Future Drell-Yan @ COMPASS and elsewhere

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...at sweet Bonn, IWHSS 2018

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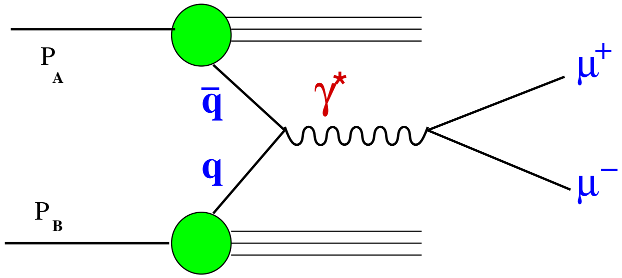
Outline

- Drell-Yan as a tool for PDF and TMD PDF studies
- (un)polarized Drell-Yan at COMPASS
- beyond COMPASS Drell-Yan: a new experiment
  - pion structure
  - kaon structure
  - antiproton/proton (spin) structure
- Direct competition and complementarity

...many more Drell-Yan measurements being planned, which are not mentioned in this talk, since not directly competing with the new proposed one – but undoubtfully important also.

Drell-Yan at COMPASS



$\bar{q}q \rightarrow \gamma^* \rightarrow \mu^+\mu^-$

COMPASS Drell-Yan: measure transverse spin asymmetries

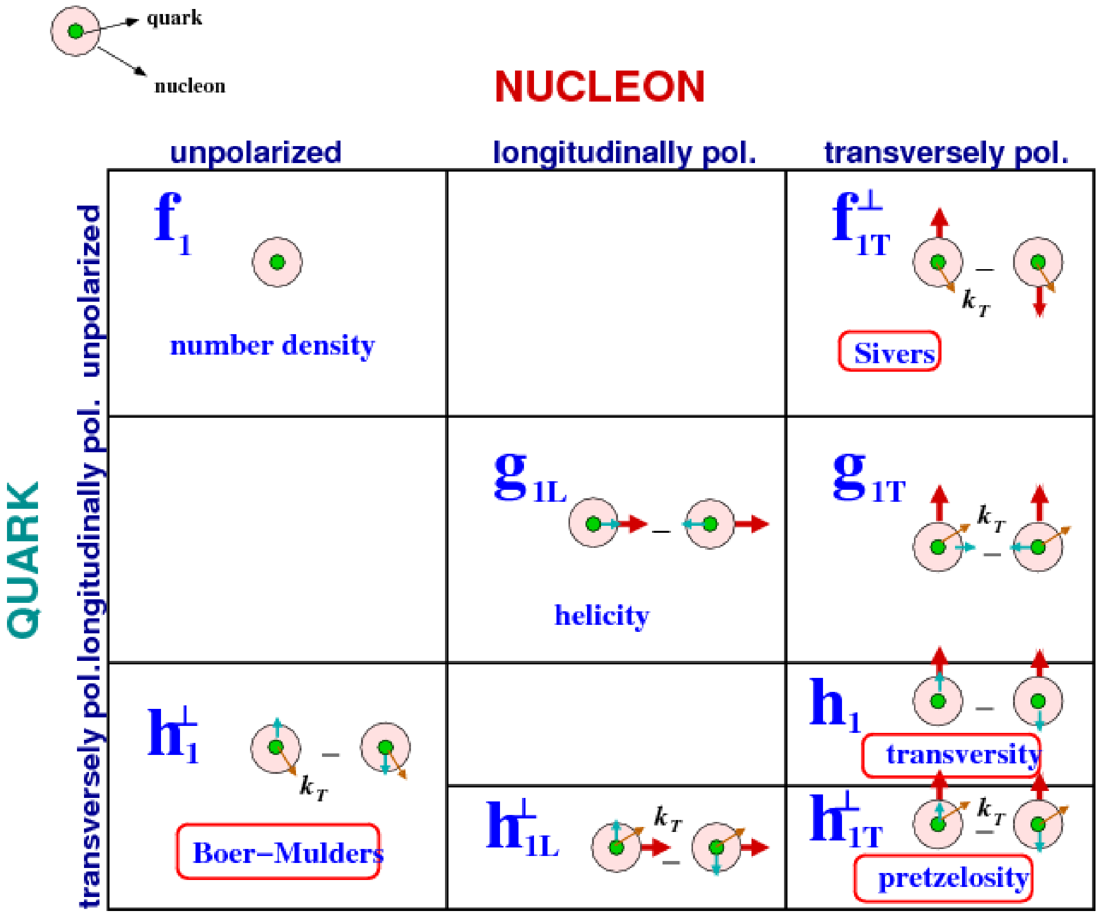
$\hookrightarrow$ access convolutions of TMD PDFs

$$\frac{d\sigma_{AB\rightarrow l\bar{l}X}}{dQ^2dy} = \sum_{ab}\int_0^1 dx_a \int_0^1 dx_b \; \Phi_a^A(x_a,\mu)\; \Phi_b^B(x_b,\mu)\; \frac{d\hat{\sigma}_{ab\rightarrow l\bar{l}}(x_a,x_b,Q,\mu)}{dQ^2dy}$$

- Hadron A: π^- beam
- Hadron B: $p^\uparrow$ in polarized NH_3 target

u-quark dominance: mostly access TMD PDFs of the u-quark

Drell-Yan: a tool for TMD studies

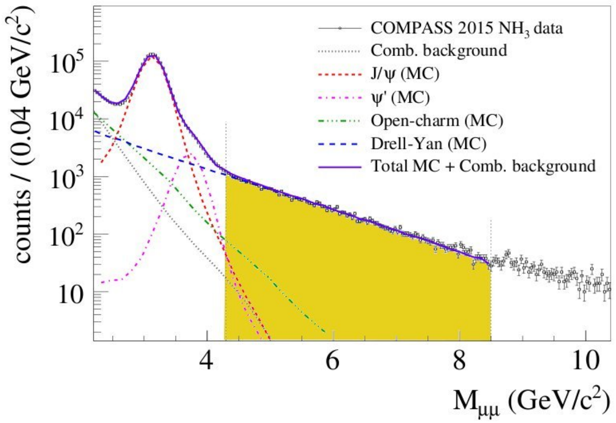


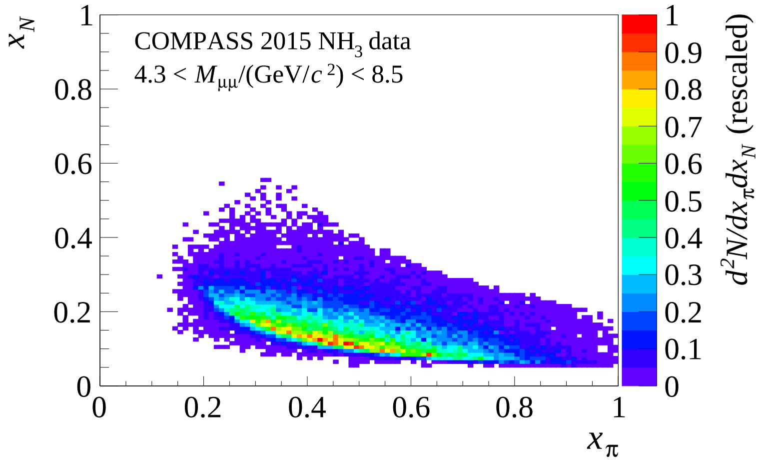
A crucial check of the role of k_T and the TMD approach is the predicted **sign change of the Sivers TMD PDF** between SIDIS and DY:

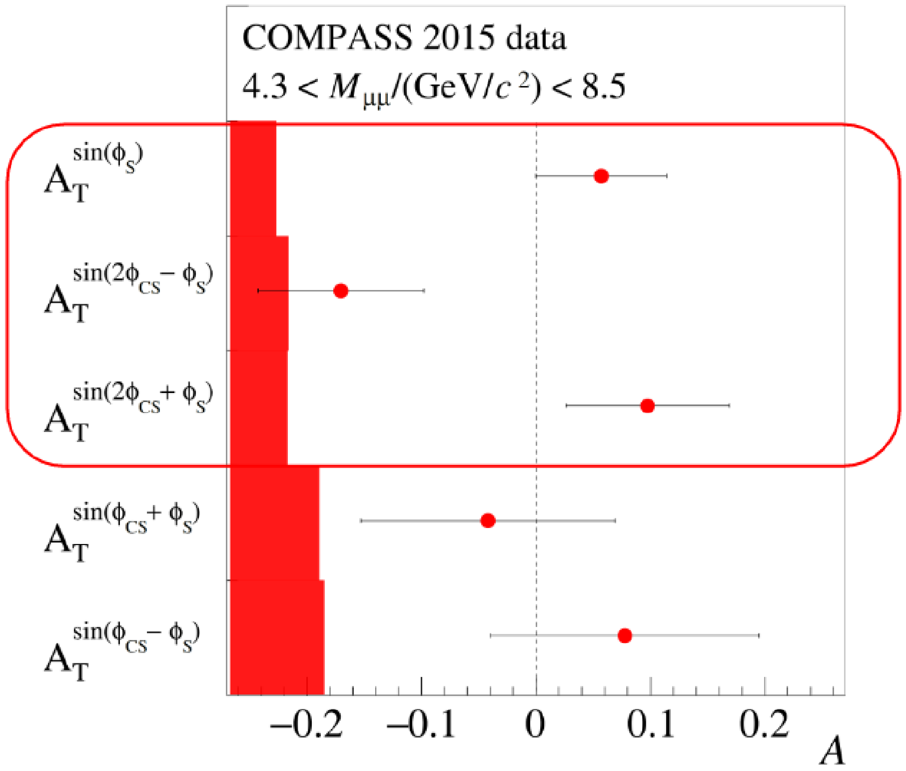
$$f_{1T}^{\perp}(SIDIS) = -f_{1T}^{\perp}(DY)$$

TSAs from COMPASS DY

COMPASS, Phys.Rev.Lett. **119**, 112002 (2017)







see Riccardo Longo's talk

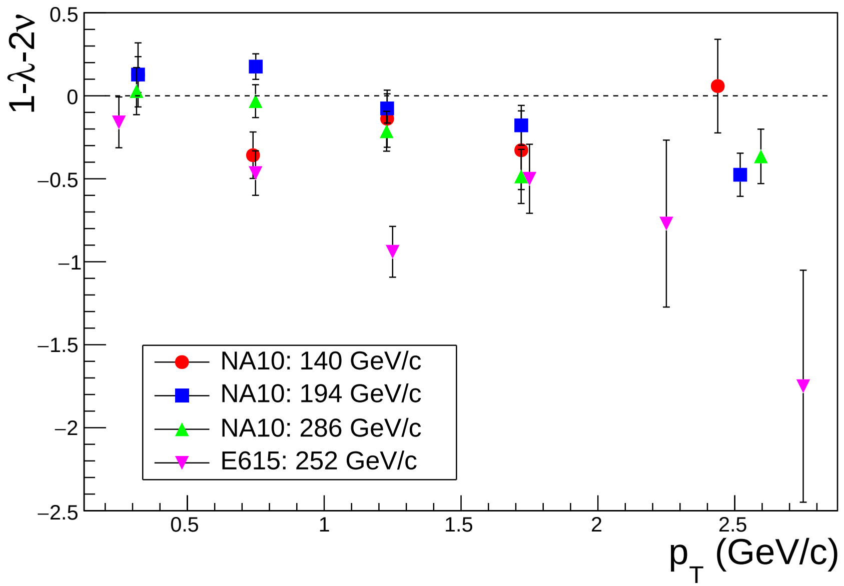
The Lam-Tung sum rule

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

LO DY: Lam-Tung sum rule

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

NA10 and E615: **Lam-Tung does not hold!**



NA3, Phys.Lett.B **104**, 335 (1981)

NA10, Phys.Lett.B **193**, 368 (1987)

- **COMPASS data analysis is ongoing**

Understanding Drell-Yan: Lam-Tung violation

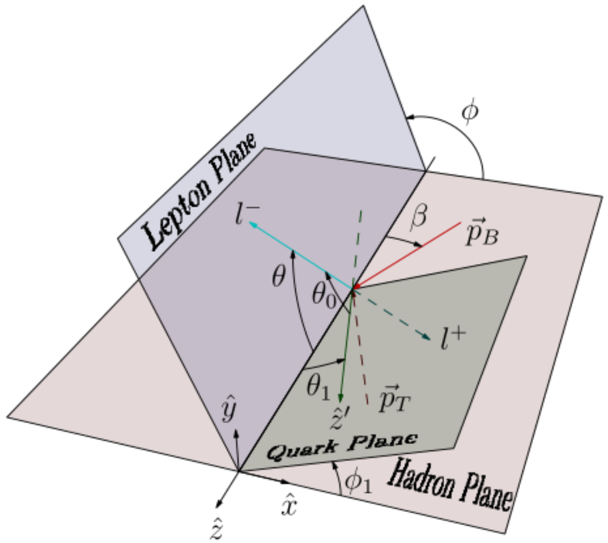
J-C.Peng, W-C. Chang, R.E. McClellan, O. Teryaev, Phys.Lett.B **758**, 384 (2016):
The mechanism by which these features are generated is qualitatively understood: the non-coplanarity of the axis of the incoming partons wrt the hadron plane.

M. Lambertsen and W. Vogelsang, Phys.Rev. D **93**, 114013 (2016):
Lam-Tung violation is "reproduced" by including NNLO QCD corrections.

This non-coplanarity can be attributed to:

- QCD radiative effects at $O(\geq \alpha_s^2)$
- At the scale of the pion-induced DY experiments, also intrinsic k_T might have a role

$\hookrightarrow$ Boer-Mulders **TMD PDF**



On the pion side

σ_{DY}: a sum of convolutions of 2 TMDs. To access the proton information we need some **pion input**.

But what do we really know about the pion?

- the lightest pseudo-scalar meson (S=0, $m_\pi = 140$ MeV)
- described by 2 TMD PDFS of quarks: $f_{1,\pi}$ and $h_{1,\pi}^{\perp}$
- 95% of the pion mass comes from dynamics (gluons+sea)
- The valence is responsible for 50-60% of the pion momentum
- Pion structure information from only few DY experiments from the 80's

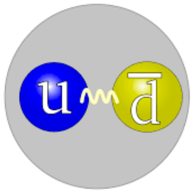
Jen-Chieh Peng and Stephane Platchkov talks

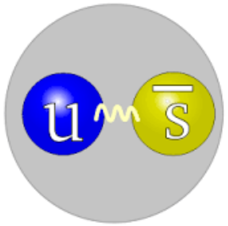
Why do we care about the pion?

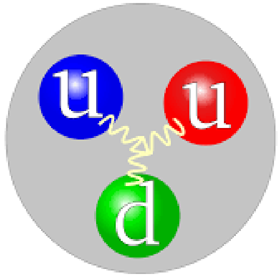
Over the last decades, the proton structure was thoroughly explored.

Other hadrons are still unexplored. Pions and kaons are apparently simple, yet mysterious objects.

In their different structure (and internal dynamics) hides the answer to the **mystery of the hadron mass hierarchy**.







MASS	nearly massless – a near cancellation of dressed quarks	still 2 light quarks, but heavier bound state	3 light quarks – super heavy dressed ones
SPIN	S=0 implies an exact cancellation – a symmetry	S=0 – exact cancellation	S=1/2 – the good-old spin puzzle

A roadmap for progress in this field

Strong motivation for new Drell-Yan measurements, with ultimate goals:

- Contribute in the hadron mass hierarchy puzzle
- Contribute in the hadron spin puzzles

Measurements should include and be accompanied by:

- Meson-induced Drell-Yan with both beam charges: sea-valence separation
- (Un)polarized Drell-Yan: hadron TMDs characterization
- Meson-induced prompt photon production: glue component
- Good understanding of meson fragmentation functions at $z_h \to 1$

Pion induced Drell-Yan

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	$4.05 - 8.55$	5000 30000
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	$4.2 - 8.5$	1767 4961
NA10	120cm D_2	286 140	π^-	65×10^7	$4.2 - 8.5$ $4.35 - 8.5$	7800 3200
	12cm W	286 194 140	π^-	65×10^7	$4.2 - 8.5$ $4.07 - 8.5$ $4.35 - 8.5$	49600 155000 29300
COMPASS 2015 COMPASS 2018	110cm NH_3	190	π^-	7.0×10^7	$4.3 - 8.5$	35000 > 35000

- After 30 years, finally new data on pion-induced DY
- W and Pt: non-negligible nuclear effects have to be considered
- NA3 did not publish cross-sections
- **COMPASS Drell-Yan cross-sections analysis ongoing**

Pion structure

pion: $valence + sea + glue$

Valence:

$$v^\pi(x_1) = \bar{u}_v^{\pi^-}(x_1) = d_v^{\pi^-}(x_1) = u_v^{\pi^+}(x_1) = \bar{d}_v^{\pi^+}(x_1)$$

Sea (SU(3) symmetry):

$$S^\pi(x) = \bar{u}_s^\pi(x) = u_s^\pi(x) = \bar{d}_s^\pi(x) = d_s^\pi(x) = \bar{s}_s^\pi(x) = s_s^\pi(x)$$

Pion induced DY with both beam charges: most direct way to separate pion valence and sea.

In LO PDFs can be parametrized as (simplistic description):

pion	proton
$v^\pi(x_1) = A^\pi x_1^{\alpha^\pi} (1 - x_1)^{\beta^\pi}$	$u_v^p(x_2) = A_u^p x_2^{\alpha_u^p} (1 - x_2)^{\beta_u^p}$ $d_v^p(x_2) = A_d^p x_2^{\alpha_d^p} (1 - x_2)^{\beta_d^p}$
$S^\pi(x_1) = A_s^\pi (1 - x_1)^{\gamma^\pi}$	$S^p(x_2) = A_s^p (1 - x_2)^{\gamma^p}$

Sea-valence separation

In the Drell-Yan cross-section: **valence-valence**, **valence-sea**, **sea-sea** terms.

The valence-sea and sea-sea terms are the same with π^+ and π^-, but the valence-valence part not.

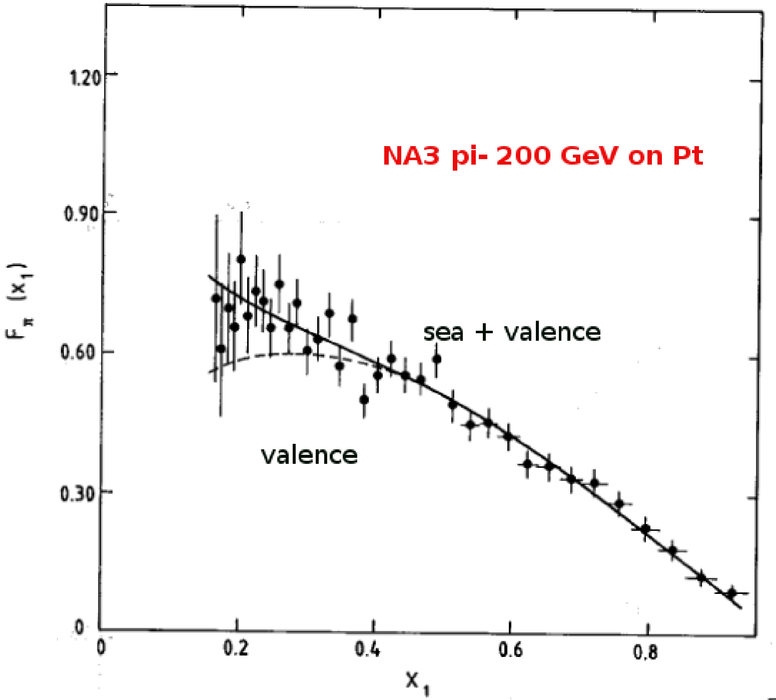
Assuming charge and isospin conjugation symmetry for valence and sea quarks:

$$\Sigma_v^{\pi p} = \sigma^{\pi^- p} - \sigma^{\pi^+ p} \propto \frac{1}{3}\, u_v^\pi\, (u_v^p + d_v^p) \quad \rightarrow \text{Only valence-valence terms}$$

$$\Sigma_s^{\pi p} = 4\sigma^{\pi^+ p} - \sigma^{\pi^- p} \quad \rightarrow \text{No valence-valence terms}$$

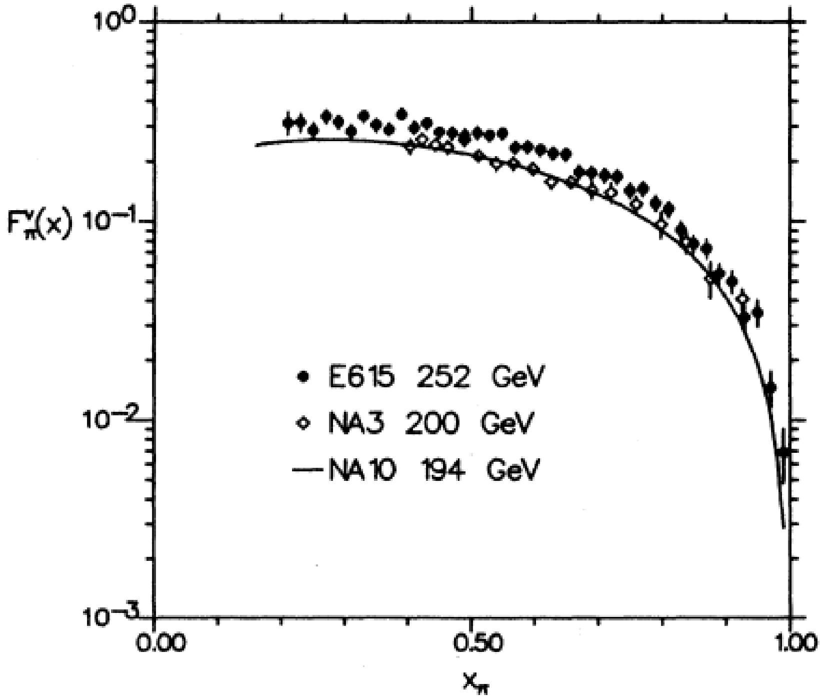
Pion Structure Function: $F_\pi(x_1)$

$v^\pi(x_1)$



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

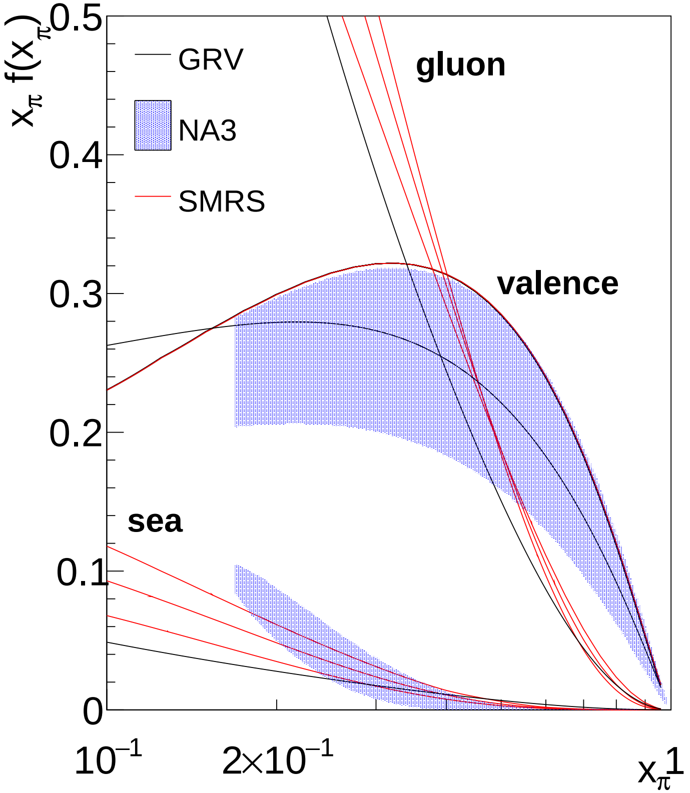
NA3 Coll.; Z.Phys.C **18** (1983) 281-287



Discrepancy by 20% between E615 and NA3/NA10, even if all 3 use the value extracted by NA3, $\langle g_\pi \rangle = 0.47$.

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

Global fits



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

SMRS: P.J. Sutton et al, Phys.Rev.D **45** (1992) 23492359

- SMRS did not use π^+ NA3 data. Instead, they assume 3 levels of sea: 10%, 15% or 20%.
- GRV neither. They constrain the pion gluon distribution from pion-induced direct photon production (NA24, WA70)
- NA3 did not publish cross-sections. They extract pion valence and sea based solely on their (scarce) data.
- Large discrepancies. No error treatment.

$\hookrightarrow$ **COMPASS data will provide new input on the pion valence.**

Pion gluon distribution: g^{π}

The gluon distribution in the pion can be accessed from:

direct photons

- From gluon Compton scattering:
  $gq(\bar{q}) \rightarrow \gamma q(\bar{q})$
- From quark-antiquark annihilation:
  $q\bar{q} \rightarrow \gamma g$

First mechanism dominates.

Important background of minimum bias photons from π^o and η decays.

$\hookrightarrow$ Past measurements from WA70 and NA24.

J/ψ

Mechanism of charmonia production not well understood, models differ:

- NRQCD (color octet+singlet):
  gg fusion dominance.
- Color Evaporation Model:
  $q\bar{q}$ annihilation dominance.

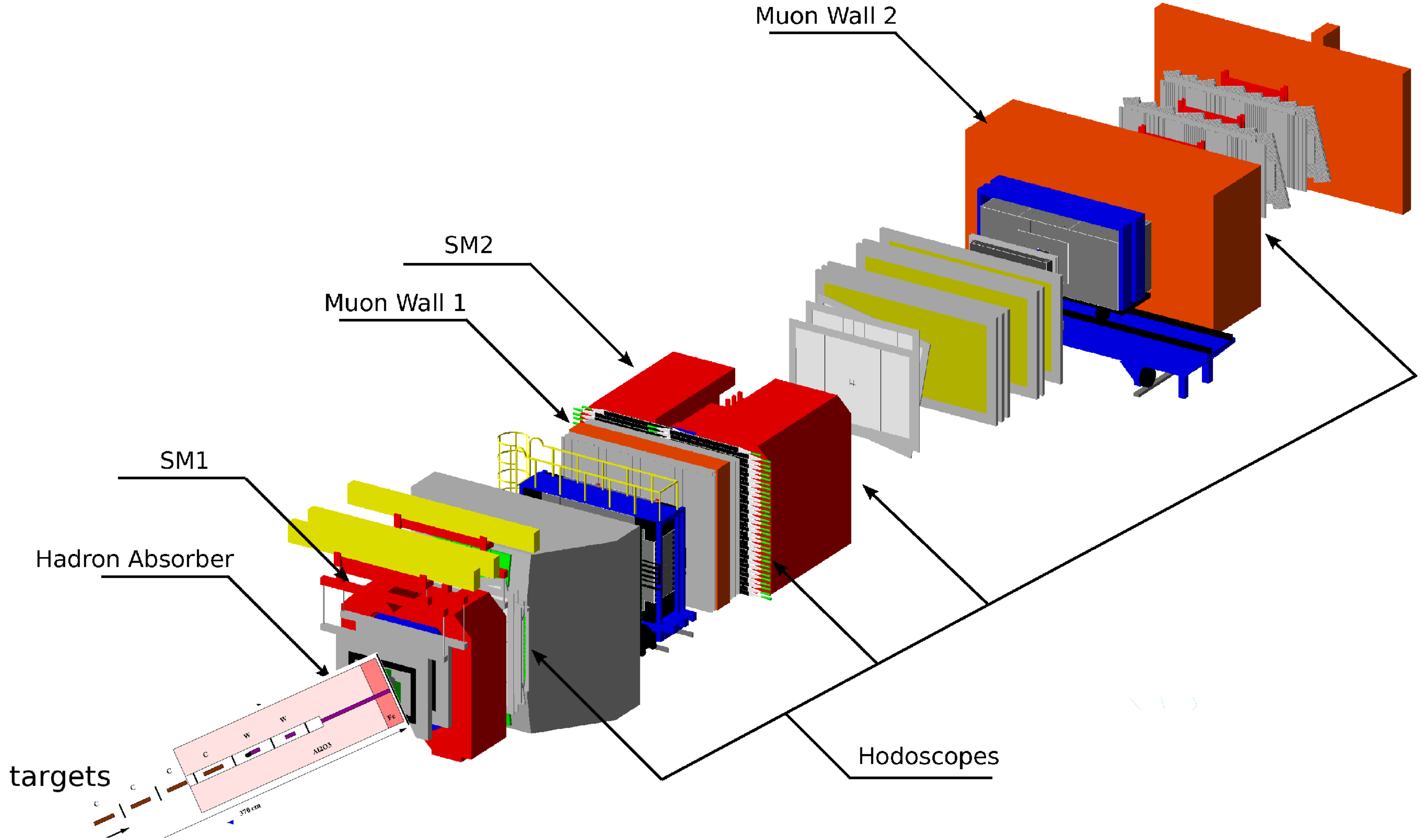
charmonia and their polarization may shed light into production mechanisms, eventually allow separation and access the gluon distribution.

A new Drell-Yan experiment

- Both beam charges are needed
- A light isoscalar target is preferable, to avoid nuclear effects.
- DY has low cross-section (6 orders of magnitude below the hadronic cross-section) → high luminosity needed
- Lots of hadronic products flying in the forward direction → need a hadron absorber, to keep the spectrometer at reasonable occupancies

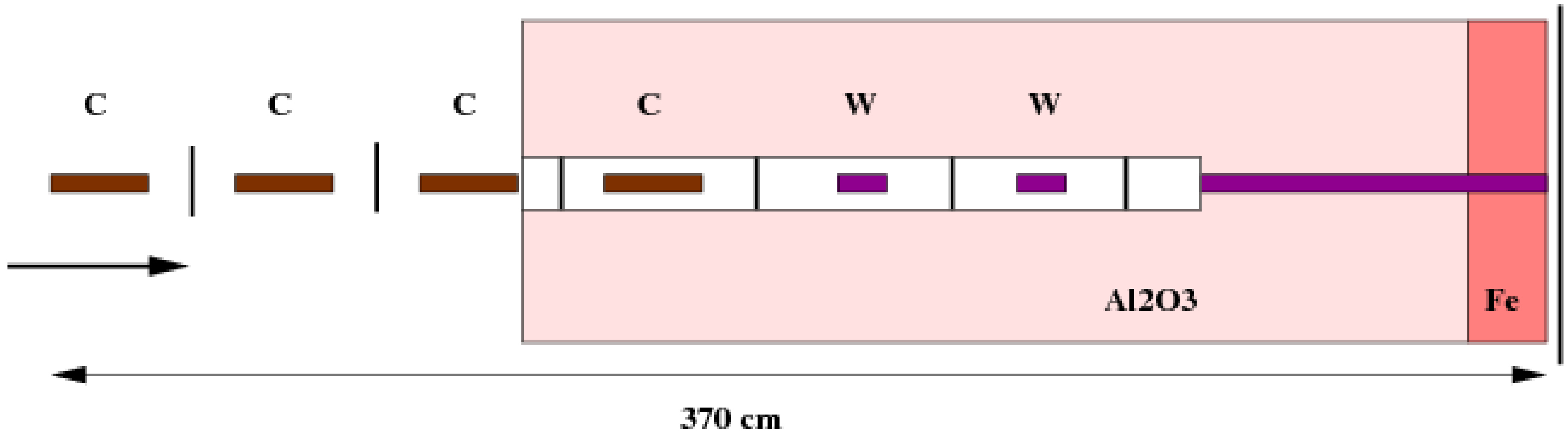
  ↪ preferably an **active absorber**
- As large acceptance as possible – keep first part of spectrometer compact
- Good beam particle identification is mandatory

First step: addressing pion structure



COMPASS-like. Only target and absorber are modified.

Target: possible design



The nuclear effects of $u_v(x)$ in Carbon are very **small**:

⇓

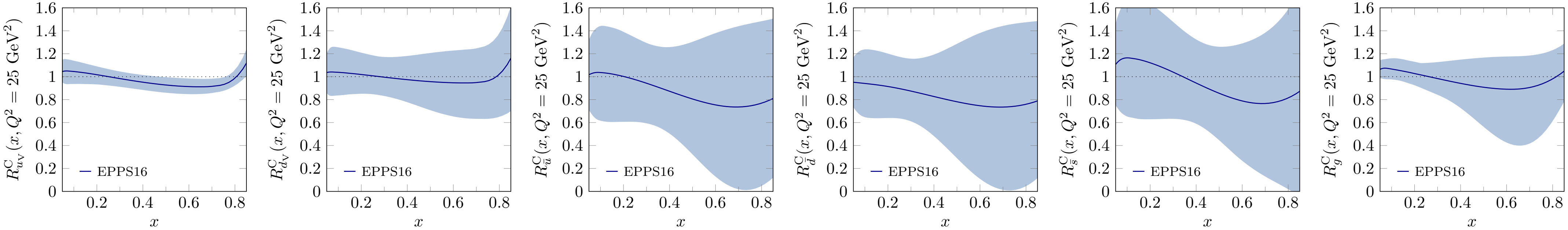


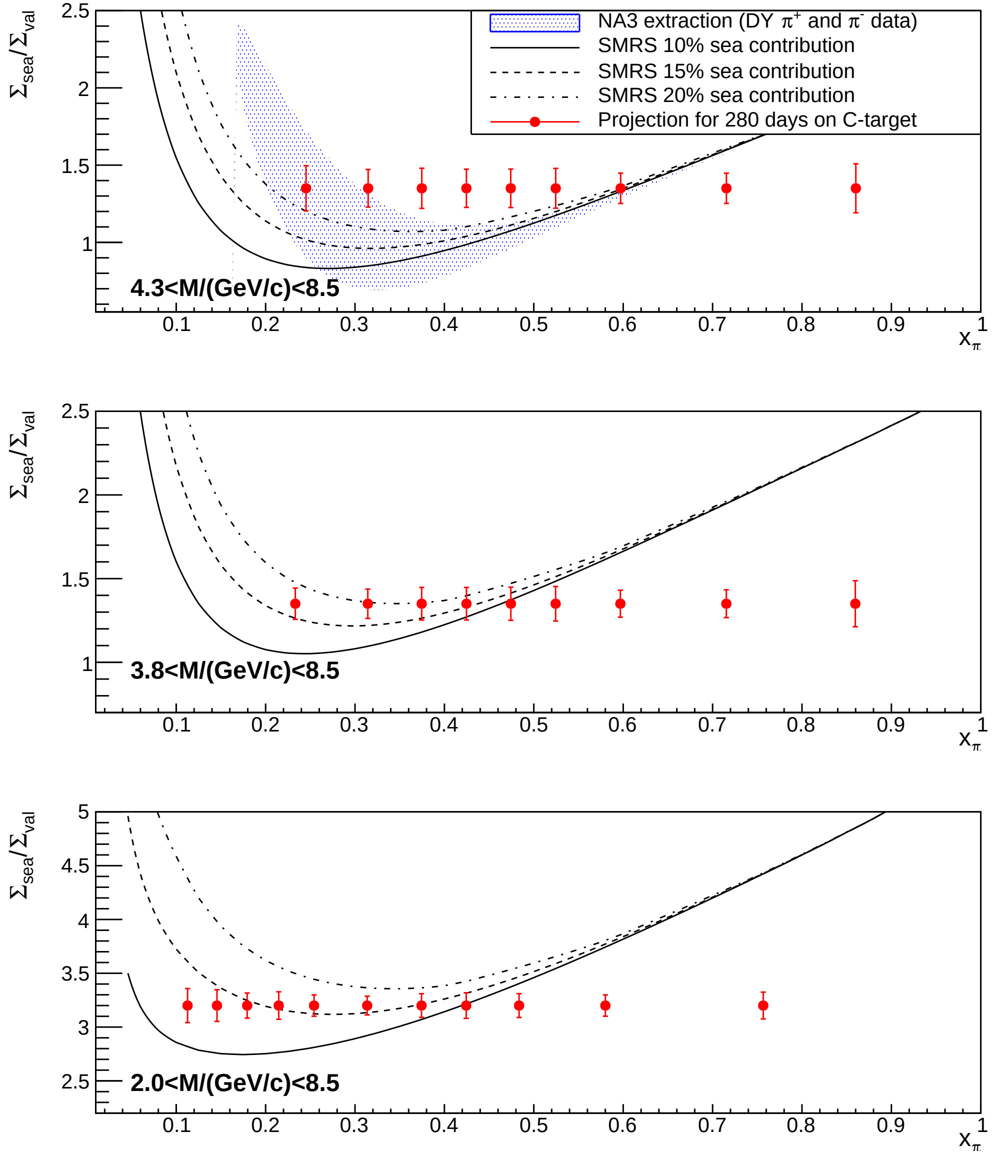
Figure provided by P. Paakkinen, EPPS16

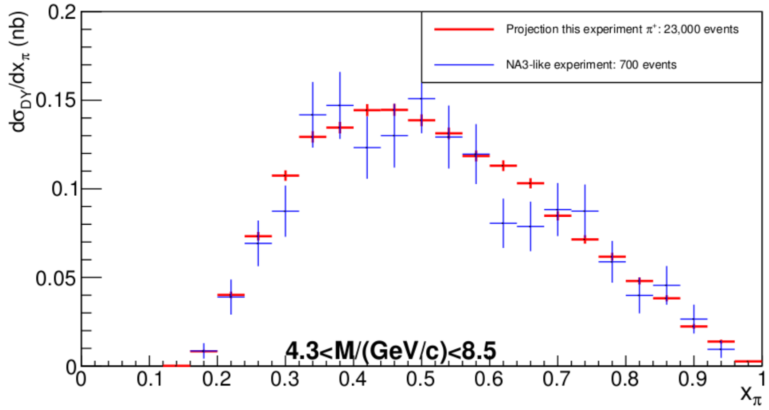
Expected statistics

Experiment	Beam type (GeV)	Beam intensity (part/sec)	Target type	DY mass (GeV/c^2)	DY events
This exp	π^+ 190	1.7×10^7	100cm C	$4.3 - 8.5$	23000
				$3.8 - 4.3$	14000
				$2.0 - 3.8$	133000
This exp	π^- 190	6.8×10^7	100cm C	$4.3 - 8.5$	22000
				$3.8 - 4.3$	12000
				$2.0 - 3.8$	127000
This exp	π^+ 190	0.2×10^7	24cm W	$4.3 - 8.5$	7000
				$3.8 - 4.3$	4000
				$2.0 - 3.8$	40000
This exp	π^- 190	1.0×10^7	24cm W	$4.3 - 8.5$	6000
				$3.8 - 4.3$	3000
				$2.0 - 3.8$	39000

- Consider 255 days with π^+ beam and 25 days with π^- beam
- Assumed efficiencies similar to those in COMPASS measurements, CEDAR efficiency 90%.
- positive hadron beam: 73% p; 24% π^+; 3% K$^+$
- negative hadron beam: 97% π^-; 2.5% K$^-$; $< 1\%$ $\bar{p}$
- DY in extended mass ranges: events weighted by their signal probability, as given by neural network / machine learning techniques (assumed efficiency of 80%)

New DY experiment: pion sea to valence ratio





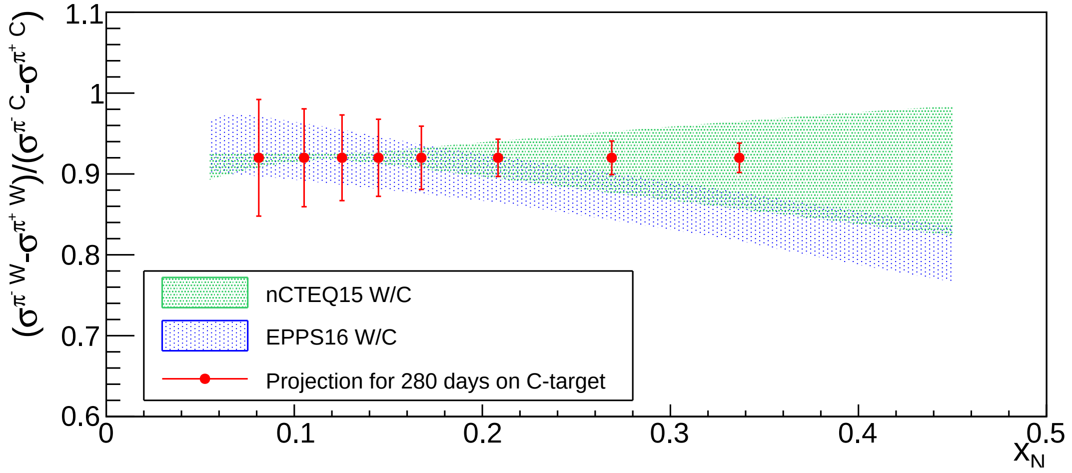
- Collect at least a factor 10 more statistics than presently available
- Minimize nuclear effects on target side
  - Projection for 2 years of Drell-Yan data taking
  - π^+ to π^- 10:1 time sharing
  - 190 GeV beams on Carbon target $(1.9\lambda_{int}^{\pi})$

Contribution to nuclear PDFs

EPPS16: nuclear PDF effects from global fits, including new data on pion-induced DY, neutrino DIS, and LHC p+Pb dijet, W and Z production.

P. Paakkinen et al, arXiv:1612.05741v1

- No tension in the fit when pion-induced DY data is added.
- But: the statistical weight of these data is not enough to add significant additional constraints to the nuclear PDFs.
- COMPASS data may contribute
- **The new experiment may have a large impact**

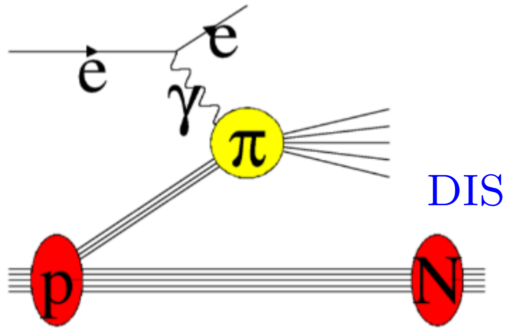


Summarizing: the pion case

- The key point: to have an adequately balanced sample of π^+ and π^- induced Drell-Yan events.
- Second key point: reliable and efficient beam PID
- Extract valence and sea pion structure functions from the combinations of cross-sections – using the carbon target: isoscalar, small nuclear effects.
- J/ψ cross-section, using DY setup and pion beam – learn about mechanism
- Extract the gluon structure function from the dedicated prompt photons measurement – different setup, no absorber, probably to be done in a second phase.
- Drell-Yan cross-sections with tungsten target – input for nuclear PDFs

Competition: pion structure at JLab 12 and EIC

At 12 GeV JLab, access **pion form factor** F_π: the electron beam can probe the **pion cloud** of the proton, at $Q^2 = 5 - 10$ GeV^2 – experiment approved for 2018/2019



DIS - Sullivan process

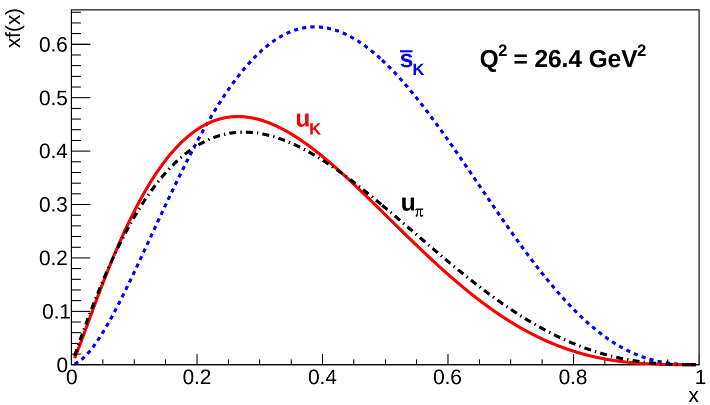
At EIC, apply the same idea to access the pion structure function, down to very low $x_\pi \approx 0.01$

The same process was already used at HERA to reach F_2^π at even lower x_π

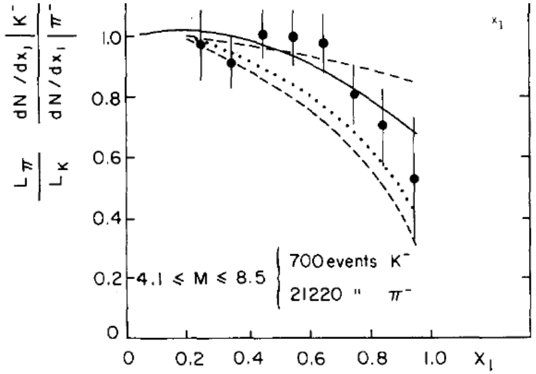
see Tanja Horn talk

Second step: kaon structure

Heavier s-quark $\Longrightarrow$ different valence distribution: $\int V^K(x_1) > \int V^\pi(x_1) \Longrightarrow$ **much less glue carried by the kaons than by pions**.

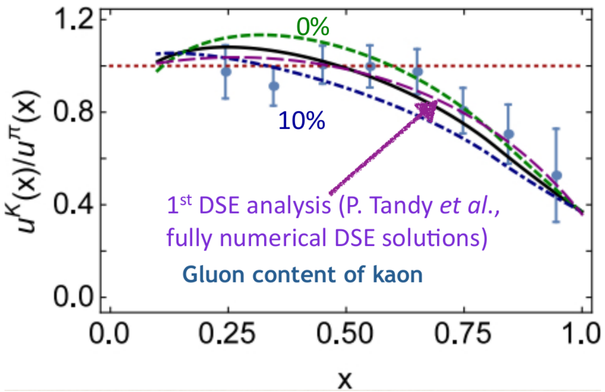


Expectation using Dyson-Schwinger Eq. framework



NA3, Phys.Lett.B 93 (1980) 354

The DSE prediction from C. Chen et al., PRD 93 074021, 2016 indicates the best fit to data is for gluons in kaon to carry 5% of momentum only $\rightarrow$

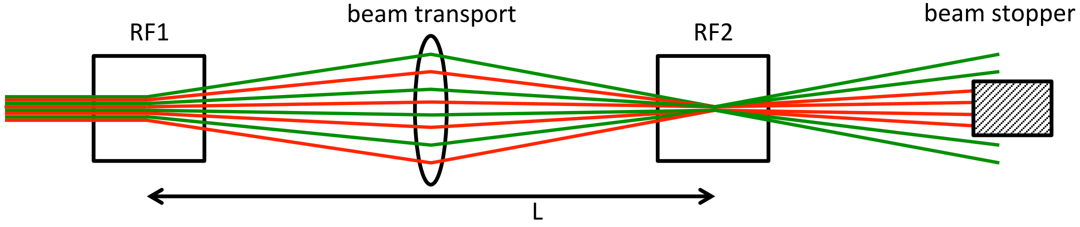


K^+-induced DY cross-section: no valence-valence terms

$$\Sigma_{val} = \sigma^{K^- C} - \sigma^{K^+ C} \qquad R_{s/v} = \sigma^{K^+ C}/\Sigma_{val}$$

Kaon beams

High intensity kaon beam required $\Longrightarrow$ Radio-Frequency separated beam



see Johannes Bernhard talk

- At least 2 RF-cavities required. The frequency of existing cavities limits the beam energy to ≈100 GeV

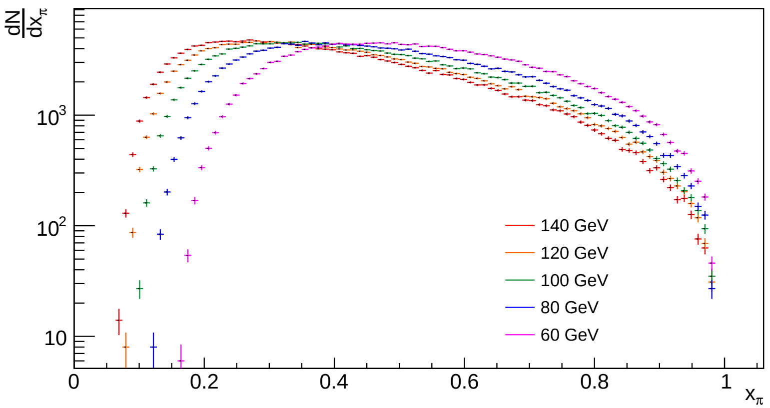
- Beam will not be pure. In the 7×10^7 had/s of the beam at the experiment, expect 30-50% kaon purity.

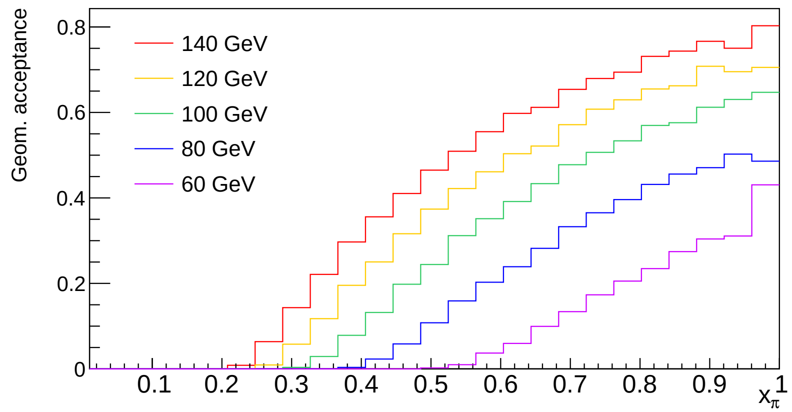
- Lower beam energy $\Longrightarrow$ for a DY geometrical acceptance ≈40% we need to cover 250 mrad.

$\hookrightarrow$ **new detector concept**

Kaon/pion beam energy and dimuons acceptance

Pion case shown here. Identical behavior for kaons is expected.



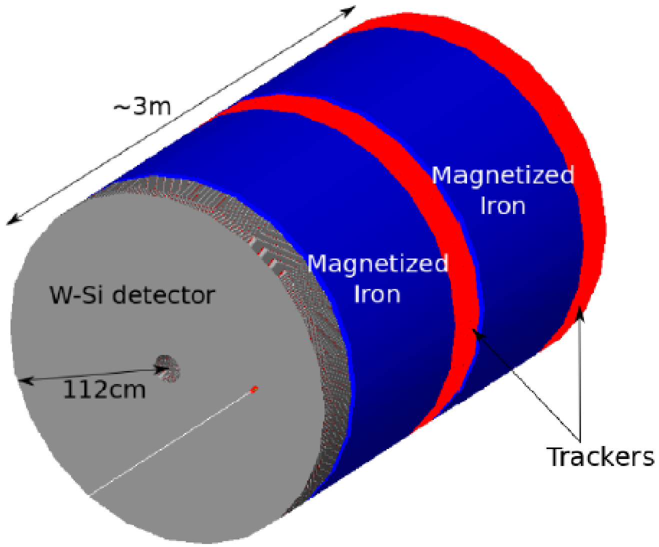


- larger beam energy means larger DY cross-section
- larger beam energy means access to lower x_K

$\hookrightarrow$ But, at the moment, the RF separation technique may work for kaon beam $\approx$ 80 GeV, at most.

A new detector concept

Keep the spectrometer as compact as possible by having **a muons detector that is also stopping hadronic products**, immersed in a magnetic field.



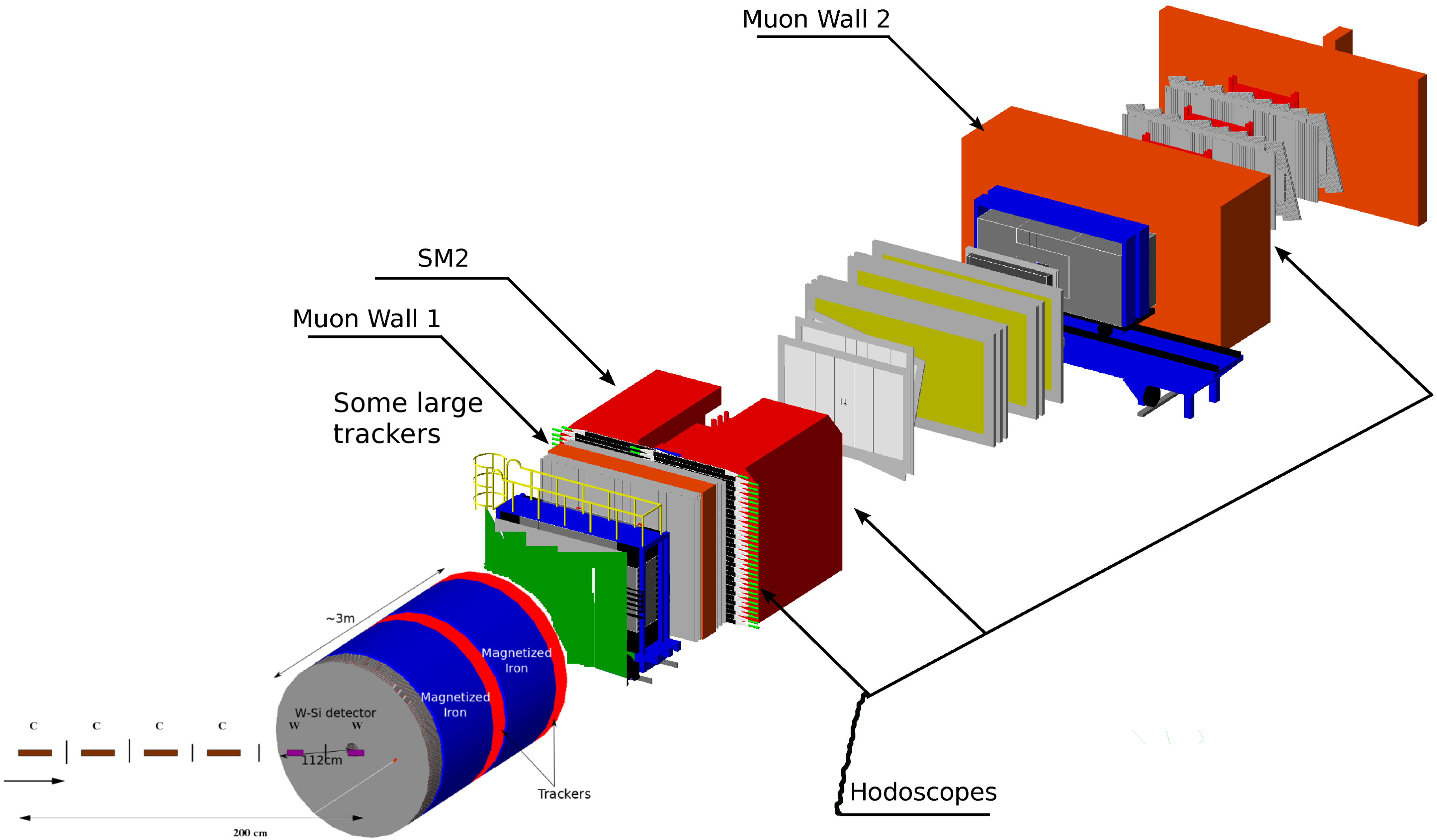
Inspired in:

- BabyMIND detector,
M. Antonova et al., arXiv:1704.08079

- W-Si detectors, as at BNL AnDY and PHENIX detectors

- muon tracker with good (x,y) resolution
- large acceptance: > 250 mrad
- momentum measurement
- capable of detecting also DY e^+e^- pairs $\Rightarrow$ **double statistics**
- compact, with large X/X0

Tentative setup



Expected statistics

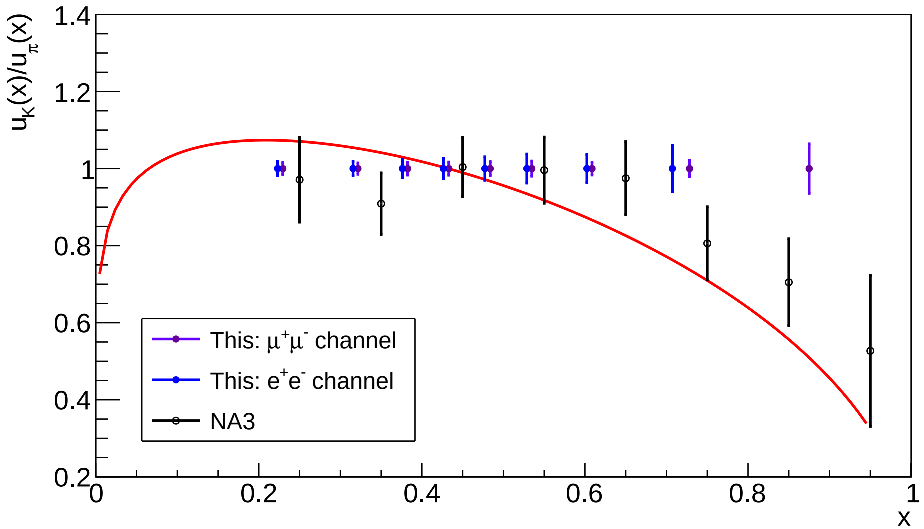
Experiment	Target type	Beam type	Beam intensity (part/sec)	Beam energy (GeV)	DY mass (GeV/c^2)	DY events $\mu^+\mu^-$	DY events e^+e^-
NA3	6cm Pt	K$^-$	1.6×10^6	150	4.1 – 8.5	700	0
This exp.	100cm C	K$^-$	2.1×10^7	80	4.0 – 8.5	25,000	13,700
				100		40,000	17,700
				120		54,000	20,700
		K$^+$	2.1×10^7	80	4.0 – 8.5	2,800	1,300
				100		5,200	2,000
				120		8,000	2,400
This exp.	100cm C	π^-	4.8×10^7	80	4.0 – 8.5	65,500	29,700
				100		95,500	36,000
				120		123,600	39,800

Assuming 140 days for each beam charge and realistic efficiencies.

This 1:1 time sharing is optimal for: good valence extraction, but still manage some sea-valence separation.

A time sharing 3:1 would be the best for optimal sea-valence separation.

Precision on valence kaon/pion ratio



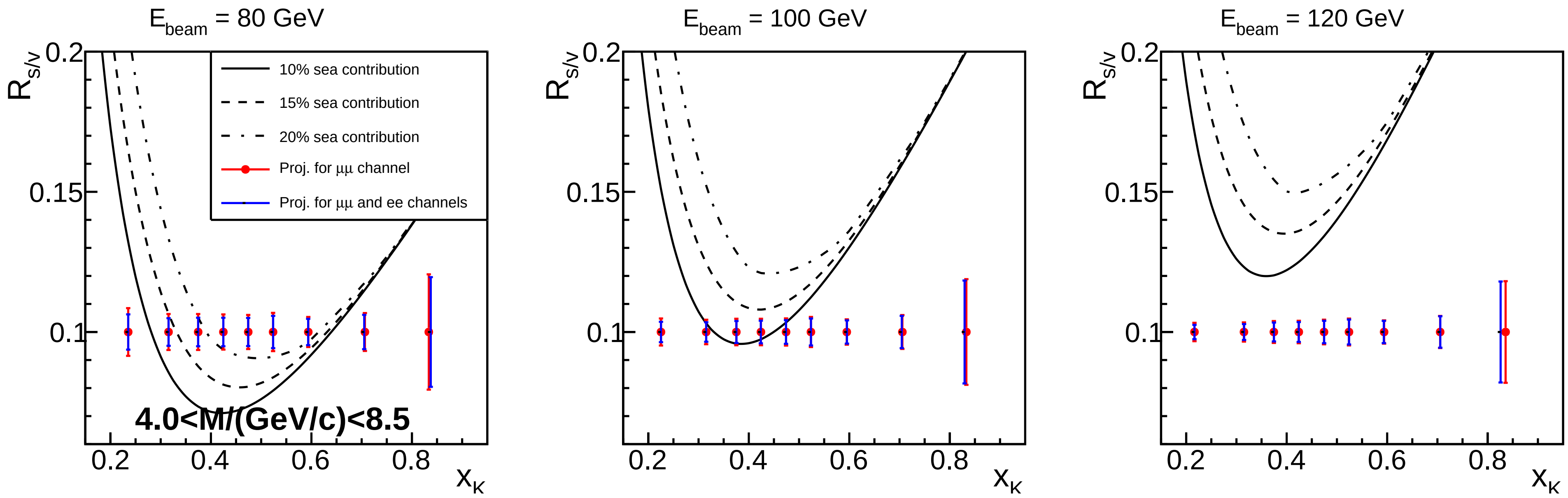
• • 140 days of K^- beam of 100 GeV momentum

line: DSE prediction, following C. Chen et al., PRD 93 074021, 2016

- Discriminating power between the existing kaon models

Kaon valence-sea separation

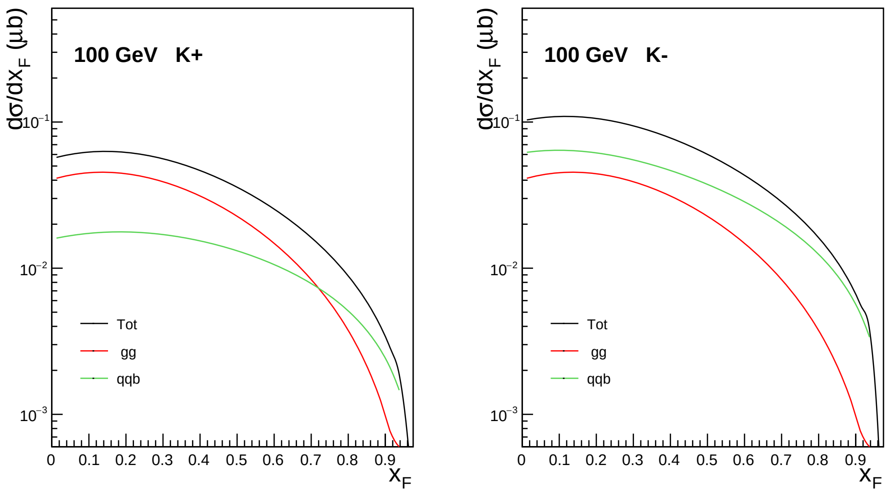
A **first ever** measurement



2 years measurement, 140 days for each kaon beam charge, with intensity 2×10^7 kaons/second

J/ψ production: a look at the kaon gluon distribution

with Color Evaporation Model



While the gg contribution is the same for the 2 kaon beam charges, there is a factor 3 difference for the $q\bar{q}$ contribution. Thus:

$$\bar{u}^K u^N \propto \sigma^{K}_{J/\psi} - \sigma^{K^+}_{J/\psi}$$

From the knowledge of valence, within a given model we extract the $g^K g^N$ term.

Summarizing: the kaon case

- The key point: high intensity kaon beam – RF-separation makes it possible
- Second key point: new paradigm of Drell-Yan detector – a mini-spectrometer active absorber all-in-one
- Valence and sea kaon structure functions extracted from combinations different charge DY cross-sections
- In 2 years time, precision close to that of pions can be achieved.
- If only 1 year: precise extraction of valence; sea-valence separation in kaon at same level as NA3 for pions.
- Independent access to u_v^K from J/ψ production – and model dependent first look at the kaon gluon distribution

Third step: spin physics with antiproton beam

The main uncertainty to access the proton TMD PDFs from COMPASS single spin asymmetries is that they come convoluted with pion TMD PDFs.

$\hookrightarrow$ **Single polarized Drell-Yan with antiproton beam** is cleaner

$$\frac{d\sigma}{dq^4 d\Omega} \propto \hat{\sigma}_U \Big\{ 1 + D_2 A_U^{\cos 2\phi} \cos 2\phi + S_T \Big[D_1 A_T^{\sin\phi_S} \sin\phi_S + \\ + D_2 \Big(A_T^{\sin(2\phi-\phi_S)} \sin(2\phi - \phi_S) \qquad + A_T^{\sin(2\phi+\phi_S)} \sin(2\phi+\phi_S) \Big) \Big] \Big\}$$

- $A_U^{\cos 2\phi}$: $h_1^{\perp}(x_2, k_{T2}) \otimes \bar{h}_1^{\perp}(x_1, k_{T1})$
- $A_T^{\sin\phi_S}$: $f_1(x_2, k_{T2}) \otimes \bar{f}_{1T}^{\perp}(x_1, k_{T1})$
- $A_T^{\sin(2\phi-\phi_S)}$: $h_1^{\perp}(x_2, k_{T2}) \otimes \bar{h}_1(x_1, k_{T1})$
- $A_T^{\sin(2\phi+\phi_S)}$: $h_1^{\perp}(x_2, k_{T2}) \otimes \bar{h}_{1T}^{\perp}(x_1, k_{T1})$

5 "unknown" functions and 4 modulations from DY data. But on $f_1(x_2, k_{T2})$ we have some knowledge

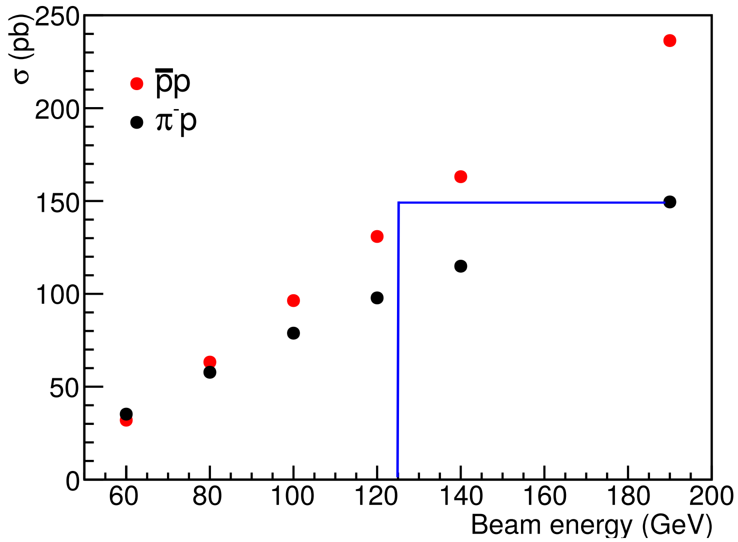
RF-separated antiproton beam

Same limitations as with RF-separated beam:

- beam momentum $\approx$ 110 GeV, at most
- Purity of 30-50% – antiprotons come mixed with pions

$\Longrightarrow$ **transversely polarized protons** using a NH_3 COMPASS-like target

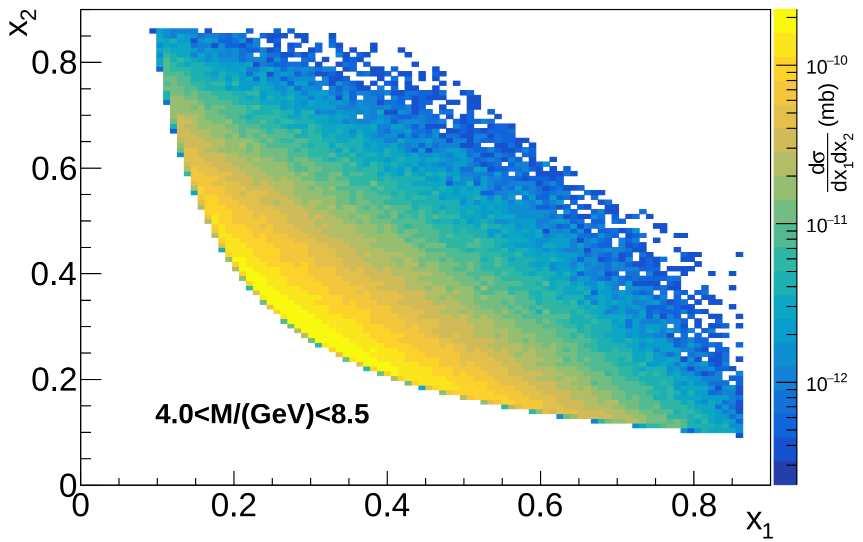
Use a mini-spectrometer active absorber, to access Drell-Yan $\mu^+\mu^-$ and e^+e^-

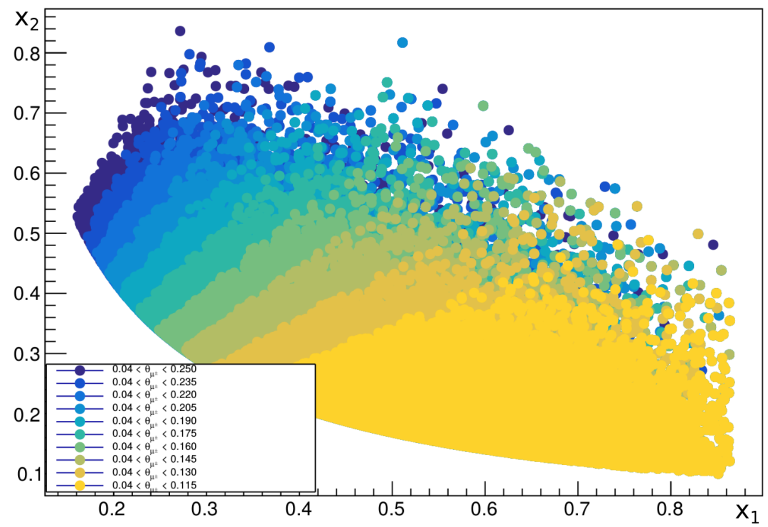


With antiproton beam at these energies one gets in the most favorable region to access valence distributions.

$\leftarrow$ For the same beam energy, the Drell-Yan cross-section is higher with antiproton beam than with pion beam (3 quarks vs 2 quarks)

Phase-space coverage and statistics





By extending the acceptance to larger muon angles one accesses lower x_1

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		40,000	27,300
				140		52,000	32,500

Expected in 140 days. Realistic efficiencies used.

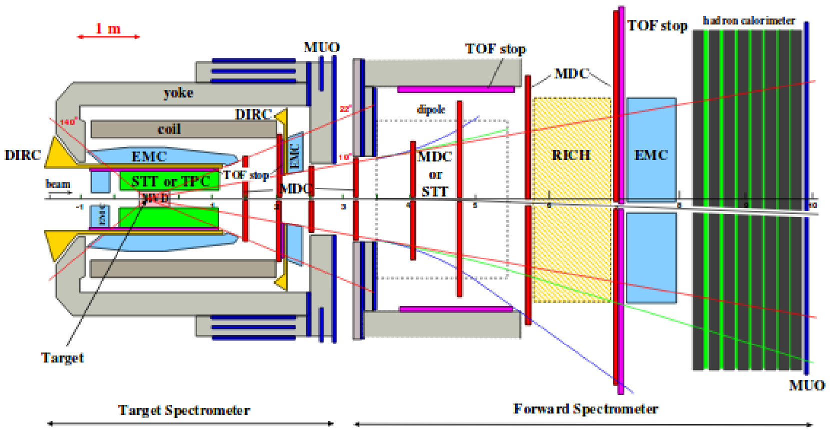
Summarizing: the antiproton case

- The key point: high intensity antiproton beam – RF-separation makes it possible
- Second key point: a new mini-spectrometer-active-absorber and a COMPASS-like transversely polarized target
- Measurement of transverse spin asymmetries. Statistical accuracy can be improved by event-weighting with use of signal probability given by neural network/machine learning techniques
- Best control of systematic uncertainties – analysis not dependent of outside input.
- Optimal access to TMD PDFs of the nucleon

Competition: Drell-Yan measurements at PANDA

The PANDA experiment at FAIR plans to study antiproton-induced Drell-Yan, in the dimuon mass range 1.5 - 2.5 GeV, in order to measure transverse spin asymmetries.

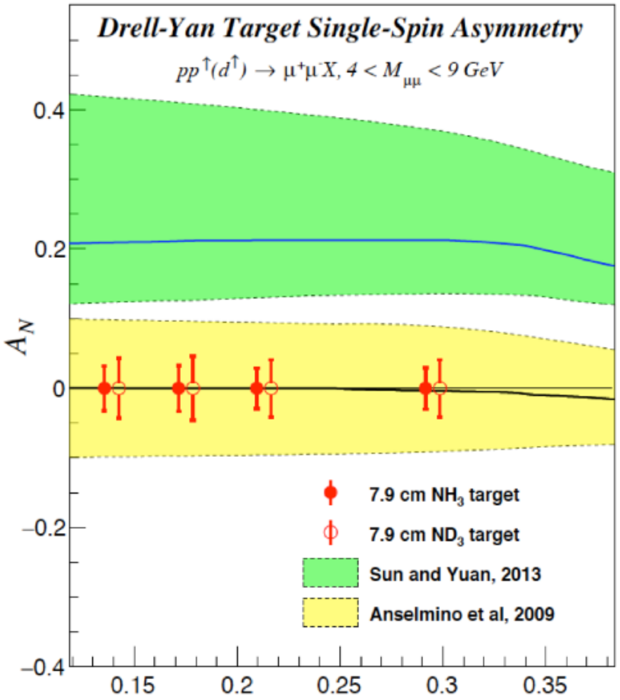
With maximum $\sqrt{s} = 5.5$ GeV, an internal polarized gas target could be used, in high luminosity mode: up to 2×10^{32} cm^{-2} s^{-1}. In these conditions, 130,000 Drell-Yan events are expected per month.



$\hookrightarrow$ Very challenging measurement, since enourmous background – a reduction factor of 10^7 is required.

Competition: E-1039 at Fermilab

The SeaQuest experiment is going to proceed, with the E-1039 proposal: a polarized fixed target pp experiment, to study transverse spin asymmetries.



Statistics achievable in 2 years of running: factor ≈4 larger as compared to COMPASS 2015+2018

Commissioning by the Fall 2018. Data taking could follow from Winter 2018 to 2020, but financing is not clear.
(P. Reimer, ECT* Workshop on dimuon production, 09/11/2017)

Competition: SPD experiment at NICA

SPD @ NICA is a **polarized** ***pp*** **collider experiment** dedicated to nucleon spin structure studies from the Drell-Yan process.

Measurement of transverse spin asymmetries contain only sea-valence and sea-sea TMD PDF convolution terms.

NICA-SPD Letter of Intent, LoI, 02/06/2014

Experiment	CERN, COMPASS-II	FAIR, PANDA	FNAL, E-906	RHIC, STAR	RHIC-PHENIX	NICA, SPD
mode	*fixed target*	*fixed target*	*fixed target*	*collider*	*collider*	*collider*
Beam/target	*π- , p*	*anti-p, p*	*π- , p*	*pp*	*pp*	*pp, pd,dd*
Polarization:b/t	*0; 0.8*	*0; 0*	*0; 0*	*0.5*	*0.5*	*0.9*
Luminosity	$2\cdot10^{33}$	$2\cdot10^{32}$	$3.5\cdot10^{35}$	$5\cdot10^{32}$	$5\cdot10^{32}$	10^{32}
√s , GeV	*14*	*6*	*16*	*200, 500*	*200, 500*	*10-26*
$x_{1(beam)}$ *range*	*0.1-0.9*	*0.1-0.6*	*0.1-0.5*	*0.03-1.0*	*0.03-1.0*	*0.1-0.8*
q_T*, GeV*	*0.5 -4.0*	*0.5 -1.5*	*0.5 -3.0*	*1.0 -10.0*	*1.0 -10.0*	*0.5 -6.0*
Lepton pairs,	*μ-μ+*	*μ-μ+*	*μ-μ+*	*μ-μ+*	*μ-μ+*	*μ-μ+, e+e-*
Data taking	*2014*	*>2018*	*2013*	*>2016*	*>2016*	*>2018*
Transversity	NO	NO	NO	YES	YES	YES
Boer-Mulders	YES	YES	YES	YES	YES	YES
Sivers	YES	YES	YES	YES	YES	YES
Pretzelosity	YES (?)	NO	NO	NO	YES	YES
Worm Gear	YES (?)	NO	NO	NO	NO	YES
J/Ψ	YES	YES	NO	NO	NO	YES
Flavour separ	NO	NO	YES	NO	NO	YES
Direct γ	NO	NO	NO	YES	YES	YES

Summary

The potential of the Drell-Yan process to access hadron structure, namely in the valence region, is enormous:

- COMPASS is presently accessing the TMD PDFs of the nucleon
- COMPASS measurements of the Drell-Yan and J/ψ differential cross-sections will certainly have important impact
  - pion valence structure function
  - charmonium production mechanism
  - constraints to nuclear PDFs

- A future Drell-Yan experiment is proposed, to study meson structure.
- New, precise determination of the pion structure functions: valence, sea and gluon contributions.
- The first-ever determination of the kaon structure, making use of RF-separated kaon beam of high intensity.
- A unique opportunity to make antiproton-induced Drell-Yan with transversely polarized proton target, and measure TSAs with significantly reduced systematic error.

Thank you!

SPARE: Alternatives excluded

liquid deuterium target

material	liq D_2
Z	1
A	2.01 g/mol
λ^{π}_{int}	672.3 cm
density	0.1638 g/cm^3
length	200 cm
configuration	1 × 200 cm
effective length	173 cm

Beam (GeV/c, /sec)	Target type	DY mass (GeV/c^2)	DY events
π^+ 190, 1.7×10^7	200cm D_2	4.3 – 8.5	7000
		3.8 – 4.3	4000
		2.0 – 3.8	40000
π^- 190, 6.8×10^7	200cm D_2	4.3 – 8.5	7000
		3.8 – 4.3	3000
		2.0 – 3.8	38000

^{6}LiD target

material	^{6}LiD
Z	2.47
A	4.93 g/mol
λ^{π}_{int}	232 cm
density	0.462 g/cm^3
length	110 cm
configuration	1 × 110 cm
effective length	87.6 cm

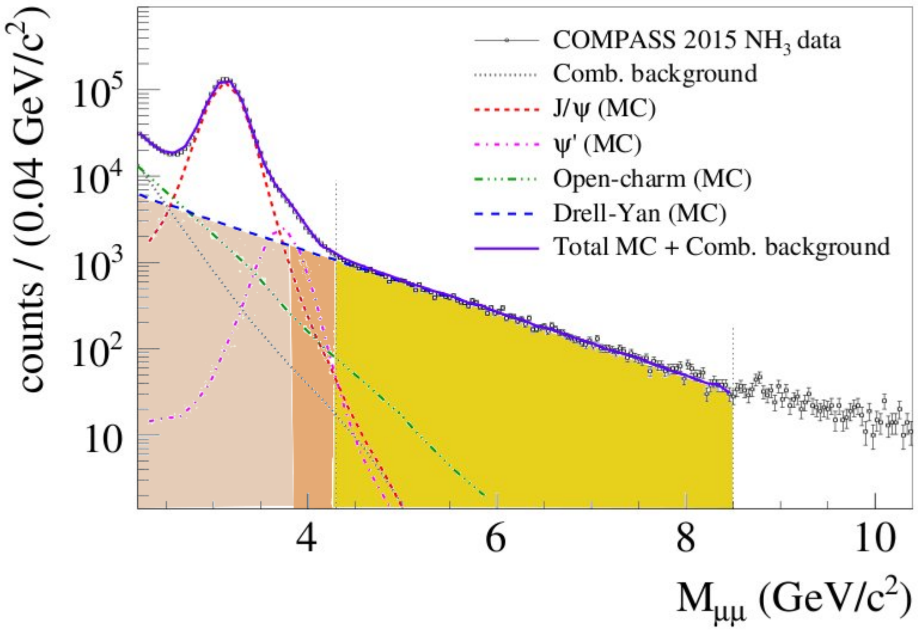
Beam (GeV/c, /sec)	Target type	DY mass (GeV/c^2)	DY events
π^+ 190, 1.7×10^7	110cm ^{6}LiD	4.3 – 8.5	9000
		3.8 – 4.3	5000
		2.0 – 3.8	51000
π^- 190, 6.8×10^7	110cm ^{6}LiD	4.3 – 8.5	8000
		3.8 – 4.3	4000
		2.0 – 3.8	49000

SPARE: separating signal from background

One main difficulty with Drell-Yan is the **scarce statistics**: up to now, isolating DY events from background required $4.3 < M_{\mu\mu} < 8.5$ GeV.

With adequate multivariate input, a **machine learning technique** can be used to clusterize data of similar behavior.

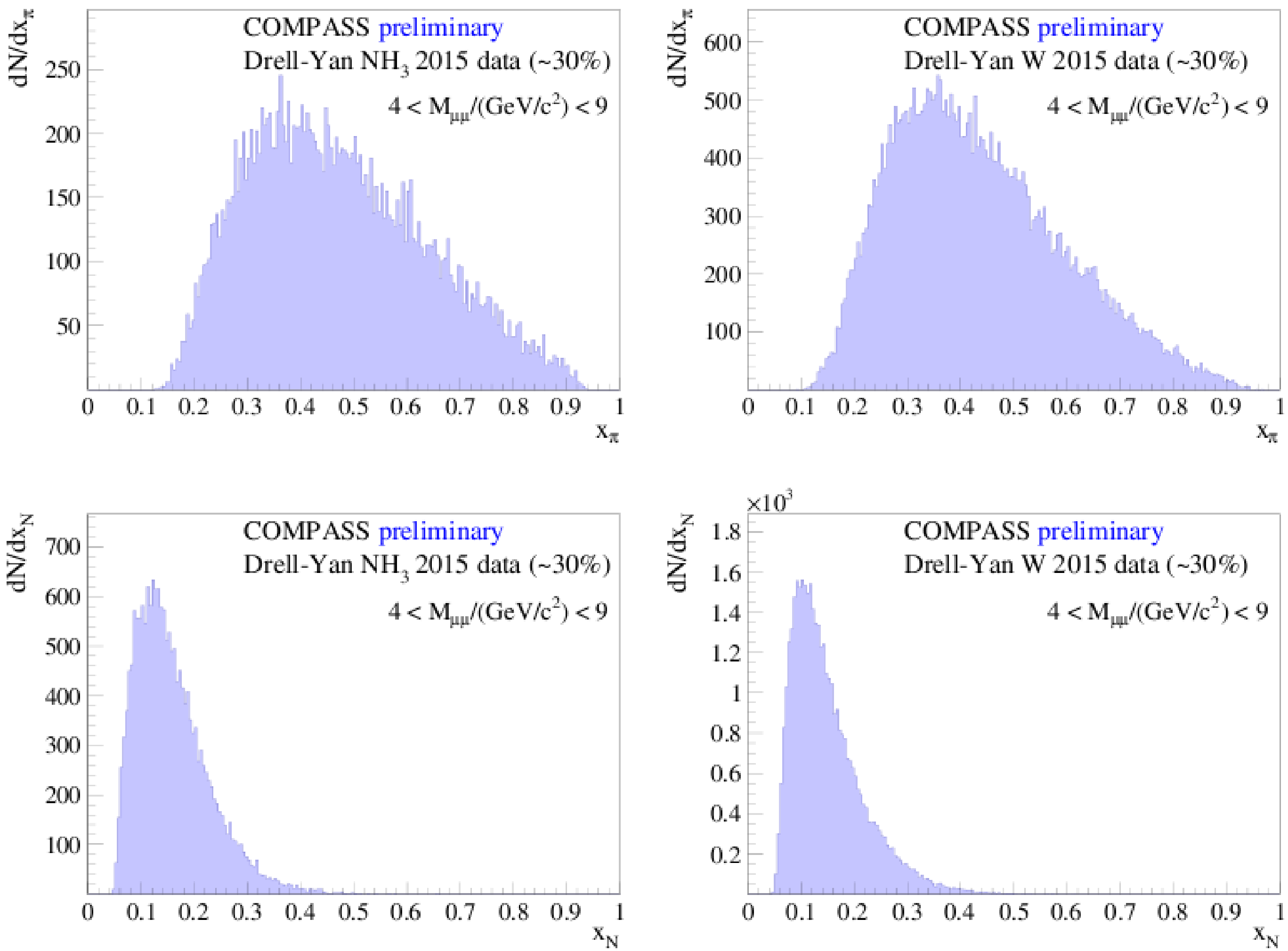
These clusters are used to train a deep neural network that attributes a probability for each event to be signal – as done in past COMPASS analyses.



↪Access to Drell-Yan in regions with background contamination

- $4.3 < M < 8.5$ GeV: standard Drell-Yan pure range
- $3.8 < M < 4.3$ GeV
- $2.0 < M < 3.8$ GeV

SPARE: COMPASS coverage



35 000 DY events from NH_3 15 000 DY events from W

SPARE: Absorber and spectrometer

experiment	Beam/tgt	I_{beam} (/s)	Absorber (cm)	λ^{π}_{int} (abs)	θ_{scat}	Accept (%)
E615	π^- 252/20cm W	20×10^7	110 BeO +322 Be+412 C	15.99	0.131/p	4
NA3	π^- 200/6cm Pt	3×10^7	150 Fe	7.34	0.208/p	20
NA10	π^- 194/12cm W	65×10^7	320 C+160 Fe	13.84	0.232/p	10
COMPASS	π^- 190/110cm NH3	7×10^7	36Al+200Al_2O_3+20Fe	7.83	0.141/p	40
New exp	π^- 190/100cm C	7×10^7	240Al_2O_3+20Fe	8.35	0.146/p	43
New exp	π^- 190/24cm W	1×10^7	130Al_2O_3+20Fe	6.03	0.172/p	46

- A dimuon trigger based on hodoscopes, charge symmetric, and with target pointing capability
- A beam telescope including a new detector for luminosity measurement with precision ≈3%
- Very good **beam PID**, provided by CEDARs standing high intensity beams is essential.

  ↪ Might be achieved with the present upgrade being done to the 2 COMPASS CEDARs.

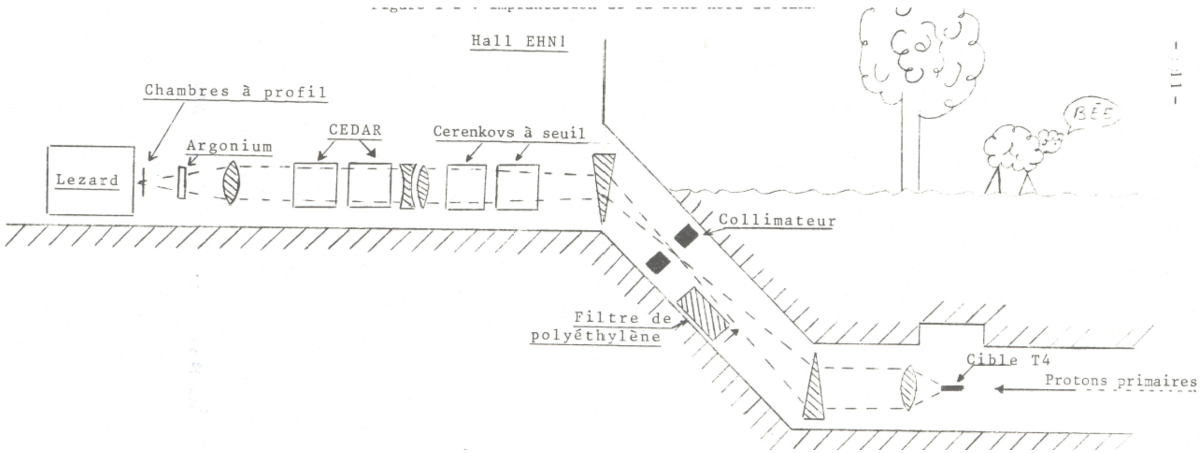
SPARE: Pion beam expected statistics

Experiment	Beam type (GeV)	Beam intensity (part/sec)	Target type	DY mass (GeV/c^2)	DY events
E615	π^+ 252	17.6×10^7	20cm W	4.05 – 8.55	5000
E615	π^- 252	18.6×10^7	20cm W	4.05 – 8.55	30000
NA3	π^+ 200	2.0×10^7	30cm H_2	4.1 – 8.5	40
NA3	π^- 200	3.0×10^7	30cm H_2	4.1 – 8.5	121
NA3	π^- 200	3.0×10^7	6cm Pt	4.2 – 8.5	4961
NA3	π^+ 200	2.0×10^7	6cm Pt	4.2 – 8.5	1767
NA10	π^- 286	65×10^7	120cm D_2	4.2 – 8.5	7800
NA10	π^- 140	65×10^7	120cm D_2	4.35 – 8.5	3200
NA10	π^- 286	65×10^7	12cm W	4.2 – 8.5	49600
NA10	π^- 140	65×10^7	12cm W	4.35 – 8.5	29300
COMPASS 2015	π^- 190	7.0×10^7	110cm NH_3	4.3 – 8.5	35000
COMPASS 2018	π^- 190	7.0×10^7	110cm NH_3	4.3 – 8.5	52000
This exp	π^+ 190	1.7×10^7	100cm C	4.3 – 8.5	23000
				3.8 – 4.3	14000
				2.0 – 3.8	133000
This exp	π^- 190	6.8×10^7	100cm C	4.3 – 8.5	22000
				3.8 – 4.3	12000
				2.0 – 3.8	127000
This exp	π^+ 190	0.2×10^7	24cm W	4.3 – 8.5	7000
				3.8 – 4.3	4000
				2.0 – 3.8	40000
This exp	π^- 190	1.0×10^7	24cm W	4.3 – 8.5	6000
				3.8 – 4.3	3000
				2.0 – 3.8	39000

*: conservative estimates

SPARE: Margin for improvements to pion measurements

- Standard beam composition is assumed up to now:
  - positive hadron beam: 73% p; 24% π^+; 3% K^+
  - negative hadron beam: 97% π^-; 2.5% K^-; $< 1\%$ $\bar{p}$
- The use of a **differential absorber** in the beam line (ex: 2 m polyethylene, as NA3) may increase the π^+ fraction of beam to 40%



$\hookrightarrow$ 55% increase in the final statistics for each beam charge

- Beam intensity limited by environmental radiation issues. With better shielding of target and absorber, the intensity could increase by a factor 4 (if primary target T6 future intensity $> 1.5 \times 10^{13}$ ppp).
- The balance between carbon events and tungsten events might be changed.