signal_inputs_rinv13.cmnd

Main Program Settings

>> Main:numberOfEvents = 100000

- We need many events for the Machine Learning algorithm

>> Main:timesAllowErrors = 100

- The number of allowed errors is proportional to the number of events.
- Though I do not know why but there are errors when running a BSM program

>> Beams:idA = 2212

- Proton beam

>> Beams:idB = 2212

- Proton beam

>> Beams:eCM = 13000.0

- The center of mass energy of the system

Hard Process (Primary Interaction)

>> PhaseSpace:pTHatMin = 0.0

- Means there is no lower limit for the hard scattering process
- Usually hard process have high momentum transfer

Event Generation

>> PartonLevel:MPI = off

- No multiparticle interactions since we are only interested with the primary process
- The pythia file is a signal injection to the background

>> PartonLevel:ISR = on

- Since fermions can still emit while in the initial state that might affect the phenomenology of the process

>> PartonLevel:FSR = on

- Final state leptons and hadrons can radiate photon and gluon respectively.

>> HiddenValley:alphaOrder = 1

- This is connected to the hidden sector quark confinement of the hidden meson.
- In analogy to SM model alpha_s
    - The beta function describes how alpha changes with energy which is just dependent on the flavor and energy
- While in the Hidden Valley model
    - The beta function is dependent on the N_gauge (Number of gauge) and N_flav (Number of flavors)
    - N_flavors (SM)
        - Up
        - Down
    - N_gauge
        - SU(N)

>> HiddenValley:FSR = on

- This is the same as PartonLevel:FSR but in the HiddenValley Particles. There is no HiddenValley:ISR since there is no dark stuff before the interaction

>> HiddenValley:fragment = on

- Allows showering in the hidden valley sector
- Allows string fragmentation
    - This is the hadronization of high energy quarks or gluons while moving

>> SpaceShower:QCDshower = on

- Yes to ISR SM showering
- simulates the radiative processes of partons (quarks and gluons) as they propagate through space. This is part of the Parton Shower framework, which describes how a high-energy parton undergoes multiple emissions of softer partons due to quantum chromodynamics (QCD) interactions.
- This process includes the emissions of gluons from a parton due to its color charge and the resulting evolution of the parton distribution as it radiates energy and momentum. It effectively models how a hard scattering event evolves into a set of partons that will eventually hadronize.

>> TimeShower:QCDshower = on

- temporal evolution of the partons. It accounts for the emissions of partons based on their time of flight, reflecting the dynamics of particle production as they propagate through time after a collision.

>> HardronLevel:Hadronize = on

- I am bit confused in this section since the .cmnd said that no SM Hadronization but it is on but I think it is on to change the hadronization option that is default of PYTHIA

```
HadronLevel:Hadronize = on                                        ! No SM Hadronization
```

Sector Structure Settings

>> HiddenValley:Ngauge = 3

- Number of Gauge symmetry which is the same as SU(3)

>> HiddenValley:nFlav = 3

- This is the number of flavor

>> HiddenValley:Lambda = 500.

- This is the confinement scale
- This is the max energy level at which the hidden sector quarks and gluons combine and higher than that it will boom

>> HiddenValley:pTminFSR = 550.

- This is the minimum pT emission of the Final State particles.

>> HiddenValley:spinFv = 0

- Dark quark have spin 0, this means they are scalar particles unlike SM model quarks they have spin of ½

Dark Quark Mass
>> 4900101:m0 = 250.0
>> 4900102:m0 = 250.0
>> 4900103:m0 = 250.0

Since the nFlav of this specific BSM model, we need to defined 3 dark quark masses. They are defined to have a mass of 250 GeV (why?)

>> 4900023:m0 = 4000

- This is the dark Z boson mass which is set to be 4TeV

>> HiddenValley:probVector = 0.75

- The implementation of the theory predicts that ¾ of the HV-meson will have spin 1 and the ¼ will have spin 0 (pseudoscalar)
    - Assuming qv has spin ½ and the mass splitting is small

>> 4900111:m0 = 500.0 ! Dark Diagonal Pion Mass
>> 4900113:m0 = 500.0 ! Dark Diagonal Rho Mass
>> 4900211:m0 = 500.0 ! Dark Off-Diagonal Pion Mass
>> 4900213:m0 = 500.0 ! Dark Off-Diagonal Rho Mass

>> HiddenValley:aLund = 0.3
- This is the **a** parameter for the Lund symmetric fragmentation function

>> HiddenValley:bmqv2 = 0.8
- This is the **b** parameter for the Lund symmetric fragmentation function

>> HiddenValley:rFactqv = 1.0
- The Bowler correction factor to the Lund symmetric fragmentation function

+ Lund symmetric fragmentation function is part of Lund string model used to describe how quarks and gluons form hadrons (hadronization)

In the **Lund string model**, the fragmentation of quarks and gluons is conceptualized as a color string stretching between a quark and an anti-quark (or between multiple partons in the case of gluons). As these particles move apart, the string stretches and eventually breaks, creating new quark-antiquark pairs, which then hadronize into observable particles. The breaking process continues until stable hadrons are formed.

The **Lund symmetric fragmentation function** gives the probability distribution for how energy is shared between these new quarks and anti-quarks as they form hadrons.

$$f(z) = N\frac{(1-z)^a}{z}e^{\frac{-bm_\perp^2}{z}}$$

Where:
- N = Normalization Constant
- z = fraction of the remaining energy-momentum that hadron takes
- m = denotes the sum of squares of the hadrons mass and transverse momentum
- a = dimensionless parameter related to the type of breakup
- b = universal parameter with dimension GeV^-2

The Bowler correction is a modification applied to the Lund symmetric fragmentation function to account for massive quark effects in hadronization, specifically for heavy quarks like charm and bottom quarks. The original Lund model is tailored mainly for light quarks, so the Bowler correction provides an adjustment when dealing with the hadronization of more massive particles, where the mass plays a more significant role in energy distribution.

Lund–Bowler modified shape for heavy quarks:

$$f(x) \propto \frac{1}{z^{1+bm_q^2}} \exp\left(-\frac{bm_\perp^2}{z}\right).$$

Where:

- m_q = mass of the heavy quark

Dark Hadron Stability

>> 4900111:oneChannel = mayDecay = off ! Dark Diagonal Pion Stability
>> 4900113:oneChannel = mayDecay = off ! Dark Diagonal Rho Stability
>> 4900211:oneChannel = 1 1.0000000 91 1 -1 ! Dark Off-Diagonal Pion Stability
>> 4900213:oneChannel = 1 1.0000000 91 1 -1 ! Dark Off-Diagonal Rho Stability

+ This means that the Dark Diagonal Pion and Rho cannot decay and Dark Off-Diagonal Pion and Rho can decay
+ The difference:
  + Dark Diagonal
    - flavor-diagonal under the gauge symmetries of the dark sector.
    - couple to the dark sector's analog of the photon or Z' boson. Their interactions are usually limited to the dark sector and may have suppressed interactions with Standard Model particles.
    - suppressed decay modes to maintain a dark sector structure.
  + Dark Off-Diagonal
    - flavor-changing particles within the dark sector.
    - mediate transitions between different flavors of dark quarks, analogous to flavor-changing neutral currents in the Standard Model. They may decay into a quark-antiquark pair (with different flavors) or to other dark particles.
+ About the decay
  + Dark Off-Diagonal has one decay channel, with a 100% branching ratio, where it decays into a "string" final state (hadronization), producing a down quark (1) and an anti-down quark (-1).

Z' Stability

```
>> 4900023:onMode = off
>> 4900023:onIfany = -4900101 4900101 4900102 -4900102 4900103 -4900103
```

+ This sets the decay of Z’ to
    - ± 4900101
    - ± 4900102
    - ± 4900103

Changes to QCD to Match Analytics

```
>> SigmaProcess:alphaSvalue = 0.1265                 ! Value from Analytic Code
>> SigmaProcess:alphaSorder = 1                      ! Running Order of Coupling

>> MultipartonInteractions:alphaSvalue = 0.1265      ! Value from Analytic Code
>> MultipartonInteractions:alphaSorder = 1           ! Running Order of Coupling
>> MultipartonInteractions:pTmin = 0.5               ! Parton Shower Cutoff

>> SpaceShower:alphaSvalue = 0.1265                  ! Value from Analytic Code
>> SpaceShower:alphaSorder = 1                       ! Running Order of Coupling
>> SpaceShower:pTmin = 0.5                           ! Parton Shower Cutoff

>> TimeShower:alphaSvalue = 0.1265                   ! Value from Analytic Code
>> TimeShower:alphaSorder = 1                        ! Running Order of Coupling
>> TimeShower:pTmin = 0.5                            ! Parton Shower Cutoff
```