COMPASS Status report

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On behalf of COMPASS

- **Physics results from hadron beam data**
- **„ „ from muon beam data**
- **2012 run**
- **Preparation for 2015 polarized Drell-Yan**

Physics from hadron beam

Rich program on hadron spectroscopy at COMPASS,
search for exotic mesons

- Diffractive resonance production
- Central production

π, K, p beams - 190 GeV : large energy transfer spectrum t
Spectrometer : flat acceptance, ECALs/ HCALs, RICH id.
charged & neutral channels
Huge statistics

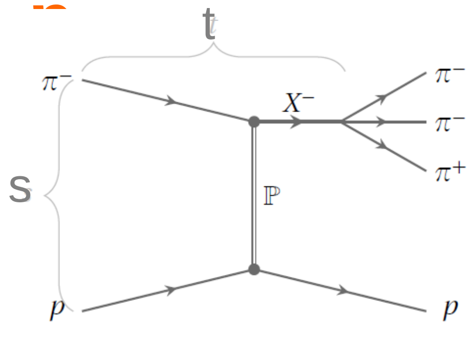
Major progress on analysis
Potential for discovery of small intensity eventual new states

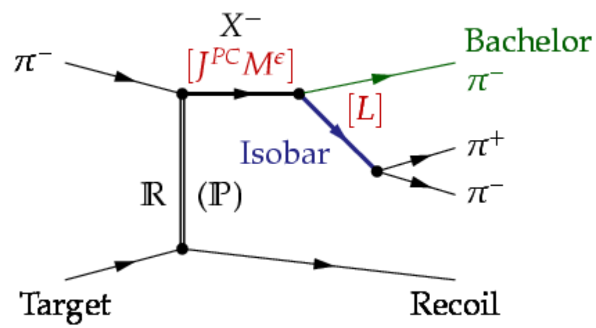
Selected results

- Diffractive processes $\pi^- p \rightarrow \pi^-\pi^+\pi^- p_{recoil}$
- Central production $p\ p \rightarrow p K^+ K^- p$

- Pion polarisability $\pi^-\ Ni \rightarrow \pi^-\ Ni\ \gamma$ - (2009 Primakoff)

Diffractive resonance production in $\pi^- p \rightarrow \pi^-\pi^+\pi^-$





Isobar model

Partial waves :

J^{PC} M^{ε} [isobar] L

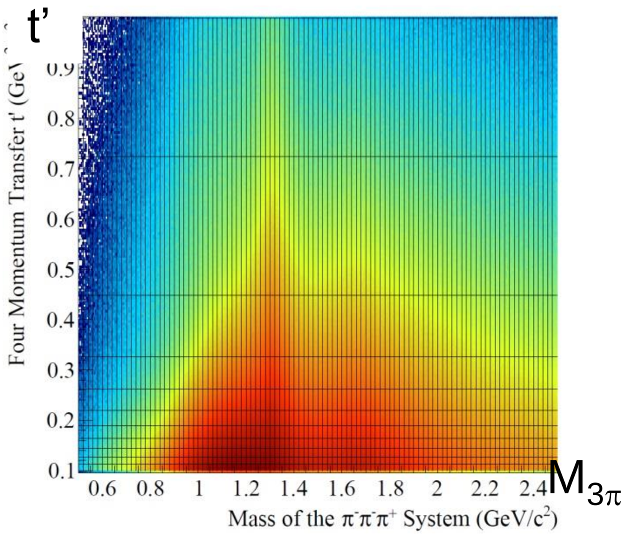
J^{PC}**-exotic** mesons

Study 2008 data, large statistics

Partial Wave Analysis (PWA):

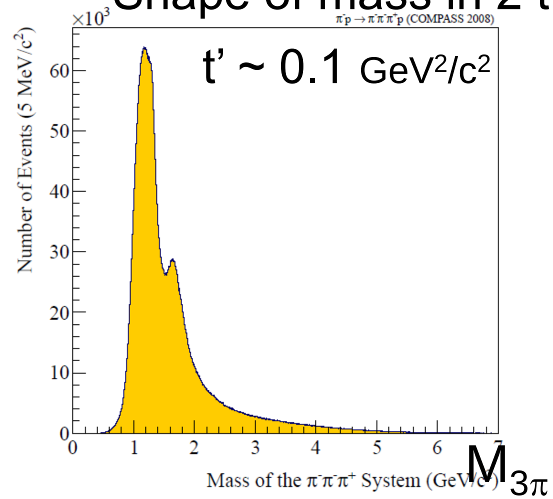
Step 1: In ($M_{3\pi}$, t') bins, 88 PW, (27 with thresholds)
Impose isobar description

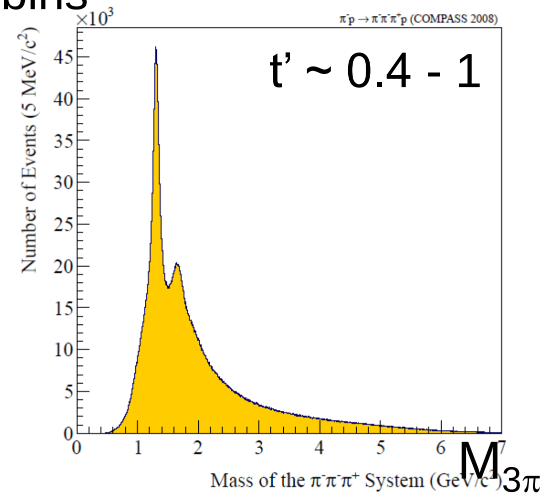
Step 2: $M_{3\pi}$ dependent fits on selected waves,
combined fit of t' bins
(same mass, width; different background and couplings)
Extract resonance parameters



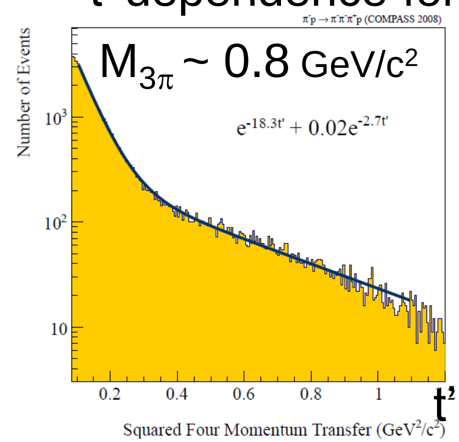
11 x 100 (t', $M_{3\pi}$) bins

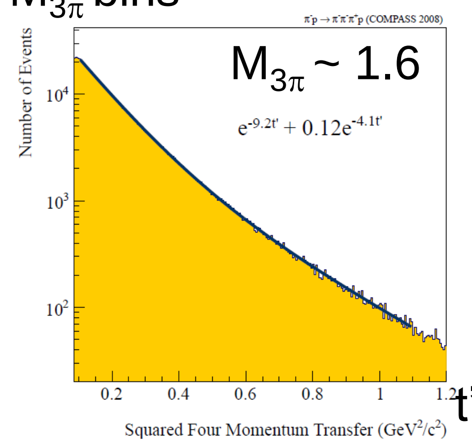
Shape of mass in 2 t' bins





t' dependence for 2 $M_{3\pi}$ bins





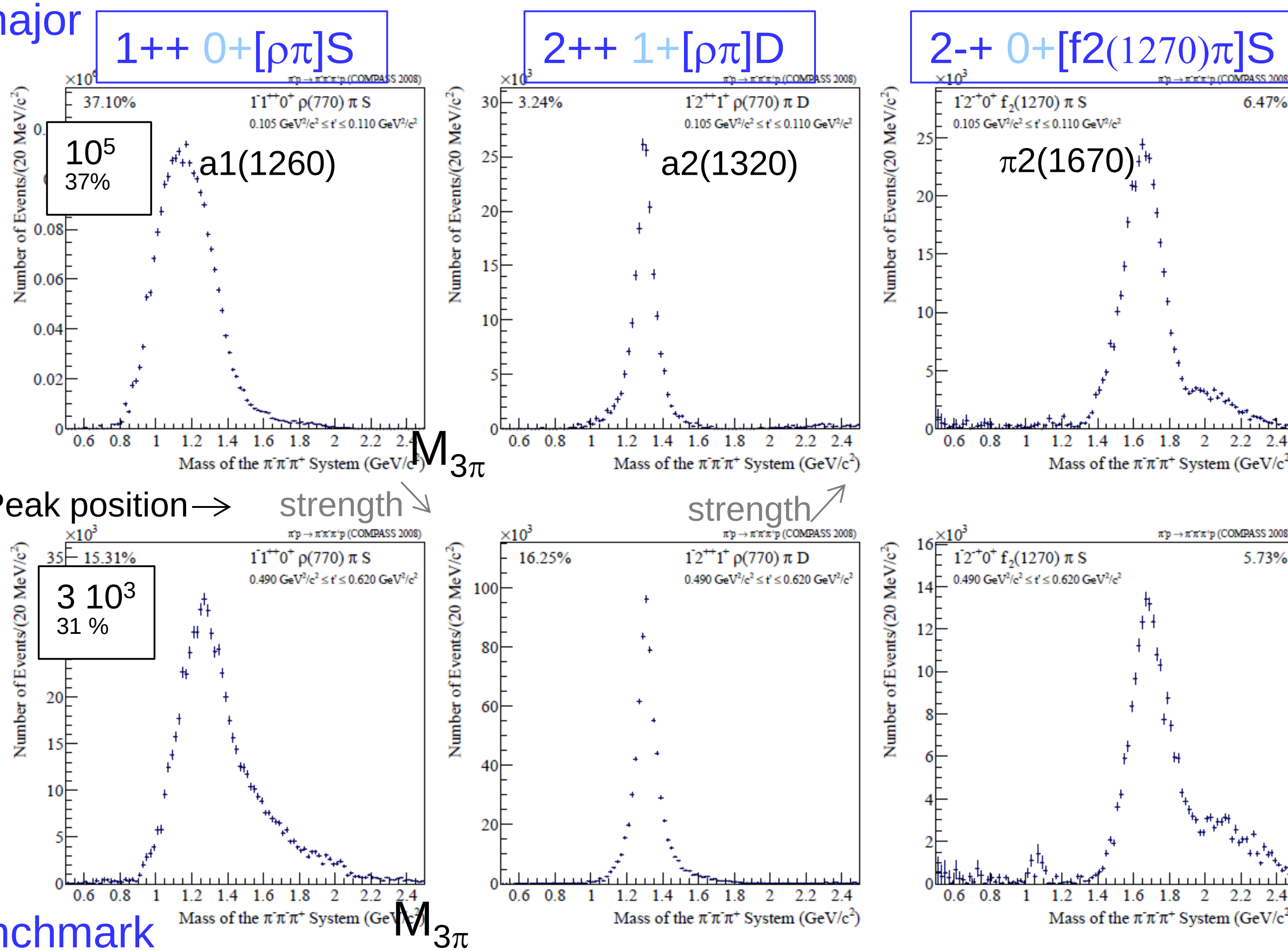
Step 1: PWA in (M, t') bins

Intensities for 3 major waves vs $M_{3\pi}$

t'~0.1 (GeV^2/c^2)

100 $M_{3\pi}$ bins

t'~0.5

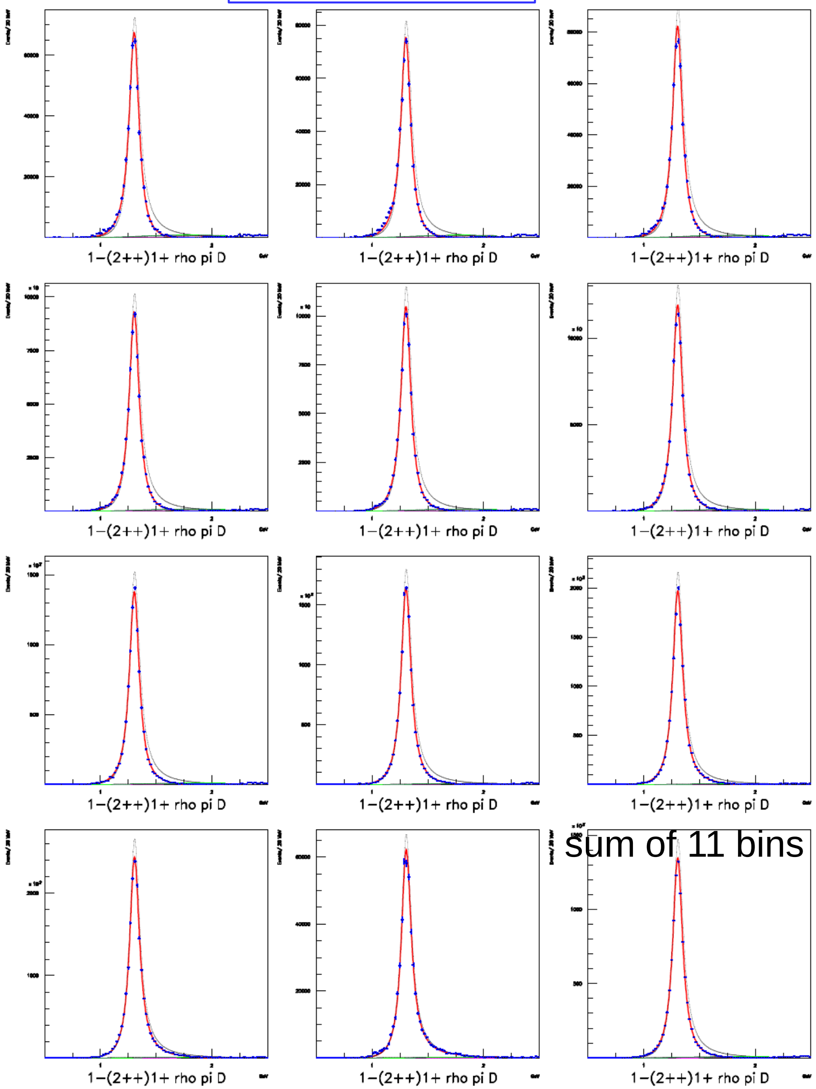


- a1 as benchmark
- Possibility of separation of resonant and non resonant content

high statistics & fine binning

Step 2 : PWA $M_{3\pi}$ dependent fit, ex: 2++

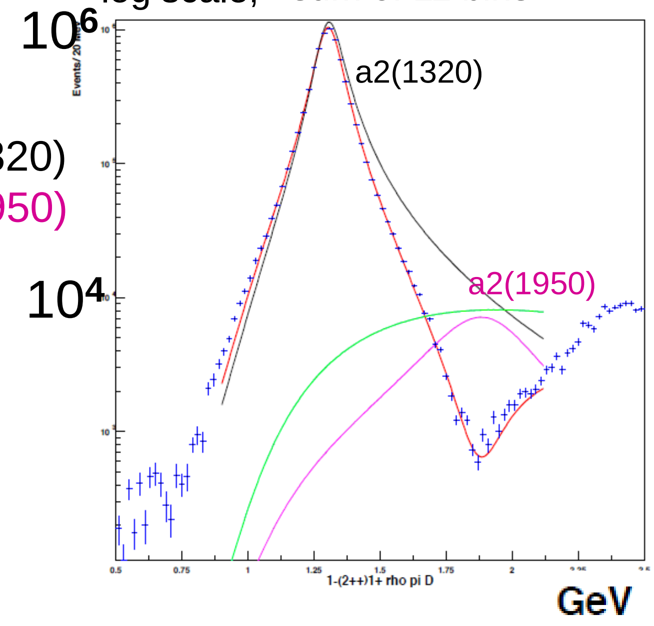
2++ 1+[ρπ]D



- Mass dependent fits for 5 selected waves, using a model for 3π resonance + bkgd.
- 11 t' bins
- Work in progress

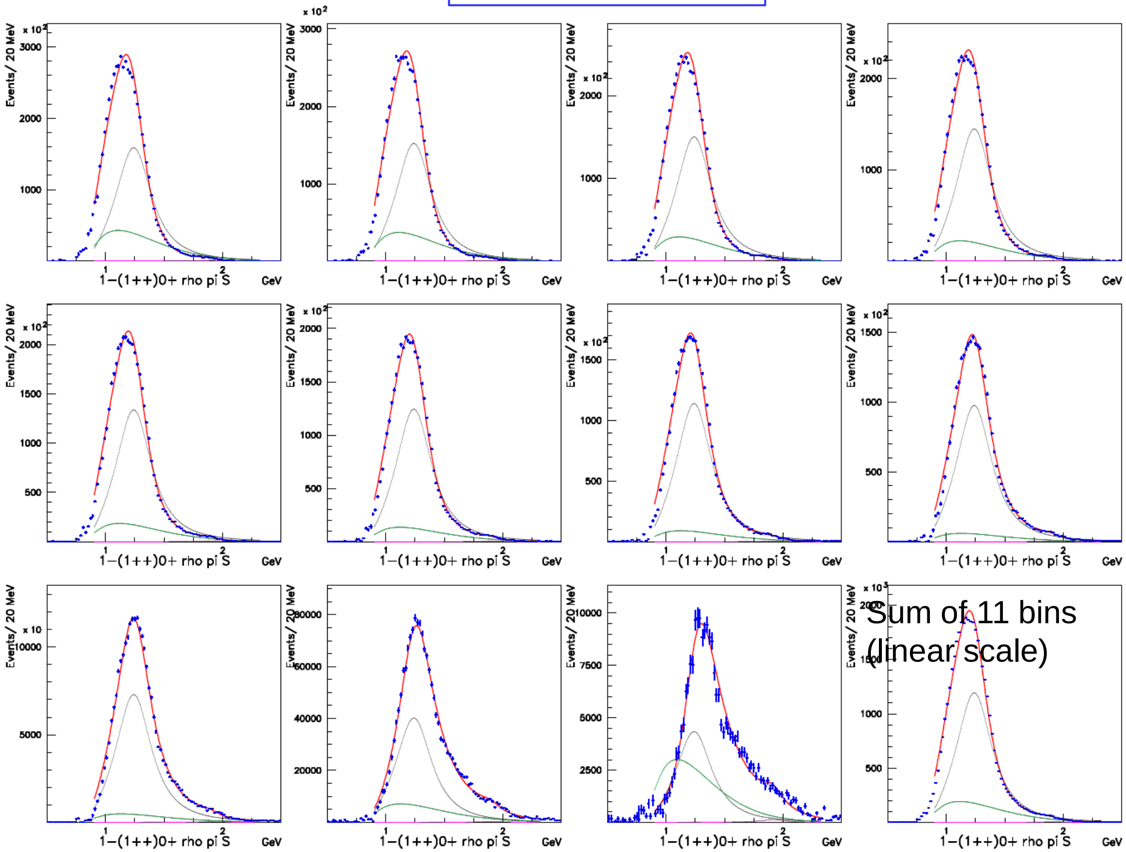
log scale, sum of 11 bins

• data
--- model :
BW-a2 (1320)
+ BW-a2 (1950)
+ Bkgd



PWA $M_{3\pi}$ dependent fit, ex: 1++

1++ 0+[ρπ]S



- data

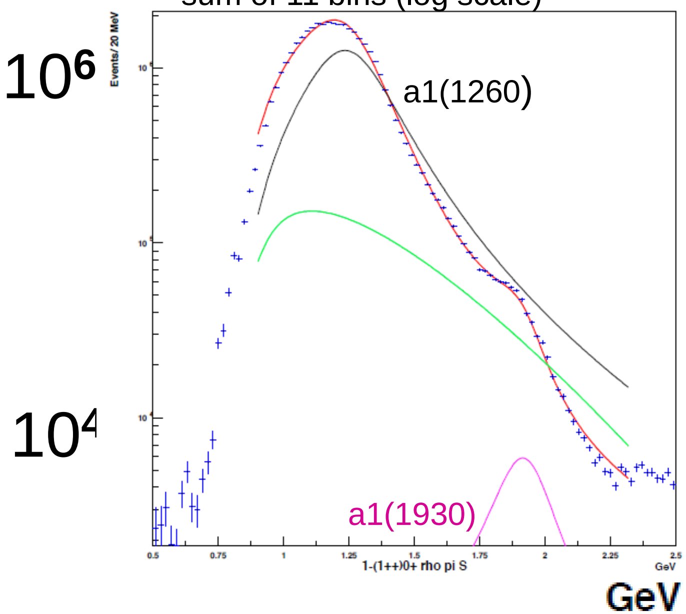
--- model :

BW-a1 (1260)

+ BW-a1 (1930)

+ Bckgd

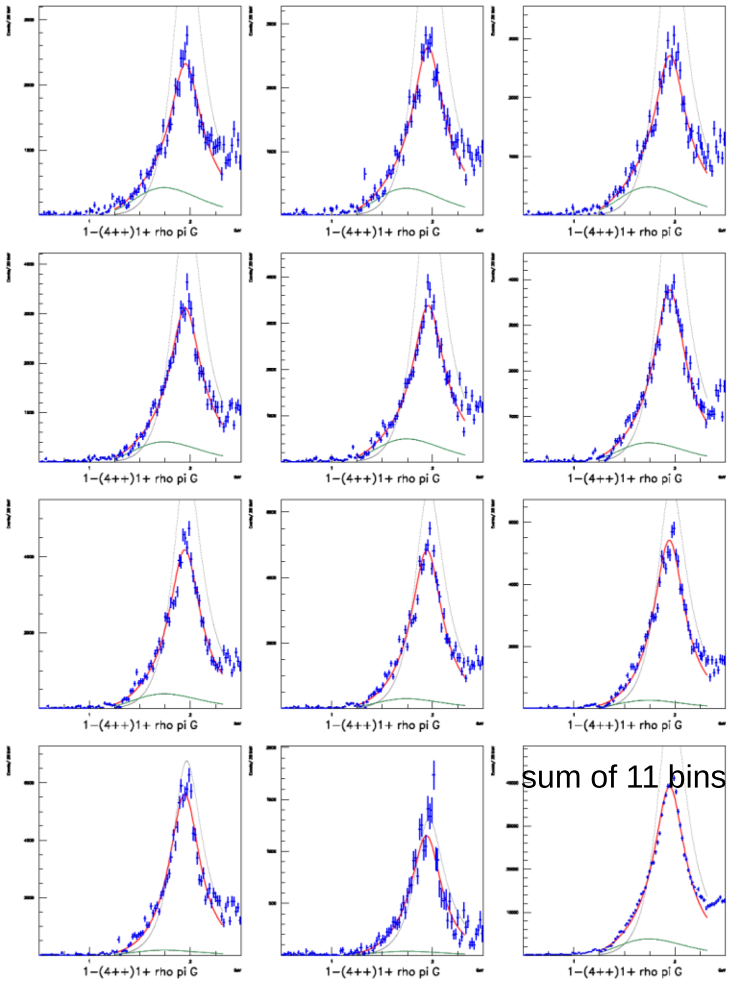
sum of 11 bins (log scale)



PWA M3π dependent fit, ex: small wave 4++

4++ 1+[ρπ]G

<1% of total intensity,
a4(2040) well established



- data

--- model :
BW-a4 (2040)
+ Bckgd

Diffractive resonance production - conclusion

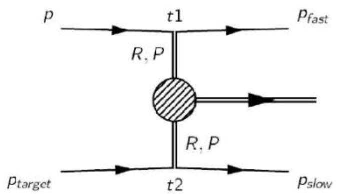
• Mass dependent PWA of 3π charged channel,
Huge statistics , 50 M events, 10 times more than previous expts
11 t' bins

• Well established resonances serve as benchmark

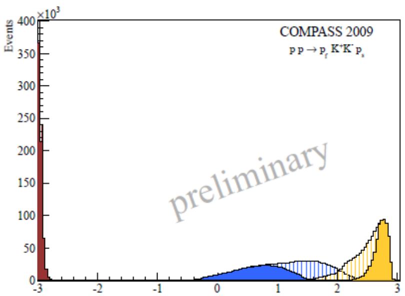
• Analysis proves the potential for establishing new small waves with firm grounds

• Spin exotic $\pi_1(1600)$ not shown here.
High dependence on model, in particular background shape.
Ongoing studies.

Central production p p→ pK$^+$K$^-$p



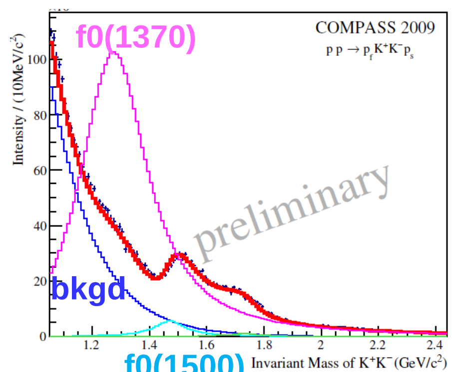
Double Pomeron exchange → glue rich environment
Production of non q-$\bar{q}$ meson (glueballs, hybrids) at central rapidities



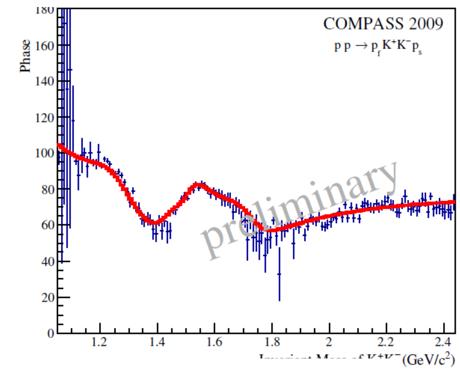
rapidities

pK+K-p channel
Selection of central production
Cut on p(p_{fast}) >140 GeV;
K id (RICH)

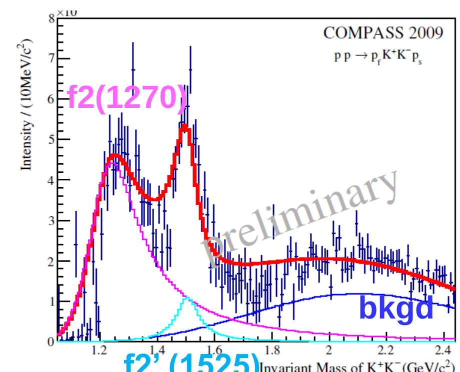
Intensity of S wave



Phase S-D



Intensity of D wave



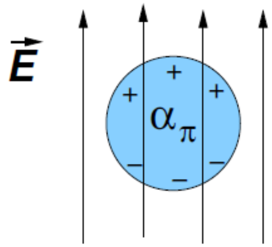
Mass dependent PWA

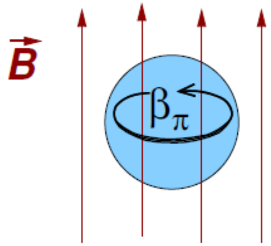
- Preliminary fit requires strong f0(1370) signal
- Strong background (non resonant contributions at low mass)

Pion polarisabilities - Primakoff 2009 data

Polarisabilities: deviation from pointlike particle

electric (α) and magnetic (β)





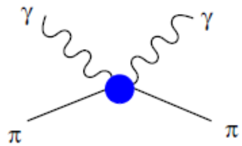
Predictions from Ch PT:

$$\alpha_\pi + \beta_\pi = (0.2 \pm 0.1) \cdot 10^{-4}\mathrm{fm}^3$$
$$\alpha_\pi - \beta_\pi = (5.7 \pm 1.0) \cdot 10^{-4}\mathrm{fm}^3$$
$$\alpha_\pi = (2.9 \pm 0.5) \cdot 10^{-4}\mathrm{fm}^3$$

Experiments inconclusive:

$\alpha_\pi - \beta_\pi$ = 4 -14 . 10^{-4}

assuming ($\alpha_\pi + \beta_\pi = 0$)



At LO, Compton cross section is proportional to $\alpha_\pi - \beta_\pi$

$\pi\,\gamma \rightarrow \pi\,\gamma$ measured via $\pi\,Z \rightarrow \pi\,Z\;\gamma$

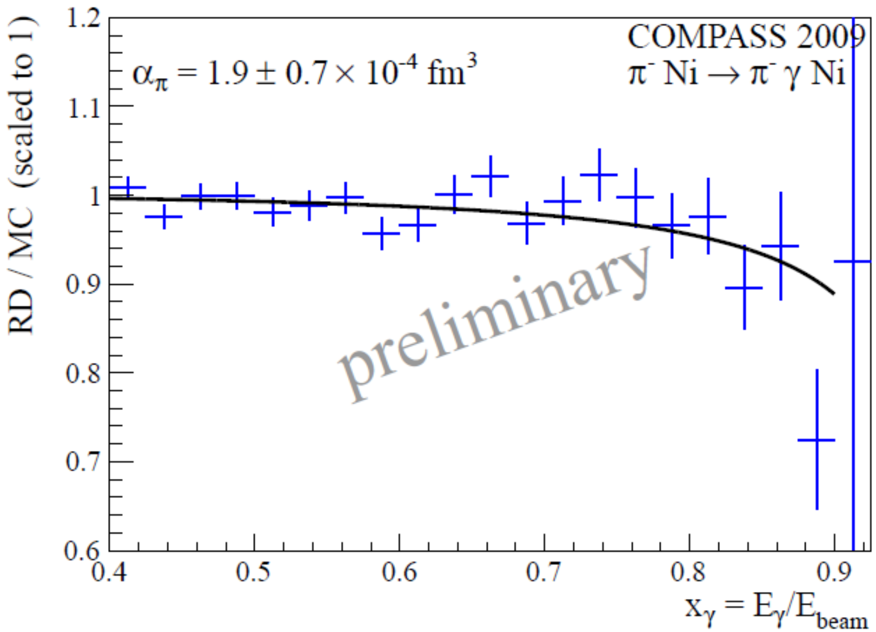
Pion polarisability - result

2009 data $\pi^- Ni \rightarrow \pi^- Ni\ \gamma$ exclusive reaction

- high resolution vertexing, precise calorimetry, calibrations, alignment
- precise MC description of spectrometer performance,

$\alpha_\pi - \beta_\pi$ extracted from comparison of data to MC(pointlike)

Ratio:
data/MC
(pointlike)

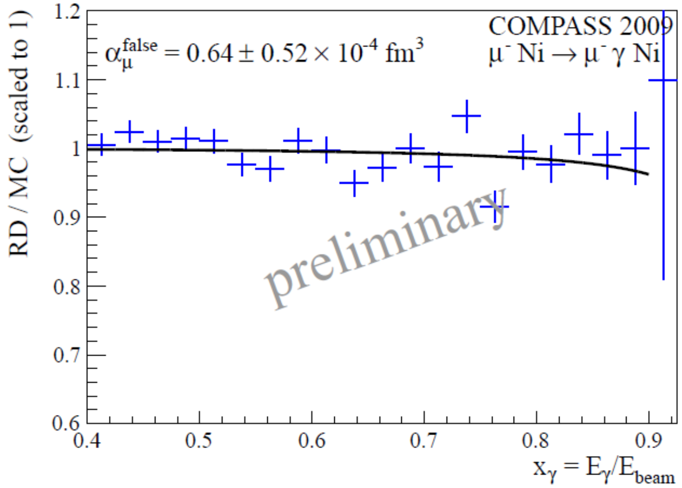


$\alpha_\pi - \beta_\pi$ = (3.7 ± 1.4) x 10^{-4} fm^3

α_π = (1.9 ± 0.7)x 10^{-4} fm^3 (assuming $\alpha_\pi + \beta_\pi = 0$)

π Polarisability - systematic uncertainties

μ control measurement



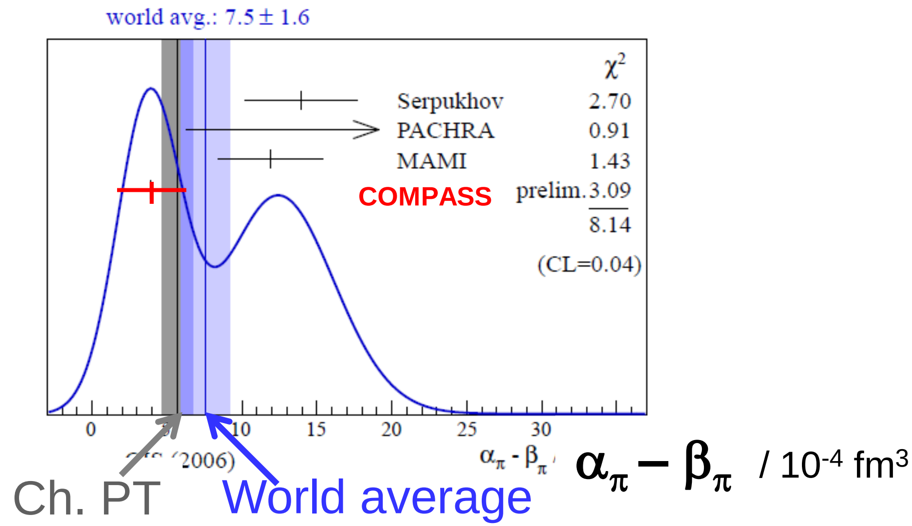
Result for μ compatible with expectation from simulation

→ Gives an upper limit on systematic uncertainty from sources common to μ and π

source of systematic uncertainty	estimated magnitude $CL = 68\,\%$ $[10^{-4}\ fm^3]$
tracking	0.6
radiative corrections	0.3
background subtraction in Q	0.4
pion electron scattering	0.2
quadratic sum	0.8

Pion polarisability – result vs world data

COMPASS result :
in agreement with ChPT expectation,
does not confirm other dedicated measurements



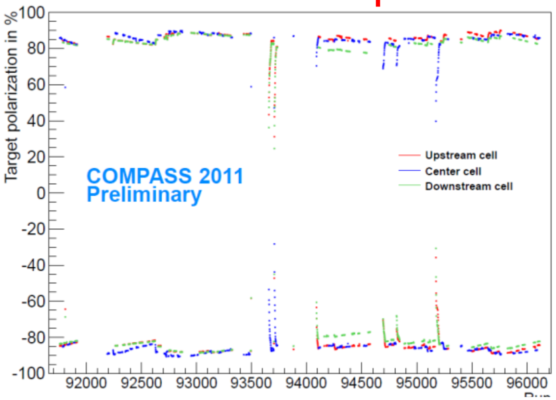
2012 data: 5-6 times more statistics & extended kin range

Results from muon beam data

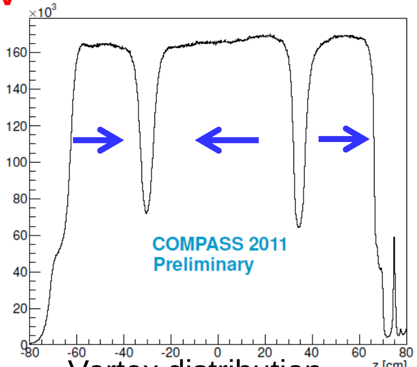
	Target spin
• g_1^p spin structure function 200GeV (2011)	**L**
• **π, K multiplicities** for quark FF	
• **Collins/ Sivers** asymmetries for **π / K**	**T**
• 2-h asym. (π / K) + 2-h multiplicities	**T**
• Six T T-spin asymmetries (TMDs)	**T**
• Cross section: high p_T hadron γ-prod.	
• **DVCS** 2009 test run	

g_1^p spin structure function

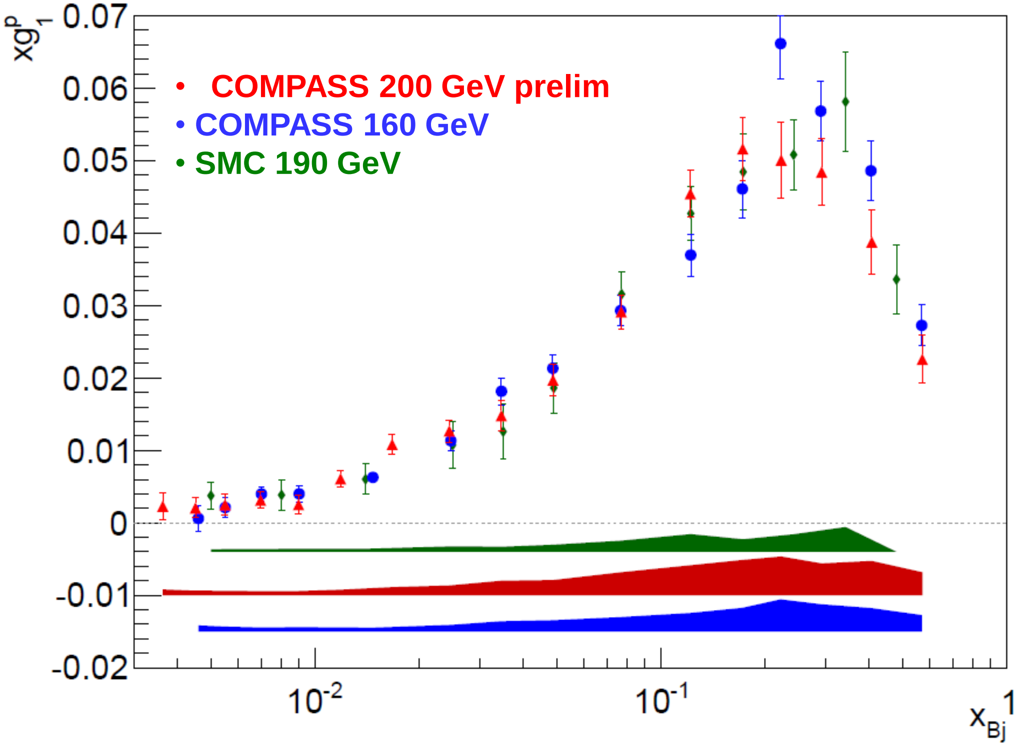
2011 data - First polarised DIS data at 200 GeV



NH3 target, P_T85%

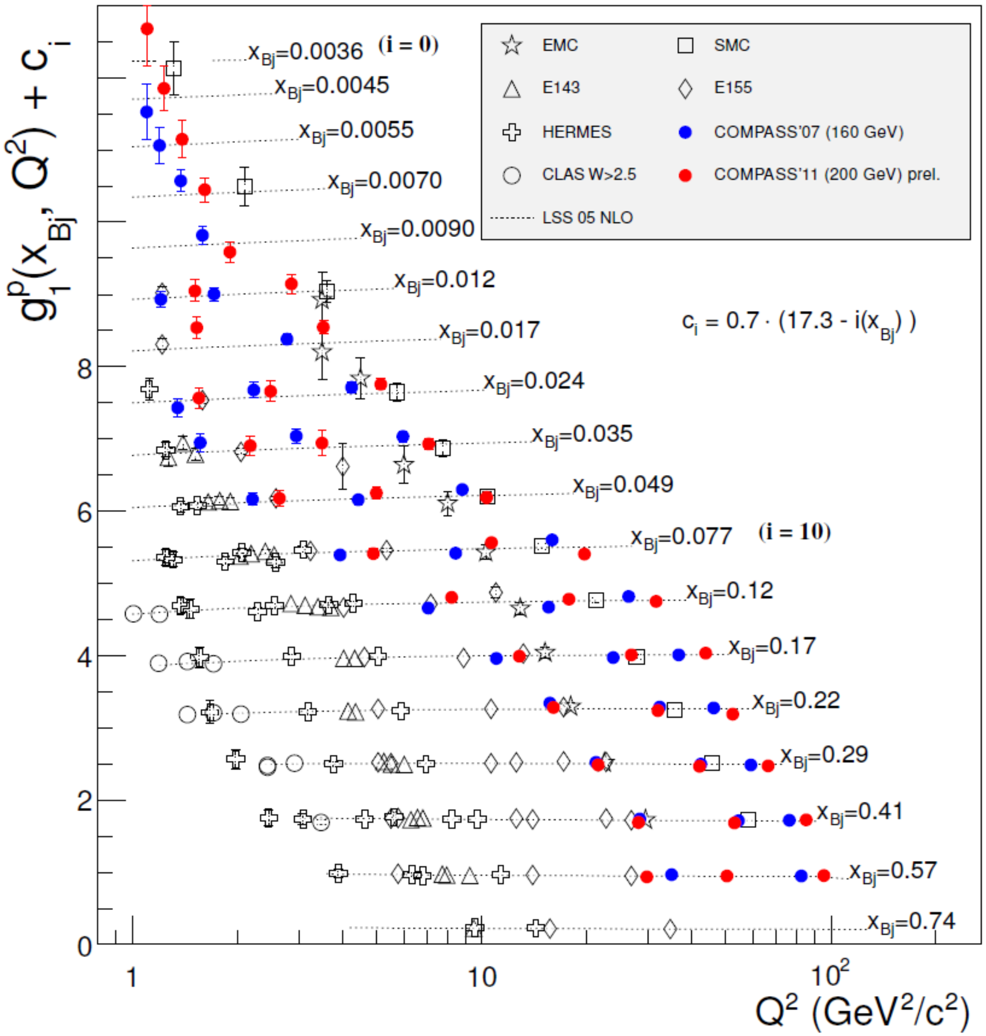


Vertex distribution



- Error reduction factor 3-4 vs SMC in less beam time; gain in FoM > one order of magnitude: COMPASS objective achieved.
- **With slightly higher Q^2, and to lower x, data complete the 2007 - 160 GeV data,**
- Important to reduce systematics in low x region of integrals, and for sea quark flavor separation
- **Increase the Q^2 lever arm for QCD analyses**

g_1^p world data



- COMPASS 200 GeV
- COMPASS 160 GeV

--- LSS QCD fit

- Large set of data, extending to lower x and higher Q^2 region
- Will be included in QCD global analyses

Next step:

- Bjorken Sum Rule – update

- Flavor separation, especially $\Delta s(x)$, $\Delta\bar{u}(x)$ & $\Delta\bar{d}(x)$.

Pion and kaon multiplicities

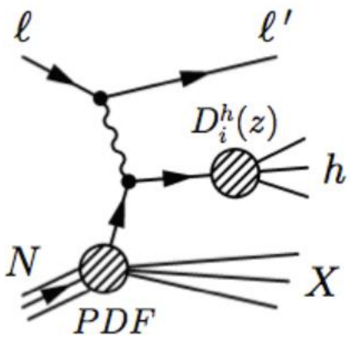
Goal: access to strange quark fragmentation functions

(largest contribution to uncertainty in Δs extraction from polarized SIDIS)

Hadron production in semi inclusive DIS ***$\mu^+ d \rightarrow \mu^+ h^\pm X$***

PDFs FFs

$$\frac{dM^h(x,Q^2,z)}{dz} \underset{\text{at LO}}{=} \frac{\sum_q e_q^2 f_q(x,Q^2) D_q^h(z,Q^2)}{\sum_q e_q^2 f_q(x,Q^2)}$$



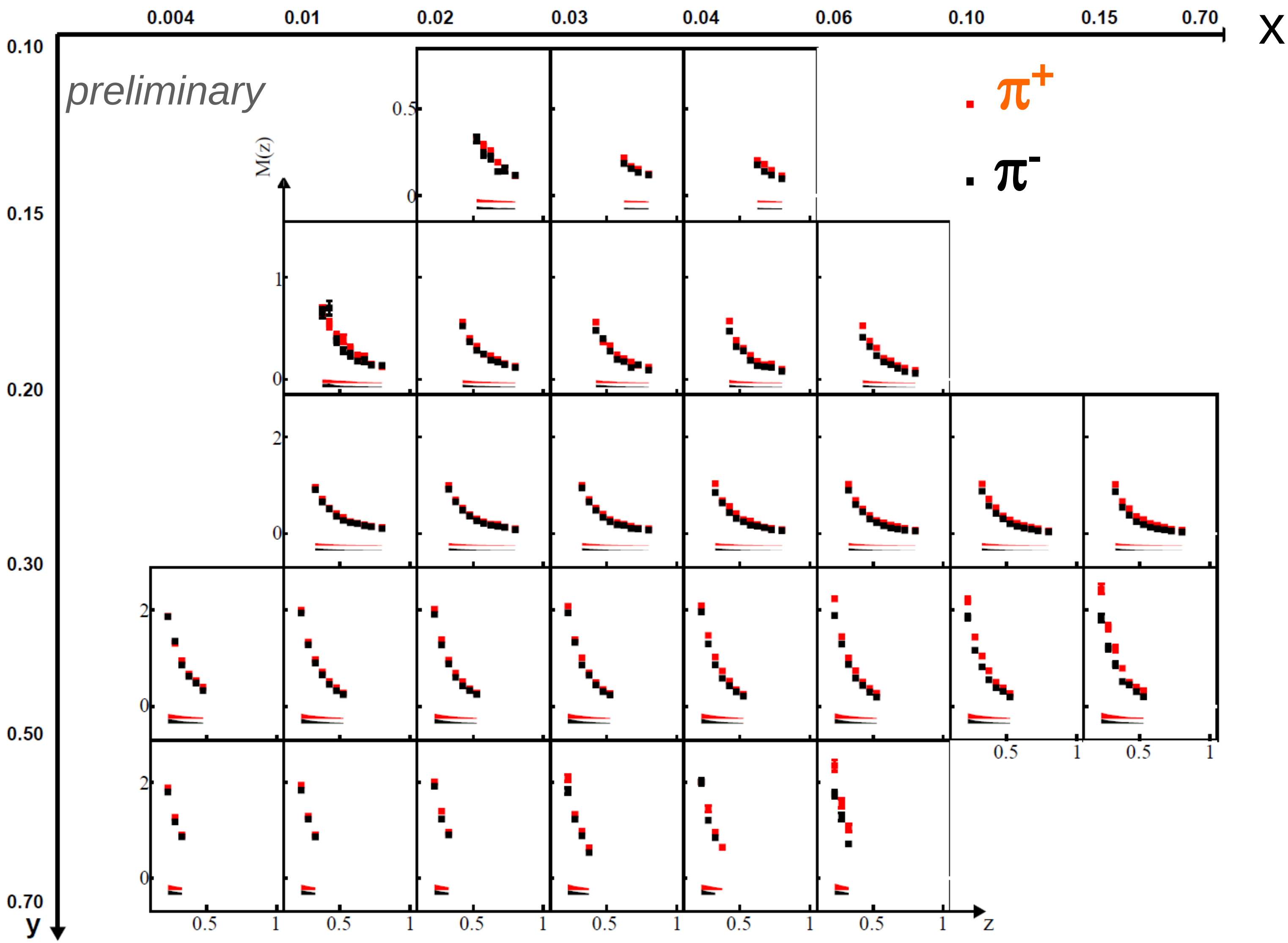
2006 data analyzed. Huge statistics with 3 weeks

Full agreement with 2004 data

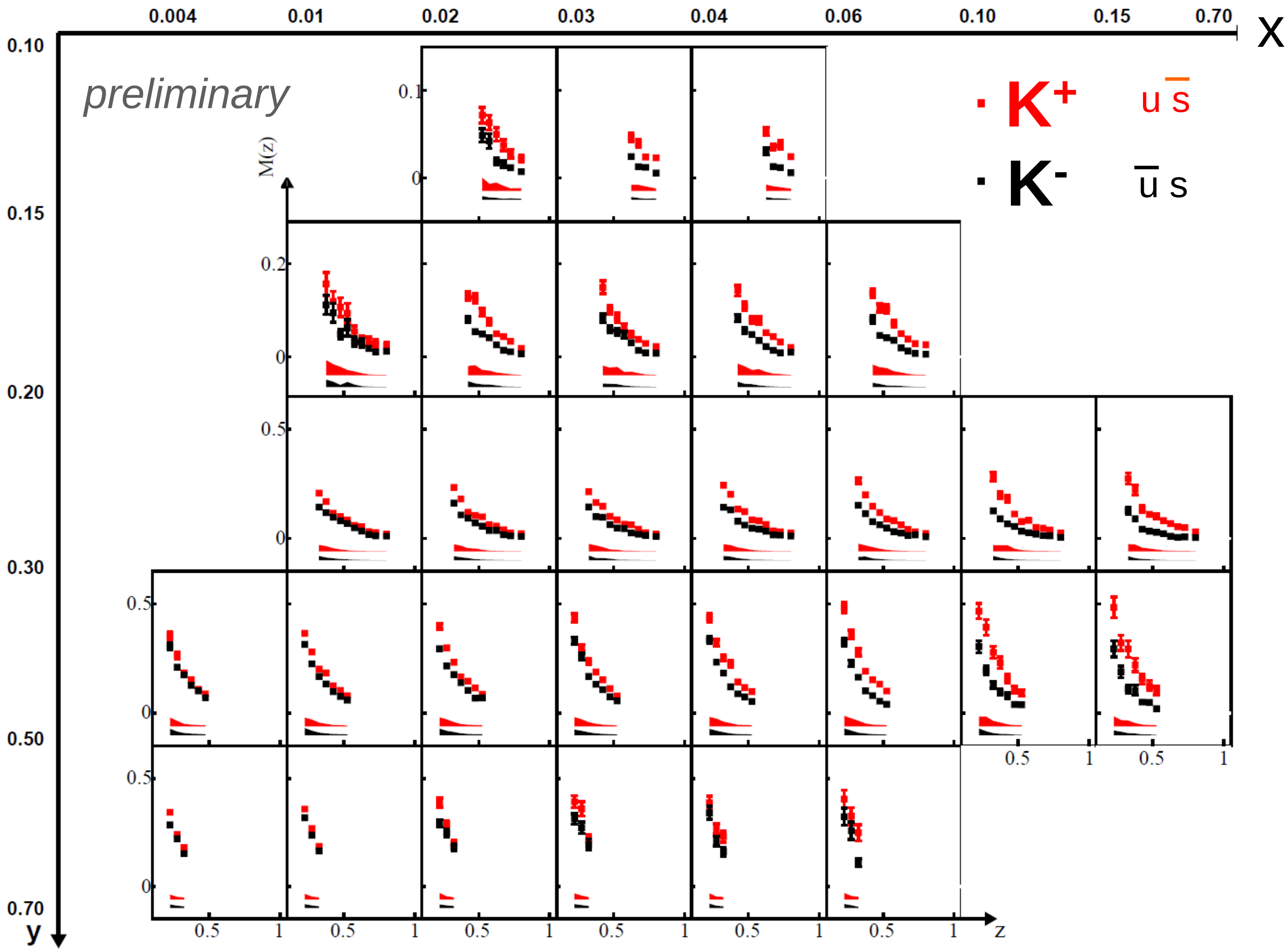
Fine binning in x, z, Q^2

- **Input to global NLO QCD analyses to extract quark FF**
- **LO analysis, in progress within COMPASS**

π^+ and π^- multiplicities vs z in (x,y) bins



K^+ and K^- multiplicities vs z in (x,y) bins



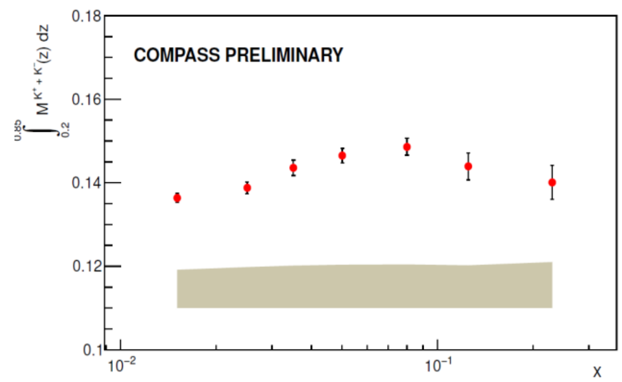
Kaon multiplicities & D_s^K

M(K+) + M(K-)

Valence region sensitive to D_u^K

Sea region - - - $\frac{s(x)}{u(x)} D_s^K$

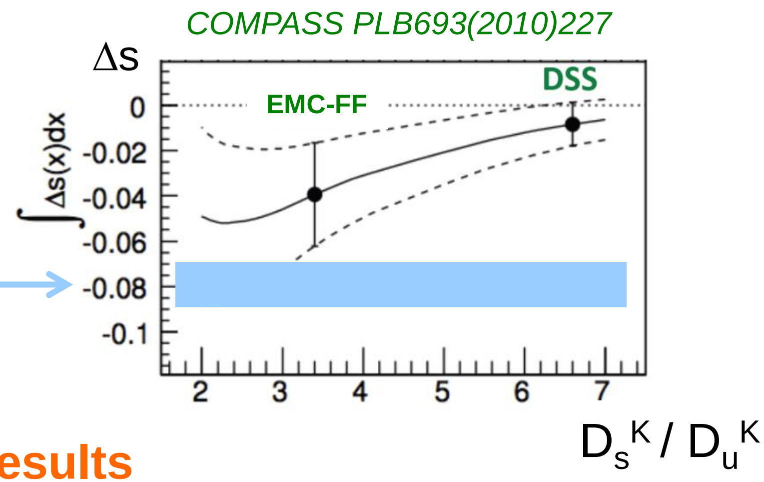
→ Hint for small D_s^K



D_s^K is a key ingredient for Δs, strange quark polarization, from SIDIS

Δs from COMPASS SIDIS using 2 values for D_s^K

Δs from inclusive data →



Small value of D_s^K could reconcile results

Work ongoing – error on multiplicities still dominated by systematics.

Transversity- Collins and Sivers asymmetries

- T polarized target, SIDIS: $\mu p^{\uparrow} \rightarrow \mu p\, h^{+/-}$
- Measure azimuthal asymmetries:

Collins: Outgoing hadron direction & quark transverse spin

Sivers: Nucleon spin & quark transverse momentum k_T

at LO:

Collins

q transverse spin distr.

$$A_{Coll} = \frac{\sum_q e_q^2 \cdot \Delta_T q \otimes \Delta_T{}^{\circ} D_q^h}{\sum_q e_q^2 q \otimes D_q^h}$$

Collins fragmentation function, depends on spin

Sivers

TMD

Quark fragmentation function

$$A_{Siv} = \frac{\sum_q e_q^2 f_{1Tq}^{\perp} \otimes D_q^h}{\sum_q e_q^2 q \otimes D_q^h}$$

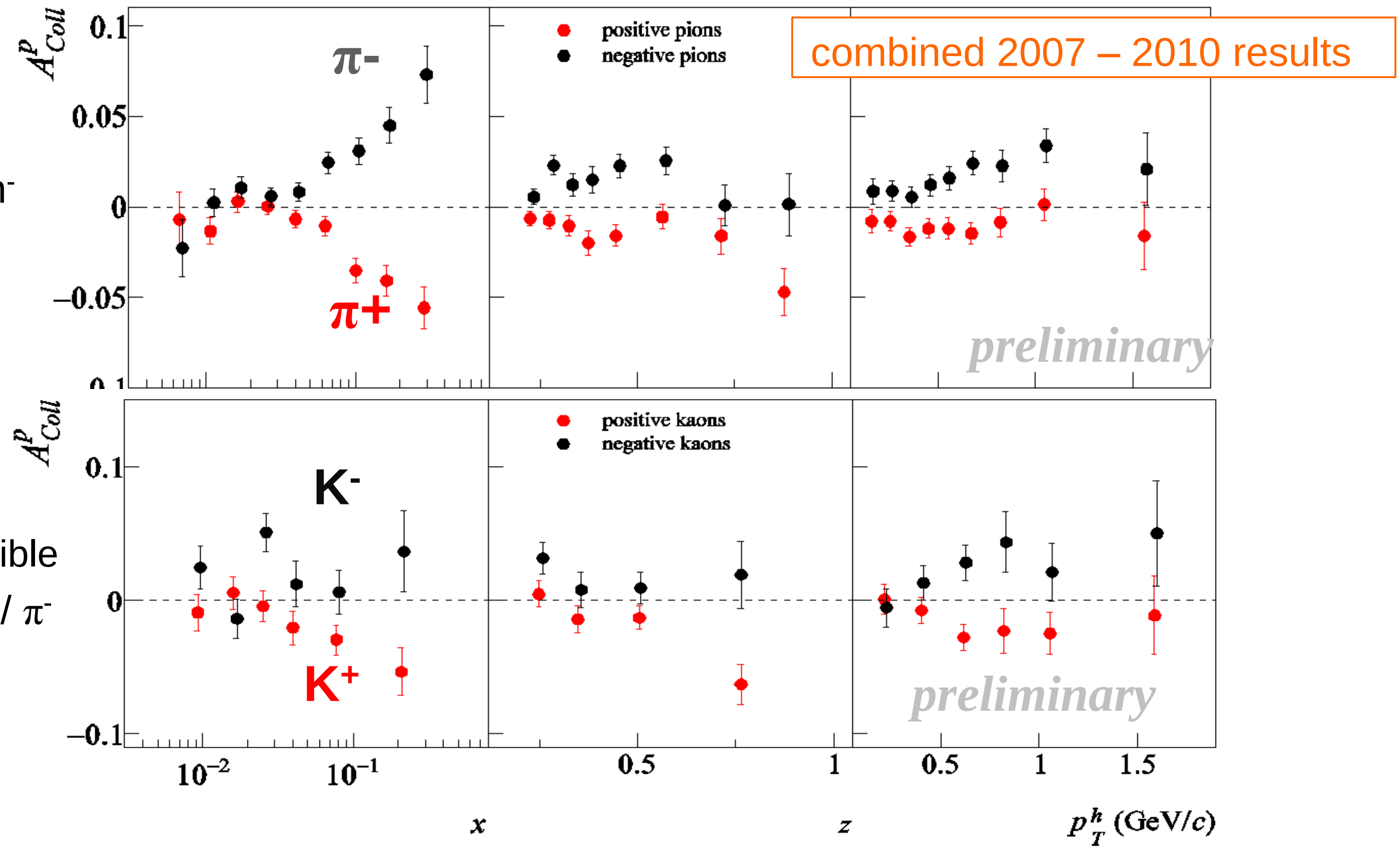
note: $\Delta_T q$ also measured using
''Two hadron'' fragmentation function

Collins Asymmetry on proton - π, K id.

Correlation between outgoing hadron & quark transverse spin → $\Delta_T u$ & $\Delta_T d$

~ h^+ / h^-

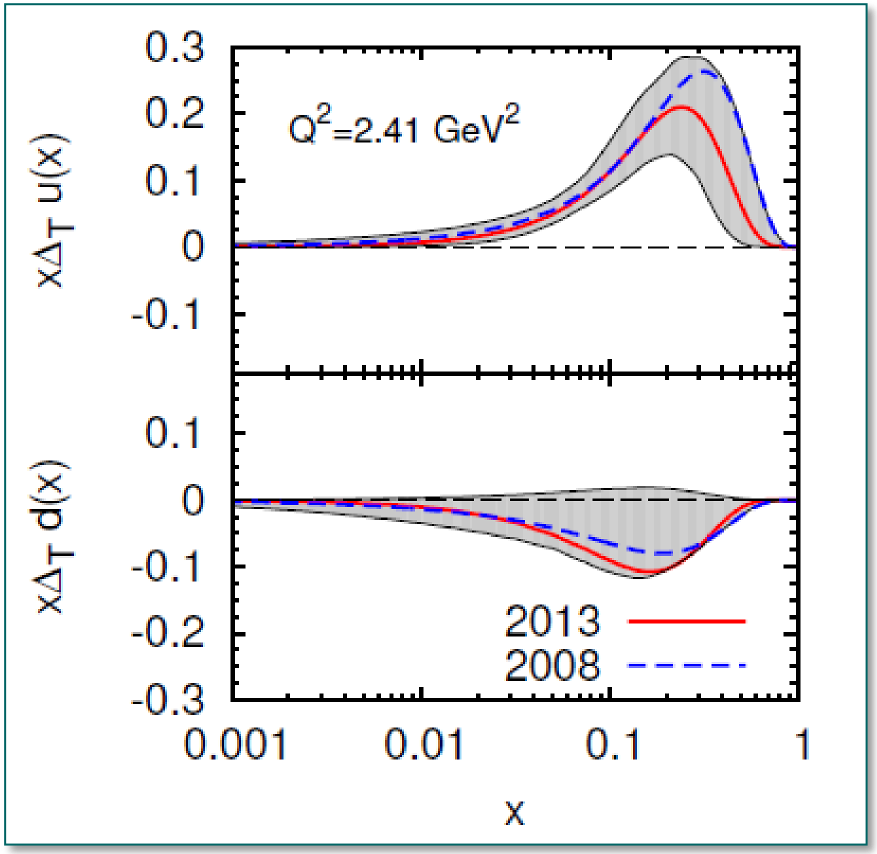
compatible with π^+ / π^-



- **Agreement HERMES/COMPASS (not shown)** → **no Q^2 dependence seen** (factor of ~3 inQ^2)
- **Now also produced in bins of z and y**

Transversity – from Collins Asymmetry

Combined analyses of **HERMES, COMPASS** and **BELLE fragm.fct.** data



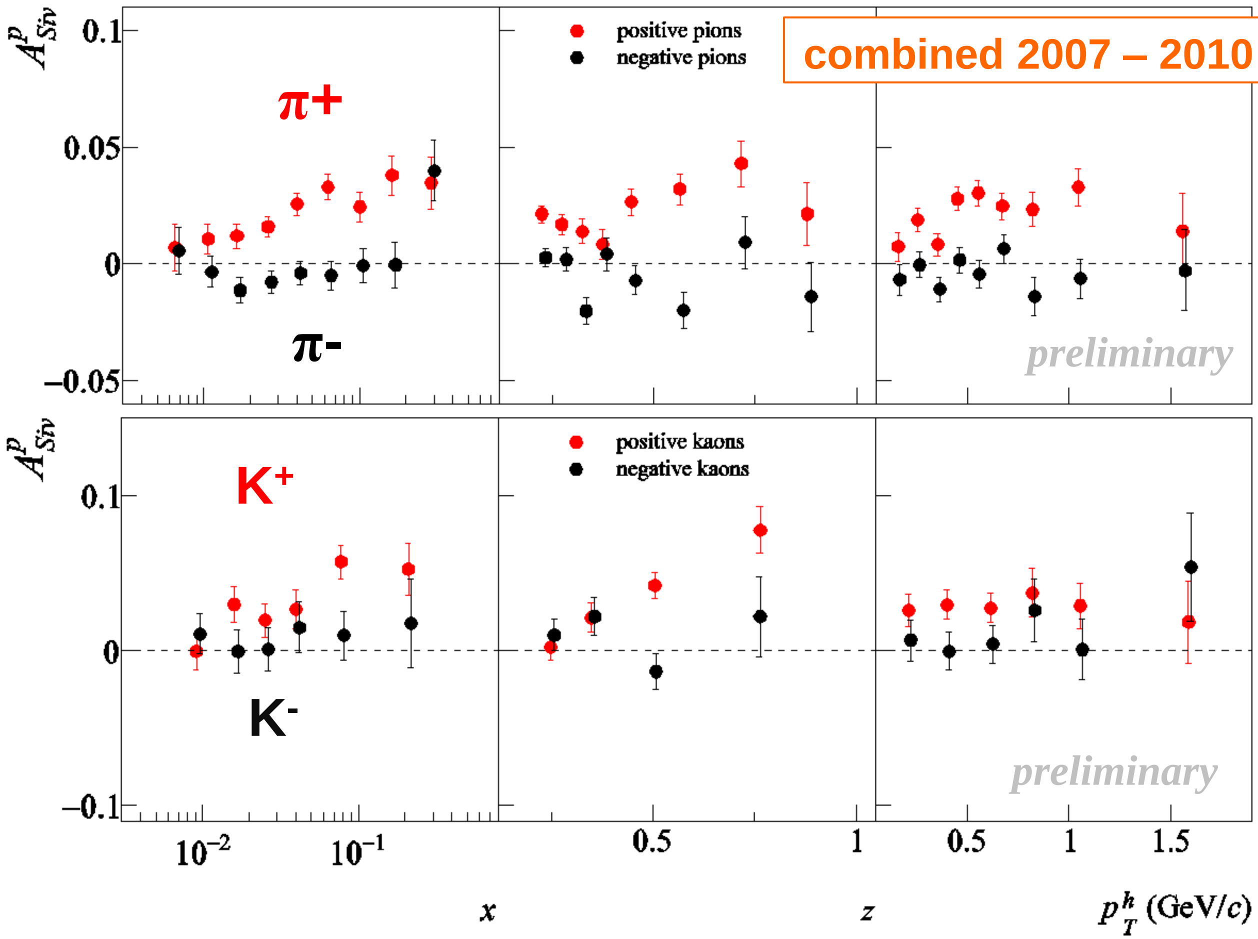
Anselmino et al. arXiv: 1303.3822

Sivers Asymmetry on proton - π, K id.

Correlation between nucleon spin & **quark transverse momentum k_T**

~ h^+ / h^-

larger than for π^+

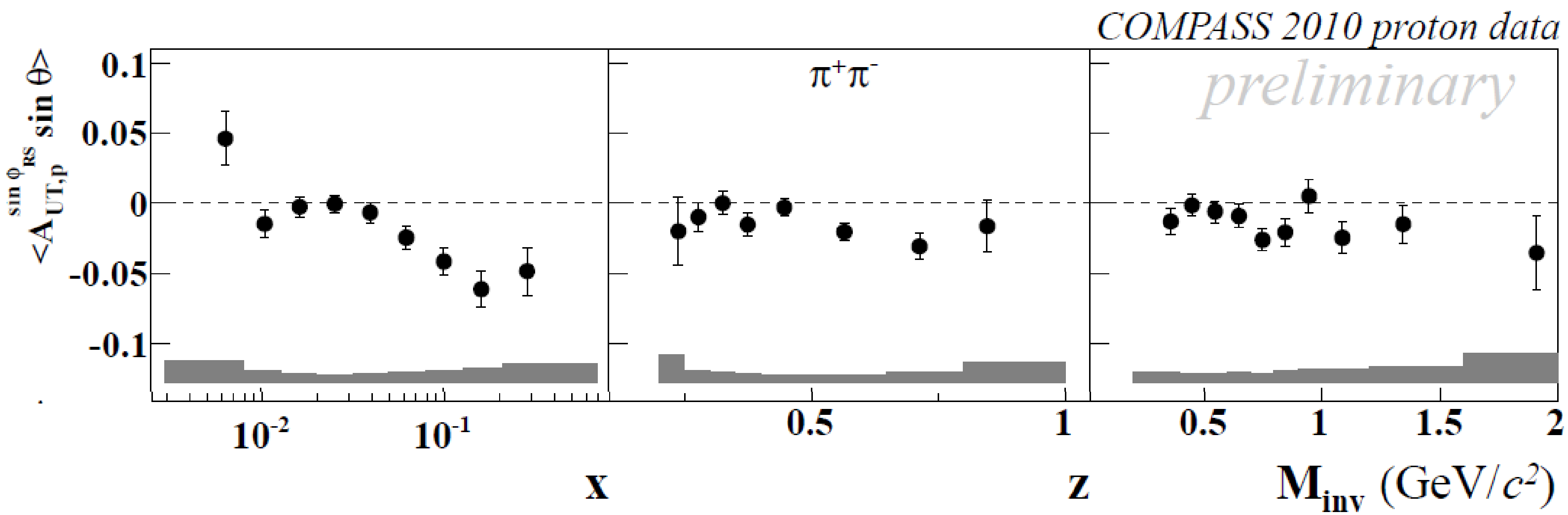


- **In region of overlap, agreement with HERMES, but smaller strength**
- **Now also produced in separate bins of z and y.**

2-hadron asymmetries

T target

$<A_{UT,p}^{\sin\phi_{RS}} \sin\theta>$ Another access to transversity h_1

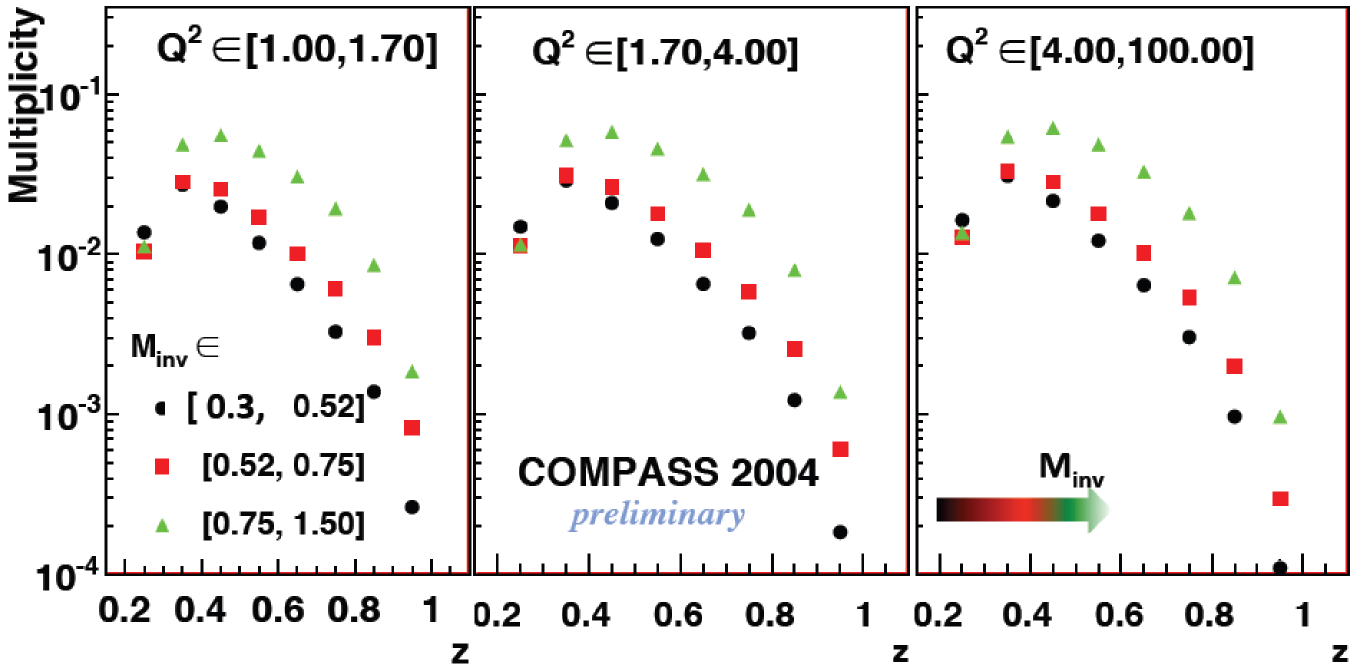


$$A_{RS} = \frac{1}{f \cdot P_T \cdot D} \cdot A = \frac{\sum_q e_q^2 \cdot \Delta_T q(x) \cdot H_q^{\angle}(z, M_h^2)}{\sum_q e_q^2 \cdot q(x) \cdot D_q^h(z, M_h^2)}$$

- **h_1^u & h_1^d extraction**
- **Also measured for the first time for K^+K^-, π^+K^- and $K^+\pi^-$ pairs**

2-h multiplicities

- First time measured in lp
- Needed for pol. PDF extraction; will complete e+ e- data



Six Transverse Target spin asymmetries

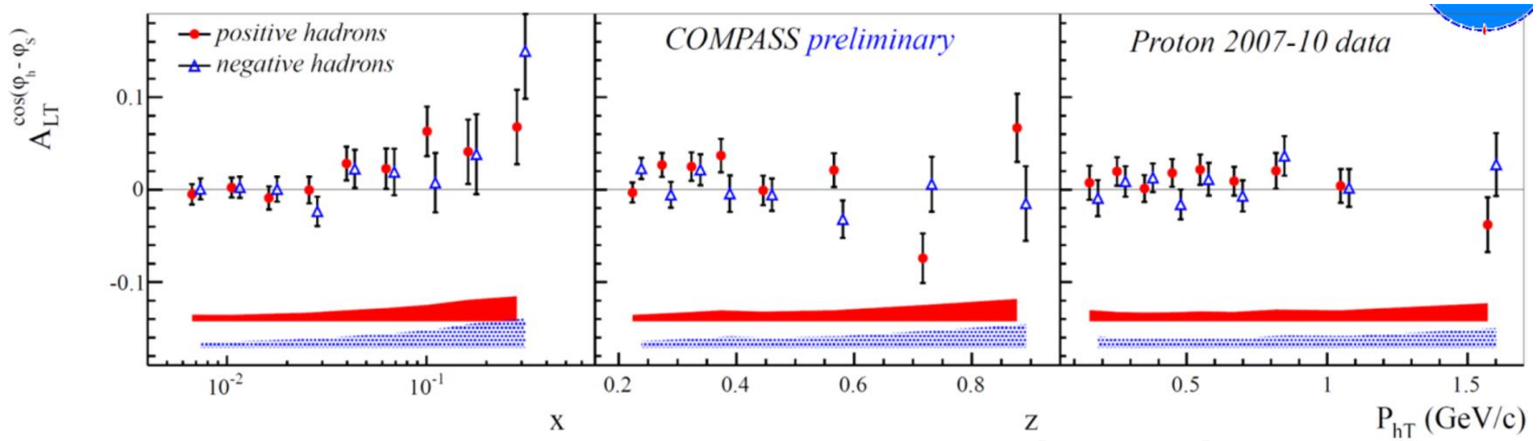
beyond Collins & Sivers, access TMDs

$\mu\, p^{\uparrow} \rightarrow \mu\, p\, h^{+/-}$

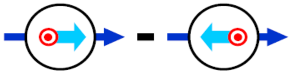
k_T effects → modulations in SIDIS cross-section

- **Major progress in TMD measurement**
- **Powerful tool to understand correlations**

$A_{LT}^{\cos(\varphi_h - \varphi_s)}$ shown as example



$A_{LT}^{\cos(\phi_h - \phi_s)} \propto g_{1T}^{q} \otimes D_{1q}^{h}$, "Worm Gear" PDF g_{1T}^{q} :

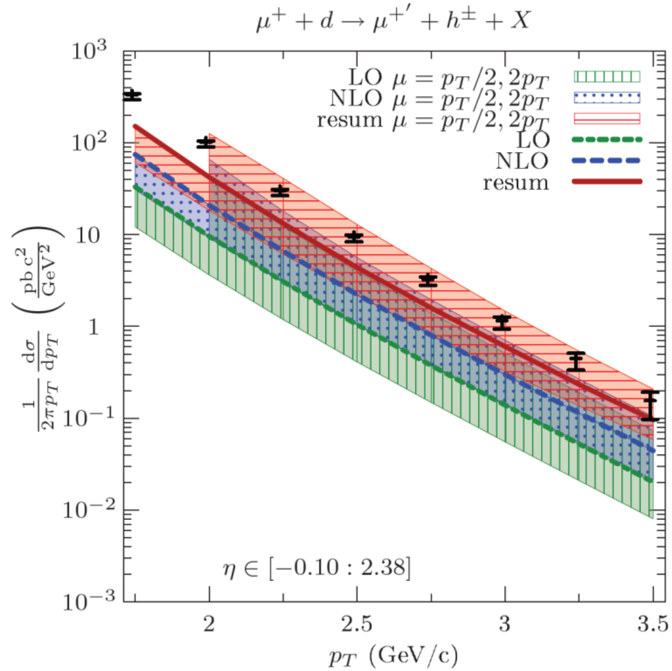


In agreement with HERMES prelim., and with theoretical predictions

High p_T hadron photo prod. cross-section

Absolute cross-section measurement $\mu d \rightarrow \mu' h^{+/-} X$ 2004 data, 4 weeks

New: pQCD calculation with resummation 'all orders' (soft gluons, leading logs)



De Florian, Pfeuffer; Schaeffer, Vogelsang, APS/123-QED

Data / theory in agreement over 4 orders of magnitude

→ Settles the theory framework for ΔG high p_T

Ongoing: spin asymmetries $A_{LL}(p_T)$ for same events

2009 DVCS test run data

Re-analysis of one week of data

small scale setup of DVCS $\mu\ p\ \rightarrow \mu\ p\ \gamma$

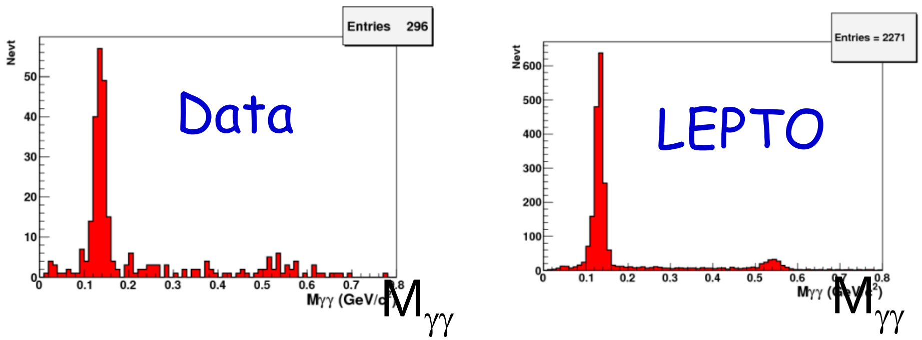
New features:

- Estimation of luminosity

- ECAL1/2 precise calibration using Laser/LED and calibration cell by cell using π^0 mass value.

- Evaluation of π^0 background with **full MC** (HEPGEN/exclusive and LEPTO/semi-inclusive)

π^0 (η) in ECAL1



Background from π^0 up to 50%, BUT:

- very limited statistics (Data)

- large uncertainty on cross-section in MC

- Increase by × 10 with 2012 Data

2012 Run

- Primakoff $\pi^- Ni \rightarrow \pi^- Ni \, \gamma$
- DVCS $\mu^{+/-} p \rightarrow \mu^{+/-} \gamma \; p_{recoil}$

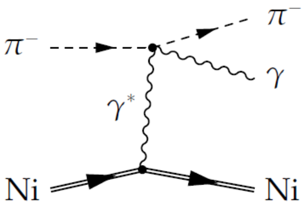
Changeover for installation of full scale DVCS setup.

Squeezed in 3 weeks, since no beam stop - cancelation of ion run.

2012 Primakoff run

Goal: high statistics for polarisabilities

- separate determination of α_π and β_π
- s dependent quadrupole polarisabilities α_2 and β_2
- kaon polarisabilities



2012 Running:

- Long commissioning ~ 1 month
- ECAL2 digital trigger commissioning, with data taking
- 50 days full data taking
- 15 days lost due to vacuum problems in beam line

Overall efficiency : 70 %

- 88% SPS (excluding vacuum problems)
- 80% COMPASS spectro + beam line magnets

Error projection: factor 5-6 + extended kinematic range

2012 DVCS pilot run

GPD (Generalized Parton Distributions)
by exclusive reactions **DVCS**, DVMP

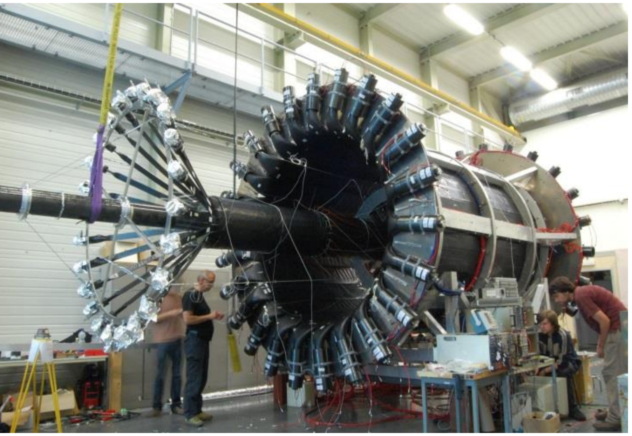
$\mu \; p \rightarrow \mu \; p \; \gamma$

Goal of the run:

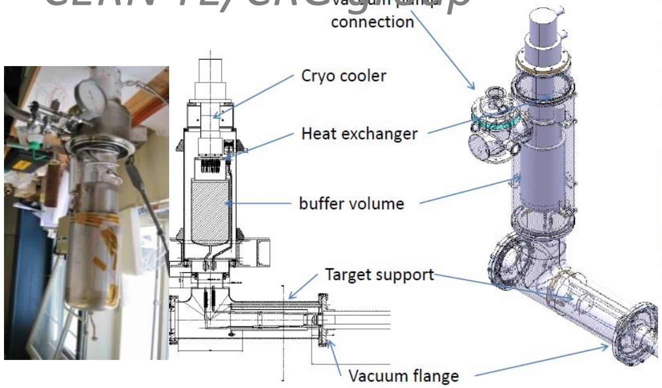
- Full scale measurement with almost full setup
- Measurement with μ^+ and μ^- beams
- Study background
- Physics : evaluation of t-slope (transverse size of nucleon)

Detectors ready by fall 2012- initial plans were after LS1

Recoil proton detector
CAMERA + Gandalf FE



LH2 2.5 m long target
CERN TE/CRG group

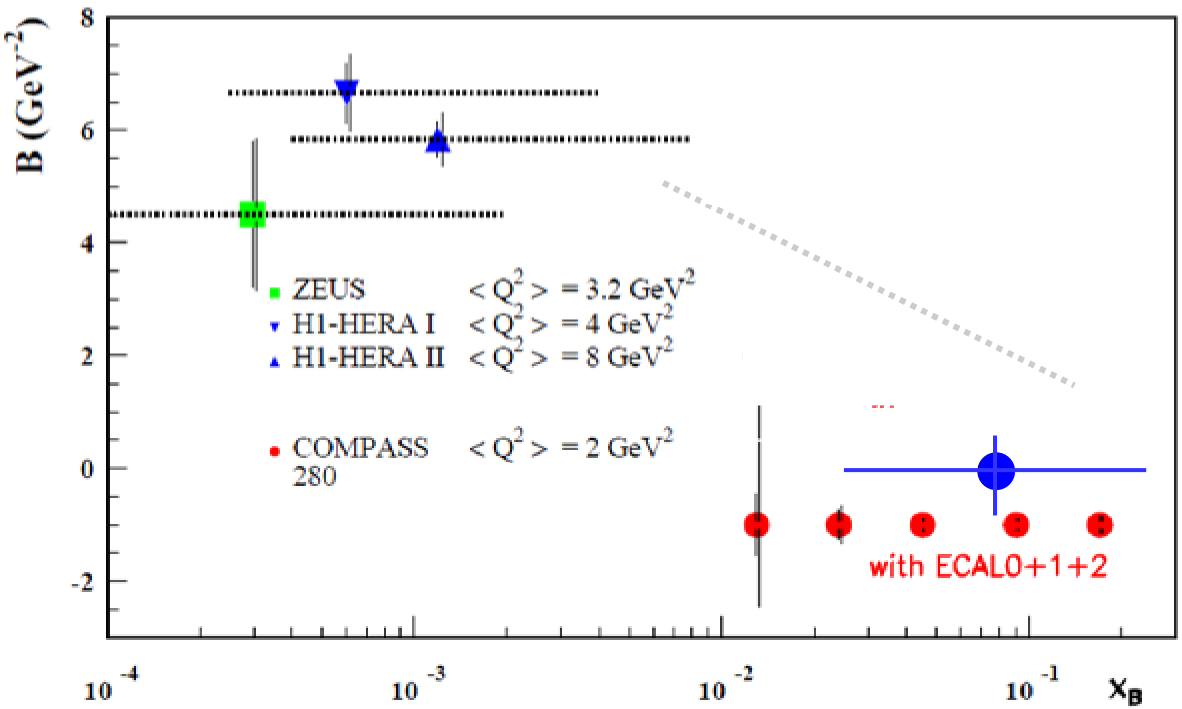


First part of Elec.Calo ECAL0

DVCS 2012 pilot run - Projection for t-slope

COMPASS

$\sigma^{DVCS}/dt \sim \exp^{-B|t|}$ $\quad B(x_B) = ½ < r_{\perp}^2(x_B) >$ transverse size of the nucleon



- **2 weeks in 2012**
- **40 weeks > 2015**

Projection for ~ 2 weeks : $B \approx 5 \pm 0.7$ ~ 80 DVCS events.

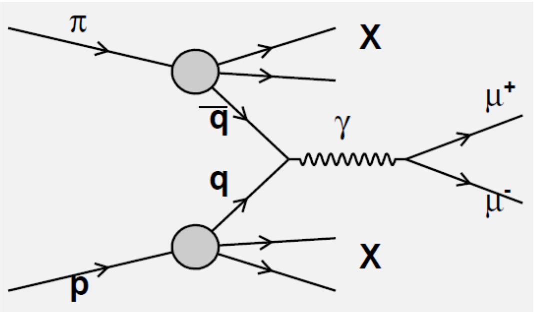
Recall, full experiment : 40 weeks **$B \approx 5 \pm 0.15$**

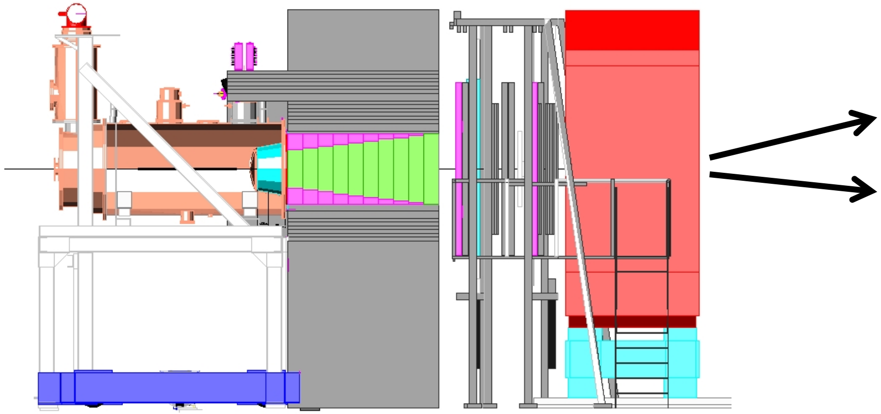
5 bins in x_B x 5 bins in t

COMPASS Future : Polarized Drell-Yan

Polarized Drell-Yan $\pi^- p\uparrow \rightarrow \mu^+\mu^- X$
→ TMDs, Sivers & Boer-Mulders

Fundamental test of universality of TMDs
Expect change of sign in Drell-Yan vs SIDIS

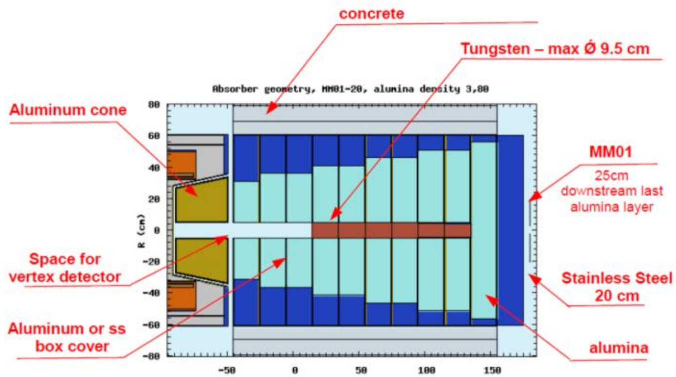




Preparation for Polarized Drell-Yan 2015

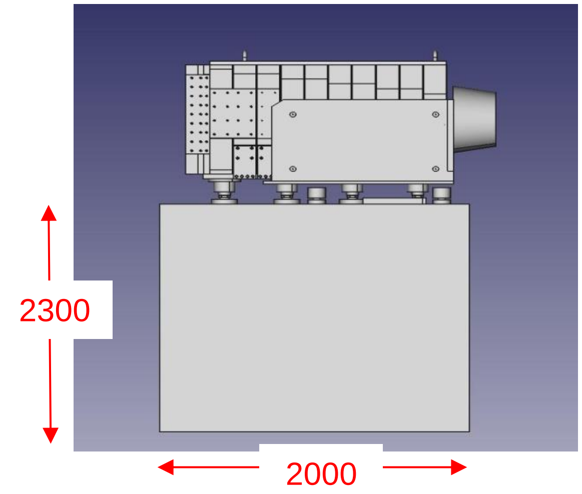
- Modification of area in target region to include the 2m long dedicated absorber
- Magnet repair and re-instrumentation
- Polarized target
- Move Control room from 888 (expt. Hall) to 892 (office bldg)

Absorber design

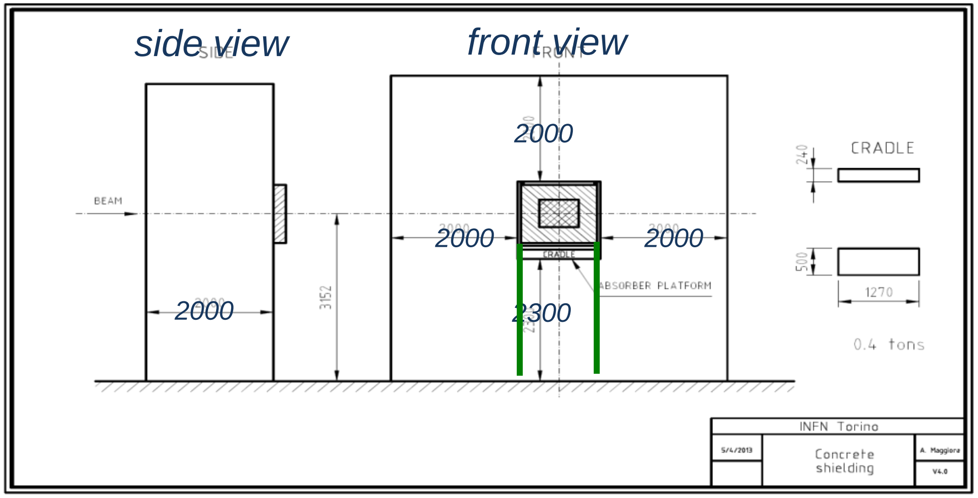


tungsten beam plug, alumina absorber, stainless steel shielding sandwiches

Absorber + concrete platform



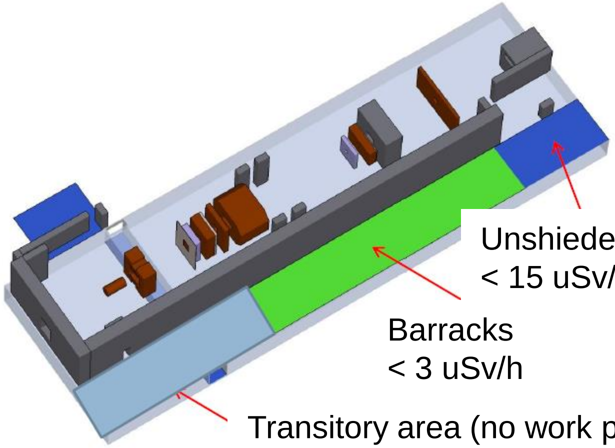
Absorber will be surrounded by 2 m of shielding of iron-free concrete on each side.



Radiation Protection

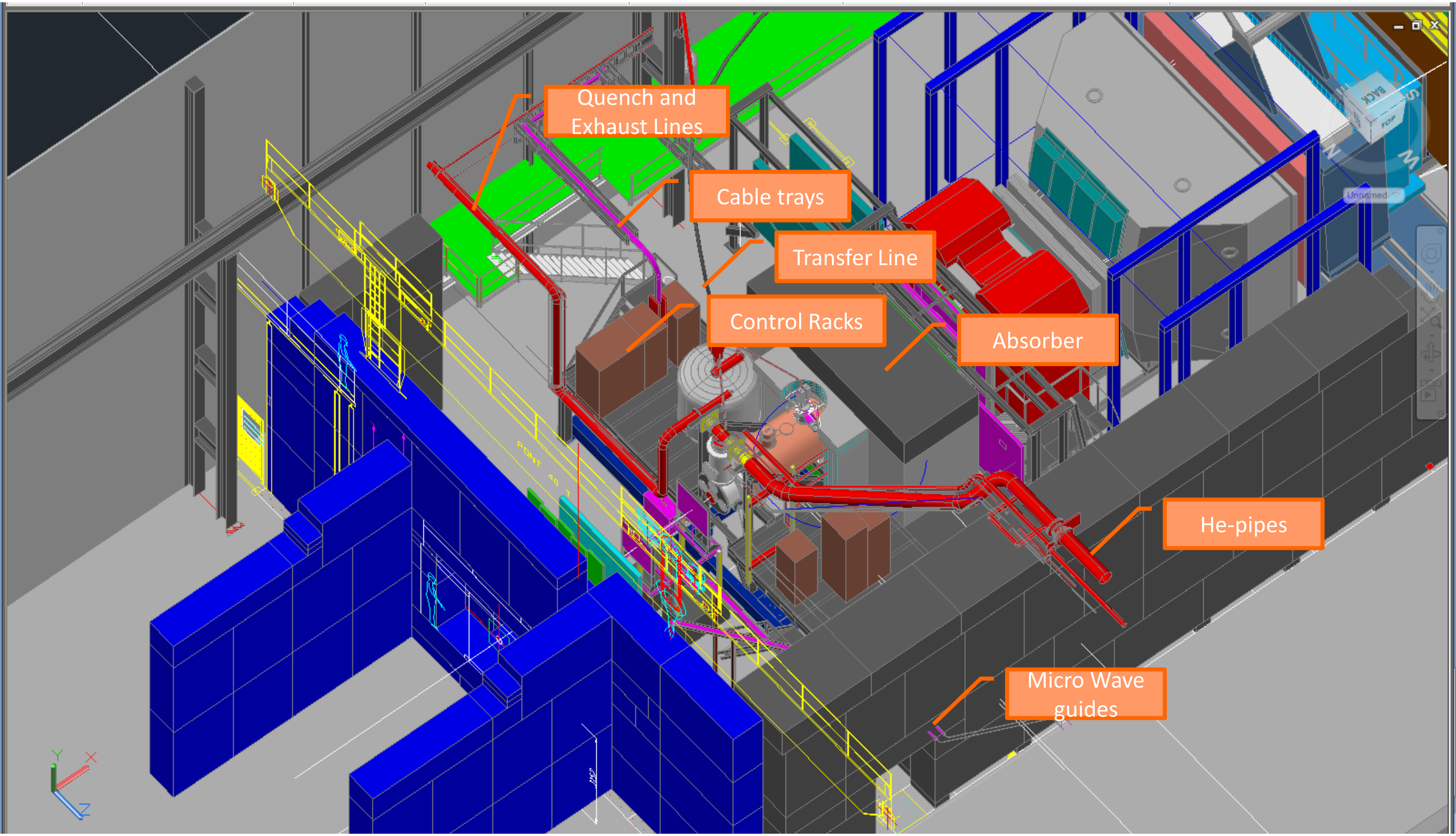
Recommandations from RP group:
Remove counting room from 888

- No change in classification
- No need to add shielding on main wall



Sketch of platform

Reconfiguration of many equipments



Target magnet repair and instrumentation

Magnet (major) repair CERN/ ATLAS magnet team:

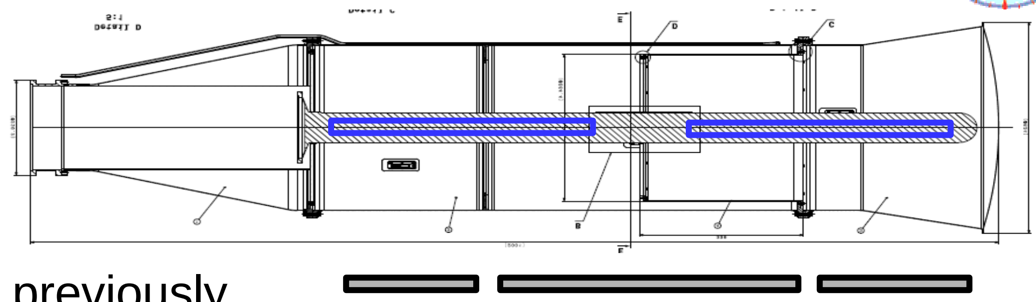
- **Full diagnostic** on opened magnet;
  confirmed earlier observations of problems on trim coils
  (burned superconducting lines, and burned protection resistors, bad soldering, bad insulations…)

- **Major work:** New trim coil connections, new wiring and diodes, new heaters and sensors on cold mass, new precooling circuit, improved thermal shield cooling…

New Security and Control Systems (MSS, MCS):

Built by CERN/ PH/ DT

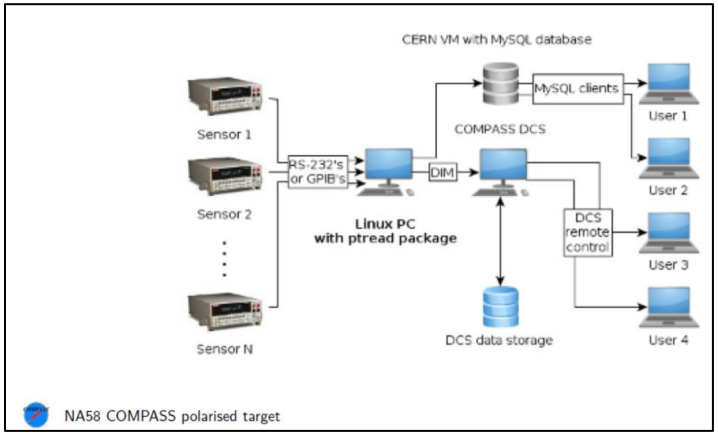
Polarized target for Drell-Yan



- 2-cell target instead of 3-cell previously. thick absorber deteriorates the resolution on the vertex reconstruction.

- new MW cavity

- New remote monitoring system



- New heat exchangers for the ^{3}He-^{4}He dilution refrigerator

Publications and conferences

Publications last 12 months

1. Measurement of the cross section for high-p_T hadron production in scattering of 160 GeV/c muons off nucleons, submitted PRD and CERN-PH-EP-2012-189
2. Exclusive ρ^0 muoproduction on transversely polarised protons and deuterons, Nucl. Phys. **B 865** (2012) 1 and CERN-PH-EP/2012-208.
3. D^* and D meson production in muon-nucleon interactions at 160 GeV/c, Eur. Phys. Jou. **C 72** (2012) 2253 and CERN-PH-EP/2012-339
4. Leading and next-to-leading order gluon polarisation in the nucleon and longitudinal double spin asymmetries from open charm muoproduction, Phys. Rev. **D 87** (2013) 052018 and CERN-PH-EP/2012-350
5. Study of $\Sigma(1385)$ and $\Xi(1321)$ hyperon and antihyperon production in deep inelastic scattering, submitted EPJC and CERN-PH-EP/2013-052
6. Hadron Transverse Momentum Distributions in Muon Deep Inelastic Scattering at 160 GeV/c, submitted EPJC and CERN-PH-EP/2013-091

+ 13 papers being drafted

Conferences

- 84 presentations to Conferences and Workshops in 2012;
- 55 presentations to Conferences or Workshops in 2013, till June 15.

Papers being drafted

- OZI
- PWA 3 pion (PRD)
- Radiative widths of a_2 and π_2
- PWA 5 pion (PRD)
- PWA of $\pi\ \eta$ and $\pi\ \eta'$ final states (PLB)
- Pion Polarisability (PRL)

- transverse spin asymmetries beyond Collins and Sivers (all p and d)
- Collins and Sivers (pions and kaons) from 2007 and 2010 (p)
- 2h transverse spin asymmetries (charged hadrons) from 2010 p data
- Azim. hadron asym. in unpolarised deuterons

- Multiplicities pions (2006 data)
- g_1^p

- Spectrometer Paper (NIM)

General news

MoU signed by CERN directorate, February 2013

New institutes joining

- IUIC, Illinois, US

  Building new large drift chambers DC5-6, to replace straw detectors

  Using design and expertise from Saclay (DC4)

- Taipei

  FEE for DC5-6 chamber

- Aveiro, Portugal

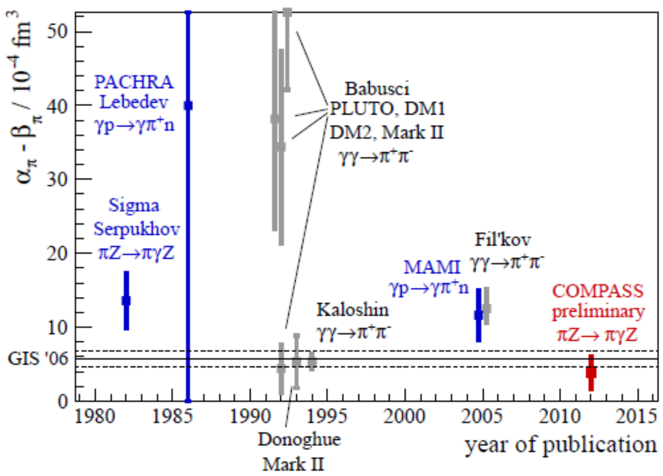
  Thick GeMs for RICH upgrade

ESRG COMPASS well cited in final report of P. Newman

Nucleon structure
https://indico.cern.ch/contributionDisplay.py?contribId=60&confId=175067
Spectroscopy
https://indico.cern.ch/contributionDisplay.py?contribId=119&confId=175067

spares

Primakoff world data



VM production and polarisation & OZI rule

Measure exclusive production of ϕ and ω:

$p\,p \rightarrow p\,\phi/\omega\,p$

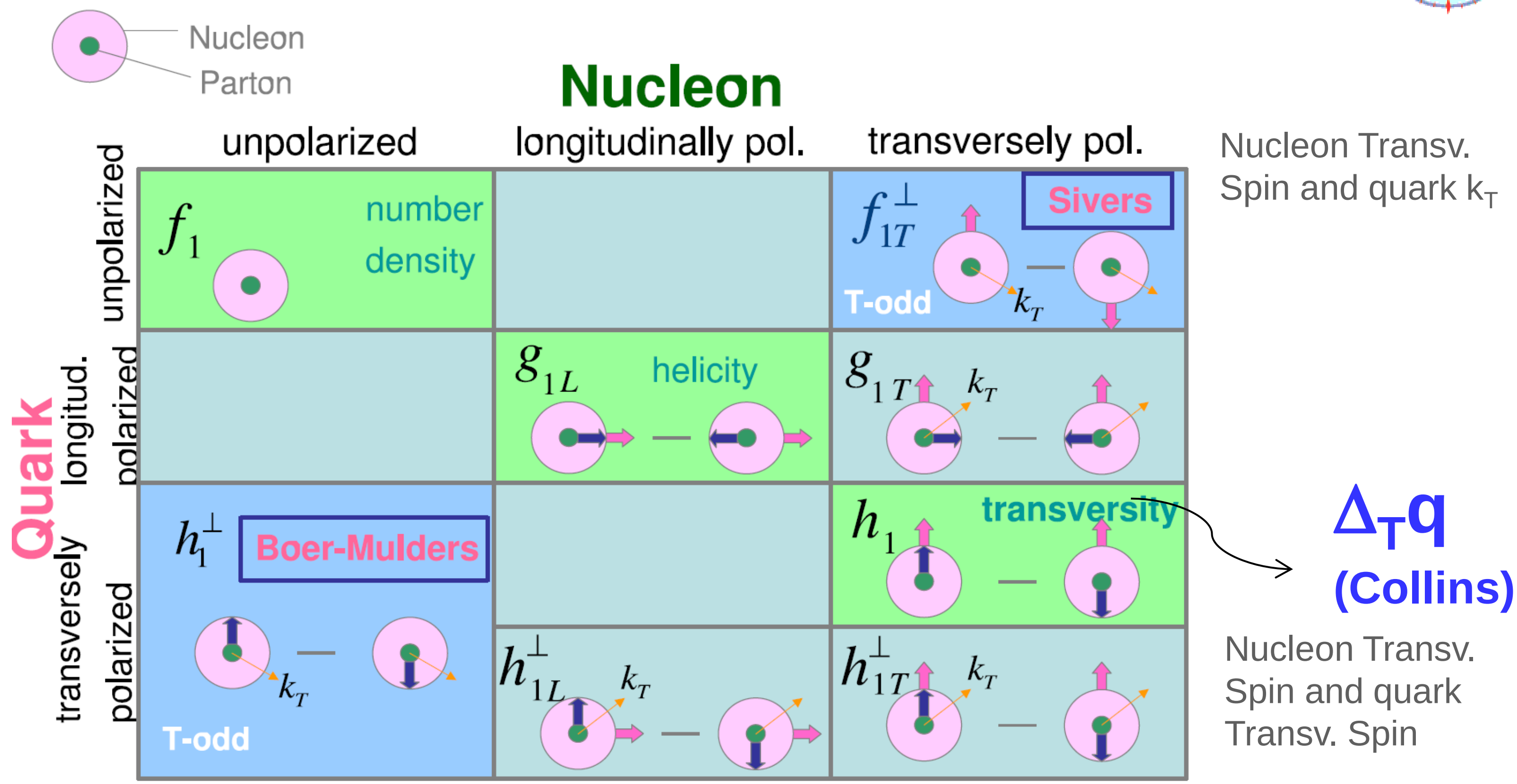
OZI rule predicts ϕ suppression wrt to ω.

→ **Significant violation of OZI rule** found, by factor of 3 to 8,
in agreement with earlier findings
Study of x_F and kin. dependence to understand the scale governing
the hidden strangeness production.

Measure spin density matrices

→ **Production mechanisms :** progress in understanding the competition between processes (diffractive production of resonances, central production) by comparing spin alignments.

Nucleon Structure Functions



Off diagonal: Transverse Momentum (k_T) Dependent

- **TMDs express correlations between spin, momentum,…**
- **Experimentally: azimuthal modulations of outgoing hadron in SIDIS cross section *lp → lp h***

Semi-Inclusive Deep Inelastic Scattering

$$\frac{d\sigma}{dx\,dy\,d\psi\,dz\,d\phi_h\,dP_{h\perp}^2} =$$

$$\frac{\alpha^2}{xyQ^2}\frac{y^2}{2\,(1-\varepsilon)}\left(1+\frac{\gamma^2}{2x}\right)\Big\{F_{UU,T}+\varepsilon F_{UU,L}+\sqrt{2\,\varepsilon(1+\varepsilon)}\,\cos\phi_h\,F_{UU}^{\cos\phi_h}$$

$$+\,\varepsilon\cos(2\phi_h)\,F_{UU}^{\cos 2\phi_h}+\lambda_e\,\sqrt{2\,\varepsilon(1-\varepsilon)}\,\sin\phi_h\,F_{LU}^{\sin\phi_h}$$

$$+\,S_\parallel\left[\sqrt{2\,\varepsilon(1+\varepsilon)}\,\sin\phi_h\,F_{UL}^{\sin\phi_h}+\varepsilon\sin(2\phi_h)\,F_{UL}^{\sin 2\phi_h}\right]+S_\parallel\lambda_e\left[\sqrt{1-\varepsilon^2}\,F_{LL}+\sqrt{2\,\varepsilon(1-\varepsilon)}\,\cos\phi_h\,F_{LL}^{\cos\phi_h}\right]$$

Sivers asymmetry

$$+\,|\boldsymbol{S}_\perp|\Big[\sin(\phi_h-\phi_S)\left(F_{UT,T}^{\sin(\phi_h-\phi_S)}+\varepsilon\,F_{UT,L}^{\sin(\phi_h-\phi_S)}\right)$$

$$+\,\varepsilon\,\sin(\phi_h+\phi_S)\,F_{UT}^{\sin(\phi_h+\phi_S)}+\varepsilon\,\sin(3\phi_h-\phi_S)\,F_{UT}^{\sin(3\phi_h-\phi_S)}$$

Collins asymmetry

$$+\,\sqrt{2\,\varepsilon(1+\varepsilon)}\,\sin\phi_S\,F_{UT}^{\sin\phi_S}+\sqrt{2\,\varepsilon(1+\varepsilon)}\,\sin(2\phi_h-\phi_S)\,F_{UT}^{\sin(2\phi_h-\phi_S)}\Big]$$

$$+\,|\boldsymbol{S}_\perp|\lambda_e\Big[\sqrt{1-\varepsilon^2}\,\cos(\phi_h-\phi_S)\,F_{LT}^{\cos(\phi_h-\phi_S)}+\sqrt{2\,\varepsilon(1-\varepsilon)}\,\cos\phi_S\,F_{LT}^{\cos\phi_S}$$

$$+\,\sqrt{2\,\varepsilon(1-\varepsilon)}\,\cos(2\phi_h-\phi_S)\,F_{LT}^{\cos(2\phi_h-\phi_S)}\Big]\Big\},$$

18 structure functions

14 independent azimuthal modulations

all the 14 amplitudes are been measured in COMPASS

Collins asymmetry on proton

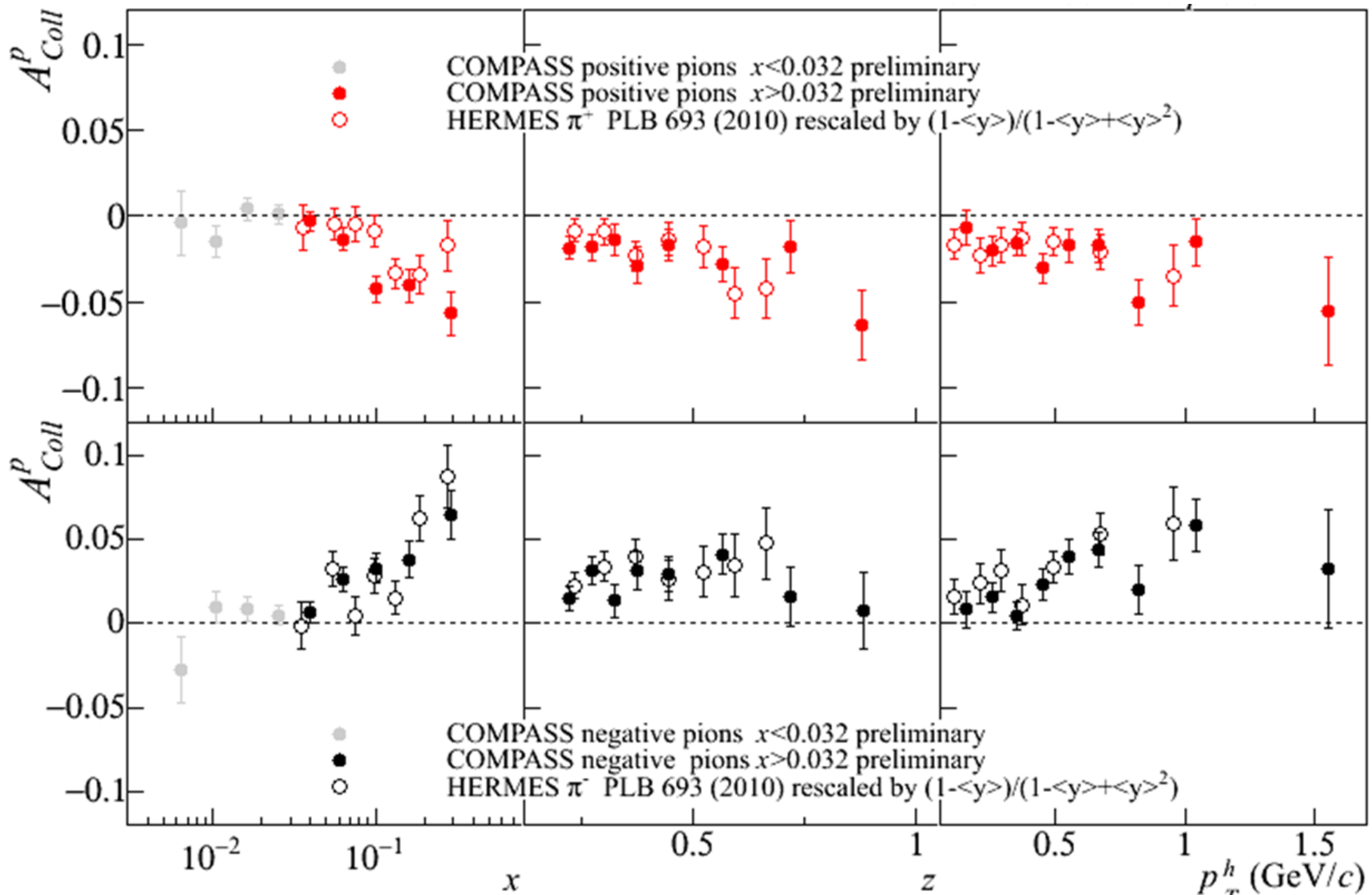
x > 0.032 region

charged pions (and kaons), 2010 data

comparison with HERMES results

π+

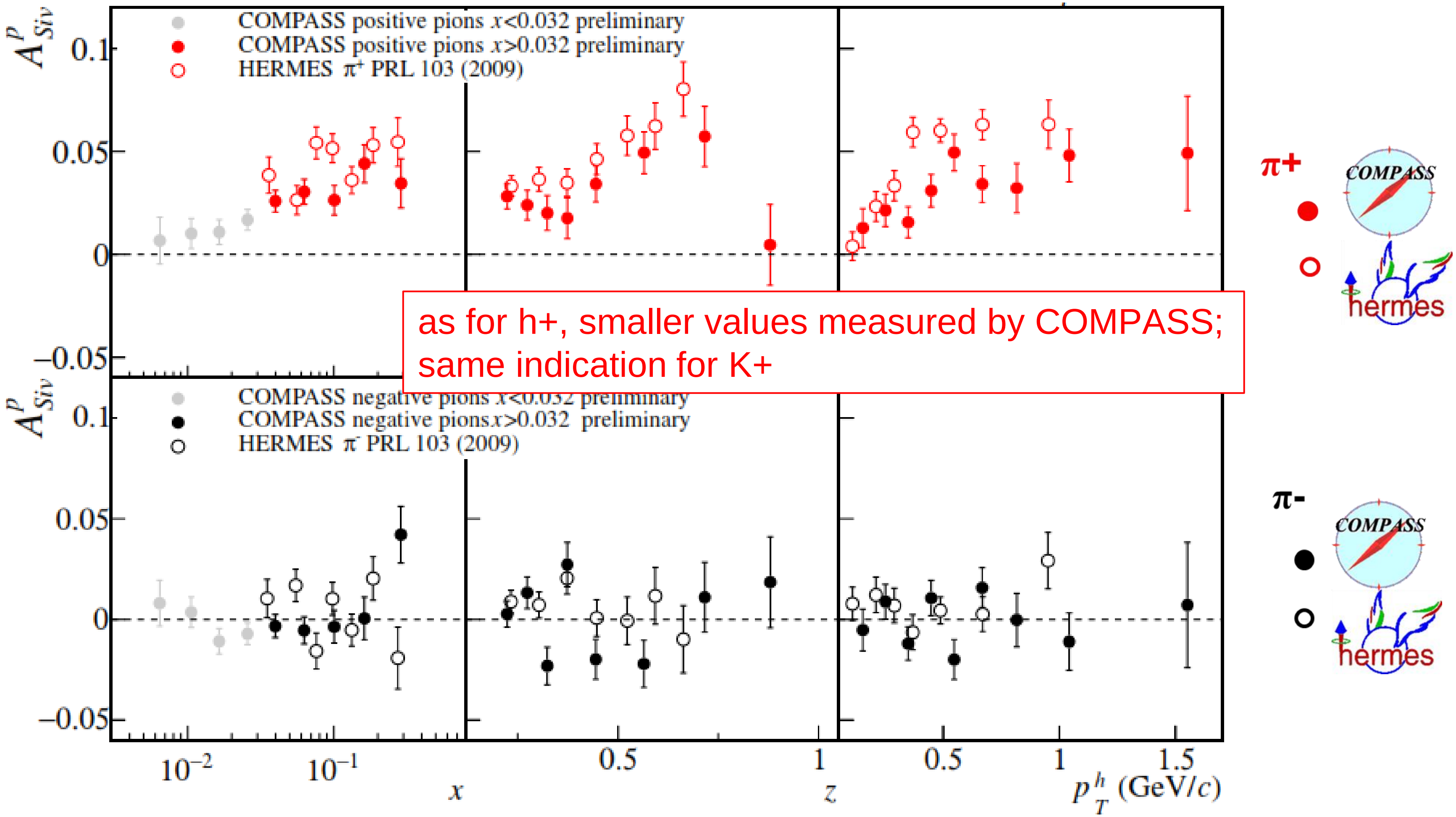
π-



Sivers asymmetry on proton x > 0.032

charged pions (and kaons), 2010 data

comparison with HERMES results

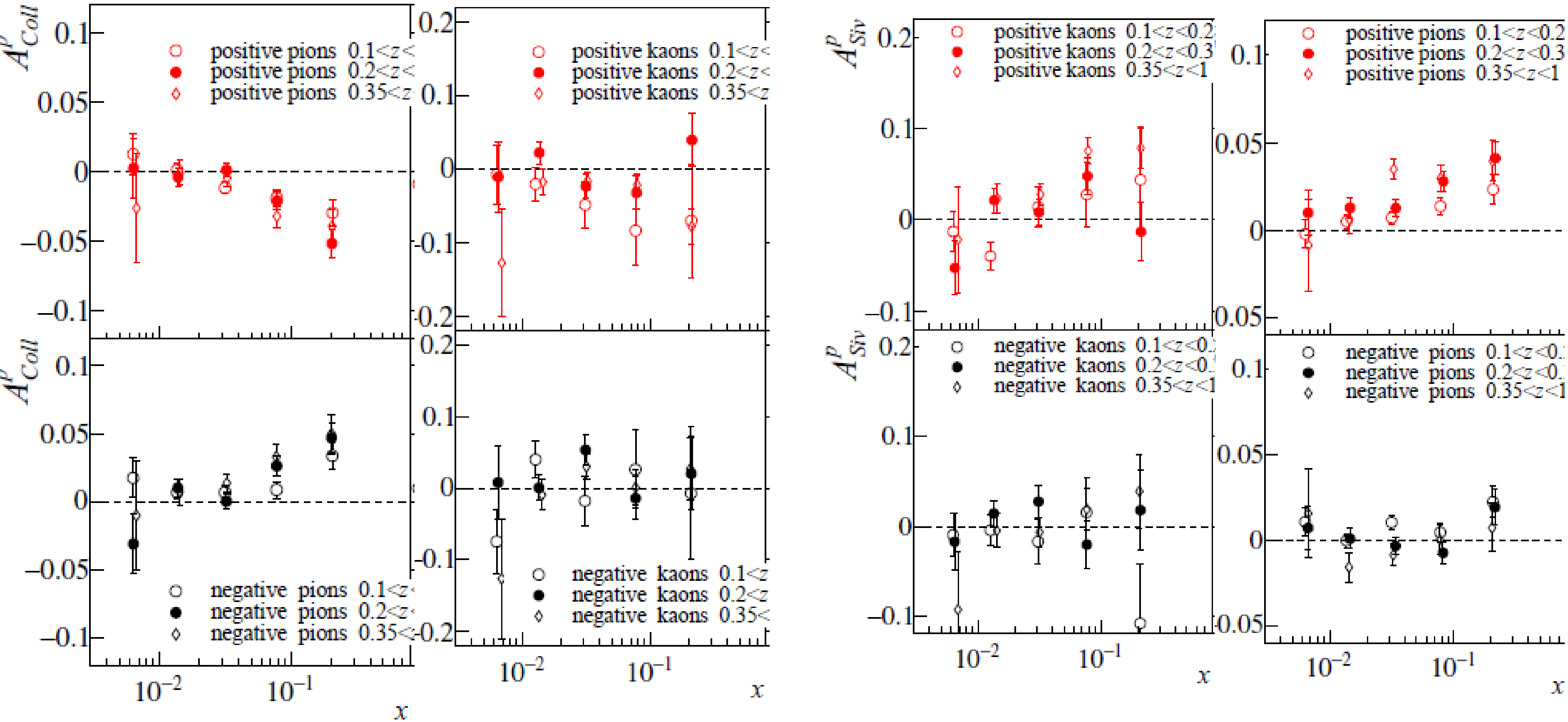


as for h+, smaller values measured by COMPASS; same indication for K+

3 z bins

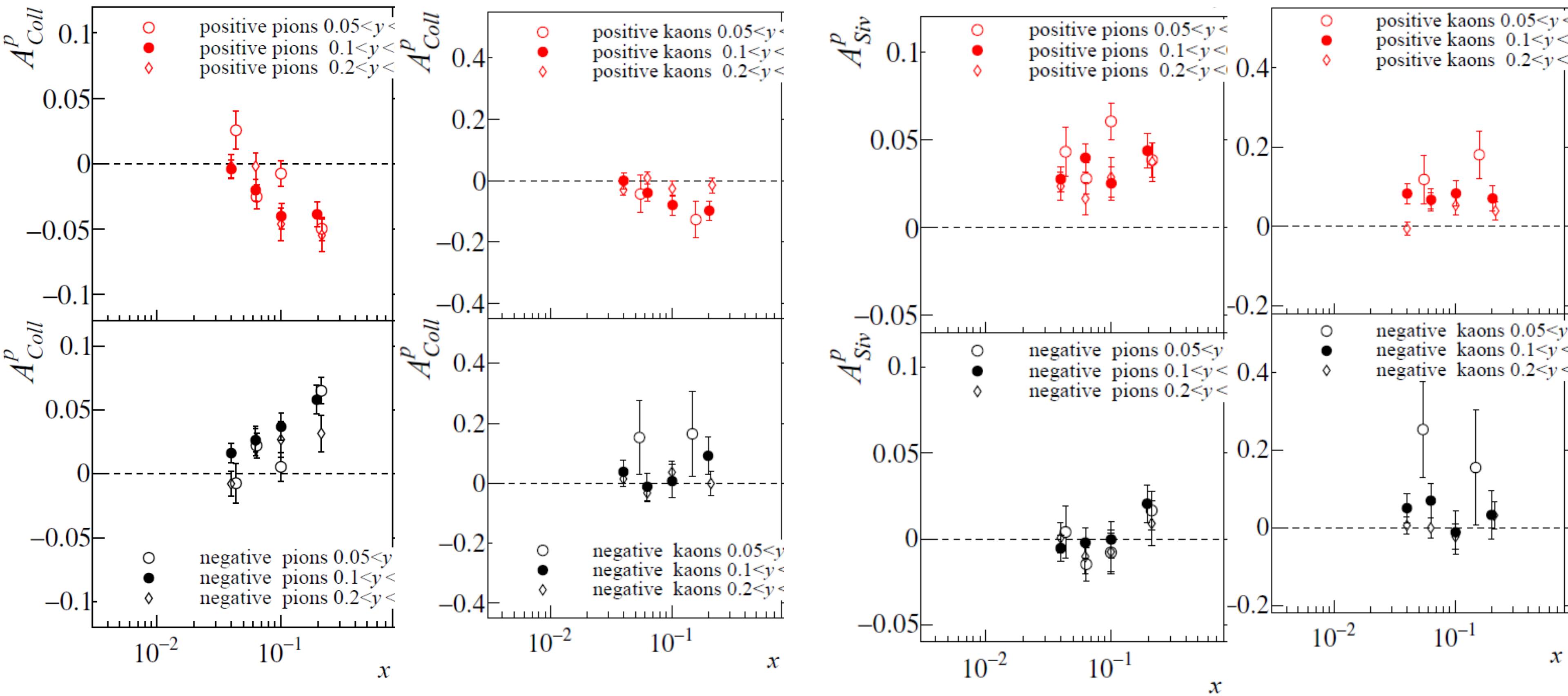
○ ○ $0.1<z<0.2$
● ● $0.2<z<0.35$
◇ ◇ $0.35<z<1$

Collins π Collins K Sivers π Sivers K



3 y bins

Collins π | Collins K | Sivers π | Sivers K



Interpretation of the transverse asymmetries

Bacchetta, Diehl, Goeke, Metz, Mulders and Schlegel JHEP 0702:093 (2007).

Within QCD parton model $\uparrow A_i \propto DF \otimes FF \quad (i = 1,..8)$

Twist-2:

$$A_{UT}^{\sin(\phi_h+\phi_s)} \propto h_1^q \otimes H_{1q}^{\perp h}$$
$$A_{UT}^{\sin(\phi_h-\phi_s)} \propto f_{1T}^{\perp q} \otimes D_{1q}^h$$
$$A_{UT}^{\sin(3\phi_h-\phi_s)} \propto h_{1T}^{\perp q} \otimes H_{1q}^{\perp h}$$

$$A_{LT}^{\cos(\phi_h-\phi_s)} \propto g_{1T}^q \otimes D_{1q}^h$$

single spin

double spin

Twist-2 + k_T/Q kinematical corrections:

$$A_{UT}^{\sin(\phi_s)} \propto \frac{M}{Q}\left(h_1^q \otimes H_{1q}^{\perp h} + f_{1T}^{\perp q} \otimes D_{1q}^h + \ldots\right)$$
$$A_{UT}^{\sin(2\phi_h-\phi_s)} \propto \frac{M}{Q}\left(h_{1T}^{\perp q} \otimes H_{1q}^{\perp h} + f_{1T}^{\perp q} \otimes D_{1q}^h + \ldots\right)$$

$$A_{LT}^{\cos(\phi_s)} \propto \frac{M}{Q}\left(g_{1T}^q \otimes D_{1q}^h \ldots\right.$$
$$A_{LT}^{\cos(2\phi_h-\phi_s)} \propto \frac{M}{Q}\left(g_{1T}^q \otimes \ldots\right.$$