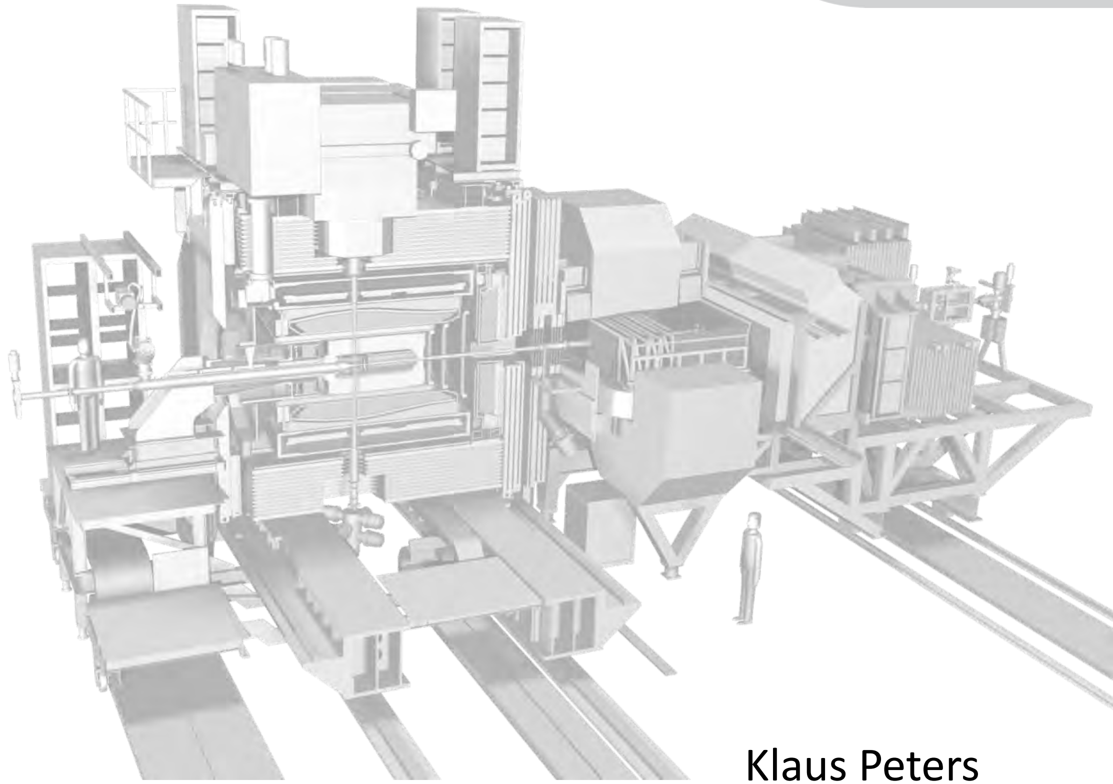
Status of PANDA @ FAIR

Newport News, May 16, 2017

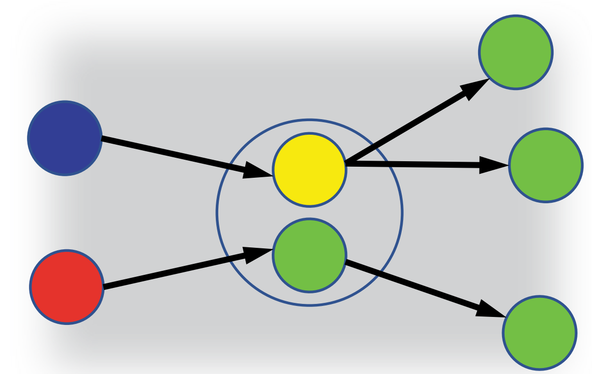


Klaus Peters
GSI/U Frankfurt

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

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

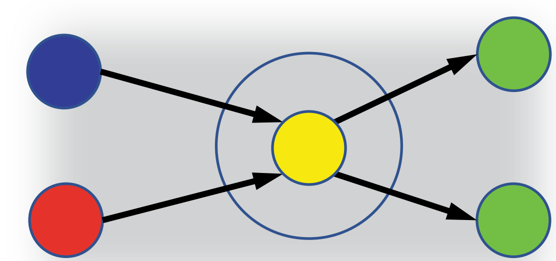
- high discovery potential
- associated, access to all quantum numbers (exotic)



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

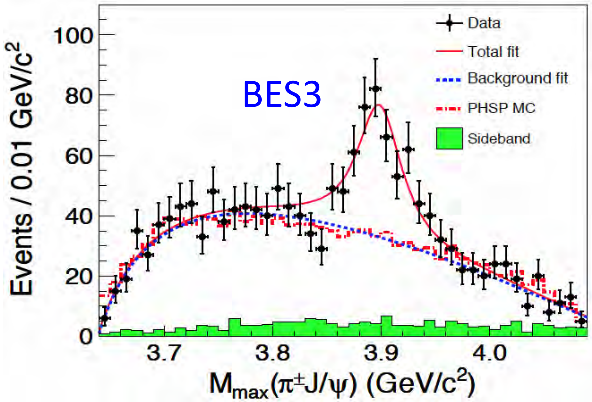


quantum numbers like $\bar{p}p$

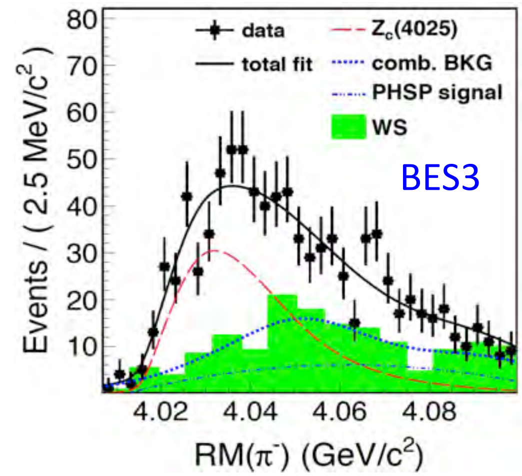
antiproton probe unique and decisive

Discovery of the $Z^+(3900)$

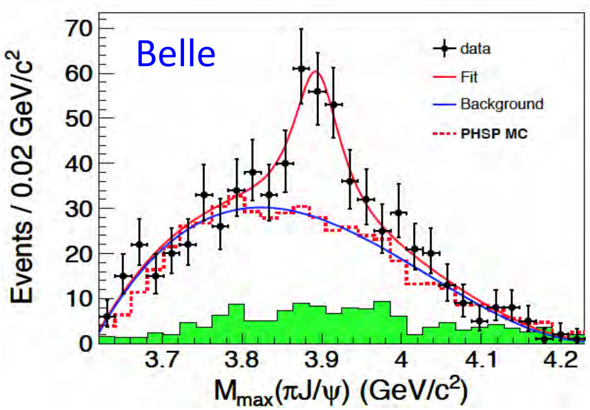
2013

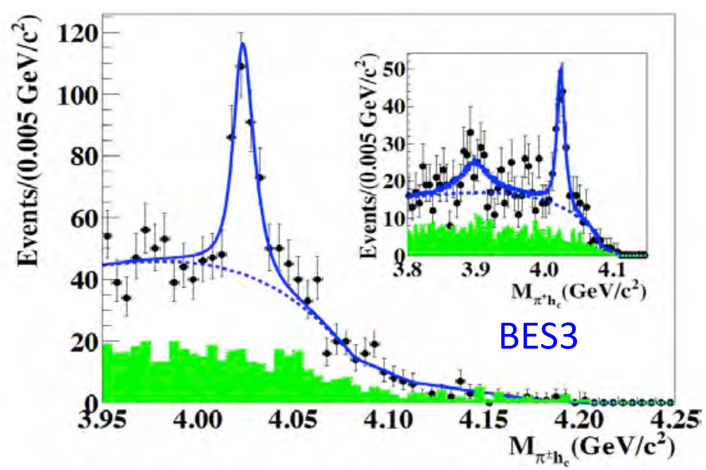


Discovery of the $Z_c^{+/-}$(3900) in the J/ψ $\pi^{+/-}$ invariant mass spectrum in the decay Y(4260) → J/ψ $\pi^+\pi^-$



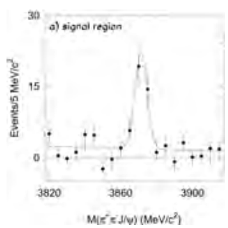
Observation of the $Z_c^{+/-}$(4025) in the $h_c\pi^{+/-}$ and $\overline{D}$*D* invariant spectrum in Y(4260/4360) decays



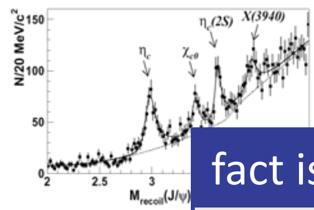


New Charmonium-like Discoveries

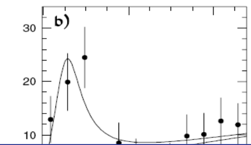
X(3872)
PRL 91,262001 (2003)



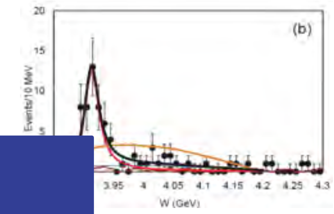
X(3940)
PRL 98,082001 (2007)



Y(3940)
PRL 94,182002 (2005)



X(3915)
PRL 104,092001 (2010)

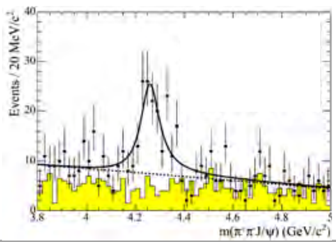


fact is

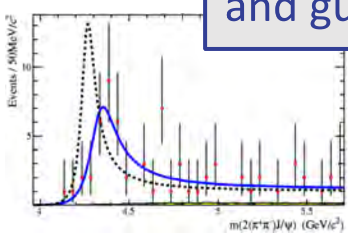
charmonium is very complicated

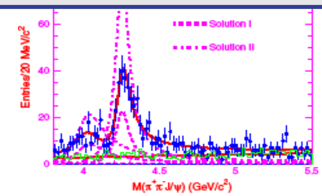
and guides us into a terra incognita

Y(4260)
PRL 95,142001 (2005)

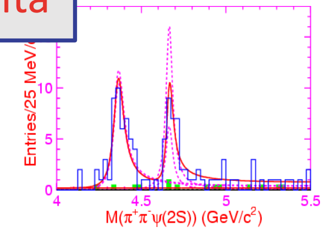


Y(435
PRL 98,21200



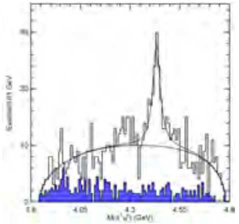


Y(4660)
99,142002 (2007)

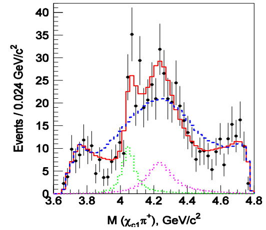


Z(4430)⁻

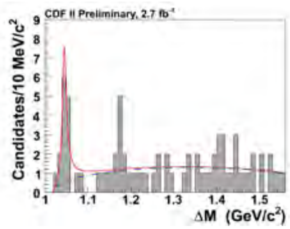
PRL 100,142001 (2008)



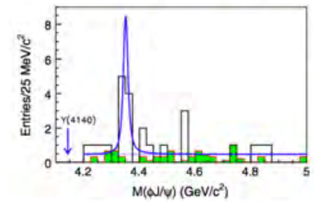
Z_1^- & Z_2^-
PRD 78,072004 (2008)



Y(4140)
PRL 102,242002 (2009)

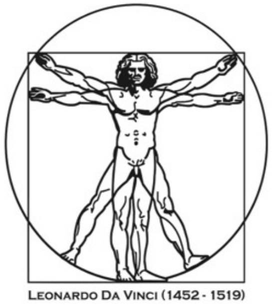


X(4350)
PRL 104,112004 (2010)

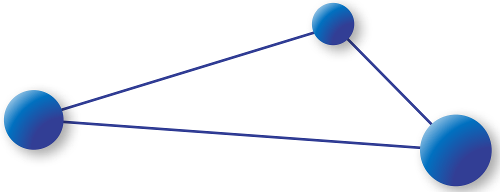


Frontiers

Complexity Frontier



Intensity Frontier



Energy Frontier

Precision Frontier

Complexity

Complexity Frontier

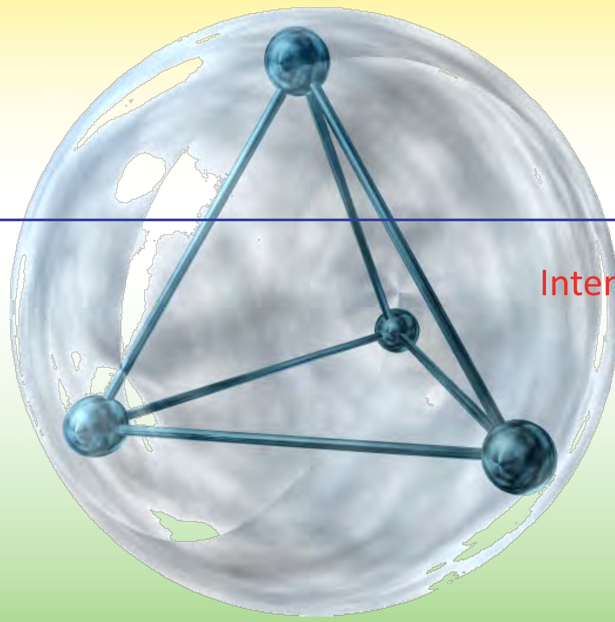
REALITY

SIMPLICITY

Intensity Frontier

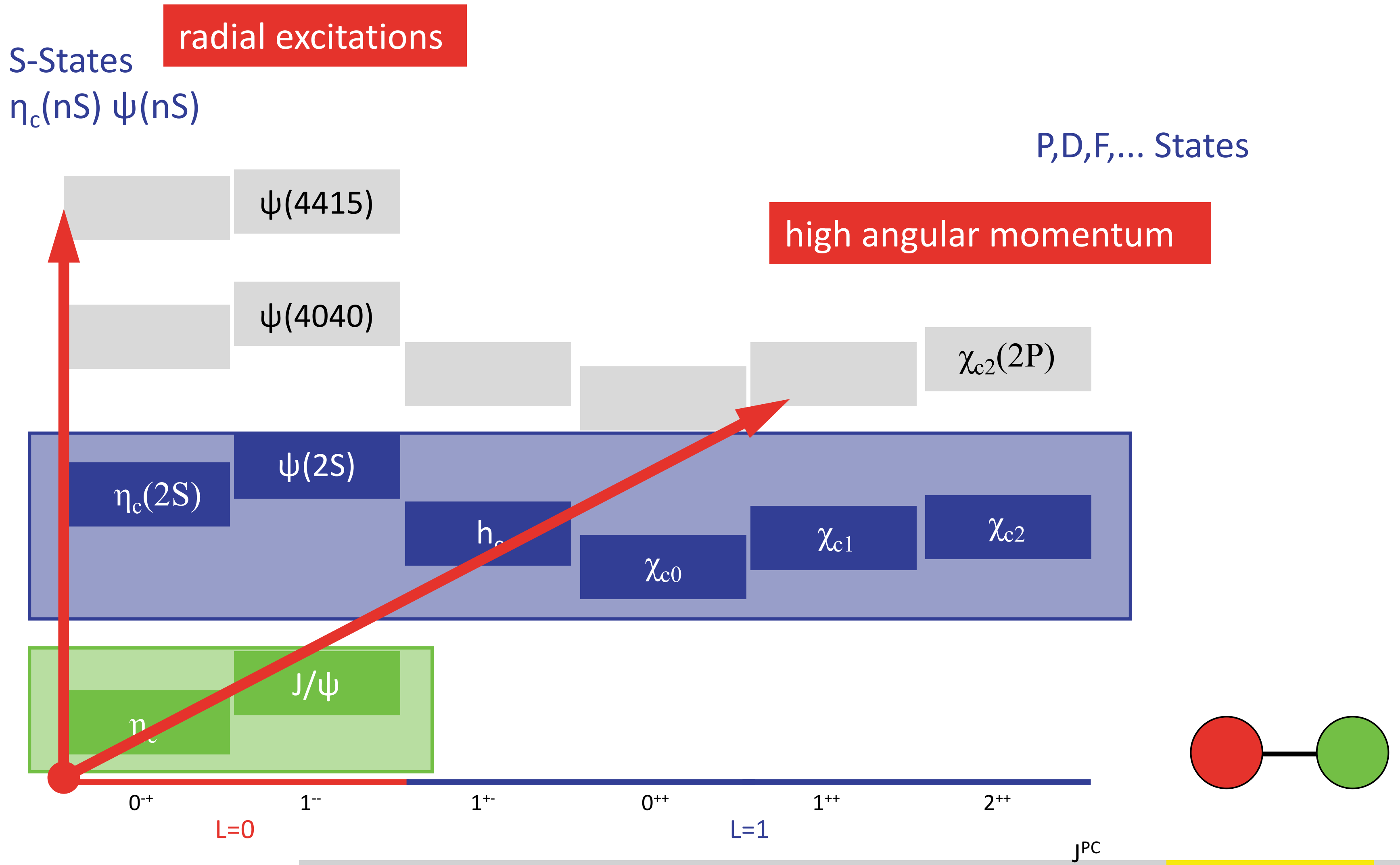
Energy Frontier

Precision Frontier

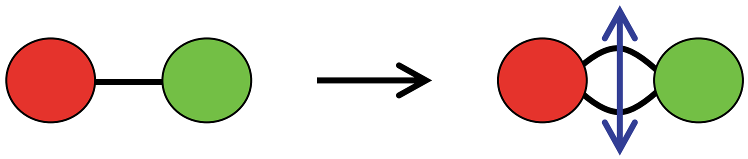


Charmonium

Several golden ways to heaven

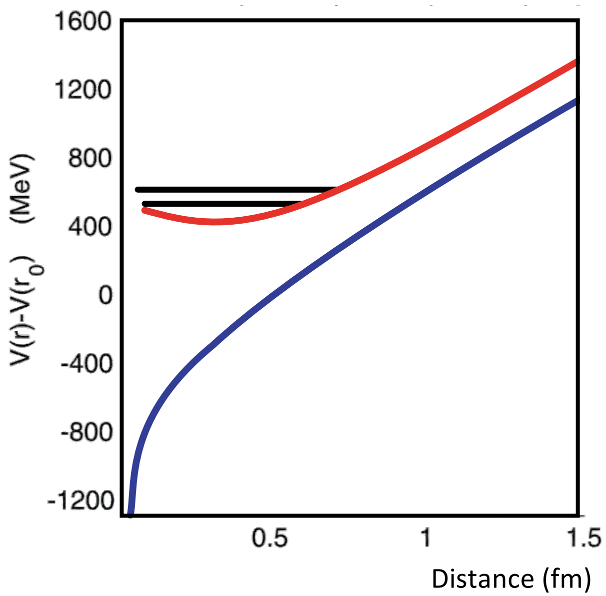


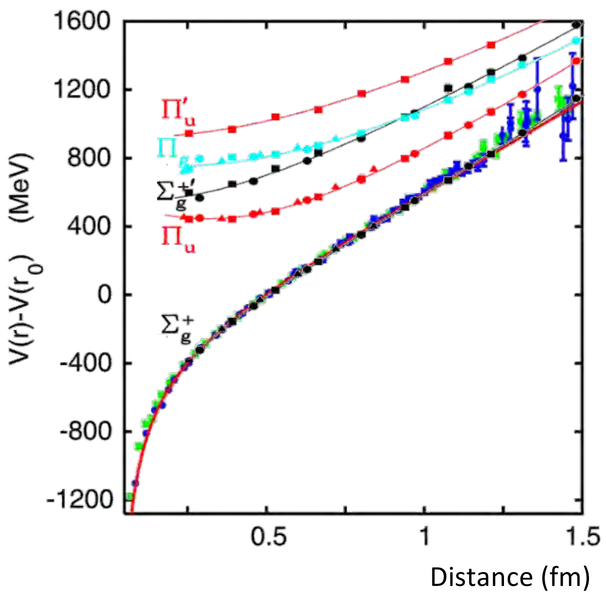
Charmonium – other degrees of freedom ?



different "potential"

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

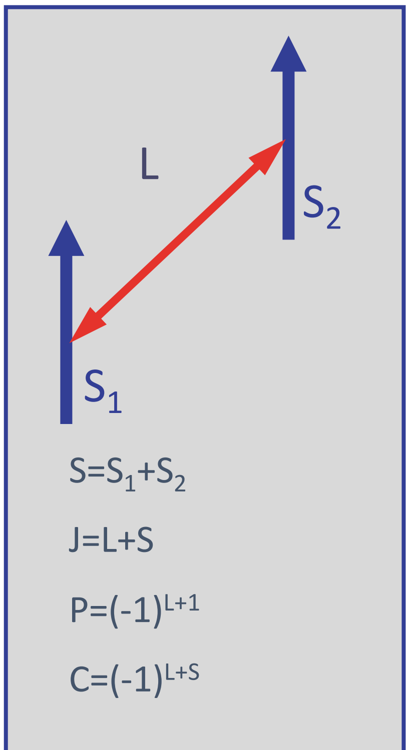




Eliminating Conventional States

remove the leading term
by selecting quantum numbers

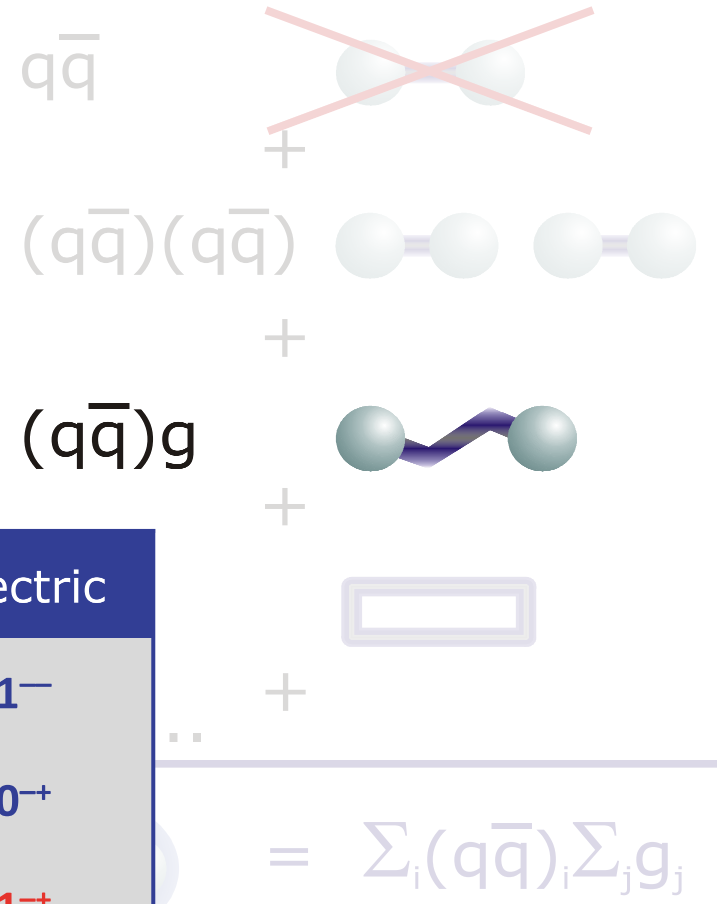
e.g. for hybrids



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^{-+}

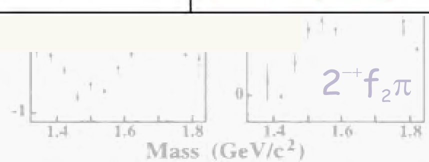


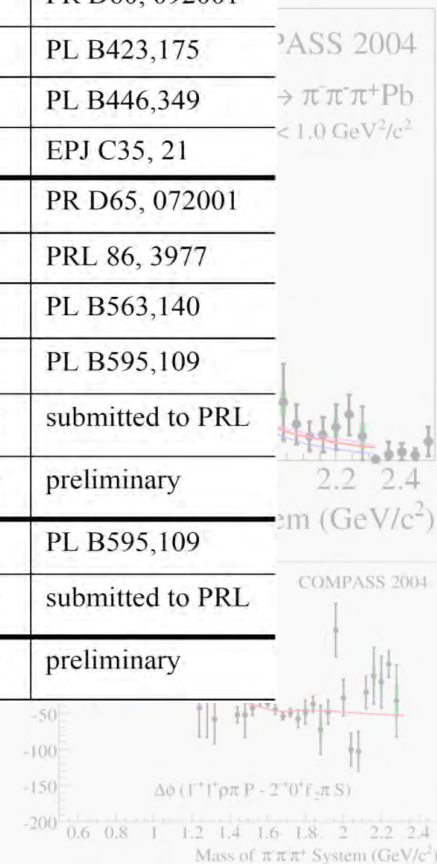
$\pi_1(1600)$ etc....E852 - $\rho\pi$ in 1997 and COMPASS

thanks to G. Adams, RPI

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

	Experiment	Mass	Width	Decay	Citation
$\pi_1(1400)$	E852	1359 (+16-14) (+10-24)	314 (+31-29) (+9-66)	$\eta\pi$	PR D60, 092001
	Crystal Barrel	1400 (+20-20) (+20-20)	310 (+50-50) (+50-30)	$\eta\pi$	PL B423,175
	Crystal Barrel	1360 (+25-25)	220 (+90-90)	$\eta\pi$	PL B446,349
	Obelix	1384 (+28-28)	378 (+58-58)	$\rho\pi$	EPJ C35, 21
$\pi_1(1600)$	E852	1593 (+8-8) (+29-47)	168 (+20-20) (+150-12)	$\rho\pi$	PR D65, 072001
	E852	1597 (+10-10) (+45-10)	340 (+40-40) (+50-50)	$\eta'\pi$	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
$\pi_1(2000)$	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)

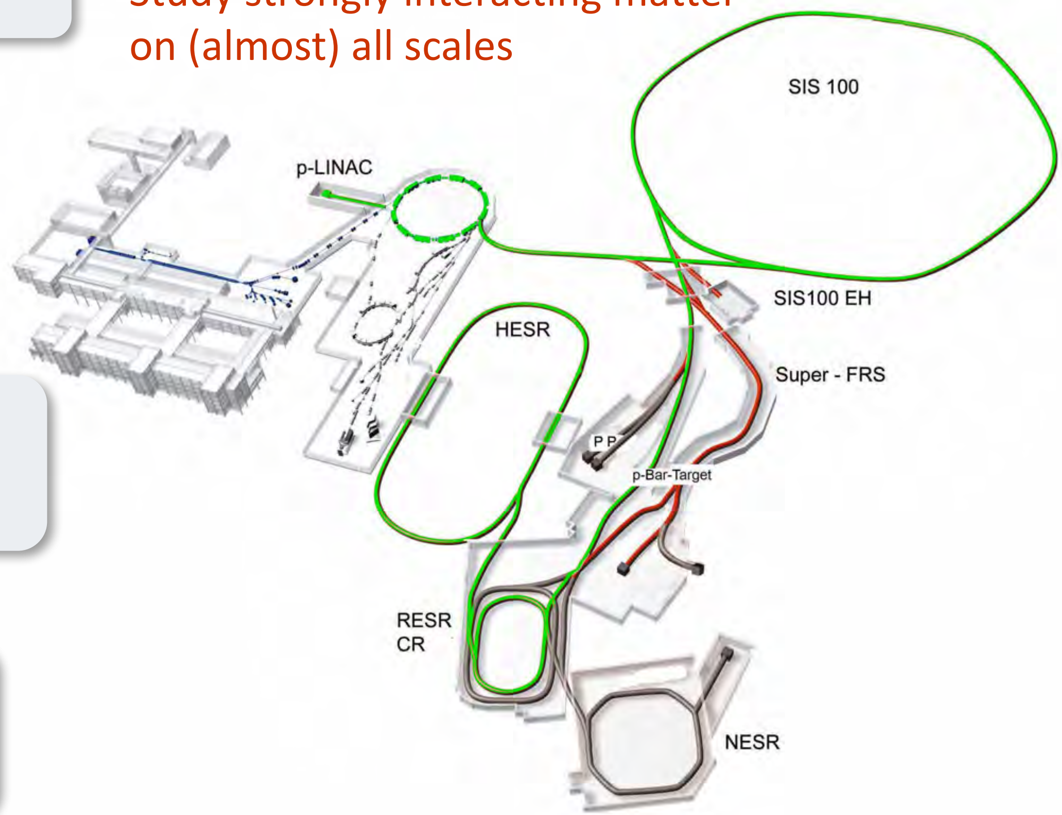
QCD-Phase Diagram
(HI beams 2 to 45 GeV/u)

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

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

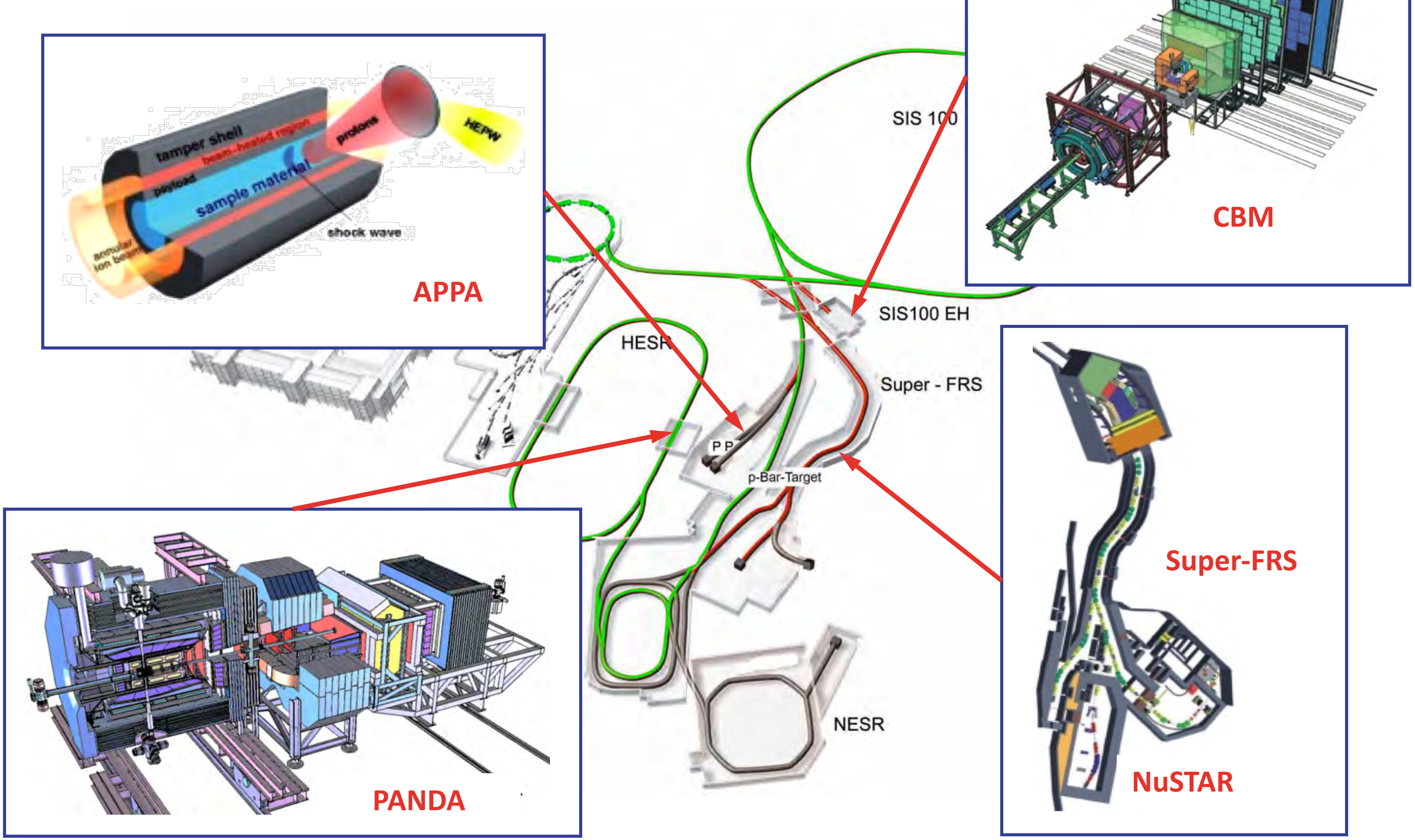
Materials Science & Radiation Biology
(ion & anti-proton beams)

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

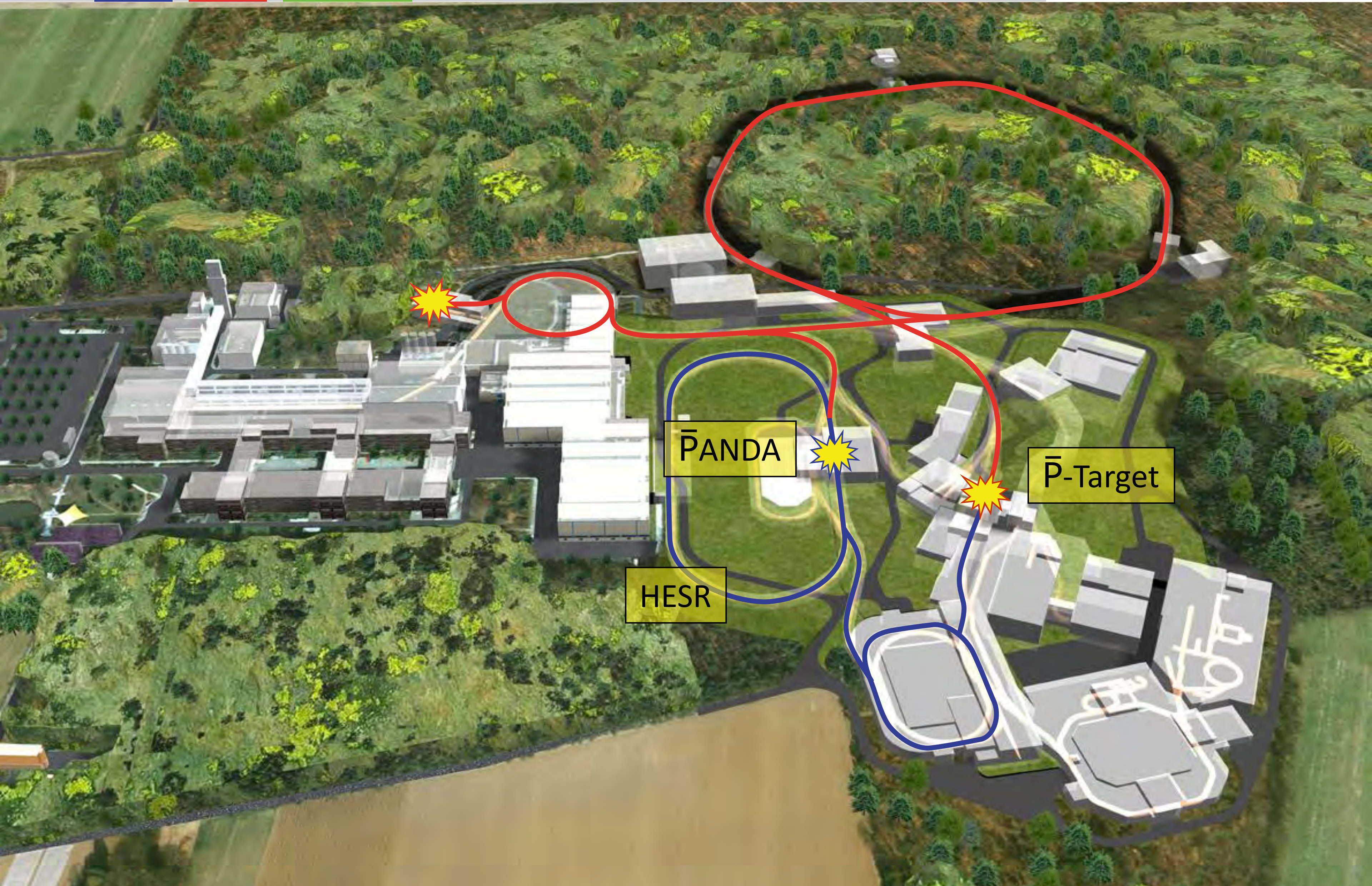


Accelerator Physics

FAIR Experiments



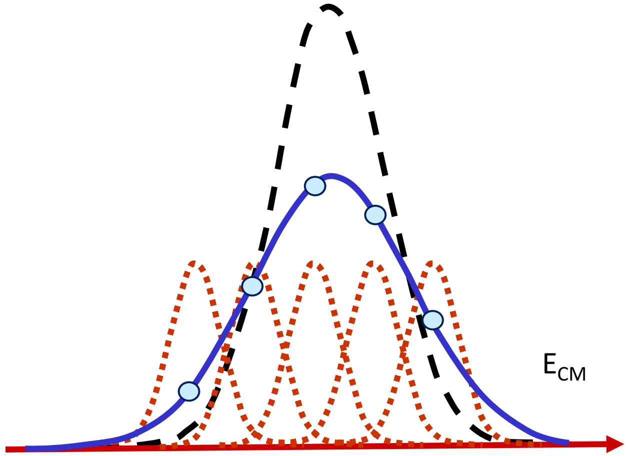
HESR, PANDA and FAIR



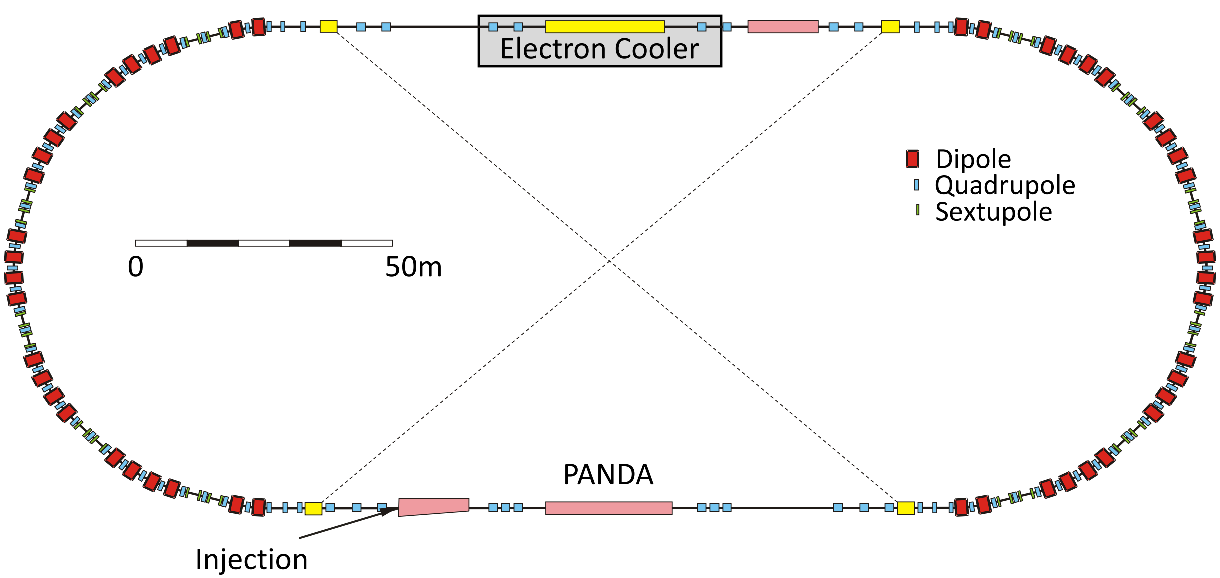
HESR – Storage Ring for Antiprotons

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



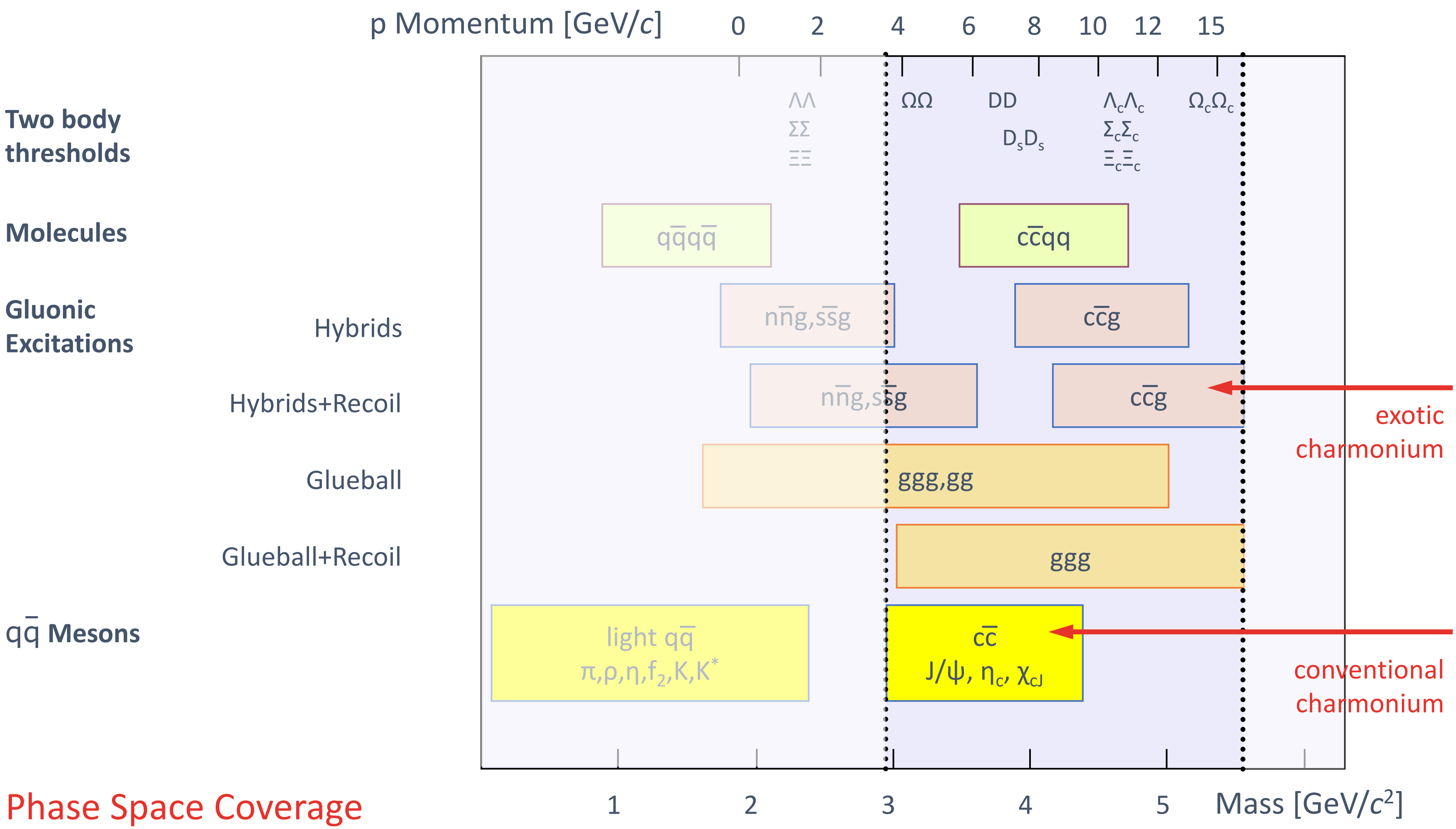
Resonance scan

energy resolution ~50 keV

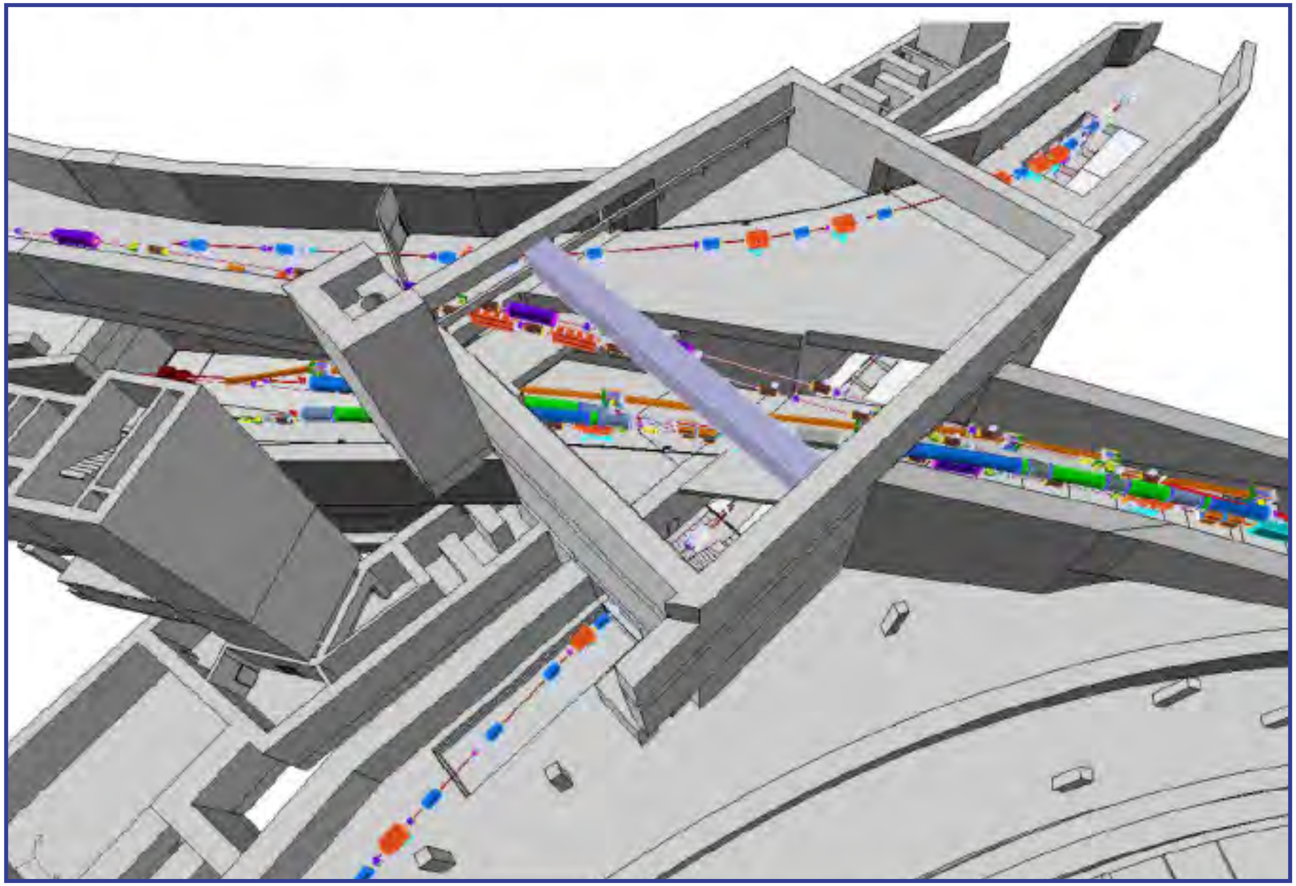
tune E_{CM} to probe resonance

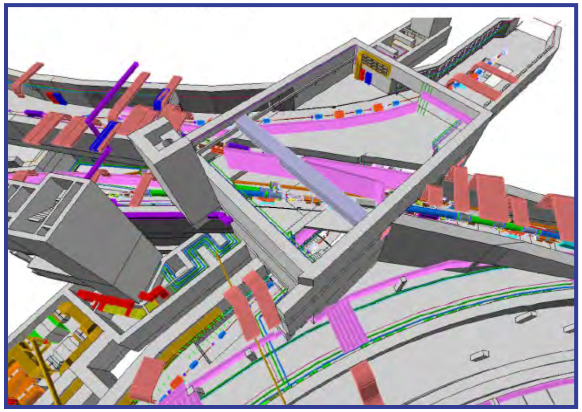
get precise mass and width

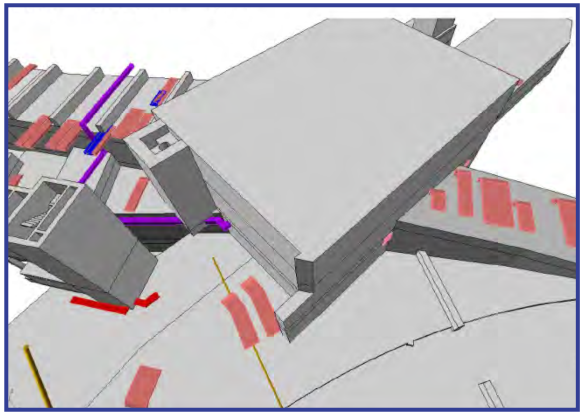
Accessible Hadrons at PANDA



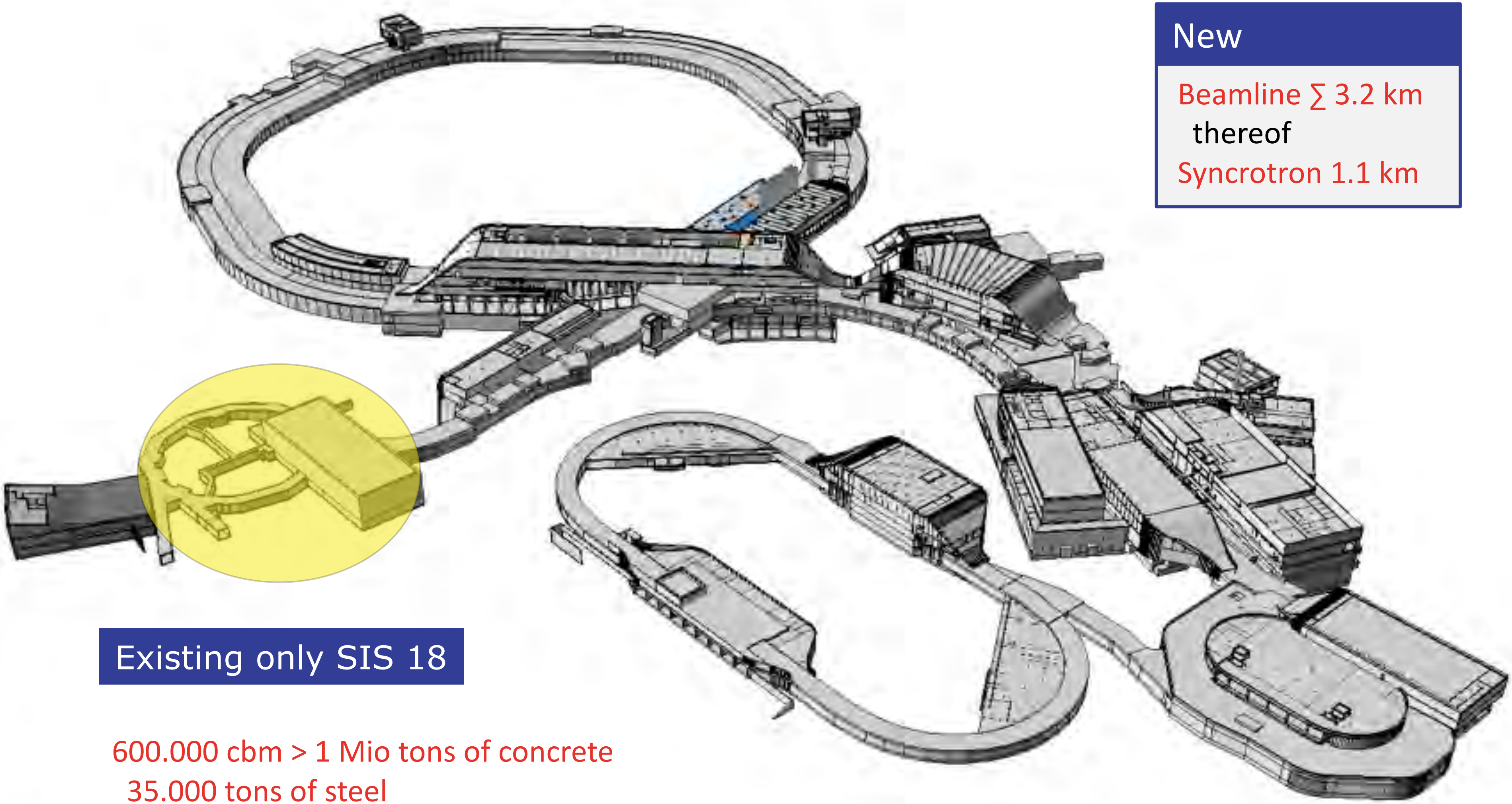
Planning Activities – almost finished







Civil Engineering



New

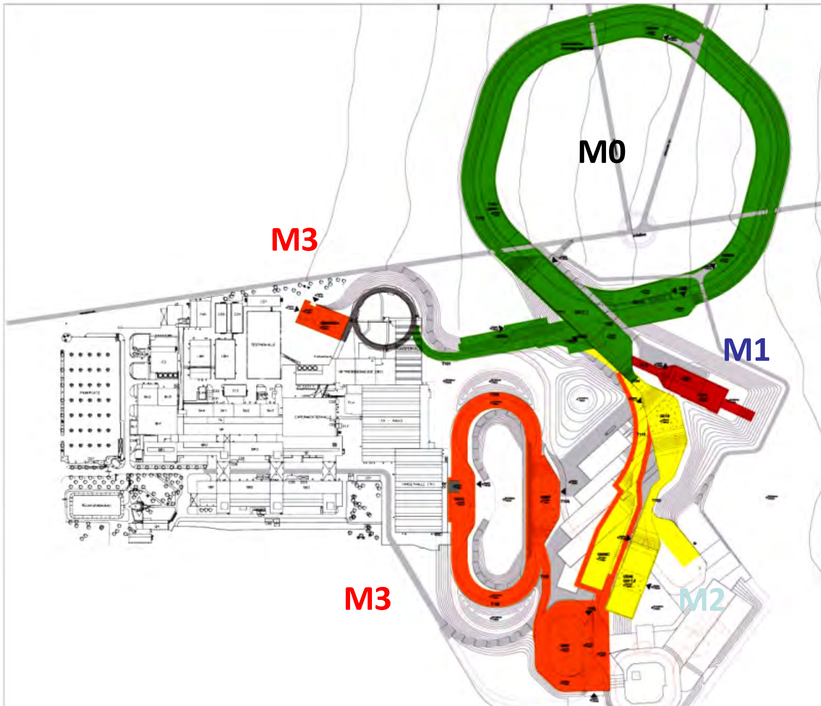
Beamline ∑ 3.2 km
thereof
Syncrotron 1.1 km

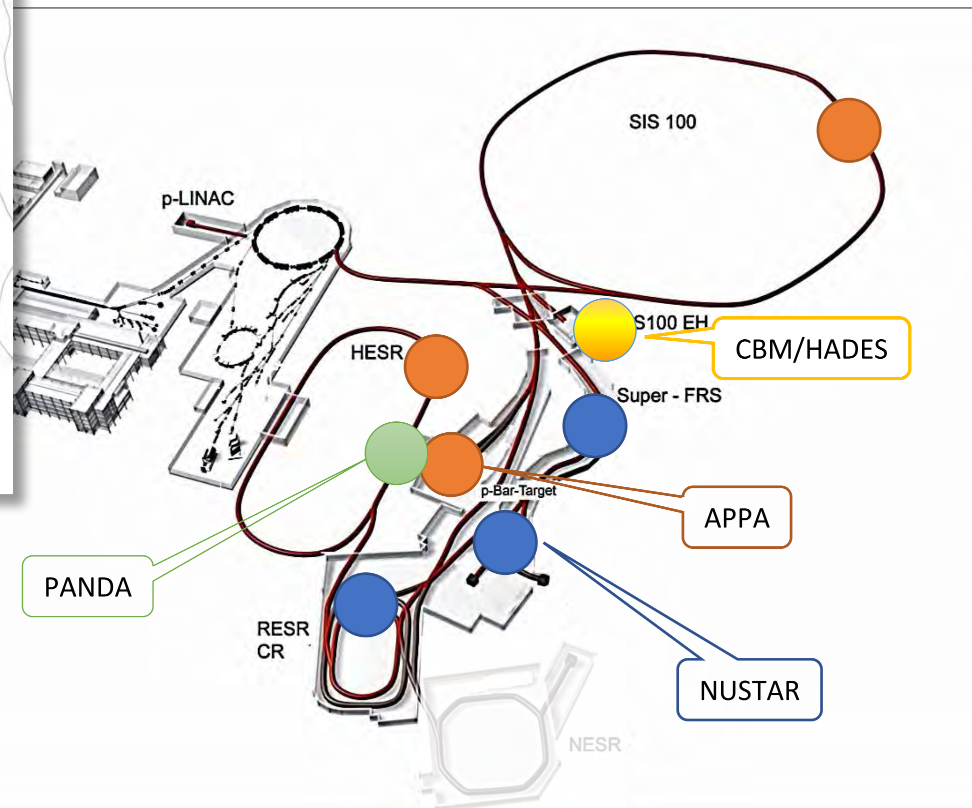
Existing only SIS 18

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

Modularized Start Version (MSV)

Cost about 1.6 billion by 2018
(1 billion 2005 Euros)

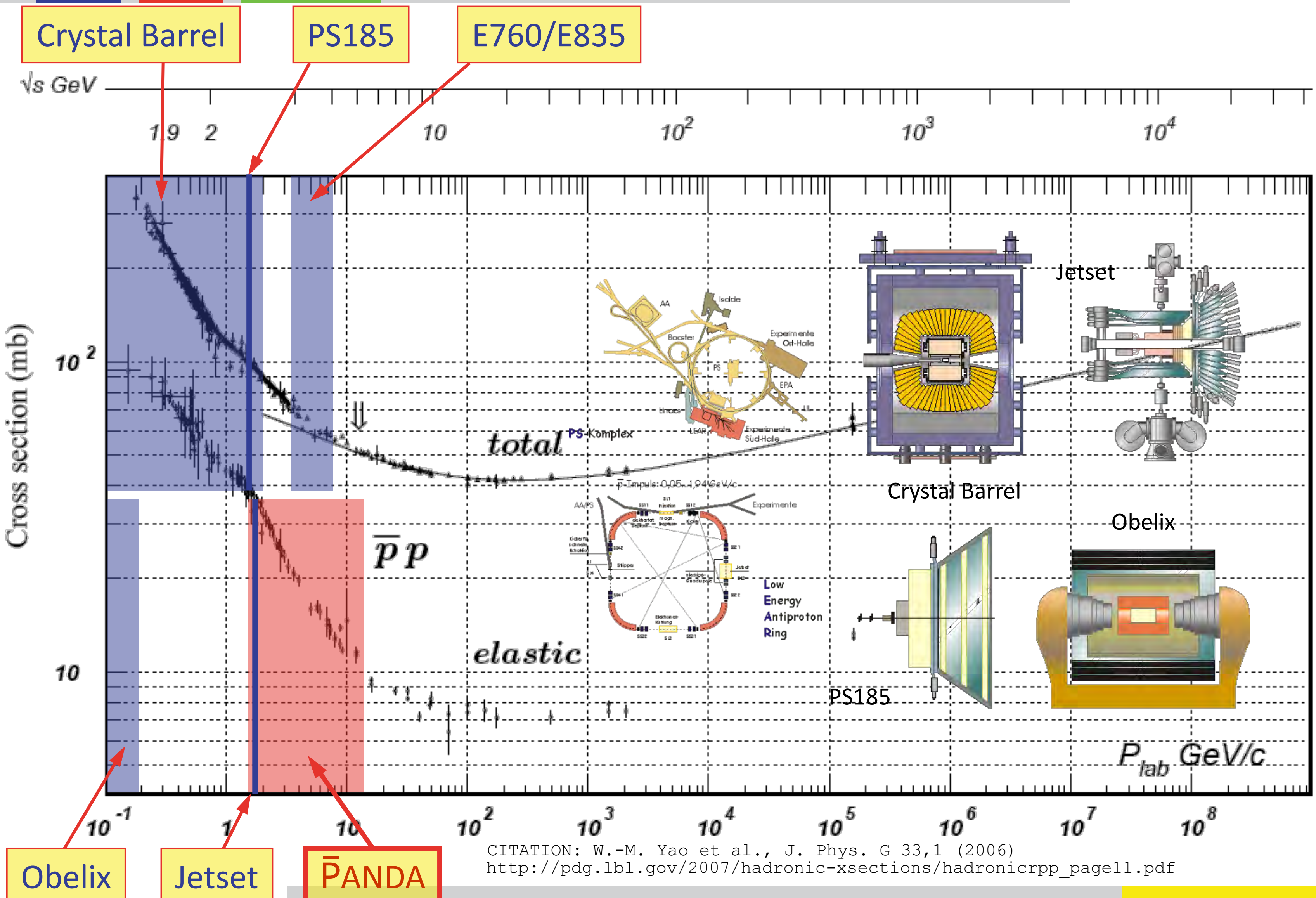




Modules
M0: SIS100
M1: APPA
M1: CBM/HADES
M2: NUSTAR
M3: PANDA, NuSTAR, APPA

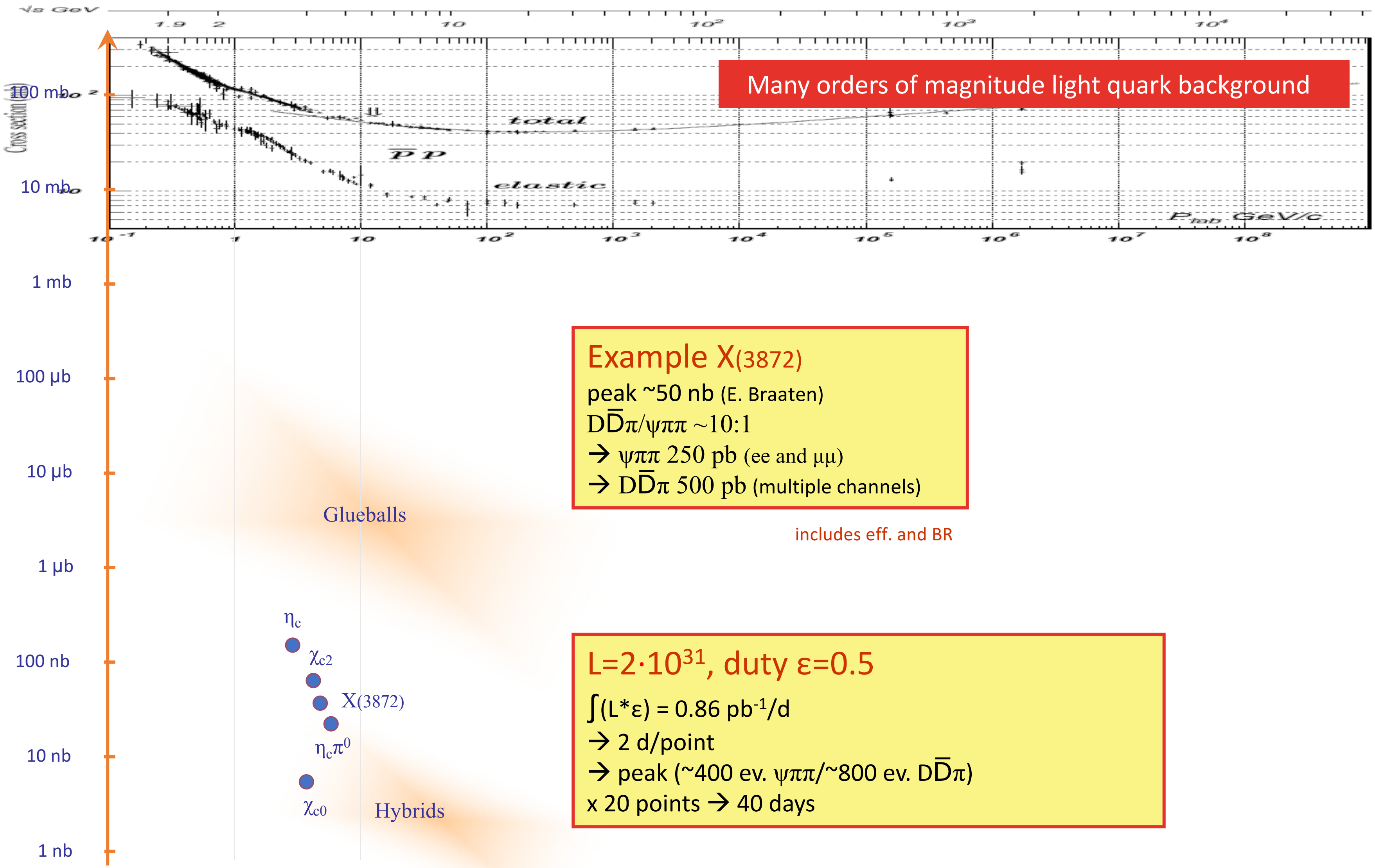
Construction Site (almost today)

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

$\bar{p}p$ 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 ε=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

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

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

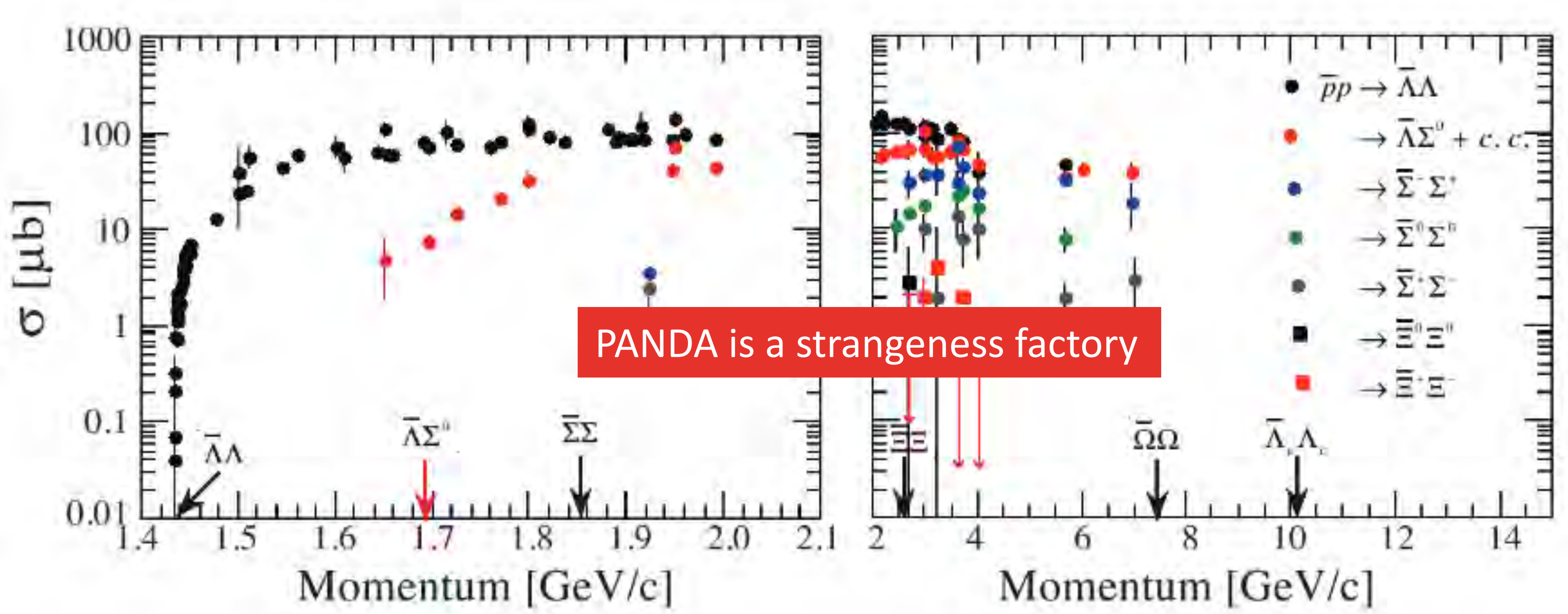
Strange baryons:
Spectroscopy
Polarization

Nuclear Physics

Hypernuclear physics:
Double Λ hypernuclei
Hyperon interaction

Hadrons in nuclei:
Charm and strangeness in the medium

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}

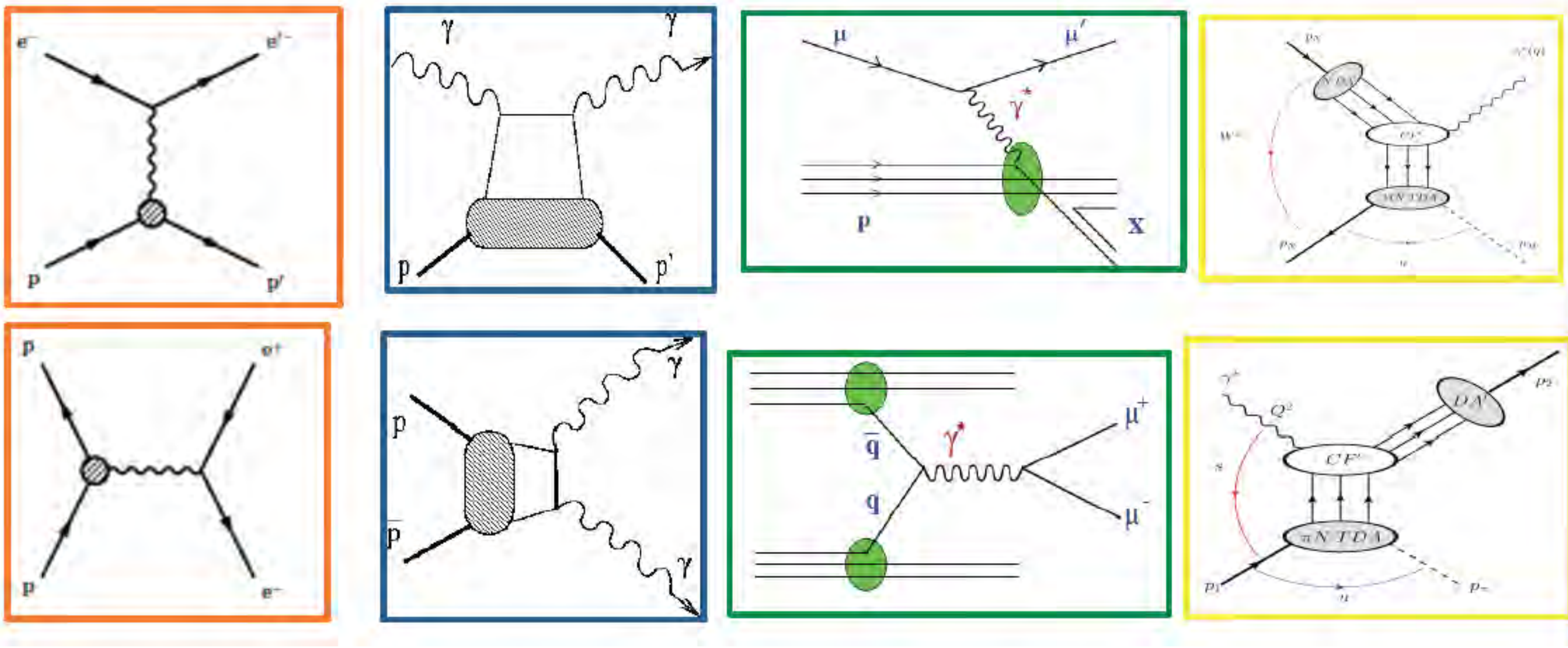
Gain a factor of 100 with inclusive measurement

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.

Nucleon Electromagnetic Final States

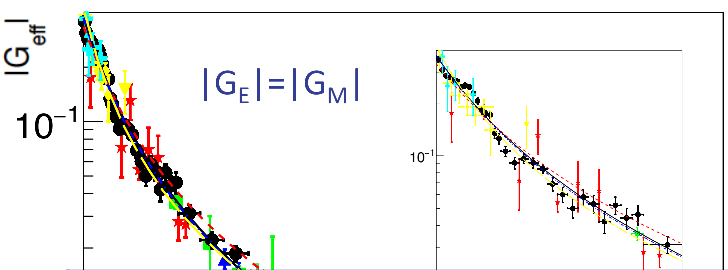
Background Suppression ~ 10^{-8}



Time-Like proton electromagnetic FFs

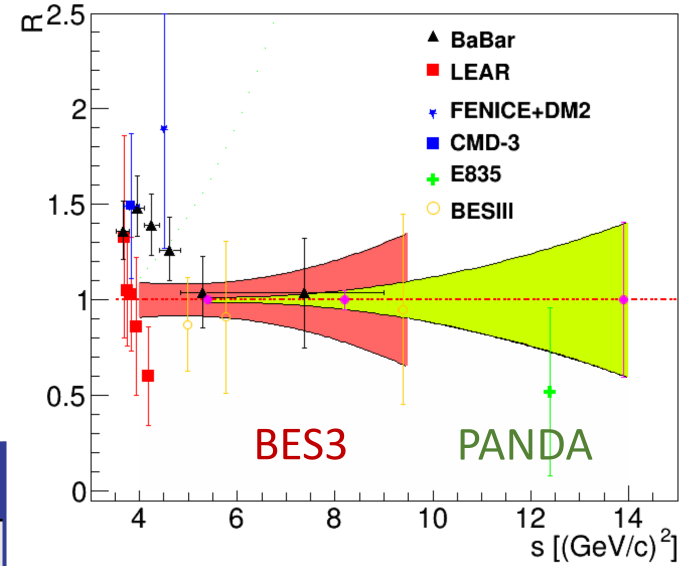
The effective FF can be measured
up to q^2 ~30 GeV^2
but no individual determination of G_E and G_M so far

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}

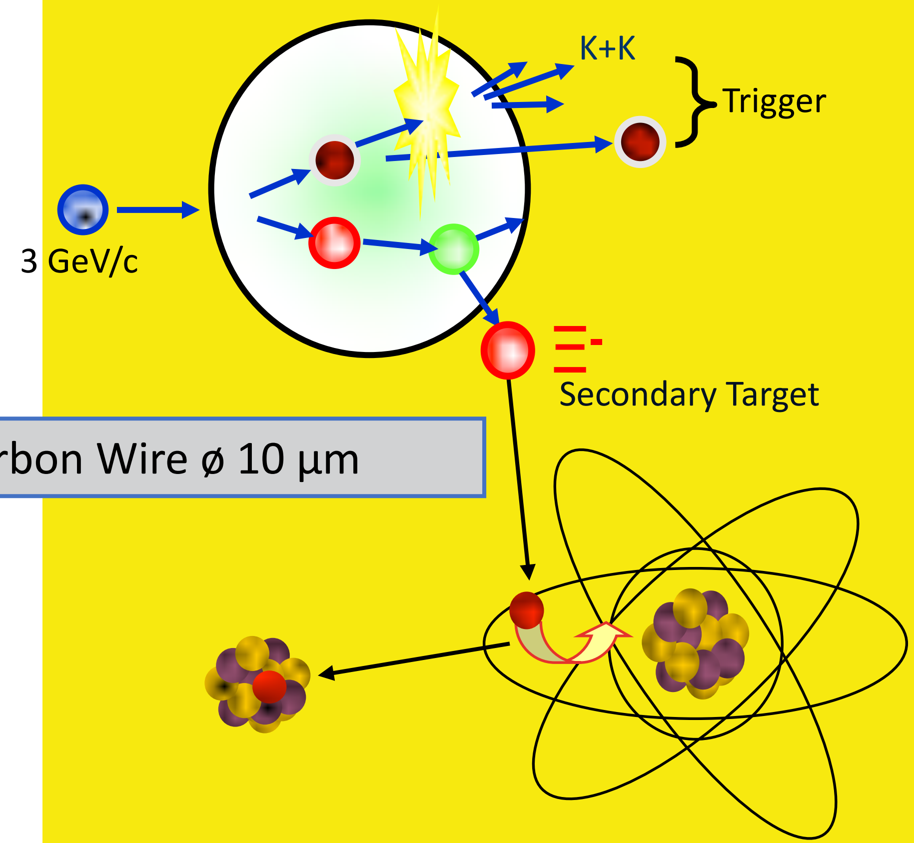
Eur.Phys.J. A52 (2016) no.10, 325



with transverse polarized target

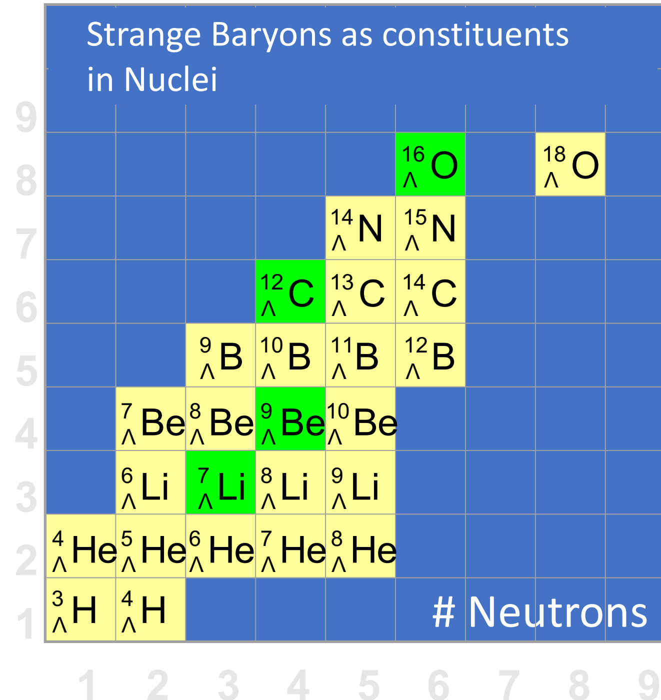
$$\left(\frac{d\sigma}{d\Omega}\right)_0 A_{1,y} \propto \sin 2\Theta \, \mathrm{Im}\left(G_M G_E^*\right)$$

Hypernuclear Physics @ PANDA



Ξ^-(dss)p(uud) → Λ(uds)Λ(uds)

Minimum 8 months full running



Limiting factor

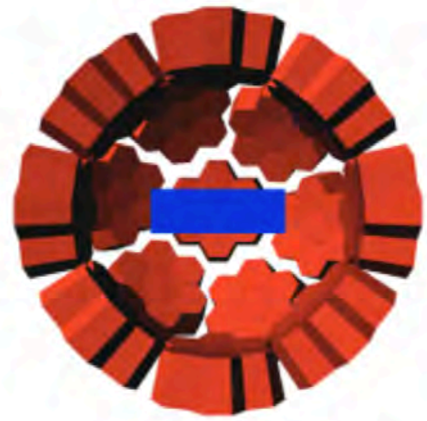
charged particle load on central detector (0.6-1.0)$\cdot 10^7$

L=(3-5)$\cdot 10^{30}$ $cm^{-2}s^{-1}$

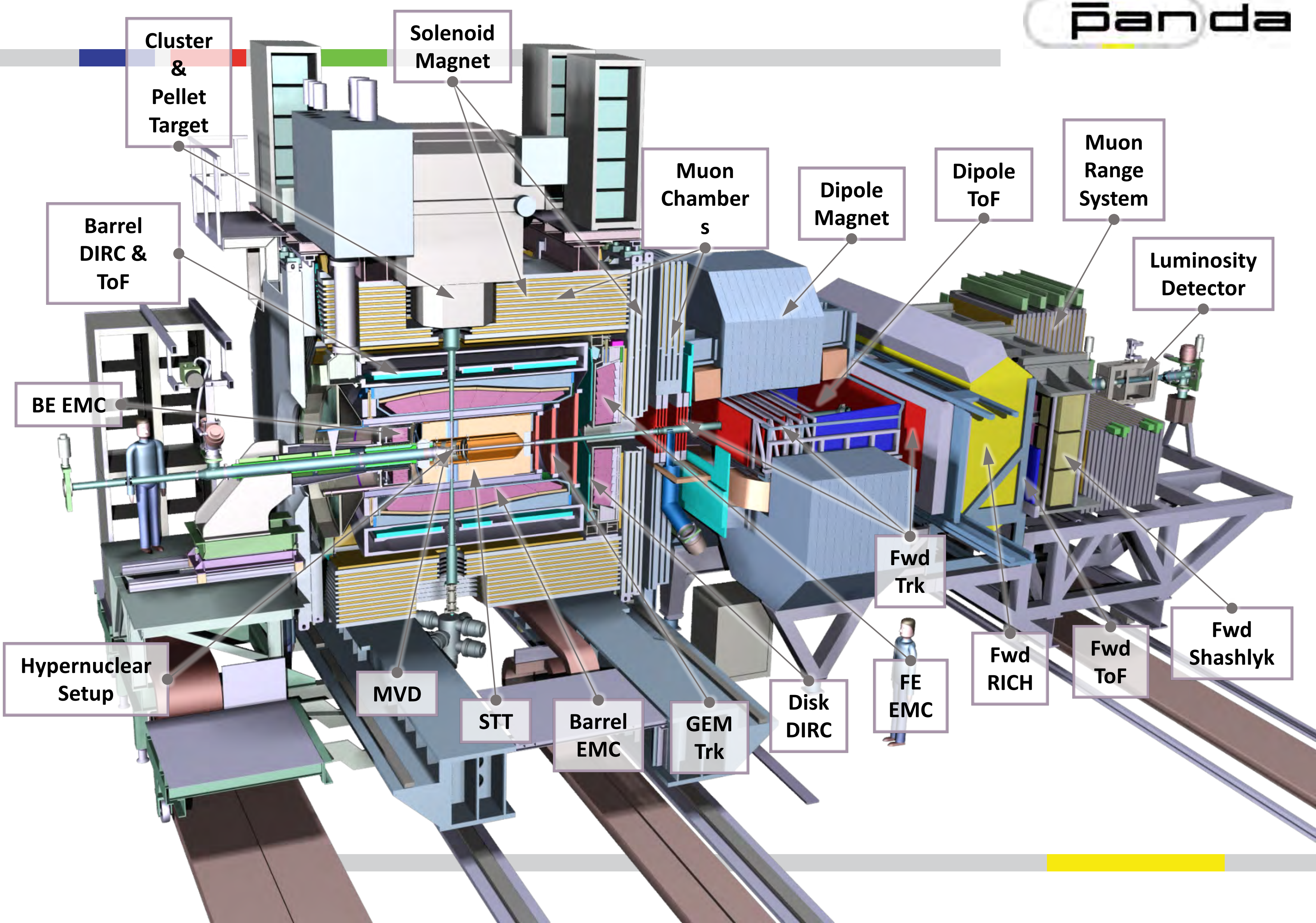
$\bar{p}$ re-storage < $6\cdot 10^6$

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



Cluster & Pellet Target
Solenoid Magnet
Muon Chamber s
Dipole Magnet
Dipole ToF
Muon Range System
Luminosity Detector
Barrel DIRC & ToF
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

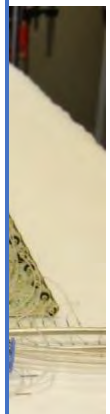
4600 straws in 21-27 layers,
of which 8 layers skewed at ~3°
Tube made of 27 μm thin Al-mylar, ø=1cm
R_{in}= 150 mm, R_{out}= 420 mm, l=1500 mm
Self-supporting straw double layers at ~1 bar overpressure (Ar/CO_2)
Readout with ASIC+TDC or FADC

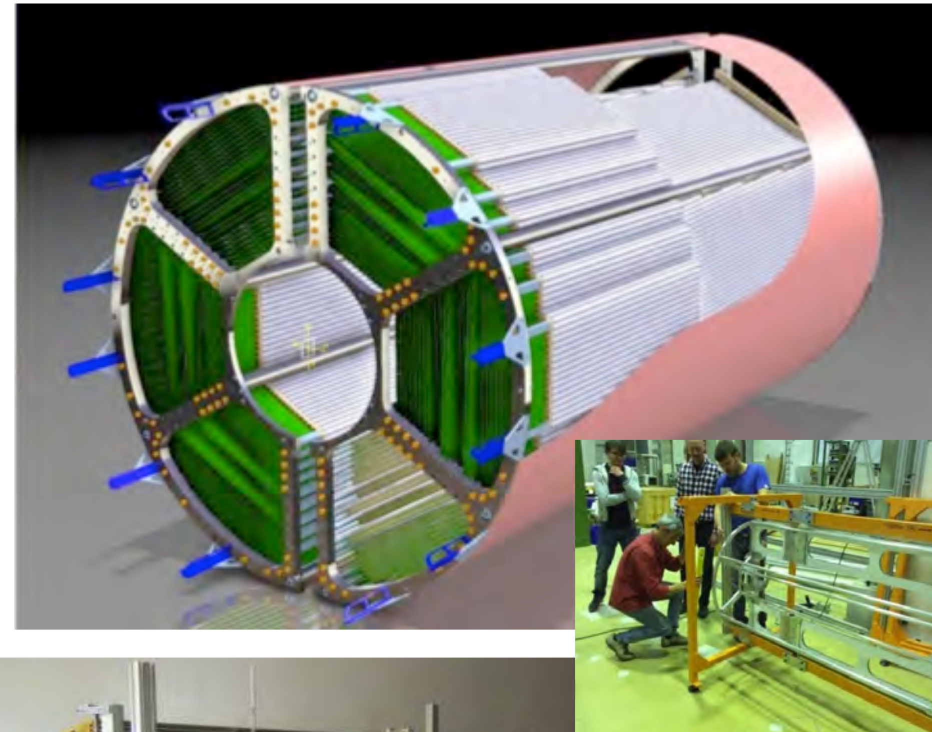
Material Budget

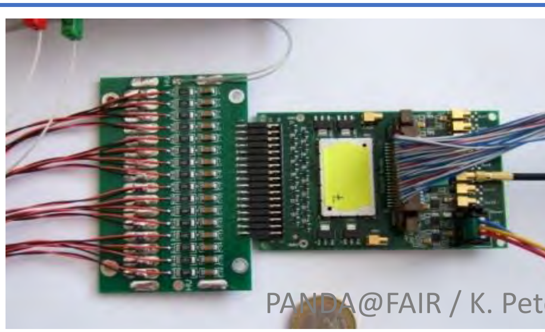
Max. 26 layers,
0.05 % X/X_0 per layer
Total 1.3% X/X_0

Project Status

3000 Straws produced
Readout prototypes and beam tests
Ageing tests: up to 1.2 C/cm²







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 %

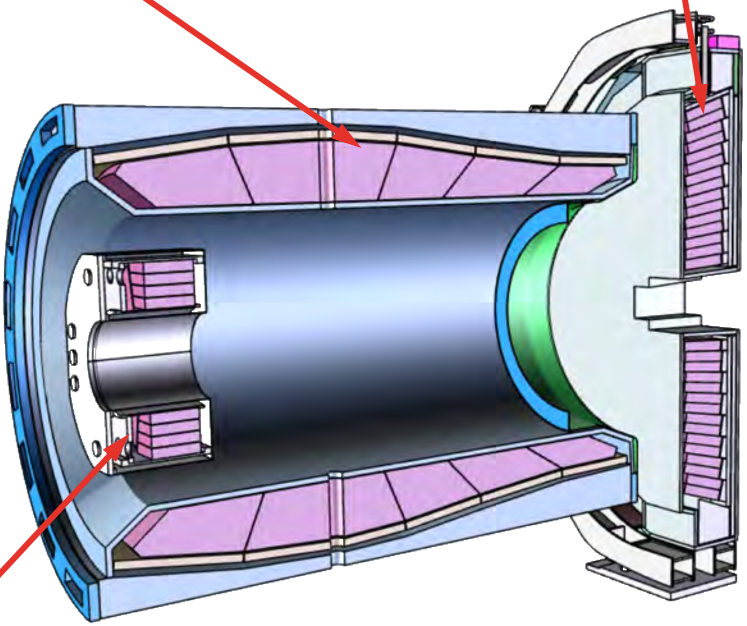
Large Area APDs

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

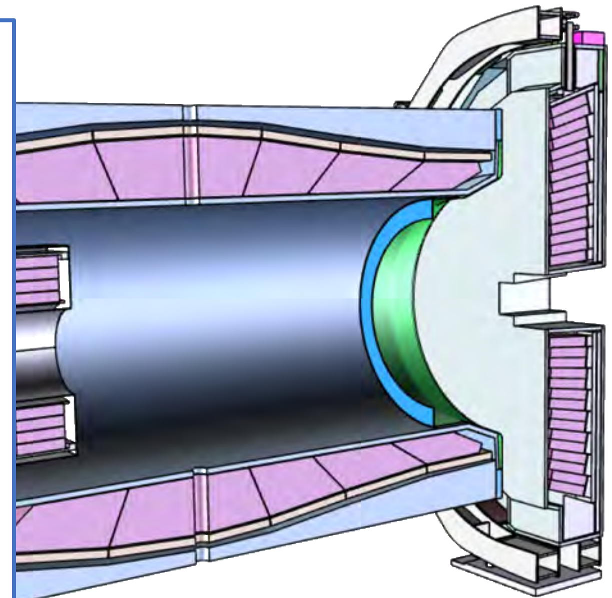
Assembly

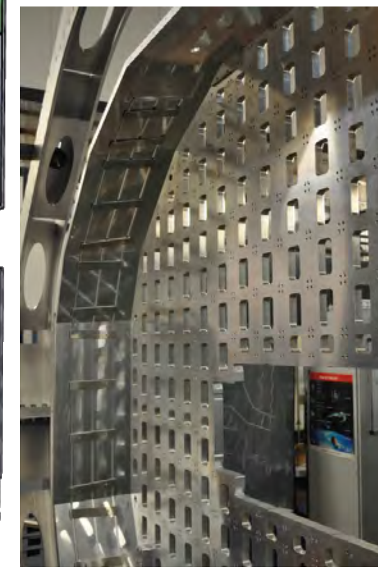
Forward-EMC full completion ‘til 2018

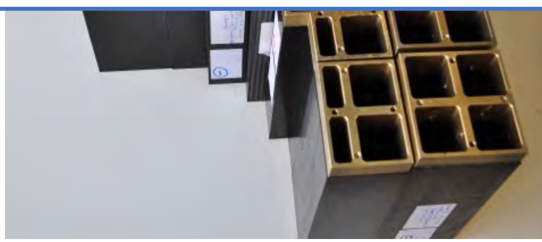
Backward-EMC prototype-tests successful

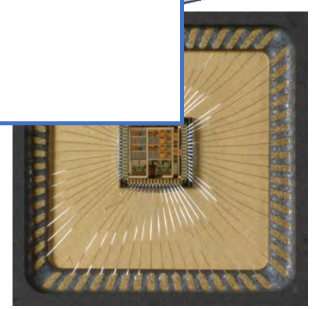
Barrel-EMC: alveoles produced

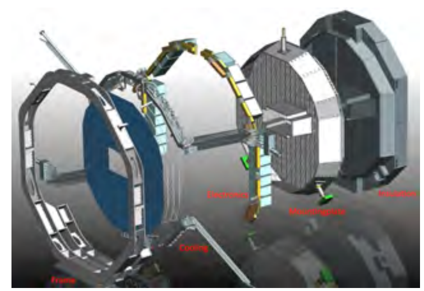
1st slice in construction

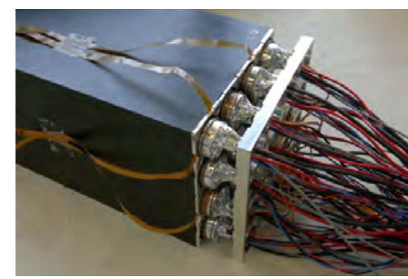


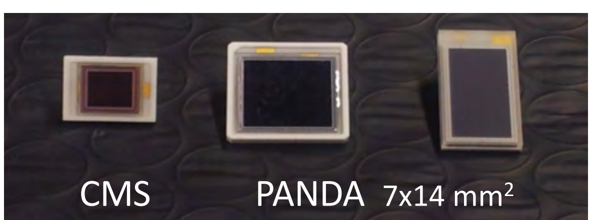


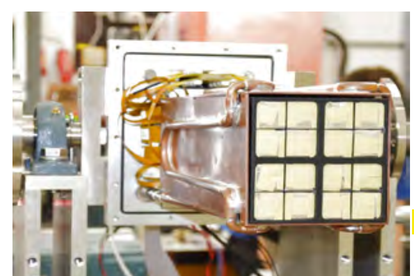




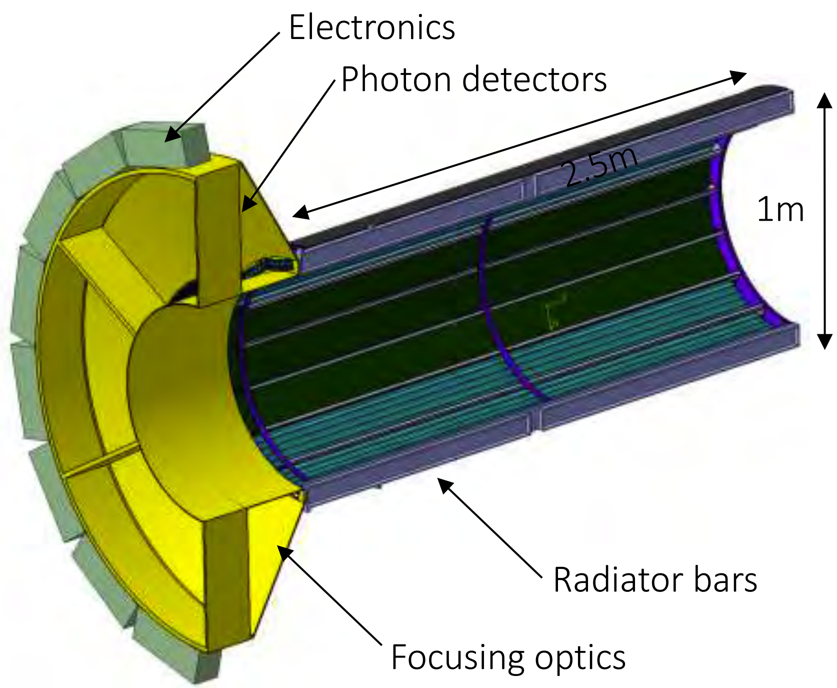








Barrel DIRC



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

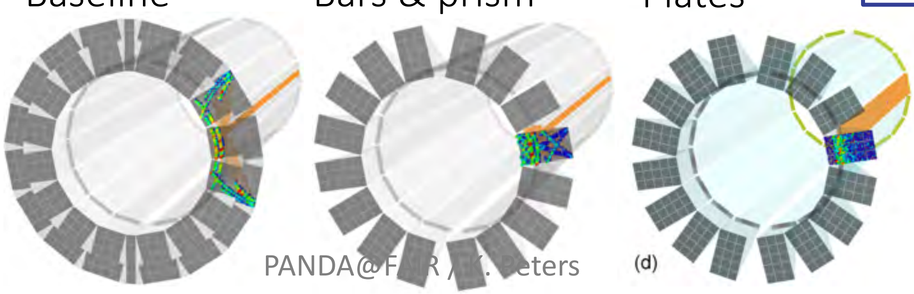
Plates as more economic radiator

Project status

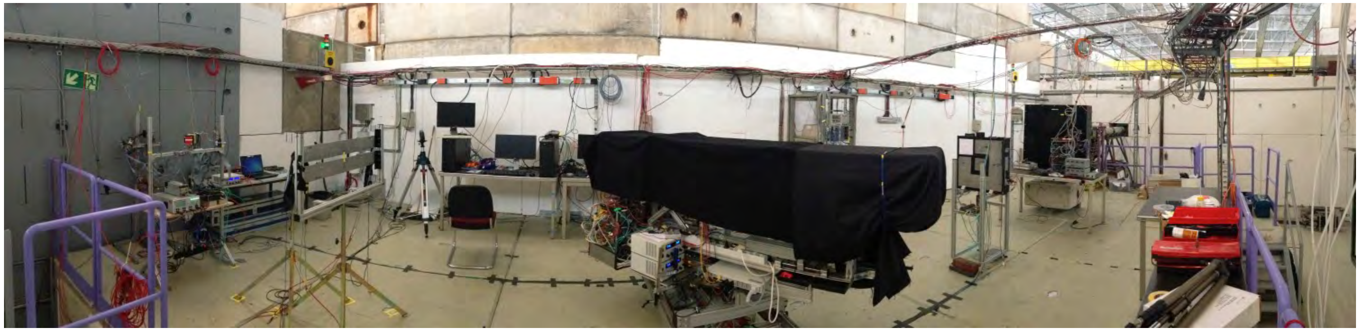
Baseline and Plate design verified

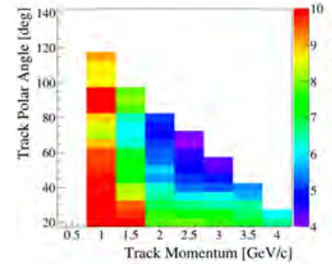
Awaiting approval of TDR

Baseline Bars & prism Plates



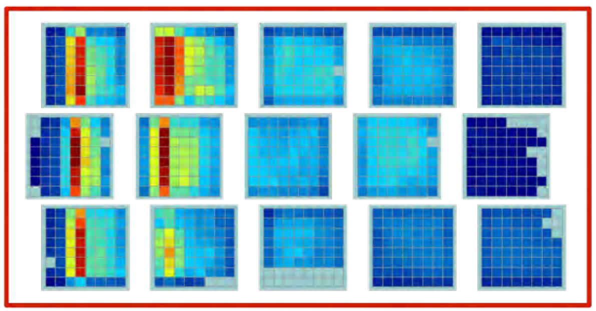
Barrel DIRC (beam tests)





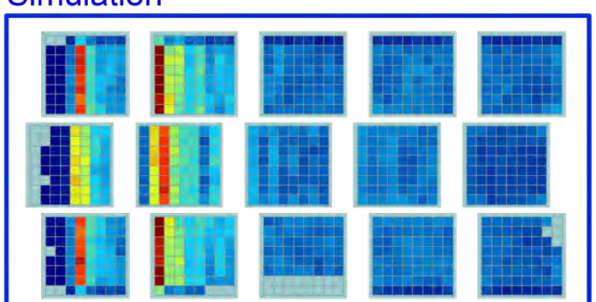
Simulated separation of π/p at test-beam

Data



cylindrical lens

Simulation



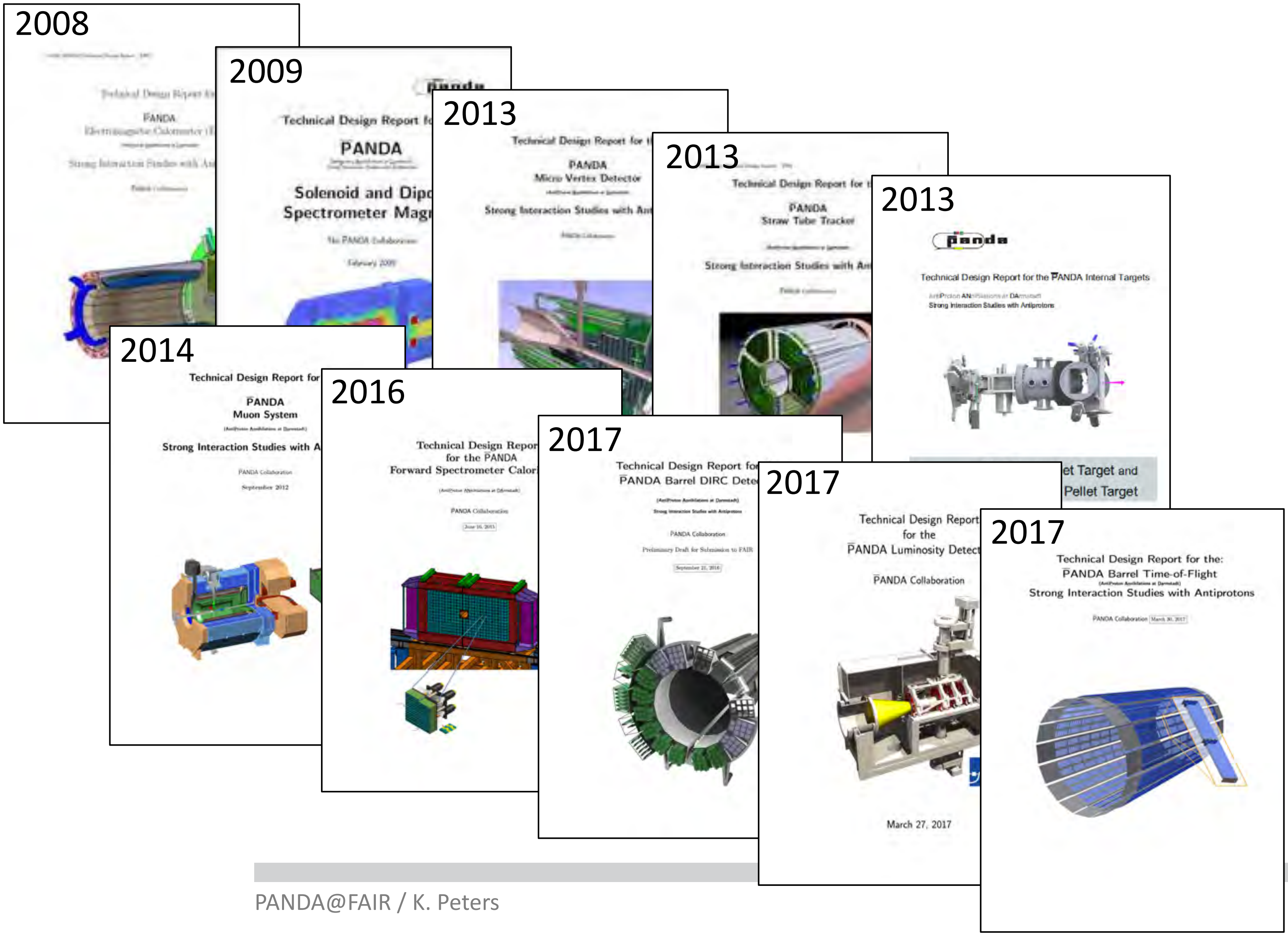
Test beam campaign at CERN T9

- 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

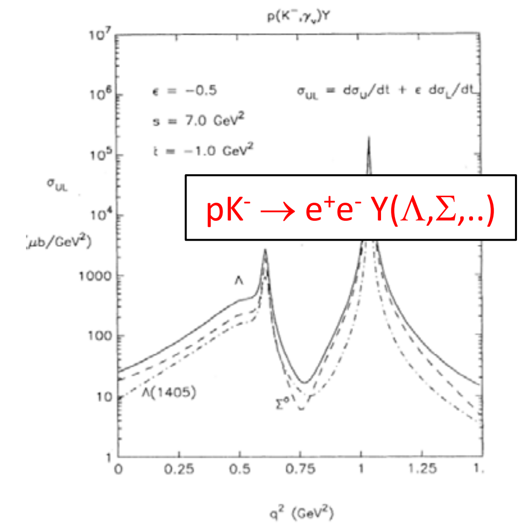
Phase 3
Experiments beyond MSV (needs RESR)

Phase 0: Experiments together with HADES

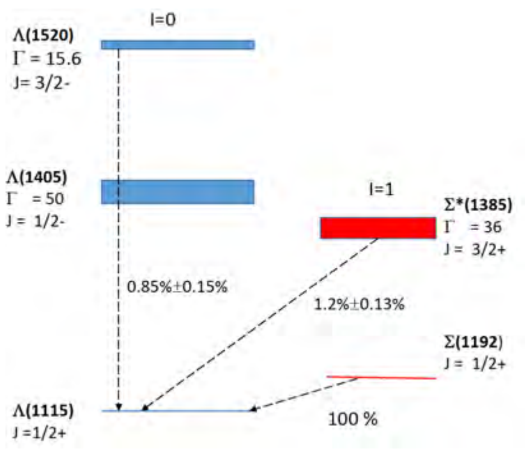
Goal: Hyperon structure, extend our understanding of the nucleon
How: Hyperon Dalitz decay Transition FF

well connected to the PANDA physics program

Role of ρ-baryon coupling (VMD?)



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



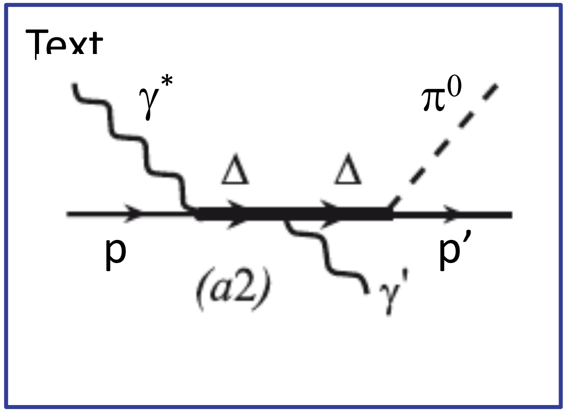
- Only few measurements of radiative decays:
  e.g. $\Sigma^{0(*)} \to \Lambda\gamma$ $\Lambda(1520) \to \Lambda\gamma$
- $Y \to \Lambda e^+e^-$ never measured !
- Proposed reaction:
  $pp(A) \to Y\ (any)\ X \to \Lambda e^+e^-\ X$

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

Phase 0: Backward EMC @ MAMI

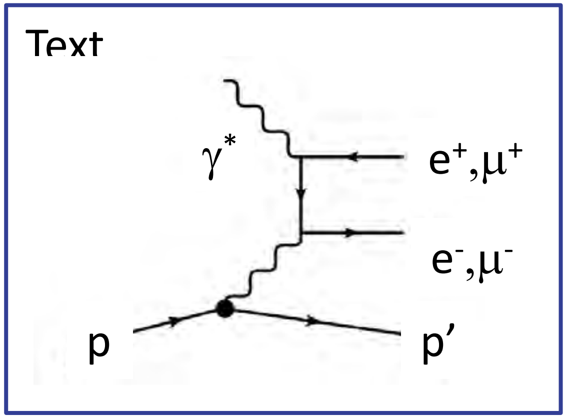
Magnetic Moment of the Δ(1232) by

- $e\,p \rightarrow e\,p\,\pi^0\gamma$
- Additional calorimeter for π^0 and γ detection
- Virtual photon flux higher in e-production
- S_{11}-Resonance



Electron-Muon-Universality (Proton Radius Puzzle)

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



Multi-π^0-Production

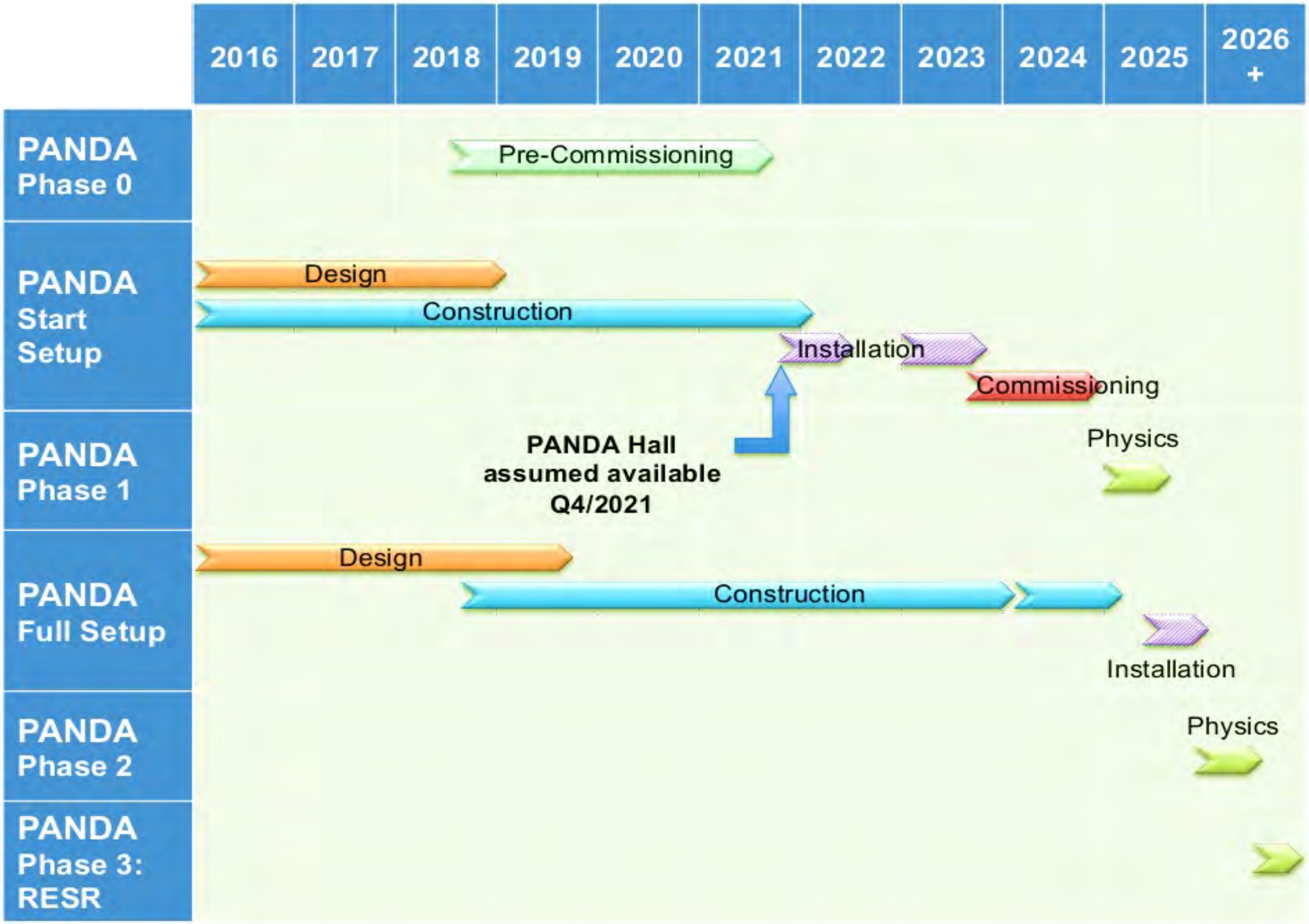
- $e\,p \rightarrow e\,p\,\pi^0\pi^0$ etc.
- Unknown transition amplitudes, calibration and commissioning of calorimeter

Phase-0: Preparation for Data Analysis

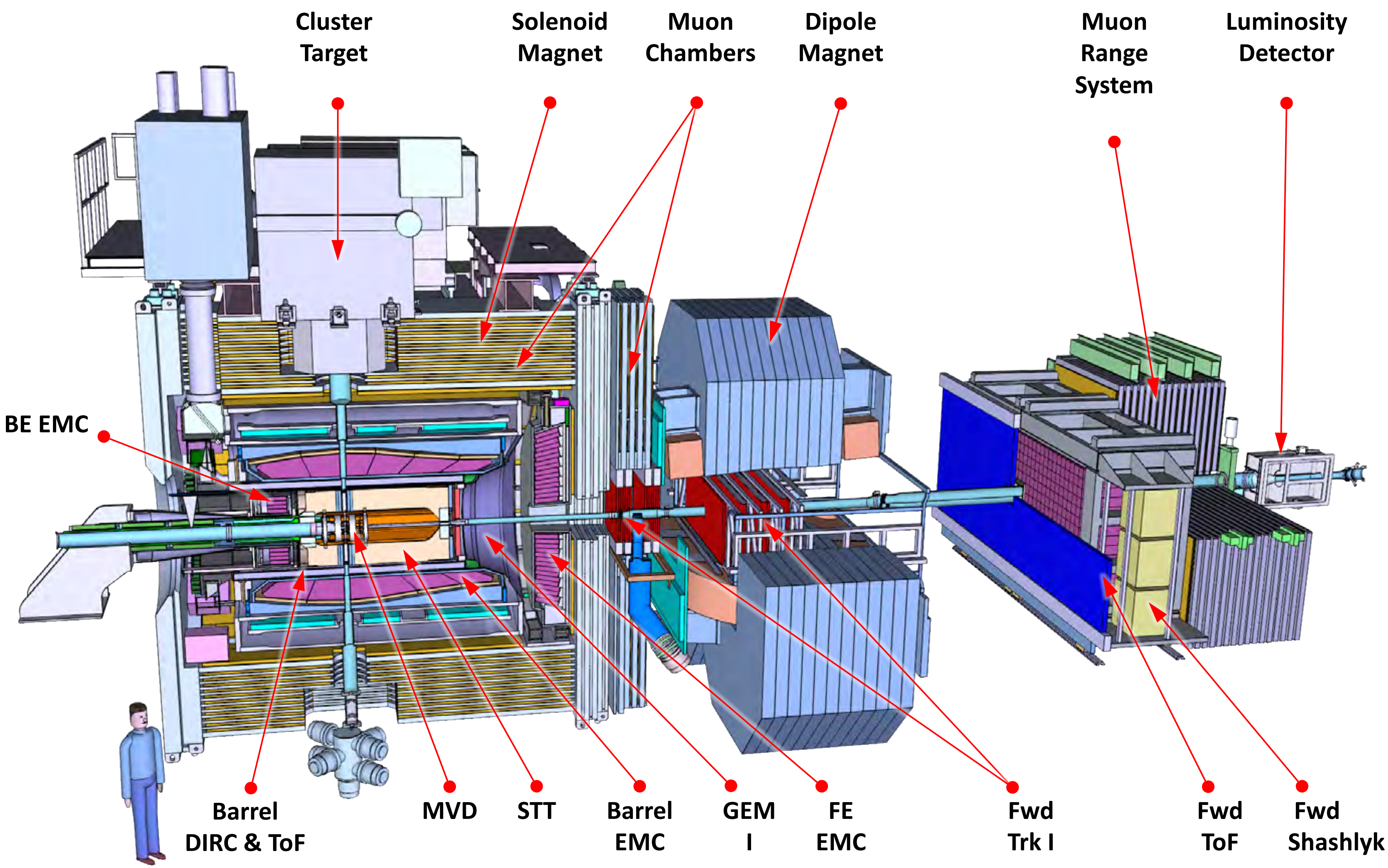
Mandate from our Science Council: prepare for the future !

- R&D / Q&A of analysis software → fast start asa data is available
- We have already two software packages
  - PAWIAN – quite feature loaded – monolithic but partly expandable, ready to use for many cases
  - ComPWA – new bottom-up development after a design requirements process – module based and fully open by design, but only a few cases implemented (*from Nov 11- Sep 12 → 12 page Document*)
- Goal: further developments and perform 2018/19 a data challenge → double blind feasibility study for various light quark channels
  - create blinded data with one package and one group and analyze it with a different software from a different group
  - this will help us debugging the software and adding important features for the ease of the process

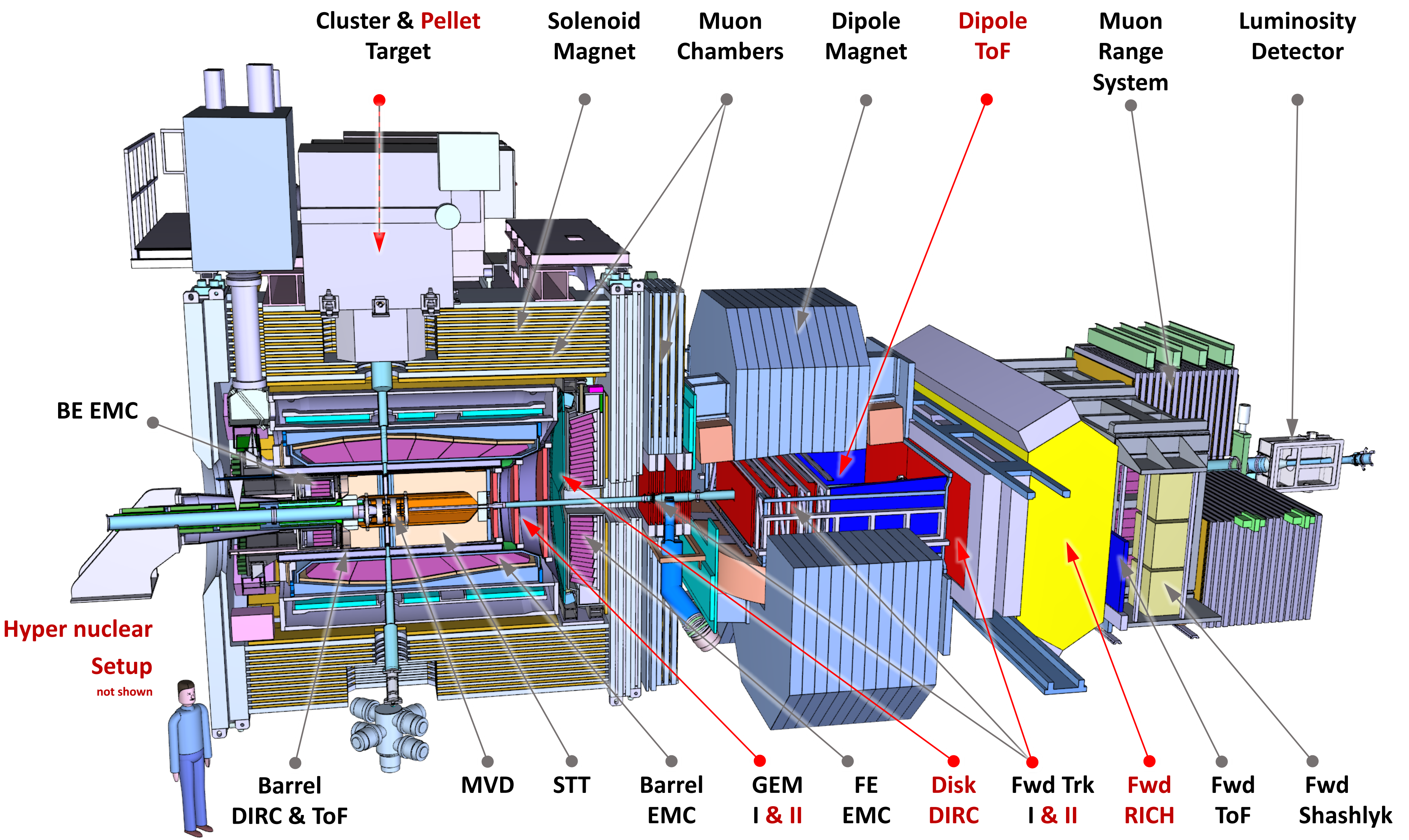
PANDA Schedule



Start-Setup (Phase-1)



Full Setup (Phase-2)



PANDA Collaboration

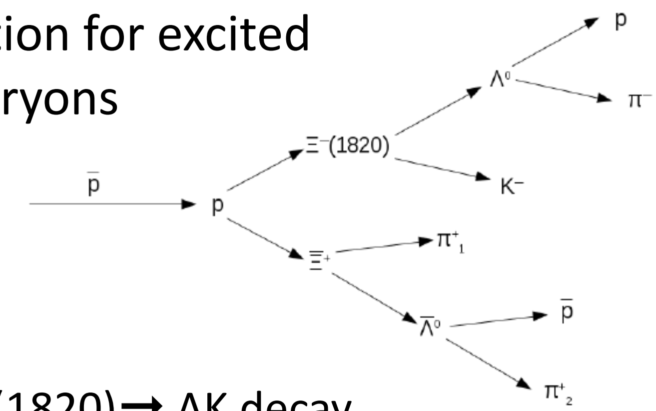
Aligarh Muslim U
U Basel
IHEP Beijing
U Bochum
Magadh U, Bodh Gaya
BARC Mumbai
IIT Bombay
U Bonn
IFIN-HH Bucharest
U & INFN Brescia
U & INFN Catania
NIT, Chandigarh
AGH UST Cracow
JU Cracow
U Cracow
IFJ PAN Cracow
FAIR
GSI Darmstadt
Karnatak U, Dharwad
TU Dresden
JINR Dubna
U Edinburgh
U Erlangen
NWU Evanston
U & INFN Ferrara
FIAS Frankfurt
LNF-INFN Frascati
U & INFN Genova
U Glasgow
U Gießen
Birla IT&S, Goa
KVI Groningen
Sadar Patel U, Gujart
Gauhati U, Guwahati
IIT Guwahati
Jülich CHP
Saha INP, Kolkata
U Katowice
IMP Lanzhou
INFN Legnaro
U Lund
HI Mainz
U Mainz
U Minsk
ITEP Moscow
MPEI Moscow
U Münster
BINP Novosibirsk
Novosibirsk State U
IPN Orsay
U & INFN Pavia
Charles U, Prague
Czech TU, Prague
IHEP Protvino
PNPI St. Petersburg
U of Sidney
U of Silesia, Catowice
U Stockholm
KTH Stockholm
Suranree University
South Gujarat U, Surat
U & INFN Torino
Politecnico di Torino
U & INFN Trieste
U Tübingen
U Uppsala
U Valencia
SMI Vienna
SINS Warsaw
TU Warsaw

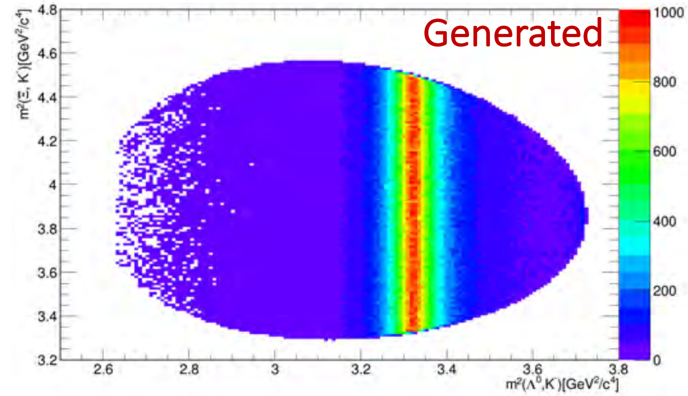
more than 450 physicists from
more than 60 institutions in 19 countries

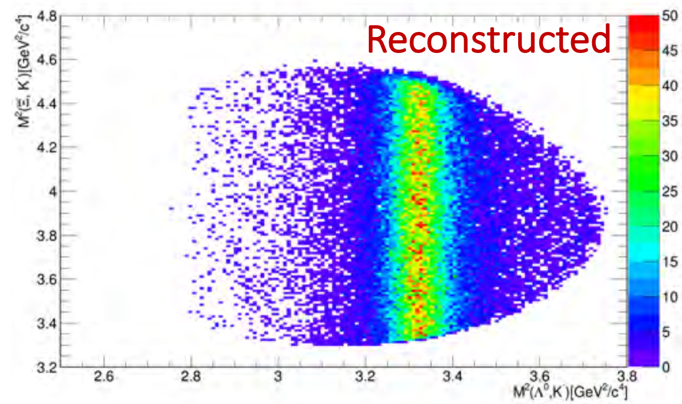
Thank you

Ξ(1820)

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







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

- Consider the $\Xi^{*-}(1820) \rightarrow \Lambda K$ decay,
  - assume BR = 100% and σ = 1 μb
- Simplified MC framework
- Day-1 luminosity: $10^{31} cm^{-2} s^{-1}$

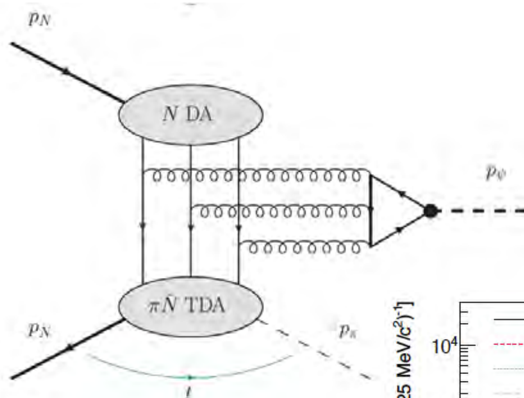
Results

- ~30 % inclusive efficiency for $\Xi^{*-}(1820)$
- ~5 % exclusive efficiency for $\bar{\Xi}^{+}\Xi^{*-}(1820)$
- Low background level ➞ ~15000 exclusive events / day

Transverse Momentum Dependent PDFs

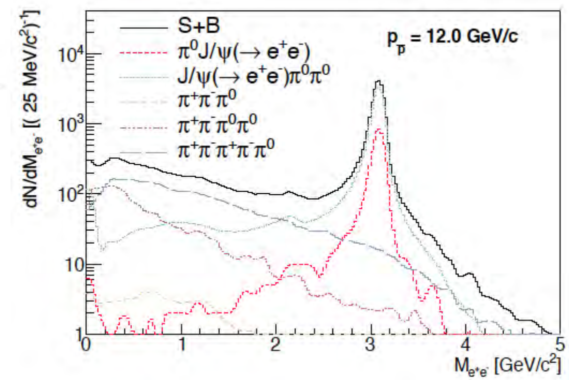
arXiv:1610.02149

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



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