LXXXVIII CONGRESSO NAZIONALE
SOCIETÀ ITALIANA DI FISICA

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GSI: the new frontier for antiproton physics

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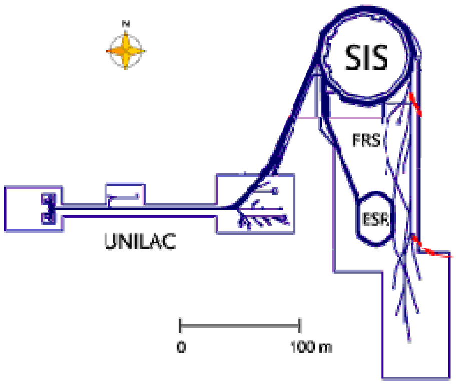
I.N.F.N. - Sezione di Torino

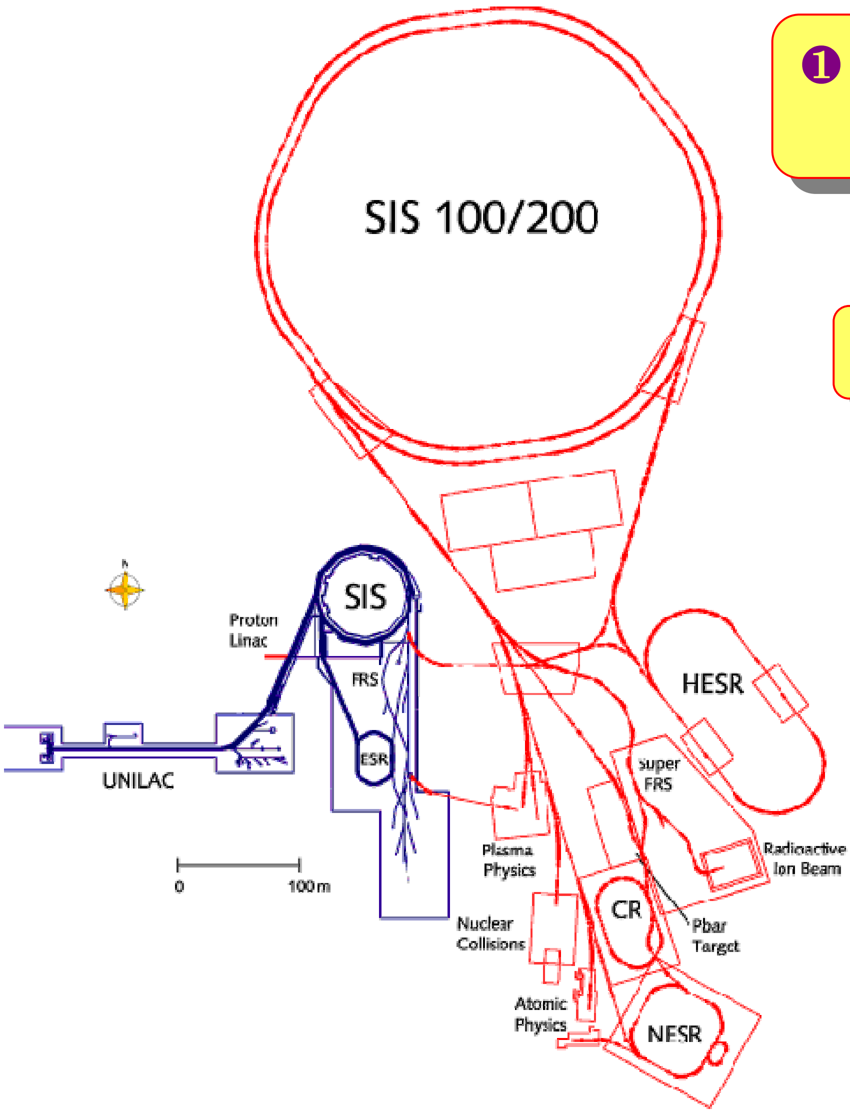
Outline

- The GSI future upgrade
- The science case
- The antiproton facility
- The antiproton physics program
- The PANDA detector concept
- Conclusions

The GSI future upgrade



The GSI future upgrade



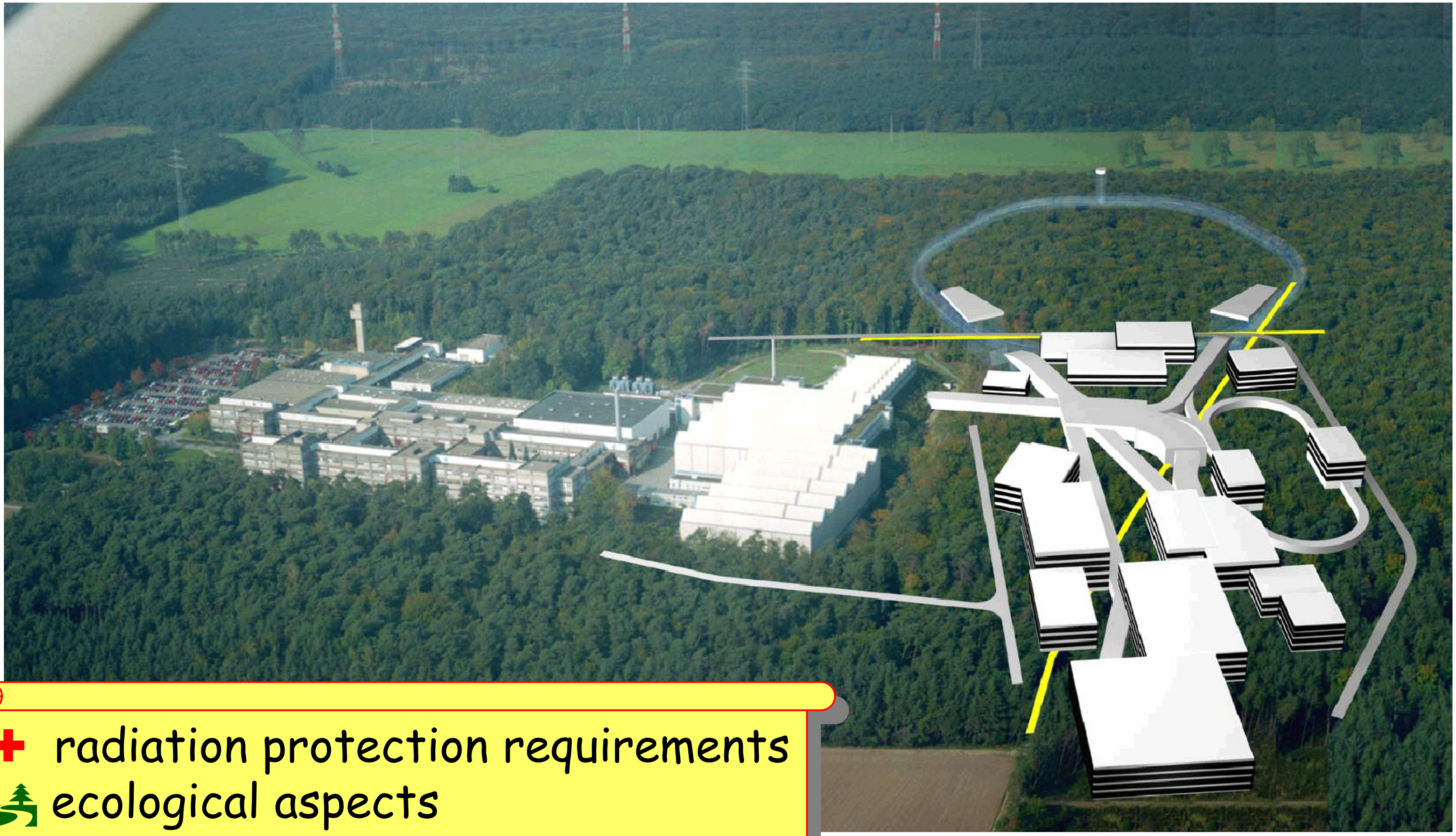
❶ higher beam intensity (100 ×)
☛ fast cycling synchrotrons

❷ higher beam energy (15 ×)

❸ higher beam quality
☛ stochastic and electron cooling
☛ bunch compression (50 ns)

❹ high parallelism in operation

The GSI planned facility



- radiation protection requirements
- ecological aspects
- cost minimization

The science case

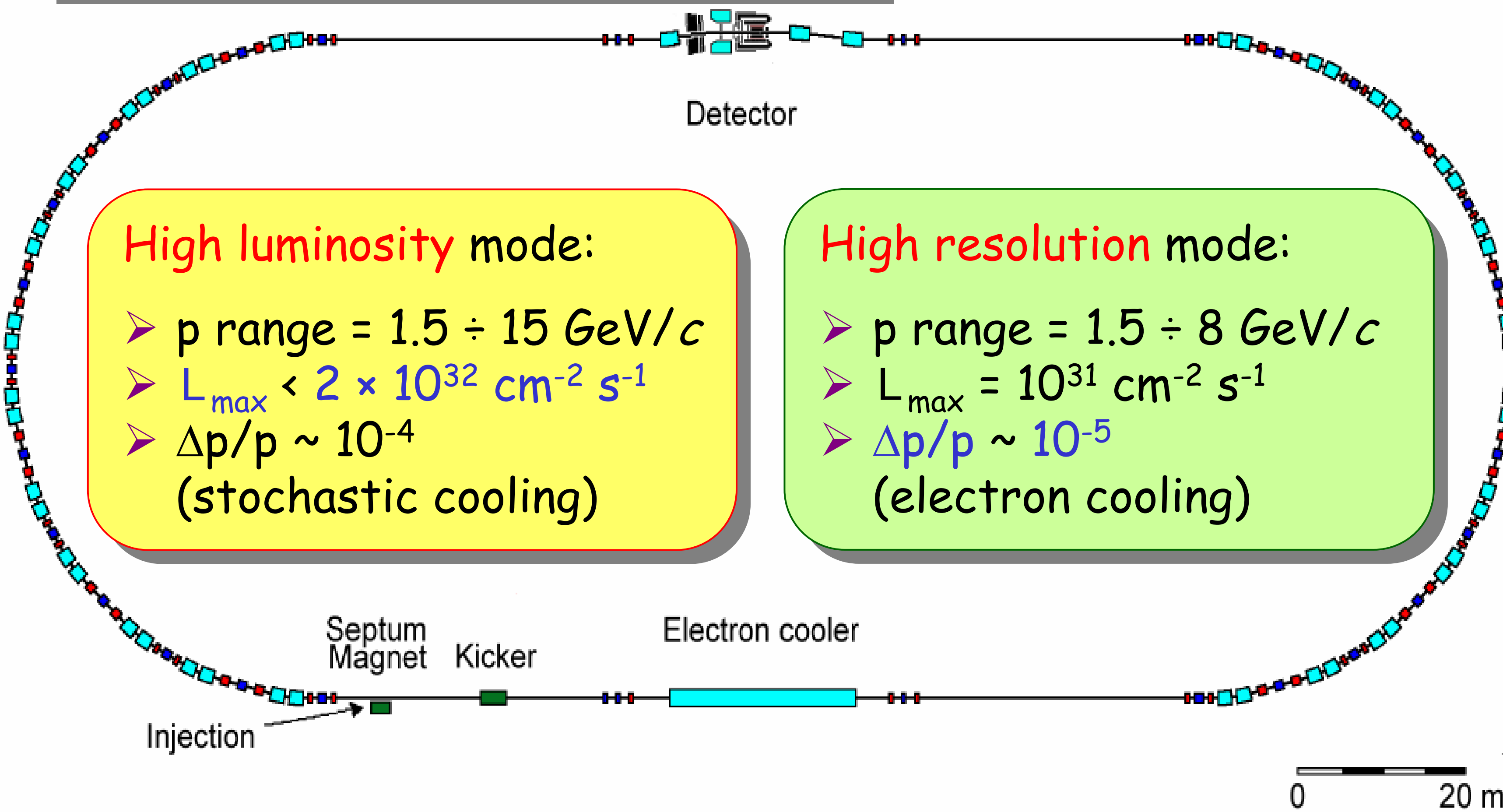
- research with rare-isotope beam
  nuclei far from stability
- nucleus-nucleus collisions at high energy
  compressed nuclear matter
- ion beam and laser beam induced plasmas
  high energy density in bulk matter
- from fundamentals to applications
  QED, strong fields, ion-matter interactions
- ☛ research with antiprotons
  hadron spectroscopy and hadronic matter

The antiproton physics program

- Charmonium spectroscopy
- Search for charmed hybrids and glueball
- Hidden and open charm mesons in nuclei
- Hypernuclear physics
- Further options
  - CP violation (D/Λ-sector)
  - D meson spectroscopy
  - Inverted deeply virtual Compton scattering
  - Nucleon time-like form factors
  - Low energy antiproton physics (hopefully)

The High Energy Storage Ring

- $\bar{p}$ production rate = 10^7/s
- max stored $\bar{p}$ = 5×10^{10}
- beam momentum = 1.5 ÷ 15 GeV/c



High luminosity mode:

- p range = 1.5 ÷ 15 GeV/c
- $L_{max} < 2 \times 10^{32}$ cm^{-2} s^{-1}
- $\Delta p/p \sim 10^{-4}$ (stochastic cooling)

High resolution mode:

- p range = 1.5 ÷ 8 GeV/c
- $L_{max} = 10^{31}$ cm^{-2} s^{-1}
- $\Delta p/p \sim 10^{-5}$ (electron cooling)

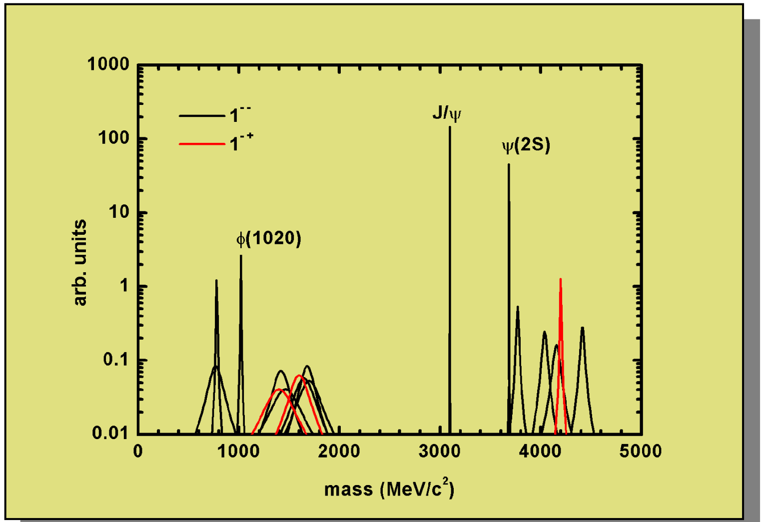
Why to push up beam energy?

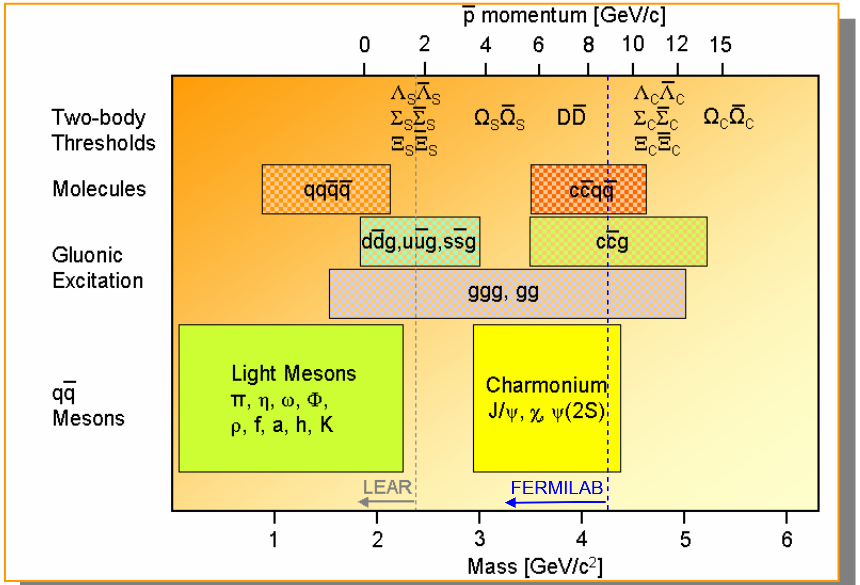
$q\bar{q}$ interaction can be studied with quarks of any flavour

but…

light quark systems are complex

- ~ 100 states below 2 GeV
- M_x: 1 ÷ 2 GeV, Γ_x: 100 ÷ 400 MeV
- mixing with "ordinary" mesons
- $\alpha_s \rightarrow$ no perturbation theory
- sizeable relativistic effect





Why to push up beam energy?

$q\bar{q}$ interaction can be studied with quarks of any flavour

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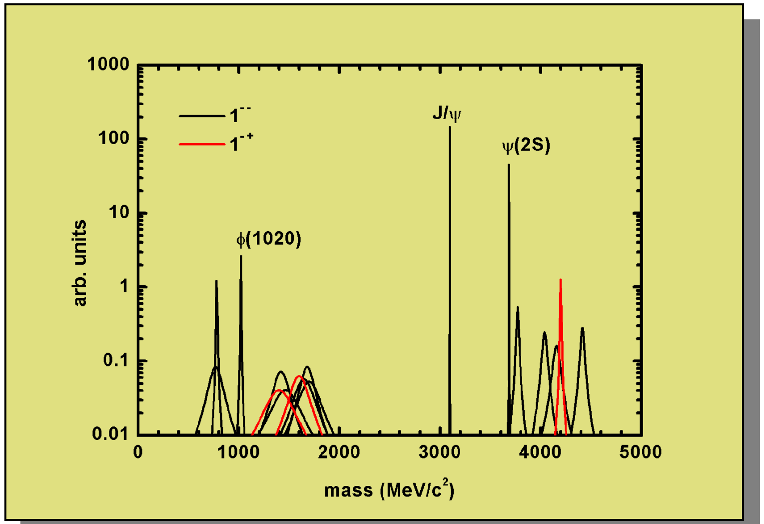
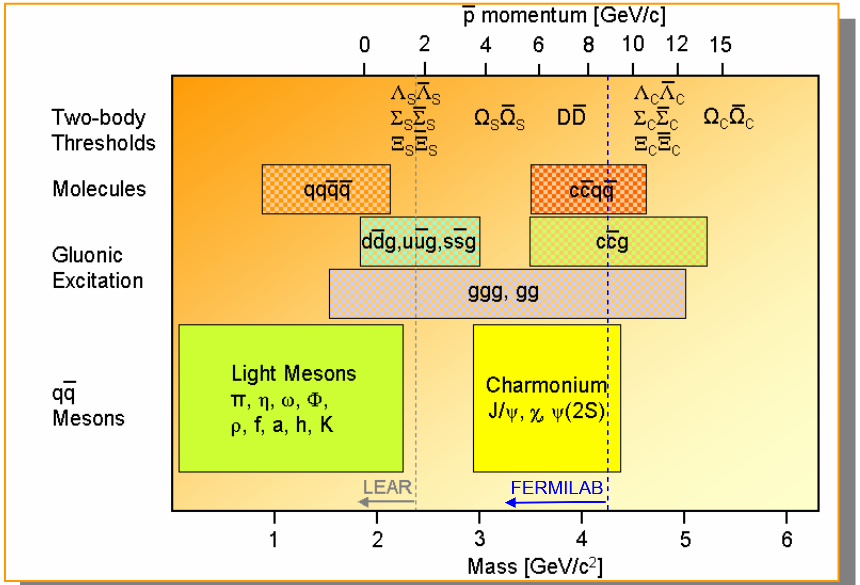
light quark systems are complex

on the contrary…

charmonium system has been proved to be a powerful tool for the understanding of strong interaction

- only 8 bound states in a 0.8 GeV range
- Γ really very narrow ($\leq$ 20 MeV)





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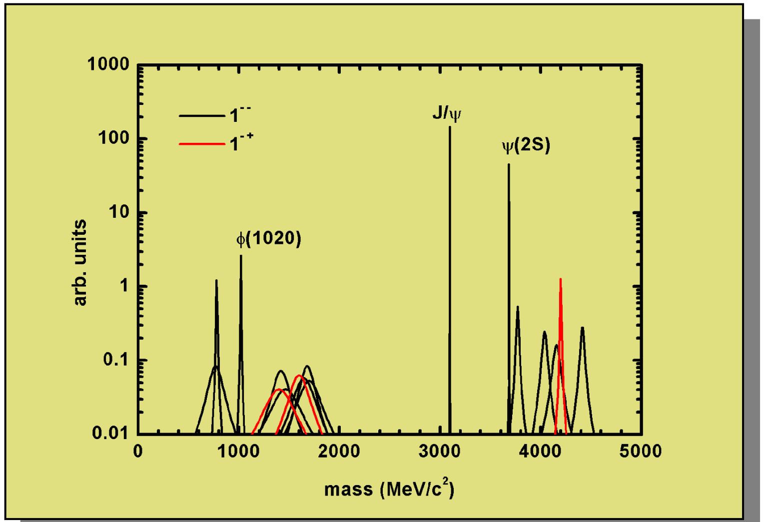
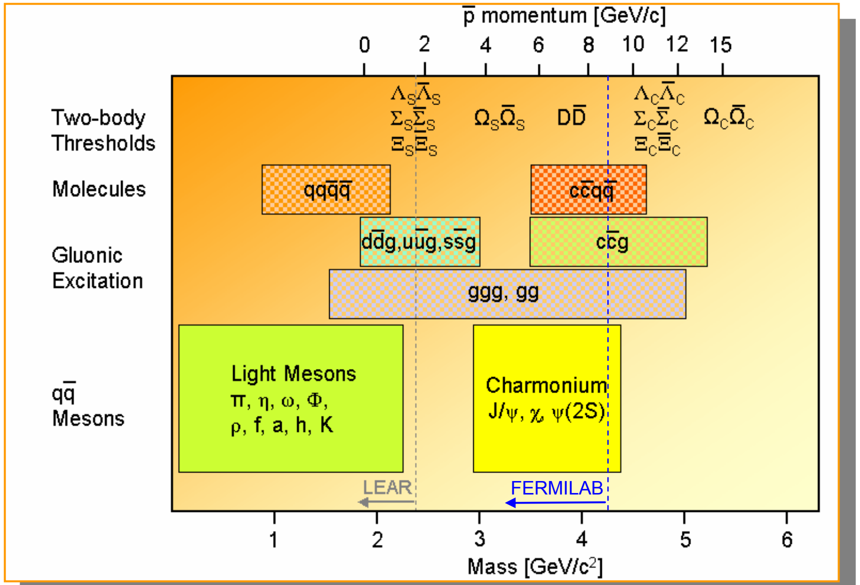




Why antiprotons?

(heavy) $q\bar{q}$ spectroscopy can be studied at e^+e^- colliders

- point-like probe
- "clean" interaction

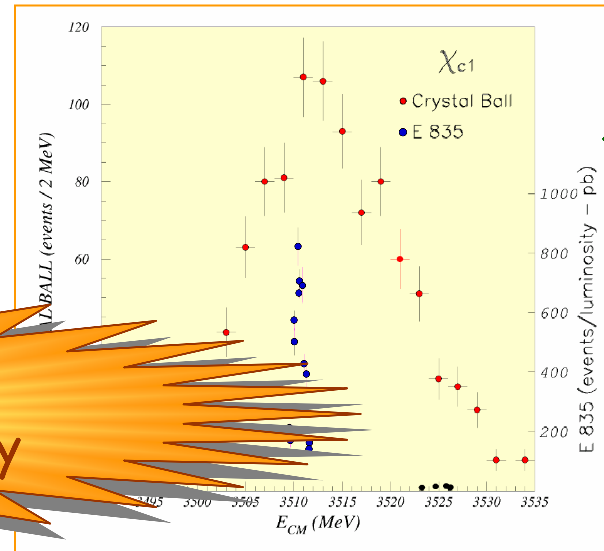
but…

- only vector state ($J^{PC} = 1^{--}$) are directly formed

poor energy resolution

on the contrary, in $\bar{p}p$ annihilation

- "brilliant" source of particle-antiparticle pairs
- gluon rich environment
- states of any q.n. are directly accessed
- beam cooling → $\Delta p/p \sim 10^{-5}$



$\bar{p}$ is an ideal tool for hadronic structure study

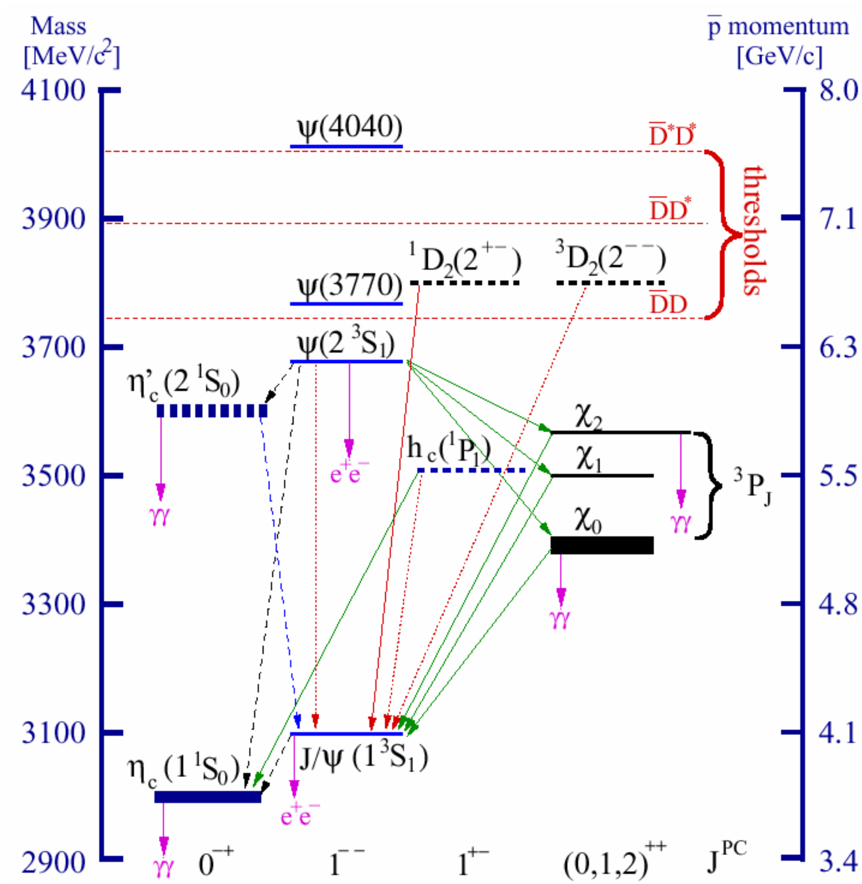
Charmonium spectroscopy

(As usual) spectroscopy provides information about potential

but…

A lot of work remains to do:

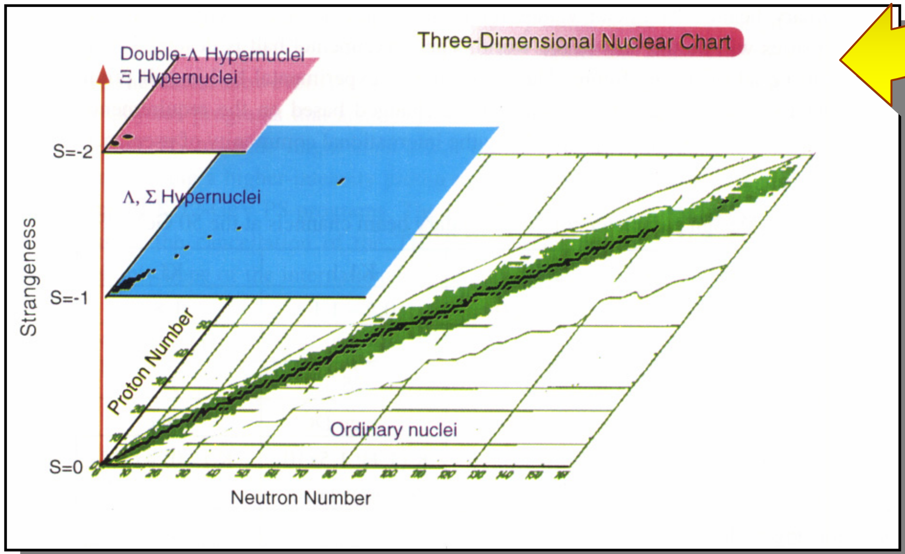
- ☹ many levels still missing
- ☹ many states poorly known
- ☹ region above $D\bar{D}$ threshold unexplored



Hypernuclear physics

A hypernucleus is the outcome of a genetic engineering manipulation applied to the nuclear physics domain

new degree of freedom



Why hypernuclear physics?

spectroscopy and decay

- textbook evidence for the validity of the shell model
- spin-orbit term in the optical potential
- glue-role of the Λ (nuclear medium effect)

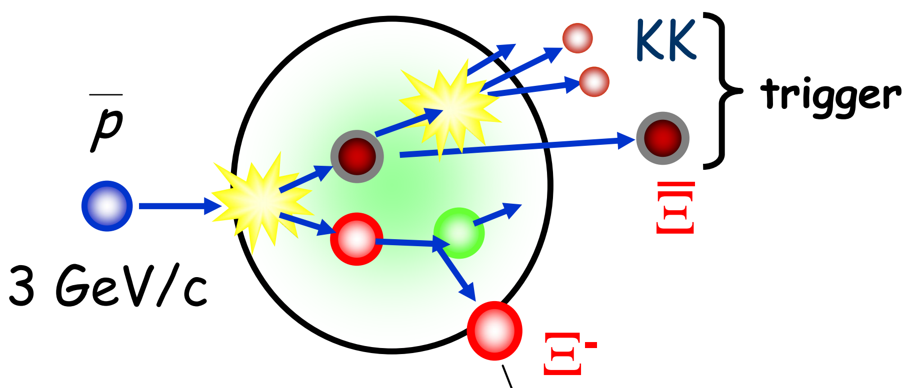
very clean nuclear physics!

- 4 baryon weak interaction $\Lambda\mathcal{N} \rightarrow \mathcal{N}\mathcal{N}$ (validity of $\Delta I = \frac{1}{2}$ rule)
- low energy $\Lambda\mathcal{N}$ scattering (short range aspects of the nuclear force)

- $\Lambda\Lambda$ interaction
- search for H particle

unique particle physics!

ΛΛ-hypernuclei production



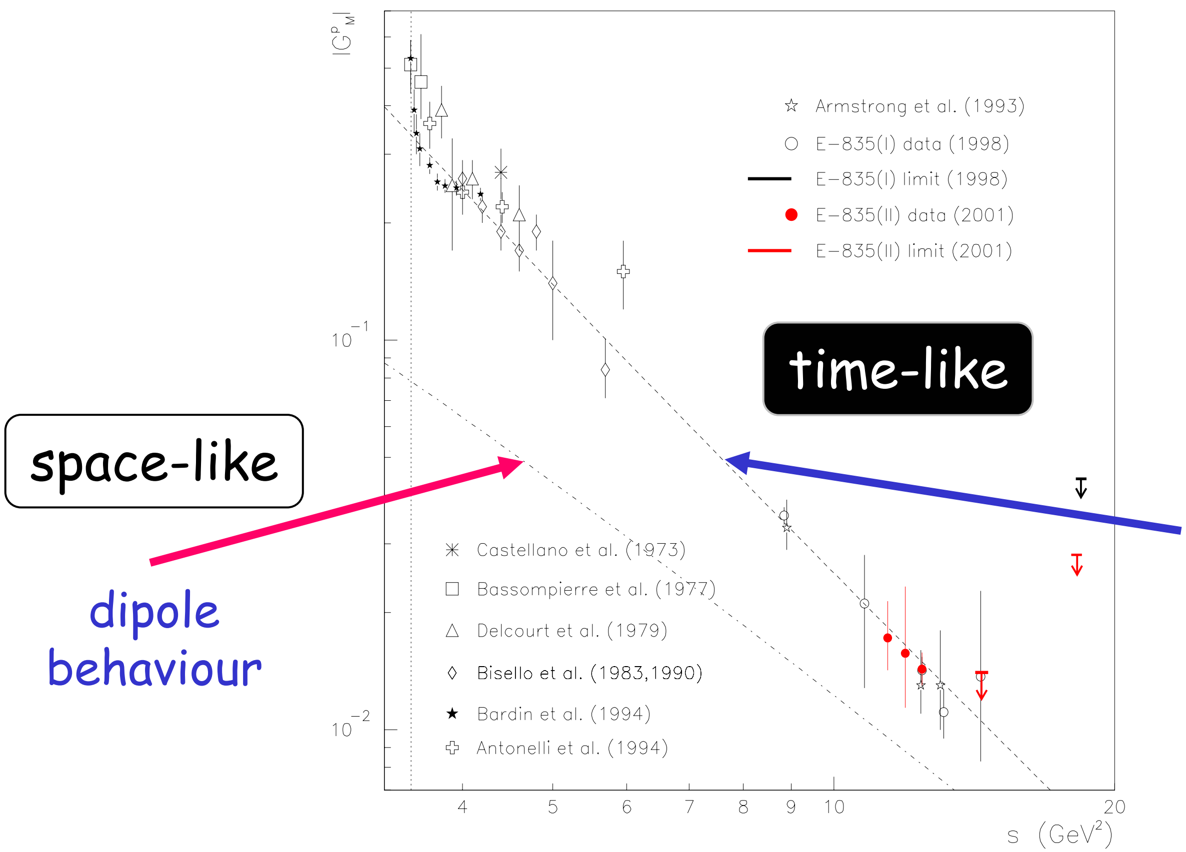
${}^{10}_{\Lambda\Lambda}Be$	1963:	emulsion
${}^{6}_{\Lambda\Lambda}He$	1966:	emulsion; Dalitz criticizes the interpretation
${}^{10}_{\Lambda\Lambda}Be$ or ${}^{13}_{\Lambda\Lambda}B$	1991:	emulsion/counter hybrid experiment KEK-E176
${}^{4}_{\Lambda\Lambda}H$	2001:	AGS-E906
${}^{6}_{\Lambda\Lambda}He$	2001:	KEK-E373

Ξ^-(dss) p(uud) $\rightarrow$ Λ(uds) Λ(uds)

Proton form factors at large Q^2

$\bar{p}p \to e^+e^-$

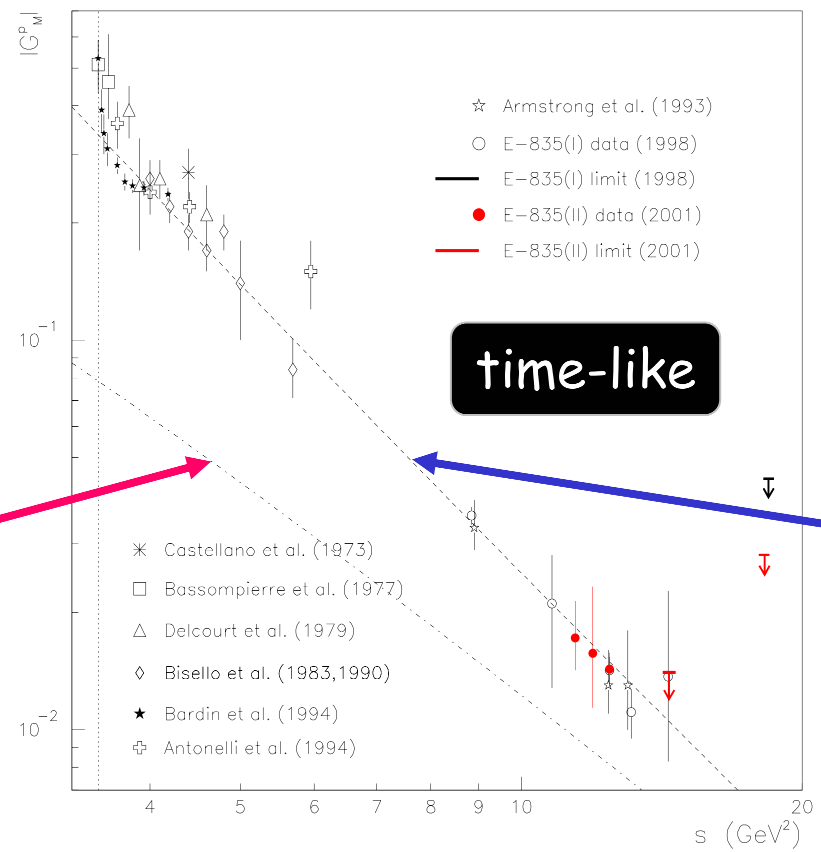
$$\frac{d\sigma}{d(\cos\vartheta)} = \frac{\pi\alpha^2\hbar^2c^2}{2xs}\left[|G_M|^2(1+\cos^2\vartheta) + \frac{4m_p^2}{s}|G_E|^2(1-\cos^2\vartheta)\right]$$



$$\frac{|G_M|}{\mu_p} = \frac{C}{s^2\ln^2\left(\frac{s}{\Lambda^2}\right)}$$

Proton form factors at large Q^2

HESR will allow to explore the region up to 25 GeV^2



space-like

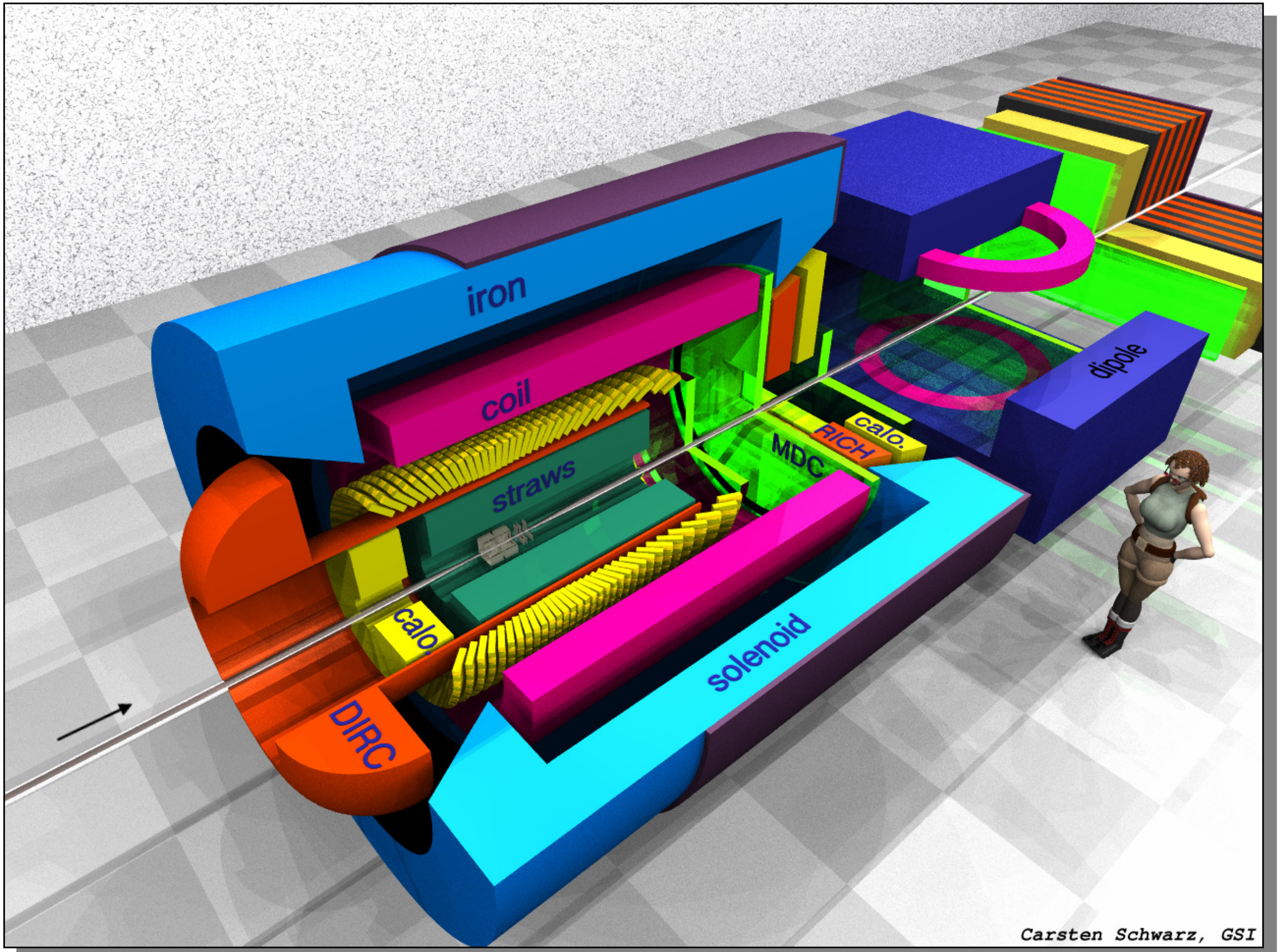
dipole behaviour

$$\frac{|G_M|}{\mu_p} = \frac{C}{s^2 \ln^2\left(\frac{s}{\Lambda^2}\right)}$$

Detector's requirements

- ★ radiation hardness
  up to 10^7 annihilations / s
- ★ good particle identification
  γ, e, μ, π, K, p
- ★ good momentum resolution
- ★ secondary vertices identification
  D, K_S^0, Λ
- ★ maximum acceptance
  partial wave analysis
- ★ efficient trigger

The detector concept



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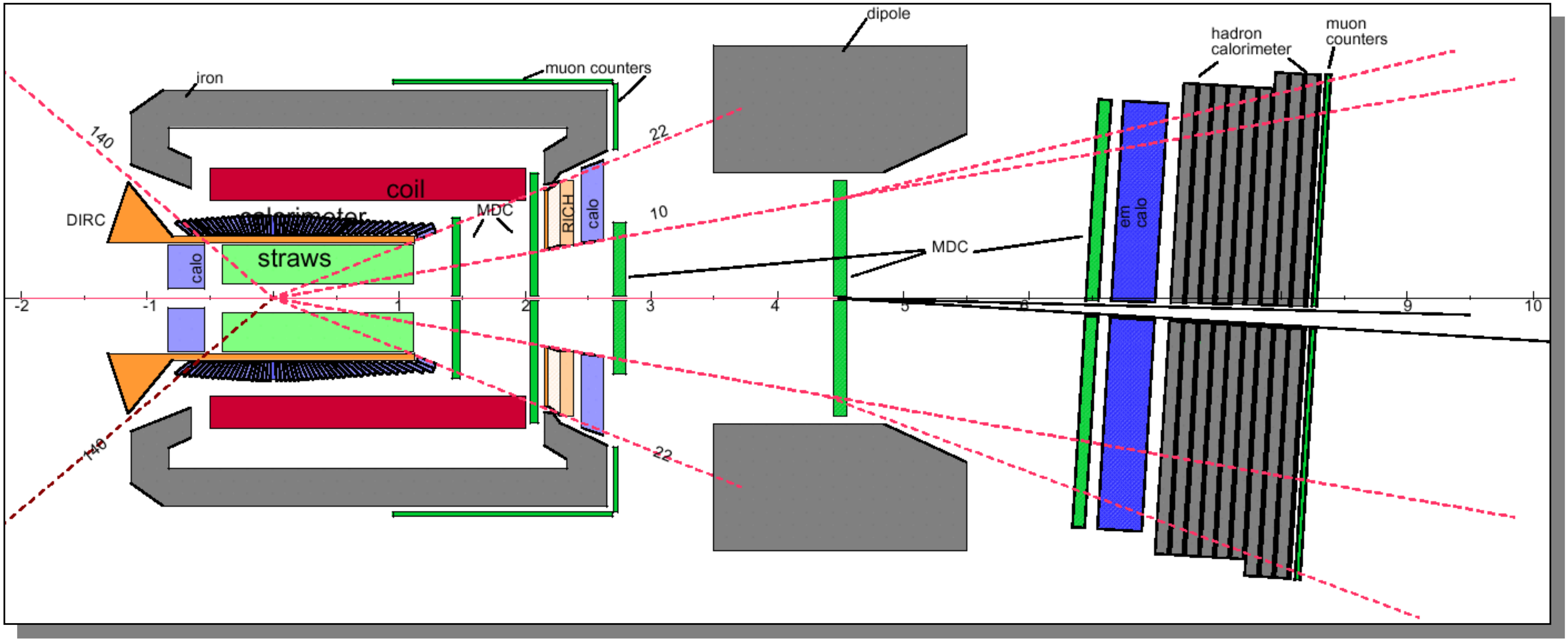
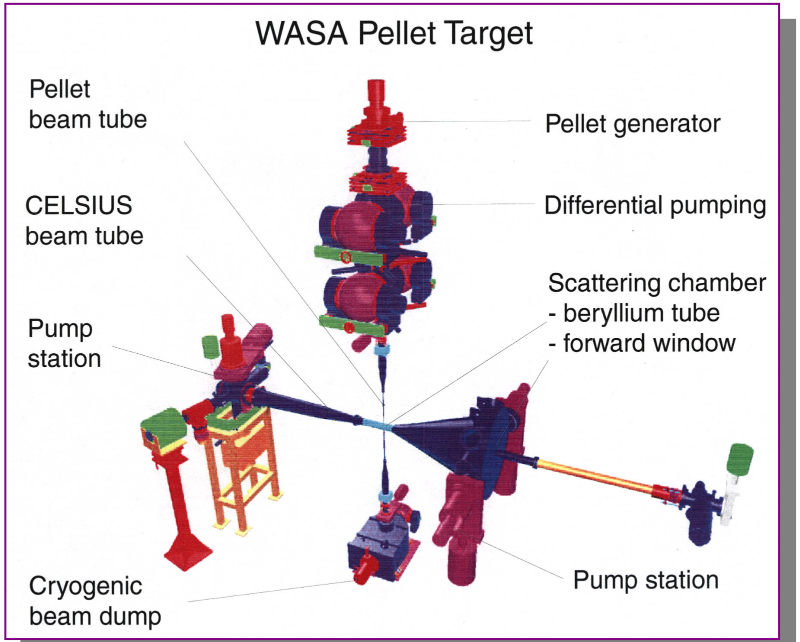
The PANDA detector

Proton ANtiproton at DArmstadt



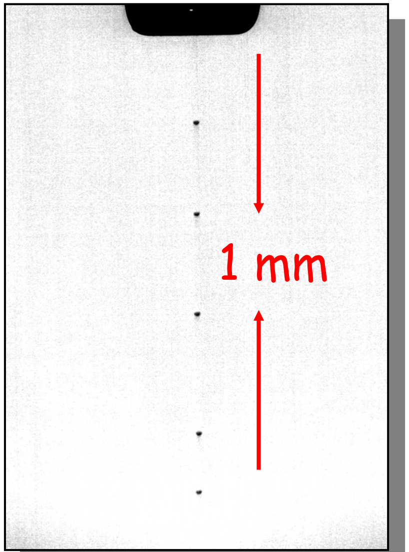
TOP view

The target



Frozen hydrogen (deuterium) pellets

- Ø = 20 ÷ 40 μm
- thickness ~ $10^{14} \div 10^{16}$ atoms/cm2
- Δx = ± 1 mm (± 0.04°)
- speed = 60 m/s
- intensity = 7×10^{4} pellets/s



Open problem:

☛ beam heating

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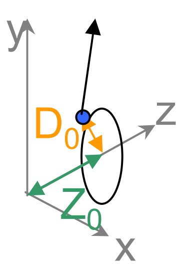
The microvertex detector

- ★ max acceptance
- ★ min material
- ★ high resolution

each layer:
- ✓ 200 μm thick
- ✓ 0.25 % X_0

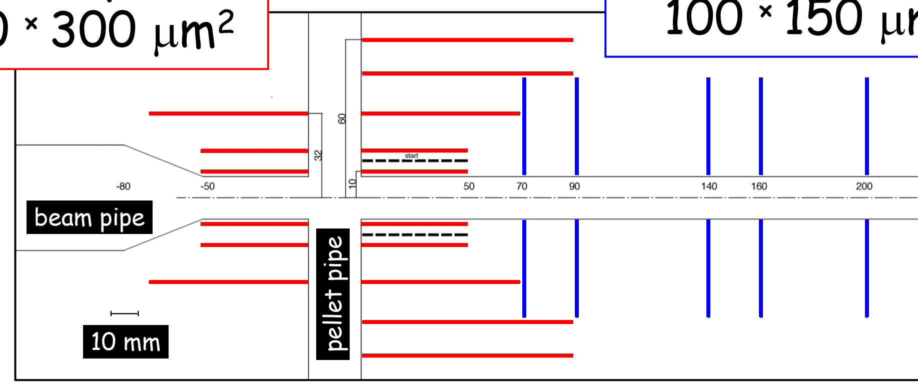
$\bar{p}p \rightarrow 2\pi^+ 2\pi^-$

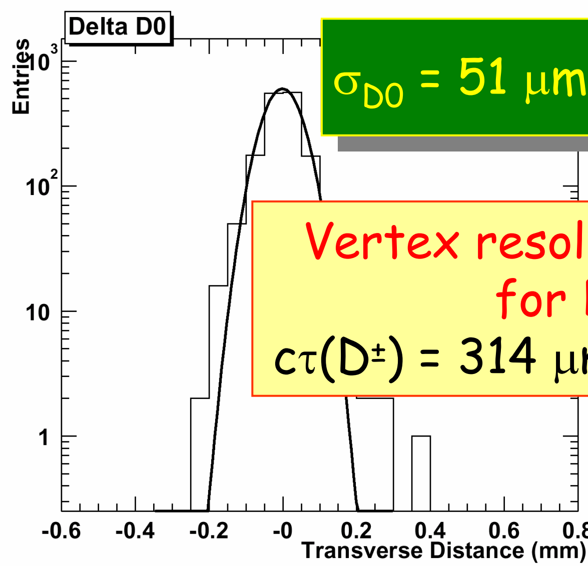
@ 8.5 GeV



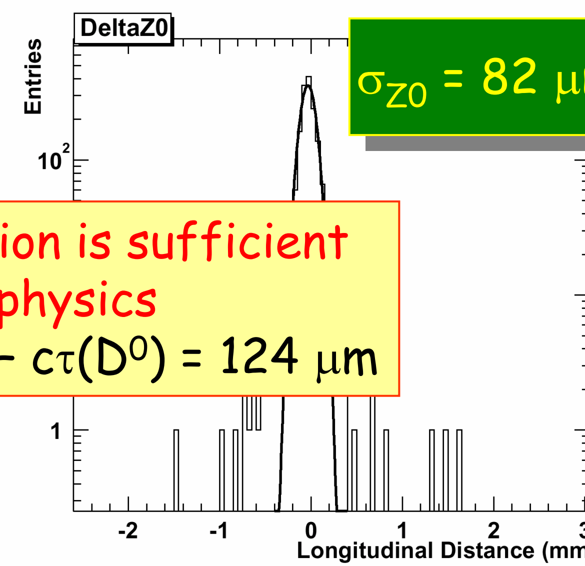
5 layer barrel
7.2 Mpixel
30 × 300 μm²

5 forward layers
2.0 Mpixel
100 × 150 μm²





σ_{D0} = 51 μm



σ_{Z0} = 82 μm

Vertex resolution is sufficient for D physics

$c\tau(D^{\pm})$ = 314 μm – $c\tau(D^0)$ = 124 μm

Secondary vertex finder

$$\bar{p}p \rightarrow \pi^+\pi^- 2K_s^0$$

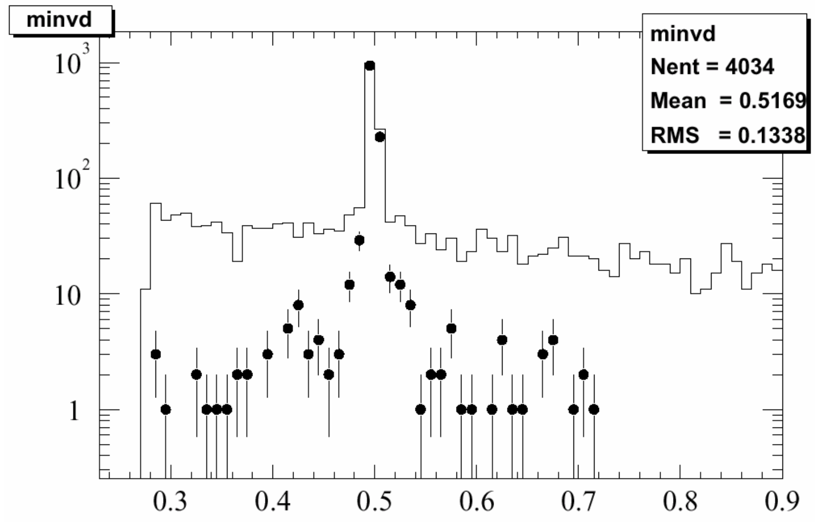
track first selection criteria:

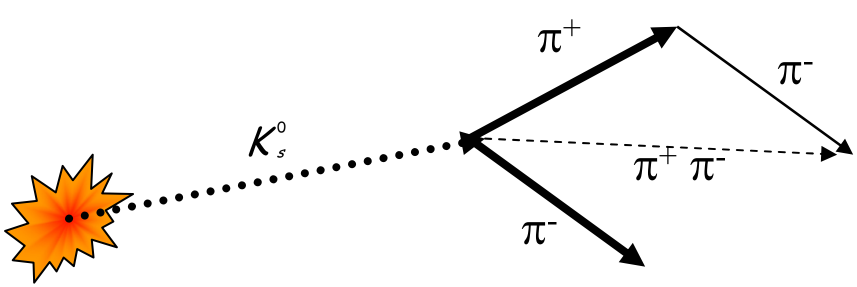
- |D0| > 0.4 mm or
- |Z0| > 0.5 mm

~~tracks belonging to primary vertex~~

kinematical fit
(constraint = common vertex)

3-momentum conservation



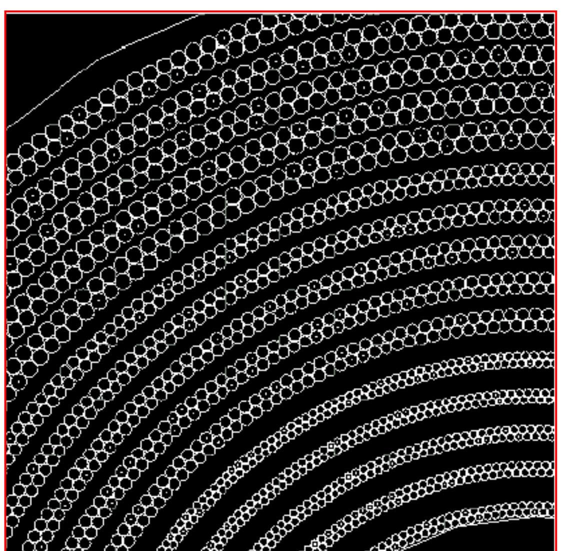


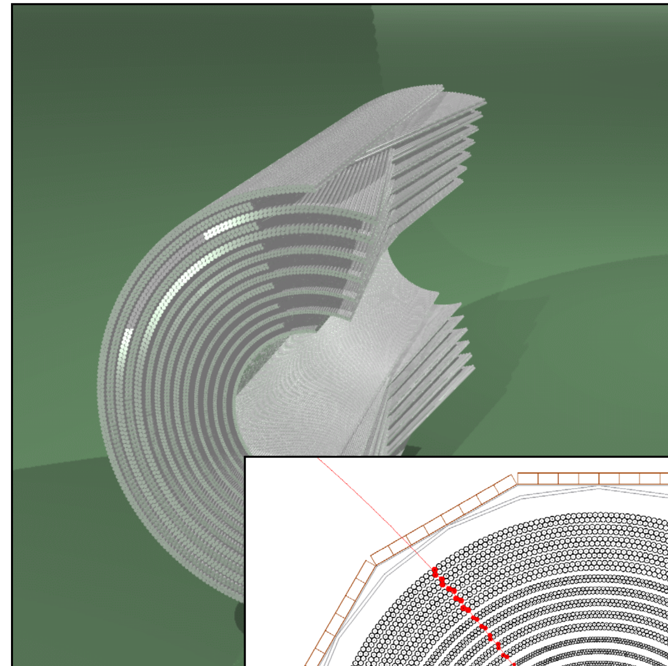
The inner tracker

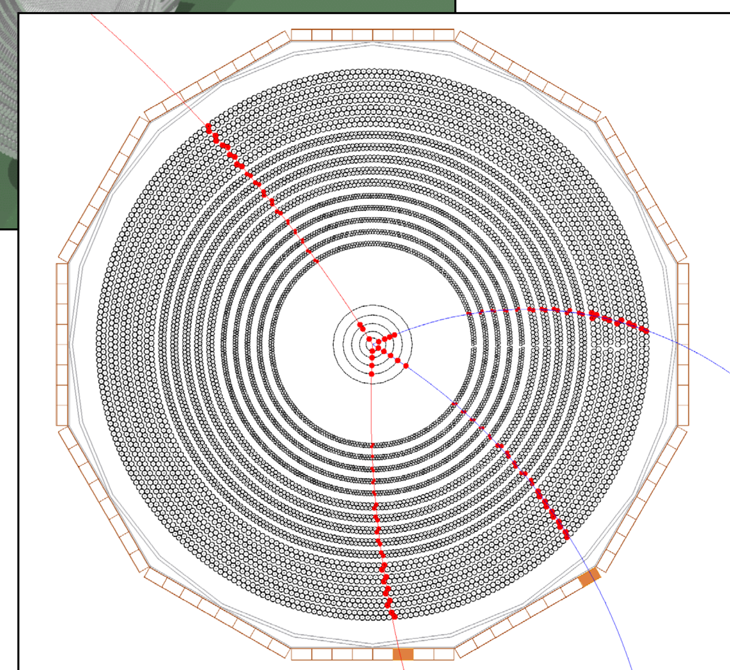
★ good momentum resolution

15 double layers:

- ✓ 8734 straw tubes
- ✓ Ø = 4, 6, 8 mm
- ✓ He + C_4H_{10} (90 + 10%)
- ✓ σ_{xy} = 150 μm
- ✓ σ_z = 1 mm





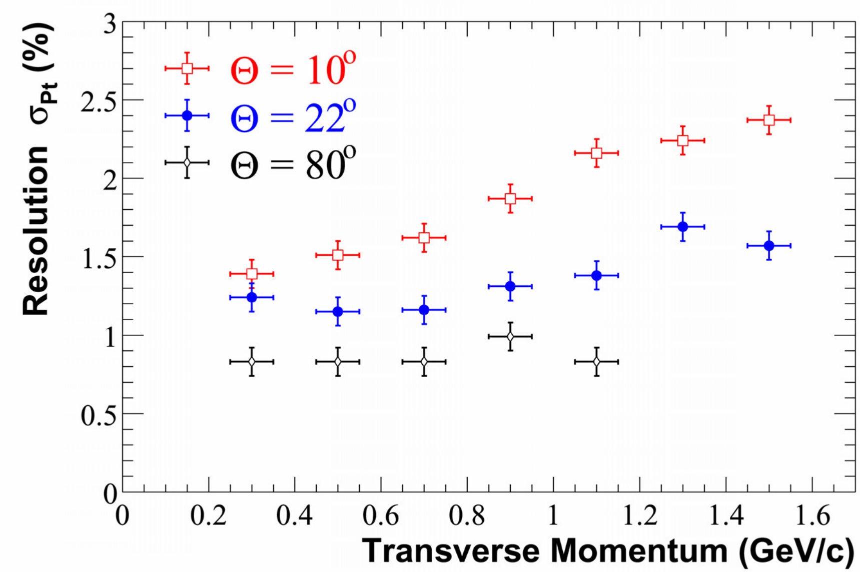


$\bar{p}p \to \phi\phi$

Momentum resolution

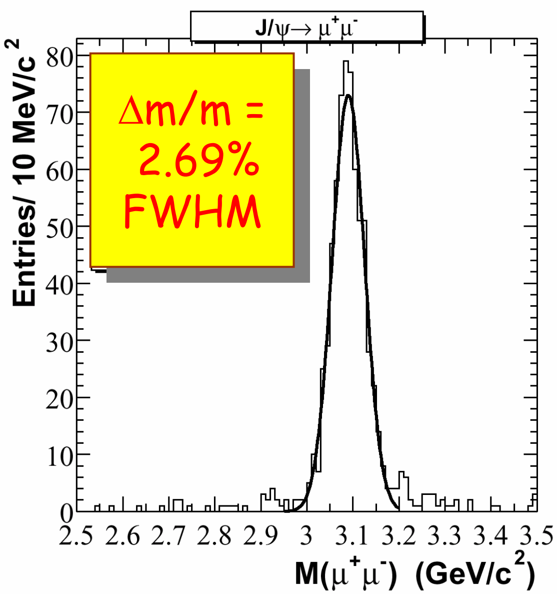
$$\bar{p}p \rightarrow J/\Psi + \phi$$

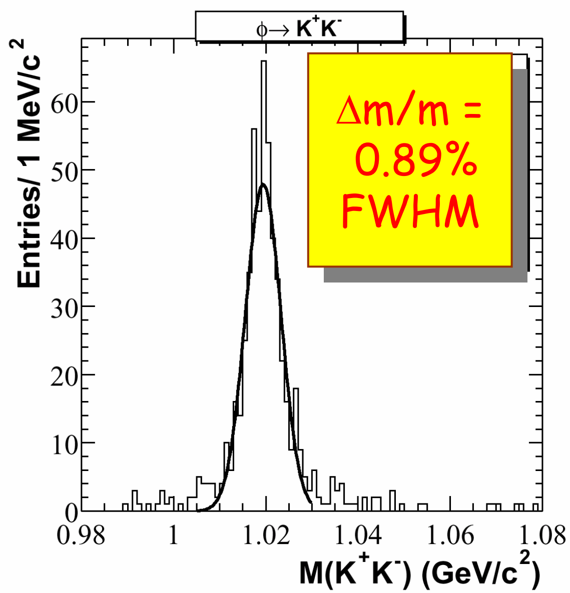
$$@ \sqrt{s} = 4.4\ GeV/c^2$$



Information from:

MVD + STT + MDC





$\Delta p/p \approx 1 \div 2\%$

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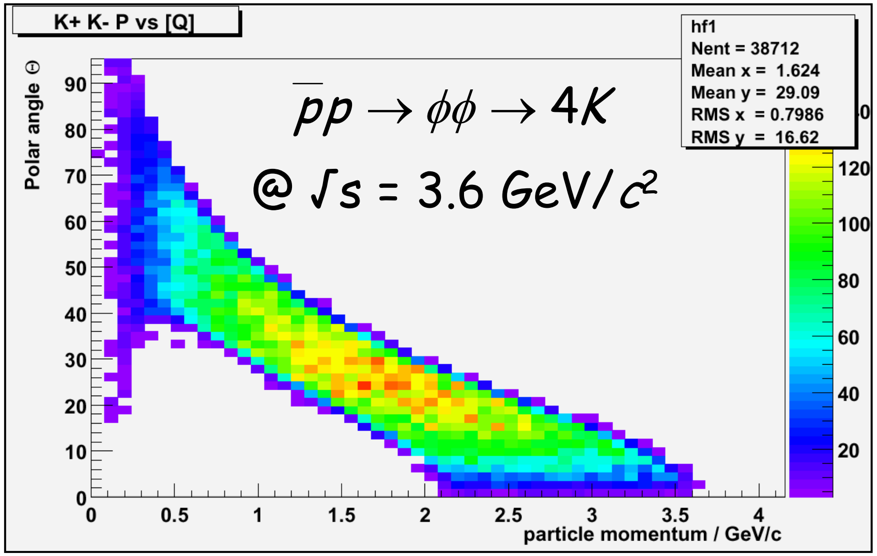
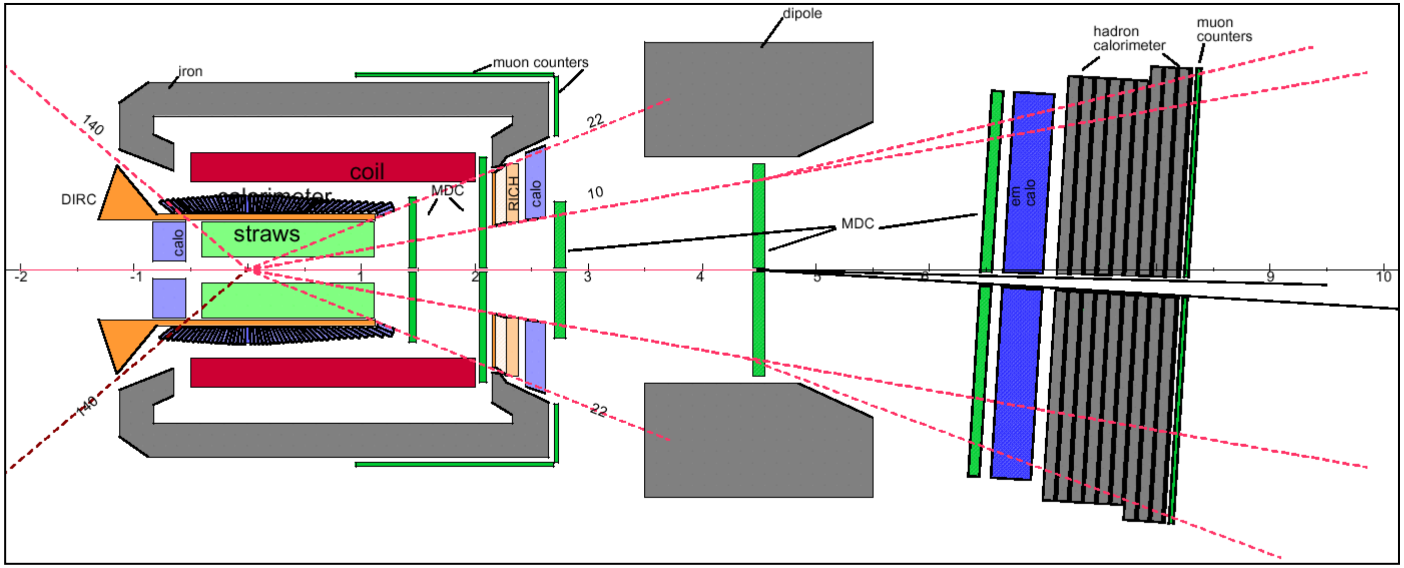
Particle identification



π/K separation needed at forward angle up to 3 GeV/c

- 0° < ϑ < 5° → hadronic calorimeter
- 5° < ϑ < 22° → aereogel Čerenkov
- 22° < ϑ < 140° → DIRC (0.19 X_0)



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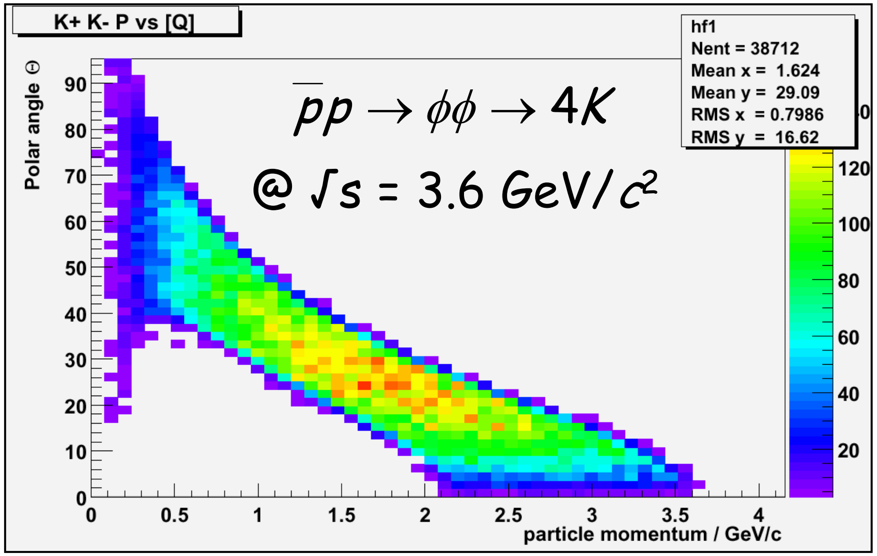

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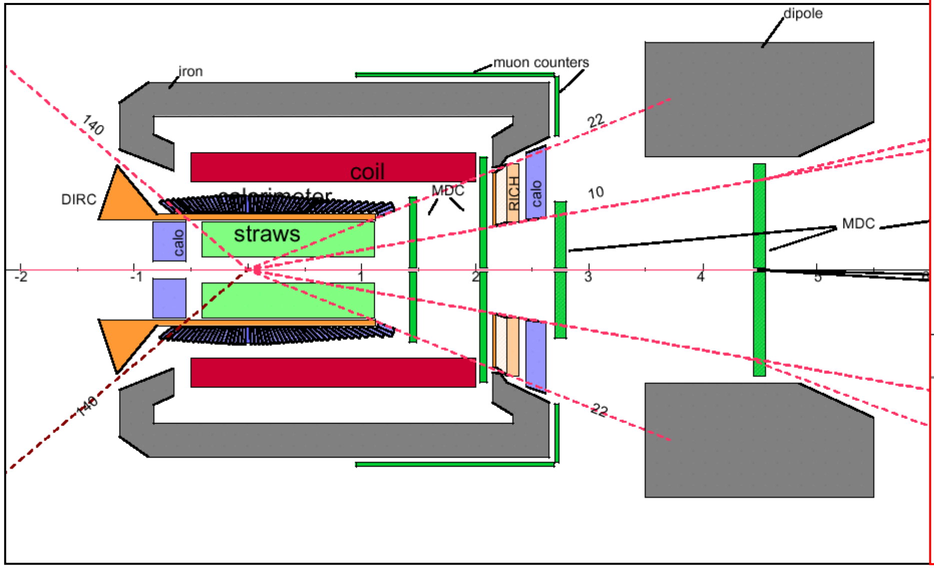

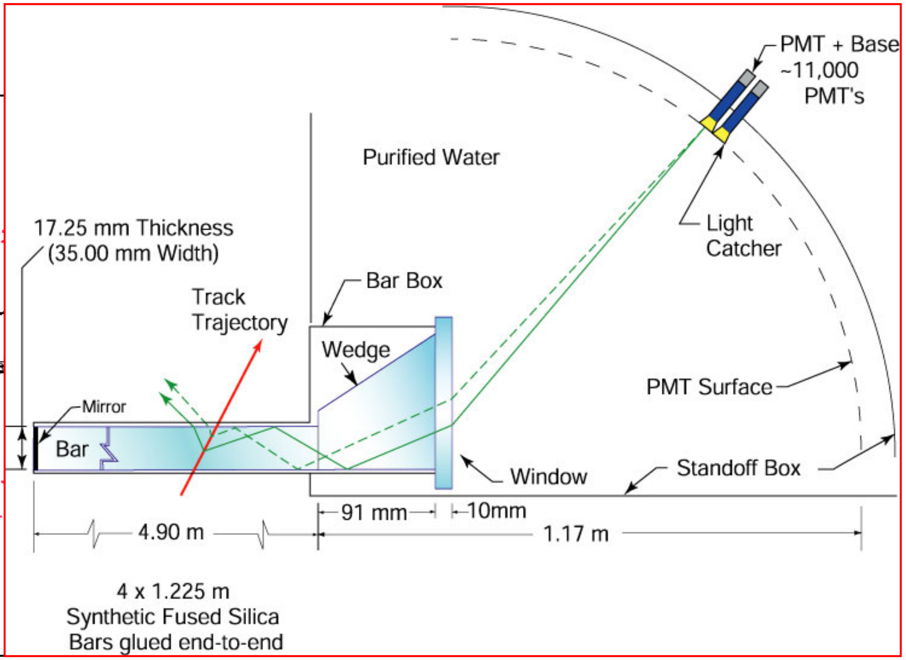

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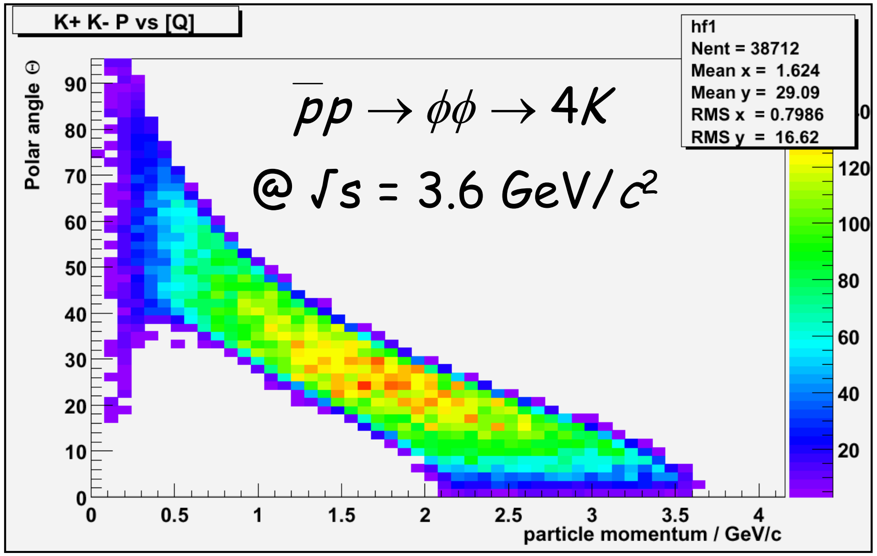

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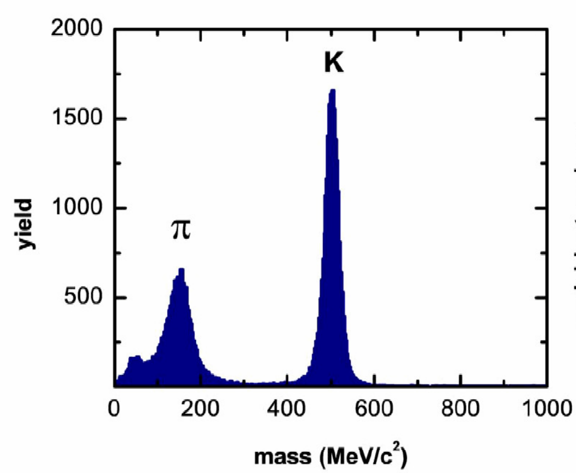
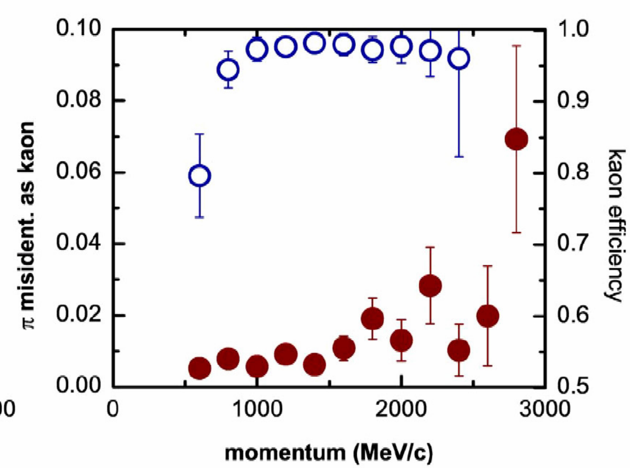
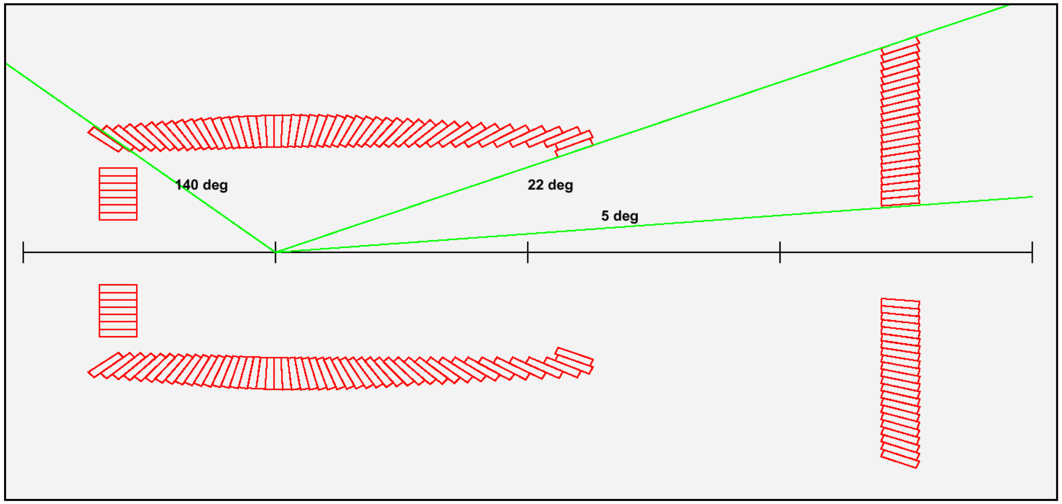
Information from:
tracking + Čerenkovs



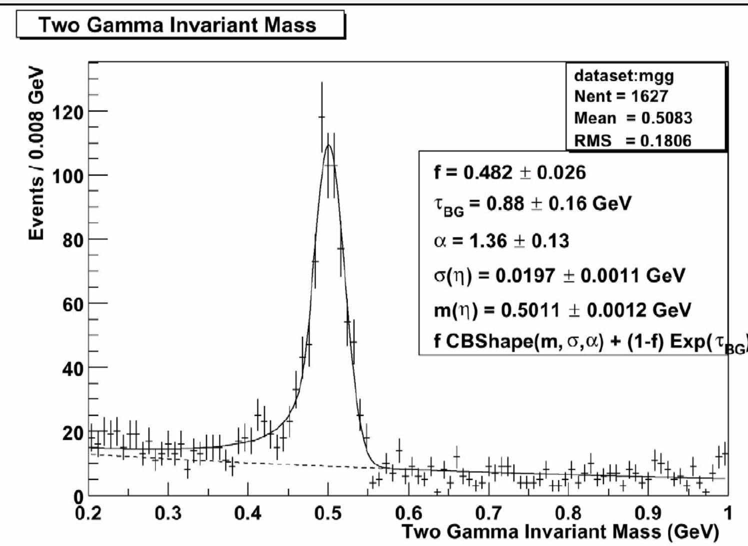


The e.m. calorimeter



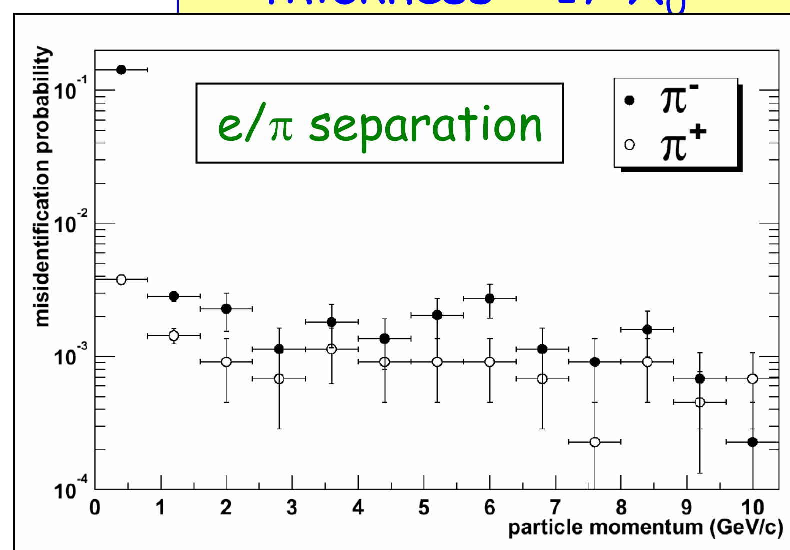
- ★ high granularity
- ★ hermetic
- ★ fast
- ★ min material

7150 $PbWO_4$ crystals:
- ✓ $3.5 \times 3.5 \times 15.0\ cm^3$
- ✓ $\Delta\Omega = 0.96 \times 4\pi$
- ✓ $\sigma_t < 20$ ns
- ✓ thickness = 17 X_0
- %

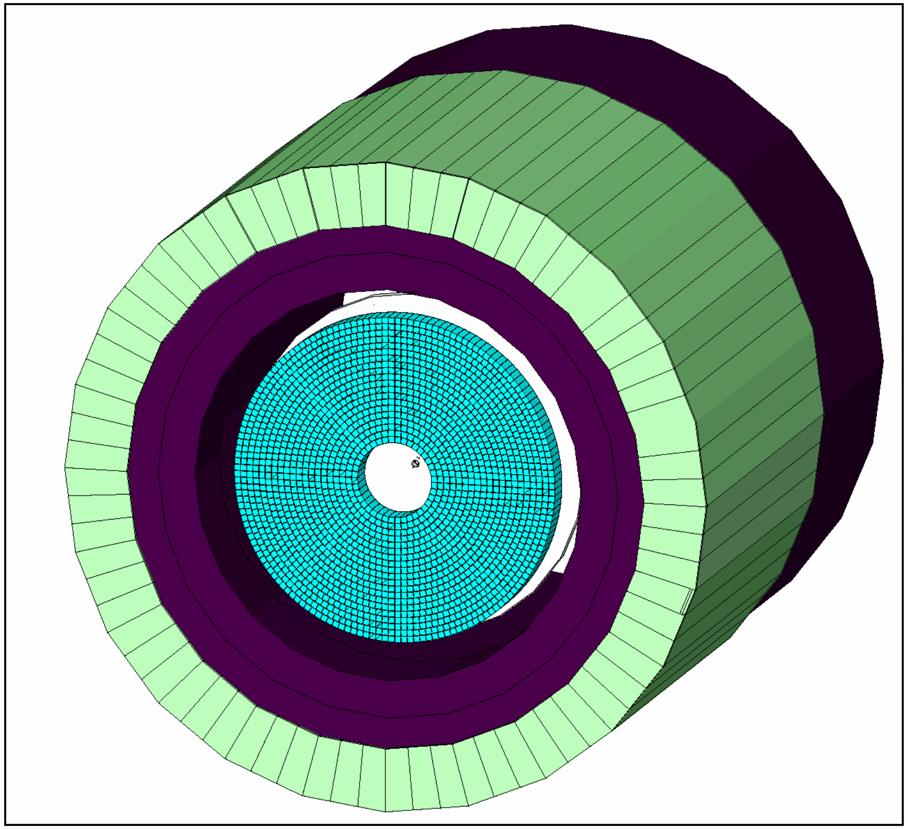


$$\bar{p}p \rightarrow J/\Psi + \eta \rightarrow \mu^+ + \mu^- + 2\gamma$$

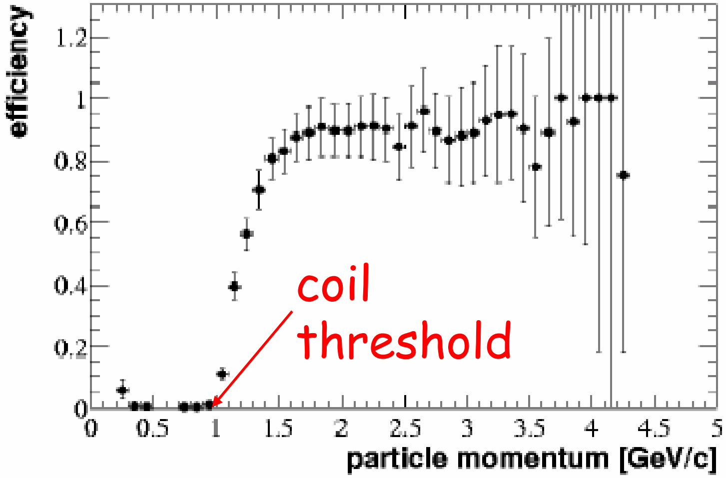
$$@ \sqrt{s} = 4.4\ GeV/c^2$$

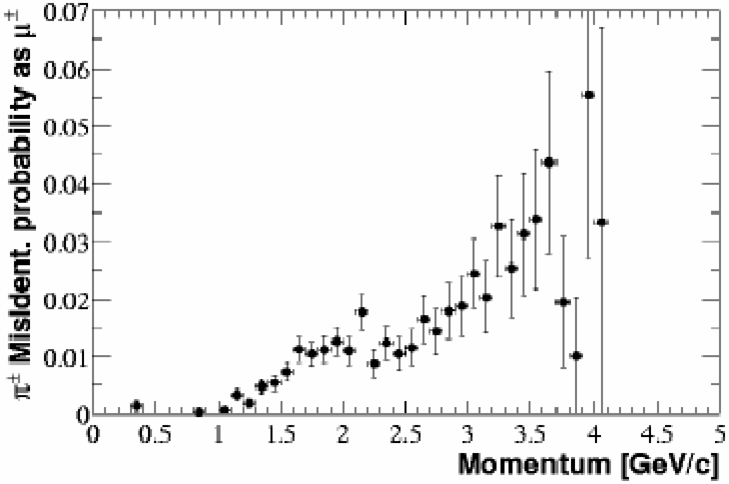


The muon detector

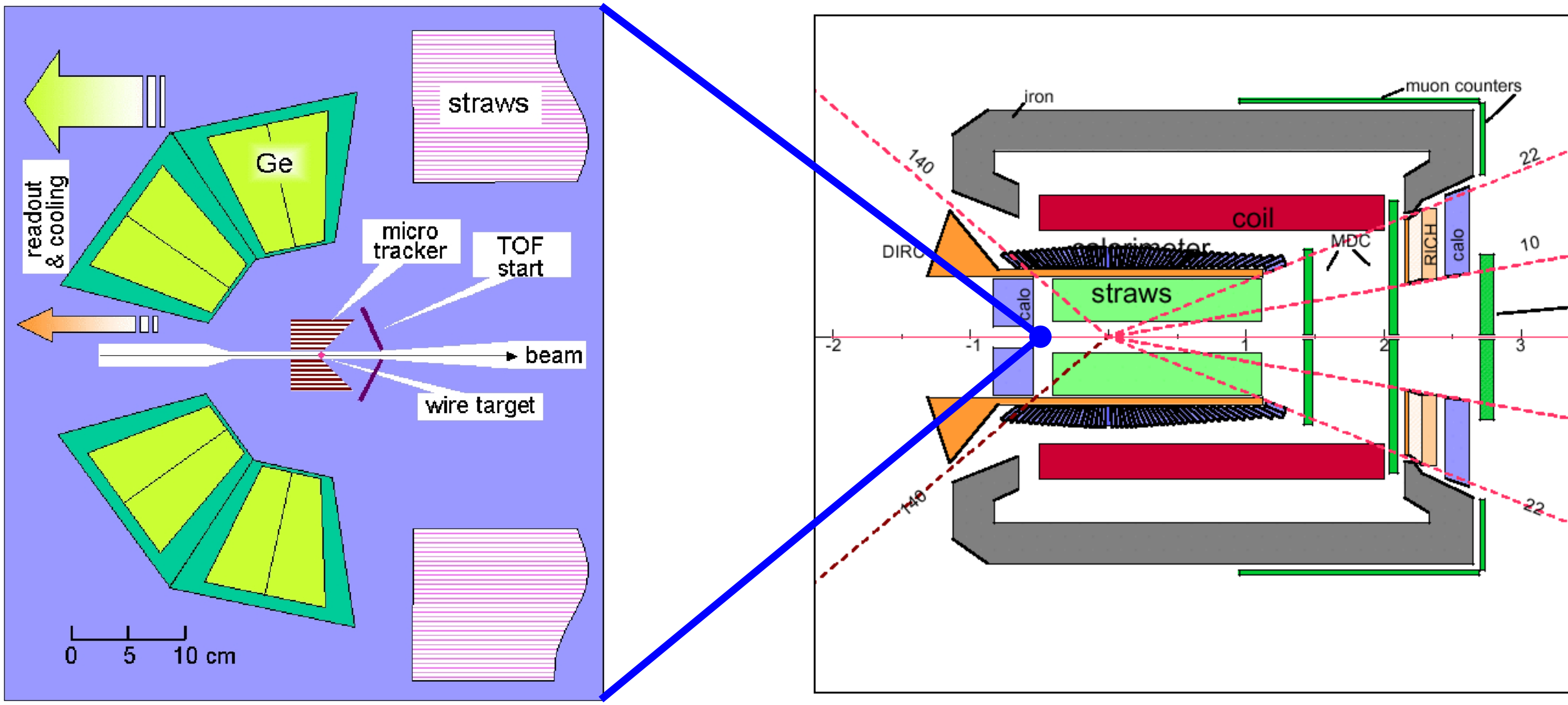


72 plastic scintillators:
✓16 × 2 × 250 cm³ slabs





Ge array for hypernuclei



- solid state micro-tracker
  - thickness ~ 3 cm
  - capillar (2D) or pixel (3D) detector
- high rate Ge detector

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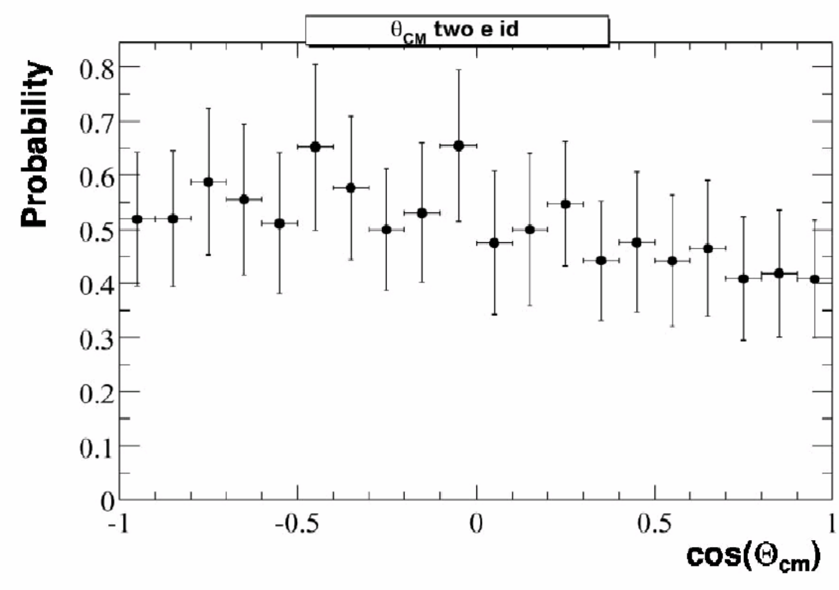
Overall performances

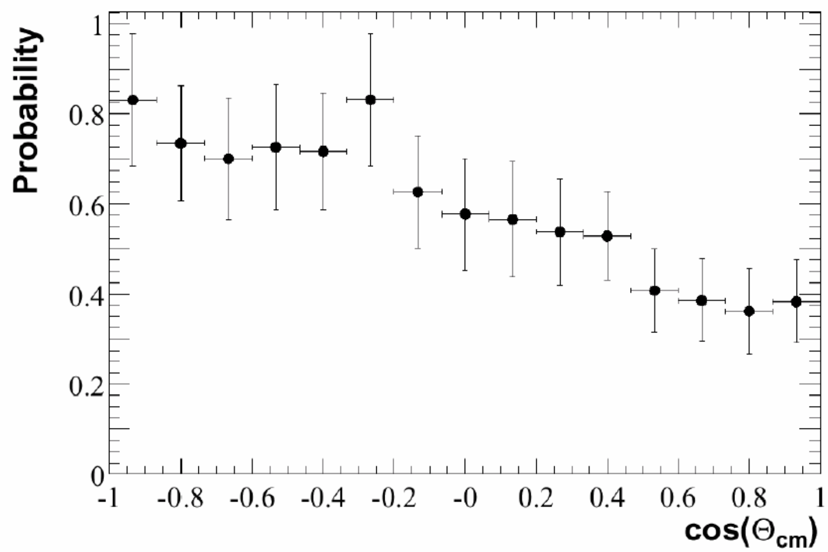
$$\bar{p}p \to J/\Psi + \eta$$

$@ \sqrt{s} = 4.4\ GeV/c^2$

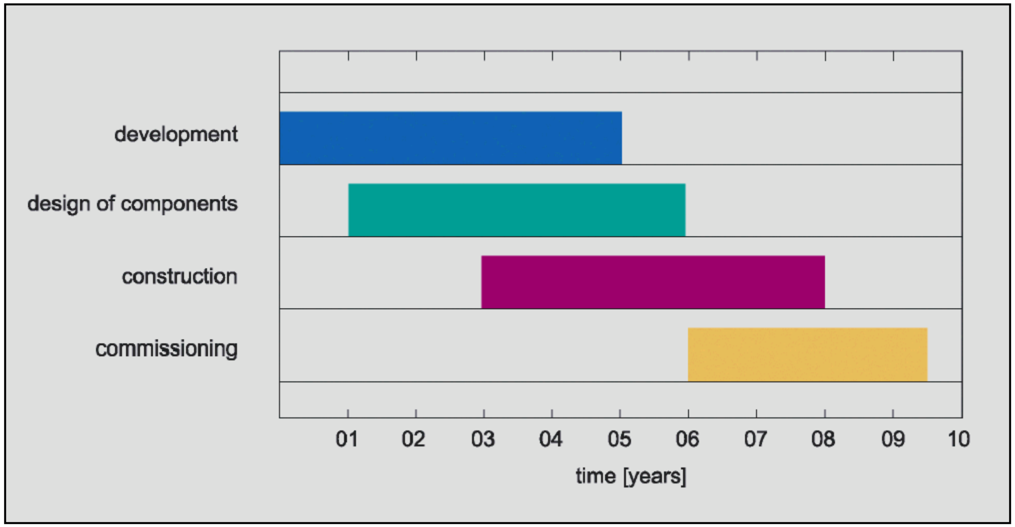
$J/\Psi \to e^+e^-$



$J/\Psi \to \mu^+\mu^-$

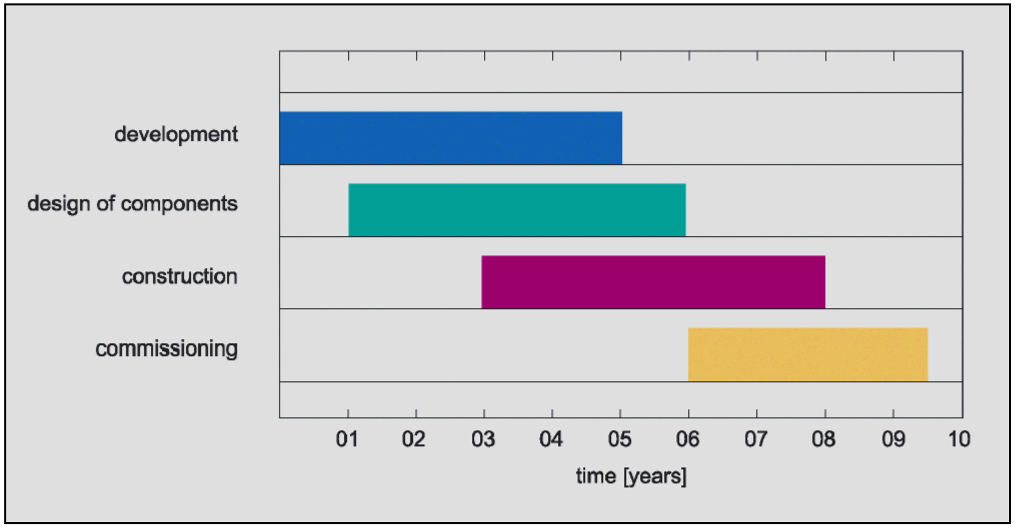


Time schedule and costs



✓ Civil construction and infrastructure	225 M€
✓ Accelerator components	265 M€
✓ Instrumentation and detectors	185 M€
Sum	675 M€

Time schedule and costs



✓ Civil construction and infrastructure	225 M€
✓ Accelerator components	265 M€
✓ Instrumentation and detectors	185 M€
Sum	675 M€

PANDA apparatus

✓ Solenoid	2.5 M€
✓ Calorimeter	12.5 M€
✓ Tracker	3.0 M€
✓ Čerenkov	3.5 M€
✓ Hypernuclei	2.0 M€
✓ Varia	1.9 M€
✓ Trigger	1.5 M€
✓ Infrastructure	2.0 M€
✓ Contingency	2.0 M€
Sum	30.9 M€

Conclusions

- high quality antiproton induced reactions are of high relevance for the understanding of several open questions in various fields of physics
- GSI could represent the dawn of a new era for antiproton physics

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GSI: the new frontier for antiproton physics

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