Taller Más allá del Modelo Estándar y Astropartículas

SPACEMATH

Breve introducción de uso para SpaceMath v.2.0

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Tomás Antonio Valencia Pérez

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Contenido

¿Qué es SpaceMath?

La idea

- Una paquetería de Mathematica para la búsqueda del espacio de parámetros más allá del Modelo Estándar.

SpaceMath v.1.0

SpaceMath v1.0 es capaz de encontrar regiones permitidas para parámetros libres de modelos de extensión usando los datos de bosón de Higgs dentro de una interfaz amigable y en un entorno intuitivo en el que los usuarios ingresan los acoplamientos, establecen parámetros y ejecutan Mathematica de la manera tradicional. Como resultado, son generadas tablas y gráficos con valores y áreas en concordancia con los datos experimentales.

SpaceMath v.2.0

El propósito de esta guía es describir cómo instalar y usar SpaceMath v.2.0 utilizando las observables físicas: the Higgs boson data (HBD) & Lepton Flavor-Violanting Processes (LFV) con 2 formas de manejo para el usuario: Modo Experto y Modo Amigable.

SpaceMath v.2.0: Detalles técnicos, requisitos para instalación

Información

- Nombre de la paquetería de Mathematica: `SpaceMath` (más precisamente, en esta guía usaremos `SpaceMath v.2.0`).
- Desarrolladores: The SpaceMath team, compuesto por Marco A. Arroyo-Ureña y Tomás A. Valencia Pérez.
- Colaboradores: Myriam Mondragón Ceballos.
- Repositorio: `https://github.com/spacemathapp`
- Sitio web: `https://spacemath-project.gitbook.io/api-docs/`
- Manual: DOI: 10.31349/RevMexFisE.19.020206.

Requisitos

- Para usar esta guía, necesitará una computadora con un sistema operativo que ejecute Wolfram Mathematica (la versión de SpaceMath que vamos a usar necesita Mathematica v.12.0 o superior).
- Además de este requisito, es muy recomendable que la computadora tenga 4 Gb de RAM o más.
- También necesitará una buena conexión a Internet para descargar la paquetería.
- Es útil conocer el manejo básico del lenguaje Wolfram, pero no es obligatorio. Los comandos necesarios se darán y explicarán en esta guía.

Instalación de SpaceMath v.2.0

Verificación del sistema

- Verifique que Mathematica v.12.0++ este instalado en su computadora.
- Abra un notebook de Mathematica y corra la siguiente instrucción:

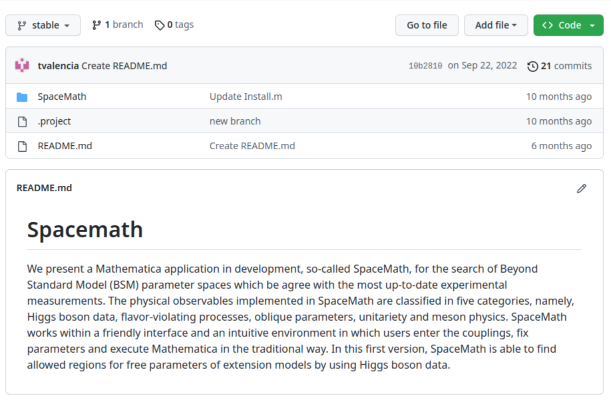
```
In[1]:=  $Version

Out[1]=  13.1.0 for Microsoft Windows (64-bit) (June 16, 2022)
```

- Si su computadora tiene una versión anterior, es posible que algunas características de SpaceMath v.2.0 no estén disponibles.

Instalación de SpaceMath v.2.0

- Vaya al sitio del repositorio de SpaceMath y descargue el archivo *SpaceMath-2.0.paclet*.



Instalación de SpaceMath v.2.0

- Si descargó el archivo en su directorio *Documents* entonces ejecute las instrucciones siguientes:

```
In[2]:= LocalPath = $UserDocumentsDirectory
Out[2]= /home/valencia/Documents

In[3]:= PacletInstall[FileNameJoin[{LocalPath, "SpaceMath-2.0.paclet"}]]
Out[3]= PacletObject[ Name: SpaceMath
                      Version: 2.0 ]
```

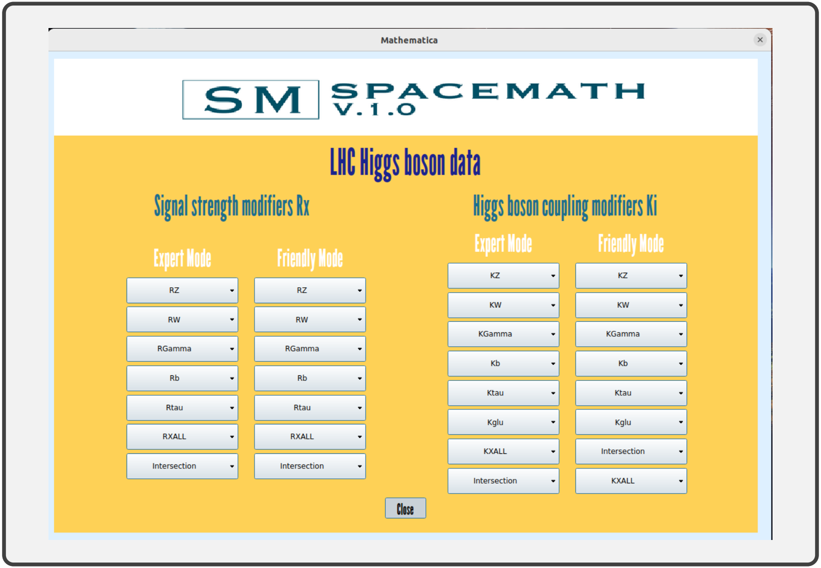
Instalación de SpaceMath v.2.0

- Ahora, simplemente ejecute el siguiente comando y SpaceMath será cargado en su entorno de trabajo en Mathematica.

Uso básico de SpaceMath v.2.0

Formas de trabajo

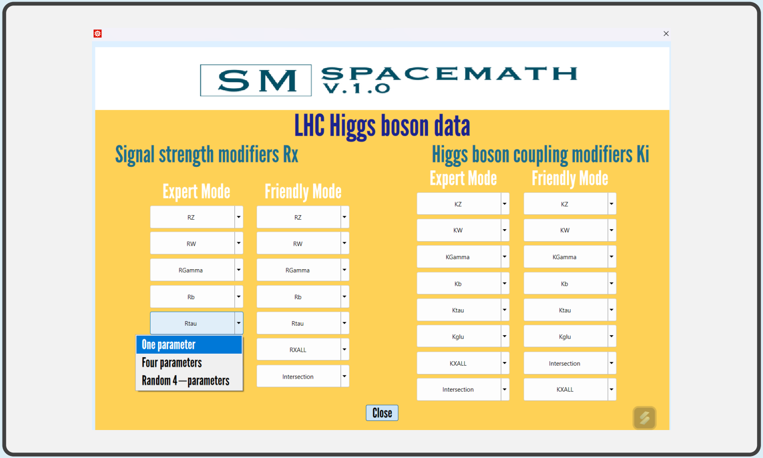
- SpaceMath v.2.0 ofrece al usuario 2 formas de trabajar: **Expert Mode** y **Friendly Mode**.
- Tomemos como ejemplo a la observable **LHC Higgs boson data**:



Mathematica
SM
SPACEMATH
V.1.0
LHC Higgs boson data
Signal strength modifiers Rx
Higgs boson coupling modifiers Ki
Expert Mode
Friendly Mode
RZ
RW
RGamma
Rb
Rtau
RXALL
Intersection
KZ
KW
KGamma
Kb
Ktau
Kglu
KXALL
Intersection
Close

Expert Mode

- Disponible para fijar desde 1 hasta 4 parámetros.



LHC Higgs boson dat

Signal strength modifiers R_τ

Rtau

Expert Mode

Load SpaceMath package:

```
<<SpaceMath`
```

Input couplings:

- THDM – III couplings taken from arXiv : hep – ph / 0509353 v2

The Yukawa Lagrangian in term of physical states is given as follows:

$$
\begin{aligned}
\mathcal{L}_Y = & \frac{g}{2}\left(\frac{m_d}{m_W}\right)\bar{d}_i\left[\frac{\cos\alpha}{\cos\beta}\delta_{ij}+\frac{\sqrt{2}\sin(\alpha-\beta)}{g\cos\beta}\left(\frac{m_W}{m_d}\right)\left(\tilde{Y}_2^d\right)_{ij}\right]d_j H \\
& + \frac{g}{2}\left(\frac{m_d}{m_W}\right)\bar{d}_i\left[-\frac{\sin\alpha}{\cos\beta}\delta_{ij}+\frac{\sqrt{2}\cos(\alpha-\beta)}{g\cos\beta}\left(\frac{m_W}{m_d}\right)\left(\tilde{Y}_2^d\right)_{ij}\right]d_j h \\
& + i\frac{g}{2}\left(\frac{m_d}{m_W}\right)\bar{d}_i\left[-\tan\beta\delta_{ij}+\frac{\sqrt{2}}{g\cos\beta}\left(\frac{m_W}{m_d}\right)\left(\tilde{Y}_2^d\right)_{ij}\right]\gamma^5 d_j A \\
& + \frac{g}{2}\left(\frac{m_u}{m_W}\right)\bar{u}_i\left[\frac{\sin\alpha}{\sin\beta}\delta_{ij}-\frac{\sqrt{2}\sin(\alpha-\beta)}{g\sin\beta}\left(\frac{m_W}{m_u}\right)\left(\tilde{Y}_2^u\right)_{ij}\right]u_j H \\
& + \frac{g}{2}\left(\frac{m_u}{m_W}\right)\bar{u}_i\left[\frac{\cos\alpha}{\sin\beta}\delta_{ij}-\frac{\sqrt{2}\cos(\alpha-\beta)}{g\sin\beta}\left(\frac{m_W}{m_u}\right)\left(\tilde{Y}_2^u\right)_{ij}\right]u_j h \\
& + i\frac{g}{2}\left(\frac{m_u}{m_W}\right)\bar{u}_i\left[-\cot\beta\delta_{ij}+\frac{\sqrt{2}}{g\sin\beta}\left(\frac{m_W}{m_u}\right)\left(\tilde{Y}_2^u\right)_{ij}\right]\gamma^5 u_j A,
\end{aligned}
$$

where i and j stand for the fermion flavors, with $i \neq j$, in general. As far as the lepton interactions, it is similar to type-down quarks part with the exchange $d \to \ell$ and $m_d \to m_\ell$.

```
ghtt[a_,Att_,Cab_,tb_]:=(g/2) (mt/mW) ((Cos[a]/(tb*Cos[ArcTan[tb]]))-(Sqrt[2] Cab/(g*tb*Cos[ArcTan[tb]]) (mW/mt)*(mt/vev*Att)))
ghbb[a_,Abb_,Cab_,tb_]:=(g/2) (mb/mW) (((-Sin[a]*tb)/Sin[ArcTan[tb]])+(Sqrt[2] (Cab*tb)/(g*Sin[ArcTan[tb]]) (mW/mb)*(mb/vev*Abb)))
ghtautau[a_,Atata_,Cab_,tb_]:=(g/2) (mtau/mW) (((-Sin[a]*tb)/Sin[ArcTan[tb]])+(Sqrt[2] (Cab*tb)/(g*Sin[ArcTan[tb]]) (mW/mtau)*(mtau/vev*Atata)))
ghWW[sab_]:=gw*mW*sab
ghZZ[sab_]:=gz*mZ*sab
```

Execute the command:

```
Rtau[
    ghtt[ArcCos[cab]+ArcTan[tb],Att,cab,tb],
    ghbb[ArcCos[cab]+ArcTan[tb],Abb,cab,tb],
    ghtautau[ArcCos[cab]+ArcTan[tb],1,cab,tb],
    cab,tb,-1,1,1,15,
    "cos(α-β)","tanβ",Att,Abb,
    0.9,1,0.05,0.9,1,0.05,"Att","Abb",
    30
  ][[2]]
```

If you need to get a data list:

```
TableRtau[
        ghtt[ArcCos[cab]+ArcTan[tb],1,cab,tb],
        ghbb[ArcCos[cab]+ArcTan[tb],1,cab,tb],
        ghtautau[ArcCos[cab]+ArcTan[tb],1,cab,tb],
        cab,-1,1,0.1,
        tb,1,15,1
        ]
```

For more details:

```
?Rtau

?TableRtau
```

Table 1: Left: THDM-III ghXX couplings. Right: Intries for SpaceMath v1.0

Coupling from Yukawa Lagrangian in eq. (4)	Input to SpaceMath v1.0
ghtt = $\frac{g}{2}\frac{m_t}{m_W}\left[\frac{\cos\alpha}{\sin\beta}\delta_{ij} - \frac{\sqrt{2}\cos(\alpha-\beta)}{g\sin\beta}\left(\frac{m_W}{m_t}\right)\left(\tilde{Y}_2^U\right)_{tt}\right]$	`ghtt[a_,Att_,Cab_,tb_]:=(g/2)(mt/mW) ((Cos[a]/tb*Cos[ArcTan[tb]])- (Sqrt[2]*Cab/(g*tb*Cos[ArcTan[tb]])*(mW/mt)*(mt/vev*Att)))`
ghbb = $\frac{g}{2}\frac{m_b}{m_W}\left[-\frac{\sin\alpha}{\cos\beta}\delta_{ij} - \frac{\sqrt{2}\cos(\alpha-\beta)}{g\cos\beta}\left(\frac{m_W}{m_b}\right)\left(\tilde{Y}_2^D\right)_{bb}\right]$	`ghbb[a_,Abb_,Cab_,tb_]:=(g/2)(mb/mW) ((-Sin[a]*tb/Sin[ArcTan[tb]])+ (Sqrt[2]*(Cab*tb)/(g*Sin[ArcTan[tb]])*(mW/mb)*(mb/vev*Abb)))`
$gh\tau\tau$ = $\frac{g}{2}\frac{m_\tau}{m_W}\left[-\frac{\sin\alpha}{\cos\beta}\delta_{ij} - \frac{\sqrt{2}\cos(\alpha-\beta)}{g\cos\beta}\left(\frac{m_W}{m_\tau}\right)\left(\tilde{Y}_2^\ell\right)_{\tau\tau}\right]$	`ghtautau[a_,Atata_,Cab_,tb_]:=(g/2)(mtau/mW) ((-Sin[a]*tb/Sin[ArcTan[tb]])+ (Sqrt[2]*(Cab*tb)/(g*Sin[ArcTan[tb]])*(mW/mtau)*(mtau/vev*Atata)))`

Description

- We define a=α, Cab=$\cos(\alpha-\beta)$, sab=$\sin(\alpha-\beta)$, tb=$\tan\beta$, $\left(\tilde{Y}_2^F\right)_{ij} = \sqrt{m_i m_j}A_{ij}/v$ and $\sin\beta = \tan\beta\cos(\tan^{-1}(\tan\beta))$.
- The terms `mf (f= fermions)`, `mV (V=Z, W)`, `g` and `vev` are the fermion masses, gauge boson masses, $SU(2)$ coupling constant and the vacuum expectation value, respectively. These quantities are loaded once `SpaceMath v1.0` is executed.

For more details:

In[60]:= `?Rtau`

Symbol

Out[60]=

Rtau[ghtt_, ghbb_,ghtautau_,x_,y_,xmin_,xmax_,ymin_,ymax_,xlabel_,ylabel_,xfor_,yfor_,xformin_,xformax_,xforstep_,yformin_,yformax_,yforstep_,xforlabel_,yforlabel_,PP_][[i]]→

This command evaluates R_τ, when there is dependence on two or more parameters. The arguments ghtt, ghbb and ghtautau are the htt, hbb and htautau couplings. Here, h represents to SM–like Higgs boson while t, b and tau are the top and bottom quarks and the tau–lepton. Labels x and y indicate the parameters to constrain, while xmin (ymin) and xmax (ymax) are the initial and final values defined by users. Argument xlabel (ylabel) is used for indicates the X axis label (Y axis label). The arguments xfor (yfor), xformin (yformin), xforstep (yforstep) represent an additional parameter to constrain, namely: initial value, final value and the steps from xformin (yformin) to xformax (yformax), respectively. Label [[i]] stands for confidence level, i=1 (2) indicates 1σ (2σ), Finally, PP is an option for plotting functions that specifies how many initial sample points to use.

ghtt: Coupling of the Higgs boson to a top quark pair.

ghbb: Coupling of the Higgs boson to a bottom quark pair.

ghtautau: Coupling of the Higgs boson to a τ lepton pair.

ghVV: Coupling of the Higgs boson to a $V = W, Z$ gauge boson pair.

gCH: Coupling of the Higgs boson to a charged scalar boson pair.

x, y, xfor, yfor: Parameters to be constrained.

xmin, xmax: Interval from xmin to xmax for parameter x: xmin$\leq$ x$\leq$ xmax.

ymin, ymax: Interval from ymin to ymax for parameter y: ymin$\leq$ y$\leq$ ymax.

xformin, xformax: Interval from xformin to xformax for parameter xfor: xformin$\leq$ xfor$\leq$ xformax.

Commands to generate $\mathcal{R}_X$ graphs.

SpaceMath v1.0

5. RV[ghtt_, ghbb_, ghVV_, x_, y_, xmin_, xmax_, ymin_, ymax_, xlabel_, ylabel_, xfor_, yfor_, xformin_, xformax_, xforstep_, yformin_, yformax_, yforstep_, PP_][[i]]
This command graphs $\mathcal{R}_V$ $(V = W, Z)$ as a function of the parameters to be constrained: x, y, xfor, yfor.
6. RGam[ghtt_, ghbb_, ghWW_, gCH_, mCH_, x_, y_, xmin_, xmax_, ymin_, ymax_, xlabel_, ylabel_, xfor_, yfor_, xformin_, xformax_, xforstep_, yformin_, yformax_, yforstep_, PP_][[i]]
This command graphs $\mathcal{R}_\gamma$ as a function of the parameters to be constrained: x, y, xfor, yfor.
7. Rtau[ghtt_, ghbb_, ghtautau_, x_, y_, xmin_, xmax_, ymin_, ymax_, xlabel_, ylabel_, xfor_, yfor_, xformin_, xformax_, xforstep_, yformin_, yformax_, yforstep_, PP_] [[i]]
This command graphs $\mathcal{R}_\tau$ as a function of the parameters to be constrained: x, y, xfor, yfor.
8. Rb[ghtt_, ghbb_, x_, y_, xmin_, xmax_, ymin_, ymax_, xlabel_, ylabel_, xfor_, yfor_, xformin_, xformax_, xforstep_, yformin_, yformax_, yforstep_, PP_][[i]]
This command graphs $\mathcal{R}_b$ as a function of the parameters to be constrained: x, y, xfor, yfor.

yformin, yformax: Interval from yformin to yformax for parameter yfor: yformin$\leq$ yfor$\leq$ yformax.

xforstep: Steps from xformin to xformax.

yforstep: Steps from yformin to yformax .

xlabel (ylabel): Label for x axis (y axis).

PP: Sample points to use for plotting functions.

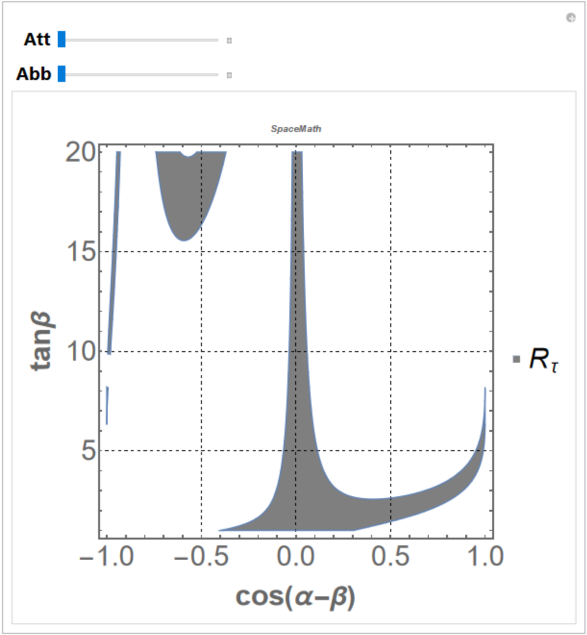
NN: Number of random values to generate.

[[i]]: Stands for confidence level i=1 (2), indicates 1σ (2σ).

mCH: Charged scalar mass.

xi: Random values parameters to be generated.

Out[62]=



LHC Higgs boson data

Signal strength modifiers R_τ

RtauRandom

Expert Mode

Load SpaceMath package:

```
<<SpaceMath`
```

Input couplings:

- **THDM – III couplings taken from arXiv : hep – ph / 0 509 353 v2**

```
ghtt[a_,Att_,Cab_,tb_]:=(g/2) (mt/mW) ((Cos[a]/(tb*Cos[ArcTan[tb]]))-(Sqrt[2] Cab/(g*tb*Cos[ArcTan[tb]]) (mW/mt)*(mt/vev*Att)))
ghbb[a_,Abb_,Cab_,tb_]:=(g/2) (mb/mW) (((-Sin[a]*tb)/Sin[ArcTan[tb]])+(Sqrt[2] (Cab*tb)/(g*Sin[ArcTan[tb]]) (mW/mb)*(mb/vev*Abb)))
ghtautau[a_,Atata_,Cab_,tb_]:=(g/2) (mtau/mW) (((-Sin[a]*tb)/Sin[ArcTan[tb]])+(Sqrt[2] (Cab*tb)/(g*Sin[ArcTan[tb]]) (mW/mtau)*(mtau/vev*Atata)))
ghWW[sab_]:=gw*mW*sab
ghZZ[sab_]:=gz*mZ*sab
```

Execute the command:

```
RtauRandom[
        ghtt[ArcCos[cab]+ArcTan[tb],Att,cab,tb],
        ghbb[ArcCos[cab]+ArcTan[tb],Abb,cab,tb],
        ghtautau[ArcCos[cab]+ArcTan[tb],1,cab,tb],
        cab,-1,1,
        tb,1,15,
        Att,0.9,1,
        Abb,0.9,1,
        5000
       ];
```

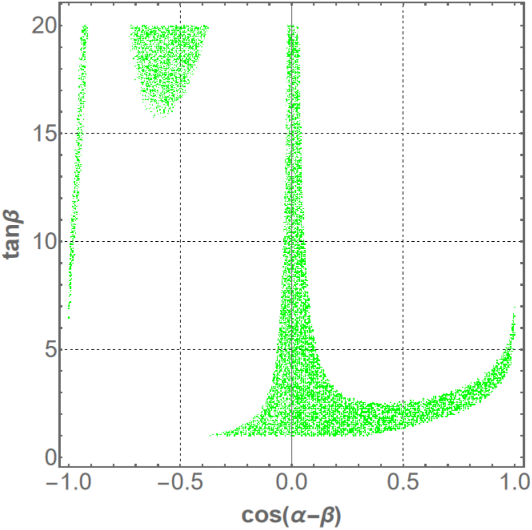
```
PlotRtauRandom[1,2,"cos(α-β)","tanβ"][[2]]
```

For more details:

```
?RtauRandom
```

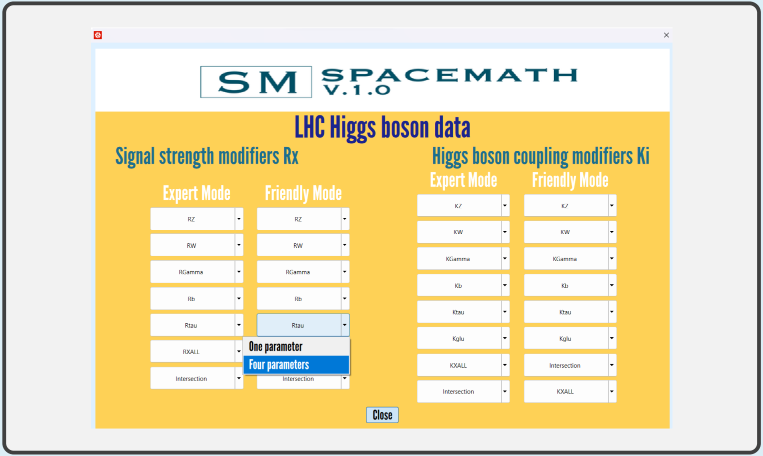
```
?PlotRtauRandom
```

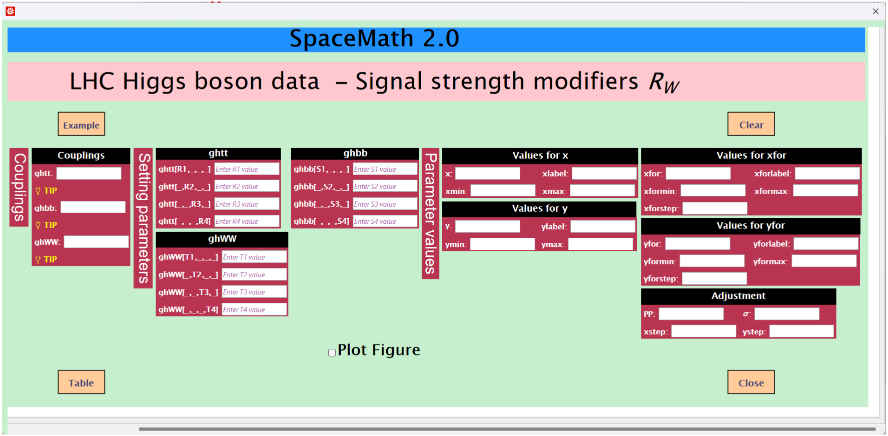
Out[82]=

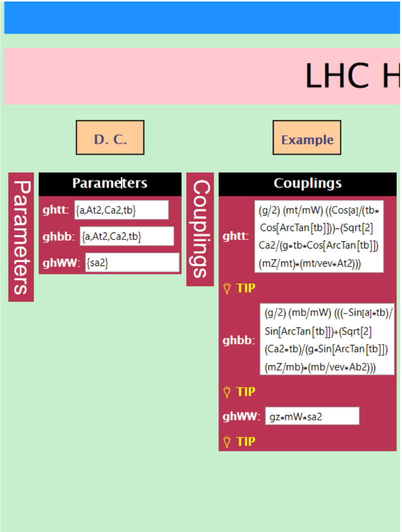


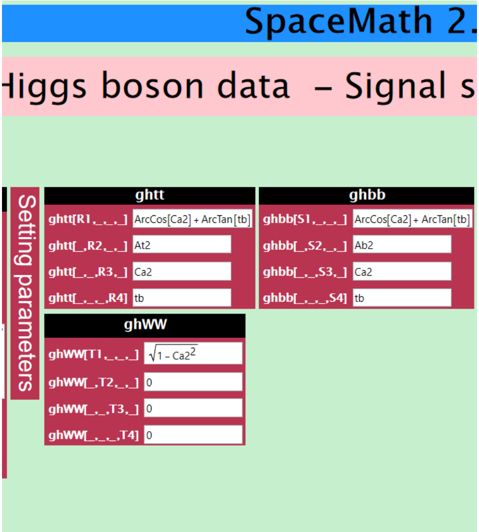
Friendly Mode

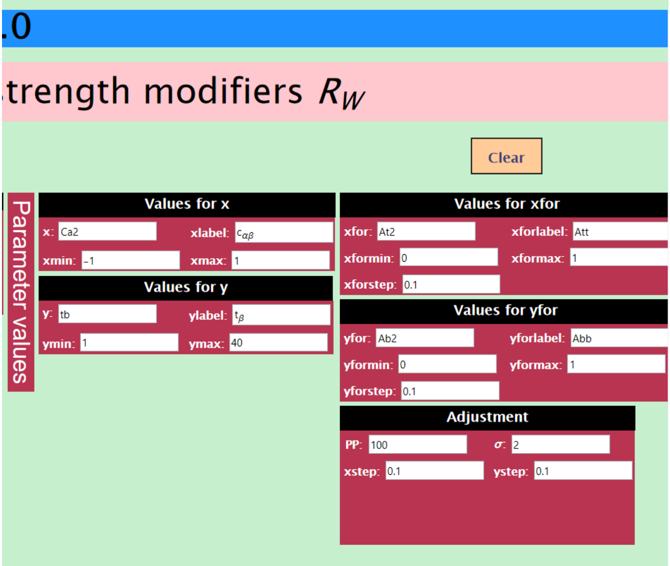
- Disponible para fijar desde 1 hasta 4 parámetros.

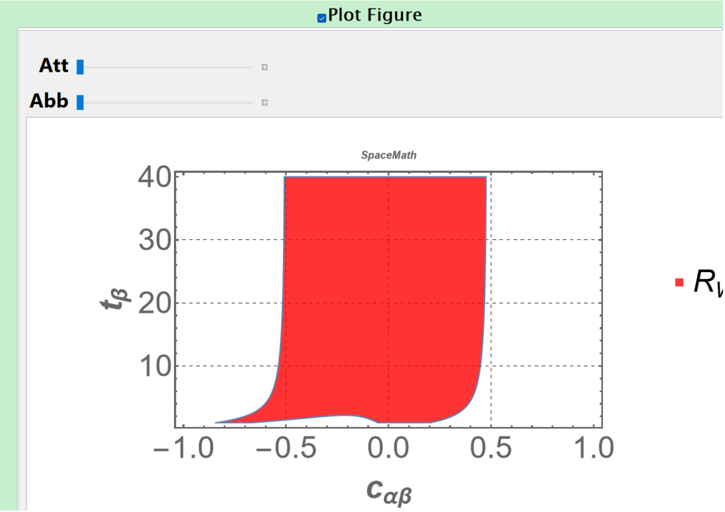



SpaceMath 2.0
LHC Higgs boson data – Signal strength modifiers R_W
Example
Clear
Couplings
Couplings
ghtt:
TIP
ghbb:
TIP
ghWW:
TIP
Setting parameters
ghtt
ghtt[R1,_,_,_]
ghtt[_,R2,_,_]
ghtt[_,_,R3,_]
ghtt[_,_,_,R4]
Enter R1 value
Enter R2 value
Enter R3 value
Enter R4 value
ghWW
ghWW[T1,_,_,_]
ghWW[_,T2,_,_]
ghWW[_,_,T3,_]
ghWW[_,_,_,T4]
Enter T1 value
Enter T2 value
Enter T3 value
Enter T4 value
ghbb
ghbb[S1,_,_,_]
ghbb[_,S2,_,_]
ghbb[_,_,S3,_]
ghbb[_,_,_,S4]
Enter S1 value
Enter S2 value
Enter S3 value
Enter S4 value
Parameter values
Values for x
x:
xlabel:
xmin:
xmax:
Values for y
y:
ylabel:
ymin:
ymax:
Values for xfor
xfor:
xforlabel:
xformin:
xformax:
xforstep:
Values for yfor
yfor:
yforlabel:
yformin:
yformax:
yforstep:
Adjustment
PP:
σ:
xstep:
ystep:
Plot Figure
Table
Close


LHC H
D. C.
Example
Parameters
Parameters
ghtt: {a,At2,Ca2,tb}
ghbb: {a,At2,Ca2,tb}
ghWW: {sa2}
Couplings
Couplings
ghtt: (g/2) (mt/mW) ((Cos[a]/(tb* Cos[ArcTan[tb]]))-(Sqrt[2] Ca2/(g*tb*Cos[ArcTan[tb]]) (mZ/mt)*(mt/vev*At2)))
TIP
ghbb: (g/2) (mb/mW) (((-Sin[a]*tb)/ Sin[ArcTan[tb]])+(Sqrt[2] (Ca2*tb)/(g*Sin[ArcTan[tb]]) (mZ/mb)*(mb/vev*Ab2)))
TIP
ghWW: gz*mW*sa2
TIP


SpaceMath 2.
Higgs boson data – Signal s
Setting parameters
ghtt
ghtt[R1,_,_,_] ArcCos[Ca2] + ArcTan[tb]
ghtt[_,R2,_,_] At2
ghtt[_,_,R3,_] Ca2
ghtt[_,_,_,R4] tb
ghbb
ghbb[S1,_,_,_] ArcCos[Ca2] + ArcTan[tb]
ghbb[_,S2,_,_] Ab2
ghbb[_,_,S3,_] Ca2
ghbb[_,_,_,S4] tb
ghWW
ghWW[T1,_,_,_] √1 - Ca2^2
ghWW[_,T2,_,_] 0
ghWW[_,_,T3,_] 0
ghWW[_,_,_,T4] 0

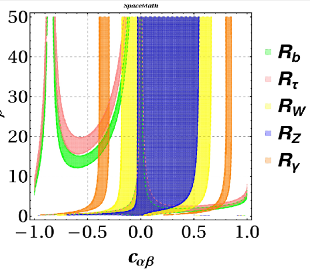

.0
trength modifiers R_W
Clear
Parameter values
Values for x
x: Ca2
xlabel: $c_{\alpha\beta}$
xmin: −1
xmax: 1
Values for y
y: tb
ylabel: t_β
ymin: 1
ymax: 40
Values for xfor
xfor: At2
xforlabel: Att
xformin: 0
xformax: 1
xforstep: 0.1
Values for yfor
yfor: Ab2
yforlabel: Abb
yformin: 0
yformax: 1
yforstep: 0.1
Adjustment
PP: 100
σ: 2
xstep: 0.1
ystep: 0.1



Plot Figure
Att
Abb
SpaceMath
40
30
20
10
t_β
−1.0
−0.5
0.0
0.5
1.0
$c_{\alpha\beta}$

All Signal strength

```
RXALL[ghtt[ArcCos[Cab] + ArcTan[tb], Att, Cab, tb],
      ghbb[ArcCos[Cab] + ArcTan[tb], Abb, Cab, tb],
      ghZZ[Sqrt[1 - Cab^2]], ghWW[Sqrt[1 - Cab^2]]
    ghtautau[ArcCos[Cab] + ArcTan[tb], 1, Cab, tb],
        0, mCH, Cab, tb, -1, 1, 0.1, 50,"cos(α − β)",
"tan β", Att, Abb, 0.9, 1, 0.1, 0.9, 1, 0.1, 80][[2]]
```



Conclusiones

Conclusiones y perspectivas

- Ha sido publicada la primera versión de SpaceMath habilitada con datos del bosón de Higgs.
- Por concluir la construcción de la segunda versión de SpaceMath habilitada con datos del bosón de Higgs, procesos con violación de sabor leptónico y con 2 forma de trabajo para el usuario.
- Estudiar el espacio de parámetros de diversos modelos.
- Que sea usado por los estudiantes e investigadores

CITAS

8 results | cite all

Citation Summary | Most Recent

Lepton flavor violation in the Littlest Higgs model with T-parity realizing an inverse seesaw #1

Iván Pacheco (CINVESTAV, IPN) (Sep 19, 2022)

links | cite | claim | reference search | 0 citations

Lepton flavour violation in hadron decays of the tau lepton within the littlest Higgs model with T-parity #2

Iván Pacheco (CINVESTAV, IPN), Pablo Roig (CINVESTAV, IPN) (Jul 8, 2022)

Published in: *JHEP* 09 (2022) 144 • e-Print: 2207.04085 [hep-ph]

pdf | DOI | cite | claim | reference search | 6 citations

Higgs Pair Production at the LHC through the Flavon #3

Marco A. Arroyo-Ureña (Unlisted, MX and Mexico U.), Amit Chakraborty (SRM U., Amaravati), J. Lorenzo Díaz-Cruz (Unlisted, MX and Puebla U., Mexico), Dilip Kumar Ghosh (IACS, Kolkata), Najimuddin Khan (Harish-Chandra Res. Inst.) et al. (May 25, 2022)

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Single top production via FCNC couplings at an e^-e^+ collider with center-of-mass energy $\sqrt{s} = 240$ GeV #4

M.A. Arroyo-Ureña (Mexico U., Cuautitlan), J. Lorenzo Díaz-Cruz (Puebla U., Mexico), R. Gaitán (Mexico U., Cuautitlan), J.H. Montes de Oca (Mexico U., Cuautitlan), T.A. Valencia-Pérez (Mexico U.) (Feb 9, 2022)

GRACIAS
POR SU ATENCIÓN