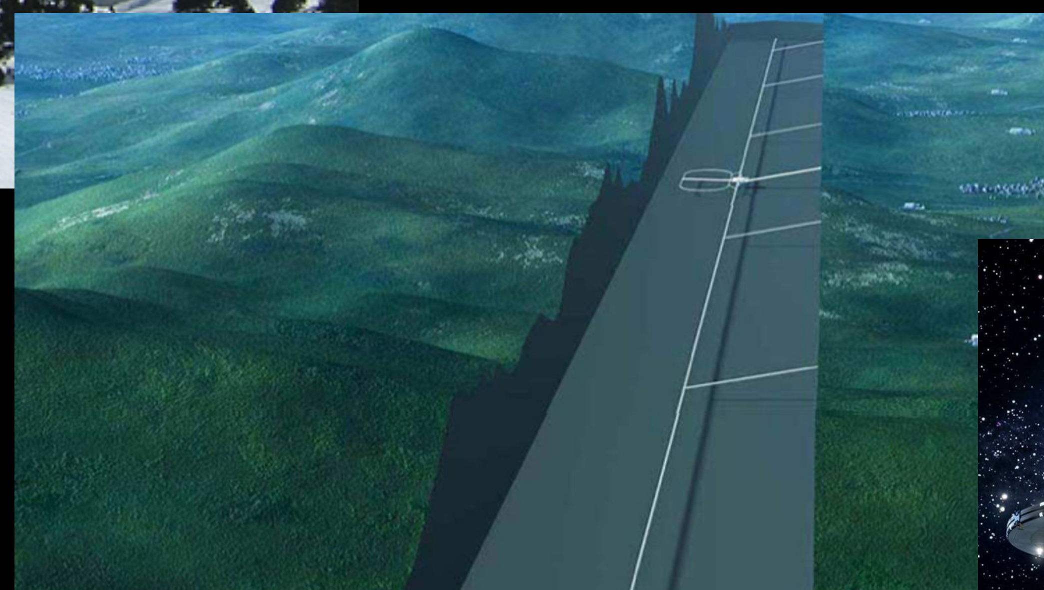
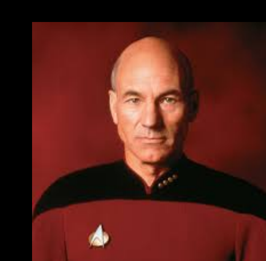
Higgs Physics:
The Next Generation

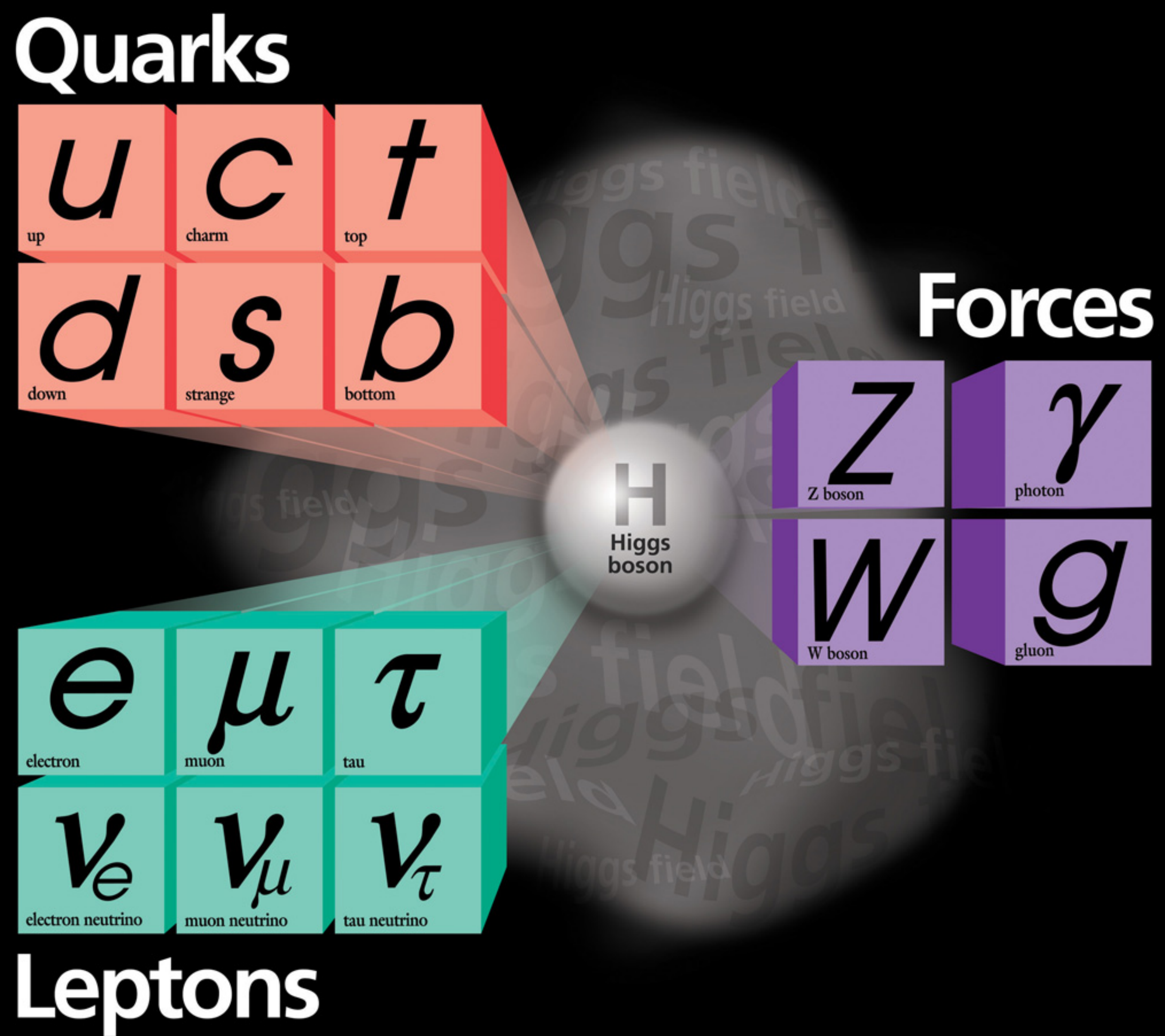


Chris Hays

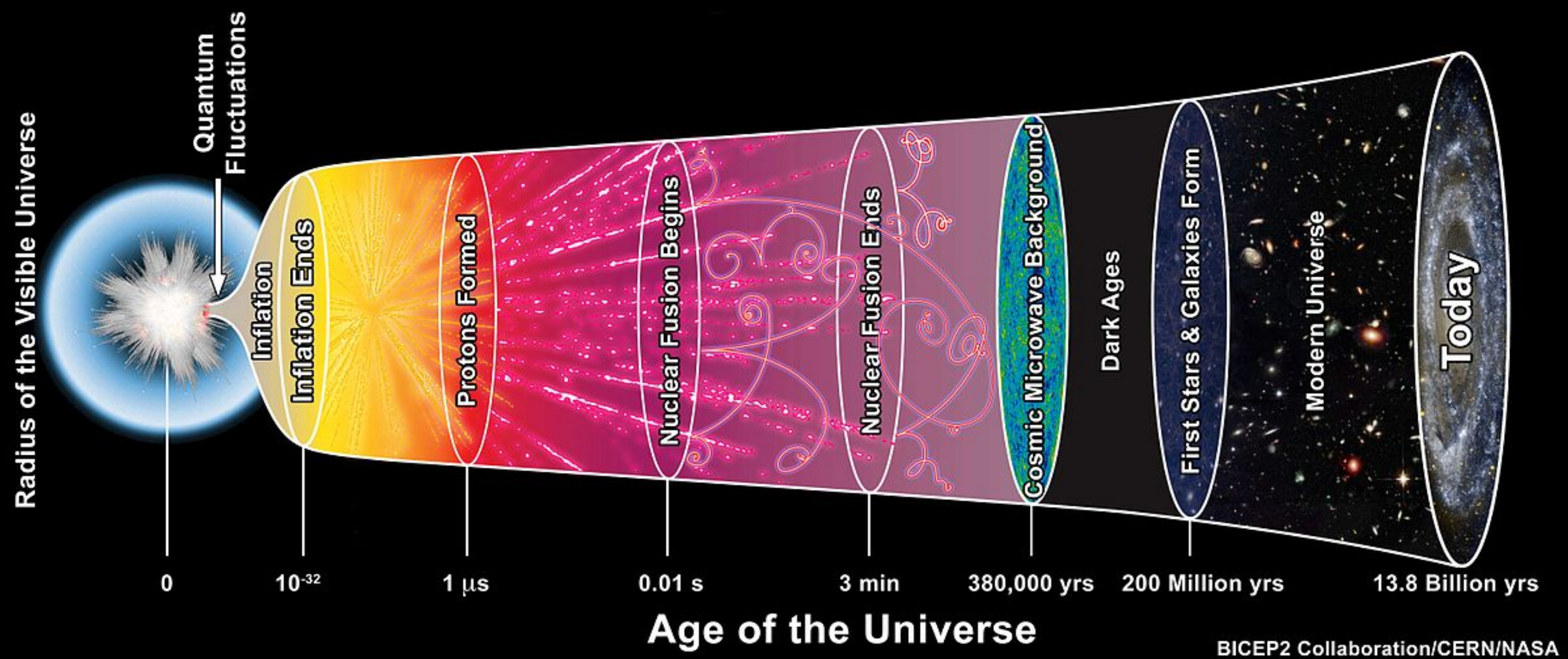
Oxford University Seminar
October 14, 2020

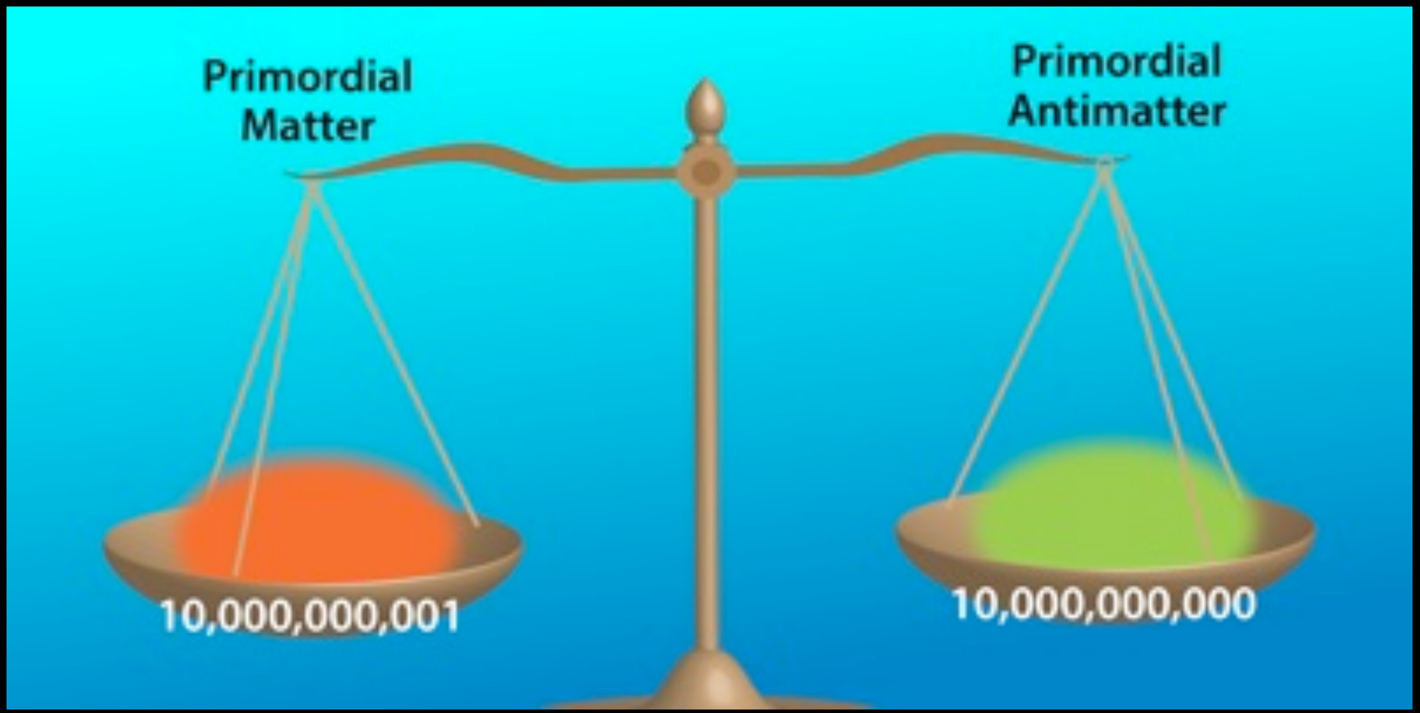


THE SOURCE OF MASS

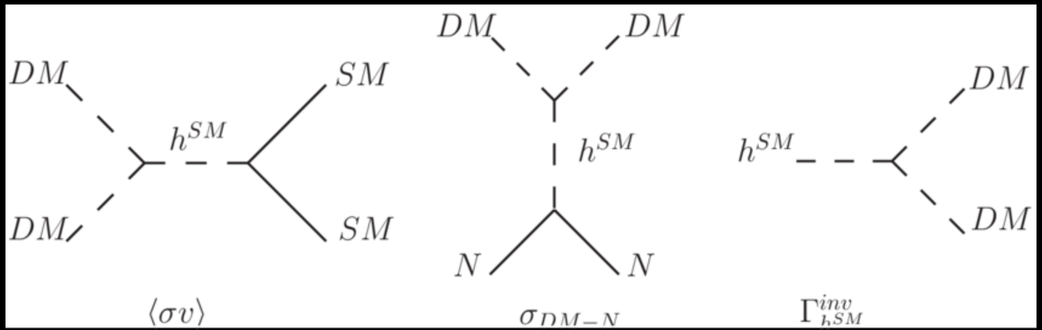


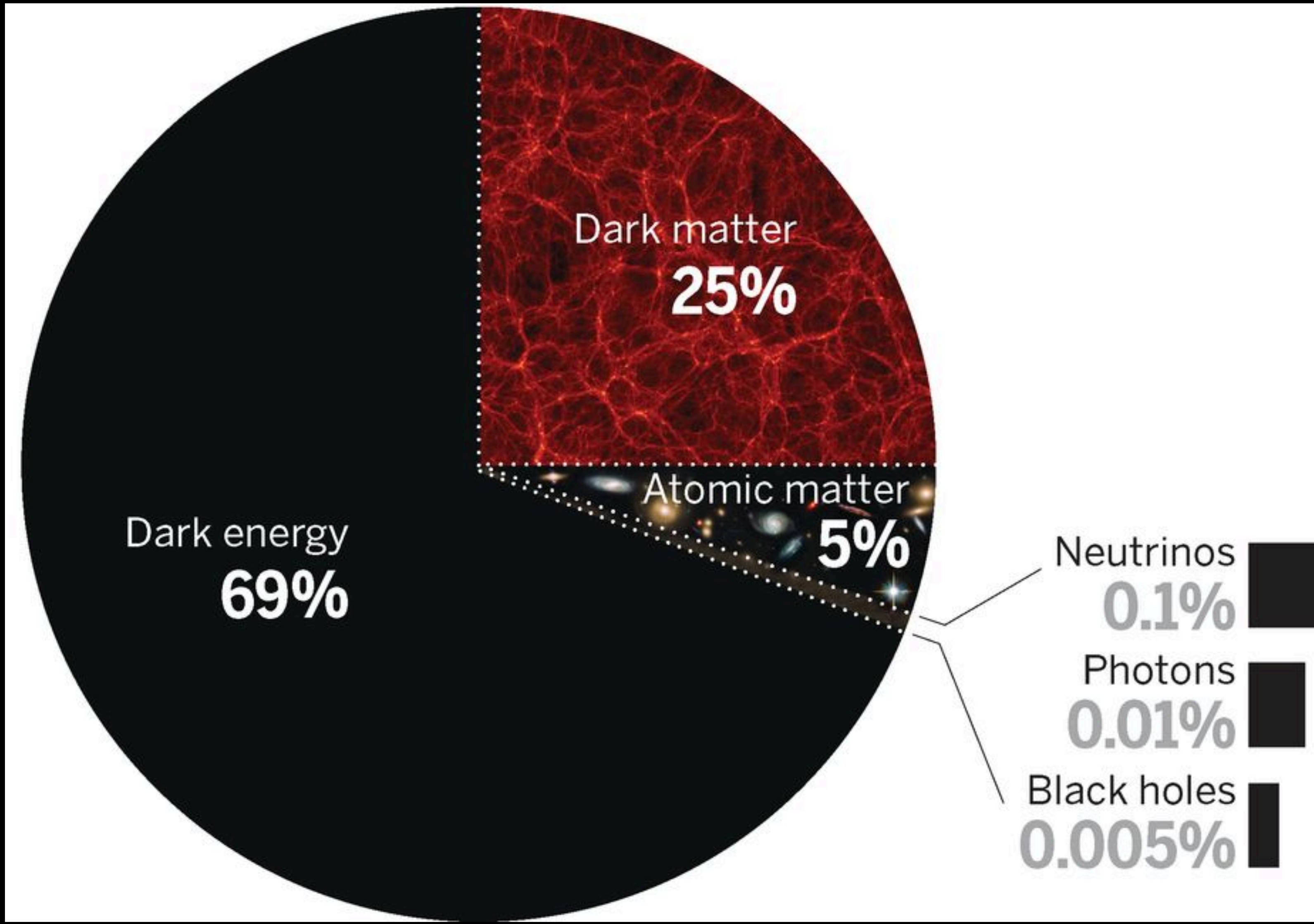
Matter in the Universe





Dark Matter in the Universe





D. N. Spergel
Science 347 (2015) 1100

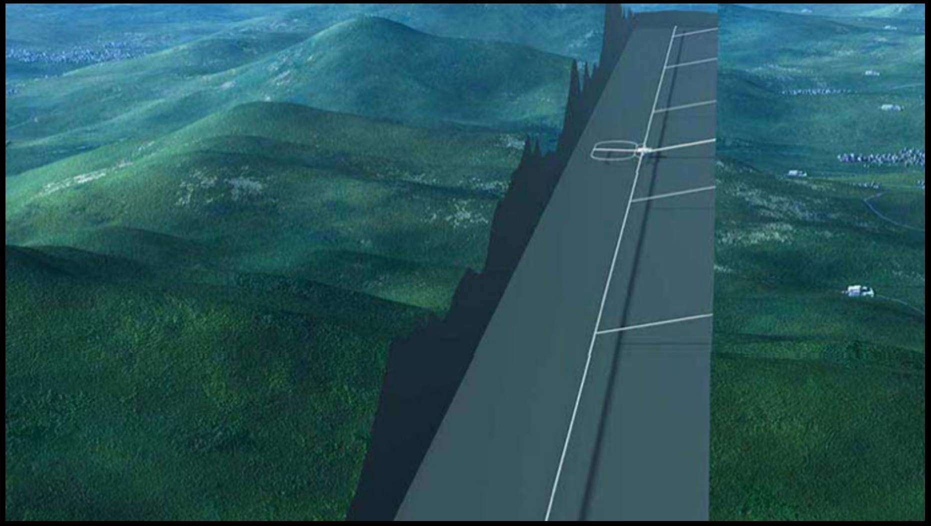
The Next Generation of Accelerators

$3 \cdot 10^8$ H

$3 \cdot 10^9$ H

$2 \cdot 10^{10}$ H

$2 \cdot 10^6$ ZH



$4 \cdot 10^5$ ZH

Collider	Type	$\sqrt{s}$	$\mathcal{P}$ [%] $[e^-/e^+]$	N(Det.)	$\mathcal{L}_{\text{inst}}$ $[10^{34}]$ $\text{cm}^{-2}\text{s}^{-1}$	$\mathcal{L}$ $[\text{ab}^{-1}]$	Time [years]
HL-LHC	pp	14 TeV	—	2	5	6.0	12
HE-LHC	pp	27 TeV	—	2	16	15.0	20
FCC-hh$^{(*)}$	pp	100 TeV	—	2	30	30.0	25
FCC-ee	ee	M_Z	0/0	2	100/200	150	4
		$2M_W$	0/0	2	25	10	1–2
		240 GeV	0/0	2	7	5	3
		$2m_{\text{top}}$	0/0	2	0.8/1.4	1.5	5 (+1)
ILC	ee	250 GeV	±80/±30	1	1.35/2.7	2.0	11.5
		350 GeV	±80/±30	1	1.6	0.2	1
		500 GeV	±80/±30	1	1.8/3.6	4.0	8.5 (+1)
		1000 GeV	±80/±20	1	3.6/7.2	8.0	8.5 (+1-2)
CEPC	ee	M_Z	0/0	2	17/32	16	2
		$2M_W$	0/0	2	10	2.6	1
		240 GeV	0/0	2	3	5.6	7
CLIC	ee	380 GeV	±80/0	1	1.5	1.0	8
		1.5 TeV	±80/0	1	3.7	2.5	7
		3.0 TeV	±80/0	1	6.0	5.0	8 (+4)
LHeC	ep	1.3 TeV	—	1	0.8	1.0	15
HE-LHeC	ep	1.8 TeV	—	1	1.5	2.0	20
FCC-eh	ep	3.5 TeV	—	1	1.5	2.0	25

J de Blas et al, JHEP 01 (2020) 139

INFINITY AND BEYOND

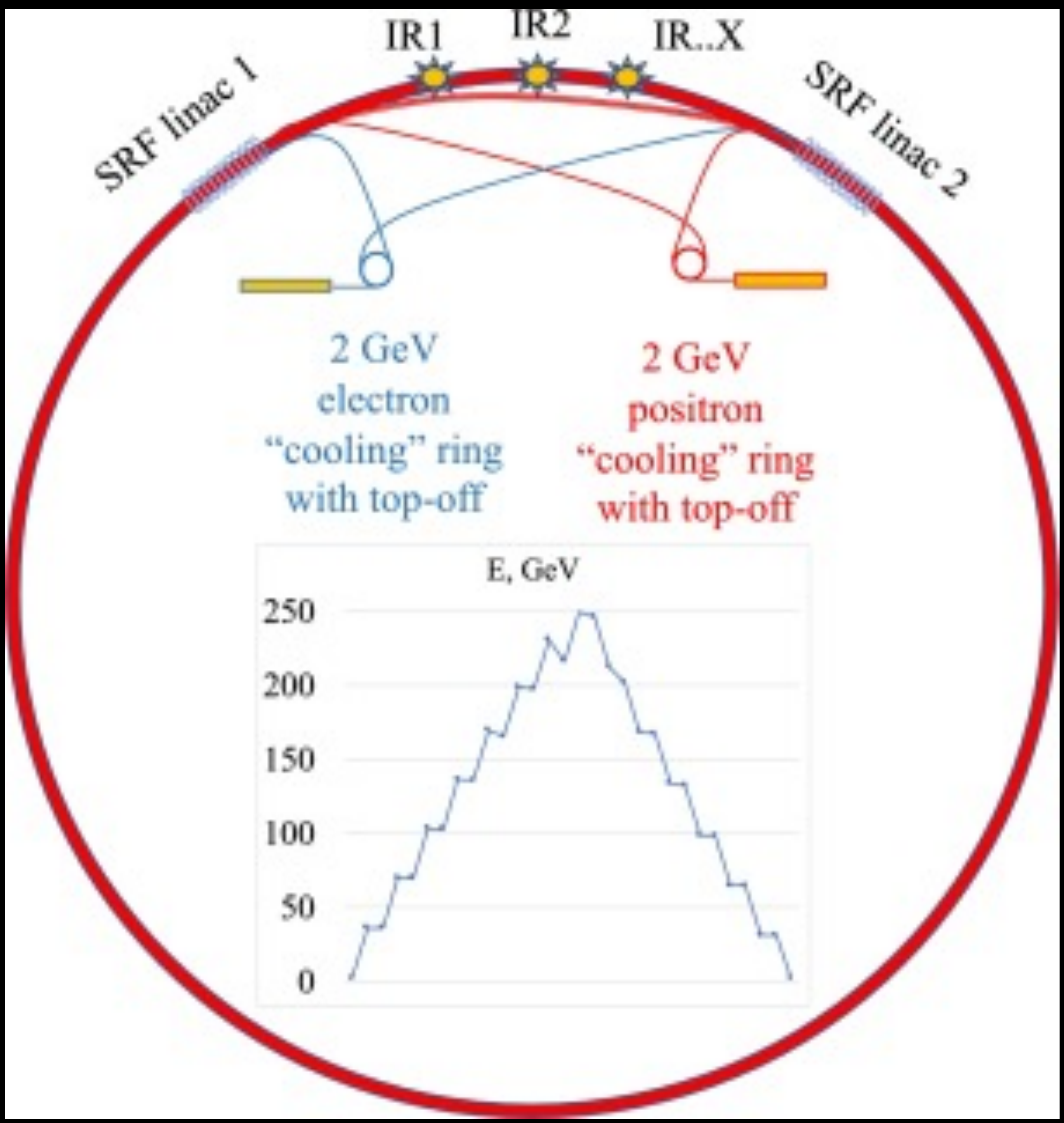


Table 1
ERL e^+e^- integrated luminosity per year assuming a running time and efficiency as in reference [2].

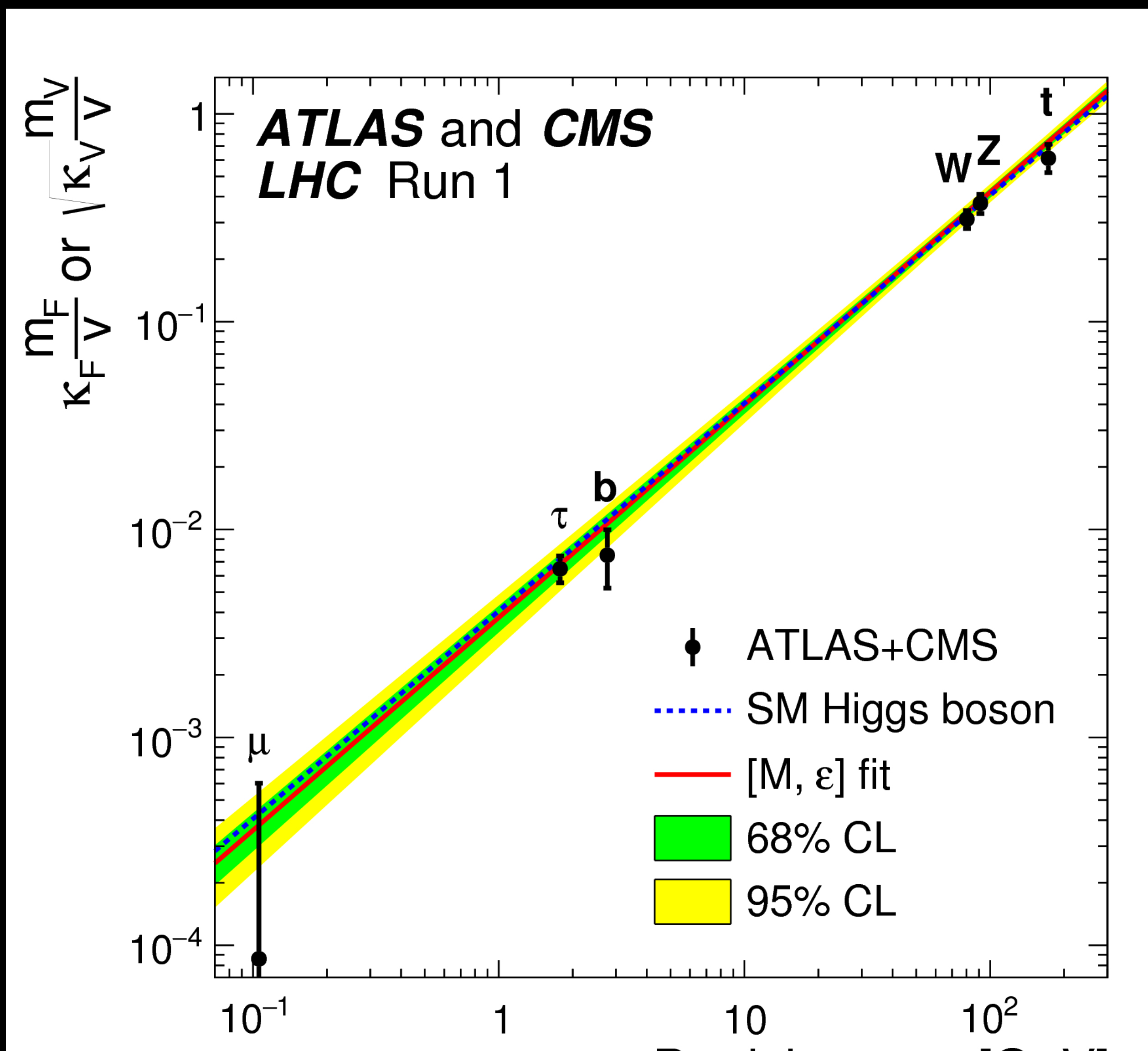
	$\sqrt{s}$ [GeV]	$\mathcal{L}$/year [ab^{-1}]
Z	91	11.5
WW	160	14.1
HZ	240	8.8
tt	365	4.2
ZHH	500	1.7
ttH	600	1.0

5X FCC-ee LUMINOSITY

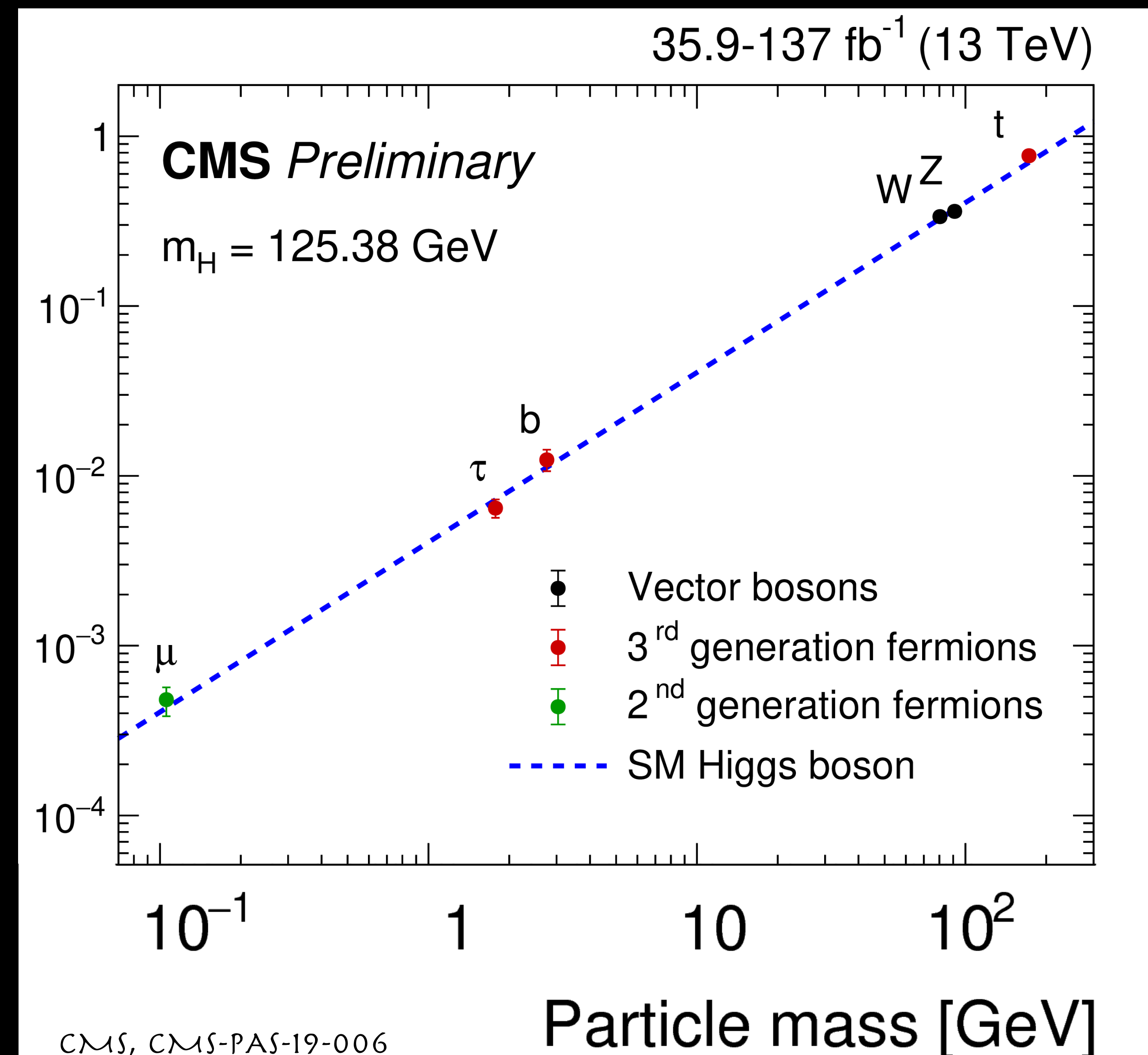
LITVINENKO, ROSER, CHAMIZO-LLATAS, PLB 804 (2020) 135394

THE SOURCE OF MASS

$$\mathcal{L} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} + |D_\mu\phi|^2 + i\bar{\psi}\not{D}\psi + \psi_i y_{ij}\psi_j\phi + h.c$$



ATLAS & CMS, JHEP 08 (2016) 045



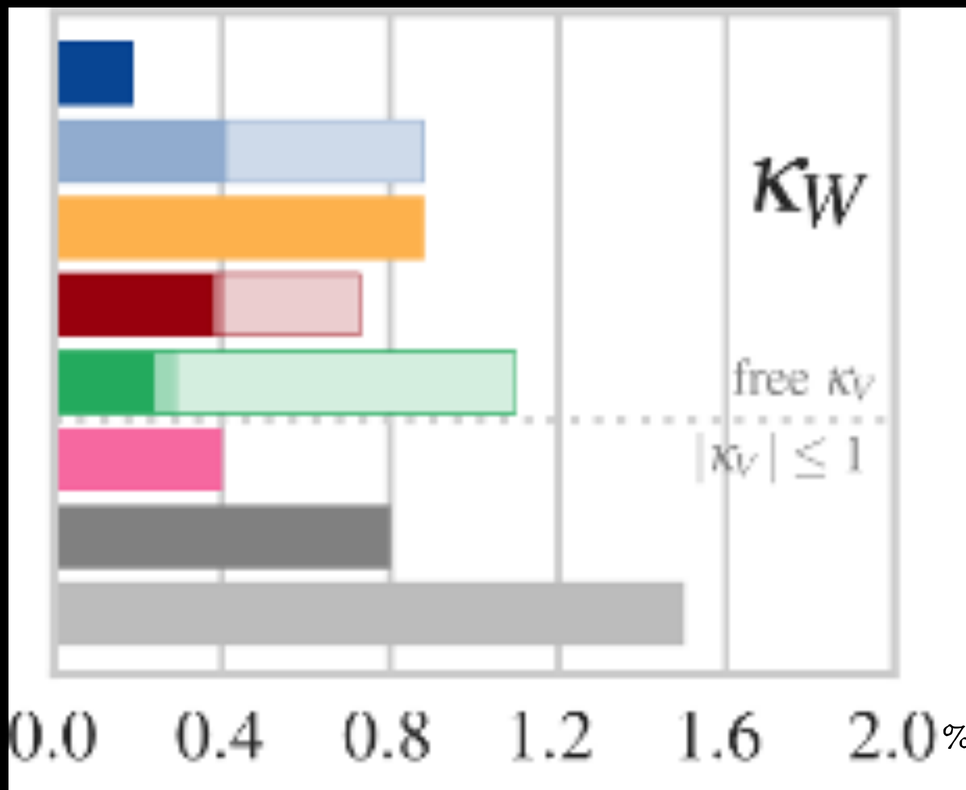
CMS, CMS-PAS-19-006

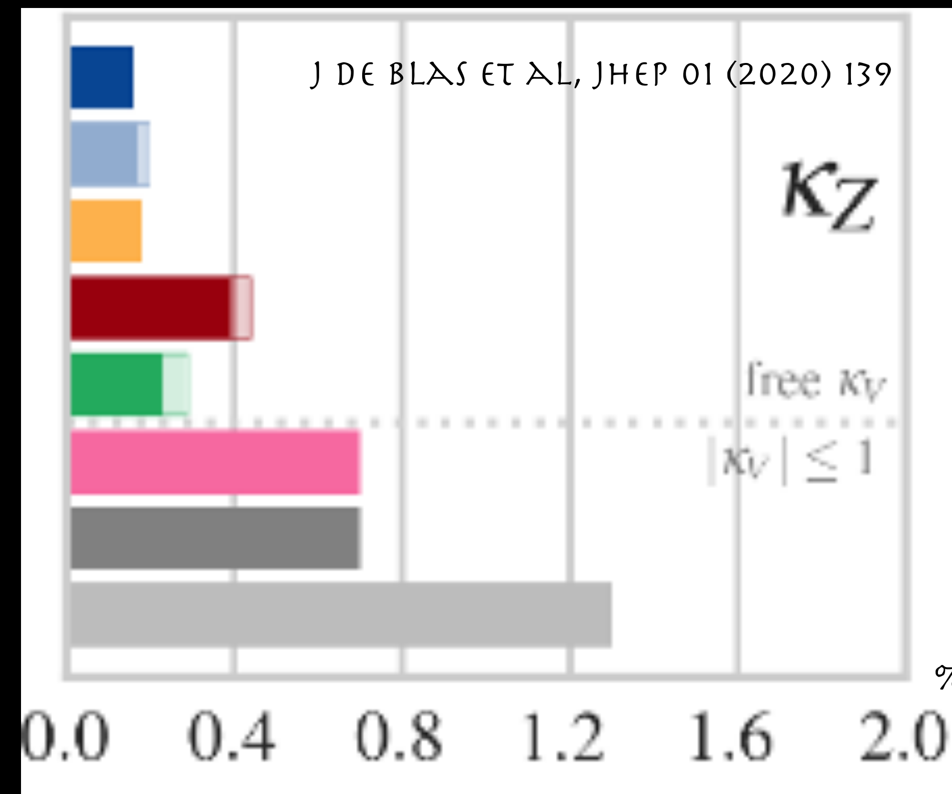
2016

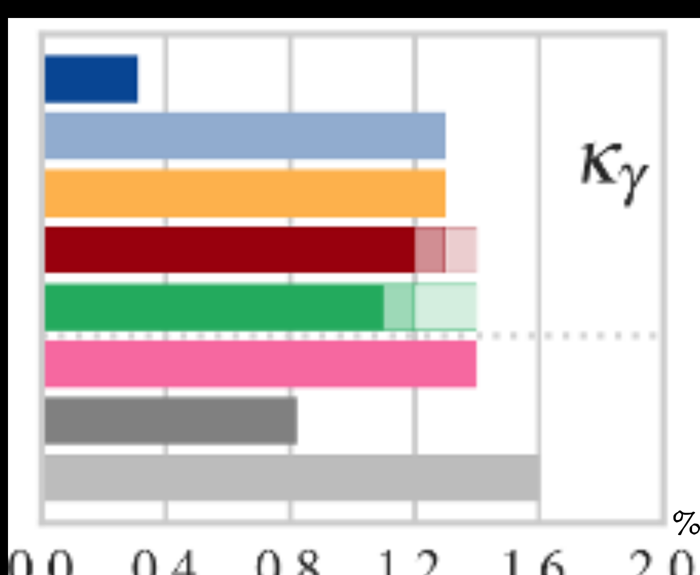
TODAY

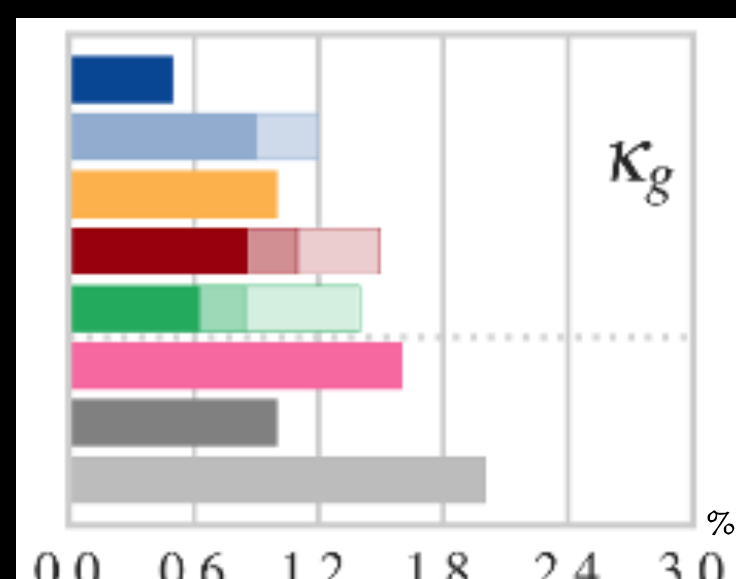
HIGGS COUPLINGS TO VECTOR BOSONS

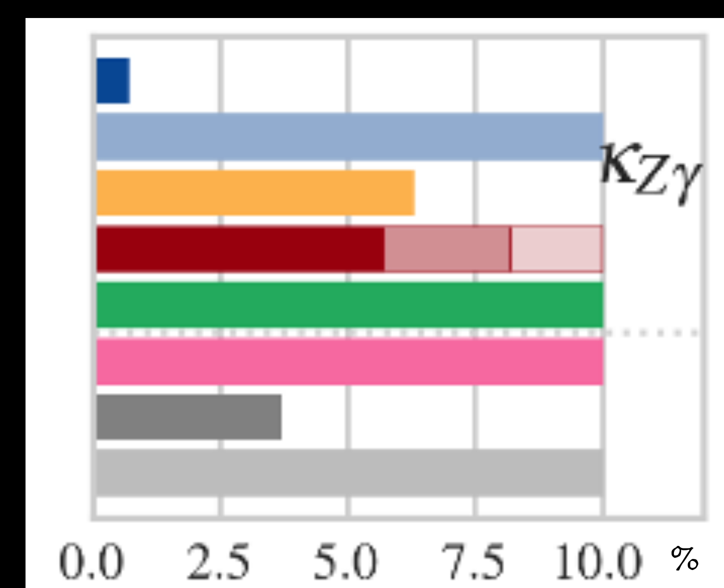
ALL FCC
FCC-ee
CEPC
CLIC
ILC
LHeC
HE-LHC
HL-LHC







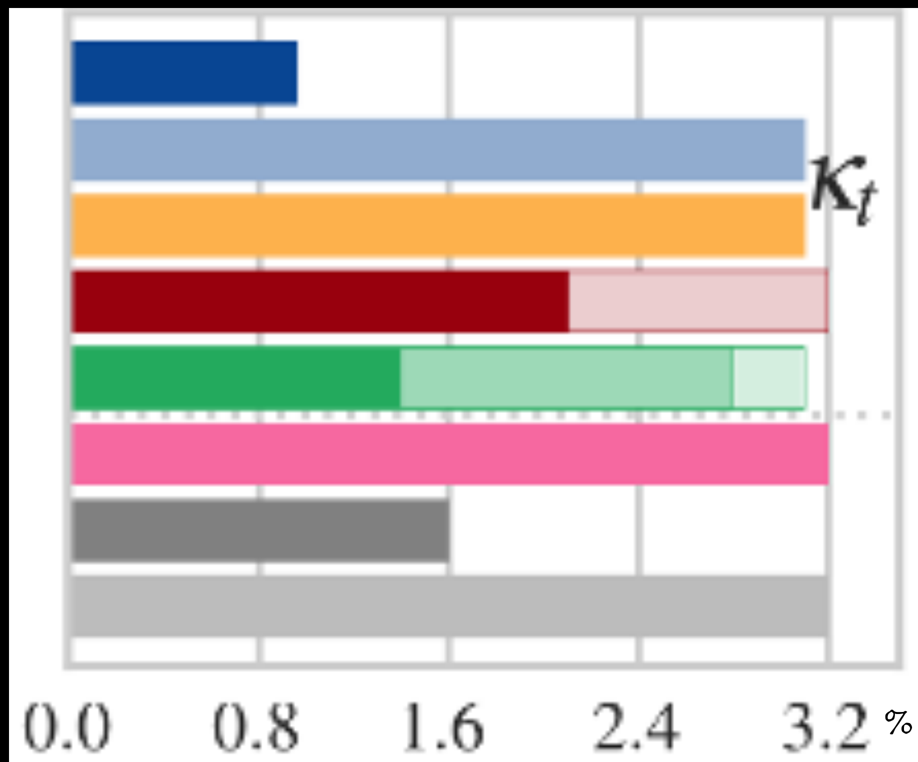


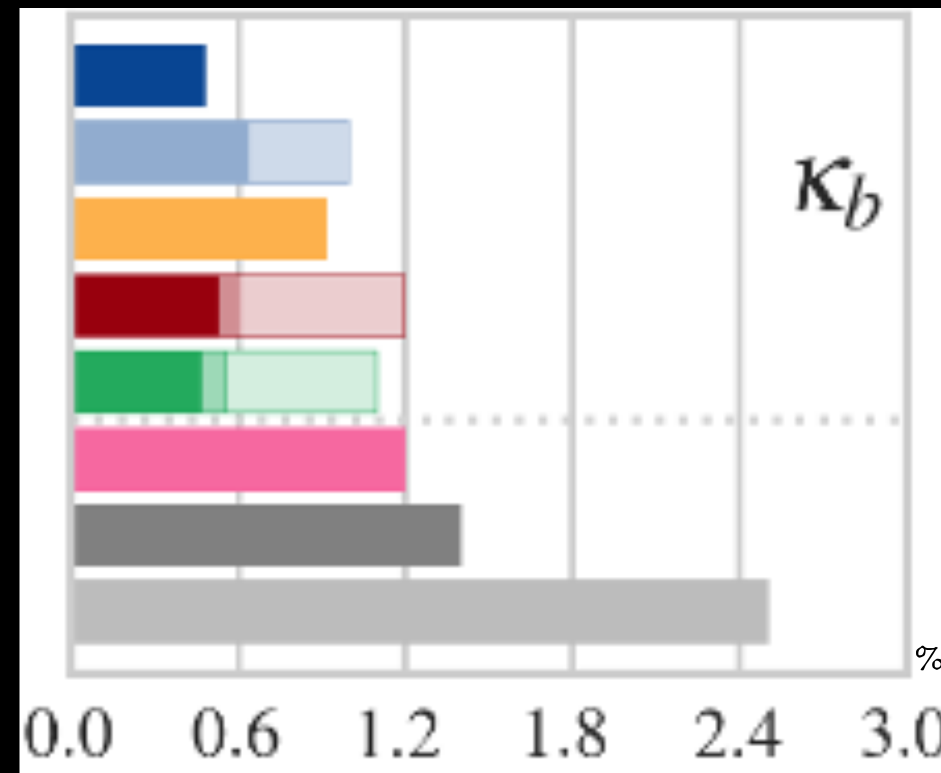


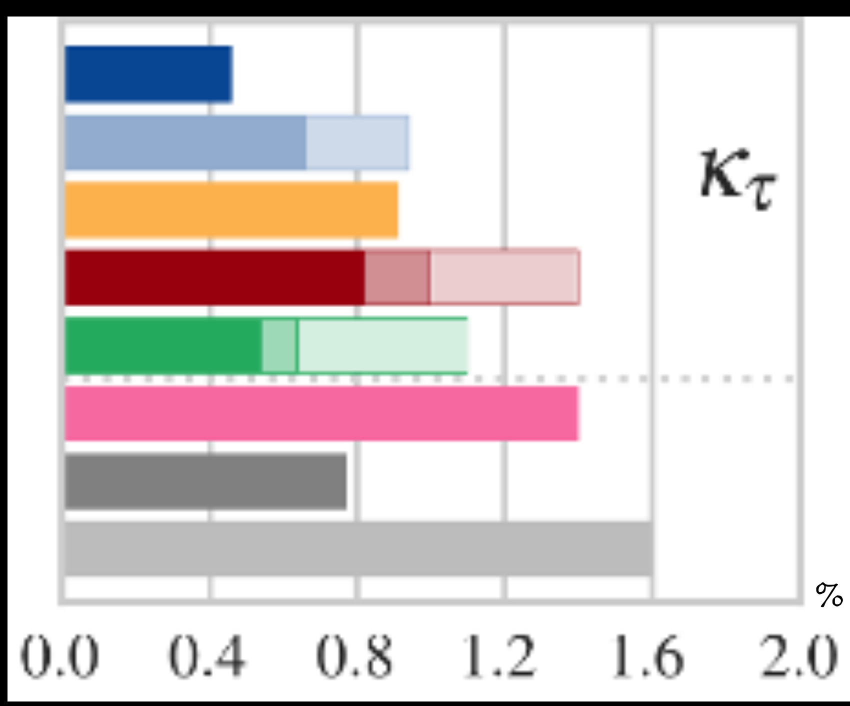
Higgs couplings to the third generation

$\bar{\psi}_i y_{ij} \psi_j \phi + h.c$

ALL FCC
FCC-ee
CEPC
CLIC
ILC
LHeC
HE-LHC
HL-LHC



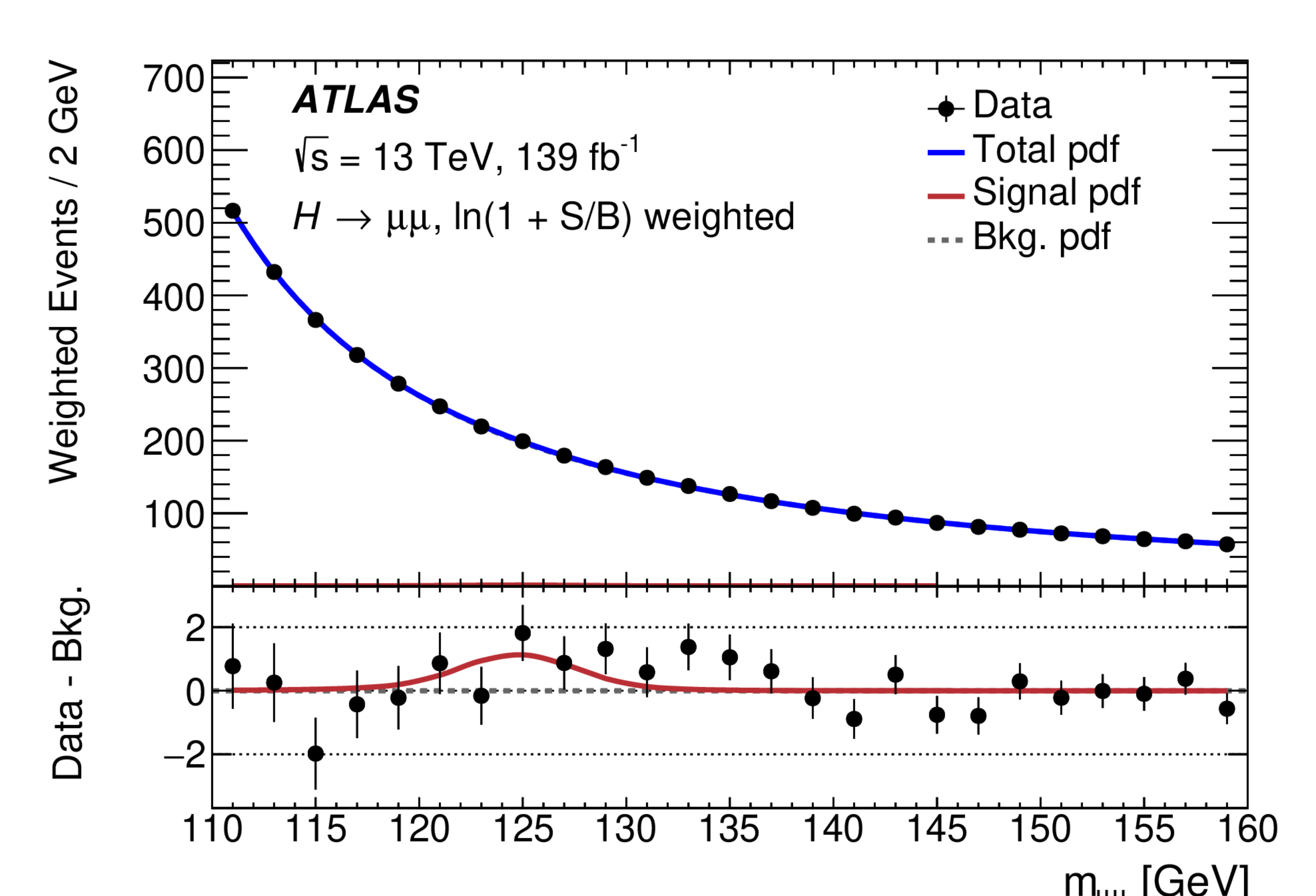




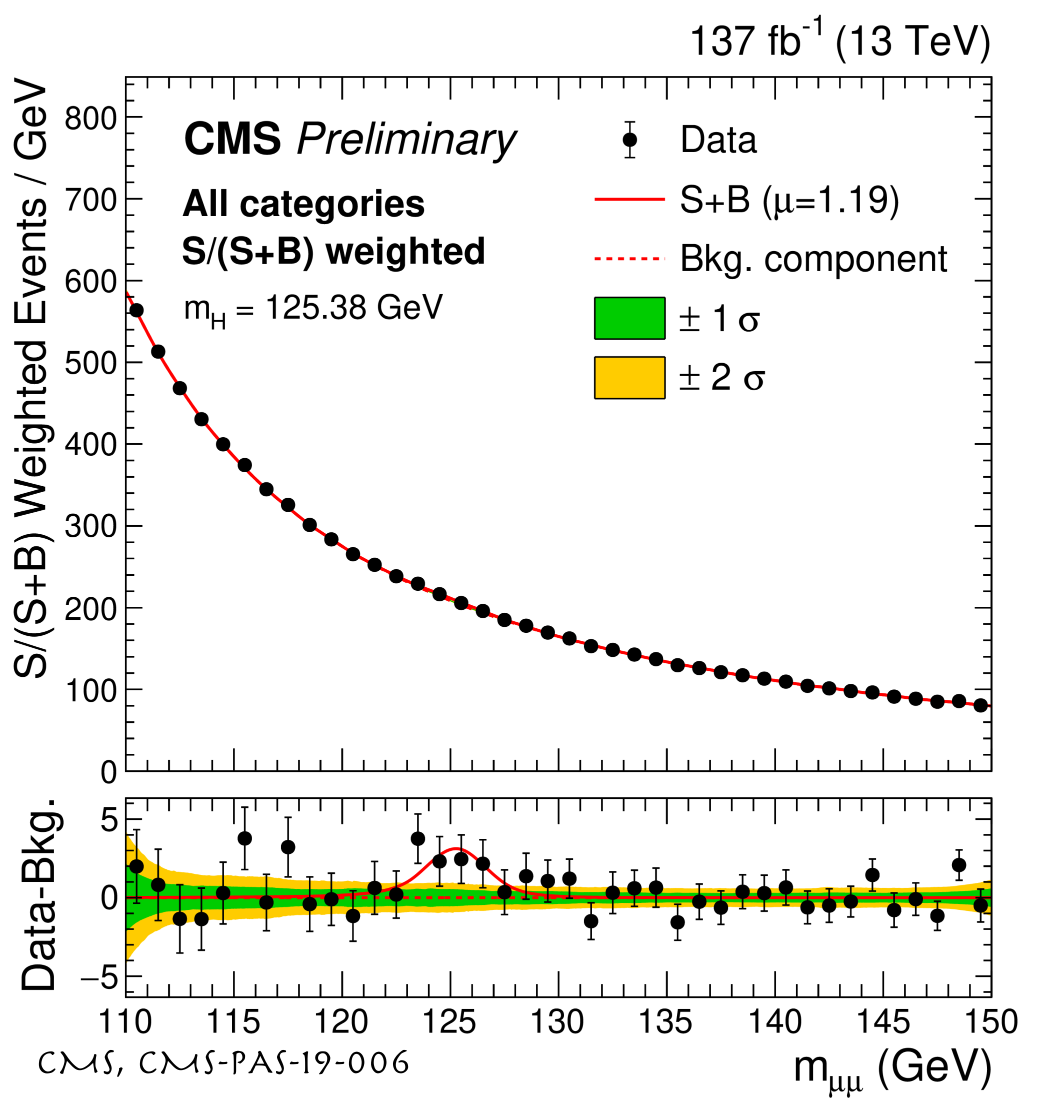
J de Blas et al, JHEP 01 (2020

Higgs couplings: the next generation

$\psi_i y_{ij} \psi_j \phi + h.c$



ATLAS, arXiv:2007.07830 (2020)

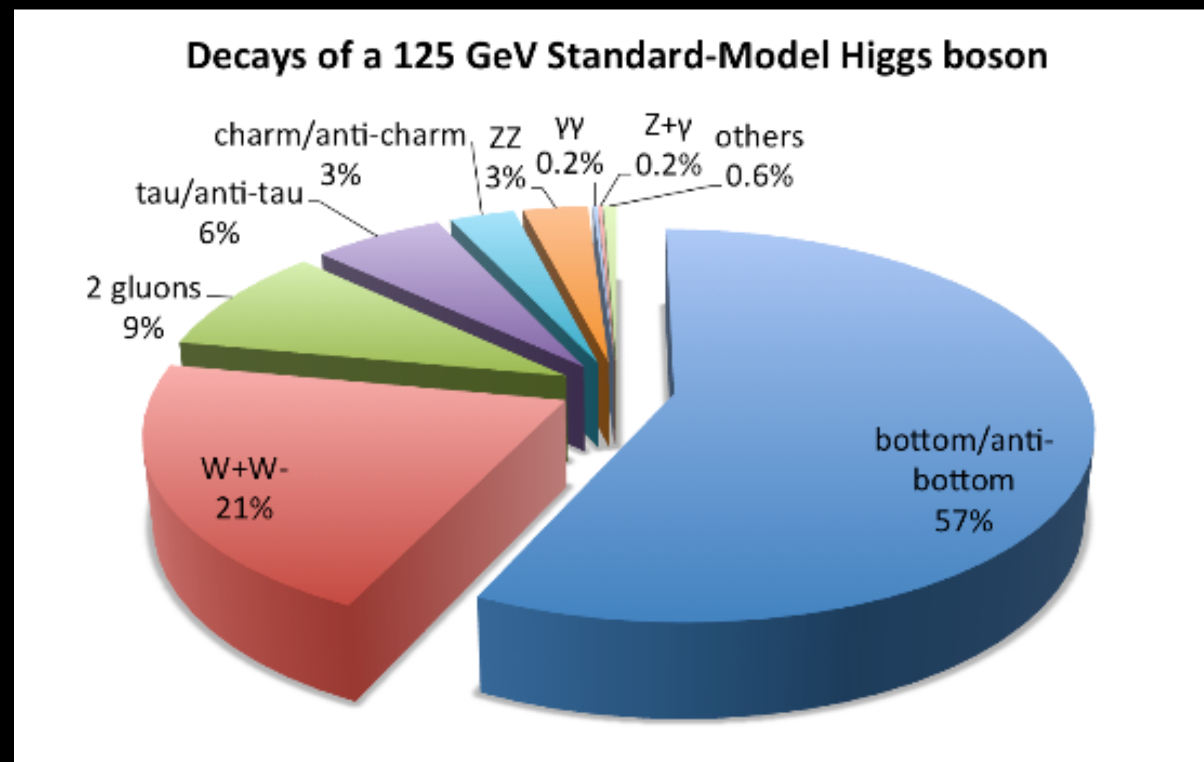


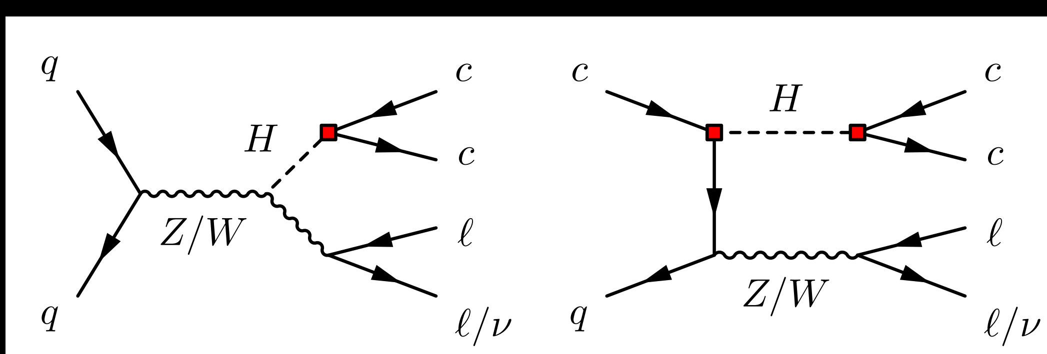
CMS, CMS-PAS-19-006

Giacomo Artoni
CERN seminar 8 Sep 2020

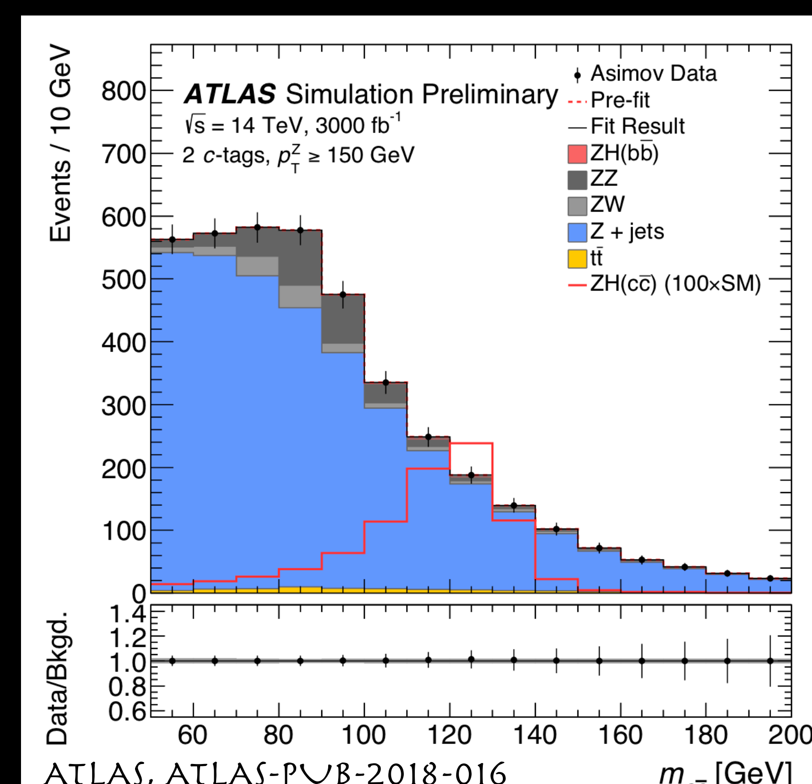
Higgs couplings to the second generation

$\bar{\psi}_i y_{ij} \psi_j \phi + h.c$





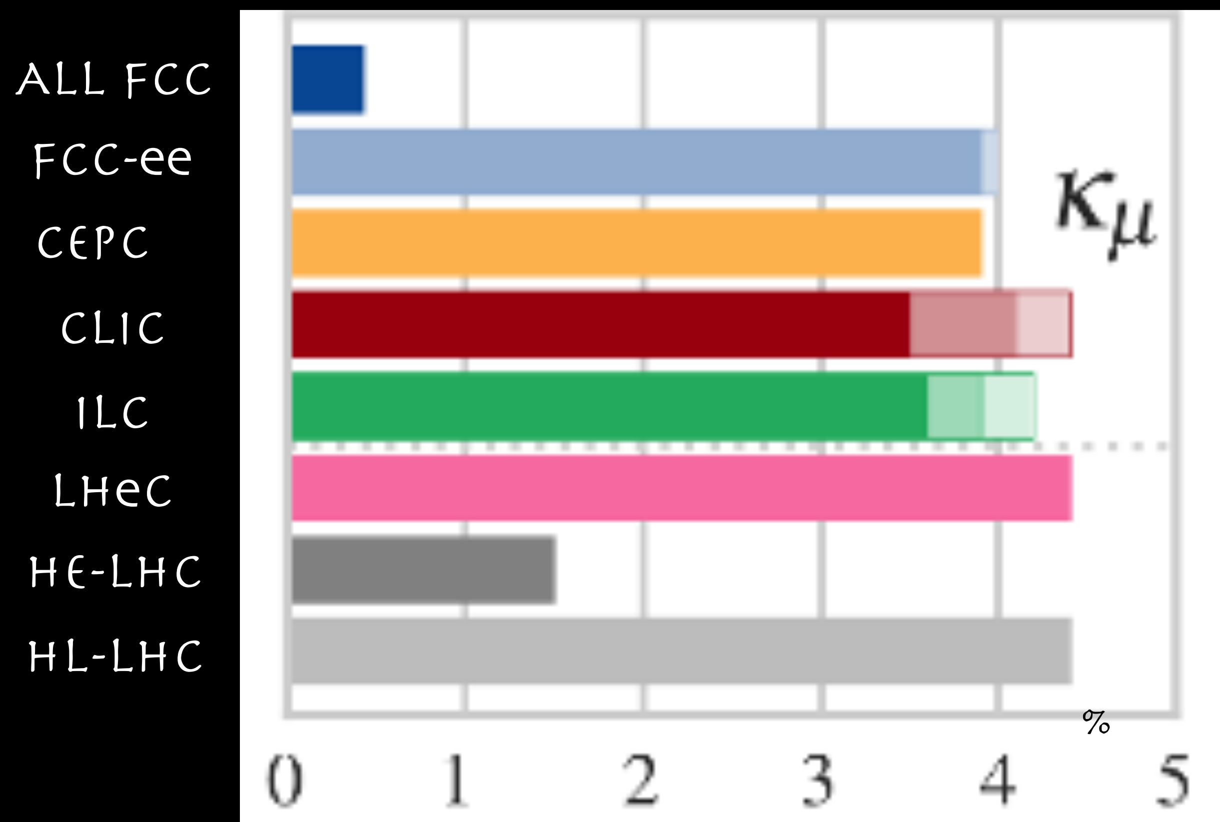
M Cepeda et al, arXiv:1902.00134

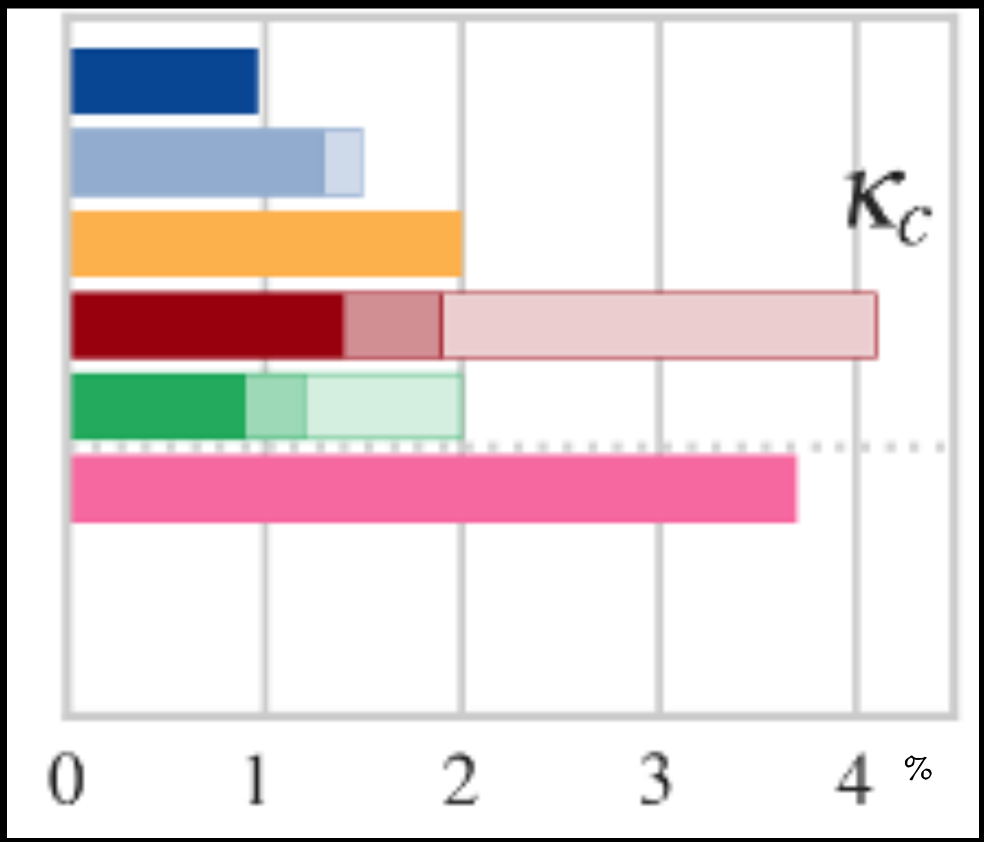


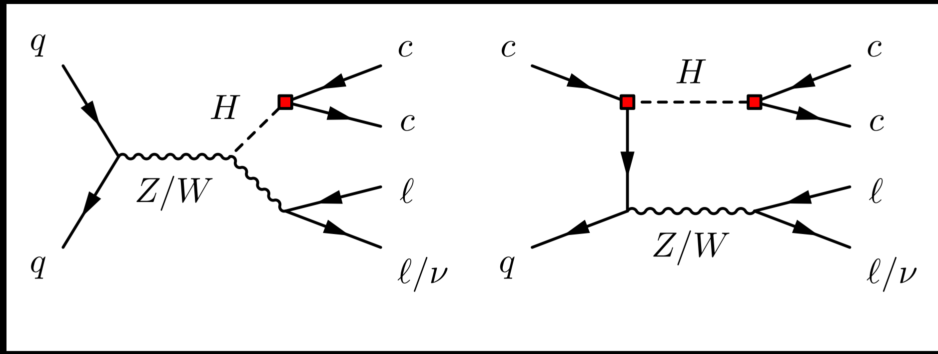
ATLAS, ATLAS-PUB-2018-016

HIGGS COUPLINGS TO THE SECOND GENERATION

$\psi_i Y_{ij} \psi_j \phi + h.c$







$\kappa_s < 7$ with 20 ab^{-1} e^+e^- using jet tagging

J Duarte-Campderros et al, PRD 101, 115005 (2020)

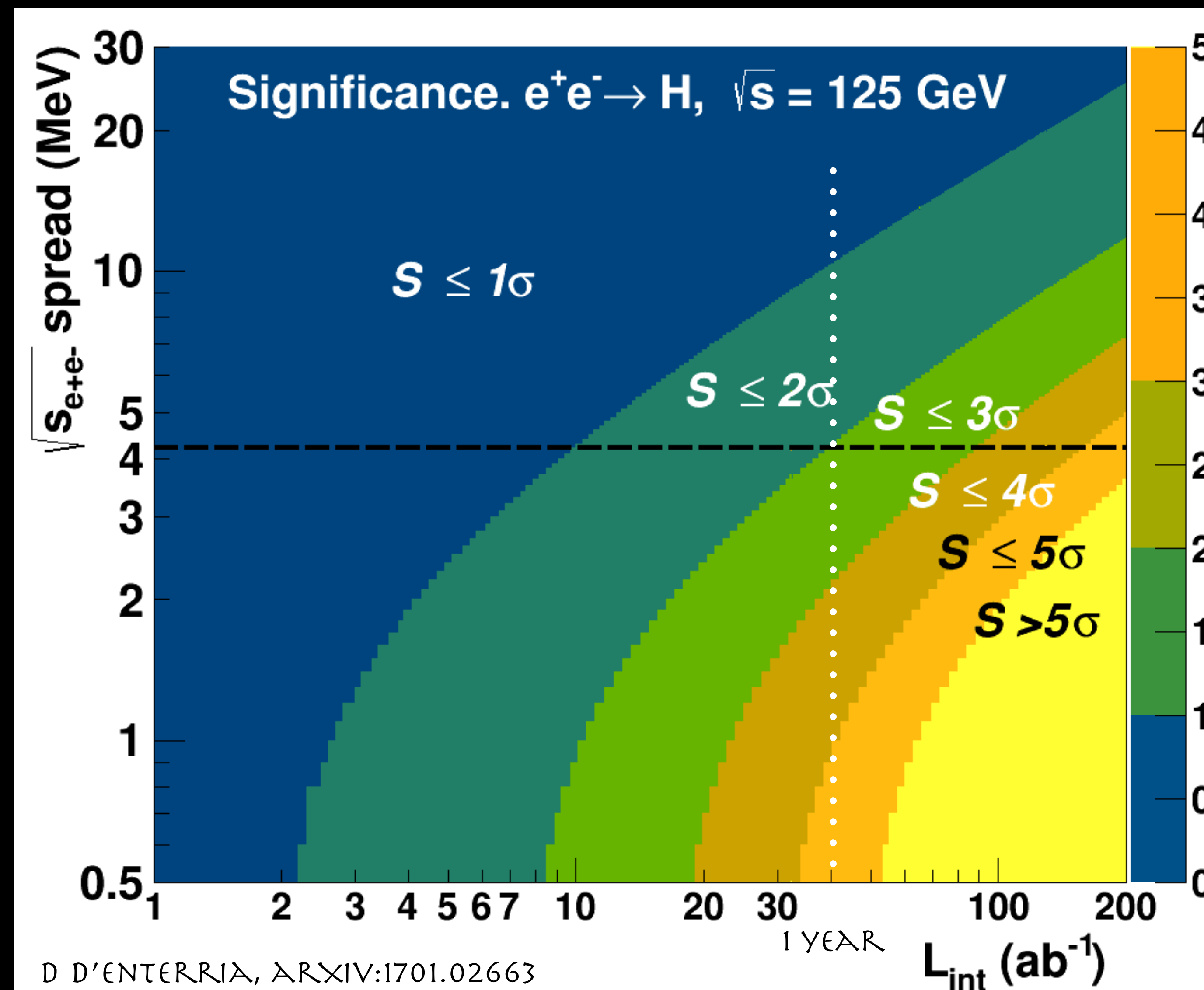
Higgs couplings: the last generation

$\psi_i y_{ij} \psi_j \phi + h.c$

Table 1: Optimized monochromatization parameters for constant vertical emittance (case 1) or emittance ratio (case 2) at the same c.o.m. energy spread $\sigma_W \approx 6$ MeV.

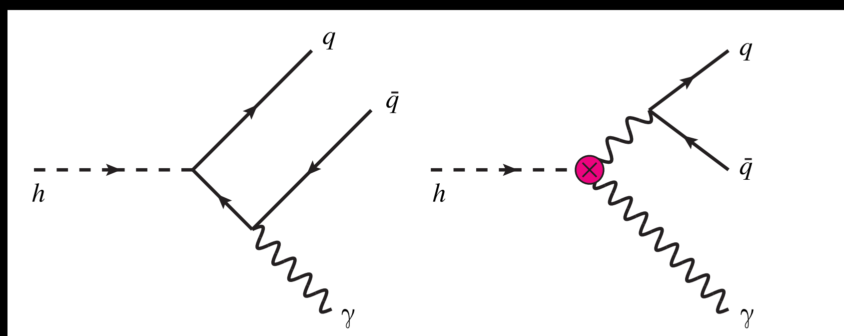
parameter	case 1	case 2
E_b [GeV]	62.50	62.50
circumference C [km]	97.76	97.76
I_b [mA]	418	418
$n_{b,\mathrm{opt}}$	15950	8700
$N_{b,\mathrm{opt}}$ [10^{10}]	5.33	9.77
$\varepsilon_{x,\mathrm{SR}}$ [nm]	0.51	0.51
$\varepsilon_{x,\mathrm{opt}}$ [nm]	2.30	1.45
$\varepsilon_{y,\mathrm{SR}}$ [pm]	1.00	1.00
$\varepsilon_{y,\mathrm{opt}}$ [pm]	1.00	2.85
α_c [10^{-6}]	14.80	14.80
$\beta^*_{x,\mathrm{opt}}$ [m]	0.24	1.25
β^*_y [mm]	1.00	1.00
$D^*_{x,\mathrm{opt}}$ [m]	0.1624	0.3712
$\sigma_{x,\mathrm{opt}}$ [µm]	119.2	269.5
$\sigma_{y,\mathrm{opt}}$ [nm]	31.6	53.4
$\sigma_{z,\mathrm{SR}}$ [mm]	1.64	1.64
$\sigma_{z,\mathrm{opt}}$ [mm]	1.65	1.65
$\sigma_{\delta,\mathrm{SR}}$ [%]	0.0714	0.0714
$\sigma_{\delta,\mathrm{opt}}$ [%]	0.0720	0.0717
U_0 [GeV]	0.1254	0.1254
V_{rf} [GV]	2.0	2.0
Q_s	0.1002	0.1002
τ_E [ms]	162.5	162.5
L_{opt} [10^{35} cm^{-2}s^{-1}]	2.87	1.38
$\xi_{x,\mathrm{opt}}$	0.0033	0.0062
$\xi_{y,\mathrm{opt}}$	0.0518	0.0249
$\sigma_{w,\mathrm{opt}}$ [MeV]	6.03	6.00

M A Valdivia Garcia & U Guanajuato, IPAC2019

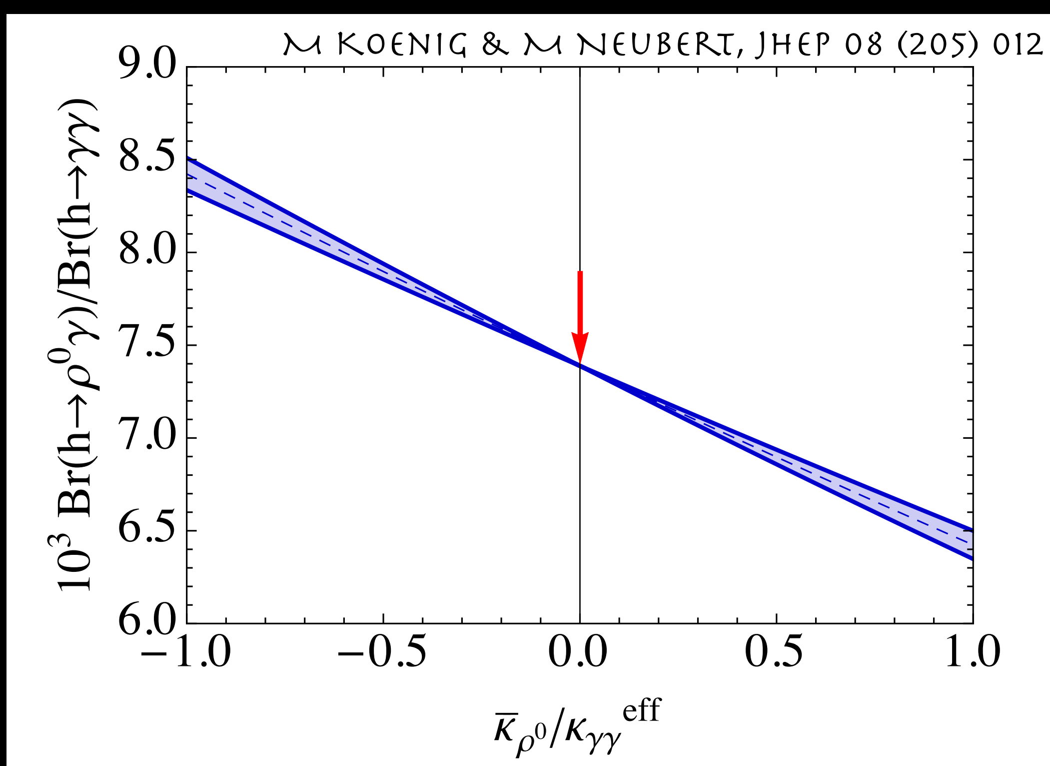


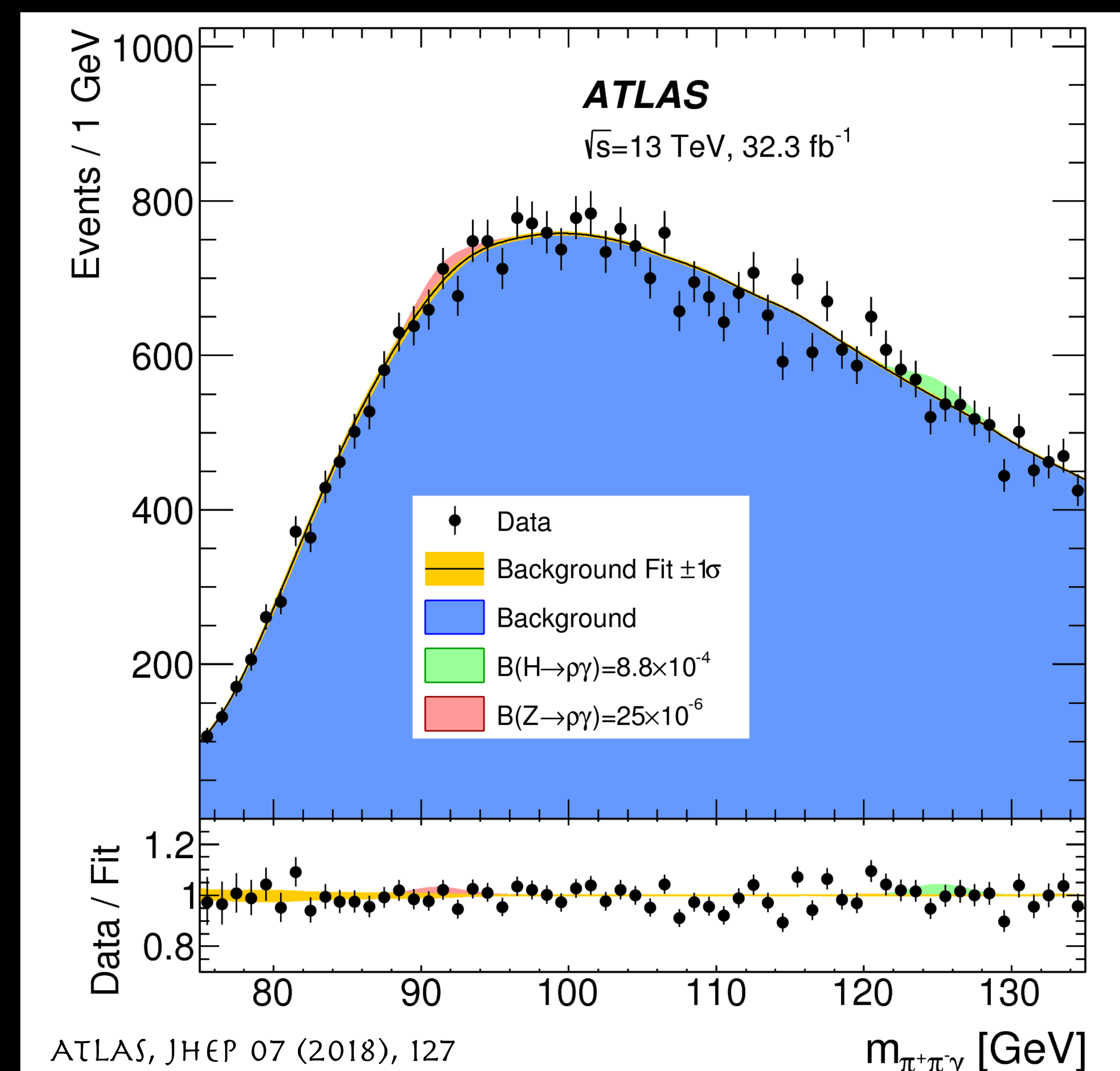
HIGGS COUPLINGS TO THE FIRST GENERATION

$\psi_i y_{ij} \psi_j \phi + h.c$



ATLAS: $H \to \rho\gamma$ BR $< 8.8 \times 10^{-4}$



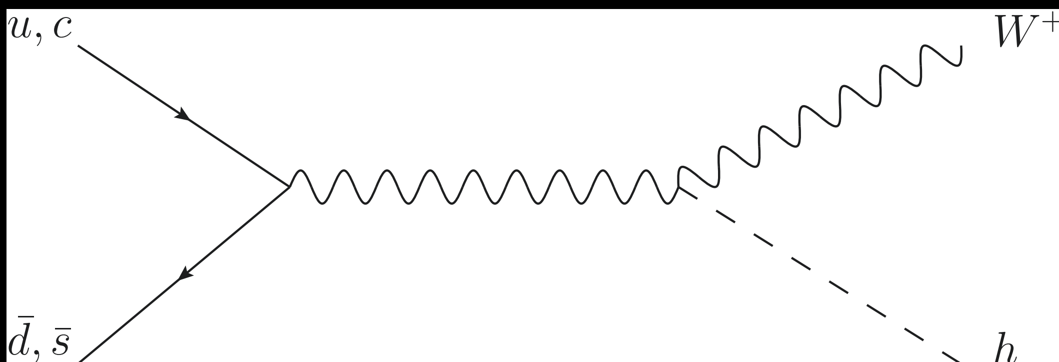


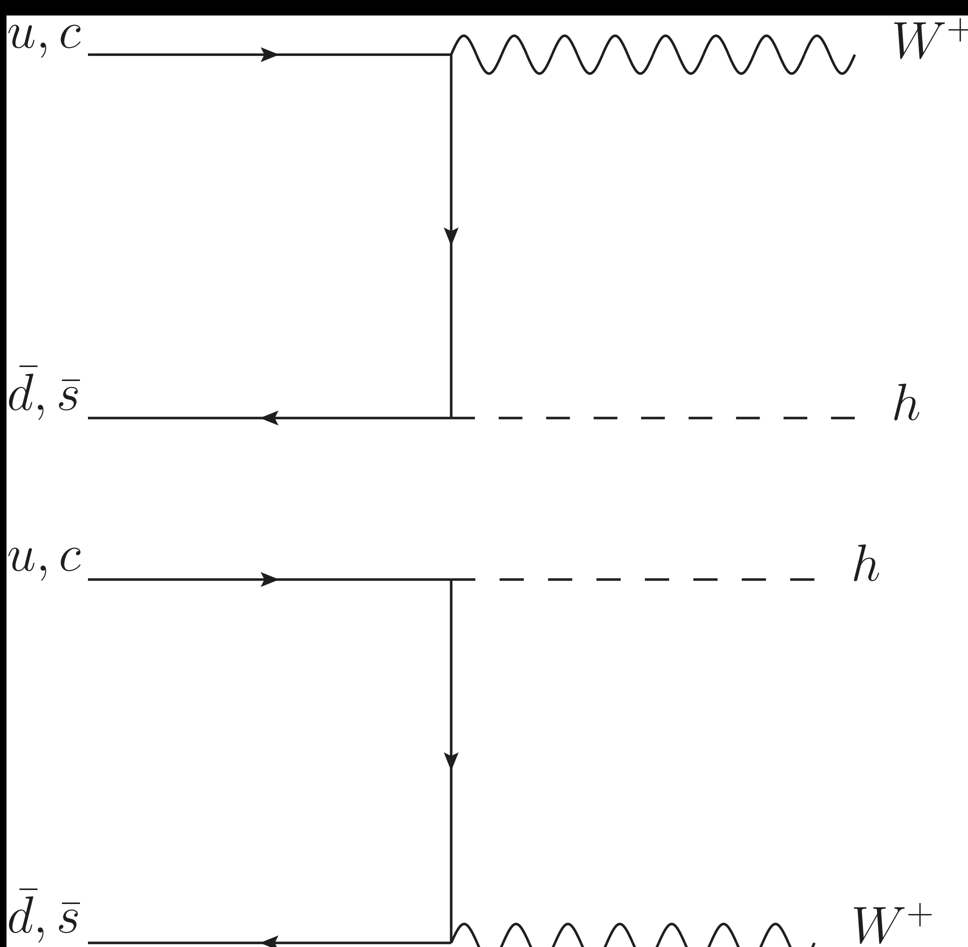
SM: $H \to \rho\gamma$ BR $= 1.7 \times 10^{-5}$

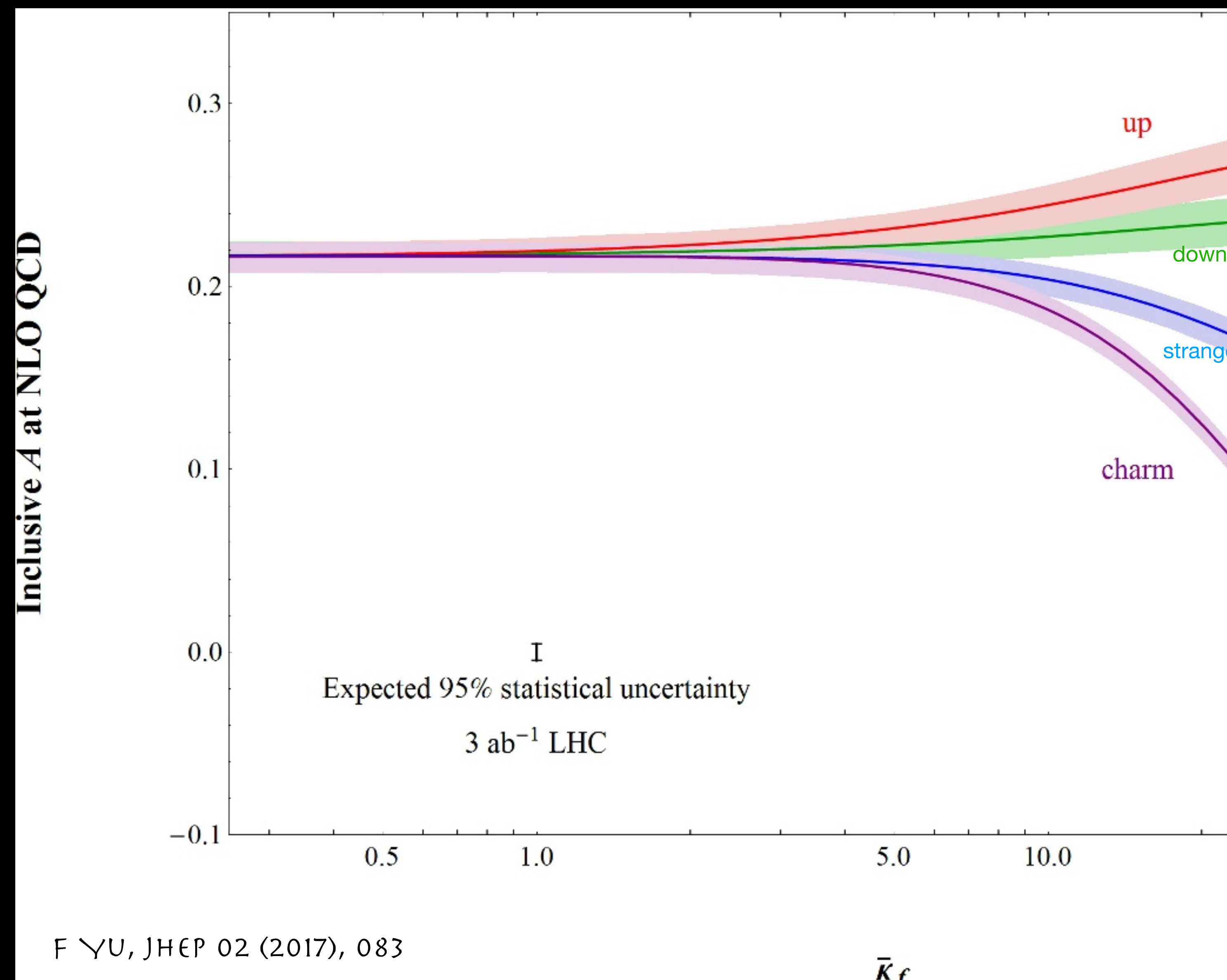
10% measurement: $\kappa_{u,d} < 1000$

Higgs couplings to the first generation

$\bar{\psi}_i y_{ij} \psi_j \phi + h.c$





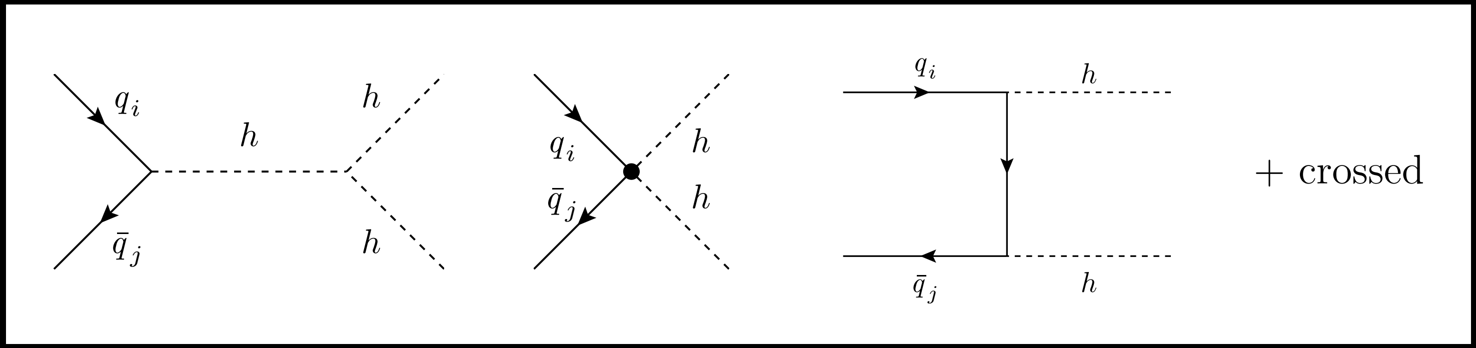


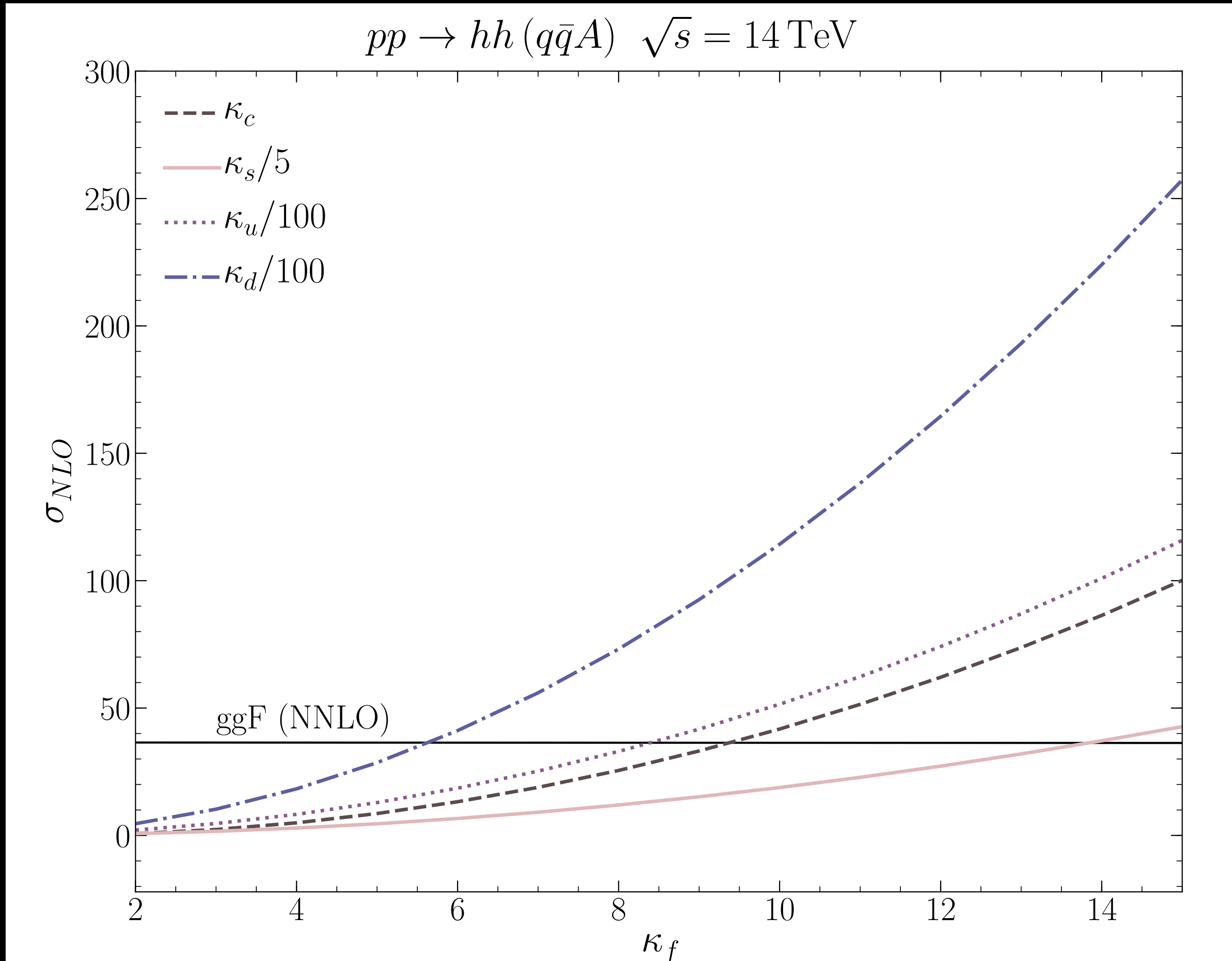
F Yu, JHEP 02 (2017), 083

$\kappa_{u,d} < 10000$ using charge asymmetry at LHC?

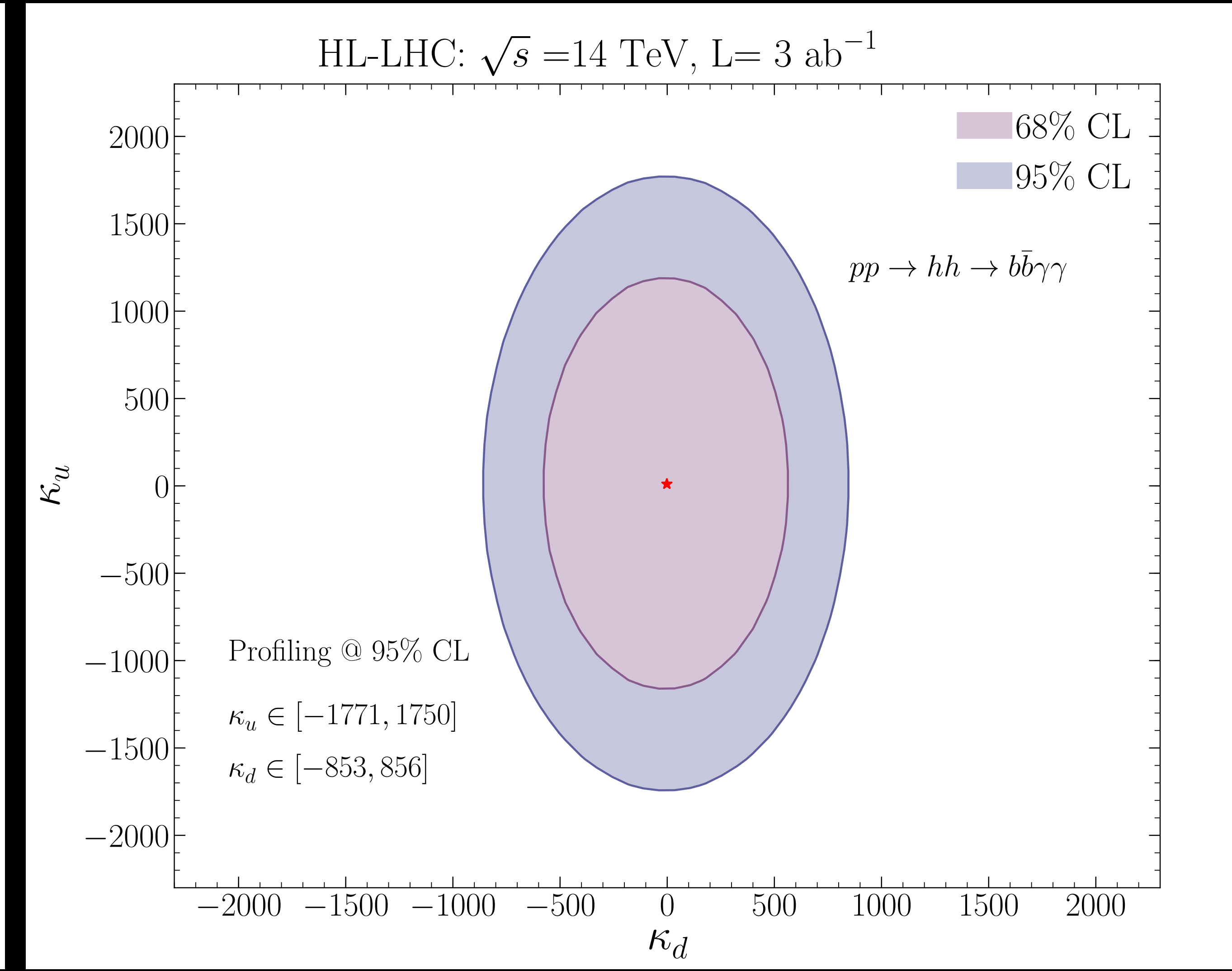
Higgs couplings to the first generation

$\psi_i y_{ij} \psi_j \phi + h.c$



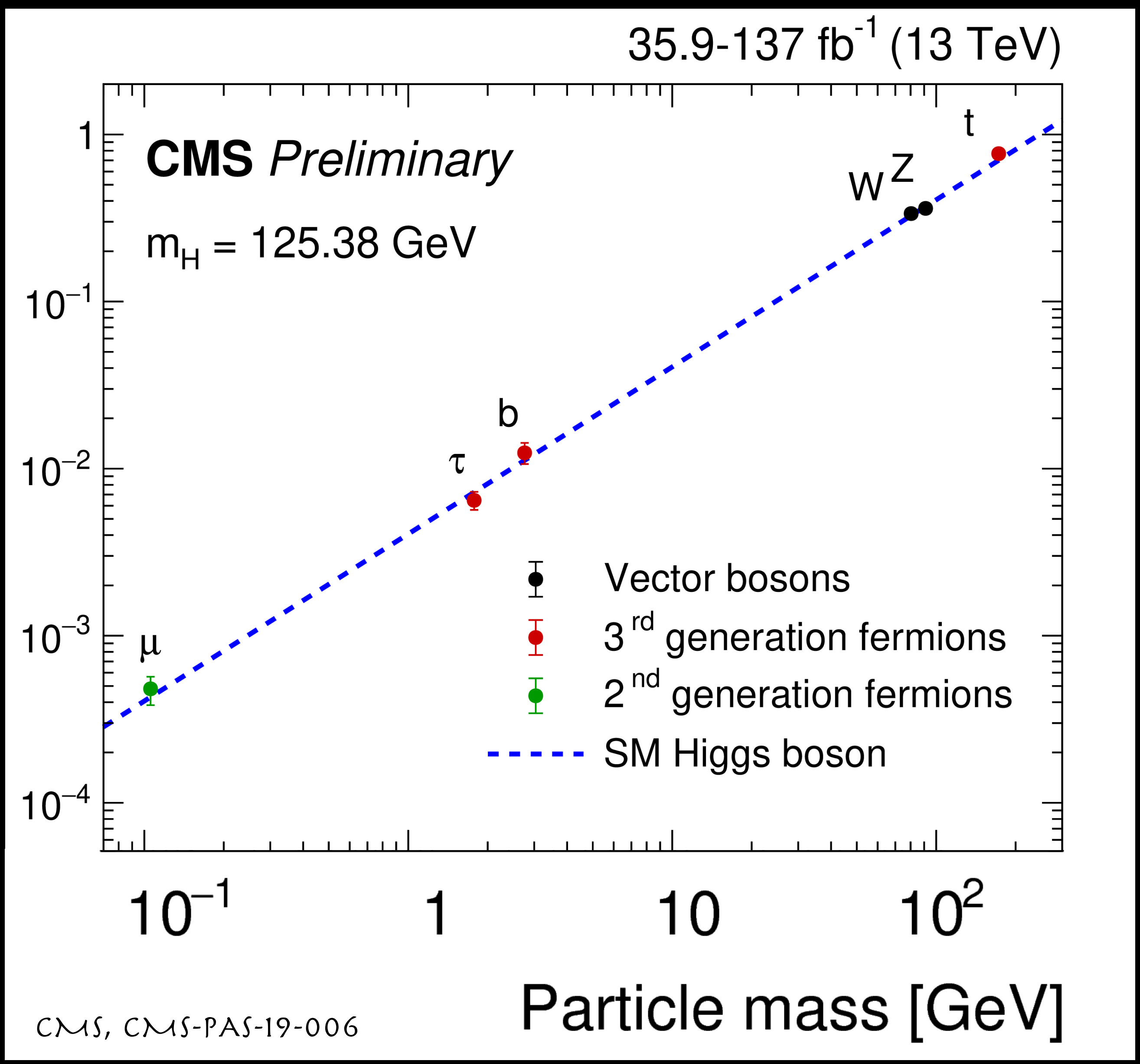


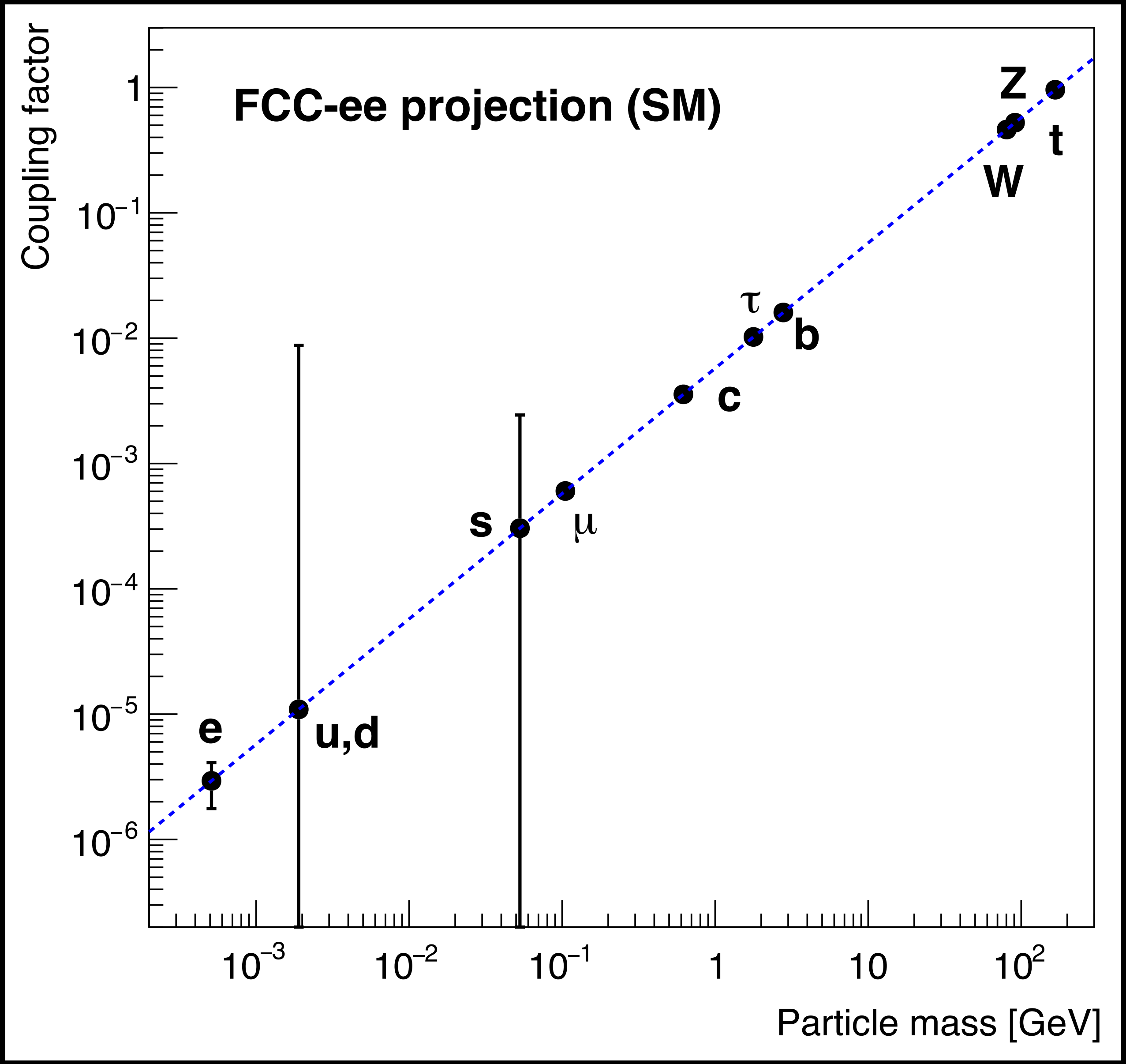
L Alasfar, R C Lopez, R Groeber, JHEP 11 (2019) 088



THE SOURCE OF MASS

$$\mathcal{L} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} + |D_\mu\phi|^2 + i\bar{\psi}\not{D}\psi + \psi_i y_{ij}\psi_j\phi + h.c$$



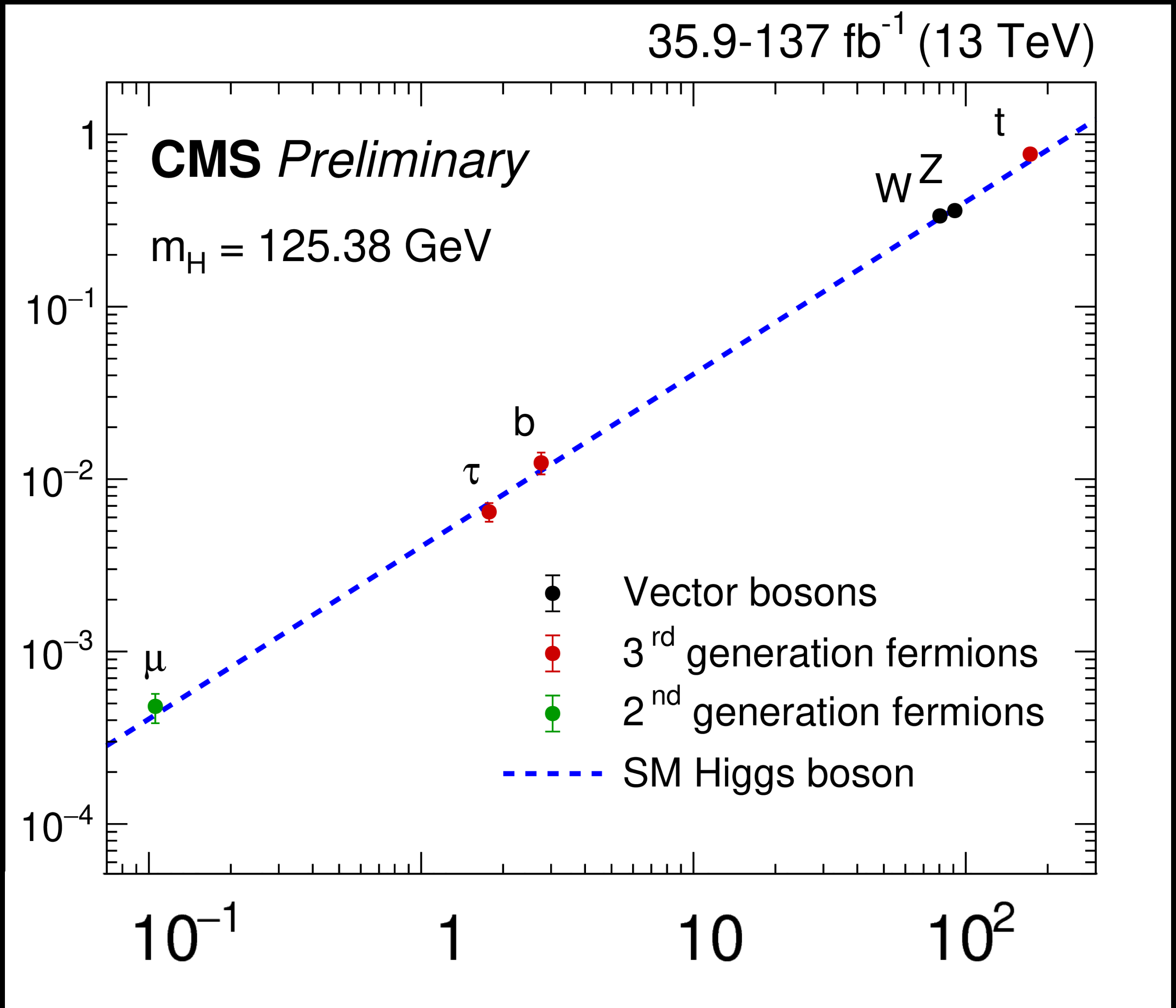


TODAY

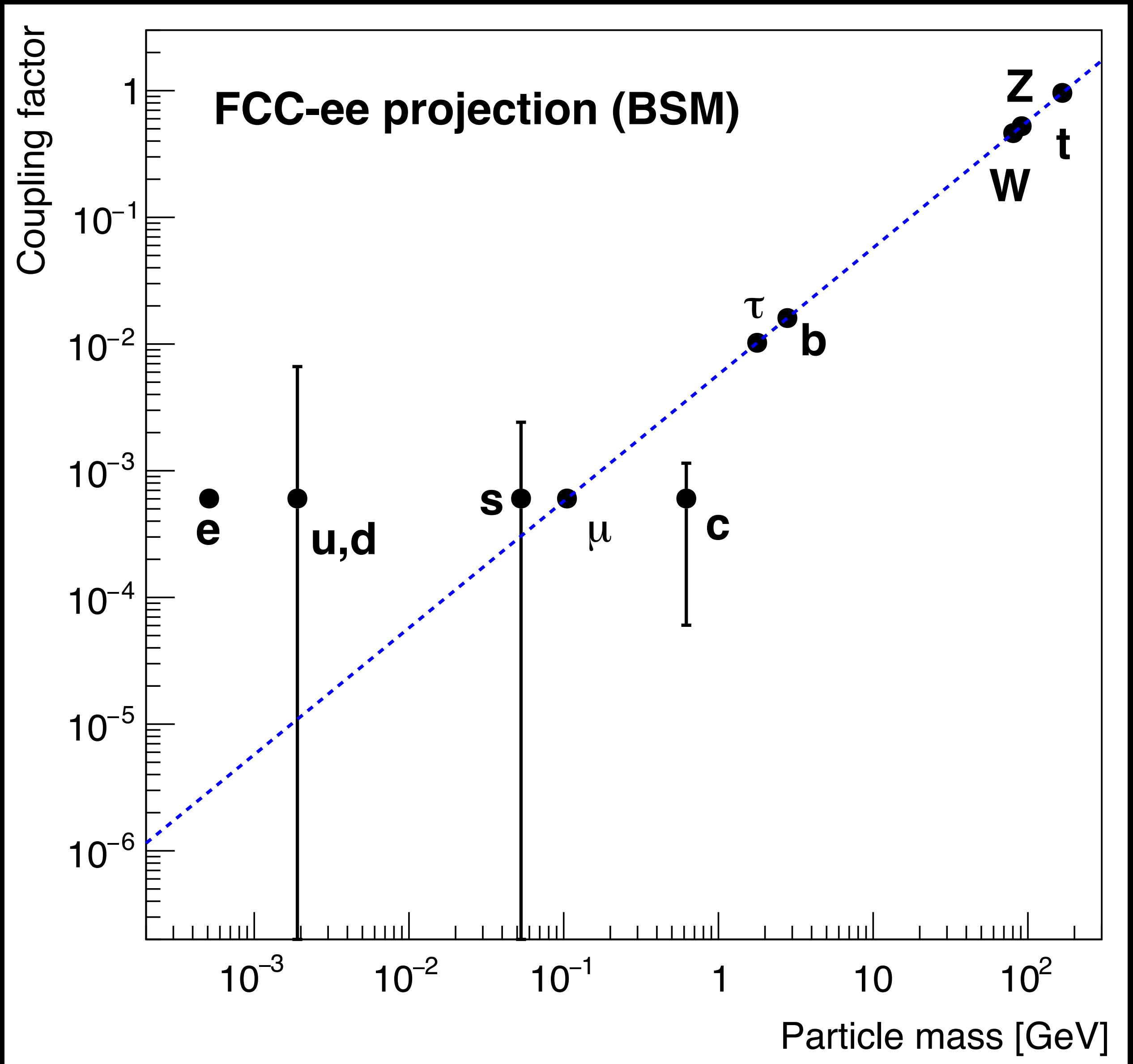
2050?

THE SOURCE OF MASS

$$\mathcal{L} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} + |D_\mu \phi|^2 + i\bar{\psi}\not{D}\psi + \psi_i y_{ij}\psi_j \phi + h.c$$



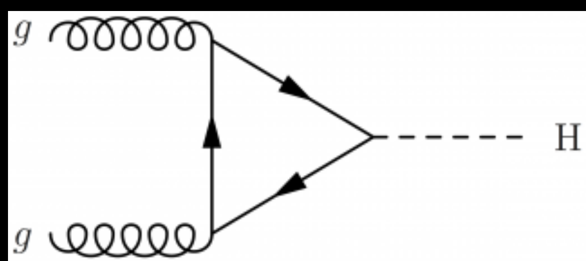
CMS, CMS-PAS-19-006

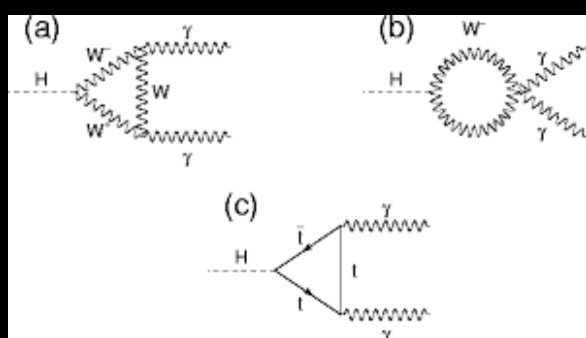


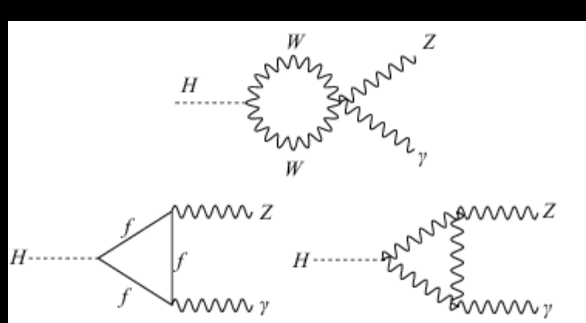
TODAY

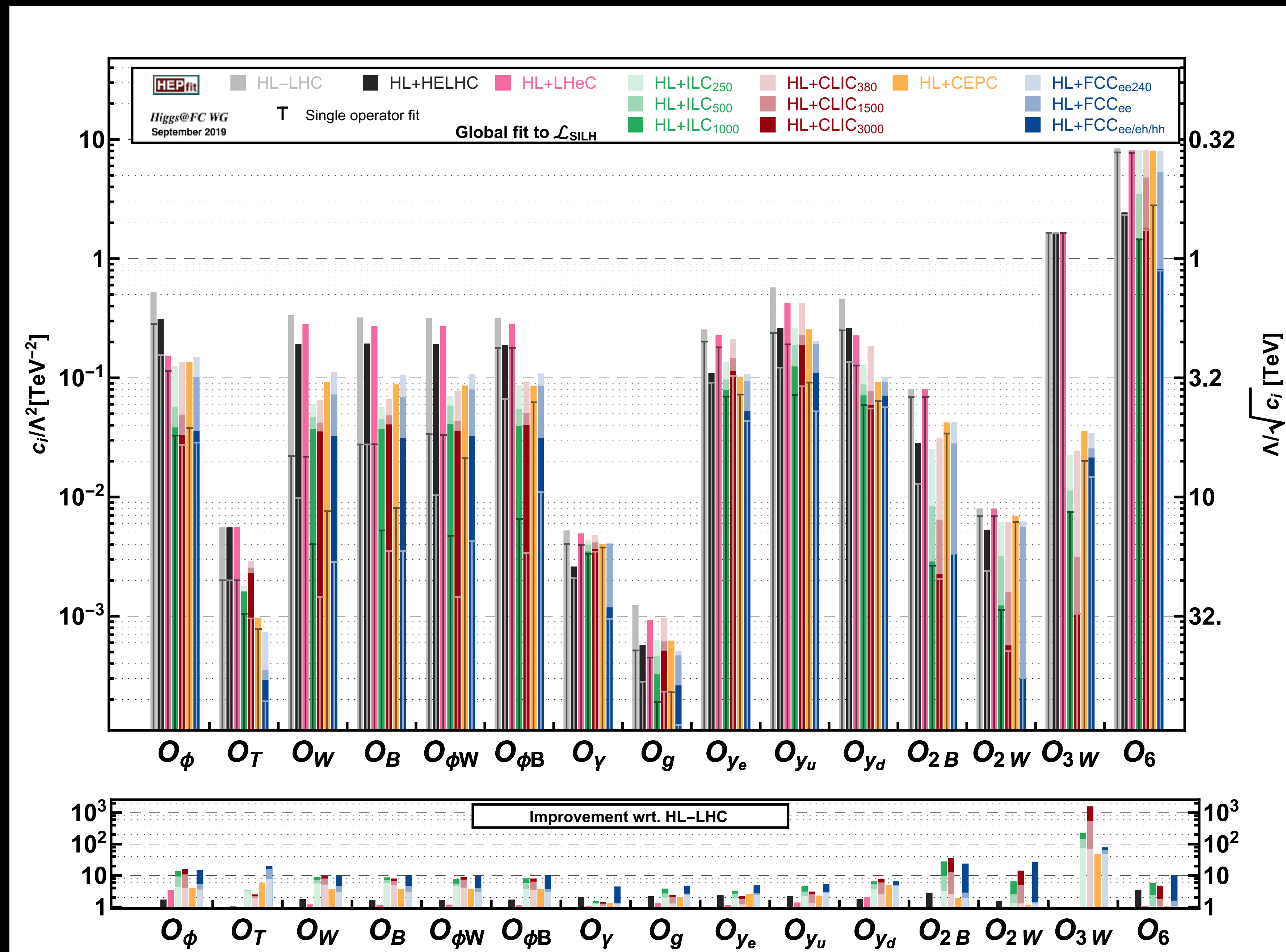
2050?

Sensitivity to high-scale physics









J de Blas et al, JHEP 01 (2020) 139

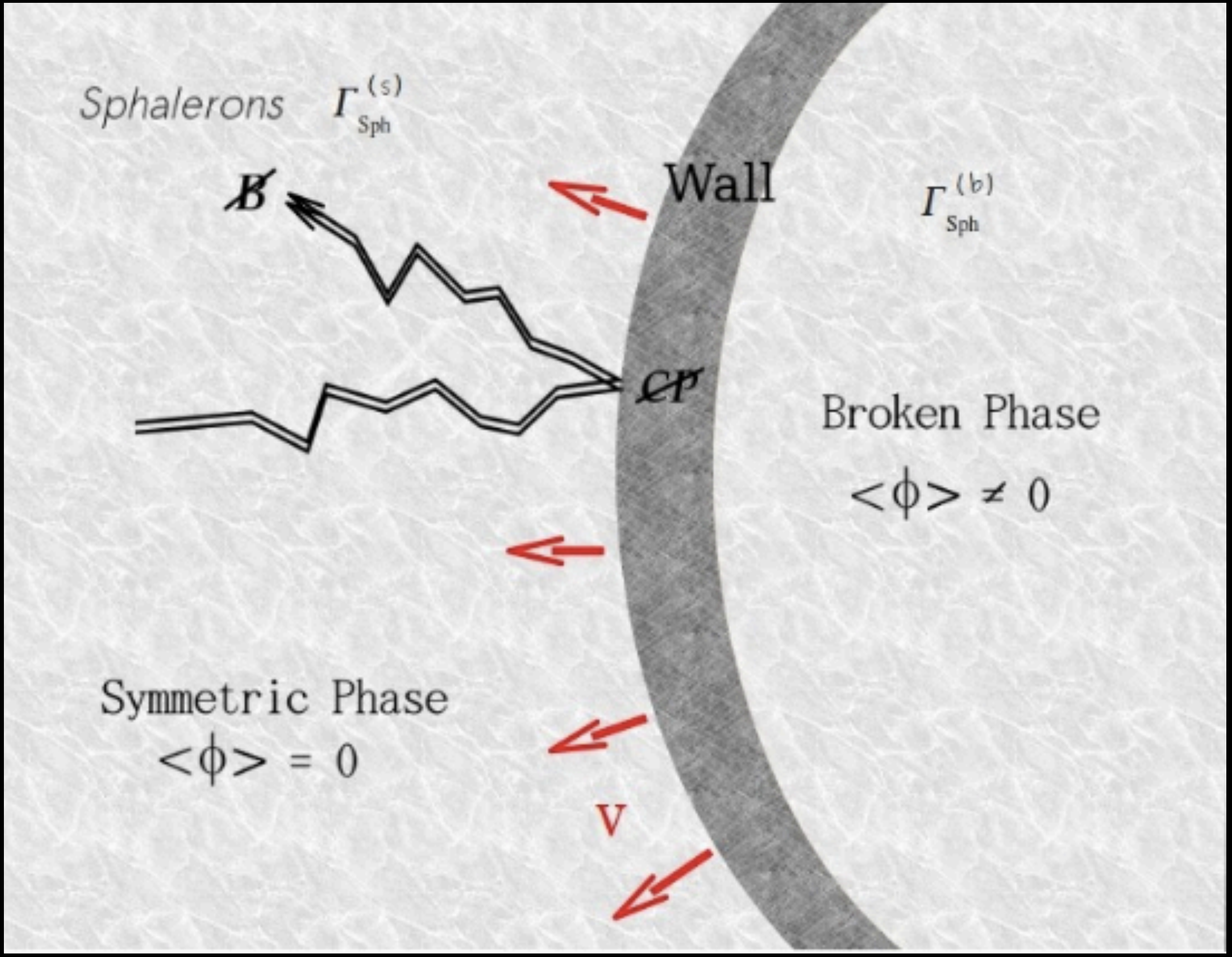
Matter in the Universe

Sakharov conditions:

Baryon number violation
Sphalerons

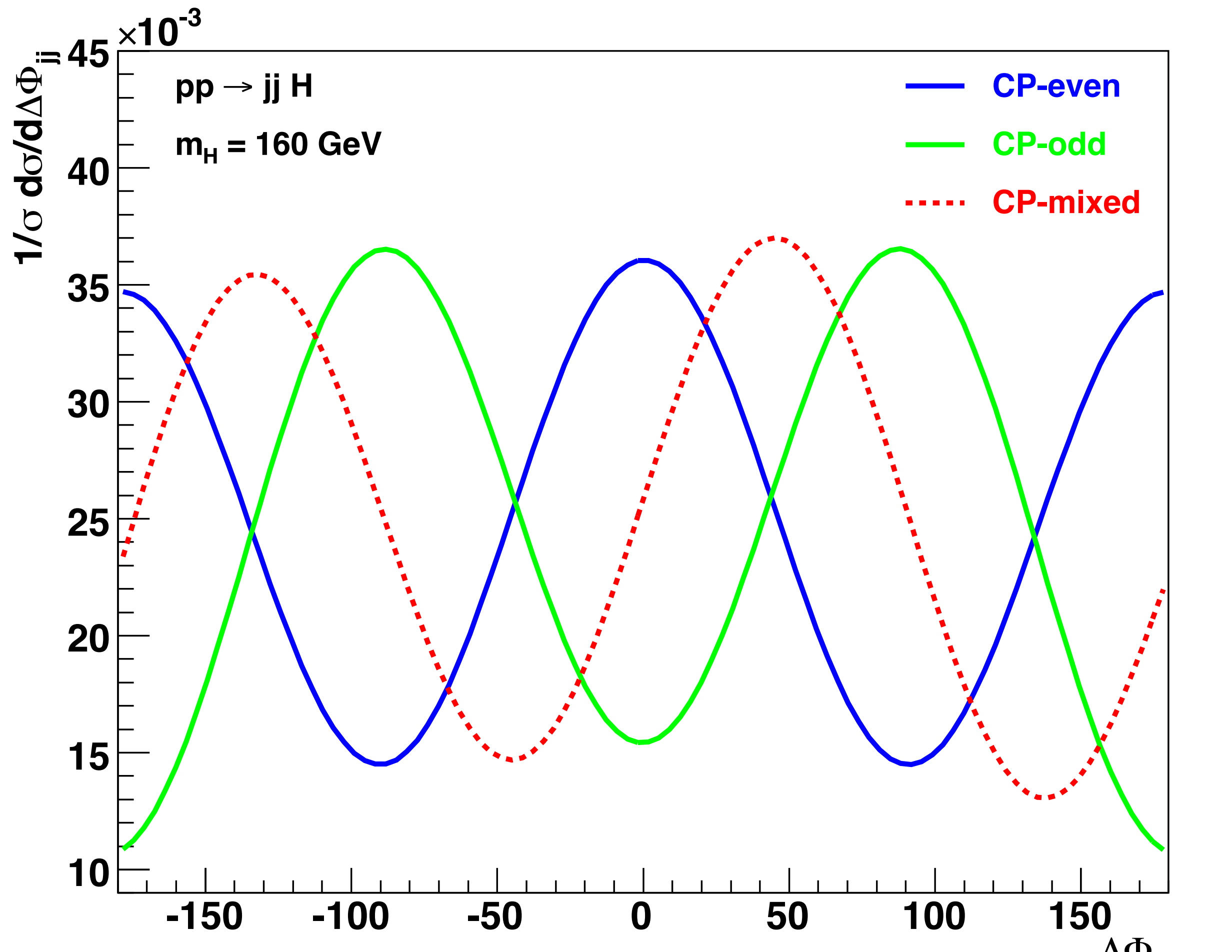
CP violation
?

Departure from thermal equilibrium
?

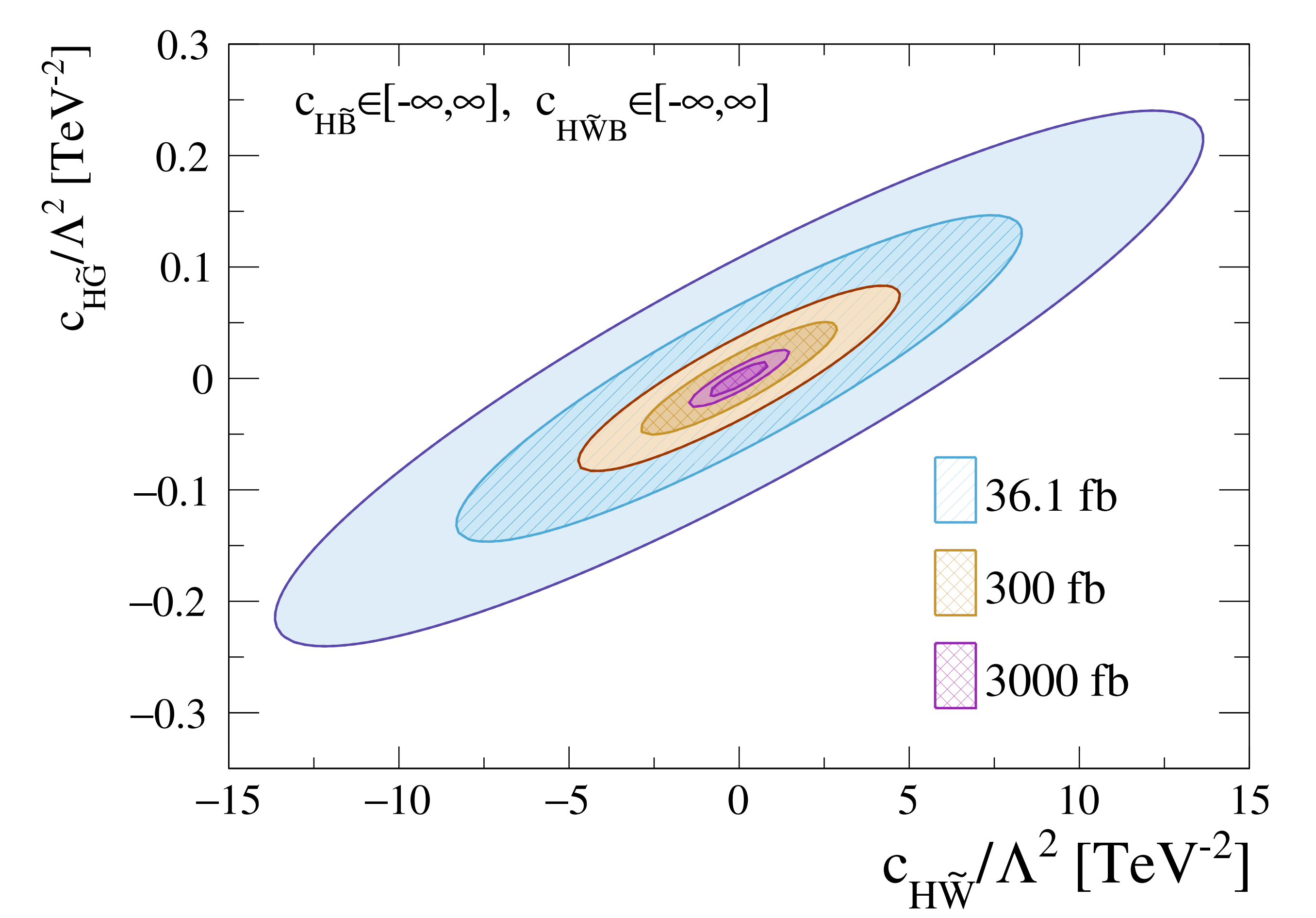


CP VIOLATION IN HVV & HGG COUPLINGS

$$\Delta\Phi_{jj} = \phi_{\eta>0} - \phi_{\eta<0}$$

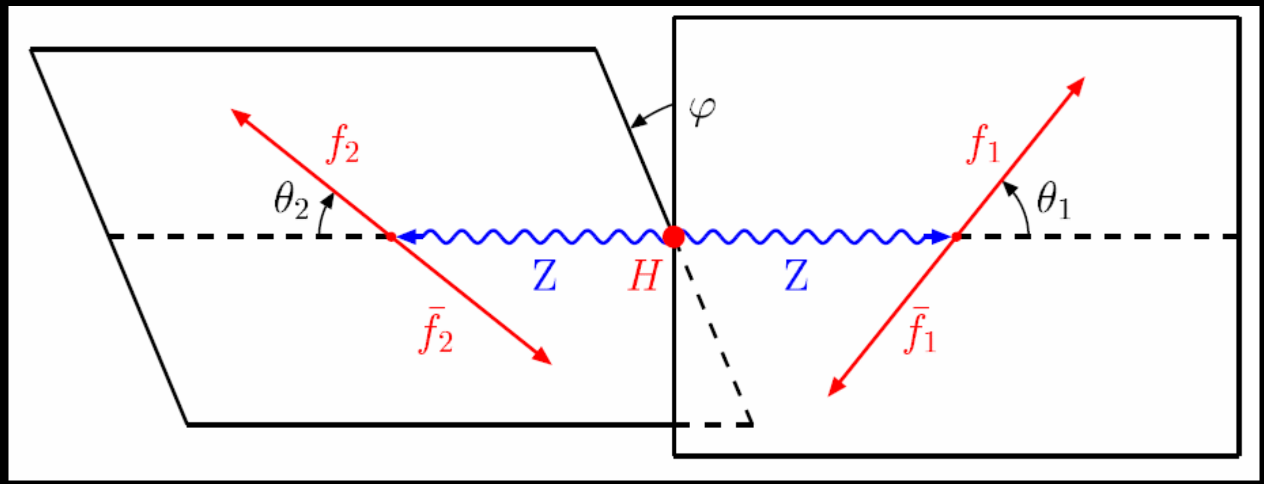


G KLAMKE & D ZEPPENFELD, JHEP 0704 (2007) 052



F BERNLOCHER ET AL, PLB 790 (2019) 372

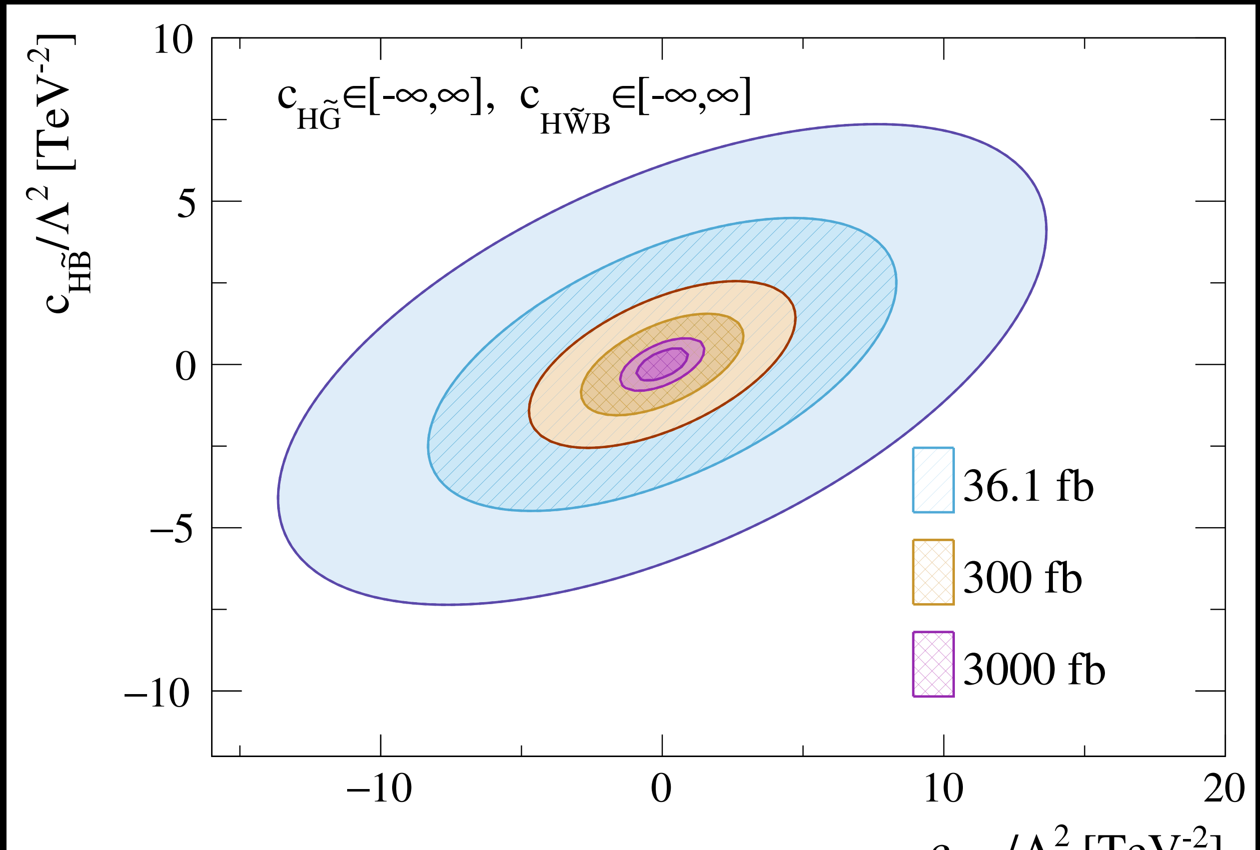
CP violation in HZZ couplings



$$\cos\Phi = \left.\frac{(\mathbf{p}_{\ell^-}\times\mathbf{p}_{\ell^+})\cdot(\mathbf{p}_{\ell'^-}\times\mathbf{p}_{\ell'^+})}{\sqrt{(\mathbf{p}_{\ell^-}\times\mathbf{p}_{\ell^+})^2\,(\mathbf{p}_{\ell'^-}\times\mathbf{p}_{\ell'^+})^2}}\right|_h$$

Expected 1D constraints on Wilson coefficients for each EFT operator, in units of TeV^{-2}, after marginalising over all other coefficients.

Coefficient [TeV^{-2}]	36.1 fb^{-1}	300 fb^{-1}	3000 fb^{-1}
$c_{H\tilde{G}}/\Lambda^2$	$[-0.19, 0.19]$	$[-0.067, 0.067]$	$[-0.021, 0.021]$
$c_{H\tilde{W}}/\Lambda^2$	$[-11, 11]$	$[-3.8, 3.8]$	$[-1.2, 1.2]$
$c_{H\tilde{B}}/\Lambda^2$	$[-5.9, 5.9]$	$[-2.1, 2.1]$	$[-0.65, 0.65]$
$c_{H\tilde{W}B}/\Lambda^2$	$[-14, 14]$	$[-4.9, 4.9]$	$[-1.5, 1.5]$

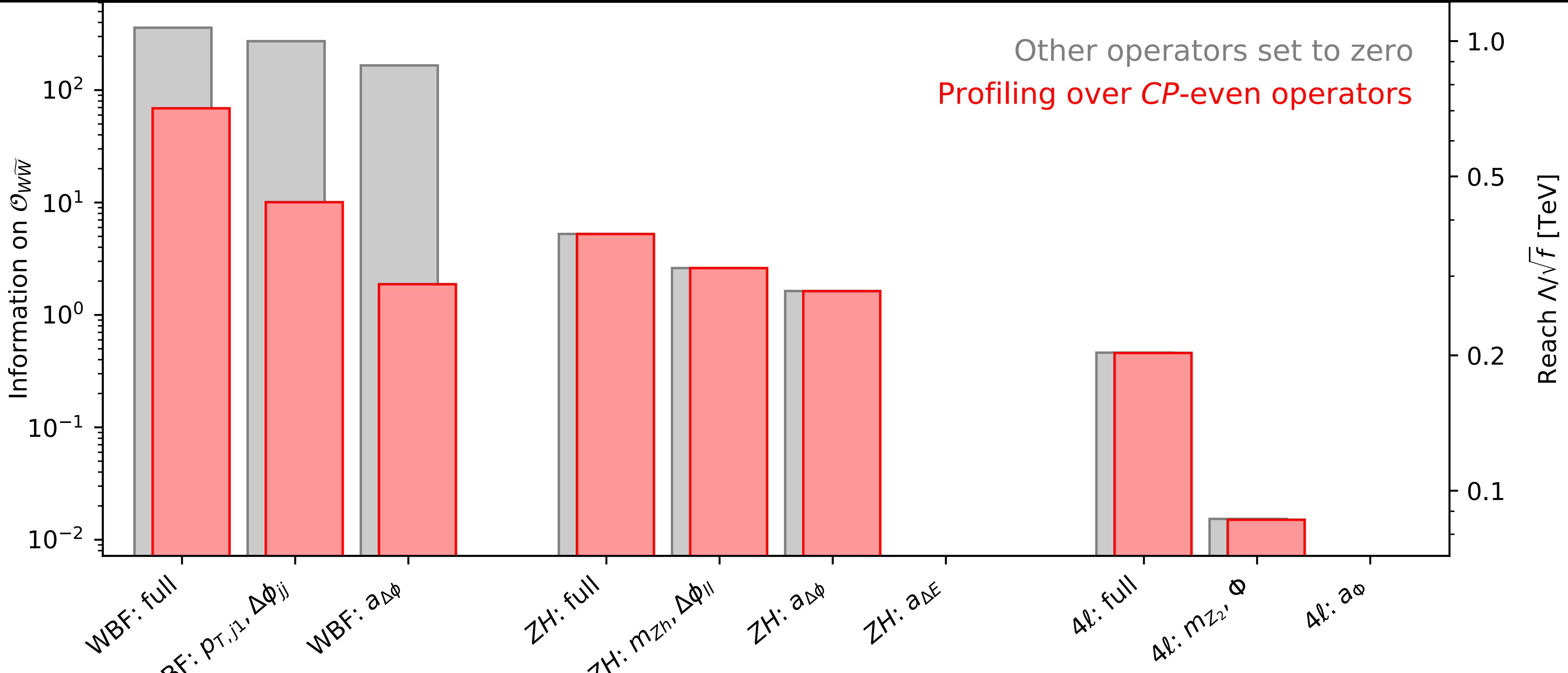


F Bernlocher et al, PLB 790 (2019) 372

Factor of 3 improvement in $H \to 4\ell$ at CEPC
F An et al, CPC 43 (2019) 043002

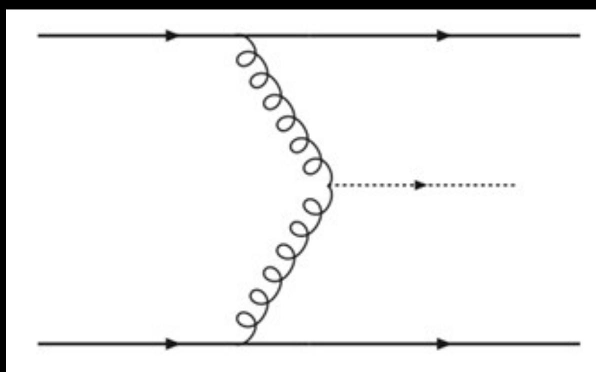
Also: $HZ(\to \ell\ell)$ via signed angle between leptons
J Brehmer, F Kling, T Plehn, T Tait,
PRD 97 (2018) 095017

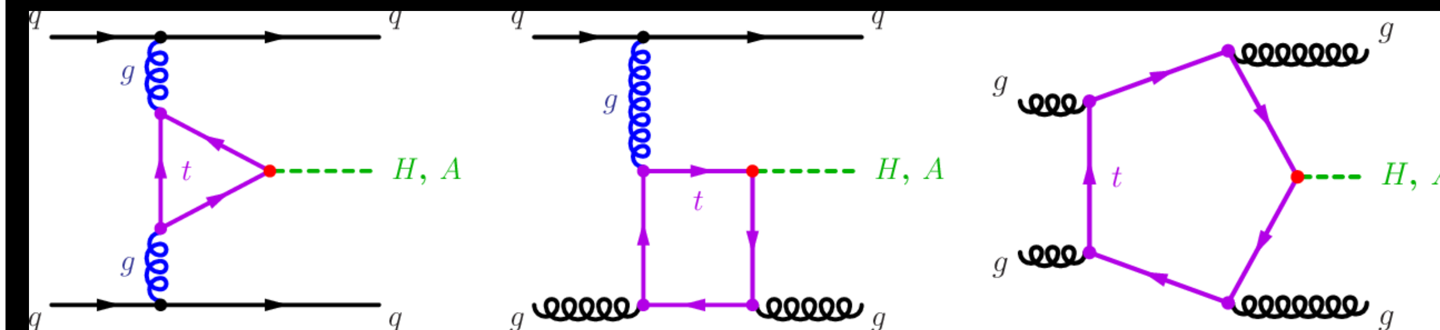
CP violation in HVV couplings

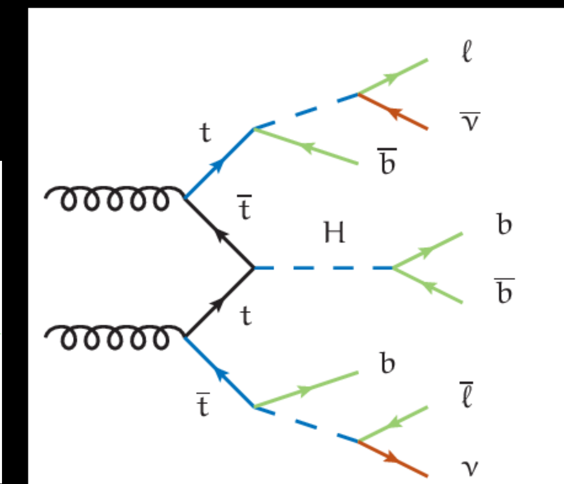


J Brehmer, F Kling, T Plehn, T Tait, PRD 97 (2018) 095017

CP violation in tth couplings

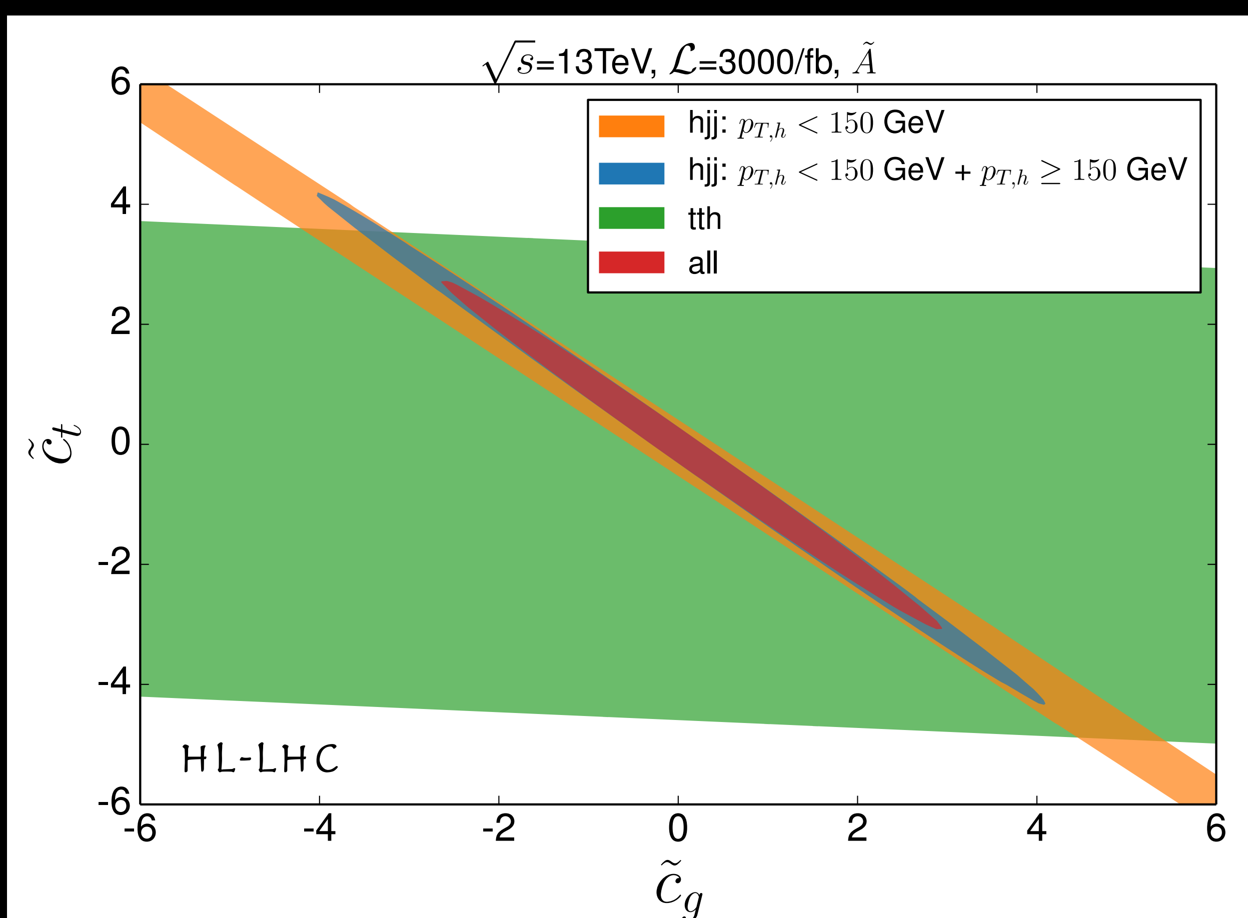


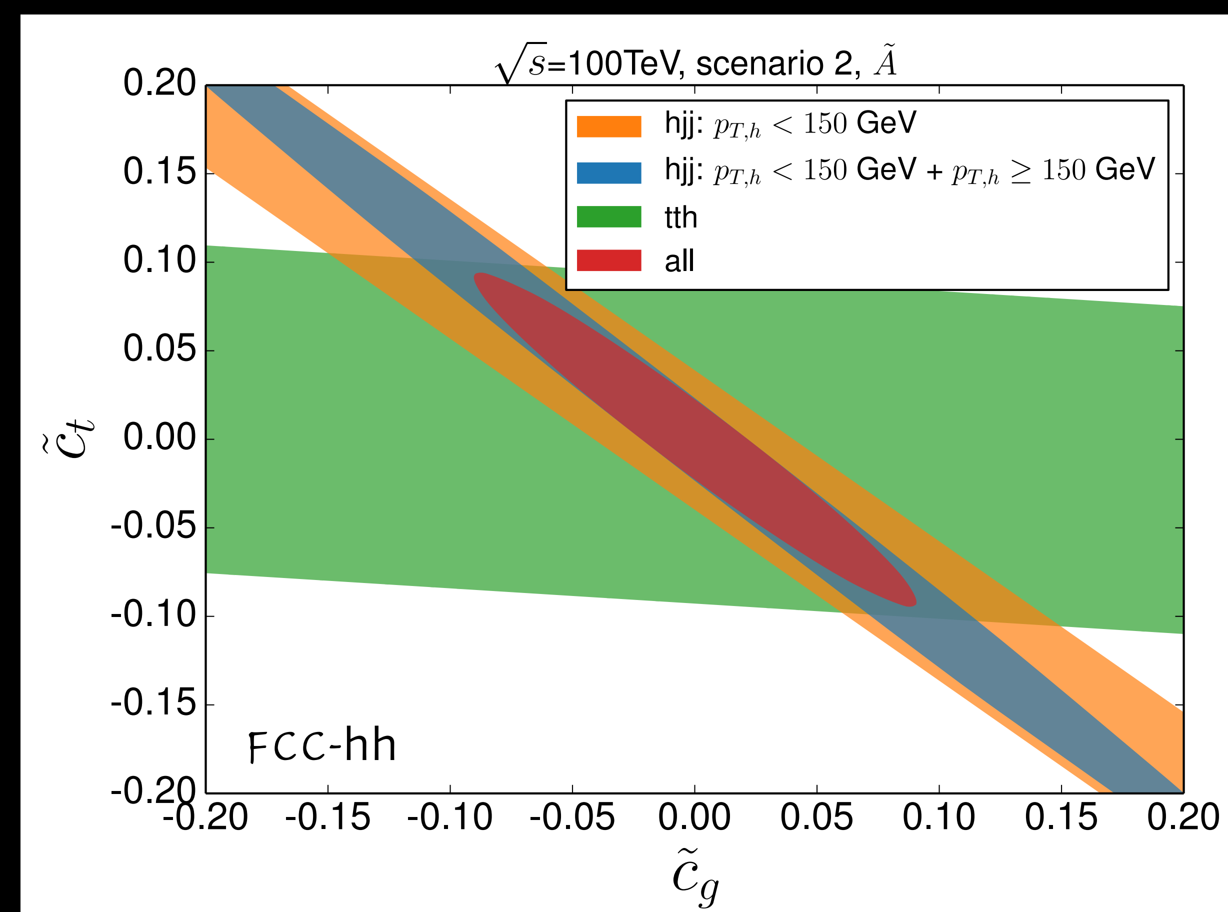




$$\Delta\Phi_{jj} = \phi_{\eta>0} - \phi_{\eta<0}$$

$$\Delta\Phi_{\ell\ell} = \phi_{\eta>0} - \phi_{\eta<0}$$





C Englert, P Galler, A Pilkington, M Spannowsky, PRD 99 (2019), 095007

CP violation in bbH couplings

Study in progress with
R Alonso, M Spannowsky, C Fraser-Taliente

10 years of FCC-ee with Energy Recovery Linac (90 ab^{-1}): 11 million $ZH(\to bb)$ events

b

$\downarrow$

Λ_b

0.5 % $\quad$ 0.15 %

$p\mu X \qquad \Lambda(\to p\pi)\ell X$

DELPHI,
Z Phys C 68, 375 (1995)

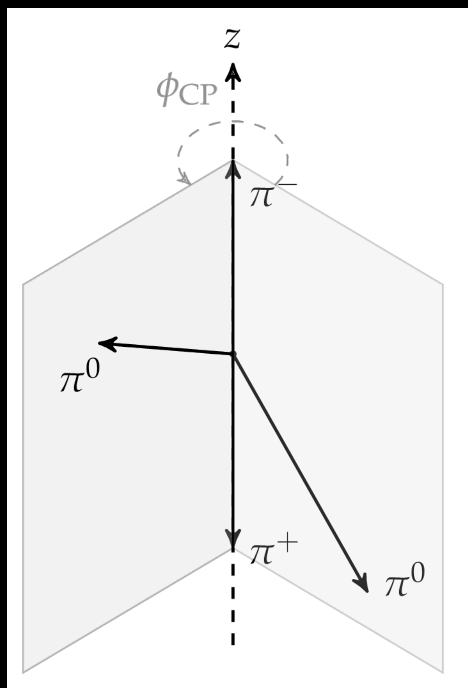
Fragmentation to Λ_b with identifiable semileptonic decays: 700 events

1) Require dijet mass to be consistent with Higgs mass

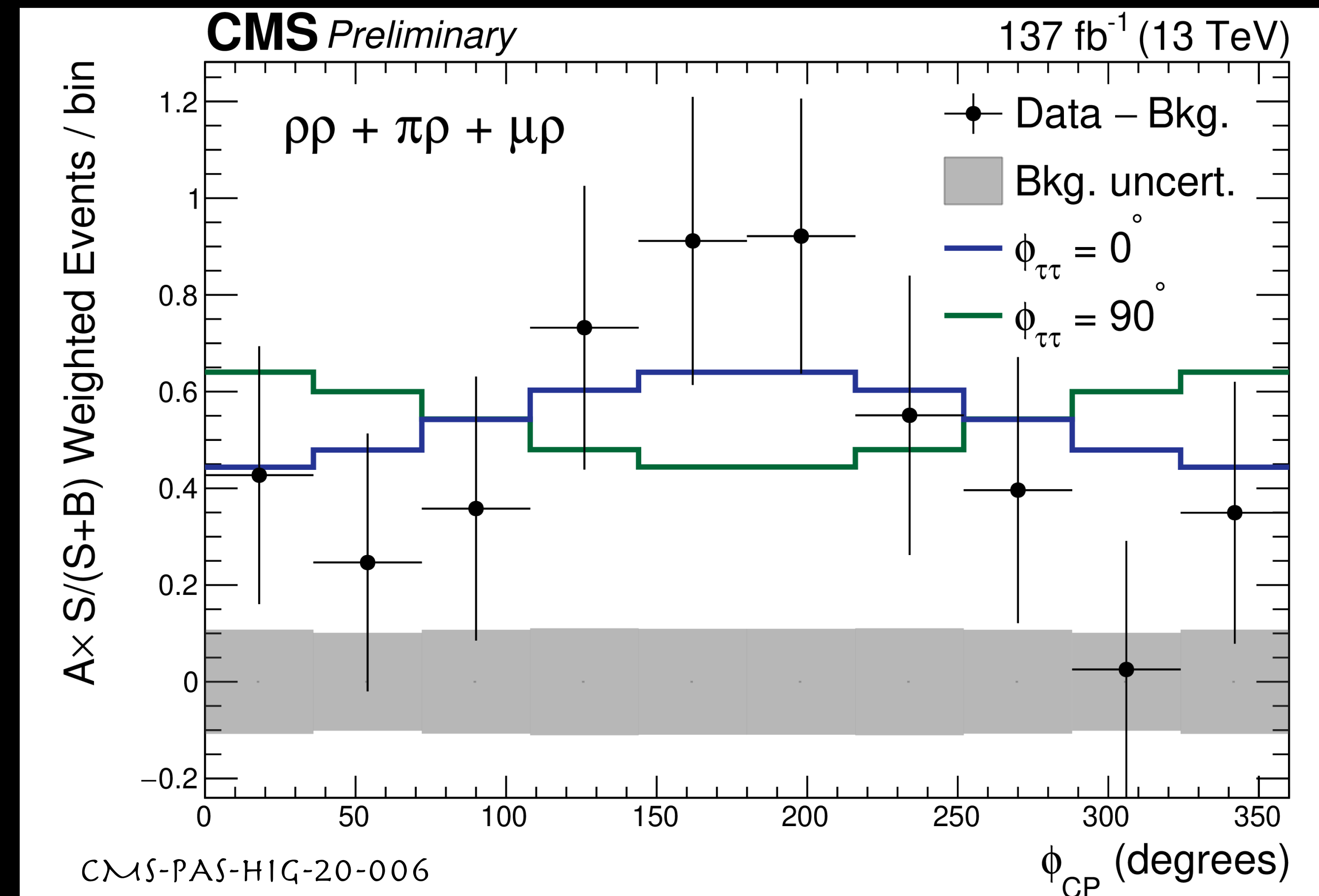
2) Estimate Λ_b vertex from intersection of lepton and proton or Λ

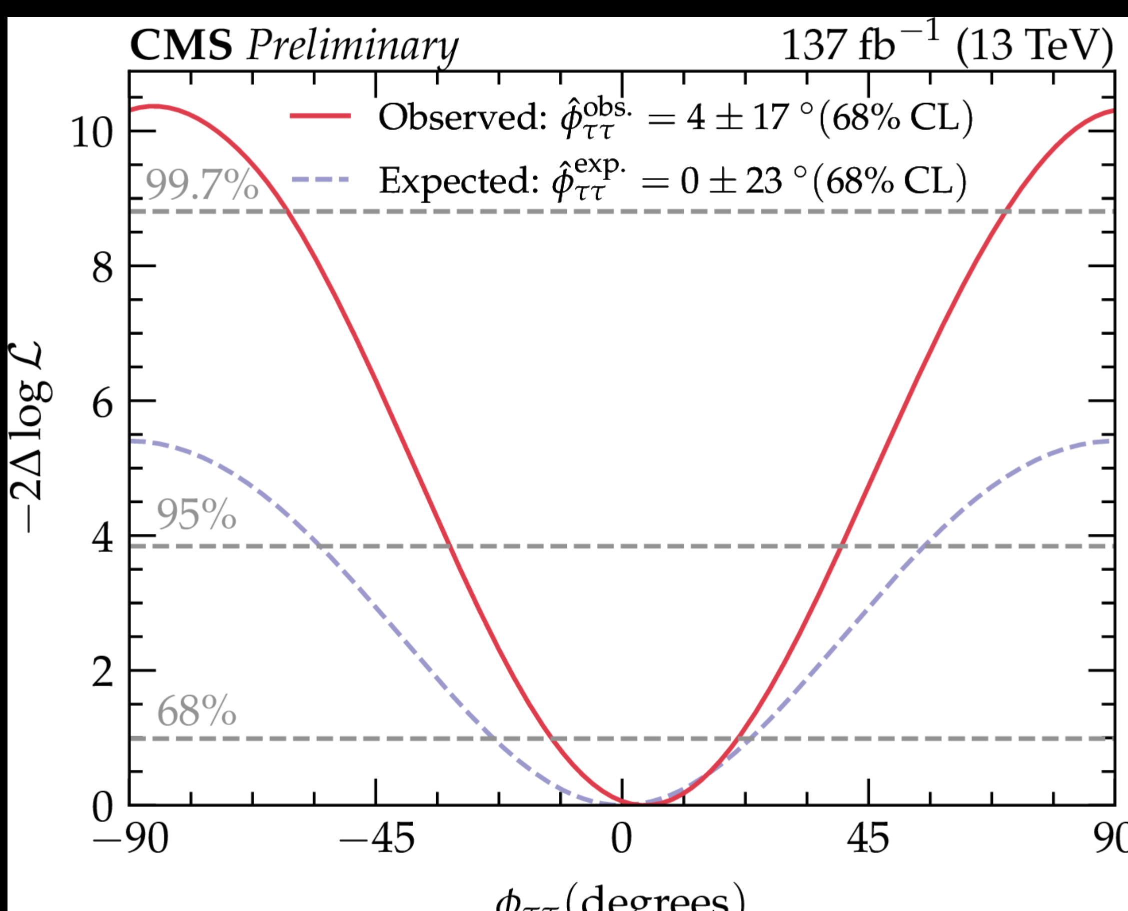
3) Calculate relative angle between leptons using Λ_b momentum axis

CP violation in $\tau\tau$H couplings



Decay mode	Expected sensitivity
$\tau_\mu\tau_h$	1.47
$\mu\rho$	1.16
$\mu\pi$	0.71
μa_1^{3pr}	0.51
μa_1^{1pr}	0.24
$\tau_h\tau_h$	1.8
$\rho\rho$	1.09
$\rho\pi$	1.04
ρa_1^{3pr}	0.64
$\pi\pi$	0.38
πa_1^{3pr}	0.46
$a_1^{1pr}\rho$ and $a_1^{1pr}a_1^{1pr}$	0.30
πa_1^{1pr}	0.23
$a_1^{3pr}a_1^{3pr}$	0.13
$a_1^{3pr}a_1^{1pr}$	0.11
Combined	2.33





Future precision:

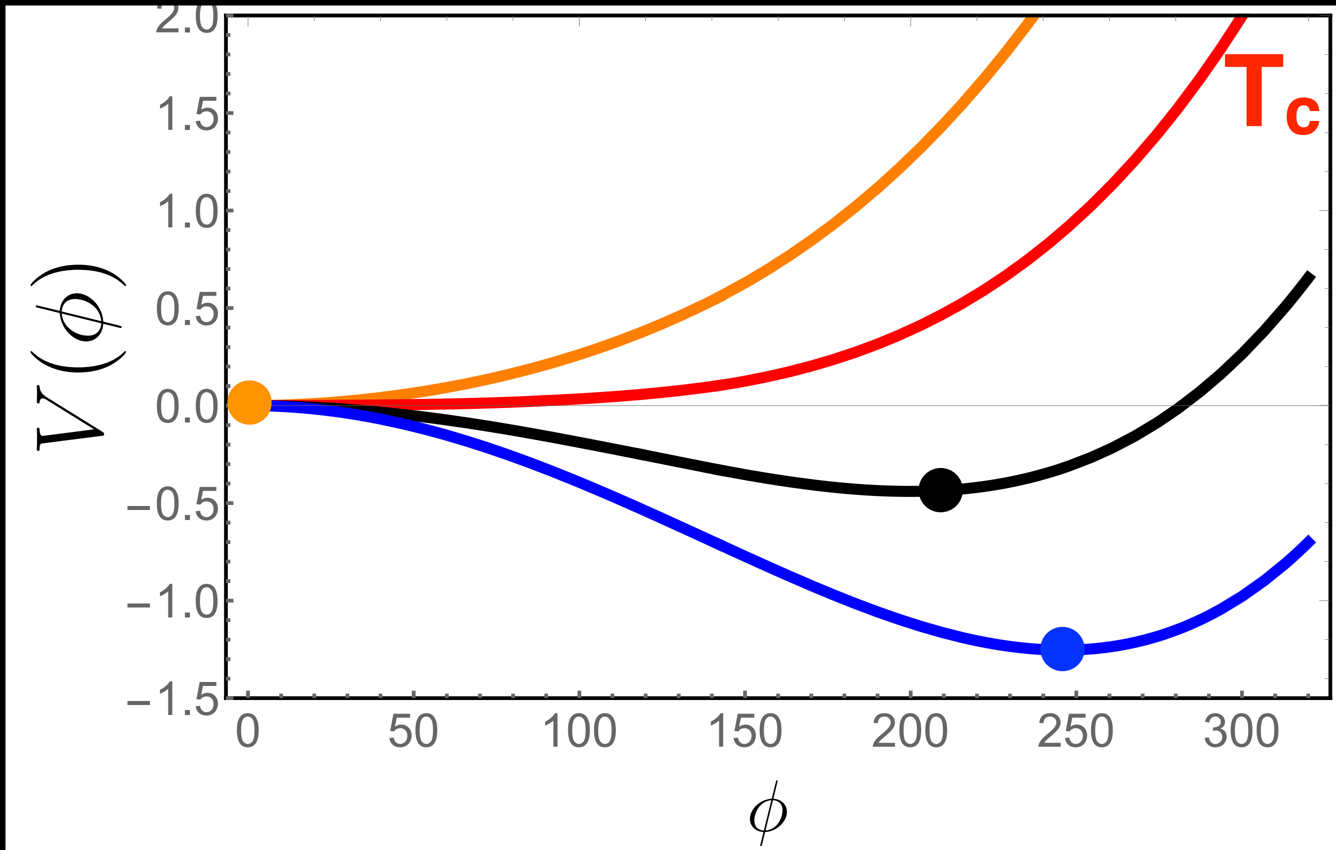
5.2° at HL-LHC

X Chan and Y Wu, Phys Lett B 790 (2019), 332

2.9° with 5 ab^{-1} e^+e^-

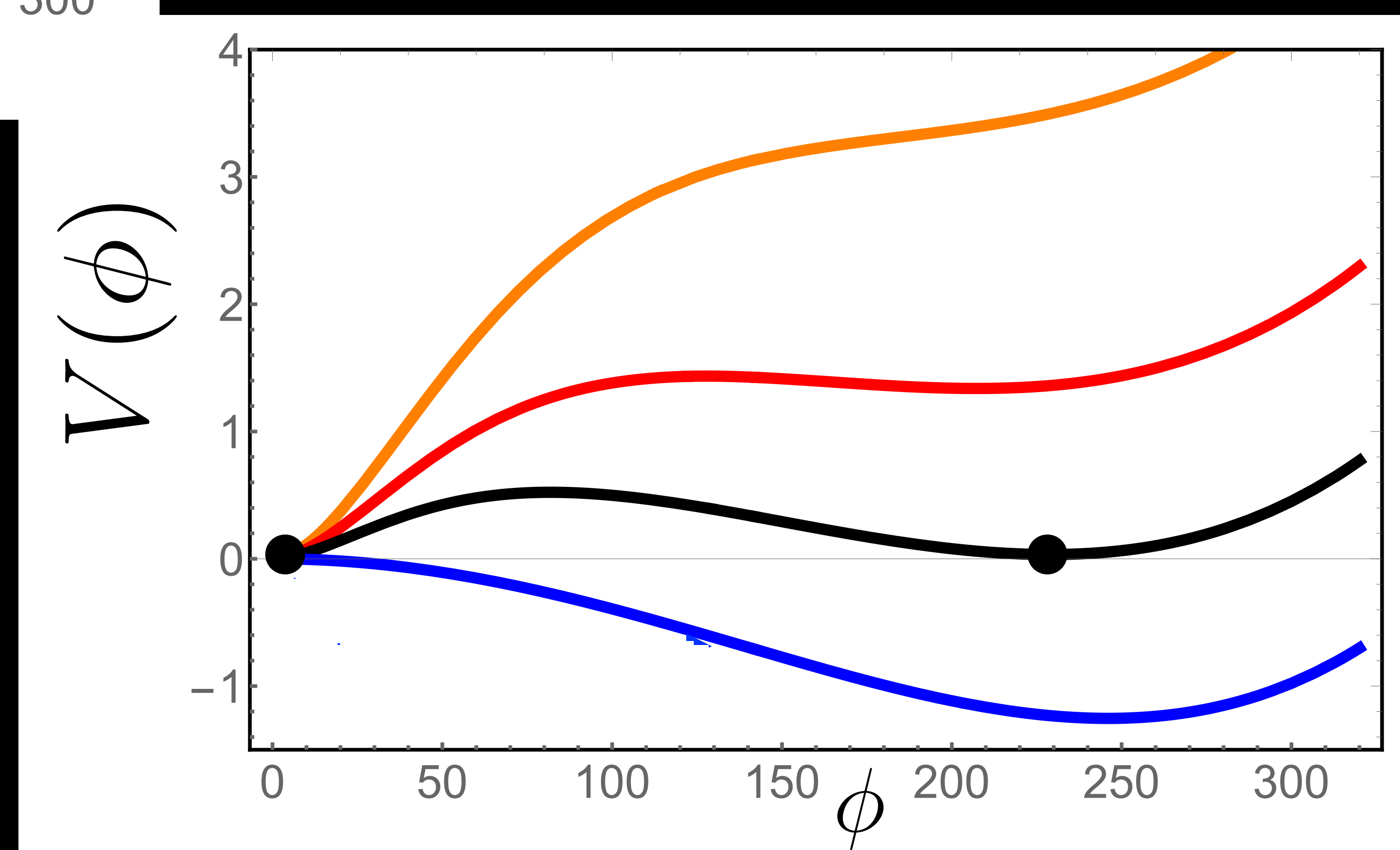
X Chan and Y Wu, Eur Phys J C 77 (2017), 697

Matter in the Universe



$$\mathcal{L} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} + |D_\mu\phi|^2 + i\bar{\psi}\not{D}\psi + \bar{\psi}_i y_{ij} \psi_j \phi + h.c$$
$$-V(\phi)$$

SM:
No departure from thermal equilibrium



BSM:
First order phase transition

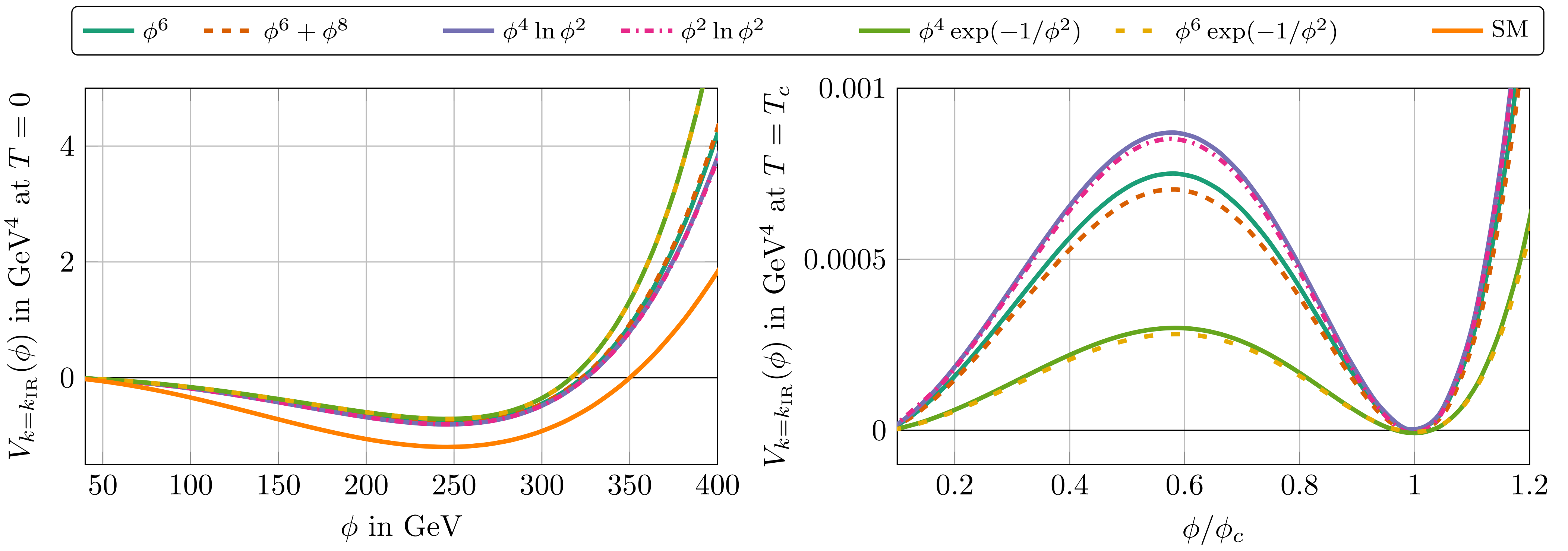
The Higgs potential

$$V_{k=\Lambda} = \frac{\mu^2}{2}\,\phi^2 + \frac{\lambda_4}{4}\,\phi^4 + \Delta V$$

$$\Delta V_6 = \lambda_6\,\frac{\phi^6}{\Lambda^2}\,, \qquad \Delta V_8 = \lambda_6\,\frac{\phi^6}{\Lambda^2} + \lambda_8\,\frac{\phi^8}{\Lambda^4}\,,$$

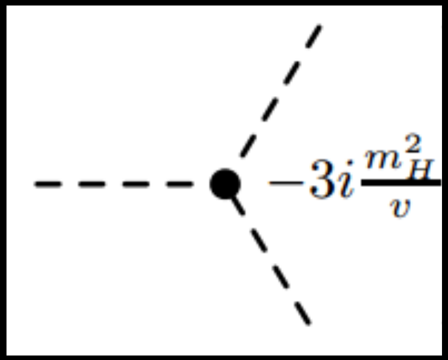
$$\Delta V_{\mathrm{ln},2} = -\lambda_{\mathrm{ln},2}\,\frac{\phi^2\Lambda^2}{100}\;\ln\frac{\phi^2}{2\Lambda^2}\,, \qquad \Delta V_{\mathrm{ln},4} = \lambda_{\mathrm{ln},4}\,\frac{\phi^4}{10}\;\ln\frac{\phi^2}{2\Lambda^2}\,,$$

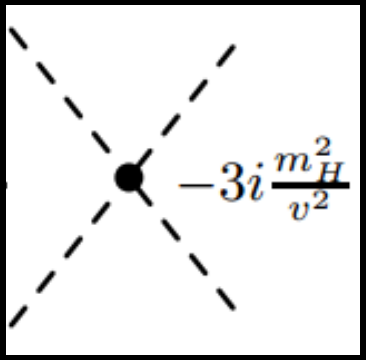
$$\Delta V_{\mathrm{exp},4} = \lambda_{\mathrm{exp},4}\phi^4\,\exp\left(-\frac{2\Lambda^2}{\phi^2}\right)\,, \qquad \Delta V_{\mathrm{exp},6} = \lambda_{\mathrm{exp},6}\,\frac{\phi^6}{\Lambda^2}\,\exp\left(-\frac{2\Lambda^2}{\phi^2}\right)$$

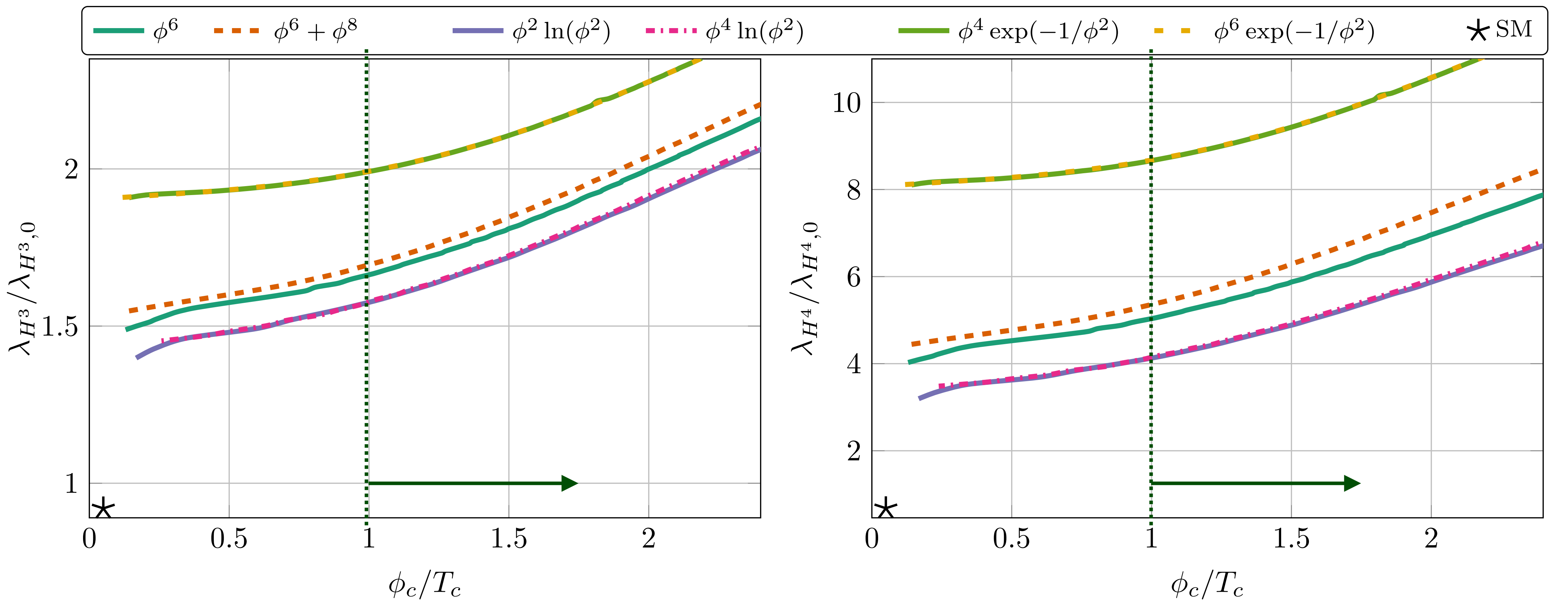


M Reichert, A Eichhorn, H Gies, J M Pawlowski, T Plehn, M M Scherer, PRD 97 (2018) 075008

Higgs Self-Interaction



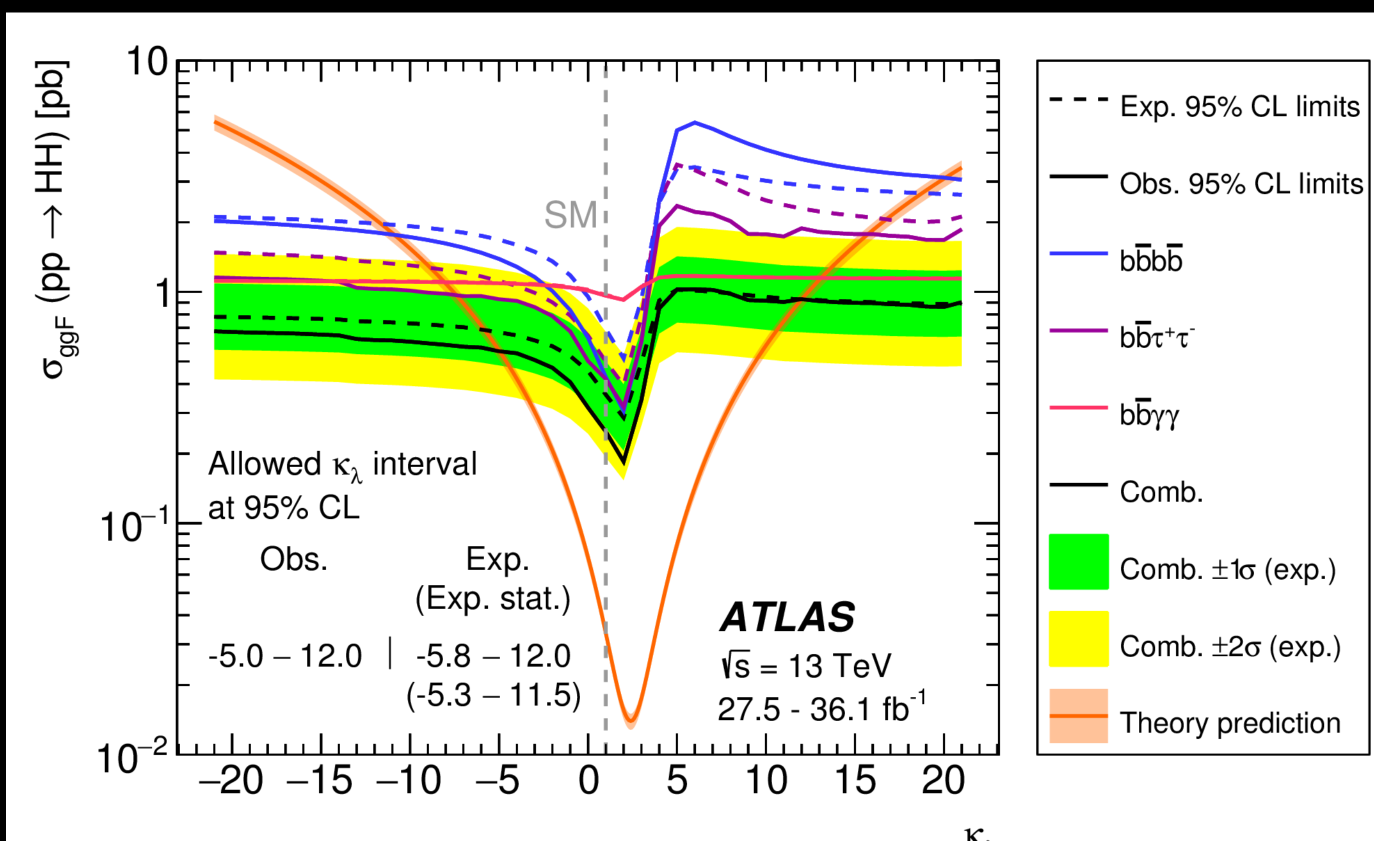




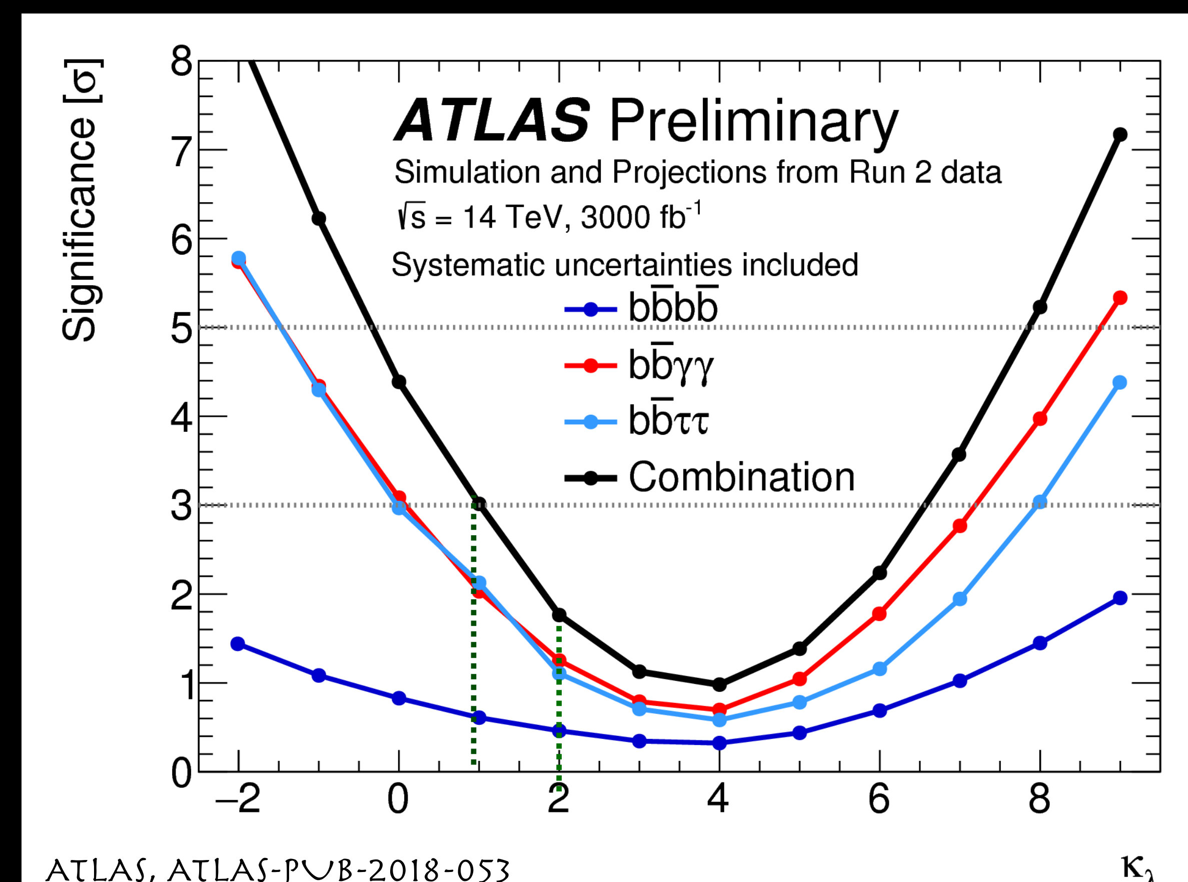
M Reichert, A Eichhorn, H Gies, J M Pawlowski, T Plehn, M M Scherer, PRD 97 (2018) 075008

DI-HIGGS PRODUCTION

Decay channel	Branching ratio
$b\bar{b}b\bar{b}$	$3.33 \cdot 10^{-1}$
$\tau\tau b\bar{b}$	$7.29 \cdot 10^{-2}$
$W^{+}(\to l\nu)W^{-}(\to l\nu)b\bar{b}$	$1.09 \cdot 10^{-2}$
$\tau\tau\tau\tau$	$3.99 \cdot 10^{-3}$
$\gamma\gamma b\bar{b}$	$2.63 \cdot 10^{-3}$
$W^{+}(\to l\nu)W^{-}(\to l\nu)\tau\tau$	$1.20 \cdot 10^{-3}$

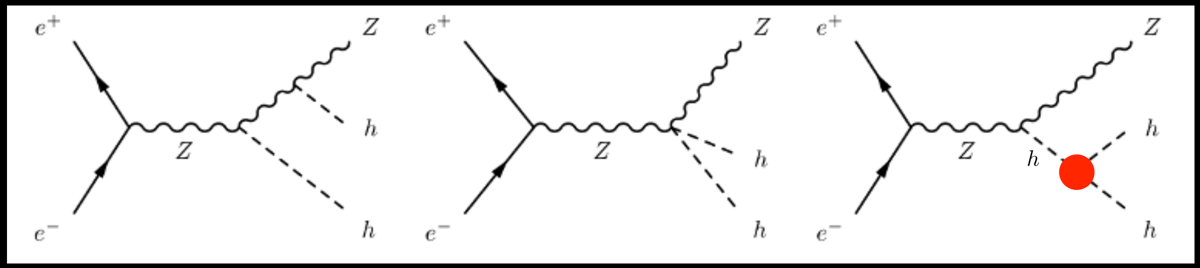


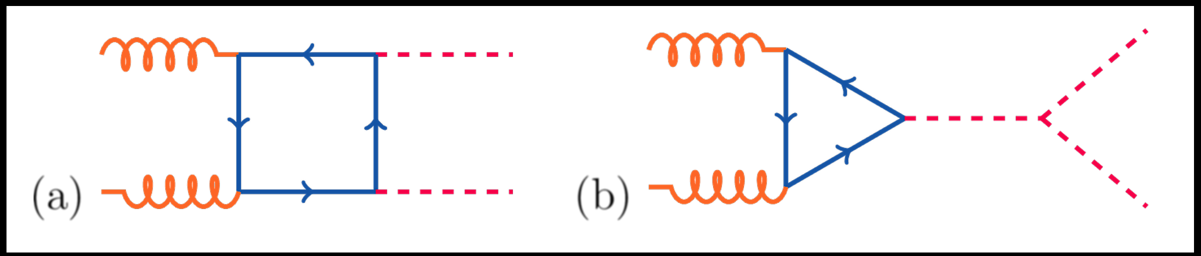
ATLAS, PLB 800 (2020), 135103

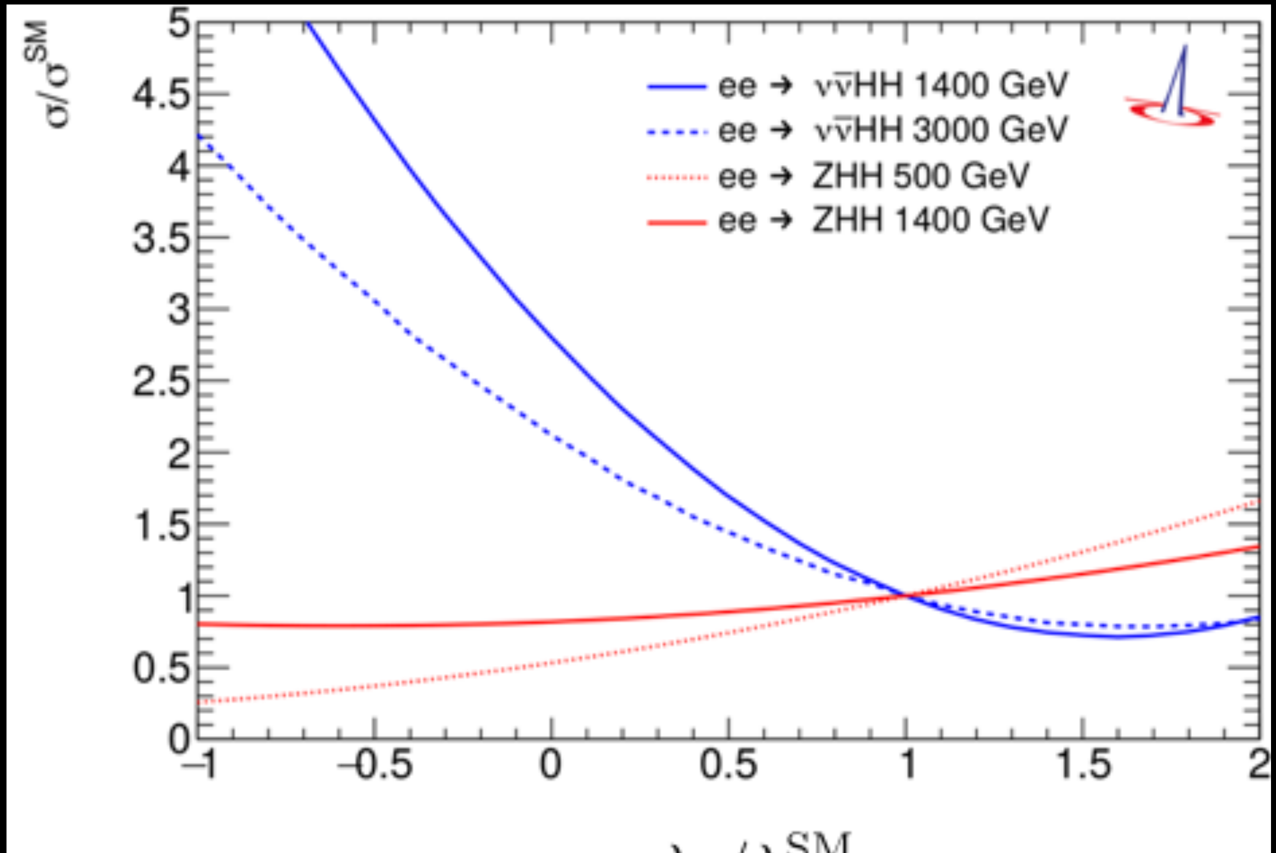


ATLAS, ATLAS-PUB-2018-053

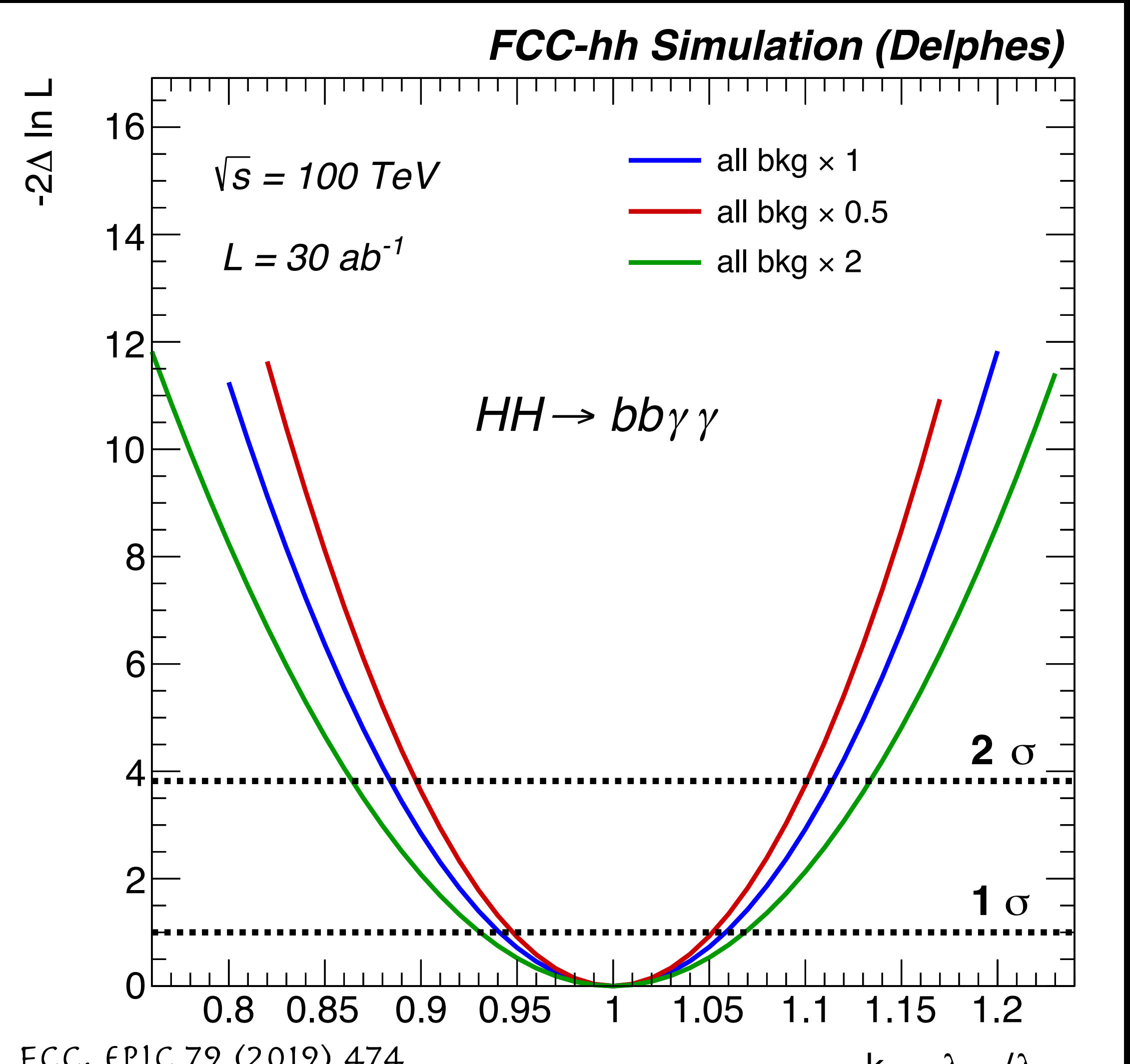
Di-Higgs production







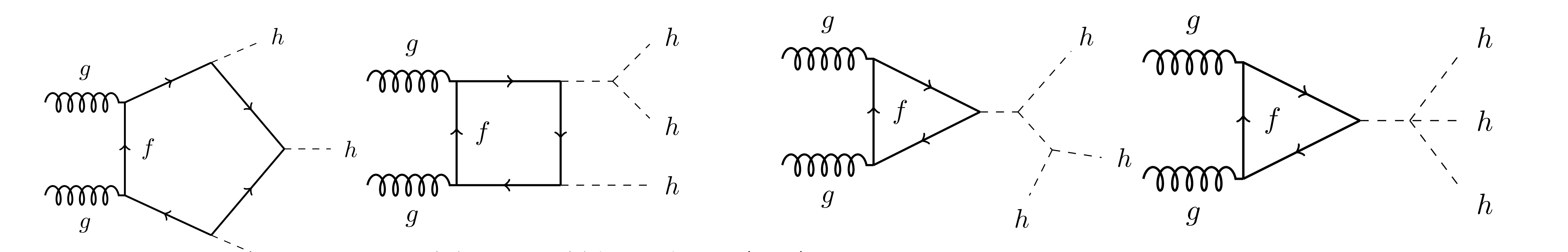
J de Blas et al, JHEP 01 (2020) 139



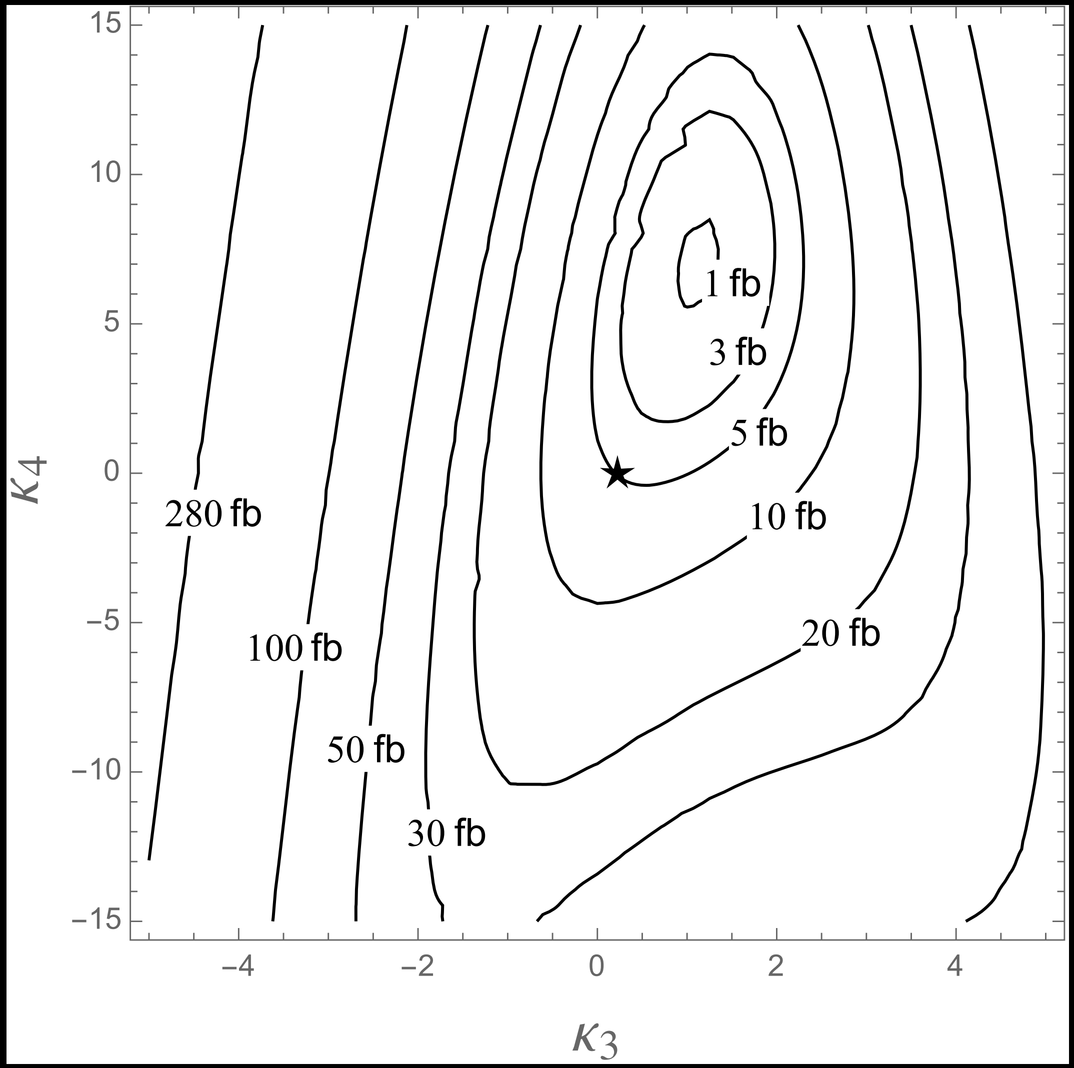
FCC, EPJC 79 (2019) 474

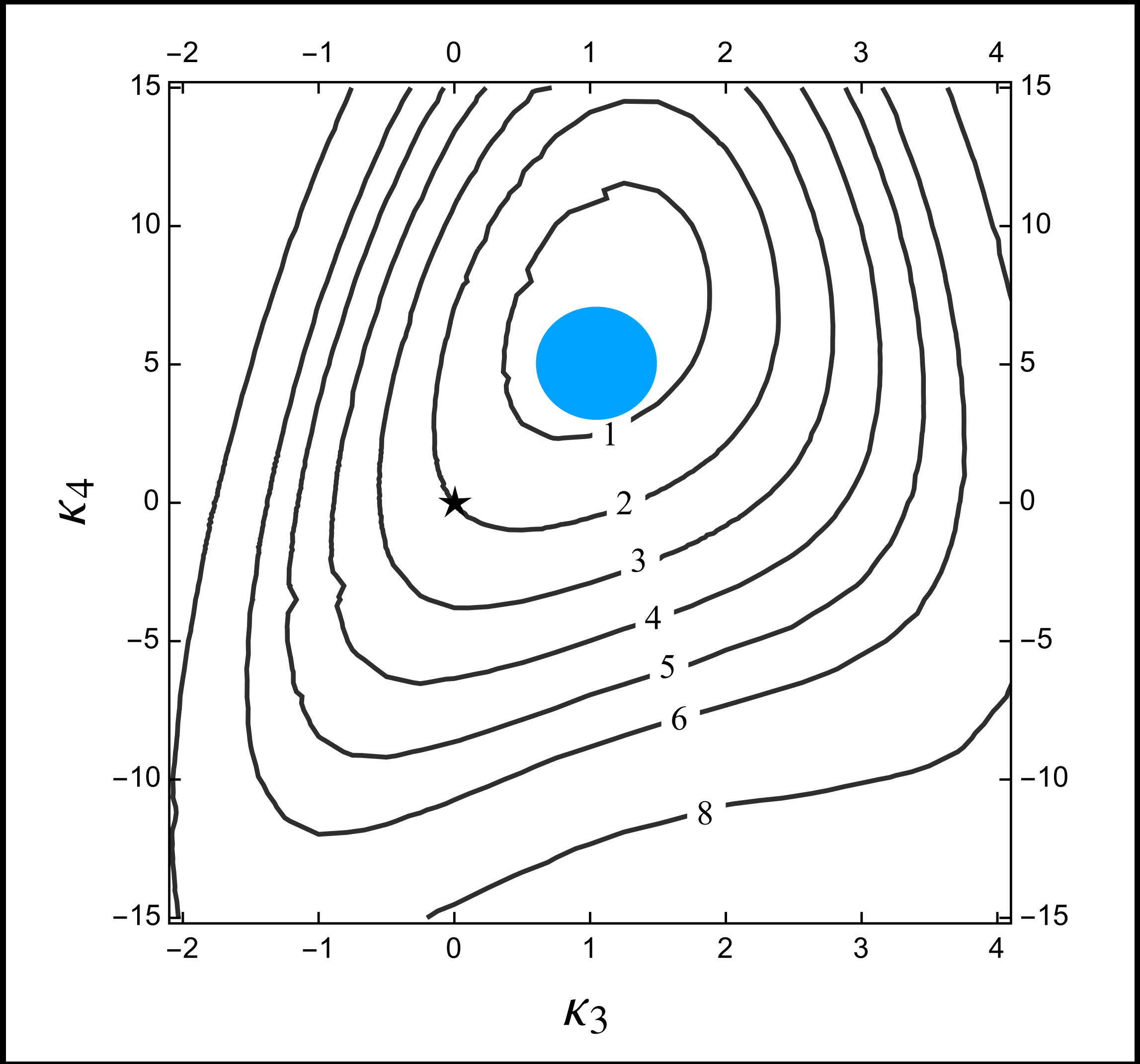
SM: 27% precision with 500 GeV e+e- ILC

TRI-HIGGS PRODUCTION

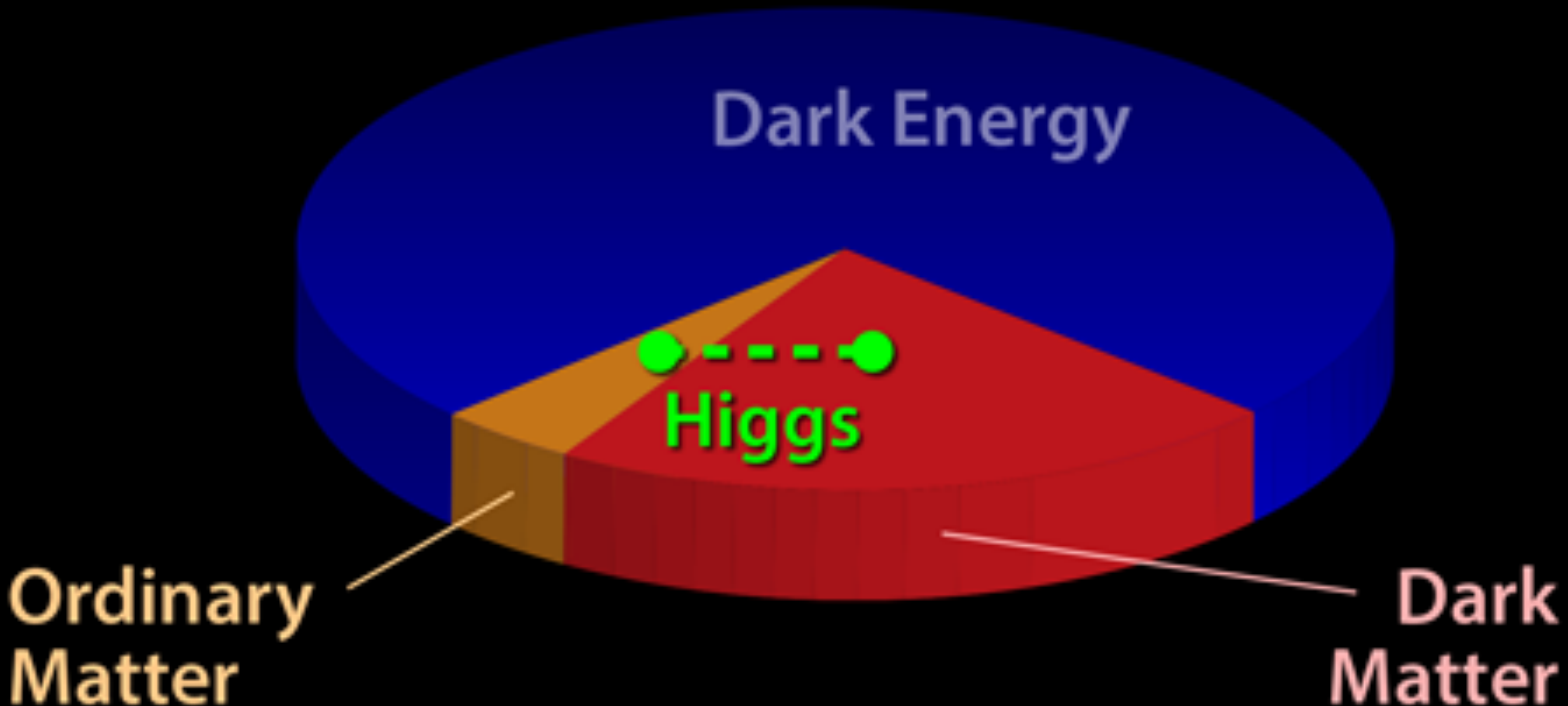


B FUKS, J H KIM, S J LEE, PLB 771 (2017) 354

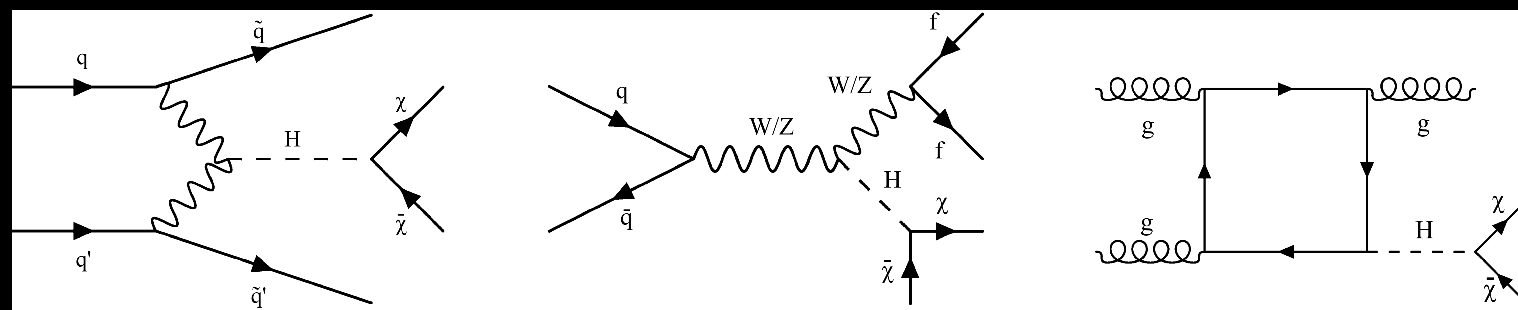


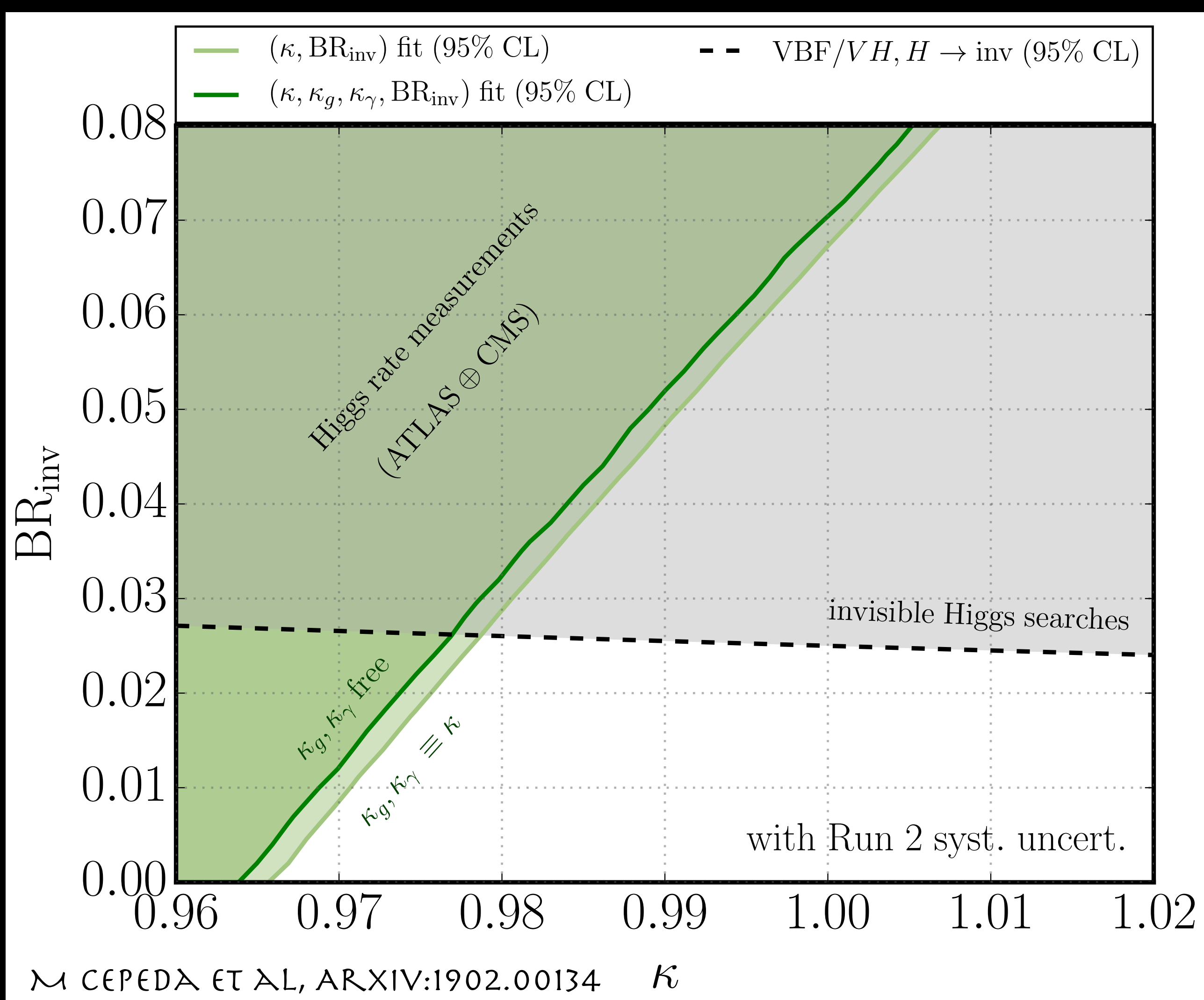


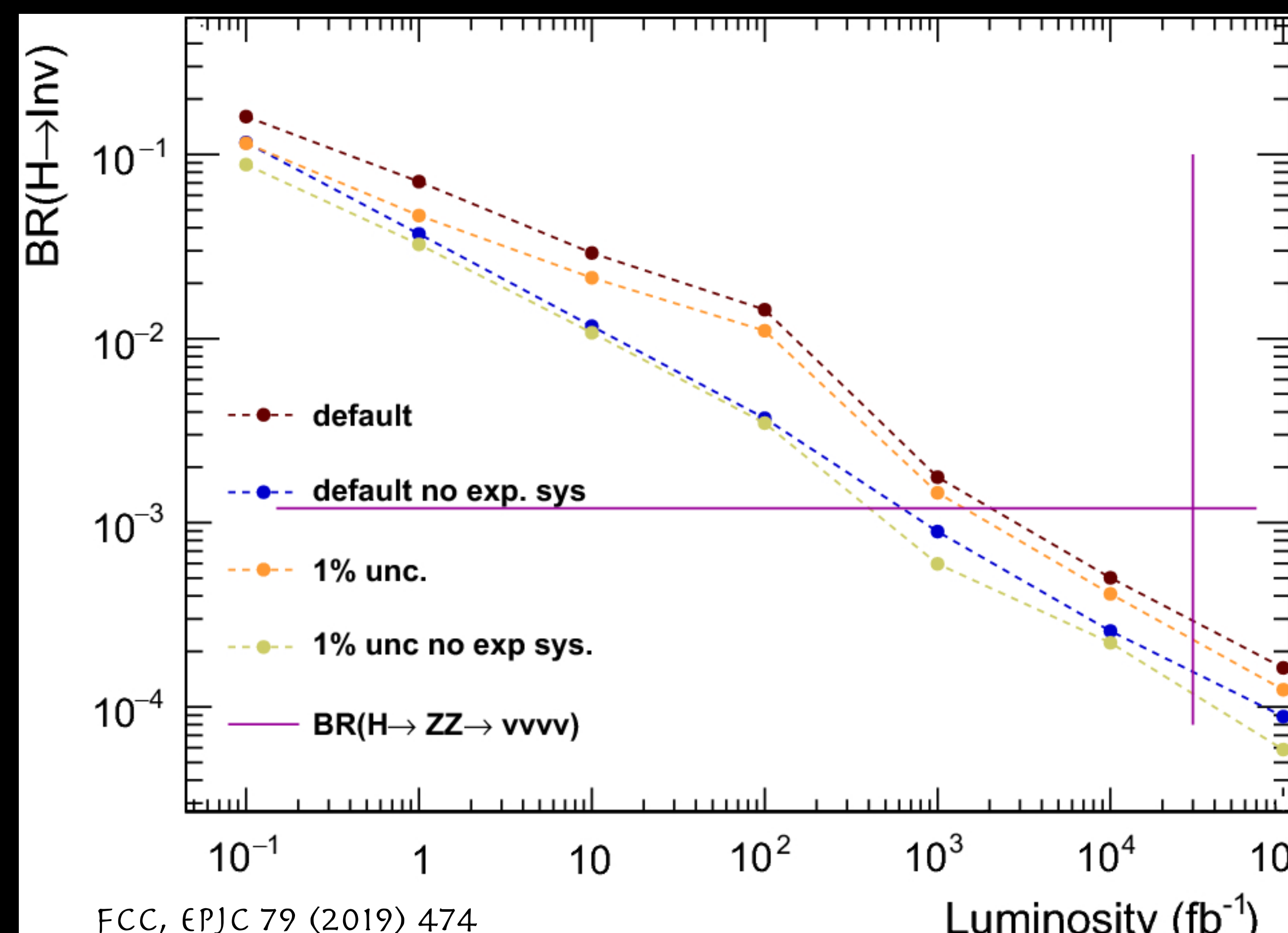
Dark Matter



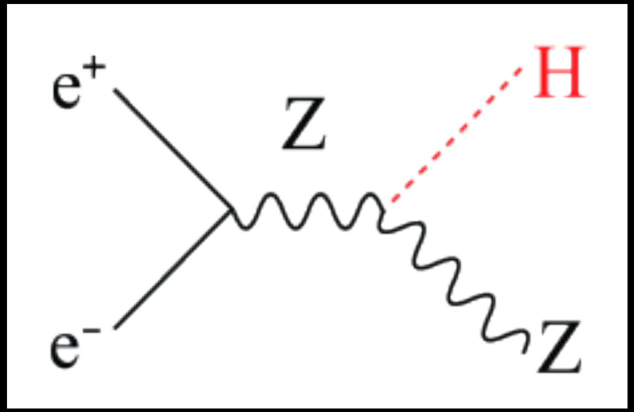
Invisible Higgs decays



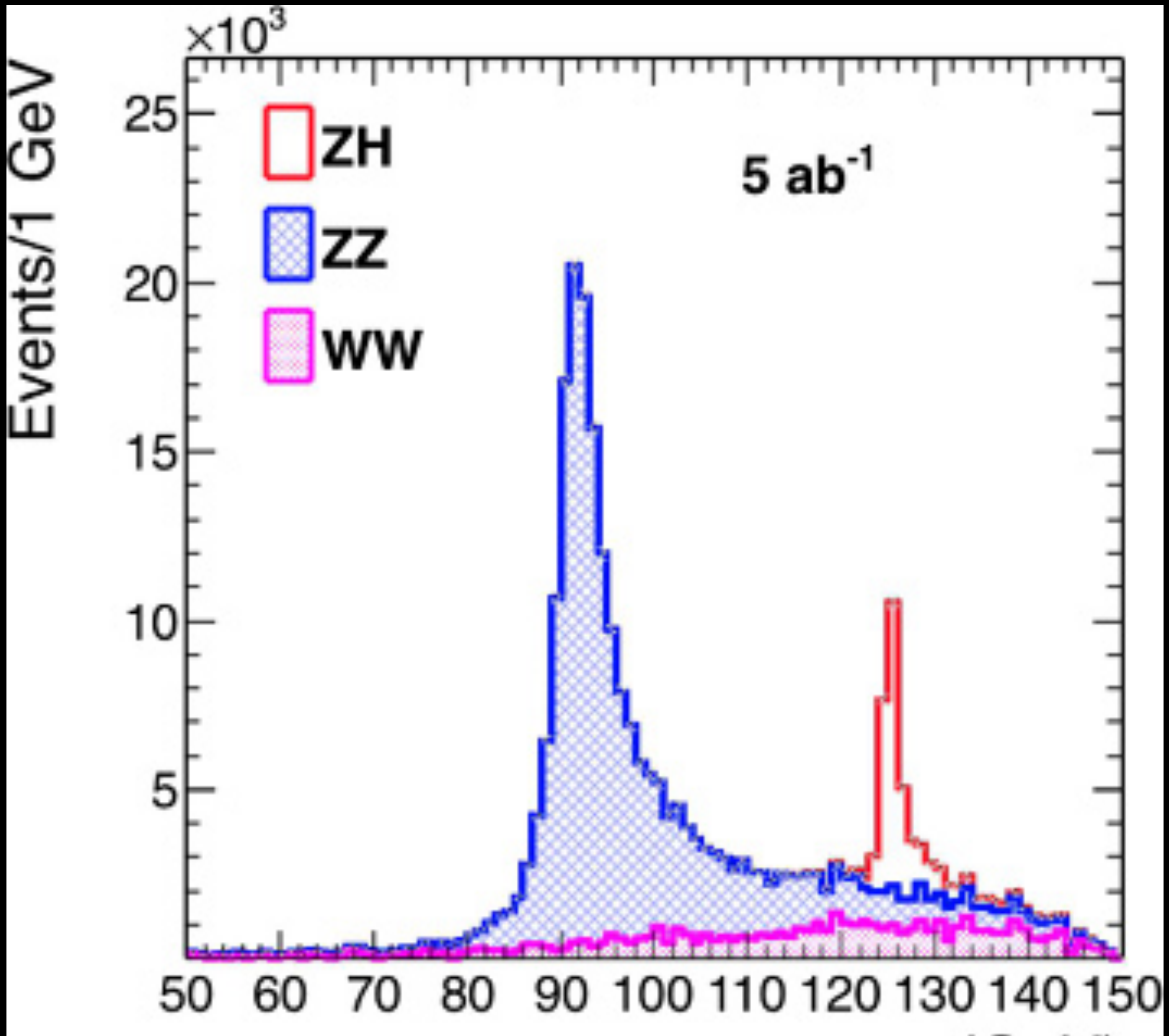




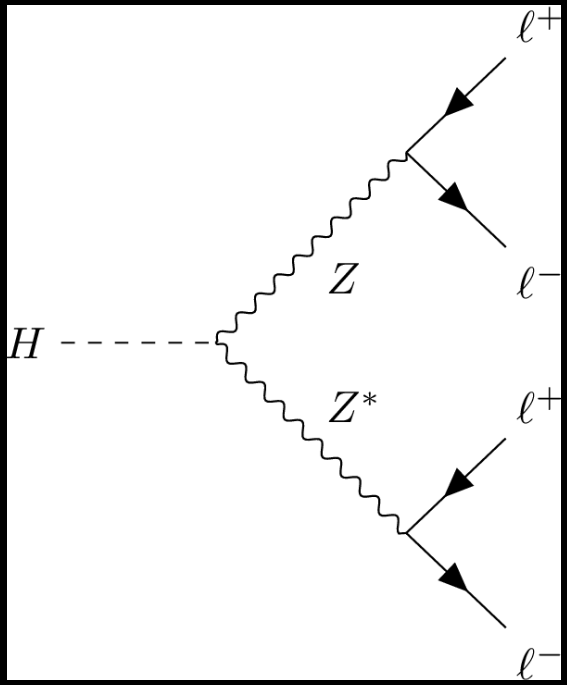
Invisible Higgs decays



BR(H→inv) <0.3% at 240 GeV e+e-

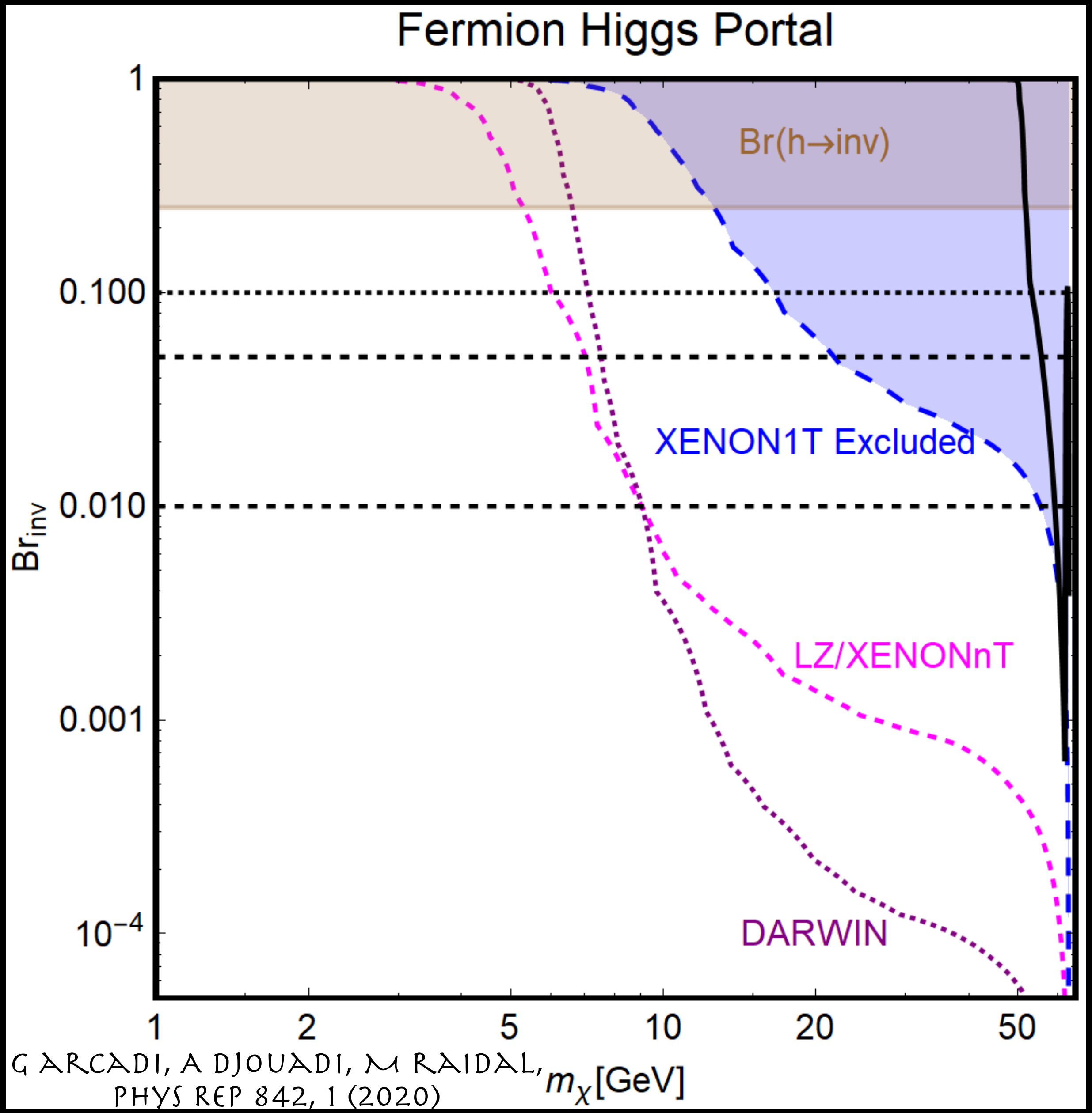


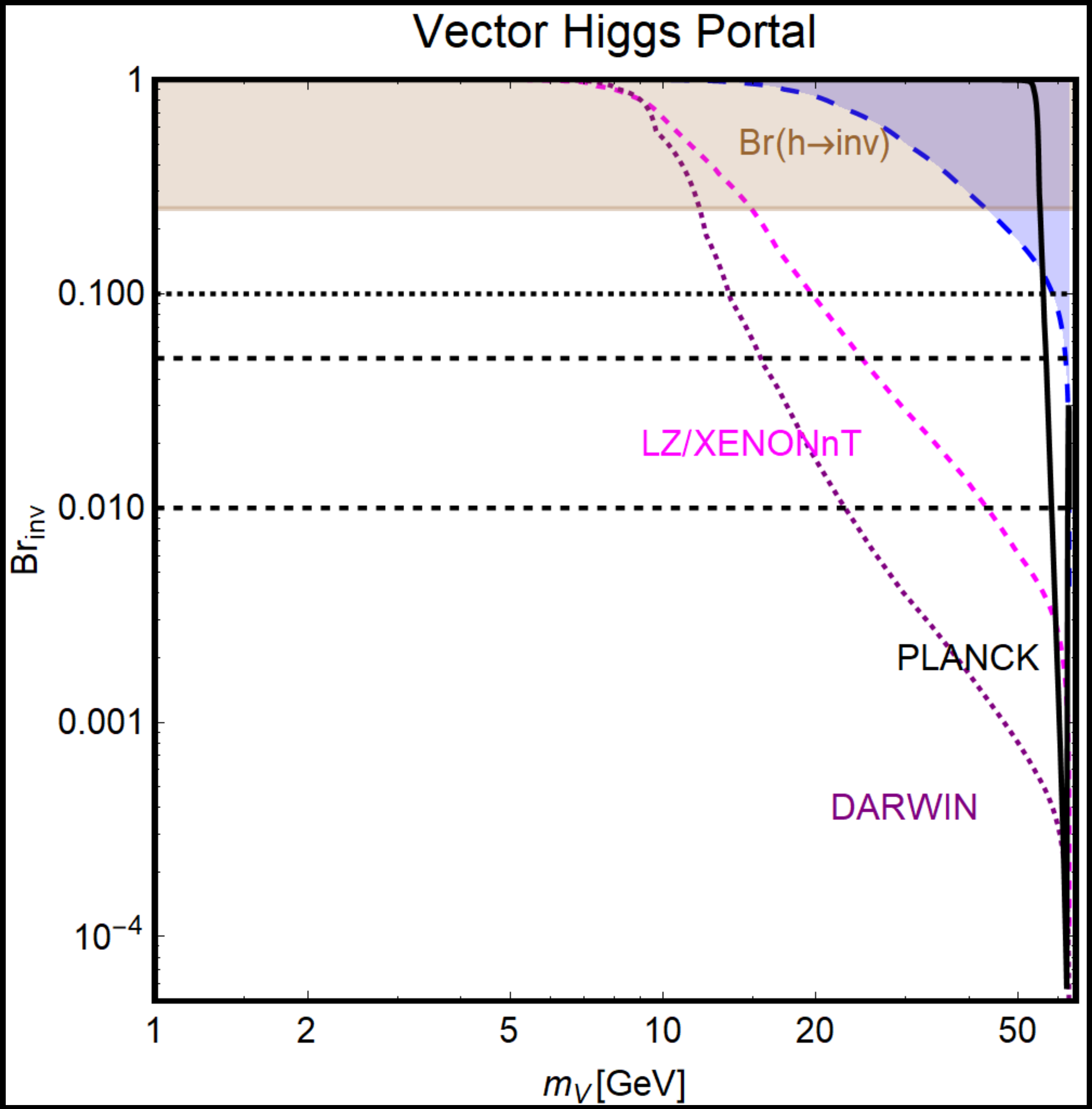
FCC, EPJC 79 (2019) 474



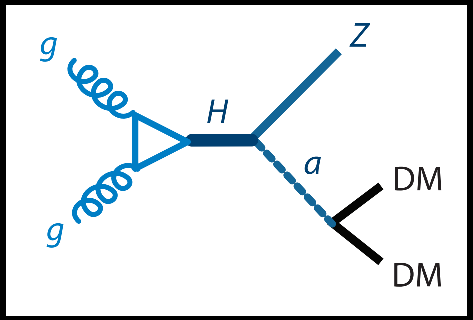
Total cross section + H→ZZ measurements determine total width to 1%

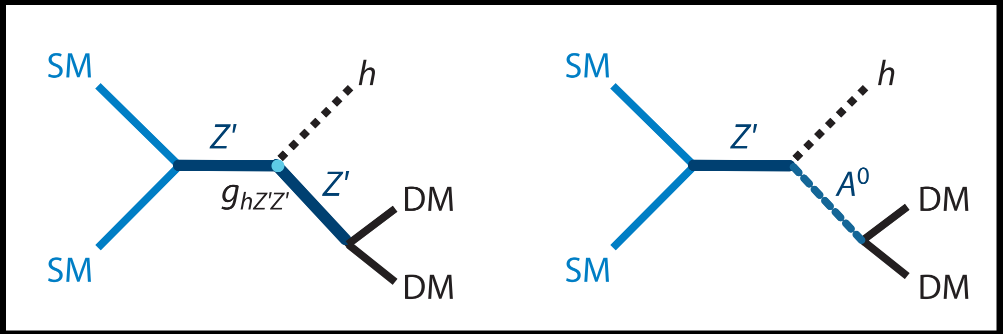
INVISIBLE HIGGS DECAYS

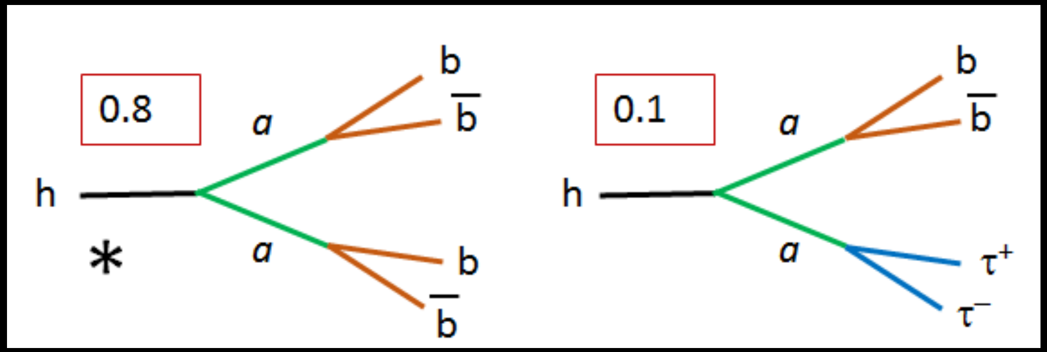


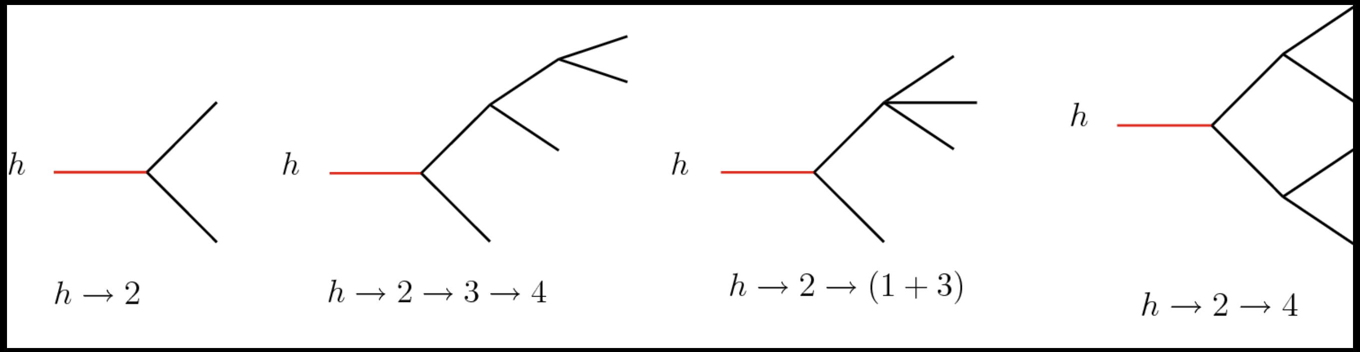


Extended Dark Sector

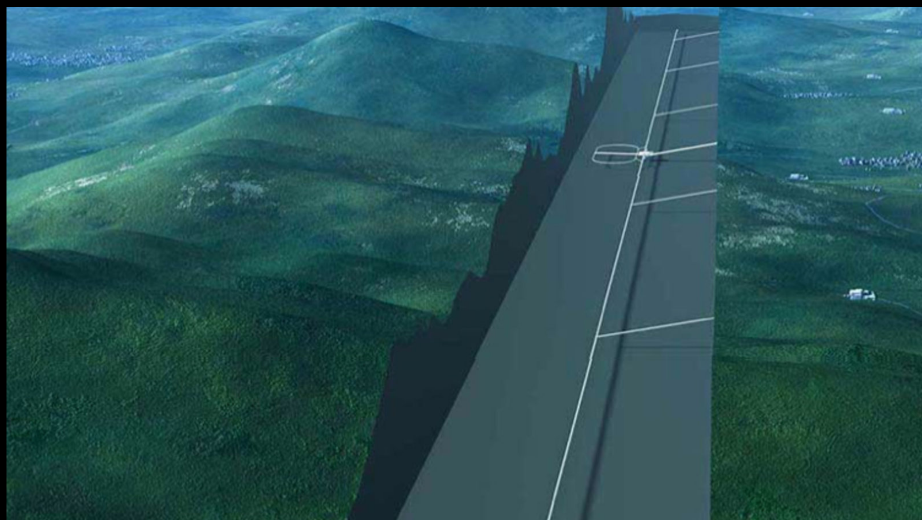




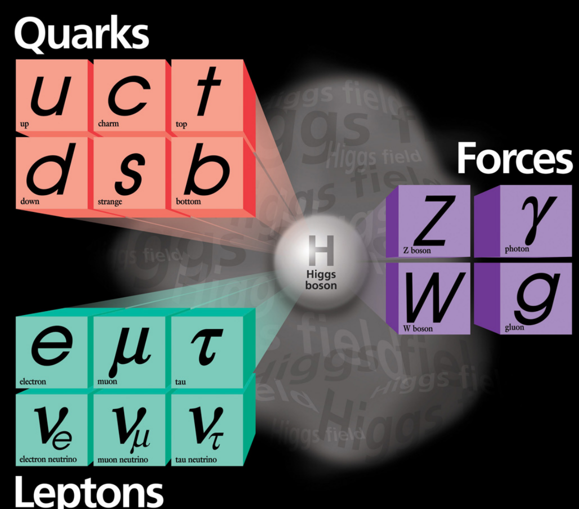


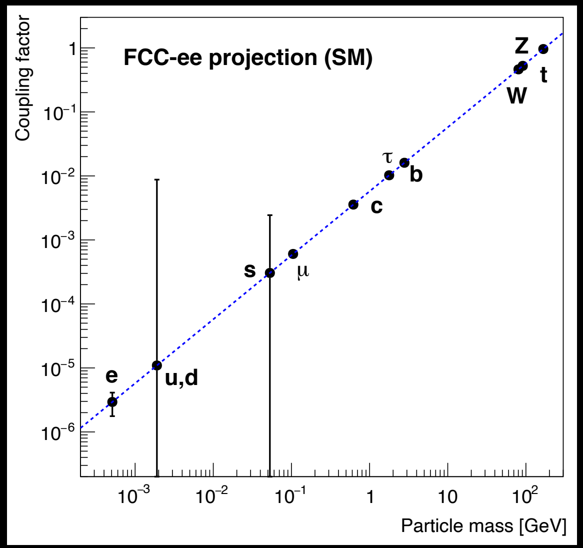


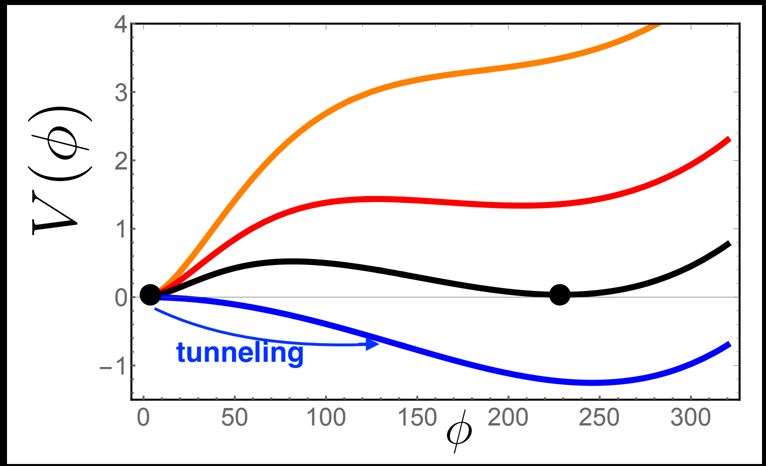
SUMMARY

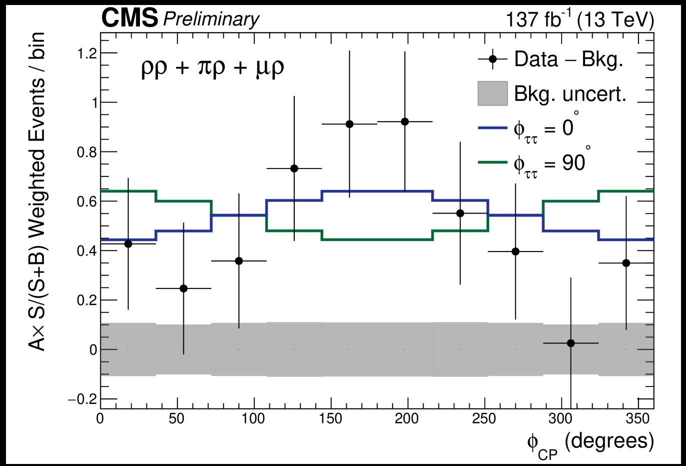


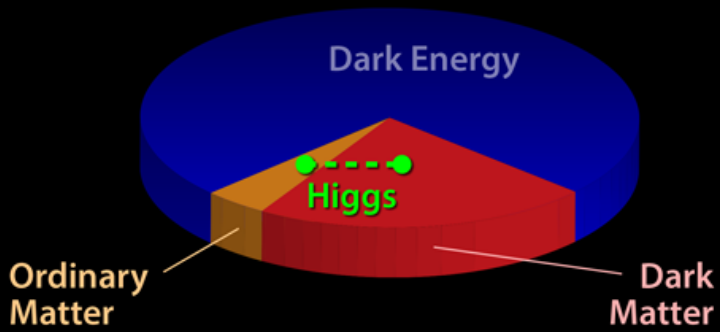

高能所
抚宁县
秦皇岛市
Google earth


Quarks
u
c
t
d
s
b
Forces
Z
γ
W
g
H
Higgs boson
e
μ
τ
νe
νμ
ντ
Leptons

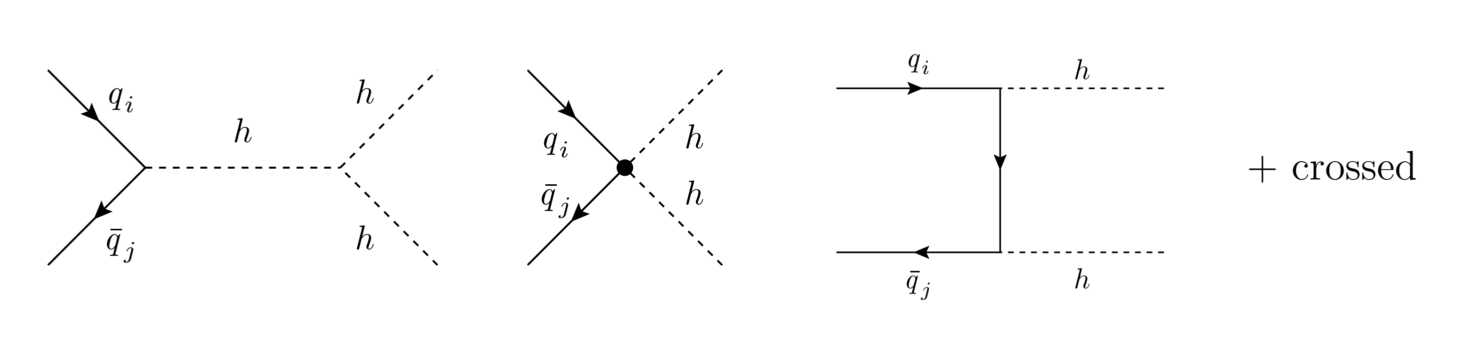

FCC-ee projection (SM)
Coupling factor
Particle mass [GeV]
e
u,d
s
μ
c
τ
b
W
Z
t

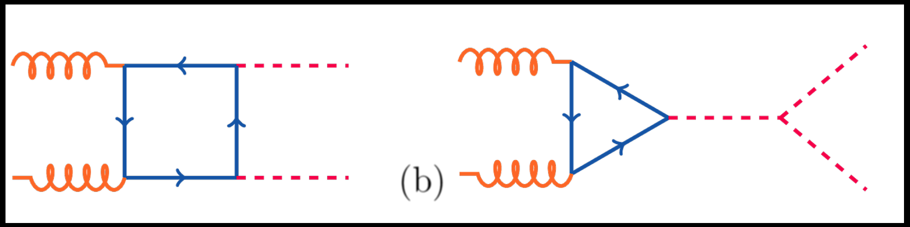

V(φ)
φ
tunneling

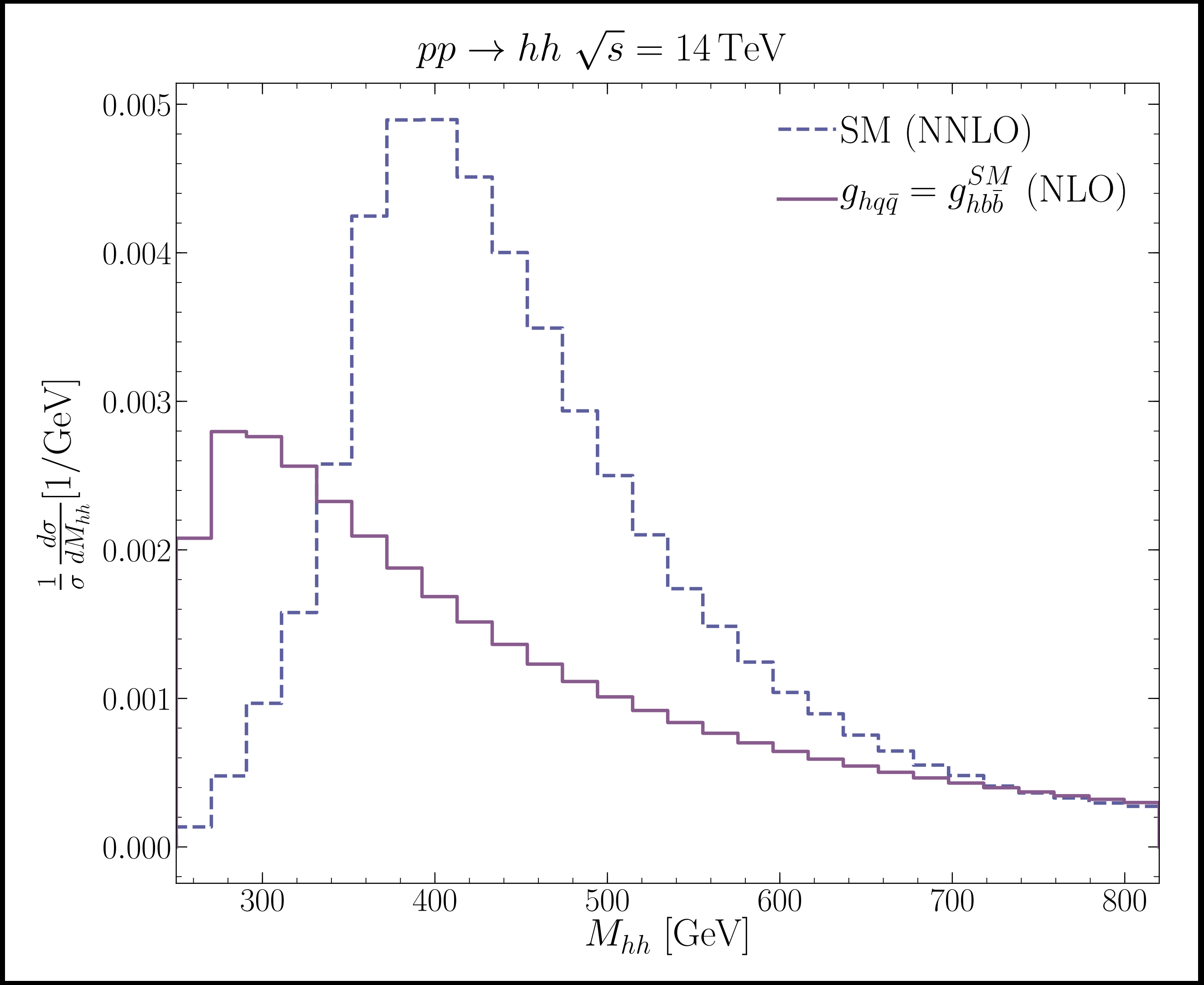

CMS Preliminary
137 fb-1 (13 TeV)
ρρ + πρ + μρ
Data – Bkg.
Bkg. uncert.
φττ = 0°
φττ = 90°
A× S/(S+B) Weighted Events / bin
φCP (degrees)

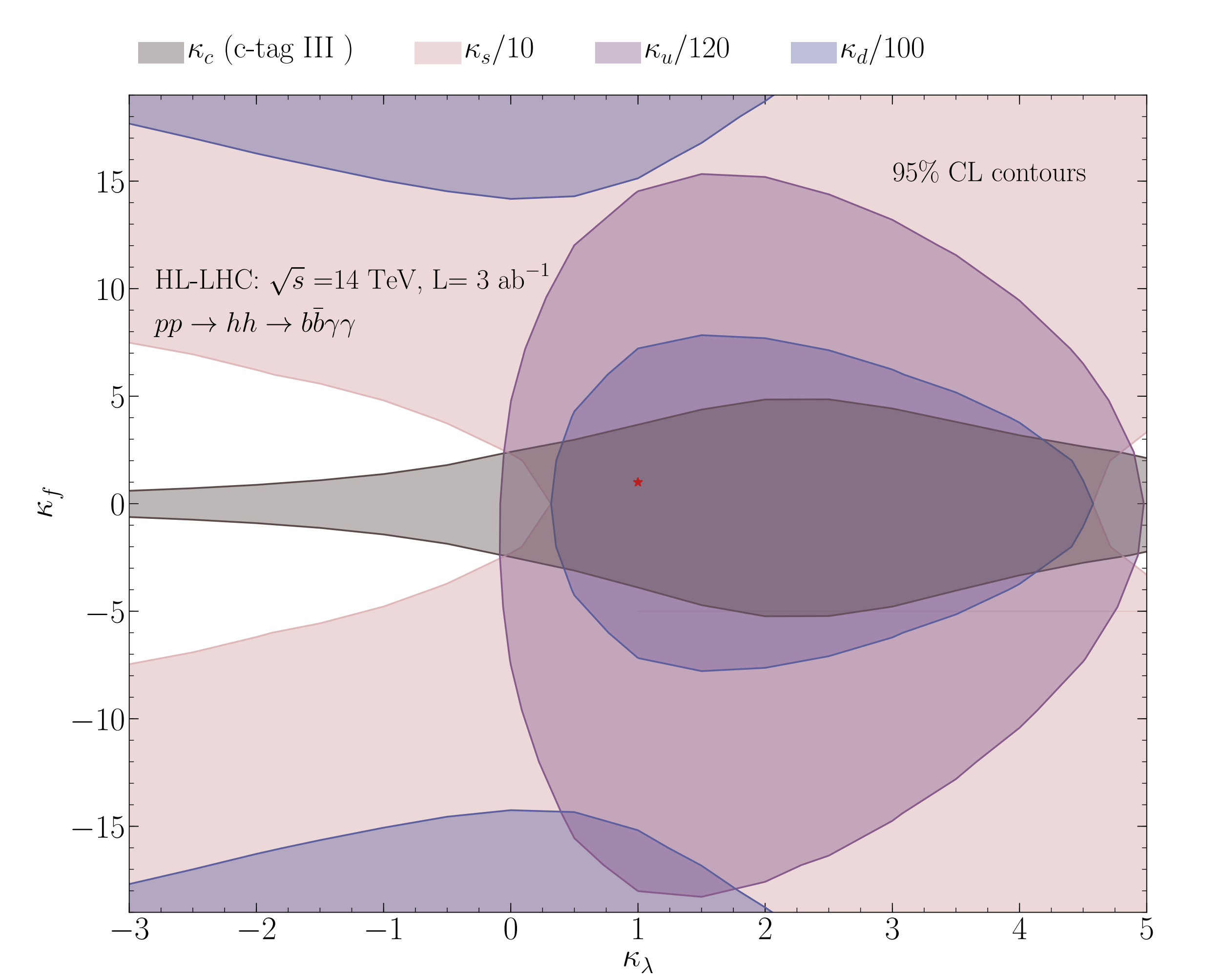

Dark Energy
Higgs
Ordinary Matter
Dark Matter

HIGGS COUPLINGS TO THE FIRST GENERATION



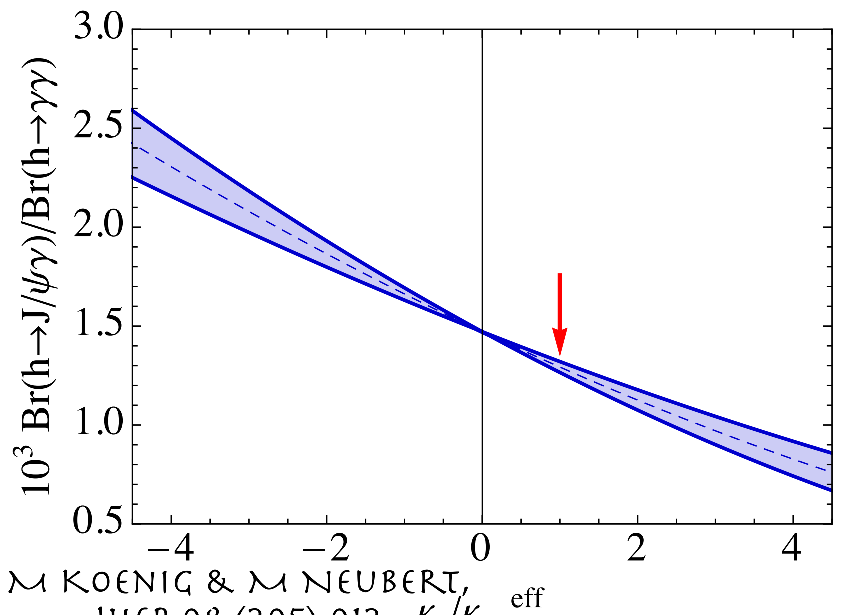




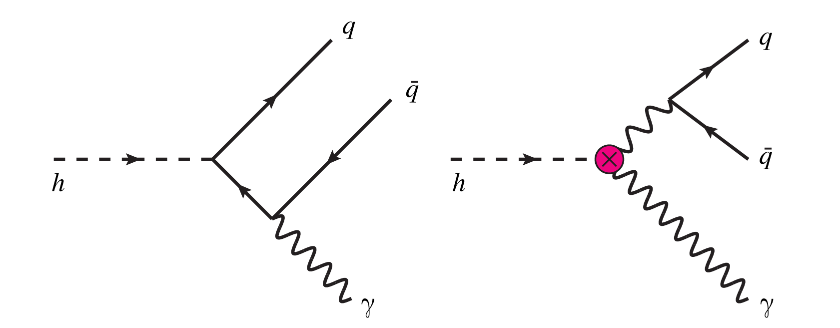


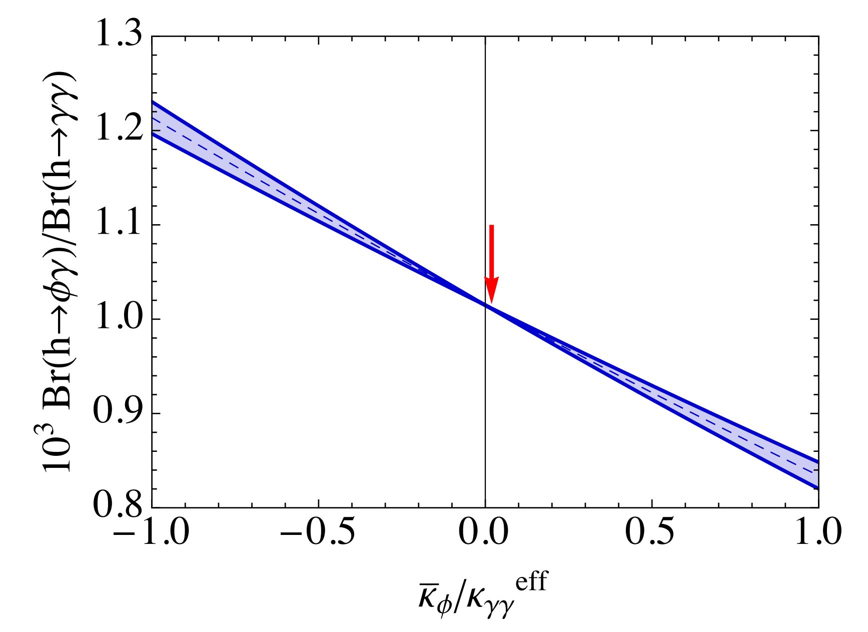
L Alasfar, R C Lopez, R Groeber, JHEP 11 (2019) 088

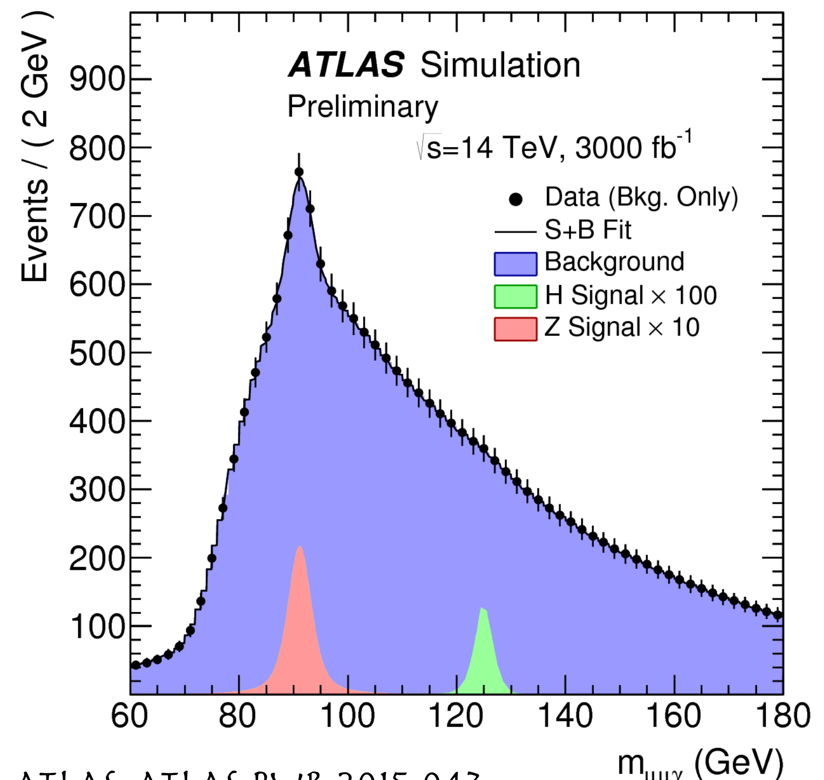
Higgs couplings to the second generation



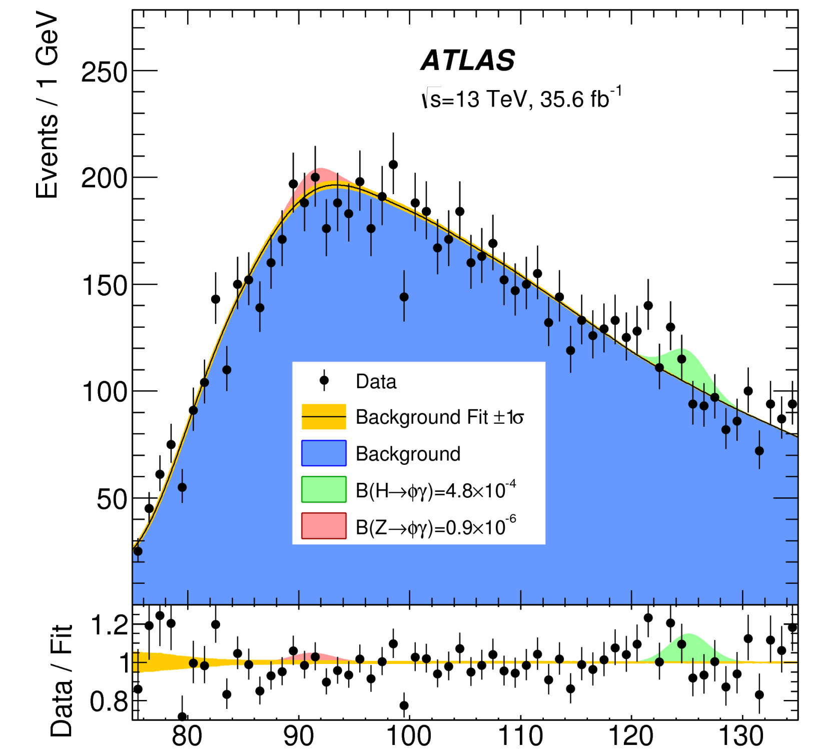
M Koenig & M Neubert, JHEP 08 (205) 012





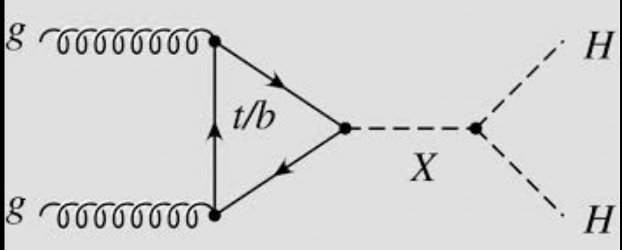


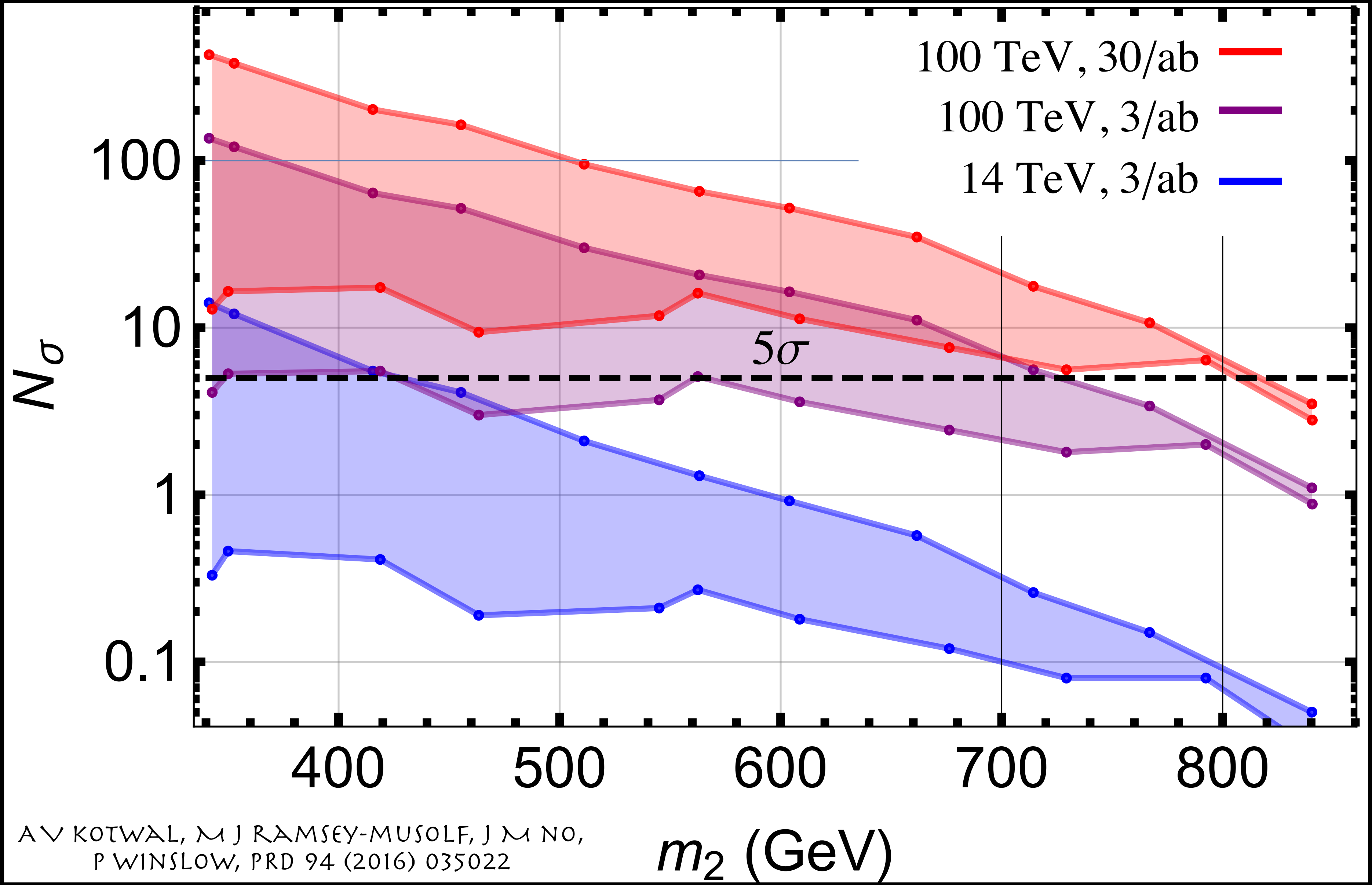
ATLAS, ATLAS-PUB-2015-043



ATLAS, JHEP 07 (2018) 127

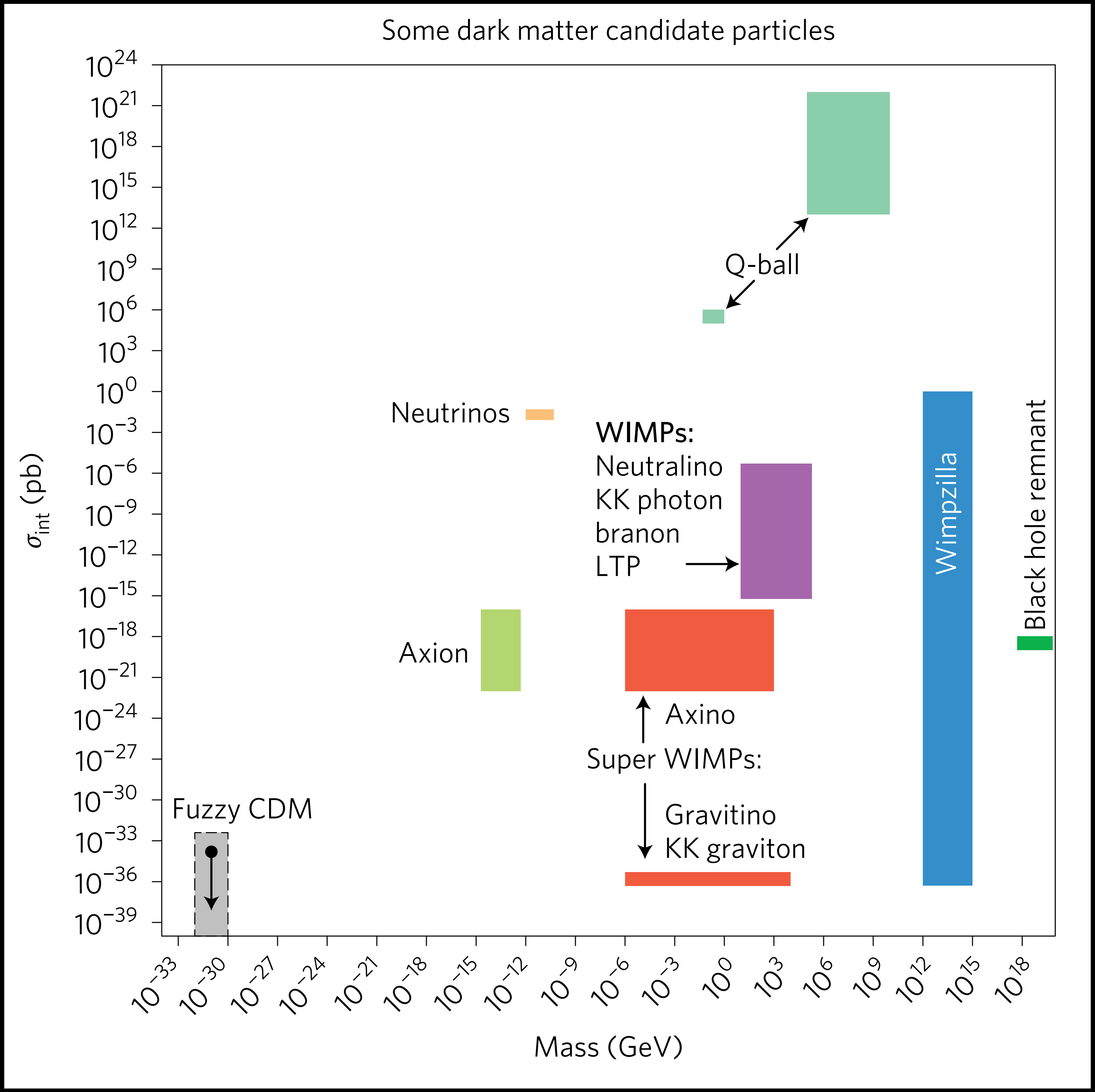
Electroweak Phase Transition



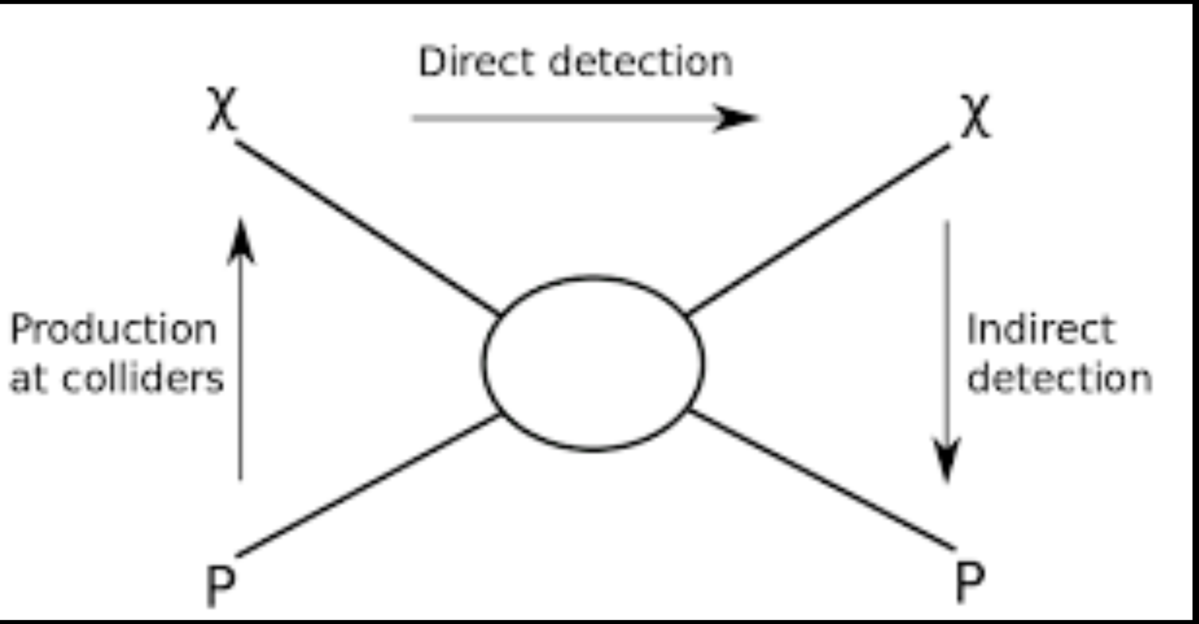


A V Kotwal, M J Ramsey-Musolf, J M No,
P Winslow, PRD 94 (2016) 035022

Dark Matter

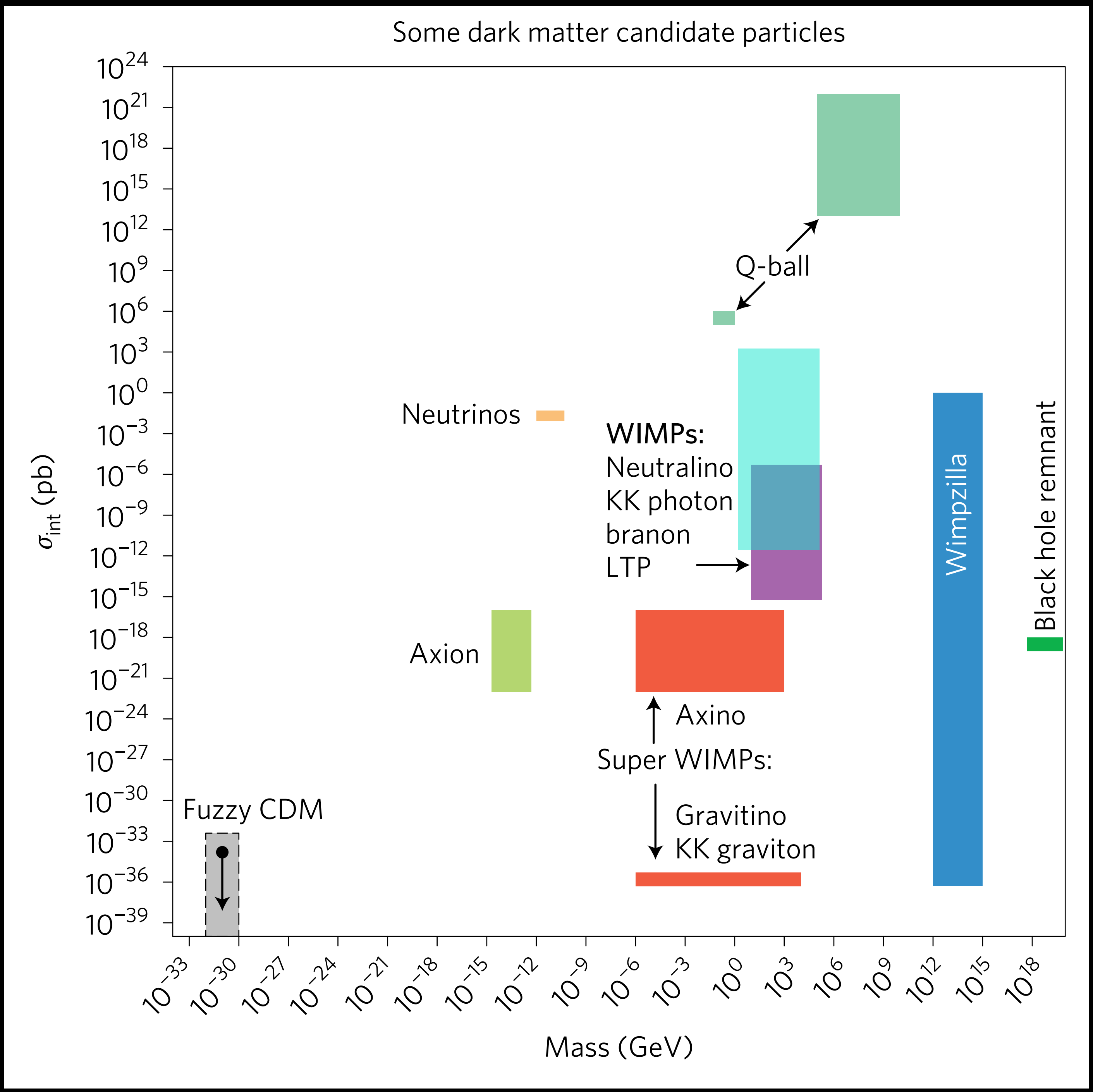


Some dark matter candidate particles
σ_{int} (pb)
Mass (GeV)
Q-ball
Neutrinos
WIMPs:
Neutralino
KK photon
branon
LTP
Axion
Axino
Super WIMPs:
Gravitino
KK graviton
Fuzzy CDM
Wimpzilla
Black hole remnant

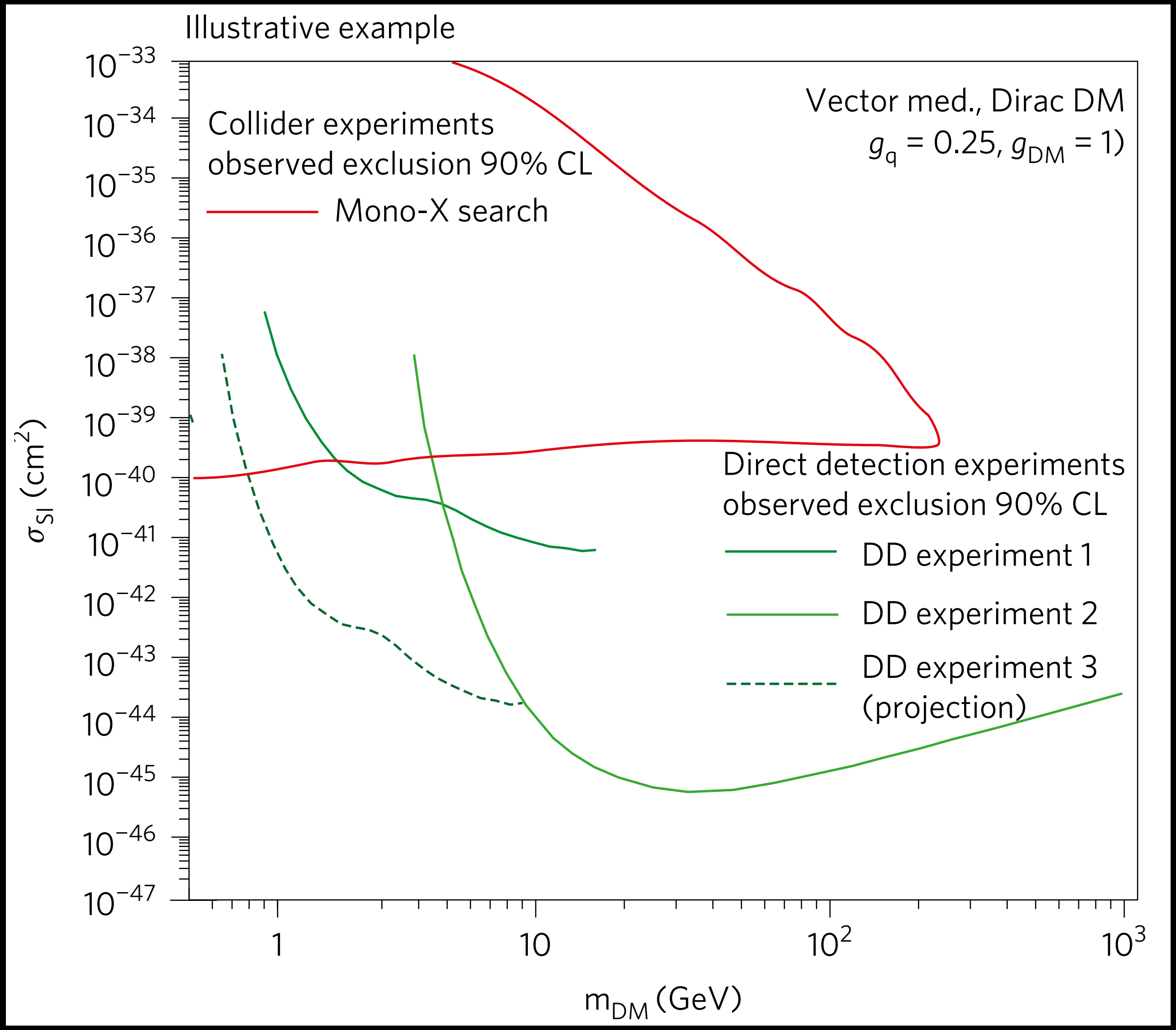


Direct detection
χ
χ
Production
at colliders
Indirect
detection
P
P

DARK MATTER

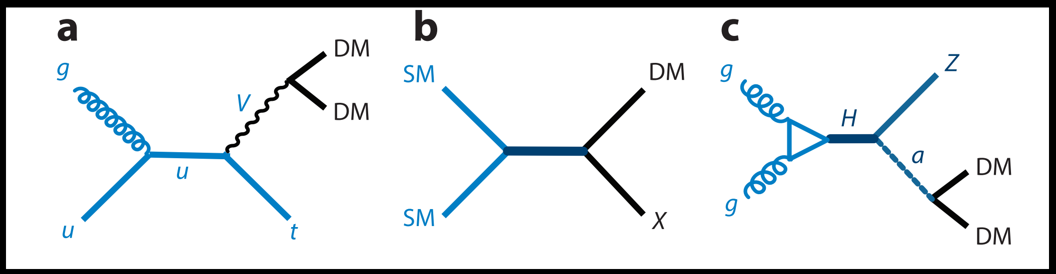


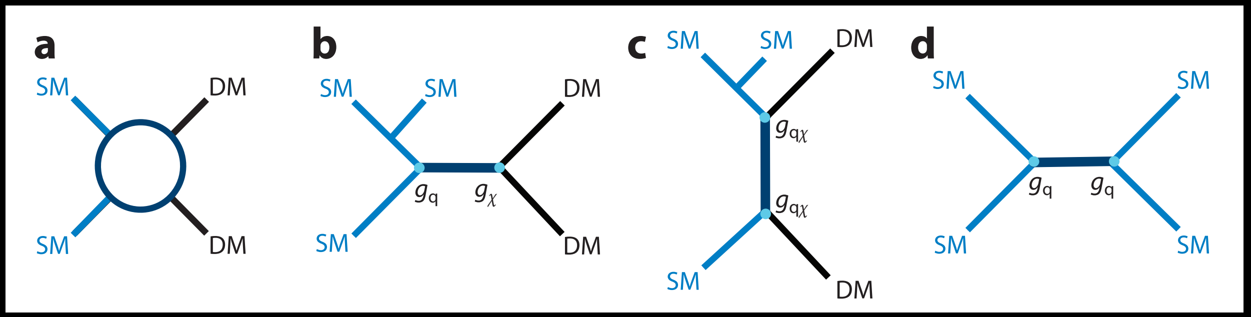
Some dark matter candidate particles
σ_{int} (pb)
Mass (GeV)
Q-ball
Neutrinos
WIMPs:
Neutralino
KK photon
branon
LTP
Wimpzilla
Black hole remnant
Axion
Axino
Super WIMPs:
Gravitino
KK graviton
Fuzzy CDM

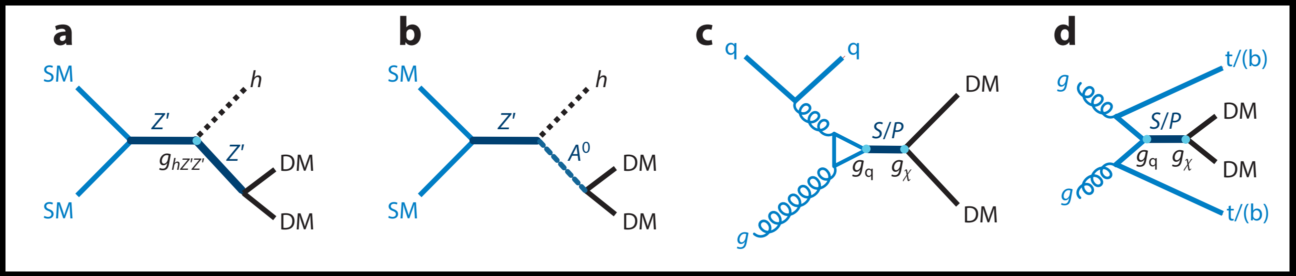


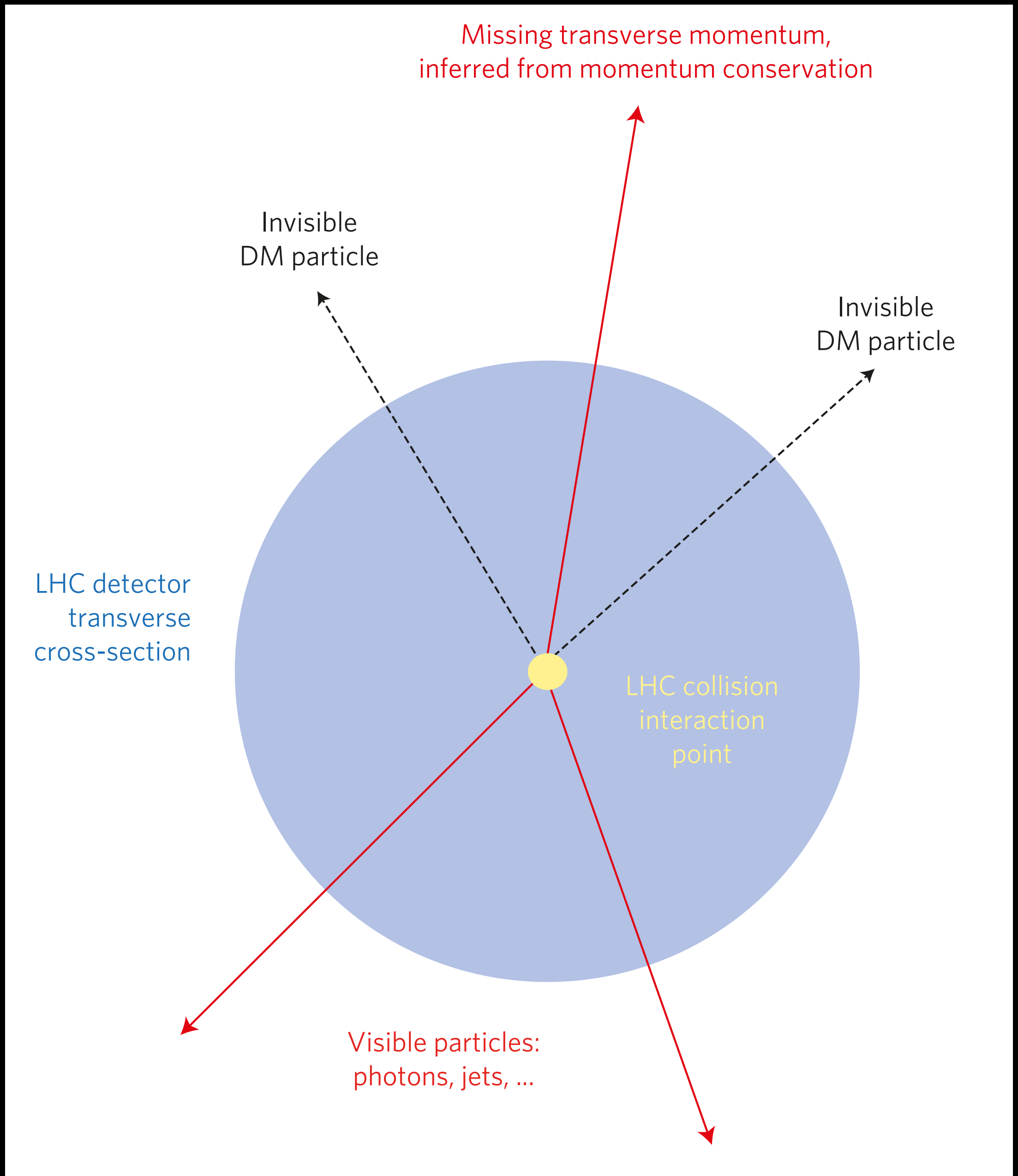
Illustrative example
Collider experiments
observed exclusion 90% CL
Mono-X search
Vector med., Dirac DM
$g_q = 0.25, g_{DM} = 1$)
Direct detection experiments
observed exclusion 90% CL
DD experiment 1
DD experiment 2
DD experiment 3
(projection)
σ_{SI} (cm^2)
m_{DM} (GeV)

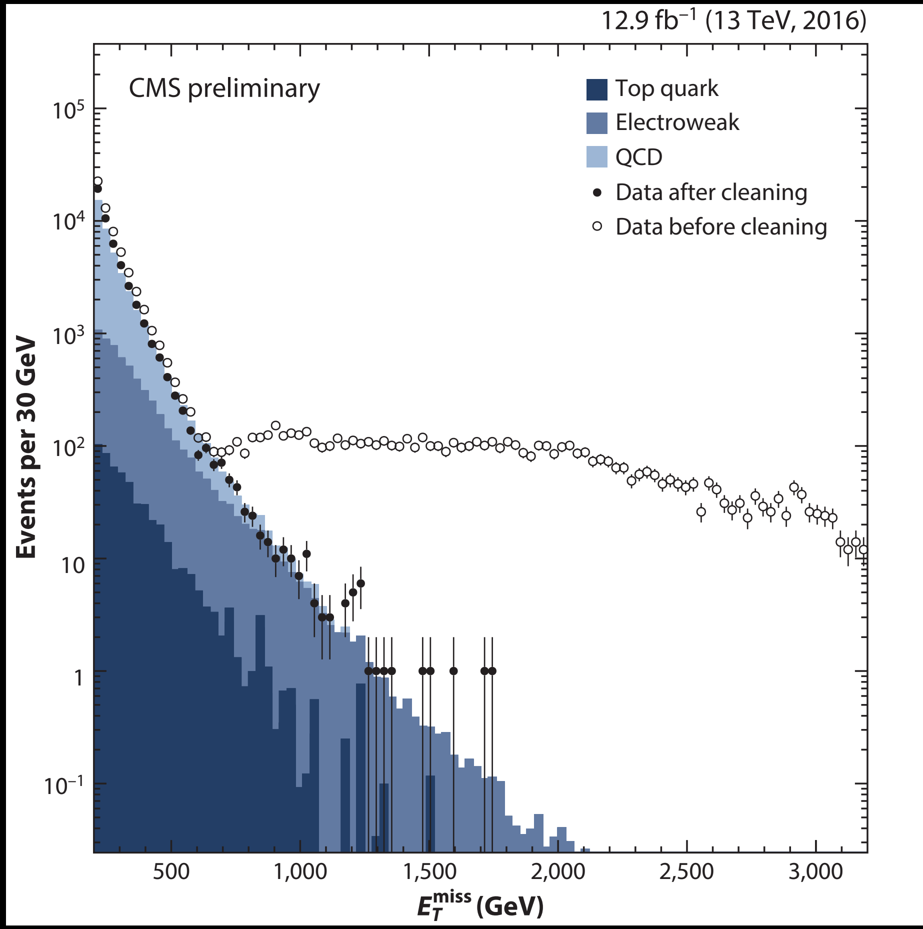
DARK MATTER


a
b
c
DM
DM
SM
SM
X
Z
DM
DM

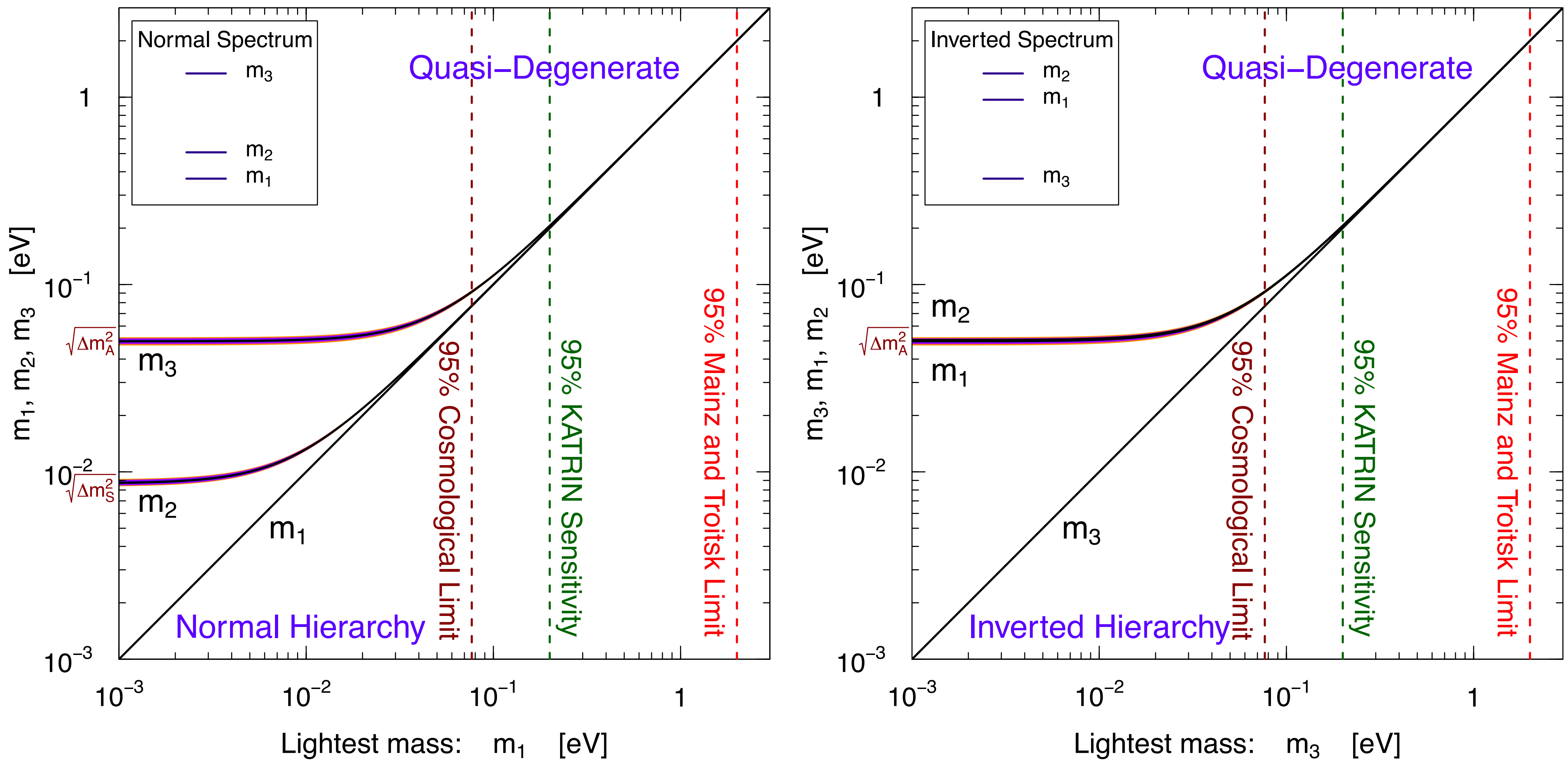

a
b
c
d
SM
DM


a
b
c
d
SM
DM
t/(b)


Missing transverse momentum,
inferred from momentum conservation
Invisible
DM particle
Invisible
DM particle
LHC detector
transverse
cross-section
LHC collision
interaction
point
Visible particles:
photons, jets, ...

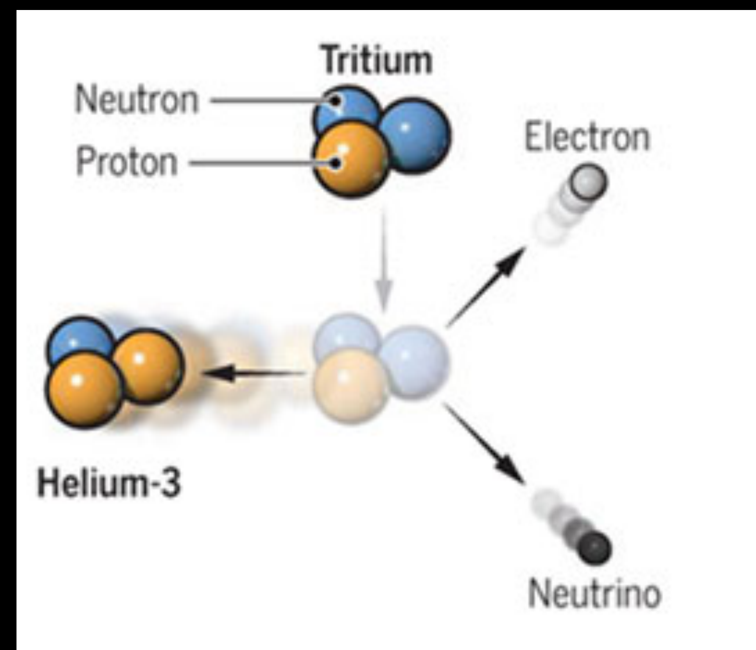

12.9 fb^{-1} (13 TeV, 2016)
CMS preliminary
Top quark
Electroweak
QCD
Data after cleaning
Data before cleaning
Events per 30 GeV
E_T^{miss} (GeV)

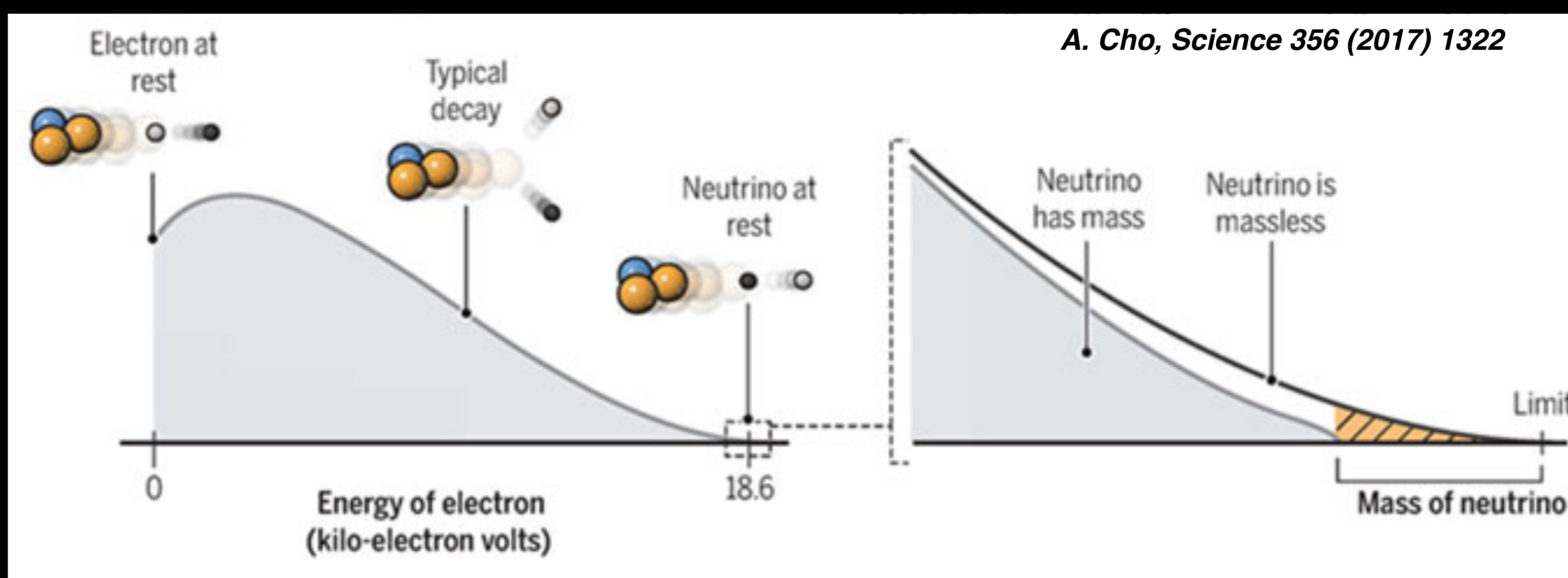
Neutrino Mass



S. M. Bilenky & C. Giunti, Int. Jour. Mod. Phys. A 30 (2015) 1530001

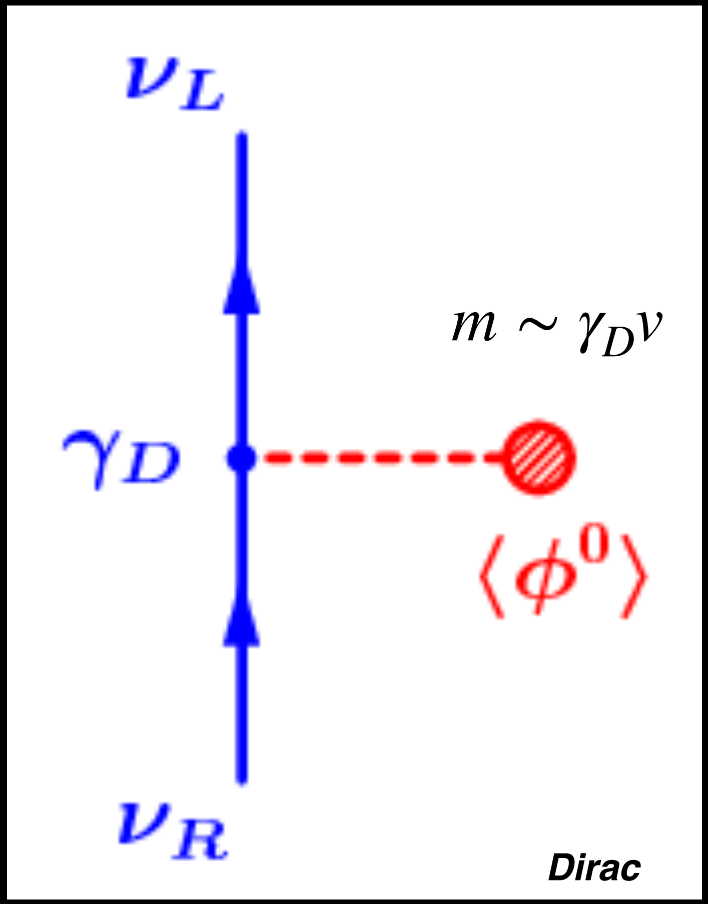
Neutrino Mass

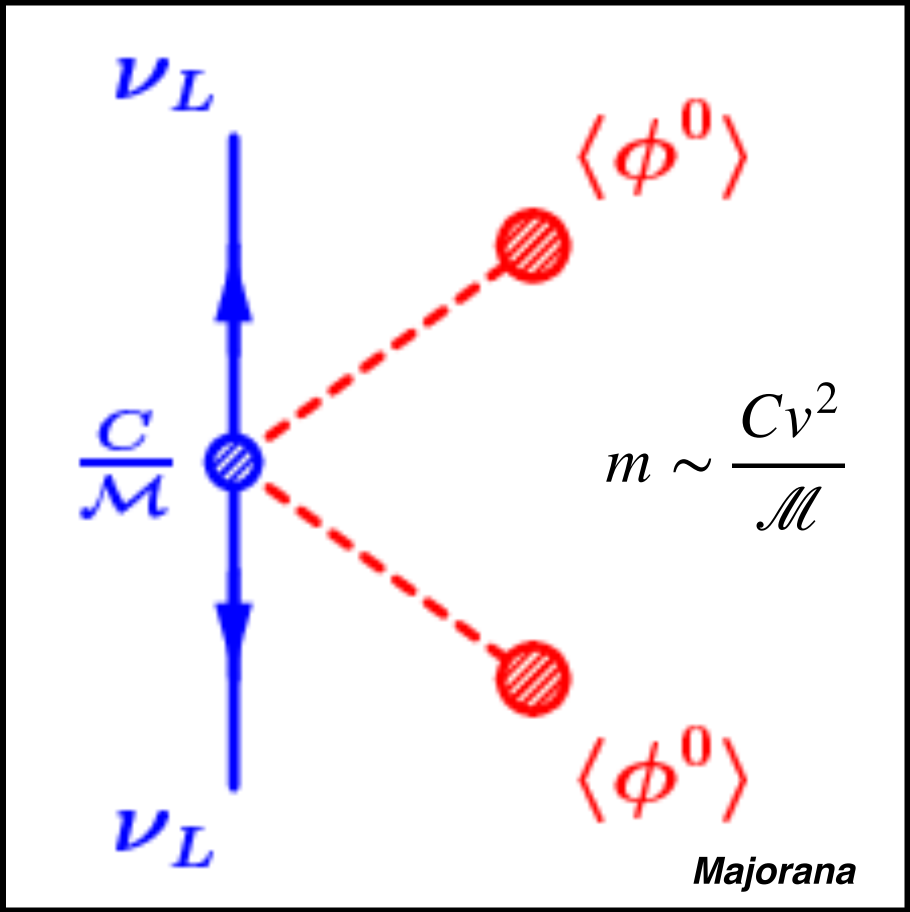




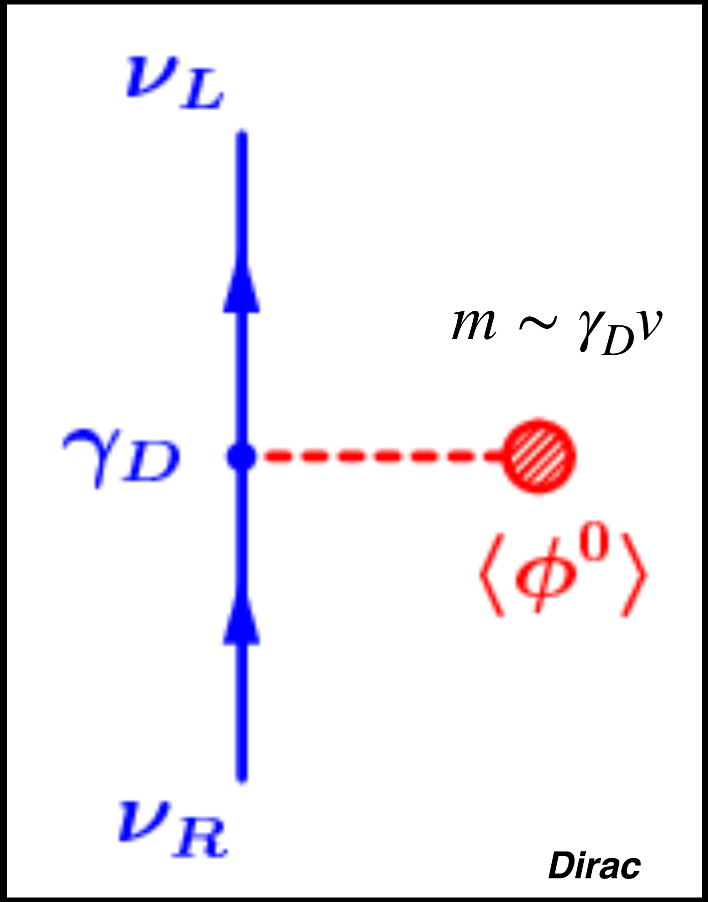
A. Cho, Science 356 (2017) 1322

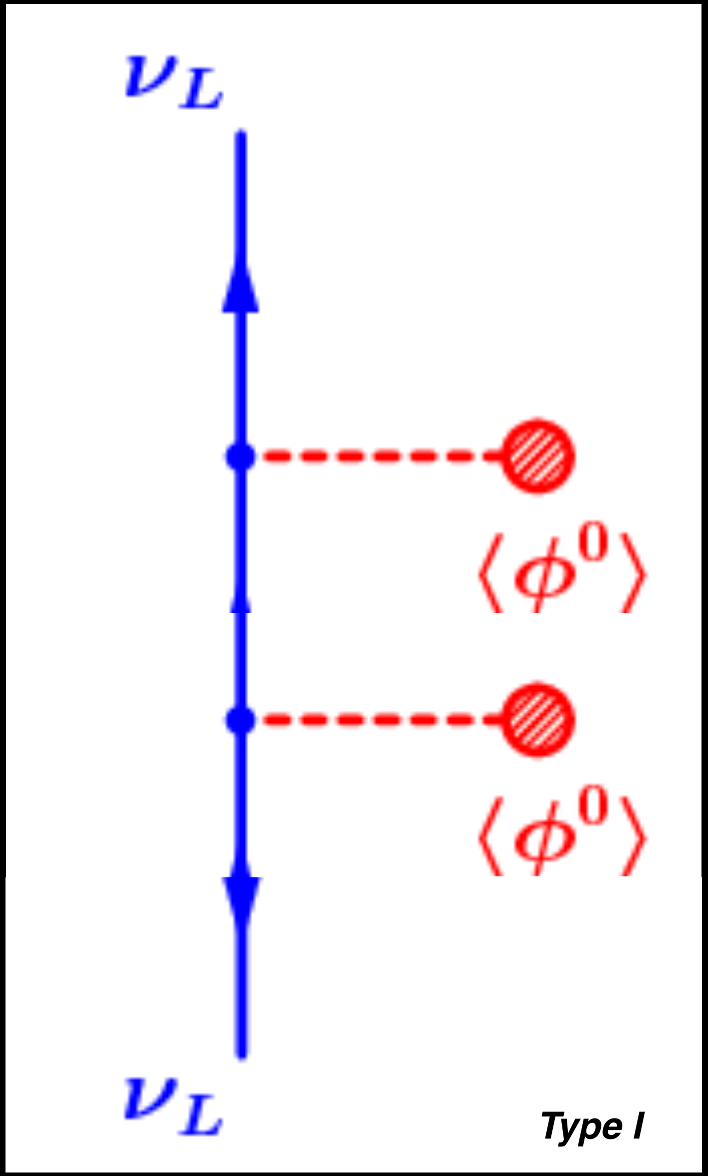
Neutrino Mass



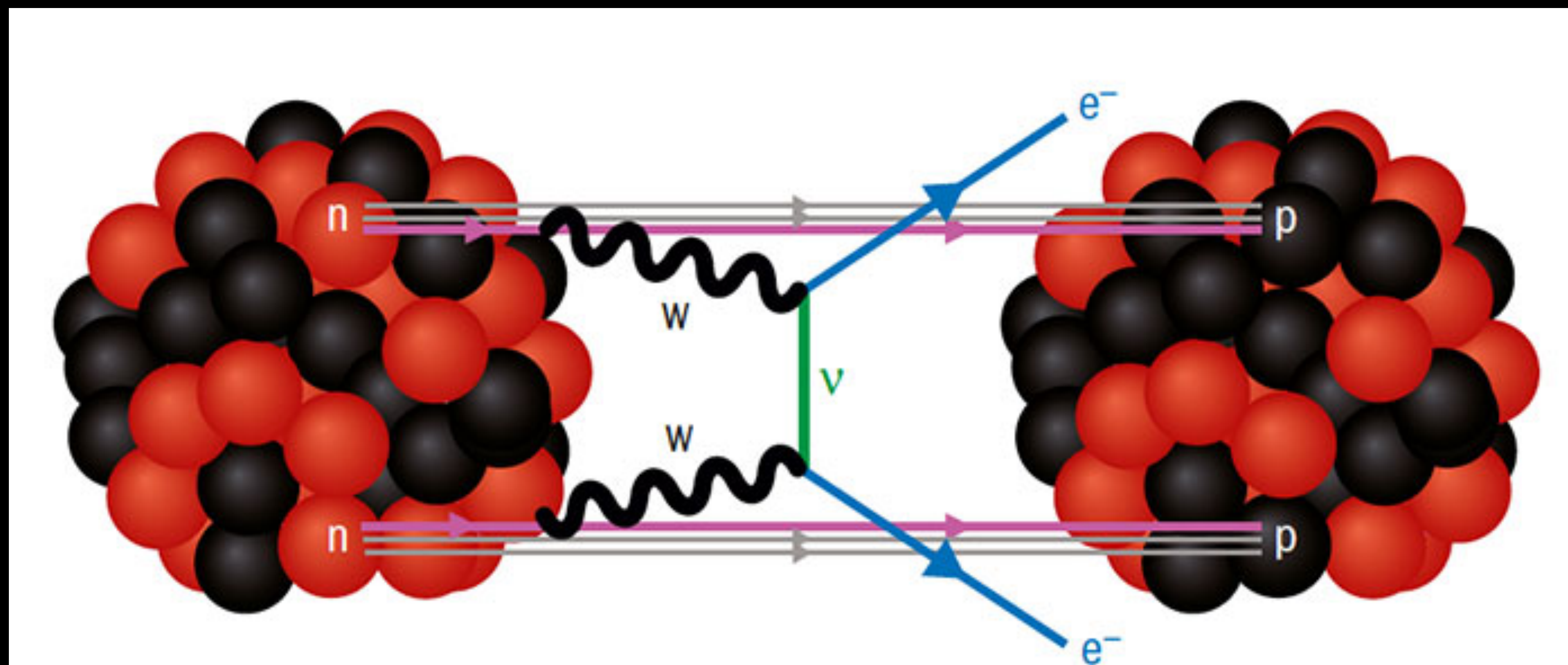


Neutrino Mass





Neutrinoless Double Beta Decay

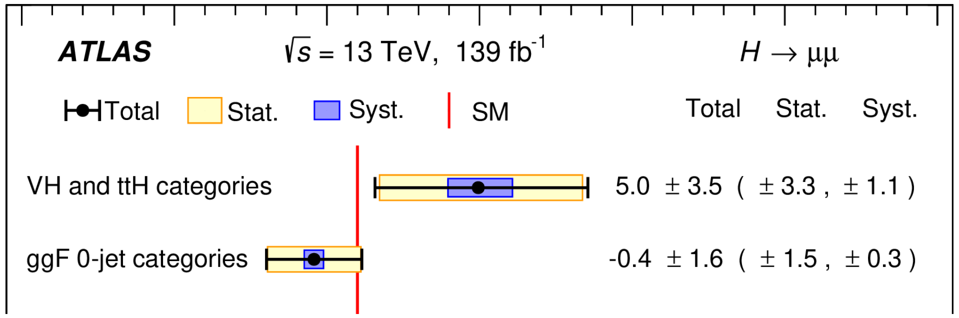


S. Pascoli, CERN Courier, July 8 2016

$$|m_{\beta\beta}| = |c_{13}^2 c_{12}^2 e^{2i\alpha_1} m_1 + c_{13}^2 s_{12}^2 e^{2i\alpha_2} m_2 + s_{13}^2 m_3|$$

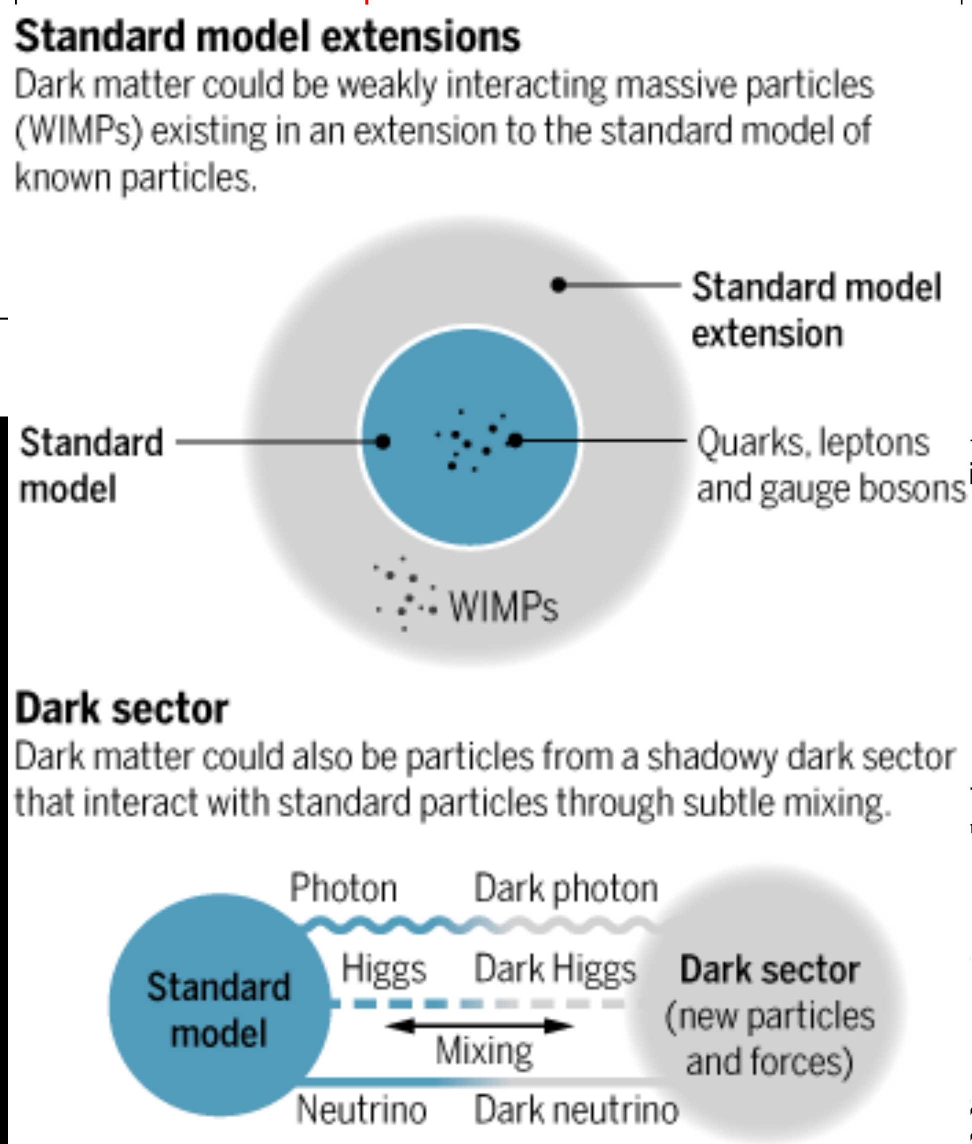
Decay rate ~ $|\nu_e$ effective mass$|^2$ × |nuclear matrix element$|^2$ × phase space

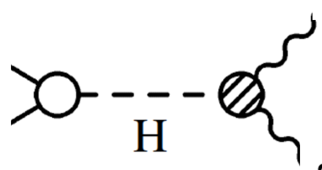
~ 1 / 10^{27} yr (!)

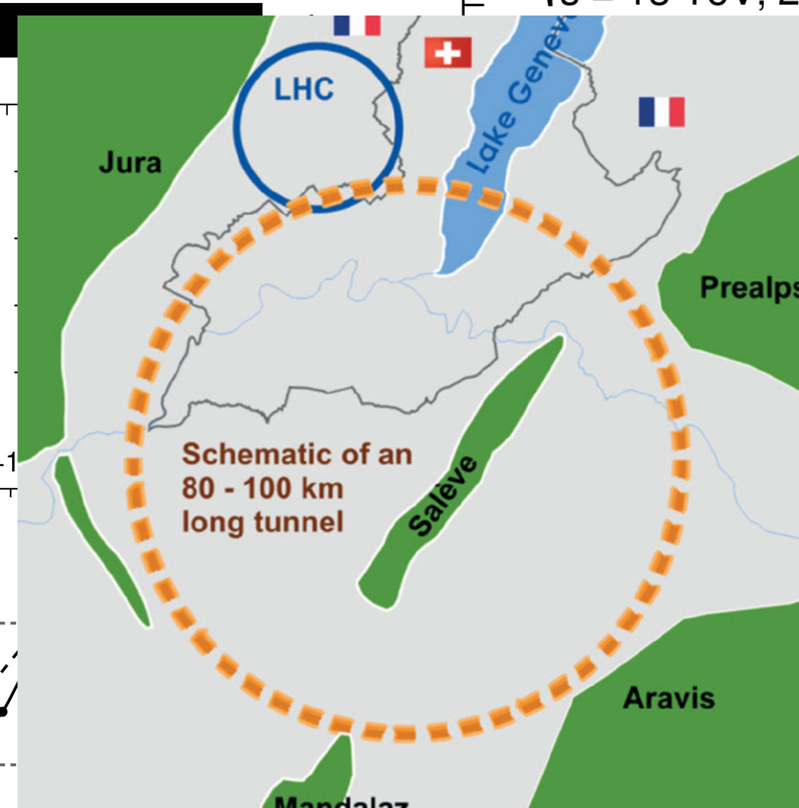


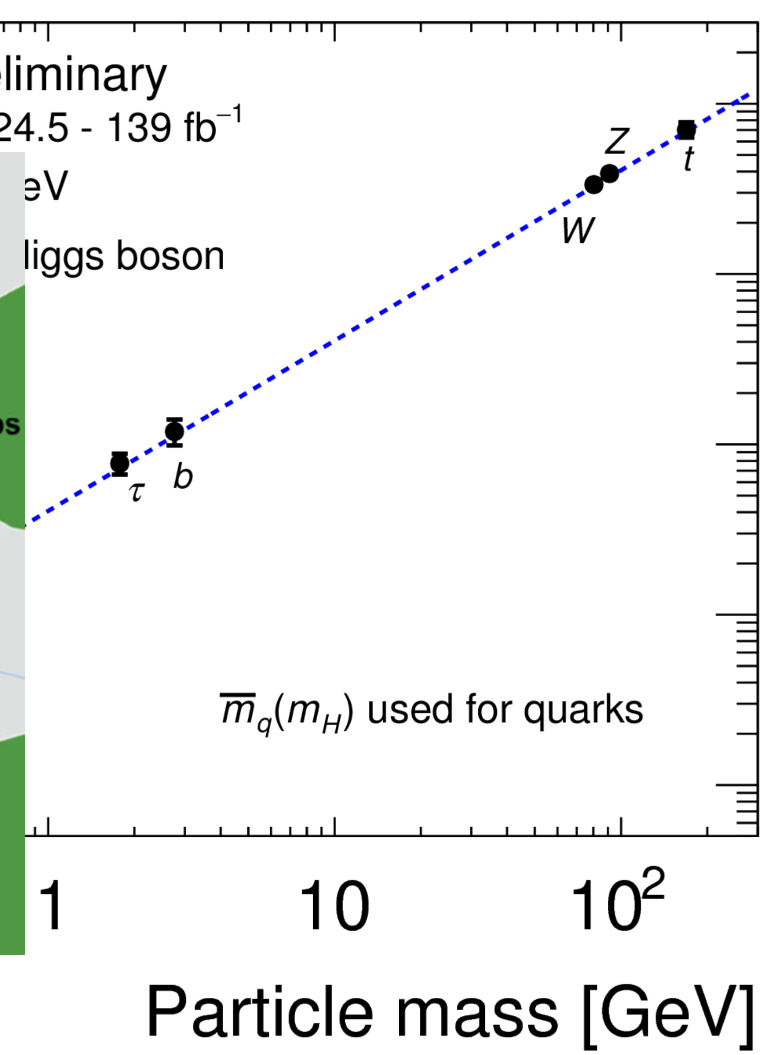
Expected 1D constraints on Wilson coefficients for each EFT operator, in units of TeV^{-2}, after marginalising over all other coefficients.

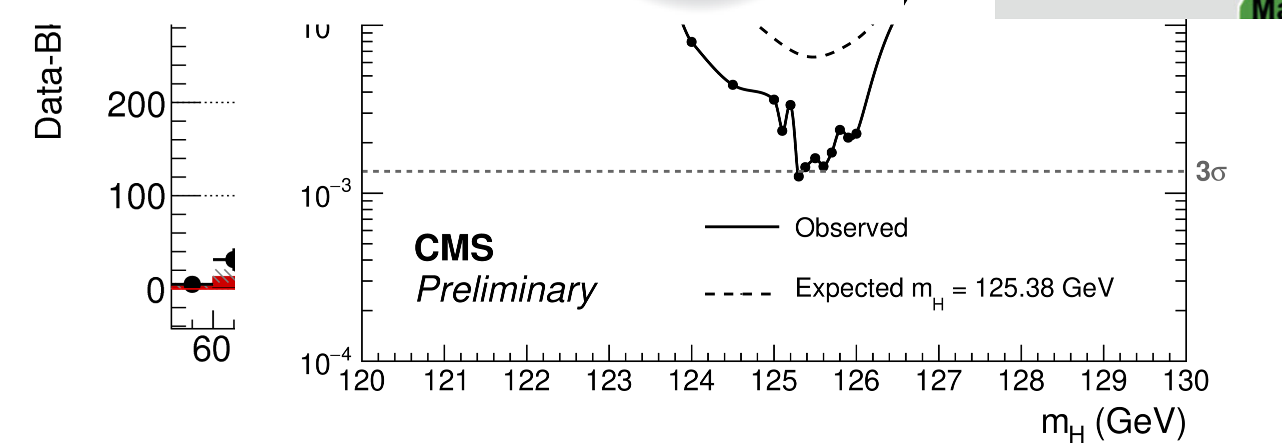
Coefficient [TeV^{-2}]	36.1 fb^{-1}	300 fb^{-1}	3000 fb^{-1}
$c_{H\tilde{G}}/\Lambda^2$	[−0.19, 0.19]	[−0.067, 0.067]	[−0.021, 0.021]
$c_{H\tilde{W}}/\Lambda^2$	[−11, 11]	[−3.8, 3.8]	[−1.2, 1.2]
$c_{H\tilde{B}}/\Lambda^2$	[−5.9, 5.9]	[−2.1, 2.1]	[−0.65, 0.65]
$c_{H\tilde{W}B}/\Lambda^2$	[−14, 14]	[−4.9, 4.9]	[−1.5, 1.5]

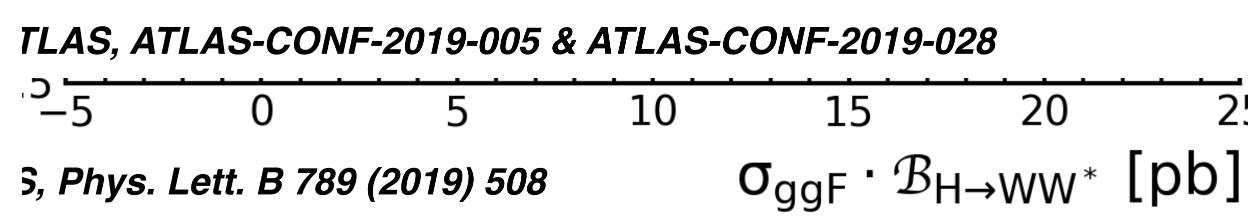






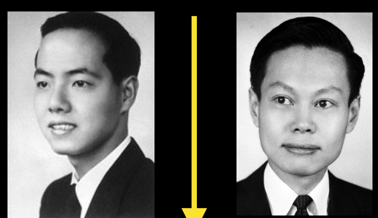






HISTORY

Prediction of parity violation

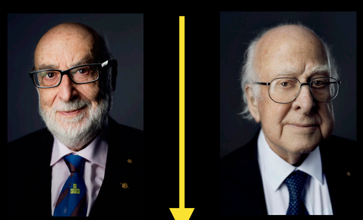


Birth of the SM

W & Z discoveries

top discovery

Higgs discovery



13.79999995 billion years

13.8 billion years