PANDA experiment status

С.Белостоцкий

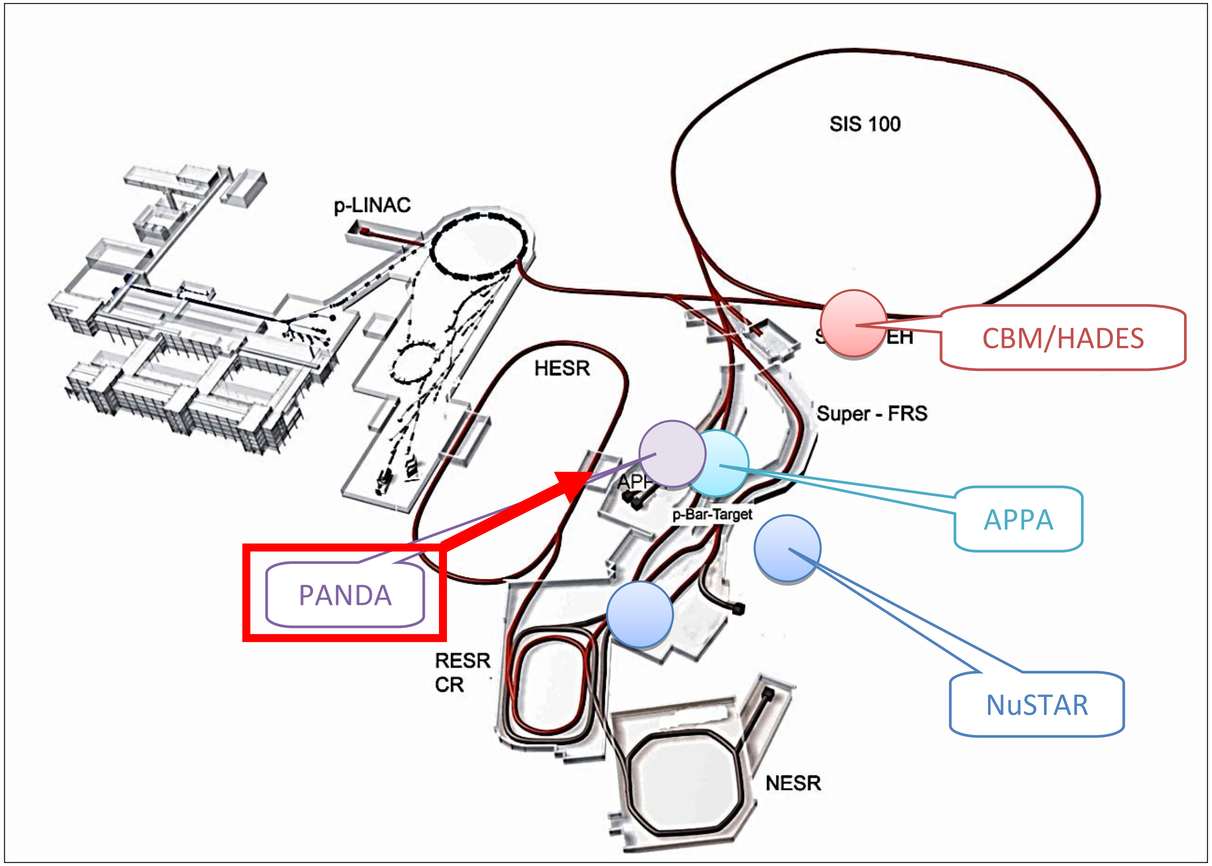
ОФВЭ , 26 марта 2013

Accelerator facilities and experiments @GSI

FAIR **F**acility for **A**ntiproton and **I**on **R**esearch

Experiments

M1: APPA
M1: CBM/HADES
M2: NuSTAR
M3: PANDA



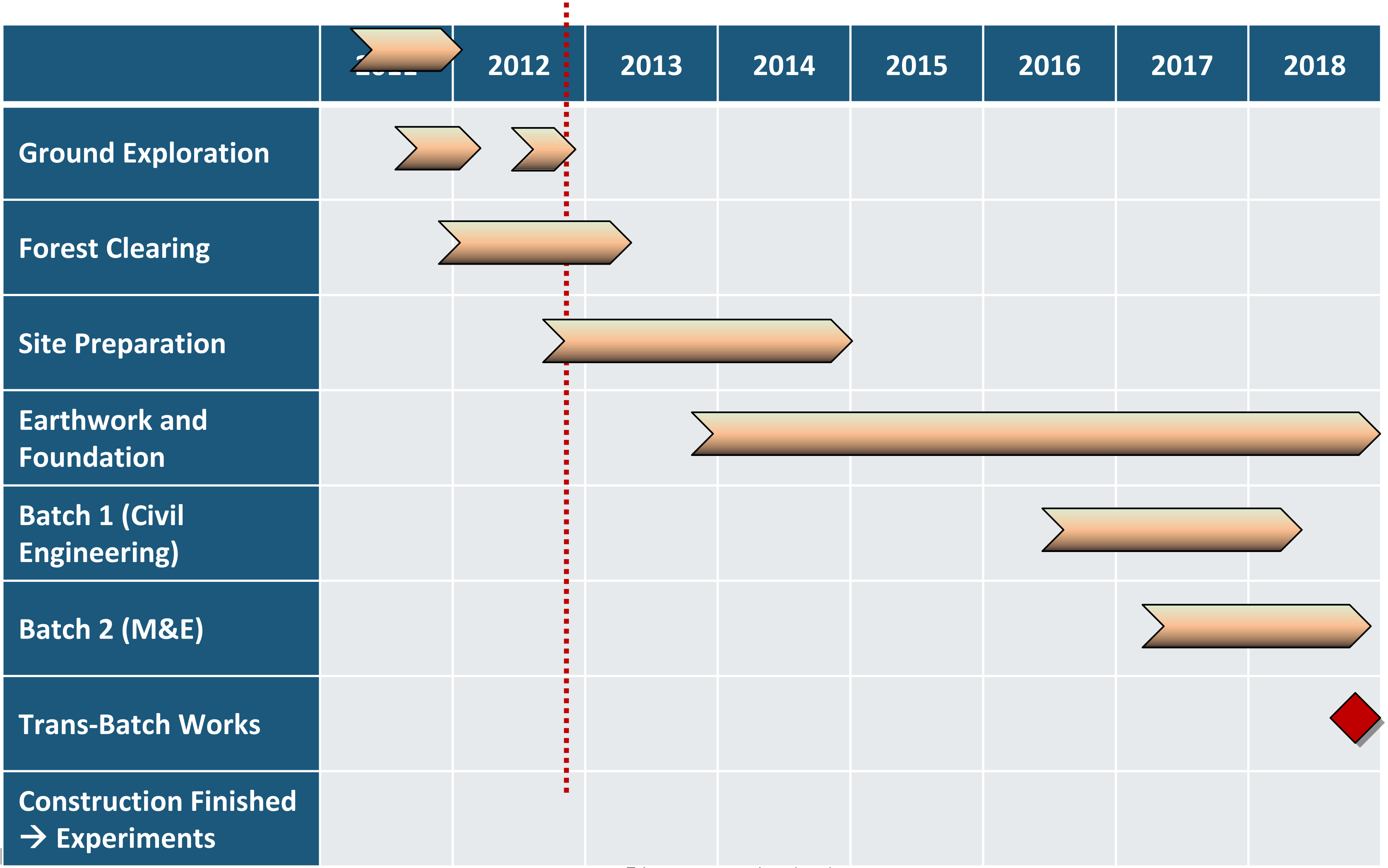
Important contribution

- 526 M€ German contribution to civil construction
  - largest BMBF grant ever
  - approved in July 2014

FAIR operation cost

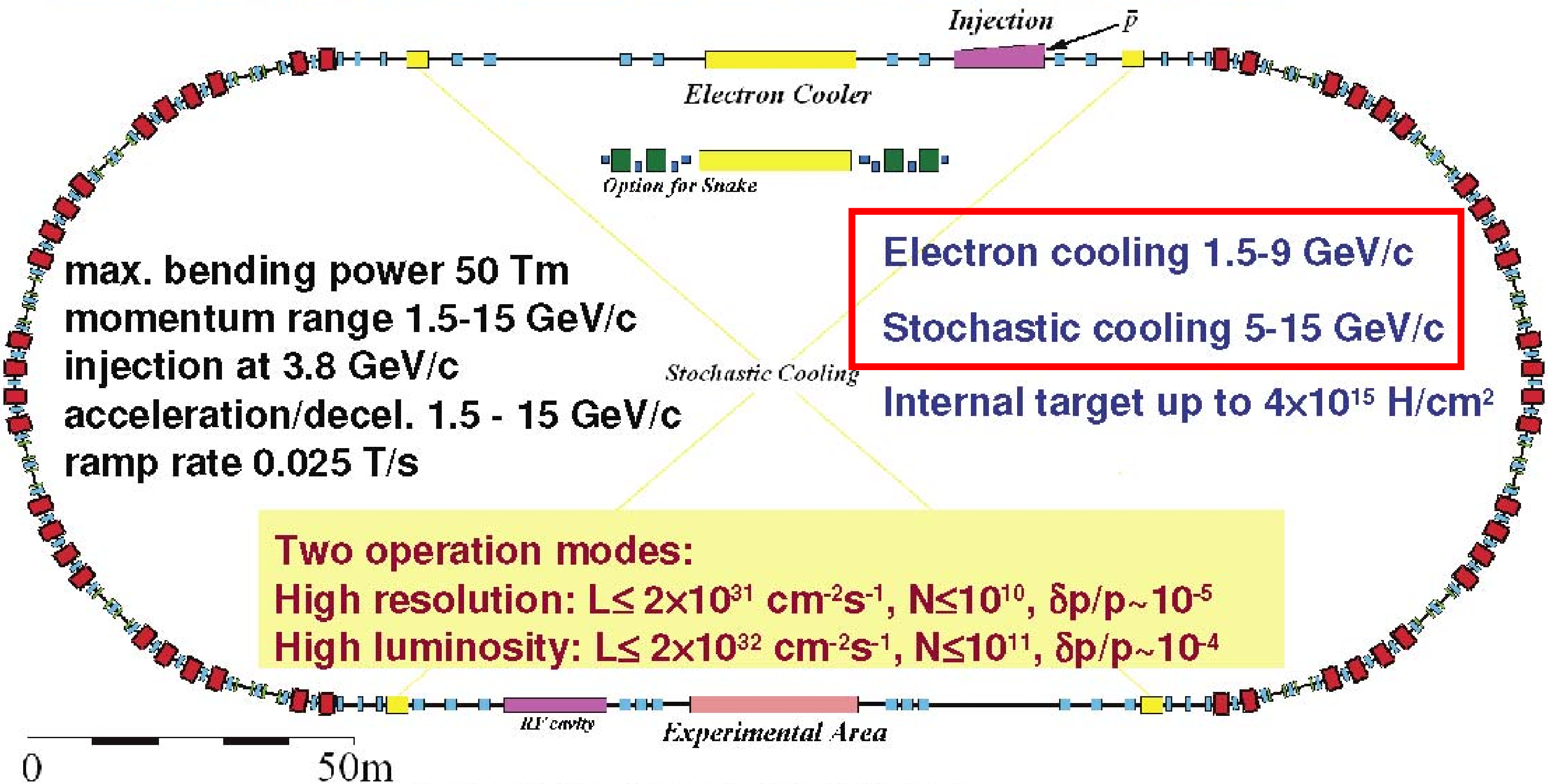
118 M€ per year

Roadmap Civil Construction



The High Energy Storage Ring HESR

designed by a consortium between FZ Jülich, TSL Uppsala, GSI



max. bending power 50 Tm
momentum range 1.5-15 GeV/c
injection at 3.8 GeV/c
acceleration/decel. 1.5 - 15 GeV/c
ramp rate 0.025 T/s

Electron cooling 1.5-9 GeV/c

Stochastic cooling 5-15 GeV/c

Internal target up to 4×10^{15} H/cm^2

Two operation modes:
High resolution: $L\leq 2\times10^{31}$ cm^{-2}s^{-1}, $N\leq10^{10}$, $\delta p/p\sim10^{-5}$
High luminosity: $L\leq 2\times10^{32}$ cm^{-2}s^{-1}, $N\leq10^{11}$, $\delta p/p\sim10^{-4}$

straight sections of 132 m length
ring circumference 574 m.

Main HESR parameters

Experimental Requirements	
Ion species	Antiprotons
$\overline{p}$ production rate	$2 \cdot 10^7$ /s ($1.2 \cdot 10^{10}$ per 10 min)
Momentum / Kinetic energy range	1.5 to 15 GeV/c / 0.83 to 14.1 GeV
Number of particles	10^{10} to 10^{11}
Target thickness	$4 \cdot 10^{15}$ atoms/cm^2 (H_2 pellets)
Transverse emittance	< 1 mm $\cdot$ mrad
Betatron amplitude E-Cooler	25–200 m
Betatron amplitude at IP	1–15 m

Operation Modes	
High resolution (HR)	Luminosity of $2 \cdot 10^{31}$ cm^{-2}s^{-1} for 10^{10} $\overline{p}$ rms momentum spread $\sigma_p/p \leq 2 \cdot 10^{-5}$, 1.5 to 9 GeV/$c$, electron cooling up to 9 GeV/c
High luminosity (HL)	Luminosity of $2 \cdot 10^{32}$ cm^{-2}s^{-1} for 10^{11} $\overline{p}$ rms momentum spread $\sigma_p/p \sim 10^{-4}$, 1.5 to 15 GeV/c, stochastic cooling above 3.8 GeV/c

Invariant mass $M(p\overline{p}) = m_p \sqrt{\mathbf{2(1+\gamma_p}}$ $\gamma_p = \frac{E_p}{m_p}$ $\mathbf{2.25} < M(p\overline{p}) < \mathbf{5.46}\,\mathrm{GeV}$

PANDA detector

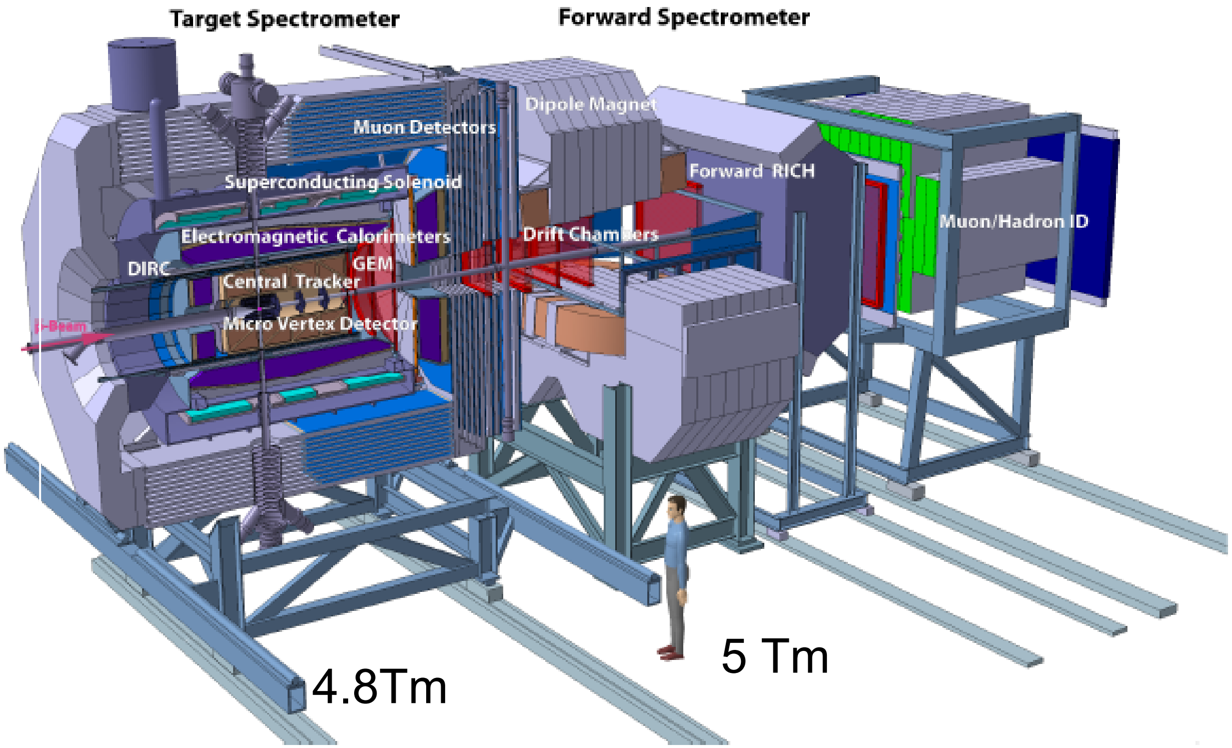


Figure 2.1: Artistic view of the $\overline{\text{P}}$ANDA Detector

- ❑ 100 KeV mass resolution by beam momentum scan
- ❑1% produced particle momentum resolution
- ❑ $2x10^7$ s^{-1} event rate capability
- ❑stand 10^{32} cm^{-2} s^{-1} inst. luminosity
- ❑nearly 4π acceptance, high detection efficiency
- ❑secondary vertex reconstruction for D, K^0_S, Λ ($c\tau$ = 317 μm for $D^{\pm}$)
- ❑PID (γ, e, μ, π, K, p)
- ❑photon detection 1 MeV – 10 GeV
- ❑beam deflection 2.2deg.

Targets: pellet H(D) target

frozen drops of 25-40μm, controlled position;
Target station for hyper-nucleus physics;
Wire targets for pbar-A interaction
He3 polarized target (under design)

Total integrated luminosity about 1.5 fb^{-1} /6 months with 50% run efficiency

PANDA Collaboration

(AntiProton ANnihilation at DArmstadt)

more than 500 participants from 8 Europian countries (Germany, Russia, Italy,France,…) and from China, India, USA

PANDA main documents

Public Letter of Intent 2004
Letter of Intent 2004
Public Technical progress report 2005
Full Technical progress report 2005
Physics Performance Report 2009

TDRs

EMC Technical Design Report”
Magnets Technical Design Report
Micro Vertex Detector Technical Design Report
Straw Tube Tracker Technical Design Report
Targets Technical Design Report
Muon Detectors Technical Design Report

Expected 16 more

PANDA Physics

- Hadron spectroscopy in the region of charm quarks.
  High mass/width resolution measurements

$\bar{p}p \to \bar{c}c$ states

$\bar{c}c \to J/\Psi\pi^+\pi^-, J/\Psi\gamma\gamma, \ldots$

- Further exploration of recently found X,Y,Z (CCbar like) states.
  Search for exotic states like hybrids, glueballs, multiquarks

- Study of properties of hadrons inside nuclear matter. Mass
  and width modifications also in charm region

- Study of proton structure – time-like form factors.

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

  Study of GPDs in time-like Hand Bag approach

$\bar{p}p \to \gamma\gamma, \gamma\gamma^* \quad \gamma^* \to e^+e^-$

- Pertubative and non-pertubative dynamics in hyperon
  production including spin.
  Direct CP violation in hyperon decay.

$\bar{p}p \to \bar{Y}Y$

$Y = \Lambda, \Sigma, \Xi, \ldots \Lambda_c \ldots \Omega_c$

$\alpha_\Lambda \neq -\alpha_{\bar{\Lambda}}$

- ΛΛ hypernucleus

Colliders and experiments active in hadron, C and B physics

$L = \mathbf{2{\bullet}10^{34}}\ cm^{-2}s^{-1}$ world record

e^+e^- colliders

VEPP-4M	BINP, Novosibirsk	1994-	Circular, 366m	6.0 GeV	6.0 GeV	KEDR	Precise measurement of Υ-meson masses
PEP-II	SLAC	1998–2008	Circular, 2.2 km	9 GeV	3.1 GeV	BaBar	Discovery of CP violation in B meson system
KEKB	KEK	1999–2009	Circular, 3 km	8.0 GeV	3.5 GeV	Belle	Discovery of CP violation in B meson system
CESR-c	Cornell University	2002–2008	Circular, 768m	6 GeV	6 GeV	CHESS, CLEO-c BES τ-factory	

Essential feature of $e^+ e^-$ colliders   e+ e- → γ^* restricted to $\mathbf{1}^{--}$ state only

Hadron colliders

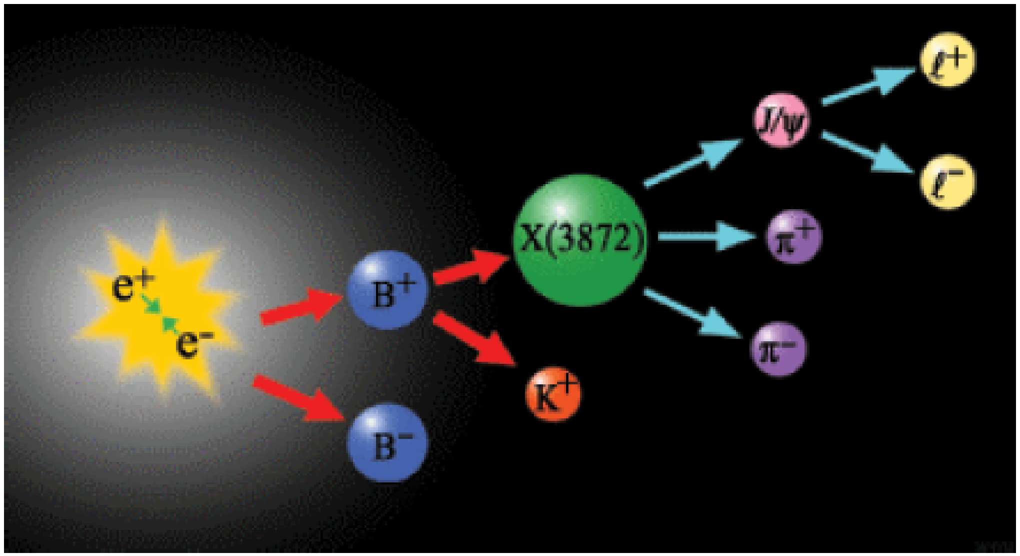
Tevatron Run I	Fermilab	1992–1995	Circular ring (6.3 km around)	Proton/ Antiproton	900 GeV	CDF, D0
Tevatron Run II	Fermilab	2001–2011	Circular ring (6.3 km around)	Proton/ Antiproton	980 GeV	CDF, D0

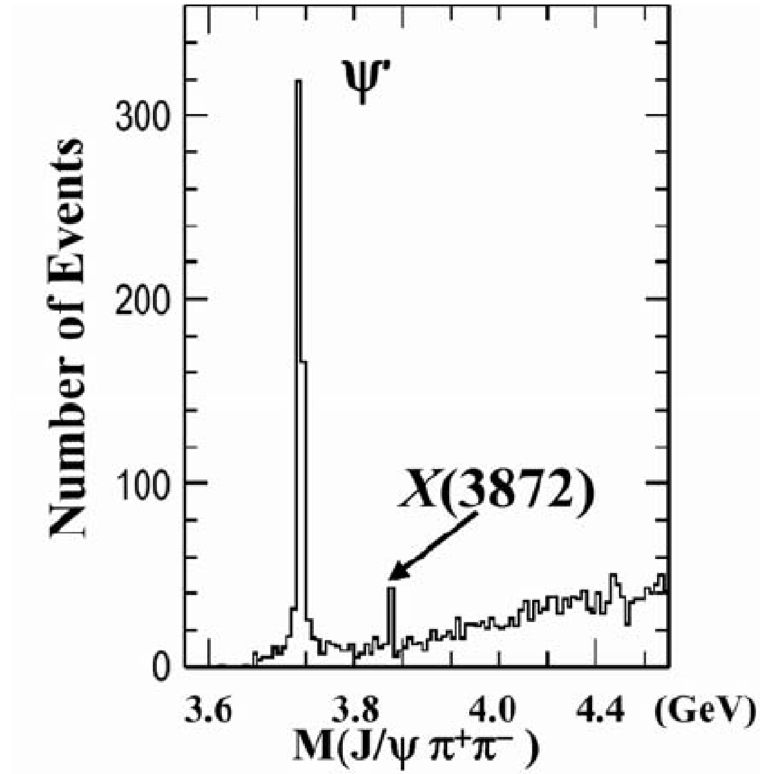
LHCb (LHC pp collider) $L \sim \mathbf{10^{32} - 10^{33}},\ \sim \mathbf{10^{12}}\ b\bar{b}$ / year

Pbar P fixed-target @FNAL E835 (recently shutdown)

Charm (C Cbar) physics.
Hybrids, gluons.

Belle KEKB electron-positron collider
X(3872)





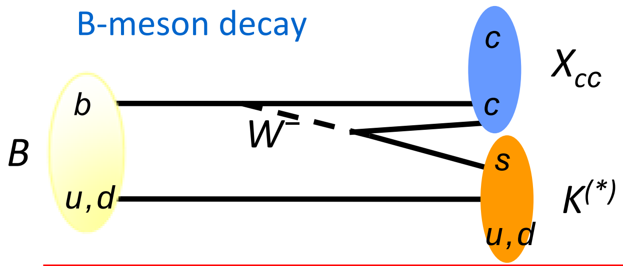
Assumed to be CCbar state,
however
X(3872) structure is not understood till now:
4-quark, DDbar molecule, change color force structure…

Belle 2003
(BaBar 2005)

The XYZ States, more not understood…

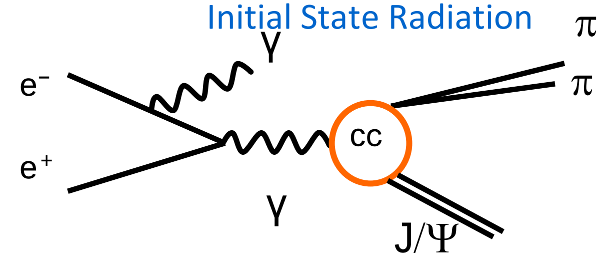
Over past few years a wealth of new states has been discovered, mostly at the B-factories, in the region above open charm threshold. These states are usually associated to charmonium, because they decay into charmonium, but their nature is not at all understood.

B-meson decay



X(3872) Belle, Babar, Cleo, CDF, D0
Y(3940) Belle, Babar
Y(4140)? CDF
Z(4430)
Z_1(4050)
Z_2(4250)
} Belle

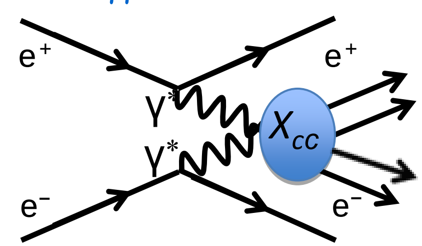
Initial State Radiation



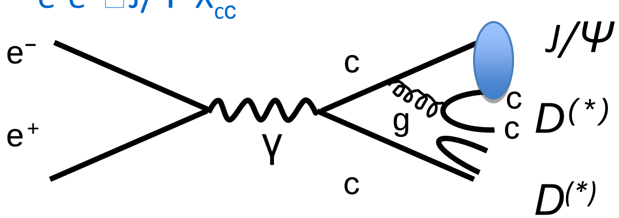
1^{--} states
X(4008)? Belle
Y(4260) BaBar, Belle, Cleo
Y(4350) BaBar, Belle
Y(4660) Belle

X(3915) Belle
Z(3930) Belle
Y(4350) Belle

γγ-collisions



Associate production
$e^+e^- \to J/\Psi\ X_{cc}$



X(3940) Belle
X(4160) Belle

CCbar states predicted and observed

$c\bar{c}$	
	$I^G(J^{PC})$
$\eta_c(1S)$	$0^+(0^{-+})$
$J/\psi(1S)$	$0^-(1^{--})$
$\chi_{c0}(1P)$	$0^+(0^{++})$
$\chi_{c1}(1P)$	$0^+(1^{++})$
$h_c(1P)$	$?^?(1^{+-})$
$\chi_{c2}(1P)$	$0^+(2^{++})$
$\eta_c(2S)$	$0^+(0^{-+})$
$\psi(2S)$	$0^-(1^{--})$
$\psi(3770)$	$0^-(1^{--})$

X(3872)	$0^?(?^{?+})$
X(3915)	$0^+(?^{?+})$
$\chi_{c2}(2P)$	$0^+(2^{++})$
X(3940)	$?^?(?^{??})$
$\psi(4040)$	$0^-(1^{--})$
$X(4050)^{\pm}$	$?(?^?)$
X(4140)	$0^+(?^{?+})$
$\psi(4160)$	$0^-(1^{--})$
X(4160)	$?^?(?^{??})$
$X(4250)^{\pm}$	$?(?^?)$
X(4260)	$?^?(1^{--})$
X(4350)	$0^+(?^{?+})$

DDbar Thresold 3729.7 MeV

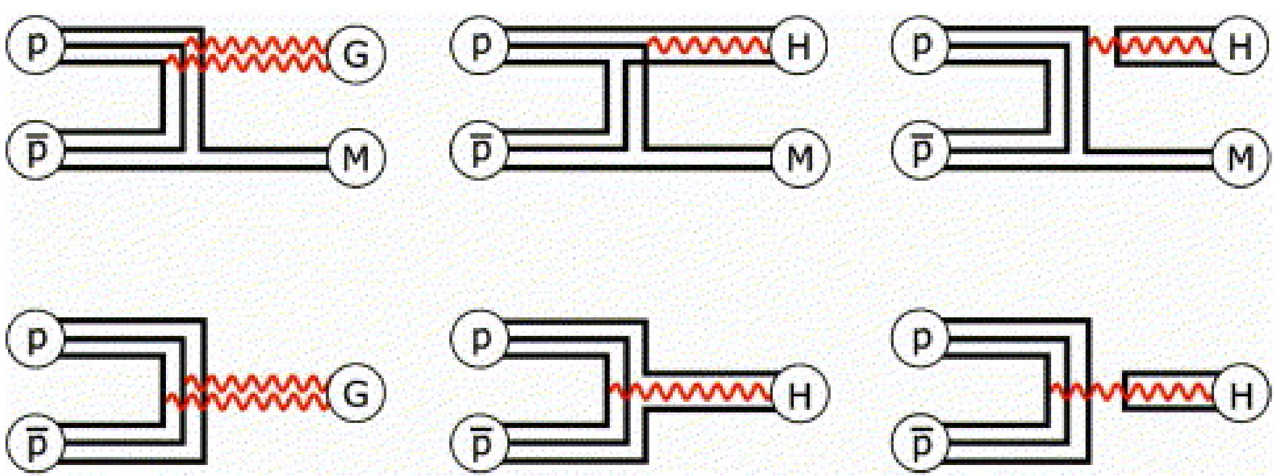
Table 3.6: Predicted and observed masses of $c\bar{c}$ states (in MeV).

	State	Expt	GI85 [171]	EQ94 [196]	FU91 [175]	GJ96 [179]	EFG03 [173]	ZVR95 [180]
$J/\Psi(1S)$	1^3S_1	3096.87 ± 0.04	3098	3097	3104	3097	3096	3100
$\eta_c(1S)$	1^1S_0	2979.8 ± 1.8	2975	2980	2987	2979	2979	3000
$\chi_{c3}(1P)$	1^3P_2	3556.18 ± 0.13	3550	3507	3557	3557	3556	3540
$\chi_{c2}(1P)$	1^3P_1	3510.51 ± 0.12	3510	3486	3513	3511	3510	3500
$\chi_{c0}(1P)$	1^3P_0	3415.0 ± 0.8	3445	3436	3404	3415	3424	3440
$h_c(1P)$	1^1P_1		3517	3493	3529	3526	3526	3510
$\Psi(2S)$	2^3S_1	3685.96 ± 0.09	3676	3686	3670	3686	3686	3730
$\eta_c(2S)$	2^1S_0	3654 ± 10	3623	3608	3584	3618	3588	3670
	1^3D_3		3849		3884		3815	3830
	1^3D_2		3838		3871		3813	3820
	1^3D_1	3769.9 ± 2.5	3819		3840		3798	3800
	1^1D_2		3837		3872		3811	3820
	2^3P_2		3979				3972	4020
	2^3P_1		3953				3929	3990
	2^3P_0		3916				3854	3940
	2^1P_1		3956				3945	3990
	3^3S_1		4100				4088	4180
	3^1S_0		4064				3991	4130

Hybrid and glueball states

Long lived gluon excitation: q qbar gluon system. Presence of gluon changes quantum numbers to exotic ones, i.e., those excluded for "standard" qqbar meson system. Glueballs are pure gluon exitation

production mechanism in p pba anihilation



Charm hybrid gCCbar

predictions based on quark bag model, LQCD

hybrids with both exotic

$J^{pc} = \mathbf{0}^{+-}, \mathbf{1}^{-+}, \mathbf{2}^{+-}$

and

non – exotic

$J^{pc} = \mathbf{0}^{-+}, \mathbf{1}^{+-}, \mathbf{2}^{-+}$

quantum numbers

expected

(a)	m($c\bar{c}$g), 1^{-+}	Group	Ref.
	4 390±80±200	MILC97	[59]
	4 317±150	MILC99	[60]
	4 287	JKM99	[61]
	4 369±37±99	ZSU02	[62]

(b)	m($c\bar{c}$g,1^{-+})-m($c\bar{c}$,1^{--})	Group	Ref.
	1 340±80±200	MILC97	[59]
	1 220±150	MILC99	[60]
	1 323±130	CP-PACS99	[63]
	1 190	JKM99	[61]
	1 302±37±99	ZSU02	[62]

Expected to be as narrow (or narrower) as CCbar states, high energy resolution of HESR is important (!)

Latice QCD prediction for glueball states

The lightest oddball
to study at PANDA

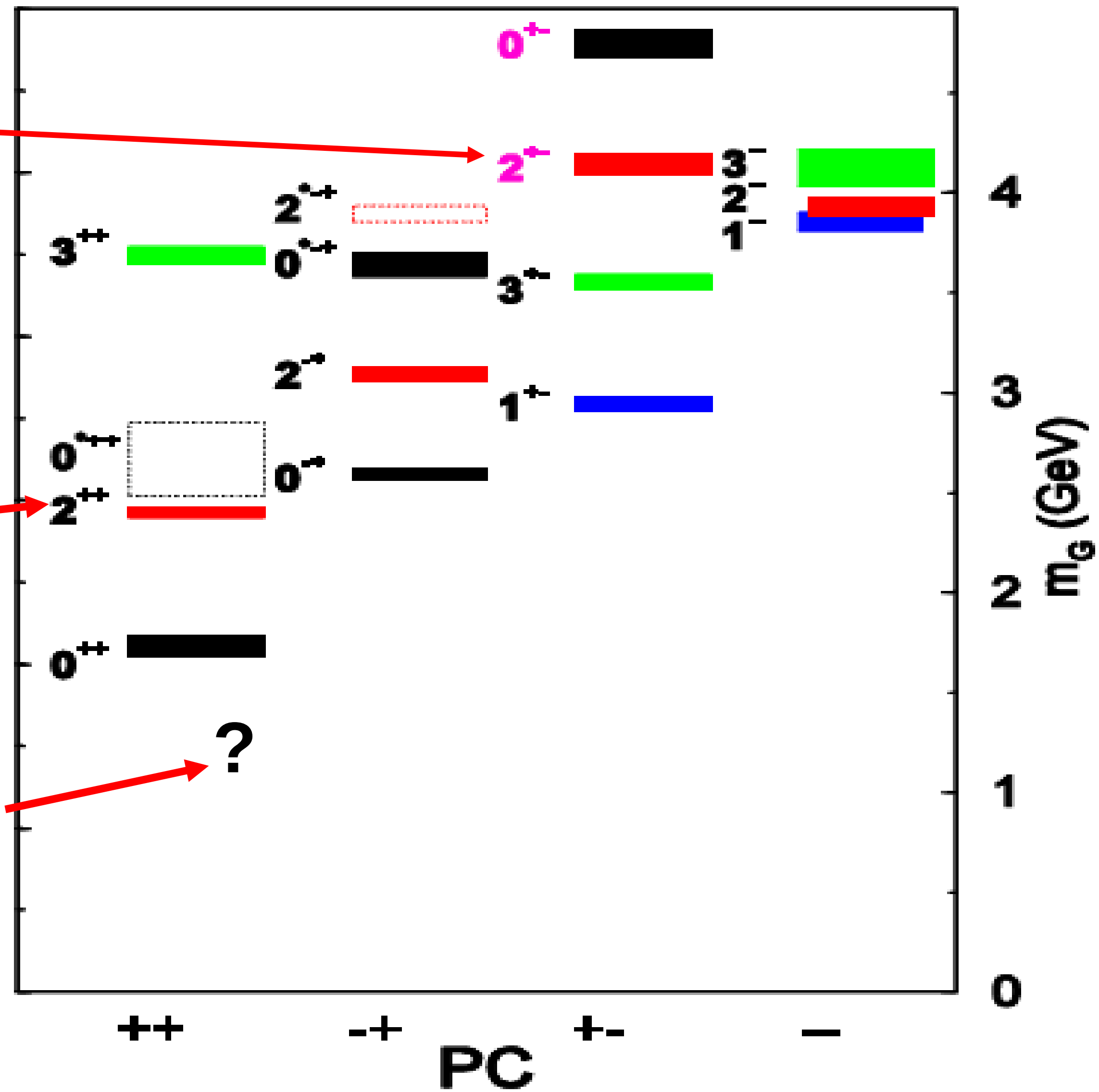
$$2^{+-}\ (4.3\,\mathrm{GeV})\ \bar{p}p \rightarrow \phi\phi$$

LEAR exp.

tensor state
(not exotic)
seen, poor
statistics…

PANDA factor 100
In statistics

η_L **(1440)** not widely accepted
to be glueball state



Charmonium/exotic states at $\overline{\text{P}}$ANDA

- At $2\times10^{32}cm^{-2}s^{-1}$ accumulate 8 pb^{-1}/day (assuming 50 % overall efficiency) $\Rightarrow$ $10^4 \div 10^7$ (CCbar states/day).
  Total integrated luminosity 1.5 fb^{-1}/year (at $2\times10^{32}cm^{-2}s^{-1}$, assuming 6 months/year data taking).

- Improvements with respect to Fermilab E760/E835:
  - Up to ten times higher instantaneous luminosity.
  - Better beam momentum resolution $\Delta p/p = 10^{-5}$ (GSI) vs 2×10^{-4} (FNAL)
  - Better detector (higher angular coverage, magnetic field, ability to detect hadronic decay modes). Fine scans to measure masses to $\approx$ 100 KeV, widths to $\approx$ 10 %.

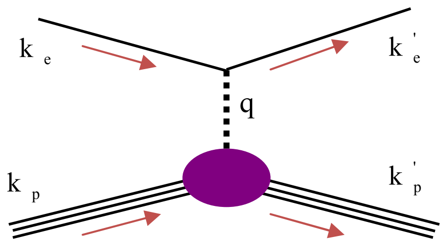
- Explore entire region below and above open charm threshold.
  Decay channels J/ψ+X , $J/\psi \rightarrow e^+e^-$, $J/\psi \rightarrow \mu^+\mu^-$,$\gamma\gamma$, hadrons, $D\bar{D}$

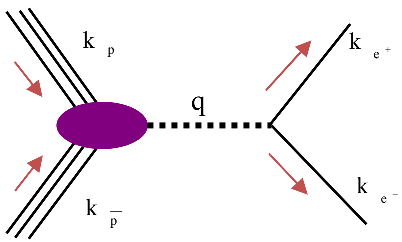
- High statistics/high mass resolution study of exotic states

Main competitors: Belle II, LHCb

Time-like Form Factors.
Hand Bag diagram.

Space-like and Time –like (TL) FF





$$m_\gamma^2 = q^2 = \left(k_e^{'} - k_e\right)^2 = \left(k_p^{'} - k_p\right)^2$$

CM frame $q^2 = -4k^2 \sin^2 \frac{\theta_{CM}}{2} = Q^2$

$$m_\gamma^2 = q^2 = \left(k_{e^+} + k_{e^-}\right)^2 = \left(k_p + k_{\bar{p}}\right)^2,$$

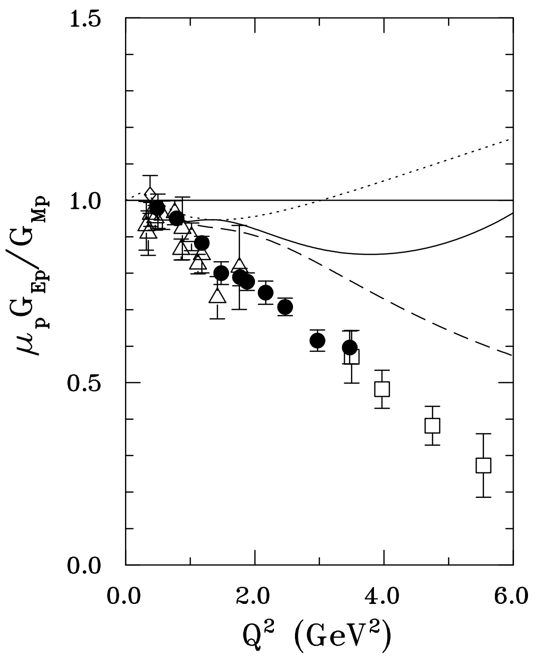
In CM frame $q^2 = 4k^2 = -Q^2$

Both SLFF and TLFF problem of $\frac{\mu_p G_E^2(Q^2)}{G_M^2(Q^2)} \neq 1$

(OLYMPUS, VEPP3, JLAB)

TLFF still poorly studied at $q^2 > 10 GeV^2$

SLFF/ TLFF->1 in the limit of pQCD $(Q^2 \gg 1\ GeV^2)$

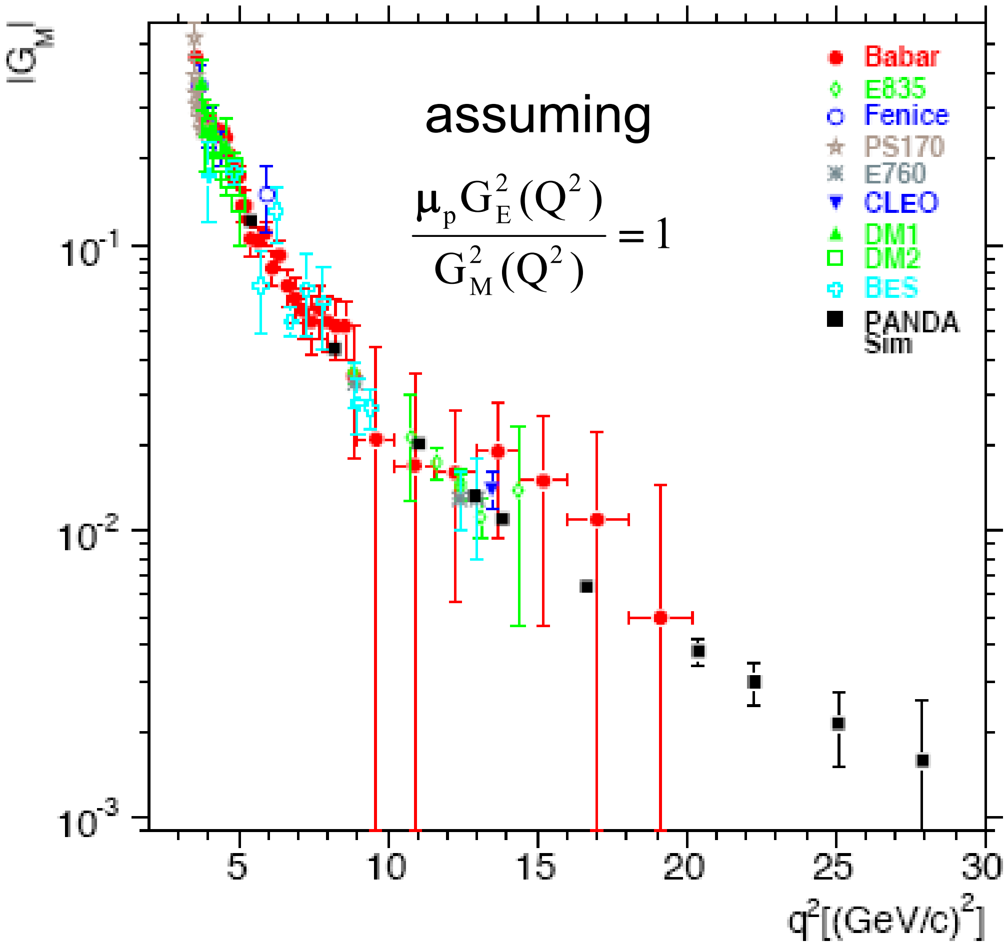


Expected from PANDA

For $e^+e^- \to p\bar{p}$, the differential cross section is

$$\frac{d\sigma_0(s,\theta)_p}{d\Omega} = \frac{\alpha^2}{4s}\beta_p\left[|G_M^p(s)|^2(1+\cos^2\theta) + \tau|G_E^p(s)|^2\sin^2\theta\right], \quad \tau \equiv \frac{4m_p^2}{s}$$

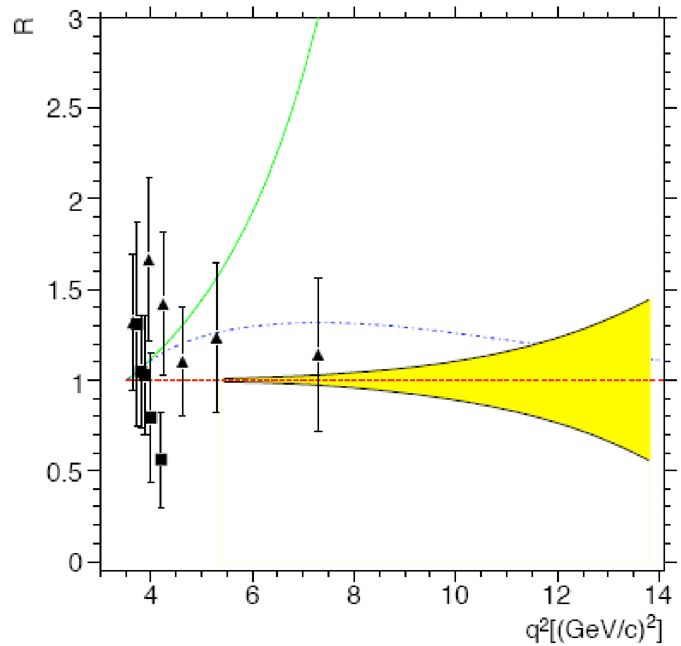
(For $p\bar{p} \to e^+e^-$, replace β_p by $1/\beta_p$.)



assuming

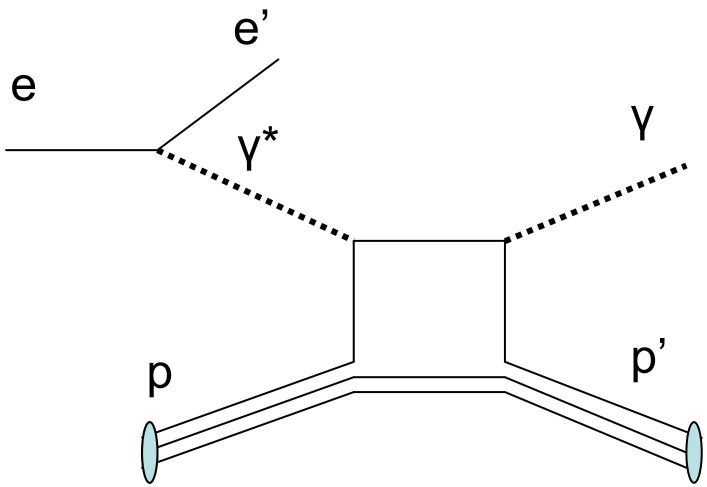
$$\frac{\mu_p G_E^2(Q^2)}{G_M^2(Q^2)} = 1$$

$$\frac{\mu_p G_E^2(Q^2)}{G_M^2(Q^2)}$$ ratio



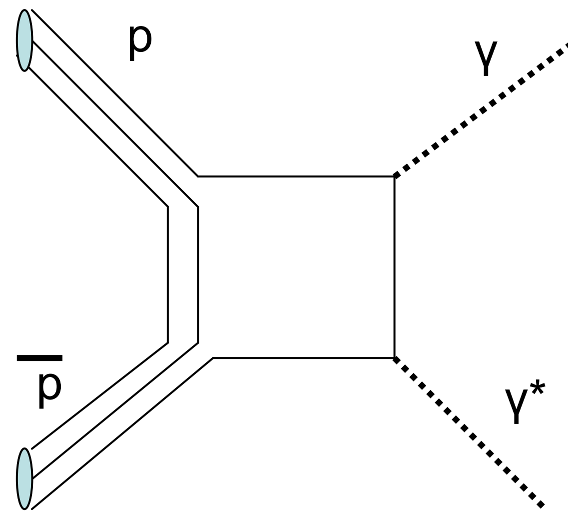
Study of Generalized Parton Distributions GPDs

$$\tilde{\gamma} p \to \gamma' p$$



Space-like Hand Bag diagram

$$\bar{p}p \to \gamma\gamma, \gamma\gamma^* \quad \gamma^* \to e^+e^-$$



Time-like Hand Bag diagram

Hyperon physics.
CP violation.

Hyperon physics at Panda

$\bar{p}p \to \bar{Y}Y \quad Y = \Lambda, \Sigma, \Xi, \ldots \Lambda_c \ldots \Omega_c$

Reaction mechanism, Ozi rule violation, Polarization and spin-correlations

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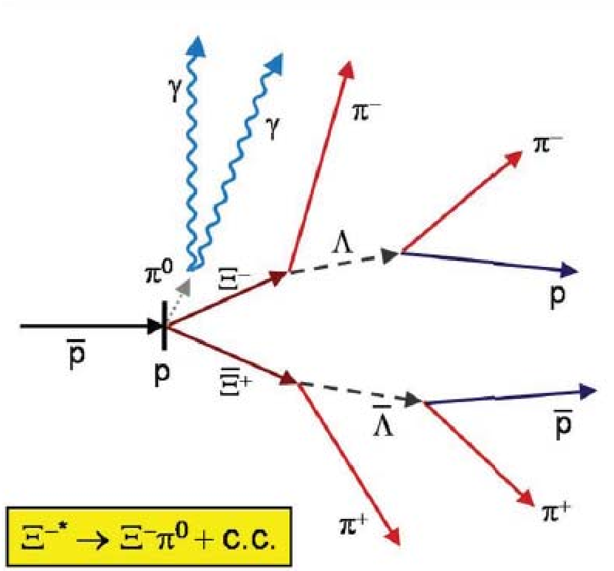
$\bar{p}p \to \bar{Y}Y^*$

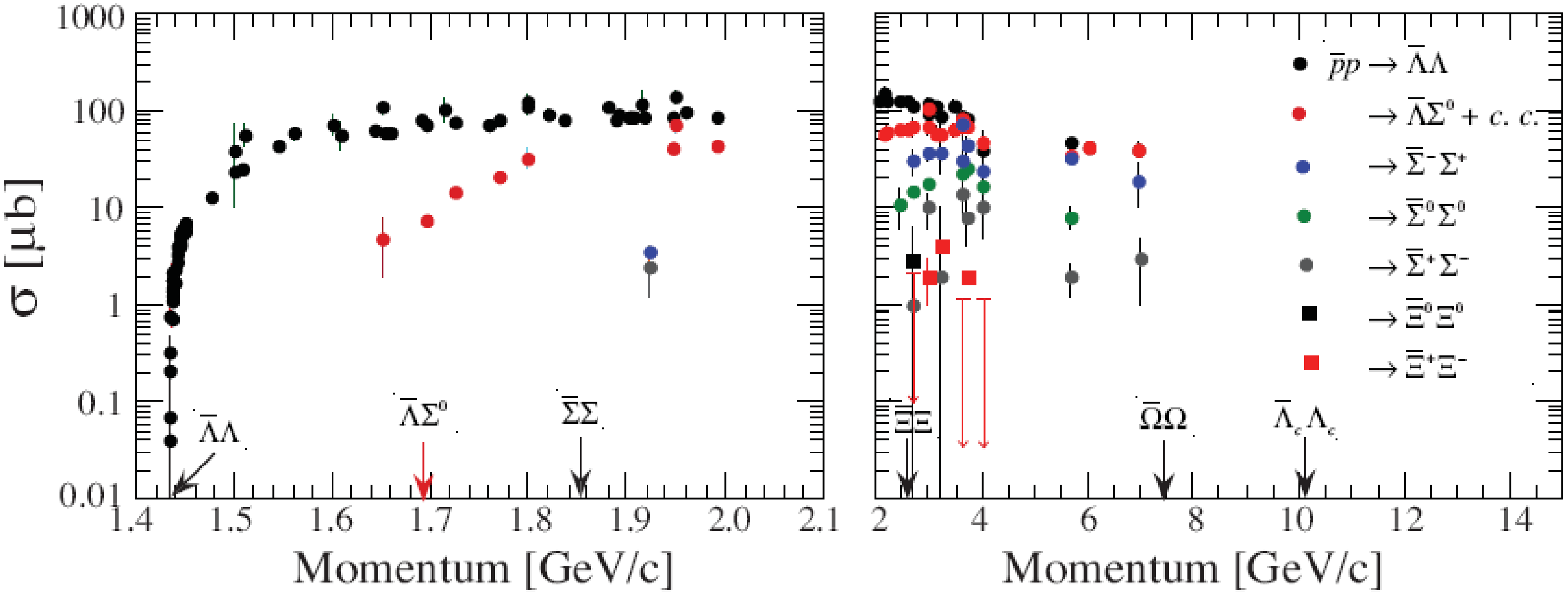
S and C(?) hyperon spectroscopy



Octet members			Singlets
$\Lambda(1116)$	$\Sigma(1193)$	$\Xi(1318)$	
$\Lambda(1600)$	$\Sigma(1660)$	$\Xi(?)$	
$\Lambda(1670)$	$\Sigma(1620)$	$\Xi(?)$	$\Lambda(1405)$
$\Lambda(1690)$	$\Sigma(1670)$	$\Xi(1820)$	$\Lambda(1520)$
$\Lambda(1800)$	$\Sigma(1750)$	$\Xi(?)$	
$\Lambda(?)$	$\Sigma(?)$	$\Xi(?)$	
$\Lambda(1830)$	$\Sigma(1775)$	$\Xi(?)$	
$\Lambda(1810)$	$\Sigma(1880)$	$\Xi(?)$	$\Lambda(?)$
$\Lambda(1890)$	$\Sigma(?)$	$\Xi(?)$	
$\Lambda(1820)$	$\Sigma(1915)$	$\Xi(2030)$	
$\Lambda(?)$	$\Sigma(?)$	$\Xi(?)$	$\Lambda(2100)$
$\Lambda(?)$	$\Sigma(?)$	$\Xi(?)$	
$\Lambda(2350)$	$\Sigma(?)$	$\Xi(?)$	

	Decuplet members			
3/2	$\Delta(1232)$	$\Sigma(1385)$	$\Xi(1530)$	$\Omega(1672)$
3/2	$\Delta(1600)$	$\Sigma(?)$	$\Xi(?)$	$\Omega(?)$
1/2	$\Delta(1620)$	$\Sigma(?)$	$\Xi(?)$	$\Omega(?)$
1/2	$\Delta(1700)$	$\Sigma(?)$	$\Xi(?)$	$\Omega(?)$
3/2	$\Delta(1905)$	$\Sigma(?)$	$\Xi(?)$	$\Omega(?)$
3/2	$\Delta(1950)$	$\Sigma(2030)$	$\Xi(?)$	$\Omega(?)$
3/2	$\Delta(2420)$	$\Sigma(?)$	$\Xi(?)$	$\Omega(?)$

$\bar{p}p \to \bar{Y}Y$ reaction mechanism



$\sigma\,(\bar{p}p \to \bar{\Lambda}\Lambda) \approx 70\mu b$ $\qquad 7\cdot 10^{10}$ ev @ 1fb^{-1}

$\sigma\,(\bar{p}p \to \bar{\Lambda}_c\Lambda_c) \sim 0.2\mu b$ $\qquad 2\cdot 10^{8}$ ev @ 1fb^{-1}

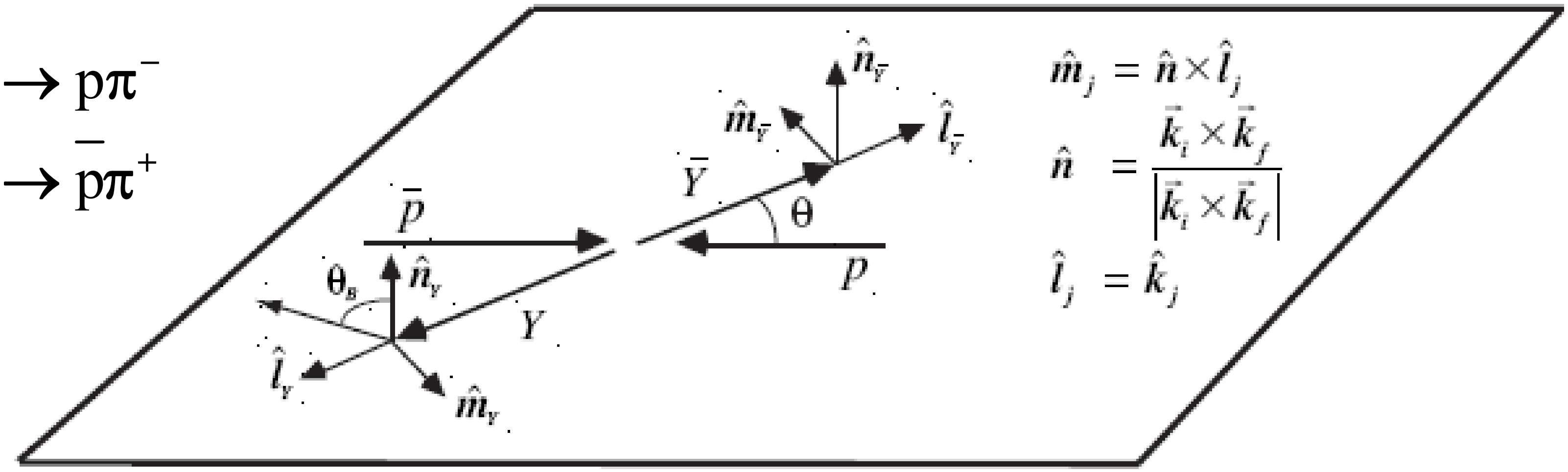
⇩

Differential cross sections and polarization with unprecedented precision

$\bar{p}p \to \bar{Y}Y$ polarization

$\Lambda \to p\pi^-$

$\bar{\Lambda} \to \bar{p}\pi^+$



$$I(\theta_B) = \frac{1}{4\pi}\left(1 + \alpha_Y P^Y \cos\theta_B\right)$$ Correlation polarizations

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CP violation

CP preserves $\alpha_Y = -\alpha_{\bar{Y}} \quad \Gamma_Y = \Gamma_{\bar{Y}}$

direct CP violation $$A = \frac{\alpha_Y\Gamma_Y + \alpha_{\bar{Y}}\Gamma_{\bar{Y}}}{\alpha_Y\Gamma_Y - \alpha_{\bar{Y}}\Gamma_{\bar{Y}}} \approx \frac{\alpha_Y + \alpha_{\bar{Y}}}{\alpha_Y - \alpha_{\bar{Y}}} \approx \mathbf{2 \cdot 10^{-5}}$$ according to SM

Some models beyond SM predict $A \sim \mathbf{2 \cdot 10^{-4}}$

Russia and PNPI
in
PANDA.

Russia in PANDA

Russian in-kind contribution to PANDA detector 23 M (CBM 22M)
Germany in-kind contribution to PANDA detector 21 M (CBM 25M)
of total investment of 69 M

PANDA [WBS 1.3] Work Packages

part of the [1.0 Experiments] FAIR Work Packages

Total PANDA detector cost is 65. 8 M Euro based on 2005 cost book numbers.

Total sum out of 2005 cost book for requested "Russian in-kind contribution" is 22. 988 M **Euro**
Summing request of all Russian institutions in PANDA to Rosatom is 27. 55 M **Euro.**

	WBS1.3.1 Forward EMC (without electronics)	WBS 1.3.2 Barrel EMC (without photodetectors and electronics)	WBS 1.3.3 Forward MVD (without electronics)	WBS 1.3.4 Muon Detector	WBS 1.3.5 DIRC radiators	WBS 1.3.6 Solenoid Magnet iron yoke	WBS 1.3.7 Forward TOF	WBS 1.3.8 Pellet Target	WBS 1.3.9 Licenced Software	WBS 1.3.10 Barrel TOF	Sum
Cost Book numbers, M Euro	1.36	14.268	1.30	2.25	1.00	1.00	0.45	0.70	0.31	0.35	***22.988***
Requested funds (in 2005 costs)	2.23	14.268	1.30	2.72	1.83	1.39	0.88	1.60	0.31	1.02	***27.55***
Requested/CostBook, %	***162***	**100**	**100**	121	***183***	139	***198***	***229***	**100**	***291***	***120***

Из обшей суммы российского вклада 178 M на эксперименты 10% (18 M)

ПИЯФ в эксперименте ПАНДА

Commitment: Forward TOF Wall (FTOF)

Финансы

450 К euro after approval of TDR

about 20 K Hadron Physics 3 (SiPM) equipment and travel

5 К PANDA management travel

3 М руб.Оборудование и командировки ПИЯФ

0.6 М руб. Гранты РФФИ (Study of the scintillation detector ...)

Участники

С. Белостоцкий	координация
Д.Веретенников	разработка/испытания прототипа
В.Вихров (?)	TOF wall design, count rates
Г. Гаврилов	SiPM, aging
А.Изотов	разработка/испытания прототипа
А.Кащук	frontend electronics
А.Киселев(?)	startless TOF formalism
П.Кравченко(?)	MC study light yield, time resolution
О.Левицкая	MC studies/hyperon production
О.Миклухо	разработка/испытания прототипа
Ю.Нарышкин	MC studies/hyperon production

Студенты ВГУ

К.Суворов

К.Байбиз

Н.Евсеев

....

....

BACKUP SLIDES

Light quark hybrids (exotic).

Large widths

Experiment	Exotic	J^{PC}	Mass [MeV/c^2]		Width [MeV/c^2]		Decay	Refs.
E852	$\pi_1(1400)$	1^{-+}	1359	$^{+16}_{-14}\ ^{+10}_{-24}$	314	$^{+31}_{-29}\ ^{+9}_{-66}$	$\eta\pi$	[42]
Crystal Barrel	$\pi_1(1400)$	1^{-+}	1400	$\pm20\pm20$	310	$\pm50\ ^{+50}_{-30}$	$\eta\pi$	[40]
Crystal Barrel	$\pi_1(1400)$	1^{-+}	1360	±25	220	±90	$\eta\pi$	[43]
Obelix	$\pi_1(1400)$	1^{-+}	1384	±28	378	±58	$\rho\pi$	[44]
E852	$\pi_1(1600)$	1^{-+}	1593	$\pm8\ ^{+29}_{-47}$	168	$\pm20\ ^{+150}_{-12}$	$\rho\pi$	[45]
E852	$\pi_1(1600)$	1^{-+}	1597	$\pm10\ ^{+45}_{-10}$	340	$\pm40\pm50$	$\eta'\pi$	[45]
Crystal Barrel	$\pi_1(1600)$	1^{-+}	1590	±50	280	±75	$b_1\pi$	[46]
Crystal Barrel	$\pi_1(1600)$	1^{-+}	1555	±50	468	±80	$\eta'\pi$	[41]
E852	$\pi_1(1600)$	1^{-+}	1709	$\pm24\pm41$	403	$\pm80\pm115$	$f_1\pi$	[47]
E852	$\pi_1(1600)$	1^{-+}	1664	$\pm8\pm10$	185	$\pm25\pm28$	$\omega\pi\pi$	[48]
E852	$\pi_1(2000)$	1^{-+}	2001	$\pm30\pm92$	333	$\pm52\pm49$	$f_1\pi$	[47]
E852	$\pi_1(2000)$	1^{-+}	2014	$\pm20\pm16$	230	$\pm32\pm73$	$\omega\pi\pi$	[48]
E852	$h_2(1950)$	2^{+-}	1954	±8	138	±3	$\omega\pi\pi$	[49]

Table 4.22: Light states with exotic quantum numbers. The experiment E852 at BNL was performed with a pion beam on a hydrogen target, while Crystal Barrel was a $p\bar{p}$ spectroscopy experiment at LEAR.

N.Brambila et al 2005

Interpretation

- the $Z(3931)$ [21], observed in two-photon fusion and decaying predominantly into $D\overline{D}$, is tentatively identified with the $\chi_{c2}(2P)$;
- the $X(3940)$ [22], observed in double charmonium events, is tentatively identified with the $\eta_c(3S)$;
- for all other new states ($X(3872)$, $Y(3940)$, $Y(4260)$, $Y(4320)$ and so on) the interpretation is not at all clear, with speculations ranging from the missing $c\bar{c}$ states, to molecules, tetraquark states, and hybrids. It is obvious that further measurements are needed to determine the nature of these new resonances.

Pbar P fixed-target @FNAL (E835)

The E835 experiment was located in the Fermilab Antiproton Accumulator, where a stochastically cooled ($\Delta p/p \sim 10^{-4}$) beam intersects an internal jet target of molecular hydrogen. The $\bar{p}$ beam was injected in the Accumulator with an energy of 8.9 GeV and decelerated to the 3.7–6.4 GeV energy range, to form the charmonium states. Stochastic cooling allowed to reduce RMS spreads on $\sqrt{s}$ to less than 250 keV. The E835 experiment was the continuation of the E760 experiment, that took data in years 1990–91, at a typical instantaneous luminosity $\mathcal{L} \sim 0.5 \cdot 10^{31}$. The E760/E835 detector, described in

Table 2.5: Integrated luminosities $\mathcal{L}dt$ (in pb^{-1}) taken by E760, E835-I, E835-II

State	Decay Channels	E760	E835-I	E835-II
η_c	$\gamma\gamma$	2.76	17.7	–
J/ψ	e^+e^-	0.63	1.69	–
χ_{c0}	$J/\psi\gamma, \gamma\gamma, 2\pi^0, 2\eta$	–	2.57	32.8
χ_{c1}	$J/\psi\gamma$	1.03	7.26	6.3
$h_c(1P)$ search	$J/\psi\pi^0, \eta_c\gamma$	15.9	46.9	50.5
χ_{c2}	$J/\psi\gamma, \gamma\gamma$	1.16	12.4	1.1
$\eta_c(2S)$ search	$\gamma\gamma$	6.36	35.0	–
ψ'	$e^+e^-, \chi_{cJ}\gamma, J/\psi\pi^0,$ $J/\psi\pi^+\pi^-, J/\psi\pi^0\pi^0, J/\psi\eta$	1.47	11.8	15.0
above	J/ψ+X	–	2.6	7.5

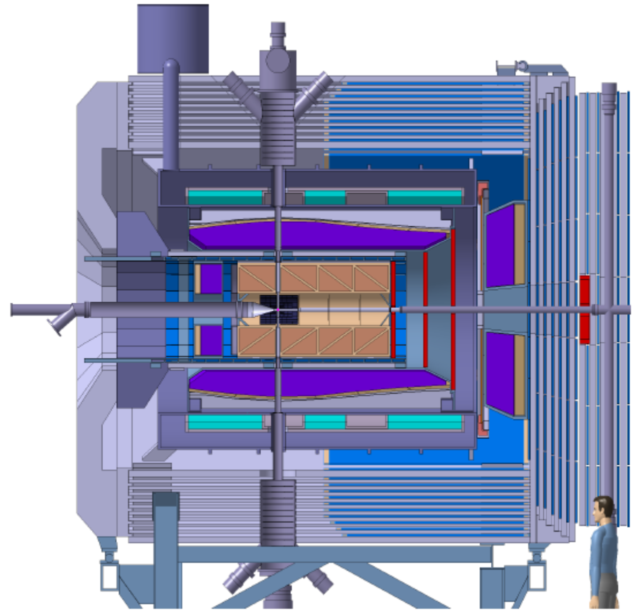
Table 4.43: Properties of strange and charmed ground state hyperons [11] that are energetically accessible at $\overline{\text{P}}$ANDA. The hyperon, its valence quark composition, mass, decay length $c\tau$, main decay mode, branching ratio $\mathcal{B}$ and the decay asymmetry parameter α_Y are listed.

Hyperon	Quarks	Mass [MeV/c^2]	$c\tau$ [cm]	Main decay	$\mathcal{B}$ [%]	α_Y
Λ	uds	1116	8.0	$p\pi^-$	64	+0.64
Σ^+	uus	1189	2.4	$p\pi^0$	52	-0.98
Σ^0	uds	1193	$2.2 \cdot 10^{-9}$	$\Lambda\gamma$	100	-
Σ^-	dds	1197	2.4	$n\pi^-$	100	-0.07
Ξ^0	uss	1315	8.7	$\Lambda\pi^0$	99	-0.41
Ξ^-	dss	1321	4.9	$\Lambda\pi^-$	100	-0.46
Ω^-	sss	1672	2.5	ΛK^-	68	-0.03
Λ_c^+	udc	2286	$6.0 \cdot 10^{-3}$	$\Lambda\pi^+$	1	-0.91(15)
Σ_c^{++}	uuc	2454		$\Lambda_c^+\pi^+$	100	
Σ_c^+	udc	2453		$\Lambda_c^+\pi^0$	100	
Σ_c^0	ddc	2454		$\Lambda_c^+\pi^-$	100	
Ξ_c^+	usc	2468	$1.2 \cdot 10^{-2}$	$\Xi^-\pi^+\pi^+$	seen	
Ξ_c^0	dsc	2471	$2.9 \cdot 10^{-3}$	$\Xi^-\pi^+$	seen	-0.6(4)
Ω_c^0	ssc	2697	$1.9 \cdot 10^{-3}$	$\Omega^-\pi^+$	seen	

Target spectrometer

Rin=0.9m
L=2.8m
Bmax=2T

Pellet target
10^{15} atoms/cm^2



Muon det.
Forward GEMs
MVDs
DIRCs
EM calo
Barrel TOF(?)

MVDs

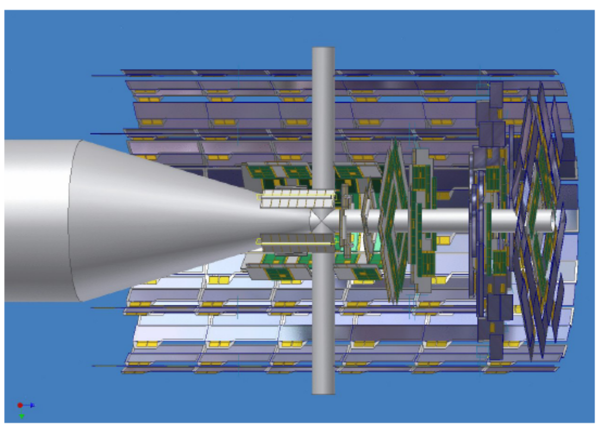


Figure 2.4: The Micro-vertex detector of $\overline{\text{P}}$ANDA

STT

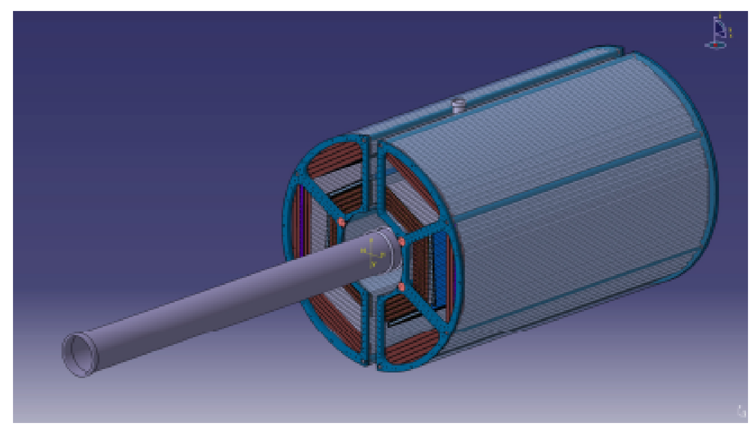


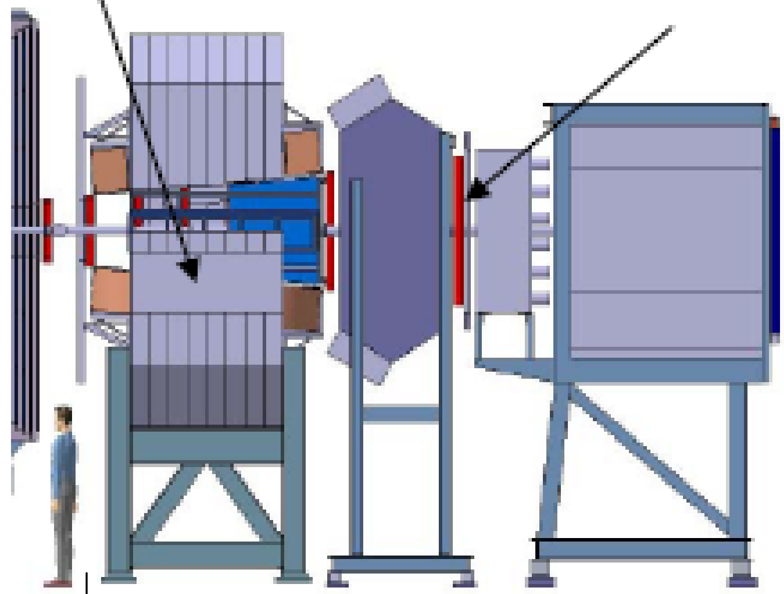
Figure 2.5: Straw Tube Tracker in the Target Spectrometer.

Forward spectrometer

Dipole magnet
1m(vert) x 2m(hor)
Bmax=2T
L=2.5m
15GeV deviated by 2.2deg.

Forward acceptance

$\pm 10\,\mathbf{deg.}$ (horiz.) $\pm 5\,\mathbf{deg.}$ (vert.)

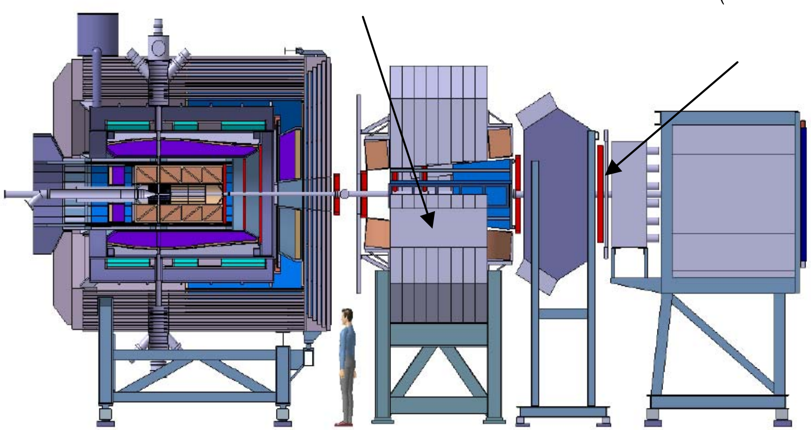


Tracking system
FTOF
RICH
FEM calo
FMuon system

PANDA Forward TOF Walls

Side TOF walls in dipole Magnet SiPM/PMT187

Forward TOF wall (FTOF) PMT's



Forward Wall

Plastic: B408

*46x(140*10*2.5) cm³*

*20x(140*5*2.5) cm³*

high time resolution

PMs Hamamatsu

R4998, R2083,

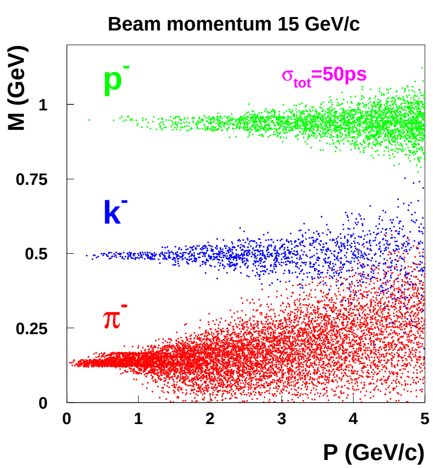
(SiPM ??)

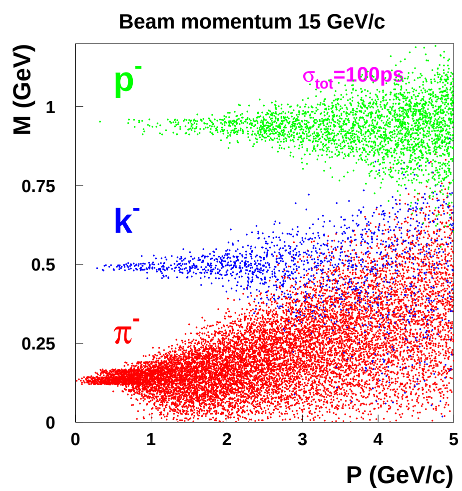
Side Walls

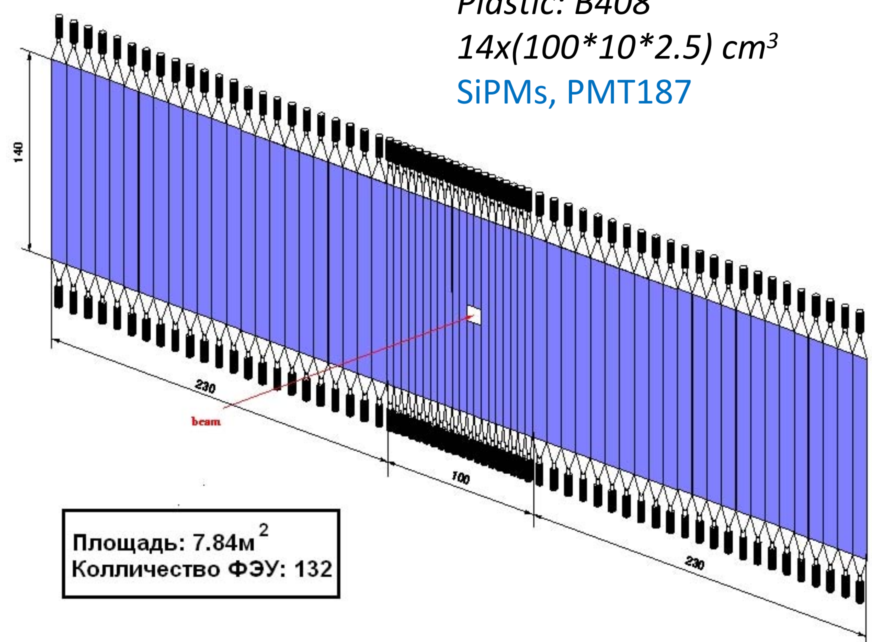
Plastic: B408

*14x(100*10*2.5) cm³*

SiPMs, PMT187







PNPI @ PANDA

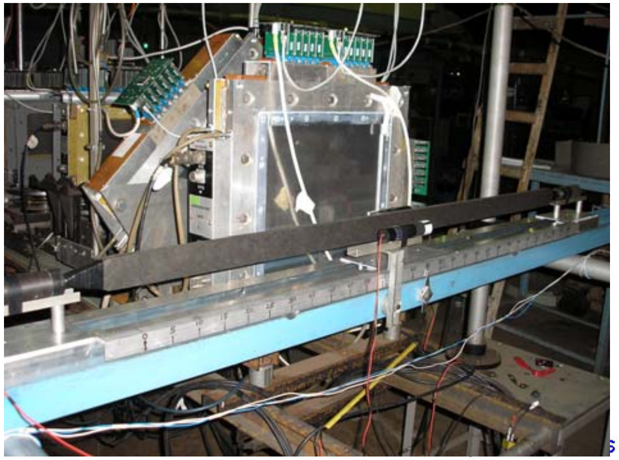
Anton A. Izotov,

Gatchina 26.03.13

Done in last years:

- PMT test stand prototyping,
- PANDA prototype test @ PNPI-2009,
- Startless TOF reconstruction methodic,
- SiPM test stand prototyping,
- SiPM radiation hardness test,
- SiPM's @ OLYMPUS,
- PANDA prototype MC simulation,
- PANDA prototype test @ PNPI-2012,
- PANDA prototype test @ COSY-2012.

Prototyping @ PNPI 2009 (Preprint PNPI).



Readout

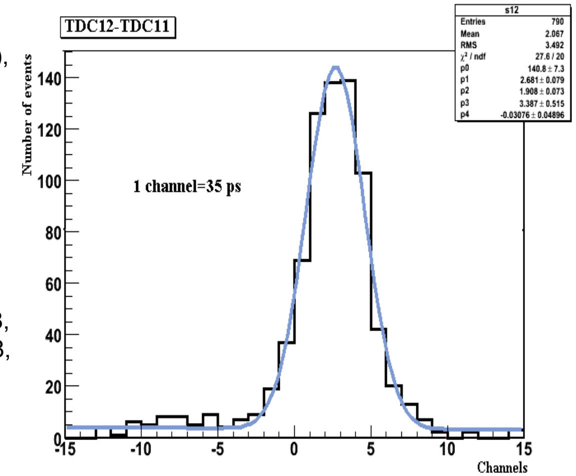
- TDC CAEN V775N (35 psec),
- QDC CAEN V792

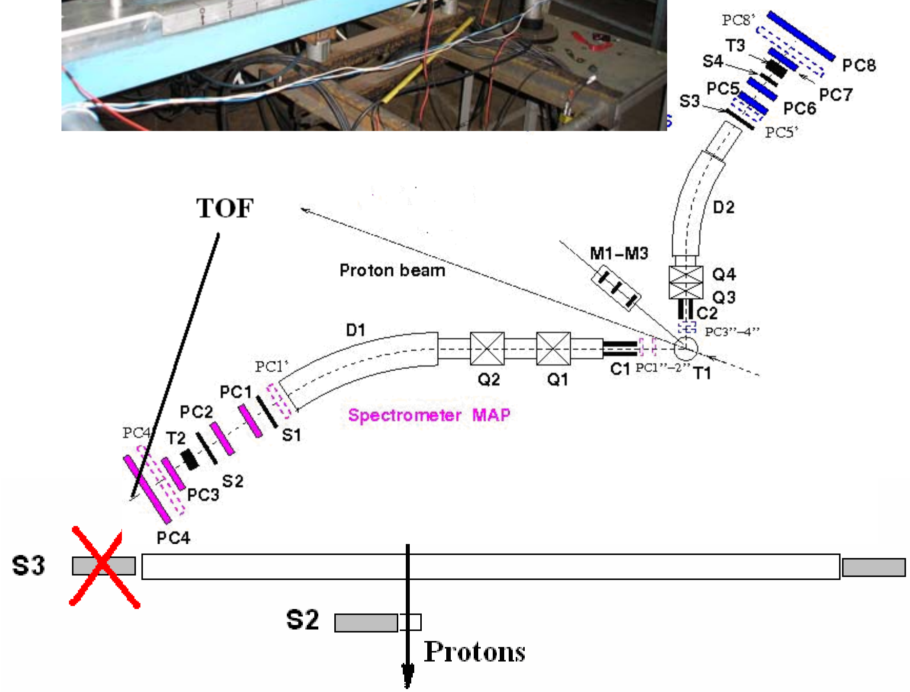
Beam

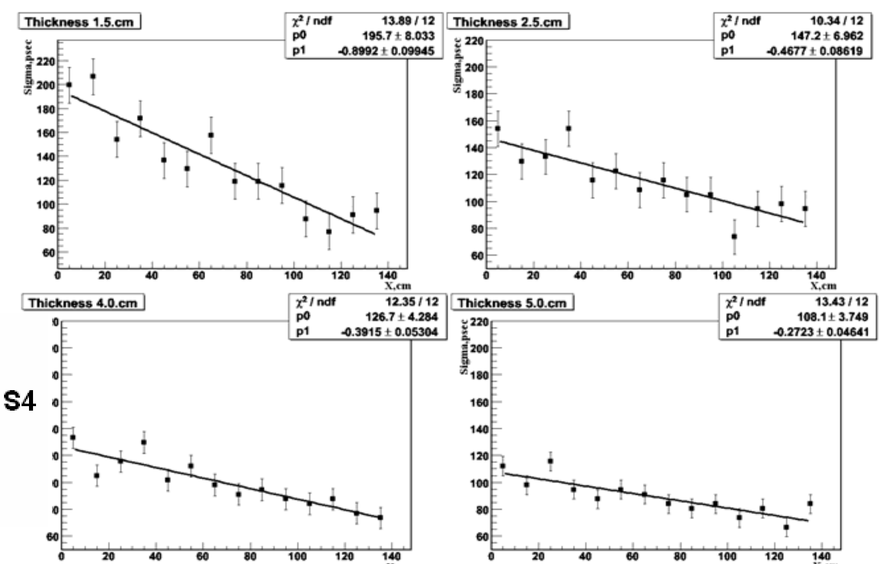
- Protons 730 MeV

Prototype

- Two 2x2x2 cm^3 B408, R4998,
- 140x5x1.5 cm^3, B408, R4998,
- Offline correction



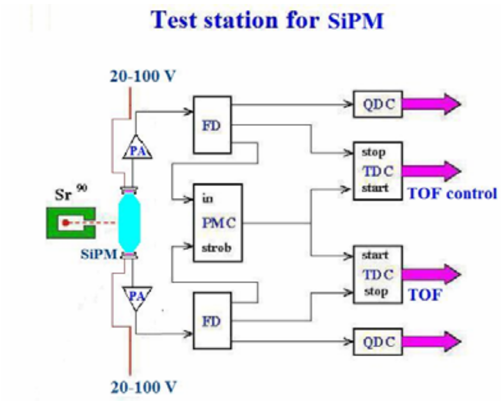


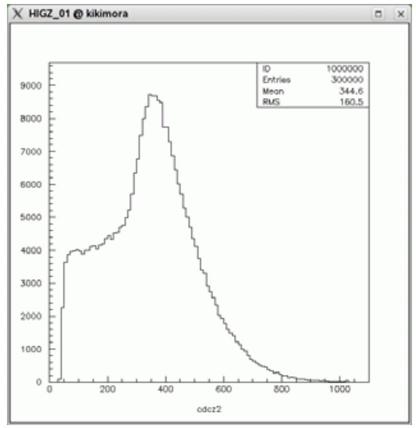


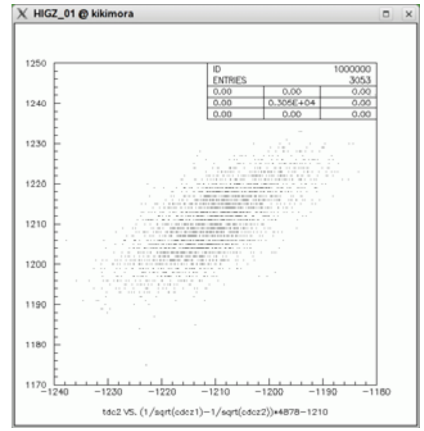
$$\Delta t = t_n - t_k - a - b(x-c) - d(q_n - e) + f(q_k - g), n \neq k = 1,2,4$$

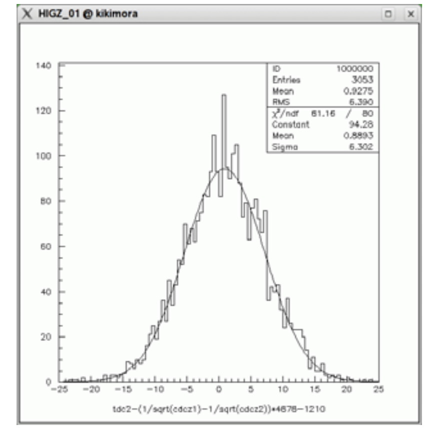
PMT R4998 & SiPM S10931-50p at the Test Stand.

$$\Delta t = \Delta t_0 - A\left(\frac{1}{\sqrt{q_1}} - \frac{1}{\sqrt{q_2}}\right) - b$$







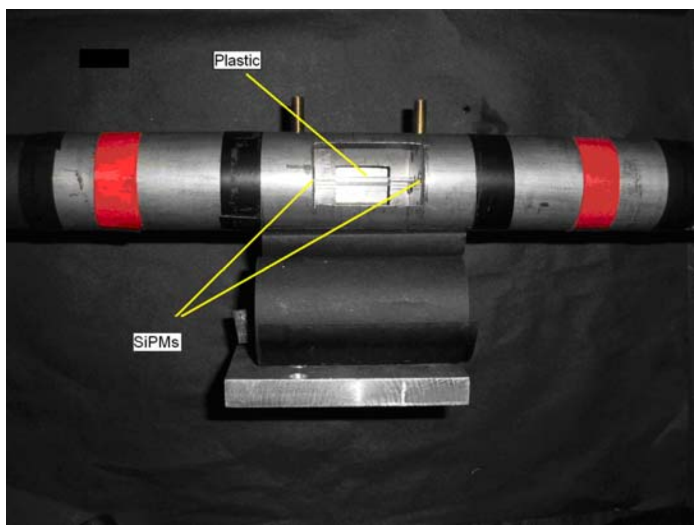


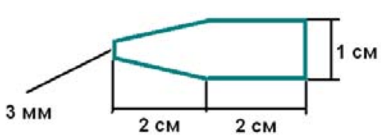
B408 – 3x3x40 mm³

TDC – 25 ps/chan

PA - ~8 times

Source - ^{90}Sr





R4998

Run	σ_0	σ_1	σ_2
40366	326	168	149
40367	497	170	142
40368	486	176	147

S10931-50p

Run	σ_0	σ_1	σ_2
40366	608	195	157
40367	543	199	151
40368	557	193	150

σ worse than 160 ps

SiPM Radiation hardness test @ 1GeV PNPI proton beam.

- The absolute beam intensity was determined in a standard way by measuring induced radioactivity of irradiated aluminum foils.
- The beam intensity during the tests was varied in the range 1.3 - 2.1x10^8 $cm^{-2}s^{-1}$.
- The SiPM sample was not powered!
- Radiation was exposed in 10 successive periods about 10 minutes each. The integrated number of protons passing through the sensitive surface of the SiPM sample with the cross-section of 3x3 mm^2 was 0.9*10^{11}. By our estimations, such dose corresponds approximately to irradiation to be collected by a similar SiPM installed on a central scintillation bar of the Forward wall during 10 years of continuous beam producing hadrons off the PANDA target.
- SiPM parameters (dark noise, amplitude and time characteristics for different values of high voltage) were measured before and after the radiation test using test station with ^{90}Sr electron source.

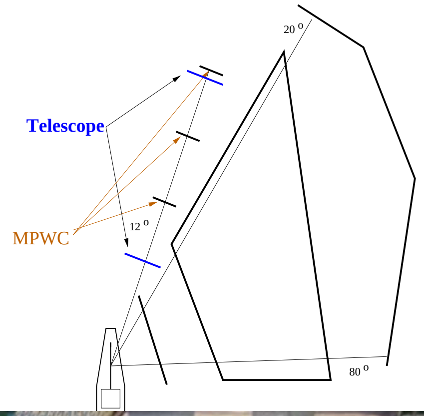
U,V	I, μA	A, mV	Noise	Noise+^{90}Sr
72.06	0.15	40	1550	8700
72.53	0.30	80	4230	18500
72.06	81.0	4	2800	6200
72.53	113.0	6	99000	102000

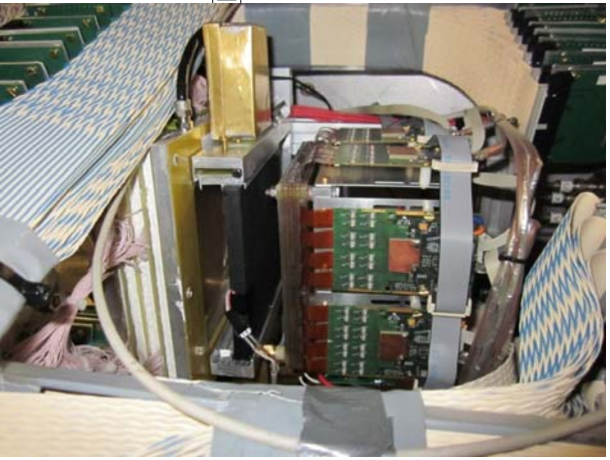
As it is seen from the table the SiPM was practically killed by this dose the value of which can be taken as upper limit,

- Yet it is important to find out at which dose the sample start malfunctioning,
- It is also important to compare irradiation effect on unpowered and powered samples,
- All this will constitute our nearest experimental program with SiPM samples.

$$dT = 0.056\ C^o$$

SiPM's @ OLYMPUS. DESY TB22.





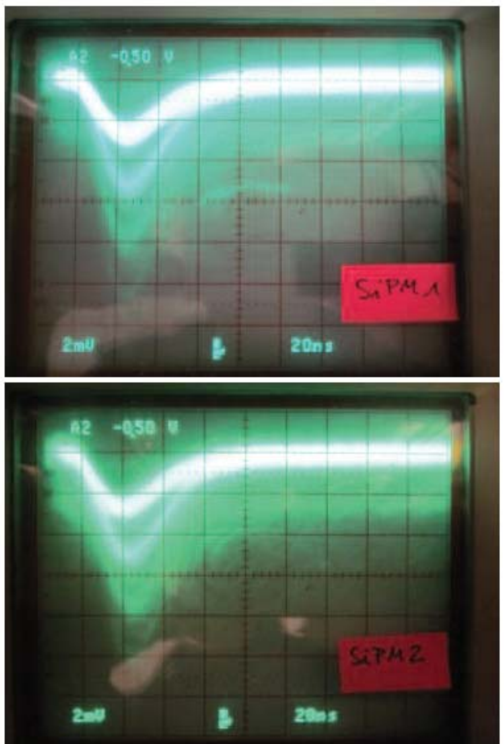
Counters: 8mm/2SiPM's, 4mm/2SiPM's (corners), 4mm/2SiPM's (sides),
Readout: 25x preamp (electronics workshop, KPH Mainz)

- QDC spectra to see light yield,
- QDC spectra with prescaled baseline triger mixed into determine gain for each spectrum,
- Triple coincidence from beam trigger finger conciliators (2 with PMT's, 1 with SiPM)
- Quadruple coincidence (3 PMT's, 1 SiPM and single SiPM
    - efficiency scan,
    - maximum efficiency reachable with single SiPM

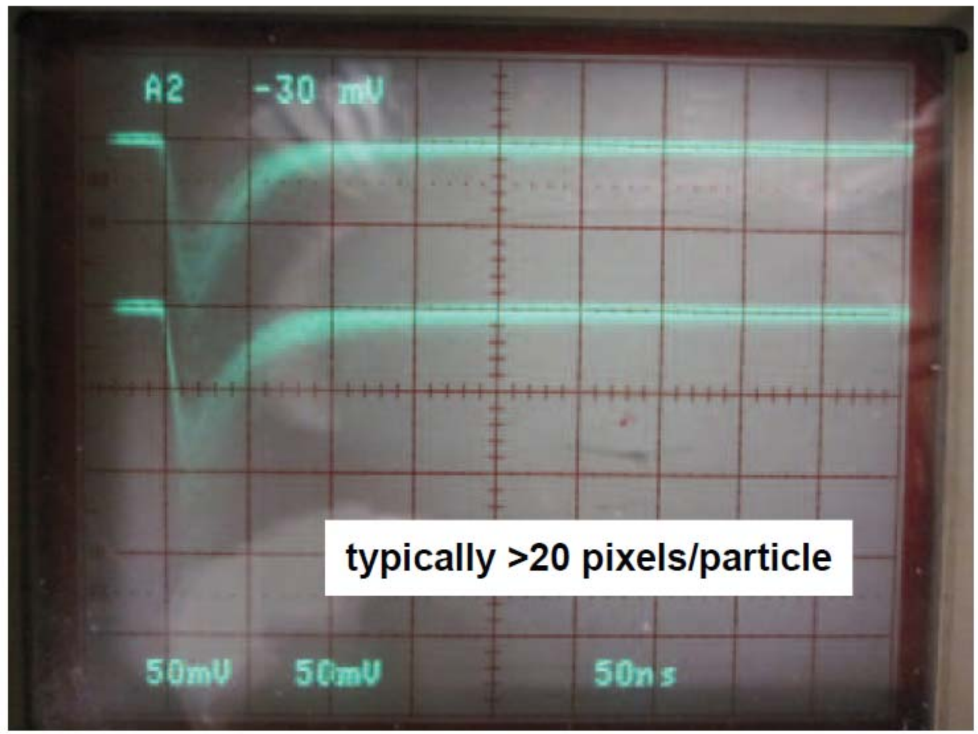
Analog Signals.

Examples for analog signals after 25x preamp and 20m RG58

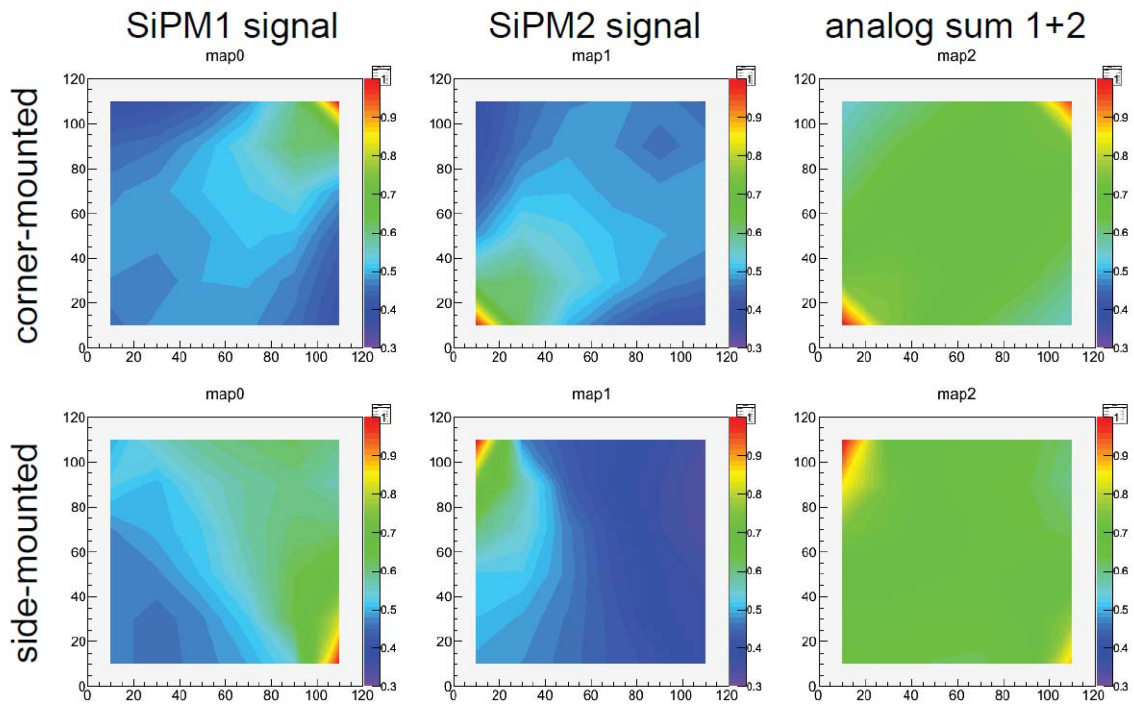
SiPM noise
(20MHz BW, total gain 25x)



SiPM signals with beam
(200MHz BW, total gain 25x)



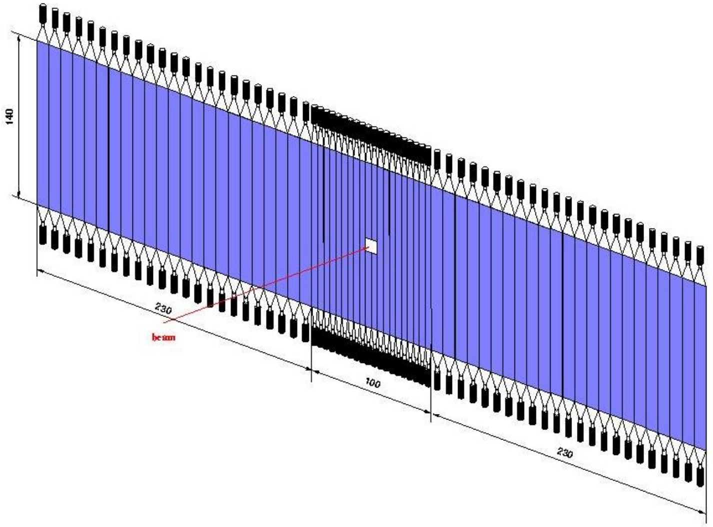
Light Yield and Trigger Scans.



- Both side-mounting and corner-mounting, counters have yields,
- Blind spots exist in both configurations,
- Side-mounting is easier,
- Trigger scan shows, that even one SiPM is enough with proper threshold

Prototype MC simulation.

- Simulation of optical processes in GEANT4.
- MC studies. Time distributions.
- First estimations for time resolution.



TOF WALL

BICRON 408

46 plates 140*10*2.5 cm³

20 plates 140* 5*2.5 cm³

PMT:

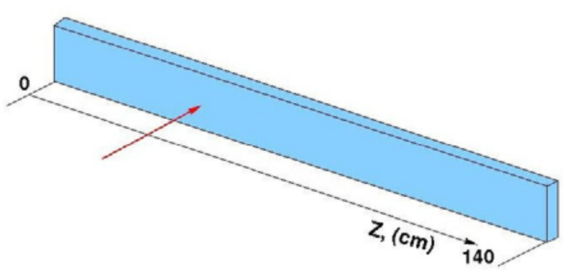
Hamamatsu R2083, R4998

TOF Side

14 plates 100*10*2.5 cm³

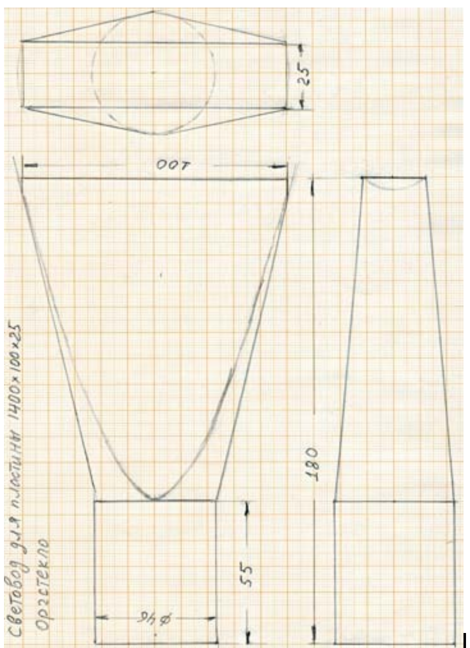
SiPM

Scintillator BC 408

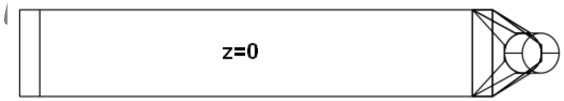


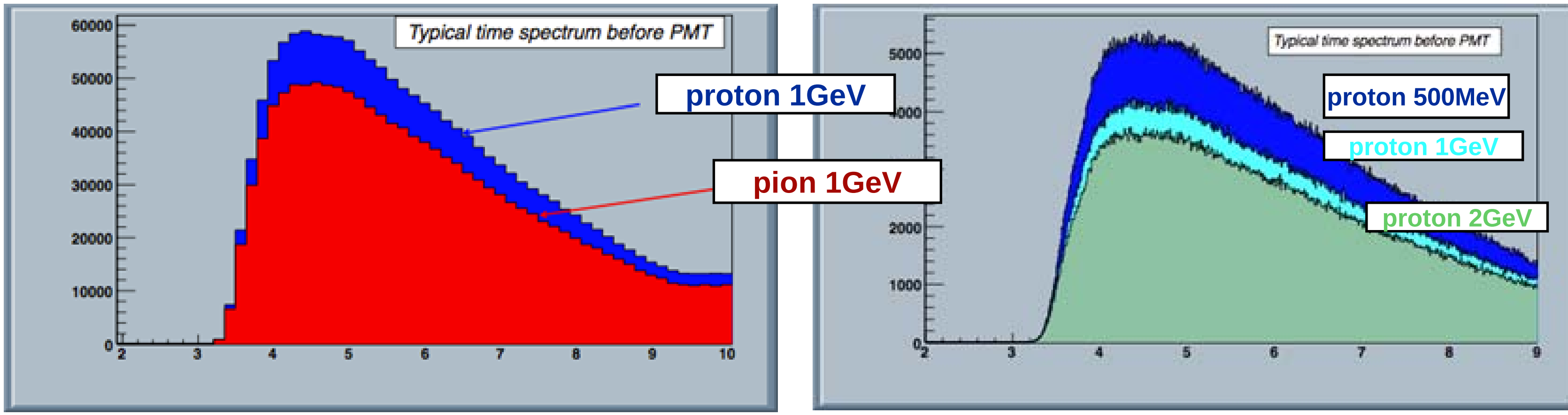
with light guides
for 2” PMT (46 mm diameter)

Plexiglass
Mylar wrapping

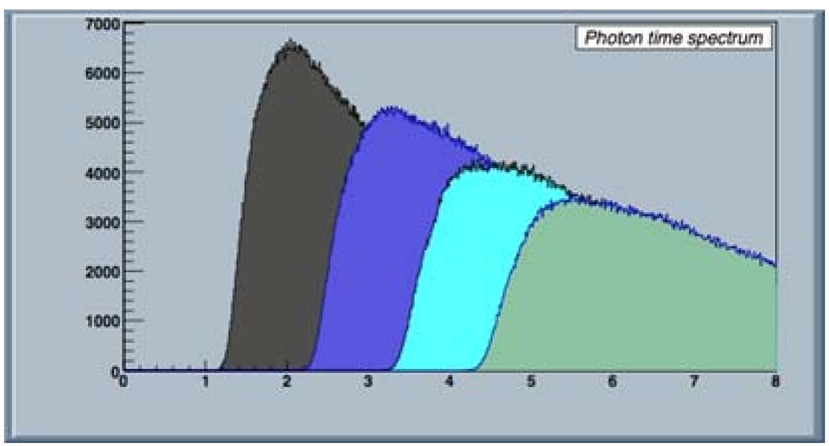


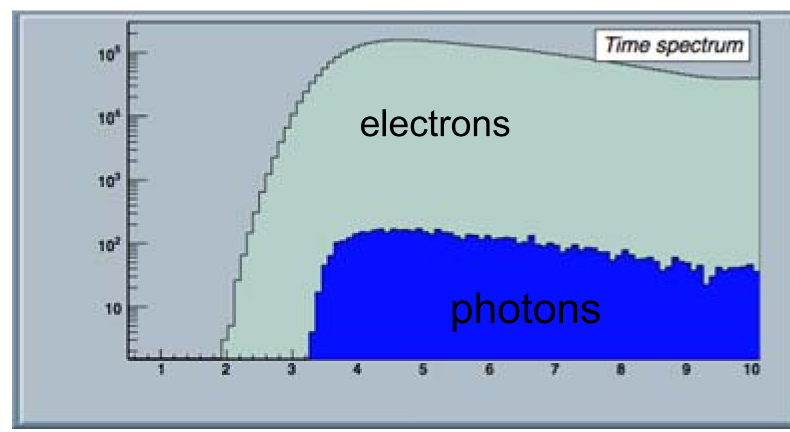
MC Distributions



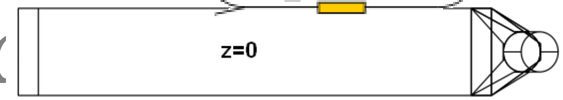


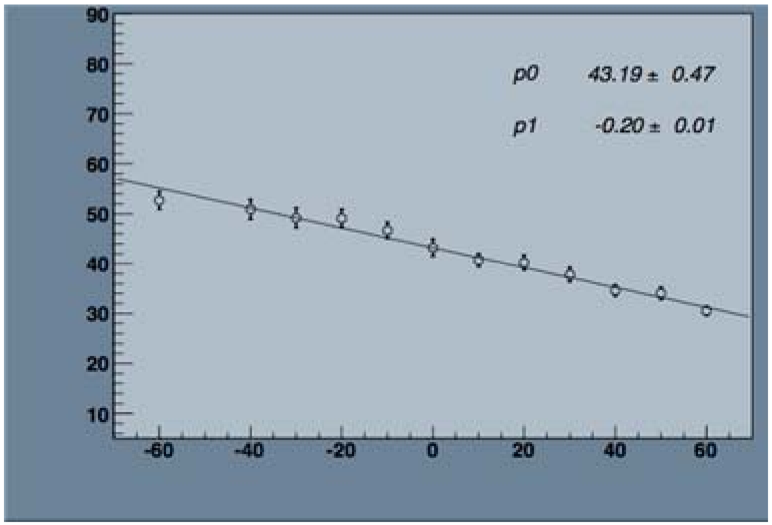
PMT R2083 Hamamatsu 10^6 e^- with σ~370ps

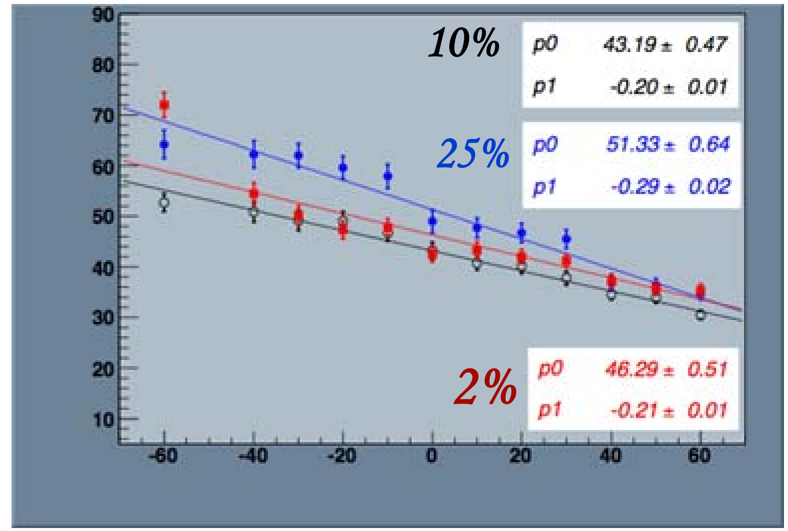


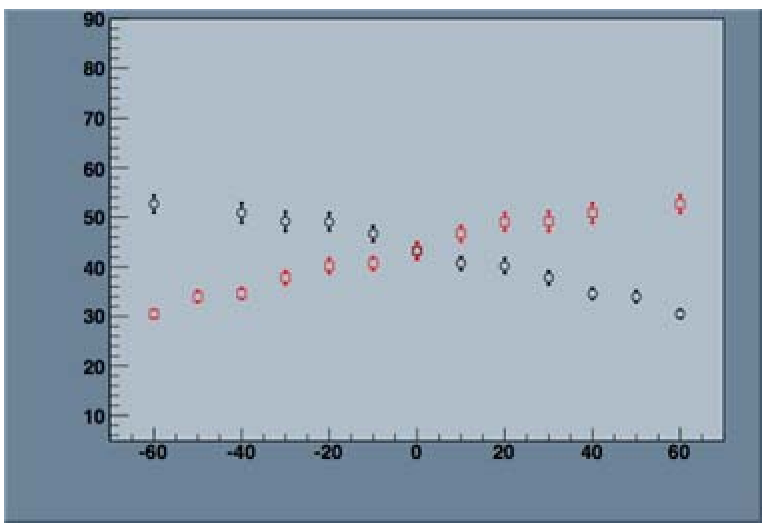


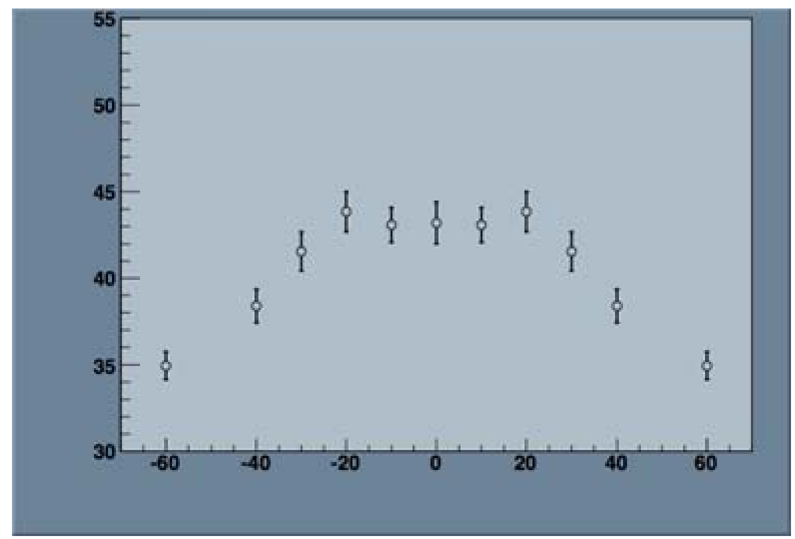
Time resoluti



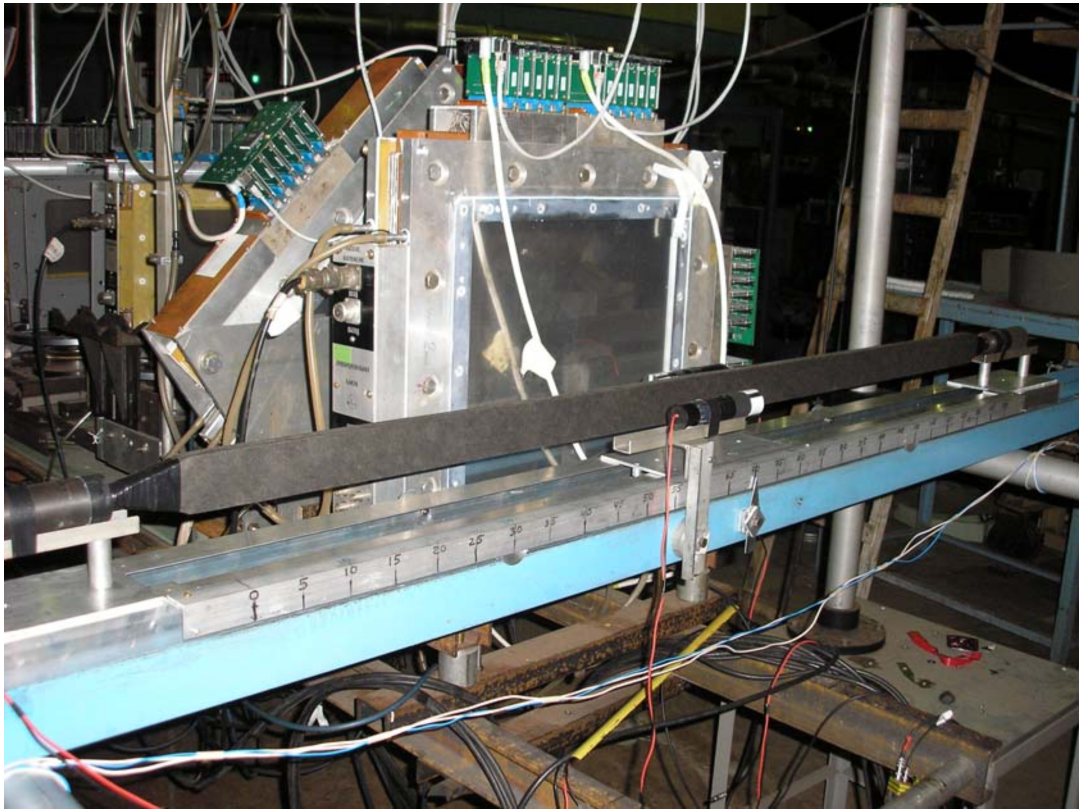




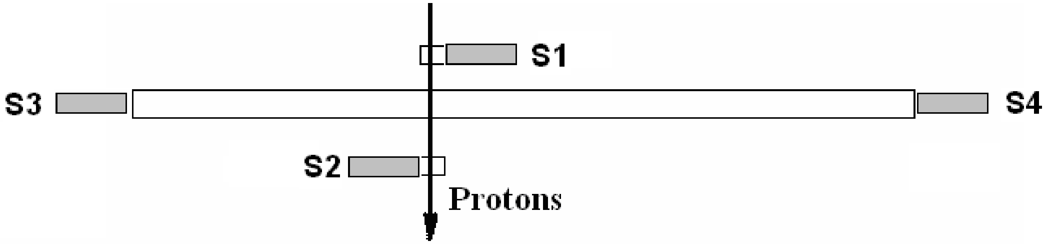


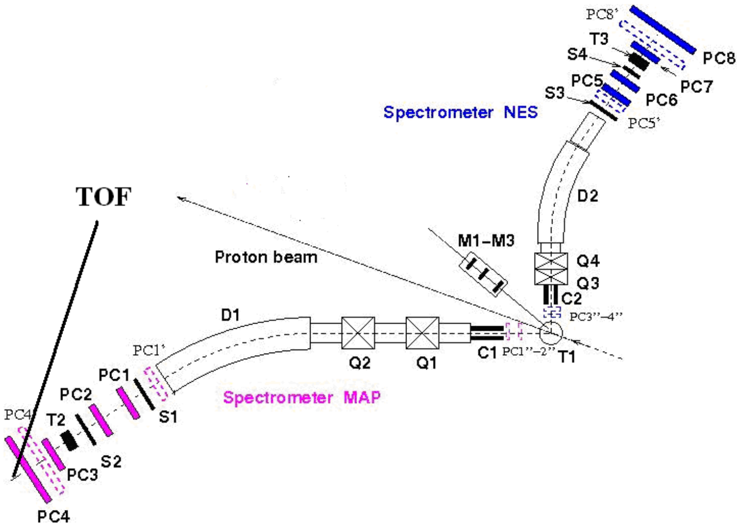


Измерения на пучке ПИЯФ.



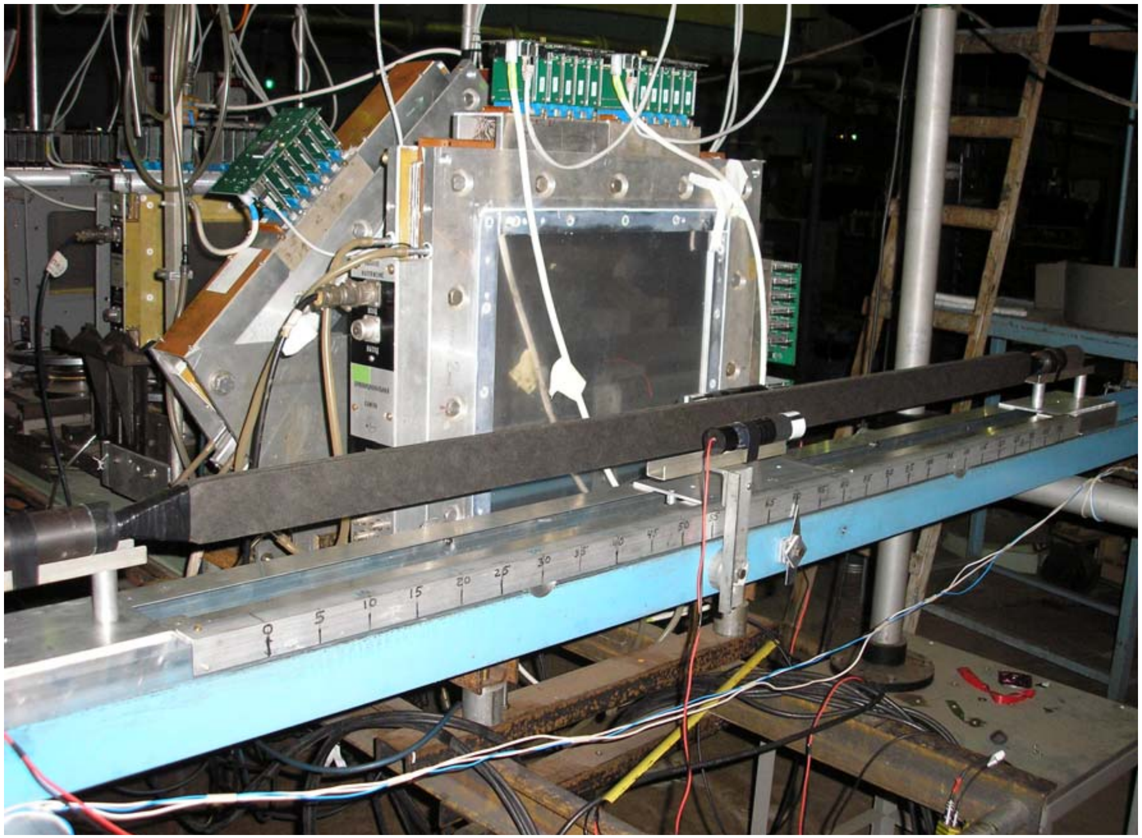
Protons: 900 MeV
Plastic: B408
140x5x2.5 cm
140x10x2.5 cm
PMT's: R4998, R2083
TDC: CAEN V775N
QDC: PNPI 8CDC





Лучше 100 пс

Измерения на пучке ПИЯФ.



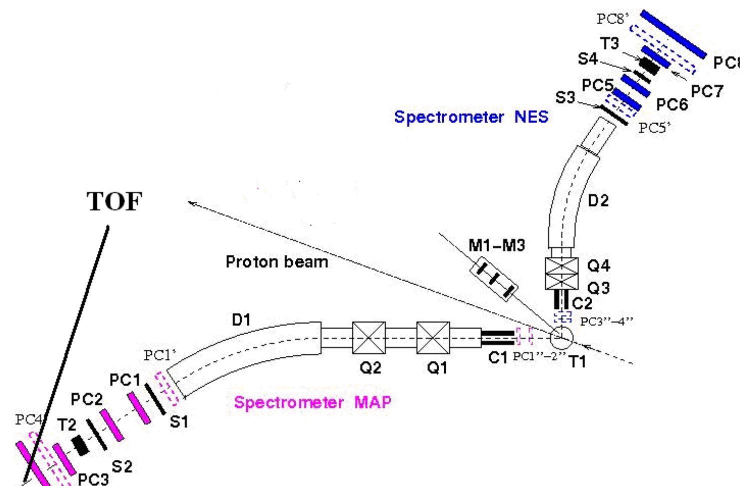
Протоны: 900 МэВ

Пластик: 140x5x2.5 см

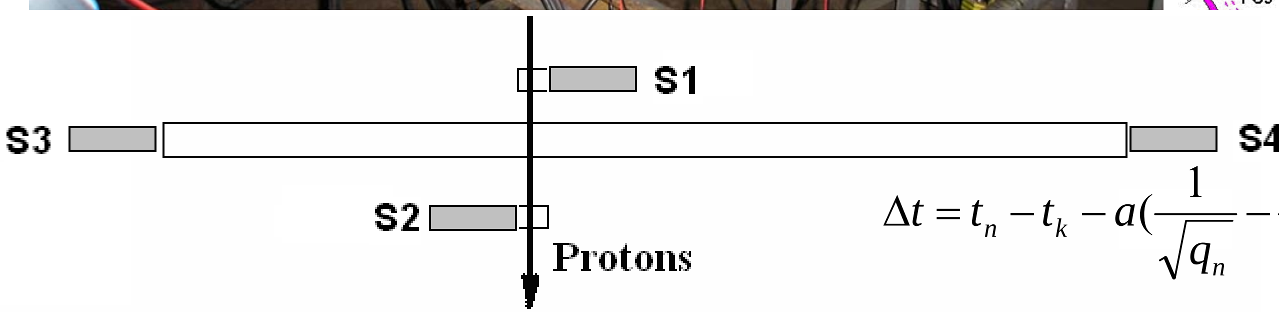
140x10x2.5 см

Тип : B408

ФЭУ: R4998, R2083



Лучше 100 пс



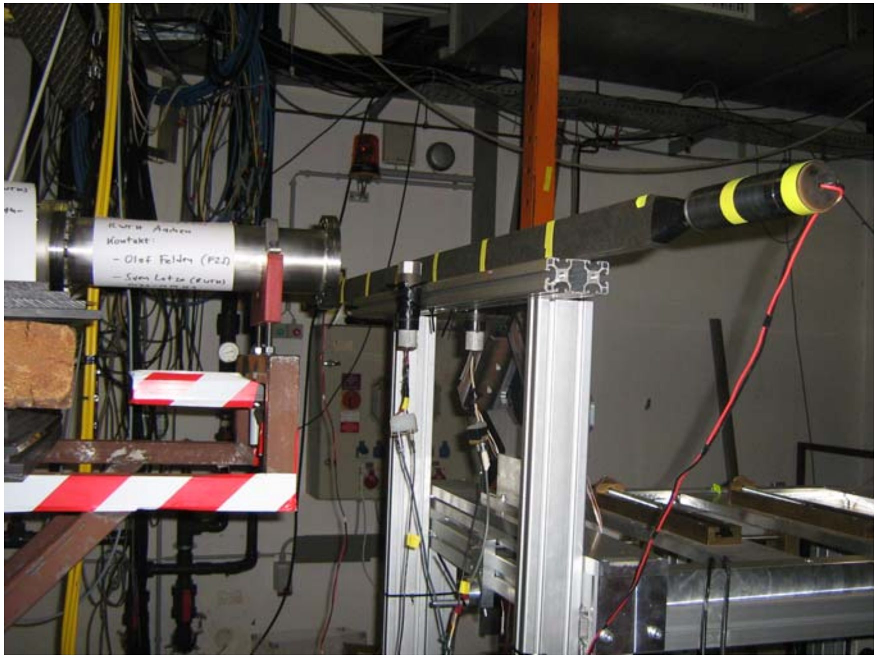
$$\Delta t = t_n - t_k - a\left(\frac{1}{\sqrt{q_n}} - \frac{1}{\sqrt{q_k}}\right) - bx - c, n \neq k = 1,2,3,4$$

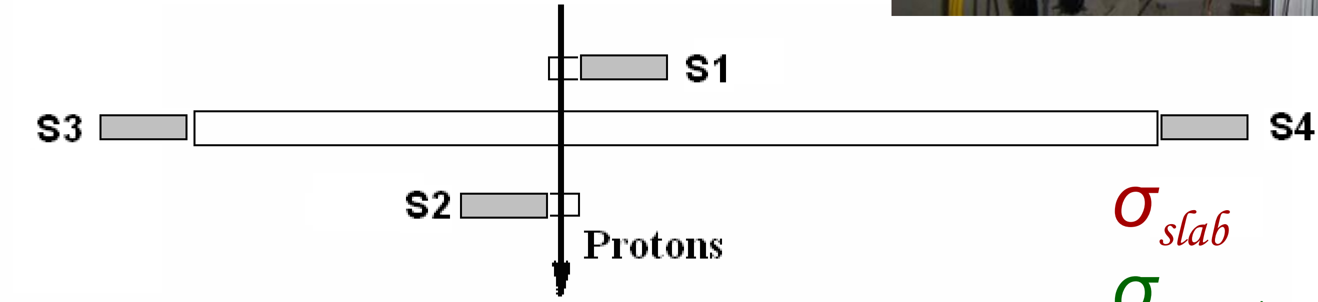
Prototyping @ COSY.

- *Counter: B408, 140x5x1.5 cm^3, R4998X2,*
- *Two counters: B408, 1x1x1 cm^3, PMT-187,*
- *Flash QDC 24 ps/ch*

(Marek Palka, Jagellonian University, Krakow),

- *Beam: protons E=2GeV, d=3cm,*
- *Collimator 0.2x3 cm.*





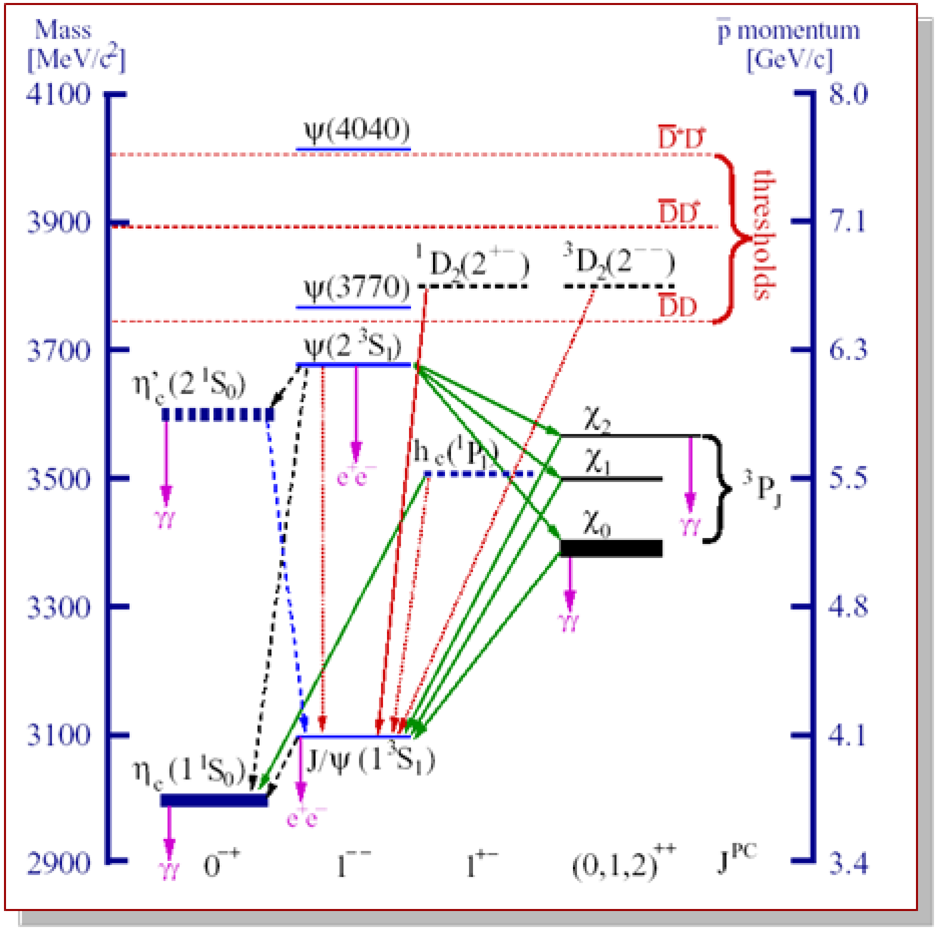
$\sigma_{slab} > 200ps$

$\sigma_{PMT-187} \leq 70\ ps$

Plans:

- SiPM?
- MC development,
- Side TOF Wall prototype,
- TDR.

Charmonium Spectrumm



Main issues

•All 8 states below threshold observed, some (precision) measurements still missing:

•h_c (e.g. width)

•$\eta_c(1S)$

•$\eta_c(2S)$ (small splitting from $\psi(2S)$)

•The region above open charm threshold must be explored in great detail:

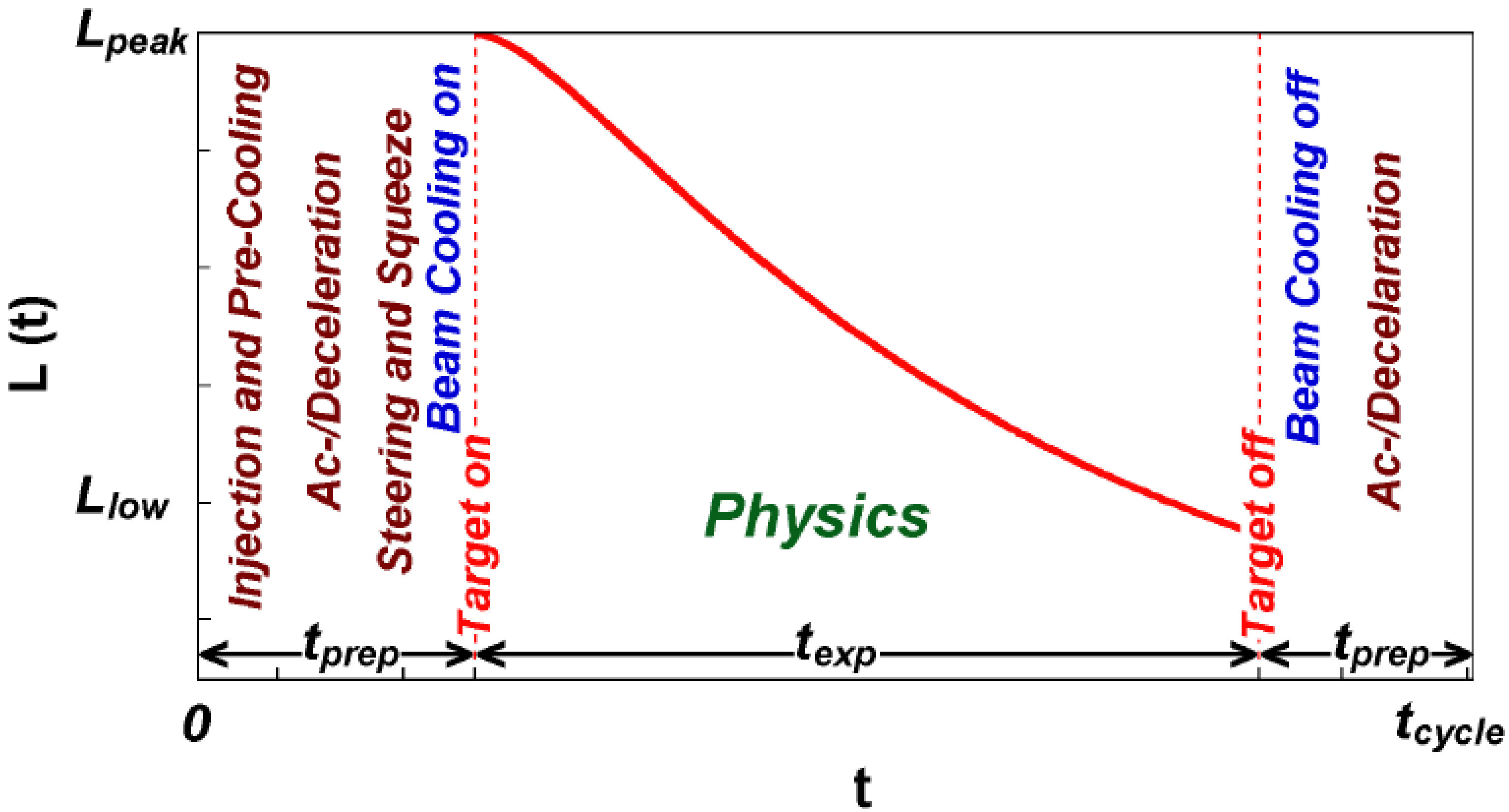
•find missing D-wave states

$^3D_1 \leftrightarrow \psi(3770)$ $^1D_2$, $^3D_2$, $^3D_3$ narrow

•explain newly discovered states

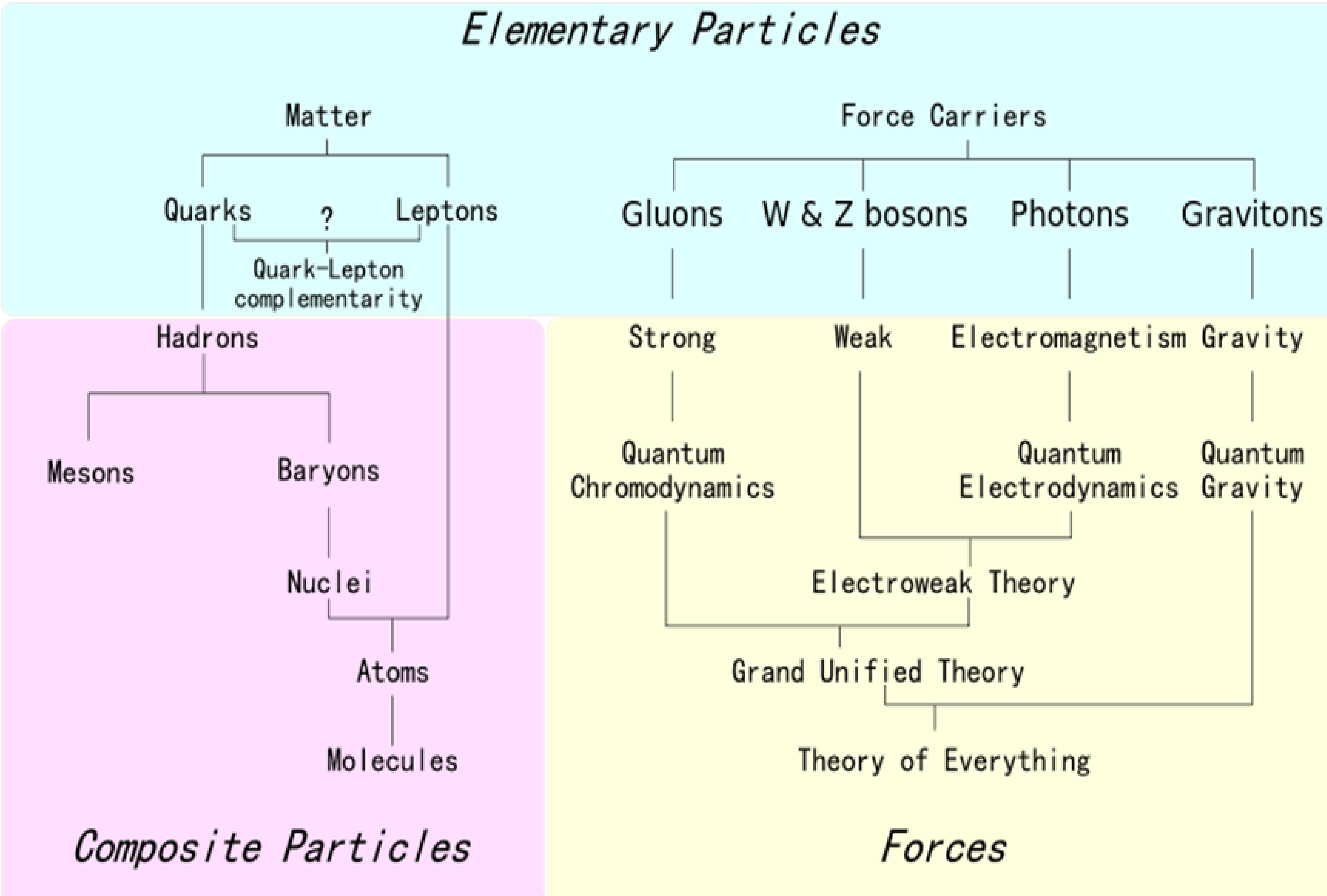
(X, Y, Z, $c\bar{c}$ or other)

•confirm vector states seen in R

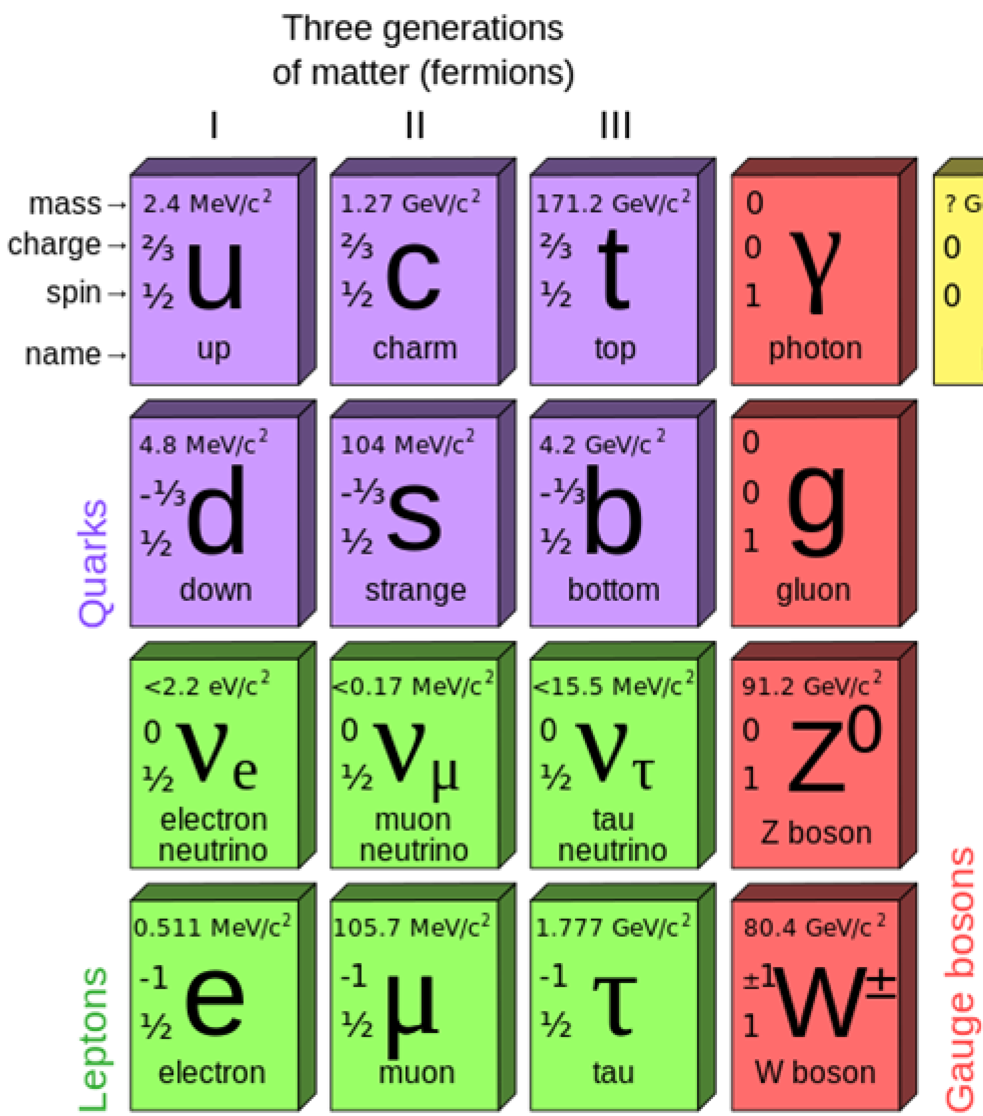


L (t)
L_{peak}
L_{low}
Injection and Pre-Cooling
Ac-/Deceleration
Steering and Squeeze
Beam Cooling on
Target on
Physics
Target off
Beam Cooling off
Ac-/Decelaration
t_{prep}
t_{exp}
t_{prep}
0
t_{cycle}
t

Matter and interaction

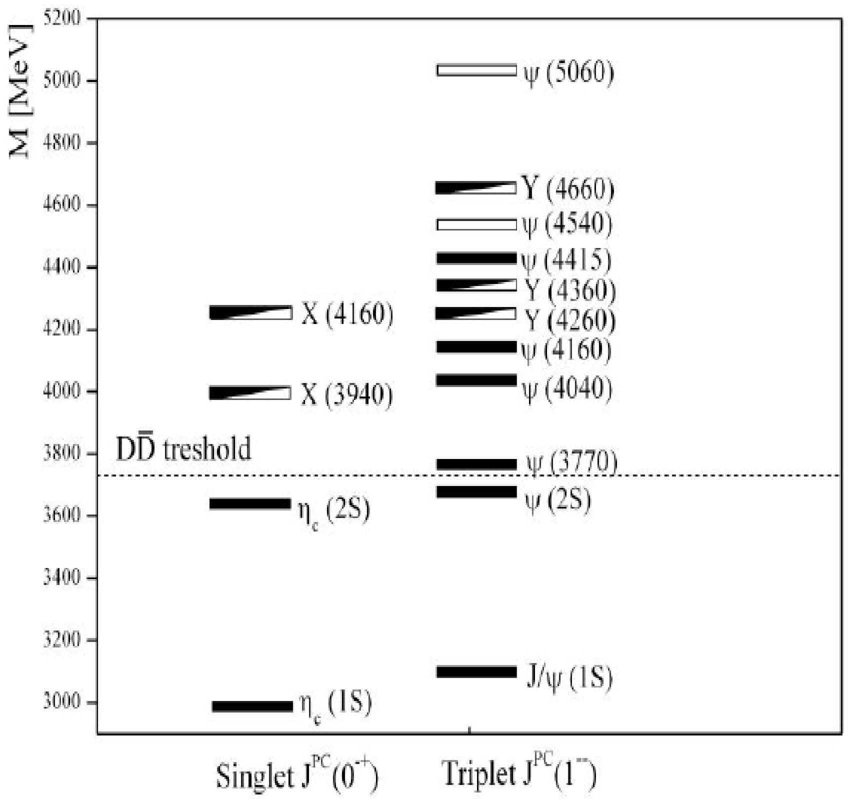


Standard Model. Where we are ?



Very succesful
but obviously
Not final

Charmonium states



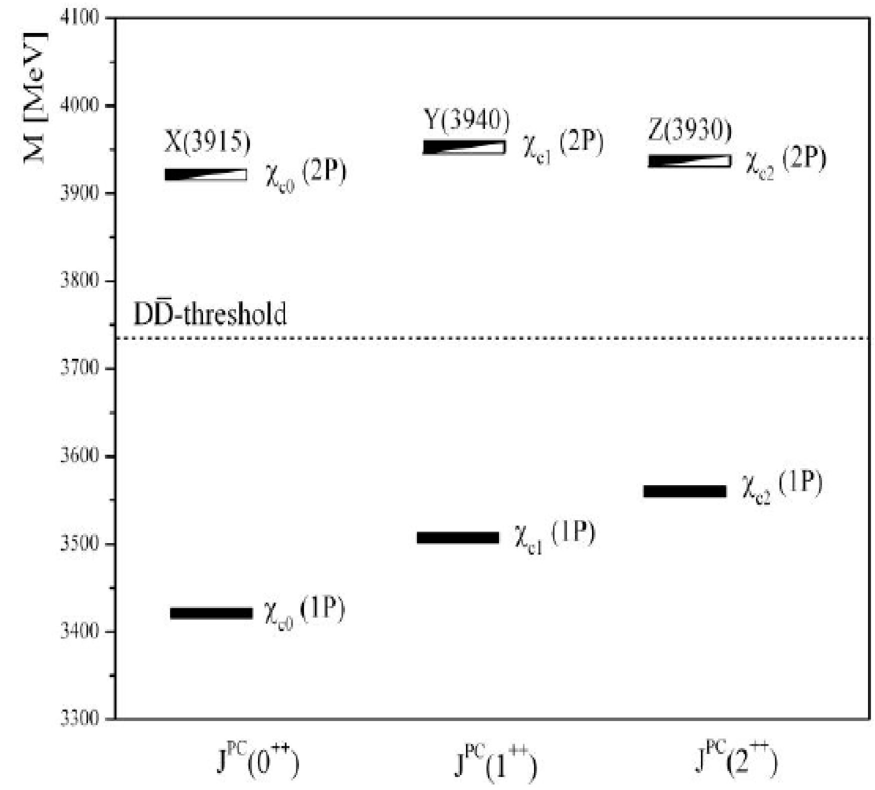
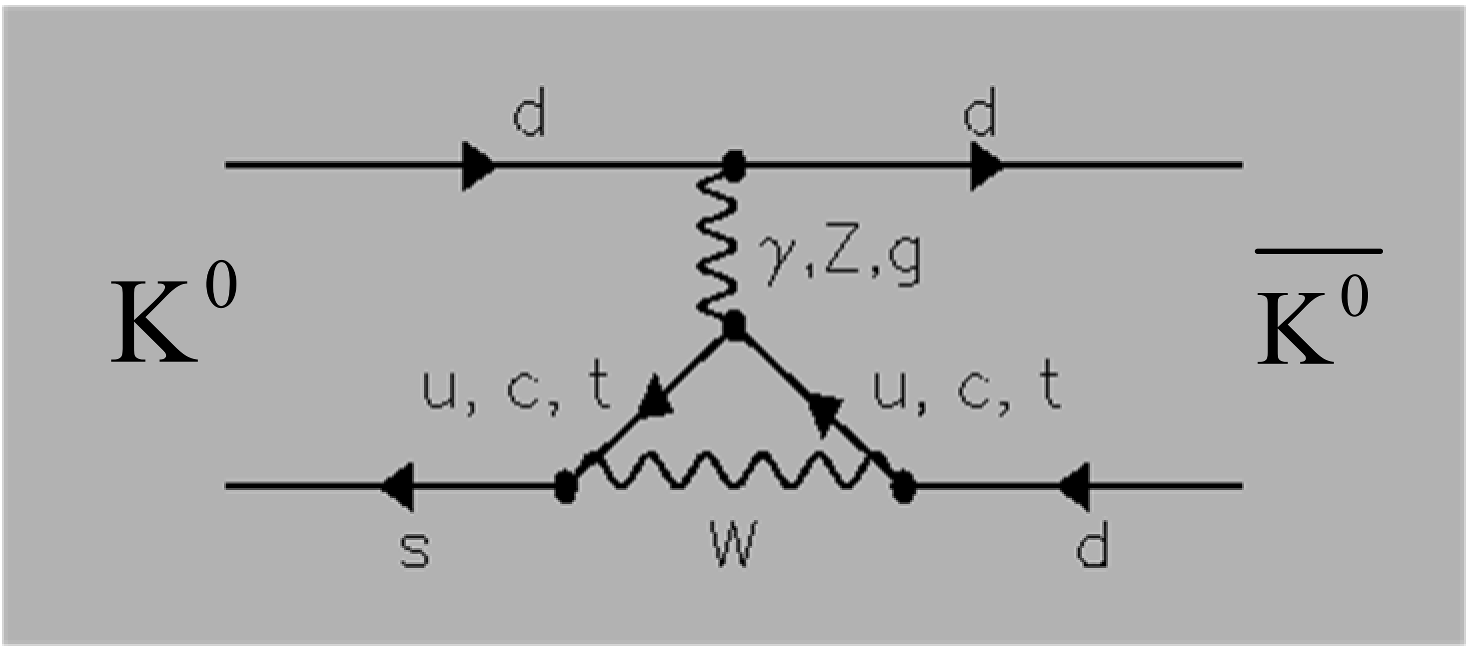


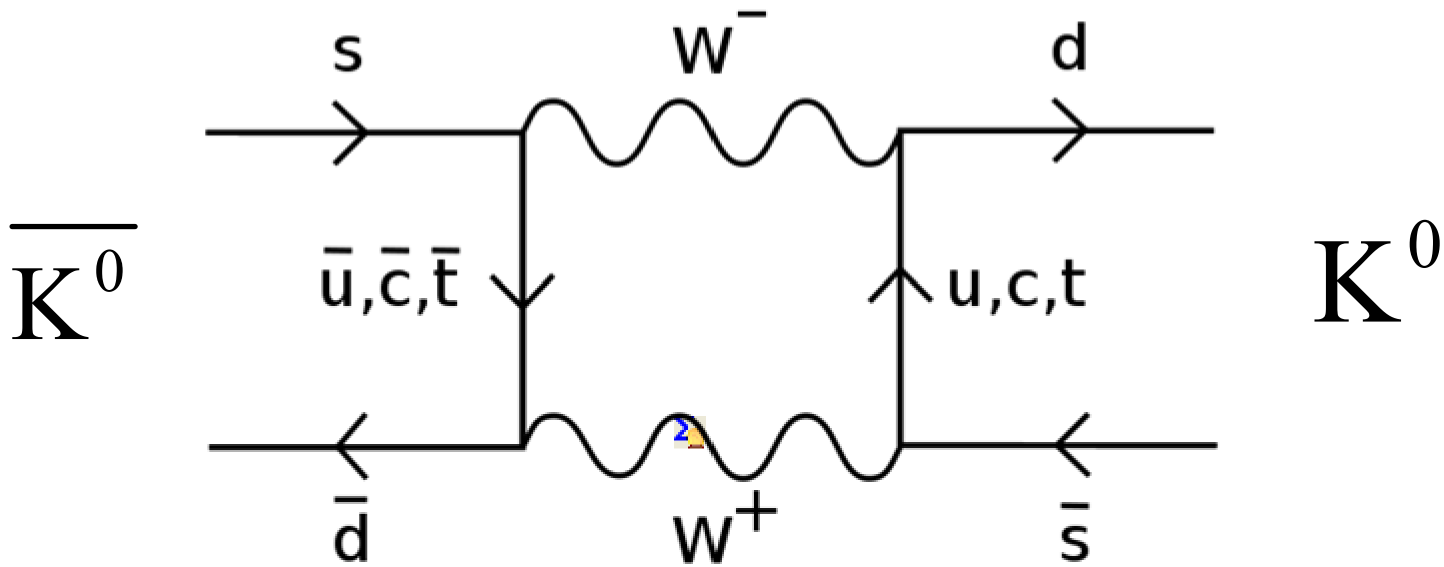
Table 3.5: Predicted and observed masses of $b\bar{b}$ states.

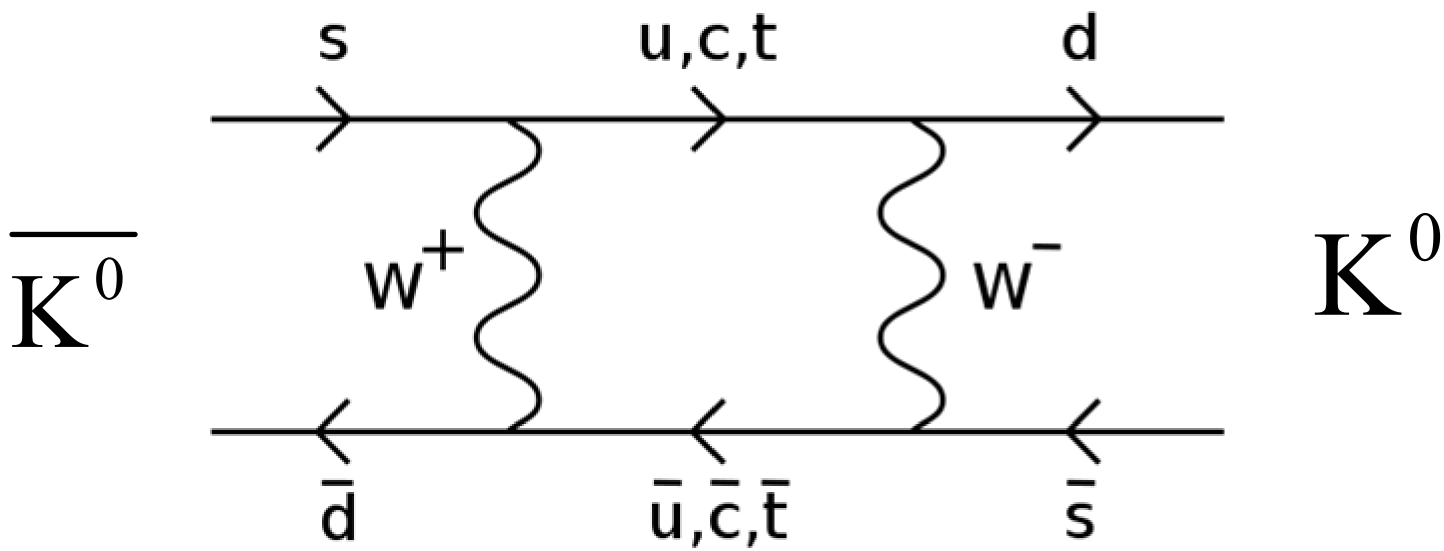
State	expt	GI85 [171]	FU91 [175]	EQ94 [196]	GJ96 [179]	EFG03 [173]	ZVR95 [180]
1^3S_1	9460	9465	9459	9464	9460	9460	9460
1^1S_0		9402	9413	9377	9408	9400	9410
1^3P_2	9913	9897	9911	9886	9914	9913	9890
1^3P_1	9893	9876	9893	9864	9893	9892	9870
1^3P_0	9860	9847	9865	9834	9862	9863	9850
1^1P_1		9882	9900	9873	9901	9901	9880
2^3S_1	10023	10003	10015	10007	10016	10023	10020
2^1S_0		9976	9992	9963	9991	9993	10000
1^3D_3		10155	10172	10130		10162	10150
1^3D_2	10162	10147	10166	10126		10158	10150
1^3D_1		10138	10158	10120		10153	10140
1^1D_2		10148	10167	10127		10158	10150
2^3P_2	10269	10261	10269	10242	10270	10268	10280
2^3P_1	10255	10246	10256	10224	10254	10255	10260
2^3P_0	10232	10226	10234	10199	10229	10234	10240
2^1P_1		10250	10261	10231	10259	10261	10270
3^3S_1	10355	10354	10356	10339	10358	10355	10390
3^1S_0		10336	10338	10298	10338	10328	10370

penguin graph, responsible for direct CP-violation



Indirect CP violation in kaon system
(K0 antiK0 mixing)





Charmonium in Nuclei

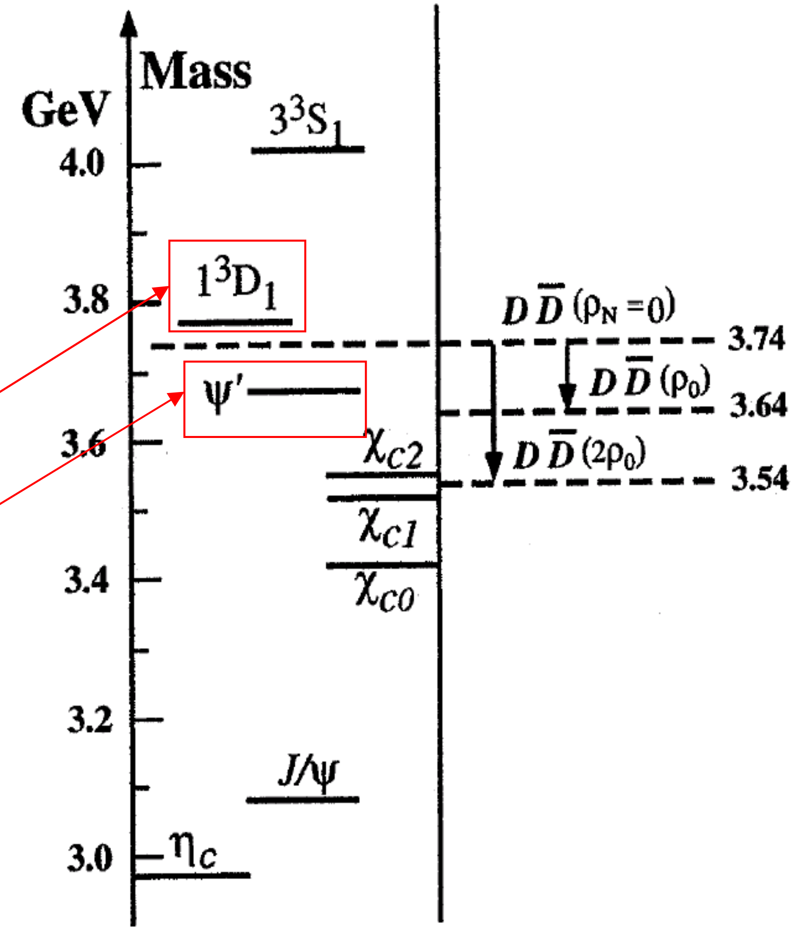
- Measure J/ψ and D production cross section in $\bar{p}$ annihilation on a series of nuclear targets.
- J/ψ nucleus dissociation cross section
- Lowering of the D^+D^- mass would allow charmonium states to decay into this channel, thus resulting in a dramatic increase of width

  ψ(1D) 20 MeV → 40 MeV

  ψ(2S) .28 MeV → 2.7 MeV

⇒Study relative changes of yield and width of the charmonium states.

- In medium mass reconstructed from dilepton (c $\bar{c}$) or hadronic decays (D)



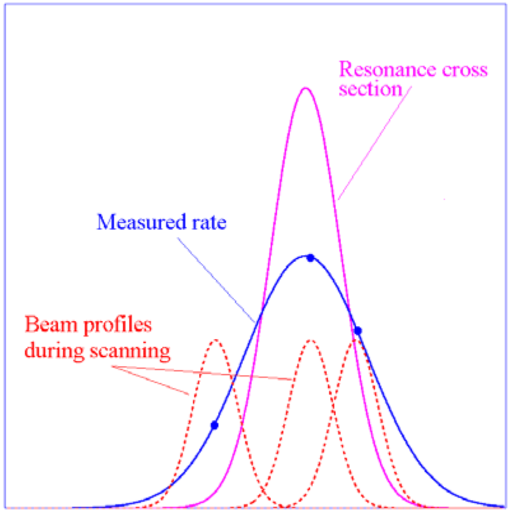
Experimental Method

The cross section for the process:

$\bar{p}p \rightarrow R \rightarrow$ final state

is given by the Breit-Wigner formula:

$$\sigma_{BW} = \frac{2J+1}{4} \frac{\pi}{k^2} \frac{B_{in} B_{out} \Gamma_R^2}{(E - M_R)^2 + \Gamma_R^2 / 4}$$



The production rate ν is a convolution of the BW cross section and the beam energy distribution function *f(E,ΔE)*:

$$\nu = L_0 \left\{ \varepsilon \int dE f(E, \Delta E) \sigma_{BW}(E) + \sigma_b \right\}$$

The resonance mass M_R, total width Γ_R and product of branching ratios into the initial and final state $B_{in}B_{out}$ can be extracted by measuring the formation rate for that resonance as a function of the cm energy *E*.

Beam Energy and Width Measurement

In $\bar{p}p$ annihilation the precision in the measurement of mass and width is determined by the precision in the measurement of the beam energy and beam energy width, respectively.

$$E_{cm} = \sqrt{2} m_p (1+\gamma)^{1/2} \qquad \gamma = \frac{E_{beam}}{m_p} = \frac{1}{\sqrt{1-\beta^2}} \qquad \beta = f \cdot L$$

$$\frac{\delta E_{cm}}{E_{cm}} = \frac{\beta^2 \gamma^3}{2(1+\gamma)} \sqrt{\left(\frac{\delta f}{f}\right)^2 + \left(\frac{\delta L}{L}\right)^2}$$

The beam revolution frequency f can be measured to 1 part in 10^7 from the beam current Schottky noise. In order to measure the orbit length L to the required precision (better than 1 mm) it is necessary to calibrate using the known mass of a resonance, e.g. the ψ' for which ΔM = 34 keV.

η is a machine parameter which can be measured to ~ 10 %

$$\frac{\delta p}{p} = -\frac{1}{\eta} \frac{\delta f}{f}$$

η machine slip factor

PDG List of $\bar{c}c$ States

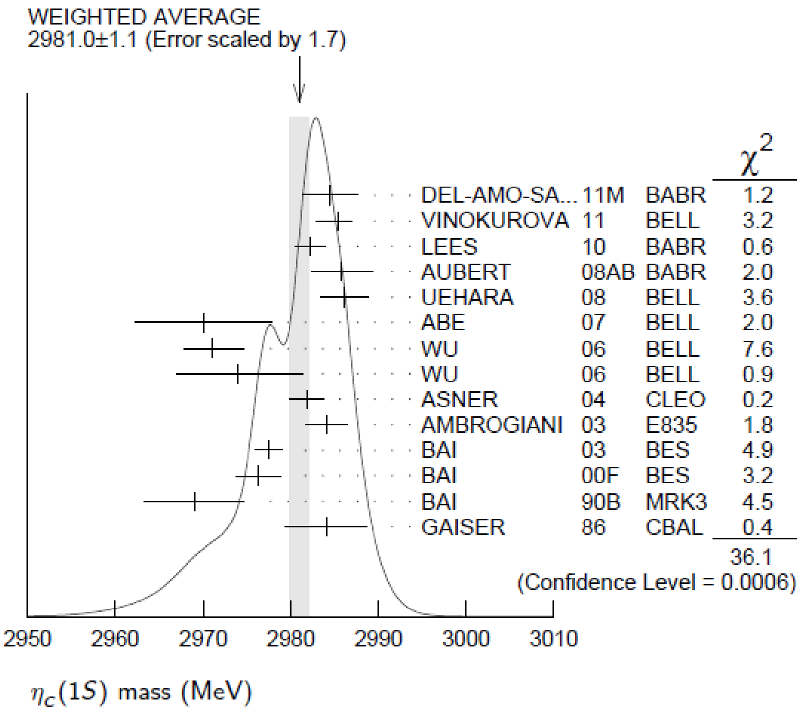
$\eta_c(1S)$ $J/\psi(1S)$ $\chi_{c0}(1P)$ $\chi_{c1}(1P)$ $\chi_{c2}(1P)$ $h_c(1P)$ $\eta_c(2S)$ $\psi(2S)$

$\psi(3770)$ X(3872) X(3915) $\chi_{c2}(2P)$ X(3940) $\psi(4040)$

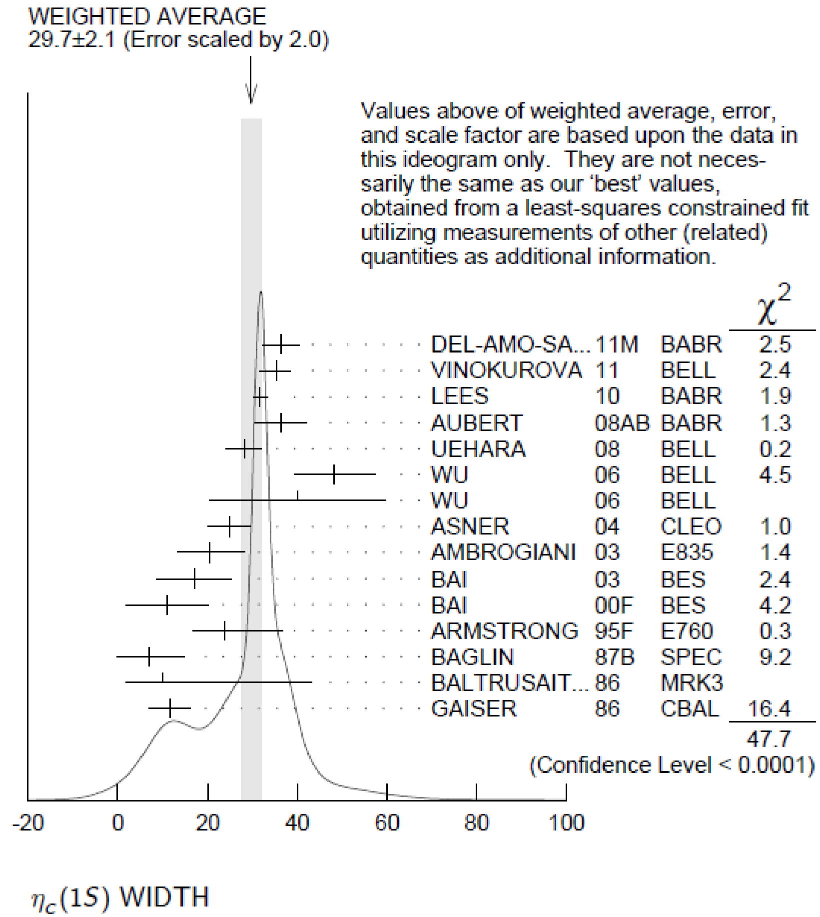
$X(4050)^{\pm}$ X(4140) $\psi(4160)$ X(4160) $X(4250)^{\pm}$ X(4260)

X(4350) X(4360) $\psi(4415)$ $X(4430)^{\pm}$ X(4660)

$\eta_c(1S)$



WEIGHTED AVERAGE
2981.0±1.1 (Error scaled by 1.7)
χ2
DEL-AMO-SA... 11M BABR 1.2
VINOKUROVA 11 BELL 3.2
LEES 10 BABR 0.6
AUBERT 08AB BABR 2.0
UEHARA 08 BELL 3.6
ABE 07 BELL 2.0
WU 06 BELL 7.6
WU 06 BELL 0.9
ASNER 04 CLEO 0.2
AMBROGIANI 03 E835 1.8
BAI 03 BES 4.9
BAI 00F BES 3.2
BAI 90B MRK3 4.5
GAISER 86 CBAL 0.4
36.1
(Confidence Level = 0.0006)
2950
2960
2970
2980
2990
3000
3010
ηc(1S) mass (MeV)



WEIGHTED AVERAGE
29.7±2.1 (Error scaled by 2.0)
Values above of weighted average, error, and scale factor are based upon the data in this ideogram only. They are not necessarily the same as our 'best' values, obtained from a least-squares constrained fit utilizing measurements of other (related) quantities as additional information.
χ2
DEL-AMO-SA... 11M BABR 2.5
VINOKUROVA 11 BELL 2.4
LEES 10 BABR 1.9
AUBERT 08AB BABR 1.3
UEHARA 08 BELL 0.2
WU 06 BELL 4.5
WU 06 BELL
ASNER 04 CLEO 1.0
AMBROGIANI 03 E835 1.4
BAI 03 BES 2.4
BAI 00F BES 4.2
ARMSTRONG 95F E760 0.3
BAGLIN 87B SPEC 9.2
BALTRUSAIT... 86 MRK3
GAISER 86 CBAL 16.4
47.7
(Confidence Level < 0.0001)
-20
0
20
40
60
80
100
ηc(1S) WIDTH

$h_c(1P)$

$h_c(1P)$

$I^G(J^{PC}) = ?^?(1^{+-})$

Quantum numbers are quark model prediction, $C = -$ established by $\eta_c\gamma$ decay.

$h_c(1P)$ MASS

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
3525.41±0.16 OUR AVERAGE		Error includes scale factor of 1.2.			
3525.40±0.13±0.18	3679	ABLIKIM	10B	BES3	$\psi(2S) \to \pi^0\gamma\eta_c$
3525.20±0.18±0.12	1282	[1] DOBBS	08A	CLEO	$\psi(2S) \to \pi^0\eta_c\gamma$
3525.8 ±0.2 ±0.2	13	ANDREOTTI	05B	E835	$\overline{p}p \to \eta_c\gamma$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
3525.6 ±0.5	92^{+23}_{-22}	ADAMS	09	CLEO	$\psi(2S) \to 2(\pi^+\pi^-\pi^0)$
3524.4 ±0.6 ±0.4	168 ± 40	[2] ROSNER	05	CLEO	$\psi(2S) \to \pi^0\eta_c\gamma$
3527 ±8	42	ANTONIAZZI	94	E705	300 $\pi^\pm$, pLi $\to J/\psi\pi^0 X$
3526.28±0.18±0.19	59	[3] ARMSTRONG	92D	E760	$\overline{p}p \to J/\psi\pi^0$
3525.4 ±0.8 ±0.4	5	BAGLIN	86	SPEC	$\overline{p}p \to J/\psi X$

[1] Combination of exclusive and inclusive analyses for the reaction $\psi(2S) \to \pi^0 h_c \to \pi^0\eta_c\gamma$. This result is the average of DOBBS 08A and ROSNER 05.

[2] Superseded by DOBBS 08A.

[3] Mass central value and systematic error recalculated by us according to Eq. (16) in ARMSTRONG 93B, using the value for the $\psi(2S)$ mass from AULCHENKO 03.

$h_c(1P)$ WIDTH

VALUE (MeV)	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
<1		13	ANDREOTTI	05B	E835	$\overline{p}p \to \eta_c\gamma$
• • • We do not use the following data for averages, fits, limits, etc. • • •						
<1.44	90	3679	[4] ABLIKIM	10B	BES3	$\psi(2S) \to \pi^0\gamma\eta_c$
<1.1	90	59	ARMSTRONG	92D	E760	$\overline{p}p \to J/\psi\pi^0$

[4] The central value is $\Gamma = 0.73 \pm 0.45 \pm 0.28$ MeV.

$\eta_c(2S)$

$\eta_c(2S)$ MASS

VALUE (MeV)	EVTS	DOCUMENT ID	TECN	COMMENT
3638.9±1.3 OUR AVERAGE				
3638.5±1.5±0.8	624	[1] DEL-AMO-SA...11M	BABR	$\gamma\gamma \to K^0_S K^\pm \pi^\mp$
3640.5±3.2±2.5	1201	[1] DEL-AMO-SA...11M	BABR	$\gamma\gamma \to K^+ K^- \pi^+ \pi^- \pi^0$
$3636.1^{+3.9}_{-4.2}{}^{+0.7}_{-2.0}$	128	[2] VINOKUROVA 11	BELL	$B^\pm \to K^\pm (K^0_S K^\pm \pi^\mp)$
3626 ±5 ±6	311	[3] ABE 07	BELL	$e^+ e^- \to J/\psi (c\overline{c})$
$3645.0\pm5.5^{+4.9}_{-7.8}$	121 ± 27	AUBERT 05C	BABR	$e^+ e^- \to J/\psi c\overline{c}$
3642.9±3.1±1.5	61	ASNER 04	CLEO	$\gamma\gamma \to \eta_c \to K^0_S K^\pm \pi^\mp$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
3639 ±7	98 ± 52	[4] AUBERT 06E	BABR	$B^\pm \to K^\pm X_{c\overline{c}}$
3630.8±3.4±1.0	112 ± 24	[5] AUBERT 04D	BABR	$\gamma\gamma \to \eta_c(2S) \to K \overline{K} \pi$
3654 ±6 ±8	39 ± 11	[6] CHOI 02	BELL	$B \to K K_S K^- \pi^+$
3594 ±5		[7] EDWARDS 82C	CBAL	$e^+ e^- \to \gamma X$

[1] Ignoring possible interference with continuum.
[2] Accounts for interference with non-resonant continuum.
[3] From a fit of the J/ψ recoil mass spectrum. Supersedes ABE,K 02 and ABE 04G.
[4] From the fit of the kaon momentum spectrum. Systematic errors not evaluated.
[5] Superseded by DEL-AMO-SANCHEZ 11M.
[6] Superseded by VINOKUROVA 11.
[7] Assuming mass of $\psi(2S)$ = 3686 MeV.

$\eta_c(2S)$ WIDTH

VALUE (MeV)	CL%	EVTS	DOCUMENT ID	TECN	COMMENT
10 ± 4 OUR AVERAGE					
13.4± 4.6±3.2		624	[8] DEL-AMO-SA...11M	BABR	$\gamma\gamma \to K^0_S K^\pm \pi^\mp$
$6.6^{+8.4}_{-5.1}{}^{+2.6}_{-0.9}$		128	[9] VINOKUROVA 11	BELL	$B^\pm \to K^\pm (K^0_S K^\pm \pi^\mp)$
6.3±12.4±4.0		61	ASNER 04	CLEO	$\gamma\gamma \to \eta_c \to K^0_S K^\pm \pi^\mp$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<23	90	98 ± 52	[10] AUBERT 06E	BABR	$B^\pm \to K^\pm X_{c\overline{c}}$
22 ±14		121 ± 27	AUBERT 05C	BABR	$e^+ e^- \to J/\psi c\overline{c}$
17.0± 8.3±2.5		112 ± 24	[11] AUBERT 04D	BABR	$\gamma\gamma \to \eta_c(2S) \to K \overline{K} \pi$
<55	90	39 ± 11	[12] CHOI 02	BELL	$B \to K K_S K^- \pi^+$
<8.0	95		[13] EDWARDS 82C	CBAL	$e^+ e^- \to \gamma X$

$\chi_{c2}(2P)$

$I^G(J^{PC}) = 0^+(2^{++})$

$\chi_{c2}(2P)$ MASS

VALUE (MeV)	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
3927.2±2.6 OUR AVERAGE					
3926.7±2.7±1.1	76 ± 17	AUBERT	10G	BABR	10.6 $e^+e^- \to e^+e^- D\overline{D}$
3929 ±5 ±2	64	UEHARA	06	BELL	10.6 $e^+e^- \to e^+e^- D\overline{D}$

$\chi_{c2}(2P)$ WIDTH

VALUE (MeV)	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
24 ± 6 OUR AVERAGE					
21.3± 6.8±3.6	76 ± 17	AUBERT	10G	BABR	10.6 $e^+e^- \to e^+e^- D\overline{D}$
29 ±10 ±2	64	UEHARA	06	BELL	10.6 $e^+e^- \to e^+e^- D\overline{D}$

$\chi_{c2}(2P)$ DECAY MODES

	Mode	Fraction (Γ_i/Γ)
Γ_1	$\gamma\gamma$	seen
Γ_2	$K\overline{K}\pi$	
Γ_3	$K^+K^-\pi^+\pi^-\pi^0$	
Γ_4	$D\overline{D}$	seen
Γ_5	D^+D^-	seen
Γ_6	$D^0\overline{D}^0$	seen

Stochastic and electron cooling

Stochastic cooling is a form of particle beam cooling. It is used in some particle accelerators and storage rings to control the emittance of the particle beams in the machine. This process uses the electrical signals that the individual charged particles generate in a feedback loop to reduce the tendency of individual particles to move away from the other particles in the beam. It is accurate to think of this as thermodynamic cooling, or the reduction of entropy, in much the same way that a refrigerator or an air conditioner cools its contents.

Electron cooling
From Wikipedia, the free encyclopedia
Jump to: navigation, search
Electron cooling is a process to shrink the size, divergence, and energy spread of charged particle beams without removing particles from the beam. Since the number of particles remains unchanged and the space coordinates and their derivatives (angles) are reduced, this means that the phase space occupied by the stored particles is compressed.
It is equivalent to reducing the temperature of the beam. See also stochastic cooling.
It was invented by Gersh Budker (INP, Novosibirsk) in 1966 for the purpose of increasing luminosity of hadron colliders.[1] It was first tested in 1974 with 68 MeV protons at NAP-M storage ring at INP.
Electron cooler (left) at LEIR/CERN. The electron source and dump are installed in the upper metallic cylinders.
Basically, electron cooling works as follows:
The velocity of the electrons is made equal to the average velocity of the ions.
The ions undergo Coulomb scattering in the electron “gas” and lose energy, which is transferred from the ions to the co-streaming electrons until some thermal equilibrium is attained.