Generation SM particles that subsequently decay into millicharged particles

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1 Introduction

In this document we discuss the generation of SM particles that in a subsequent step will be made to decay into milliCharged particles. The key features of our approach are the following

- Use theory or published data, or some MC to generate P_T distributions for SM particles saved as histograms in ROOT files (Drell Yan is an exception, see discussion in Section 2).
- Sample the ROOT histograms to generate SM particles of a given P_T
- Pick azimuthal angles ϕ and pseudorapity η in a limited range, matched to the acceptance of milliqan.
- Decay the SM particles into milliCharged particles (this step is described in a separate note).
- When possible, keep track of theoretical uncertainties.
- In general it is sufficient to generate SM particles at low and moderate P_T since that is where the cross-section is largest.

2 Drell Yan

Golf needs to fix his bugs.

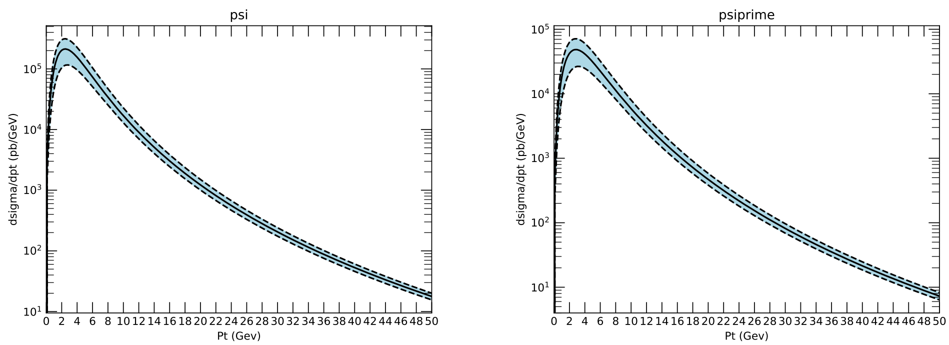

Figure 1: Transverse momentum distributions of J/ψ (left) and ψ' from bottom quark decays. Note: this is from a single b, multiply by two to include $\bar{b}$. The units are pb/GeV and the distributions are integrated over $|\eta| < 1.0$.

3 J/ψ and ψ' from b-decays

We use the tool available in
http://www.lpthe.jussieu.fr/ cacciari/fonll/fonllform.html
to generate histograms of P_T distributions (cross-sections) for charmonium from bottom decays, including theoretical uncertainties[1, 2]. See Figure 1

4 Direct onia production

4.1 Direct bottonium

There have been many measurement of the P_T spectra od Υ in pp collisions at the LHC by CMS [3, 4, 5, 6], Atlas [7, 8], and LHCb [9, 10, 11, 12, 13]. The LHCb measurements are in the forward region. The only measurement at 13 TeV in the central region is from CMS [6]. Unfortunately, it is limited to $P_T > 20$ GeV.

Due to the lack of 13 TeV data, initially we planned to use theoretical predictions as a basis of the Υ event generation. We contacted the theorists [14] that provided the state-of-the art calculations used to confront the data in Reference [6]. We asked them to extend their predictions to lower P_T, unfortunately they claim that these are unreliable below 15 GeV.

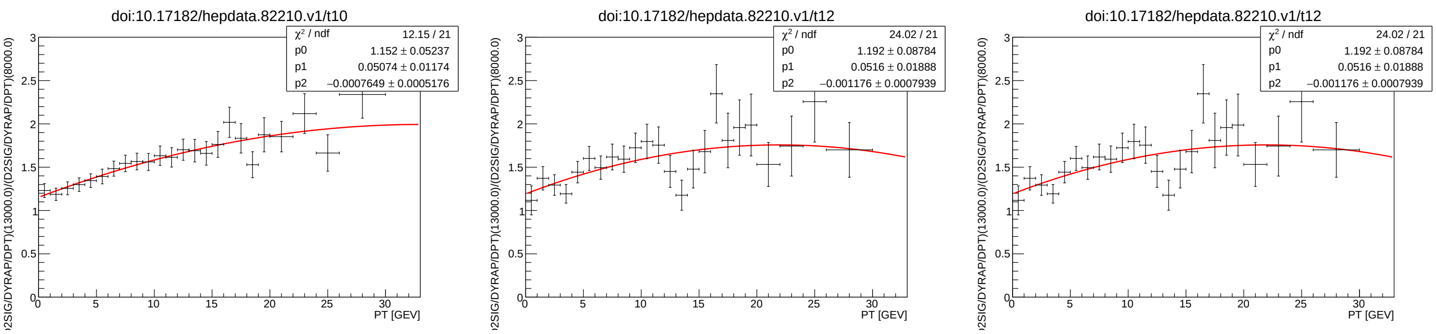

Figure 2: Ratio of 13 to 7 GeV Υ cross-section for $2.0 < |\eta| < 2.5$ from LHCb [9]. From left to right: 1S, 2S, 3S. The quadratic fits are ours.

As a result we decided to use 7 TeV data for $P_T < 20$ GeV and the CMS 13 TeV data at higher P_T. A key ingredient is the ratio of 13 and 7 GeV Υ production cross-sections. These have been measured for $P_T > 20$ GeV and $|\eta| < 1.2$ by CMS, see Figure 2 of Reference [6]. The ratios are about 1.7 at $P_T = 20$ GeV, irrespective of Υ state (1S, 2S, or 3S), and increase slowly to about 2 at $P_T = 40$ GeV. The ratios have also been measured by LHCb [9] all the way down to zero P_T for $2.0 < |\eta| < 2.5$, see Figure 2. These ratios in the 20-30 GeV region are in agreement with the central ratios measured by CMS.

We rescale the measured 7 GeV central low P_T Υ spectra to 13 TeV using the fitted curves of Figure 2; we combine these with the 13 TeV measured central high P_T spectra to obtain an inclusive 13 TeV spectrum. The 7 TeV data is from Atlas [8], and the 13 TeV spectrum is from CMS [6]. We demonstrate in Figure 3 that the matching of the Atlas and CMS cross-sections works well. The combined spectrum to be used in the event generation is in Figure 4.

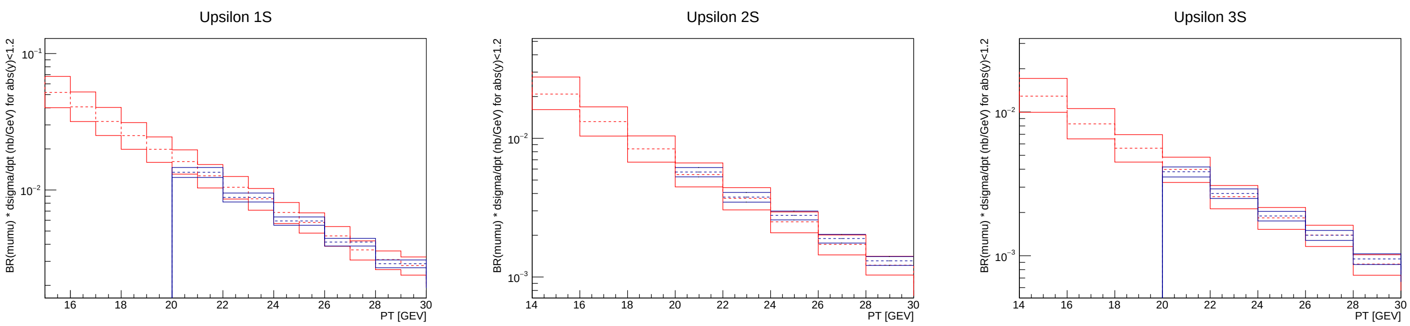

Figure 3: Comparison of the rescaled 7 GeV Atlas Υ spectra (red) with the 13 GeV CMS spectra (blue) in the neighborhood of 20 GeV, where the matching of the two spectra takes place. From left to right: 1S, 2S, 3S. The dashed lines represent the central values, the solid lines cover the uncertainty range. This is $\mathcal{B}(\Upsilon \to \mu\mu) \cdot \mathrm{d}\sigma/\mathrm{dP_T}$ in nb/GeV integrated over $|\eta| < 1.2$.

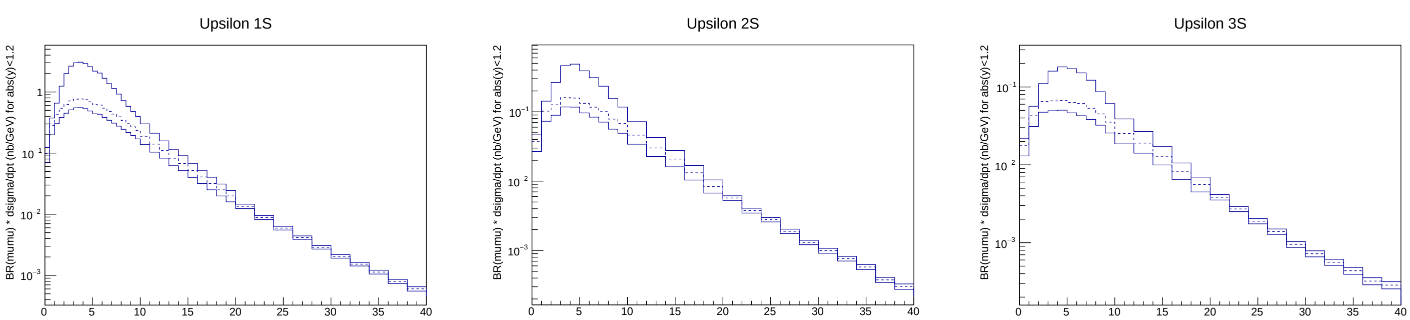

Figure 4: Combined Atlas 7 TeV, CMS 13 TeV Υ spectra. From left to right: 1S, 2S, 3S. The dashed line represent the central value, the solid lines cover the uncertainty range. This is $\mathcal{B}(\Upsilon \to \mu\mu) \cdot \mathrm{d}\sigma/\mathrm{dP_T}$ in nb/GeV integrated over $|\eta| < 1.2$.

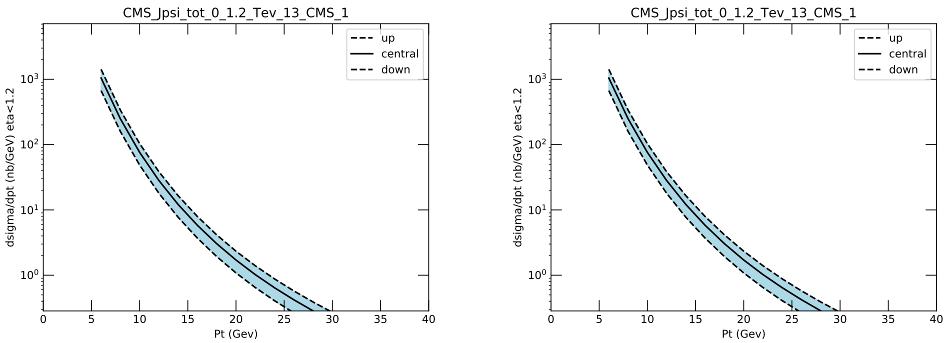

Figure 5: Transverse momentum distributions of J/ψ (left) and ψ' from direct production. The units are nb/GeV and the distributions are integrated over $|\eta| < 1.2$.

4.2 Direct charmonium

We take the charmonium spectra from theory [15, 16], see Figure 5. **NOTE: THESE ONLY GO DOWN TO 6 GEV BUT THE THEORISTS WILL PROVIDE CALCULATIONS TO LOWER PTs.**

5 π^0, η, η', ϕ, ρ, and ω

We generate these from Pythia. The measurement of the $\pi^{\pm}$ P_T spectrum from CMS[17] is in good agreement with Pythia 8 Minimum Bias at low momentum. We use this MC for all mesons. We do not attempt to use QCD $2 \to 2$ at very low P_T since the process is infrared divergent. Note that Pythia `SoftQcd:nonDiffractive` includes all hard QCD processes[18] so in principle this is all that is needed. However, one runs out of statistics at high P_T. So at high P_T we stitch together the minimum bias distributions with distributions obtained from QCD $2 \to 2$ at moderate P_T.

Eventually we will generate Pythia events in "standalone" mode to be independent of CMS software. For now we use existing CMS Monte Carlos for Minimum Bias and for QCD. The CMS QCD samples are "P_T-binned", (15-30 GeV, 30-50 GeV, and 50-80 GeV). The Minimum Bias cross-section is taken to be 78.4 mb. Then the stitching procedure is the following:

- The QCD samples are first normalized to their LO cross-sections.

- next, we estimate a "qcd-minbias scale factor" by integrating over some region where the ratio is roughly flat

- the QCD samples are renormalized by this scale factor

- the samples are then stitched together by visually picking the P_t where the curves cross each other.

The resulting P_T curves are shown in Figure 6. It is not clear what kind of uncertainties we should assign. Let's first see how important these are at the end of the day before going crazy.

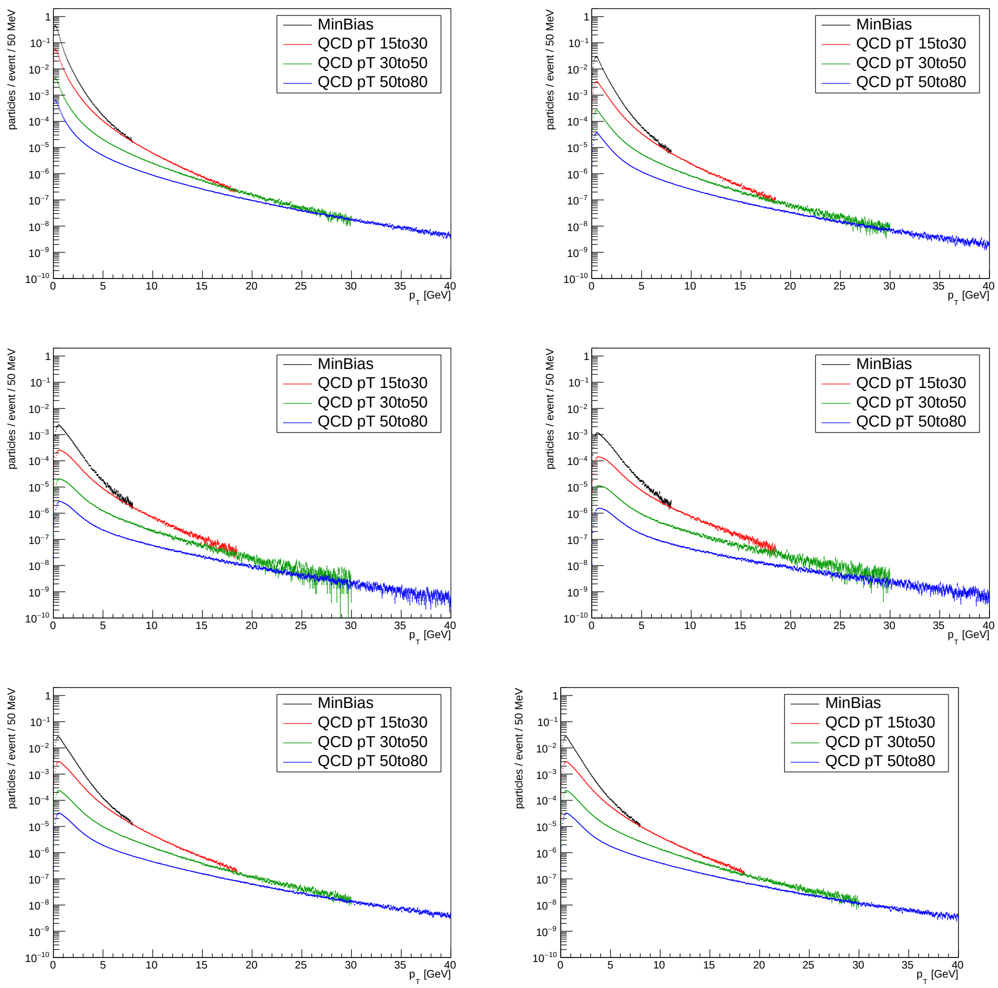

Figure 6: Transverse momentum distributions of π^0, η, η', ϕ, ρ, and ω, top left to bottom right, for $|\eta| < 1$.

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