PAX

Polarized Antiproton Experiment

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ASSIA Collaboration:

101 Collaborators, 10 Institutions

PAX + ASSIA:

203 collaborators

25 institutions

Outline

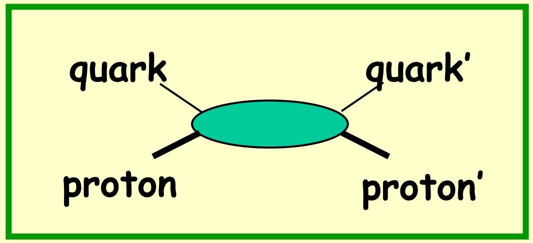
- WHY? The physics case
- HOW? Antiproton polarization
- WHERE? The FAIR project at Darmstadt
- WHAT?
  - Transversity measurement by Drell-Yan at PAX
  - Rates
  - Angular distribution
  - Background
  - Detector concept
- WHEN? The time schedule
- Conclusions

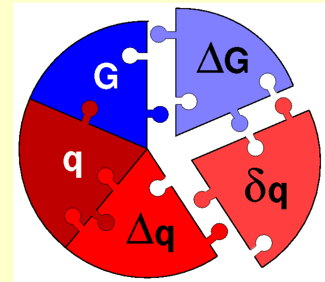
PAX Physics Case

- Transversity
- Single-Spin Asymmetries
- Electromagnetic Form Factors
- Hard Scattering Effects
- Soft Scattering
  - Low-t Physics
  - Total Cross Section
  - pbar-p interaction

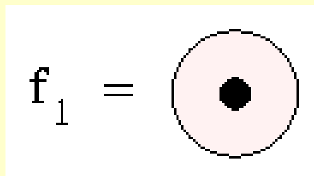
Twist 2 distribution functions

Probabilistic interpretation in helicity base:



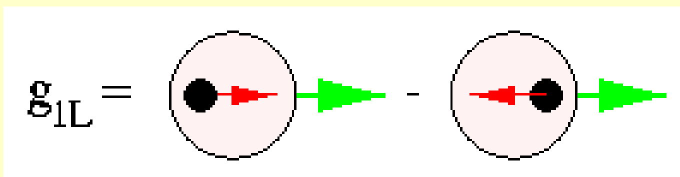


$f_1(X)$



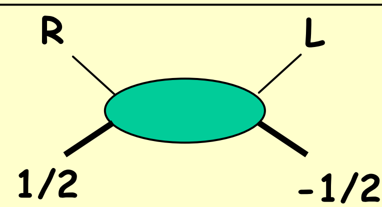
→ q(x) spin averaged (well known)

$g_1(X)$



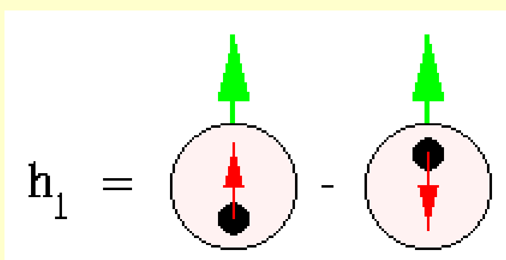
→ Δq(x) helicity diff (known)

$h_1(X)$



- No probabilstic interpretation in the helicity base (off diagonal)

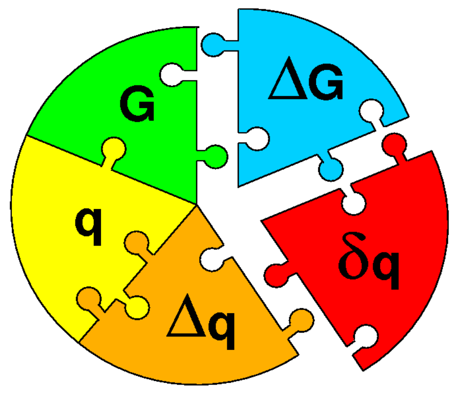
NEW BASE



Transversity base

→ δq(x) helicity flip (unknown)

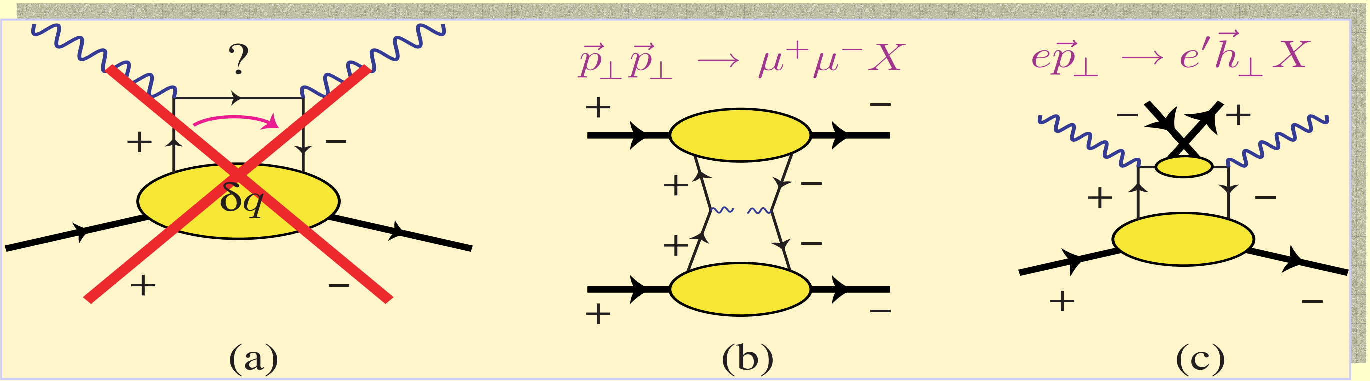
Transversity



Properties:

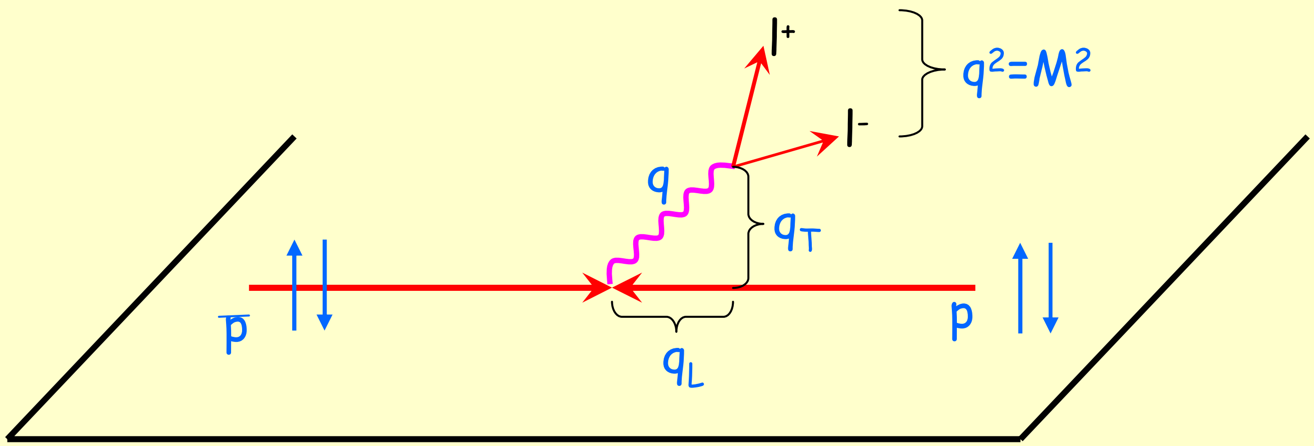
- Probes relativistic nature of quarks
- No gluon analog for spin-1/2 nucleon
- Different Q^2 evolution than Δq
- Sensitive to valence quark polarization

Chiral-odd: requires another chiral-odd partner



Transversity in Drell-Yan processes

PAX: Polarized antiproton beam → polarized proton target (both transverse)



$$A_{TT} \equiv \frac{d\sigma^{\uparrow\uparrow} - d\sigma^{\uparrow\downarrow}}{d\sigma^{\uparrow\uparrow} + d\sigma^{\uparrow\downarrow}} = \hat{a}_{TT} \frac{\sum_q e_q^2 h_1^q(x_1, M^2) h_1^{\bar{q}}(x_2, M^2)}{\sum_q e_q^2 q(x_1, M^2) \bar{q}(x_2, M^2)}$$

$q = u, \bar{u}, d, \bar{d}, \ldots$

M invariant Mass of lepton pair

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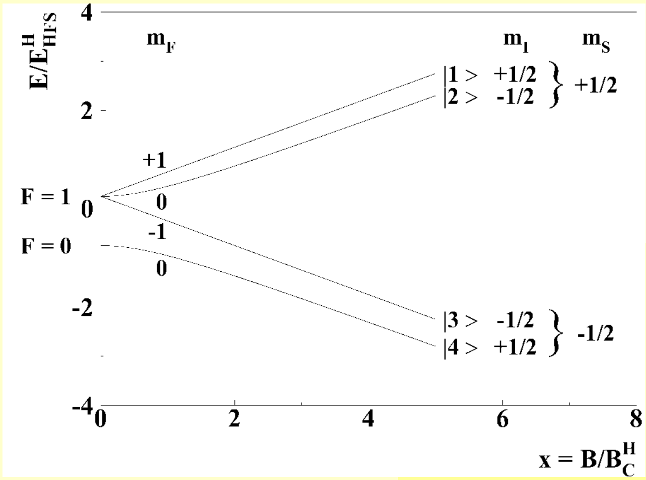
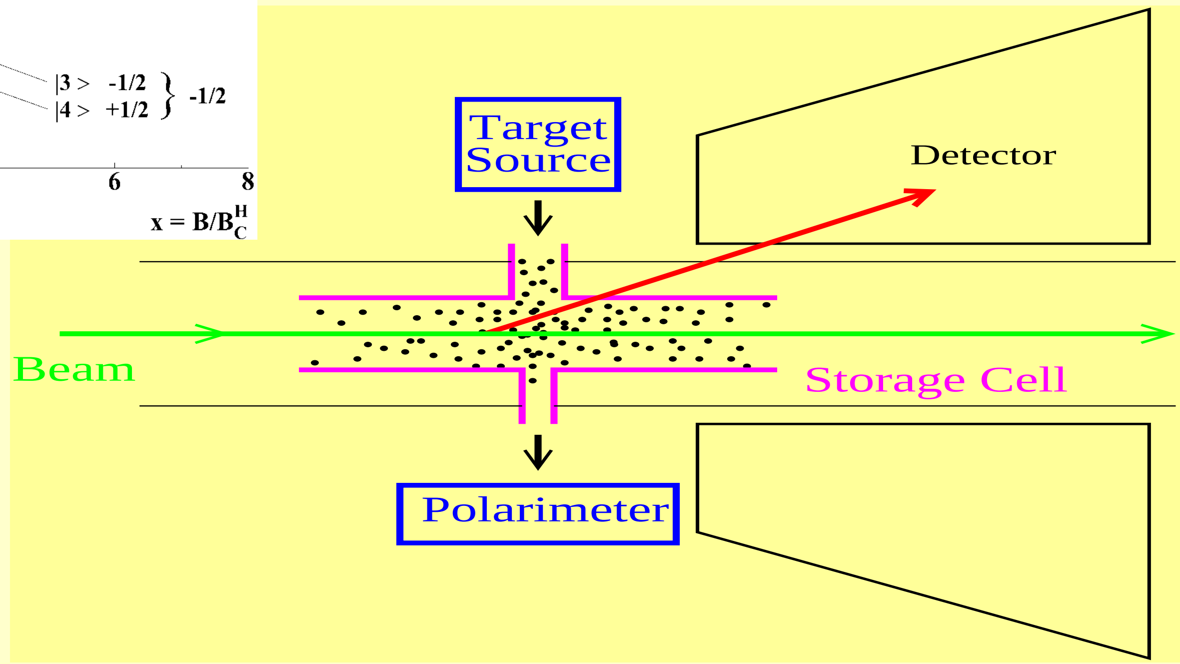
Polarized internal target

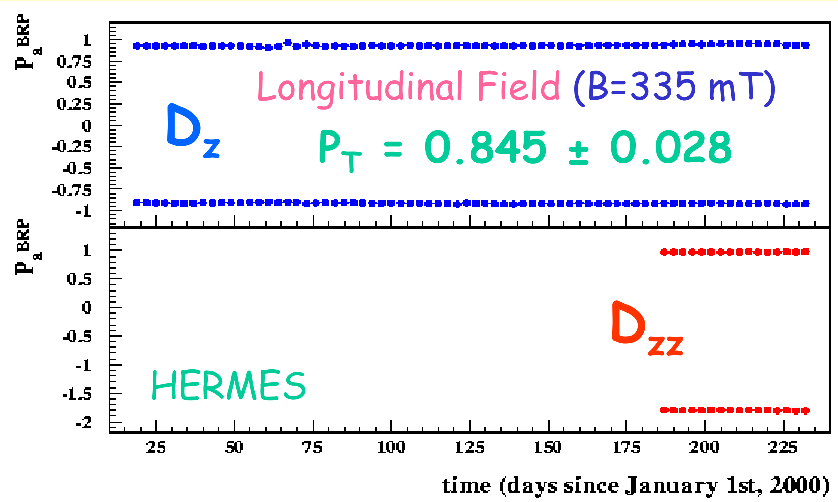


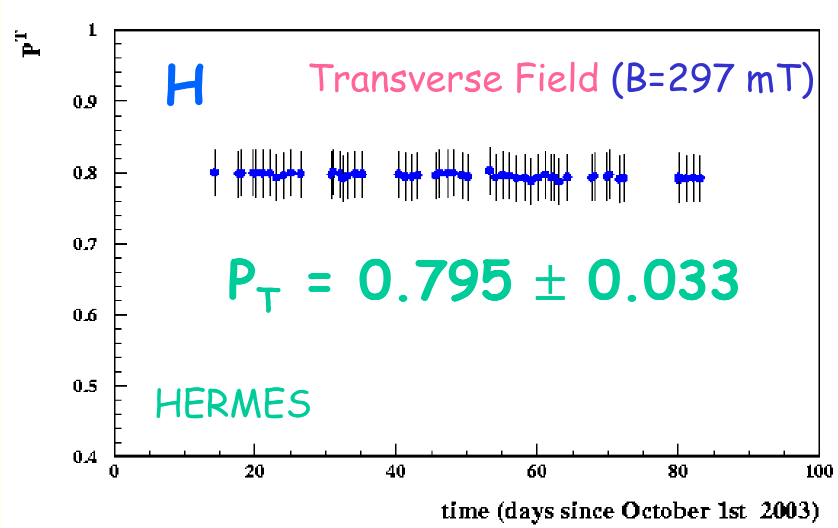


point-like	5-10 mm	free jet	low density	10^{12} cm^{-2}
extended	200-500 mm	storage cell	high density	10^{14} cm^{-2}

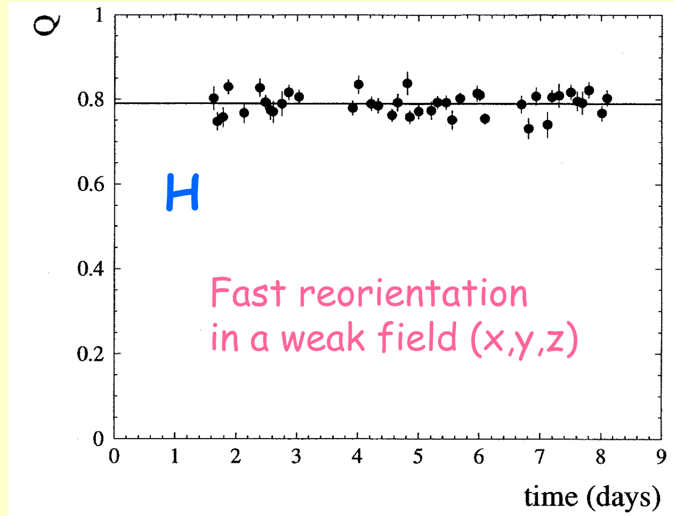
Performance of Polarized Internal Targets

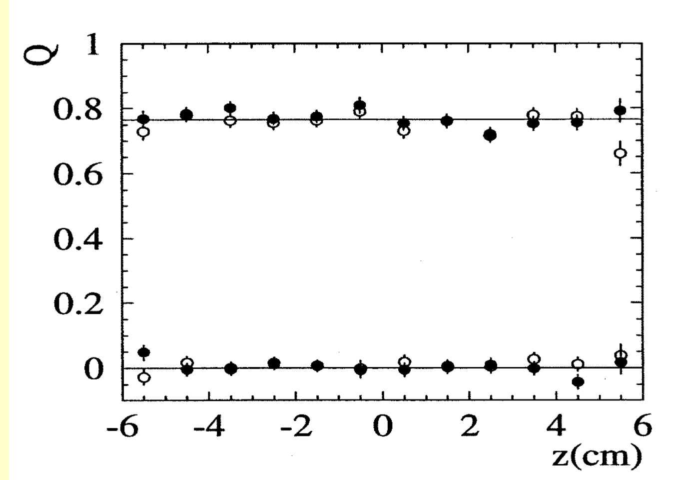
HERMES: Stored Positrons





PINTEX: Stored Protons





Targets work very reliably (many months of stable operation)

Principle of spin filter method

$$\sigma_{tot} = \sigma_0 + \sigma_\perp \cdot \vec{P} \cdot \vec{Q} + \sigma_{||} \cdot (\vec{P} \cdot \vec{k})(\vec{Q} \cdot \vec{k})$$

P beam polarization
Q target polarization
k || beam direction

For initially equally populated spin states: ↑ (m=+½) and ↓ (m=-½)

transverse case:

$$\sigma_{tot\pm} = \sigma_0 \pm \sigma_\perp \cdot Q$$

longitudinal case:

$$\sigma_{tot\pm} = \sigma_0 \pm (\sigma_\perp + \sigma_{||}) \cdot Q$$

For low energy pp scattering:
$\sigma_1 < 0 \Rightarrow \sigma_{tot+} < \sigma_{tot-}$

Expectation	
Target	**Beam**
↑	↑
↓	↓

Spin transfer from electrons to protons

$$p + \vec{e} \longrightarrow \vec{p} + e$$

$$\sigma_{EM\perp} = -\frac{1}{2}\left[\frac{4\pi\alpha^2(1+\lambda_p)m_e}{p^2 m_p}\right] C_0^2 \left[\frac{\nu}{2\alpha}\right] \times \sin\left[\frac{2\alpha \ln(2pa_0)}{\nu}\right]$$

$$\sigma_{EM\|} = 2 \cdot \sigma_{EM\perp}$$

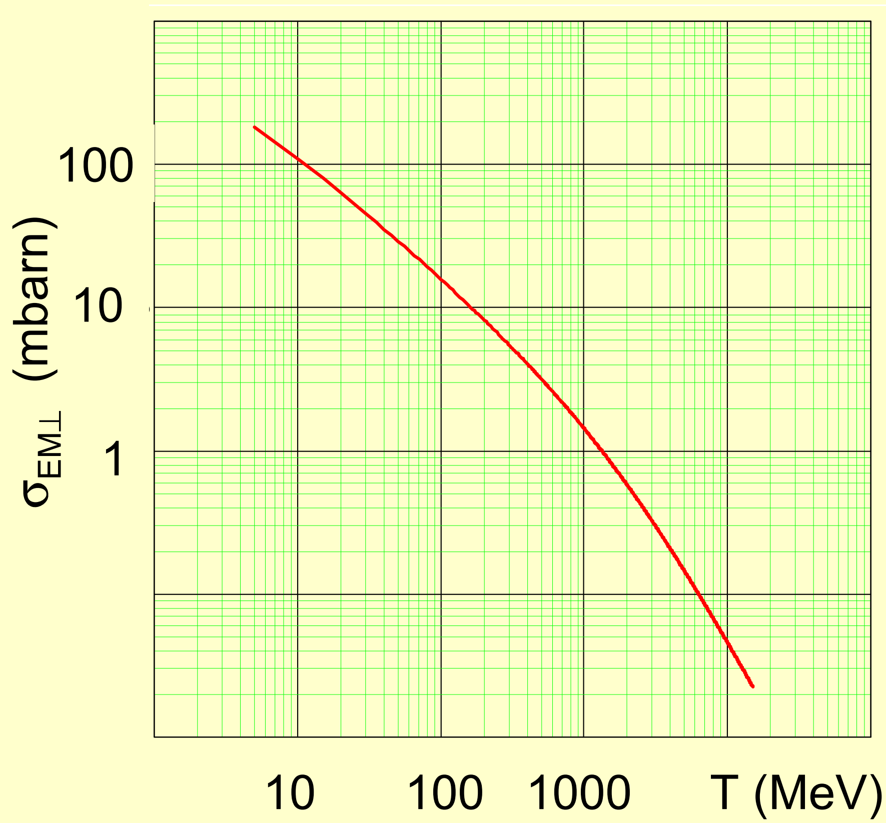
Horowitz & Meyer, PRL 72, 3981 (1994)
H.O. Meyer, PRE 50, 1485 (1994)

α	fine structure constant
$\lambda_p=(g-2)/2=1.793$	anomalous magnetic moment
m_e, m_p	rest masses
p	cm momentum
a_0	Bohr radius
$C_0^2=2\pi\eta/[\exp(2\pi\eta)-1]$	Coulomb wave function
$\eta=z\alpha/v$	Coulomb parameter (negative for antiprotons)
v	relative lab. velocity between p and e
z	beam charge number

PAX will exploit spin-transfer from polarized electrons of the target to antiprotons

Spin Transfer Cross Section

$$p + \vec{e} \rightarrow \vec{p} + e$$



Beam lifetimes in the AP

Beam Lifetime

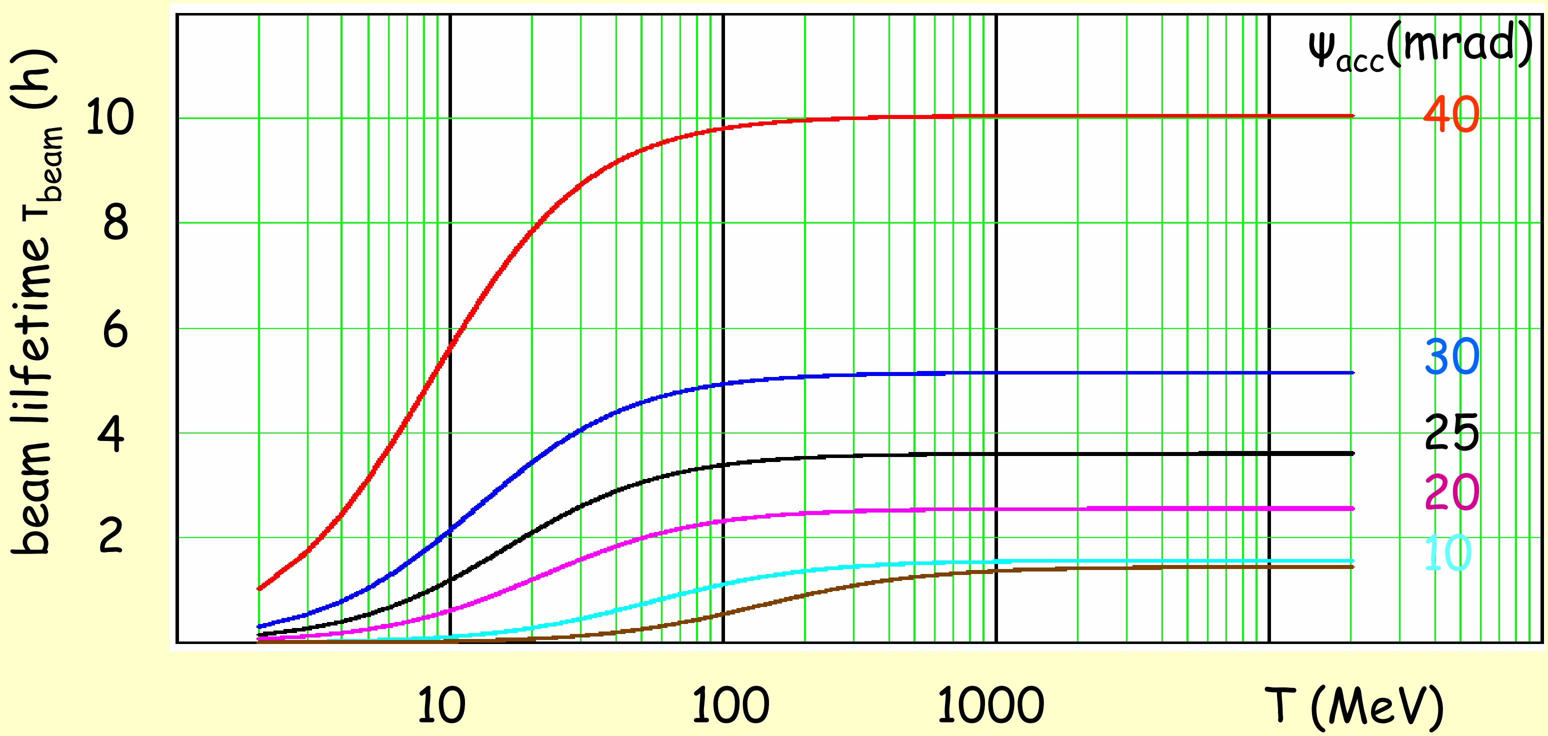
$$\tau_{beam}(T,\Psi_{acc}) = \frac{1}{(\Delta\sigma_C(T,\Psi_{acc}) + \sigma_0(T)) \cdot d_t(\Psi_{acc}) \cdot f_{rev}(T)}$$

Coulomb Loss

$$\Delta\sigma_C(T,\Psi_{acc}) = \int_{\theta_{min}}^{\theta_{max}} \left(\frac{d\sigma}{d\Omega}\right)_{Ruth.} d\Omega = 4\pi\alpha^2 \frac{(s(T)-2m_p{}^2)^2 4m_p{}^2}{s(T)^2(s(T)-4m_p{}^2)^2} \left(\frac{1}{\psi_{acc}^2} - \frac{s(T)}{4m_p{}^2}\right)$$

Total Hadronic

$$\sigma_0(T) = \sigma_{tot\,p\bar{p}}(T)$$



Polarization Buildup: optimal polarization time

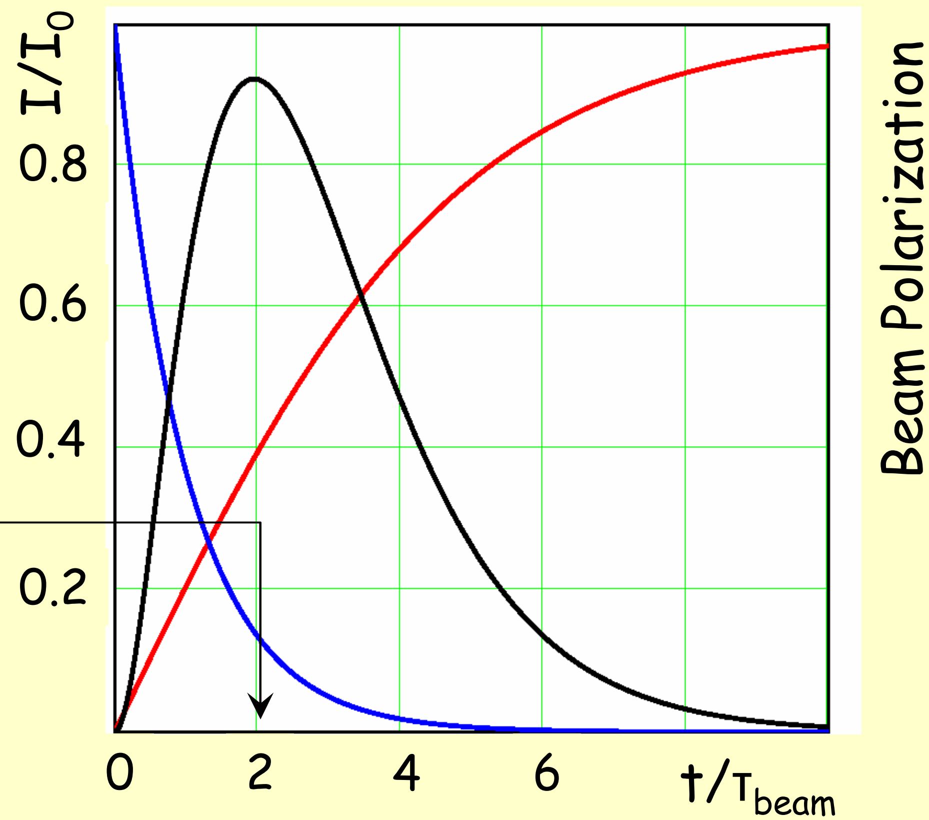
statistical error of a double polarization observable (A_{TT})

$$\delta_{A_{TT}} = \frac{1}{P \cdot Q \cdot \sqrt{N}}$$

(N ~ I)

Measuring time t to achieve a certain error $\delta_{A_{TT}} \sim \text{FOM} = P^2 \cdot I$

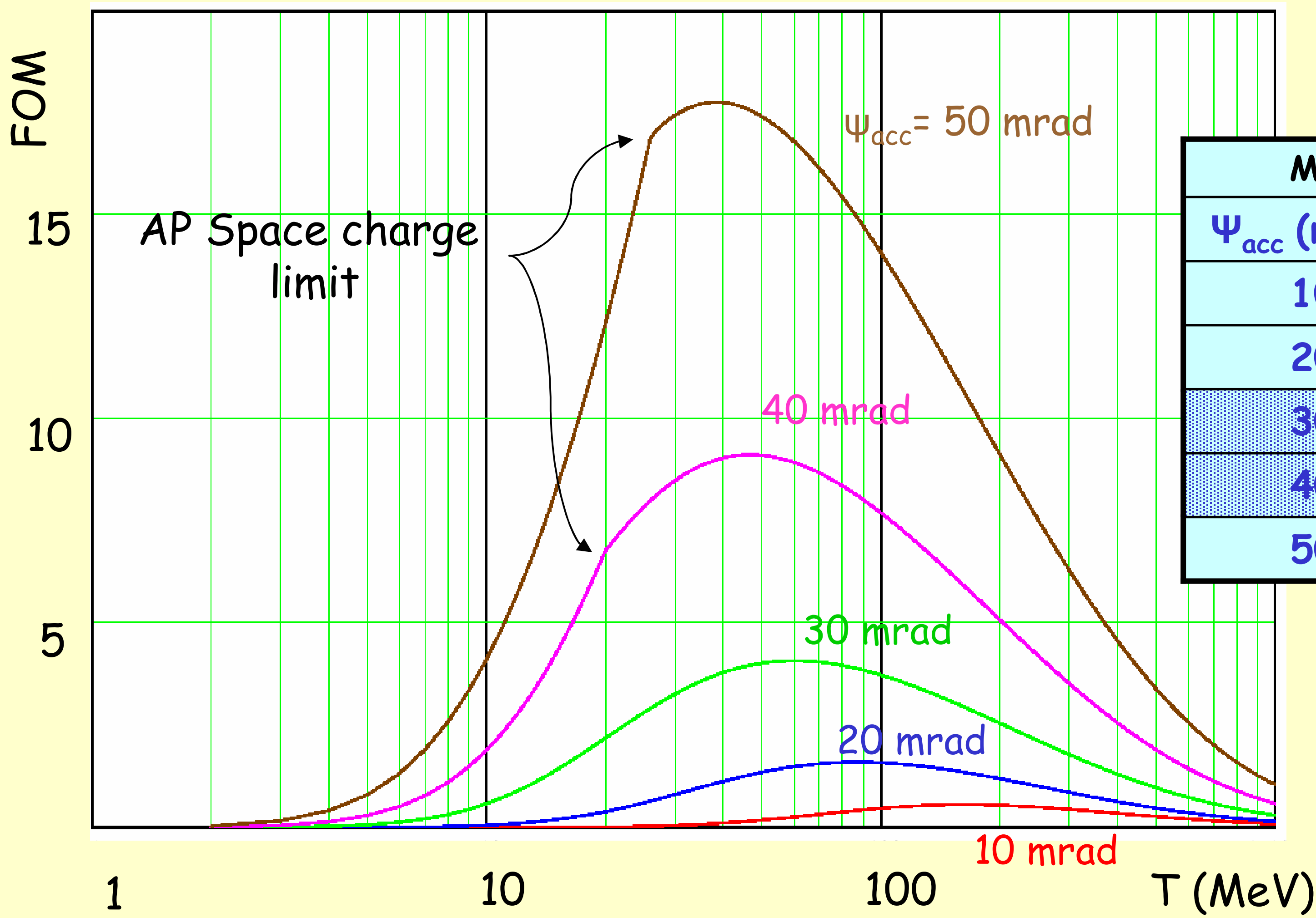
Optimimum time for Polarization Buildup given by maximum of FOM(t)
$t_{filter} = 2 \cdot \tau_{beam}$



Parameters for Calculation of Polarization Buildup

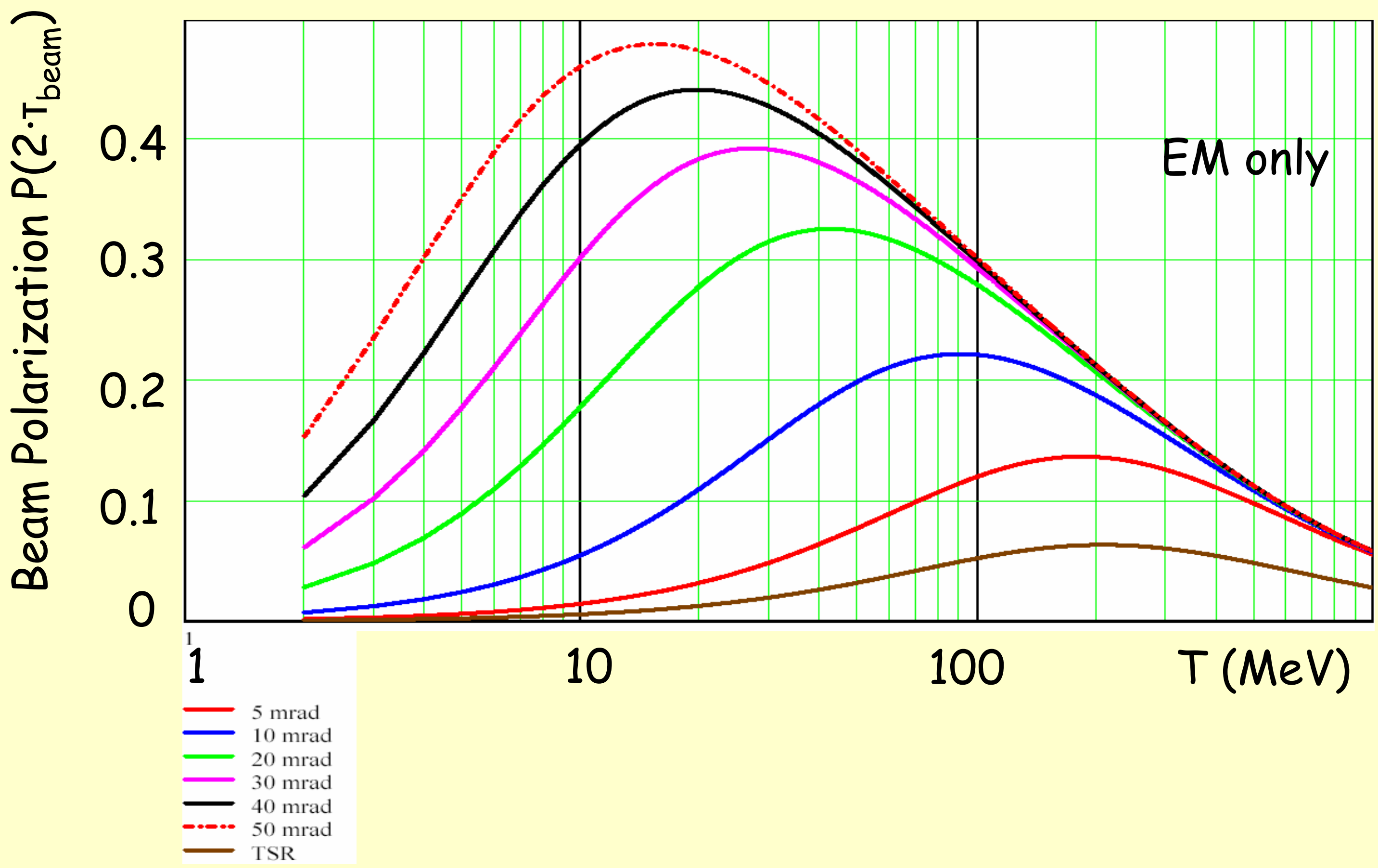
- **Dedicated Ring Antiproton Polarizer (AP)**
  - 150 m circumference
- **β-function at polarizing target β_{target} = 0.2 m**
- **ABS H-Flow $1.5 \cdot 10^{17}$ atoms/s (2 states)**
  - (20% above existing performance)
- **Internal Target**
  - storage cell diameter $d_b=\psi_{acc} \cdot \beta \cdot 2$ → target density $d_t=d_t(\psi_{acc})$
  - length l_b=40 cm (=2·β), feed tube d_f=1 cm, l_f=15 cm
  - T=100 K
  - target polarization longitudinal $(\sigma_{EM\|} = 2 \cdot \sigma_{EM\perp})$
    - holding field (300 mT)

Optimum beam energies for buildup in AP



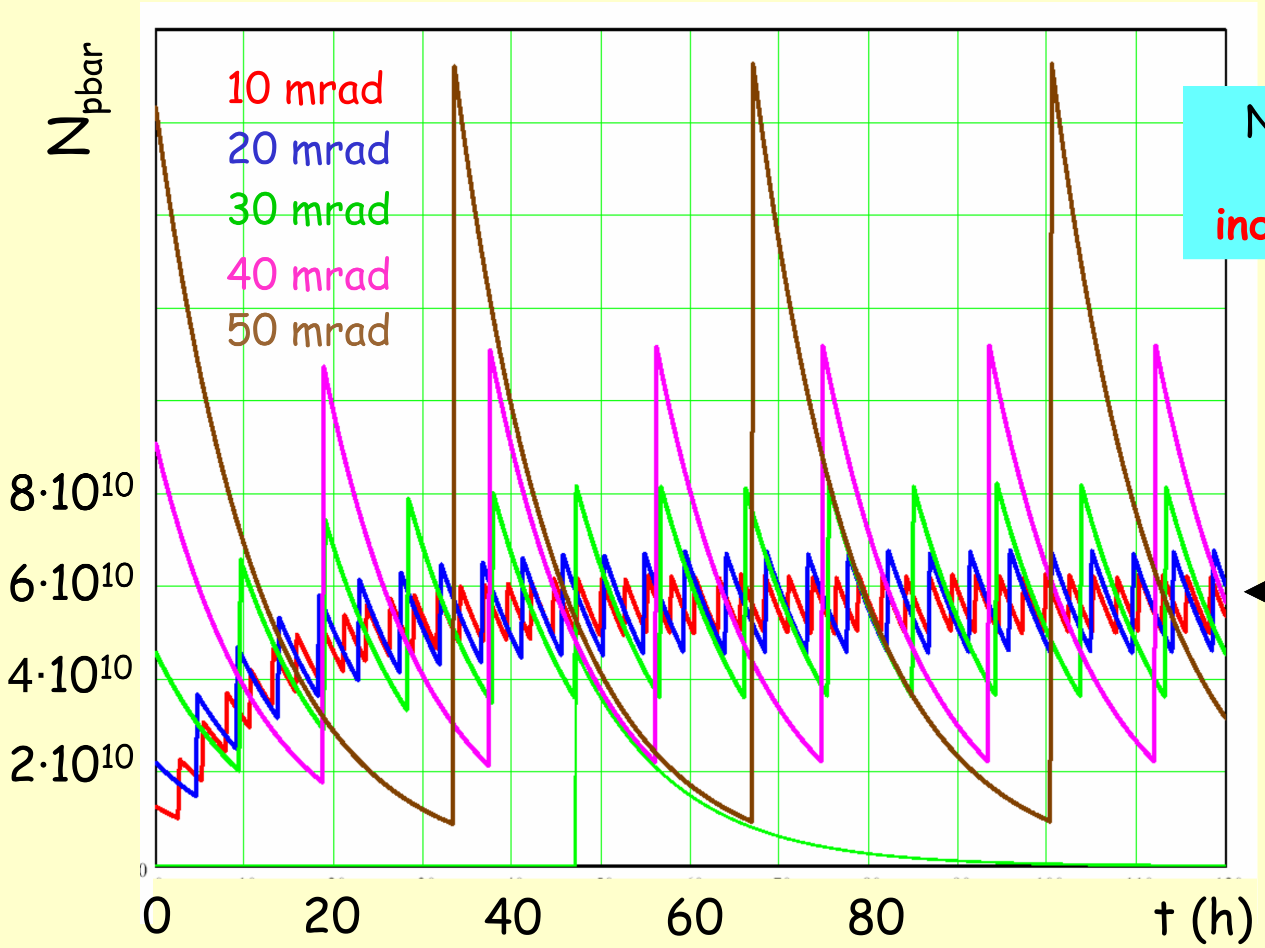
Maximum FOM	
Ψ_{acc} (mrad)	T (MeV)
10	163
20	88
30	61
40	47
50	38

Beam Polarization in a dedicated AP ring



Accumulation of polarized beam in HESR

PIT: $d_t = 7.2\cdot10^{14}$ atoms/cm^2
$\tau_{HESR} = 11.5$ h



Number of accumulated pbars in equilibrium **independent** of acceptance

$$\overline{N}_{\bar{p}} = 5.6\cdot10^{10}$$

Estimated luminosity

Luminosity for double polarization

Internal target

$$L = t \times f \times N_{pbar}$$

t = areal density
f = revolution frequency
N_{pbar} = number of pbar stored in HESR

$$L = 7.2 \cdot 10^{14} \times 6 \cdot 10^{5} \times 5.6 \cdot 10^{10} = 2.4 \cdot 10^{31}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$$

$Q_{target} = 0.85$

$P_{beam} = 0.3$

(factor 70 in measuring time for A_{TT} respect to extracted beam on solid target)

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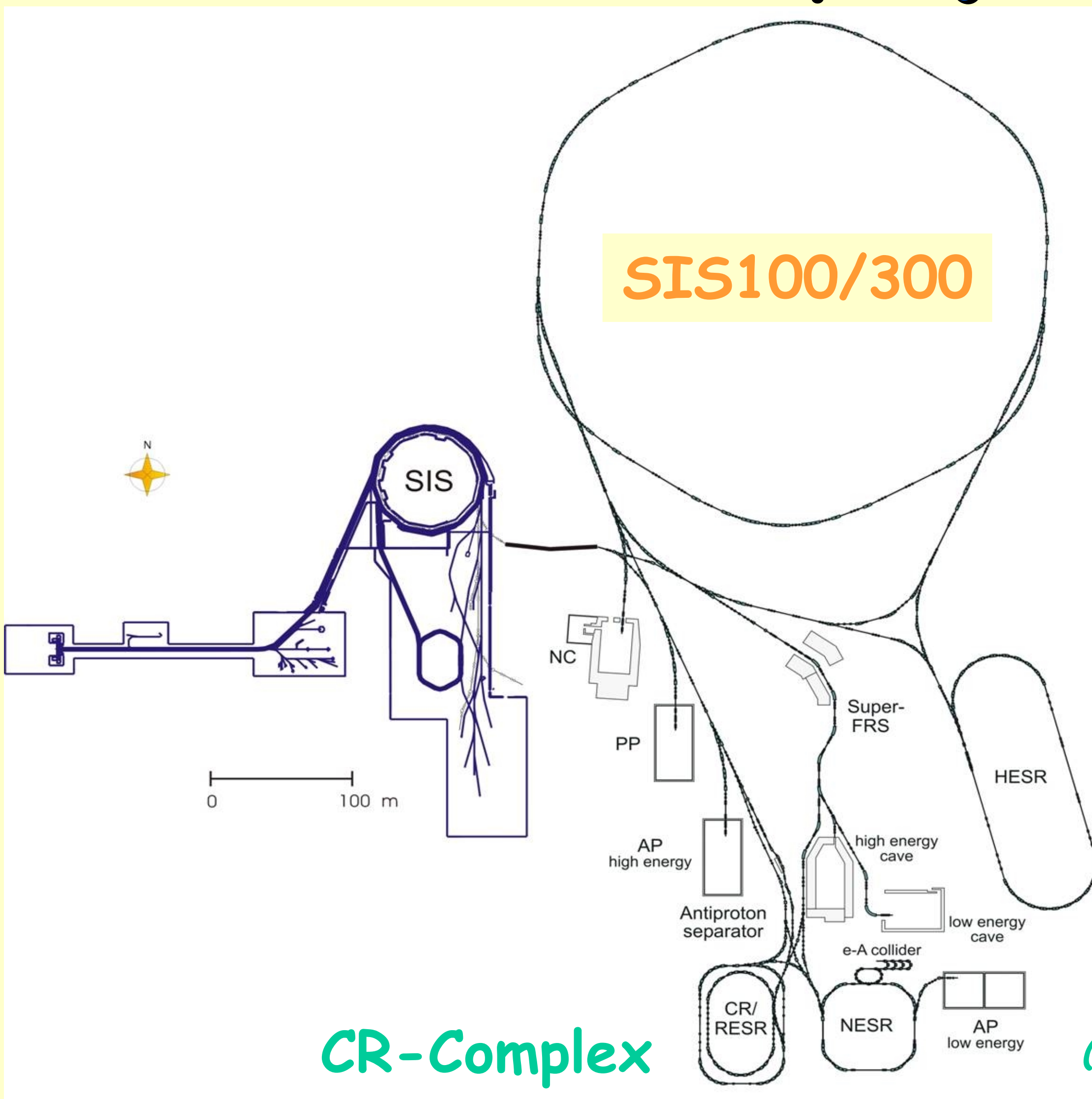
The FAIR project at GSI

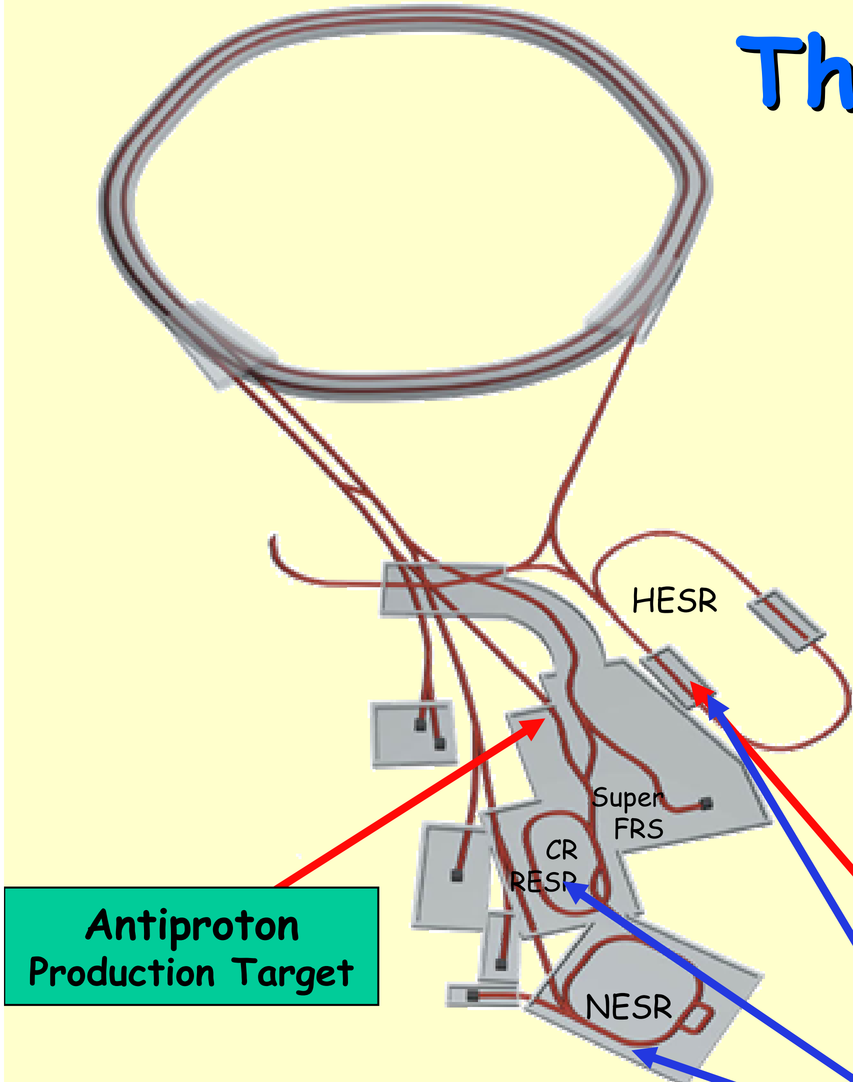


HESR:
PANDA and PAX

NESR

FLAIR:
(Facility for very Low energy Anti-protons and fully stripped Ions)

The Antiproton Facility



HESR (High Energy Storage Ring)

- Length 442 m
- Bρ = 50 Tm
- N = 5 x 10^{10} antiprotons

High luminosity mode

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

High resolution mode

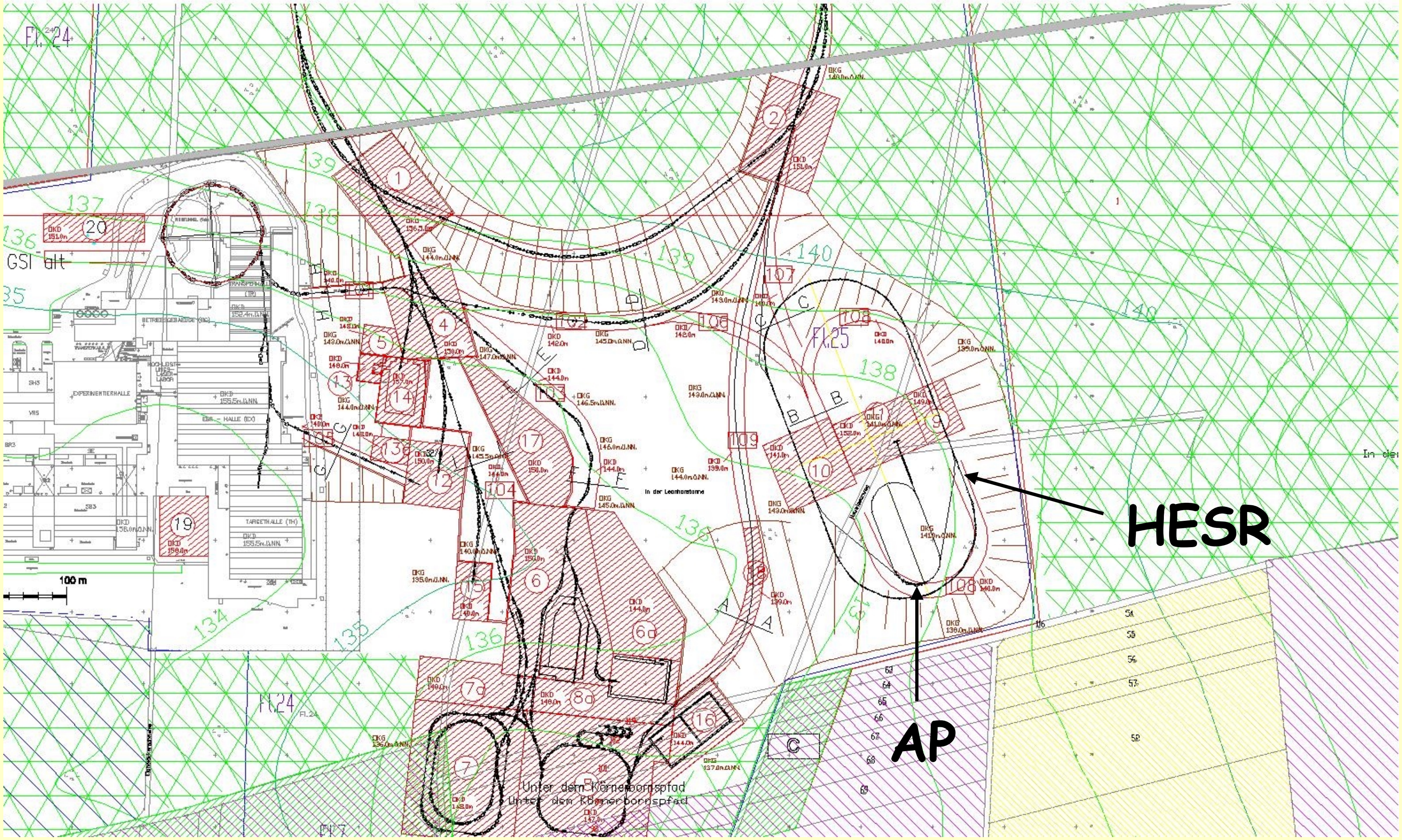
- Δp/p ~ 10^{-5} (8 MV HE e-cooling)
- Luminosity = 10^{31} $cm^{-2}s^{-1}$

Gas Target and Pellet Target:
cooling power determines thickness

Cooling – e^- and/or stochastic
2MV prototype e-cooling at COSY

- Antiproton production similar to CERN
- Production rate 10^7/sec at 30 GeV
- Energy = 1.5 - 15 GeV/*c* (22 GeV)

The new polarization facility



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Transvertsity in Drell-Yan processes

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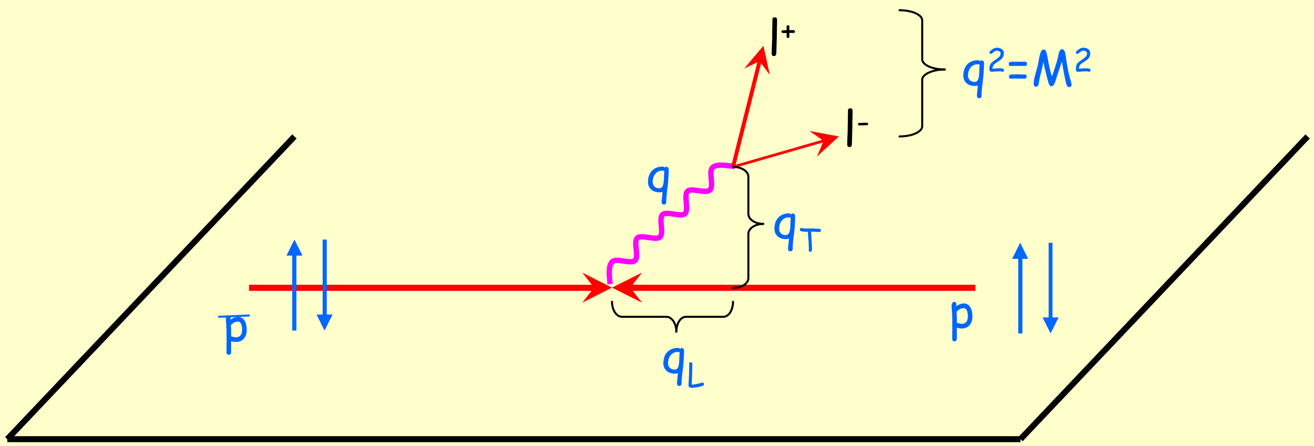


$$A_{TT} \equiv \frac{d\sigma^{\uparrow\uparrow} - d\sigma^{\uparrow\downarrow}}{d\sigma^{\uparrow\uparrow} + d\sigma^{\uparrow\downarrow}} = \hat{a}_{TT} \frac{\sum_q e_q^2 h_1^q(x_1, M^2) h_1^{\bar{q}}(x_2, M^2)}{\sum_q e_q^2 q(x_1, M^2) \bar{q}(x_2, M^2)}$$

$q = u, \bar{u}, d, \bar{d}, \ldots$

M invariant Mass of lepton pair

A_{TT} for PAX kinematic conditions

RHIC: $\tau = x_1 x_2 = M^2/s \sim 10^{-3}$
→ **Exploration of the sea quark content (polarizations small!)**
A_{TT} very small (~ 1 %)

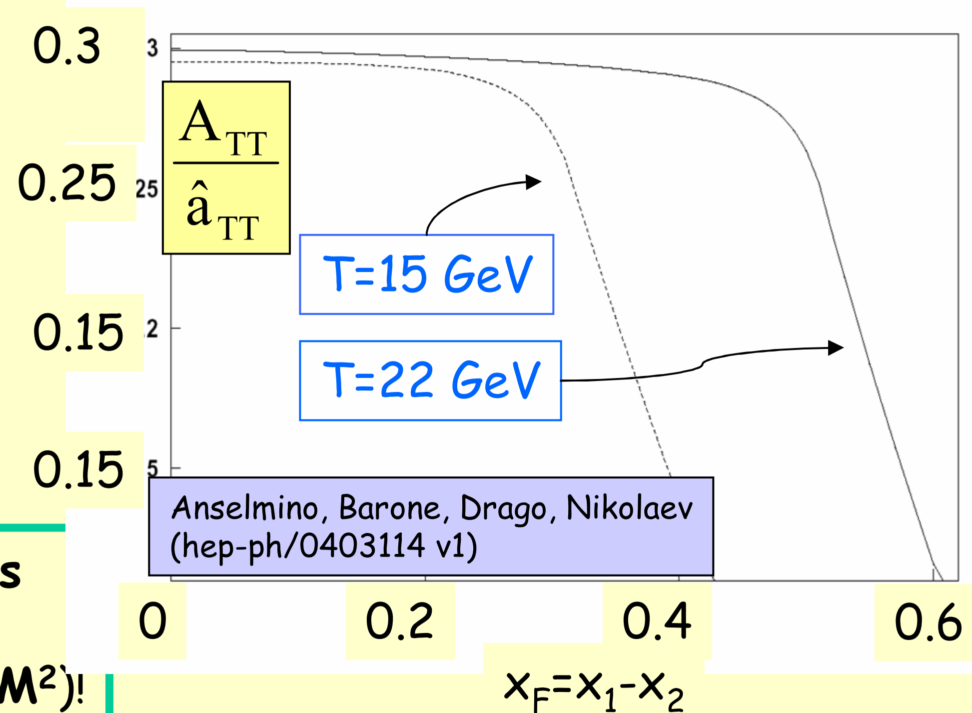
PAX: $M^2 \sim 10$ GeV^2, $s \sim 30\text{-}50$ GeV^2, $\tau = x_1 x_2 = M^2/s \sim 0.2\text{-}0.3$
→ **Exploration of valence quarks ($h_1^q(x,Q^2)$) large)**

$A_{TT}/a_{TT} > 0.3$
Models predict $|h_1^u| \gg |h_1^d|$

$$A_{TT} = \hat{a}_{TT} \frac{h_1^u(x_1,M^2) h_1^u(x_1,M^2)}{u(x_1,M^2) u(x_1,M^2)}$$

$$(\text{where } \bar{q}^{\bar{p}} = q^p = q)$$

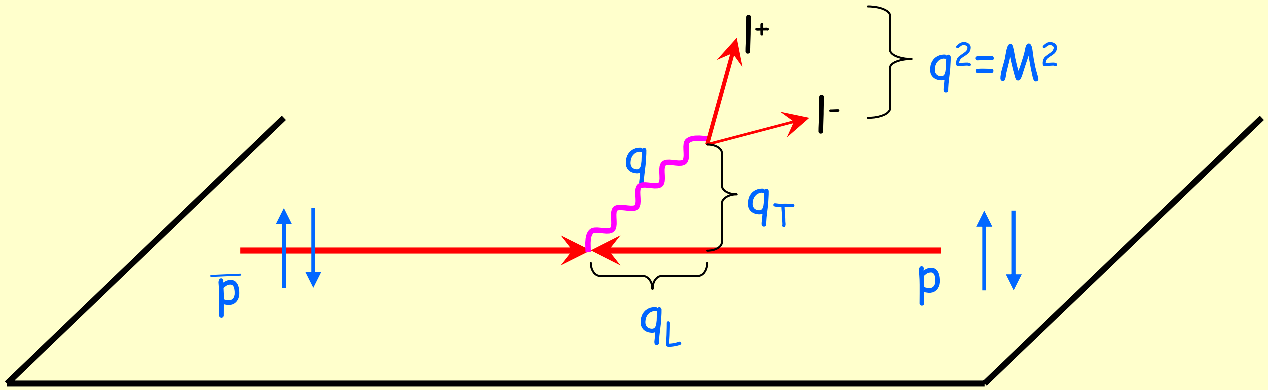
Main contribution to Drell-Yan events at PAX from $x_1 \sim x_2 \sim \sqrt{\tau}$
deduction of x-dependence of $h_1^u(x,M^2)$!



Anselmino, Barone, Drago, Nikolaev (hep-ph/0403114 v1)

Signal estimation

Polarized antiproton beam → polarized proton target (both transverse)



1) Count rate estimate.

$$\frac{d^2\sigma}{dM^2 dx_F} = \frac{4\alpha^2\pi}{9M^2 s(x_1+x_2)} \bullet \sum_q e_q^2 \left[q(x_1,M^2)q(x_2,M^2) + \bar{q}(x_1,M^2)\bar{q}(x_2,M^2) \right]$$

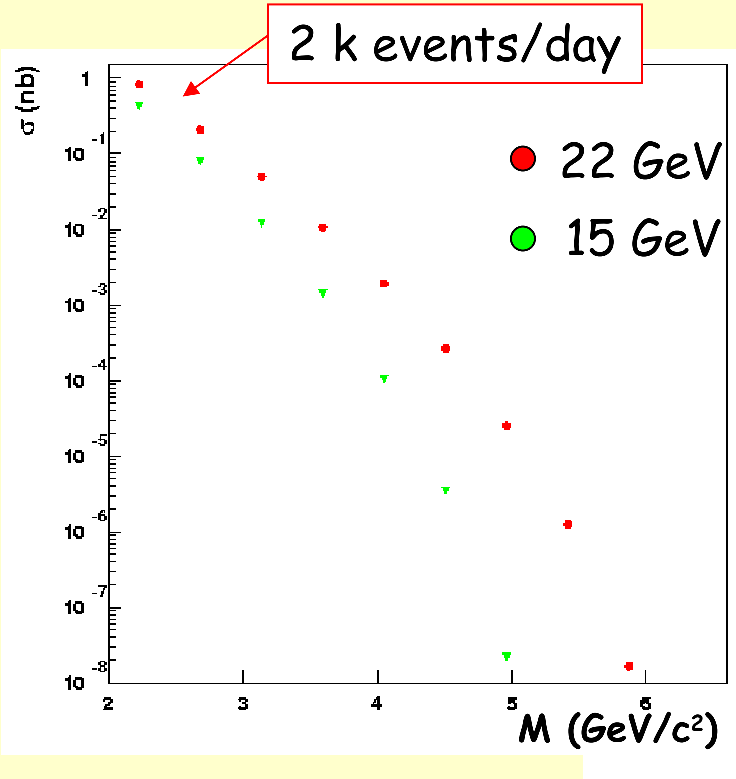
2) Angular distribution of the asymmetry.

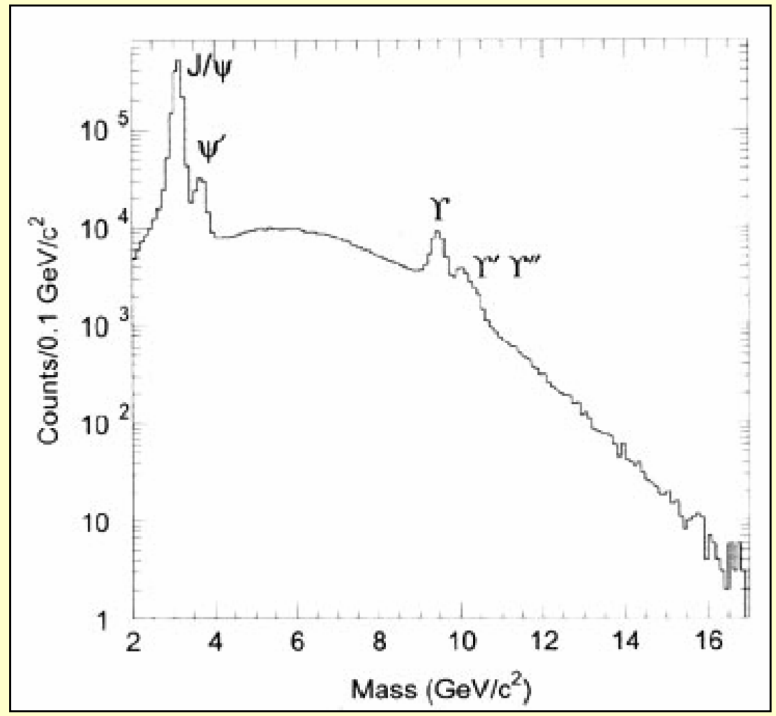
$$A_{TT} \equiv \frac{d\Delta\sigma}{d\sigma} = \hat{a}_{TT} \frac{h_1^u(x_1,M^2)h_1^u(x_2,M^2)}{u(x_1,M^2)u(x_2,M^2)}$$

Drell-Yan cross section and event rate

$$\frac{d^2\sigma}{dM^2dx_F} = \frac{4\alpha^2\pi}{9M^2 s(x_1+x_2)} \bullet \sum_q e_q^2\left[q(x_1,M^2)q(x_2,M^2)+\bar{q}(x_1,M^2)\bar{q}(x_2,M^2)\right]$$

- $M^2 = s\, x_1 x_2$
- $x_F = 2q_L/\sqrt{s} = x_1 - x_2$





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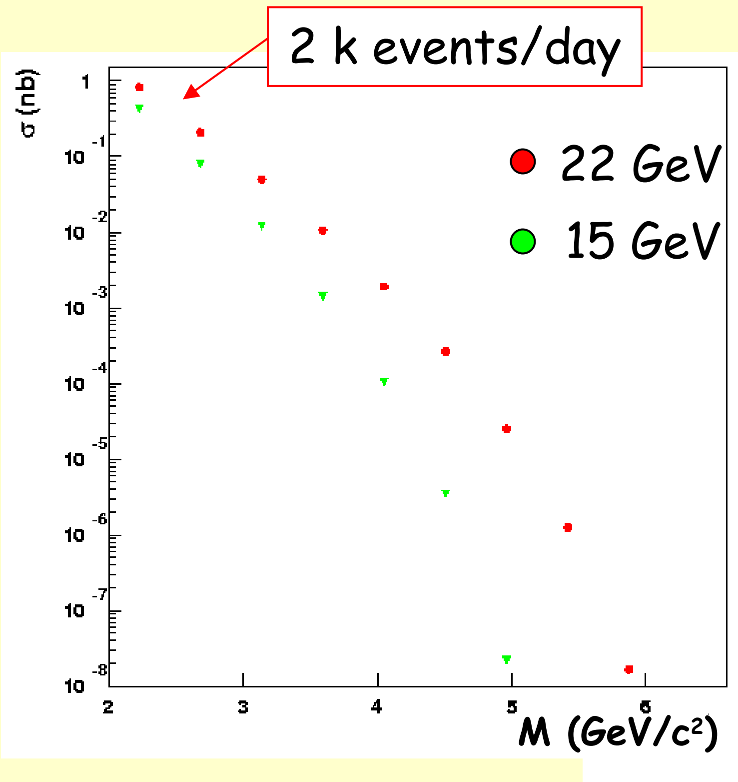
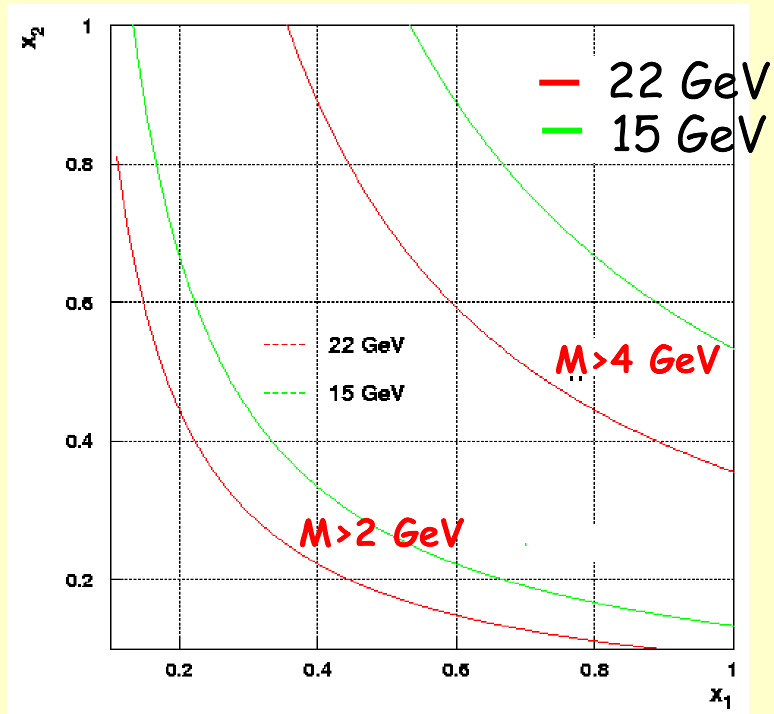
$$\frac{d^2\sigma}{dM^2 dx_F} = \frac{4\alpha^2\pi}{9M^2 s(x_1+x_2)} \bullet \sum_q e_q^2 \left[q(x_1,M^2)\bar{q}(x_2,M^2) + \bar{q}(x_1,M^2)q(x_2,M^2) \right]$$

- $M^2 = s\, x_1 x_2$
- $x_F = 2q_L/\sqrt{s} = x_1 - x_2$

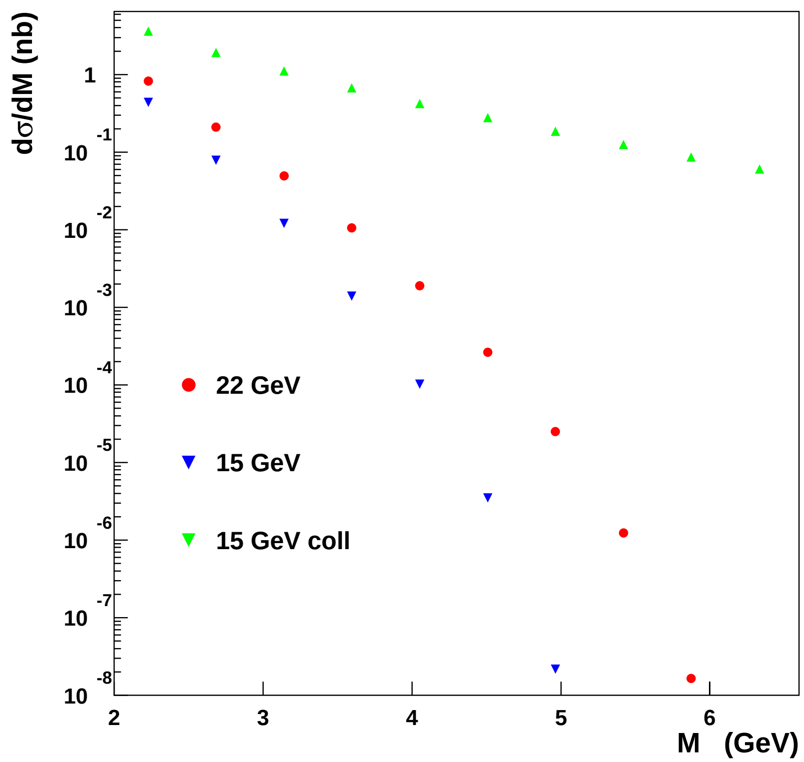


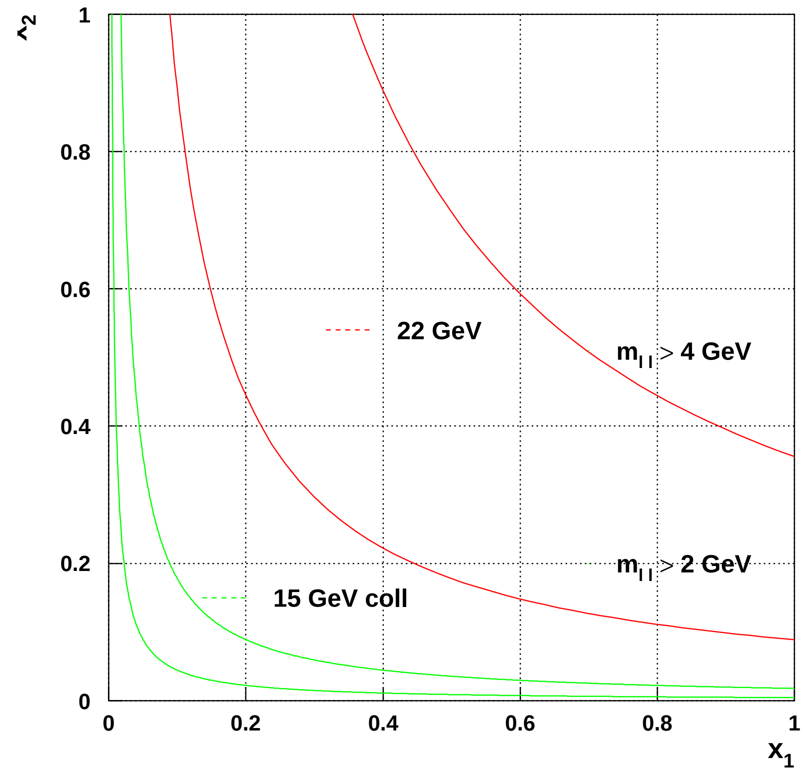


- $x_1 x_2 = M^2/s$

- Mandatory use of the invariant mass region below the J/ψ (2 to 3 GeV).
- 22 GeV preferable to 15 GeV

Possible option: collider ring (15 GeV)



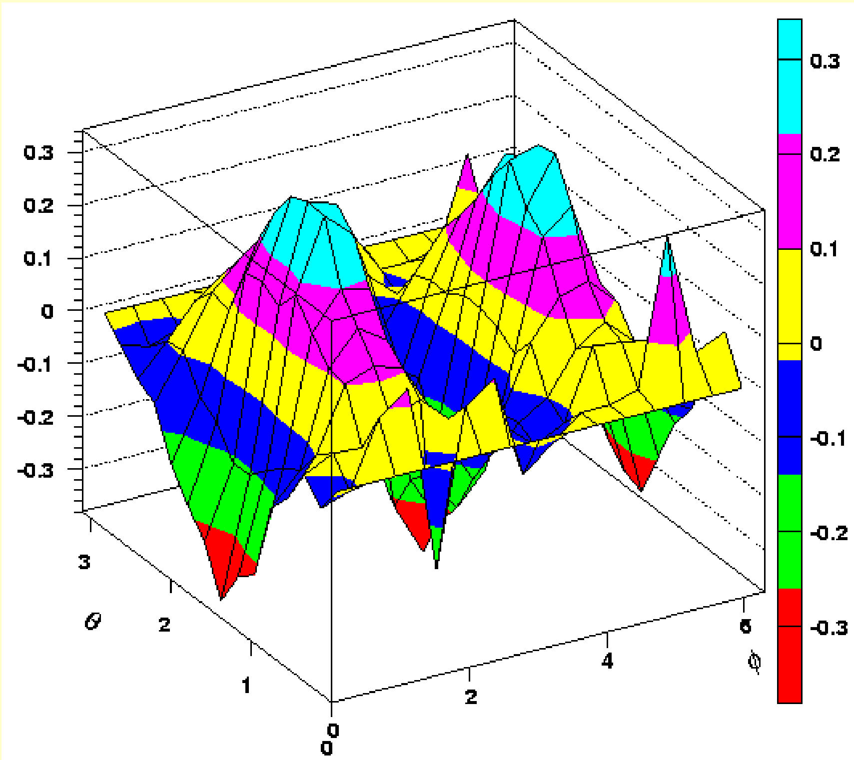


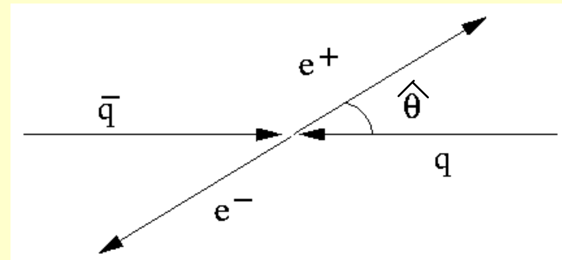
L > $10^{30}cm^{-2}s^{-1}$ to get comparable rates

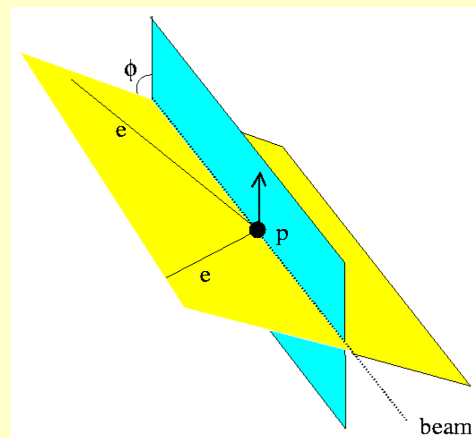
A_{TT} asymmetry: angular distribution

$$A_{TT} \equiv \frac{d\Delta\sigma}{d\sigma} = \hat{a}_{TT} \frac{h_1^u(x_1, M^2) h_1^u(x_2, M^2)}{u(x_1, M^2) u(x_2, M^2)}$$

$$\hat{a}_{TT}(\hat{\theta}, \phi) = \frac{\sin^2 \hat{\theta}}{(1+\cos^2 \hat{\theta})} \bullet \cos(2\phi)$$





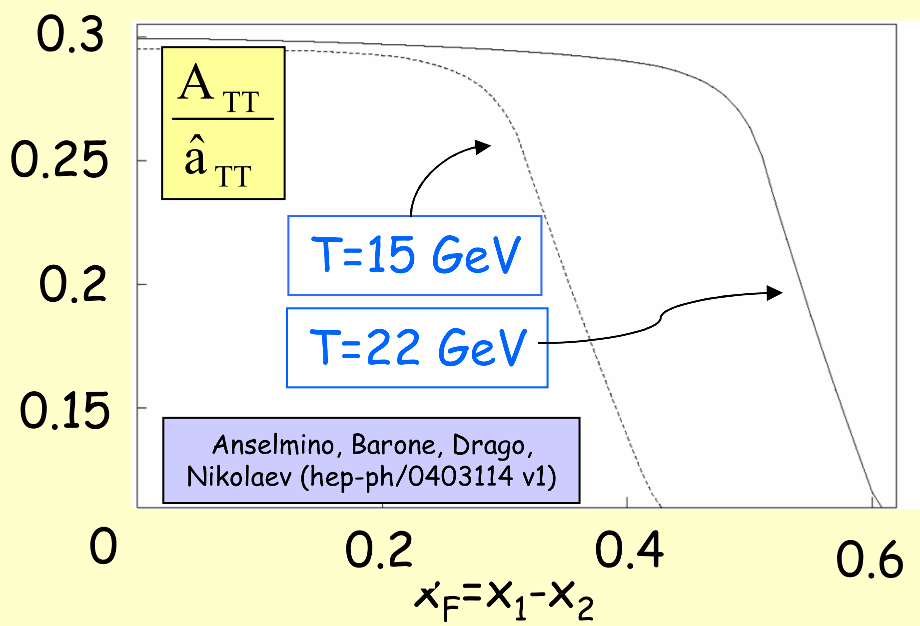


- The asymmetry is maximal for angles $\hat{\theta}$ =90°
- The asymmetry has a cos(2ϕ) azimuthal asymmetry.

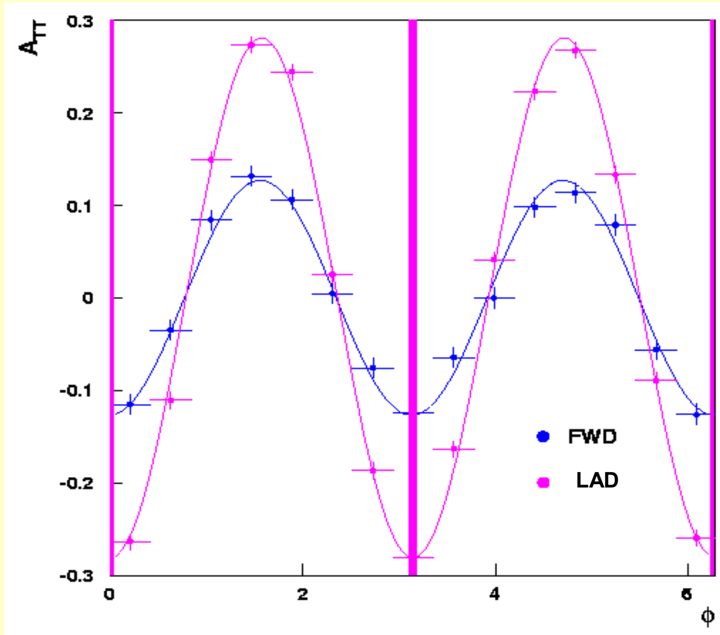
The asymmetry is large in the large acceptance detector (LAD)

Theoretical prediction

Asymmetry amplitude



Angular modulation



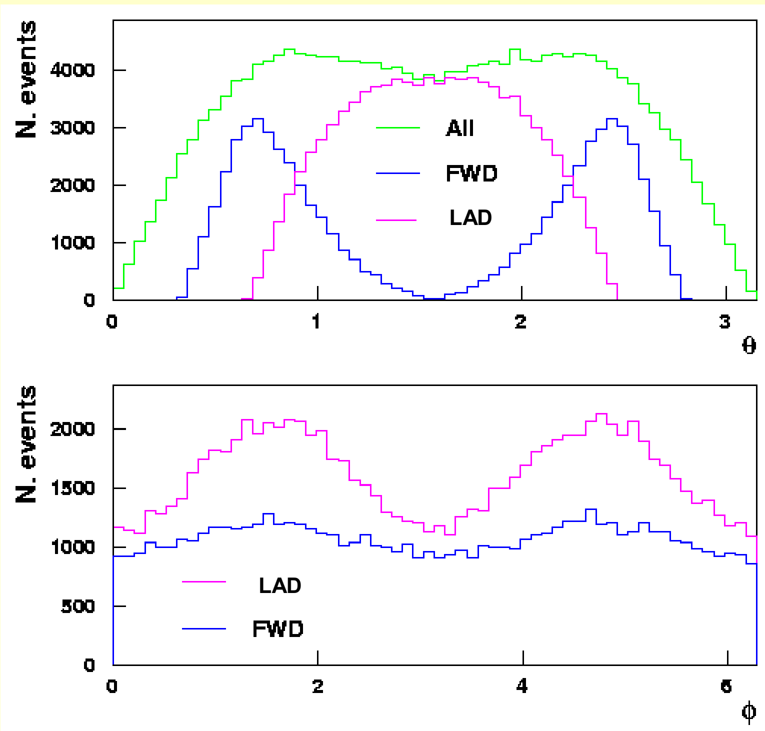
FWD: $\theta_{lab} < 8°$

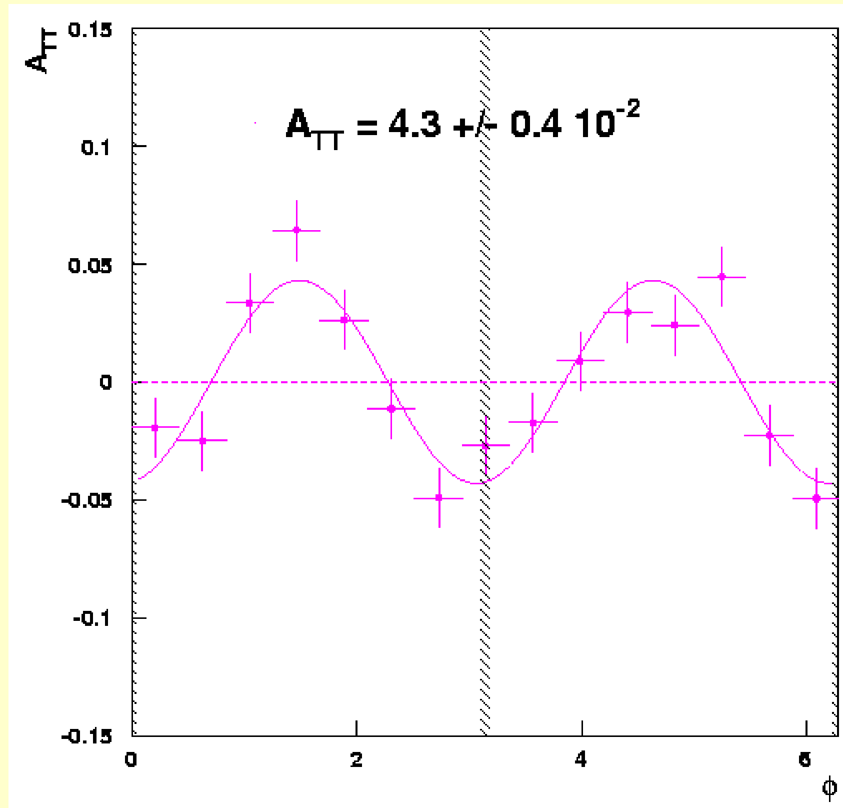
LAD: $8° < \theta_{lab} < 50°$

P=Q=1

Estimated signal

- 120 k events sample
  - 60 days at $L=2.1 \cdot 10^{31}$ cm^2 s^{-2}, P = 0.3, Q = 0.85





Events under J/y can double the statistics.
→ Good momentum resolution requested

Background

$\sigma_{p\bar{p}} = 50mb$

$\sigma_{DY} \leq 1nb$

$\rightarrow$ 10^8-10^9 rejection factor against background

- DY pairs can have non-zero transverse momentum ($\langle p_T \rangle$ = 0.5 GeV)
  $\rightarrow$coplanarity cut between DY and beam not applicable

- Background higher in the forward direction (where the asymmetry is lower).

- Background higher for μ than for e (meson decay)
  $\rightarrow$ hadronic absorber needed for μ $\rightarrow$ inhibits additonal physics chan.

- Sensitivity to charge helps to subtract background from wrong-charge pairs
  $\rightarrow$ Magnetic field envisaged

Background for $\bar{p}p \to e^+e^- X$

Average multiplicity: 4 charged + 2 neutral particle per event.
Combinatorial background from meson decay.

$$\bar{p}p \to h_1 h_2 \, X$$

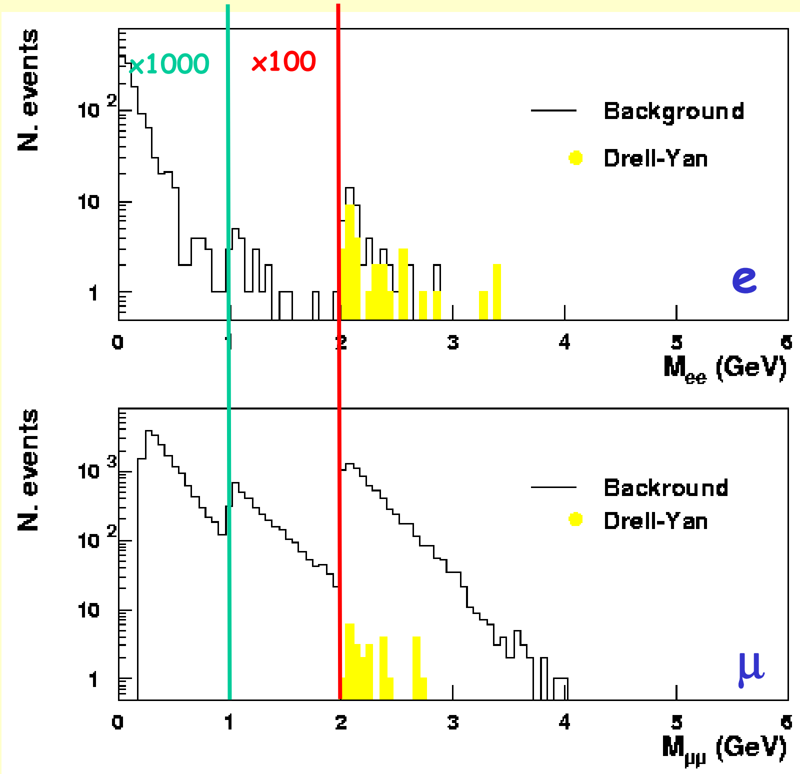
$$h_1 h_2 \equiv \begin{cases} \pi^0 \to e^+e^-\gamma \\ K^{+/-} \to \pi_0 e^{+/-}\nu_e \\ K^0 \to \pi^{+/-}e^{-/+}\nu_e \\ \eta \to \pi^+\pi^-e^+e^- \\ \eta \to \gamma e^+e^- \\ \ldots \end{cases}$$

Prelim. estimation of most of the processes shows background under control.

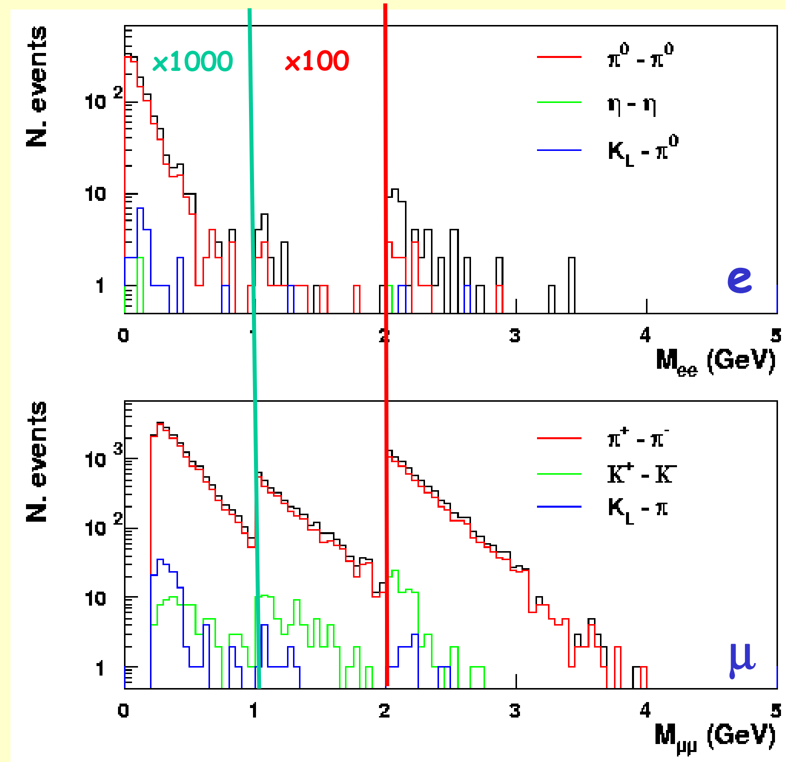
Background for $\bar{p}p \to e^+e^-X$

Preliminary PYTHIA result ($2 \cdot 10^9$ events)

Total background



Background origin



- Background higher for μ than for e
- Background from charge coniugated mesons negligible for e.

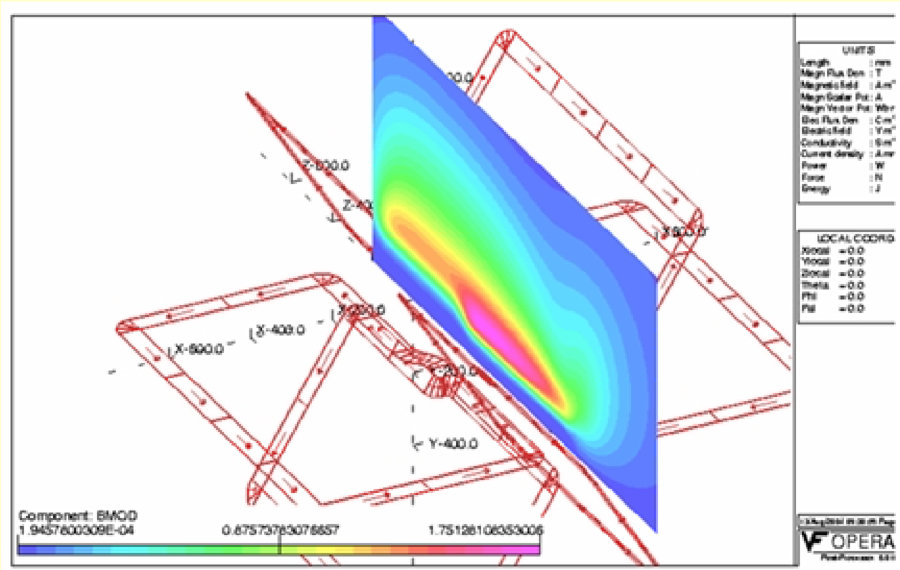
Detector concept

- Drell-Yan process requires a large acceptance detector

- Good hadron rejection needed
  - 10^2 at trigger level, 10^4 after data analysis for single track.

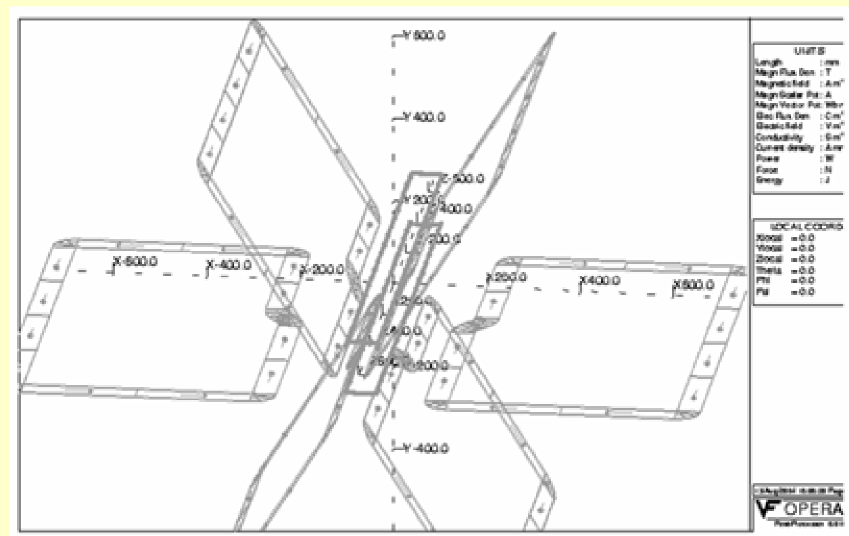
- Magnetic field envisaged
  - Increased invariant mass resolution with respect to simple calorimeter
  - Improved PID through E/p ratio
  - Separation of wrong charge combinatorial background
  - Toroid?
    - Zero field on axis compatible with polarized target.

Possible solution: 6 superconducting coils



- 800 x 600 mm coils
- 3 x 50 mm section (1450 A/mm^2)
- average integrated field: 0.6 Tm
- free acceptance > 80 %

Sperconducting coils for the target do not affect azimuthal acceptance.



(8 coils solution also under study)

- WHY? The physics case
- HOW? Antiproton polarization
- WHERE? The FAIR project at Darmstadt
- WHAT?
  - Transversity measurement by Drell-Yan at PAX
  - Rates
  - Angular distribution
  - Background
  - Detector concept
- WHEN? The time schedule
- Conclusions

Time schedule

Jan. 04	LOI submitted
15.06.04	PACS meeting at GSI
18-19.08.04	Workshop on polarized antiprotons at GSI
15.09.04	Additional document on polarization at GSI
15.01.05	Techn. Report (with Milesones)
	Evaluations & Green Light for Construction
2005-2008	Technical Design Reports (for Milestones)
2012	Commissioning of HESR

Conclusions

- Rich phsysics program accessible with a polarized antiproton beam.

- Polarized antiprotons offer uniquely access to the proton spin.

- Projections for HESR fed by AP:
  - P_{beam} > 0.30 for a stored beam of $5 \cdot 10^{10}$ antiprotons.
  - $L \approx 2 \cdot 10^{31}$ $cm^{-2}s^{-1}$

- Preliminary DY rates background estimation promising for A_{TT}

- Detector concept:
  - Large acceptance detector with a toroidal magnet.

- A collider might represent an attractive perspective.

The world (of hadron physics) needs … PAX

Let's go after it!