SYSTEMATIC STUDY OF SPIN EFFECTS AT THE SPASCHARM EXPERIMENT

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on behalf of the SPASCHARM collaboration

CONTENTS

- Physics goals of the SPASCHARM (SPin ASymmetries in CHARMonium production) experiment
- SPASCHARM Detector
- Polarized proton and anti-proton beam
- First day physics
- Conclusions

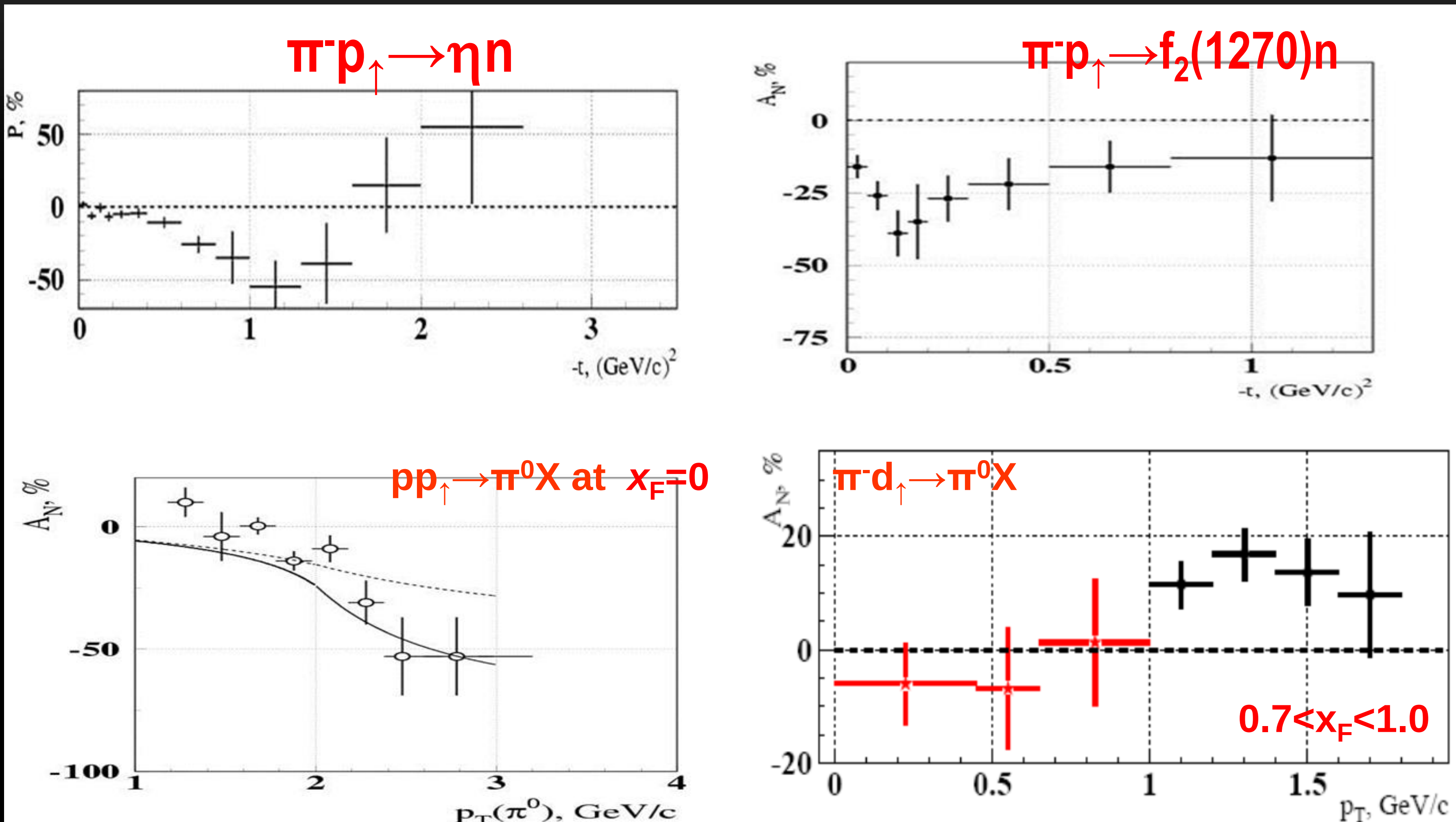
PHYSICS (SHORT)

- **Single–spin asymmeties**: inclusive and exclusive reactions, including elastic, of the light (u, d, s – quarks) hadrons in the beam fragmentation region with polarized beam or target
- The hyperon and vector mesons **polarization** and depolarization
- Study dependence on kinematic values ($0<x_F<1$, $0<p_T<2.5$, $12<E_{Beam}<70$ GeV), event multiplicity and atomic number with high precision due to full azimuthal coverage within the wide aperture
- **Double-spin asymmetry** A_{LL} in charmonium production to study gluon polarization $\Delta G/G(x)$ at large x_F

STAGE 1 PHYSICS

- Systematic study of spin effects for the particles from light (u,d,s) quarks:
  - Single-spin asymmetry in unpolarized beam fragmentation region
    - Exclusive meson production with the registration both neutral and charged particle. Expected asymmetry 30-40% and oscillation.
    - Asymmetry in the reaction $\pi^- p_\uparrow \rightarrow a_0(980)n \rightarrow \eta(550)\pi^0 n$ will be measured for the first timeI
    - Inclusive reactions
    - Hyperon(?) and vector-meson study
- Single spin effects with polarized proton and antiproton beams

EXISTING EXCLUSIVE AND INCLUSIVE MEASUREMENTS



INCLUSIVE STATISTICS WITH Π⁻ -BEAM

№	particle	N_{EV}	B/S	№	Particle	N_{EV}	B/S
1	• π^+	$4.2 \cdot 10^9$		20	$\eta \to \pi^+ \pi^- \pi^0$	$5.3 \cdot 10^6$	0.2
2	π^-	$8.7 \cdot 10^9$		21	$\omega(782) \to \pi^+ \pi^- \pi^0$	$3.5 \cdot 10^7$	0.25
3	K^+	$6.7 \cdot 10^8$		22	$\omega(782) \to \gamma \pi^0$	$3.8 \cdot 10^7$	2.0
4	K^-	$9.0 \cdot 10^8$		23	$\varphi(1020) \to K^+ K^-$	$4.3 \cdot 10^6$	0.3
5	p	$9.2 \cdot 10^7$		24	$\rho^+(770) \to \pi^+ \pi^0$	$2.9 \cdot 10^8$	6.0
6	p·	$2.6 \cdot 10^8$		25	$\rho^-(770) \to \pi^- \pi^0$	$7.5 \cdot 10^8$	3.0
7	n	$3.2 \cdot 10^8$		26	$K^0_S \to \pi^0 \pi^0$	$1.7 \cdot 10^7$	3.5
8	n·	$8.0 \cdot 10^7$		27	$a_0(980) \to \eta \pi^0$	$1.8 \cdot 10^7$	9.0
9	K^0_L	$1.0 \cdot 10^8$		28	$\Lambda \to p \pi^-$	$1.4 \cdot 10^6$	0.1
10	$\pi^0 \to \gamma\gamma$	$4.3 \cdot 10^9$	0.1	29	$\tilde{\Lambda} \to \tilde{p} \pi^+$	$1.1 \cdot 10^6$	0.05
11	$\eta \to \gamma\gamma$	$4.2 \cdot 10^8$	0.5	30	$\Lambda \to n \pi^0$	$1.8 \cdot 10^6$	3.0
12	$\eta' \to \pi^+ \pi^- \eta$	$8.3 \cdot 10^5$	0.05	31	$\tilde{\Lambda} \to \tilde{n} \pi^0$	$7.7 \cdot 10^5$	0.45
13	$K^0_S \to \pi^+ \pi^-$	$1.3 \cdot 10^7$	0.3	32	$\tilde{\Delta}^{++} \to p \pi^+$	$9.3 \cdot 10^6$	2.0
14	$\rho^0(770) \to \pi^+ \pi^-$	$4.2 \cdot 10^8$	2.5	33	$\Delta^{--} \to$ p· π^-	$2.5 \cdot 10^7$	5.5
15	$K^{0*}(892) \to K^+ \pi^-$	$1.1 \cdot 10^8$	0.7	34	$\Xi^- \to \Lambda \pi^-$	$1.9 \cdot 10^6$	0.1
16	$\tilde{K}^{0*}(892) \to K^- \pi^+$	$4.3 \cdot 10^7$	2.0	35	$\tilde{\Xi}^+ \to \tilde{\Lambda} \pi^+$	$1.6 \cdot 10^6$	0.1
17	$K^{+*}(892) \to K^+ \pi^0$	$1.9 \cdot 10^7$	2.6	36	$\Sigma^0 \to \Lambda \gamma$	$1.2 \cdot 10^6$	0.5
18	$\tilde{K}^{-*}(892) \to K^- \pi^0$	$3.8 \cdot 10^7$	1.3	37	$\Sigma^0(1385) \to \Lambda \pi^0$	$3.9 \cdot 10^6$	0.2
19	$\omega(782) \to e^+ e^-$	$1.7 \cdot 10^5$	0.5	38	$\rho^0(770) \to \mu^+ \mu^-$	$9.7 \cdot 10^4$	0.7

SPASCHARM WITH K^- -BEAM AND ANTIPROTONS

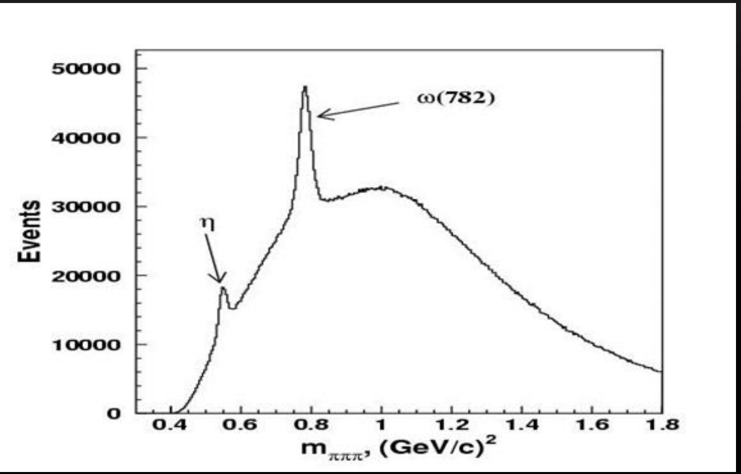
№	particle	N_{EV}	B/S	№	particle	N_{EV}	B/S
1	π^+	$6.7\cdot10^8$		13	$\rho^-(770)\to \pi^- \pi^0$	$7.5\cdot10^7$	3.8
2	π^-	$8.9\cdot10^8$		14	$\eta'\to \gamma\gamma$	$7.3\cdot10^5$	6.0
3	K^+	$8.9\cdot10^7$		15	$\varphi(1020)\to K^+ K^-$	$1.0\cdot10^7$	0.05
4	K^-	$4.0\cdot10^8$		16	$K^{0*}(892)\to K^+ \pi^-$	$1.3\cdot10^7$	1.2
5	p	$6.8\cdot10^7$		17	$\tilde{K}^{0*}(892)\to K^- \pi^+$	$6.6\cdot10^7$	0.8
6	p·	$3.7\cdot10^7$		18	$K^{-*}(892) \to K^- \pi^0$	$3.4\cdot10^7$	2.2
7	n	$6.2\cdot10^7$		19	$\Xi^-\to \Lambda \pi^-$	$2.5\cdot10^6$	0.02
8	$\pi^0\to\gamma\gamma$	$4.2\cdot10^8$	0.13	20	$\Lambda\to p \pi^-$	$1.8\cdot10^6$	0.02
9	$\eta\to\gamma\gamma$	$2.5\cdot10^7$	0.8	21	$\tilde{\Lambda}\to \tilde{p} \pi^+$	$2.9\cdot10^5$	0.08
10	$K^0_S\to \pi^+ \pi^-$	$2.2\cdot10^7$	0.25	22	$\Lambda\to n \pi^0$	$4.0\cdot10^5$	0.6
11	$\rho^0(770)\to \pi^+ \pi^-$	$6.8\cdot10^7$	2.7	23	$\Sigma^-\to n \pi^-$	$3.1\cdot10^6$	5.0
12	$K^0_S\to \pi^0 \pi^0$	$4.2\cdot10^6$	1.1				

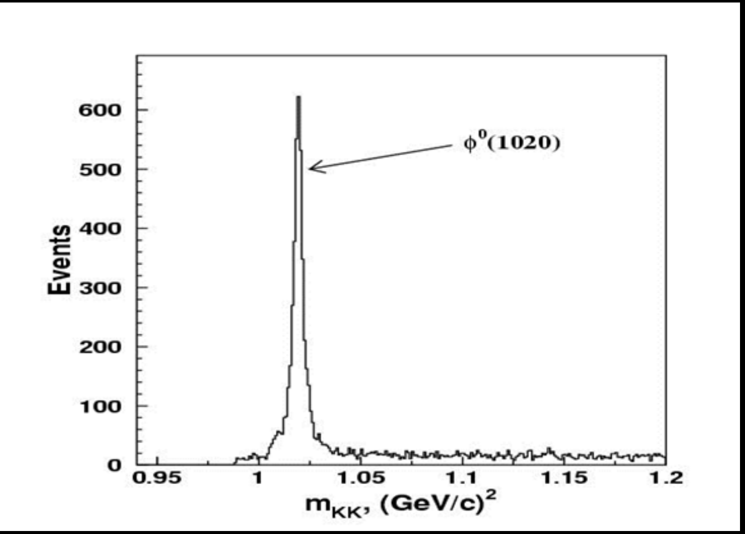
№	частица	N_{EV}	S/B	№	частица	N_{EV}	S/B
1	π^+	$2.1\cdot10^8$		7	n	$1.6\cdot10^7$	
2	π^-	$2.6\cdot10^8$		8	$\tilde{n}$	$1.4\cdot10^8$	
3	K^+	$1.7\cdot10^7$		9	$\tilde{\Lambda}\to \tilde{p}\ \pi^+$	$2.1\cdot10^6$	10
4	K^-	$2.2\cdot10^7$		10	$\tilde{\Lambda}\to \tilde{n}\ \pi^0$	$1.1\cdot10^6$	0.13
5	p	$1.6\cdot10^7$		11	$\tilde{\Delta}^{--}\to \tilde{p}\ \pi^-$	$4.2\cdot10^7$	0.14
6	$\tilde{p}$	$1.8\cdot10^8$		12	$\Xi^-\to \Lambda \pi^-$	$1.0\cdot10^5$	10

EXPECTATIONS (SIMULATIONS) FOR INCLUSIVE REACTIONS

- Asymmetry measurement statistic errors in reactions

  $\pi^- p_\uparrow \to$ ω(782)X, ρX, η'(958)X are 0.3÷3% for different kinematic intervals
- Accuracy in the reaction $\pi^- p_\uparrow \to f_2(1270)$ X is even better (0.1÷1%)



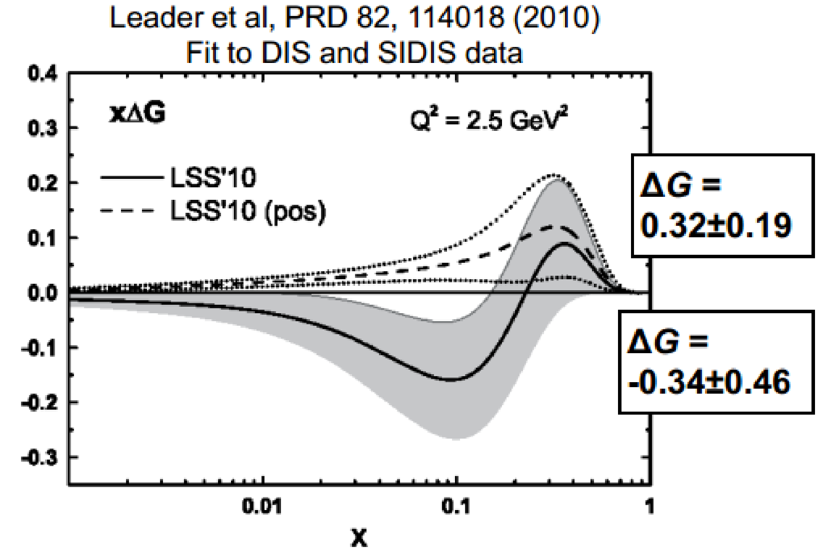


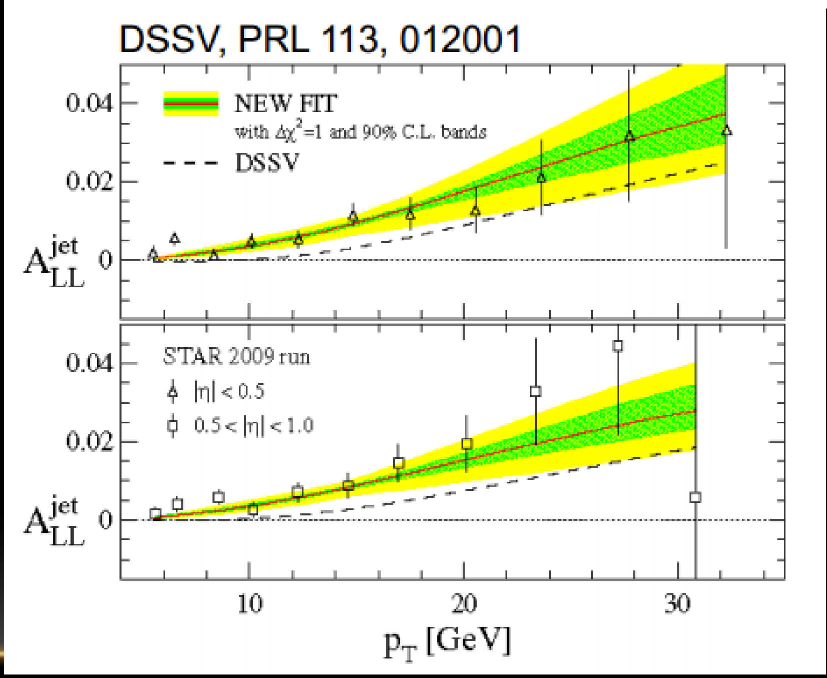
STAGE 2 PHYSICS

- Stage 2 with polarized and un-polarized beams and without polarized target:
  - Single-spin asymmetry A_N in J/ψ and χ_1/χ_2 inclusive production polarized proton beam. Expected statistics (conservative) for 40 days of data taking is:
    - p (40 GeV) beam (10^7 p/cycle): 20000 J/ψ and 2500 χ_1/χ_2 states.
  - Statistic error of J/Ψ asymmetry measurements is 7% for
  - The **cross-section ratio for** χ_1/χ_2 production will be measured to determine the **mechanism of charmonium production using pion and proton beams**.
- Stage 2 with longitudinally polarized beam and target:
  - Double-spin asymmetry A_{LL} measurements to study $\Delta G/G(x)$.
  - A_{NN} measurements for Drell-Yan pairs to study transverslity ***h(x).*** Simultaneously A_{NN} and A_N in J/ψ, χ_1/χ_2. production will be studied.
  - Double spin asymmetry measurements at different channels

PROTON SPIN STRUCTURE

- EMC, HERMES, CMS discovered, that spin of the proton is not the sum of quark spins (only 30%)
- Gluon contribution seems also small (between 0 and 20%)
- Orbital moment contribution is required
- Nevertheless RHIC announced first observation of non-zero ΔG/G. evidence for positive gluon polarization:
  - 0.23 ± 0.07 for 0.05 < x < 0.5
  - 0.19 ± 0.05 – this Conference

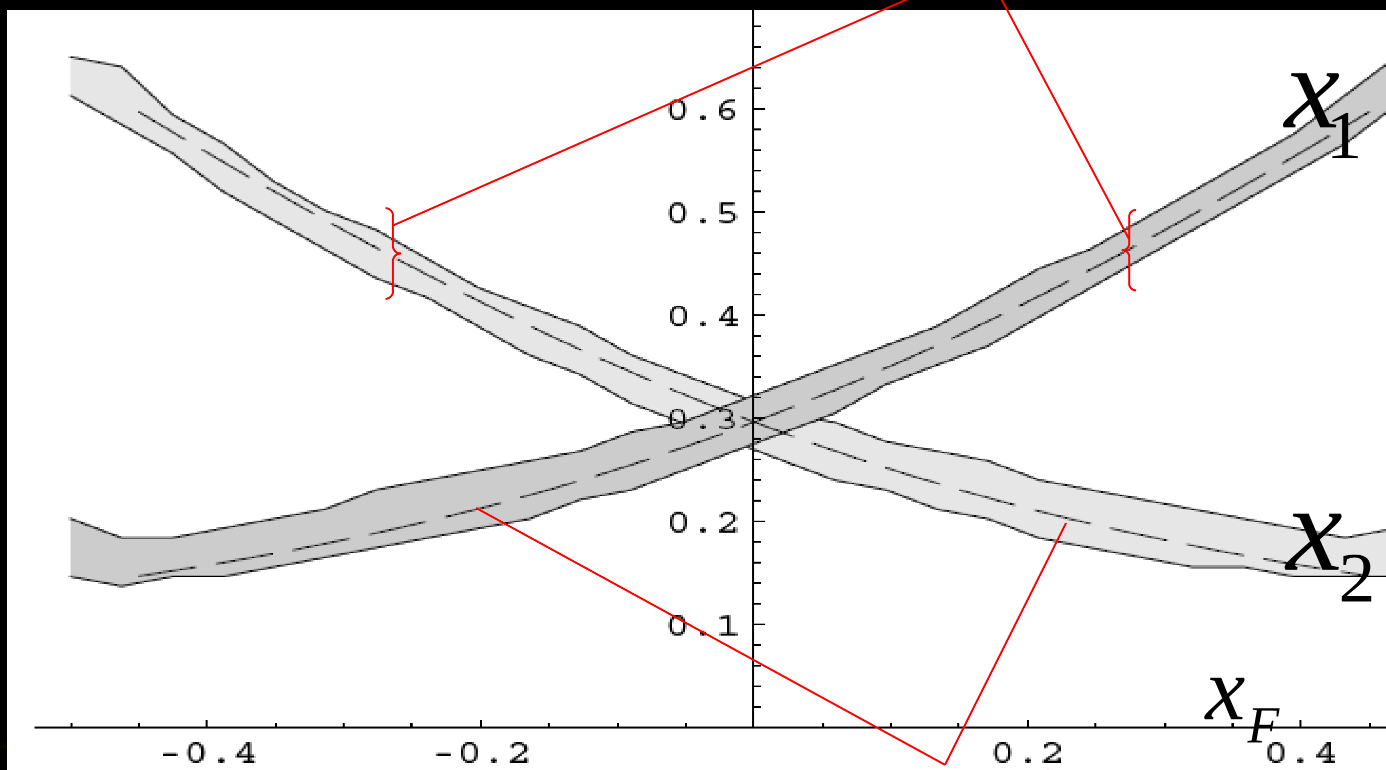




REGISTERED $X_F \rightarrow (X_1, X_2)$

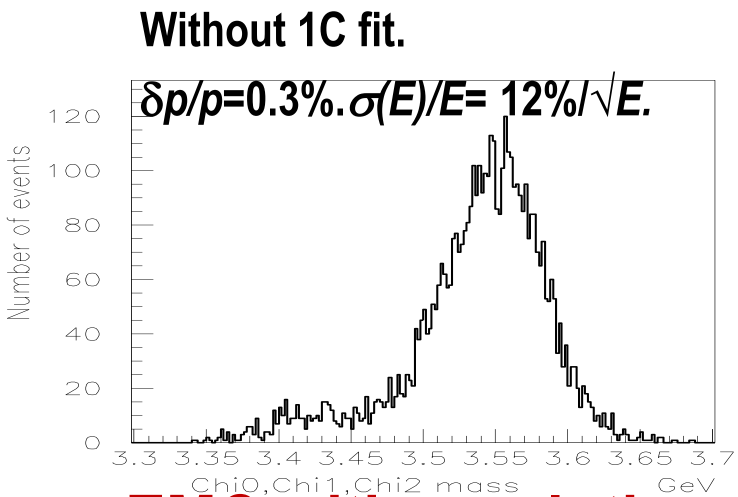
$$x_F = \frac{\hat{s} - M^2}{2\hat{s}}(x_1 - x_2) + \frac{\hat{s} - M^2}{2\hat{s}}\cos\hat{\theta}_{13}(x_1 + x_2) \Rightarrow x_{1,2} = \frac{1}{2}\left(\sqrt{x_F^2 + \frac{4\hat{s}}{s}} \pm x_F\right)$$

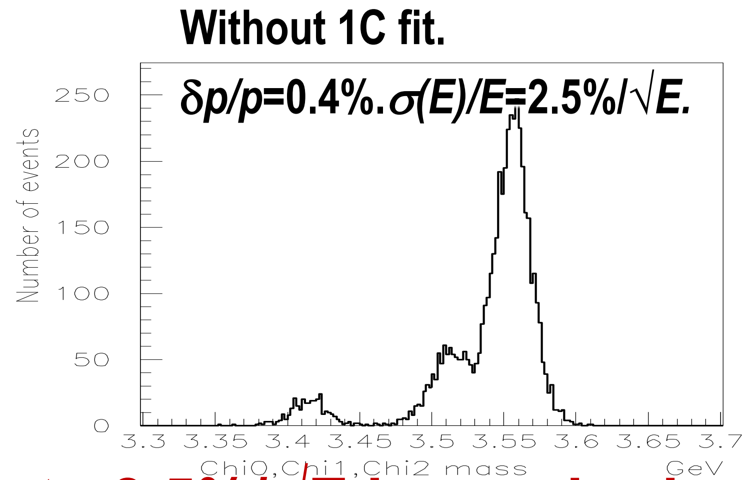
$$\frac{d^2\sigma}{dx_F dx_{1,2}} > \frac{1}{2}\left(\frac{d^2\sigma}{dx_F dx_{1,2}}\right)_{max}$$



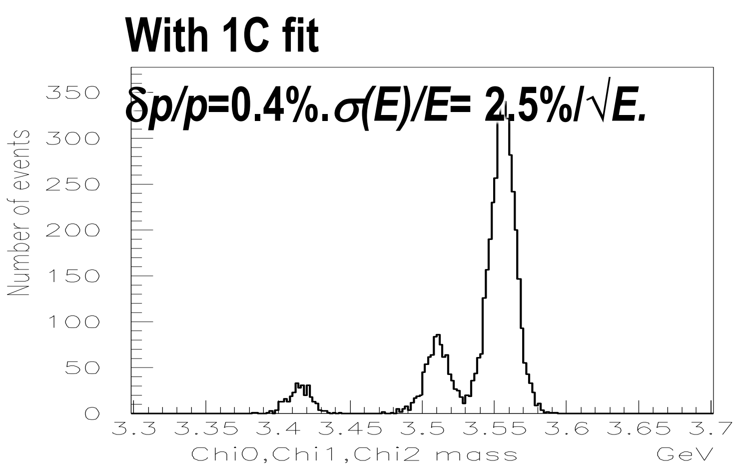
$\hat{s} = 1.3M^2$

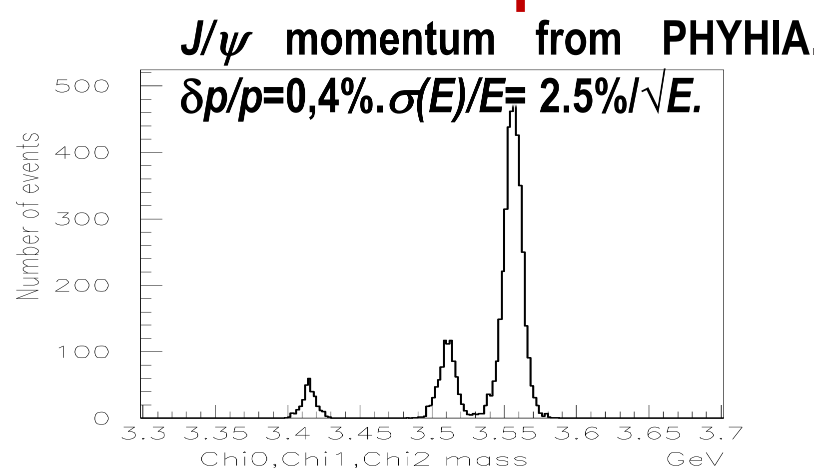
CHARMONIUM MONTE-CARLO SIMULATION



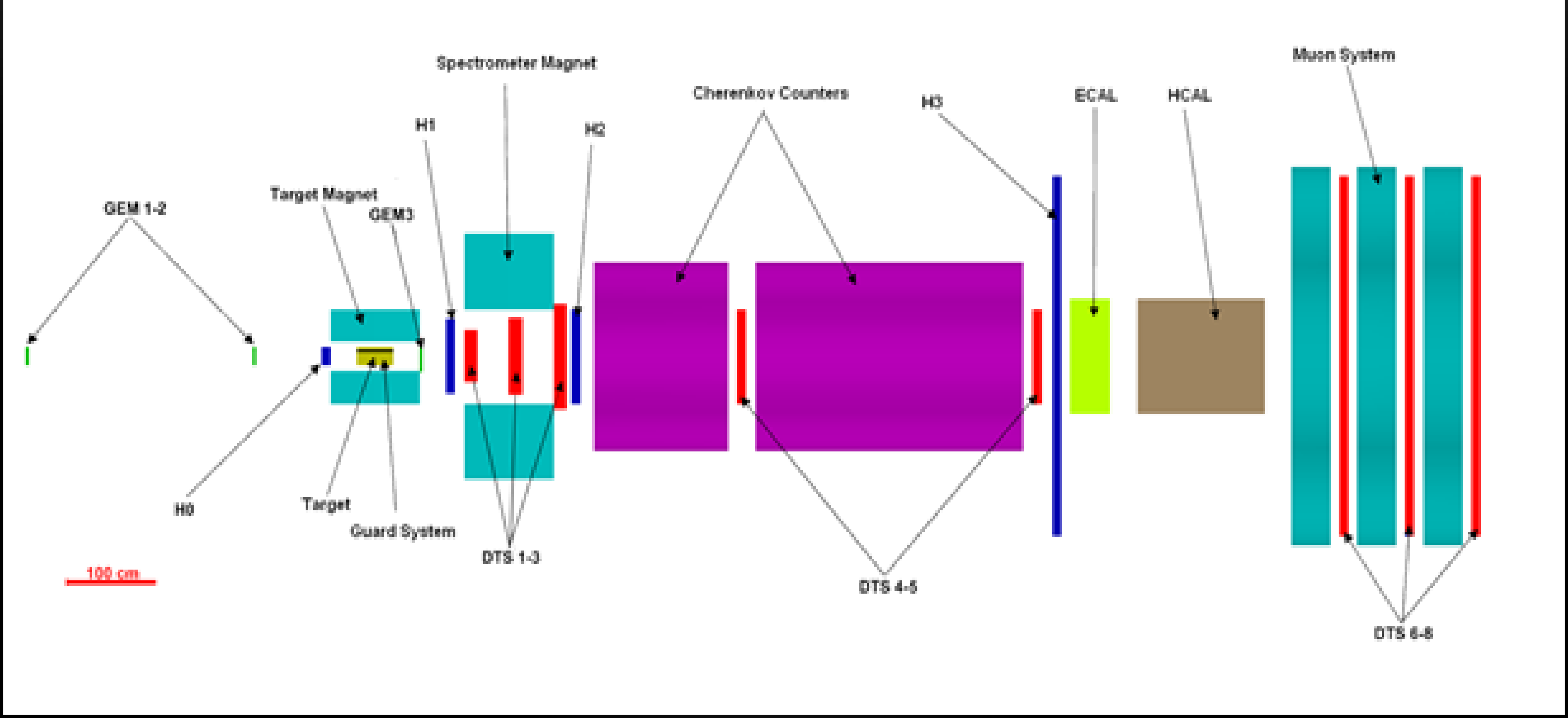


EMC with resolution close to 2.5%/√E is required





SPASCHARM SETUP – MULTIPURPOSE DETECTOR



DETECTOR DESCRIPTION

- Tracking system ΔP/P=0.4% at 10 GeV/c:
  - Spectrometer magnet (1.5 Tm Field), full aperture 250x500 mrad,
  - 2 GEM stations,
  - 5 thin-wall drift tube chamber stations (20 plates, 60 sub-planes)
- Particle identification
  - Cherenkov 1: pions above 3 GeV/c, kaons above 11 GeV/c,
  - Cherenkov 2: pions above 6 GeV/c and kaons above 23 GeV/c,
  - Hodoscopes as TOF (p/K-separation up to 2.5 GeV, K/pi up to 1.5 GeV)

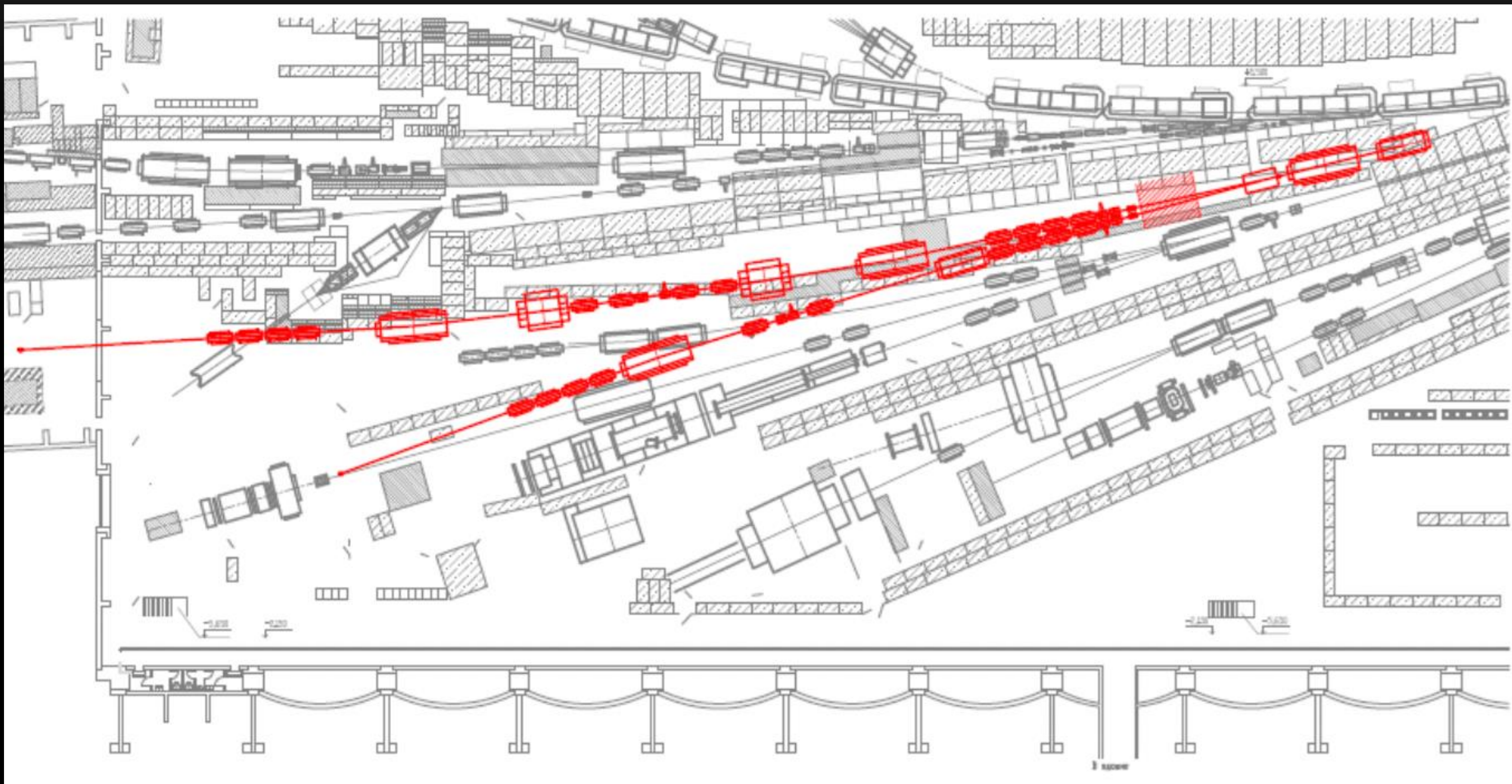
DETECTOR 2

- Calorimetry:
  - Fine-segmented lead-scintillator electromagnetic calorimeter (shashlyk-type): $\sigma(E)/E=1.3\oplus2.8/\mathrm{sqrt}(E)$, 5.5x5.5 cm cell size (Full transverse size 2x3 m)
  - Compensated lead-scintillator hadron-calorimeter (sandwich, 7 int. length, about 50/sqrt(E))
- Muon detector
- Beam detectors: 2 Scintillation fiber hodoscopes (fiber width 0.44 cm), GEM station, Threshold Cherenkov counters
- Polarimetry
  - Tagging system in the intermediate focus, beam momentum measurements and absolute polarimeter (P.Semenov, Talk on Monday)

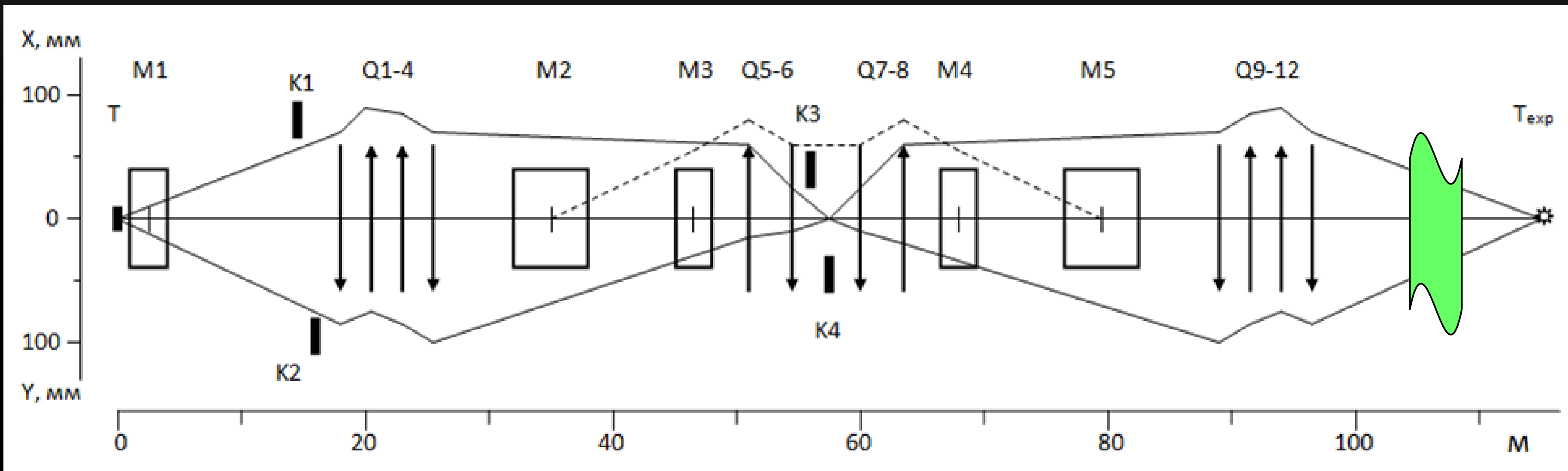
SPASCHARM POLARIZED BEAM OPTION

- Beam will be delivered to external target (up to $2{\cdot}10^{13}$ p/cyc.) to create secondary beams in the beam-line 24
  - 24A – polarized beam channel (polarized protons and antiprotons, unpolarized hadron and electron beams)
  - 24B – unpolarized hadron and electron beams

SPASCHARM BEAM-LINE 24A



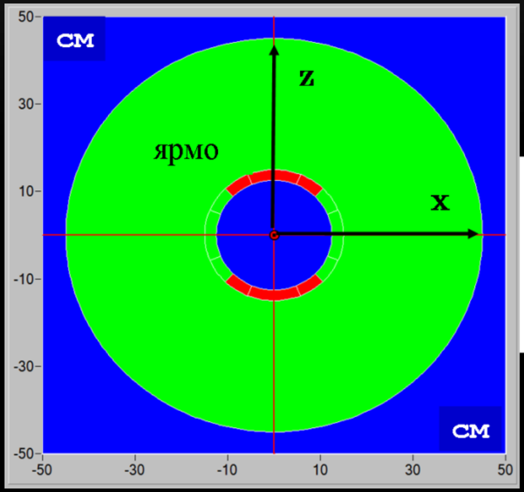
OPTICAL SCHEME CHANNEL 24A



Main optic scheme for polarized beam p≤40 GeV/c from hyperon-decay. *Q – quads, M – dipoles K – collimators, T , T_{exp} – targets (channel and experiment), green – spin flipper (Novosibirsk - Shatunov – see SPIN2012)*

Polarimetry was discussed in P.Semenov Talk (Monday)

SPIN FLIPPER (SHATUNOV TALK)



2 Helical magnets:

B_{max} = 47 kGs; λ= 2.5 m

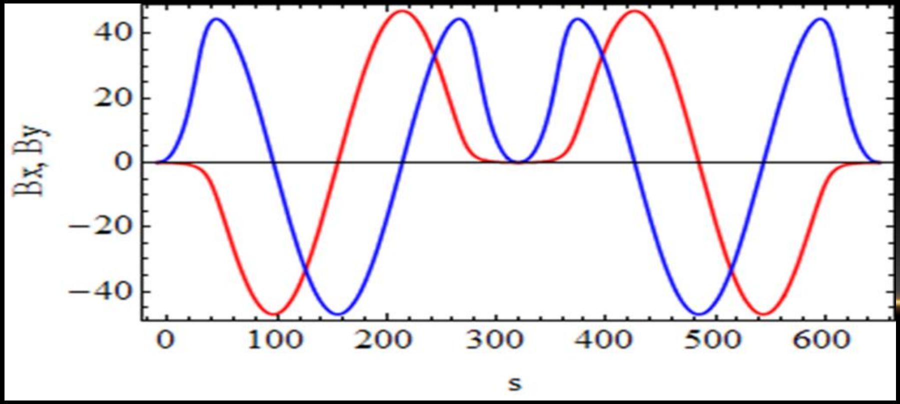
Correctors:*L*=30 cm; B= 23 kGs;

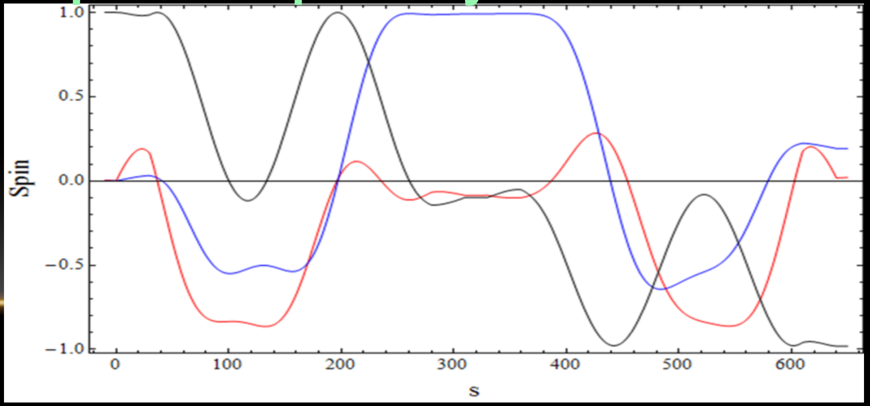
tilt = ± 0.1 rad;

Total length 6.5 m

Flipper optics: practically is equal to empty straight 6.5 m;

Spin transparency ≈ 97%





POLARIZED PROTON BEAM 40 GEV/C

Momentum collimator position	Min	Max
Momentum spread $\Delta p/p$, %	±4.5 (σ=2.1)	11.0 (σ=5.3)
Beam size, $\sigma_X \times \sigma_Y$, mm	13 × 11	17 × 14
Beam divergence $\sigma_X \times \sigma_Y$, mrad	1.6 × 2.0	1.5 × 1.9
Full intensity for 10^{13} protons in the target at 60 GeV	4.9×10^7	1.3×10^8

Polarized proton beam energy may vary between 12 and 50 GeV

POLARIZED ANTIPROTON BEAM (14 GEV/C)

Momentum collimator position	Min	Max
Momentum interval $\Delta p/p$, %	± 5.5 (σ=2.3)	12.0 (σ=5.6)
Beam size, $\sigma_X \times \sigma_Y$, mm	18 × 19	20 × 19
Beam divergence $\sigma_X \times \sigma_Y$, mrad	1.6 × 1.9	1.5 × 2.0
Full intensity for 10^{13} protons	1.4×10^5	3.9×10^5

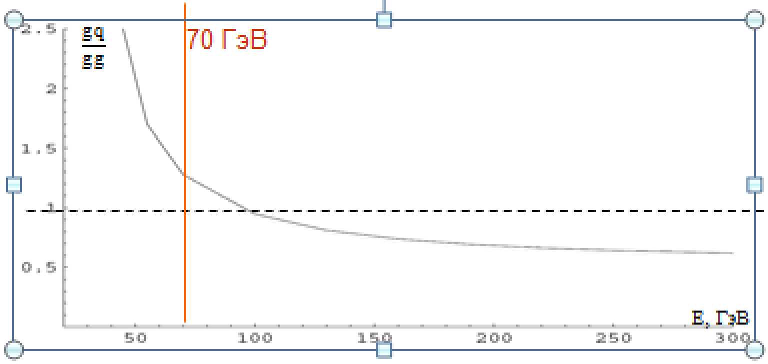
Anti-proton P, GeV/c	Full anti-proton beam intensity for 10^{13} p/cyc. @ ext. target
10	1.9×10^5
14	3.9×10^5
20	3.4×10^5
30	9.3×10^4
40	1.6×10^4

WHY ANTI-P P IS INTERESTING?

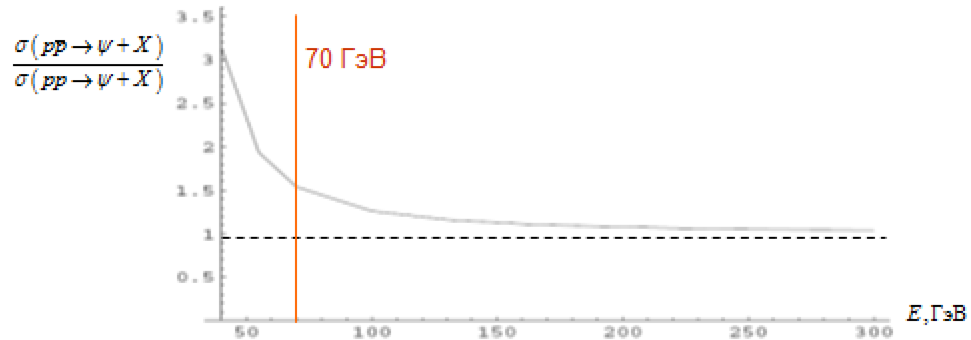
1. Simply there are no (almost) data.
2. Direct access to annihilation channel (pp reactions give mainly access to *qg* processes and *gg*-processes):
   - Access to "heavy" (*c,s*) quarks…, light glueballs (if higher intensity - exotics, hybrids…)
   - Access to the nucleon spin structure (DY, transversity…)
   - Even Possibility to search for CP violation in polarization experiments (not SPASCHARM task)

COMBINATION OF P-P,PI-P AND ANTI-P-P STUDIES

$$\sigma^{pp}(Q) = \sigma^{pp}_{gg}(Q) + 2\left[\sigma^{pp}_{ug}(Q) + \sigma^{pp}_{dg}(Q)\right] + \text{море}$$



$$\sigma^{p\bar{p}}(Q) = \sigma^{p\bar{p}}_{gg}(Q) + 2\left[\sigma^{p\bar{p}}_{ug}(Q) + \sigma^{p\bar{p}}_{dg}(Q)\right] + \sigma^{p\bar{p}}_{u\bar{u}}(Q) + \sigma^{p\bar{p}}_{d\bar{d}}(Q) + \text{море}$$



Charmonium J/ψ and χ_1/χ_2 production:
In pp-reaction q-q(bar) contribution is less than 10%,
In pp(bar)– qq-bar annihilation gives 95% contribution
Similar behavior for ϕ(1020) meson(?)

SPASCHARM SCHEDULE

- SPASCHARM
  - 2014 – Setup commissioning
  - 2014-2016 – SSA measurements with the new Dubna polarized target at the beam-line 14
  - 2017 – Transition to the beam-line 24
  - 2017 – Start of the SSA measurements with the polarized beam
- Polarized beam at the beam-line 24
  - 2014 – Final design
  - 2015-2016 – Construction
  - 2017 - Commissioning

SPASCHARM "FIRST DAY" EXPERIMENTS

- "First Day" – 3 years of measurements:
- 2015 – Single spin asymmetry in charge pion production ($\pi^{\pm}$ and their combinations-ρ…)
- 2016 – combination of neutral and charged pions (η, η', $\omega(783)$, a0(980), f2(1270), …) both inclusive and exclusive.
- 2016-2017 – Kaon kombination ($K^{\pm}$, ϕ…) and moving to polarized beam channel

THE SPASCHARM TEAM

- IHEP, Protvino: V.Abramov, A.Afonin, N.Belikov, A. Borisov, S.Bukreeva, A.Chernichenko, P.Chirkov, V.Garkusha, Y.Goncharenko, V.Grishin, A.Davidenko, A.Derevschikov, R.Fahrutdinov, Y.Fedotov, V.Ilyukin, V.Kachanov, Y.Karpekov, V.Kartashev, V.Kharlov, Y.Khodyrev, A.Kozhin, S.Kozub, V.Kormilitsin, E.Lyudmirsky, Y.Melnik, A.Meschanin, N.Minaev, A.Minchenko, V.Mochalov, D.Morozov, L.Nogach, S.Nurushev, V.Petrov, A.Prudkoglyad, A.Ryazantsev, S.Ryzhikov, P.Semenov, V.Senko, N.Shalanda, I. Shein, M. Soldatov, L.Soloviev, A.Sukhih, A.Uzunian, A.Vasiliev, A.Vovenko, V. Yakimchuk, A.Yakutin, V.Zarucheisky, V.Zapolsky
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CONCLUSIONS

- New experiment SPASCHARM, devoted to systematic study of polarization phenomena in hadron-hadron interactions, is under preparation (commisioning is started)
- Detection of charged and neutral particles in the final state in a wide solid angle will allow to explore dozens of reactions (spin PDG) using different beams and targets
- A special feature of the experiment is the simultaneous measurements of different spin-dependent physical observables (SSA, the polarization of hyperons, the spin density matrix elements for vector mesons, spin transfer parameters)
- Polarized anti-proton beam gives us unique possibility

CONCLUSIONS-2

- The Setup allows to detect particles kinematic parameters with high precision, which is crucial for charmonium study as well as for the separation of resonances from combinatorial background
- SPASCHARM will measure polarization effects with unprecendent accuracy, especially with polarized beam
- SPASCHARM will start physics in 2014 (2017(?) with polarized beam)
- We are expecting to present first physics result next SPIN-2016