

Highlights of the Workshop

Franco Bradamante



IWHSS 2013
International Workshop on
Hadron Structure and
Spectroscopy

Erlangen, 22-24 July 2013

Thanks to Wolfgang Eyrich

and to all the speakers

- very good talks
- a huge amount of material
- a good show of the variety of physics which can be done at COMPASS

and apologies to

Volker Burkert

Andrea Ferrero

Klaus Peters

Alexander Nagaytsev

JLAB 12

COMPASS II

FAIR

NICA



opening lecture:

beautiful review of DIS by K. Rith ...

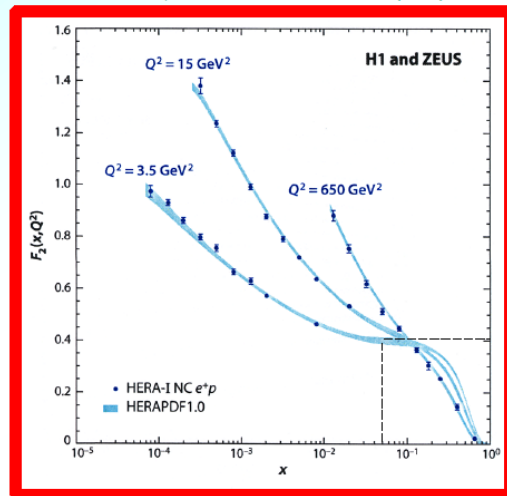
... mostly everything!

in particular the achievements of the HERA Collider

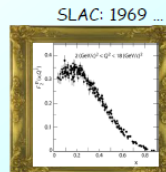
HERA measurements of $F_2^p(x, Q^2)$ - I

40 years later

C. Diaconu et al., Ann. Rev. Nucl. Part. Sci. 60 (2010) 259



$E_e = 27.6 \text{ GeV}, E_p = 920 \text{ GeV}$

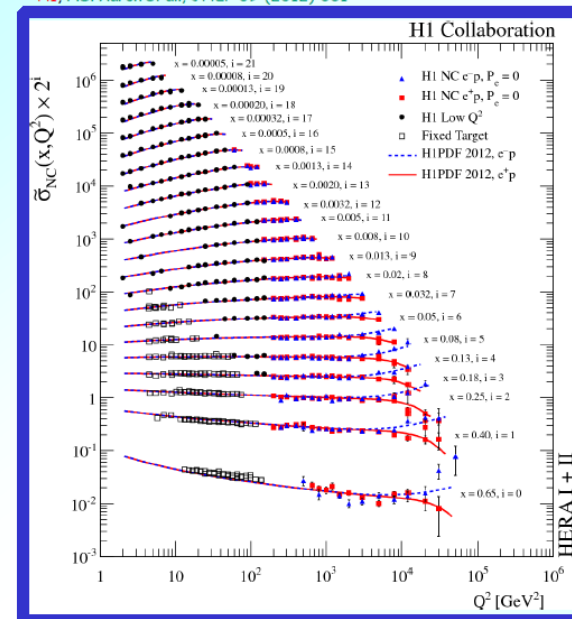


K.R.

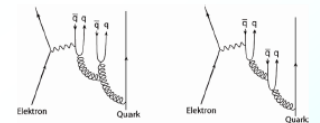
4

HERA measurements of $F_2^p(x, Q^2)$ - II

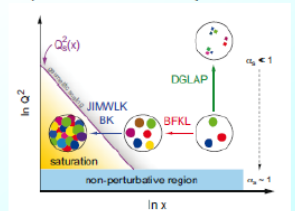
H1, F.D. Aaron et al., JHEP 09 (2012) 061



- Pattern of scalebreaking perfectly described by NNLO-QCD (DGLAP)



- No evidence for non-linear QCD effects (saturation)



↓
EIC, LHeC

K.R.

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F. Bradamante

More Accomplishments from HERA collider

C. Diaconu et al., Ann. Rev. Nucl. Part. Sci. 60 (2010) 259

- QCD tests, $\alpha_s(Q^2)$, Jet production
- Charm and beauty production
- Diffraction
- DVCS
- Searches for new physics
-
-
-
-

But unfortunately

- no ed
- no eA
- no $\vec{e}\vec{p}$



EIC, LHeC

K. Rith



K.R.

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F. Bradamante

spectroscopy

magnificent talk by M. Pennington

**studying the spectrum &
structure of hadrons**

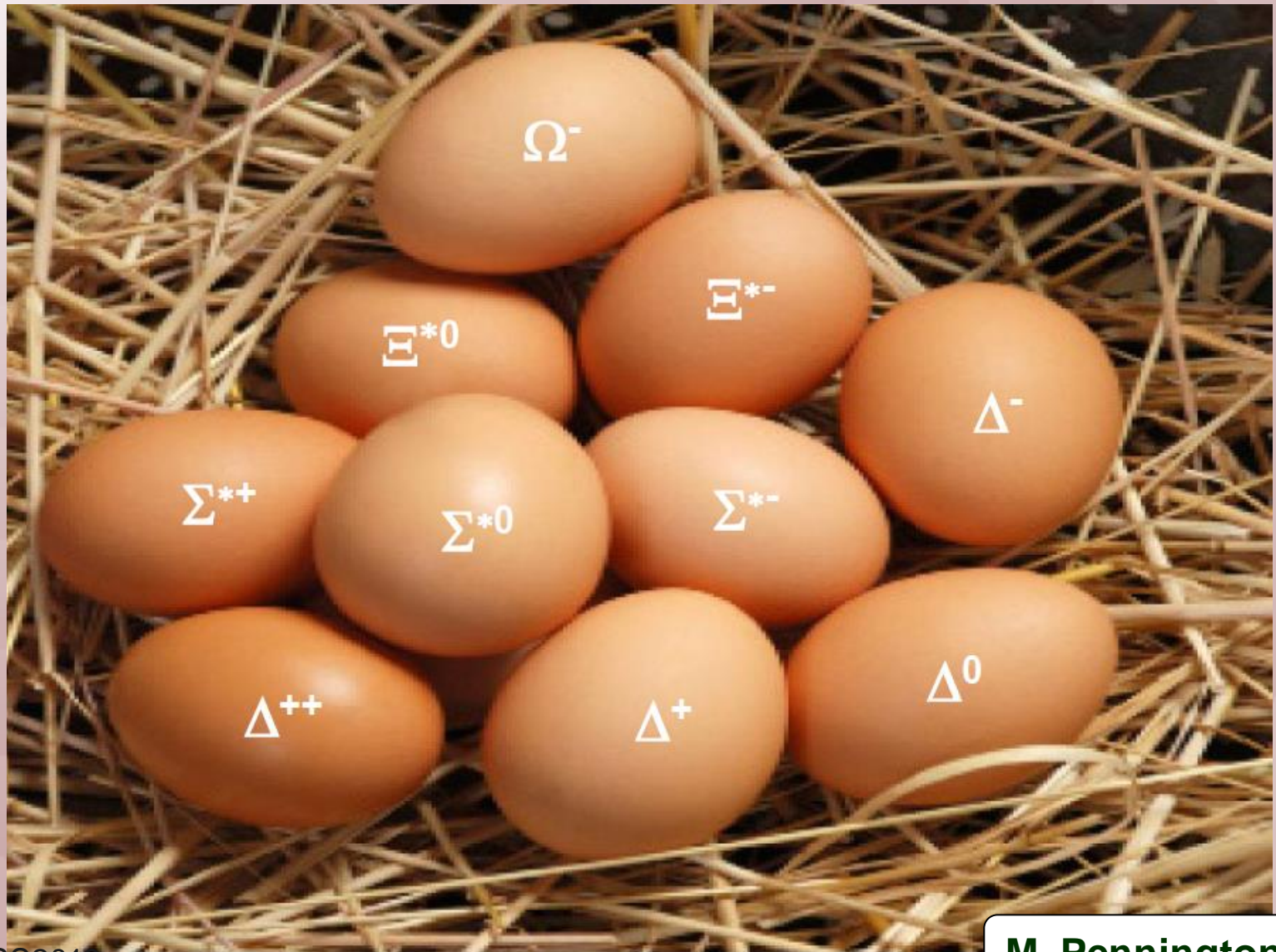
to reveal

the workings of QCD



spectroscopy

the eight-fold way ...



spectroscopy




IWHS52015


M. Pennington

A scenic view of a large, rocky mountain peak rising from the sea. The sky is a clear, pale blue. The water in the foreground shows a distinct wake from a boat, with small waves and white foam. The mountain peak is the central focus, with a sharp, jagged top. The overall atmosphere is calm and serene.

$\pi_1(1600)$

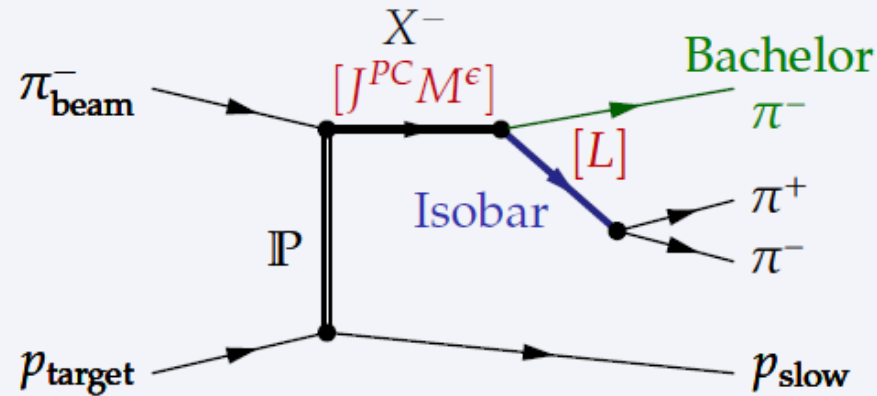


$\pi_1(1600)$



$\pi_1(1600)$

PWA of $\pi^- p \rightarrow \pi^- \pi^+ \pi^- p_{\text{slow}}$ COMPASS



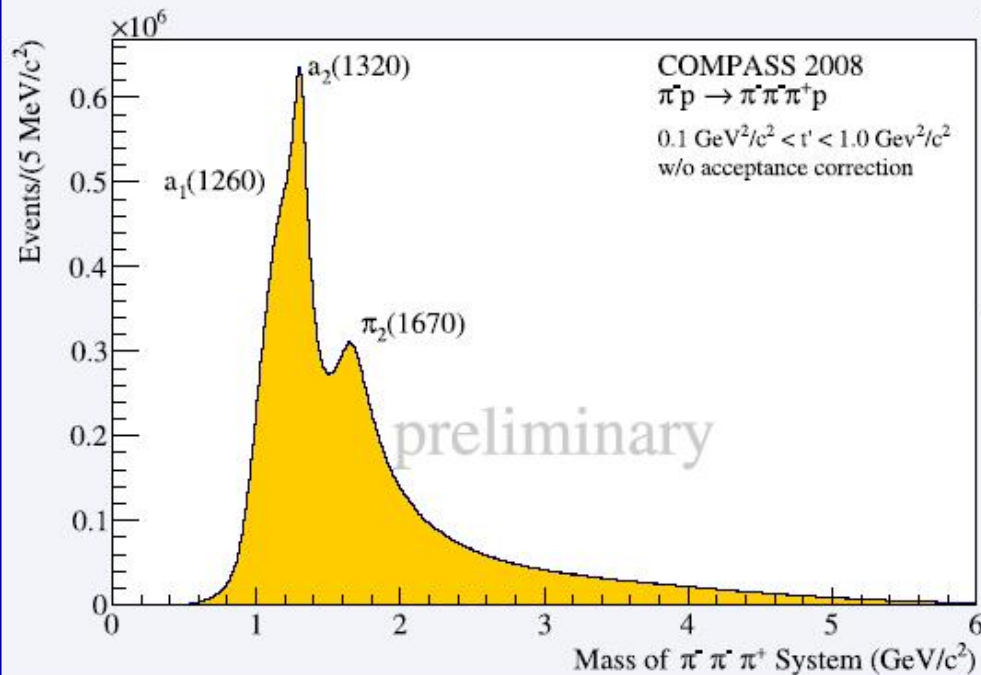
- 190 GeV/c negative hadron beam: 97 % π^- , 2 % K^- , 1 % \bar{p}
- Liquid hydrogen target
- Recoil proton p_{slow} measured by RPD
- Kinematic range $0.1 < t' < 1.0 \text{ (GeV/c)}^2$

PWA of $\pi^- p \rightarrow \pi^- \pi^+ \pi^- p_{\text{slow}}$

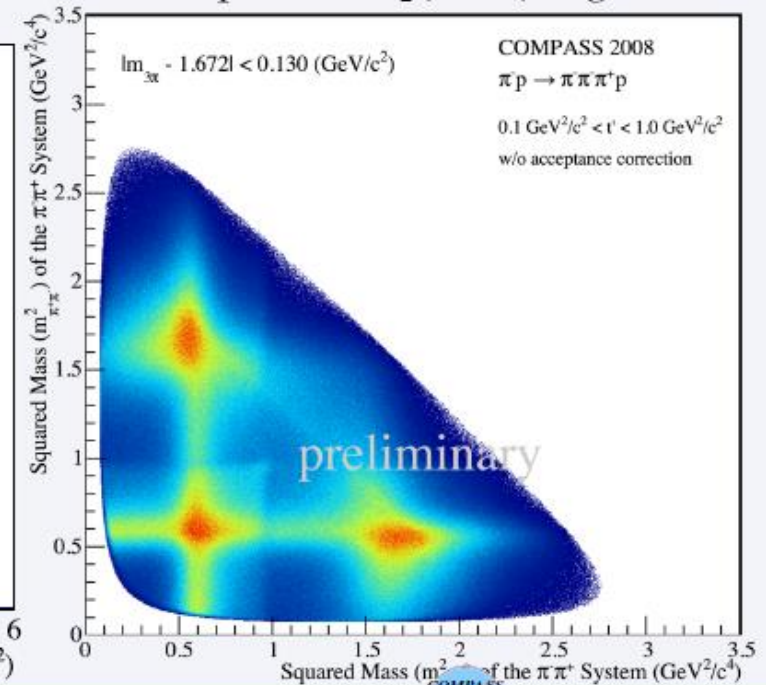
World's largest diffractive 3π data set: ≈ 50 M exclusive events

- Challenging analysis
 - Needs precise understanding of apparatus
 - Model deficiencies become visible

$\pi^- \pi^+ \pi^-$ invariant mass distribution

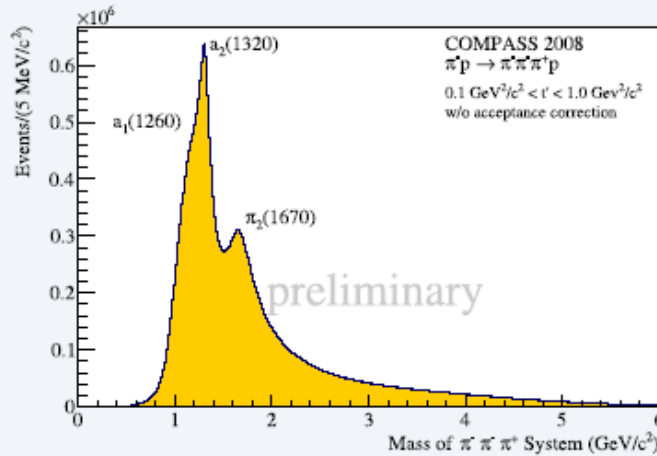


Dalitz plot for $\pi_2(1670)$ region

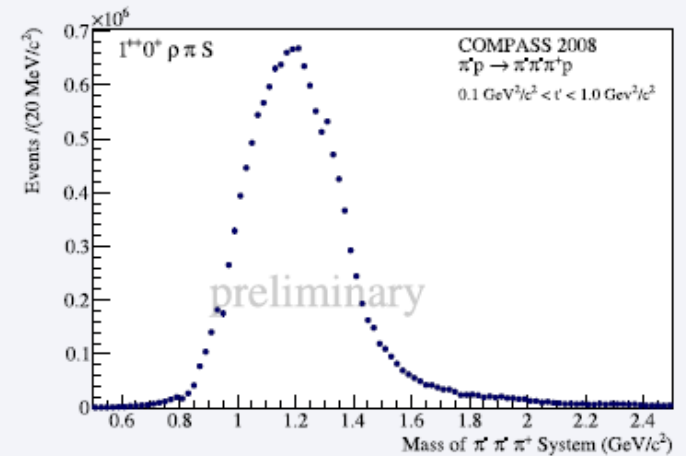


PWA of $\pi^- p \rightarrow \pi^- \pi^+ \pi^- p_{\text{slow}}$

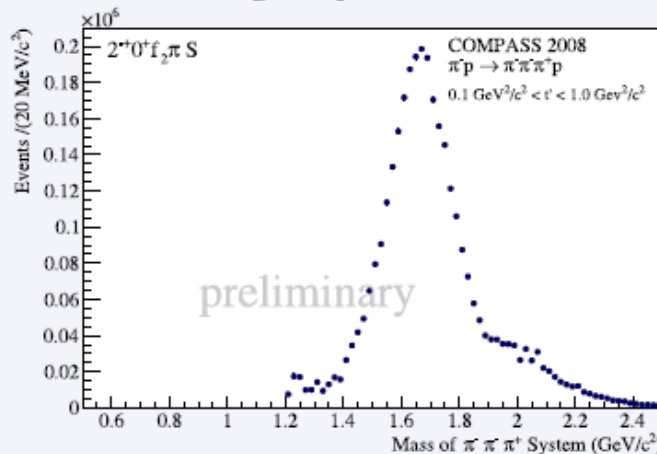
$\pi^- \pi^+ \pi^-$ invariant mass spectrum



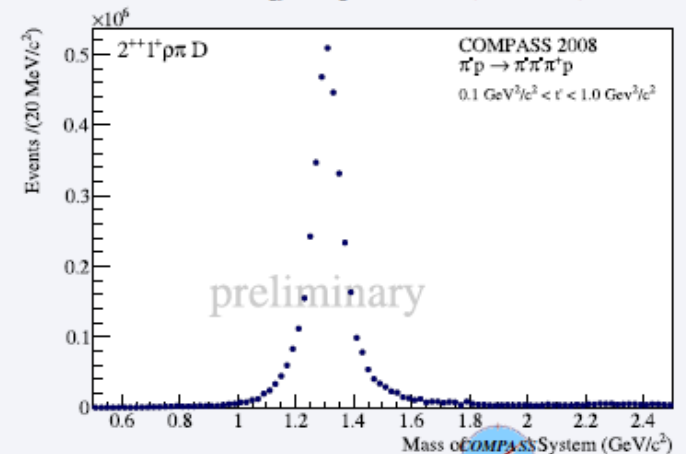
$1^{++} 0^+ [\rho\pi] S: a_1(1260)$



$2^{-+} 0^+ [f_2\pi] S: \pi_2(1670)$

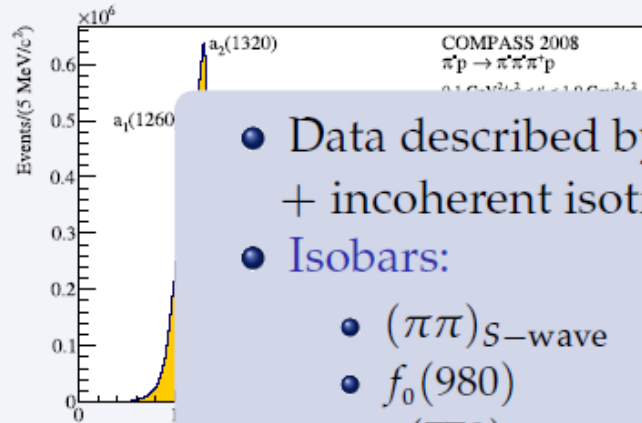


$2^{++} 1^+ [\rho\pi] D: a_2(1320)$

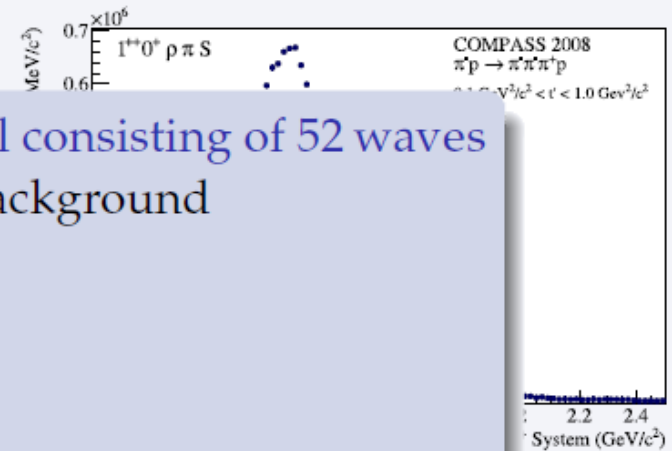


PWA of $\pi^- p \rightarrow \pi^- \pi^+ \pi^- p_{\text{slow}}$

$\pi^- \pi^+ \pi^-$ invariant mass spectrum



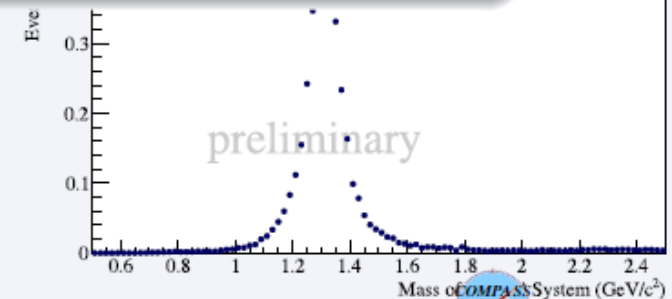
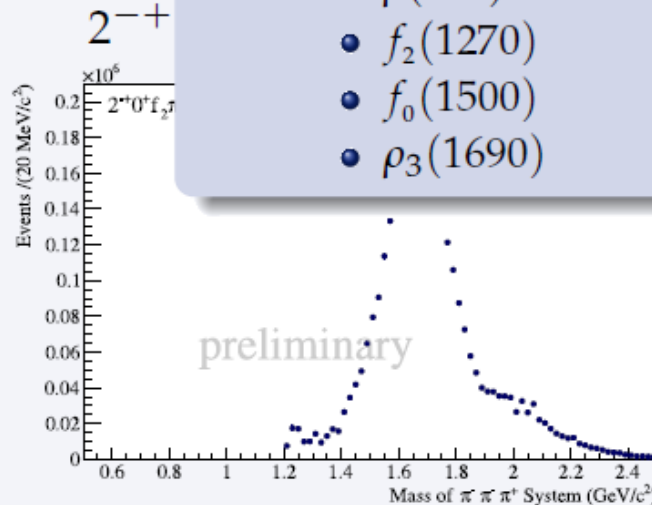
$1^{++} 0^+ [\rho\pi] S: a_1(1260)$



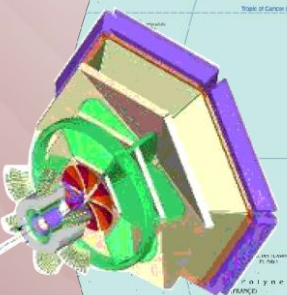
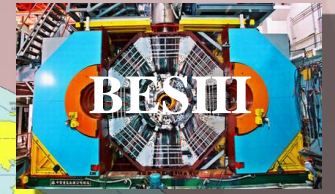
- Data described by model consisting of 52 waves + incoherent isotropic background

- Isobars:

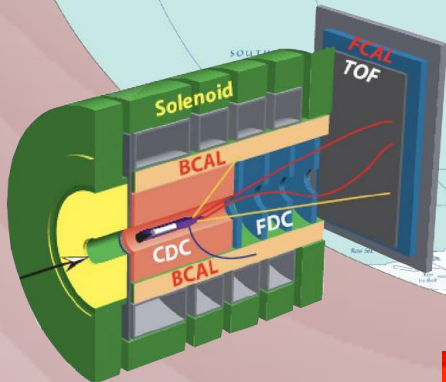
- $(\pi\pi)_S$ -wave
- $f_0(980)$
- $\rho(770)$
- $f_2(1270)$
- $f_0(1500)$
- $\rho_3(1690)$



Global working : Amplitude Analyses & Spectroscopy



CLAS12



GlueX

M. Pennington



TAPS/CB

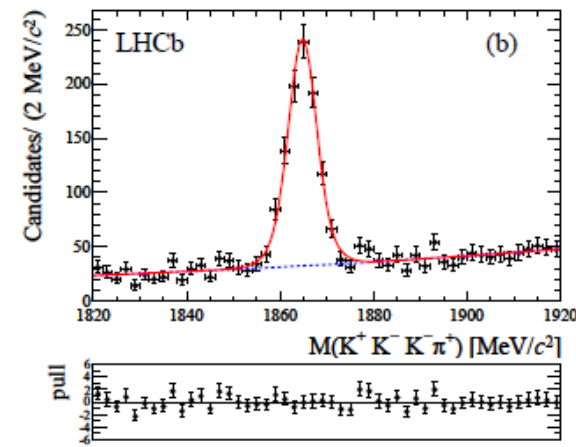
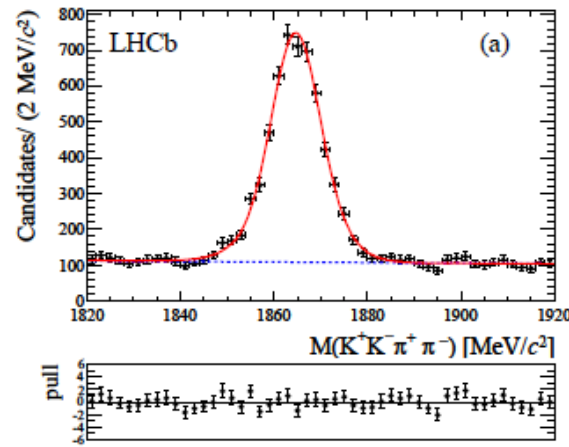
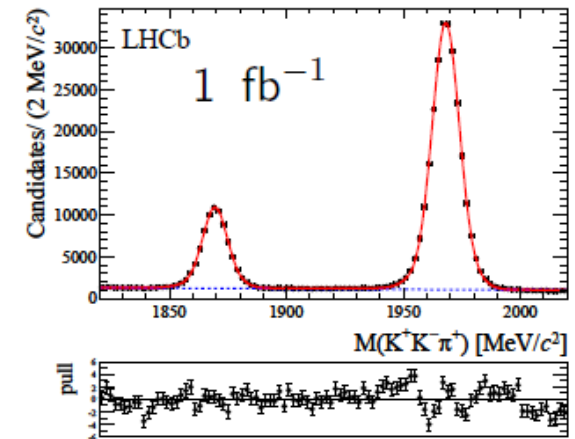


Ground state $D_{(s)}$ mesons

- Huge samples available at LHCb
- Dominant systematic uncertainty from momentum and energy loss calibration
- Smaller Q value of the decay \Rightarrow smaller sensitivity to momentum calibration
- Have large samples of other particles to calibrate momentum

THE UNIVERSITY OF
WARWICK

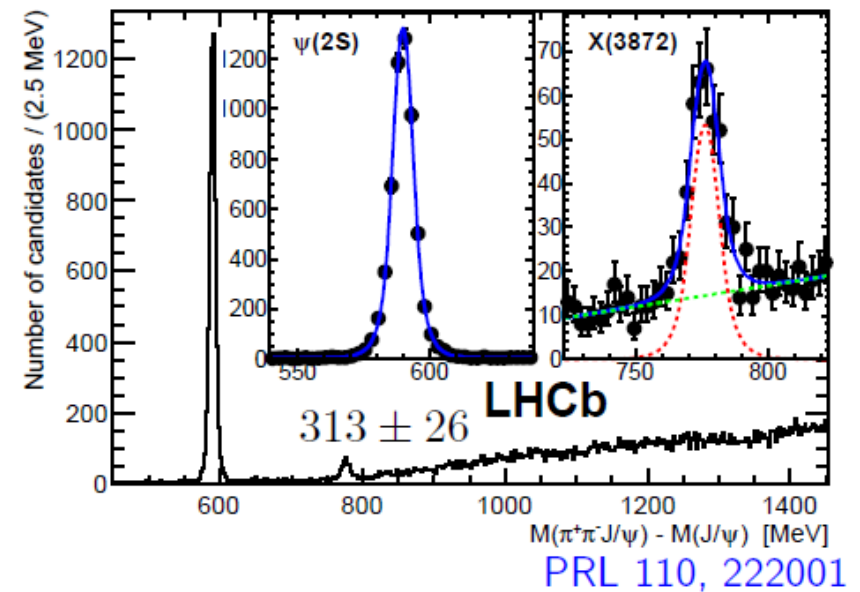
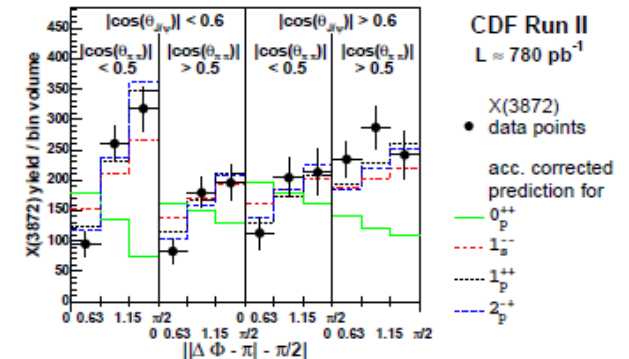
JHEP 06 (2013), 065



$X(3872)$ quantum numbers

THE UNIVERSITY OF
WARWICK

- Its 10 years since observation of $X(3872)$
- Triggered renewed interest to $c\bar{c}$ states
- Lot of speculations what $X(3872)$ is
- Determination of quantum numbers important
 - Not all hypotheses work with any J^{PC}
 - Restricts its position in spectrum
- In 2006 CDF restricted J^{PC} to 1^{++} or 2^{-+}
- BABAR favours 2^{-+} from observation of $X(3872) \rightarrow J/\psi\omega$



Primakoff reactions



IWHSS 2013

*Experimental
review of Primakoff
reactions*

COMPASS

*Guskov Alexey
JINR, Dubna*

on behalf of the COMPASS collaboration

Erlangen, 22.7.2013

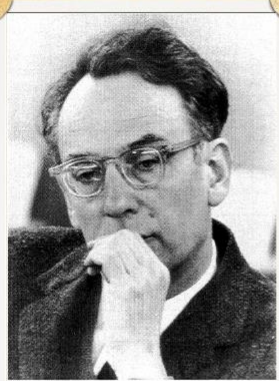
Guskov Alexey, Joint Institute for Nuclear Research, Dubna

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Primakoff reactions

Henry Primakoff



Henry Primakoff

Photo-Production of Neutral Mesons in Nuclear Electric Fields and the Mean Life of the Neutral Meson*

H. PRIMAKOFF†
 Laboratory for Nuclear Science and Engineering, Massachusetts
 Institute of Technology, Cambridge, Massachusetts
 January 2, 1951

IT has now been well established experimentally that neutral π -mesons (π^0) decay into two photons.¹ Theoretically, this two-photon type of decay implies zero π^0 spin;² in addition, the decay has been interpreted as proceeding through the mechanism of the creation and subsequent radiative recombination of a virtual proton anti-proton pair.³ Whatever the actual mechanism of the (two-photon) decay, its mere existence implies an effective interaction between the π^0 wave field, φ , and the electromagnetic wave field, \mathbf{E}, \mathbf{H} , representable in the form:

$$\text{Interaction Energy Density} = \eta(\hbar/\mu c)(\hbar c)^{-1} \varphi \mathbf{E} \cdot \mathbf{H}. \quad (1)$$

Here φ has been assumed pseudoscalar, the factors $\hbar/\mu c$ and $(\hbar c)^{-1}$ are introduced for dimensional reasons ($\mu \equiv$ rest mass of π^0),

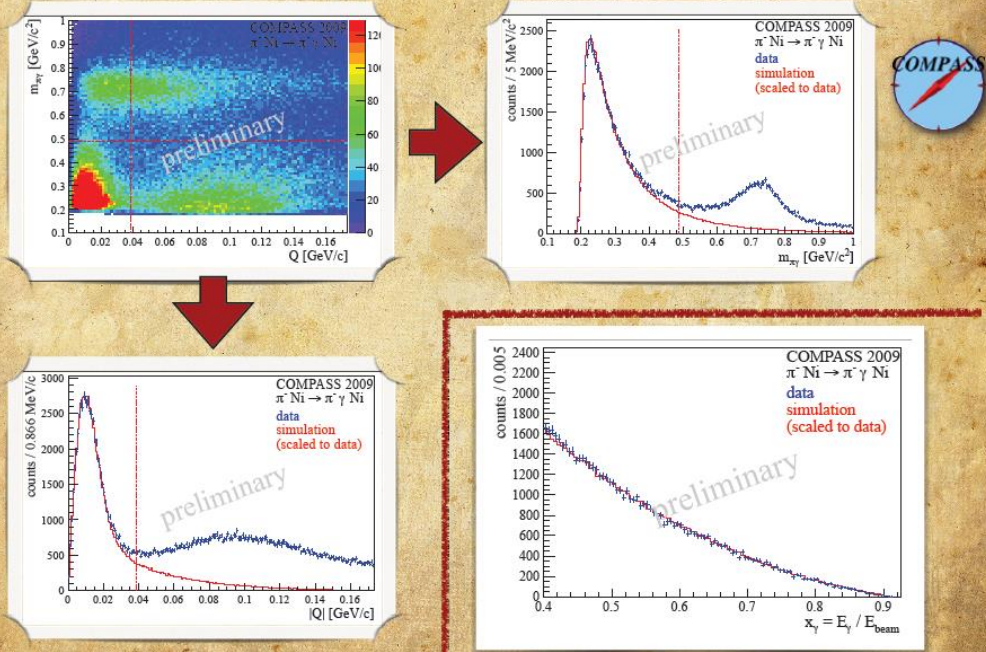
Coulomb field of nucleus can be used as photon target

Guskov Alexey, Joint Institute for Nuclear Research, Dubna

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history

Pion polarizabilities at COMPASS



Guskov Alexey, Joint Institute for Nuclear Research, Dubna

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present

future: COMPASS
 JLab



IWHSS2013

F. Bradamante

a hot issue

Unpolarised SIDIS:

- Multiplicities
- Fragmentation Functions
- k_T distributions
- p_T distributions
- Azimuthal Modulations

$\cos \phi$, $\cos 2\phi$

E.-C. Aschenauer
K. Kurek
M. Stratmann
G. Schnell
M. Radici
M. Boglione
B. Parsamyan

and connections with
unpolarised Drell-Yan



Multiplicities and Fragmentation Functions

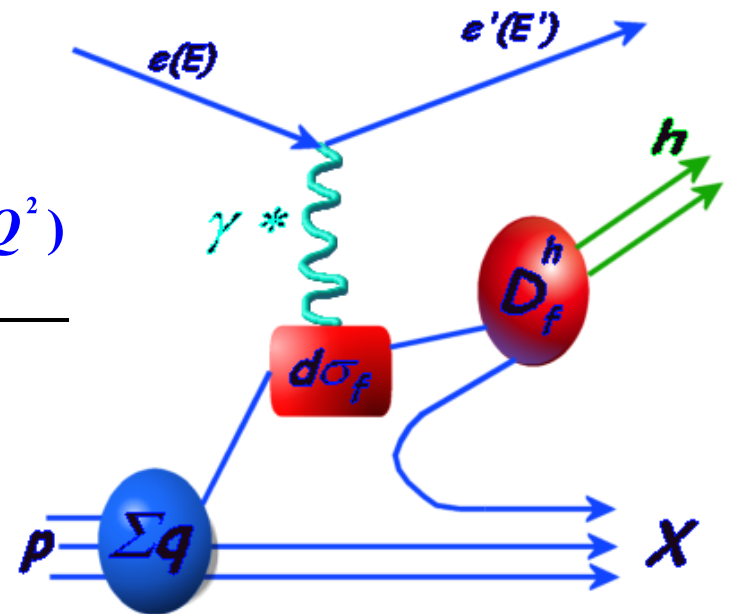
E.-C. Aschenauer



HADRON MULTIPLICITIES

New results from  and 

$$\frac{dN^h(z, p_t, x, Q^2, \phi)}{N^e(x, Q^2)} = \frac{\sum_f e_f^2 \int_0^1 dx q_f(k_t, x, Q^2) D_f^h(z, p_t, Q^2)}{\sum_f e_f^2 \int_0^1 dx q_f(k_t, x, Q^2)}$$



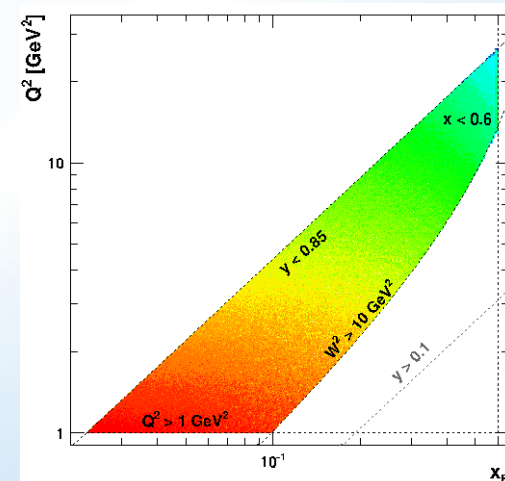
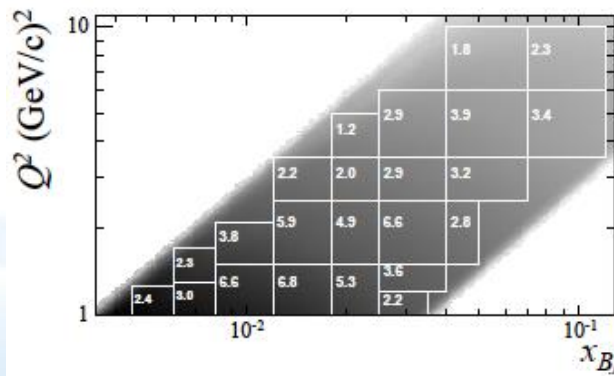
General Cuts applied:

COMPASS:

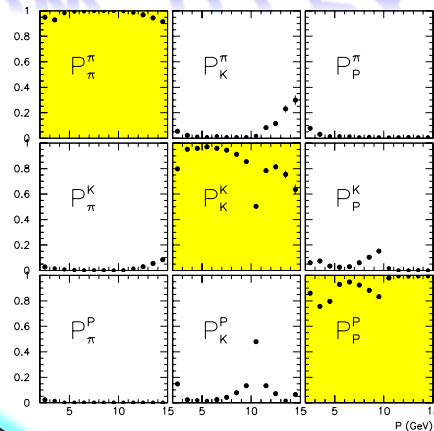
$Q^2 > 1 \text{ GeV}^2$
 $0.1 < y < 0.9$,
 $5 \text{ GeV} < W < 17 \text{ GeV}$,
 $0.003 < x < 0.7$
 $0.2 < z < 0.85$
 h^+h^- : arXiv:1305.7317
 π, K : Talk at DIS

HERMES:

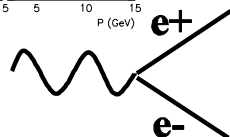
$Q^2 > 1 \text{ GeV}^2$
 $0.1 < y < 0.85$,
 $10 \text{ GeV} < W^2$
 $0.2 < z < 0.85$
 PRD87 (2013) 074029



HOW TO EXTRACT MULTIPLICITIES



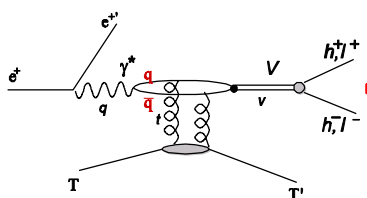
- RICH PID unfolding
- trigger efficiency correction
- charge-sym. bkg correction



unpolarised raw data

experimental multiplicities in acceptance

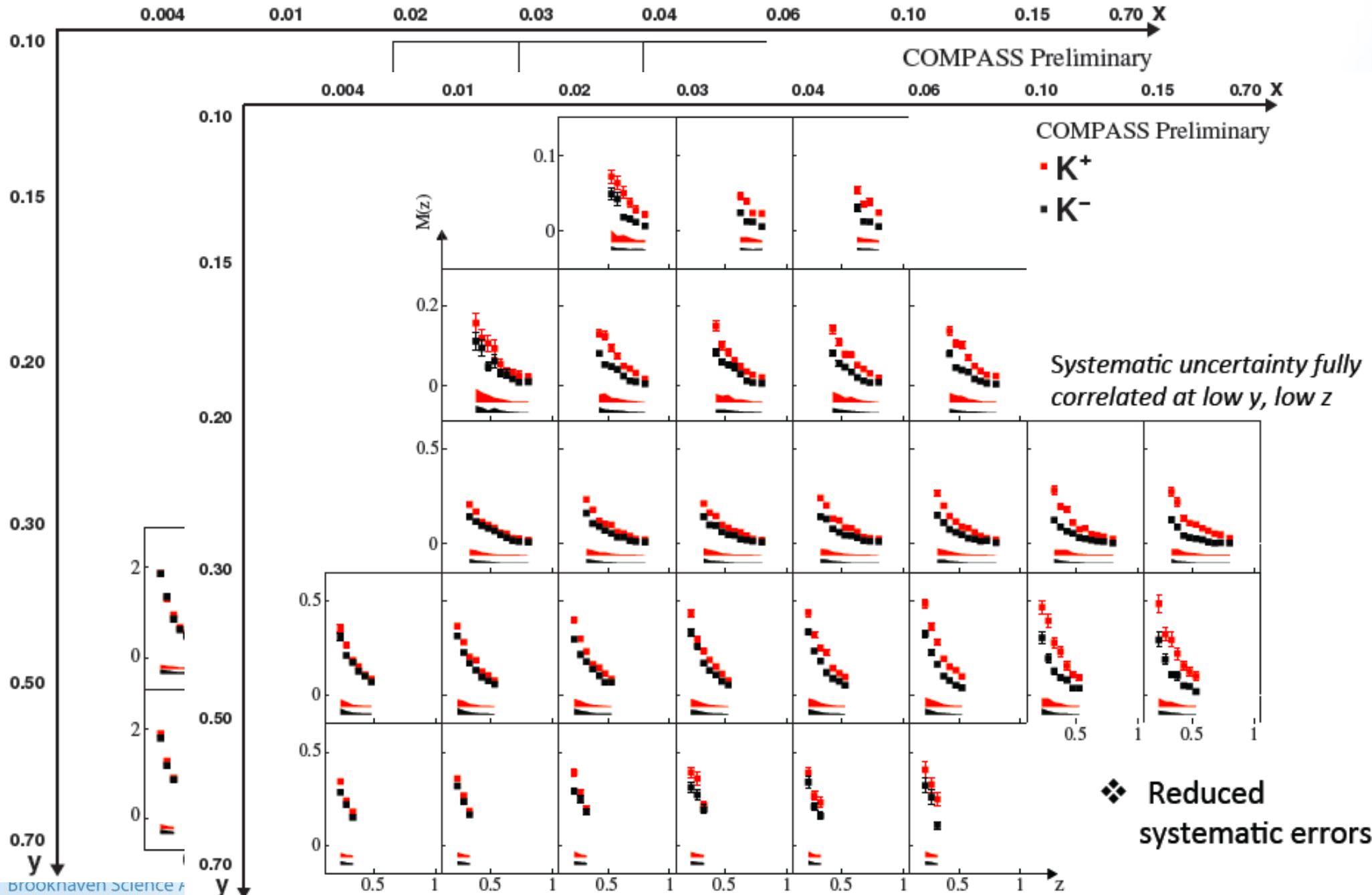
excl. VM correction



Unfolding for Detector Smearing and QED Radiative Effects

MC based corrections

Born level multiplicities

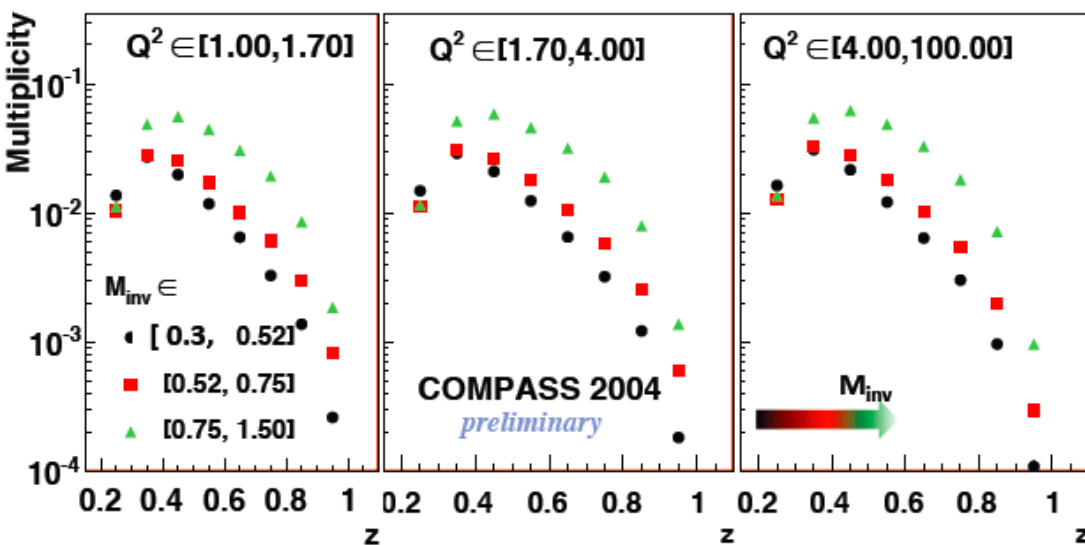




HADRON PAIR MULTIPLICITIES

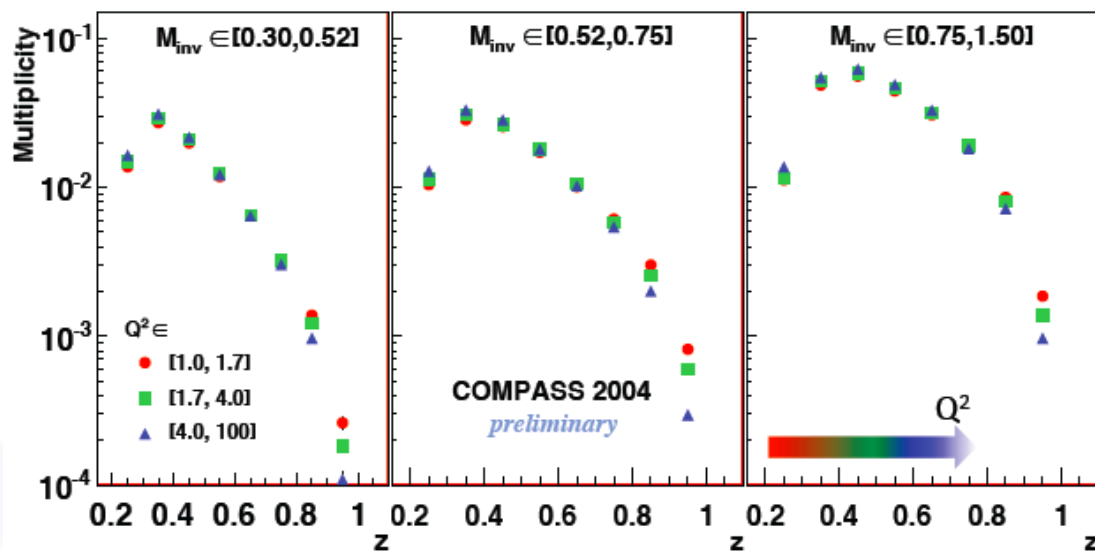
CUTS:

$Q^2 > 1 \text{ GeV}^2$; $0.1 < y < 0.9$, $5 \text{ GeV} < W < 17 \text{ GeV}$; $0.003 < x < 0.7$

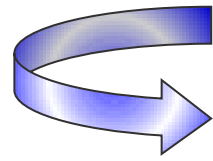
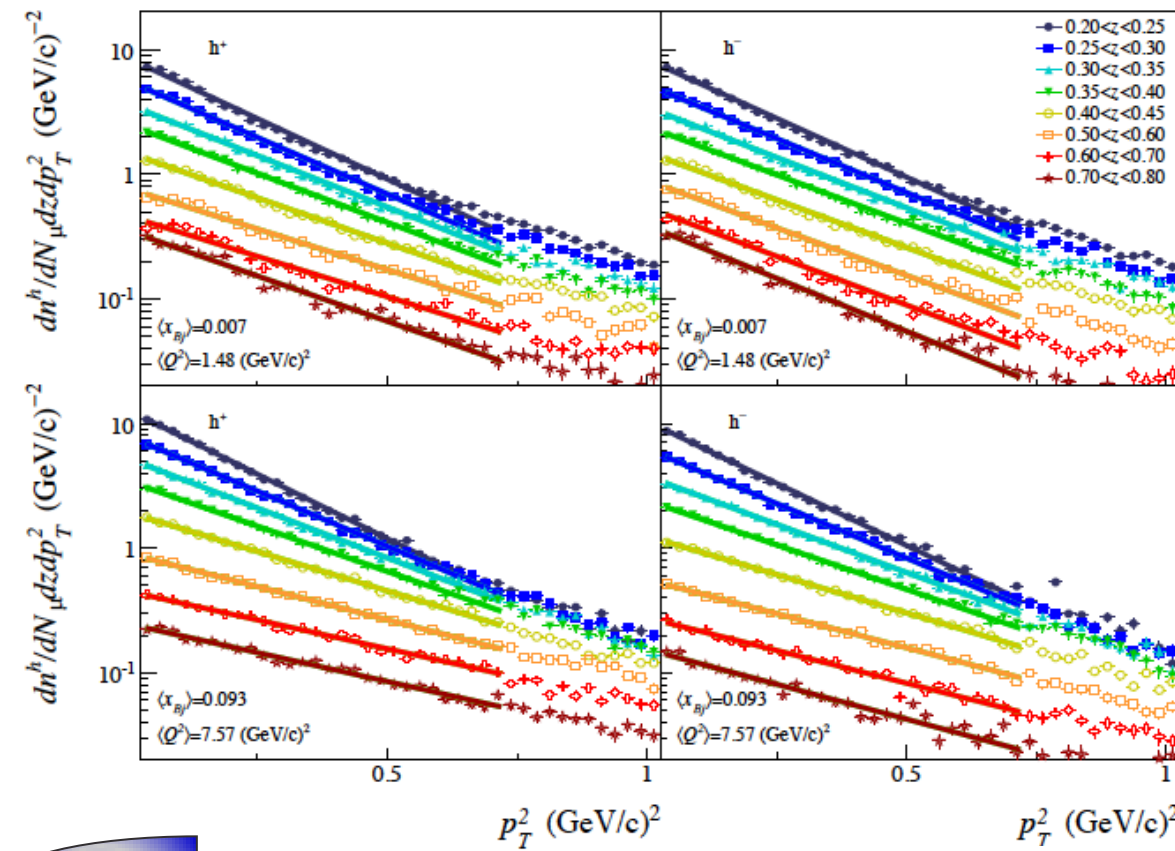


$$z = z_{h^+} + z_{h^-}$$

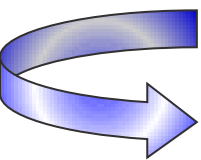
- First measurement in simultaneous (x, Q^2, M_{inv}) bins
- Non negligible dependence upon M_{inv} and z
- Weak Q^2 dependences
- Lepto reproduces dependences
- Input for fits to extract



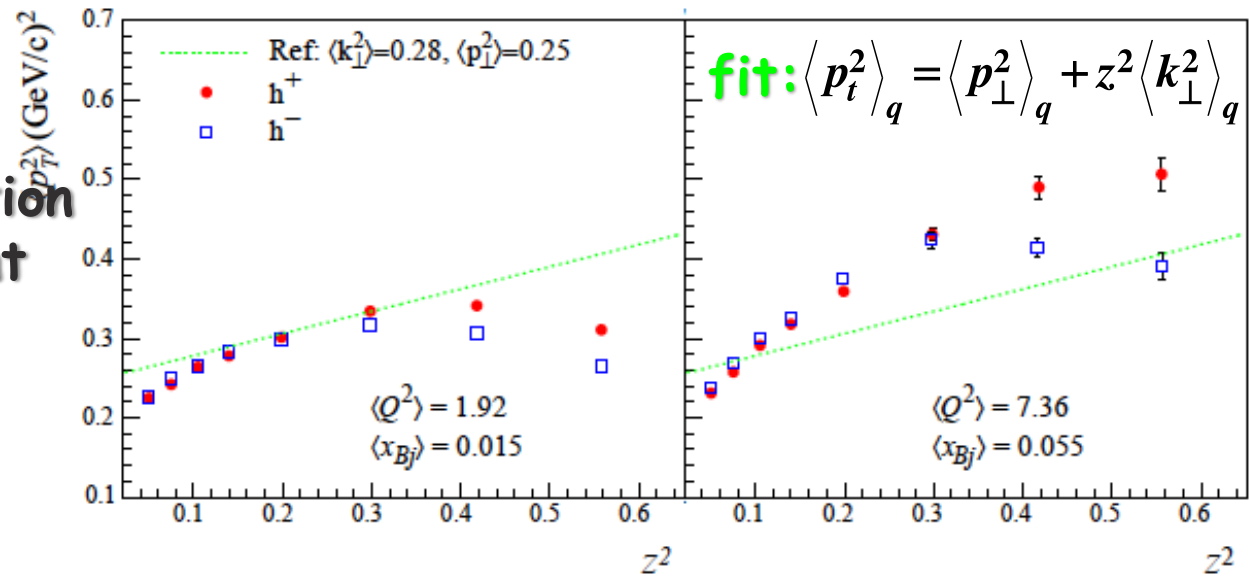
$$D_q^{h^+h^-}(z, Q^2, M_{inv})$$



very precise multidimensional data (x , Q^2 , p_T , z)



- fit is not a good representation
- need to account for different underlying sub-processes
- neglects other dependences



Extracting the unpolarized TMD

Gaussian w



Very preliminary
Anselmino, Boglione, Gonzalez, Melis

HERMES

HERMES + COMPASS fit

cuts: $Q^2 > 1.68$, $z < 0.7$, $P_T/Q < 1$, $x > 0.08$

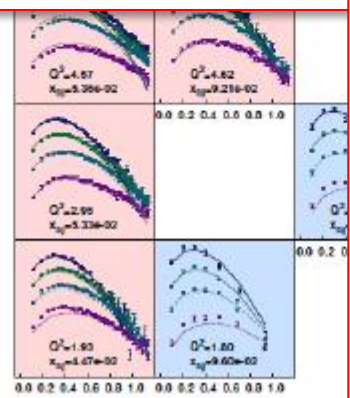
n. of fitted data points: 2873 (almost equally divided between HERMES and COMPASS)

$$\chi^2_{point} = 7.47$$

$$\langle k_{\perp}^2 \rangle = (0.55 \pm 0.21) \text{ GeV}^2$$

$$\langle p_{\perp}^2 \rangle = (0.16 \pm 0.03) \text{ GeV}^2$$

zh=0.2
zh=0.3
zh=0.4
zh=0.6



Any sign of Q^2 evolution ?

...

More work ...

More parameters ...

23/7/2013

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Multiplicities and Fragmentation Functions

E.-C. Aschenauer

M. Boggione

M. Stratmann



take away message

global QCD analyses of fragmentation functions ongoing

- pion FFs rather well constrained
- uncertainties for kaon FFs still large

many new data sets will lead to much improved sets

e^+e^-

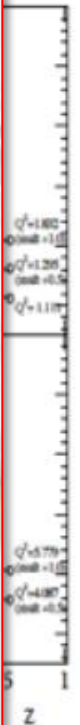
- BELLE and BaBar add precision data at different scale than LEP
- possible tension between BELLE and BaBar

$e/\mu p$

- COMPASS and HERMES pion results fit very well together
- will start with kaons as soon as COMPASS results become available

pp

- new RHIC and first LHC results in the fit
- some normalization issue with ALICE



azimuthal asymmetries in unpolarised SIDIS

B. Parsamyam

Experiments in last 35 years: part I

EMC CERN (μ -p, μ -d) @ 280 GeV



Fermilab E665 (μ -p, μ -d) @ 490 GeV

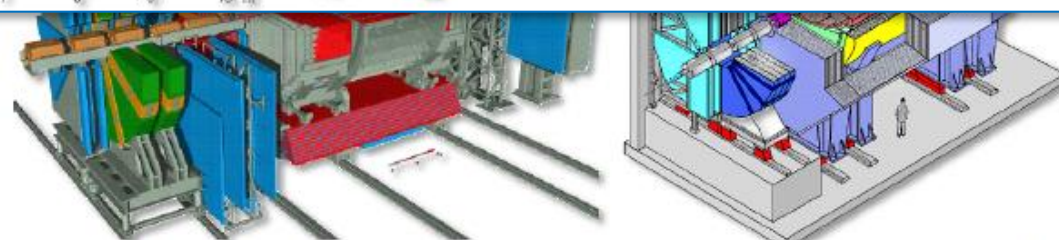
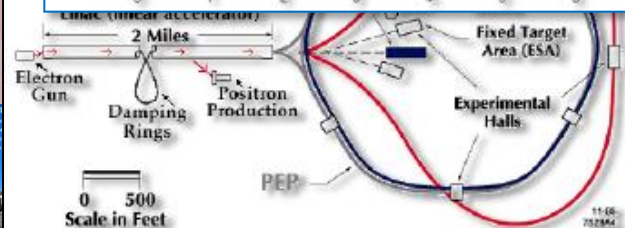
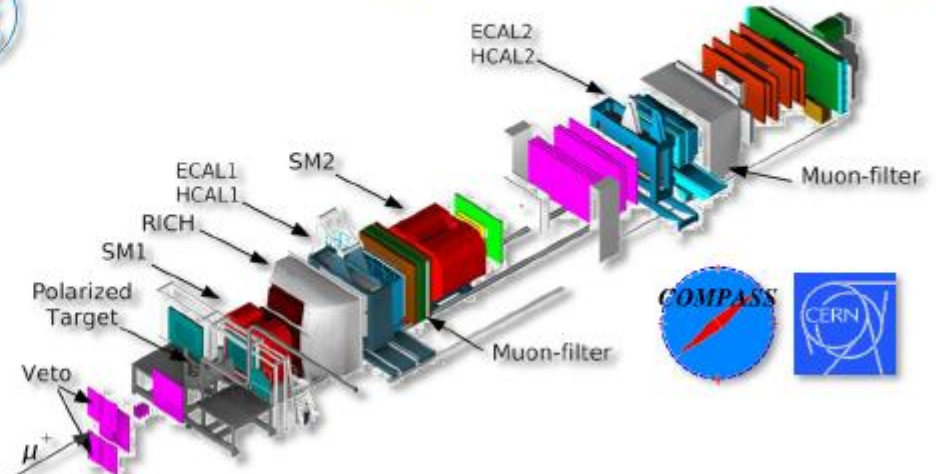
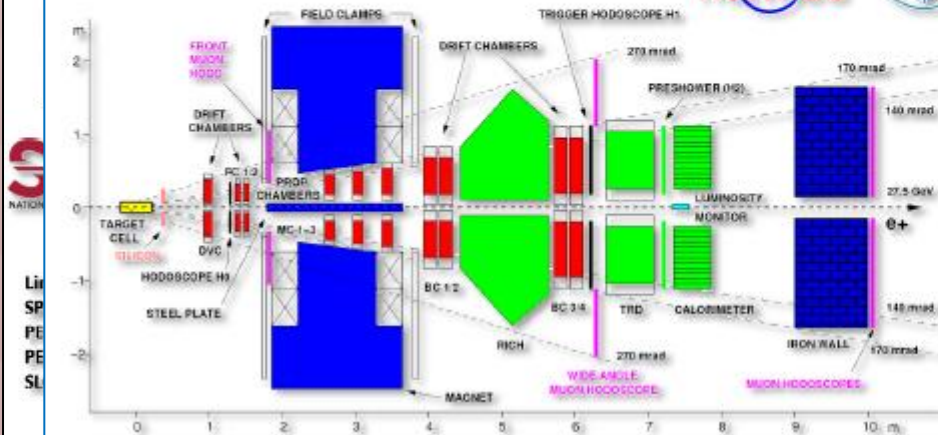


Experiments in last 35 years: part II

HERA MEasurement of Spin



COMmon Muon Proton Apparatus for Structure and Spectroscopy



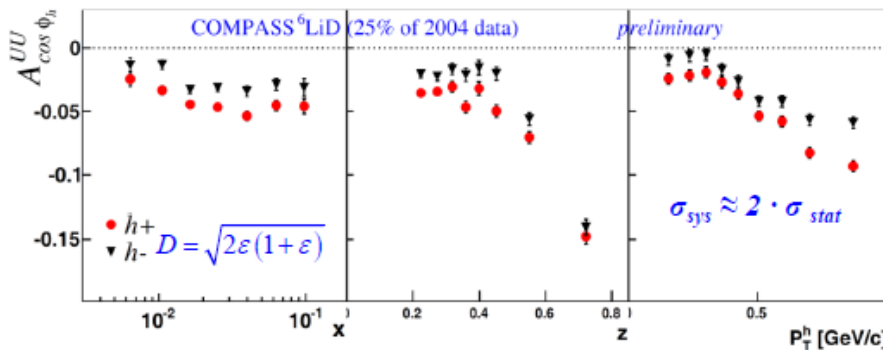
azimuthal asymmetries in unpolarised SIDIS

B. Parsamyan

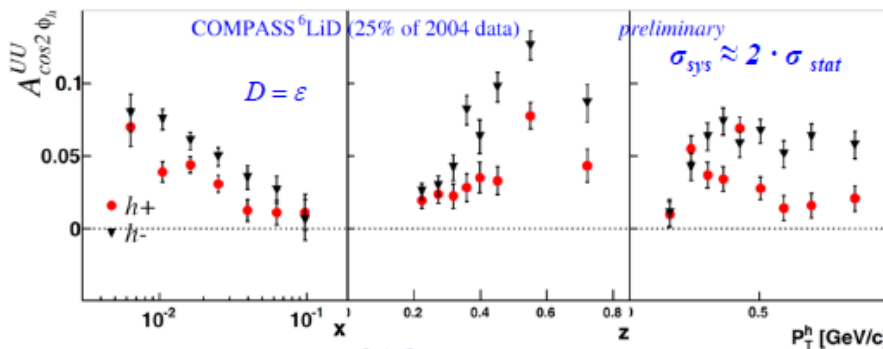
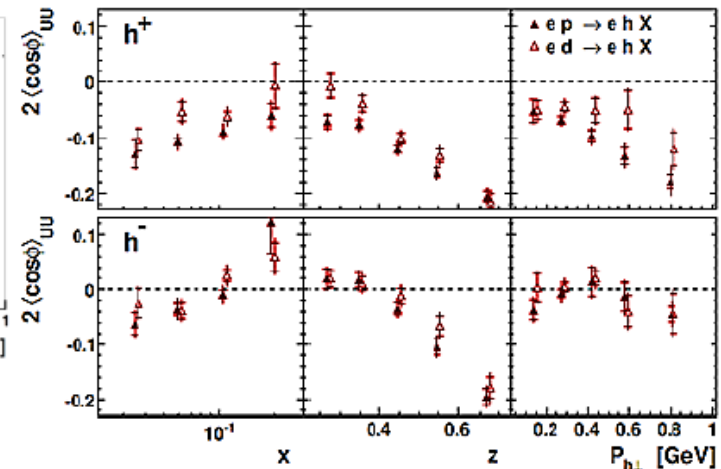
$A_{UU}^{\cos\phi}$ and $A_{UU}^{\cos 2\phi}$ amplitudes h^+/h^-



Different kinematic regions!

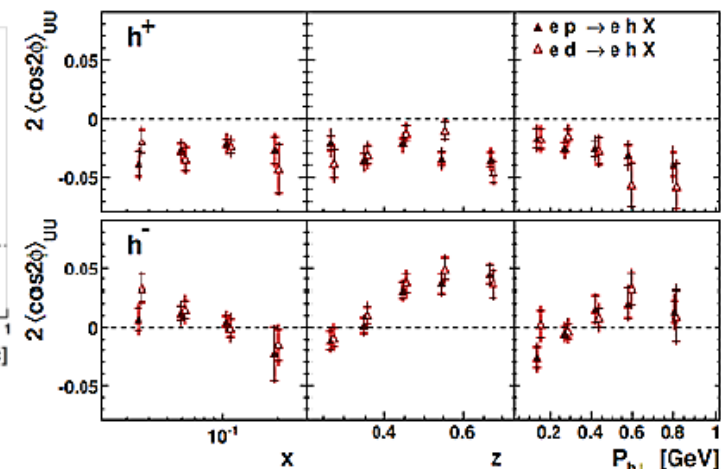


➤ Similar trends for h^+/h^-



➤ Similar trends for h^+/h^-

➤ No sign change for h^+/h^- at COMPASS



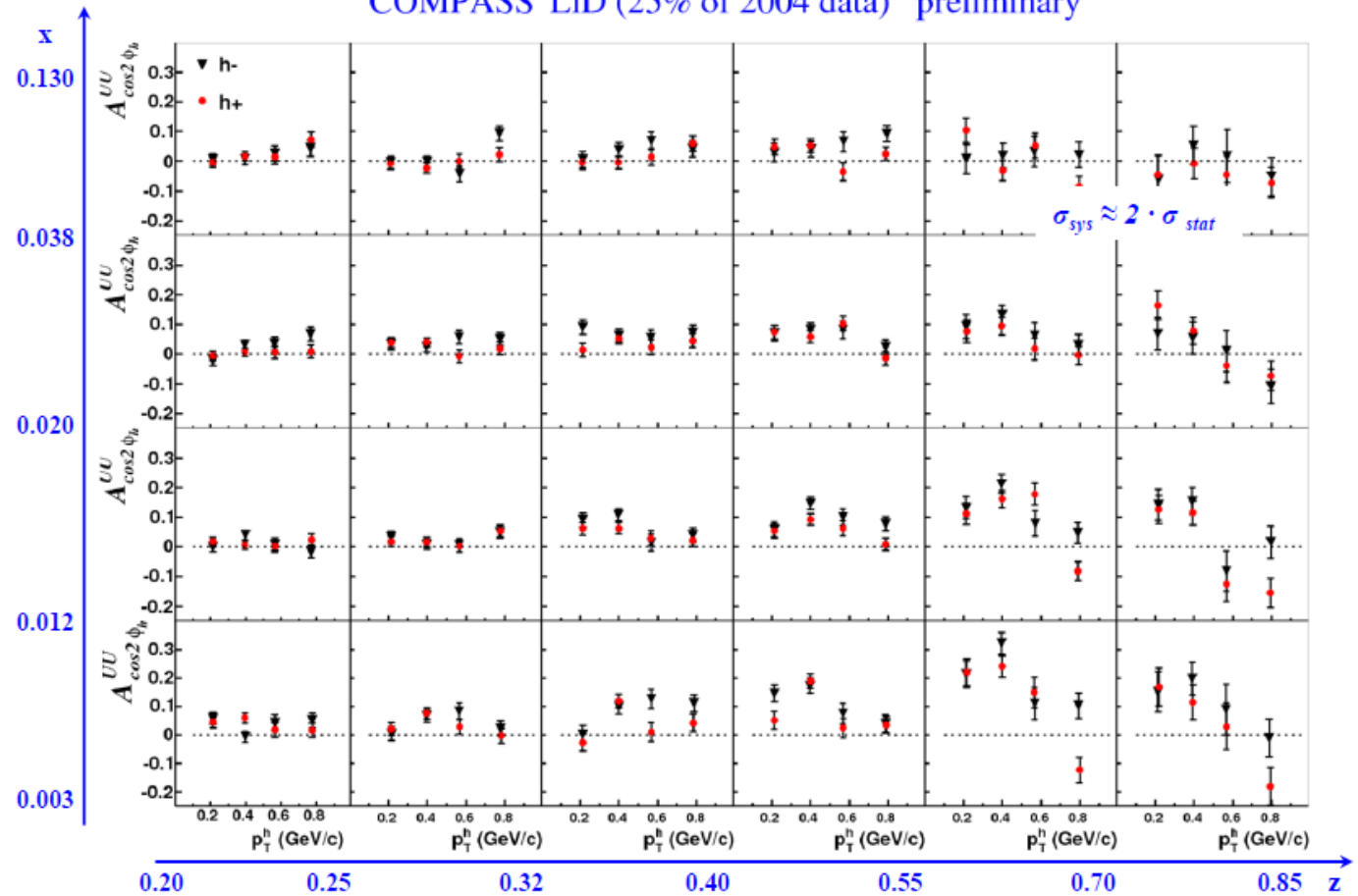
azimuthal asymmetries in unpolarised SIDIS

B. Parsamyán

$A_{UU}^{\cos 2\phi_h}$ - asymmetry (P_{hT} - dependence)



COMPASS⁶LiD (25% of 2004 data) preliminary



P_{hT} trend not described by the models arises in large z and low x region

23 July 2013

Bakur Parsamyán

51



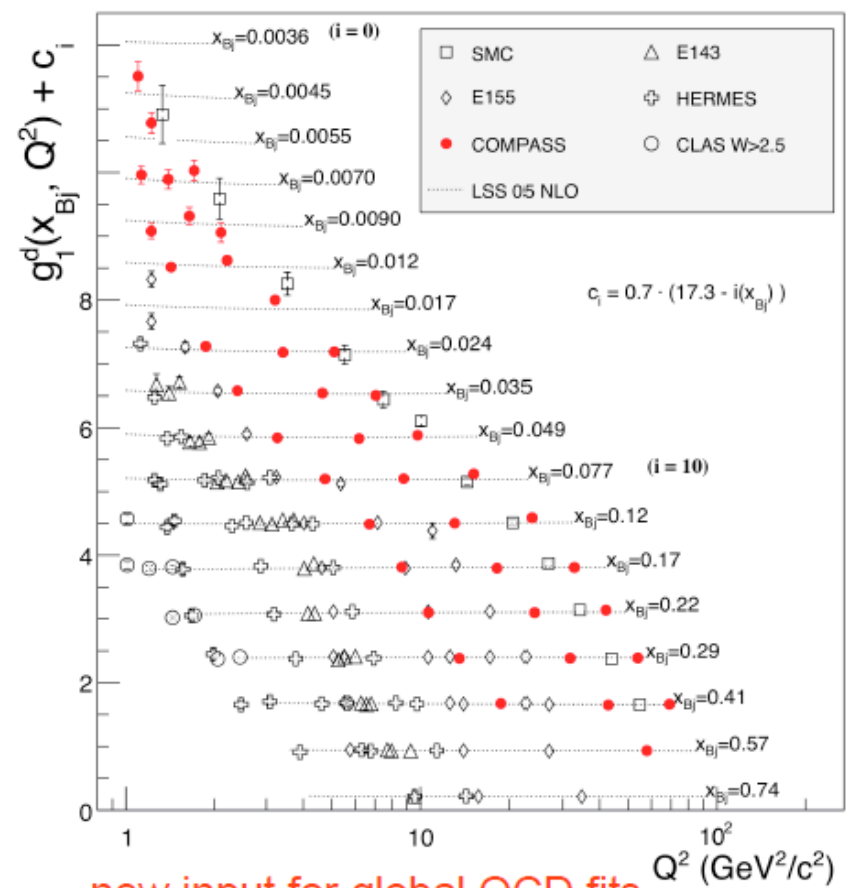
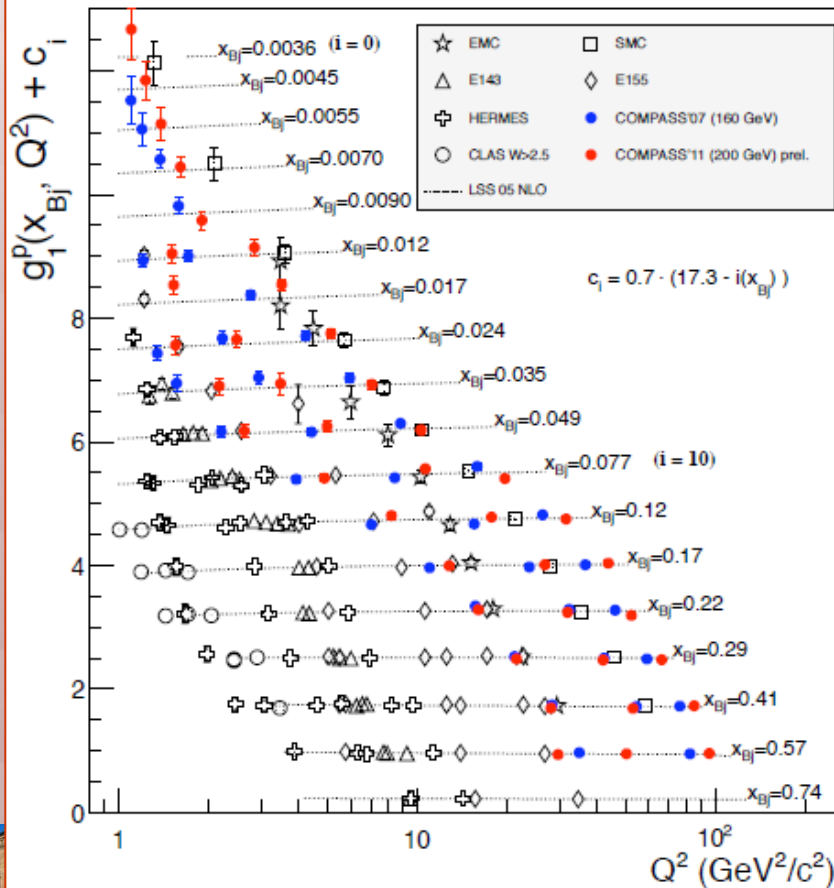
review of longitudinal spin physics

K. Kurek

Introduction
 Inclusive asymmetries and g_1 structure function
 Semi inclusive asymmetries and flavour separation
 Strange quark sea polarisation
 Gluon polarisation
 Summary

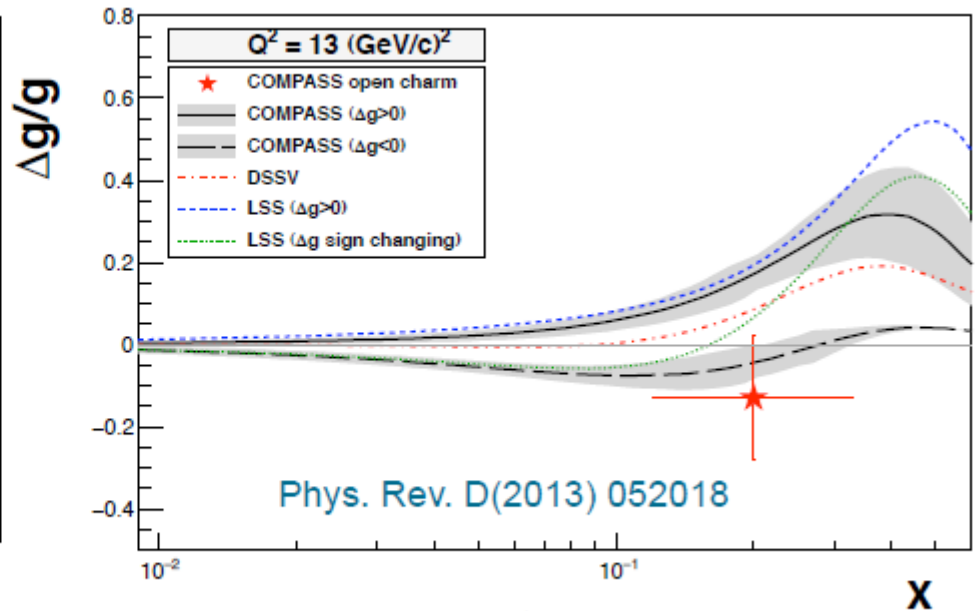
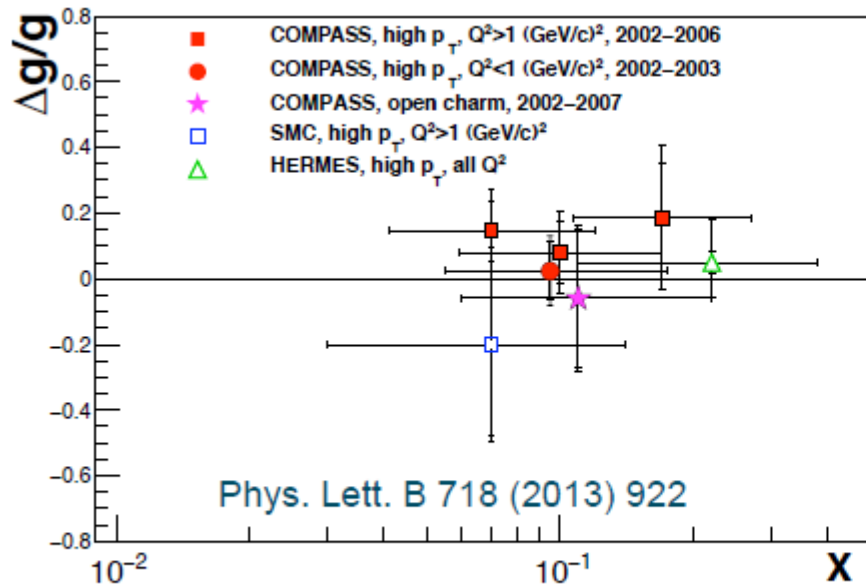
World data for proton and deuteron g_1 structure function

COMPASS proton data 2011@200 GeV included



new input for global QCD fits

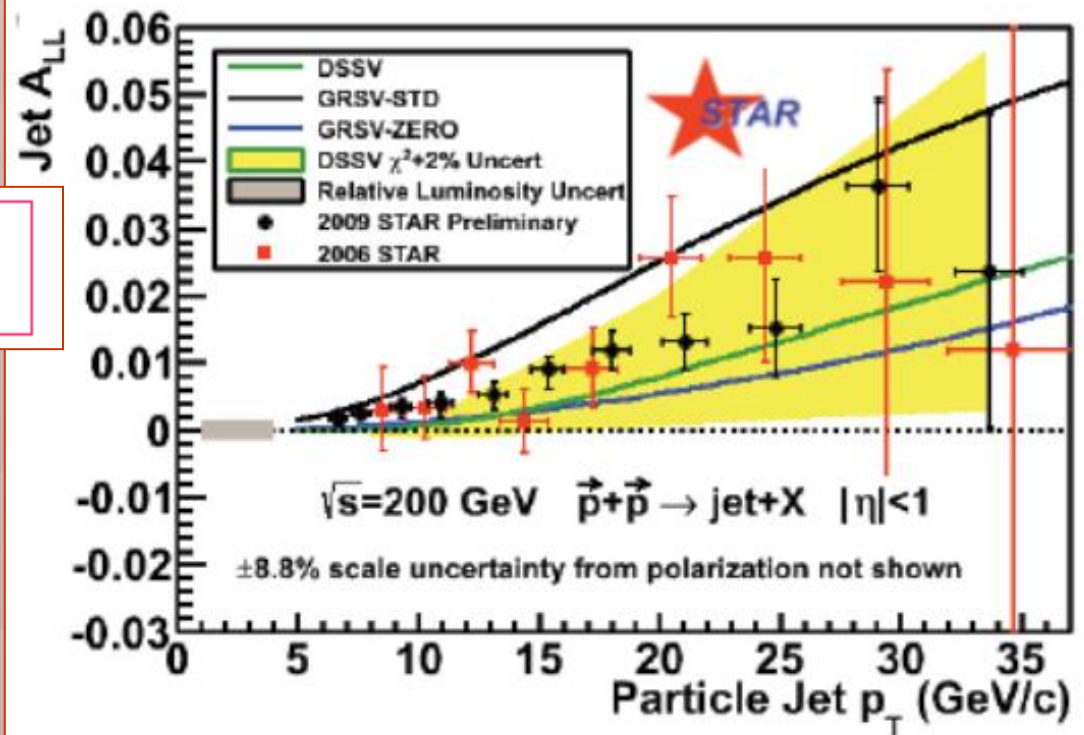




LO: all data consistent and point toward small gluon polarisation

K. Kurek

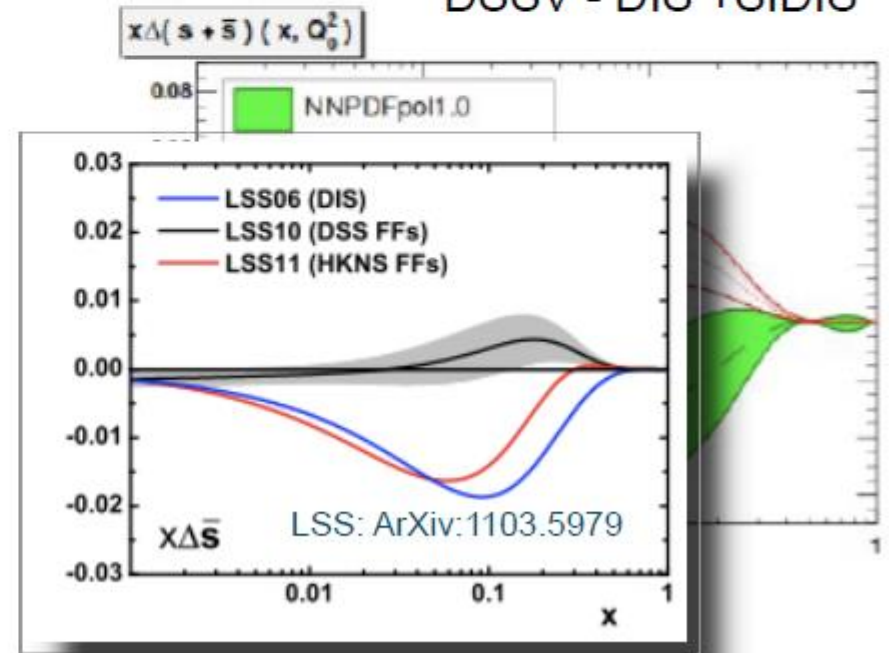
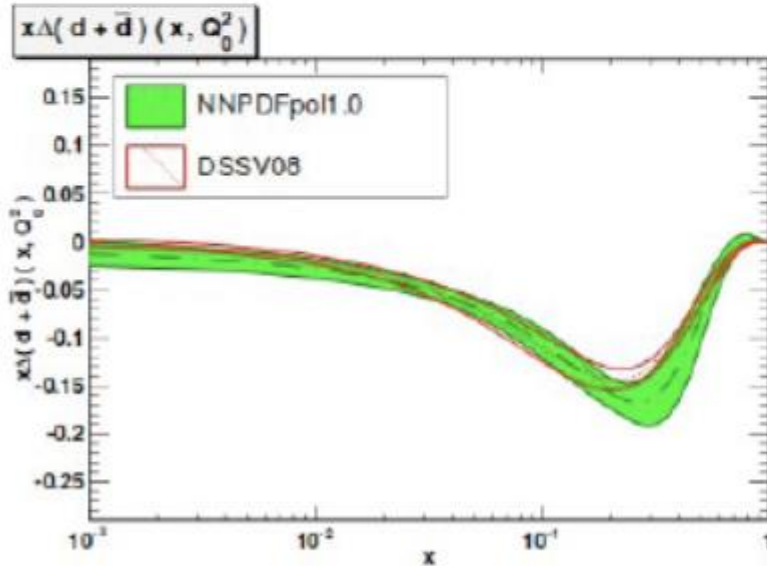
$$DSSV ++ : \int_{0.05}^{0.2} \Delta g(x) dx = 0.10^{+0.06}_{-0.07}$$



IWHSS2013

The lesson:
 Important piece of information:
 precise measurement of FFs

NNPDF - only DIS
 DSSV - DIS +SIDIS



NNPDF, R.D.Ball et al. arXiv: 1303.7236



The proton spin decomposition: observability and interpretation

C. Lorcé



The decompositions in a nutshell

$$\vec{p} = \frac{\partial L}{\partial \vec{v}}$$

$$\vec{\pi} = m\vec{v} = \vec{p} + g\vec{A}$$

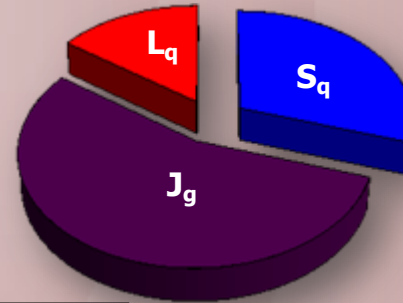
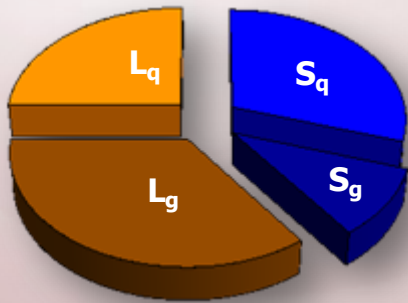
Canonical

Kinetic

[Jaffe-Manohar (1990)]

[Ji (1997)]

$$\vec{D} = \vec{\nabla} + ig\vec{A}$$



$$\begin{aligned} \vec{S}_q &= \frac{1}{2} \int d^3r \psi^\dagger \vec{\Sigma} \psi \\ \vec{L}_q &= \int d^3r \psi^\dagger \vec{r} \times (-i\vec{\nabla}) \psi \\ \vec{S}_g &= \int d^3r \vec{E}^a \times \vec{A}^a \\ \vec{L}_g &= \int d^3r E^{ai} \vec{r} \times \vec{\nabla} A^{ai} \end{aligned}$$

$$\begin{aligned} \vec{S}_q &= \frac{1}{2} \int d^3r \psi^\dagger \vec{\Sigma} \psi \\ \vec{L}_q &= \int d^3r \psi^\dagger \vec{r} \times (-i\vec{D}) \psi \\ \vec{J}_g &= \int d^3r \vec{r} \times (\vec{E}^a \times \vec{B}^a) \end{aligned}$$

Gauge non-invariant!

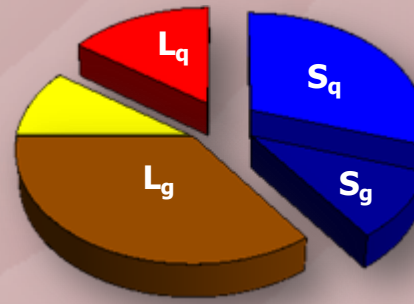
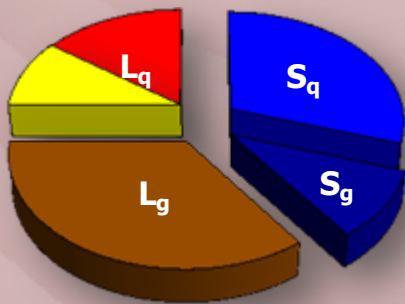


[Chen *et al.* (2008)]

$$A = A_{\text{pure}} + A_{\text{ph}}$$

[Yatsu (2010)]

$$A = A_{\text{pure}} + A_{\text{phys}}$$



$$\begin{aligned} \vec{S}_q &= \frac{1}{2} \int d^3r \psi^\dagger \vec{\Sigma} \psi \\ \vec{L}_q &= \int d^3r \psi^\dagger \vec{r} \times (-i\vec{D}_{\text{pure}}) \psi \\ \vec{S}_g &= \int d^3r \vec{E}^a \times \vec{A}_{\text{phys}}^a \\ \vec{L}_g &= \int d^3r E^{ai} \vec{r} \times \vec{D}_{\text{pure}} A_{\text{phys}}^{ai} \end{aligned}$$

$$\begin{aligned} \vec{S}_q &= \frac{1}{2} \int d^3r \psi^\dagger \vec{\Sigma} \psi \\ \vec{L}_q &= \int d^3r \psi^\dagger \vec{r} \times (-i\vec{D}) \psi \\ \vec{S}_g &= \int d^3r \vec{E}^a \times \vec{A}_{\text{phys}}^a \\ \vec{L}_g &= \left[\int d^3r \vec{r} \times (\vec{E}^a \times \vec{B}^a) \right. \\ &\quad \left. - \int d^3r \vec{E}^a \times \vec{A}_{\text{phys}}^a \right] \end{aligned}$$

Gauge-invariant extension (GIE)

$$\int d^3r \vec{r} \times [(\vec{A}_{\text{phys}}^a \times \vec{D}_{\text{pure}}) \times \vec{E}^a]$$

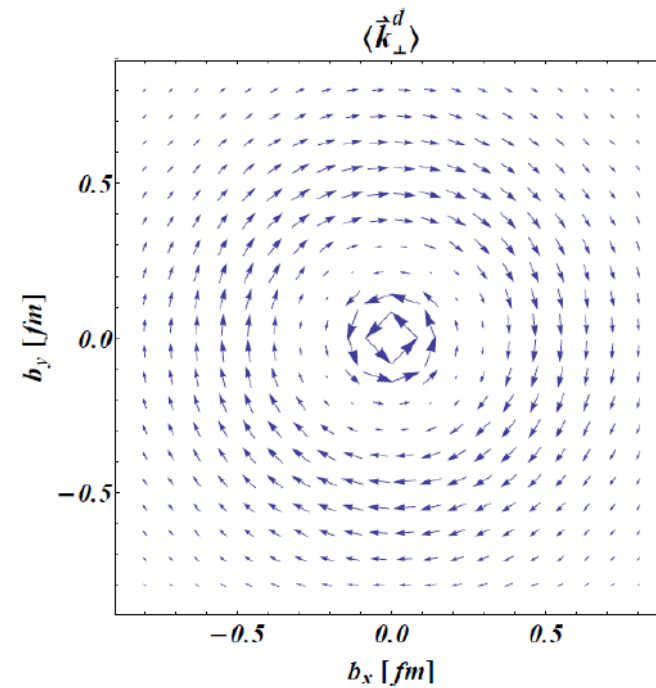
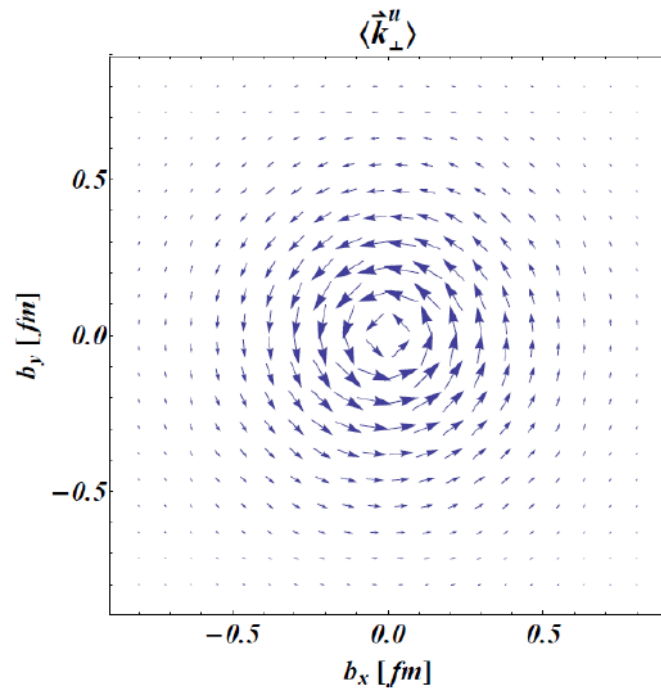
[C.L. (2013)]

The orbital motion in a light-front quark model

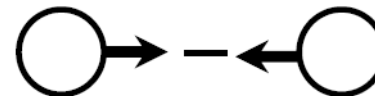
[C.L., Pasquini, Xiong, Yuan (2012)]

Average transverse quark momentum in a longitudinally polarized nucleon

$$\langle \vec{k}_\perp \rangle(\vec{b}_\perp) = \int dx d^2k_\perp \vec{k}_\perp \rho_{++}^{[\gamma^+]}(x, \vec{k}_\perp, \vec{b}_\perp)$$



F_{14}
« Vorticity »



QCD resummation for semi-inclusive hadronproduction processes

F. Ringer

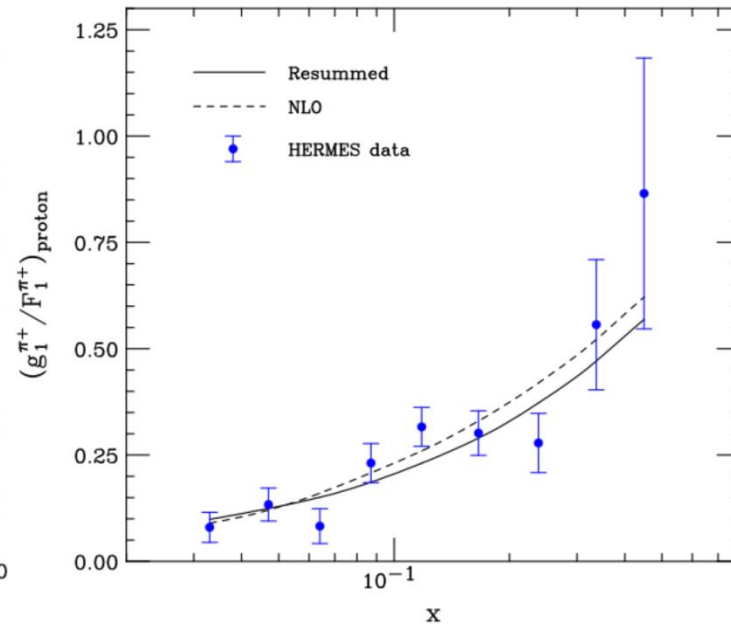
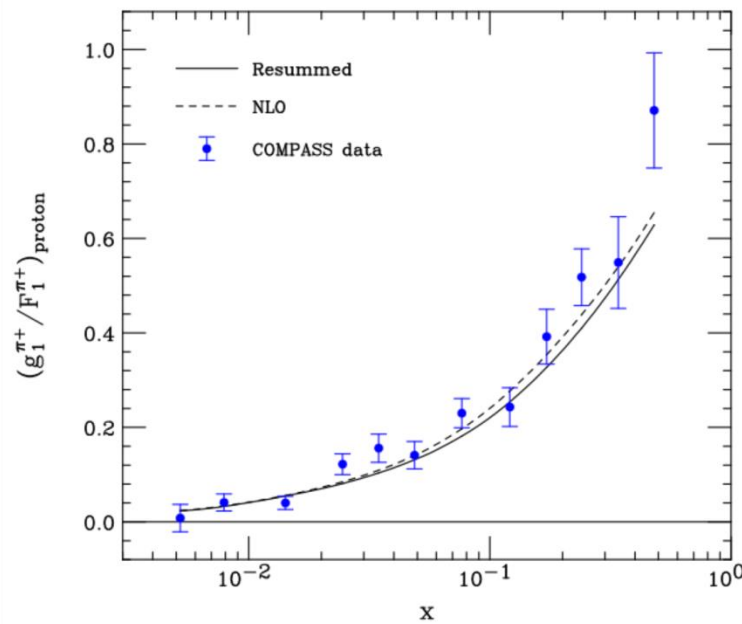
QCD Resummation for SIDIS

e^+e^- Annihilation

Longitudinal spin asymmetries

Conclusions

Semi-inclusive DIS asymmetries A_1^h



proton target $0.2 < z < 0.8$

using MRST'02/DSSV PDFs and DSS FFs

28

EBERHARD KARLS
UNIVERSITÄT
TÜBINGEN



recent progress in lattice QCD

V. Drach

Introduction

Electromagnetic form factors

○○○○○○○○

Weak FFs

○○○○○

Moments of pdfs and gpd

○○○○○○○○○○○○○○

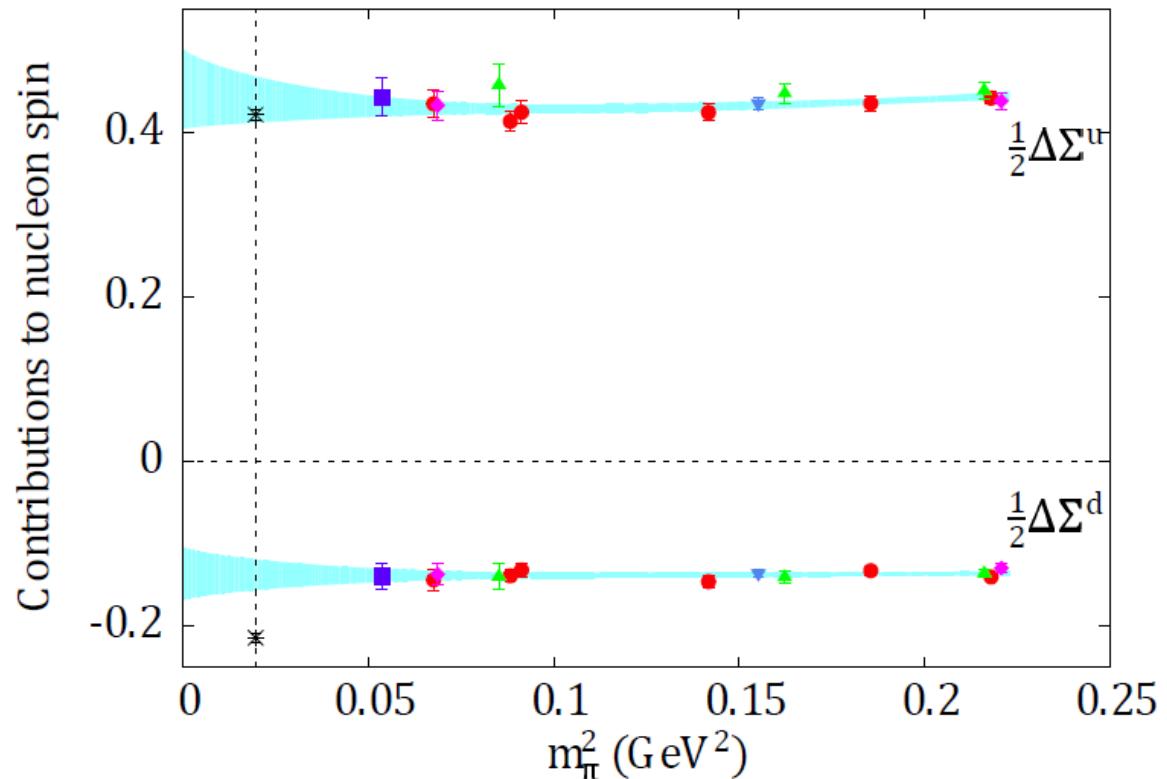
Our laboratory

BlueGene/Q : Ju...
(7th biggest com...)



to solve the (cla...
($N_{d.o.f} \sim 12 \times V$)

$\Delta\Sigma^q$
Unquenched but neglect disconnected insertion



Physical points are from the HERMES 2007 analysis.

[ETM, 1303.5979]



IWHSS2011

DVCS and GPDs

K. Rith

V. Drach

...

H. Moutard

**Review of some recent developments
on Deeply Virtual Compton Scattering**





Recent developments on DVCS

Introduction

Theoretical framework

Compton Form Factors
DVCS observables

Status

Evaluation of Compton Form Factors

Explicit Expressions
GPD Models
GK model vs DVCS data
Compton scattering

Impact on phenomenology

First extractions
COMPASS
future data

Conclusions

From QCD first principles to experimental data.
Very good theoretical control, but not easy to implement!

- **All-order proof of factorization** of DVCS amplitude.
Collins and Freund, Phys. Rev. **D59**, 074009 (1999)
- Hard scattering kernel computed at **next-to-leading order** at leading twist.
Belitsky and Müller, Phys. Lett. **B417**, 129 (1998)
- Evolution equations computed at **next-to-leading order**.
Belitsky *et al.* , Nucl. Phys. **B574**, 347 (2000)
and ref. therein
- Finite-t and target mass corrections computed at **leading order**: kinematic power corrections to **twist 4 accuracy**.
Braun *et al.* , Phys. Rev. Lett. **109**, 242001 (2012)

GPD "measurements" ?

- **Already achieved**: experimentally constrained models.
- Next step: **Measured transverse plane images**.





CEA - Saclay

Recent developments on DVCS

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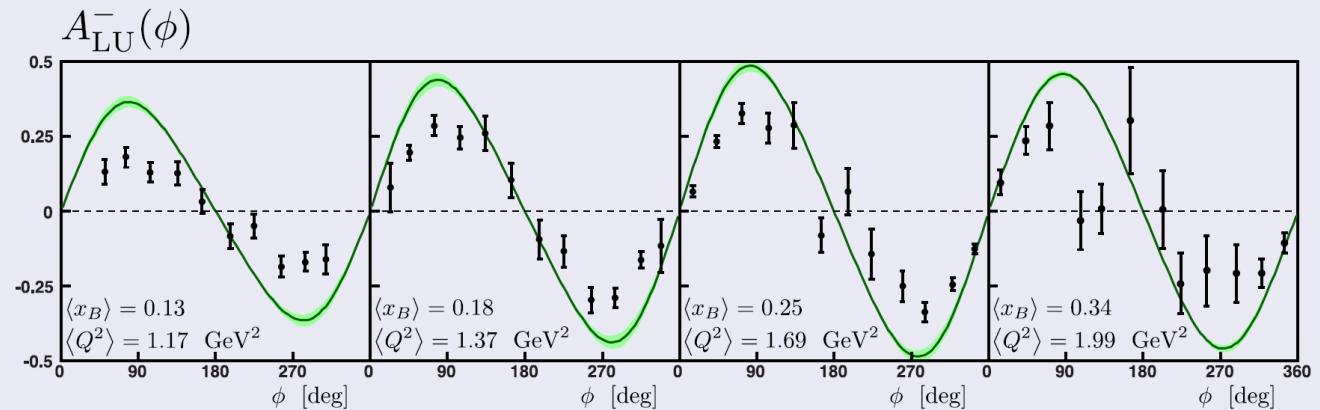
First extractions
COMPASS
future data

Conclusions

Goloskokov-Kroll (GK) model on DVCS.

No parameter of the GK model was tuned to analyse DVCS.

Beam Spin Asymmetry, CLAS



Kroll *et al.*, Eur. Phys. J C73 (2013) 2278





Recent developments on DVCS

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COMPASS future data

Conclusions

Conclusions.

The importance of spacelike and timelike Compton scattering at COMPASS.

- **Large NLO "corrections"** to DVCS amplitude.
- **Larger for TCS. Measurement of TCS at COMPASS?**
- Measurements of DVCS and TCS provide tests of **factorization** and of the **QCD understanding** of these reactions through the size of NLO corrections.
- Need global GPD fits to **separate quarks and gluon** contributions and **accurately** interpret extracted data.
- DVCS measurements at COMPASS will provide an interesting **cross-check of HERMES DVCS data**.
- **COMPASS DVCS experiment may provide a way to constrain gluon GPDs!**



Drell-Yan

...

C. Riedl

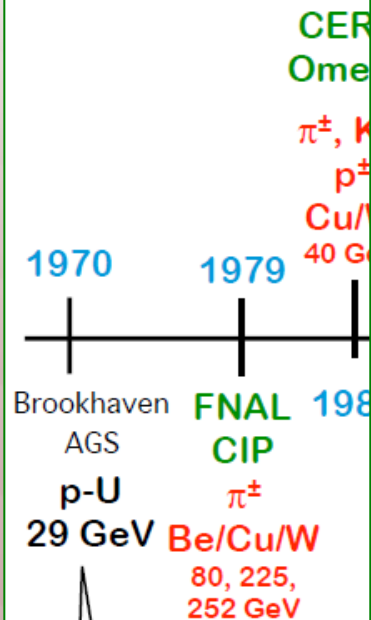
Review of Drell-Yan experiments

M. Radici

Theoretical overview of transverse spin physics in SIDIS and Drell-Yan



Selected Drell-Yan experiments of the past



First measurement:
Observation of Massive Muon Pairs in Hadron Collisions

Future Drell-Yan experiments

- Programs for future Drell-Yan measurements:

nucleon-nucleon at

- SeaQuest (Fermilab)
- RHIC (Brookhaven)
- J-PARC (KEK)
- IHEP (Protvino)
- JINR (Dubna)

anti(p)-nucleon at

- FAIR (GSI)

pion-nucleon at

- COMPASS (CERN)

Only existing meson plan!

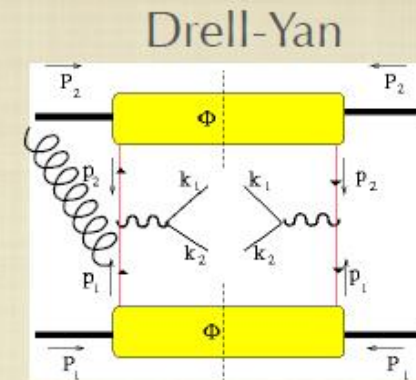
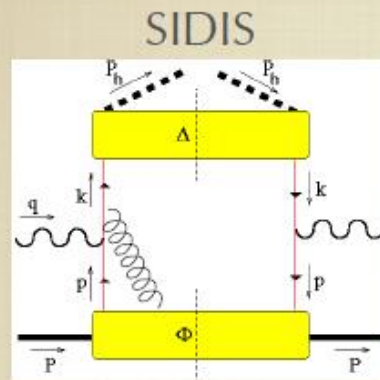
The story of the DY E-XYZ and NA* experiments will be continued

- Past measurements exclusively considered the unpolarized cross section, future ones also aim for polarization measurements.
 - transversely polarized DY: spin-dependent TMDs
 - longitudinally polarized DY: quark helicity

More details on FAIR in K. Peter's talk @ this workshop
More details on JINR in I. Savin's and A. Nagaytsev's talk
The RHIC Spin program, [arXiv:1304.0079](https://arxiv.org/abs/1304.0079)



process dependence of naïve T-odd function:
the sign change between SIDIS and Drell-Yan



“Final” residual color interactions “Initial”

QCD prediction to be tested: $\text{Sivers} \Big|_{\text{SIDIS}} = -\text{Sivers} \Big|_{\text{D-Y}}$

Collins, PL B536 (02)

it is not just checking TMD factorization,
it motivates a polarized Drell-Yan measurement..



transverse spin and momentum structure of the nucleon

K. Rith

G. Schnell

Experimental review of transverse spin physics

M. Radici

Theoretical overview of transverse spin physics in SIDIS and Drell-Yan

M. Boglione

Transverse momentum distributions – Q² evolution



G. Schnell - Experimental review of transverse spin physics

	U	L	T
U	f_1		h_1^\perp
L		g_{1L}	h_{1L}^\perp
T	f_{1T}^\perp	g_{1T}	h_1, h_{1T}^\perp

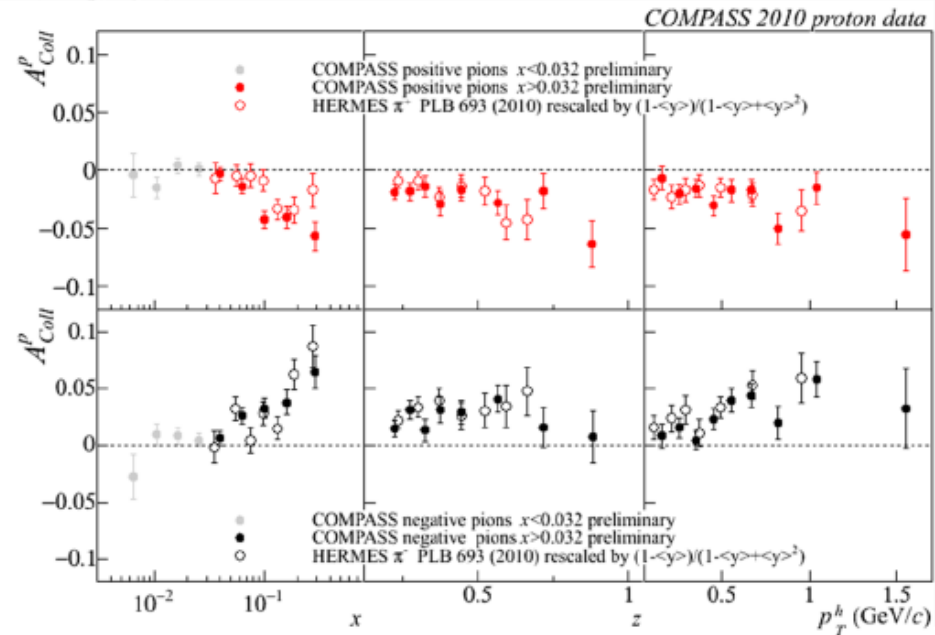
● wealth of new results:

● COMPASS
[PLB 692 (2010) 240,
PLB 717 (2012) 376]

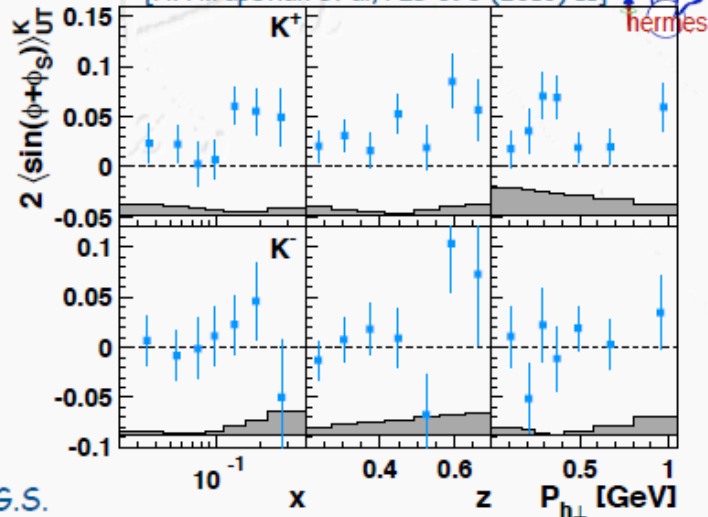
● HERMES
[PLB 693 (2010) 11]

● Jefferson Lab
[PRL 107 (2011) 072003]

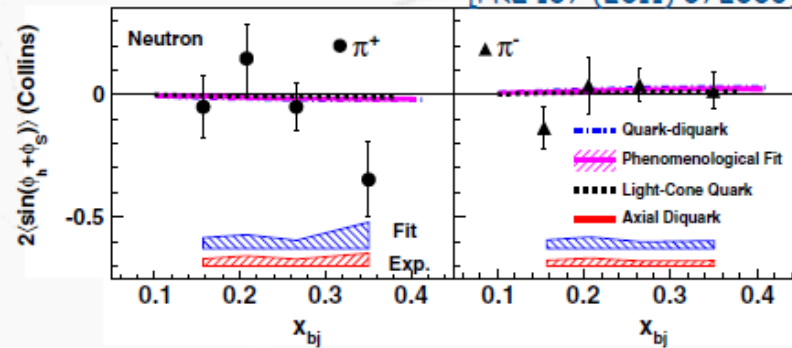
Collins amplitudes



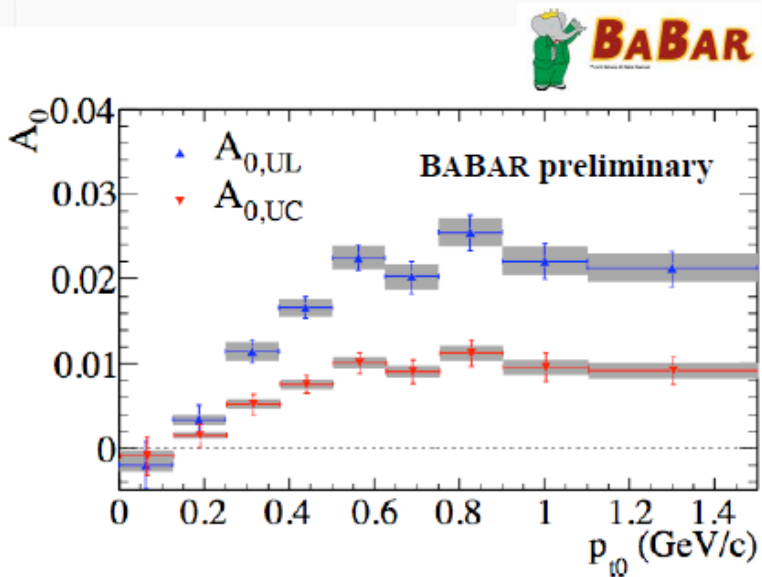
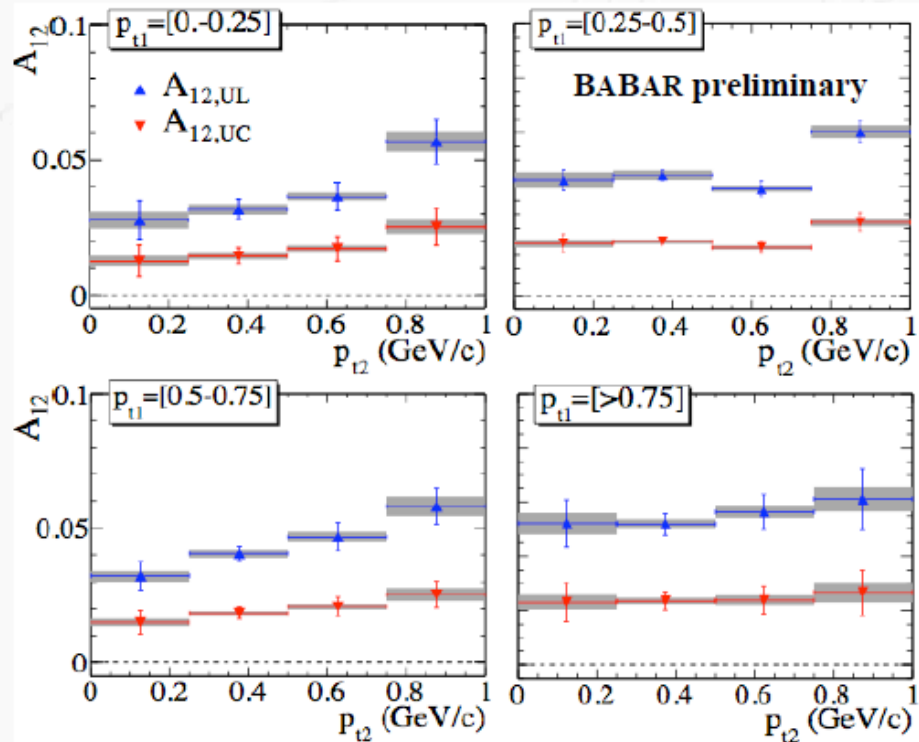
[A. Airapetian et al, PLB 693 (2010) 11]



[PRL 107 (2011) 072003]



Collins FF from e^+e^-



FIRST MEASUREMENT of Collins asymmetries vs. p_t in e^+e^- annihilation at $Q^2 \sim 110$ (GeV/c) 2 (time-like region)

• nonzero A^{UL} and A^{UC}

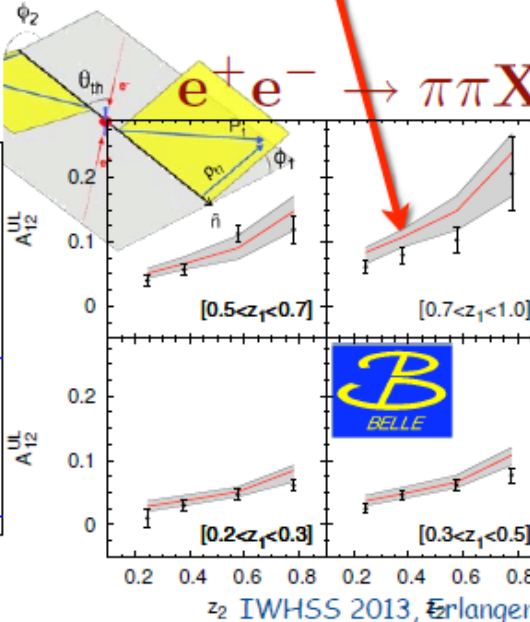
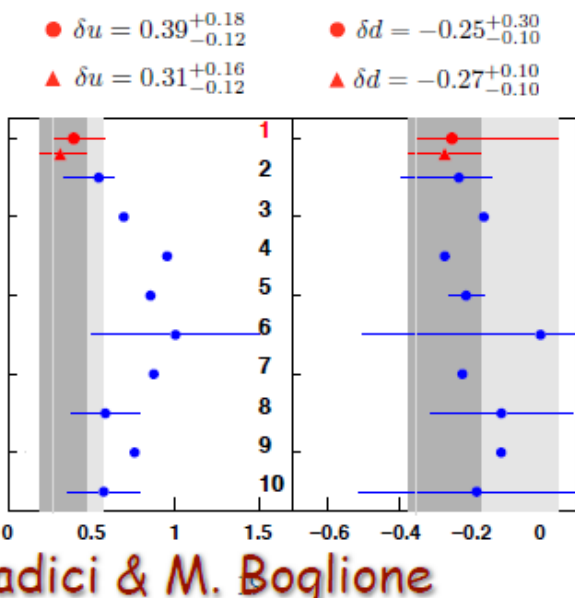
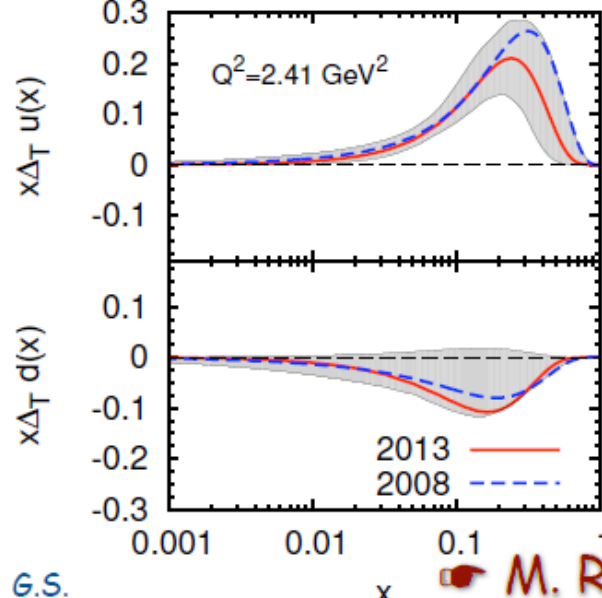
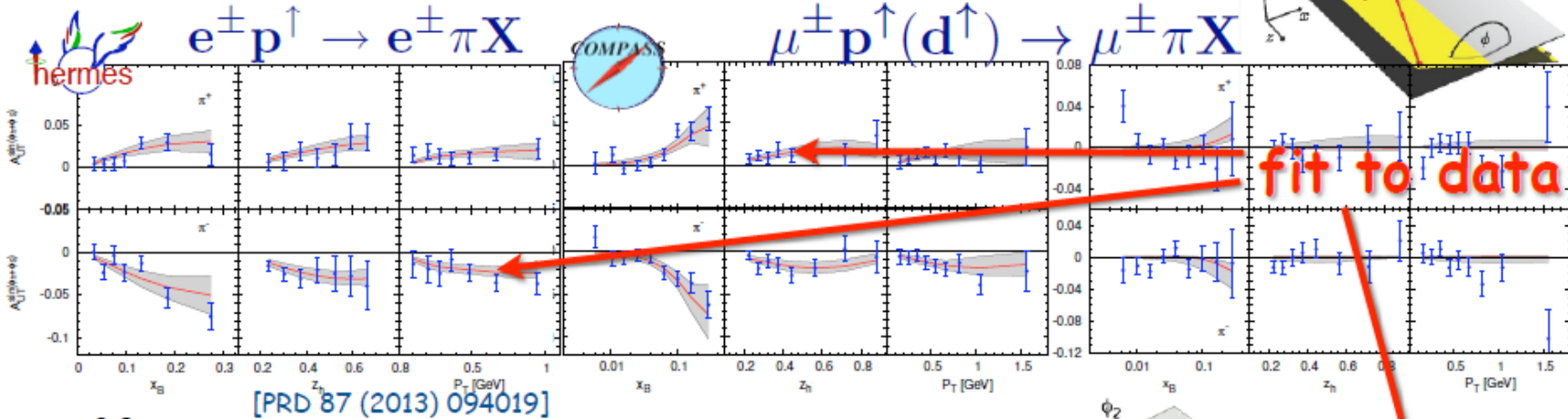
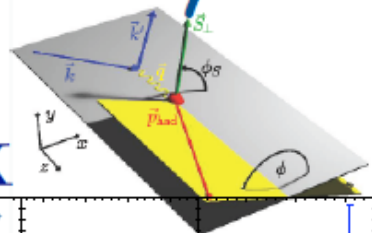
- ⇒ only modest dependence on (p_{t1}, p_{t2})
- ⇒ $A^{UC} < A^{UL}$; complementary information on $H_1^{\perp, fav}$ and $H_1^{\perp, dis}$
- ⇒ $A_0 < A_{12}$, but interesting structure in p_t

slide taken from [I. Garzia, DIS 2013]

G. Schnell - Experimental review of transverse spin physics

	U	L	T
U	f_1		h_1^\perp
L		g_{1L}	h_{1L}^\perp
T	f_{1T}^\perp	g_{1T}	h_1, h_{1T}^\perp

Collins FF and transversity fit



G.S.

M. Radici & M. Boglione

IWHSS2013

F. Bradamante

M. Radici - Theoretical overview

	U	L	T
U			
L			
T			

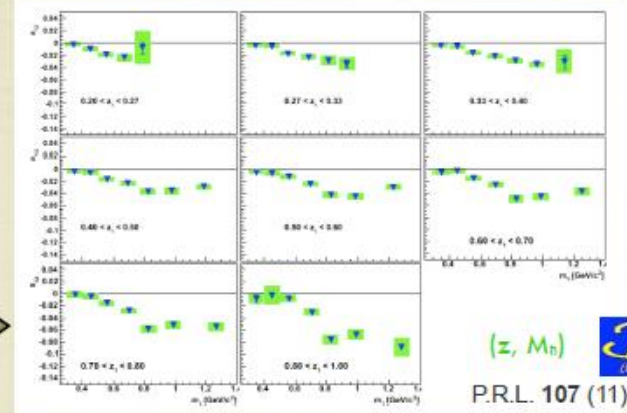
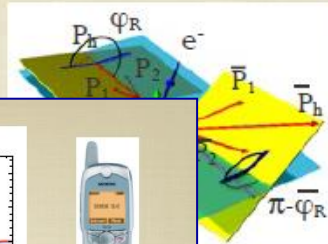
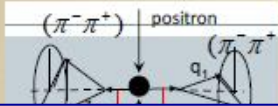
using the **di-hadron SIDIS**

$$A_{UT}^{\sin(\phi_R + \phi_S)} \propto -\frac{|R|}{M_h} \frac{\sum_q e_q^2 h_1^q(x) H_1^{\leftarrow q}(z, M_h^2)}{\sum_q e_q^2 f_1^q(x) D_1^q(z, M_h^2)}$$

Di-hadron Fragm. Funct.'s (DiFFs)

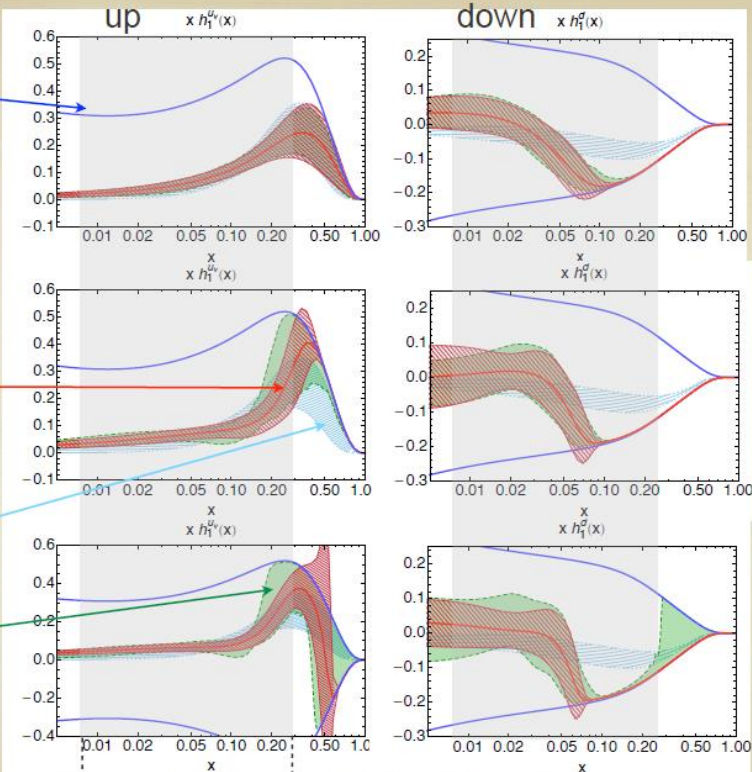
Courtoy et al., P.R. D85 (12)

take DiFFs from fitting $e^+e^- \rightarrow (\pi^+\pi^-) (\pi^+\pi^-) X$ (first time!)



$Q^2 = 2.4 \text{ GeV}^2$

Soffer bound



rigid



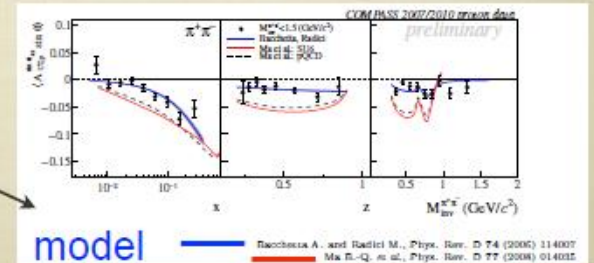
flexible



extra flexible

$$\frac{H_1^{\leftarrow q}}{D_1^q} \rightarrow$$

pol. $d\sigma^0$
at Belle kin.
polarization
previous model



non trivial!

D85 (12)

Bacchetta, Courtoy, Radici, JHEP 03 (13)

F. Bradamante

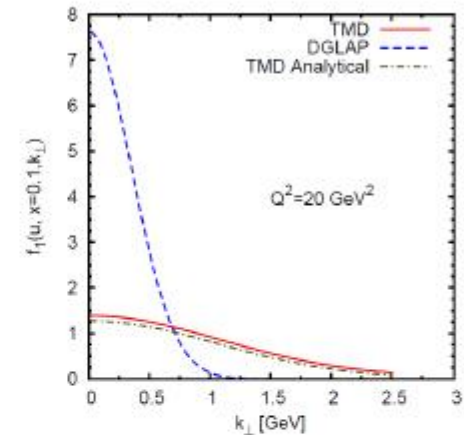
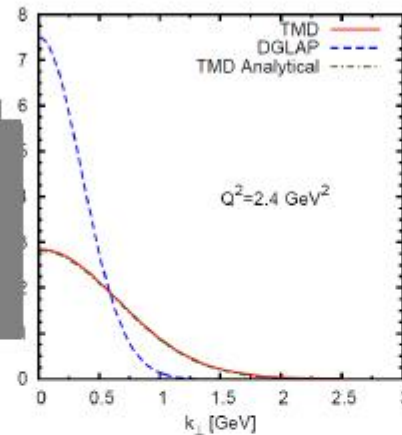
M. Boglione - Transverse momentum distributions

Q^2 evolution

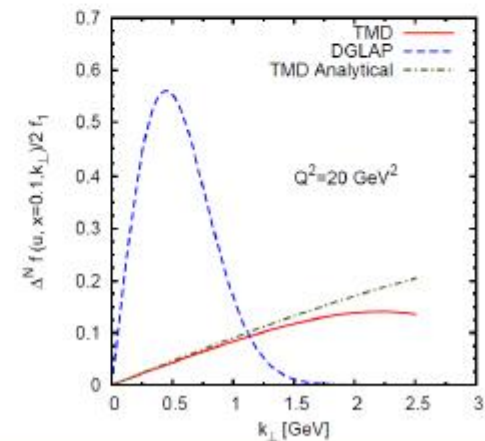
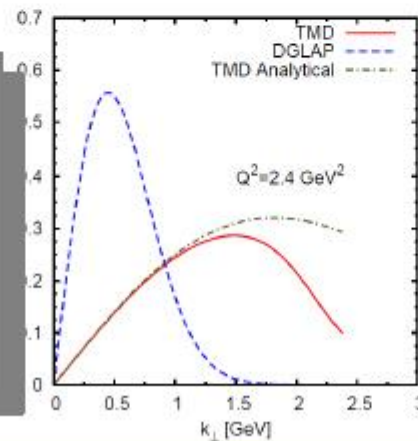
Phenomenological results



DGLAP evolution is extremely slow in this Q^2 range



TMD evolution Very rapidly widens and dilutes the functions



$\langle Q^2 \rangle = 2$
GeV²

Q^2 in +
range
[1.3 - 4]
GeV²

thank you for your participation

and for your patience

and **see you next year**

in Crimea !

