CONCLUDING REMARKS

for the

XIII International Workshop on Hadron Structure and Hadron Spectroscopy

iwhss

Suzdal, Russia, 18-20 May 2015

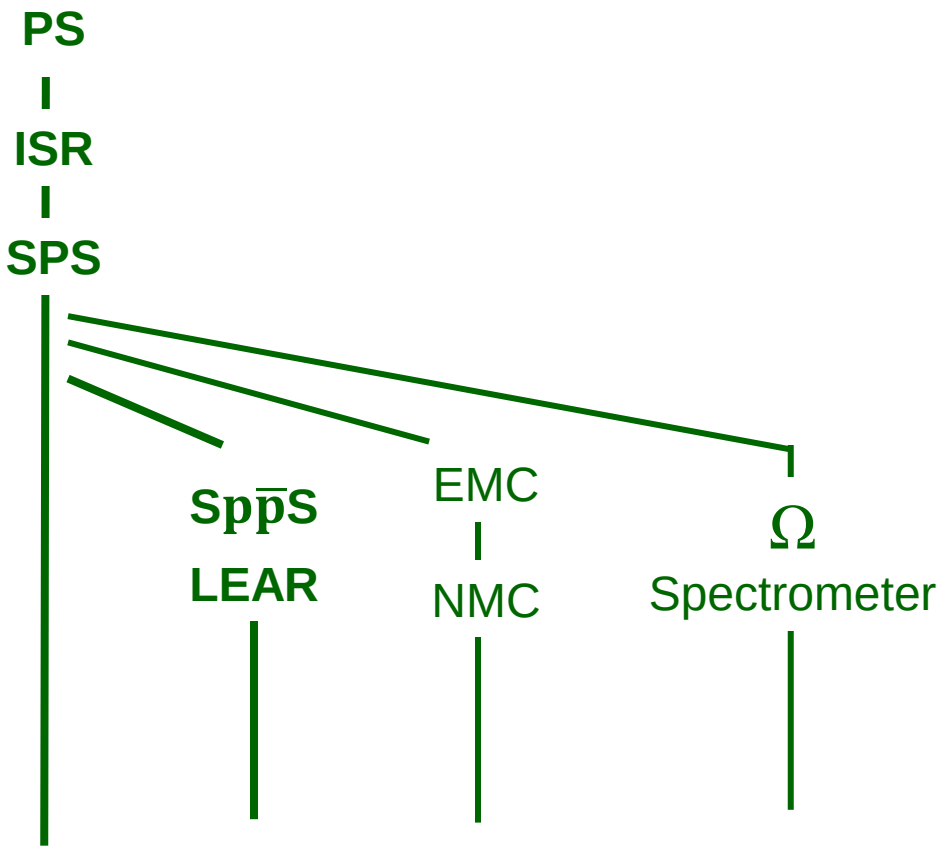
Franco Bradamante

Trieste University & INFN

WHO WE'VE BEEN AND WHERE WE'RE GOING

CERN

unlimited growth ***'62***



WHO WE'VE BEEN AND WHERE WE'RE GOING

CERN

unlimited growth '62

PS

ISR

SPS

Sp$\bar{p}$S

LEAR

EMC

NMC

SMC

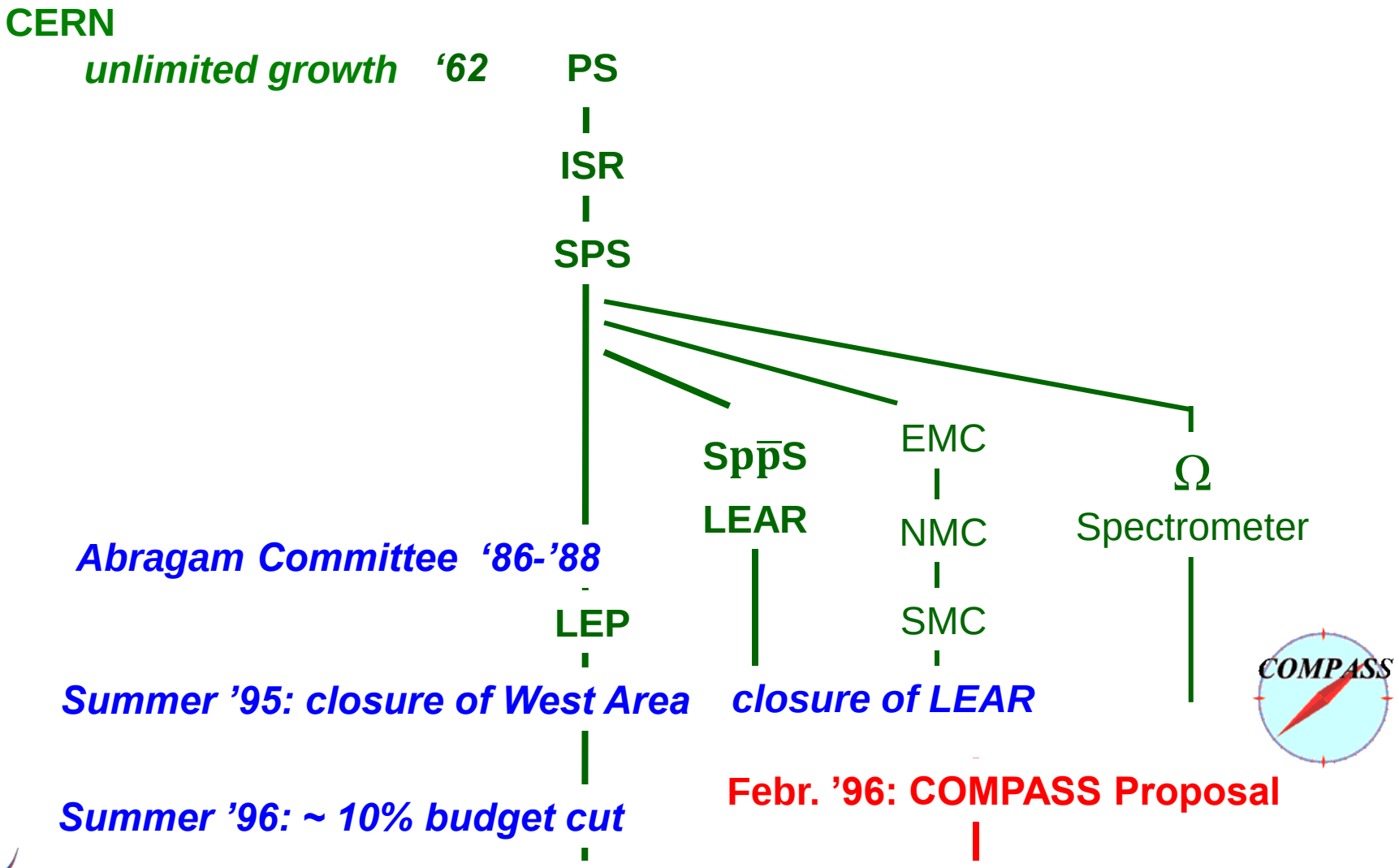
Ω

Spectrometer

Abragam Committee '86-'88

LEP

WHO WE'VE BEEN AND WHERE WE'RE GOING



WHO WE'VE BEEN AND WHERE WE'RE GOING

LEP

Summer '96: ~ 10% budget cut

Febr. '96: COMPASS Proposal

Sept. '96: recommendation from SPSC

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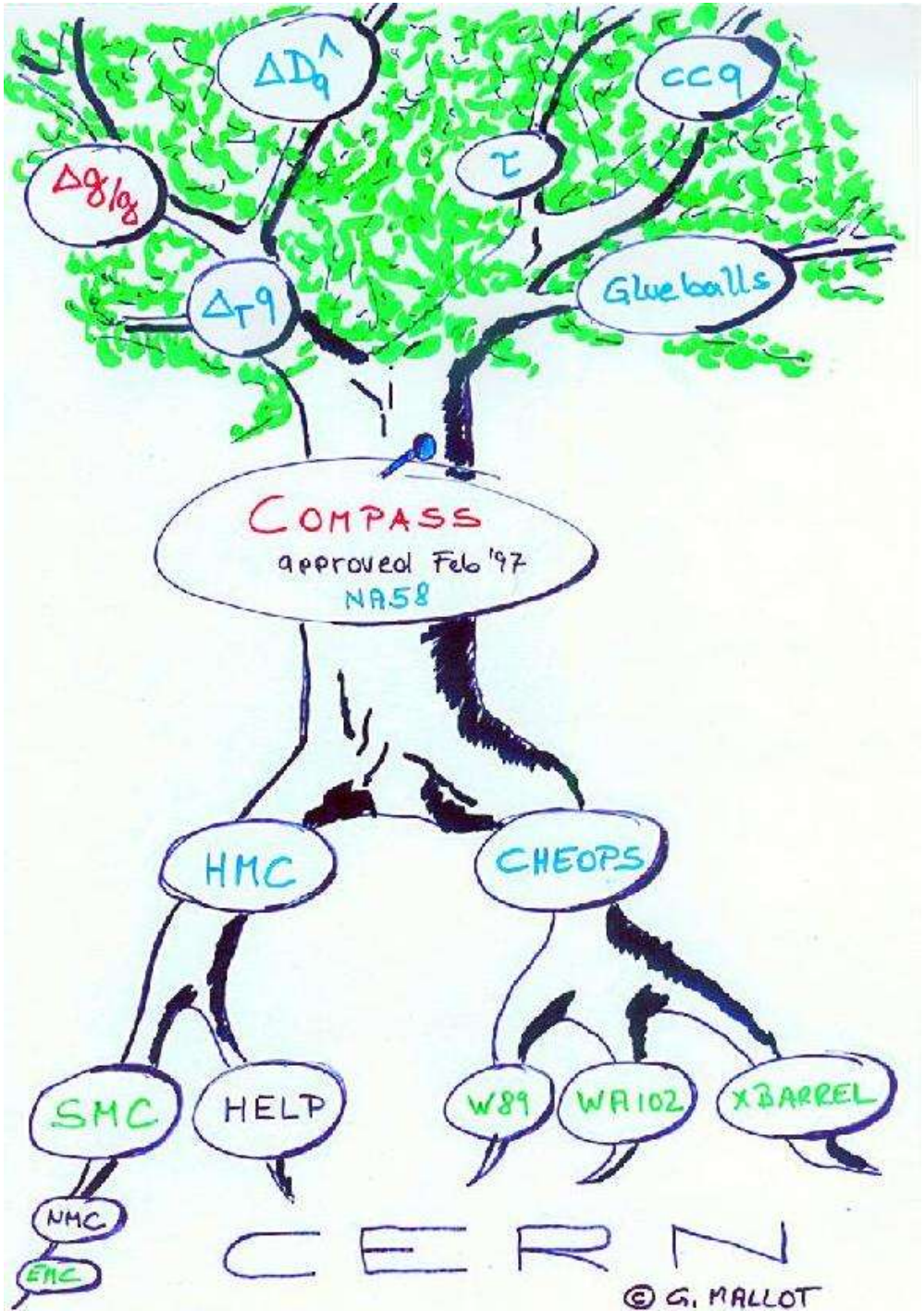
ΔD̄q
cc̄q
Δg/g
τ
Δq
Glueballs
COMPASS
approved Feb '97
NA58
HMC
CHEOPS
SMC
HELP
W89
WA102
xBARREL
NMC
EMC
CERN
© G. MALLOT

WHO WE'VE BEEN AND WHERE WE'RE GOING

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Summer '96: ~ 10% budget cut

Summer 2000: LEP shut down

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March 1, 1997

Summer 2002:
first data taking

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LHC

2012

2015

COMPASS-II

International Workshops on Structure and Spectroscopy

1999	**Oct. 11-13**	**TUM Munich**
2000	**Oct. 9-12**	**Dubna**
2002	**Feb 18-20**	**Trieste**
2003	Oct 1-3	Lisbon
2004	**Mar 1-5**	**Paris**
2005	**Aug. 1-3**	**Prague**
2006	Feb 15-17	Warsaw
2007	**Mar 19-21**	**Freiburg**
2008	**Mar 31 Apr 2**	**Torino**
2009	**Apr 2-3**	**Mainz**
2010	**Mar 14-22**	**Venice (**Venice International University /**LMU Munich)**
2011	**Apr 7-8**	**Paris**
2012	**Apr. 16-18**	**Lisbon**
2013	**July 25-26**	**Erlangen**
2015	**May 21-22**	**Suzdal (Dubna)**
2016	***Sept.5-7***	***Kloster Seeon (TUM Munich)***

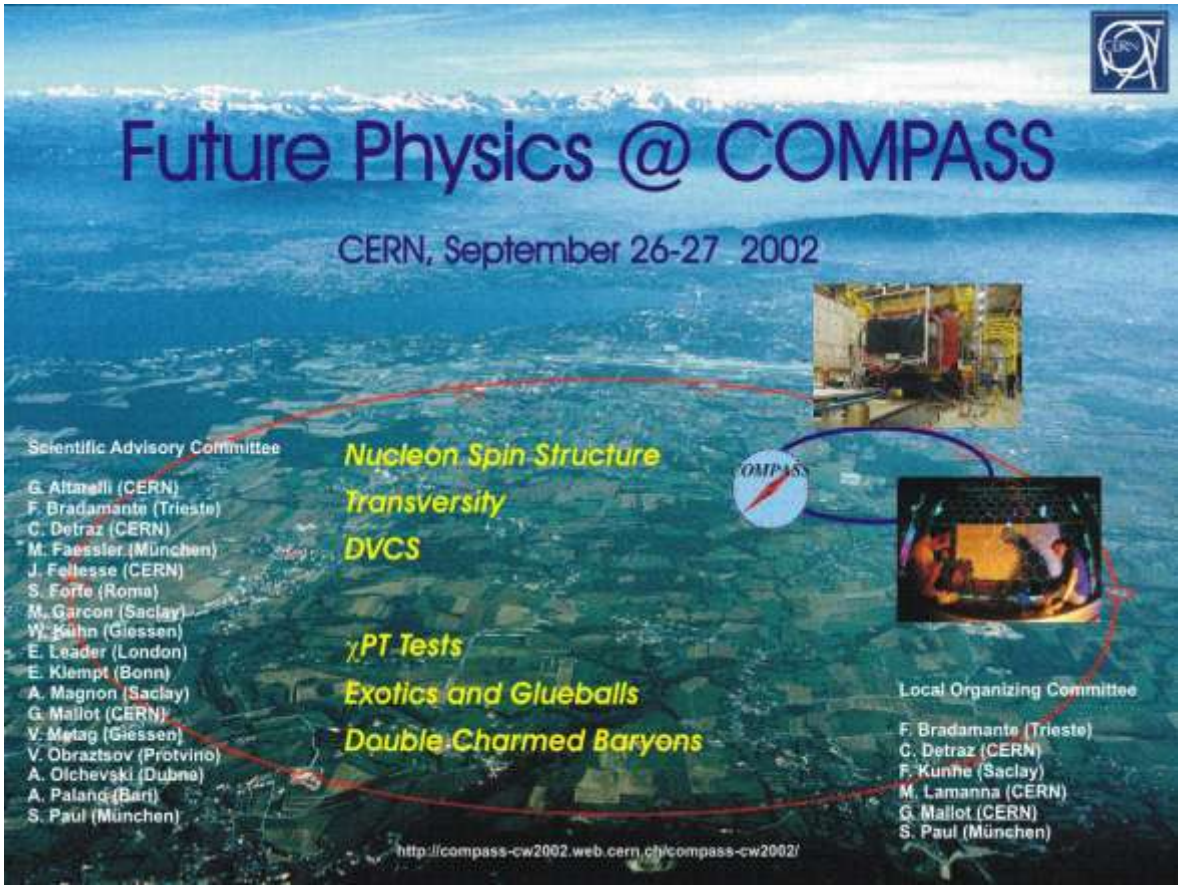
International Workshops on Structure and Spectroscopy

IN BETWEEN, several topical workshops at CERN

Future Physics at COMPASS

Sept. 26-27 2002

and outside



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International Workshops on Structure and Spectroscopy

From the web page of one of the first Workshops

Purpose of the workshop

A new experimental facility for hadron physics (COMPASS) is entering into operation at CERN in the summer of 2001.
The main objective of this workshop is to bring together theorists and experimentalists to discuss physics topics potentially accessible to this and similar facilities, with particular emphasis on

spin structure of the nucleons, e.g.

- the gluon polarization of a longitudinally polarized nucleon
- the spin structure functions of the nucleon, and their flavour decomposition

and on hadron spectroscopy and hadron structure, e.g.

- tests of chiral perturbation theory with Primakoff reactions
- light quark spectroscopy above 1.5 GeV
- spectroscopy of charmed and doubly charmed baryons

It took us 10 years, 2002 - 2012, but this programme has been fulfilled

spin structure of the nucleons, e.g.

- the gluon polarization of a longitudinally polarized nucleon ✓
- the spin structure functions of the nucleon, and their flavour decomposition ✓
  both in the helicity sector and in the transverse spin case
  MOST IMPORTANT: Sivers effect NEW!

and on hadron spectroscopy and hadron structure, e.g.

- tests of chiral perturbation theory with Primakoff reactions ✓
  CERN Press Release 2015
- light quark spectroscopy above 1.5 GeV ✓
- spectroscopy of charmed and doubly charmed baryons

most important workshop for COMPASS after the Aymar era

New Opportunities in the Physics Landscape at CERN

10-13 May 2009

recommendations of Andreas Schäfer:

- **GPD physics needs all the experimental input it can get.**
- **Naive T-odd asymmetries are sensitive to non-trivial gauge-link physics. They have to be investigated in SIDIS and Drell-Yan experiments.**

Such studies could trigger fundamental theoretical developments going beyond collinear factorization.

NEW ADDENDUM submitted in June 2009

runs 2010 – 2011 T and L polarized SIDIS

NEW PROPOSAL submitted in May 2010
and approved by CERN RB in December (!)

DRELL-YAN	**1 year**	**!! already started !!**
GPD and SIDIS	**2 years**	**2016 - 2017**

and even ideas for beyond

reports in July 2012 for the European Strategy Preparatory Group

ALL this in close contact with the international community

WHAT WE HAVE DONE

and

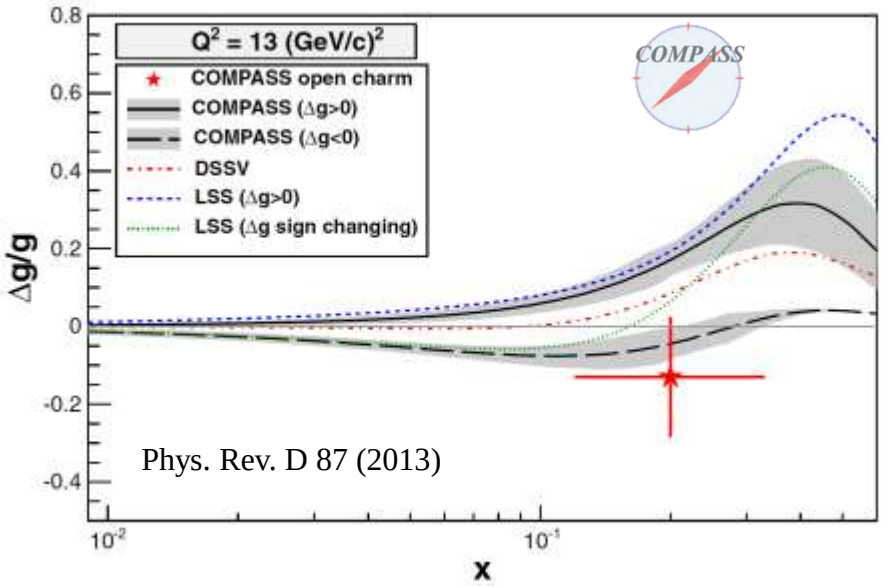
WHAT REMAINS TO BE DONE

ΔG

ΔG by **open charm**

analysing power too small

statistically limited



ΔG

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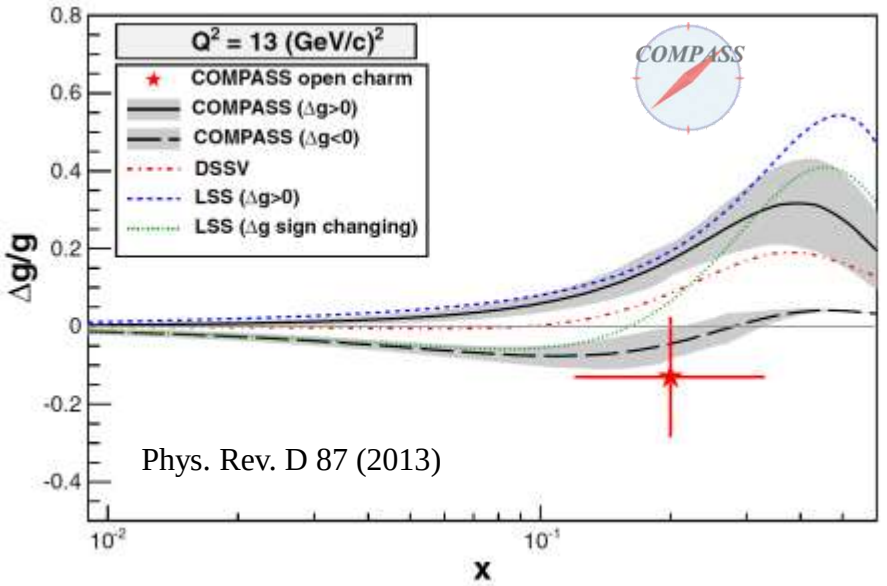
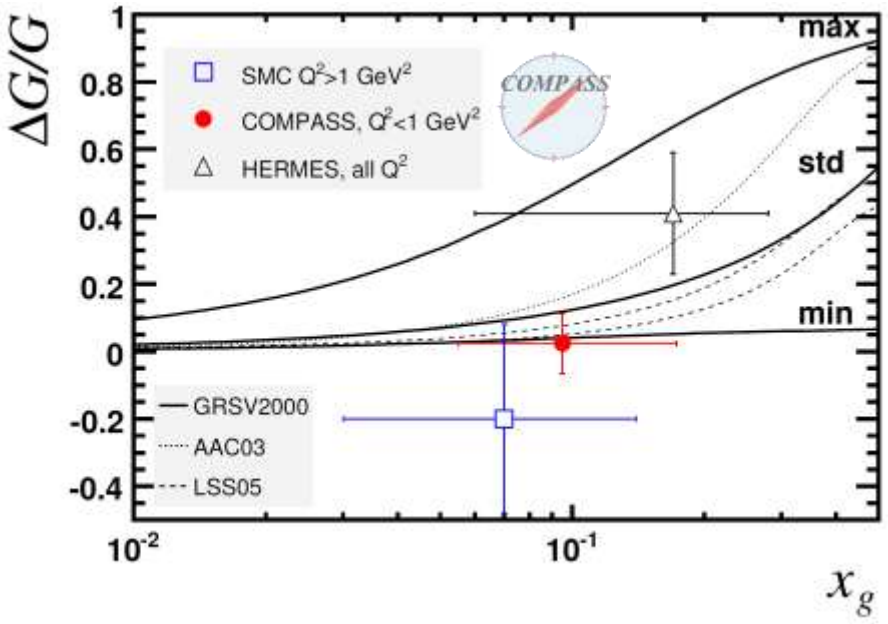


BUT we have invented the

high-pT hadron pair method

A. Bravar, D. von Harrach, A. Kotzinian, Phys.Lett. B421 (1998)

first exploited by HERMES



COMPASS first to rule out large values of ΔG

Phys. Lett. B 633 (2006)

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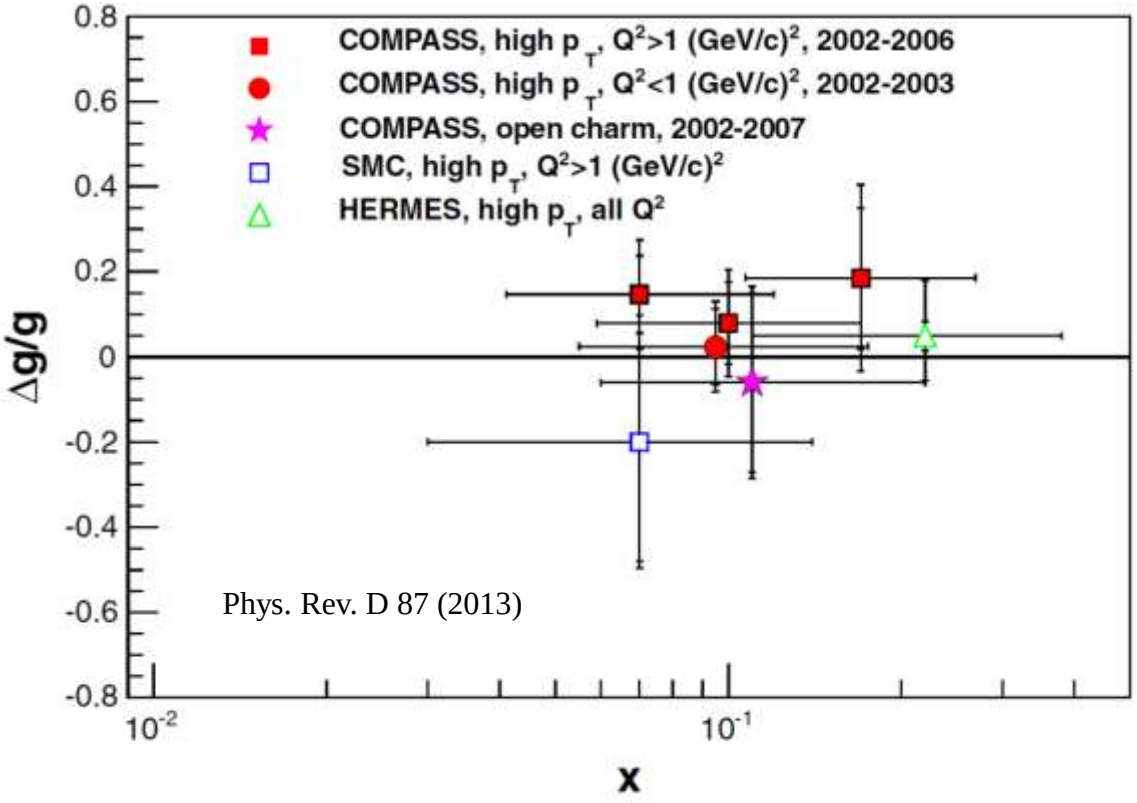
ΔG

results at LO



NB: COMPASS work on ΔG ignored in

"The RHIC SPIN Program: Achievements and Future Opportunities "

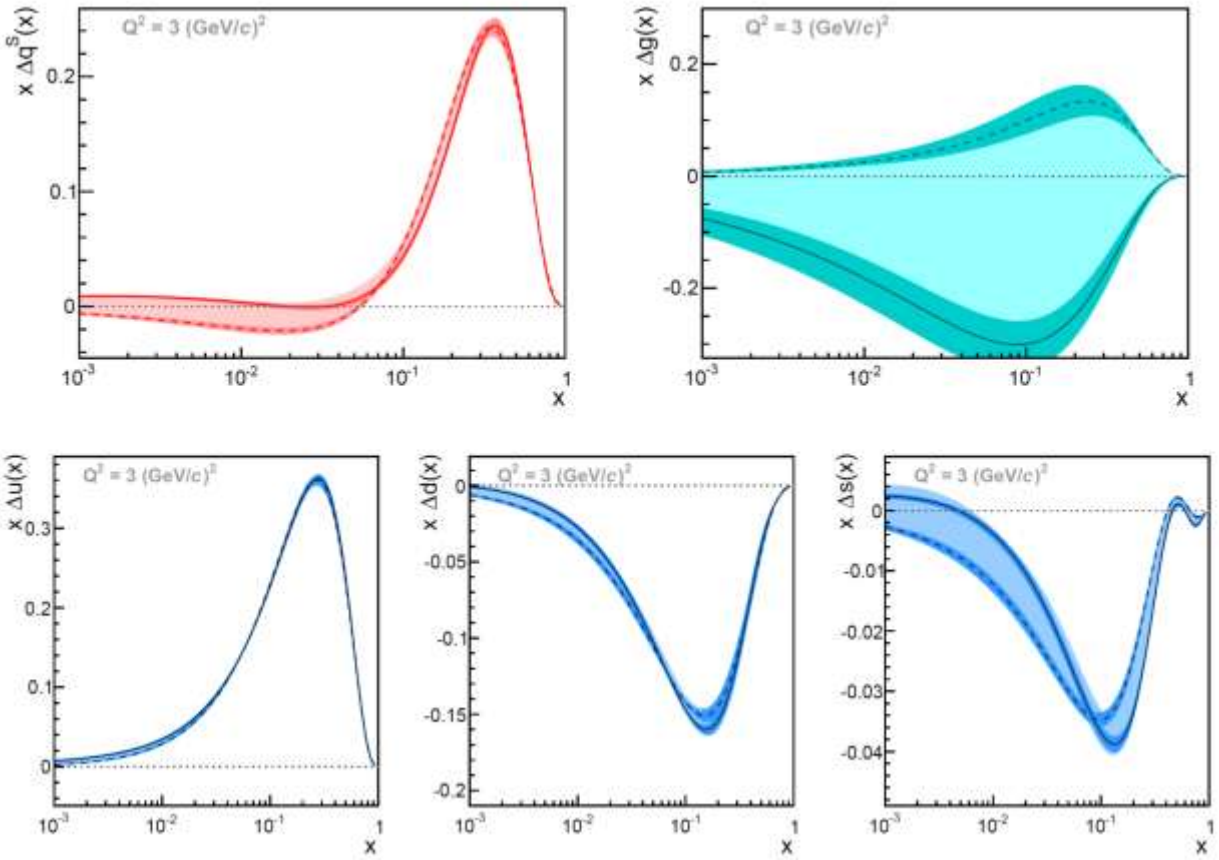
arXiv:1501.01220 [nucl-ex]

Helicity PDF and $\Delta\Sigma$

most recent QCD fits

hep-ex/1503.08935

subm. PLB



a_0 well constrained but $\Delta\Sigma$ still affected by the poor knowledge of ΔG

Extraction of Δs

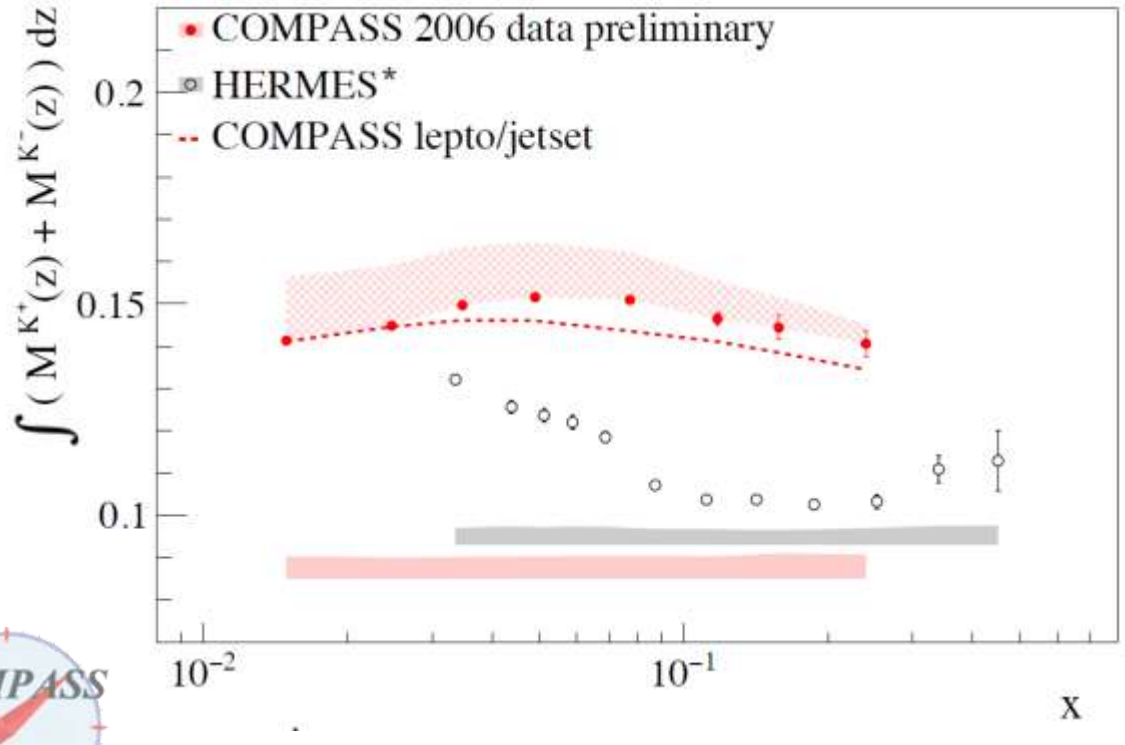
inconsistency between extraction from inclusive and semi-inclusive DIS data

uncertainty in the fragmentation functions

→ hadron multiplicities

K Multiplicities in DIS

disagreement with HERMES still to be understood

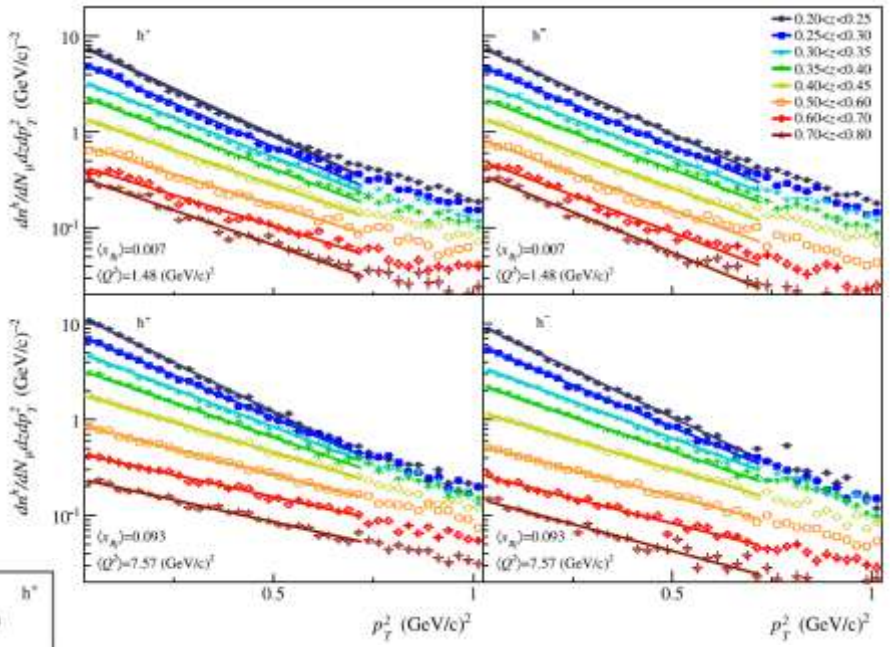


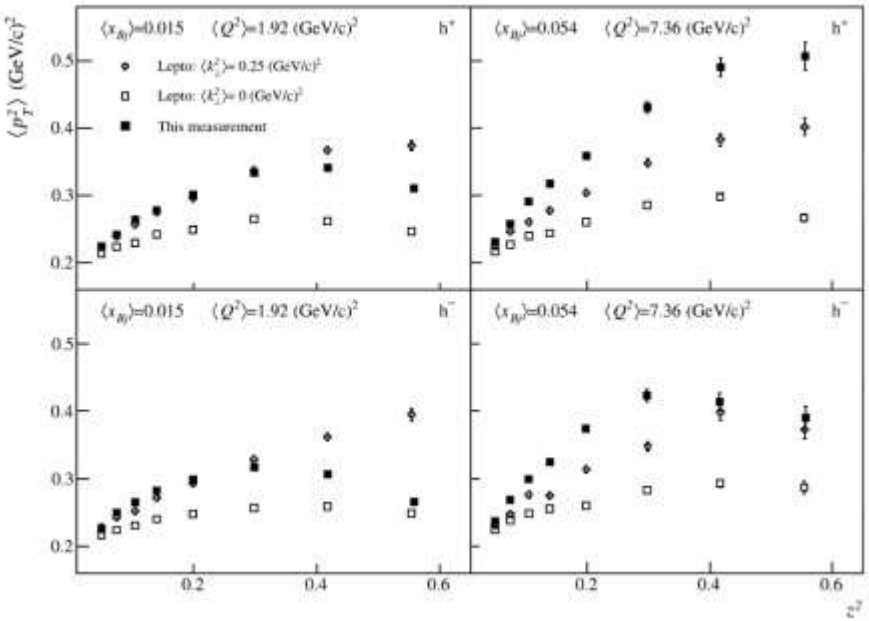
DIS2015

hadron transverse momentum distributions

huge map of x, Q^2, z, W dependence from 2004 data

Eur. Phys. J. C 73 (2013)





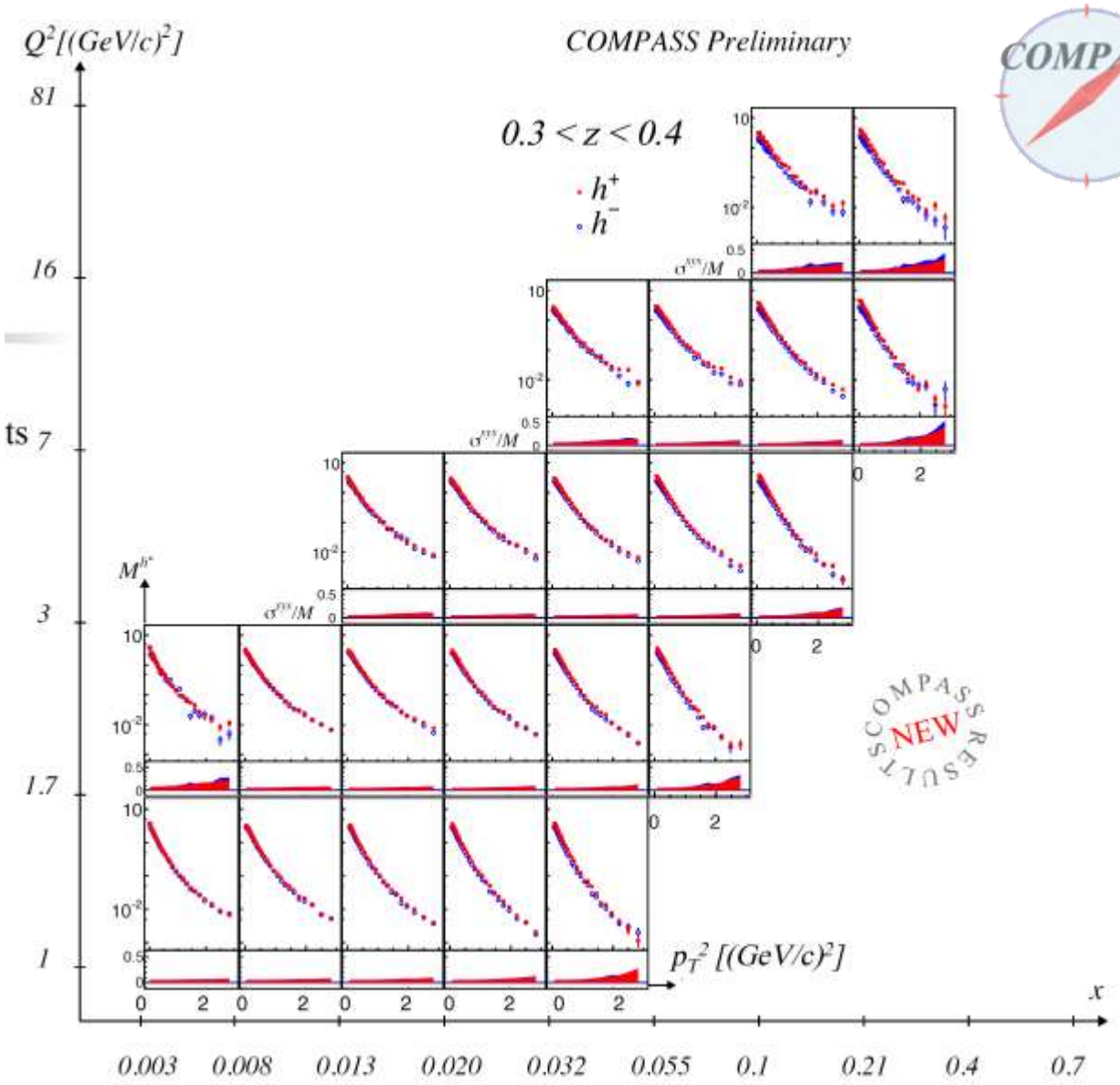
not easy to separate the intrinsic transverse momentum $k_\perp$ of the parton from the hadron transverse momentum p_T with respect to the quark direction

input from e^+e^- ?

hadron transverse momentum distributions

2006 data

SPIN2014



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Transverse spin effects – Transversity PDF

HELP experiment (L. Dick, R. Hess) **rejected by CERN:**

regarded as black magic even by our Collaboration

accepted as a compromise

20% of the running time with muon beam

Transverse spin effects – Transversity PDF

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In my opinion the best results coming from COMPASS (and HERMES) in so far, and I am not the only one

549 citations HERMES p 2005
330 citations COMPASS d 2005

MOST CITED

Transverse spin effects – Transversity PDF

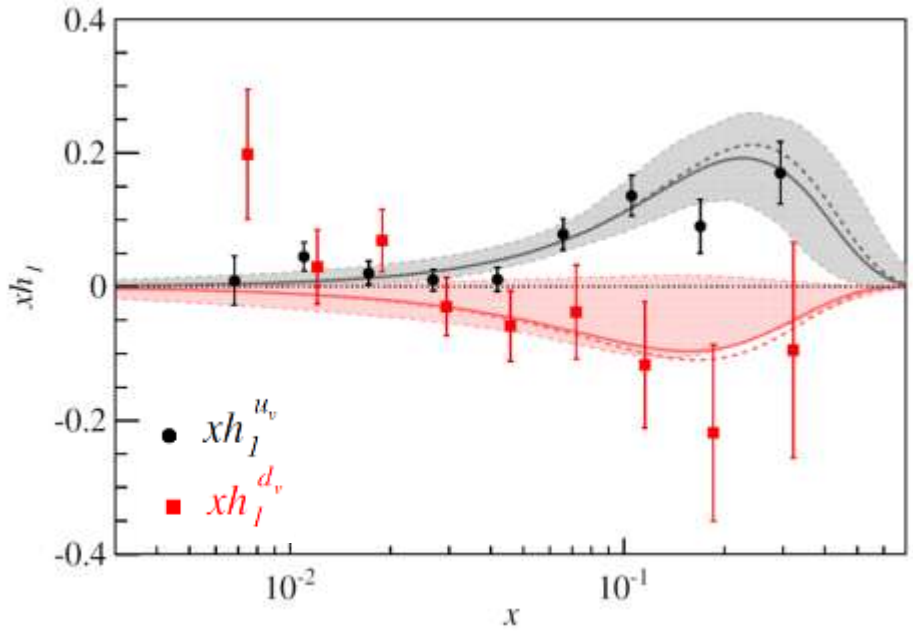
Transversity is different from zero

it has been extracted from COMPASS, HERMES and e^+e^- data

with "global" fits

and

point by point



see talk by
Anna Martin

huge activity on these data

- **Q^2 evolution of Collins FF**
- **tensor charge**

more data on deuteron needed

Transverse spin effects – Sivers PDF

the Sivers function story

a long debate

important extension of the parton model → TMD

- **1992 introduced by D. Sivers**
- **1993 J. Collins demonstrates that it must vanish**
- **2002 S. Brodsky et al.: it can be ≠ 0 because of FSI**
- **2002 J. Collins: process dependent, change of sign SIDIS ↔ DY**

….

not in our Proposal (1996)

luckily it can be measured in parallel with transversity

Transverse spin effects – Sivers PDF

happy end

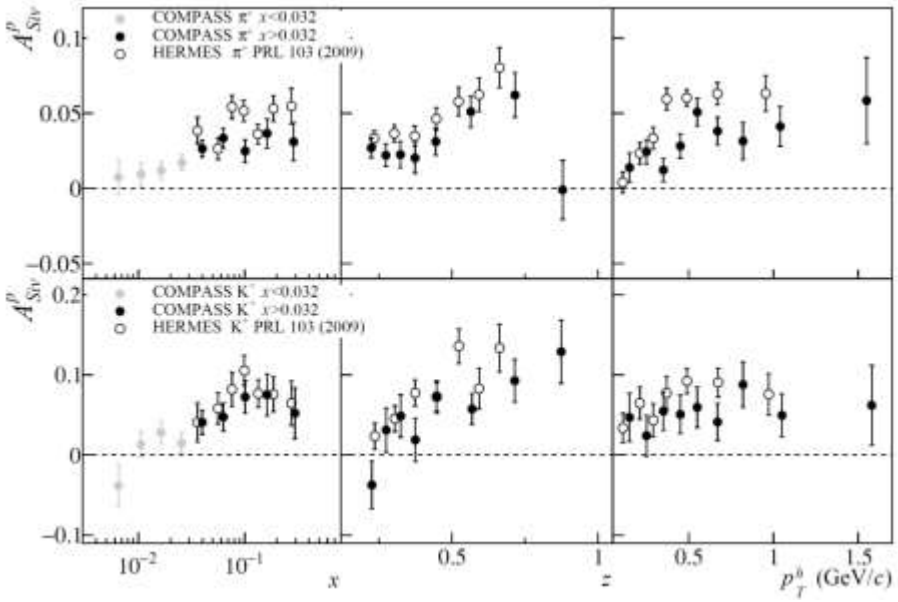
measured by HERMES and COMPASS to be different by zero

Transverse spin effects – Sivers PDF

happy end

measured by HERMES and COMPASS to be different by zero

***plus* interesting QCD evolution**



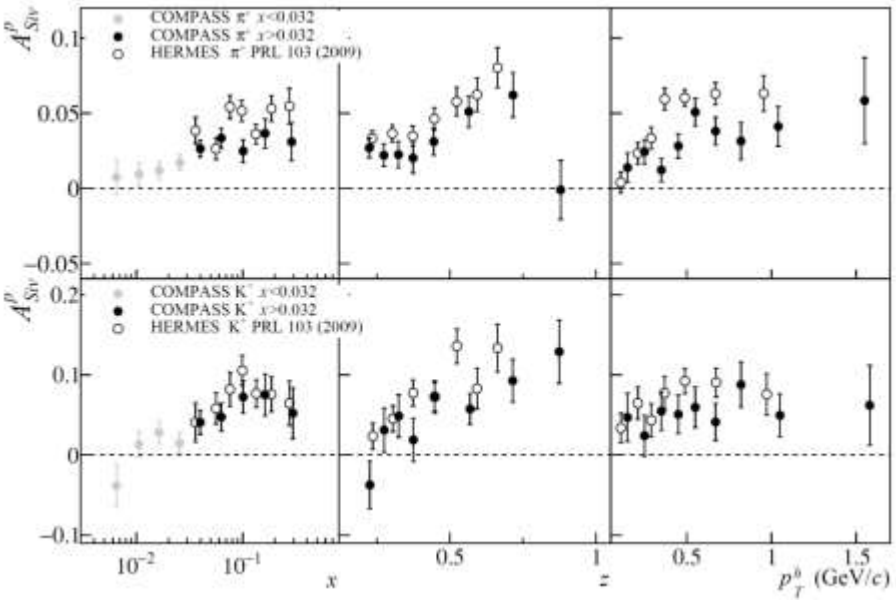
very many papers !!

Transverse spin effects – Sivers PDF

happy end

measured by HERMES and COMPASS to be different by zero

***plus* interesting QCD evolution**



very many papers !!

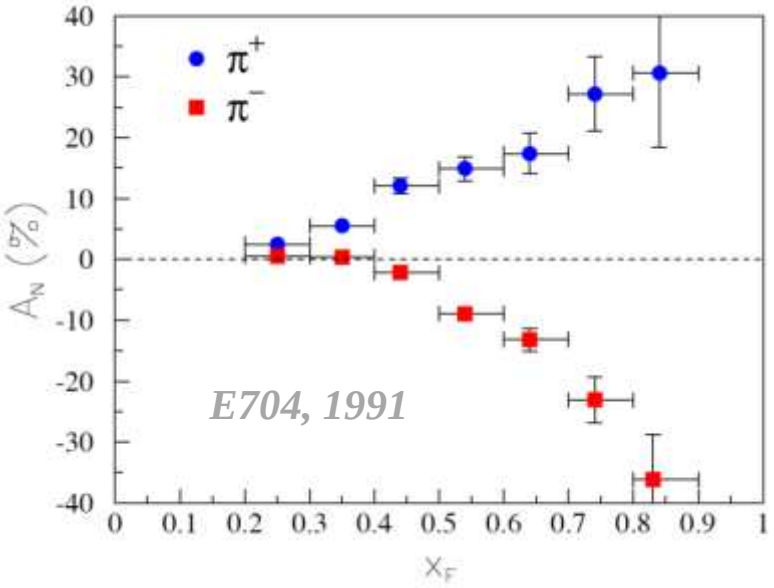
***plus* important test ongoing to check the expected change of sign when going from SIDIS to Drell-Yan**

2015: COMPASS Drell-Yan run

Transverse spin effects – Sivers PDF

still to be done:

- **link between Sivers function and OAM**
- **explain A_N in $pp^{\uparrow} \to \pi X$**



study of the 3D structure of the nucleon

will go on at COMPASS

DVCS / DVMP measurements **2016-2017**

with mu+ and mu- and a 2.5 m long LH target

proposed to COMPASS by Nicole d'Hose already in 2002

and in parallel SIDIS

DRELL-YAN measurements **2015 …**

with π^- and $p^\uparrow$ (NH3) target

proposed by COMPASS at Villars 2004

and hopefully more later on ….

LASTLY,

the OTHER side of the moon

π polarizability

had to be an “easy” measurement, to be done with an incomplete spectrometer

“the first” to be done

the lack of EM colorimetry allowed only for a short pilot run in 2004

but **the result of the 2009 run made us famous !**

PRL 114 (2015)

Press echo in spring 2015

Press echo in spring 2015

ScienceDaily

Featured Research

CERN experiment brings precision to a cornerstone of particle physics

Neue Zürcher Zeitung

PHYSIK UND CHEMIE

Pionen-Experiment am Cern

Da schwabbelt nichts

11.2.2015, 17:08 Uhr

rtz. Wieder hat ein Experiment die theoretischen Vorhersagen des Standardmodells der Teilchenphysik bestätigt. Diesmal massen die Forschenden die Verformbarkeit sogenannter Pionen. Diese gibt Aufschluss darüber, wie stark die Bindungskraft zwischen den Elementarteilchen im Inneren von Atomkernen ist.

AVENIR Fondamental

A LA UNE

Le pion se déforme moins que prévu

C'est la confirmation d'une donnée de physique fondamentale que fournit l'expérience COMPASS menée au CERN sur une mesure rel... à l'interaction forte, la force qui lie quarks, neutrons et protons.

Focus.it

SCIENZA AMBIENTE TECNOLOGIA CULTURA COMPORTAMENTO FOTO VIDEO

L'interazione forte dei quark ha meno segreti

L'esperimento COMPASS al CERN fornisce una misura chiave dell'interazione forte.

Lo spettrometro dell'esperimento COMPASS. È lungo 60 metri e lo suo interno vengono sparati raggi di particelle subatomiche ad alta intensità.

ScienceSeeker

Science news from science newsmakers

Home Add Site Generate Citations

CERN Physicists Measure Polarizability of Pion

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DA COMPASS UNA MISURA CHIAVE DELL'INTERAZIONE FORTE

cea

Irfu

Une expérience du CERN affine une mesure essentielle pour décrire l'interaction forte

Quick-Links

Press echo in spring 2015

ScienceDaily

Featured Research

CERN experiment brings precision to a cornerstone of particle physics

Neue Zürcher Zeitung

PHYSIK UNI

Pionen-Experiment am Cern

Da schwabb

11.2.2015, 17:08

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НАУКА И ЖИЗНЬ

Новости События Архив Видео Открытый формат Форум

Конкурсы Новости партнеров Подписка Магазин Реклама

Wydział Fizyki Uniwersytetu Warszawskiego

Polaryzowalność pionów: pierwszy precyzyjny pomiar w CERN z udziałem fizyków warszawskich

2015-02-19

НАУКА И ЖИЗНЬ / Новости науки и техники / Новости

19 февраля 2015

Как COMPASS пион поляризовал

Пион оказался очень «жесткой» элементарной частицей – такой вывод сделали физики ЦЕРН на основе последних результатов эксперимента COMPASS.

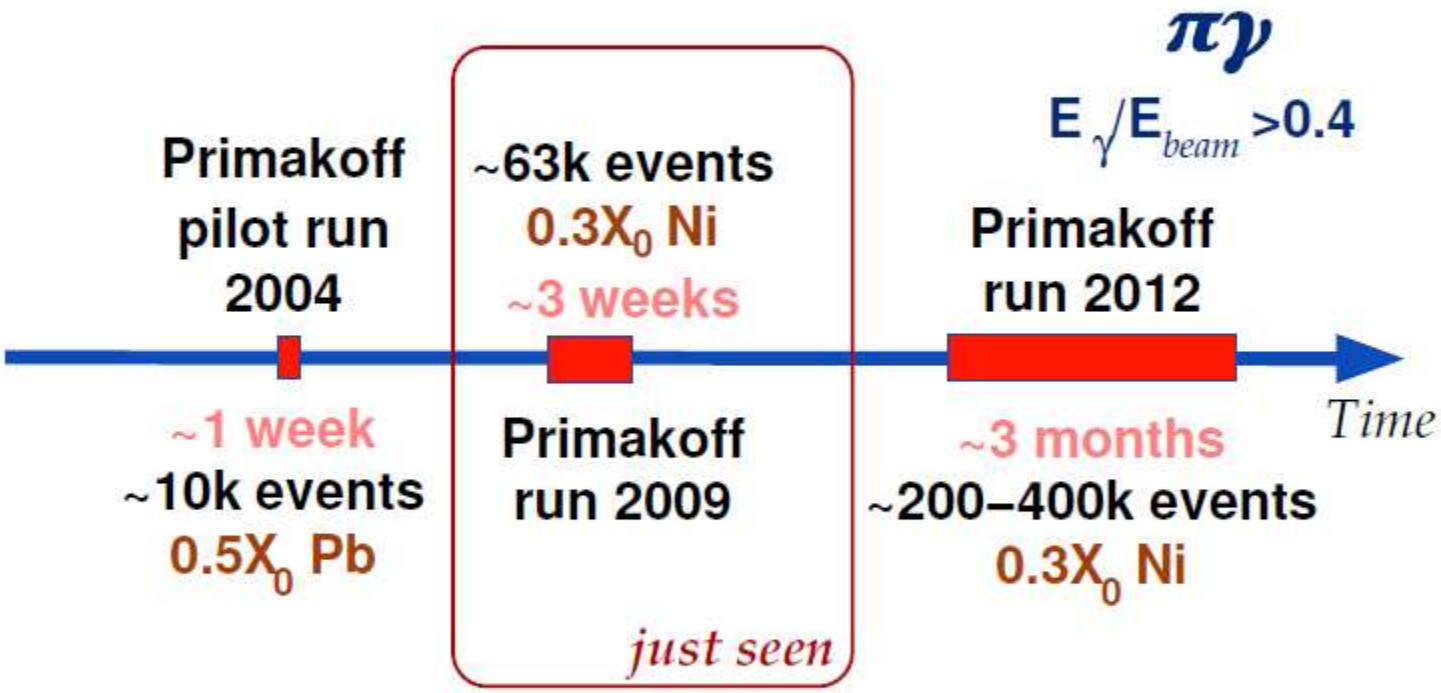
Сильное взаимодействие связывает кварки в протонах и нейтронах, а протоны и нейтроны - в ядрах всех химических элементов, из которых построена материя. Частицы, состоящие из квар антикварка, называемые пионами, являются переносчиками сильного взаимодействия между взаимодействий даёт точное предсказание для физической величины.

Irfu

Une expérience du CERN affine une mesure essentielle pour décrire l'interaction forte

Lo spettrometro dell'esperimento COMPASS. È lungo 60 metri e lo suo interno vengono sparati raggi di particelle subatomiche ad alta intensità.

Pion polarisability measurements at COMPASS

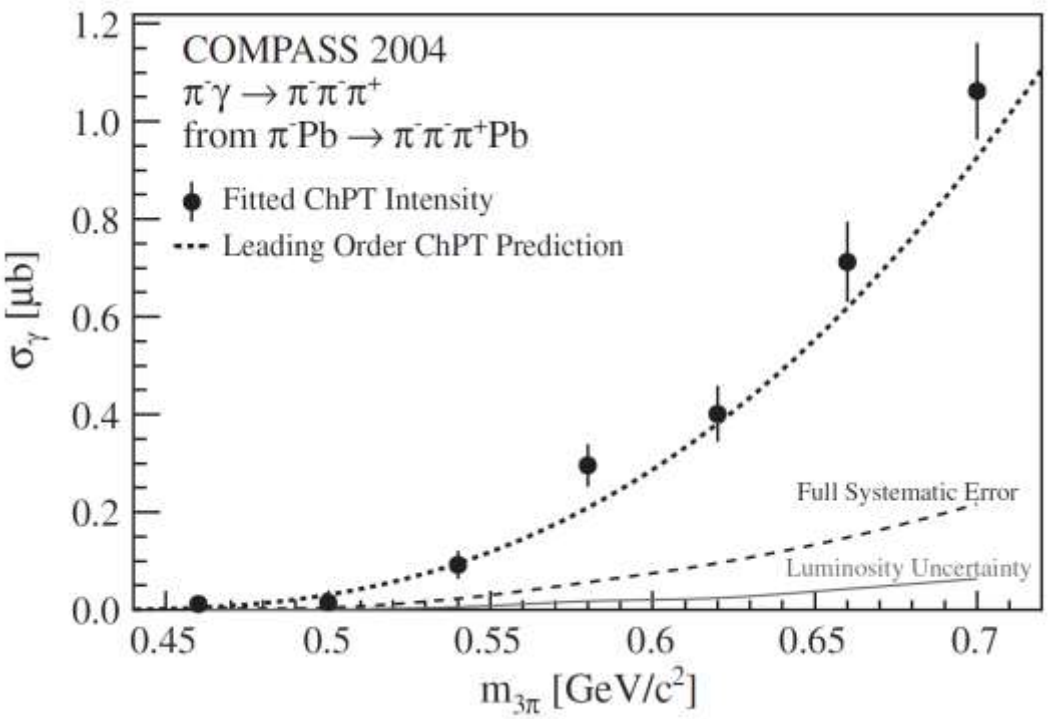


More tests of chiral dynamics

Tests of chiral dynamics also in the channel

$$\pi^- \gamma \to \pi^- \pi^- \pi^-$$

PRL 108 (2012)

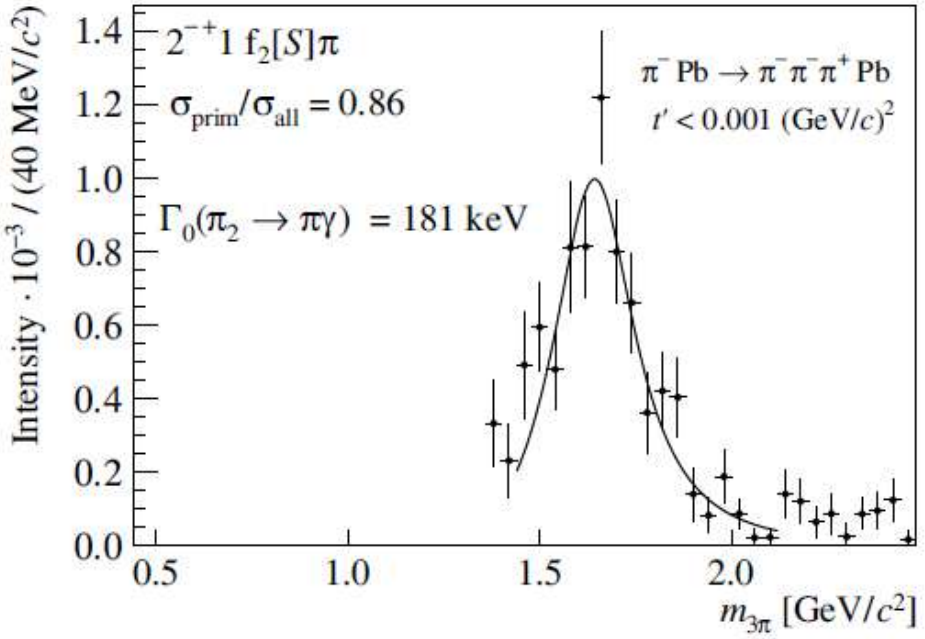


More tests of chiral dynamics

Radiative widths of $a_2(1320)$ and $\pi_2(1320)$

EPJA 50 (2014) 79

EPJ A Highlights



Light Meson Spectroscopy

Huge amount of data accumulated in 2008-2009

Open problem: $J^{PC} = 1^{-+}$ **exotic** $\pi_1(1600)$

PRL 104 (2010)

impressive phase-shift analysis

investigation still ongoing

$\pi_1(1600)$

M. Pennington

IWHSS2013

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IWHSS2013

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PRL 104 (2010)

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investigation still ongoing

Mostly rewarding: $a_1(1420)$

sub PRL

a narrow state $J^{PC} = 1^{++}$

observed in the exotic $f^0(980)\,\pi$ **channel**

but at which price !!

phase-shift analysis of $\pi^- p \to \pi^- \pi^- \pi^- p$ **:** **50 M events !**

88 waves !

Concluding Remark

the work is not over

20 years have not been enough

as the CERN Director of Research says

> **“ it has not been easy to have COMPASS approved, it will not be easy to shut it down over the third millennium ”**