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MESON 2010

JÜLICH FORSCHUNGSZENTRUM

Strong Interaction Physics with PANDA

A personal selection

June 15, 2010 | Albrecht Gillitzer

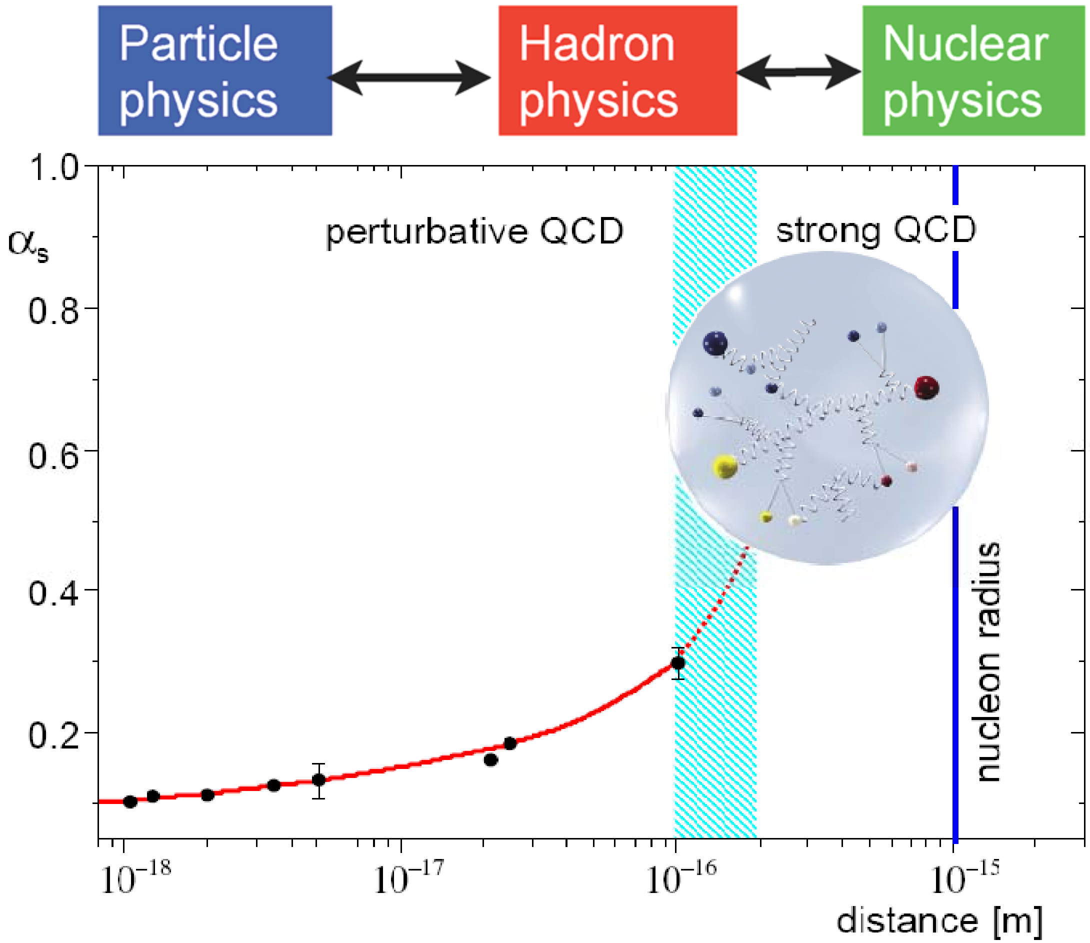
IKP, Forschungszentrum Jülich & Jülich Center for Hadron Physics

Outline

- Introduction
- The PANDA experiment: physics & detector
- Spectroscopy
  - Hidden and open charm mesons
  - Baryons
- Hadrons in the nuclear medium
- Summary

strong arguments…

- confinement of quarks and gluons
- sponanteous chiral symmetry breaking, hadron masses
- existence of non-$q\bar{q}$/qqq configurations
- interplay of hadron and quark-gluon degrees of freedom



Why antiprotons?

- difficult to make

  BUT:

- gluon rich process
- gain ~2 GeV in annihilation, reduced momentum transfer
- B = 0 system
- all fermion-antifermion quantum numbers accessible
- very high resolution in formation reactions
- high angular momentum accessible

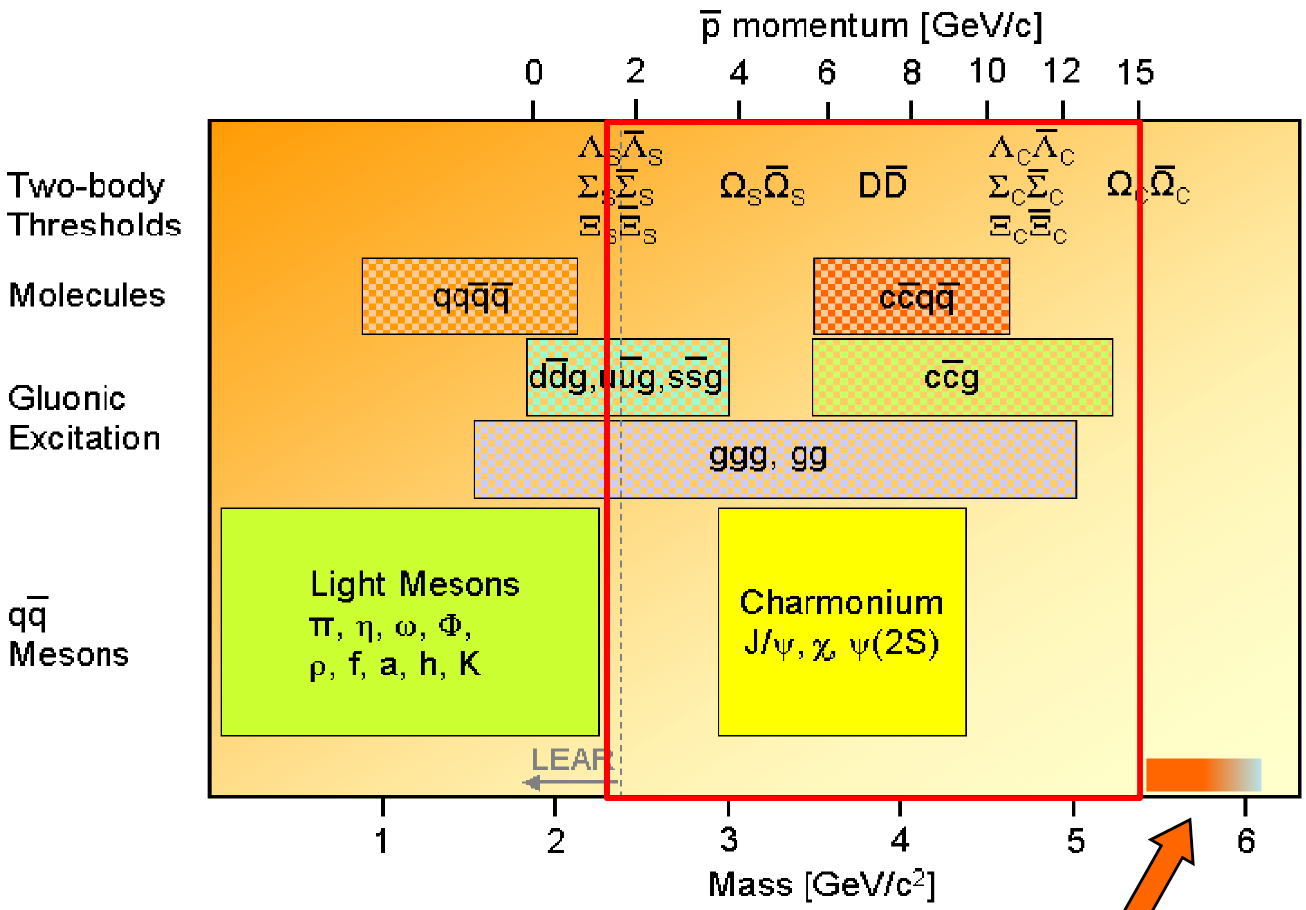
Physics Program

$\bar{p}p$, $\bar{p}d$ collisions:

- meson spectroscopy
  - *charmonium*
  - *glueballs, hybrids, tetraquarks, molecules*
  - *D mesons*
- baryon spectroscopy
- reaction dynamics
- proton structure
- CP violation

$\bar{p}A$ collisions:

- ΛΛ hypernuclei
- hadrons in the nuclear medium



little more with $\bar{p}d$

Physics & Feasibility

- 1st physics performance report for PANDA finished in 2009
- comprehensive physics program discussed
- simulations of at least one benchmark channel for each topic
- available on arXiv

Physics Performance Report for:

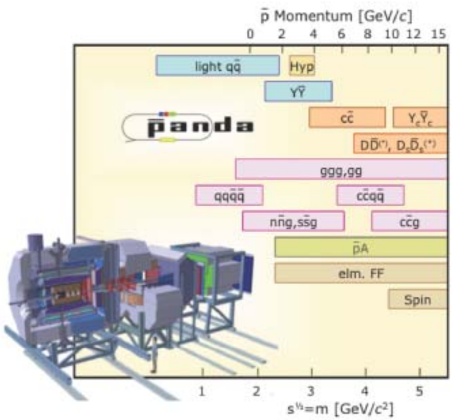
$\overline{\text{P}}$ANDA

(AntiProton Annihilations at Darmstadt)

Strong Interaction Studies with Antiprotons

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

To study fundamental questions of hadron and nuclear physics in interactions of antiprotons with nucleons and nuclei, the universal $\overline{\text{P}}$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 $\overline{\text{P}}$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 $\overline{\text{P}}$ANDA and what performance can be expected.

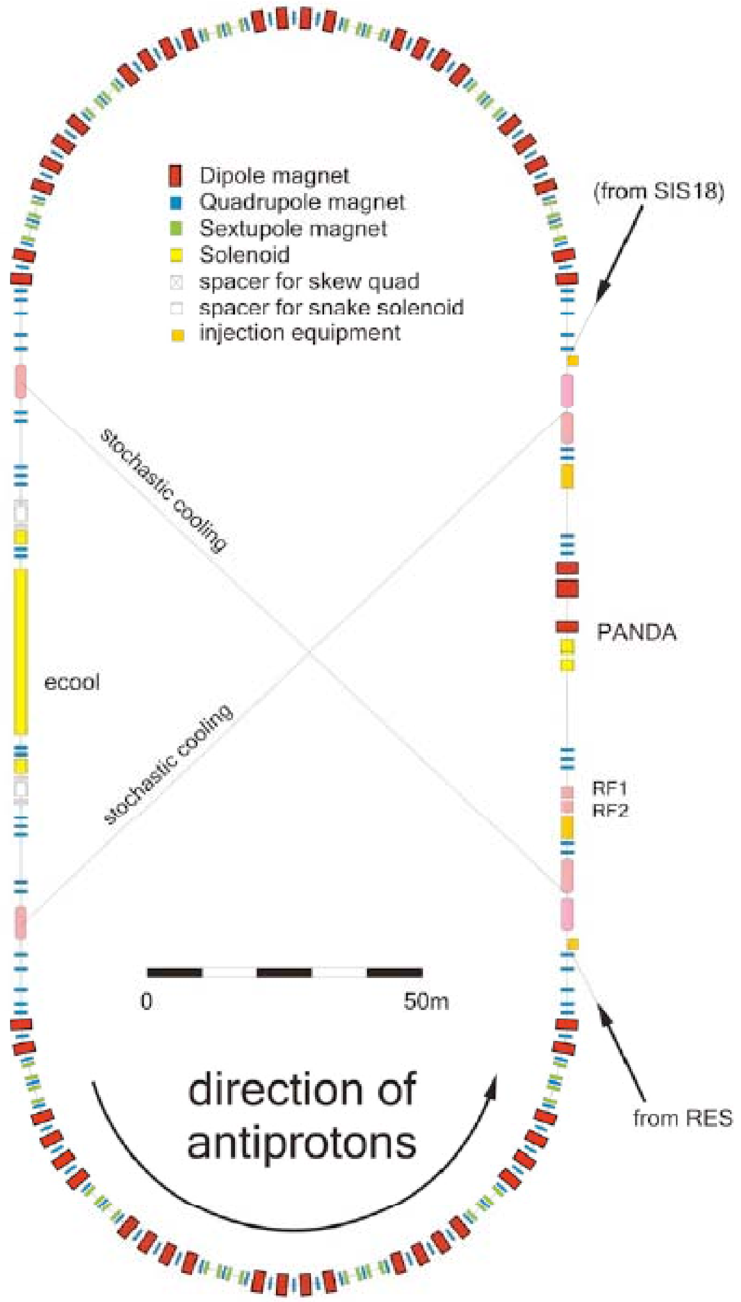


arXiv:0903.3905v1

HESR antiproton beam

Effective target thickness (pellets): 4×10^{15} cm^{-2}
Beam radius at target (rms): 0.3 mm

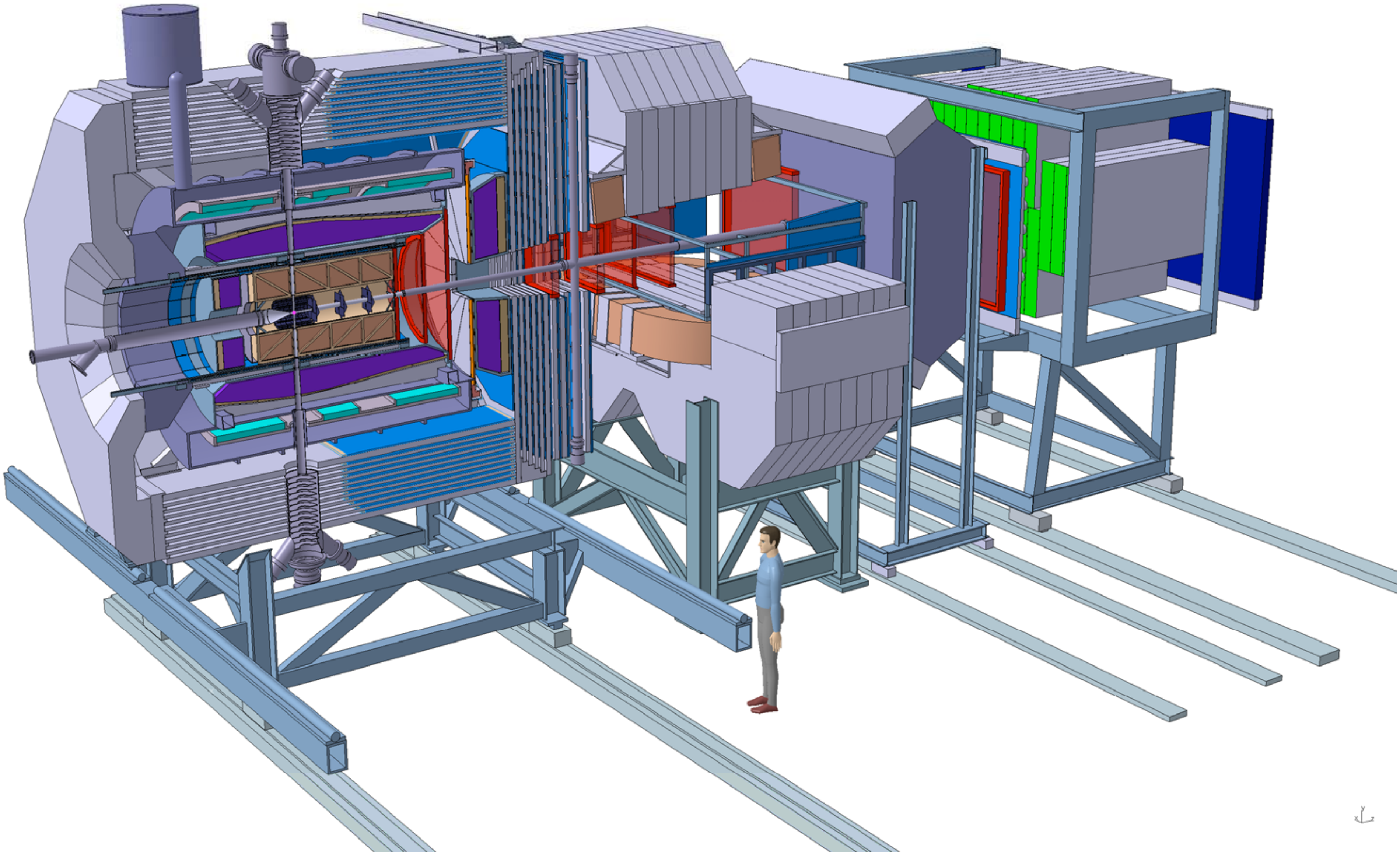
	High Resolution Mode	High Luminosity Mode
Momentum range	1.5 – 8.9 GeV/c	1.5 – 15 GeV/c
# antiprotons	10^{10}	10^{11}
Peak luminosity	2×10^{31} cm^{-2}s^{-1}	**2×10^{32} cm^{-2}s^{-1}**
Momentum spread (rms)	**$\Delta p/p \sim 3\times10^{-5}$**	$\Delta p/p \sim 1\times10^{-4}$
Beam cooler	Electron ≤ 8.9 GeV/c	Stochastic ≥ 3.8 GeV/c

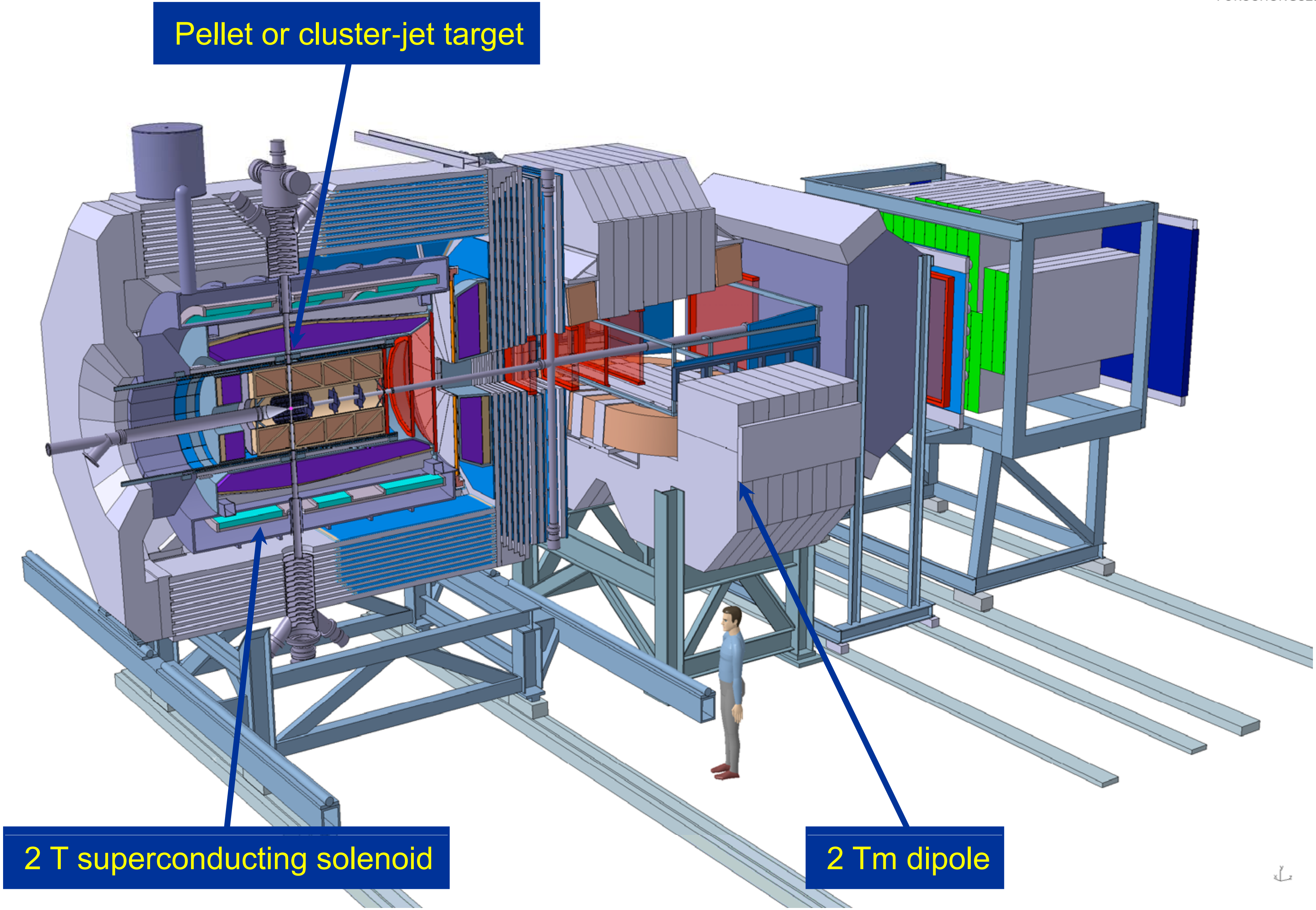


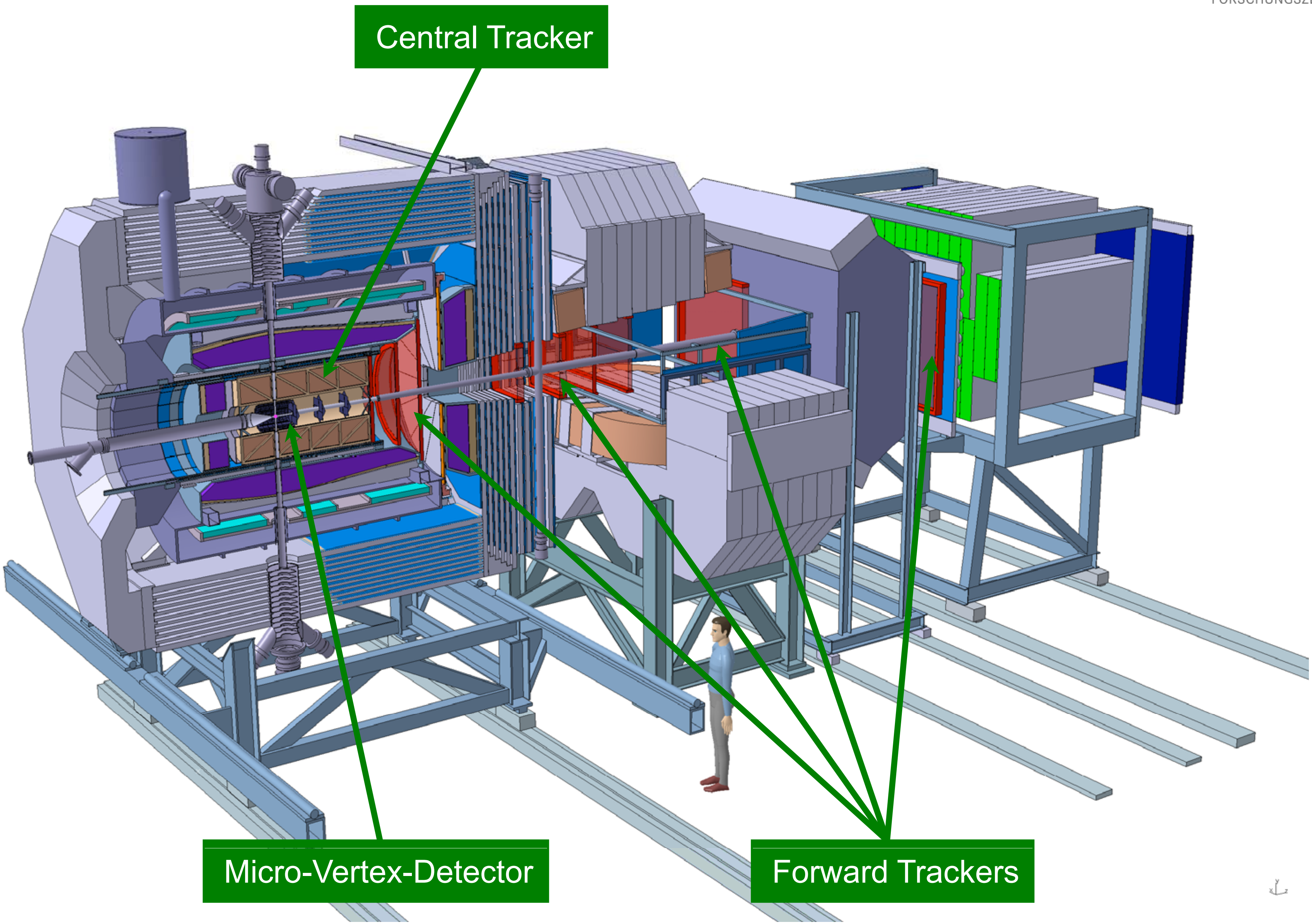
Versatile Detector

Detector requirements:

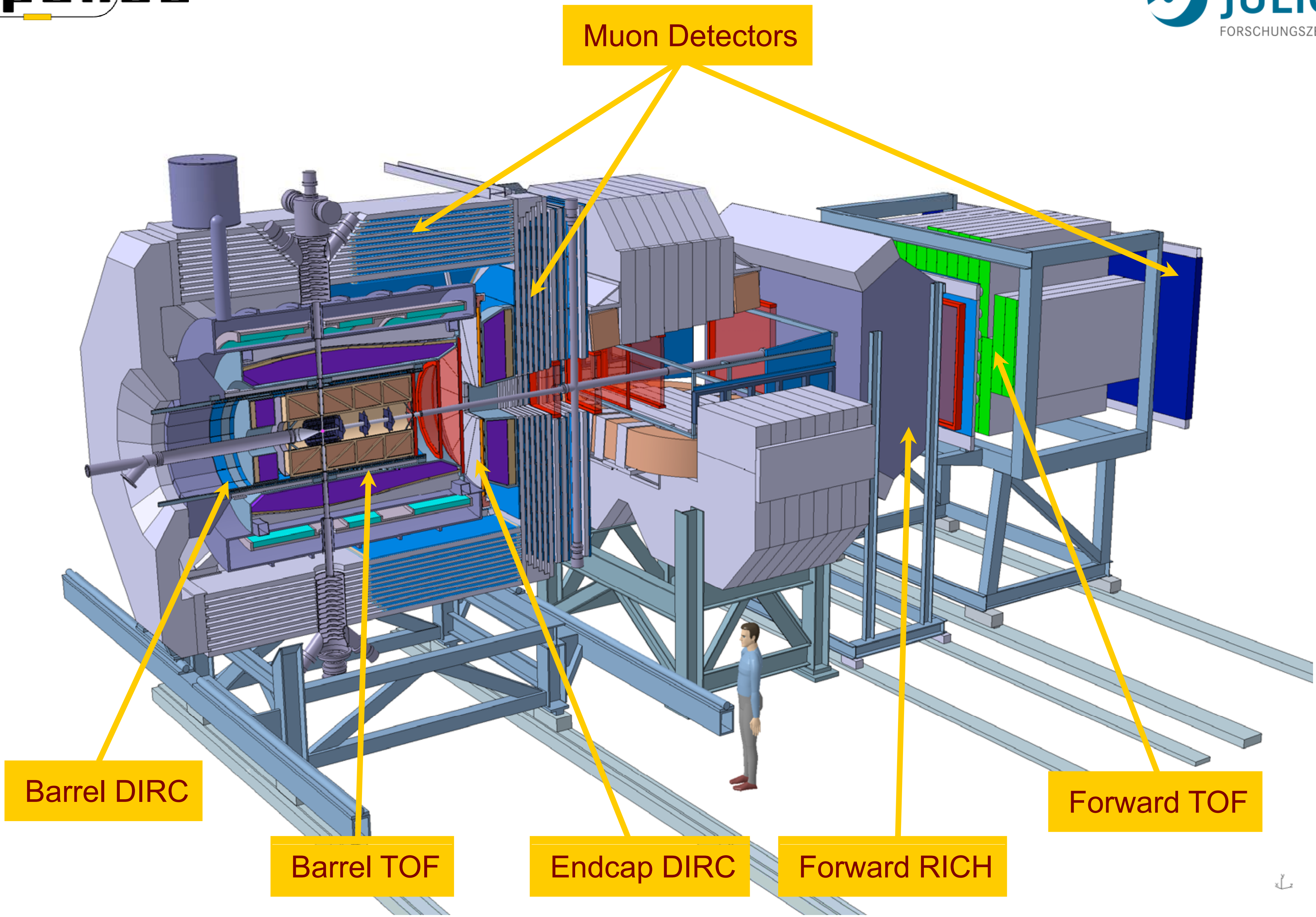
- nearly 4π solid angle (partial wave analysis)
- high rate capability ($2 \cdot 10^7$ reactions /s)
- good PID (γ, e, μ, π, K, p)
- momentum resolution (~1%)
- vertex detection for D, K_s, Λ ($c\tau$ = 317 μm for $D^{\pm}$)
- intelligent trigger (charm, strangeness, leptons)
- flexible modular design (hypernuclear physics)

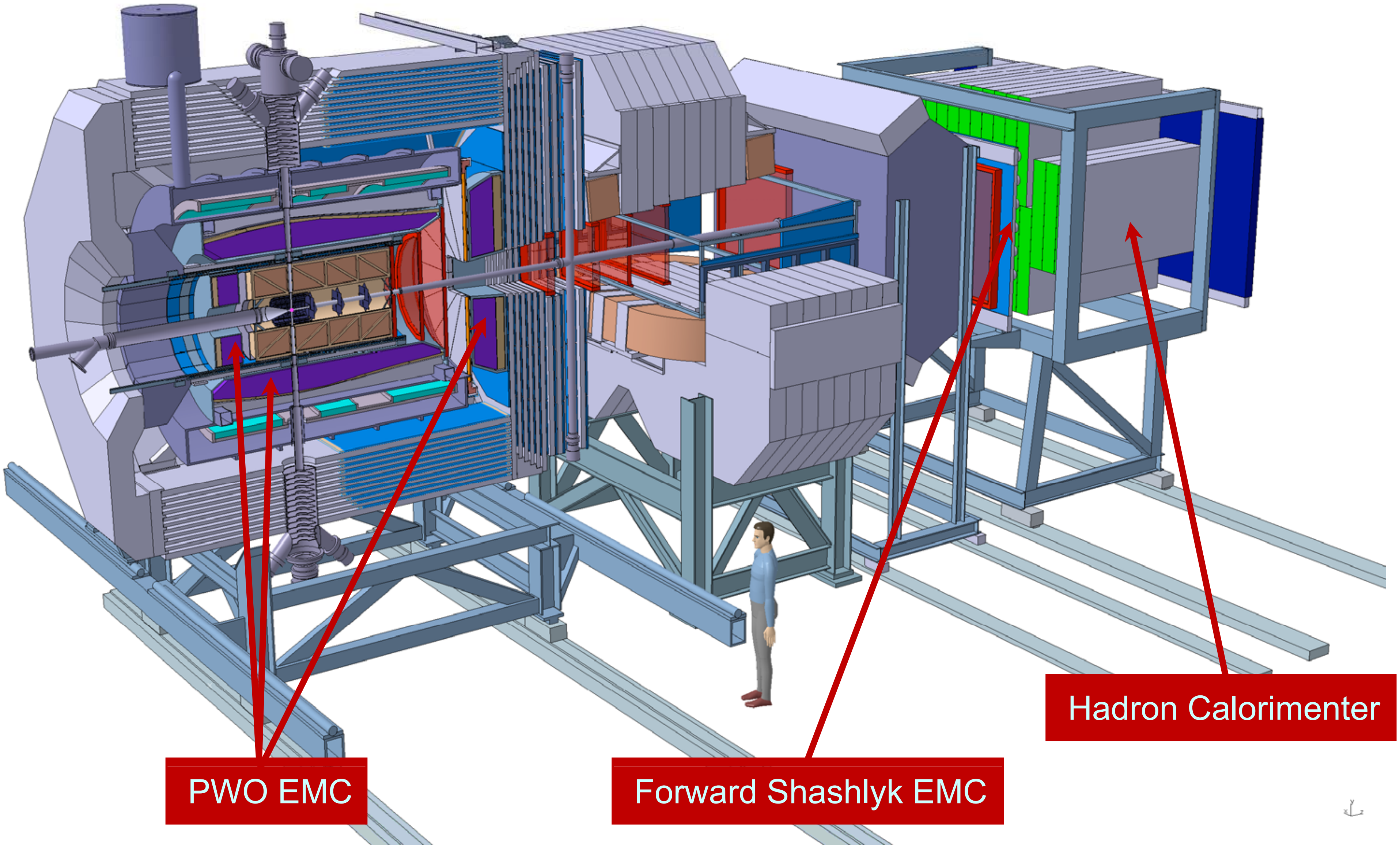



Pellet or cluster-jet target
2 T superconducting solenoid
2 Tm dipole



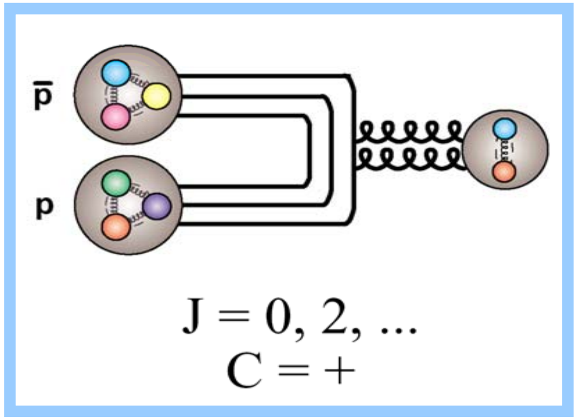
Central Tracker
Micro-Vertex-Detector
Forward Trackers

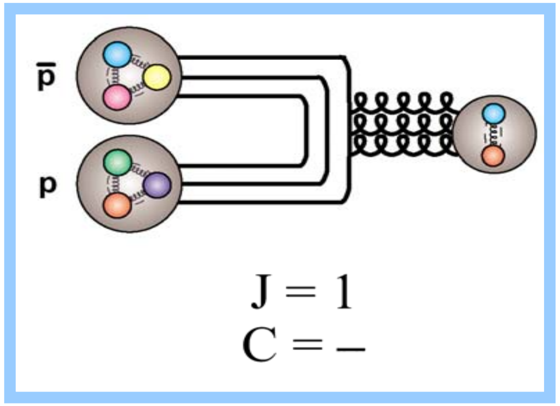

Muon Detectors
Barrel DIRC
Barrel TOF
Endcap DIRC
Forward RICH
Forward TOF


PWO EMC
Forward Shashlyk EMC
Hadron Calorimenter

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

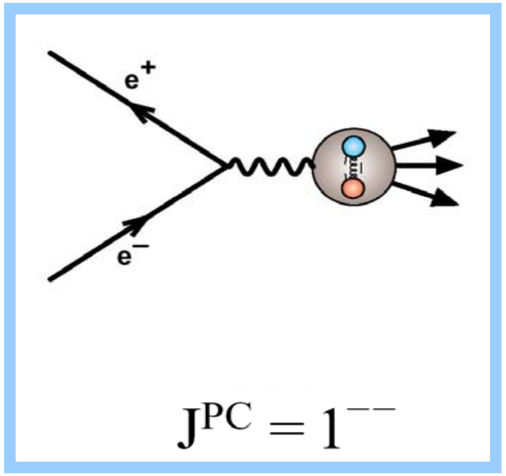
Formation:





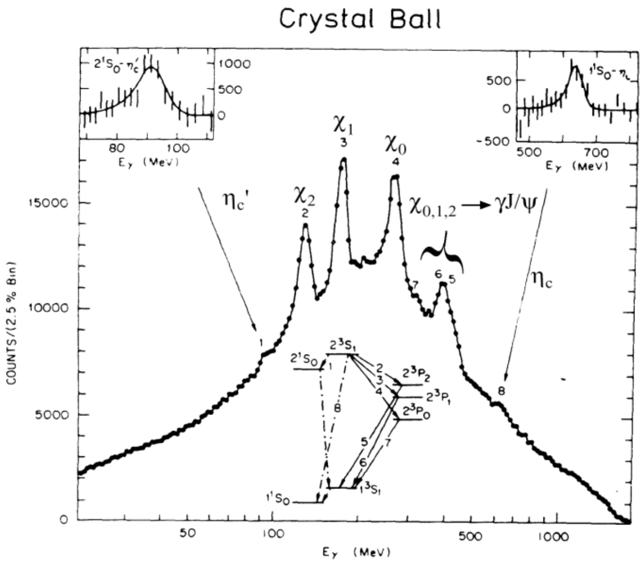
➡ All J^{PC} allowed for $(q\bar{q})$ accessible in $\bar{p}p$

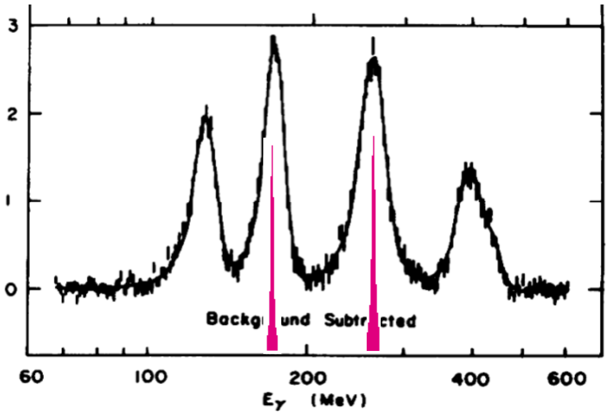
c.f.



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

Example: $\chi_{c1,2}$





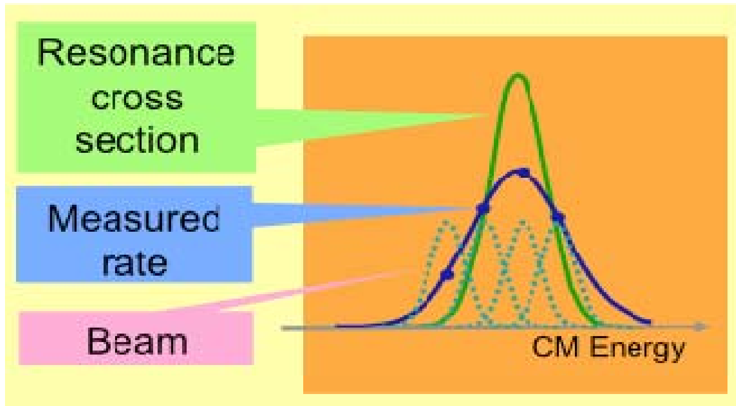
$$e^+e^- \to \psi' \to \gamma\chi_{1,2} \to \gamma(\gamma J/\psi) \to \gamma\gamma e^+e^-$$

Invariant mass reconstruction depends on the detector resolution ≈ 10 MeV

Formation:

$$\bar{p}p \to \chi_{1,2} \to \gamma J/\psi \to \gamma e^+e^-$$

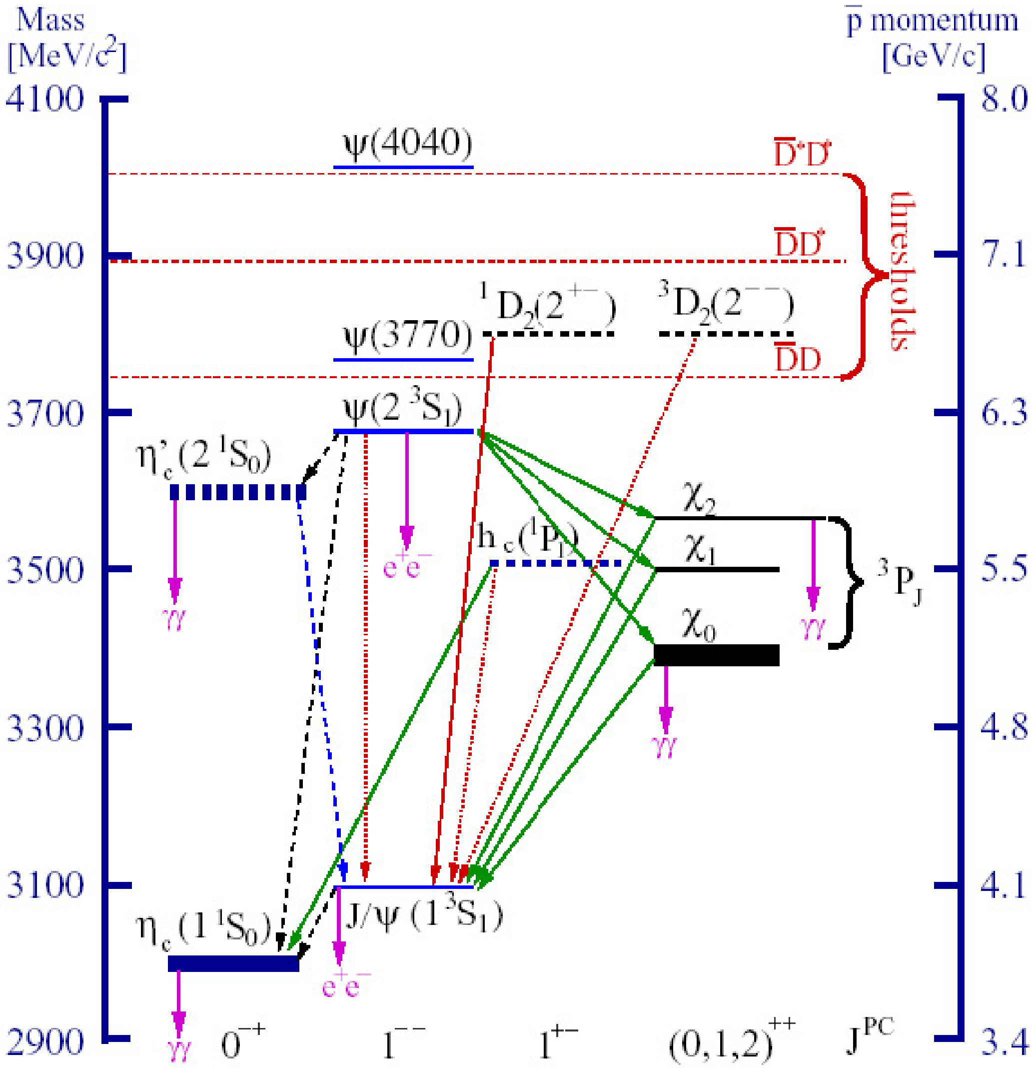
Resonance scan: Resolution depends on the beam resolution



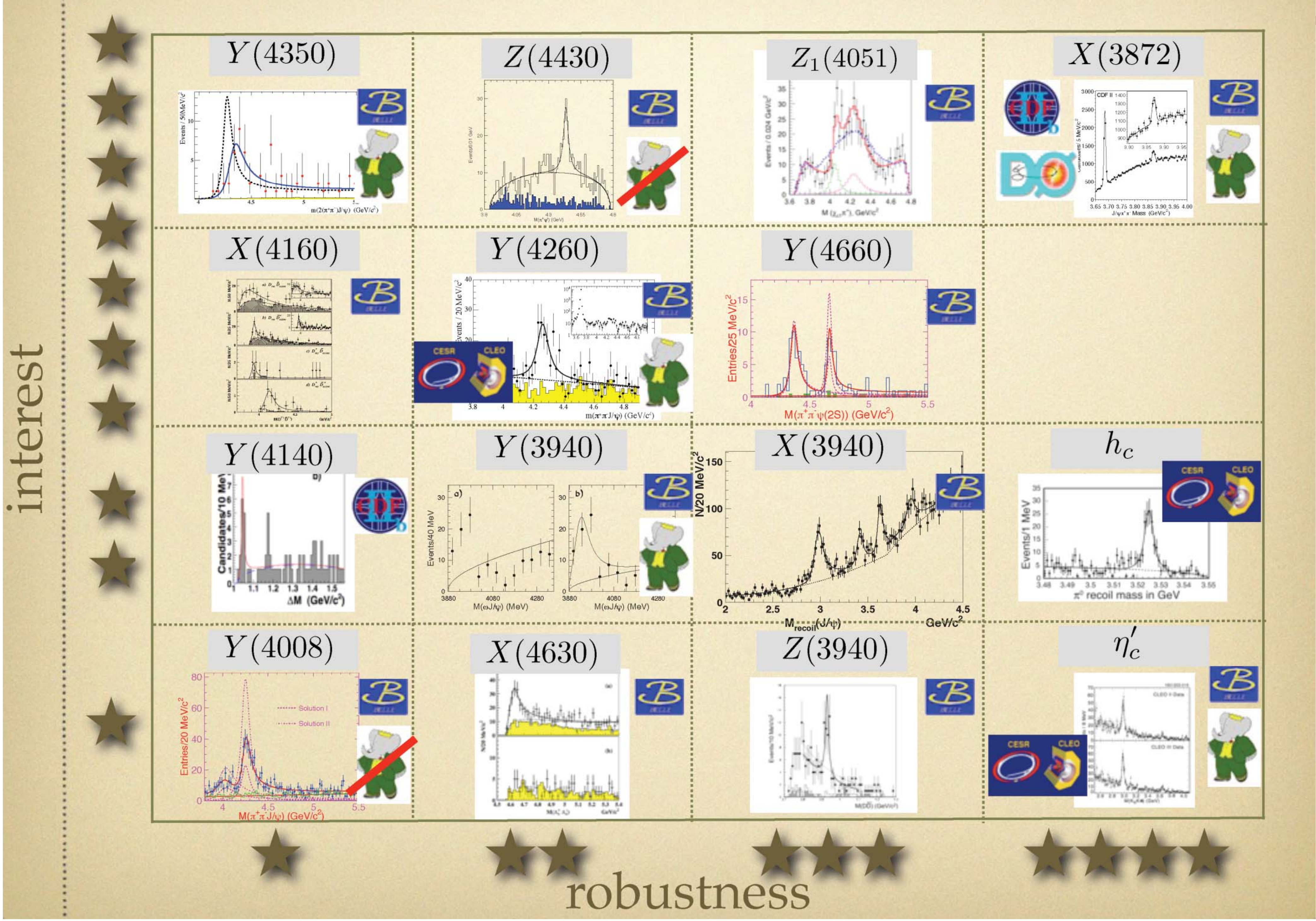
E760@Fermilab ≈ 240 keV   PANDA ≈ 30 keV

Charmonium spectroscopy

- open questions below $D\bar{D}$ threshold: widths, branching
- new „XYZ“ states (Belle, BaBar, CLEO, CDF, D0, …)
- new degrees of freedom: molecules, tetraquarks, gluonic excitations?
- conventional states above $D\bar{D}$
- high *L* states: access in $\bar{p}p$ but not in e^+e^-



E. Swanson, talk given at the Dec. 09 PANDA Meeting

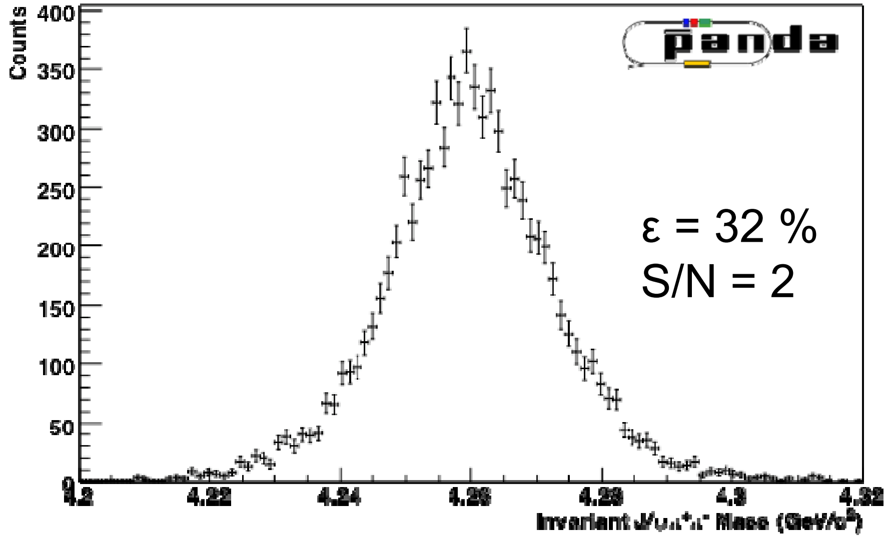


How can PANDA contribute?

- simulation studies for several channels and √s:

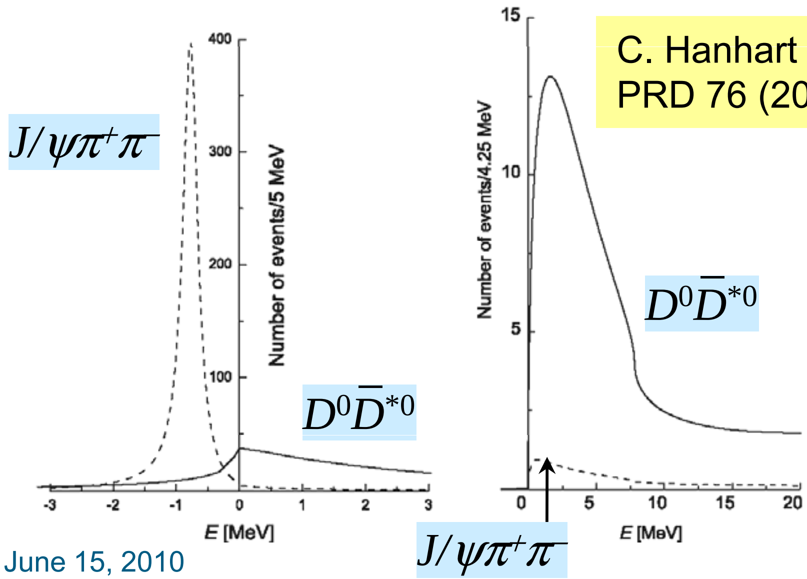
  $J/\psi\pi^+\pi^-$, $J/\psi\pi^0\pi^0$, $\chi_c\gamma \rightarrow J/\psi\gamma\gamma$, $J/\psi\gamma$, $J/\psi\eta$, $\eta_c\gamma$

- direct formation in $\bar{p}p$: line shapes !
- d target: $\bar{p}n$ with p spectator tagging, e.g. $Z^-(4430)$

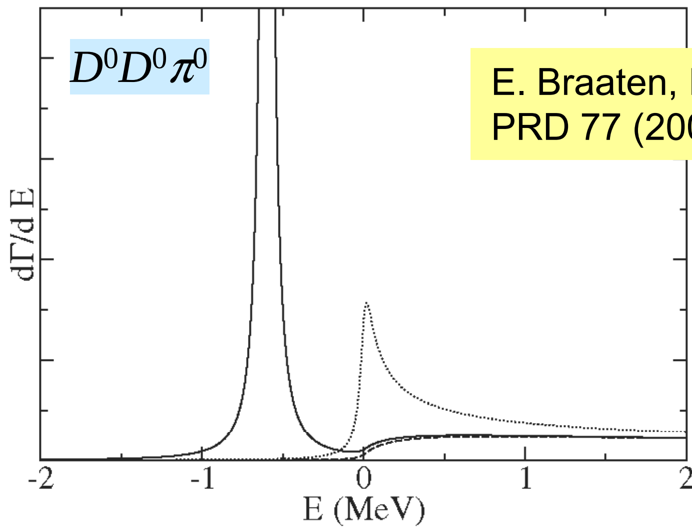


$\bar{p}p \rightarrow Y(4260) \rightarrow J/\psi\pi^+\pi^-$ ≈ 100 events/day

$\rightarrow J/\psi\pi^0\pi^0$ ≈ 40 events/day
S/N =25



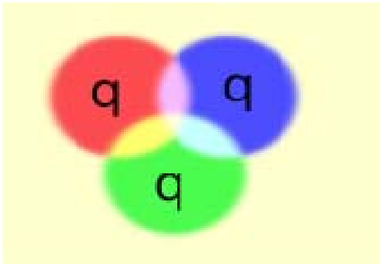
C. Hanhart *et al.*,
PRD 76 (2007) 034007



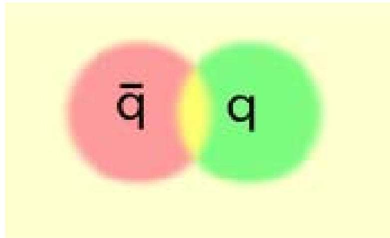
E. Braaten, M. Lu,
PRD 77 (2008) 014029

Beyond standard quark configurations

QCD allows much more than what we have observed:

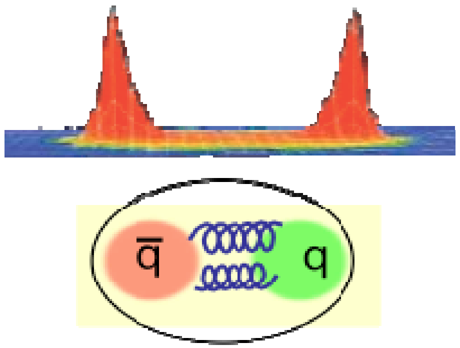


Baryons

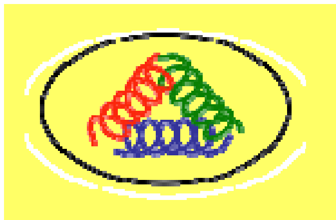


Mesons

Exotics:

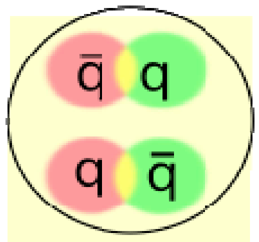


Hybrids



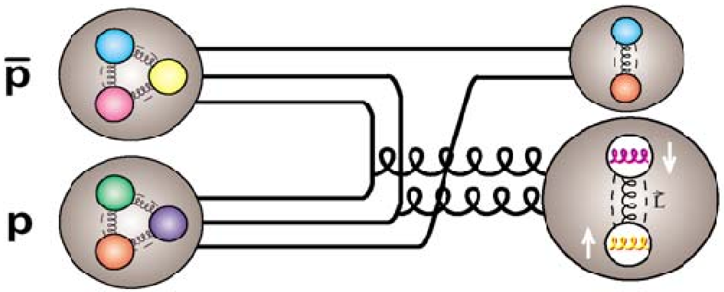
Glueballs

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



Tetraquarks
Molecules

Exotics production in $\bar{p}p$ collisions

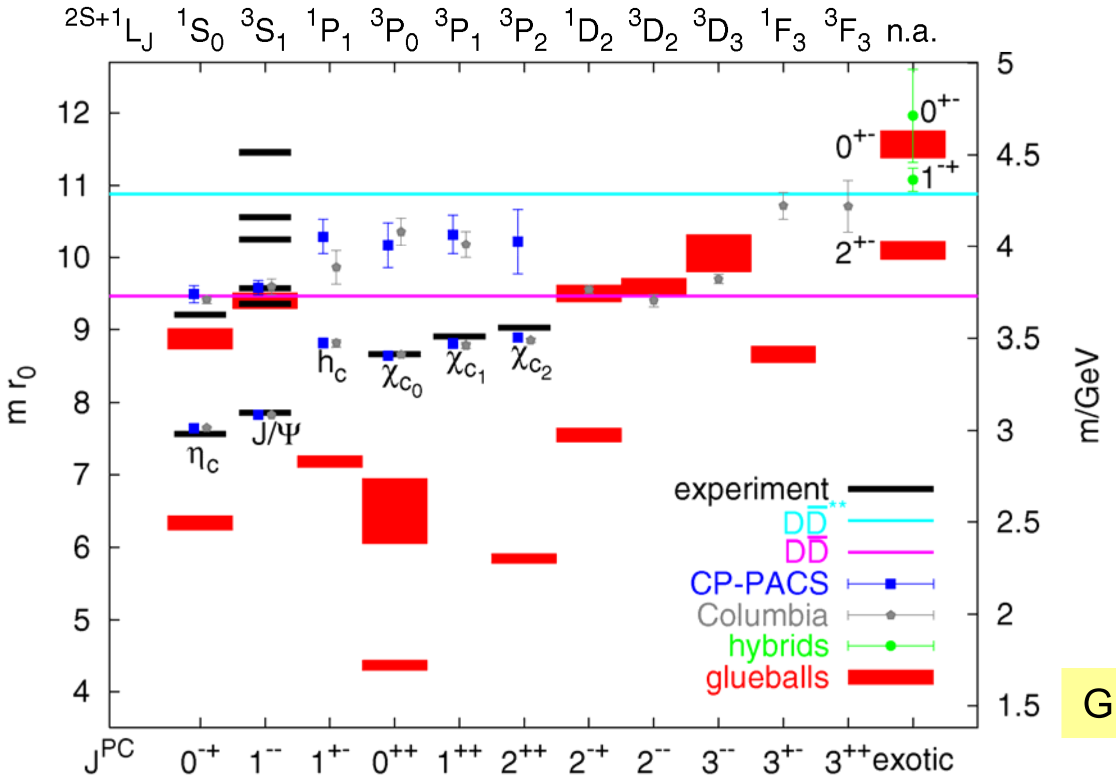


Production: all J^{PC} accessible

Hybrids

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

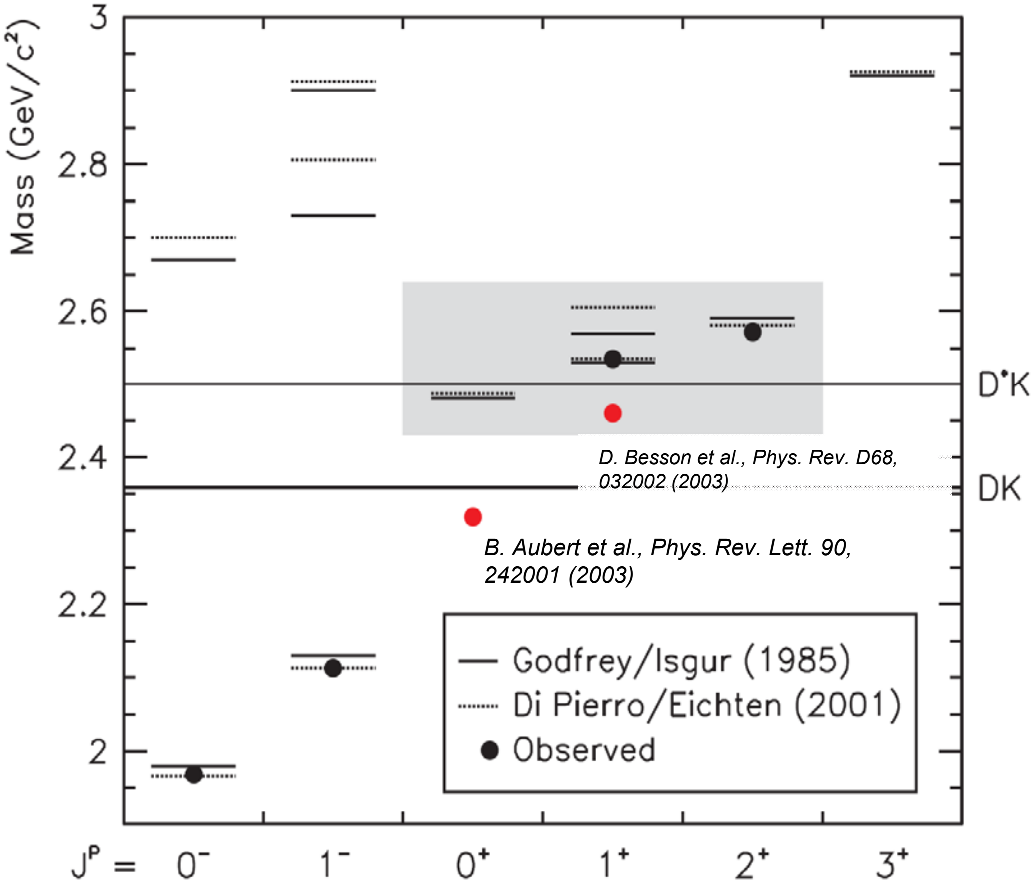
J^{PC} exotic



Exotic J^{PC} would be clear signal

G.Bali, EPJA 1 (2004) 1 (PS)

Open charm: The D_s spectrum



B. Aubert et al. (BaBar Collab.), Phys. Rev. D 74 (2006) 032007

- new narrow states $D_s^*(2317)$ and $D_s^*(2460)$ seen by BaBar, Belle, CLEO
- masses significantly lower than quark model expectation
- states are just below DK and D^*K threshold
- interpretation unclear: DK / D^*K molecules, tetraquarks, quiral doublers, …?

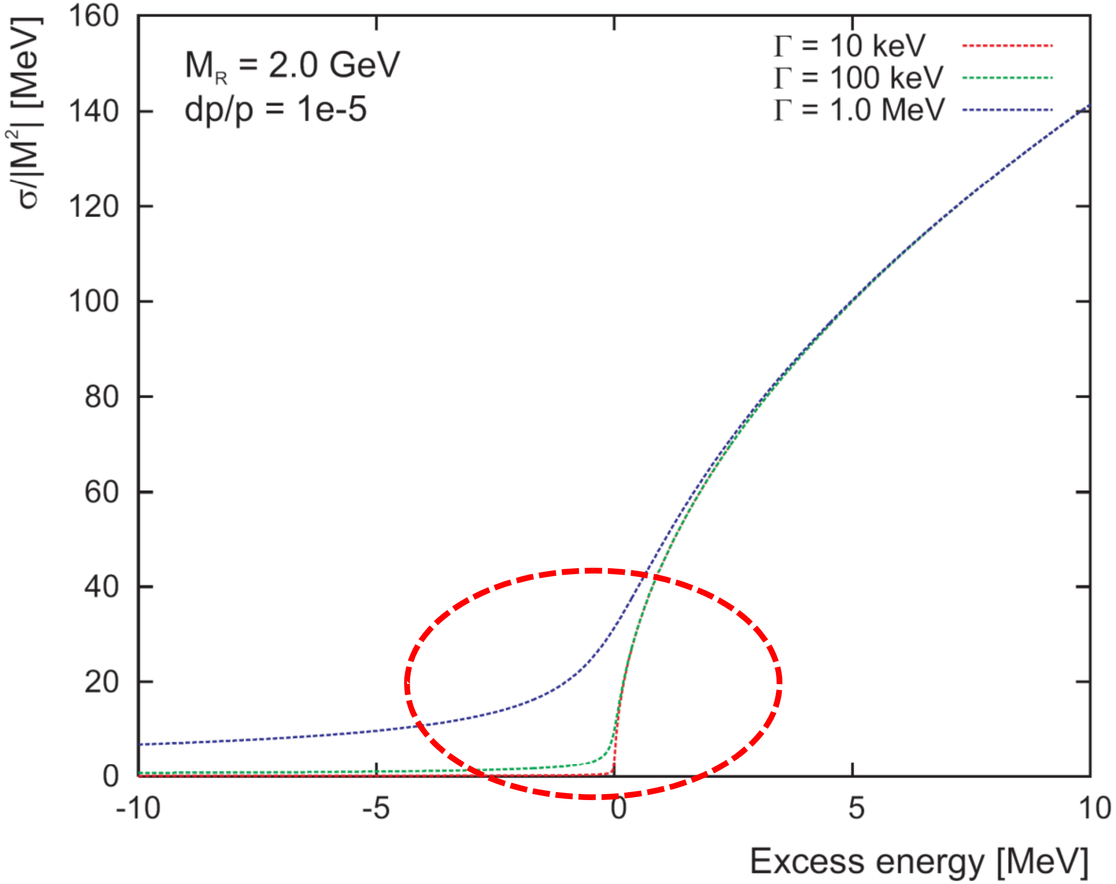
$D_{s0}^*(2317)$ theoretical predictions

Approach	$\Gamma(D_{s0}^*(2317) \rightarrow D_s\pi^0)$ (keV)
M. Nielsen, Phys. Lett. B 634, 35 (2006)	**6 ± 2**
P. Colangelo and F. De Fazio, Phys. Lett. B 570, 180 (2003)	**7 ± 1**
S. Godfrey, Phys. Lett. B 568, 254 (2003)	**10**
Fayyazuddin and Riazuddin, Phys. Rev. D 69, 114008 (2004)	**16**
W. A. Bardeen, E. J. Eichten and C. T. Hill, Phys. Rev. D 68, 054024 (2003)	**21.5**
J. Lu, X. L. Chen, W. Z. Deng and S. L. Zhu, Phys. Rev. D 73, 054012 (2006)	**32**
W. Wei, P. Z. Huang and S. L. Zhu, Phys. Rev. D 73, 034004 (2006)	**39 ± 5**
S. Ishida, M. Ishida, T. Komada, T. Maeda, M. Oda, K. Yamada and I. Yamauchi, AIP Conf. Proc. 717, 716 (2004)	**15 - 70**
H. Y. Cheng and W. S. Hou, Phys. Lett. B 566, 193 (2003)	**10 - 100**
A. Faessler, T. Gutsche, V.E. Lyubovitskij, Y.L. Ma, Phys. Rev. D 76 (2007) 133	**79.3 ± 32.6**
Y. I. Azimov and K. Goeke, Eur. Phys. J. A 21, 501 (2004)	**129 ± 43 (109 ± 16)**
M.F.M. Lutz, M. Soyeaur, arXiv: 0710.1545 [hep-ph]	**140**
Feng-Kun Guo, Christoph Hanhart, Siegfried Krewald, Ulf-G. Meißner Phys Lett. B 666 (2008) 251-255	**180 ± 40 ± 100**

Method: threshold scan

- reaction: $\bar{p}p \rightarrow D_s^{\pm} D_{s0}^{*}(2317)^{\mp}$

$$\Rightarrow \quad \frac{\sigma(s)}{|M^2|} = \frac{\Gamma}{4\pi\sqrt{s}} \int_{-\infty}^{\sqrt{s}-m_{D_s}} \mathrm{d}m \frac{\sqrt{\left(s-(m+m_{D_s})^2\right)\left(s-(m-m_{D_s})^2\right)}}{\left(m-m_{D(2317)}\right)^2+(\Gamma/2)^2}$$

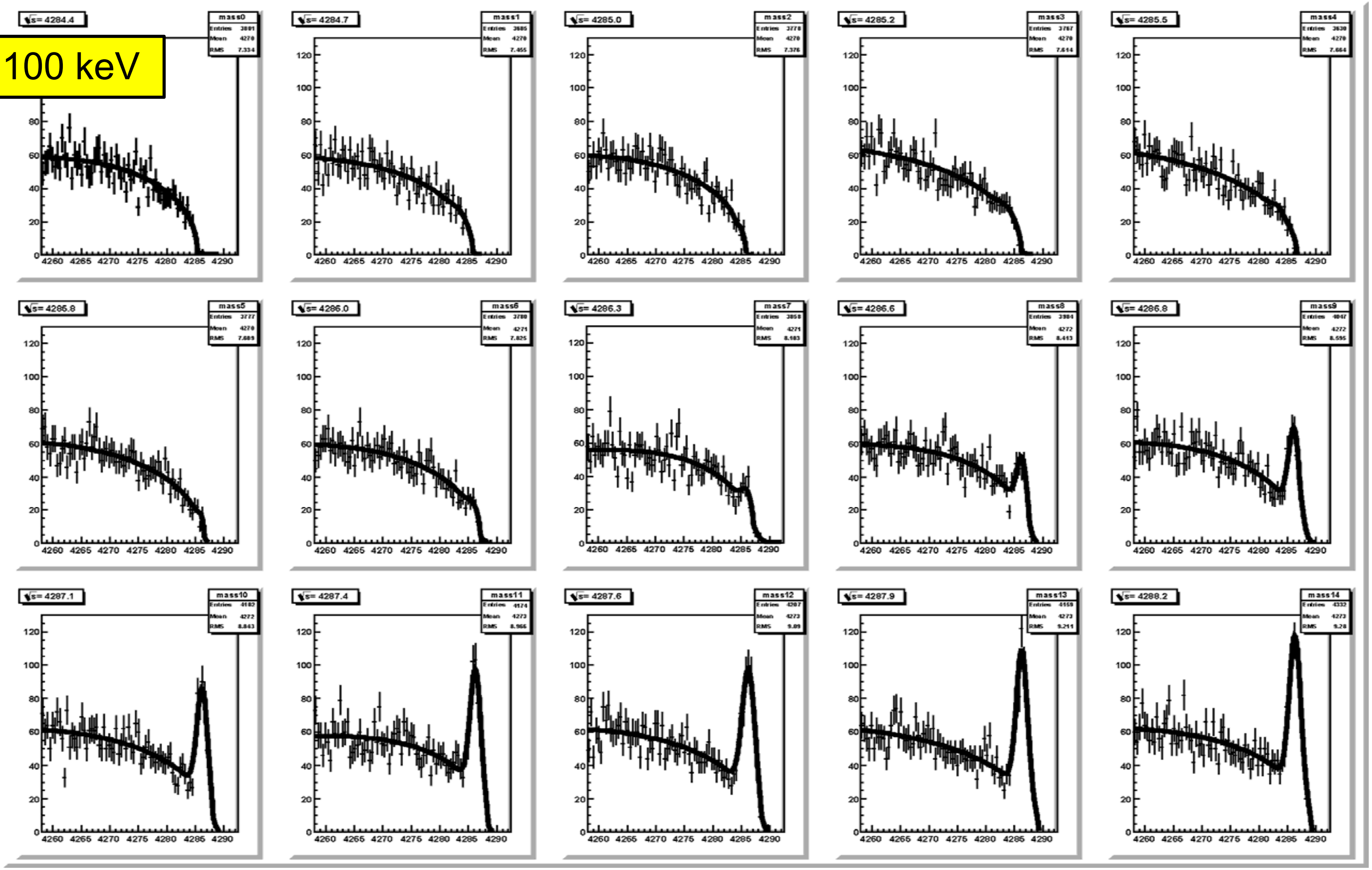


- excitation function only depends on m and Γ of $D_s(2317)$
- experimental accuracy determined by beam quality (Δp, σ_p/p), not by detector resolution

Simulation results: energy scan

$M_{sum} = M_{miss}(D_s) + M(D_s)$

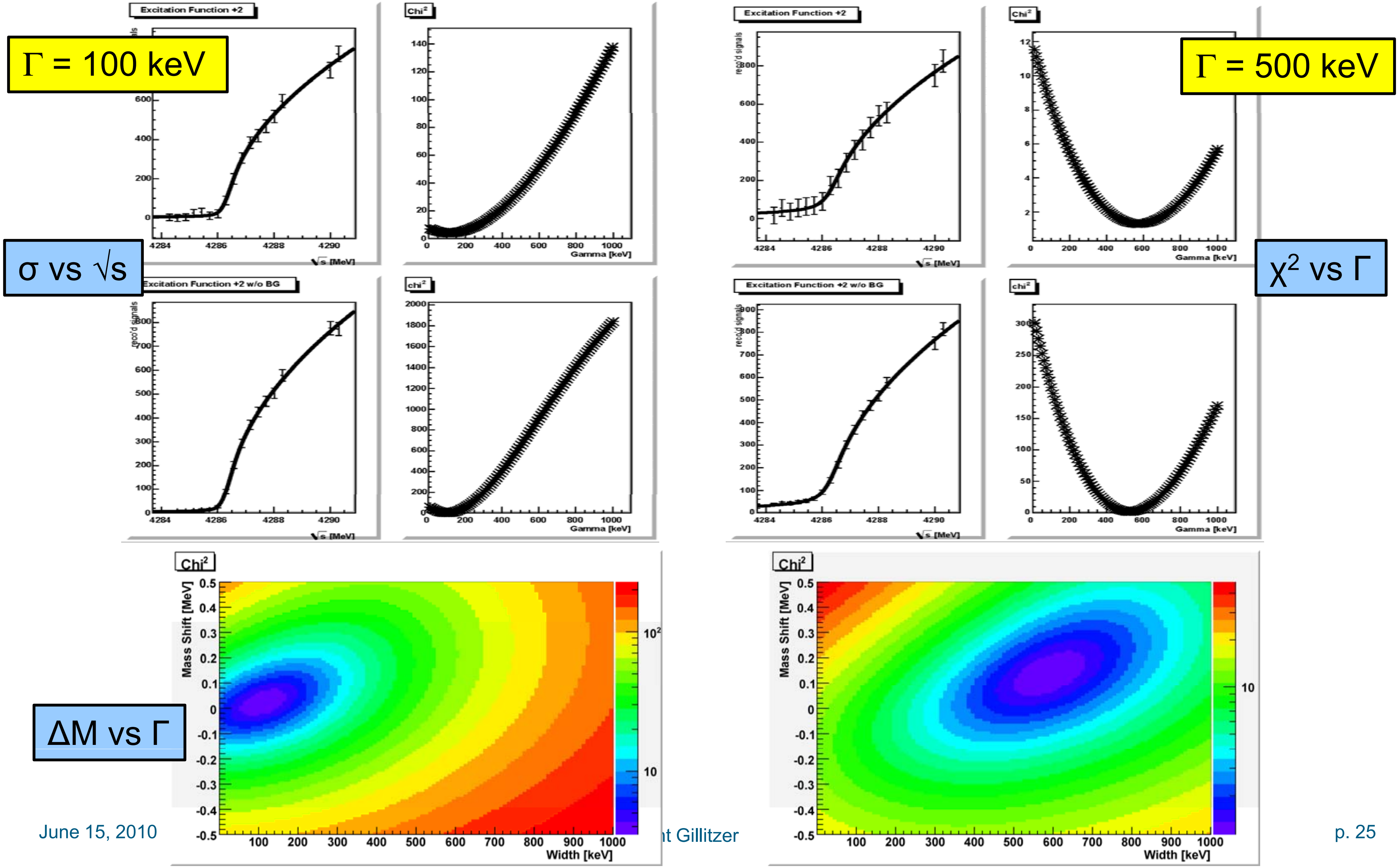
Γ = 100 keV



M. Mertens PhD thesis in preparation

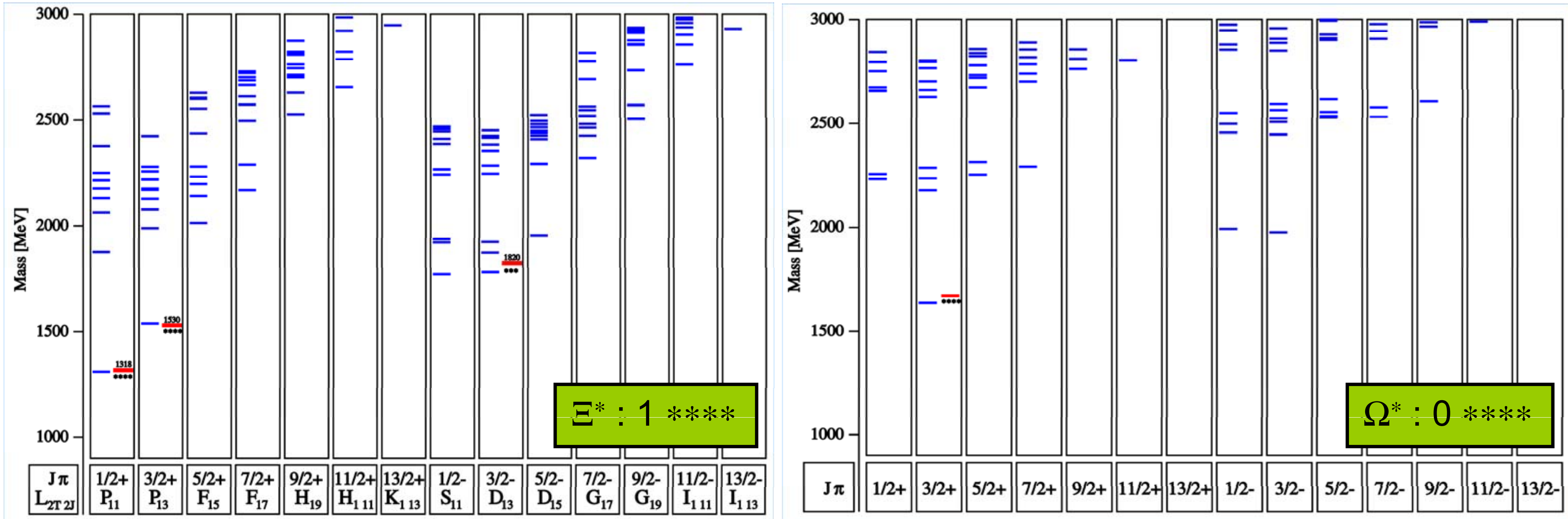
Simulation results: energy scan

M. Mertens PhD thesis in preparation



Baryon spectroscopy

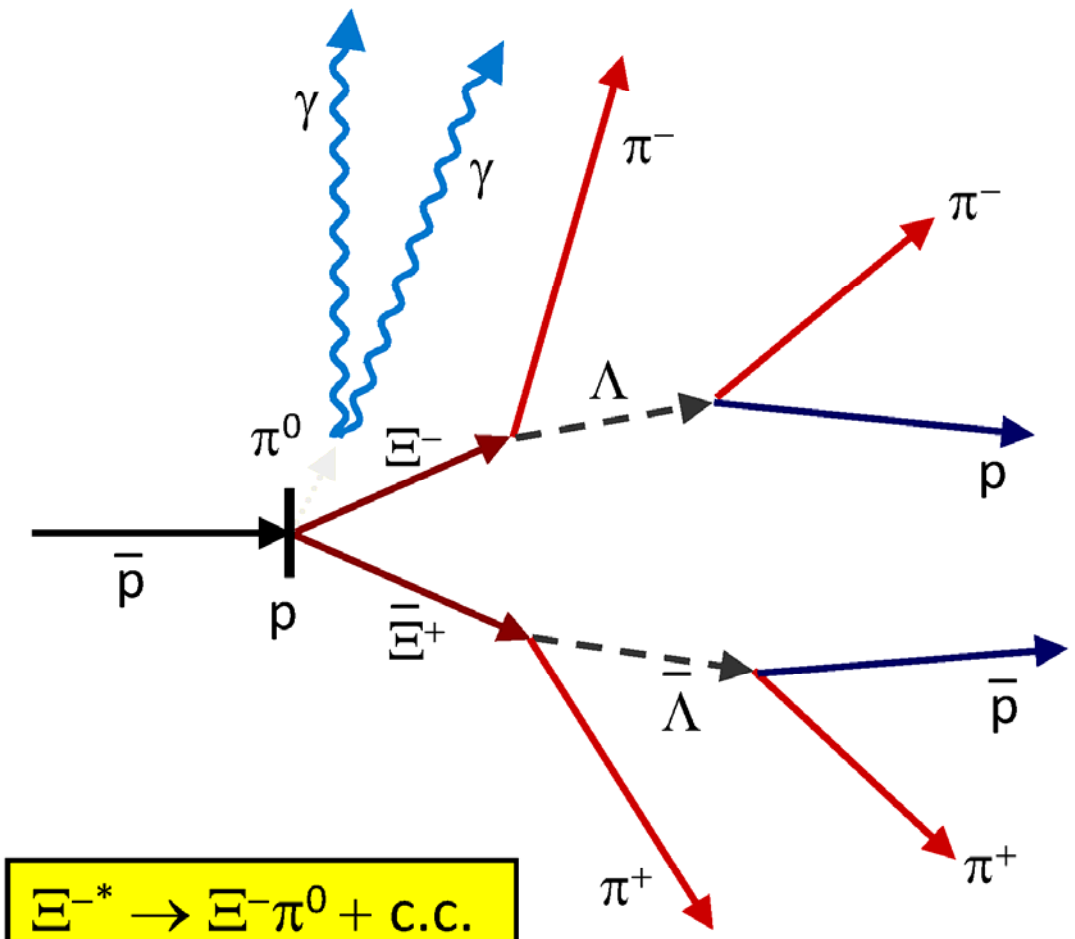
- similar cross section for annihilation to mesons and for final states with baryon-antibaryon
- baryons formed largely via excited states
- particularly large discovery potential in multi-strange baryons: very little known in Ξ and Ω spectrum
- charmed baryons, exotic baryons with hidden charm



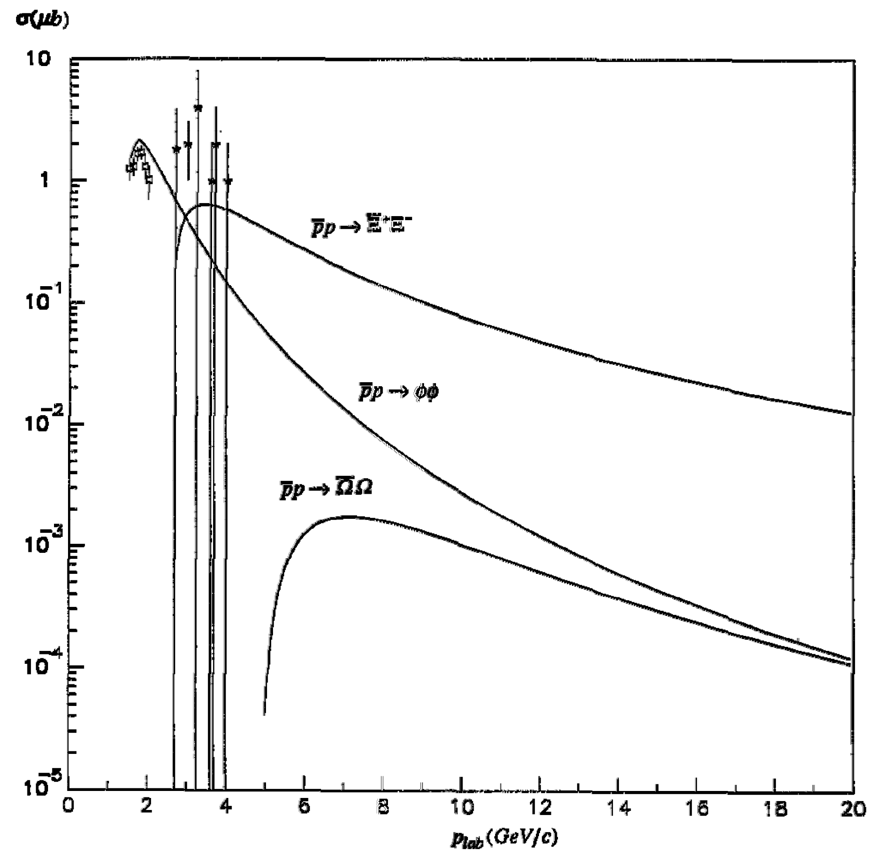
U. Löring, B.Ch. Metsch, H.R. Petry, Eur. Phys. J A 10 (2001) 447

Baryon spectroscopy

- characteristic event topology of $\bar{\Xi}\Xi^*$ and $\bar{\Omega}\Omega^*$ events
- ~μb cross section for $\bar{\Xi}\Xi$ ⇨ ~10^7 Ξ /day produced with full luminosity



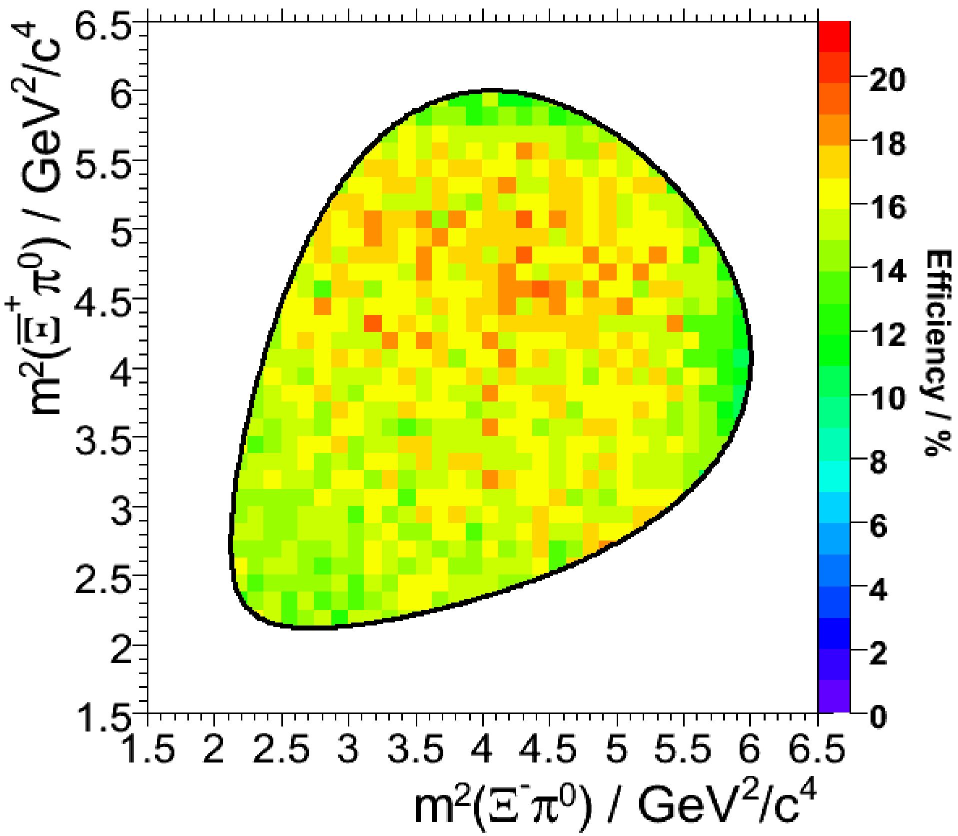
$\Xi^{-*} \rightarrow \Xi^- \pi^0 + \text{c.c.}$

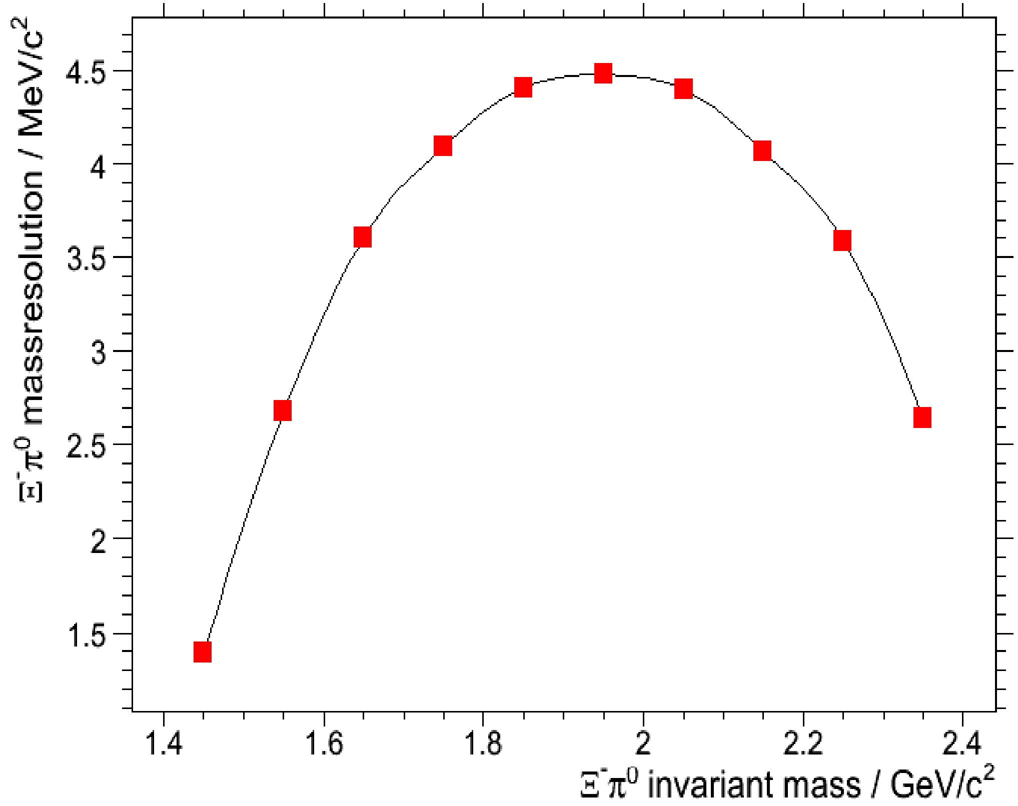


A.B. Kaidalov, E.P.Volkovitsky, ZPC 63 (94) 514

Simulation: $\bar{p}p \rightarrow \bar{\Xi}^+\Xi^-\pi^0$

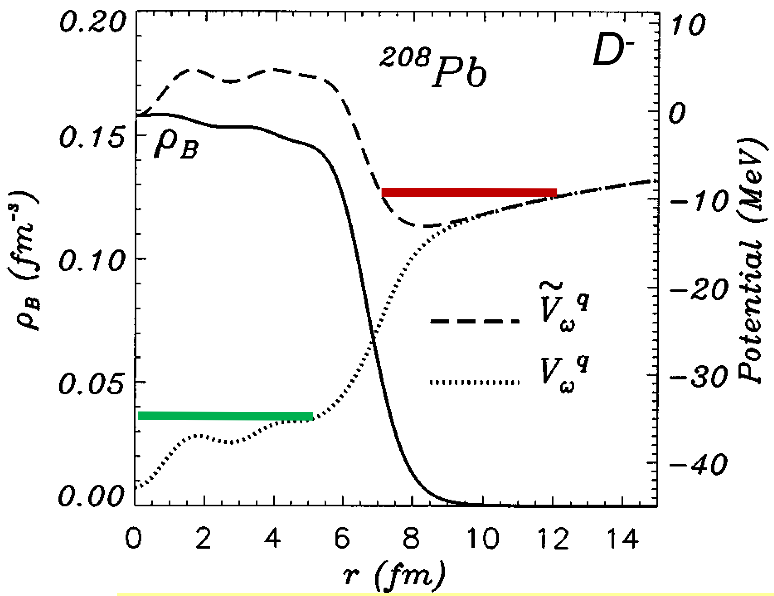
- benchmark channel for the study of Ξ resonances
- no empty regions or discontinuities in Dalitz plot
- $\Xi^-\pi^0$ mass resolution ~4 MeV



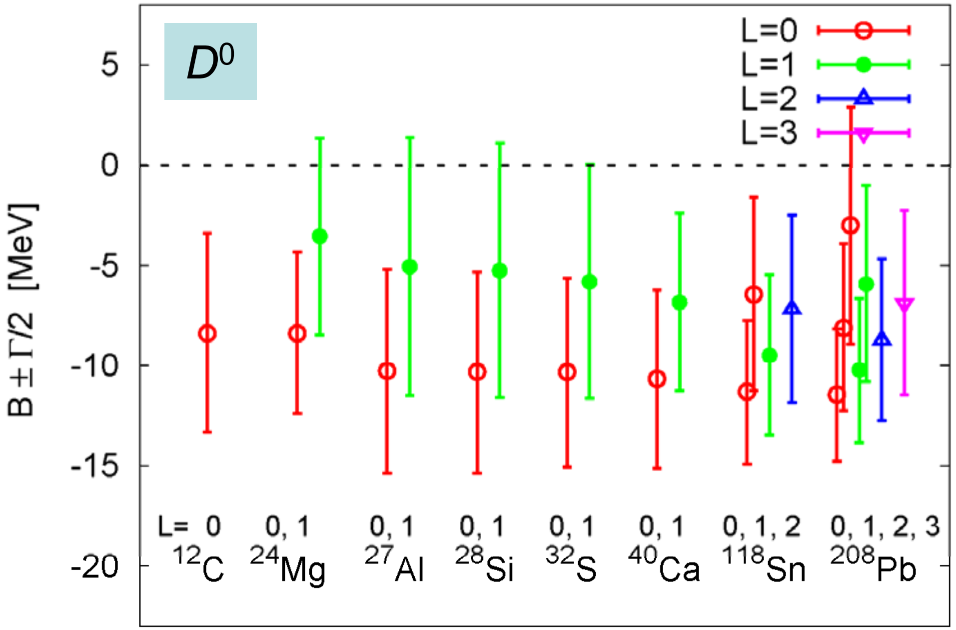


Hadrons in the nuclear medium

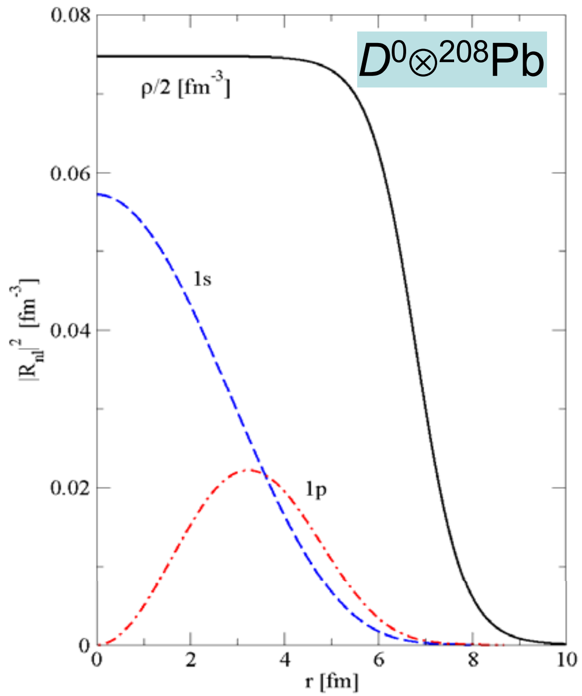
- original idea: mass shift of charmed hadrons in nuclear matter
- D mesons: attractive potential and/or bound states predicted
- problem: large momentum transfer ⇨ multistep processes required



K. Tsushima *et al.*, PRC 59 (1999) 2824



D^0-nucleus bound states



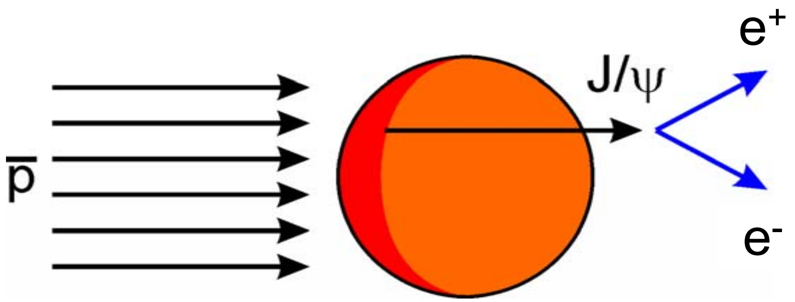
C. Garcia-Recio *et al.* arXiv:1004.2634

Hadrons in the medium: J/ψ absorption

- related to QGP signal in HI collisions

$\bar{p} + A \rightarrow J/\psi + X \rightarrow e^+e^- + X$

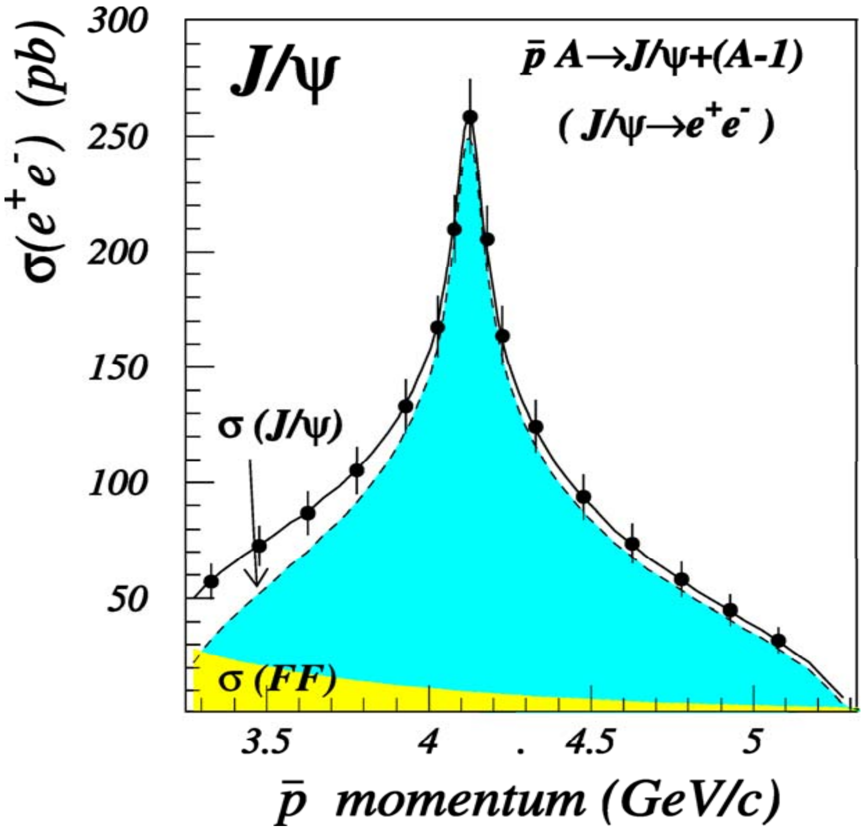
$\bar{p} + A \rightarrow J/\psi + X \rightarrow \mu^+\mu^- + X$



$$P = e^{-\sigma\rho \mathrm{d}l}$$

measure cross section as function of A and $p_{\bar{p}}$

deduce J/ψN dissociation cross section at *lower, well-defined* J/ψ momentum



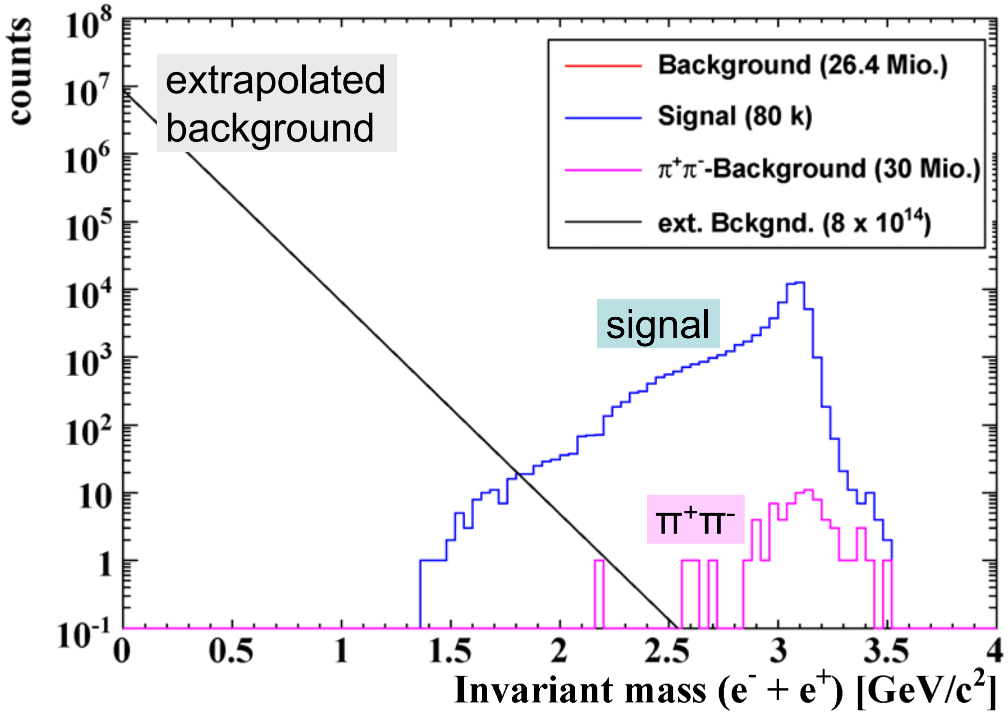
K. Seth, Proc. Hirschegg 2001

note: $\sigma_{\bar{p}A \rightarrow J/\psi X} << \sigma_{\bar{p}p \rightarrow J/\psi}$

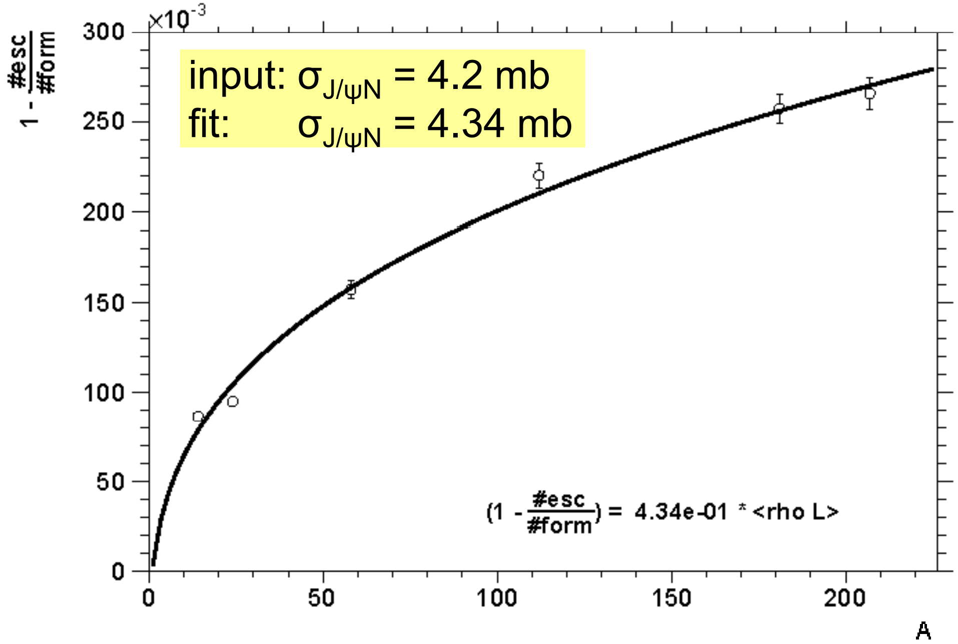
need to detect S/B = 10^{-10} !

Hadrons in the medium: J/ψ absorption

- first detailed simulations of 4.05 GeV/c p + ^{40}Ca → J/ψ + X → e^+e^- + X
- reconstruction efficiency ε_{signal} = 0.73
- σ_{peak} ~ 0.3 nb → #J/ψ ~ 200 /day at maximum luminosity
- background seems to be controllable



$\sigma_{J/\psi N}$ extracted from A-dependence



Summary

- Using $\bar{p}p$ and $\bar{p}A$ collisions, PANDA is complementary to other experiments
- PANDA is well-suited to answer key questions regarding:
  - normal and exotic hidden charm mesons
  - multi-strange (and charmed) baryons
  - properties of hadrons in the nuclear medium
- much wider physics program
- high degree of flexibility: capability to respond to new topics arising in the future

International collaboration:

- > 400 scientists
- > 40 institutions
- 16 countries