Pion-Induced Drell-Yan at COMPASS

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International Workshop on Hadron Structure and Spectroscopy
Joint Institute for Nuclear Research
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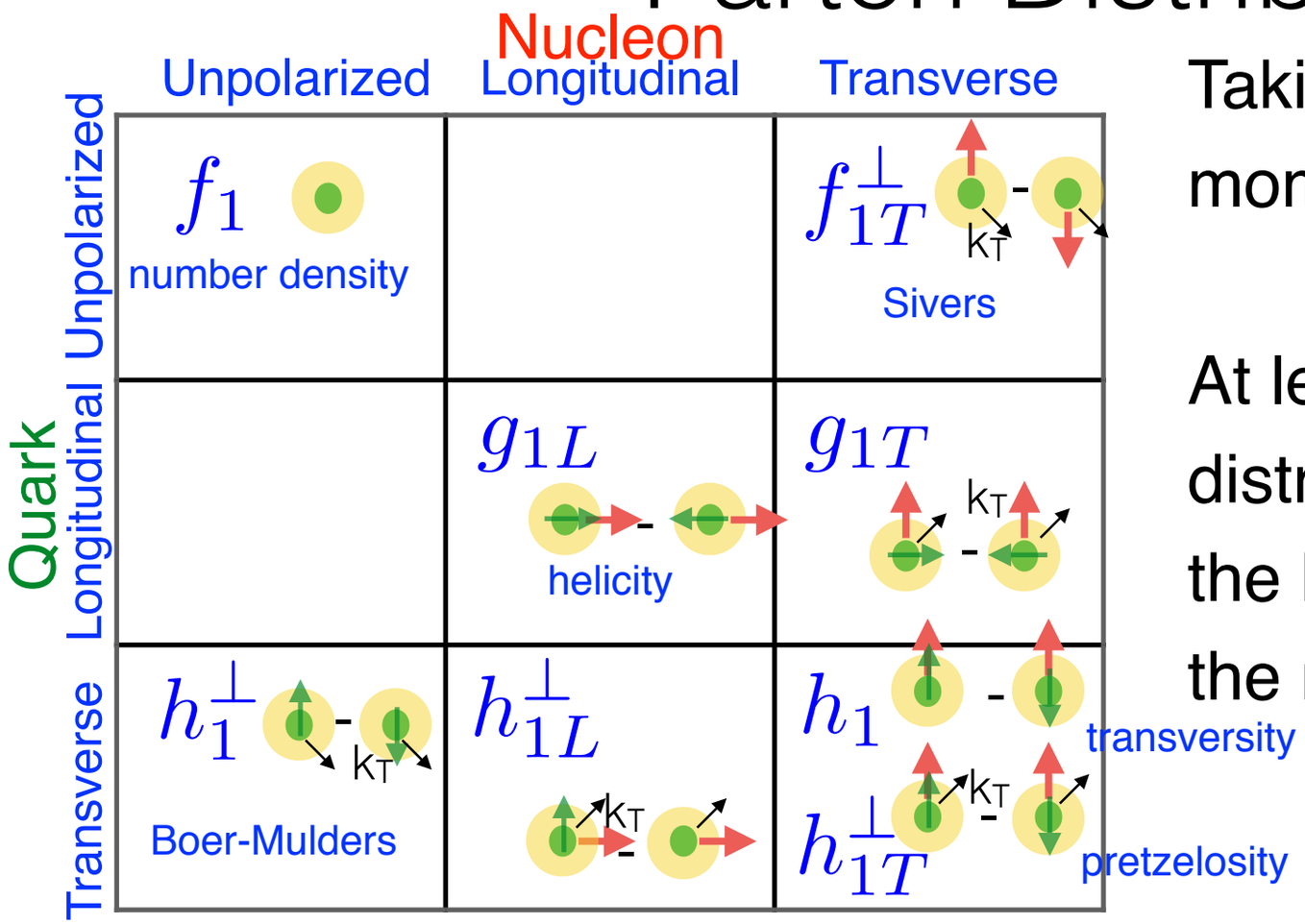
Outline

- Sivers and Boer-Mulders functions
- Drell-Yan to study Sivers and Boer-Mulders effects
- COMPASS @ CERN is an ideal place to study Drell-Yan and the sign flip of T-odd TMDs
- How COMPASS will measure Drell-Yan

Transverse Momentum Dependent (TMD) Parton Distributions



Taking into account transverse parton momentum $k_T > 0$.

At leading twist 8 TMD parton distribution functions parameterize the hard scattering cross section of the nucleon.

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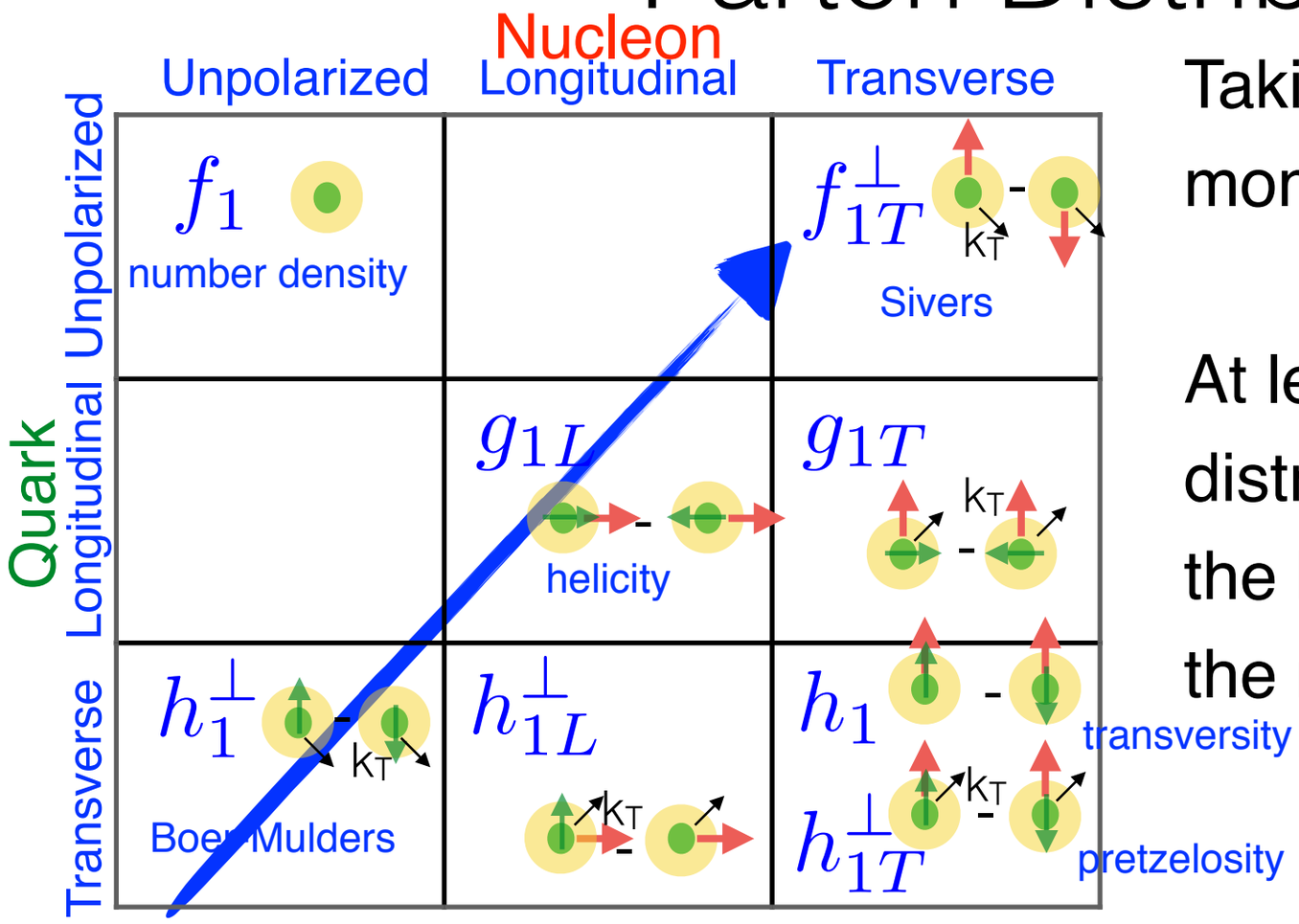

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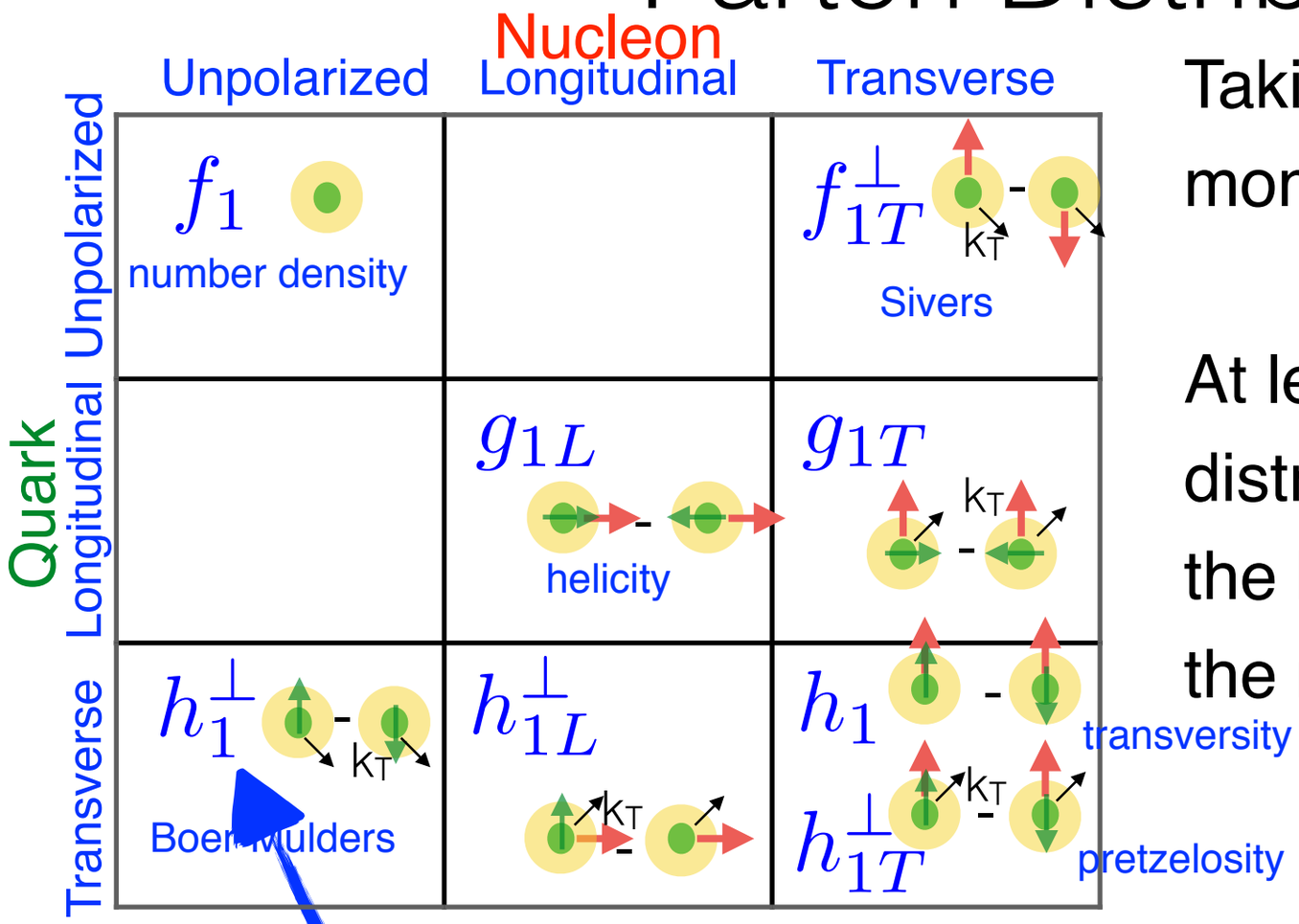

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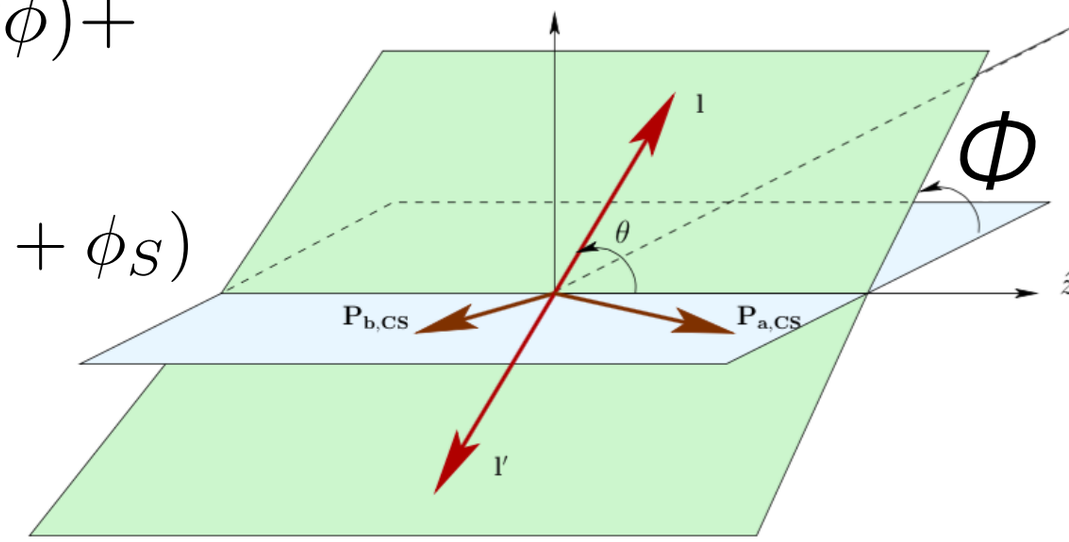
Drell-Yan is Sensitive to TMDs

Leading order differential cross section for transversely polarized target and unpolarized beam

$$\frac{d\sigma}{d^4q d\Omega} \overset{LO}{=} \frac{\alpha_{em}^2}{Fq^2}\hat{\sigma}_U \Bigg[(1 + D_{[sin^2\theta]} A_U^{cos2\phi} cos2\phi) +$$

$$|S_T| \Big(A_T^{sin\phi_S} sin\phi_S + D_{[sin^2\theta]} \{ A_T^{sin(2\phi+\phi_S)} sin(2\phi+\phi_S)$$

$$+ A_T^{sin(2\phi-\phi_S)} sin(2\phi-\phi_S) \} \Big) \Bigg]$$



Collins-Soper frame: center of mass frame of out going lepton pair.

Extracting single spin asymmetries (SSA) from measured data:

SSA data from Drell-Yan data gives access to Sivers function

The Sivers function can also be extracted from SSA data from semi-inclusive deep inelastic scattering (SIDIS)

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Sivers

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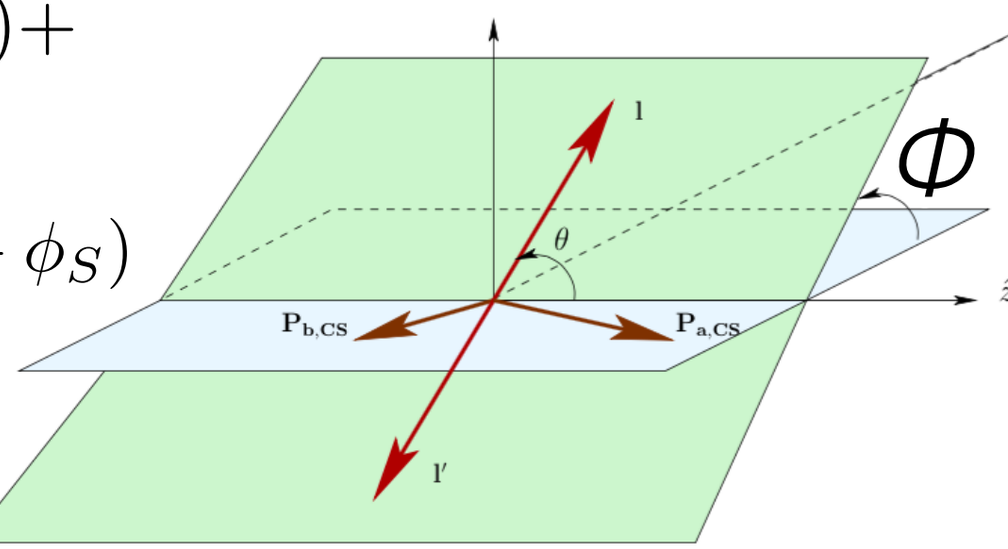

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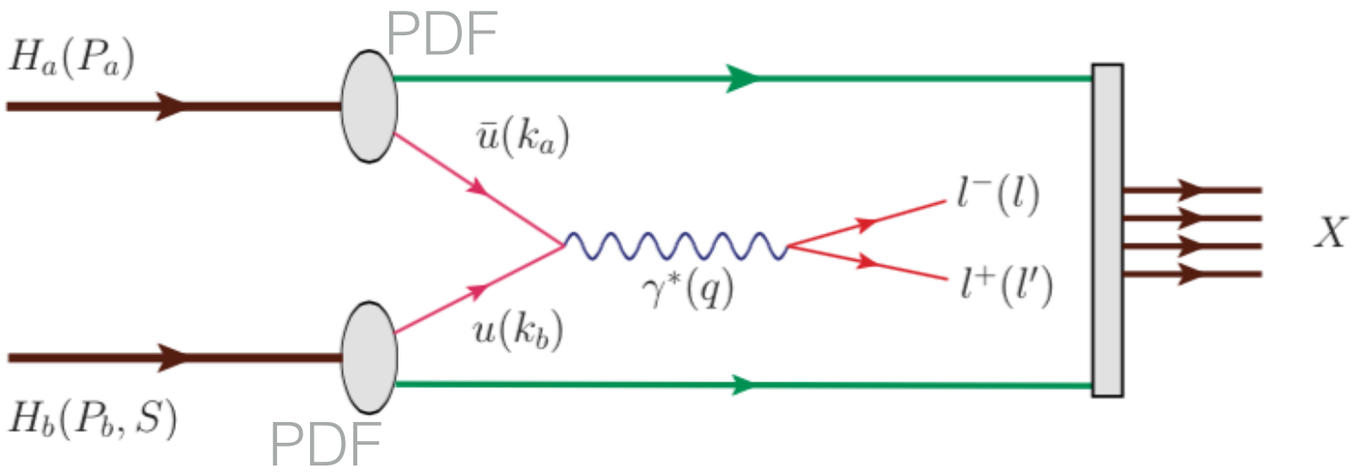
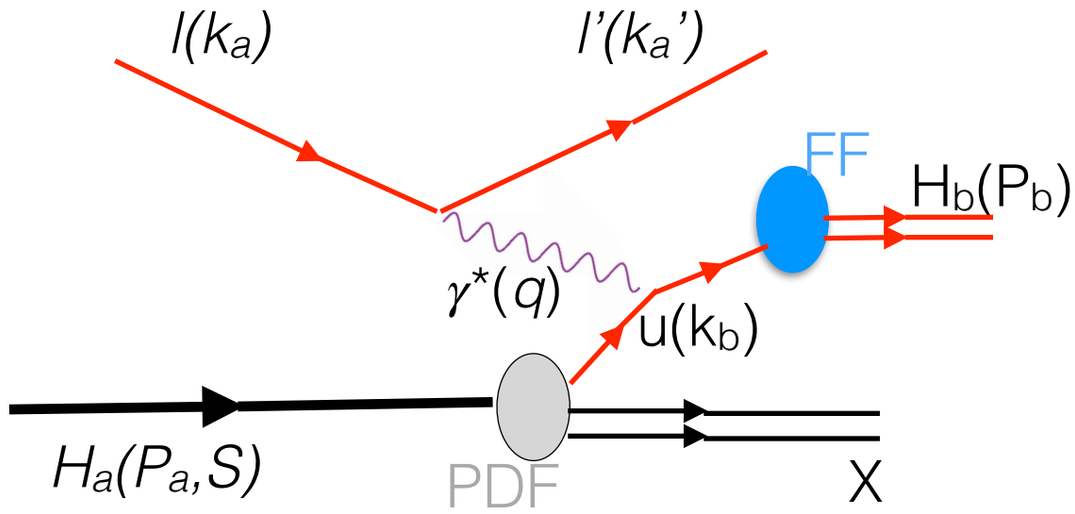
Drell-Yan vs. SIDIS



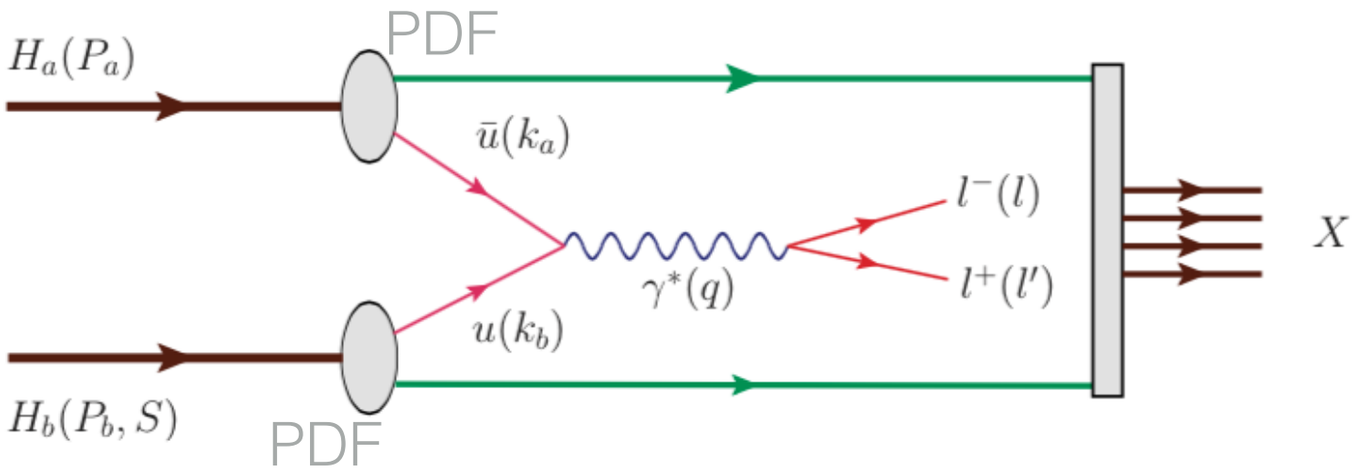
X

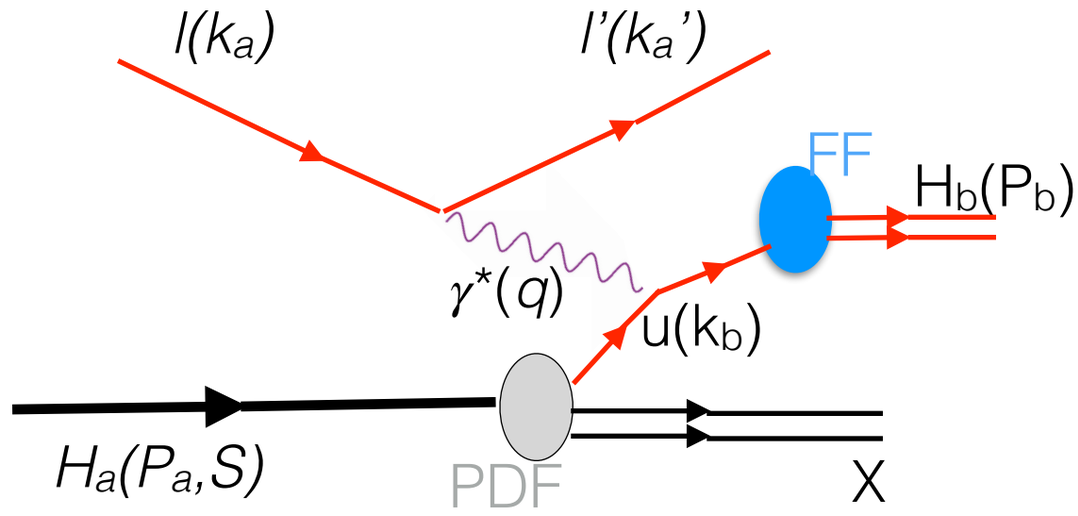


$x_{a(b)} = q^2/(2P_{a(b)} \cdot q)$ x-Bjorken $M^2_{\mu\mu} = Q^2 = s x_a x_b$ Invariant mass squared

$x_F = x_a - x_b$ Feynman Variable $z = \dfrac{P \cdot P_h}{P \cdot q}$ Ratio of hadron energy to transferred photon energy

Drell-Yan vs. SIDIS





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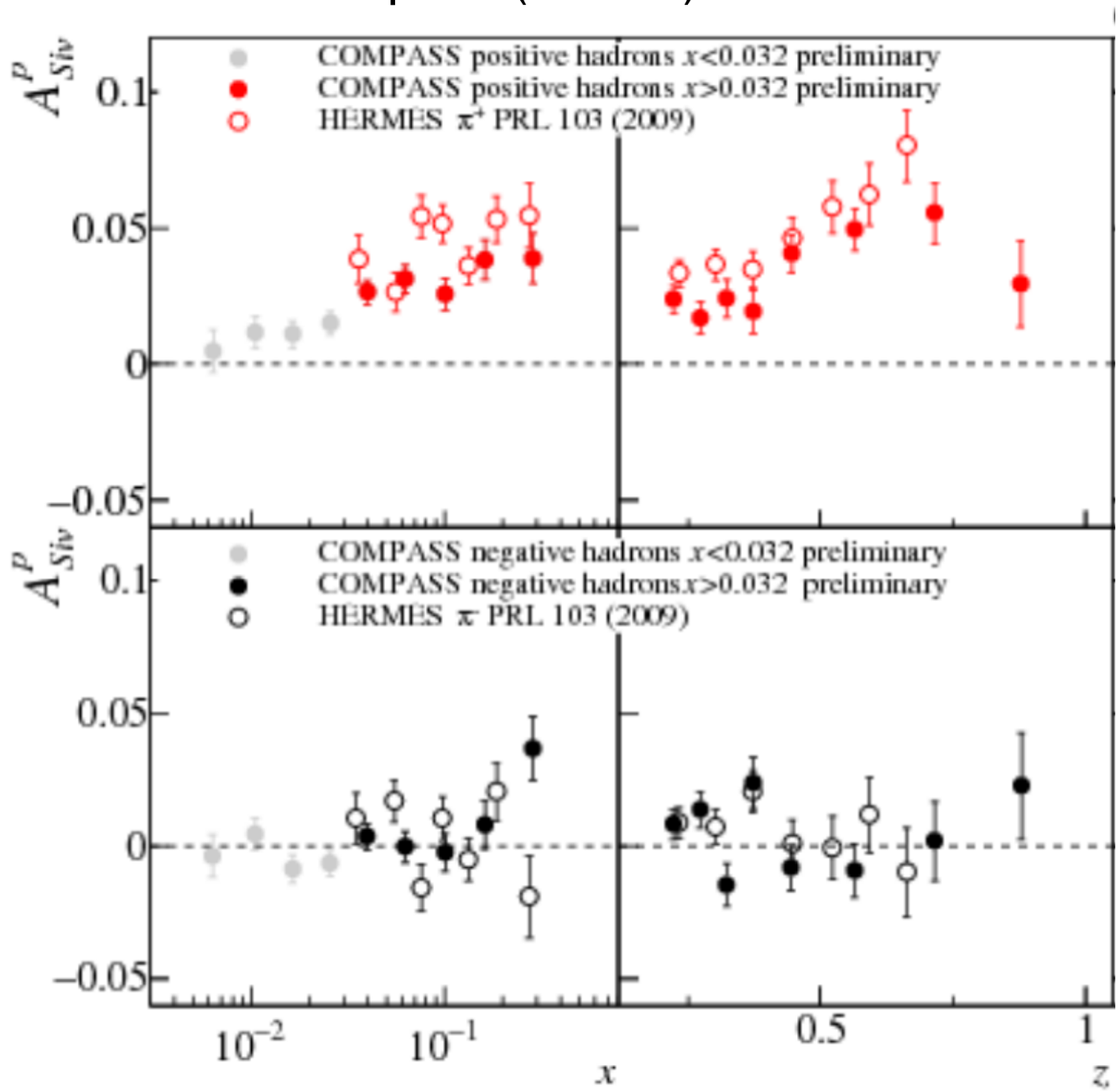
The SIDIS cross section involves the convolution between a parton distribution function (PDF) and a fragmentation function (FF) $\sigma_{SIDIS} \propto PDF \otimes FF$.

In contrast the Drell-Yan cross section only has the convolution of two parton distribution functions $\sigma_{DY} \propto PDF \otimes PDF$.

Drell-Yan allows for a more independent measurement of TMDs without relying on FF.

Large Sivers Asymmetries Observed in SIDIS

SSA from SIDIS sensitive to u-quark (top) and u-quark and d-quark (bottom) Sivers functions



http://arxiv.org/abs/1408.4405

- Both HERMES and COMPASS measured a non-zero Sivers function from SIDIS processes

Process Dependence of Sivers and Boer-Mulders

A consistent description of TMD effects is possible by introducing gauge link integrals in the scattering matrix elements of hard scattering processes.

Scattering matrix elements integrate soft gluon exchange in the initial and final states of high energy partonic reactions.

==> This framework suggests the Sivers and Boer-Mulders asymmetries are T-odd and have opposite sign in SIDIS and Drell-Yan.

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$$f_{1T}^{\perp}|_{DY} = -f_{1T}^{\perp}|_{SIDIS} \qquad h_1^{\perp}|_{DY} = -h_1^{\perp}|_{SIDIS}$$

Sivers and Boer-Mulders functions have modified universality and can only be non-zero if there is a sign flip.

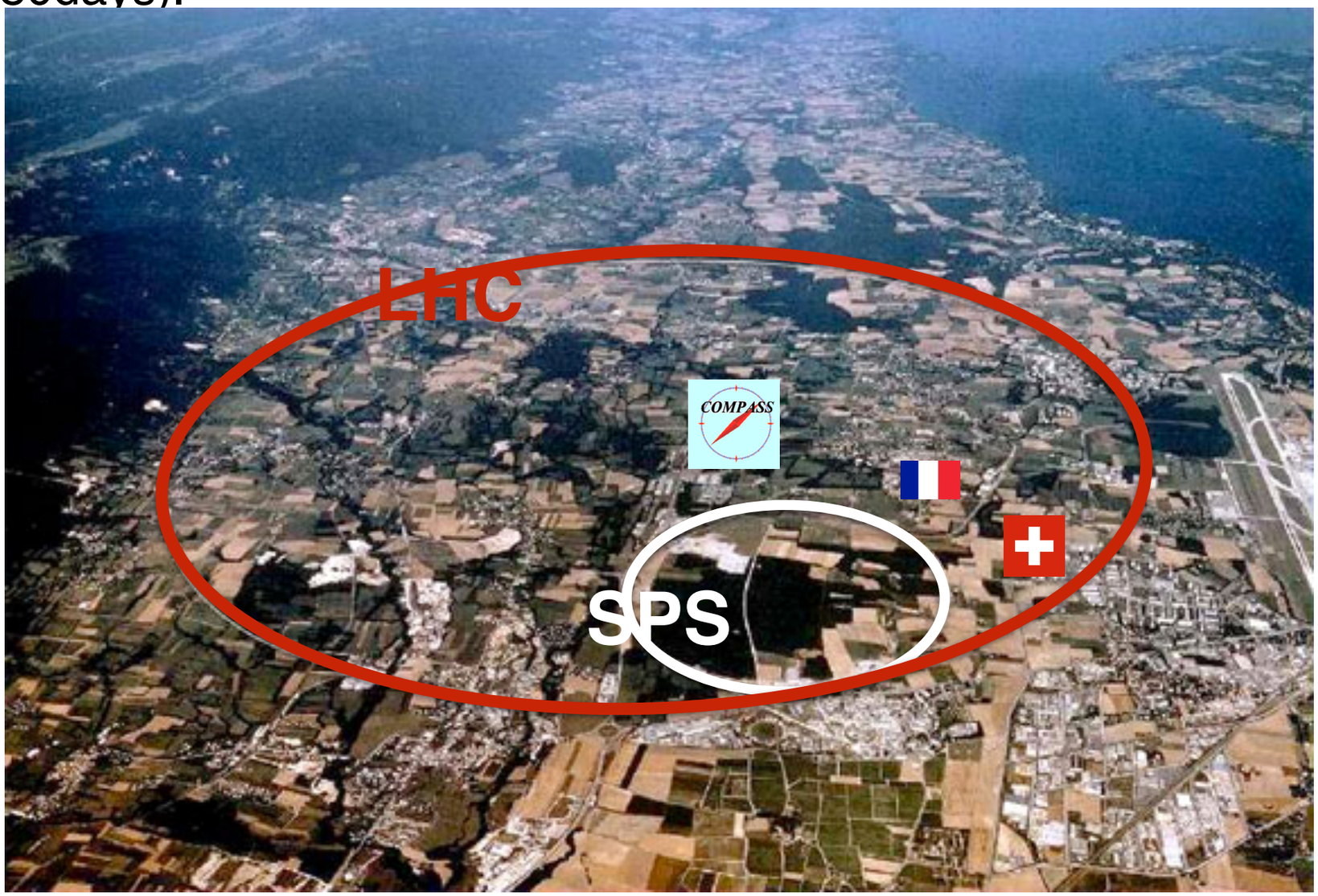
Testing for this opposite sign Sivers and Boer-Mulders effect is a fundamental test of the underlying theory.

COMPASS 2015 Drell-Yan

COMPASS will study the Drell-Yan process from a π⁻ beam on a transversely polarized NH_3 target. Intensity $I_{beam} = 6x10^7 \pi^-/sec.$

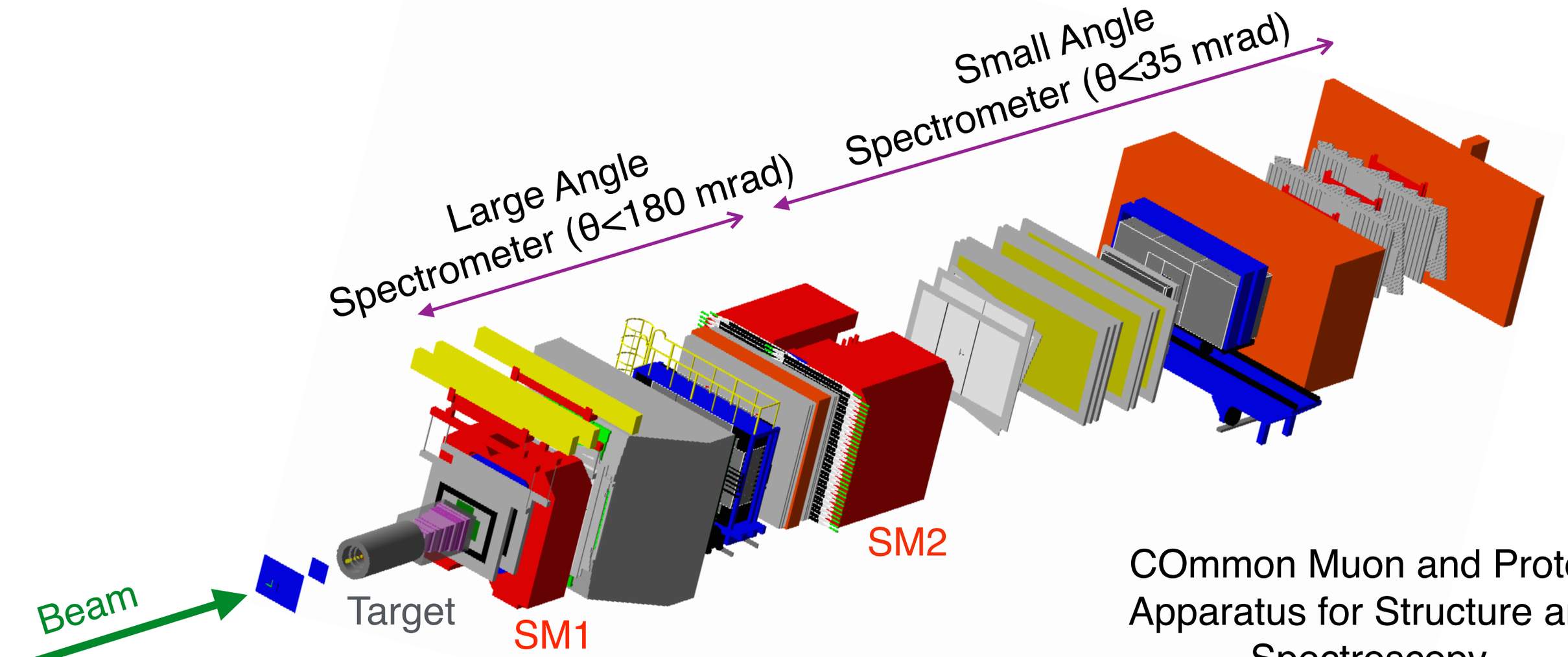
π⁻ beam selectively probes u-quark Sivers distribution in Drell-Yan.

Data taking has been approved at CERN and is taking place from May into November, 2015 (~180days).



COMPASS-II

- SPS M2 hadron or polarized muon beam: 190GeV or 160GeV
- NH_3 transversely polarized target or liquid H target
- Fixed target experiment which started in 2002



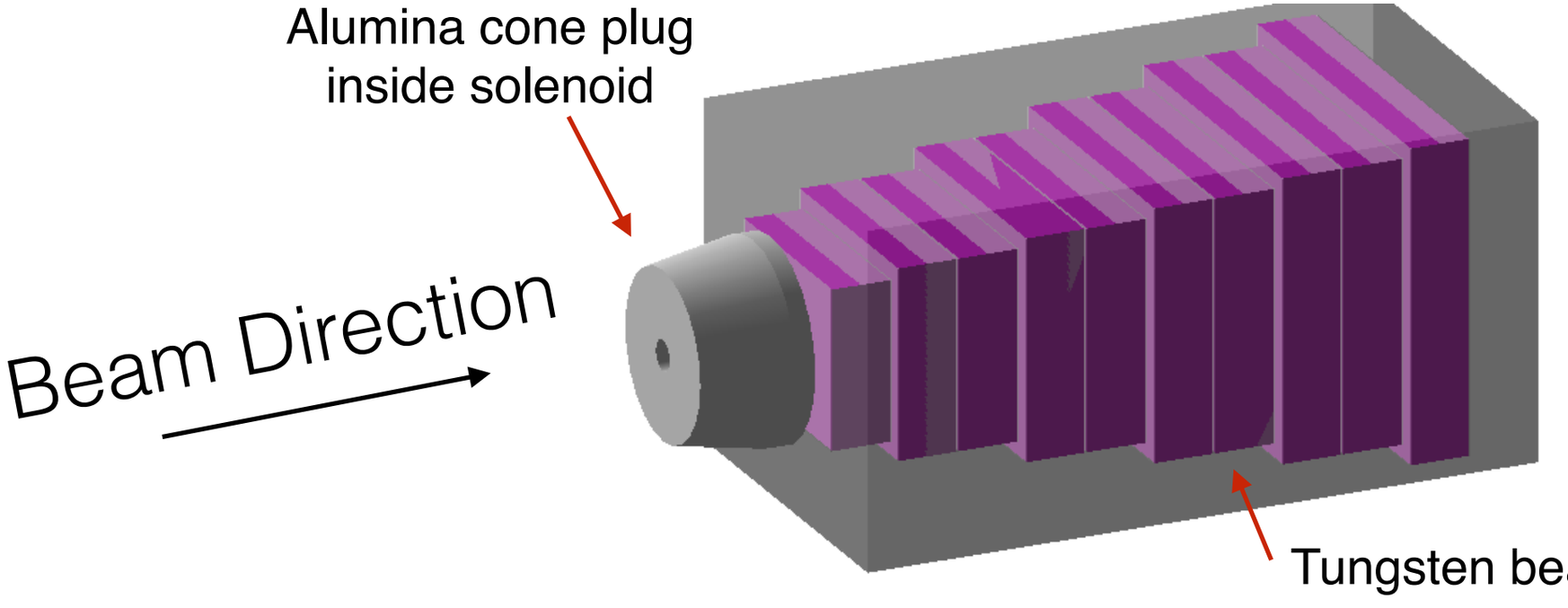
COmmon Muon and Proton Apparatus for Structure and Spectroscopy

First Drell-Yan Test at COMPASS

The Drell-Yan intensity was investigated in both 2007 and 2008 in an open configuration.

Intensity I = 4×10^6 π/sec in 2007 and I = 6.5×10^6 π/sec in 2008.

The results of these tests showed data can be reconstructed but there was high occupancy in the first tracking stations.



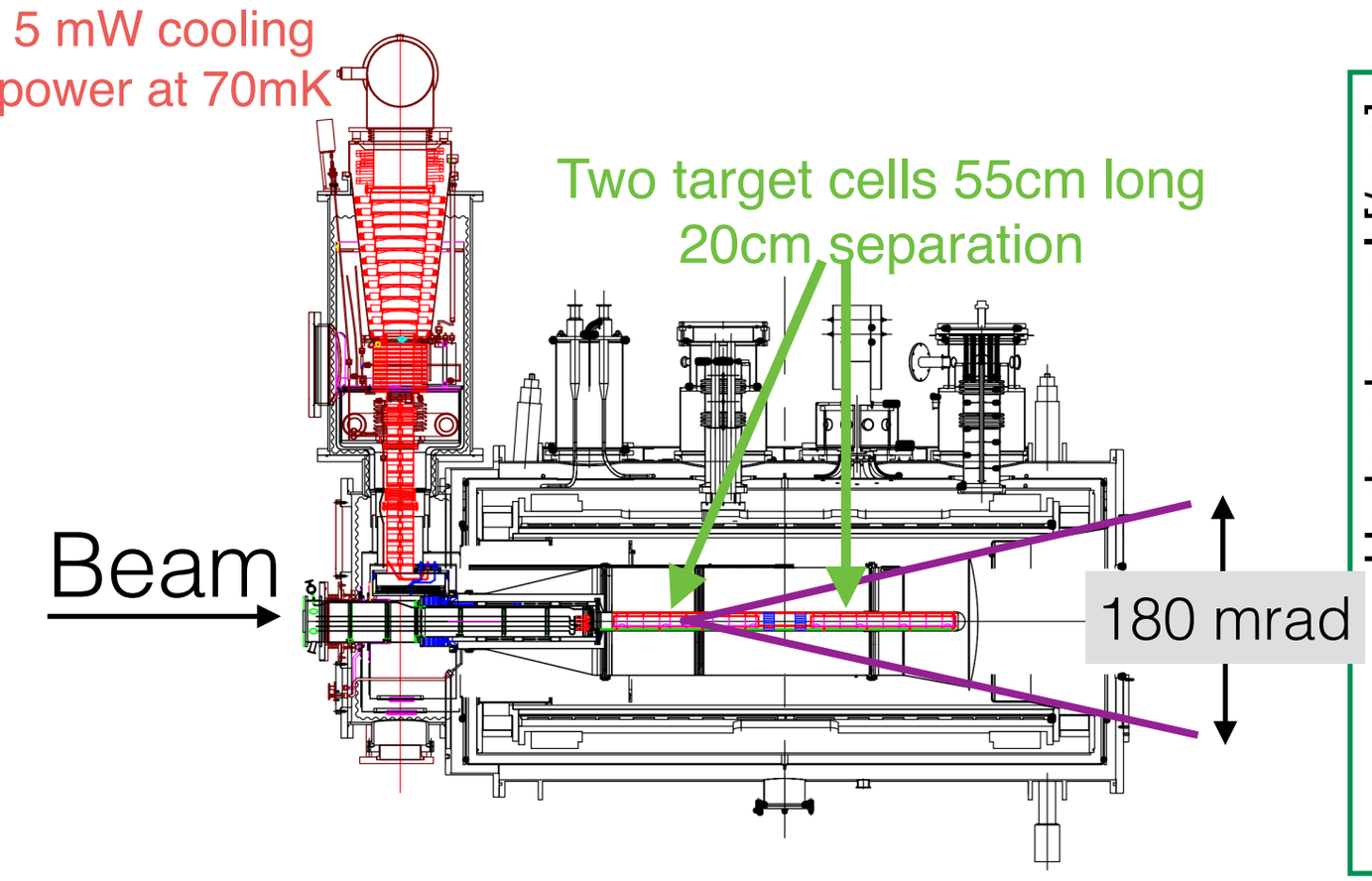
Absorber:
Good stopping power for hadrons and limited multiple scattering for leptons

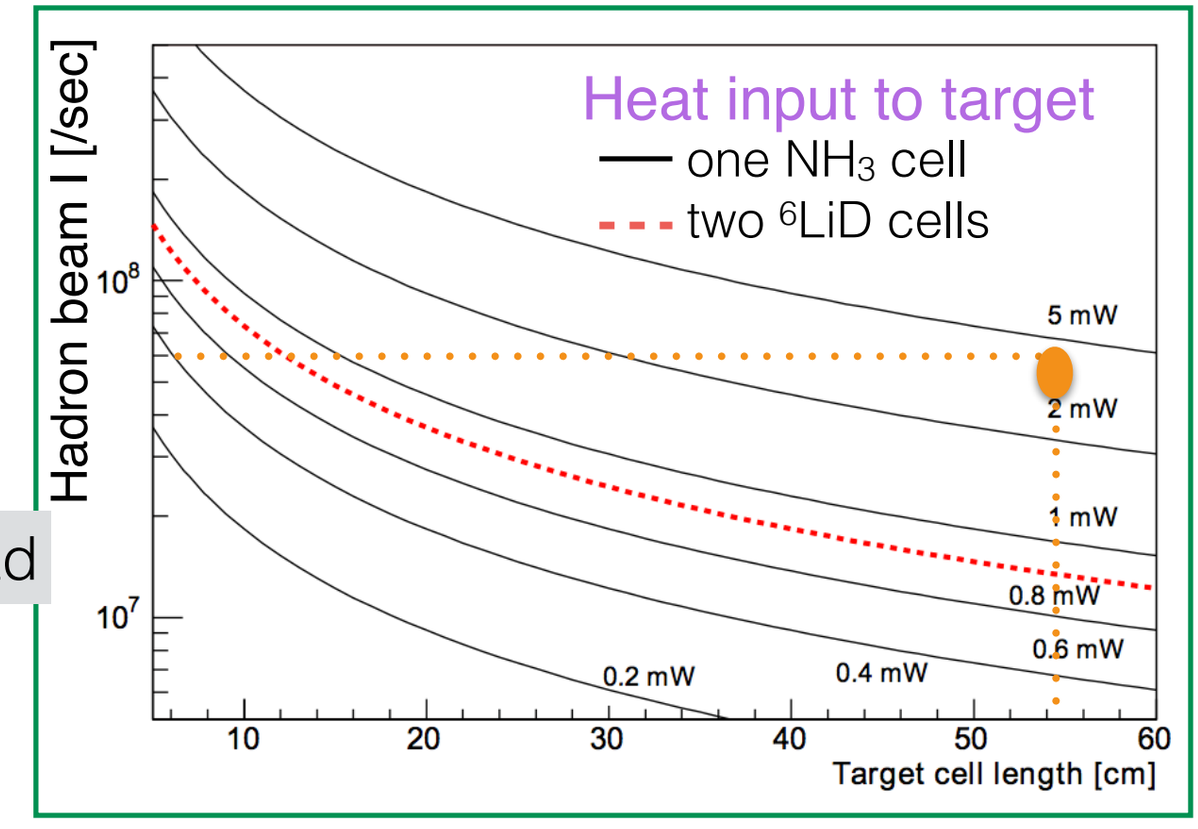
A hadron absorber was proposed to limit the physics output to events producing muons.

Transversely Polarized NH_3 Target

The target is first longitudinally polarized with a 2.5 T solenoid magnet using the dynamic nuclear polarization (DNP) method.

Target is then transversely polarized with a 0.6 T dipole magnet

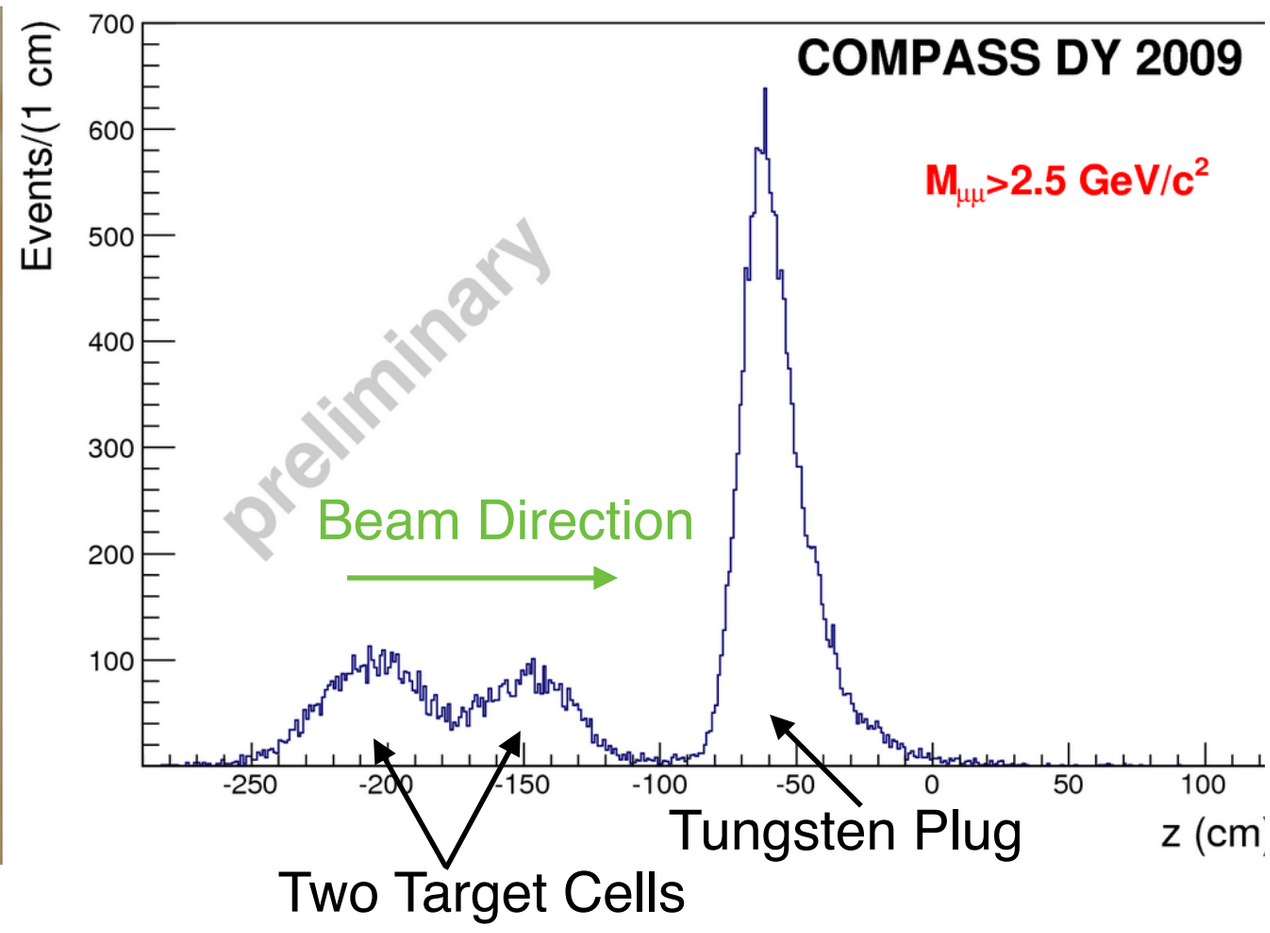


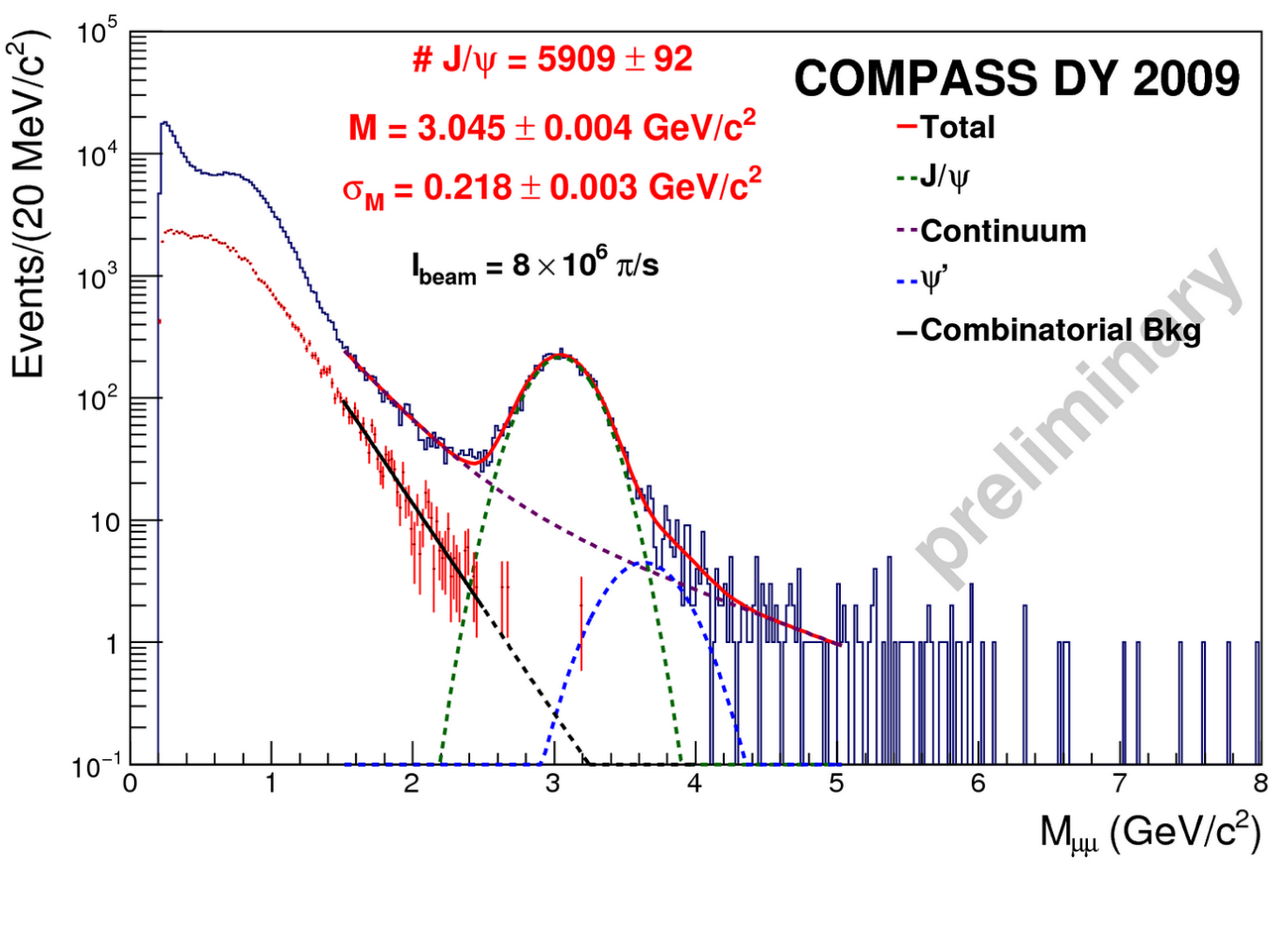


This NH_3 target was studied during the 2007 run and found to be suitable for transverse polarization.

Further Drell-Yan Test: 2009

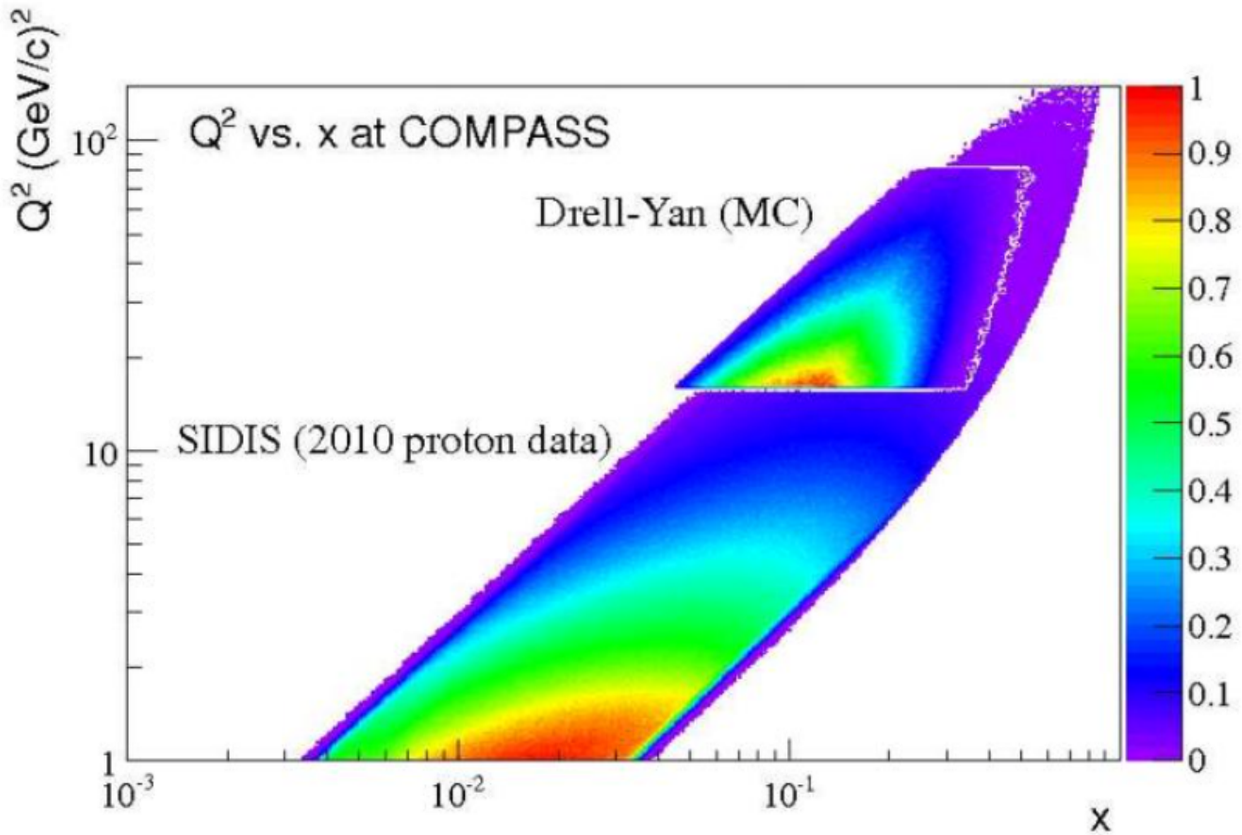
- 2 target cells and absorber with beam plug for ~3 days.
- First look at spin-independent Drell-Yan data.
- Experiment can reconstruct muon pairs and distinguish their vertices with an intensity = 1.6×10^7 π^-/sec and energy = 190GeV.





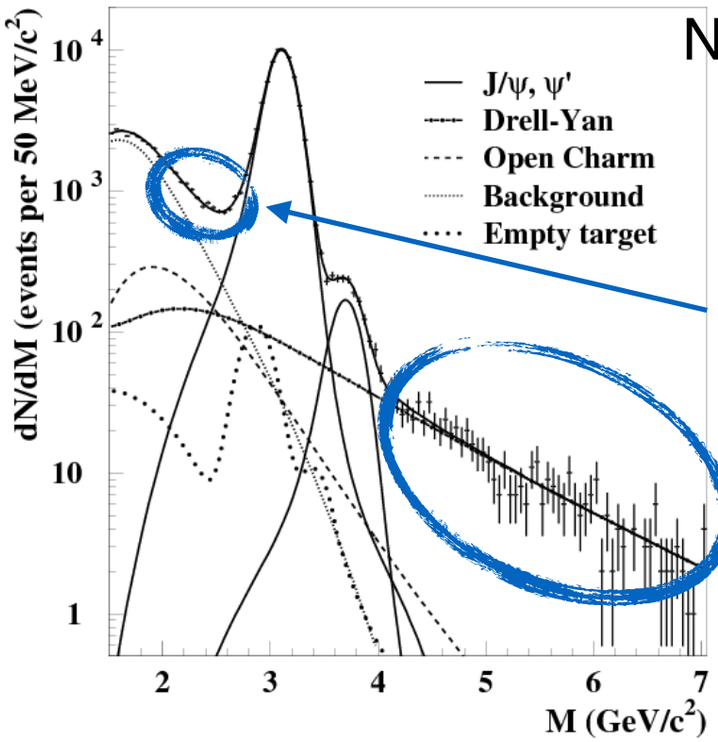
SIDIS and Drell-Yan at COMPASS

- COMPASS preformed a SIDIS run on a transversely polarized ^{6}LiD target in 2010.
- Phase space overlap between 2010 SIDIS data and upcoming Drell-Yan data.



- Limited systematic error in comparison between SIDIS and Drell-Yan.
- Higher accuracy comparing the Sivers function in the two processes.

Ideal to Measure Sivers



NA50 Collaboration
pp @ 400GeV

Higher signal to background ratio in 2-2.5 GeV and 4-9GeV

Cleaner region

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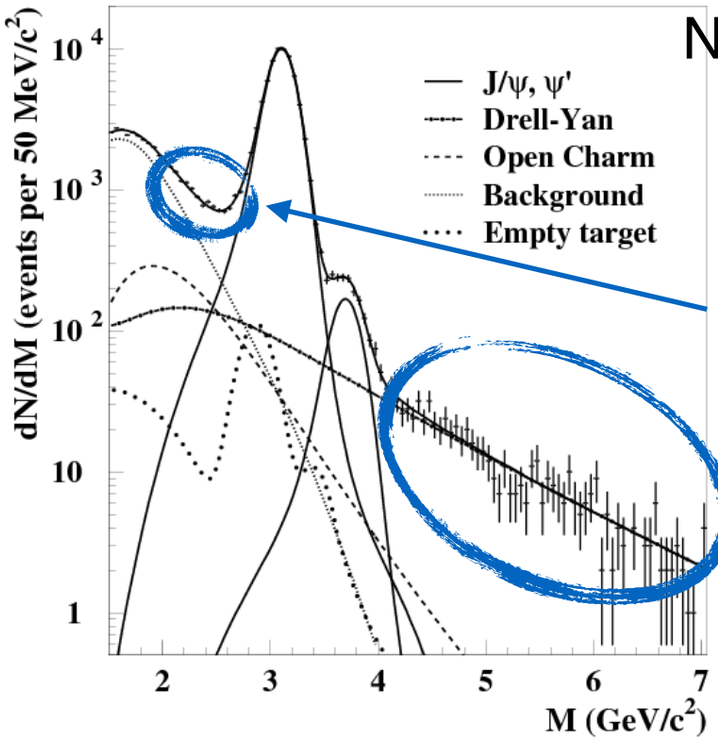

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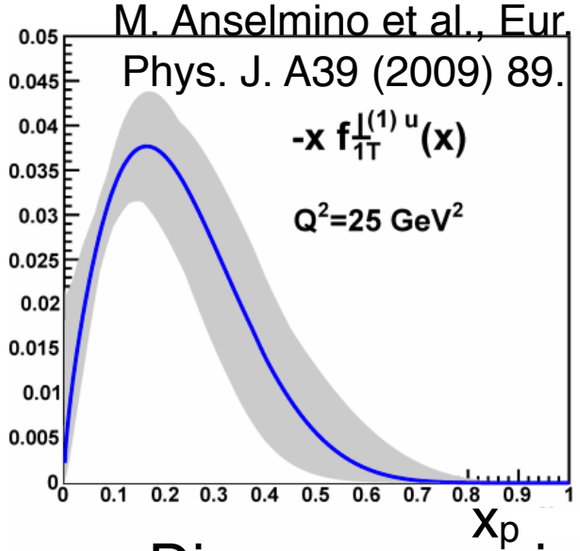
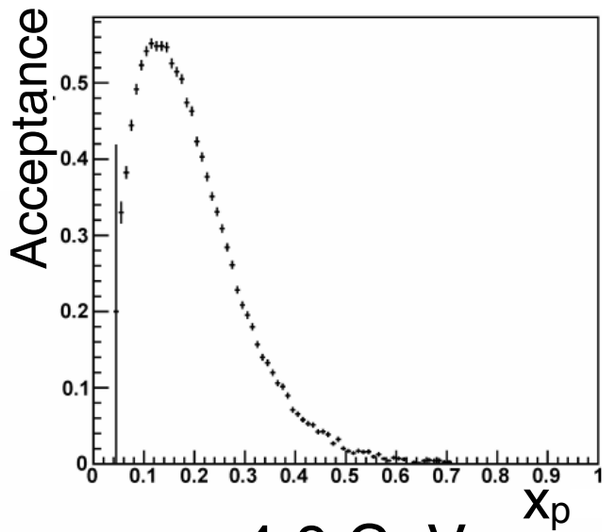
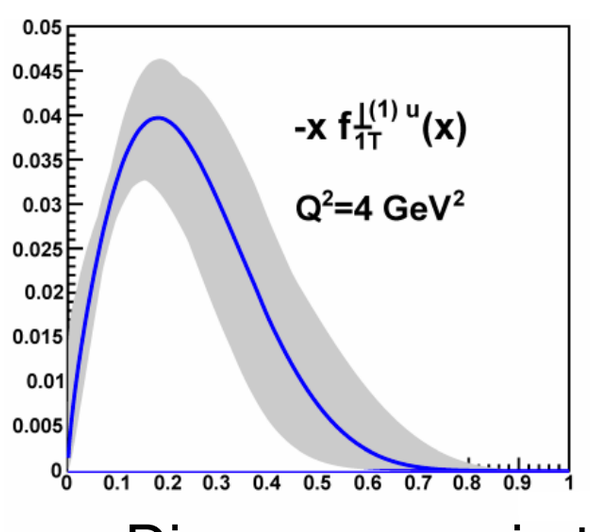
Large acceptance around Sivers function both in 4-9 GeV and 2-2.5 GeV mass ranges

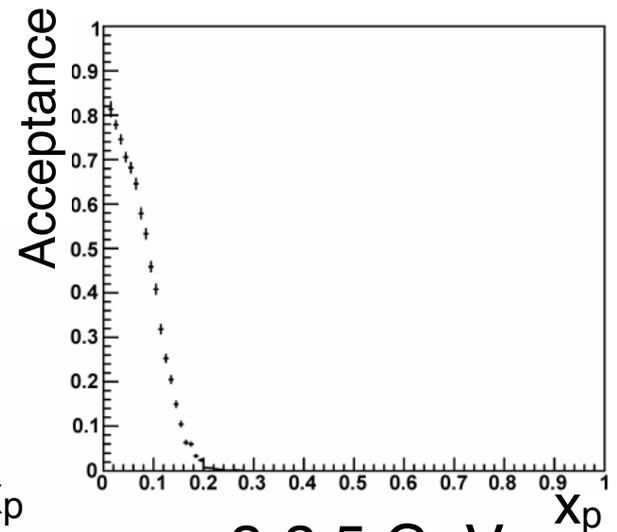
M. Anselmino et al., Eur. Phys. J. A39 (2009) 89.





Dimuon mass in the range 4-9 GeV

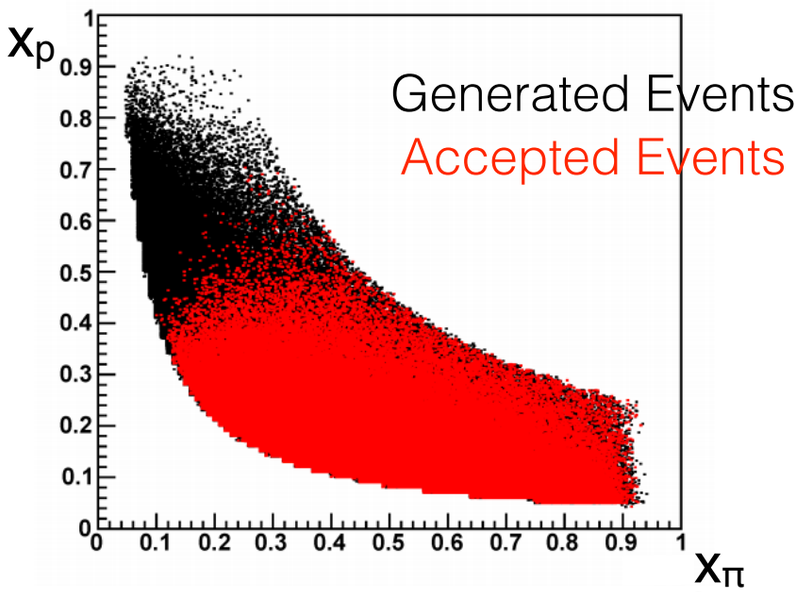




Dimuon mass in the range 2-2.5 GeV

Ideal to Measure Sivers

Large acceptance in valence region $x_{target} \gtrsim 0.05$ susceptible to polarizability.



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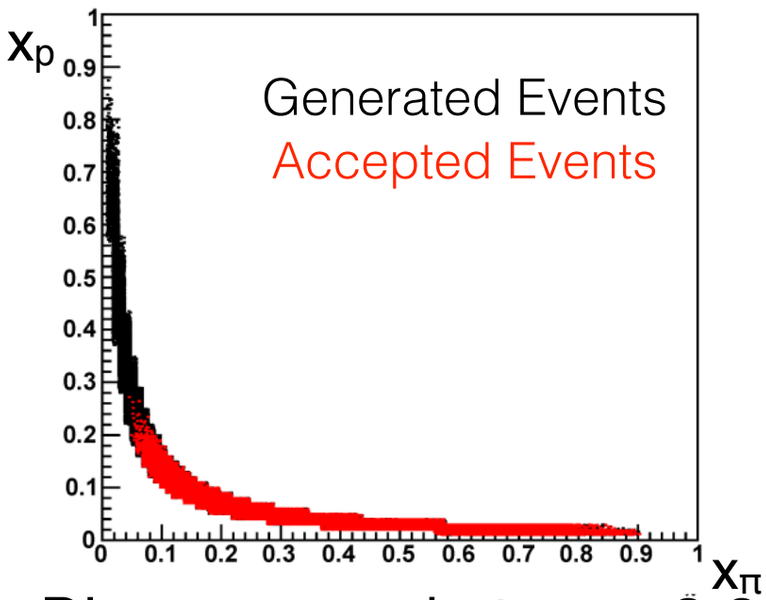

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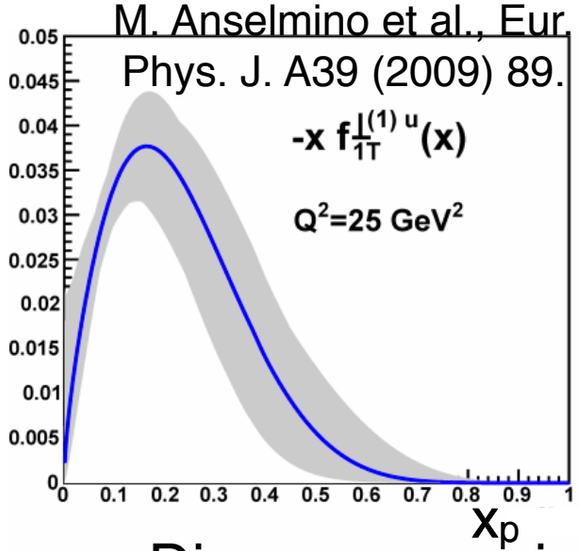

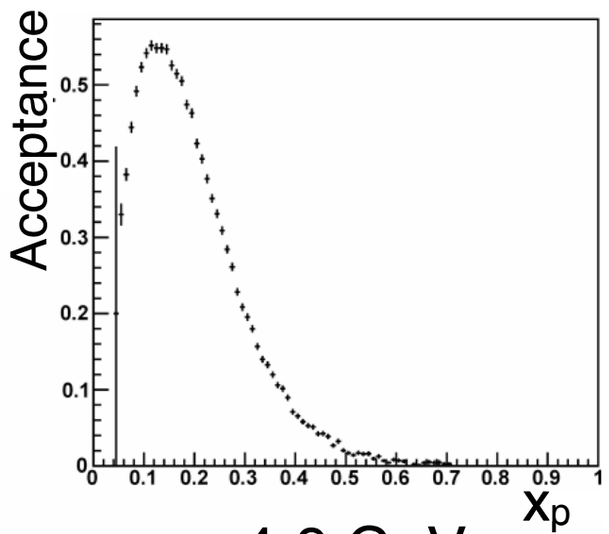

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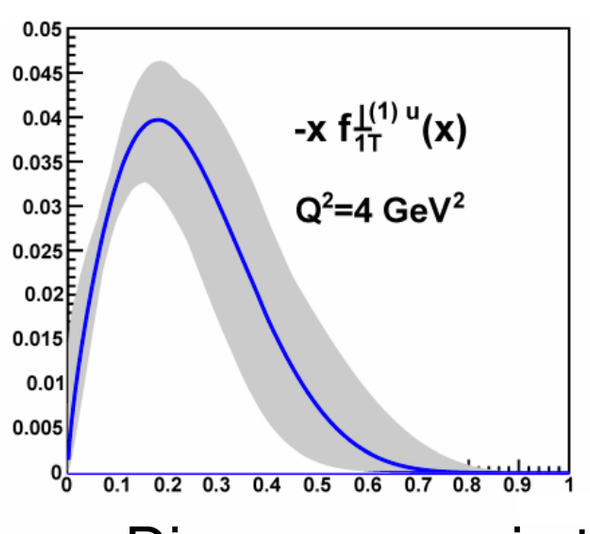
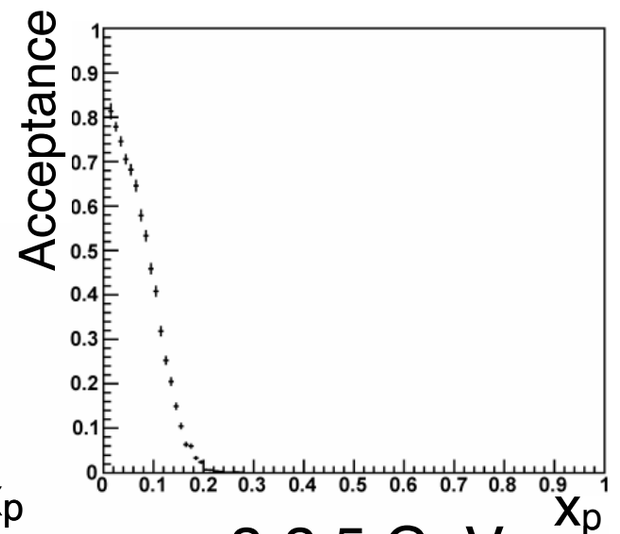




Dimuon mass in the range 2-2.5 GeV

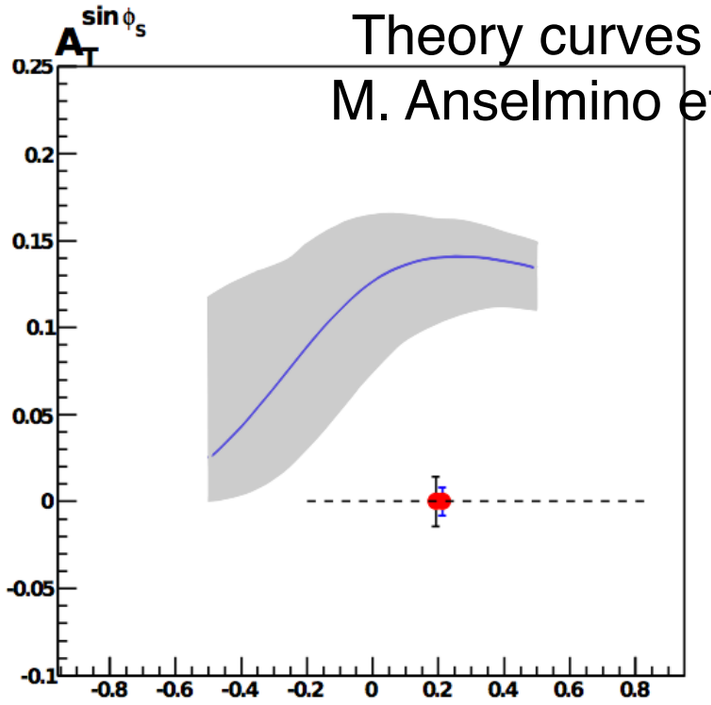
Drell-Yan Statistics

Luminosity L = $1.18 \times 10^{32} cm^{-2} s^{-1}$

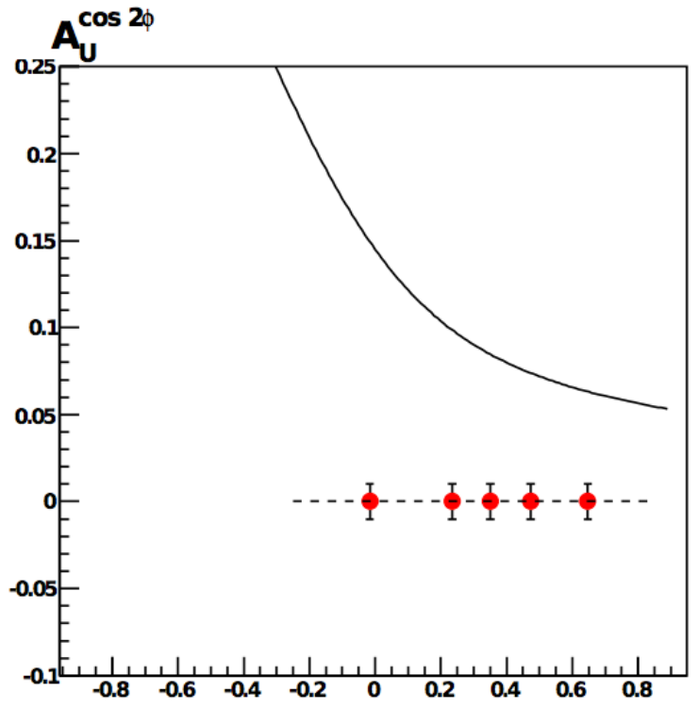
Expected statistical precision of Sivers amplitude from 140 days of data taking at COMPASS-II Drell-Yan run.

Data from generate for proposal

Theory curves by M. Anselmino et al.



$x_F = x_\pi - x_p$



$x_F = x_\pi - x_p$

Asymmetry	Dimuon mass (GeV/c^2)		
	$2 < M_{\mu\mu} < 2.5$	J/ψ region	$4 < M_{\mu\mu} < 9$
$\delta A_U^{\cos 2\phi}$	0.0020	0.0013	0.0045
$\delta A_T^{\sin \phi_S}$	0.0062	0.0040	0.0142

High mass range $4 < M_{\mu\mu} < 9$ GeV

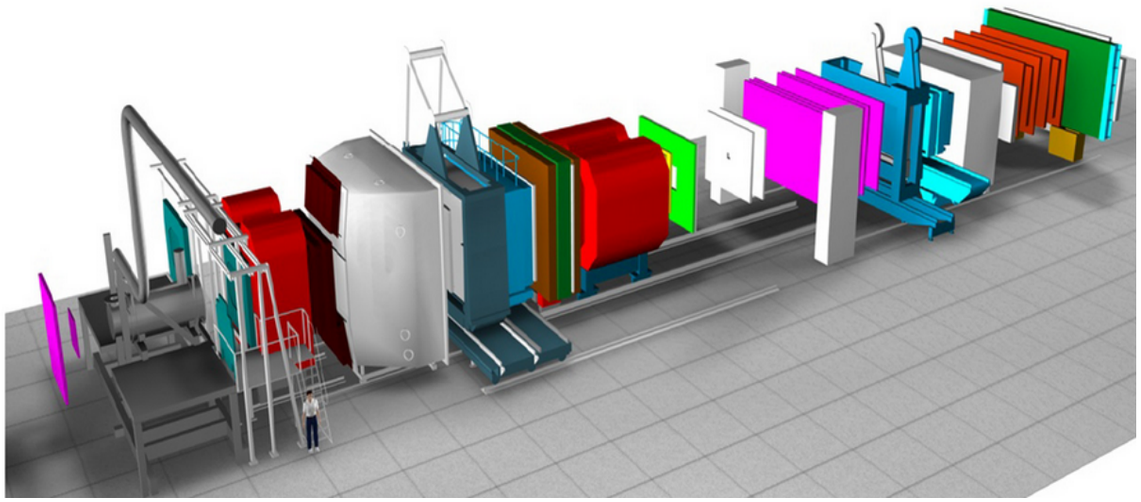
Summary

- Sivers and Boer-Mulders functions are predicted to be process dependent and flip sign between the Drell-Yan and SIDIS processes

- COMPASS has measured Sivers from the SIDIS process and is setup to measure it in Drell-Yan

- COMPASS is unique in that it uses a π⁻ beam to measure the u-quark Sivers function and the timing is right to study Drell-Yan

- COMPASS is taking data now!



Back Up

Test

2007

160 GeV beam on longitudinally polarized NH3 target with 3 target cells.

~12 hours of data taking

2008

190 GeV beam and polyethylene target

2009

190 GeV beam and 2 Cell polyethylene target (CH2)

Target

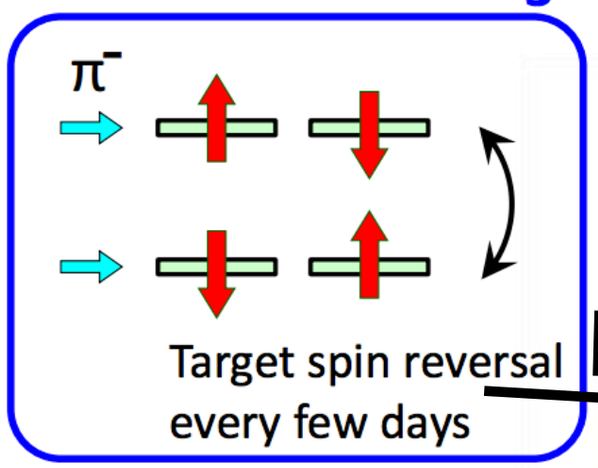
2 microwave systems ~70GHz corresponding to Zeeman splitting for electrons

Polarization can be maintained at below 100mK

Ammonia reaches 80% polarization after 1 day

Experimental Setup

Polarized NH_3 target



Target

- Materials: p(NH_3)
- Dilution factor: 0.22
- Polarization: > 90%

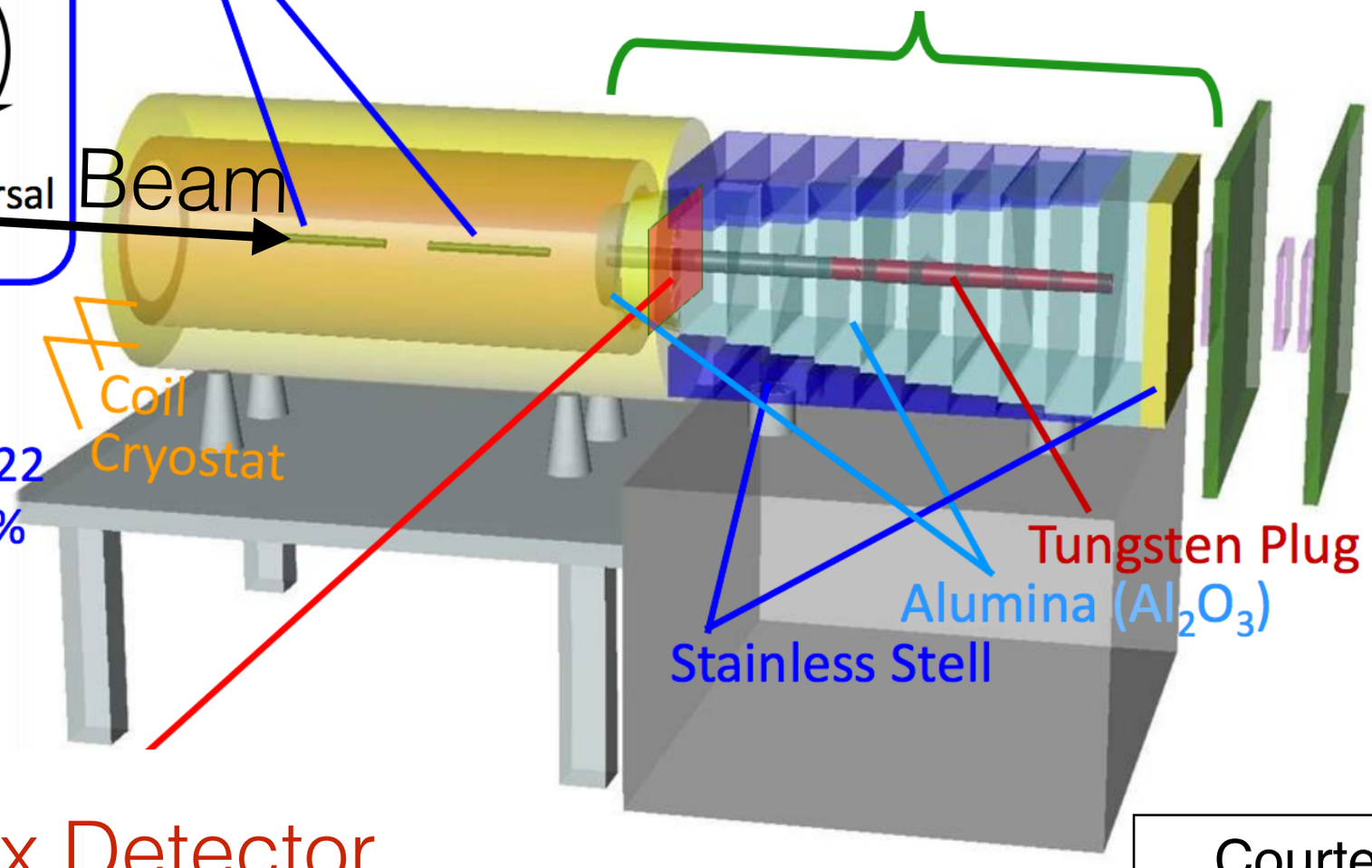
Magnet

- Solenoid : 2.5 T
- Dipole : 0.5 T

Absorber

Large stopping power for hadrons

Minimal multiple scattering for muons



Vertex Detector

Courtesy of Takahiro Sawada