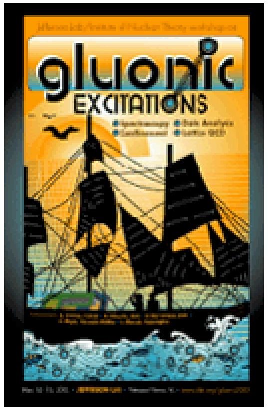
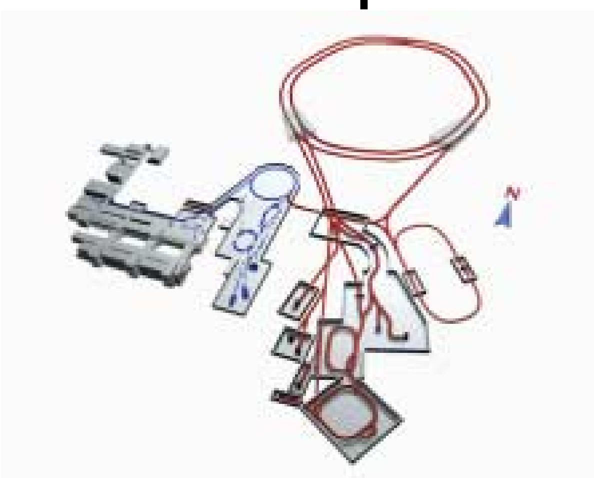


Klaus Peters
Ruhr-Universität Bochum

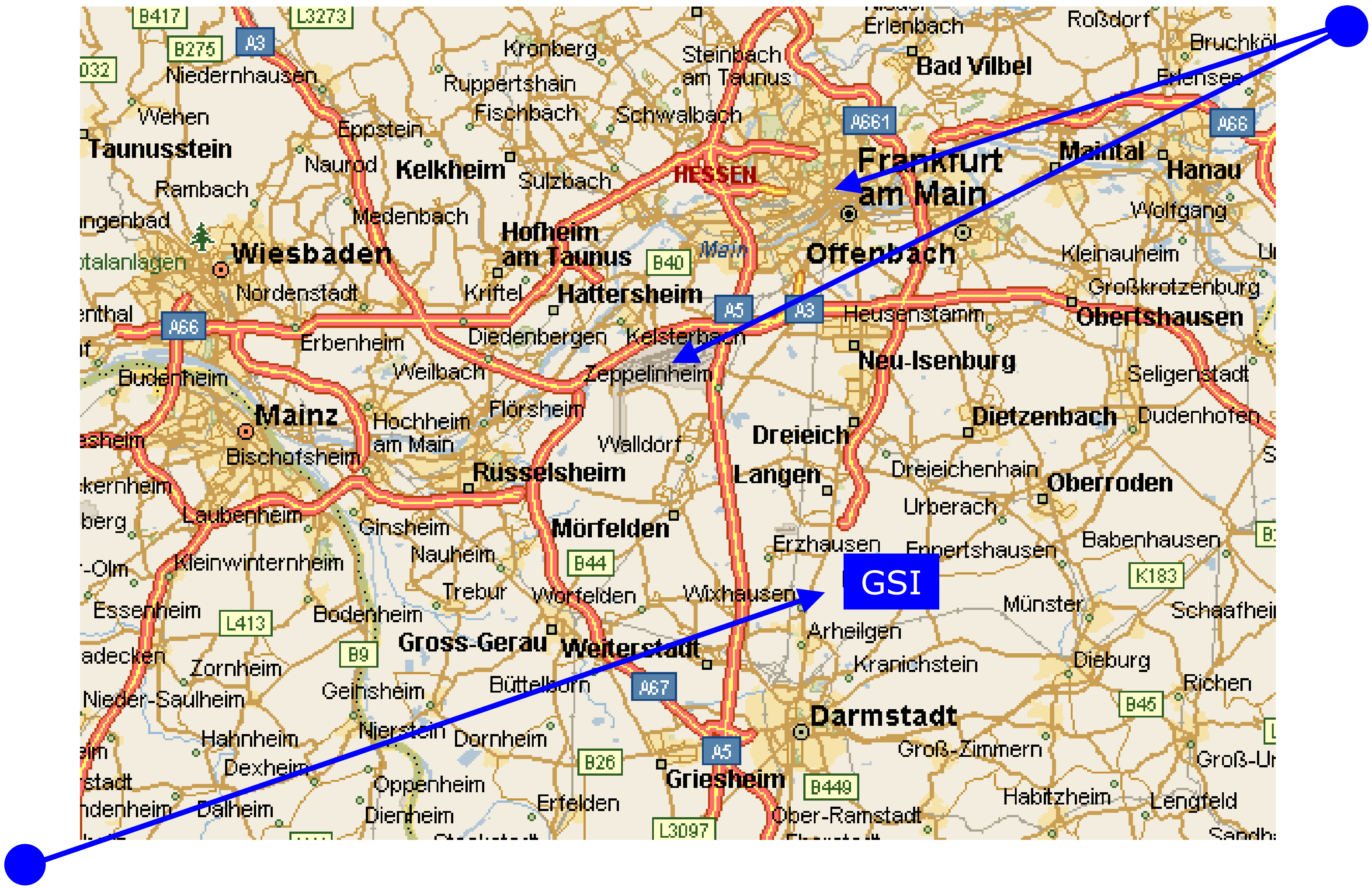
GLUONIC 2003
Jefferson Lab
Newport News, May 15, 2003



Exotic Hadrons @

Proton ANtiproton DArmstadt (PANDA)

Where is Darmstadt ?



The GSI Future Facility

History

since 1996	Discussion about GSI future International workshops, reviews, accelerator R&D
May 1999	Letter of Intend for an antiproton facility (40 authors) Studies for detector concept
Jan. 2001	Detector simulation with GEANT4
Nov. 2001	Conceptual Design Report of an „International Accelerator Facility for Beams of Ions and Antiprotons”
Nov. 2001	Review by an international review committee of the „Deutscher Wissenschaftsrat“
April 2002	International p-Workshop at GSI
July 2002	Positive Votum by the „Deutscher Wissenschaftsrat“
Feb. 5, 2003	Positive Decision by the „bmb+f”

Press Release 16/2003, http://www.bmbf.de

05.02.2003

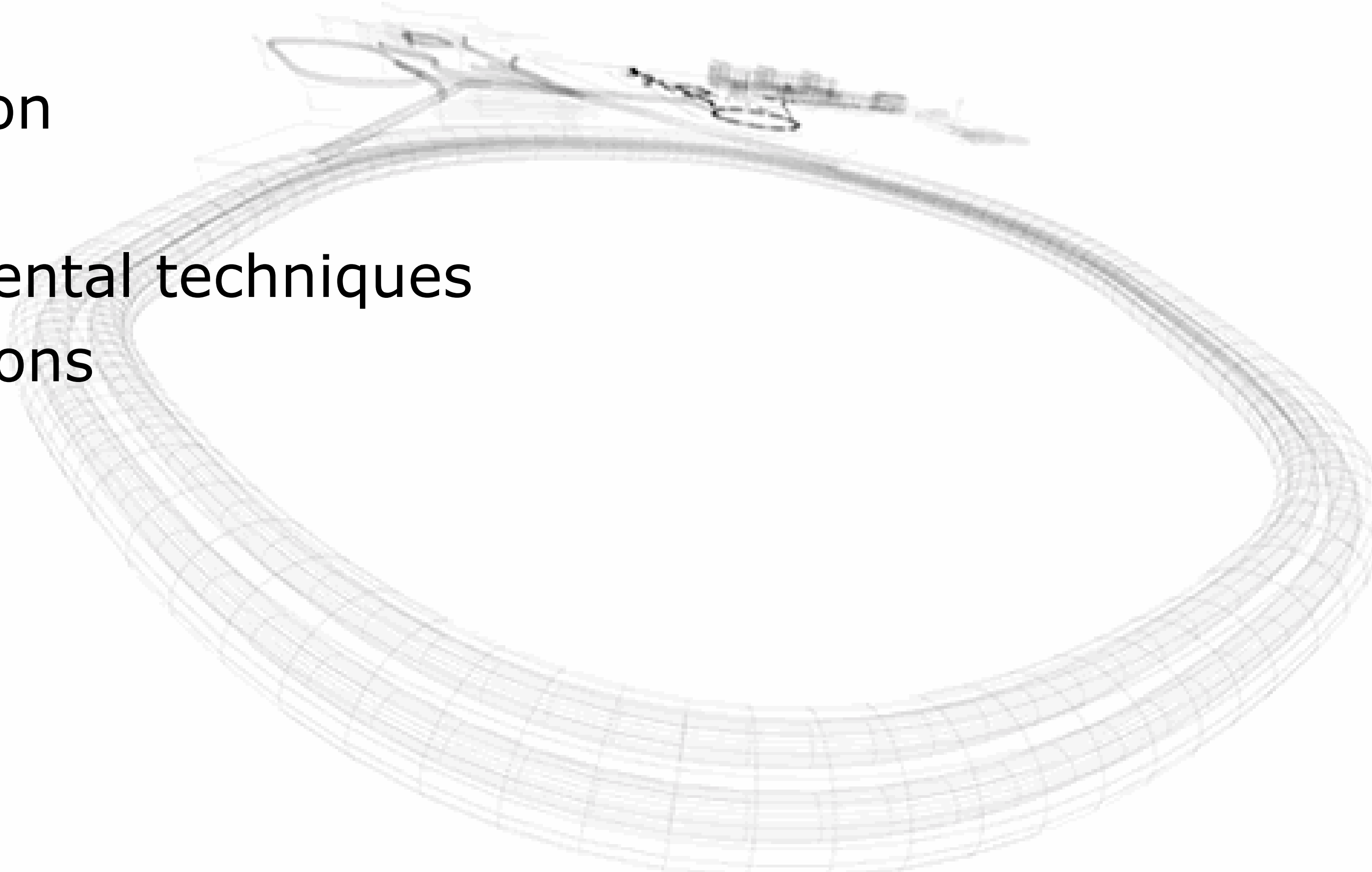
Bulmahn gives green light for large-scale research equipment
"We are securing an international top position for German basic research"

...Basic research in the natural sciences has a long tradition in Germany. Its success is inextricably linked with the use of large-scale equipment at national and international research centres. "With the new concept, basic research in Germany will start from an excellent position when entering a new decade of successful work", Minister Bulmahn said.

Together with European partners, the Gesellschaft für Schwerionenforschung (GSI) in Darmstadt is to develop further its equipment in a phased approach and become a leading european physics centre. At least 25% of the costs amounting to €675 million are to be shouldered by foreign partners.

Overview

- Motivation
- Goals
- Experimental techniques
- Conclusions



Hadrons are very complicated

$q\bar{q}$

+

$(q\bar{q})(q\bar{q})$

+

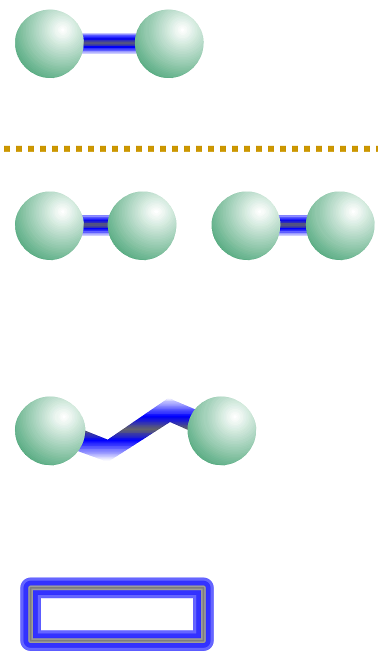
$(q\bar{q})g$

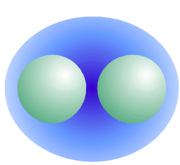
+

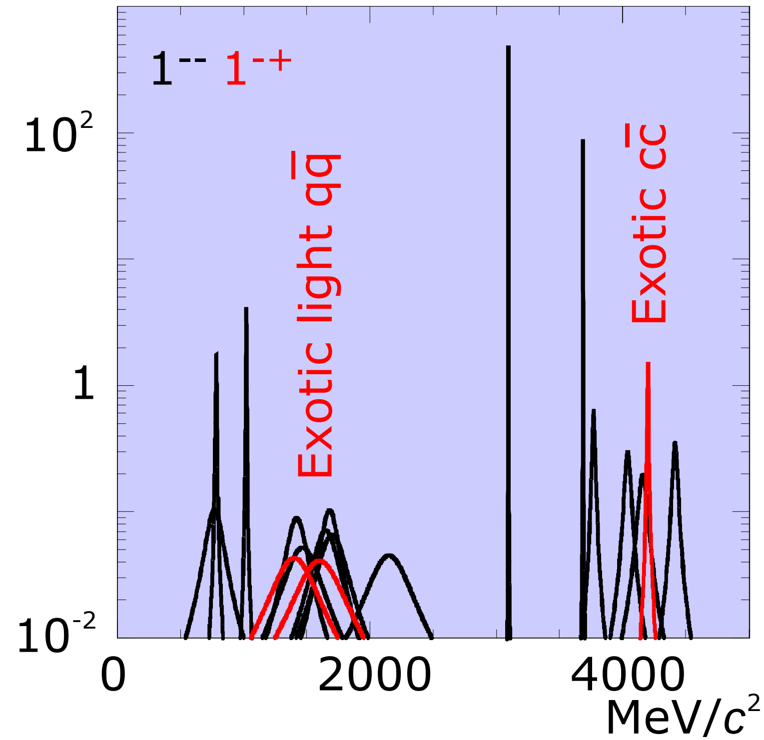
gg

+

……..



 $= \Sigma_i(q\bar{q})_i\Sigma_j g_j$



Simplest Hybrids

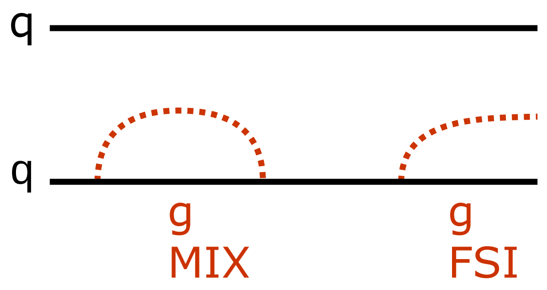
S-Wave+Gluon $(qq)_8g$ with $()_8$=coloured

$^1S_0$ ↑↓ $^3S_1$ ↑↑

combined with a 1^+ or 1^- gluon

Gluon	1^{-} (TM)	1^{+} (TE)
$^1S_0$, 0^{-+}	1^{++}	1^{--}
$^3S_1$, 1^{--}	0^{+-}	0^{-+}
	1^{+-}	1^{-+}
	2^{+-}	2^{-+}

Meson – Hybrid Mixing



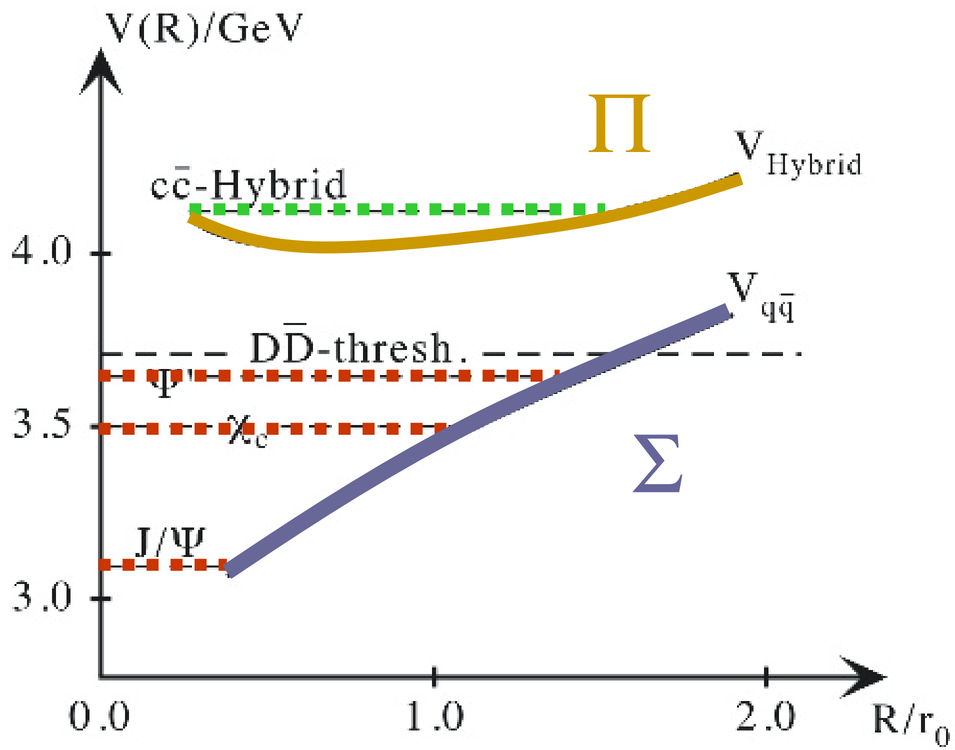
Charmed Hybrids

Gluonic excitations of the quark-antiquark-potential may lead to bound states

LQCD:

- Π-potential
- $m_H \sim 4.2\text{-}4.5$ GeV

Light charmed hybrids could be as narrow as → O(5-50 MeV)



important <r²> and $r_{Breakup}$

LQCD ccg 1^{-+} vs. cc 1^{--} (J/ψ)

1^{-+} m(ccg)	Model	Group	Reference
4390 ±80 ±200	isotropic	MILC97	PRD56(1997)7039
4317 ±150	isotropic	MILC99	NPB93Supp(1999)264
4287	isotropic	JKM99	PRL82(1999)4400
4369 ±37 ±99	anisotropic	ZSU02	hep-lat 0206012
$\Delta(1^{-+},1^{--})$ m(ccg) - m(cc)			
1340 ±80 ±200	isotropic	MILC97	PRD56(1997)7039
1220 ±150	isotropic	MILC99	NPB93Supp(1999)264
1323 ±130	anisotropic	CP-PACS99	PRL82(1999)4396
1190	isotropic	JKM99	PRL82(1999)4400
1302 ±37 ±99	anisotropic	ZSU02	hep-lat 0206012

Charmed Hybrid Level Scheme

$1^{--}\,(0,1,2)^{-+} < 1^{++}\,(0,1,2)^{+-}$

- JKM00, NPB83Suppl83(2000)304 and Manke, PRD57(1998)3829

L-Splitting

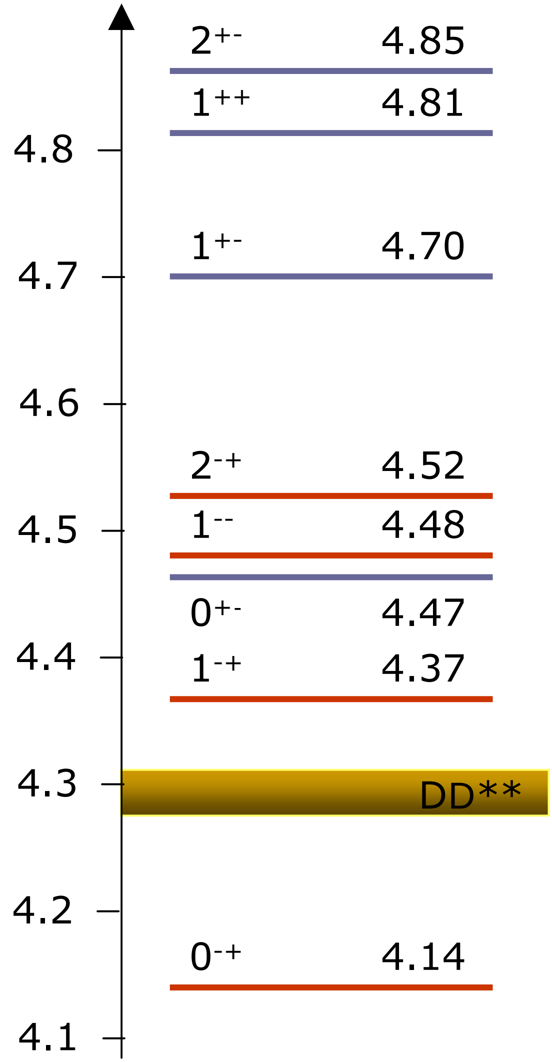
- Δm ~ 100-250 MeV/c^2 for 1^{-+} to 0^{+-}

S-Splittings

- Page thesis,1995 and PRD35(1987)1668
- 4.14 (0^{-+}) to 4.52 GeV/c^2 (2^{-+})

consistent w/LQCD

- JKM, NPB86suppl(2000)397, PLB478(2000) 151



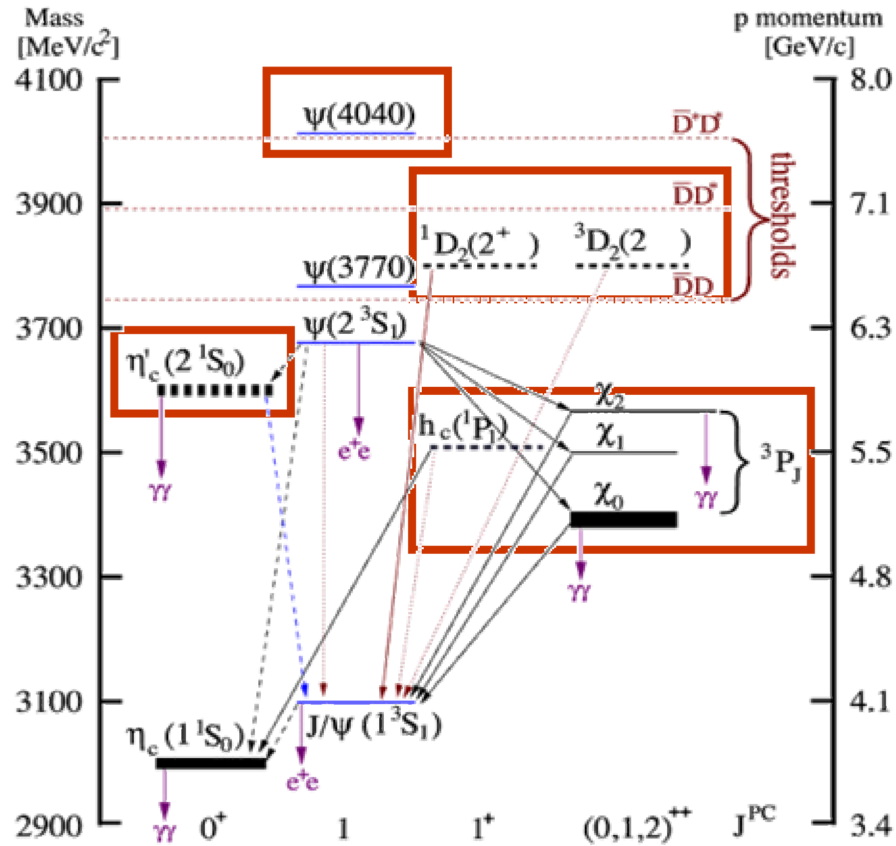
Charmonium Physics

Open questions …

- η_c' (2^1S_0) not established
- h_{1c} ($^1P_1$) unconfirmed
- Peculiar decays of ψ(4040)
- Terra incognita for any 2P and D-States

… Exclusive Channels

- Helicity violation
- G-Parity violation
- Higher Fock state contributions



Charmonium Physics

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

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

e^+e^- interactions:

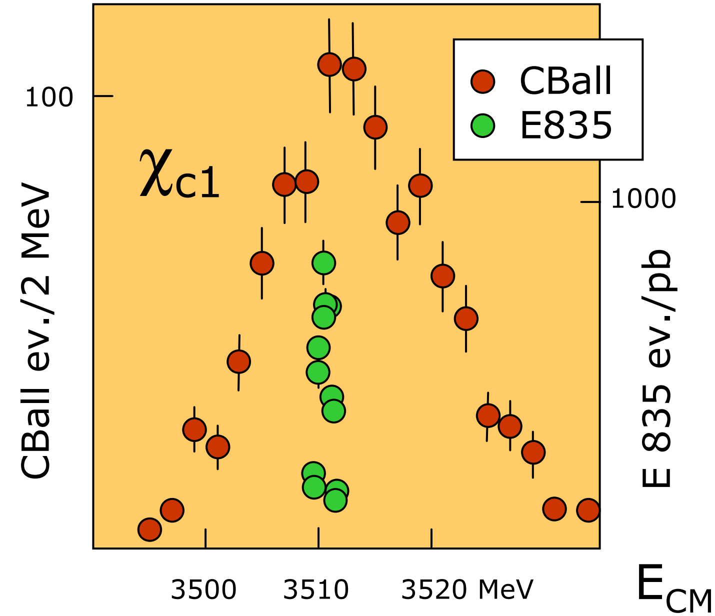
- Only 1^{--} states are formed

Existing experiments:

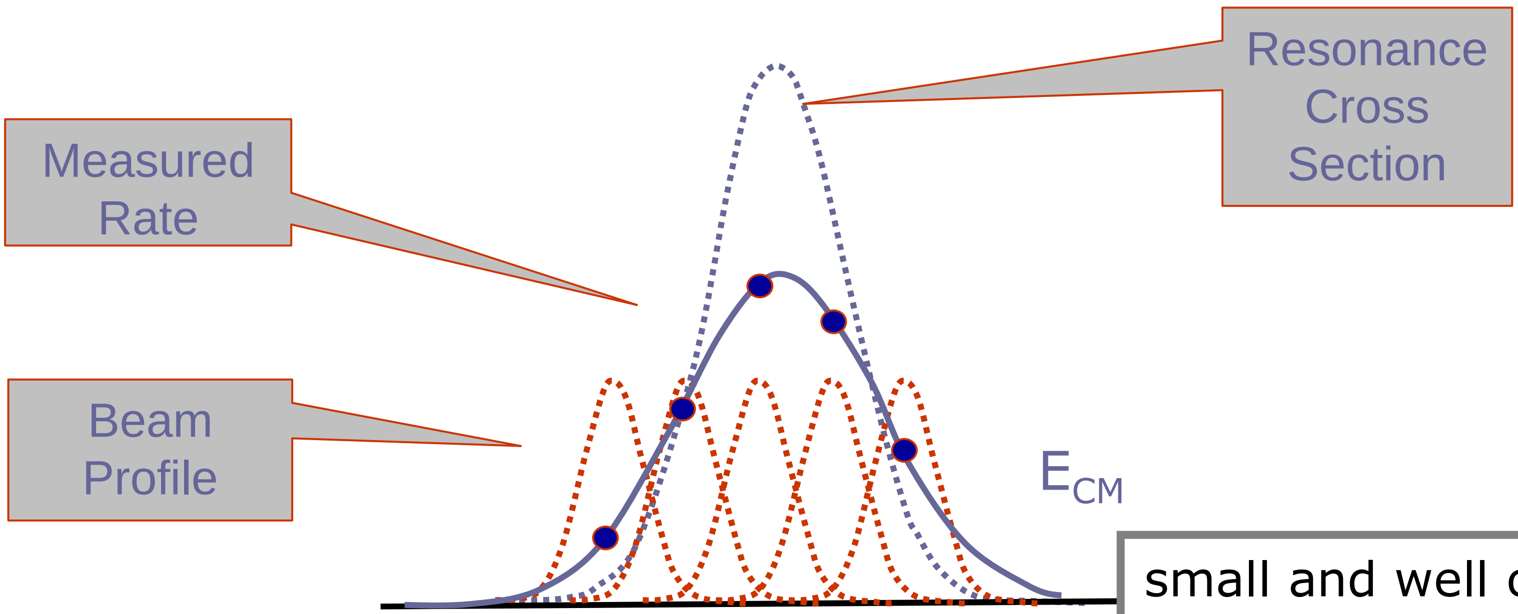
- no B-field, beam time
- beam momentum reproducibility

pp reactions:

- All states directly formed
  (very good mass resolution)



Resonance Scan



small and well controlled beam momentum spread
$\Delta p/p$
is extremely important

Charmonium Physics

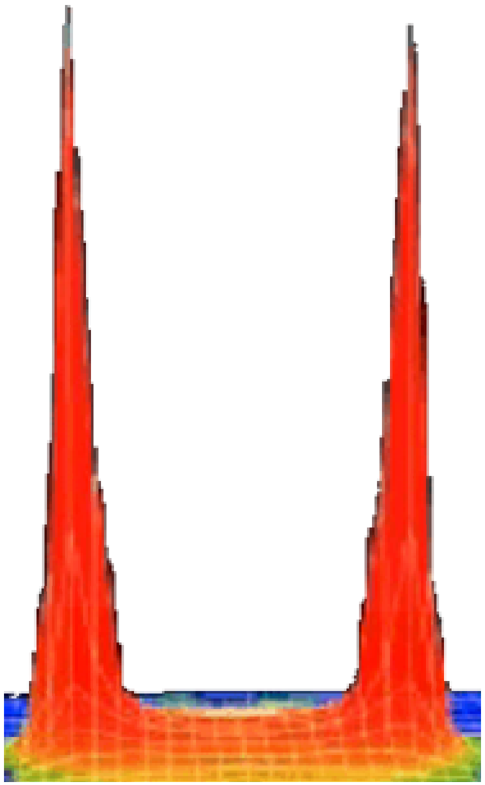
Expect 1-2 fb^{-1} (like CLEO-C)

- pp (>5.5 GeV/*c*) $\rightarrow J/\psi$ — 10^7/d
- pp (>5.5 GeV/*c*) $\rightarrow \chi_{c2}\ (\rightarrow J/\psi\ \gamma)$ — 10^5/d
- pp (>5.5 GeV/*c*) $\rightarrow \eta_c`(\rightarrow \phi\phi)$ — $10^4/d|_{rec.}$?

Comparison to E835

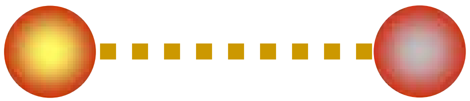
- Maximum energy 15 GeV/*c* instead of 9 GeV/*c*
- Luminosity 10*x* higher
- Detector with magnetic field
- $\Delta p/p$ 10*x* better
- Dedicated machine with stable conditions

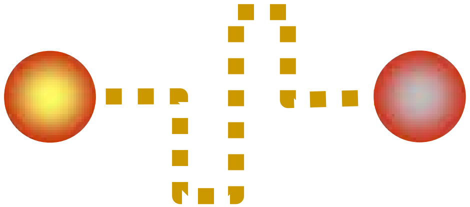
Fluxtube



~ Simplified Lattice Approach

Meson





Hybrid

Flux (excited Gluon) carries angular momentum

Charmed Hybrids – Decays

Fluxtube-Model predicts DD** (+c.c.) decays

- if $m_H < 4290$ MeV/c^2 below DD_0(+c.c.)
- $\rightarrow$ $\Gamma_H <$ 50 MeV/c^2

Some exotics can decay neither to DD nor to DD* (+c.c.)

- e.g.: $J^{PC}(H)=0^{+-}$
  - fluxtube forbidden: $J/\psi f_2$, $J/\psi(\pi\pi)_S$, $\eta_c h_1$
  - fluxtube allowed: $\chi_{c0}\omega$, $\chi_{c0}\phi$, $\chi_{c2}\omega$, $\chi_{c2}\phi$, $h_{1c}\eta$
- Small number of final states with small phase space
  - favours a narrow resonance
- if DD** (+c.c.) possible $\rightarrow$ still very small phase space

But! be prepared for surprises
measure DD nor to DD* (+c.c.) waves as well

Charmed Hybrids – Decays of 1^{-+}

a very likely decay mode will (could?) be $\chi_c(\pi\pi)_S$

- C. Michael, hep-lat 0207017
- preferably using $\pi^0\pi^0$ to avoid $\rho(770)$ contamination
- use charged mode $\pi^+\pi^-$ for comparison

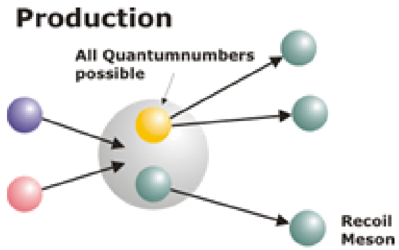
detect the χ_c in the radiative decay to J/ψ

- detect the soft photon
- and the lepton pair

Proton-Antiproton @ Rest/Flight

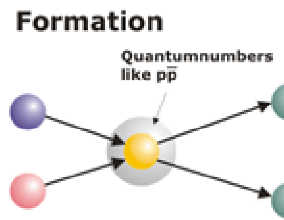
Production

all J^{PC} available



Formation

only selected J^{PC}



Proton-Antiproton @ Rest/Flight

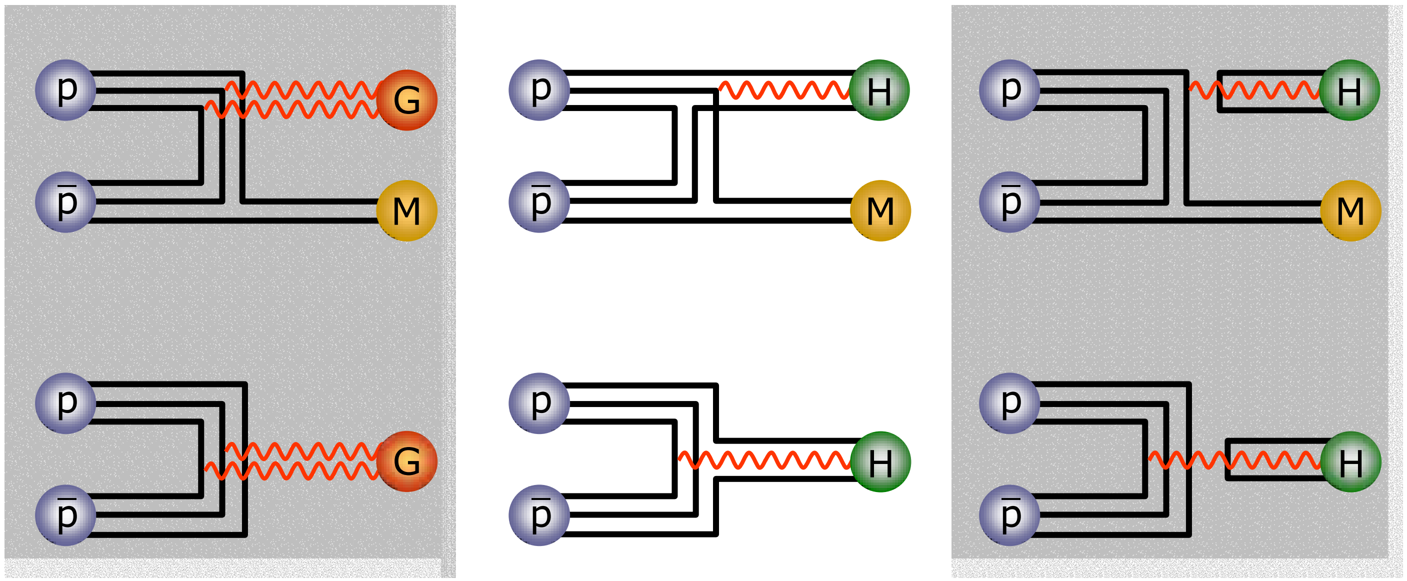
nng ssg/ccg

Production

all J^{PC} available

Formation

only selected J^{PC}



Gluon rich process creates gluonic excitation in a direct way

- cc requires the quarks to annihilate (no rearrangement)
- yield comparable to charmonium production
- even at low momenta large exotic content has been proven

Momentum range for a survey $p_{p} \to \sim 15$ GeV

But also Glueball Formation

Heavy Glueballs

Light gg/ggg-systems are complicated to identify

Exotic heavy glueballs

- $m(0^{+-}) = 4140(50)(200)$ MeV
- $m(2^{+-}) = 4740(70)(230)$ MeV

Width unknown, but!

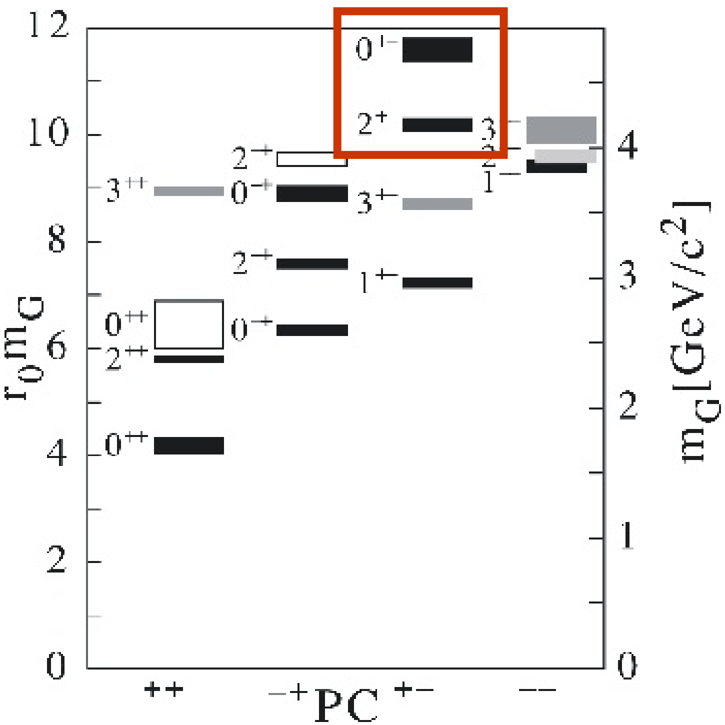
- nature invests more likely in mass than in momentum
- newest proof: double cc yield in e^+e^-

Flavour-blindness

- predicts decays into charmed final states too

Same run period as hybrids

- In addition: scan m>2 GeV/c^2



Morningstar und Peardon, PRD60 (1999) 034509
Morningstar und Peardon, PRD56 (1997) 4043

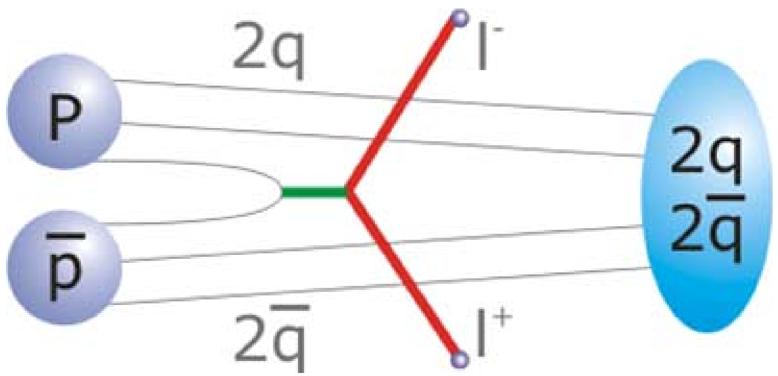
4-Quark Formation

Proton-Antiproton contains already a 4-Quark-System

Idea: Dilepton-Tag from Drell-Yan-Production

Advantages

- Trigger
- less J^{PC}-Ambiguities
- 1200 E./day @ 12 GeV
- 300 E./day @ 5-8 GeV antiproton-Beam (for $L=10^{32}cm^{-2}s^{-1}$)



Bannikov, Gornuschkin, Kopeliovich, Krumshtein and Sapozhnikov, JINR E1-92-344 (1992)

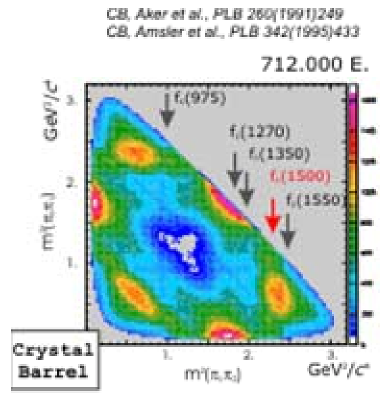
Exotics in Proton-Antiproton

Exotics are heavily produced in $p\bar{p}$ reactions

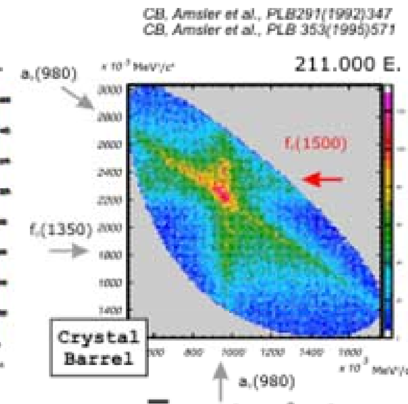
High production yields for exotic mesons (or with a large fraction of it)

- $f_0(1500)\pi \to$ ~25 % in $3\pi^0$
- $f_0(1500)\pi \to$ ~25 % in $2\eta\pi^0$
- $\pi_1(1400)\pi \to$ >10 % in $\pi^\pm\pi^0\eta$

Interference with other well known (conventional) states is mandatory for the phase analysis

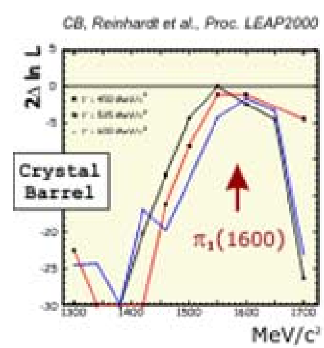


$p\bar{p} \to 3\pi^0$ @ rest

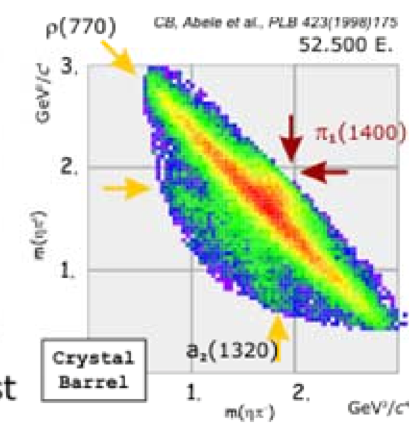


$p\bar{p} \to 2\eta\pi^0$ @ rest

Crystal Barrel

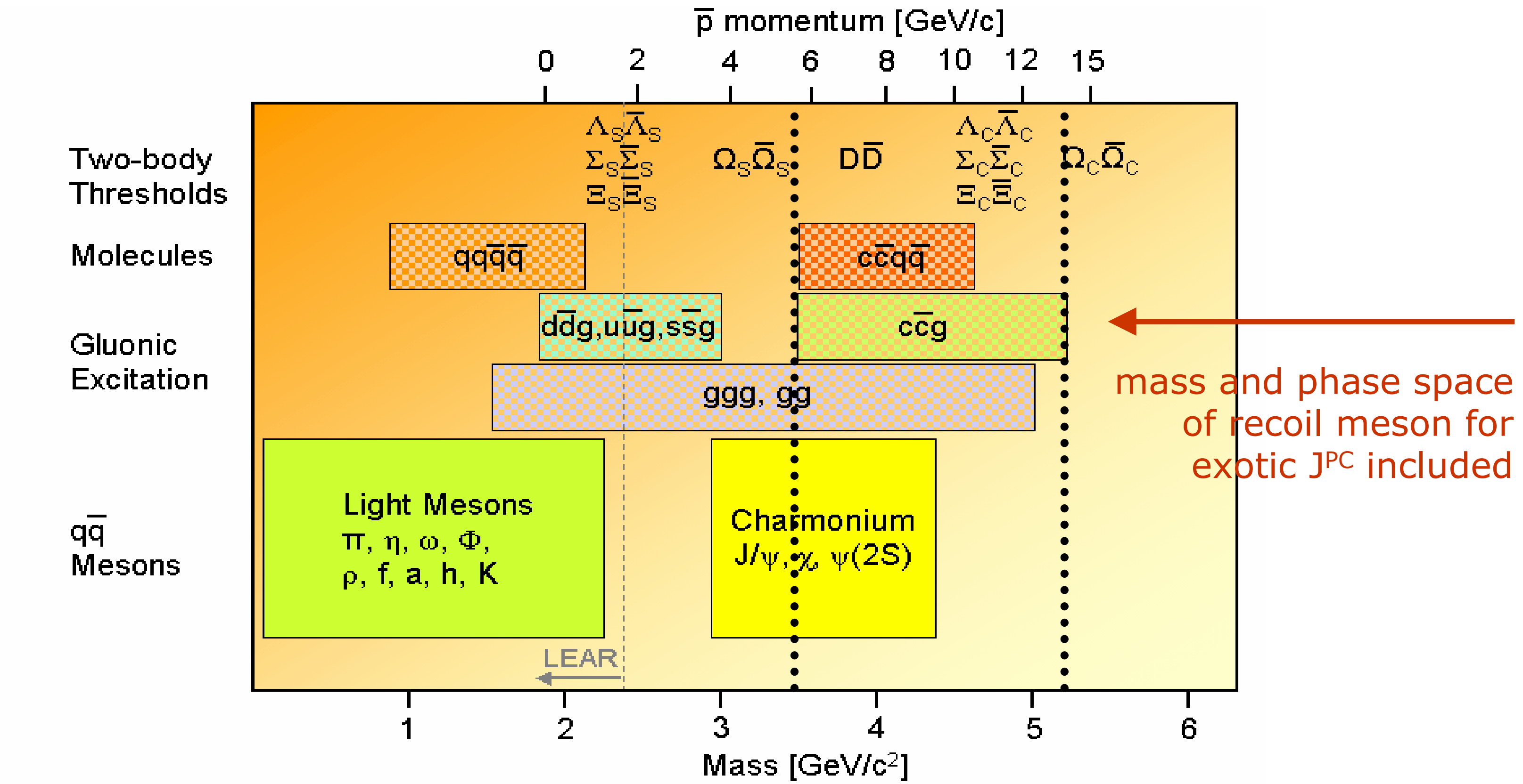


$p\bar{p} \to \eta'\pi^0\pi^0$ @ rest



$\bar{p}d \to \pi^-\pi^0\eta\, p$ @ rest

Accessible Hadrons

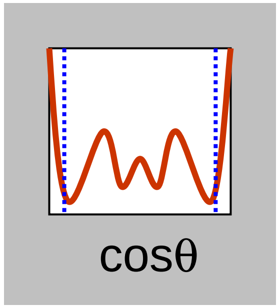


Other exotics with identical decay channels → same region

Lessons from LEAR

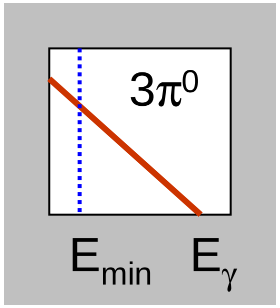
Full solid angle

- no missing particles (photons!)
- no "dead" regions



Merged π^0 are easy to handle

- "moderate" angular resolution sufficient



Low thresholds

- E_{min}~20 MeV in electromagnetic detector

K-Trigger/K-Id

- K_S-Trigger
- Kaon ID @ high Energies

Signatures, Potential Problems

"Leading charmonia"

- J/ψ, ψ`, $\eta^{(`)}{}_c$, χ_{cj}, [DD] a.o.m.?

DiLeptons

- e^+e^- (Ecal,Trk)
- $\mu^+\mu^-$ (Trk,Hcal)

ϕ (ϕ)-Tag

- $\phi\phi$ and recoil ϕ (Trk,Cherenkov)

K_S ($+K^\pm$)-Tag

- η_c and h_c (Vtx,Trk,Cherenkov)

Photon-Pairs

- $\gamma\gamma$ from cc (Ecal,no-Trk)
- $\gamma\gamma$ from π^0 and η (Ecal)

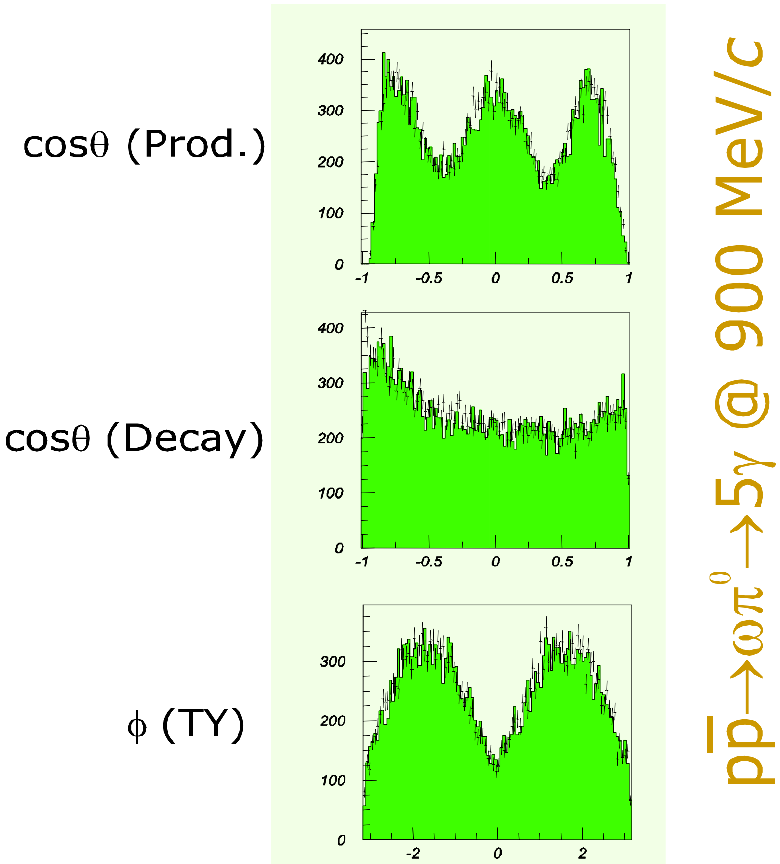
Many information needed on "trigger" level !

p in Flight – no longer a challenge!

Crystal Barrel proved
- annihilation in flight can be analyzed unambiguously

Formation:
- two body decays, where at least one particle carries spin!
- ~10k events L up to 6

Production:
- small recoil momenta reduce the available phase space and the contributing waves dramatically
- alternative: integration of the production process



Peters, NPA 692(2001)295

Further Experiments

Hypernuclear physics

- 3rd dimension of nuclear chart
- Focus Double Hypernuclei

WACS (previously noted as “Inverted DVCS”)

- Measure dynamics of quarks and gluons in a hadron
- Handbag diagram

Proton Formfactors at large Q^2

- s up to 25 GeV^2/c^4

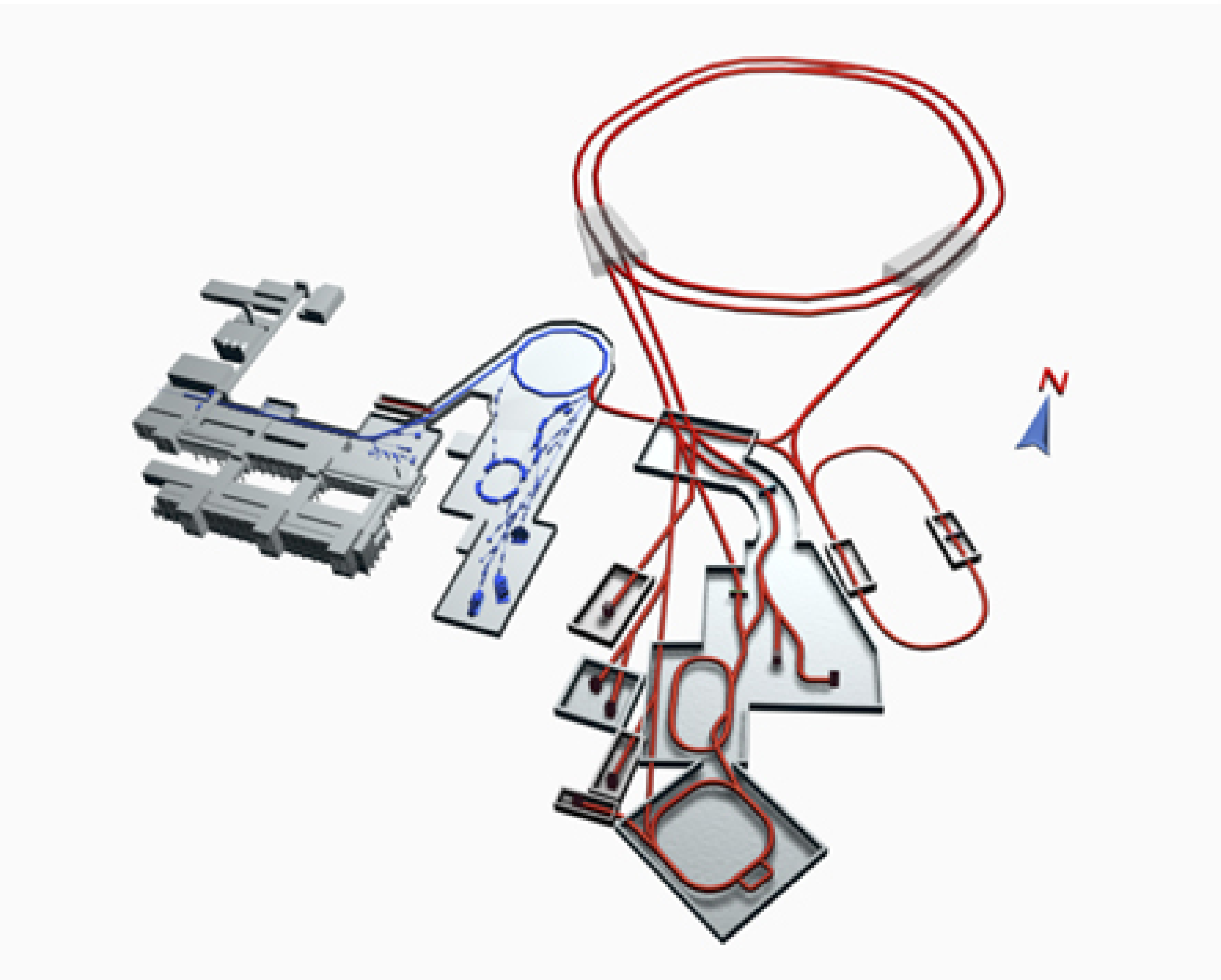
$D_{(S)}$-Physics

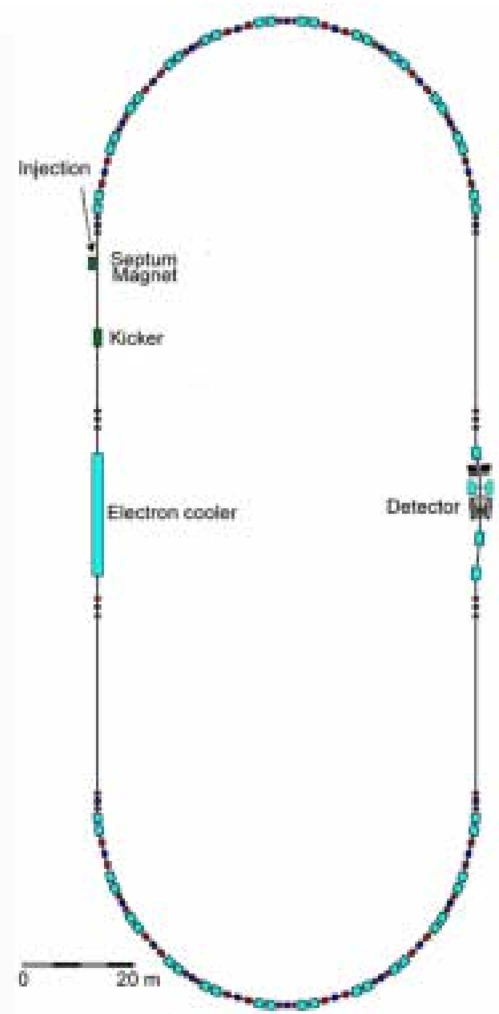
- BR and decay dalitzplots w/ high statistics

CP-Violation in the D-Sector

- also possible $pp \rightarrow p\Sigma_c^+D^0$

The Antiproton Facility





The Antiproton Facility

Antiproton production similar to CERN,

HESR = High Energy Storage Ring

- Production rate 10^7/sec
- P_{beam} = 1.5 - 15 GeV/c
- N_{stored} = 5 x 10^{10} p

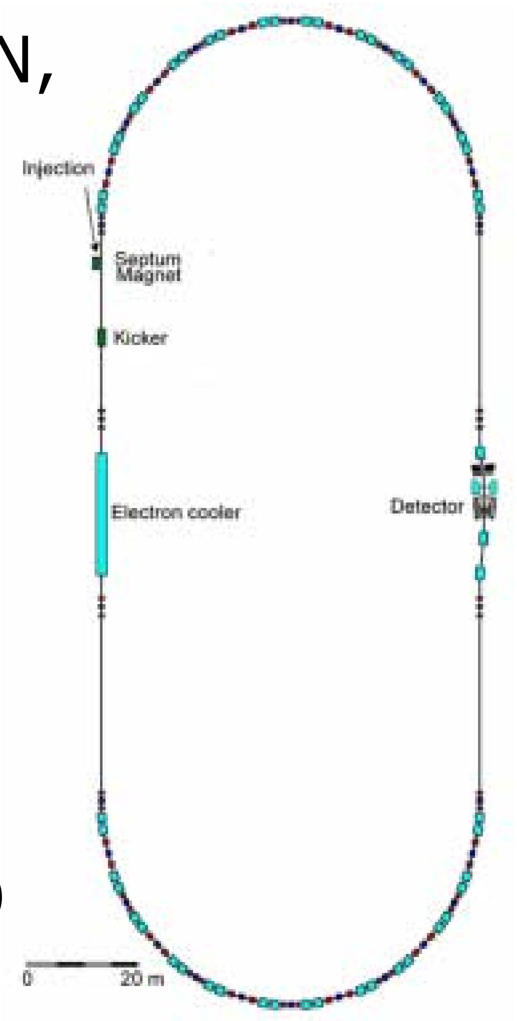
Gas-Jet (or Cluster) Target

High luminosity mode

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

High resolution mode

- $\Delta p/p \sim 10^{-5}$ (electron cooling < 8 GeV/c)
- Luminosity = 10^{31} $cm^{-2}s^{-1}$



Proposed Detector (Overview)

High Rates

- Total σ ~ 55 mb
- 10^7 interactions/s

Vertexing

- $(\sigma_p, K_S, \Lambda, \ldots)$

Charged particle ID

- $(e^\pm, \mu^\pm, \pi^\pm, p, \ldots)$

Magnetic tracking

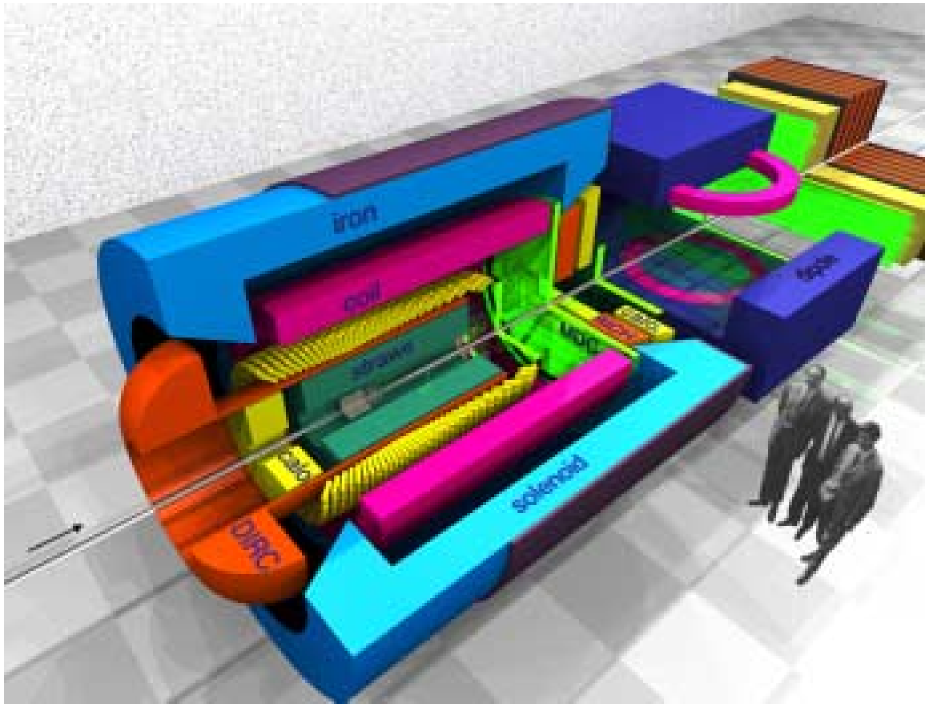
Elm. Calorimetry

- (γ, π^0, η)

Forward capabilities

- (leading particles)

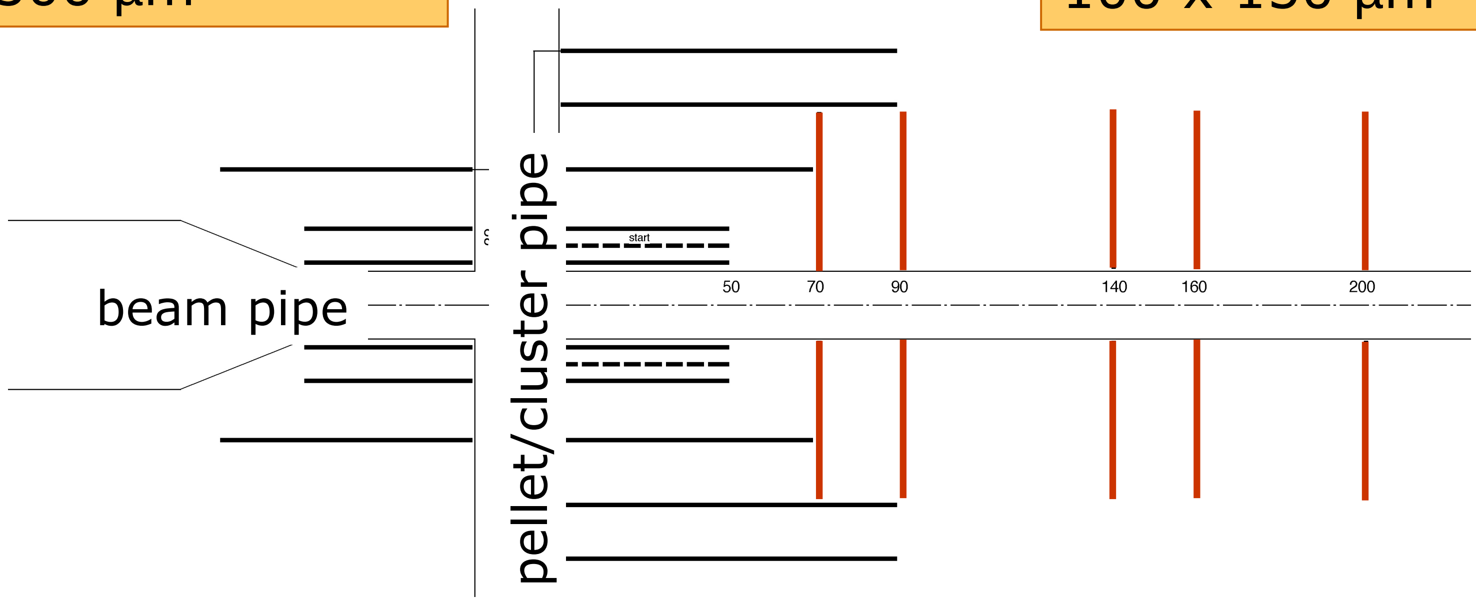
Sophisticated Trigger(s)



Vertexing: Micro Vertex Detector

7.2 mio. barrel pixels
50 x 300 µm

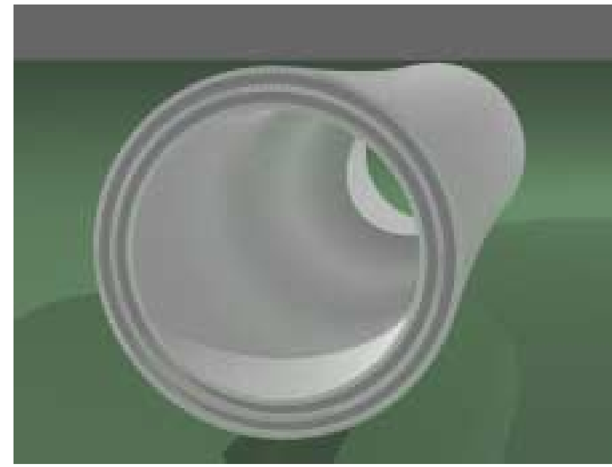
2 mio. forward pixels
100 x 150 µm

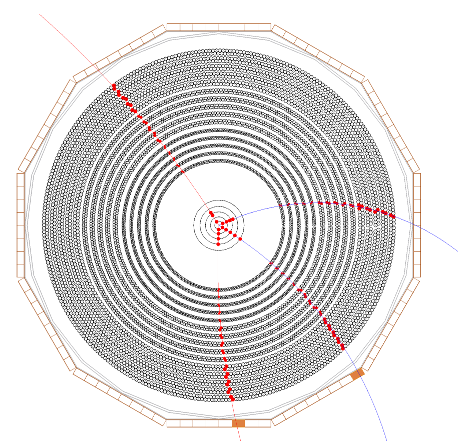


Readout: ASICs (ATLAS/CMS) 0.37% X_0
or pixel one side – readout other side (TESLA)

Tracking: Straw Tube Tracker

Number of double layers Skew angle of dbl layers 1 and 15 Skew angle of dbl layers 2-14	15 0^{o} 2^{o}-3^{o}
Straw tube wall thickness Wire thickness Gas Length Diameter of tubes in double layers 1-5, 6-10, and 11-15 Number of straw tubes	26 mm 20 mm 90%He 10%C_4H_{10} 150 cm 4 mm 6 mm 8 mm 8734
Transverse resolution $s_{x,y}$ Longitudinal resolution s_z	150 mm 1 mm



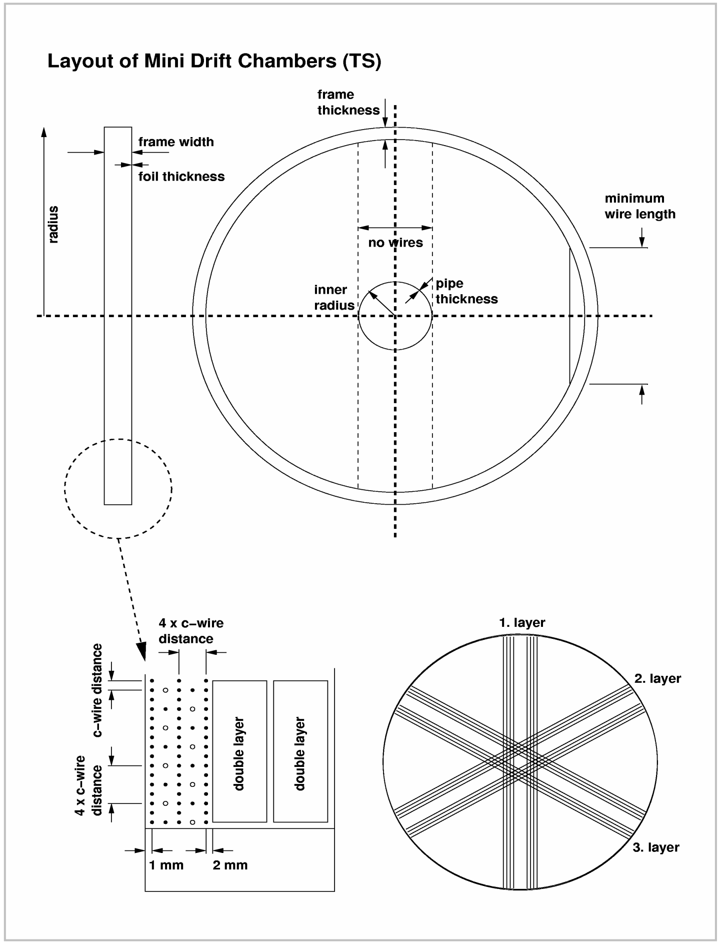


Tracking: Forward MDC

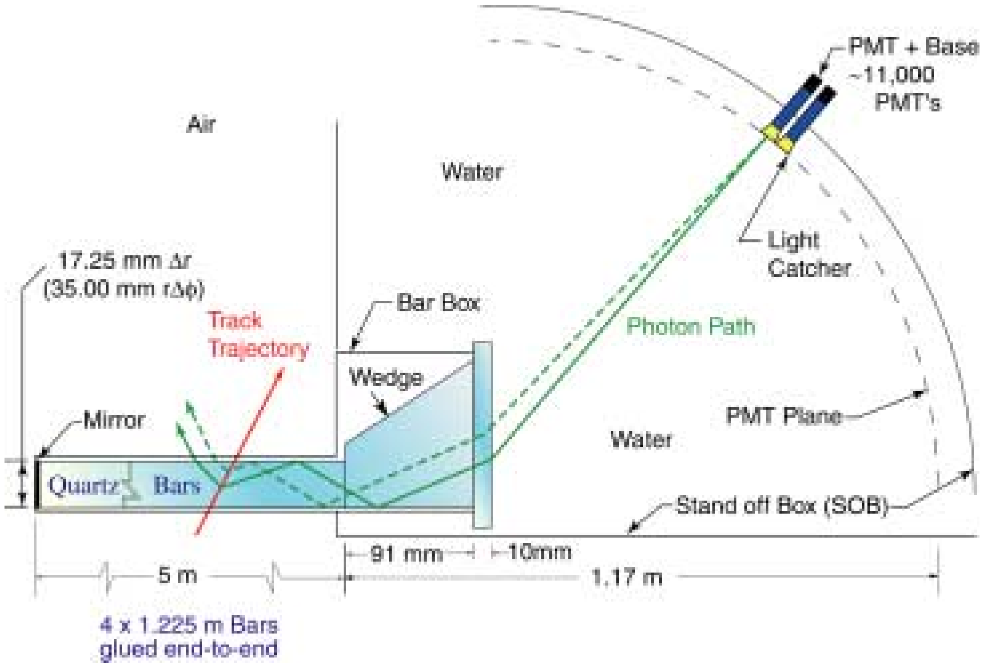
6 layers of sense wires in
3 double layers (y,u,v)
not stretched radially (mass)
realized at HADES

- high counting rates
- position resolution 70μm

HADES@GSI

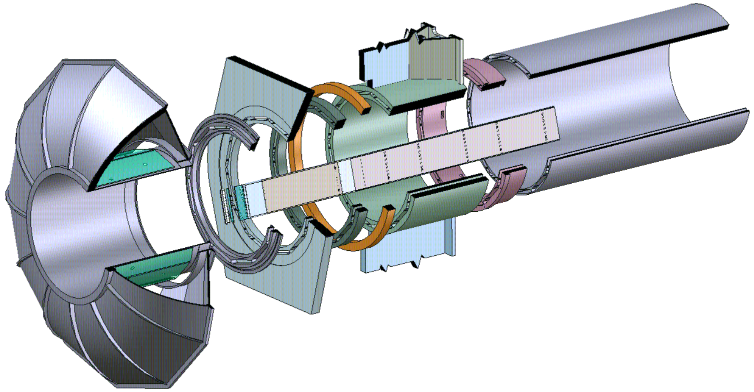


PID: DIRC (Cherenkov)

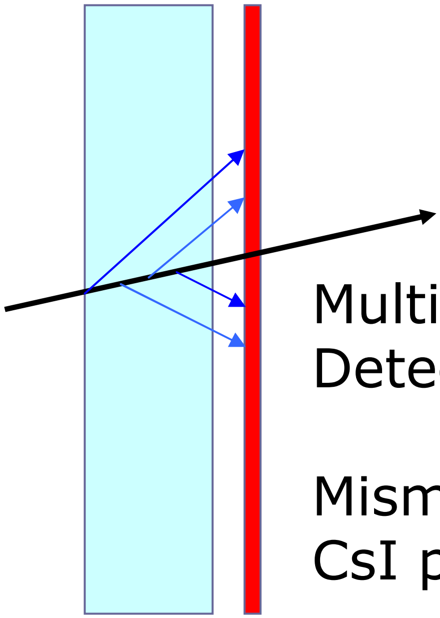


BaBar@SLAC

less space than aero gel
→ costs of calorimeter
no problems with field



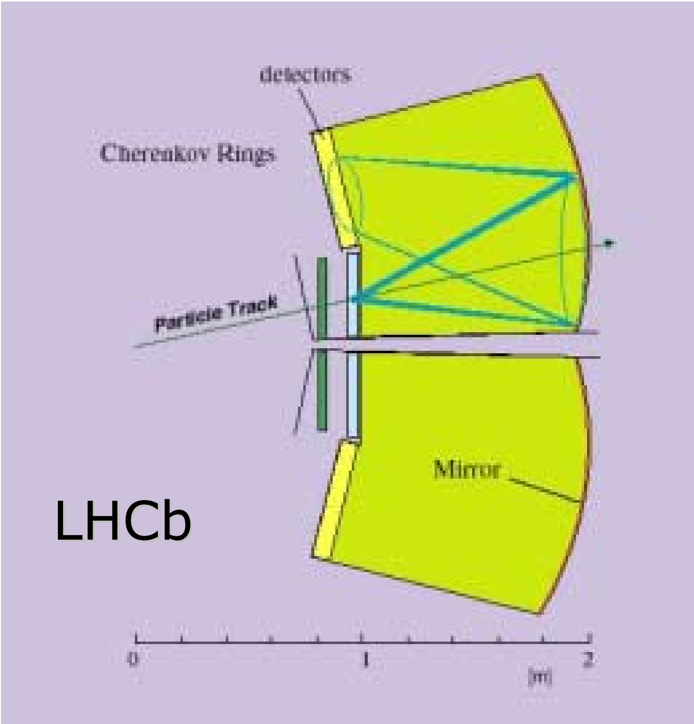
PID: Forward RICH



Multi pad gas Detector

Mismatch photons ←→ CsI photon conversion

Aerogel
n=1.02

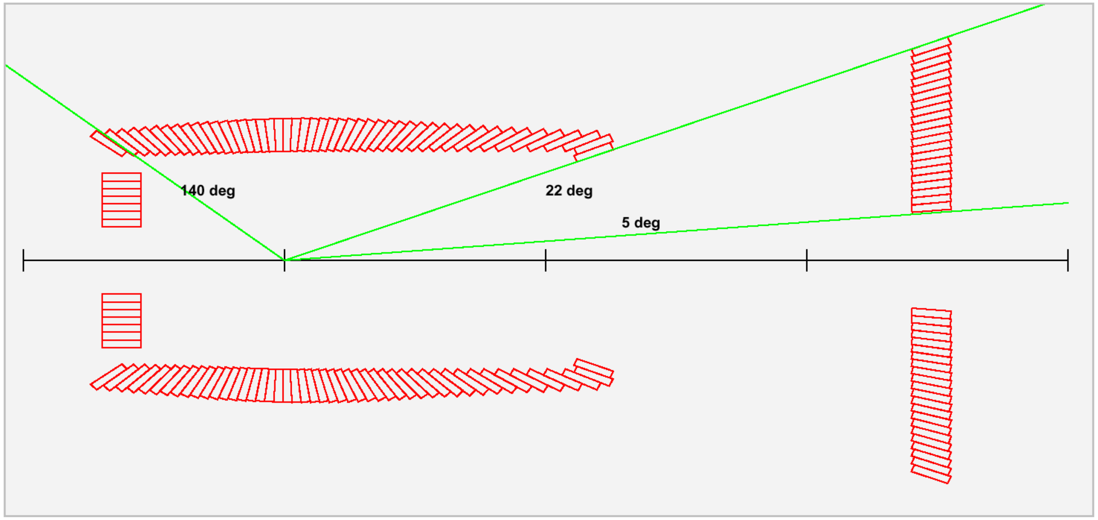


LHCb

proximity focusing ←→ mirrors

Electromagnetic Calorimeter

Detector material Photo sensors	$PbWO_4$ (or BGO) Avalanche Photo Diodes
Crystal size	≈ 35 x 35 x 150 mm³ (i.e 1.5 x 1.5 R_M^2 x 17 X_0)
Energy resolution Time resolution	1.54 % / √E[GeV] + 0.3 % (PWO) σ ≈ 130 ps
Total number of crystals	7150



Participating Institutes
(with Representative in the Coordination Board)

40 Institutes (32 Locations) from 9 Countries:
Austria - Germany – Italy – Netherlands – Poland – Russia – Sweden – U.K. – U.S.

U Bochum
U Bonn
U & INFN Brescia
U Catania
U Cracow
GSI Darmstadt
TU Dresden
JINR Dubna I + II
U Erlangen
NWU Evanston
U & INFN Ferrara
U Frankfurt
LNF-INFN Frascati
U & INFN Genova
U Glasgow
U Gießen
KVI Groningen
IKP Jülich I + II
U Katowice
LANL Los Alamos
U Mainz
TU München
U Münster
BINP Novosibirsk
U Pavia
U of Silesia
U Torino
Politechnico di Torino
U & INFN Trieste
U Tübingen
U & TSL Uppsala
ÖAdW Vienna
SINS Warsaw

Why Antiprotons ?

high resolution spectroscopy with p-beams in formation experiments:

- $\Delta E \approx \Delta E_{beam}$

high yields in pp of gluonic excitations

- glueballs, hybrids

event tagging by pair wise associated production,

- (particle, anti-particle) e.g. $pp \rightarrow \Xi\Xi bar$

large $\sqrt{s}$ at low momentum transfer

- important for in-medium "implantation" of hadrons:
- study of in-medium effects

Summary & Outlook

Investigation of charmed exotics is one key tool for the investigation of gluonic degrees of freedom inside hadrons

HESR @ GSI will survey the whole ccX mass region in formation and production processes ...

... to measure the whole spectrum of heavy exotics