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PANDA at FAIR

Tord Johansson
Uppsala University, Sweden
representing the PANDA collaboration

Excited QCD 2012

Peniche, Portugal
6 -12 May 2012

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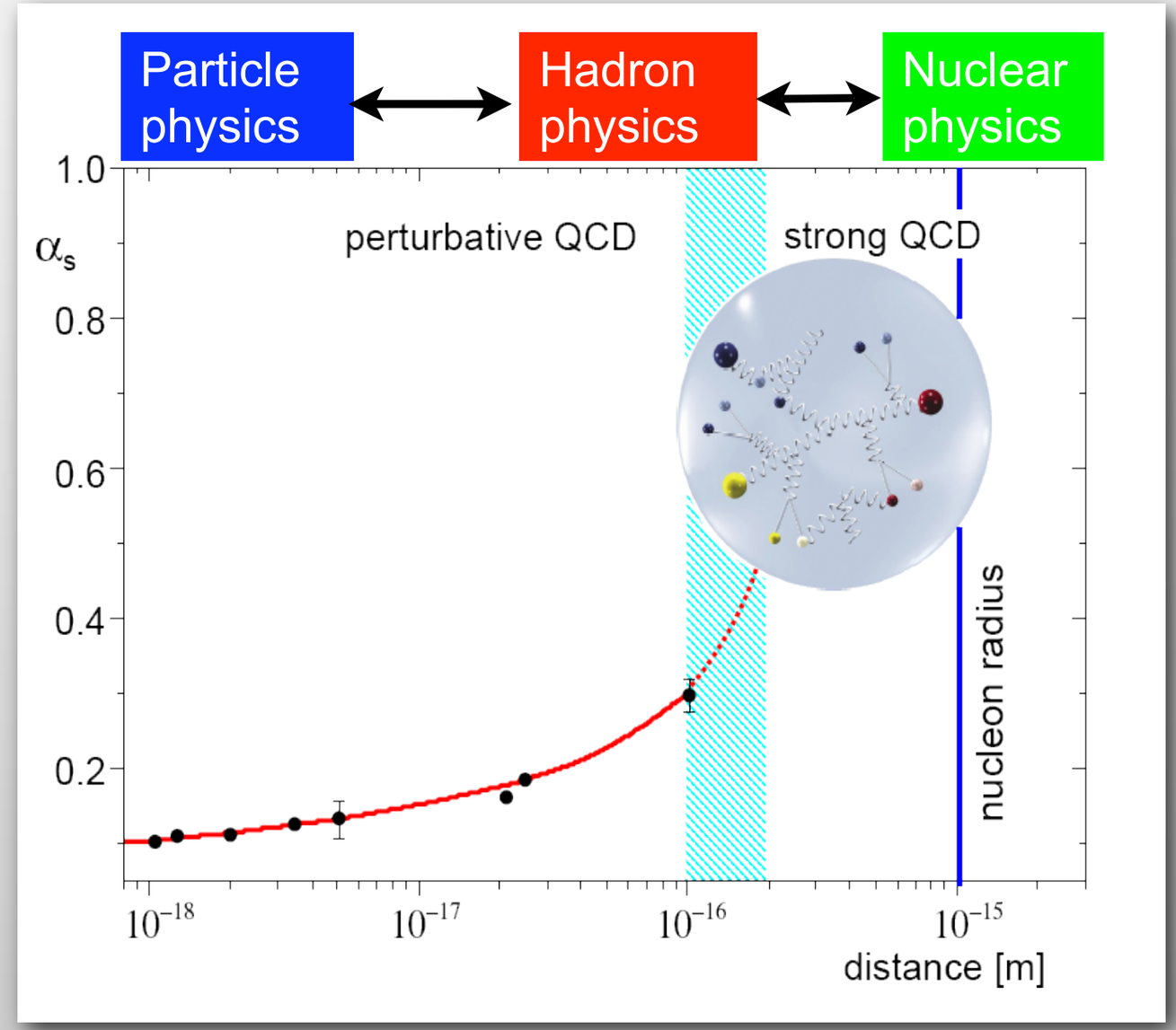
Hadron physics with PANDA:

Study of the **strong interaction** in the transition region between perturbative QCD and nuclear phenomena



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Open questions to be addressed:

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- Spin degrees of freedom?

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Physics with antiprotons:

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- interaction of hadrons

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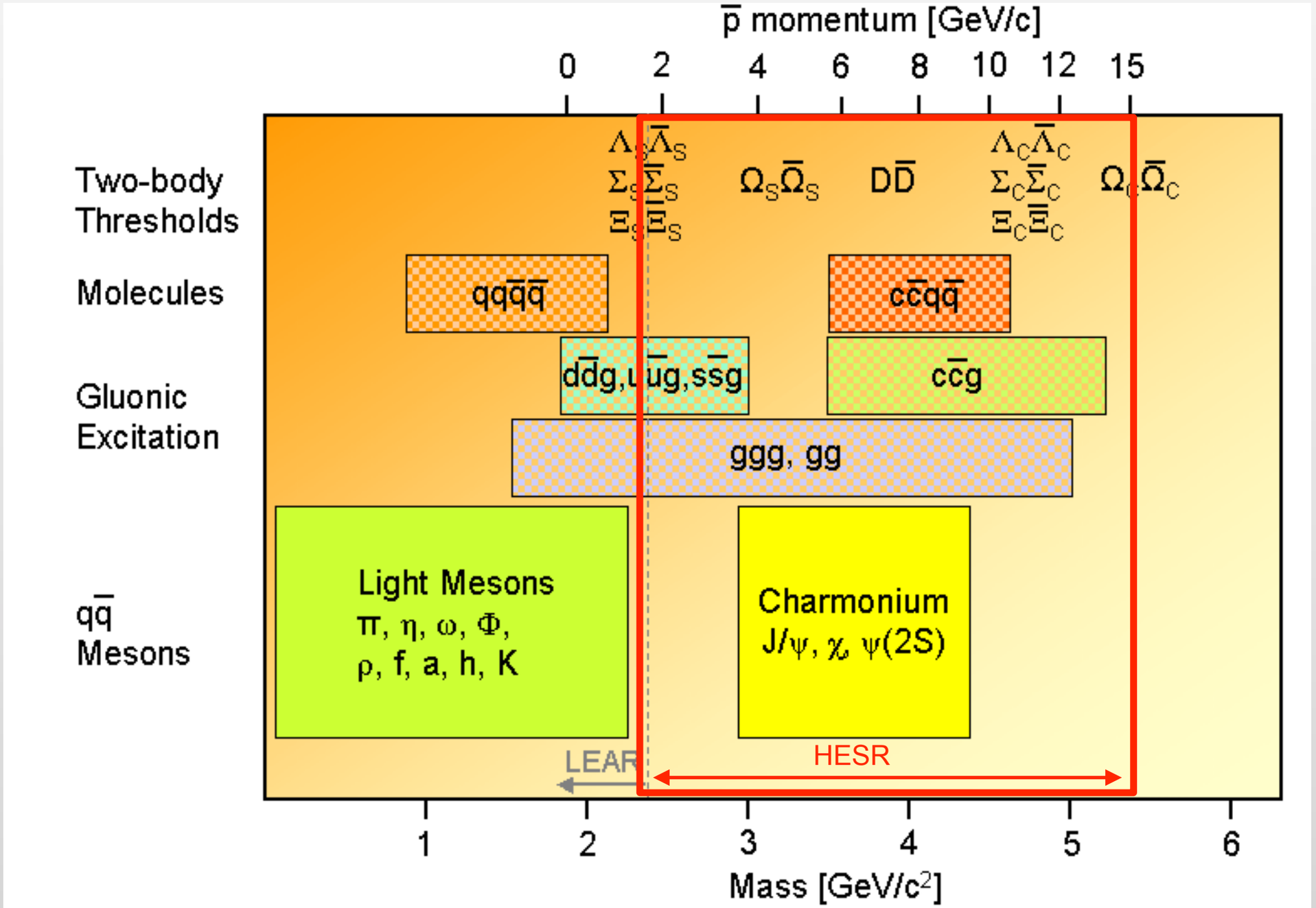

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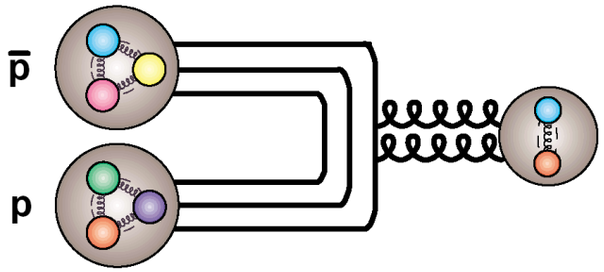
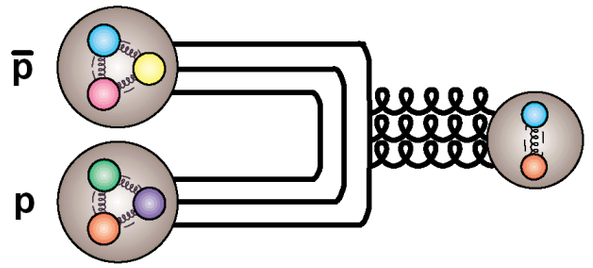
Particle production in $\bar{p}p$ interaction

Formation:



$J = 0, 2, \ldots$
$C = +$



$J = 1$
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All J^{PC} allowed for $(q\bar{q})$ are accessible in $\bar{p}p$

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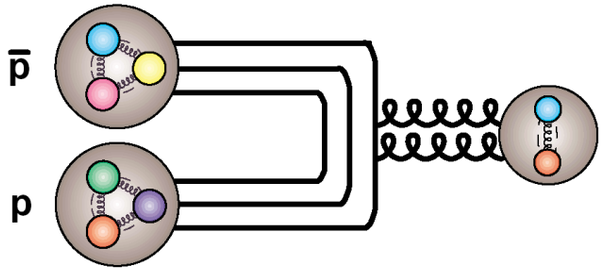

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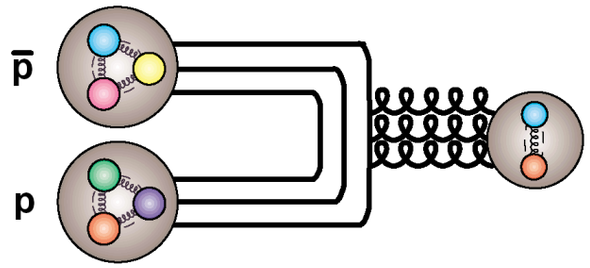

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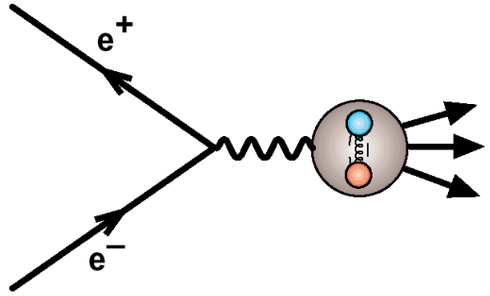

$J^{PC} = 1^{--}$

Only $J^{PC} = 1^{--}$ allowed in e^+e^-

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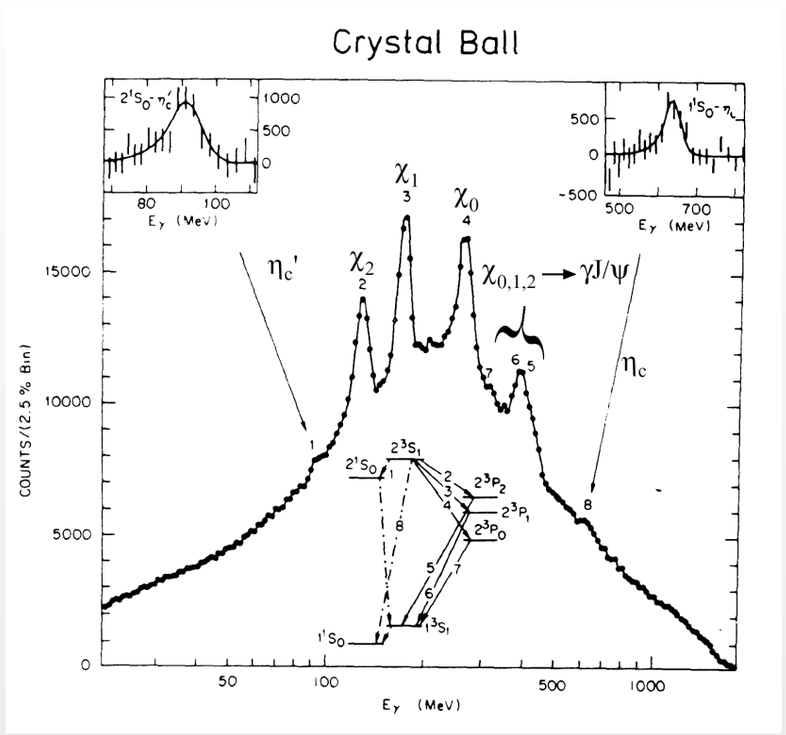
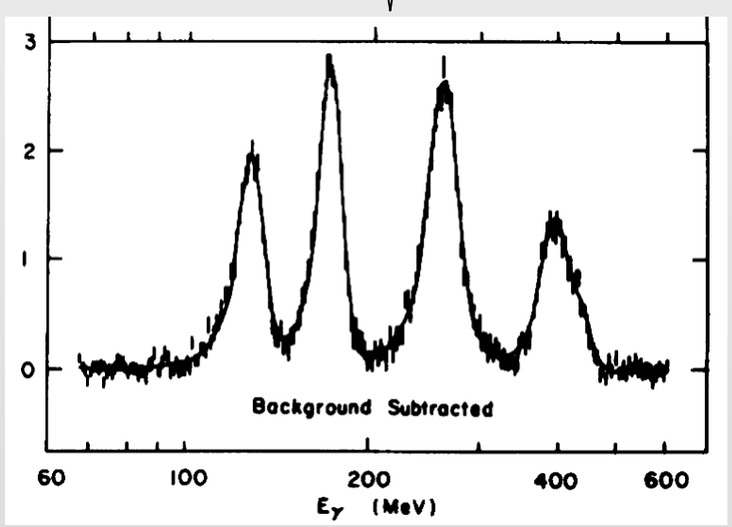
$\chi_{1,2}$





$$e^+e^- \rightarrow \psi' \rightarrow \gamma\chi_{1,2} \rightarrow \gamma\left(\gamma \mathrm{J}/\psi\right) \rightarrow \gamma\gamma e^+e^-$$

Invariant mass reconstruction depends the the detector resolution ≈ 10 MeV

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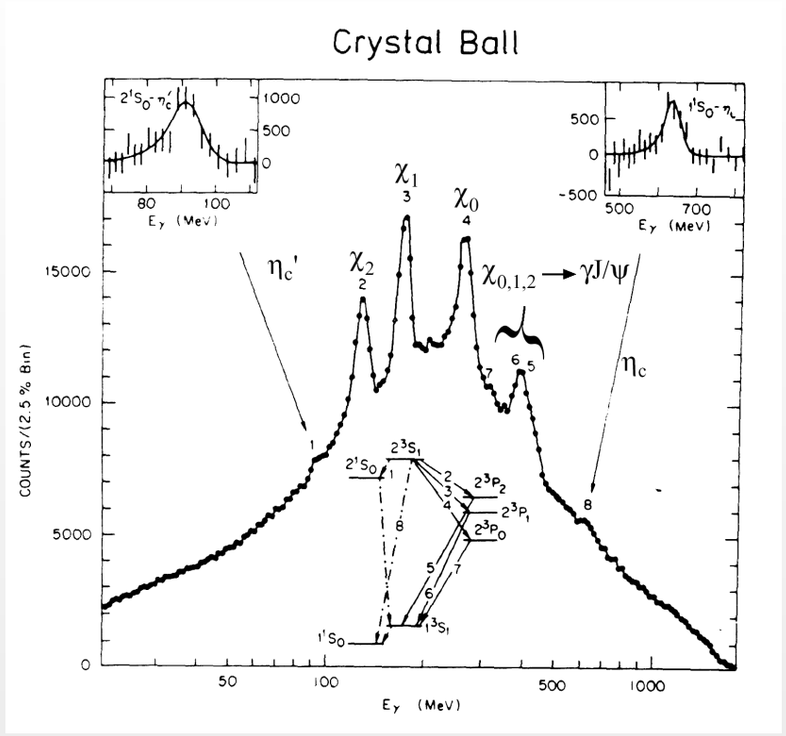

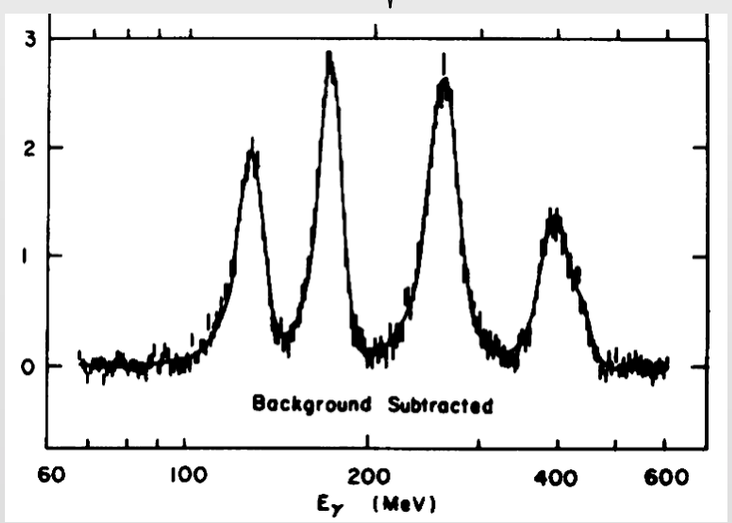

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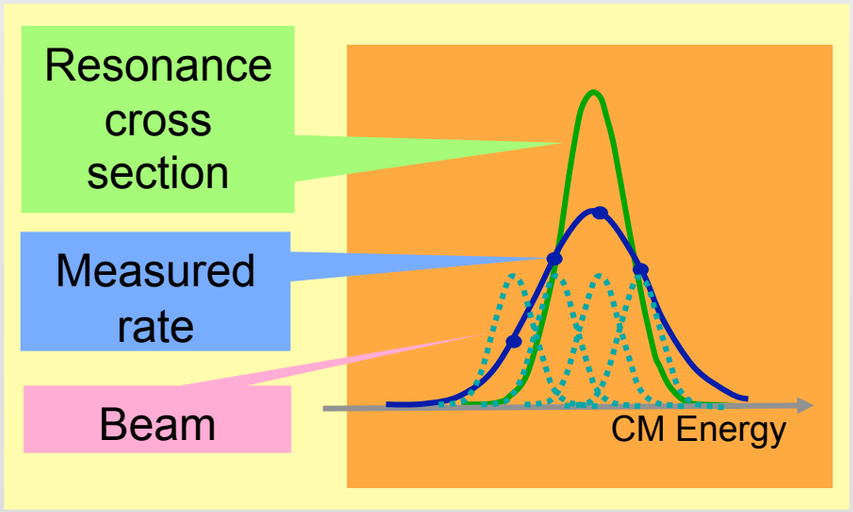

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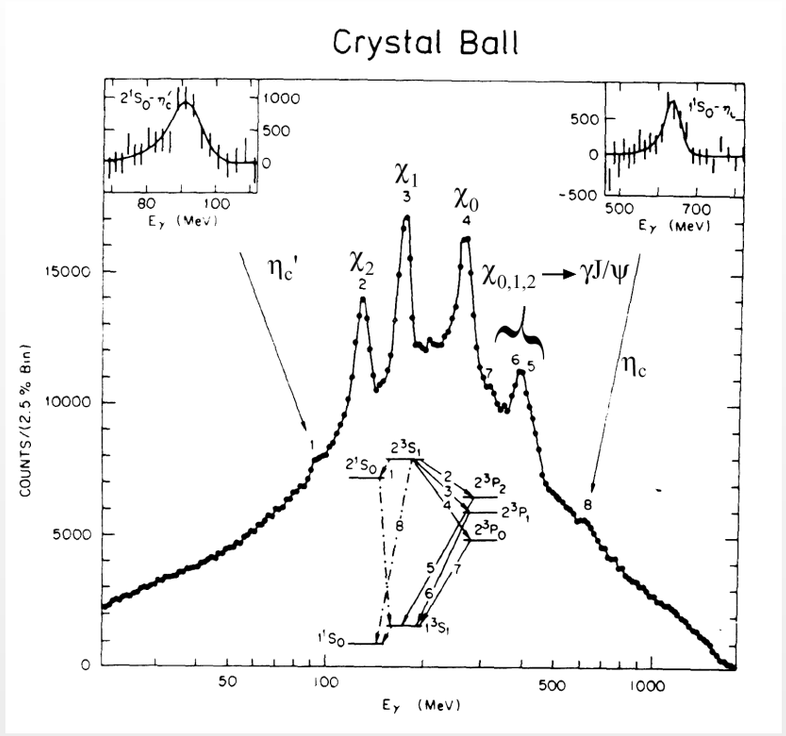

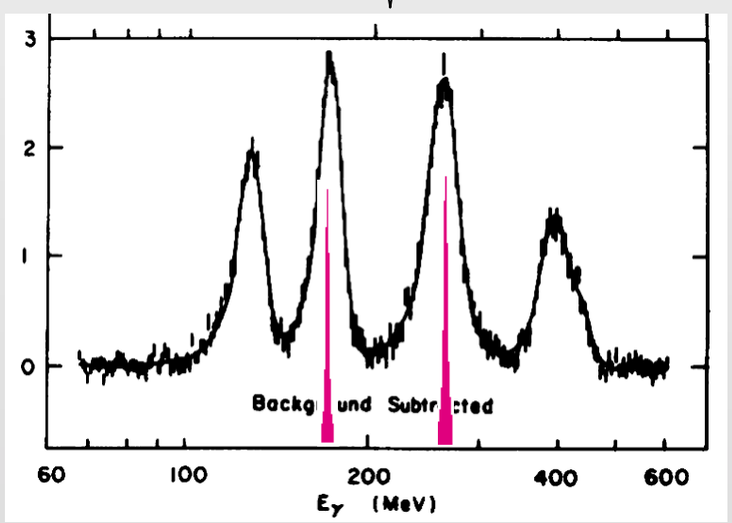

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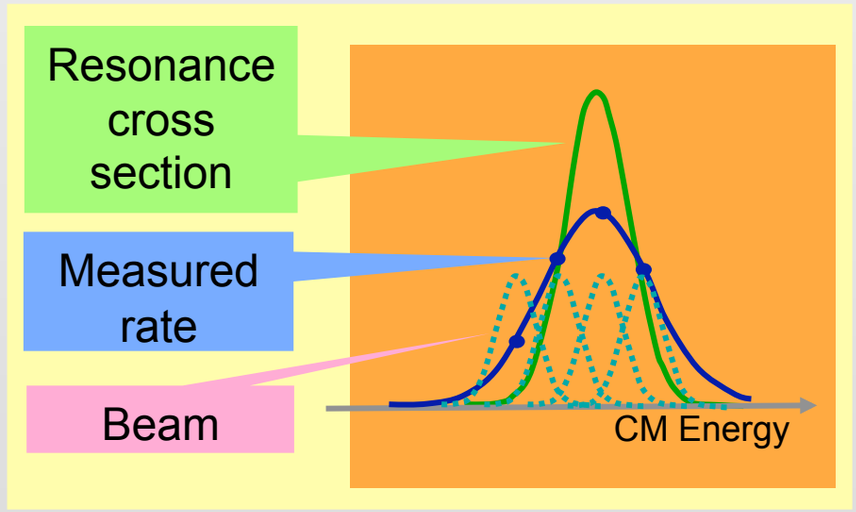

E760@Fermilab ≈ 240 keV

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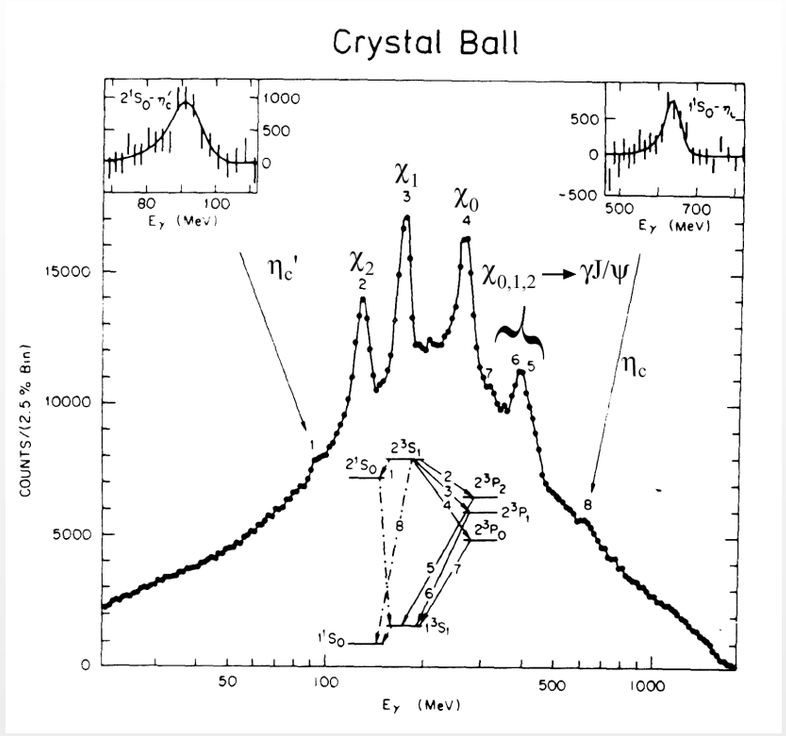

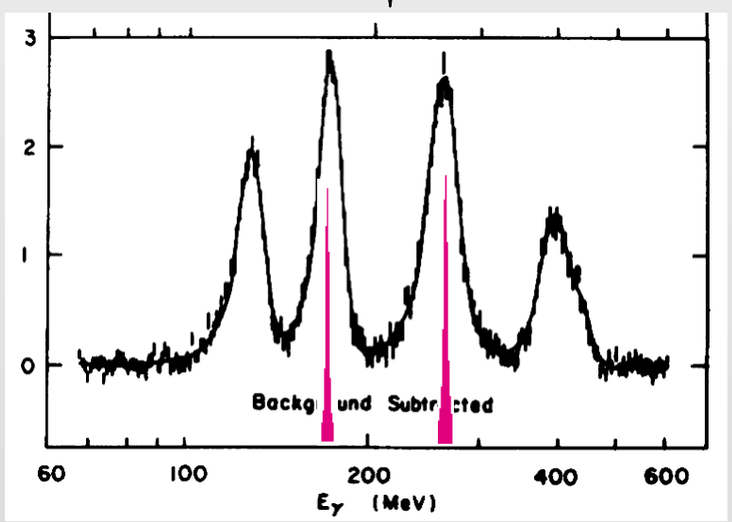

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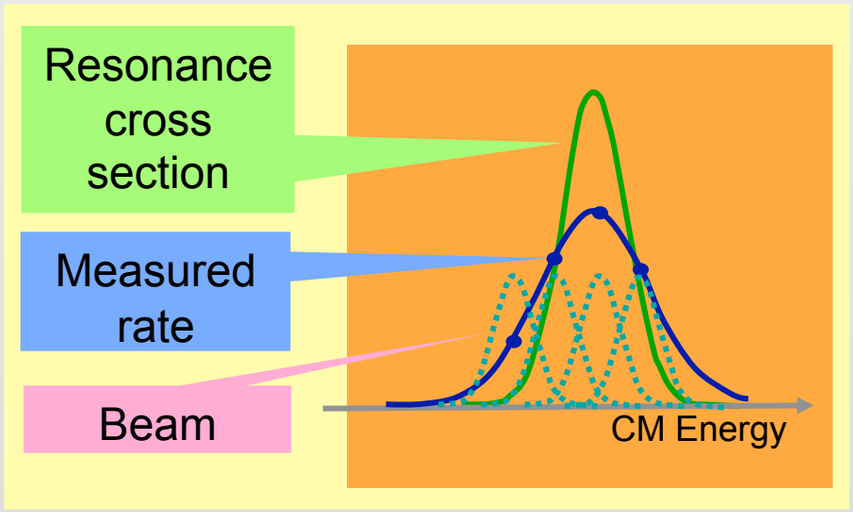

E760@Fermilab ≈ 240 keV

PANDA ≈ 50 keV

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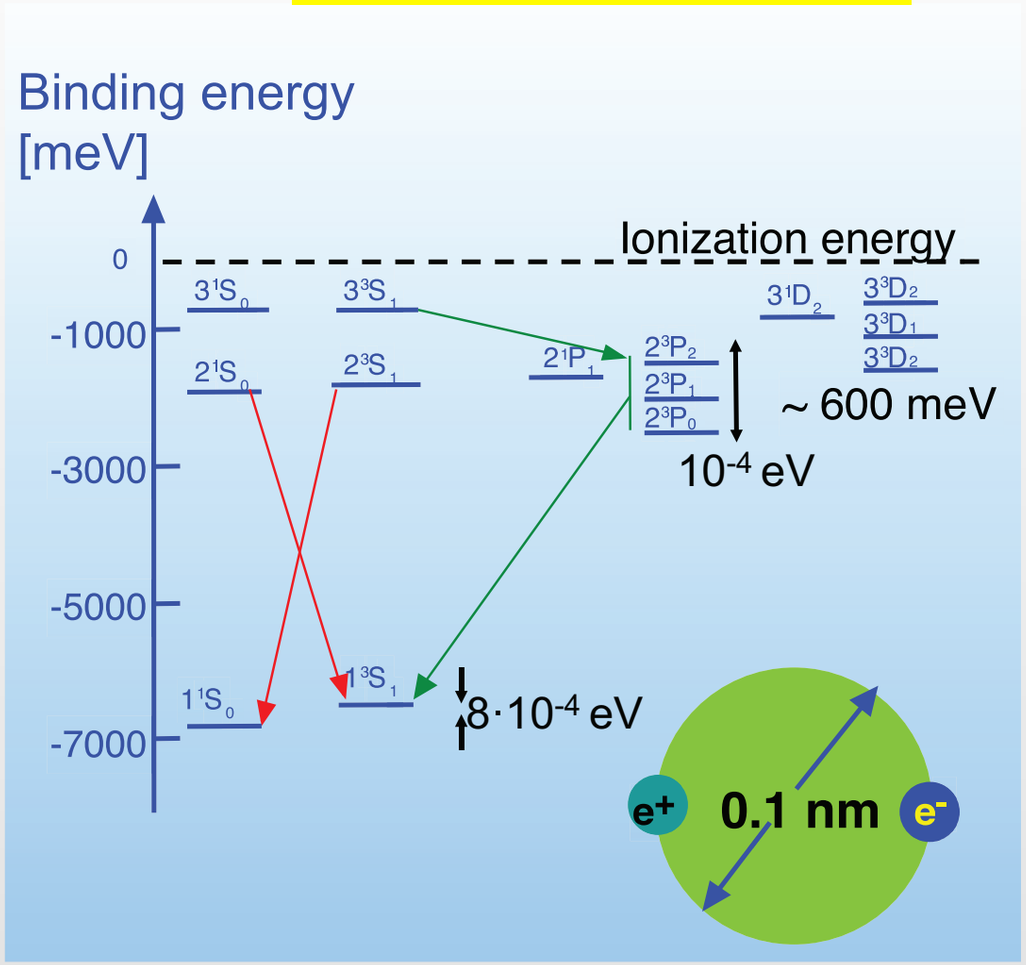
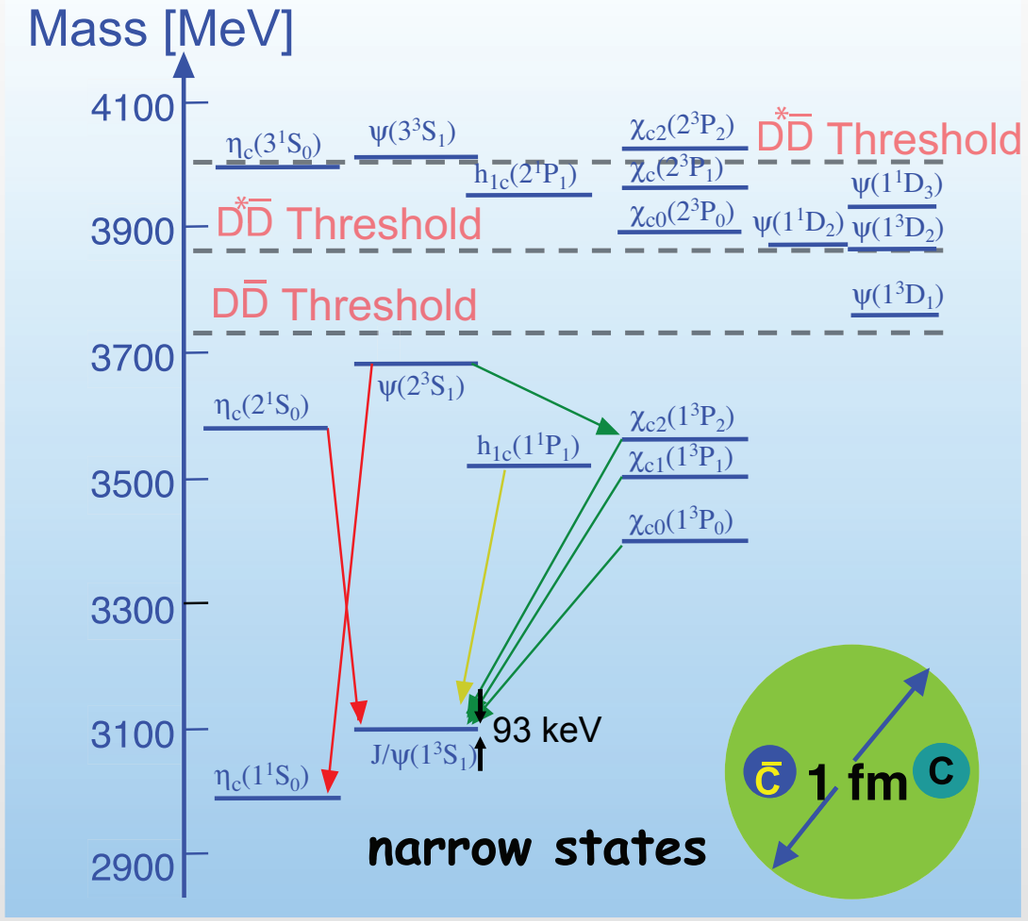
Positronium - QED



Charmonium - QCD



Coulomb-like potential: $V(r) = -\frac{4}{3}\frac{\alpha_s(r)\hbar c}{r} + kr \quad ; k \approx 0.9$ GeV/fm

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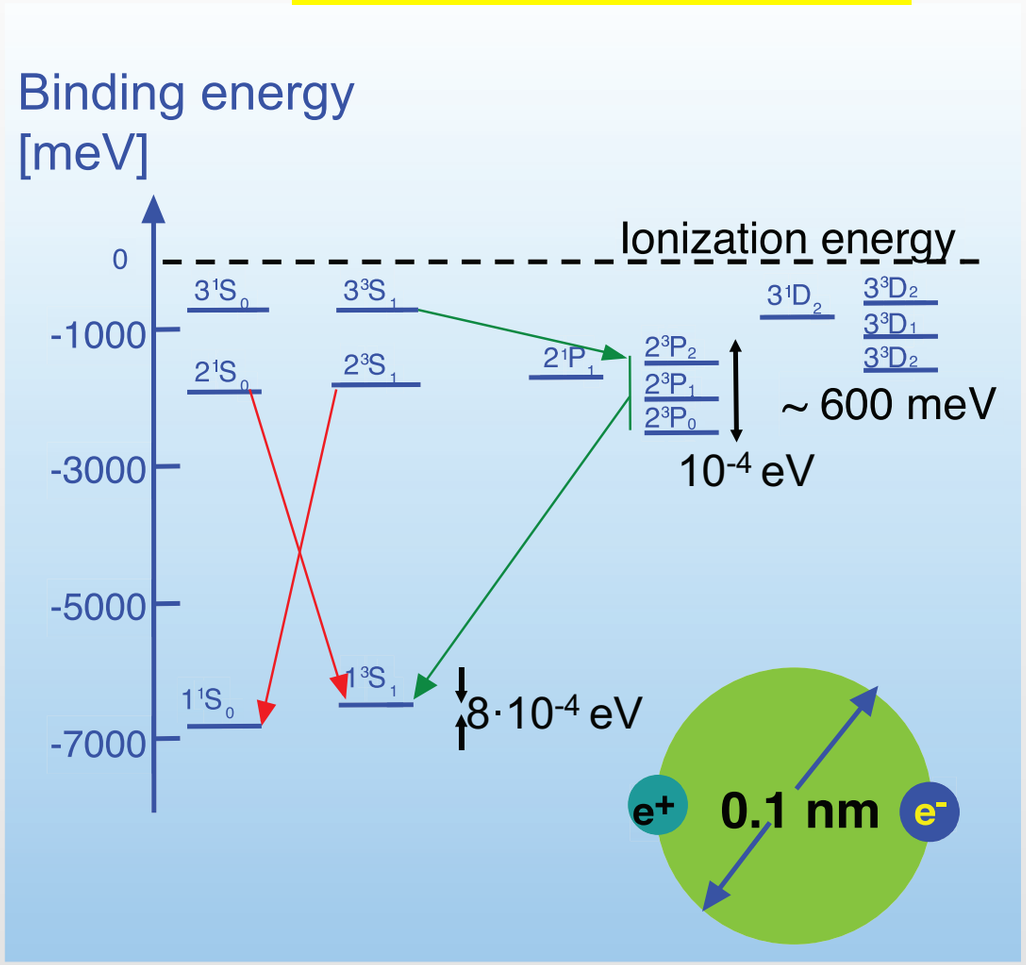

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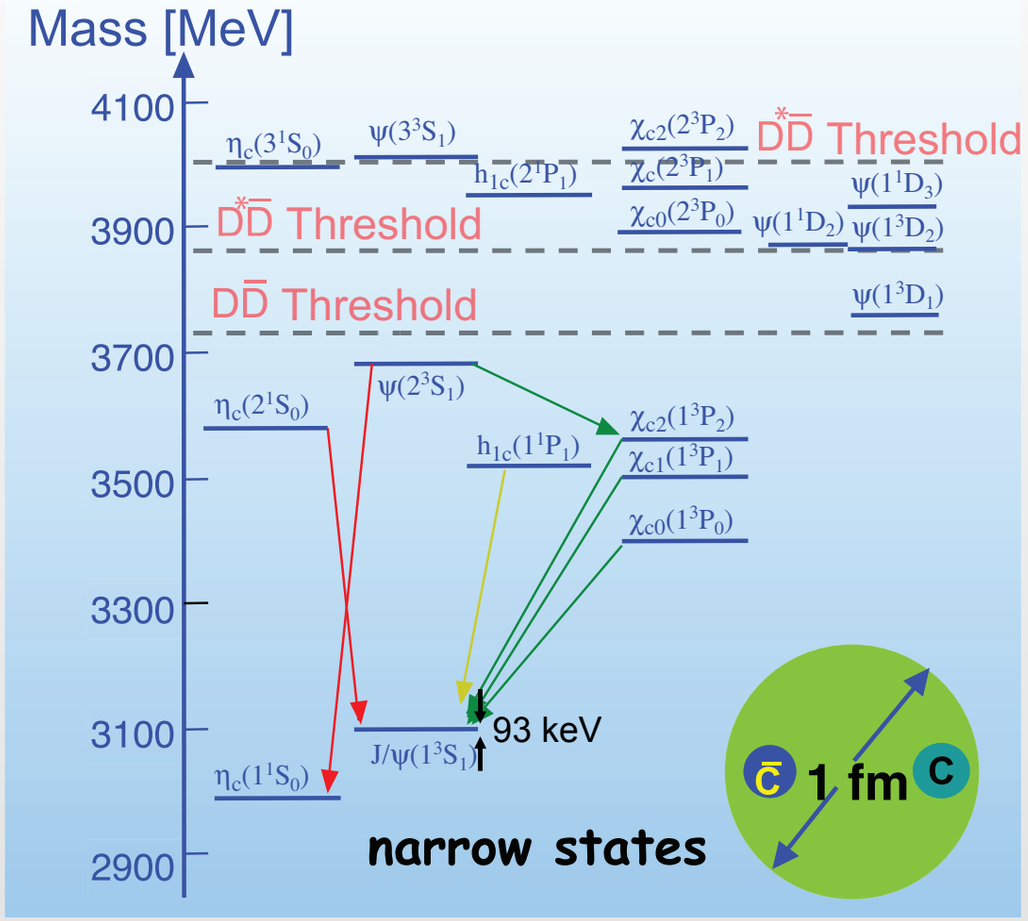

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Works for lower part of the spectrum

Info on confinement potential and spin contributions

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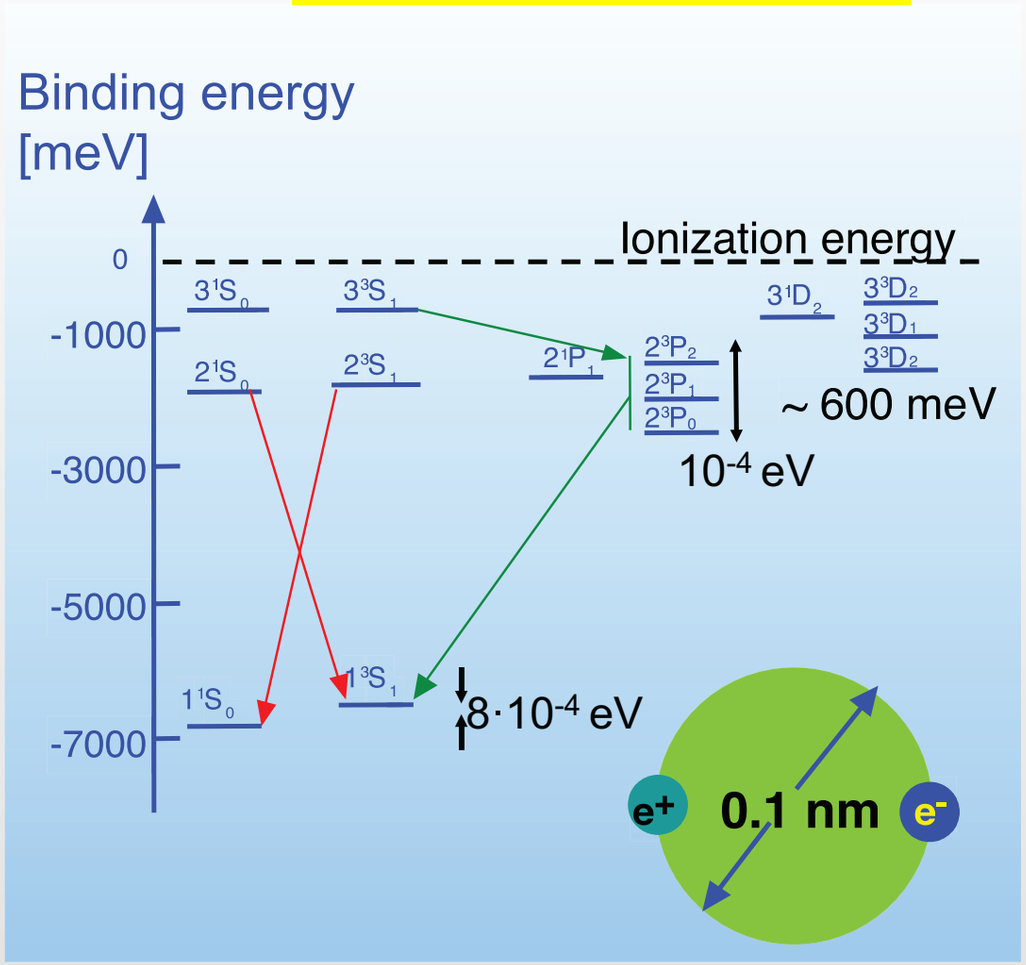

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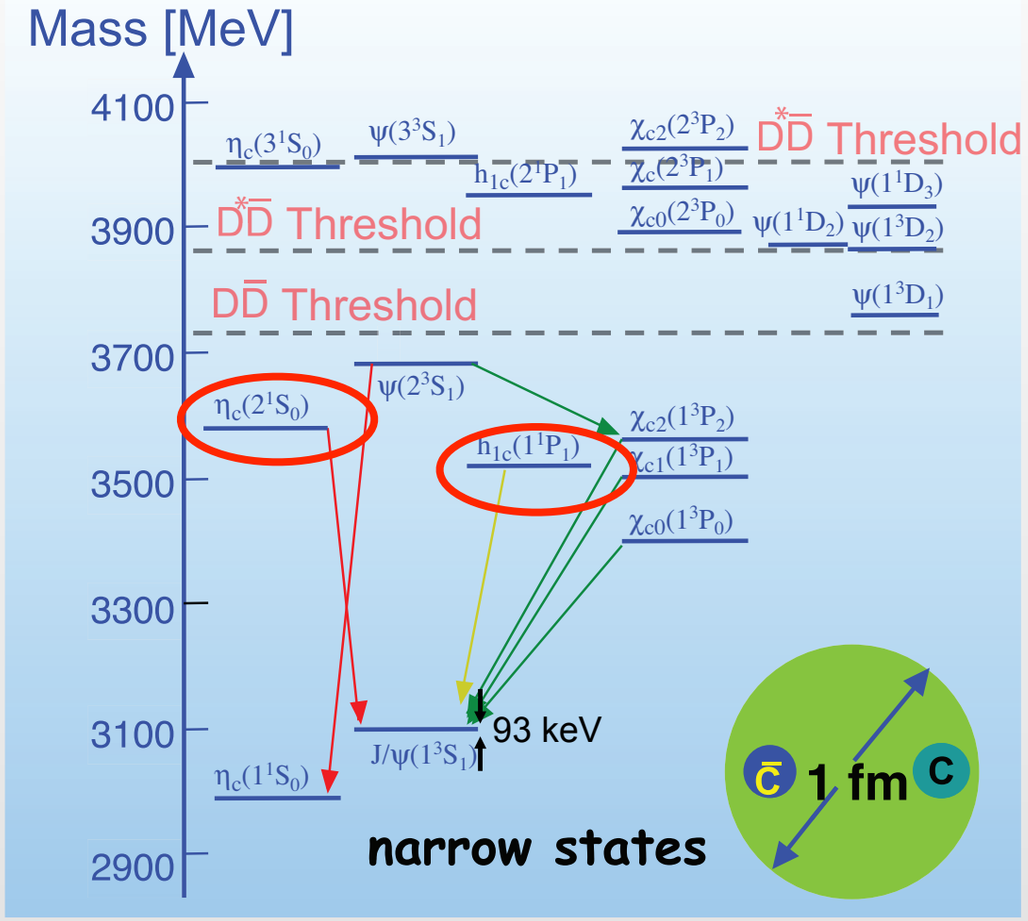

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Unconfirmed/unobserved states

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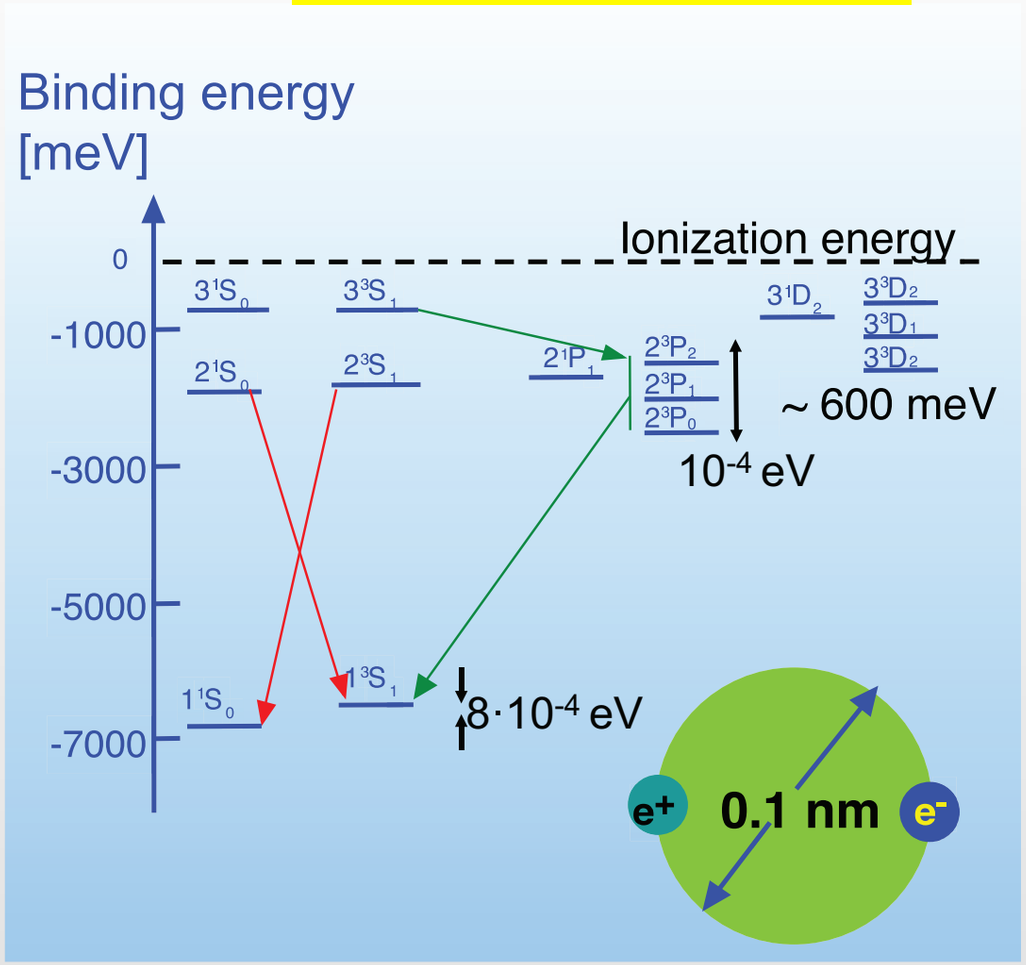

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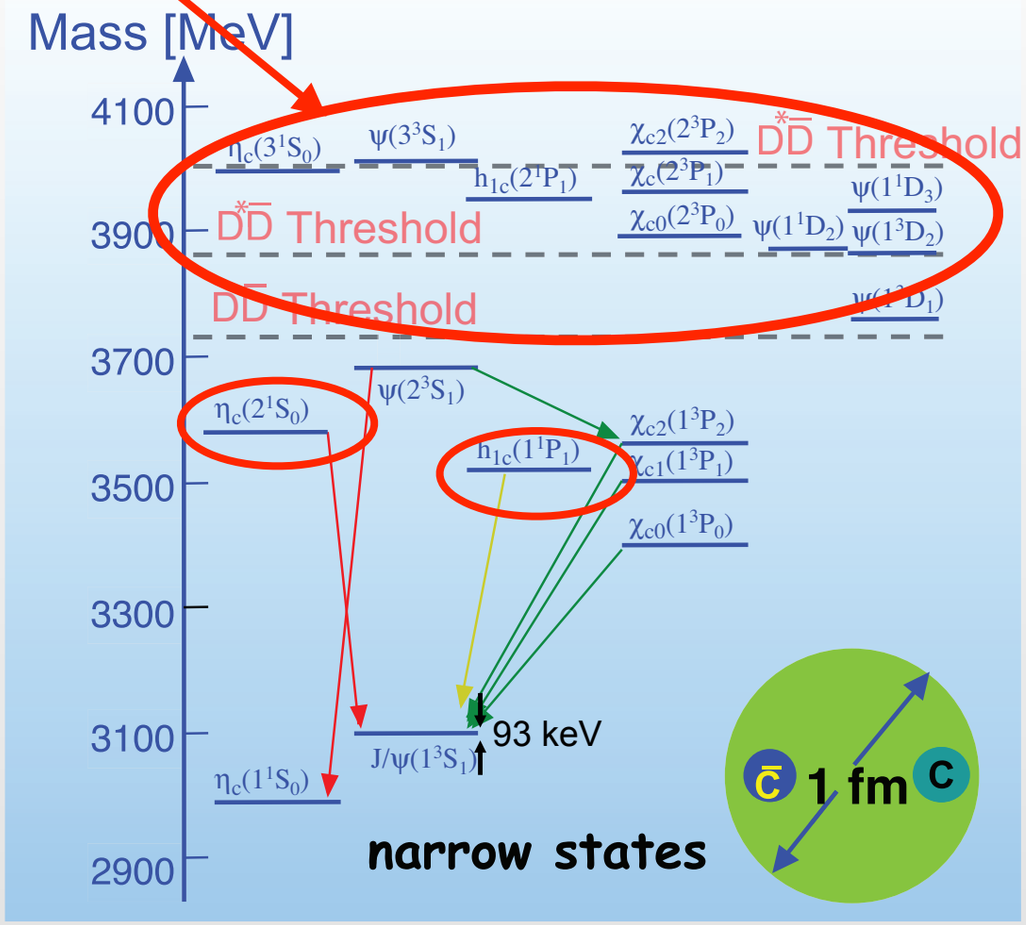

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Many new and narrow states recently observed in Charmonium region above $D\bar{D}$ threshold (X,Y,Z states)

State	Γ [MeV]	Experiment	1
X(3872)	3 ± 2	Belle, BaBar,CDF,D0	1^{++},2^{-+}?, D^0D^* molecule, tetraquark
X(3930)	29 ± 10	Belle	2^{++} χ_{c2} (2P)
X(3940)	< 52	Belle	$?^{??}$????
X(3945)	40 ± 18	Belle,BaBar	$?^{?+}$ η_c(3S)?
X(4160)	139±113	Belle	$?^{??}$????
Y(4260)	95 ± 9	BaBar, CLEO, Belle	1^{--} Hybrid, threshold effect
Y(4360)	75 ± 14	BaBar, Belle	1^{--} ????
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⋮

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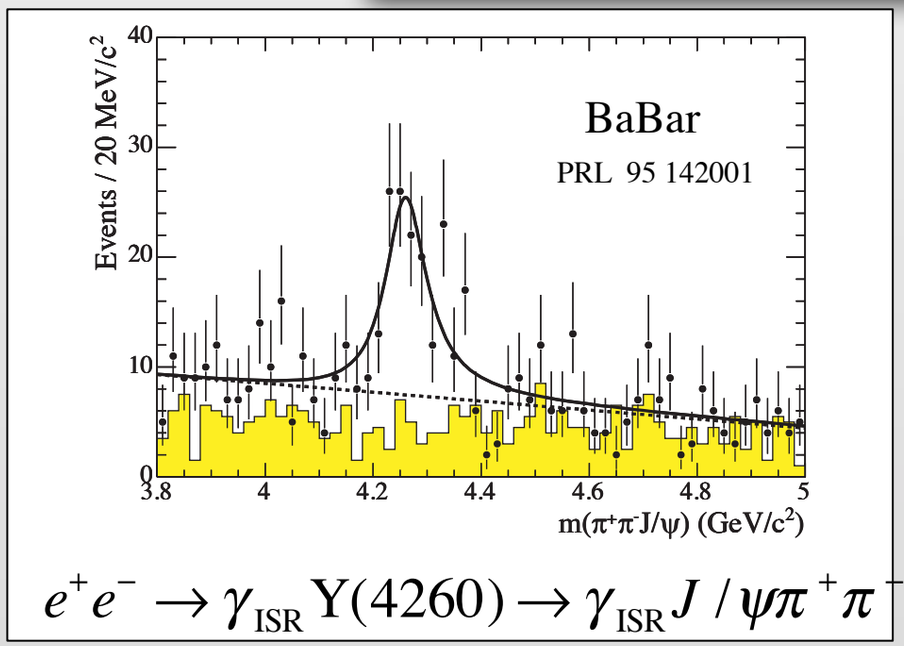

$$e^+e^- \to \gamma_{ISR}\,\mathrm{Y}(4260) \to \gamma_{ISR}\,J/\psi\pi^+\pi^-$$

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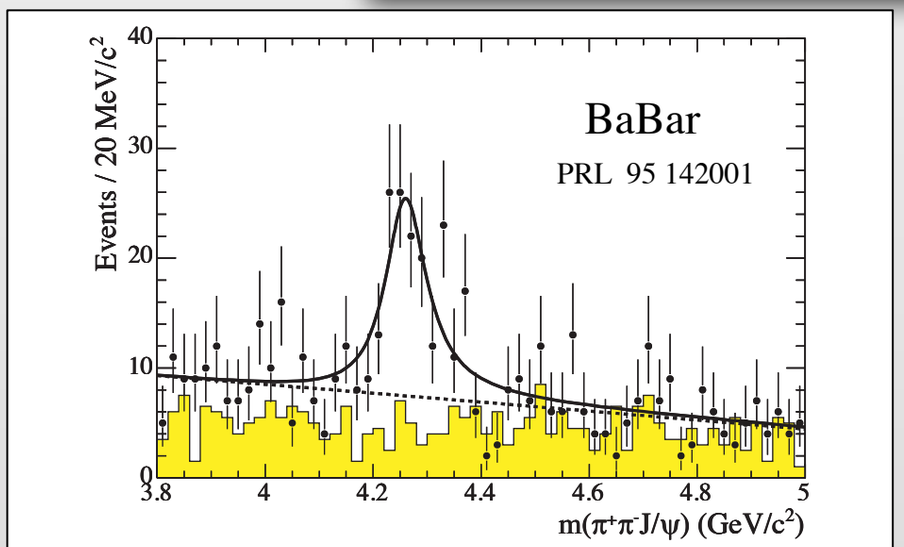

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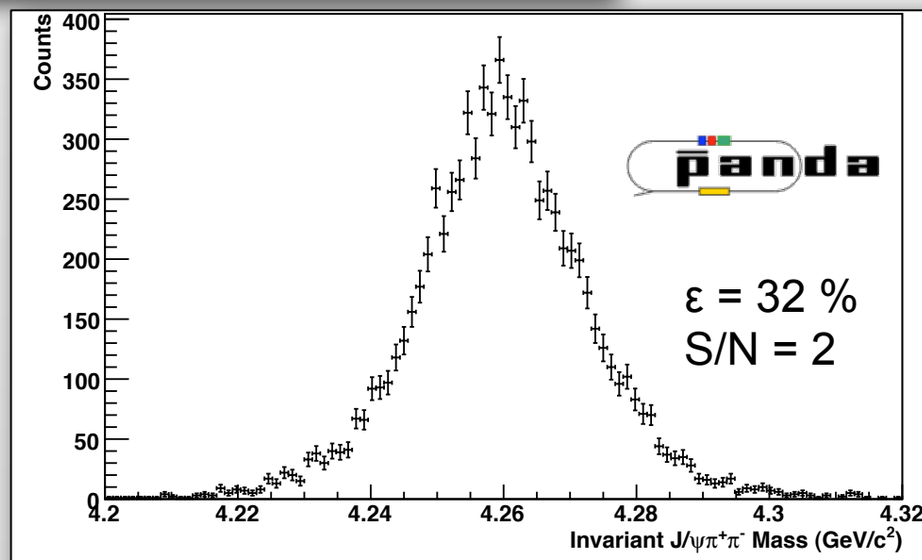

$$\bar{p}p \to \mathrm{Y}(4260) \to J/\psi\pi^+\pi^- \approx 100 \text{ events/day}$$

$$\to J/\psi\pi^0\pi^0 \approx 40 \text{ events/day}$$

S/N =25

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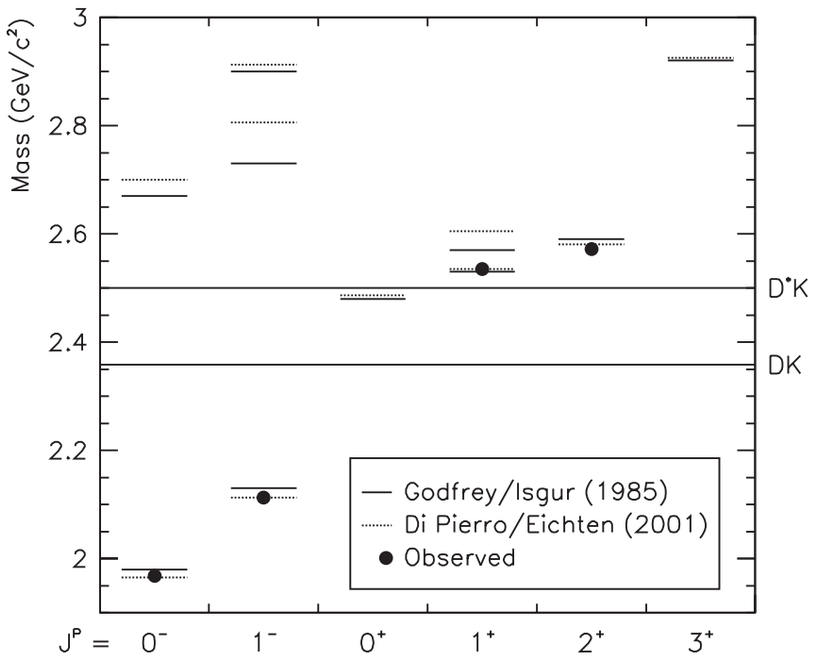
Open charm mesons

Hydrogen of QCD



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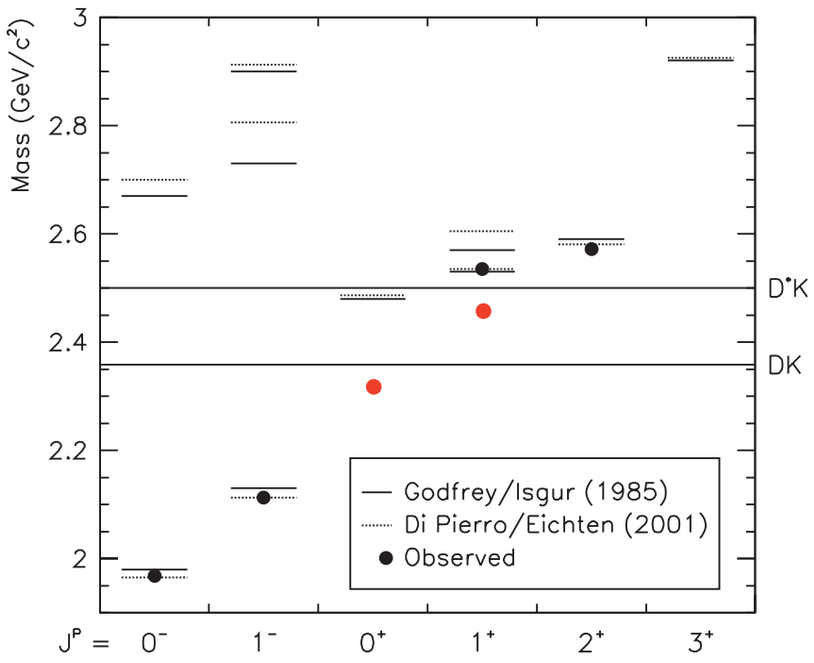
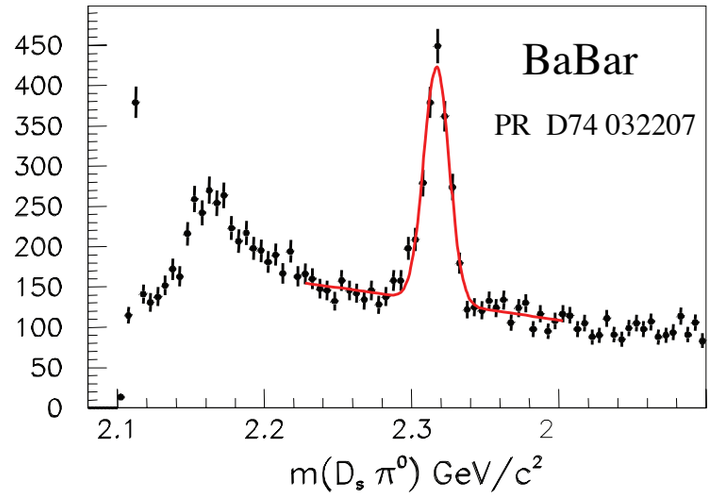


$D^*_{s0}(2317)$, $\Gamma < 3.8$ MeV



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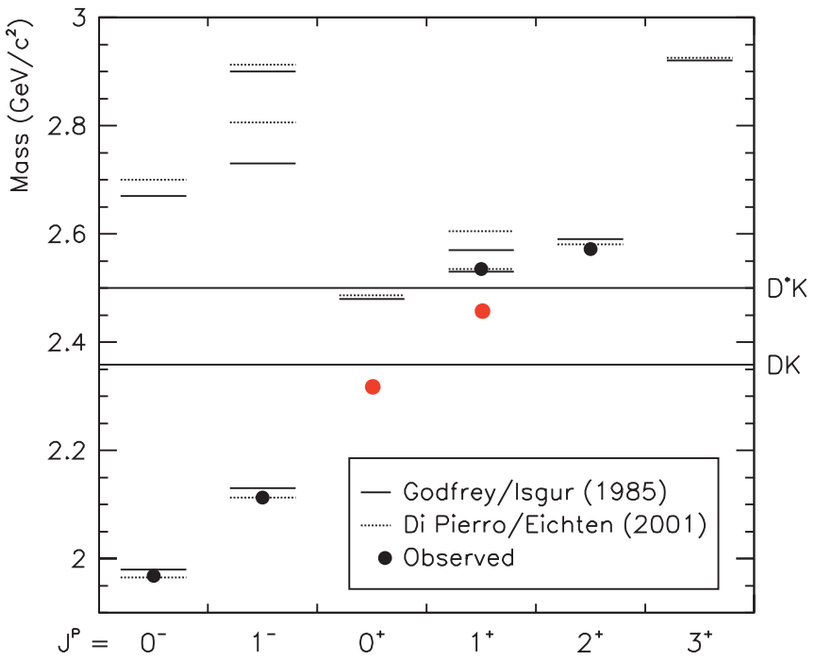

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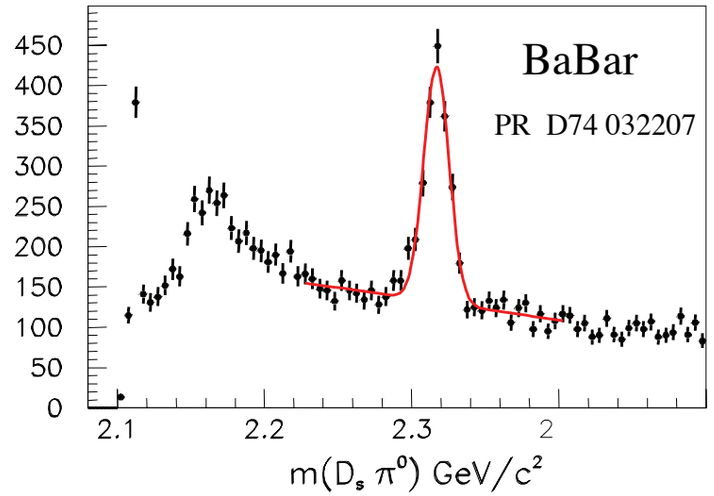

PANDA: $\bar{p}p \rightarrow D_s^{\pm} D_s^{*}(2317)^{\mp}$

14 days threshold scan

$\Delta\Gamma/\Gamma$ = 30% (Γ = 1 MeV)

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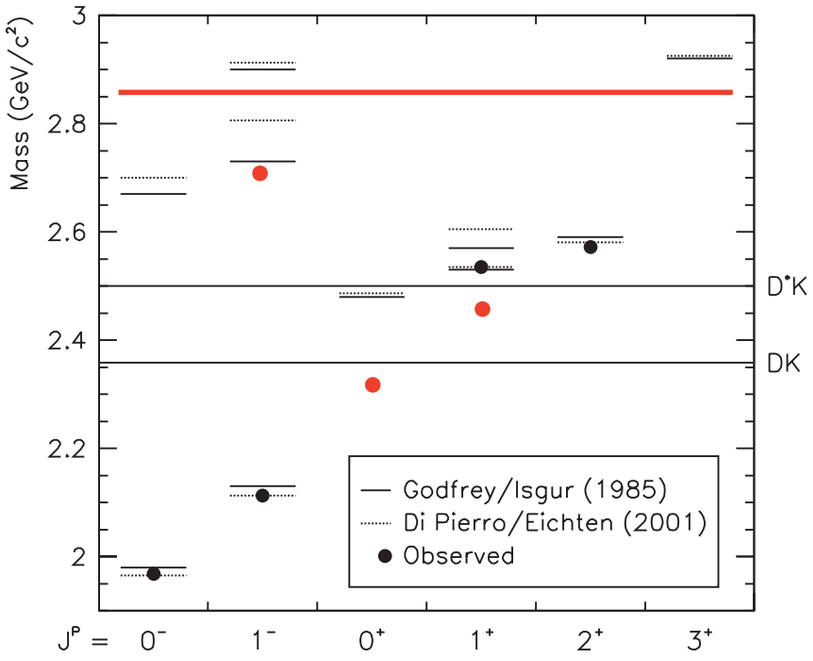
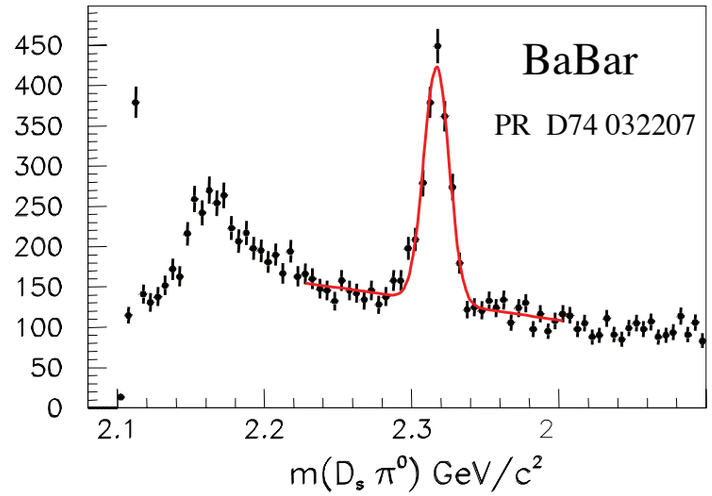
Hydrogen of QCD

BaBar PRL 97 (06) 222001
Belle PRL 100 (08) 092001



$D^*_{s0}(2317)$, $\Gamma < 3.8$ MeV



PANDA: $\bar{p}p \rightarrow D_s^{\pm} D_s^{*}(2317)^{\mp}$

14 days threshold scan

$\Delta\Gamma/\Gamma$ = 30% (Γ = 1 MeV)

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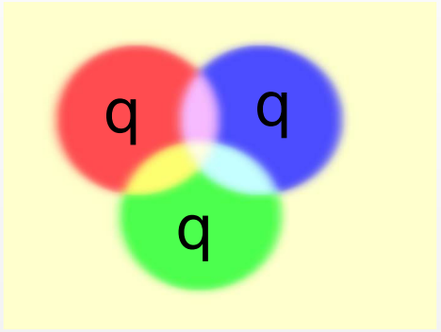
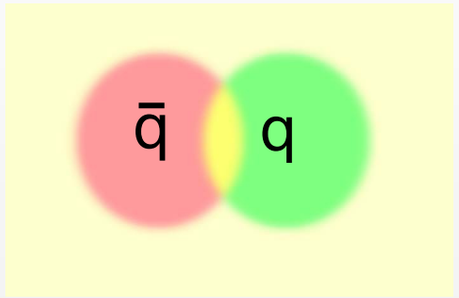
Beyond standard quark configurations

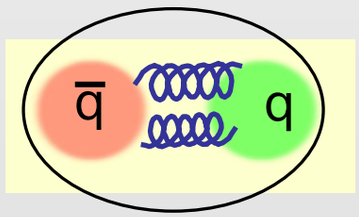


Baryons

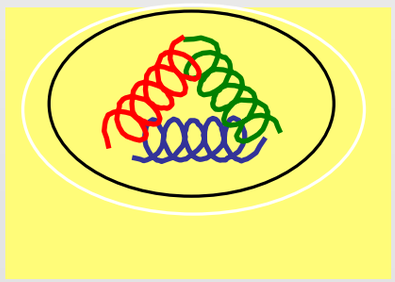


Mesons

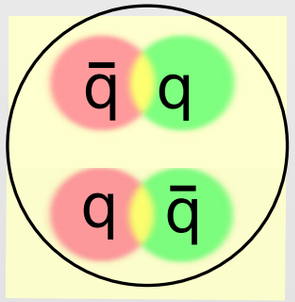
Exotics



Hybrids



Glueballs



Molecules

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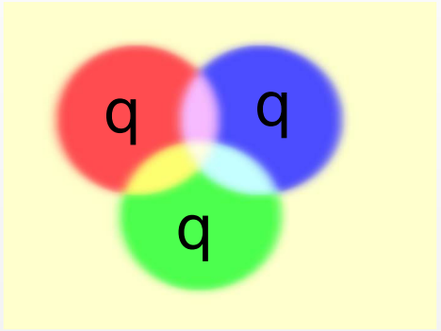
Beyond standard quark configurations



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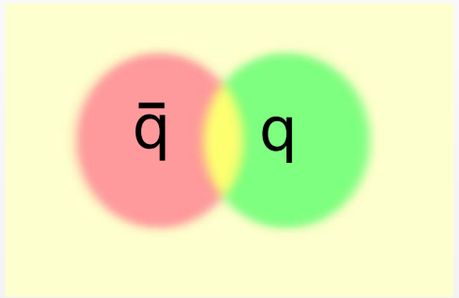

Mesons

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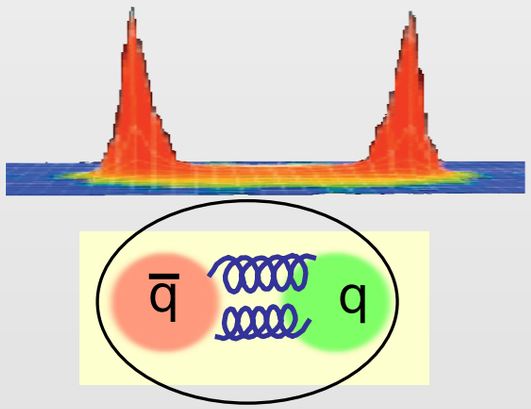

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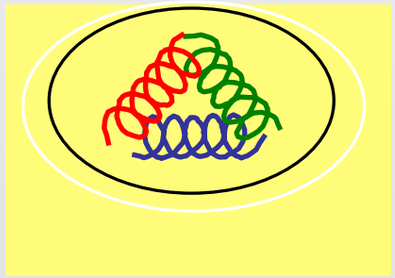

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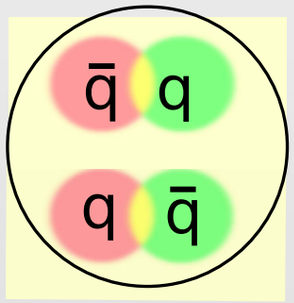

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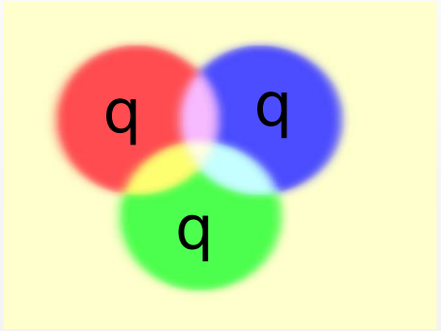

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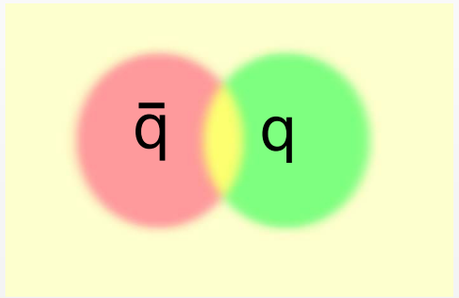

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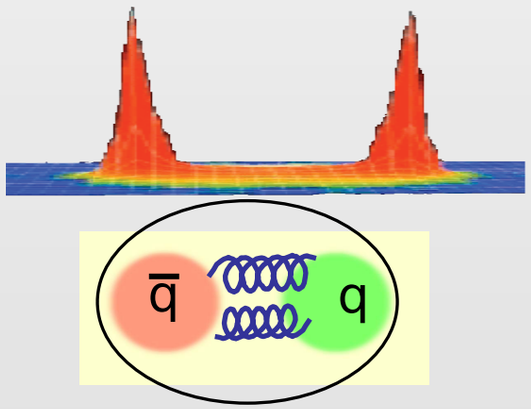

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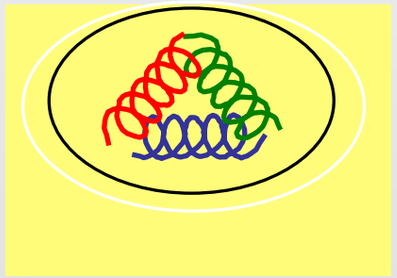

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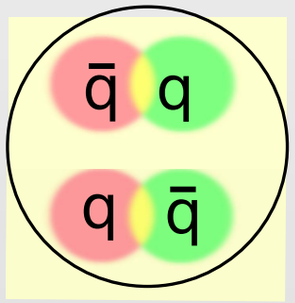

Molecules

J^{PC} not allowed for $q\bar{q}$ possible

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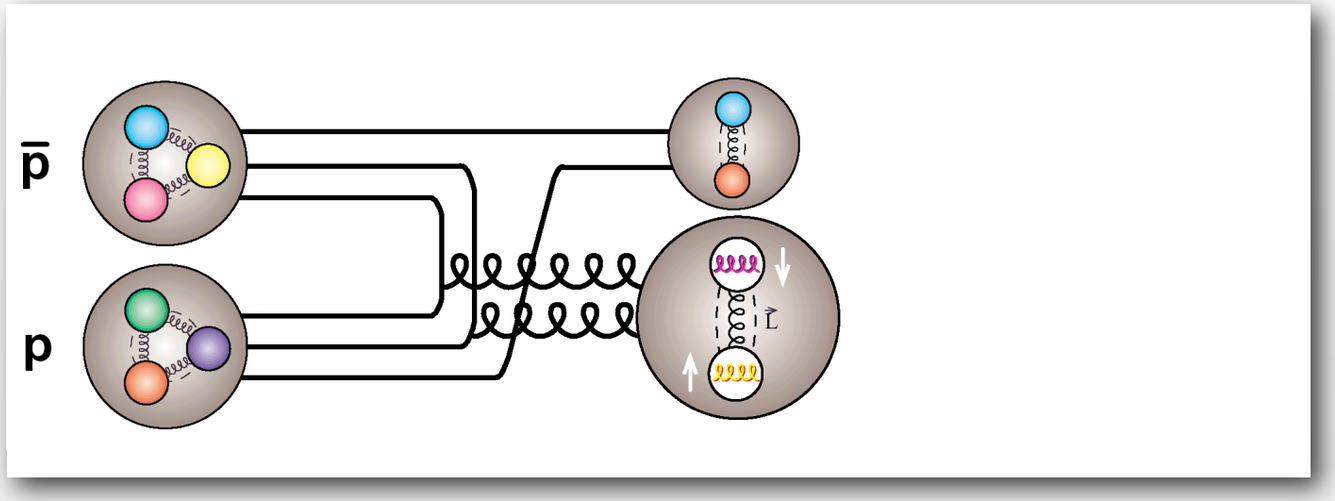
Particle production in $\bar{p}p$ interaction

Production:



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Good hunting ground for exotics

Fluxtube Hybrids

$q\bar{q}$ \ Gluon	1^{--} (TM)	1^{+-} (TE)
$^1S_0$, 0^{-+}	1^{++}	1^{--}
$^3S_1$, 1^{--}	0^{+-}	0^{-+}
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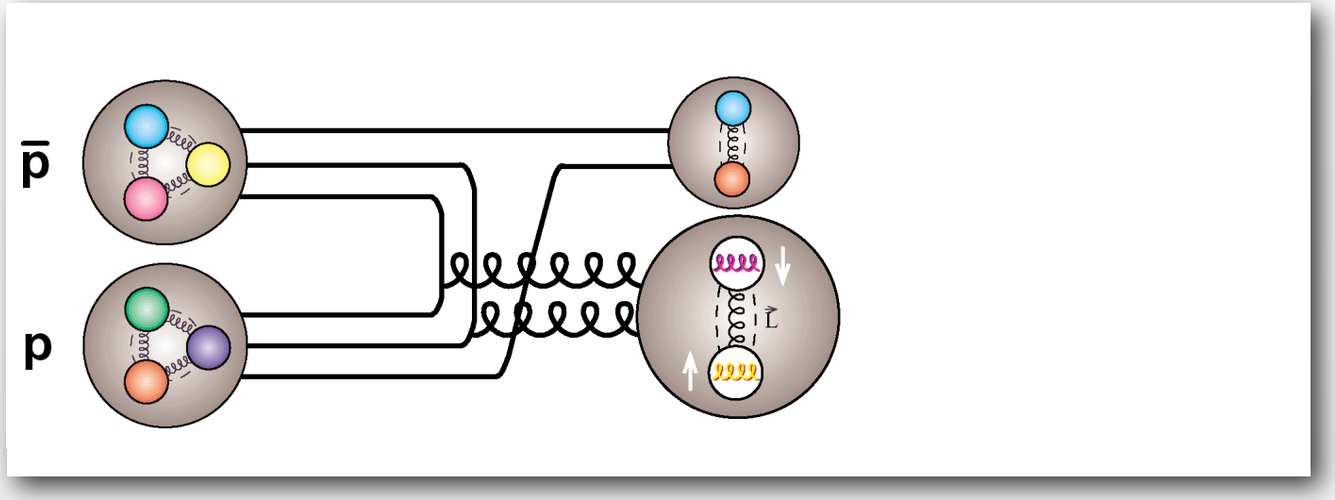

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Exotic

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Light-quark sector:

Non-qq candidates	
$f_0(980)$	4q state - molecule
$f_0(1500)$	0^{++} glueball candidate
$f_0(1370)$	0^{++} glueball candidate
$f_0(1710)$	0^{++} glueball candidate
h(1410); h(1460)	0^{-+} glueball candidate
$f_1(1420)$	hybrid, 4q state
$\pi_1(1400)$	hybrid candidate 1^{-+}
$\pi_1(1600)$	hybrid candidate 1^{-+}
$\pi(1800)$	hybrid candidate 0^{-+}
$\pi_2(1900)$	hybrid candidate 2^{-+}
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$a_2'(2100)$	hybrid candidate 1^{++}

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☺ most candidates observed in $\bar{p}p$ annihilation

☺ ≈ equal population as into ordinary states

☹ broad and overlapping states

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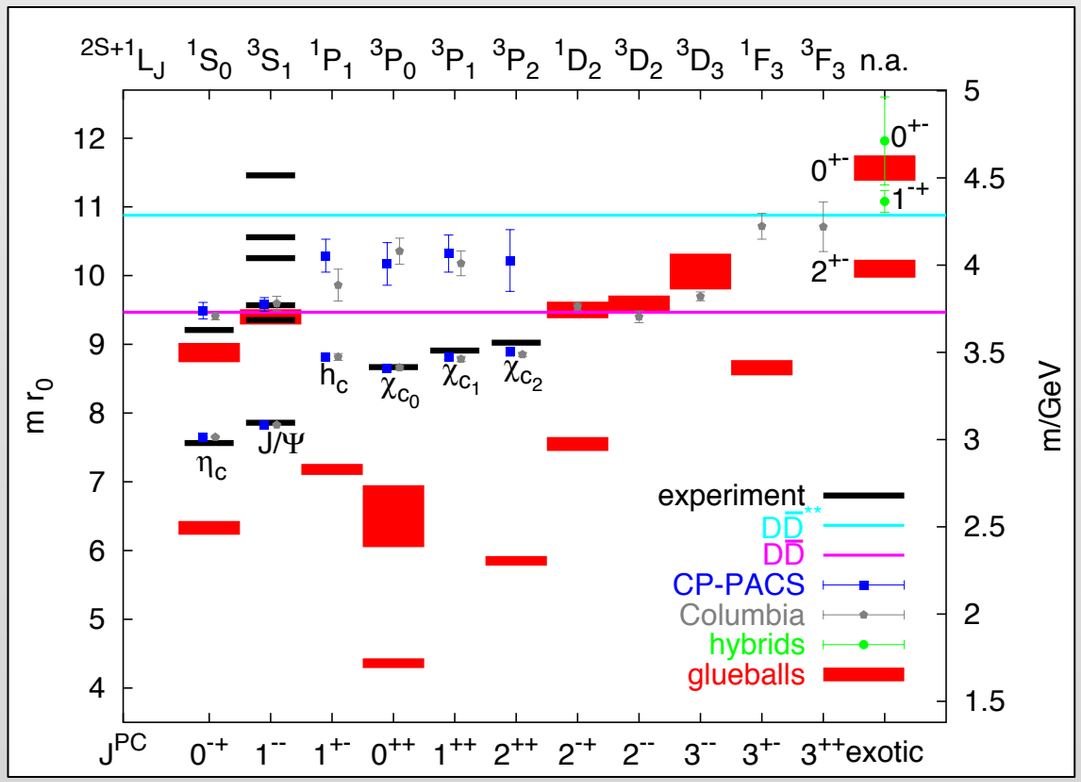
Charmed-quark sector:

☺ hybrid states are expected to be narrow
☺ less crowded region
☺ glueballs with exotic quantum numbers (0^{+-},2^{+-}) "oddballs", predicted in this region

Hybrids
Exotic charm.hybrid
Flux-tube model:
$J^{PC} = 1^{-+}$
M = 4.2 - 4.5 GeV
Γ < 50 MeV

Glueballs
Oddballs
LatticeQCD:
$J^{PC} = 0^{+-},2^{+-}$
M = 4 - 5 GeV
Γ < 50 MeV



Bali, EPJ A19 (04) 1

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Many open questions in meson sepctroscopy:

- Charmonum singlet states poorly measured
- Where are the radial excitations of the S and P states?
- Where are the missing 1D states?
- What is the nature of the alphabet (X,Y,Z) states?
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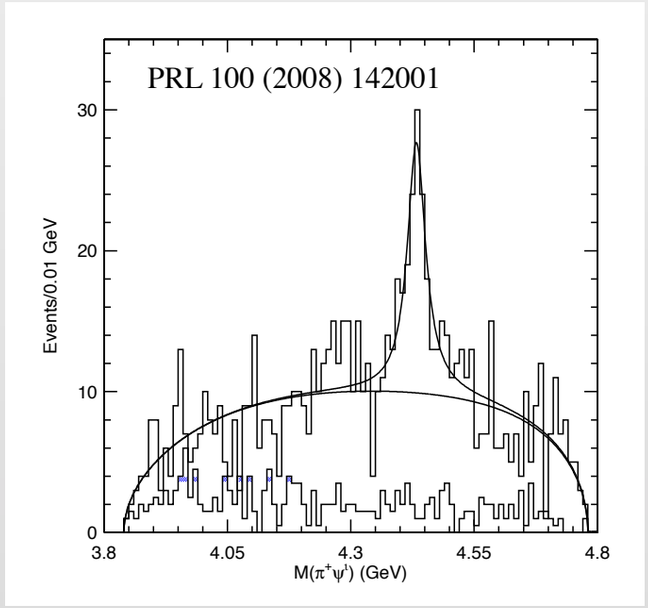
Z(4430) seen in B-decay from Belle:



$$B \to \psi' \pi^{\pm}$$

Z(4430): charged and decays into $c\bar{c}$

→ Prime candidate for a multiquark state.

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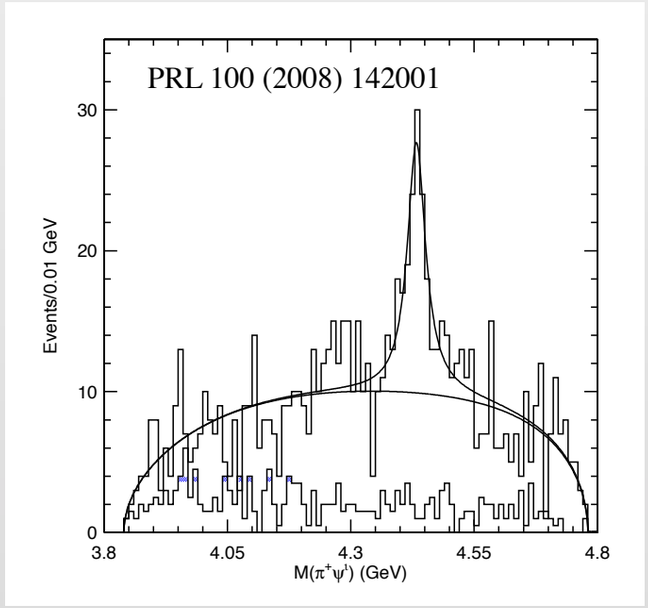

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Statistics is needed for PWA analysis

$\bar{p}p \to \pi^0\pi^0\pi^0$ Crystal Barrel@LEAR

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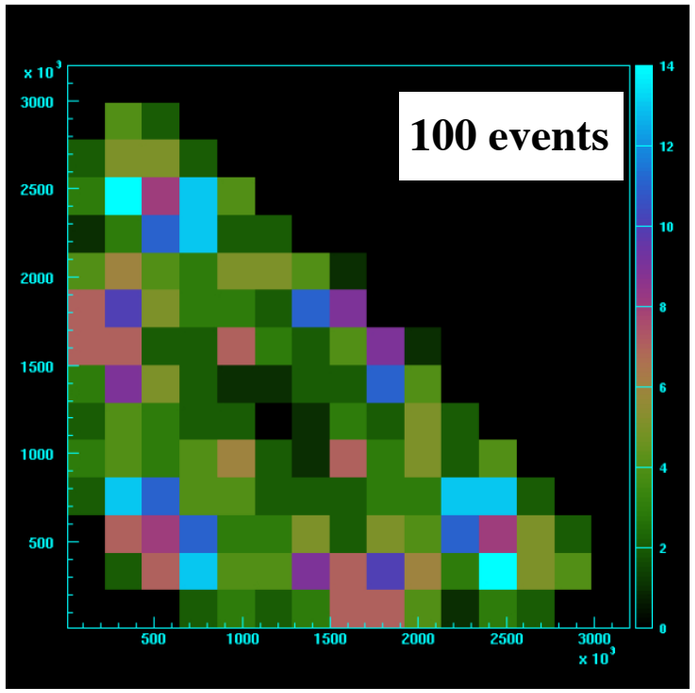

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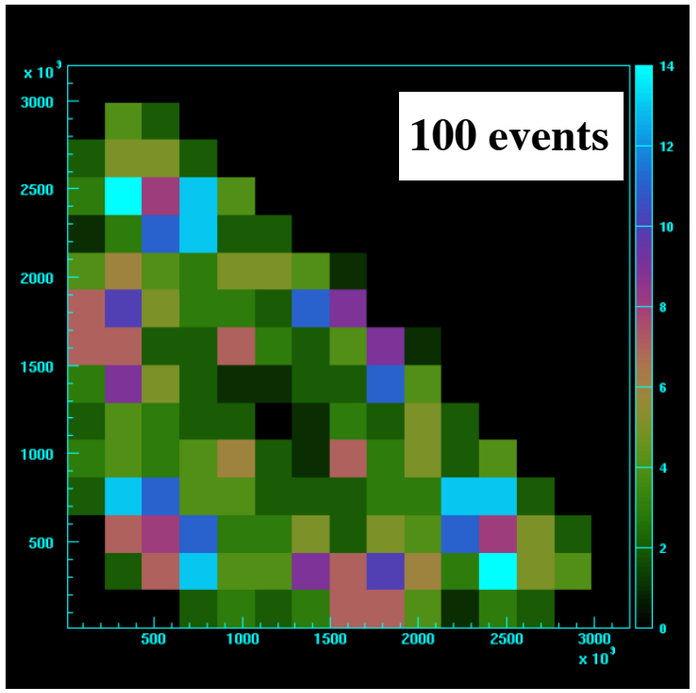

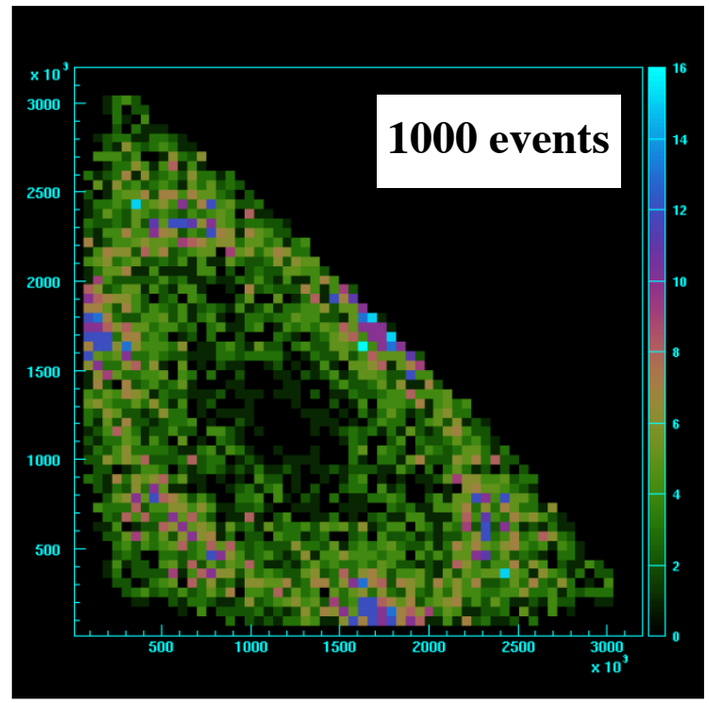

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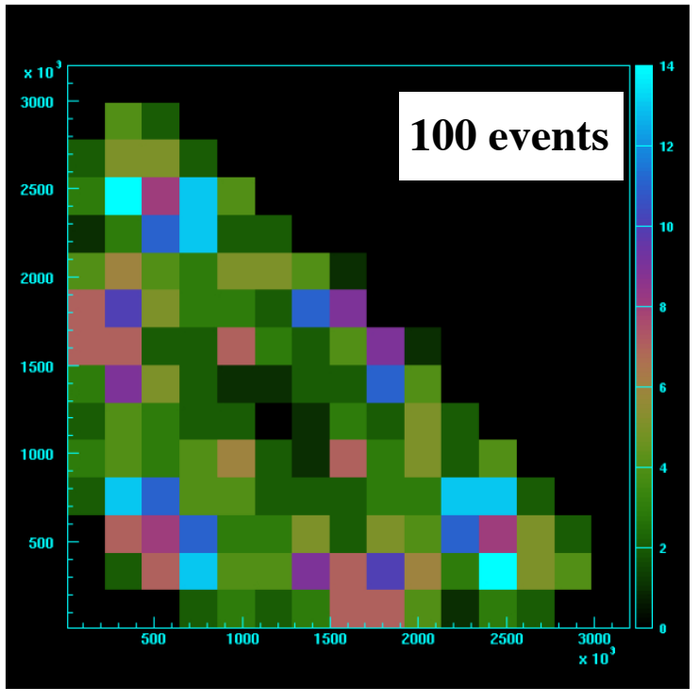

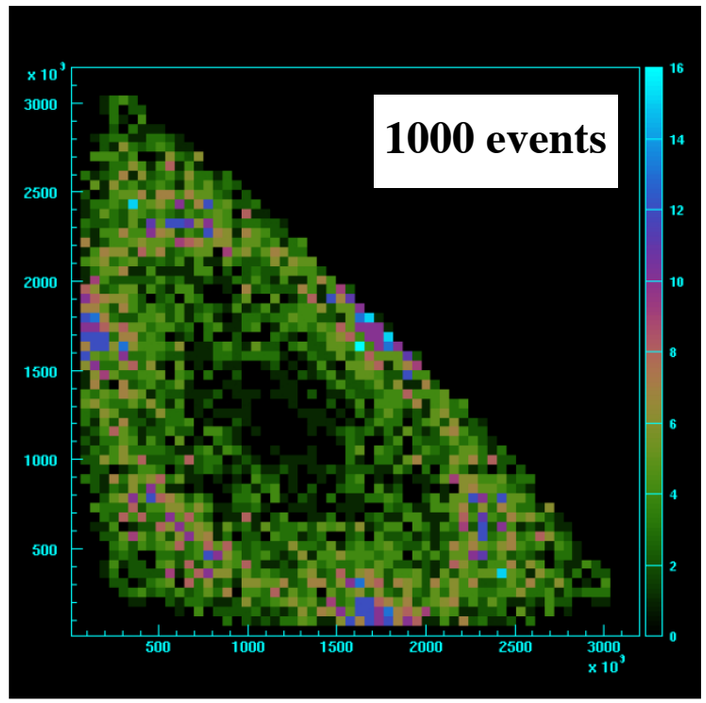

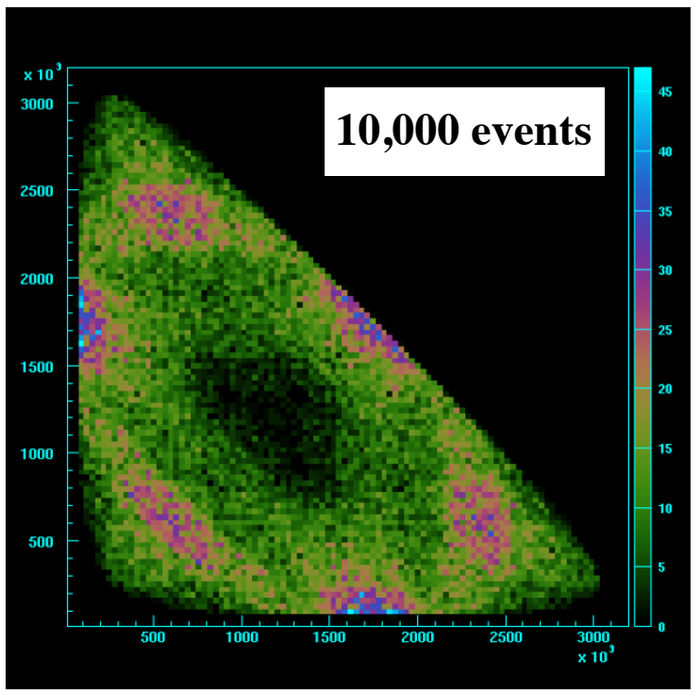

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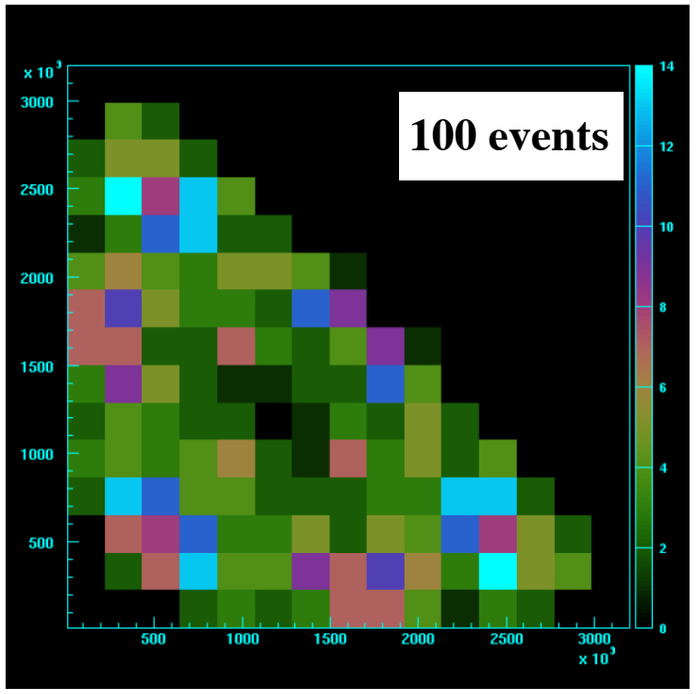

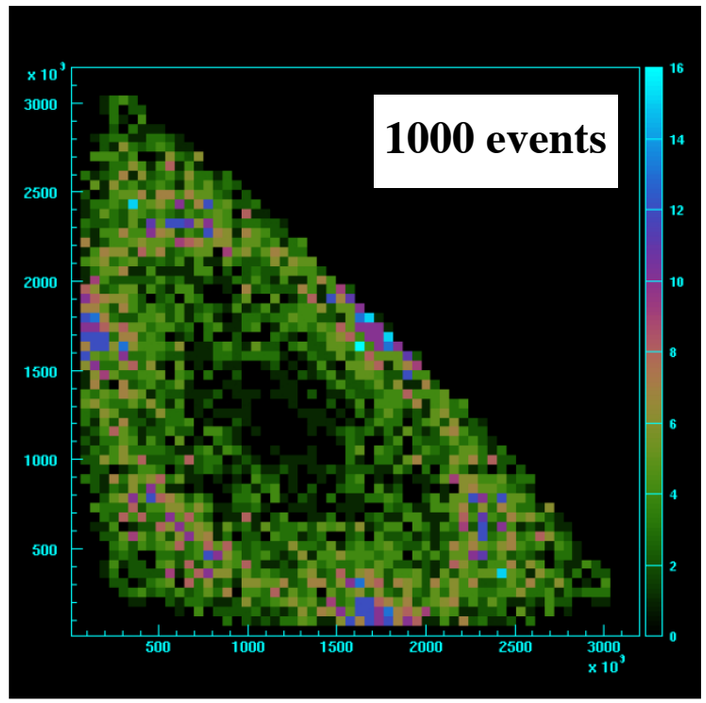

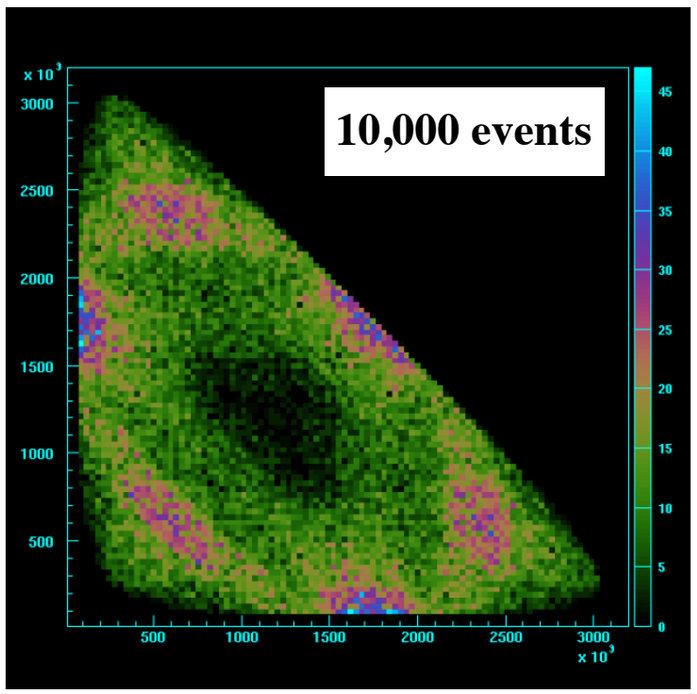

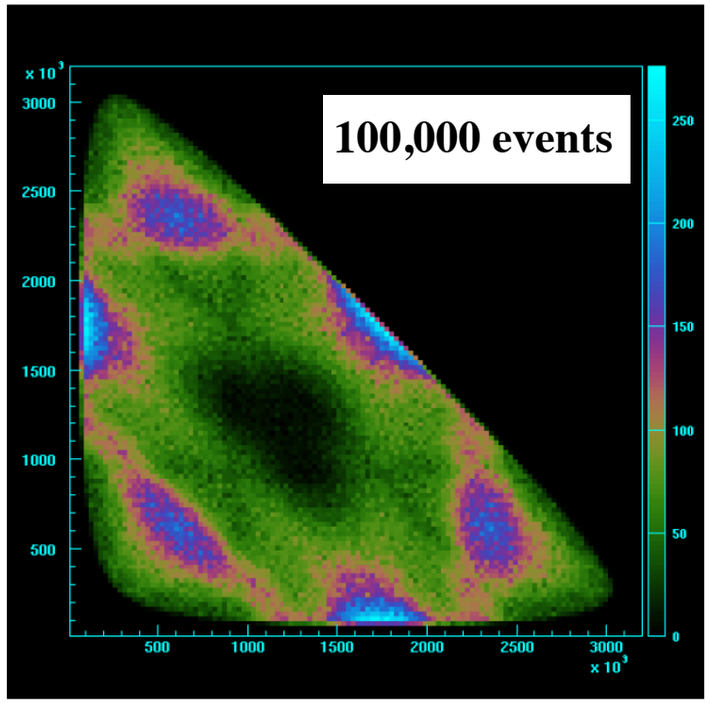

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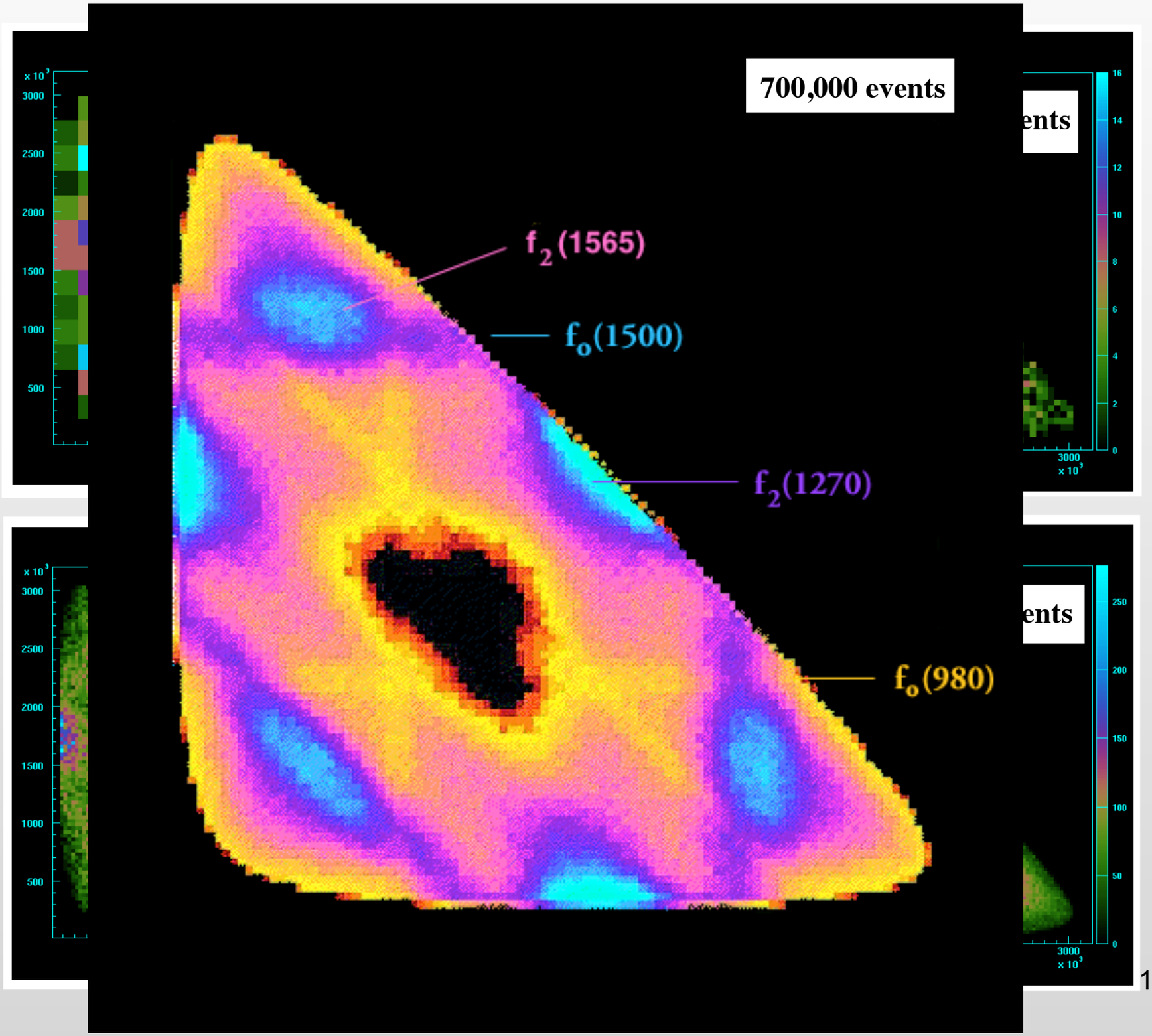

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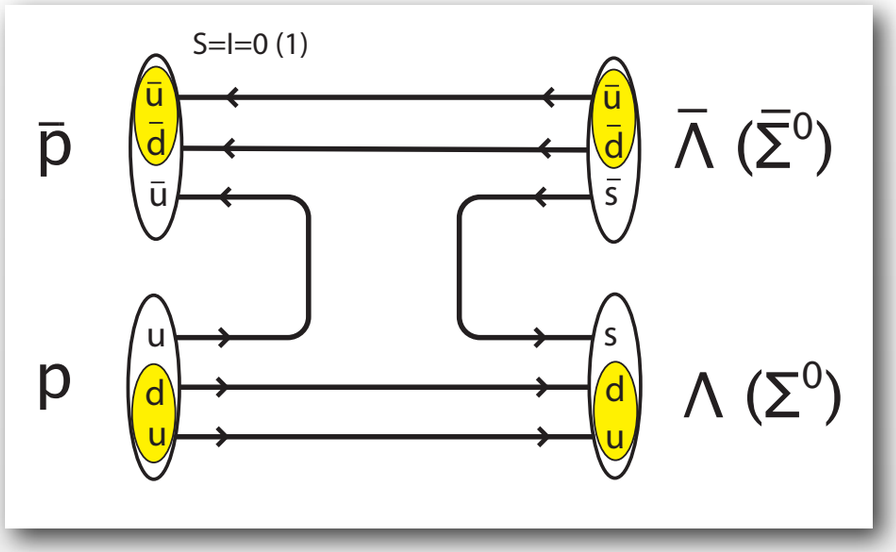
Antibaryon-Baryon Production

The self-analysing weak decay of hyperons give access to spin observables.

The spin of the $\bar{\Lambda}/\Lambda$ is primarily carried by the $\bar{s}/s$ quarks

=>

Spin degrees of freedom in $\bar{s}s$ production accessible.



Same argument for $\bar{\Lambda}_c\Lambda_c$

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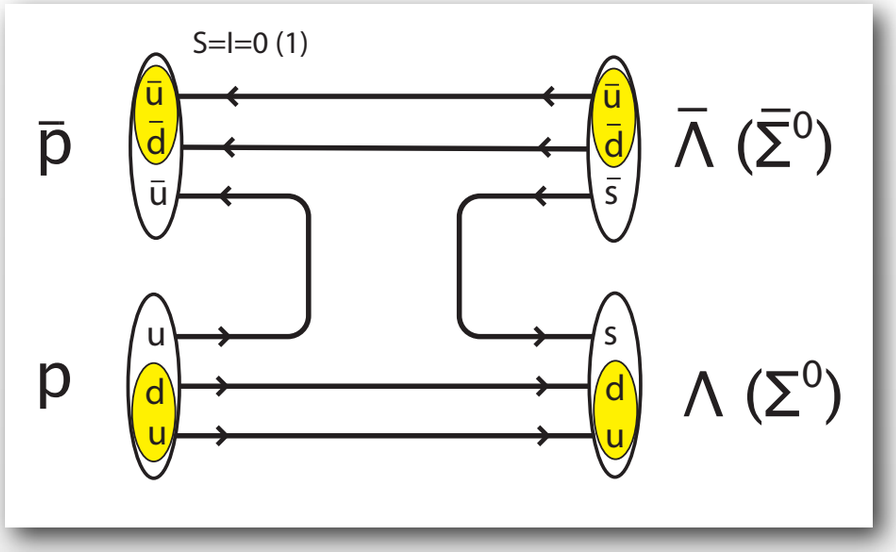

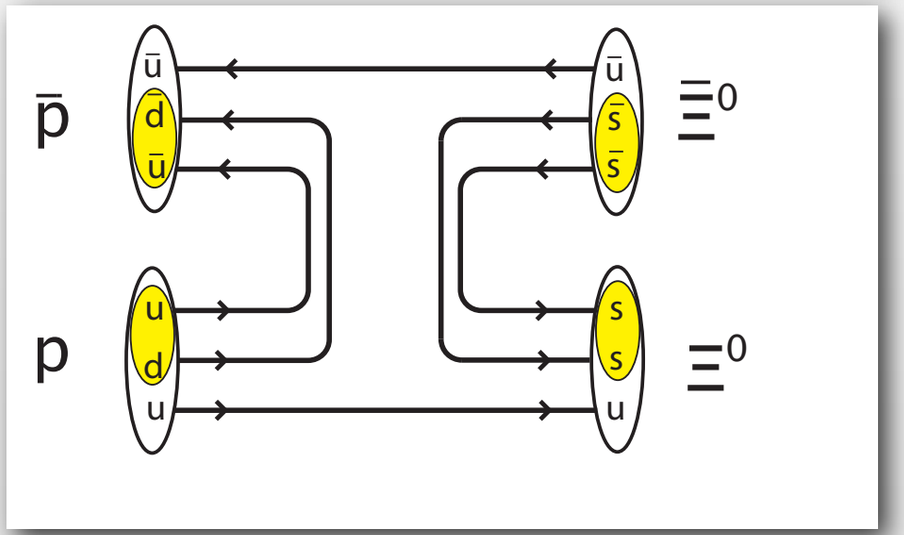

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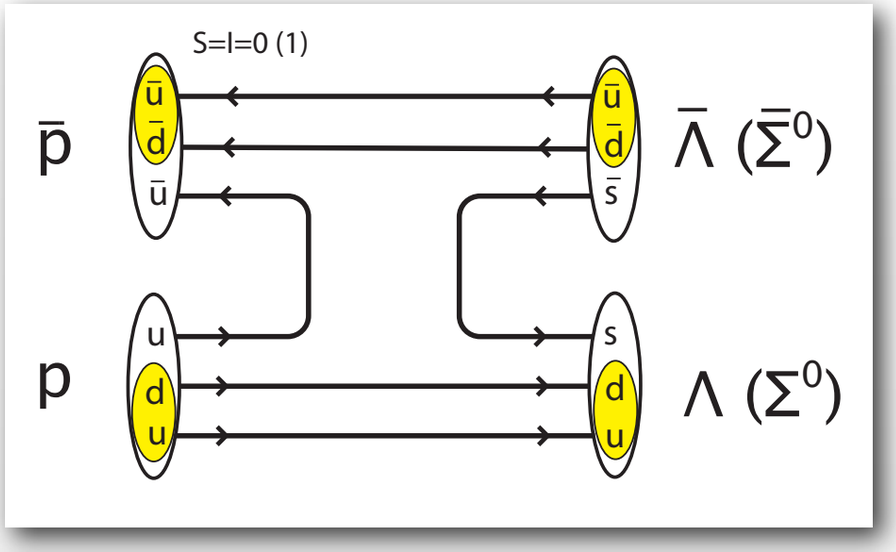

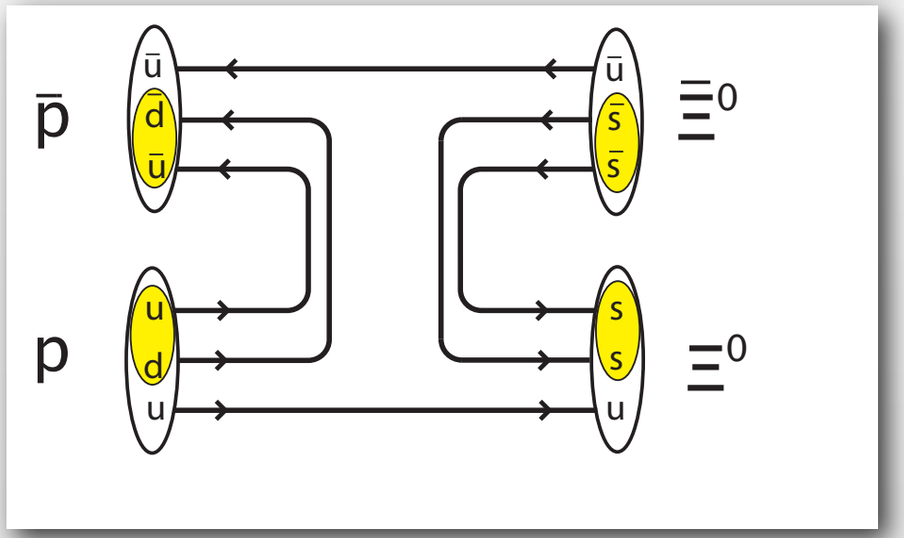

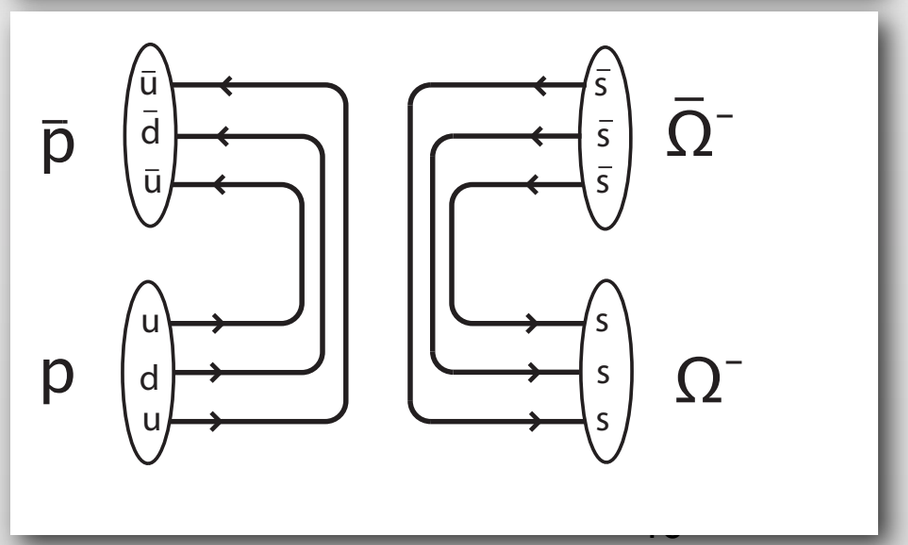

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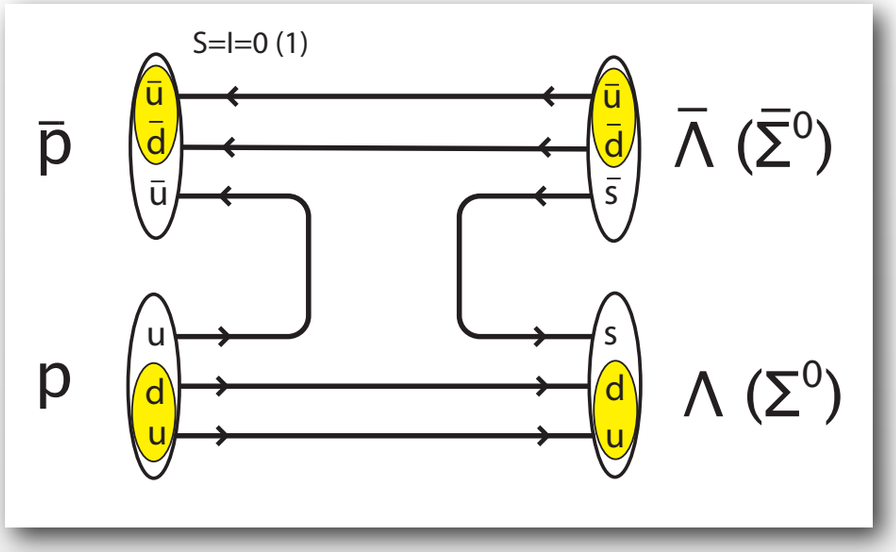
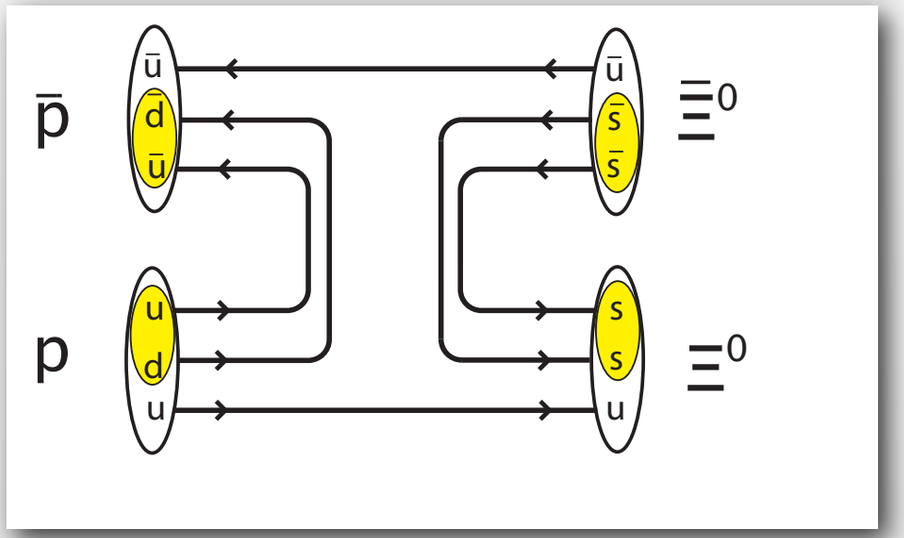
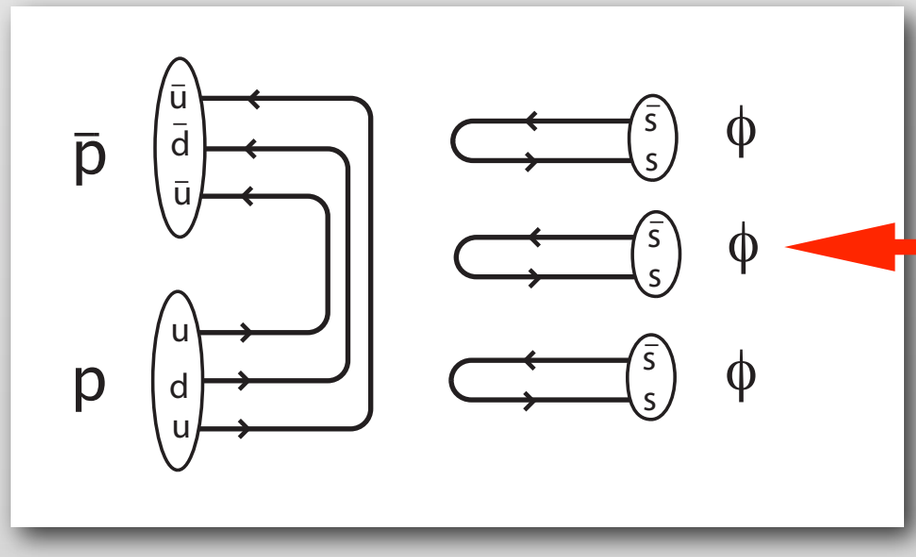
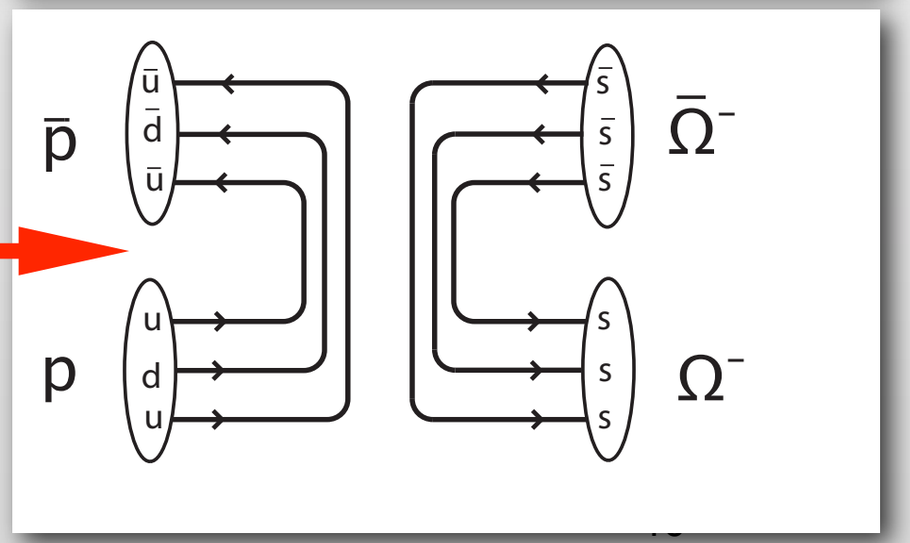
Same argument for $\bar{\Lambda}_c\Lambda_c$









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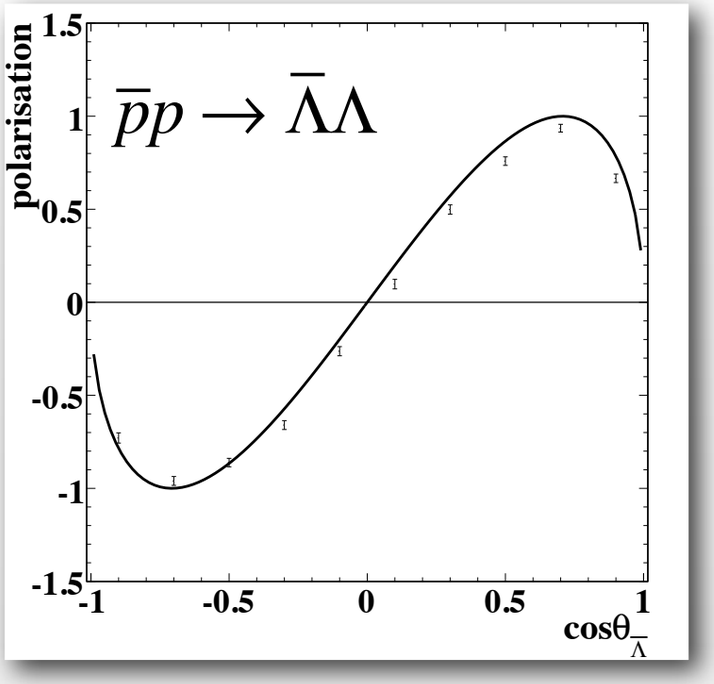
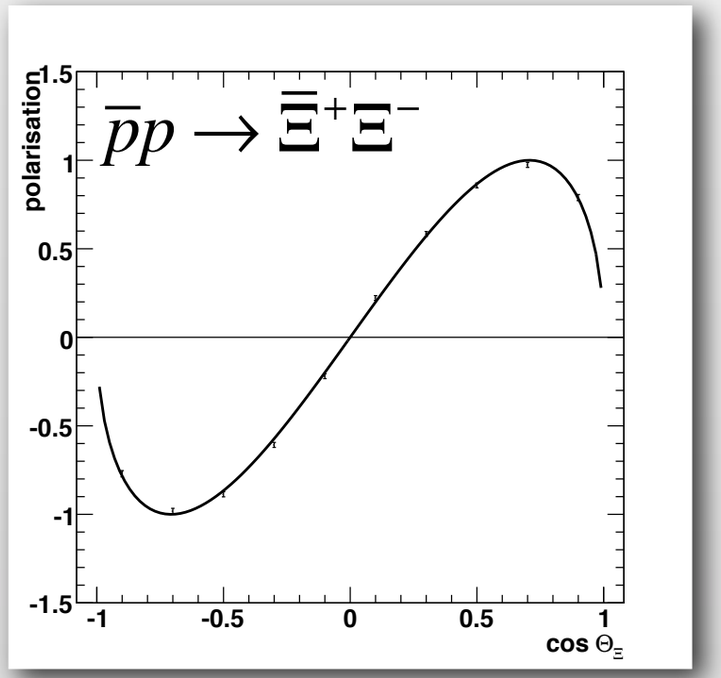
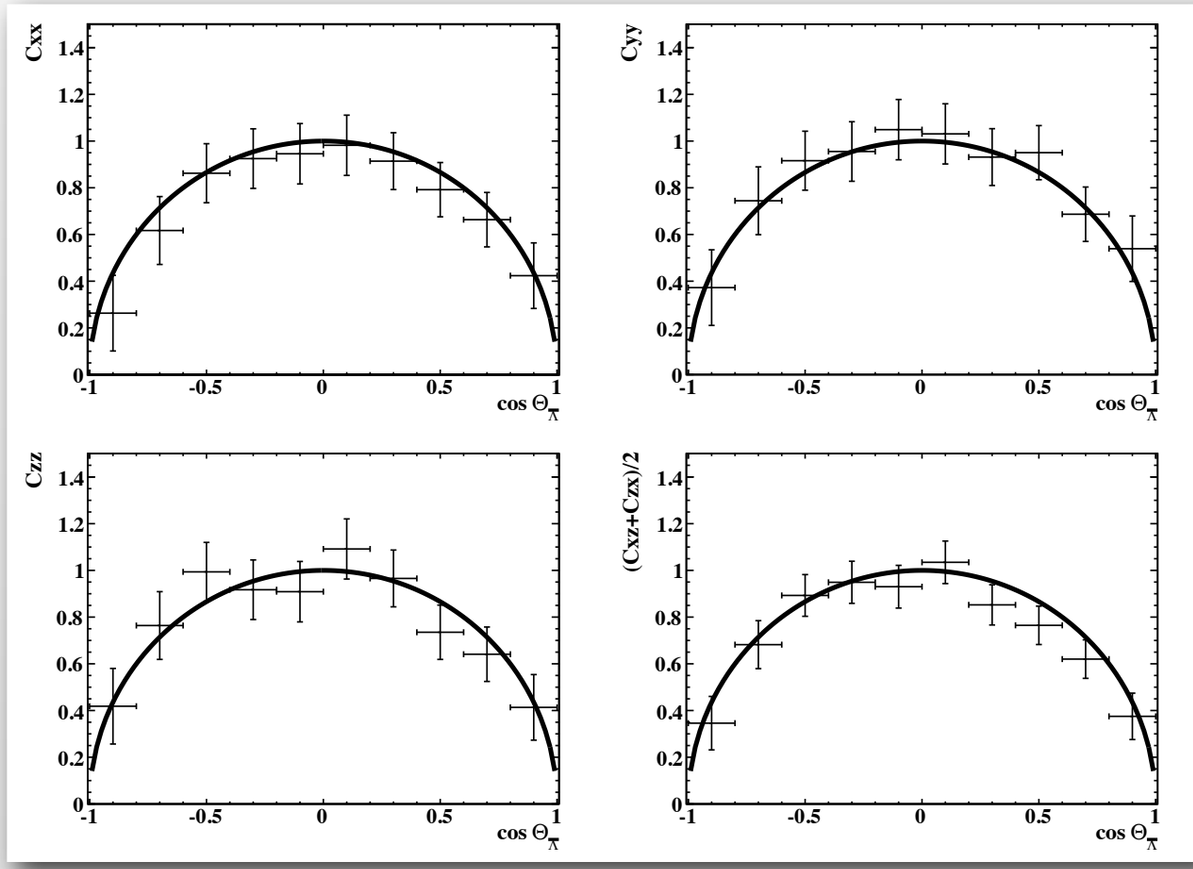
$\bar{p}p \to \bar{\Lambda}\Lambda$ simulations





$\bar{p}p \to \bar{\Lambda}\Lambda$



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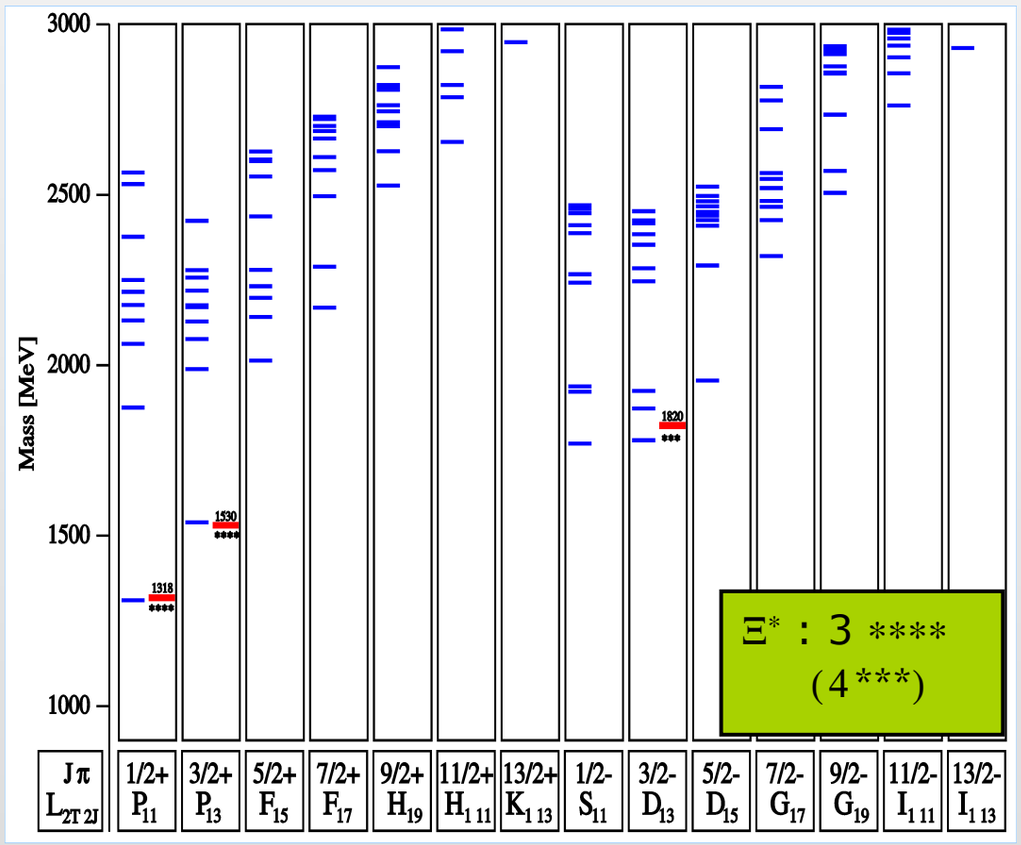
Strange Baryon spectroscopy

≈ equal ratio between baryonic final states and annihilation into mesons in $\bar{p}p$ inteactions

Baryonic final states largely formed via exited states
=> high discovery potential

S = 2



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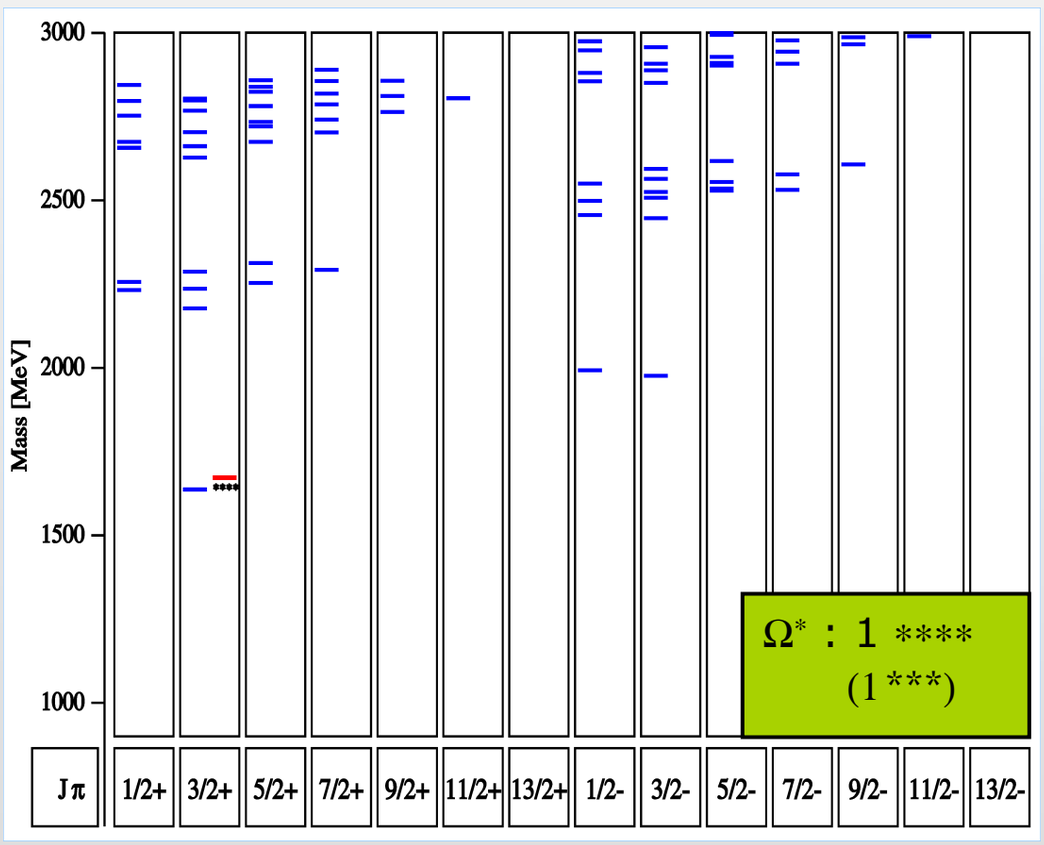

Löhring, Metsch, Petry EPJ A10 (2001) 395

Many missing states!

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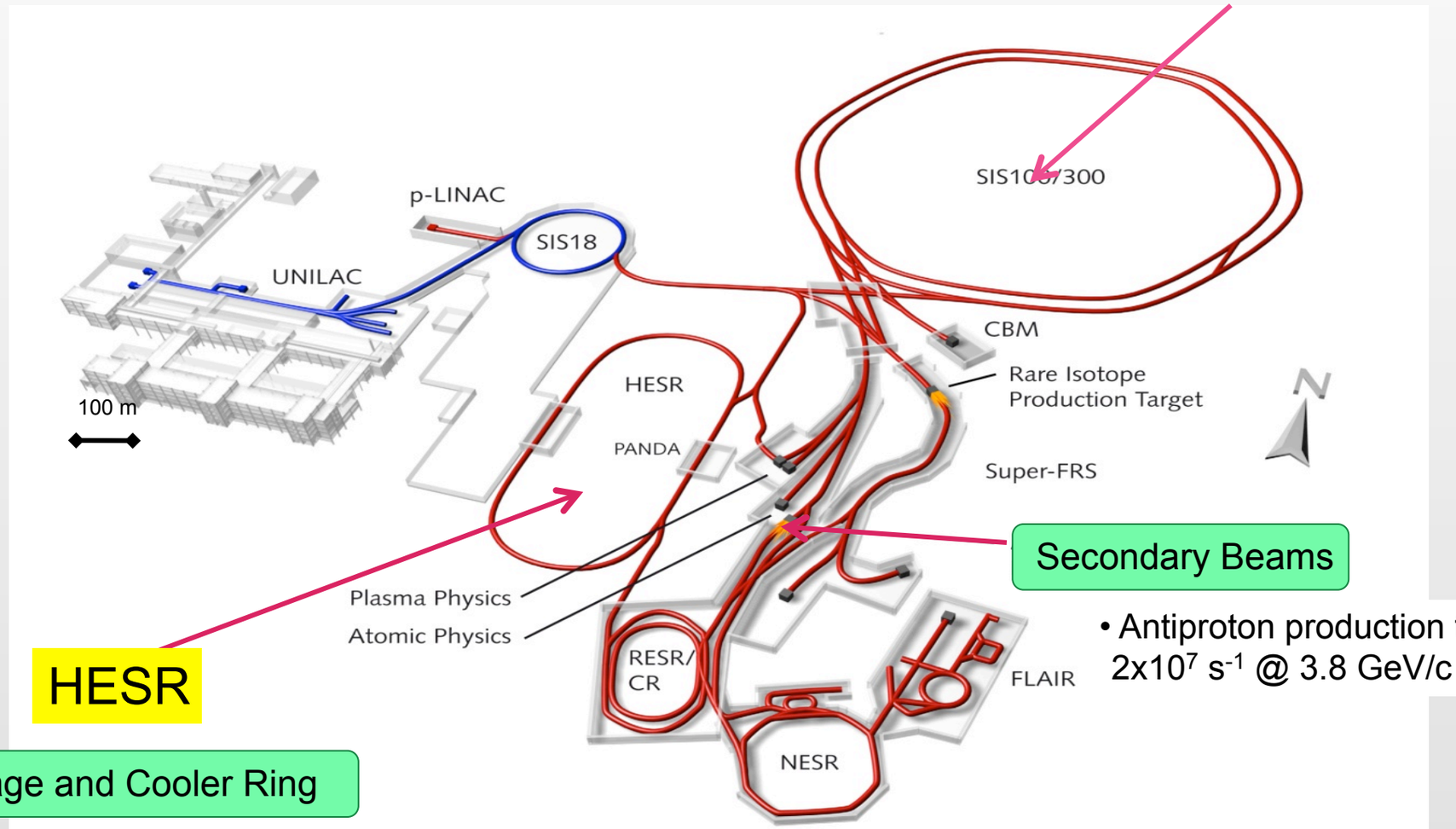
Facility for Antiproton and Ion Research FAIR

Primary Beams

•30 GeV protons 2(4)x10^{13} s^{-1}



Secondary Beams

HESR

Storage and Cooler Ring

• Antiproton production target
2x10^{7} s^{-1} @ 3.8 GeV/c

• 10^{11} stored and cooled 1.5 - 14.5 GeV/c antiprotons

High resolution mode

• $\delta p/p < 2x10^{-5}$ (electron cooling)
• Luminosity = 2x10^{31} cm^{-2} s^{-1}

High luminosity mode

• Luminosity = 2 x 10^{32} cm^{-2} s^{-1}
• $\delta p/p \sim 10^{-4}$ (stochastic cooling)

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PANDA physics not covered:

Hadrons in the Nuclear Medium

Hypernuclear Physics

Nucleon Structure from EM processes

Electroweak Physics

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Physics Performance Report for:

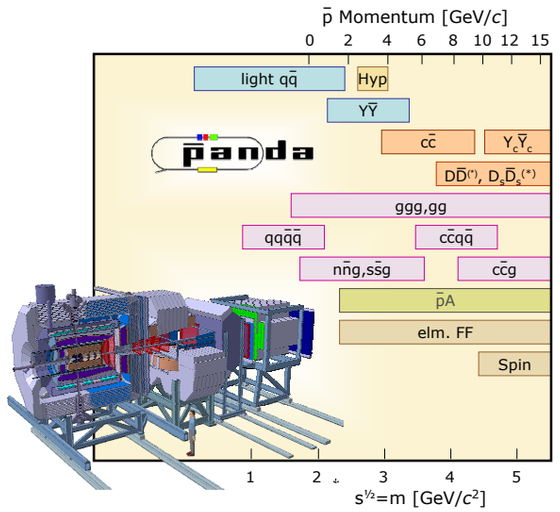
$\overline{\mathrm{P}}$ANDA

(AntiProton Annihilations at Darmstadt)

Strong Interaction Studies with Antiprotons

$\overline{\mathrm{P}}$ANDA Collaboration

To study fundamental questions of hadron and nuclear physics in interactions of antiprotons with nucleons and nuclei, the universal $\overline{\mathrm{P}}$ANDA detector will be build. Gluonic excitations, the physics of strange and charm quarks and nucleon structure studies will be performed with unprecedented accuracy thereby allowing high-precision tests of the strong interaction. The proposed $\overline{\mathrm{P}}$ANDA detector is a state-of-the-art internal target detector at the HESR at FAIR allowing the detection and identification of neutral and charged particles generated within the relevant angular and energy range.
This report presents a summary of the physics accessible at $\overline{\mathrm{P}}$ANDA and what performance can be expected.



arXiv:0903.3905v1

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: Versatile physic program

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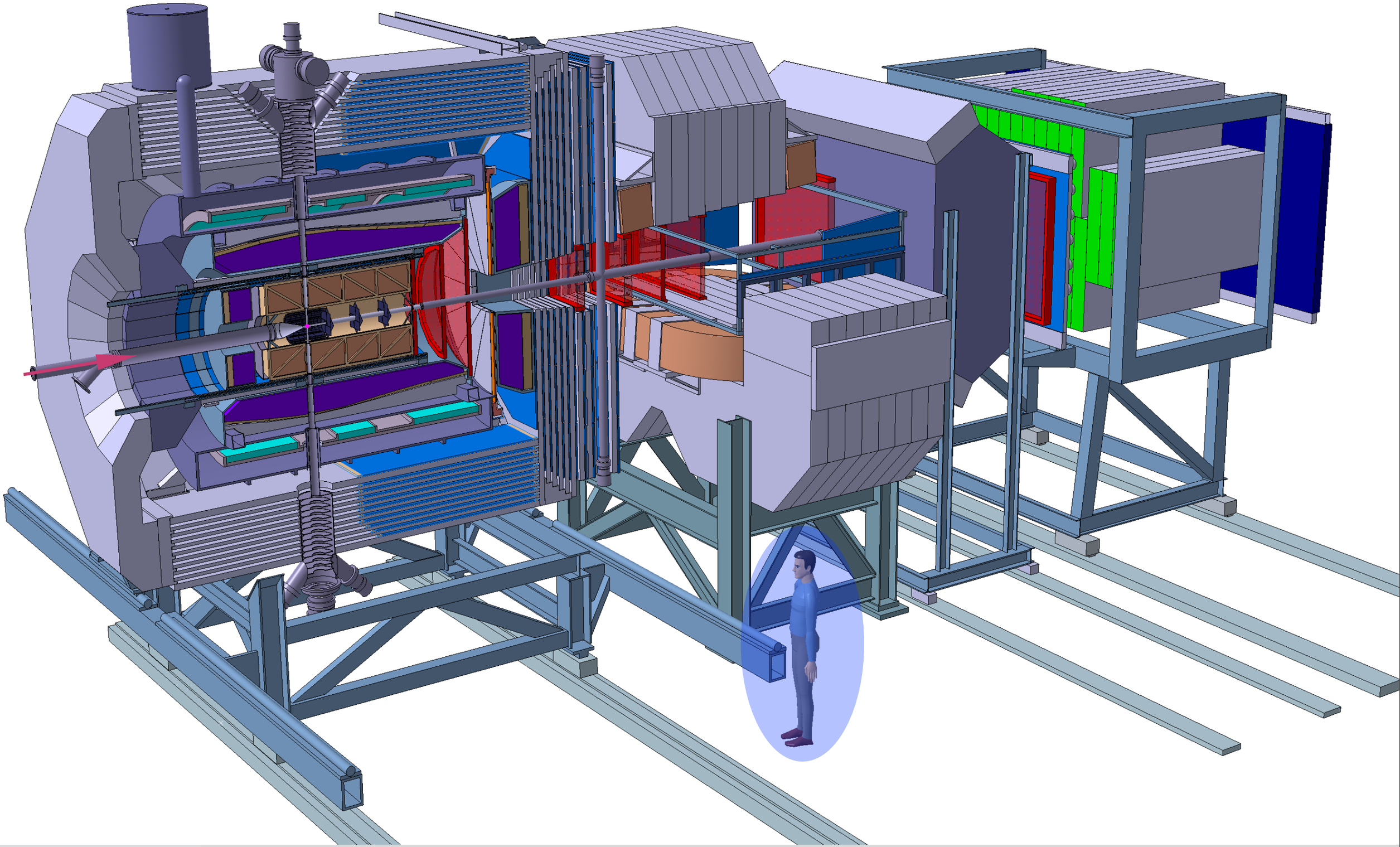
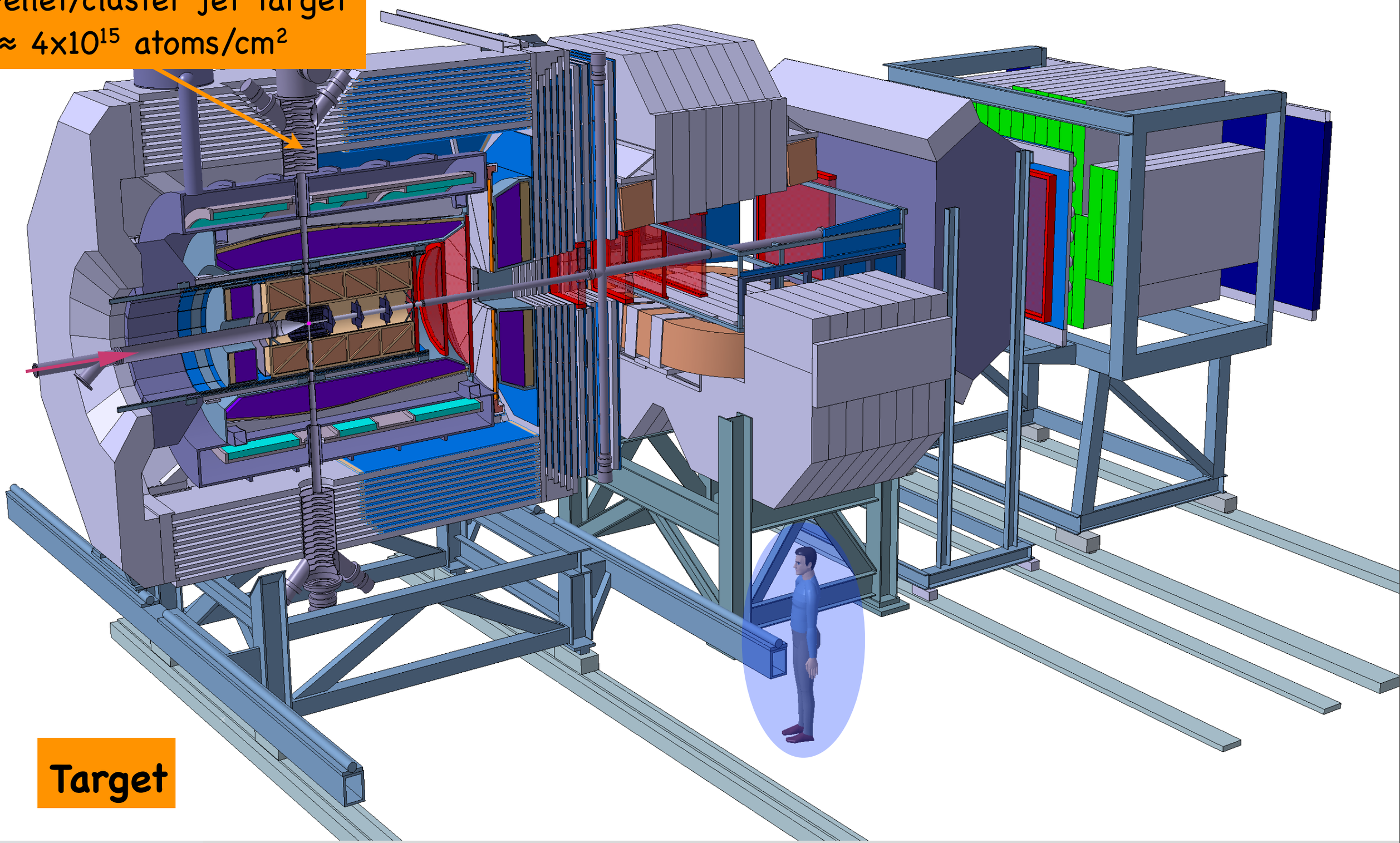
panda : Versatile physic program

Need a versatile tool …



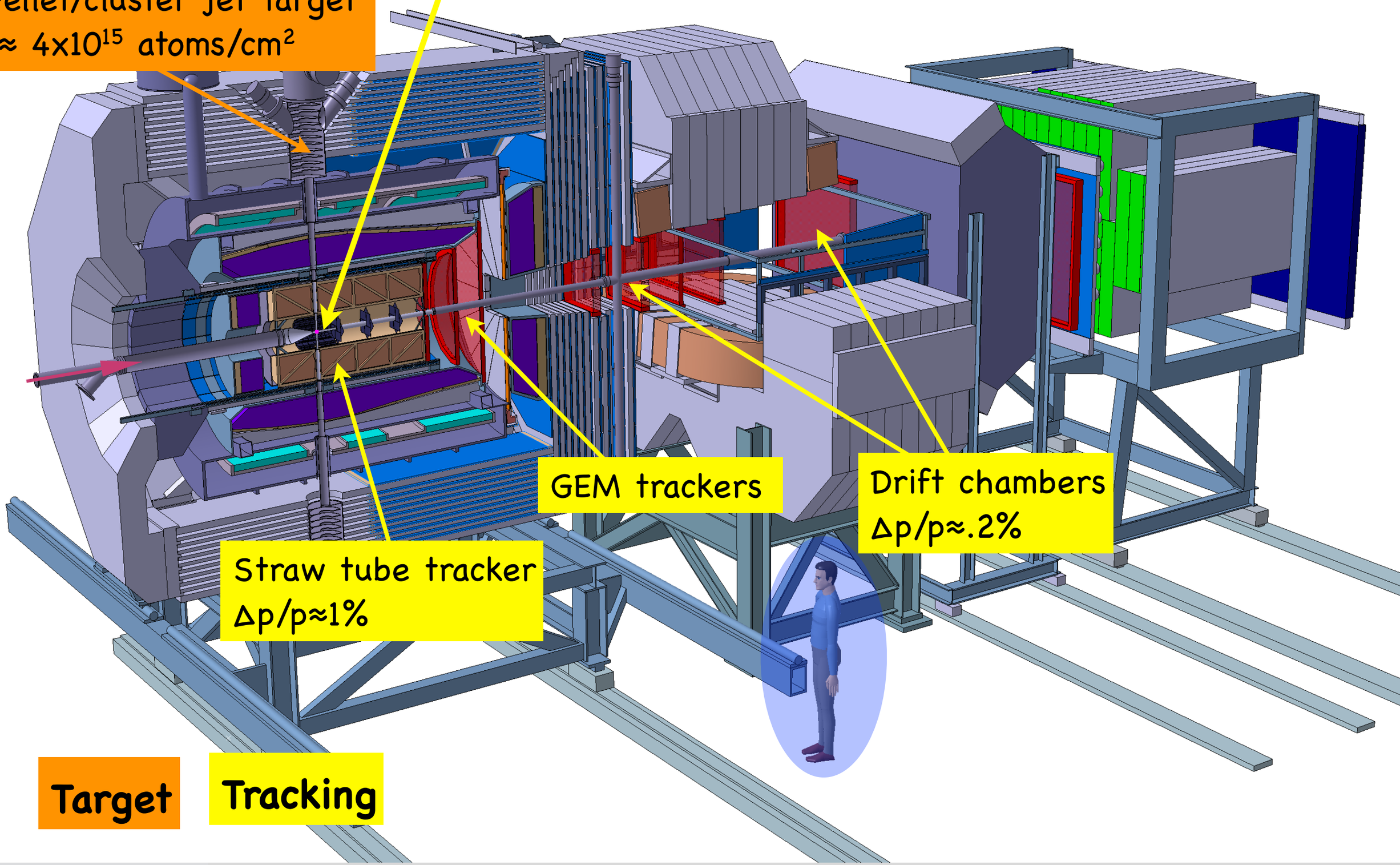
Pellet/cluster jet target
≈ 4×10^{15} atoms/cm^2



Target

Si pixel/strip detector
σ(vertex) ≈ 50 μm

Pellet/cluster jet target
≈ 4×10^{15} atoms/cm^2



GEM trackers

Drift chambers
Δp/p≈.2%

Straw tube tracker
Δp/p≈1%

Target

Tracking

Si pixel/strip detector
σ(vertex) ≈ 50 μm

EMC: PWO crystals
1 MeV - 10 GeV
σ(E)/√E < 2 %

EMC: Shashlyk
σ(E)/√E ≈ 4 %

Pellet/cluster jet target
≈ 4×10^{15} atoms/cm^2

GEM trackers

Drift chambers
Δp/p≈.2%

Straw tube tracker
Δp/p≈1%

Target **Tracking** **EMC**

Si pixel/strip detector
σ(vertex) ≈ 50 μm
dE/dx

EMC: PWO crystals
1 MeV – 10 GeV
σ(E)/√E < 2 %

EMC: Shashlyk
σ(E)/√E ≈ 4 %

Pellet/cluster jet target
≈ 4×10^{15} atoms/cm^2

Muon chambers

DIRC
π/K/p
> 1 GeV/c

ToF
π/K/p
< 2.8 GeV/c

RHIC
π/K/p
> 2.8 GeV/c

GEM trackers

Drift chambers
Δp/p≈.2%

Straw tube tracker
Δp/p≈1%
dE/dx

Target **Tracking** **EMC** **PID**

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PANDA : Hadron Physics with antiprotons

Strong and international collaboration:

≈ 500 scientists

53 institutions

17 countries

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panda

QCD is exciting!