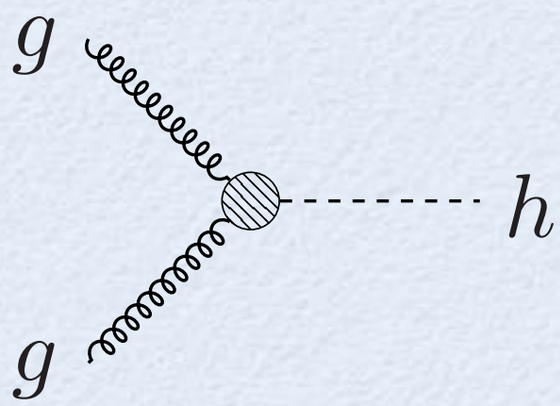
Higgs Kinematics

HIGGS KINEMATICS

Higgs production

SM (dominant)



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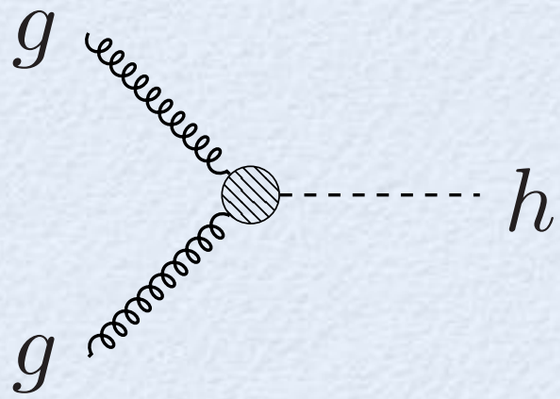
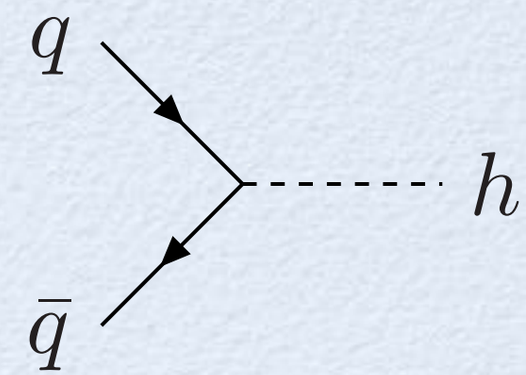


large light quarks Yukawa
($y_q \lesssim y_{b,\mathrm{sm}}$ allowed by data)



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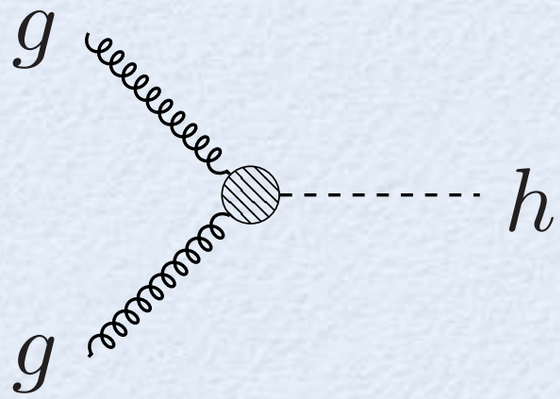

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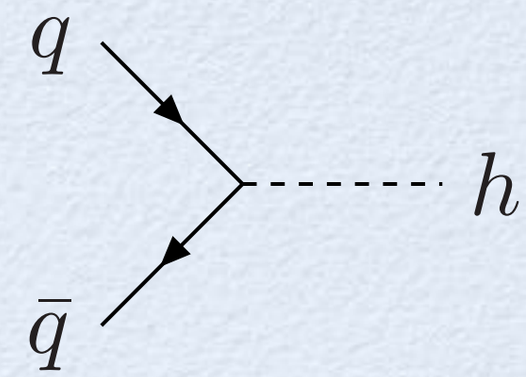


modify

Higgs rapidity

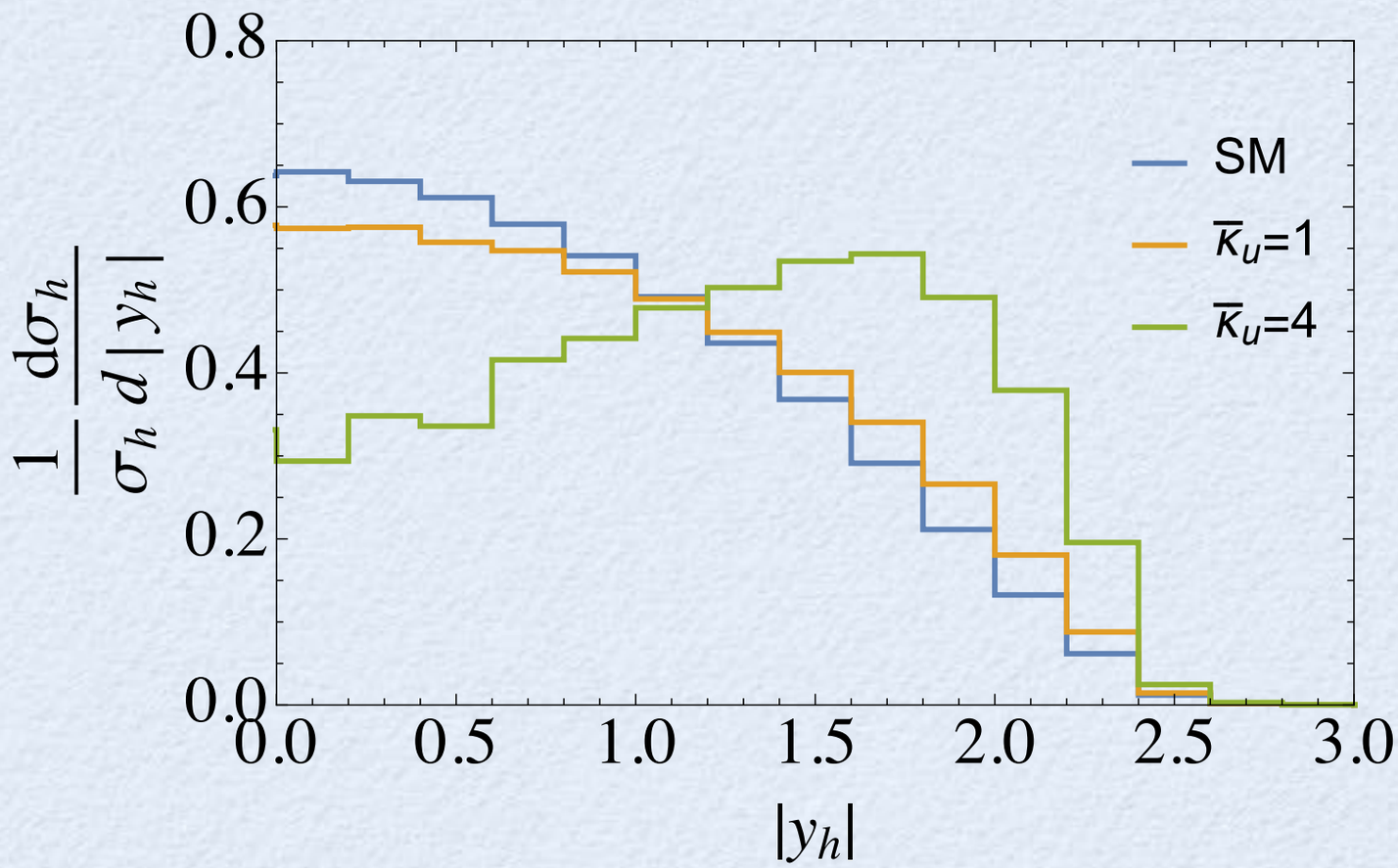
Higgs p_T

RAPIDITY DISTRIBUTION

valance quarks carry larger fraction of the proton momentum

more forward y_h spectrum

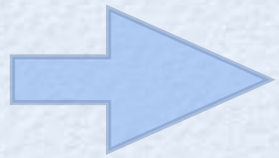
(quark has larger momenta than the anti-quark)



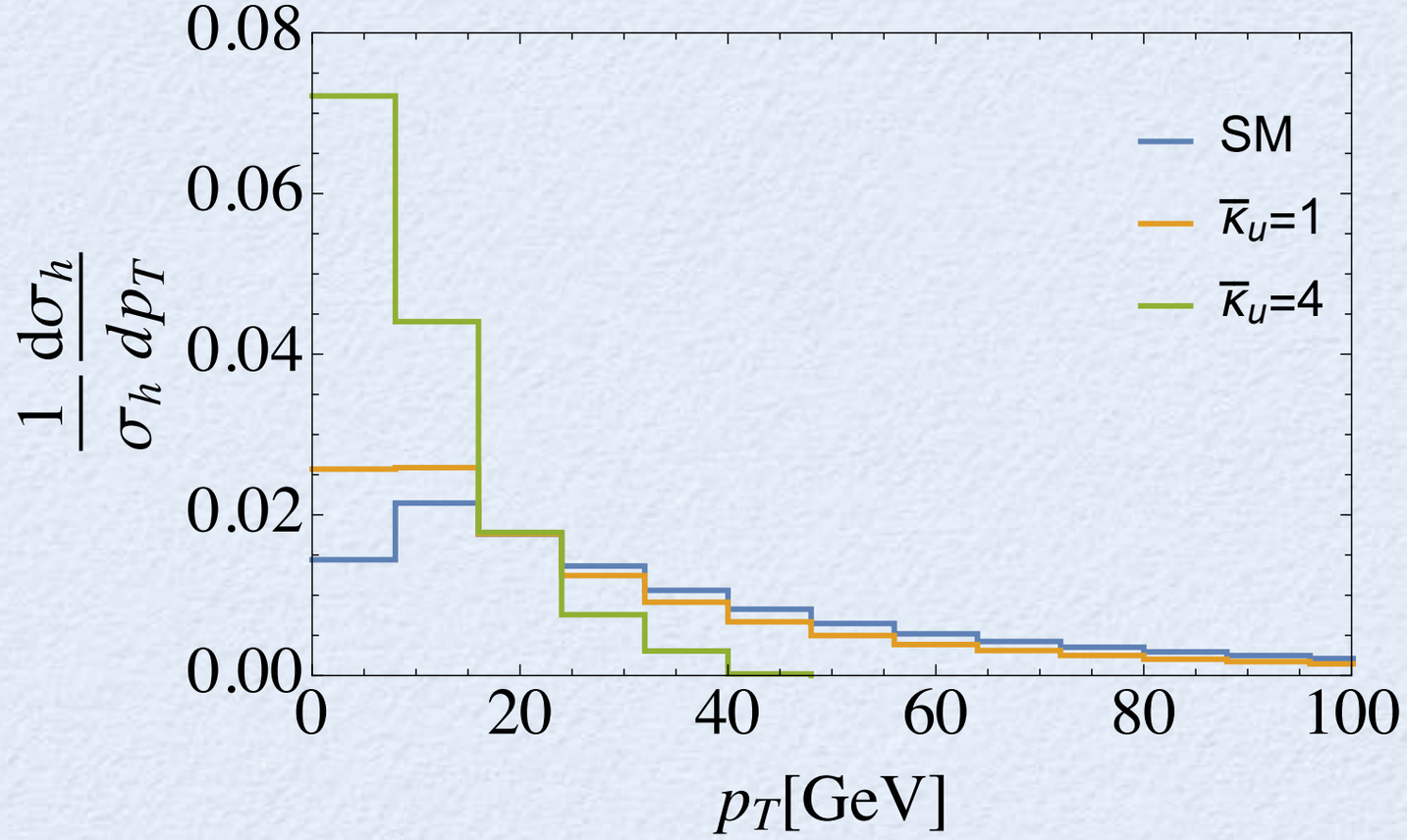
$$\bar{\kappa}_q \equiv y_q / y_b^{\rm SM}$$

P_T DISTRIBUTION

gluons has stronger radiation than quarks



softer p_T spectrum in presence of quark fusion



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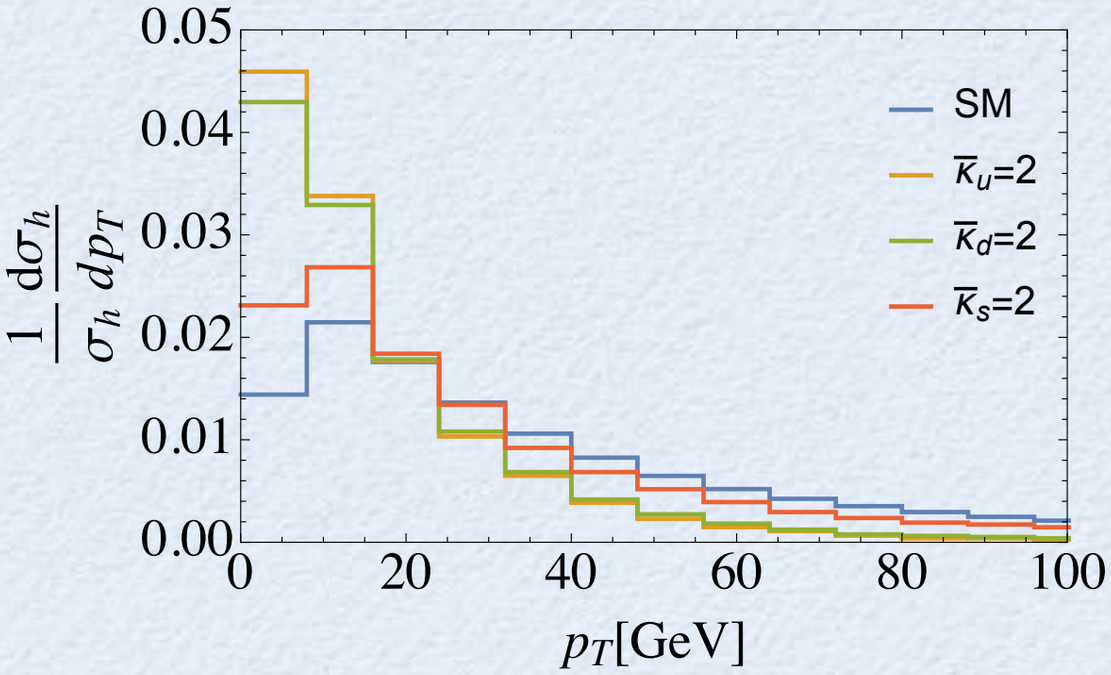
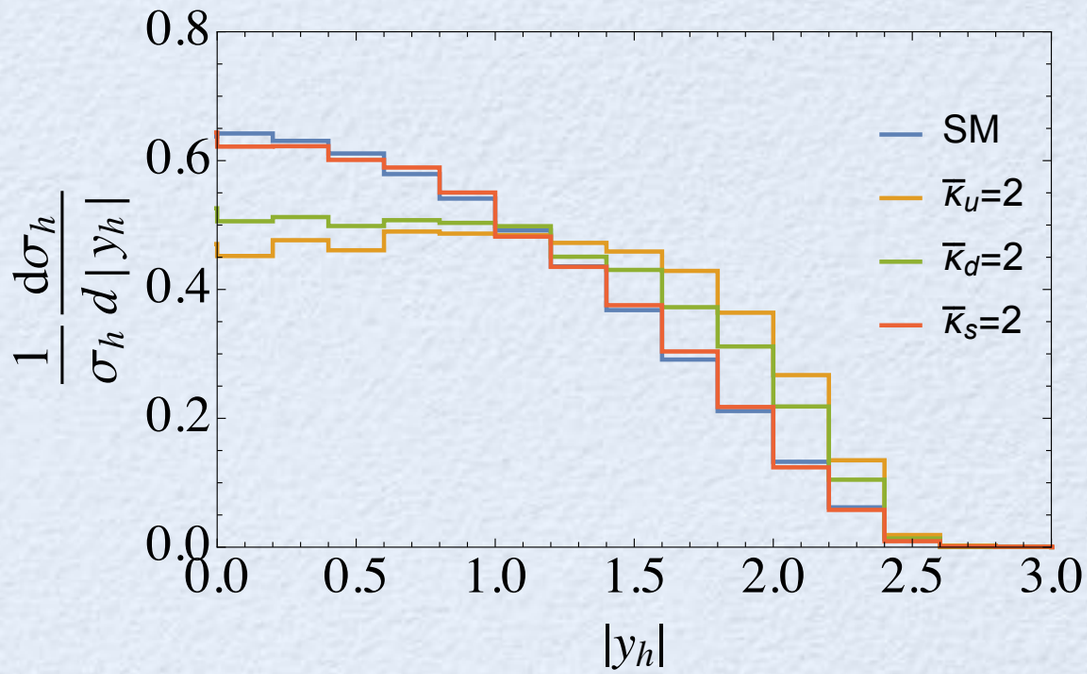
HIGGS KINEMATICS

larger sensitivity to valence quarks



softer p_T spectrum



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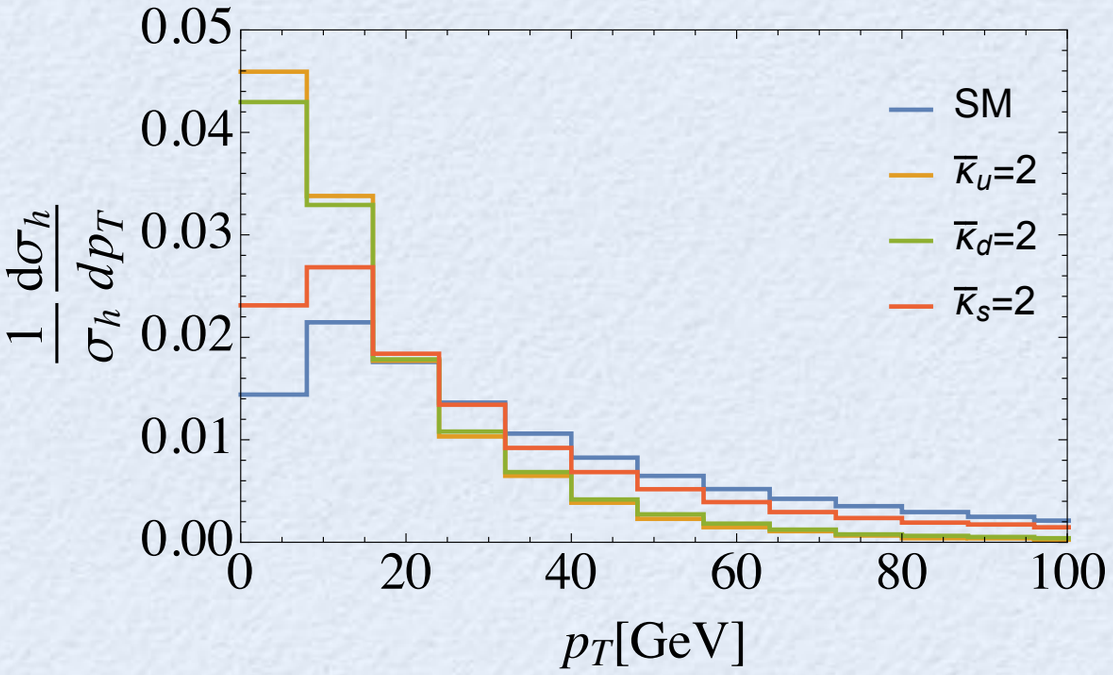
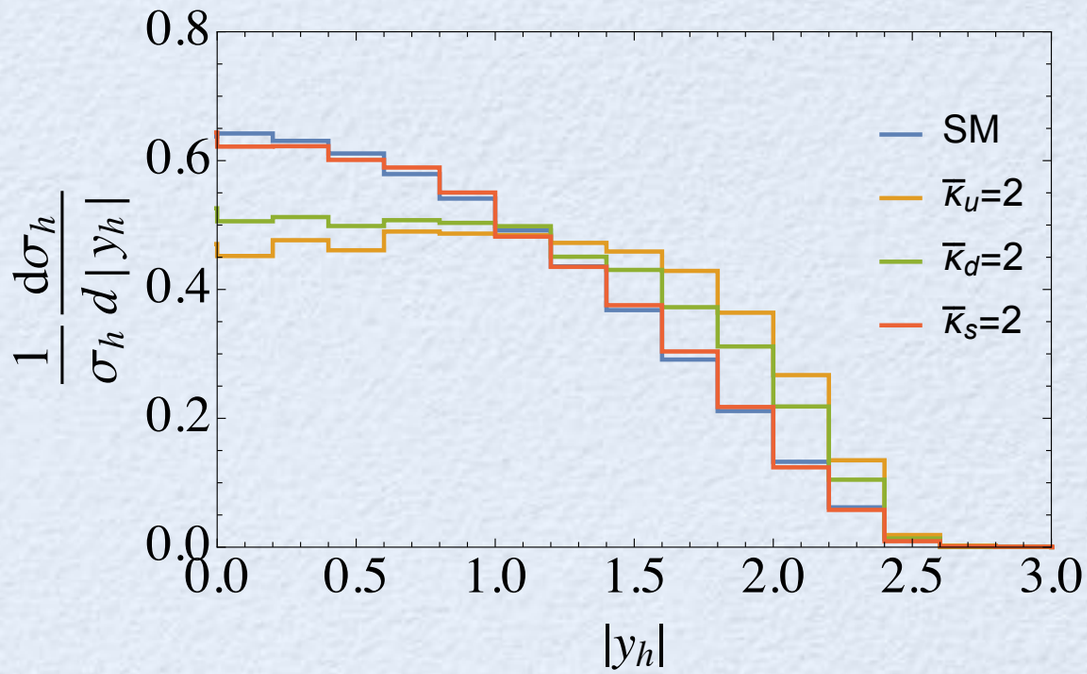
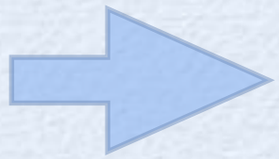
HIGGS KINEMATICS

larger sensitivity to valence quarks





normalized distributions

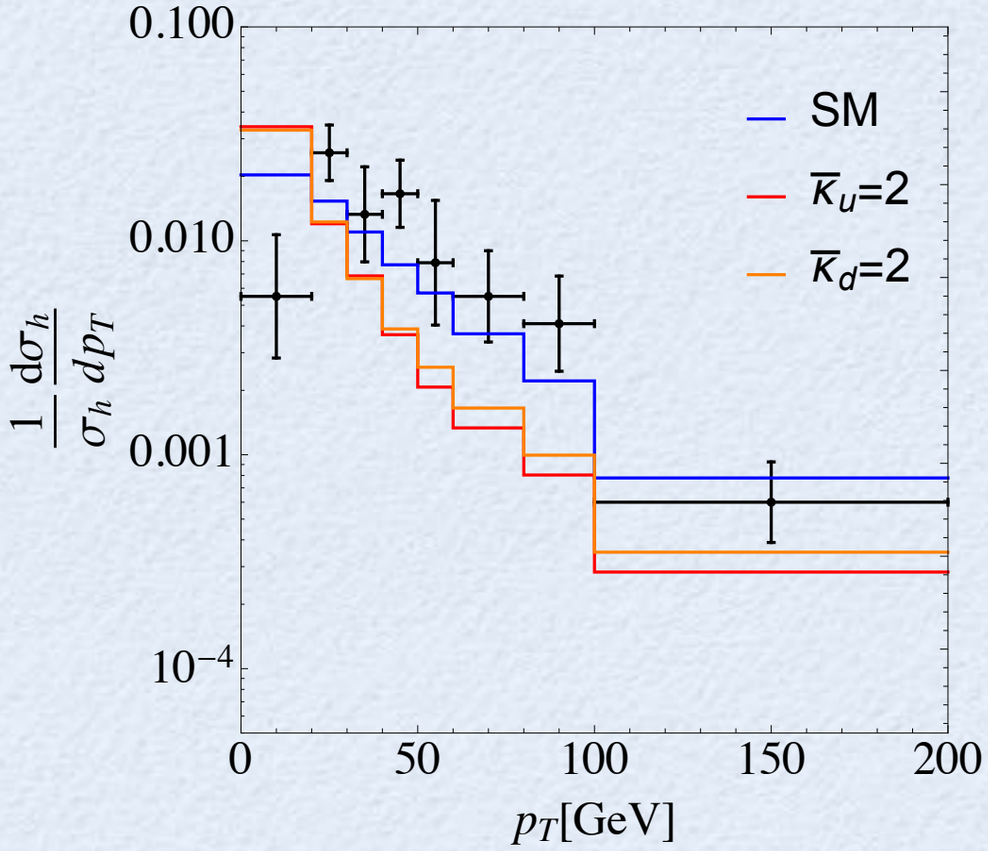


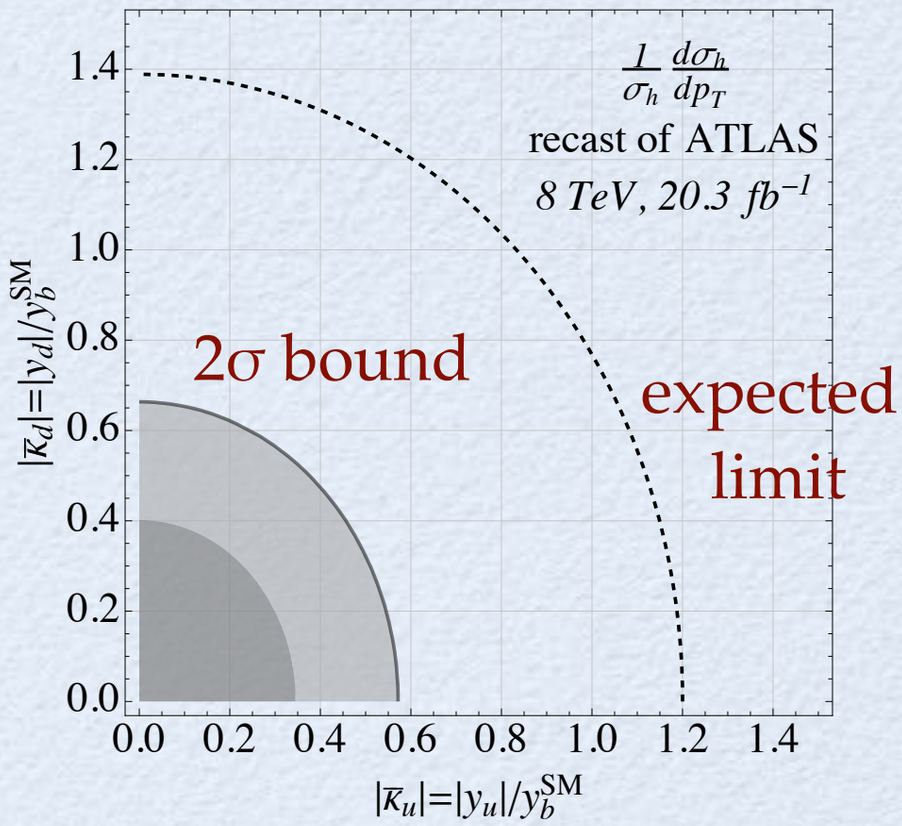
better theoretical and experimental control

$$\bar{\kappa}_q \equiv y_q / y_b^{\mathrm{SM}}$$

HIGGS KINEMATICS

use Run-1 ATLAS data





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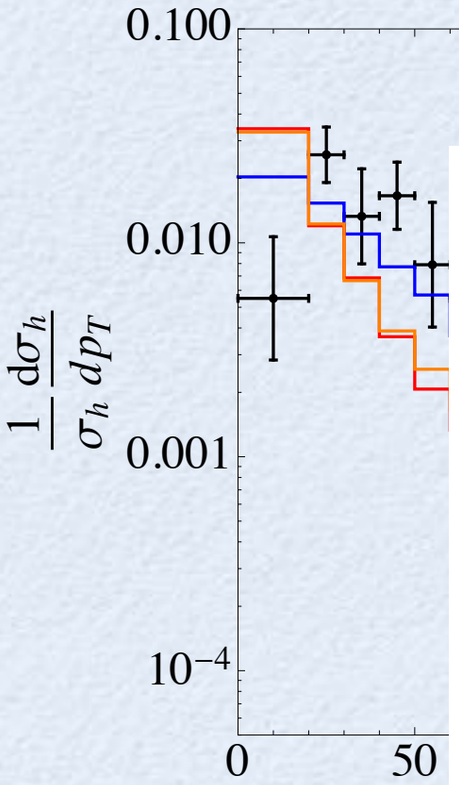
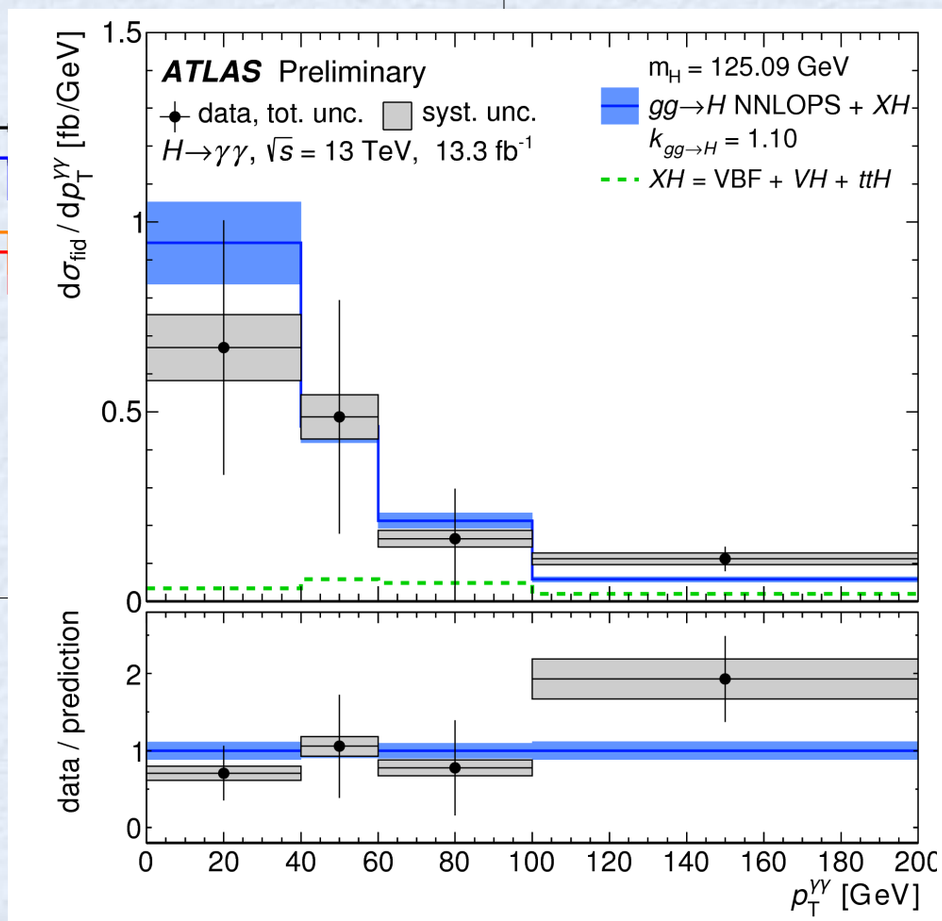
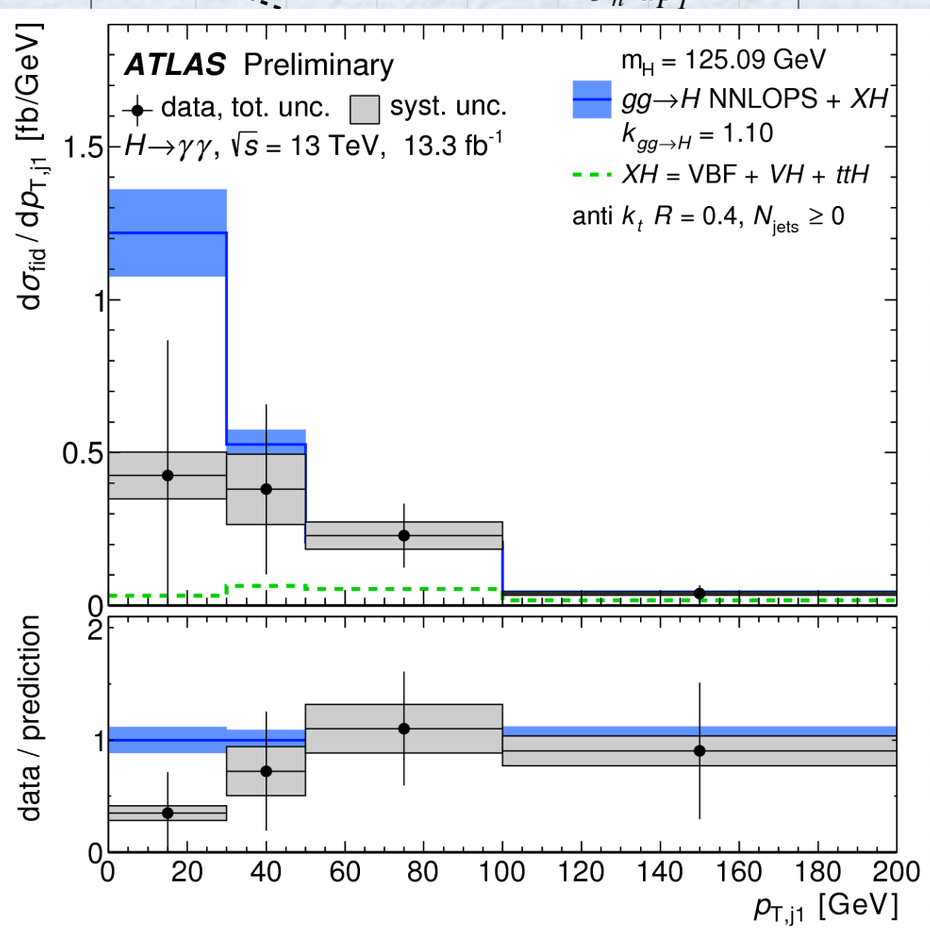
HIGGS KINEMATICS

use Run-1 ATLAS data







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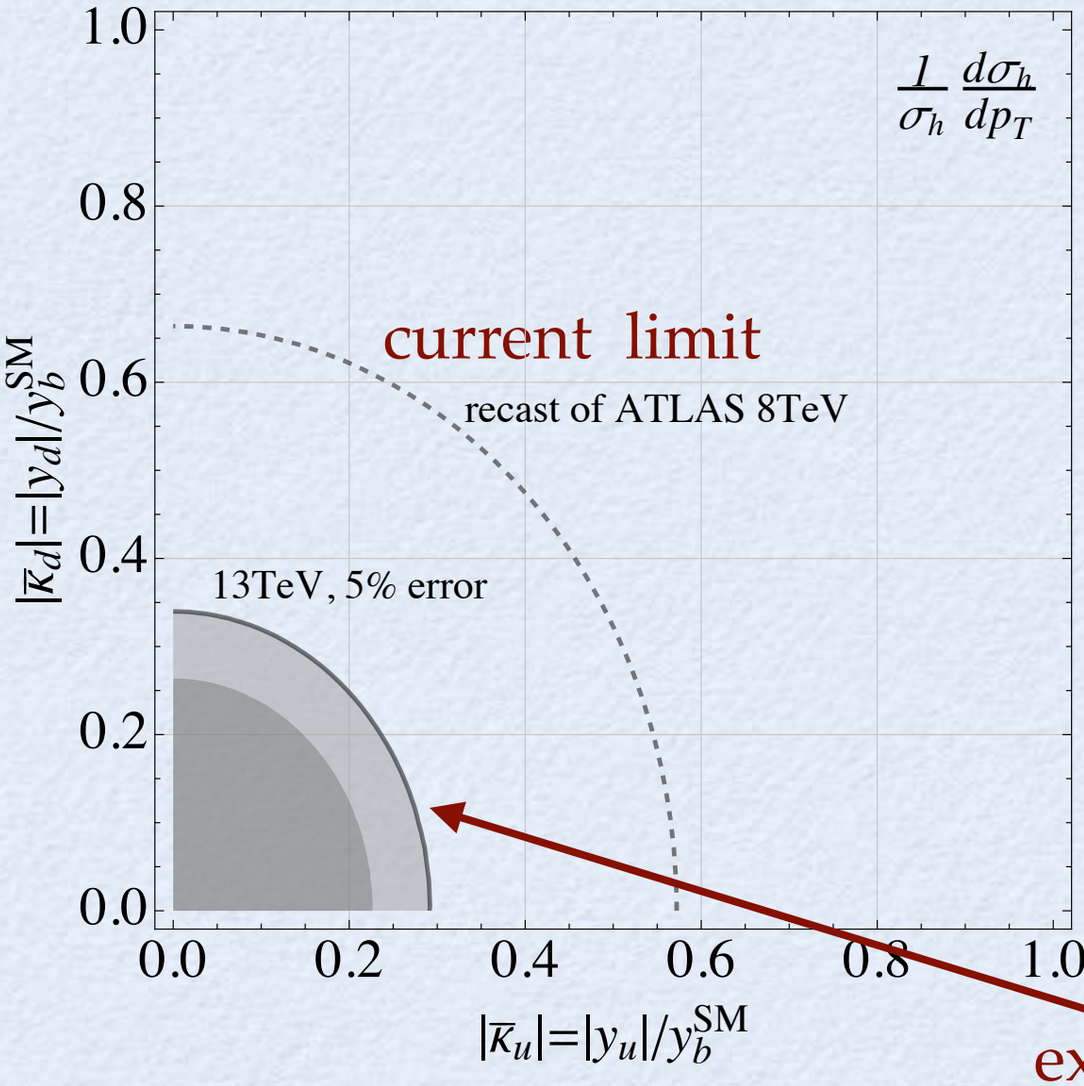
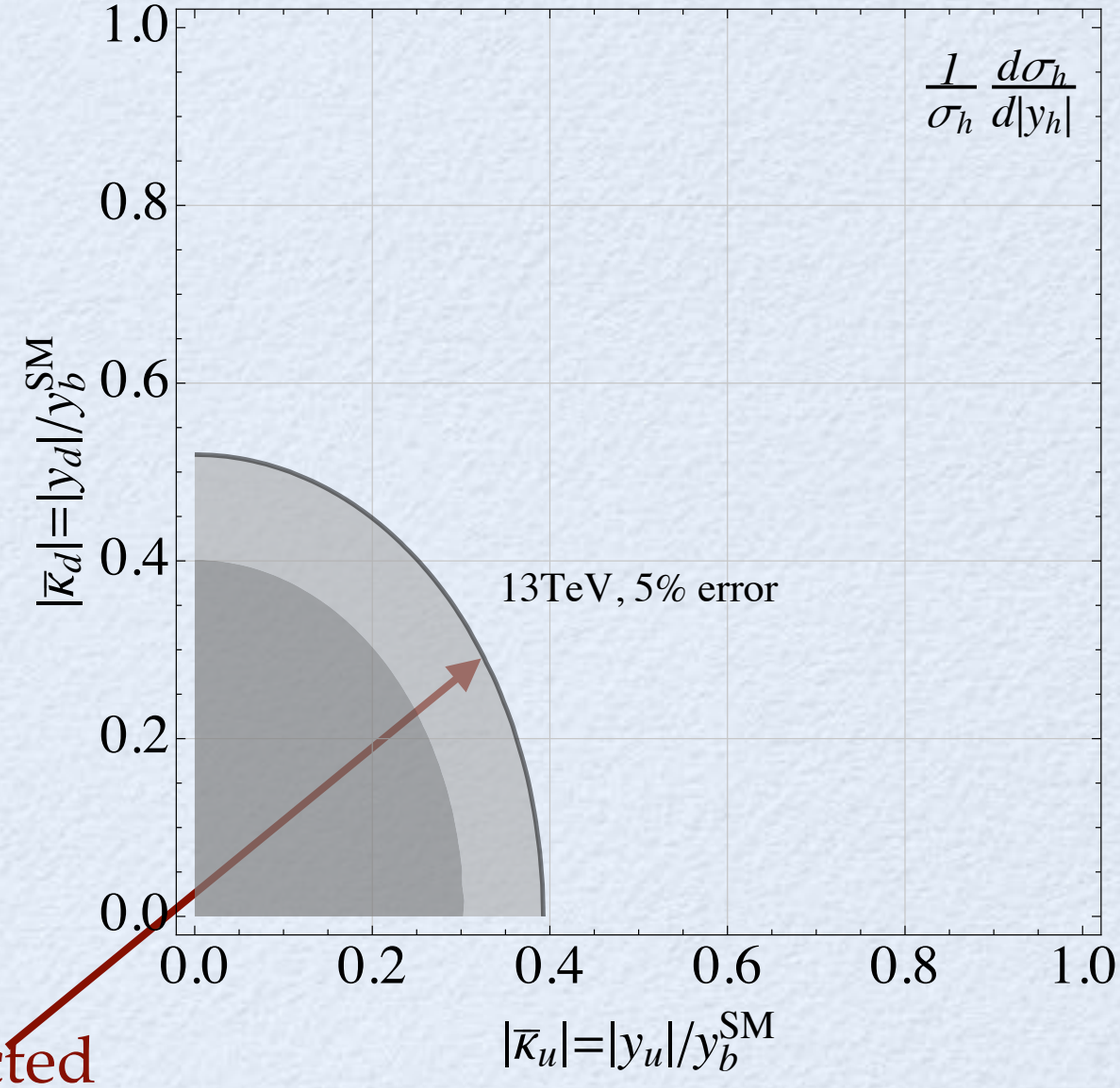
HIGGS KINEMATICS

prospect for Run-2 (with ~ 2 ab^{-1})



p_T distribution



rapidity distribution

expected

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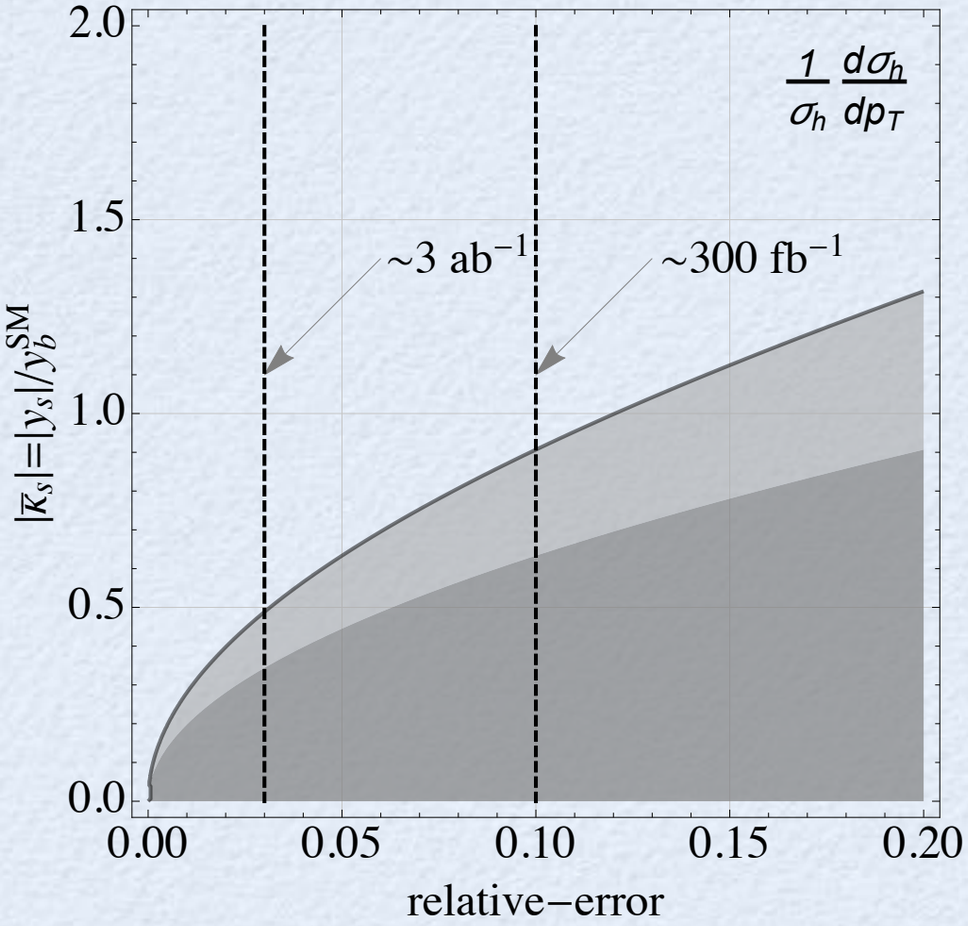
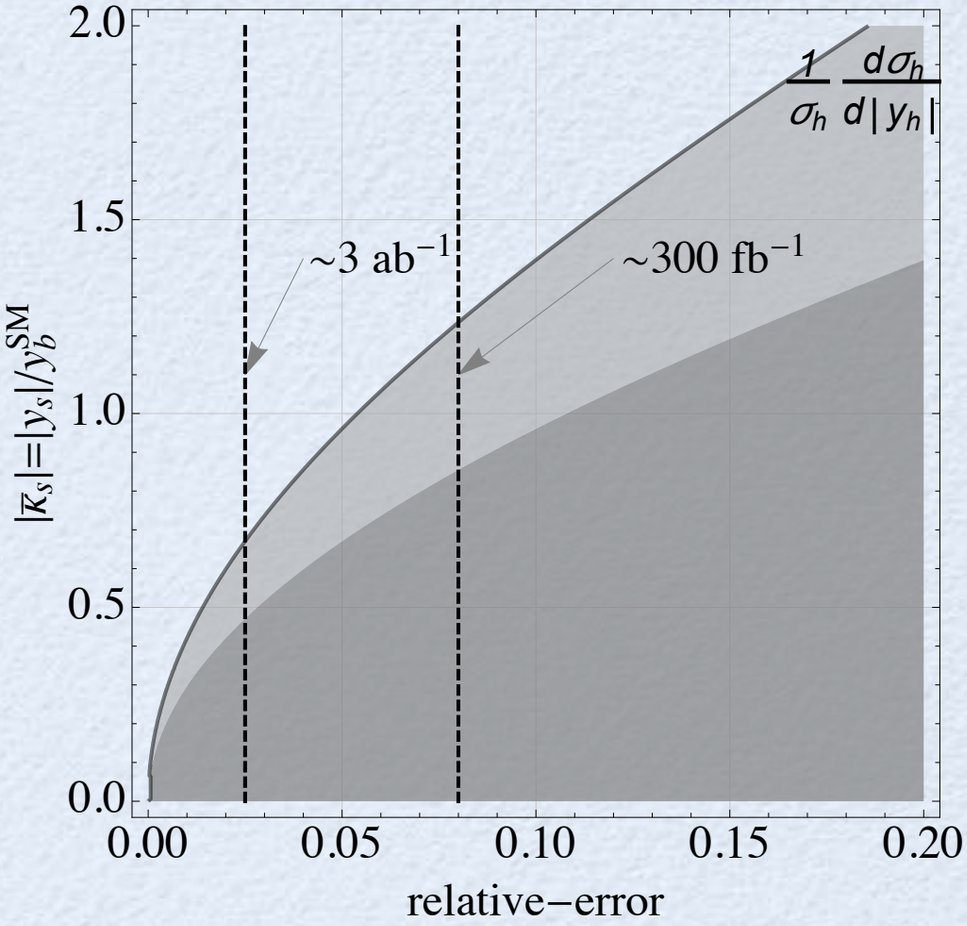
HIGGS KINEMATICS

prospect for Run-2 (for strange)



p_T distribution



rapidity distribution

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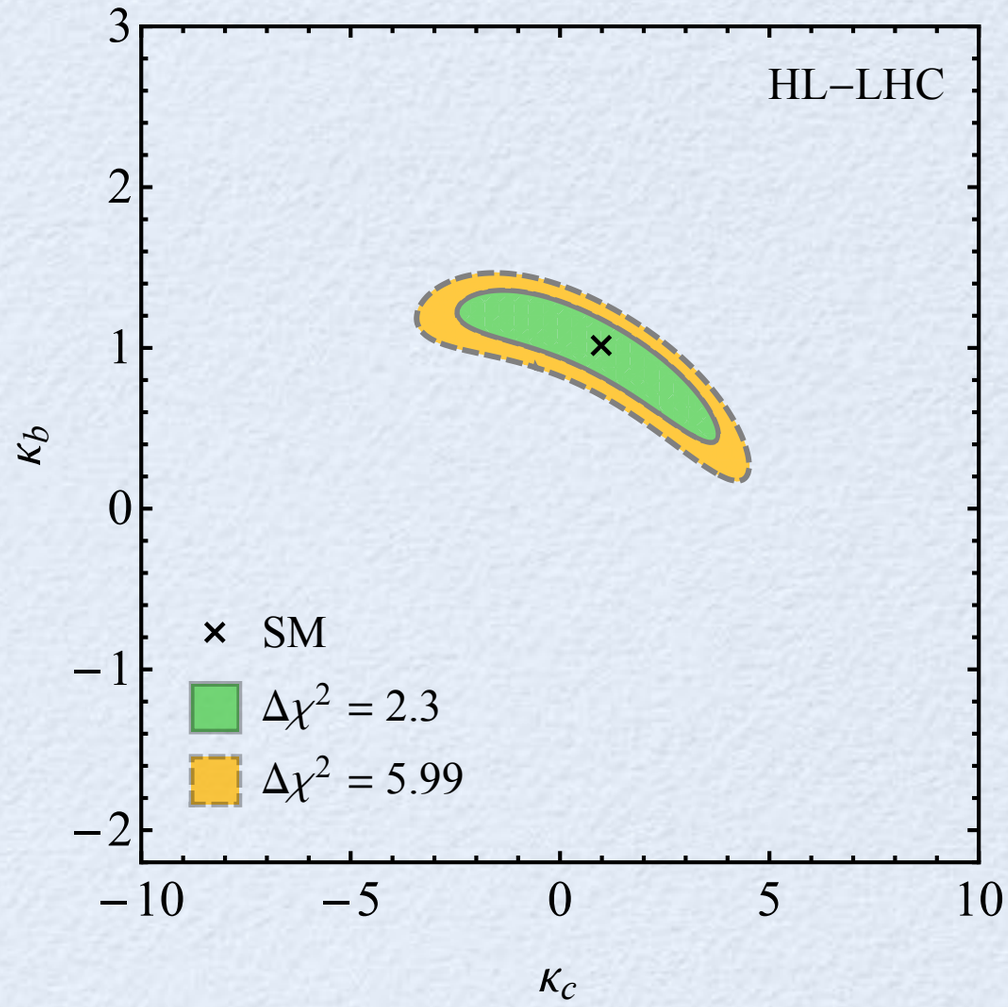
HIGGS KINEMATICS

sensitivity to the charm Yukawa

loop effect in
gluon function

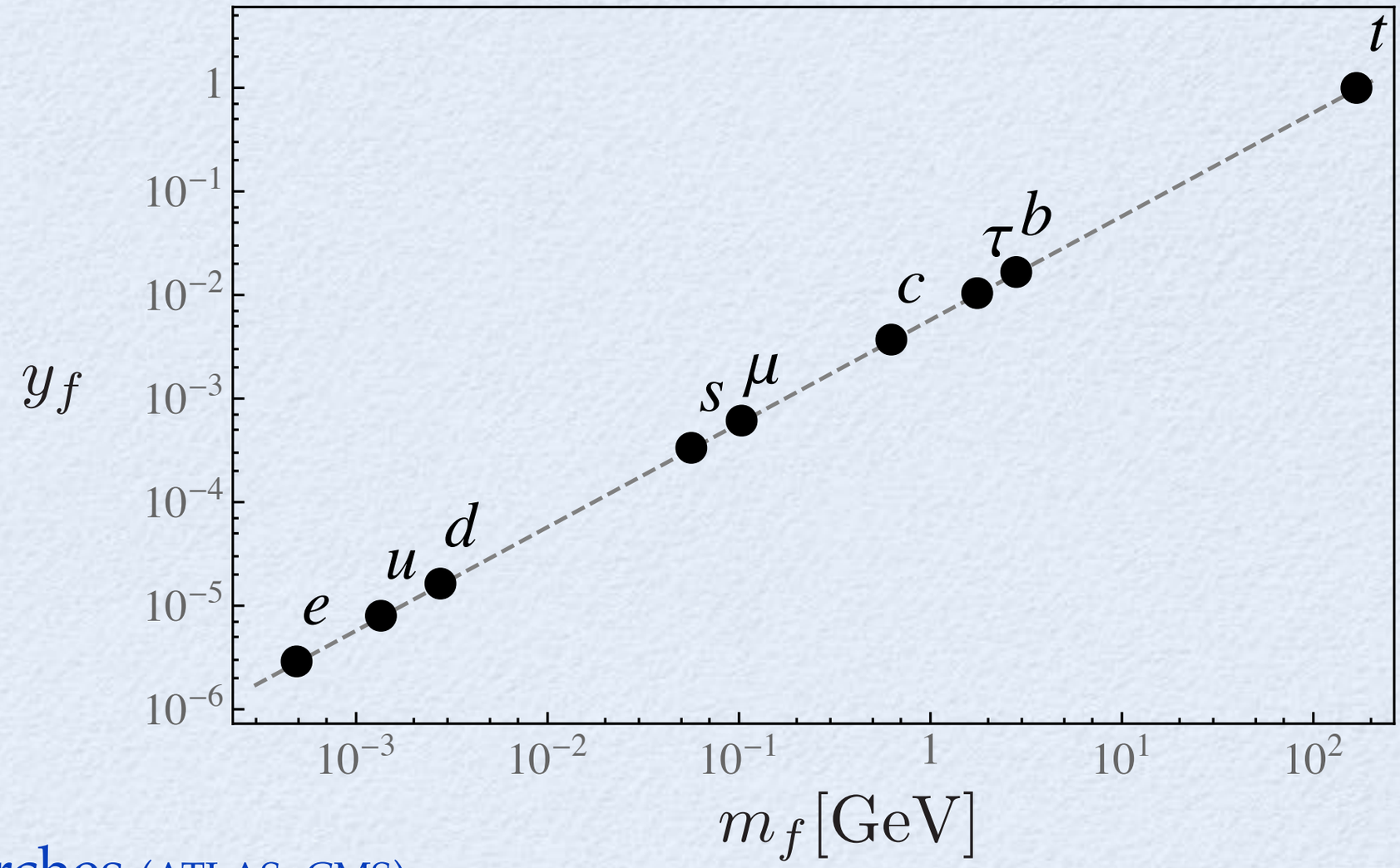
log enhancement

$$\kappa_Q \frac{m_Q^2}{m_h^2} \log^2\left(\frac{p_T^2}{m_Q^2}\right)$$



Bishara, Haisch, Monni, Re
1606.09253

CURRENT BOUNDS SUMMARY



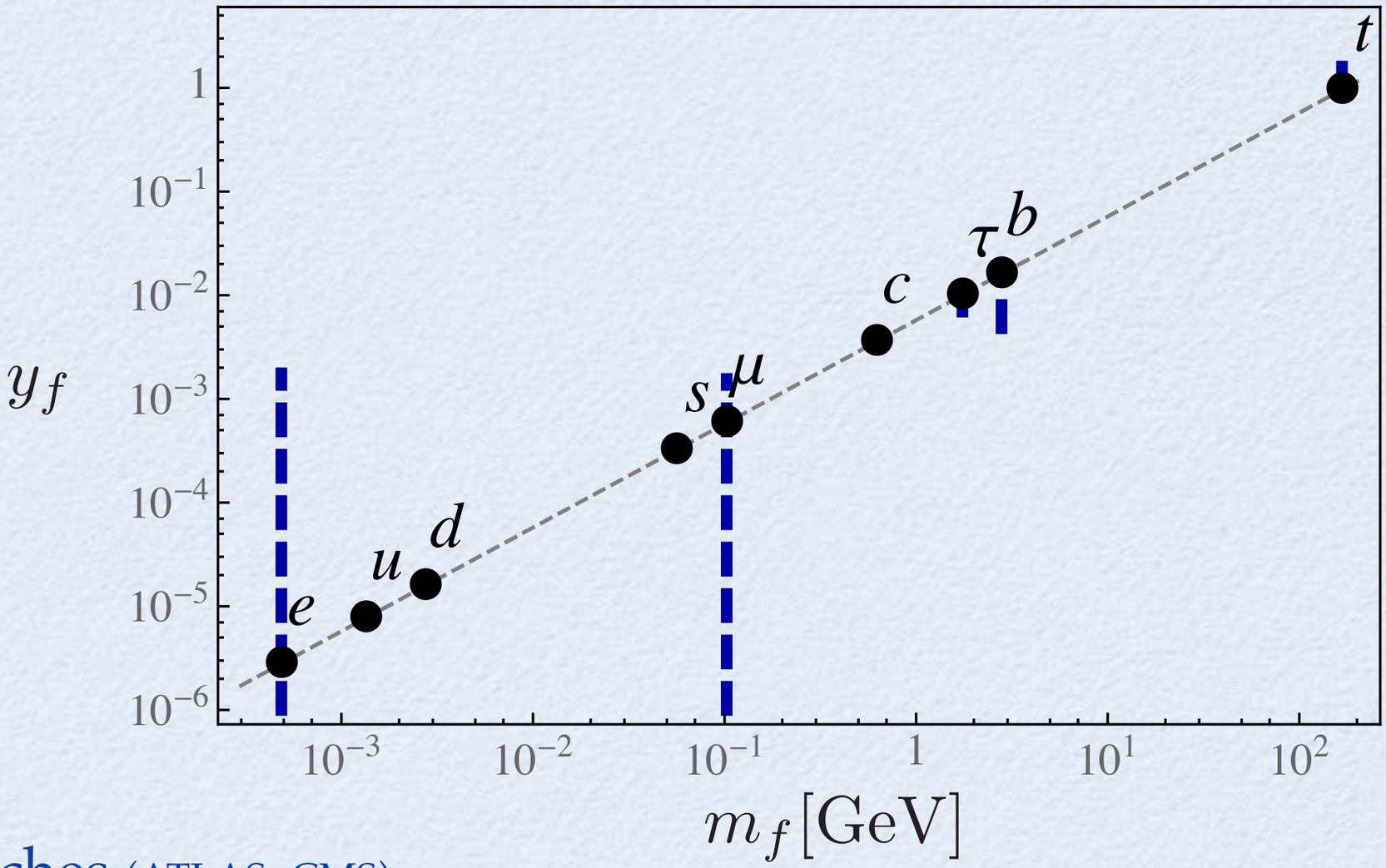
direct searches (ATLAS+CMS)

Γ_h<1.7 GeV (CMS)

global analysis

p_T distribution

CURRENT BOUNDS SUMMARY



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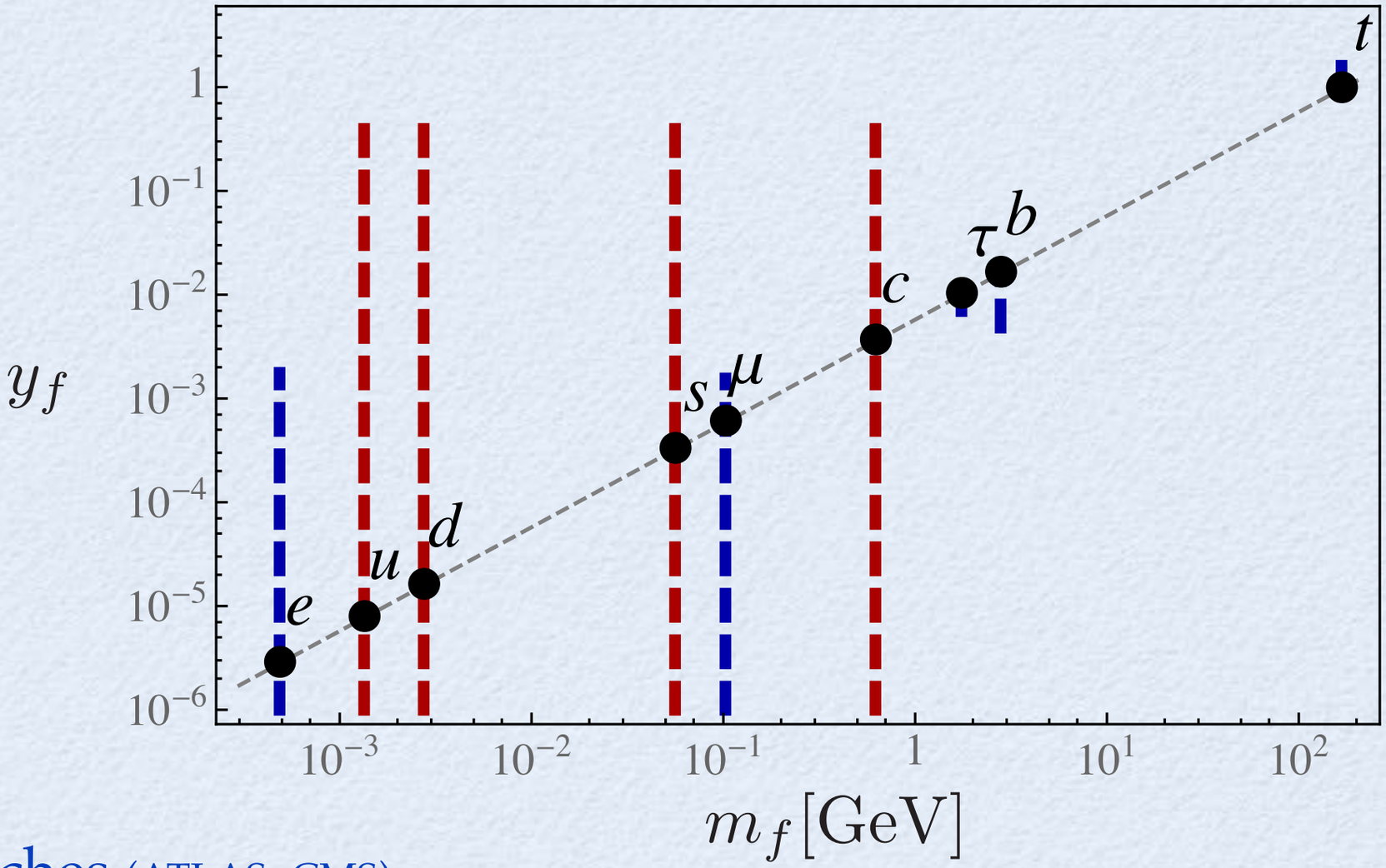
global analysis

p_T distribution

CURRENT BOUNDS SUMMARY



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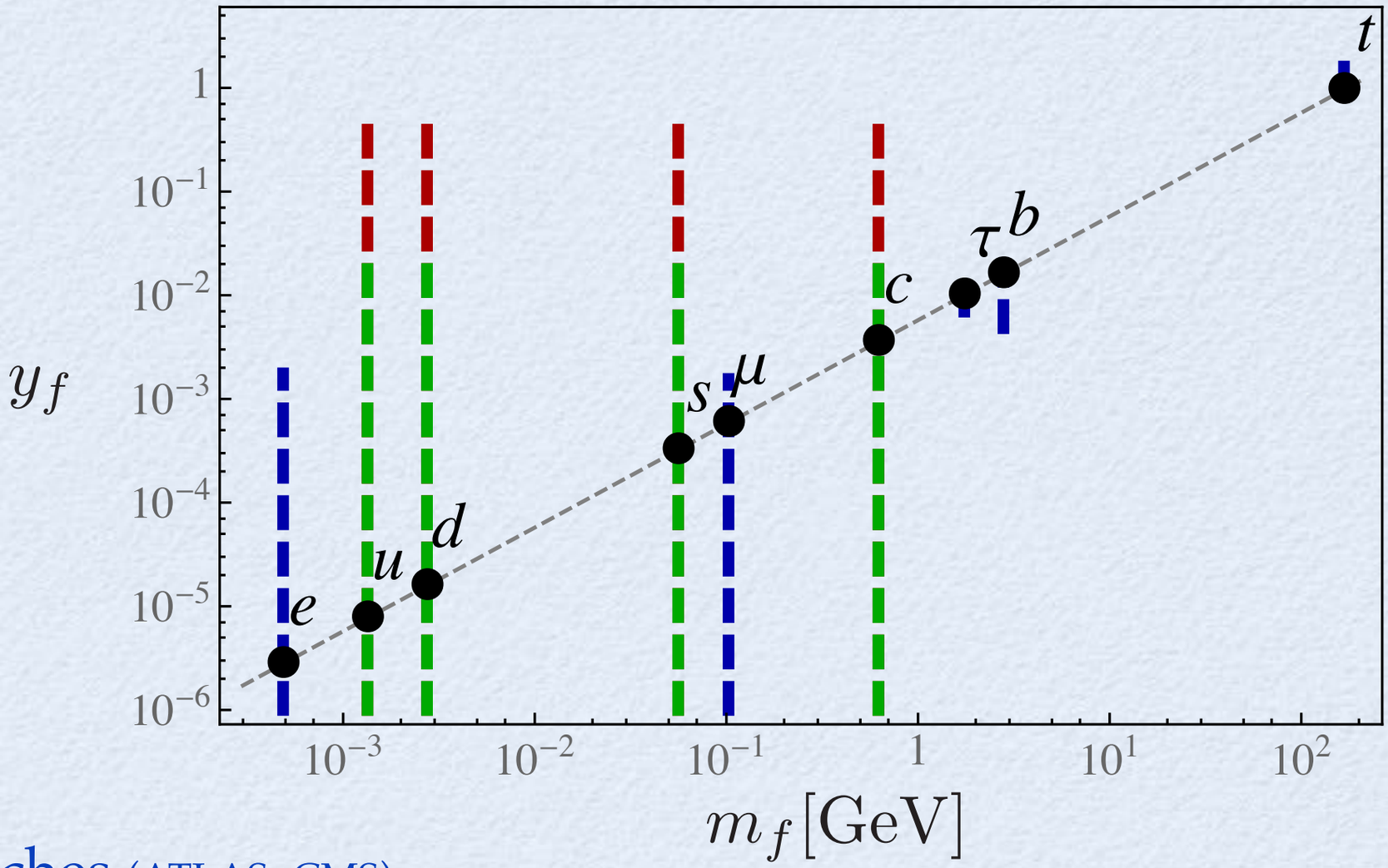

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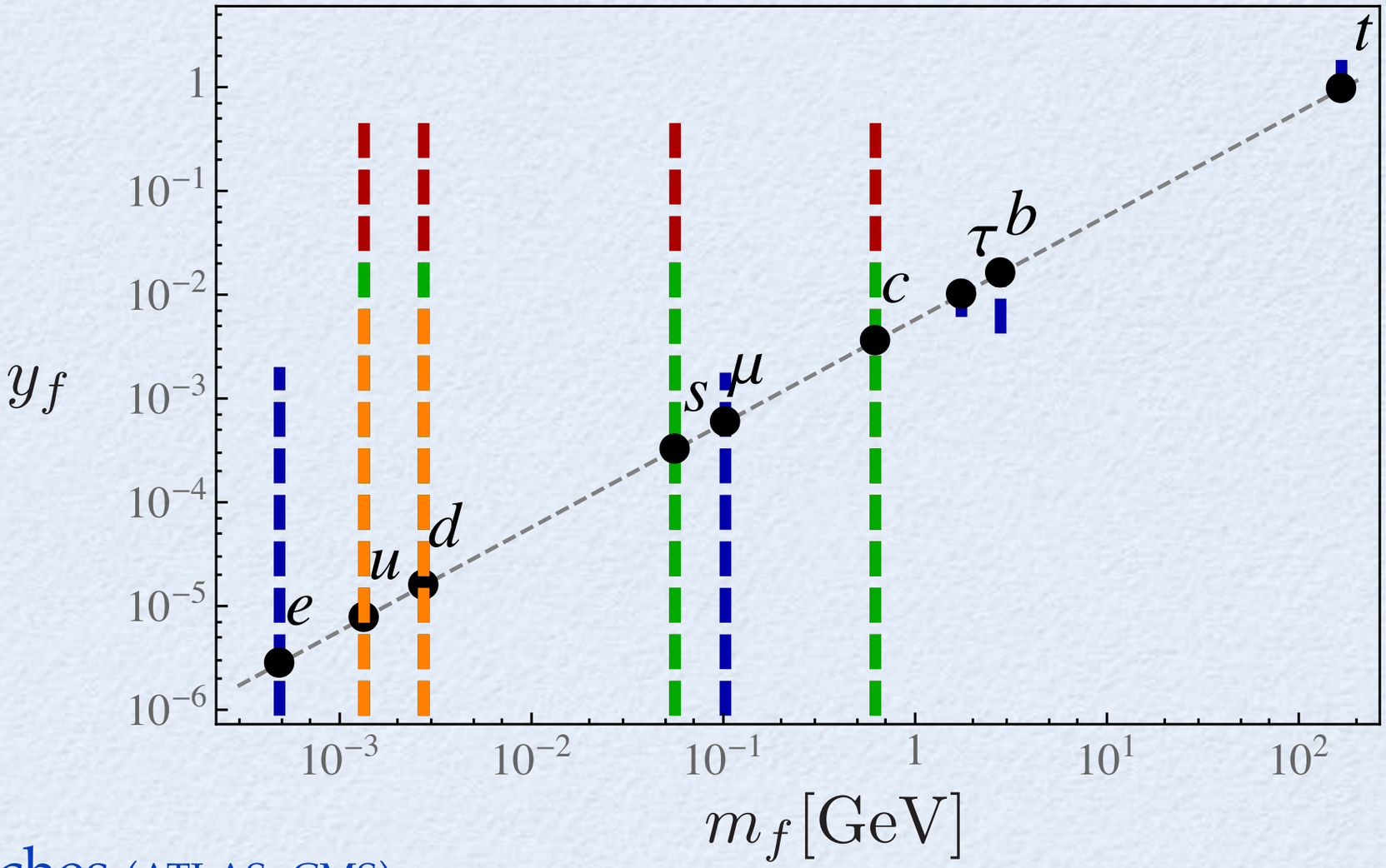
CURRENT BOUNDS SUMMARY



direct searches (ATLAS+CMS)

Γ_h<1.7 GeV (CMS)

global analysis

p_T distribution

SUMMARY

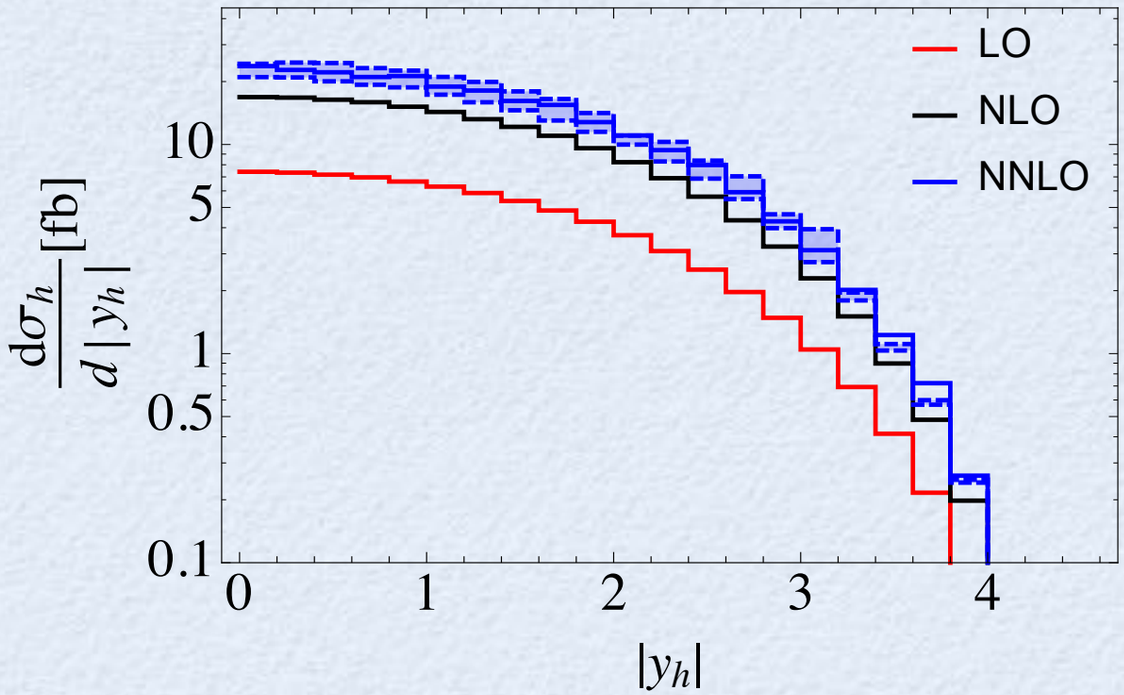
- the Higgs couplings to light quarks (u,d,s,c) can be large as the SM bottom Yukawa

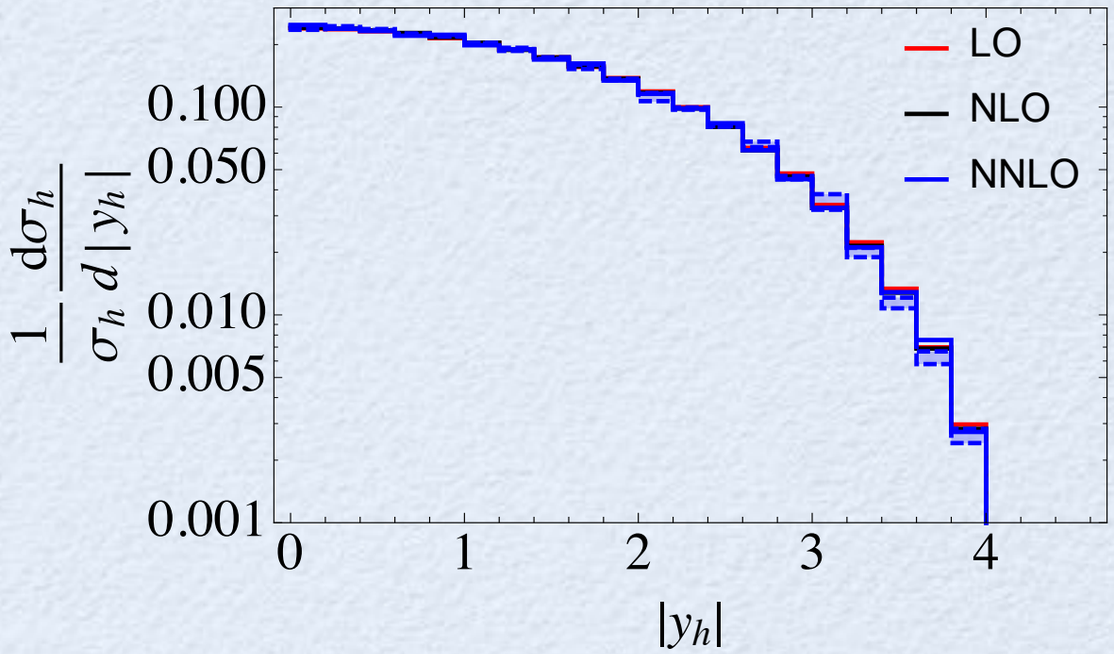
- light quarks Yukawa can be directly probed by inclusive rates and exclusive rates

- the Higgs kinematical distributions are sensitive to large modifications of light quarks Yukawa (mainly up and down), currently give the tighter indirect constrains on y_u and y_d

BACKUP SLIDES

NORMALIZED DISTRIBUTION





NORMALIZED DISTRIBUTION