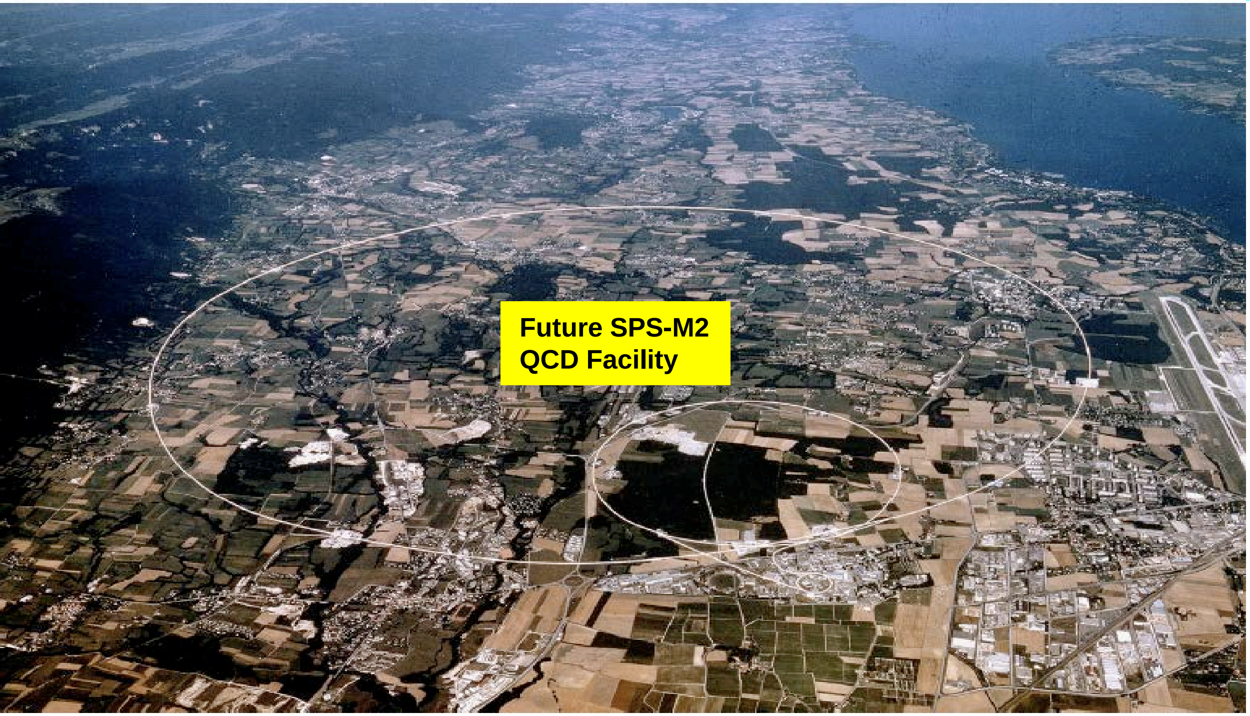
Physics from Drell Yan and Direct Photon Production with High Intensity Kaon and Anti-Proton Beams



Mini Workshop on the Physics at a Future SPS QCD Facility
June 20, 2018

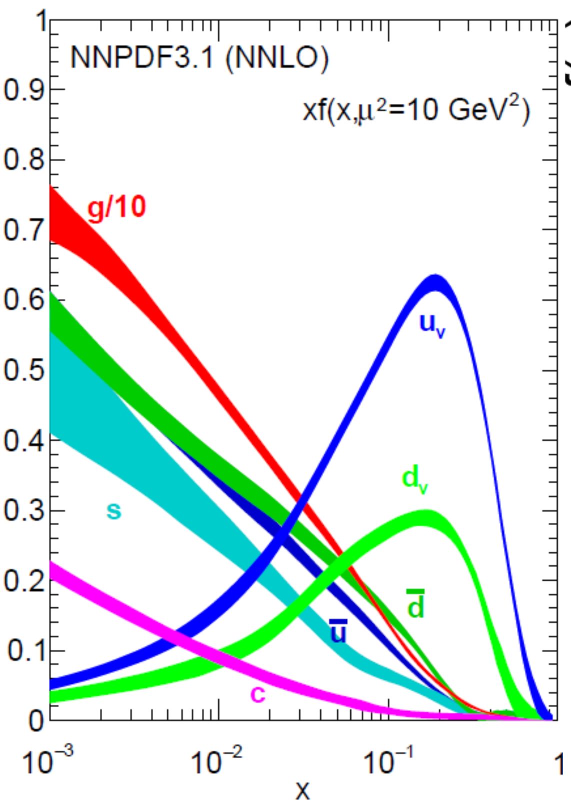
M. Grosse Perdekamp, University of Illinois

Hadron Structure with Kaon- and Anti-Proton Beams

- **Why Pion and Kaon Structure?**
- **RF separated Kaon and Anti-Proton Beams**
- **Apparatus**
- **Kaon quark- and gluon-structure**
  - **Direct Photons**
  - **(J/ψ)**
  - **Drell-Yan**
- **Anti-Proton Beam**
  - **Boer-Mulders**

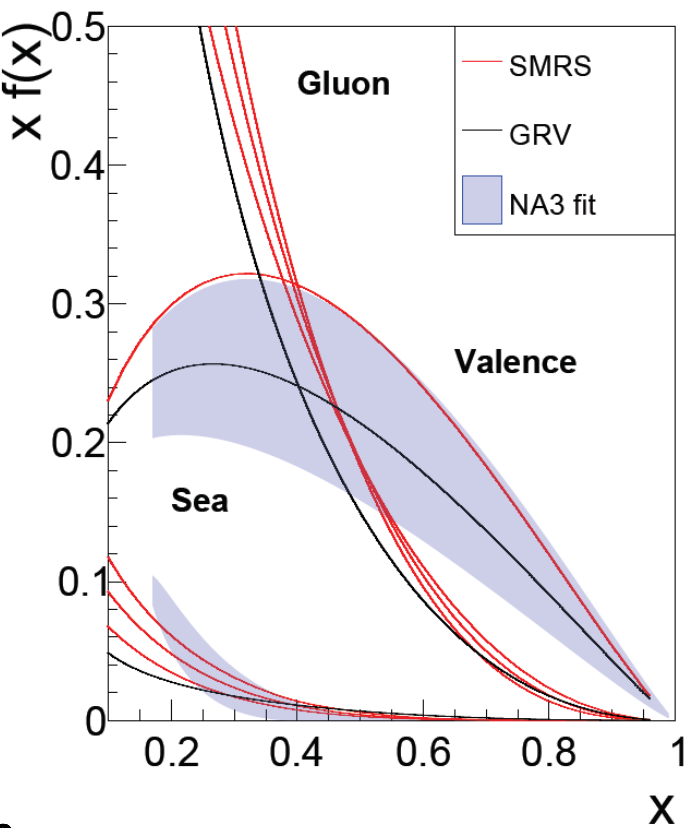
Towards Precision Measurements of Pion and Kaon Structure

Proton PDFs



NNPDF3.1: EPJ C77 (2017) 663

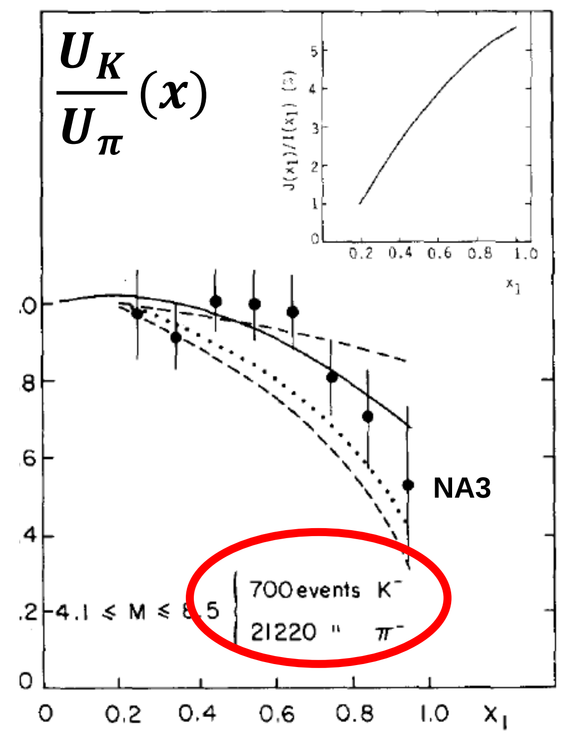
Pion PDFs



GRV: M. Gluck et al, Z.Phys.C 53 (1992) 651

SMRS: P.J. Sutton et al, Phys.Rev.D 45 (1992) 2349

Kaon PDFs



J. Badier et al., Phys. Lett. B 93 (1980) 354

Towards Precision Measurements of Pion and Kaon Structure

Knowledge of (unpolarized) proton PDFs currently driven by need of precise input for SM and BYSM physics at LHC

Two mechanisms for the emergence of mass in SM

- ➔ **EW symmetry breaking provides current masses**
- ➔ **Strong Interaction chiral symmetry breaking leads to large hadron masses (>95% of visible mass)**

Precise ab initio understanding of the strong interaction sector of the SM requires

- ➔ **ability of precise calculations ab initio QCD**
- ➔ **precise experimental information on the structure of different hadrons and the hadronic mass spectrum**

(I) Precise Calculations ab Initio QCD

Large-momentum effective theory (LaMET)

Ji, PRL 2013, Sci. China Phys. Mech. Astro., 2014

Progress in the theoretical development of LaMET

- **Renormalization:**

Ji and Zhang, 2015; Ishikawa et al., 2016, 2017; Chen, Ji and Zhang, 2016;

Xiong, Luu and Meiβner, 2017; Constantinou and Panagopoulos, 2017; Ji, Zhang, and Y.Z., 2017; J. Green et al., 2017; Ishikawa et al. (LP3), 2017; Wang, Zhao and Zhu, 2017; Spanoudes and Panagopoulos, 2018.

- **Factorization:**

Ma and Qiu, 2014, 2015, 2017; Izubuchi, Ji, Jin, Stewart and Y.Z., 2018.

- **One-loop matching:**

Xiong, Ji, Zhang and Y.Z., 2014; Ji, Schaefer, Xiong and Zhang, 2015; Xiong and Zhang, 2015; Constantinou and Panagopoulos, 2017; I. Stewart and Y. Z., 2017; Wang, Zhao and Zhu, 2017; Izubuchi, Ji, Jin, Stewart and Y.Z., 2018.

- **Power corrections:**

J.-W. Chen et al., 2016; A. Radyushkin, 2017.

- **Transvers momentum dependent parton distribution function:**

Ji, Xiong, Sun, Yuan, 2015; Ji, Jin, Yuan, Zhang and Y.Z., 2018; Ebert, Stewart and Y.Z., in progress.

from Yong Zhao
at Intersections, June 2018

(I) Precise Calculations ab Initio QCD

Large-momentum effective theory (LaMET)

Ji, PRL 2013, Sci. China Phys. Mech. Astro., 2014

Accomplishment of lattice calculations with LaMET so far

- **Gluon helicity contribution to proton spin**
  - Gluon spin provides about half of the proton spin — χQCD Collaboration, 2017
- **Unpolarized iso-vector quark distribution**
  - Gottfried sum rule violation, i.e., $\bar{d}(x) > \bar{u}(x)$ — H.-W. Lin et al. (LP3), 2014, 2016, 2017,2018; ETMC Collaboration, 2015, 2016, 2018.
- **Polarized iso-vector quark distribution**
  - Primitive results show $\Delta\bar{u}(x)>\Delta\bar{d}(x)$ — H.-W. Lin et al. (LP3), 2014, 2016; ETMC Collaboration, 2016, 2017, 2018.
- **Transversity iso-vector quark distribution**
  - Primitive results show $\delta\bar{d}(x) >\delta\bar{u}(x)$ — H.-W. Lin et al. (LP3), 2016; ETMC Collaboration, 2016.
- **Meson distribution amplitudes (PDA)**
  - Single-hump structure of pion PDA; Asymmetry of kaon PDA with respect to $x=1/2$ — J.-W. Chen, J.-H. Zhang, H.-W. Lin et al. (LP3), 2017.
- **Pion PDF**
  - LP3 collaboration, 2018;

from Yong Zhao at Intersections, June 2018

(I) Precise Calculations ab Initio QCD

Other proposals

from Yong Zhao at Intersections June 2018

- Restoration of rotational symmetry to calculate higher moments
  Z. Davoudi and M. Savage, 2012.
- OPE of flavor-changing current-current correlation
  D. Lin and W. Detmold, 2006.
- OPE of the Compton amplitude — A. J. Chambers et al. (QCDSF), 2017.
- Direct computation of the physical hadronic tensor
  K.F. Liu (et al.), 1994, 1999, 1998, 2000, 2017.
- Smeared Quasi-PDF with Gradient flow — C. Monahan and K. Orginos, 2017.
- Pseudo-PDF (alternative to quasi-PDF) — A. Radyushkin, 2017; K. Orginos et al., 2017.
- Lattice cross section — Y.-Q. Ma and J. Qiu, 2014, 2017.
- Factorization of Euclidean correlations in coordinate space
  V. M. Braun and D. Mueller, 2008;G. S. Bali, V. M. Braun, A. Schaefer, et al., 2017.

(I) Systematic Lattice QCD Calculations of Parton Structure Physics from LaMET Makes Vigorous Progress

In 5~10 years, expect:

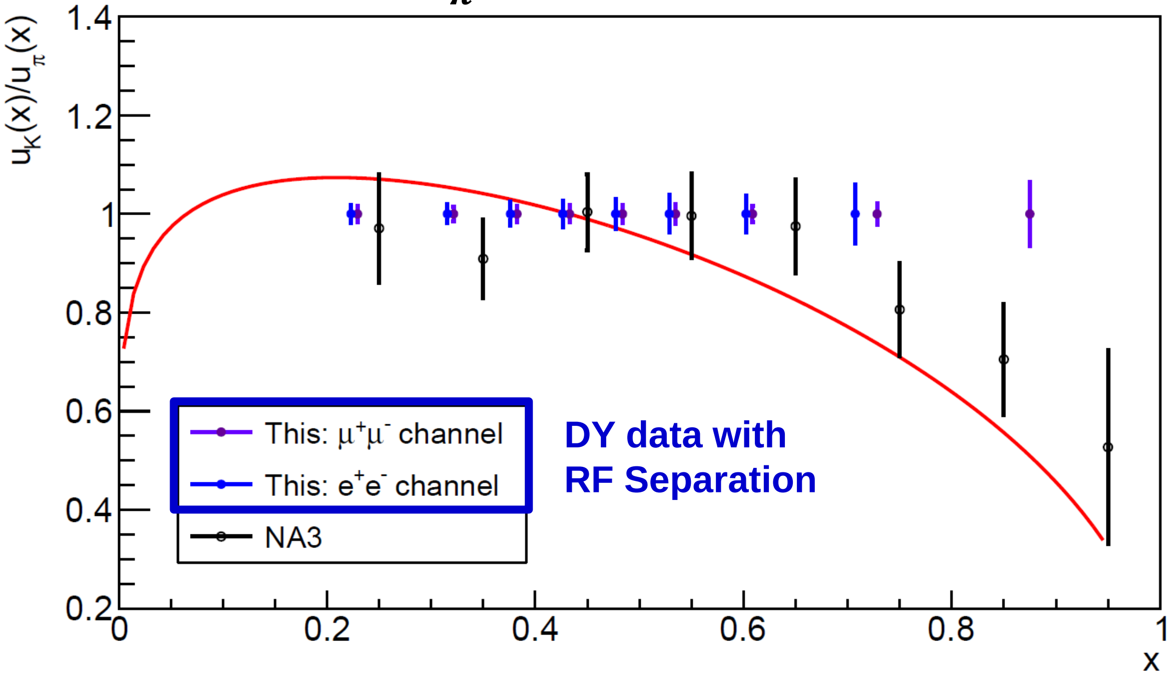
- Lattice calculation of quark PDFs to be within 10% accuracy or even better;
- Constraints on the flavor structure of PDF at x~1 and the sea quark distributions be better than experiments;
- Reaching smaller x region with larger nucleon momentum;
- Lattice calculation of other distributions including TMD, GPD, gluon distributions, etc...

from Yong Zhao
at Intersections June 2018

(II) Precise Information on the Structure of Hadrons (and on their Mass Spectrum)

Future QCD Facility with RF-Separated Beams at the SPS

Example: $\frac{U_K}{U_\pi}(x)$



- **Determine quark and gluon structure of the pion and kaon**
- **Verify Lattice QCD PDFs with high precision**
- **Gain quantitative understanding of chiral dynamics in both protons:** m_p ~ **Binding Energy + dressed quark masses**

  and mesons: $m_{\pi,K}$ ~ **Binding Energy - dressed quark masses**

including the mass dependence.

Significant Interest in Meson Structure Measurements Elsewhere

Meson structure using the Sullivan process at Jlab and possibly EIC

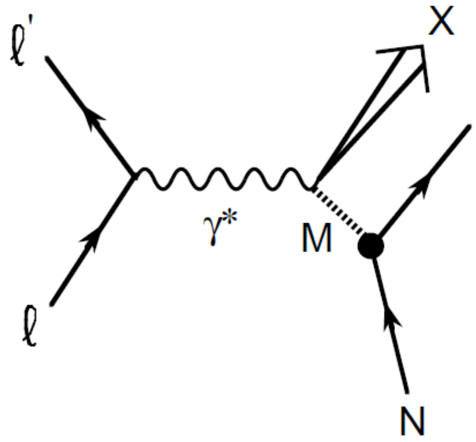


FIG. 1. The Sullivan process in which the virtual photon scatters off the meson cloud in the nucleon.

Argonne workshop on Pion and Kaon Structure at an Electron-Ion Collider, June 2017

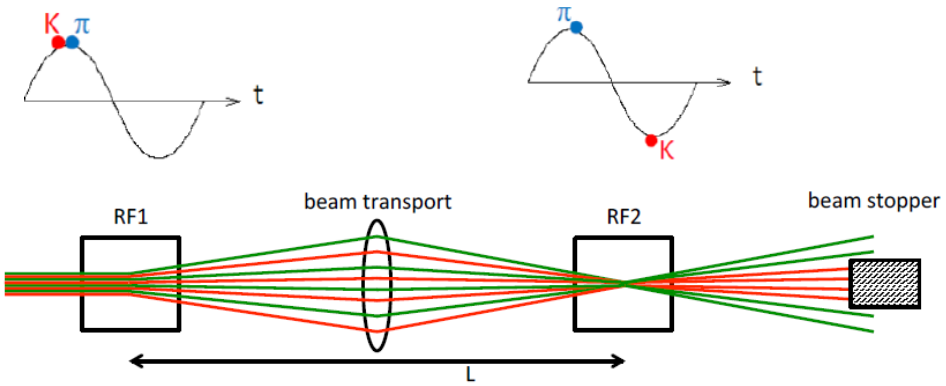
- **Determine quark and gluon structure of the pion and kaon**
- **Verify Lattice QCD PDFs with high precision**
- **Gain quantitative understanding of chiral dynamics in both protons:** m_p ~ **Binding Energy**
  + dressed quark masses
  and
  mesons: $m_{\pi,K}$ ~ **Binding Energy**
  - dressed quark masses

including the mass dependence.

JPARC: secondary beamlines for DY physics at low energy.

RF Separated Kaon and Anti-Proton Beams at SPS-M2 after LS3 for LHC Luminosity Upgrades

- Deflection with 2 cavities
- Relative phase $= 0 \rightarrow$ dump
- Deflection of wanted particle given by
  $\Delta\phi \approx \frac{\pi f L}{c} \frac{m_w^2 - m_u^2}{p^2}$



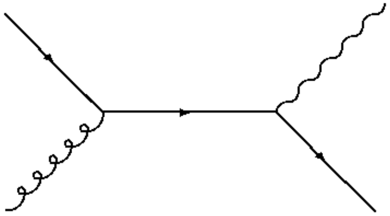
To keep good separation, L should increase as $p^2 \rightarrow$ limits the beam momentum

- Kaon With the current RP limits, for total beam flux of 7×10^7 particles/s:
  $I_{K-} \sim 2 \times 10^7$/s at 100 GeV
  $I_{K+} \sim 2 \times 10^7$/s at 100 GeV
- High intensity antiproton beam:
  $\sim 5 \times 10^7$ with current RP

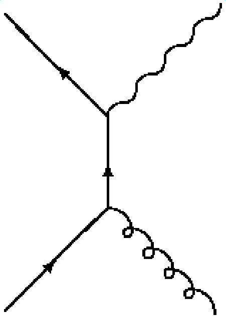
Apparatus

- **targets:** ***H*, polarized NH_3, *C***
- **experimental probes:**
    - **e^+e^- and $\mu^+\mu^-$ Drell Yan pairs**
    - **direct photons**
    - **J/ψ**
- **instrumentation:**
    - **Updated COMPASS spectrometer optimized for different experimental probes**
    - **New large acceptance DY spectrometer for electron (W-Si Calorimeter, PHENIX NCC & MPC-EX) and muon DY (Magnetized Iron Detector, Baby MIND)**
- **Ample room for ideas and contributions!**

Kaon Gluon Distribution from Direct Photon Production



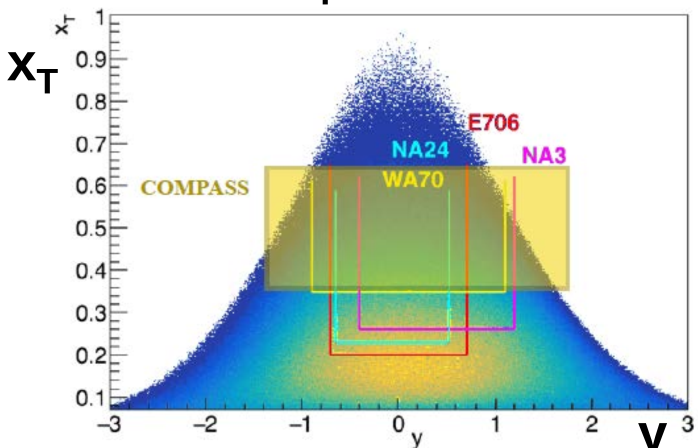
Gluon Compton

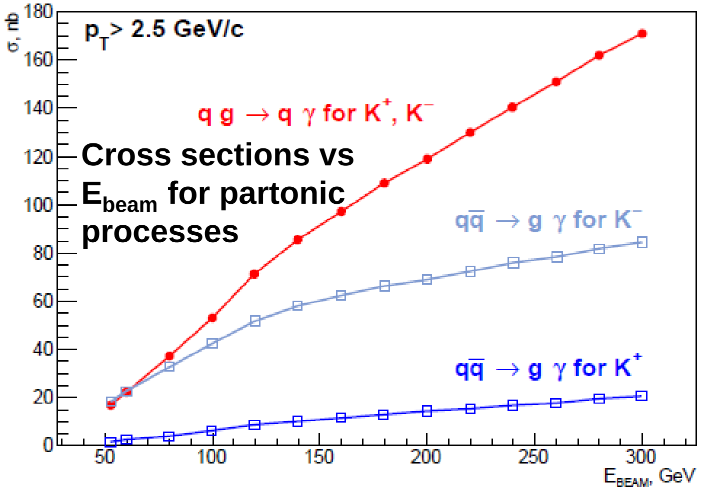


Annihilation

In addition, fragmentation photons: 10-20%

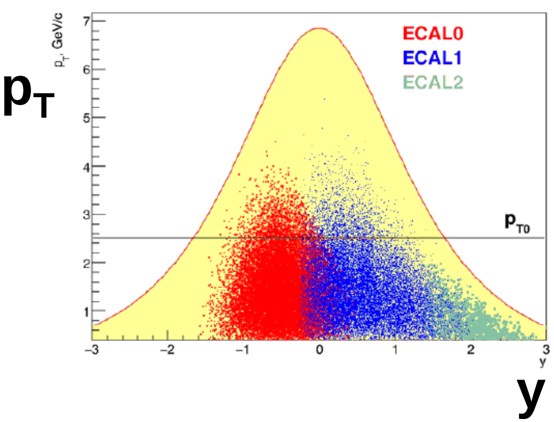
Kinematic coverage:
Previous experiments vs COMPASS

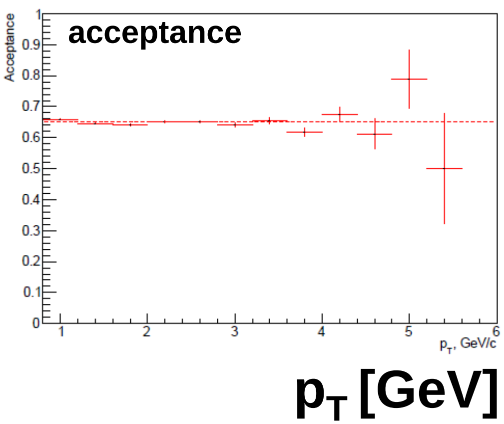




MC simulation using current COMPASS detector configuration for GPDs:

p_T >2.5 GeV/c and 1.4<y<18
140 days → 0.85 x 10^6 events



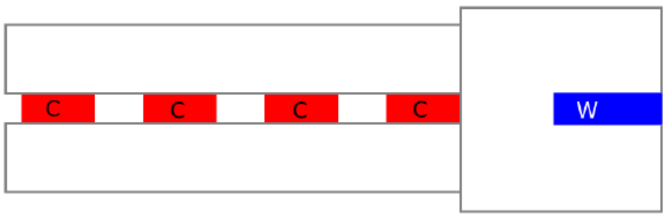


Kaon DY - MC Projections, E_{beam}=80,100,120 GeV expected DY yields: at 100 GeV ~ 58k K^-, 7k K^+

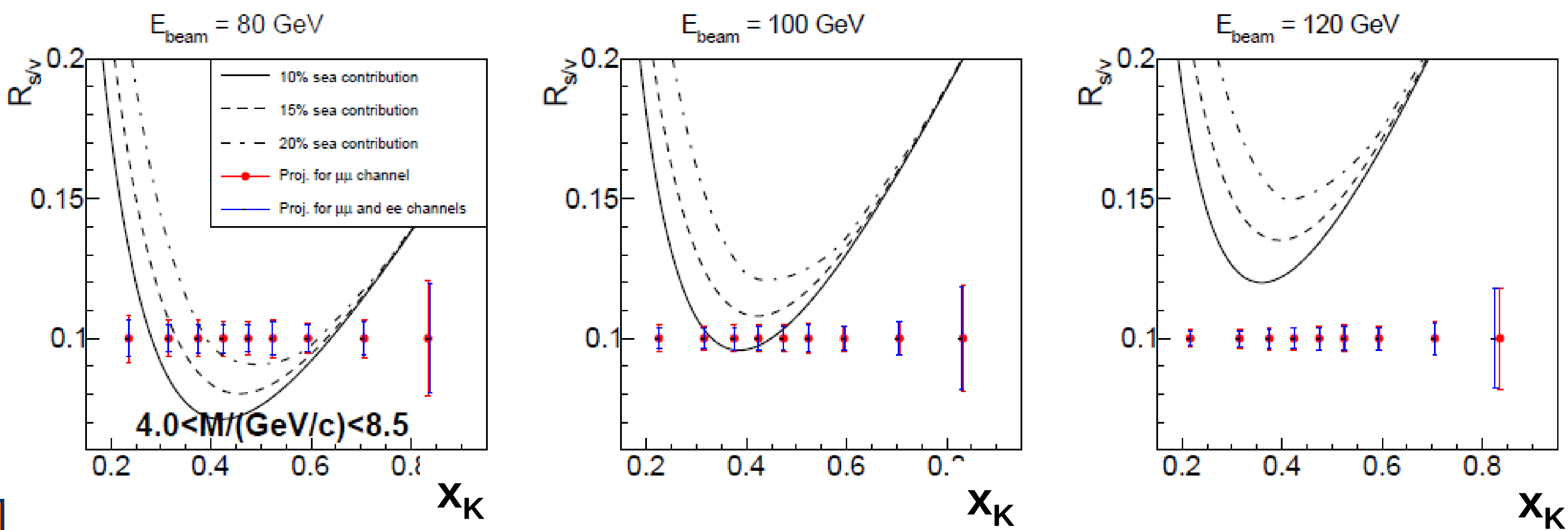
Experiment	Target type	Beam type	Beam intensity (part/sec)	Beam energy (GeV)	DY mass (GeV/c^2)	DY events $\mu^+\mu^-$	DY events e^+e^-
NA3	6cm Pt	K^-		200	4.2 – 8.5	700	0
This exp.	100cm C	K^-	2.1×10^7	80	4.0 – 8.5	25,000	13,700
				100	4.0 – 8.5	40,000	17,700
				120	4.0 – 8.5	54,000	20,700
		K^+	2.1×10^7	80	4.0 – 8.5	2,800	1,300
				100	4.0 – 8.5	5,200	2,000
				120	4.0 – 8.5	8,000	2,400
This exp.	100cm C	π^-	4.8×10^7	80	4.0 – 8.5	65,500	29,700
				100	4.0 – 8.5	95,500	36,000
				120	4.0 – 8.5	123,600	39,800

Kaon DY - MC Projections, E_{beam}=80,100,120 GeV for Sea to Valence Ratio: $R_{S/V}$

- Dense & not too long for counting rate and acceptance considerations
- Isoscalar for sea-valence separation: J.T. Londergan *et al.*, PLB 380 (1996)
  - $\Sigma_S = \sigma_{DY}^{K^+D}$: Sensitive to valence and sea terms
  - $\Sigma_V = \sigma_{DY}^{K^-D} - \sigma_{DY}^{K^+D} = \frac{4}{9}\bar{u}_v^{K^-}(u_v^p + d_v^p)$: only valence sensitive
- Low A to minimize nuclear effect: Carbon target

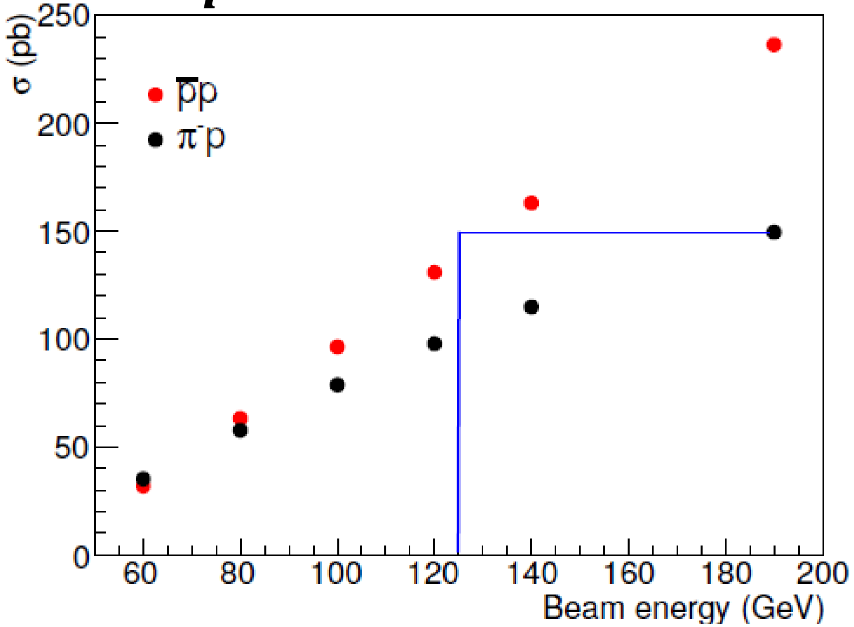


First measurement of Sea to Valence Ratio and precise measurement of quark distributions (earlier slides)



Anti-Proton DY – TMDs -> Boer-Mulders Function (BMF)

Cross sections for π^- and $\overline{p}$ induced Drell Yan



Experiment	Target type	Beam type	Beam intensity (part/sec)	Beam energy (GeV)	DY mass (GeV/c^2)	DY events $\mu^+\mu^-$	DY events e^+e^-
This exp.	110cm NH_3	$\bar{p}$	3.5×10^7	100	4.0 – 8.5	28,000	21,000
				120	4.0 – 8.5	40,000	27,300
				140	4.0 – 8.5	52,000	32,500

Table 3: Achievable statistics of the new experiment with an active absorber and 140 days of beam time.

$\overline{p}$ BMF

$$A_T^{cos(2\varphi_{CS}-\varphi_S)} \propto h_{1,\overline{p}}^{\perp q} \otimes h_{1,,p}^{q}$$

Target transversity

Clean measurement of $\overline{p}$ BMF

Summary

- LaMET in Lattice QCD enables ab initio quantitative analysis of hadron structure

- Comparison with precision data on the quark and gluon structure of mesons will provide the information needed for a systematic study of chiral dynamics and the emergence of the large hadron masses

- A future QCD facility with RF separated beams at the SPS will provide precise information on pion and kaon structure without significant model dependencies.

- Anti proton beams allow clean access to important TMDs that are difficult to extract from SIDIS.