Studying meson and proton structure at the CERN M2 beam line

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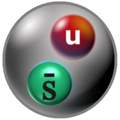
ECT* Mapping parton distribution amplitudes and functions
September 10^{th}-14^{th}

Motivations

Pion

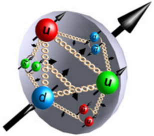
- $M_\pi \sim$ 140MeV
- Spin 0
- 2 light valence quarks
- 2 TMD PDFs at LT

Kaon



- $M_K \sim$ 490MeV
- Spin 0
- 1 light and 1 "heavy" valence quarks
- 2 TMD PDFs at LT

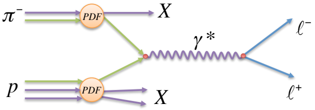
Proton



- $M_p \sim$ 940MeV
- Spin 1/2
- 3 light valence quarks
- 8 TMD PDFs at LT

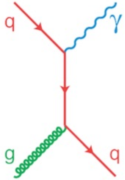
3 QCD objects, different structures, different properties, understanding differences and similarities teaches us about QCD

Drell-Yan:



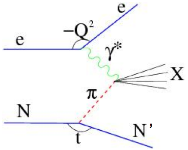
- 90's: NA3, NA10, E615
- 10's: COMPASS-II
- 20's: New Experiment

Prompt photon production:



- 90's NA24, W70
- 20's New experiment

DIS with leading N:

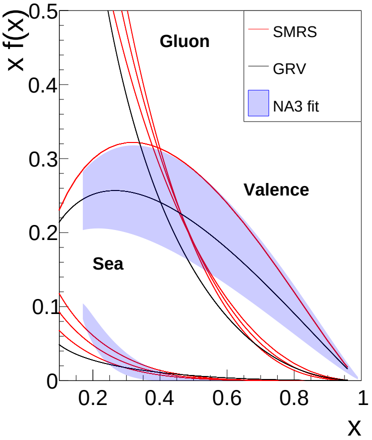


- 90's: H1, ZEUS
- 10's: JLAB TDIS
- 30's: EIC

Almost all what we know about pion structure

GRV: M. Gluck et al, Z.Phys.C **53** (1992) 651-655

SMRS: P.J. Sutton et al, Phys.Rev.D **45** (1992) 2349–2359



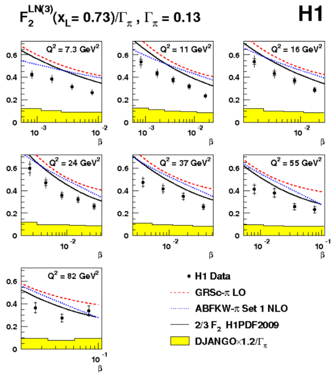
Example with three fits:

- Large untainties or not even at all
- Not enough data to directly constrain all PDFs → use of: Momentum Sum rules, constituent quark model...
- Sea no direct constraints

More data is needed, with better control of uncertainties, and full error treatment.

How to access the sea

DIS with di-jet and leading neutron

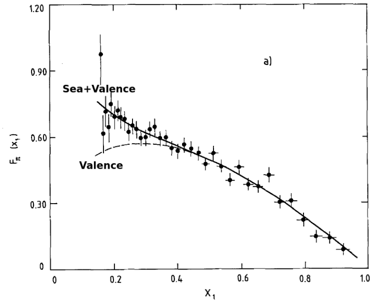


Aaron *et al.* Eur. Phys. J. C68, 2010

- Wide x coverage
- Estimation of pion flux introduce a strong model dependence

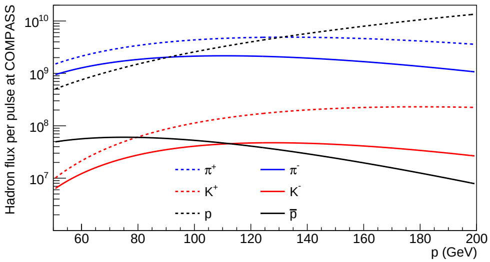
Drell-Yan NA3

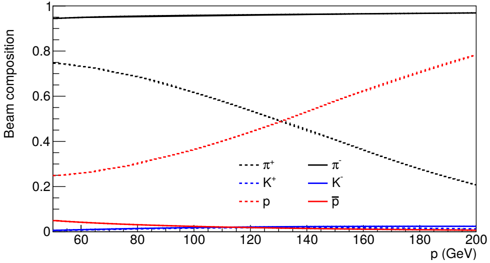
Badier *et al.*, Z. Phys. C18, 1983



- Limited statistics: 4.7k π^--event (shown) and 1.7k π^+-event
- Heavy nuclear target (Pt)

Beam possibilities at the CERN M2 beamline

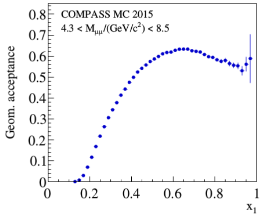




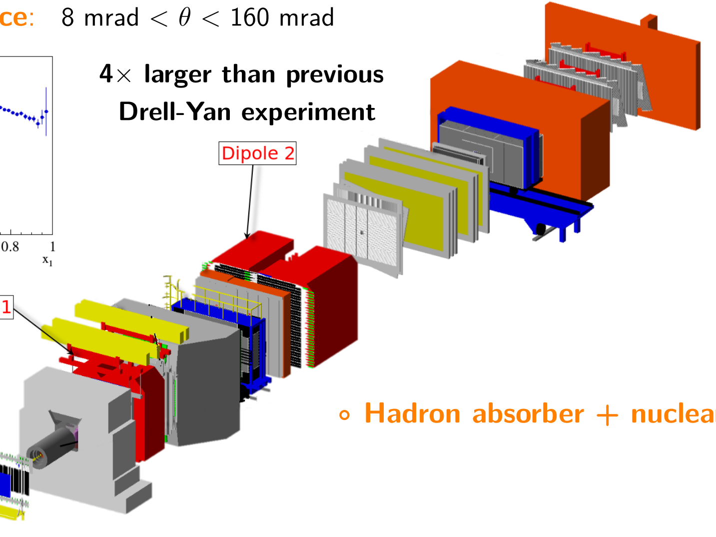
- High intensities available
- Almost pure π^- beam
- Reasonable contribution of π^+ for positive beam

COMPASS-like spectrometer for initial simulation studies

- **Large acceptance:** 8 mrad $< \theta <$ 160 mrad



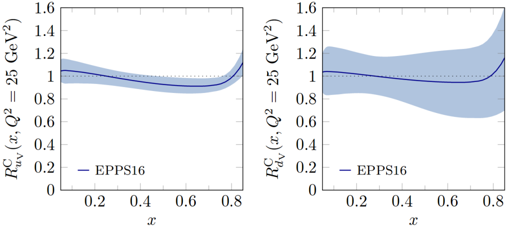
4× larger than previous Drell-Yan experiment

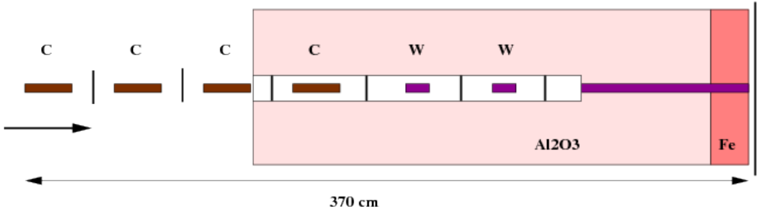


- **Hadron absorber + nuclear targets**

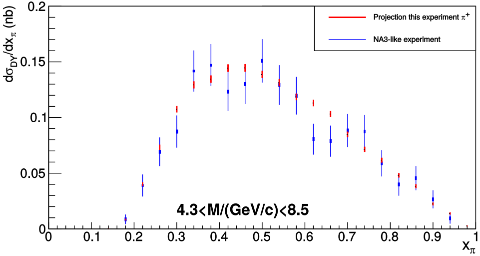
Choice of target

- Isoscalar for sea-valence separation
- Minimize nuclear effect: Carbon
- Embbedded in an absorber for high intensity
- Segmented with vertex tagging for flux and resolution





Projection Pions (2 years)

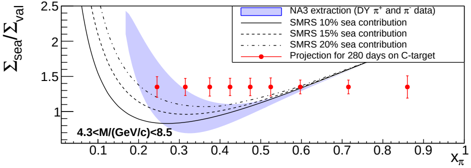


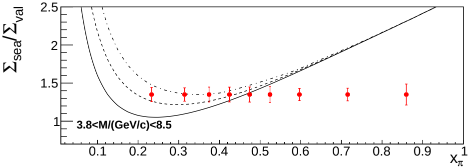
Expected accuracy compared to NA3 result

- Collect at least a **factor 10 more statistics** than presently available
- Aim at the first precise direct measurement of the pion sea contribution

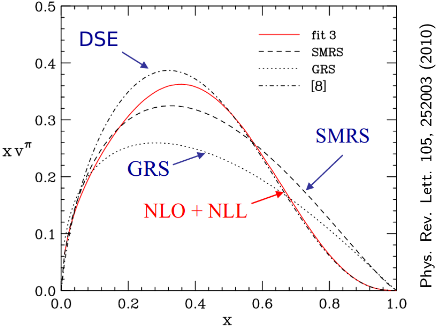
$$\Sigma_{val} = \sigma^{\pi^- C} - \sigma^{\pi^+ C}\text{: only valence-valence}$$

$$\Sigma_{sea} = 4\sigma^{\pi^+ C} - \sigma^{\pi^- C}\text{: no valence-valence}$$



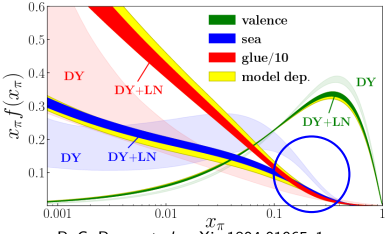


- Recent reanalysis at NLL
- Agreement restored between DSE and data
- Sea and gluon from GRS
- Nuclear effects ignored



- First MC global QCD analysis ("model dependence")
- Hera data (DIS with leading neutron) included
- Clear impact on sea and gluon distribution

Direct data would constrain the circled area and check the method.

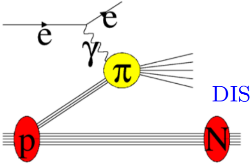


P. C. Barry *et al.* arXiv:1804.01965v1

Foreseen meson structure measurements

Tagged DIS at JLab → See talk by C. Keppel

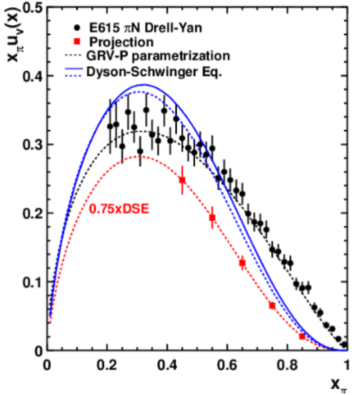
- Same approach as H1 and Zeus:



DIS - Sullivan process

- Test of pion cloud
- Caveat: Model depedence from the unknown pion flux

PR12-15-006



Provide complementary data at large x
Same process is also foreseen for the future EIC to reach very low x

Pion induced Drell-Yan statistics

Experiment	Target type	Beam energy (GeV)	Beam type	Beam intensity (part/sec)	DY mass (GeV/c^2)	DY events
E615	20cm W	252	π^+ π^-	17.6×10^7 18.6×10^7	$4.05 - 8.55$	5,000 30,000
NA3	30cm H_2	200	π^+ π^-	2.0×10^7 3.0×10^7	$4.1 - 8.5$	40 121
	6cm Pt	200	π^+ π^-	2.0×10^7 3.0×10^7	$4.2 - 8.5$	1,767 4,961
NA10	120cm D_2	286 140	π^-	65×10^7	$4.2 - 8.5$ $4.35 - 8.5$	7,800 3,200
	12cm W	286 140	π^-	65×10^7	$4.2 - 8.5$ $4.35 - 8.5$	49,600 29,300
COMPASS 2015 COMPASS 2018	110cm NH_3	190	π^-	7.0×10^7	$4.3 - 8.5$	35,000 52,000
This exp	100cm C	190	π^+	1.7×10^7	$4.3 - 8.5$ $3.8 - 8.5$	**23,000** 37,000
		190	π^-	6.8×10^7	$4.3 - 8.5$ $3.8 - 8.5$	22,000 34,000
	24cm W	190	π^+	0.2×10^7	$4.3 - 8.5$ $3.8 - 8.5$	7,000 11,000
		190	π^-	1.0×10^7	$4.3 - 8.5$ $3.8 - 8.5$	6,000 9,000

Also 100 of thousands of J/ψ available for free

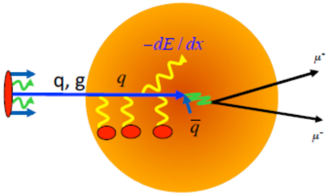
Parallel studies

Energy loss: $\rightarrow$ See talk by S. Platchkov

- Multiple scattering of incoming quark in large nuclei
- No energy loss in the final state

$\rightarrow$ Fixed target regime especially suited

$\rightarrow$ Comparison between DY and J/ψ complementary information

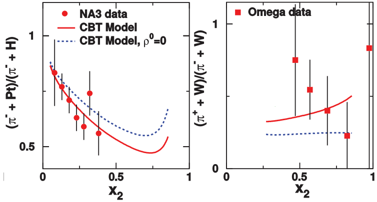


Flavour dependent EMC effect:

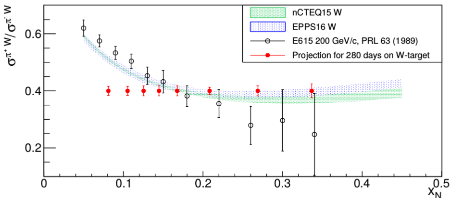
Iso-vector ρ^0 mean field generated in $N \neq Z$ nuclei can modify nucleon's u and d PDF differently

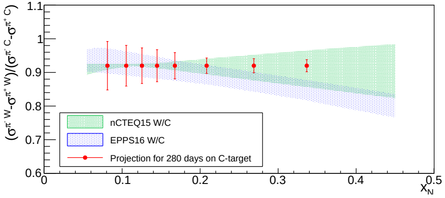
- NA3 π on Pt favours flavour dependence
- Omega π on W not conclusive

$\rightarrow$ Meson induced Drell-Yan process tags flavours

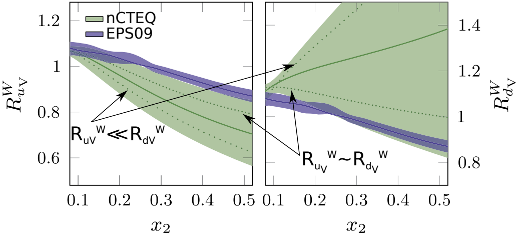


Parallel measurement: EMC effects





P. Paakkinen *et al.* PLB 768 (2017) 7



Using two π beam charges and two targets, one can add constraints on the EMC flavour dependence

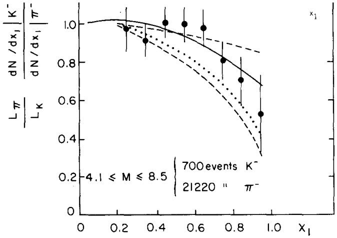
Should play a significant role in nPDFs uncertainties and EMC effect

What do we know about kaon structure?

Sole measurement from NA3

J. Badier *et al.*, PLB93 354 (1984)

- Limited statistics: 700 events with K^-
- Sensitivity to $SU(3)_f$ breaking
- Mostly only model predictions

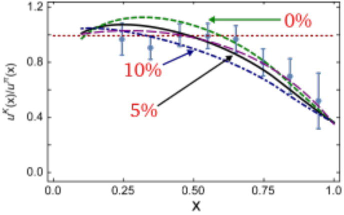


Interesting observation: At hadronic scale gluons carry only 5% of K's momentum *vs* ∼30% in π

- Scarce data on *u*-valence
- No measurements on gluons
- No measurements on sea quarks

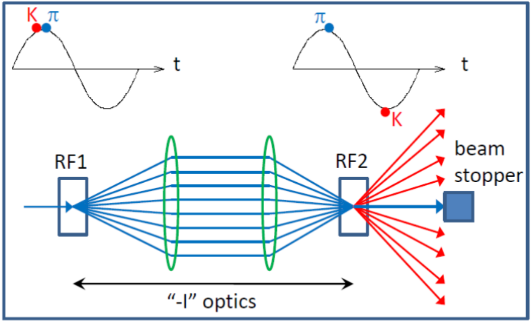
How to improve the situation?

C. Chen *et al.*, PRD 93 074021, 2016



Unique opportunities with RF separated beam

- Deflection with 2 cavities
- Relative phase = 0 → 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:

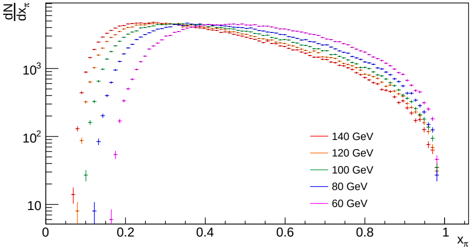
L should increase as p^2 for a given f → limits the beam momentum

Initial expectations before further *R&D*:

∼ 80 GeV Kaon beam
∼ 110 GeV Anti-proton beam

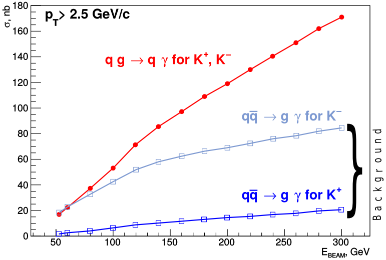
Kaon RF separated

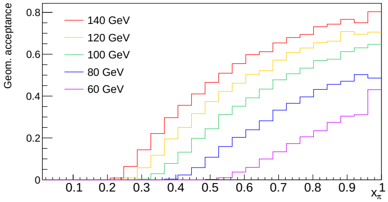
DY cross-section



- Highest beam energy to access low x
- Highest beam energy to increase signal/bgd ratio
- Favorable also COMPASS-like apparatus

Prompt photon cross-section





Improvement of acceptance

Requirements: Active absorber

- Trackers
- Magnetic field
- Good resolution for vertexing
- Large area
- Capabilitity to collect e^+e^- DY pairs

Initial detector consideration:

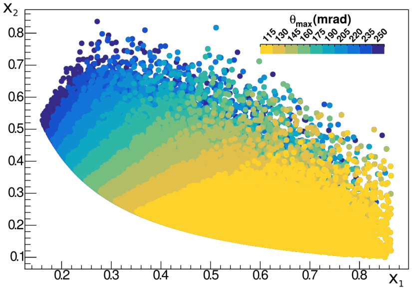
Combination of

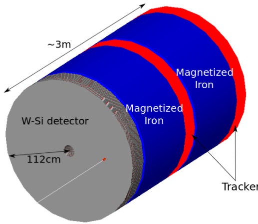
- Baby-Mind detector

  M. Antonova *et al.* arXiv:1704.08079

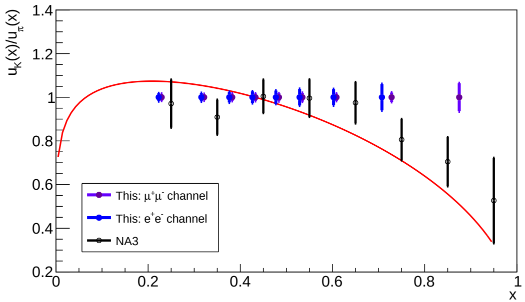
- W-Si detectors, a la BNL

  AnDY | Phenix MPCEX | Phenix NCC

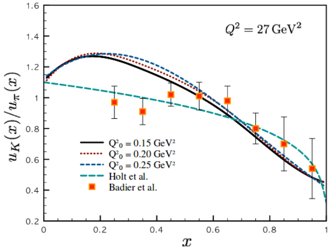




Projections for Kaon structure

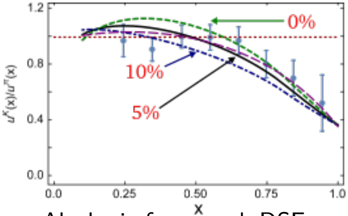


S-i. Nam PRD 86, 074005, 2012



Gauge-invariant nonlocal chiral-quark model

C. Chen *et al.*, PRD 93 074021, 2016

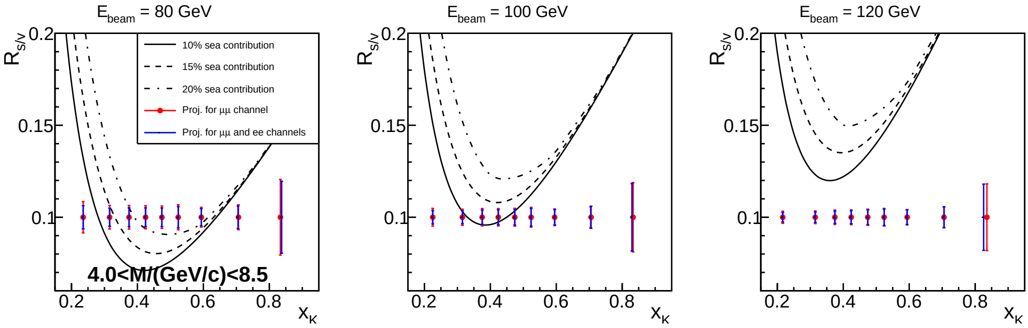


Algebraic framework DSE

- More data points and more precise compared to NA3
- Discriminating power between models
- 1 year with $2 \times 10^7\ s^{-1}$ 100 GeV K^- beam
- π taken simultanously

Unique and Promising

Projections for valence/sea separation for Kaons



- **First measurement of sea in kaons**
- Requires an additional year with K^+ beam to complement the former K^- data
- Assuming the intensity for K^+ and K^-: $2 \times 10^7\ s^{-1}$

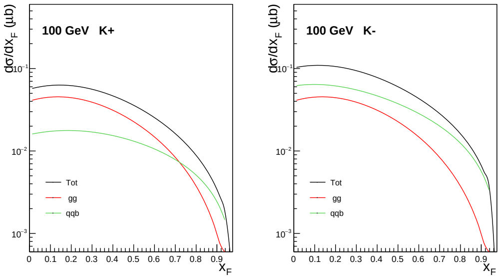
Parallel measurement: J/ψ production

Purely strong interaction: all partons contribute on the same footing

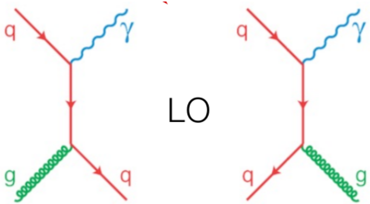
Using two kaon beam charges, one can access:

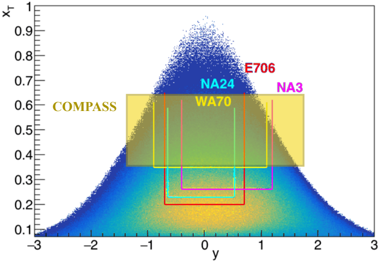
- $\bar{u}^K u^N \propto \sigma^{K^-}_{J/\psi} - \sigma^{K^+}_{J/\psi}$
- Infer the kaon gluon distribution in a model dependent way

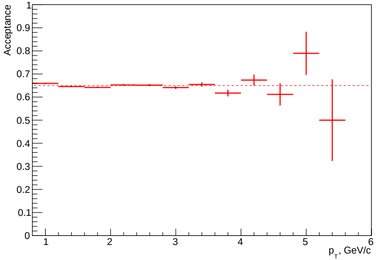
J/ψ subprocess contribution as obtained from the Color Evaporation Model



Gluon structure in Kaon through prompt photon production







- Model independent way
- Large cross-section
- Large acceptance
- Experimentally difficult (huge background)

No competitors

Unpolarised Drell-Yan angular dependencies

$$\frac{dN}{d\Omega} = \frac{3}{4\pi}\frac{1}{\lambda+3}\left(1+\lambda\cos^2(\theta)+\mu\sin(2\theta)\cos(\phi)+\frac{\nu}{2}\sin^2(\theta)\cos(2\phi)\right)$$

In naive Drell-Yan model, no k_T and no QCD processes involving gluons:

$$\lambda = 1,\ \ \mu = 0,\ \ \nu = 0$$

The Lam-Tung relation, derived from the fermionic nature of quarks, predicts:

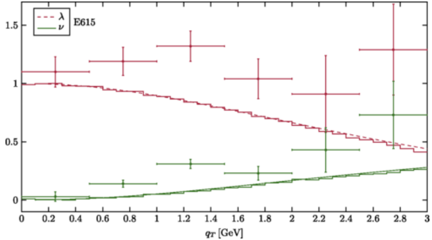
$$1-\lambda-2\nu = 0$$

Analog of DIS Callan-Gross relation for Drell-Yan

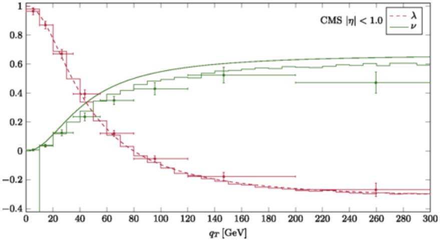
C.S. Lam and W.K. Tung, Phys. Rev. D 18, 2447 (1978)

QCD Lam-Tung relation

E615 PRD 39, 92 (1989)



CMS PLB 750, 154 (2015)



- Recent evidence in terms of QCD: radiative effects describe well data at large q_T
  - J.-C. Peng *et al.* PLB 758, 384 (2016)
  - M. Lambertsen and W. Vogelsang PRD93, 114013 (2016)

$\rightarrow$ See talk by J.-C. Peng

- Boer Mulders expected at low q_T $\rightarrow$ fixed target regime
- Verify Lam-Tung relation for Kaon beam
- To single out Boer Mulders effects very precise data are necessary

Transverse momentum dependent PDFs

So far, I talked only about mesons but what about the nucleon?

		Nucleon Polarization		
		U	**L**	**T**
Quark Polarization	**U**	$f_1^q(x, \mathbf{k_T^2})$ Number Density		$f_{1T}^{q\perp}(x, \mathbf{k_T^2})$ Sivers
	L		$g_1^q(x, \mathbf{k_T^2})$ Helicity	$g_{1T}^{q\perp}(x, \mathbf{k_T^2})$ Worm-Gear T
	T	$h_1^{q\perp}(x, \mathbf{k_T^2})$ Boer-Mulders	$h_{1L}^{q\perp}(x, \mathbf{k_T^2})$ Worm-Gear L	$h_{1T}^q(x, \mathbf{k_T^2})$ Transversity; $h_{1T}^{q\perp}(x, \mathbf{k_T^2})$ Pretzelosity

Nucleon · Nucleon spin · quark · quark spin · $\mathbf{k_T}$

At LO QCD, the nucleon can be decomposed into 8 twist-2 TMD PDFs.

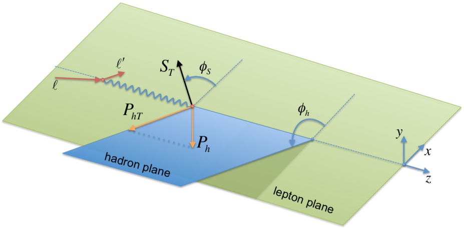
Using a transversally polarised target, one can access in SIDIS as well as in Drell-Yan:

- Sivers
- Transversity
- Pretzelosity

Drell-Yan and SIDIS cross-section modulations

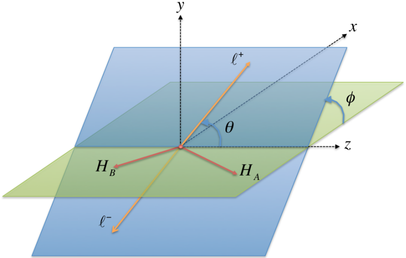
SIDIS:

$$\frac{d\sigma}{dxdydzd\phi_S d\phi_h dP_{hT}^2} \overset{\text{LO}}{=} \frac{\alpha^2}{xyQ^2}\frac{y^2}{2(1-\epsilon)}\left(1\frac{\gamma^2}{2x}\right)\hat{\sigma_U}\Big\{1+\epsilon A_{UU}^{\cos(2\phi_h)}\cos(2\phi_h)$$
$$+S_T\Big[A_{UT}^{\sin(\phi_h-\phi_S)}\sin(\phi_h-\phi_S)+\epsilon A_{UT}^{\sin(\phi_h+\phi_S)}\sin(\phi_h-\phi_S)$$
$$+\epsilon A_{UT}^{\sin(3\phi_h-\phi_S)}\sin(3\phi_h-\phi_S)\Big]$$
$$+S_T P_l\left[\sqrt{1-\epsilon^2}\cos(\phi_h-\phi_S)A_{LT}^{\cos\phi_h-\phi_S}\right]\Big\}$$



DY:

$$\frac{d\sigma}{d^4qd\Omega} \overset{\text{LO}}{=} \frac{\alpha^2}{Fq^2}\hat{\sigma_U}\Big\{\left(1+\cos^2(\theta)+\sin^2(\theta)A_{UU}^{\cos(2\phi)}\cos(2\phi)\right)$$
$$+S_T\Big[(1+\cos^2(\theta))A_{UT}^{\sin(\phi_S)}\sin(\phi_S)$$
$$+\sin^2(\theta)\left(A_{UT}^{\sin(2\phi+\phi_S)}\sin(2\phi+\phi_S)+A_{UT}^{\sin(2\phi-\phi_S)}\sin(2\phi-\phi_S)\right)\Big]\Big\}$$



Synergy DY *vs* SIDIS

DY:					SIDIS:			
$A_{UU}^{\cos(2\phi)}$	$\propto h_{1,h}^{\perp q}$	$\otimes$	$h_{1,p}^{\perp q}$	Boer-Mulders	$A_{UU}^{\cos(2\phi_h)}$	$\propto h_{1,p}^{\perp q}$	$\otimes$	$H_{1q}^{\perp h}$
$A_{UT}^{\sin(\phi_S)}$	$\propto f_{1,h}^{q}$	$\otimes$	$f_{1T,p}^{\perp q}$	Sivers	$A_{UT}^{\sin(\phi_h-\phi_S)}$	$\propto f_{1T,p}^{\perp q}$	$\otimes$	D_{1q}^{h}
$A_{UT}^{\sin(2\phi-\phi_S)}$	$\propto h_{1,h}^{\perp q}$	$\otimes$	$h_{1,p}^{q}$	Transversity	$A_{UT}^{\sin(\phi_h+\phi_S)}$	$\propto h_{1,p}^{q}$	$\otimes$	$H_{1q}^{\perp h}$
$A_{UT}^{\sin(2\phi+\phi_S)}$	$\propto h_{1,h}^{\perp q}$	$\otimes$	$h_{1T,p}^{\perp q}$	Pretzelosity	$A_{UT}^{\sin(3\phi_h-\phi_S)}$	$\propto h_{1T,p}^{\perp q}$	$\otimes$	$H_{1q}^{\perp h}$

TMD PDFs are **universal** but
final state interaction (SIDIS) *vs.* initial state interaction (DY) $\rightarrow$ **Sign flip** for naive T-odd TMD PDFs

$$f_{1T}^{\perp q}\ |_{\text{SIDIS}} = -f_{1T}^{\perp q}\ |_{\text{DY}}$$
$$h_{1}^{\perp q}\ |_{\text{SIDIS}} = -h_{1}^{\perp q}\ |_{\text{DY}}$$

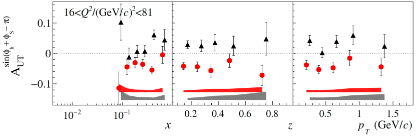
Crucial test of TMD framework in QCD

COMPASS DY and SIDIS

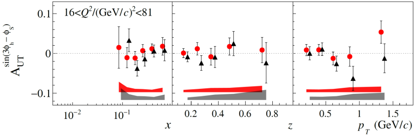
SIDIS TSA in HM range

COMPASS, PLB 770 (2017) 138

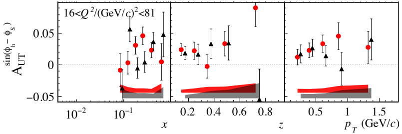
$A^{sin(\phi_h+\phi_s)} \propto h^q_{1,p} \otimes H^{\perp h}_{1q}$



$A^{sin(3\phi_h-\phi_s)} \propto h^{\perp q}_{1T,p} \otimes H^{\perp h}_{1q}$



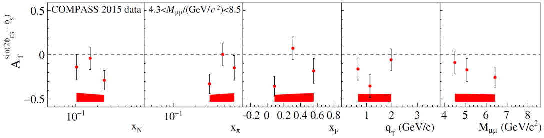
$A^{sin(\phi_h-\phi_s)} \propto f^{\perp q}_{1T,p} \otimes D^h_{1q}$



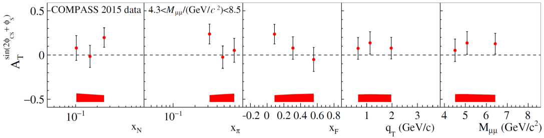
DY TSA in MH range

COMPASS, PRL 119 112002 (2017)

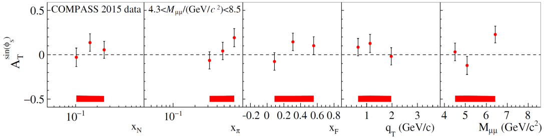
$A^{sin(2\phi_{CS}-\phi_s)} \propto h^{\perp q}_{1,\pi} \otimes h^h_{1,p}$ Transversity



$A^{sin(2\phi_{CS}+\phi_s)} \propto h^{\perp q}_{1,\pi} \otimes h^{\perp q}_{1T,p}$ Pretzelosity



$A^{sin(\phi_s)} \propto f^q_{1,\pi} \otimes f^{\perp q}_{1T,p}$ Sivers

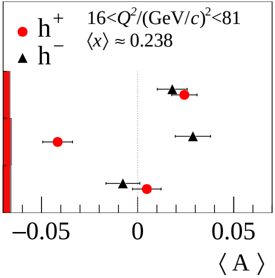


COMPASS DY and SIDIS

Sivers $A^{sin(\phi_h-\phi_s)} \propto f_{1T,p}^{\perp q} \otimes D_{1q}^{h}$

Transversity $A^{sin(\phi_h+\phi_s)} \propto h_{1,p}^{q} \otimes H_{1q}^{\perp h}$

Pretzelosity $A^{sin(3\phi_h-\phi_s)} \propto h_{1T,p}^{\perp q} \otimes H_{1q}^{\perp h}$



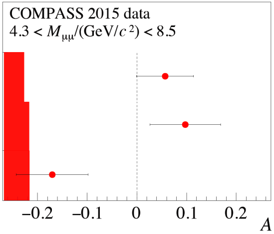
SIDIS:

All sizeable except Pretzelosity

Sivers $A^{sin(\phi_s)} \propto f_{1,\pi}^{q} \otimes f_{1T,p}^{\perp q}$

Pretzelosity $A^{sin(2\phi_h+\phi_s)} \propto h_{1,\pi}^{\perp q} \otimes h_{1T,p}^{\perp q}$

Transversity $A^{sin(2\phi_{CS}-\phi_s)} \propto h_{1,\pi}^{\perp q} \otimes h_{1,p}^{h}$

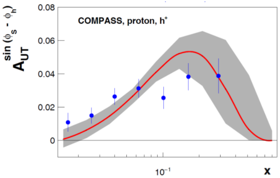


DY:

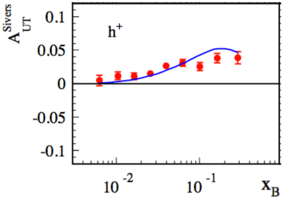
- Sivers found at 1 sigma from zero
- Pretzelosity pretty large
- Still large uncertainties

Focus on Sivers sign change

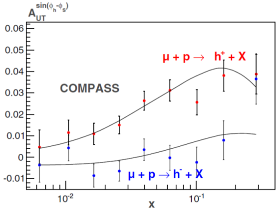
DGLAP (2016)
M. Anselmino *et al.*, JHEP 1704 (2017) 046



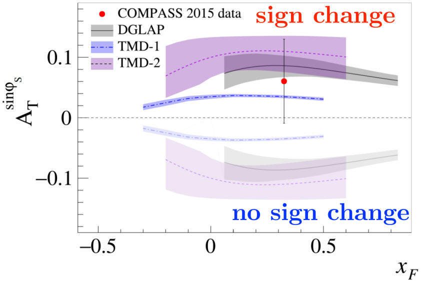
TMD-1 (2014)
M.G. Echevarria *et al.*, PRD 89 074013



TMD-2 (2013)
P. Sun, F. Yuan, PRD 88, 114012



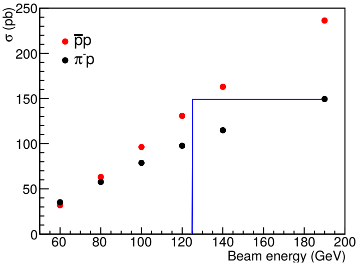
Favour sign-change scenario



Second data taking campaign, ongoing!

Anti-proton with a RF separated beam

Possibility to study valence proton TMD PDFs in a model free way



- cross-sections for $\bar{p}$ induced-DY at 120 GeV $\sim$ π^- induced-DY at 190 GeV
- Combined statistics from $\mu^+\mu^-$ and e^+e^- channels $\sim$ 2 years of COMPASS-II data taking
- With active absorber: better acceptance in θ_{CS}

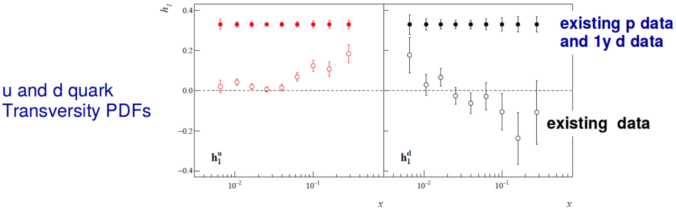
Experiment	Target type	Beam type	Beam intensity (part/sec)	Beam energy (GeV)	DY mass (GeV/c^2)	DY events $\mu^+\mu^-$	DY events e^+e^-
This exp.	110cm NH_3	$\bar{p}$	3.5×10^7	100	4.0 – 8.5	28,000	21,000
				120	4.0 – 8.5	40,000	27,300
				140	4.0 – 8.5	52,000	32,500

Anti-proton beam: Synergy DY and SIDIS

Additional insight with $\bar{p}$ on Boer Mulders (private exchange with Andreas Metz)

- Transversity modulation less affected by QCD effects
- Smooth matching between TMD approach and QCD

$\rightarrow$ Extract transversity from SIDIS $A_{UT}^{sin(\phi_h+\phi_S)} \propto h_{1,p}^{q} \otimes H_{1q}^{\perp h}$ measurements



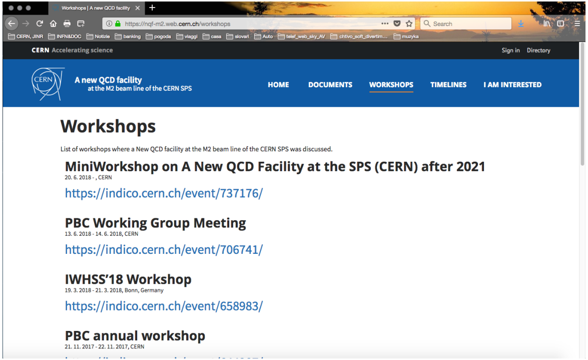
- Use DY measured $A^{sin(2\phi-\phi_S)} \propto h_{1,h}^{\perp q} \otimes h_{1,p}^{q}$ and SIDIS transversity knowledge

Obtain Boer-Mulders $h_1^{\perp q}$ for **proton and meson with antiproton and meson beams**

Complementary to SIDIS, where Cahn effects can be difficult to disentangle from Boer-Mulders effects

A new QCD facility

- Letter of Intent
  arXiv:1808.00848
  DY, Spectroscopy, muon-p elastics scattering, . . .
- A web page
- Can register to stay informed



New ideas and collaborators are welcome

Outlook

Near term future: Current beams

- **Precise** determination of **pion structure** and valuable inputs for nuclear effects (nPDFs, EMC, J/ψ, ...)

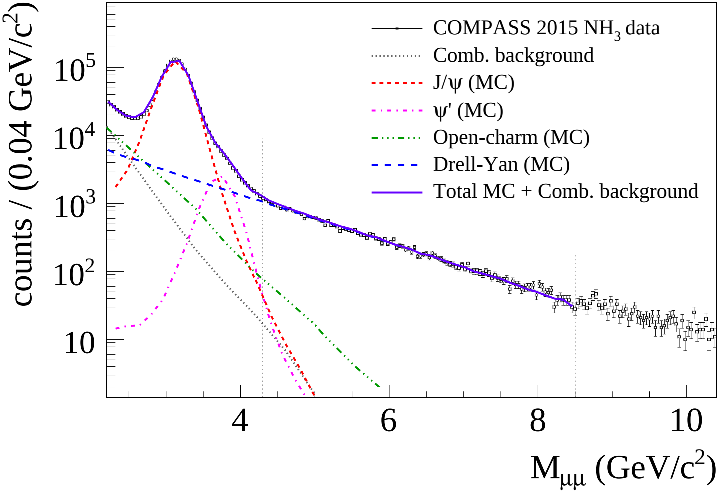
Long term future: RF-separated beams

- **Unprecedented** studies of **Kaon structure**
- **Unique** opportunity to study **proton valence TMD PDFs** in a model free way

Many other valuables measurements described in the LoI for both short and long term future

BACKUP

Mass spectrum



Background less than 4% in $4.3 < M_{\mu\mu}/(GeV) < 8.5$

Target choice and sea-valence separation

With π^+ and π^- beam and isoscalar target:

$$\sigma(\pi^+ d) \propto \frac{4}{9}[u^\pi \cdot (\bar{u}^p_s + \bar{d}^p_s)] + \frac{4}{9}[\bar{u}^\pi_s \cdot (u^p + d^p)] + \frac{1}{9}[\bar{d}^\pi \cdot (d^p + u^p)] + \frac{1}{9}[d^\pi_s \cdot (\bar{d}^p_s + \bar{u}^p_s)]$$

$$\sigma(\pi^- d) \propto \frac{4}{9}[u^\pi_s \cdot (\bar{u}^p_s + \bar{d}^p_s)] + \frac{4}{9}[\bar{u}^\pi \cdot (u^p + d^p)] + \frac{1}{9}[\bar{d}^\pi_s \cdot (d^p + u^p)] + \frac{1}{9}[d^\pi \cdot (\bar{d}^p_s + \bar{u}^p_s)]$$

- Assumption:
  - Charge conjugation and $SU(2)_f$ for valence: $u_v^{\pi^+} = \bar{u}_v^{\pi^-} = \bar{d}_v^{\pi^+} = d_v^{\pi^+}$
  - Charge conjugation and $SU(3)_f$ for sea:
    $u_s^{\pi^+} = \bar{u}_s^{\pi^-} = u_s^{\pi^-} = \bar{u}_s^{\pi^+} = \bar{d}_s^{\pi^+} = d_s^{\pi^+} = \bar{d}_s^{\pi^-} = d_s^{\pi^+} = s_s^{\pi^+} = s_s^{\pi^-} = \bar{s}_s^{\pi^+} = \bar{s}_s^{\pi^-}$
- Two linear combination
  - Only valence sensitive: $\Sigma_v^{\pi D} = -\sigma^{\pi^+ D} + \sigma^{\pi^- D} \propto \frac{1}{3} u_v^\pi (u_v^p + d_v^p)$
  - Sea sensitive : $\Sigma_s^{\pi D} = 4\sigma^{\pi^+ D} - \sigma^{\pi^- D}$

Kaon induced Drell-Yan statistics

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	6 cm Pt	K^-		200	4.2 – 8.5	700	0
This exp.	100 cm 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.	100 cm 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

Achievable statistics of the new experiment, assuming 2×140 days of data taking with equal time sharing between the two beam charges. For comparison, the collected statistics from NA3 is also shown.

Requirements per topic

Program	Beam Energy [GeV]	Beam Intensity [/s]	Trigger Rate [kHz]	Beam Type	Target	Hardware Additions	R	C
Proton radius	100	$4 \cdot 10^6$	100	$\mu^\pm$	high-pr. H2	active TPC, SciFi trigger, silicon veto		
GPD E	160	10^7	10	$\mu^\pm$	NH3↑	recoil silicon, modified PT magnet		
Anti-matter	190	$5 \cdot 10^5$	25	p	LH2, LHe	recoil TOF	×	×
Spectroscopy $\bar{p}$	12, 20	$5 \cdot 10^7$	25	$\bar{p}$	LH2	target spectrometer: tracking, calorimetry	×	×
Drell-Yan conv	190	$6.8 \cdot 10^7$	25	$\pi^\pm$	C/W	vertex detector		×
Drell-Yan RF	∼100	10^8	25-50	$K^\pm$, $\bar{p}$	NH_3 ↑, C/W	"active absorber", vertex detector		×
Primakoff	∼100	$5 \cdot 10^6$	> 10	K^-	Ni		×	×
Prompt photon	100	$5 \cdot 10^6$	10-100	K^+	LH2	hodoscope		×
Spectroscopy K^-	50-100	$3.7 \cdot 10^6$	25	K^-	LH2	recoil TOF	×	×

Requirements for the future programs at the M2 beam line after 2021.. Standard muon beams are in blue, standard hadron beams in orange, and RF-separated hadron beams in red. The common baseline is the COMPASS-II setup without RICH-1. "R" refers to RICH-1 and if possible RICH-0, "C" to CEDARs.