Physics with pion induced Drell-Yan at COMPASS and future experiment

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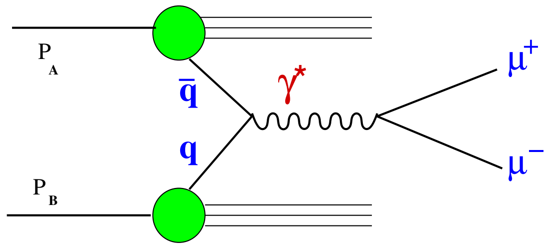
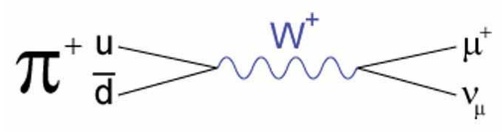
07 November 2017

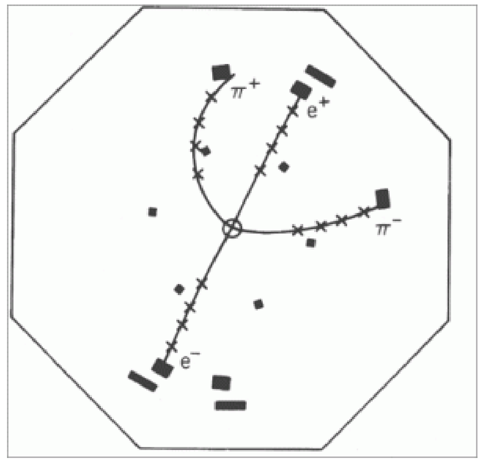
Outline



- Drell-Yan process
- Pion induced Drell-Yan
  - Why, where and how
  - Past, present and future
- Pion structure
  - Pion PDFs today
  - Pion valence and sea separation
  - Pion gluon distribution
- misterious J/ψ
- PDFs: Nuclear versus nucleon
- Designing the next-level DY Experiment

particle	valence quarks	rest mass	spin	decays
π^+	$u\bar{d}$	0.139 GeV	0	$\mu^+\nu_\mu$
π^-	$\bar{u}d$	0.139 GeV	0	$\mu^-\bar{\nu_\mu}$



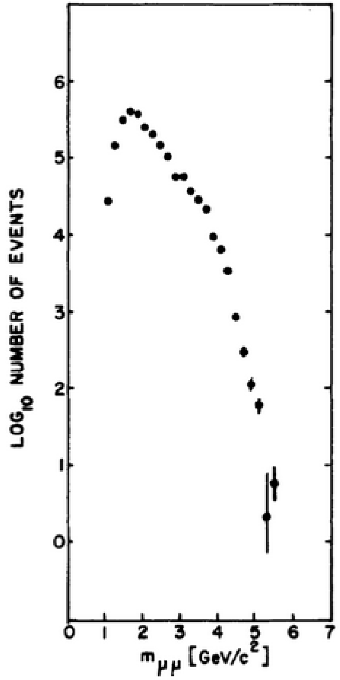


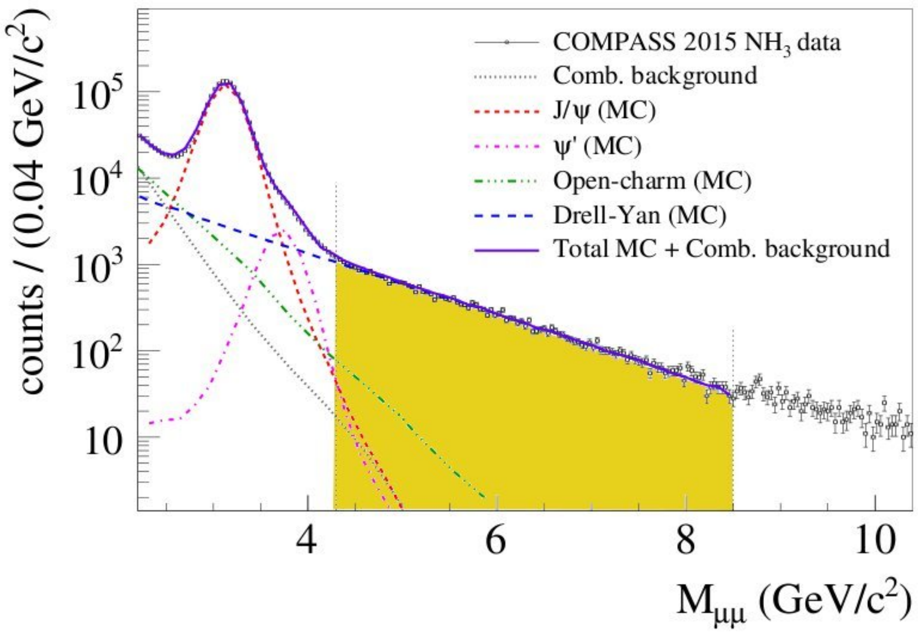
J/ψ

Drell-Yan process

Proposed in **1970** to explain the **massive dilepton spectrum** from hadronic collisions, first observed at BNL.

↪ S.D. Drell and T.M. Yan, Phys.Rev.Lett. **25**, 316 (1970)





Christenson et al, Phys.Rev.Lett. **25**, 1523 (1970)

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

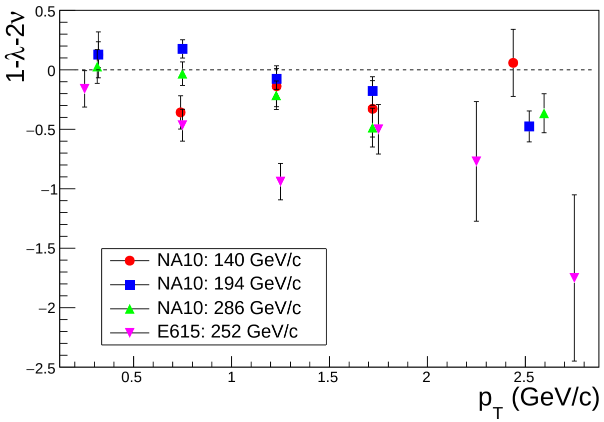
Drell-Yan: simple, but still...

Soon it was understood one needs to go beyond the naive parton model picture, and include QCD effects of gluon emission/absorption/scattering to fix problems:

- Too large experimental cross-sections: $k_{DY} \approx 2$
- Too large dileptons transverse momentum
- Strong azimuthal asymmetries

Unpolarized Drell-Yan angular distribution:

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



Lam-Tung rule violation: $\boxed{1 - \lambda - 2\nu \neq 0}$ **in π-induced DY experiments!**

Drell-Yan Generalized

At LO, the Drell-Yan process is a purely electromagnetic $q\bar{q}$ annihilation producing a γ^* that then converts into a leptons pair.

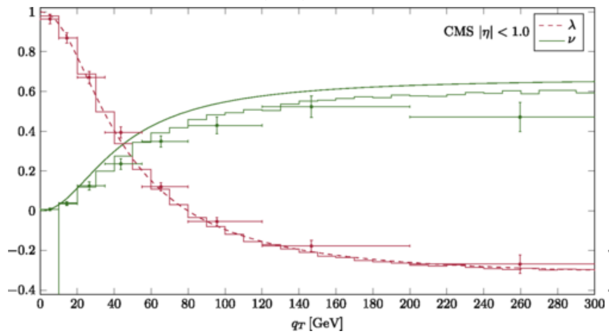
The Drell-Yan process can be generalized, to have other electroweak Gauge bosons as mediators to the $q\bar{q}$ annihilation and production of lepton pair: γ, but also Z and W.

In a collision of hadrons A and B, the leading power (first term in the expansion in powers of 1/Q) Drell-Yan cross-section can be expressed as convolutions of 2 **PDFs** (target Φ $\otimes$ beam Φ):

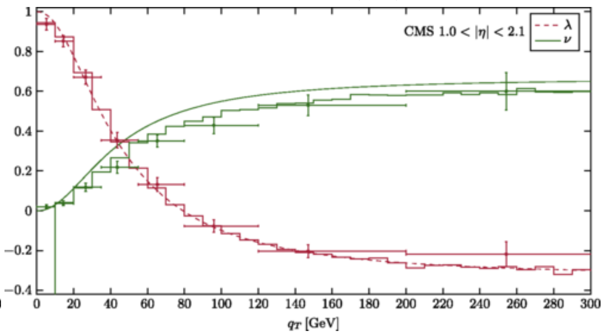
$$\frac{d\sigma^{LP}_{AB\to l\bar{l}X}}{dQ^2dy} = \sum_{ab}\int_0^1 dx_a \int_0^1 dx_b \; \Phi_a^A(x_a,\mu)\; \Phi_b^B(x_b,\mu)\; \frac{d\hat{\sigma}_{ab\to l\bar{l}}(x_a,x_b,Q,\mu)}{dQ^2dy}$$

Understanding Drell-Yan

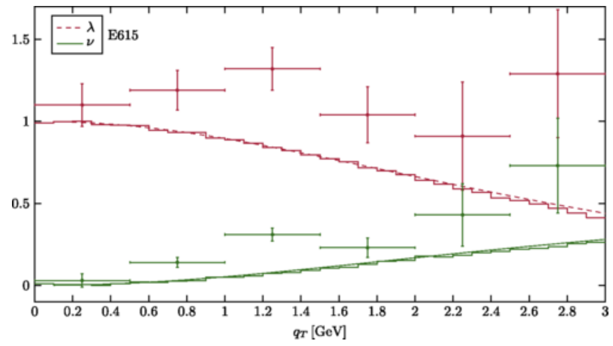
CMS: $|\eta| < 1$



CMS: $1 < |\eta| < 2.1$



E615



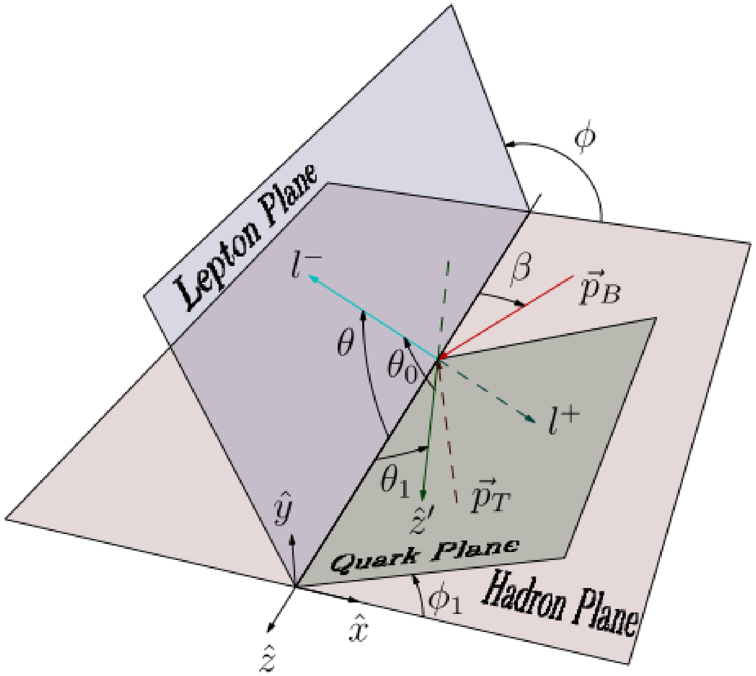
M. Lambertsen and W. Vogelsang, Phys.Rev. D **93**, 114013 (2016)

NNLO QCD corrections explain Lam-Tung violation observed at LHC energies.

To a large extent, they can also explain the observed features in pion induced DY – given the large experimental uncertainties, at least.

Understanding Drell-Yan

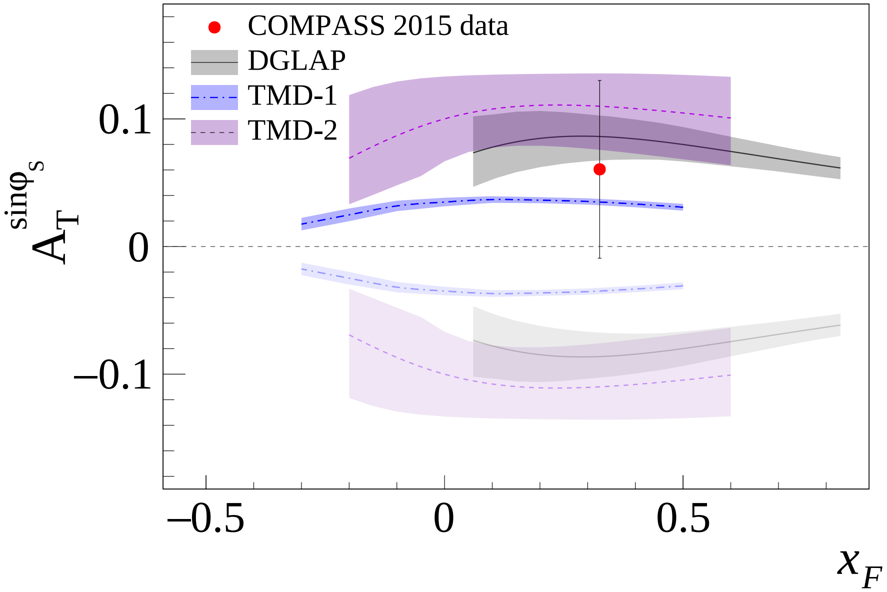
The mechanisms by which these features are generated is also understood: the non-coplanarity of the axis of the incoming partons wrt the hadron plane, due to QCD radiative effects at $O(\geq \alpha_s^2)$.



J-C.Peng, W-C. Chang, R.E. McClellan, O. Teryaev, Phys.Lett.B **758**, 384 (2016)

Drell-Yan as a tool for QCD studies

Crucial tests of non-perturbative QCD and of the important role of intrinsic transverse momentum of partons.



The predicted sign change of the Sivers TMD PDF between SIDIS and DY seems to be favoured by the COMPASS Drell-Yan data.

★ previous talk by Bakur Parsamyan

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

But other interesting possibilities at hand: **meson structure**.

Structure functions: valence and sea

- Structure functions are non-perturbative objects – need to be measured!
- They can be divided in a valence part $v(x)$ and a sea part $S(x)$.

In fixed-target pion-induced Drell-Yan we constrain mostly valence.

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

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

The gluon fraction of momentum from pion and proton, $\langle g^p \rangle$ and $\langle g^{\pi} \rangle$ can be measured from **pion-induced direct photon production or J/ψ production**.

★ monday talk, by Alexey Guskov

Structure functions: How to measure?

Pion-induced Drell-Yan, using both beam polarities, is the **most direct way** to access the pion structure: valence, sea and gluons.

In pion-induced Drell-Yan, for the **pion valence part** we assume

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

The **pion sea part** is usually assumed **SU(3) symmetric**:

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

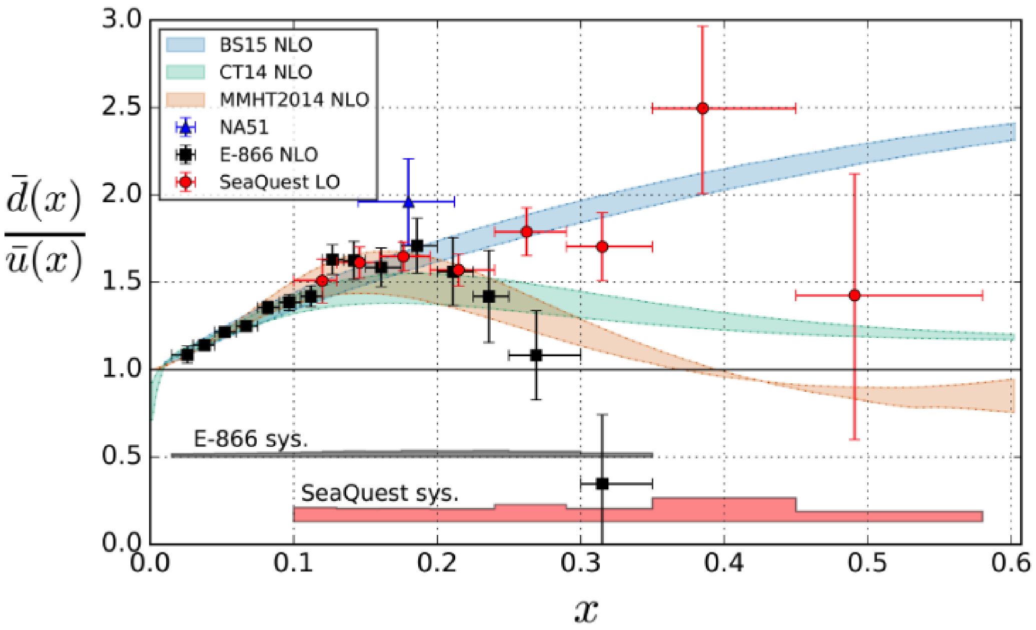
But: is it really?

The proton sea was proven not to be symmetric

The nucleon light sea

The proton light sea is not symmetric

$$\boxed{\bar{u}_s^p(x) \;<\; \bar{d}_s^p(x)}$$



↪NA51 Coll.; Phys.Lett.B **332** (1994) 244–250;

↪E866 Coll.; Phys.Rev.D **64** (2001) 052002;

↪SeaQuest (E906 Coll.), preliminary.

Pion induced Drell-Yan – Why?

- Access to the nucleon structure functions;
- complementary to DIS;
- unique way to access meson structure functions;
- access to quarks valence region

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:

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

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

★ monday talk by Stephane Platchkov

Pion induced Drell-Yan – How?

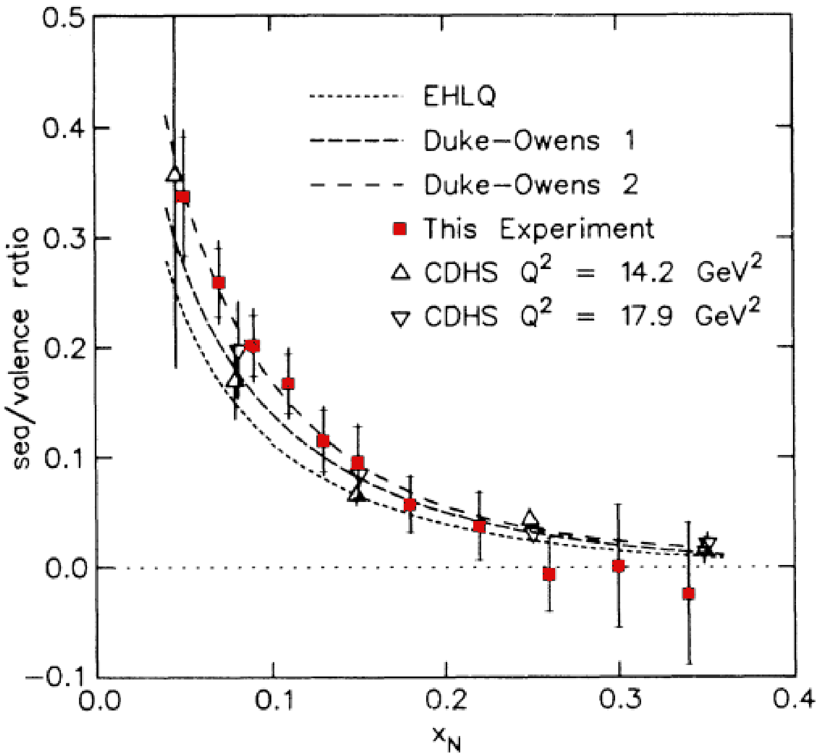
- DY has low cross-section (6 orders of magnitude below the hadronic cross-section) → high luminosity needed
- Lots of hadronic products flying in the forward direction → need a hadron absorber, to keep the spectrometer at reasonable occupancies
- Acceptance limited by spectrometer bending magnet size, and by the lenght of hadron absorber

Several past experiments did it in this way:
NA3, E615 and NA10 are the main ones.

Nucleon Valence and Sea: $\frac{S^p}{u_v^p + d_v^p}$

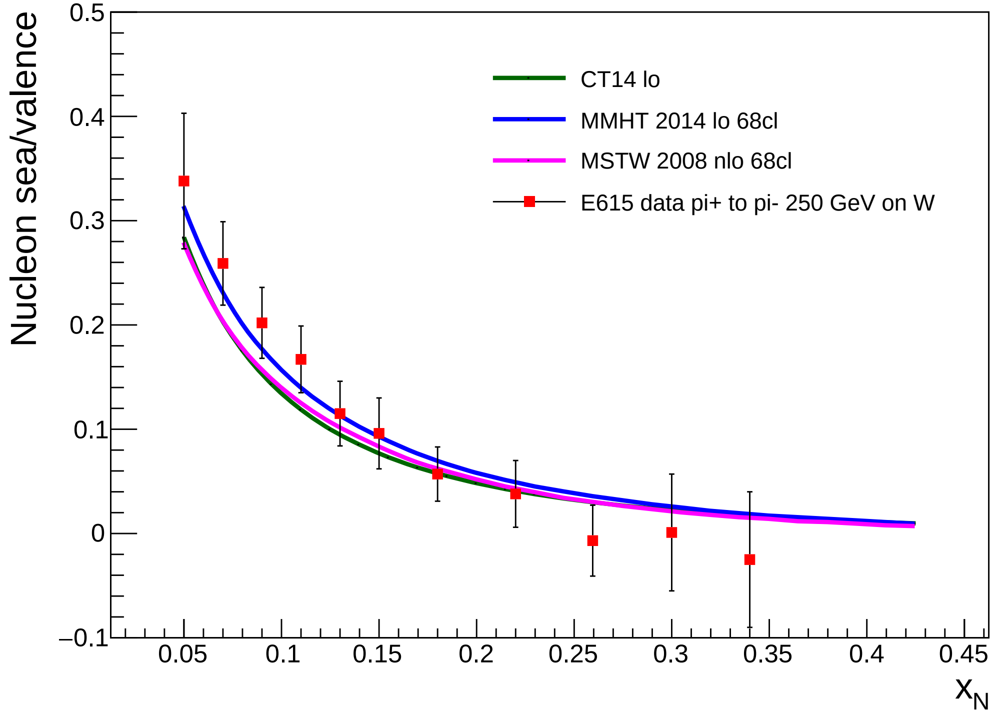
E615 nucleon sea/valence ratio

(Select $x_\pi > 0.36 \Rightarrow$ avoid pion sea)



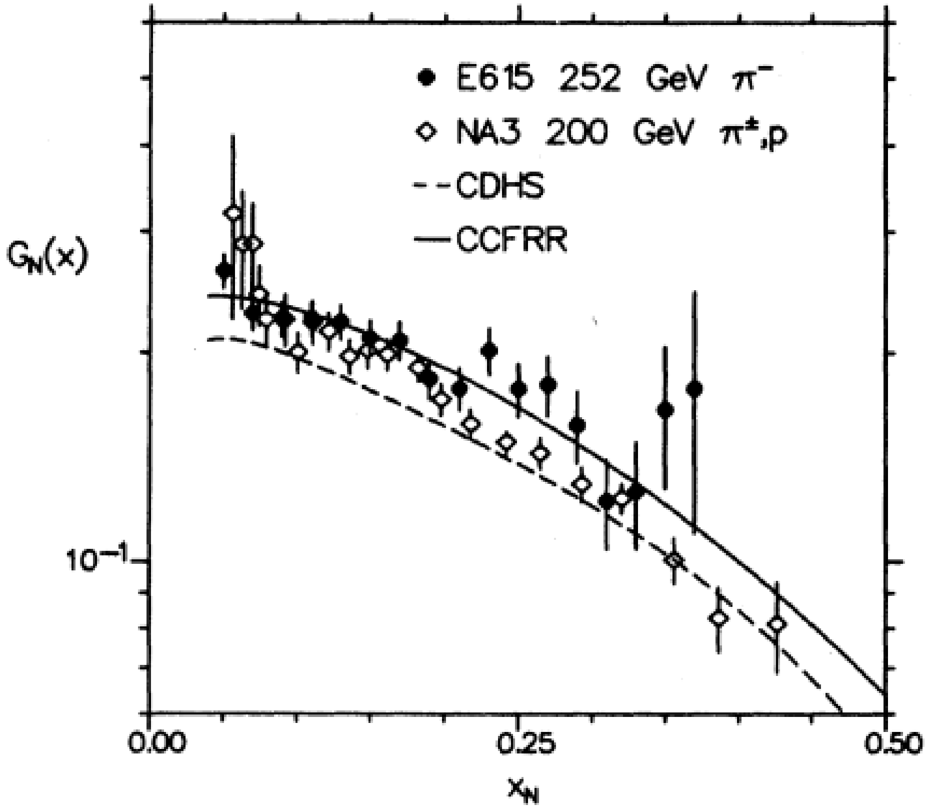
Derived from the ratio $\sigma^{\pi^+W}/\sigma^{\pi^-W}$ (with isoscalar correction included)

E615 Coll.; Phys.Rev.Lett. **63** (1989) 356-359



Same E615 datapoints, plotted against modern PDF sets (global fits not including pion-induced DY data). Simple exercise with TMD plotter, nuclear effects not included.

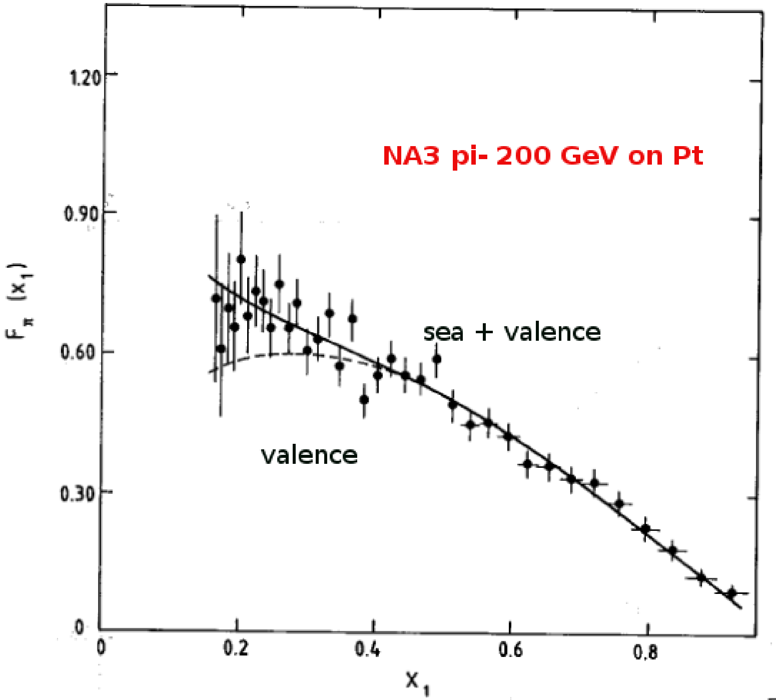
Nucleon Structure Function: $G_N(x_2)$



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

- Good global agreement between E615 and NA3
- Normalizations depend on fraction of gluon momentum included:
  - NA3 gets it from their global fit: $\langle g_N \rangle = 0.43$
  - E615 assumes the value obtained by CCFRF experiment: $\langle g_N \rangle = 0.48$

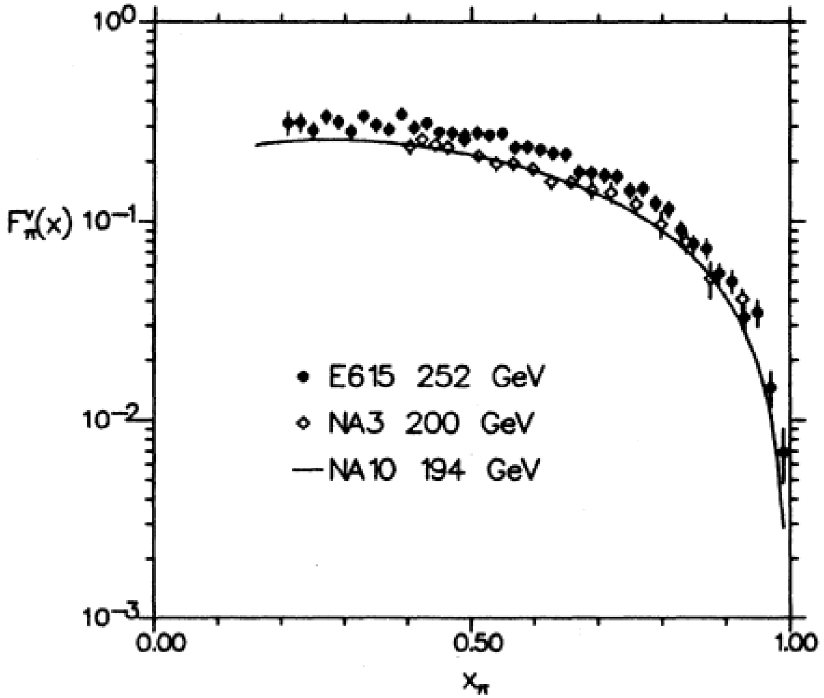
Pion Structure Function: $F_\pi(x_1)$



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

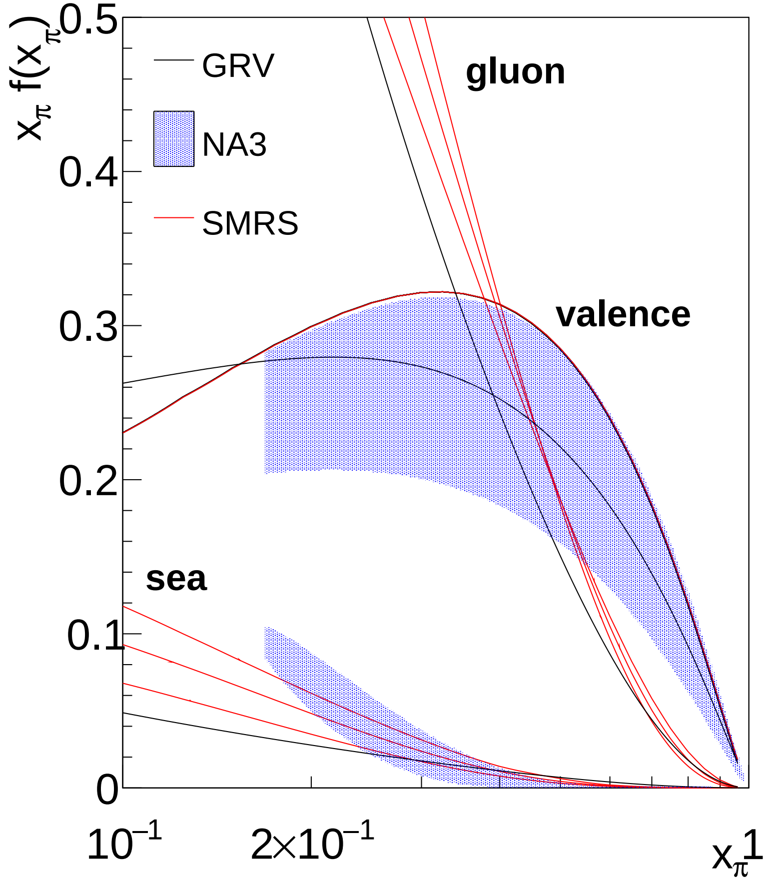
$v^\pi(x_1)$



Discrepancy by 20% between E615 and NA3/NA10, 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

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



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 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)
- The available pion PDF sets differ a lot. More data is needed, with better control of uncertainties, and full error treatment.
- Include Drell-Yan data with both pion beam charges **and** direct photon data in future global fits.

Pion gluon distribution: J/ψ ?

The gluon momentum distribution in the pion can be accessed from direct photons produced in hadron collisions. ⋆monday talk, Alexey Guskov.

Another, alternative way, could be the J/ψ production.

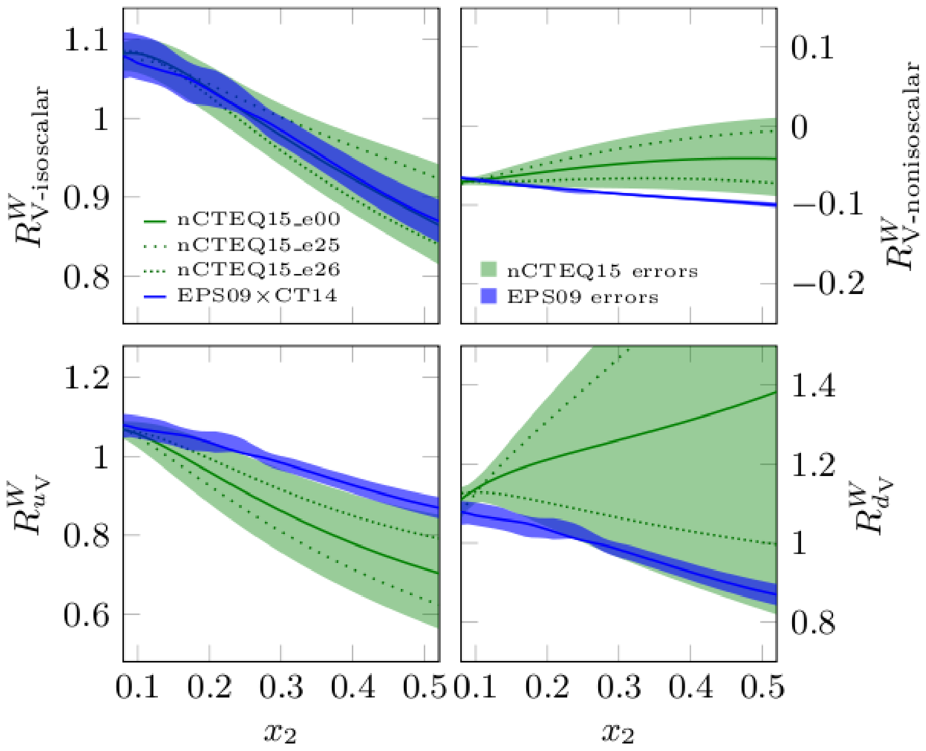
- The mechanism of charmonia production is still not well understood
- Different models predict different dominating mechanisms, at our typical energies:
  - NRQCD (color octet+singlet) predicts $g - g$ fusion dominance;
  - Color Evaporation Model predicts $q - \bar{q}$ annihilation dominance.
- From NRQCD, expect that J/ψ gives access to the gluon distribution in the pion
- From CEM, expect some duality between Drell-Yan and J/ψ

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

$\hookrightarrow$An interesting topic of research in itself

Nuclear PDFs

It was recently realized that the **pion-induced Drell-Yan data can be used to constrain nuclear PDFs** in the region of large x_N, concerning possible differences in the nuclear modifications R of the valence quarks u_v^A and d_v^A.



Pion induced DY data was not included in the global fits:

- nCTEQ15 allows flavor dependence of valence nuclear modification – unconstrained, thus very large errors.
- EPS09 flavor dependence of valence nuclear modifications not allowed – thus underestimated error bands.

P. Paakkinen et al, Phys.Lett.B **768** (2017) 7-11.

Pion-induced DY and Nuclear PDFs

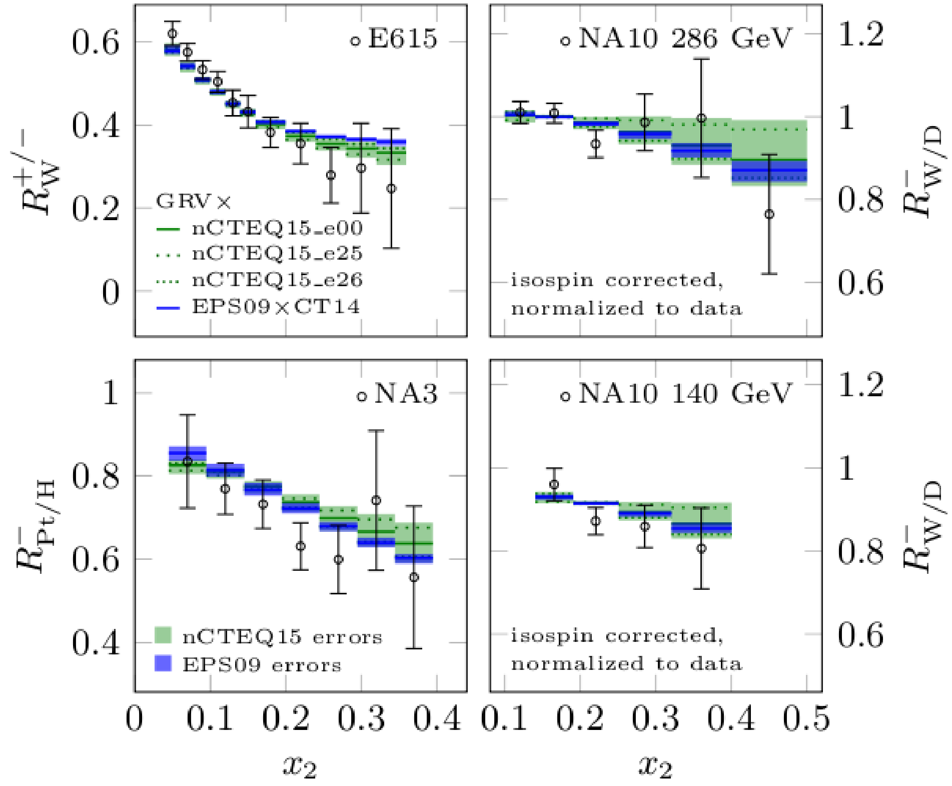
The DY cross-section ratios of the **2 pion beam charges** or of **a light and a heavy target** are practically independent of pion PDFs (in LO).

$$R_A^{+/-} \equiv \frac{d\sigma_{DY}^{\pi^+ A}/dx_2}{d\sigma_{DY}^{\pi^- A}/dx_2} \approx \frac{4\bar{u}_A(x_2)+d_A(x_2)}{4u_A(x_2)+\bar{d}_A(x_2)}$$

$$R^-_{A_1/A_2} \equiv \frac{\frac{1}{A_1} d\sigma_{DY}^{\pi^- A_1}/dx_2}{\frac{1}{A_2} d\sigma_{DY}^{\pi^- A_2}/dx_2} \approx \frac{4u_{A_1}(x_2)+\bar{d}_{A_1}(x_2)}{4u_{A_2}(x_2)+\bar{d}_{A_2}(x_2)}$$

nCTEQ15_25 means $R^A_{u_v} \ll R^A_{d_v}$, while nCTEQ15_26 means $R^A_{u_v} \approx R^A_{d_v}$.

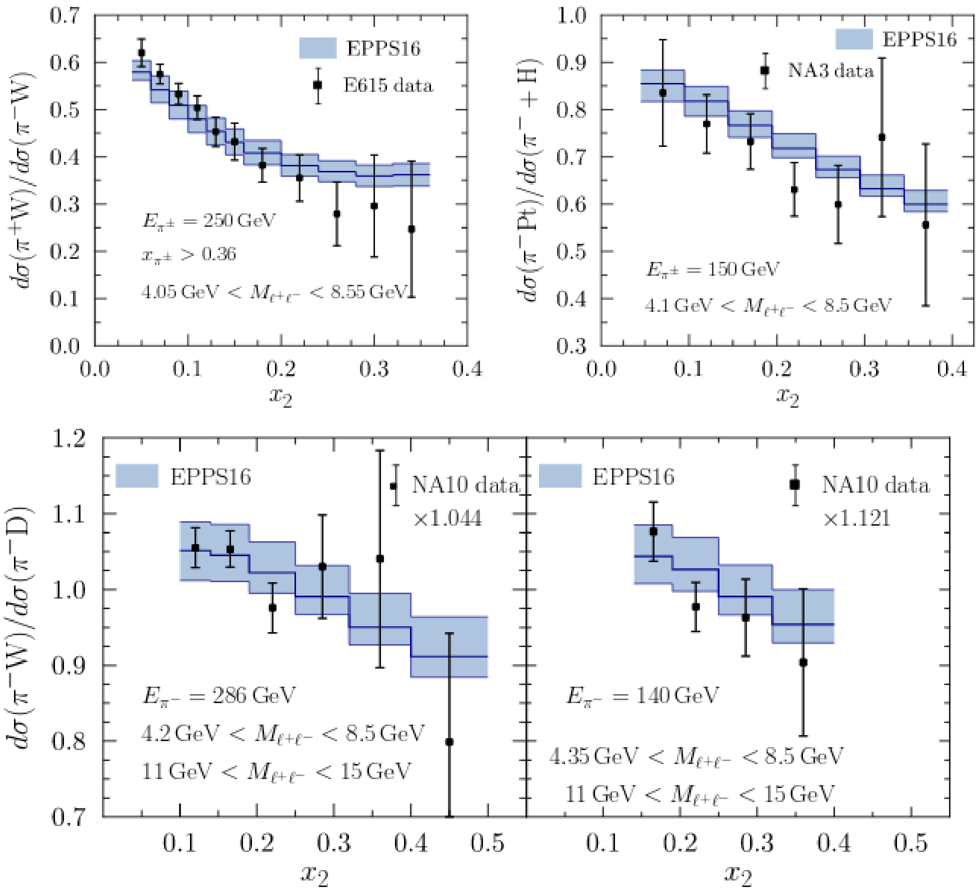
$\hookrightarrow$DY data show sensitivity to distinguish these 2.



P. Paakkinen et al, Phys.Lett.B **768** (2017) 7-11.

EPPS16: new set of nuclear PDFs

Global fits including new data on neutrino DIS, pion-induced DY, 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.

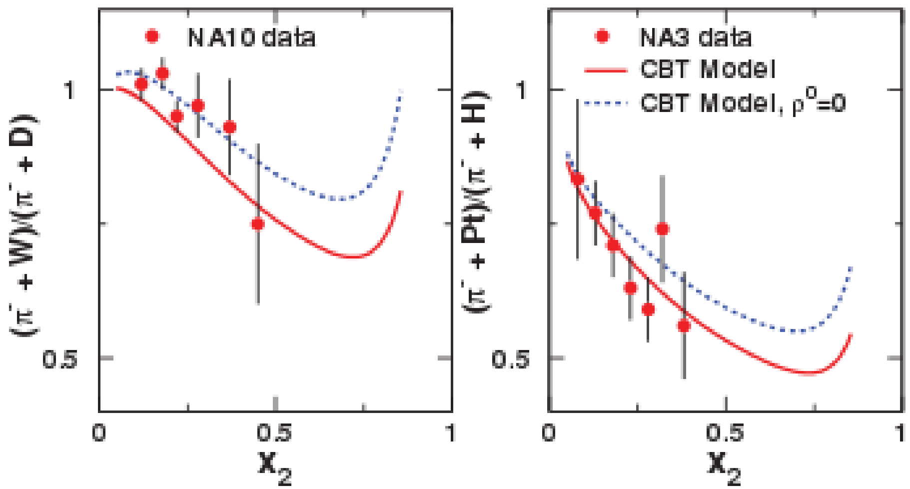
But: the statistical weight of these data is not enough to add significant additional constraints to the nuclear PDFs.
$\hookrightarrow$ Will COMPASS data do?

Flavor dependence of the EMC effect

- The observed nuclear modification of the nucleon PDFs in the region $0.1 < x_2 < 0.5$ is called EMC effect.

  EMC Coll.; Phys.Lett.B **123** (1983) 275-278.

- The EMC effect might be flavor dependent, as shown by the large uncertainties still showing in nPDFs.
- Pion induced Drell-Yan might help clarify.



Cloet, Bentz and Thomas model (CBT): the ρ^0 mean field in a $(A-Z) \neq Z$ nucleus makes that u and d quark distributions are modified differently.

Cloet et al, Phys.Lett.B **642**, 210 (2006); D. Dutta et al, Phys.Rev. C **83** 042201 (2011)

Predictions from Dutta et al, of the CBT model applied to pion-induced DY data. But: past data not precise enough to answer.

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

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

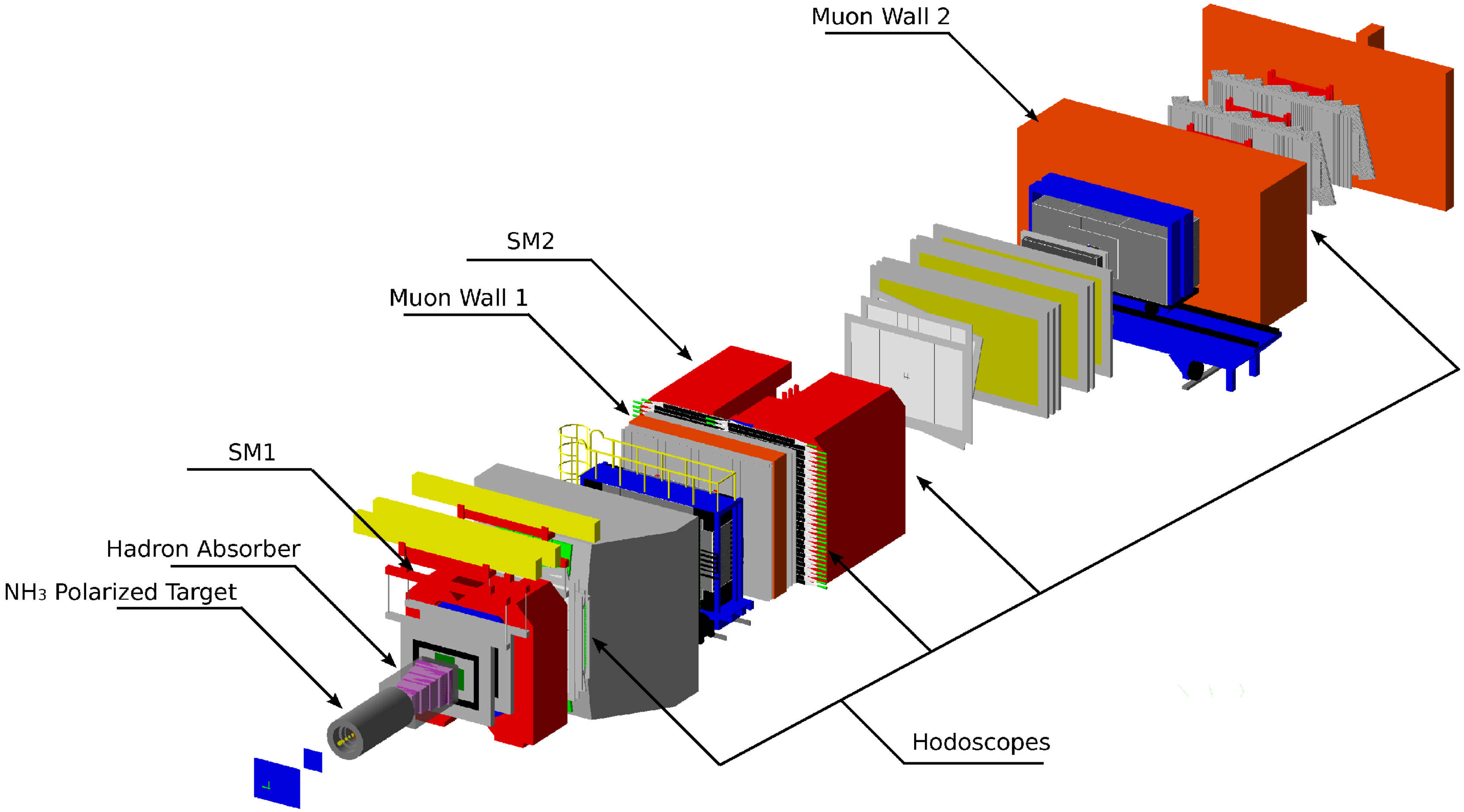
Problems with past data

- Data with both pion beam polarities exist only from NA3 and E615.
- Limited statistics.
- 20% discrepancy in absolute normalization between the 2 experiments.
- Both used heavy targets – important nuclear effects on the nucleon side.

Future possible solutions

- A new Drell-Yan experiment with pion beams of high intensity and both polarities
- Large geometrical acceptance required
- Use of modern multidimensional analysis techniques to separate physics components – avoid hard cuts, optimal use of available statistics
- Use of light isoscalar targets, for minimal nuclear effects
- Simultaneous use of heavy targets to further study nuclear effects
- Very good beam particle identification

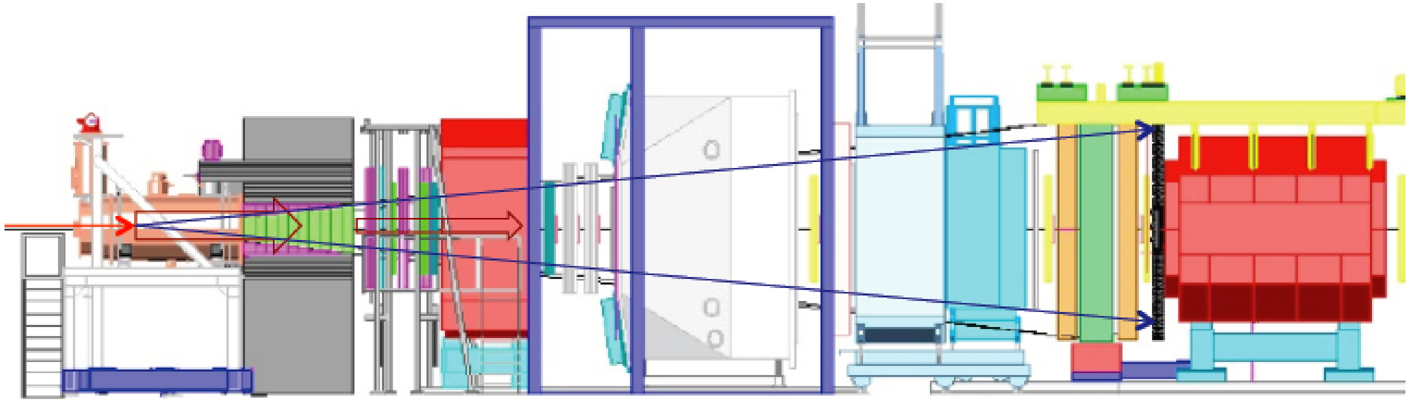
The present: COMPASS



COMPASS took data in 2015, and will continue in 2018, with π^- beam 190 GeV on targets of transversely polarized NH_3 and tungsten.

Pion induced Drell-Yan – Present

COMPASS @ CERN



...

- π^- beam at 190 GeV
- Hadron beam intensity 7×10^7/second
- 110 cm NH_3 target + 7 cm Al target + 120 cm W target
- 240cm Absorber, 120 cm W beam plug
- dimuons geometrical acceptance $\approx$ 40%

COMPASS Coll.; Phys.Rev.Lett. **119** (2017) 112002; CERN-SPSC-2010-014

COMPASS results to come

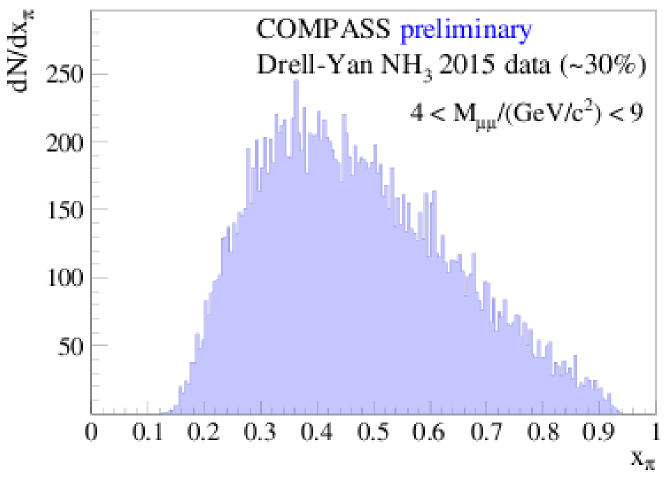
The Drell-Yan results from COMPASS are just starting to emerge. In the near future, expect:

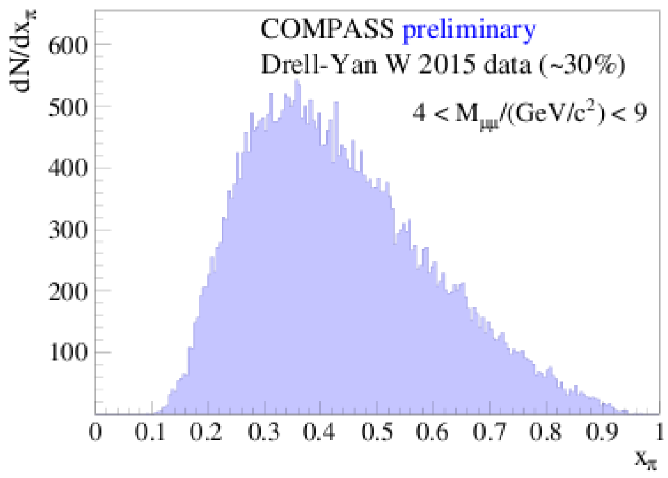
- Unpolarized Drell-Yan angular distributions from π^- on NH_3
- Absolute Drell-Yan cross-sections of pion collisions on NH_3 and on W targets
- Nuclear effects from the ratio of Drell-Yan on W to NH_3

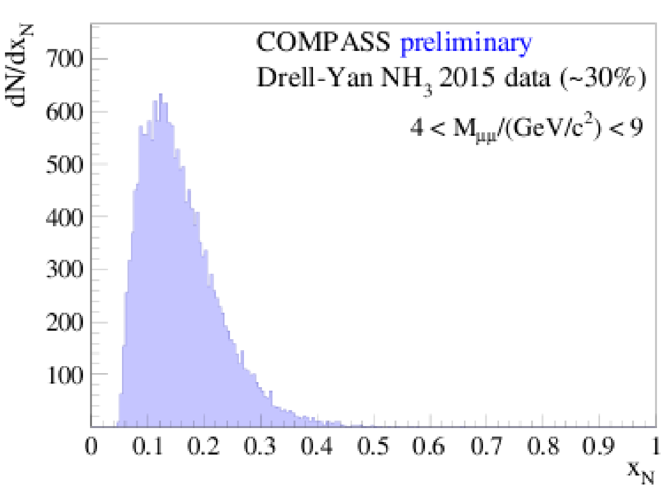
These results will allow to clarify already a number of open issues:

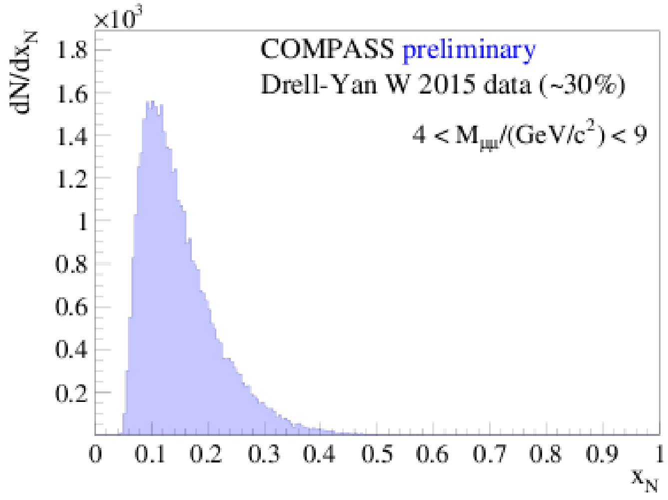
- Solve normalization issue between NA10 and E615 data
- Repeat the studies of nuclear effects from pion-induced Drell-Yan, as done by NA10
- Ultimately new global fits towards pion PDFs
- Global fits of nPDFs including new pion induced Drell-Yan data, as EPPS16

COMPASS coverage









35 000 DY events from NH_3

15 000 DY events from W

New DY experiment with $\pi^{\pm}$ beams

...And while we analyse these COMPASS data, we plan the next Drell-Yan challenge: a new experiment for meson structure studies

- High intensity pion beams of high energy: π^+ and π^- at 190 GeV
- Optimal time sharing (wrt DY process) between the 2 beam polarities
- Light isoscalar target: carbon (4 cells); and heavy target: tungsten (2 cells)
- Large acceptance spectrometer – as COMPASS
- A fully charge-symmetric dimuon trigger system
- CEDARs system standing high intensity beams
- Multidimensional analysis techniques

Dimuon spectrum – a multidimensional problem

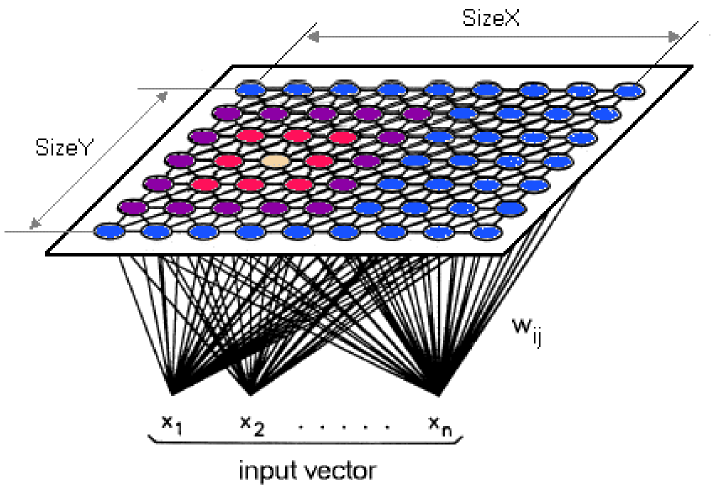
One main difficulty with Drell-Yan is the **scarce statistics**: up to now, isolating DY events from background required $4.3 < M_{\mu\mu} < 8.5$ GeV.

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

Self organizing map:

Unsupervised learning algorithm capable of finding clusters in data without priviledged knowledge a priori.

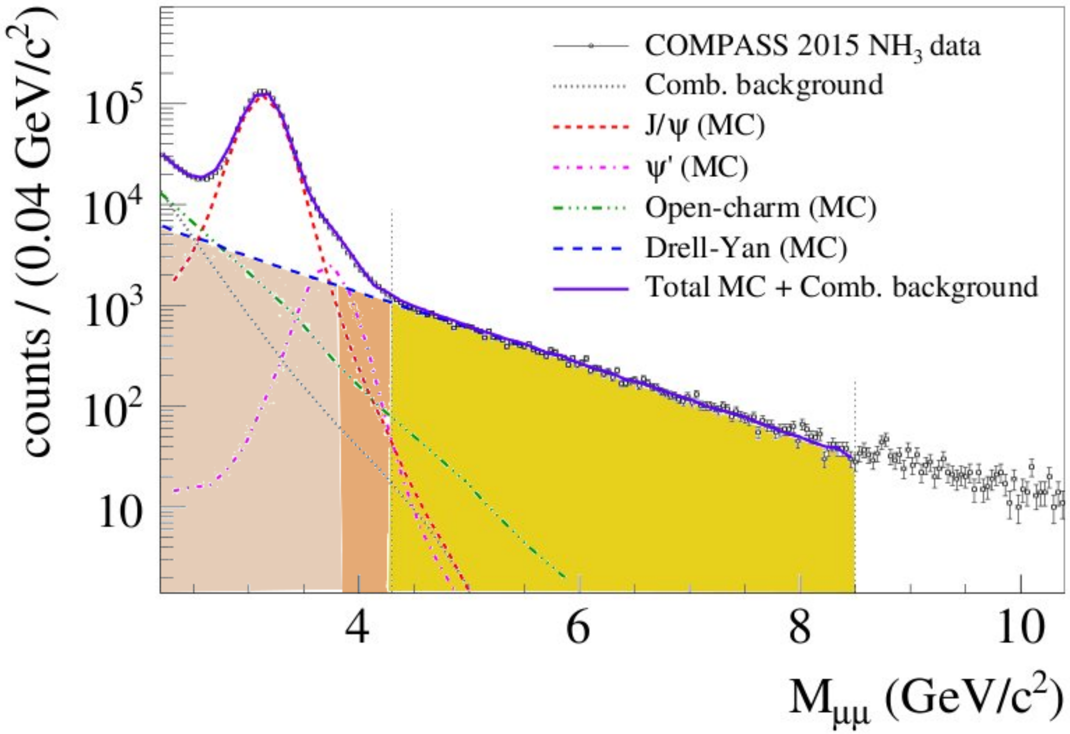
These clusters are used to train a deep neural network that attributes a probability for each event to be signal.



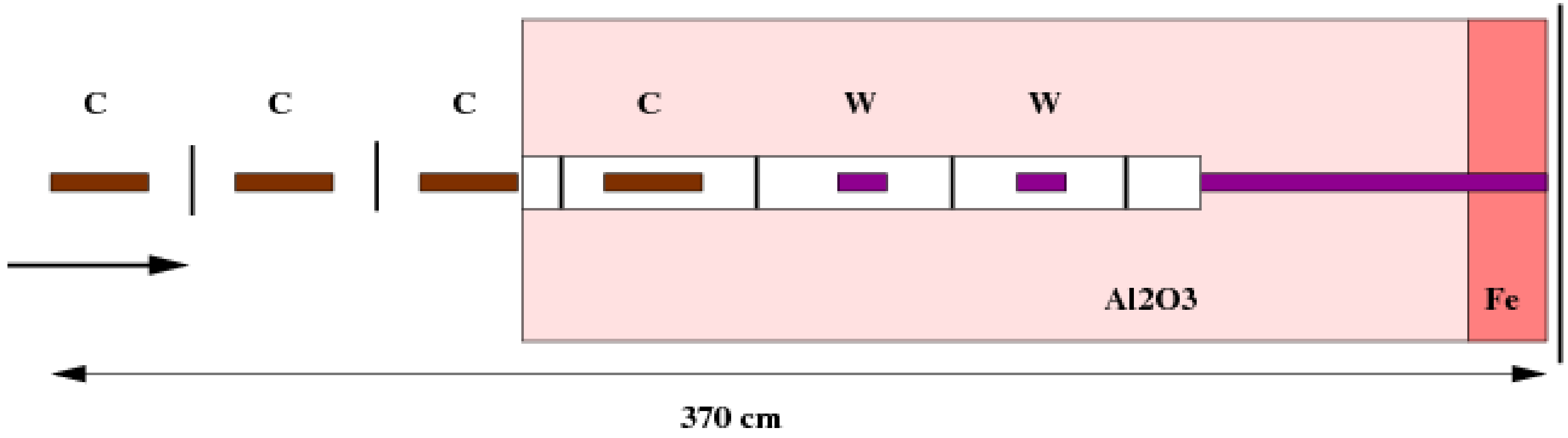
Extended accessible Drell-Yan range

- Past COMPASS analyses successfully used neural networks for optimal use of statistics available.
- Machine learning techniques are presently being tested in Drell-Yan COMPASS data of 2015.

$\hookrightarrow$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: extend to a region of charmonium tails and open-charm contamination
- $2.0 < M < 3.8$ GeV: all processes mixed



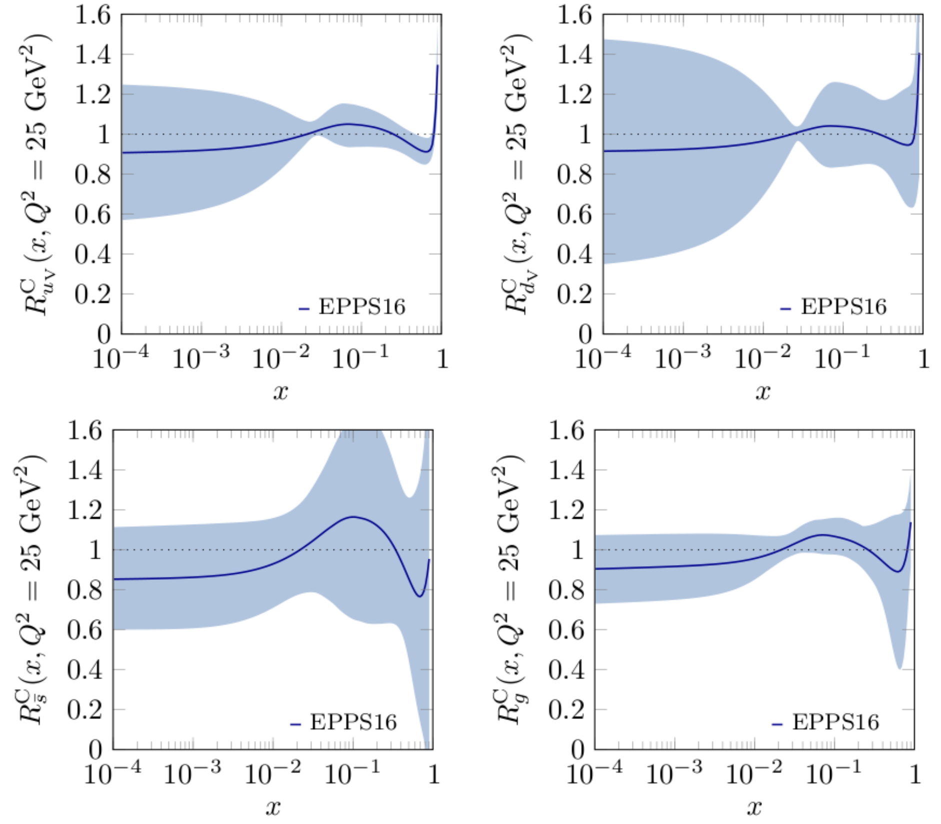
Target: possible design

material	carbon
Z	6
A	12.01 g/mol
λ_{int}^{π}	52 cm
density	2.265 g/cm^3
configuration	4×25 cm
effective lenght	44.4 cm

material	tungsten
Z	74
A	183.84 g/mol
λ_{int}^{π}	11.3 cm
density	19.3 g/cm^3
configuration	2×12 cm
effective lenght	9.97 cm

Carbon as light isoscalar target

- The first choice for target would be hydrogen or deuterium. **But:** low statistics!
- carbon is light and isoscalar, close in A to NH_3 used by COMPASS.
- Can nuclear effects in carbon be neglected?



Figures provided by P. Paakkinen, EPPS16

The nuclear effects in carbon are actually not negligible, but they are small for the valence quarks, 5 - 10 %.

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.

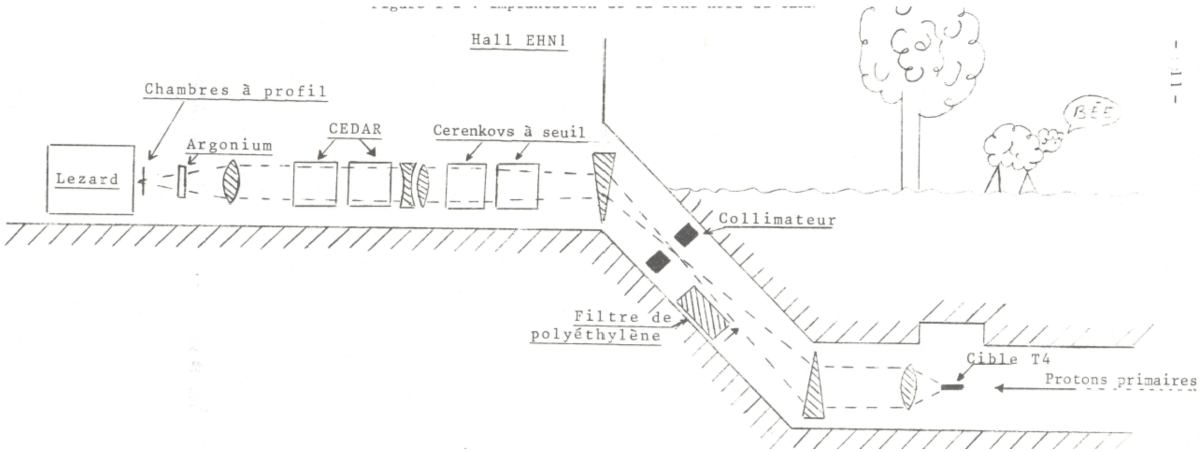
Expected statistics

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

Margin for improvements

- Standard beam composition is assumed up to now:
  - positive hadron beam: 73% p; 24% π^+; 3% K^+
  - negative hadrom 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%

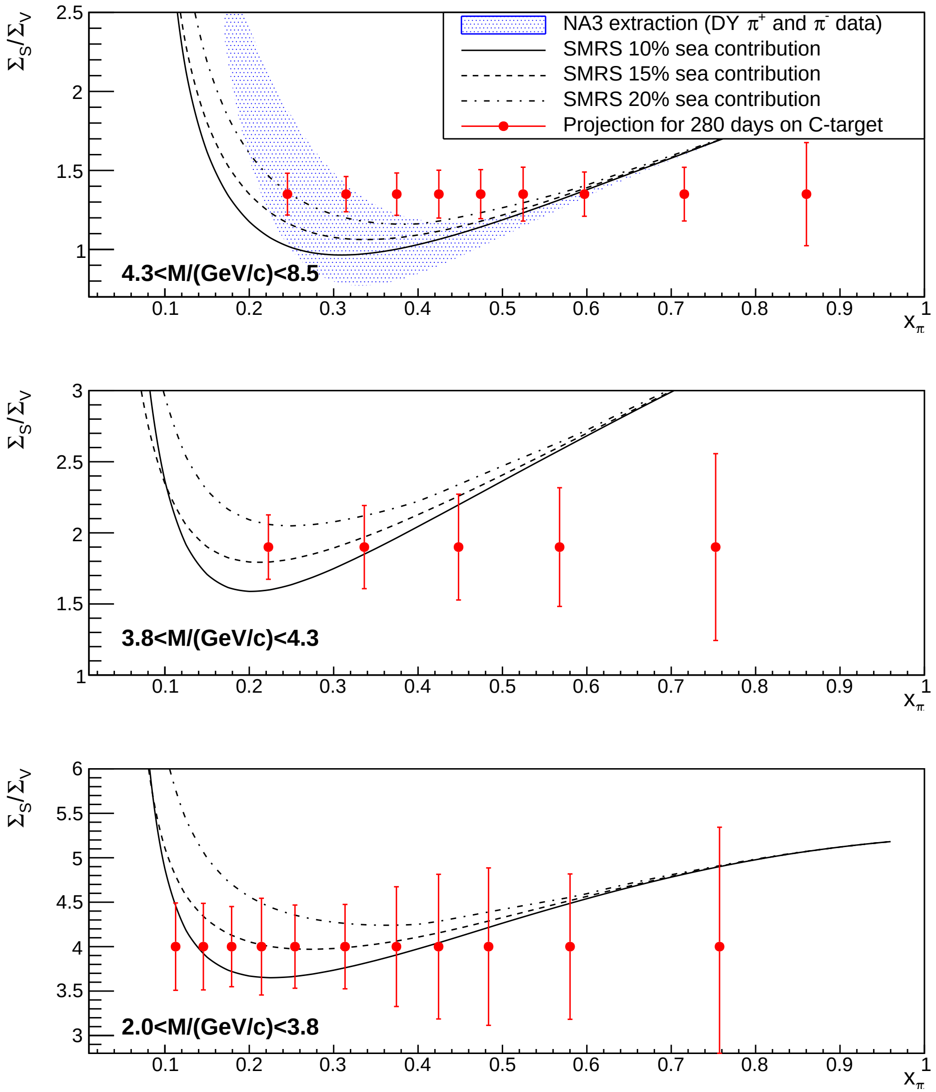


$\hookrightarrow$ 55% increase in the final statistics for each beam charge

- 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 can be changed. The possibility to have 3×25 cm C + 2×12 cm W is being studied.

New DY experiment: pion sea to valence ratio

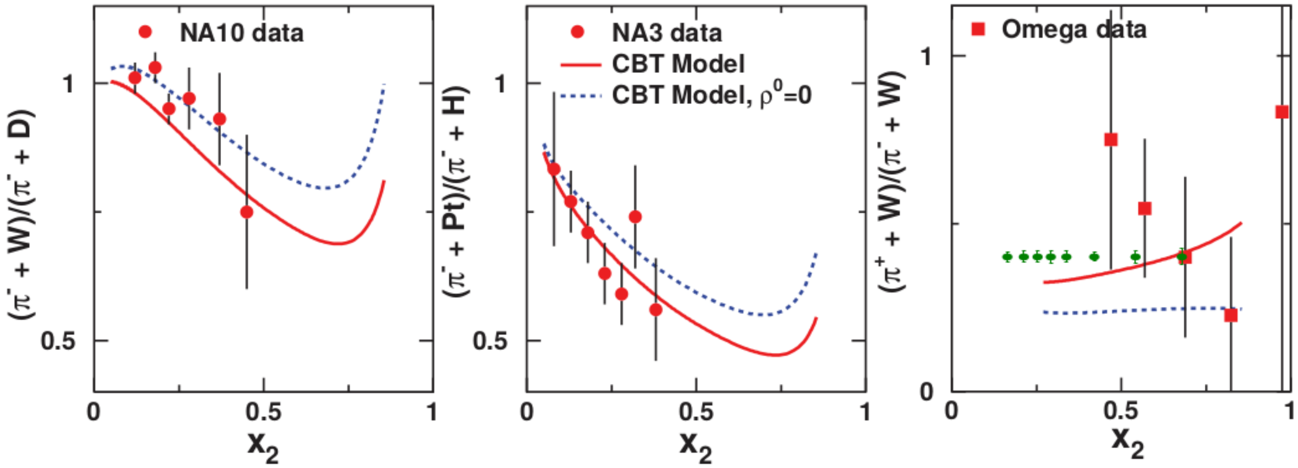
Expected accuracy compared to NA3 result



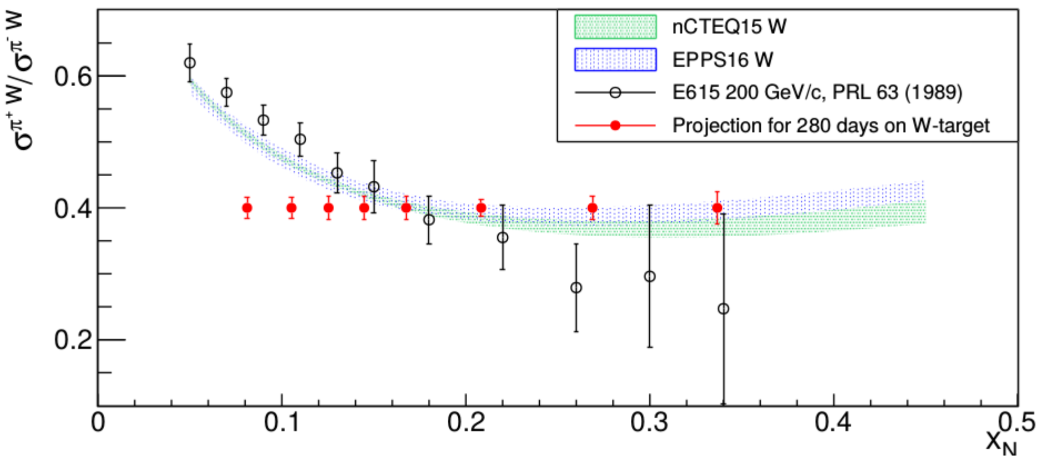
- Collect at least a factor 10 more statistics than presently available
- Minimize nuclear effects on target side
  - Projection for 2 years of Drell-Yan data taking
  - π^+ to π^- 10:1 time sharing
  - 190 GeV beams on Carbon target $(1.9\lambda^{\pi}_{int})$

Nuclear effects: π^+/π^- ratio on W

Expected accuracy compared to Omega and sensitivity to CBT model

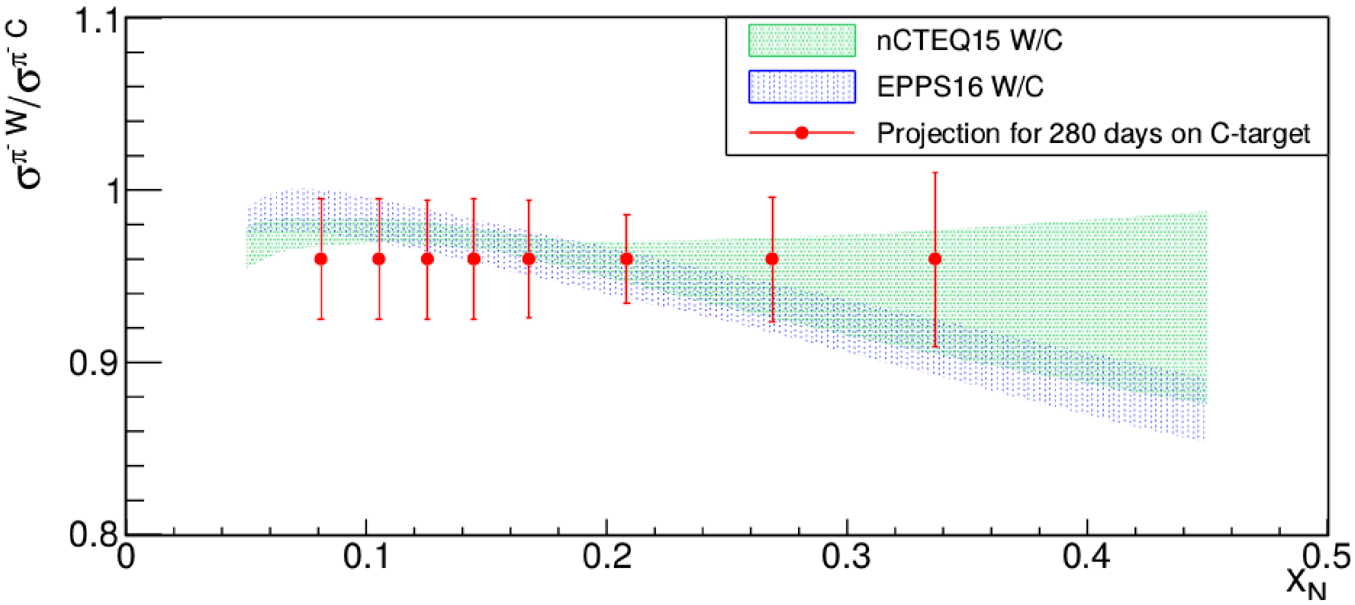


Expected accuracy compared to E615 and nPDF sets



Nuclear effects: DY ratio W/C with π^- beam

Expected accuracy compared with nPDF sets uncertainties

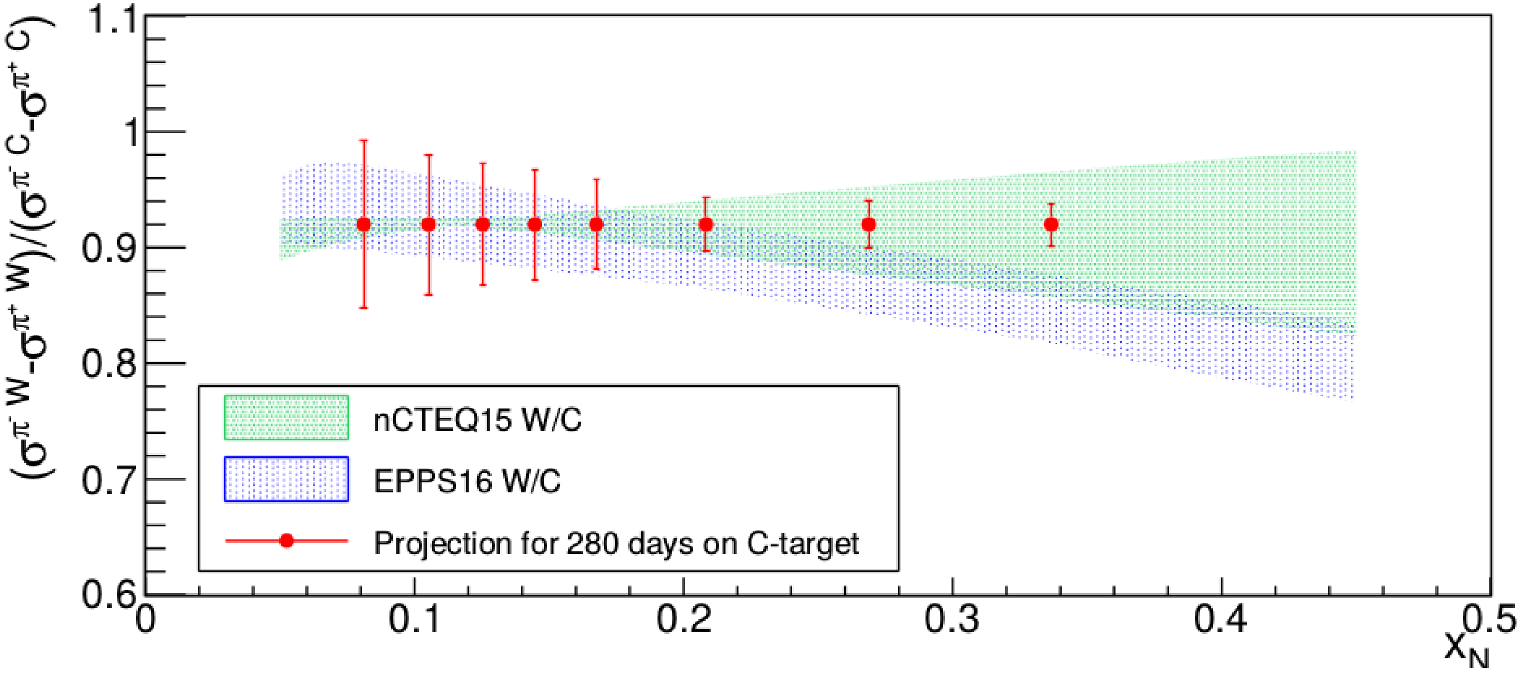


This type of ratio is also accessible to COMPASS: DY ratio W/NH_3 with π^- beam

$\hookrightarrow$ Expect it soon!

Nuclear effects: best constraint

DY ratio W/C of cross-section differences $(\pi^- - \pi^+)$



P. Paakkinen et al, arXiv:1710.05736 (DIS 2017 proceedings)

Summary

We propose a new Drell-Yan experiment to study meson structure functions: a first time extraction in the case of kaons, and with unprecedented precision in the case of pions.

- Do valence-sea separation by using beams of both polarities.
- Use a ligh isocalar target of carbon, for easier interpretation of the results.
- Study also nuclear effects to the nucleon structure, by comparing Drell-Yan in carbon and tungsten targets.
- Overcome statistics limitations by using novel machine learning techniques that multidimentionally separate signal from background, in phase-space regions where Drell-Yan has other competitors.
- In parallel the study of J/ψ polarization may lead to better understand its production mechanisms – ultimately, this channel may become useful for the measurement of the gluon distribution in the pion.
- A measurement technically simple with a COMPASS-like spectrometer. It could be performed just after COMPASS programme completion.
- From its results, new more precise global fits are expected to lead to precise knowledge of the pion structure. They may also significantly constrain the nuclear PDFs extraction.

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
lenght	200 cm
configuration	1 $\times$ 200 cm
effective lenght	173 cm

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

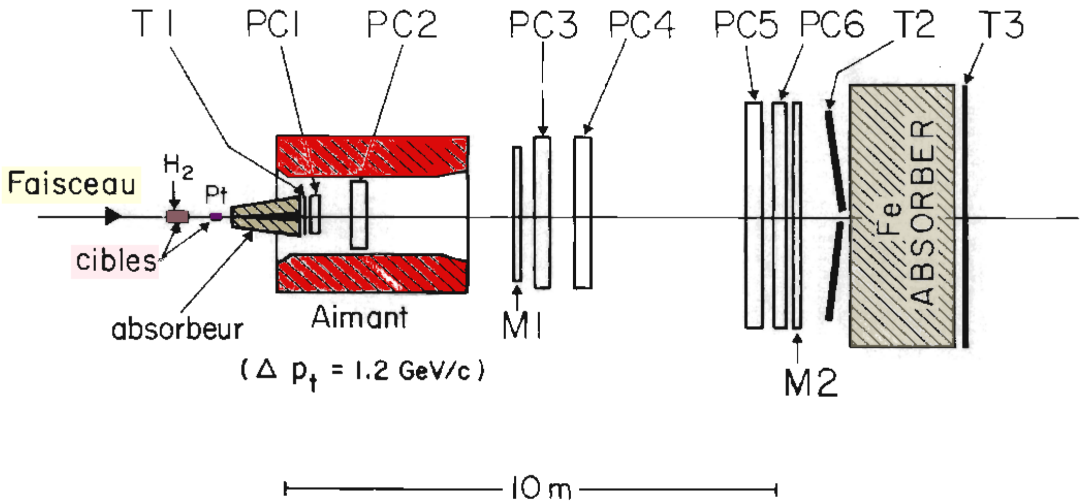
^{6}LiD target

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

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

SPARE: Pion induced Drell-Yan – Where?

NA3 @ CERN

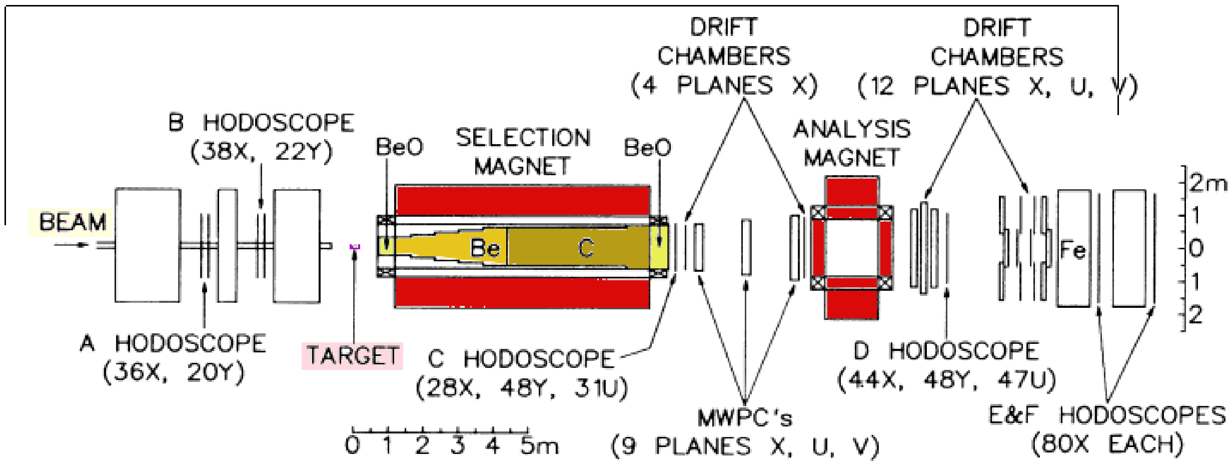


- $\pi^{\pm}$ and $K^{\pm}$ beams at 200 GeV and 150 GeV; π^- beam at 280 GeV
- Hadron beam intensity 3×10^7/second
- 30 cm (50 cm for 280 GeV beam) H_2 target + 6 cm Pt target
- 150 cm long Fe absorber, 150 cm W (U) beam plug
- dimuons geometrical acceptance 25%

NA3 Coll.; Z.Phys.C **11** (1981) 195–202; Z.Phys. C **18** (1983) 281–287

SPARE: Pion induced Drell-Yan – Where?

E615 @ Fermilab

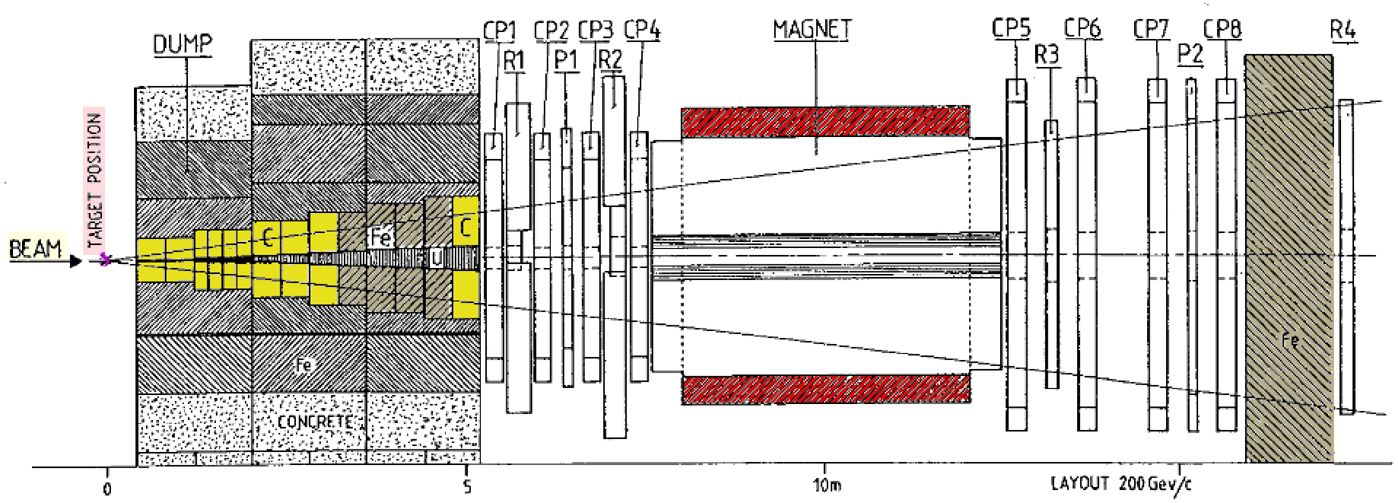


- $\pi^{\pm}$ beams at 252 GeV; π^- beam at 80 GeV
- Hadron beam intensity 2×10^8/second
- 20 cm W target
- 875 cm light Absorber, no beam plug
- dimuons geometrical acceptance $\approx 4\%$

E615 Coll.; Phys.Rev. D **39** (1989) 92–122; Phys.Rev.Lett. **4** (1989)356–359

SPARE: Pion induced Drell-Yan – Where?

NA10 @ CERN



- π^- beam at 140, 194 and 286 GeV
- Hadron beam intensity 1×10^9/second
- 12 cm (6 cm) W target + 120 cm D_2 target (only with 140 and 286 GeV beams)
- 480cm Absorber, 120 cm W+U beam plug
- dimuons geometrical acceptance $\approx 10\%$

NA10 Coll.; Z.Phys.C **28** (1985) 9–14; Phys.Lett.B **193** (1987)368–375