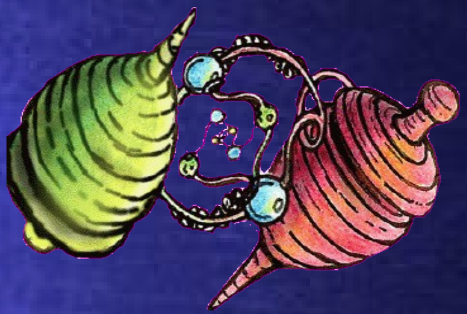
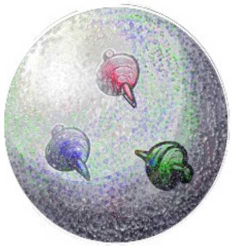
Hard Quasi-real photo-production at Compass Energies

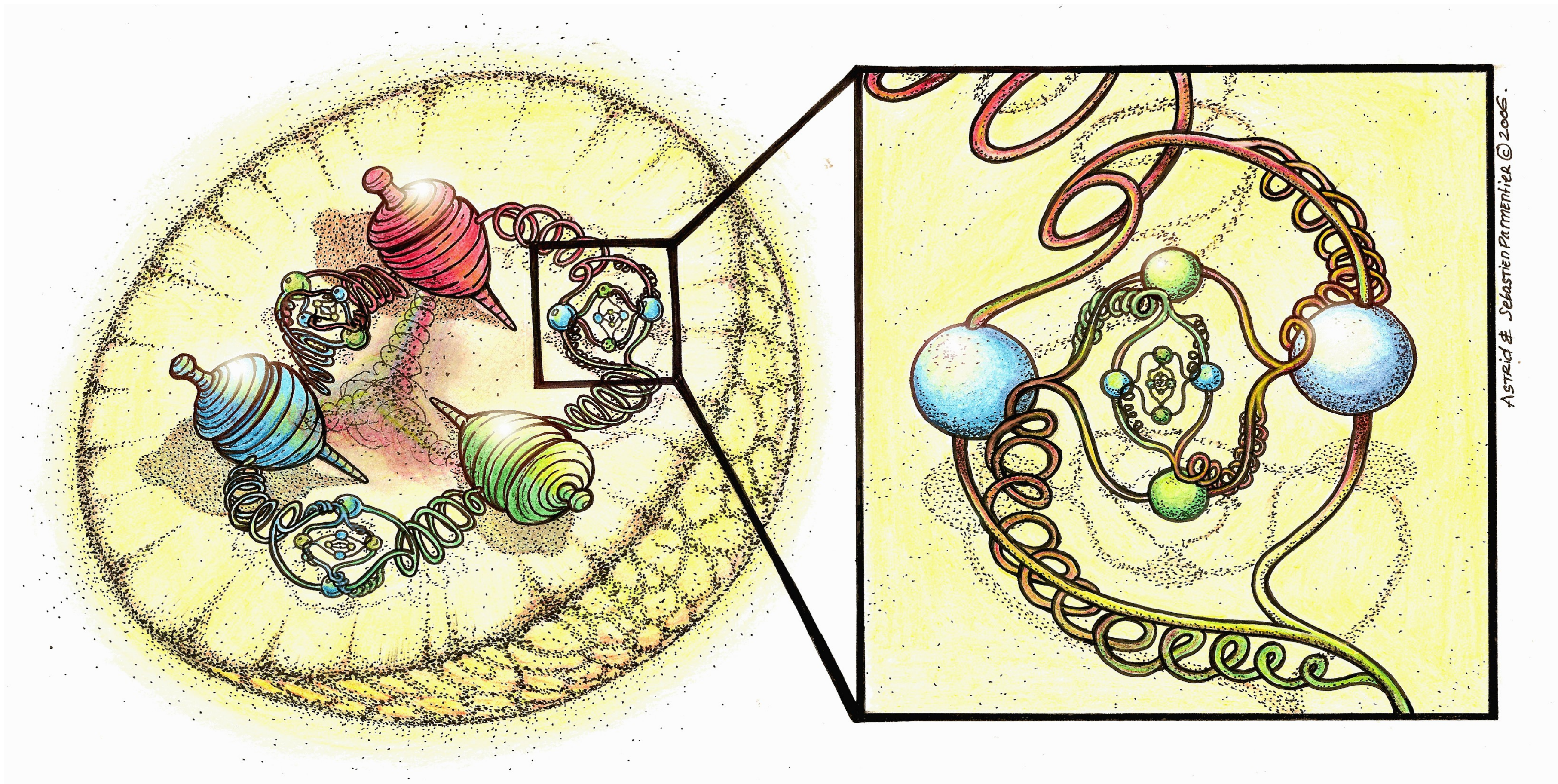


Spin 2010. Jülich, Germany

Astrid Morreale for the Compass Collaboration
French Atomic and Alternative Energies Commission -IRFU
and The American National Science Foundation.



The QCD Proton Picture



Nucleon Spin is Subtle: Quarks, gluons and their angular momentum caused by their high speed motion within the nucleon are contributors to the Nucleon's spin.

What else carries the proton spin

Longitudinal Spin Sum Rule:

$$\frac{1}{2} = S_z = \frac{1}{2}\Sigma\Delta q_i + \Delta G + L_z$$

W-production (pp)

Double Spin Asymmetries (pp,SIDIS, **Inclusive DIS)**

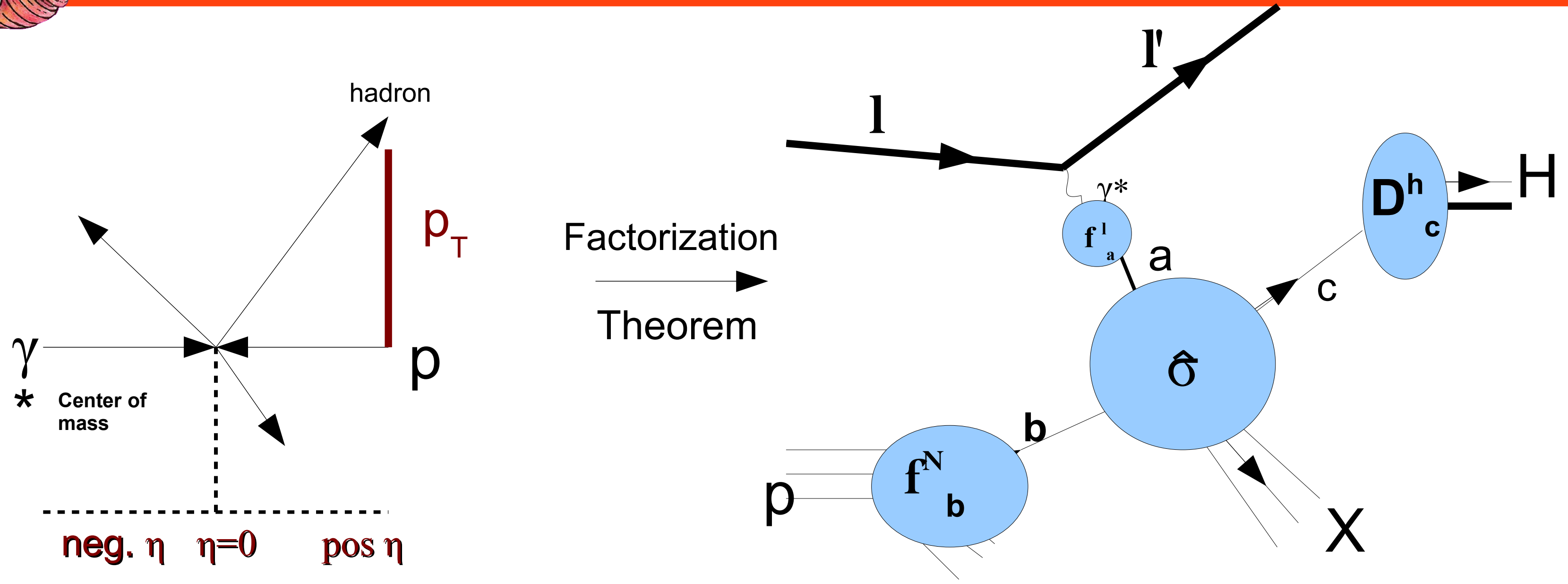
Exclusive processes (DVCS)

- ΔG , $\Delta \mathbf{q}_i$=are difference in the probabilities of finding a gluon/quark/antiquark with spin parallel and spin anti parallel to the spin of a longitudinally polarized nucleon.

- L_z :orbital angular momenta of the quarks and gluons

Also a transverse spin sum rule, beyond the scope of this talk..

Factorization Theorem

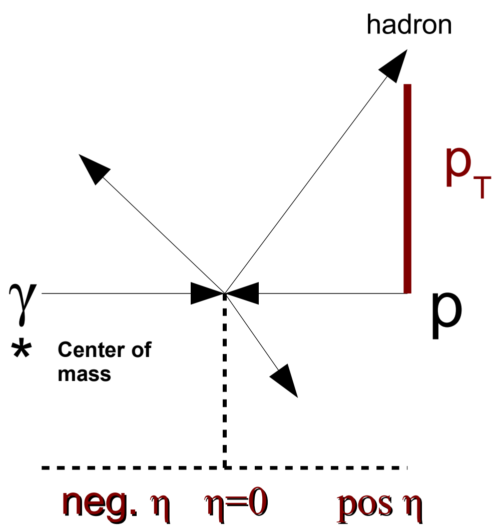


η_{cm}=-log(tan(θ/2))-0.5*log(2P_{beam}/M_p)

$$d\Delta\sigma \equiv \frac{1}{2}\left[d\sigma_{++} - d\sigma_{+-}\right]$$

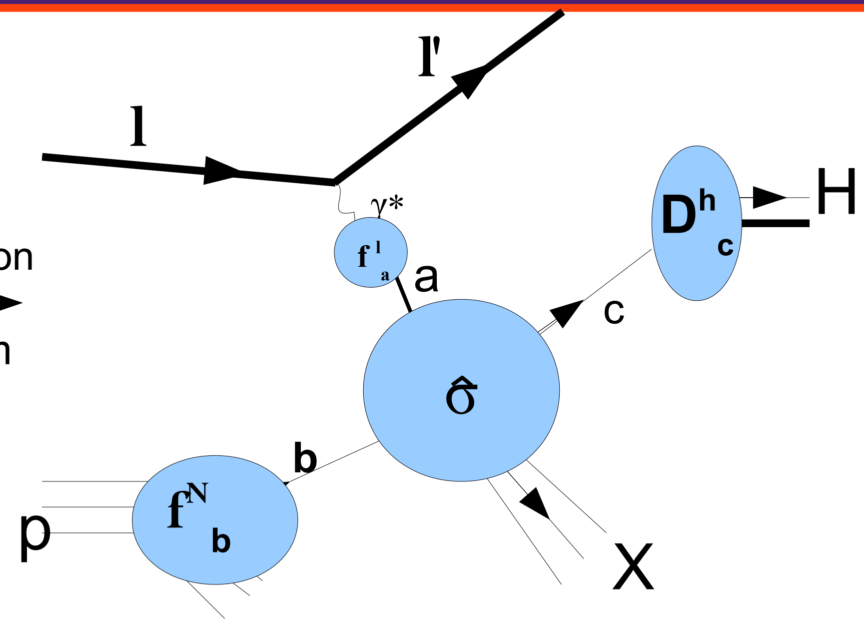
$$= \sum_{a,b,c} \int dx_a\, dx_b\, dz_c\, \Delta f_a^l \Delta f_b^N \times d\Delta\hat{\sigma}_{ab\to cX}\, D_c^H$$

Factorization Theorem



Factorization

Theorem



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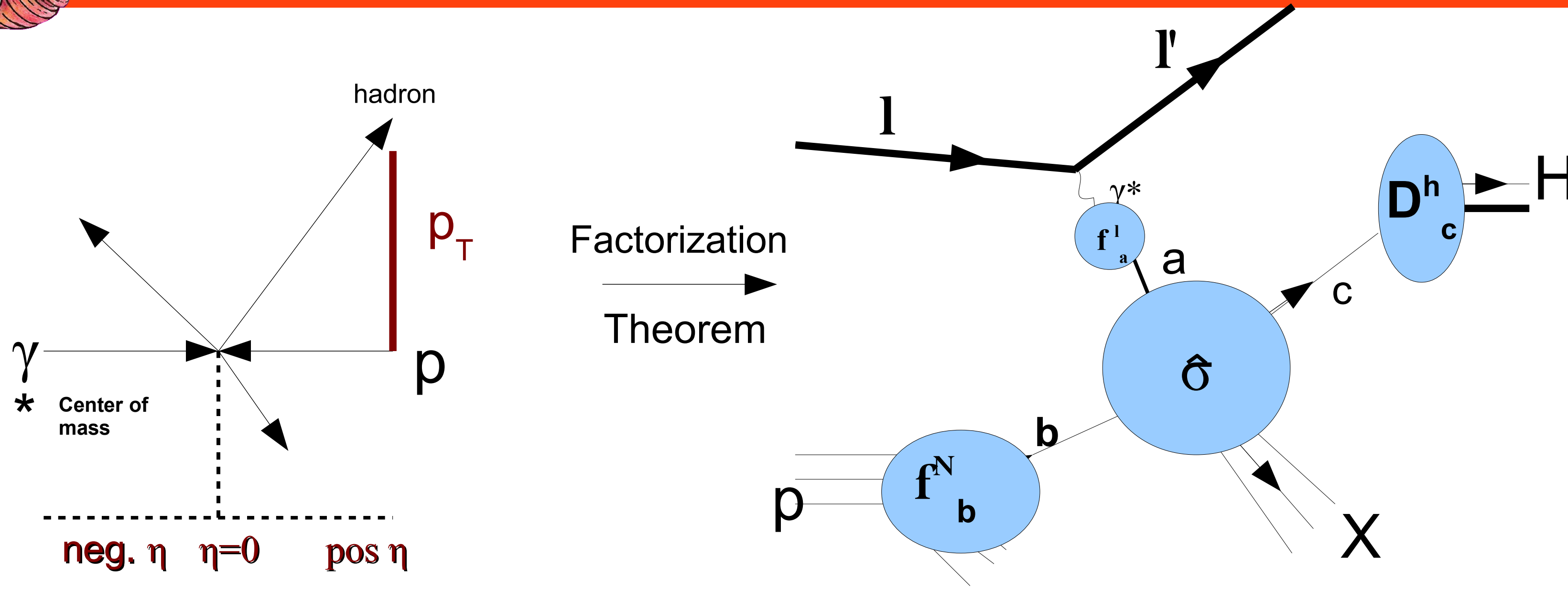
$$A_{LL} = \frac{\sigma_{++} - \sigma_{+-}}{\sigma_{++} + \sigma_{+-}} = \frac{\Delta\sigma}{\sigma}$$

Factorization Theorem

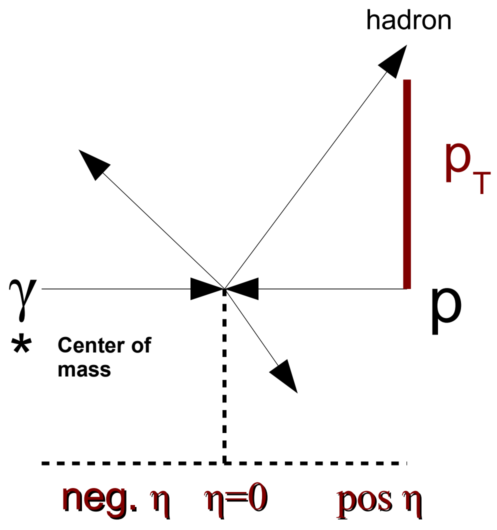


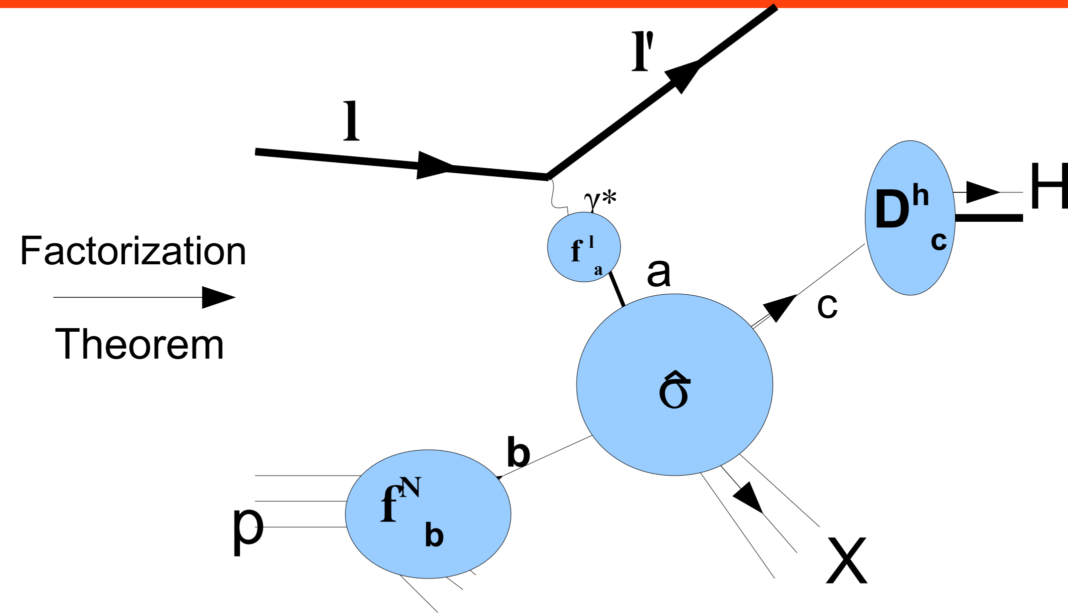
η_{cm}=-log(tan(θ/2))-0.5*log(2P_{beam}/M_p) $^{1}{}_{p})$

$$A_{LL}=\frac{\sigma_{++}-\sigma_{+-}}{\sigma_{++}+\sigma_{+-}}=\frac{\Delta\sigma}{\sigma} \longrightarrow A_{LL}=\frac{1}{\mathcal{F}P_{beam}P_{target}}\frac{N_{++}-N_{+-}}{N_{++}+N_{+-}}$$

(N_{ij}) Number of events with nucleon's spin parallel (++)
or anti-parallel(+-) to the lepton spin.
($\mathcal{F}$) Dilution Factor.
(P) Polarization in beam or target.

Factorization Theorem





η_{cm}=-log(tan(θ/2))-0.5*log($2P_{beam}/M_p$) [1]

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(N_{ij}) Number of events with nucleon's spin parallel (++)
or anti-parallel(+-) to the lepton spin.
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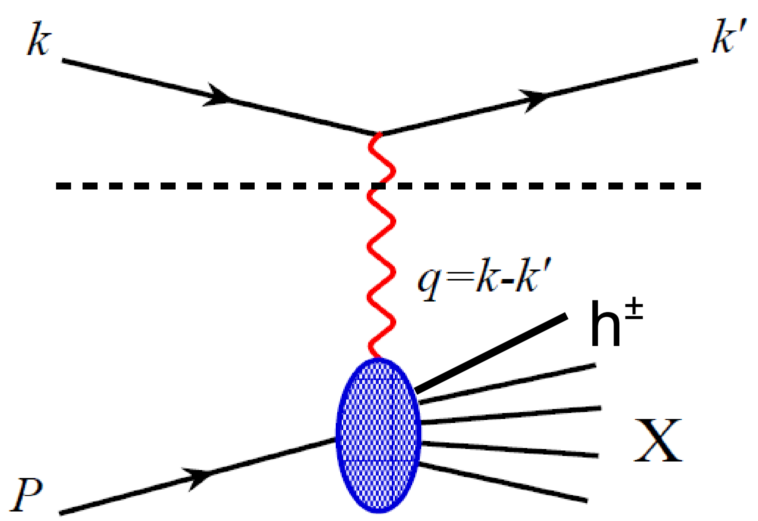
(P) Polarization in beam or target.

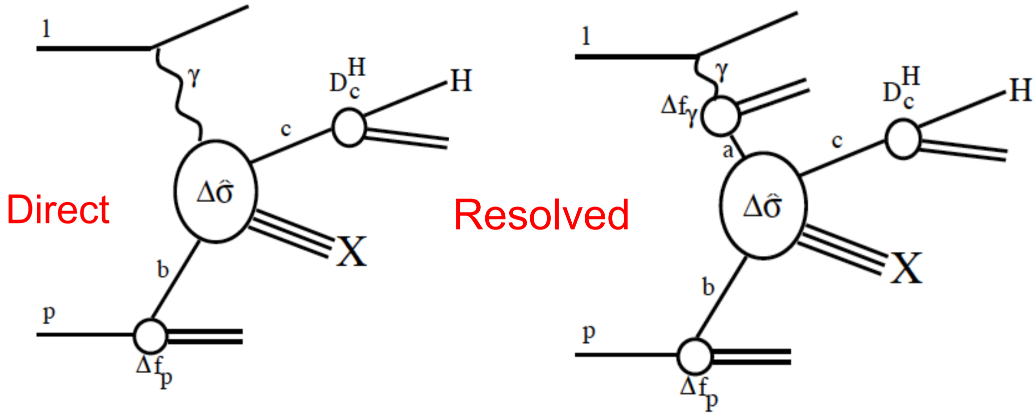
Asymmetries can give us access to polarized parton information.

Quick Reminder of Kinematical Variables

- $Q^2 = -(k-k')^2$ → Virtuality of γ
- $x = Q^2/2P\bullet q$ → Fraction of the nucleon's momentum carried by the parton(LO)
  For an elastic collision x=1
- $\nu = P\bullet q/M$ → Energy lost by the μ
- $y = \nu/E$ → Energy transfer from μ to γ (inelasticity.)
- $z = E_{hadron}/\nu$ → Relative energy of produced hadron
- $W^2 = (P+q)^2$ → Invariant mass of the hadronic state



NLO pQCD: Quasi Real Photo-production of high p_T hadrons

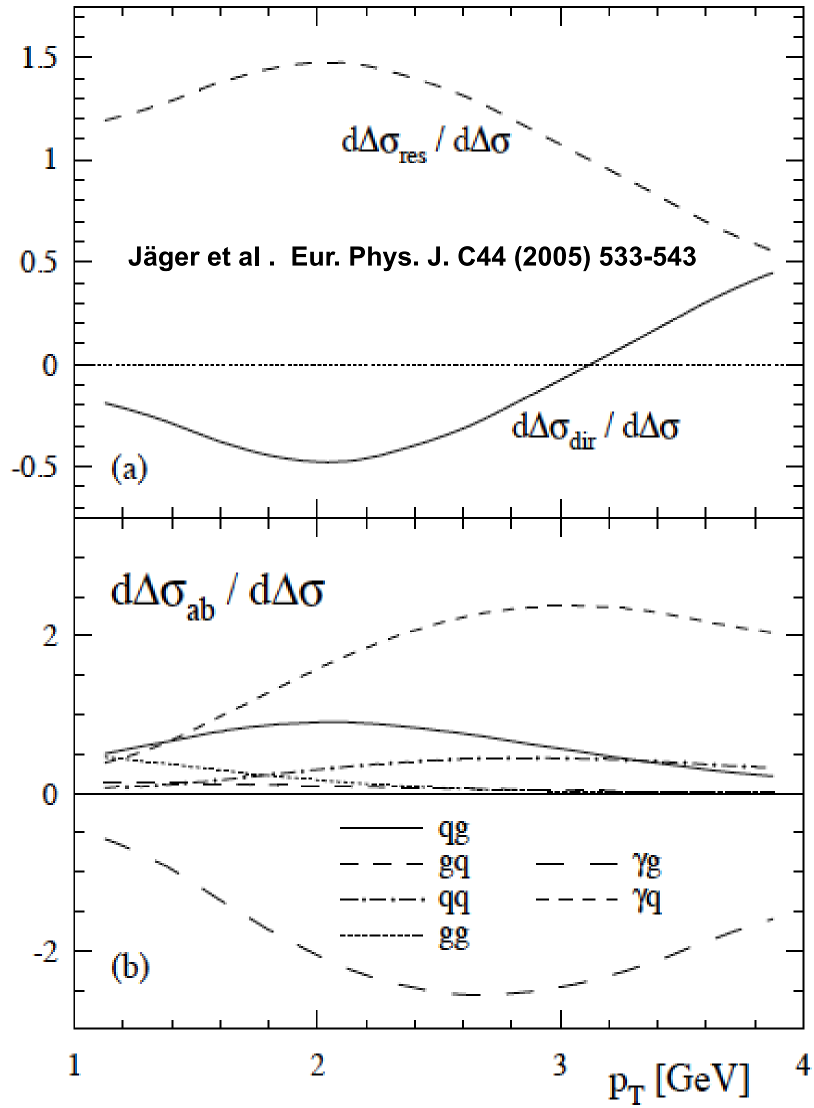


→ Low Q^2 (<0.1GeV/c) and high p_T.

→ NLO Calculation exists for Compass Kinematics.

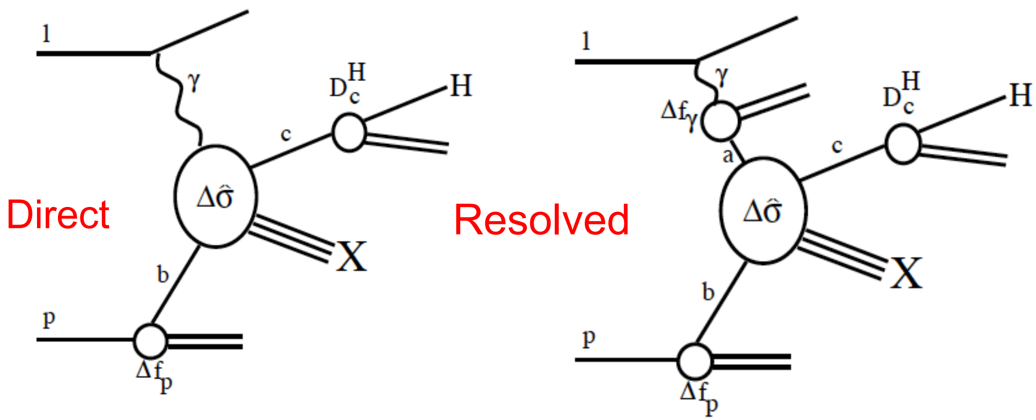
→ This process has an advantage of higher production rates of hadrons than in (DIS) electro-production.

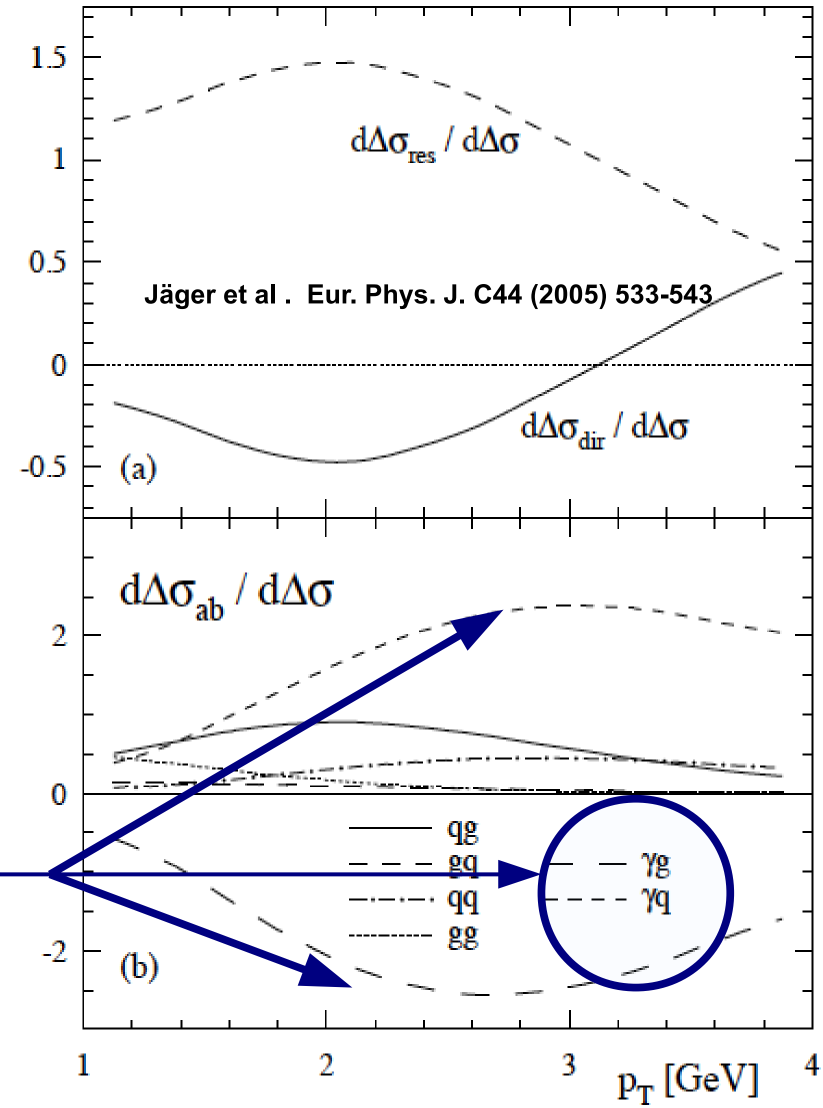
→ The selected hadron H is at high p_T(>1GeV/c) : large momentum transfer, p_T sets the scale



Partonic contributions to the production of high p_T hadrons at low Q^2 (<0.5GeV^2) in lepton nucleon scattering. c.m= 18 GeV

NLO pQCD: Quasi Real Photo-production of high p_T hadrons





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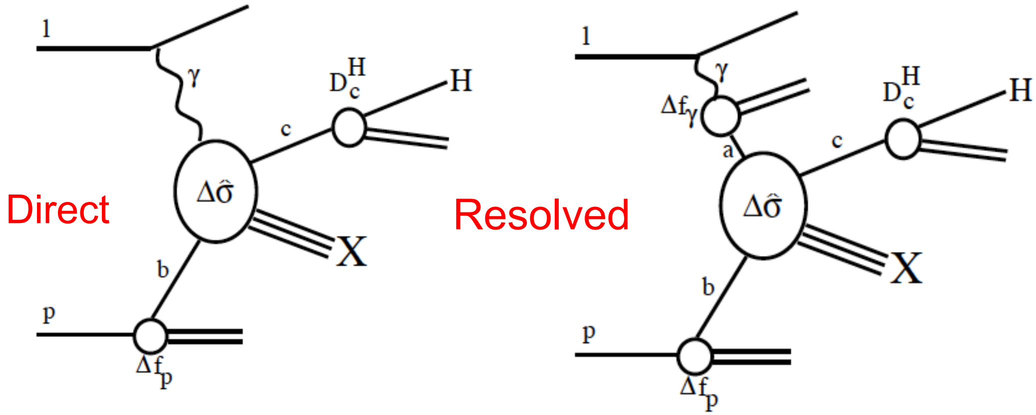

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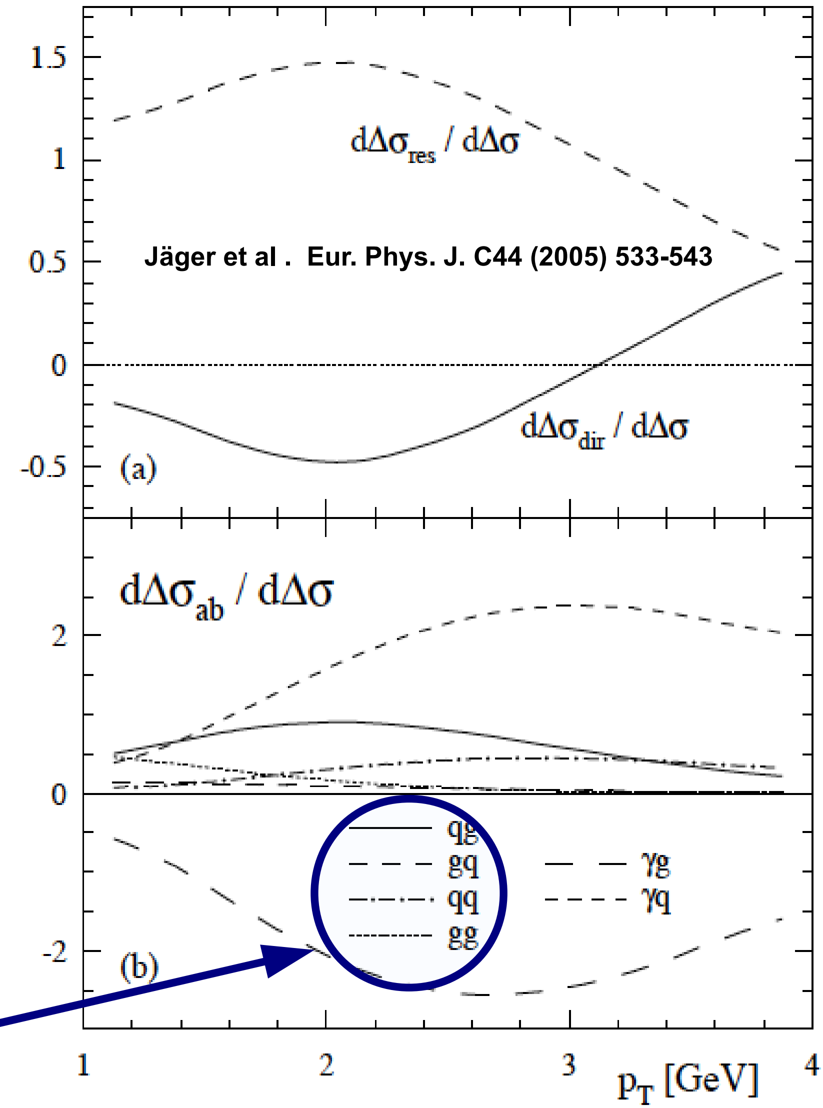
→ Direct Processes contribute with different sign (γg, γq)

→ **Resolved processes** contribute with the same sign for a positive ΔG (qg, gq, qq, gg)



Partonic contributions to the production of high p_T hadrons at low Q^2 (<0.5GeV^2) in lepton nucleon scattering. c.m= 18 GeV

The **Goals**

In a NLO pQCD framework , factorization is employed to separate long and short distance elements.

To test the framework on which asymmetry results are used to extract ΔG we will measure the unpolarized cross section.

→ This is the denominator to the definition of $A_{LL}(p_T)$

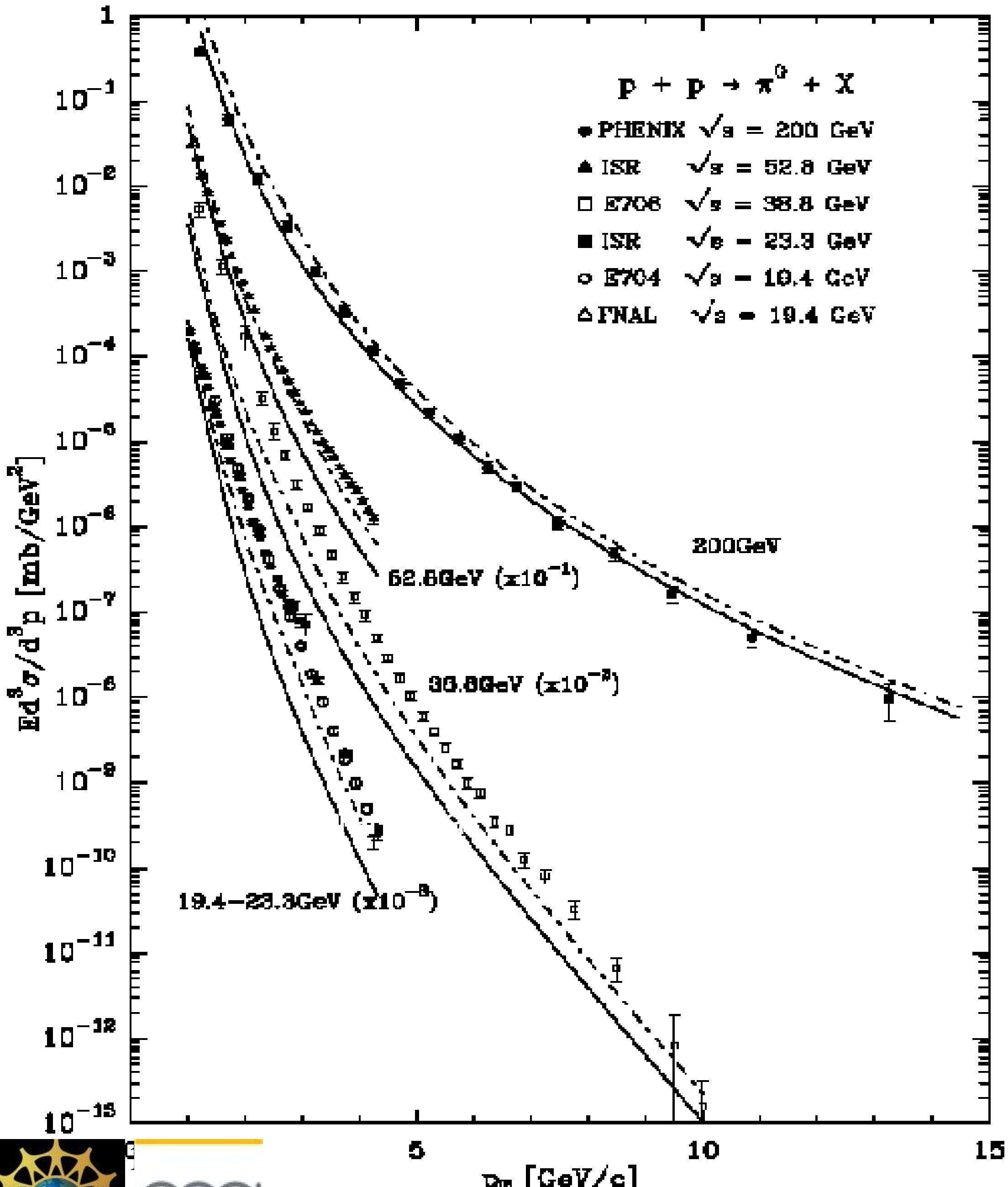
→ **A benchmark measurement**

1. Measure the unpolarized differential Cross Section to confirm that the pQCD framework is applicable to data.

2. Measure double spin asymmetries (A_{LL}) to to extract ΔG(x)

→ The pQCD unpolarized cross section

π^0 Cross-Sections compared to pQCD (p+p data)



π^0 Cross-Sections at y = 0 Experiment vs Theory

- √s=200 GeV (RHIC) Agreement
- √s=52.8 GeV (ISR) Agreement (scale dependent)
- √s=38.8 GeV (E706) Disagreement
- √s=19.4 GeV (FNAL/E704) Disagreement

Disagreement at lower center of mass energies Observed in p+p data

→Work needed to understand lower energies?

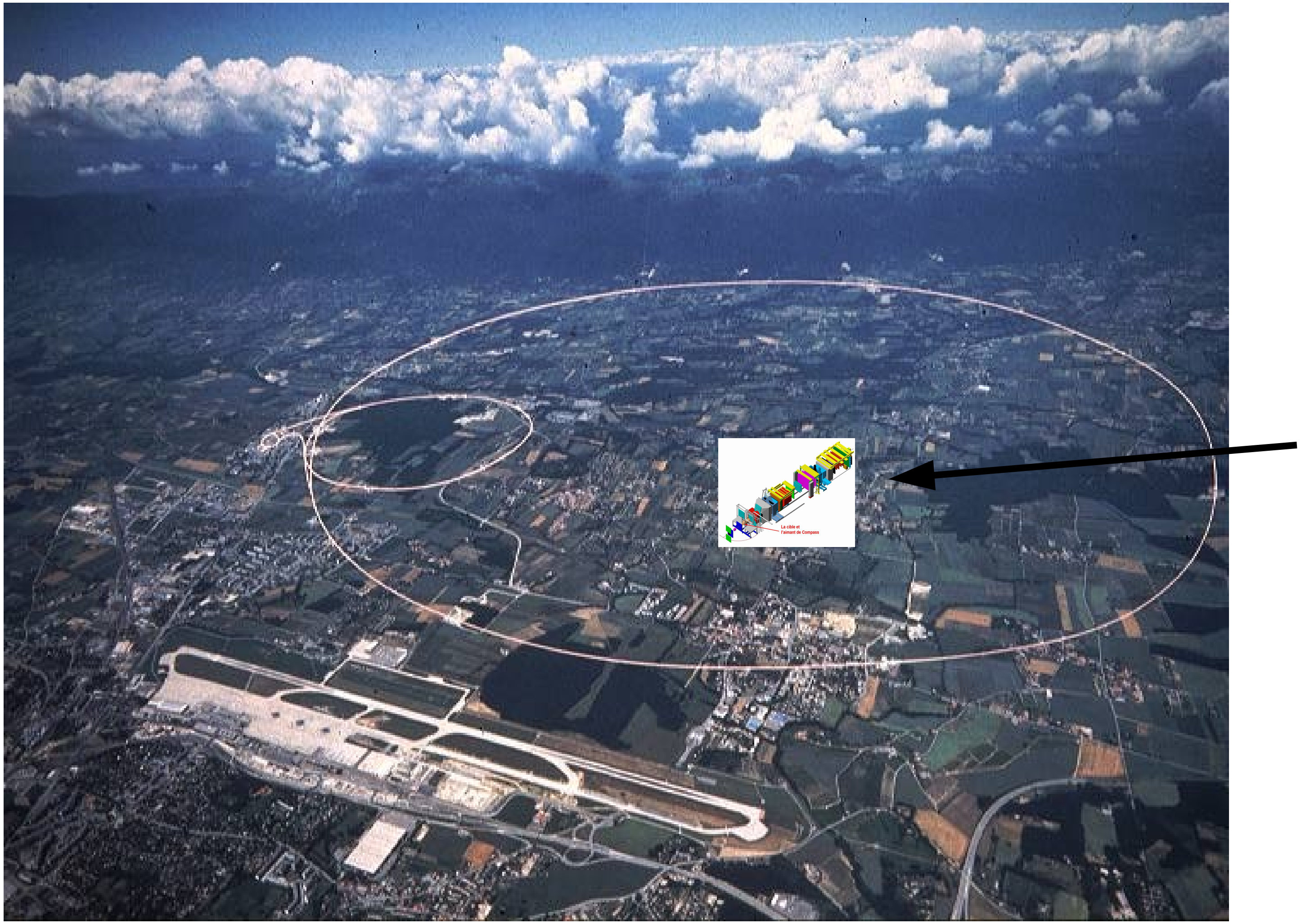
Bourrely et al, Eur.Phys.J.C36:371-374,2004

What about SIDIS: $\mu + d \rightarrow \mu' hX$?

The experiment:

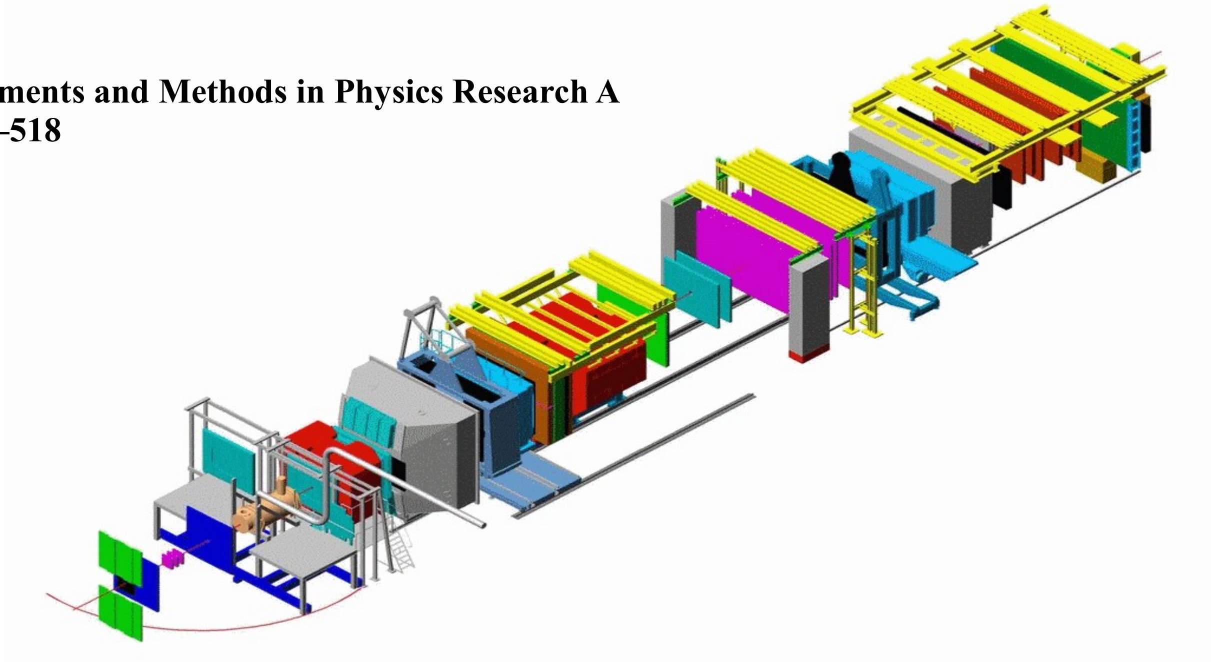
COMPASS @CERN (Prevessin):

COMMON APPARATUS FOR MUON SPECTROSCOPY:



Tertiary beam of positive muons produced in the M2 beamline at the CERN SPS.

The COMPASS detector at CERN's SPS



Nuclear Instruments and Methods in Physics Research A 577 (2007) 455–518

→ Spill cycle every 16.8 seconds (Flat top extraction 4.8 seconds)

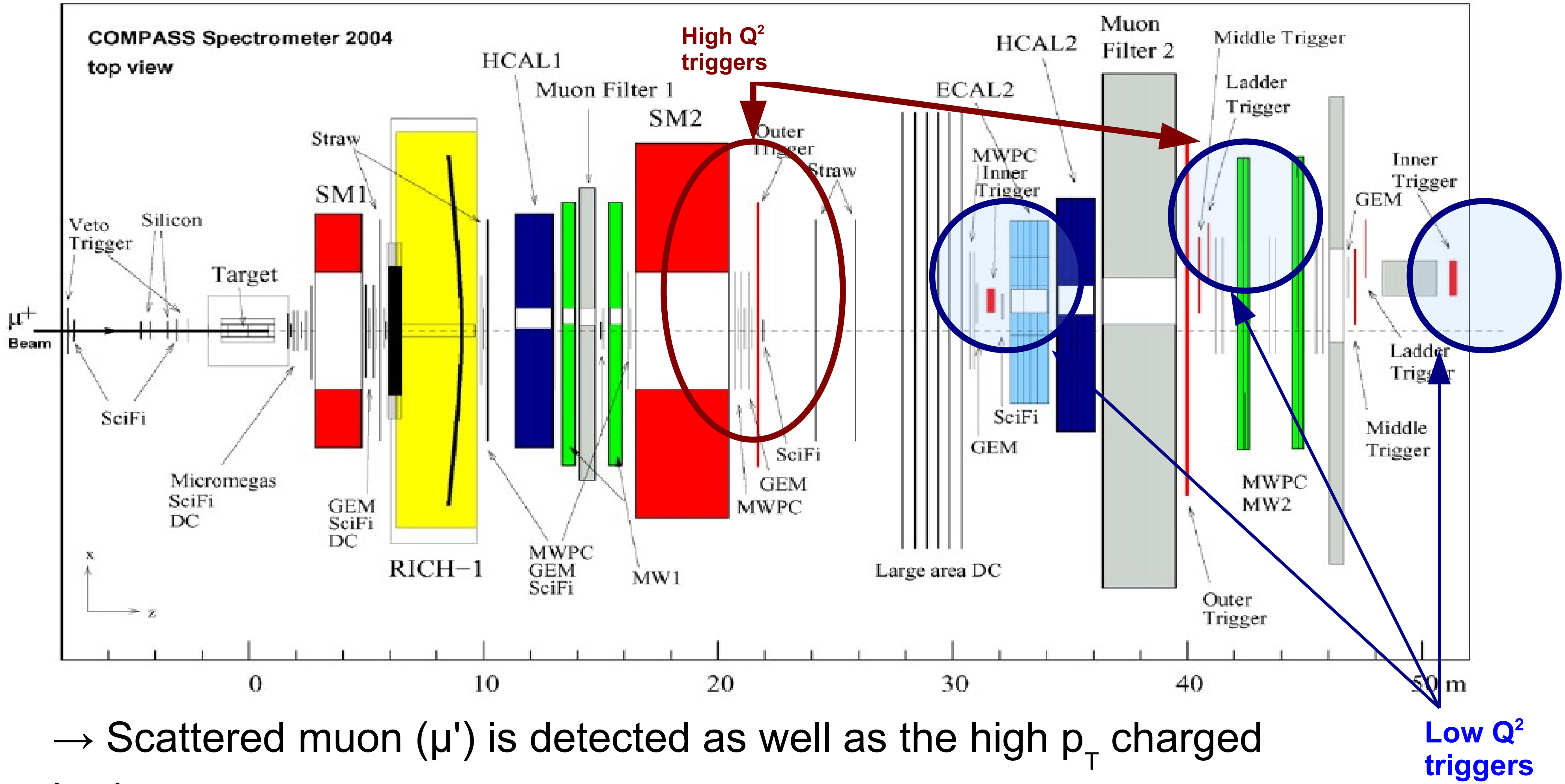
→ Polarized μ scattering off deuterons in a polarized 6 LiD solid-state target.

→ Beam energy is E_μ = 160 GeV → lepton-nucleon c.m.s. energy of $\sqrt{S} \simeq$ 18 GeV.

→ Average beam polarization: $P\mu \simeq$ 80%.

→ About $F_d \simeq$ 50% ("dilution factor") of the nucleon can be polarized, with an average polarization of $P_d \simeq$ 50%.

The versatility of the detector



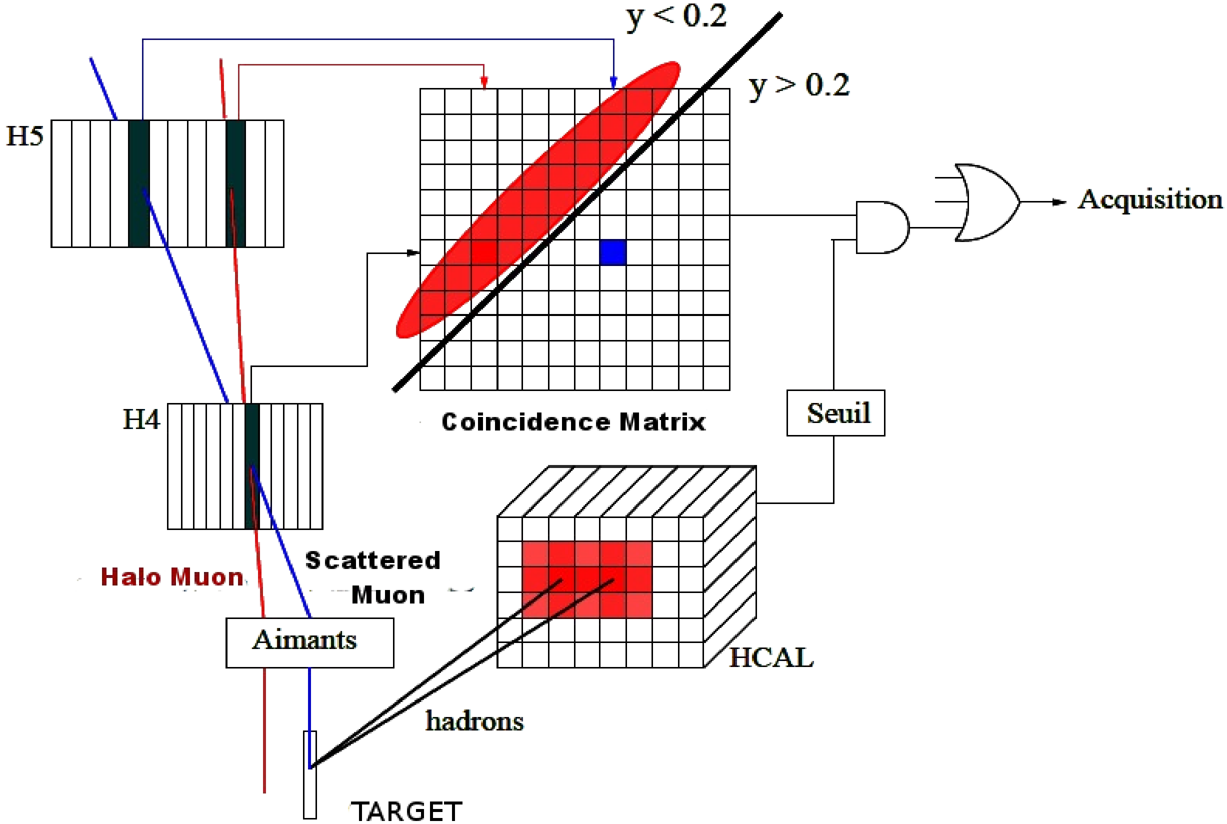
→ Scattered muon (μ') is detected as well as the high p_T charged hadrons

→ We have access to detailed information on the kinematics of the event:

Q^2, y, x_{bj}, z, W, p_T with respect to γ^* or hadron z axis

The high efficiency triggers give us access to different phase space regions (Q^2, y)

Detecting low Q^2 events

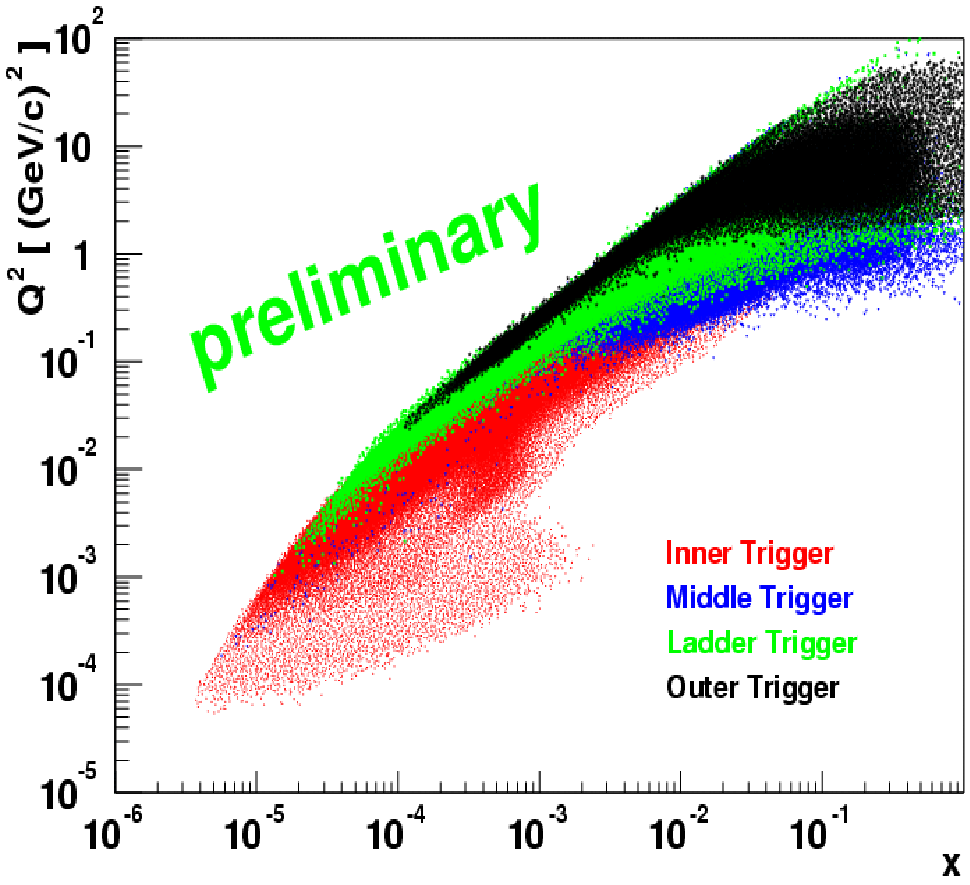


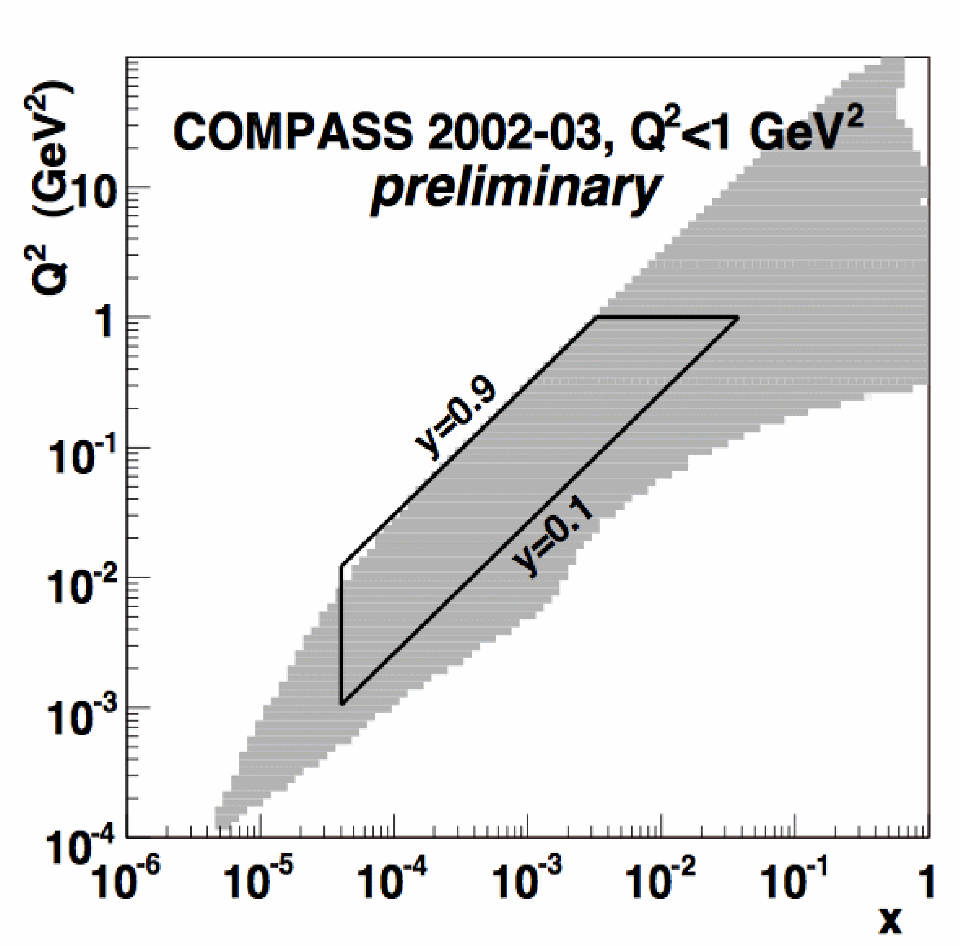
→ Kinematical regions of interest can be converted to angular region via the relation: **$Q^2=4EE'\sin^2\theta/2$**

→ At small Q^2 the μ' is very close to the beam, a series of hodoscopes, muon filters In combination with a hadronic energy deposition in the calorimeter are employed

→ Time of passage of the μ' (μ) is known with precision of better than 1ns.

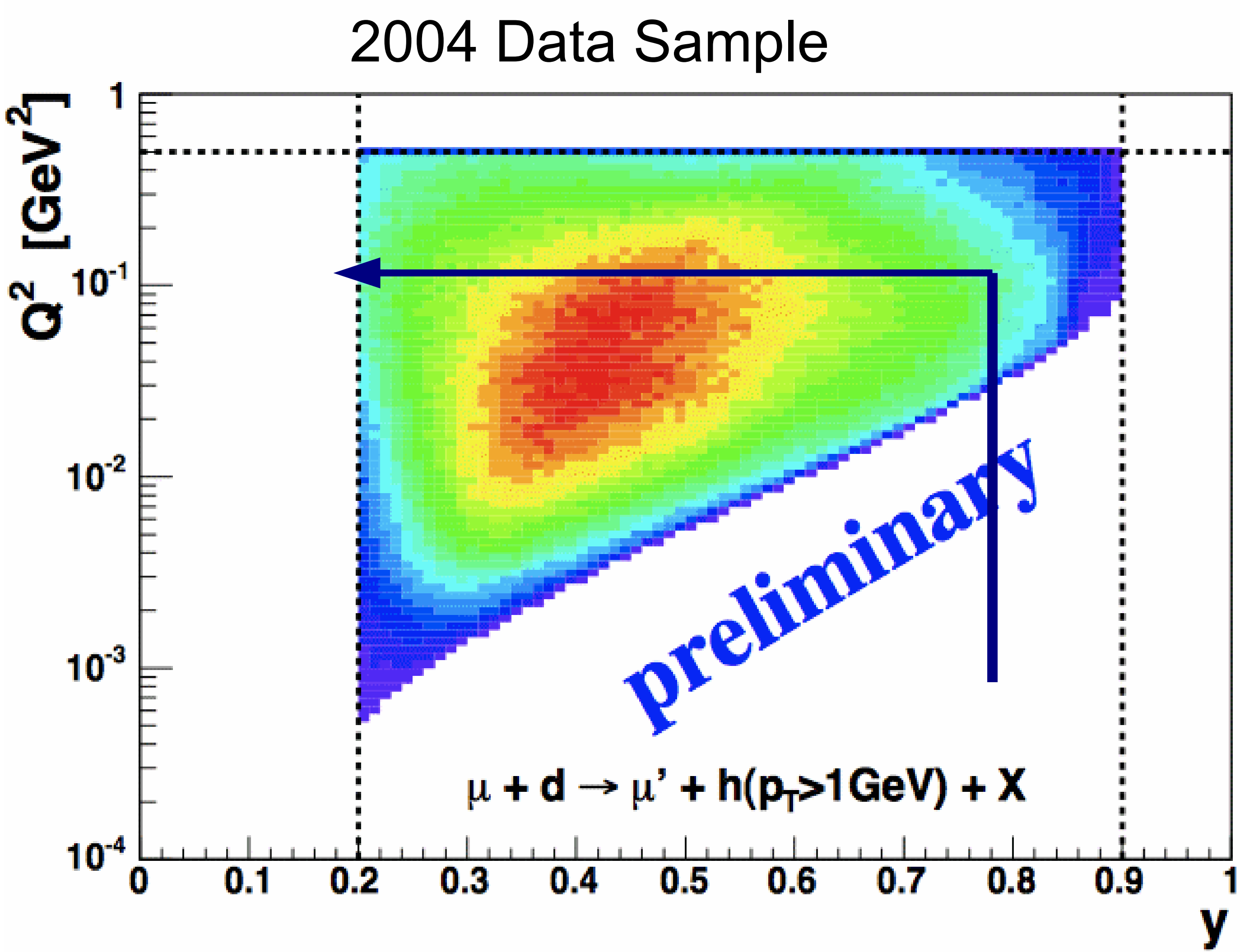
Compass' Triggers Kinematic Reach





→ We can reach these low Q^2 values using the High efficiency **ladder** and **Inner** Triggers

Compass Kinematic Reach



→ The detailed kinematical information on the event allows us to stay away from regions which could potentially contain events which are not of interest .

Measuring Cross sections: The Method

$$\frac{1}{2\pi\, p_T}\cdot\frac{d^2\sigma}{dp_T dy} \Rightarrow \frac{1}{L^*}\cdot\frac{1}{2\pi\, p_T}\cdot\frac{d^2N}{dp_T dy} \Rightarrow \frac{1}{2\pi p_T}\frac{N_{h^\pm}(p_T)}{\int L dt\, \epsilon_{Acc}\Delta p_T \Delta\eta}$$

L* – integrated luminosity, measured within the target volume.

→ **Measured within 10% accuracy.**

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→ **Sufficient statistics to reach p_T above 3GeV/c**

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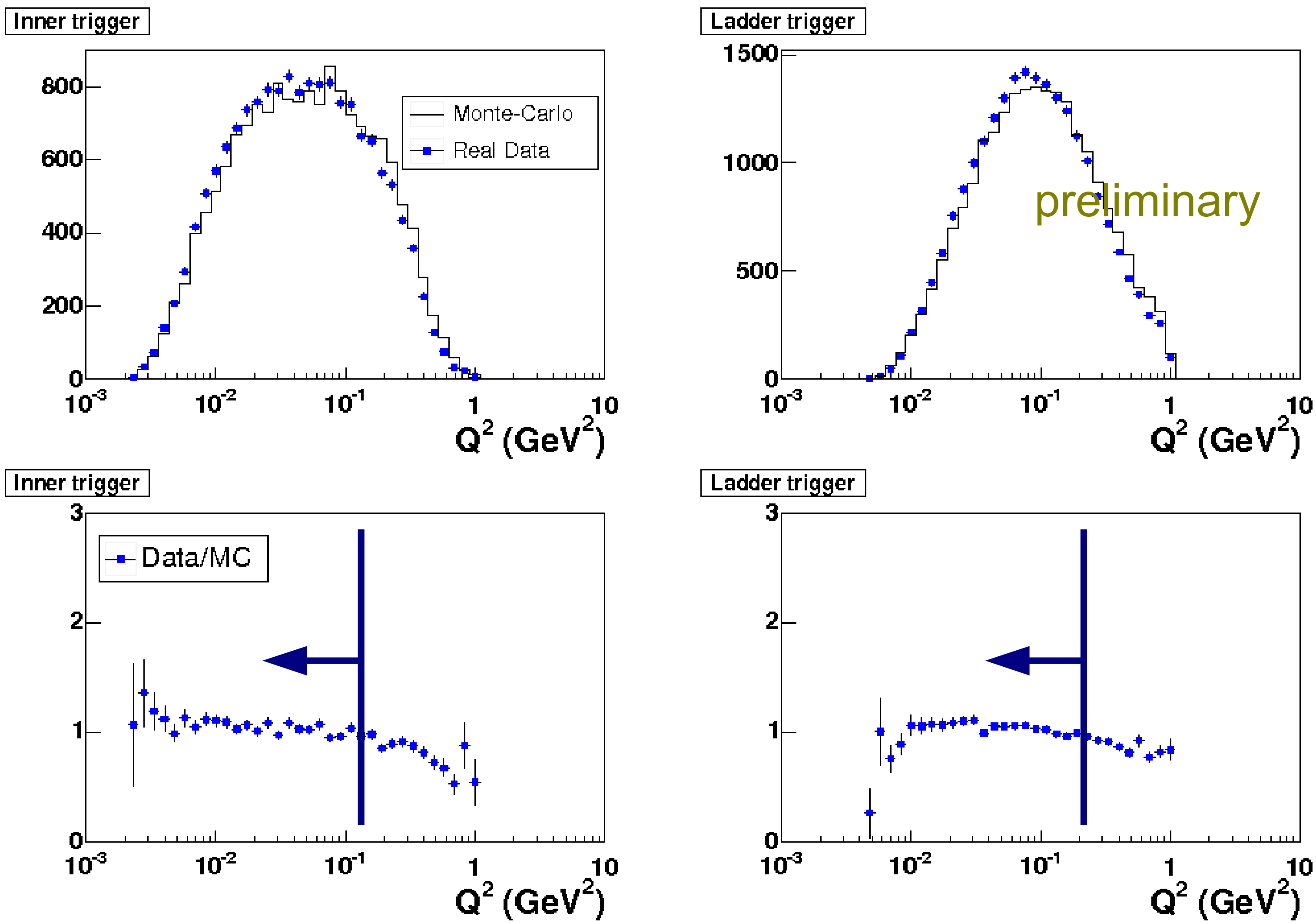
→ Sufficient statistics to reach p_T above 3GeV/c

ε_{Acc} -Detector's geometrical acceptance, reconstruction algorithm, detection inefficiencies.
→ **Extracted with a MC simulation.**

MC Description of Detector



We are not interested in PYTHIA's pQCD description but only in accurate Apparatus description (GEANT). → **Extraction of Acceptance corrections.**

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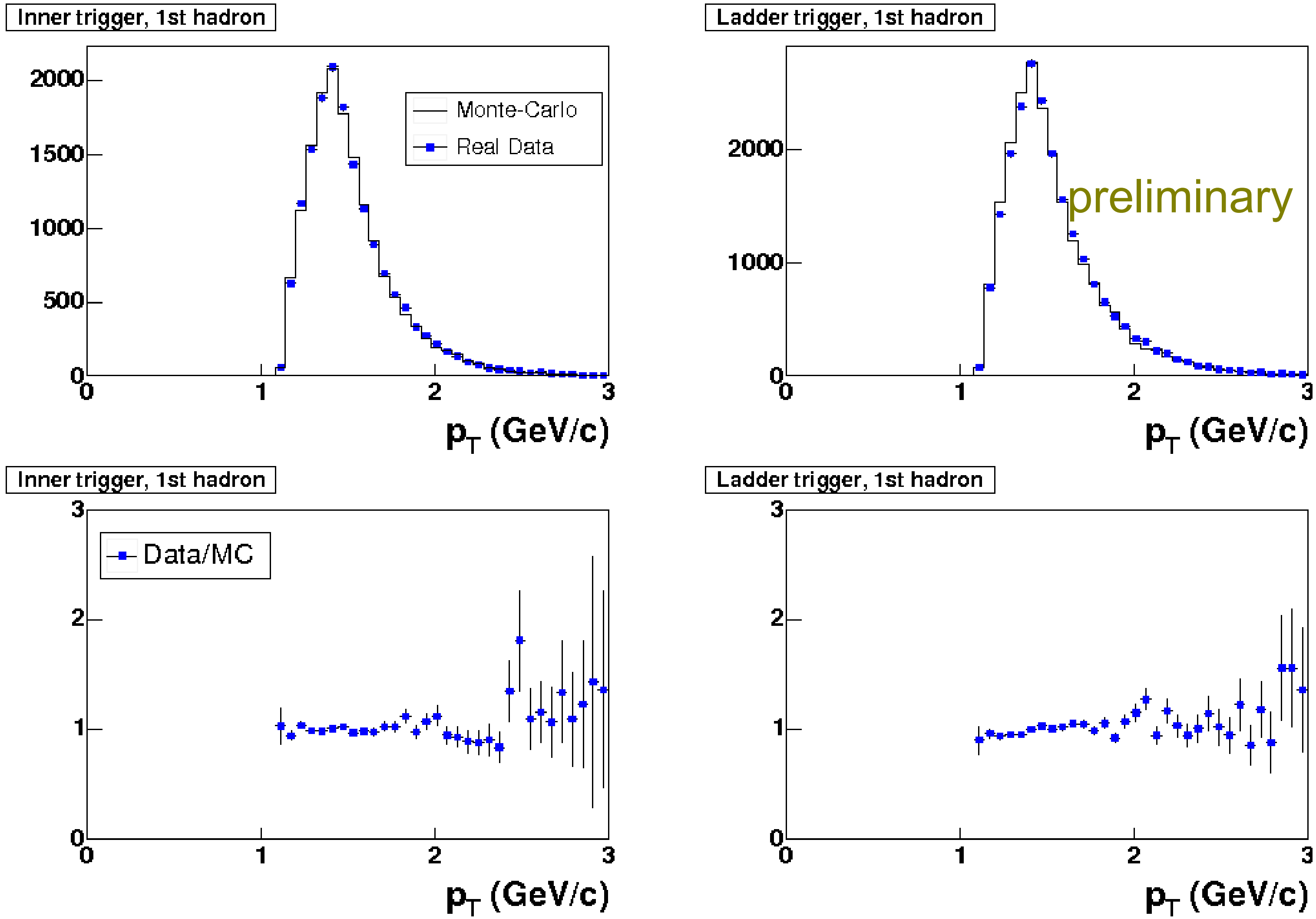


We are not interested in PYTHIA's pQCD description but only in accurate Apparatus description (GEANT). → **Extraction of Acceptance corrections.**

Full simulation with GEANT of the spectrometer performance is incorporated at COMPASS.

Luminosity

→ Luminosity is measured using the beam scalers spill by spill.

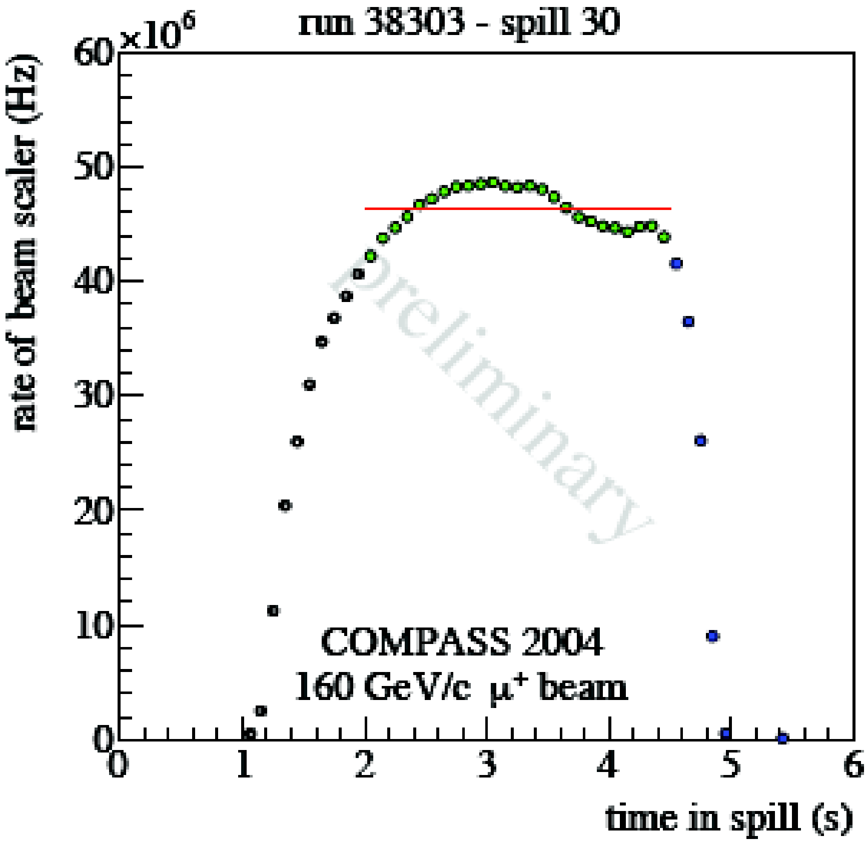
→ Each spill corresponds to the beam delivered by SPS.

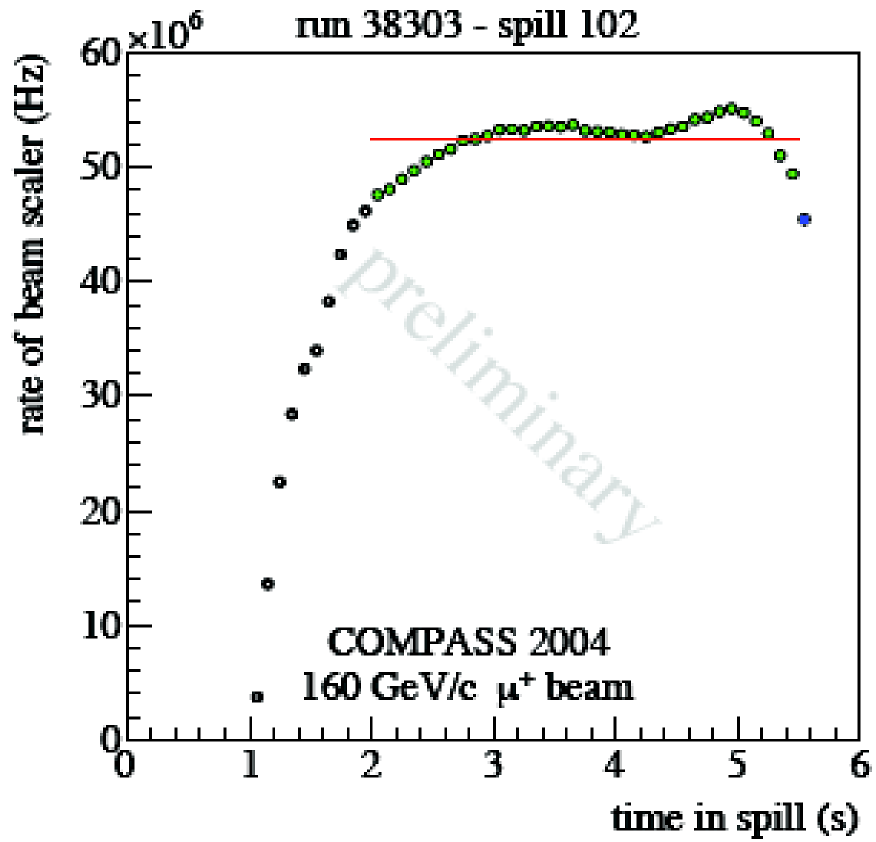
-Every 16.8 seconds (Flattop duration of 4.8 seconds).

→ Detector effects which affect the total beam rate are accounted for: Acquisition, veto (beam halo) deadtimes.

For the data sample of interest the luminosity has been determined within 10% accuracy.

Luminosity: Flattop selection

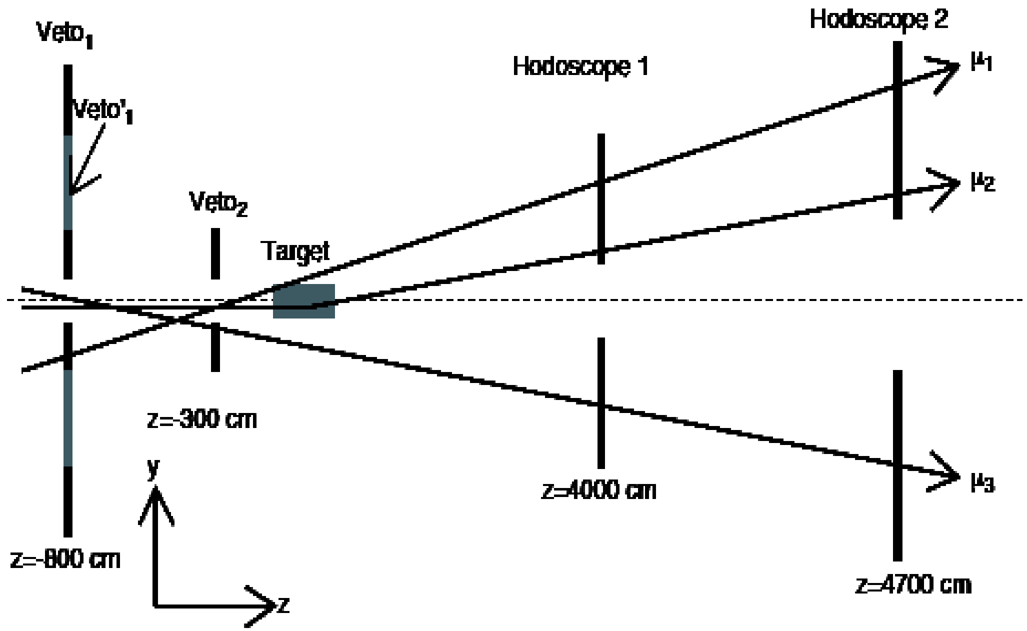




→ Evaluate the spill rates as seen by the beam scaler as a function of time.
→ Only events within the flattop are considered (red line)

COMPASS Veto System

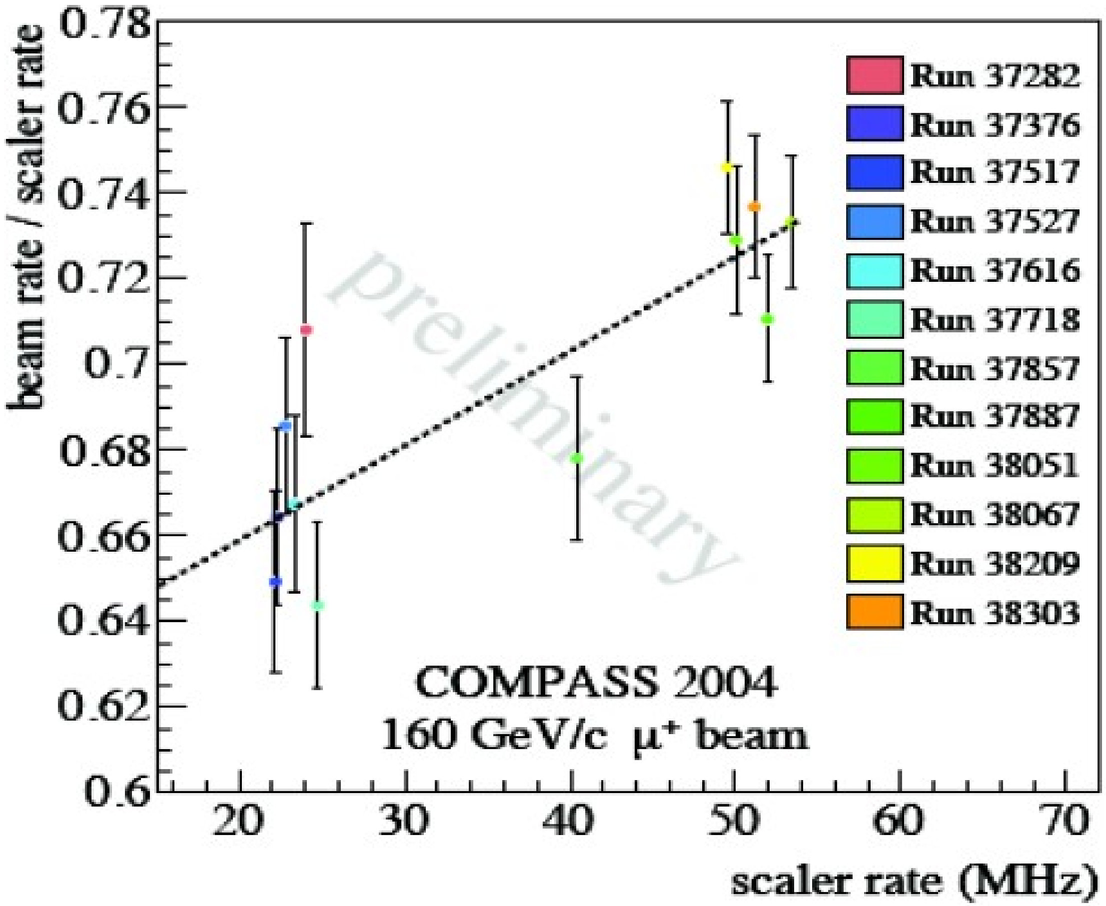
Bernet et al. NIMA 550(2005) 217-240.



The compass veto system prevents a large fraction of beam halo tracks from contaminating the trigger sample

During high veto signal times no triggers are taken (this includes good events)
→ **The "dead time" effect is taken into account in the Luminosity calculation**

Luminosity: Beam Rate



→ Ratio of the rates as measured with the random triggers and scalers is dependent on the beam intensity

→ The observed dispersion of the ratio as a consequence of the intensity dependence is accounted for in the systematic uncertainty (~5%)

Luminosity

→ Evaluation of stable data and spectrometer conditions.

This is particularly important for the Cross section normalization.

→ Integrated luminosity in the data set under interest is 142.4 pb^{-1}

→ Dominant errors (conservative) arise mainly from uncertainty in beam flux measurement and dead times. Total 10% uncertainty.

The NLO pQCD parametrizations

Eur. Phys. J. C 36, 371–374 (2004)

NLO Calculations by
B. Jaeger, M. Stratmann, V. Wogelsang

→ pi0 production prediction: difficult to compare at the time.

→ The updated calculations for charged hadron production at Compass' full kinematics have been performed by V. Wogelsang

→ Radiative contributions calculation, however small, has been calculated by A. Afanasiev.

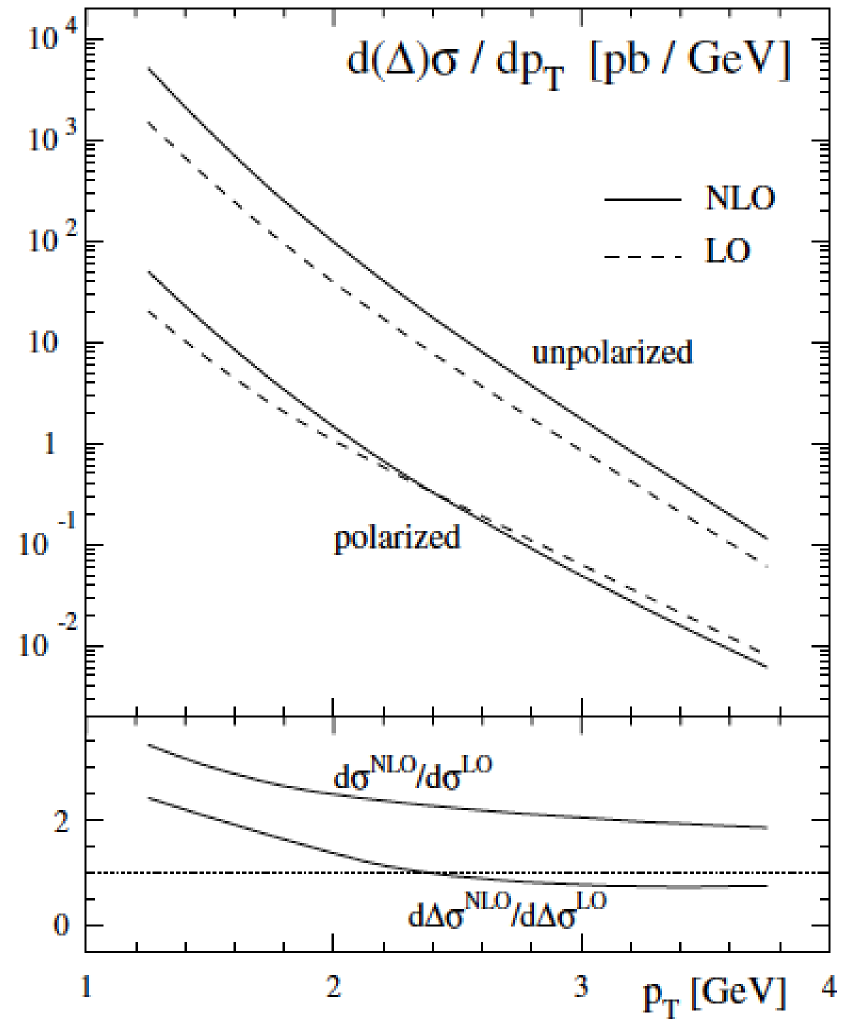
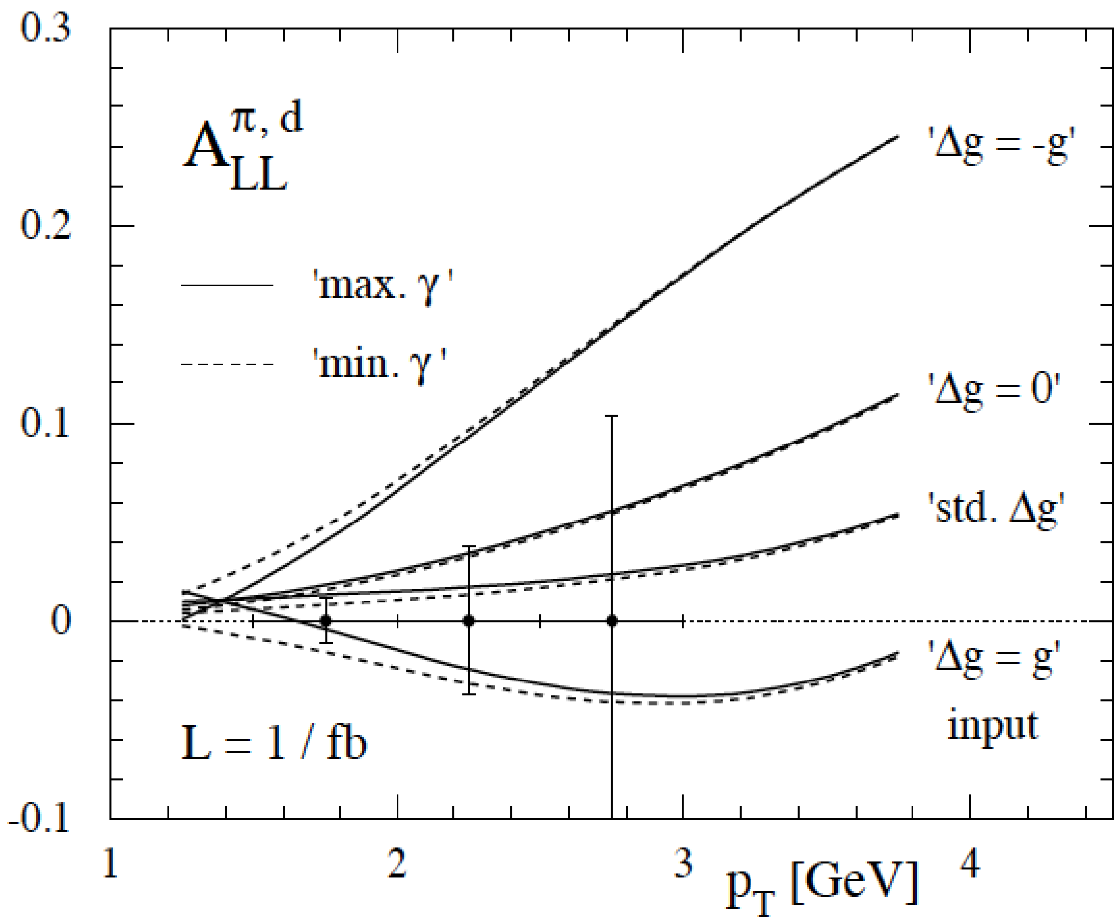


Fig. 2. Unpolarized and polarized p_T-differential single-inclusive cross sections at LO (dashed) and NLO (solid) for the photoproduction of neutral pions, $\mu d \to \mu' \pi^0 X$ at $\sqrt{S} = 18\,\text{GeV}$, integrated over the angular acceptance of Compass. The lower panel shows the ratios of NLO to LO contributions (K-factor)

The NLO pQCD parametrizations: Asymmetries

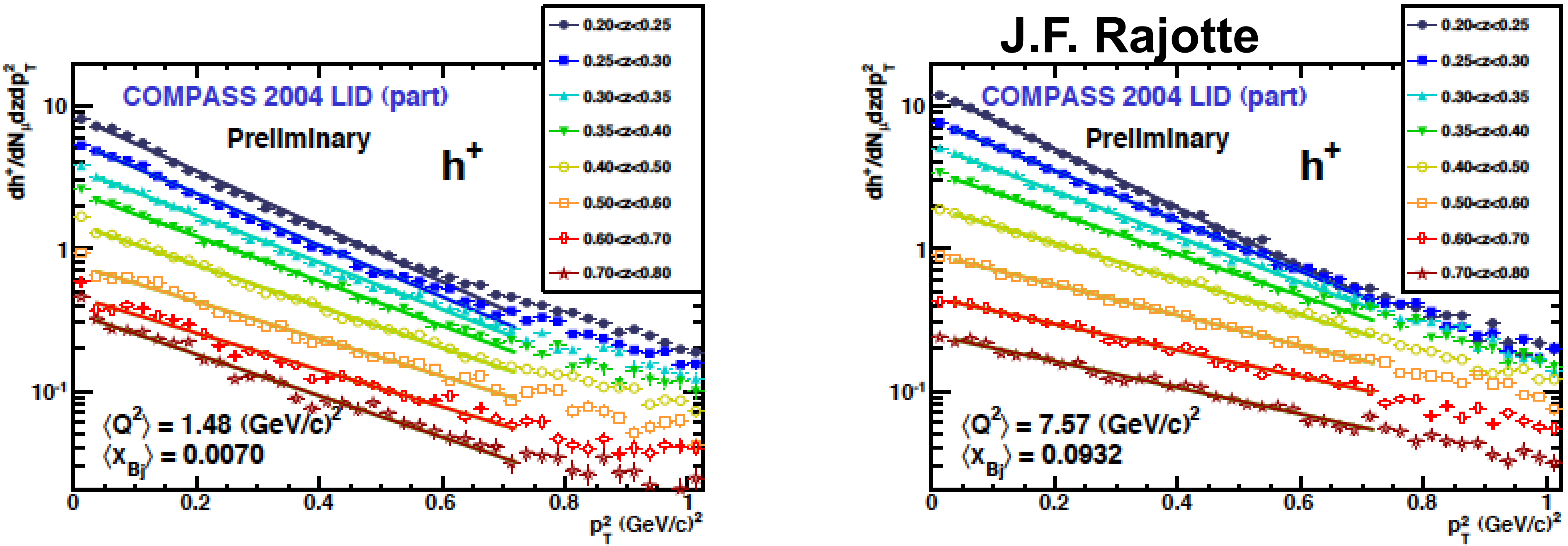


Max γ and min γ correspond to minimal and maximal saturation of the polarized photon densities.

B. Jäger et al. Eur. Phys J. C 36, 371-374 (2004)

→ Additional ongoing effort by A. Afanasiev to produce a parametrization that takes into account higher twist effects.
→ We expect to make available the comparisons between these Models with compass measurements soon.

Other Cross sections: Hadron production at high Q^2.



→ Low p_T^2 production and high Q^2.

→ Cross section is calculated in z bins.

→ The turn over description of hadron production from an exponential to a power like description can give insights about partonic behavior.

→ Would like to verify the pQCD description of hadron production rates at low Q^2 and high Q^2 (production rates are about an order of magnitude higher for low Q^2)

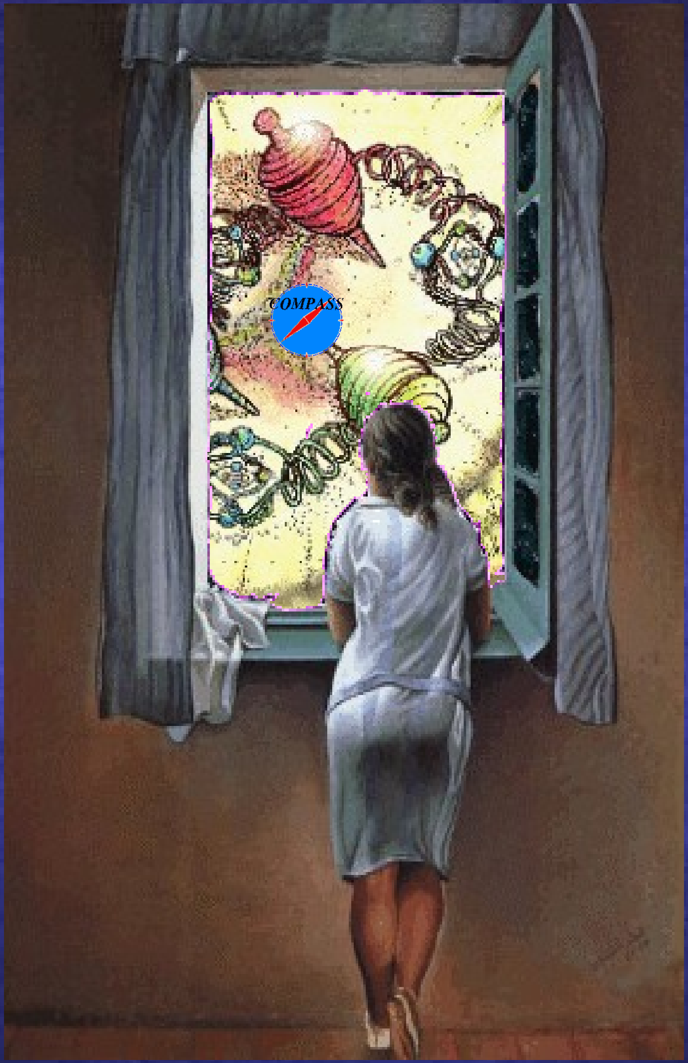
Summary

→ Unpolarized cross sections for production of high p_T hadrons will be available soon.

→These results will be a benchmark to test the sum over flavors NLO pQCD framework at compass energies.

→The double spin asymmetries a function of p_T will provide an additional precise measurement of $\Delta G(x)$ will follow.

Thank You for Listening

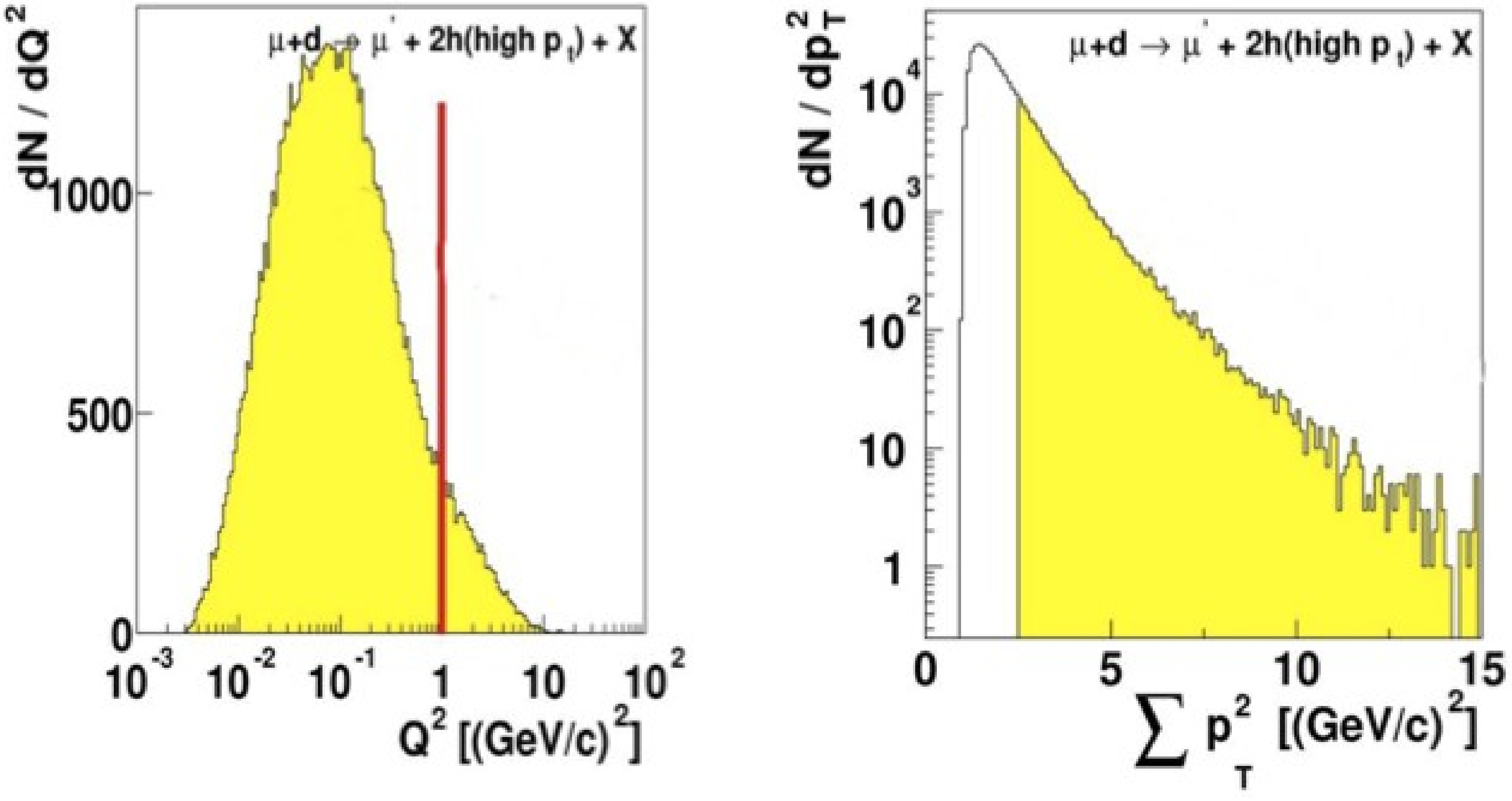


Astrid Morreale,
CEA Saclay, Irfu/SPhN, NSF

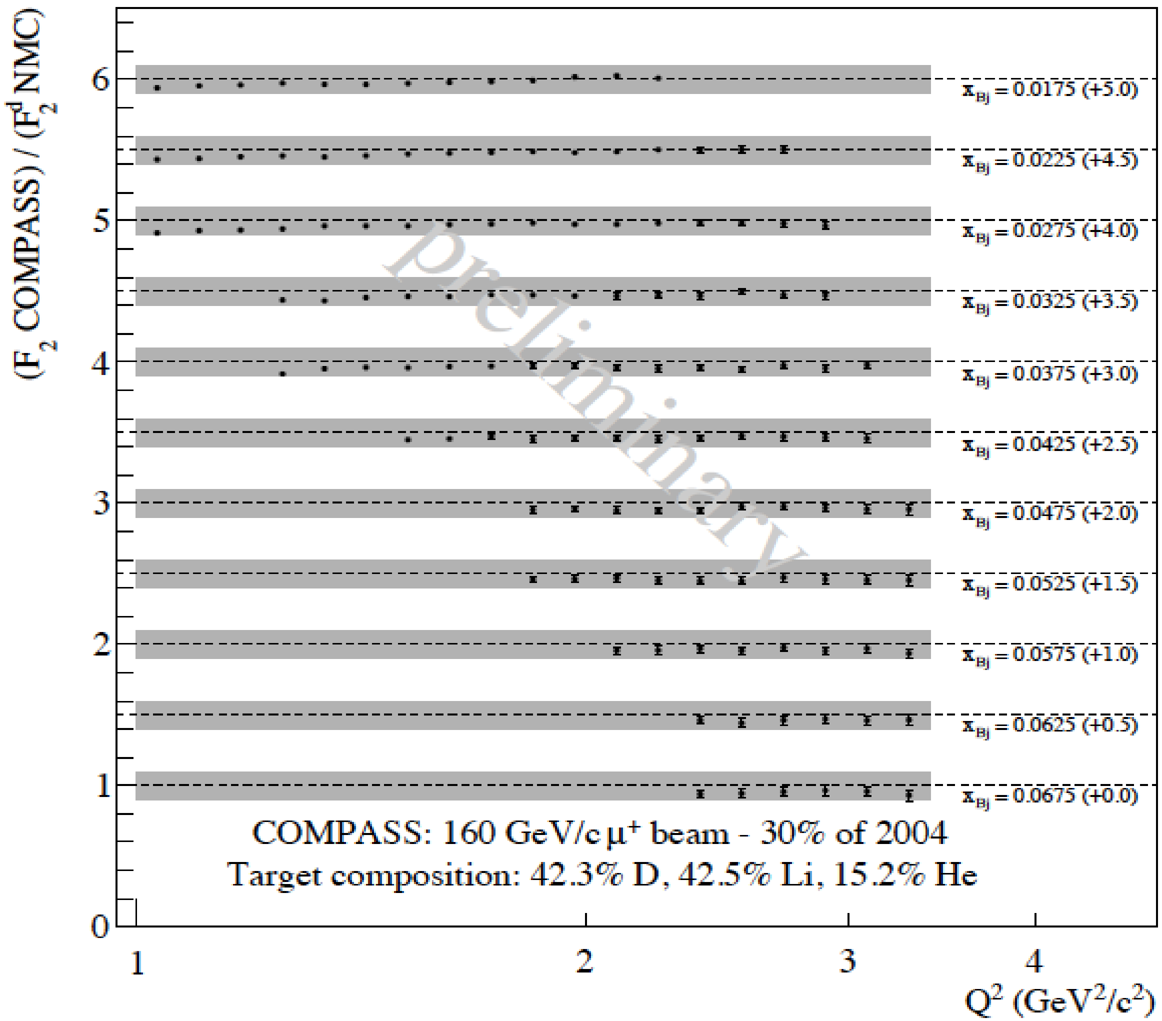
Backup

Hadron production at high and low Q^2.

Q^2 and p_t distributions



A cross check on the method



Ratio of F2 measured at compass to F2 measured at NMC.
The agreement between the measurements provides confidence
In the method of calculating the total integrated luminosity.