Working Group 5 Summary

David Christian
Fermilab

Context: the antiproton source & the rest of the FNAL program

- Main Injector operation is designed to support optimal antiproton production AND (almost) optimal neutrino beam production.
- The pbar source is currently 100% devoted to the Tevatron collider.

The antiproton source with a proton driver

- Presentation by Paul Derwent (to the Tevatron collider group):
  - 5x increase in number of protons delivered by Main Injector may translate into 2x increase in pbar stacking rate
- The increased stacking rate could be used to support >2E32 Tevatron luminosity, or could enable additional pbar experiments to run concurrently with the collider.

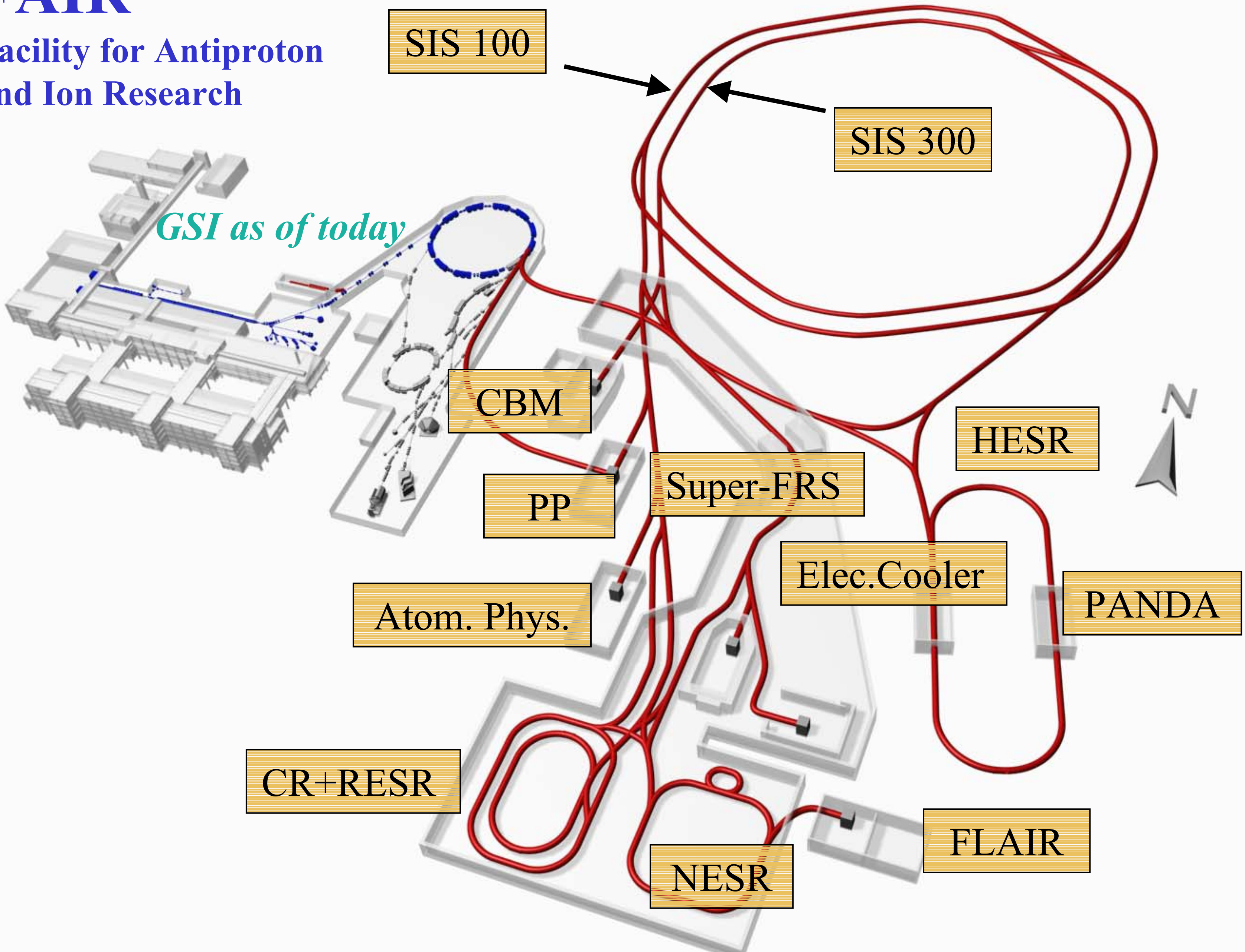
The world context

- Existing pbar sources (2004): FNAL & CERN.
- Planned source: GSI
  - Antiproton beams play a large part in the GSI physics program.
  - Summary presented by Diego Bettoni

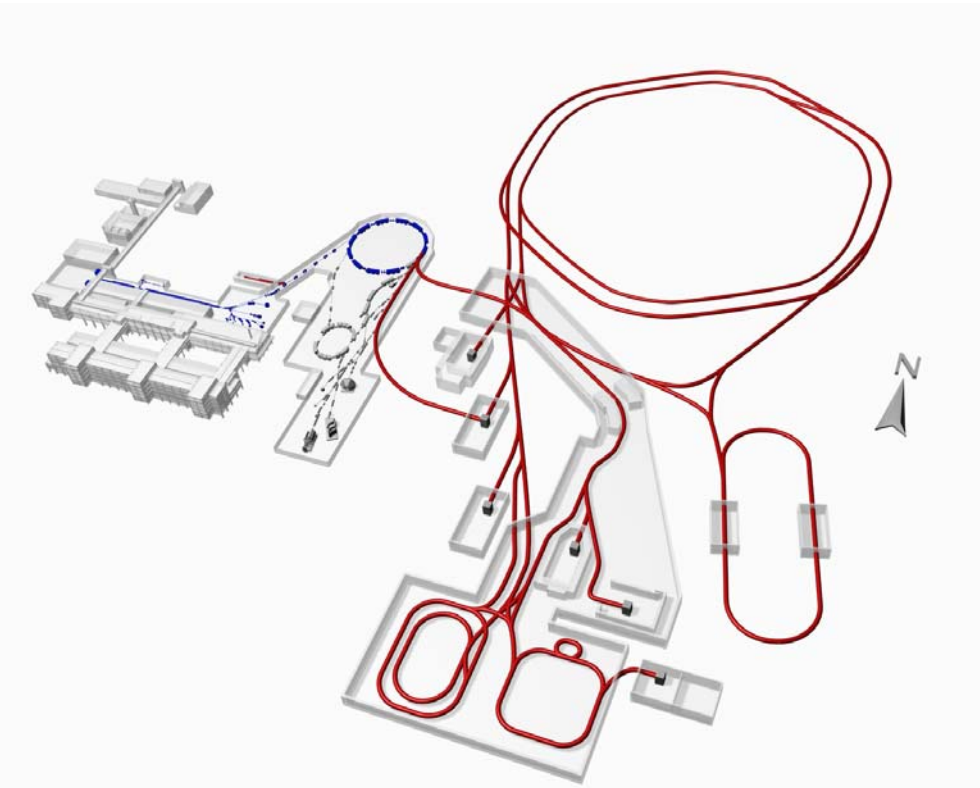
The GSI FAIR Facility

FAIR

Facility for Antiproton and Ion Research



FAIR: Facility for Antiproton and Ion Research



Primary Beams

- 10^{12}/s; 1.5 GeV/u; $^{238}U^{28+}$
- Factor 100-1000 over present in intensity
- $2(4)\times10^{13}$/s 30 GeV protons
- 10^{10}/s $^{238}U^{73+}$ up to 25 (- 35) GeV/u

Secondary Beams

- Broad range of radioactive beams up to 1.5 - 2 GeV/u; up to factor 10 000 in intensity over present
- Antiprotons 3 - 30 GeV

Storage and Cooler Rings

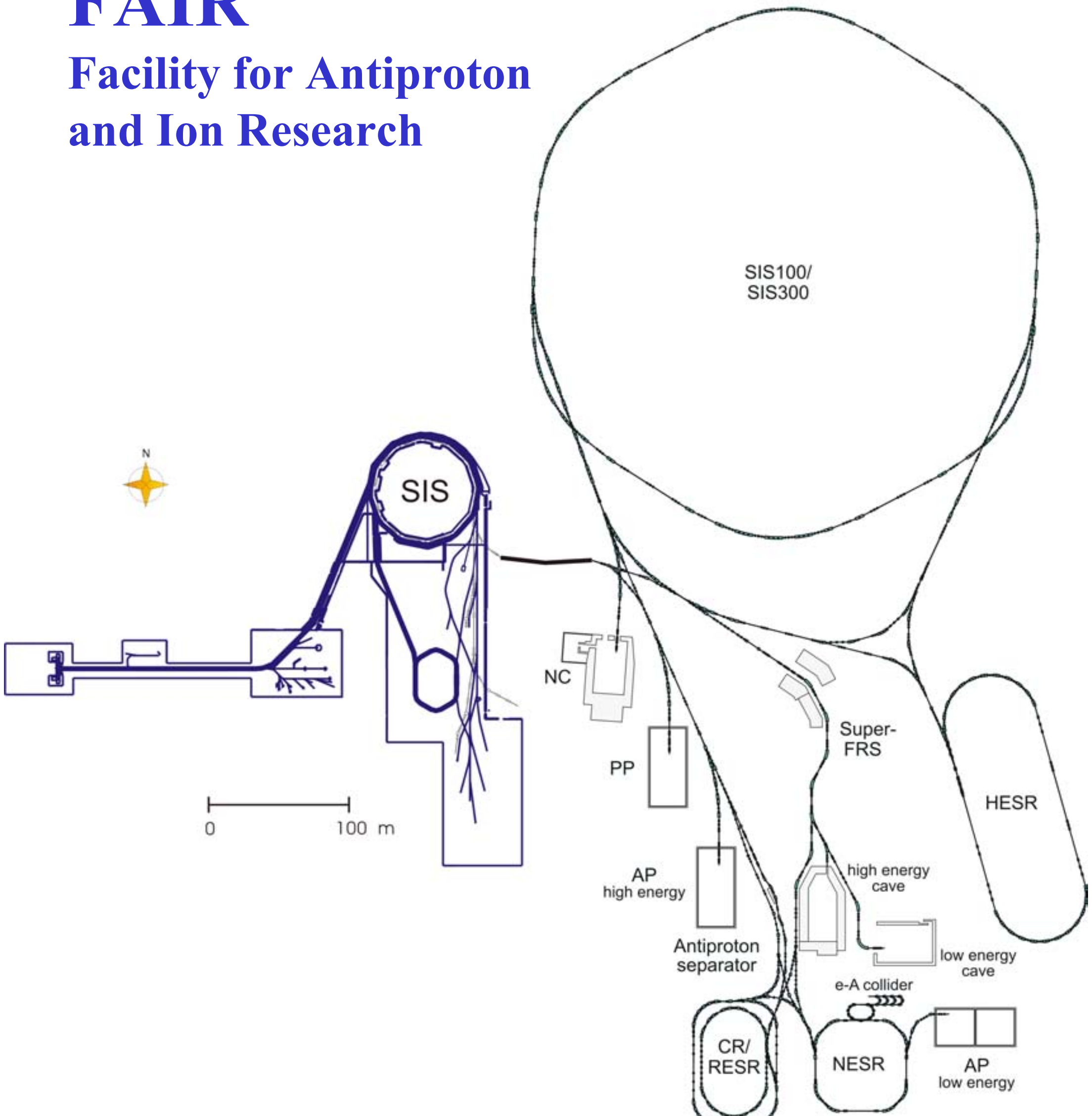
- Radioactive beams
- e – A collider
- 10^{11} stored and cooled 0.8 - 14.5 GeV antiprotons

Key Technical Features

- Cooled beams
- Rapidly cycling superconducting magnets

FAIR

Facility for Antiproton and Ion Research



research areas:

- **Nuclear Structure Physics and Nuclear Astrophysics with Radioactive Ion-Beams**
- **Hadron Physics with $\bar{p}$ - Beams**
- **Physics of Nuclear Matter with Relativistic Nuclear Collisions**
- **Plasma Physics with highly bunched Laser- and Ion-Beams**
- **Atomic Physics and Applied Science**
- **Accelerator Physics**

Antiproton Physics Program

- Charmonium Spectroscopy. Precision measurement of masses, widths and branching ratios of all ($c\bar{c}$) states (hydrogen atom of QCD).
- Search for gluonic excitations (hybrids, glueballs) in the charmonium mass range (3-5 GeV/c^2).
- Search for modifications of meson properties in the nuclear medium, and their possible relation to the partial restoration of chiral symmetry for light quarks.
- Precision γ-ray spectroscopy of single and double hypernuclei, to extract information on their structure and on the hyperon-nucleon and hyperon-hyperon interaction.

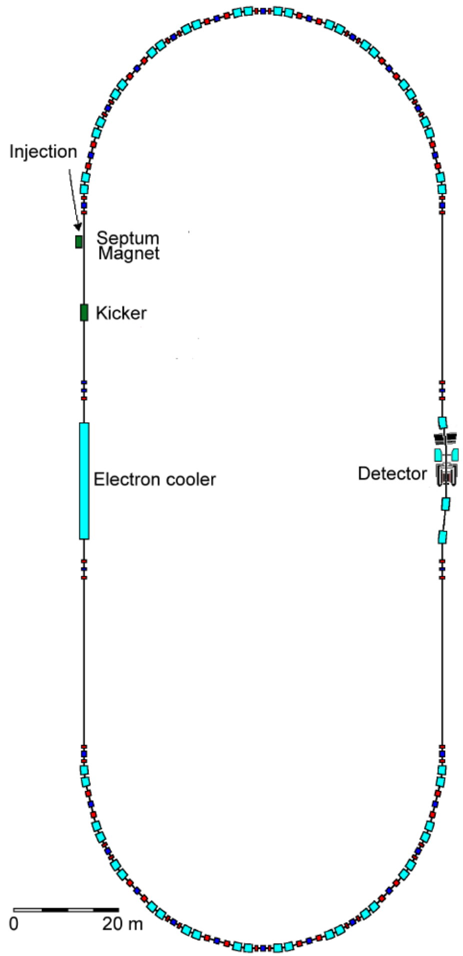
The GSI $\bar{p}$ Facility

HESR = High Energy Storage Ring
L = 442 m

- Production rate $2x10^7$/sec
- P_{beam} = 1 - 15 GeV/c
- N_{stored} = $5x10^{10}$ $\bar{p}$

High luminosity mode
- Luminosity = $2x10^{32}$ $cm^{-2}s^{-1}$
- $dp/p \sim 10^{-4}$ (stochastic cooling)

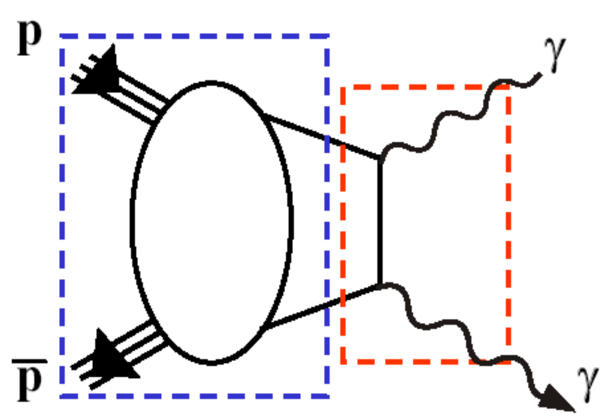
High resolution mode
- $dp/p \sim 10^{-5}$ (el. cooling < 8 GeV/c)
- Luminosity = 10^{31} $cm^{-2}s^{-1}$



Other Physics Topics

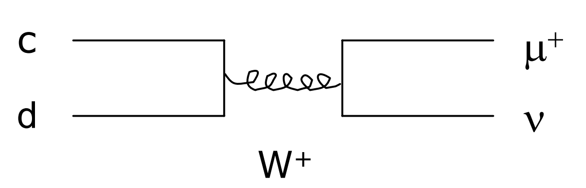
- Reversed Deeply Virtual Compton Scattering
- Drell-Yan Process – Transverse Quark Distributions (see app.)

- CP-violation (D/Λ – sector)
  - D^0D^0 mixing
    SM prediction < 10^{-8}
  - compare angular decay asymmetries for $\Lambda\bar{\Lambda}$
    SM prediction ~ $2\cdot10^{-5}$

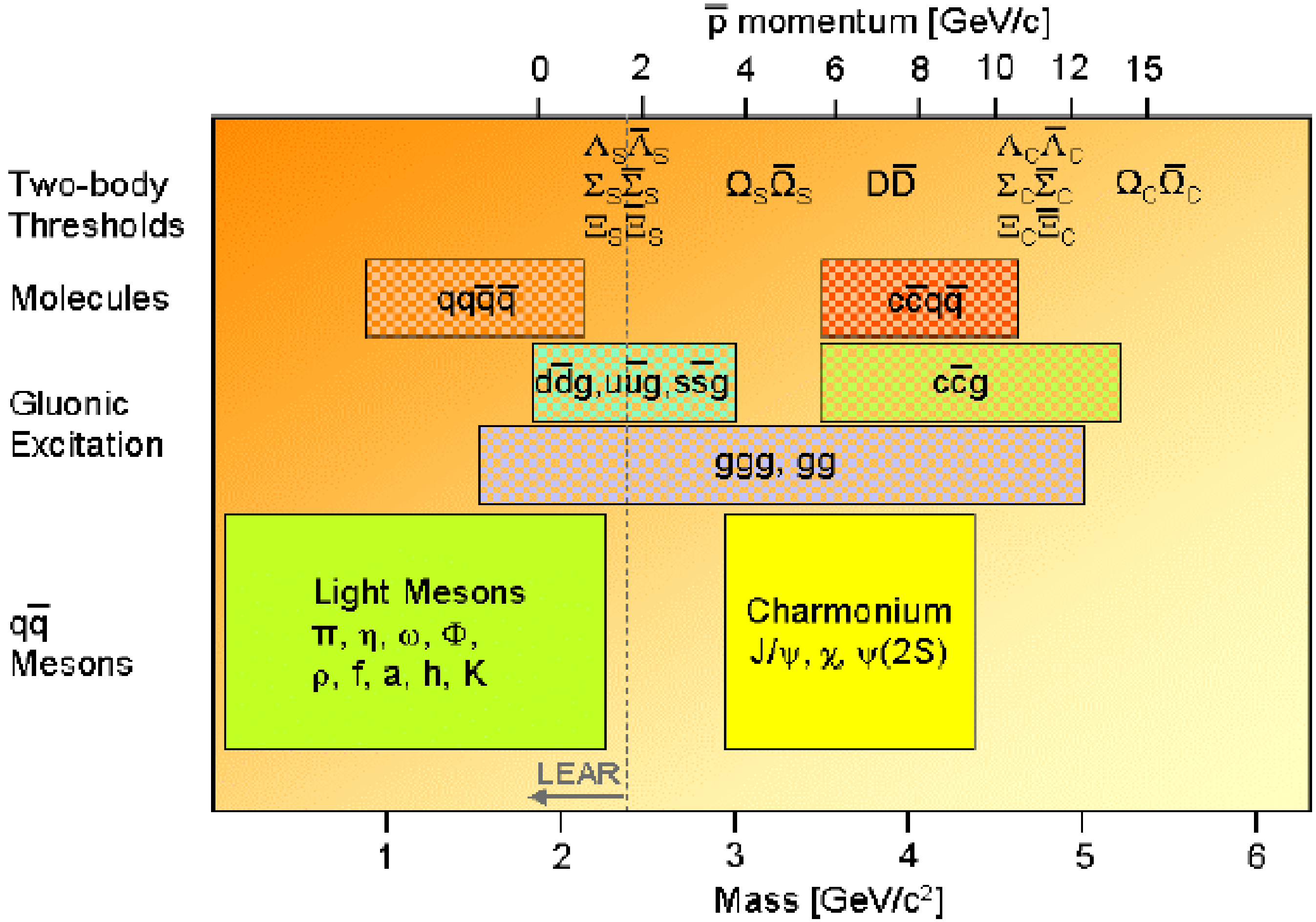


Cross section σ ≈ 2.5pb @ s ≈10 GeV^2
L = $2\cdot10^{32}$ cm-2 s-1→ 10^3 events per month

- Rare D-decays:
  $D^+ \rightarrow \mu^+\nu$ (BR 10^{-4})



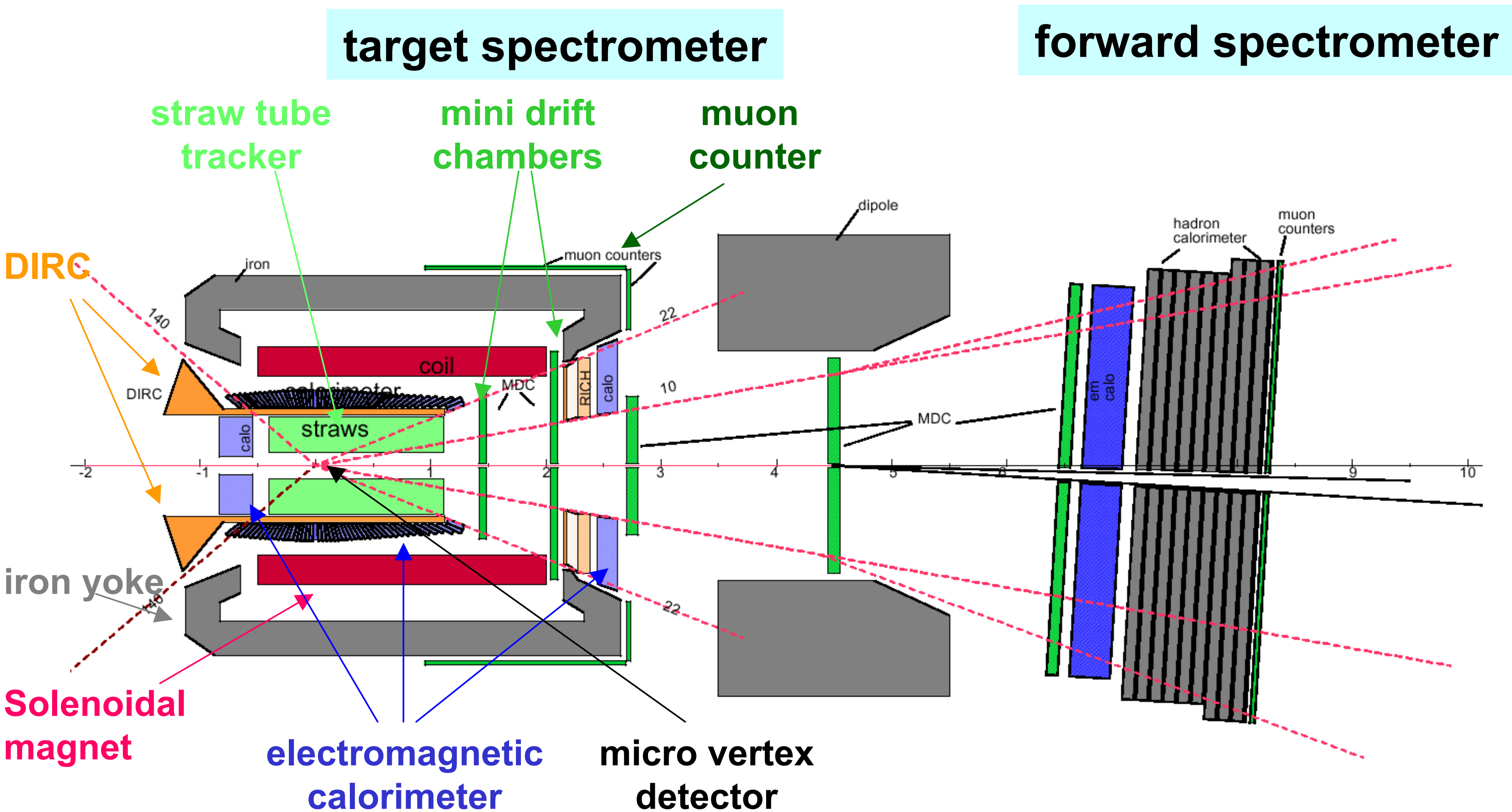
QCD Systems to be studied in Panda



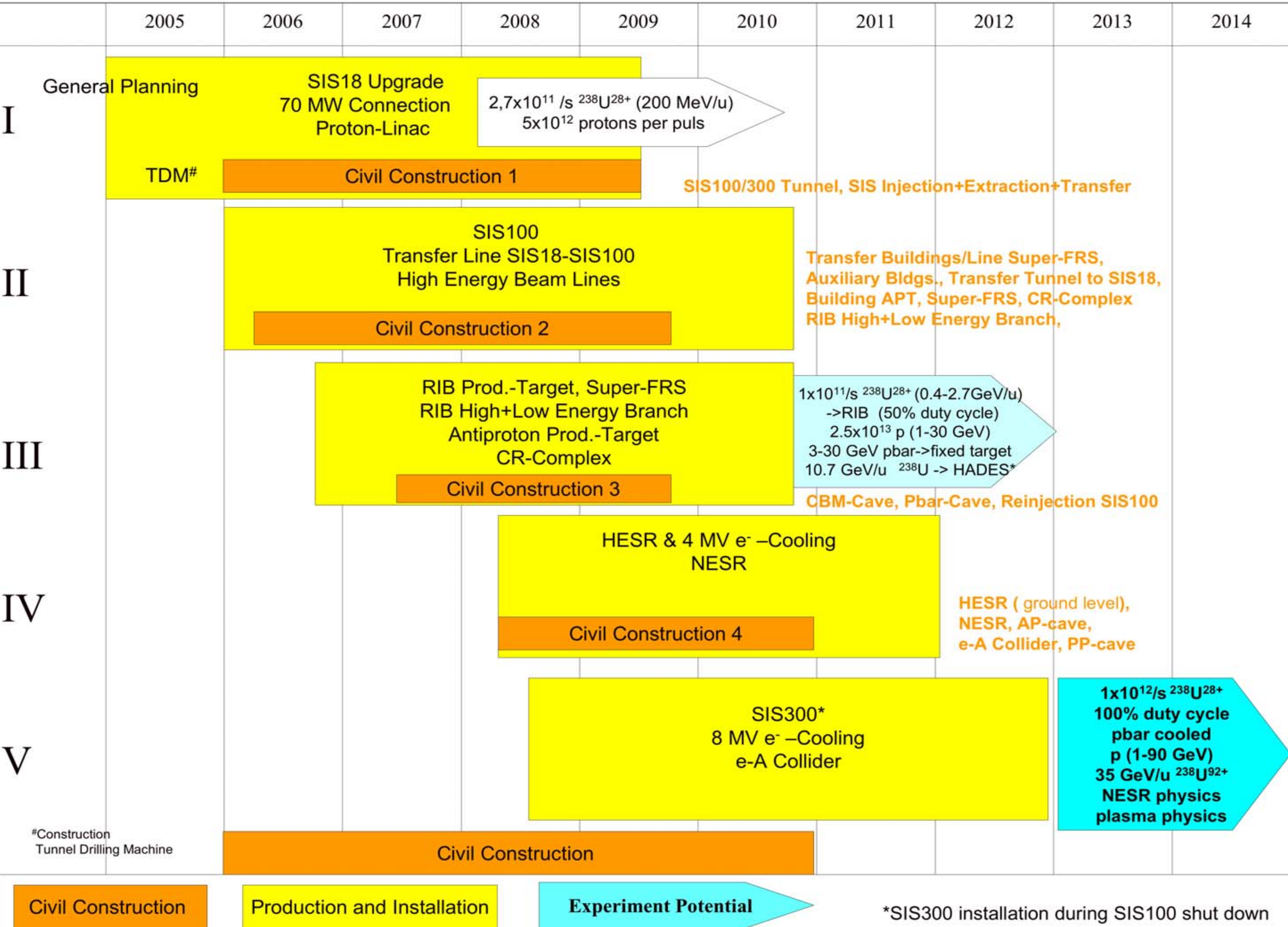
The detector

- Detector Requirements:
  - (Nearly) 4π solid angle coverage (partial wave analysis)
  - High-rate capability   (2×10^7 annihilations/s)
  - Good PID (γ, e, μ, π, K, p)
  - Momentum resolution ($\approx$ 1 %)
  - Vertex reconstruction for D, K^0_s, Λ
  - Efficient trigger
  - Modular design
- For Charmonium:
  - Pointlike interaction region
  - Lepton identification
  - Excellent calorimetry

Panda Detector Concept



Concept for staged Construction of the International Facility for Beams of Ions and Antiprotons



Topics considered by WG5

- Bottomonium formation (Mandelkern, Jackson)
- CP violation in hyperon decays (Rapidis, Kaplan)
- Hadron spectroscopy (Peaslee)
- (Stopping antiproton experiments/antihydrogen)
- Use of the pbar source as a prototype neutrino factory (Christian, Flemming).

$b\bar{b}$ in $p\bar{p}$?

What do we know?

- Scarse and old literature, rough estimates:

P. Dalpiaz, M. Fabbri and E. Luppi
Fine Bottomonium Spectroscopy in ppbar Annihilation, Proceedings of the Workshop on Nucleon-Antinucleon Interactions, (Moscow, ITEP, 8-11 July 1991) pag. 1486

Branching ratios

$$\frac{Br(b\bar{b}\to p\bar{p})}{Br(c\bar{c}\to p\bar{p})} \approx \left(\frac{m_c}{m_b}\right)^8 \approx 10^{-4}$$

$$\frac{Br(b\bar{b}\to p\bar{p})}{Br(c\bar{c}\to p\bar{p})} \approx \left(\frac{m_c}{m_b}\right)^{10} \approx 10^{-5}$$

$$J^{PC} = 1^{--}, 1^{++}, 2^{++}$$

$$J^{PC} = 0^{-+}, 0^{++}, 1^{+-}$$

Cross sections

$$\sigma(p\bar{p}\to \eta_b) \approx 2\,pb$$

$$\sigma(p\bar{p}\to \Upsilon) \approx 100\,pb$$

$$\sigma(p\bar{p}\to \chi_b) \approx 10\,pb$$

- Hopefully, new limits will be *(soon)* set
  - CLEO III $\Upsilon(1,2,3S) \to$ ppbar ($\approx 10^{-6}$)
  - CLEO-c $\psi(3770) \to$ ppbar ($\approx 10^{-6}$)

(from Diego Bettoni)

From a presentation by Sandra Malvezzi to Villars SPSC meeting 09/2004

Bottomonium from ppbar

Physics Goals:
- complements e+e- studies on such system.
- can measure more precisely masses and widths of P states
- unique alternative in etab searches

Physics challenges:
- Luminosities about 1.E32 will give ~10 Mhz hadronic rates:
- Detection of exclusive EM channels : very fast detectors, excellent electron + muon ID.
- Narrow resonance width require ultracool pbar beams dP/P<1.E-4
- Peak Cross Sections (detecting EM final states) will be:
  - Upsilons: ~0.1 pb (BRin/1.E-6)/(dP/P/1.E-4)
  - Chi-B: ~1 pb (BRin/1.E-6)
  - Eta-B: ~.05 pb (BRin/1.E-6) * (BRout/1.E-3)

---> CLEO can measure BRin at 1.E-6 with currently available data 29 M Y(1S), 9 M Y(2S), 6 M Y(3S).

---> Dalpiaz et al: bbbar/ccbar ~ 10-4 => BR ~ 1.e-7 or below.

- Machine requirements: interaction rate is high enough to require debunched beams
  - minicollider : 5+5 GeV ppbar collider with state of the art cooling
  - fixed target: storage of pbars with Ebeam ~ 45 to 55 GeV. Acceleration or deceleration to the resonance energy

Prototype Neutrino Factory

- In normal operation of the pbar source, pions as well as antiprotons are captured by the debuncher.
- Pi → mu → e decays yield
  - Nu-mu from pi decays
  - Nu-mu & Nu-e from Muon decays

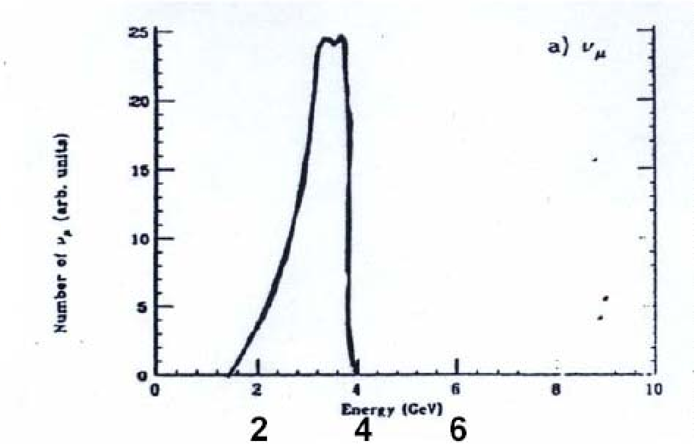
(From John Cooper)

Debuncher Neutrino Energy Spectra

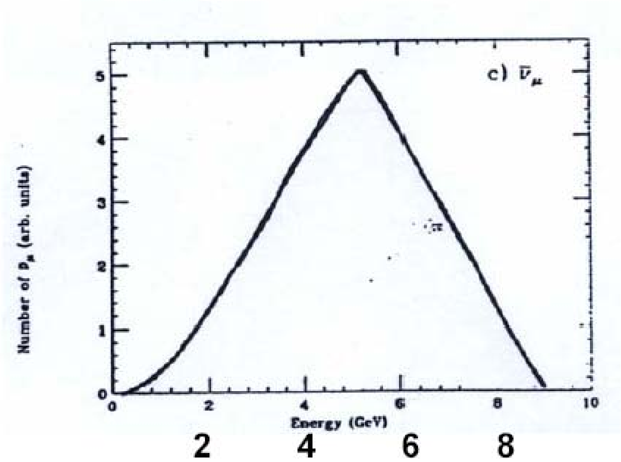
for +- 10 mrad cone forward

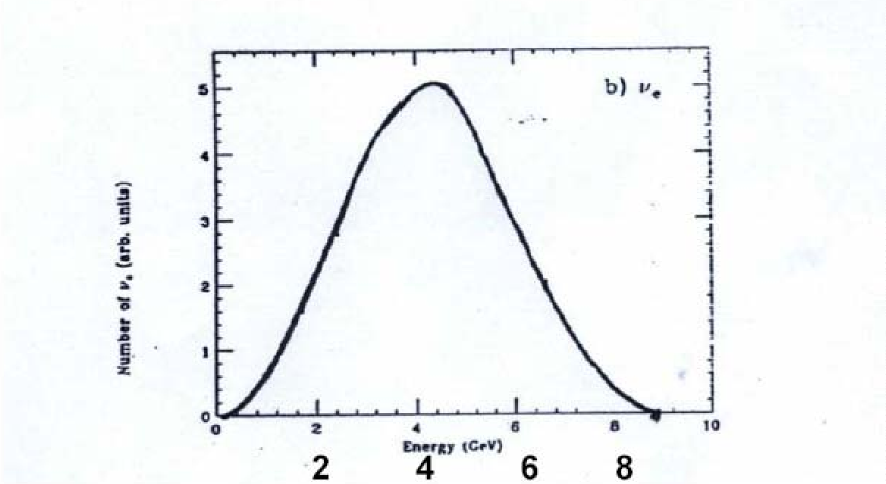
- Get 20 π's for every pbar produced

This is a two body decay, so angle & Energy are correlated at your prototype detector, giving a handle on the Neutral Currents



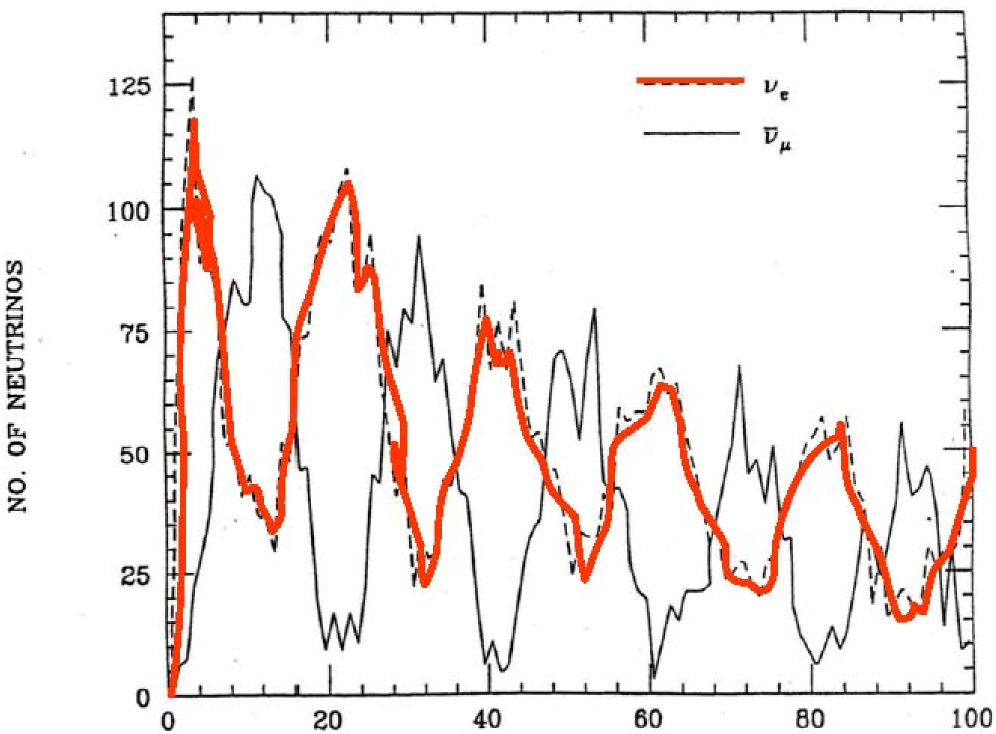
- Get 1 μ for every pbar produced





Actually get "Tagged" ν_μ *and* $\overline{\nu}_e$

- Muons captured in the Debuncher have to be within +- 2% of the momentum aperture, so only forward decays survive. V-A means that the muons are polarized
- Muon spin precesses in the magnetic field
  - Spin precession period ~ 20 turns
  - So there is a time separation of ν_μ and $\overline{\nu}_e$
- **THIS BEGINS TO LOOK LIKE A TEST BEAM !**



Number of turns →

Also note the FIRST turn is very dominantly from π decay (no μ's yet)

CP violation in hyperon decays

- 10-4 may be reached by HyperCP
- P859 (Rapidis, et al) proposed to reach 10-4 using pbar p → lambda, antilambda in 3 months of running, burning 6 mA/hr.
- If systematics can be handled, 10-5 (100x event sample) could be accumulated in a few years, even using ½ of the pbars (assuming ~80 mA/hr capacity).