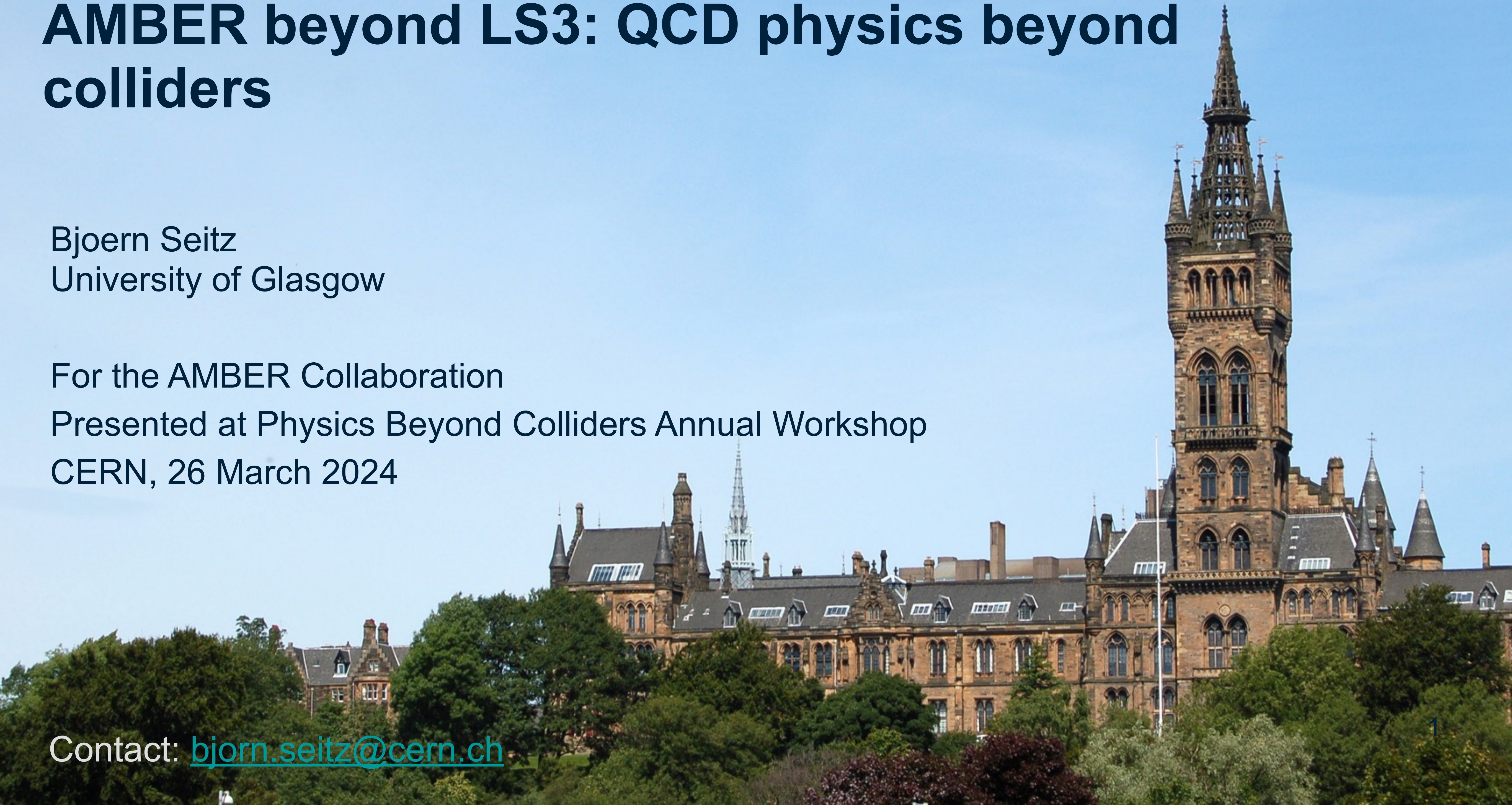
AMBER beyond LS3: QCD physics beyond colliders

Bjoern Seitz
University of Glasgow

For the AMBER Collaboration

Presented at Physics Beyond Colliders Annual Workshop
CERN, 26 March 2024



Contact: bjorn.seitz@cern.ch

Physics beyond Colliders - Emergent Phenomena

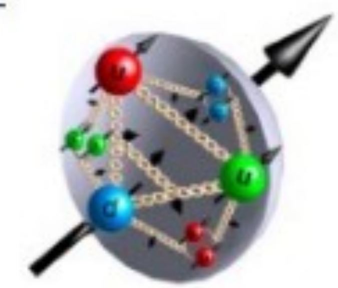
Pion

- $M_\pi \sim 140$MeV
- Spin 0
- 2 light valence quarks

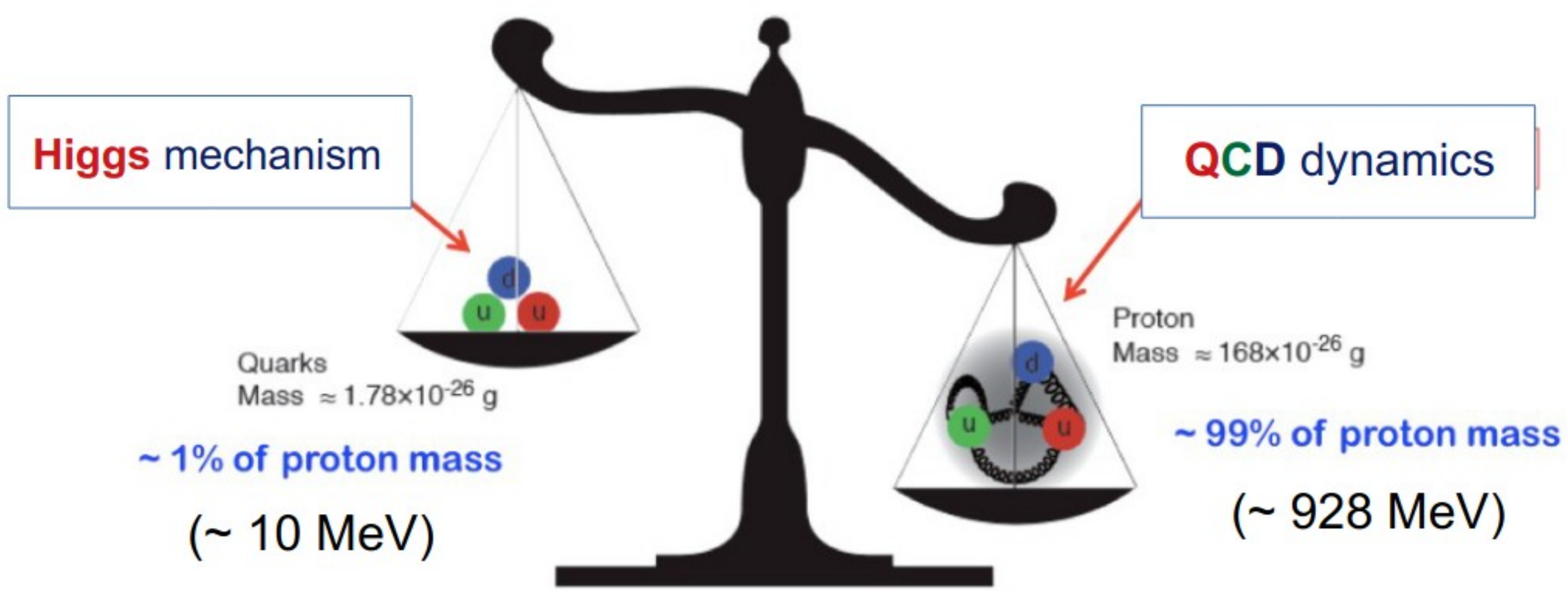
Kaon

- $M_K \sim 490$MeV
- Spin 0
- 1 light and 1 "heavy" valence quarks

Proton



- $M_p \sim 940$MeV
- Spin 1/2
- 3 light valence quarks



Explore QCD in detail to understand emergent phenomena

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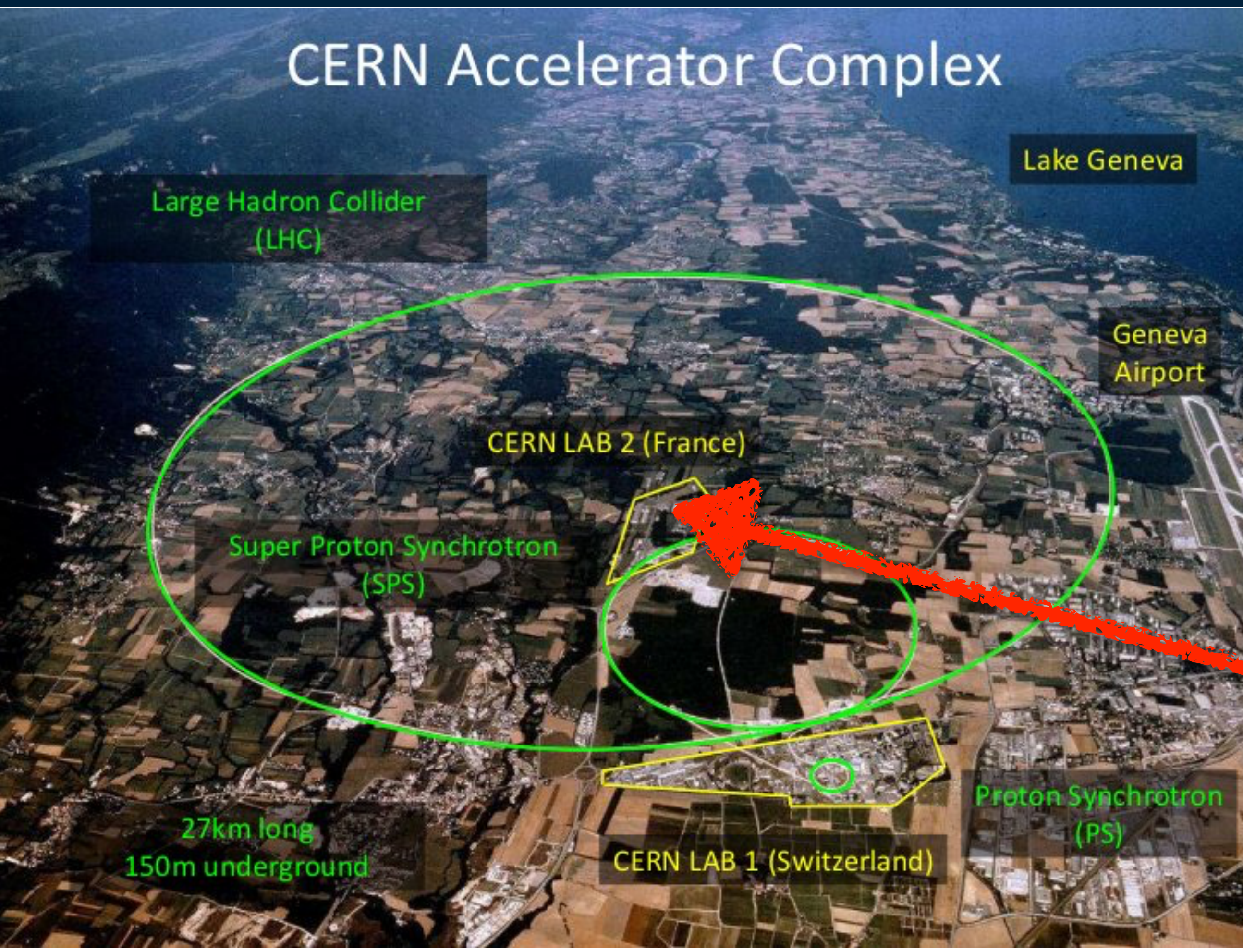
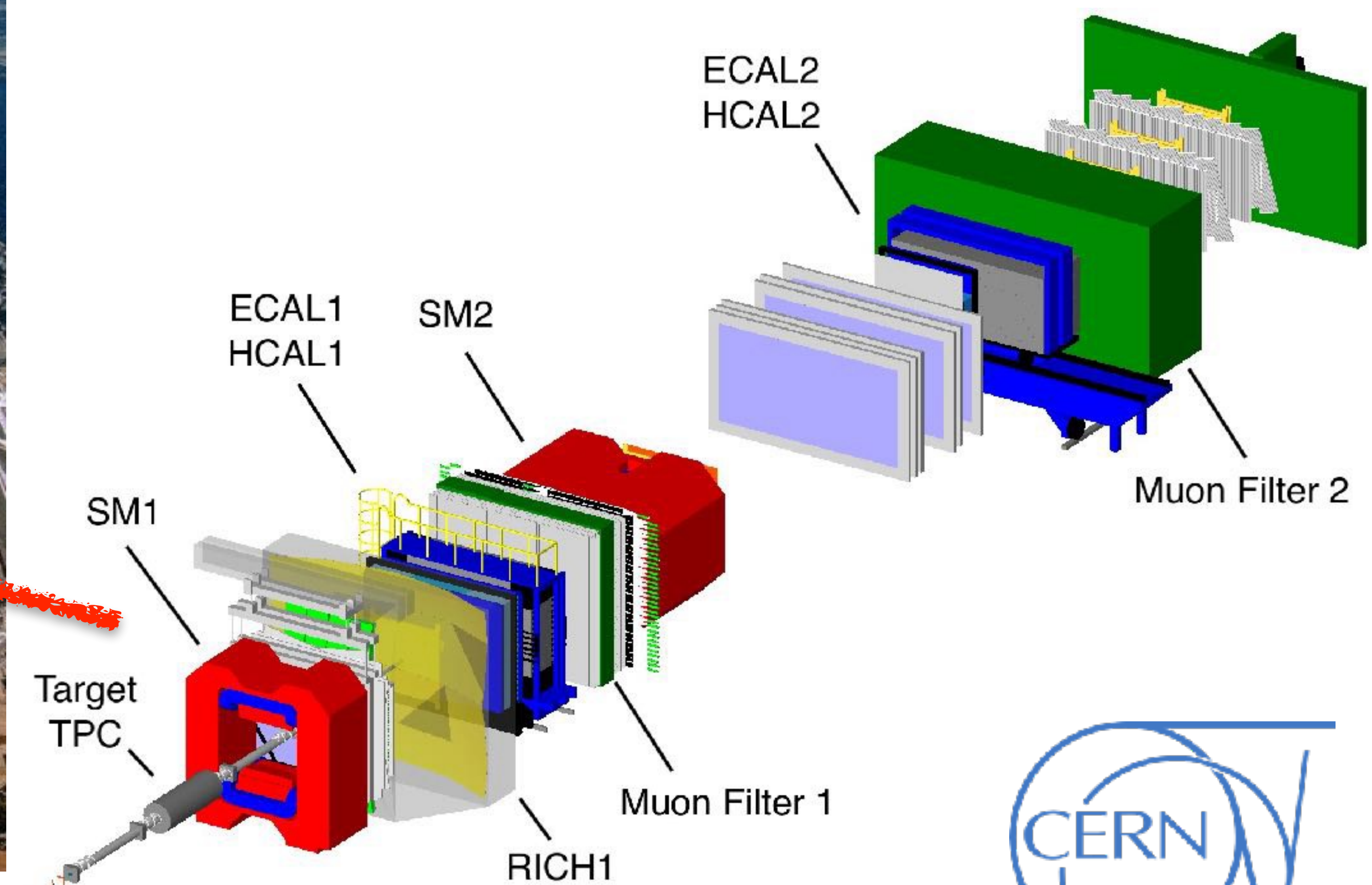
Apparatus for Meson and Baryon Experimental Research





- Use M2 beam in the CERN/SPS North Area
- Versatile beams (muons and hadrons of both charges)
- Beam momenta ranging from 50 - 280 GeV/c
- Improved beam properties post LS3 (NA-CONS)
- Intensity limited by radiation protection
- New Detector components for physics post LS3

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Apparatus for Meson and Baryon Experimental Research

	Beam	*Target*	*Additional Hardware*
Proton radius measurement	*100 GeV muons*	*high pressure Hydrogen*	*active target TPC, tracking stations (SciFi, Silicon)*
Antiproton production cross section	*50 GeV - 280 GeV protons*	*LH_2, LHe*	*Liquid He target*
Drell-Yan measurements with pions	*190 GeV charged pions*	*Carbon, Tungsten*	
Drell-Yan measurements with Kaons	*~100 GeV charged Kaons*	*Carbon, Tungsten*	*vertex detectors, 'active absorber'*
Prompt photon measurements	*> 100 GeV charged Kaon/pion beams*	*LH_2, Nickel*	*hodoscopes*
K-induced spectroscopy	*50 GeV - 100 GeV charged Kaons*	*LH_2*	*recoil ToF, forward PID*

Phase 1 (approved)

Phase 2 (in preparation)

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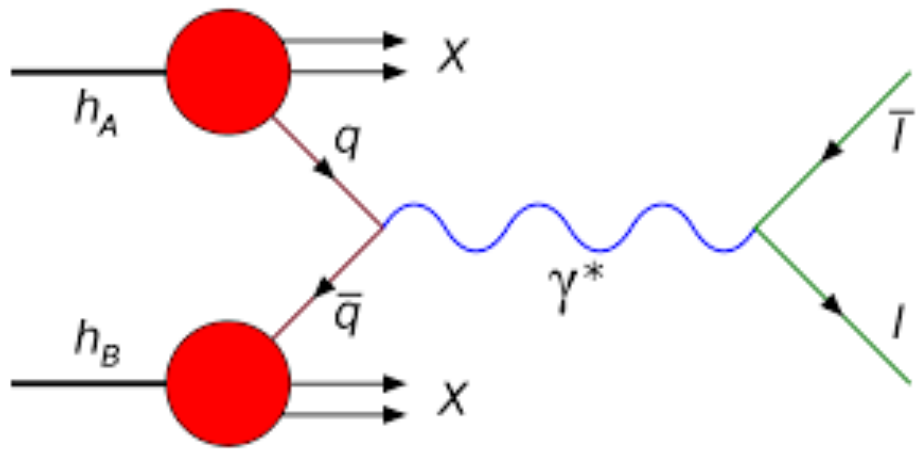

		Target	Additional Hardware
[illegible]	[illegible]	high pressure Hydrogen	active target TPC, tracking stations (SciFi, Silicon)
se[illegible]	[illegible]	LH_2, LHe	Liquid He target
Dre[illegible]Yan mea[illegible]urements with pion[illegible]	190 GeV charged pions	Carbon, Tungsten	
Drell-Yan measurements with Kaons	~100 GeV charged Kaons	Carbon, Tungsten	vertex detectors, ‘active absorber’
Prompt photon measurements	> 100 GeV charged Kaon/pion beams	LH_2, Nickel	hodoscopes
K-induced spectroscopy	50 GeV - 100 GeV charged Kaons	LH_2	recoil ToF, forward PID

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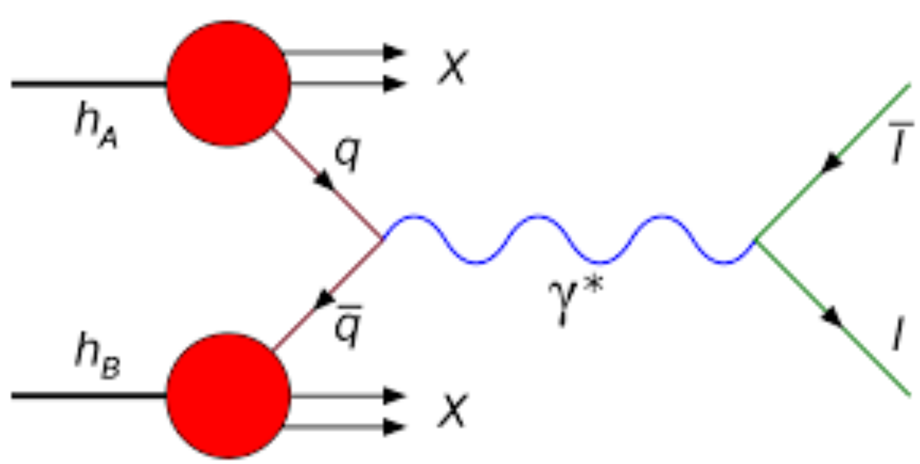

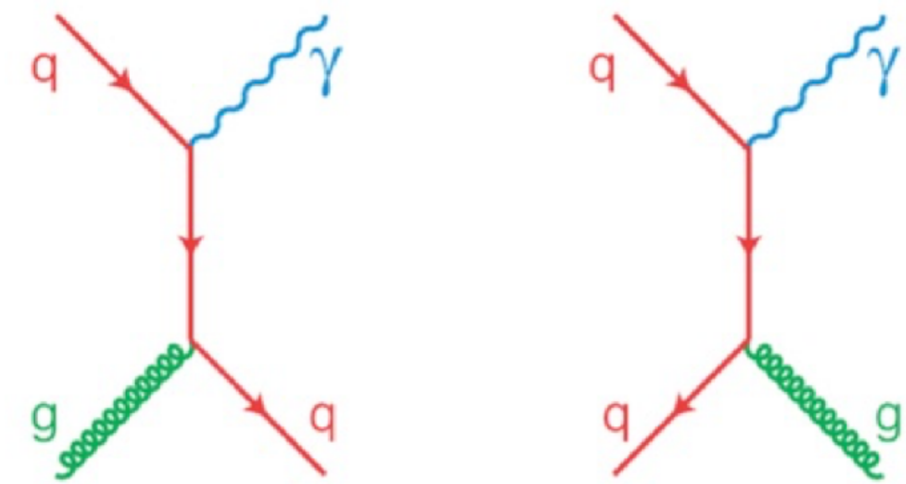

		Ta	
		hig Hy	
se		LH	
Dre Yan mea urements with pion	190 GeV charg pions	Carbon, Tungsten	
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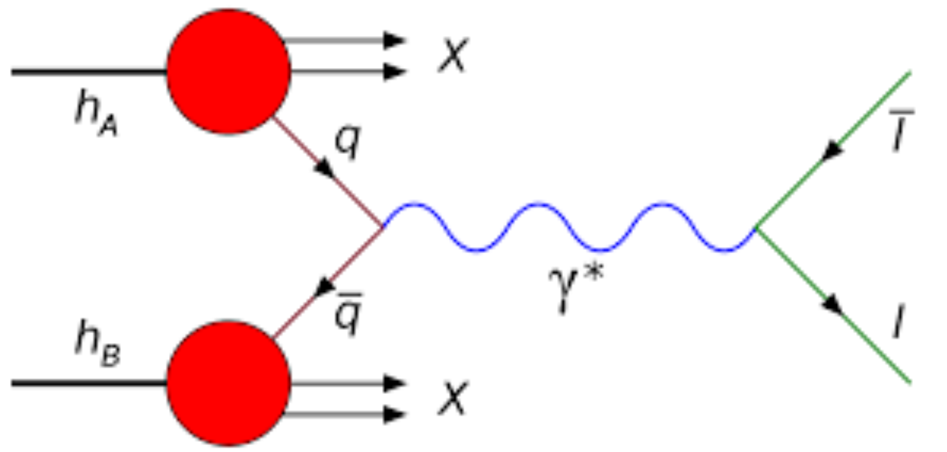

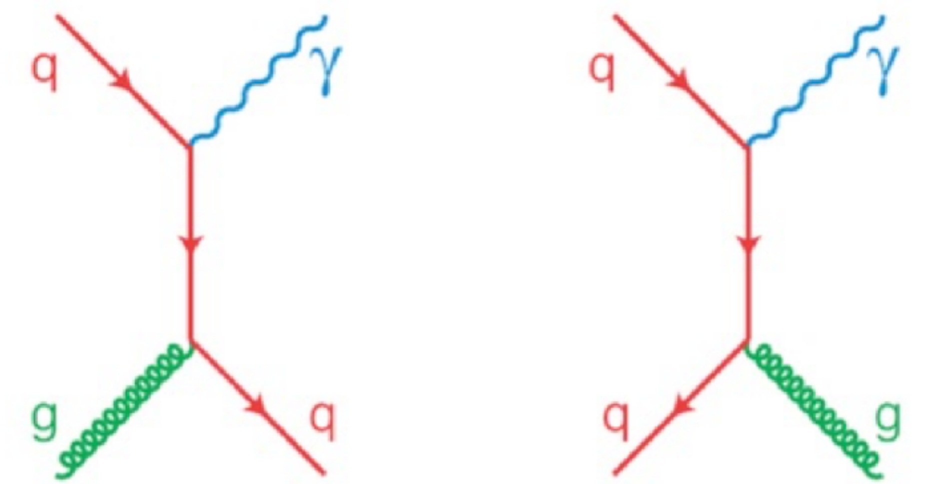

	Ta…		
	hig… Hy…		
	LH…		
se…			
Dre… Yan mea…urements with pion…	190 GeV charg… pions	Carbon, Tungst…	
Drell-Yan measurements with Kaons	~100 G…V charged Ka…s	Carbon, Tungs…	
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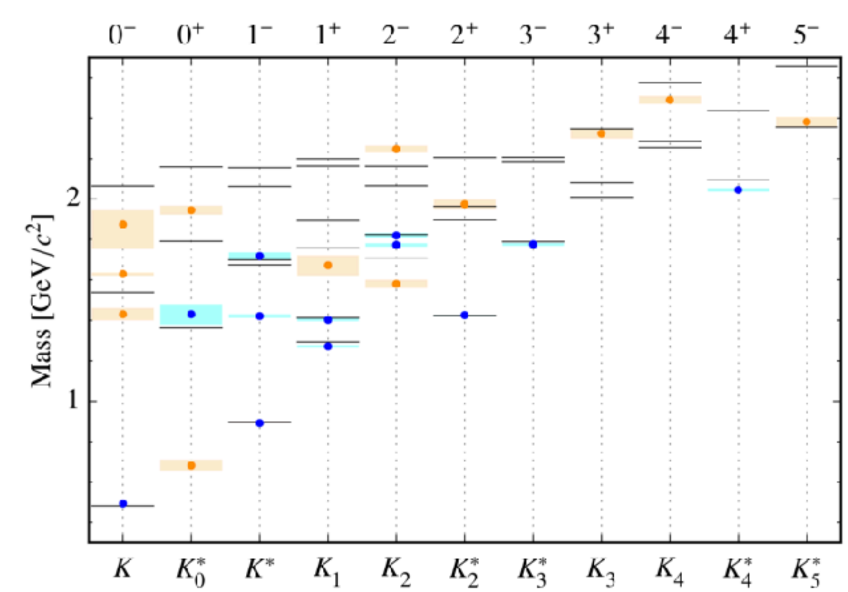
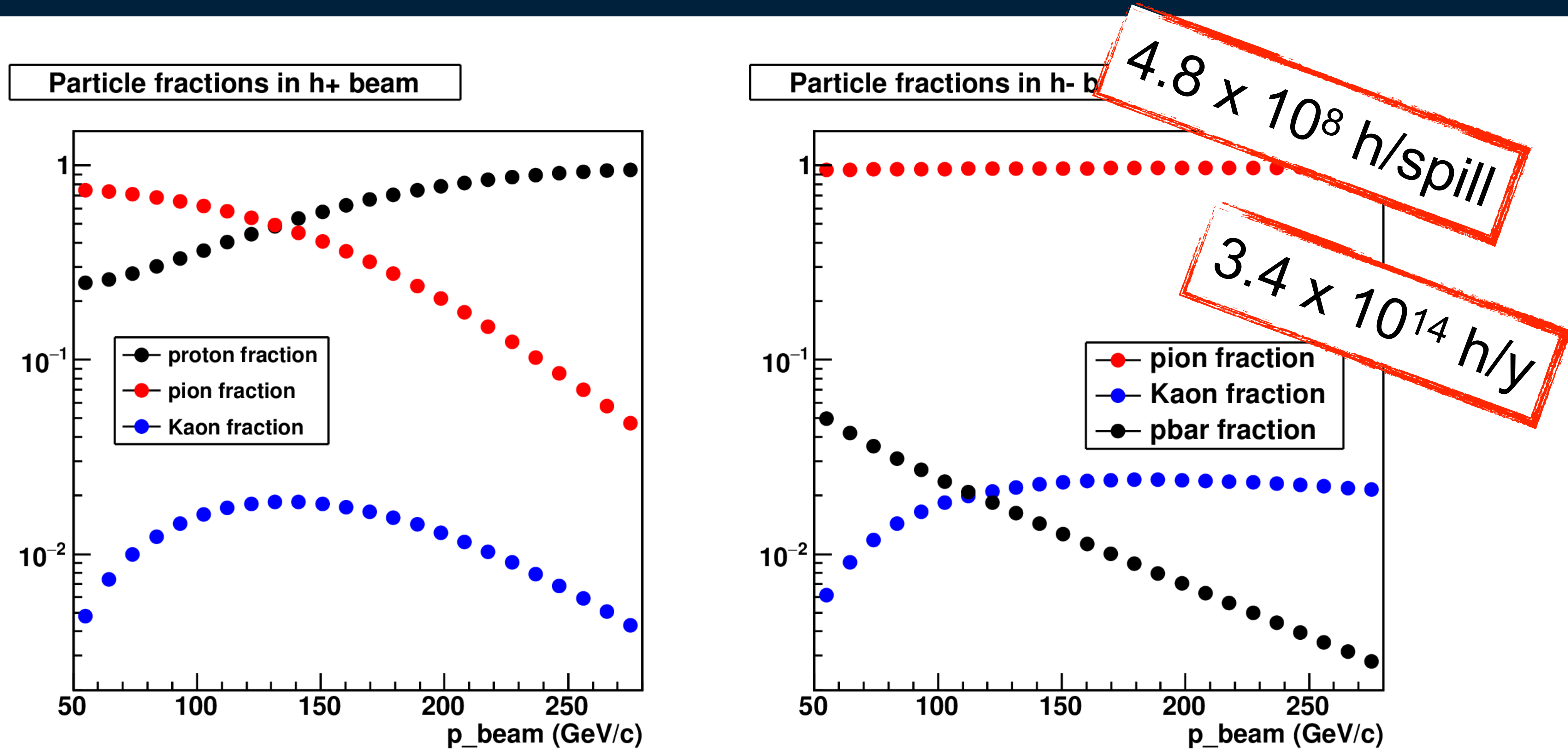


Phase 1 (approved)

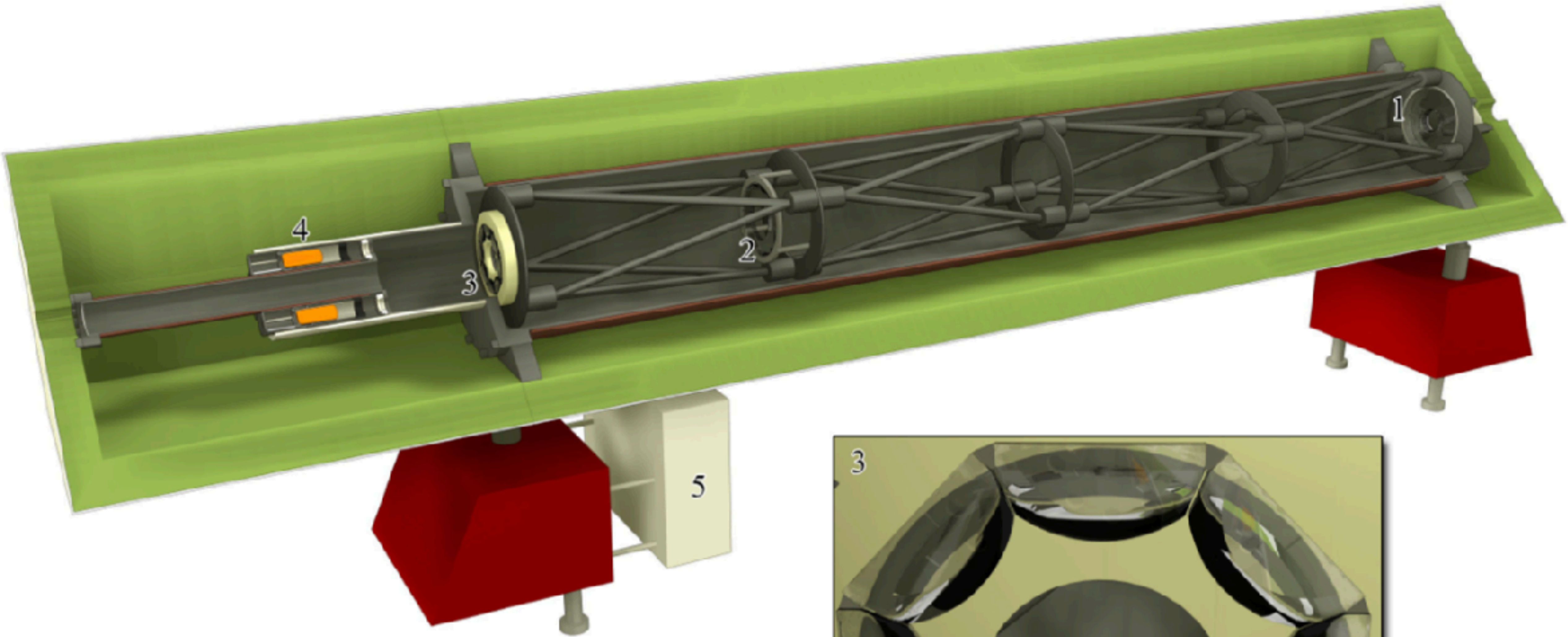
Phas… (in p…)

The wish: Kaon, Kaons, Kaons



	π^+ fraction	K^+ fraction	p fraction	π^- fraction	K^- fraction	$\bar{p}$ fraction
p_{beam} = 160 GeV/c	0.3611	0.0175	0.6214	0.9650	0.0237	0.0113
p_{beam} = 190 GeV/c	0.2402	0.0142	0.7456	0.9680	0.0241	0.0079

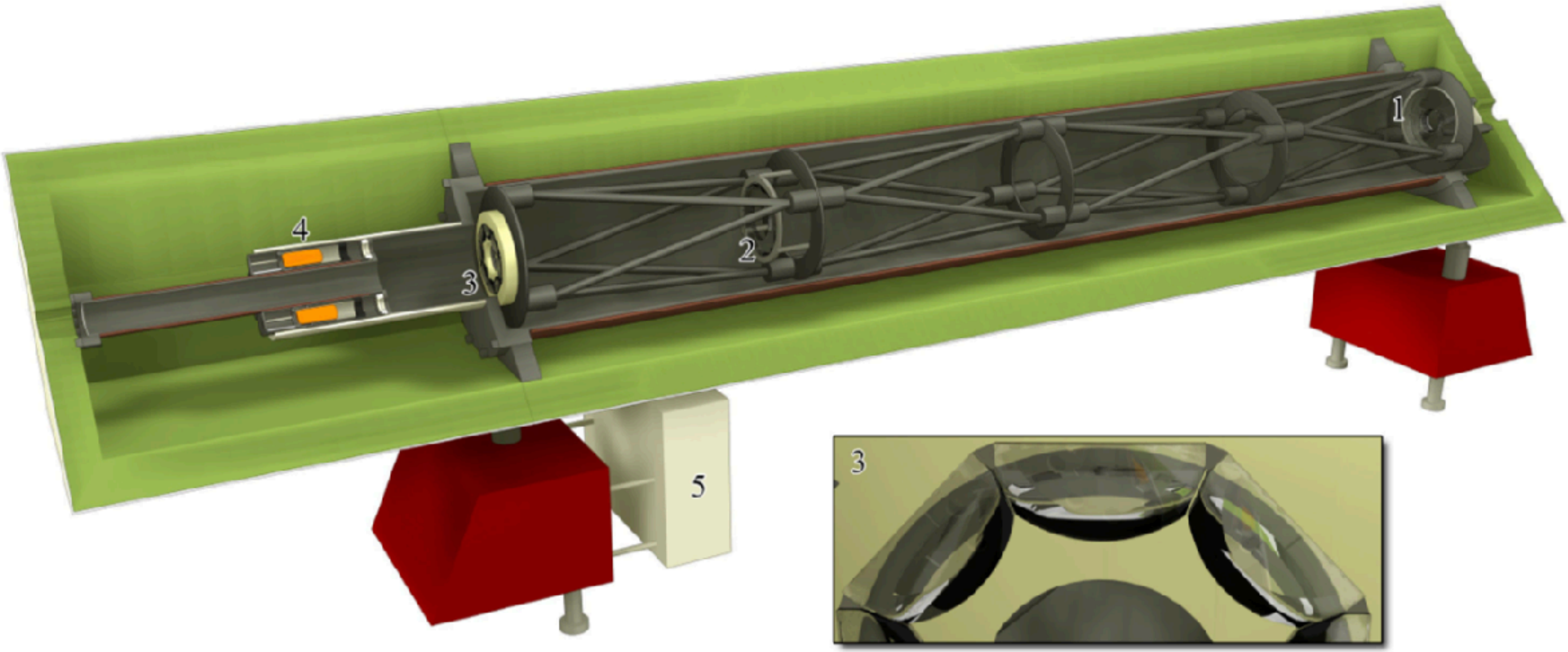
Beam particle identification: CEDARs



Differential Cherenkov counter provides π,K,p separation
Differences in Cherenkov angle are small

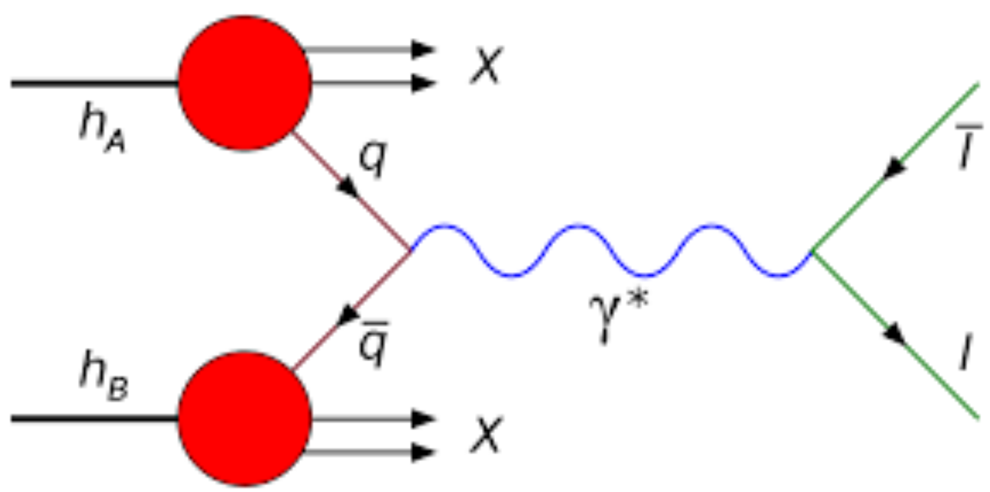
➜ Need parallel beam and excellent tracking

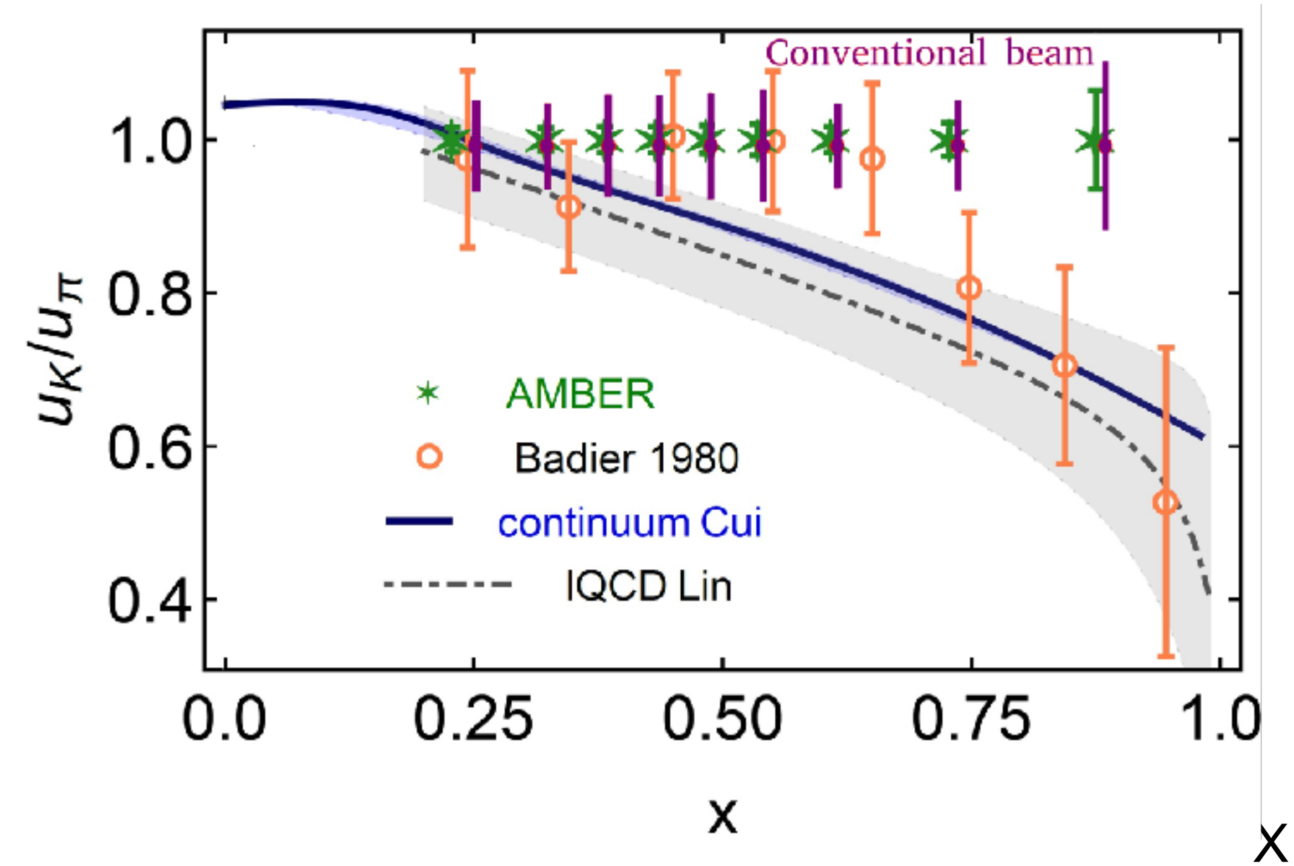
Beam particle identification: CEDARs



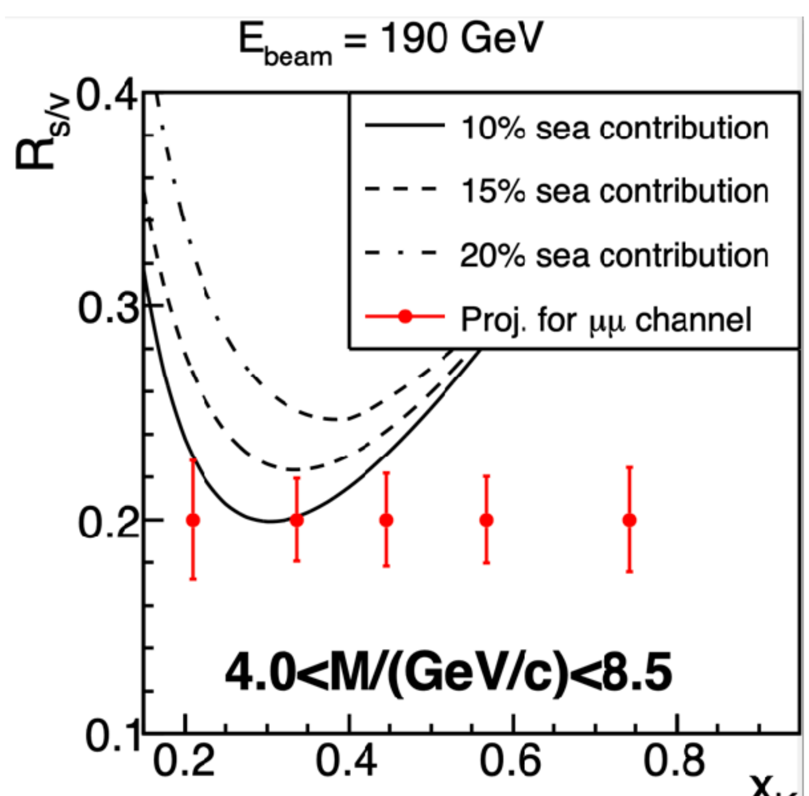
Request for vacuum improvements as studied by BE-EA, as well as CEDAR refurbishments including improvements in precision and stability of the diaphragm and motor controls.

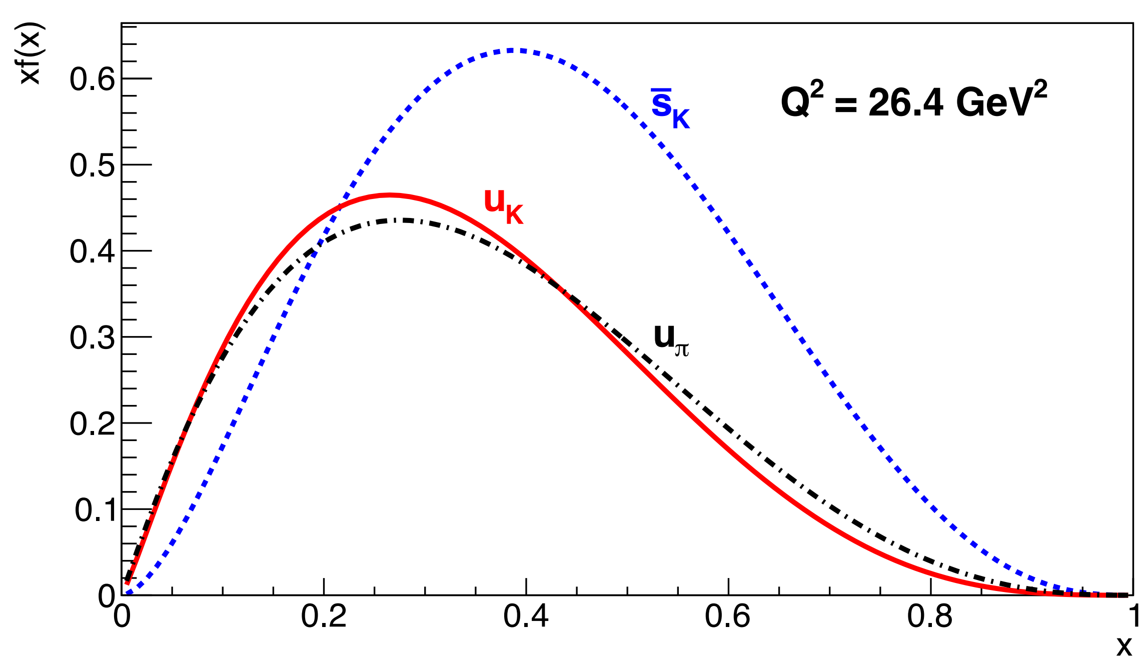
From π± to K± - Drell Yan process



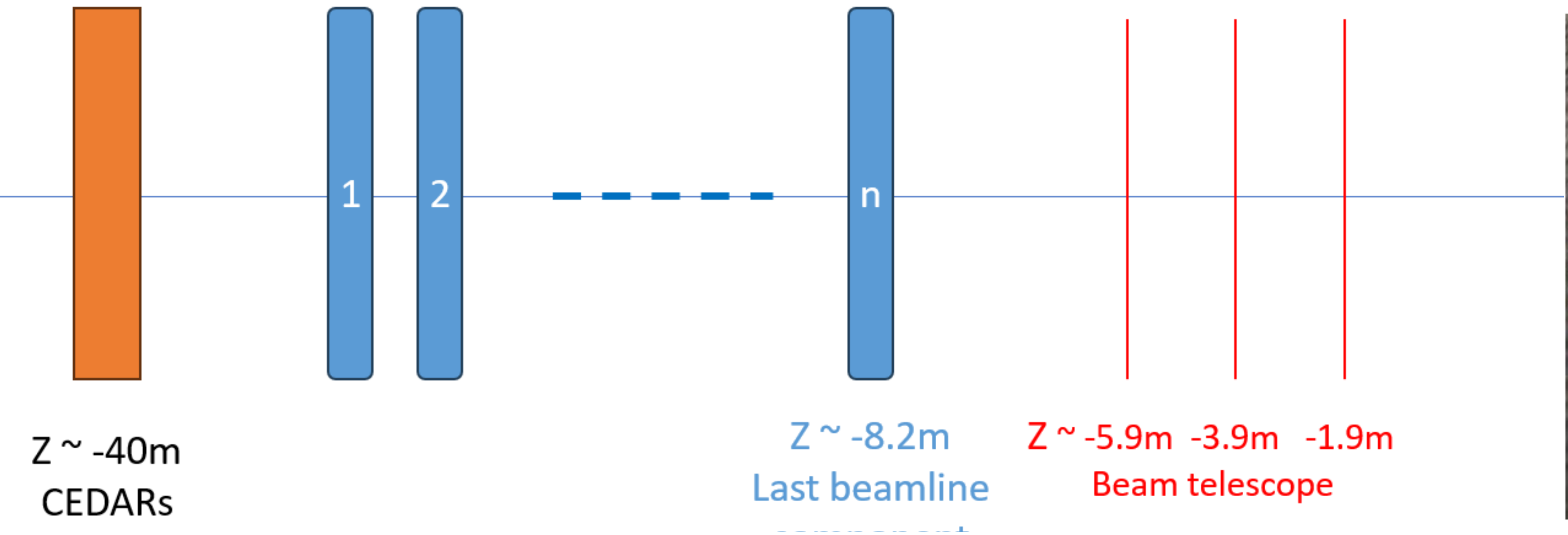


Inclusive di-lepton measurement

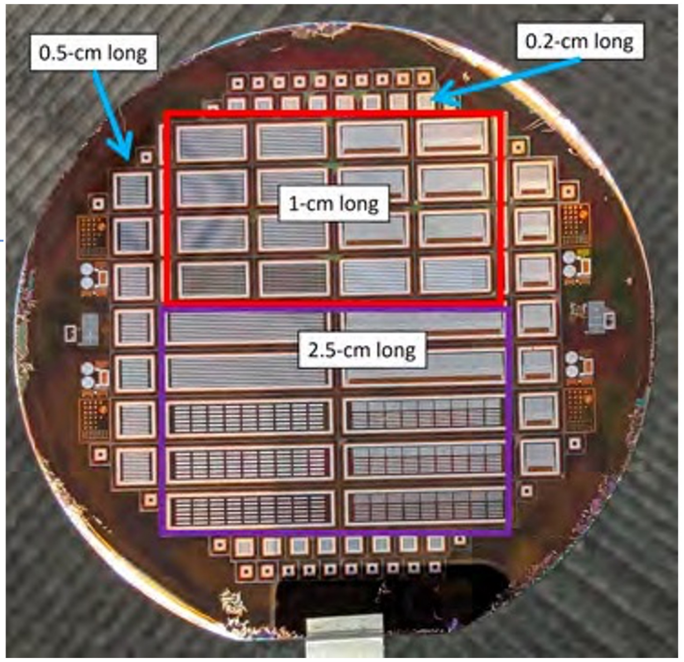


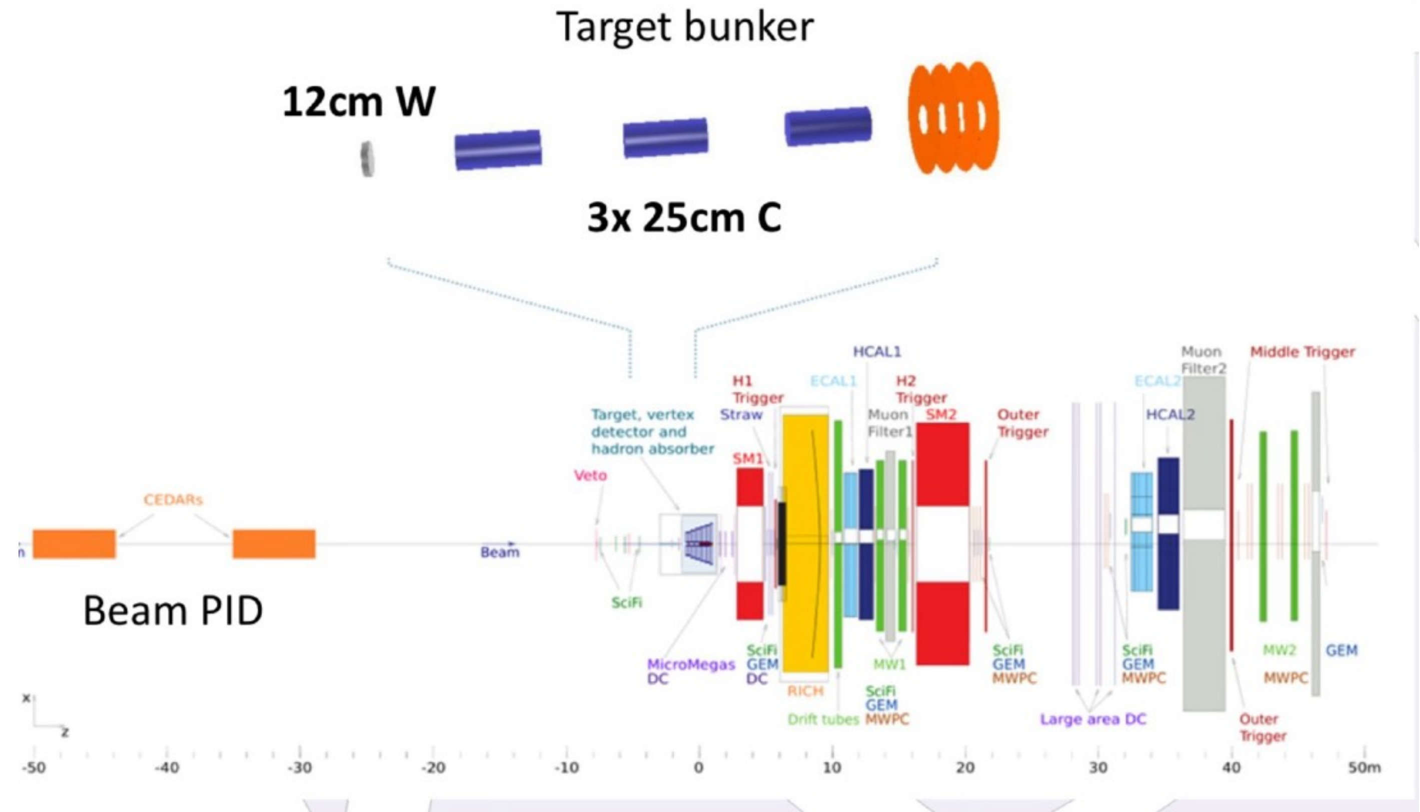


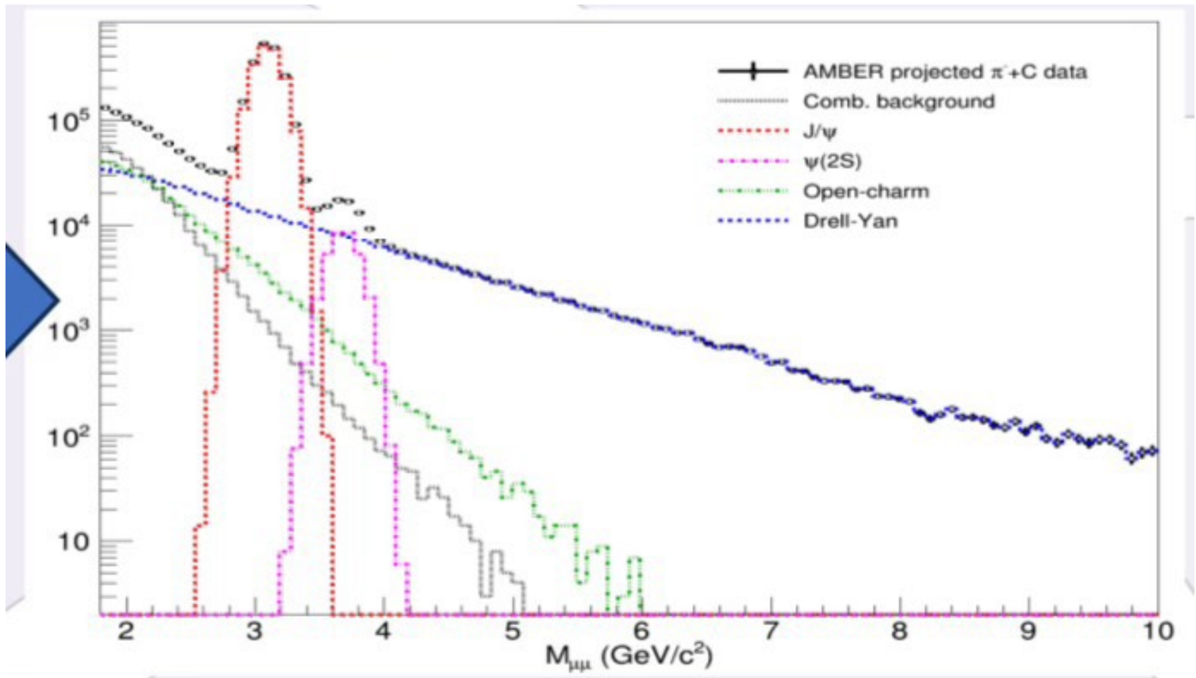
Detector Improvements



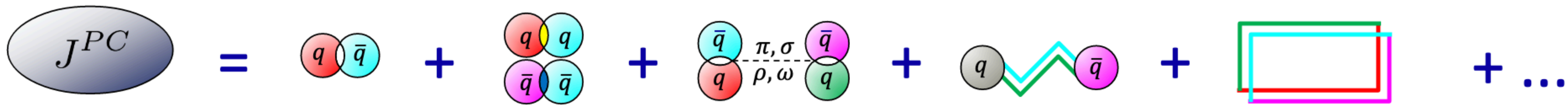
AC-LGAD prototype sensor







Meson spectroscopy



$(q\bar{q})_0$ $(qq)_8(\bar{q}\bar{q})_8$ $(q\bar{q})_0(q\bar{q})_0$ $(q\bar{q})_8 g$ $(gg)_0$

Tetraquark Molecule Hybrid Glueball

Where are they?

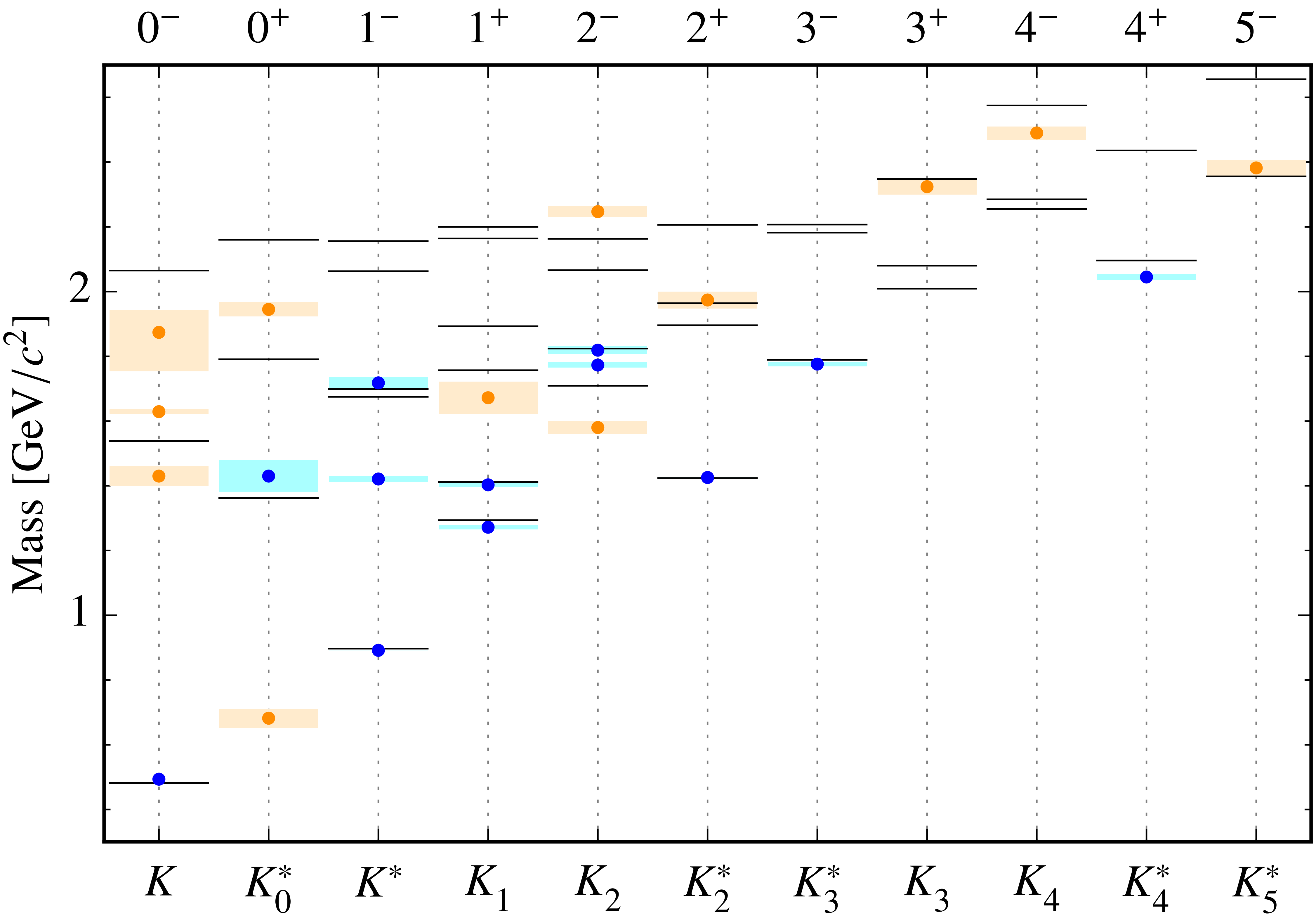
How to identify them?

- Spin-exotic: $J^{PC} = 0^{--}, 0^{+-}, 1^{-+}, \ldots$
- Supernumerary states
- Flavor-exotic: $|Q|, |I_3|, |S|, |C| \geq 2$
- Comparison with models, lattice

Need:

- Large data sets with small statistical uncertainties
- Complementary experiments
  - production mechanisms
  - final states
- Advanced analysis methods
  - reaction models
  - theoretical constraints

Kaonic mass spectrum



Detector Improvements

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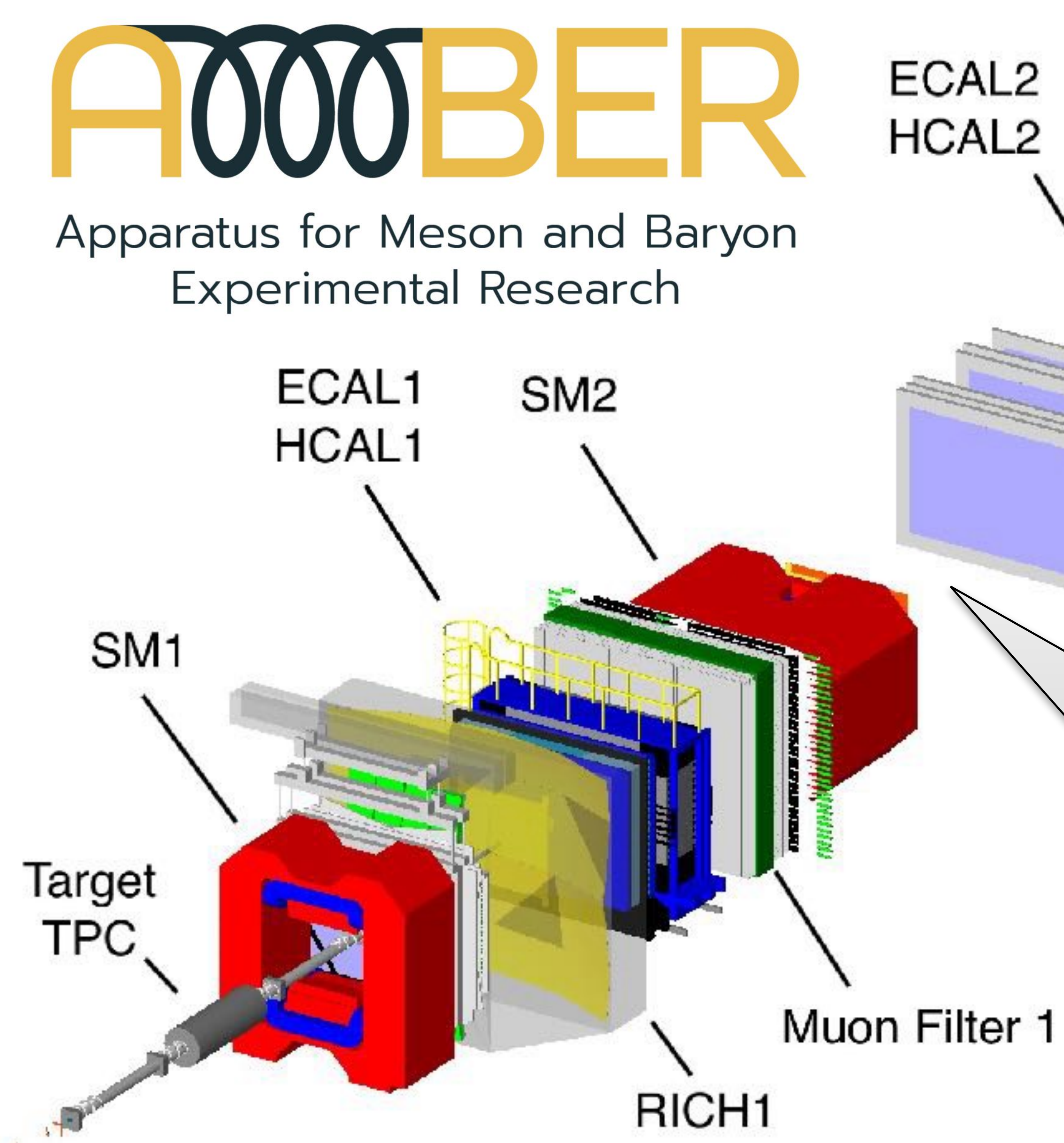
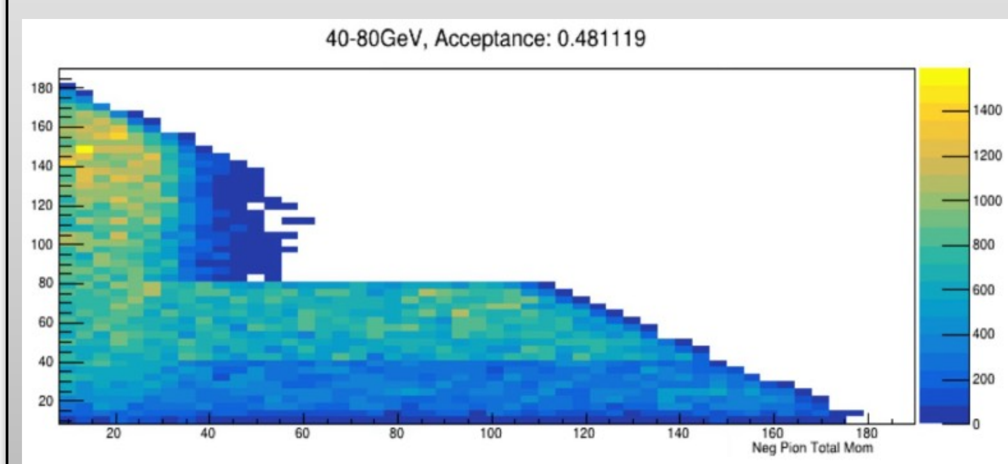
Apparatus for Meson and Baryon Experimental Research

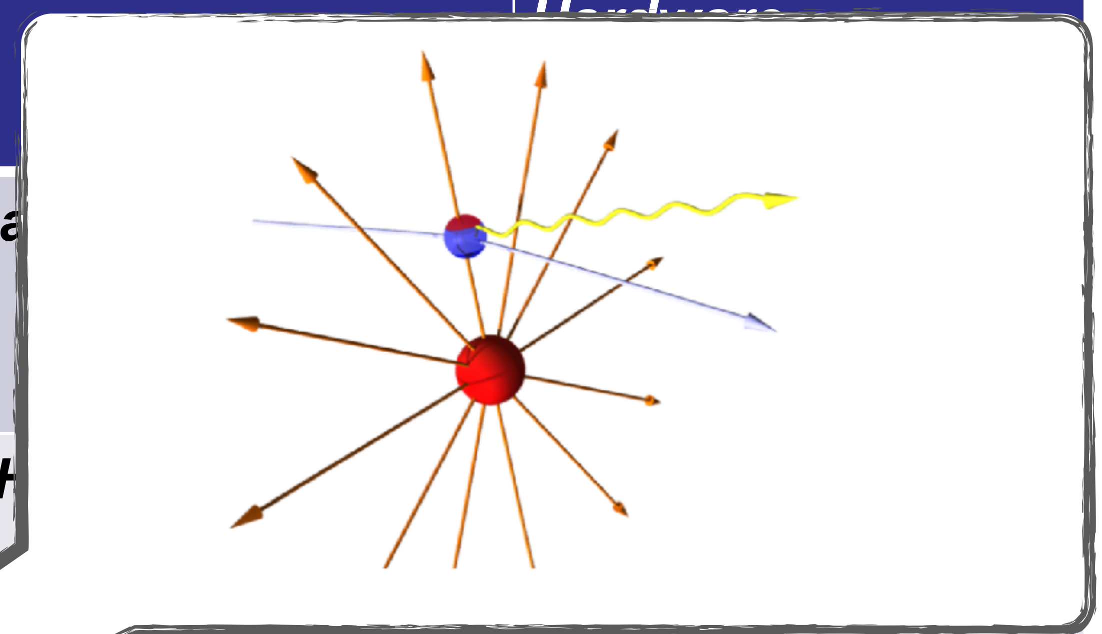


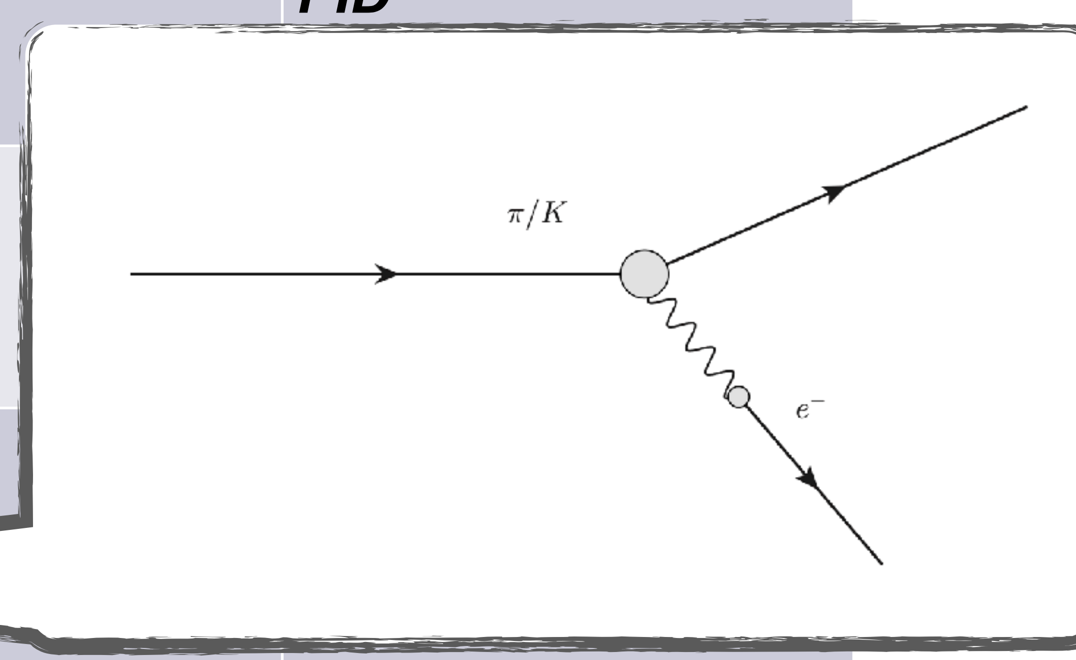
Insert RICH here..



And there is more

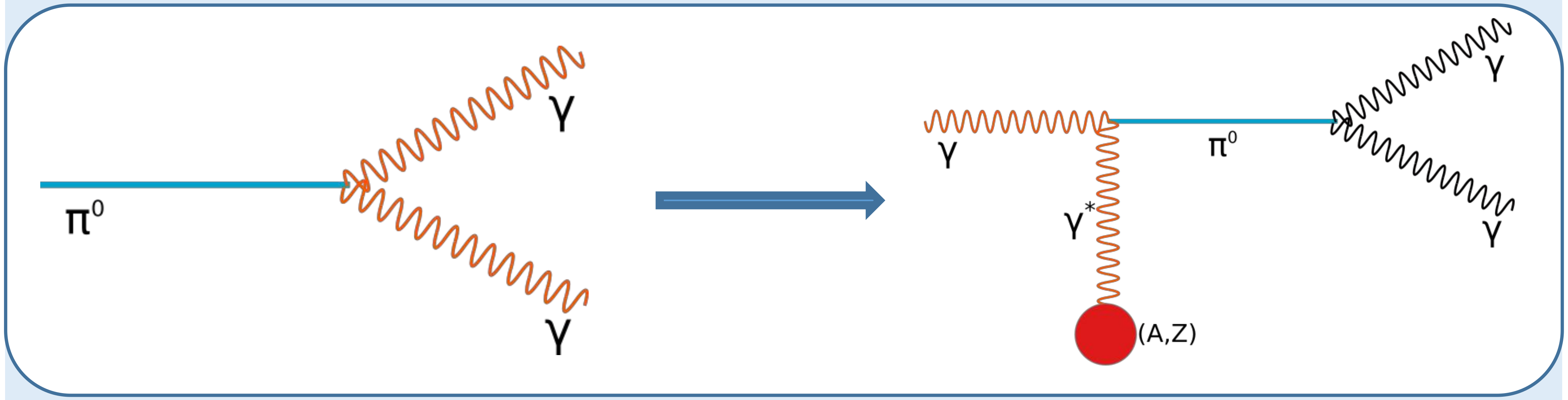
	Beam	Target	Additional
Drell-Yan measurements with Kaons	~100 GeV charged Kaons	Ca	
Prompt photon measurements	> 100 GeV charged Kaon/pion beams	LH	
K-induced spectroscopy	50 GeV - 100 charged	LH_2	recoil ToF, forward PID
Primakoff reactions	~ 100 GeV charged Kaons	Nickel	
Meson radii	50 GeV to 280 GeV charged pions and Kaons		



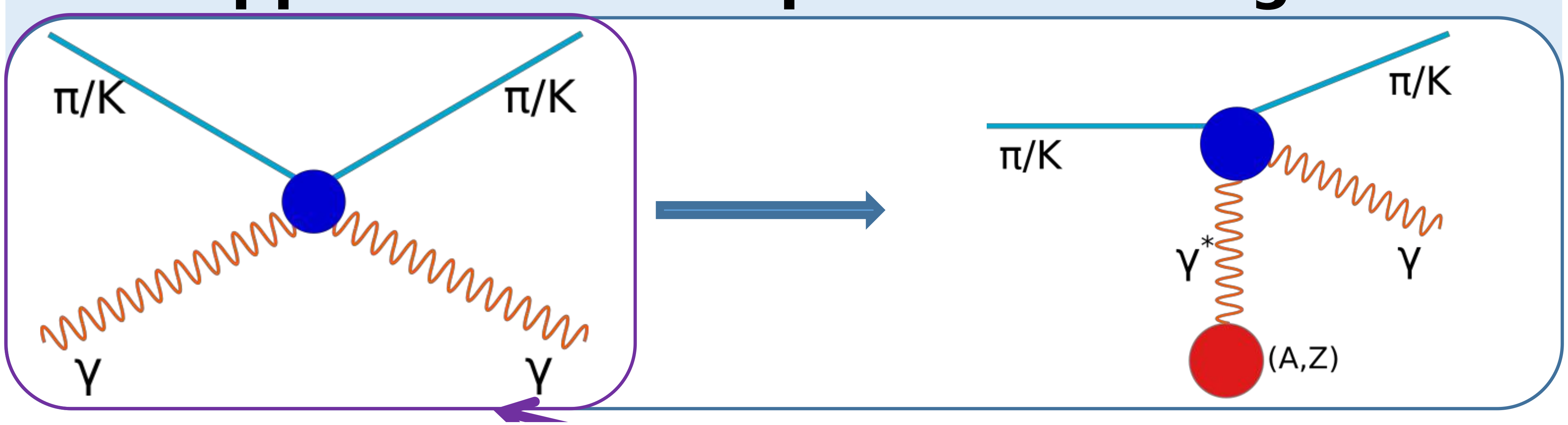


Prompt Photons and Primakoff Effect

Initial idea of Henry Primakoff:
Electromagnetic field of nucleus = photon target!



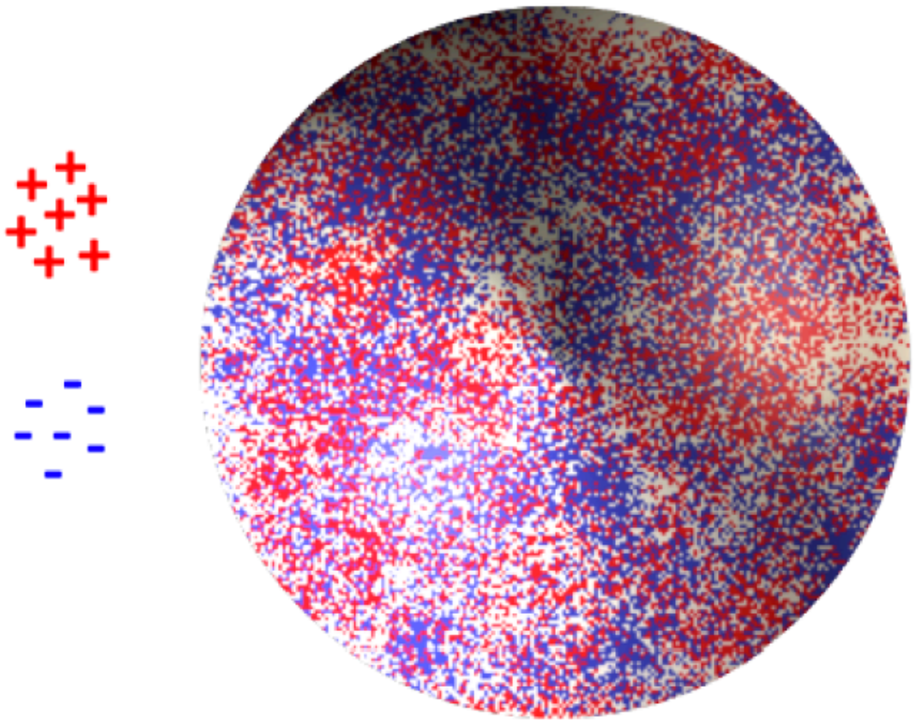
Also applicable to compton scattering:

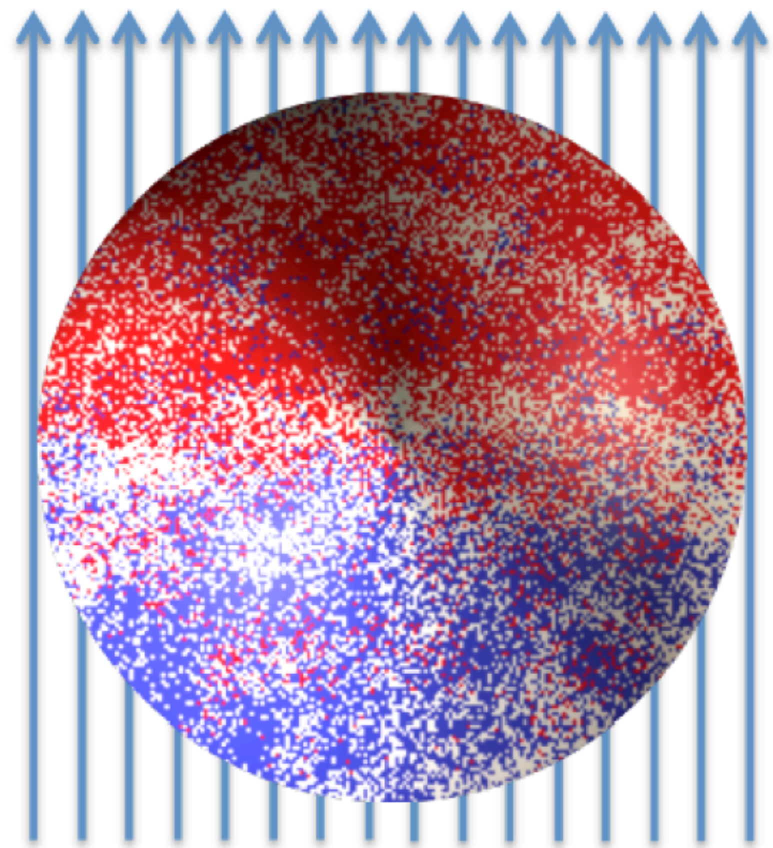


graphics from A. Maltsev, EHM Workshop 2021

Kaon polarisabilites at AMBER

pictures from Temple Univ



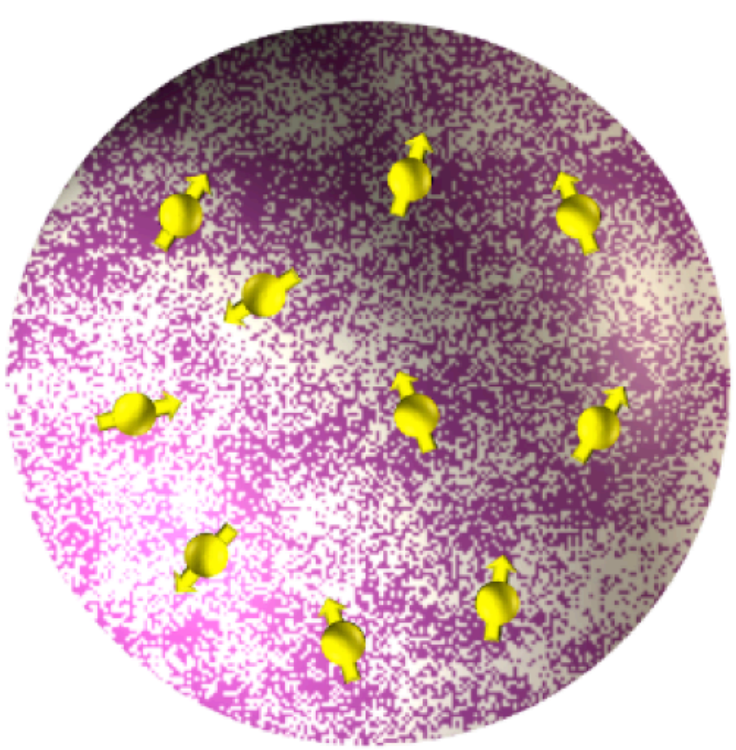


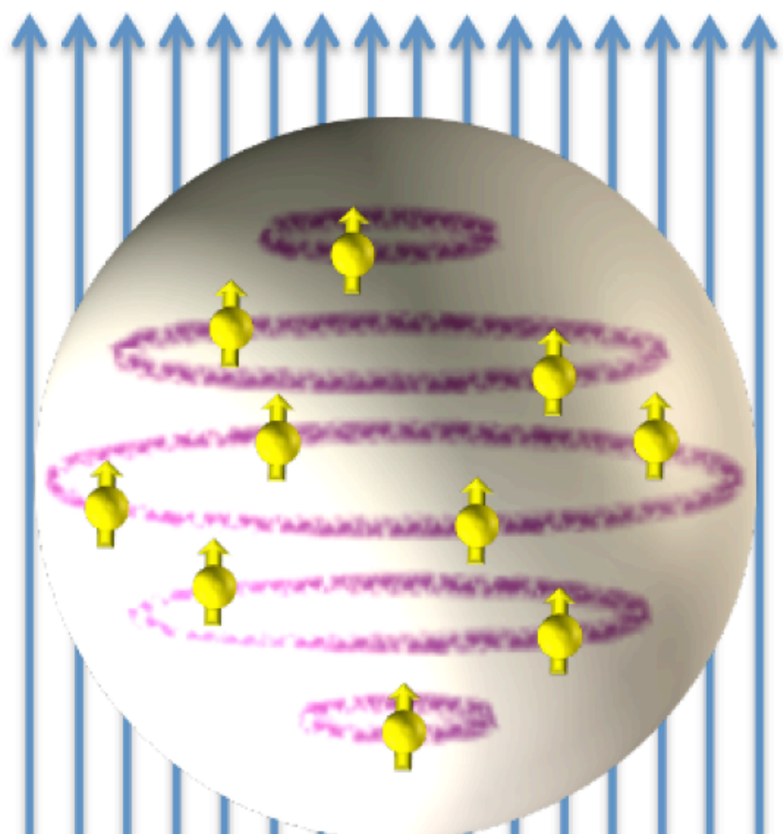
$\vec{E}$

"stretchability"

$\vec{d}_{E\ \mathrm{induced}} \sim \alpha\, \vec{E}$

External field deforms the charge distribution





$\vec{B}$

"alignability"

$\vec{d}_{M\ \mathrm{induced}} \sim \beta\, \vec{B}$

$\beta_{para} > 0$

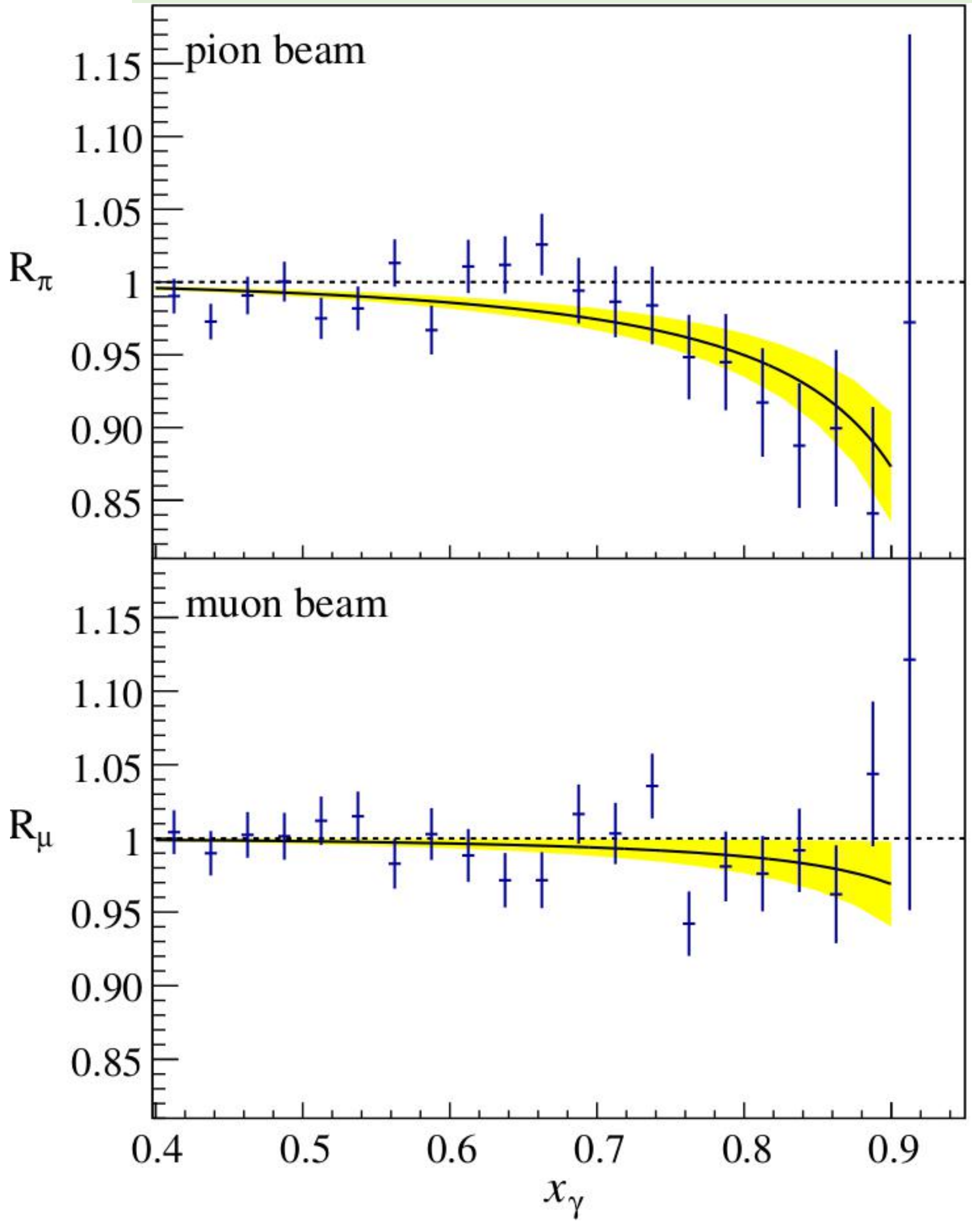
$\beta_{diam} < 0$

Paramagnetic: proton spin aligns with the external magnetic field

Diamagnetic: π-cloud induction produces field counter to the external one

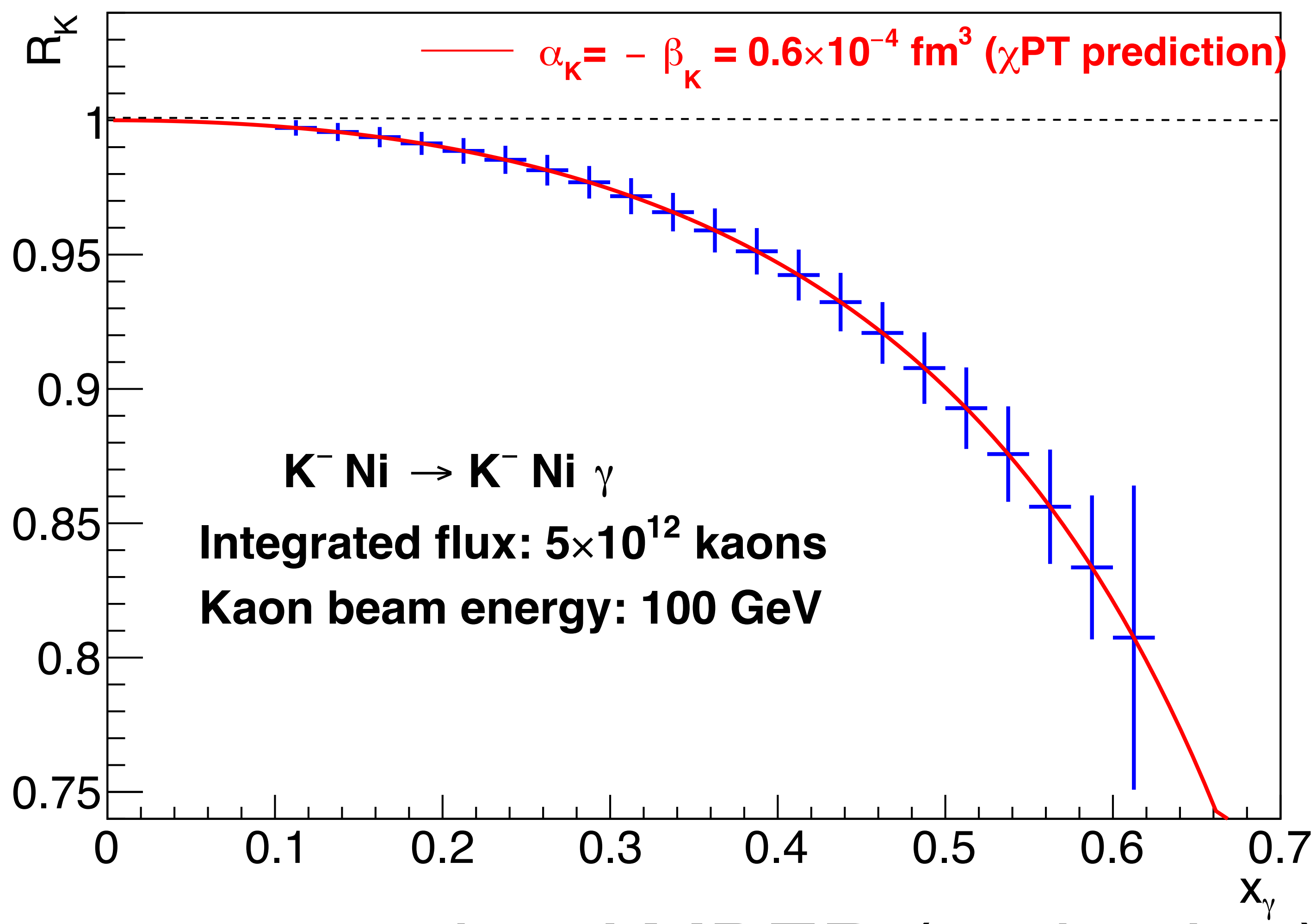
Kaon polarisabilites at AMBER

PRL 114, 062002 (2015)



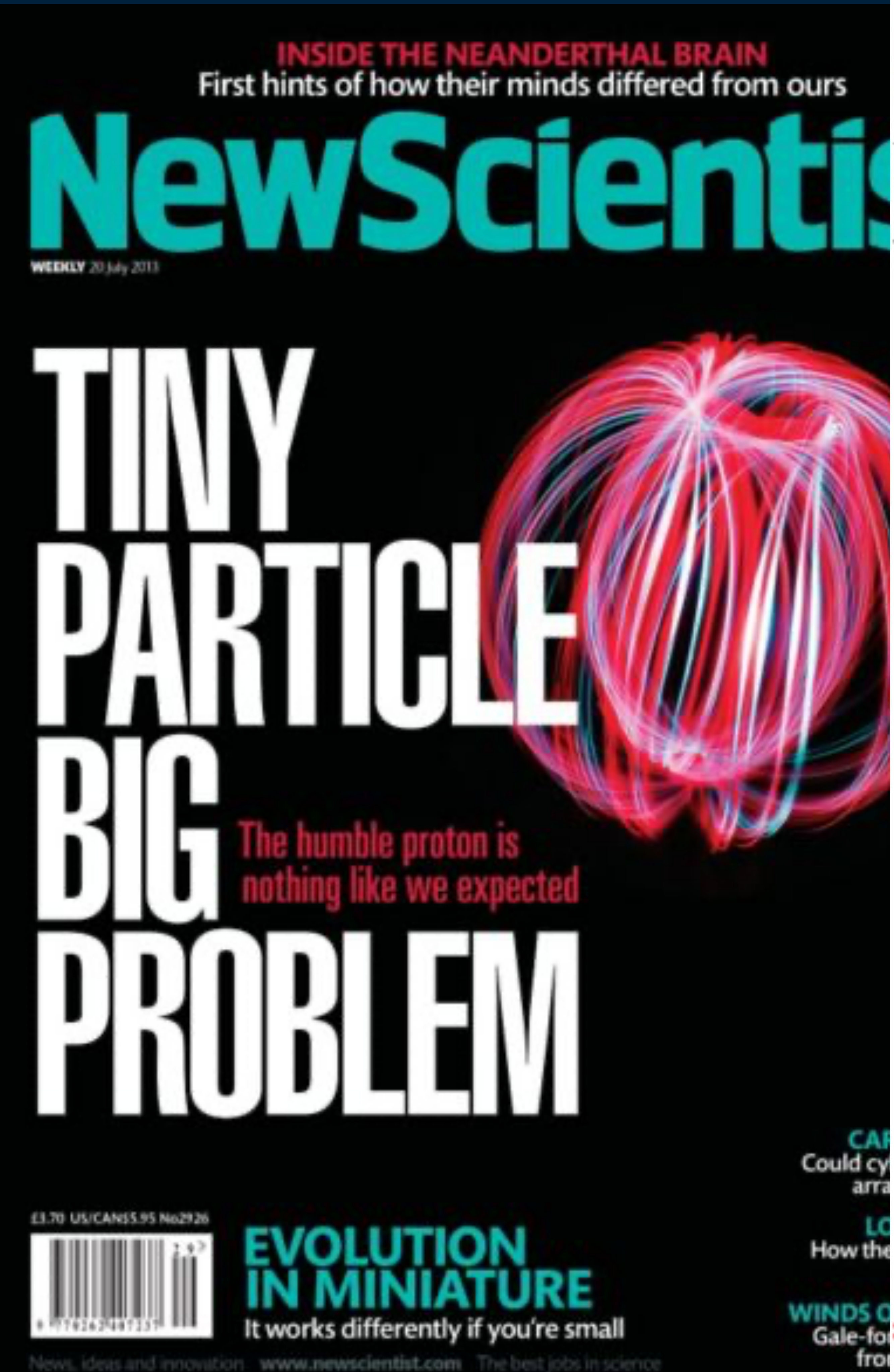
α_π at COMPASS

$\alpha_\pi = (2.0 \pm 0.6 \pm 0.7) \times 10^{-4} fm^3$



α_K extracted at AMBER (projection)

- Expected statistical accuracy in α_K-β_K: $\sigma = 0.03 \times 10^{-4}$ fm^3
- Unique measurement
- Prediction α_K-β_K~1-4x10^{-4}fm^3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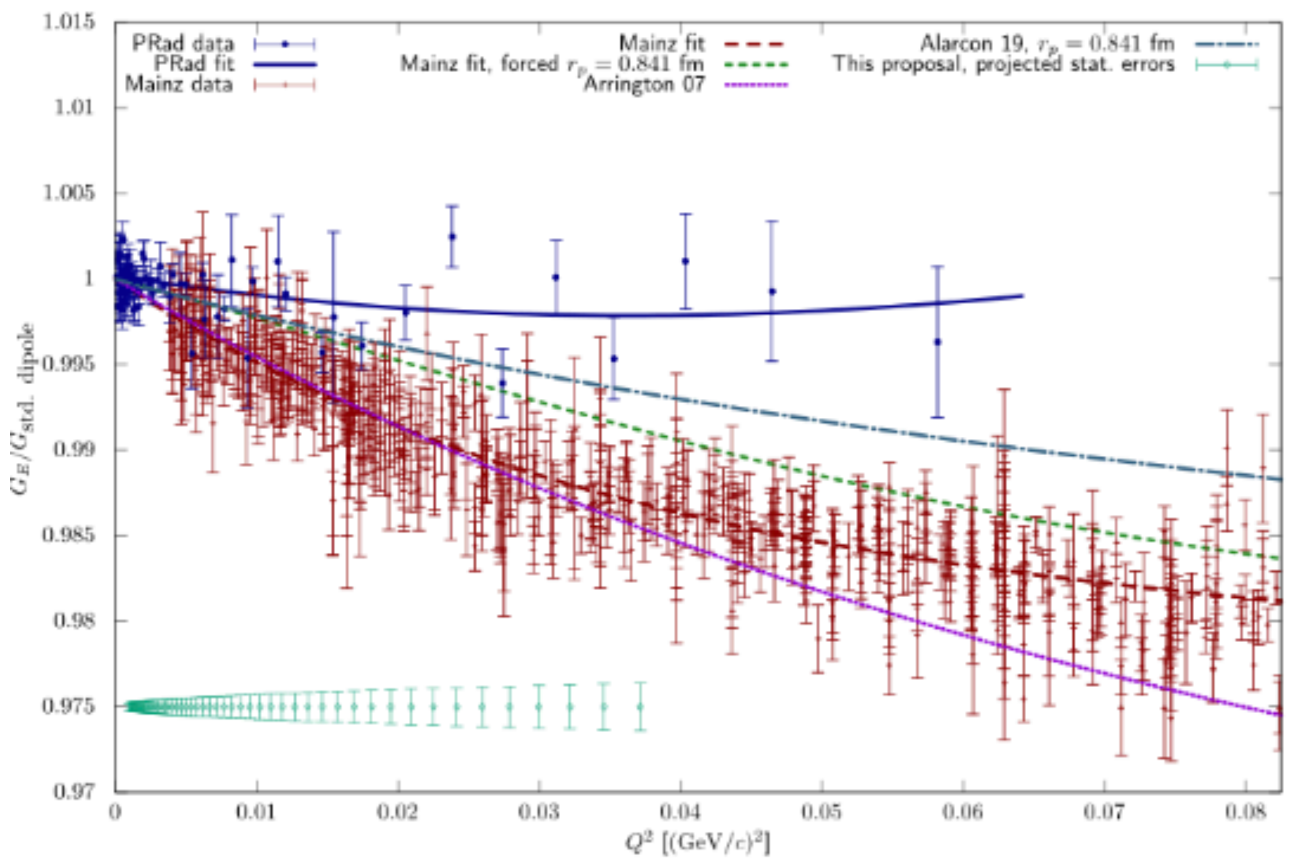
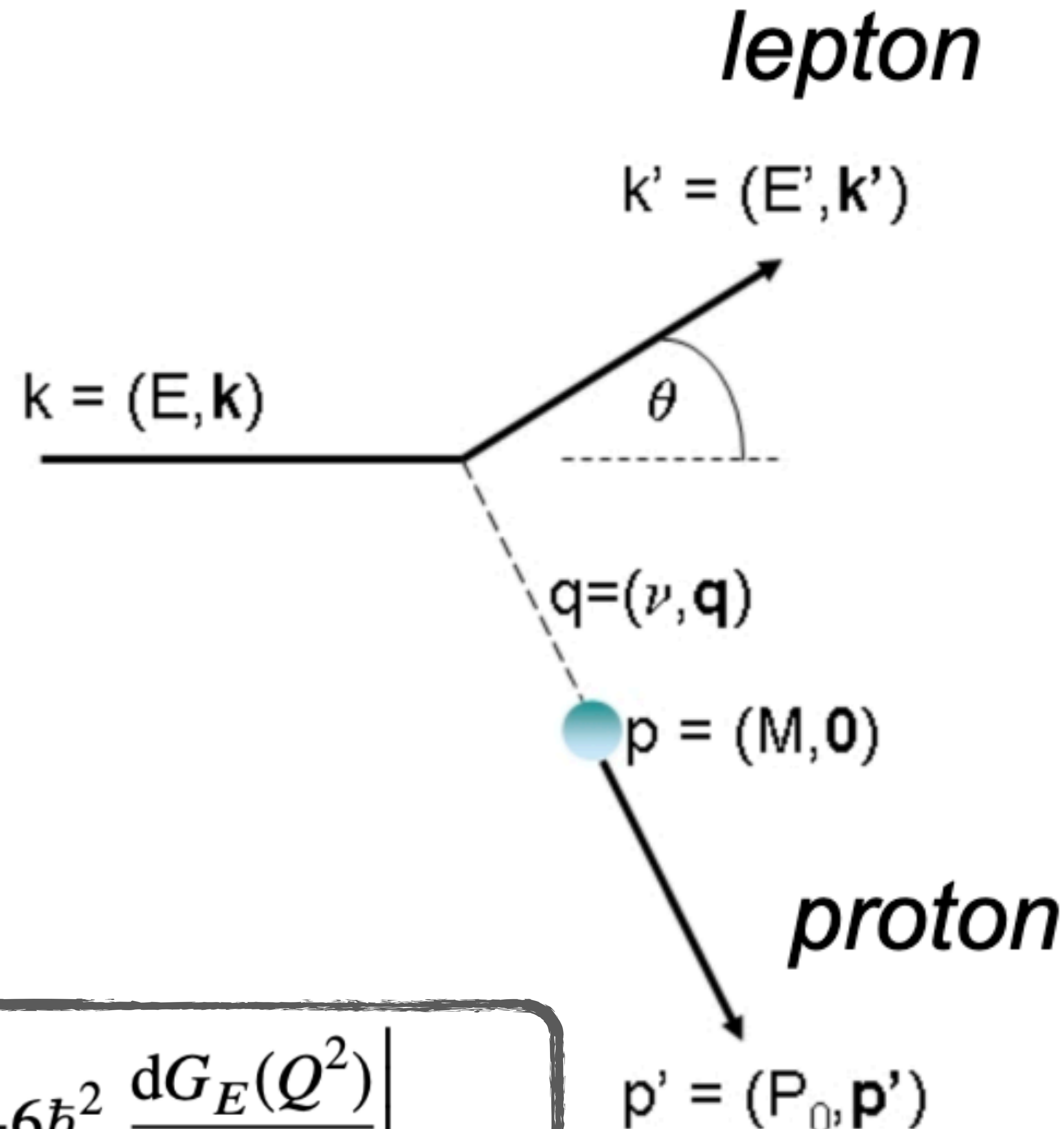
Hadron charge radii



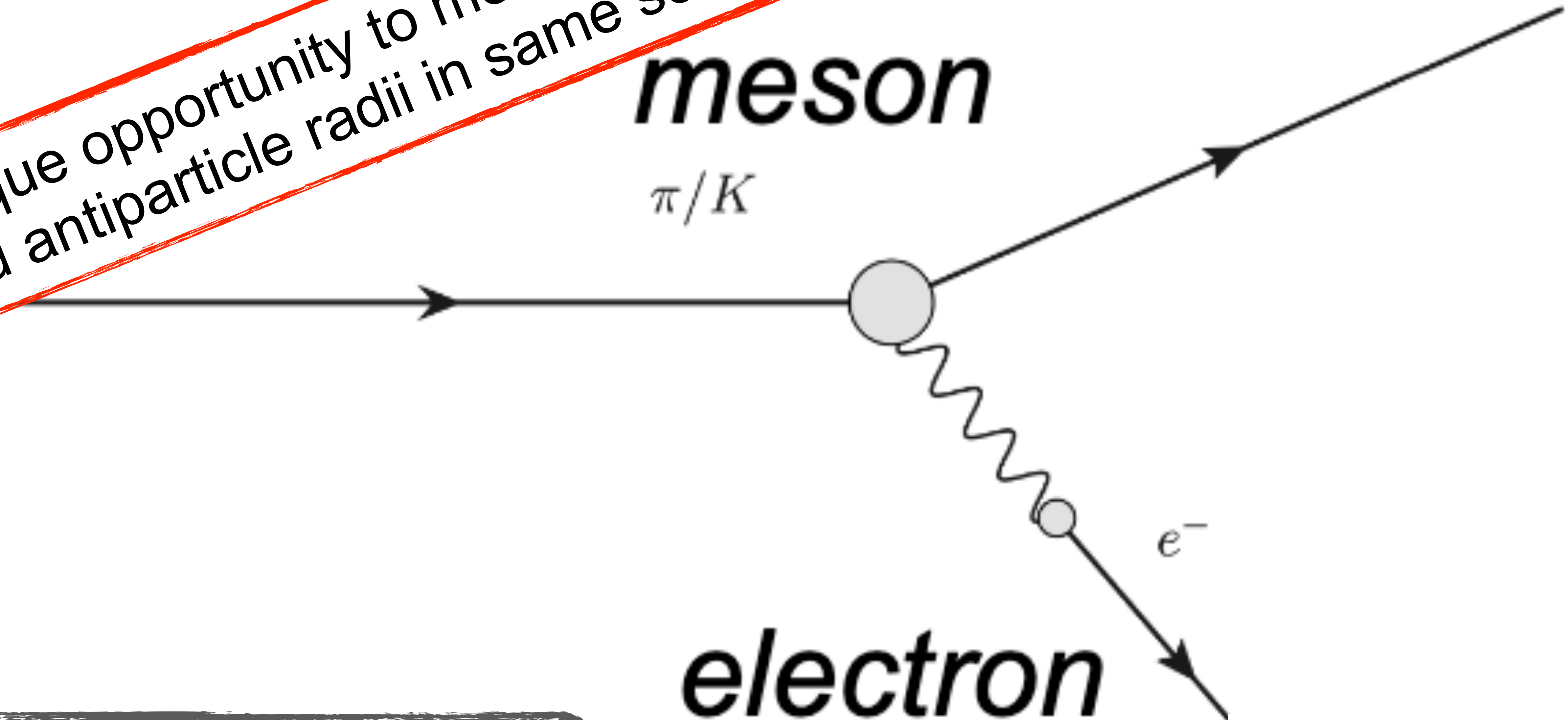
$$\frac{d\sigma}{dQ^2} = \frac{4\pi\alpha^2}{Q^4} R \left(\varepsilon G_E^2 + \tau G_M^2\right)$$

$$\langle r_E^2 \rangle = -6\hbar^2 \left.\frac{\mathrm{d}G_E(Q^2)}{\mathrm{d}Q^2}\right|_{Q^2 \to 0}$$



Hadron charge radii

Unique opportunity to measure particle and antiparticle radii in same setup



$$\langle r_E^2 \rangle = -6\hbar^2 \left. \frac{dG_E(Q^2)}{dQ^2} \right|_{Q^2 \to 0}$$

Summary and Conclusion

- Understanding QCD means understanding the emergent properties of Baryons and Mesons
- Unique opportunities to study QCD provided by CERN M2 beam line with high energy and high intensity π/K/p beam
- Exciting improvements in beam delivery (NA-CONS)
- AMBER beyond LS3 focussing on
  - Drell-Yan with Kaons and Kaon structure
  - Kaon induced meson spectroscopy
  - Meson polarisabilities using Primakoff reactions
  - Meson radii in inverse kinematics

Physics Beyond Colliders

A big Thank You to PBC and CERN-BE for their continued support

Contact: Bjorn.Seitz@cern.ch