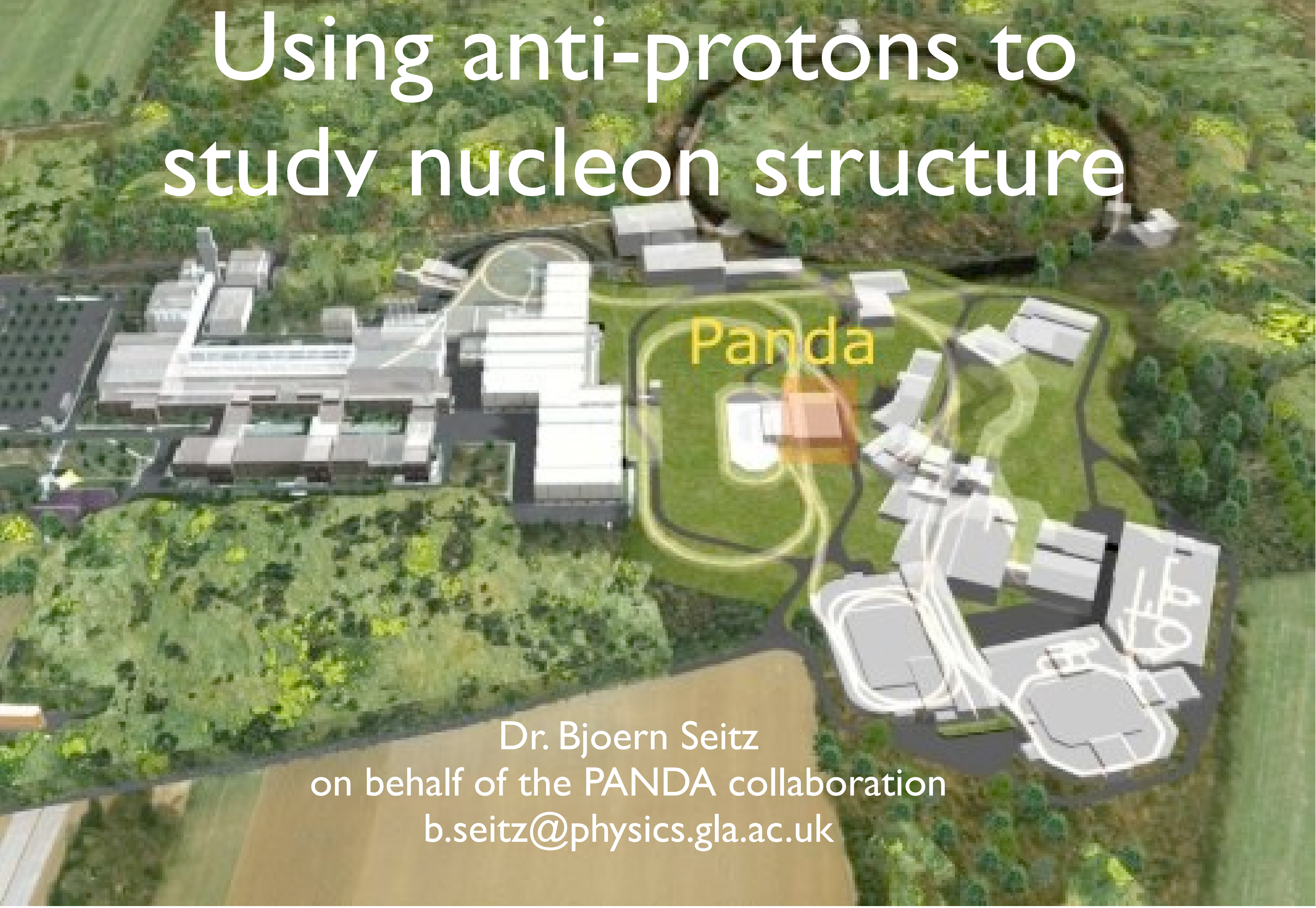
Using anti-protons to study nucleon structure



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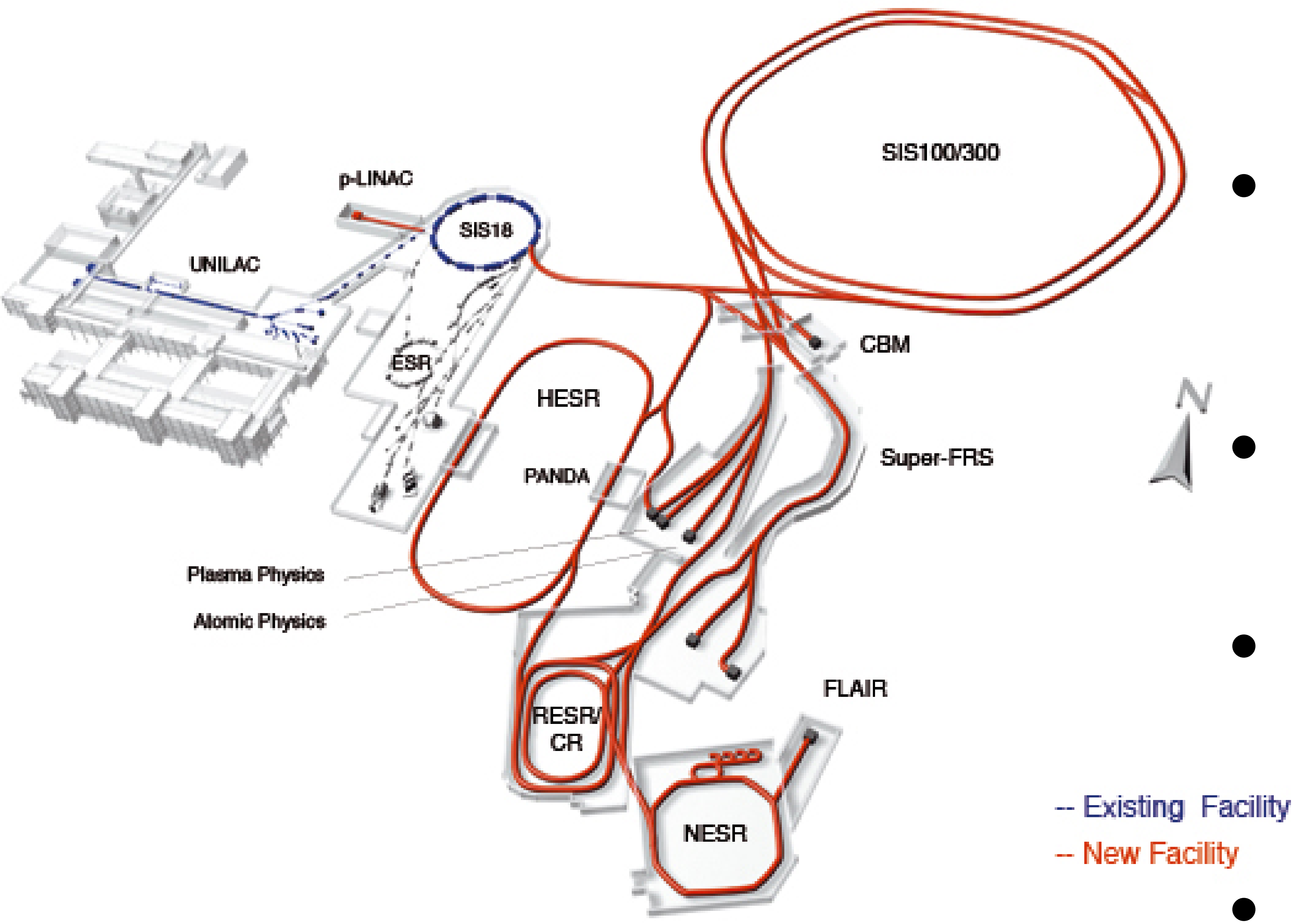
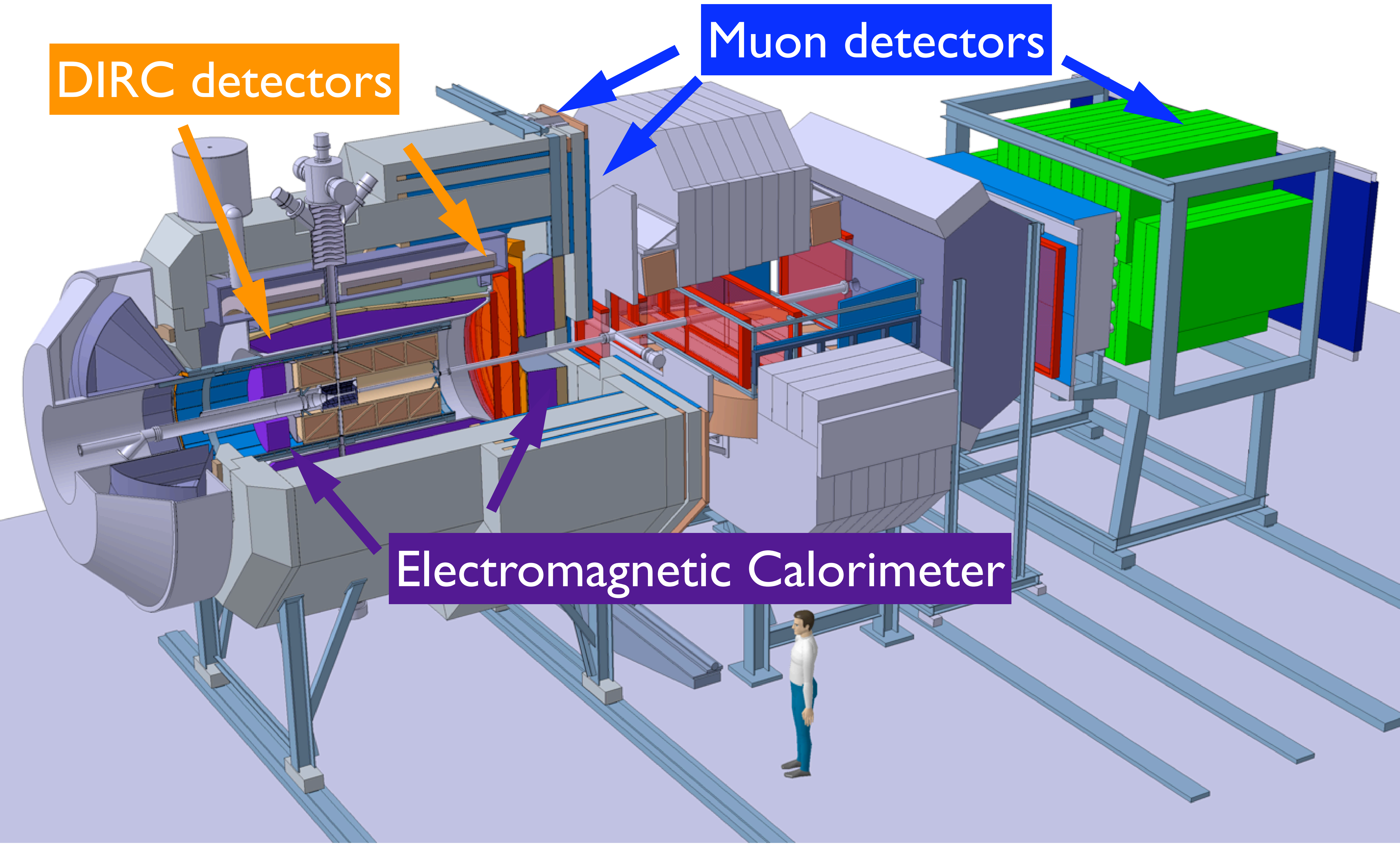
The anti-proton beam



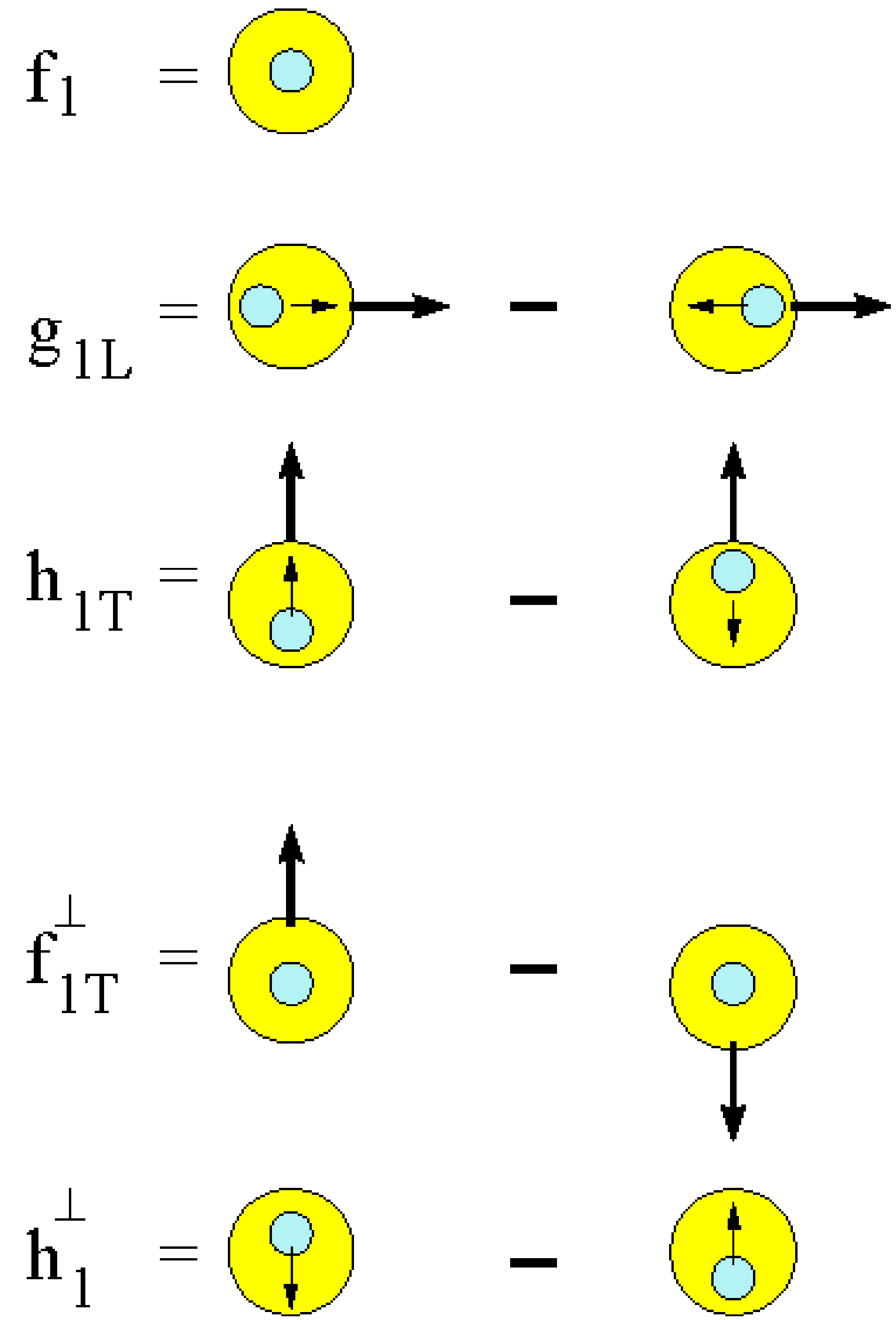
- Parallel operation for large physics programme
- FAIR will provide cooled anti-proton beams from 0 -15 GeV/c
- HESR: $N_{\bar{p}} = 5\text{x}10^{10}$
  1.5 GeV/c < p_{beam} < 15 GeV/c
- High luminosity mode
  $\Delta p/p = 10^{-4}$ with stochastic cooling, $L=10^{32}cm^{-2}s^{-1}$
- High precision mode
  $\Delta p/p = 3\text{x}10^{-5}$ with electron cooling, $L=10^{31}cm^{-2}s^{-1}$

The PANDA Detector



Hot Topics in DIS

- Non-k_t integrated quark distribution functions (cf. session Spin-4):
  - transversity distribution
  - Collins function
  - Sivers function
  - Boer-Mulders function

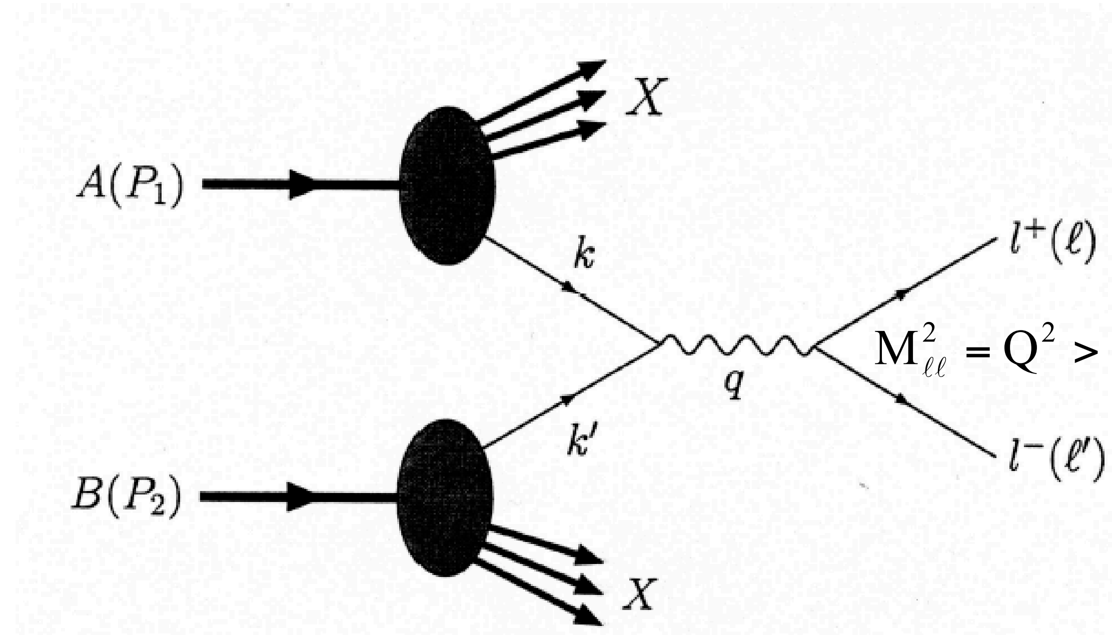


Hot topics in proton annihilation with electromagnetic final states

- un-polarised and polarised Drell - Yan processes
  - access to Boer-Mulders function
  - access to transversity distribution

The Drell-Yan process

- process complementary to DIS
- cross section directly related to parton distribution functions
- no fragmentation functions involved
- all valence quarks will contribute in anti-proton annihilation
- wealth of (spin)-observables

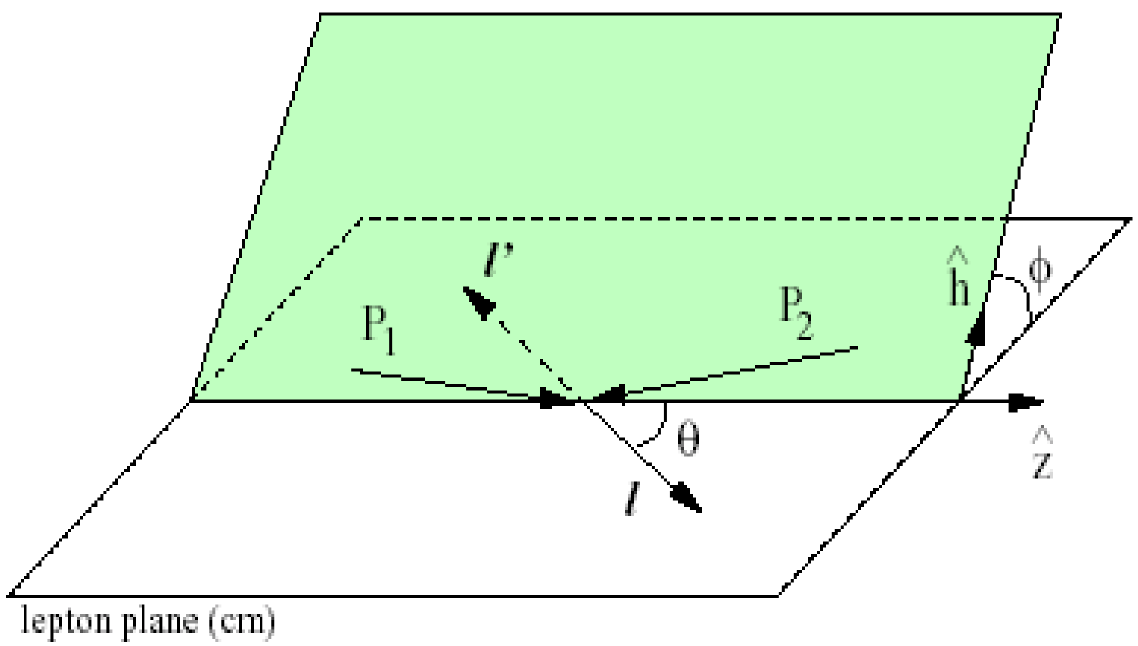


$$\frac{1}{\sigma}\frac{d\sigma}{d\Omega} \propto \frac{\nu}{2}\sin^2\theta\cos 2\phi$$

$$\nu \propto \sum_q e_q^2 \frac{h_1^\perp \bar{h}_1^\perp}{f_1 \bar{f}_1}$$

$$A_{TT} \propto \frac{\sum_q e_q^2 \left(h_1 \bar{h}_1\right)}{\sum_q e_q^2 \left(f_1 \bar{f}_1\right)}$$

Drell-Yan angular distribution



$\text{Lam} - \text{Tung SR}: \ 1 - \lambda = 2\nu$

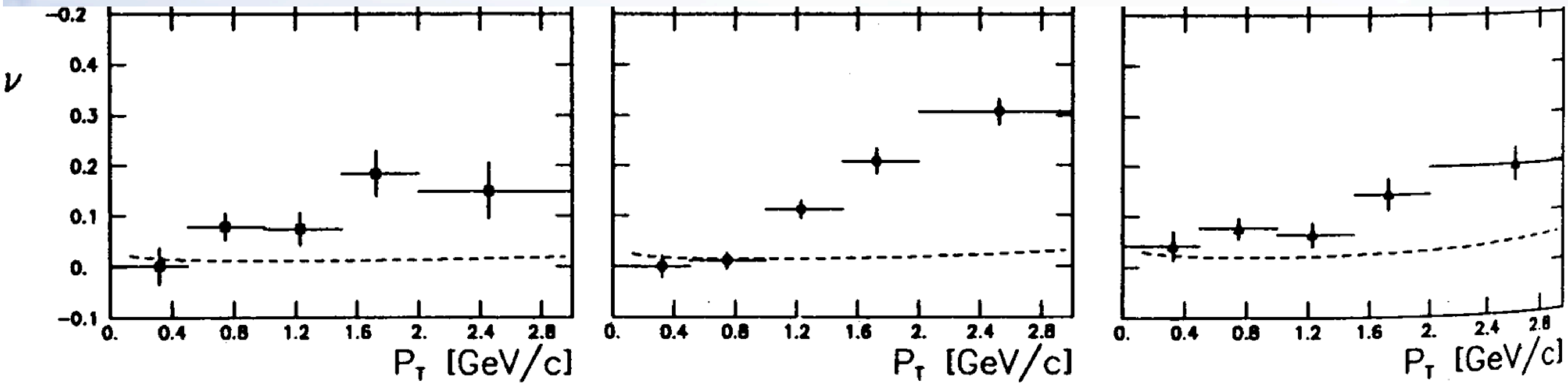
$\text{NLO pQCD}: \lambda \approx 1 \ \mu \approx 0 \ \nu \approx 0$

$\text{experiment}: \ \nu \approx 0.3$

- Experimentally, a violation of the Lam-Tung sum rule is observed by sizeable cos2Φ moments
- Several model explanations
  - higher twist
  - spin correlation due to non-trival QCD vacuum
  - Non-zero Boer Mulders function

$$\frac{1}{\sigma}\frac{d\sigma}{d\Omega} = \frac{3}{4\pi}\frac{1}{\lambda+3}\left(1 + \lambda\cos^2\theta + \mu\sin2\theta\cos\phi + \frac{\nu}{2}\sin^2\theta\cos2\phi\right)$$

A first glimpse



- NA10 at CERN: 140/194/268 GeV π^- W
  (Z. Phys. C37(1988) 545)
- Data can be fit in terms of the Boer Mulders function
  (Boer, Phys. Rev. D60(1999) 014012)

- Model expectations
  - sign change compared to SIDIS
    (Collins, PLB536 (2002) 43)
  - Boer Mulders function larger than Sivers function
    (Burkhardt, hep-ph/0611256)

Hot Topics in DIS

- Non-k_t integrated quark distribution functions (cf. session Spin-4):
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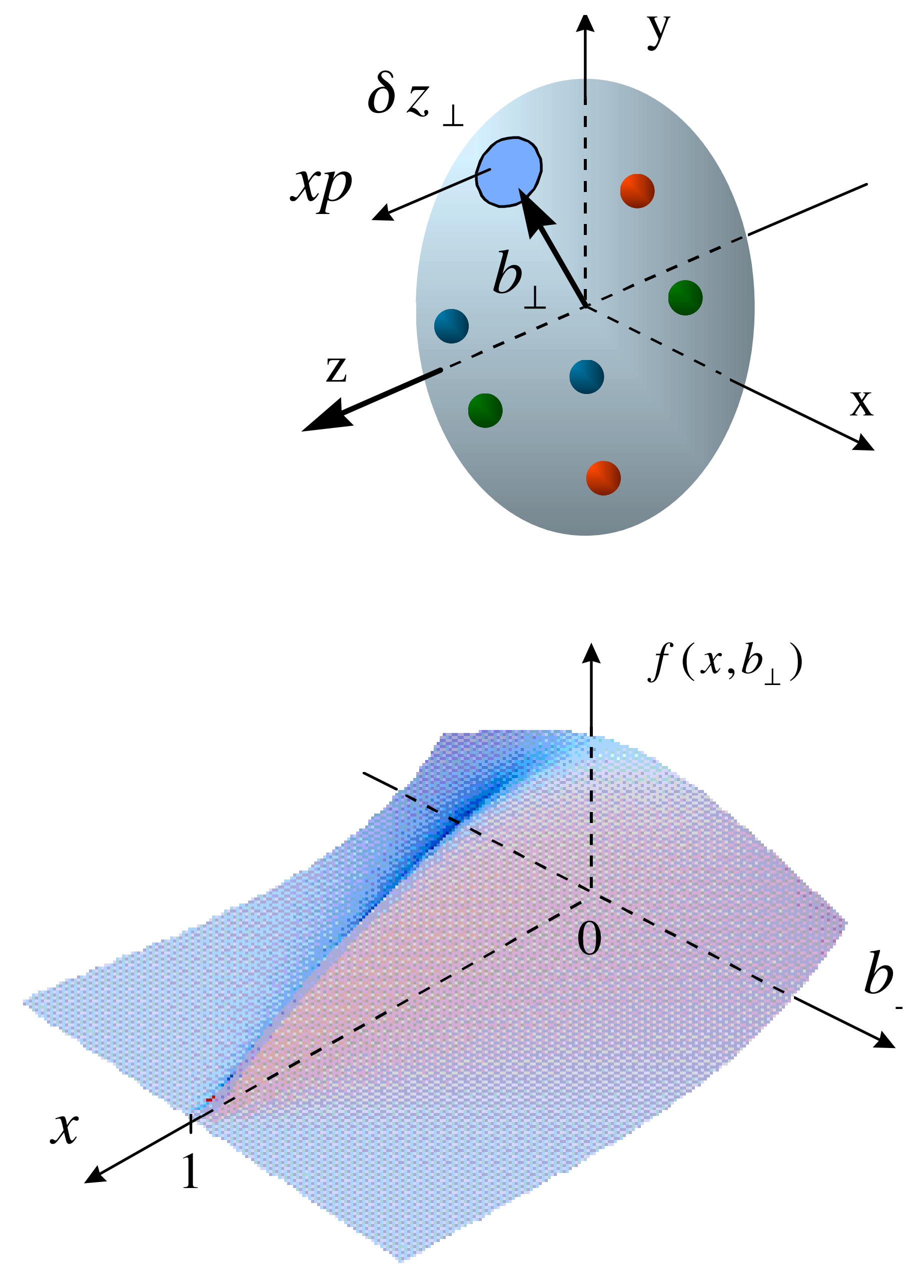
    - Collins fragmentation function
    - Sivers fragmentation function
    - Boer-Mulders function
- Generalised Parton Distributions (cf. sessions Spin-6/7 (Diff 7/8))



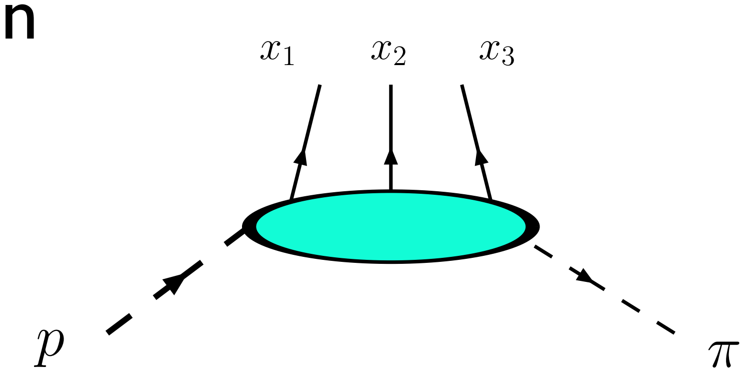
Generalised Parton Distribution

Hot topics in proton annihilation with electromagnetic final states

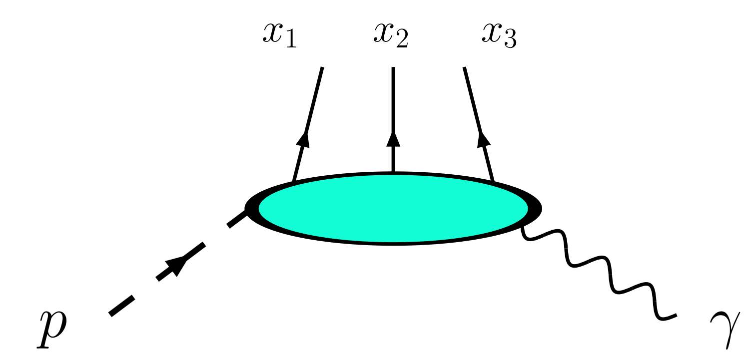
- un-polarised and polarised Drell - Yan processes
  - access to Boer Mulders function
  - access to transversity distribution
- Exclusive final states
  - access to Generalised Distribution Amplitudes and Transition Distribution Amplitudes

Generalised Distribution Amplitudes

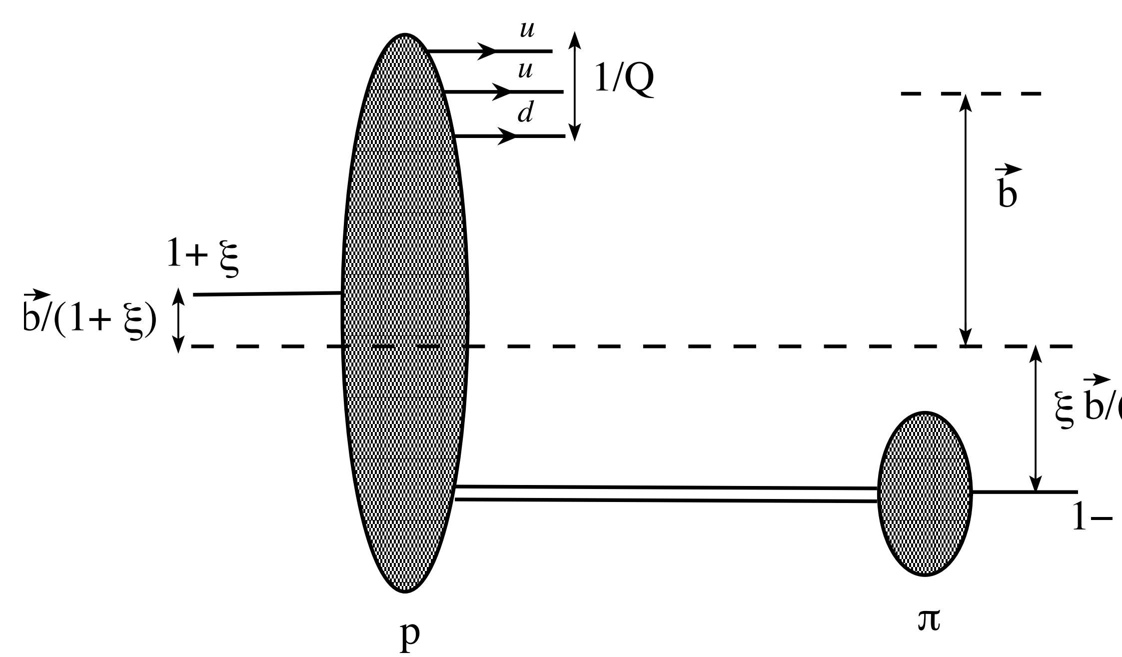
- Distribution amplitudes describe how quarks are distributed in hadrons
- Provide information on the amplitude level
- DA gives information in the minimal Fock state of the baryon
- TDA provides information on the next to minimal Fock state
- Transverse picture of the pion cloud inside the nucleon
- Additionally, GPD inspired cross section estimates for exclusive processes



proton $\to \pi$



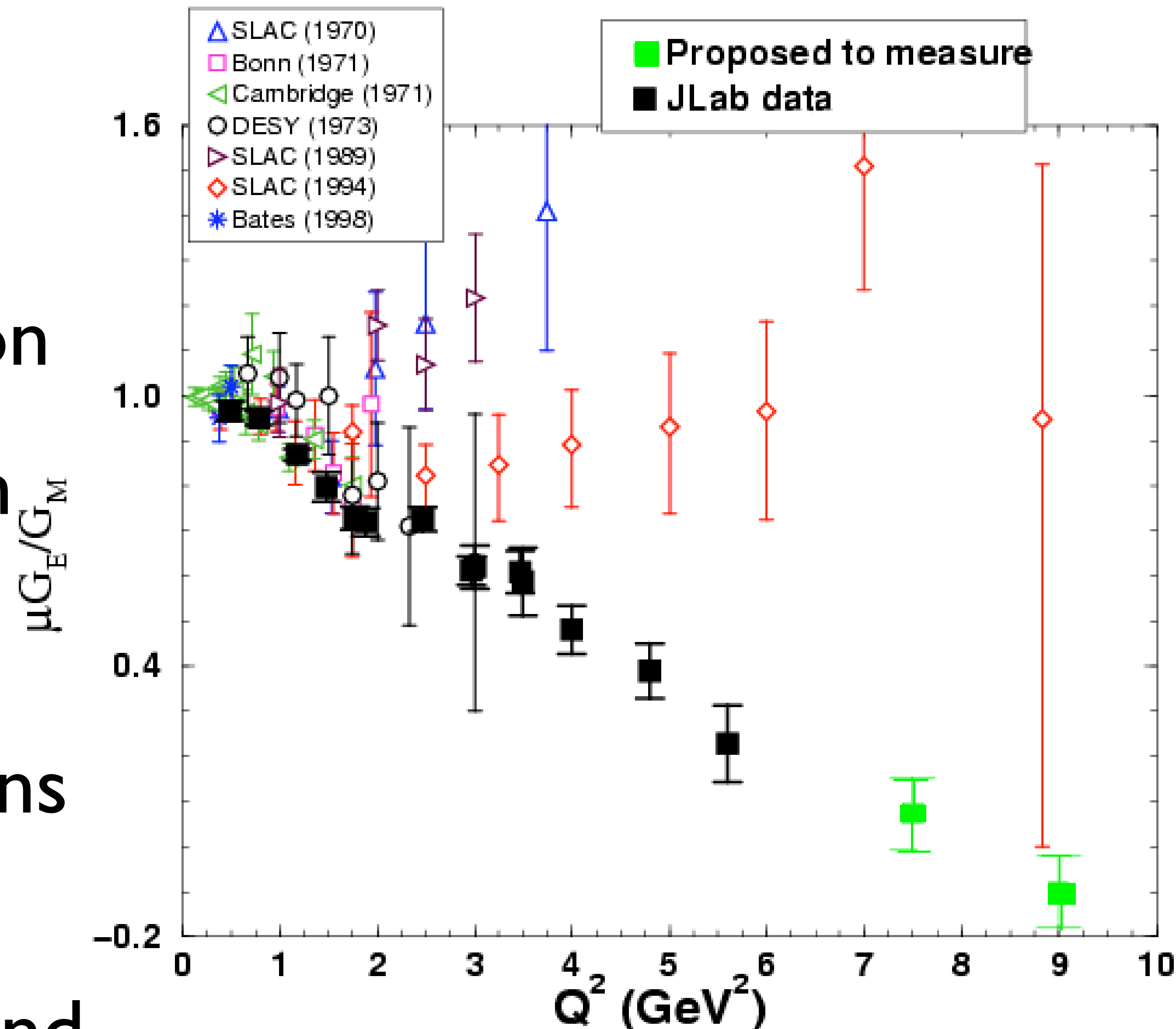
proton $\to \gamma$



B. Pire , PANDA workshop on EM physics, Orsay, March 2007 and hep/ph/0701125

Hot Topics in DIS

- Non-k_t integrated quark distribution functions (cf. session Spin-4):
  - transversity distribution
  - Collins fragmentation function
  - Sivers fragmentation function
  - Boer-Mulders function
- Generalised Parton Distributions (cf. sessions Spin-6/7 (Diff 7/8))
- Measurements of G_E and G_M (and associated discrepancies)



JLab E93-027 and E99-007
PRL 84(2000) 1398
PRL 88(2002)092301

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- un-polarised and polarised Drell - Yan processes
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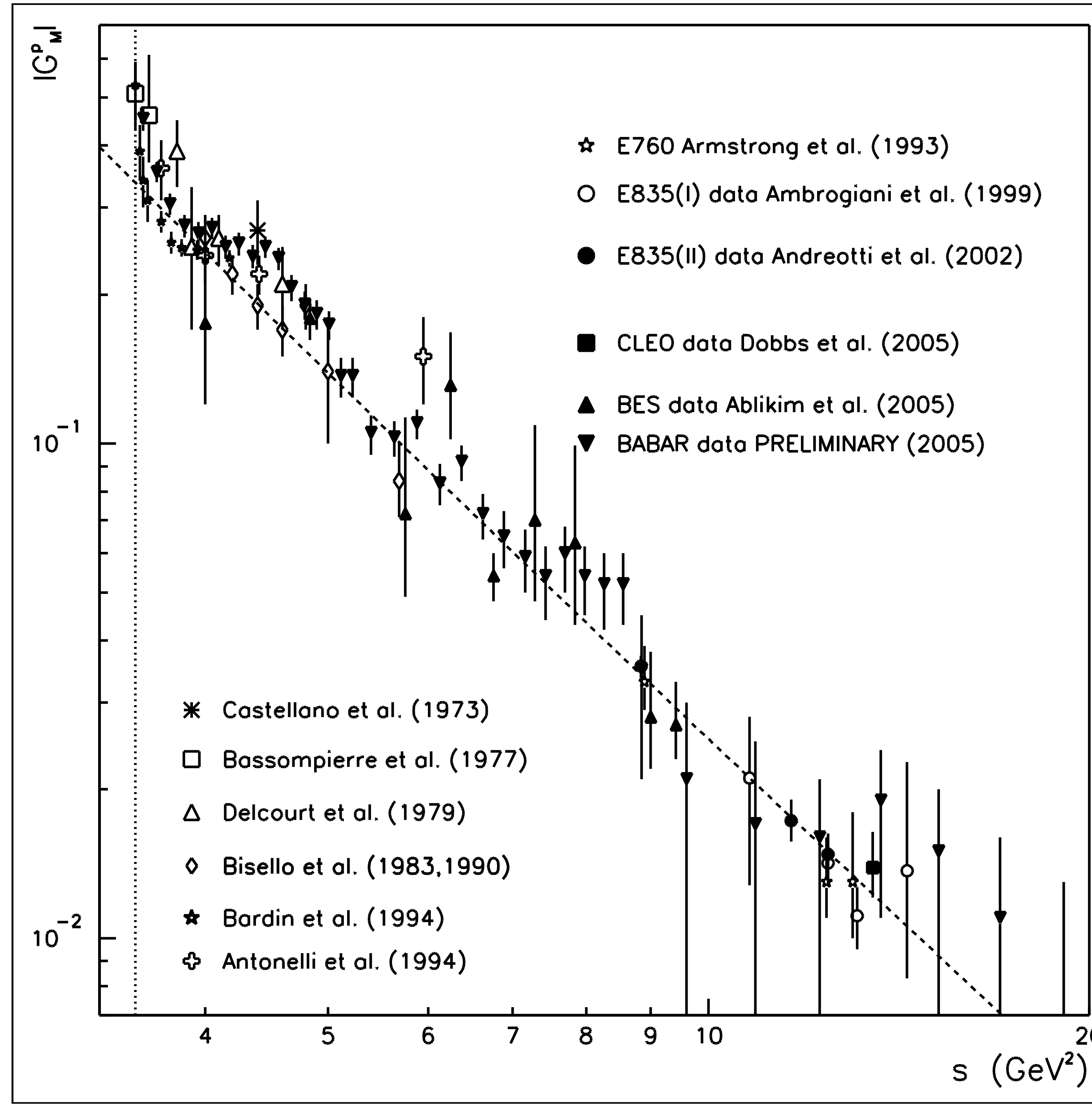
- Exclusive final states
  - access to Generalised Distribution Amplitudes and Transition Distribution Amplitudes
- Time-like electromagnetic Form-Factors

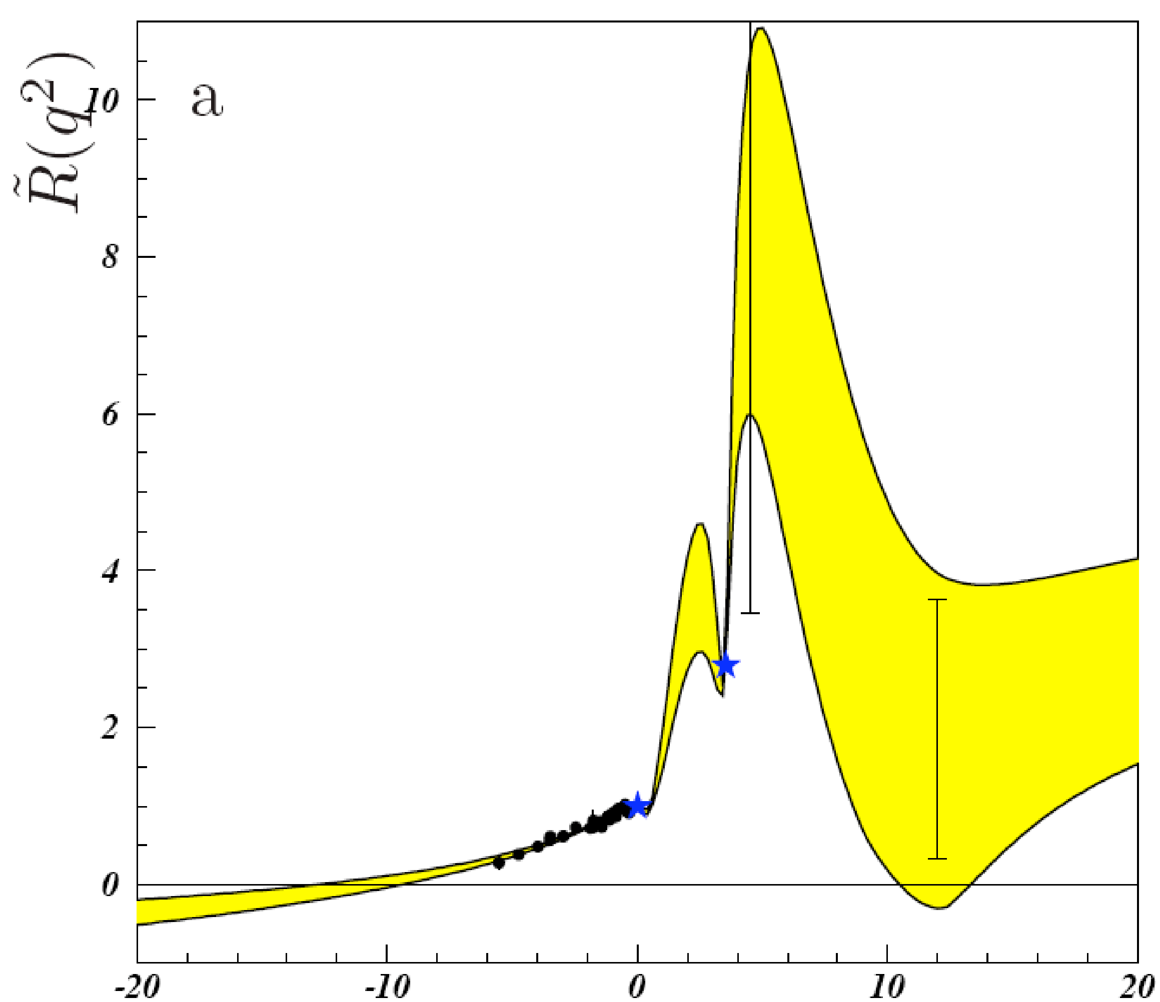
Time-like Form Factors

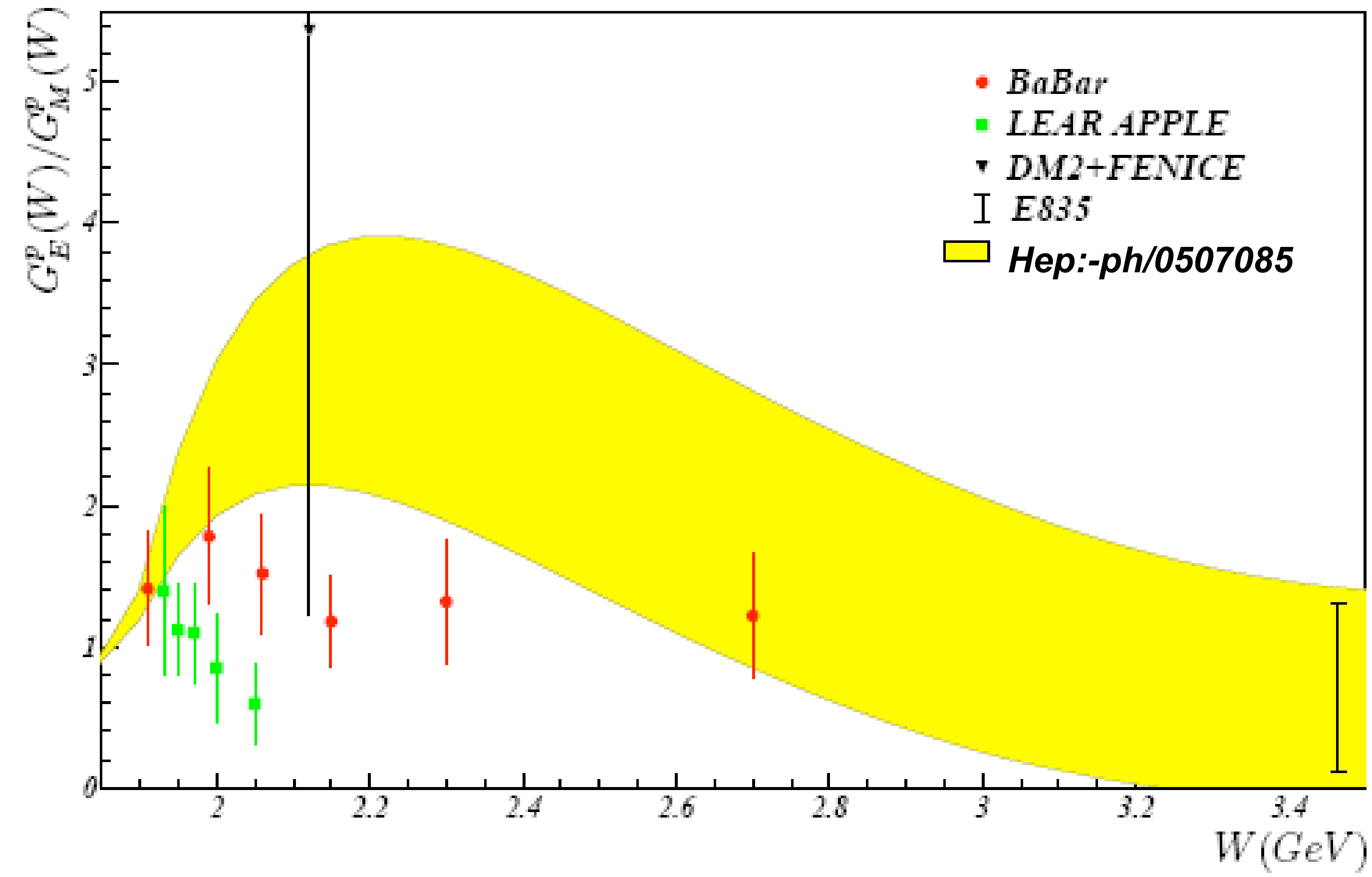
- All data measure absolute cross section $G_E = G_M$
- PANDA will provide independent measurement of G_E and G_M
- widest kinematic range in a single experiment
- Time-like form factors are complex
- precision experiments will reveal these structures



PANDA range

More to explore





R. Baldini et al. EPJ C 46(2006) 412

- Time-like form factors are analytically connected to space-like form factors
- Time-like form factors are complex, get phase in addition
- expect a rich structure in time-like region from dispersion relation model
- even more to learn from single spin asymmetries

Outlook

- Electromagnetic final state observed in proton annihilation offers a novel, unique and complementary approach to nucleon structure
- Access to Boer-Mulders function at early phase of the experiment, additional observables possible with polarised beam
- Access to GDA and TDA in exclusive measurements
- Measurement of time-like form factors over a large kinematic range
- PANDA has a large and vibrant working group on nucleon structure physics with electromagnetic final states anticipating exciting physics from 2013 onwards