Neutron Skin at the LHC

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Introduction

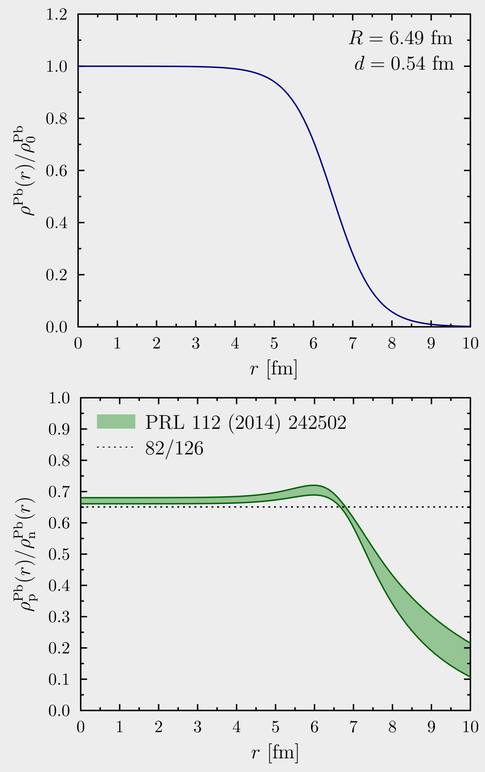
Nuclear density profile necessary input for Glauber models in centrality classification

- Standard choice: 2-parameter Fermi distribution (2pF)

$$\rho^A(r) = \frac{\rho_0^A}{1+\exp[\frac{r-R^A}{d^A}]}$$

R^A = nuclear radius

d^A = thickness of the surface



Neutron-skin (NS) effect: neutron density extends farther than proton density

- Observed in nuclear physics experiments
- Use different 2pF parameters for protons and neutrons in Pb-nucleus [1]

$$R_{\rm p}^{\rm Pb} = 6.680 \text{ fm},\ R_{\rm n}^{\rm Pb} = 6.70 \pm 0.03 \text{ fm}$$
$$d_{\rm p}^{\rm Pb} = 0.447 \text{ fm},\ d_{\rm n}^{\rm Pb} = 0.55 \pm 0.03 \text{ fm}$$

$\Rightarrow$ Fraction of neutrons grows at large r

$\Rightarrow f_{\rm u}(x,Q^2)/f_{\rm d}(x,Q^2)$ decrease with centrality

Aim: Study whether this has a measurable influence on EW-sensitive observables in Pb+Pb (p+Pb) collisions at the LHC [2,3]

Framework

Centrality classification with Optical Glauber model

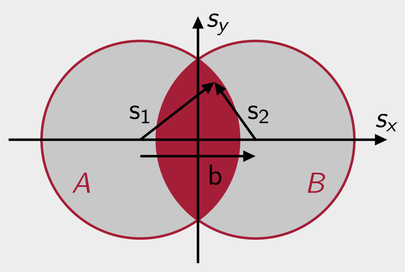
- Total inelastic cross section in A+B collision

$$\sigma_{AB}^{\rm inel}(\sqrt{s_{\rm NN}}) = \int {\rm d}^2\mathbf{b}\left[1 - {\rm e}^{-T_{AB}(\mathbf{b})\,\sigma_{NN}^{\rm inel}(\sqrt{s_{\rm NN}})}\right]$$

- Where nuclear overlap function

$$T_{AB}(\mathbf{b}) = \int {\rm d}^2\mathbf{s}\left[T_{\rm p}^A(\mathbf{s}_1) + T_{\rm n}^A(\mathbf{s}_1)\right]\left[T_{\rm p}^B(\mathbf{s}_2) + T_{\rm n}^B(\mathbf{s}_2)\right]$$

and $T_i^A(\mathbf{s}) = \int {\rm d}z\,\rho_i^A(\mathbf{r})$



- Impact-parameter interval for a given centrality class obtained by requiring a certain fraction of the total inelastic cross section when integrating over $b = |\mathbf{b}|$
- Normalization for centrality class $\mathcal{C}_k$ given by $T_{AB}(\mathcal{C}_k) = 2\pi\int_{b_k}^{b_{k+1}} {\rm d}b\,b\,T_{AB}(b)$

Collinear factorization

- Hard-process cross section in A+B collisions for a given centrality class

$$\mathrm{d}\sigma_{AB}^{\rm hard}(\mathcal{C}_k) = 2\pi\int_{b_k}^{b_{k+1}} \mathrm{d}b\,b\int \mathrm{d}^2\mathbf{s}\sum_{i,j} T_i^A(\mathbf{s}_1)\,T_j^B(\mathbf{s}_2)\,\mathrm{d}\sigma_{ij}^{\rm hard}(A,B,\mathbf{s}_1,\mathbf{s}_2)$$

where $i,j = {\rm p},{\rm n}$

- Impact-parameter dependence from spatially dependent nuclear PDFs

$$\mathrm{d}\sigma_{ij}^{\rm hard}(A,B,\mathbf{s}_1,\mathbf{s}_2) = \sum_{k,l} f_k^{i/A}(x_1,Q^2,\mathbf{s}_1)\otimes f_l^{j/B}(x_2,Q^2,\mathbf{s}_2)\otimes \mathrm{d}\hat{\sigma}_{ij}^{kl\to\text{observable}}$$

where

$$f_k^{i/A}(x,Q^2,\mathbf{s}) = r_k^{i/A}(x,Q^2,\mathbf{s})\,f_k^i(x,Q^2)$$

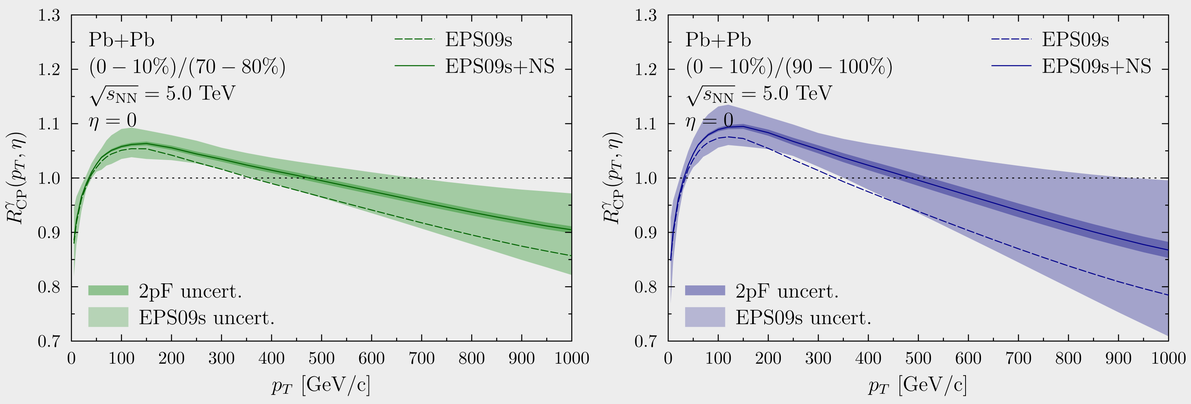
and $r_k^{i/A}(x,Q^2,\mathbf{s})$ from EPS09s [4]

Direct photons [2]

- Expect suppression of photons in peripheral collisions due to NS effect
- Observable: Central-to-peripheral ratio

$$R_{CP} = \frac{1}{T_{\rm PbPb}(C)}\frac{\mathrm{d}\sigma_{\rm PbPb}^{\gamma}(C)}{\mathrm{d}p_{\rm T}\mathrm{d}\eta}\Big/\frac{1}{T_{\rm PbPb}(P)}\frac{\mathrm{d}\sigma_{\rm PbPb}^{\gamma}(P)}{\mathrm{d}p_{\rm T}\mathrm{d}\eta}$$

  - Sensitive only to centrality-dependent effects
  - Some experimental uncertainties expected to cancel out
  - Cross sections calculated at NLO in pQCD with INCNLO



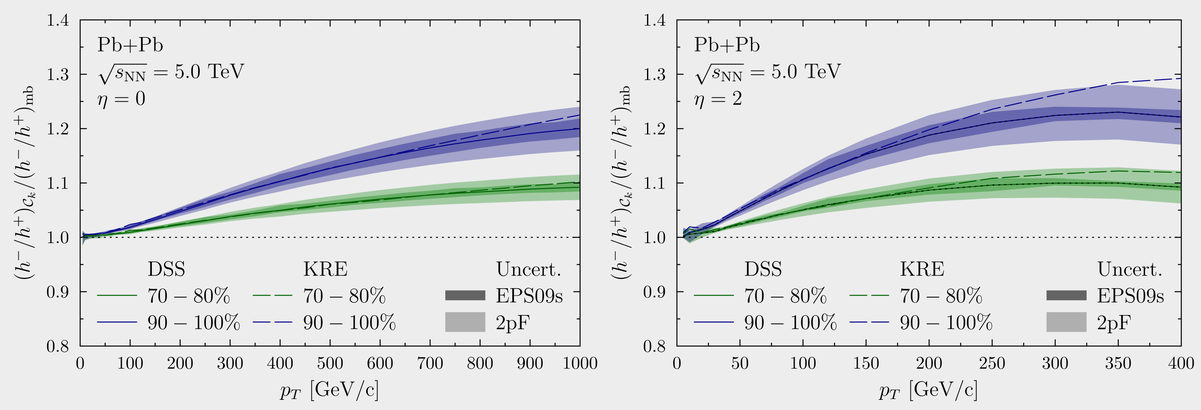
- Need a very high-$p_{\rm T}$ ($\simeq$ large x) to see the influence of the NS effect
- Effect larger for more peripheral events, still $\lesssim$ 10 % effect
- nPDF-originating uncertainties of the same order than the expected NS effect (somewhat smaller nPDF uncertainties at $\eta = 2$)

Charged hadrons [2]

- Expect an increased concentration of negative hadrons in peripheral collisions
- Observable: Ratio between negatively and positively charged hadrons

$$\frac{h^-}{h^+}(\mathcal{C}_k) = \frac{\mathrm{d}\sigma_{\rm PbPb}^{h^-}(\mathcal{C}_k)}{\mathrm{d}p_{\rm T}\mathrm{d}\eta}\Big/\frac{\mathrm{d}\sigma_{\rm PbPb}^{h^+}(\mathcal{C}_k)}{\mathrm{d}p_{\rm T}\mathrm{d}\eta}$$

  - Cross sections calculated at NLO in pQCD with INCNLO, hadronization with fragmentation functions (FFs)
  - nPDF effects (also centrality dependent) effectively cancel in the ratio
  - Some dependence on the applied FFs
    $\Rightarrow$ Normalize with minimum bias (MB) result to reduce the FF dependence
  - No final-state effects included (energy loss independent of EM charge)
    - Flavour independence supported also by unmodified K/π and p/π ratios



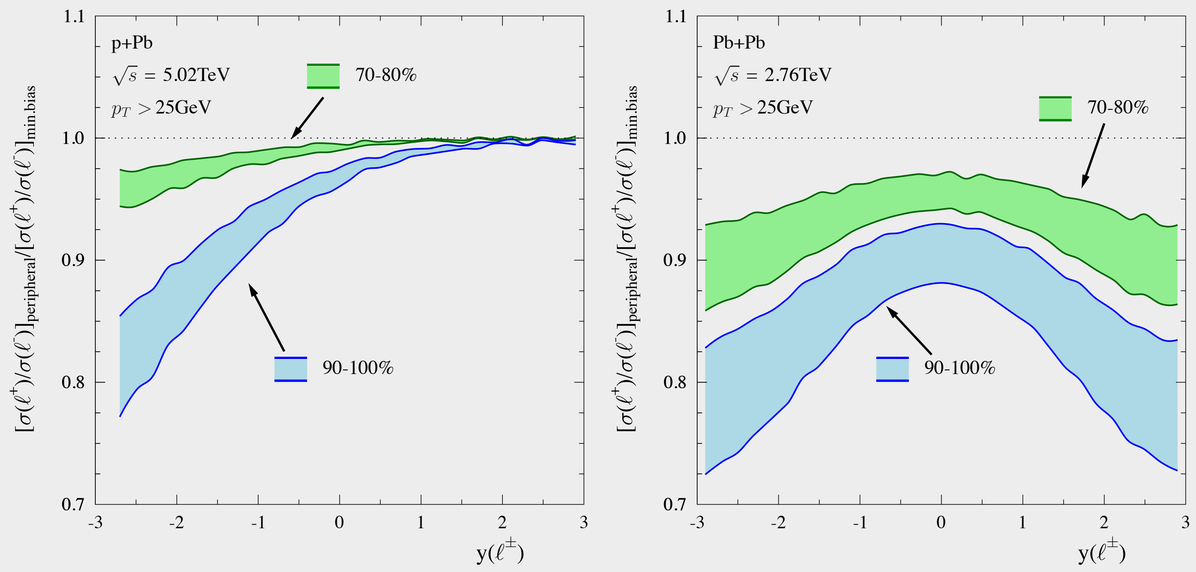
- Very small nPDF uncertainties, some from density parametrization
- Only small dependence on the applied FF due to normalization with MB
- Still need high-$p_{\rm T}$ to see $\sim$ 10 % effect

W$^{\pm}$ production [3]

- Expect enhanced W$^-$ and decreased W$^+$ production in peripheral collisions
- Observable: Ratio between + and - charged leptons from W$^{\pm}\to l^{\pm}\nu$ decays

$$\frac{\sigma(l^+)}{\sigma(l^-)}(\mathcal{C}_k) = \frac{\mathrm{d}\sigma^{l^+}(\mathcal{C}_k)}{\mathrm{d}y\mathrm{d}p_{\rm T}}\Big/\frac{\mathrm{d}\sigma^{l^-}(\mathcal{C}_k)}{\mathrm{d}y\mathrm{d}p_{\rm T}}$$

- Cross sections calculated at NLO using MCFM code with $Q^2 = M_{\rm W}^2$ and integrating over $p_{\rm T}^l > 25$ GeV/c
- nPDF effects expected to cancel out, calculations with free proton PDFs only
- Normalized with $\sigma(l^+)/\sigma(l^-)(\mathcal{C}_{\rm MB})$



- Larger influence at small y (p+Pb) or large $|y|$ (Pb+Pb) (larger nuclear-x)
- Fine centrality binning required (ATLAS data: most peripheral bin 40–80 %)

Conclusions

- Difficult to unambiguously study NS effect with direct photons since only $\sim$ few-percent effects even at very high-$p_{\rm T}$ and sizeable nPDF uncertainties
- For h^-/h^+ the nPDFs effects cancel out and effects of the order 10 %, though very high-$p_{\rm T}$ hadrons are still required (beyond the LHC capabilities?)
- $\sim$ 10 % effects for W$^{\pm}$ production, statistics of the $\sqrt{s} = 2.76$ TeV data limited
- NS effect could provide additional handle to study the centrality classification

References

[1] C.M. Tarbert *et al.*, PRL **112** (2014) 24, 242502
[2] I. Helenius, H. Paukkunen and K. J. Eskola, arXiv:1606.06910 [hep-ph]
[3] H. Paukkunen, Phys. Lett. B **745** (2015) 73
[4] I. Helenius, K. J. Eskola, H. Honkanen and C. A. Salgado, JHEP **1207** (2012) 073

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