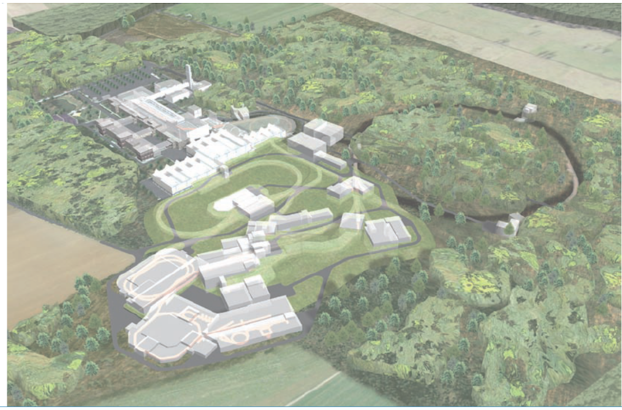
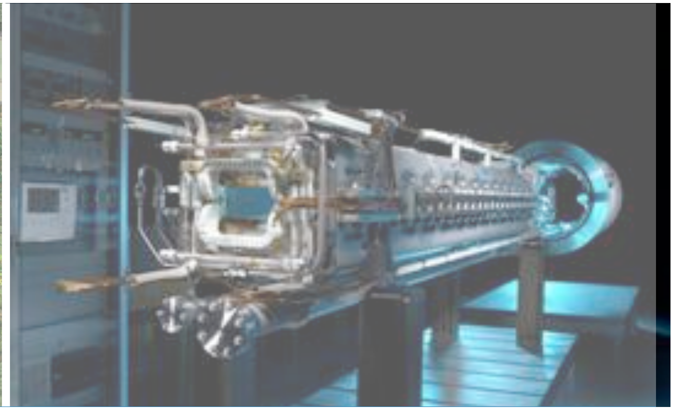


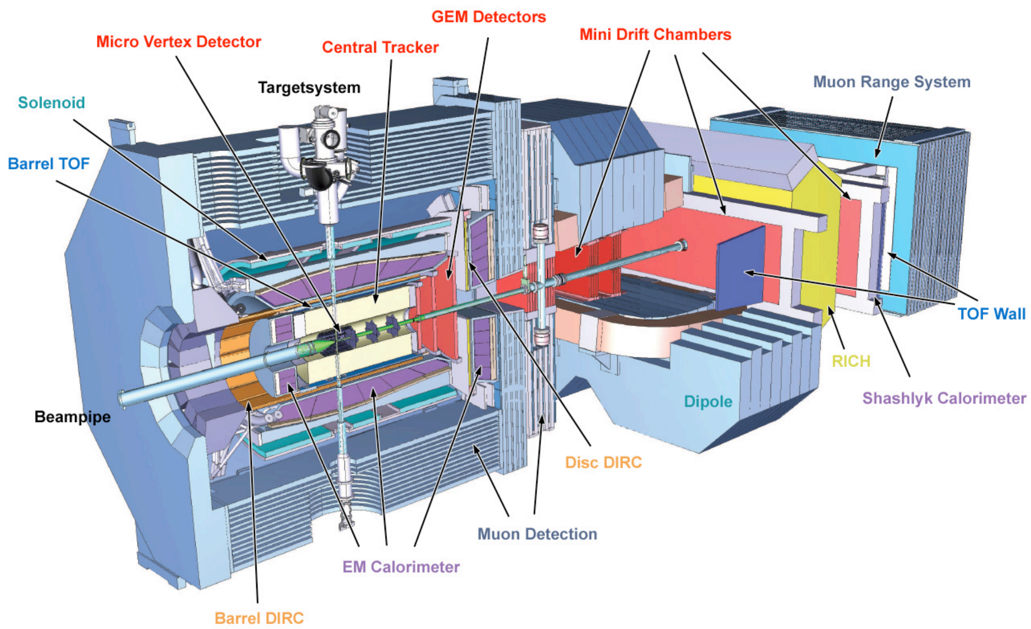


# Antiproton Physics with $\bar{P}$ANDA at FAIR

Paola Gianotti
INFN Istituto Nazionale di Fisica Nucleare

# PANDA Scientific Program

- Charmonium/open charm spectroscopy
- Exotic states
- Strange and charmed baryons
- Hadrons in the nuclear medium
- Hypernuclear physics
- Nucleon structure via e.m. processes



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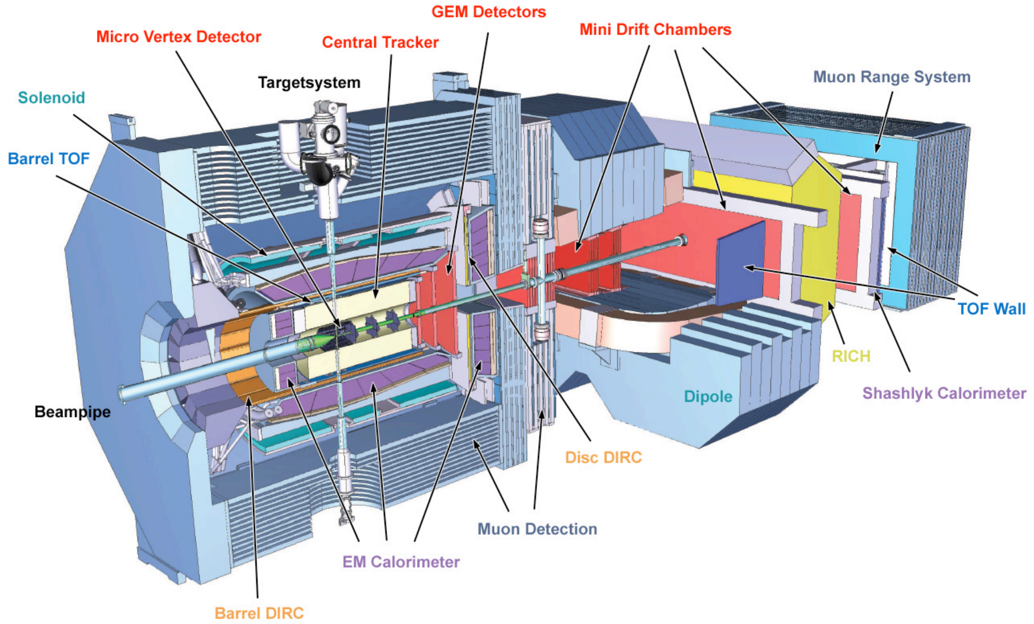
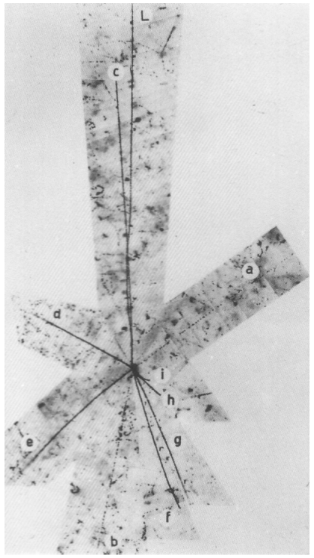


# Antiproton physics has a great past

- $\bar{p}p$-Colliders (SPS CERN, Tevatron Fermilab)
- Conventional $\bar{p}$-beams (LBL, BNL, CERN, Fermilab, KEK, ...)
- $\bar{p}$-Storage Rings (LEAR, AD (CERN); Antiproton Accumulator (Fermilab))

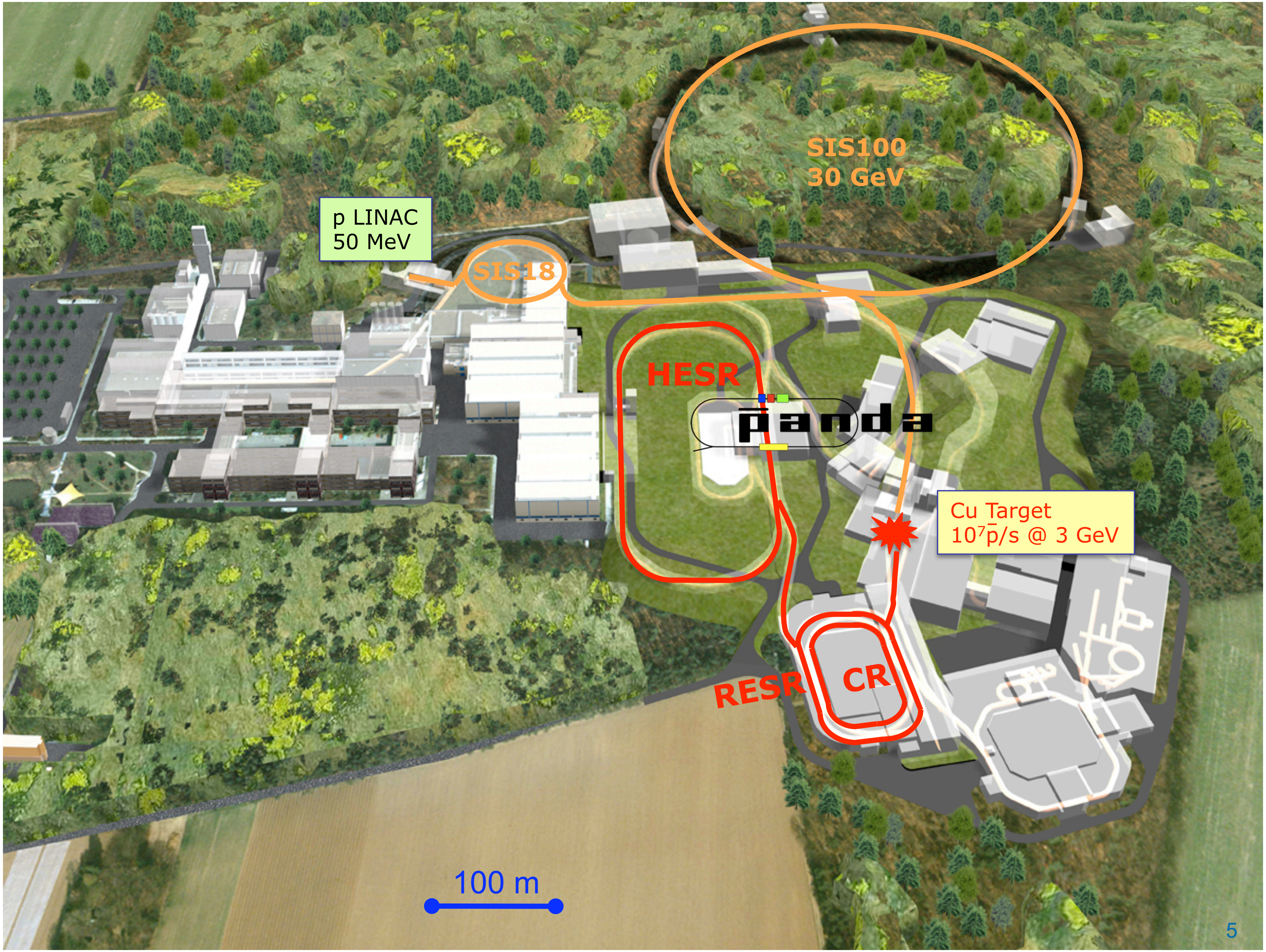
**Big and fundamental discoveries and precision measurements where possible thanks to antiprotons:**

- Z, $W^{\pm}$ bosons discovery;
- top quark discovery;
- $B_s$ oscillation discovery
- anti-hydrogen production;
- Meson Spectroscopy (u, d, s, c);
- $\bar{p}$-nucleus interaction;
- $\bar{p}$-Atoms;
- $\bar{p}$/p-mass ratio;
- hadron therapy study.

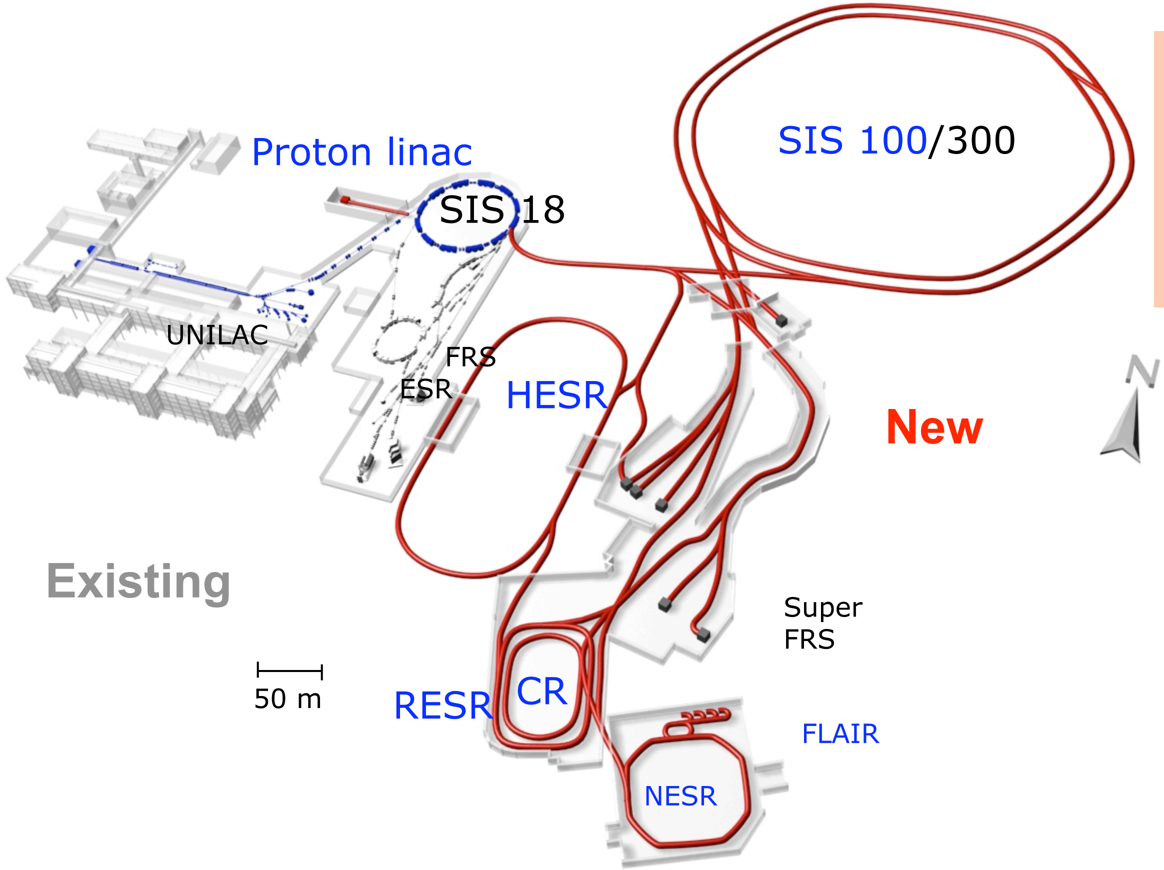


first $\bar{p}$ star obesrved at Berkley by E.Segrè and coll.

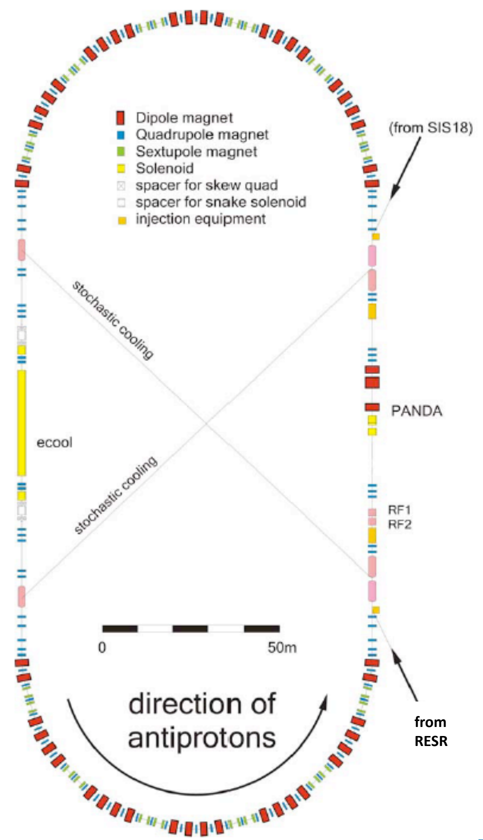
# Which is the future of antiproton physics?


SIS100
30 GeV
p LINAC
50 MeV
SIS18
HESR
p̄anda
Cu Target
$10^7 \bar{p}$/s @ 3 GeV
RESR
CR
100 m

# Facility for Antiproton and Ion Research

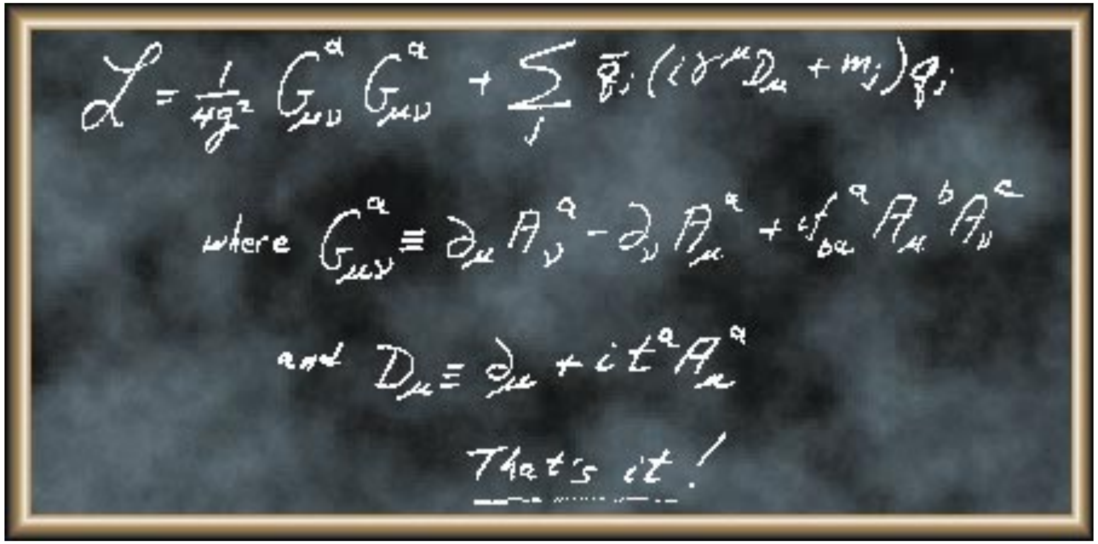



**Antiproton production**
- Proton Linac 50 MeV
- Accelerate p in SIS18 / 100
- Produce $\bar{p}$ on target
- Collect in CR, cool in RESR




**HESR:** Storage ring for $\bar{p}$
- Injection of $\bar{p}$ at 3.7 GeV/*c*
- Slow synchrotron (1.5-15 GeV/*c*)
- Luminosity up to L~ $2\times10^{32}$ $cm^{-2}s^{-1}$
- Beam cooling (stochastic & electron)

# Quantum Chromodynamics

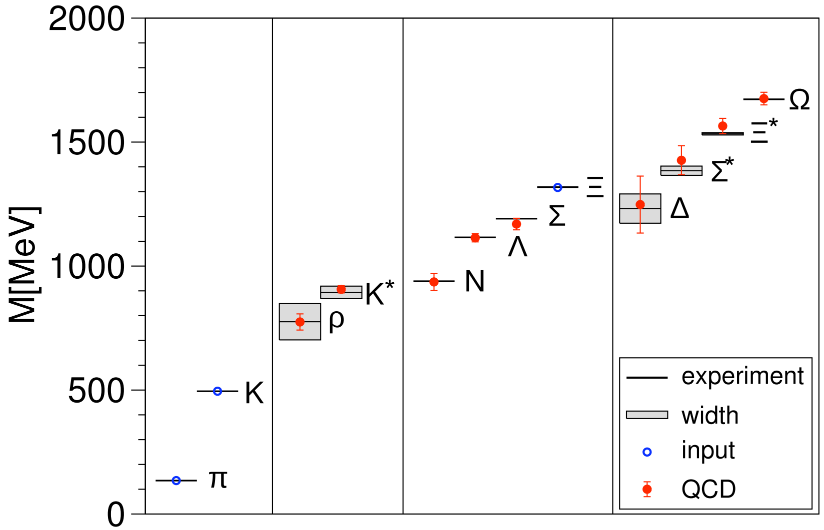



**The QCD Lagrangian** is, in principle, a complete description of the strong interaction.
There is just one overall coupling constant $g$ , and six quark-mass parameters $m_j$ for the six quark flavors

But,
it leads to equations that are hard to solve

# Theoretical approaches

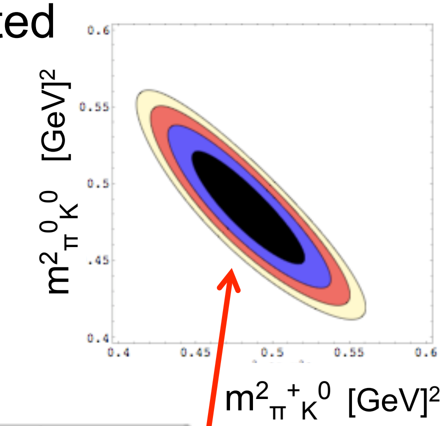
The first approach, Lattice QCD, solves the equations numerically.
That's not easy.
Fortunately, powerful modern computers have made it possible to calculate a few of the key predictions of QCD directly.

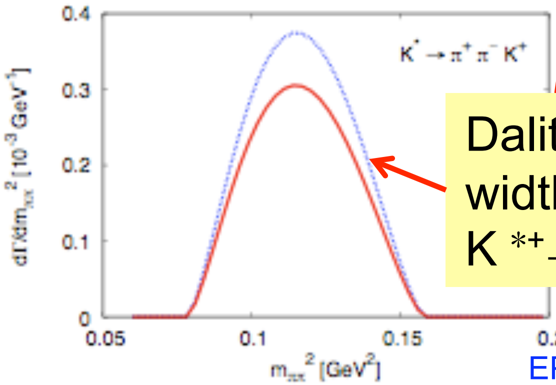



Science **322** (2008) 1224
[arXiv:0906.3599 [hep-lat]].

The agreement with the measured masses is at the few% level.

The second approach, Effective Field Theories, creates phenomenological models that are simpler to deal with, but keep resemblance to the real things.
Cross-sections and branching fractions can be predicted



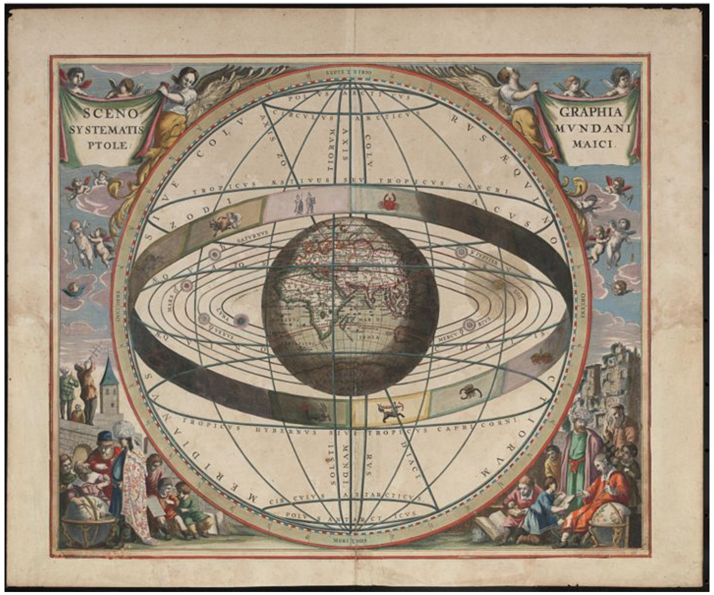




Dalitz plot and decay width for the channel
$K^{*+} \longrightarrow \pi^+ K^0 \pi^0$

EPJA39:205,2009
arXiv:0807.4686 [hep-ph]

# Can we be satisfied?

Today QCD predictions can reach a precision of about 10% at the GeV scale, and also the phenomenological models are not doing better!
Can we be satisfied of this accuracy?



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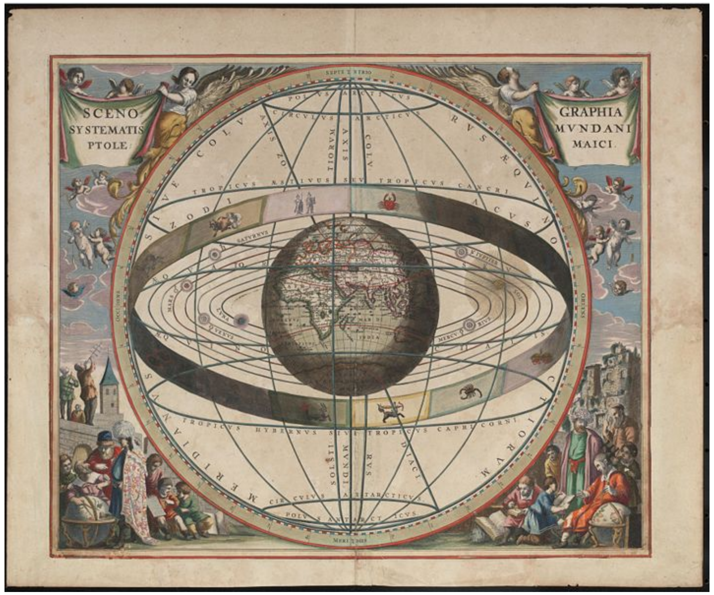
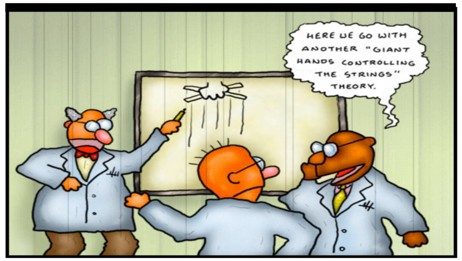



Just a note: the Ptolemaic system allowed to predict the position of the planets with the same level of accuracy…..

but it was wrong!

We have also to keep an eye to new theoretical developments….

# Other approaches



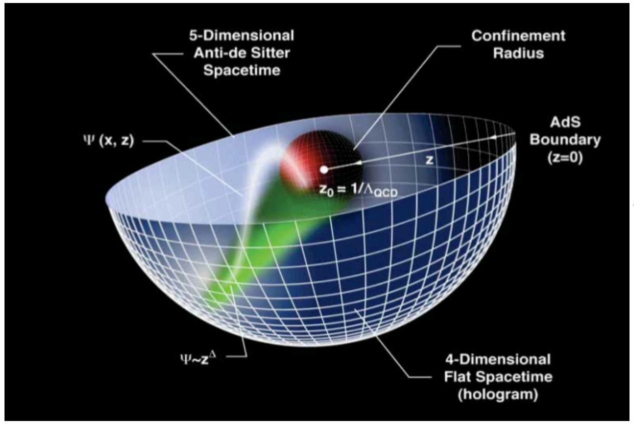



String theory is today a candidate for a quantum theory of gravity.

Nevertheless, string theory was introduced in an attempt to describe the large number of mesons and hadrons that were experimentally discovered in the 1960's.

The idea was to view all these particles as different oscillation modes of a string.
It was later discovered that hadrons and mesons are actually made of quarks and that they are described by QCD.

Recently, there has been remarkable progress in the study of the strong coupling dynamics of gauge theories by employing duality between gauge theory and string theory.



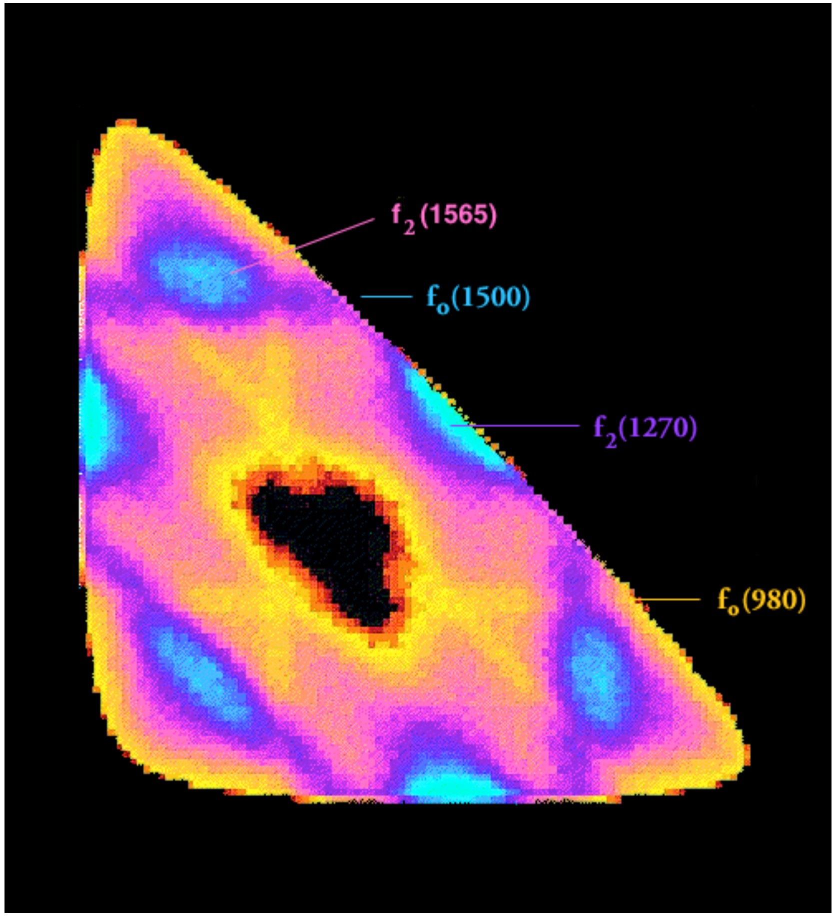

courtesy of S. Brodsky & G. de Teramond

Initiated by the discovery of the AdS/CFT correspondence intensive attempts to apply the idea of the gauge/string duality to QCD has been made. (EPJA35:81 (2008), PRL96, 201601 (2006), Phys.Rept.323:183,(2000))

A better understanding of QCD could help in developing this theory

# Antiproton power

$\bar{p}p$-cross sections high → Data with very high statistics
Low final state multiplicities: Clean spectra, Good for PWA




*PLB 342 (1995) 433*

Example: $\bar{p}p \rightarrow \pi^0\pi^0\pi^0$ (LEAR) → $f_0(1500)$ best candidate for the Glueball ground state

# Antiproton power

- $e^+e^-$ interactions:

- $p\bar{p}$ reactions:

# Antiproton power

- $e^+e^-$ interactions:

  - Only $1^{--}$ states are formed
  - Other states only by secondary decays (moderate mass resolution related to the detector)

- $p\bar{p}$ reactions:

  - Most states directly formed (very good mass resolution; $\bar{p}$-beam can be efficiently cooled)

# Antiproton power

$e^+e^- \rightarrow \Psi'$
$\rightarrow \boxed{\gamma\chi_{1,2}}$
$\rightarrow \gamma\gamma J/\psi$
$\rightarrow \gamma\gamma e^+e^-$

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

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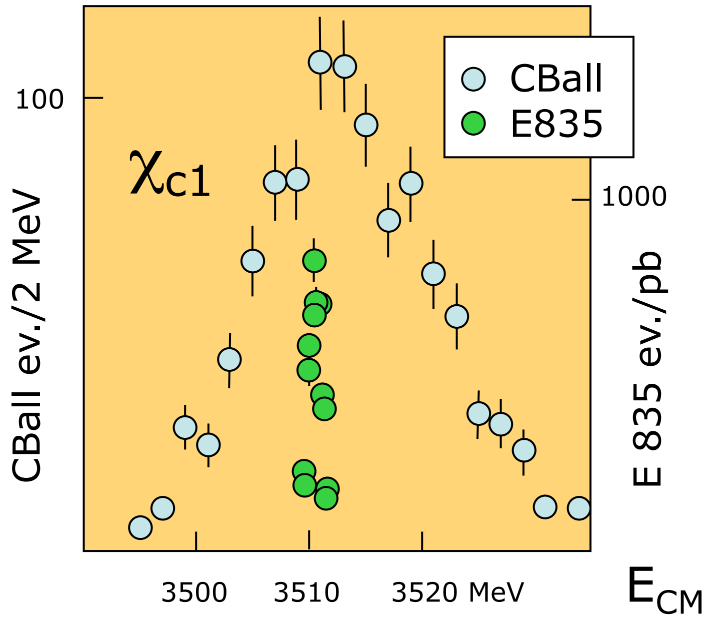

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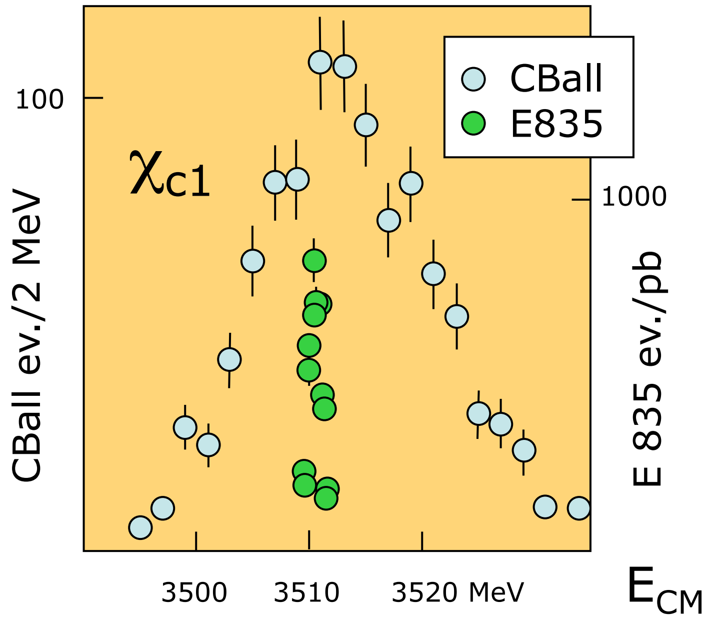



$Br(p\bar{p} \rightarrow \eta_c) = 1.2\ 10^{-3}$

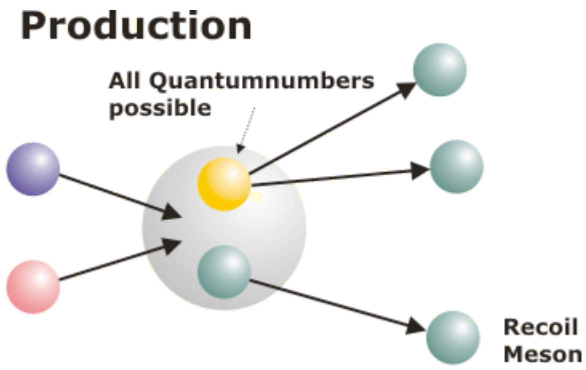
$Br(e^+e^- \rightarrow \psi) \cdot Br(\psi \rightarrow \gamma\eta_c) = 2.5\ 10^{-5}$

# Spectroscopy with antiprotons

There are two mechanisms to access particular final states:

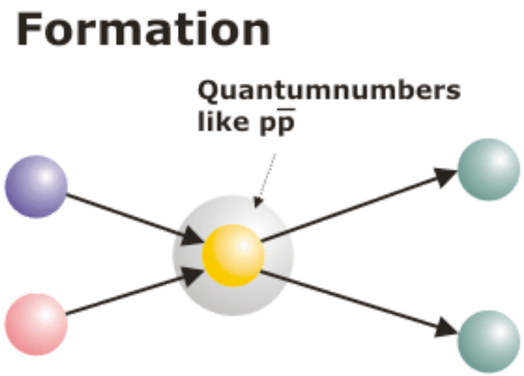
**Production**

all $J^{PC}$ available




**Formation**

only selected $J^{PC}$



# Spectroscopy with antiprotons

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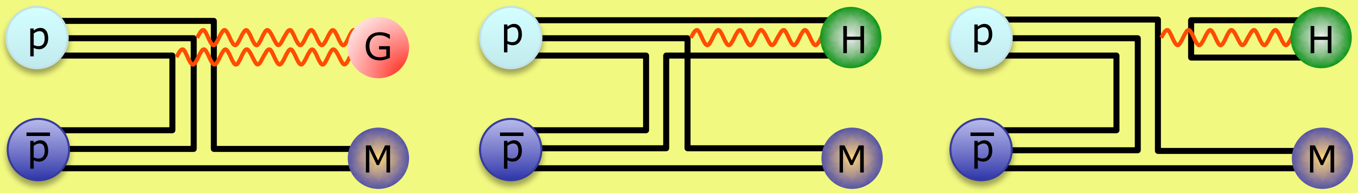
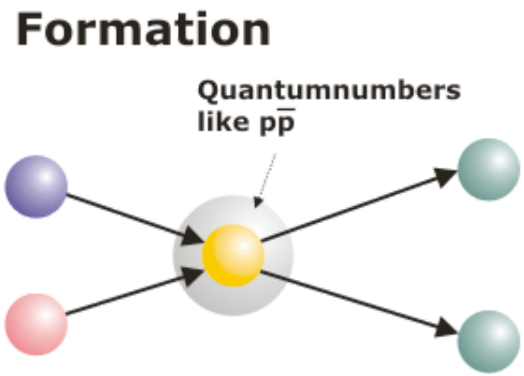



Even exotic quantum numbers can be reached σ ~100 pb

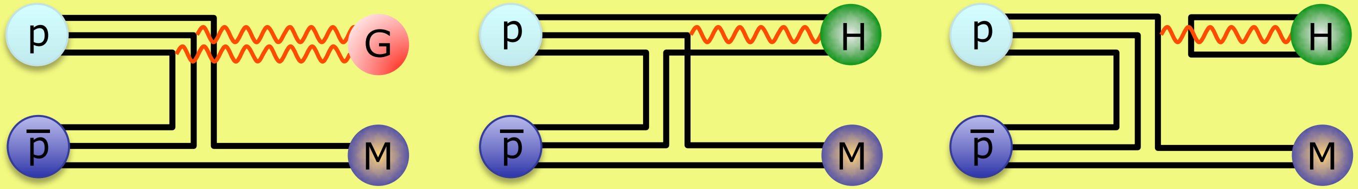
**Formation**

only selected $J^{PC}$



# Spectroscopy with antiprotons

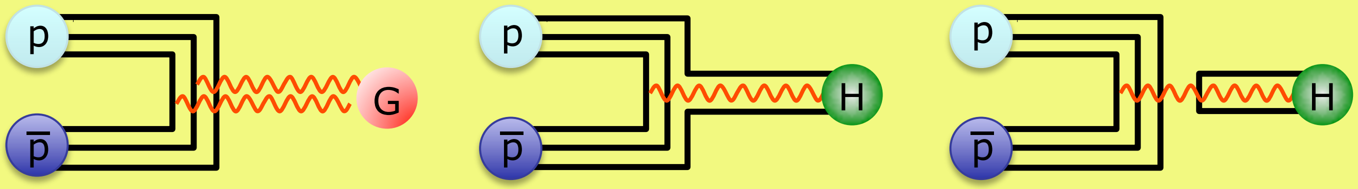
Production




Even exotic quantum numbers
can be reached σ ~100 pb

All ordinary quantum numbers
can be reached σ ~1 μb

Formation

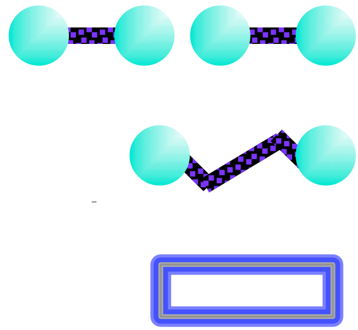


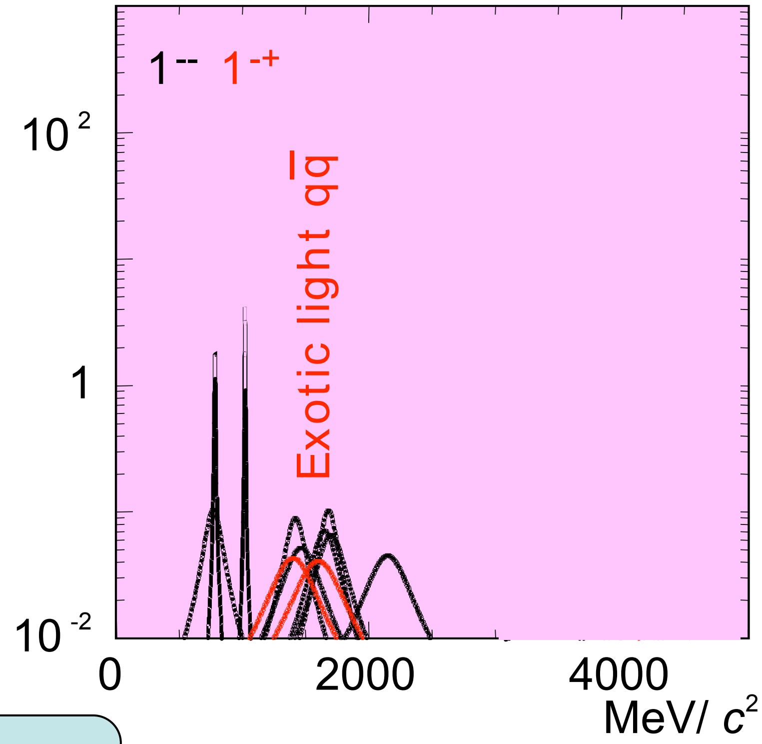
# Exotic hadrons

The QCD spectrum is much rich than that of the naive quark model also the gluons can act as hadron components

The "exotic hadrons" fall in 3 general categories:

| | | |
|---|---|---|
| Multiquarks | $(q\bar{q})(q\bar{q})$ | |
| Hybrids | $(q\bar{q})\ g$ | |
| Glueballs | $gg$ | |






In the light meson spectrum exotic states overlap with conventional states

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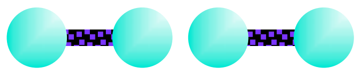
| Multiquarks | $(q\bar{q})(q\bar{q})$ |  |
| Hybrids | $(q\bar{q})\,g$ |  |
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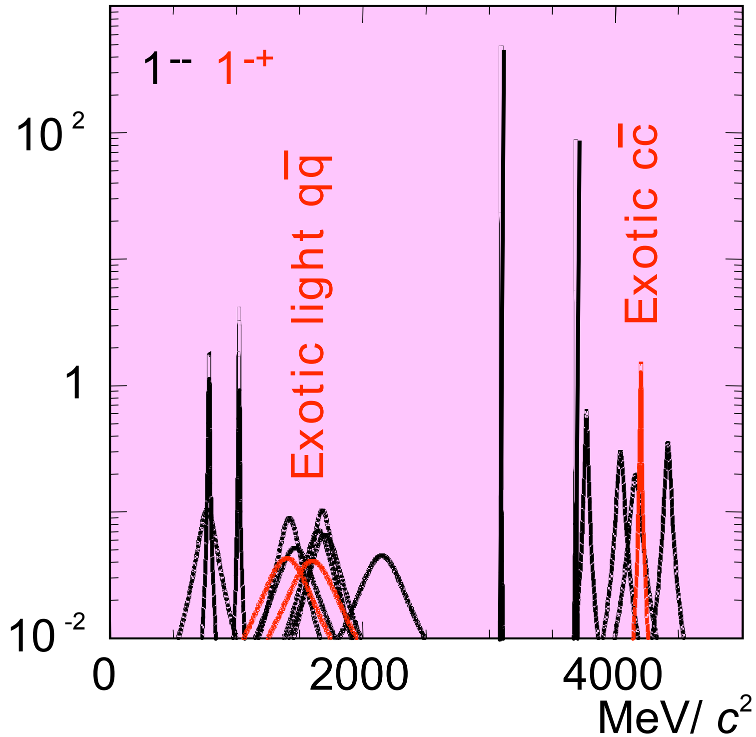
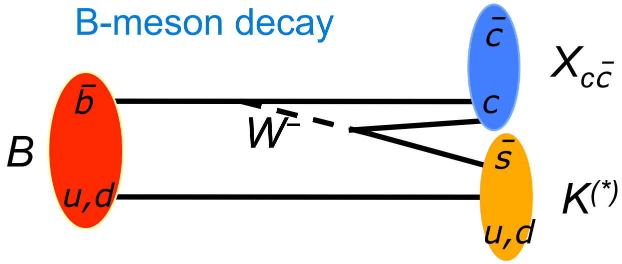



In the $c\bar{c}$ meson spectrum the density of states is lower and therefore the overlap

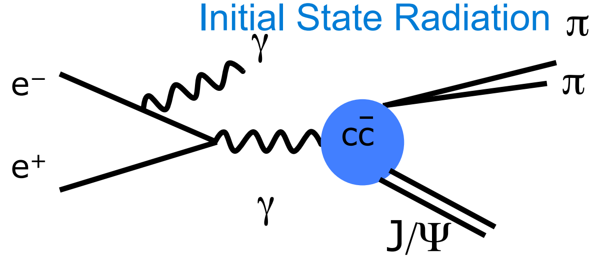
# XYZ Mesons

B-meson decay




X(3872) Belle, Babar, Cleo, CDF, D0
Y(3940) Belle, Babar
Y(4140)? CDF
Z(4430)
$Z_1$(4050)
$Z_2$(4250)
} Belle

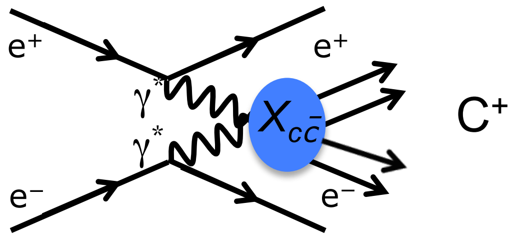
Initial State Radiation



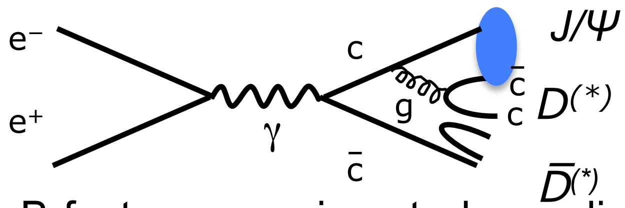

$1^{--}$ states
X(4008)? Belle
Y(4260) BaBar, Belle,CLEO
Y(4350) BaBar, Belle
Y(4660) Belle

X(3915) Belle
Z(3930) Belle
Y(4350) Belle

γγ-collisions




Associate production
$e^+e^- \longrightarrow J/\Psi\ X_{c\bar{c}}$




X(3940) Belle
X(4160) Belle

The B-factory experiments have discovered a large number of candidates for charmonium and charmonium-like meson states, many of which can not be easily accommodated by theory. State parameters are still largely unknown. Few events collected in 10 years of running

**PANDA will detect 100 events per day**

# XYZ Mesons

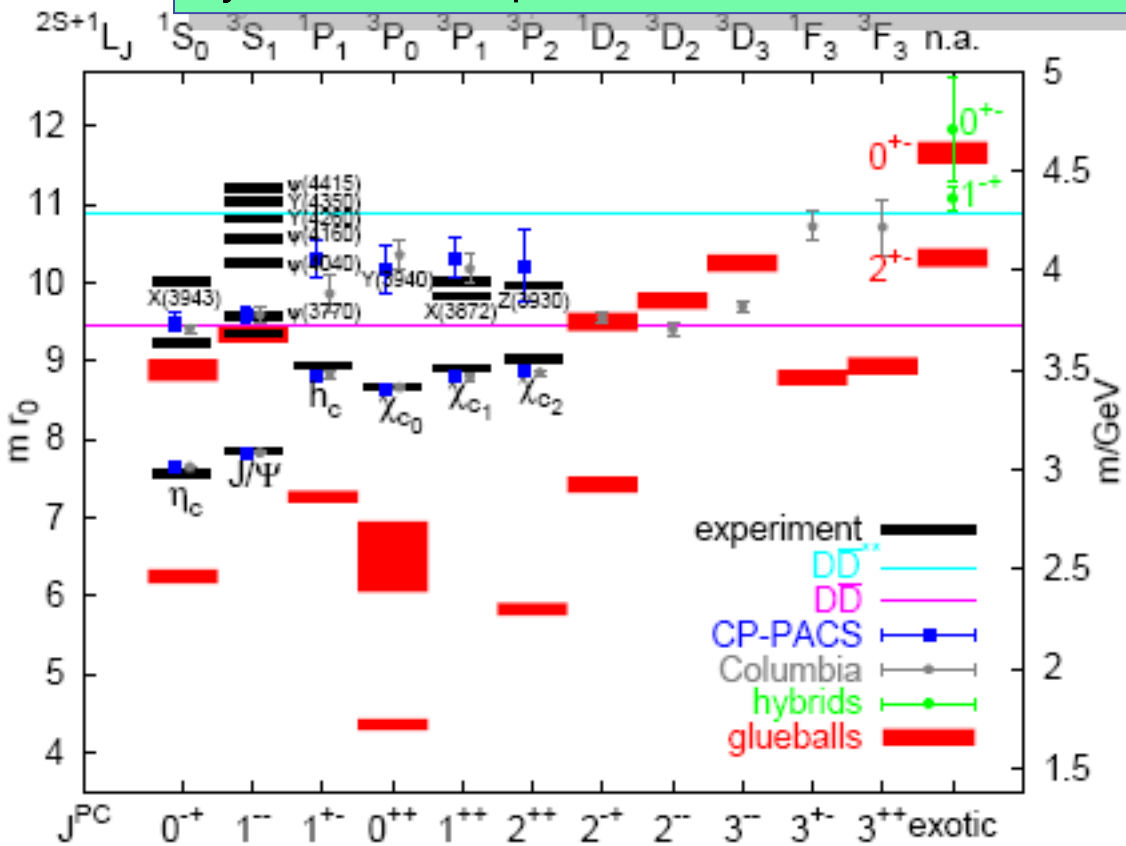
A number of models have been proposed to explain these states, including meson-antimeson molecules, diquark-diantiquark bound states, $c\bar{c}$-gluon hybrids and threshold effects. None of the proposed mechanisms easily accounts for all of the observations.

| state | $M$ (MeV) | $\Gamma$ (MeV) | $J^{PC}$ | Decay Modes | Production Modes |
|---|---|---|---|---|---|
| $Y_s(2175)$ | $2175 \pm 8$ | $58 \pm 26$ | $1^{--}$ | $\phi f_0(980)$ | $e^+e^-$ (ISR), $J/\psi$ decay |
| $X(3872)$ | $3871.4 \pm 0.6$ | $< 2.3$ | $1^{++}$ | $\pi^+\pi^- J/\psi, \gamma J/\psi$ | $B \to KX(3872)$, $p\bar{p}$ |
| $X(3875)$ | $3875.5 \pm 1.5$ | $3.0^{+2.1}_{-1.7}$ | | $D^0\bar{D}^0\pi^0$ | $B \to KX(3875)$ |
| $Z(3940)$ | $3929 \pm 5$ | $29 \pm 10$ | $2^{++}$ | $D\bar{D}$ | $\gamma\gamma$ |
| $X(3940)$ | $3942 \pm 9$ | $37 \pm 17$ | $J^{P+}$ | $D\bar{D}^*$ | $e^+e^- \to J/\psi X(3940)$ |
| $Y(3940)$ | $3943 \pm 17$ | $87 \pm 34$ | $J^{P+}$ | $\omega J/\psi$ | $B \to KY(3940)$ |
| $Y(4008)$ | $4008^{+82}_{-49}$ | $226^{+97}_{-80}$ | $1^{--}$ | $\pi^+\pi^- J/\psi$ | $e^+e^-$(ISR) |
| $X(4160)$ | $4156 \pm 29$ | $139^{+113}_{-65}$ | $J^{P+}$ | $D^*\bar{D}^*$ | $e^+e^- \to J/\psi X(4160)$ |
| $Y(4260)$ | $4264 \pm 12$ | $83 \pm 22$ | $1^{--}$ | $\pi^+\pi^- J/\psi$ | $e^+e^-$(ISR ) |
| $Y(4350)$ | $4361 \pm 13$ | $74 \pm 18$ | $1^{--}$ | $\pi^+\pi^- \psi'$ | $e^+e^-$(ISR) |
| $Z(4430)$ | $4433 \pm 5$ | $45^{+35}_{-18}$ | ? | $\pi^\pm \psi'$ | $B \to KZ^\pm(4430)$ |
| $Y(4660)$ | $4664 \pm 12$ | $48 \pm 15$ | $1^{--}$ | $\pi^+\pi^- \psi'$ | $e^+e^-$(ISR) |
| $Y_b$ | $\sim 10,870$ | ? | $1^{--}$ | $\pi^+\pi^- \Upsilon(nS)$ | $e^+e^-$ |

Godfrey&Olsen-arXiv:0801.3867 [hep-ph]

# Charmonium region

Charmonium spectrum, glueballs, spin-exotics $c\bar{c}$-glue hybrids with experimental results



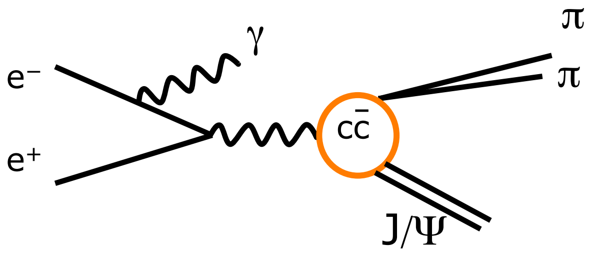

From G. S. Bali, Int.J.Mod.Phys. A21 (2006) 5610-5617

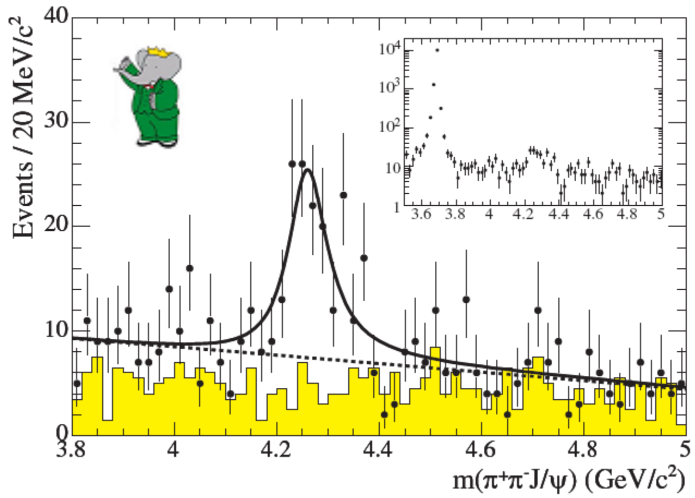
arXiv:hep-lat/0608004

Quantum numbers assignment become clear only with high statistics and different final states

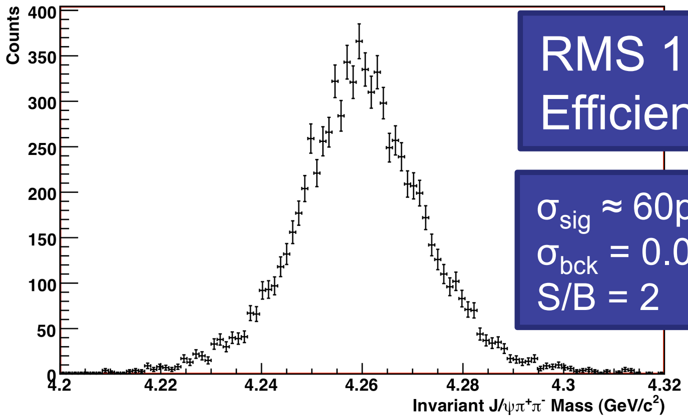
# Y(4260)

This state has been discovered by BaBar with the technique of initial state radiation in one year of data taking PRL95, 142001 (2005)



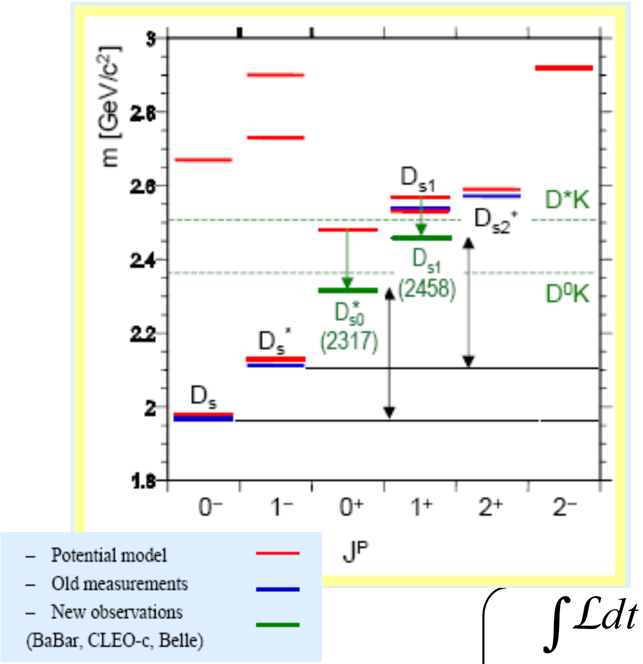

Panda can study $\bar{p}p \rightarrow Y(4260) \rightarrow J/\Psi\pi^+\pi^-$




RMS 13.4 MeV
Efficiency 33%

$\sigma_{sig} \approx 60$pb
$\sigma_{bck} = 0.046$mb
S/B = 2

# Open Charm: $D_{S0}(2317)$




New mesons consisting of a heavy and a light constituent have been detected. These states are narrow, and due to detector resolution an upper limit for the Γ of few MeV has been defined.

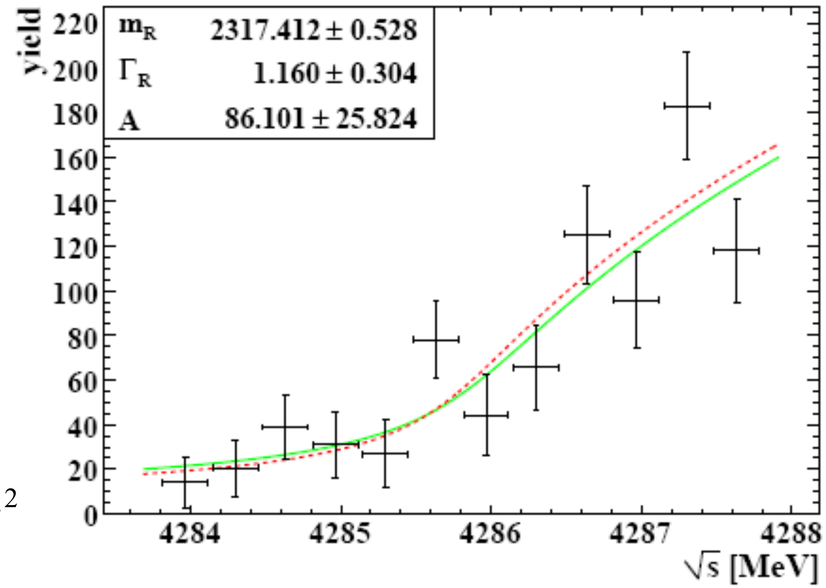
With PANDA a different experimental approach can be tempted since the production cross section around threshold depends on the total width.

input

$$\int \mathcal{L}dt = 126\ pb^{-1} \text{(14 days)}$$
$$S/B = 1/3$$
$$\Gamma = 1\ MeV$$
$$m = 2317.30\ MeV/c^2$$

output

$$\Gamma = (1.16 \pm 0.30)\ MeV$$
$$m = (2317.41 \pm 0.53)\ MeV/c^2$$



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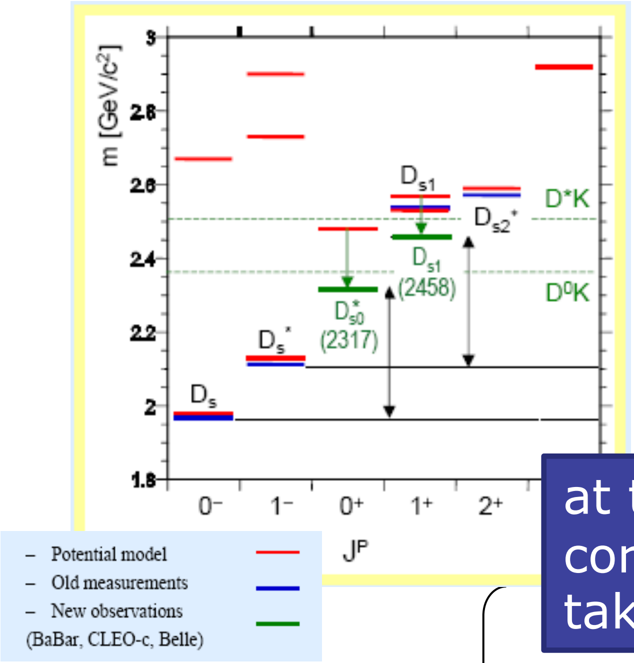


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at the luminosity of $2\times10^{32}$ this corresponds a 14 days of data taking

input

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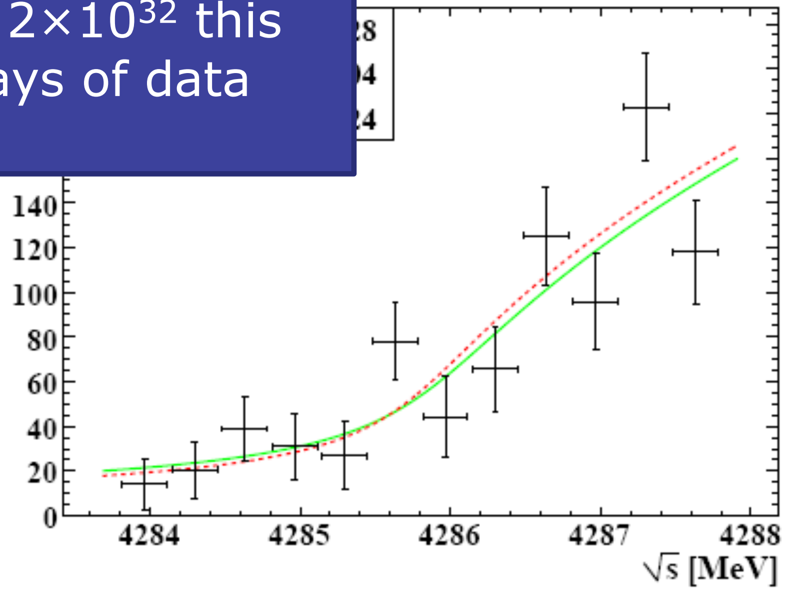
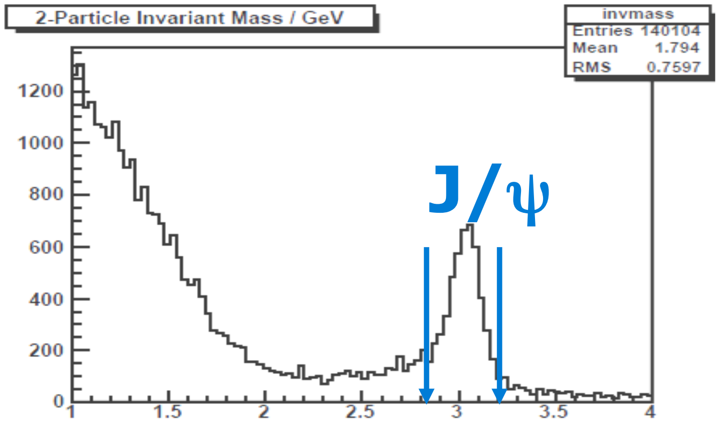
output

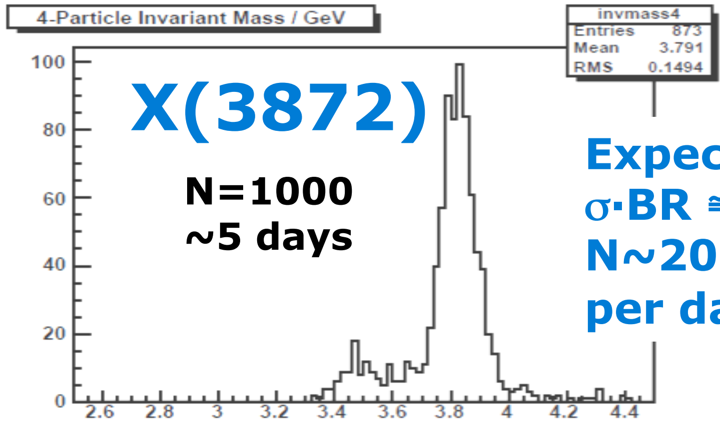
$$\Gamma = (1.16 \pm 0.30)\ MeV$$
$$m = (2317.41 \pm 0.53)\ MeV/c^2$$



# X(3872) at PANDA $\bar{p}p \rightarrow J/\Psi\pi^+\pi^-$

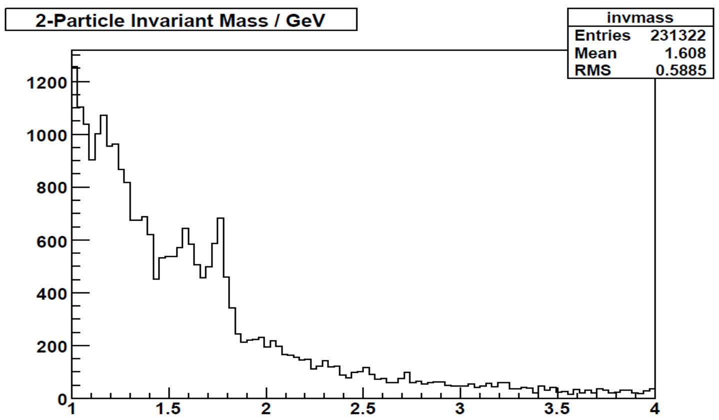



2-Particle Invariant Mass / GeV



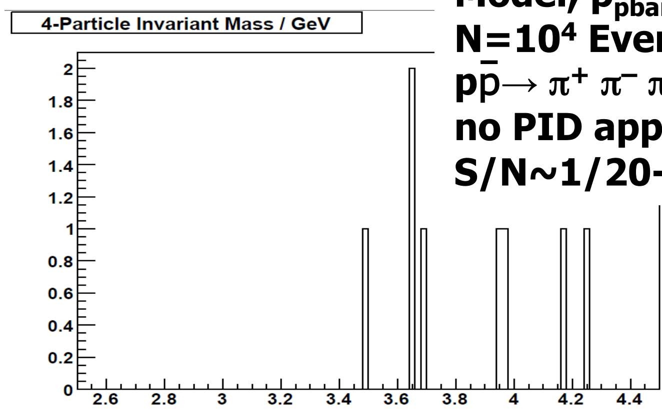

4-Particle Invariant Mass / GeV

**Expected Yield:**
**$\sigma \cdot BR \cong 250$ pb**
**N~200 events per day**




2-Particle Invariant Mass / GeV

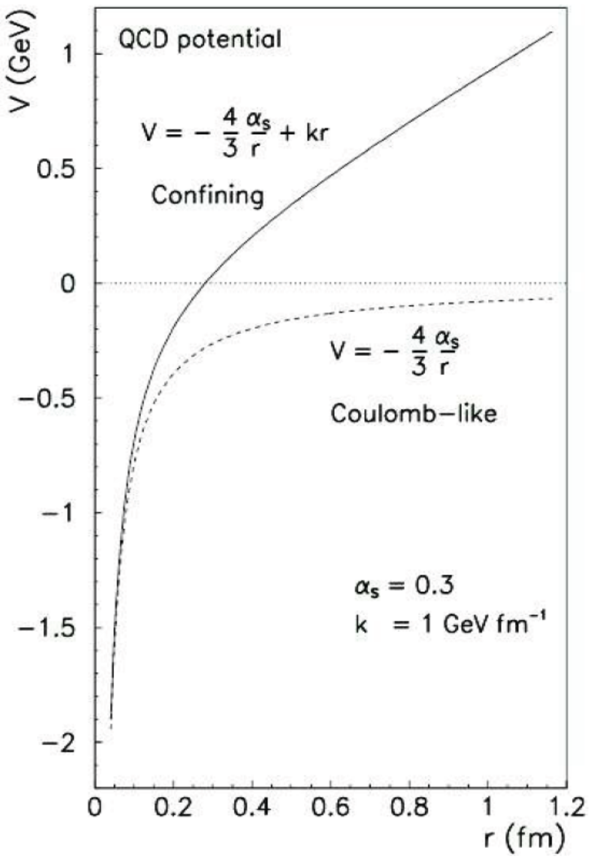
**Background: Dual Parton Model, $p_{pbar}$=6.991 GeV/c, N=$10^4$ Events**
**$\bar{p}p \rightarrow \pi^+ \pi^- \pi^+ \pi^-$ $\sigma$~0.05 mb**
**no PID applied**
**S/N~1/20-1/30**




4-Particle Invariant Mass / GeV

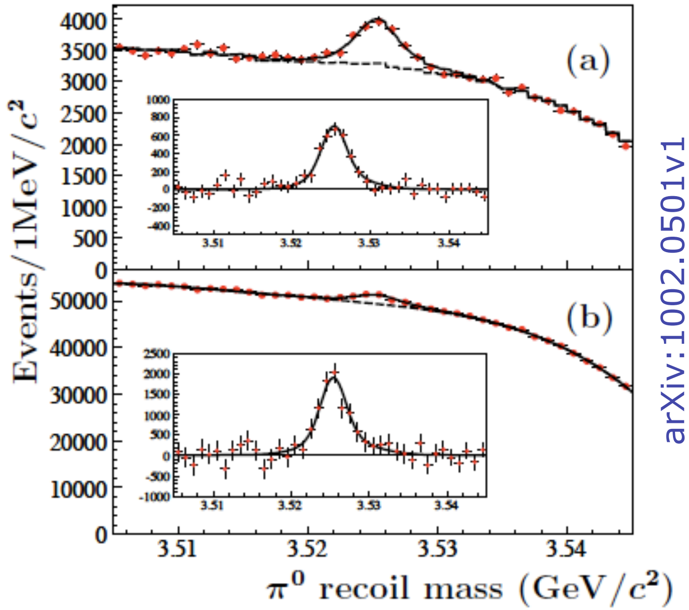
# $h_c$ $^1_1P$ state

A precise knowledge of $h_c$ parameters will determine the spin component of $q\bar{q}$ potential.




$$V(r) = -\frac{4}{3}\frac{\alpha_s}{r} + kr + V_{LS} + V_{SS} + V_T$$

Seen in $e^+e^- \rightarrow \Psi(2S) \rightarrow \pi^0 h_c \rightarrow \pi^0 \gamma \eta_c$




arXiv:1002.0501v1

# $h_c$ $^1_1P$ state

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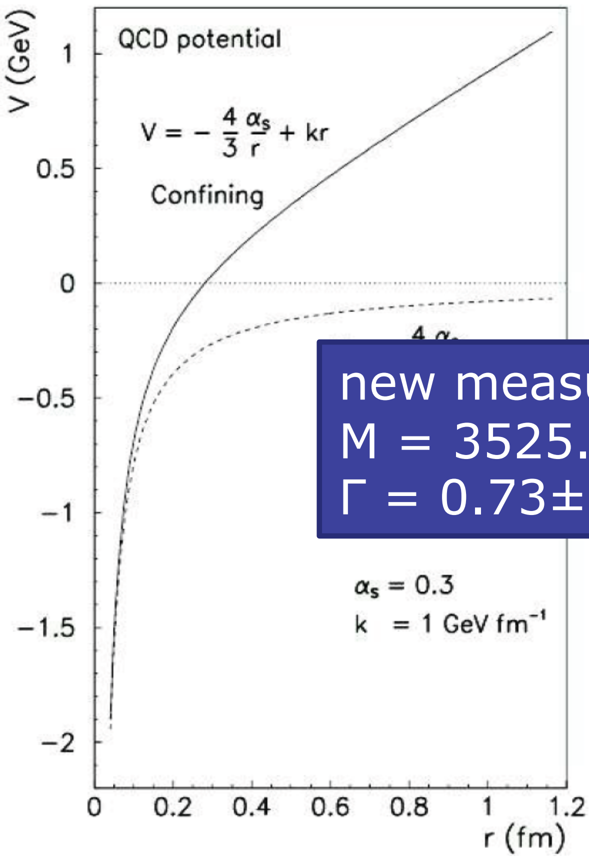
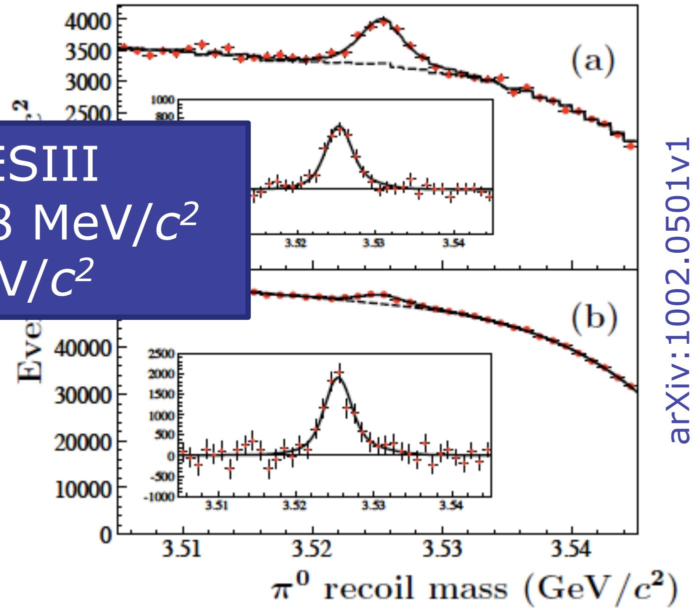
$$V(r) = -\frac{4}{3}\frac{\alpha_s}{r} + kr + V_{LS} + V_{SS} + V_T$$




Seen in $e^+e^- \to \Psi(2S) \to \pi^0 h_c \to \pi^0 \gamma \eta_c$




new measurement by BESIII
M = 3525.40±0.13±0.18 MeV/$c^2$
Γ = 0.73±0.45±0.28 MeV/$c^2$

arXiv:1002.0501v1

# $h_c$ $^1{}_1P$ state @ $\bar{P}ANDA$

**$h_c \longrightarrow \eta_c\gamma \longrightarrow 3\gamma$**

Good tag with $E_\gamma$=503MeV
signal eff. 8.2%

In high luminosity mode
we expect 20 signal events/day

Rejection of main sources of bck

| Channel | S/B ratio |
|---|---|
| $\bar{p}p \to \pi^0\pi^0$ | $> 94$ |
| $\bar{p}p \to \pi^0\gamma$ | $> 164$ |
| $\bar{p}p \to \pi^0\eta$ | $> 88$ |
| $\bar{p}p \to \eta\eta$ | $> 87$ |
| $\bar{p}p \to \pi^0\eta'$ | $> 250$ |

**$h_c \longrightarrow \eta_c\gamma \longrightarrow \phi\phi\gamma \longrightarrow 4K\gamma$**

Good tag with $E_\gamma$=503MeV
signal eff. 25%

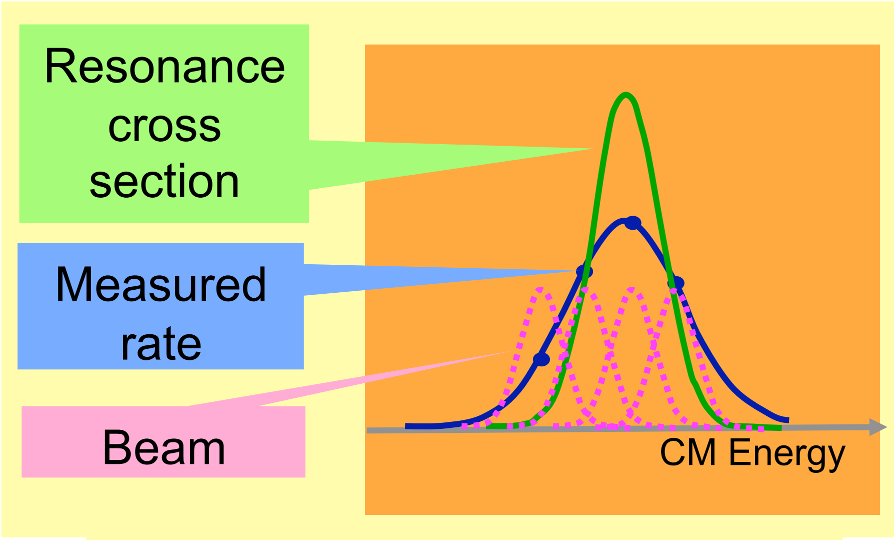
In high luminosity mode
we expect 92 signal
events/day

Rejection of main sources of bck

| channel | Signal/Background |
|---|---|
| $\bar{p}p \to K^+K^-K^+K^-\pi^0$ | 8 |
| $\bar{p}p \to \phi K^+K^-\pi^0$ | 8 |
| $\bar{p}p \to \phi\phi\pi^0$ | $> 10$ |
| $\bar{p}p \to K^+K^-\pi^+\pi^-\pi^0$ | $> 12$ |

# Antiproton's power

$\bar{p}$-beams can be cooled → Excellent resonance resolution




- $e^+e^-$: typical mass res. ~ 10 MeV
- Fermilab: 240 keV
- HESR: ~30 keV

The production rate of a certain final state $\nu$ is a convolution of the BW cross section and the beam energy distribution function $f(E,\Delta E)$:

$$\nu = L_0 \left\{ \varepsilon \int dE f(E,\Delta E) \sigma_{BW}(E) + \sigma_b \right\}$$

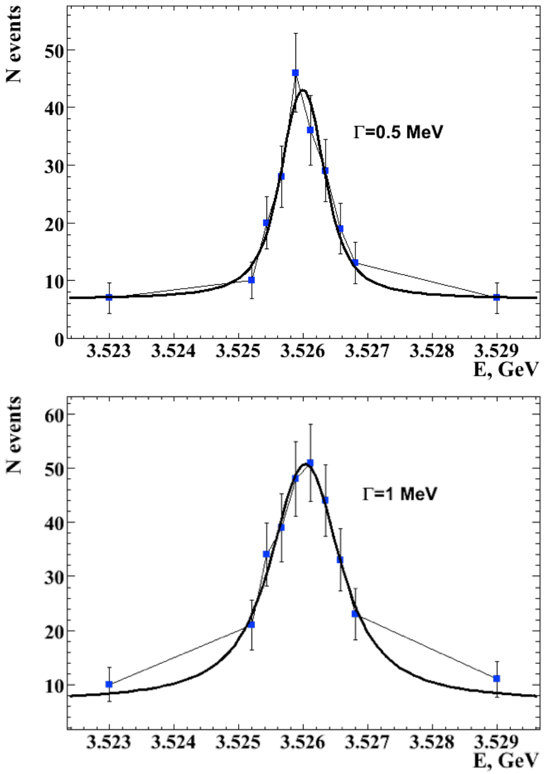
The resonance mass $M_R$, total width $\Gamma_R$ and product of branching ratios into the initial and final state $B_{in}B_{out}$ can be extracted by measuring the formation rate for that resonance as a function of the cm energy $E$.

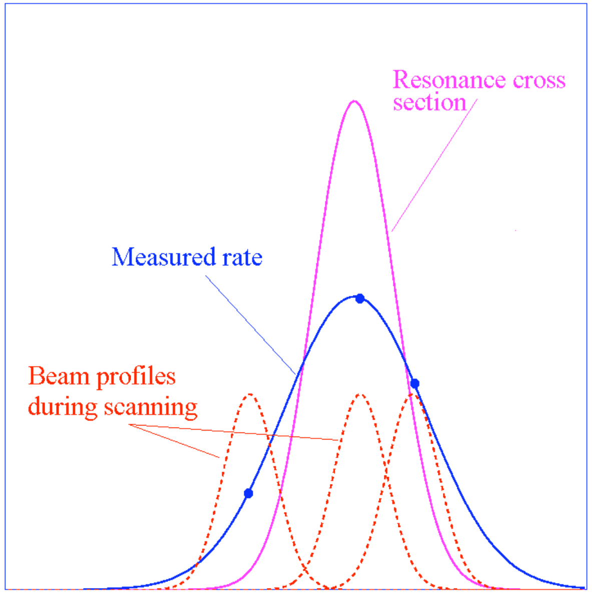

33

# Charmonium states width

Thanks to the precise HESR momentum definition, widths of known states can be precisely measured with an energy scan.

Energy scan of 10 values around the $h_c$ mass, width upper limit is 1MeV; each point represents a 5 day data taking in high luminosity mode, module 5 available, for the channel: $h_c \rightarrow \eta_c\gamma \rightarrow \phi\phi\gamma \rightarrow 4K\gamma$ with a S/B 8:1




Sensitivity

| $\Gamma_{R,MC}$[MeV] | $\Gamma_{R,reco}$[MeV] | $\Delta\Gamma_R$[MeV] |
|---|---|---|
| 1 | 0.92 | 0.24 |
| 0.75 | 0.72 | 0.18 |
| 0.5 | 0.52 | 0.14 |

# Charmonium states width

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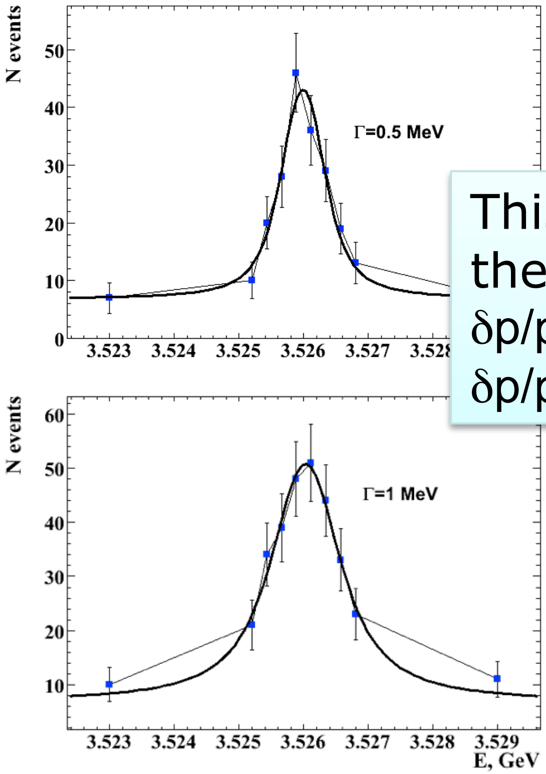
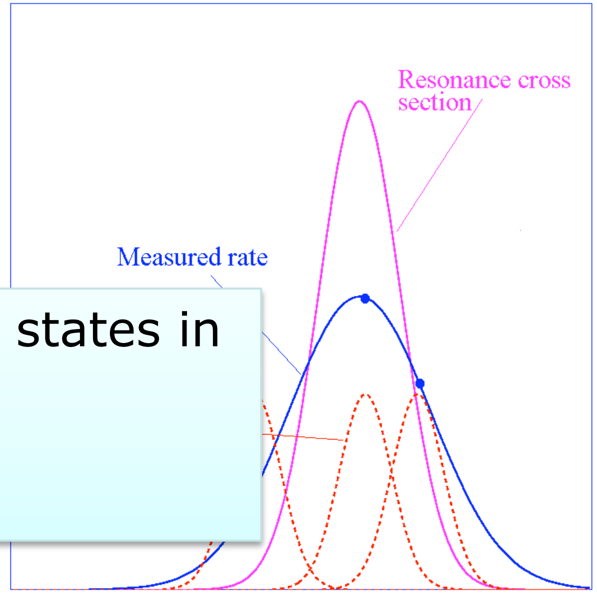
Energy scan of 10 values around the $h_c$ mass, width upper limit is 1MeV; each point represents a 5 day data taking in high luminosity mode, module 5 available, for the channel: $h_c \rightarrow \eta_c\gamma \rightarrow \phi\phi\gamma \rightarrow 4K\gamma$ with a S/B 8:1




This holds for all known states in the charmonium region
$\delta p/p\ 10^{-4} \rightarrow \Gamma$ 100 KeV
$\delta p/p\ 10^{-5} \rightarrow \Gamma$ 10 KeV

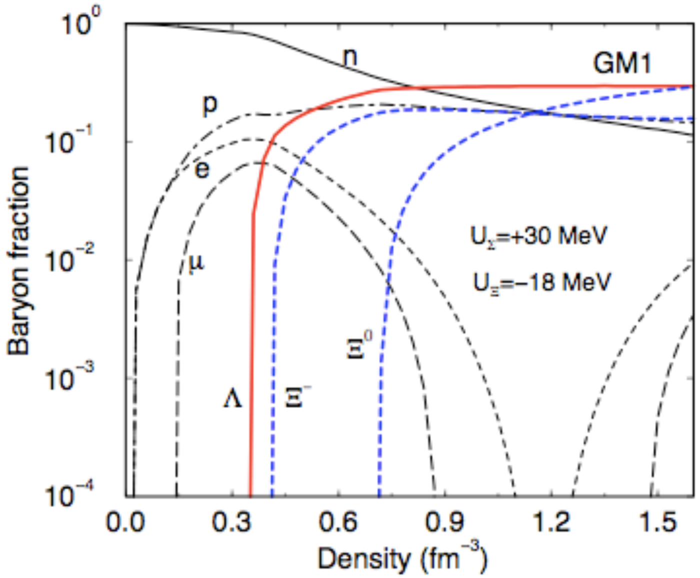



Sensitivity

| $\Gamma_{R,MC}$[MeV] | $\Gamma_{R,reco}$[MeV] | $\Delta\Gamma_R$[MeV] |
|---|---|---|
| 1 | 0.92 | 0.24 |
| 0.75 | 0.72 | 0.18 |
| 0.5 | 0.52 | 0.14 |

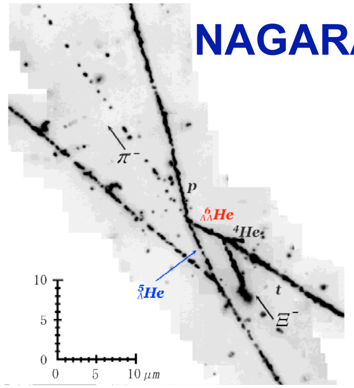
# Baryon-Baryon Interaction

The knowledge of Baryon-Baryon potential is essential for the understanding of the composition of nuclear matter.




The fraction of baryons and leptons in neutron star matter arXiv:0801.3791v1

Nuclear *NN* forces are known, *YN* interaction, thanks to hypernuclear physics, is relatively known, but *YY* interaction is completely unknown, there are just a few double Λ hypernuclear events.




ΛΛ-hypernuclei, Ξ-atoms, Ω-atoms allow to have an insight to more complex nuclear systems containing strangeness (neutron stars, hyperon-stars, strange-quark stars, …)

# A new way for double strange systems

✓ **Up to now double strange systems have been produced by $K^-$ beams in the reaction:**

$K^-$ (N, $\Xi^-$) $K^+$ (N- quasi free or bound in nucleus)

➢ **S=-2 baryon can be produced via:**

$$\bar{p} + p \rightarrow \Xi^- + \Xi^+$$
$$\bar{p} + n \rightarrow \Xi^- + \bar{\Xi}^0$$

$\sigma_{reaction}$ = 2$\mu$b at 3GeV/c

700.000$\Xi^-\bar{\Xi}$bar /h

Goal:

**maximize the "stopped $\Xi^-$" with a suitable set-up**

✓ **Choice of the target:**

**free protons** (hydrogen target) **or** protons and neutrons in a **nucleus** (quasi-free reactions)

➢ **Advantages of nuclear target** ☺ :

a) higher cross section (scaling as ~$A^{2/3}$)

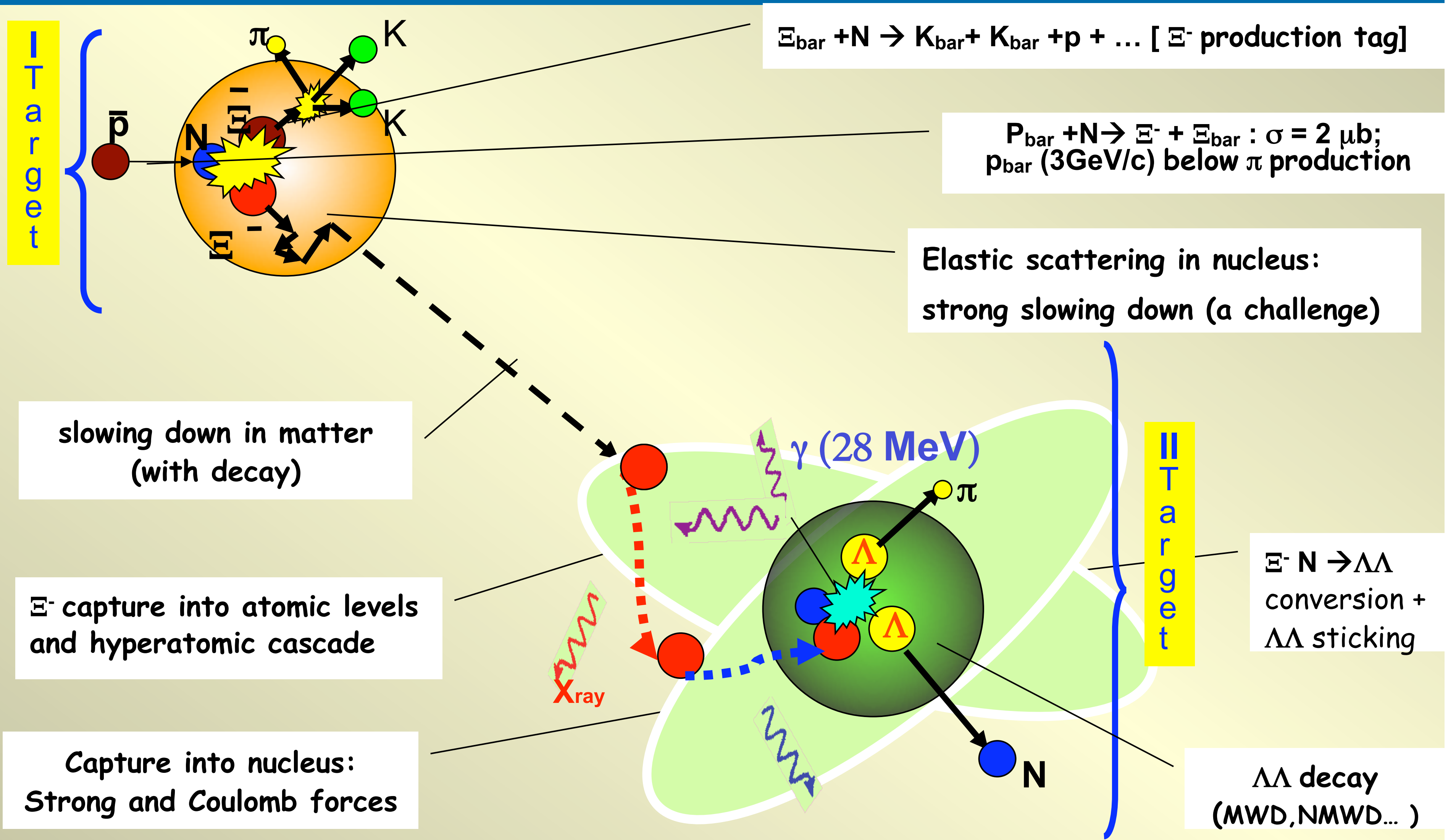
b) $\Xi^-$ slowing down in dense (nuclear) matter

➢ **Disadvantages of nuclear target** ☹ :

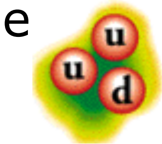
c) high background (annihilation)

d) high beam consuming (beam losses)

# 70 Double Strange Systems/h are expected within $\bar{\text{P}}$ANDA

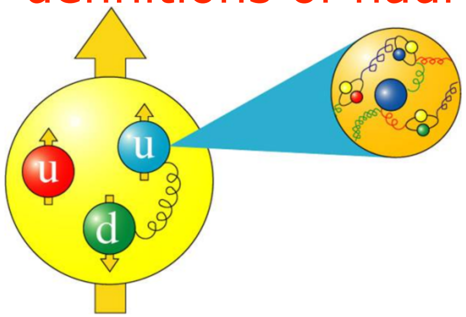


# The Hadron's structure



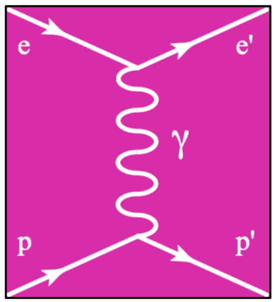

Properties of hadrons are only determined to a small degree by the constituent quarks.

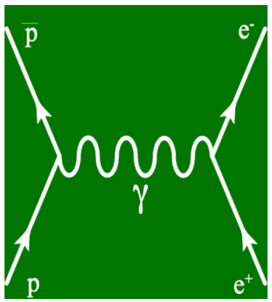
Quarks and gluons dynamics plays a fundamental role in the definitions of hadron's properties: mass, spin, etc…



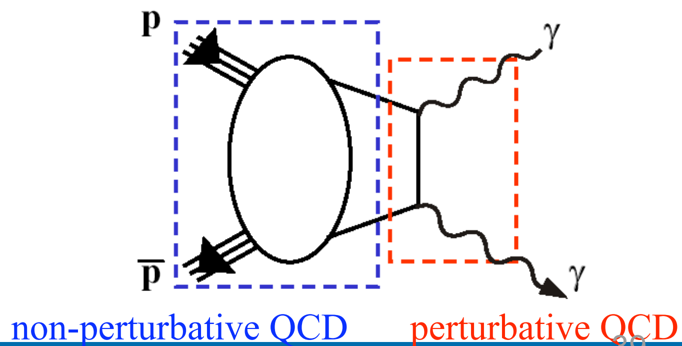

Generalized Parton Distributions (GPDs) contain both the usual form factors and structure functions, but in addition they include correlations between states of different longitudinal and transverse momenta. GPDs give a three-dimensional picture of the nucleon.

Nucleon Form Factors have been mainly studied using electromagnetic probes, but the physical diagrams can be inverted… and a complementary approach can be used



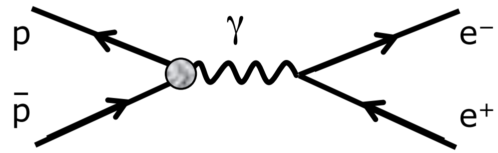




In a similar way Deeply Virtual Compton Scattering (DVCS) can be crossed-studied



# Proton Form Factors in Time-Like region: $G_E$ and $G_M$

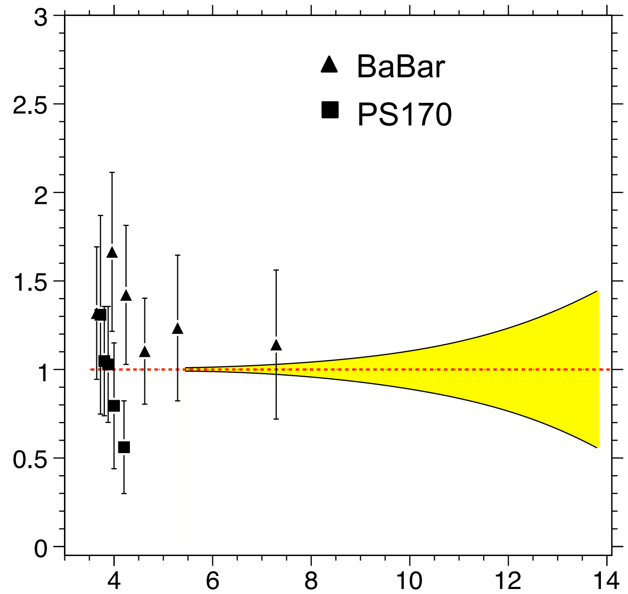
Form Factors in the Time Like region in a wide $q^2>0$ range




$$\frac{d\sigma}{d\Omega}=\frac{\alpha^2\beta C}{4s}\left[|G_M(s)|^2(1+\cos^2\theta^*)+\frac{4m_N^2}{s}|G_E(s)|^2\sin^2\theta^*\right]$$

$$\sigma=\frac{4\alpha^2\pi\beta C}{3s}\left[|G_M(s)|^2+\frac{2m_N^2}{s}|G_E(s)|^2\right]$$

$R=|G_E|/|G_M|$




Born approx. $q^2=s$

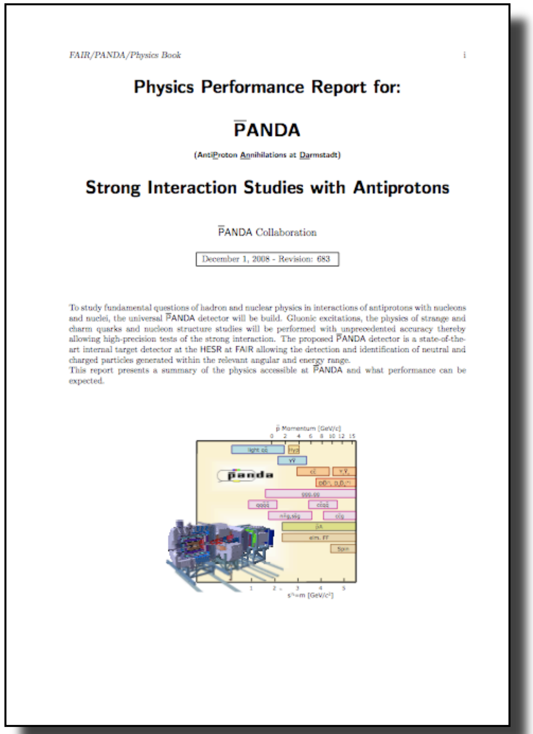
Expected errors on R as a function on $q^2$ for $G_E=G_M$.
BaBar and PS170 data are shown for comparison

π rejection @ $10^9 \div 10^{10}$

# Physics Performance Report

2008 has seen the Collaboration preparing the first $\overline{\text{P}}$ANDA Physics Book.

Within this document, we produced a complete description of all the aspects of the scientific program. Detailed simulations have been performed to evaluate detector performance on many benchmark channels.



*FAIR/PANDA/Physics Book* i

**Physics Performance Report for:**

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

(AntiProton Annihilations at Darmstadt)

**Strong Interaction Studies with Antiprotons**

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

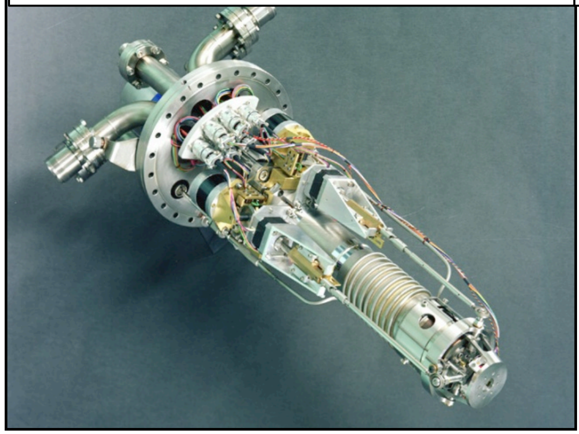
December 1, 2008 - Revision: 683

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.

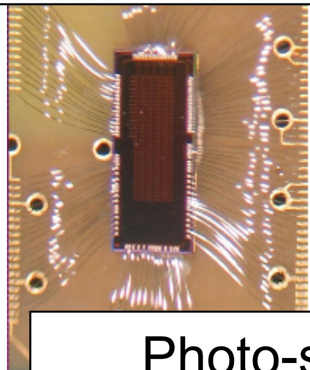
arXiv:0903.3905v1

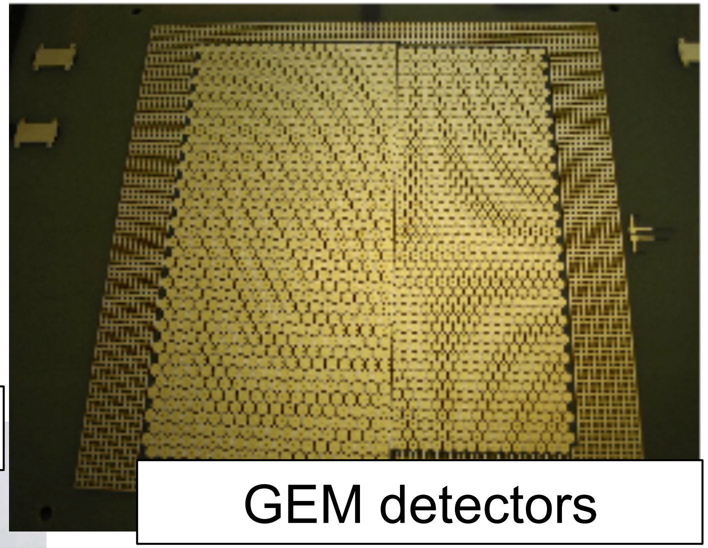
# R&D activity within P̄ANDA

Nozzle and cold head



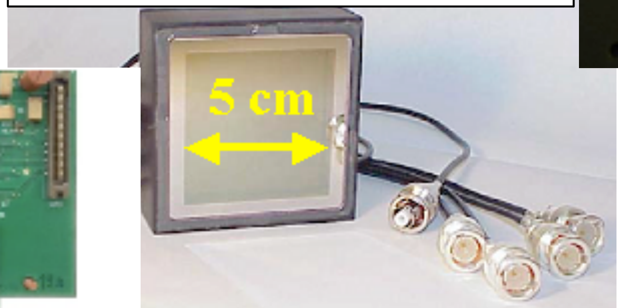
ASICS:CMOS 130 nm

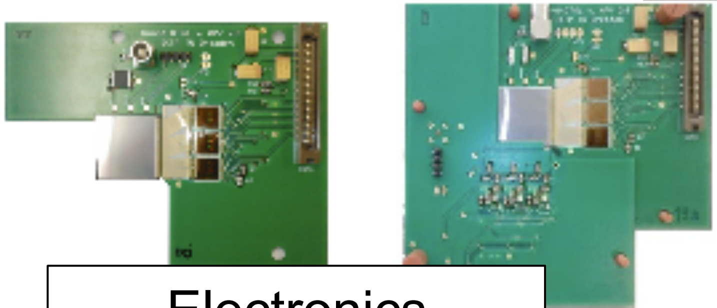




GEM detectors

Photo-sensors



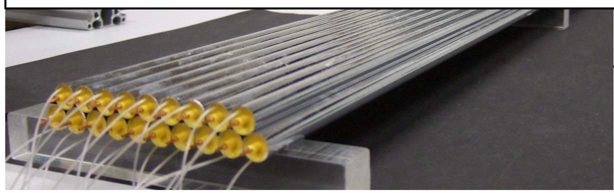



Electronics

Shashlyk

EMC crystals

Straw Tubes detectors



# Summary

$\bar{p}$-induced reactions studied with $\bar{P}$ANDA@FAIR have an enormous impact in particle physics

- All $q\bar{q}$ states can be formed directly (not only $1^{--}$)
  ↳ Discovery potential
- $\bar{p}$ momentum can be tuned
  ↳ Precision studies can be performed
- High probability for production of exotic states
  ↳ 2 states $1^{-+}$ are predicted in the charmonium energy region
- Low final state multiplicities
  ↳ Allows complete PWA
- $\bar{p}$ are extremely versatile
  ↳ Nucleon structure can be studied, DDS, etc…
- High luminosity
  ↳ Maximizes the yield, and then rare phenomena can be studied

# The Collaboration

At present 410 physicists from 53 institutions in 16 countries

Basel, Beijing, Bochum, IIT Bombay, Bonn, Brescia, IFIN Bucharest, Catania, IIT Chicago, Cracow, IFJ PAN Cracow, Cracow UT, Edinburgh, Erlangen, Ferrara, Frankfurt, Genova, Giessen, Glasgow, GSI, FZ Jülich, JINR Dubna, Katowice, KVI Groningen, Lanzhou, LNF, Lund, Mainz, Minsk, ITEP Moscow, MPEI Moscow,TU München, Münster, Northwestern, BINP Novosibirsk, IPN Orsay, Pavia, IHEP Protvino, PNPI St.Petersburg, KTH Stockholm, Stockholm, Dep. A. Avogadro Torino, Dep. Fis. Sperimentale Torino, Torino Politecnico, Trieste, TSL Uppsala, Tübingen, Uppsala, Valencia, SINS Warsaw, TU Warsaw, AAS Wien

# Backup slides

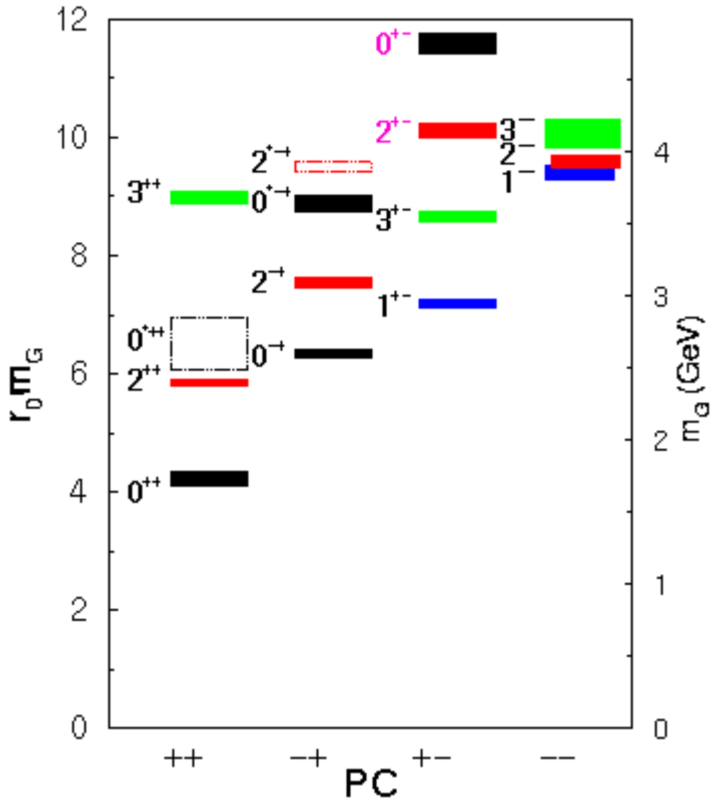
# Hadron's masses

The elementary particles of the Standard Model gain their mass through the Higgs mechanism.

However, only a few percent of the mass of the proton is due to the Higgs mechanism. The rest is created in an unknown way by the strong interaction.

Glueballs would be massless without the strong interaction and their predicted masses arise solely from the strong interaction.

The possibility to study a whole spectrum of glueballs might therefore be the key of understanding the mechanism of mass creation by the strong interaction.




C. Morningstar and M. Peardon, Phys. Rev. D 60, 034509 (1999)

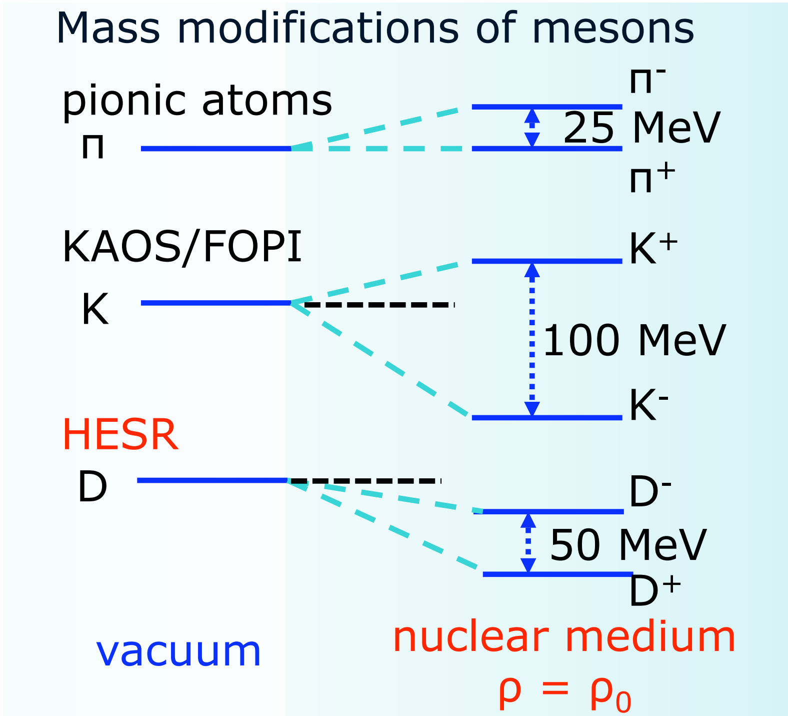
# The role of Chiral Symmetry

u and d quarks have very small and similar masses, this seems to indicate that the equations of QCD possess some additional symmetry, Chiral Symmetry, that is spontaneously broken.

this mechanism is playing an important role in the process of mass generation.

In the nuclear medium ($\rho>0$) we can restore this symmetry at least partially.

Hints of this effect have been already observed. We wants to extend these studies to charmed mesons.




*Hayashigaki, PLB 487 (2000) 96*
*Morath, Lee, Weise, priv. Comm.*

# From $\Xi^-$ production to $\Xi^-$ stop

Characteristics of the simulation:

- $5x10^5$ $\Xi^-$'s generated in primary target
- fate of each $\Xi^-$ followed up to the DSS formation or $\Xi^-$ decay ($\tau_{\Xi^-}$ = 164ps)

**Inside primary target: INC model**

- **Low momentum tail increased**
- **Xbar annihilation mostly in primary target**

**Inside the secondary target: 3 steps**

1. **Slowing down and stop: energy loss by ionization**
   stopped $\Xi^-$ / produced $\Xi^-$ : 2 – 4 x $10^{-3}$
2. **Atomic capture: Binary Encounters Bethe model:**
   (as a rough estimate of capture probability):
   captured $\Xi^-$ / stopped $\Xi^-$ : about 94%
3. **Atomic cascade: only EM decay model:**
   (as a rough estimate of cascade time) :
   in nucleus absorbed $\Xi^-$ / captured $\Xi^-$ : 78%

**DSS production rate per produced $\Xi^-$ : about $10^{-3}$ (in $^{12}$C)**

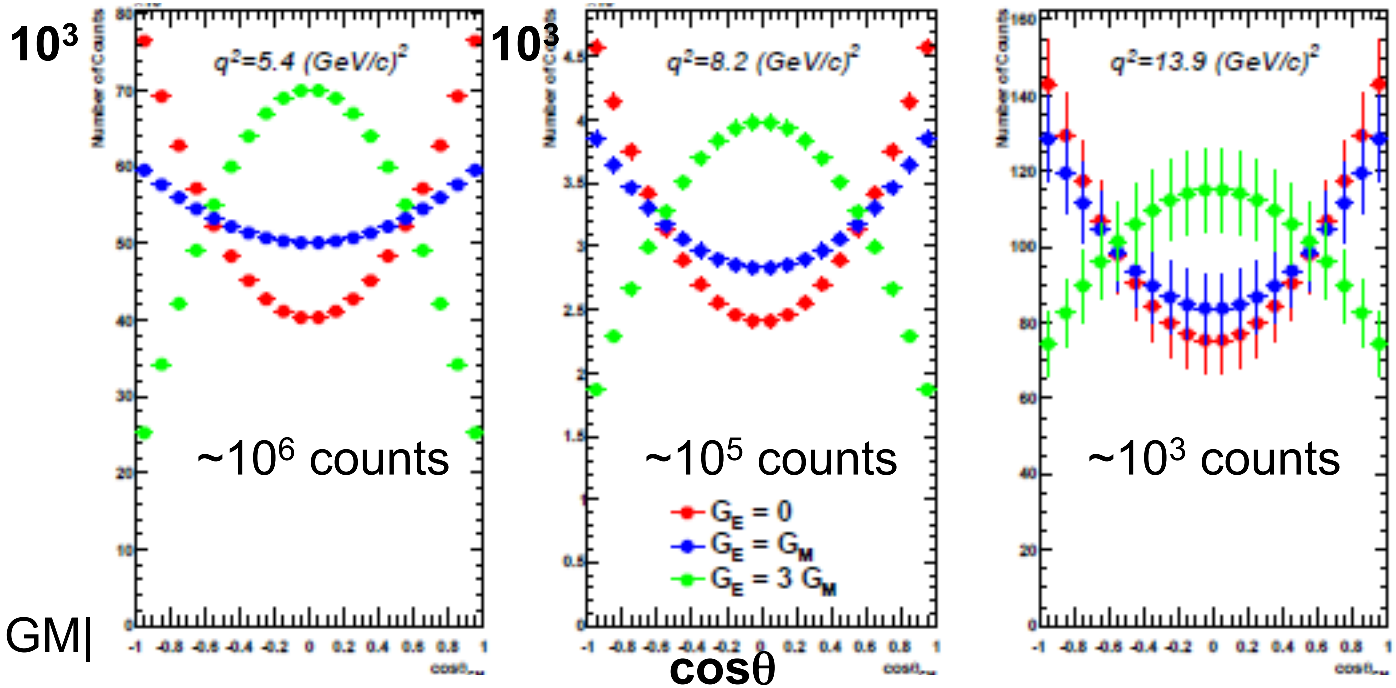
# FF Time-Like : GE et GM

**~100 days, $\mathcal{L} = 2\times10^{32}$ cm$^{-2}$s$^{-1}$**

$$d\sigma/d\Omega \propto [\ |G_M(q^2)|^2(1+\cos^2\theta)+4m_N^2/q^2\ |G_E(q^2)|^2 \sin^2\theta)]$$

**Number of counts for $\bar{p}p\rightarrow e^+e^-$**

π rej @ $10^9 \div 10^{10}$




R=|GE|/|GM|

| | | |
|---|---|---|
| **$p_{lab}$=1.7 GeV/*c***<br>**s=$q^2$=5.4 (GeV/c)$^2$** | **$p_{lab}$=3.3 GeV/*c***<br>**$q^2$= 8.2 (GeV/c)$^2$** | **$p_{lab}$=6.4 GeV/*c***<br>**$q^2$=13.9 (GeV/c)$^2$** |
| **$N_{tot}$=$10^6$** | **$N_{tot}$=124000** | **$N_{tot}$=2003** |
| **ΔR=0.6%** | **ΔR=3%** | **ΔR=30%** |

# Expected event rates

reconstructed signal events/day

assuming an integrated luminosity of $8pb^{-1}$/day and a rough cross-section of 1 nb

| | | |
|---|---|---|
| $\bar{p}p \rightarrow Y(4260) \rightarrow J/\Psi\eta$ | | Formation |
| $\hookrightarrow e^+e^-$ | $BR(Y(4260) \rightarrow J/\Psi\eta) \times 169$ events/days | |
| $\hookrightarrow \mu^+\mu^-$ | $BR(Y(4260) \rightarrow J/\Psi\eta) \times 144$ events/days | |
| $\bar{p}p \rightarrow Y(3940) \rightarrow J/\Psi\omega$ | | |
| $\hookrightarrow e^+e^-$ | $BR(Y(3940) \rightarrow J/\Psi\omega) \times 91$ events/days | |
| $\hookrightarrow \mu^+\mu^-$ | $BR(Y(3940) \rightarrow J/\Psi\omega) \times 70$ events/days | |
| $\bar{p}p \rightarrow Y(4320) \rightarrow \Psi(2s)\pi^+\pi^-$ | | |
| $\hookrightarrow J/\Psi\pi^+\pi^-$ | | |
| $\hookrightarrow e^+e^-$ | $BR(Y(4320) \rightarrow \Psi(2s)\pi^+\pi^-) \times 34$ events/days | |
| $\bar{p}p \rightarrow \eta_{c1}\eta \rightarrow (\tilde{\chi}_{c1}\pi^0\pi^0)\eta$ | | Production |
| $\hookrightarrow J/\Psi\gamma$ | | |
| $\hookrightarrow e^+e^-$ | $BR(\eta_{c1} \rightarrow \chi_{c1}\pi^0\pi^0) \times 3.1$ events/days | |
| $\hookrightarrow \mu^+\mu^-$ | $BR(\eta_{c1} \rightarrow \chi_{c1}\pi^0\pi^0) \times 3.6$ events/days | |
| $\bar{p}p \rightarrow \eta_{c1}\eta \rightarrow (D^{o*}\bar{D}^{o*})\eta$ | $BR(\eta_{c1} \rightarrow D^{o*}\bar{D}^{o*}) \times 1.9$ events/days | |

1 year run (~200 d) at $p_{\bar{p}}$=15 GeV/*c* for a survey.

Additional running at optimized momentum (tuned on finding) to improve PWA sensitivity (final goal: total ~600 d, ~3 year ?)