Hadron structure studies using $\bar{p}$ beam at J-PARC and P̄ANDA

EIC Workshop@Hongo

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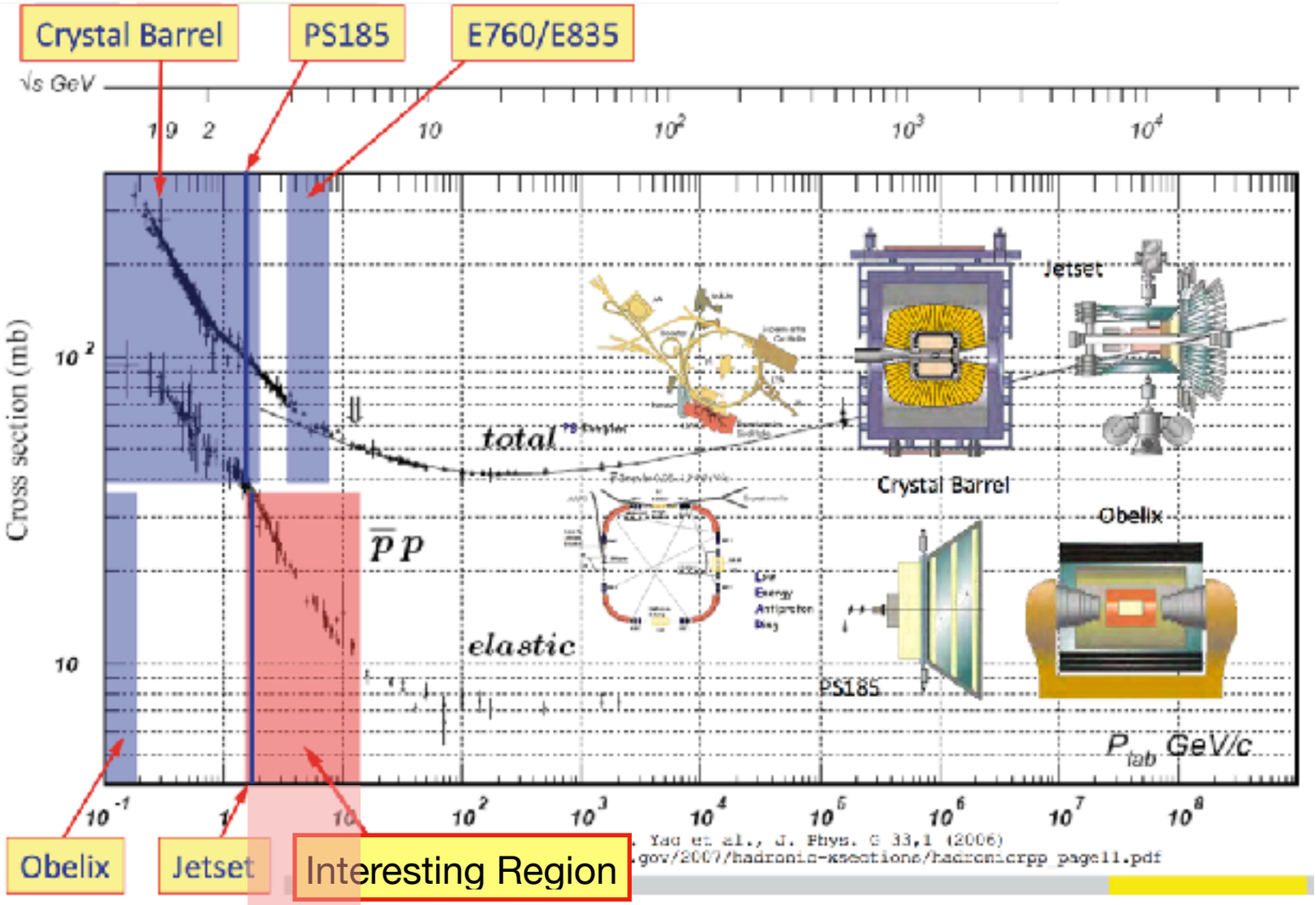
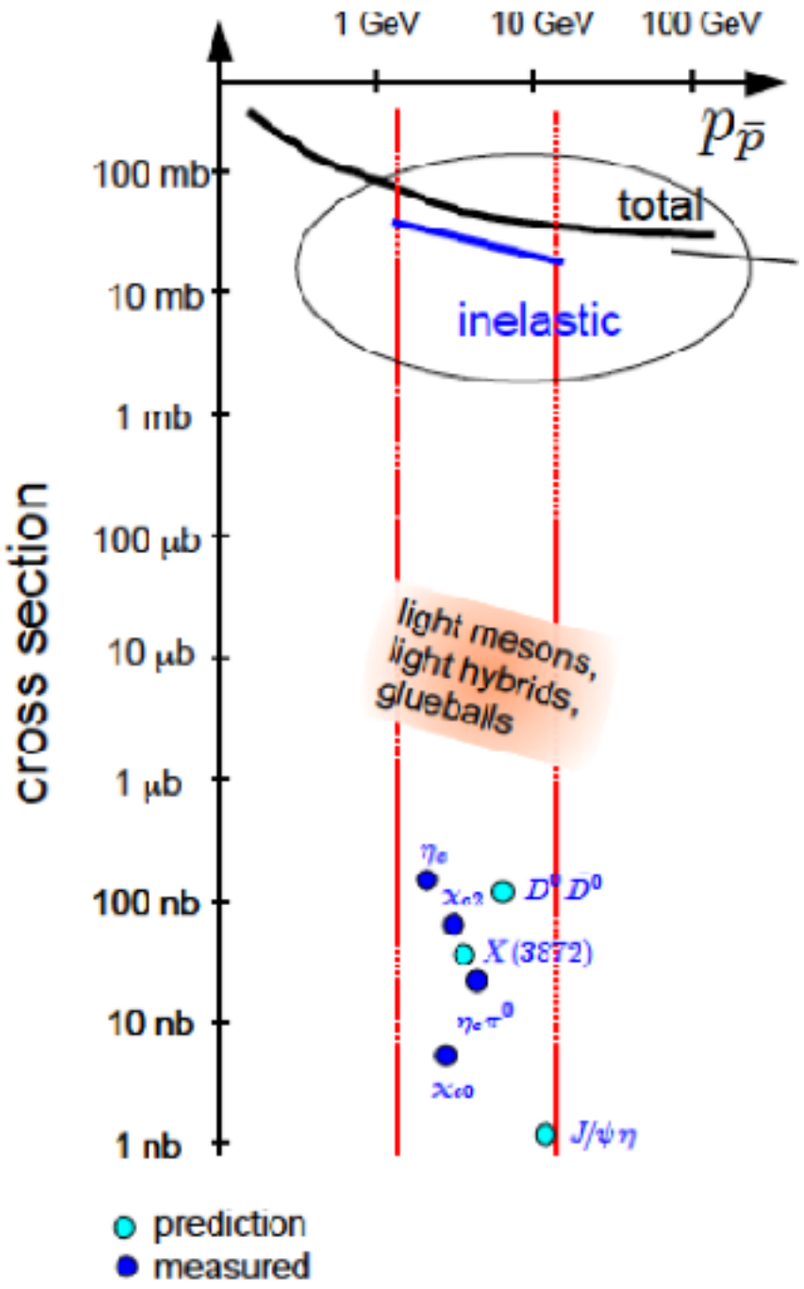
Introduction

Hadron Physics Experiments with $\bar{p}$-induced Reactions

historical overview





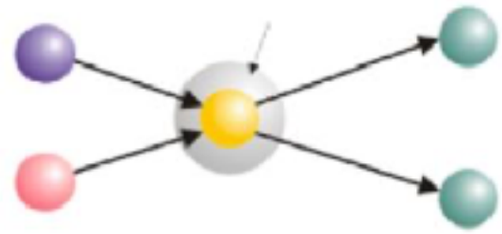
LEAR shutdown in 1996. ~30 years ago.
Interesting Region is kept untouched.

Required a high-speed DAQ and a sophisticated online filtering

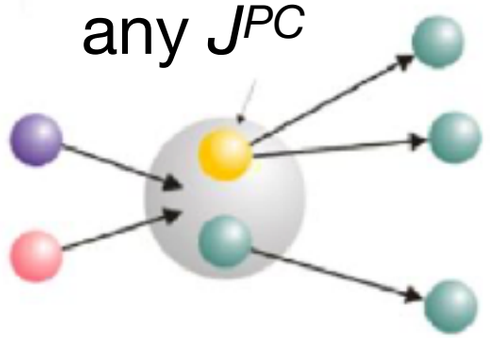
Advantages of Antiprotons

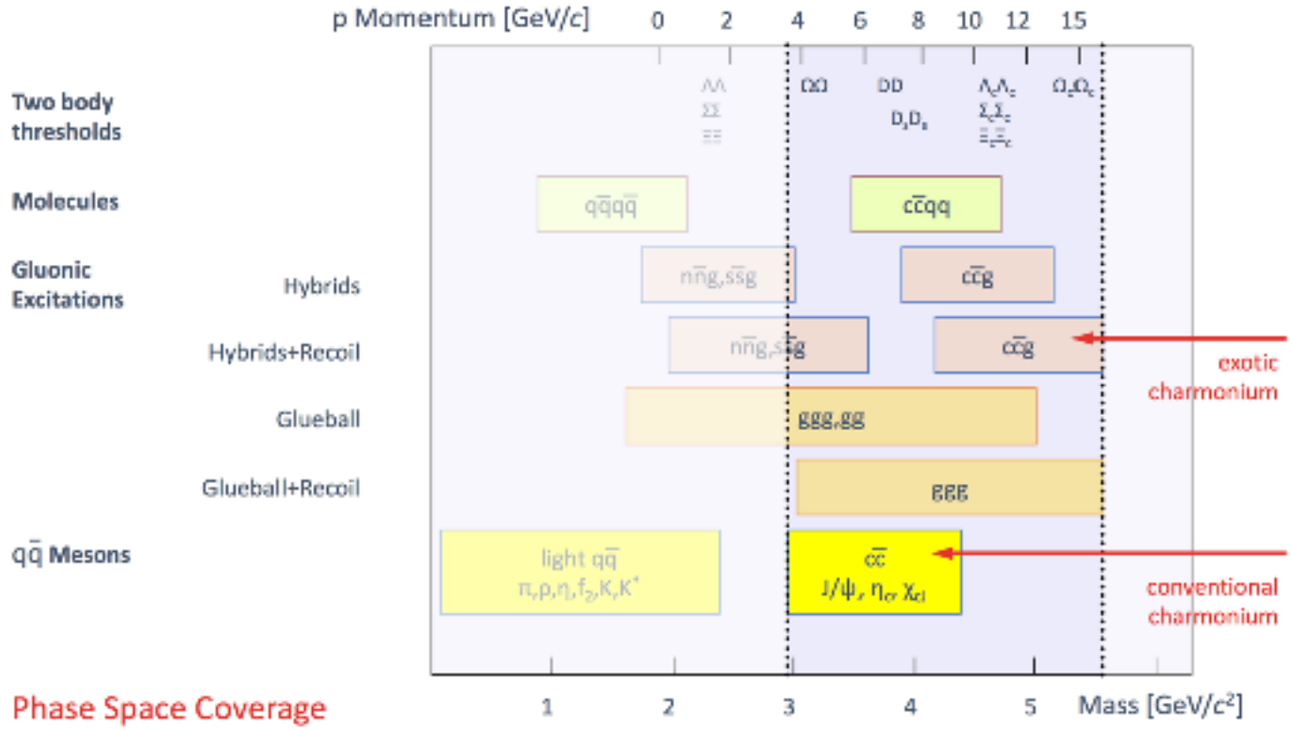
- All $\bar{q}q$-like states accessible in formation
- Gluon-rich environment
- Symmetric Baryon-Antibaryon final states

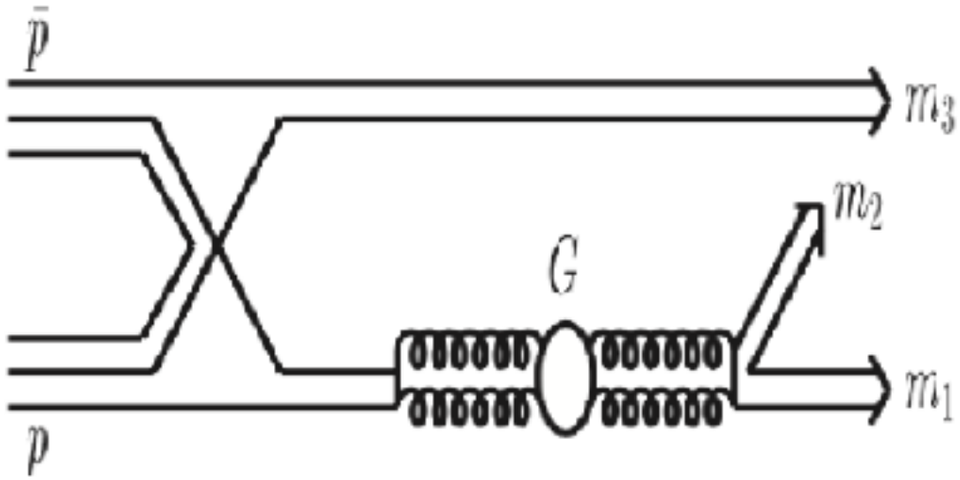
J^{PC} like $\bar{p}p$



any J^{PC}



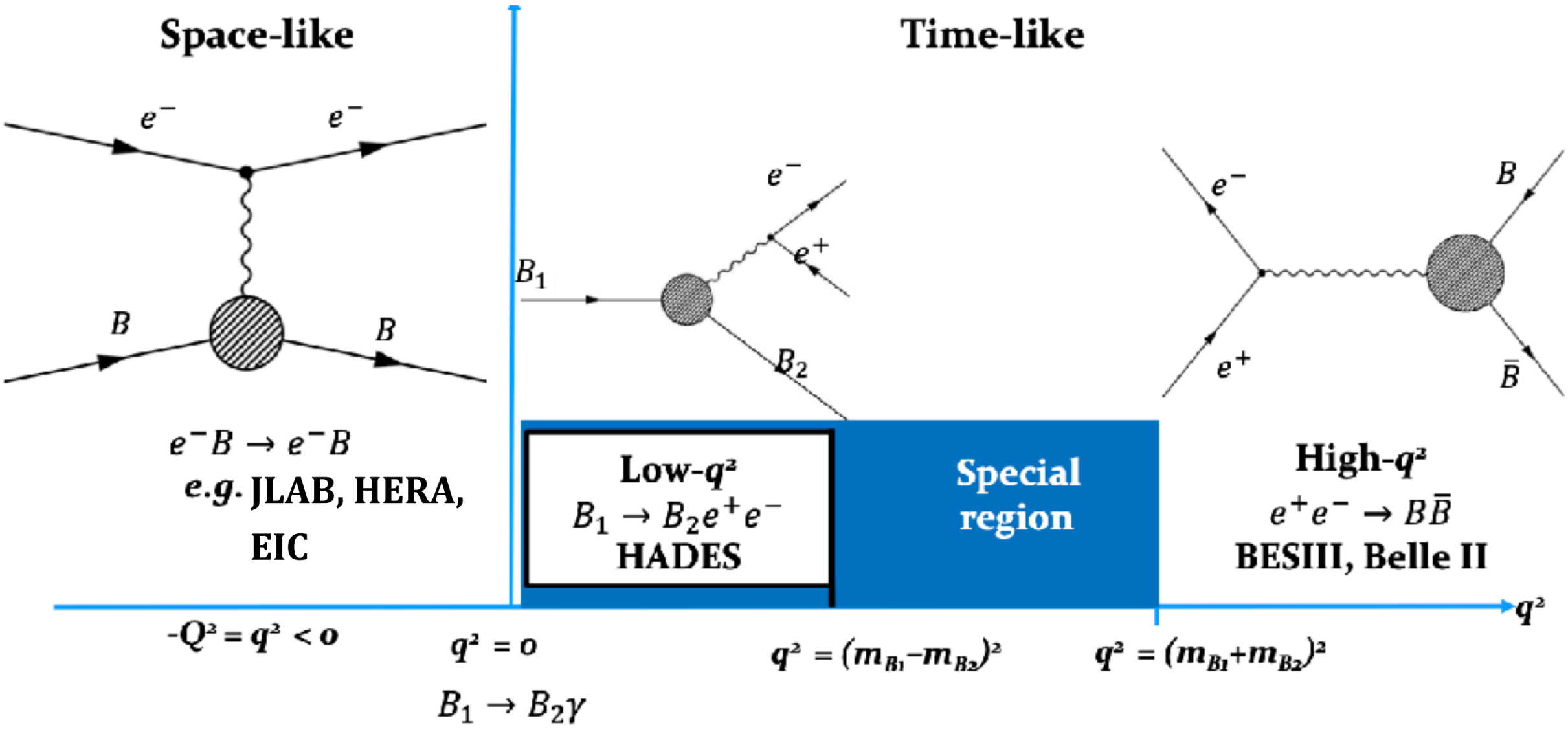




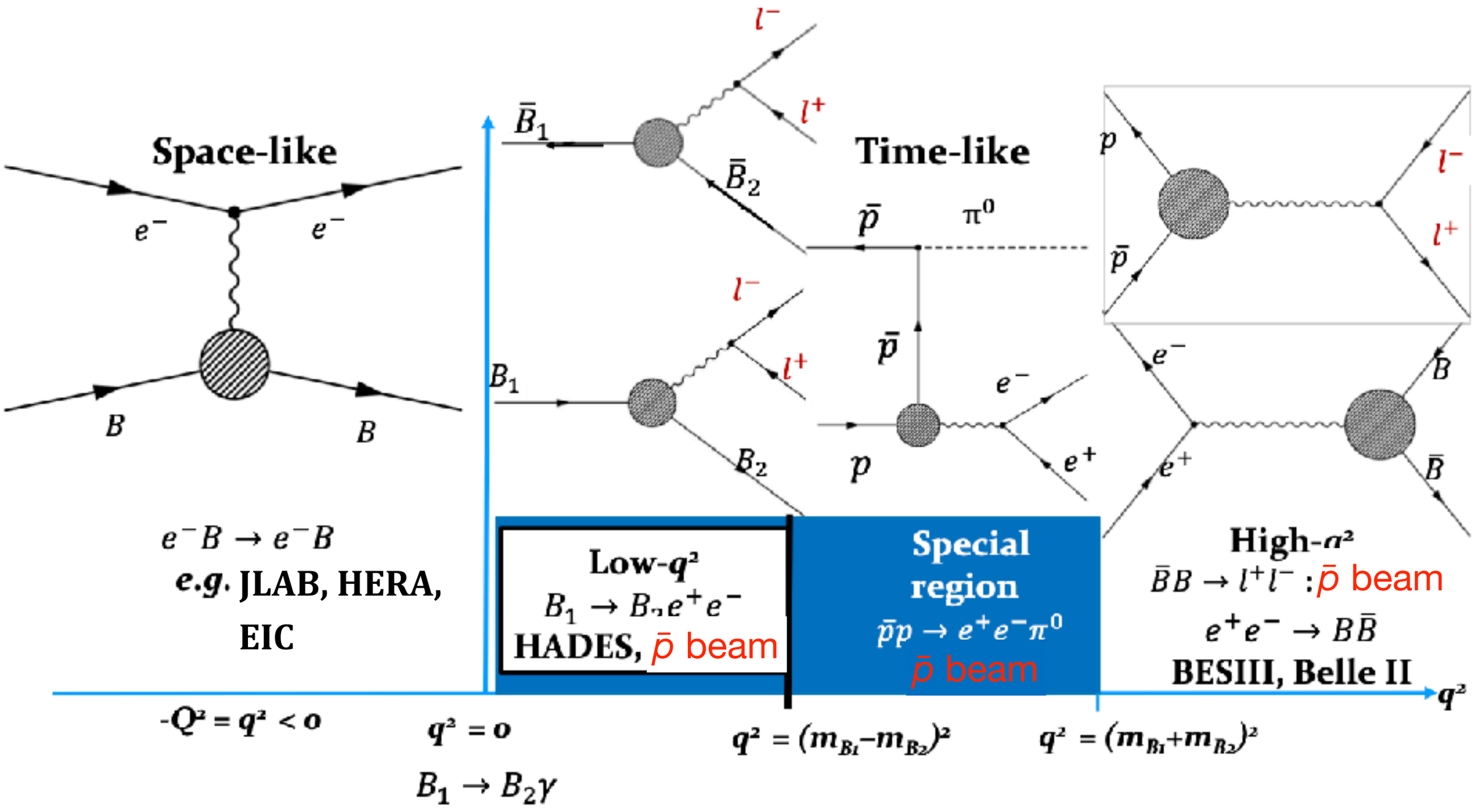
<u>It'd be worth investing efforts into hadron physics studies using $\bar{p}$ beam</u>

Nucleon structure studies using $\bar{p}$-induced reactions

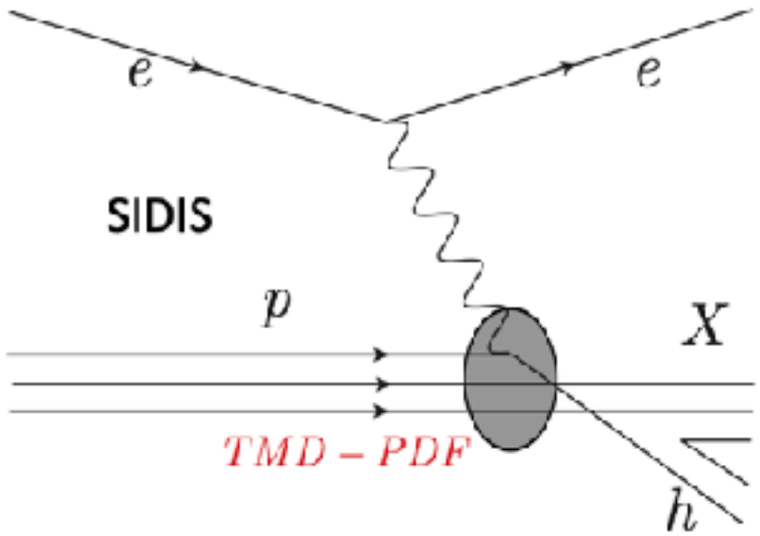
Form Factors

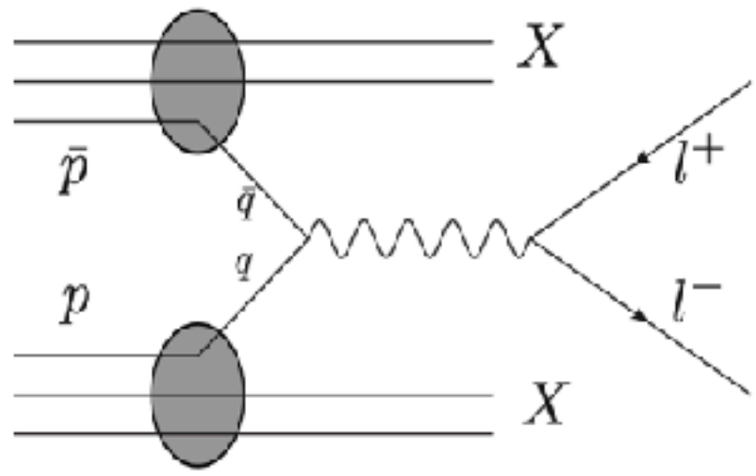


Form Factors



Drell-Yan in $\bar{p}$-induced reaction





TMD-PDFs are convoluted with the fragmentation functions

Direct access to TMD-PDFs

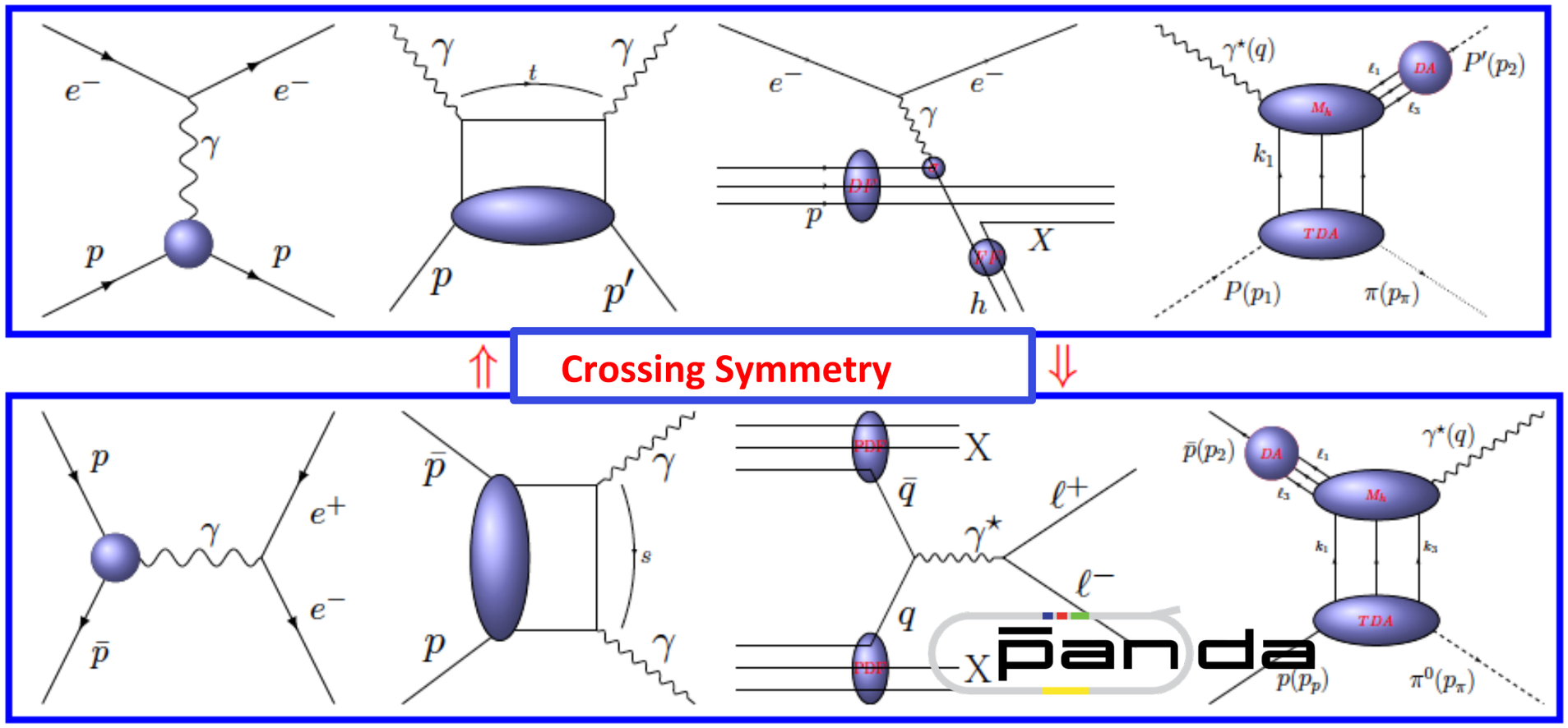
- Related to DIS (inclusive or semi-inclusive) by rotation of the Feynman diagram – Drell-Yan the *s*-channel process, SIDIS the *t*-channel process

Test of Universality
and the QCD TMD factorization

"Drell-Yan" process – Drell and Yan, PRL 25, 316 (1970); Erratum PRL 25, 902 (1970)

A. Dbeyssi

Study of the Nucleon Structure at PANDA



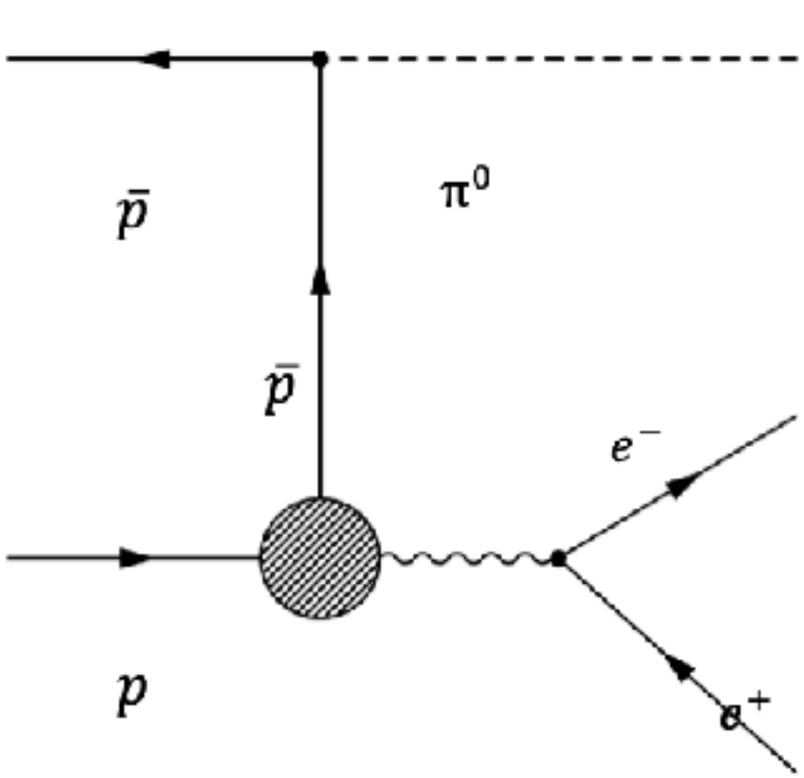
- Proton Electromagnetic Form Factors (FFs)
- Generalized Distribution Amplitudes (GDAs)
- Transverse Momentum Dependent Parton Distribution Functions (TMD-PDFs)
- Transition Distribution Amplitudes (TDAs)

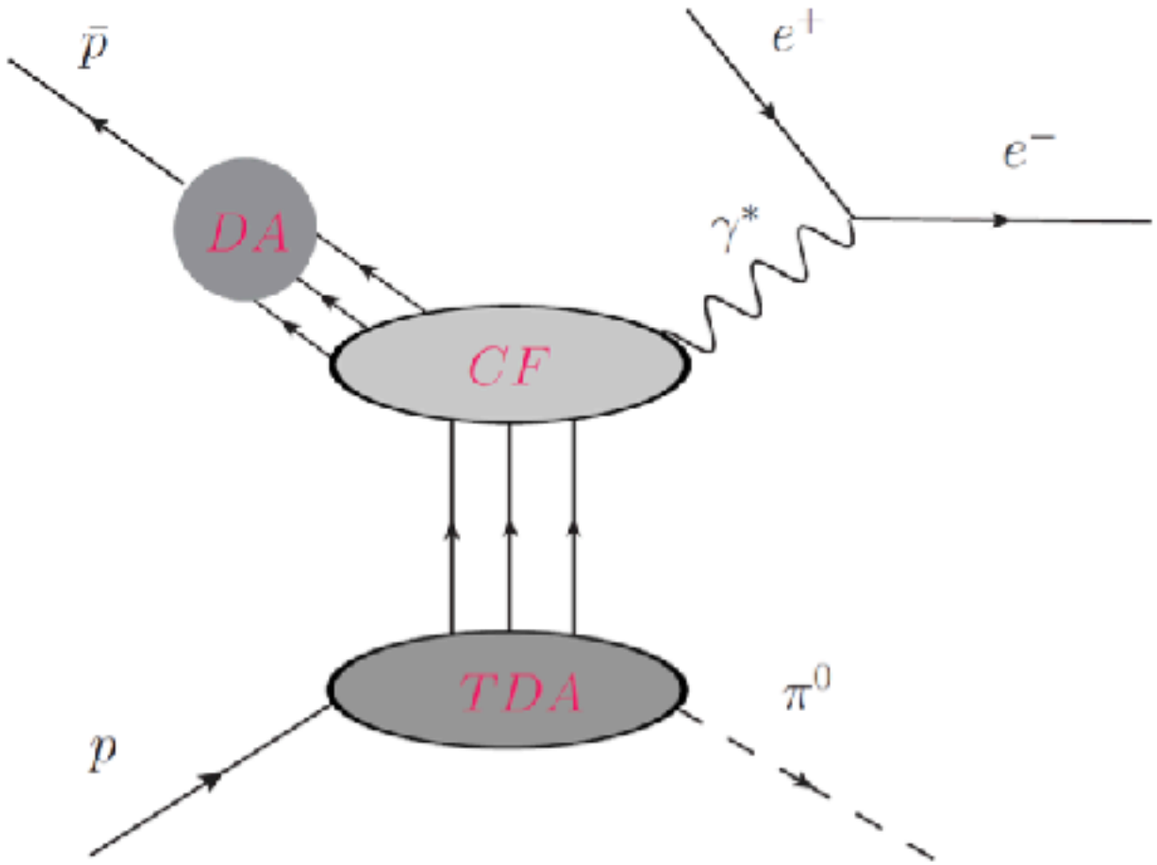
Hadron Structure

The $\bar{p}p \to \pi^0 e^+ e^-$:

- Low e^+e^- mass: Regge framework to constrain time-like form factors*
  → Phase between proton G_E and G_M for the first time
  → PANDA unique!

- High e^+e^- mass: Transition Distribution Amplitudes (TDAs)**,***
  → PANDA complementary!

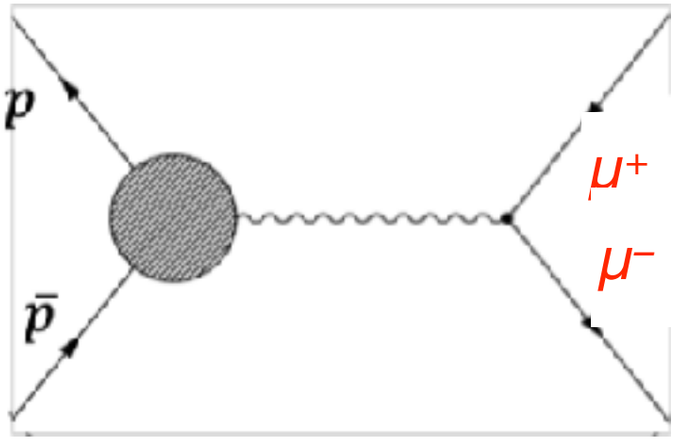




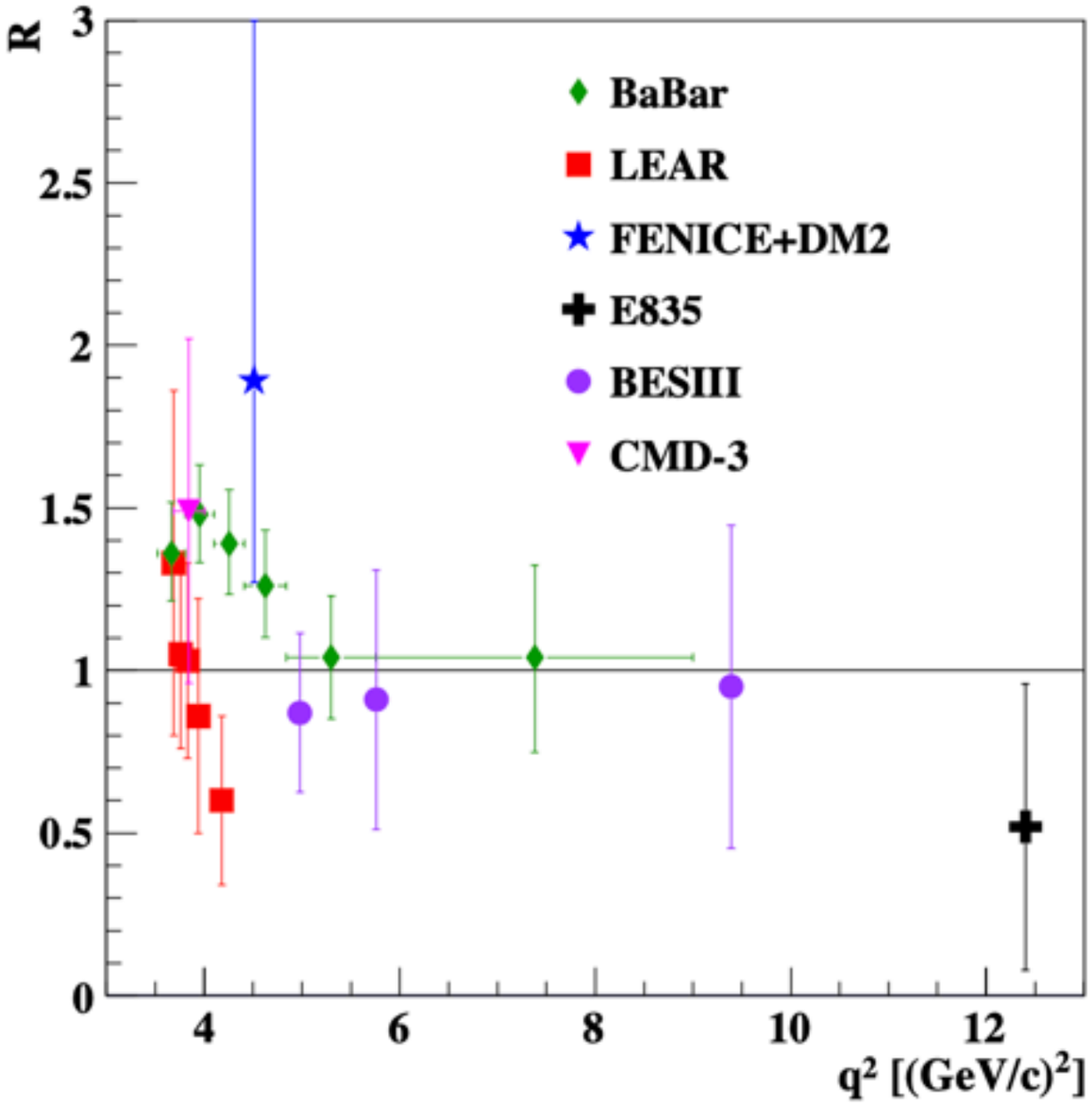
* Guttmann & Vanderhaeghen, Phys. Lett. B 719, 136-142 (2013)
**PANDA: Eur. Phys. J A 51, 107 (2015).
***PANDA: Phys. Rev. D 95, 3, 032003 (2017)

Main experimental concerns

- $l^+l^- = e^+e^-$
  - calorimeter
  - main background $\bar{p}p \rightarrow \pi^+\pi^-$, suppression of $>10^6$ needed
- $l^+l^- = \mu^+\mu^-$
  - First time measurement with muon in final state
  - μ/π PID more difficult than e/π
  - Study of radiative corrections
  - Consistency check of proton form factor data
  - Test of lepton universality
- $e^+e^-\pi^0$
  -



World record on TL proton FF Ratio



@ BaBar (SLAC): $e^+e^- \to \bar{p}p\gamma$

- data collection over wide energy range

@ PS 170 (LEAR): $\bar{p}p \to e^+e^-$

- data collection at low energies

Data from BaBar & LEAR show different trends

@ BESIII: $e^+e^- \to \bar{p}p$

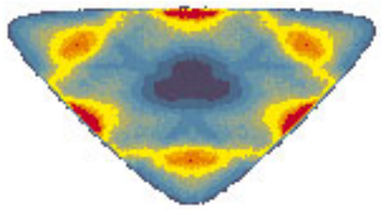
- Measurement at different energies
- Uncertainties comparable to previous experiments

@ CMD-3 (VEPP2000 collider, BINP):

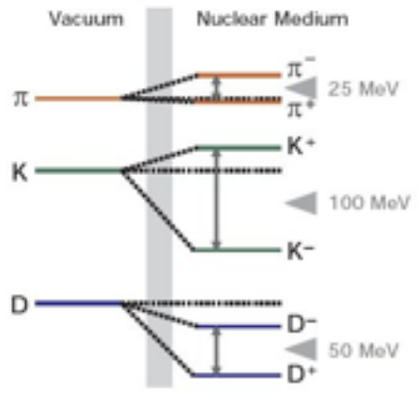
- Energy scan $\sqrt{s} = 1 - 2\ GeV$
- Uncertaincy comparable to the measurement by BaBar

Feasibility study at PANDA

P̄ANDA Physics Pillars

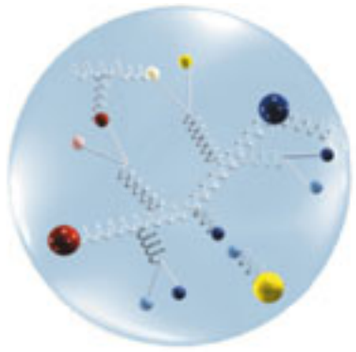


Search for exotic particles and measurement of hadron properties



Study in-medium effects of hadronic particles

Nucleon Structure

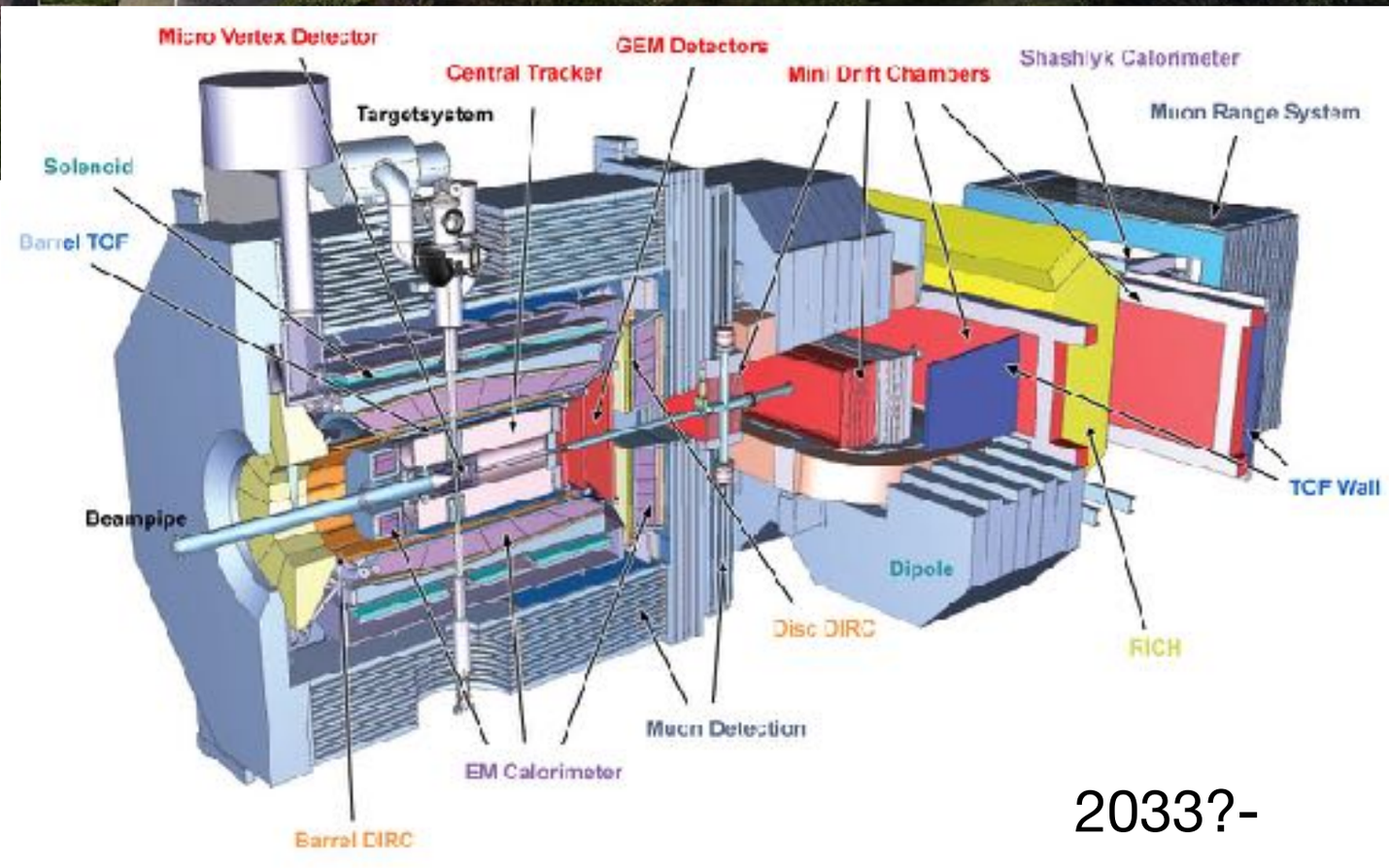


Generalised parton distribution, Drell-Yan processes and time-like form factor of the proton

Hypernuclei

Measurement of nuclear properties with an additional strangeness degree of freedom

P̄ANDA at FAIR/GSI



Antiproton Storage Ring (e/stoch.-cooling)
Fixed target (cluster jet / pellet target)
Luminosity up to $2 \cdot 10^{32}$ $cm^{-2}s^{-1}$

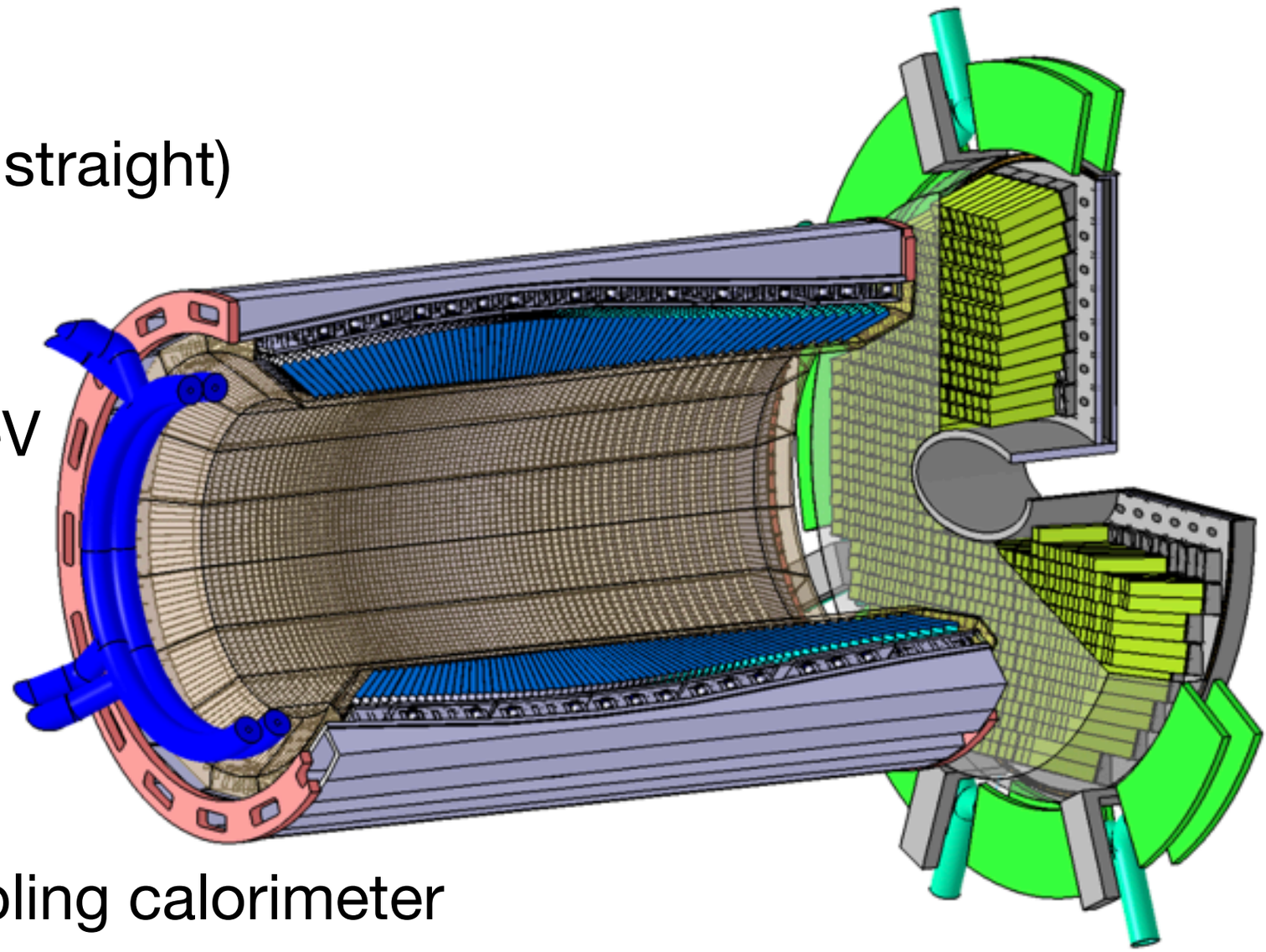
Almost 4π acceptance,
charged particles and photons
~100 μm vertex resolution; δp/p~1%
calorimetry
Luminosity monitor
trigger-less continuous readout
flexible event selection, no hardware trigger

2033?-

P̄ANDA EMC

Target region

- 16k $PbWO_4$ crystals
- ~20cm length (tapered and straight)
- –25°C operation
- APD readout
- ΔE~1%, Δx~1.1mm @10GeV

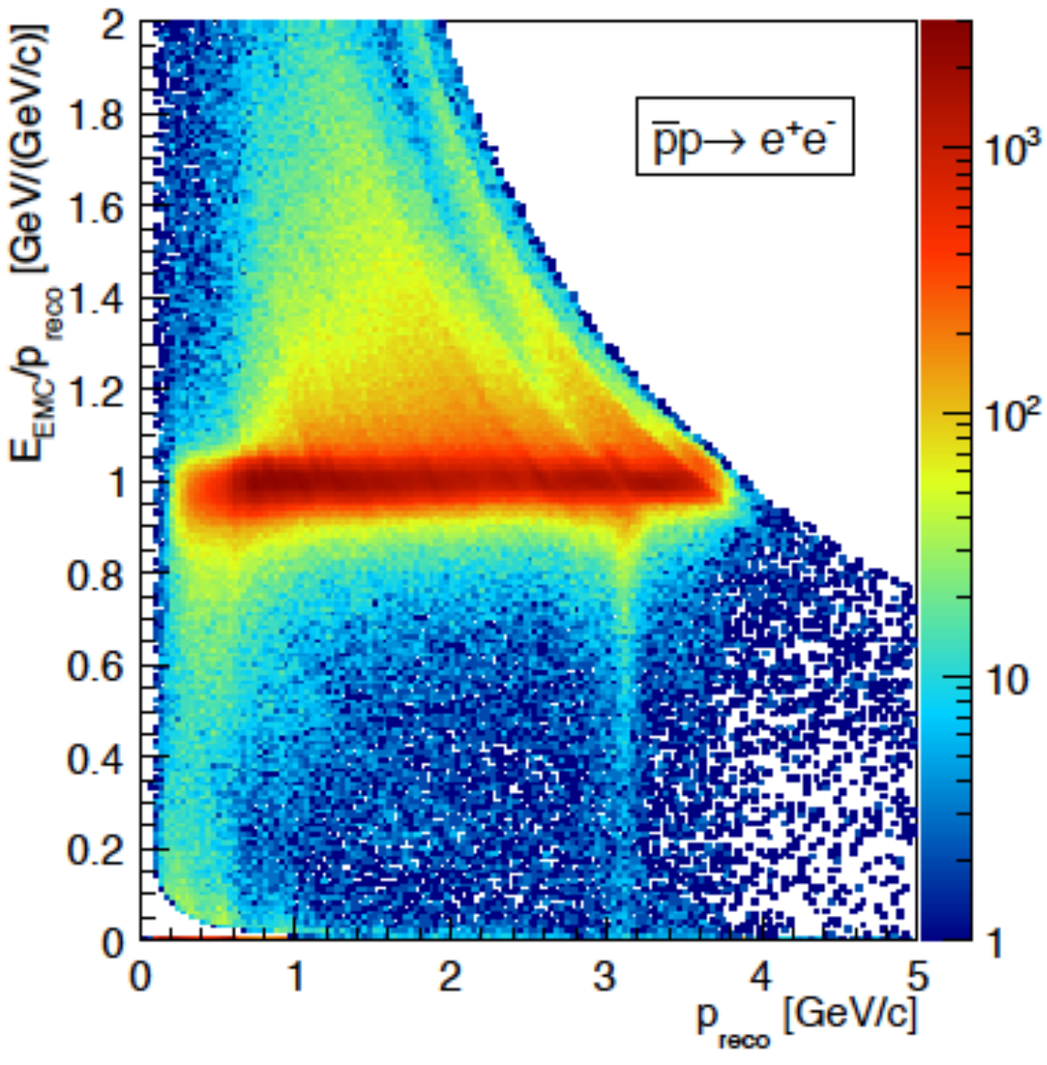


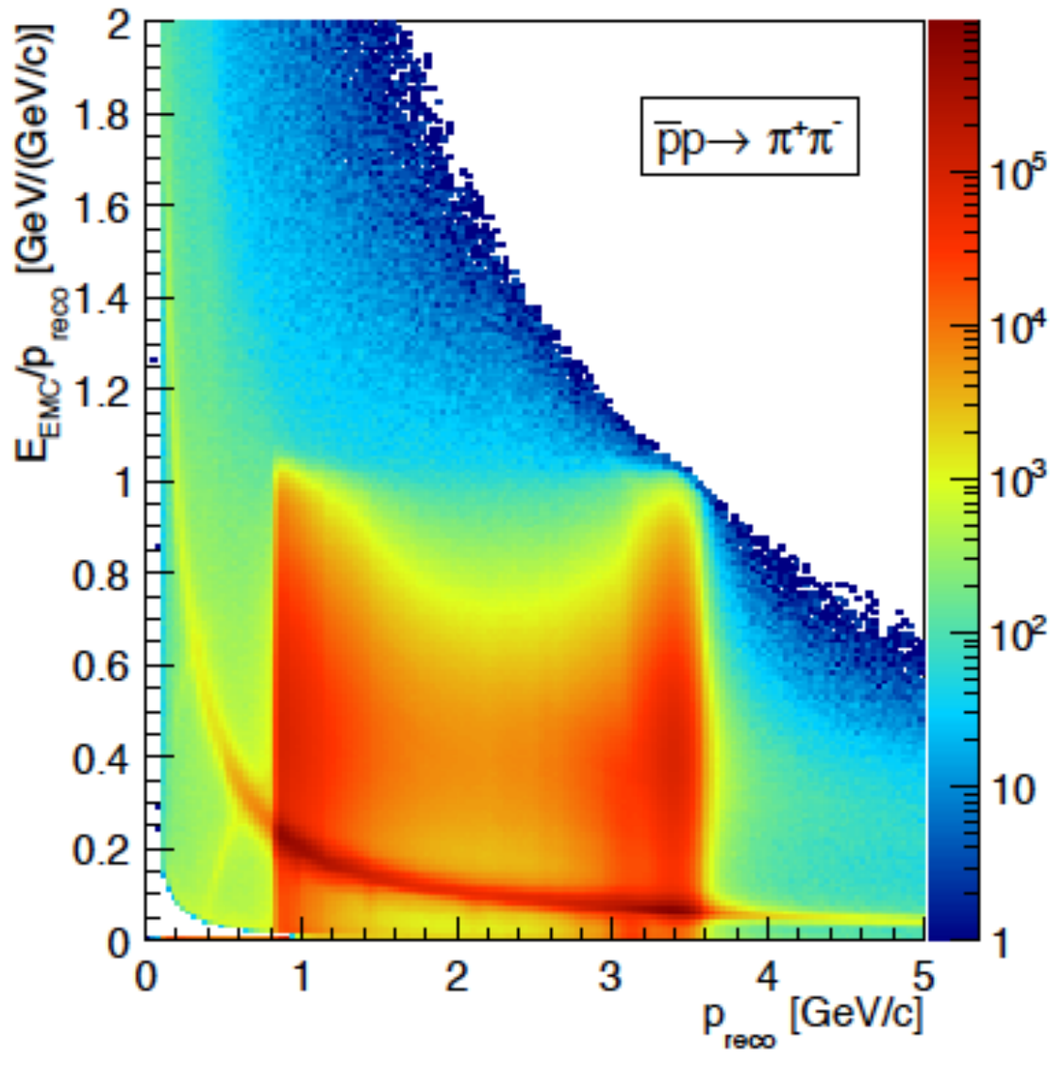
complemented with

- forward: Shashlik type sampling calorimeter
- backward endcap calorimeter

covering ~4π

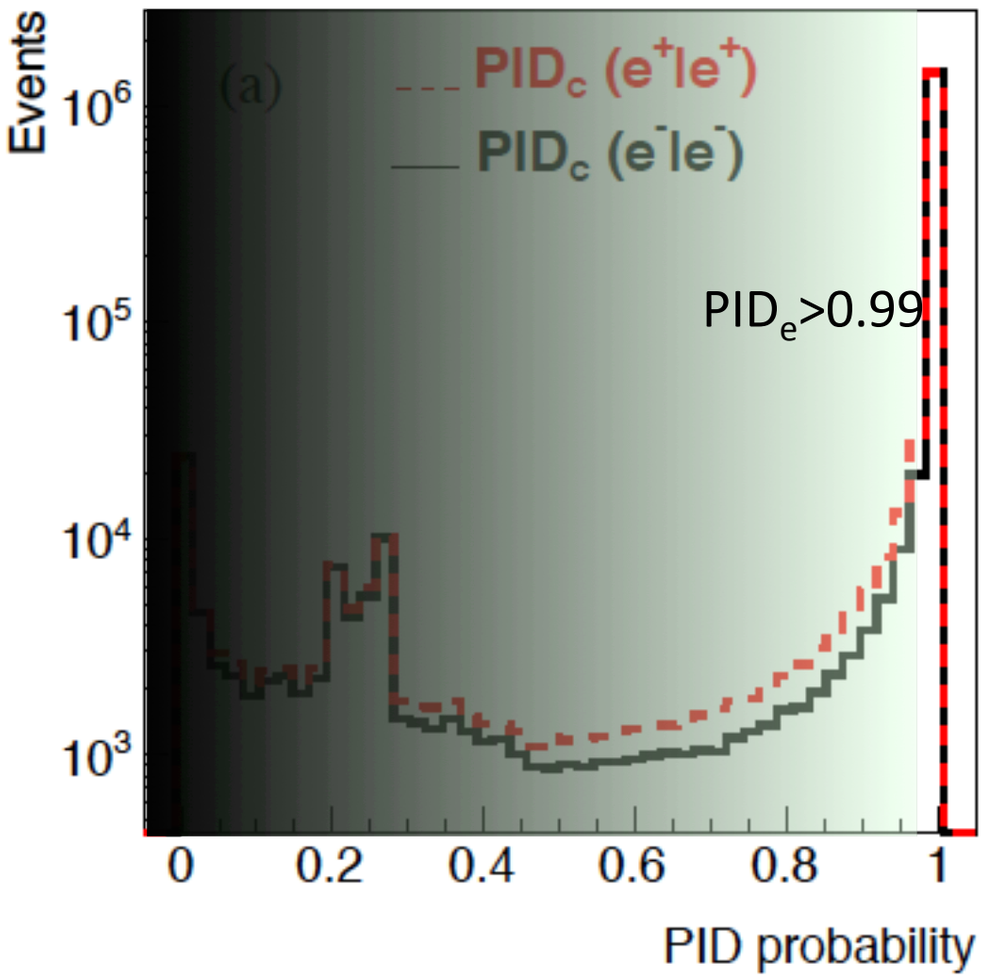
How to identify the signal from the background?

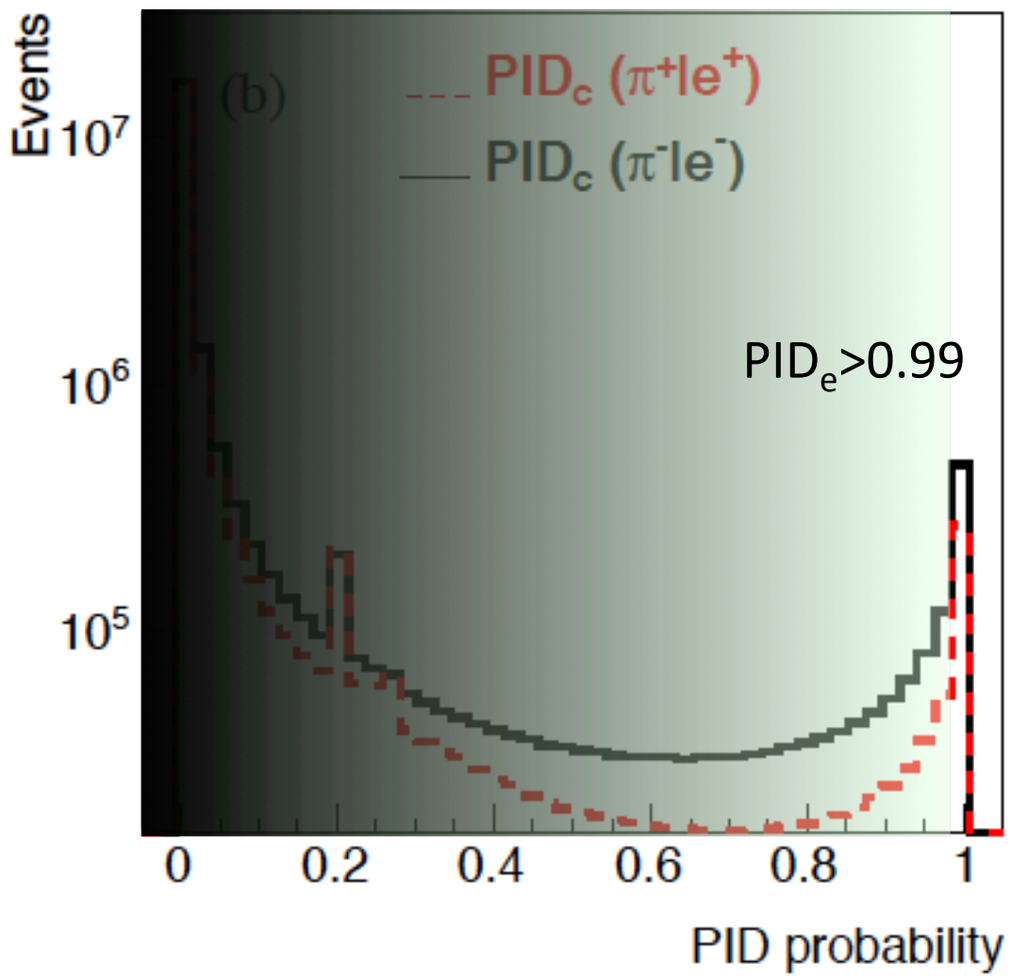




Energy deposited in the EMC over the tracking momentum: E_{EMC}/p_{rec}

How to identify the signal from the background?

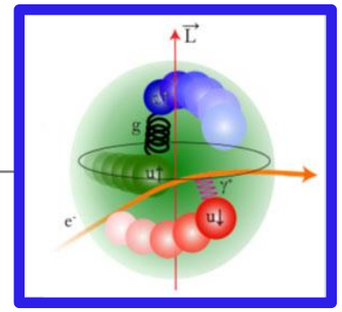




- **Background rejection ~ 10^{-8}**
  Signal pollution < 1%

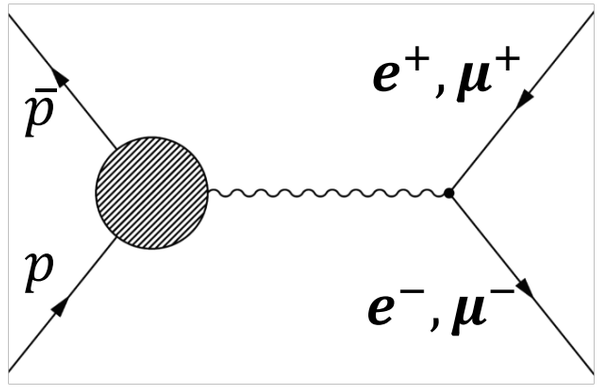
Clean signal → extraction of the proton form factors from the cross section

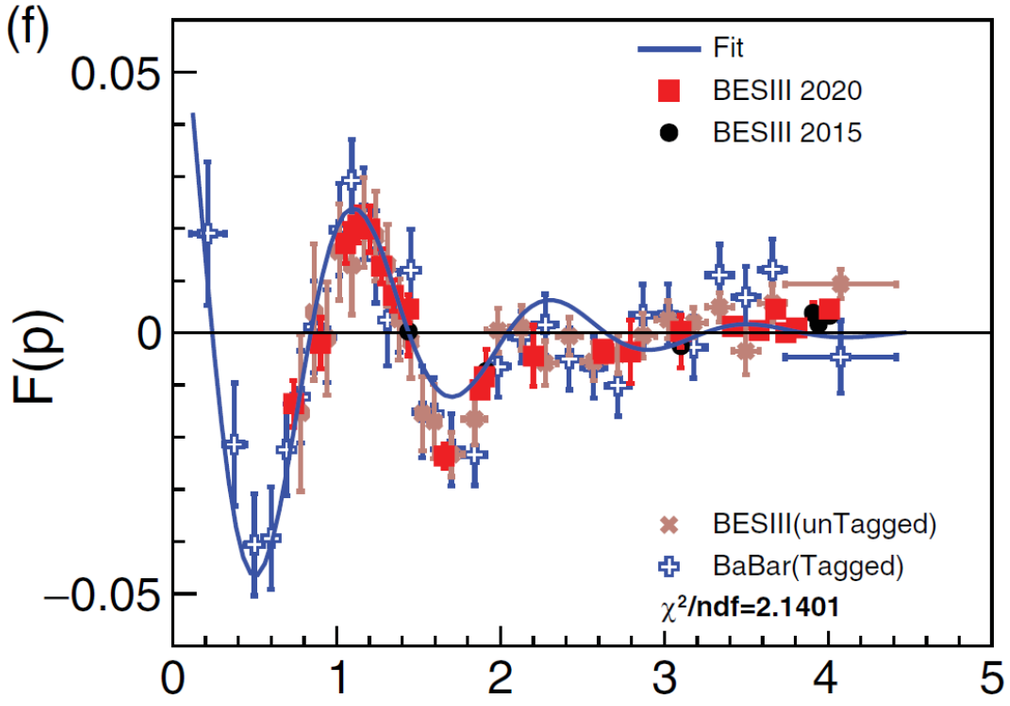
Form Factors



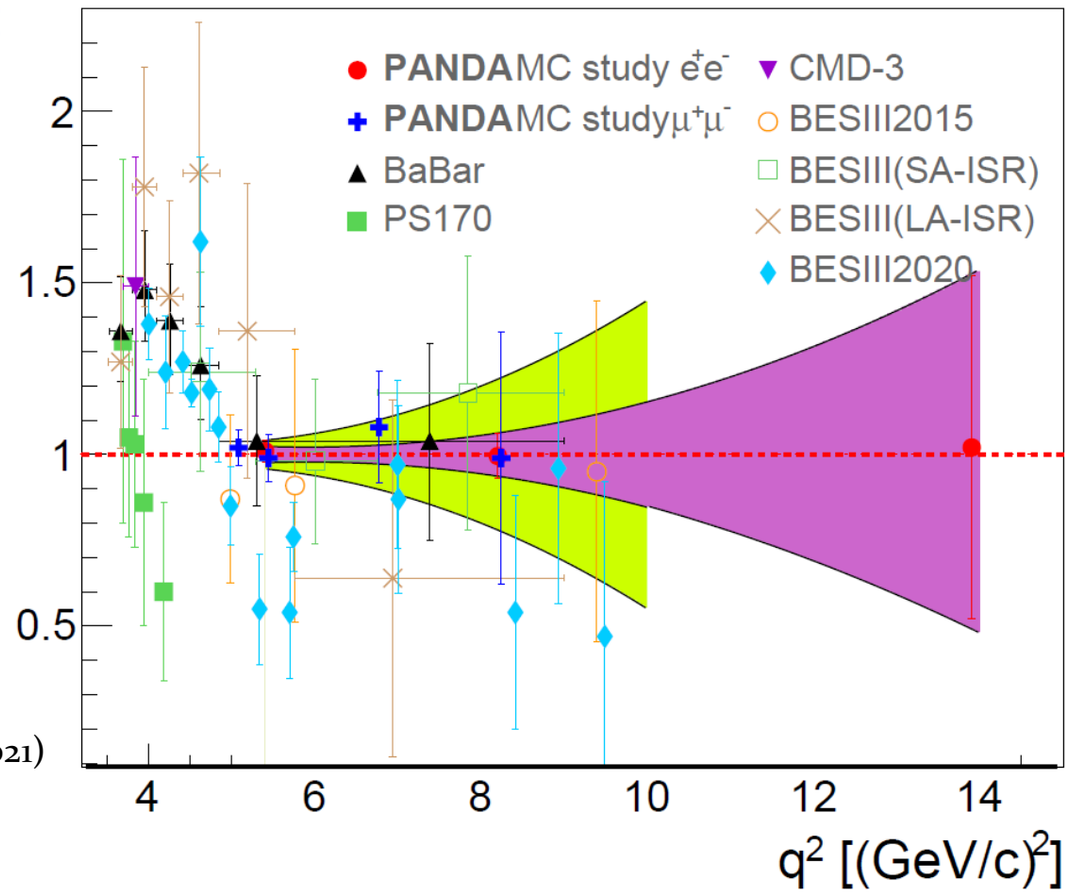
High-q^2 structure:

- Form factors with electron **and** muons.
- $e^+e^- \rightarrow \bar{p}p$ *vs.* $\bar{p}p \rightarrow e^+e^-$
  - Previous experiments reveal discrepancies*
  - New insights on oscillations**,***?
- Broad energy range .
- High precision already in Phase One.****





Stage 2 e^+e^-, Stage 3 e^+e^-, Stage 3 $\mu^+\mu^-$

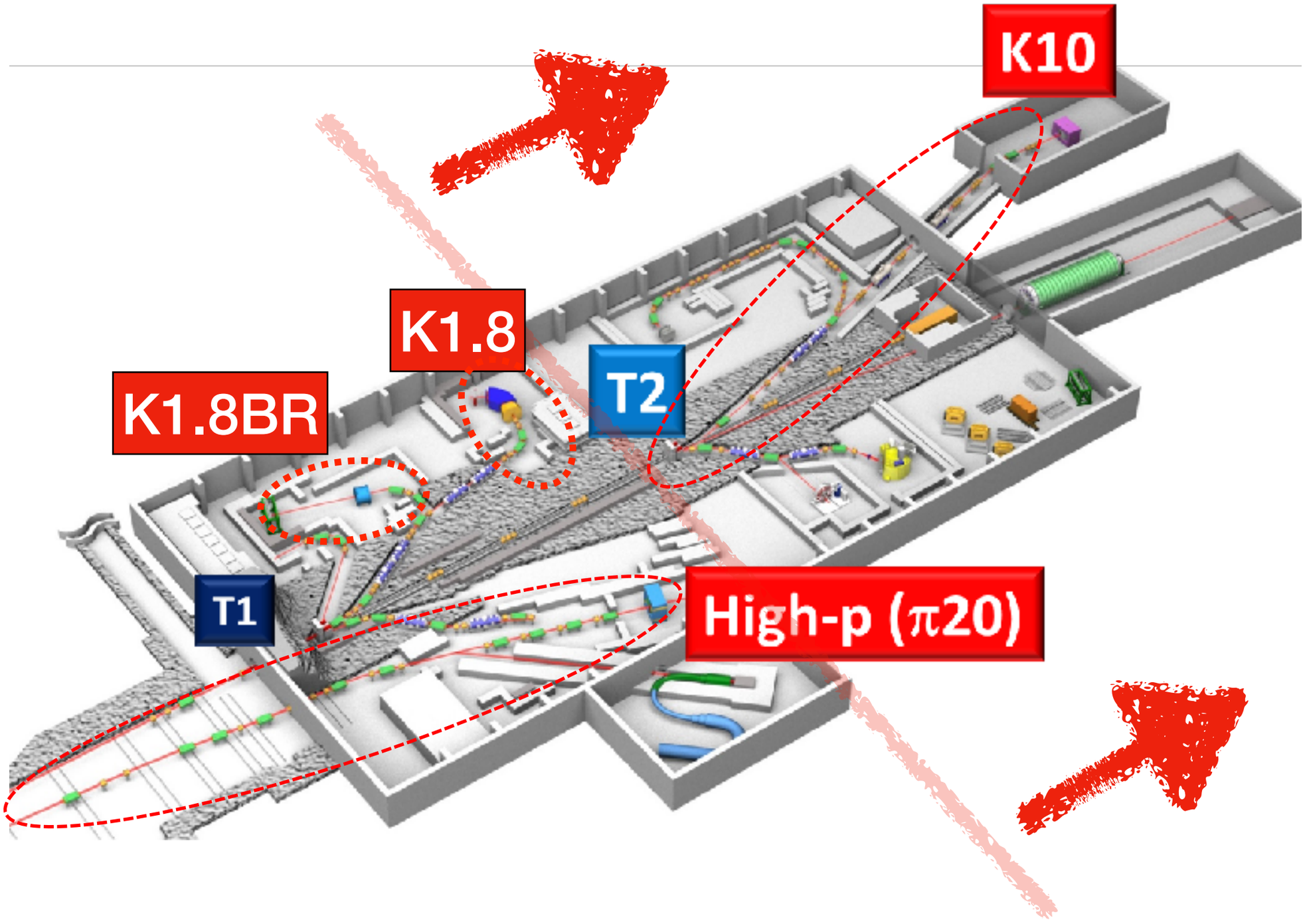


*PS170: Nucl. Phys. B 411, 3 (1994)
** BESIII: Phys. Rev. Lett. 124, 042001 (2020), BESIII: Nature Phys. 17, 1200 (2021)
***BaBar: Phys. Rev. D 87, 092005 (2013).
****PANDA: Eur. Phys. J A 57:30 (2021), PANDA: Eur. Phys. J A 57:184 (2021)
****PANDA: Eur. Phys. J A 52:10 (2016)

$\bar{p}$ beam at J-PARC and the nucleon structure study feasibility

$\bar{p}$ beam in the J-PARC Hadron Hall

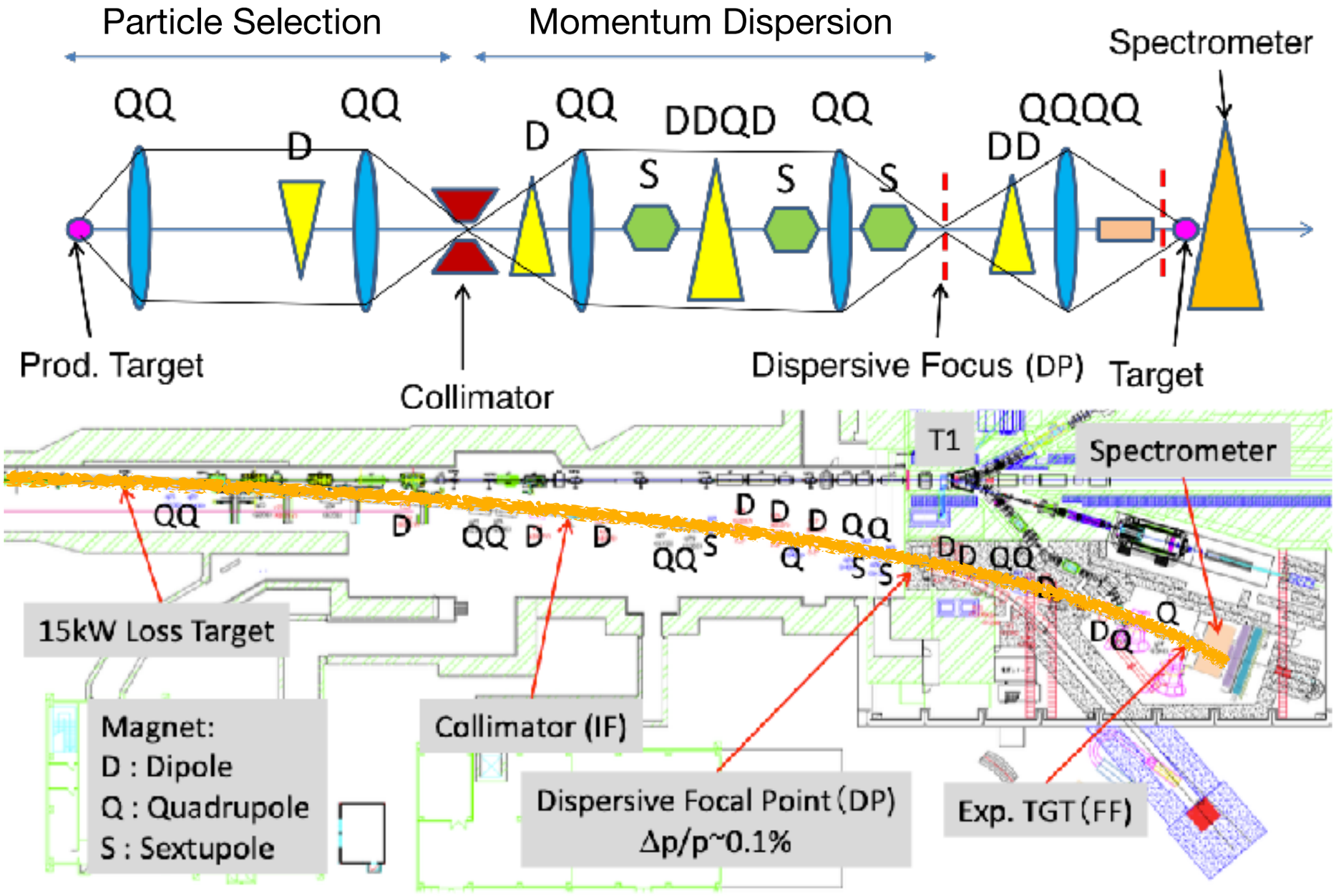
present and future



π20 beam line

High momentum, high resolution beam line

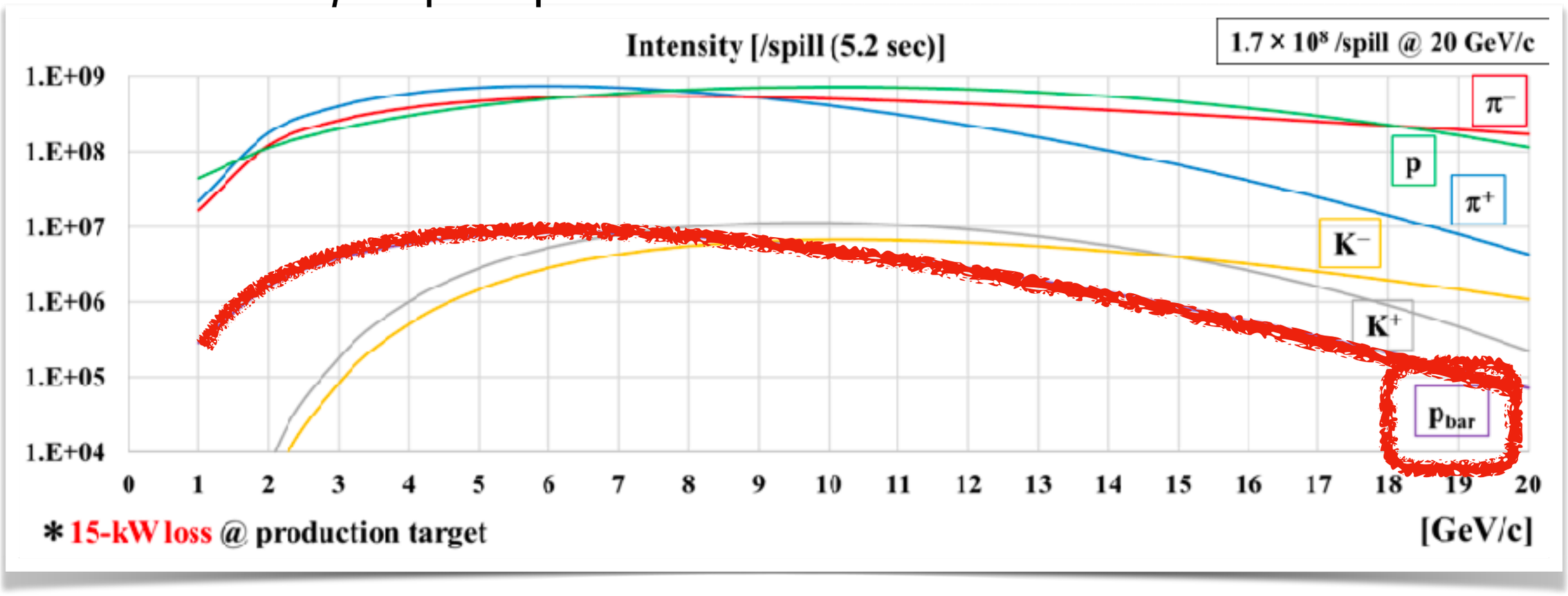
High-intensity pion beam: 2 msr・%, 1.0 x 10^7 Hz @15GeV/c



High momentum resolution Δp/p~0.1% with dispersion analysis

Expected particle intensity at π20

~1 M $\bar{p}$ /spill up to 14 GeV/c

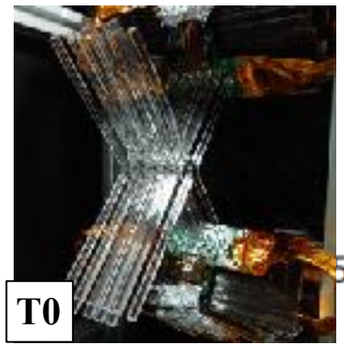


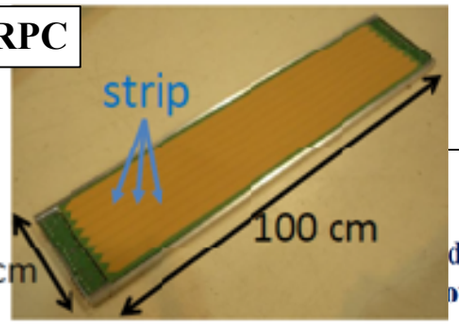
high-p beam line (primary beam, existing) to π20 beam line (2ndary)

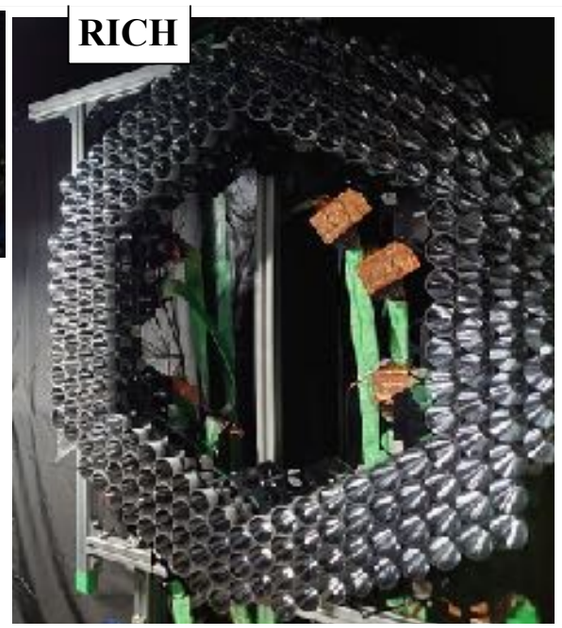
production target, additional shield, magnet power supply upgrade

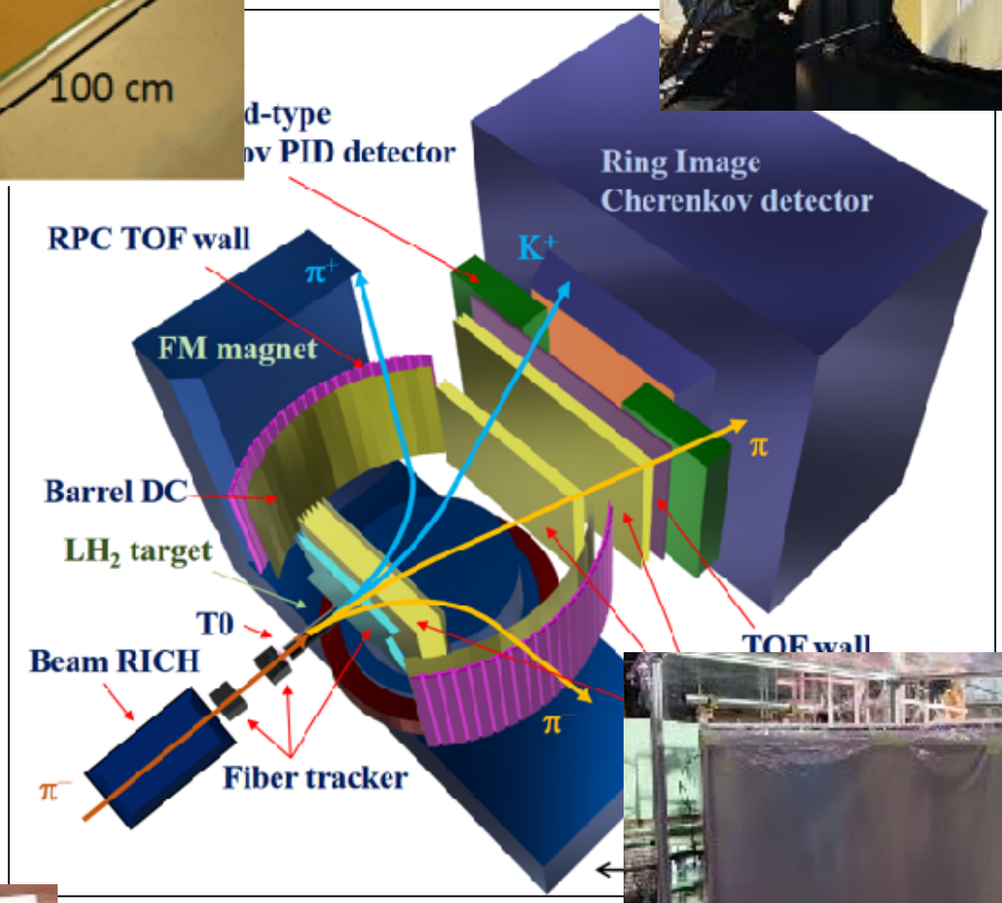
Spectrometer at π20 (E50)

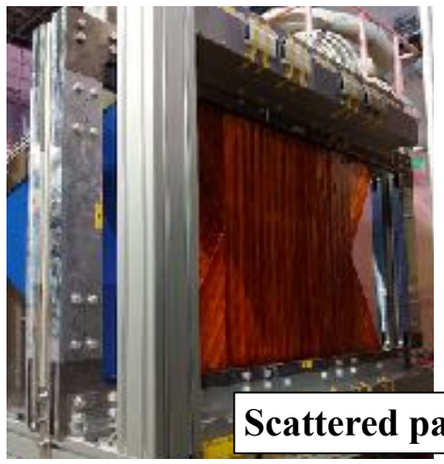
Shirotori, J-PARC HEF-Ex. Workshop (2023)

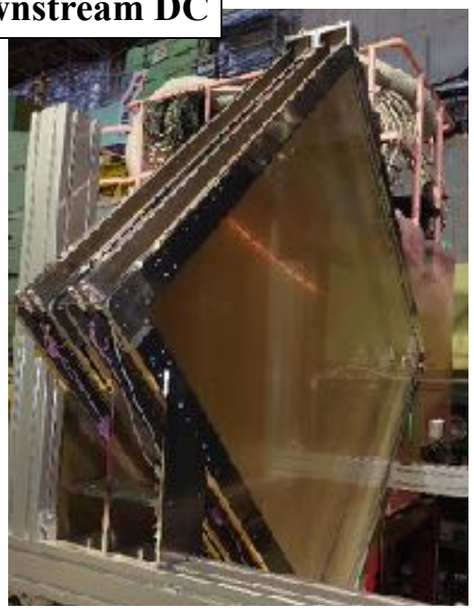












Multi-purpose spectrometer under construction (👍)

High-speed streaming DAQ under development (SPADI alliance👍)

Other Condition Comparison

	Trigger-less free-running DAQ	high-level online filter	Multi-purpose data taking	Electron, neutral particle meas.	Luminosity Measurement
MARQ @J-PARC	Yes NestDAQ	yes (WIP)	Yes (Cocktail Beam)	-	beam counters
P̄ANDA	Yes FaiirMQ/ PANDARoot	yes (WIP)	Yes	4π	$\bar{p}p$ elastic scattering

J-PARC AntiMatter Consortium

- The $\bar{p}/\bar{d}$ beam is available at J-PARC hadron hall, and there are a clear high potential to be exploited.
- Anti-deuteron Programme
  - Y. Ma
- Antiproton Programme
  - K. Suzuki
- Anti-neutron
  - Higuchi
- A handful of people with potential interests

Summary, Future Perspective

- Hadron physics with $\bar{p}$-induced reactions
  - plenty of opportunities still to be exploited
    - complementary study of nucleon structure with lepton or photon experiments
    - J-PARC, P̄ANDA@FAIR
- MARQ spectrometer
- Synergy with EIC?