Light Meson Structure with ePIC

Stephen JD Kay
University of York

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Outline

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- Meson Form Factors - Context

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- ePIC Projections - Latest Results and Improvements

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  - Properties of hadrons are emergent phenomena

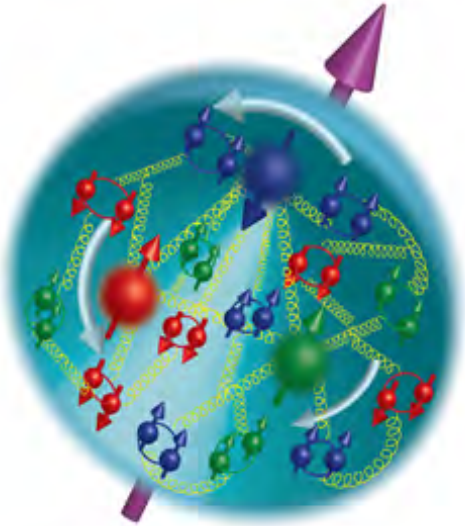

Image - A. Deshpande, Stony Brook University

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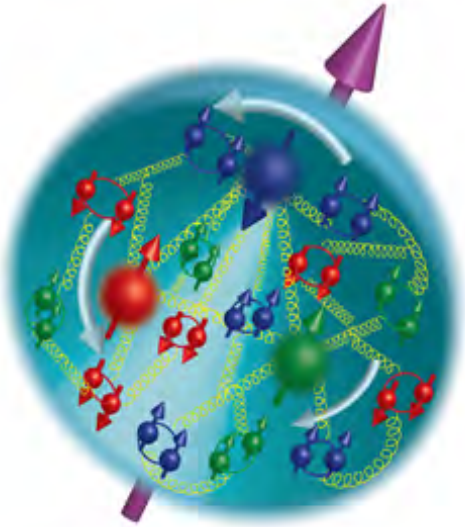

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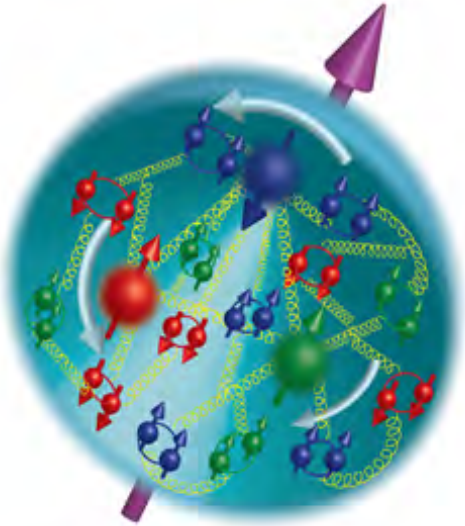

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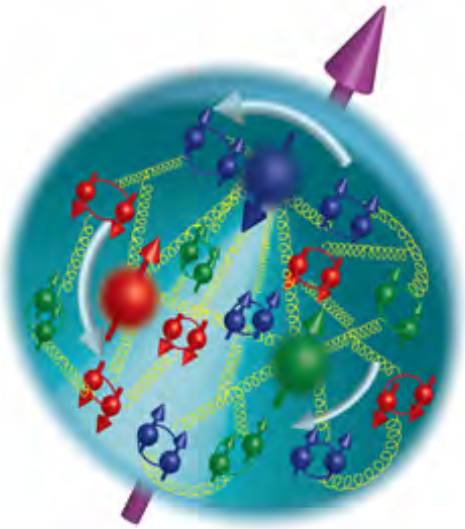

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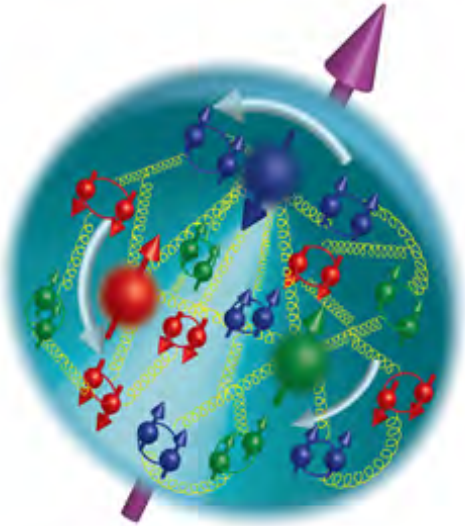

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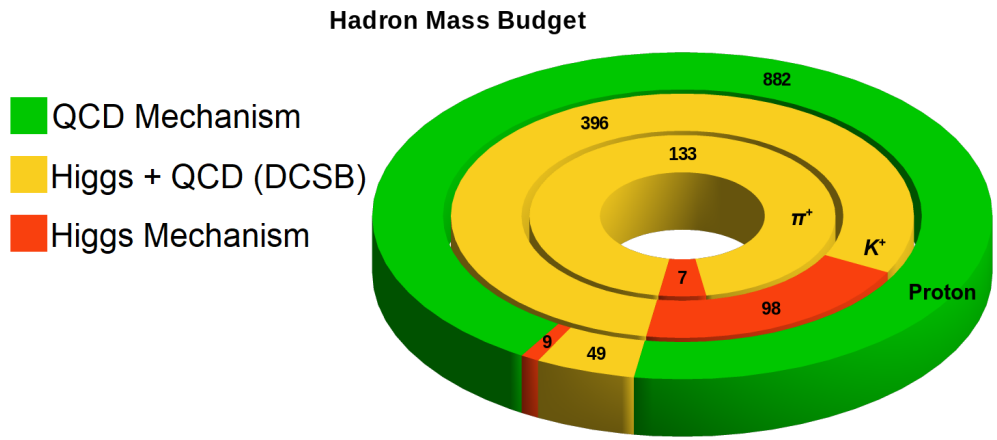
- **A major puzzle of the standard model to try and resolve!**

Hadron Mass Budgets



Revealing the structure of light pseudoscalar mesons at the electron–ion collider

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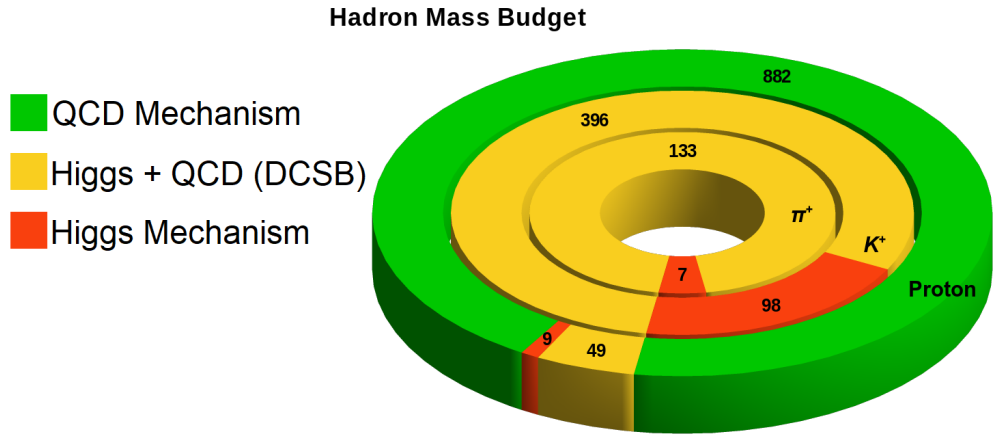

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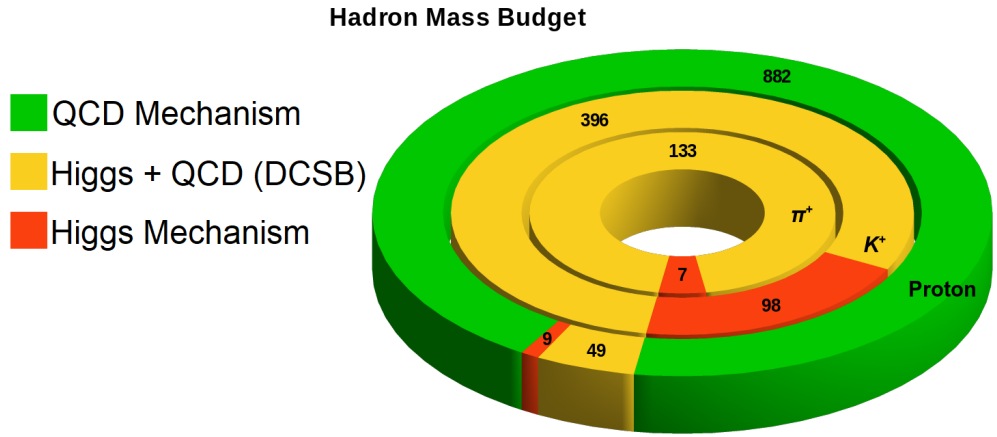

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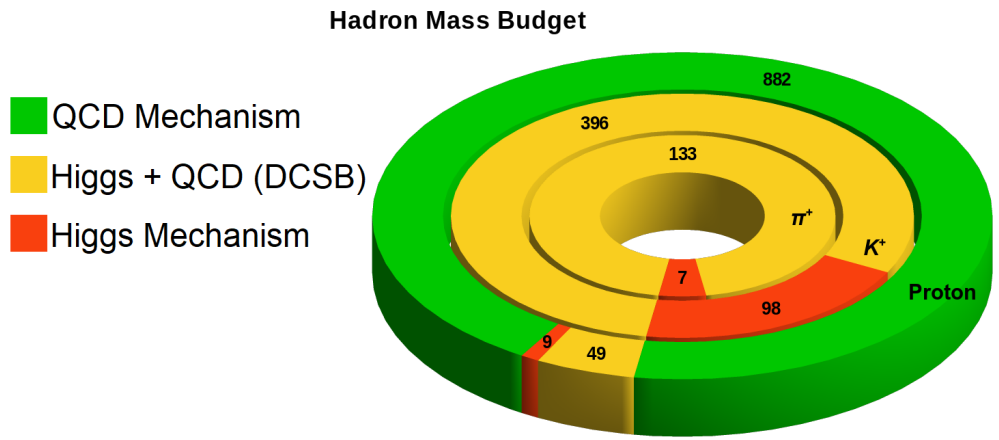

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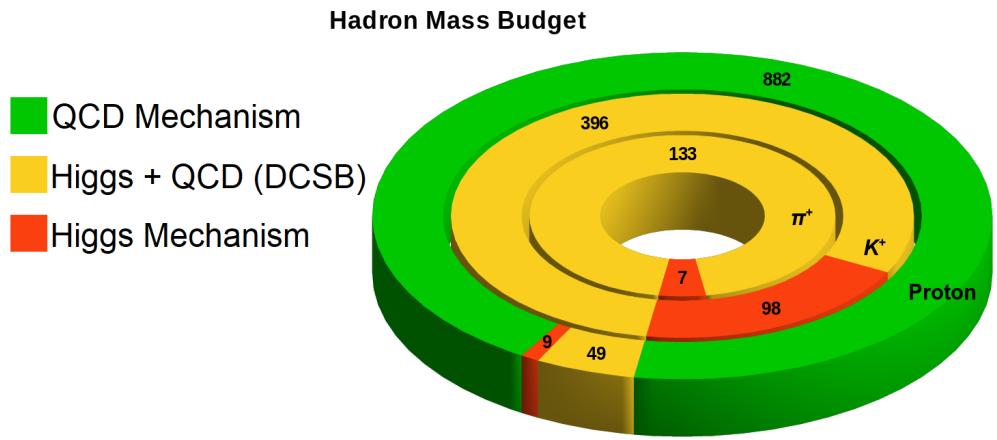

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- **The simple $q\bar{q}$ valence structure of mesons makes them an excellent testing ground**
- What can we examine to look at their structure?

Meson Form Factors

- Charged pion ($\pi^{\pm}$) and kaon ($K^{\pm}$) form factors (F_{π}, F_{K}) are key QCD observables
  - Momentum space distributions of partons within hadrons

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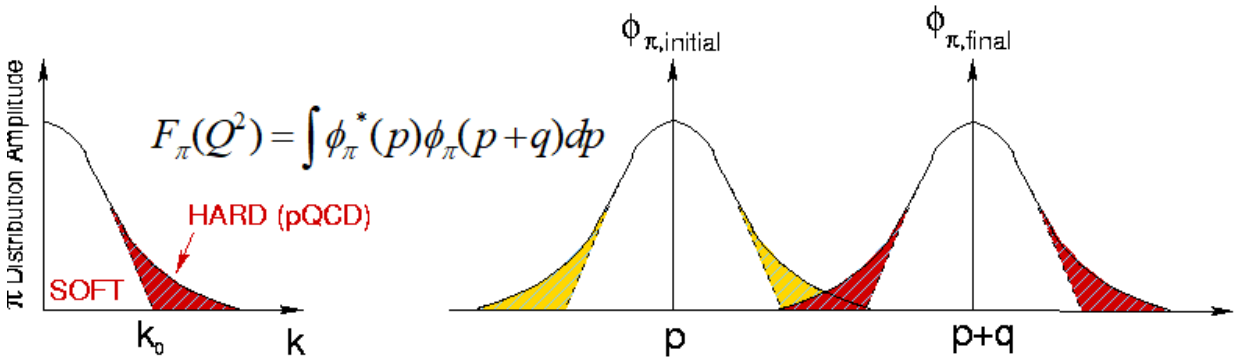

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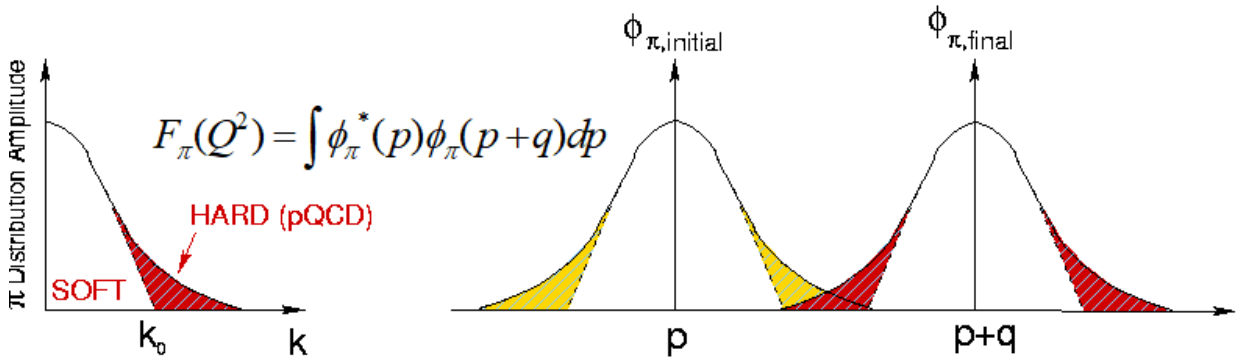

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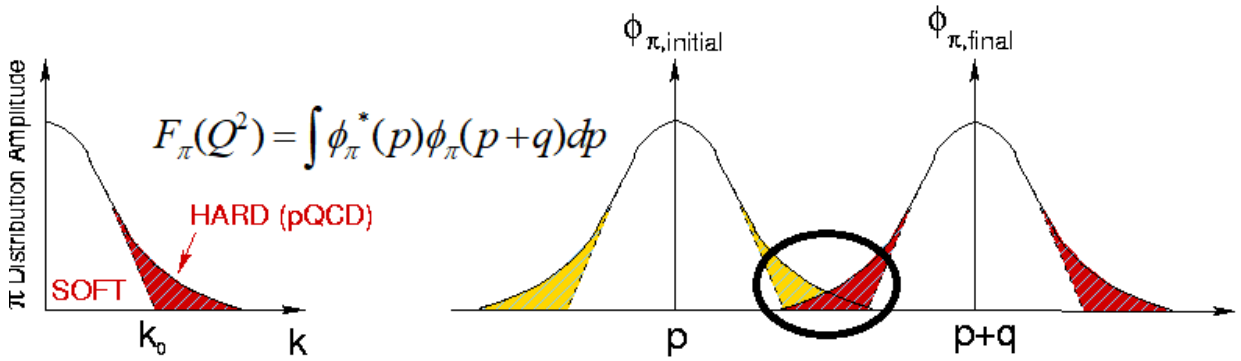

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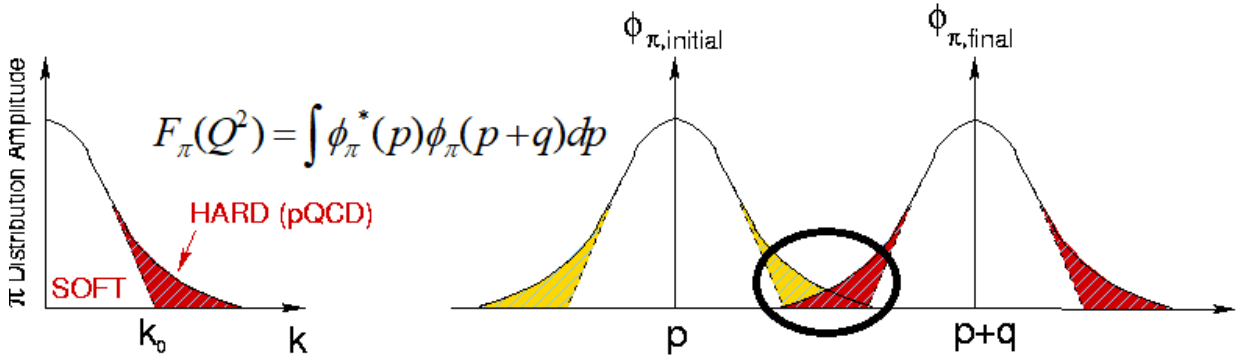

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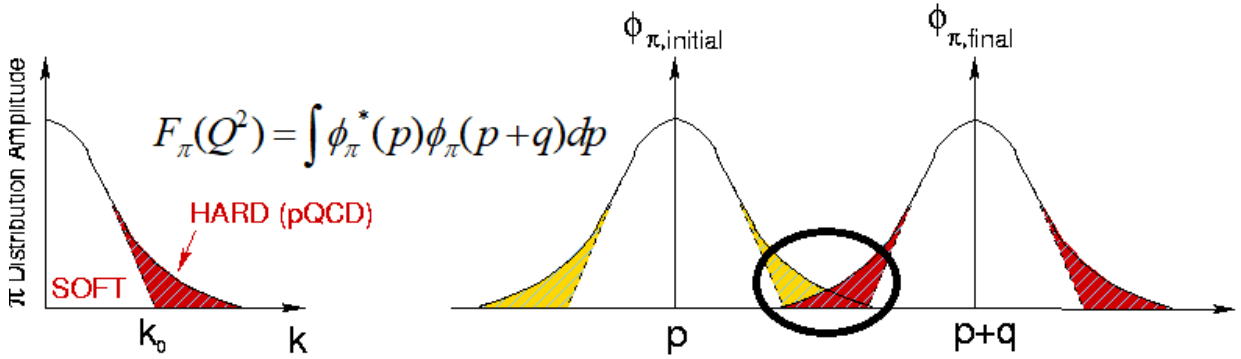

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- **F_π and F_K of special interest in hadron structure studies**
  - π - Lightest QCD quark system, simple
  - K - Another simple system, contains strange quark

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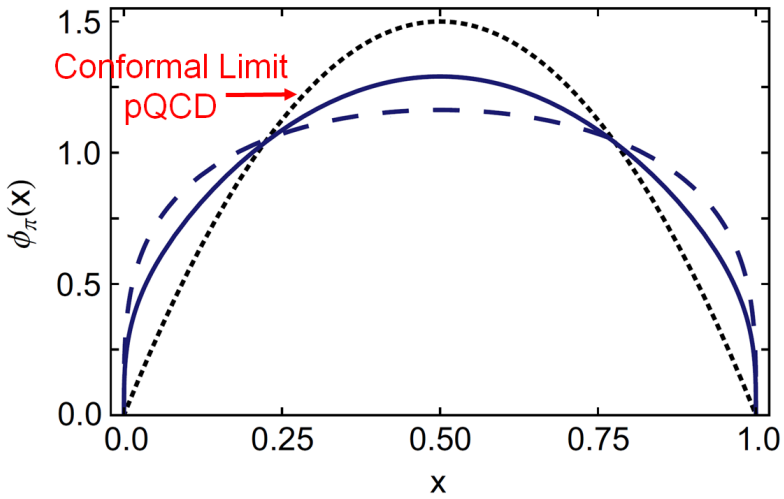
- Calculating the pion PDA, ϕ_π, without incorporating DCSB produces a broad, concave shape



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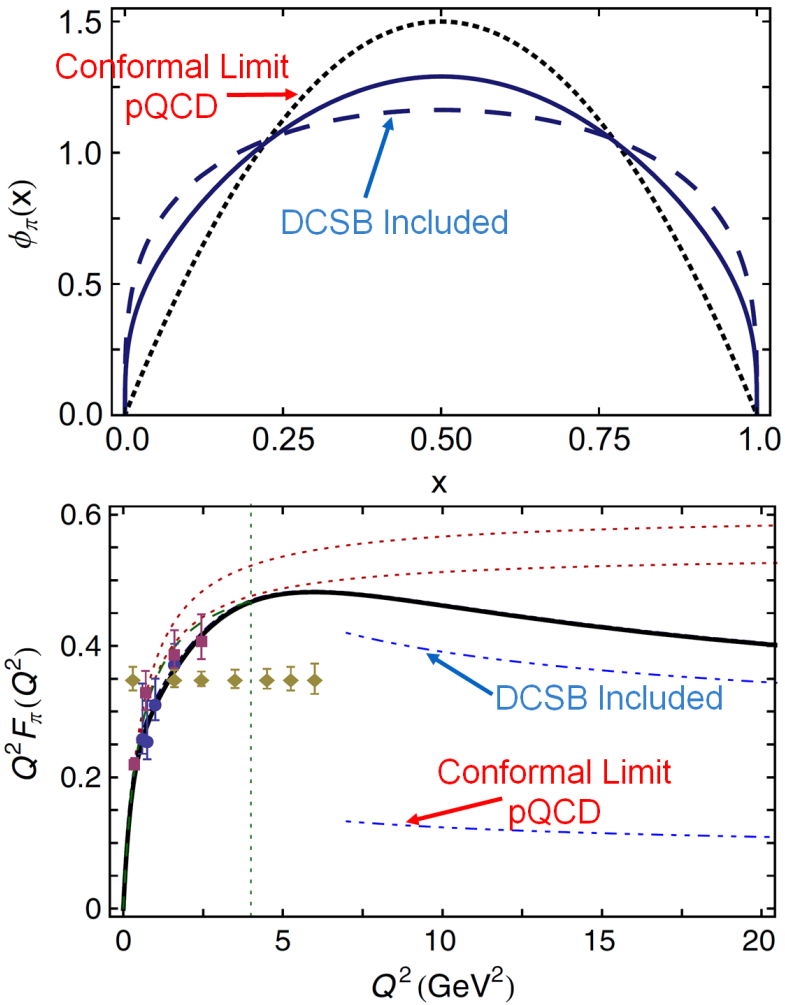

L. Chang, et al., PRL110(2013) 132001, PRL111(2013), 141802

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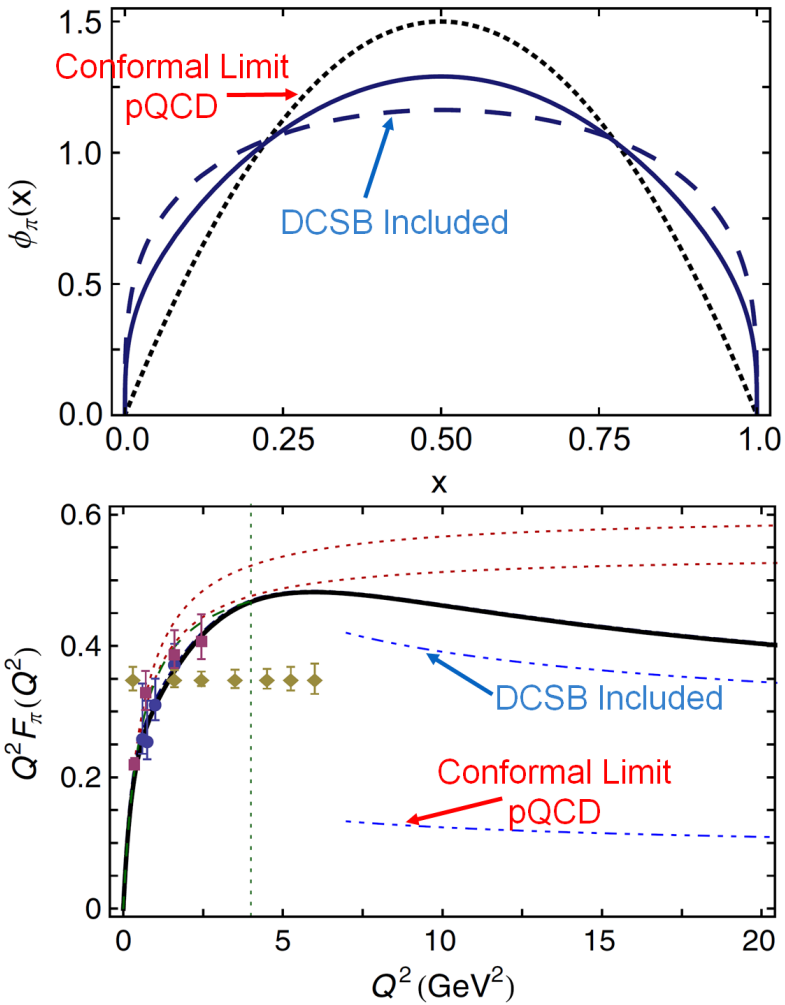
- Pion structure and hadron mass generation are interlinked



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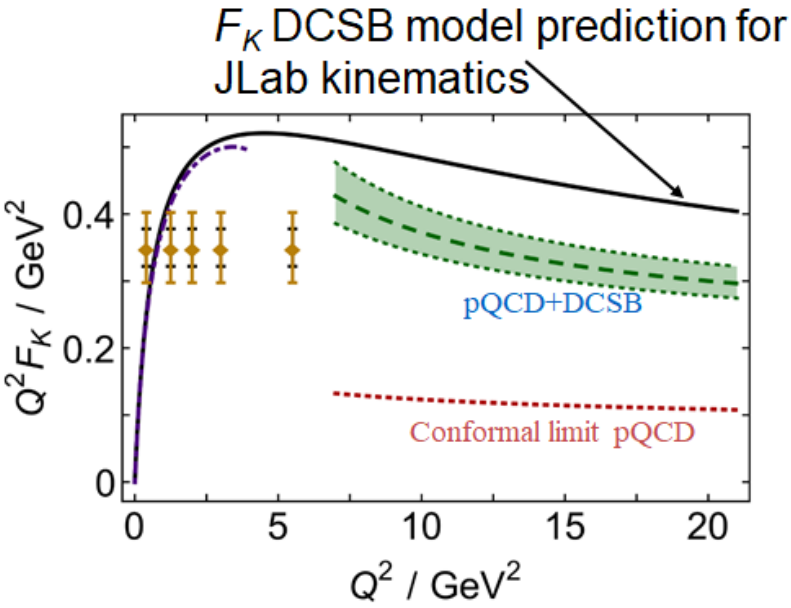

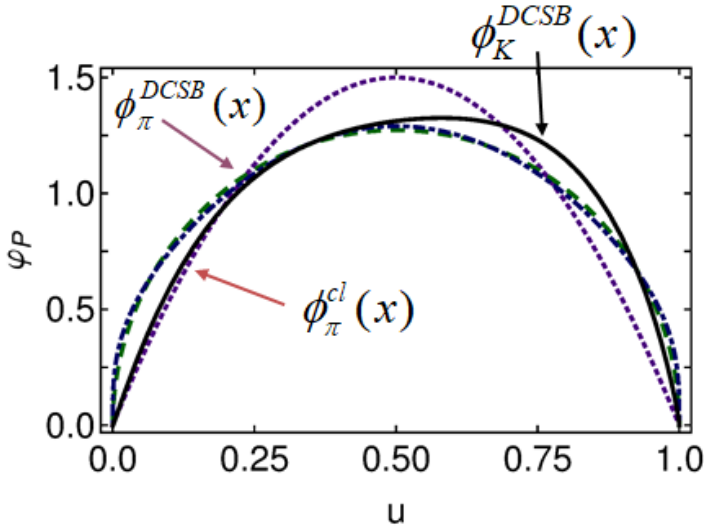

C. Shi, et al., PRD 92 (2015) 014035, F. Guo, et al., PRD 96(2017) 034024 (Full calculation)

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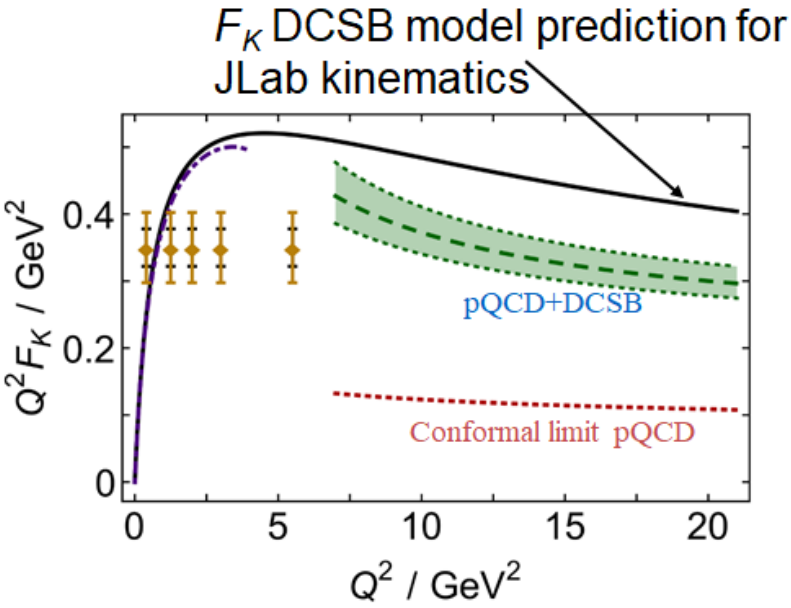
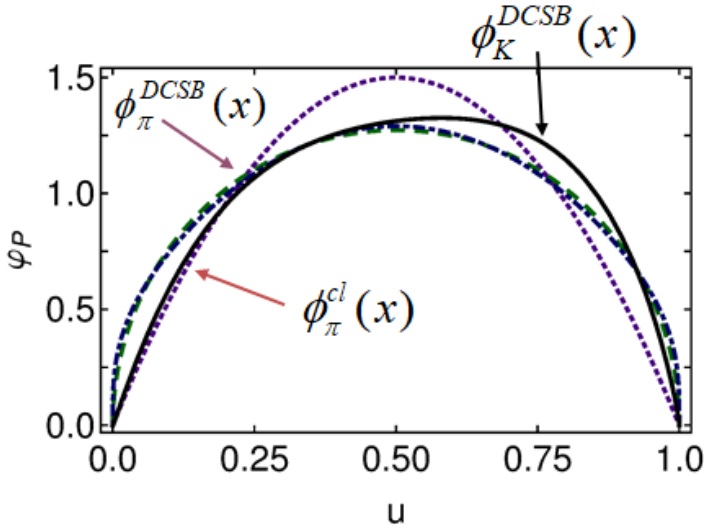
- Heavier s quark carries more bound state momentum than the u quark





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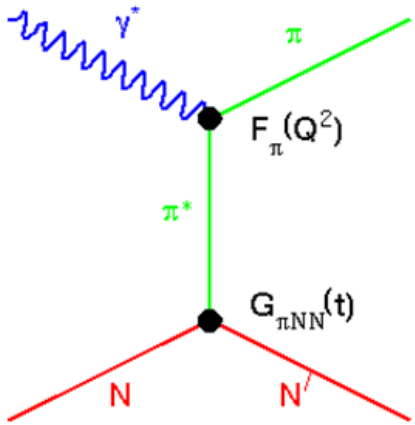

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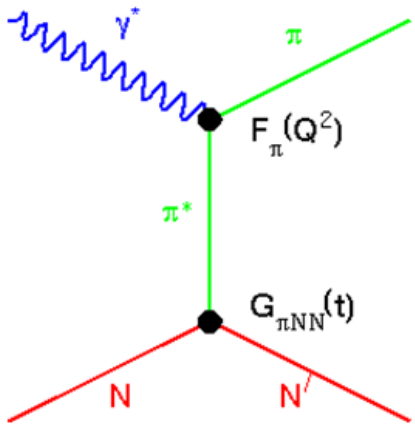

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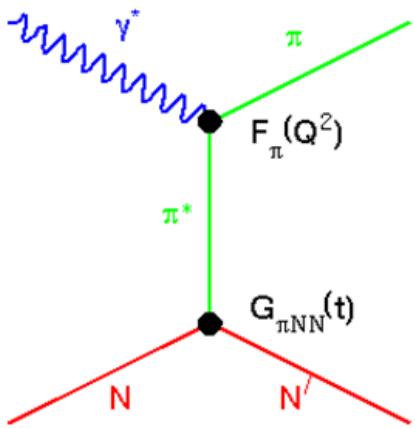

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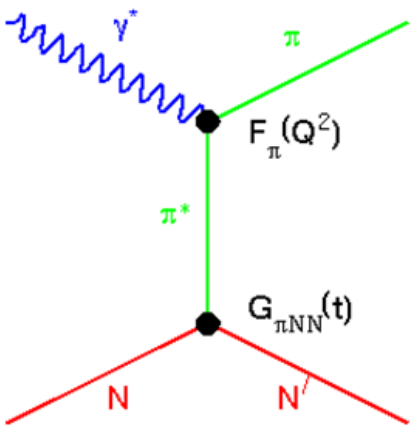

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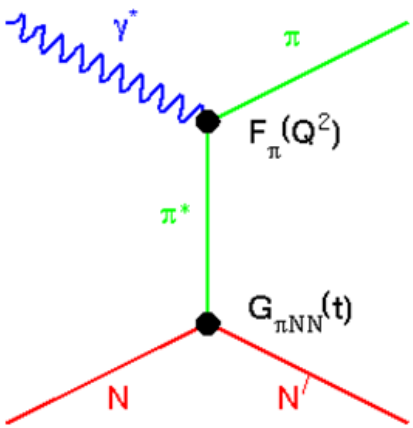

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A. Bylinkin. et. al., NIMA 1052 (2023) 168238 https://doi.org/10.1016/j.nima.2023.168238

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A. Bylinkin. et. al., NIMA 1052 (2023) 168238 https://doi.org/10.1016/j.nima.2023.168238, DEMPgen https://github.com/JeffersonLab/DEMPgen/releases/tag/v1.2.2

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- Event generator recently modified to generate kaon events
  - Next extension of studies $\rightarrow$ Can we measure F_K too?

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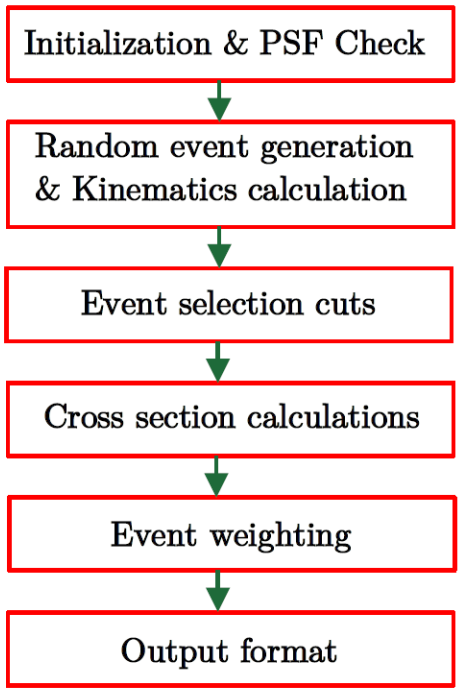

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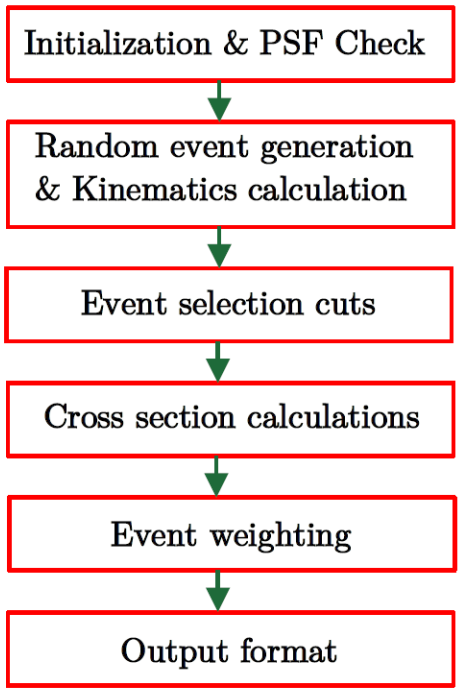

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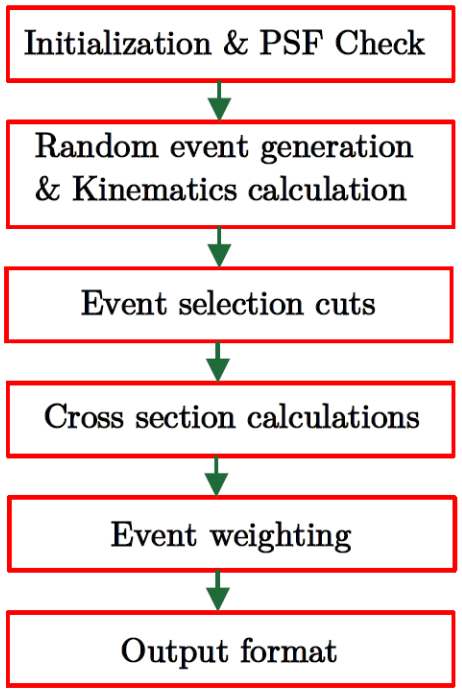
- Further details in upcoming paper



https://arxiv.org/abs/2403.06000

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Authors of model are - T.K. **C**hoi, K.J. **K**ong and B.G. **Y**u - **CKY**

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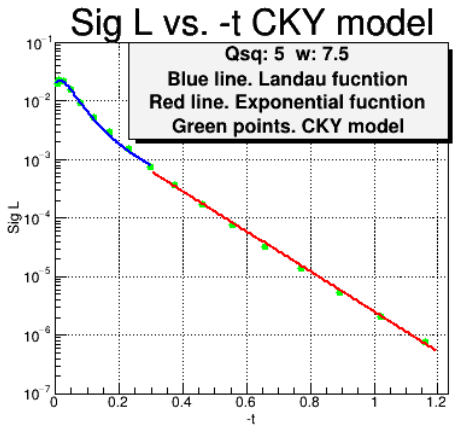

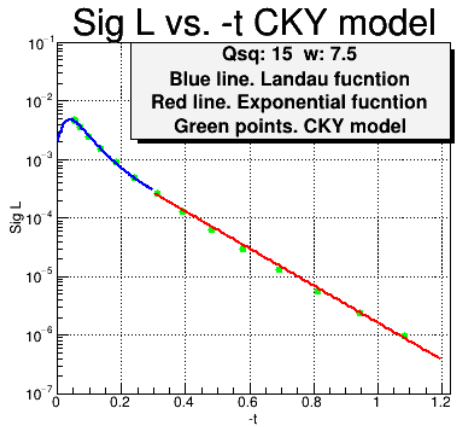

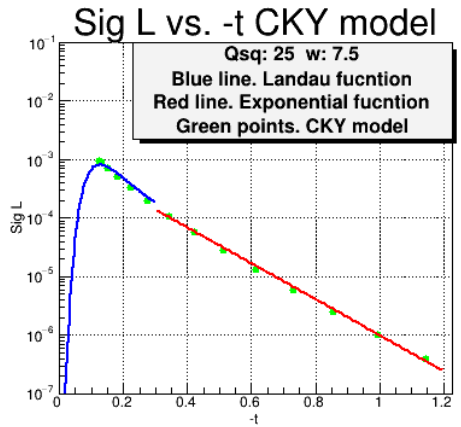

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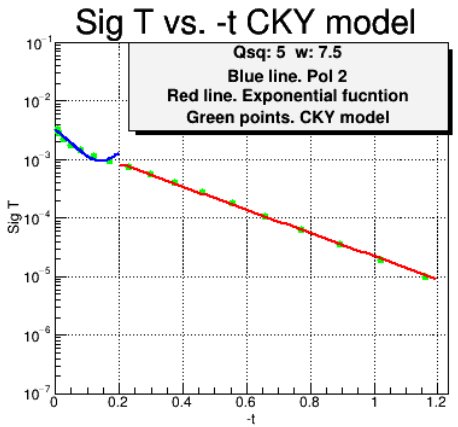

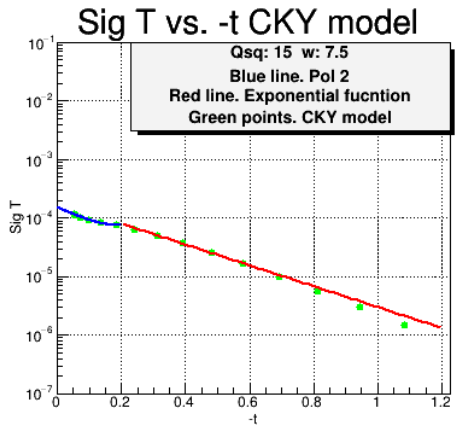

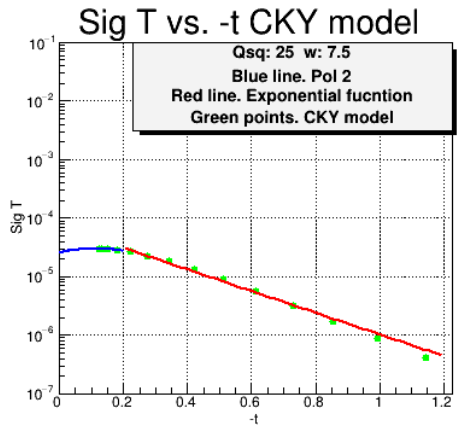

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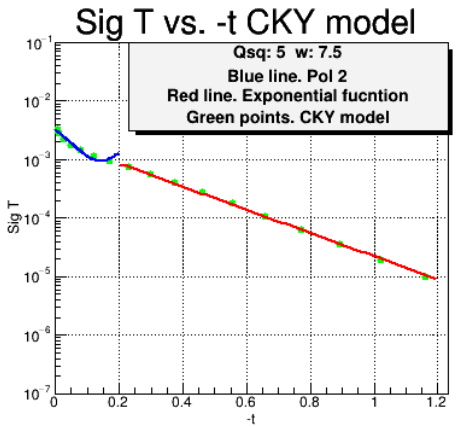

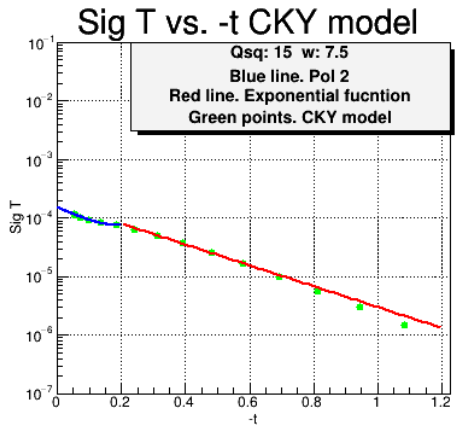

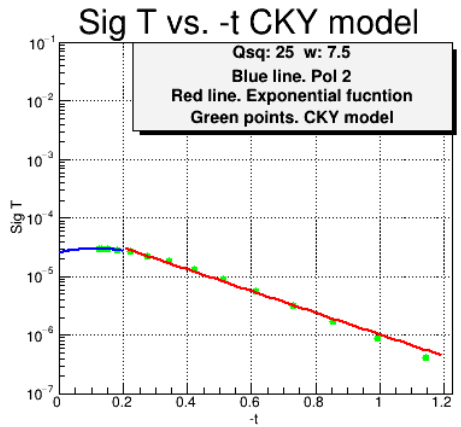

- Kaon reactions $\rightarrow$ Use VGL model

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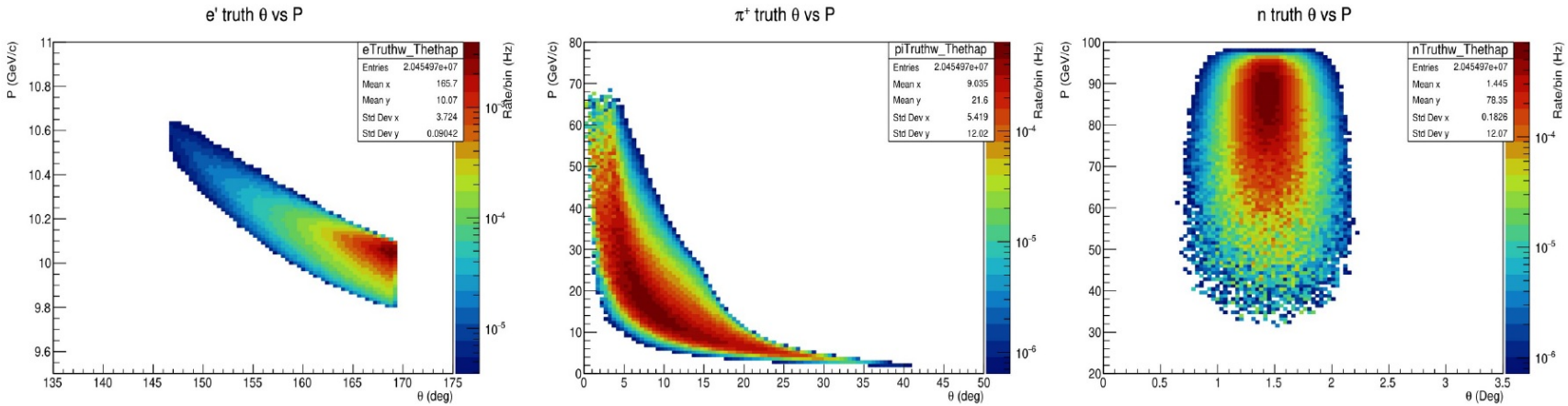

Plot from L. Preet, University of Regina
Note, in η the ranges are $-1.15 < \eta_{e'} < -2.45$, $0 < \eta_{\pi^+} < 0.9$ and $4 < \eta_n < 5.1$.

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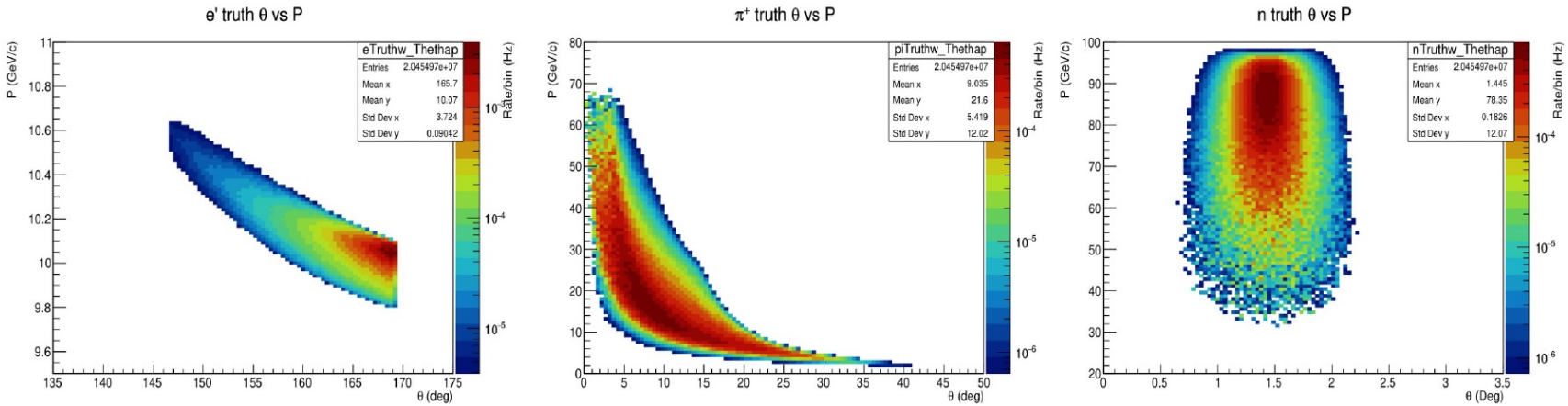

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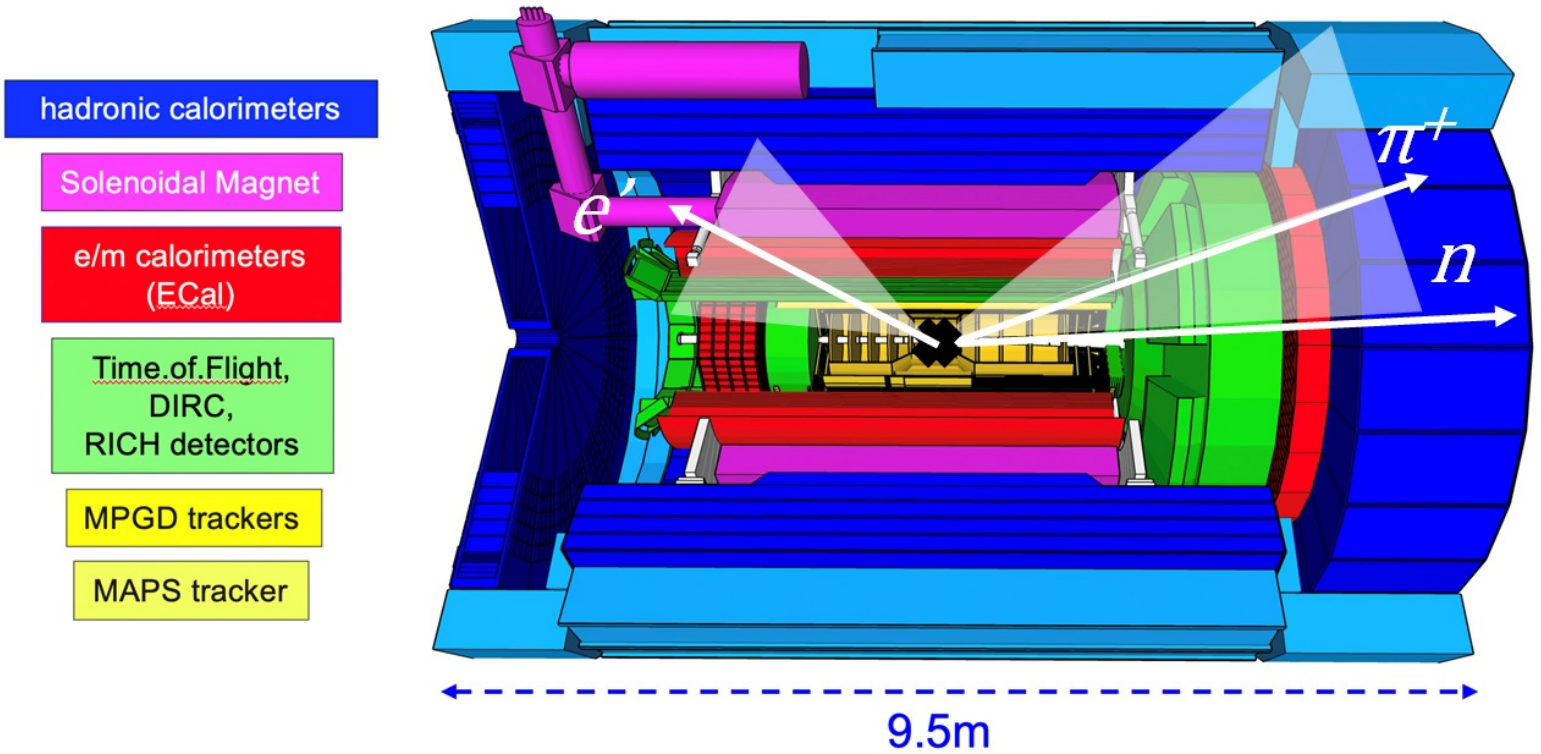

Modified from `https://wiki.bnl.gov/EPIC/images/5/5e/Epic072023.png`

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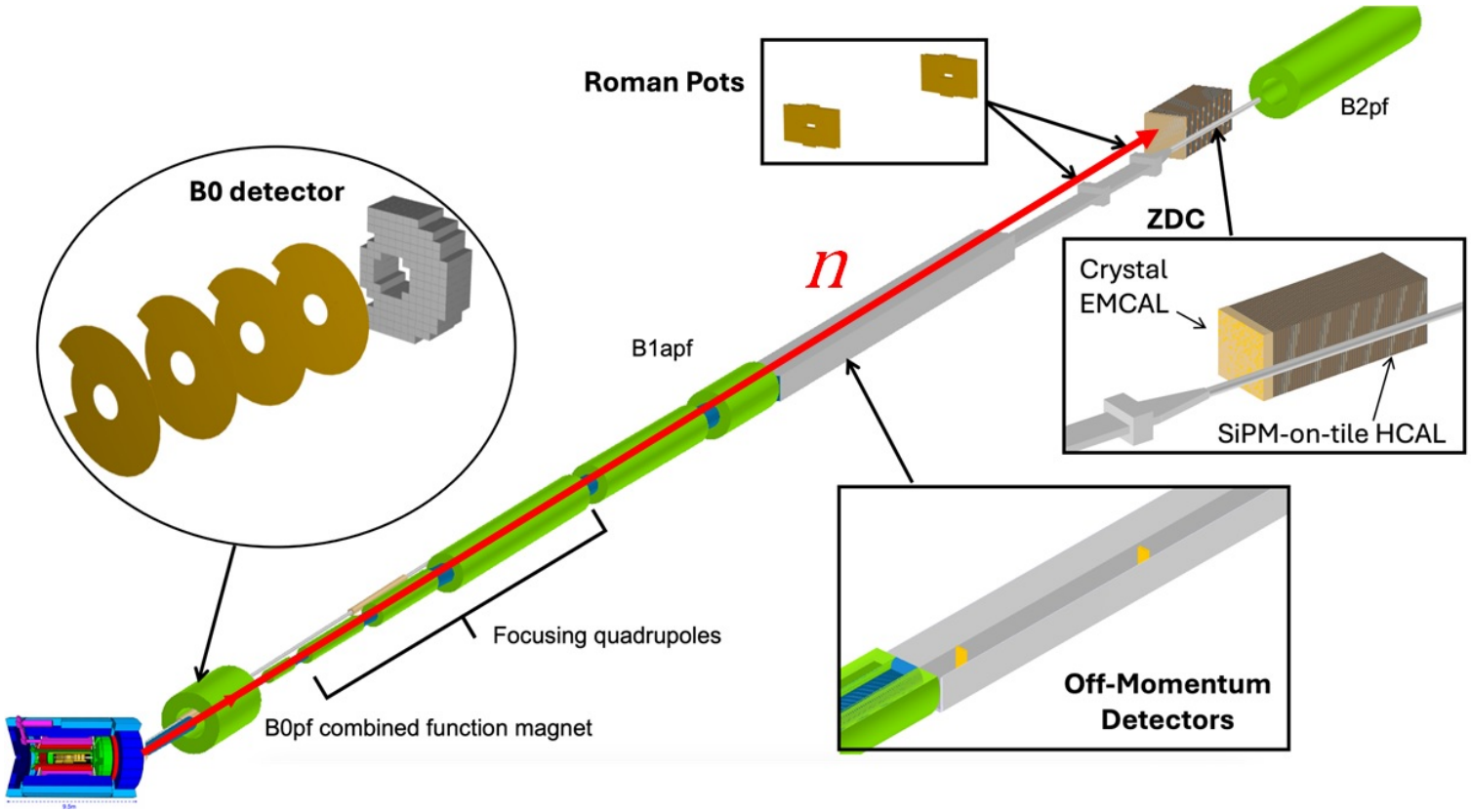

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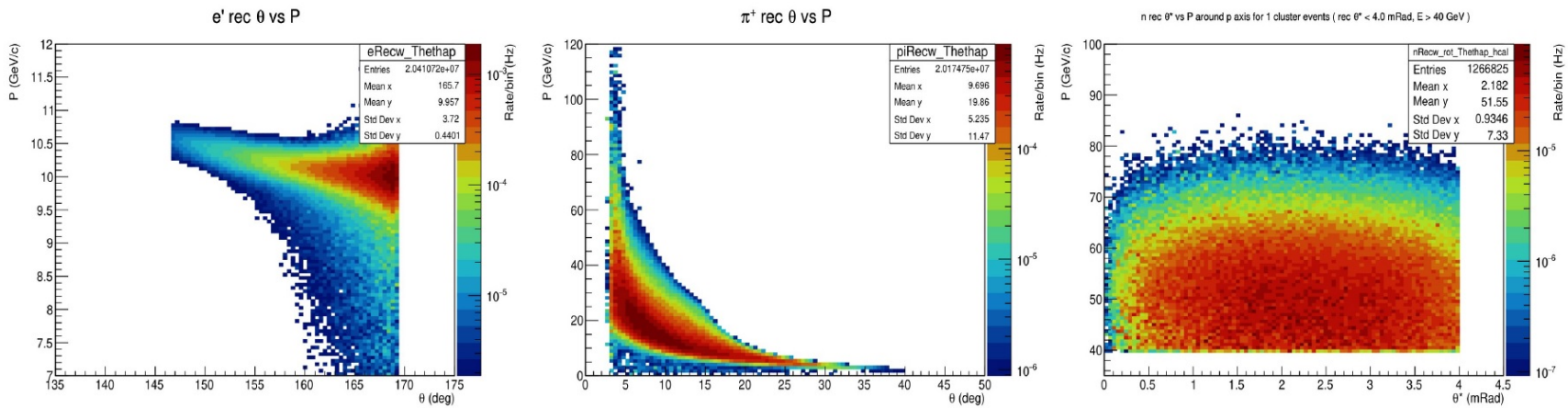

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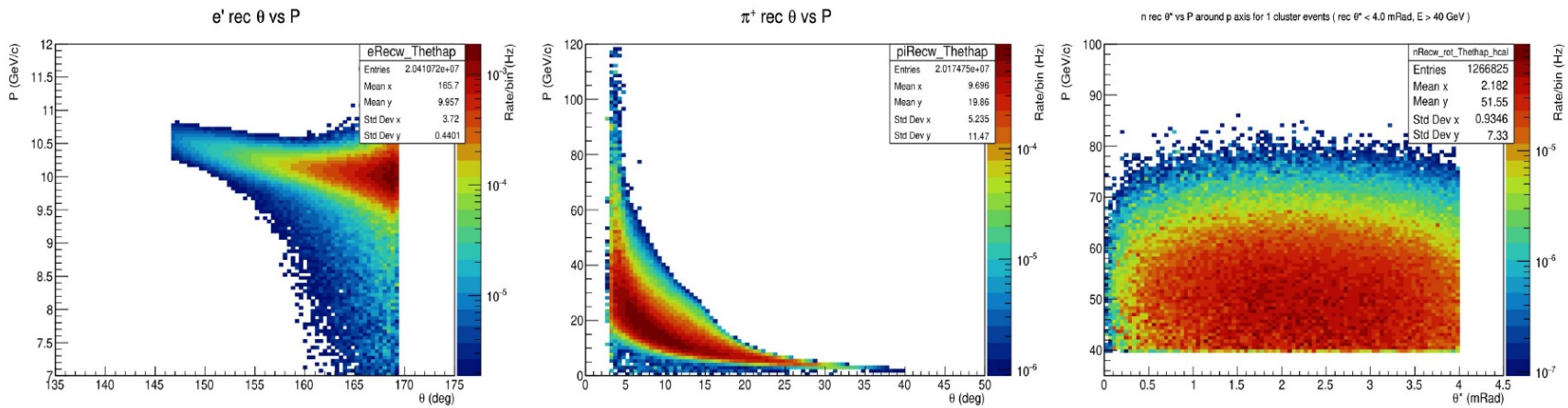

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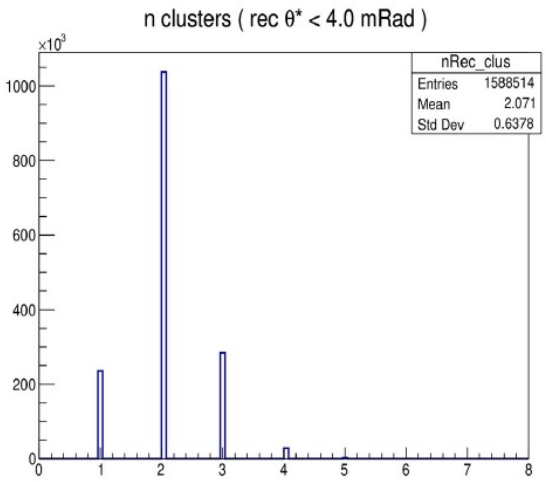

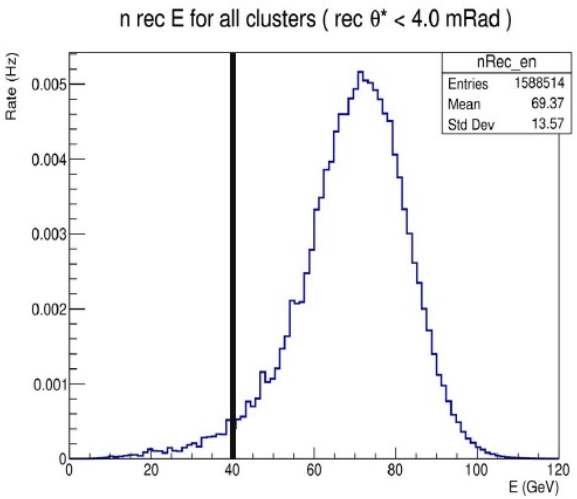

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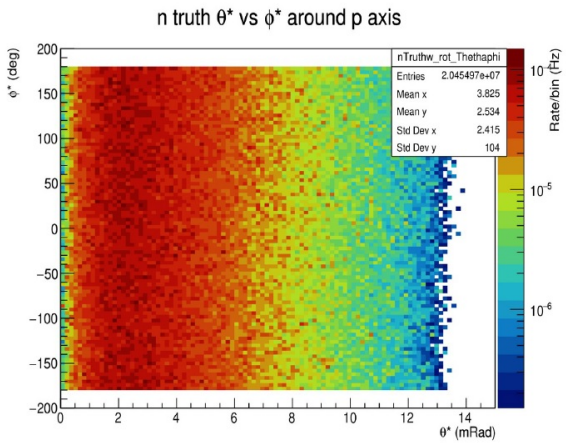

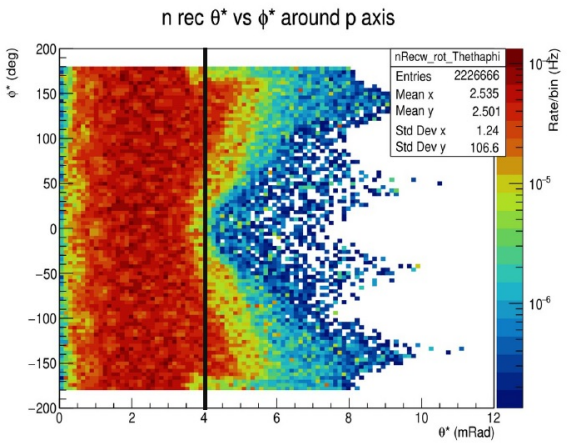

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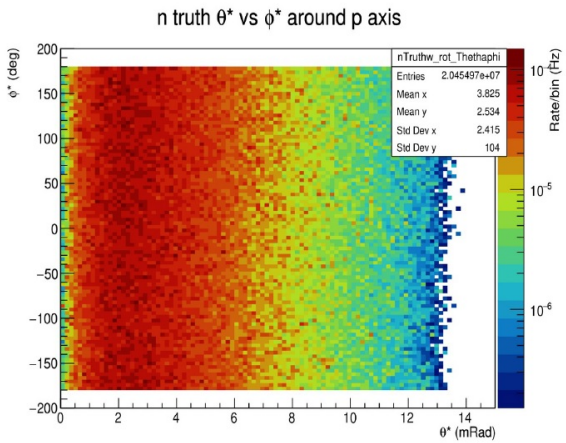

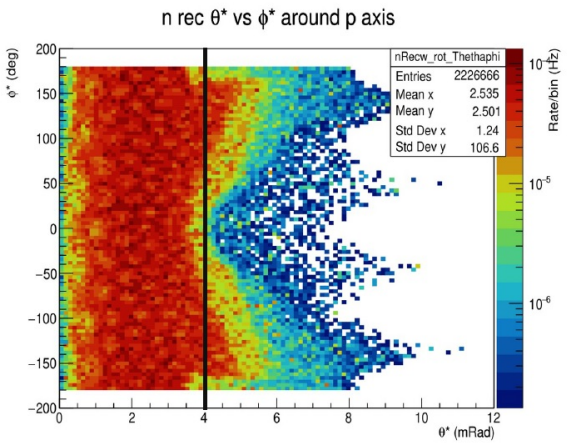

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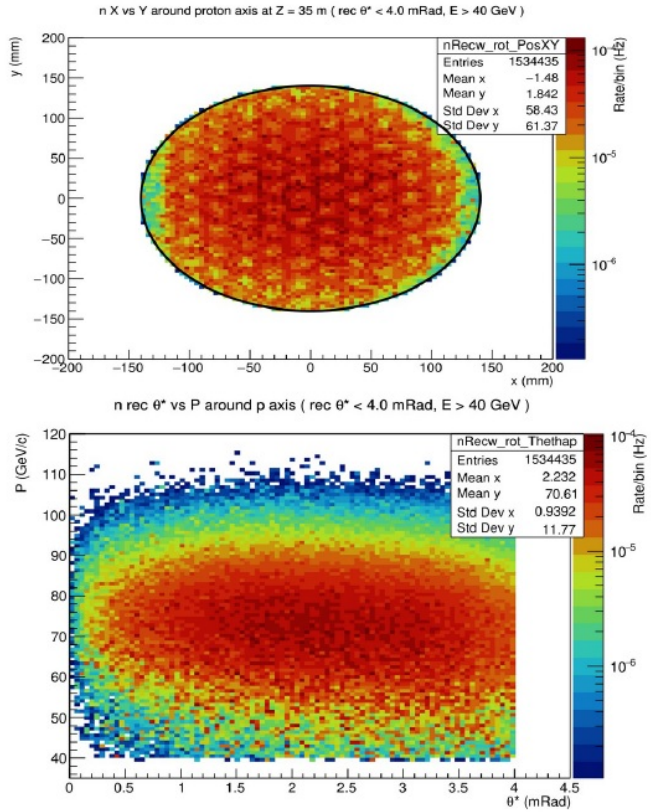

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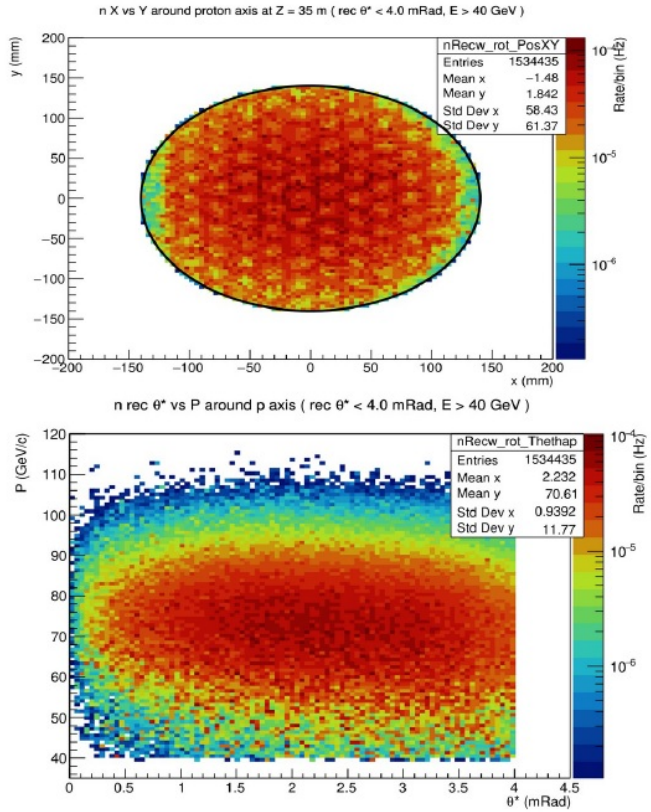

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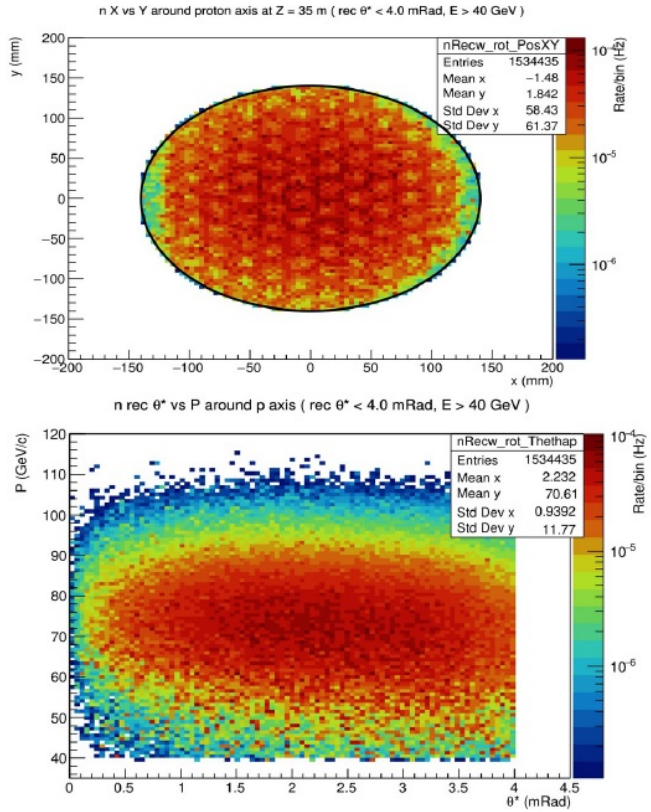

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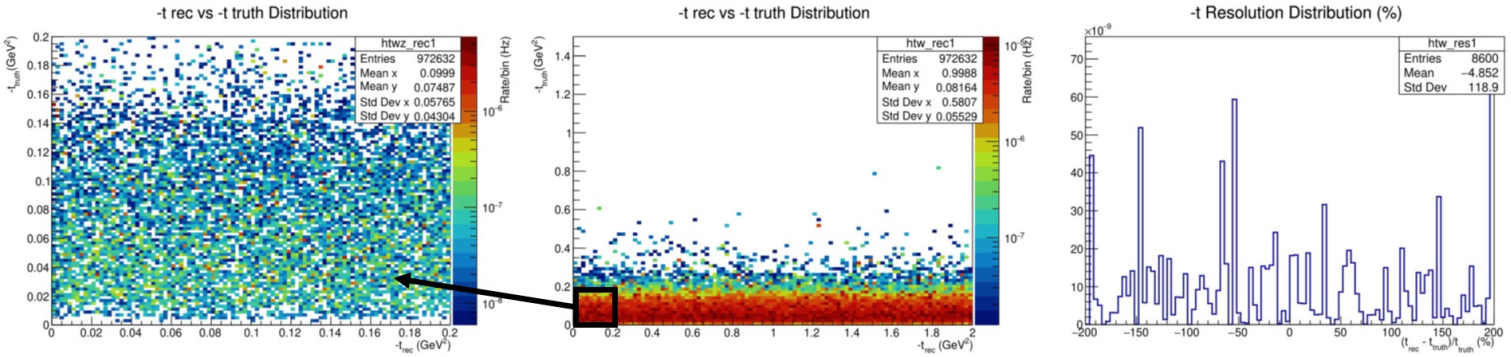

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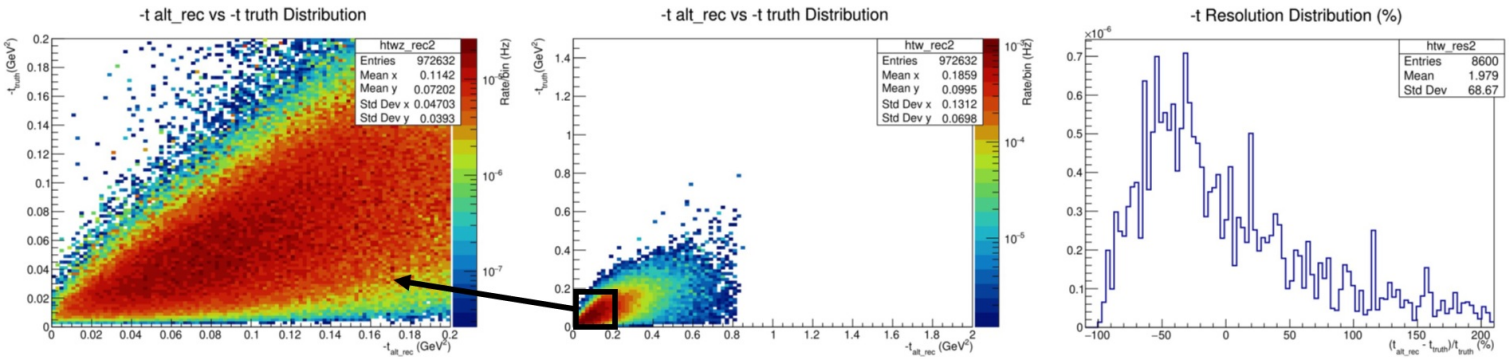
- So, maybe a different approach?
- Use the proton beam and detected neutron



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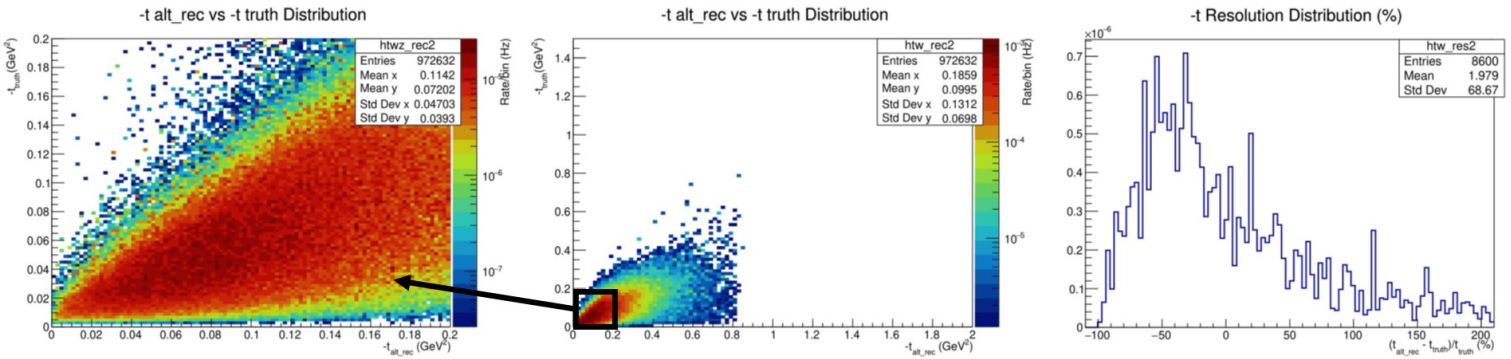
- Not great, not terrible. Try again



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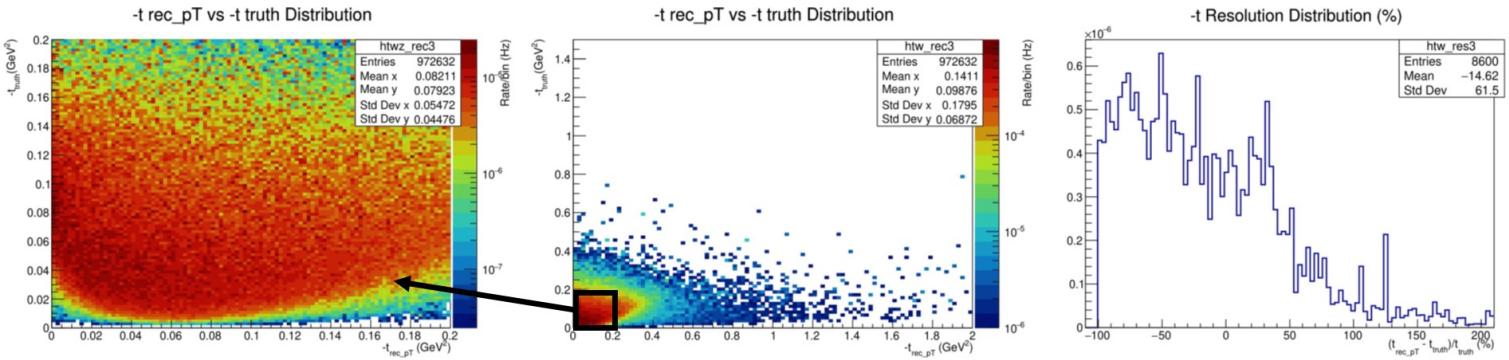

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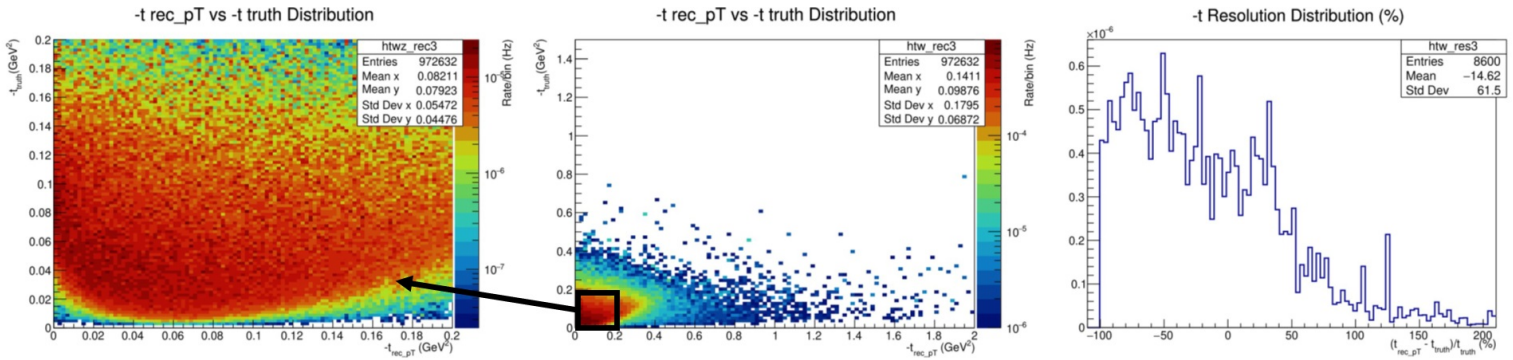
- Use P_T approach
- Even worse! Back to the proton and neutron



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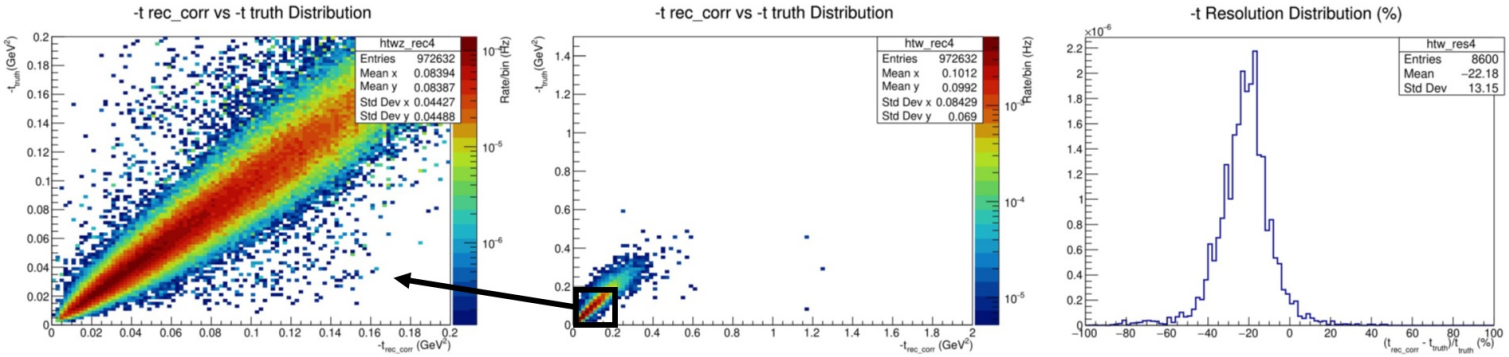
- Correct neutron 4 vector using this info - n_{corr}



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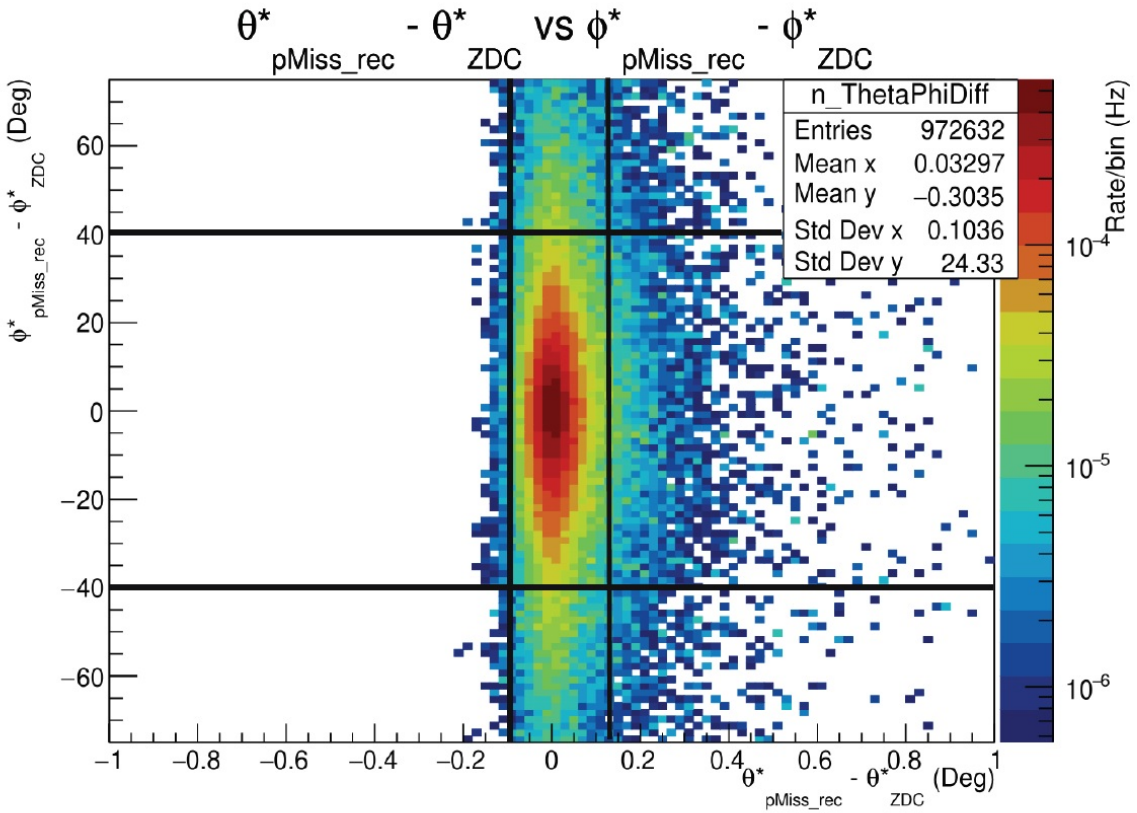
- Select $-0.09° < \Delta\theta < 0.13°$ and $-40° < \Delta\phi < 40°$



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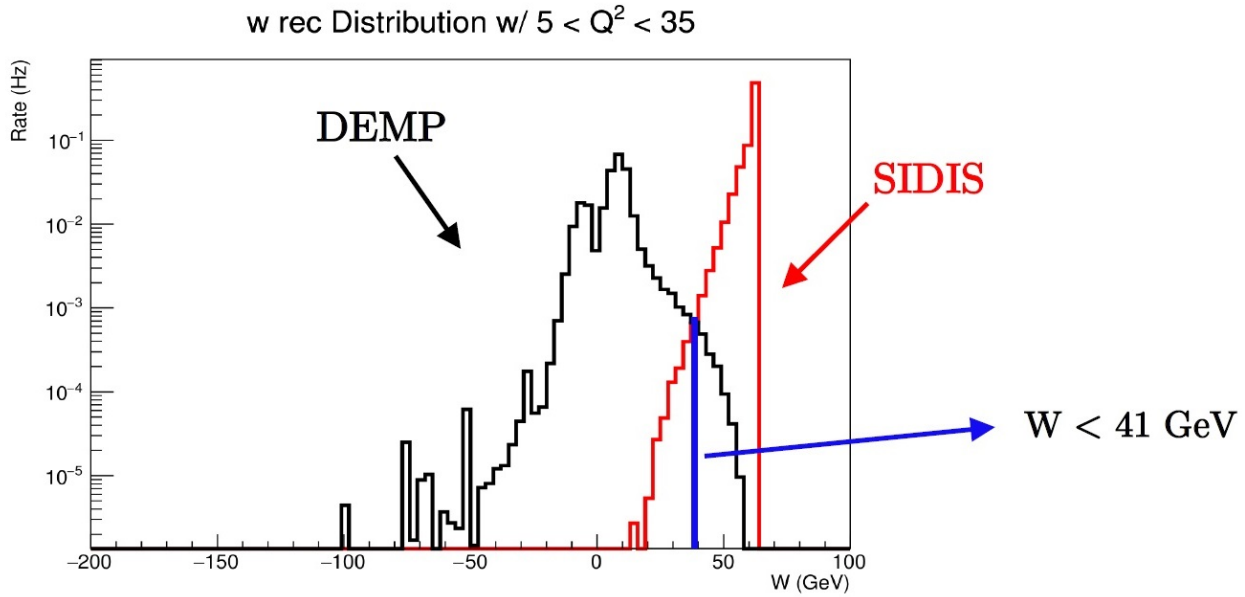

Plot from L. Preet, University of Regina

DEMP Detection Efficiency

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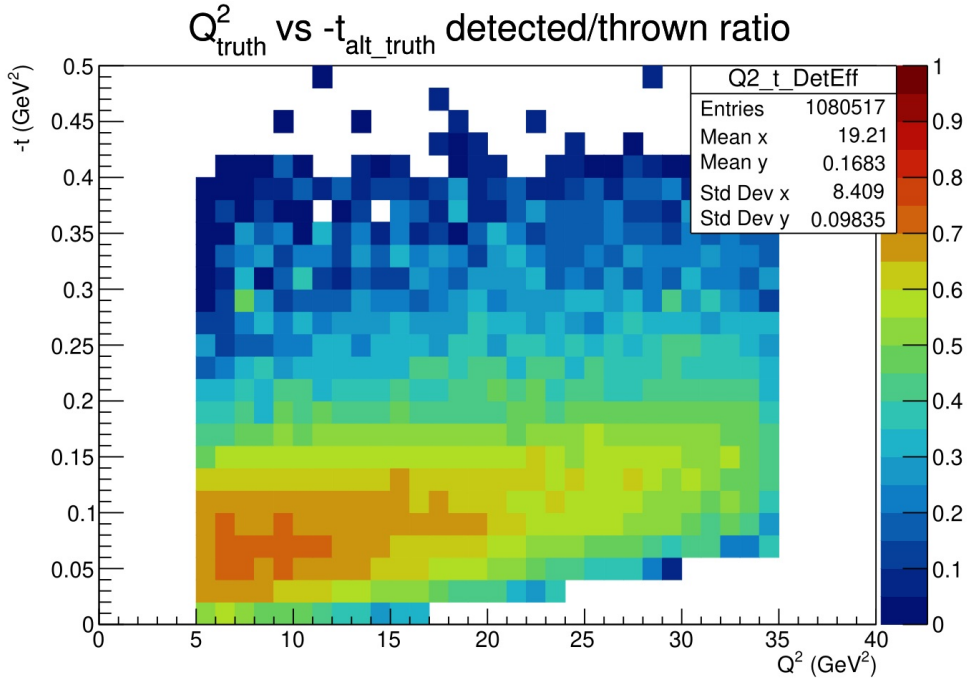
- Detection efficiency is good, comparable to previous results
  - Crucially, efficiency is highest in low $-t$ region



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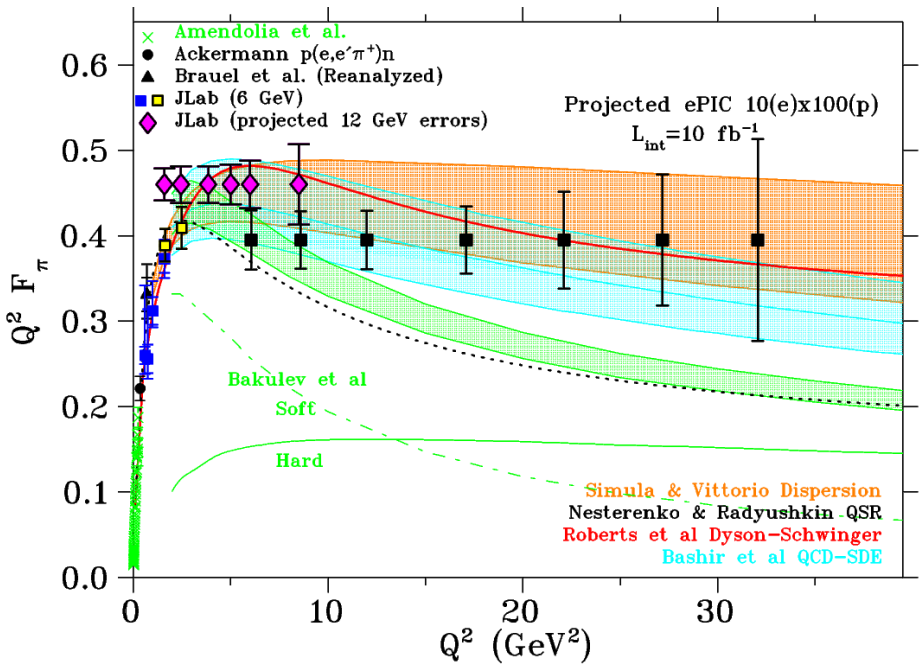

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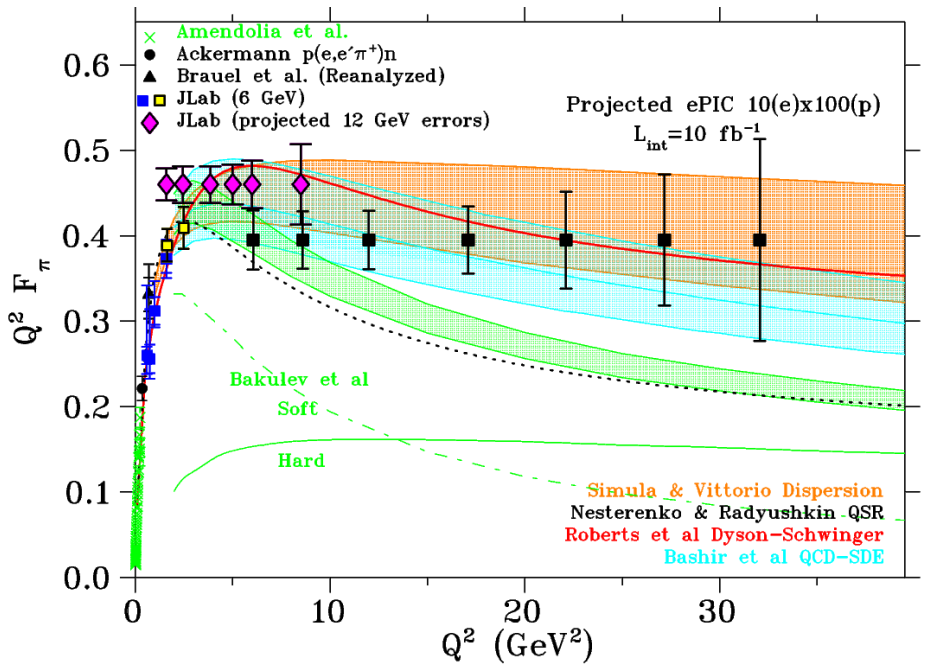

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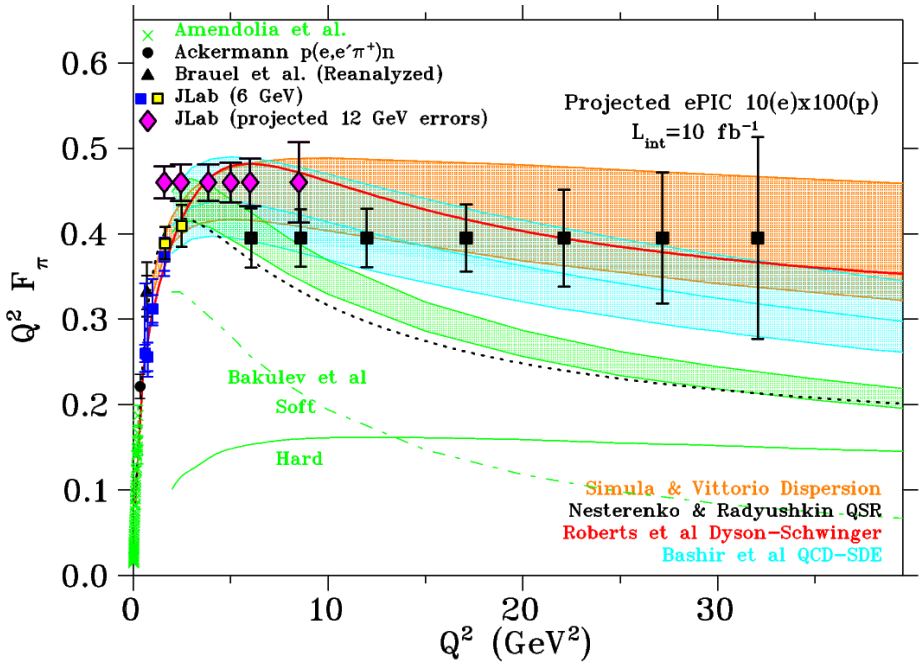

- ePIC might enable higher Q^2 points!
- Early physics programme → Need to look at π^-!

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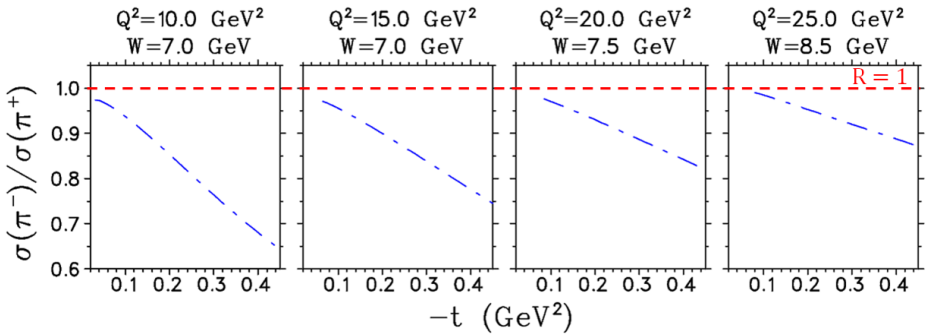

T.Vrancx, J. Ryckebusch, PRC 89(2014)025203

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- $p(e, e'\pi^+ n)$ analysis now well established ePIC analysis
- Benchmark for this channel being finalised

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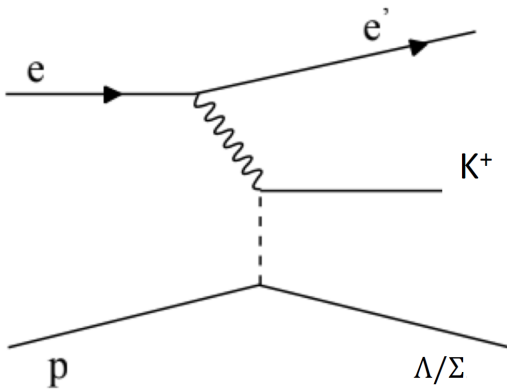

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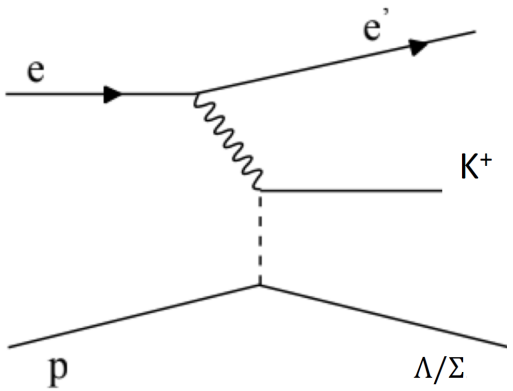

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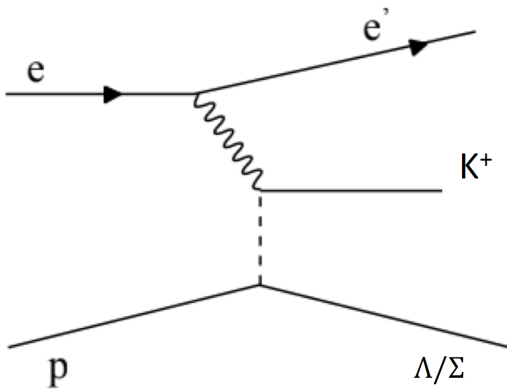

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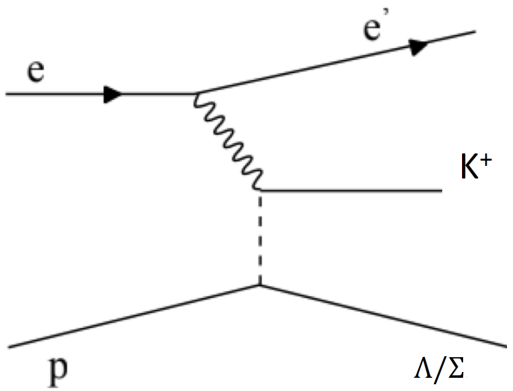

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  - Next step is to examine FF Λ reconstruction

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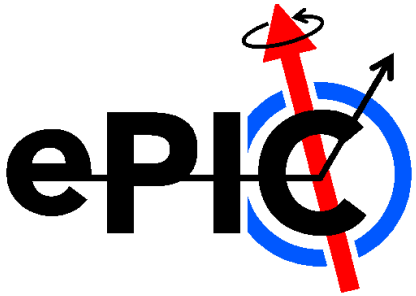
- DEMP reactions key benchmarking channel for FF detectors
- Analysis will feature in TDR and associated papers

Thanks for listening, any questions?



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Science and Technology Facilities Council

With thanks to Garth Huber and Love Preet at the University of Regina, as well as all of my colleagues in the ePIC Collaboration and the Meson Structure Working Group.

stephen.kay@york.ac.uk

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Backup Zone

Isolating σ_L from σ_T in an e-p Collider

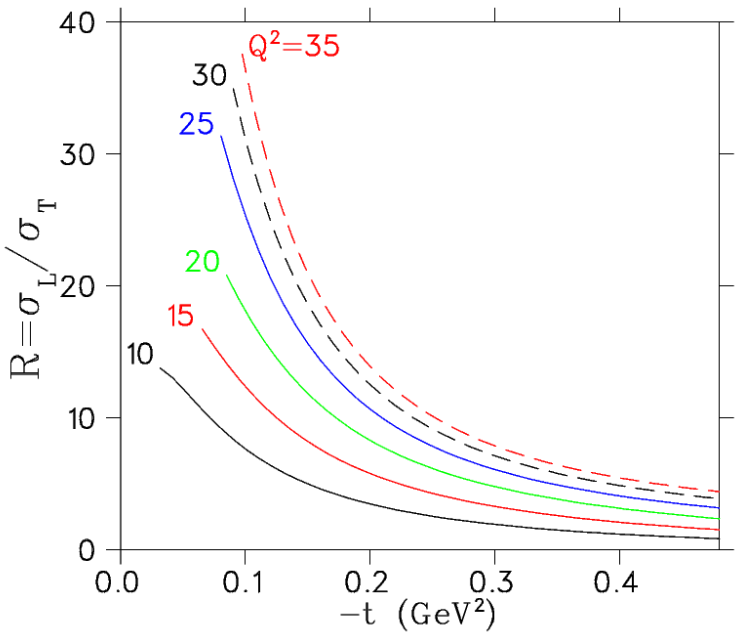
- For a collider -

$$\epsilon = \frac{2(1-y)}{1+(1-y)^2} \quad \text{with} \quad y = \frac{Q^2}{x(s_{tot} - M_N^2)}$$

  - y is the fractional energy loss
- Systematic uncertainties in σ_L magnified by $1/\Delta\epsilon$
  - Ideally, $\Delta\epsilon > 0.2$
- To access $\epsilon < 0.8$ with a collider, need $y > 0.5$
  - Only accessible at small s_{tot}
  - Requires low proton energies ($\sim 10\ GeV$),not available at the EIC
- **Conventional L-T separation not practical, need another way to determine σ_L**

σ_L Isolation with a Model at the EIC

- QCD scaling predicts $\sigma_L \propto Q^{-6}$ and $\sigma_T \propto Q^{-8}$
- At the high Q^2 and W accessible at the EIC, phenomenological models predict $\sigma_L \gg \sigma_T$ at small $-t$
- Can attempt to extract σ_L by using a model to isolate dominant $d\sigma_L/dt$ from measured $d\sigma_{UNS}/dt$
- Examine π^+/π^- ratios as a test of the model

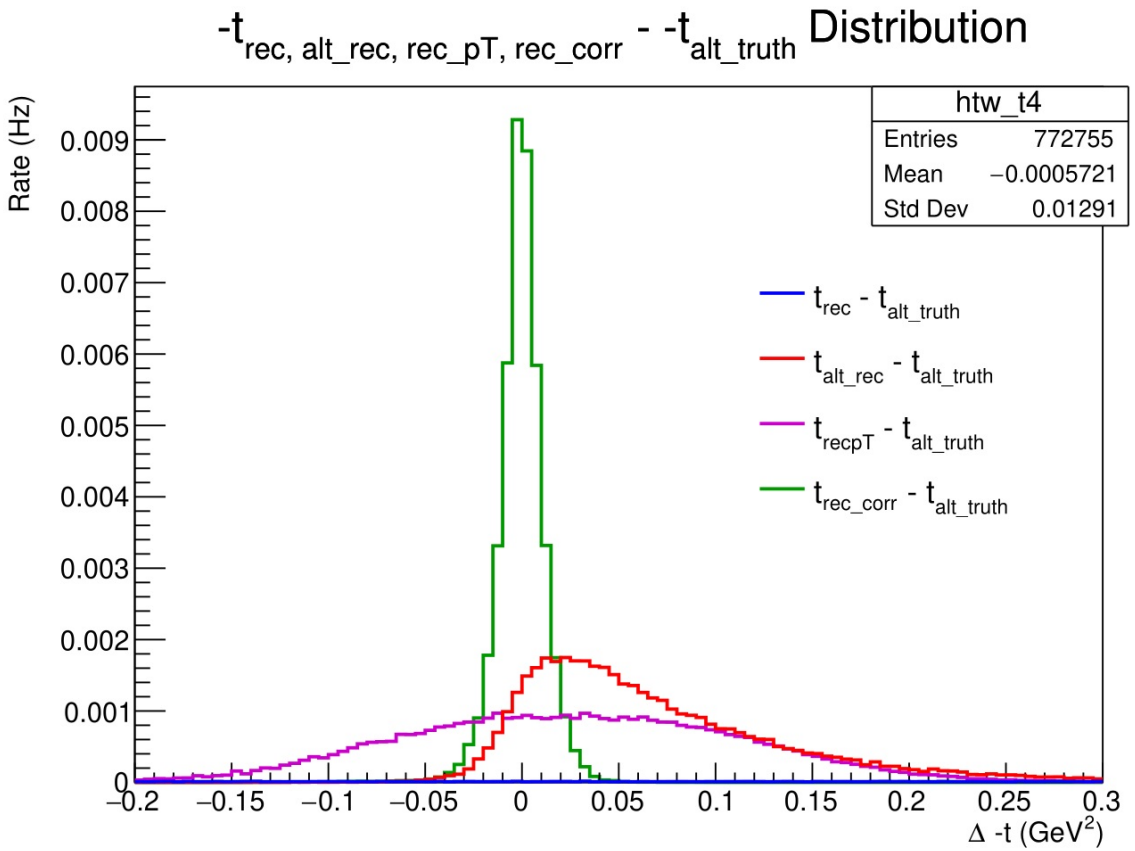


Predictions are assuming $\epsilon > 0.9995$ with the kinematic ranges seen earlier

T.Vrancx, J. Ryckebusch, PRC 89(2014)025203

Comparison of $-t$ Reconstruction Methods

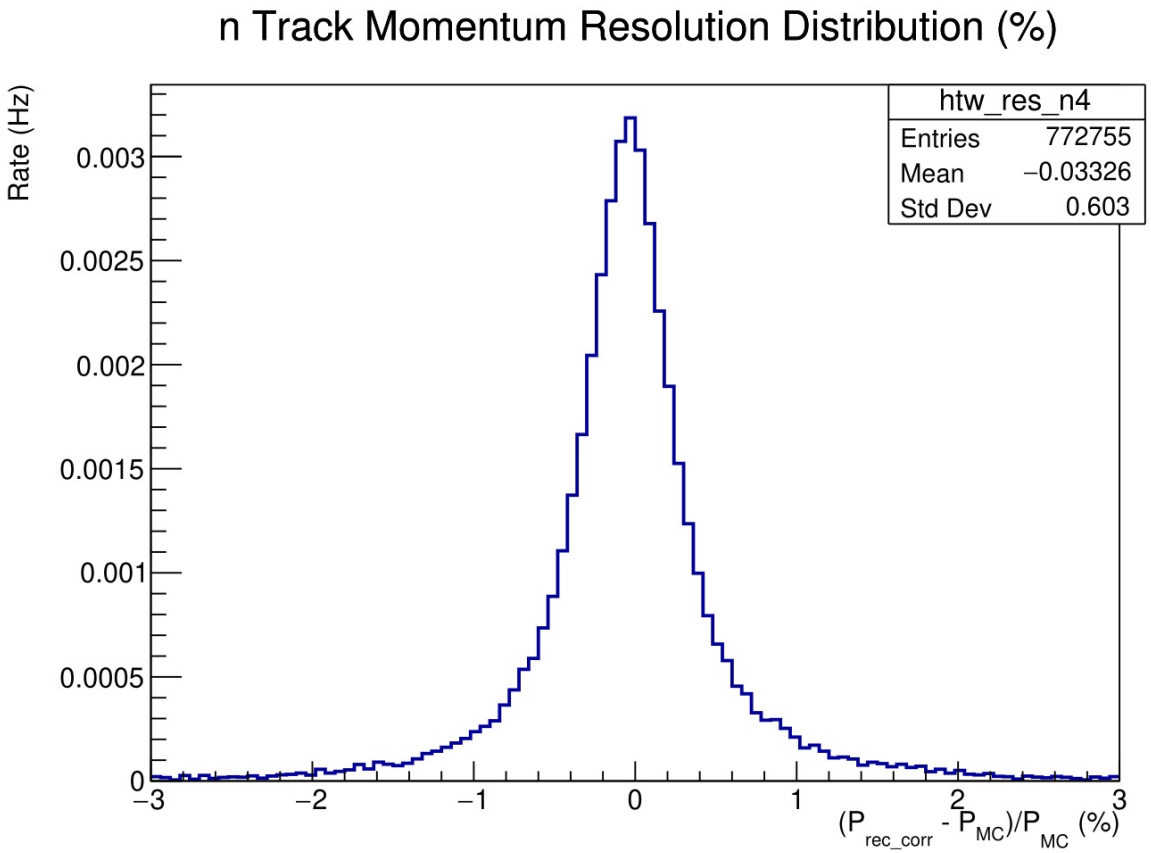
- Corrected neutron track clearly gives best $-t$ reconstruction
- $\sim \pm 0.02$ in $-t$ for this method



Plot from L. Preet, University of Regina

Simulation Results - Neutron Reconstruction

- After correction neutron 4 vector, resolution very good
- Few % resolution



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F_K at the EIC - Generator Updates

- URegina researcher Love Preet added new Kaon DEMP event generator module to DEMPgen
  - Starting with $p(e, e'K^+\Lambda)$
- Parametrise a Regge-based model
- For $p(e, e'K^+\Lambda)$ module, use the Vanderhagen, Guidal, Laget (VGL) model
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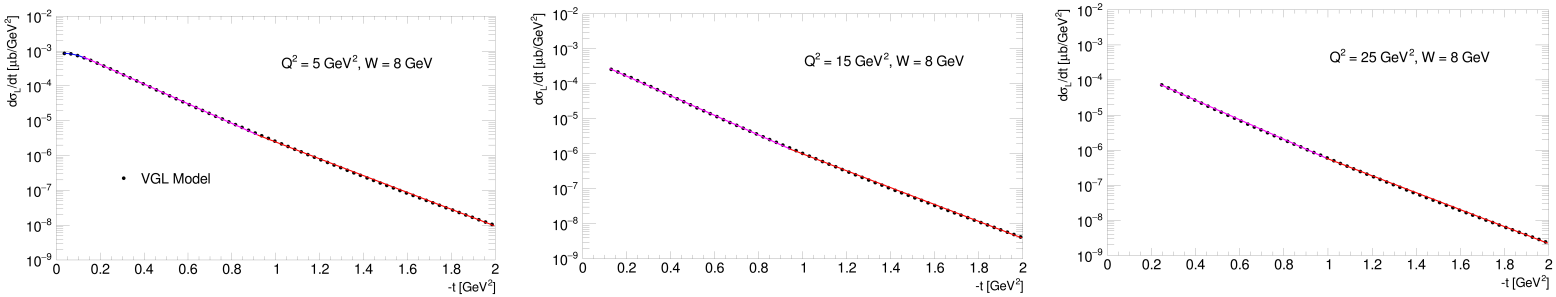

VGL Model - M. Guidal, J.-M. Laget, M. Vanderhaeghen, PRC 61 (3000) 025204

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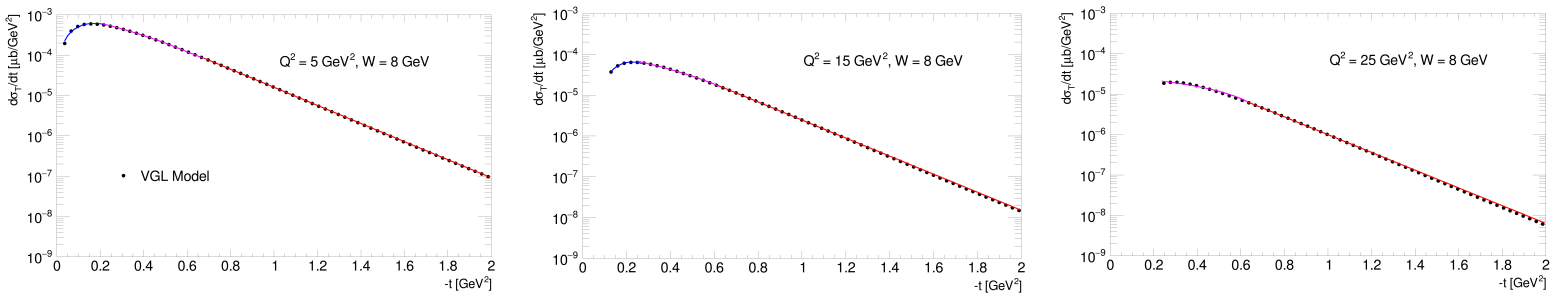

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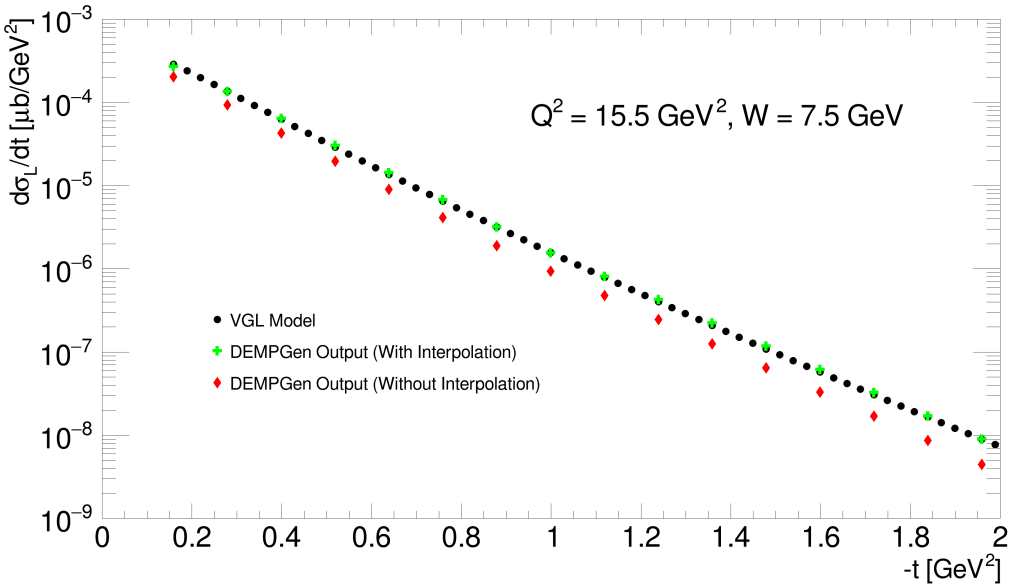
DEMPGen Improvements

- In addition to adding the $p(e, e'K^+\Lambda)$ module, improvements to the generator implemented
- New method to interpolate parametrisation
- Interpolation matches generator output very closely
  - Even at points far from the initial parametrisation
- Will incorporate improvements in pion model soon



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