CT update: towards CT17 and studies of intrinsic charm

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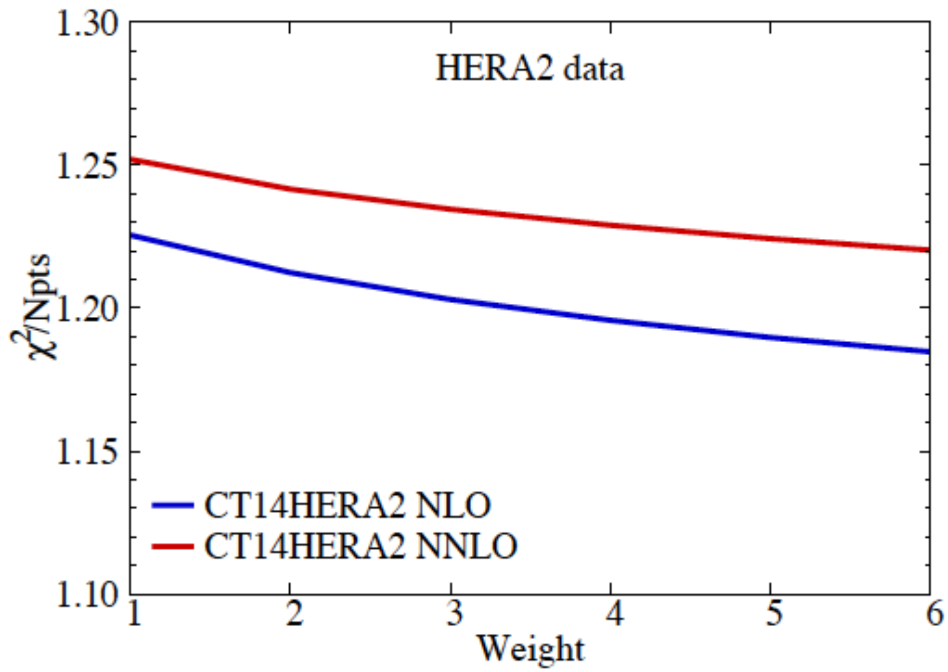
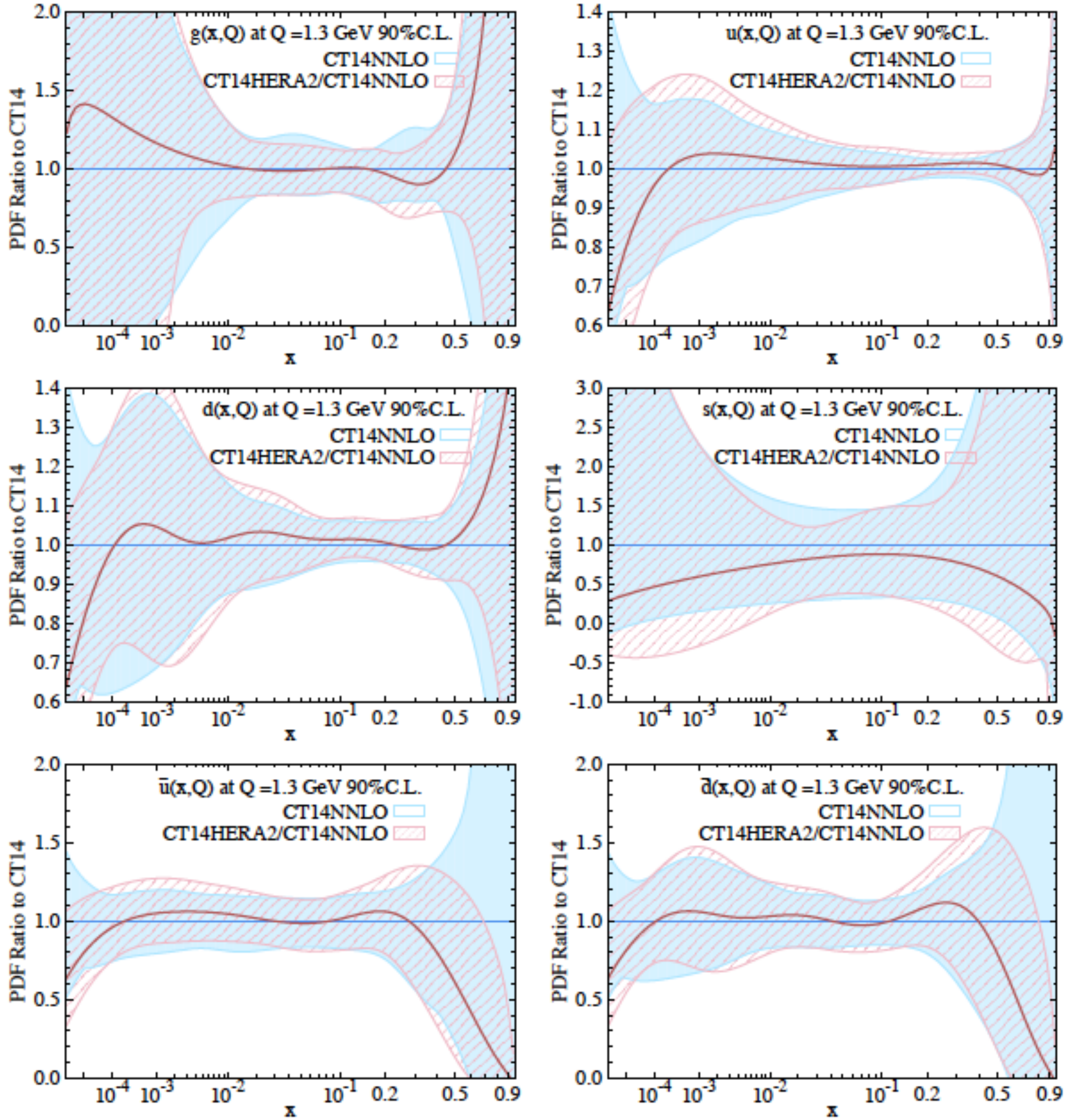
HERA2

- In CT17, HERA1 data will be replaced by HERA1+2 data
- Impact investigated in PRD95(2017)034003 (arXiV: 1609.07968)
- χ^2 slightly better at NLO than at NNLO
- χ^2 does not improve greatly as weight of the data-set is increased
- χ^2 for rest of the data does not change much if HERA2 used instead of HERA1



- Resultant changes in PDFs well within CT14 uncertainty bands
- In addition to replacing HERA1 with HERA1+2 data set in CT17, the NMC μp cross section will be dropped
  - never fit well
- Strange quark distribution no longer tied to ubar +dbar
- Consequences at low x



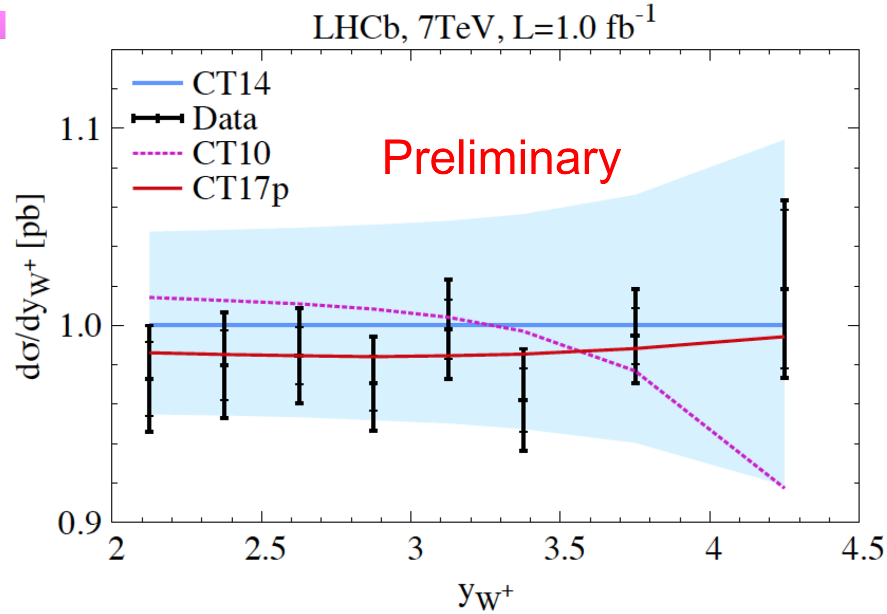
Other data sets to be included in CT17

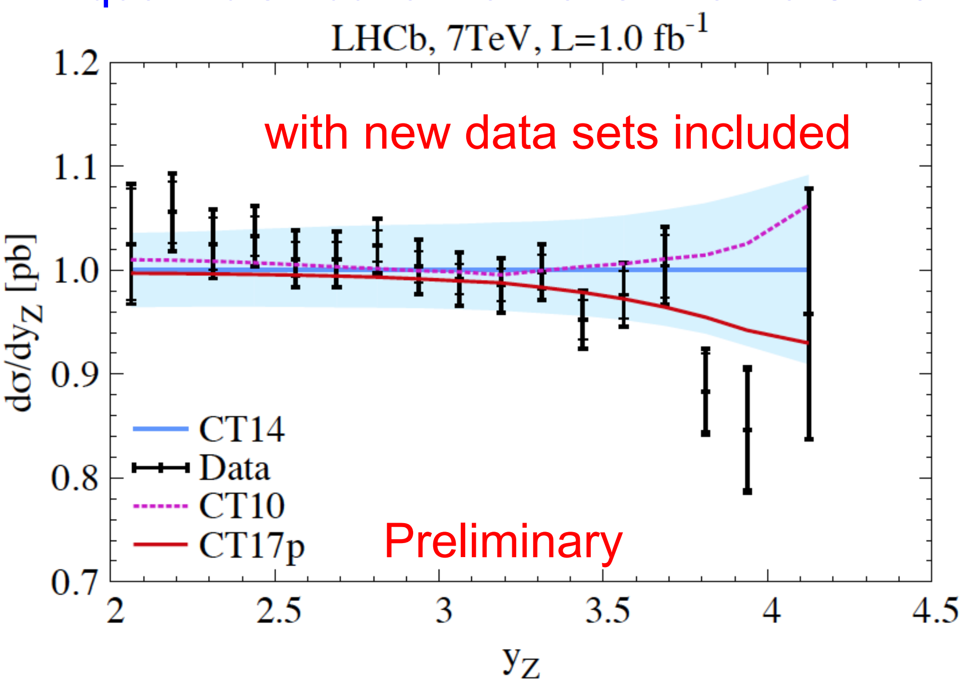
- Use as much relevant LHC data as possible using applgrid/fastNLO interfaces to data sets, with NNLO/NLO K-factors
- Implementing a parallelization of the global PDF fitting to allow for faster turn-around time
- Next few slides are a snapshot
- More details at DIS2017
- I will concentrate on impact of data in bold

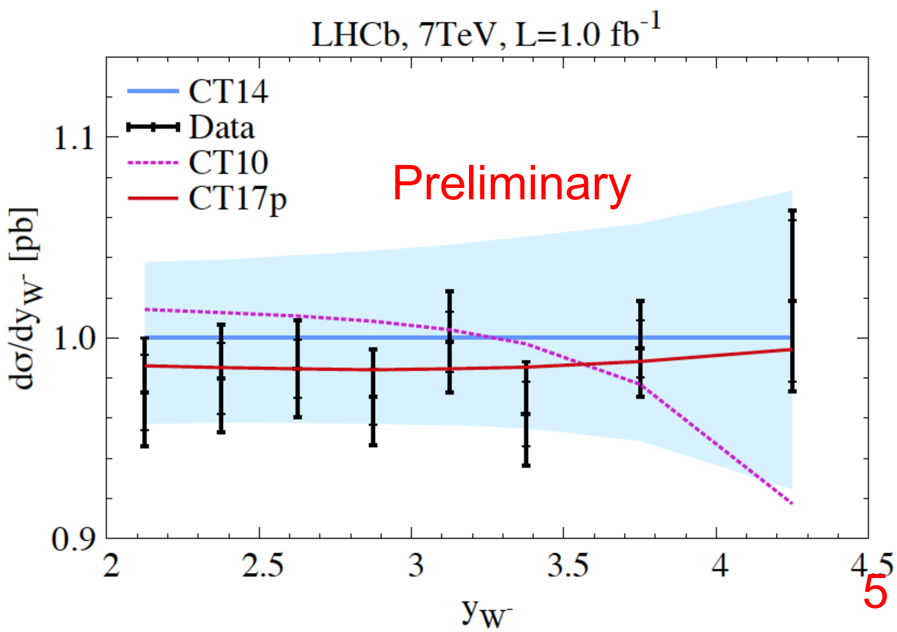
- **LHCb W/Z rapidity at 7 and 8 TeV (applgrid)**
- LHCb Z y at 13 TeV (applgrid)
- ATLAS W/Z rapidity at 7 TeV (applgrid)
- ATLAS 8 TeV DY (applgrid)
- ATLAS 7 TeV W/Z pT (applgrid)
- **ATLAS 7,8 Z p_T**, as a function of mass **(applgrid)**
- CMS W,Z p_T,as a function of y, at 8 TeV (applgrid)
- CMS W rapidity at 8 TeV (applgrid)
- CMS W/Z p_T at 8 TeV (applgrid)
- CMS inclusive jet cross section at 7 TeV with R=0.7 (fastNLO)
- **ATLAS inclusive jet cross section at 7 TeV with R=0.6 (applgrid)**
- ATLAS and CMS 7,8 TeV tT differential distributions
- ATLAS low mass/high mass Drell-Yan at 7 TeV
- CMS low mass/high mass DY at 8 TeV

LHCb W,Z rapidity data

- 7 TeV: W,Z muon rapidity
- 8 TeV Z(->ee) rapidity
- Unshifted data; outer error bars are with stat and syst errors added in quadrature; inner error bars are uncorrelated errors alone
- Major change is an increase in the strange quark distribution to that similar to CT10

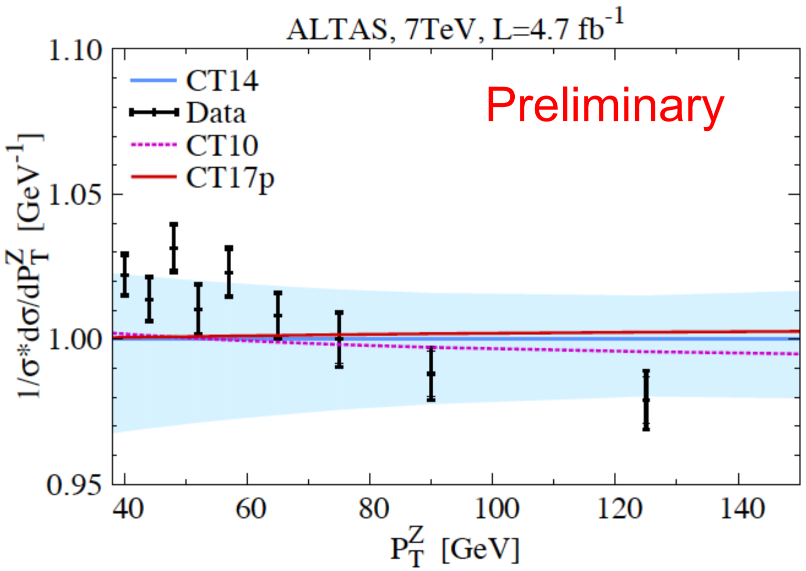


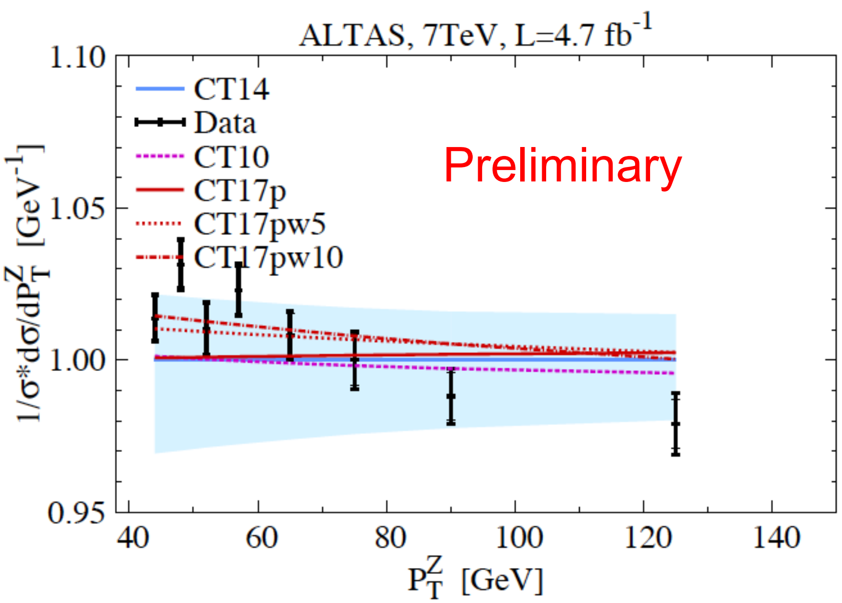




ATLAS Z p_T

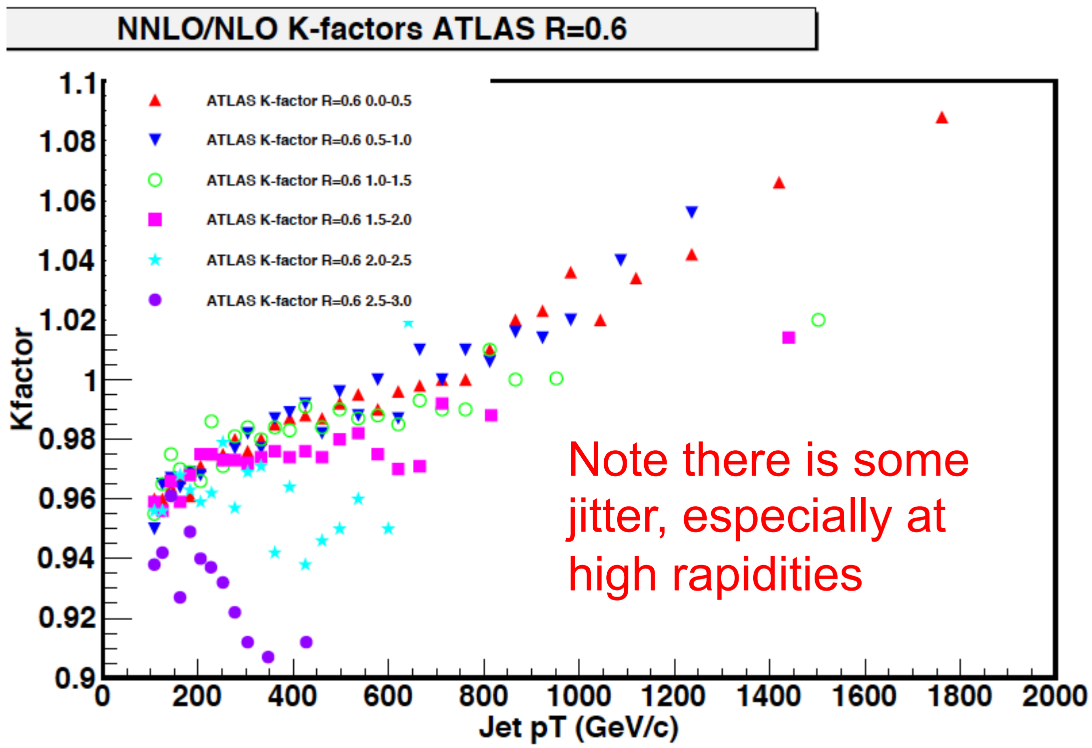
- Start with using normalized Z p_T data in range from 40 to 150 GeV/c at NLO, with $\mu_R=\mu_F=m_T$
  - prefers softer gluon at high x
  - adding additional weight improves agreement
- Also trying absolute cross section
- Will add in NNLO/NLO K-factors, extend to full range
  - NNLO/NLO K-factors for this process have jitter, need an additional uncorrelated error





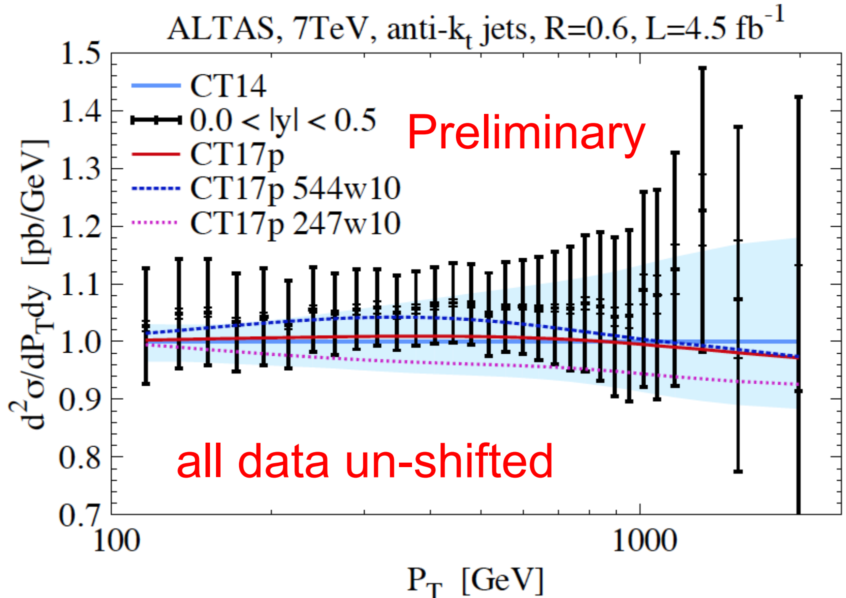
Some jet issues

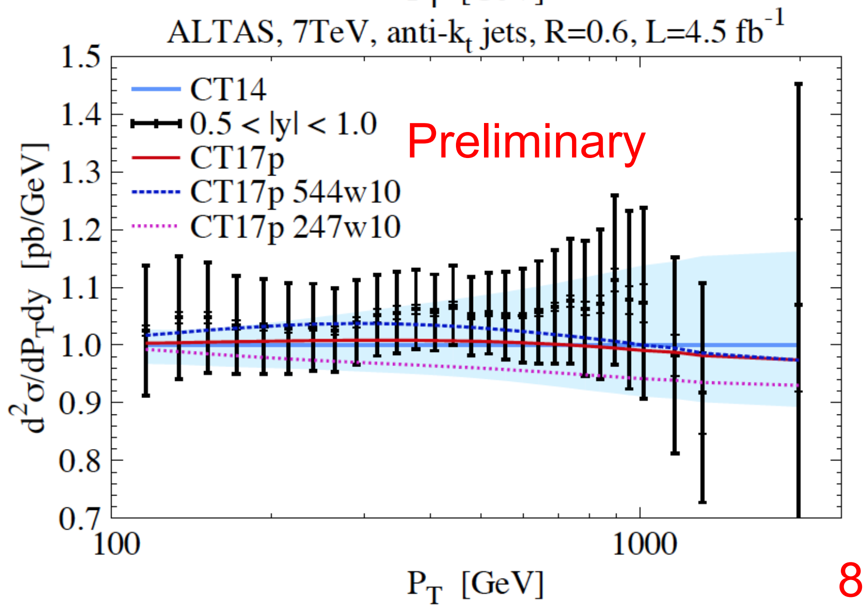
- For LHC jet cross sections, use largest jet sizes available (R=0.6 ATLAS, R=0.7 CMS) and a scale choice of p_T^{jet}
  - traditional choice for PDF fitting
- With such choices, K-factors (NNLO/NLO) constant and close to unity
- But tension within ATLAS jet rapidity data sets, as well-known within this group
- Not quite fair to choose just one rapidity interval (say 0.0-0.5) if another rapidity interval (say 0.5-1.0) gives a different PDF result
- Currently under investigation; what is the envelope of PDFs resulting from fits to individual rapidity bins, i.e. how unanimous are the rapidity bin data



ATLAS 7 TeV jet data

- Can not get a good fit simultaneously to all rapidity bins: χ^2/DOF~2, even with weight 10 for combined jet data
  - outer error bars are with stat and syst errors added in quadrature; inner error bars are uncorrelated errors alone
- Individual rapidity bins can be fit well
- In general, ATLAS jet data favors a larger gluon PDF around x=0.2
- Some tension with ATLAS Z p_T data regarding high x gluon
  - jet data likes a harder gluon (x~0.2)
  - Z p_T data (normalized) likes a softer gluon





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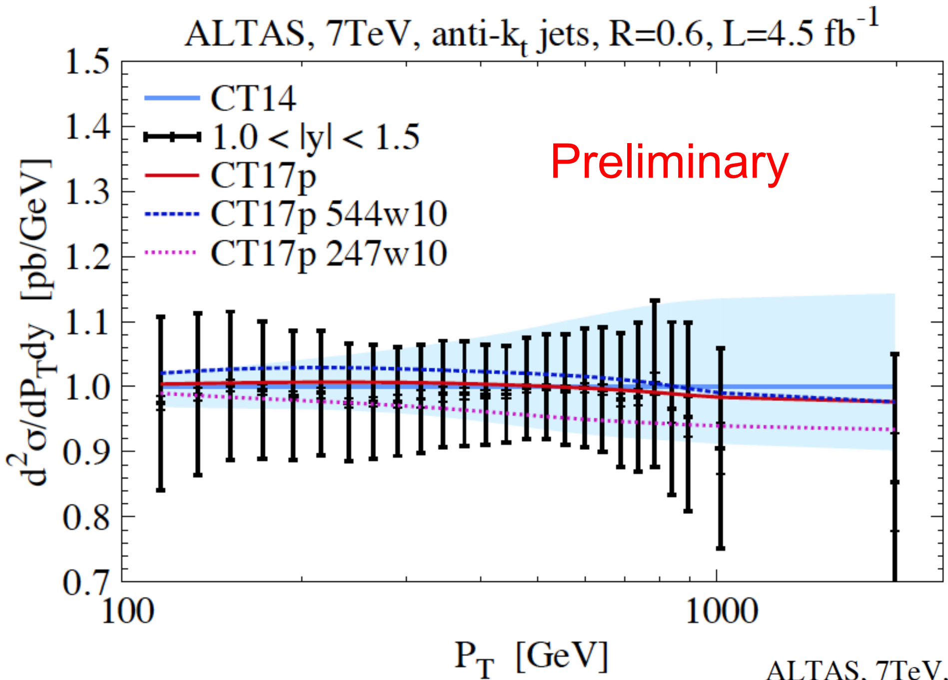
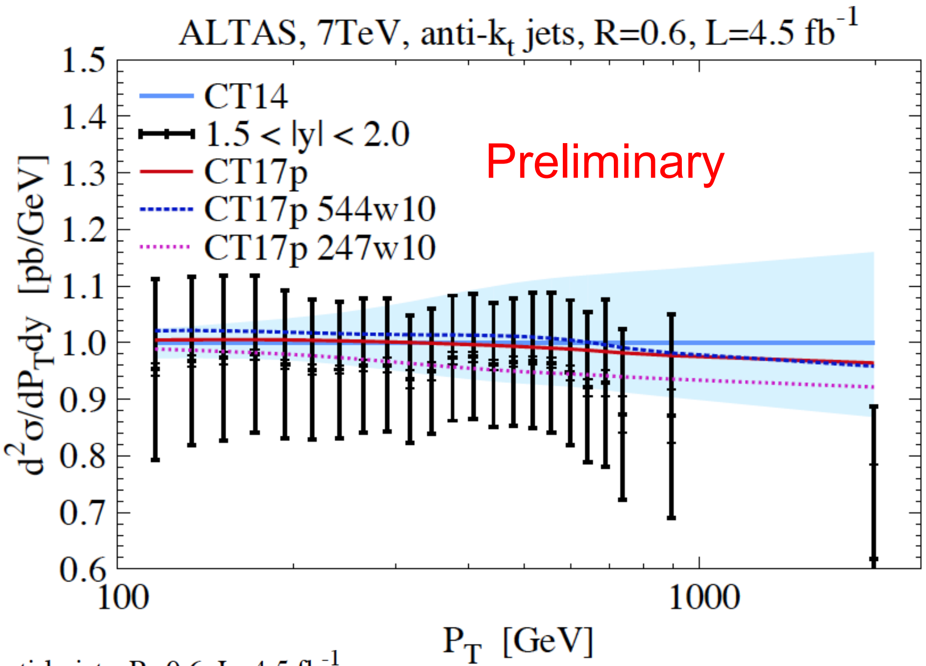
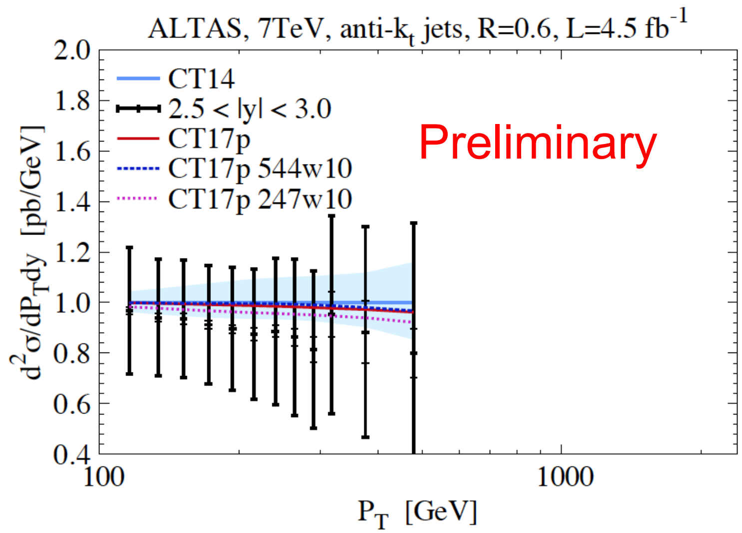
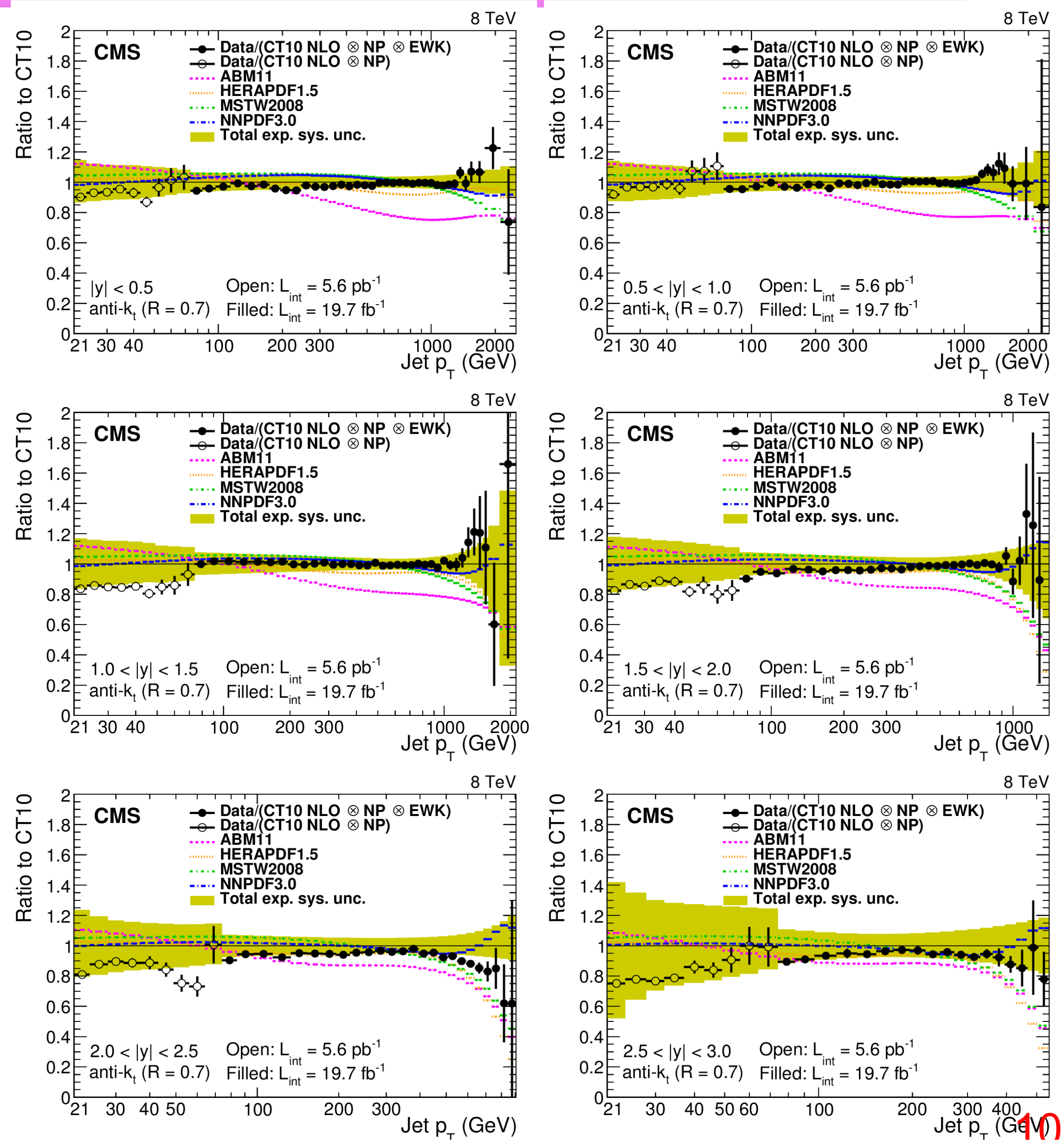






CMS 8 TeV jet data

- CT10 has a harder gluon than CT14
- CMS data seems happy with that
- I'm happy with that
- …but may point out a tension between the ATLAS and CMS jet data sets; if so, high x gluon uncertainty may not be reduced by these data sets
- Tension may need a better understanding
- Will use 8 TeV CMS data if available in near-term

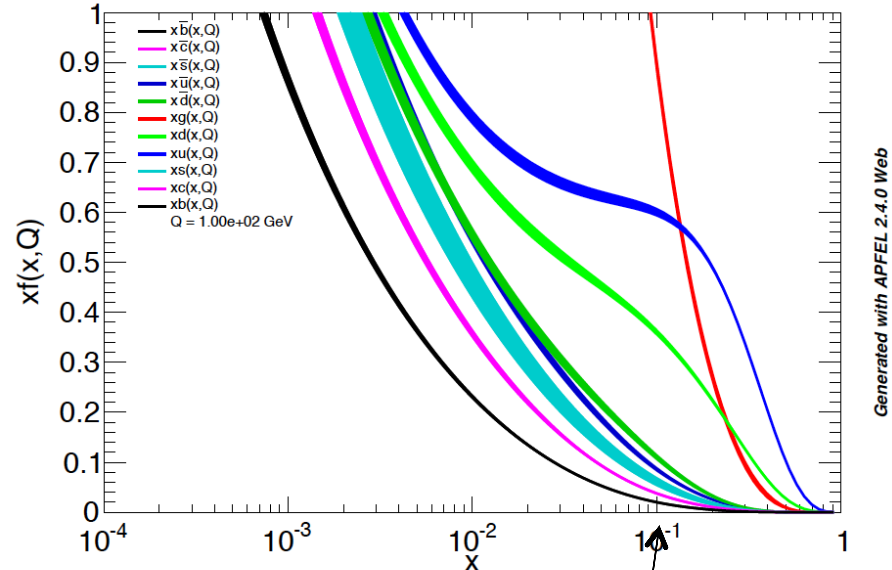


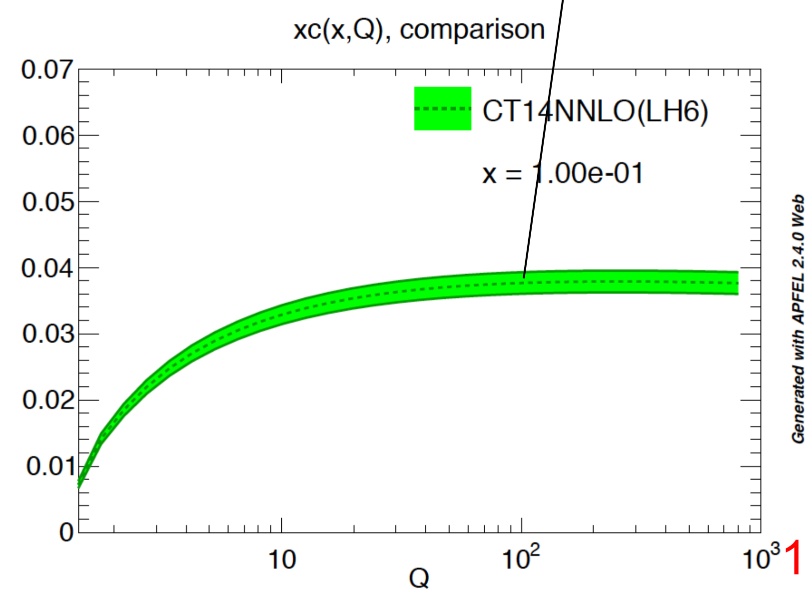
Top distributions

- There are several distributions measured by ATLAS and CMS that have information on the high x gluon
  - m_{tT}, y_{tT}, $p_T^{t,T}$ directly
  - $y_{t,T}$, p_T^{tT} indirectly
- Only one distribution should be used, unless a correlation model can be developed
  - which one?
  - do they give the same answer? if not, do we understand why?
  - how do the constraints/trends from each distribution compare?
  - similar to what we were talking about with ATLAS jet data in different y bins
- We are currently doing exploratory studies at NLO using MCFM and DiffTop and at NNLO using DiffTop
  - starting with the p_T and rapidity of the top quark
- ATLAS and CMS have different trends; in this case, ATLAS favors harder gluon at high x, CMS weaker gluon
- In general, the ATLAS and CMS top results are in tension internally, and with each other (the latter more so in the case of normalized distributions where the experimental errors are smaller)
- This is similar to the tension that exists between the ATLAS and CMS jet data, although there the tension is in the opposite direction
- If tension, then gluon PDF uncertainty may not decrease and may even increase
- Study in progress

Charm

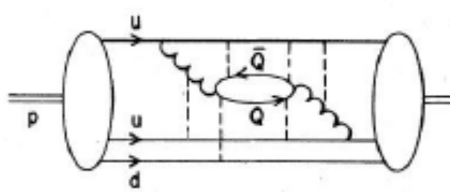
- The charm quark distribution is generated perturbatively through gluon splitting
- So normally no charm below ccbar threshold
- But what if there is an intrinsic charm present in the proton at low Q
- This has been Stan Brodsky's dream for some time

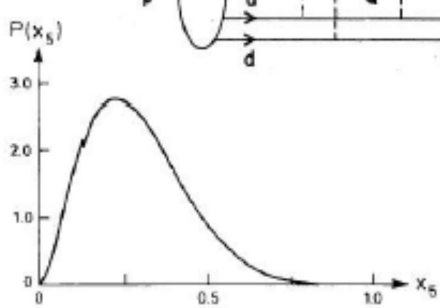




BHPS PLB93B (1980) 451

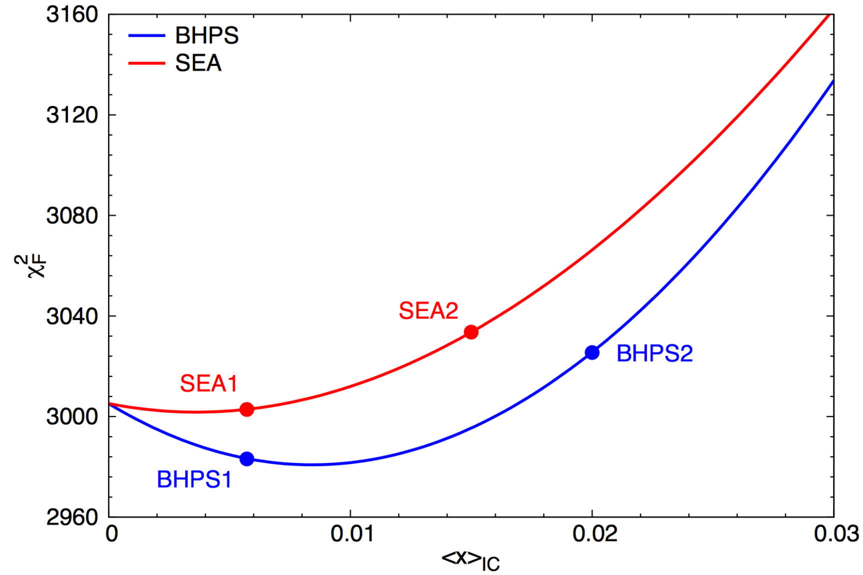
Brodsky et al: arXiv:1504.06287

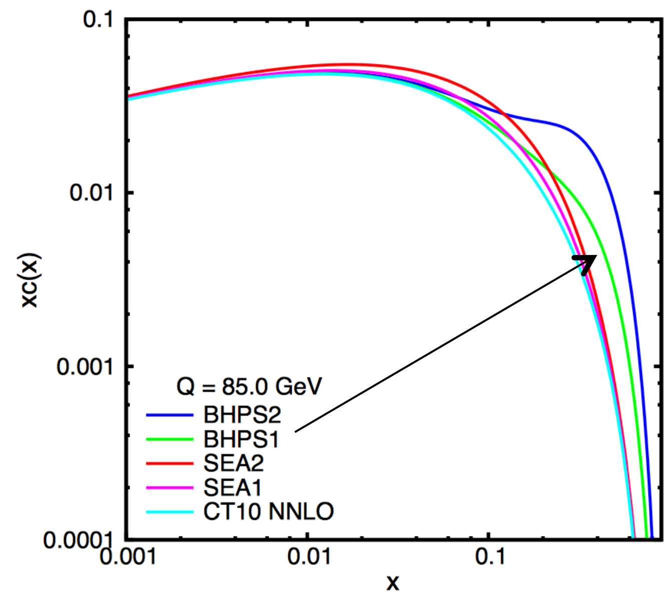




Intrinsic charm

- …and has been studied by CTEQ in, for example, arXiv: 1309.0025 and in proceedings of DIS2014
  - these analyses carried out at NNLO
- Two types of models: Brodsky-like (valence-like) or Sea-quark like
- One Brodsky-like model, BHPS1 actually leads to a modest reduction in χ^2, but as we said in the paper, it's interesting, but not enough to claim the discovery of intrinsic charm





Update

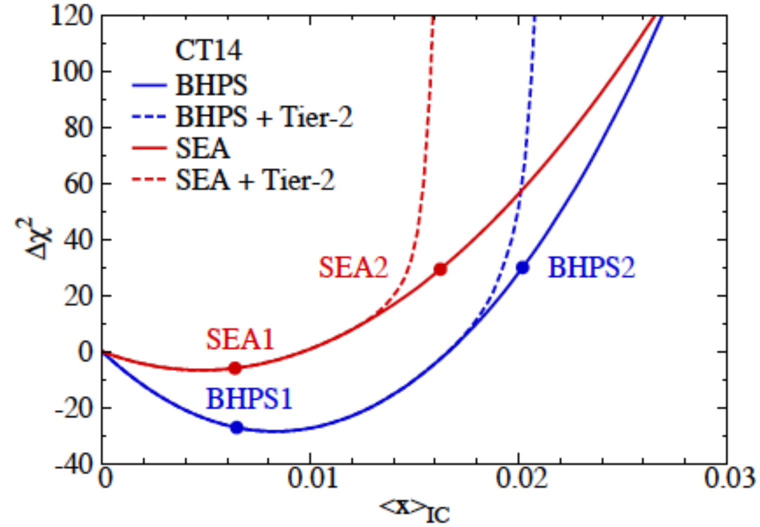
- Return to study of intrinsic charm within CT14/ CT14HERA2 framework, again with 2 models of intrinsic charm
  - Valence-like

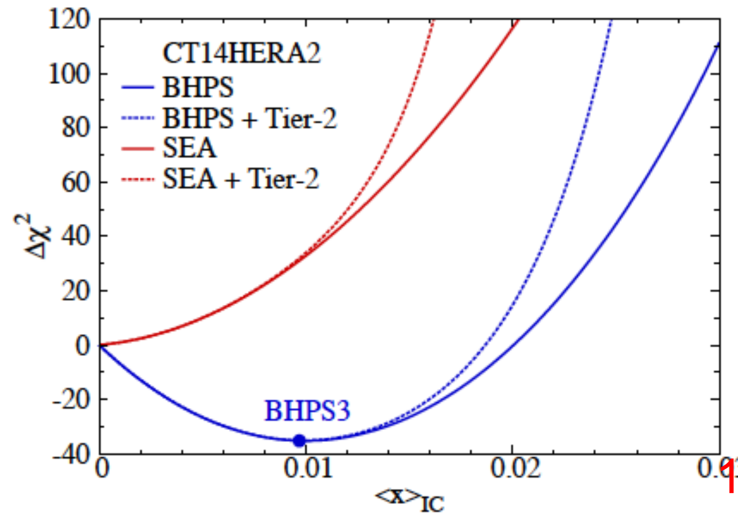
$$\hat{c}(x) = A\, x^2 \left[6x(1+x)\ln x + (1-x)(1+10x+x^2)\right]$$

  - Sea-like

$$\hat{c}(x) = A\ \left(\overline{d}(x,Q_0) + \overline{u}(x,Q_0)\right)$$

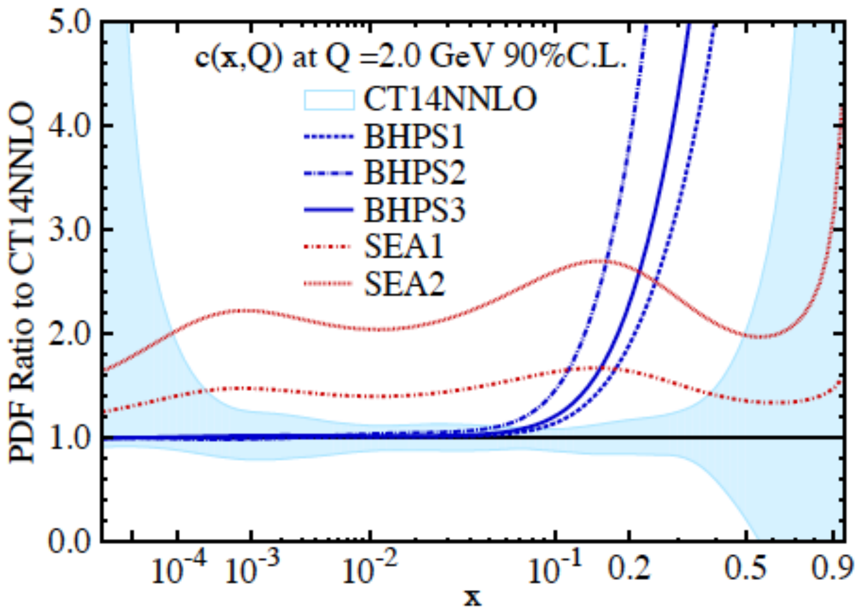
- See reduction in valence-like (BHPS) models, but with the drop in c2 interesting but less than our criterion (100)
- In addition, the decrease in c2 comes primarily from BCDMS data that does not have any particular sensitivity to charm

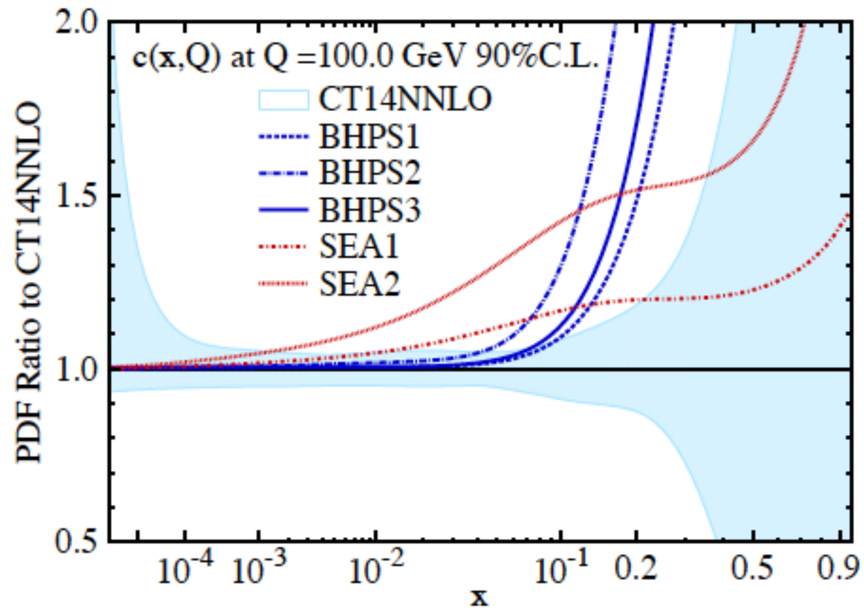




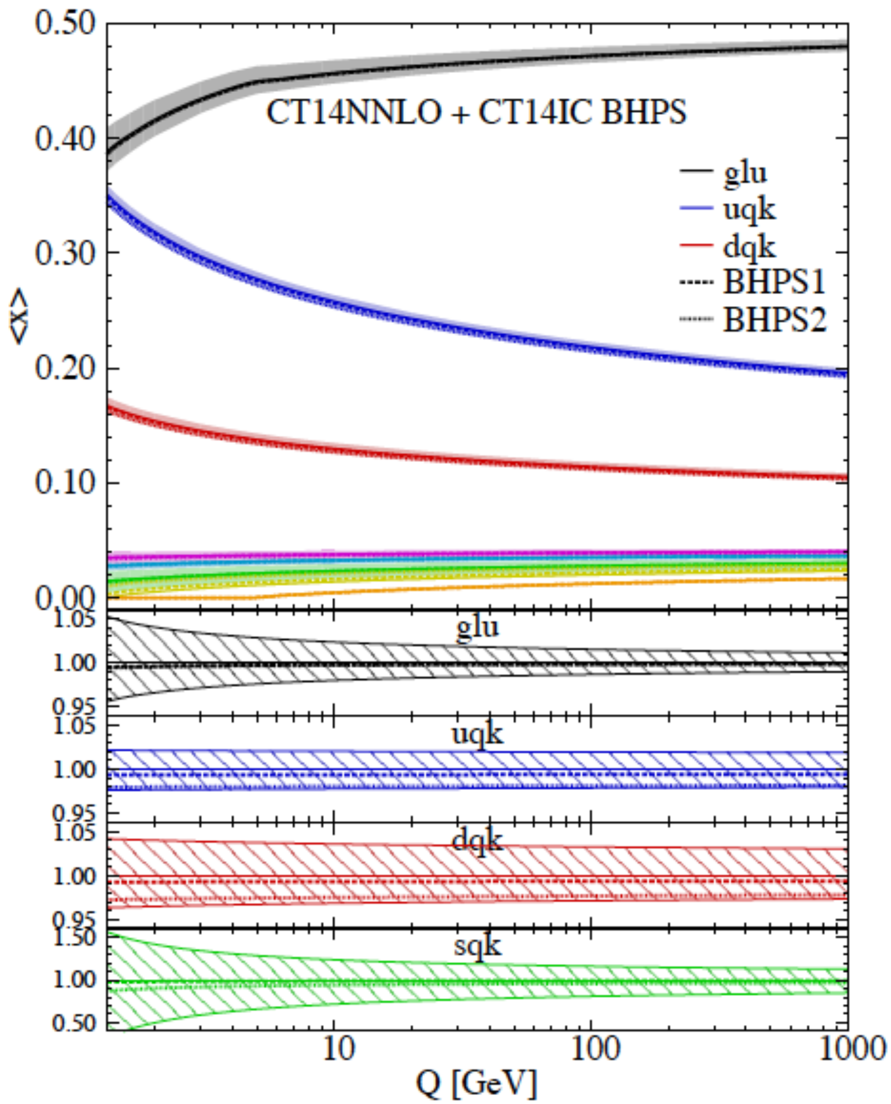
Charm quark distributions

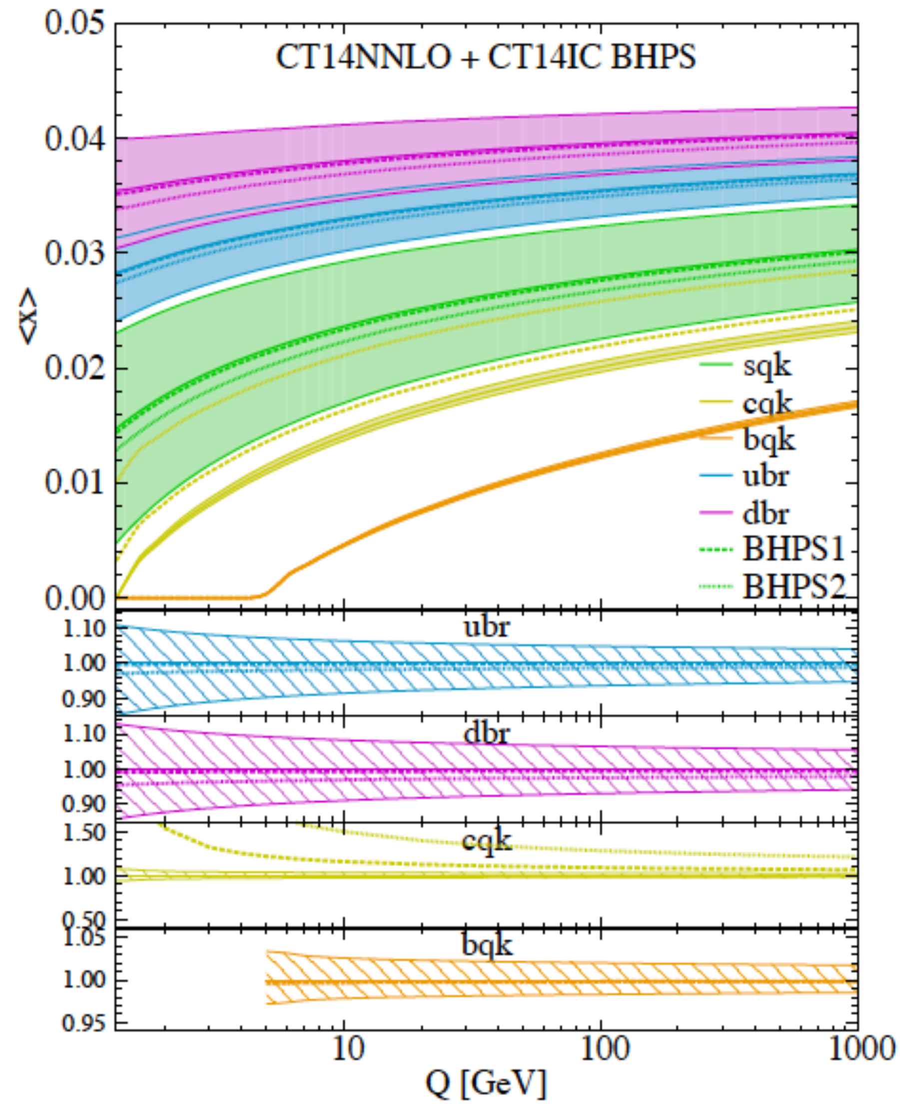
- BHPS solutions increase charm primarily at high x, as expected
- Sea-like solutions cause increase in charm at all x values





Changes to PDFs within uncertainty bands





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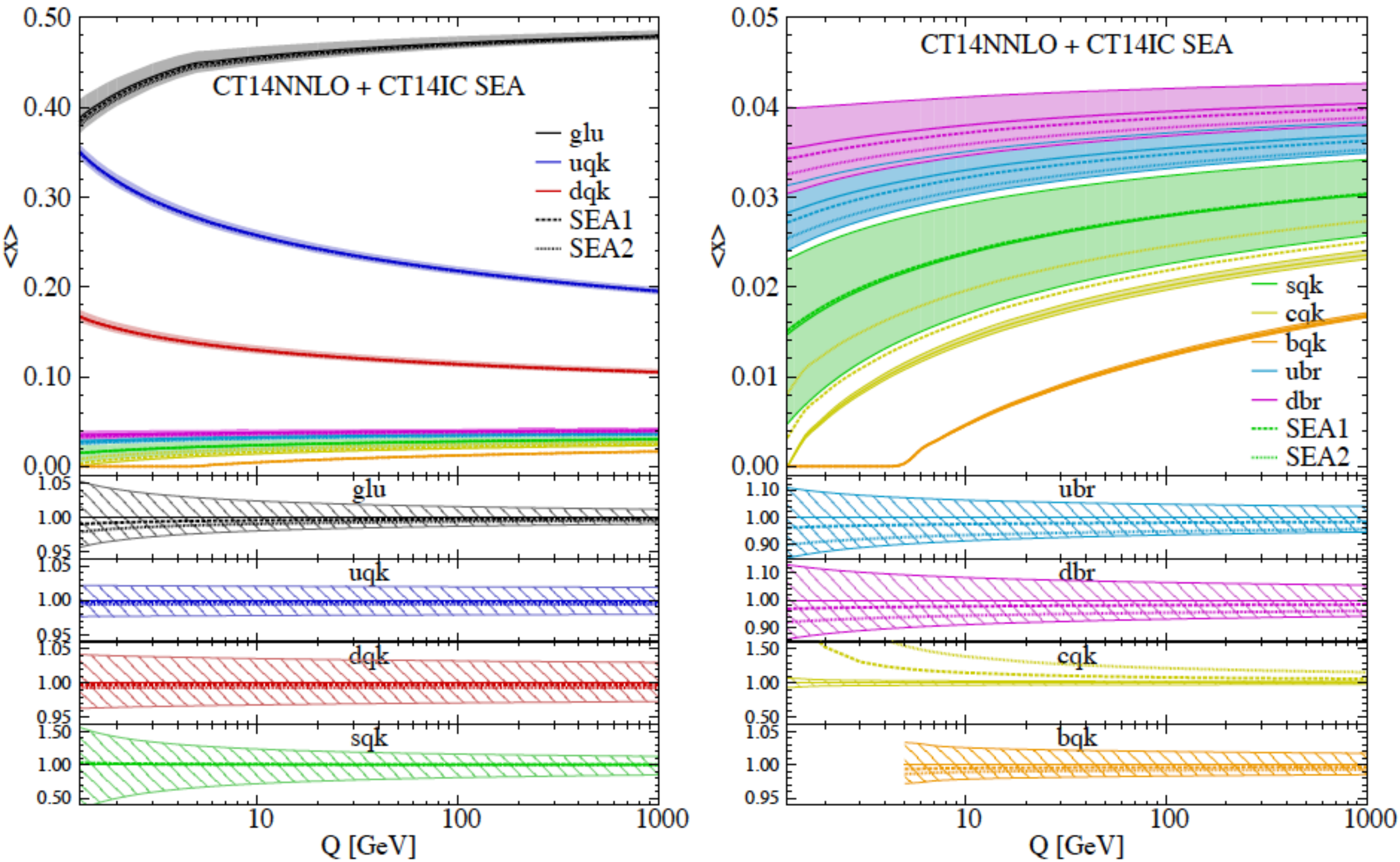
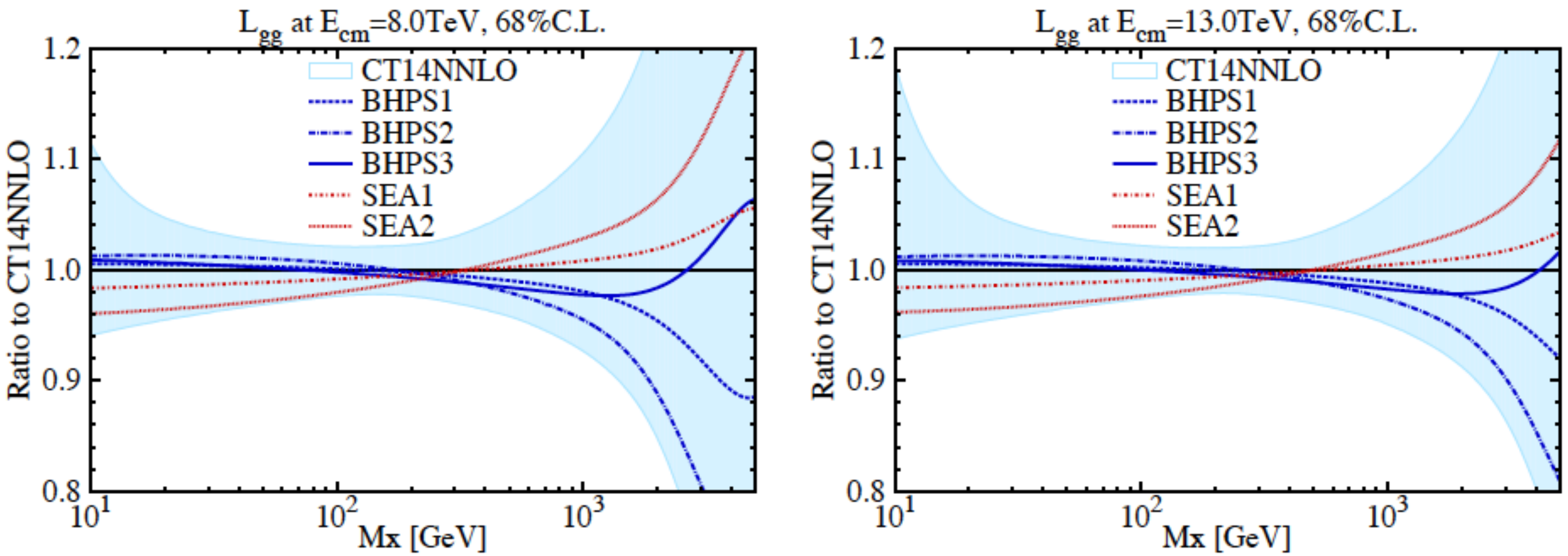


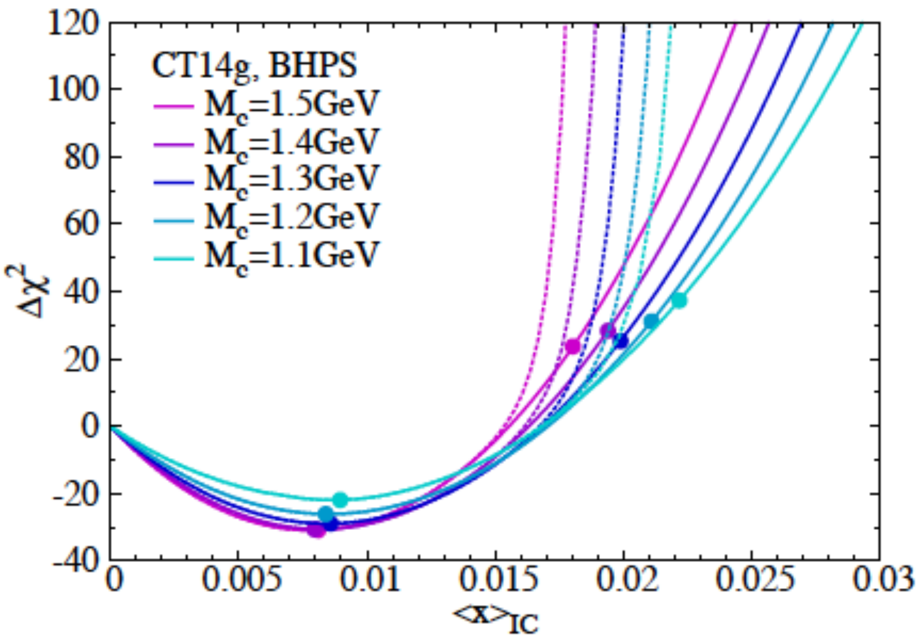
gg PDF luminosity

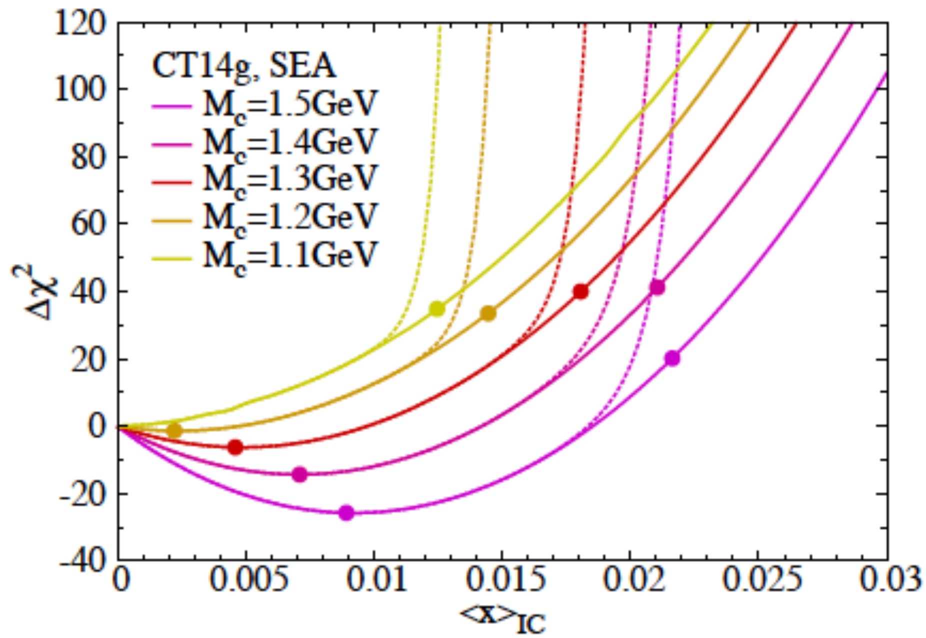
- Impact of BHPS solutions on (gg) Higgs cross sections minimal
- Impact of sea-like solutions on Higgs cross sections more noticeable
- More impact at high mass, but within uncertainties



Dependence on charm mass

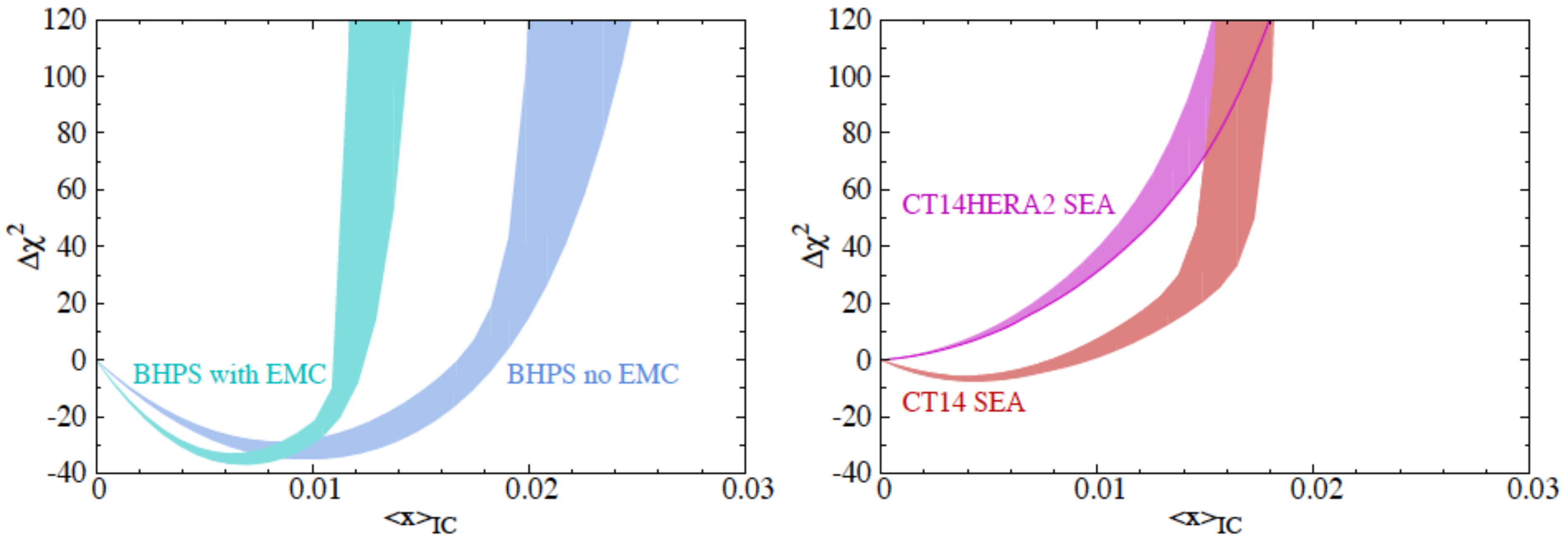
- Variations of charm mass have little impact on amount of intrinsic charm in BHPS modes, stronger effects for SEA models
  - *Note: CT14g is a special CT14 fit with a more flexible gluon parameterization necessary for Q_o=1 GeV, i.e. allowing the gluon to be negative*





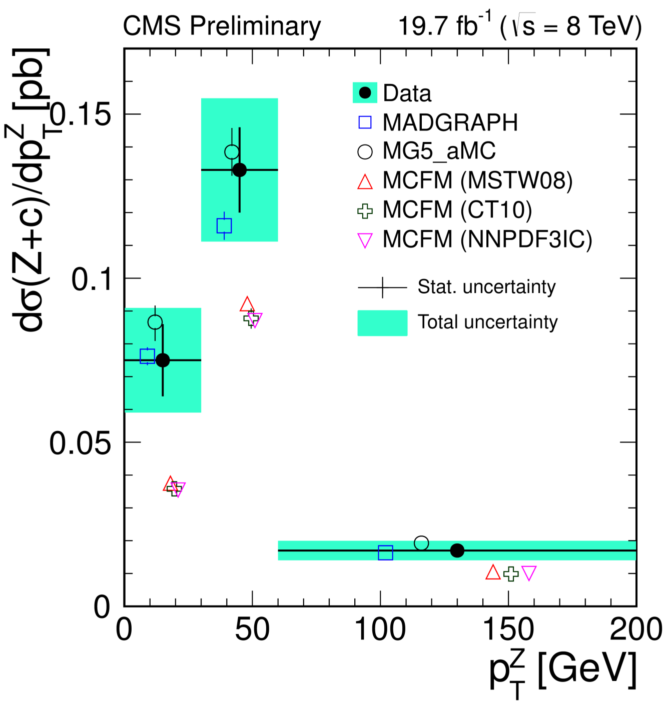
Impact of EMC data

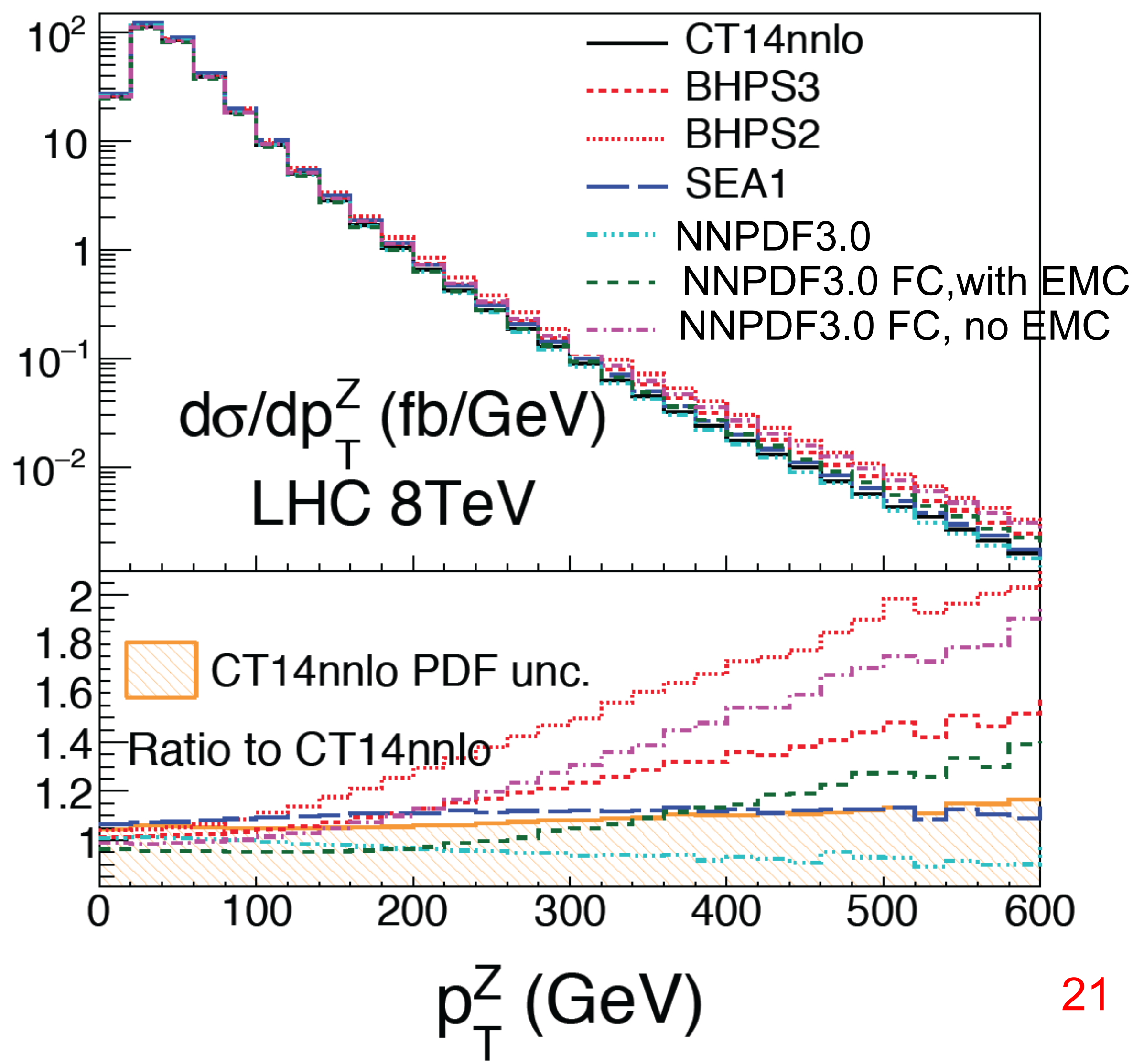
- Inclusion of EMC data in fit results in stronger limits on amount of intrinsic charm, move of minimum in χ^2 to slightly lower amounts of intrinsic charm
- EMC data is fit poorly, with or without IC, χ^2 between 2 and 3



Z+charm

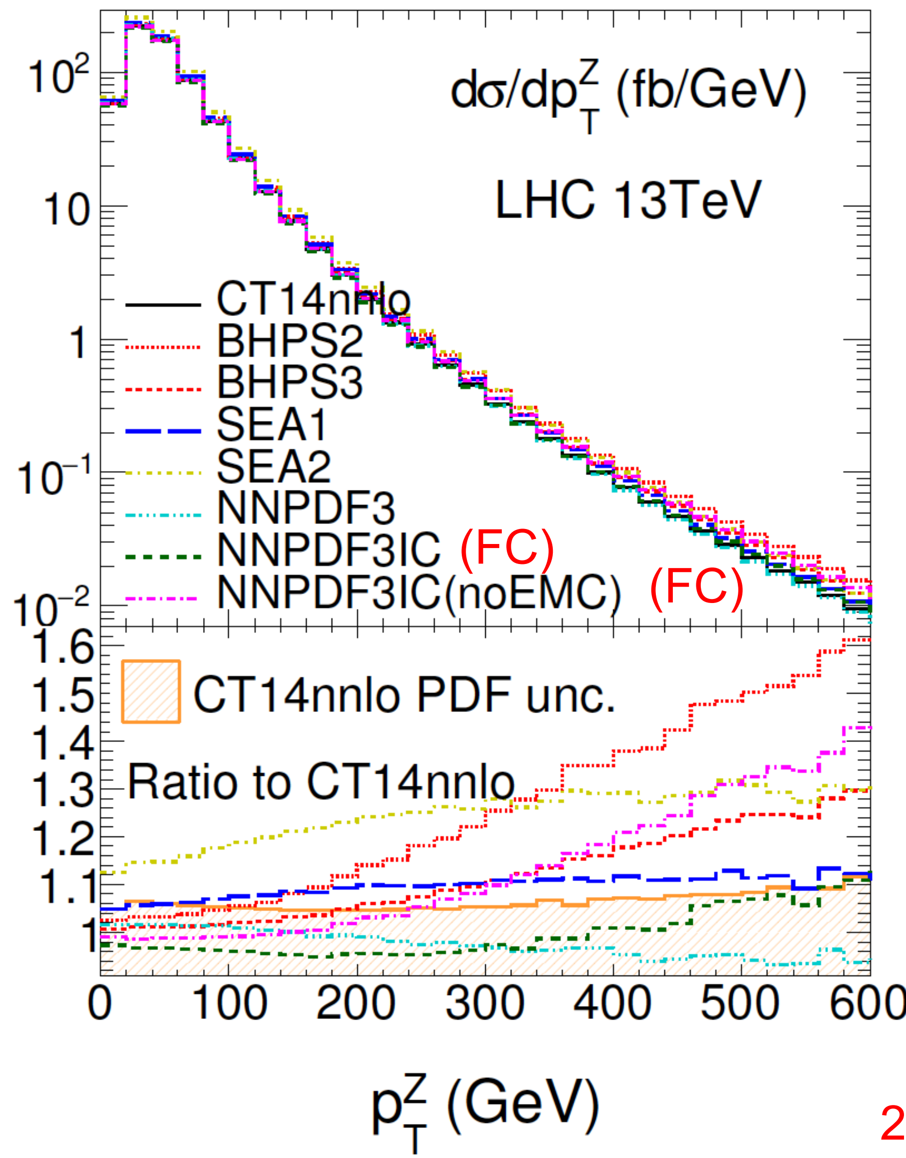
- BHPS3, for example, would take a high integrated luminosity to confirm or rule out



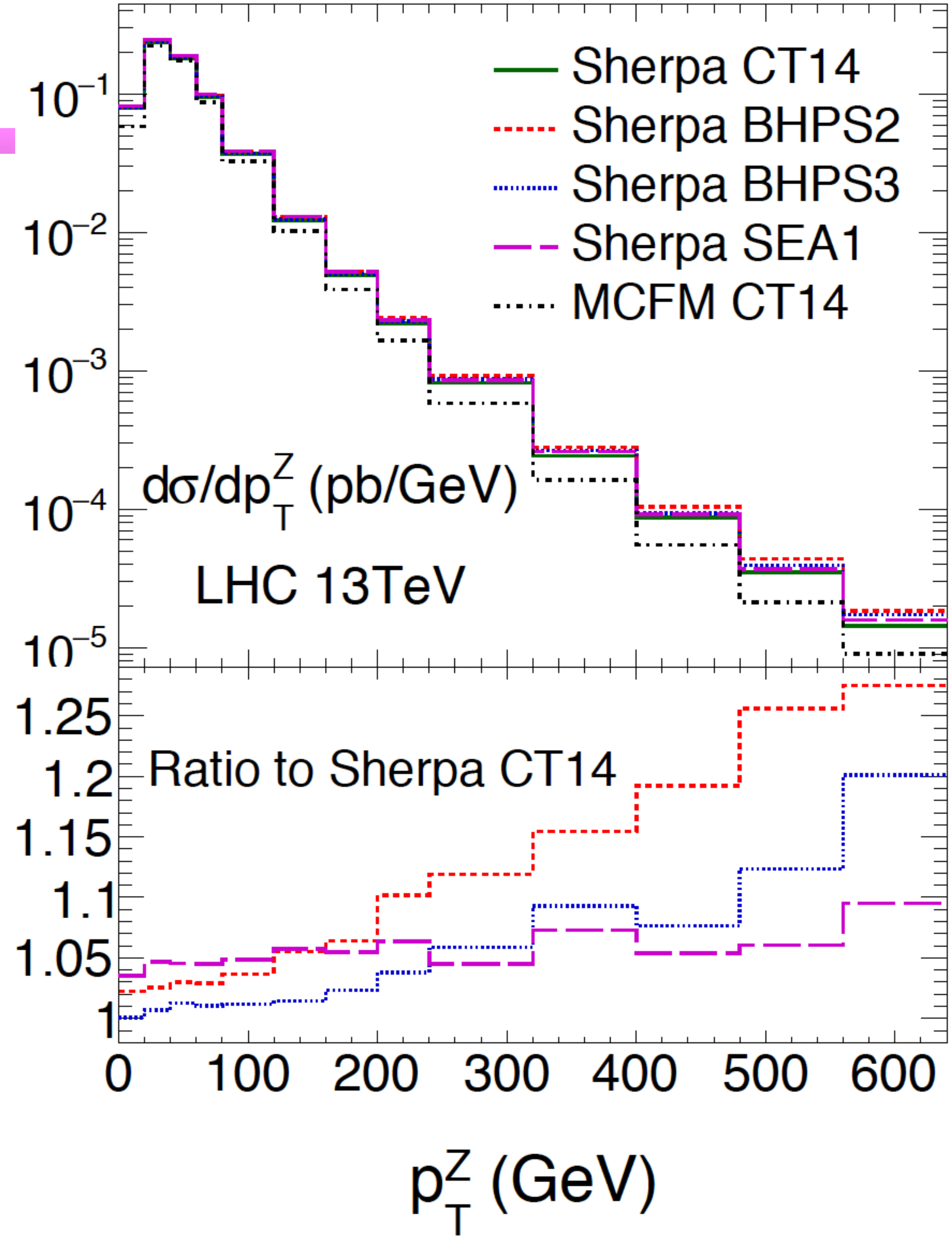


Z+charm at 13 TeV

- Higher energy means lower x for fixed p_T, so in some sense confirming models becomes more difficult at 13 TeV, without a very large amount of integrated luminosity
- Except SEA2 again which results in a fairly sizeable DC shift to the cross section



- The effect of intrinsic charm is reduced due to the effects of radiative corrections, for example Sherpa with up to 3 jets by the matrix element in the final state



Future studies/issues

- Add new processes known at NNLO
  - photon+jet
  - W+jet, Z+jet

- As more NNLO results are transferred by means of NNLO/NLO K-factors, can we agree on a standard PDF for the K-factors, i.e. PDF4LHC15?

- Scale uncertainties
  - perhaps most crucial for jet production
  - run fits with p_T^{jet} scale varied by a factor of 2
  - use $p_T^{lead\text{-}jet}$ rather than p_T^{jet}
  - add rapidity dependence to jet scales
- Conflicts between data sets
  - a better understanding of PDF uncertainties requires a better understanding of LHC data, and in particular conflicts between experiments, between data-sets, and even between observables
  - this trend will probably continue as systematic errors decrease and vanishingly small uncorrelated errors don't allow much wiggle room in PDF fits
- This is an area where PDF4LHC can contribute