Pion structure measurement at a new QCD facility at SPS

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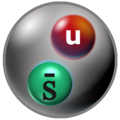
New QCD facility
Mini workshop
June 21^{st}

Motivations

Pion

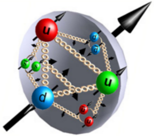
- $M_\pi \sim$ 140MeV
- Spin 0
- 2 light valence quarks
- 2 TMD PDFs at LT

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

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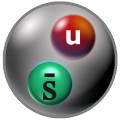

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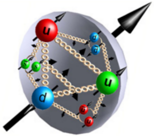
Covered by Matthias

Proton



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Almost all what we know about pion structure

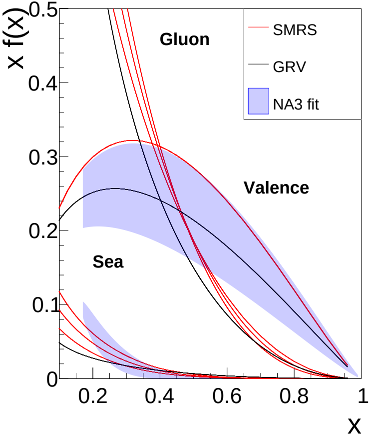
GRV: M. Gluck et al, Z.Phys.C **53** (1992) 651-655

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 is the most unknown contribution

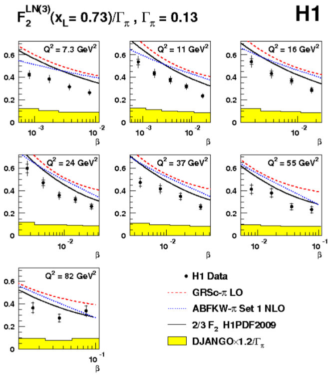
More data is needed, with better control of uncertainties, and full error treatment.



How to access the sea

DIS with di-jet and leading neutron

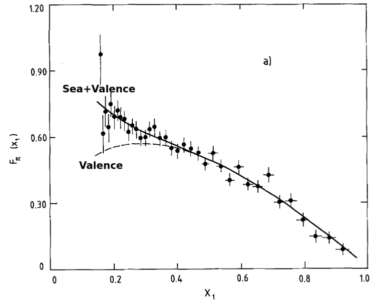
Aaron *et al.* Eur. Phys. J. C68, 2010



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

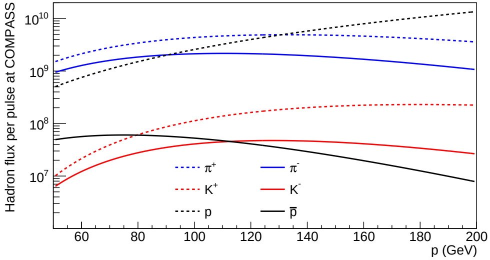
Drell-Yan NA3

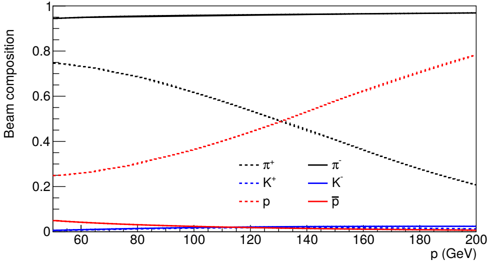
Badier *et al.*, Z. Phys. C18, 1983



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

Beam possibilities at the CERN M2 beamline

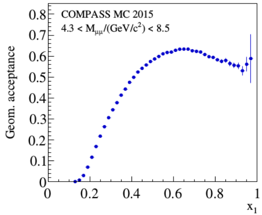




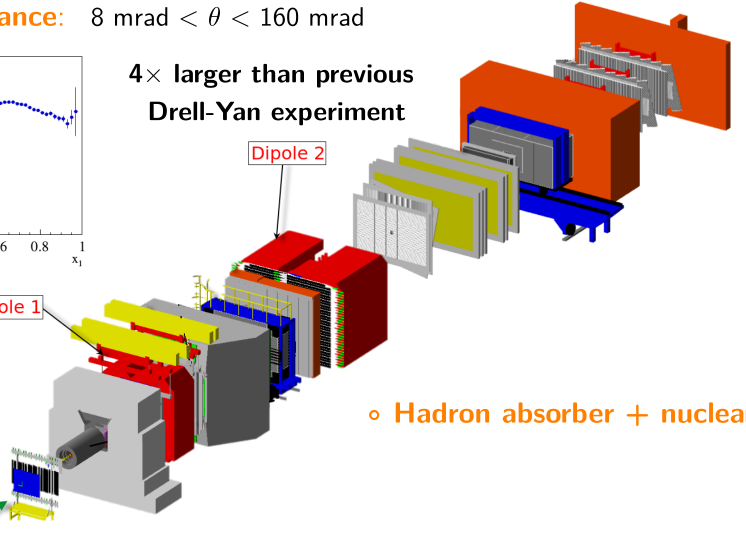
- High intensities available
- Almost pure π^- beam
- Reasonable contribution of π^+ for positive beam

COMPASS-like spectrometer for initial simulation studies

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



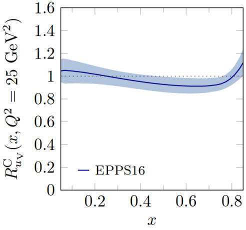
4× larger than previous Drell-Yan experiment

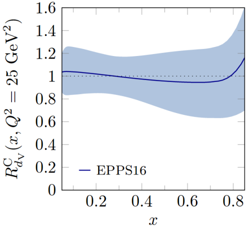


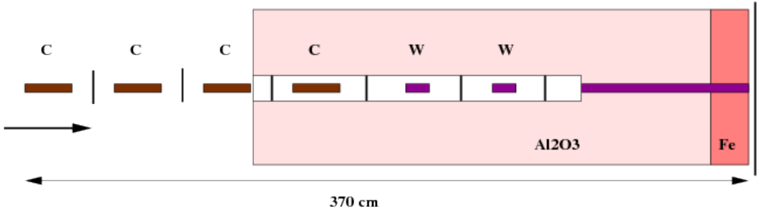
- **Hadron absorber + nuclear targets**

Choice of target

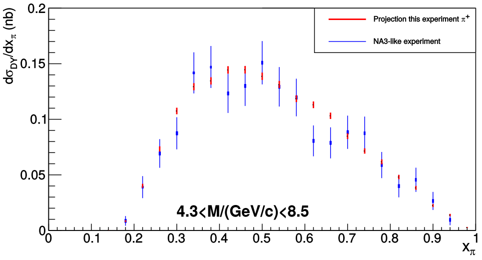
- Isoscalar for sea-valence separation
- Minimize nuclear effect: Carbon
- Embbedded in an absorber for high intensity
- Segmented with vertex tagging for flux and resolution







Projection Pions (2 years)

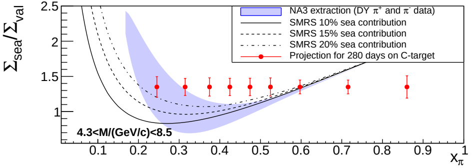


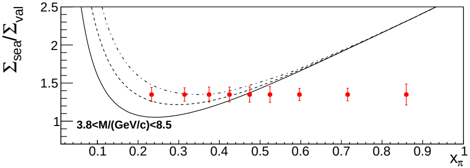
Expected accuracy compared to NA3 result

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

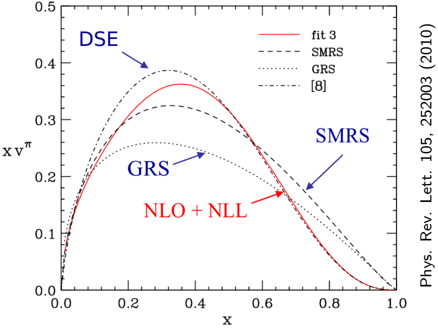
$\Sigma_{val} = \sigma^{\pi^- C} - \sigma^{\pi^+ C}$: only valence-valence

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



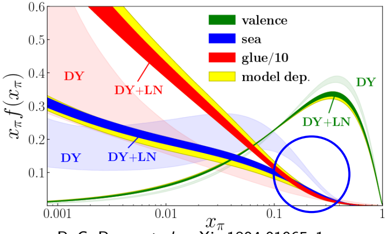


- Recent reanalysis at NLL
- Agreement restored between DSE and data
- Sea and gluon from GRS



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

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

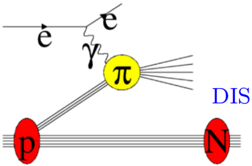


P. C. Barry *et al.* arXiv:1804.01965v1

Forseen meson structure measurements

Tagged DIS at JLab

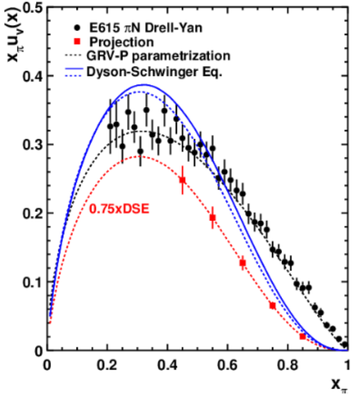
- Same approach as H1 and Zeus:



DIS - Sullivan process

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

PR12-15-006



Provide complementary data at large x

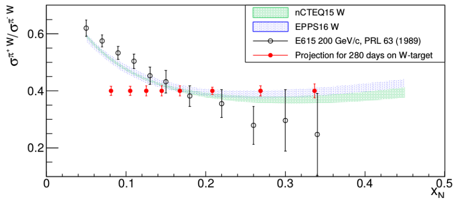
Same process is also forseen for the future EIC to reach very low x

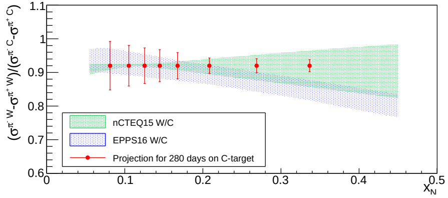
Pion induced Drell-Yan statistics

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

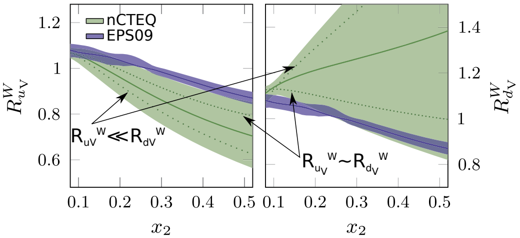
Also 100 of thousands of J/ψ available for free

Parallel 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

Outlook

With current beams:

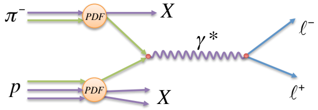
- **Precise** direct determination of **pion structure**
- Valuable measurements of nuclear effects (nPDFs, EMC, ...)
- Large sample of J/ψ available

CERN is a unique place with high energy pion beams (π^+ and π^-), where those measurements can be performed

BACKUP

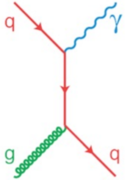
How to access meson structure

Drell-Yan:



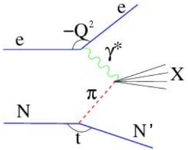
- 90's: NA3, NA10, E615
- 10's: COMPASS-II
- 20's: New Experiment

Prompt photon production:



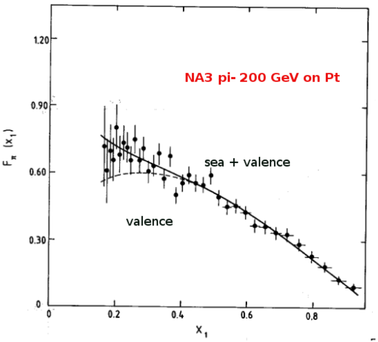
- 90's NA24, W70
- 20's New experiment

DIS with leading N:



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

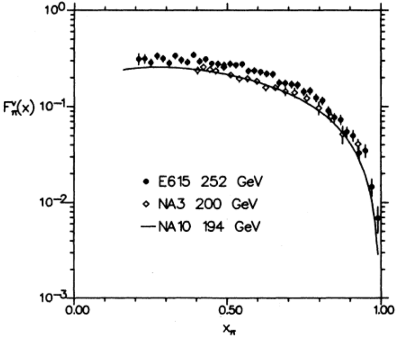
Pion Structure Function: $F_\pi(x_1)$



Simultaneous fit of NA3 π^+, π^- and p at 200 GeV Drell-Yan data, using CDHS nucleon PDF set.

NA3 Coll.; Z.Phys.C **18** (1983) 281-287

$v^\pi(x_1)$



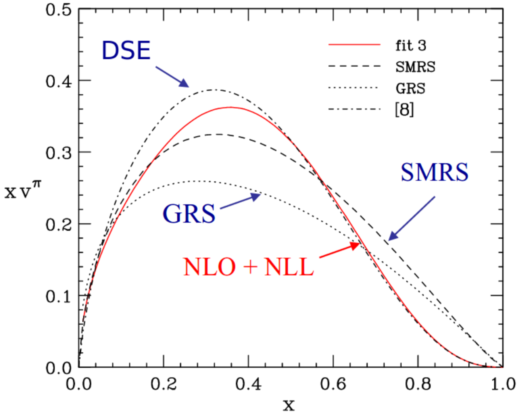
Discrepancy by 20% between E615 and NA3/NA10

E615 Coll.; Phys.Rev. D **39** (1989) 92-122

Left: Curve scaled with $K_{factor} = 2.3$; Right: Data point corrected by K_{factor}

Status of the pion structure at mid-large x

- Recent reanalysis at NLL
- Agreement resstored between DSE and dat
- Only valence quark distributions are fitted
- Sea and gluon from GRS



Target choice and sea-valence separation

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

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

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

- 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 :$\Sigma_s^{\pi D} = 4\sigma^{\pi^+ D} - \sigma^{\pi^- D}$

Requirements for pion case

- EHN2
  - Roof shielding to reduce sky-shining and satisfy RP
  - Good CEDARs (upgrade happening for 2018 run)

- Beam line
  - Beam momentum 190 GeV
  - Higher intensity: 2×10^8 particles per second
  - Differential absorber (2m polyethylene) if does not degrade too much beam parallelism

Increasing the intensity (at least 1.4×10^8/s total flux) should guarantee the projected uncertainties within a year

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 $\overline{p}$	12, 20	$5 \cdot 10^7$	25	$\overline{p}$	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	$K^\pm$, $\overline{p}$	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.

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