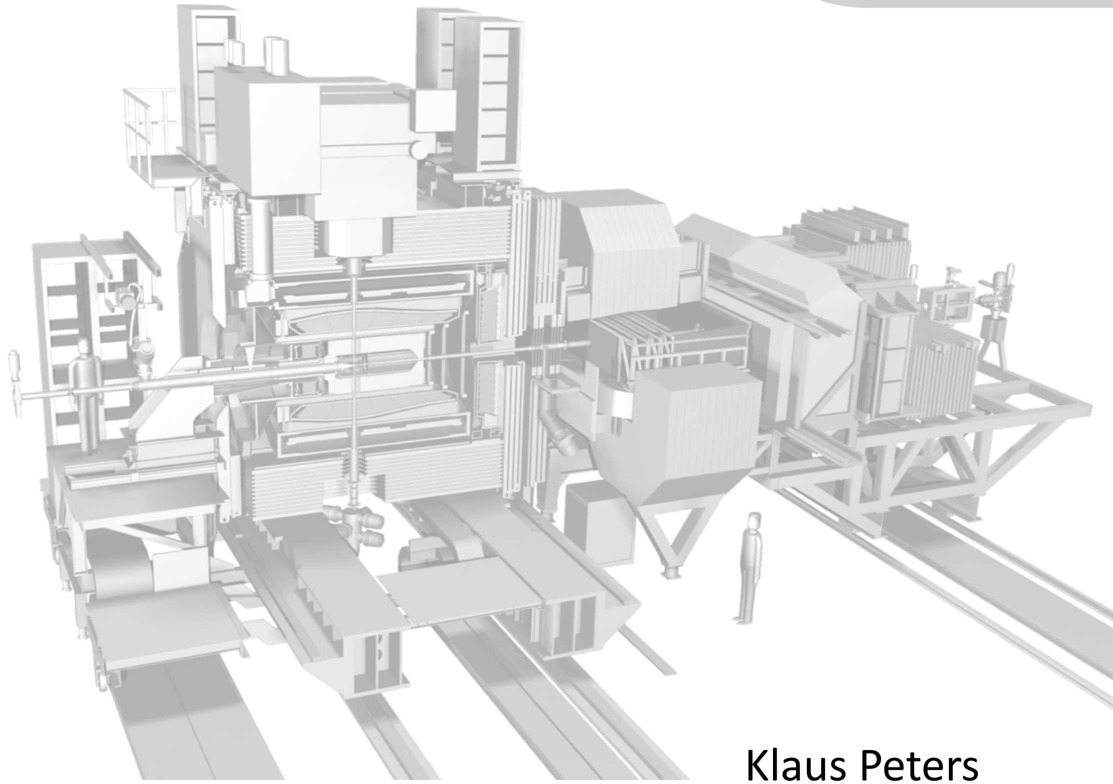
Studies of Hadrons with the PANDA Experiment @ FAIR

Heidelberg, May 9, 2017



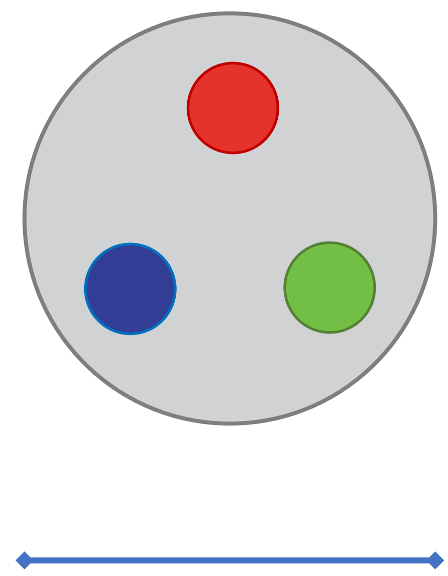
Klaus Peters
GSI/U Frankfurt

The Proton

Ubiquituos and Mysterious

3 constituents

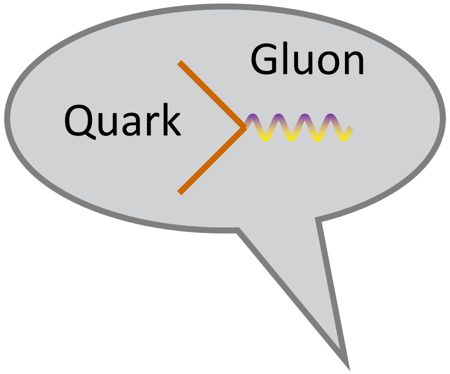
called Quarks



about 1 fm = 10^{-15} m

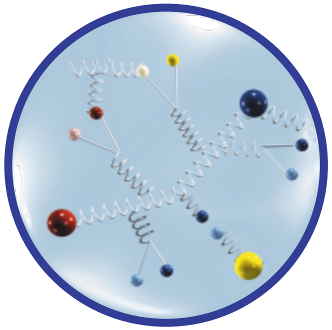
QCD – Quantum Chromo Dynamics

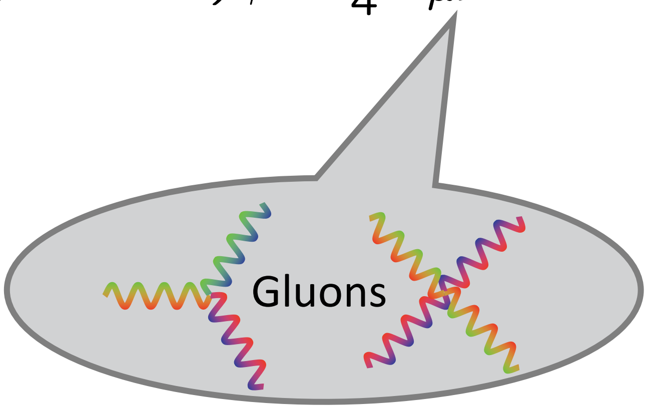
Fritzsch, Gell-Mann, Leutwyler 1973



Quark-masses

$$L_{QCD} = \bar{\psi}(i\gamma_\mu D^\mu - m)\psi - \frac{1}{4}G_{\mu\nu}G^{\mu\nu}$$





Quarks		spin=½	
Flavor		Approx. Mass GeV/c²	Charge
u	up	0.003	2/3
d	down	0.006	-1/3
c	charm	1.3	2/3
s	strange	0.1	-1/3
t	top	175	2/3
b	bottom	4.3	-1/3

Gauge Boson		spin=1	
Name		Mass GeV/c²	Charge
g	gluon	0	0

CHARM Discoveries – The Beginning

1970

1980

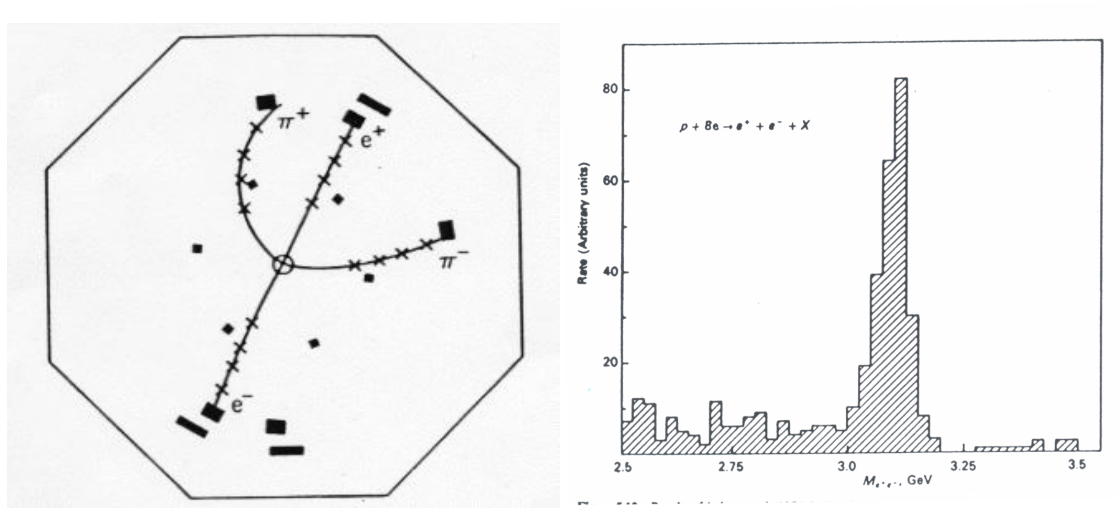
1990

2000

2010

1974

Discovery of the J/ψ

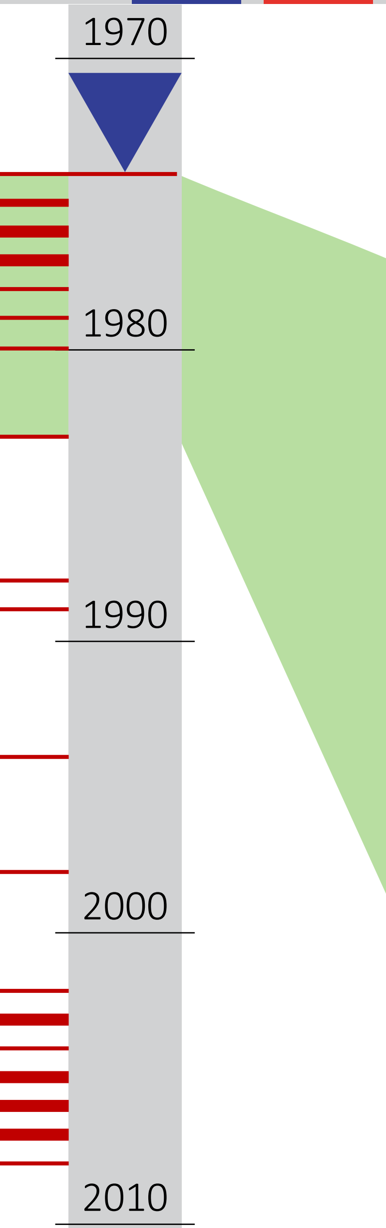


J.E. Augustin *et al.*, Mark I, Phys. Rev. Lett. 33, 1406–1408 (psi)
J.J. Aubert *et al.*, BNL, Phys. Rev. Lett. 33, 1404–1406 (J)

$c\bar{c}$ vector ground state ($^3S_1$)

Charm-Quark + Anti-Charm-Quark
bound like Positronium

CHARM Discoveries

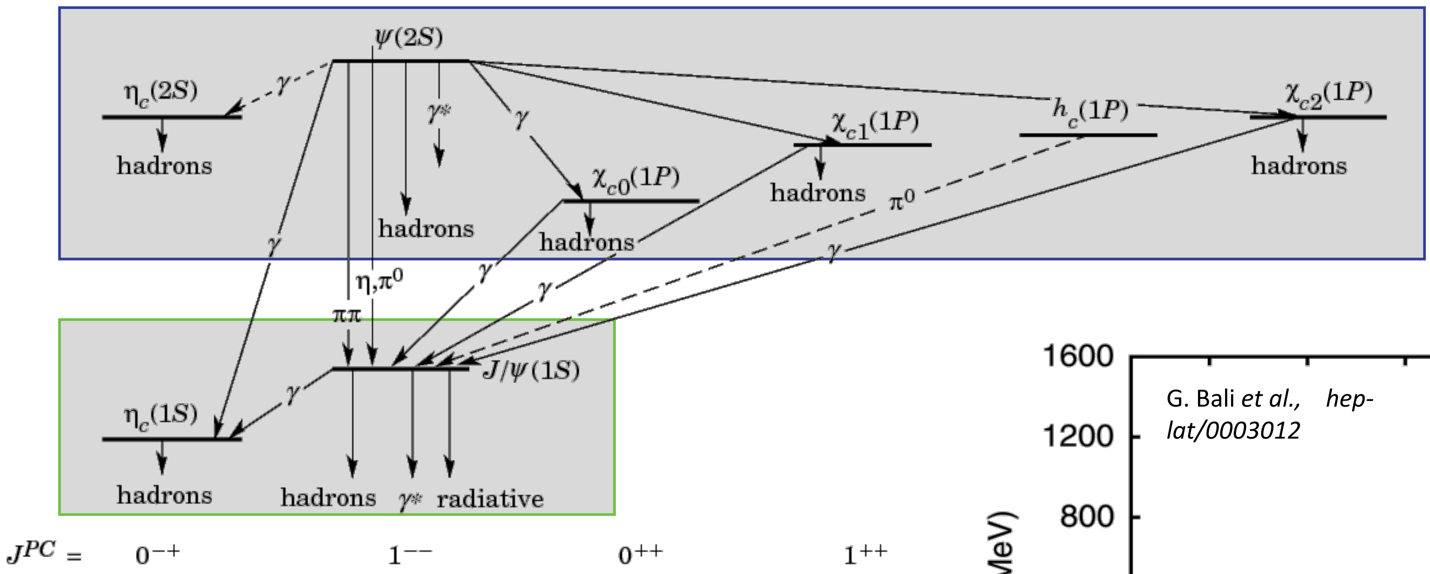


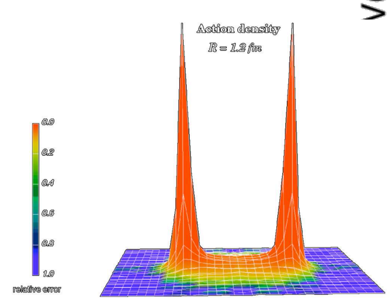
Until beginning of the 1980s - many relevant discoveries in open and hidden charm spectroscopy

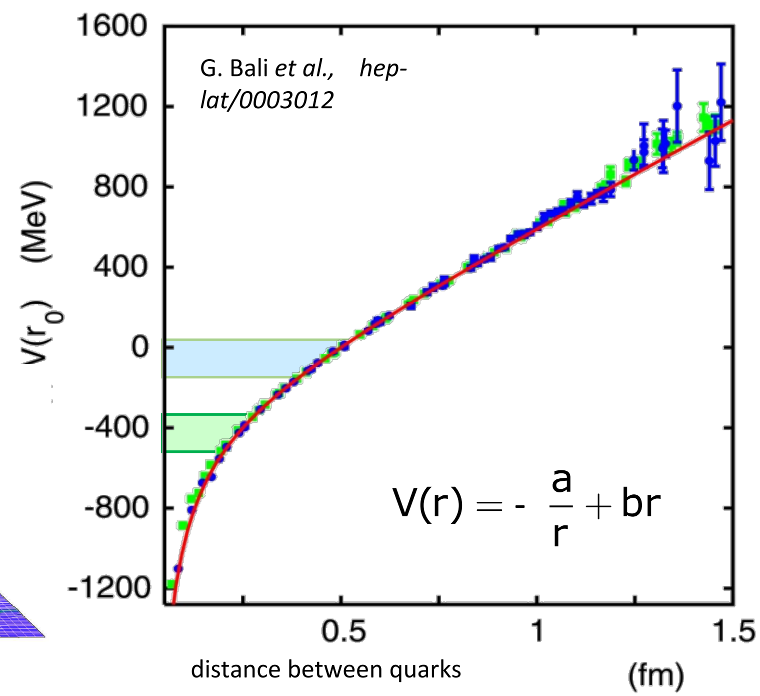
1974	Mark I/BNL	J/ψ
1975-77	Mark I/CNTR	χ_{cJ}
1975	Mark I	$\psi(3686)$
1976	Mark I	$\psi(4415)$
1976	Mark I	D
1977	Mark I	D*
1977	LGW	$\psi(3770)$
1978	Mark I	$\psi(4040/4160)$
1979	DASP	$D_s{}^*$
1980	Crystal Ball	η_c
1983	CLEO	D_s

which shaped the picture of the quark-antiquark potential

Charmonium



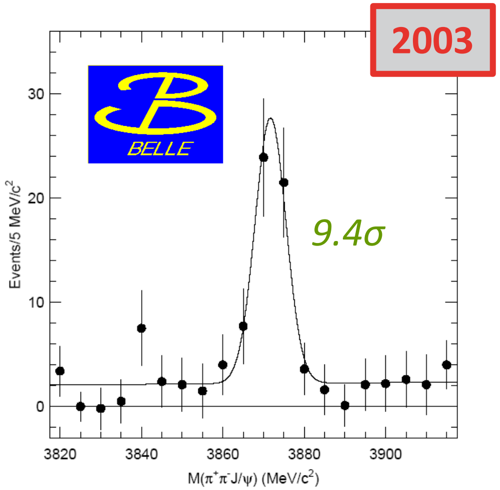




creed until 2003

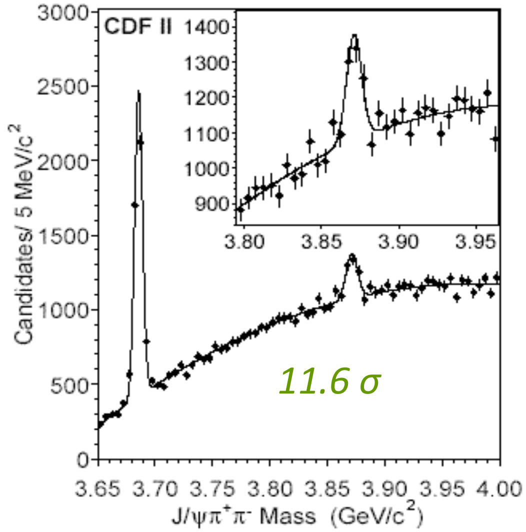
charmonium is simple

Discovery of the X(3872)

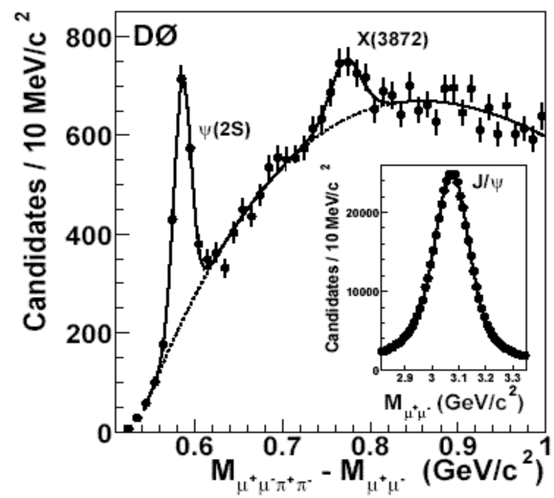


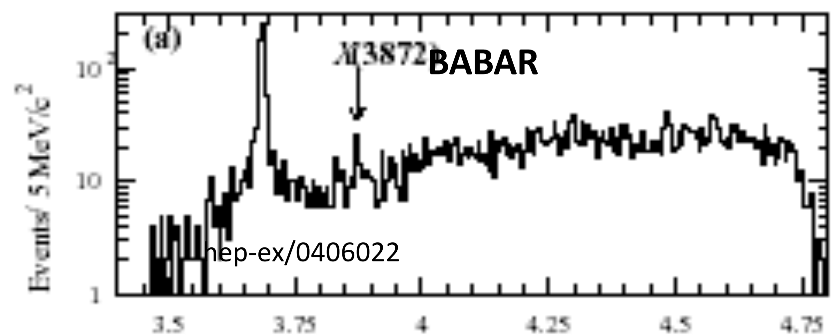
Phys. Rev. Lett. 91(2003)262001
152 Mill. BB

hep-ex/0312021

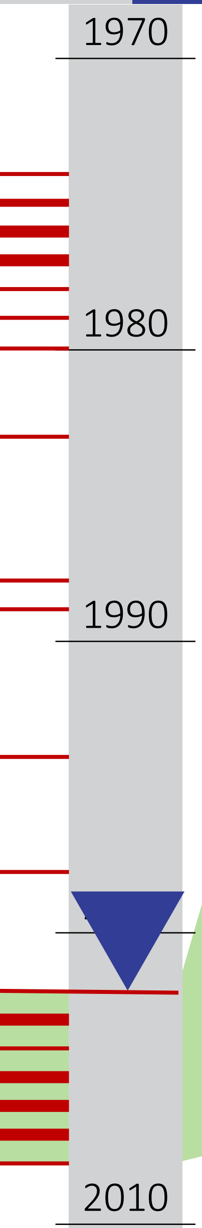


hep-ex/0405004





CHARM Discoveries



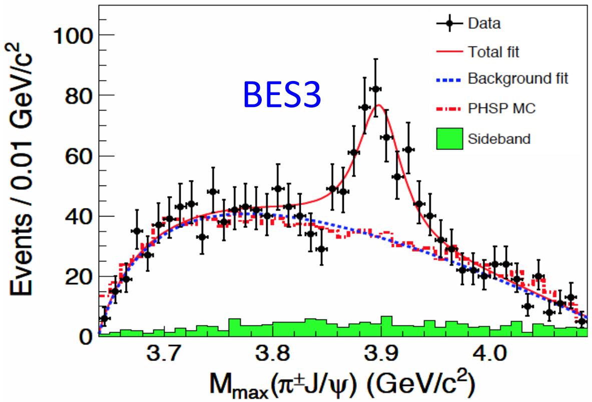
after the turn of the millennium the picture has dramatically changed

states with peculiar properties changed the thinking of the Charm sector

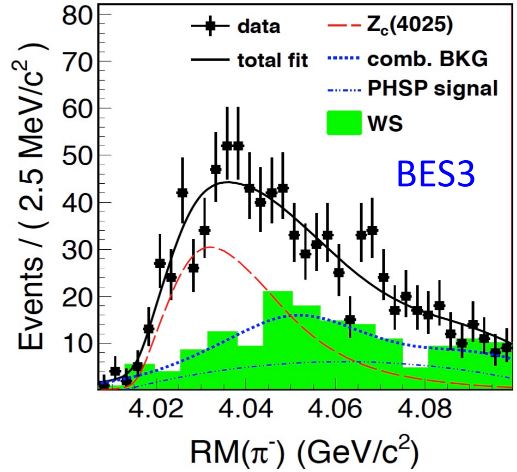
2002	Belle	η_c'
2003	BaBar	$D_{s0}^*(2317)^{\pm}$
2003	CLEO	$D_{s1}(2458)^{\pm}$
2003	Belle	X(3872)
2004	Belle	$D_0^*(2400)^0$
2005	CLEO	$h_c(3526)$
2005	BaBar	Y(4260)
2005	Belle	X(3945)
2006	Belle	$\chi_c(2P)$
2006	BaBar	$D_{s1}(2700)^{\pm}$
2006	BaBar	$D_{sJ}(2860)^{\pm}$
2007	Babar	Y(4360)
2007	Belle	Y(4660)
2007	Belle	X(3940)
2008	Belle	$Z^{\pm}(4430)$

Discovery of the Z+(3900)

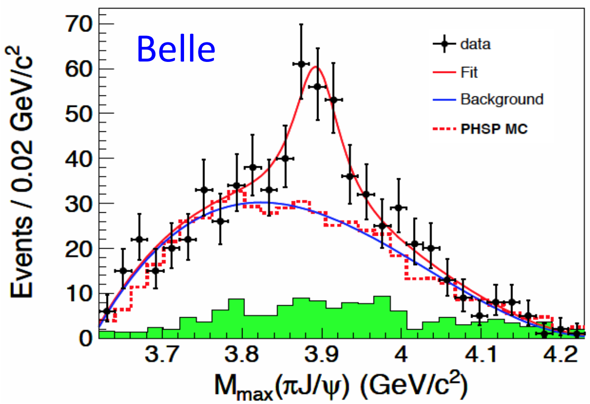
2013

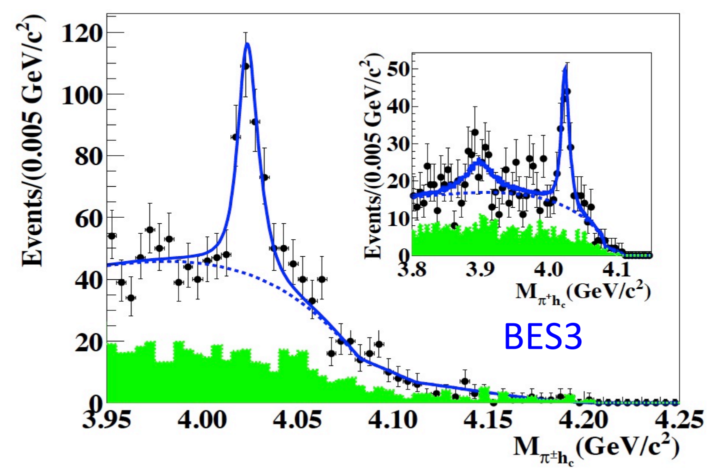


Discovery of the $Z_c^{+/-}$ (3900) in the J/ψ $\pi^{+/-}$ invariant mass spectrum in the decay Y(4260) → J/ψ $\pi^+\pi^-$



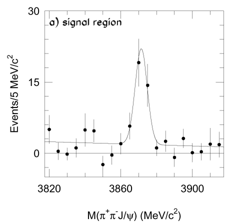
Observation of the $Z_c^{+/-}$(4025) in the $h_c\pi^{+/-}$ and $\overline{D}$*D* invariant spectrum in Y(4260/4360) decays



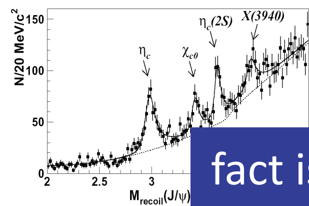


New Charmonium-like Discoveries

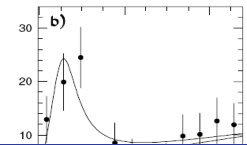
X(3872)
PRL 91,262001 (2003)



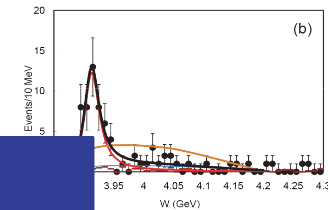
X(3940)
PRL 98,082001 (2007)



Y(3940)
PRL 94,182002 (2005)



X(3915)
PRL 104,092001 (2010)

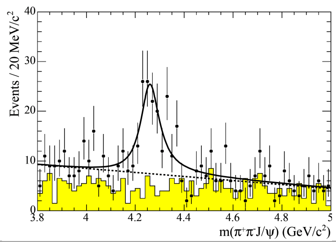


fact is

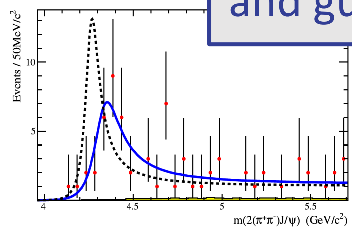
charmonium is **very complicated**

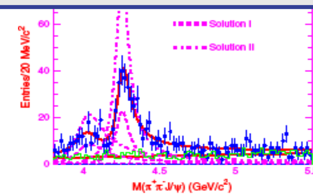
and guides us into a **terra incognita**

Y(4260)
PRL 95,142001 (2005)

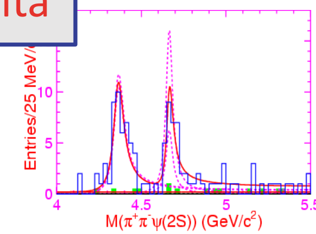


Y(435
PRL 98,21200

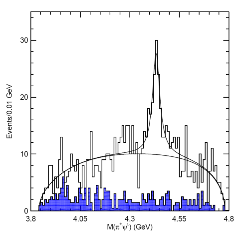




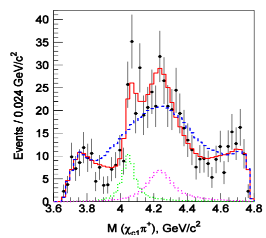
Y(4660)
99,142002 (2007)



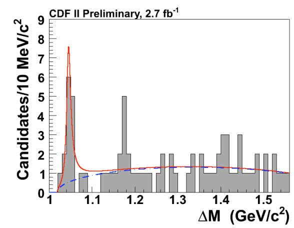
Z(4430)⁻
PRL 100,142001 (2008)



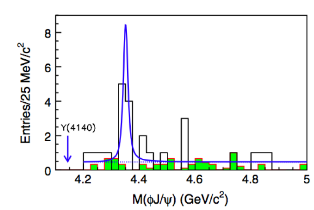
Z_1^- & Z_2^-
PRD 78,072004 (2008)



Y(4140)
PRL 102,242002 (2009)

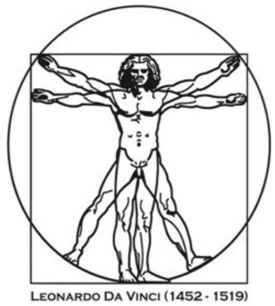


X(4350)
PRL 104,112004 (2010)

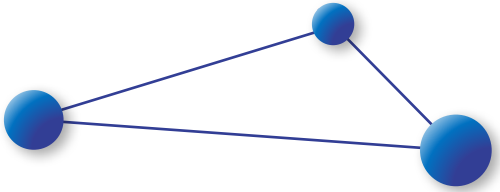


Frontiers

Complexity Frontier



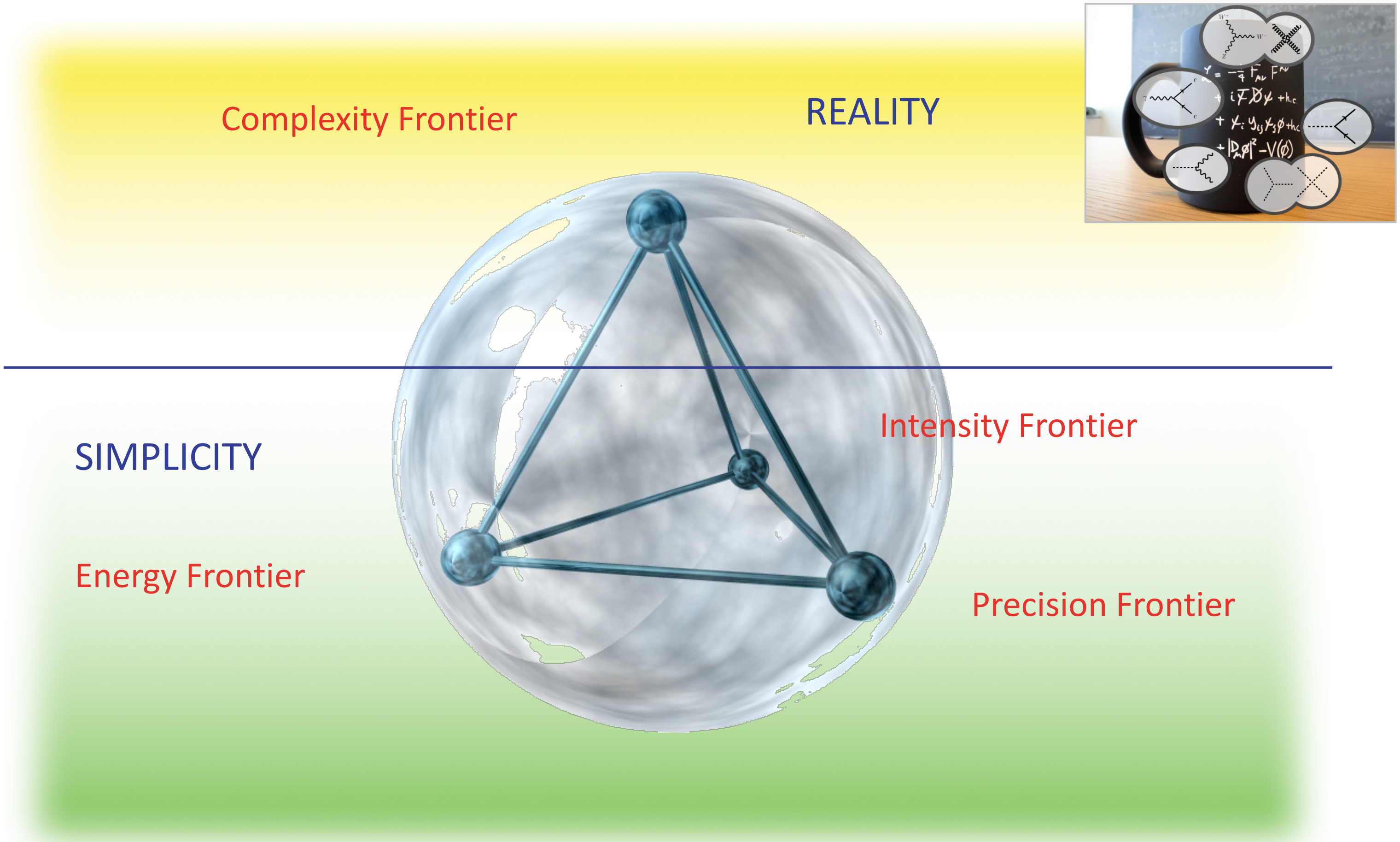
Intensity Frontier



Energy Frontier

Precision Frontier

Complexity


Complexity Frontier
REALITY
SIMPLICITY
Intensity Frontier
Energy Frontier
Precision Frontier

Complicated Structures

what are the rules for stability ?

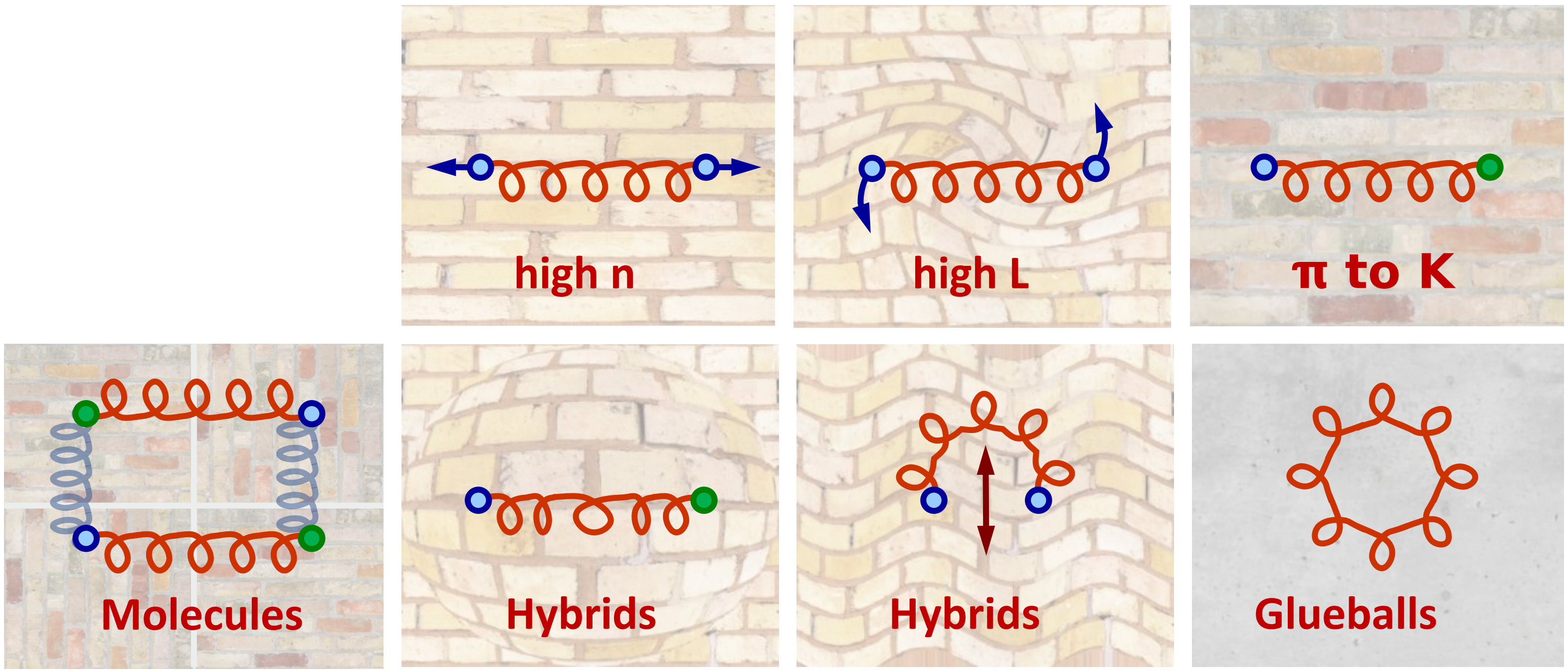
where is the link between all of them ?

at the end it's the role and properties of binding

QCD „material science“

one may drag, bend, heat or resonate walls
one may exchange stones or use compound stones
one may remove the stones and has only grout

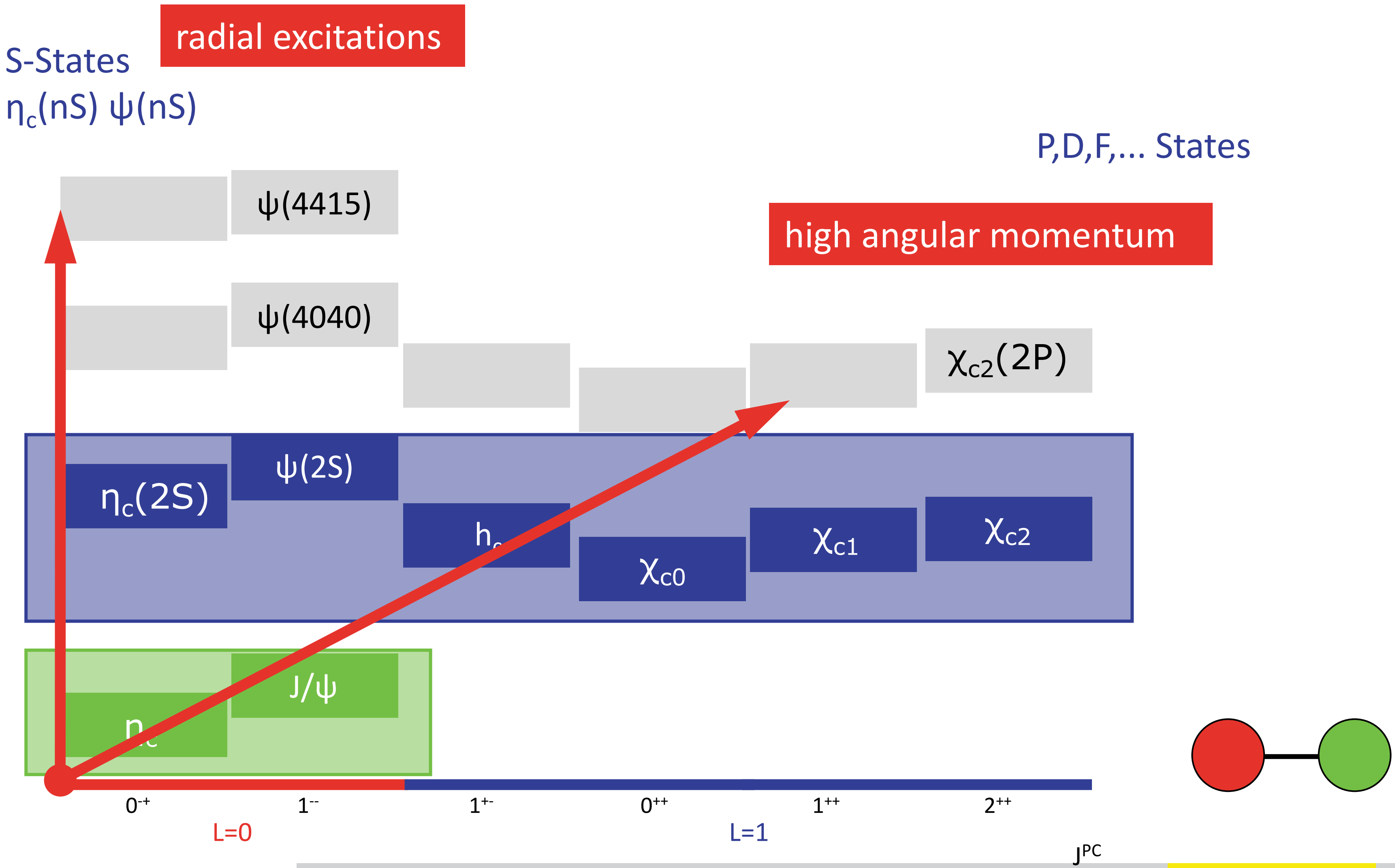
Translation to Hadrons



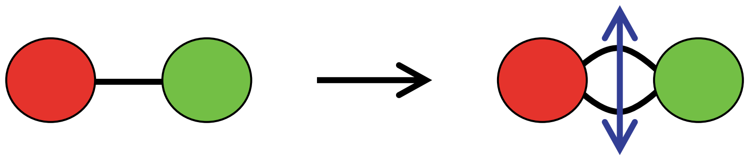
one may drag, bend, heat or resonate walls
one may exchange stones or use compound stones
one may remove the stones and has only grout

Charmonium

Several golden ways to heaven

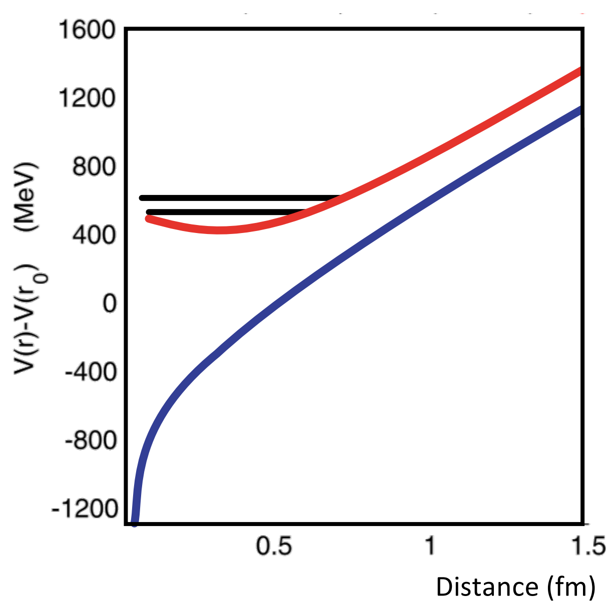


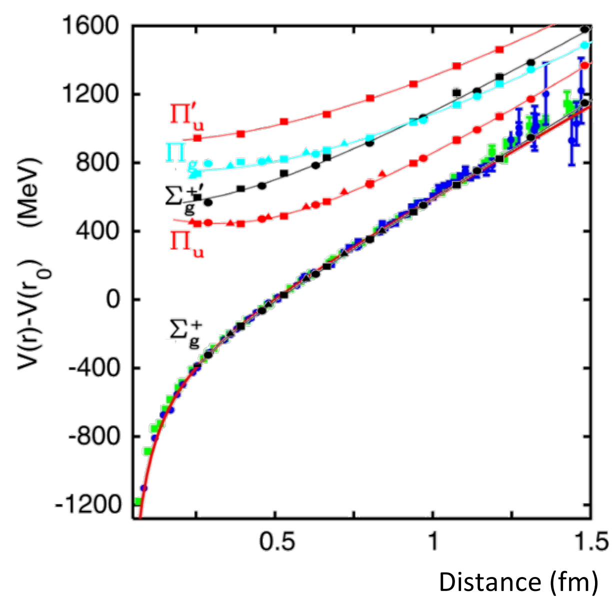
Charmonium – other degrees of freedom ?



different "potential"

K.J. Juge, J. Kuti, C. Morningstar
hep/lat 9709131

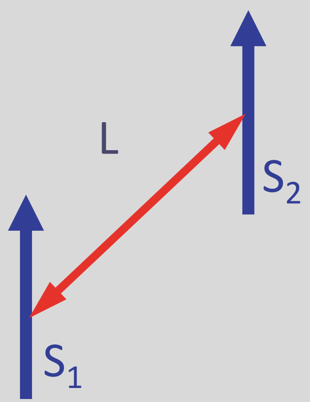




Fock-Expansion – solution to the problem?

remove the leading term
by selecting quantum numbers

e.g. for hybrids



$S=S_1+S_2$

$J=L+S$

$P=(-1)^{L+1}$

$C=(-1)^{L+S}$

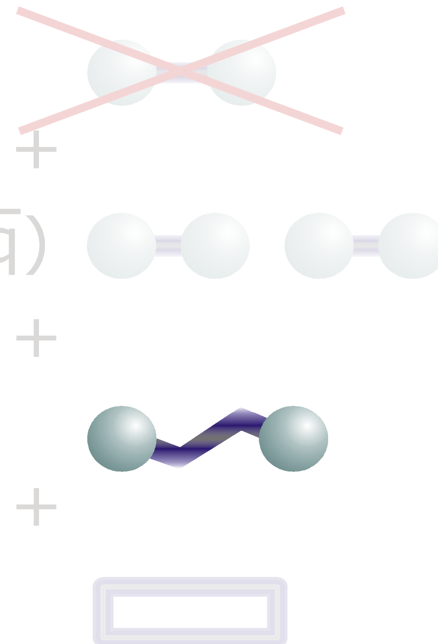
impossible for $q\bar{q}$

J^{PC} exotic

Gluon	Magnetic	Electric
$^1S_0$, 0^{-+}	1^{++}	1^{--}
$^3S_1$, 1^{--}	0^{+-}	0^{-+}
	1^{+-}	1^{-+}
	2^{+-}	2^{-+}

$q\bar{q}$ + $(q\bar{q})(q\bar{q})$ + $(q\bar{q})g$ + ... + ...

$= \Sigma_i (q\bar{q})_i \Sigma_j g_j$

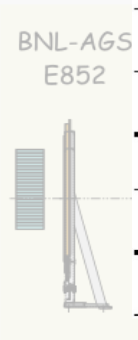


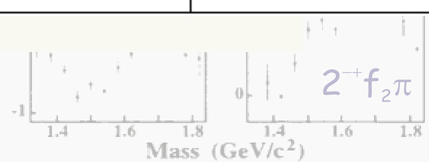
π_1(1600)…E852 - ρπ in 1997 and COMPASS today

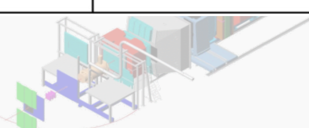
thanks to G. Adams, RPI

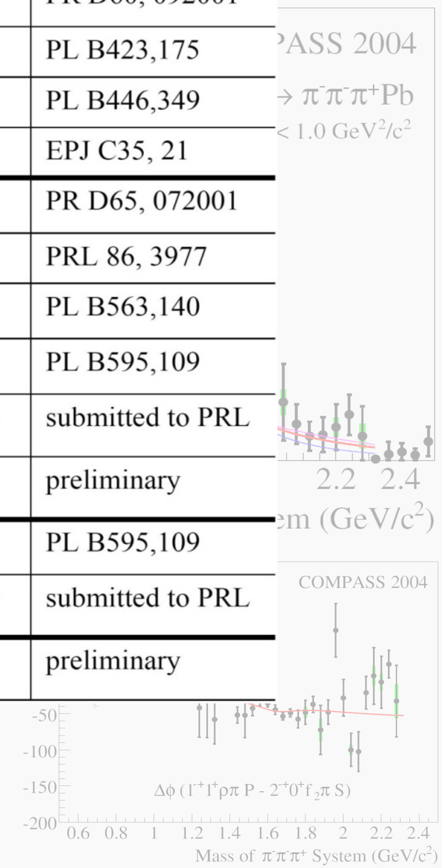
$\pi^- p \to \pi^- \rho^0 p \to \pi^- \pi^- \pi^+ p$

	Experiment	Mass	Width	Decay	Citation
π_1(1400)	E852	1359 (+16-14) (+10-24)	314 (+31-29) (+9-66)	ηπ	PR D60, 092001
	Crystal Barrel	1400 (+20-20) (+20-20)	310 (+50-50) (+50-30)	ηπ	PL B423,175
	Crystal Barrel	1360 (+25-25)	220 (+90-90)	ηπ	PL B446,349
	Obelix	1384 (+28-28)	378 (+58-58)	ρπ	EPJ C35, 21
π_1(1600)	E852	1593 (+8-8) (+29-47)	168 (+20-20) (+150-12)	ρπ	PR D65, 072001
	E852	1597 (+10-10) (+45-10)	340 (+40-40) (+50-50)	η’π	PRL 86, 3977
	Crystal Barrel	1590 (+50-50)	280 (+75-75)	$b_1\pi$	PL B563,140
	E852	1709 (+24-24) (+41-41)	403 (+80-80) (+115-115)	$f_1\pi$	PL B595,109
	E852	1664±8±10	185±25±28	$(b_1\pi)^-$	submitted to PRL
	E852	≅ 1700		$(b_1\pi)^0$	preliminary
π_1(2000)	E852	2001±30±92	333±52±49	$f_1\pi$	PL B595,109
	E852	2014±20±16	230±32±73	$(b_1\pi)^-$	submitted to PRL
h_2(1950)	E852	1954±8 (stat.)	138±3 (stat.)	$(b_1\pi)^0$	preliminary









FAIR @ Darmstadt

Nuclear Structure & Astrophysics
(rare isotope beams)

Hadron Physics
(stored and cooled
15 GeV/c anti-protons)

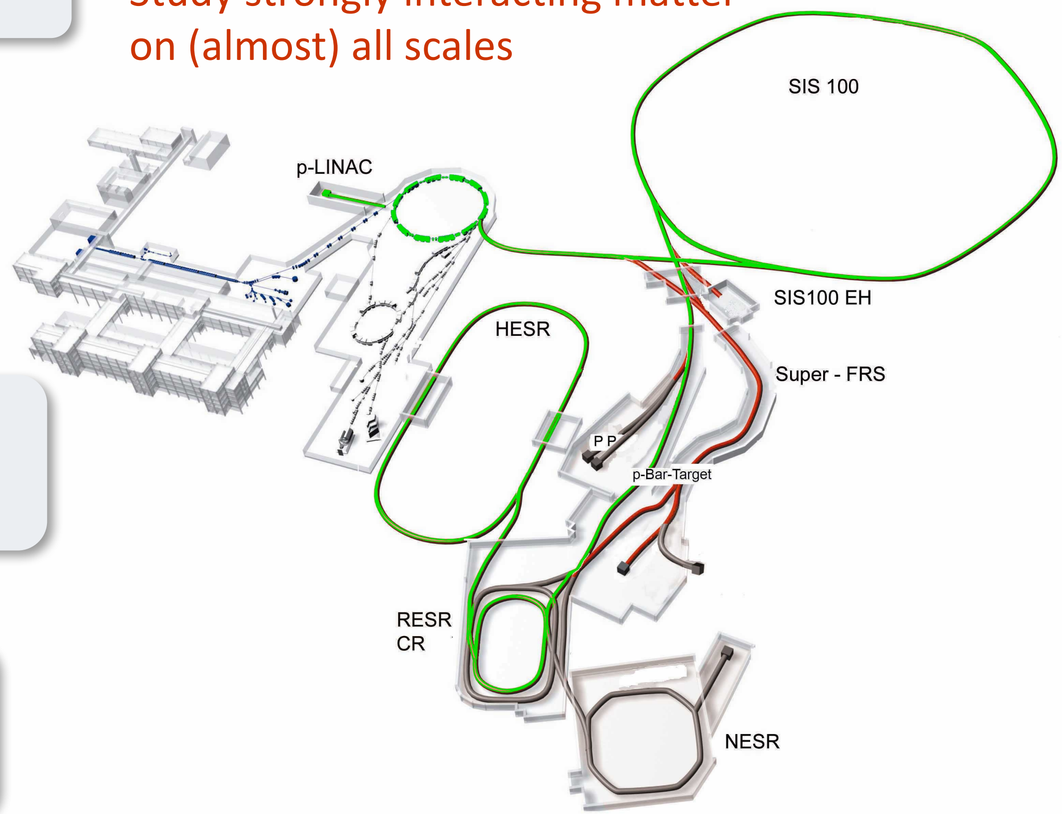
QCD-Phase Diagram
(HI beams 2 to 45 GeV/u)

Fundamental Symmetries
& Ultra-High EM Fields
(anti-protons & highly stripped ions)

Dense Bulk Plasmas
(ion beam bunch compression
& petawatt-laser)

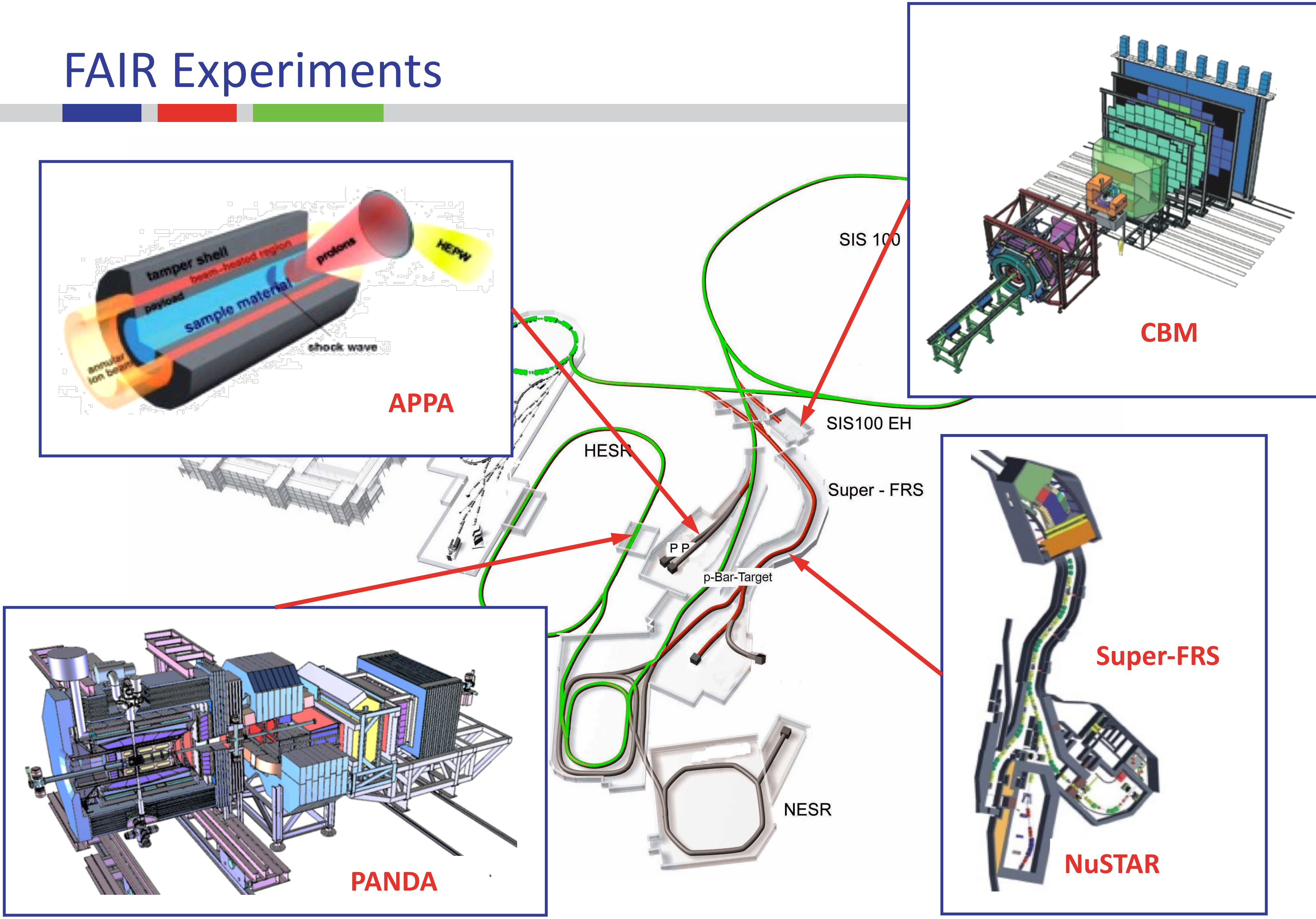
Materials Science & Radiation Biology
(ion & anti-proton beams)

Our Mission
Study strongly interacting matter
on (almost) all scales

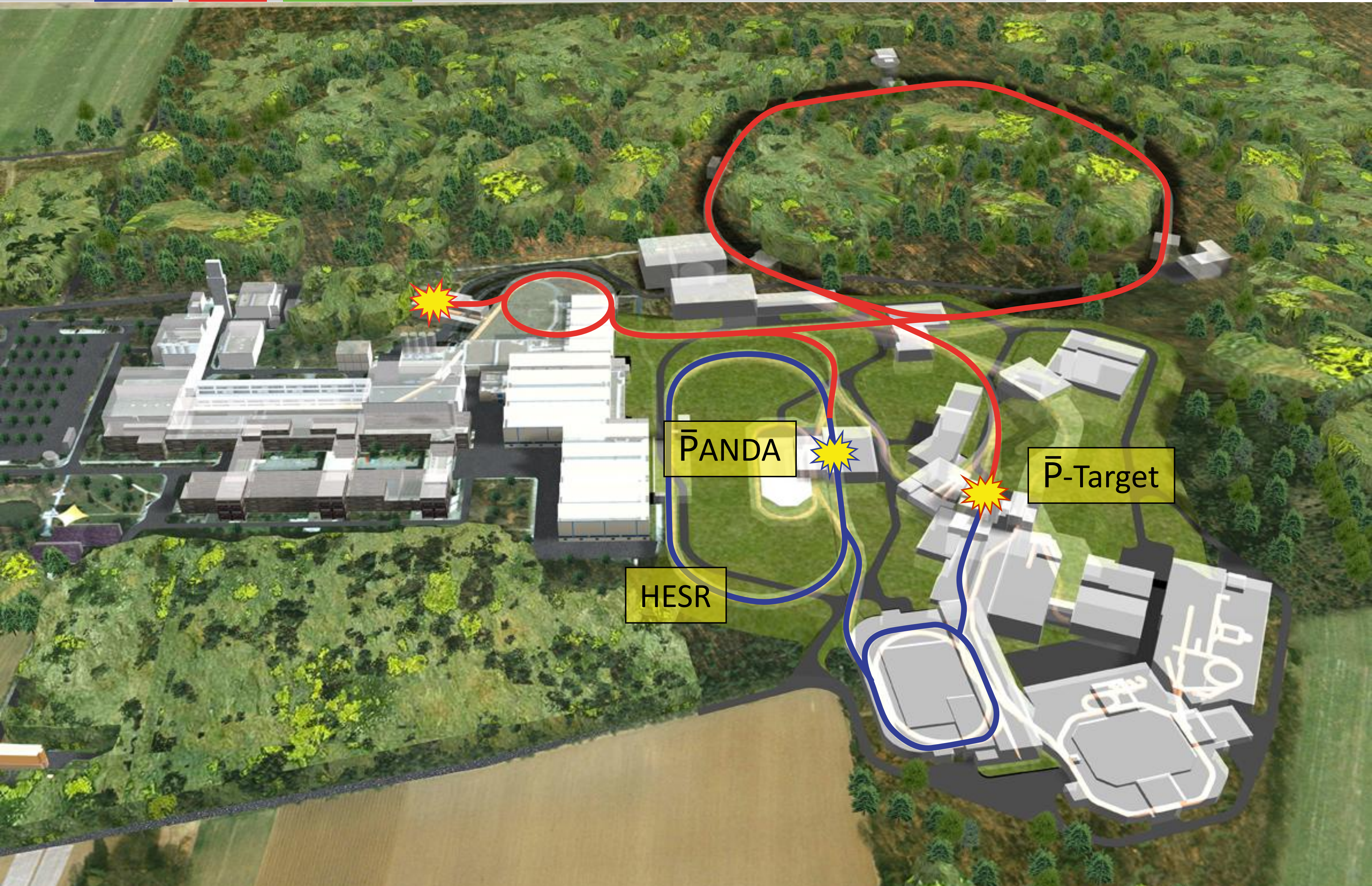


Accelerator Physics

FAIR Experiments



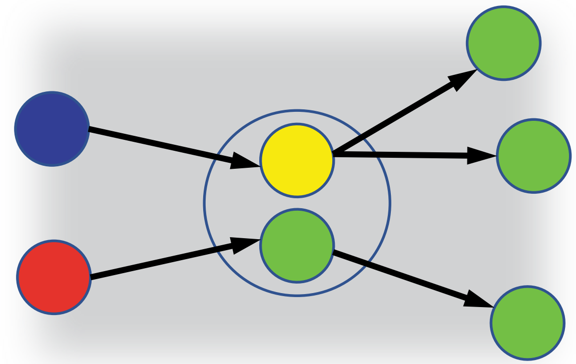
HESR, PANDA and FAIR



$\bar{p}$-Annihilations: Gluon Rich Environment

Production all exotic and non-exotic quantum numbers accessible with a recoil

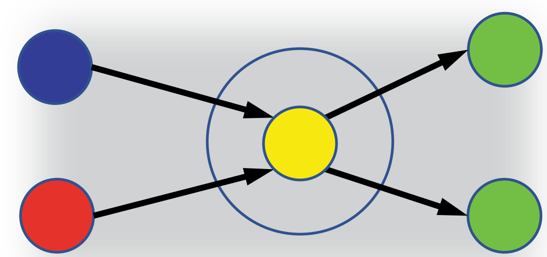
- high discovery potential
- associated, access to all quantum numbers (exotic)



all quantum numbers possible

Formation all non-exotic quantum numbers accessible

- not only limited to $J^{PC} = 1^{--}$ as e^+e^- colliders
- precision physics of known states
- resonant, high statistics, extremely good precision in mass and width



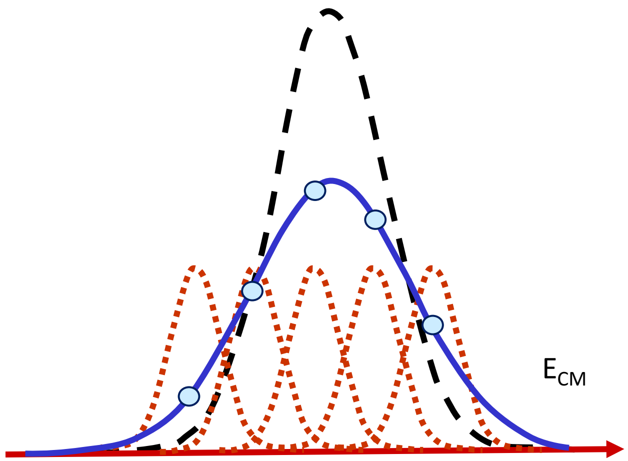
quantum numbers like $\bar{p}p$

antiproton probe unique and decisive

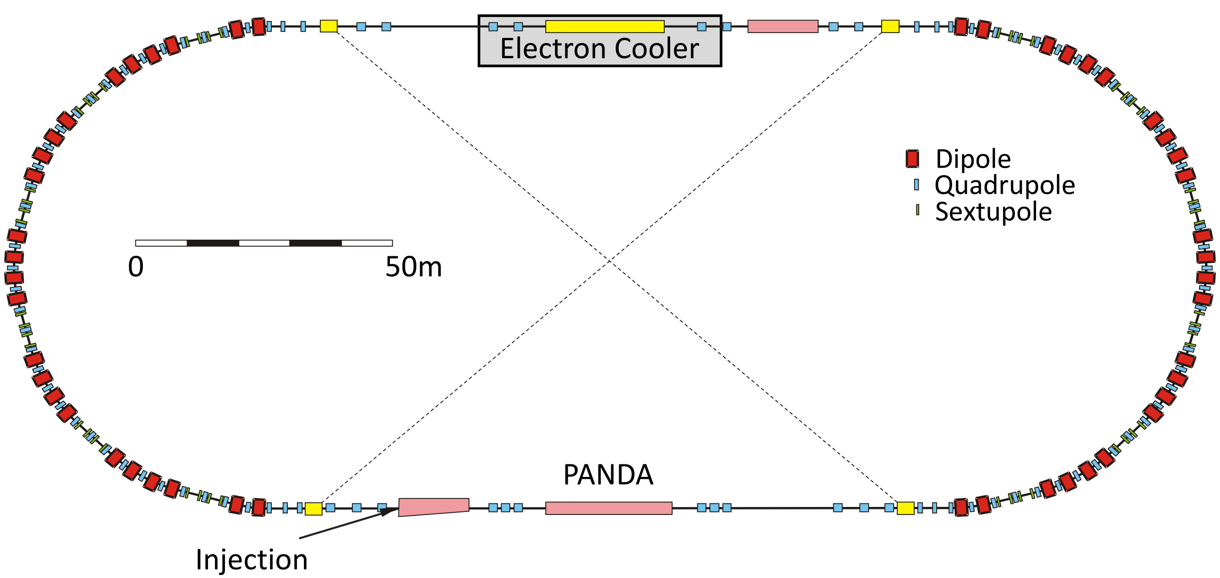
HESR – Storage Ring for Antiprotons

Parameters of HESR

injection of p at 3.7 GeV
slow synchrotron (1.5-14.5 GeV/c)
storage ring for internal target operation
luminosity up to L~ $2x10^{32}$ $cm^{-2}s^{-1}$
beam cooling (stochastic & electron)



precision spectrodcopy with $\bar{p}$ beams



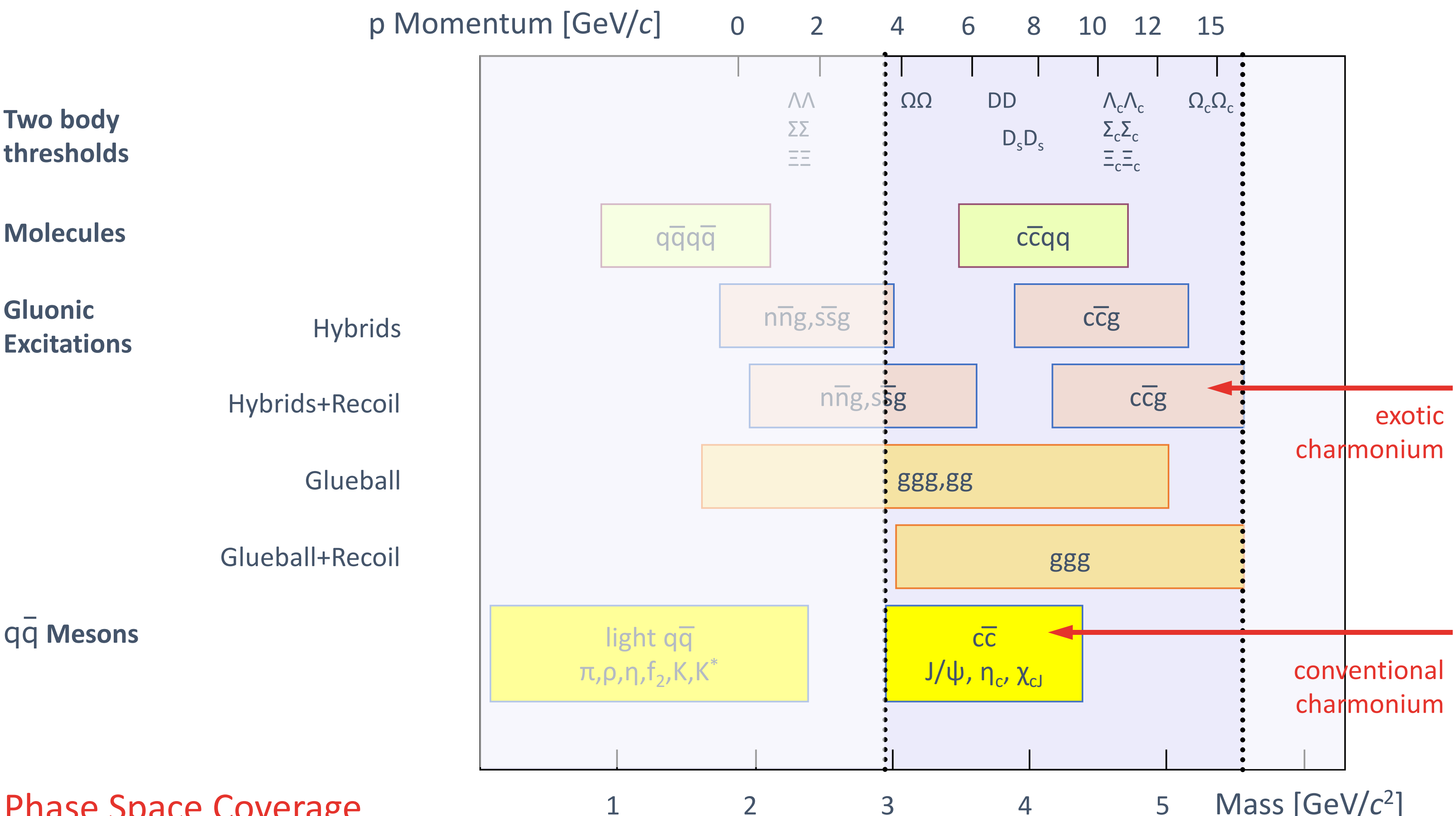
Resonance scan

energy resolution ~50 keV

tune E_{CM} to probe resonance

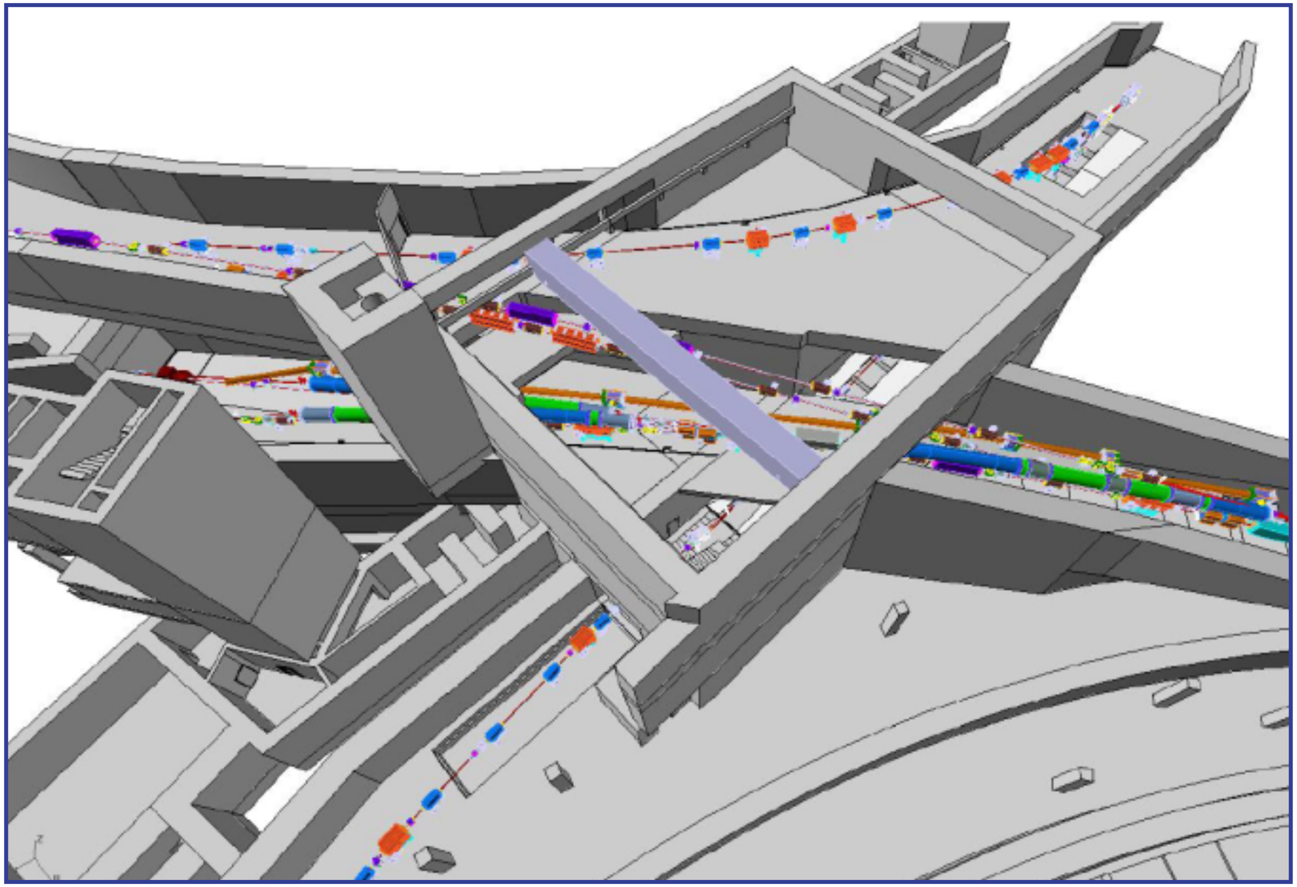
get precise mass and width

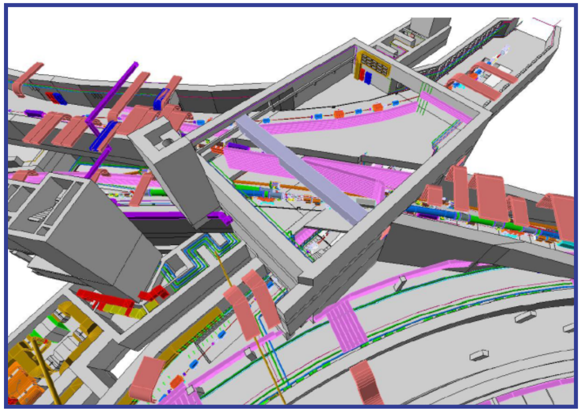
Accessible Hadrons at PANDA

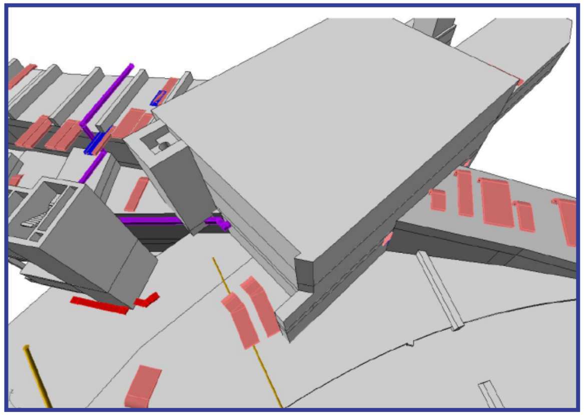


Phase Space Coverage

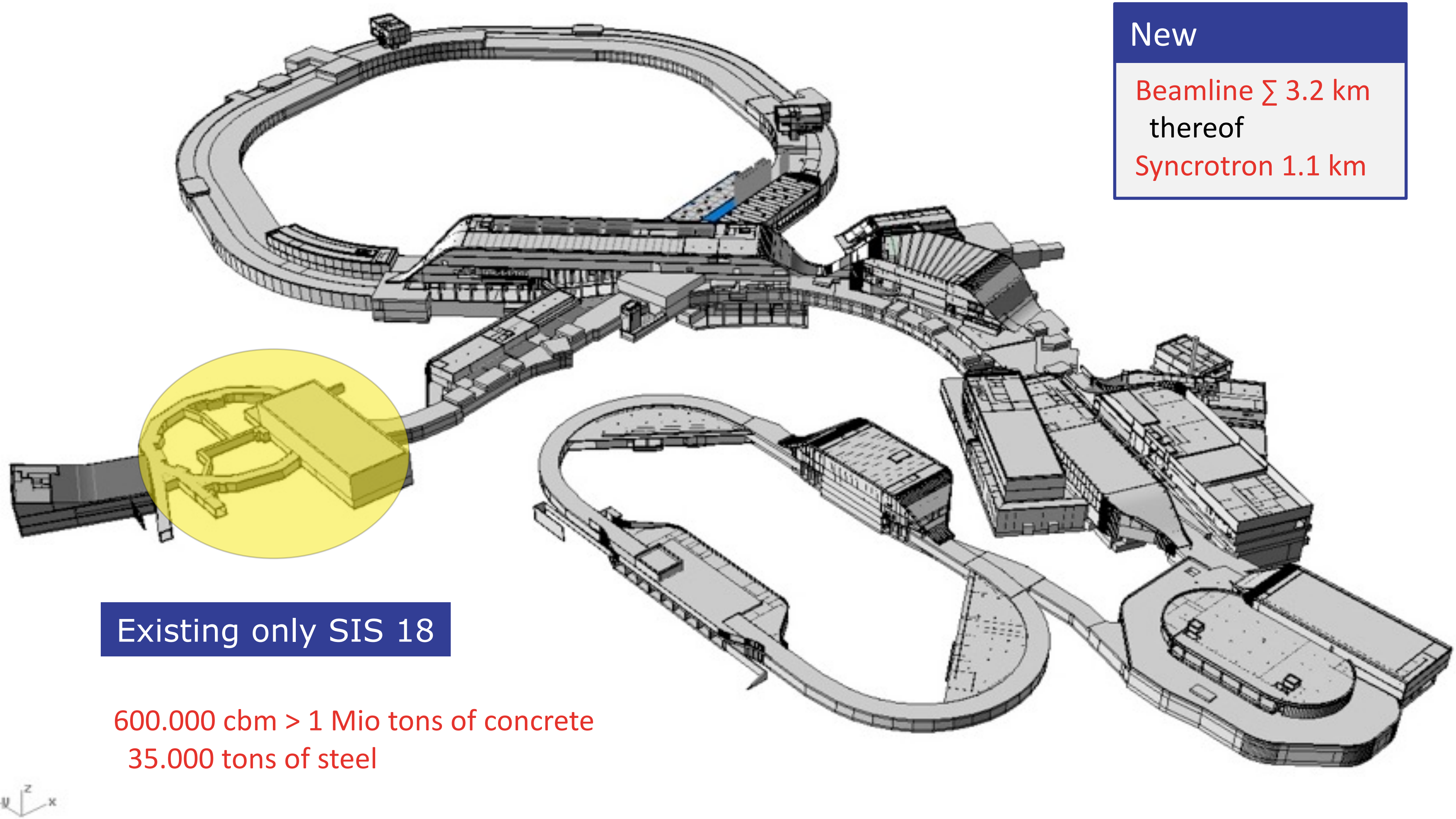
Planning Activities – almost finished







Civil Engineering



New

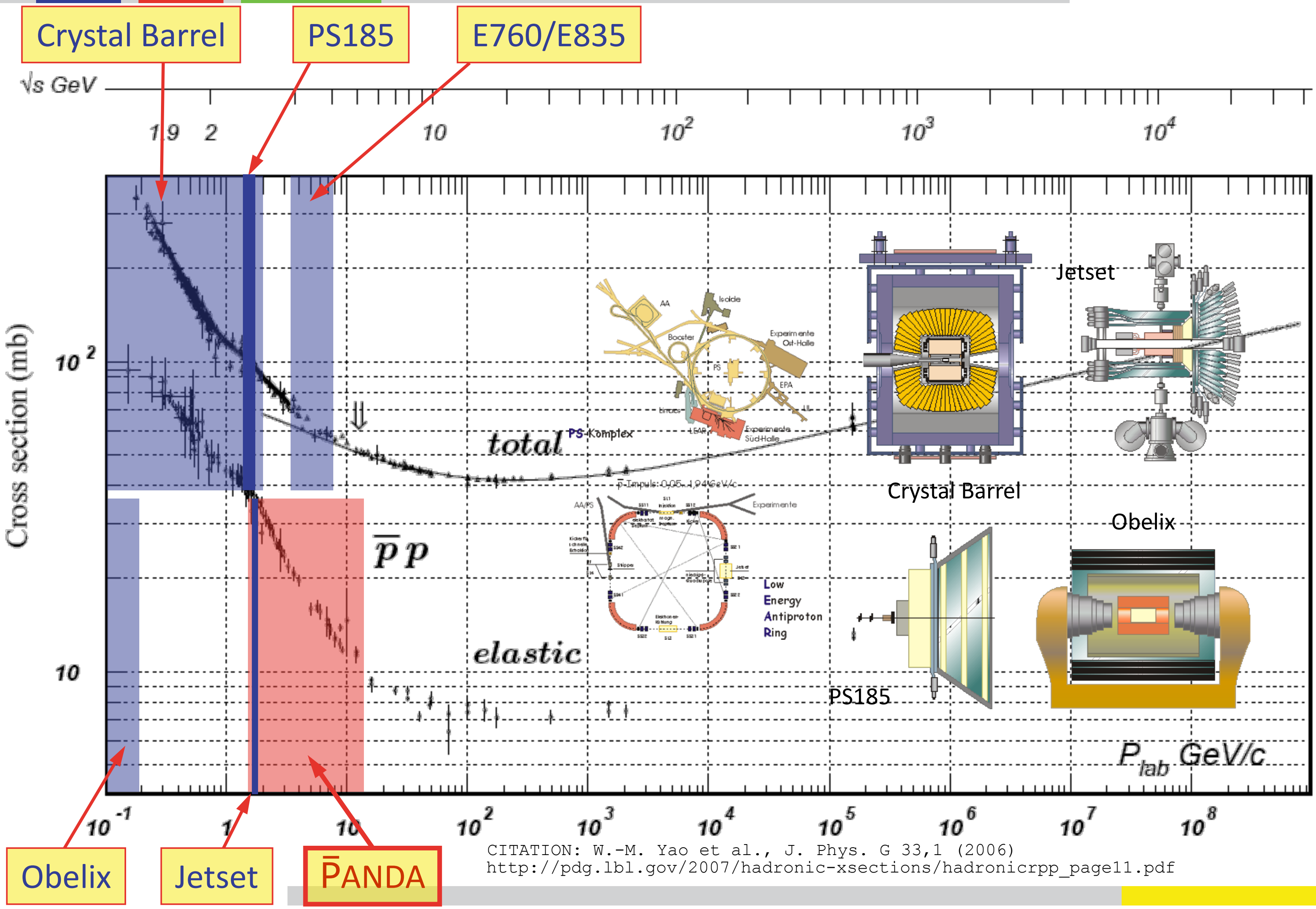
Beamline ∑ 3.2 km
thereof
Syncrotron 1.1 km

Existing only SIS 18

600.000 cbm > 1 Mio tons of concrete
35.000 tons of steel

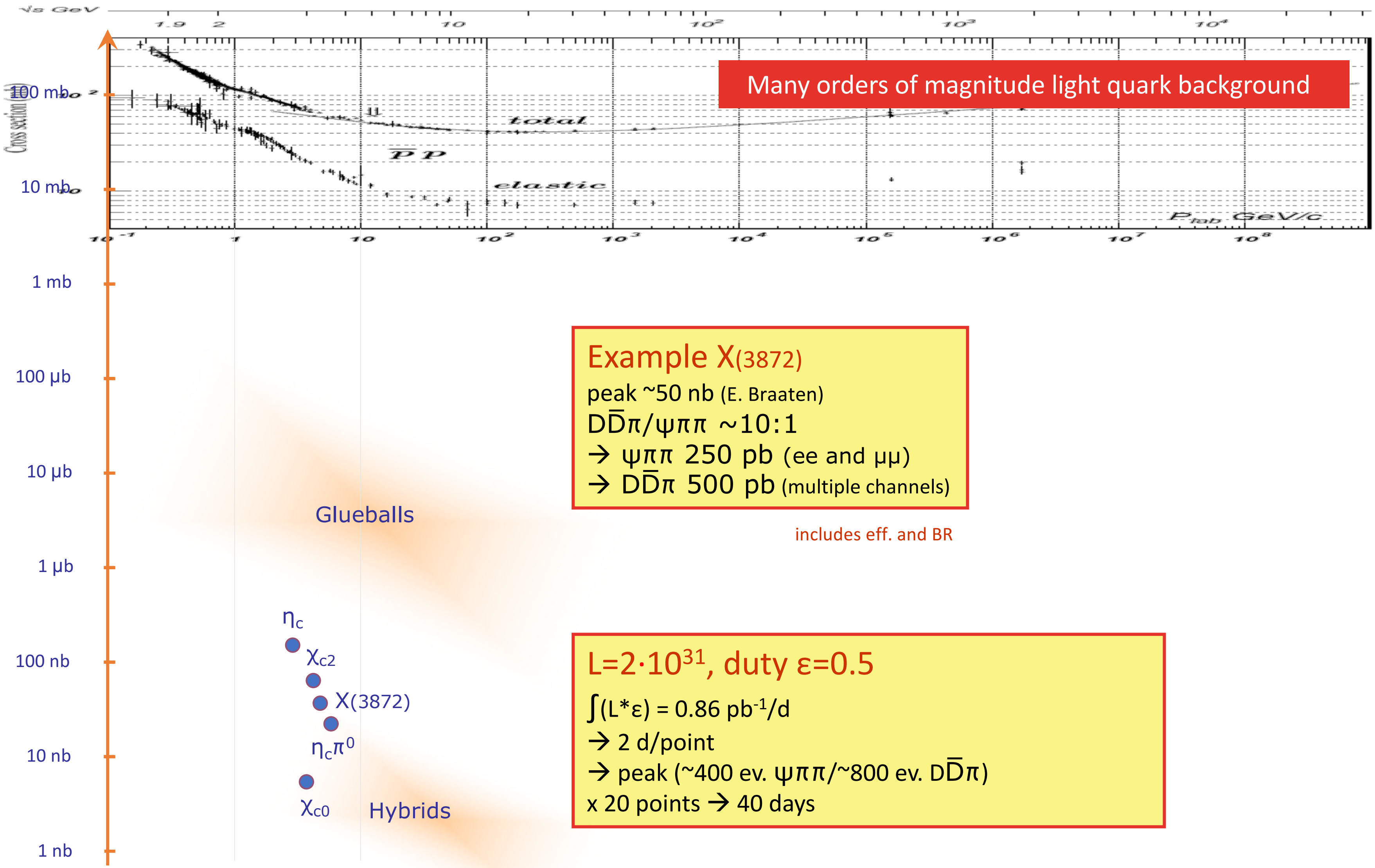
Construction Site (almost today)

p̄p cross sections



CITATION: W.-M. Yao et al., J. Phys. G 33,1 (2006)
http://pdg.lbl.gov/2007/hadronic-xsections/hadronicrpp_page11.pdf

p̄p cross sections – exclusive final states



Example X(3872)

peak ~50 nb (E. Braaten)

$D\bar{D}\pi/\psi\pi\pi$ ~10:1

→ $\psi\pi\pi$ 250 pb (ee and μμ)

→ $D\bar{D}\pi$ 500 pb (multiple channels)

includes eff. and BR

$L=2\cdot10^{31}$, duty $\varepsilon=0.5$

$\int(L^*\varepsilon) = 0.86\ pb^{-1}/d$

→ 2 d/point

→ peak (~400 ev. $\psi\pi\pi$/~800 ev. $D\bar{D}\pi$)

x 20 points → 40 days

PANDA Physics Programme

Bound States of Strong Interaction

Spectroscopy

New narrow XYZ:
Search for partner states

Production of exotic QCD states:
Glueballs & hybrids

Nucleon Structure

Generalized parton distributions:
Orbital angular momentum

Drell Yan process:
Transverse structure, valence anti-quarks

Time-like form factors:
Low and high E, e and μ pairs

Strangeness

Strange baryons:
Spectroscopy
Polarization

Nuclear Physics

Hypernuclear physics:
Double Λ hypernuclei
Hyperon interaction

Hadrons in nuclei:
Charm and strangeness in the medium

HEP underlying elementary processes

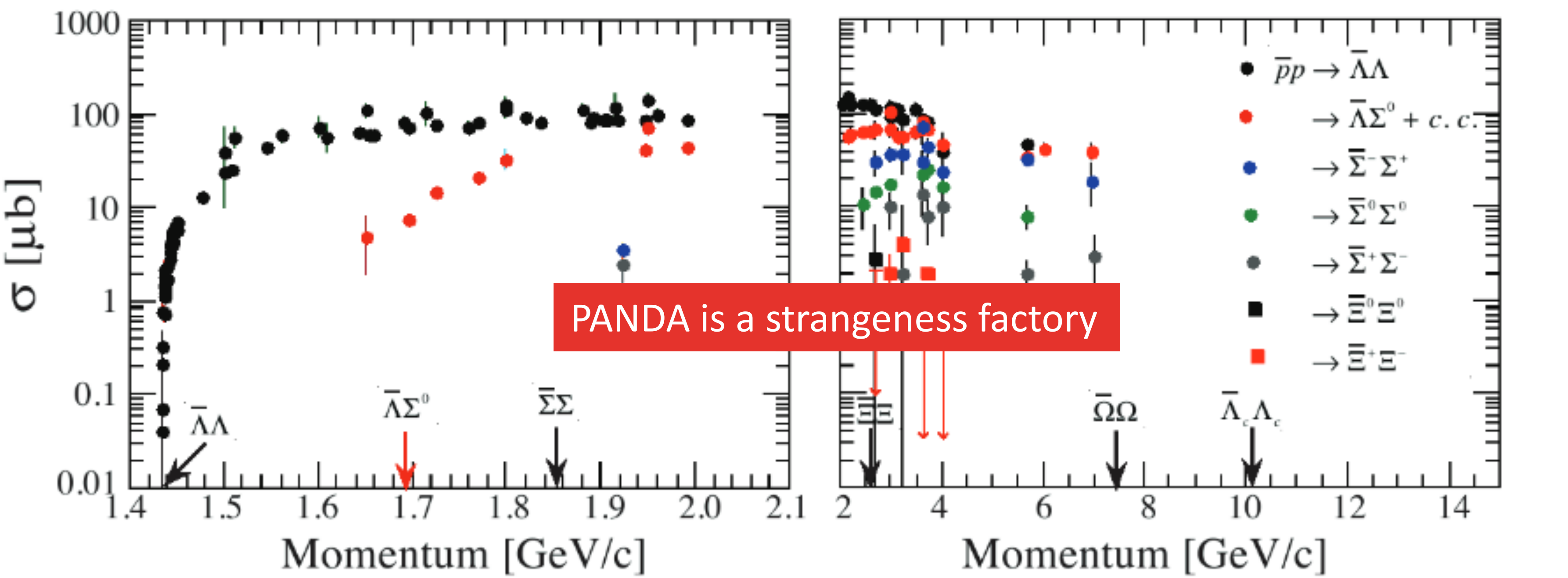
HEP: interference of coupled channels

astrophysics strange n-stars

nuclear physics hyper-nuclear spectroscopy

HI collisions comparing QGP to elementary reactions

Previous measurements of $\bar{p}p \rightarrow \bar{Y}Y$



PANDA is a strangeness factory

A lot of data on $\bar{p}p \rightarrow \bar{\Lambda}\Lambda$ near

Very scarce data bank above 4 G

Only a few bubble chamber eve

No data on $\bar{p}p \rightarrow \bar{\Omega}\Omega$ nor $\bar{p}p$

Octet Ξ states: no partner of most N* states
Decuplet Ξ and Ω states: no partner of Δ* states

PDG note on Ξ resonances:
"… nothing of significance on Ξ resonances has been added since our 1988 edition."

Prospects for PANDA

Momentum (GeV/c)	Reaction	σ (μb)	Efficiency (%)	Rate (with 10^{31} $cm^{-1}s^{-1}$)
1.64	$\bar{p}p \rightarrow \bar{\Lambda}\Lambda$	64	10	30 s^{-1}
4	$\bar{p}p \rightarrow \bar{\Lambda}\Sigma^0$	~40	30	30 s^{-1}
4	$\bar{p}p \rightarrow \bar{\Xi}^+\Xi^-$	~2	20	2 s^{-1}
12	$\bar{p}p \rightarrow \bar{\Omega}\Omega$	~0.002	30	~4 h^{-1}
12	$\bar{p}p \rightarrow \bar{\Lambda}_c\Lambda_c$	~0.1	35	~2 day^{-1}

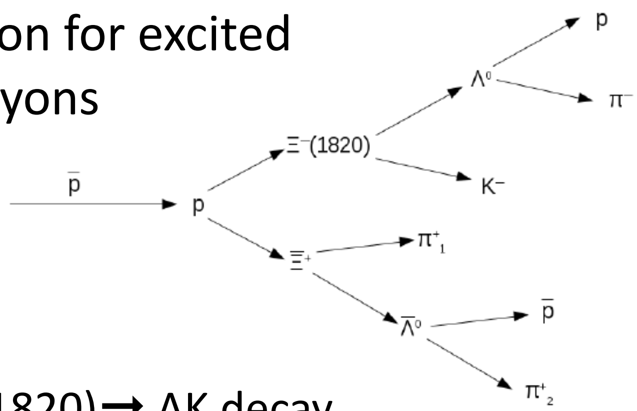
Gain a factor of 100 with inclusive measurement

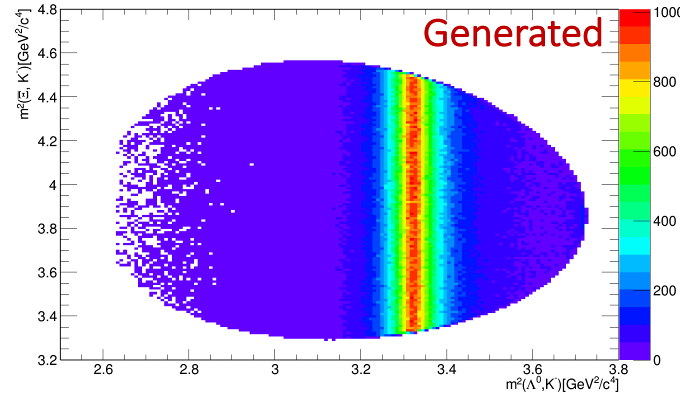
High event rates for Λ and Σ
Low background for Λ and Σ

Even with conservative cross section estimates, Ω / Λ_c channels are feasible
New efficiency studies using sophisticated MC framework underway.

Ξ(1820)

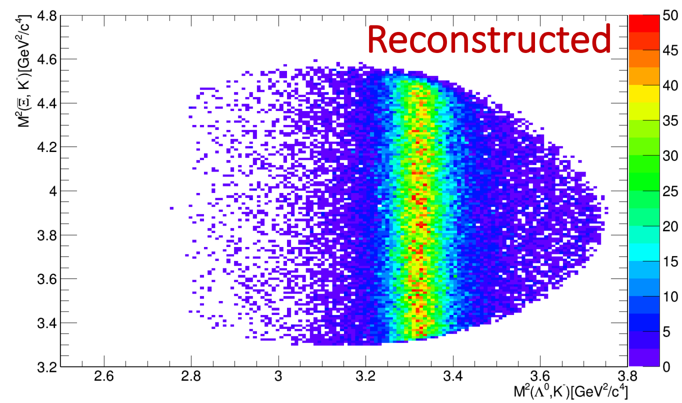
High signal rates and high background rejection for excited double strange baryons





$\bar{p}_{beam}$ = 4.6 GeV/c

- Consider the Ξ*⁻(1820)→ ΛK decay,
  - assume BR = 100% and σ = 1 μb
- Simplified MC framework
- Day-1 luminosity: $10^{31}cm^{-2}s^{-1}$

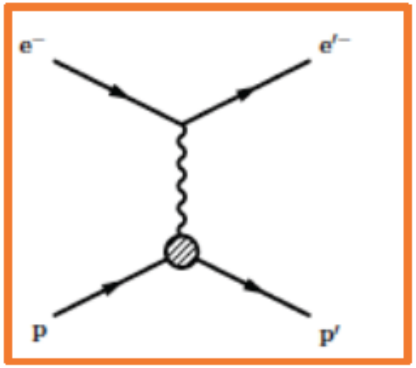


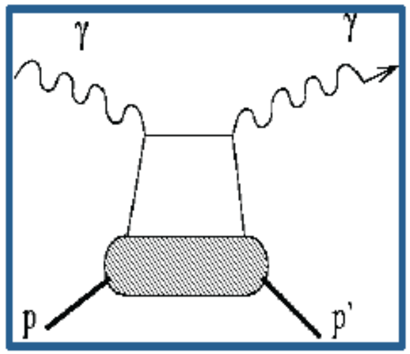
Results

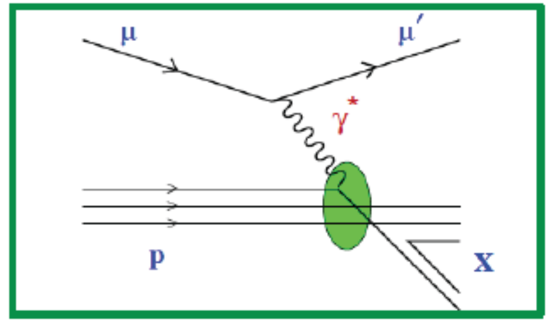
- ~30 % inclusive efficiency for Ξ*⁻(1820)
- ~5 % exclusive efficiency for Ξ̄⁺Ξ*⁻(1820)
- Low background level → ~15000 exclusive events / day

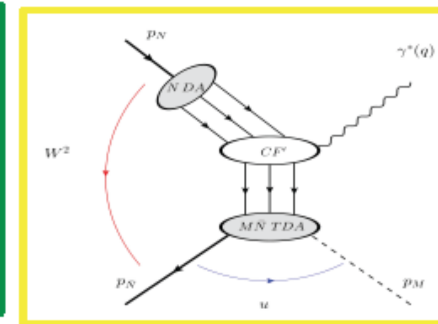
Nucleon Electromagnetic Final States

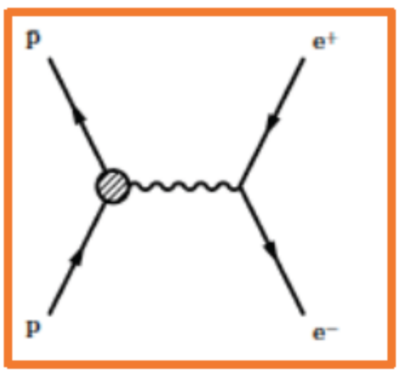
Background Suppression ~ 10^{-8}

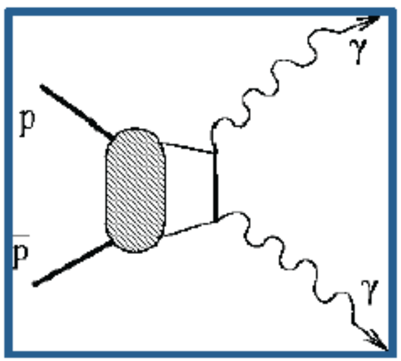


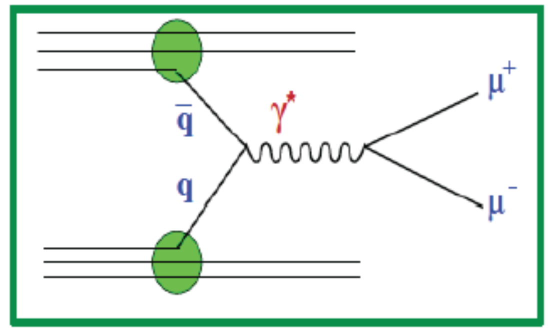


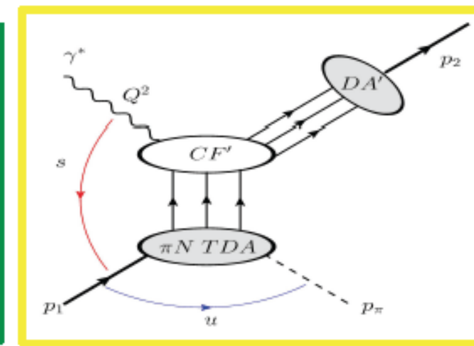










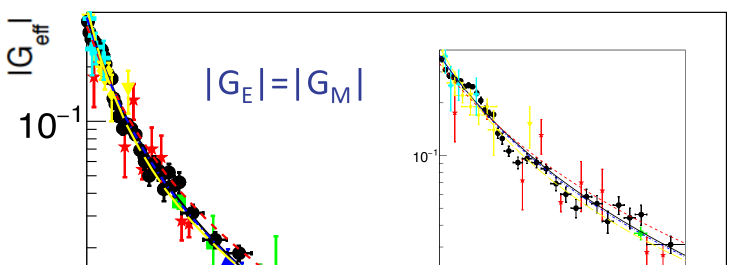


Time-Like proton electromagnetic FFs

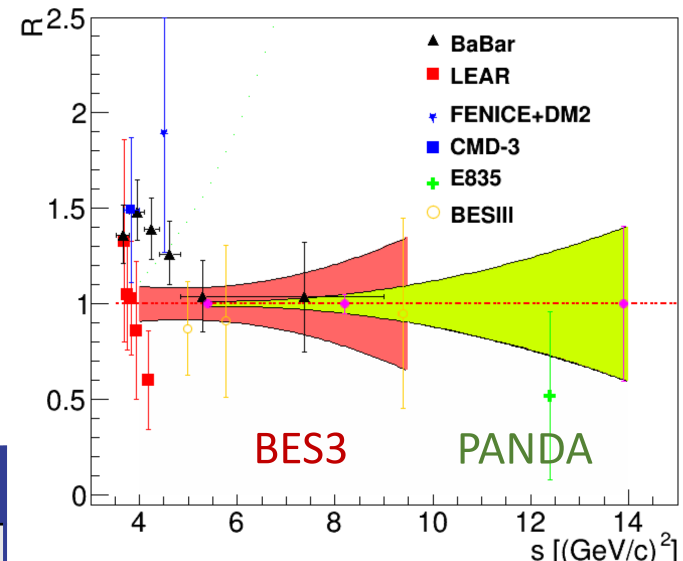
Eur.Phys.J. A52 (2016) no.10, 325

The effective FF can be measured
up to q^2 ~30 GeV^2
but no individual determination of G_E and G_M so far

PRL 114 (2015) 232301



	BESIII	PANDA
s [(GeV/c)²]	4 - 9.5	5 - 14
$R=\|G_E\|/\|G_M\|$	9 % - 35 %	1.4 % - 41 %
	21 scan points = 552 pb^{-1} (2015)	L=2 fb^{-1} 2.10^{32} cm^{-1} s^{-1}



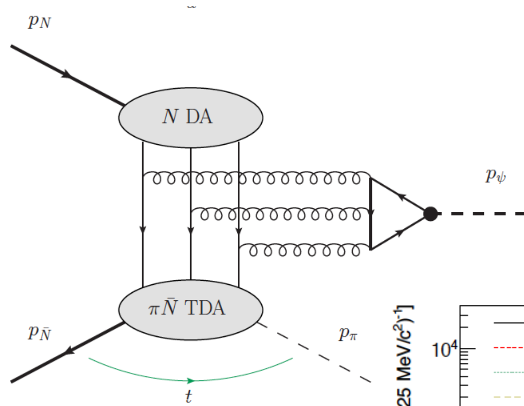
with transverse polarized target

$$\left(\frac{d\sigma}{d\Omega}\right)_0 A_{1,y} \propto \sin 2\Theta \, \mathrm{Im}\left(G_M G_E^*\right)$$

Transverse Momentum Dependent PDFs

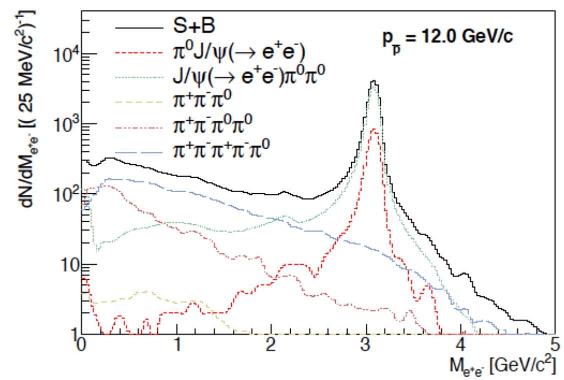
arXiv:1610.02149

$\bar{p}p \rightarrow J/\psi\pi^0 \rightarrow e^+e^-\gamma\gamma$



πN TDA's provide information on the nucleon's pion cloud

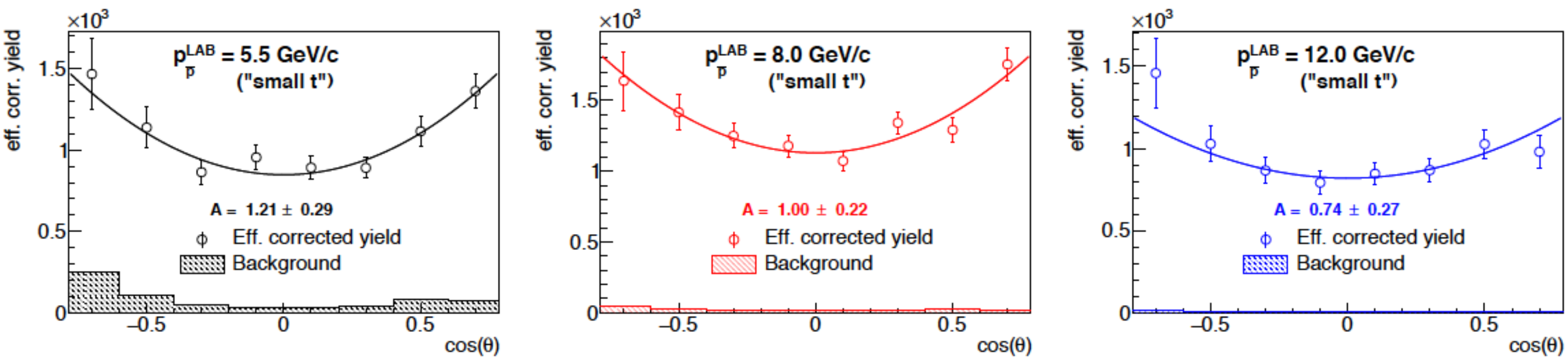
Validity of factorization ?



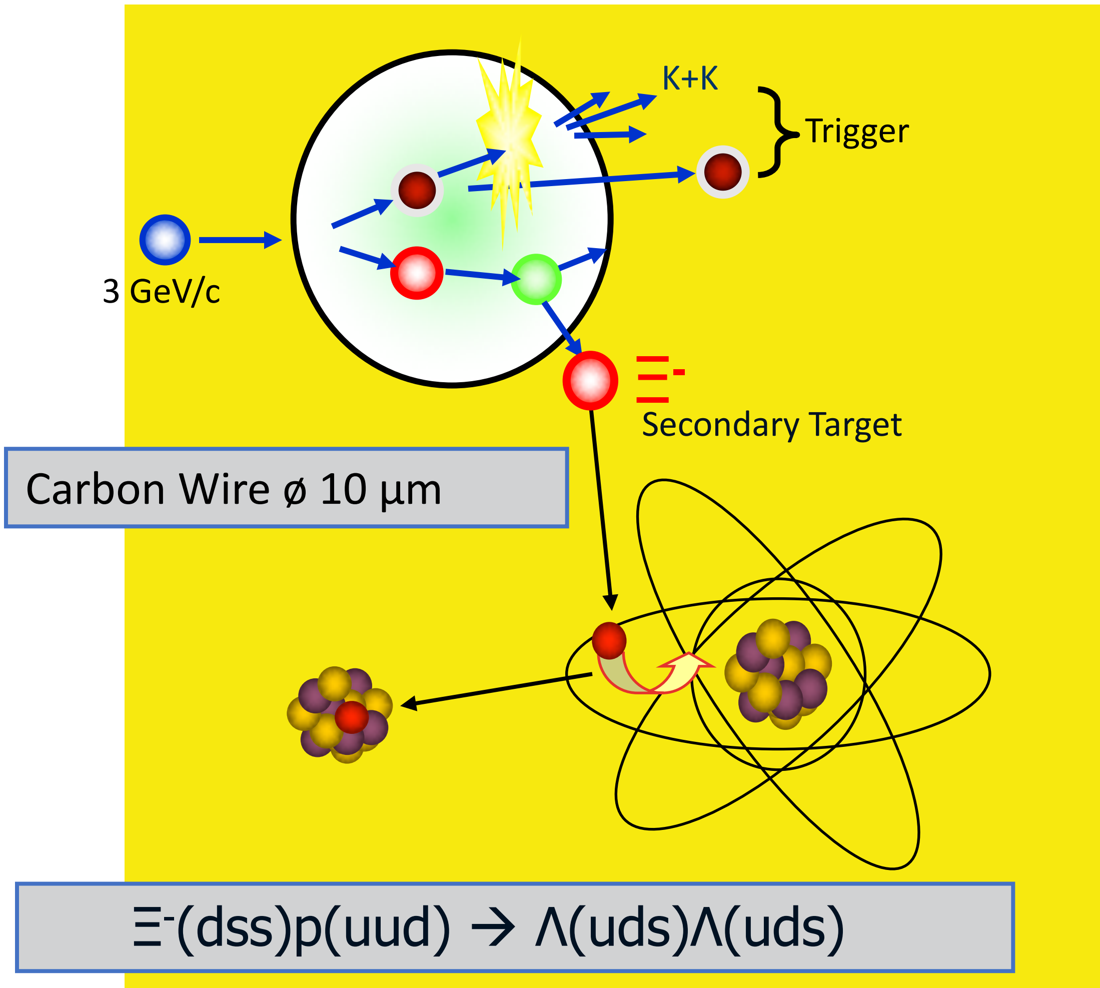
Simulation results for 4 months at L =2 x 10^{32}

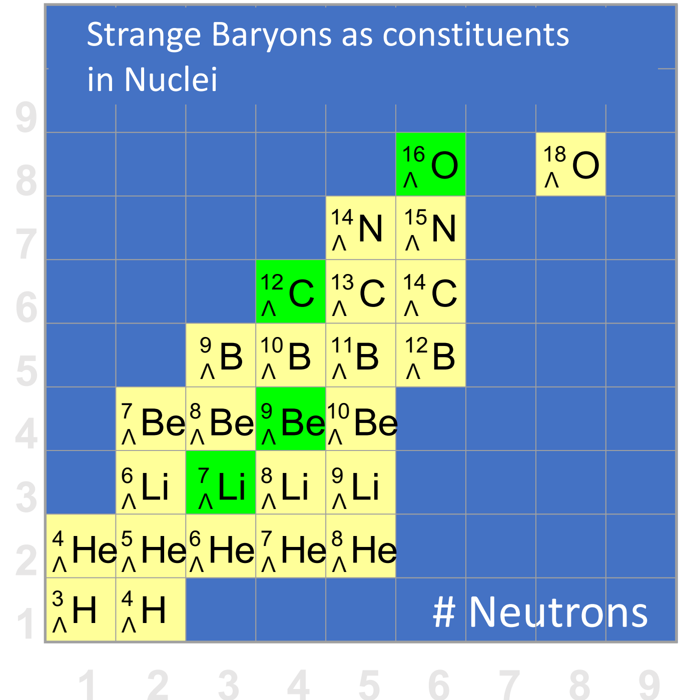
Biggest background is $J/\psi\pi^0\pi^0$ S/B > 15

after selecting N_γ (E_γ > 20 MeV) < 4



Hypernuclear Physics @ PANDA





Minimum 8 months full running

Limiting factor

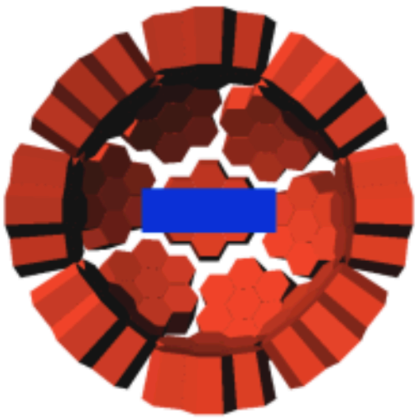
charged particle load on central detector (0.6-1.0)·10^7

L=(3-5)·10^{30} $cm^{-2}s^{-1}$

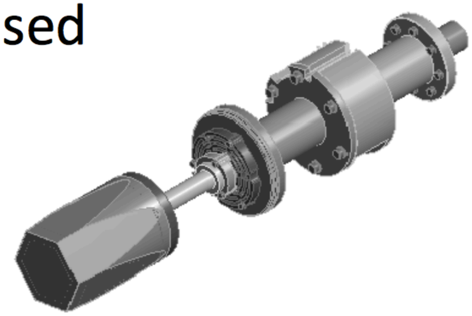
$\bar{p}$ re-storage < 6·10^6

DEGAS HPGe Array

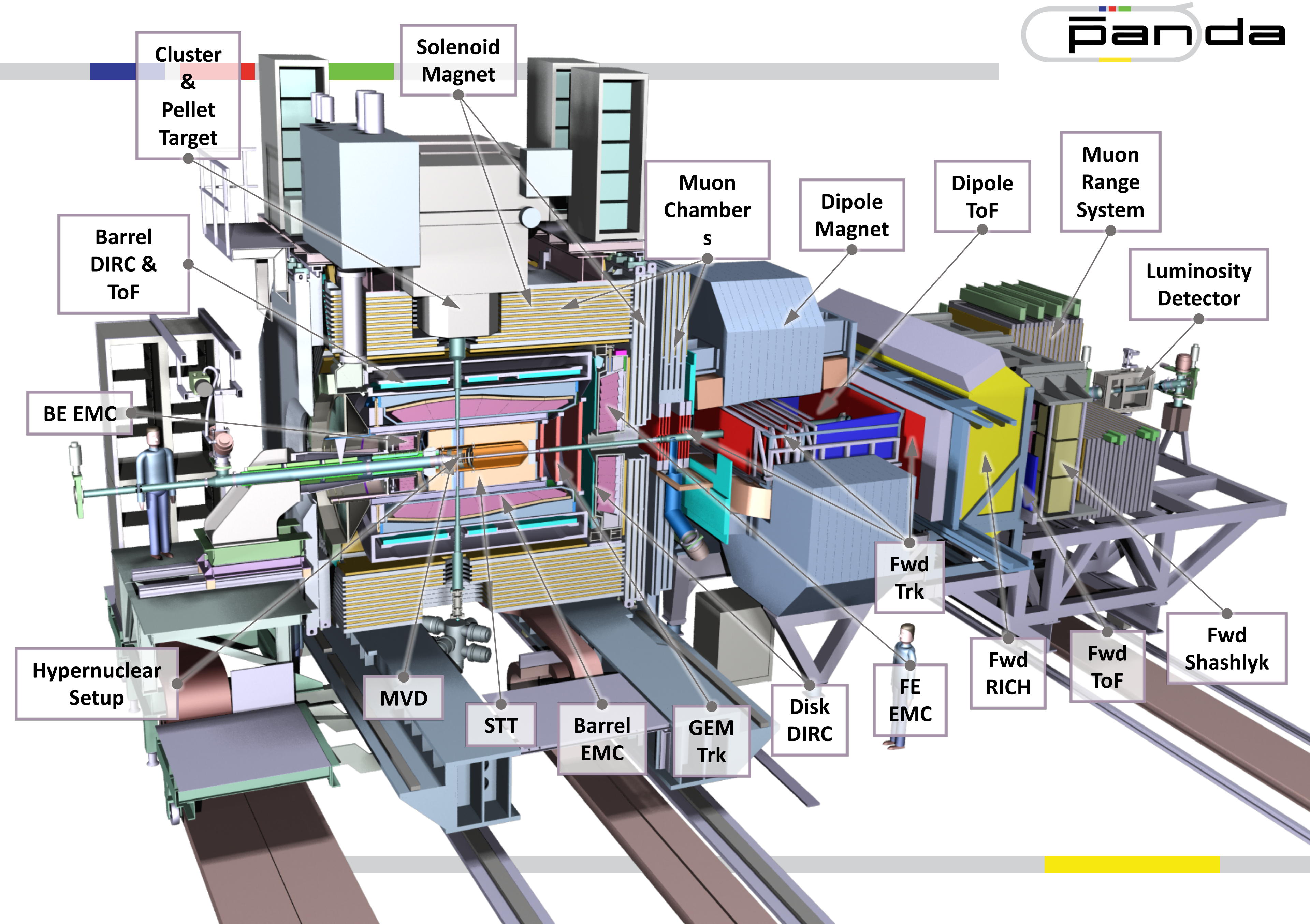
Array type	Composite Ge detector array
Energy range (keV)	50-5000
Noise threshold (keV)	15
Energy resolution (at 1.3 MeV)	2.3 keV
Full energy γ-detection efficiency (at 1 MeV)	16%
Effective full energy efficiency after prompt flash blinding	14%
P/T-value	34%
Time resolution (at 1.3 MeV)	10 ns
Overload recovery time	100 ns/MeV
Relative background suppression	5



Half sphere
EB Clusters based



What we need



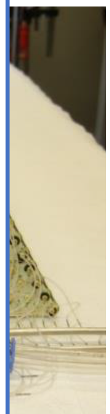
Cluster & Pellet Target
Solenoid Magnet
Barrel DIRC & ToF
Muon Chamber s
Dipole Magnet
Dipole ToF
Muon Range System
Luminosity Detector
BE EMC
Fwd Trk
Hypernuclear Setup
MVD
STT
Barrel EMC
GEM Trk
Disk DIRC
FE EMC
Fwd RICH
Fwd ToF
Fwd Shashlyk

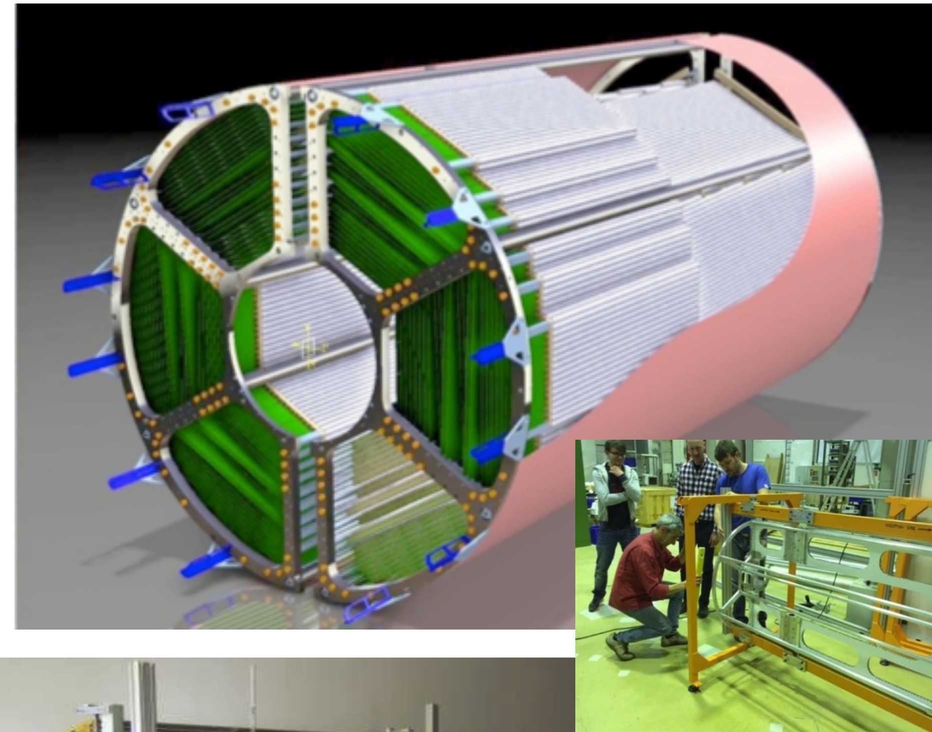
Straw Tube Tracker

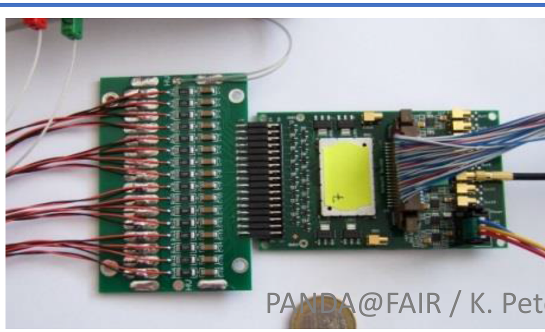
Detector Layout
4600 straws in 21-27 layers,
of which 8 layers skewed at ~3°
Tube made of 27 µm thin Al-mylar, ø=1cm
R_{in}= 150 mm, R_{out}= 420 mm, l=1500 mm
Self-supporting straw double layers
at ~1 bar overpressure (Ar/CO_2)
Readout with ASIC+TDC or FADC

Material Budget
Max. 26 layers,
0.05 % X/X_0 per layer
Total 1.3% X/X_0

Project Status
3000 Straws produced
Readout prototypes and beam tests
Ageing tests: up to 1.2 C/cm^2







Electromagnetic Calorimeter (TS)

PANDA PWO Crystals

PWO is dense and fast

Low γ threshold is a challenge

Increase light yield

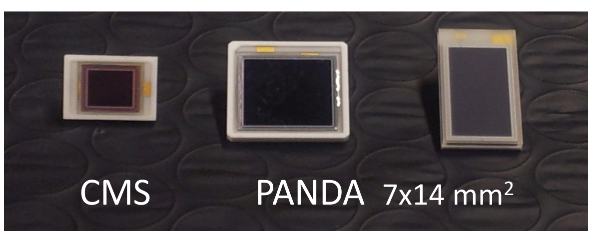
- improved PWO II (2xCMS)
- operation at -25°C (4xCMS)

Challenges

- temperature stable to 0.1°C
- control radiation damage
- low noise electronics

Delivery of crystals 54 %

Large Area APDs



Barrel Calorimeter

11000 PWO Crystals

LAAPD readout, 2x1cm^2

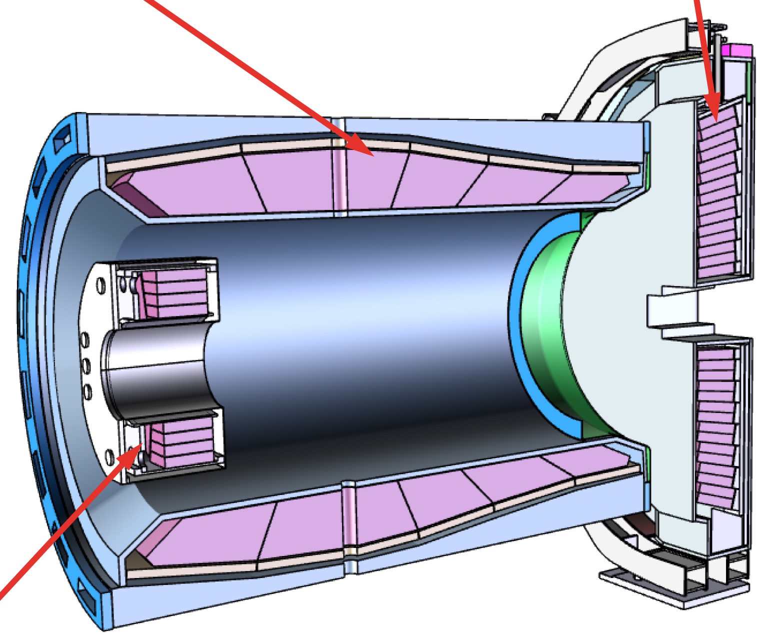
σ(E)/E~1.5%/√E + const.

Forward Endcap

4000 PWO crystals

High occupancy in center

LA APD and VPTT



Backward Endcap for hermeticity, 530 PWO crystals

Electromagnetic Calorimeter (TS)

Crystals

1st lot of crystals delivered

New producer Crytur

Test production in 2016 (~100pc)

APD/Preamp/VPTT

Screening of 30000 APDs ongoing

ASIC preamp design finalized

VPTT (Forward) characterized

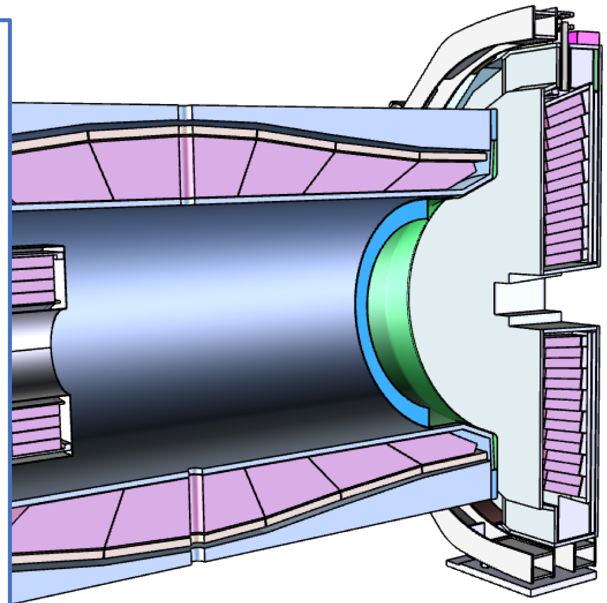
Assembly

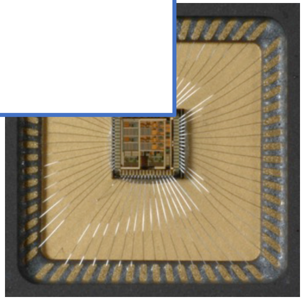
Forward-EMC full completion ‘til 2018

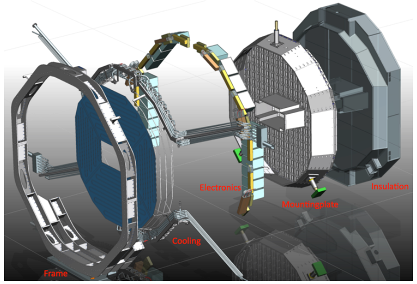
Backward-EMC prototype-tests successful

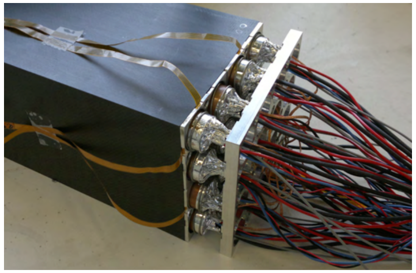
Barrel-EMC: alveoles produced

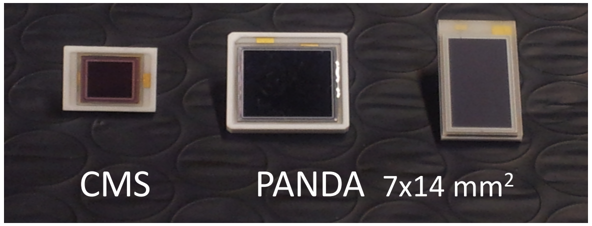
1st slice in construction

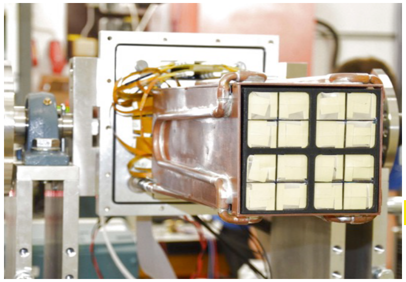




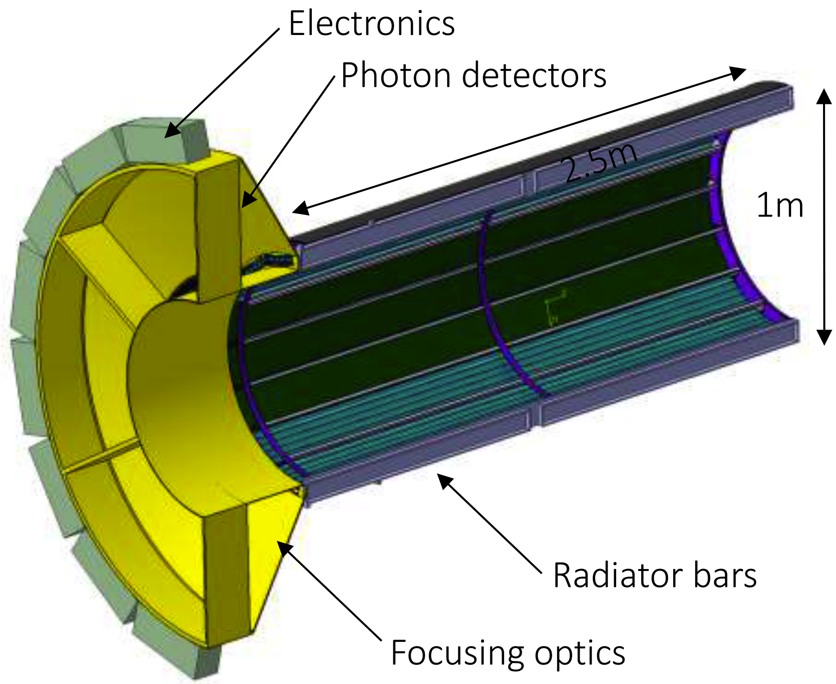








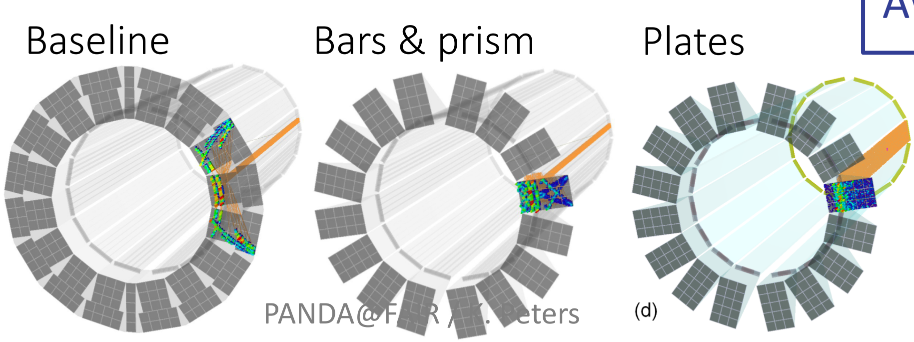
Barrel DIRC



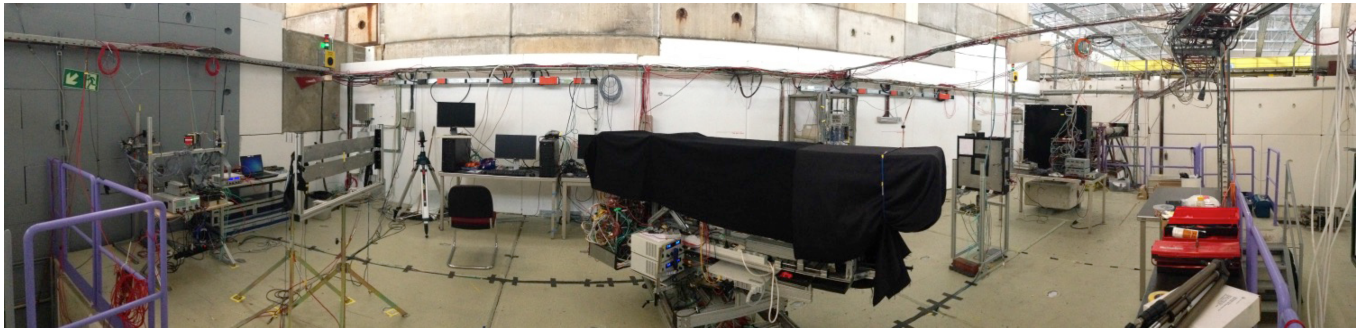
Baseline design
- DIRC: Detection of Internally Reflected Cherenkov light pioneered by BaBar
- Cherenkov detector with SiO_2 radiator
- Detected patterns give β of particles

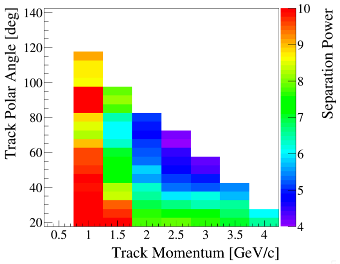
Optimization and challenges
- Focusing by lenses/mirrors
- More compact design
- Magnetic field → MCP PMT
- Fast readout to suppress BG
- Plates as more economic radiator

Project status
- Baseline and Plate design verified
- Awaiting approval of TDR

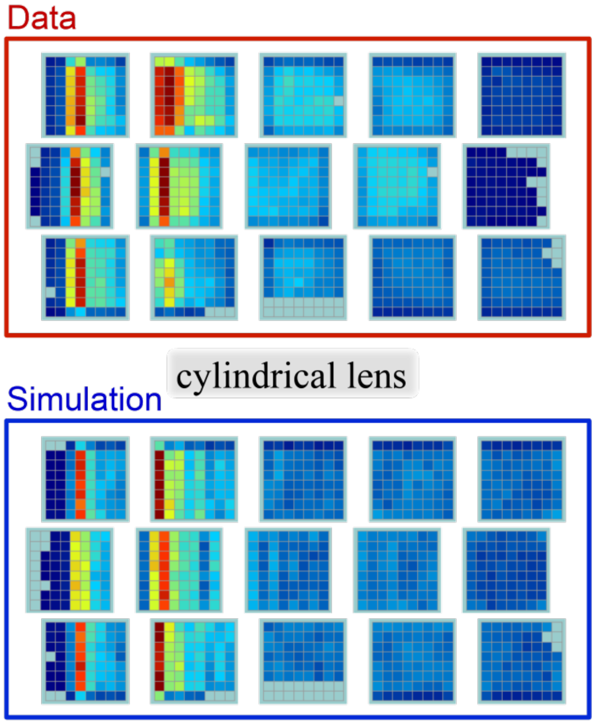


Barrel DIRC (beam tests)





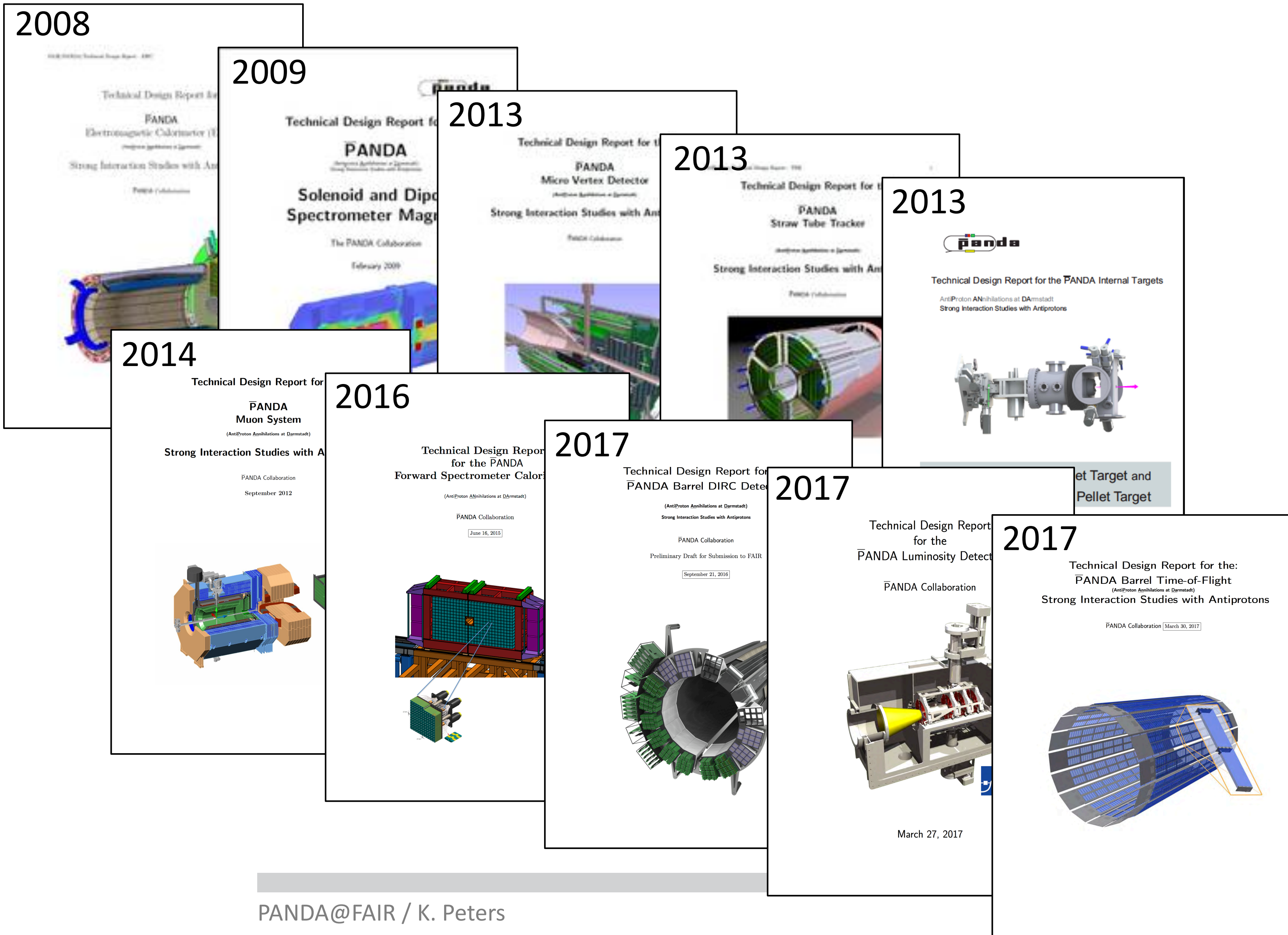
Simulated separation of π/p at test-beam



Test beam campaign at CERN T9
- 2 periods: 3+2 weeks May-July
- ToF ref. at multi-hadron beam
- Readout with TRB3/PADIWA

Measurement program
- Focusing by various lenses
- Prism as expansion volume
- Bars as baseline radiator
- Plate radiator as alternative

Status of TDRs and Construction



PANDA Phases

Phase 0
Currently PANDA detectors are being built.
They will be used in other excellent experiments until the experimental hall is available.

Phase 1
First physics experiments with the PANDA start setup using antiprotons

Phase 2
Experiments using the full setup

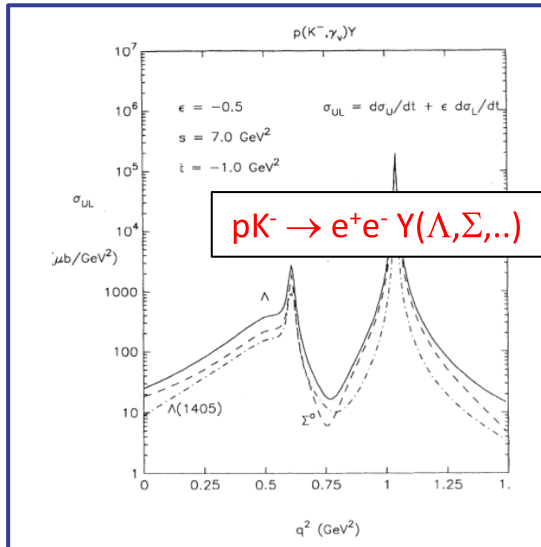
Phase 3
Experiments beyond MSV (needs RESR)

Phase 0: Experiments together with HADES

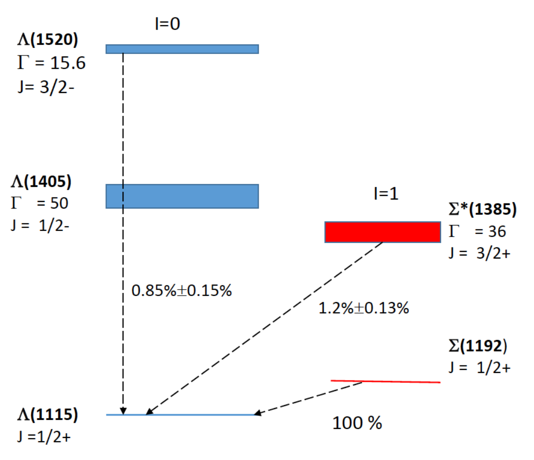
Goal: Hyperon structure, extend our understanding of the nucleon
How: Hyperon Dalitz decay Transition FF

well connected to the PANDA physics program

Role of ρ-baryon coupling (VMD?)



VMD: R. Williams et. al. PRC48(1993)



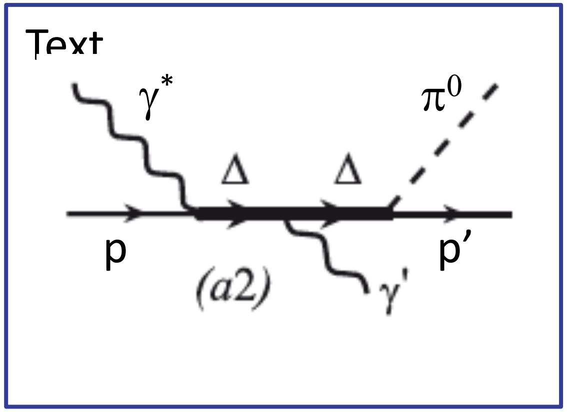
- Only few measurements of radiative decays:
  e.g. $\Sigma^{0(*)} \rightarrow \Lambda\gamma$ $\Lambda(1520) \rightarrow \Lambda\gamma$
- $Y \rightarrow \Lambda e^+e^-$ never measured !
- Proposed reaction:
  $pp(A) \rightarrow Y\ (\text{any})\ X \rightarrow \Lambda e^+e^-\ X$

Tag with $\Lambda \rightarrow \pi^- p$ BR ~ 10^{-5}

Phase 0: Backward EMC @ MAMI

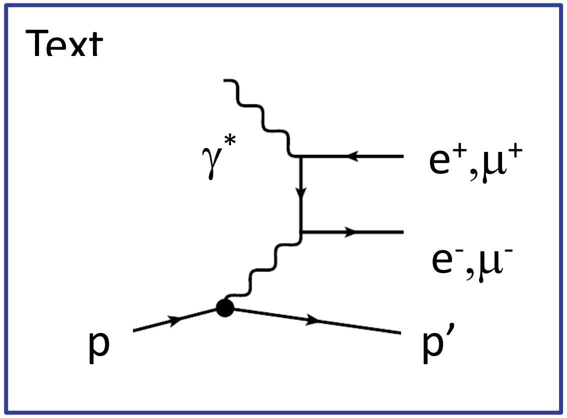
Magnetic Moment of the Δ(1232) by

- e p → e p π^0 γ
- Additional calorimeter for π^0 and γ detection
- Virtual photon flux higher in e-production
- S_{11}-Resonance



Electron-Muon-Universality (Proton Radius Puzzle)

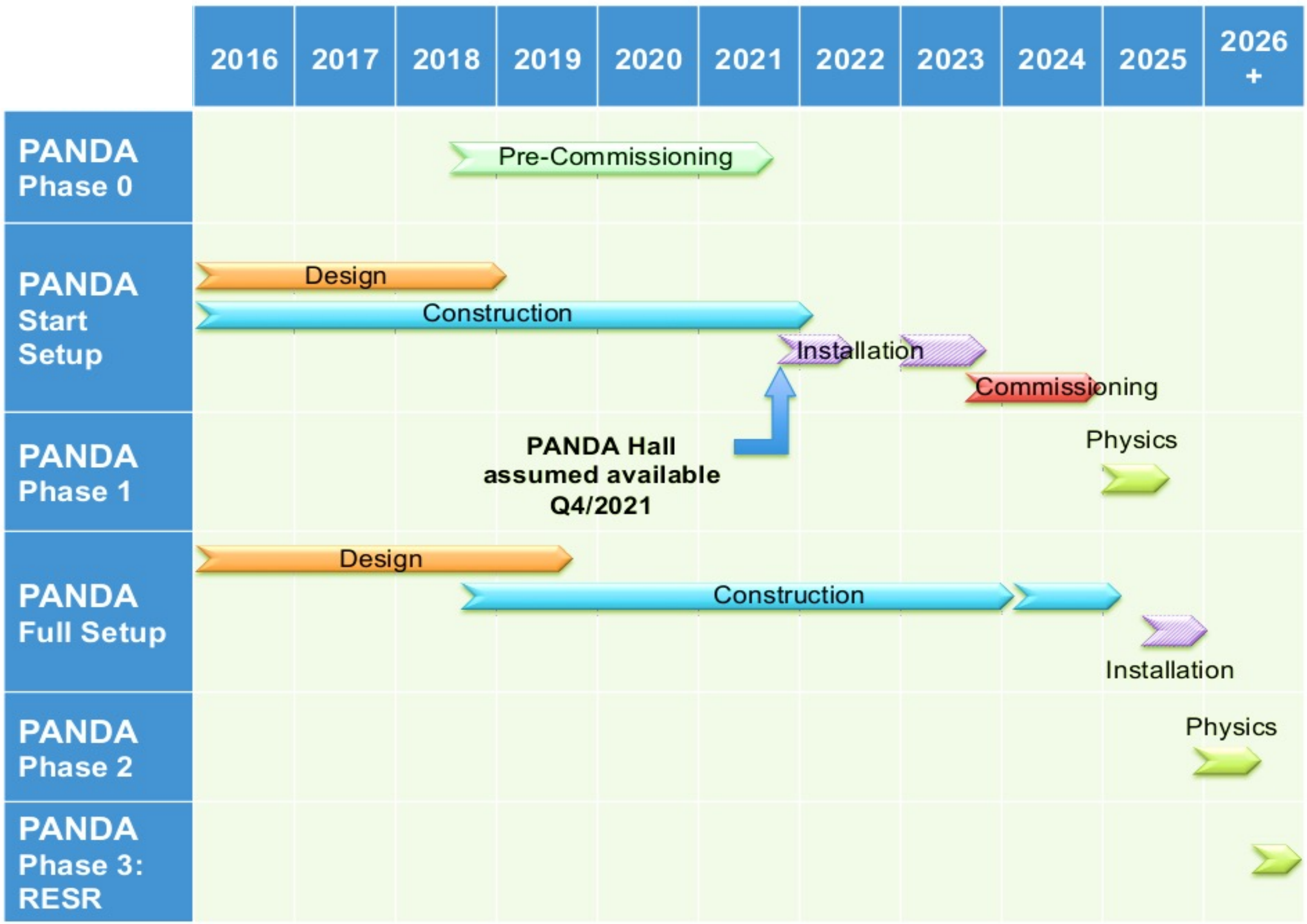
- e p -> e p l^+l^- below/above $\mu^+\mu^-$ pair threshold
- Additional calorimeter for forward angles



Multi-π^0-Production

- e p → e p $\pi^0 \pi^0$ etc.
- Unknown transition amplitudes, calibration and commissioning of calorimeter

PANDA Schedule



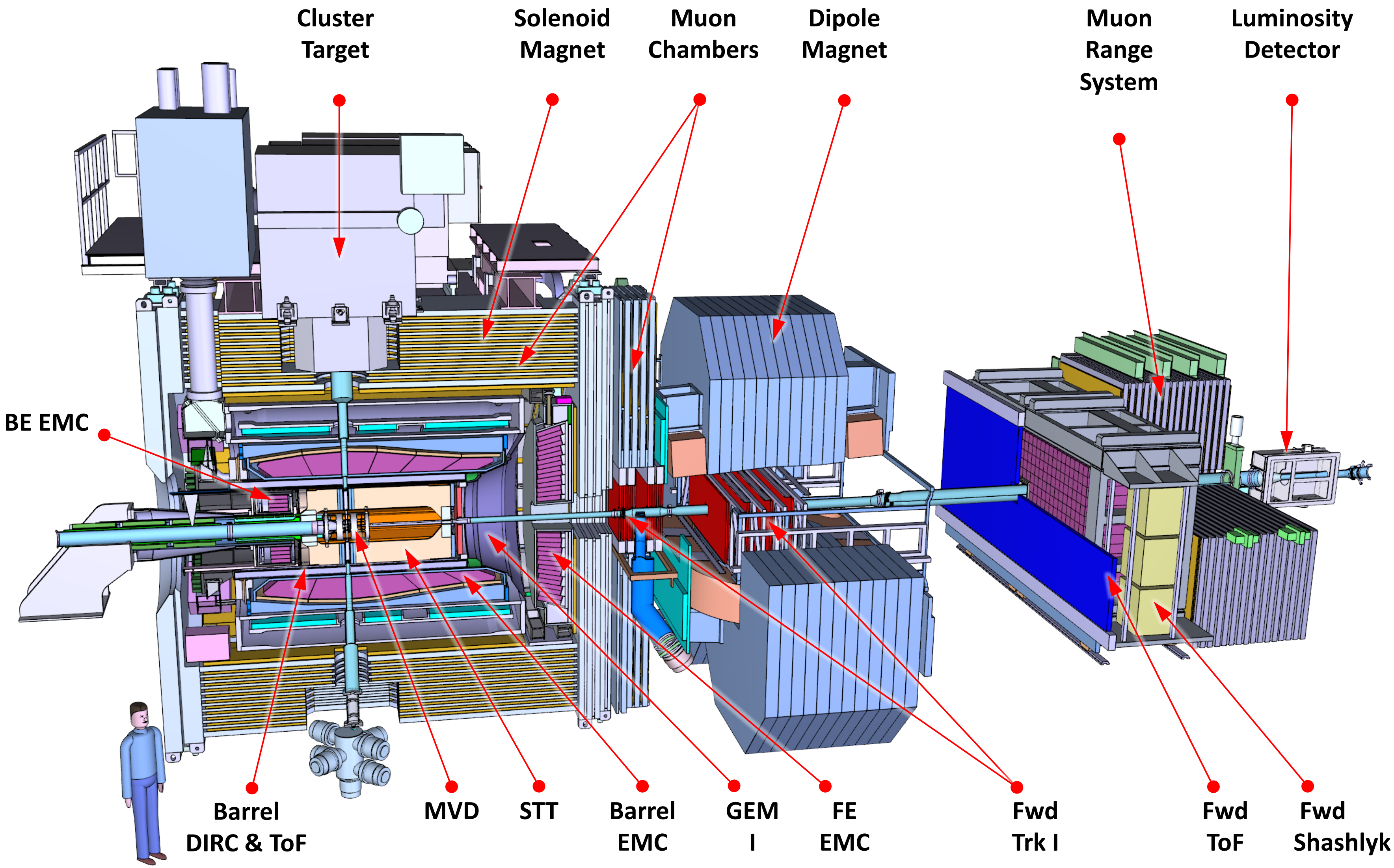
Key-Experiments of the Start Phase

Concentration on unique and forefront physics topics

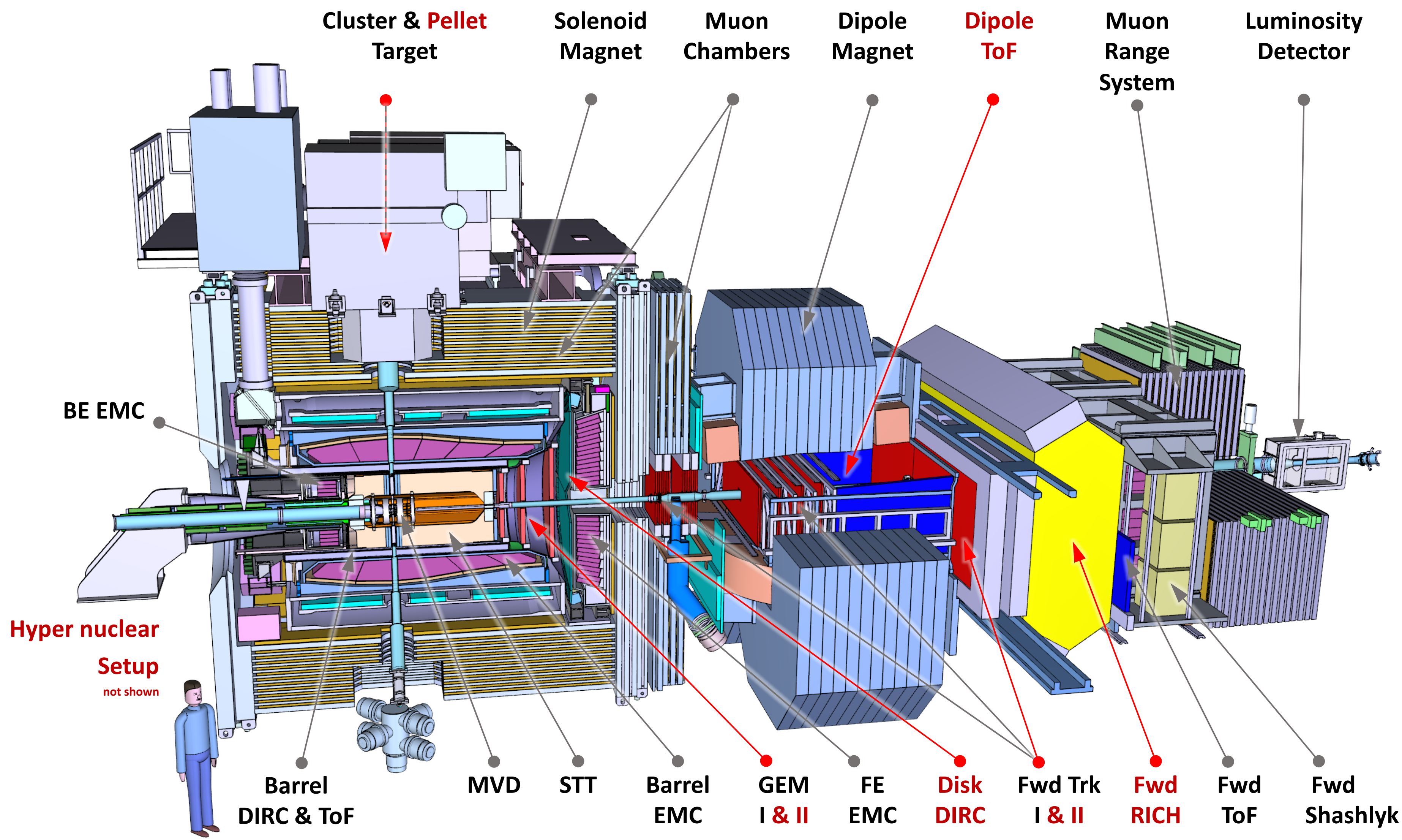
- Production of multi-strangeness baryons
  (unexplored, new territory, „Strangeness-Factory")
- Precise measurement of the line shape of narrow XYZ-states,
  e.g. X(3872)
  (only possible in proton–antiproton, counting experiment,
  clarification of the nature of the states)
- Resonant formation of the
  negative and uncharged partners of the Z-States
  (only possible in proton–antiproton, goal is the nature of the states)
- Measurement of the electromagnetic form factors of the proton in the time-like domain with electrons and muons in the final state
- Production of high spin charmonia
  (only possible in proton–antiproton)
  light mesons, baryons and production of hybrids und glueballs

XYZ-, Hyperon Factory

Start-Setup (Phase-1)



Full Setup (Phase-2)



PANDA Collaboration

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U Basel
IHEP Beijing
U Bochum
Magadh U, Bodh Gaya
BARC Mumbai
IIT Bombay
U Bonn
IFIN-HH Bucharest
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U & INFN Catania
NIT, Chandigarh
AGH UST Cracow
JU Cracow
U Cracow
IFJ PAN Cracow
FAIR
GSI Darmstadt
Karnatak U, Dharwad

TU Dresden
JINR Dubna
U Edinburgh
U Erlangen
NWU Evanston
U & INFN Ferrara
FIAS Frankfurt
LNF-INFN Frascati
U & INFN Genova
U Glasgow
U Gießen
Birla IT&S, Goa
KVI Groningen
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Gauhati U, Guwahati
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U Katowice

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HI Mainz
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U Minsk
ITEP Moscow
MPEI Moscow
U Münster
BINP Novosibirsk
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IPN Orsay
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Czech TU, Prague
IHEP Protvino
PNPI St. Petersburg
U of Sidney

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U Stockholm
KTH Stockholm
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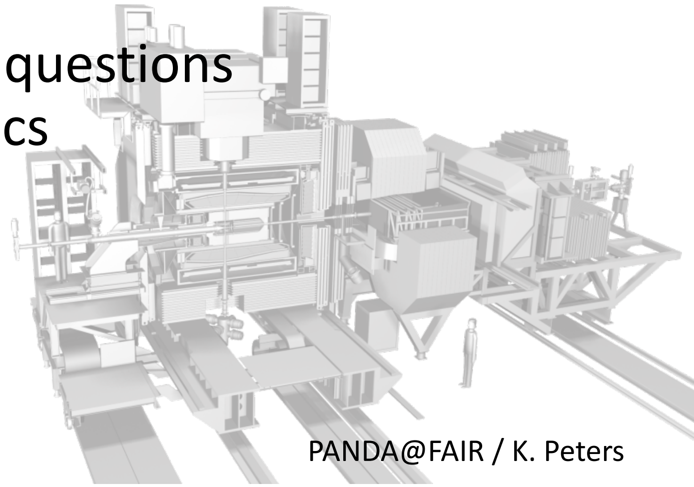
U & INFN Torino
Politecnico di Torino
U & INFN Trieste
U Tübingen
U Uppsala
U Valencia
SMI Vienna
SINS Warsaw
TU Warsaw

more than 450 physicists from
more than 60 institutions in 19 countries

Summary

- QCD at large scales is extremely fascinating
- Understanding the multifaceted effects of it
  - is complicated – a really tough job
  - but … is a must to do
  - and … it is also fun – because it is hard
- and PANDA is as key tool to challenge this field in all aspects
- the full setup covers the broadest physics case ever in hadron physics history
- already the start-setup addresses unique questions in hyperon-, charm- and light-quark-physics
- Please stay tuned for start of proton beam 2024 and anti-proton beam 2025



Thank you

Danke