$J/\psi J/\psi$ Spin-parity Analysis

——*Parton Shower Matching Study*

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P&P Meeting

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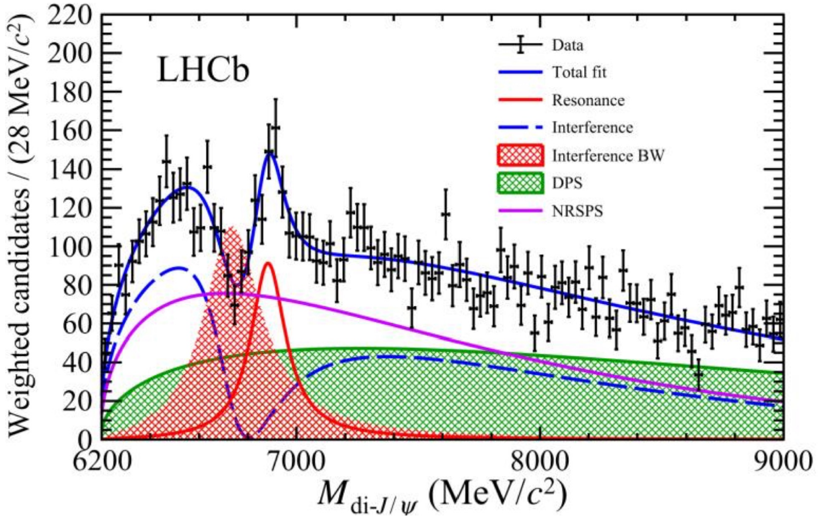
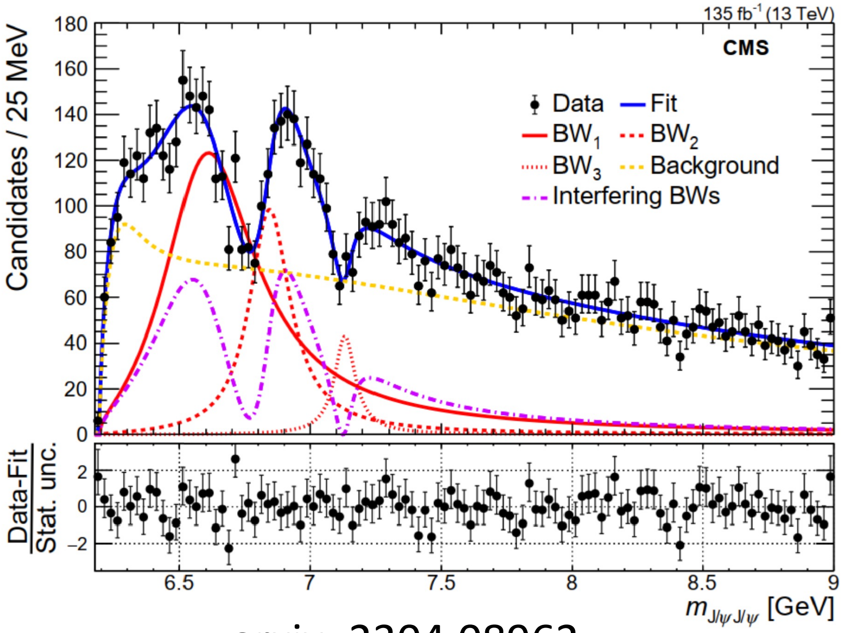
Outline

- **Recap**
  - **CMS $J/\psi J/\psi$ analysis** arXiv:2306.07164
  - **MC simulation**
- **Tuning in Pythia8**
  - **NRSPS MC**
  - **Signal MC**
- **Sideband study**

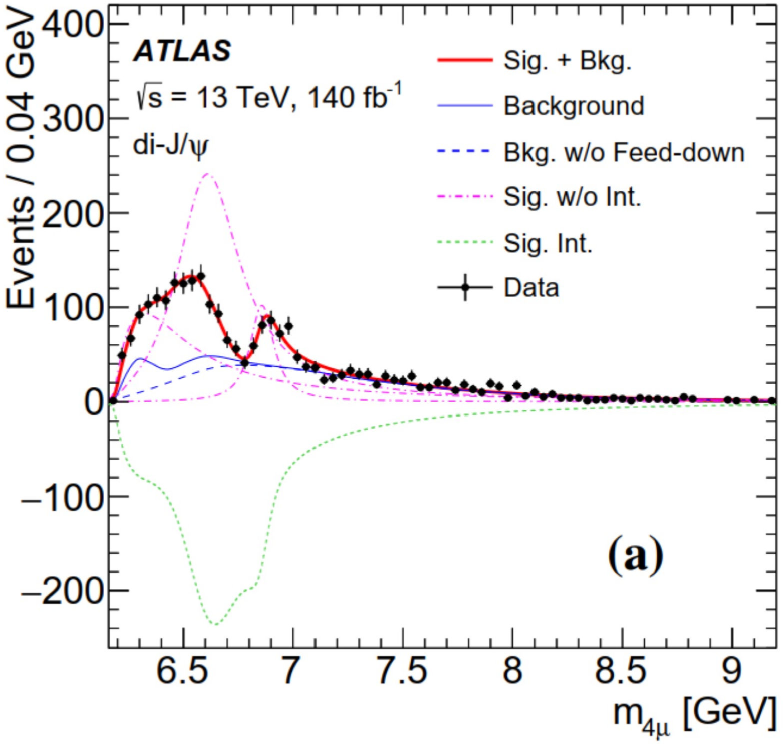
- Structures in $J/\psi J/\psi$ mass spectrum at LHCb, CMS, ATLAS
- Dips observed in data —— explained by interference in all three experiments
- Same J^{PC} between components? $J^{PC}=?$



SciBull65(2020)1983



arxiv: 2304.08962



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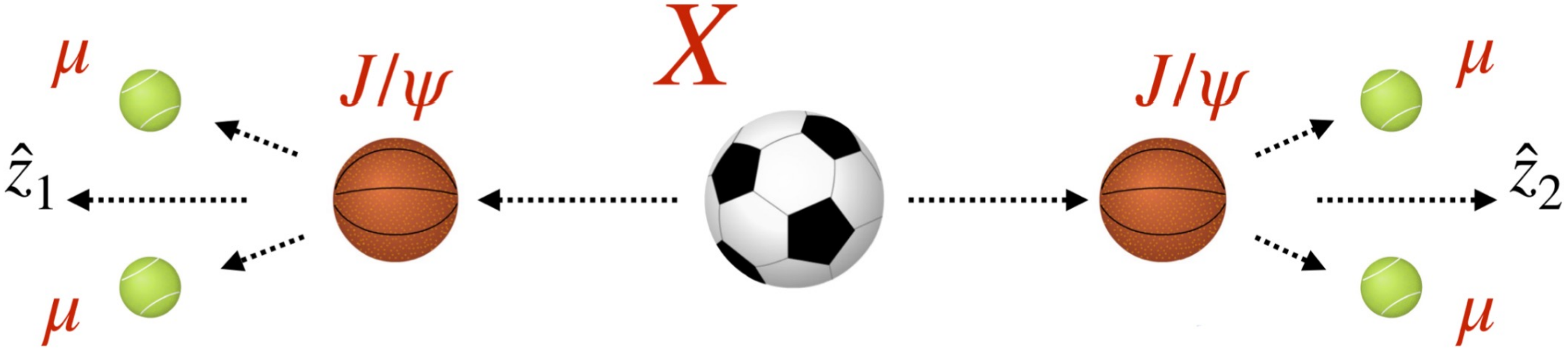
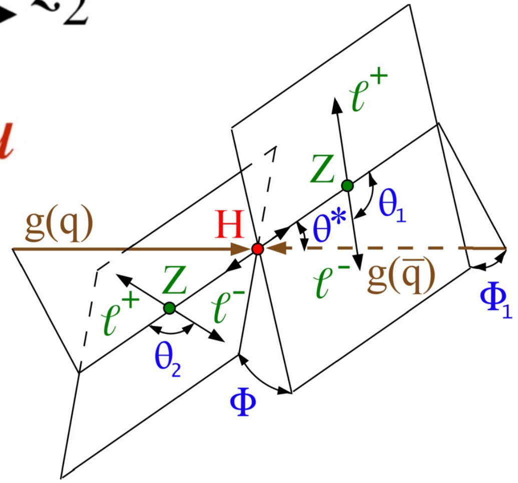




❖ MC modeling with different J^{PC}

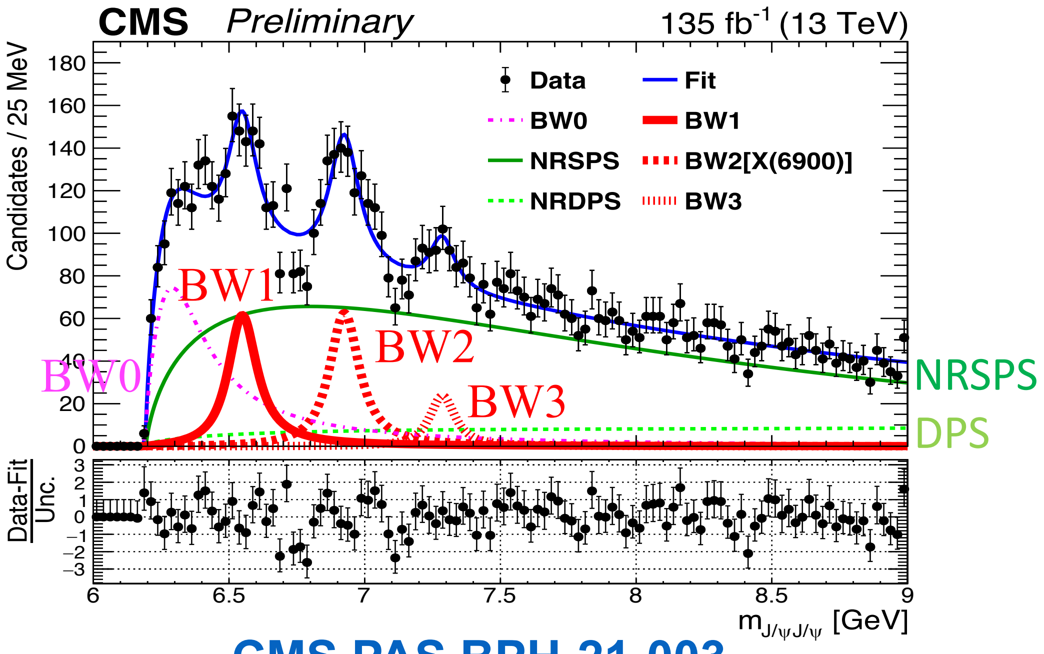
❖ Known inconsistent kinematic distributions of MC and data

- ✓ Free parameter used in 1D fit to $J/\psi J/\psi$ mass spectrum
- ➢ J^{PC} → amplitude → kinematic distributions → important for spin-parity analysis!
- ➢ Create an optimal observable (MELA) to separate J^{PC} → sensitive to p_T……

$$\mathcal{R}_{\mathrm{opt},2} = \frac{\mathcal{P}_1(\vec{x}^{\,\mathrm{full}}_{\mathrm{reco}})}{\mathcal{P}_0(\vec{x}^{\,\mathrm{full}}_{\mathrm{reco}}) + c \cdot \mathcal{P}_1(\vec{x}^{\,\mathrm{full}}_{\mathrm{reco}})}$$

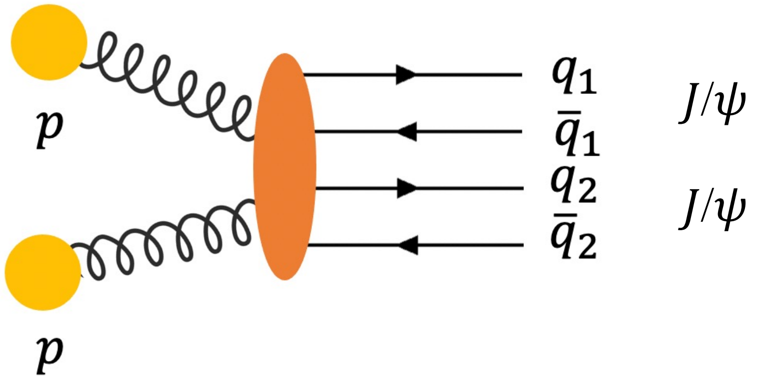
➢ Solution: apply reweight / MC tuning

- **Data**: 2016-2018, $J/\psi J/\psi$ mass spectrum [6, 9] GeV
- **Signal**: tetra-quark candidates: BW1/BW2/BW3
- **Background**
  - NRSPS—Non-Resonant Single Parton Scattering
  - DPS—Non-Resonant Double Parton Scattering

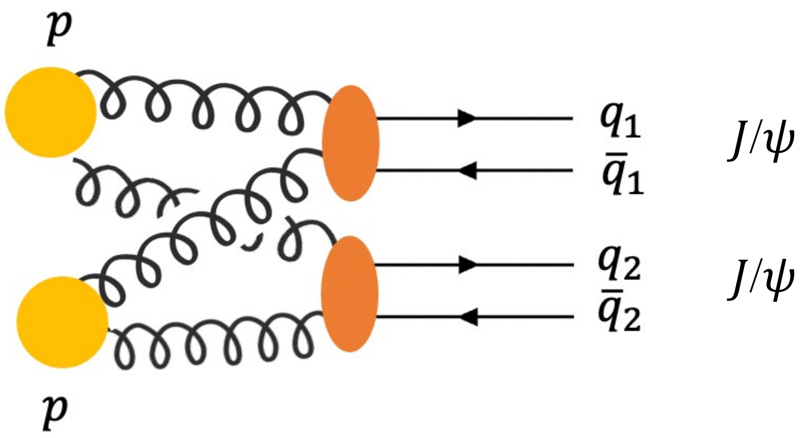


CMS PAS BPH-21-003

SPS：



DPS：



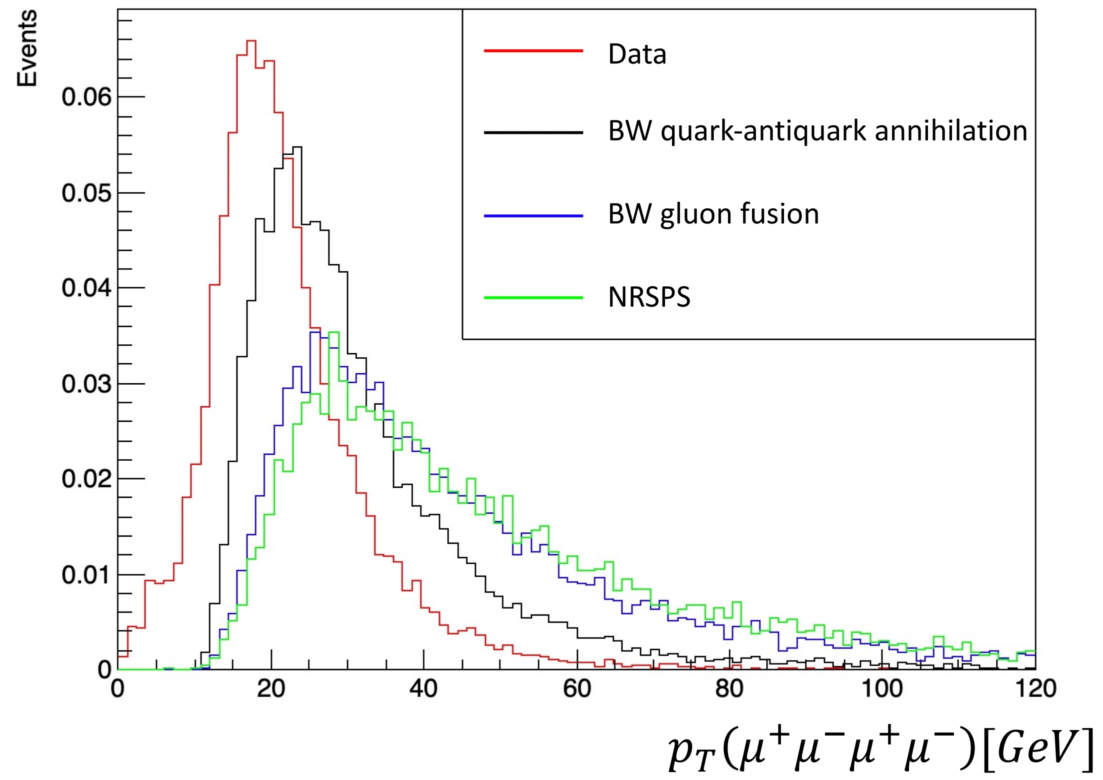
- **MC simulation (LO)**

  - ✓ **Signal MC**: JHUGen/MCFM + Pythia8
    - M[BW] = 6.552 GeV, $\Gamma[\mathrm{BW}] = 124\ \mathrm{MeV},\ J^P = 0^+$
    - Gluon fusion
      $gg \to \mathrm{BW} \to J/\psi J/\psi \to \mu^+\mu^-\mu^+\mu^-$
    - Quark-antiquark annihilation
      $q\bar{q} \to \mathrm{BW} \to J/\psi J/\psi \to \mu^+\mu^-\mu^+\mu^-$

  - ✓ **Background MC:** Pythia8
    - NRSPS—Non-Resonant Single Parton Scattering
      $gg(99\%) \to J/\psi J/\psi \to \mu^+\mu^-\mu^+\mu^-$
    - DPS—Non-Resonant Double Parton Scattering

- **Issues**:
  - Inconsistent kinematic distributions between data and MC samples (both signal & background)
  - Harder $p_T(\mu^+\mu^-\mu^+\mu^-)$ by pythia8

- **Solution**: Tuning in pythia8



Setup

❖ Fragment file for NRSPS

```
import FWCore.ParameterSet.Config as cms
from Configuration.Generator.Pythia8CommonSettings_cfi import *
from Configuration.Generator.MCTunes2017.PythiaCP5Settings_cfi import *

FourMuonFilter = cms.EDFilter("FourLepFilter", # require 4-mu in the fir
        MinPt = cms.untracked.double(1.8),
        MaxPt = cms.untracked.double(4000.0),
        MaxEta = cms.untracked.double(2.5),
        MinEta = cms.untracked.double(0.),
        ParticleID = cms.untracked.int32(13)
)
```

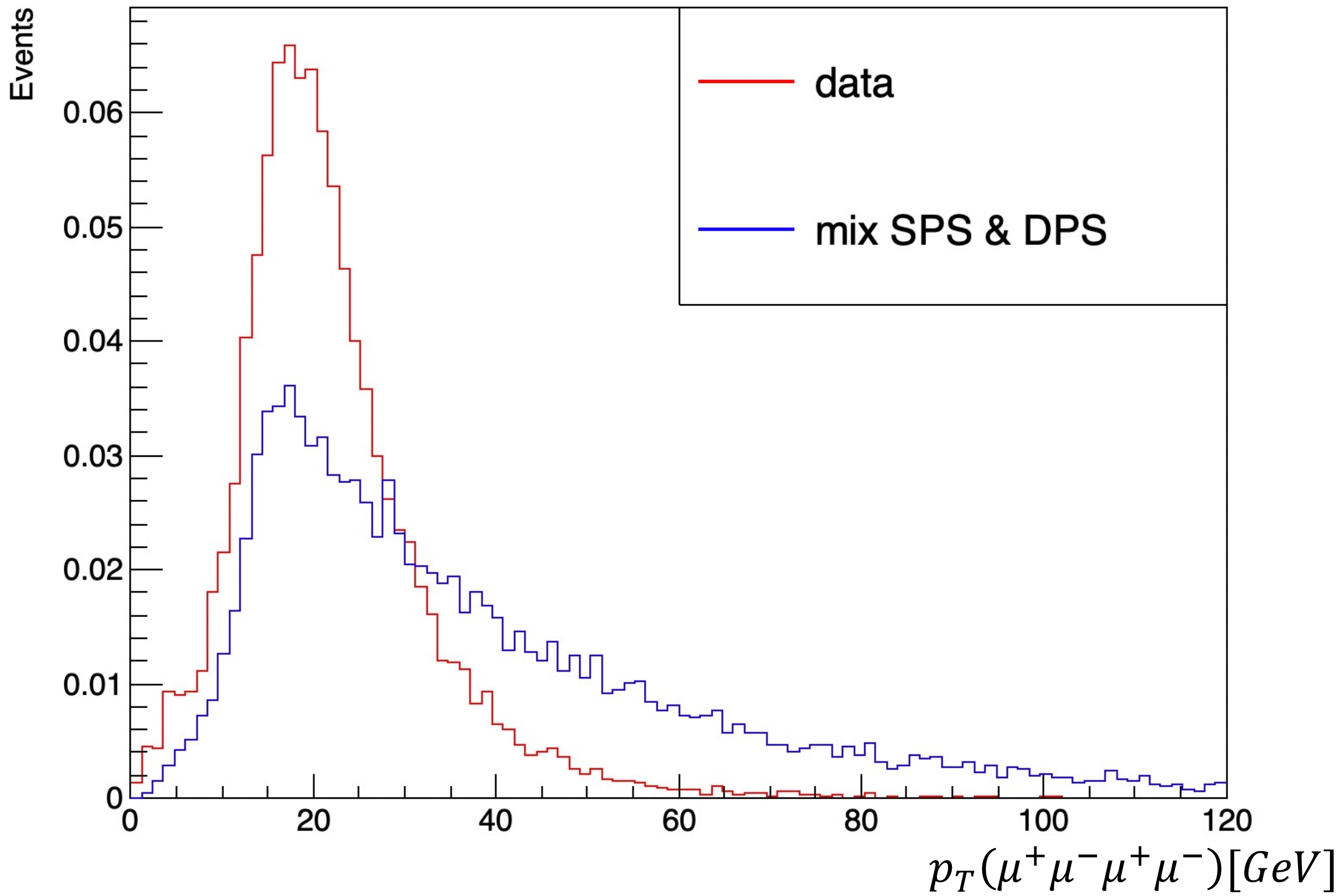
```
generator = cms.EDFilter("Pythia8GeneratorFilter",
    crossSection = cms.untracked.double(1.0),
    PythiaParameters = cms.PSet(
        pythia8CommonSettingsBlock,
        pythia8CP5SettingsBlock,
        processParameters = cms.vstring(
            'Charmonium:gg2doubleccbar(3S1)[3S1(1)] = on,off,off',
            'Charmonium:qqbar2doubleccbar(3S1)[3S1(1)] = on,off,off',
            'Charmonium:states(3S1)1  = 443,443,100443',
            'Charmonium:states(3S1)2  = 443,100443,100443',
            '443:onMode = off',
            '443:onIfMatch = 13 -13',
            'PartonLevel:MPI = on',
            'PartonLevel:ISR = on',
            'PartonLevel:FSR = on',    #off
            'HadronLevel:all = on',
            'HadronLevel:Hadronize = on',
            'HadronLevel:Decay = on',
        ),
        parameterSets = cms.vstring(
            'pythia8CommonSettings',
            'pythia8CP5Settings',
            'processParameters'
        ),
    ),
    comEnergy = cms.double(13000.0),
    maxEventsToPrint = cms.untracked.int32(0),
    pythiaHepMCVerbosity = cms.untracked.bool(False),
    pythiaPylistVerbosity = cms.untracked.int32(1)
)

ProductionFilterSequence = cms.Sequence(generator*FourMuonFilter)
```

❖ Apply looser filter after Parton Shower in Gen level to save space

- $p_T(\mu) \leq 1.8$ GeV
- $|\eta(\mu)| \leq 2.5$

- Mix of NRSPS and DPS
  - In $M[\mu^+\mu^-\mu^+\mu^-] \in$ [6, 15] GeV
  - From the fit to data, N[DPS] = 3494, N[NRSPS] = 7519
- Inconsistent p_T distributions



Tuning in PYTHIA

❖ Suggested by theorist Steve Mrenna to try:

1. Set Pythia parameters in the config file:

PythiaParameters = cms.PSet(
pythia8CommonSettingsBlock,
pythia8CP5SettingsBlock,
pythia8PSweightsSettingsBlock,
processParameters = cms.vstring(

2. Change *SpaceShower:pTdampMatch* = 1 (or 3) and check the p_T spectrum

3. Change *SpaceShower:renormMultFac* = between 0.1 and 10 to tune it further

4. Change *SpaceShower:pTmaxFudge* to tune it further if needed [Parameter definition]

Tuning for NRSPS

- How filter efficiency is affected by these parameters

  (1) *SpaceShower:pTdampMatch* → 1% or 10%

  (2) *SpaceShower:renormMultFac* → Increase or decrease by ≈ 20%

  (3) *SpaceShower:pTmaxFudge* → Increase or decrease by ≈ 1%

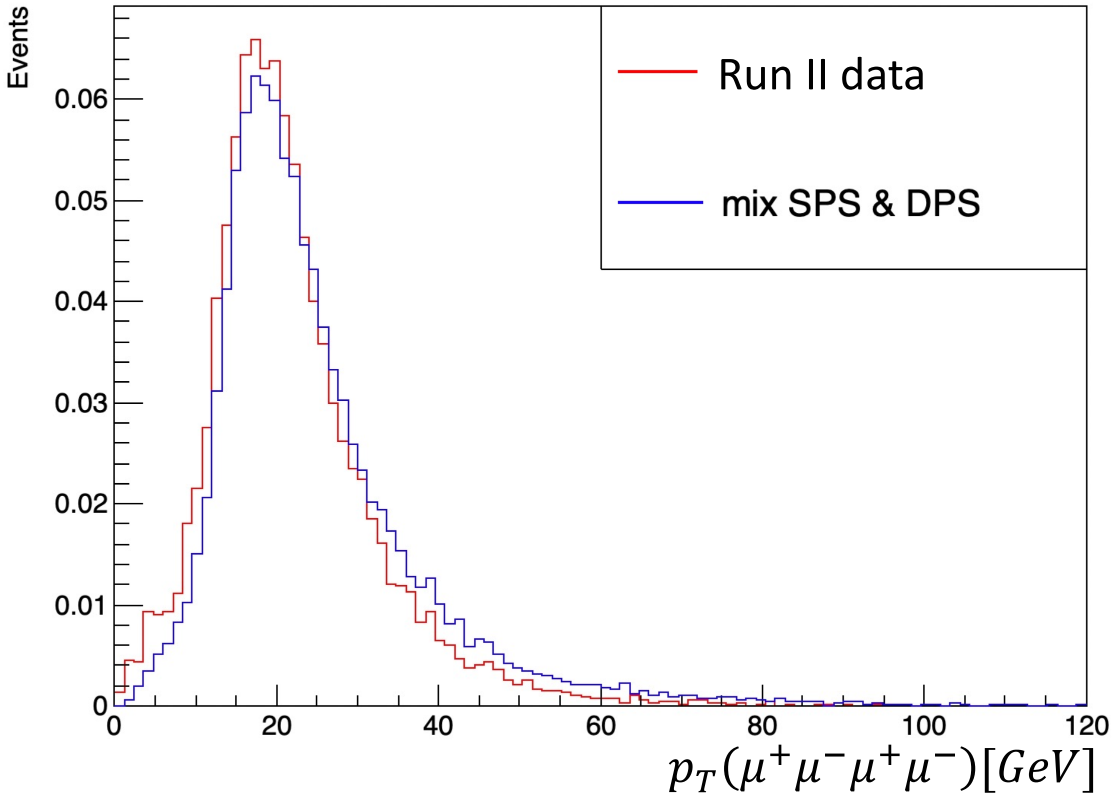
- Inconsistence due to harder p_T →

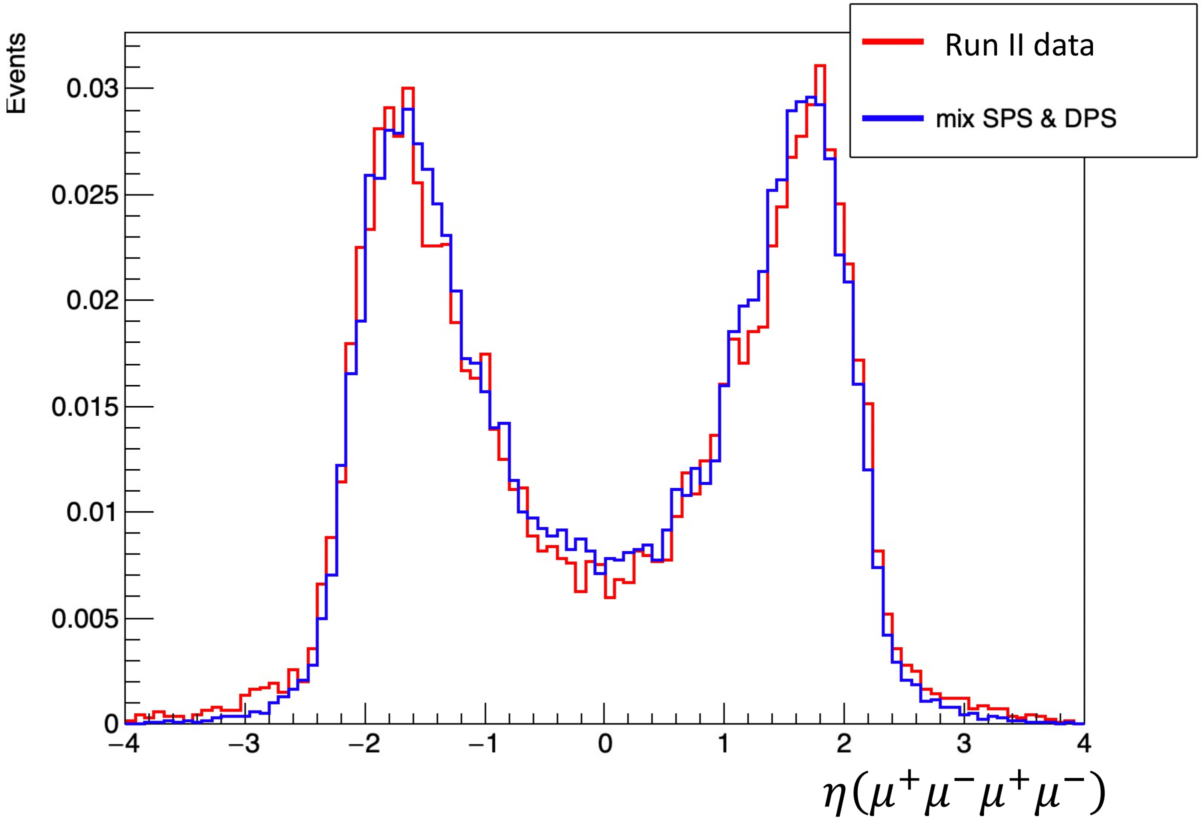
  Check the final distribution with the low filter efficiency

Tuning for NRSPS

✓ Best one (NRSPS): *pTdampMatch* = 1; *renormMultFac* = 10; *pTmaxFudge* = 2

New pythia configuration for NRSPS

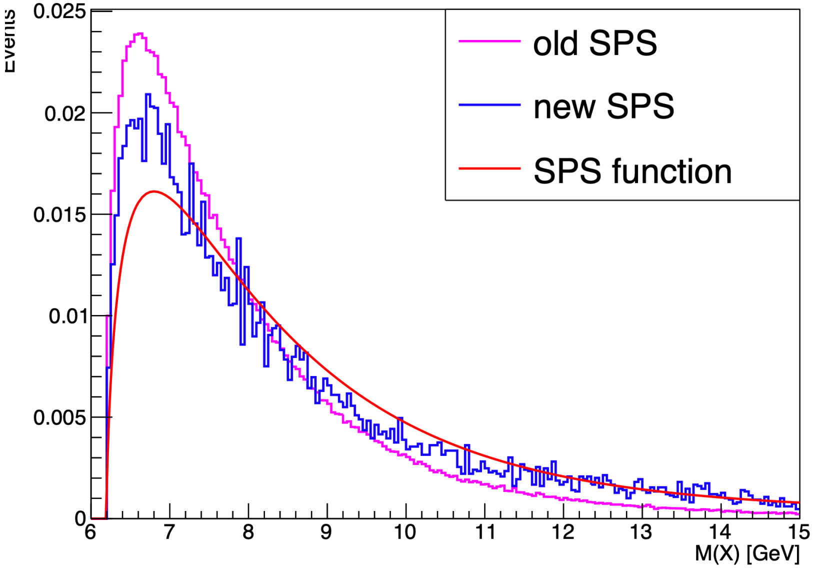




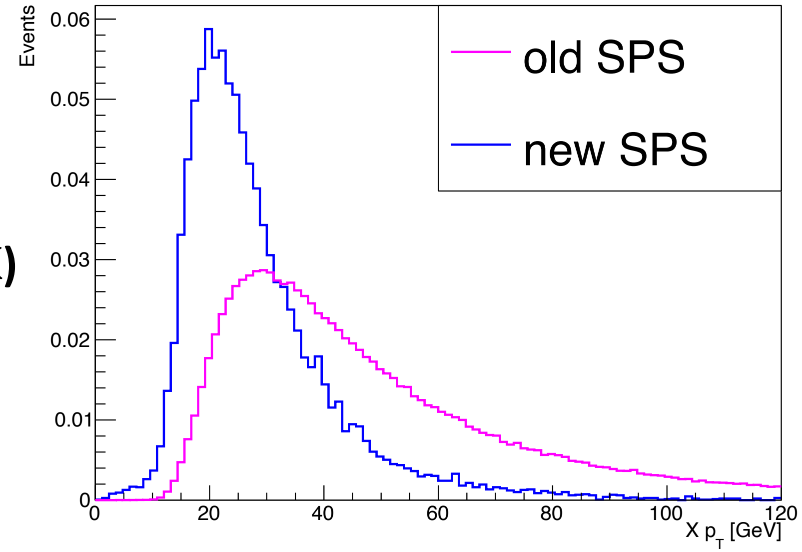
Old SPS vs. new SPS

- Old SPS vs. new SPS in mass region M[X] ∈ [6, 15] GeV

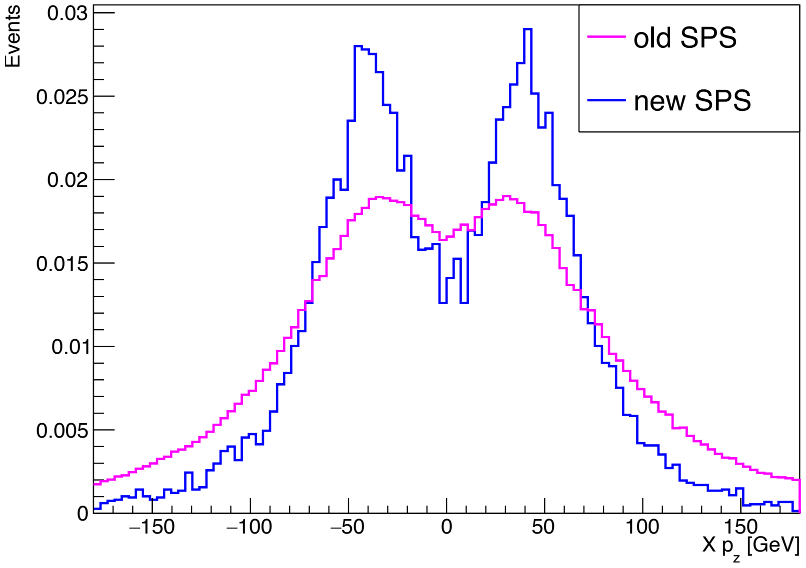
$M(X)$



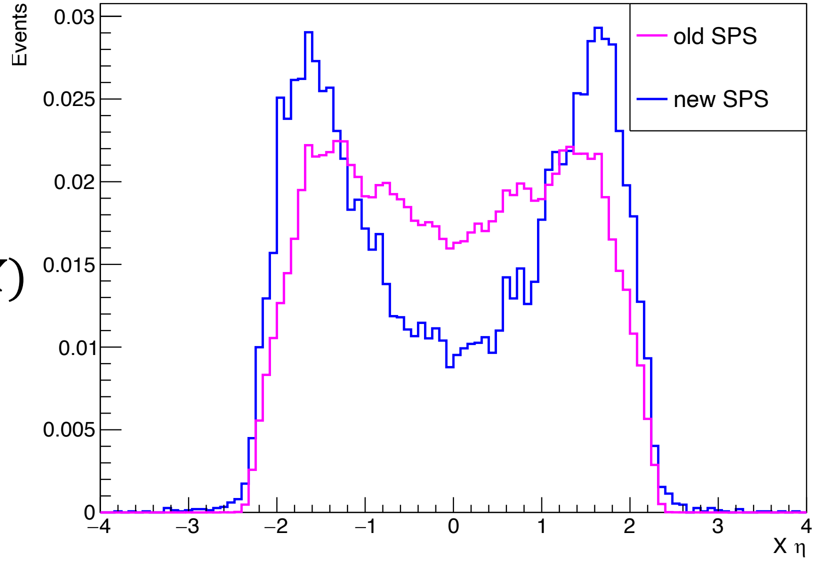
$p_T(X)$



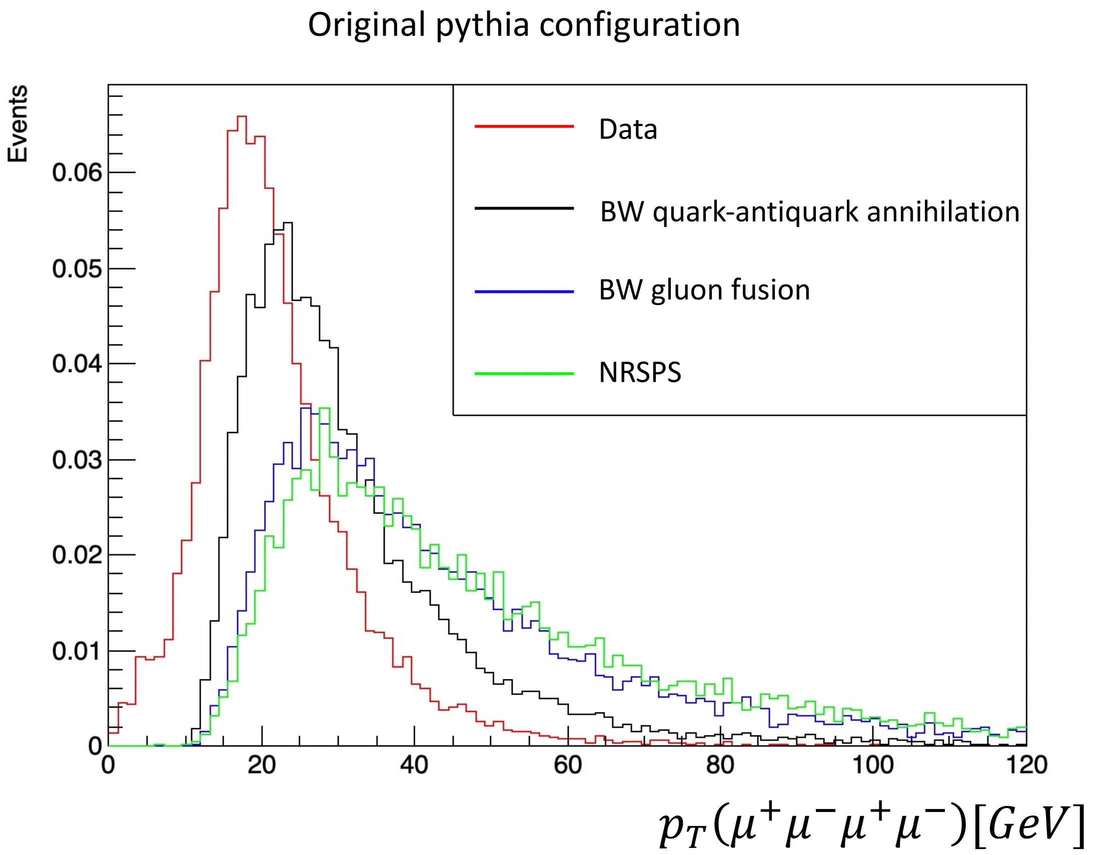
$p_z(X)$



$\eta(X)$

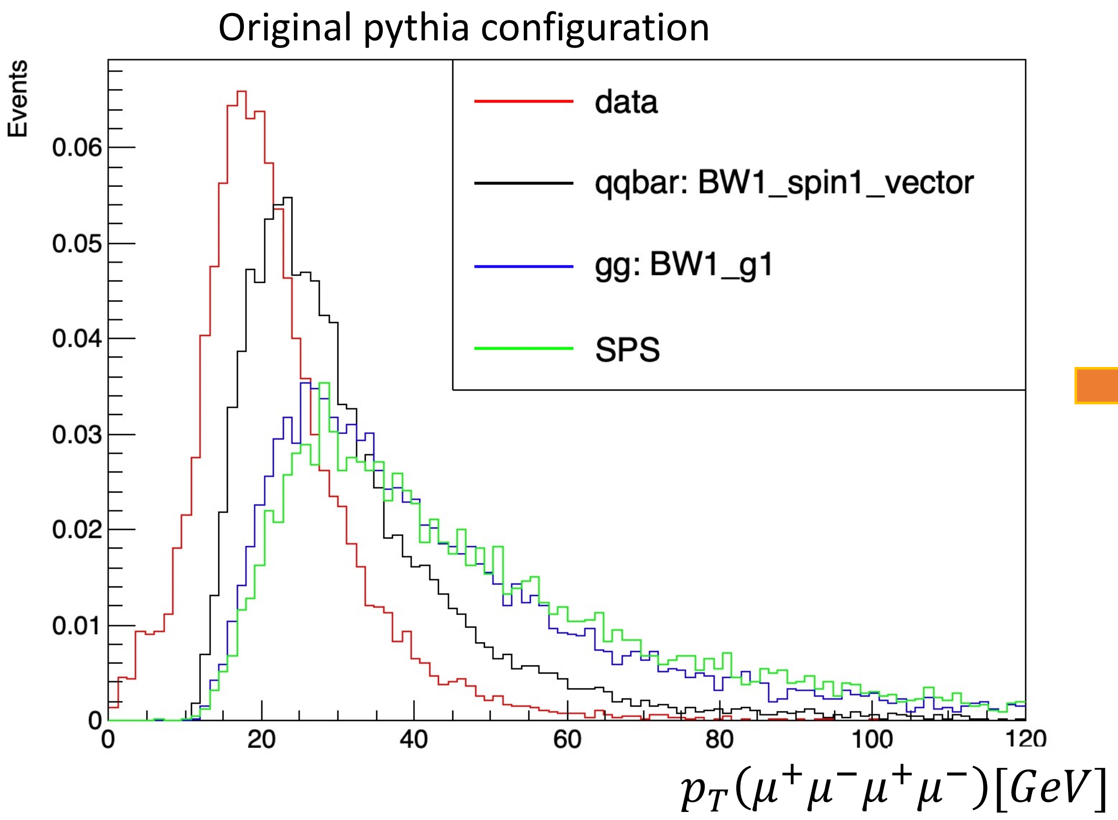


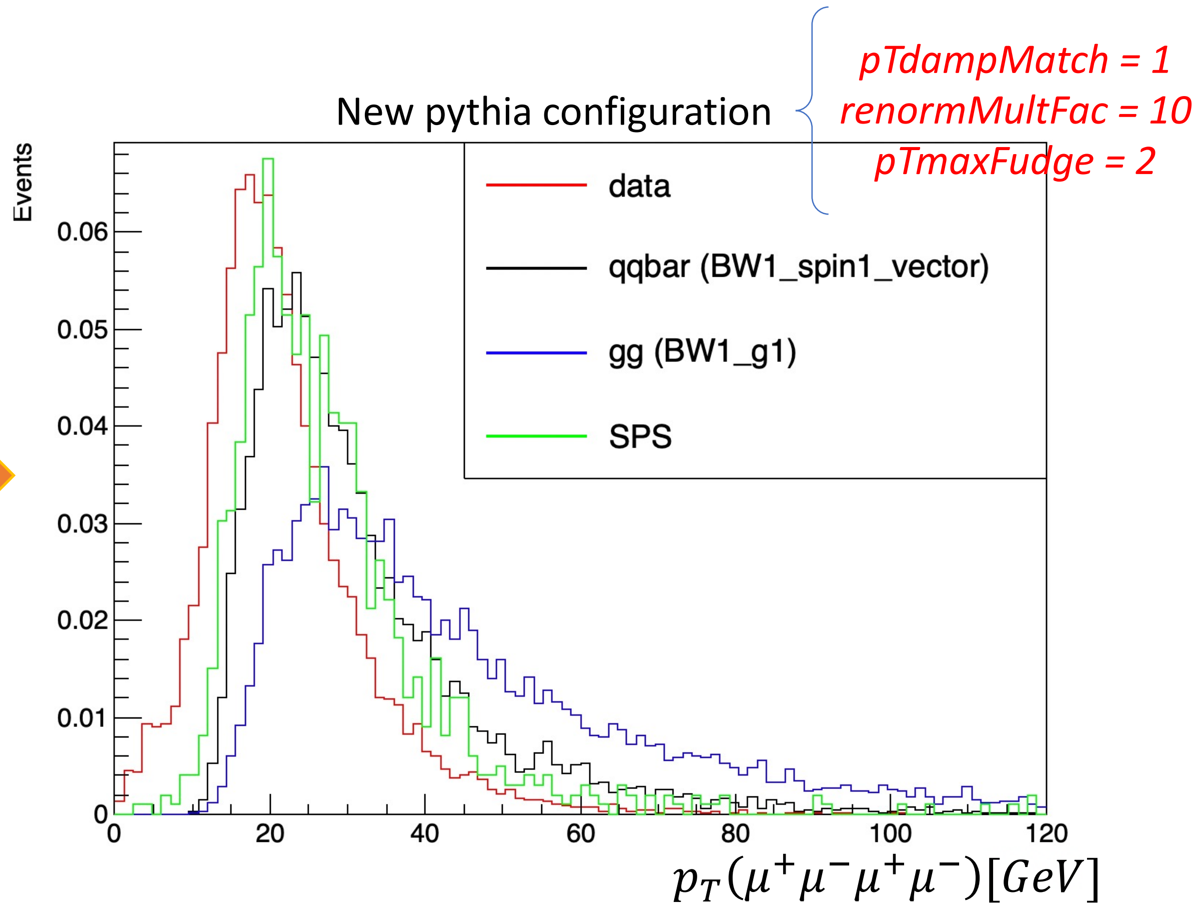
Tuning for signal MC



- NRSPS and gluon fusion signal MC look similar
- Both disagree with data
- Also need to tune down for signal MC
  - With the same new configuration in pythia?

❖ p_T distribution after final event selection





❖ Useless for *pTdampMatch*

Tuning for signal MC

- Solution
  - *SpaceShower:pTmaxMatch* (default = 0; minimum = 0; maximum = 2)

  - *SpaceShower:pTmaxMatch = 0* (handled by Pythia)
    - Pythia will decide on the scale on its own (skeptical)
  - *SpaceShower:pTmaxMatch = 1*
    - Using the factorization scale written in the LHE file for hadronization
    - Typically, f.scale=$\sqrt{s}/2$ in $JHUGen/MCFM$

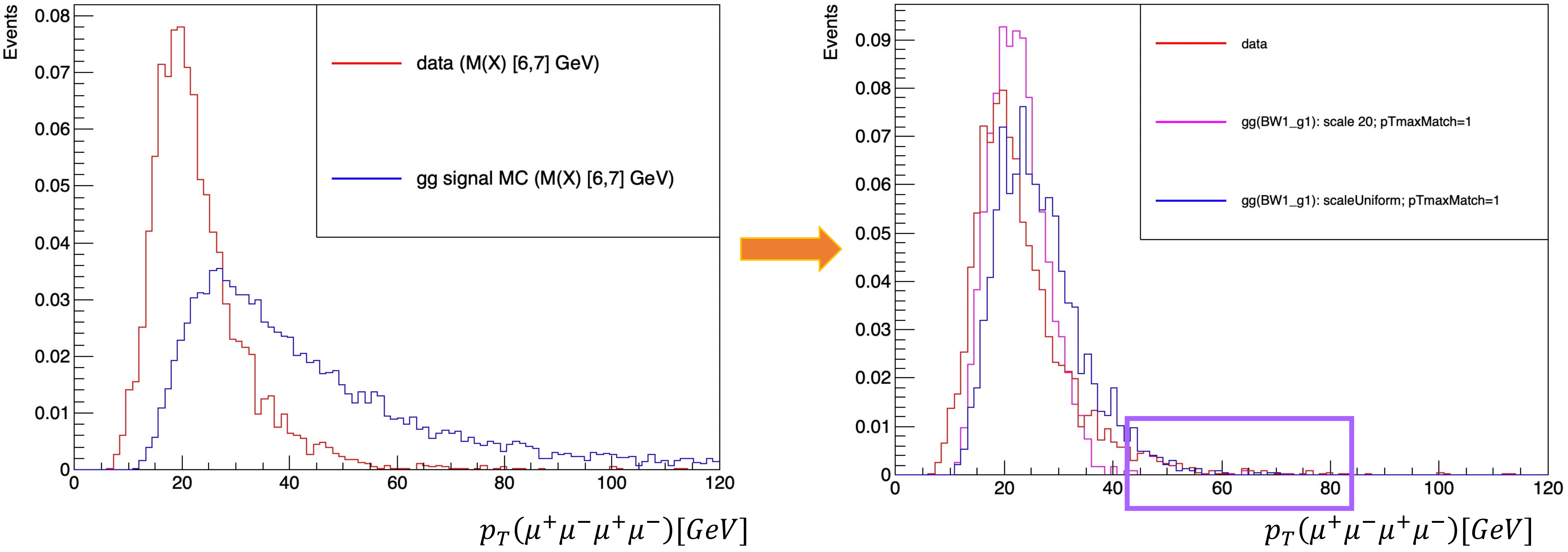
```
<event>
 9   0   1.0000000E+00   3.3773111E+00   7.8125000E-03   2.4261082E-01
       21    -1     0     0   501   502  0.00000000000E+00  0.00000000000E+00  4.37192829967E+02  4.37192829967E+02  0.00000000000E+00  0.00000000000E+00  1.
       21    -1     0     0   502   501  0.00000000000E+00  0.00000000000E+00 -2.60897011451E-02  2.60897011451E-02  0.00000000000E+00  0.00000000000E+00  1.
       25     2     1     2     0     0  5.55111512313E-17  4.44089209850E-16  4.37166740266E+02  4.37218919668E+02  6.75462220309E+00  0.00000000000E+00  1.
       23     2     3     3     0     0 -8.69450171996E-01 -4.59448687949E-01  2.77629666559E+02  2.77648701702E+02  3.09883304940E+00  0.00000000000E+00  1.
       23     2     3     3     0     0  8.69450171996E-01  4.59448687949E-01  1.59537073707E+02  1.59570217966E+02  3.09992551855E+00  0.00000000000E+00  1.
       13     1     5     5     0     0  1.01408107963E-01  2.46111044281E-02  3.44282032621E-01  3.74944615126E-01  1.05660000021E-01  0.00000000000E+00  1.
      -13     1     4     4     0     0  7.93004151926E-02 -1.63247125182E+00  1.09705510312E+02  1.09717735156E+02  1.05660000047E-01  0.00000000000E+00  1.
       13     1     4     4     0     0 -9.48750587189E-01  1.17302256387E+00  1.67924156247E+02  1.67930966546E+02  1.05660000090E-01  0.00000000000E+00  1.
      -13     1     5     5     0     0  7.68042064033E-01  4.34837583521E-01  1.59192791674E+02  1.59195273351E+02  1.05660000073E-01  0.00000000000E+00  1.
</event>
```

(2) Event information, repeated as many times as there are events
(a) one line with common event information:
NUP IDPRUP XWGTUP SCALUP AQEDUP AQCDUP
(b) NUP lines, one for each particle I in the range 1 through NUP
IDUP(I) ISTUP(I) MOTHUP(1,I) MOTHUP(2,I) ICOLUP(1,I)
ICOLUP(2,I) PUP(1,I) PUP(2,I) PUP(3,I) PUP(4,I) PUP(5,I)
VTIMUP(I) SPINUP(I)

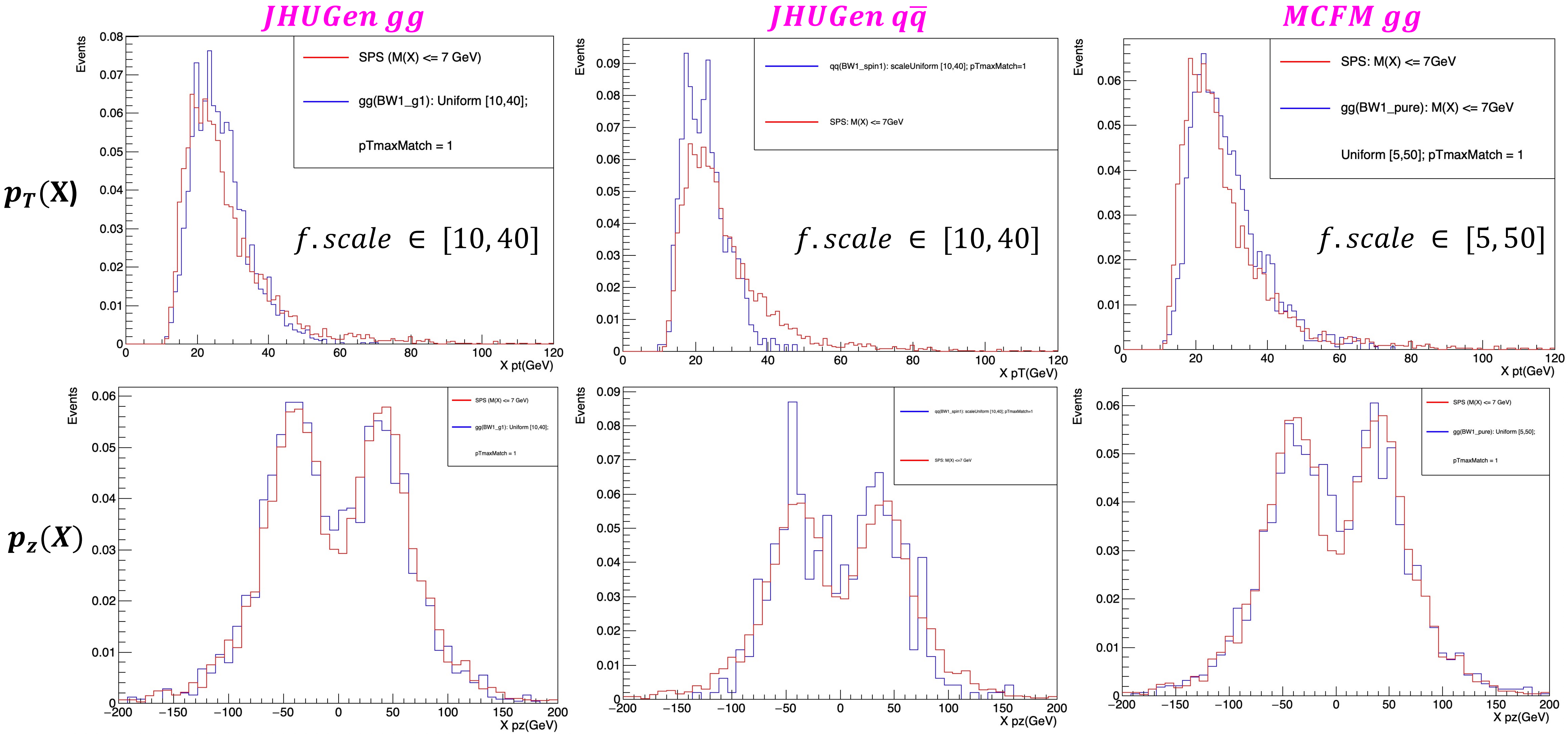
- With the *pTmaxFudge* parameter we scale radiation up or down somewhat

- To enlarge the p_T when using *ptMaxMatch = 1*, try different f.scale:
  - $f.scale$ = some large fixed numbers (e.g. 20/50/100)
  - $f.scale$ = uniformly distributed in a range (e.g. [10,40])

- Best constant: $f.scale\ =\ 20$
- To describe the right tail in data:
  - ✓ $f.scale\ \in\ Uniform\ [10, 40]$

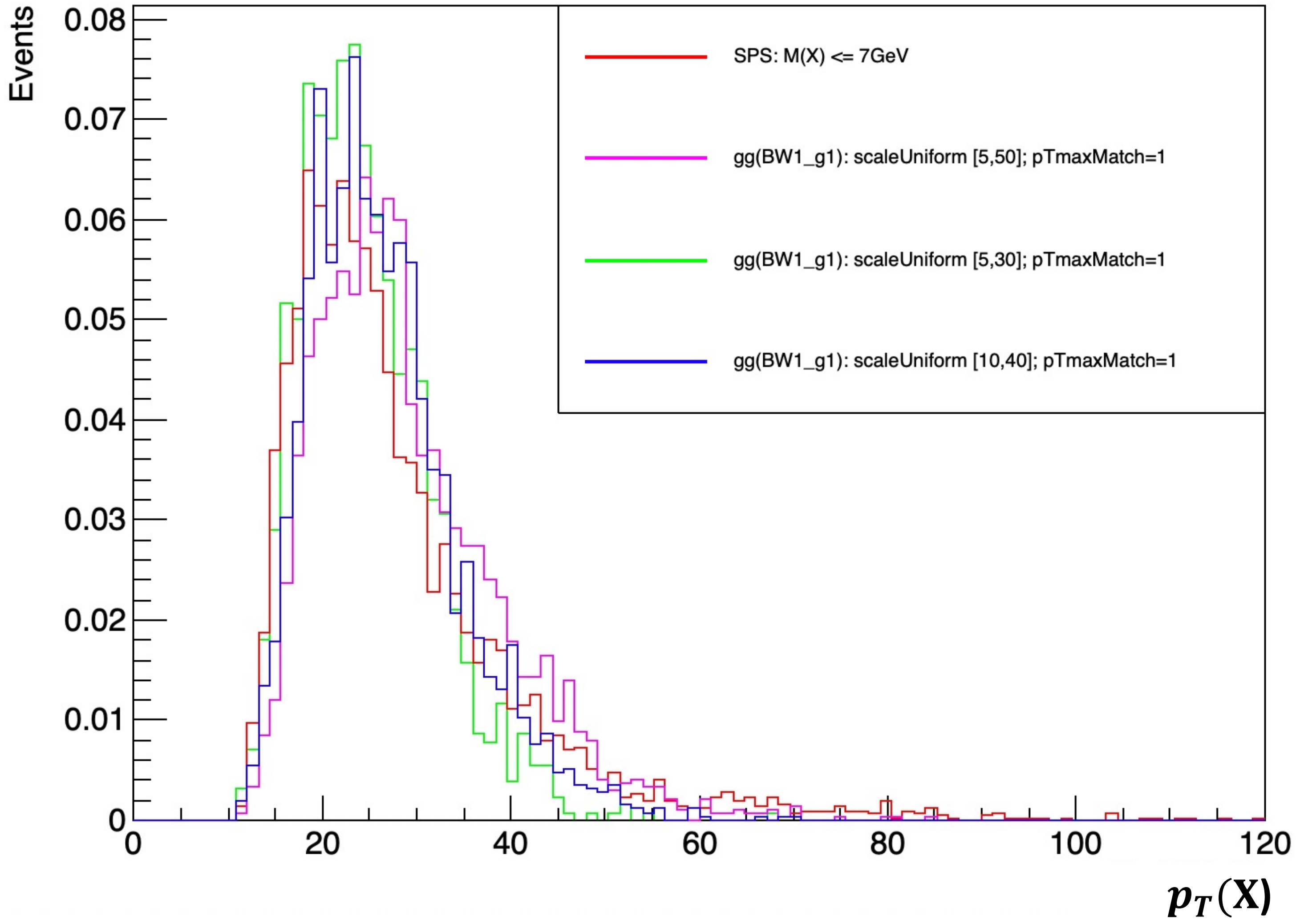


❖ SPS vs signal MC

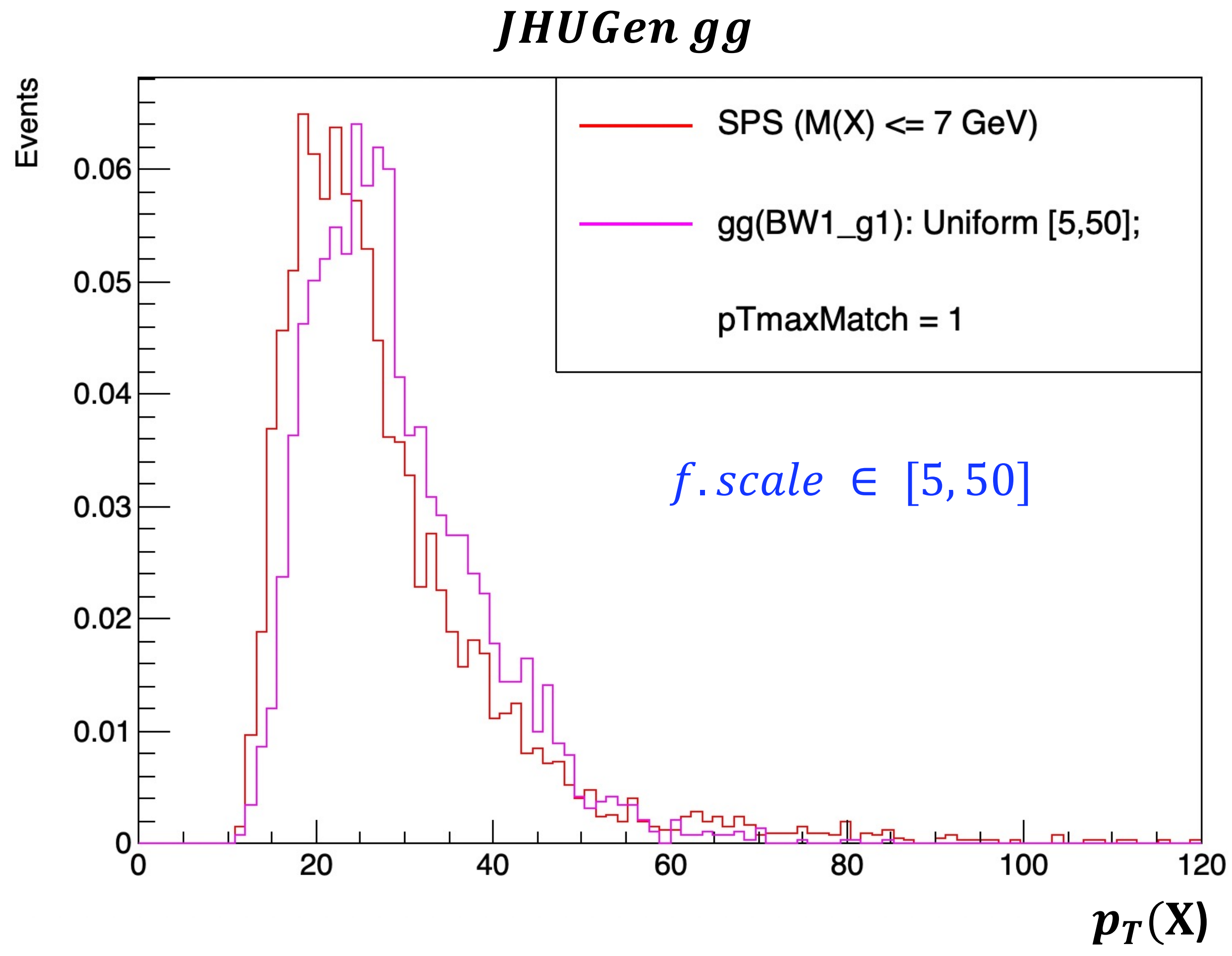


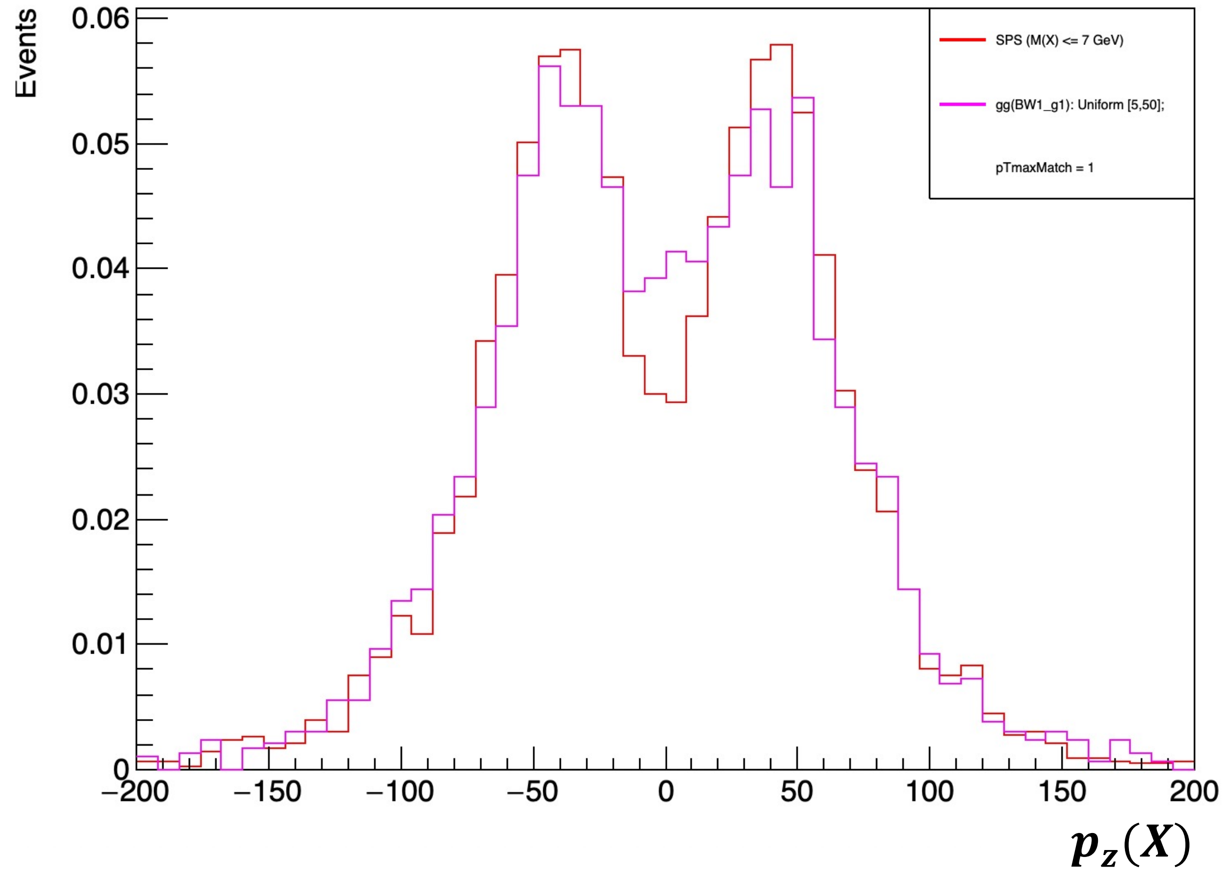
Tuning for signal MC

- $f.scale \in [5,30]/[10,40]/[5,50]$
- To cover more, choose $f.scale \in [5,50]$



- Developed a new version of the JHUGen generator with changeable $f.scale$: V7.5.4
- Check with new version:





- ❑ Inconsistent kinematic distributions between data and MC samples

- ❑ Solved mostly by tuning in pythia8 [Green light in the Generator Meeting on Oct 16]
  - **NRSPS MC**:
    - ✓ *pTdampMatch=1, renormMultFac=10, pTmaxFudge=2*
  - **Signal MC**:
    - ✓ *pTmaxMatch=1, f.scale ∈ Uniform [5, 50]*

➢ Perform **sideband** study

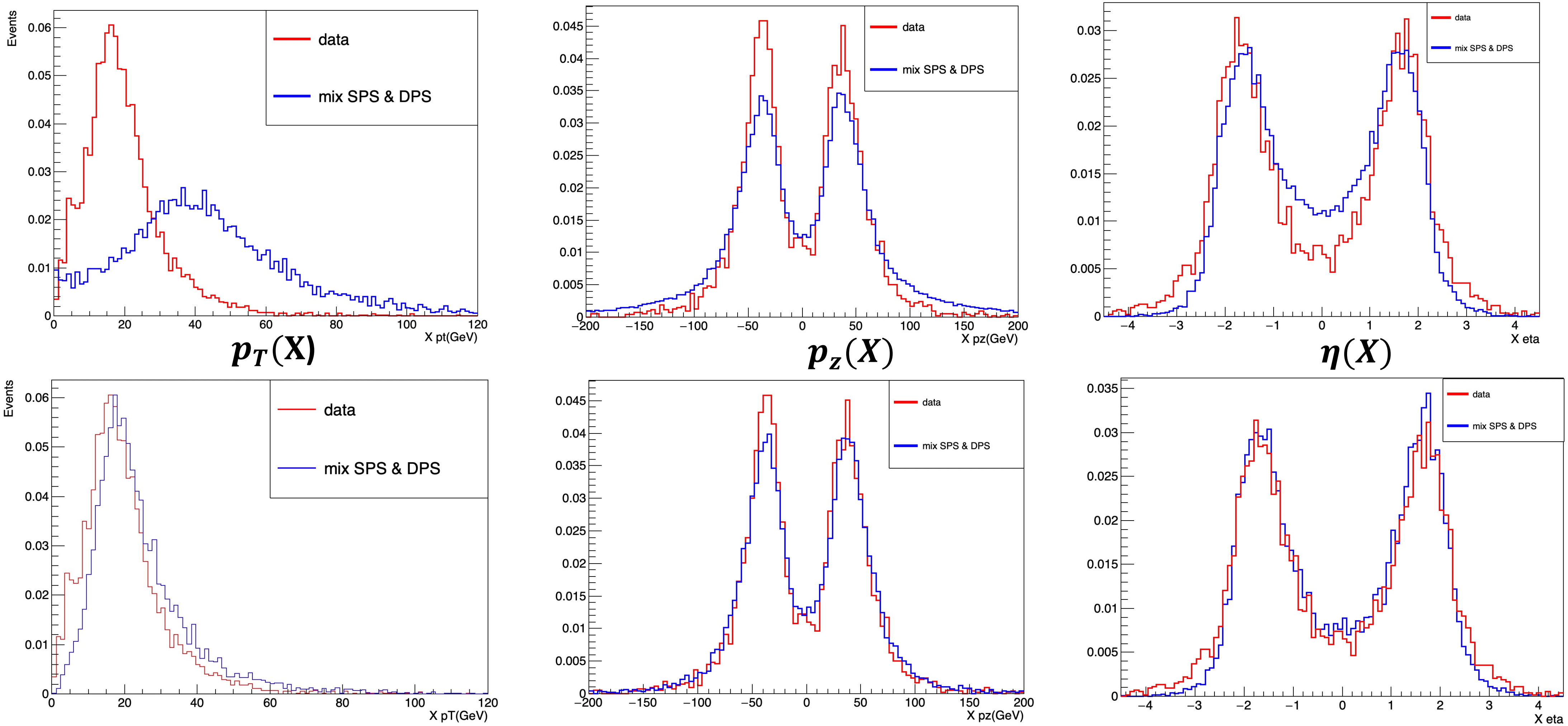
…… Let's compare in the sideband region ……

Data vs. mix of SPS & DPS in sideband

- **Sideband** mass region: M[X] ∈ [9, 15] GeV
- Kinematic distributions in sideband: data vs. mix of SPS & DPS
- More consistent with **new** SPS

Old SPS

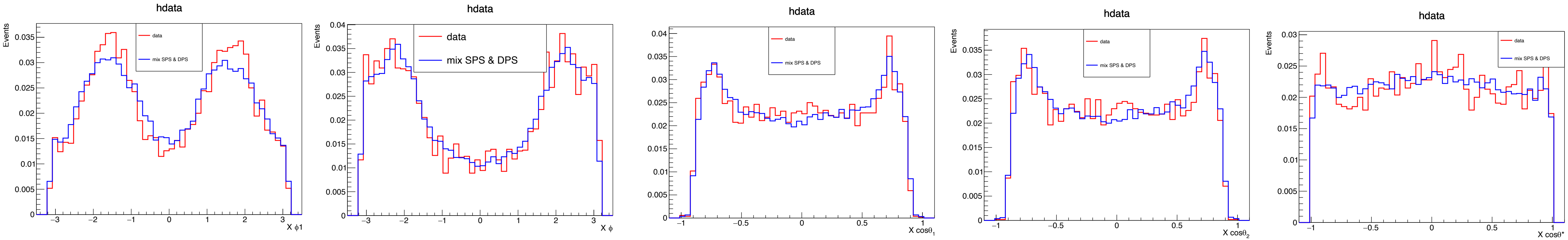
New SPS



Data vs. mix of SPS & DPS in sideband

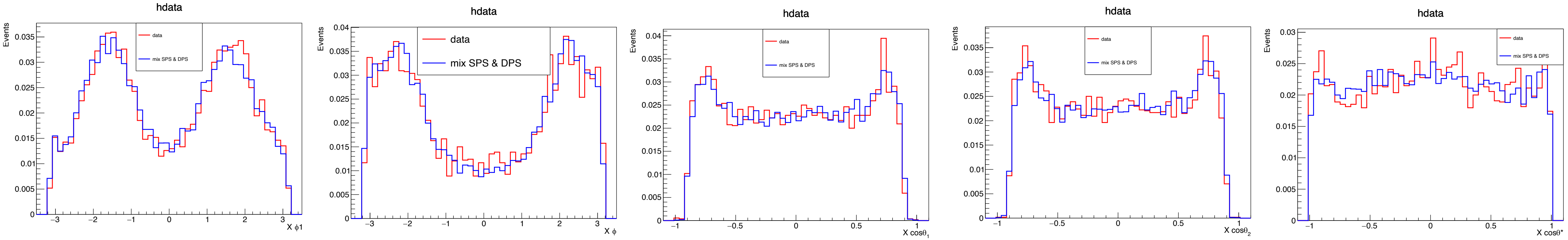
- Angle distributions in **sideband**: data vs. mix of SPS & DPS
- More consistent with **new** SPS

Old SPS

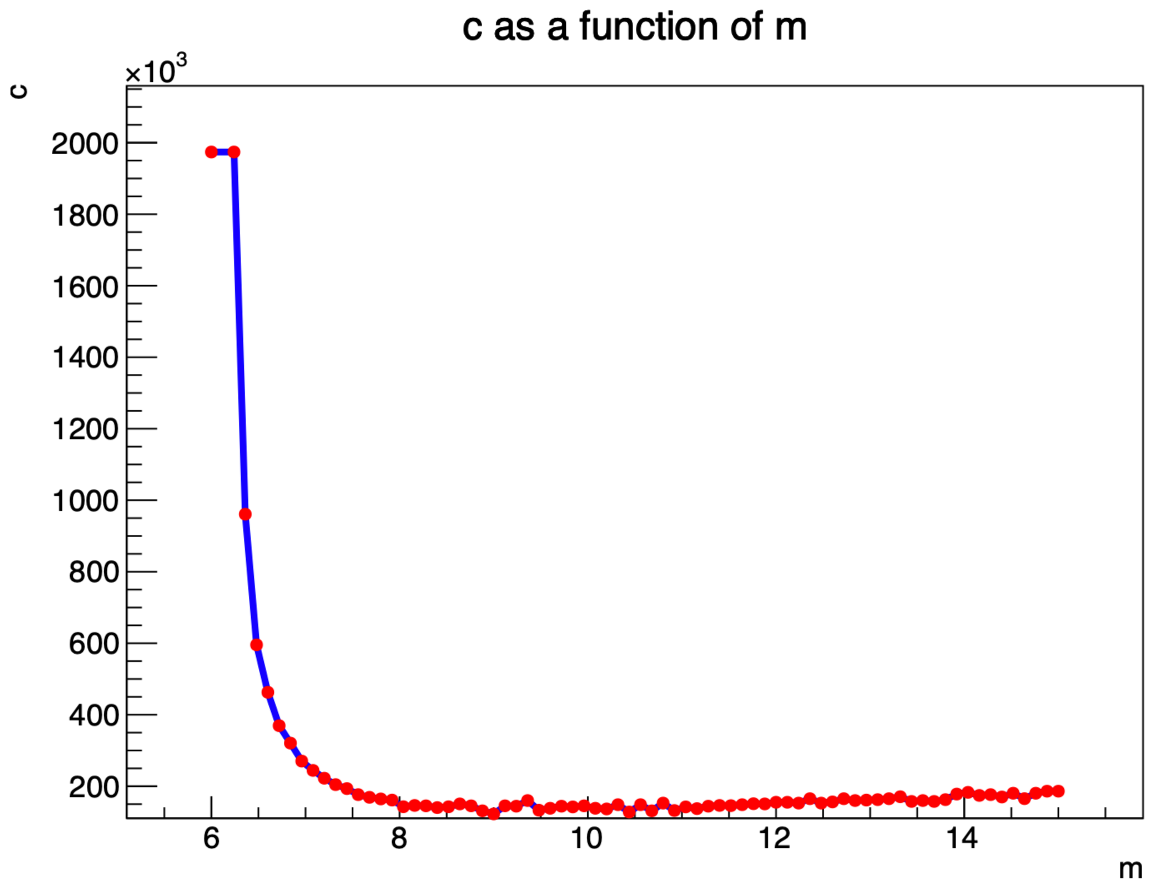


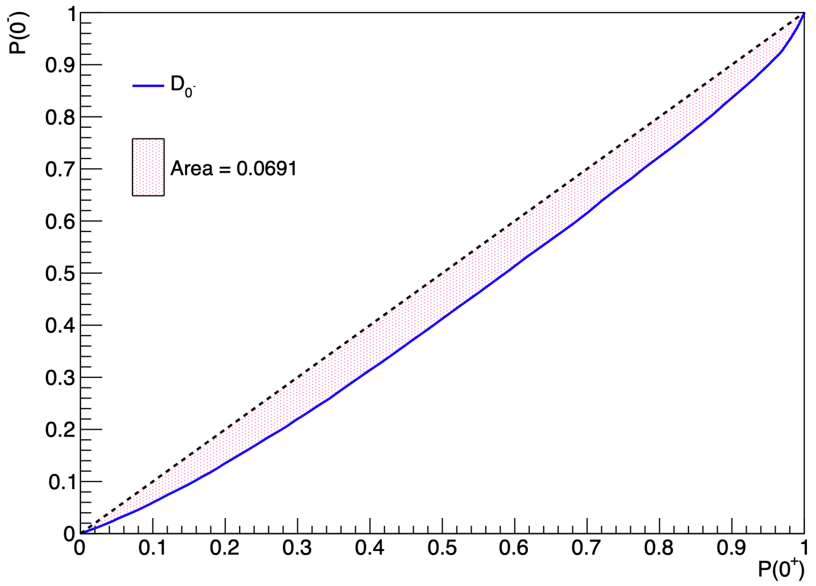
ϕ_1 ϕ $\cos\theta_1$ $\cos\theta_2$ $\cos\theta^*$

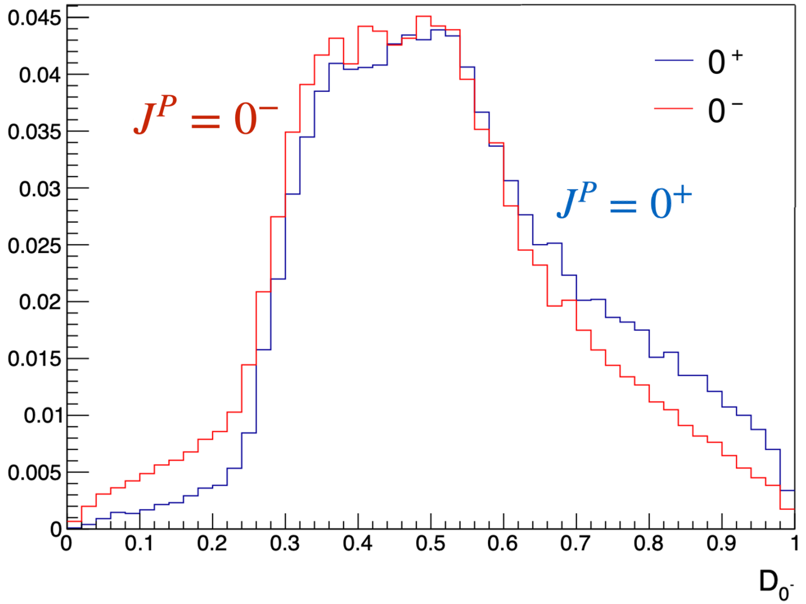
New SPS



- Get mass dependent c-curve using 0^+ and 0^- signal samples
- Discriminant to distinguish 0^+ and 0^-: $D_{0^-} = \frac{p(0^+)}{p(0^+)+cp(0^-)}$



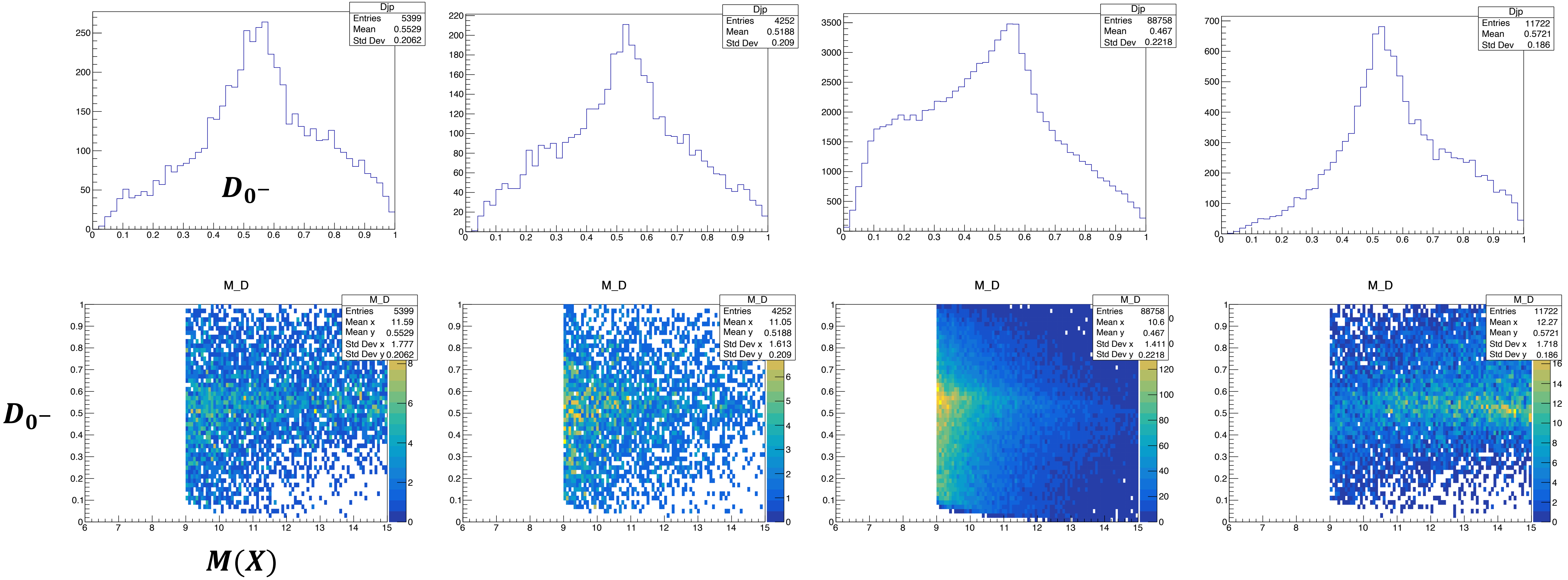




Data vs. mix of SPS & DPS in sideband

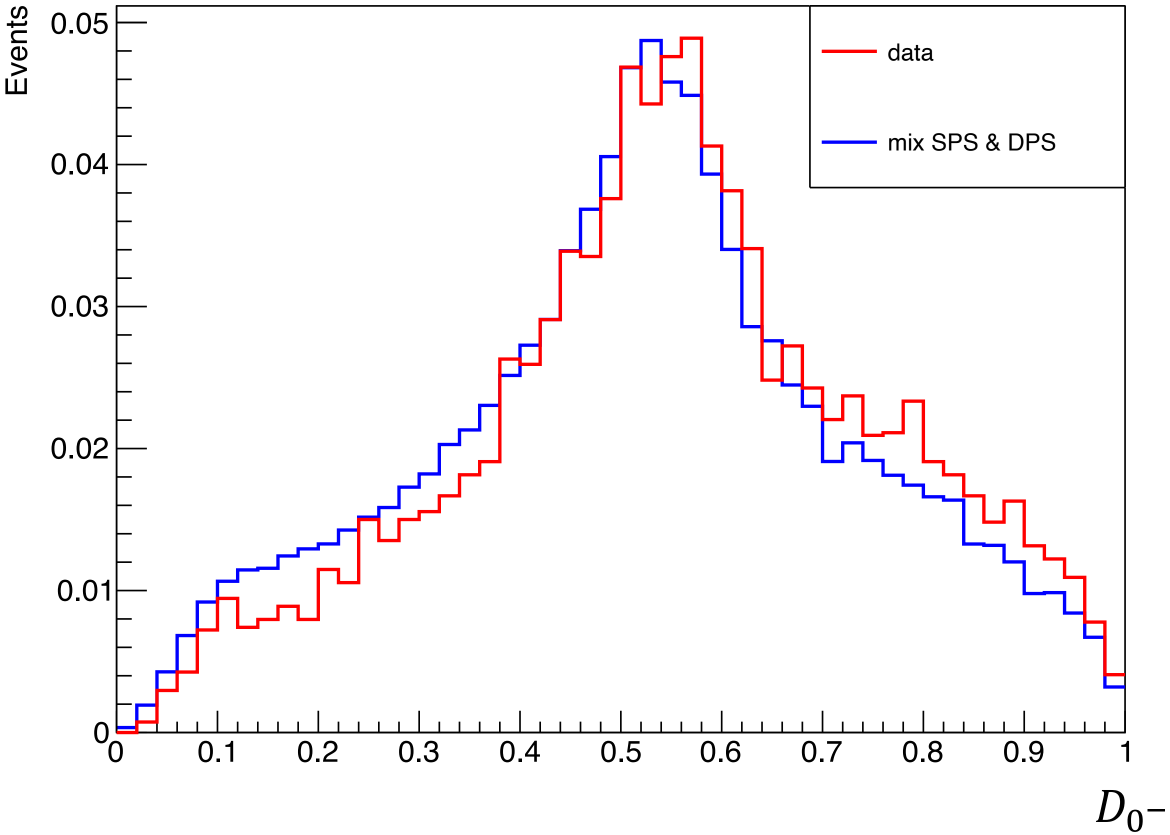
➢ D_0- **in sideband region**:

Data | **New** SPS | **Old** SPS | DPS

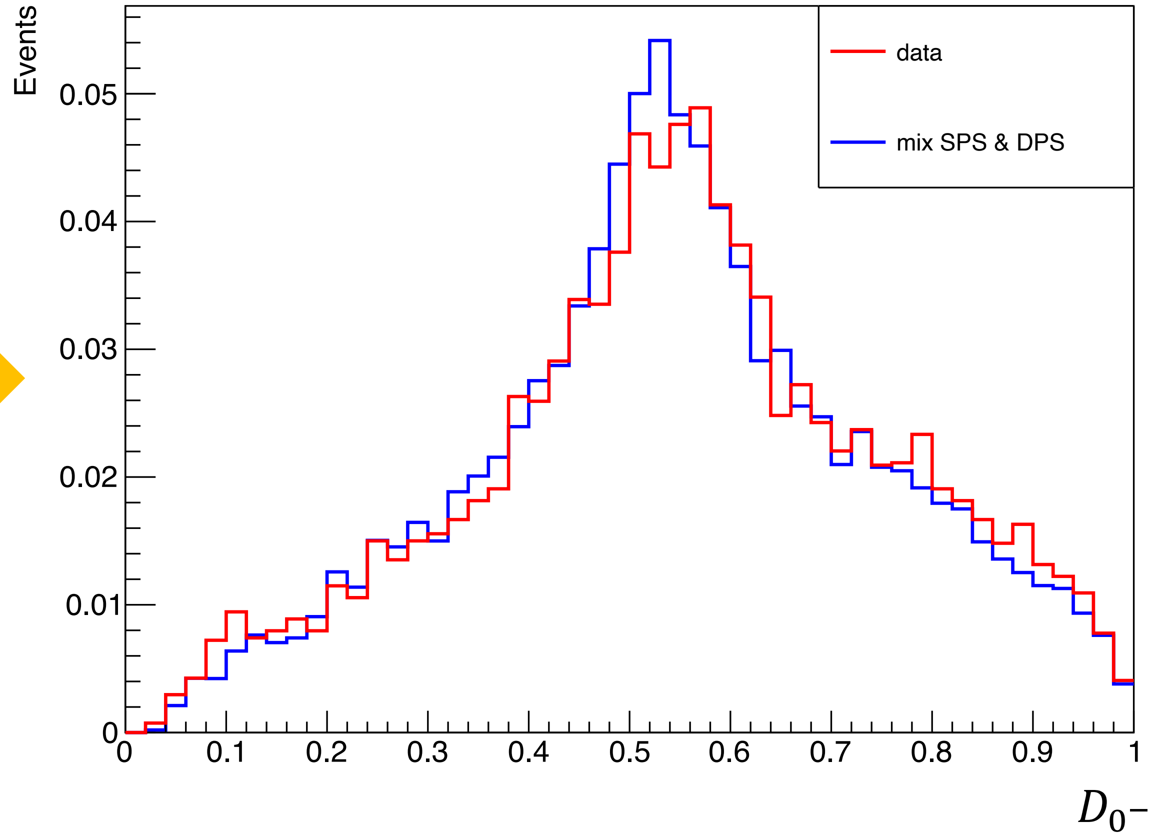


- D_{0^-} **in sideband region**: comparison of data and mix of SPS & DPS
- More consistent with **new** SPS

Old SPS



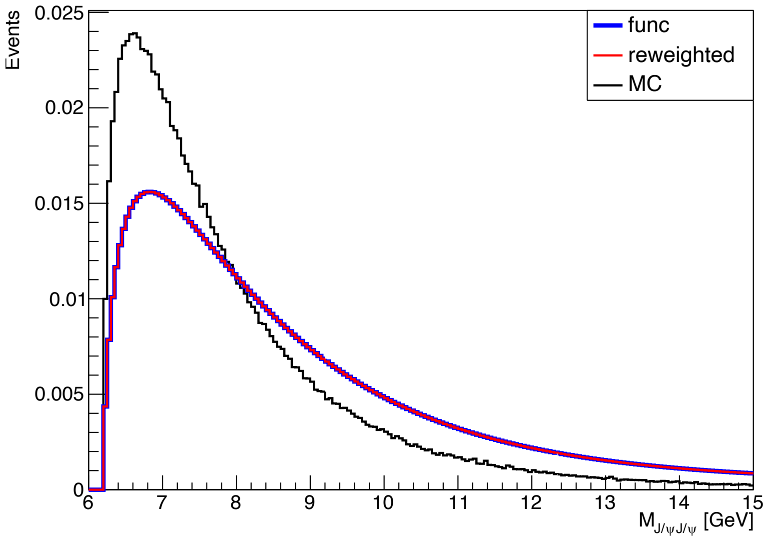
New SPS



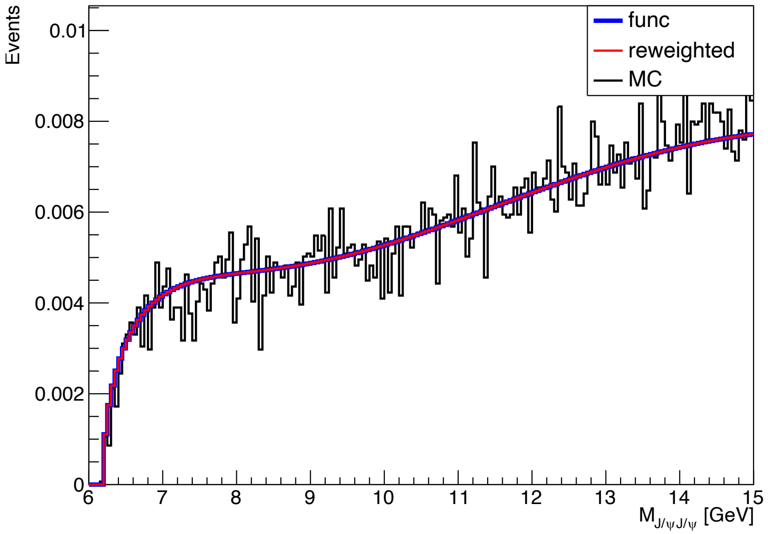
Apply reweight

- Reweight mass for SPS & DPS to the fitting functions
- $J/\psi J/\psi$ mass spectrum in [6, 15] GeV:

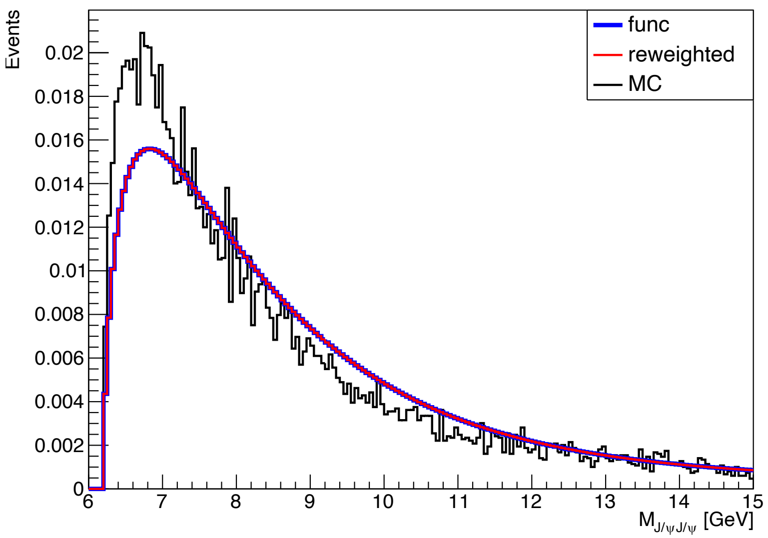
Old SPS



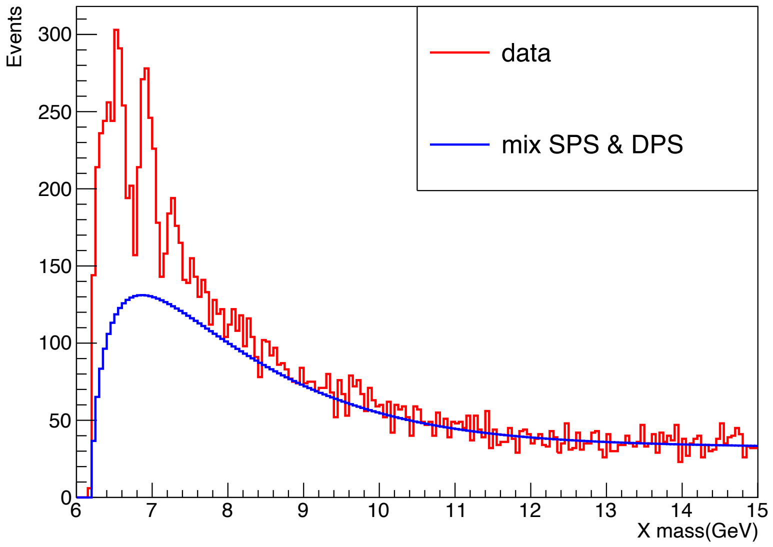
DPS



New SPS

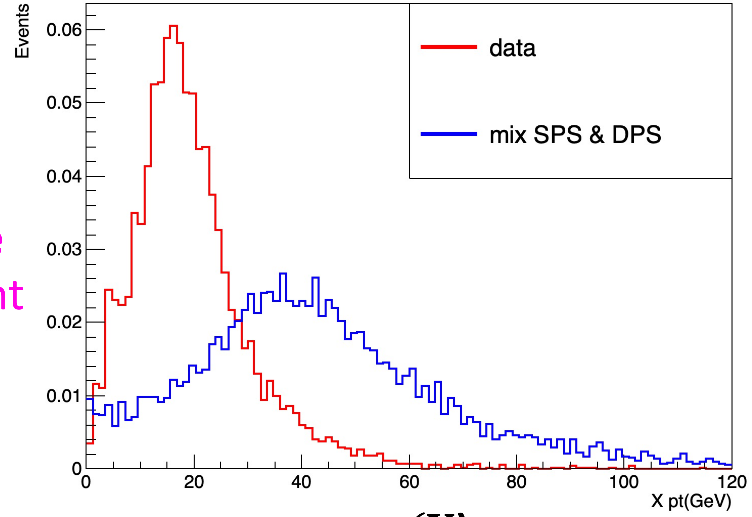


Mix of SPS & DPS

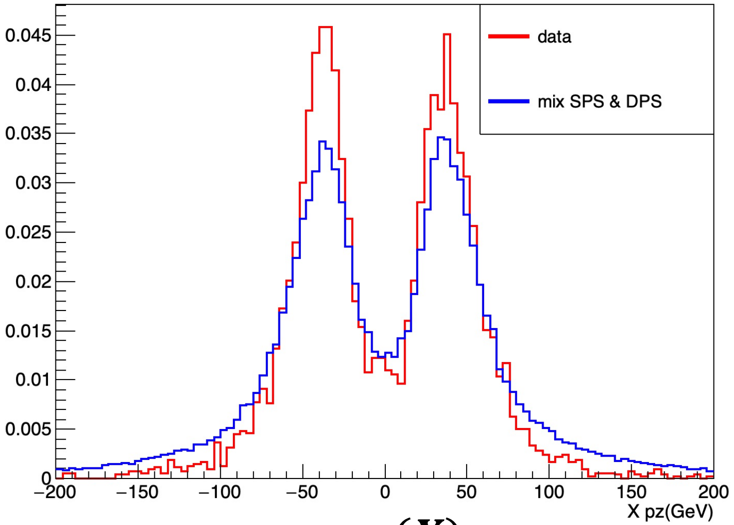


- Kinematic distributions of data vs. mix of SPS & DPS **after reweight** in sideband region:
- For **old** SPS:

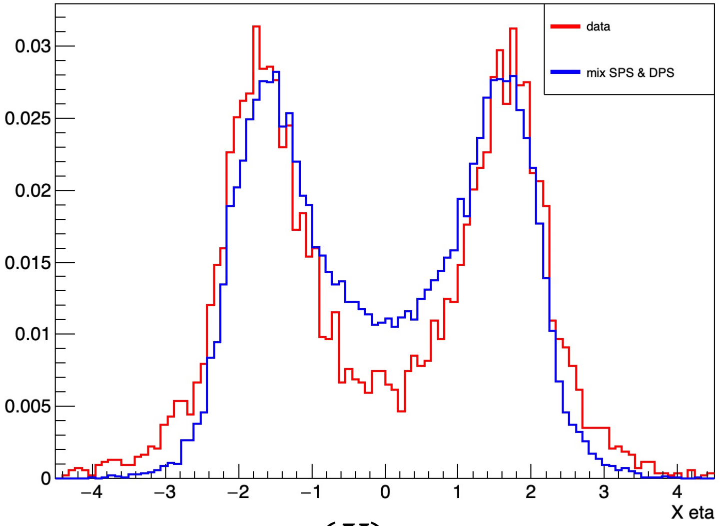
Before reweight



$p_T(\mathbf{X})$

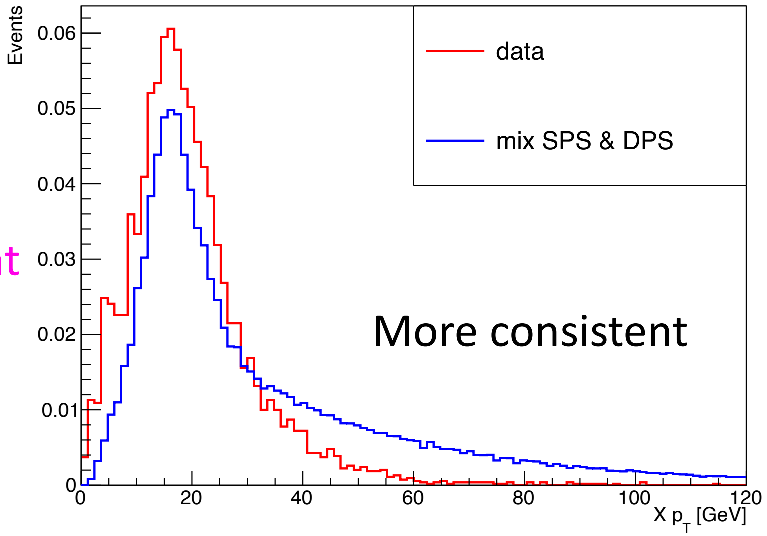


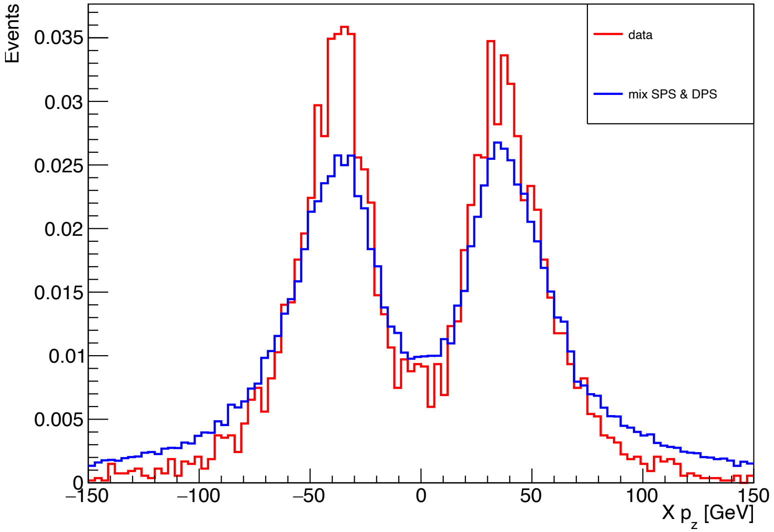
$p_z(X)$

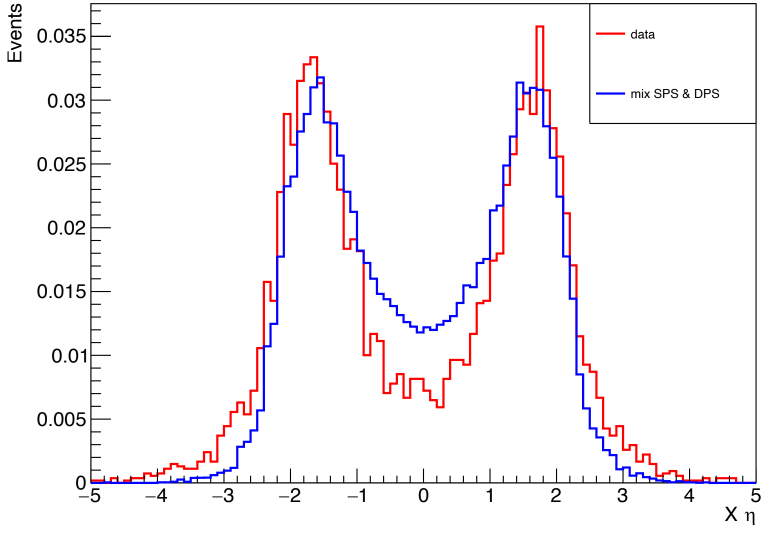


$\eta(X)$

After reweight

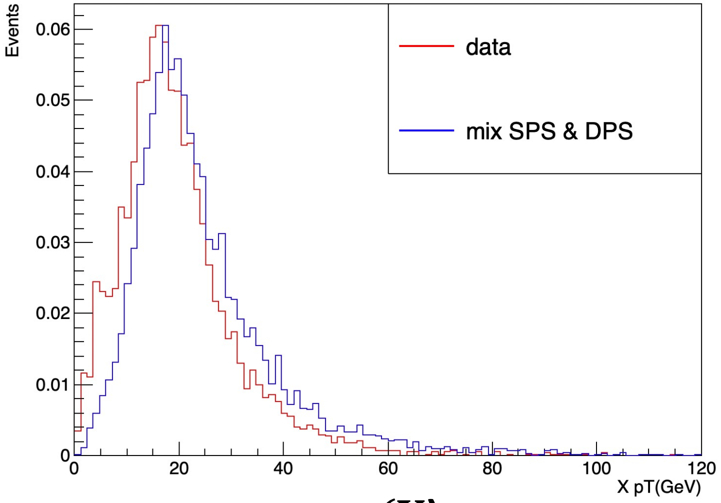




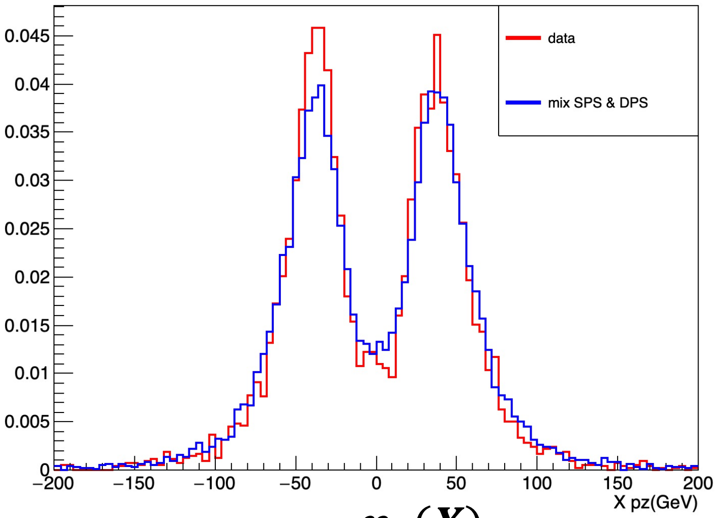


- Kinematic distributions of data vs. mix of SPS & DPS **after reweight** in sideband region:
- For **new** SPS:

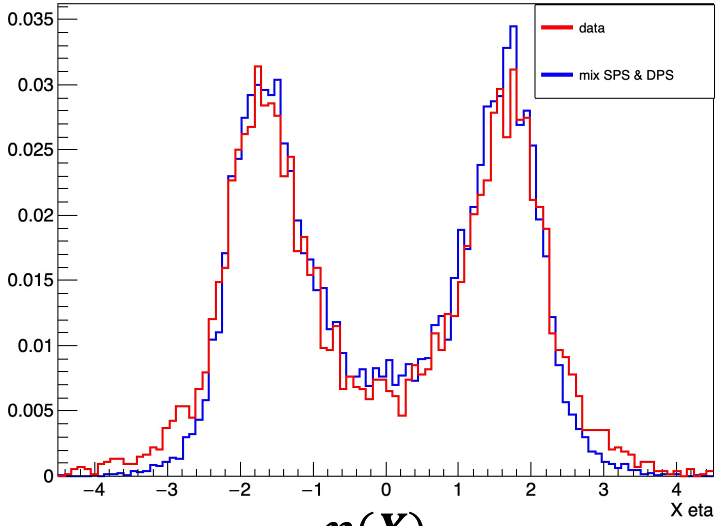
Before reweight



$p_T(X)$

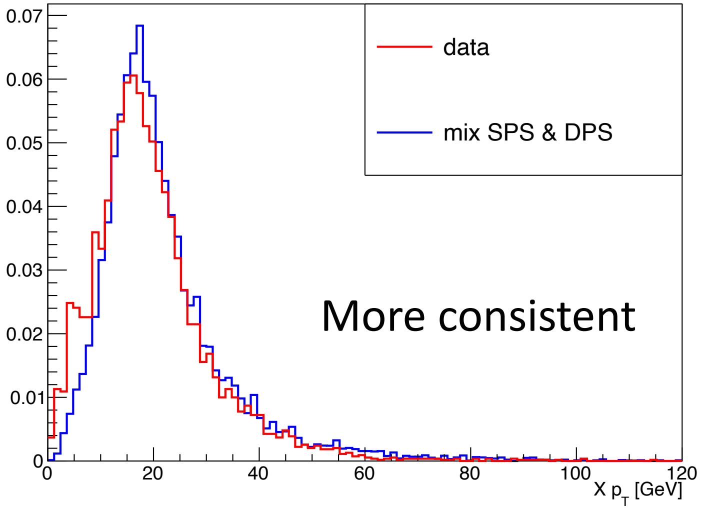


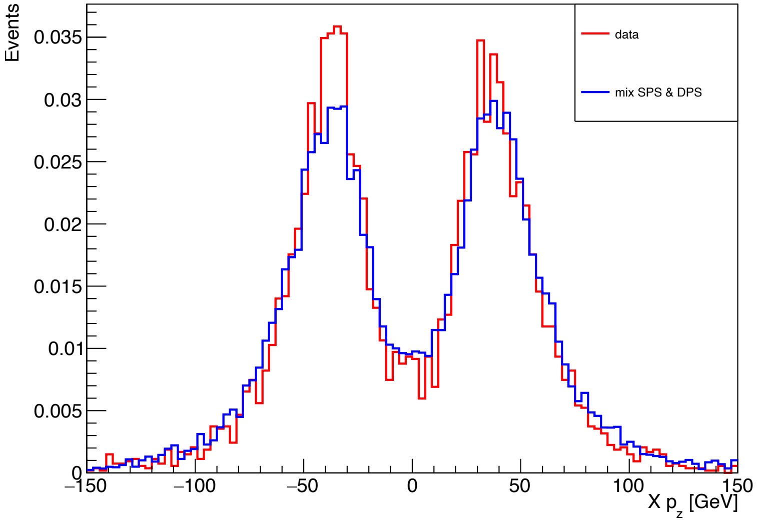
$p_z(X)$

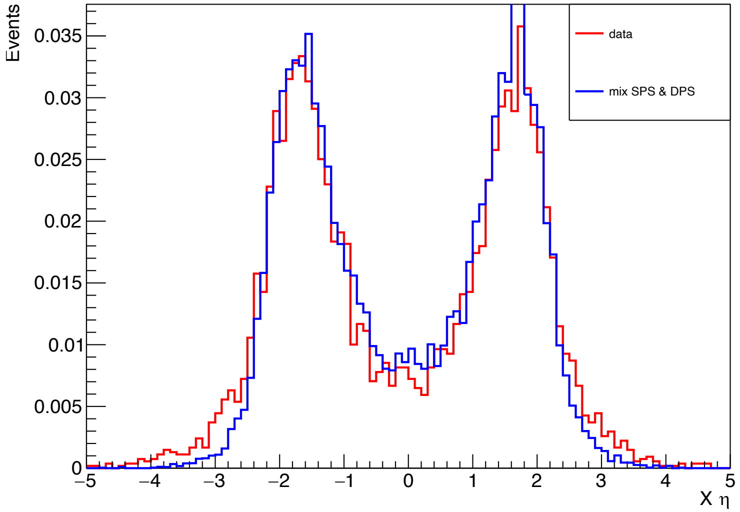


$\eta(X)$

After reweight

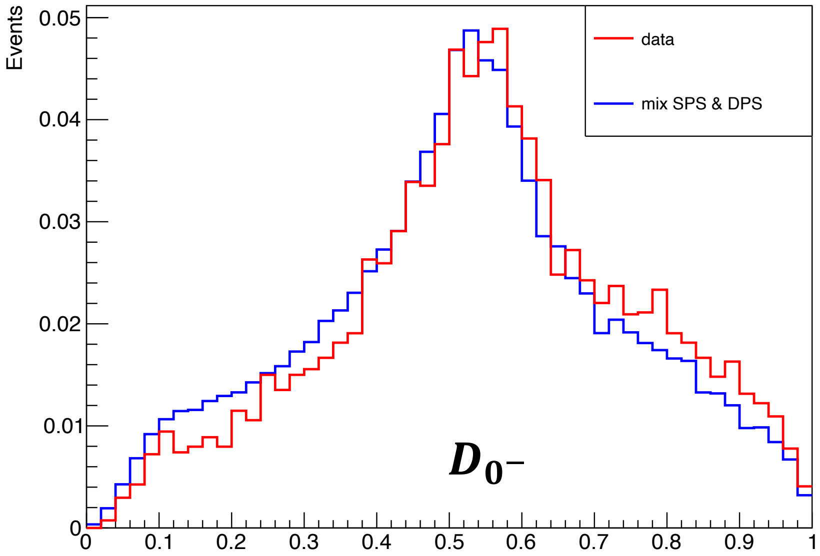




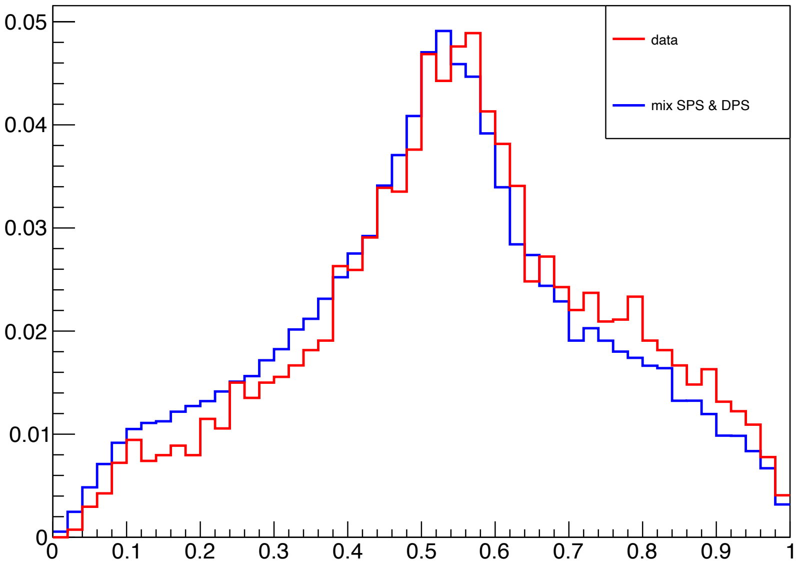


Data vs. mix of SPS & DPS in sideband

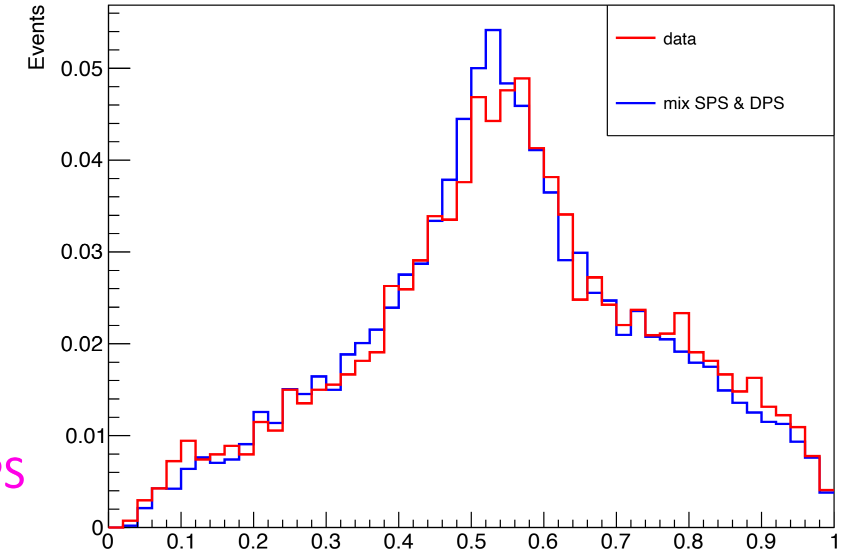
- D_0- **in sideband region**: comparison of data and mix of SPS & DPS

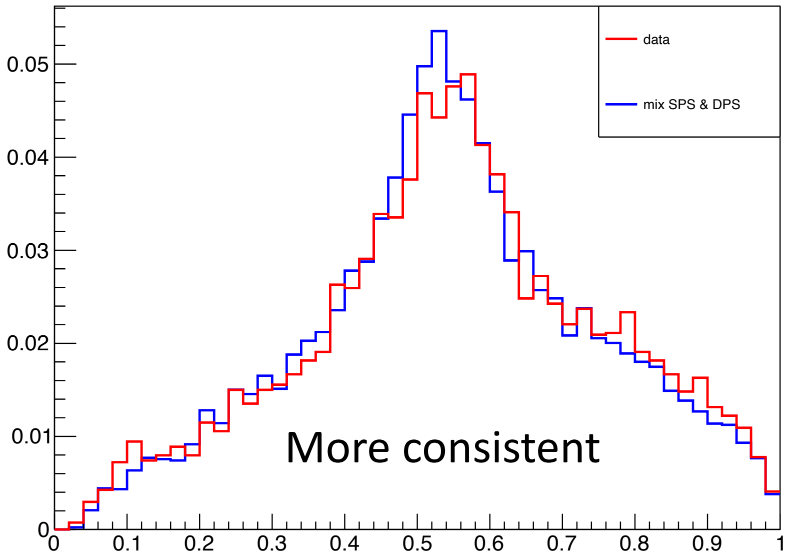


Reweight mass



Old SPS → **new** SPS





- ❖ Inconsistent kinematic distributions between data and MC samples

- ❖ Solved mostly by tuning in pythia8 [Green light in the Generator Meeting on Oct 16]
  - **NRSPS MC**:
    - ✓ *pTdampMatch=1, renormMultFac=10, pTmaxFudge=2*
  - **Gluon fusion signal MC**:
    - ✓ *pTmaxMatch=1, f.scale ∈ Uniform [5, 50]*

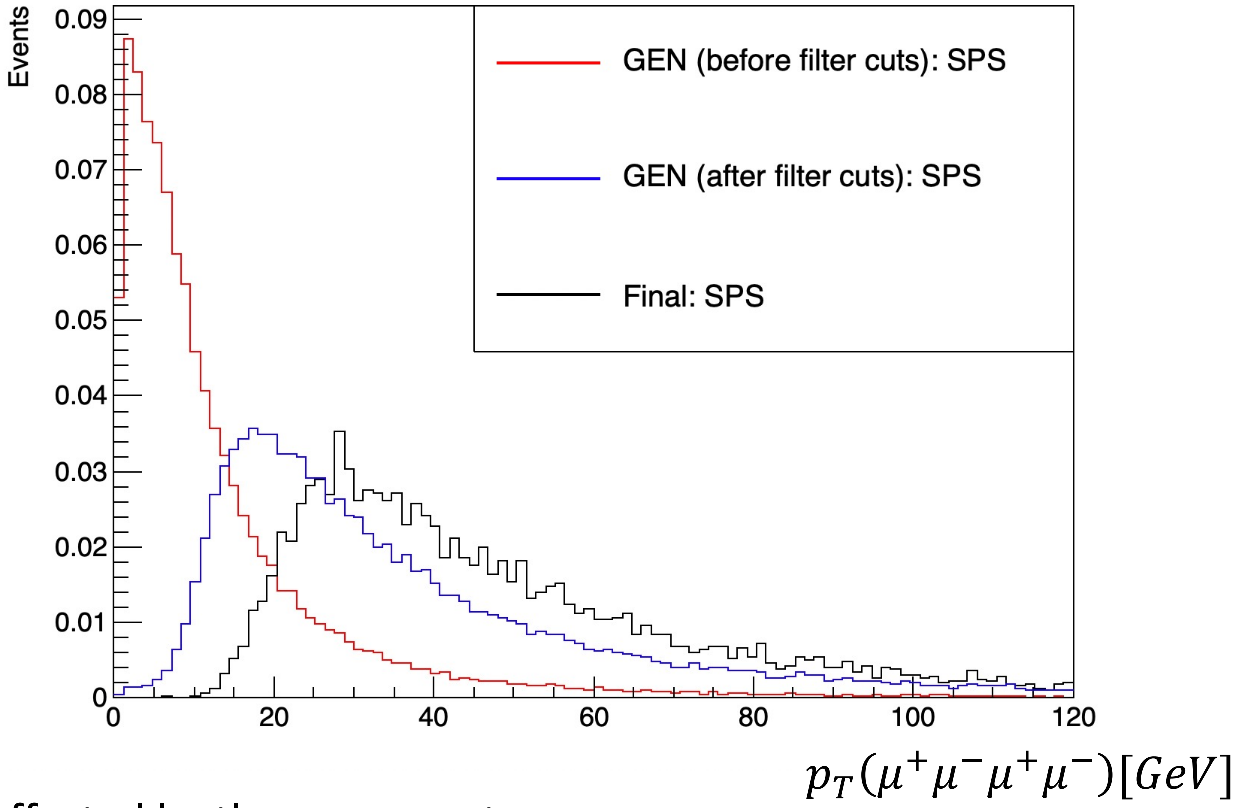
- ❖ Perform **sideband** study
  - Data vs. mix of SPS & DPS
    - ✓ More consistent with new SPS: kinematic distributions, discriminant D_{0-}
  - Reweight mass
    - ✓ More consistent for p_T distribution
    - ✓ Little effect on D_{0-}

THANKS!

Backup

Tuning for NRSPS

- p_T distributions in three stage for NRSPS
  - After Parton Shower, but before filter cuts
  - After Parton Shower, and after filter cuts
  - After final selections



- Check
  - How filter efficiency is affected by these parameters
  - $p_T(\mu^+\mu^-\mu^+\mu^-)$ distributions after final event selection

- Change *SpaceShower:pTdampMatch* = 1 (or 3) and check the pT spectrum
  - Default = 3; minimum = 0; maximum = 4
  - Filter efficiency = 1% or 10%

Configuration	Filter efficiency
origin	51153/500000=10.23%
pTdampMatch=0	50622/500000=10.12%
pTdampMatch=1	4999/500000=1.00%
pTdampMatch=2	5026/500000=1.01%
pTdampMatch=3	51052/500000=10.21%
pTdampMatch=4	51121/500000=10.22%

❖ Change *SpaceShower:renormMultFac* between 0.1 and 10 to tune it further

- Default = 1.; minimum = 0.1; maximum = 10.
- Filter efficiency: increase or decrease by ≈20%

Configuration	Filter efficiency	Configuration	Filter efficiency
pTdampMatch=1 renormMultFac=0.1	6759/500000=1.35%	pTdampMatch=3 renormMultFac=0.1	62190/500000=12.44%
pTdampMatch=1 renormMultFac=0.5	5353/500000=1.07%	pTdampMatch=3 renormMultFac=0.5	53854/500000=10.77%
pTdampMatch=1	4999/500000=1.00%	pTdampMatch=3	51052/500000=10.21%
pTdampMatch=1 renormMultFac=2	4591/500000=0.92%	pTdampMatch=3 renormMultFac=2	48147/500000=9.63%
pTdampMatch=1 renormMultFac=5	0.85%	pTdampMatch=3 renormMultFac=5	44860/500000=8.97%
pTdampMatch=1 renormMultFac=10	0.81%	pTdampMatch=3 renormMultFac=10	43519/500000=8.70%

Tuning for NRSPS

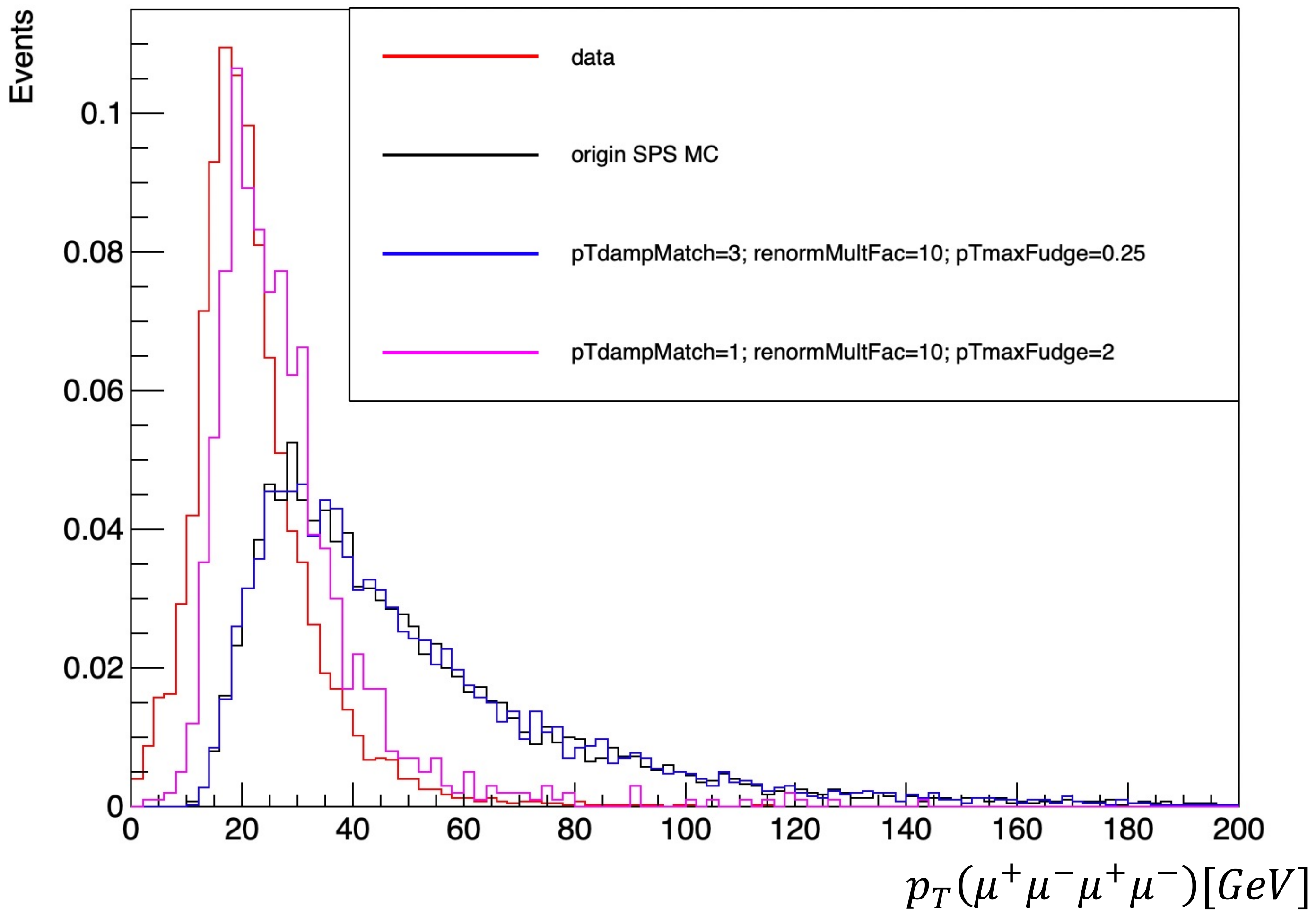
❖ Change *SpaceShower:pTmaxFudge* to tune it further if needed

- Default = 1.0; minimum = 0.25; maximum = 2.0
- Filter efficiency: increase or decrease by ≈1%

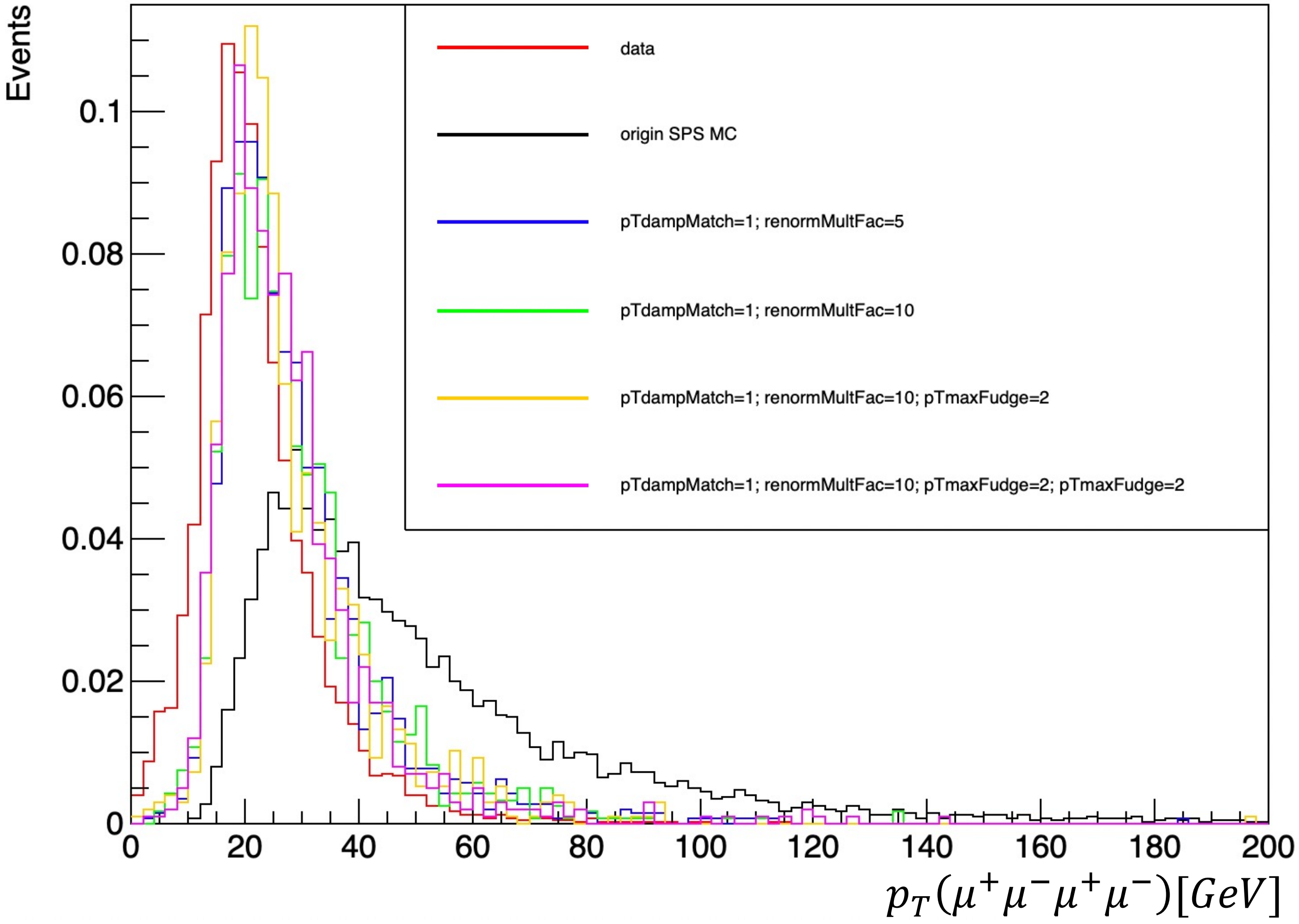
Configuration	Filter efficiency
pTdampMatch=3 renormMultFac=10 pTmaxFudge=0.25	42977/500000=8.60%
pTdampMatch=3 renormMultFac=10 pTmaxFudge=0.5	43496/500000=8.70%
pTdampMatch=3 renormMultFac=10 pTmaxFudge=2	43488/500000=8.70%

Tuning for NRSPS

- Another thing to check: $p_T(\mu^+\mu^-\mu^+\mu^-)$ distributions after final event selection
  - ✓ *pTdampMatch*=1 → data
  - ✓ *pTdampMatch*=3 → original NRSPS (default=3)



- $p_T(\mu^+\mu^-\mu^+\mu^-)$ distributions after final event selection
  - *pTdampMatch*=1 with different *renormMulFac* and *pTmaxFudge*
  - Small difference



$f.scale = const$

Original

f.scale=$\sqrt{s}/2$

```
--
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--
<event>
 9   0    1.0000000E+00   3.2761767E+00   7.8125000E-03   2.4533649E-01
--
<event>
 9   0    1.0000000E+00   3.6061682E+00   7.8125000E-03   2.3694194E-01
--
<event>
 9   0    1.0000000E+00   3.3371238E+00   7.8125000E-03   2.4367641E-01
--
<event>
 9   0    1.0000000E+00   3.2754608E+00   7.8125000E-03   2.4535632E-01
--
<event>
 9   0    1.0000000E+00   3.2784298E+00   7.8125000E-03   2.4527415E-01
```

→

f.scale=20

```
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--
<event>
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--
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<event>
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--
<event>
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```

f.scale=$\sqrt{s}/2$

```
<event>
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      21  -1    0    0  502  501  0.00000000000E+00  0.00000000000E+00 -2.60897011451E-02  2.60897011451E-02  0.00000000000E+00  0.00000000000E+00  1.
      25   2    1    2    0    0  5.55111512313E-17  4.44089209850E-16  4.37166740266E+02  4.37218919668E+02  6.75462220309E+00  0.00000000000E+00  1.
      23   2    3    3    0    0 -8.69450171996E-01 -4.59448687949E-01  2.77629666559E+02  2.77648701702E+02  3.09883304940E+00  0.00000000000E+00  1.
      23   2    3    3    0    0  8.69450171996E-01  4.59448687949E-01  1.59537073707E+02  1.59570217966E+02  3.09992551855E+00  0.00000000000E+00  1.
      13   1    5    5    0    0  1.01408107963E-01  2.46111044281E-02  3.44282032621E-01  3.74944615126E-01  1.05660000021E-01  0.00000000000E+00  1.
     -13   1    4    4    0    0  7.93004151926E-02 -1.63247125182E+00  1.09705510312E+02  1.09717735156E+02  1.05660000047E-01  0.00000000000E+00  1.
      13   1    4    4    0    0 -9.48750587189E-01  1.17302256387E+00  1.67924156247E+02  1.67930966546E+02  1.05660000090E-01  0.00000000000E+00  1.
     -13   1    5    5    0    0  7.68042064033E-01  4.34837583521E-01  1.59192791674E+02  1.59195273351E+02  1.05660000073E-01  0.00000000000E+00  1.
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f.scale=20

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      21  -1    0    0  502  501  0.00000000000E+00  0.00000000000E+00 -2.60897011451E-02  2.60897011451E-02  0.00000000000E+00  0.00000000000E+00  1.
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      23   2    3    3    0    0 -8.69450171996E-01 -4.59448687949E-01  2.77629666559E+02  2.77648701702E+02  3.09883304940E+00  0.00000000000E+00  1.
      23   2    3    3    0    0  8.69450171996E-01  4.59448687949E-01  1.59537073707E+02  1.59570217966E+02  3.09992551855E+00  0.00000000000E+00  1.
      13   1    5    5    0    0  1.01408107963E-01  2.46111044281E-02  3.44282032621E-01  3.74944615126E-01  1.05660000021E-01  0.00000000000E+00  1.
     -13   1    4    4    0    0  7.93004151926E-02 -1.63247125182E+00  1.09705510312E+02  1.09717735156E+02  1.05660000047E-01  0.00000000000E+00  1.
      13   1    4    4    0    0 -9.48750587189E-01  1.17302256387E+00  1.67924156247E+02  1.67930966546E+02  1.05660000090E-01  0.00000000000E+00  1.
     -13   1    5    5    0    0  7.68042064033E-01  4.34837583521E-01  1.59192791674E+02  1.59195273351E+02  1.05660000073E-01  0.00000000000E+00  1.
</event>
```

f.scale=50

```
<event>
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      21  -1    0    0  502  501  0.00000000000E+00  0.00000000000E+00 -2.60897011451E-02  2.60897011451E-02  0.00000000000E+00  0.00000000000E+00  1.
      25   2    1    2    0    0  5.55111512313E-17  4.44089209850E-16  4.37166740266E+02  4.37218919668E+02  6.75462220309E+00  0.00000000000E+00  1.
      23   2    3    3    0    0 -8.69450171996E-01 -4.59448687949E-01  2.77629666559E+02  2.77648701702E+02  3.09883304940E+00  0.00000000000E+00  1.
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      13   1    5    5    0    0  1.01408107963E-01  2.46111044281E-02  3.44282032621E-01  3.74944615126E-01  1.05660000021E-01  0.00000000000E+00  1.
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      13   1    4    4    0    0 -9.48750587189E-01  1.17302256387E+00  1.67924156247E+02  1.67930966546E+02  1.05660000090E-01  0.00000000000E+00  1.
     -13   1    5    5    0    0  7.68042064033E-01  4.34837583521E-01  1.59192791674E+02  1.59195273351E+02  1.05660000073E-01  0.00000000000E+00  1.
</event>
```

f.scale=100

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      21  -1    0    0  502  501  0.00000000000E+00  0.00000000000E+00 -2.60897011451E-02  2.60897011451E-02  0.00000000000E+00  0.00000000000E+00  1.
      25   2    1    2    0    0  5.55111512313E-17  4.44089209850E-16  4.37166740266E+02  4.37218919668E+02  6.75462220309E+00  0.00000000000E+00  1.
      23   2    3    3    0    0 -8.69450171996E-01 -4.59448687949E-01  2.77629666559E+02  2.77648701702E+02  3.09883304940E+00  0.00000000000E+00  1.
      23   2    3    3    0    0  8.69450171996E-01  4.59448687949E-01  1.59537073707E+02  1.59570217966E+02  3.09992551855E+00  0.00000000000E+00  1.
      13   1    5    5    0    0  1.01408107963E-01  2.46111044281E-02  3.44282032621E-01  3.74944615126E-01  1.05660000021E-01  0.00000000000E+00  1.
     -13   1    4    4    0    0  7.93004151926E-02 -1.63247125182E+00  1.09705510312E+02  1.09717735156E+02  1.05660000047E-01  0.00000000000E+00  1.
      13   1    4    4    0    0 -9.48750587189E-01  1.17302256387E+00  1.67924156247E+02  1.67930966546E+02  1.05660000090E-01  0.00000000000E+00  1.
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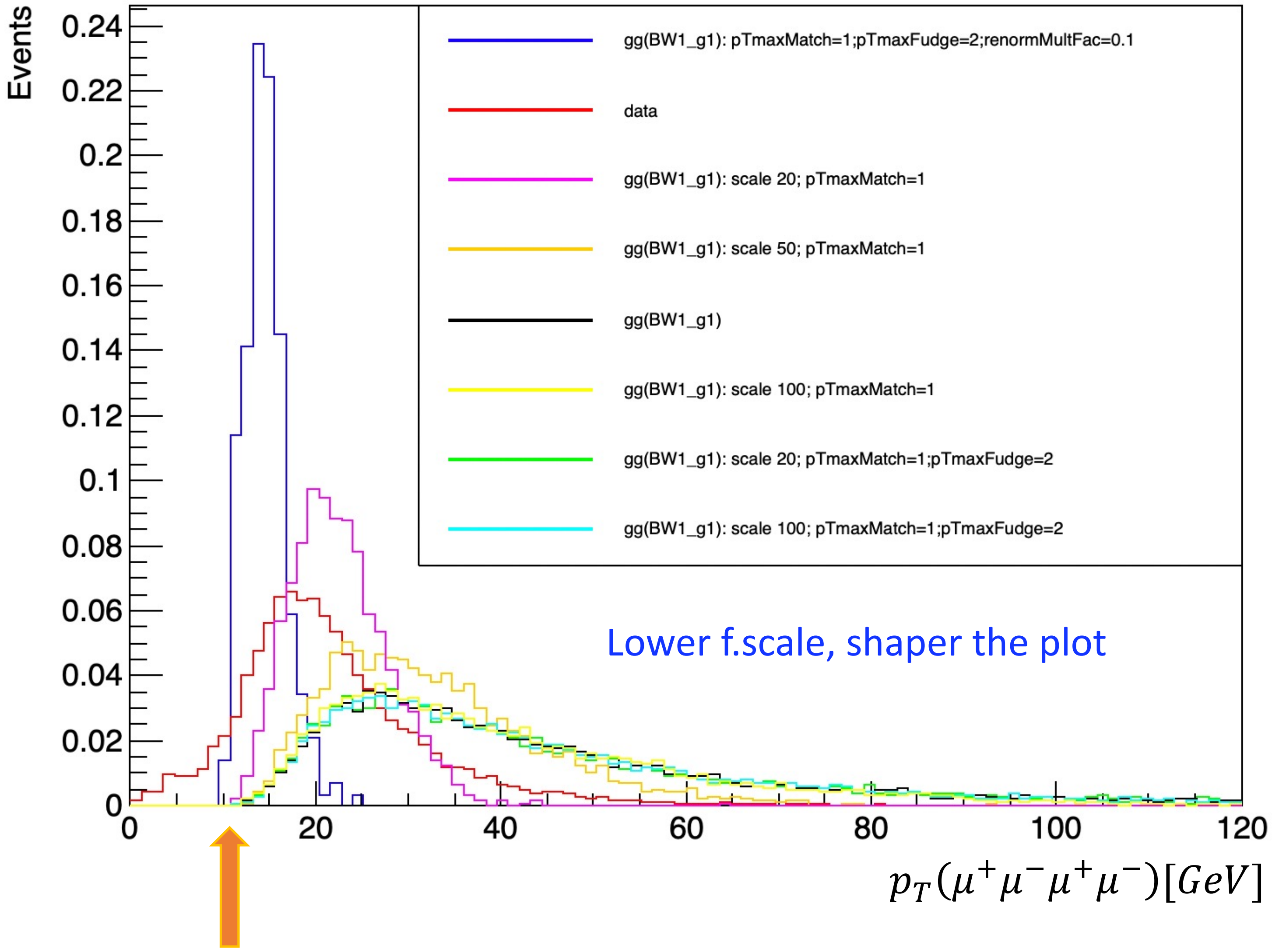
</event>
```



Issue: bigger Min[p_T] in MC, all begin with a similar point

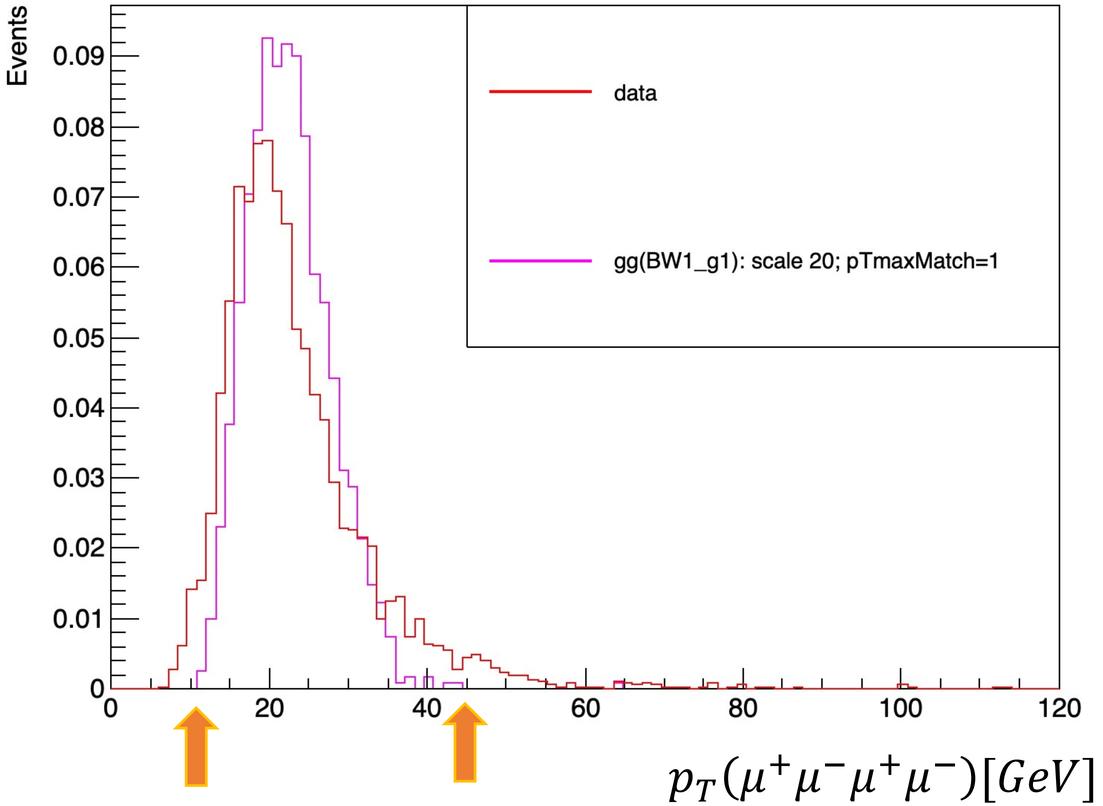
gg (BW1_g1) MC filter efficiency	pTmaxMatch=1	pTdampMatch=1 pTmaxFudge=2
Origin LHE	131./507500= 0.03%	2265./507500= 0.45%
Scale 20	21074/507500= 4.15%	41239/507500= 8.13%
Scale 50	38857/507500= 7.6%	45651/507500= 9.00%
Scale 100	45872/507500= 9.04%	48573/507500= 9.57%

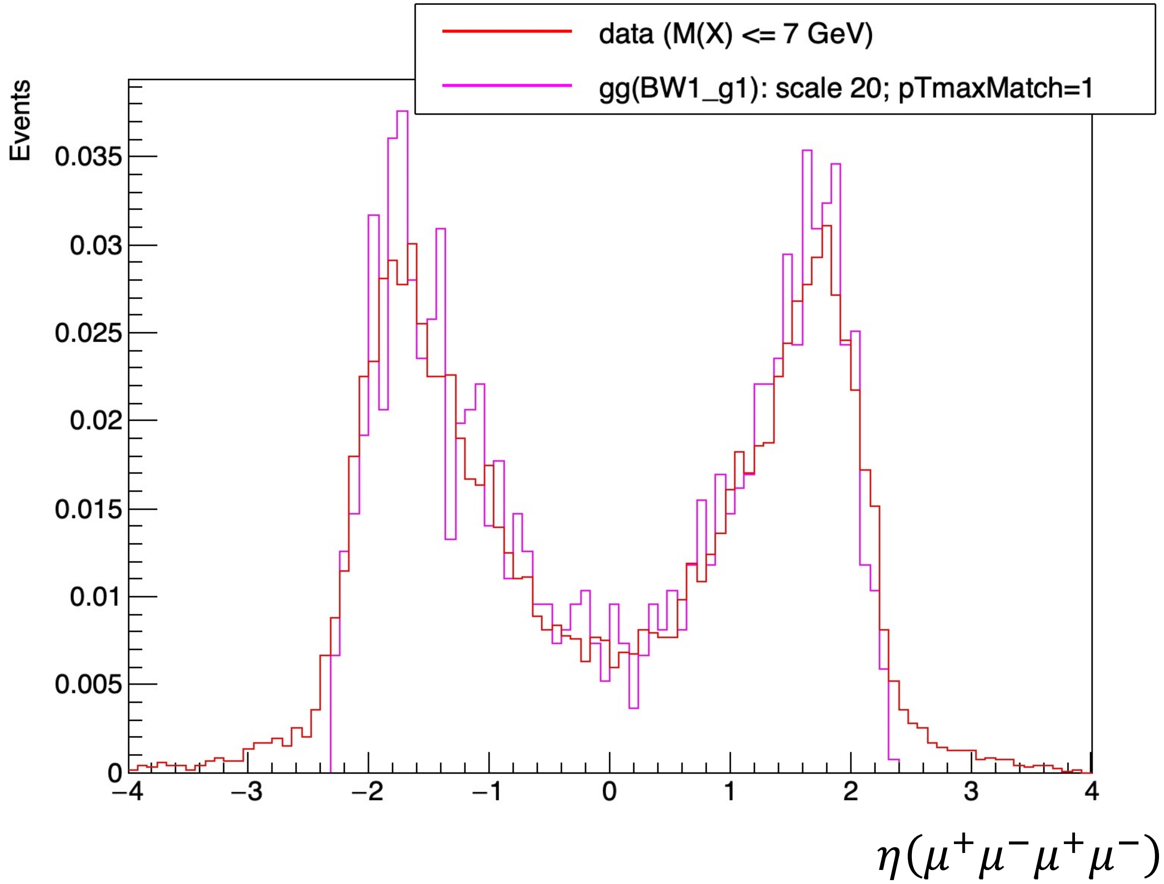
f.scale=20 GeV with pTmaxFudge=2 appears to have higher distribution than f.scale=50 GeV (with default pTmaxFudge=1). This suggests that the fudge factor is not simply increasing the f.scale value by the fudge factor, it appears to be more complicated.

✓ Best one: f.scale = 20

✓ Best one: f.scale = 20

$M(\mu^+\mu^-\mu^+\mu^-) \leq 7\ GeV$



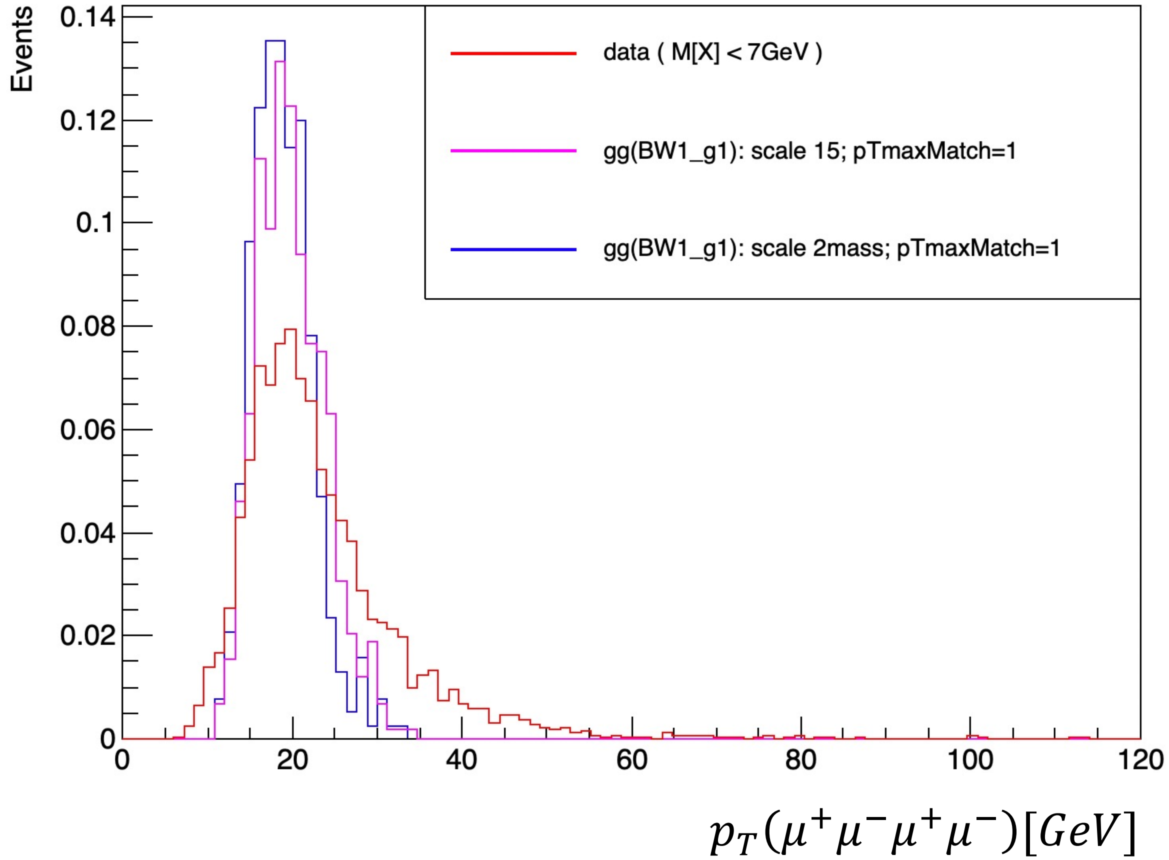


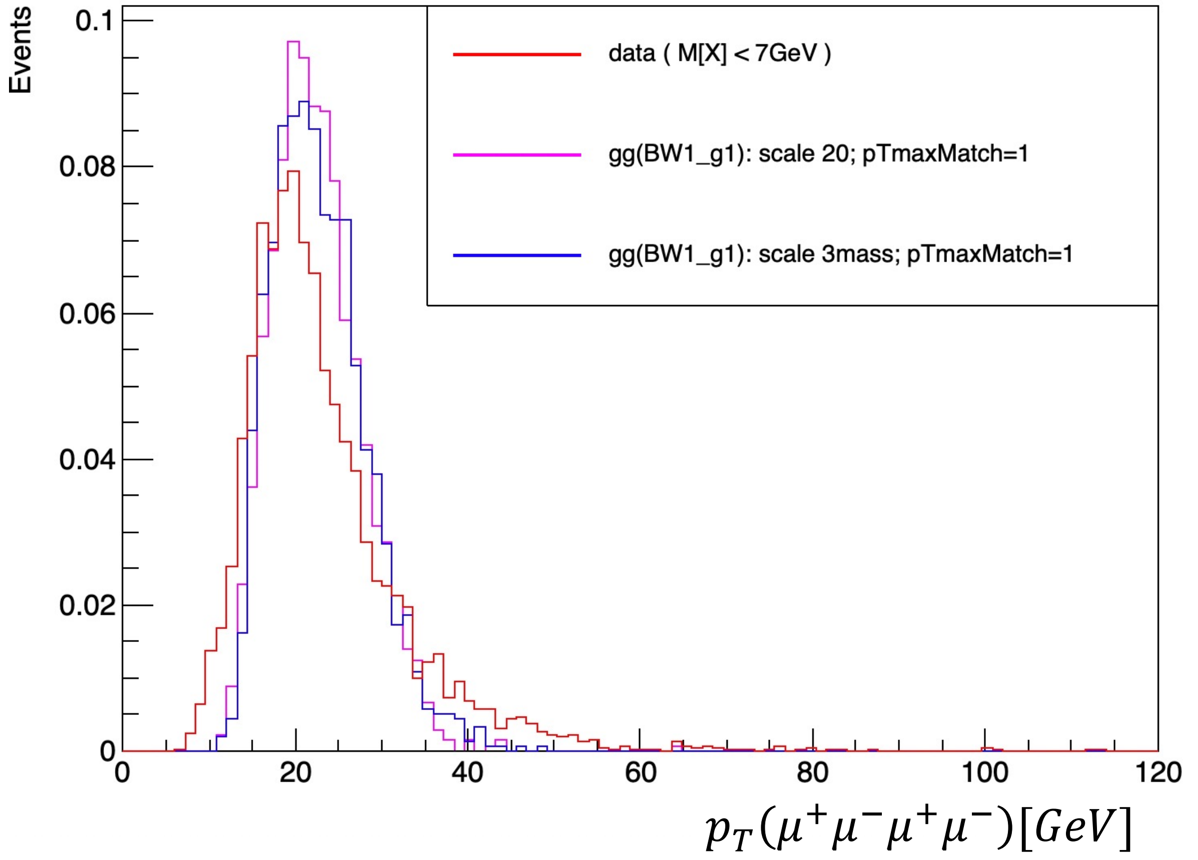
Issue: left tail & right tail

$f.scale$ = multiplicative of the resonance mass

❖ Comparison
- ✓ f.scale = 15 VS f.scale = 2×M[BW]
- ✓ f.scale = 20 VS f.scale = 3×M[BW]

$M(\mu^+\mu^-\mu^+\mu^-) \leq 7\ GeV$



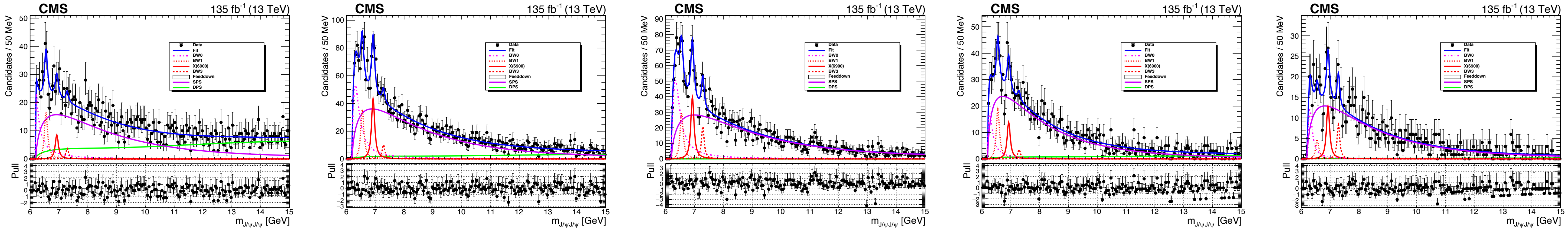


❖ To get the pt distribution of signal peak:

➢ Fix masses and widths of BW1, BW2 and BW3, and fit to data in different pt range

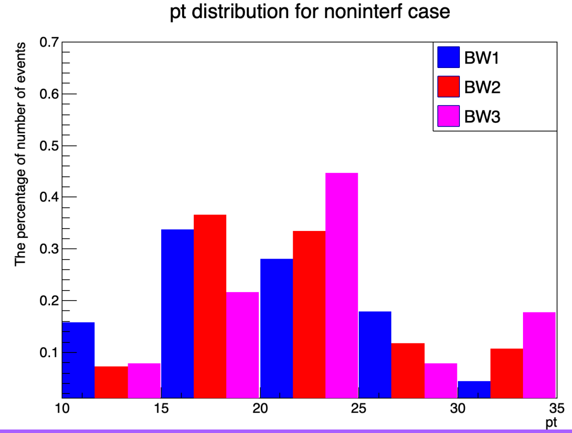
- Measured mass and width

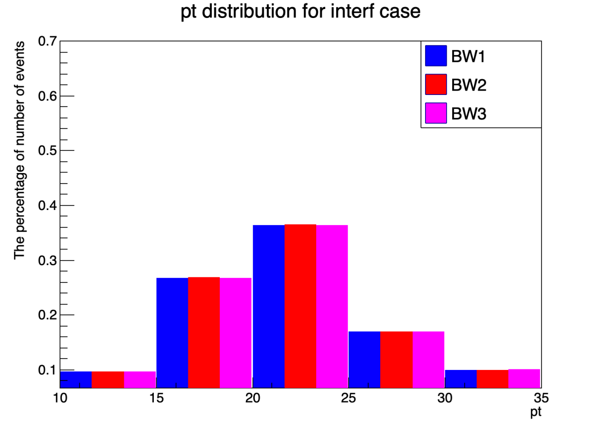
	BW1	BW2	BW3
m	$6552 \pm 10 \pm 12$	$6927 \pm 9 \pm 5$	$7287 \pm 19 \pm 5$
Γ	$124 \pm 29 \pm 34$	$122 \pm 22 \pm 19$	$95 \pm 46 \pm 20$
N	474 ± 113	492 ± 75	156 ± 56



➢ Number of signal peak from fit to J/psi J/psi mass spectrum in different X pt range

Pt bin range [GeV]	[10, 15]	[15,20]	[20,25]	[25,30]	[30,35]
N(BW1)	64	137	114	73	18
N(BW2)	34	171	156	55	50
N(BW3)	12	33	68	12	27





Tuning for gg signal MC