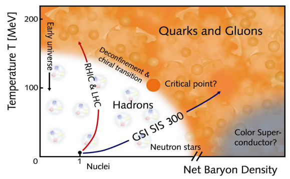
Status of FAIR and PANDA

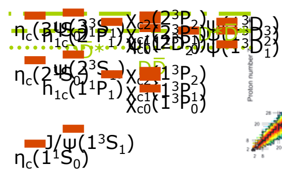
*Klaus Peters on behalf of **FAIR** and the **PANDA** Collaboration*
GSI Darmstadt and Goethe U Frankfurt
IHEP Beijing, April 26, 2013

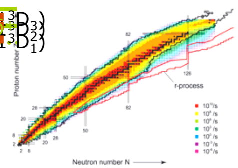
sub nuclear material research….

criteria of stability can be derived from extreme (exotic) structures

→ properties of the binding

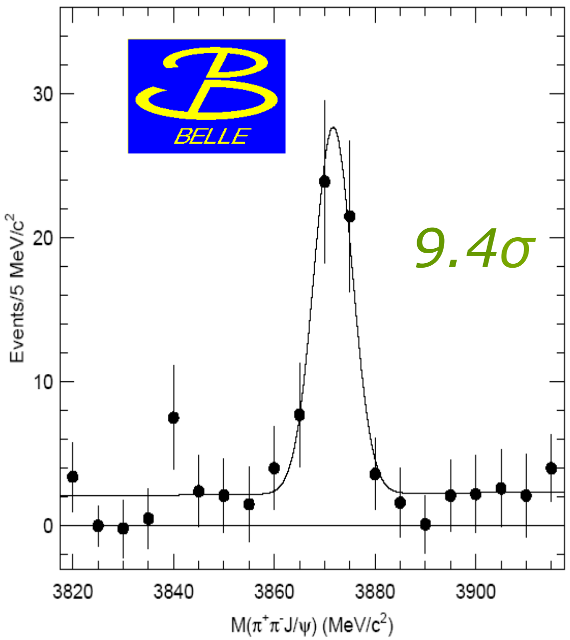






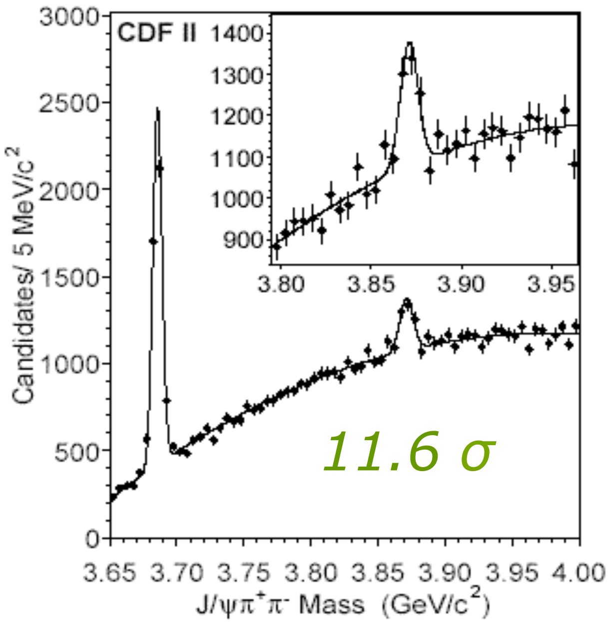
Discovery of the X(3872)

2003

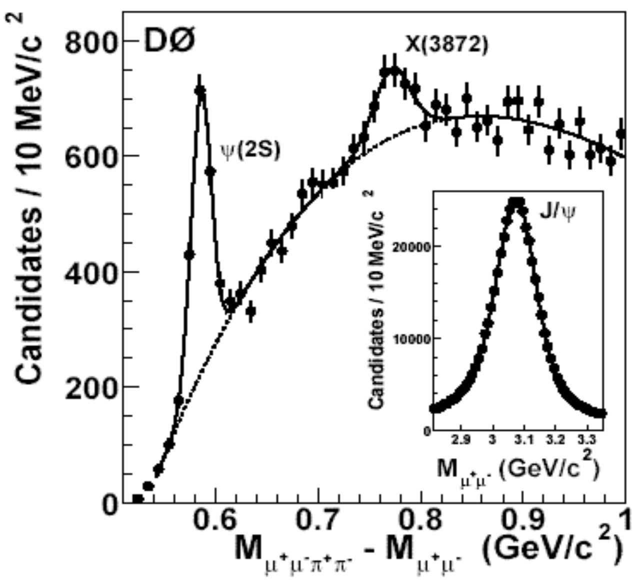


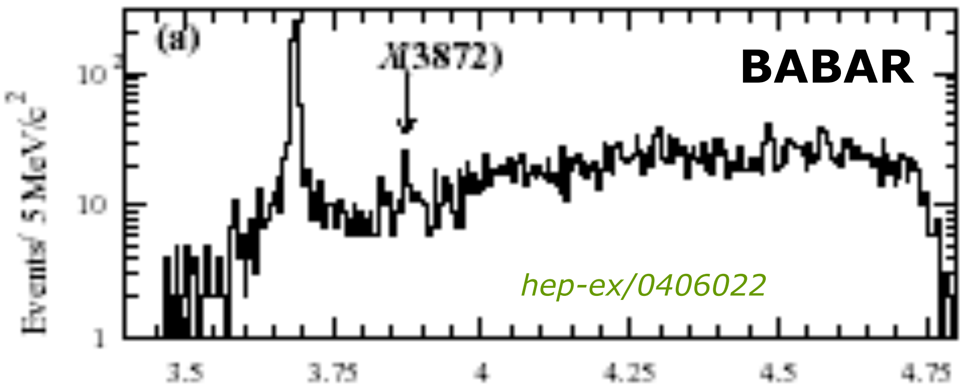
Phys. Rev. Lett. 91(2003)262001
152 Mill. BB

hep-ex/0312021



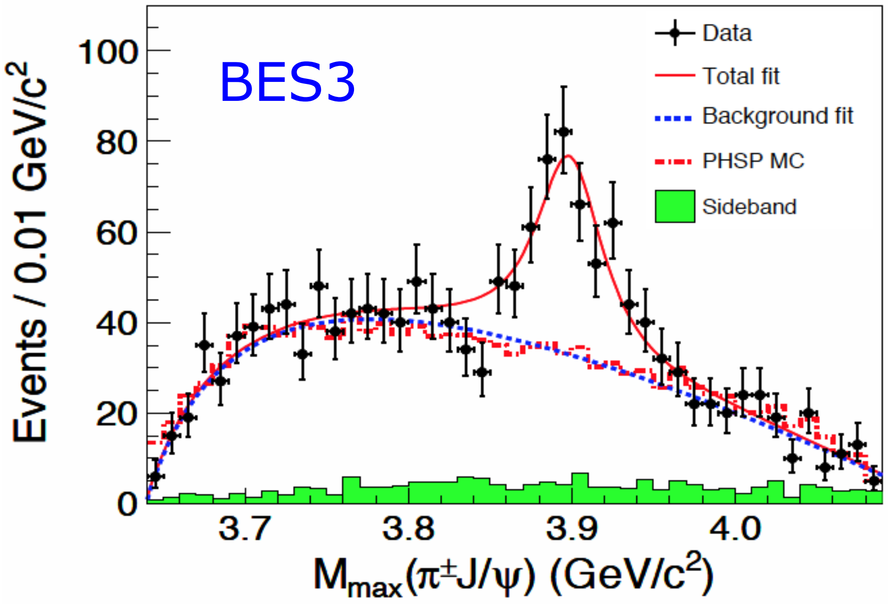
hep-ex/0405004

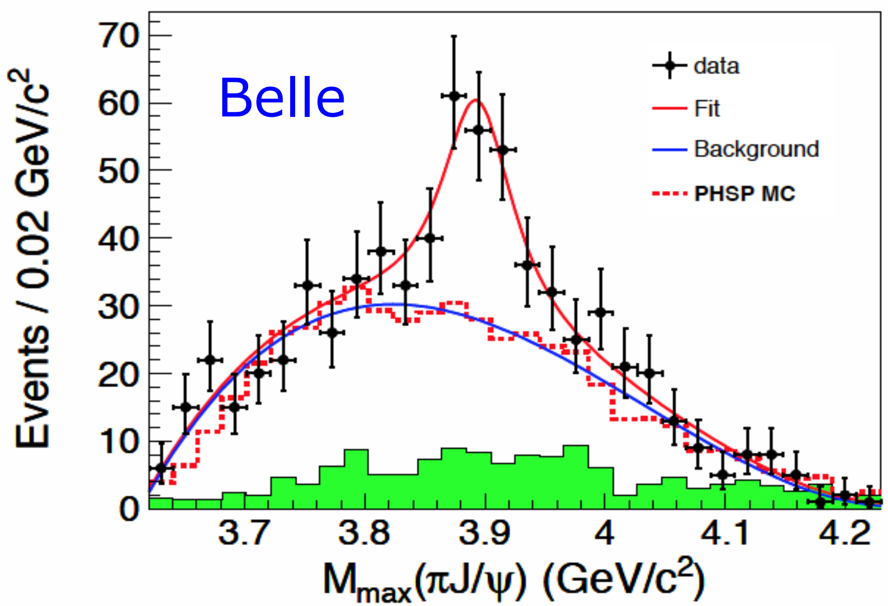


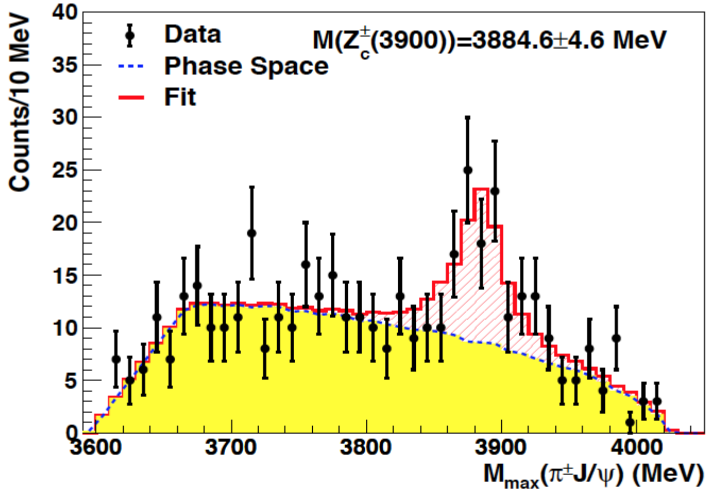


Discovery of the $Z^+(3900)$

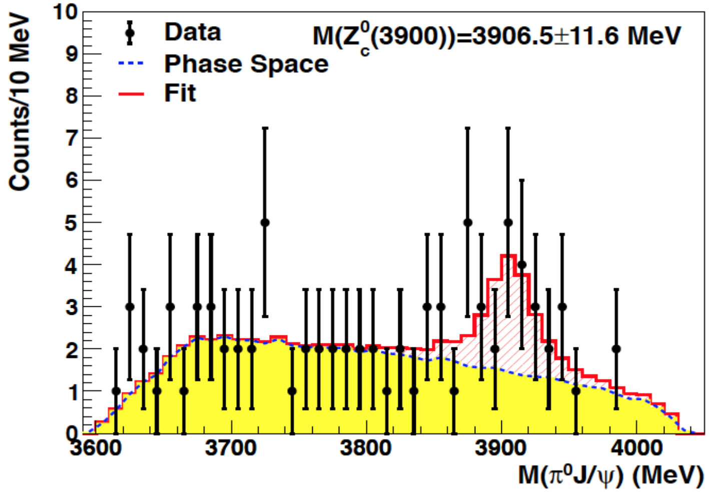
2013





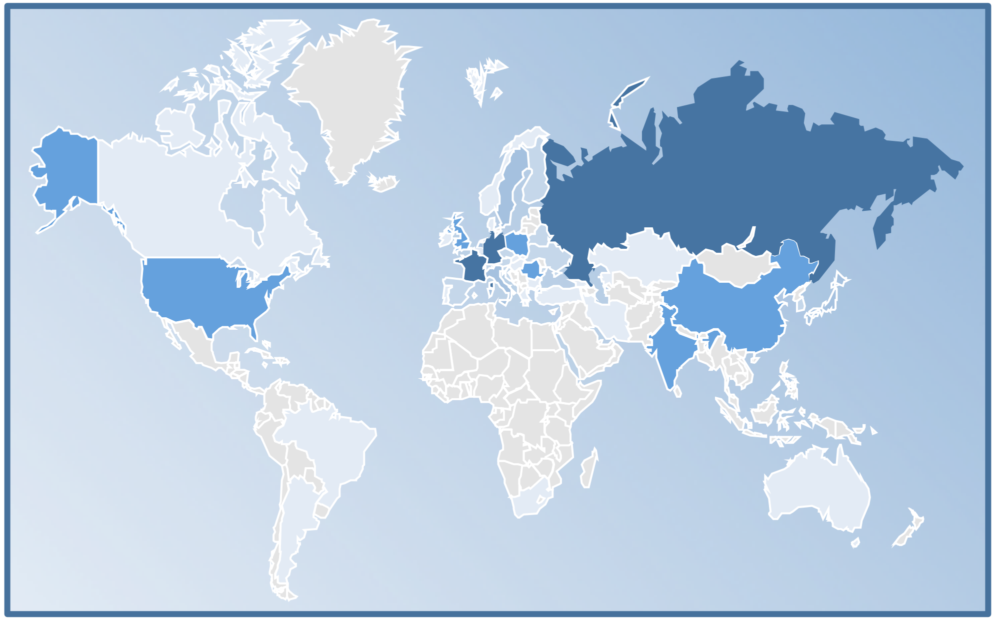


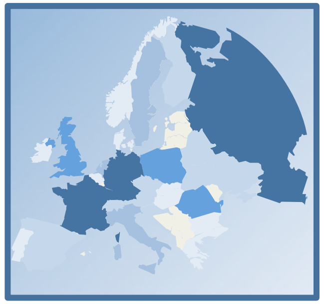
CLEO-c



4 Scientific Core Activities

more than 2’000 Scientists
hundreds of institutions





42 countries Worldwide
27 countries in Europe

FAIR @ Darmstadt

Nuclear Structure & Astrophysics
(Rare-isotope beams)

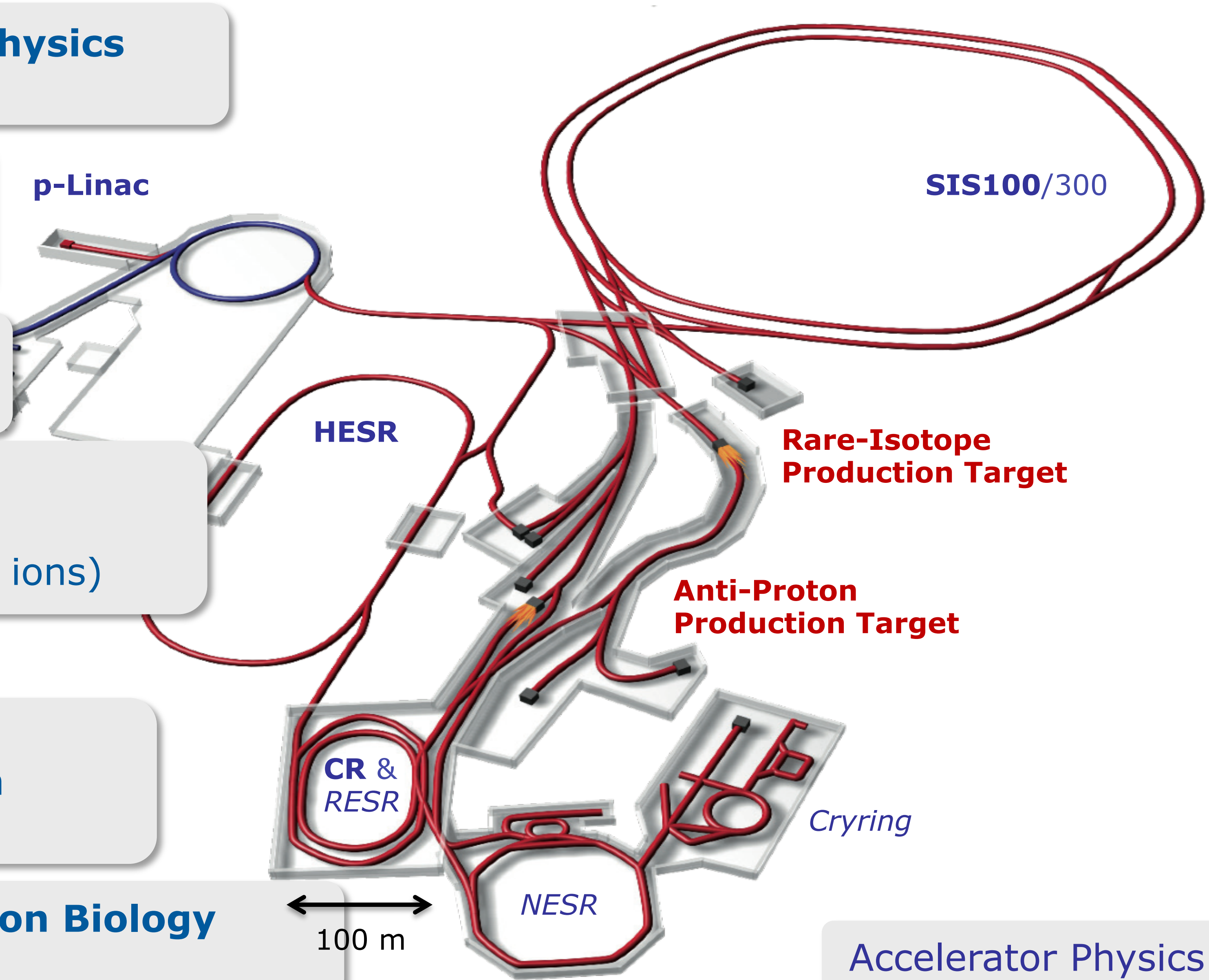
Hadron Physics
(Stored and cooled
14 GeV/c anti-protons)

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

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

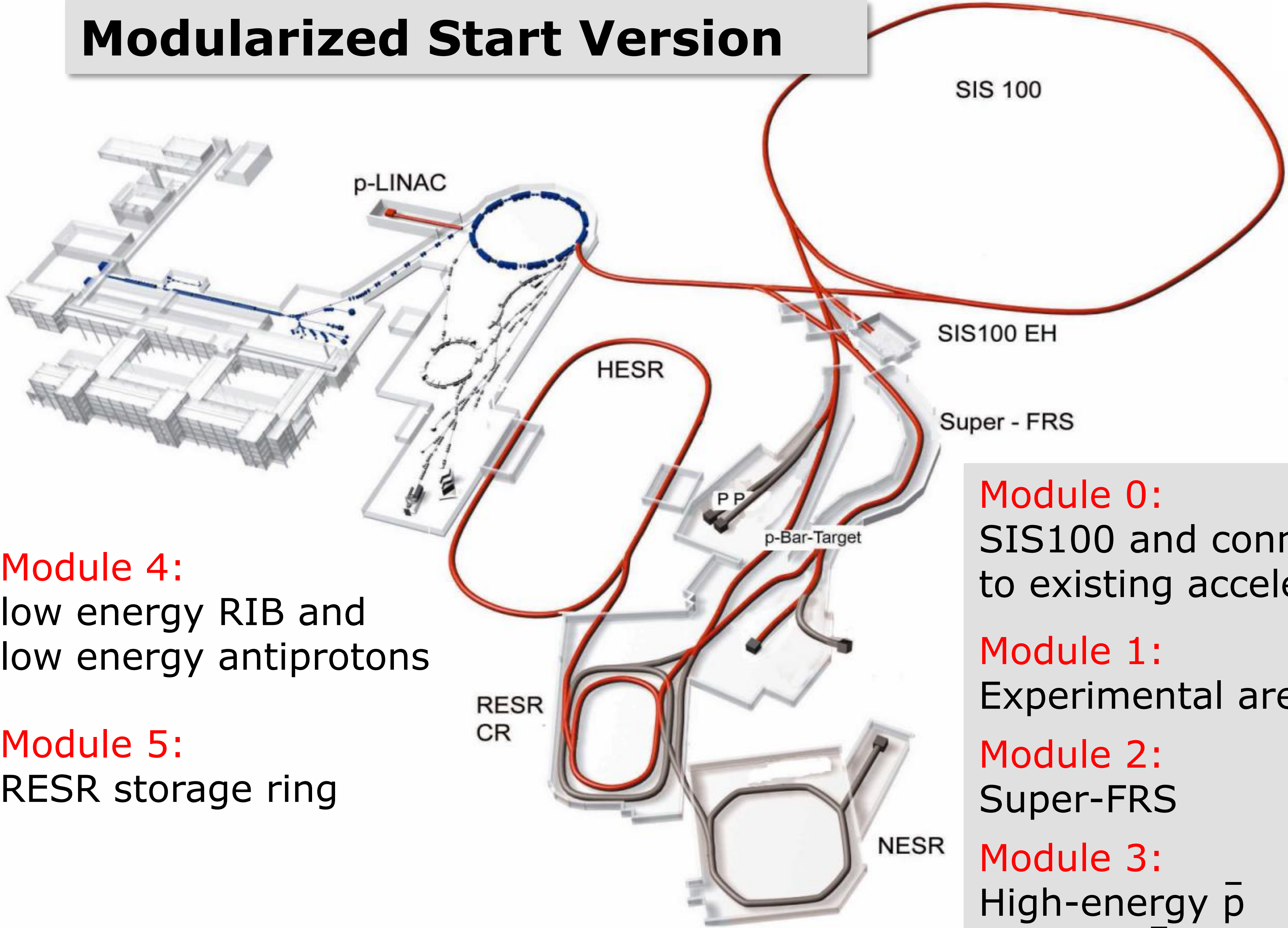
Dense Bulk Plasmas
(Ion-beam bunch compression
& petawatt-laser)

Materials Science & Radiation Biology
(Ion & antiproton beams)



Accelerator Physics

Modularized Start Version



Module 4:
low energy RIB and
low energy antiprotons

Module 5:
RESR storage ring

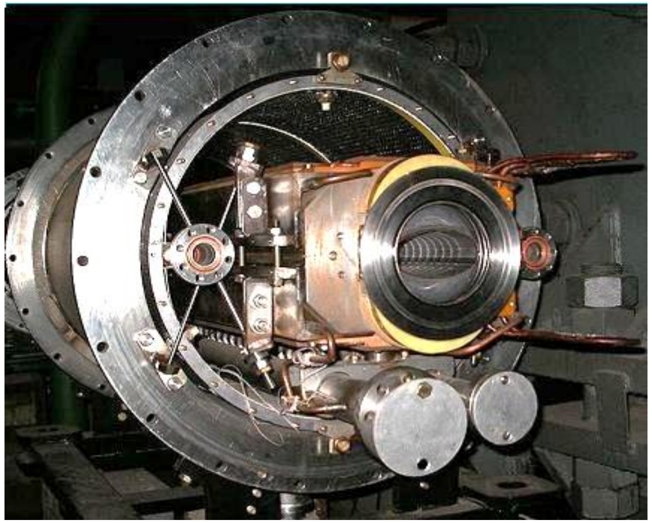
Module 0:
SIS100 and connection to existing accelerators

Module 1:
Experimental areas

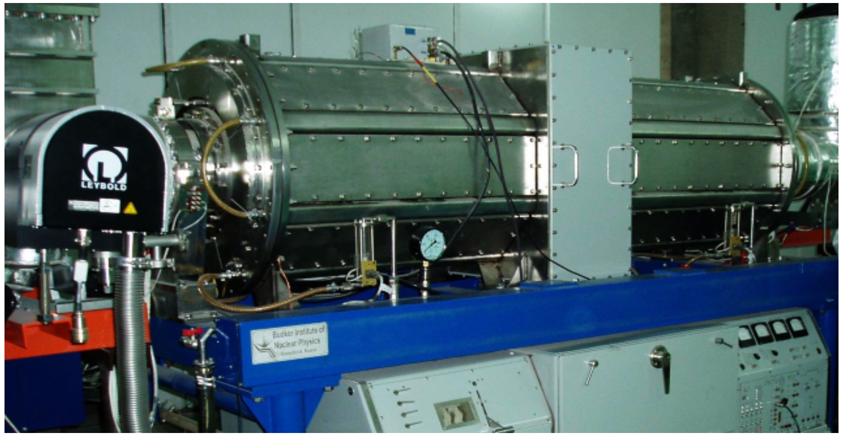
Module 2:
Super-FRS

Module 3:
High-energy $\bar{p}$
(p-linac, $\bar{p}$, CR,HESR)

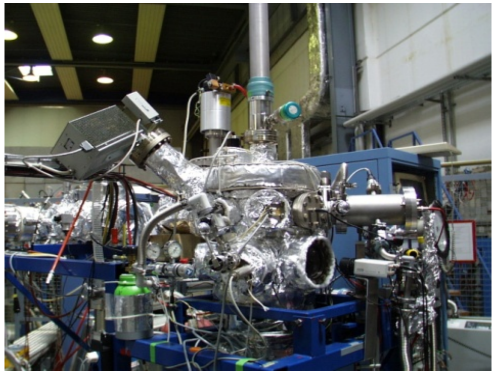
Fast cycling superconducting magnets
dB/dt ~ 4T/s



High gradient, variable frequency
Ferrite & MA loaded cavities

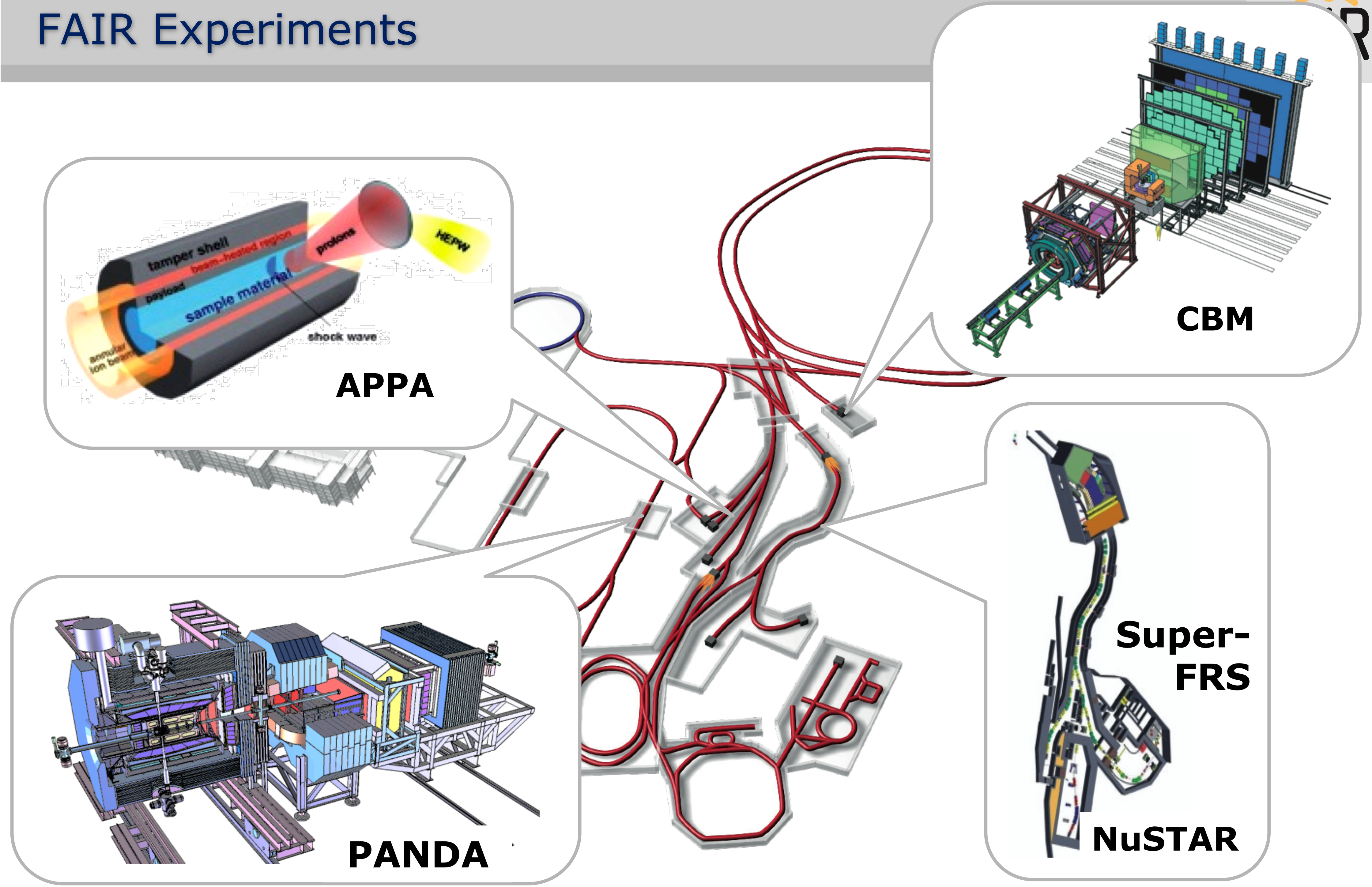


Extremely high vacuum ~10^{-13} mbar

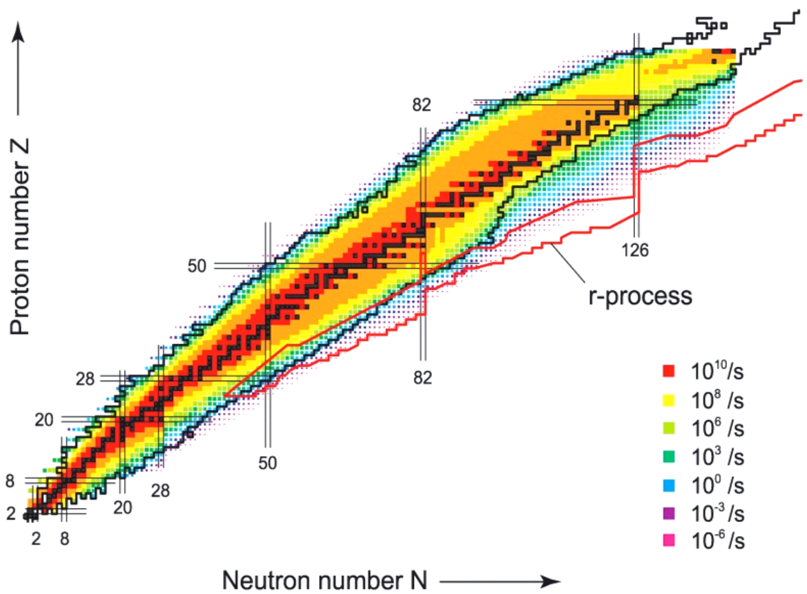


Electron & stochastic cooling

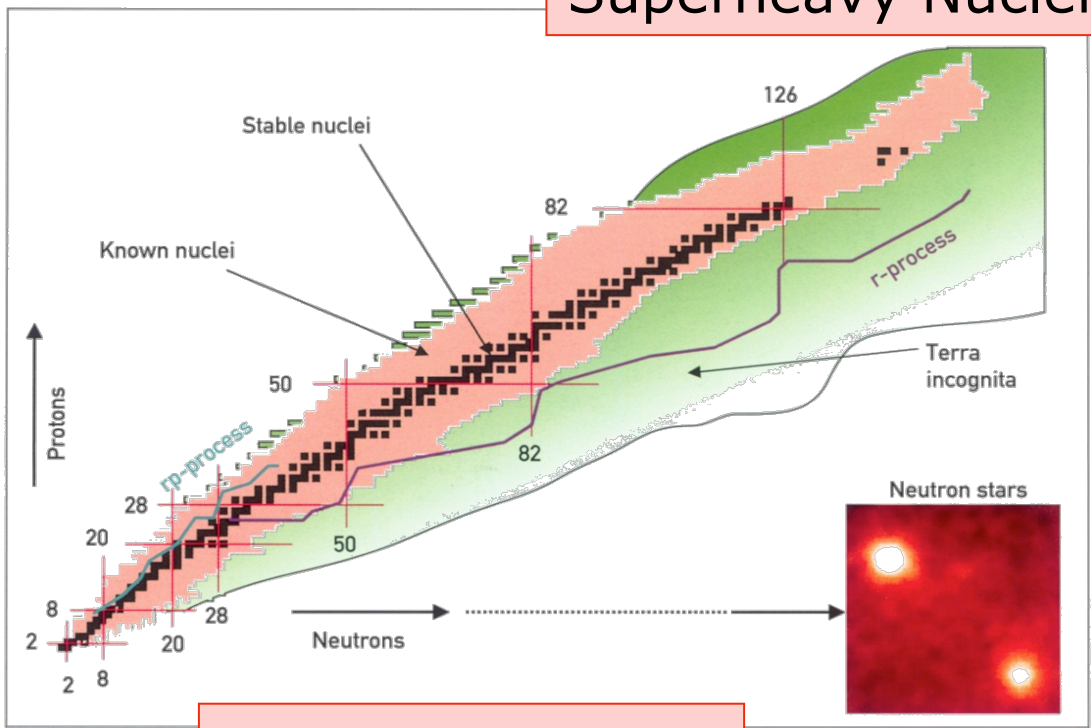
FAIR Experiments



- How Are Elements Made ?
- Structure of exotic nuclei far off stability ?
- Nuclear synthesis in stars and star explosions
- Fundamental interactions and symmetries



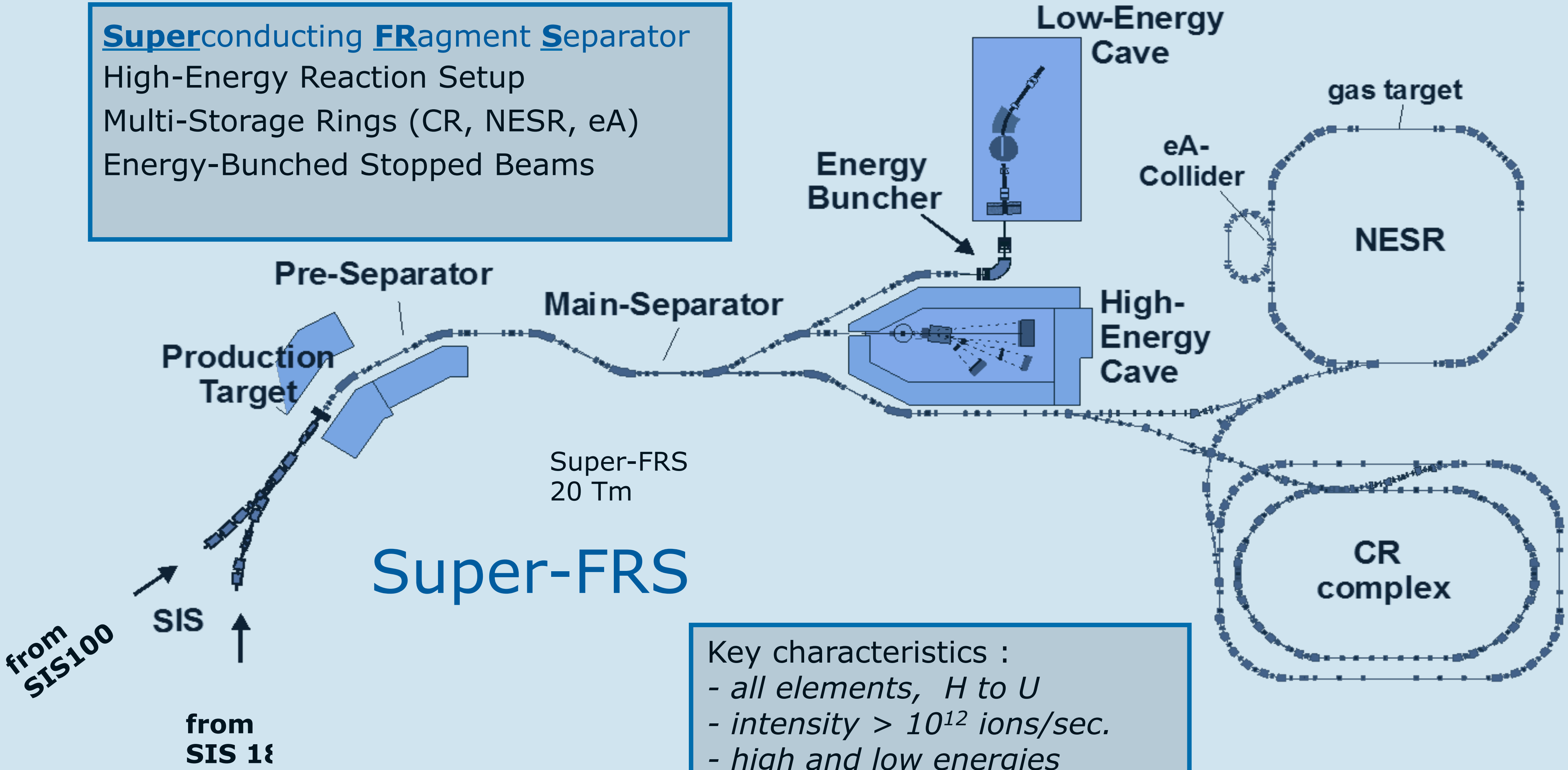
Superheavy Nuclei



Neutron Drip Line

NUSTAR @ FAIR : the installations

Superconducting **FR**agment **S**eparator
High-Energy Reaction Setup
Multi-Storage Rings (CR, NESR, eA)
Energy-Bunched Stopped Beams

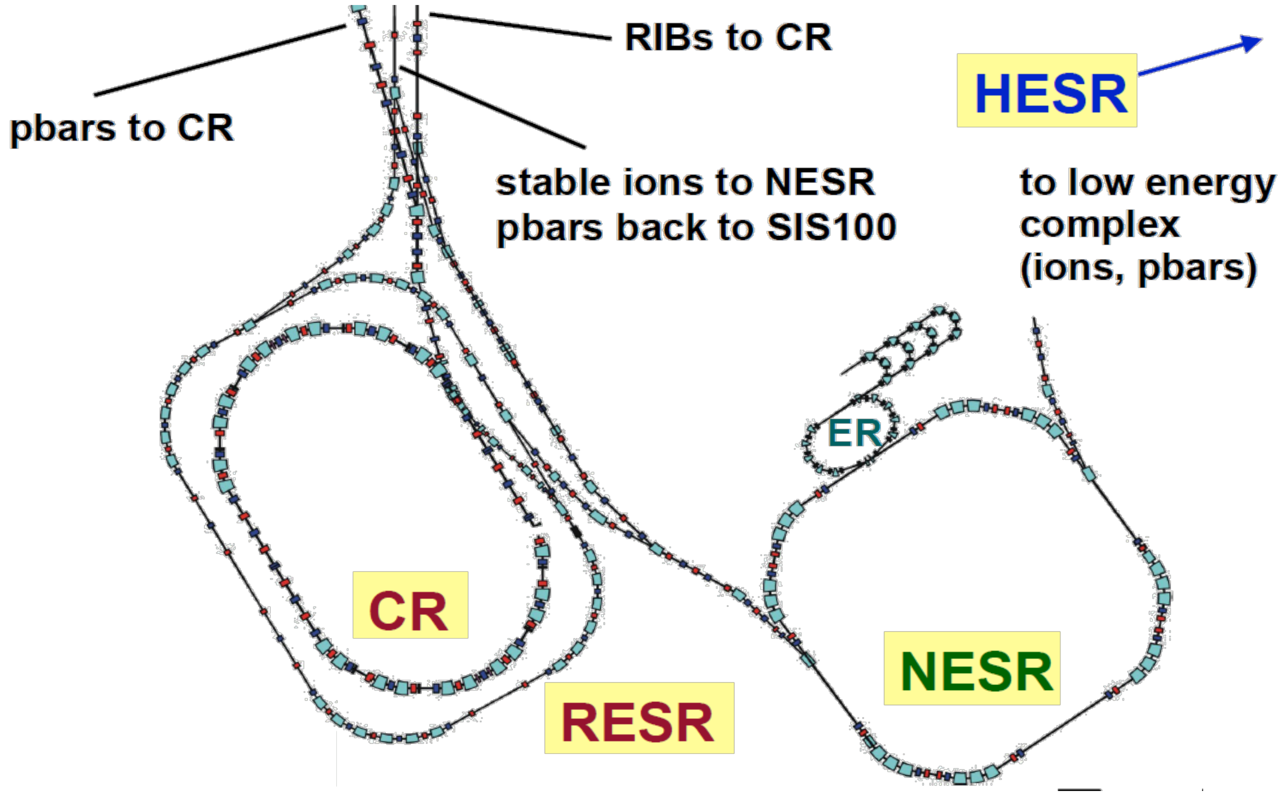


Key characteristics :
- *all elements, H to U*
- *intensity > 10^{12} ions/sec.*
- *high and low energies*
- *pulsed and CW beams*

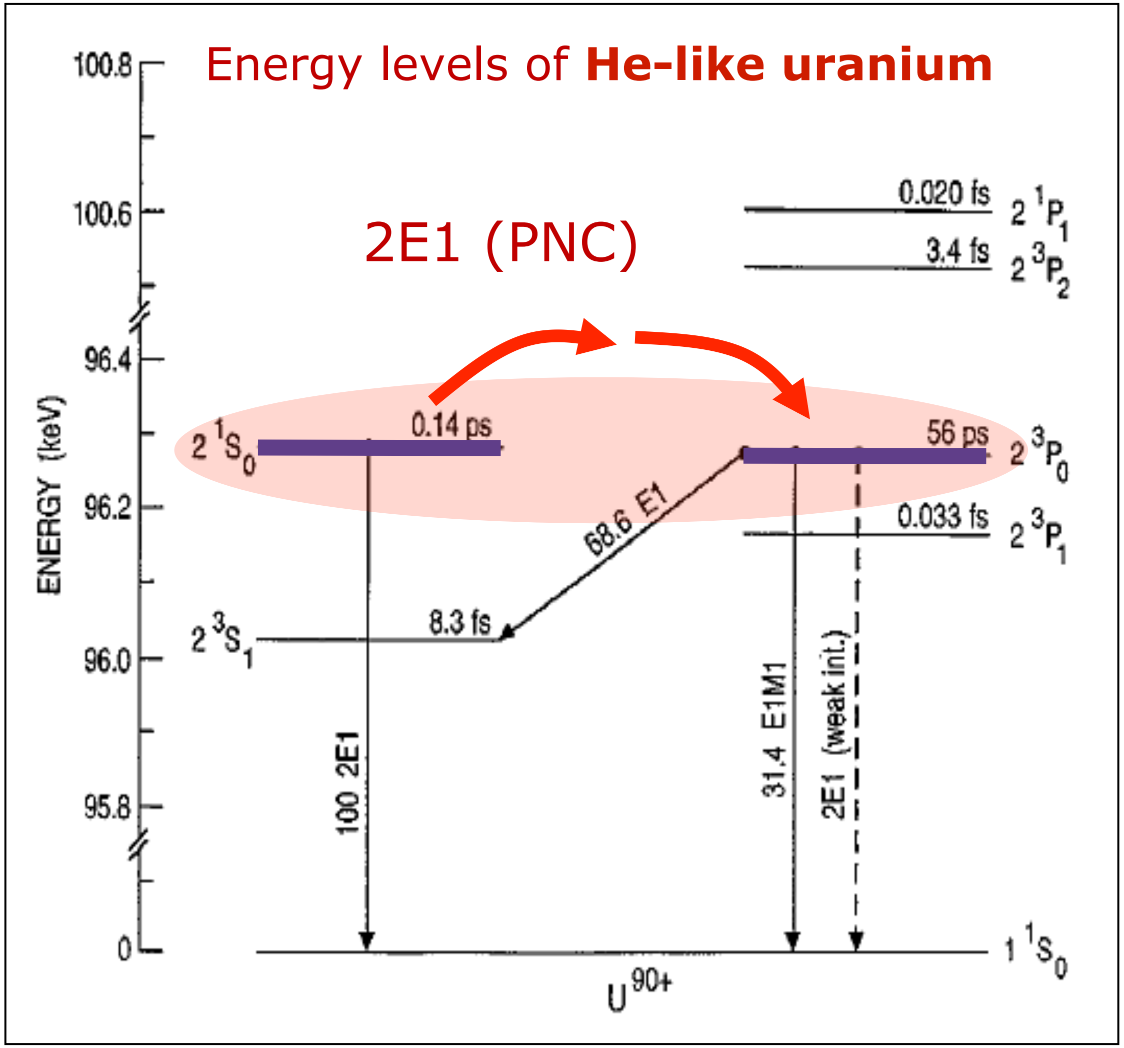
APPA at FAIR: Atomic, Plasma and Applied Physics

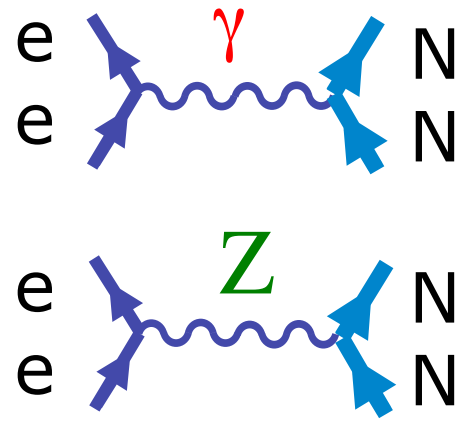
- very broad program
  too broad to be summarized here
- SPARC and HedgeHob
  are two important projects here

apart from
PLASMA cave
important rings
will be
RESR and NESR
(Module 5/6)



APPA: Parity-Violation



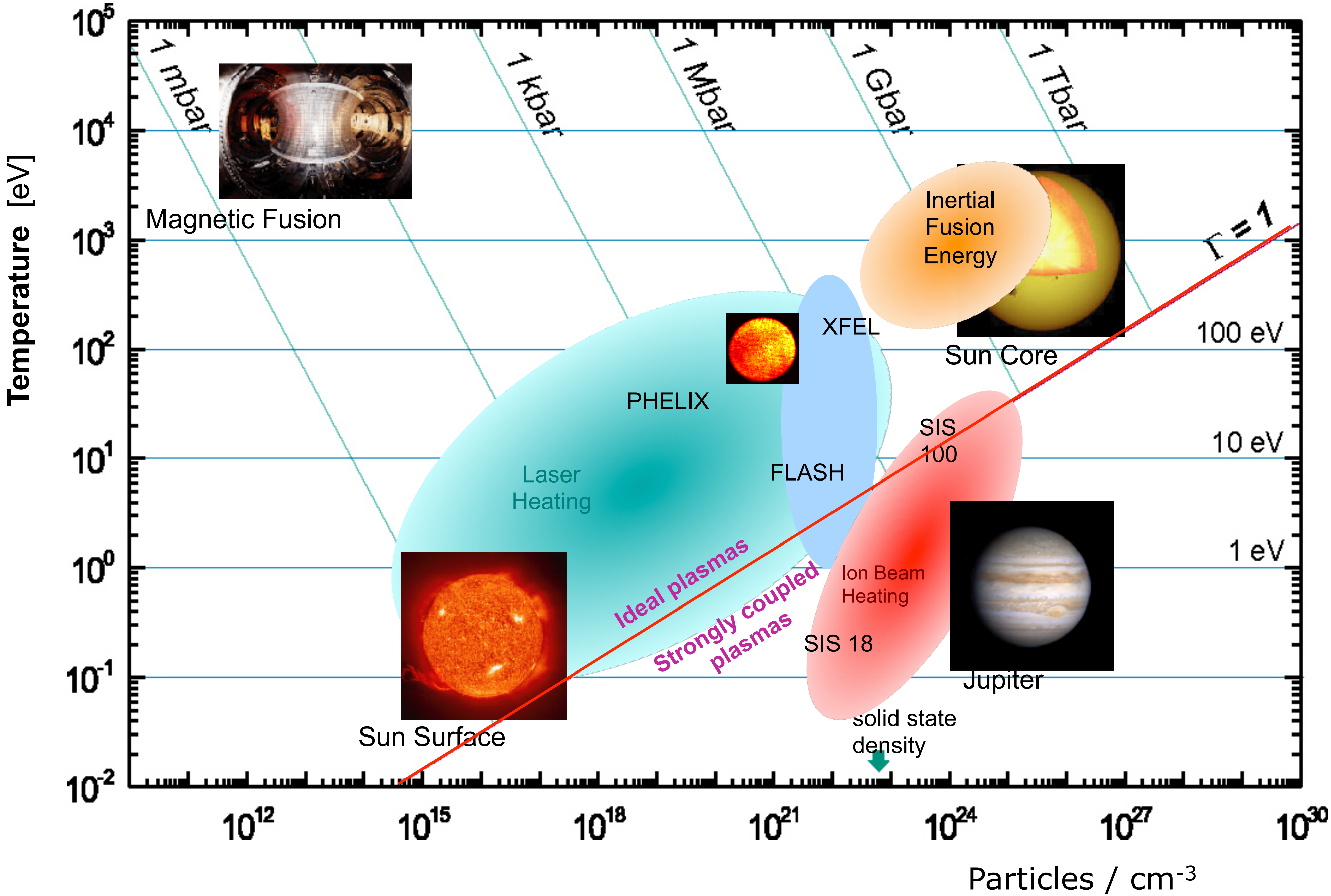


Mixing coefficient for states with opposite parities:

$$\eta = \frac{\left\langle \Psi_S \middle| G_F / 2\sqrt{2}\, Q_W\, \rho_N\, \gamma_5 \middle| \Psi_P \right\rangle}{E_S - E_P}$$

Select case with small splitting!

To "compete" with spontaneous decay channels, one needs to induce a two-photon PNC transition by polarized light with intensity 10^{20} W/cm^2



10^5
10^4
10^3
10^2
10^1
10^0
10^{-1}
10^{-2}
Temperature [eV]
1 mbar
1 kbar
1 Mbar
1 Gbar
1 Tbar
Magnetic Fusion
Inertial Fusion Energy
$\Gamma = 1$
XFEL
Sun Core
100 eV
PHELIX
SIS 100
10 eV
Laser Heating
FLASH
1 eV
Ideal plasmas
Strongly coupled plasmas
Ion Beam Heating
SIS 18
Jupiter
solid state density
Sun Surface
10^{12}
10^{15}
10^{18}
10^{21}
10^{24}
10^{27}
10^{30}
Particles / cm^{-3}

CBM: Exploring the phases of nuclear matter

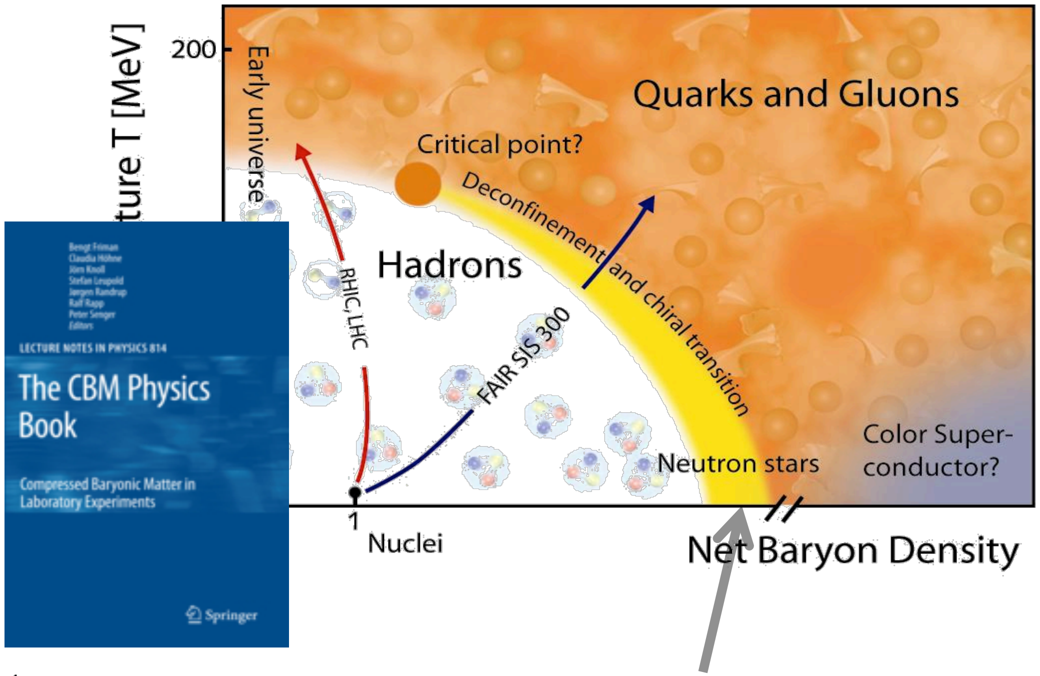
Nuclear Equation-of-state at high density

Search for phase transitions

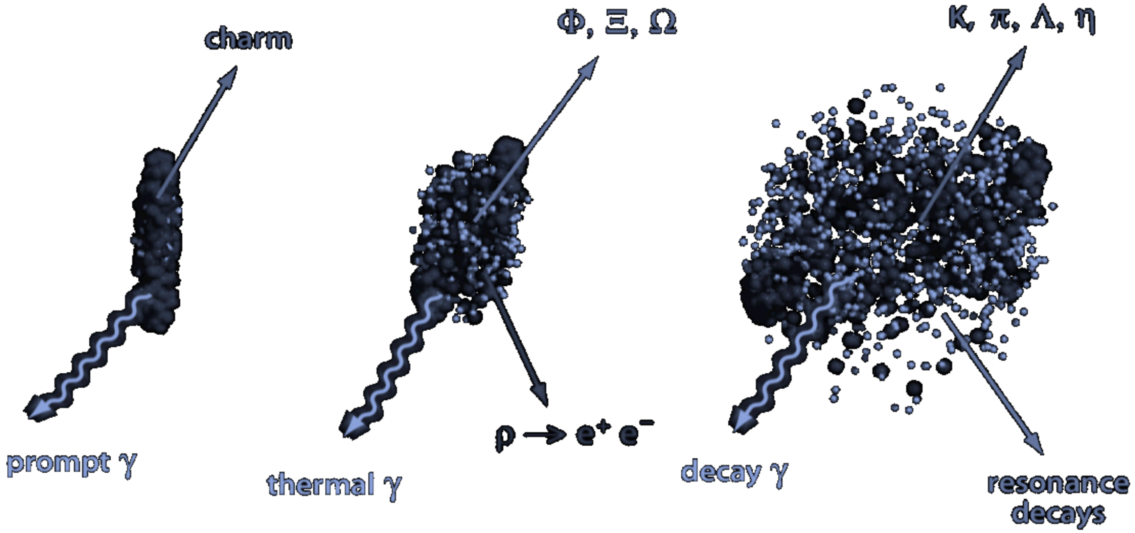
Search for the QCD critical endpoint

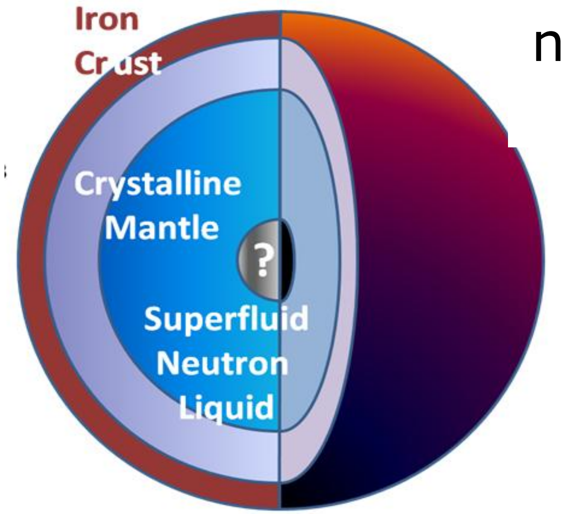
Study Chiral symmetry restoration and

the origin of the hadron mass



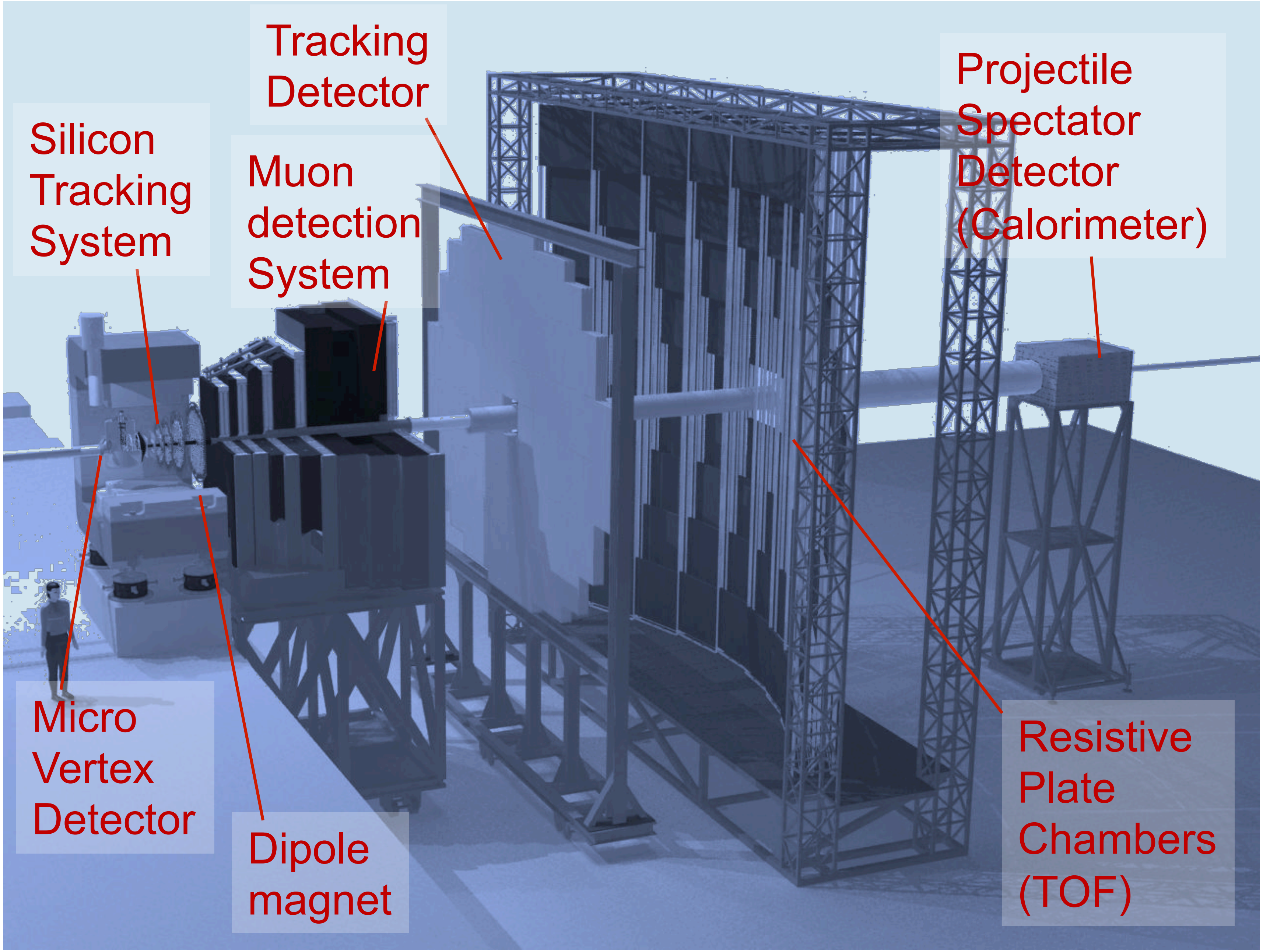
Observables





neutron star

CBM at FAIR: Detector



The study of **QCD bound states** is of fundamental importance for a better, quantitative understanding of QCD. Particle spectra can be computed within the framework of non-relativistic potential models, effective field theories and Lattice QCD. Precision measure-

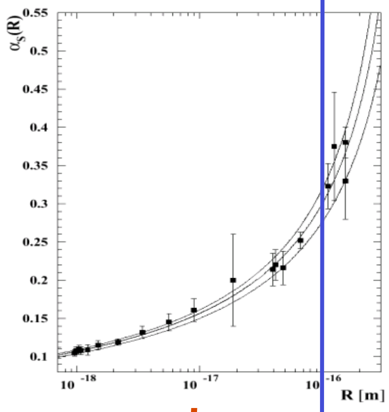
QCD Bound States
Charmonium
Exotic States

gluonic hadrons (hybrids and glueballs), multiquark and molecular states.

Electromagnetic Processes. In addition

Hadrons in matter
Absorption
Modifications

timelike region over an extended q^2 region.



Non-pert. QCD Dynamics
Strangeness and
Charm Production

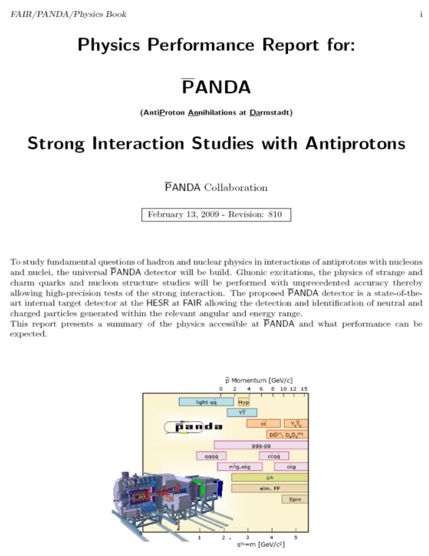
where Y denotes a hyperon. By comparing several reactions involving different quark flavours the OZI rule, and its possible violation, can be tested for different levels of disconnected quark-line diagrams separately.

Hypernuclear physics. Hypernuclei are systems in which up or down quarks are replaced by strange quarks. In this way a new quantum number, strangeness, is introduced into the nucleus. Although single and double Λ-hyp ... decades ago, o ... presently known ... at FAIR will al ... pernuclei with ... making PAND ... ledicated faciliti ... tives for nuclear structure spectroscopy and for studying the forces between hyperons and nucleons.

Hypernuclei
Molecules
Exotic nuclei

Study of ... study of ... bedded in ... standing the origin of hadron masses in the context of spontaneous chiral symmetry breaking in QCD and its partial restoration in a ... are expected to be affected primarily by the gluon condensate.

Hadron structure
DVCS
Formfaktors


FAIR/PANDA/Physics Book

Physics Performance Report for:

PANDA

(AntiProton Annihilations at Darmstadt)

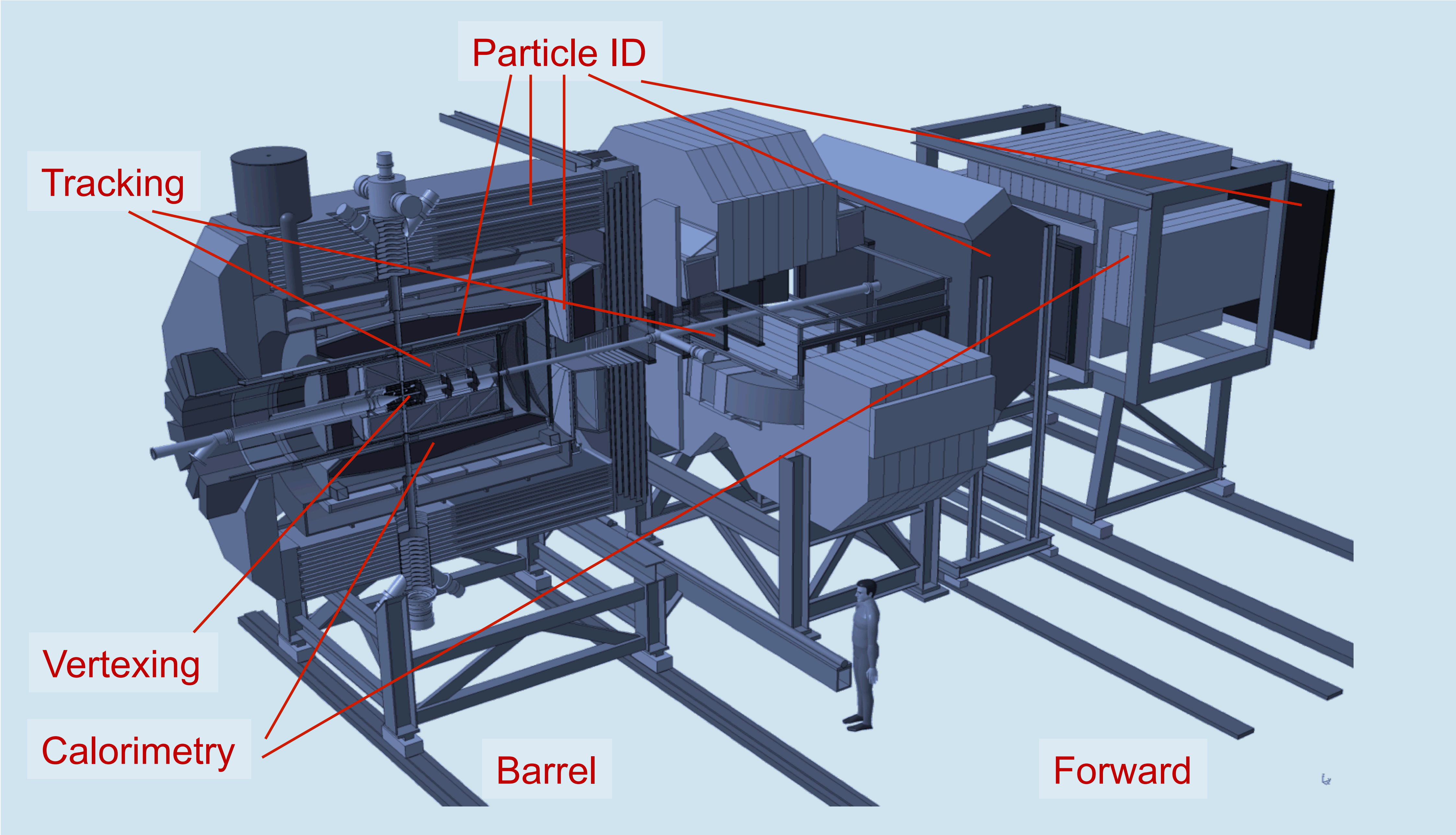
Strong Interaction Studies with Antiprotons

PANDA Collaboration

February 13, 2009 - Revision: 810

arXiv:0903.3905v1

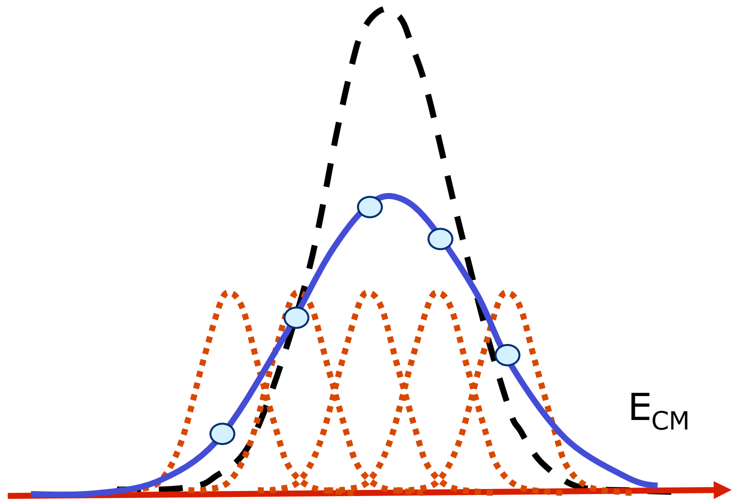
PANDA at FAIR: Detector

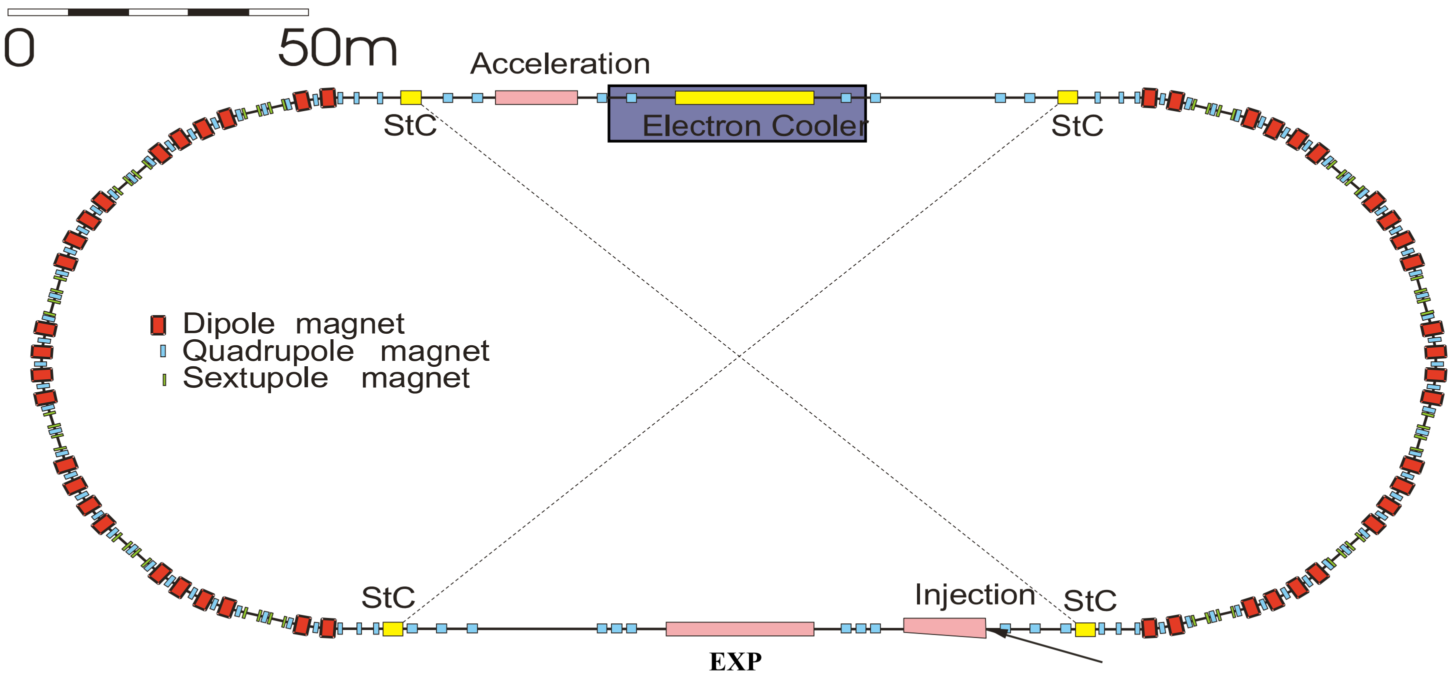


HESR – Storage Ring for Antiprotons

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)

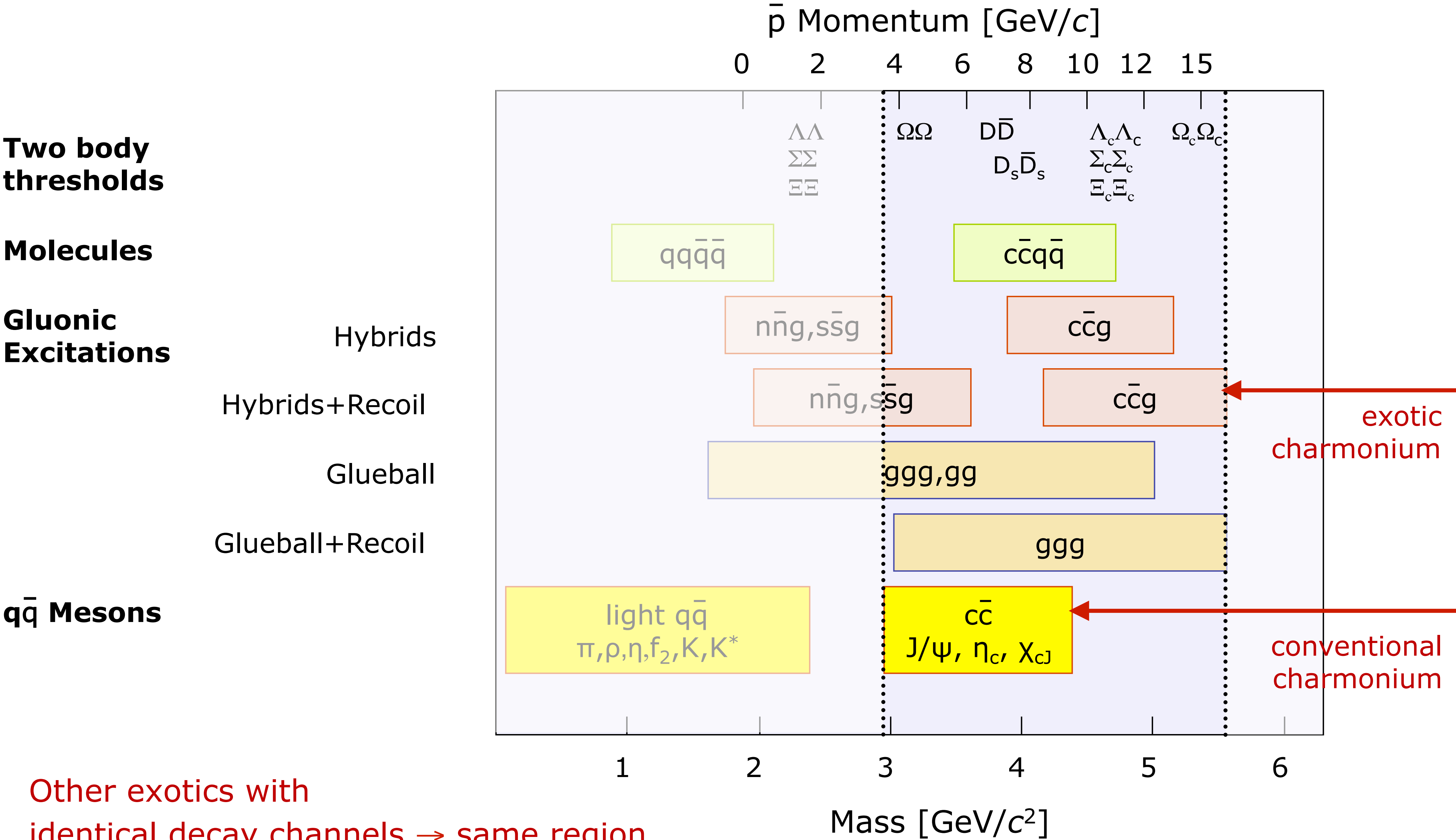




Resonance scan

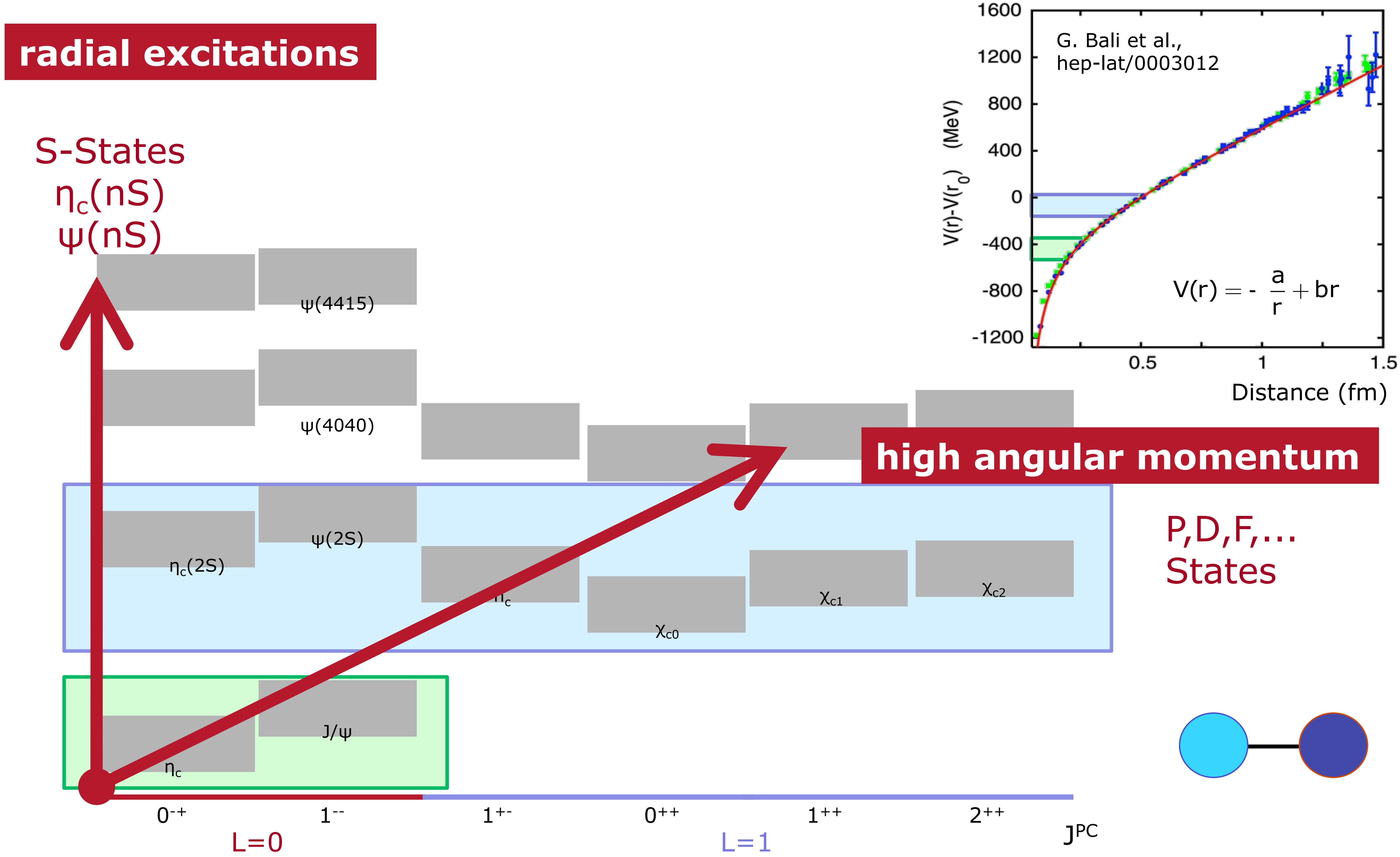
- Energy resolution ~50 keV
- Tune E_{CM} to probe resonance
- Get precise mass and width

Accessible Charmed Hadrons at P̄ANDA



Other exotics with
identical decay channels → same region

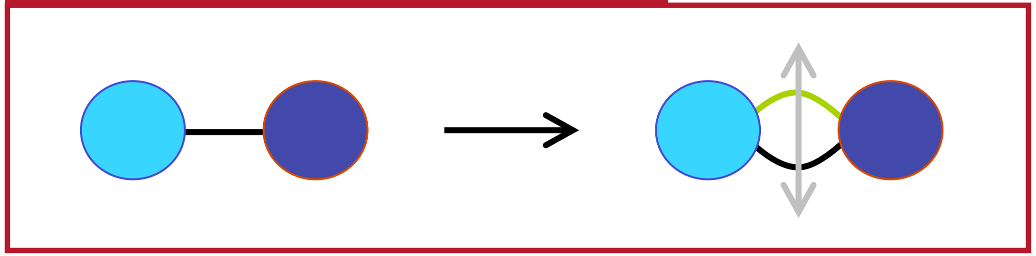
Charmonium



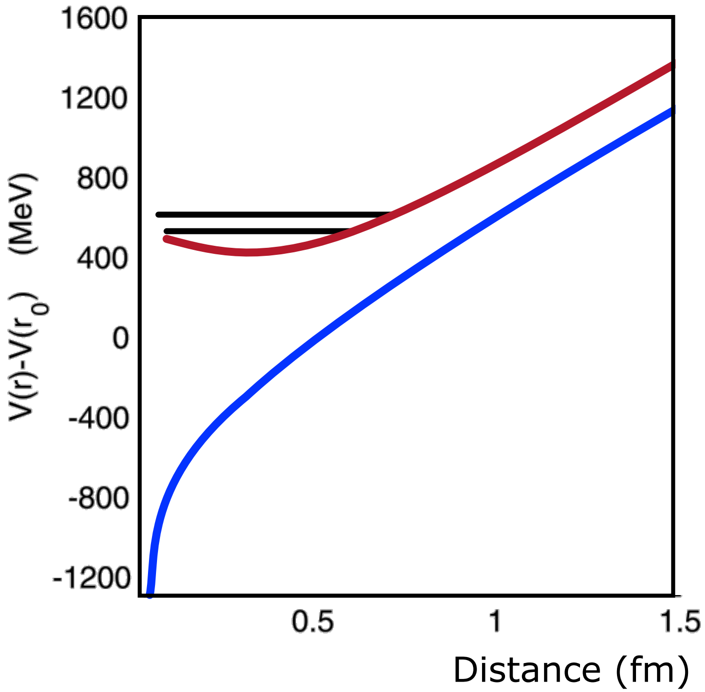
radial excitations
S-States
$\eta_c(nS)$
$\psi(nS)$
ψ(4415)
ψ(4040)
$\eta_c(2S)$
ψ(2S)
h_c
χ_{c0}
χ_{c1}
χ_{c2}
J/ψ
η_c
0^{-+}
1^{--}
1^{+-}
0^{++}
1^{++}
2^{++}
J^{PC}
L=0
L=1
high angular momentum
P,D,F,...
States
G. Bali et al.,
hep-lat/0003012
$V(r) = -\frac{a}{r} + br$
$V(r)-V(r_0)$ (MeV)
Distance (fm)
1600
1200
800
400
0
-400
-800
-1200
0.5
1
1.5

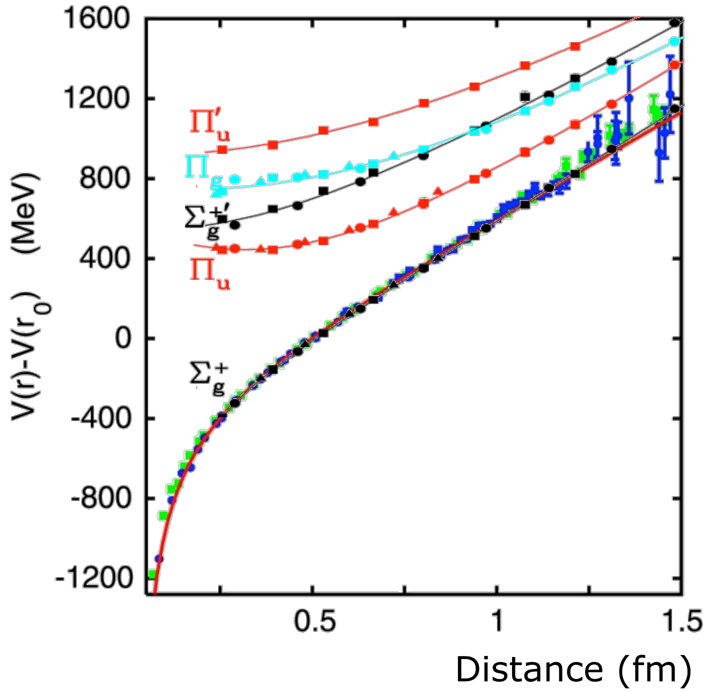
Charmonium – different degrees of freedom ?

different "potential"



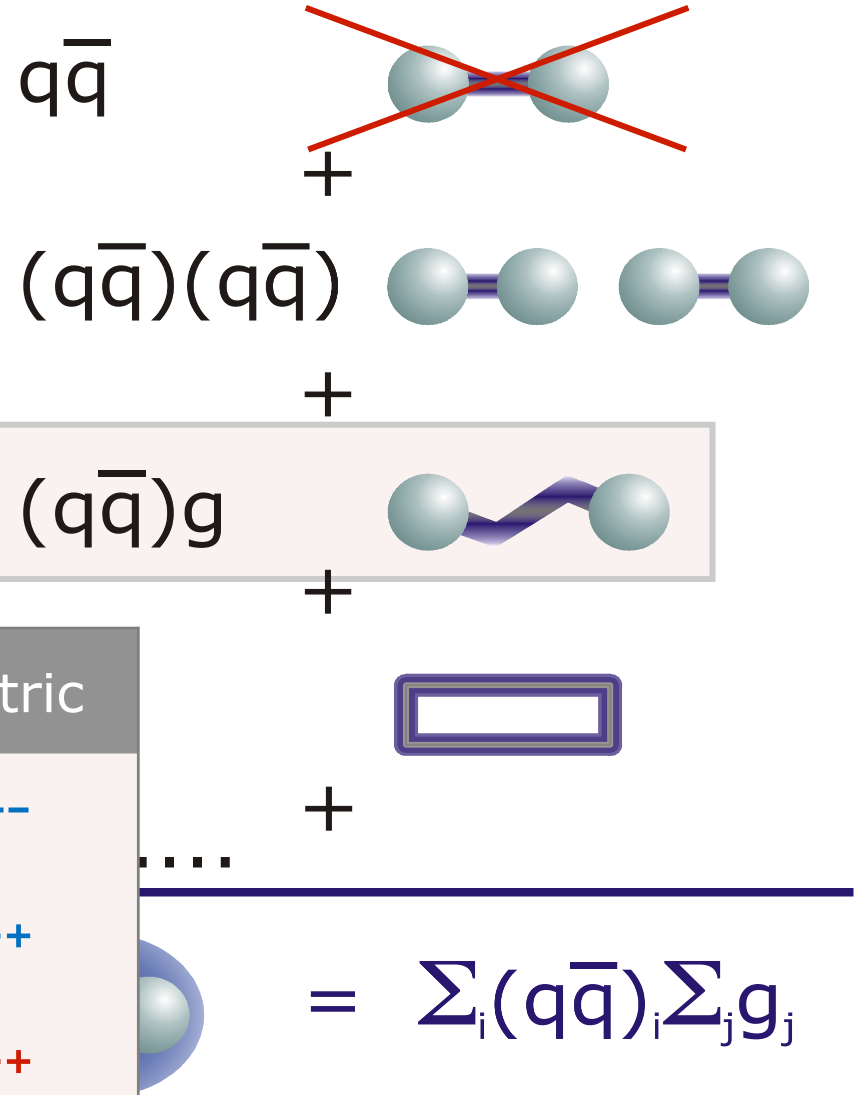
K.J. Juge, J. Kuti, C. Morningstar
hep/lat 9709131

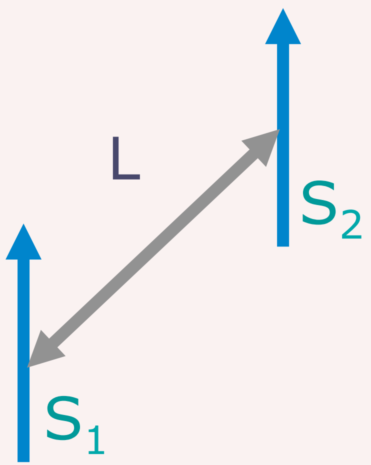




Fock-Expansion – solution to the problem

- remove the leading term due to selection of quantum numbers
- e.g. for hybrids





$S=S_1+S_2$

$J=L+S$

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

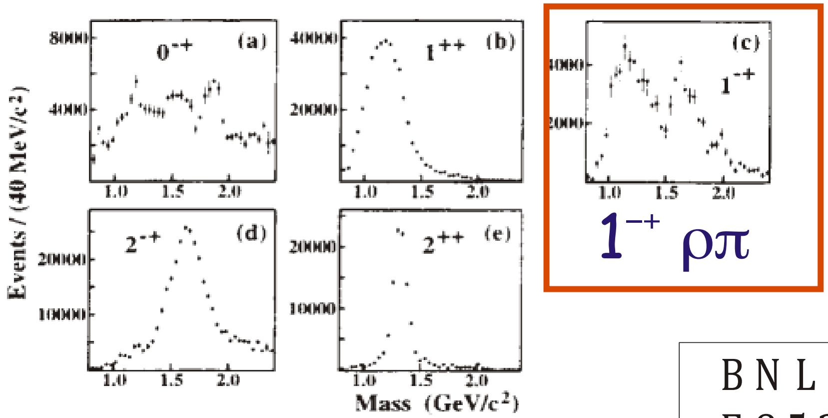
$C=(-1)^{L+S}$

impossible for $q\bar{q}$

J^{PC} exotic

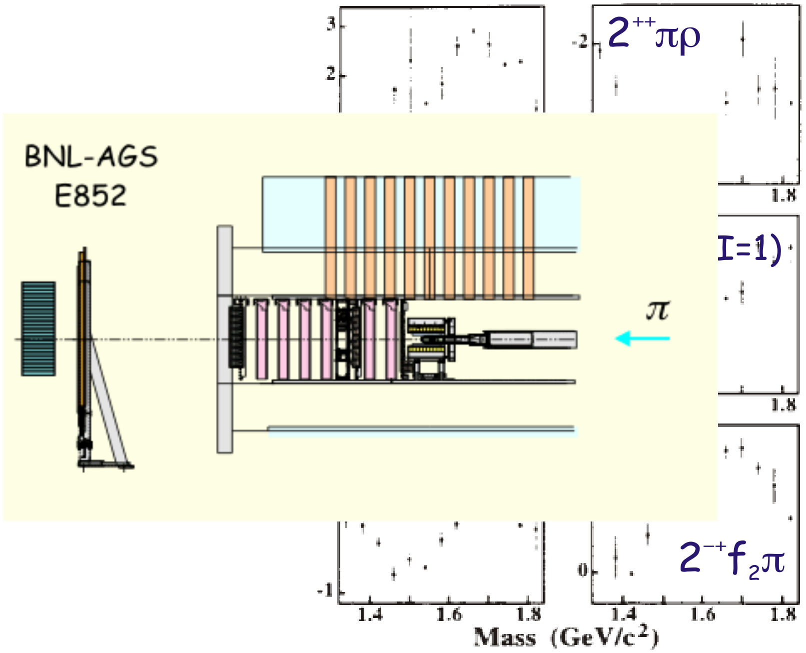
Gluon	Magnetic	Electric
$^1S_0$, 0^{-+}	1^{++}	1^{--}
$^3S_1$, 1^{--}	0^{+-}	0^{-+}
	1^{+-}	1^{-+}
	2^{+-}	2^{-+}

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

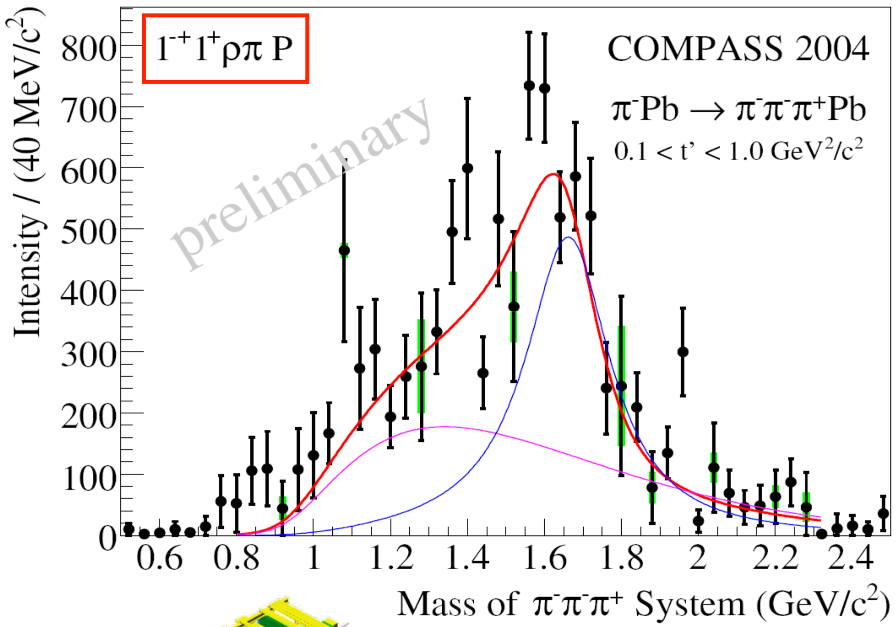


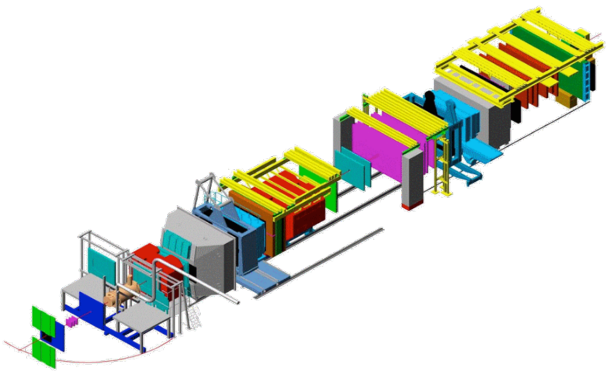
B N L
E 8 5 2

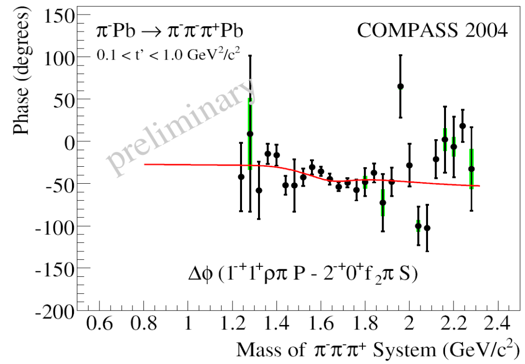
$\phi(X\text{-}1^{-+})$



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







$\pi_1(1600)$…E852 $\rho\pi$ in 1997 and COMPASS today

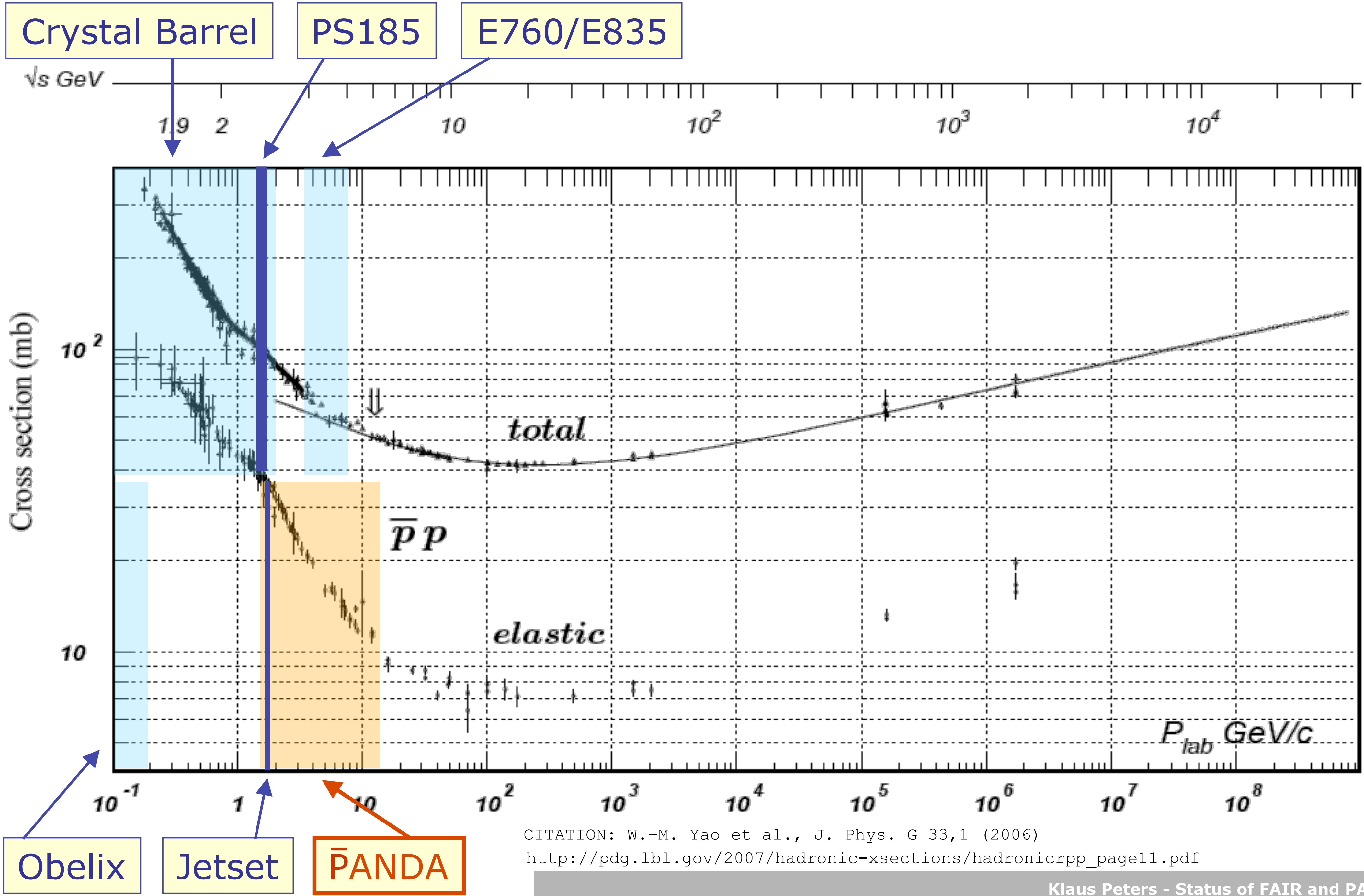
thanks to G. Adams, RPI

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

BNL-AGS E852

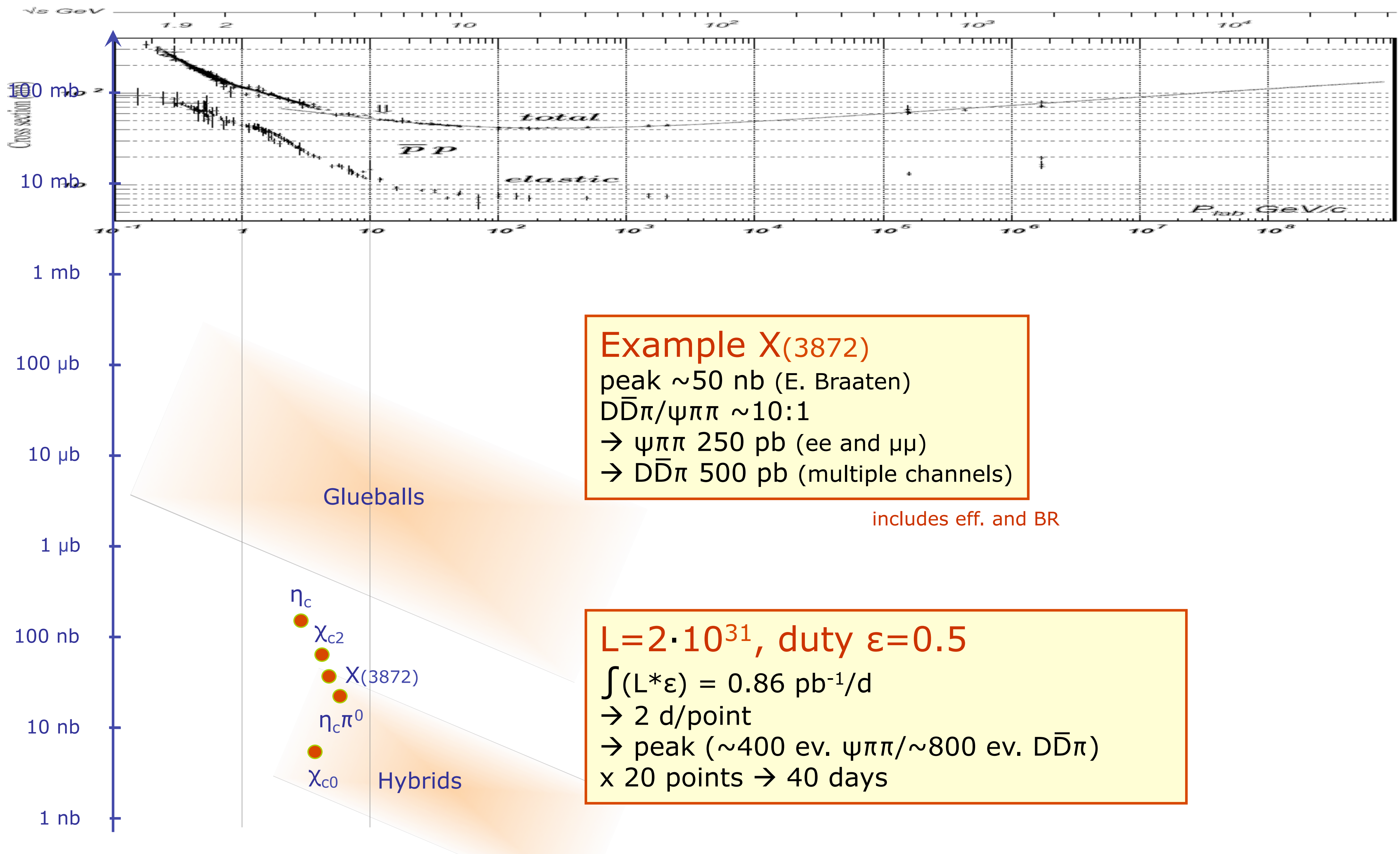
	Experiment	Mass	Width	Decay	Citation
$\pi_1(1400)$	E852	1359 (+16-14) (+10-24)	314 (+31-29) (+9-66)	$\eta\pi$	PR D60, 092001
	Crystal Barrel	1400 (+20-20) (+20-20)	310 (+50-50) (+50-30)	$\eta\pi$	PL B423,175
	Crystal Barrel	1360 (+25-25)	220 (+90-90)	$\eta\pi$	PL B446,349
	Obelix	1384 (+28-28)	378 (+58-58)	$\rho\pi$	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

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 $\varepsilon=0.5$

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

→ 2 d/point

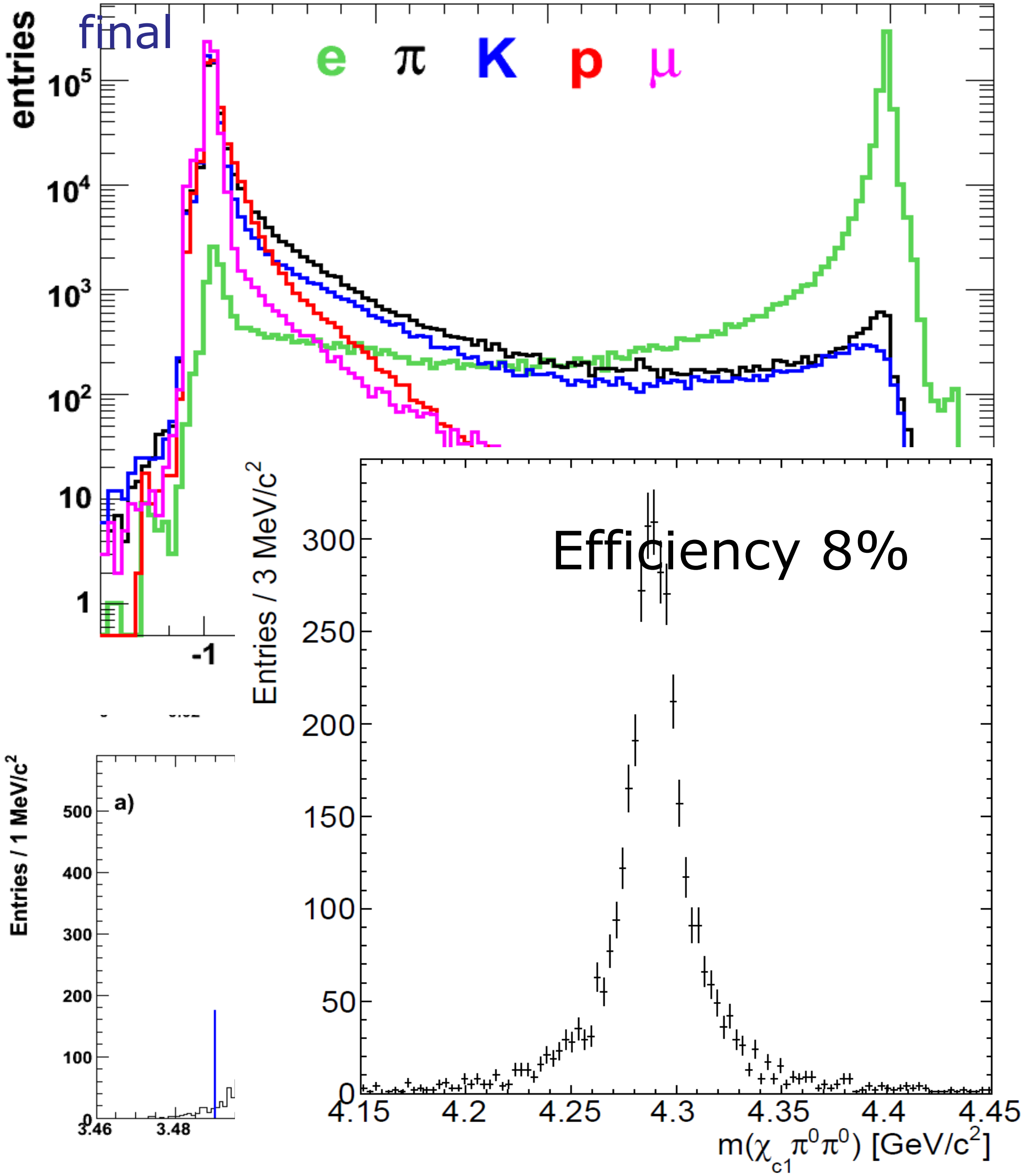
→ peak (~400 ev. $\psi\pi\pi$/~800 ev. $D\bar{D}\pi$)

x 20 points → 40 days

Benchmark $p\bar{p} \rightarrow (\chi_{c1}\pi\pi)\eta$ and $(D\bar{D}^{*}+c.c.)\eta$

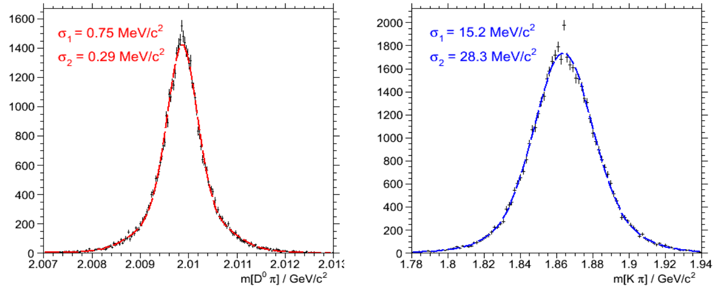
$(\chi_{c1}\pi\pi)\eta$

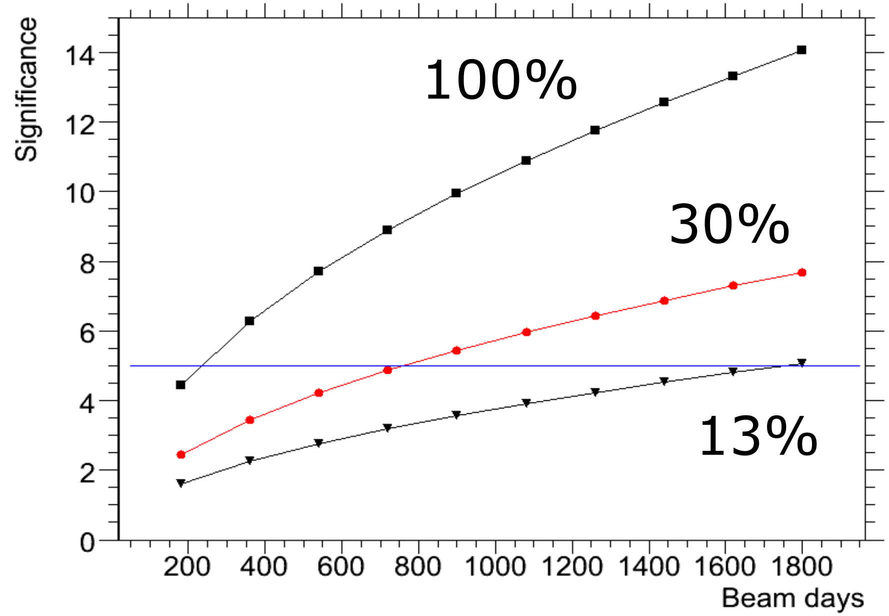
- not yet final



$(D\bar{D}^{*}+c.c.)\eta$

- 1 nb production cross section

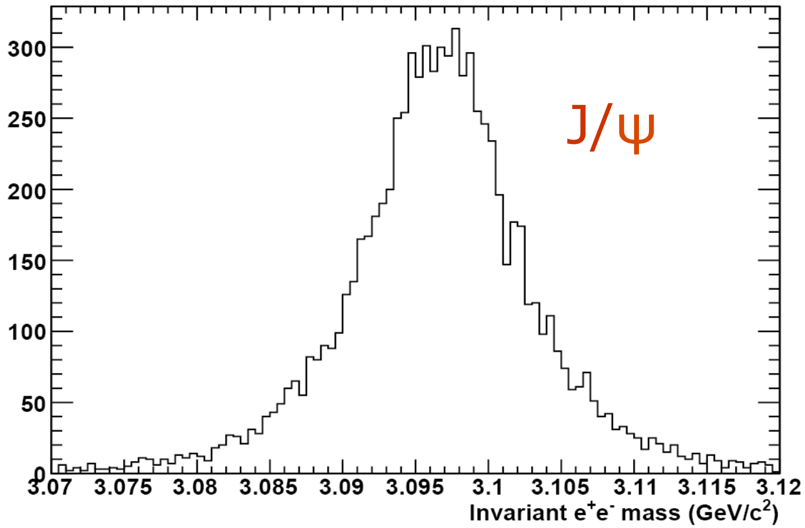


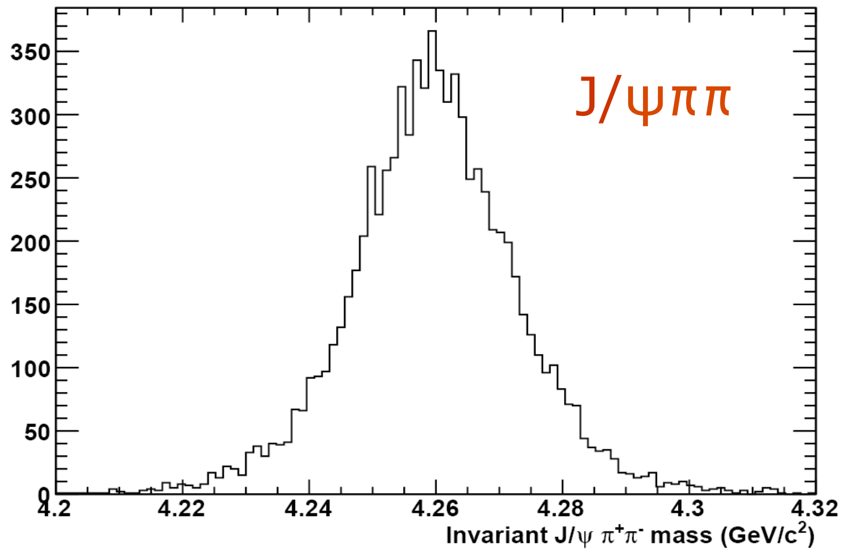


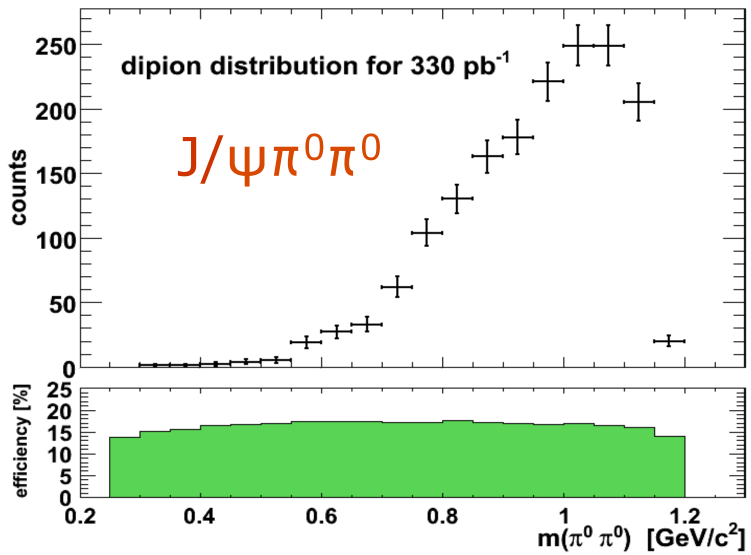
Efficiency 5%

decay branchings
already accounted for

Benchmark $p\bar{p} \rightarrow Y(4260) \rightarrow \psi\pi\pi$

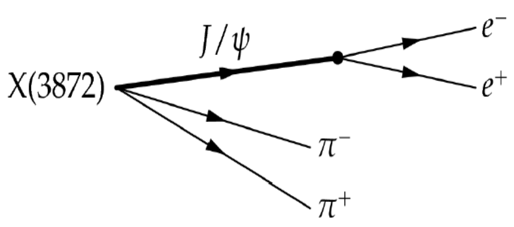


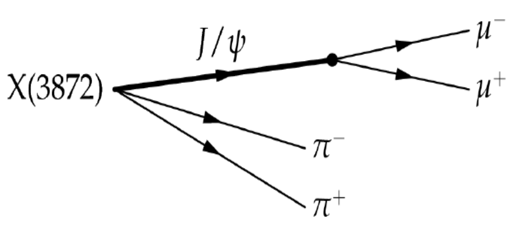


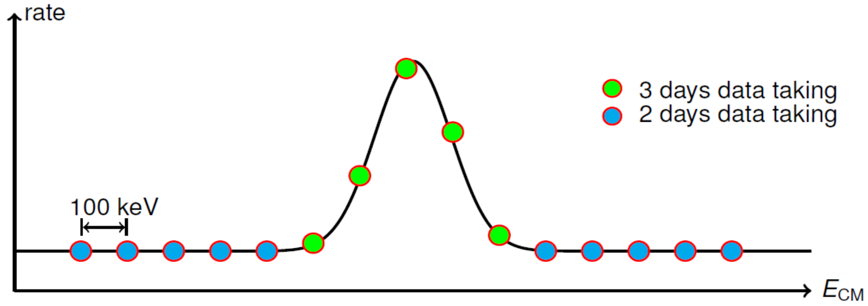


$\sqrt{s}$ [GeV]	Eff [%]	RMS [MeV]
3.526	27.52	3.7
3.686	30.90	5.7
3.872	32.07	8.3
4.260	32.58	13.4
4.600	30.60	18.5
5.000	29.70	24.3

X(3872) - Simulation of an Energy Scan







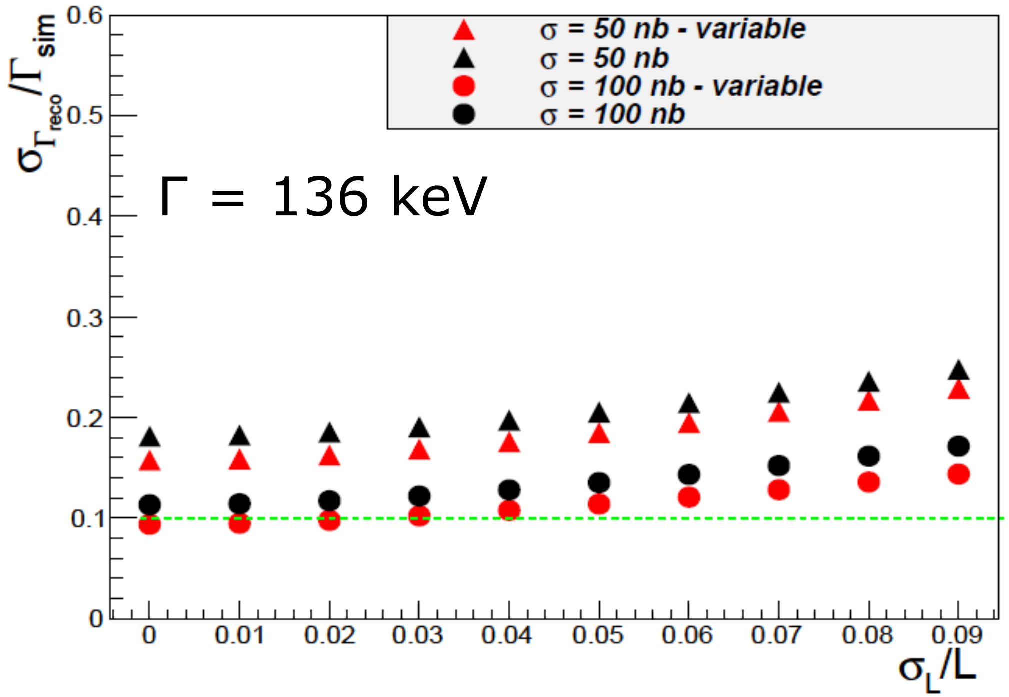
Extraction of the Width

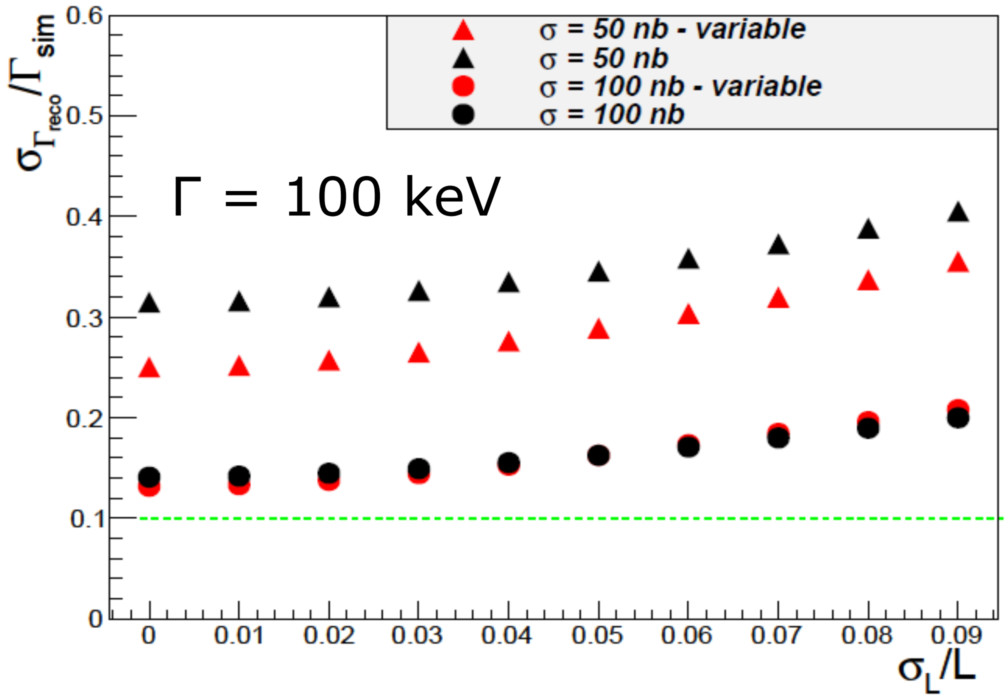
after beam profile deconvolution

16 Scan-Points

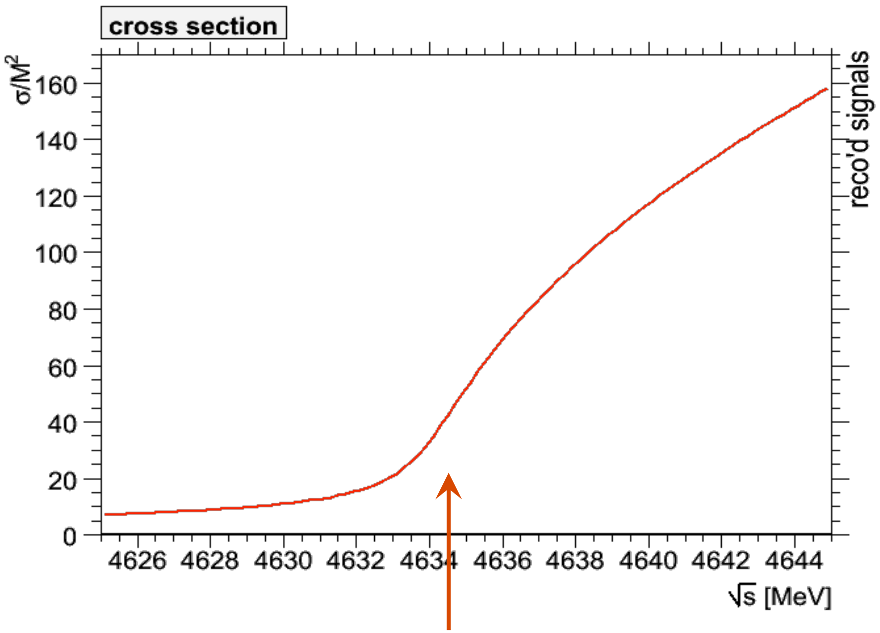
ΔE = 100 keV

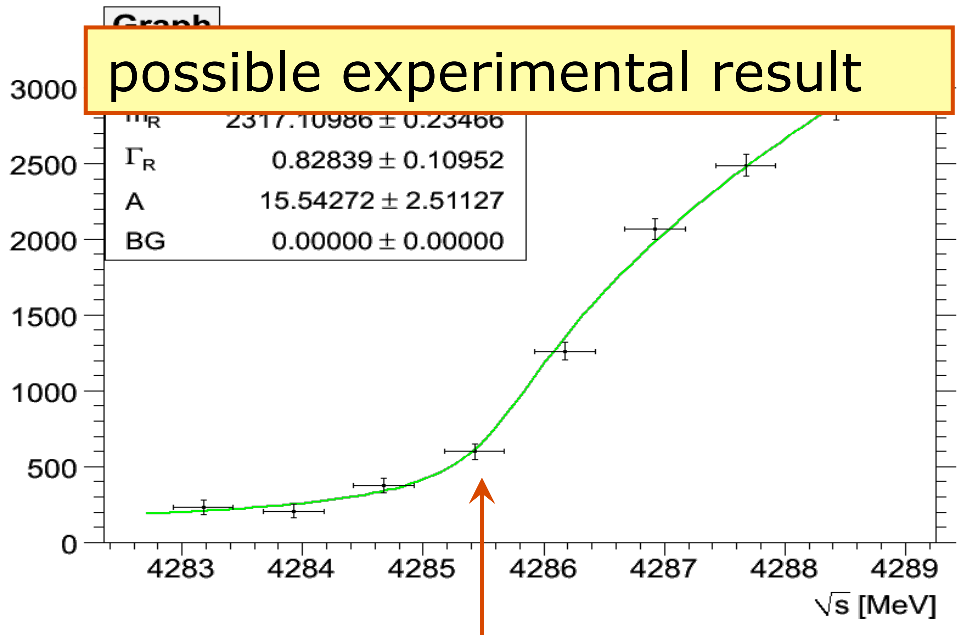
2-3 days per Scan-Point





Mass and Width Determination $D_{sJ}^{(*)}(2xxx)$





threshold $D_{s0}^{*}\overline{D_{s0}}^{*}$ threshold $D_s D_{s0}^{*}$

- Deduce mass and width from excitation function
- Many channels, but all require e-cooling at large energies

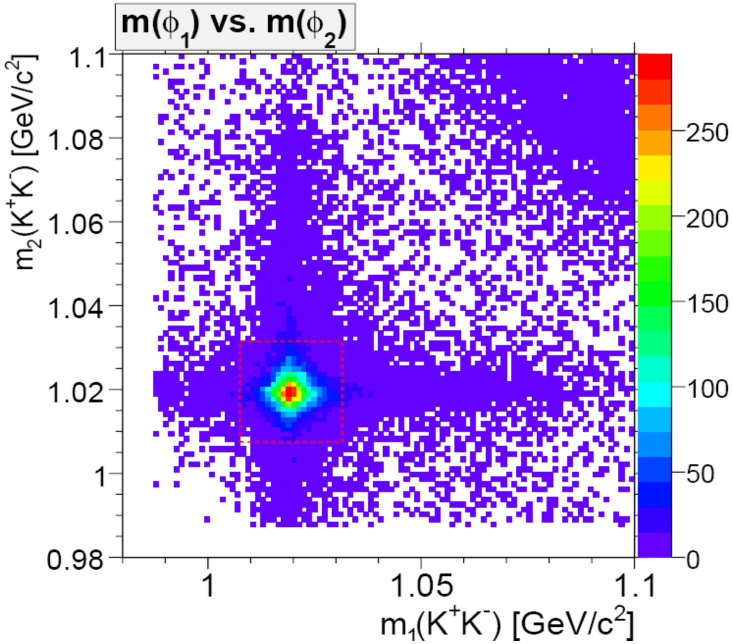
Benchmark $p\bar{p}\rightarrow\phi\phi$

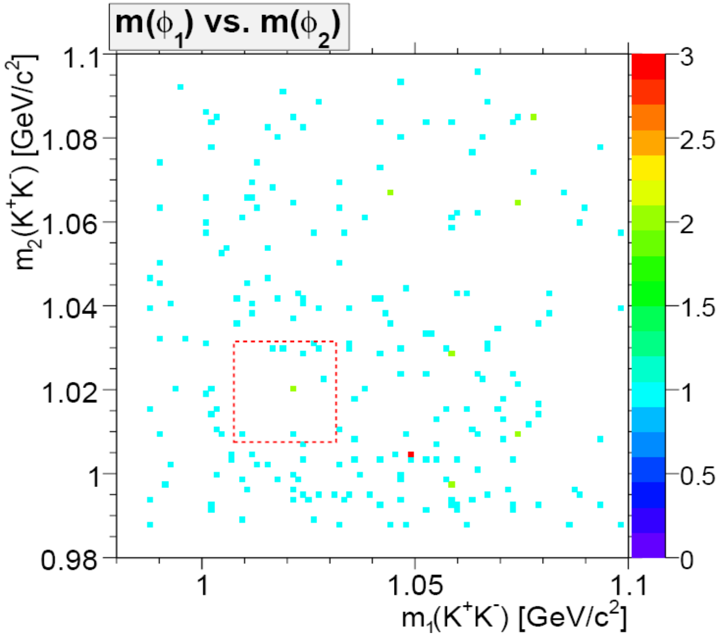
Input

$M=2.235$ GeV/c^2

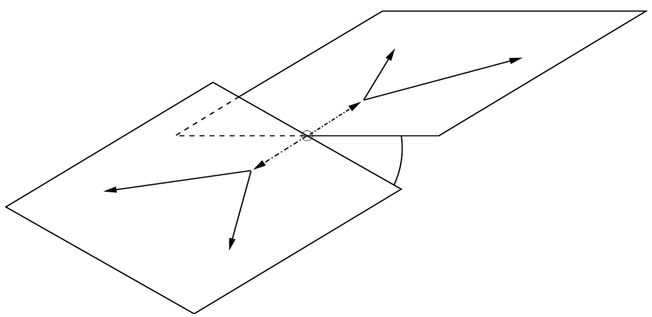
$\Gamma=15$ MeV/c^2

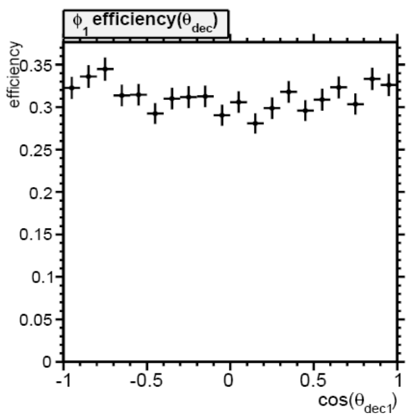
σ_S [nb]	Beam time T_b ($\approx$)
1	13.7 y
5	200 d
10	50 d
100	12 h
500	0.5 h
1000	7.2 min

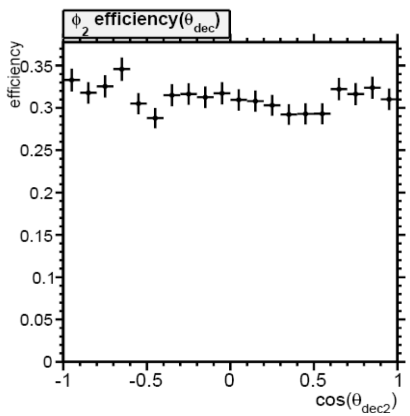


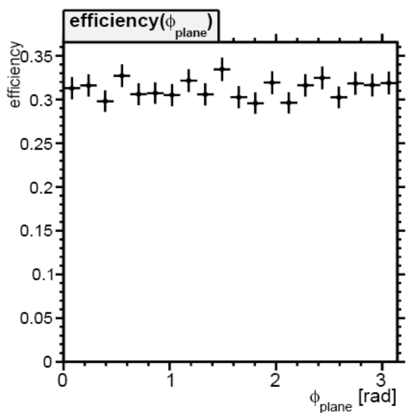


Channel	rel. X-sec	ϵ(VL)[%]	ϵ(L)[%]	ϵ(T)[%]	ϵ(VT)[%]
Signal	1	30.1	28.5	23.7	18.8
DPM generic	10^6	$< 4.3\cdot10^{-4}$	$< 4.3\cdot10^{-4}$	$< 4.3\cdot10^{-4}$	$< 4.3\cdot10^{-4}$
r_{SN}	–	$> 1:14$	$> 1:14$	$> 1:17$	$> 1:22$

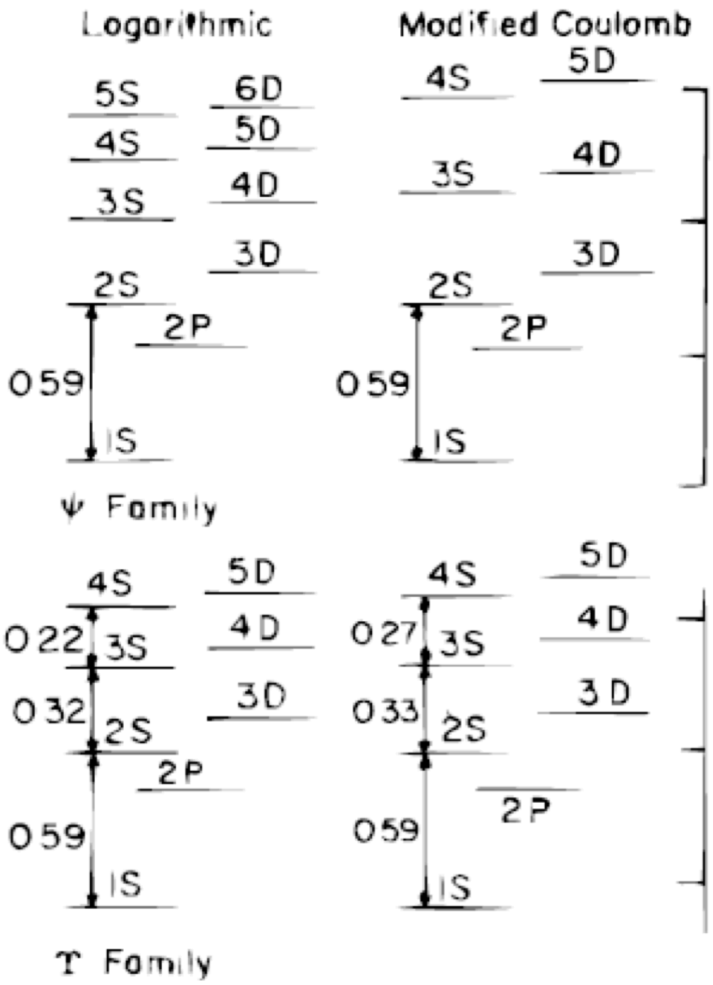


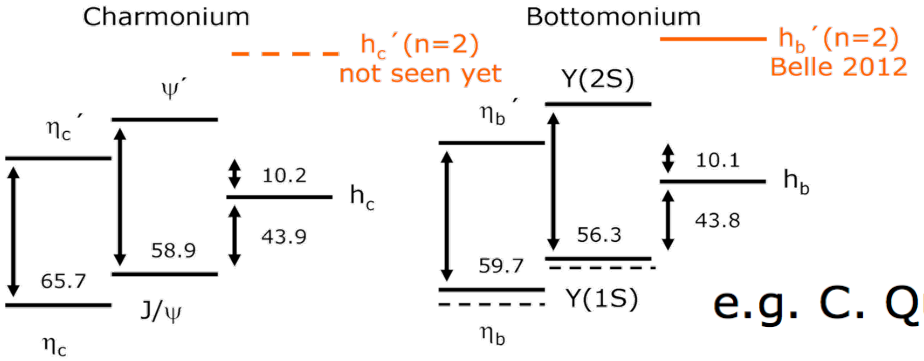




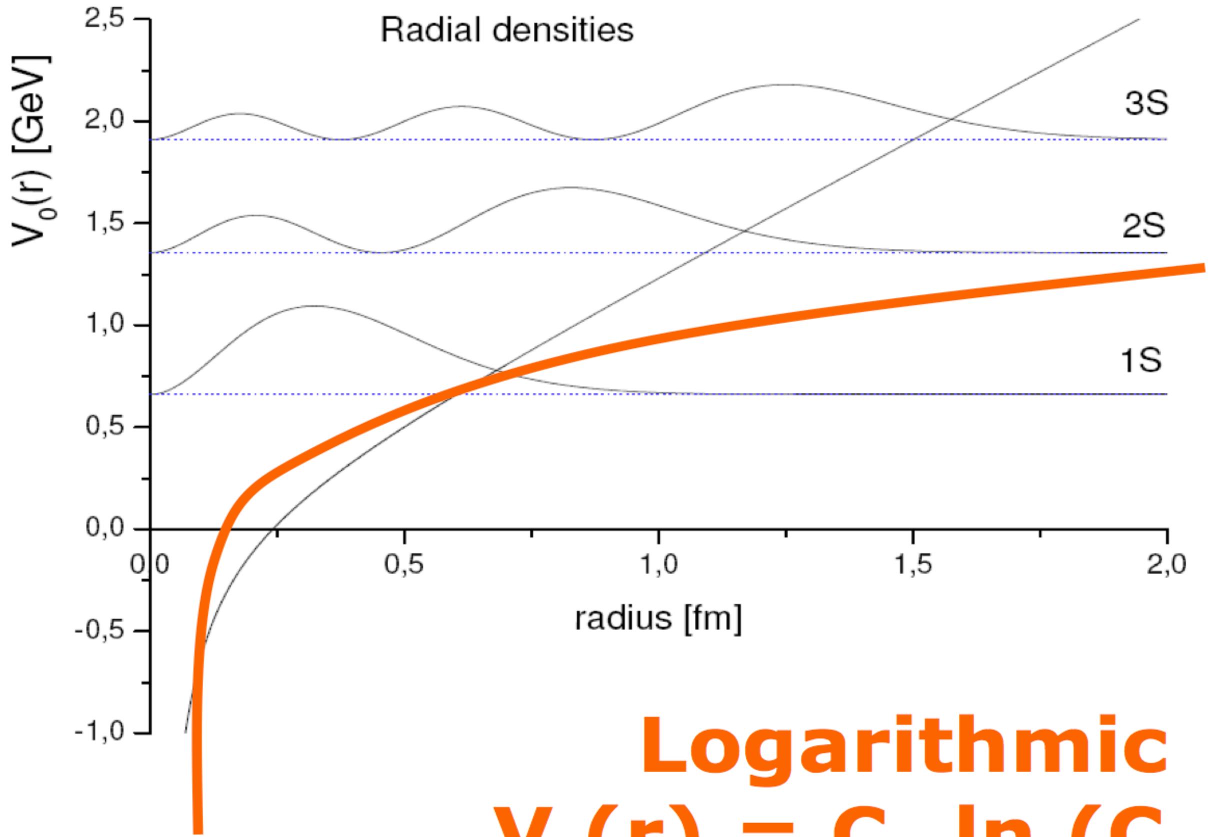


Flavor Independence - Logarithmic Potential?





e.g. C. Quigg, hep-ph/9707493



Logarithmic

$$V(r) = C_1 \ln (C_2 r)$$

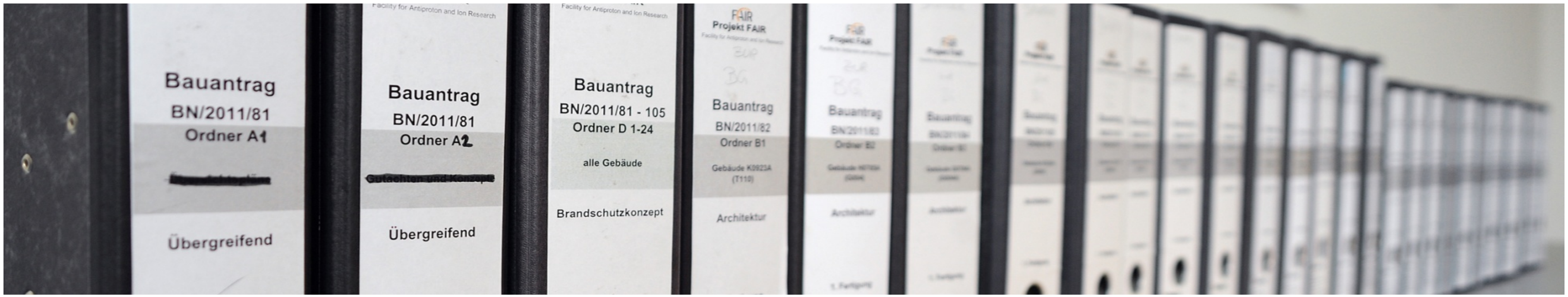
strong and international collaboration

> 400 scientists almost 60 Institutions

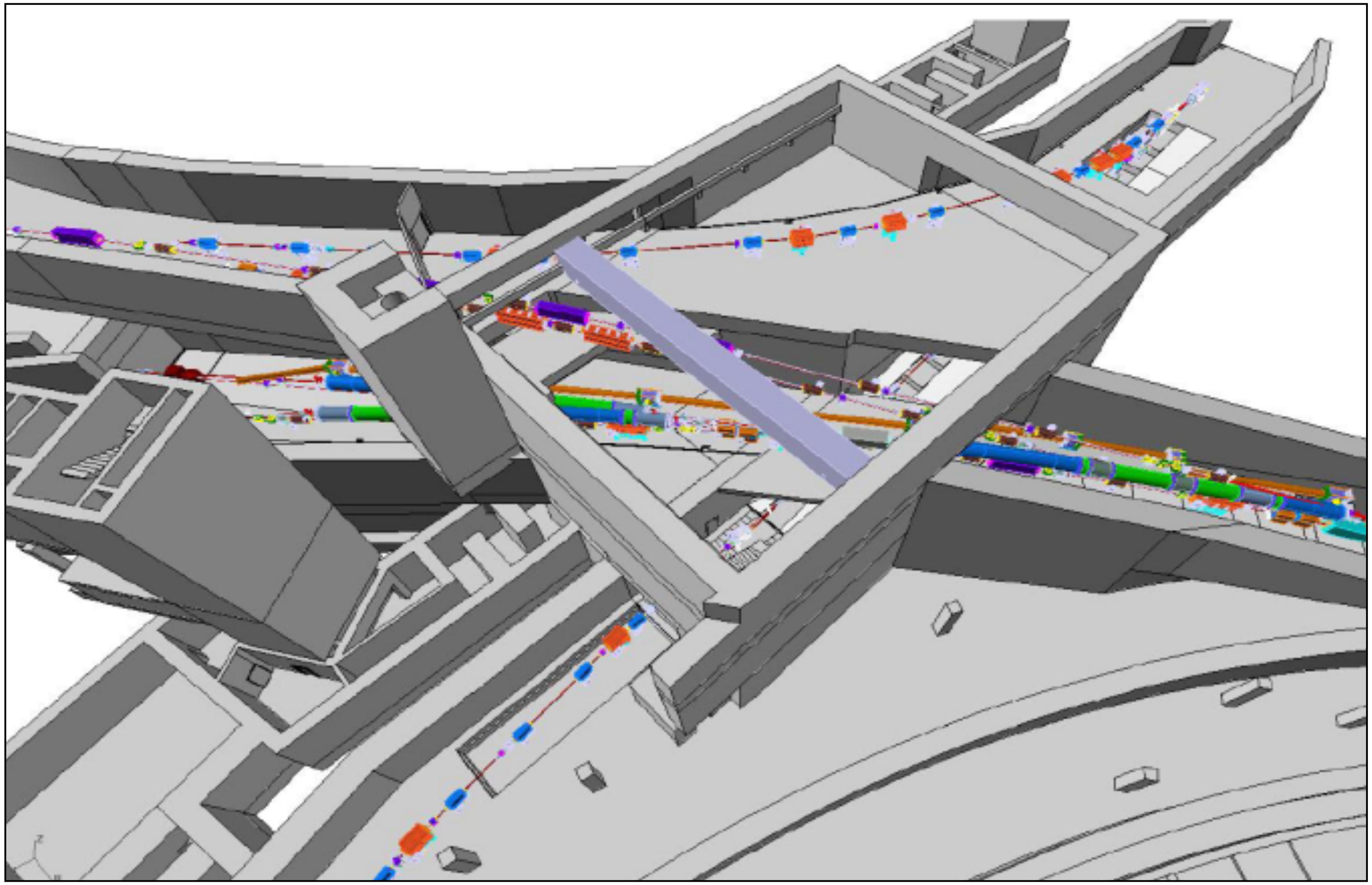
Construction Site today

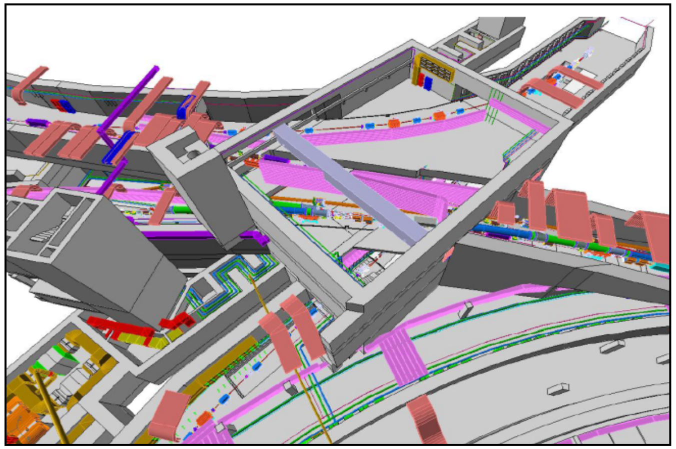
Status of Licensing Applications / Permits

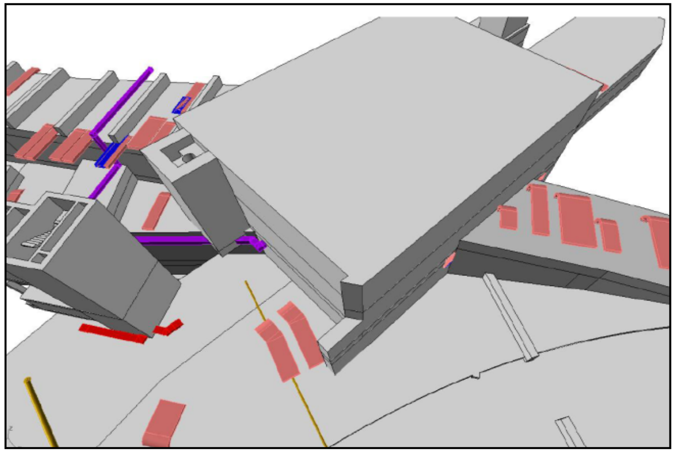
	III / 12	IV/ 1		II / 13
Building permit	**29.10.12**			
Permit for water rights (piling works)	**14.11.12**			
Permit for water rights (groundwater lowering)				**soon**
3. partial permit of radiation protection (Geb. 007)				**soon**
Complete permit of radiation protection				**soon**



Planning Activities

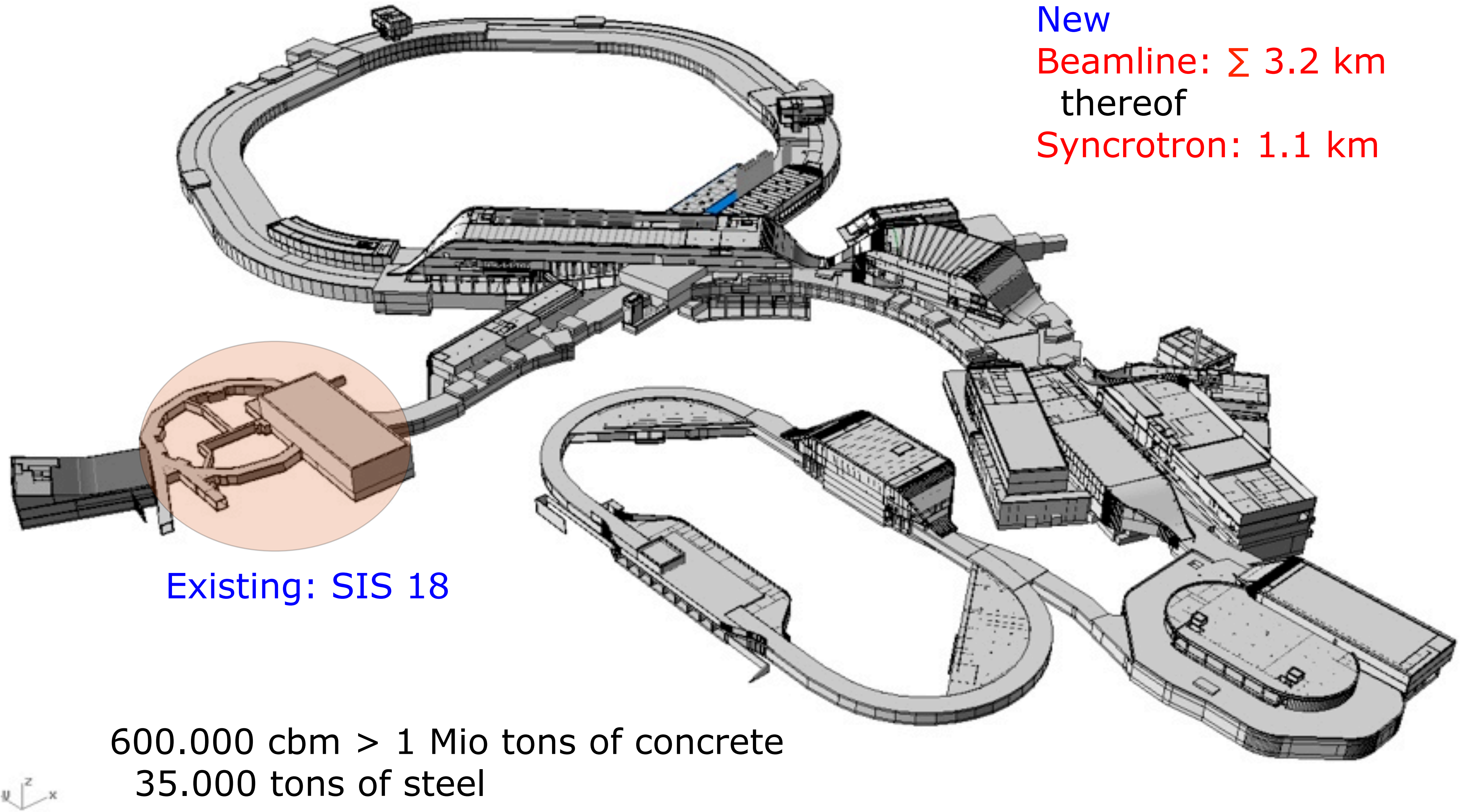






Civil Engineering

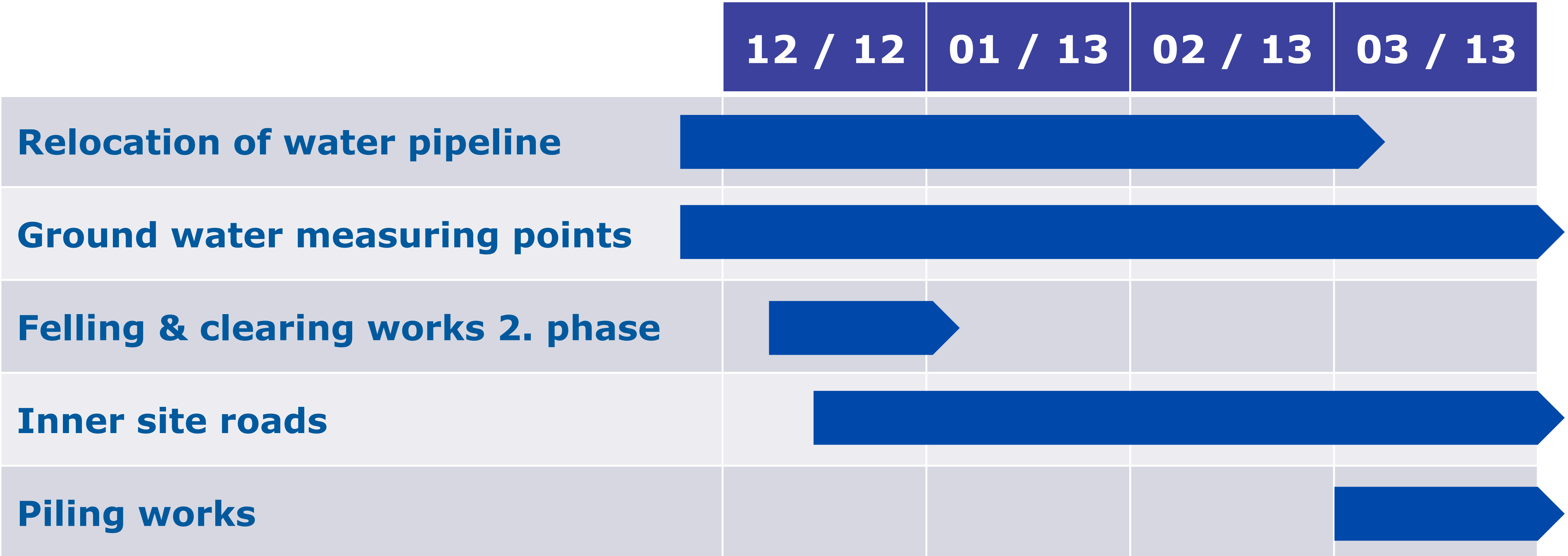
New
Beamline: ∑ 3.2 km
thereof
Syncrotron: 1.1 km



Existing: SIS 18

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

Status of Prepation / Construction Works



THANK YOU