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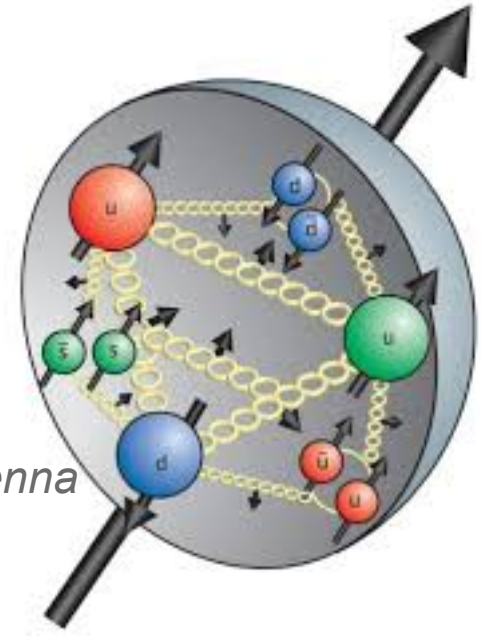
Nucleon structure

EMP current activities and future plans

FAIR
Facility for Antiproton and Ion Research in Europe GmbH

Alaa Dbeyssi, Frank Maas
On the behalf of the PANDA-EMP working group

Helmholtz-Institut Mainz
Johannes Gutenberg University

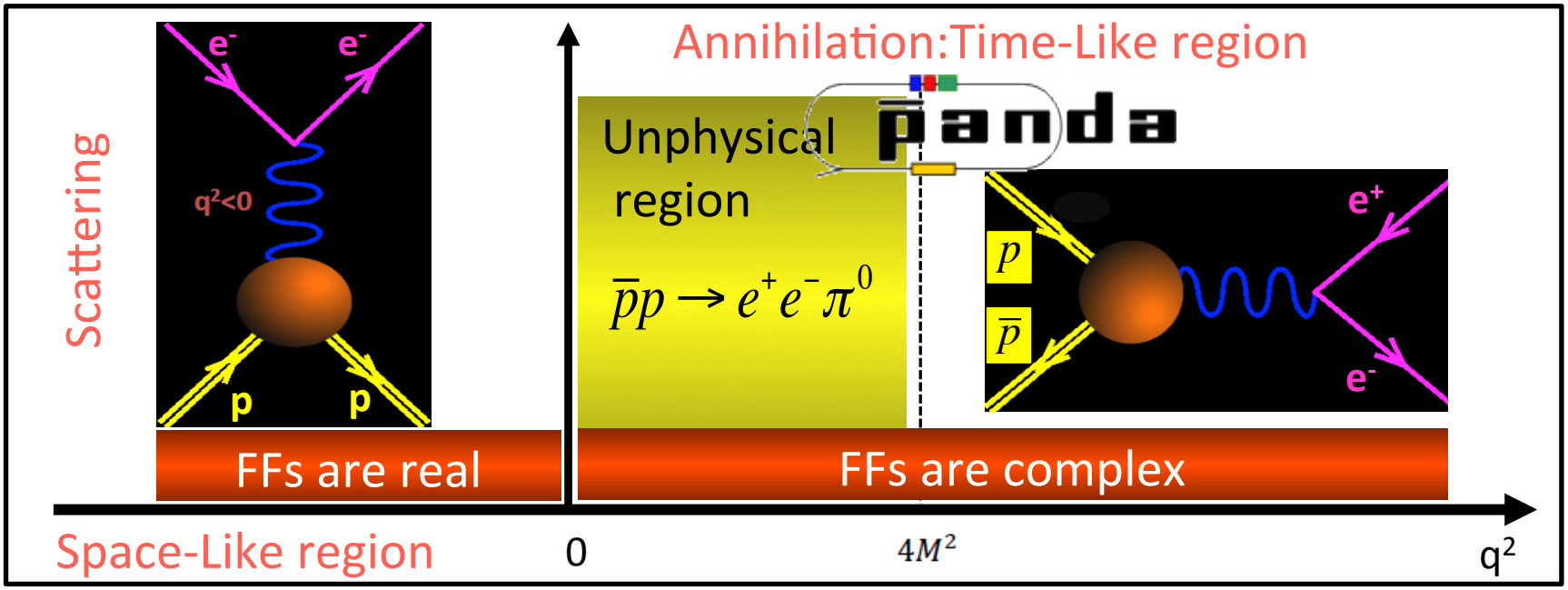


PANDA LV. Collaboration Meeting, *02.12.2015, Vienna*

Electromagnetic Processes studied for PANDA

1. Time-Like electromagnetic form factors (TL EM FFs) with lepton pair
2. Transition Distribution Amplitudes (TDAs) with meson production in ppbar annihilation
3. Transverse Parton Distribution Functions (PDFs) in Drell-Yan Production
4. Generalized Distribution Amplitudes (GDAs) with hard exclusive processes

Electromagnetic Form Factors: the analyticity



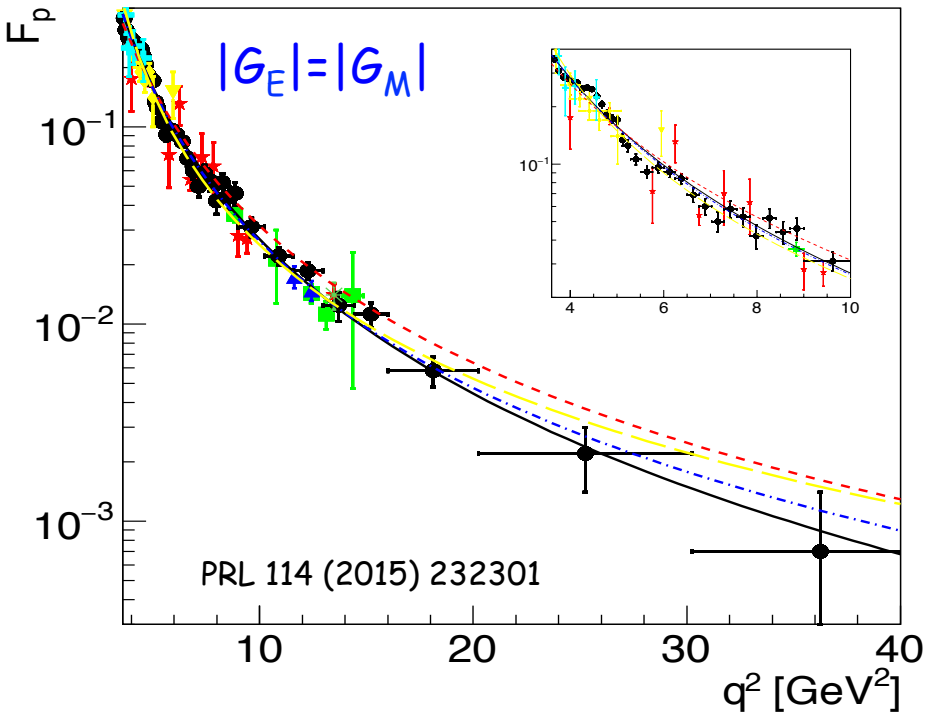
Unified frame for the description of FFs:

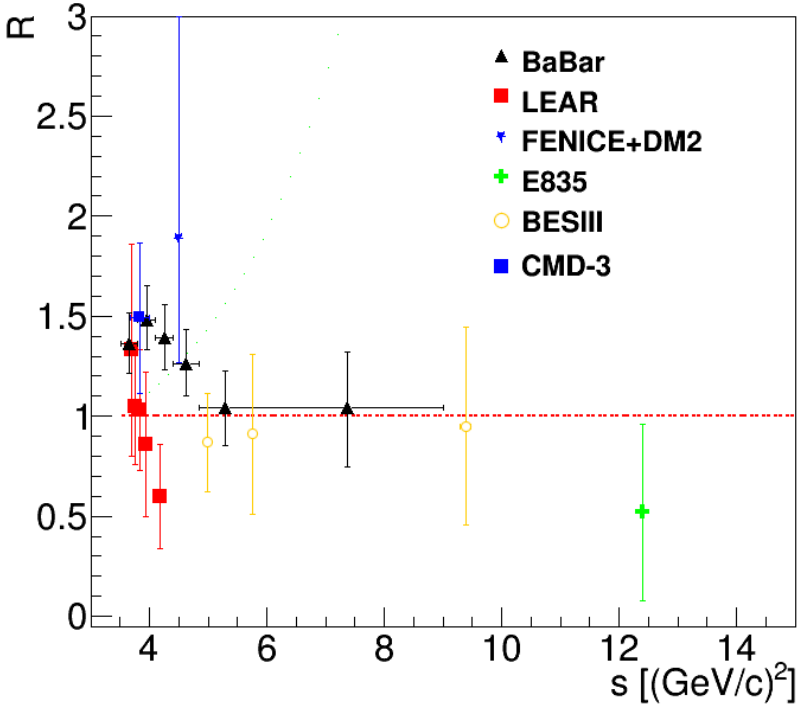
$$G(q^2) = \frac{1}{\pi}\left[\int_{4m_\pi^2}^{4m_p^2} \frac{\mathrm{Im}\,G(s)\,ds}{s-q^2} + \int_{4m_p^2}^{\infty} \frac{\mathrm{Im}\,G(s)\,ds}{s-q^2}\right]$$

$$\lim_{q^2\to-\infty} G_{E,M}^{SL}(q^2) = \lim_{q^2\to+\infty} G_{E,M}^{TL}(q^2)$$

The measurement of the Form Factors at large q^2 and in all the kinematical region: test of the analytical nature of the FFs

Time-Like proton electromagnetic form factors



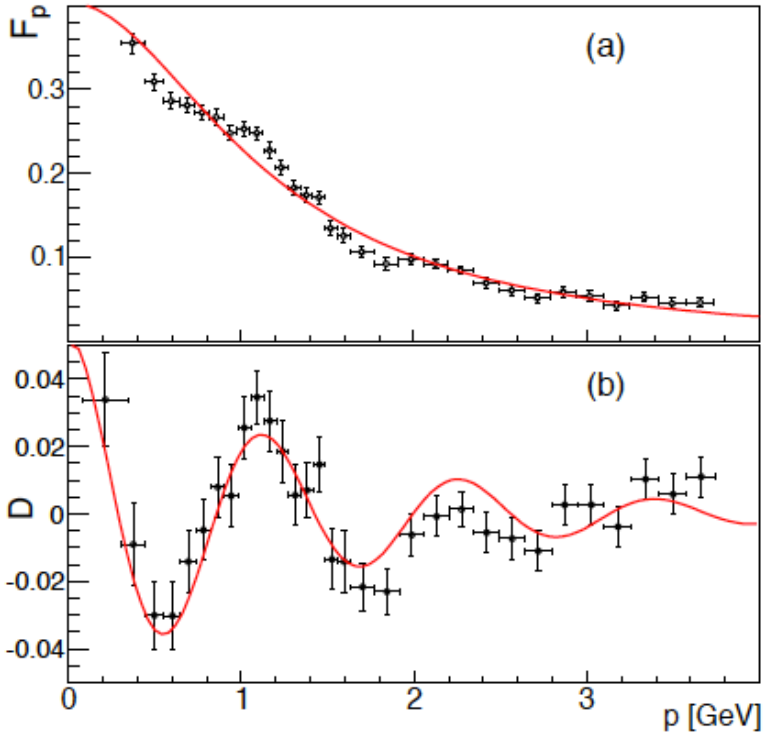


- No individual determination of GE and GM
- Steep behaviour at threshold
- Structures appeared in BaBar data?
  - Resonances (PRD 92 (2015) 034018)
  - Rescattering processes between few coherent sources (PRL 114 (2015) 232301)
- From Factor ratio: Discrepancy between LEAR-BaBar

Periodical structures in TL form factors

Andrea Bianconi, Egle Tomasi-Gustafsson (Talk in EMP session)

Phys. Rev. Lett. 114,232301 (2015), arXiv:1510.06338[nucl-th]

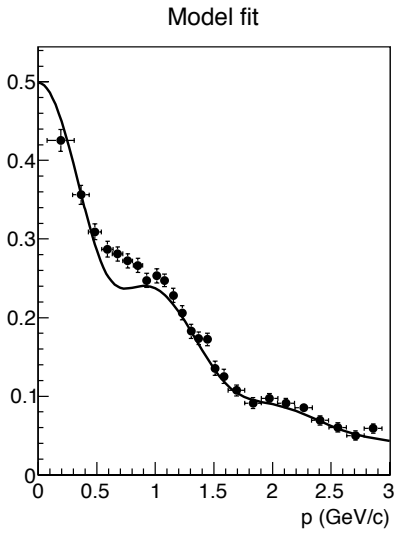


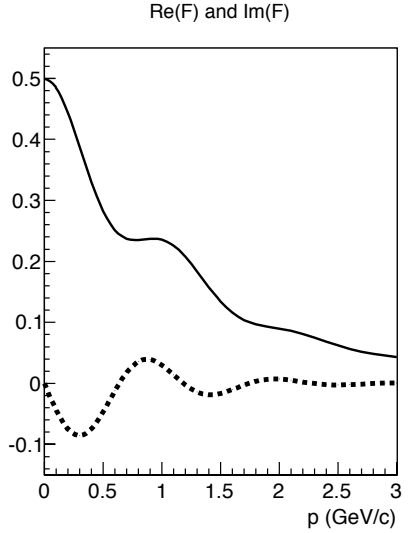
P_{Lab}

$$F_{osc}(p) \equiv A \exp(-Bp) \cos(Cp + D).$$

Optical potential analysis: double layer rescattering densities :

- feeding at small r (by decay of higher mass states into pbar-p)
- depletion at large r (from annihilation into mesons)





Looking for the current and future experiments

- Separate measurement of $|G_E|$ and $|G_M|$
- Information on the relative phase G_E/G_M
- Steep behavior at threshold
- Babar: Structures? Resonances?
  - Confirmation by other experiments? for other baryons and mesons?
  - Are time reversal related reactions equivalent?
- Analyticity:
  - FF measurement over large energy range
  - Asymptotic behavior (TL proton FFs twice larger than in SL at the same Q^2)
  - Access the unphysical region
- Proton and neutron-> global understanding of the nucleon

Current/future experiments: PANDA

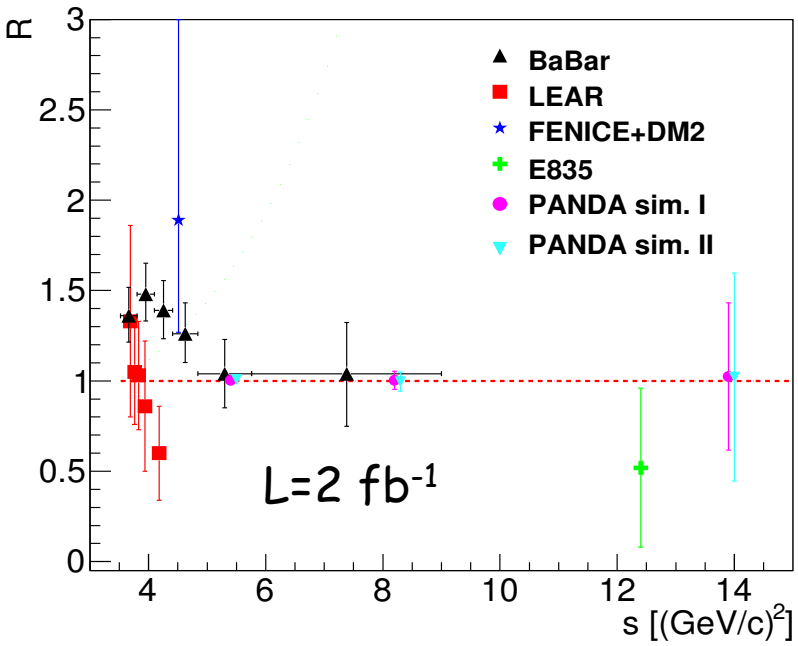
➢ Feasibility studies (PANDARoot) for measuring $\bar{p}p \to e^+e^-$ and $\bar{p}p \to \mu^+\mu^-$ at PANDA:

- Signal identification based on PID probabilities (EMC, STT,…) and kinematical cuts for electrons and Multivariate Analysis TMVA (magnet iron yoke,…) for muons

- background studies:

$$\frac{\sigma(\pi^+\pi^-)}{\sigma(l^+l^-)} \cong [10^5 - 10^6], l = e, \mu$$

A rejection at the order of 10^{-8} is required

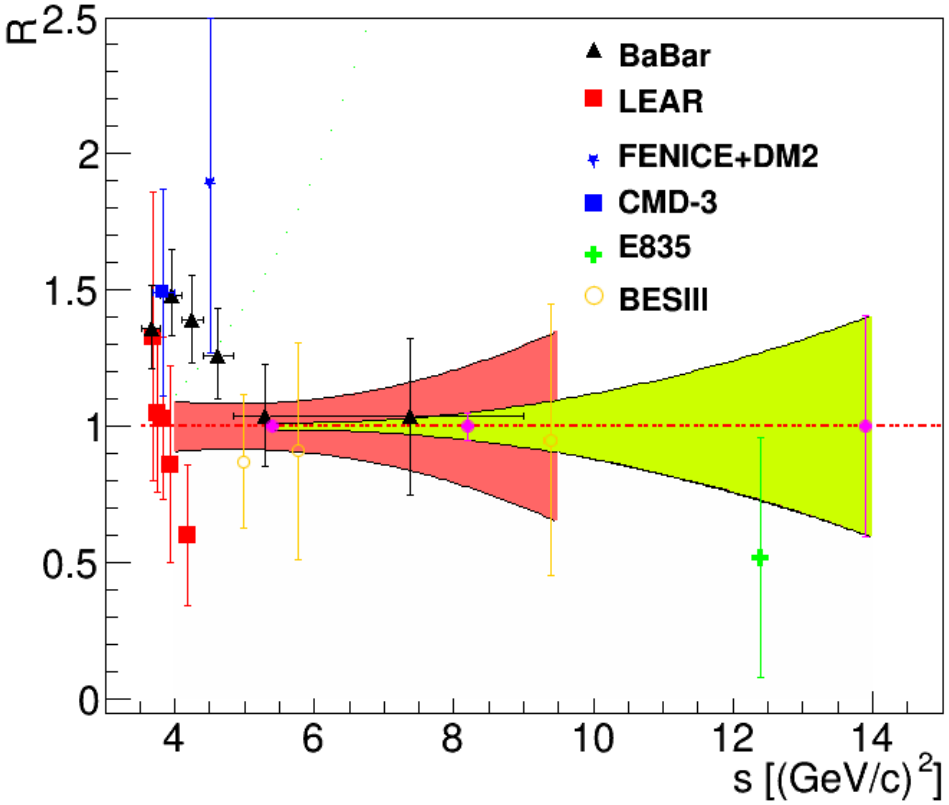


RN-EMP-2015-003
RN-EMP-2015-006

- Separate measurements of |GE|, |GM| and R (using 2 channels)
- Measurements of the proton effective form factor over a large kinematical region

- Measurement of proton FFs in the unphysical region: $\bar{p}p \to e^+e^-\pi^0$

Current/future experiments: BESII-PANDA



BESIII

21 scan points 2015 (552 pb^{-1})

Monte Carlo Sim., R=1 (C. Morales)

PANDA

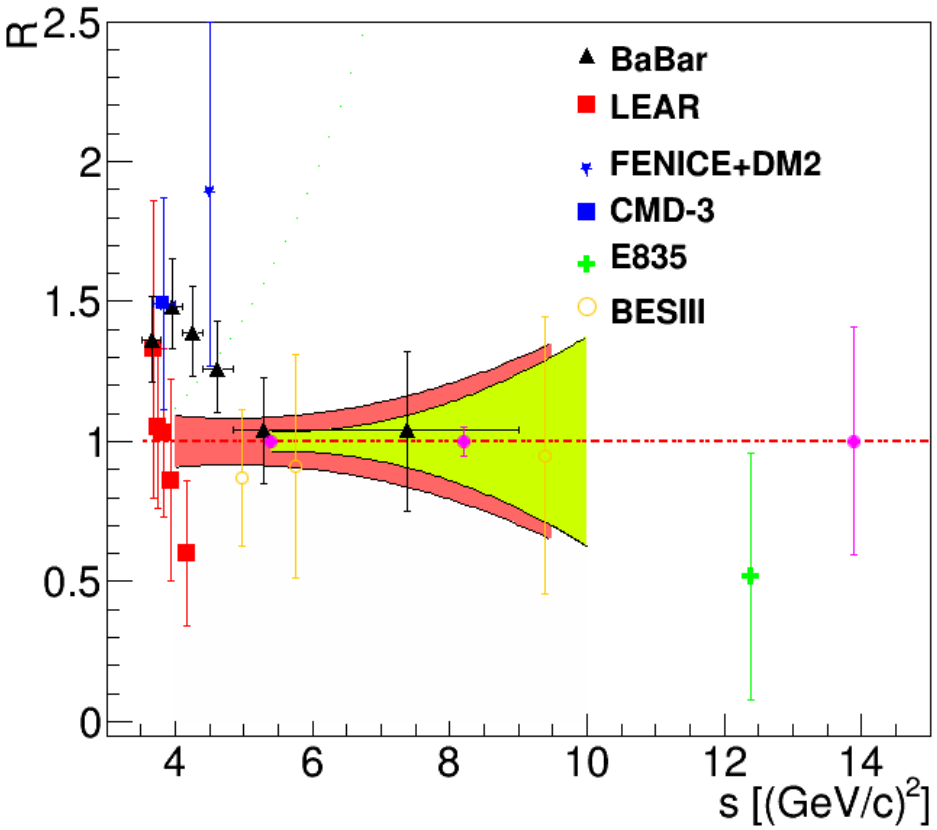
L=2 fb^{-1}

2.10^{32} cm^{-1} s^{-1}

~5 months data taking /point

	BESIII	PANDA (e^+e^-)	PANDA (mu^+mu^-)
s [(GeV/c)^2]	4 - 9.5	5 - 14	5 - ~9
R=$\|G_E\|/\|G_M\|$	9 % - 35 %	1.4 % - 41 %	5 % - 18.7 %

Current/future experiments: BESII-PANDA



BESIII

21 scan points 2015 (552 pb^{-1})

Monte Carlo Sim., R=1 (C. Morales)

panda

L=0.2 fb^{-1}

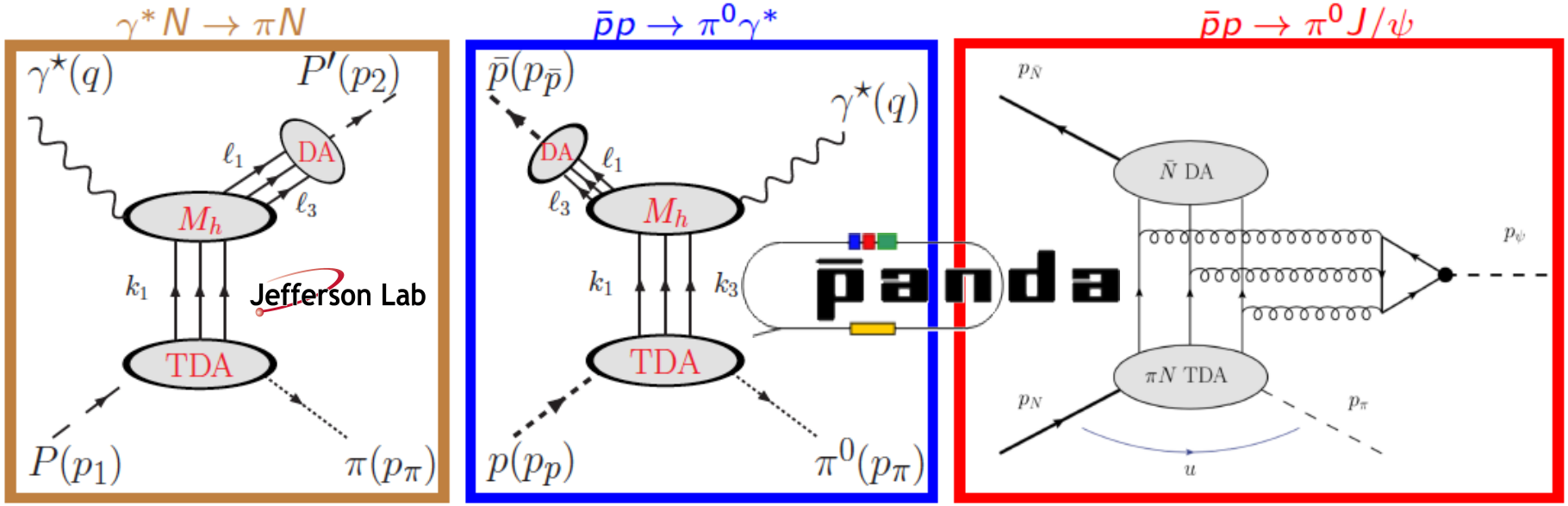
2.10^{31} cm^{-1} s^{-1}

~5 months data taking /point

	BESIII	PANDA (e^+e^-)	PANDA (mu^+mu^-)
s [(GeV/c)^2]	4 - 9.5	5 - ~10	@ 5.4
R=$\|G_E\|/\|G_M\|$	9 % - 35 %	3.5 % - 38 %	13.3 %

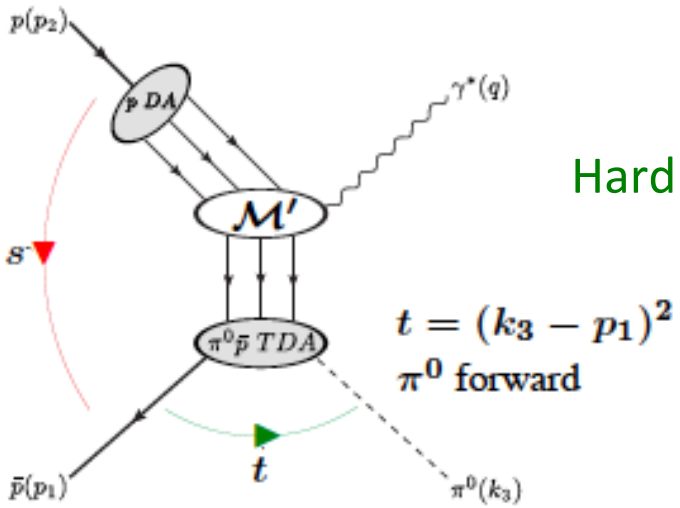
Transition Distribution Amplitudes

Nucleon to meson TDAs



- Occur in collinear factorization description of various hard exclusive processes
- Parameterized as a function of momentum fraction (x_i), skewness (ξ) and momentum transfer squared (t,u)
- Independent of reaction type, s and q^2
- Give information on pionic components of the nucleon wave-function

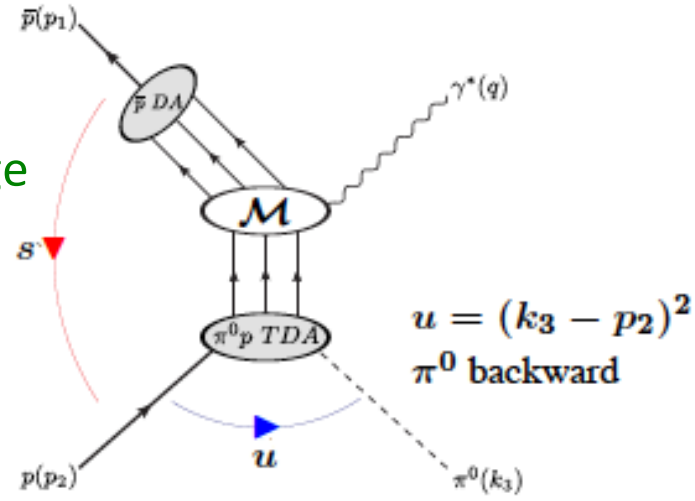
TDAs with $\bar{p}p \to \gamma^* \pi^0 -> e^+ e^- \pi^0$ channel



Hard scale: q^2 is large

$t = (k_3 - p_1)^2$

π^0 forward



$u = (k_3 - p_2)^2$

π^0 backward

t is small (forward kinematics, pi-N TDAs)

u is small (backward, pi-Nbar TDAs

Feasibility studies of measuring $\bar{p}p \to \gamma^* \pi^0 -> e^+ e^- \pi^0$ at PANDA

Luminosity= 2 fb^{-1}

i) $s = 5\ \mathrm{GeV}^2 \quad \to \quad 3.0 < q^2 < 4.3\ \mathrm{GeV}^2, \quad |\cos\theta_{\pi^0}| > 0.5$

ii) $s = 10\ \mathrm{GeV}^2 \quad \to \quad 5 < q^2 < 9\ \mathrm{GeV}^2, \quad |\cos\theta_{\pi^0}| > 0.5$

- Background suppression of the $\bar{p}p \to \pi^+ \pi^- \pi^0$ and measurement precision:

s = 5 GeV^2: 5 . 10^7 (1 . 10^7)
s = 10 GeV^2: 1 . 10^8 (6 . 10^6)

$\Delta\sigma/\sigma \sim 12\%$

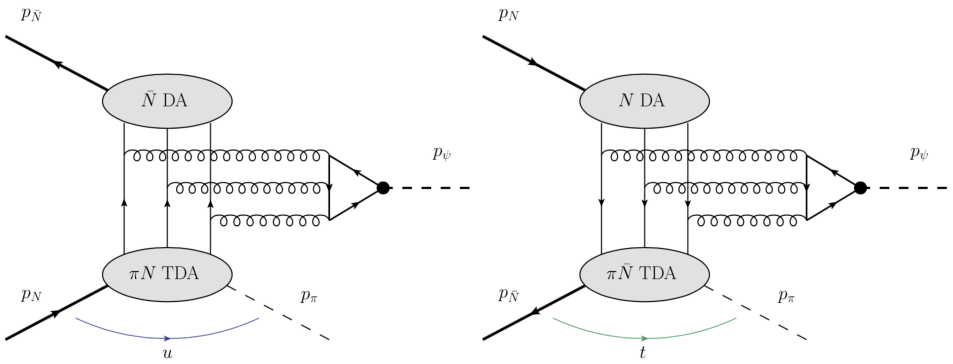
$\Delta\sigma/\sigma \sim 24\%$

Published in
Eur.Phys.J. A51 (2015) 8, 107

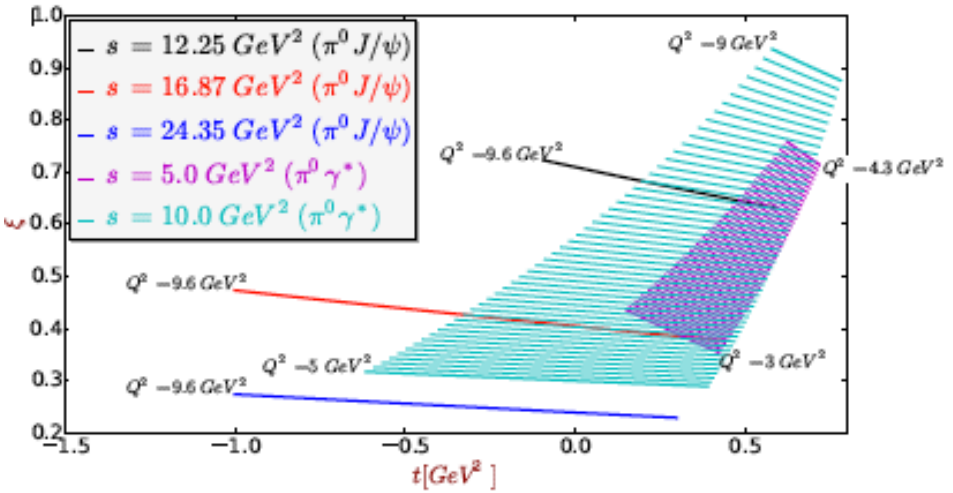
Accessing TDAs in $\bar{p}p \to J/\psi\pi^0 -> e^+e^-\pi^0$ channel

- **Test of universality of TDAs**
  - Validate independence on reaction type, Q^2 and s
  - Complementary to $\pi^0\gamma*$
  - Different phase-space coverage in skewness (ξ) vs momentum transfer (t) space
- **Comments received on first version of the note**
  - Other potential background sources
    - $\pi^0\pi^0\pi^+\pi^-$, $\pi^0\pi^+\pi^-\pi^+\pi^-$
    - $\pi^0\pi^0 J/\psi$
  - 4C kinematic fitting
    - Signal hypothesis
    - $\pi^0\pi^0 J/\psi$ background hypothesis
  - Signal purity
  - MSV luminosity

- **Two validity regimes**
  - Small |t| (Fwd. π^0, πNbar TDAs)
  - Small |u| (Bwd. π^0, πN TDAs)

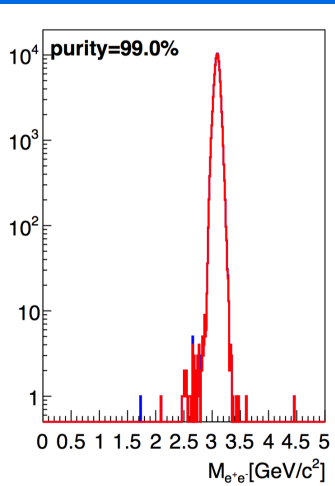


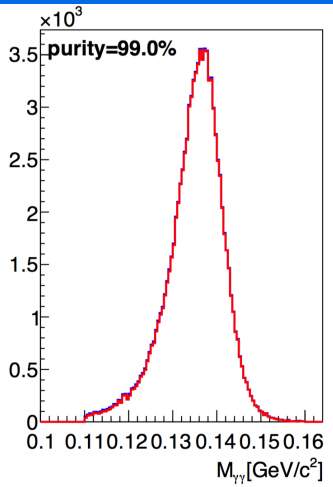
Phase space coverage for $\pi^0\gamma*$ and $\pi^0 J/\psi$

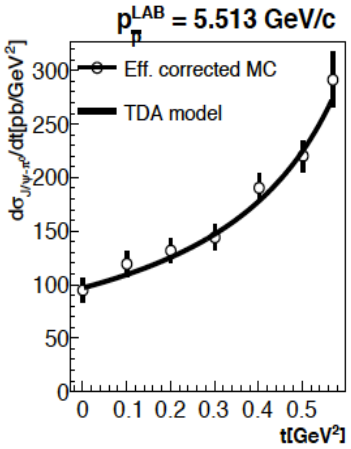


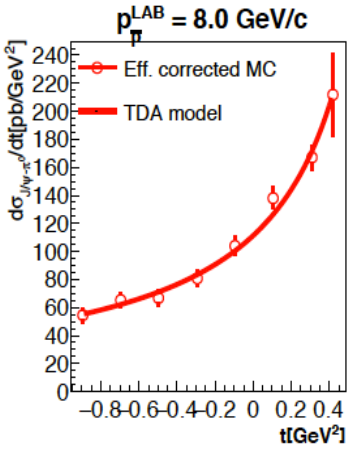
Efficiency, Purity and expected precision for $\pi^0 J/\psi \rightarrow \gamma\gamma e^+e^-$

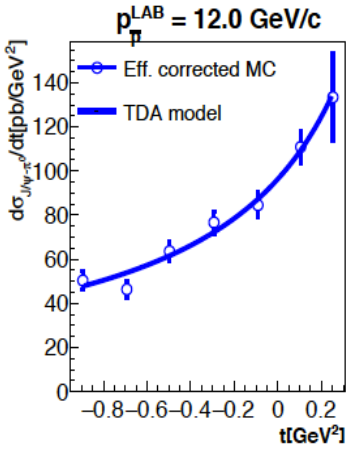
- New set of cuts including kinematic fit implemented:
  - Background contamination <~ 1% attained for all sources
  - Signal efficiency sufficient to attain 5-10% relative uncertainty with full setup ($2fb^{-1}$, 5 months)







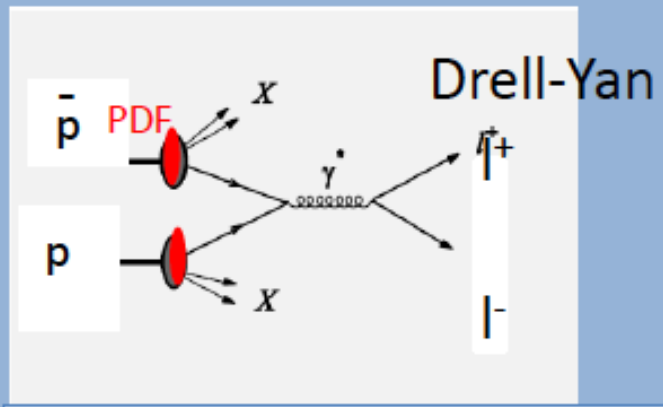




- MSV setup (4 months)
  - Statistics will be too low even for single differential cross-section measurement, but useful for
    - Checking order of magnitude of cross-sections
    - Constraining pionic background sources with cross-sections in the mb range

Transverse Parton Distribution Functions

$\bar{p}p \rightarrow \mu^+\mu^- X / e^+e^- X$



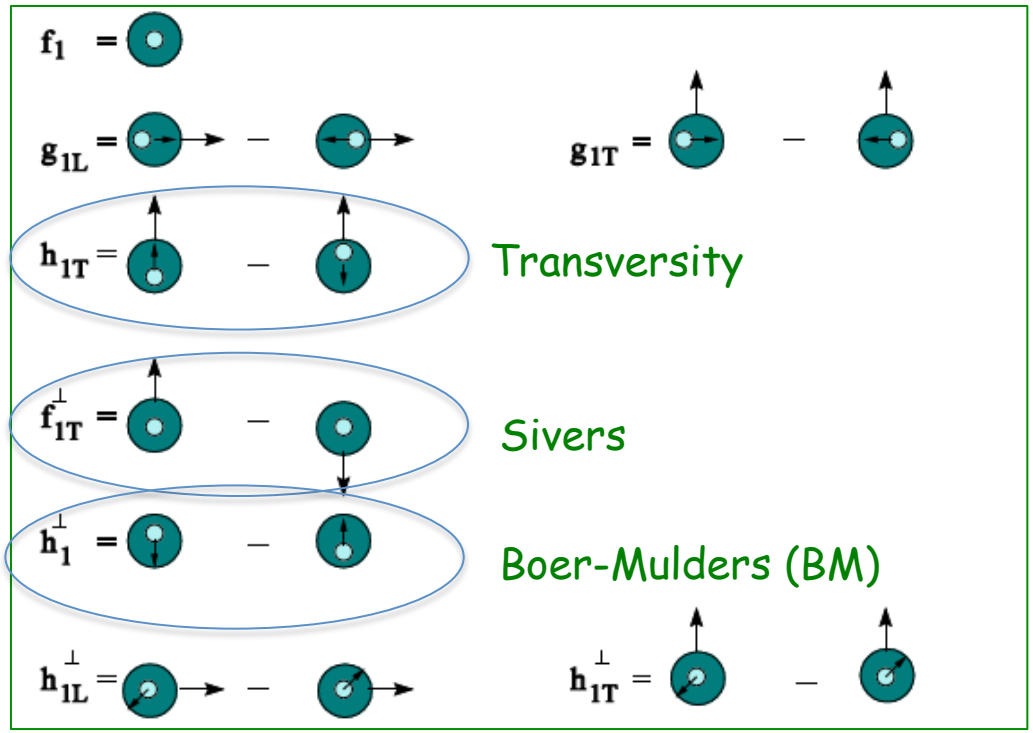
Parton Distribution Functions

@ FAIR unique energy range
up to s~30 GeV2 with PANDA
up to s~200 GeV2 with PAX

@ much higher energies
→ big contribution from sea-quarks

@ppbar annihilation each valence quark contribute to the diagram

Drell-Yan processes at PANDA



- Main background: $\bar{p}p \rightarrow n(\pi^+\pi^-)X$
  - required rejection factor ~10^7
- Simulations @ s=30 GeV^2 and

$$1.5 \leq M_{\gamma^*} \leq 2.5$$

(non resonance region, large cross section)

- N_{gen}=480 . 10^3, 5 months with L=2 . 10^{32} cm^{-2} s^{-1}

Asymmetry measurements:

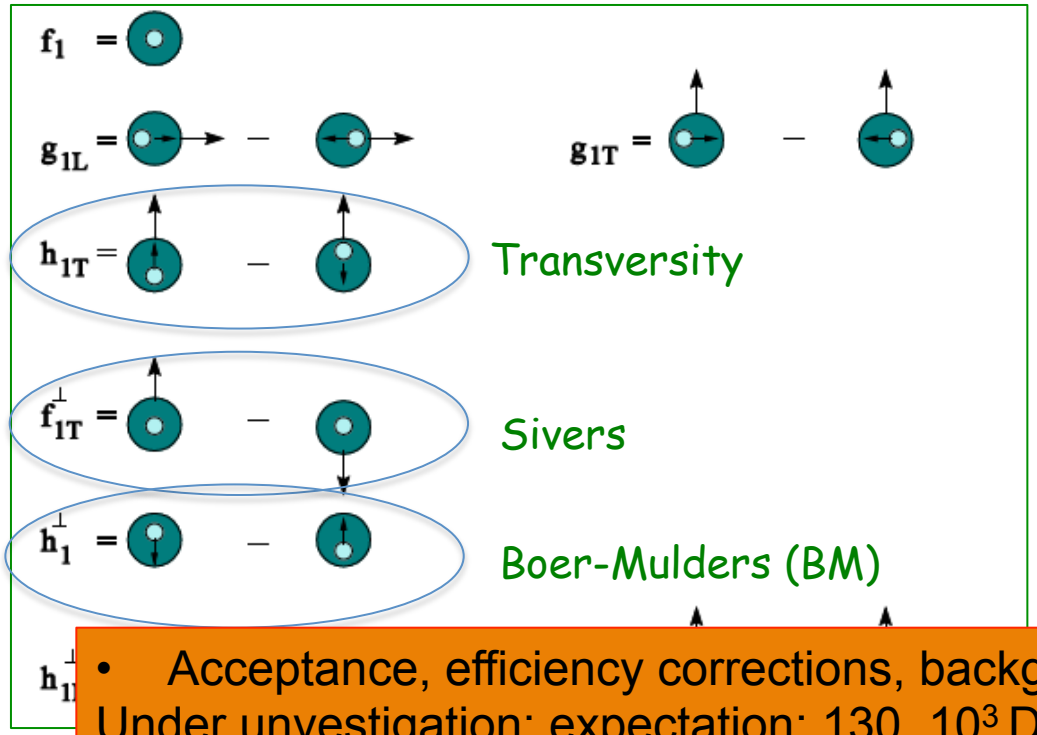
Unpolarized DY: $A^{\cos 2\varphi} \rightarrow h_1^{\perp}$

Single-polarized DY: $A^{\sin(\varphi \pm \varphi_{s2})} \rightarrow h_1^{\perp}, h_{1T}, f_{1T}^{\perp}$

φ : angle between hadron and lepton planes

φ_{s2} : angle between hadron spin and lepton plane

Drell-Yan processes at PANDA



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- N_{gen}=480 . 10^3, 5 months with
  L=2 . 10^{32} cm^{-2} s^{-1}

- Acceptance, efficiency corrections, background rejection are still Under unvestigation: expectation: 130. 10^3 DY/month
- One year data taking (L=2 . 10^{32} cm^{-2} s^{-1}): precise measurements of the azimuthal asymmetries is possible
- Reduced luminosity (L=2 . 10^{31} cm^{-2} s^{-1}): ~4 years of data taking is needed

As

nes

Single-polarized DY: $A^{\sin(\varphi \pm \varphi s 2)} \rightarrow h_1^{\perp}, h_{1T}, f_{1T}^{\perp}$

Summary

- The proton FFs can be measured at PANDA over large momentum range with unprecedented accuracy
  - Development of an event generator for radiative corrections is ongoing
- Accessing the pion-nucleon TDAs at PANDA
  - Promising results are obtained with the full luminosity mode
  - The low statistics provided by the MSV are not sufficient to make a precise measurement of the TDAs.
  - Possibility to access other meson-Nucleon TDAs at PANDA?
- PDFs will be also measured at PANDA with Drell-Yan Productions
  - Update of the feasibility studies,
  - investigation of electron channel, is planned
- Precise studies for $\bar{p}p \to \gamma\gamma$ and $\bar{p}p \to \pi^0\gamma$ is also planned
- Study of the ppbar annihilation into light meson at PANDA:
  - Effective lagrangian model for binary processes
  - Monte Carlo event generators for background processes

Summary

- 5 parallel talks are presented in this meeting:
  - Periodic structures in time-like form factors: access to hadron formation through optical model analysis (E. Tomasi-Gustafsson, SphN, Saclay).
  - Update on feasibility studies for the measurement of proton time-like form factors from pbar p -> mu(+)mu(-) (I. Zimmermann, HIM).
  - First results of a global analysis of pion production in pbar-p annihilation (Wang-Ying, IPNO).
  - Updated results on feasibility measurements of pion-N TDAs through pi0+Jpsi (E. Atomssa, IPNO).
  - Test of a superconducting shield for the PANDA polarized target (B. Froehlich, HIM).
- 1 talk for the Collaboration wide review
  - Feasibility studies of time-like proton electromagnetic form factors at PANDA at FAIR (D. Kahnefdt, HIM)
- 3 Releases Notes
  - **RN-EMP-2015-003:** Feasibility studies of time-like proton electromagnetic form factors at PANDA at FAIR (HIM)
  - **RN-EMP-2015-006:** Feasibility studies for the measurement of proton time-like electromagnetic form factors in processes of pbar p -> mu+ mu- at PANDA-FAIR (HIM)
  - **RN-EMP-2015-007:** Feasibility study for measuring pion-N TDAs in PANDA through pbab+p->pi0+J/psi reactions (IPNO)