COMPASS + *related*

future hadron structure projects

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CERN

HIM
Helmholtz-Institut Mainz

Mainz
28.4.2017

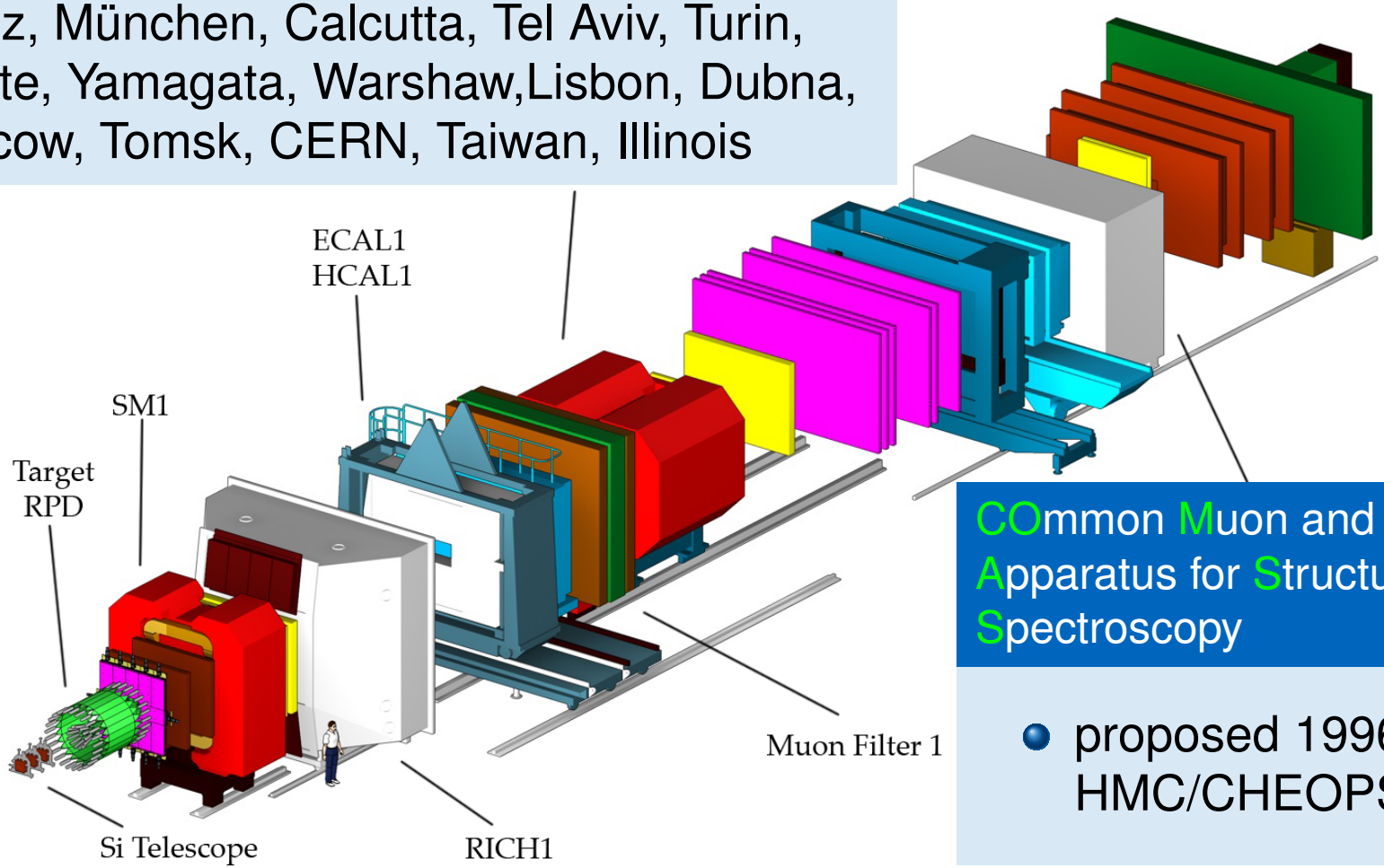
bmb+f - Förderschwerpunkt
COMPASS
Großgeräte der physikalischen Grundlagenforschung

The COMPASS Experiment

Collaboration: 249 members

22 institutes: Prague, Saclay, Bonn, Freiburg, Mainz, München, Calcutta, Tel Aviv, Turin, Trieste, Yamagata, Warshaw,Lisbon, Dubna, Moscow, Tomsk, CERN, Taiwan, Illinois

approved 1997

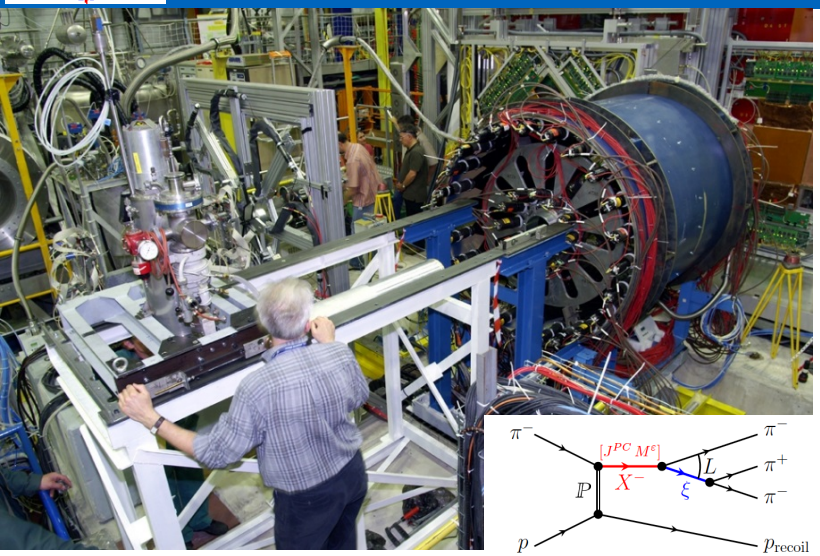


COmmon Muon and Proton Apparatus for Structure and Spectroscopy

- proposed 1996 by the HMC/CHEOPS groups

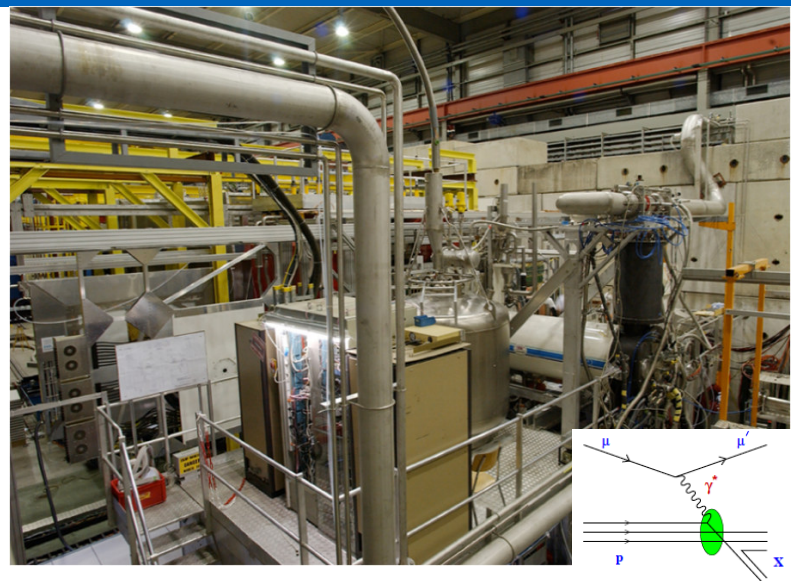
Versatile COMPASS Setup in EHN2

target region for different physics programmes

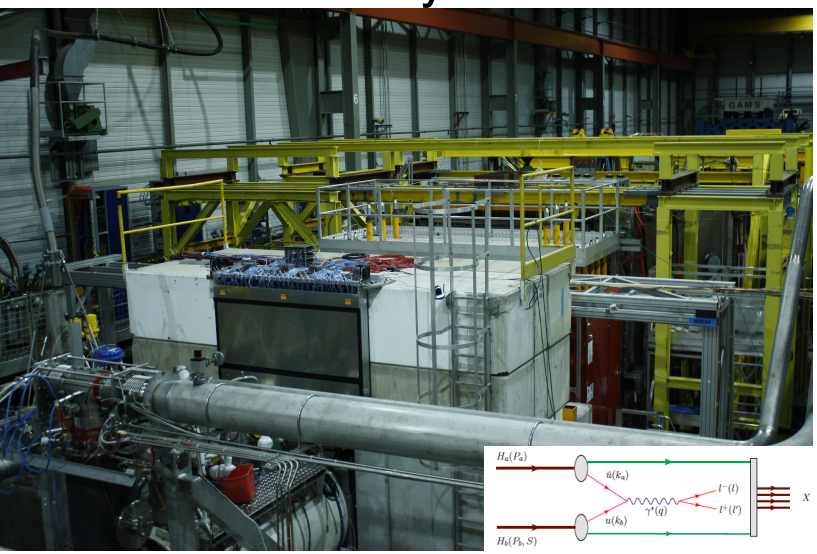


hadron spectroscopy
& chiral dynamics

COMPASS-I
1997-2011

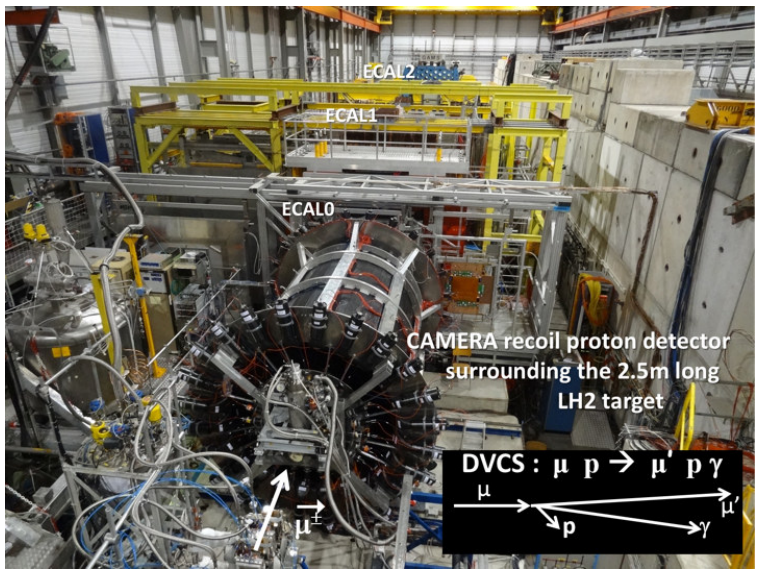


polarised SIDIS



polarised Drell-Yan

COMPASS-II
2012-2018



DVCS (GPDs), unpol. SIDIS

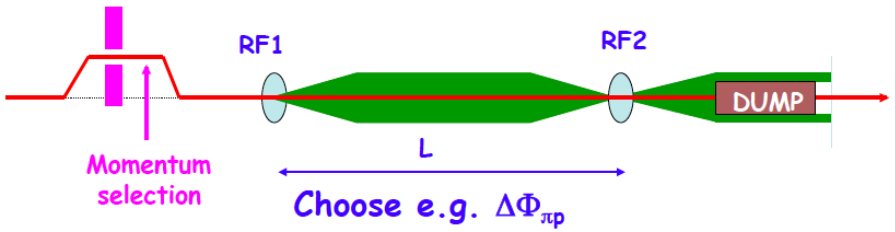
Future Plans

- COMPASS prepares a **Letter of Intent** for a new round of experiments *beyond 2020*
- we are open to new groups and ideas
- first collection of ideas on the *beyond 2020* workshop held in March 2016 at CERN
- participation in the “Physics Beyond Colliders” CERN working group
- unique opportunity: RF-separated kaon and anti-proton beams in M2
- plan: LoI in 2017, Proposal in 2018

Physics Ideas for the LoI

- **Spectroscopy with RF-separated beams**
  - Kaon: spectroscopy of diffractive dissociation
  - Kaon: polarisability and related low-energy processes
  - Kaon: gluon distribution from prompt photons
  - Antiprotons: charmonium hybrids and exotics

- **Drell-Yan with RF-separated beams**
  - Kaon: DY with both polarised and unpolarised targets, kaon structure
  - Antiprotons: DY both polarised and unpolarised $\rightarrow$ pure proton structure function, TMDs



$\Delta\Phi = 2\pi\,(L\,f\,/\,c)\,(\beta_1^{-1} - \beta_2^{-1})$ with $\beta_1^{-1} - \beta_2^{-1} = (m_1^2 - m_2^2)/2p^2$

h^- beam: 96.8% π^-, 2.4% K, 0.8% $\bar{p}$

h^- beam: 24% π^-, 1.4% K, 74.6% p

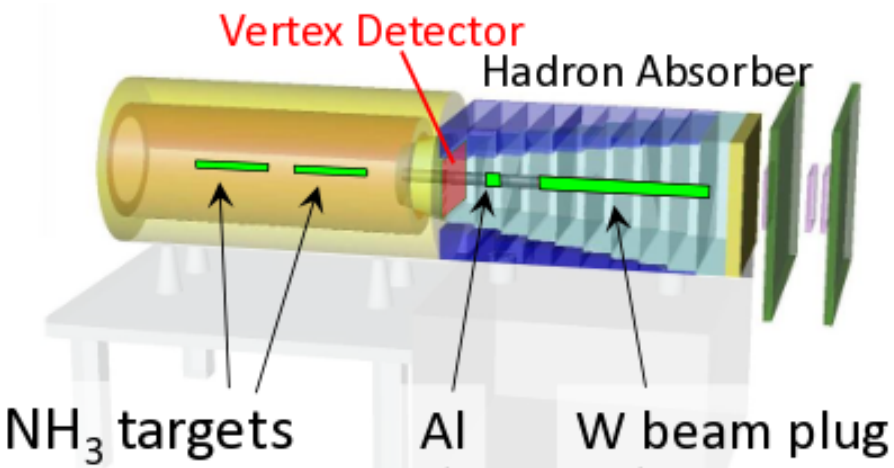
Physics Ideas for the LoI – cont'd

- **Physics with existing muon beam**
  - SIDIS with transversely polarised deuteron target
  - DVCS with transversely polarised proton target
- **Physics with existing pion/proton beams**
  - Polarised DY with deuteron target – flavor separation
  - Unpolarised DY with various targets
  - use unseparated anti-proton beam for spectroscopy ($<$20 GeV)
  - cross sections p He $\rightarrow \bar{p}\, X$ (dark matter search)

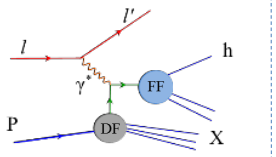
Programme with present beams for right after LS2
unless separated beams are available already

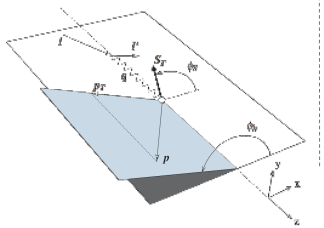
Polarised Drell-Yan

Sivers - **hot news: tendency in favor of "sign-change" scenario**

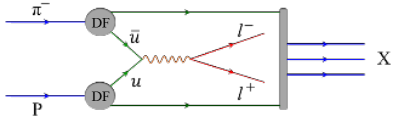


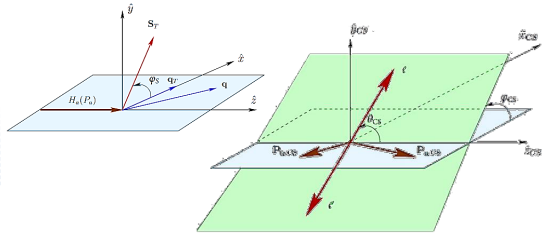
SIDIS

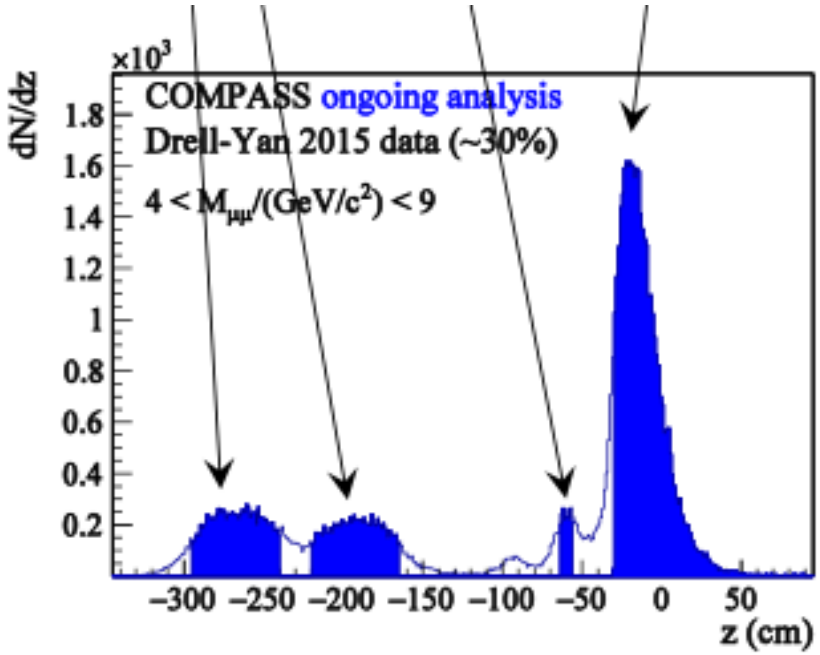


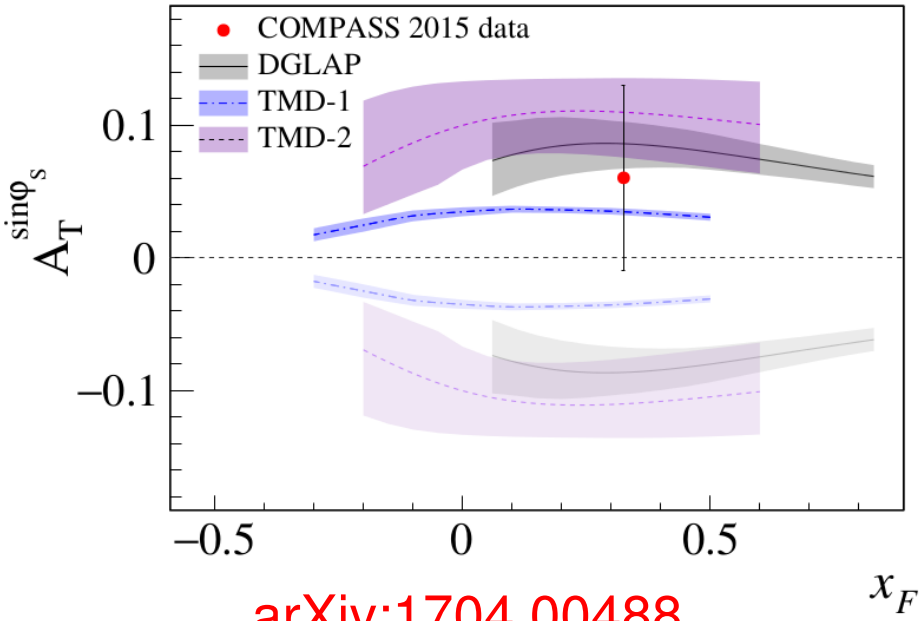


single-polarised DY









arXiv:1704.00488

Polarised DY beyond 2020

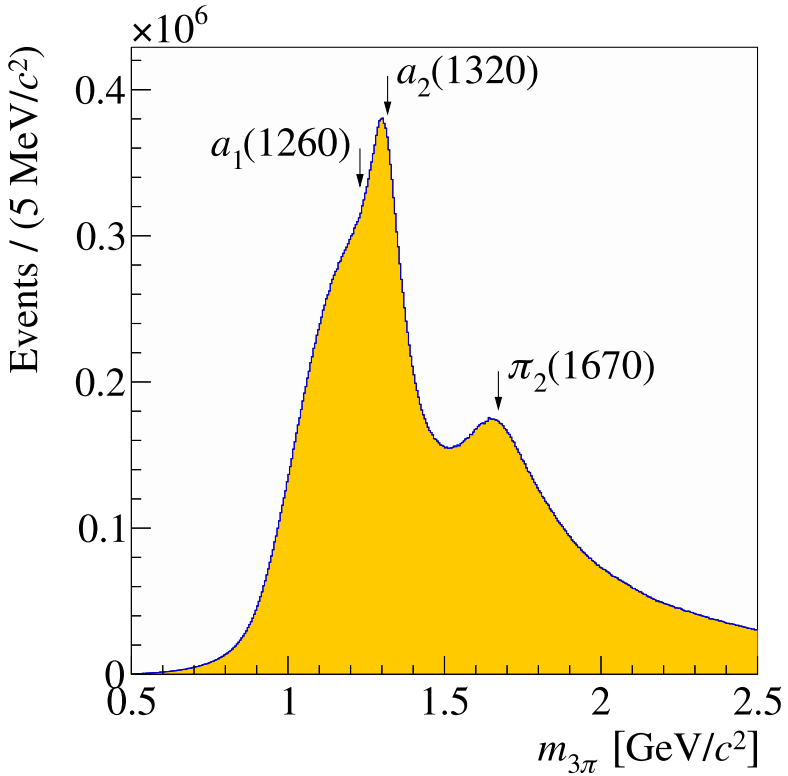
rate estimates for $K/\bar{p}$

- assumed flux RF separated beam: 10^7/s kaons / antiprotons
- high-mass range $4 < m_{\mu\mu}/\text{GeV} < 9$
- 140 days with efficiency as for pions 2015
- overall gain with RF-separated beams compared to previous experiments 50–100

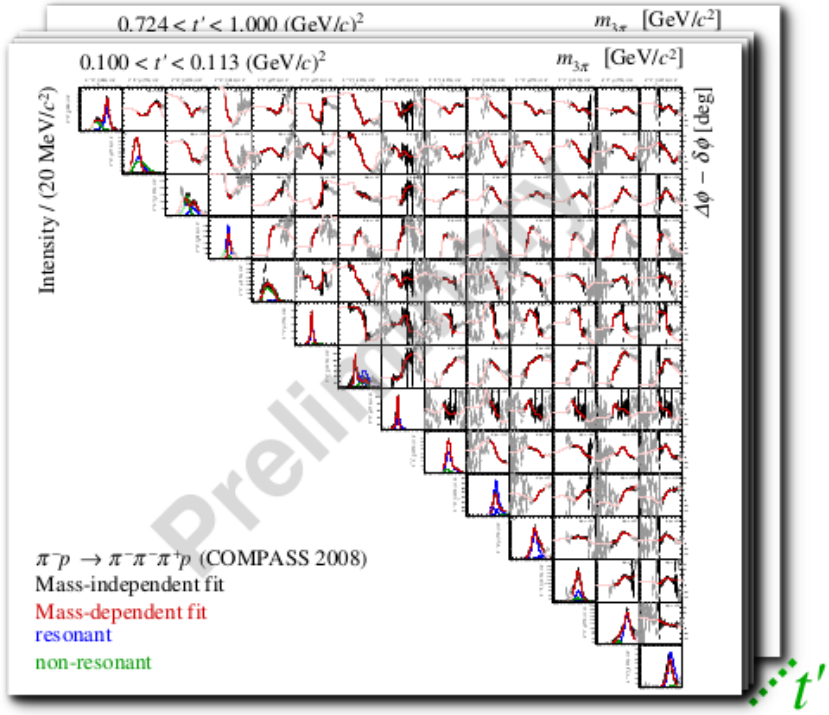
Beam	COMPASS++			NA3	E537
	NH_3	Al	W		
K^-	14 000	2 800	29 000	700	
$\bar{p}$	15 750	2 750	22 500		387

Meson spectroscopy with pion beam

arXiv:1509.00992

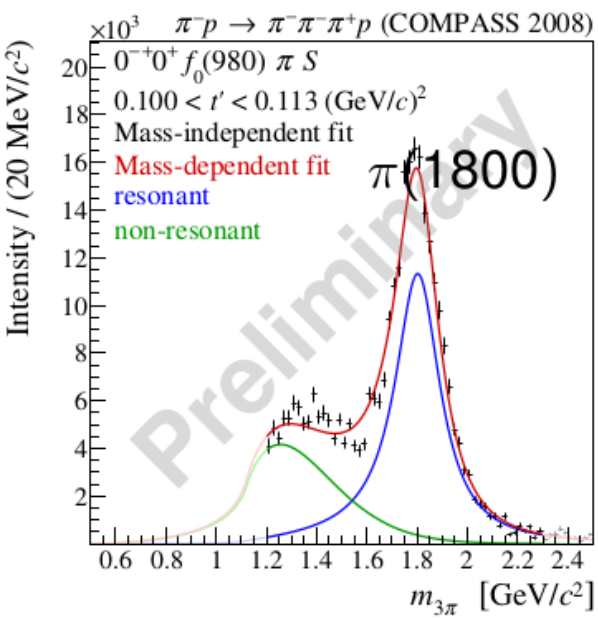


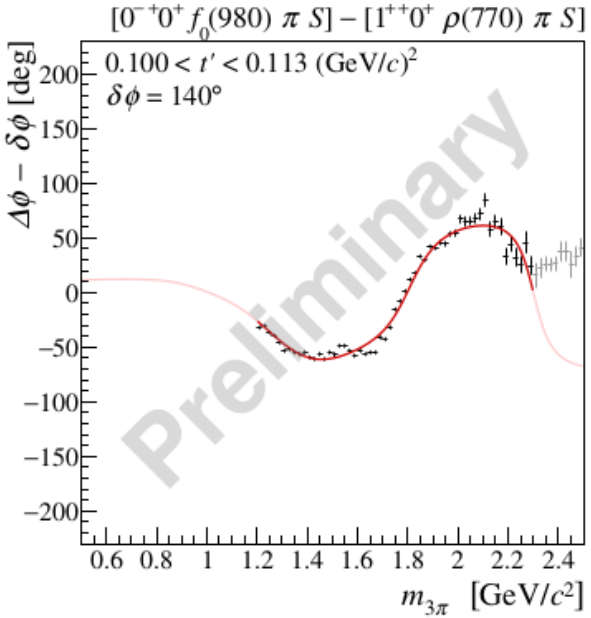
$\Rightarrow$

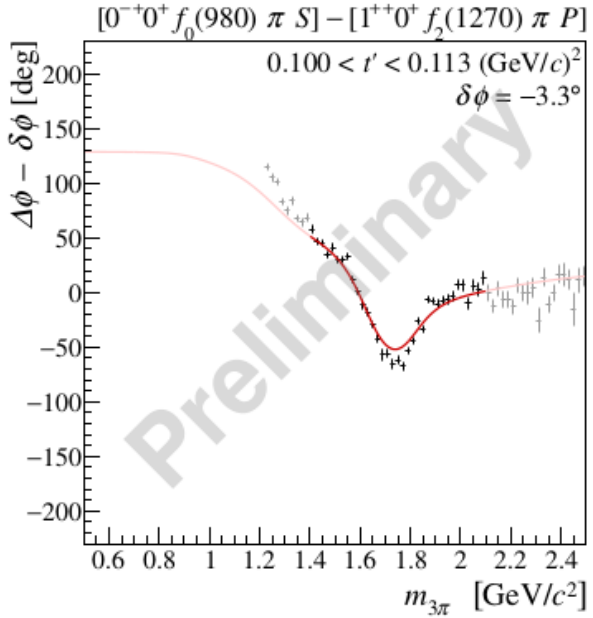


- 46 million exclusive 3π events
- partial-wave fit with 88 waves in narrow 3π-mass slices
- mass dependence fitted for 14 waves $\sim$ 75 000 data points (including interference terms)

Example: $0^{-+}0^{+}f_0(980)\pi S$ wave







$$m_{\pi(1800)} = 1802.6^{+8}_{-3.5}\,\mathrm{MeV}/c^2\ ;\ \Gamma_{\pi(1800)} = 218^{+11}_{-6}\,\mathrm{MeV}/c^2$$

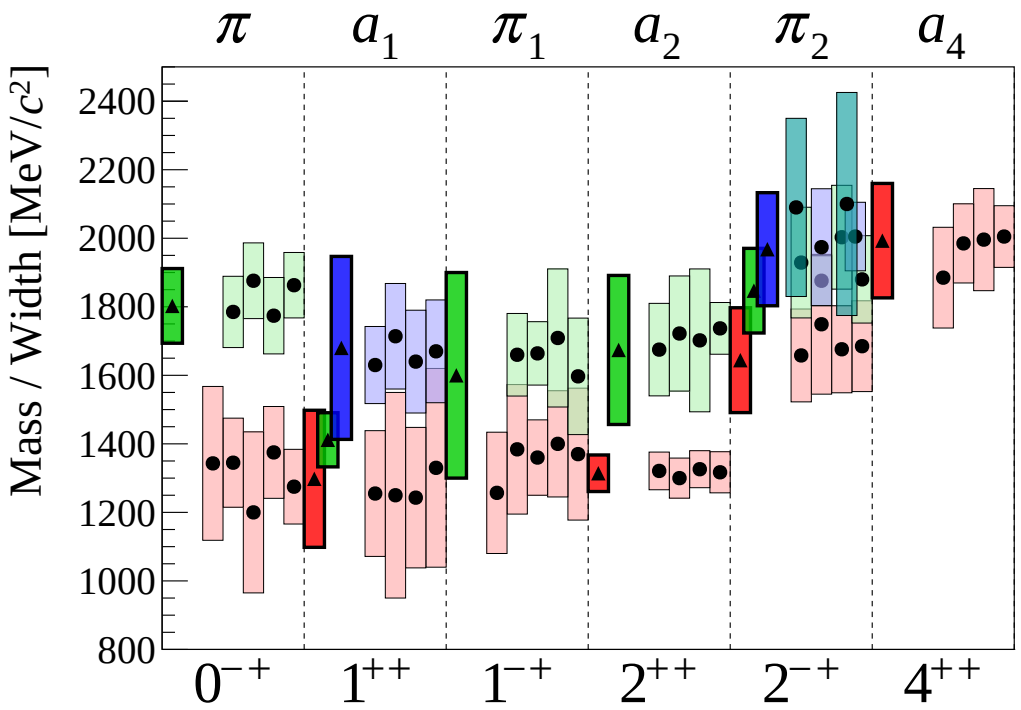
$$m^{\mathrm{PDG}}_{\pi(1800)} = 1812 \pm 12\,\mathrm{MeV}/c^2;\ \Gamma^{\mathrm{PDG}}_{\pi(1800)} = 208 \pm 12\,\mathrm{MeV}/c^2$$

- $\pi(1800)$ previously observed to decay in $f_0(980)\pi$ and $f_0(1500)\pi$ $\rightarrow$ "fixed f_0 isobars" assumed in the fit
- new analysis method: *this assumption can be tested - cf. later*

Results on 3π resonances

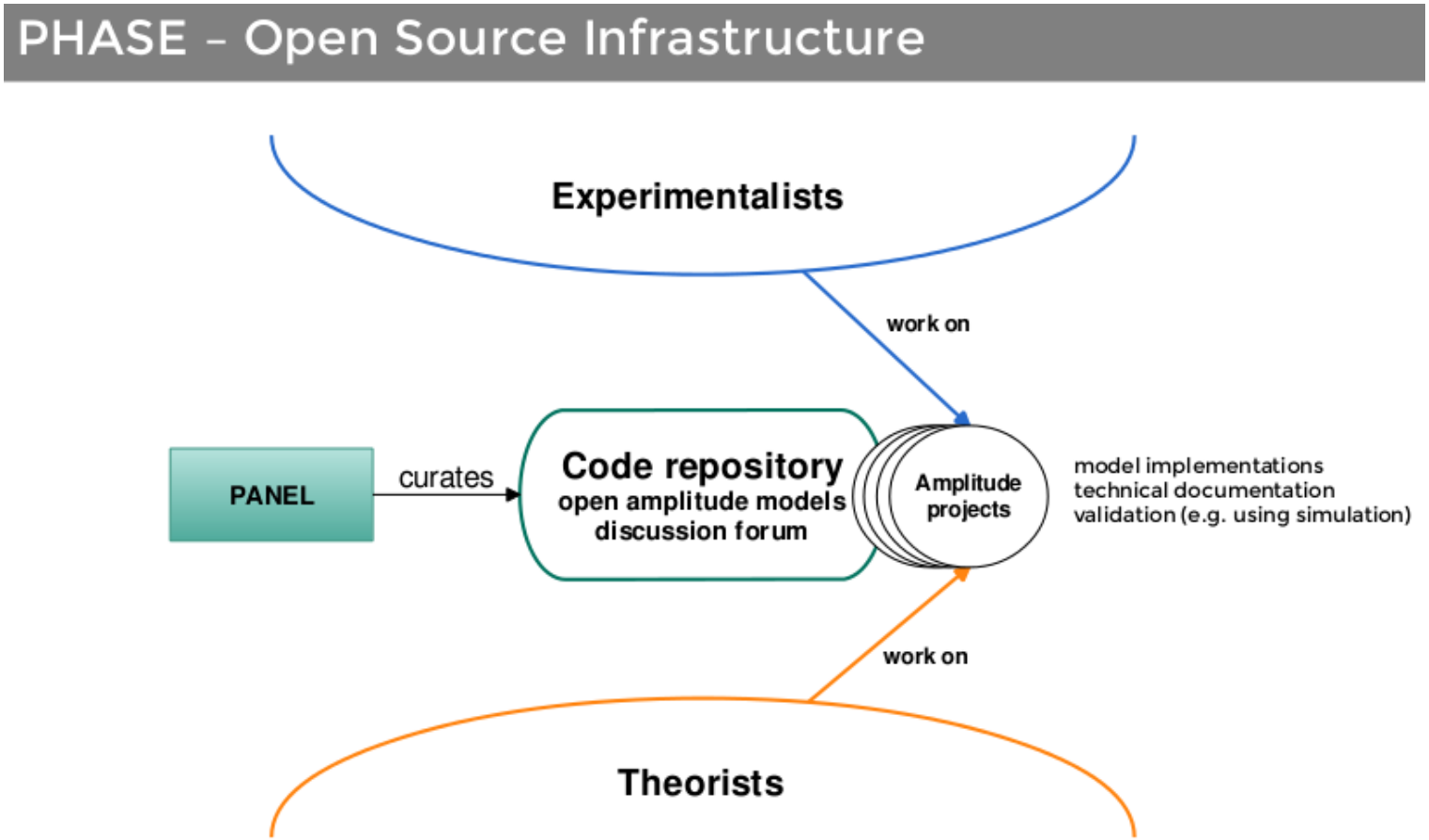
new: parameters of 11 resonances

- main known resonances reproduced
- all resonance parameters determined in one single fit
- new signal: $a_1(1420)$
- three π_2 states needed
- (broad) exotic 1^{-+} signal



Initiative: Panel for Hadronic Amplitudes

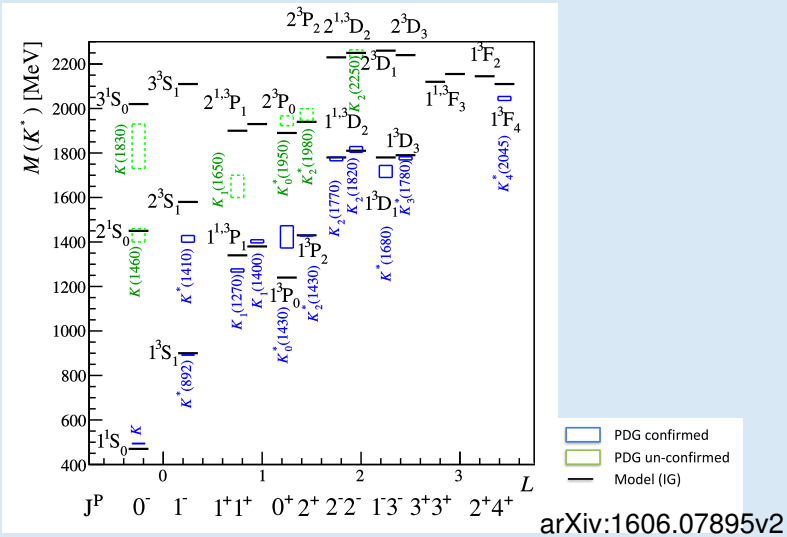
https://goo.gl/5o36g5



from: S. Neubert, ATHOS Workshop Bad Honnef March 2017

Current Knowledge on strange mesons

PDG lists 28 strange mesons



arXiv:1606.07895v2

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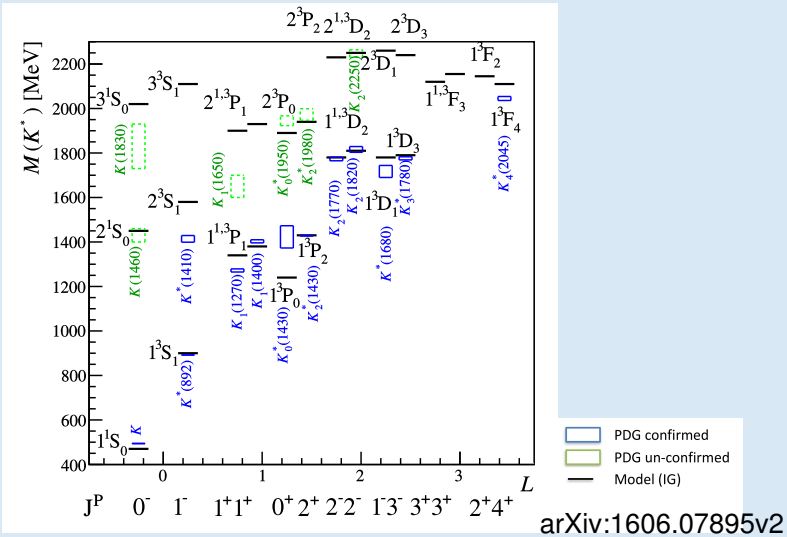

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Previous measurements

- ACCMOR [Daum, Nucl.Phys.B 1981]
  - 200 000 events
    $K^- + p \to K^- \pi^- \pi^+ + p_{\text{recoil}}$
- LASS [Aston, Nucl.Phys.B 1993]
  - 100 000 $K^- p \to K^- \omega p$ events
- τ or heavy-meson decays

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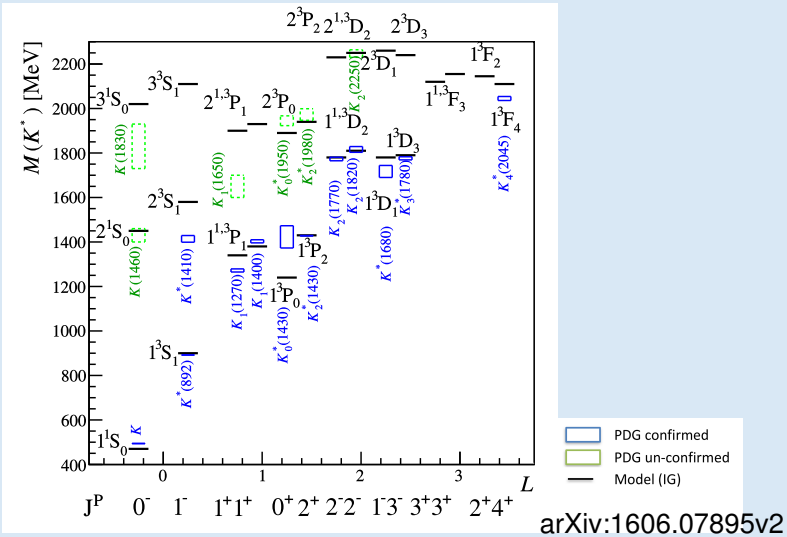

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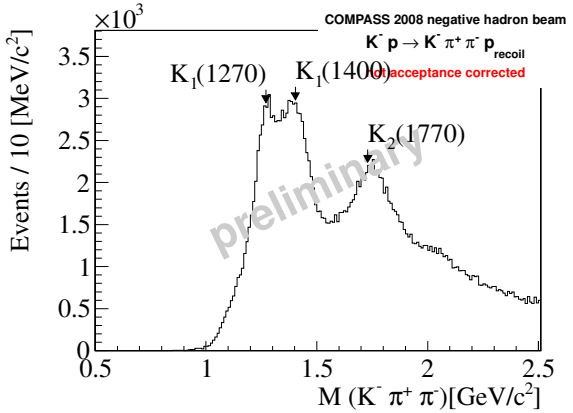
COMPASS analysis of existing data

- $\approx$ 2% K^- fraction in 190 GeV/c beam
- 270 000 exclusive
  $K^- + p \to K^-\pi^-\pi^+ + p_{\text{recoil}}$ events



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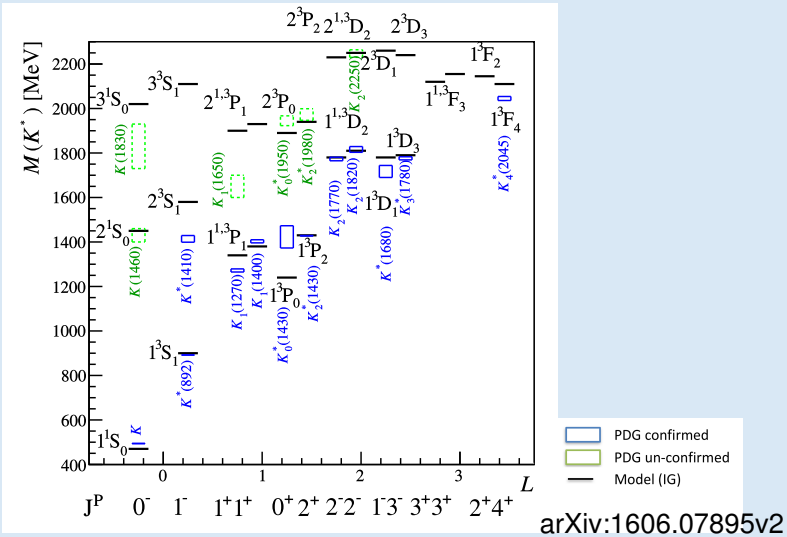

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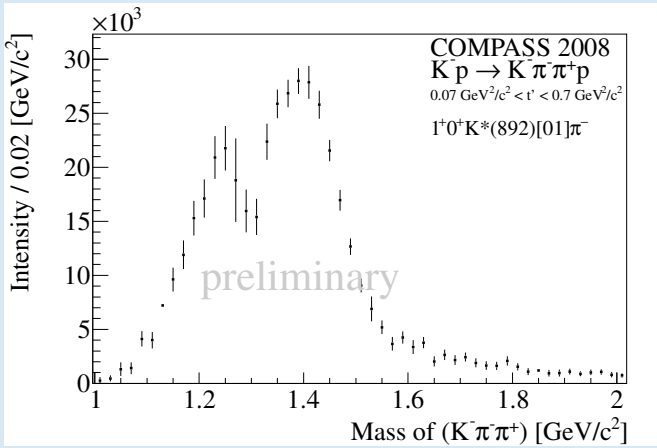
- Partial wave analysis including 19 waves



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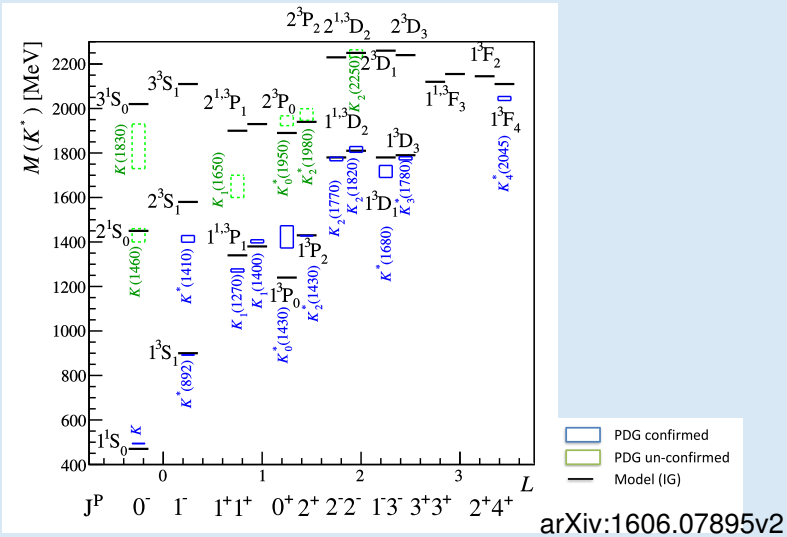

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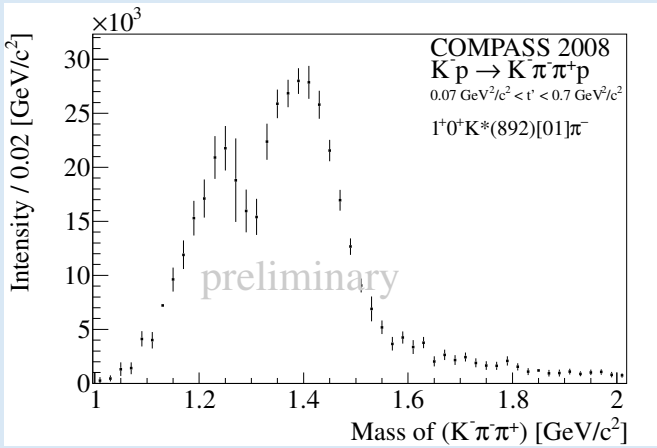
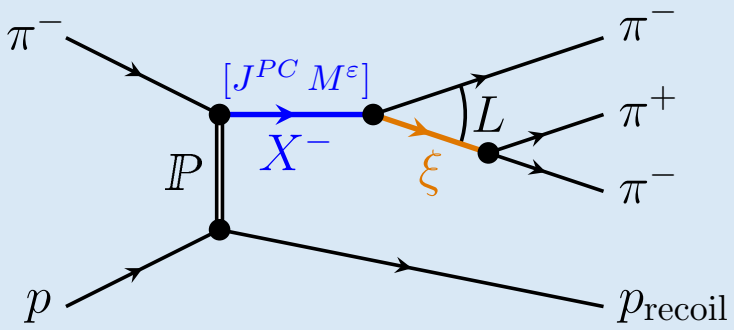
COMPASS analysis of existing data

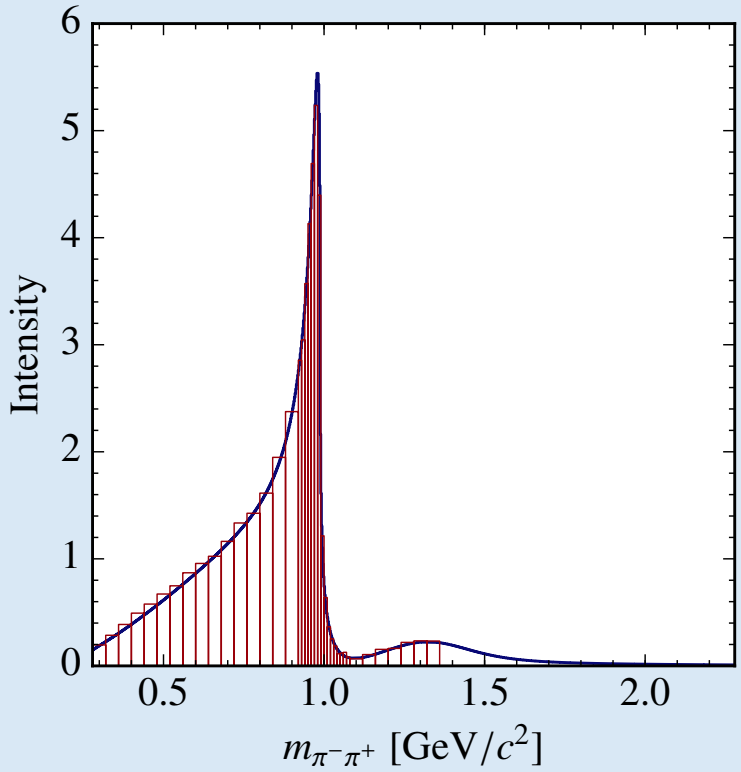
- $\approx$ 2% K^- fraction in 190 GeV/c beam
- 270 000 exclusive
  $K^- + p \to K^-\pi^-\pi^+ + p_{\text{recoil}}$ events
- Partial wave analysis including 19 waves
- Aiming for 1M events



Possibilities with high-statistics data set: Freed-isobar fits



- Replace fixed isobar-shape by step-like function



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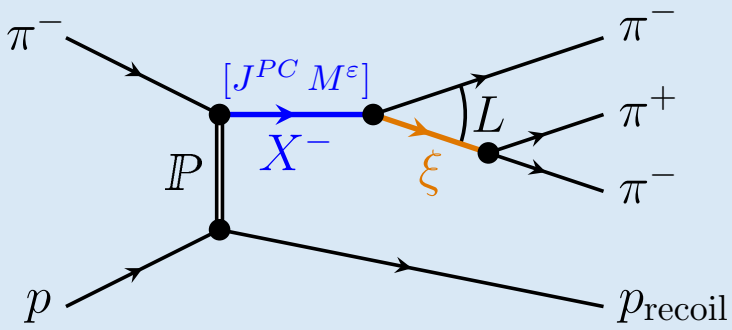
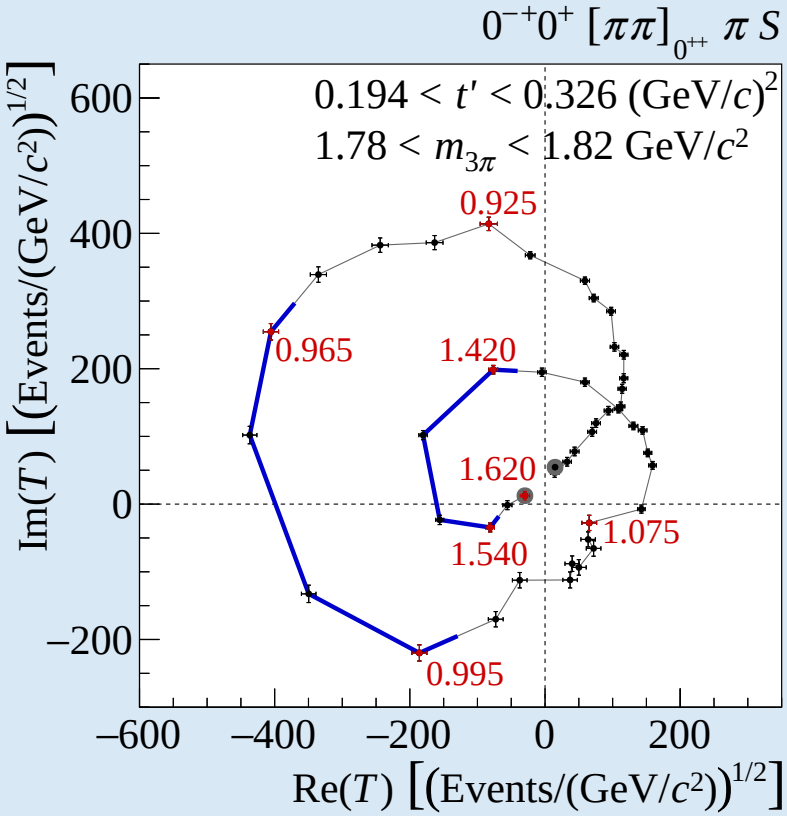


- Replace fixed isobar-shape by step-like function
- Extract information about the $\pi^+\pi^-$ and $K^-\pi^+$ subsystem

  $\Rightarrow$ *Investigate the κ state*



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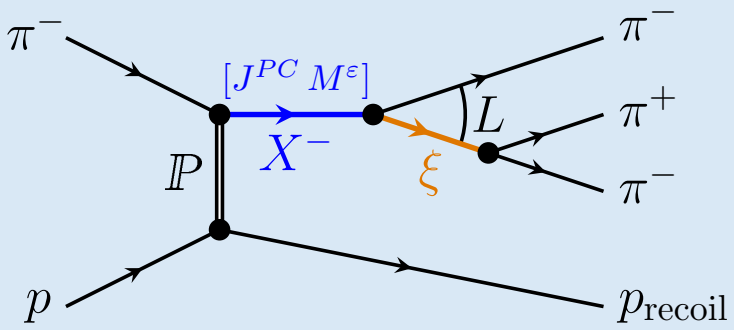
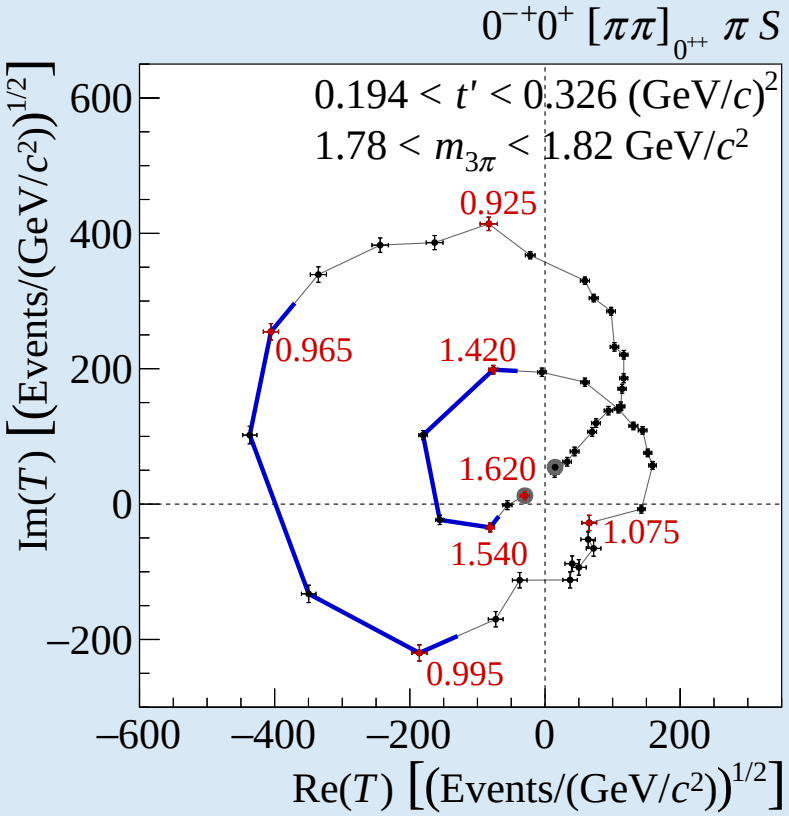


- Replace fixed isobar-shape by step-like function
- Extract information about the $\pi^+\pi^-$ and $K^-\pi^+$ subsystem
  $\Rightarrow$ *Investigate the κ state*
- $\gtrsim$ 50*M needed*



RF separated beam

- Enrich beam kaon contribution
- Aim for 8×10^6/s kaons 100 GeV/c
- Allows to collect 30-50M $K^- + p \to K^-\pi^-\pi^+ + p_{\text{recoil}}$ events per year
- Uniform detector acceptance over broad kinematic range required
- No direct competitors at the moment

Hadron spectroscopy beyond 2020

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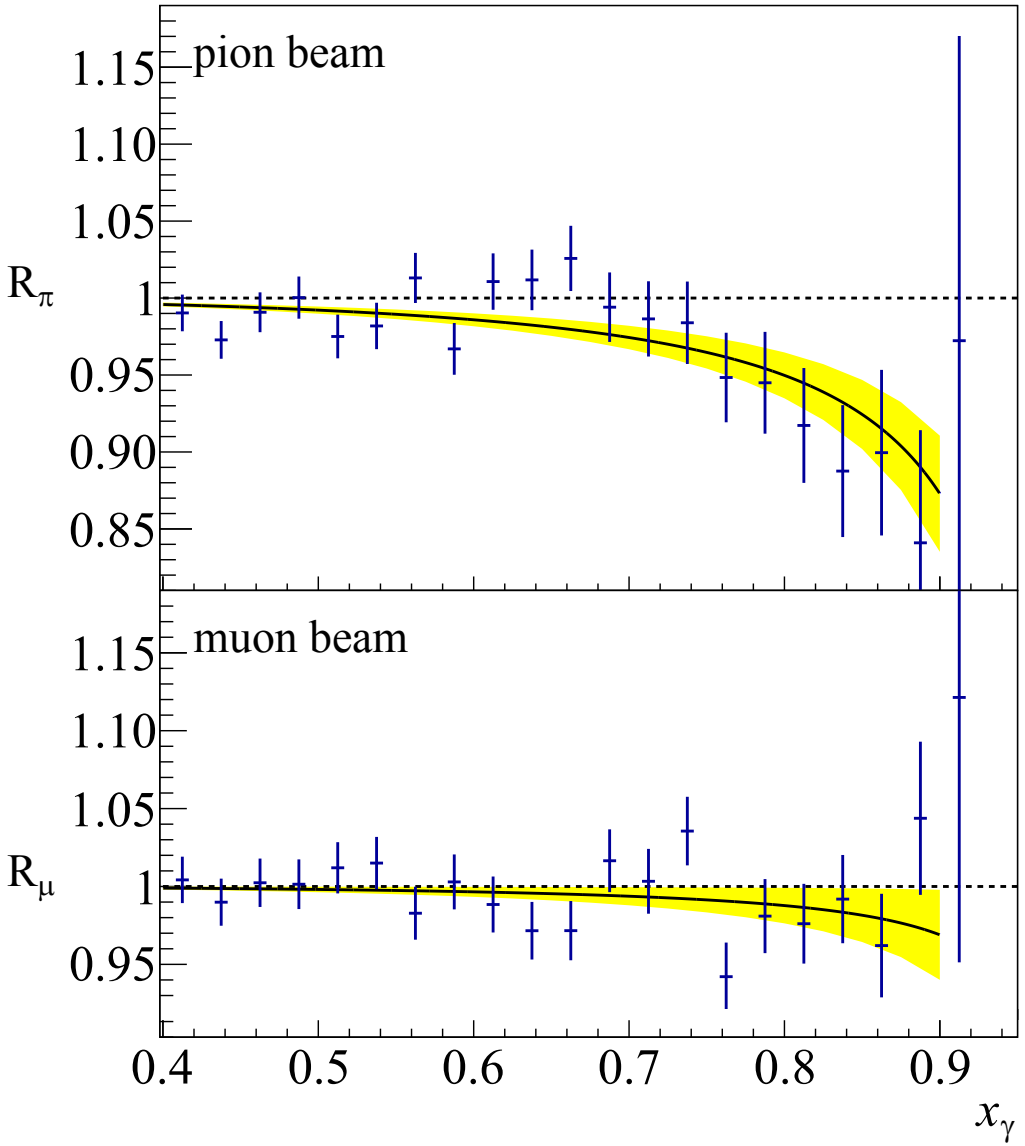
- Uniform detector acceptance over broad kinematic range required
- No direct competitors at the moment

Spectroscopy with antiprotons

- $\lesssim$ 20 GeV/c hadron beam
  - $\Rightarrow$ Enriched beam antiproton contribution
  - $\Rightarrow$ No RF separation needed
- Spectroscopy in the energy region of charmonium
- Needed: a barrel detector around the target (tracking/calorimetry) and the existing forward spectrometer

Pion Polarisability: COMPASS 2009 data



$$\alpha_\pi = (2.0 \pm 0.6_{\text{stat}}) \times 10^{-4}\,\text{fm}^3$$

(assuming $\alpha_\pi = -\beta_\pi$)

"false polarisability" (muon data):

$$(0.5 \pm 0.5_{\text{stat}}) \times 10^{-4}\,\text{fm}^3$$

PRL 114, 062002 (2015)

CERN press release 11.2.2015:
"CERN experiment brings precision to a cornerstone of particle physics"

Kaon polarisability

with RF-separated Kaon beam

Theoretical predictions:

χPT prediction $O(p^4)$:

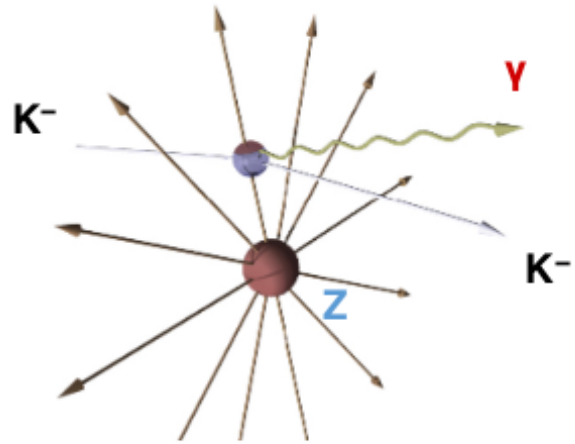
$$\alpha_K + \beta_K = 0$$

$$\alpha_K = \alpha_\pi \times \frac{m_\pi F_\pi^2}{m_K F_K^2} \approx \frac{\alpha_\pi}{5} \approx 0.6 \times 10^{-4} fm^3$$

Quark confinement model:

$$\alpha_K + \beta_K = 1.0 \times 10^{-4} fm^3$$

$$\alpha_K = 2.3 \times 10^{-4} fm^3$$



Experimental results:

$\alpha_K < 200 \times 10^{-4}$ fm^3 (1973)

- from kaonic atoms spectra

Standard COMPASS hadron beam

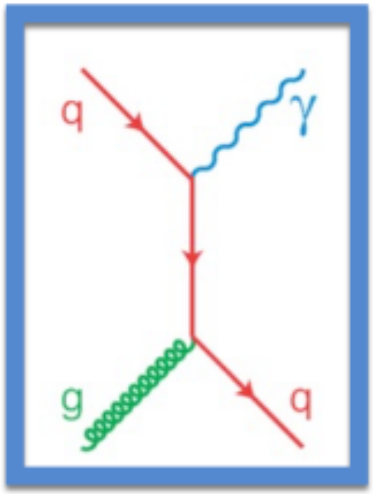
Particles	Positive beam	Negative beam
π	0.240	0.968
K	0.014	0.024
p	0.746	0.008

1 Kγ event per 500 πγ

- a full analysis of the accessible γK mass spectrum requires input from the neighbor/crossed channels $\gamma K \to K\pi$, $\gamma\pi \to K\bar{K}$

Beyond 2020: Prompt Photons

At the moment there is no experimental data on G(x) of kaon!



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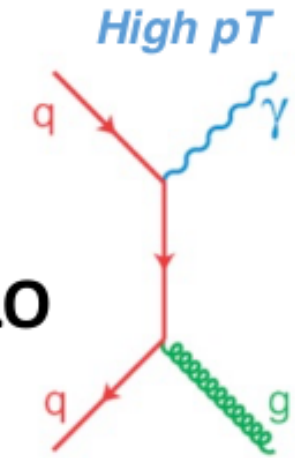
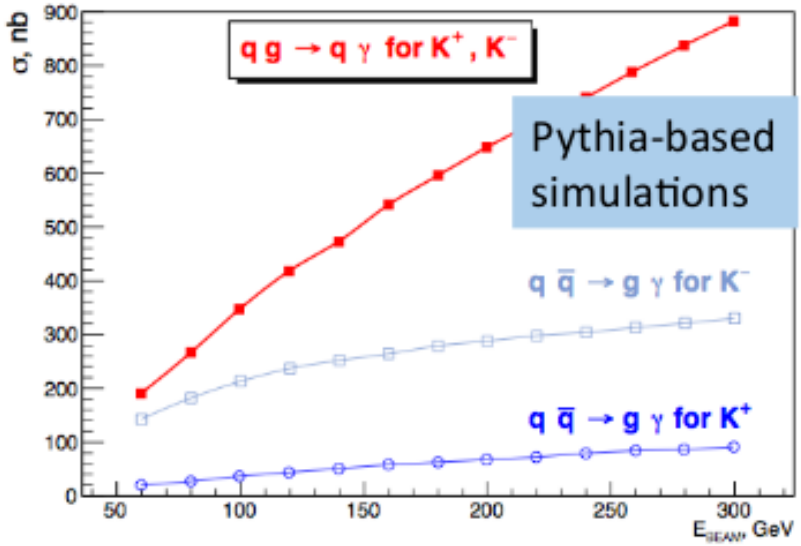




$$d\sigma_{AB} = \sum_{a,b=q,\bar{q},g} \int dx_a dx_b f_a^A(x_a,\mu^2) f_b^B(x_b,\mu^2) d\sigma_{ab\to\gamma X}(x_a,x_b,\mu^2).$$

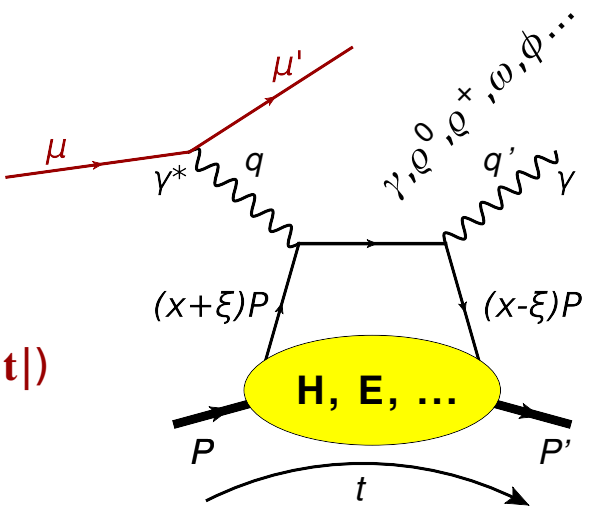
K^+ beam of 100+ GeV/c and nuclear target

High aperture system of 3 precise electromagnetic calorimeters

First observation of kaon-induced prompt photons, first measurement of kaon G(x)

DVCS: Transverse Nucleon Imaging

$$\vec{\mu}^{\pm} p \rightarrow \mu^{\pm} p \gamma$$

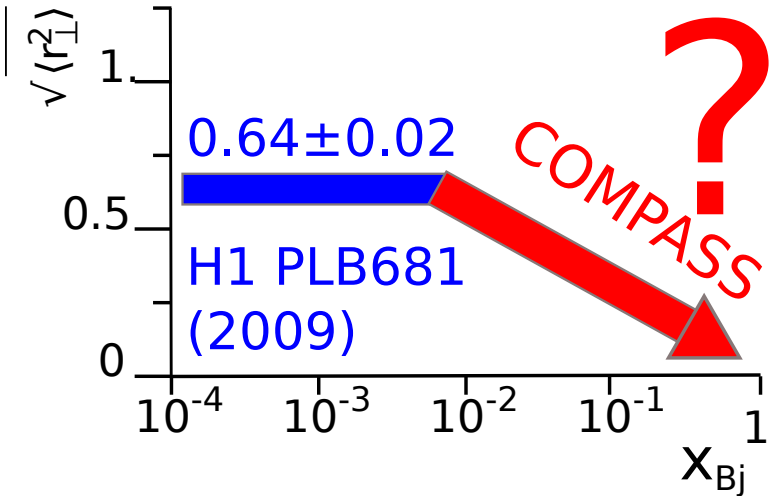


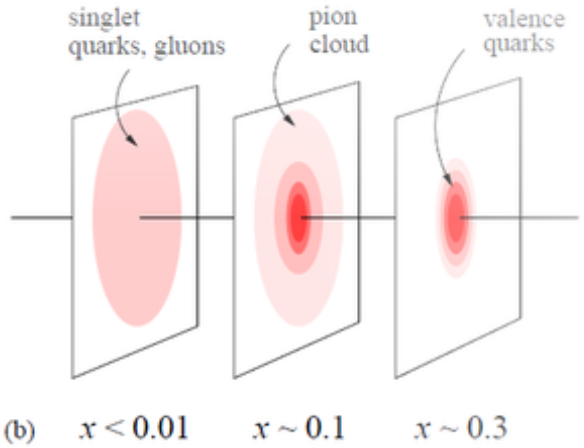
$$S_{CS,U} \equiv d\sigma(\mu^{+\leftarrow}) + d\sigma(\mu^{-\rightarrow}) \propto d\sigma^{BH} + d\sigma^{DVCS}_{unpol} + Ks_1^{Int} \sin\phi$$

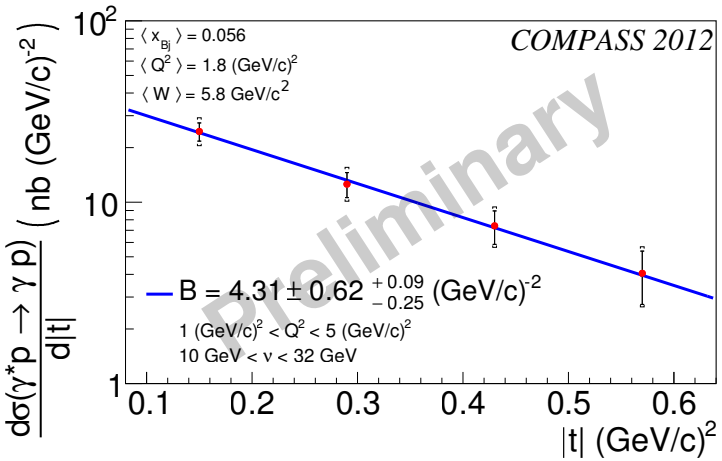
$$\rightarrow d\sigma^{DVCS}/d|t| \sim \exp(-B|t|)$$

$$< r_\perp^2(x_B) > \approx 2B(x_B)$$

$r_\perp \rightarrow$ distance between struck and spectator partons

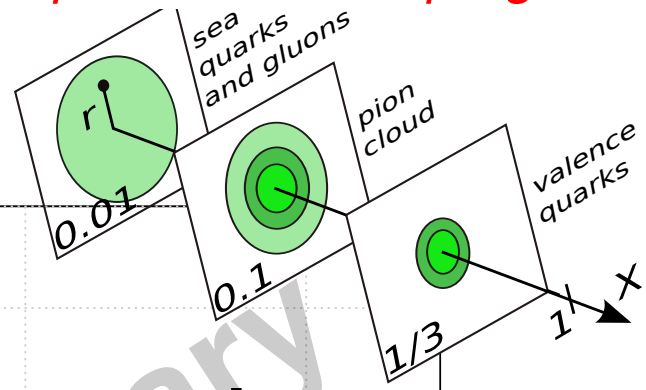


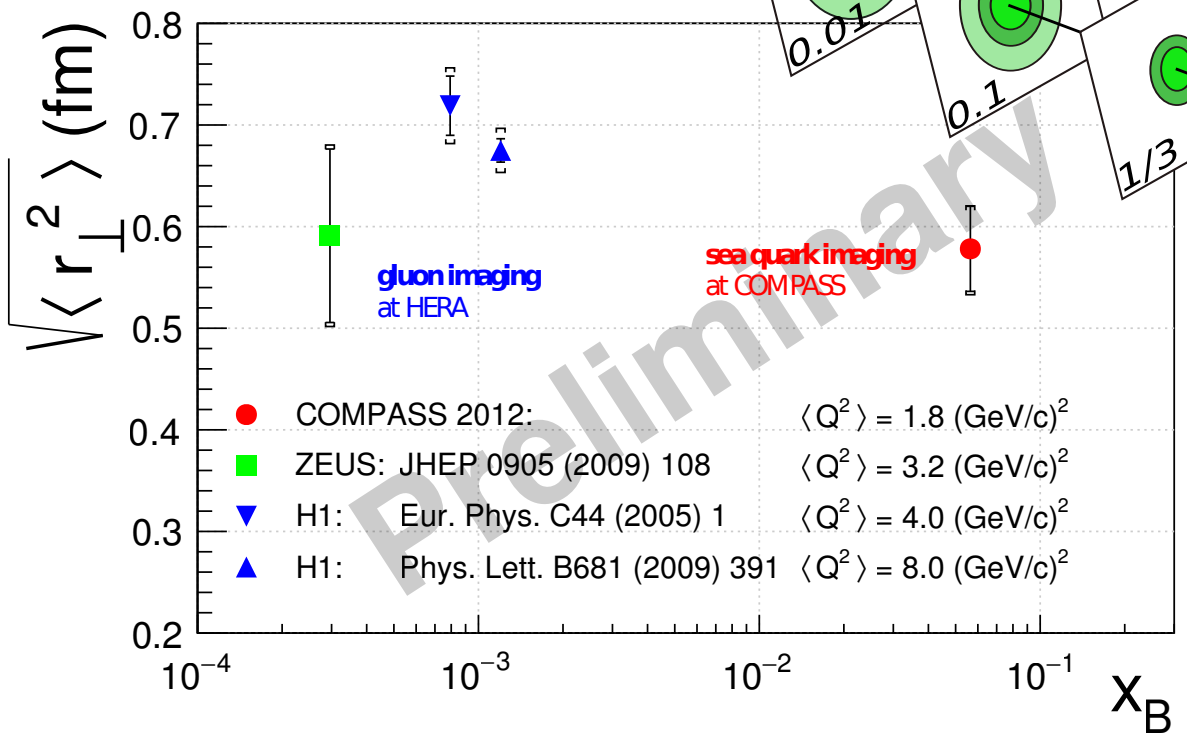




November 2016:
long run part 1 finished

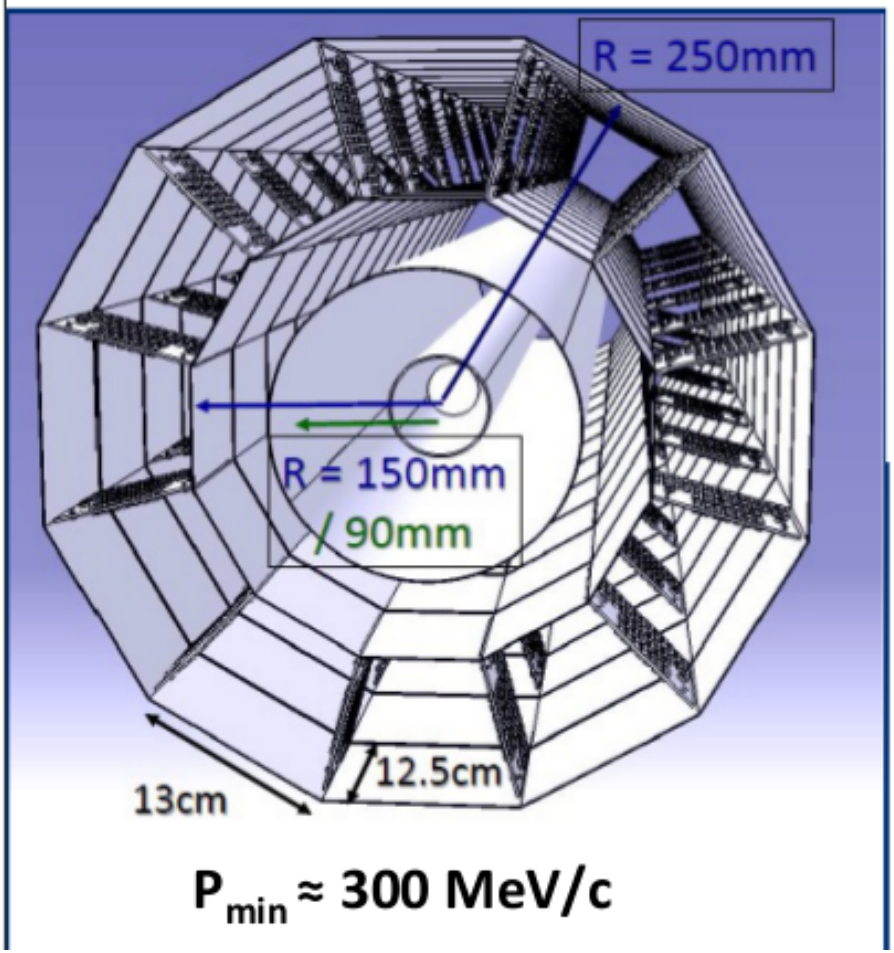
2017: continuation of unpolarised GPD program



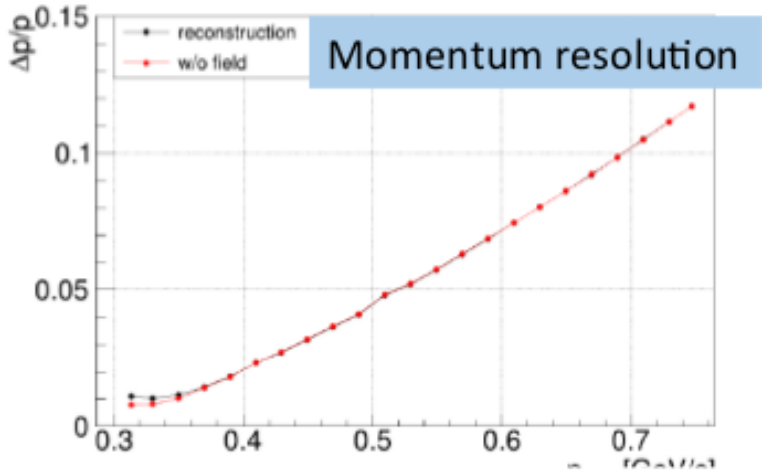


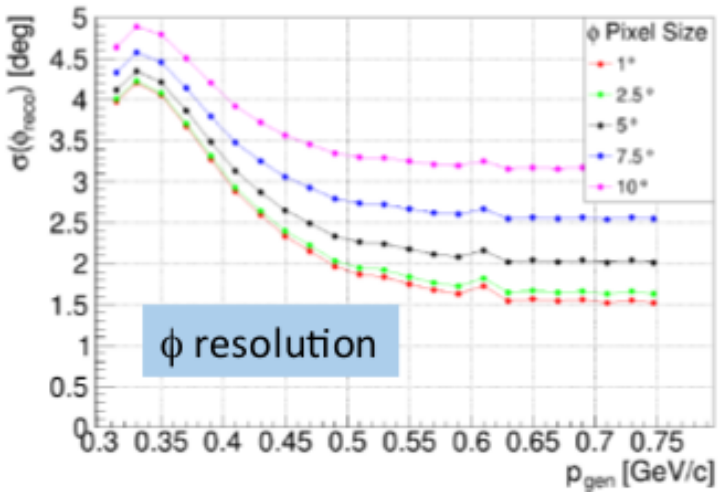
Two or three layers of **Si detectors** inside COMPASS **polarized target**

Working group from Dubna, Munich, Illinois, Freiburg...



$P_{min} \approx 300$ MeV/c





Beyond 2020: Transversity

- Only existing deuteron/neutron data sets:
  - COMPASS (^{6}LiD) and CLAS (^{3}He)
- COMPASS data only from 2002–2004
- Data set factor 4 smaller than proton set
- Need equal statistics for optimal flavour separation:

Transversity distributons

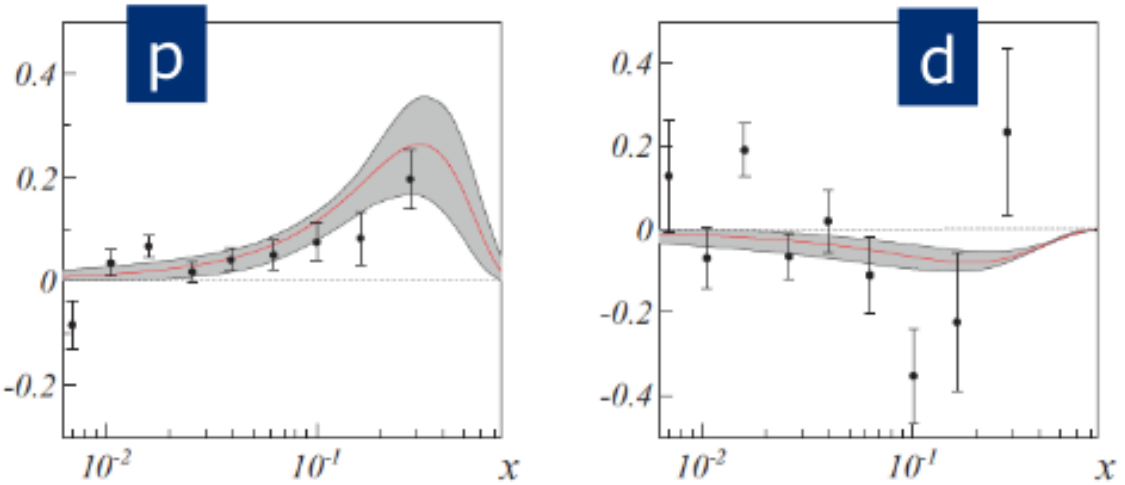
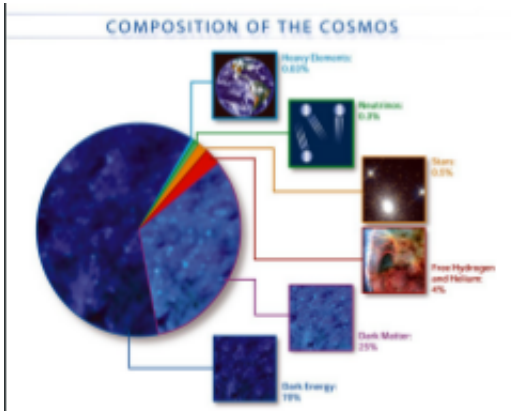


Fig. 6: $xh_1^u(x)$ (left) and $xh_1^d(x)$ (right) from the 'two hadron' asymmetries of 2010 proton and of 2002-2004 deuteron data (from[30]). The curves show the transversity PDFs obtained from a fit of Collins asymmetries [29]

Astrophysics: search for dark matter

a possible contribution from COMPASS

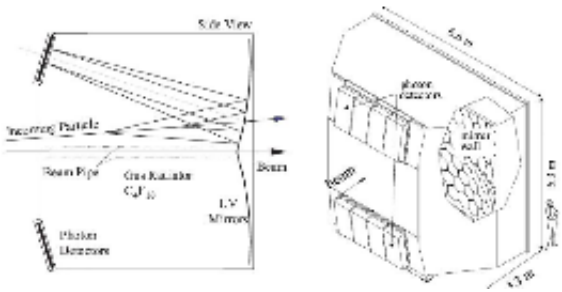


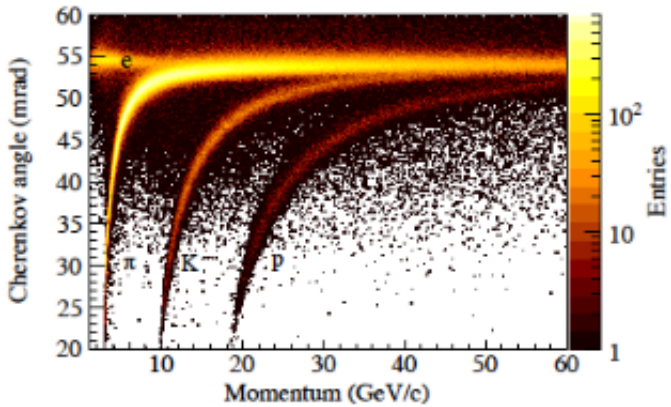
- New AMS(2) data – the antiparticle flux is well known now (few % pres.);
- Two types of processes contribute – SM interactions (proton on the ISM with the production for example antiprotons in the FS.) and contribution from dark matter annihilation;
- In order to detect a possible excess in the antiparticle flux a good knowledge of inclusive cross sections of p-He interaction with antiparticles in the FS is a must, currently the typical precision is of 30-50%.

Thus the primary goal is to measure **inclusive antiproton (positron, gamma) production cross section** in a wide kin.range with a precision <10%. **Compared to NA49 COMPASS has factor ~1000** in luminosity.

COMPASS advantages:

- Proton beam energy range 50-250 GeV
- Secondary particles identification:
  - Antiprotons (RICH)
  - Positrons and Gamma (ECals)



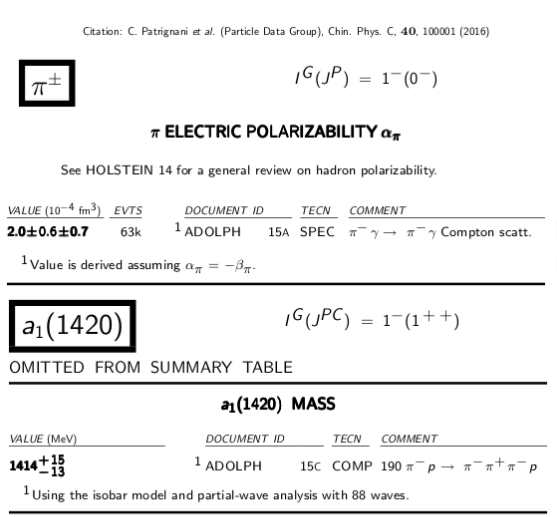


Conclusions & Outlook

COMPASS: diverse, exciting, long-range physics programme

Ongoing / completed program

- Inclusive and Semi-inclusive DIS
- Meson Spectroscopy
- Chiral Dynamics
- Polarised Drell-Yan
- Generalized Parton Distributions



Citation: C. Patrignani *et al.* (Particle Data Group), Chin. Phys. C, **40**, 100001 (2016)

$\pi^{\pm}$ $I^G(J^P) = 1^-(0^-)$

π ELECTRIC POLARIZABILITY α_π

See HOLSTEIN 14 for a general review on hadron polarizability.

VALUE (10^{-4} fm^3)	EVTS	DOCUMENT ID		TECN	COMMENT
2.0±0.6±0.7	63k	[1] ADOLPH	15A	SPEC	$\pi^-\gamma \to \pi^-\gamma$ Compton scatt.

[1] Value is derived assuming $\alpha_\pi = -\beta_\pi$.

$a_1(1420)$ $I^G(J^{PC}) = 1^-(1^{++})$

OMITTED FROM SUMMARY TABLE

$a_1(1420)$ MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
1414^{+15}_{-13}	[1] ADOLPH	15C	COMP	190 $\pi^- p \to \pi^-\pi^+\pi^- p$

[1] Using the isobar model and partial-wave analysis with 88 waves.

some of the new COMPASS entries
in the RPP2016 edition

Future vision

- Many open questions and important measurements remain on hadron structure and spectroscopy
- The COMPASS spectrometer is a unique facility and well adapted to the proposed measurements
- Upgrades in various places inevitable for a 7–8 years programme $>$2020
- An extended collaboration has to be built on the COMPASS nucleus
  - RF-separated kaon and antiproton beams would open a new chapter in structure and spectroscopy studies

Thank you for your attention!

Backup