Quantum Entanglement in High Energy Particle Collisions

April 08th:2022

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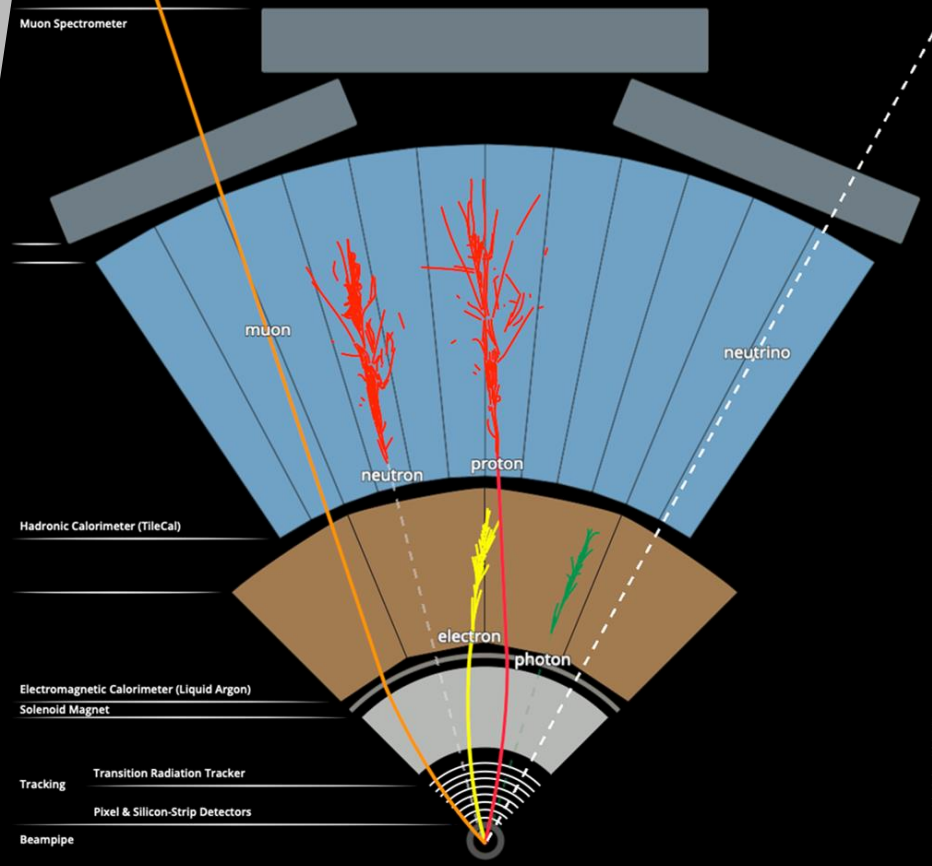
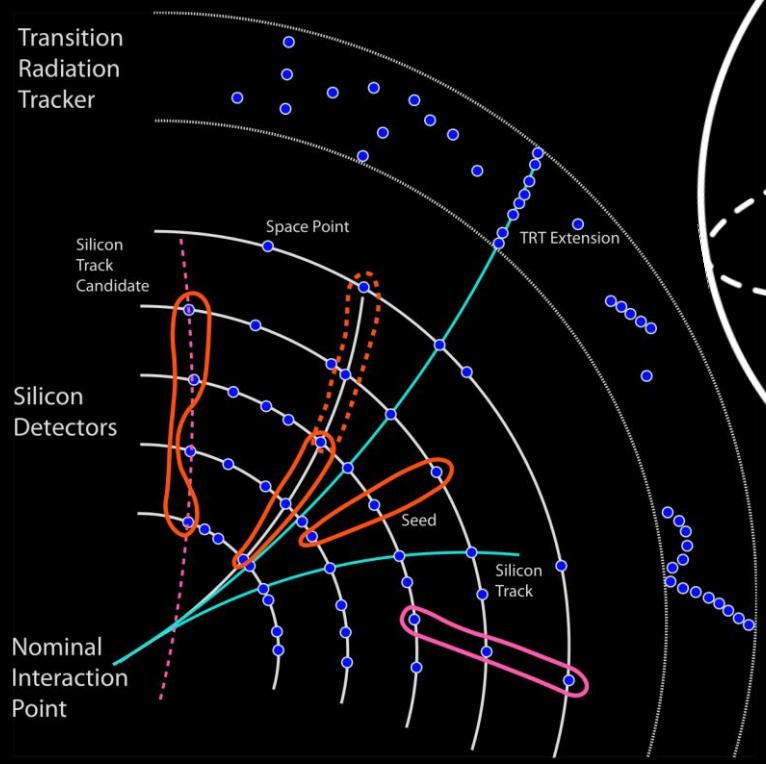
Wright Lab
Quantum Sensing Workshop

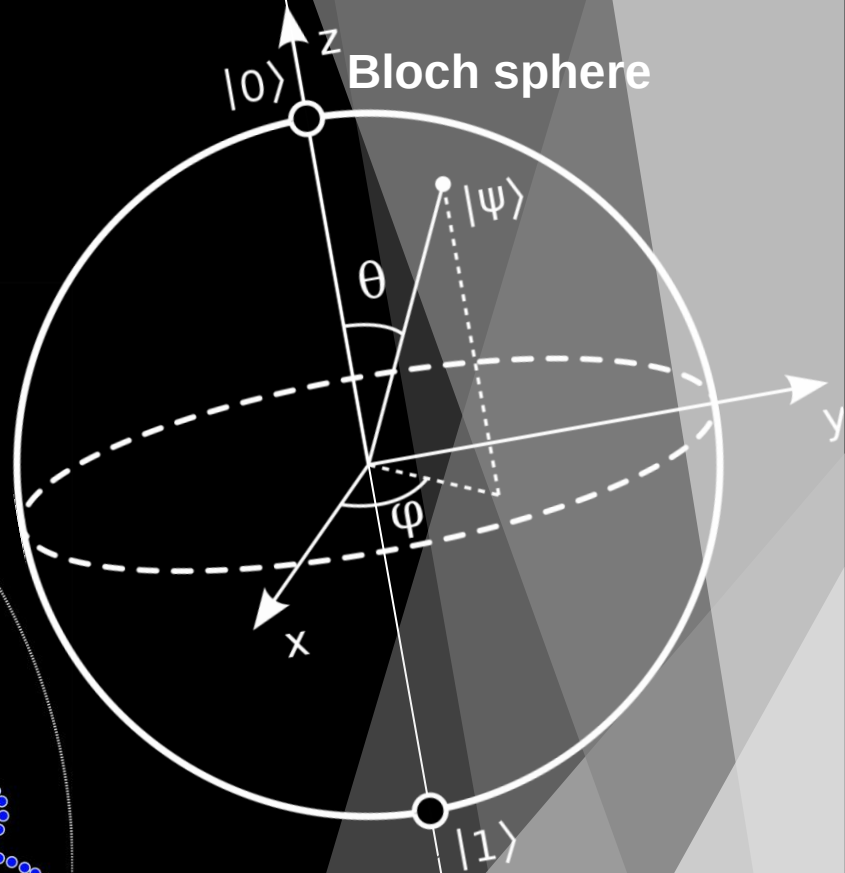
Particles in High Energy Physics

Atlas Detector cross section





track reconstruction



ATLAS EXPERIMENT

Entanglement & Collisions

Density Matrix

$$\rho_{AB} = |\Psi\rangle\langle\Psi|_{AB}$$

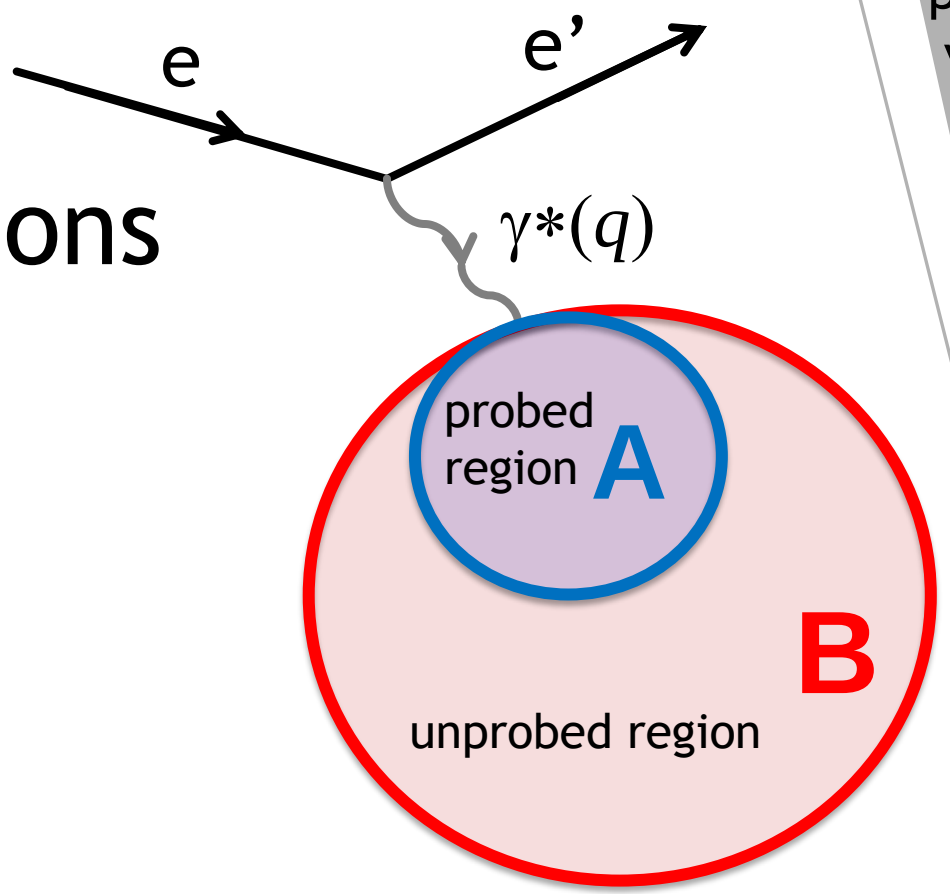
Reduced Density Matrix

$$\rho_A = Tr_B[\rho_{AB}] = \sum_n \alpha_n^2 \, |\Psi_n^A\rangle\langle\Psi_n^A|$$

$\neq 0$ if A & B entangled

Van Neuman Entropy

$$S(\rho_A) = -Tr[\rho_A \log \rho_A] = -\sum_n \alpha_n^2 \ln(\alpha_n^2)$$



proton

probed proton volume

longitudinal scale

$$l \sim \frac{1}{mx}$$

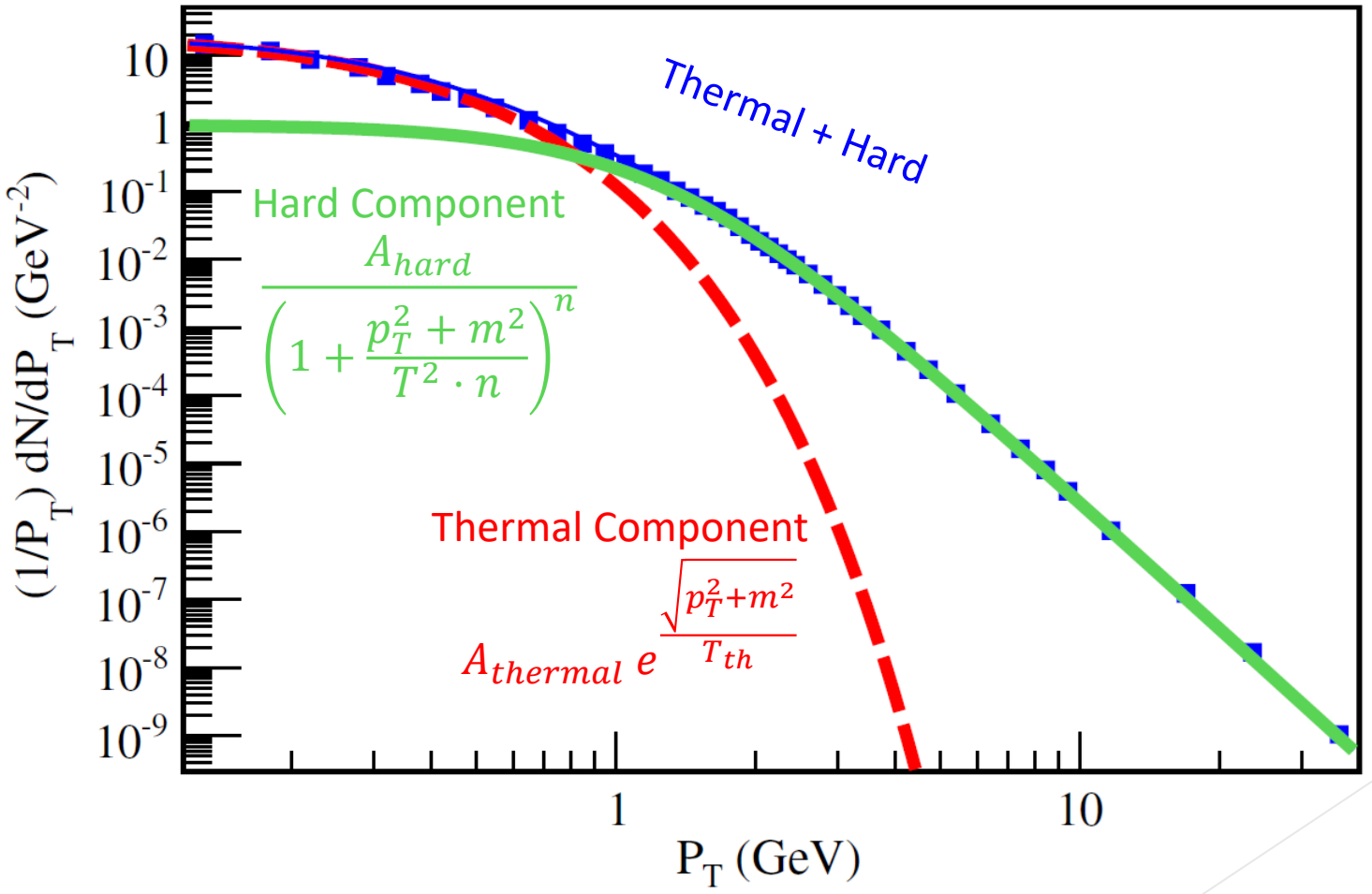
transverse scale

$$d \sim \lambda_{\text{deBroglie}} = \frac{h}{|\vec{q}|}$$

m - proton mass

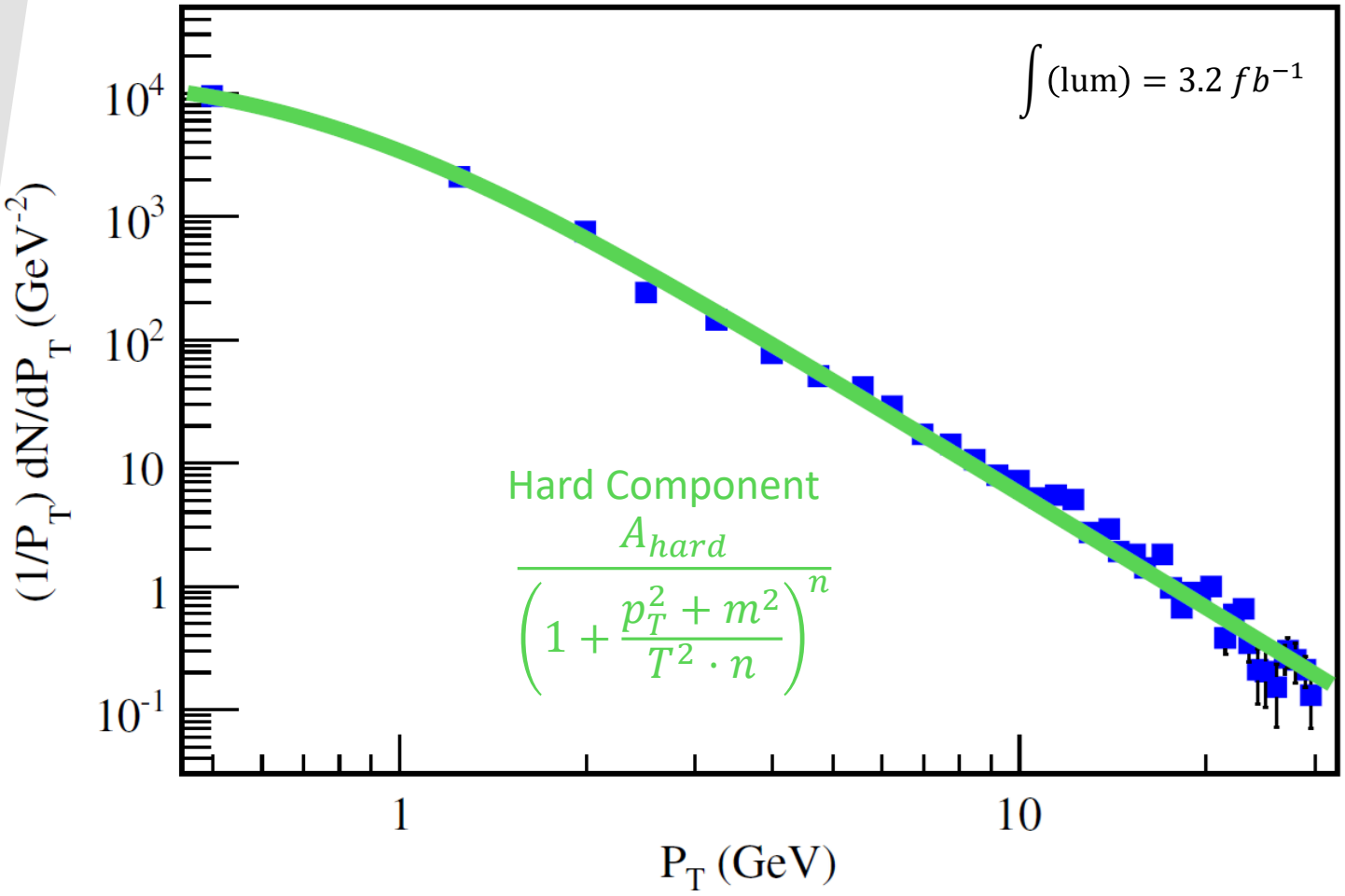
x - parton momentum fraction

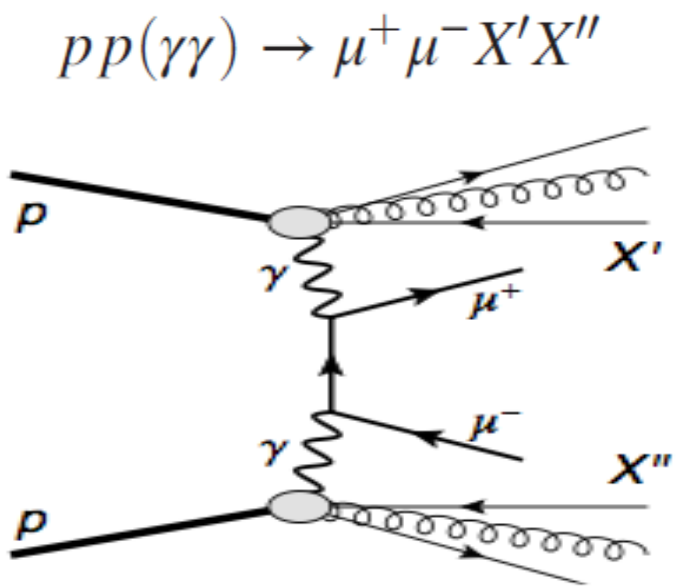
Transverse momentum distribution of charged hadrons in proton-proton collisions at $\sqrt{s} = 13$ TeV



Data: ATLAS collaboration, Eur. Phys. J. C76, 502 (2016); PLB 758 , 67 (2016)

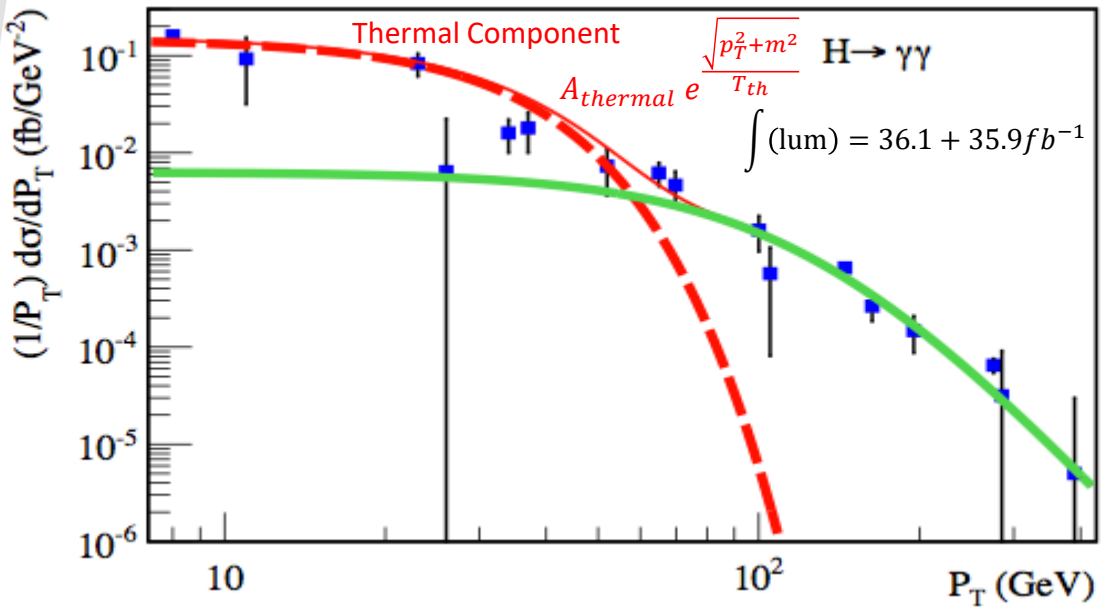
Di-Muon pair transverse momentum distribution doubly diffractive $\gamma\gamma$ scattering in pp collisions

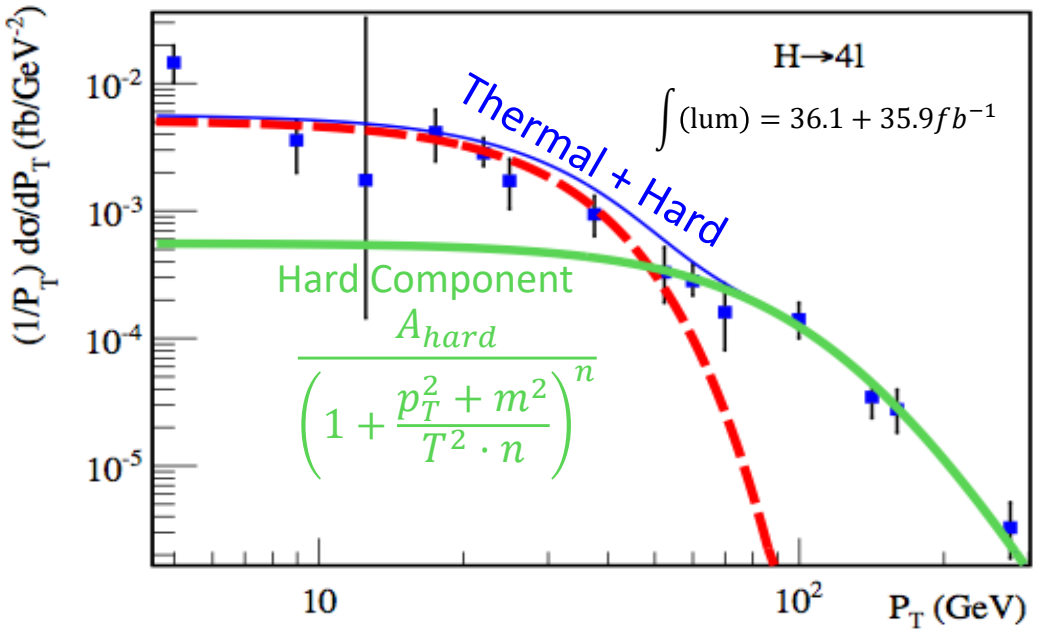




Baker, O. K., & Kharzeev, D. E. (2018). Physical Review D, 98(5), 054007

Extends to Higgs sector





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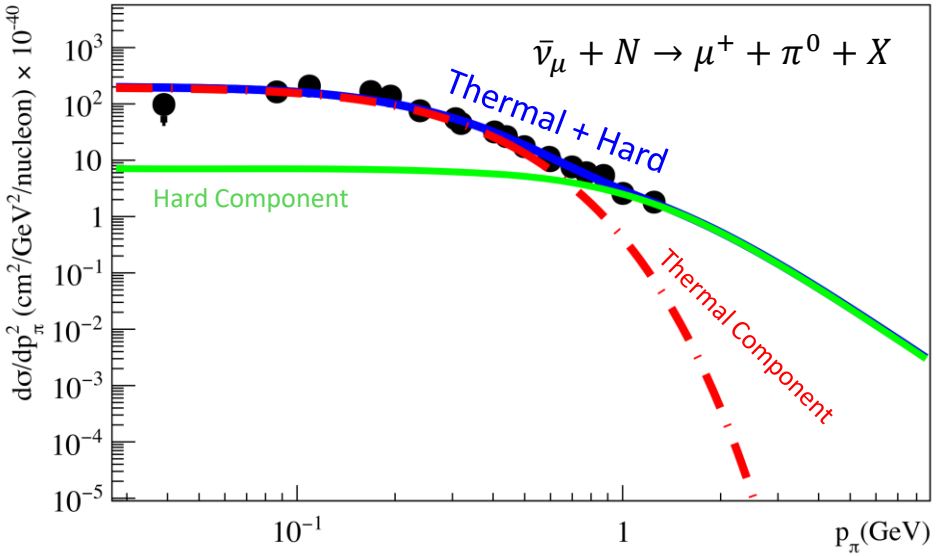
And charged-current weak Interactions too!



G. Iskander, et al., Physics Letters B 811 (2020) 135948D

Conclusion

- Observed signs of entanglement in High Energy collisions
- Raises possibility to use quantum phenomena for physics searches at colliders
  - Increased motivation to use angular variables analyses
  - Consider statistical distributions for physics searches
  - Detectors with spin-sensitivity?

End of Presentation

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