QCD Conveners' Introduction

Markus Diehl, Jan Pawlowski, Gunar Schnell

Physics Beyond Colliders Annual Workshop
CERN, 16 to 17 January 2019

Introduction

- Summary report of QCD studies appeared end of last year, 81 pp
- This talk:
  - ★ very broad overview
  - ★ selected physics highlights
  - ★ our thoughts on possible PBC QCD activities in 2019-20
  - ★ figures on following slides from report

Physics Beyond Colliders

CERN-PBC-REPORT-2018-008

Physics Beyond Colliders
QCD Working Group Report

A. Dainese[1], M. Diehl[2,*], P. Di Nezza[3], J. Friedrich[4], M. Gaździcki[5,6] G. Graziani[7], C. Hadjidakis[8], J. Jäckel[9], M. Lamont[10] J. P. Lansberg[8], A. Magnon[10], G. Mallot[10], F. Martinez Vidal[11], L. M. Massacrier[8], L. Nemenov[12], N. Neri[13], J. M. Pawlowski[9,*], S. M. Puławski[14], J. Schacher[15], G. Schnell[16,*], A. Stocchi[17], G. L. Usai[18], C. Vallée[19], G. Venanzoni[20]

Abstract: This report summarises the main findings of the QCD Working Group in the CERN Physics Beyond Colliders Study.

arXiv:1901.04482

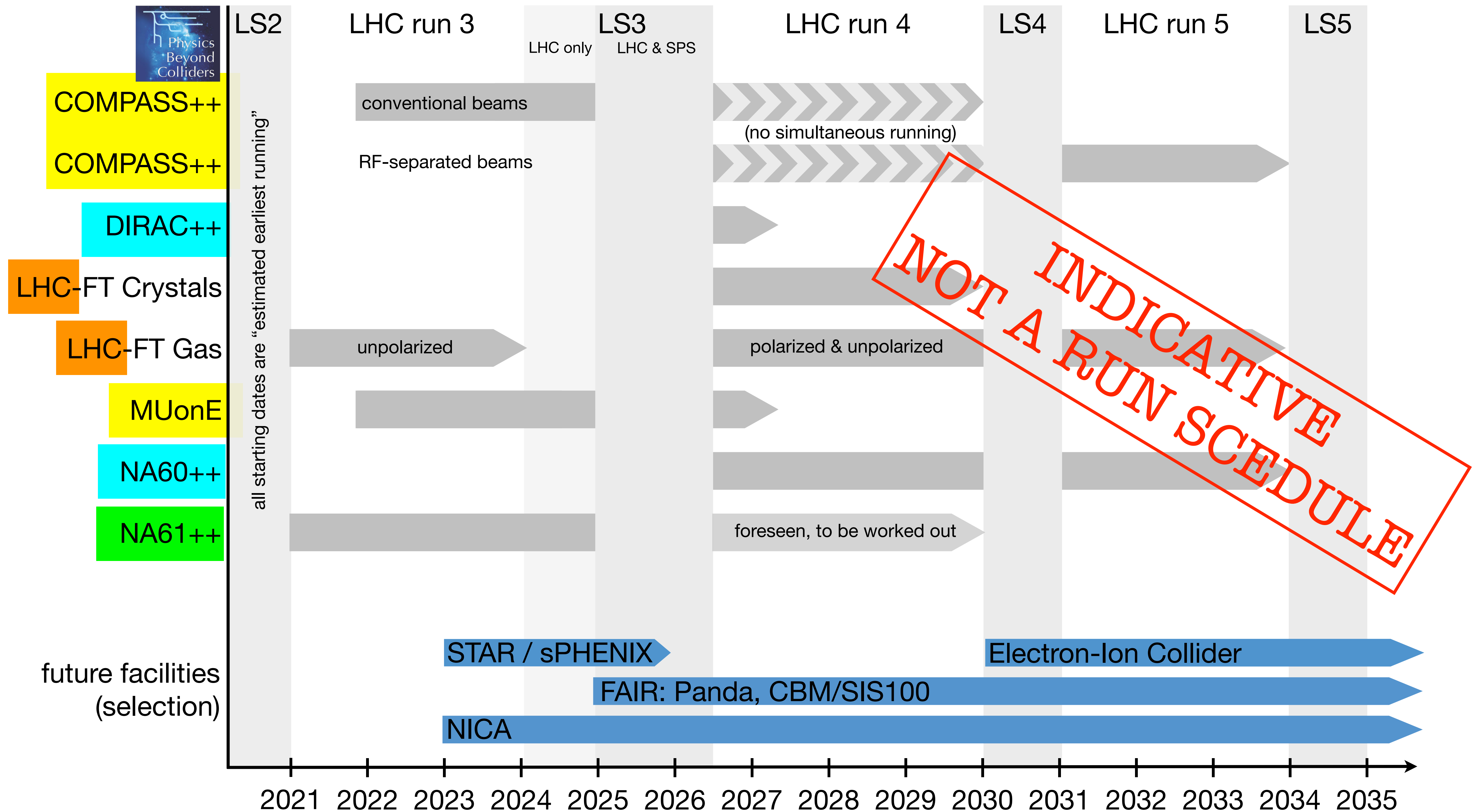
Proposals and Studies

- experiments at SPS and fixed target installations at LHC
- cover a broad range of topics in QCD
  - ★ parton densities, proton and nuclear structure
  - ★ heavy-ion physics
  - ★ low-energy dynamics
  - ★ measurements for other fields of HEP: (g-2)$_\mu$, cosmic rays, neutrinos

	LHC FT gas				LHC FT crystals	COMPASS++	MUonE	NA61++	NA60++	DIRAC++
	ALICE	LHCb	LHCSpin	AFTER@LHC						
proton PDFs	×	×		×						
nuclear PDFs	×	×		×		×				
spin physics	×		×	×		×				
meson PDFs						×				
heavy ion physics	×			×				×	×	
elast. μ scattering						×	×			
chiral dynamics						×				×
magnet. moments					×					
spectroscopy						×				
measurements for cosmic rays and neutrino physics	×	×		×		×		×		

Table 1. Schematic overview of the physics topics addressed by the studies presented in the QCD working group.

(possible) locations and time lines



M2 beamline

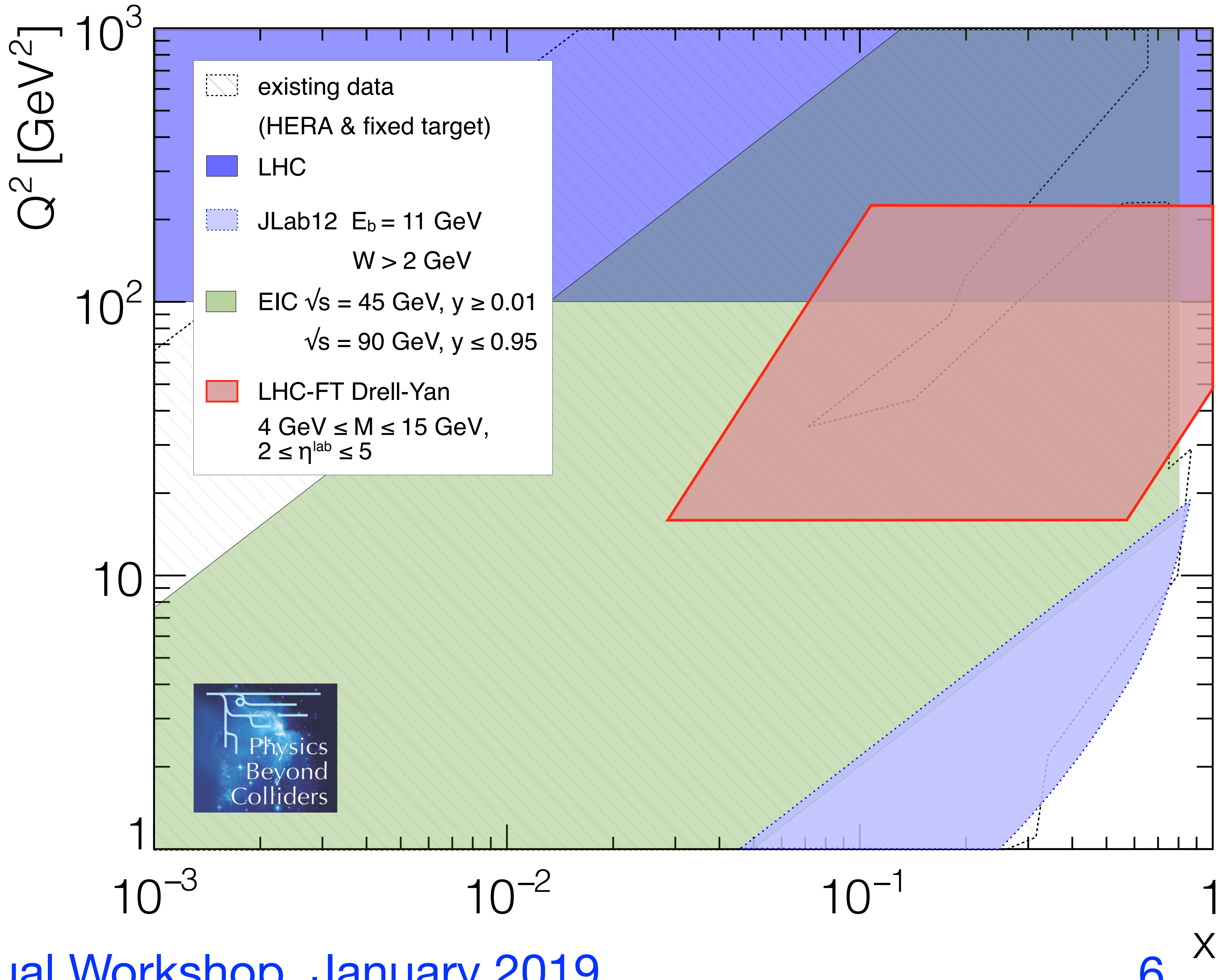
H2 beamline

ECN 3 cavern: presently used by NA62

PBC-QCD proposals

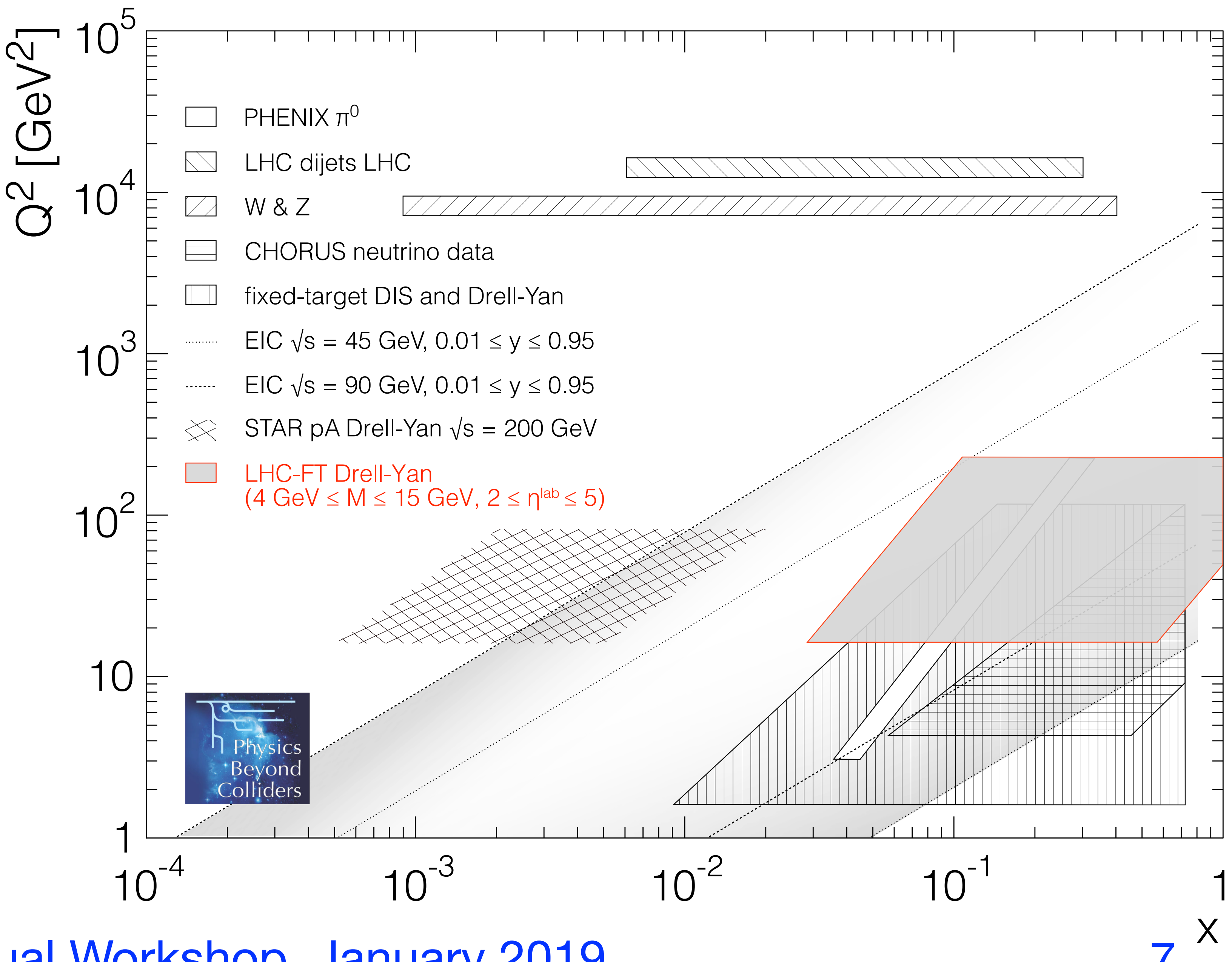
LHC Fixed Target (gas)

- fixed-target setup using LHC beam in unique kinematic domain
  - large forward boost provides access to very high x at sufficiently large scale
  - large luminosities (more difficult to reach in typical DIS setups)
- realization discussed for both LHCb and ALICE
- experience at LHCb with SMOG, to be upgraded to SMOG2 during LS2



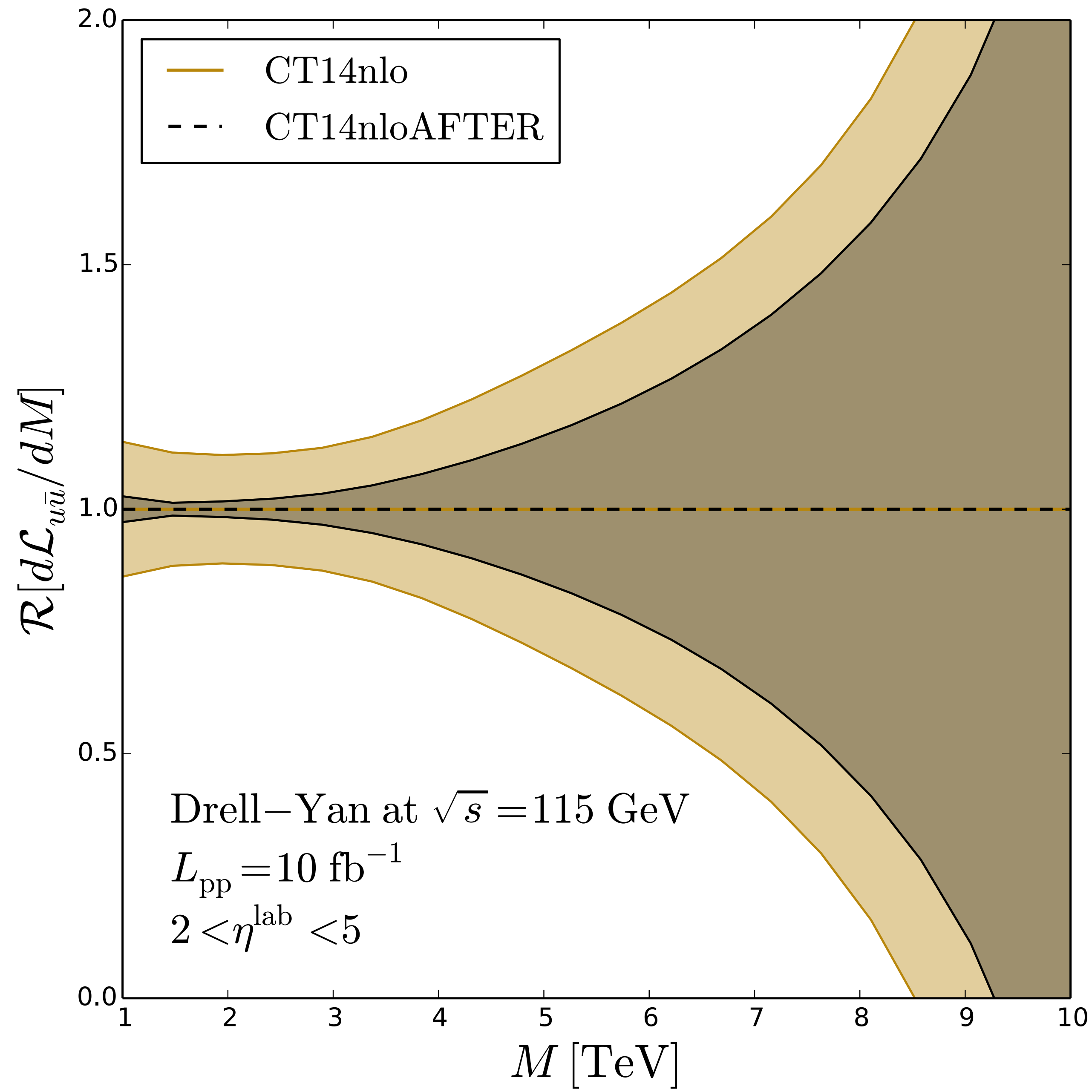
LHC Fixed Target (gas)

- fixed-target setup using LHC beam in unique kinematic domain
  - large forward boost provides access to very high x at sufficiently large scale
  - large luminosities (more difficult to reach in typical DIS setups)
- realization discussed for both LHCb and ALICE
- experience at LHCb with SMOG, to be upgraded to SMOG2 during LS2
- nuclear gas targets (or ion beam) for nPDFs



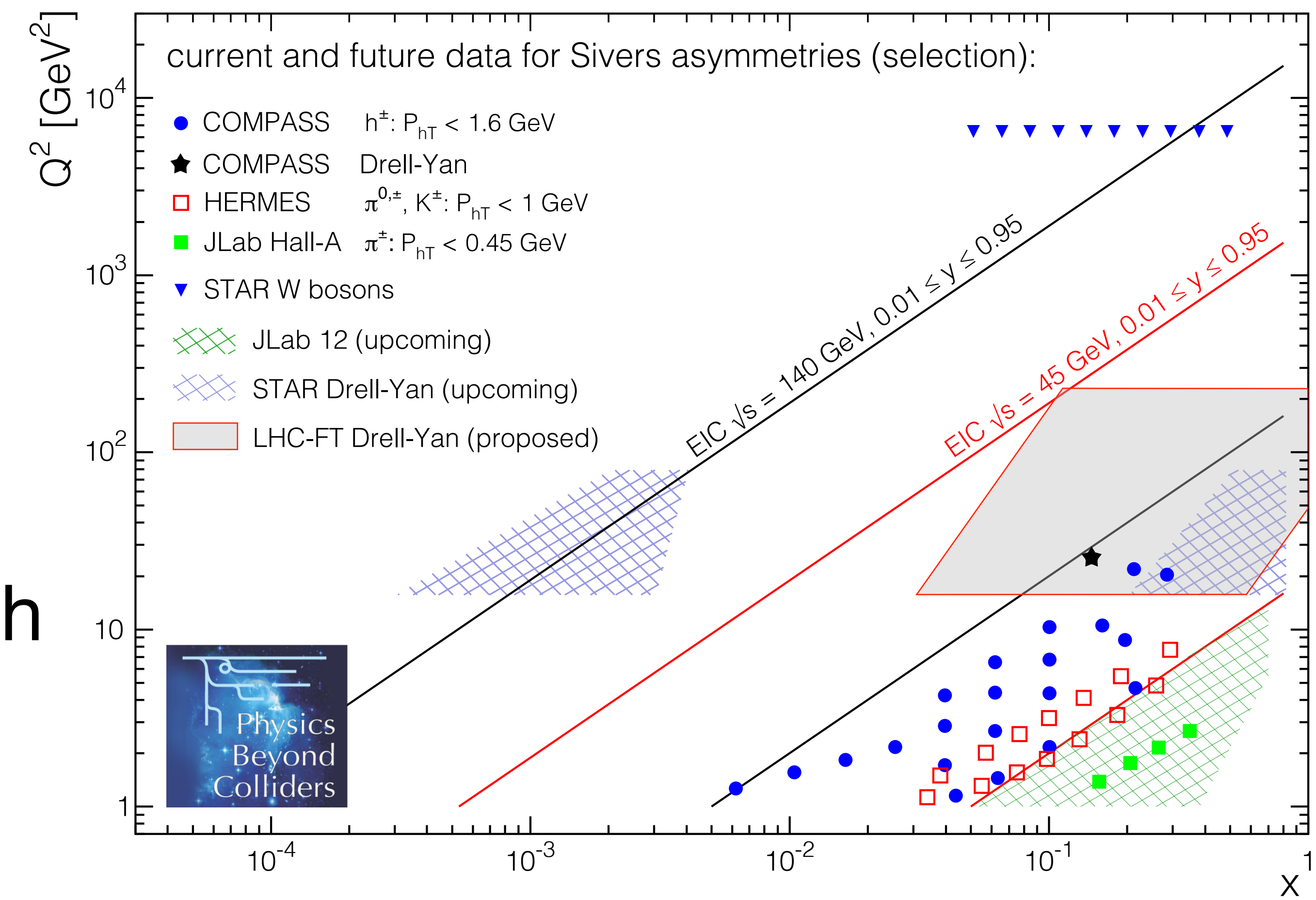
LHC Fixed Target (gas)

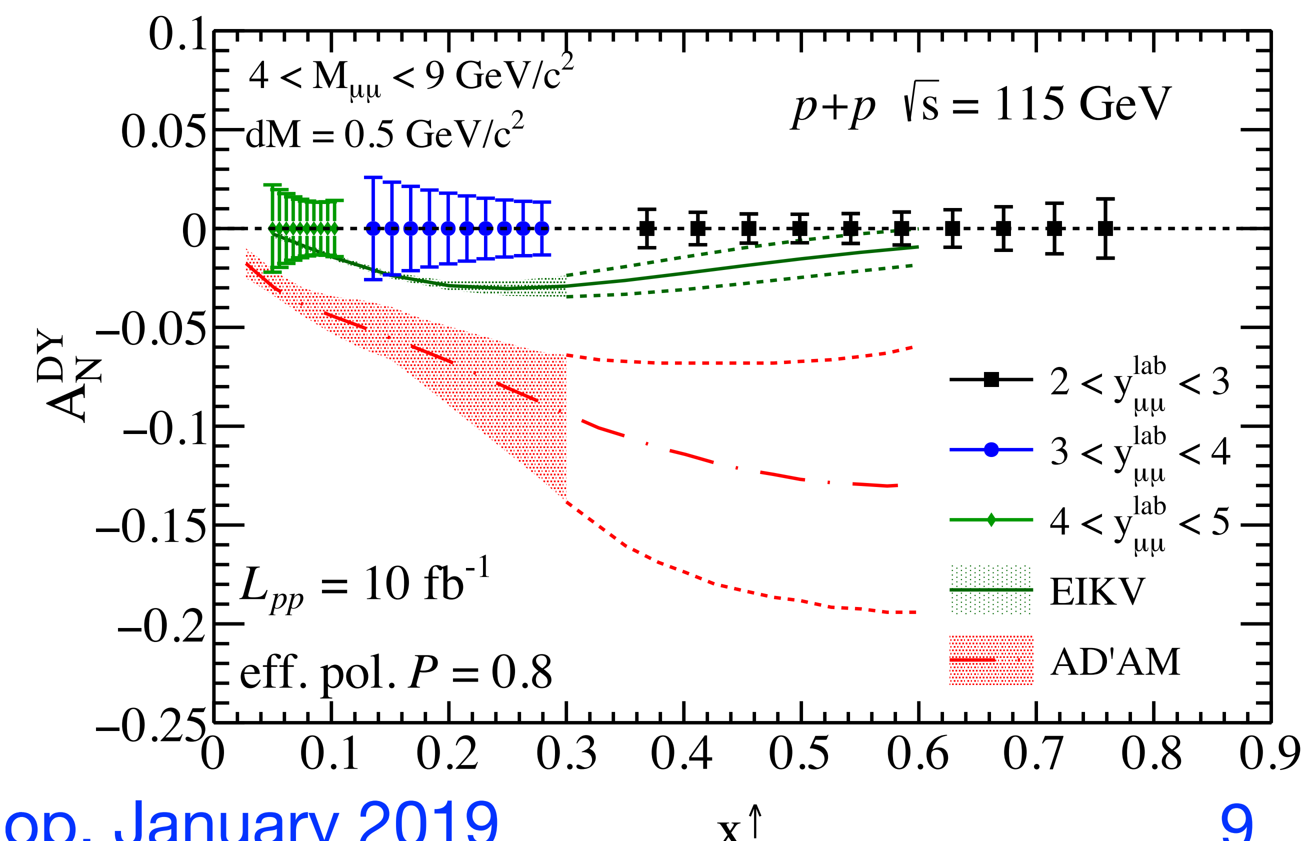
- proton PDFs at large x vital for core LHC physics program (high-mass parton luminosity) and interesting by themselves
- nPDFs even less constrained but needed for many processes, e.g., important for heavy-ion physics core programs



LHC Fixed Target with polarisation

- gas target opens door for polarised targets (H, D, ^{3}He)
  - ★ nucleon-spin physics at the LHC
  - ★ complementary field of research
- Sivers effect: important and prominent spin effect
  - ★ actively pursued at COMPASS, JLab, RHIC, and (future) EIC
  - ★ polarized LHC-FT potentially very competitive
- realisation not before LHC run 4



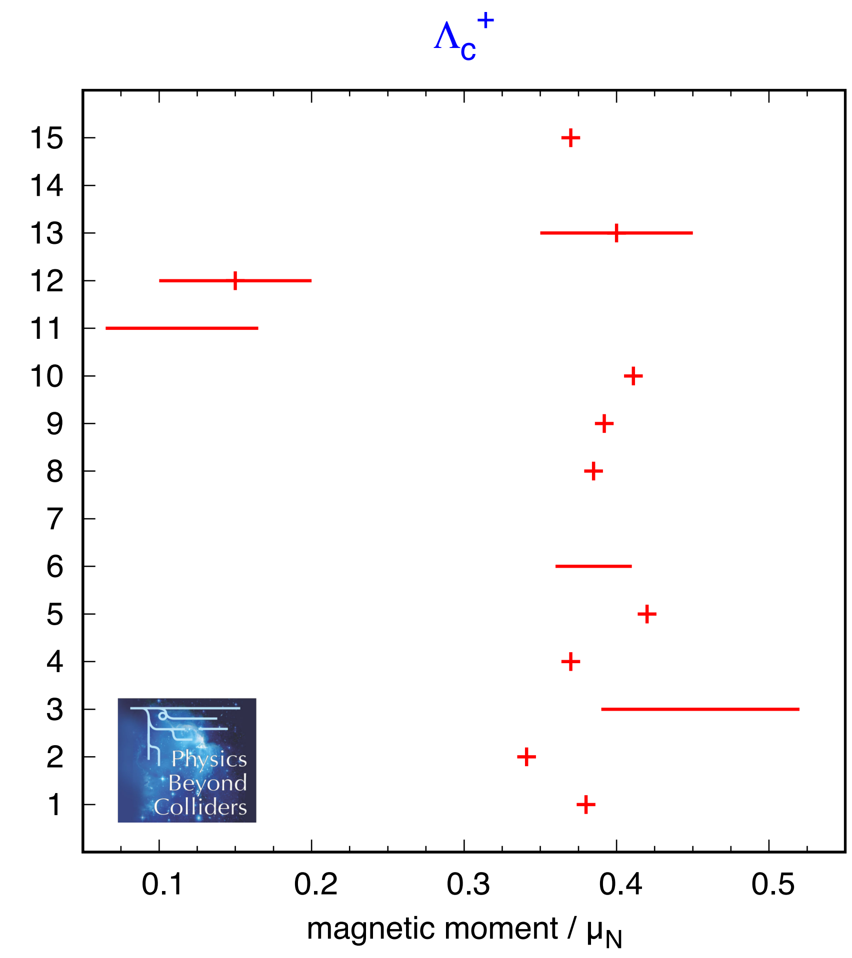


future studies

- LHC-FT running scenarios: dedicated or parasitic
  - ★ large range of corresponding integrated luminosities (differing by up to two orders of magnitude)
  - ★ benchmark studies for prolonged PBC mandate: what is needed to achieve physics goals
    - ✦ minimum luminosity
    - ✦ acceptance requirements, e.g., location of (polarized) target has strong impact on high-x reach
  - ★ exploit experience of AFTER@LHC for corresponding studies
- follow feasibility studies for technical implementation

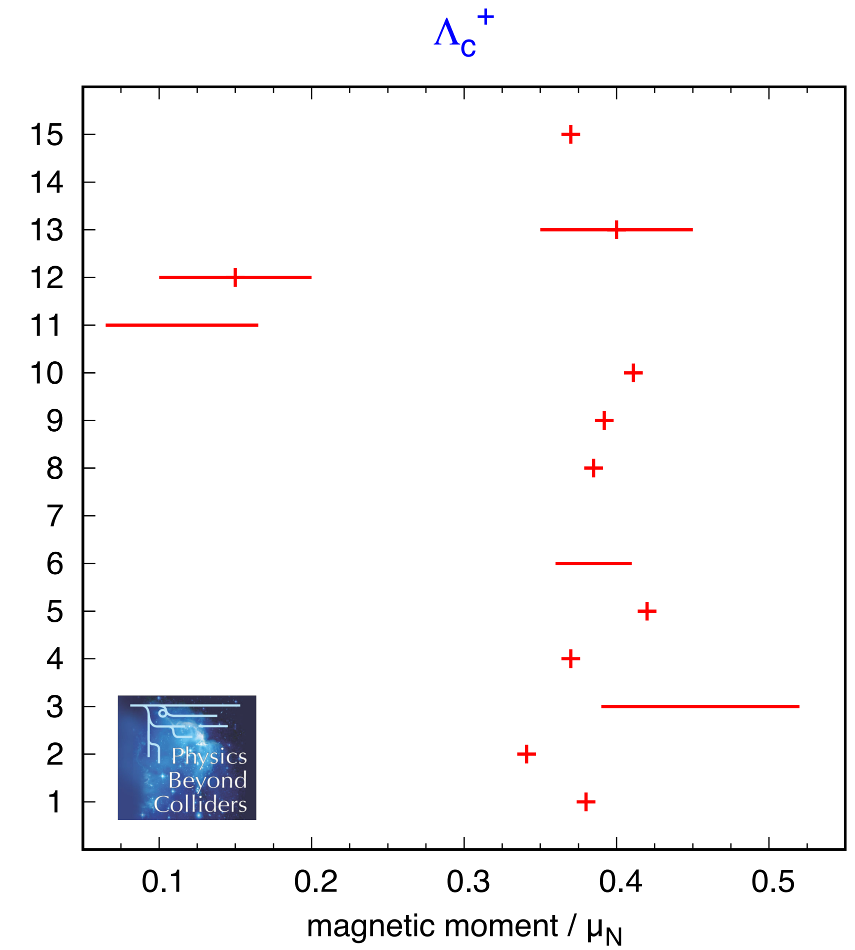
LHC Fixed Target (crystals)

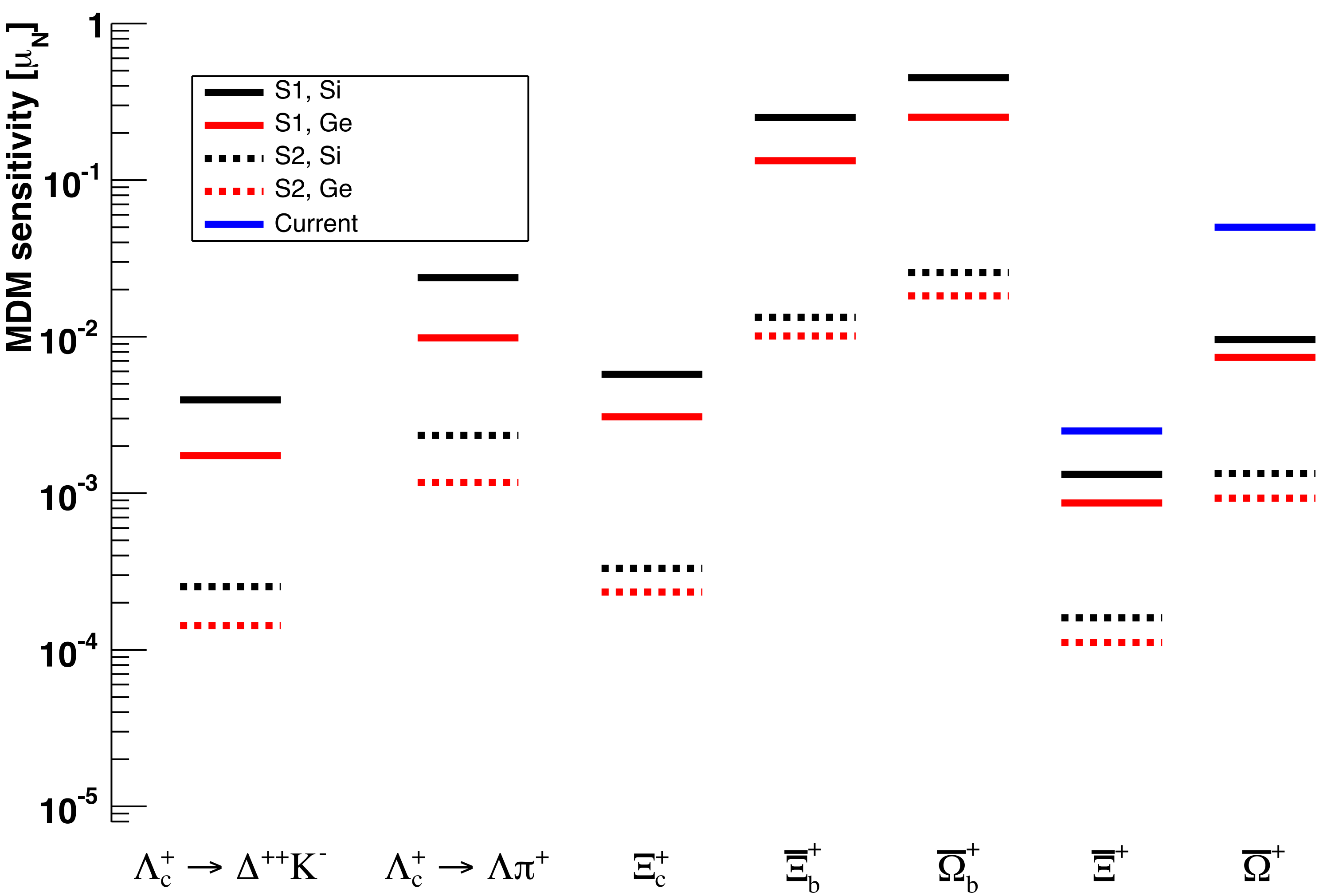
- magnetic (and electric) dipole moments of many short-lived particles (heavy baryons, τ) poorly constrained
  - ★ e.g. spread in theory predictions for Λ_c
- exploit intense fields inside bent crystals for measurement at LHC (e.g., LHCb)



LHC Fixed Target (crystals)

- magnetic (and electric) dipole moments of many short-lived particles (heavy baryons, τ) poorly constrained
  - ★ e.g. spread in theory predictions for Λ_c
- exploit intense fields inside bent crystals for measurement at LHC (e.g., LHCb)





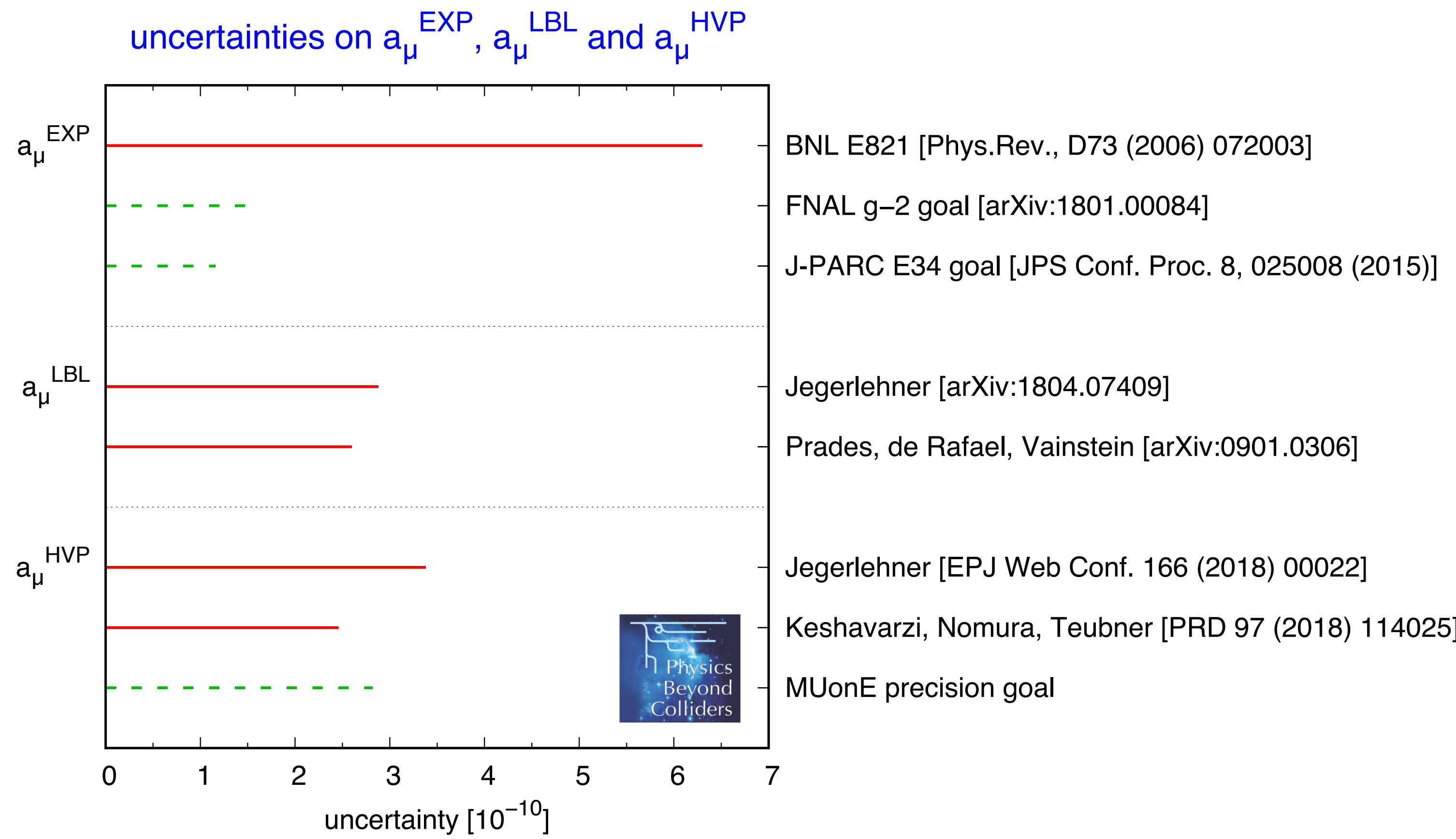
- example sensitivities for 2.4×10^{14} PoT (S1) and 2.4×10^{16} PoT (S2)
- requires production of polarized particles
  ➠ exploit SMOG2 data
- systematics evaluation
- conflict with LHC-FT gas

MUonE

anomalous magnetic moment
$a = (g-2) / 2$

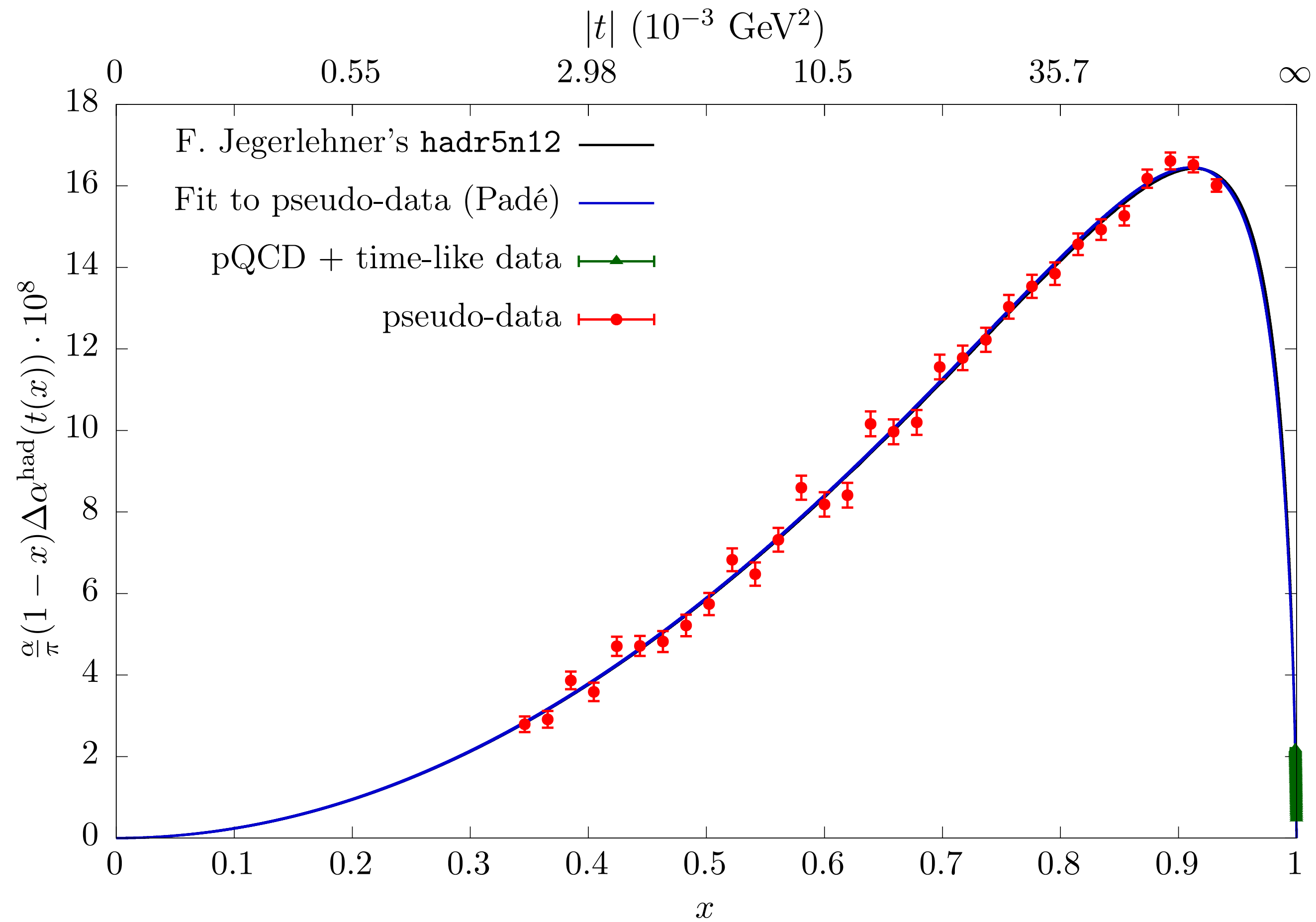
- motivation:
  - ★ persistent discrepancy between measured $(g-2)_\mu$ and SM theory
  - ★ upcoming measurements at FNAL and J-PARC
  - ★ two main theory uncertainties: hadronic vacuum polarisation (HVP) and light-by-light scattering
  - ★ aim of MUonE:

independent determination of HVP
with precision ~ extraction from $e^+ e^-$ annihilation and τ decays



MUonE

- extract a_{HVP} via sum rule from μe elastic scattering
- target precision requires μe cross section with accuracy ~ 10^{-5} (angular dependence, not absolute normalisation)
  - ➡ highest demands on experiment and theory (QED rad. corrections)
- will require feasibility tests → staged approach

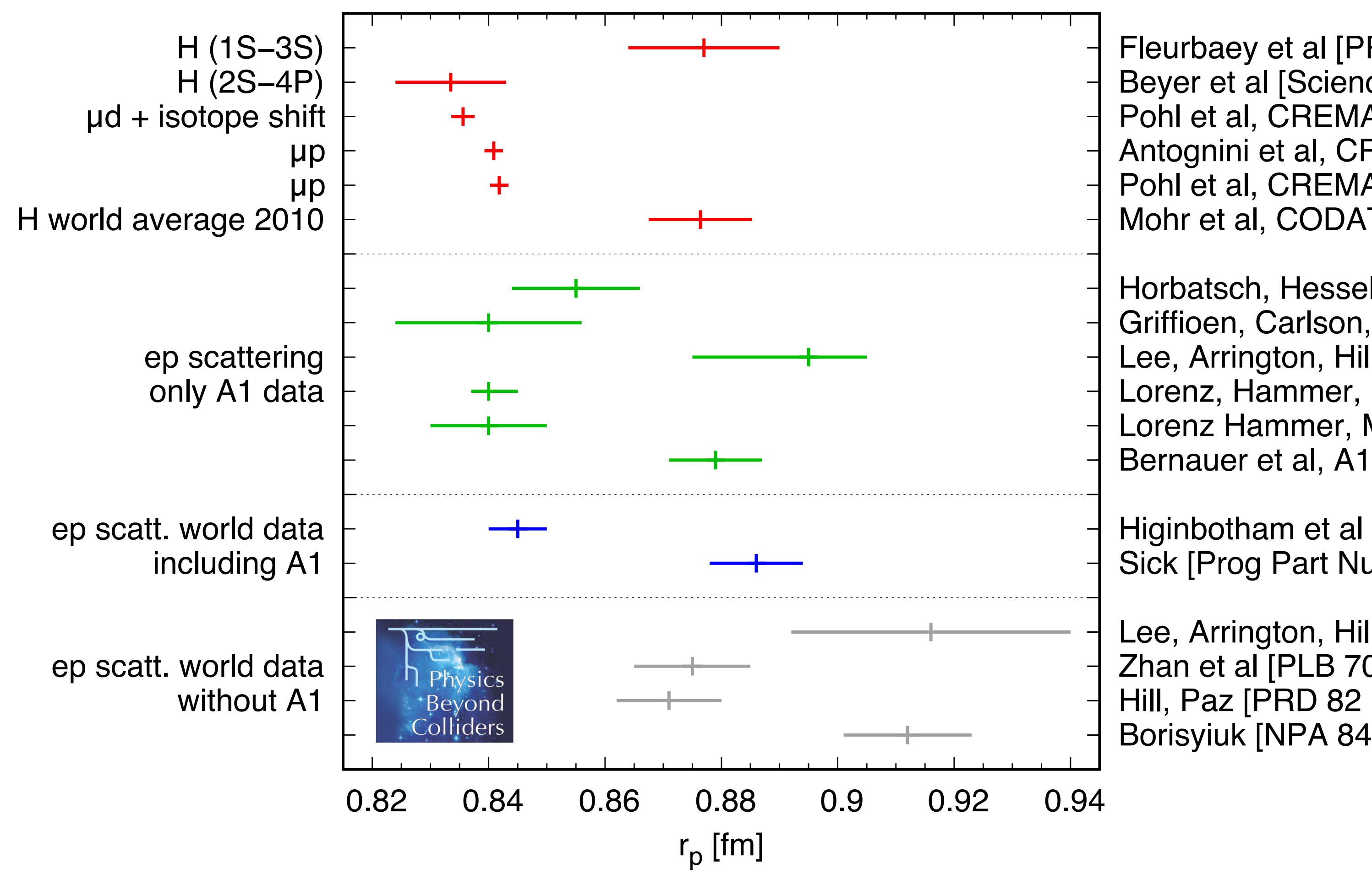


pseudo-data and fitted curve for sum rule giving a_{HVP}

COMPASS++

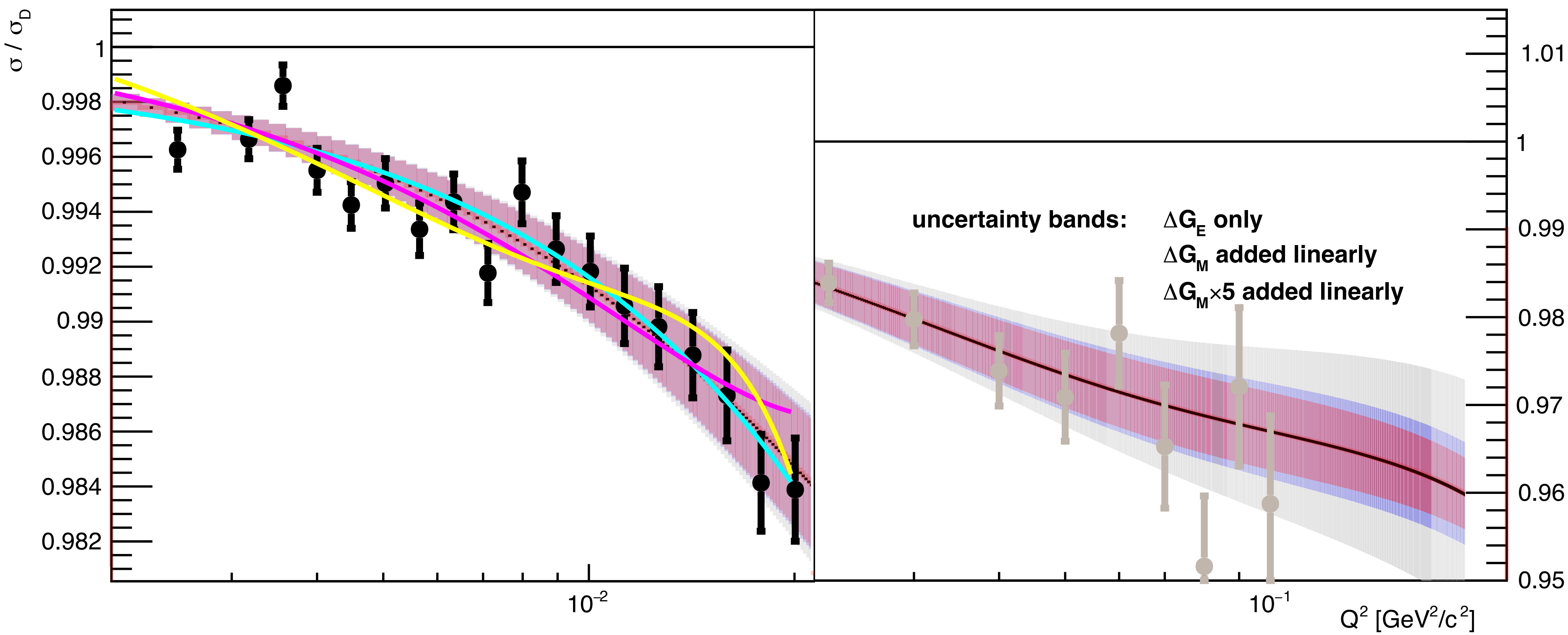
- persistent discrepancies on proton charge radius r_p determined from spectroscopy (H, muonic H) and ep elastic scattering
- different fits to ep data yield widely different r_p
- goal: r_p from high-energy μp elastic scattering
  - ★ advantages over ep scatt:
    - ✦ smaller QED radiative corrections
    - ✦ very small contamination from magnetic form factor

proton charge radius from spectroscopy or ep scattering



COMPASS++

- demanding measurement: low scatt. angle, trigger, new TPC



- pseudodata and fits
  - ★ preferred fit gives $\Delta_{stat}\, r_p = 0.013$ fm
  - ★ experimental and fitting uncertainties to be quantified

MUonE and COMPASS r_p measurement

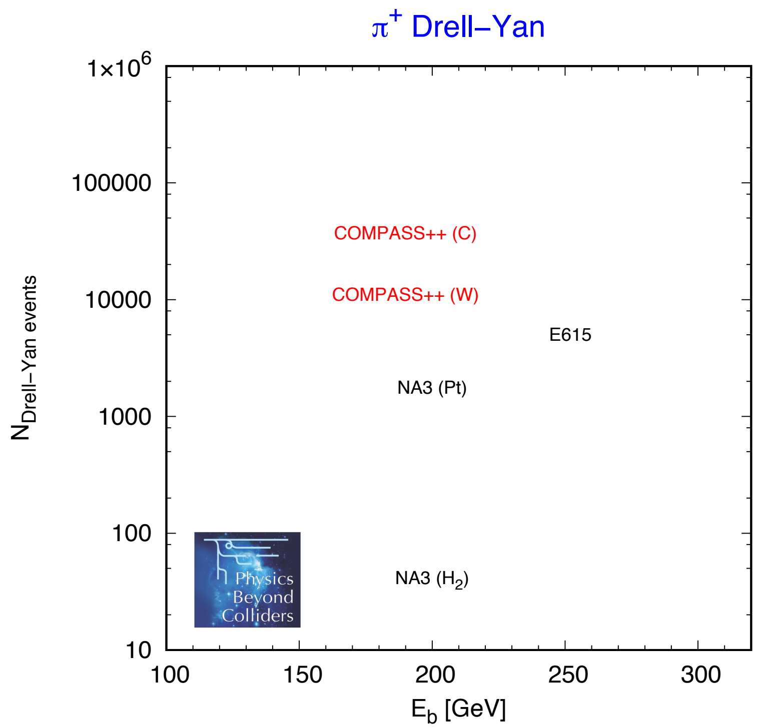
- both measurements
  - ★ are highly demanding, strict precision requirements
  - ★ should be done soon in view of worldwide activities

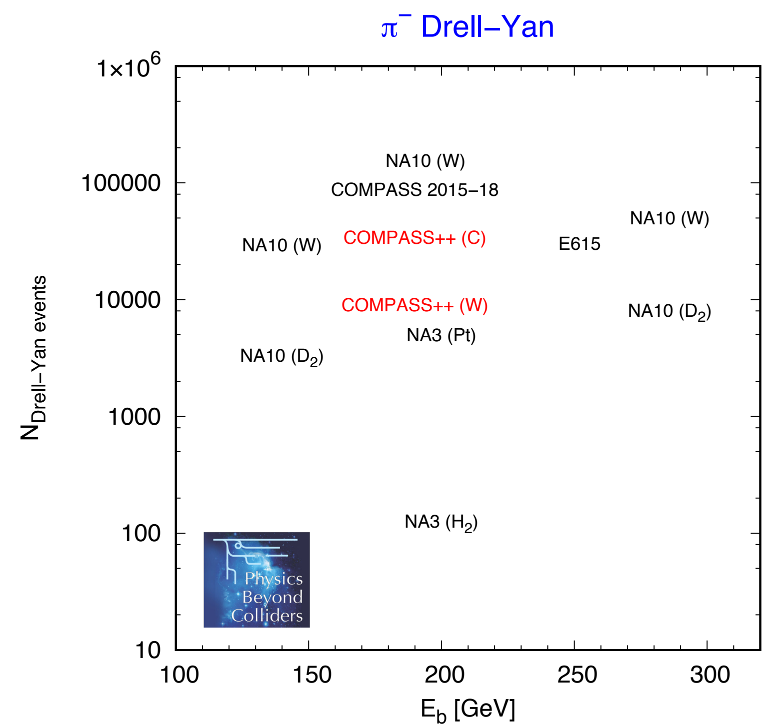
- discussions in QCD working group on running scenarios
  - ★ requirements on beam and detector setup
    parallel running possible? or interleaved running?
  - ★ conveners' opinion: to be followed up this year

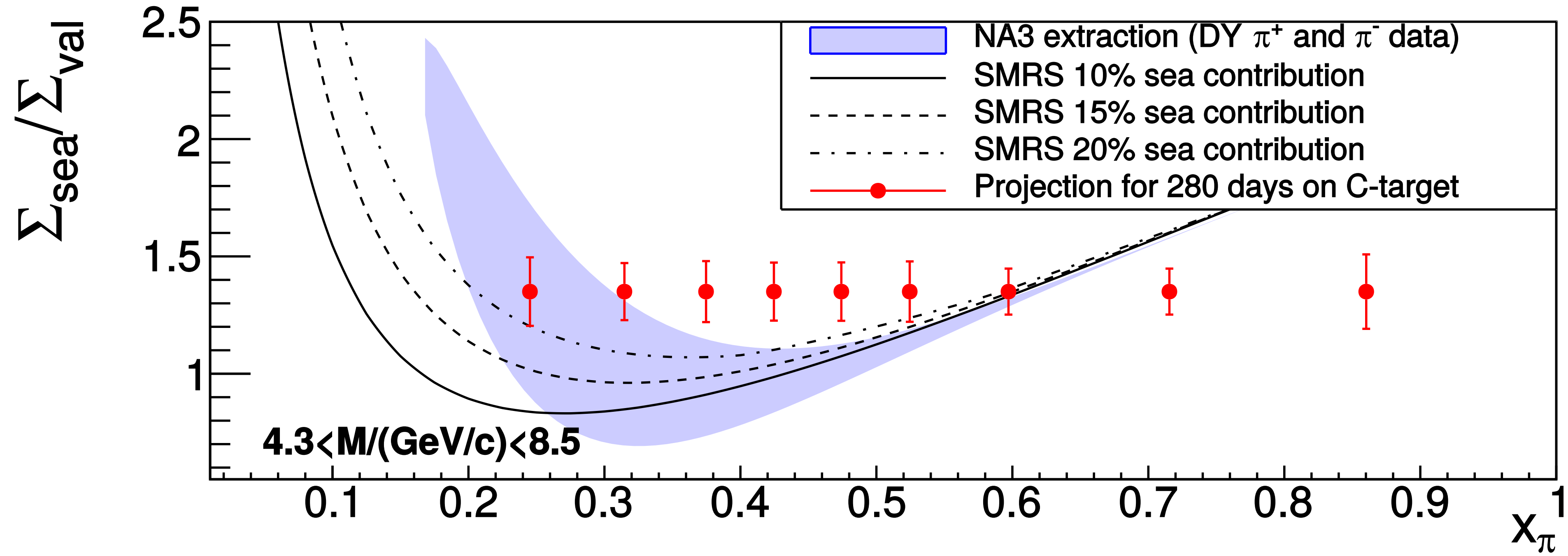
- NA64++ with muon beams (see BSM working group)
  would run at same beamline
  - ★ only short running envisaged before LS 3
  - ★ need for coordinated discussions between the projects

COMPASS++ with π beams

- pion plays special role in QCD (Goldstone boson)
- π PDFs very poorly known
- unique opportunity: Drell-Yan with π^- and π^+ beams:
  - ★ separation of sea and valence quarks
  - ★ highly complementary to plans in ep scattering (JLab, EIC)







Long-term prospect: RF separated beams

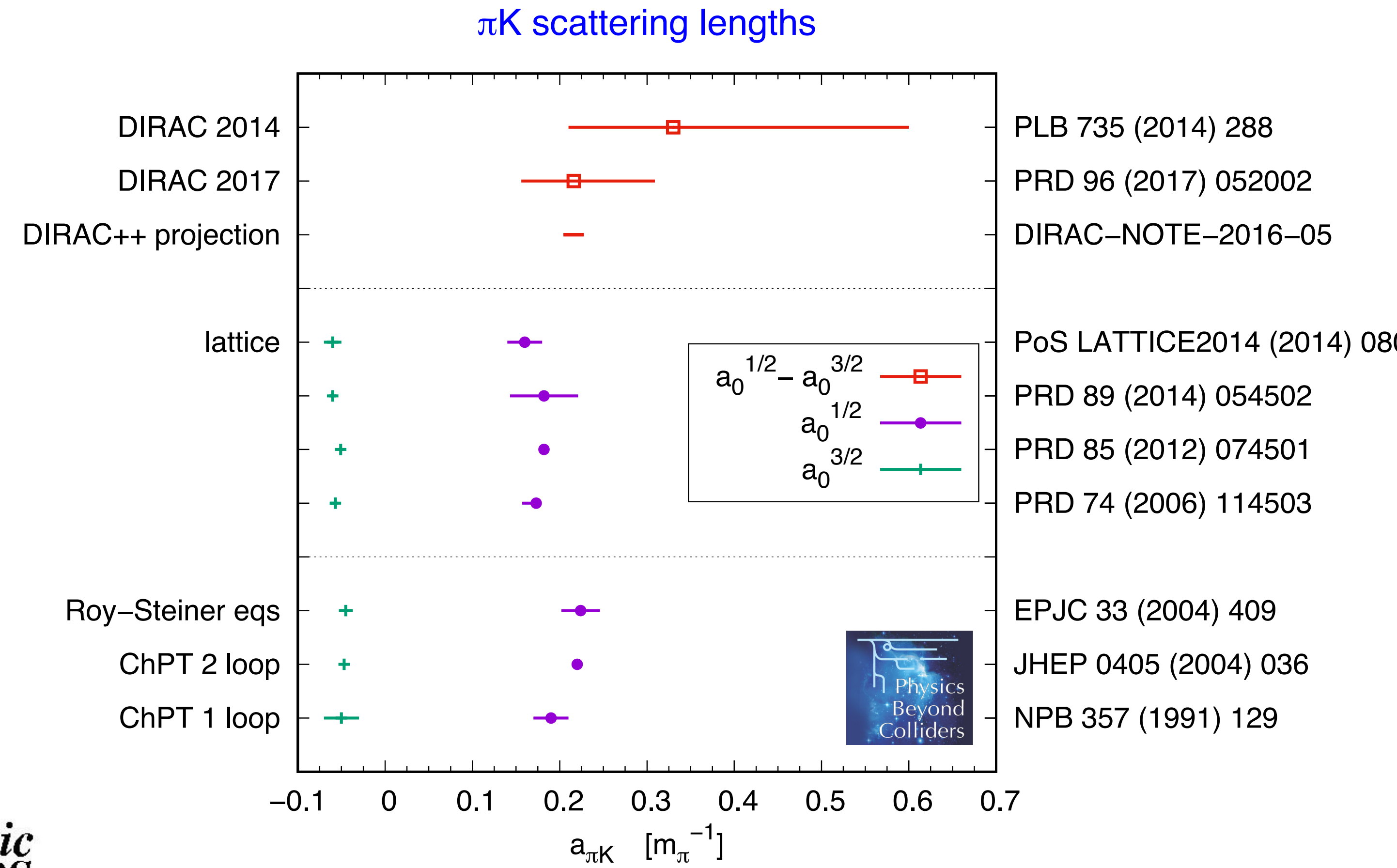
- RF separated kaon beams would allow wide range of unique QCD studies with COMPASS++
  - ★ kaon polarisabilities (Primakov reaction, chiral symm. breaking)
  - ★ PDFs (Drell-Yan, prompt photons)
  - ★ kaon spectroscopy

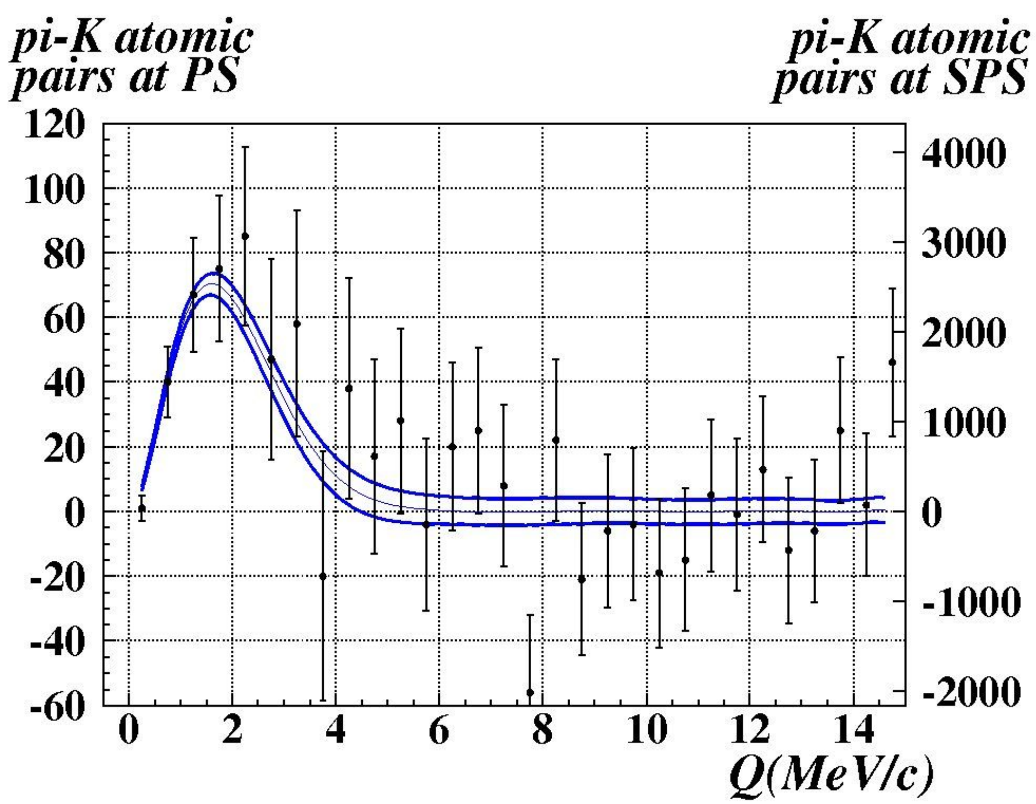
- feasibility study for RF separated beams started in conventional beams working group
  - ★ to be followed up: achievable beam parameters (energy, intensity)
  - ★ what are minimum beam requirements for the different physics studies?

DIRAC++

- πK scattering lenghts: benchmark quantities for chiral symmetry breaking in the strange quark sector

- study of πK atoms at SPS would yield exp. error ~ theory uncertainties



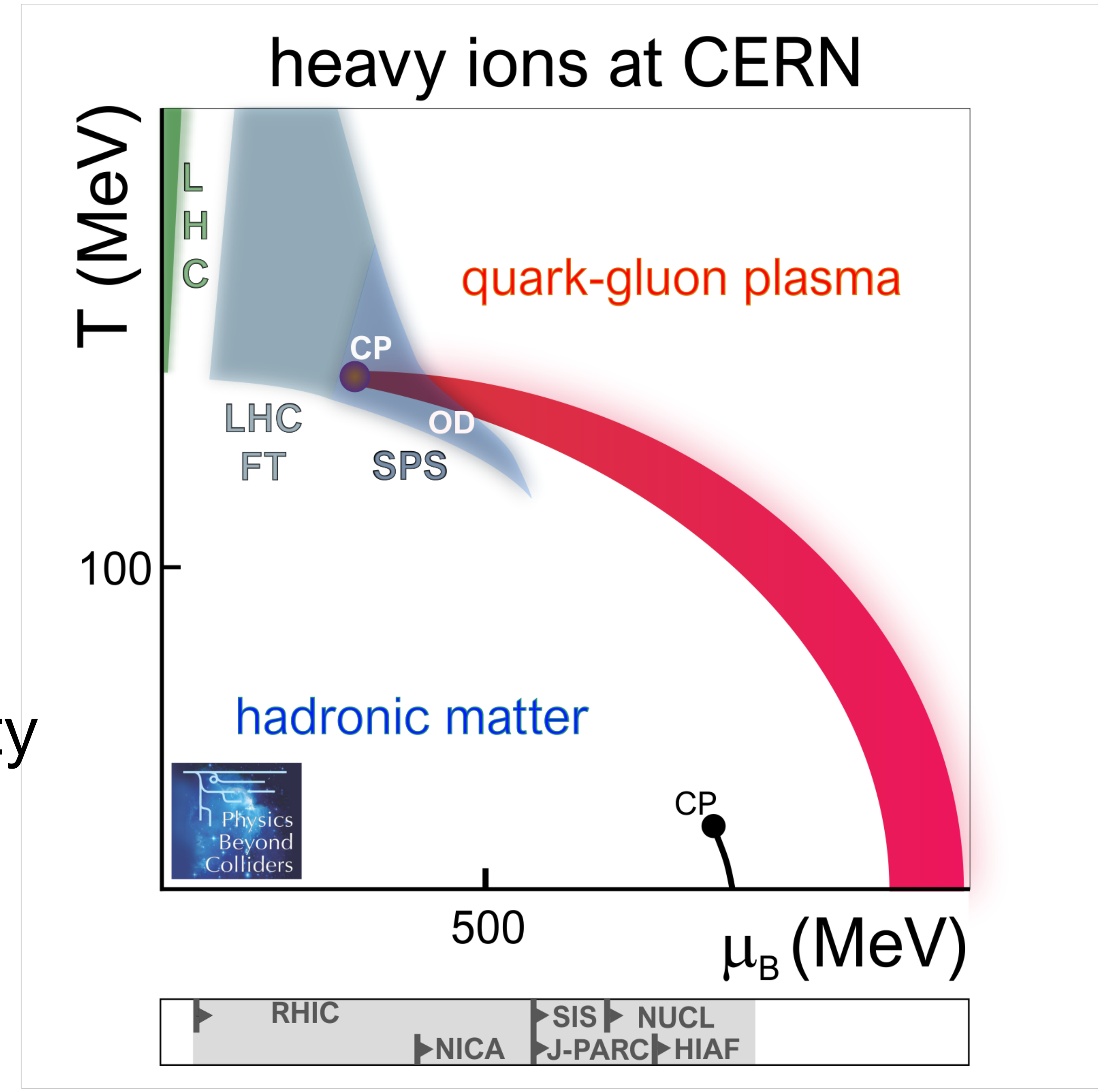


- rates at SPS ≫ at PS (DIRAC 2014, 2017)

- required beam intensity needs underground hall → ECN 3

Heavy ion physics

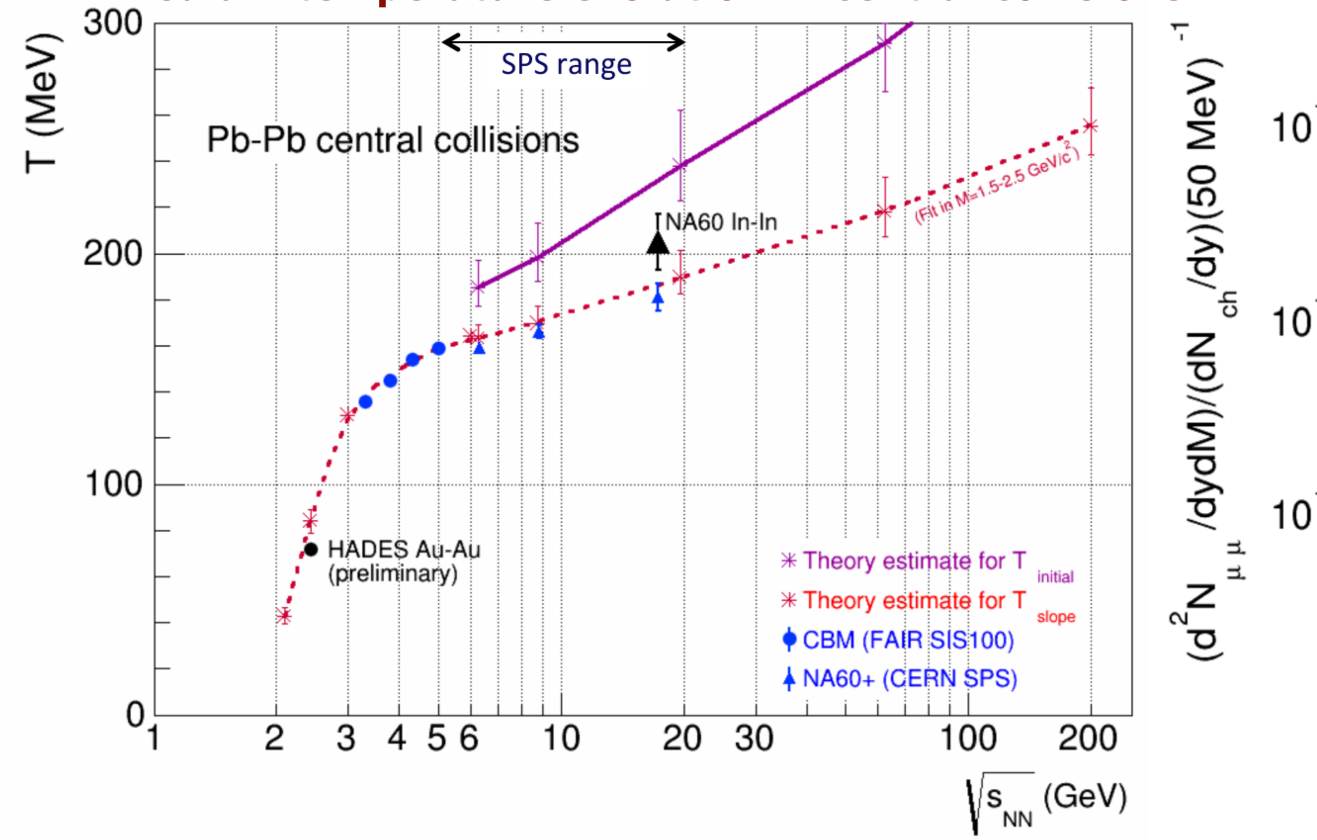
- LHC-FT & SPS experiments offer a unique coverage of a primarily interesting part of the QCD phase structure including the potential CEP (CP) & mixed phases
- Complementary to running and planned experiments
- Uniqueness:
  - ★ Combined coverage of large range in temperature and density
  - ★ Interaction rate & observables
  - ★ Timing



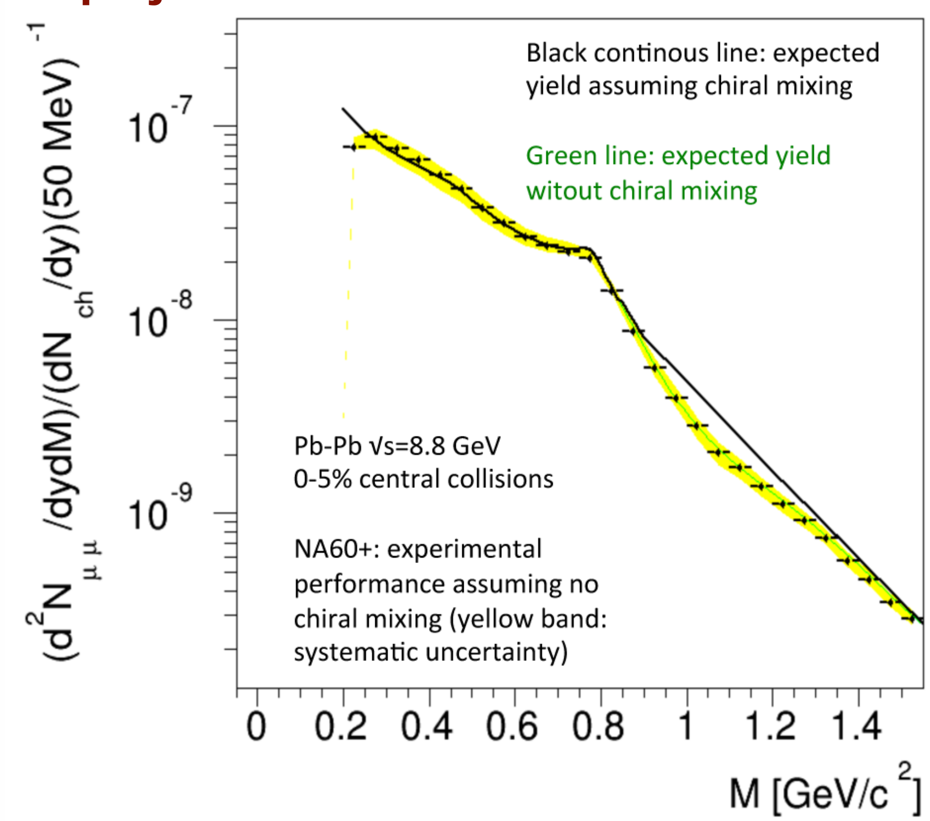
NA60++

- Motivation
  - ★ Signal of 1st oder phase transition?
  - ★ Signal for restoration of chiral symmetry?
  - ★ Transport properties at large densities?

Medium temperature evolution in central collisions



NA60++ projection for the thermal dimuon mass spectrum



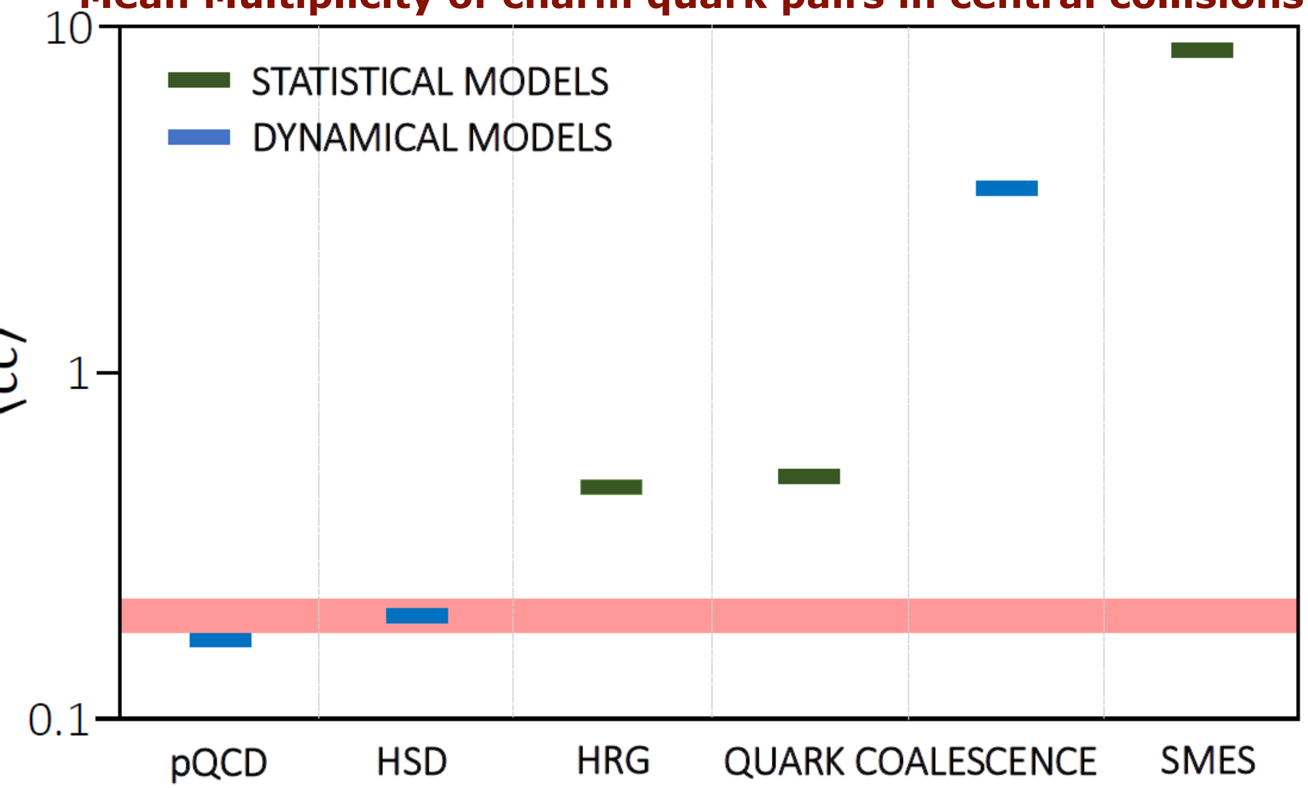
- Measurements
  - ★ mass spectrum of thermal muon pairs
  - ★ Increase of dilepton yield
  - ★ open charm (see talk of Enrico Scomparin)

NA61++

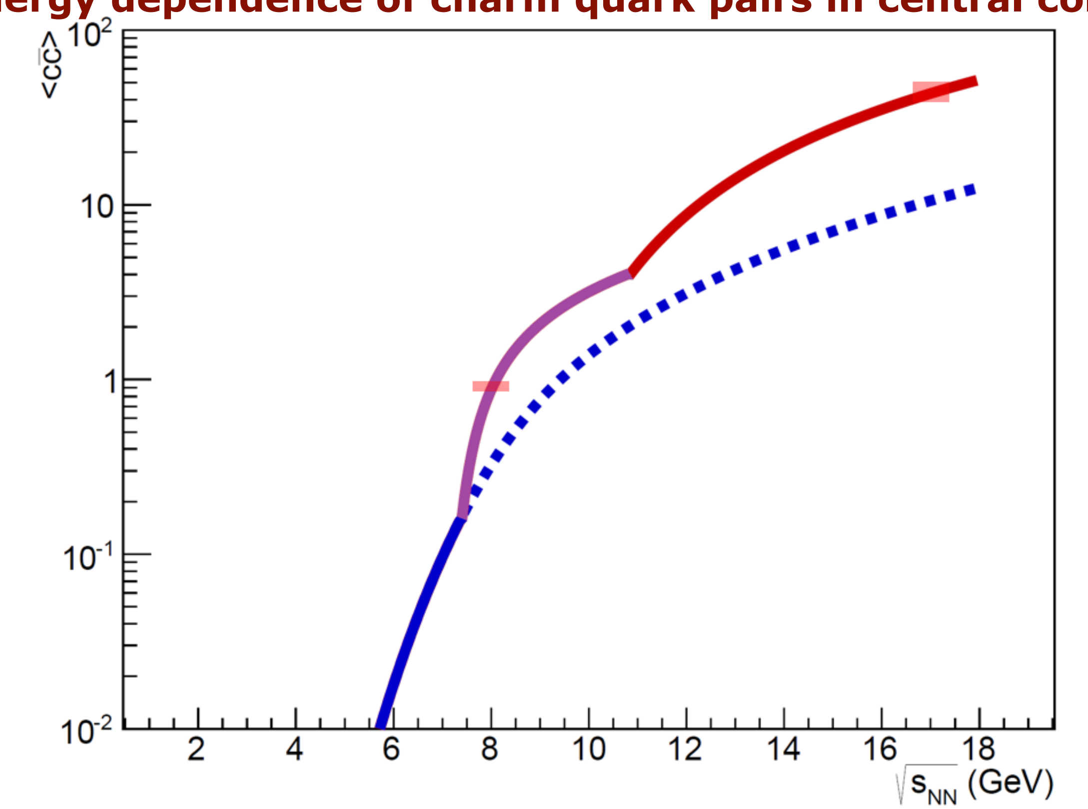
- $c\,\bar{c}$ - pairs
  - ★ Mechanism of open charm production?
  - ★ Impact of the onset of deconfinement on open charm production?
  - ★ Impact of quark-gluon plasma formation on J/ψ prod.

- nuclear fragment. cross section
  - ★ origin of cosmic rays
  - ★ cosmic ray background
- hadron product. measurements
  - ★ for T2K and Hyper-Kamiokande replica targets

Mean Multiplicity of charm quark pairs in central collisions



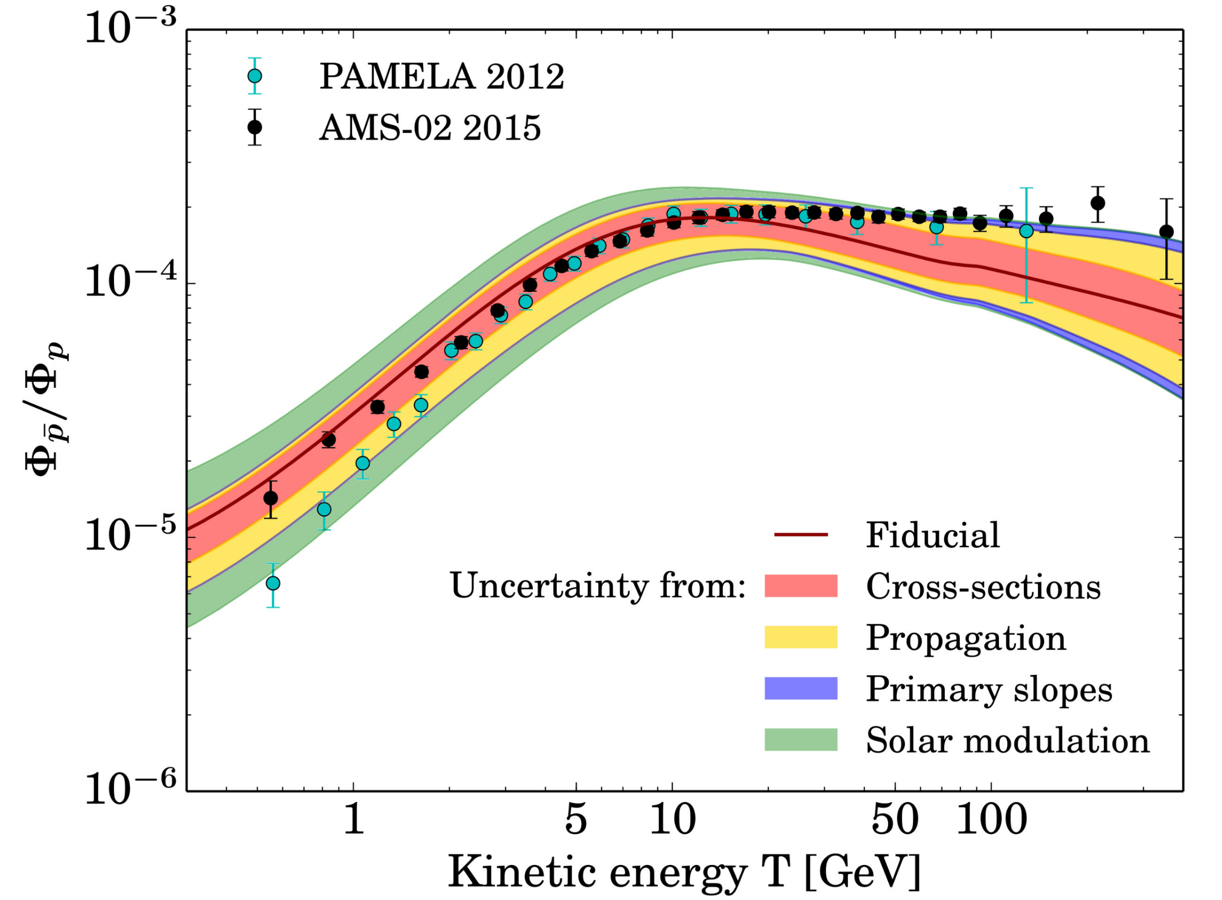
Energy dependence of charm quark pairs in central collisions



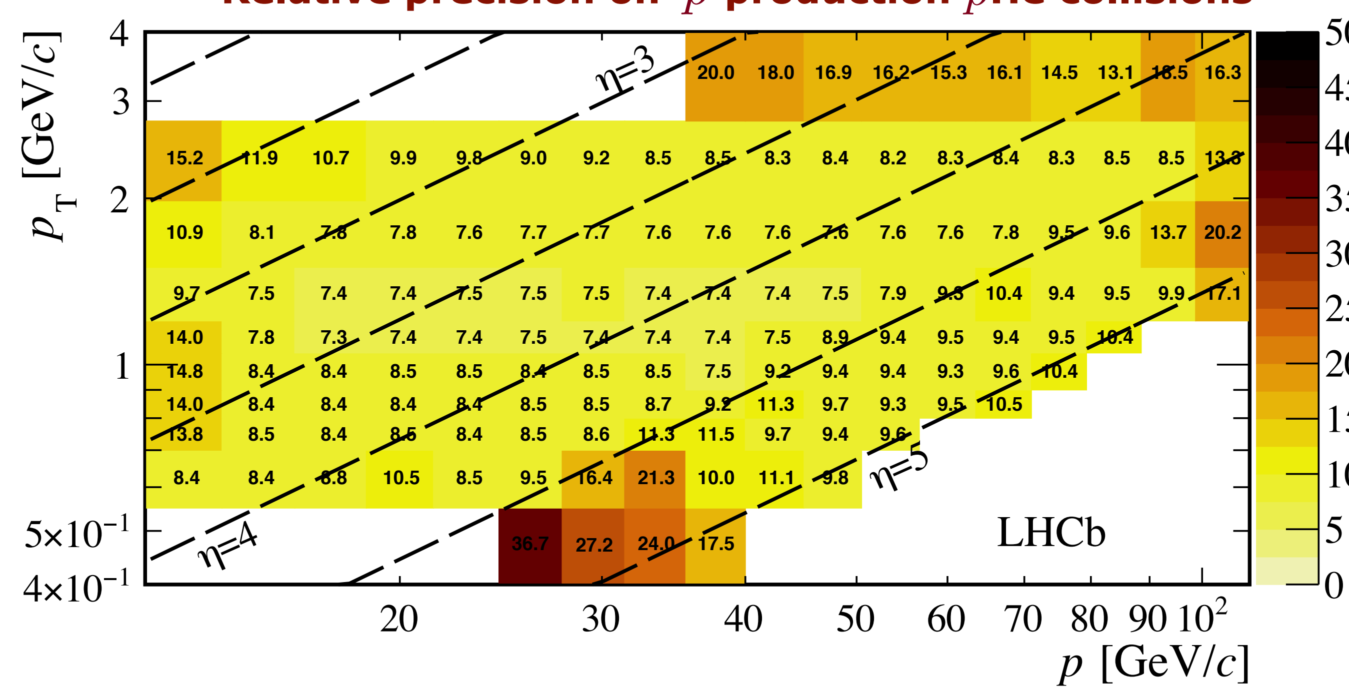
Measurements for cosmic ray physics

- Anti-proton production and nuclear fragmentation
  - ★ LHCb-FT
  - ★ ALICE-FT
  - ★ NA61++
  - ★ COMPASS++
- Charm
  - ★ LHC-FT
- Hadron production measurements
  - ★ NA61+

Examples for QCD related limitations in flux calculations

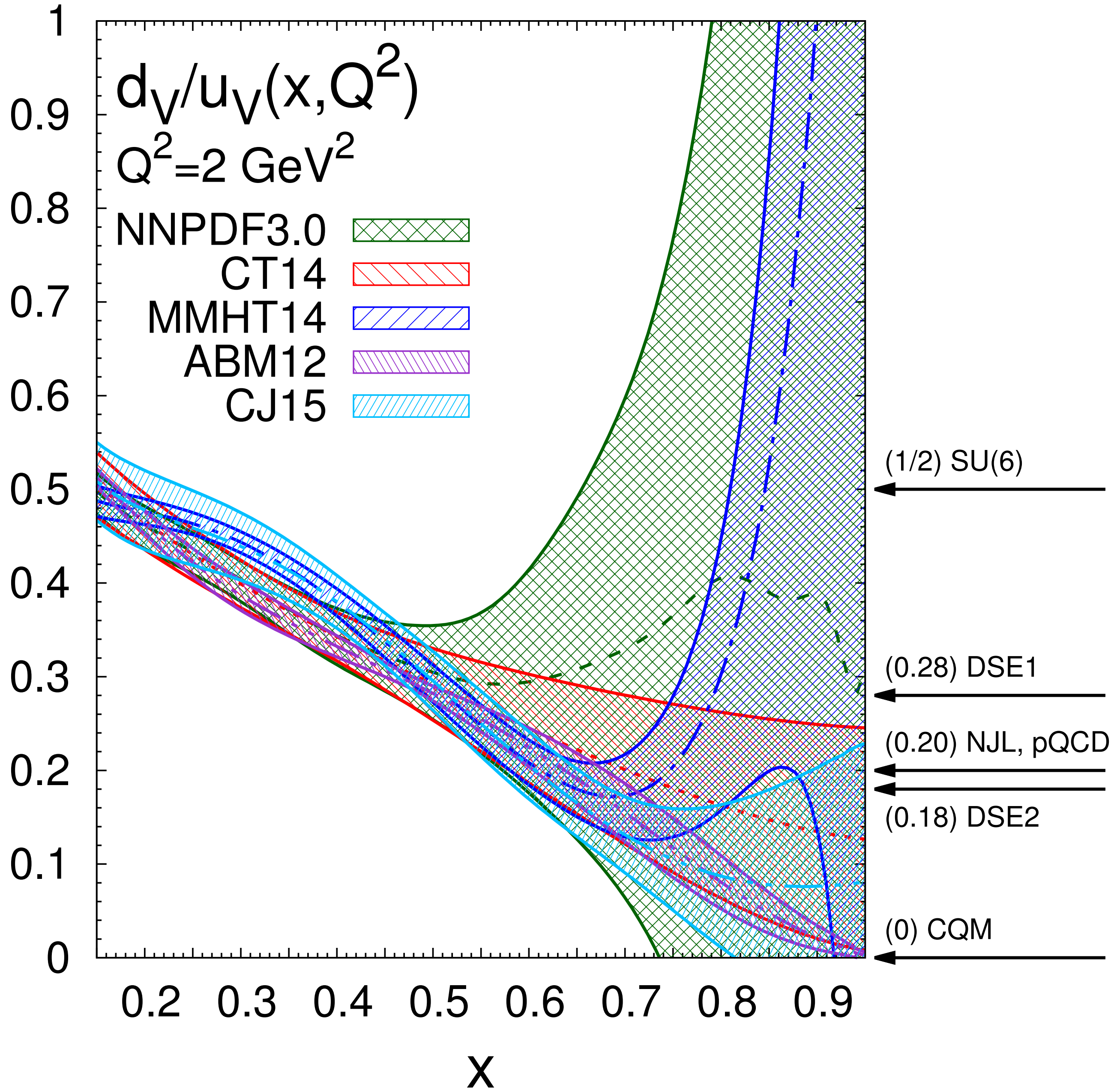


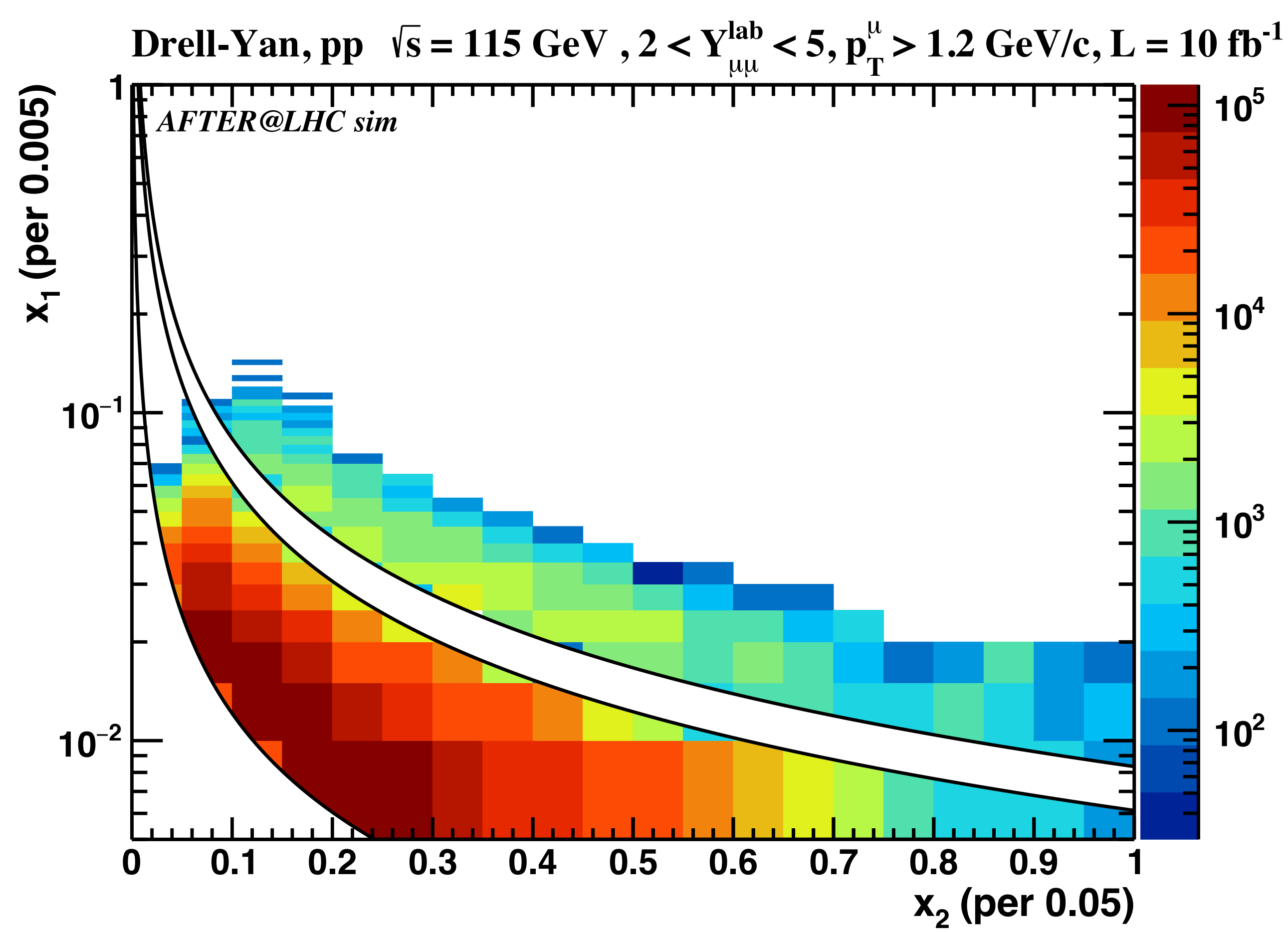
Relative precision on $\bar{p}$ production pHe collisions



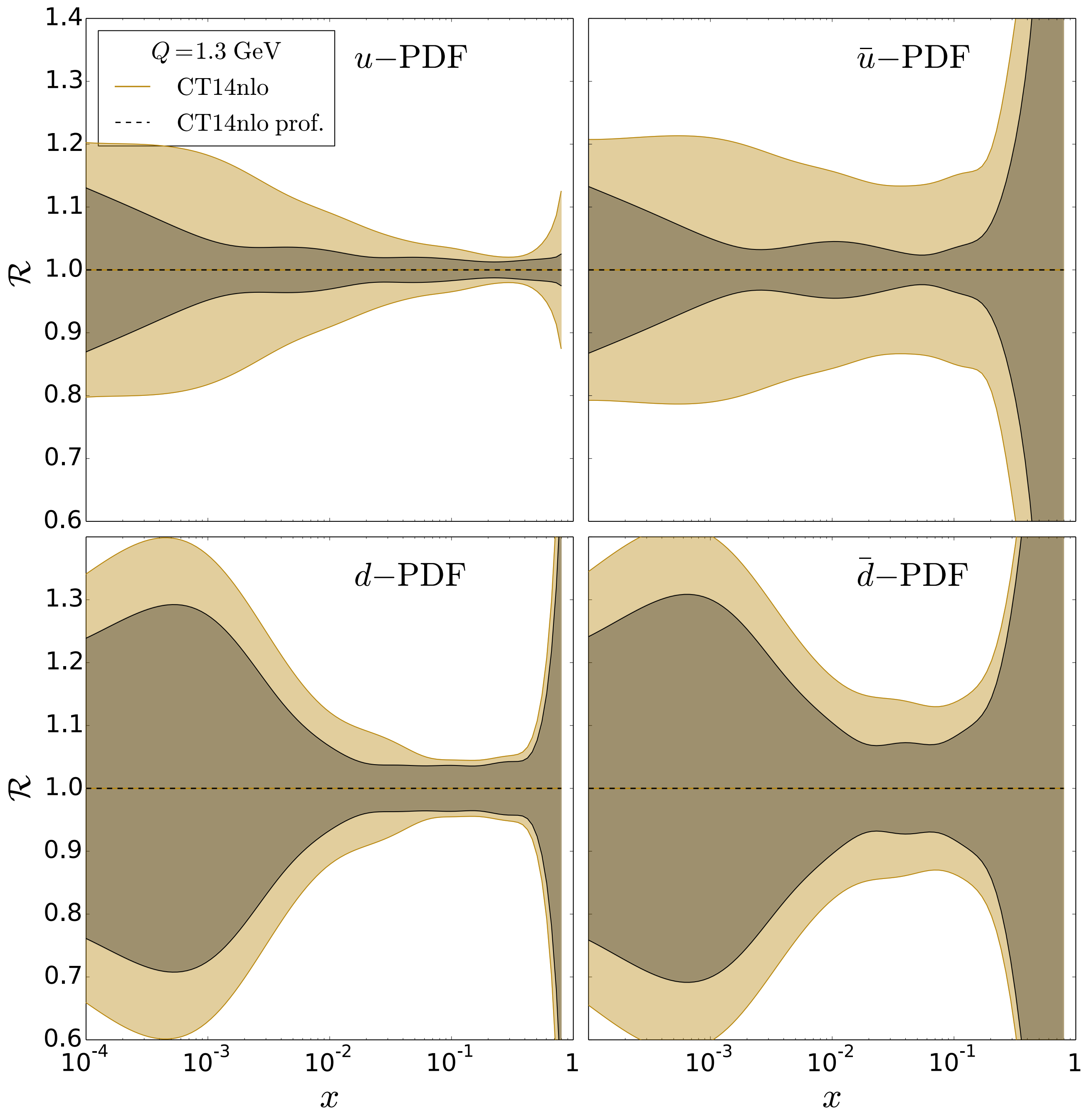
Thanks to the working group members and to the PBC coordinators backup slides

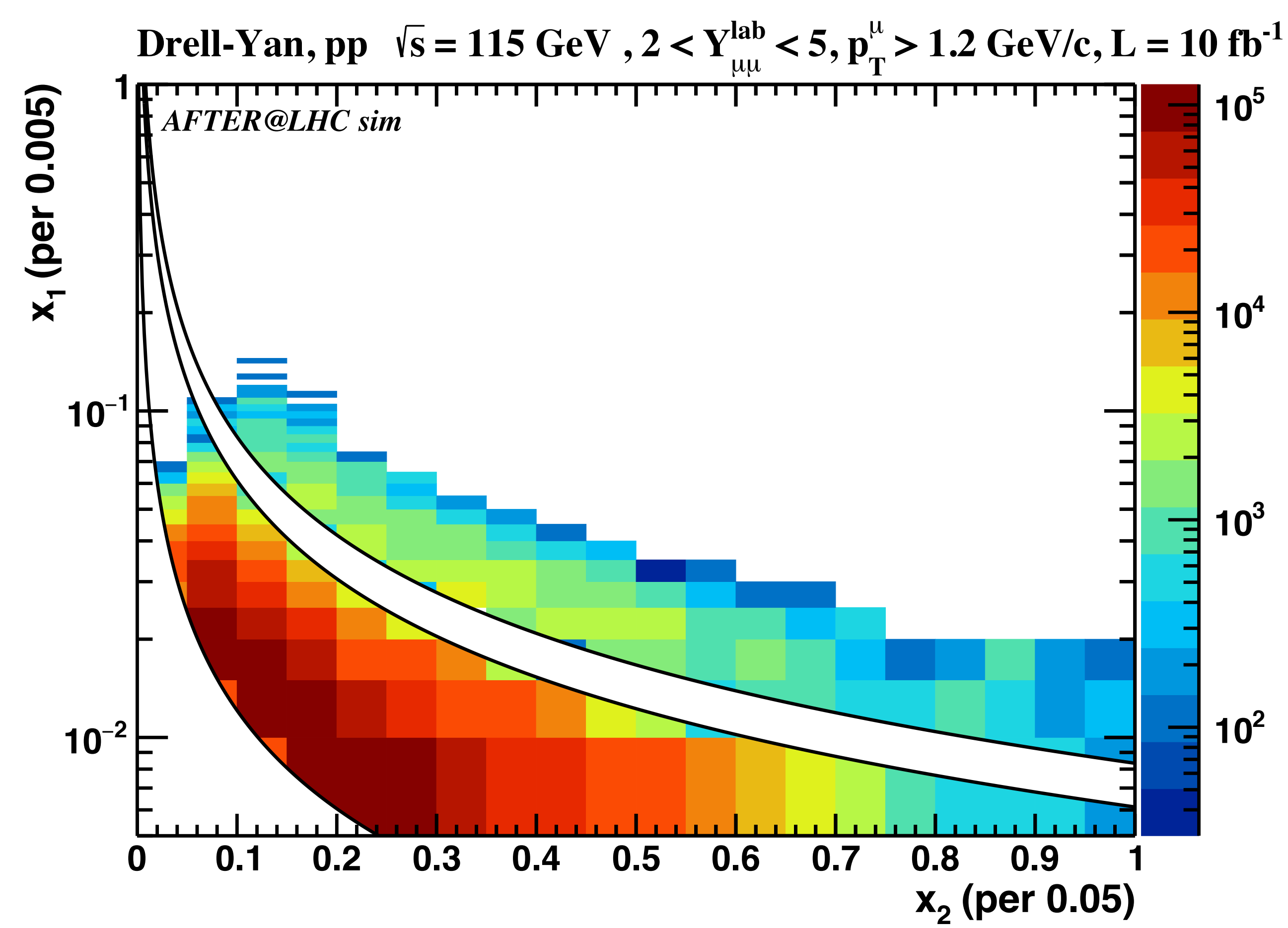
LHC-FT gas: high-x PDFs





LHC-FT gas: high-x PDFs





LHC-FT crystals: MDMs of selected baryons