

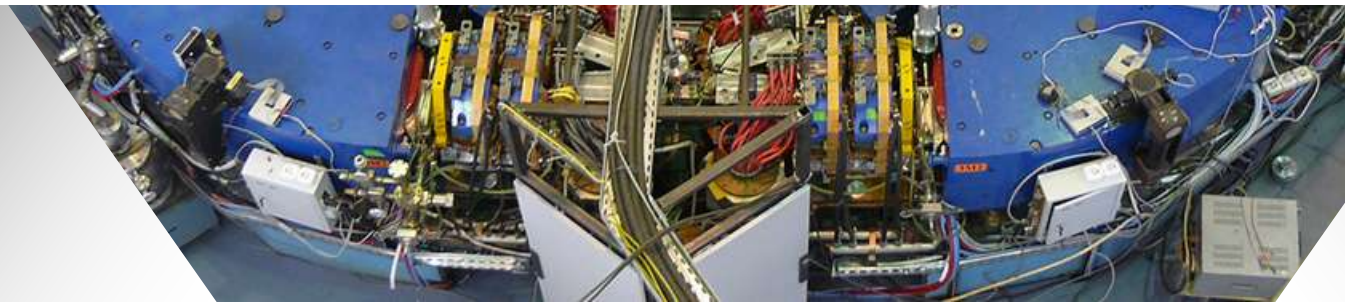


Status and Perspectives of the VEPP-2000 complex



Yu. Rogovsky on behalf of VEPP-2000 team

«XXIV Russian particle accelerators conference RUPAC 2014»
October 6–10, 2014, Obninsk, Russia



Outline

- Round Beam Conception (short)
- Vepp-2000 complex as of middle 2013
- Vepp-2000 equipment for operations
- Lattice/beam/energy measurements
- HEP experiments 2012-2013
- Upgrade motivation
- Current upgrade status
- Conclusion

Motivation of the «Round Beam» use

Luminosity increase scenario:

- ✓ Number of bunches (i.e. collision frequency)
- ✓ Bunch-by-bunch luminosity

$$L = \frac{\pi \gamma}{t_e \beta} \frac{\sigma_x \sigma_y}{\sigma_z}$$



Round Beams:

$$L = \frac{\gamma \epsilon_x \epsilon_y}{r_e \beta}$$

- ✓ Geometric factor:
- ✓ Beam-beam limit enhancement:
- ✓ IBS for low energy? Better life time!

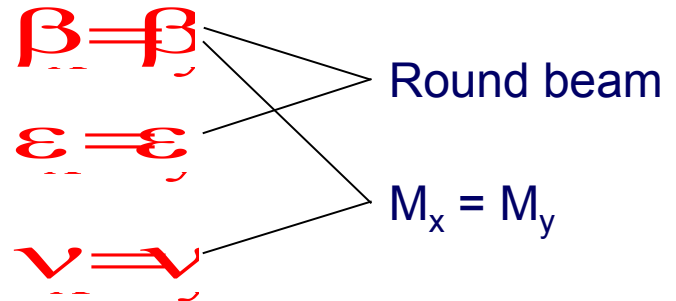
$$1 + \frac{\xi}{\xi_{\text{crit}}} = \xi \geq$$

The concept of Round Colliding Beams

Axial symmetry of counter beam force together with x-y symmetry of transfer matrix should provide additional integral of motion (angular momentum $M_z = x'y - xy'$). Particle dynamics remains nonlinear, but becomes 1D.

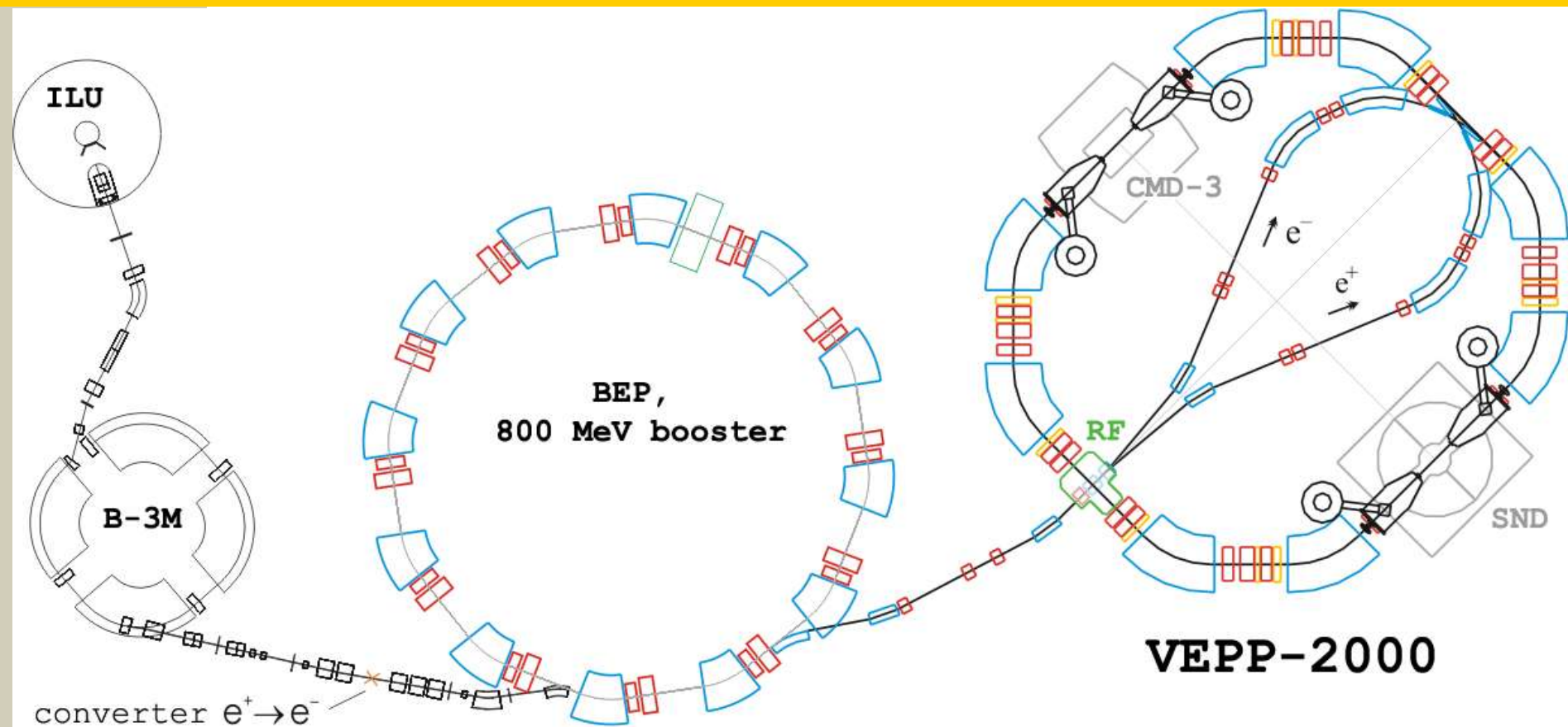
Lattice requirements:

- Head-on collisions
- Small and equal β -functions at IP:
- Equal beam emittances:
- Equal fractional parts of betatron tunes:



V.V.Danilov et al., EPAC'96, Barcelona, p.1149, (1996)

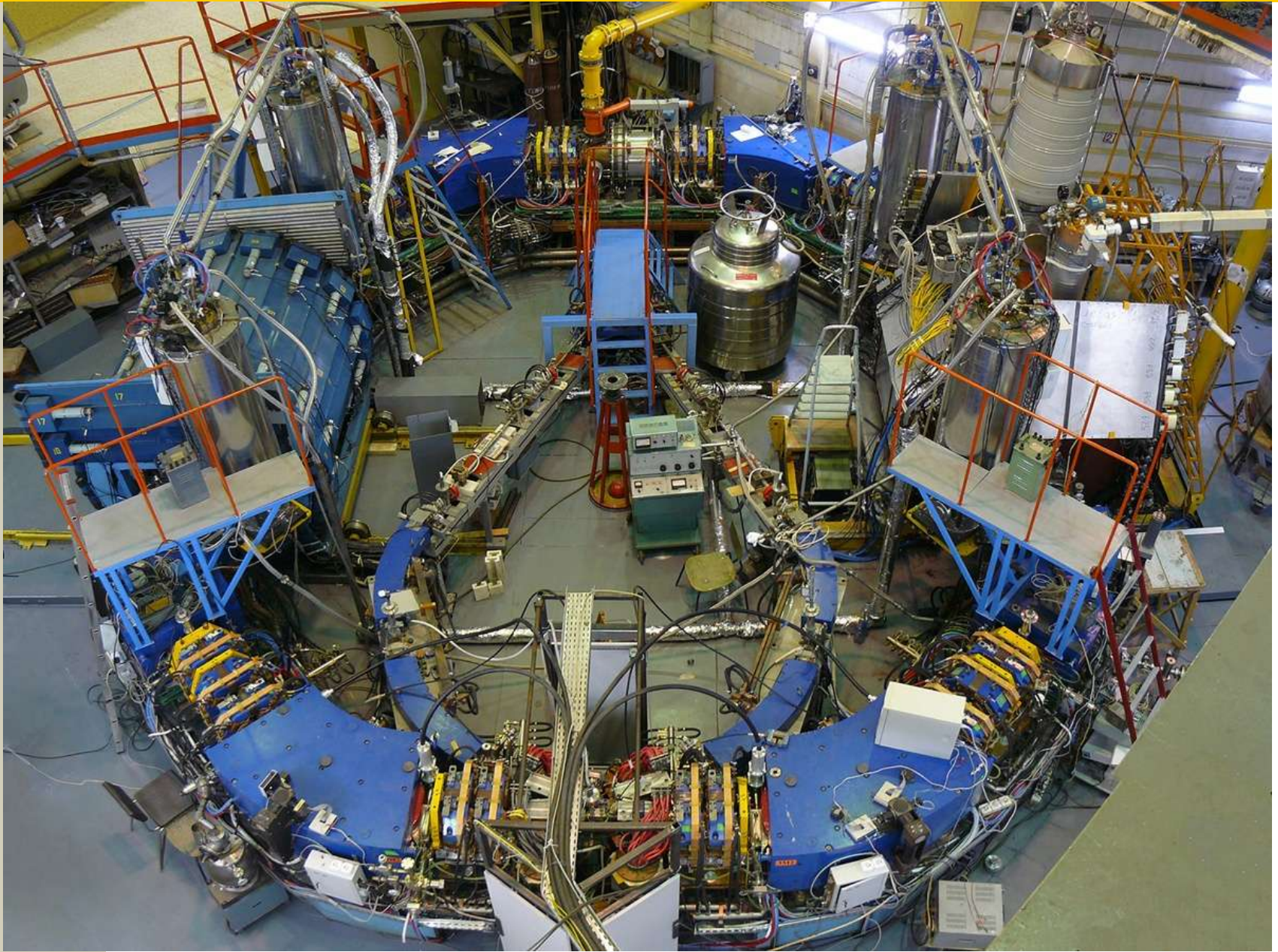
VEPP-2000 layout & parameters



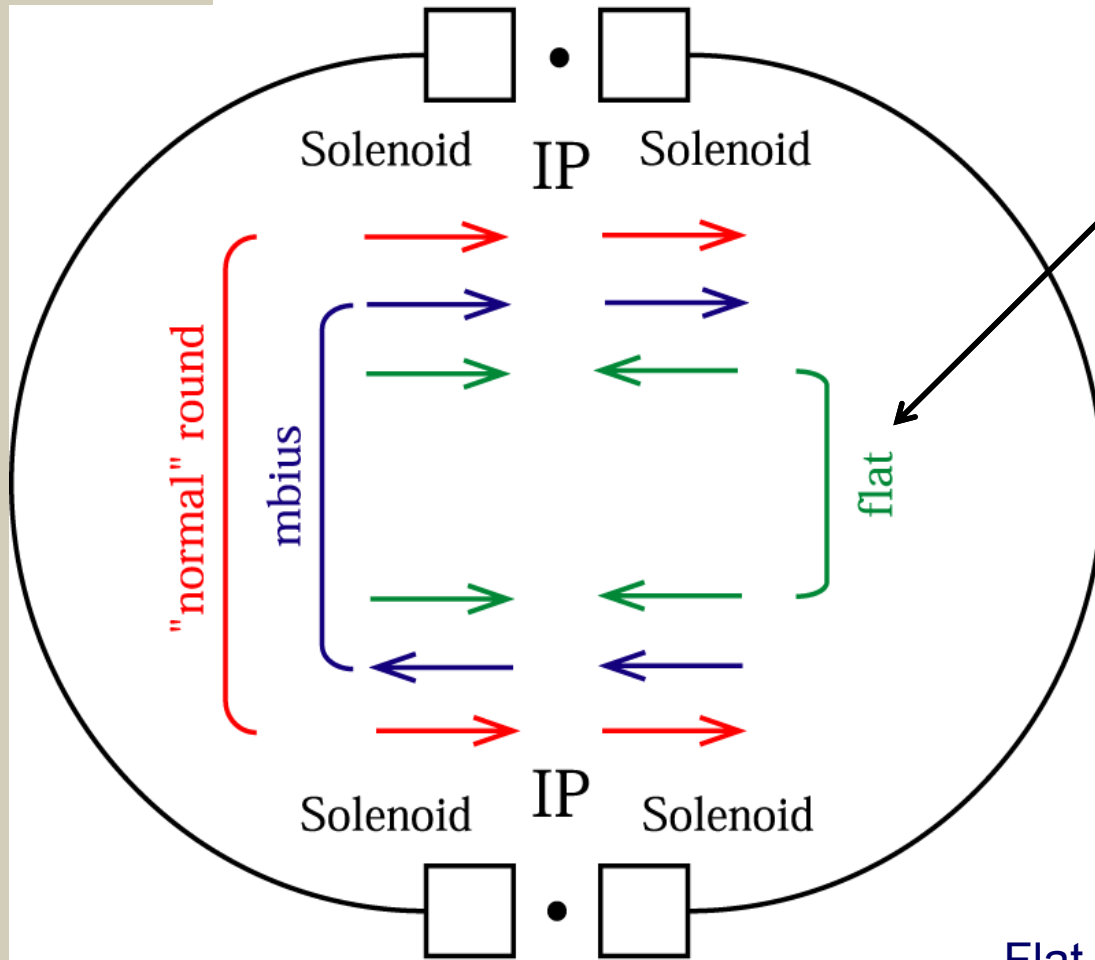
Main parameters @ 1GeV

Circumference	24.388 m	Energy	160 ÷ 1000 MeV
Number of bunches	1	Number of particles	1.0×10^{11}
Betatron tunes	4.1/2.1	Beta-functions @ IP	8.5 cm
Beam-beam param.	0.1	Luminosity	$1.0 \times 10^{32} \text{ cm}^{-2}\text{s}^{-1}$

VEPP-2000 @ begin of 2013



Round Beams Options for VEPP-2000



Round beam due to coupling resonance?
The simplest practical solution!

Both simulations and experimental tests showed insufficient dynamic aperture for regular work in circular modes options.

Flat to Round or Mobius change needs polarity switch in solenoids and new orbit correction.

Magnetic structure and diagnostics

Main lattice:

- 8 dipole magnets
- 24 quadrupole magnets
- 4 sup. cond. solenoids

Correctors:

- 24 hor. dipole corr.
- 20 vert. dipole corr
- 12 sextupoles
- 12 skew-quad

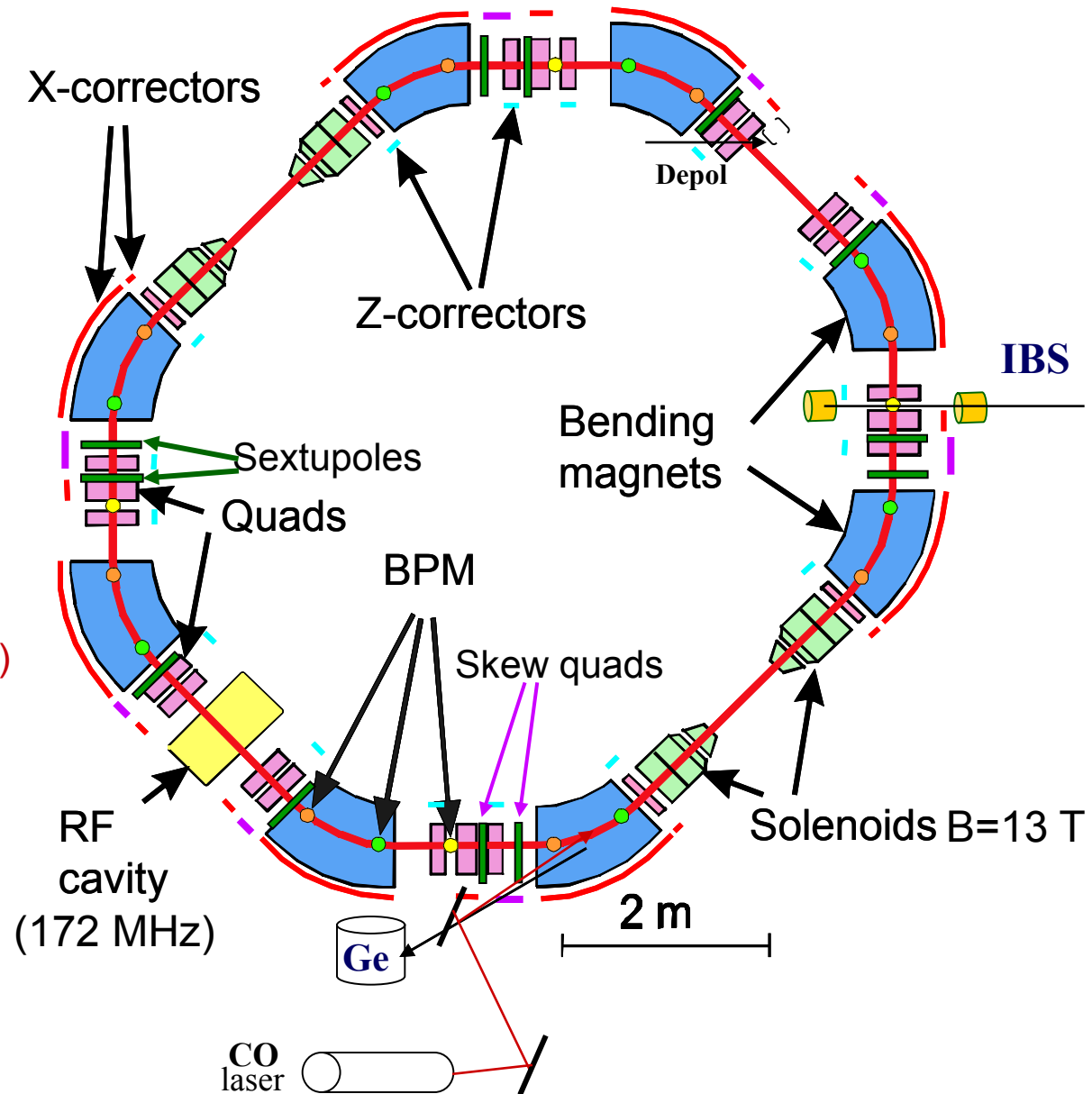
Observation:

- 16 CCD cameras (upgraded)
- 4 electrostatic BPMs (upgraded)
- 1 DCCT
- 2 PhMT (e^+ , e^-)
- 2 Phi-Dissectors (e^+ , e^-) (new)

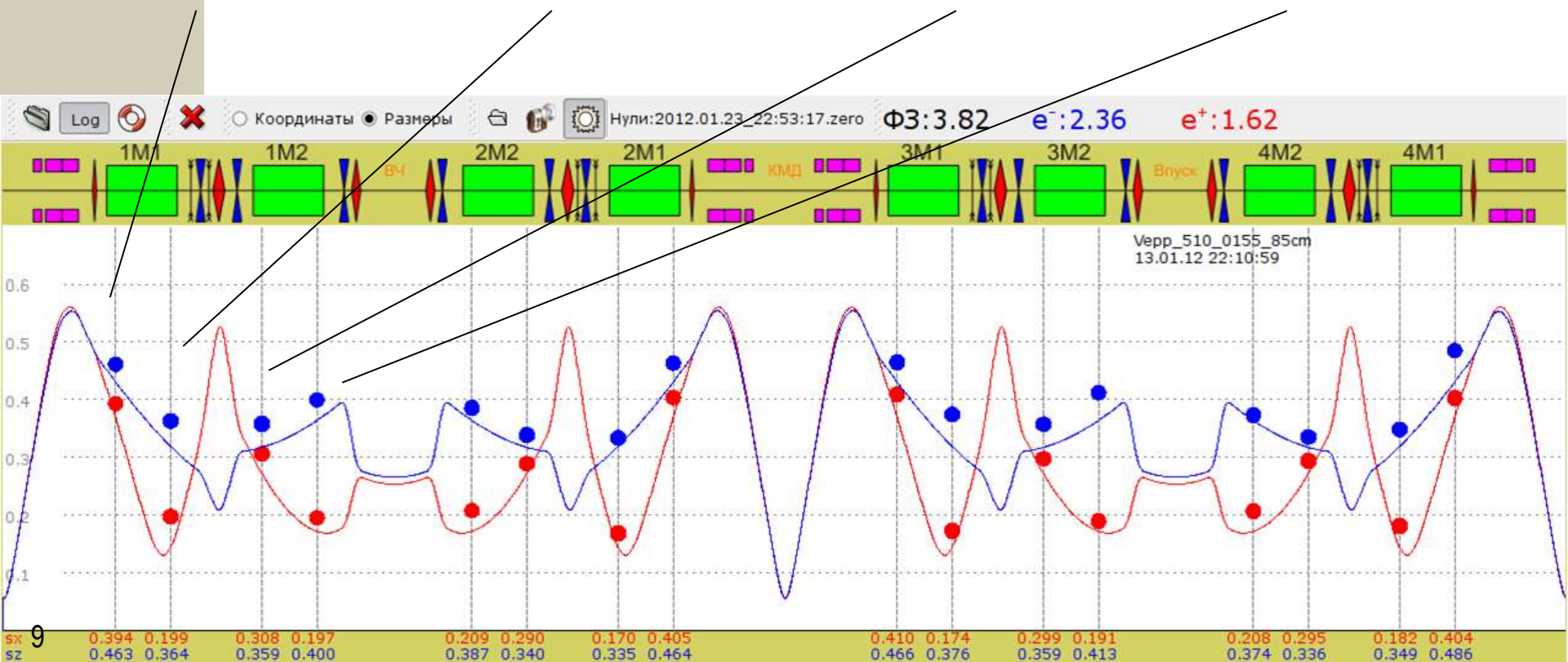
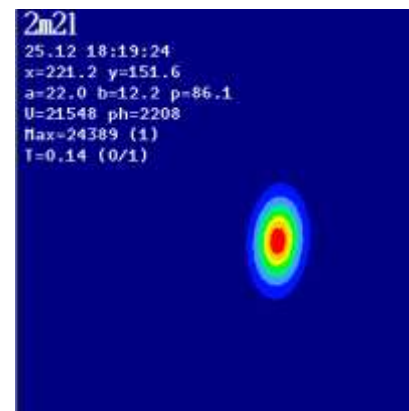
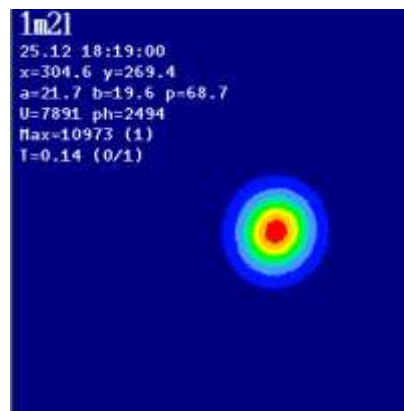
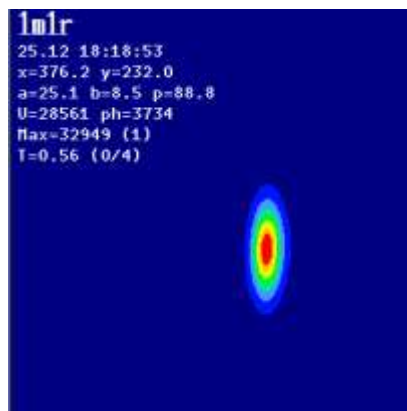
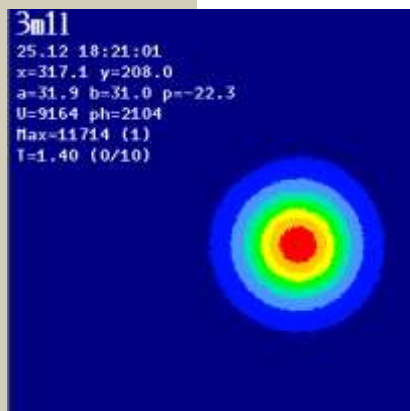
Energy meas:

- Depolarization, 16 NMR,
- Compton backscatter. (new)

Detectors: CMD-3, SND

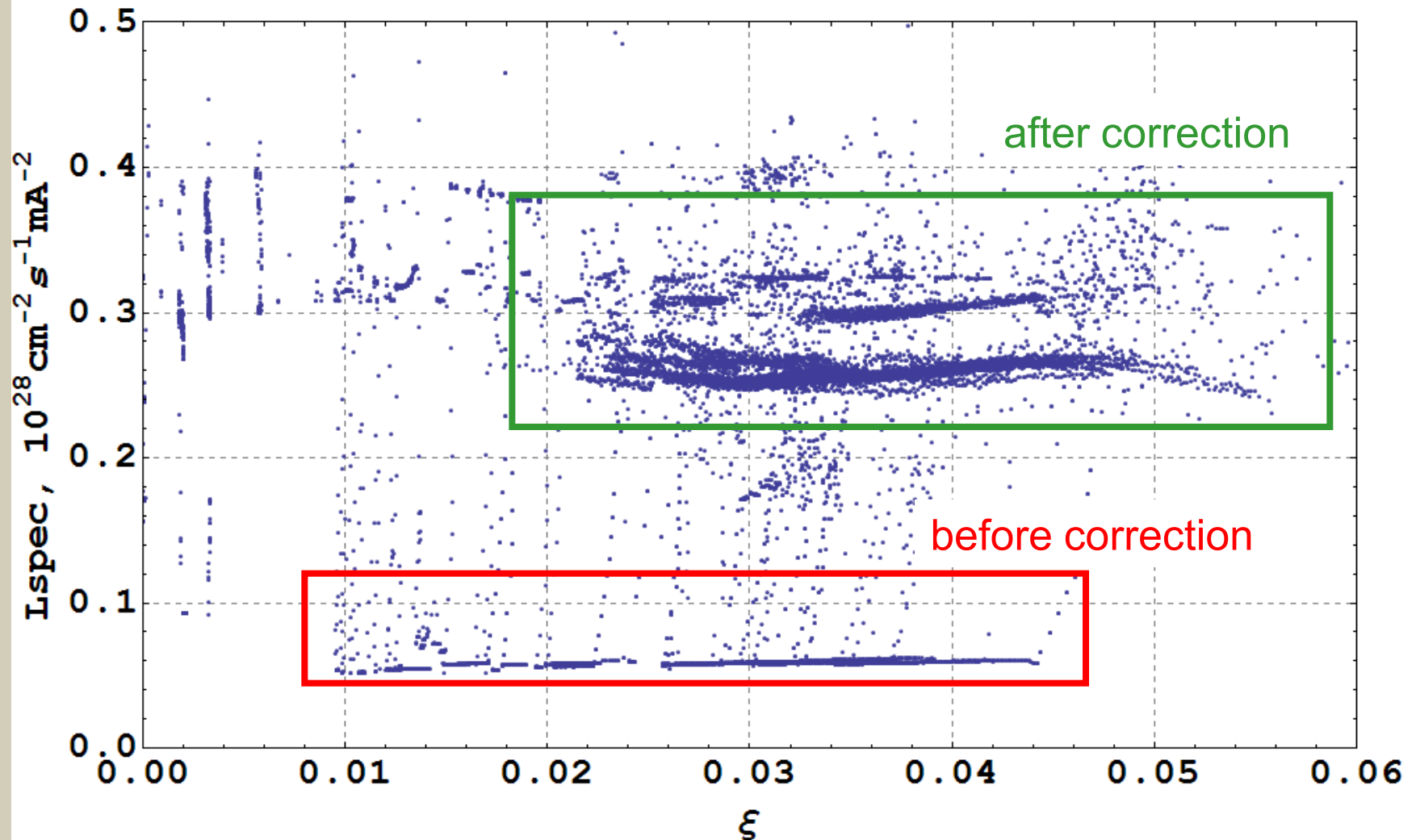


Beam orbit/profile measurements: CCD

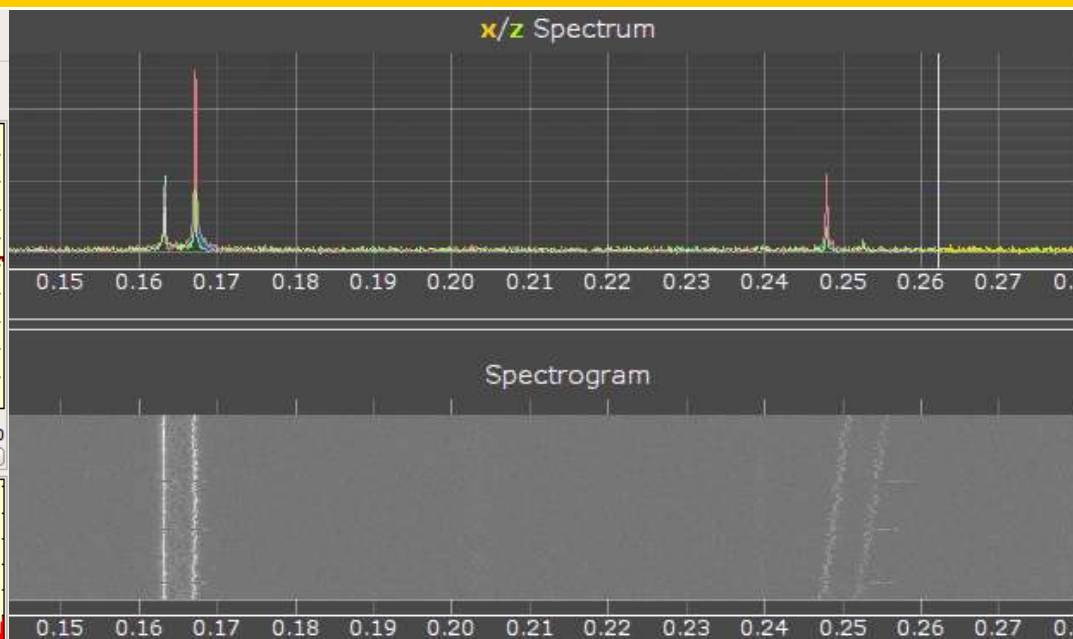
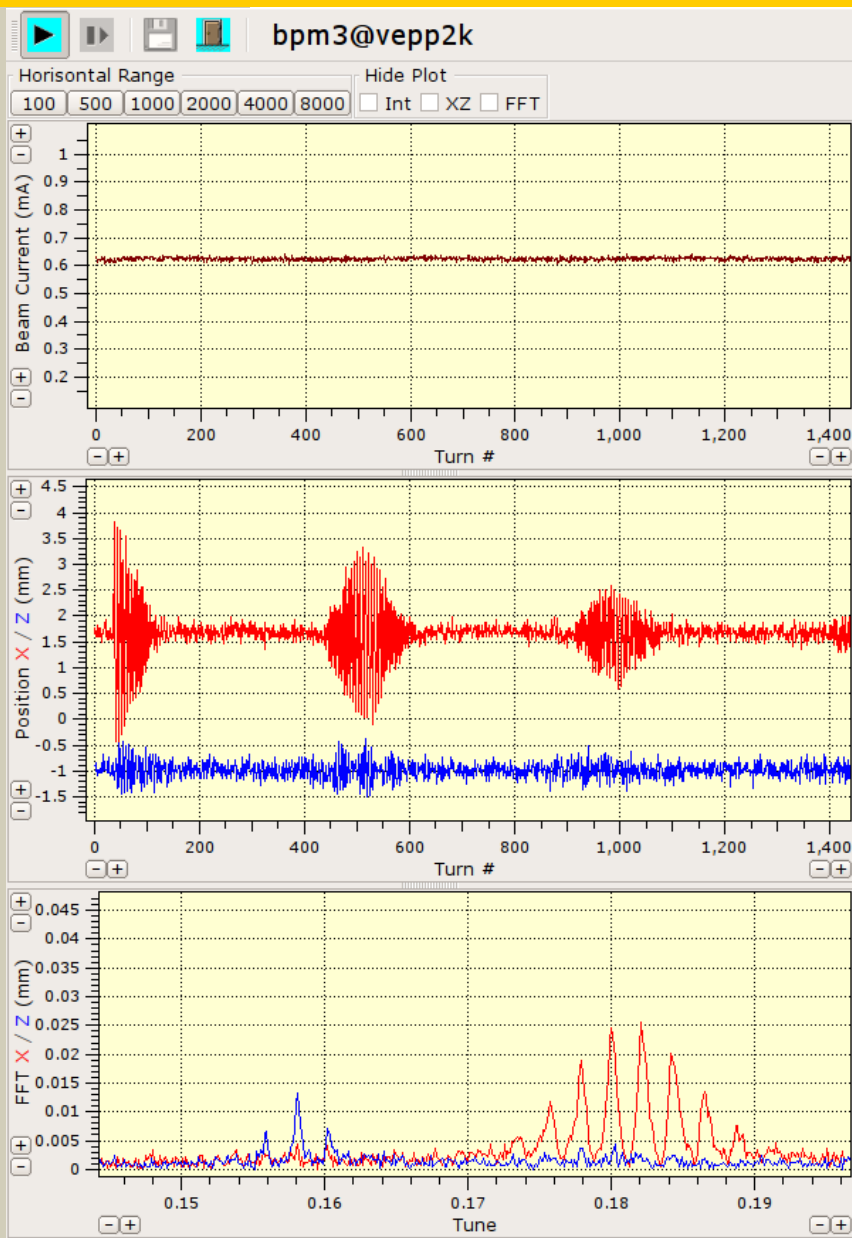


Crucial importance of optics correction

Specific luminosity vs. beam-beam parameter @ 900 MeV, 2011

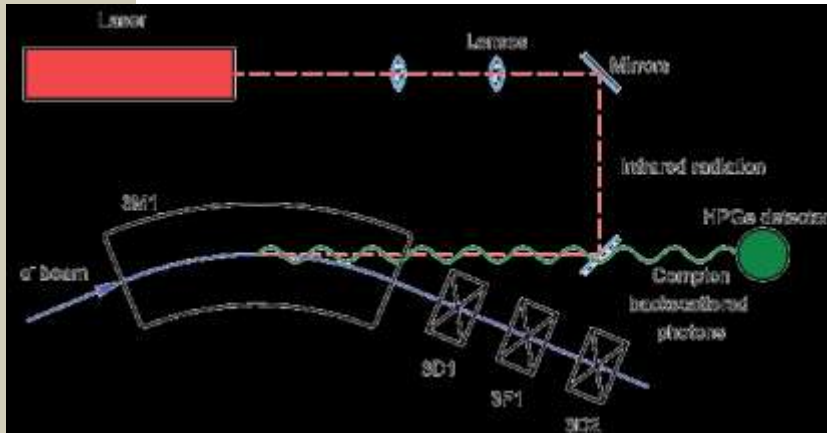


Beam orbit/tune measurements: fast BPM

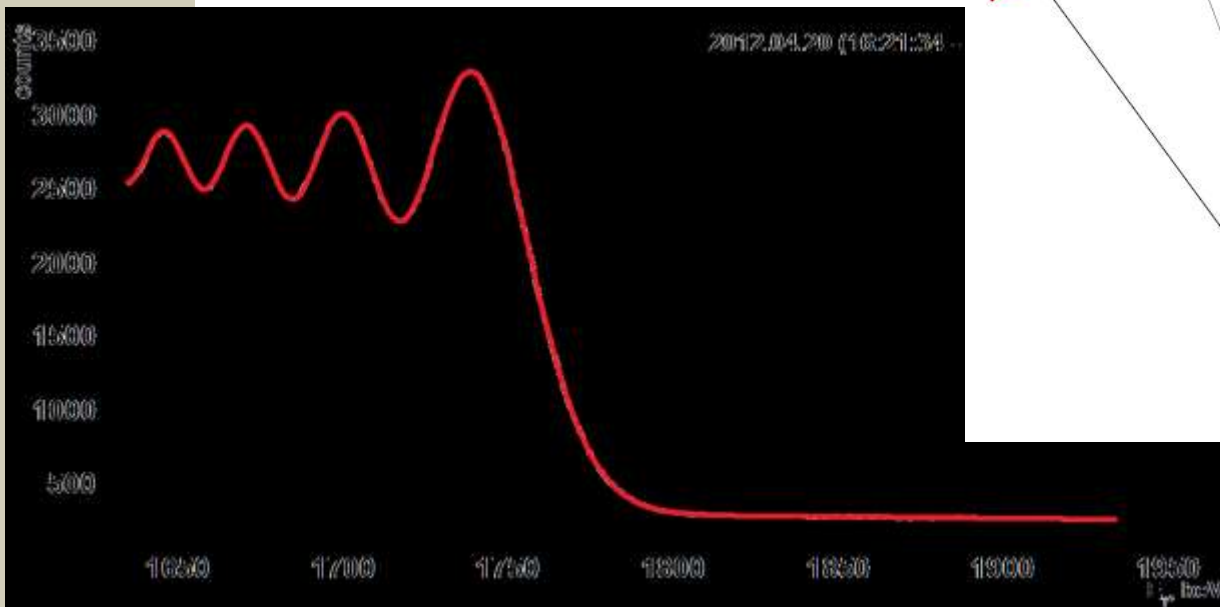
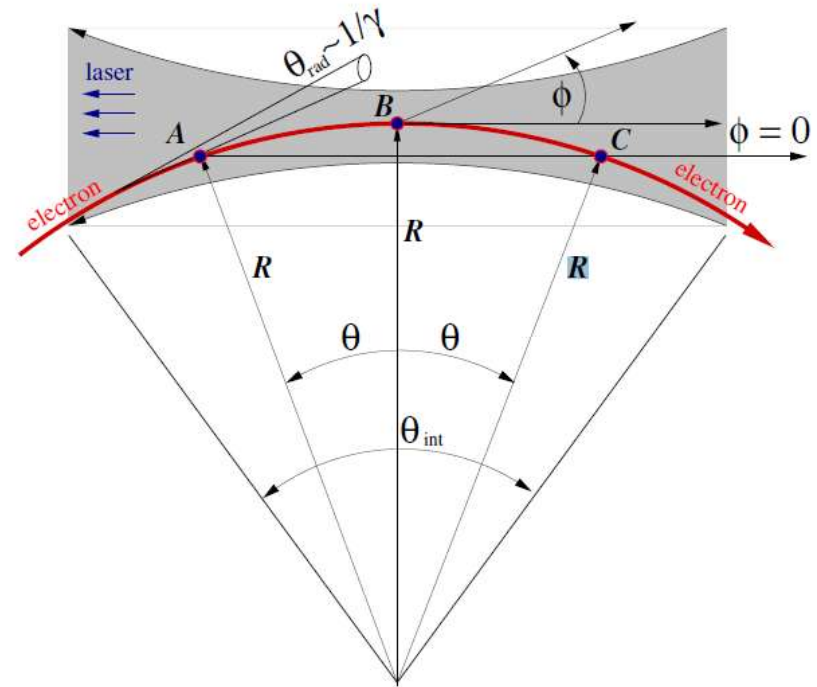


- Dynamic range 100 mA
- S/N ratio: ~1000 @ 50 mA, ~ 100 @ 1 mA
- TBT resolution: ~10 μm @ 50 mA,
~50 μm @ 1 mA
- Syst. bandw.: ~10 Hz @ 1024 avr.
~2 Hz @ 8192 tbt
- Tune measurements
- Orbit measurements
- Specific beam measurements

Compton backscattering at VEPP-2000



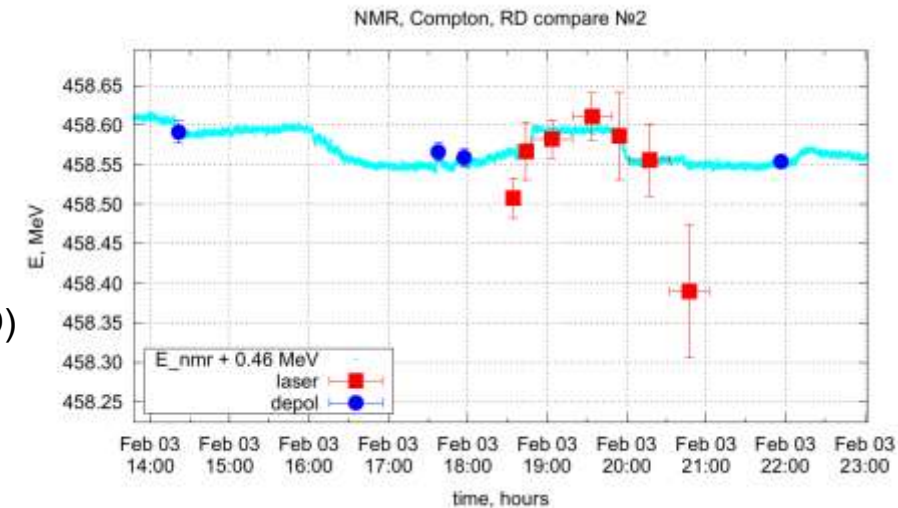
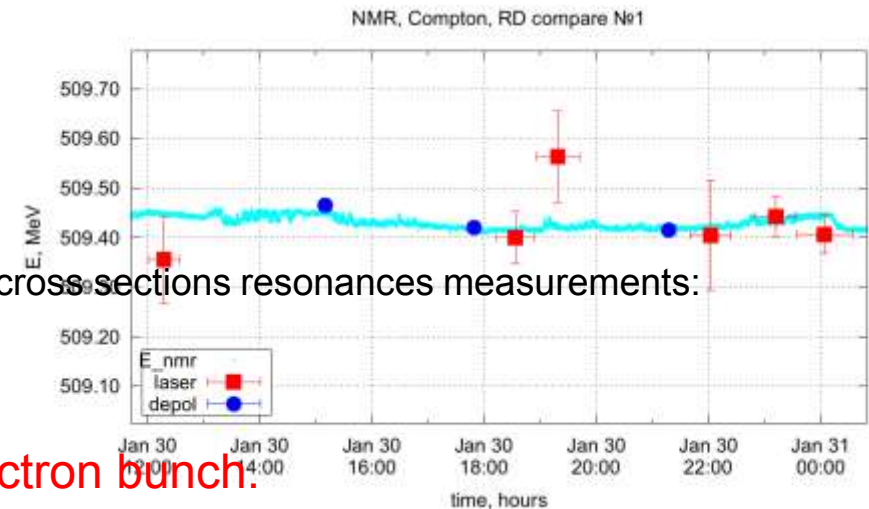
Photons interference from point A and C along $\phi = 0$ direction



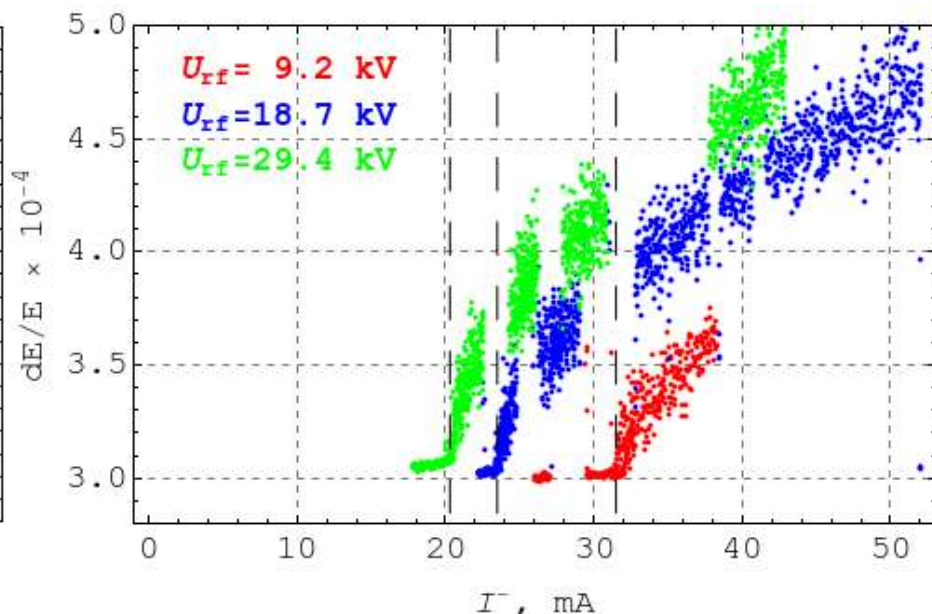
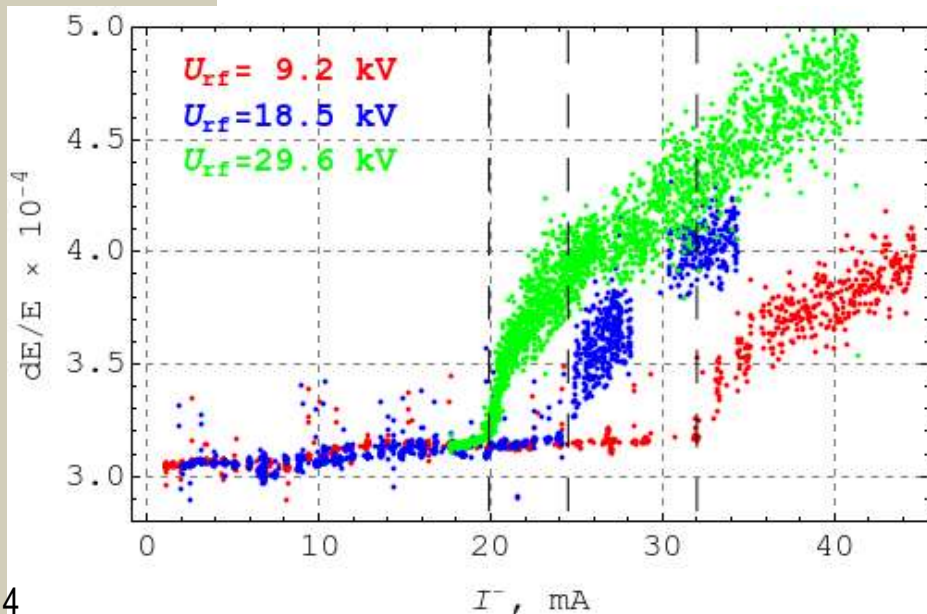
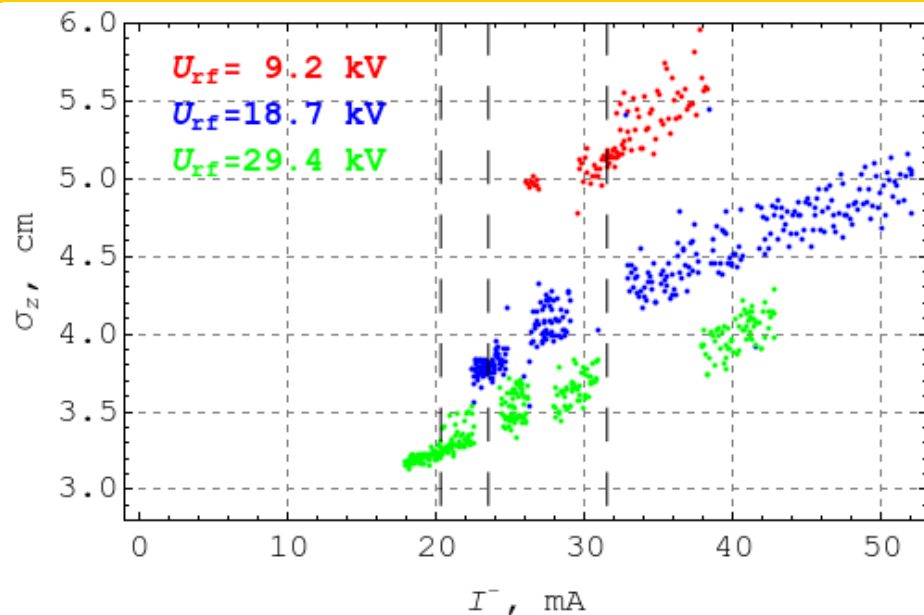
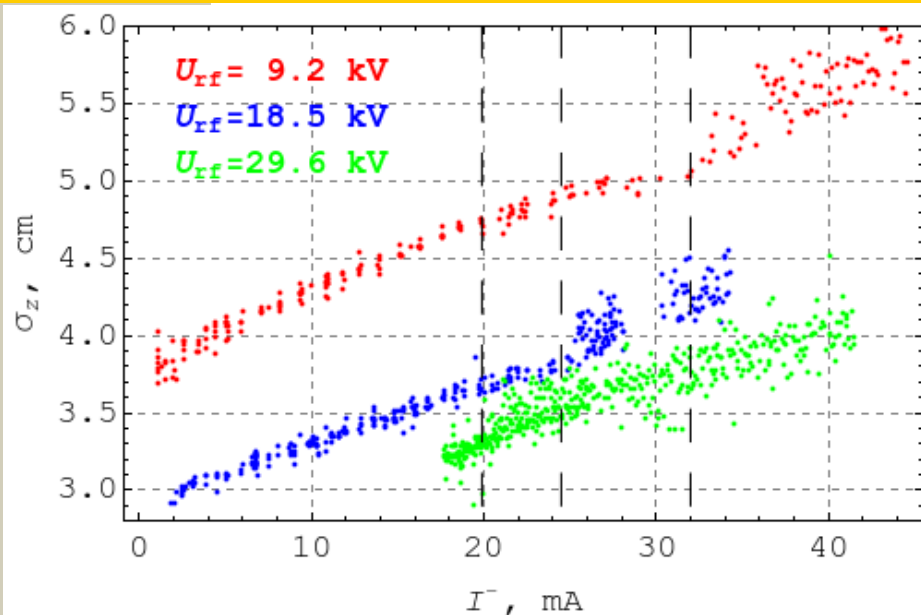
$$E = 993.662 \pm 0.016 \text{ MeV}$$

Beam Energy measurement: all methods

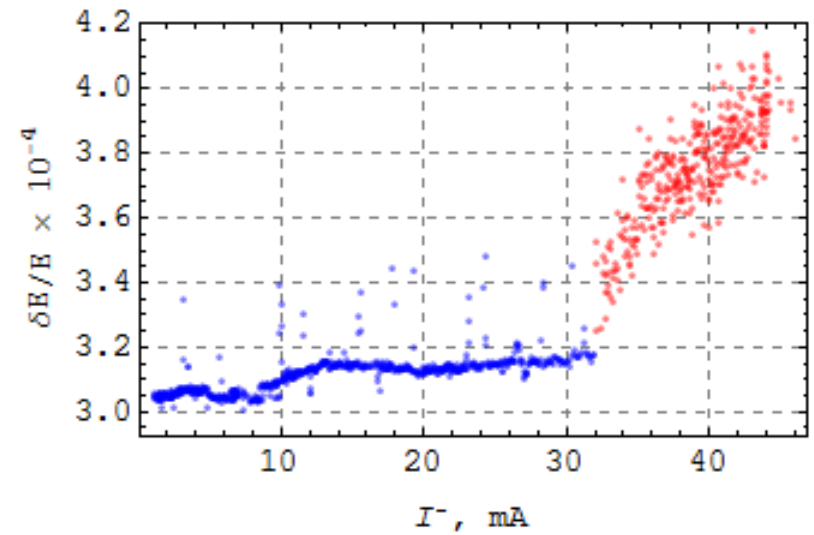
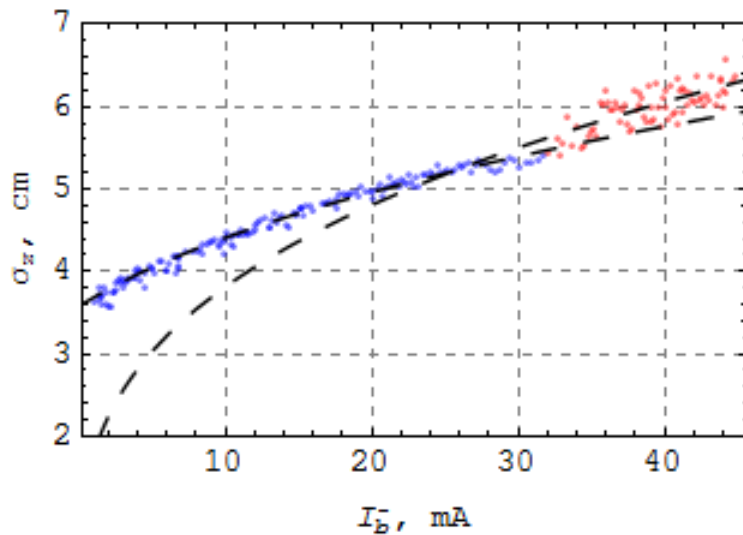
- HEP requirements $\delta E/E=10^{-4}$
- Dipole magnetic field control.
 - 8 magnets \otimes 2 NMR probes. Fast/Online control.
 - Jitter – 0.2×10^{-4} , Systematic – 10^{-3}
 - Absolute calibration – well-known particles (mesons) cross sections resonances measurements:
 ϕ ($1019.455 \pm 0.020\text{MeV}$), ω ($782.65 \pm 0.12\text{MeV}$).
- Laser beam Compton backscattering on electron bunch.
 - Tested in early 2012. Stable operations — end 2012.
 - Relatively high bunch intensity (20 mA).
- Resonance depolarization by external field.
 - High resolution ($\delta E/E < 10^{-5}$)
 - Special working regime («warm» lattice – no sol./KMD)



Bunch length measurements: Phi-dissector

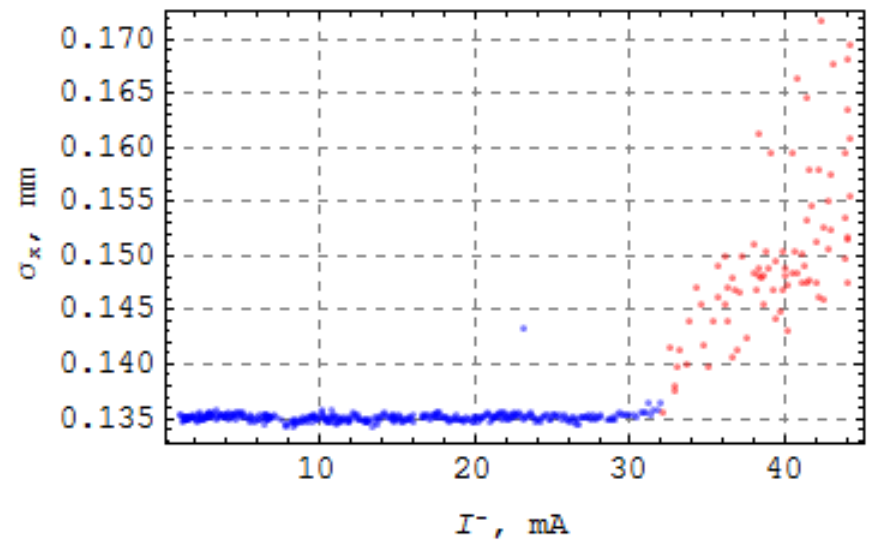


Bunch lengthening.... $|Z/n|$

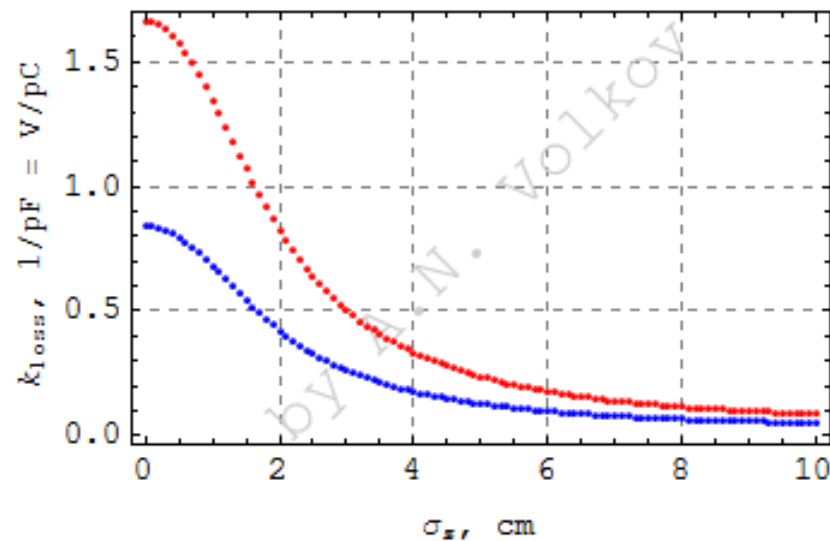
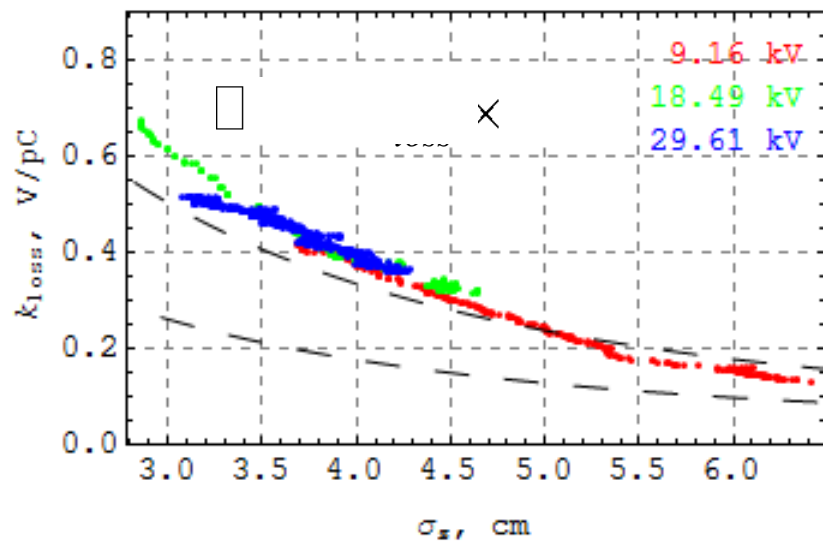
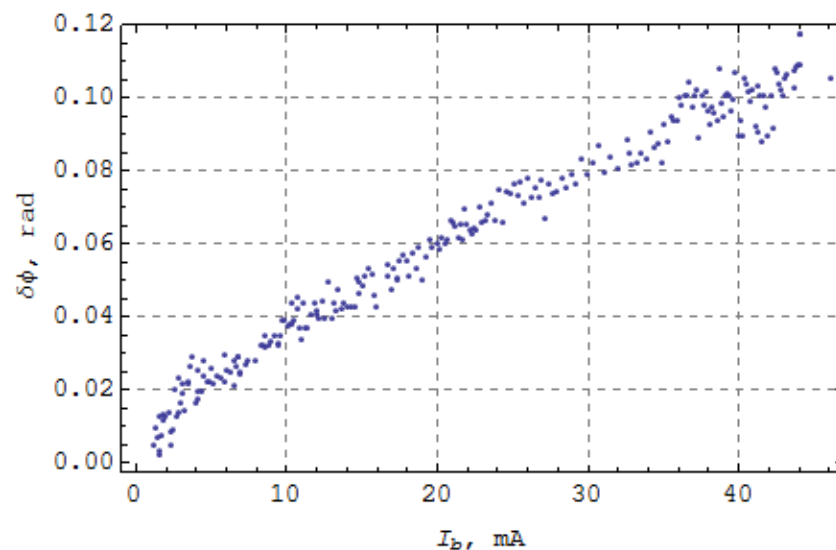
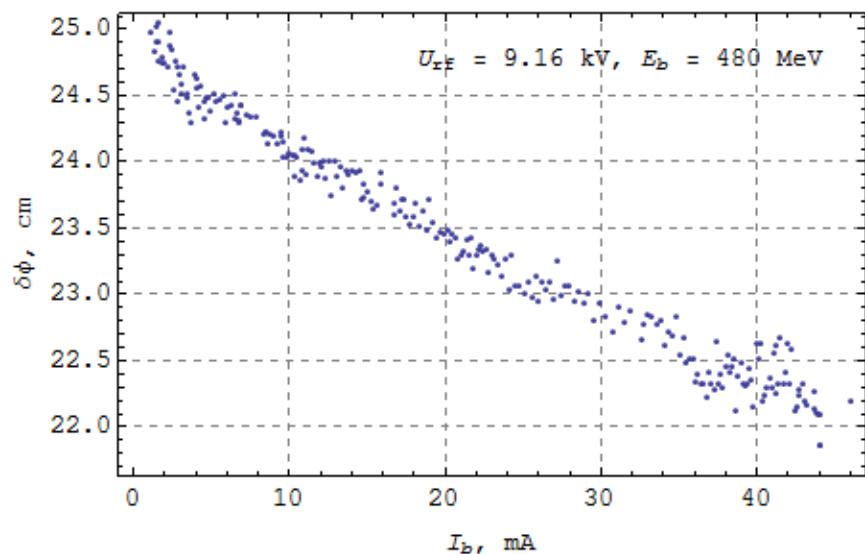


$$\sigma_z = \frac{v}{\sqrt{2\pi}} \frac{I}{\omega}$$

Below threshold: $Z/n = 2.8$ Ohm
 Above threshold: $Z/n = 5.0$ Ohm



Bunch lengthening... loss factor



Beam-beam parameter crosscheck

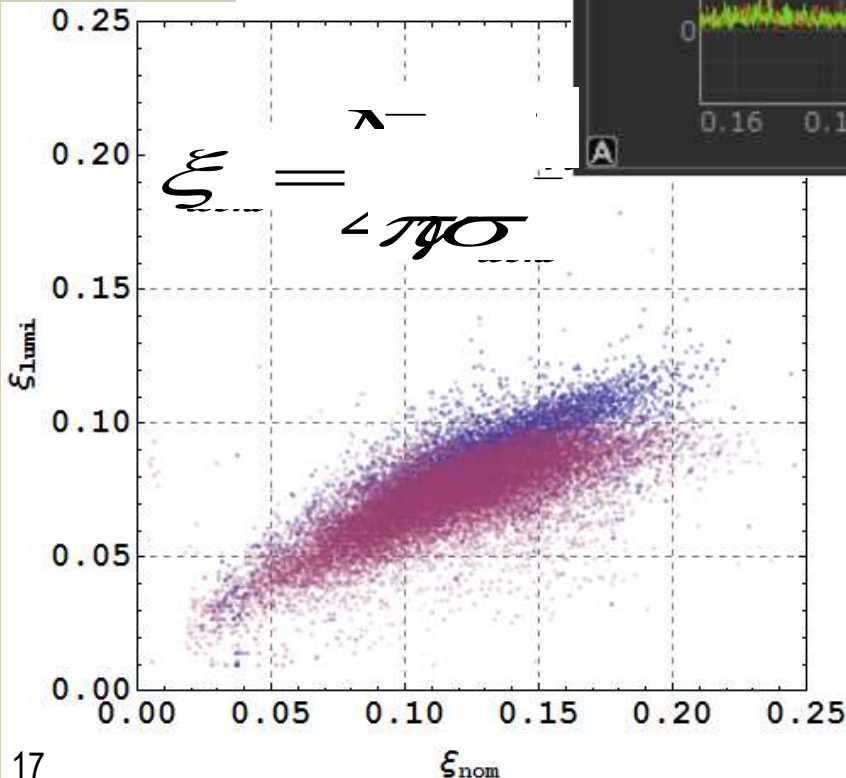
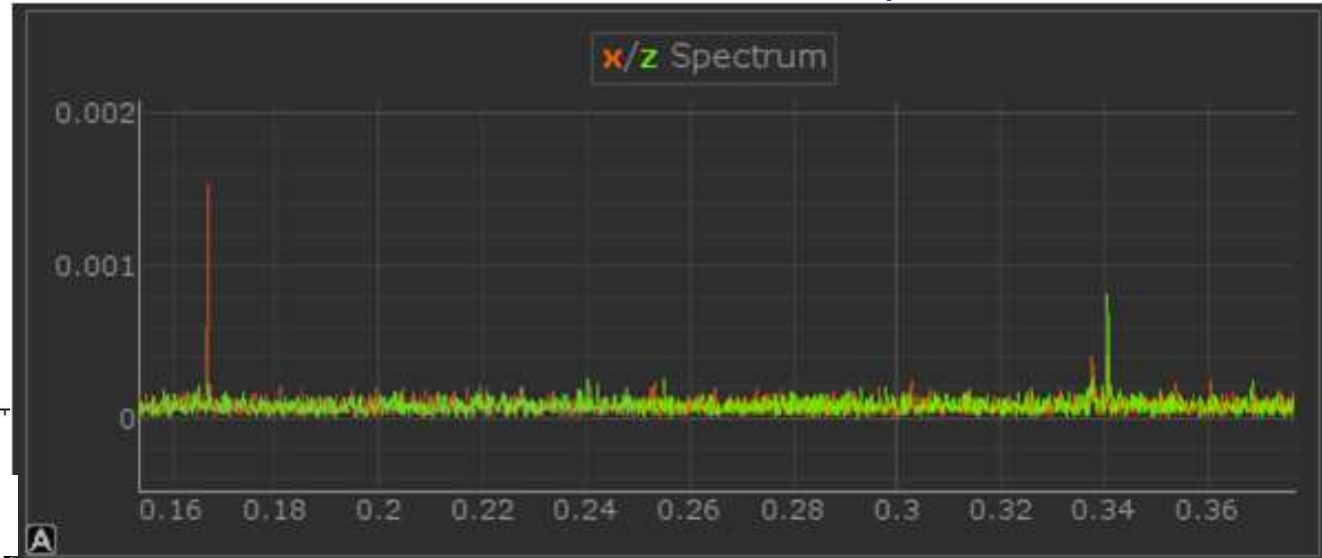
BB-threshold
improvement with beam
lengthening

E= 392.5 MeV

35 kV (purple)

17 kV (blue)

Coherent oscillations spectrum

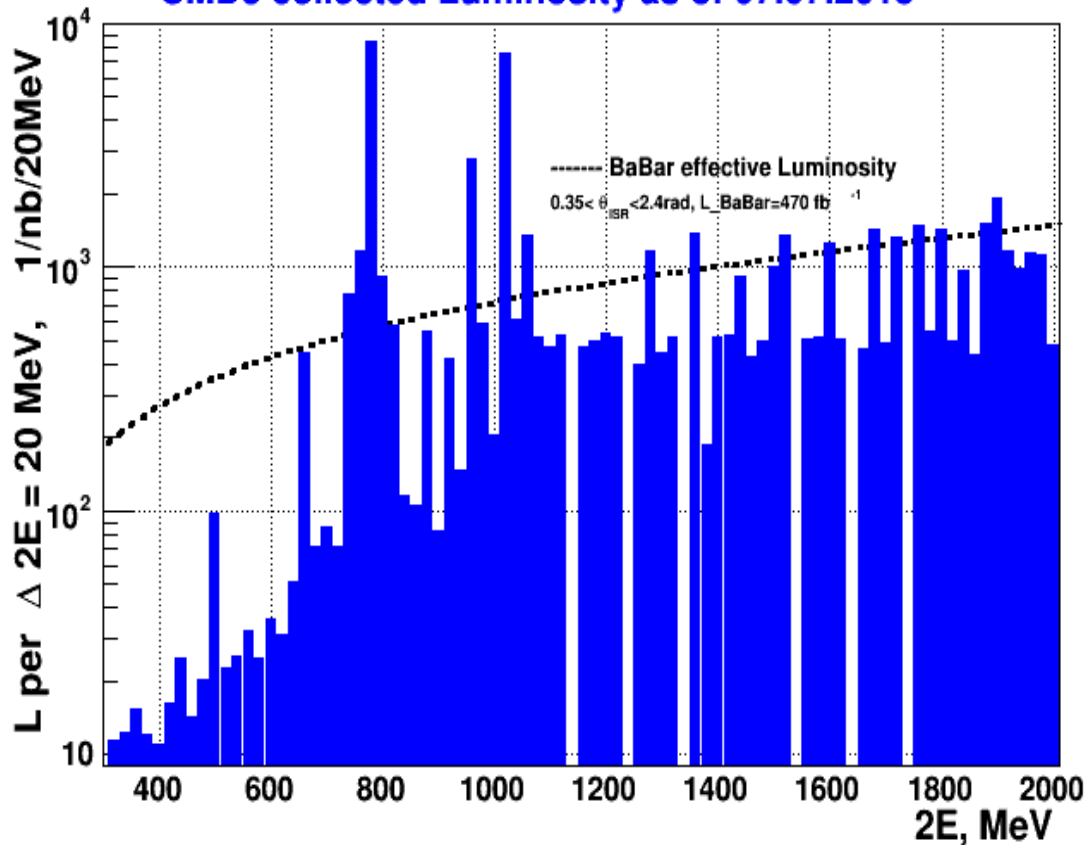


$$\Delta\nu = 0.175 \rightarrow \xi = \mathbf{0.125/IP}$$

Yokoya factor is taken equal to 1.0, due to fast kick excitation, and only 8189 turns analysis.

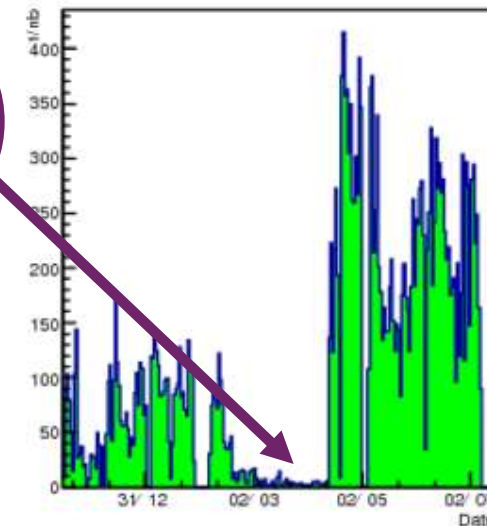
Experimental runs: RHO/OMEGA 2013

CMD3 collected Luminosity as of 07.07.2013

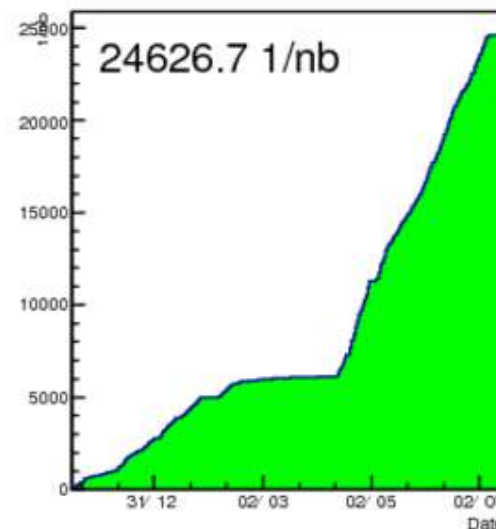


160 MeV

1/nb per day



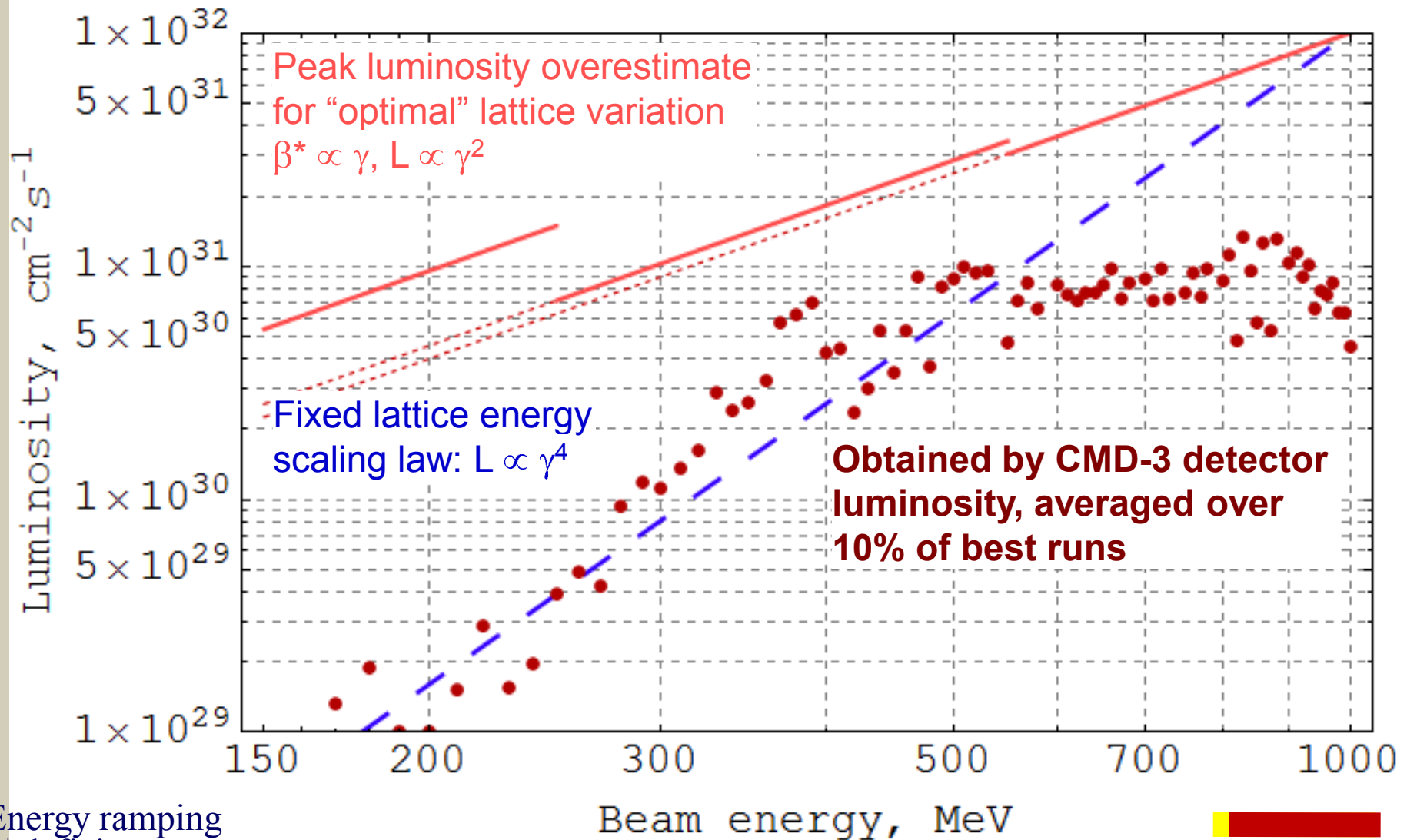
Collected 1/nb



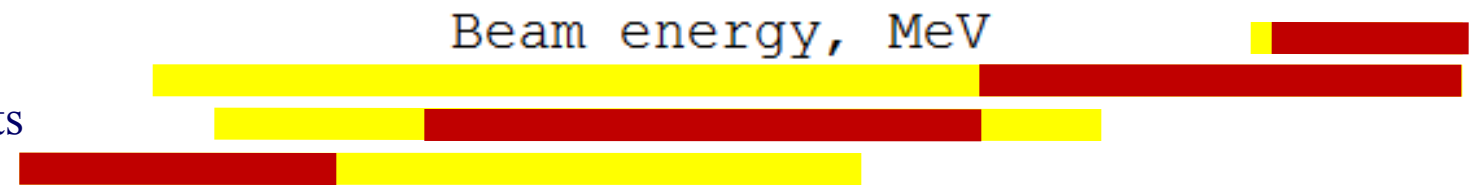
Collected L ~ 60 pb⁻¹ per detector

- 8.3 pb⁻¹ ω - region
- 9.4 pb⁻¹ < 1 GeV (except ω)
- 8.4 pb⁻¹ φ - region
- 34.5 pb⁻¹ > 1.04 GeV

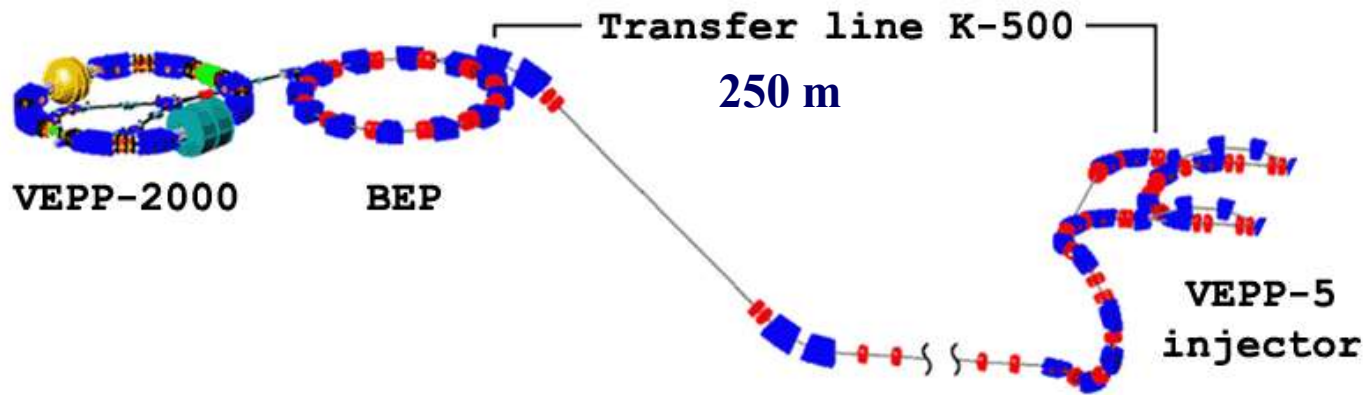
Luminosity vs. beam energy 2010-2013



Energy ramping
 e^+ deficit
 Beam-beam effects
 DA, IBS lifetime



Upgrade motivation: luminosity restrictions



Deficit of e^+

→ VEPP-5 injection complex

Energy ramping at VEPP-2000

1. Dead time
2. Extremely hard task: acceleration of colliding beams at bb-threshold
3. Unachievable bb-threshold at energy higher than injection value!



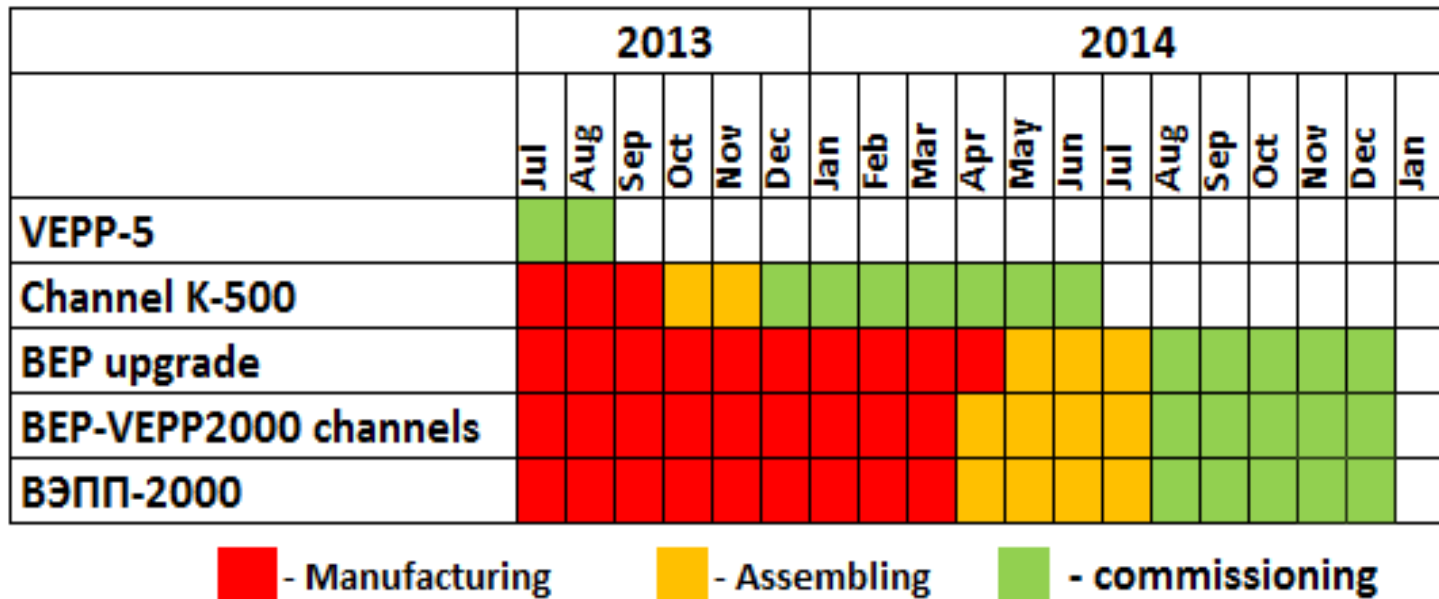
800 → 1000 MeV -20 ÷ -35%

$$L = \frac{\epsilon \epsilon}{r_e \beta}$$

-35 ÷ -60%

Upgrade milestones...

0. High intensity beams from injection complex (A.Starostenko talk).
1. Beam transport to VEPP-2000 complex (K-500) (I.Zemlyansky talk).
2. Booster reconstruction for operation up to 1.0 GeV.
3. Booster-VEPP-2000 channel modernization (extraction 1.0 GeV).
4. VEPP-2000 ring modernization for top energy injection on 1.0 GeV.



Upgrade parts 2: booster BEP

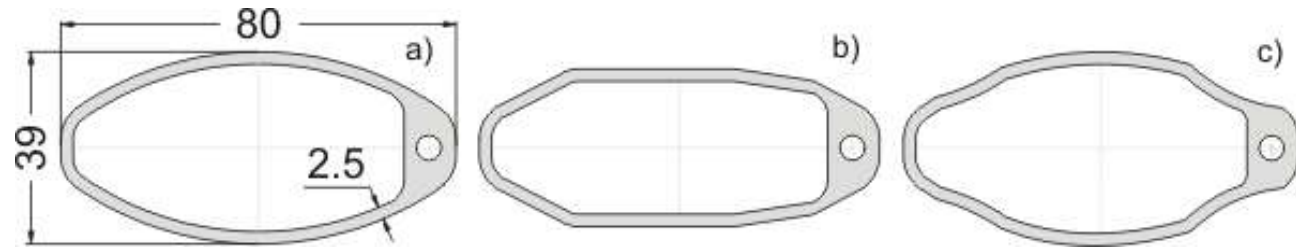
- 2.1 New injection magnet.
- 2.2 New RF cavity and RF system modifications.
- 2.3 Bending magnets (12+1) modifications: gap=40 mm \Rightarrow 32 mm, 26 kGc.
 - 2.3.1 New correction coils.
- 2.4 Quadrupole (24) modifications: G \Rightarrow 5 kGs/cm, + sextupole strength.
 - 2.4.1 New coils for F-lenses.
- 2.5 Vacuum chamber modifications.
- 2.6 New BUMP (2) magnets + its vacuum chambers.
- 2.7 New DCCT and BPM.

Upgrade results 2: RF + vacuum chamber

04.02.2014



- Shape modifications for D-lenses and dipole magnets
- Profilactics

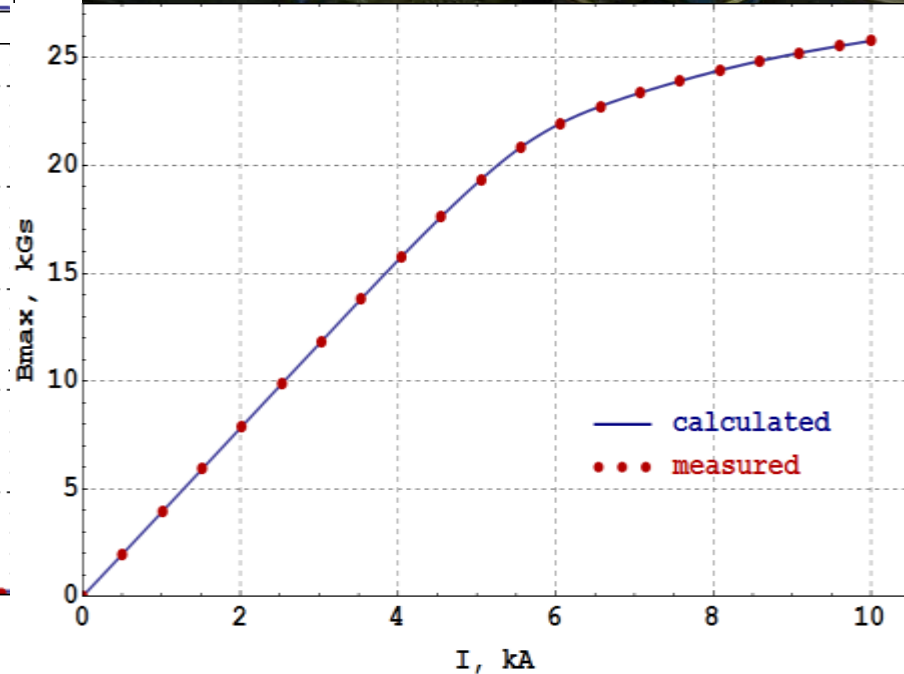
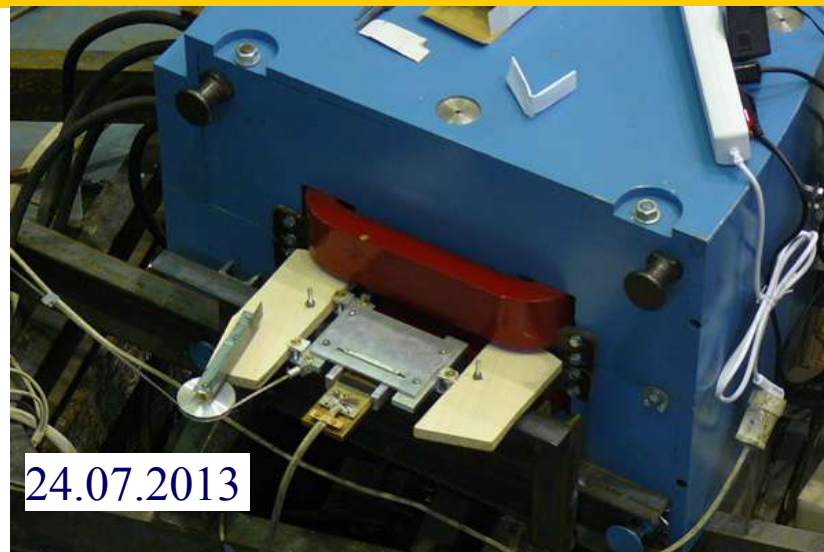
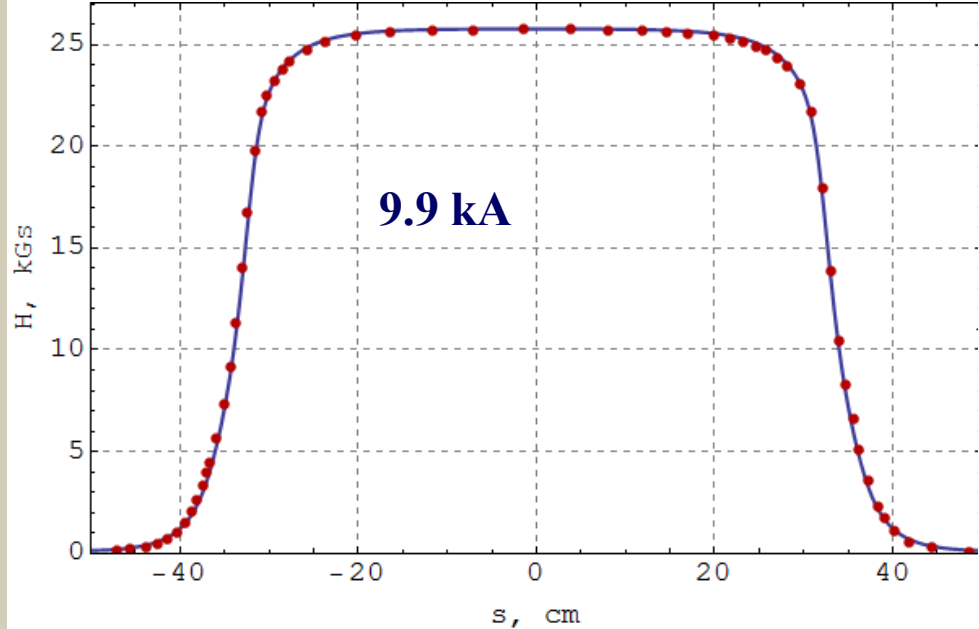
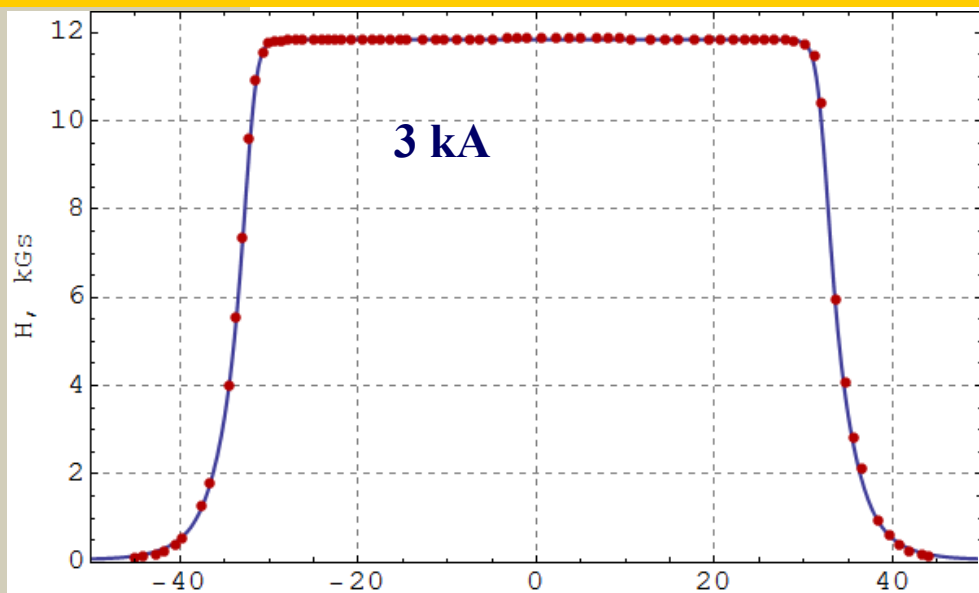


Energy loss @ 1.0 GeV:
70 keV

$f_{\text{rf}} = 174.376 \text{ MHz}$
harmonic numb = 13
 $U_{\text{rf}} = 110 \text{ kV}$



Upgrade results 2: dipole measurements

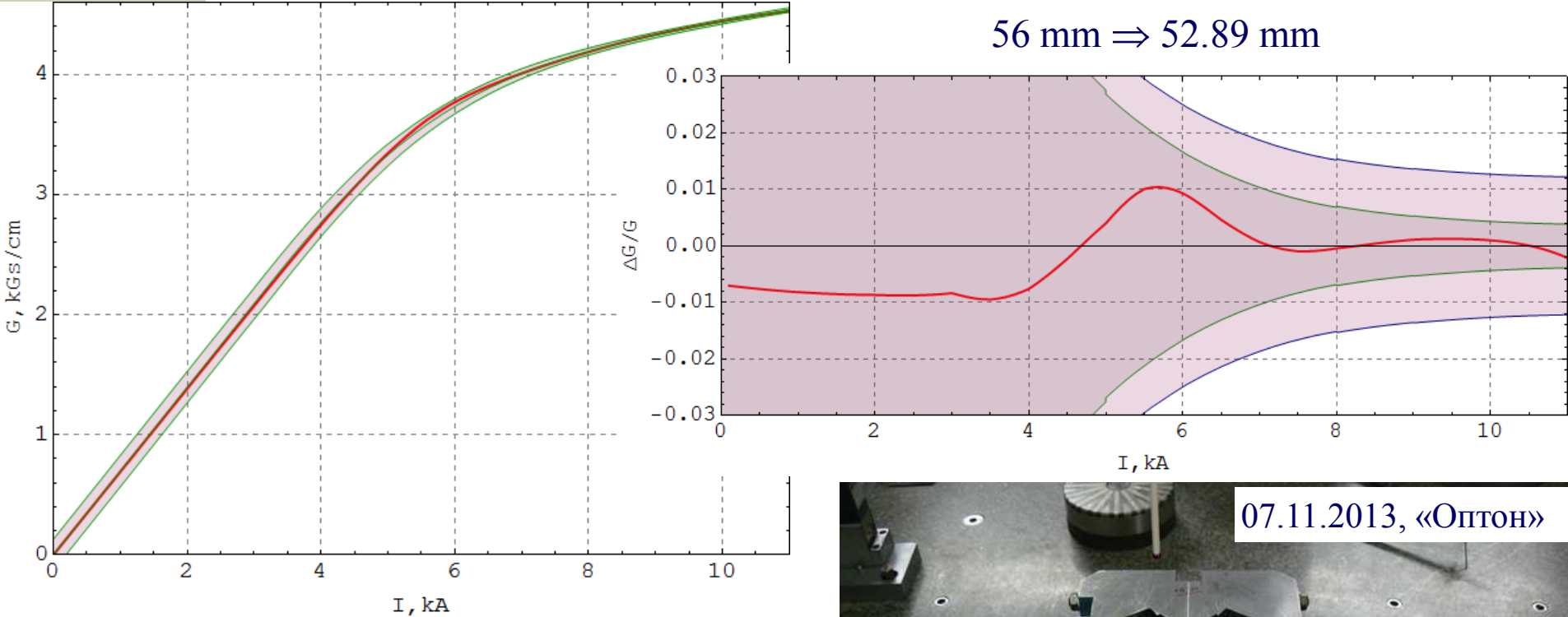


Upgrade results 2: dipole magnets reconstr.

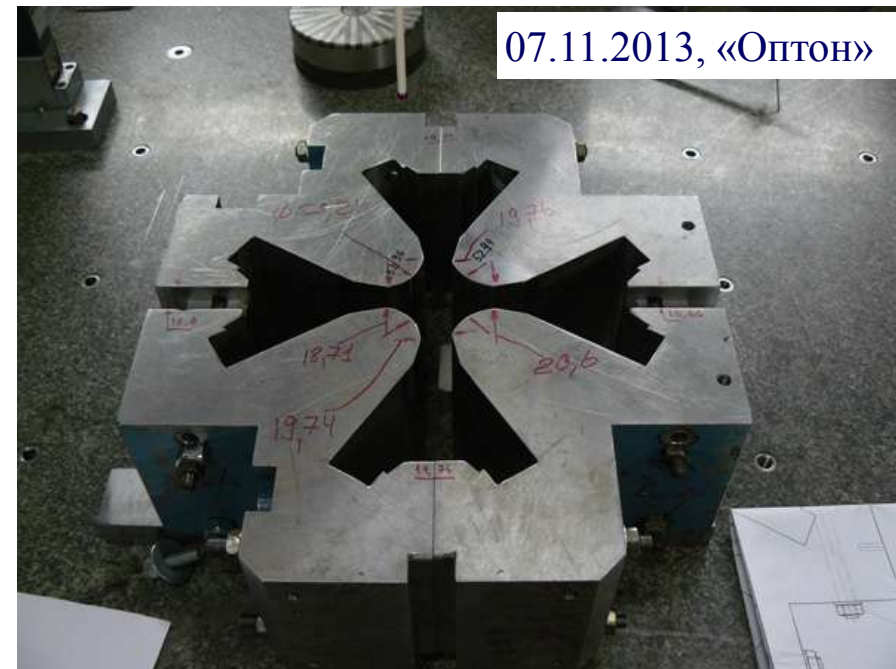


- 1) Установка накладок толщиной 4 мм на плоскость полюсов (межполюсный зазор становится 32 мм).
- 2) Установка торцевых накладок на полюс, толщиной 12 мм, для удлинения магнита. Для этого из обмоток извлекаются вклеенные внутрь корректирующие катушки.
- 3) Изготовление новых корректирующих обмоток на ярме магнитопровода.
- 4) Заужение полюса со 120 мм до 90 мм, для концентрации потока и увеличении поля.
- 5) Установка изогнутых пластин толщиной 50 мм на внутренний радиус ярма магнита, для снижения насыщения магнитопровода.

Upgrade results 2: small quadrupole D-lens



- Consistent power with other elements and dipole magnets.
- Complicate nonsymmetric pole profile: quad. + sext.



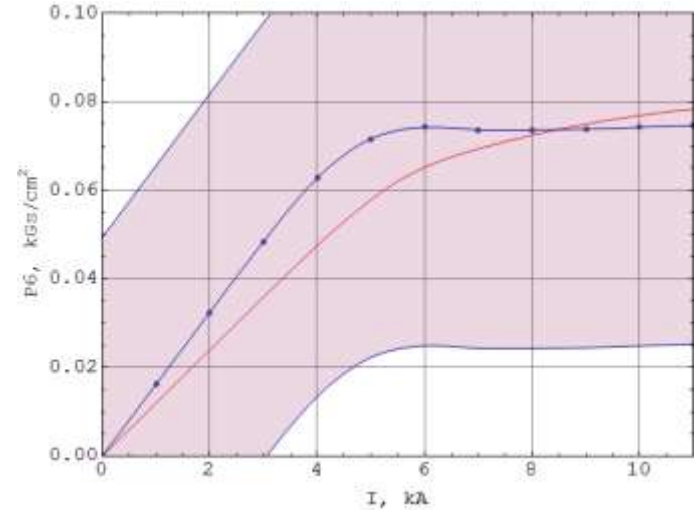
Upgrade results 2: big quadrupole F-lens

84 mm \Rightarrow 74.8 mm

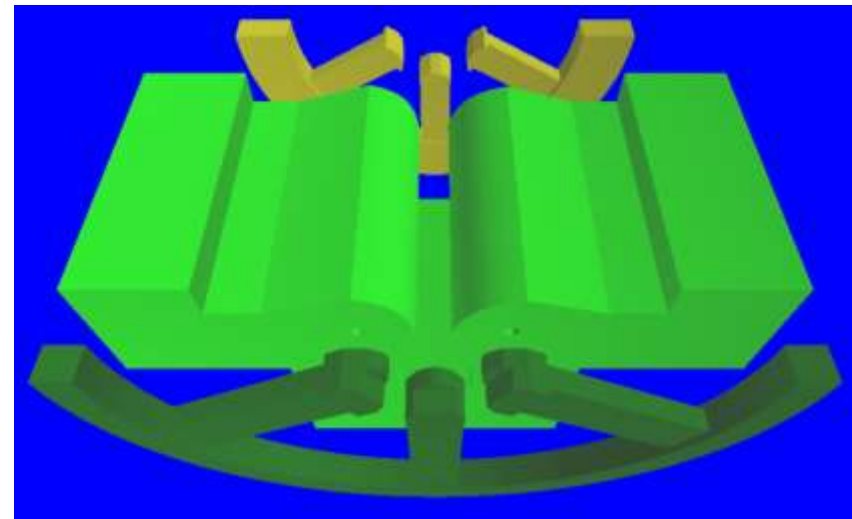


04.02.2014

QD sextupole component saturation



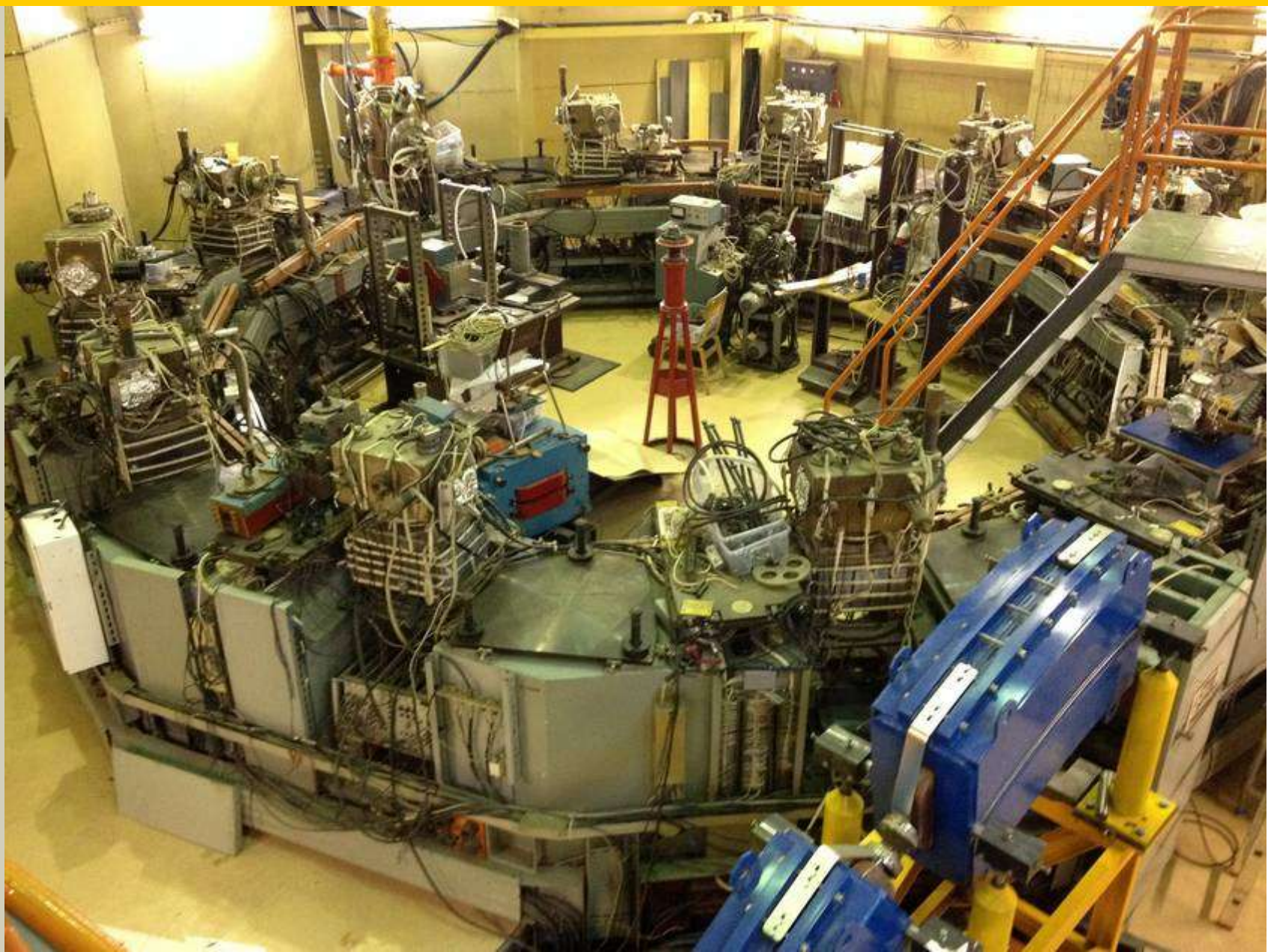
Thin sextupole corrector field influence in integral: -3.5%



Booster BEP @ 28.08.2013



Booster BEP @ 03.10.2014



«Hole» in experimental hall

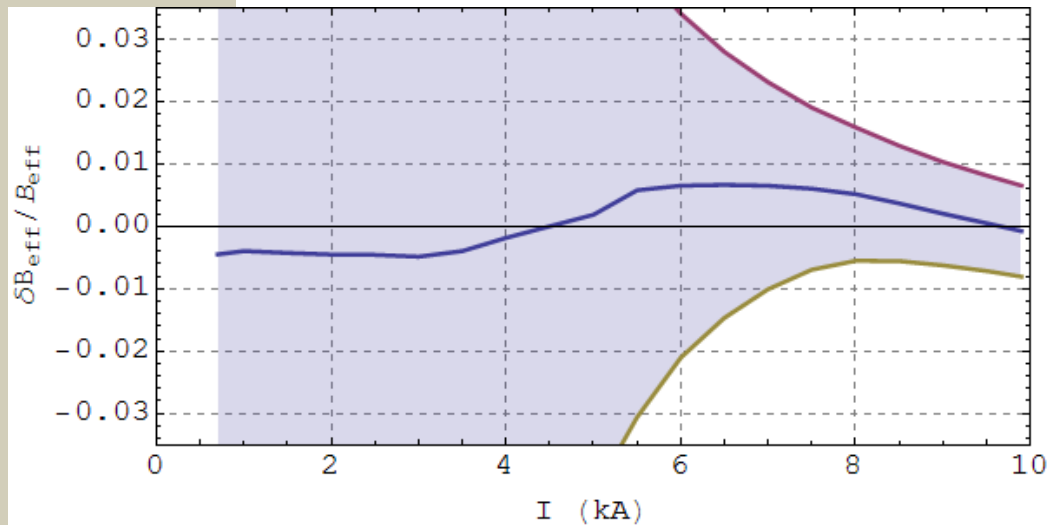
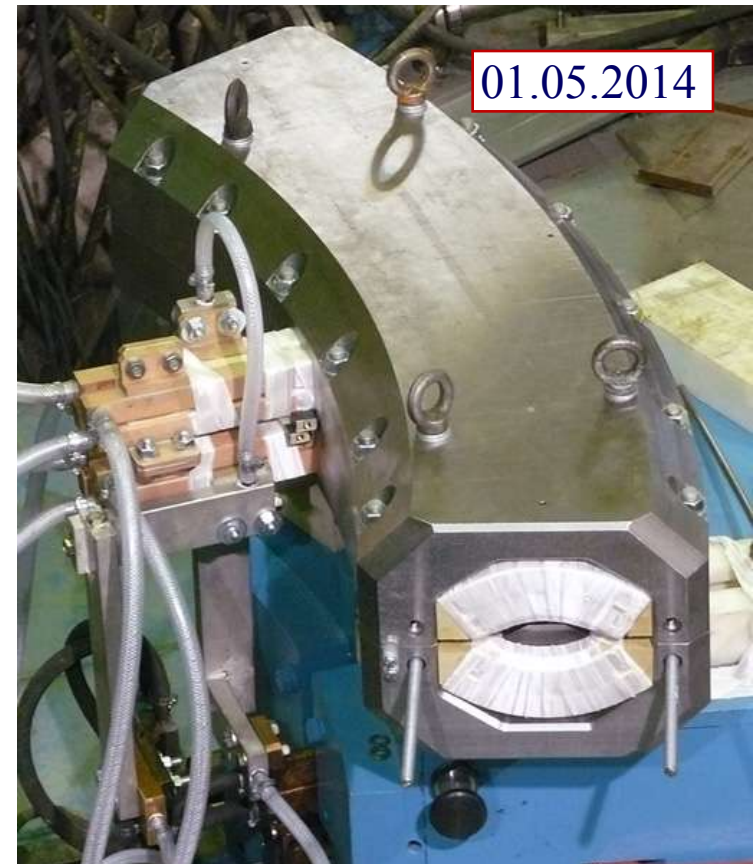


Остап остановился у входа в Провал и, трепля в руках квитанционную книжку, время от времени вскрикивал: – Приобретайте билеты, граждане! Десять копеек! Дети и красноармейцы бесплатно!

Upgrade parts 3: BEP-VEPP channel

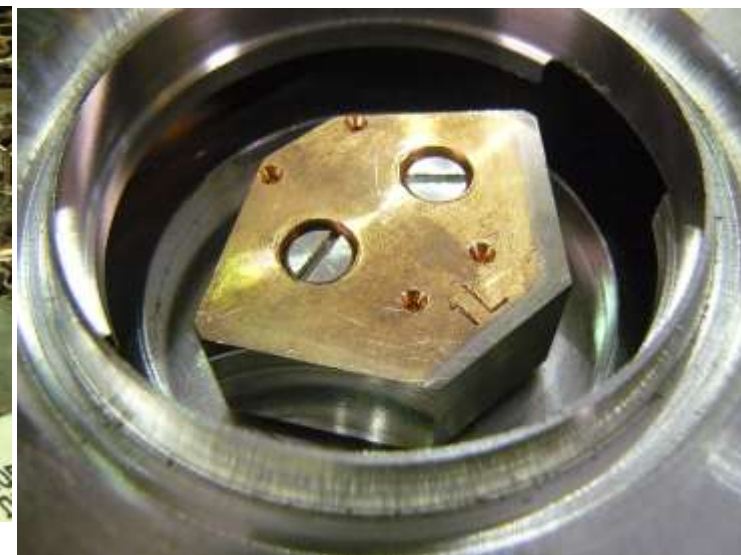
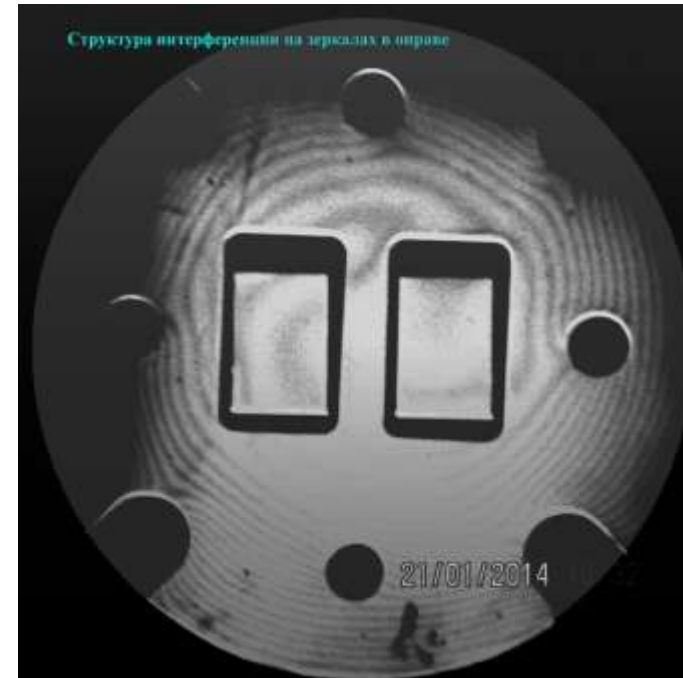


- New bending magnets (17.2°, 41.2°) (4+4) + new vacuum chamber + bus bars.
- Ceramic gap in the beginning of channel
- Synchrotron radiation output from BM for one-flight diagnostics

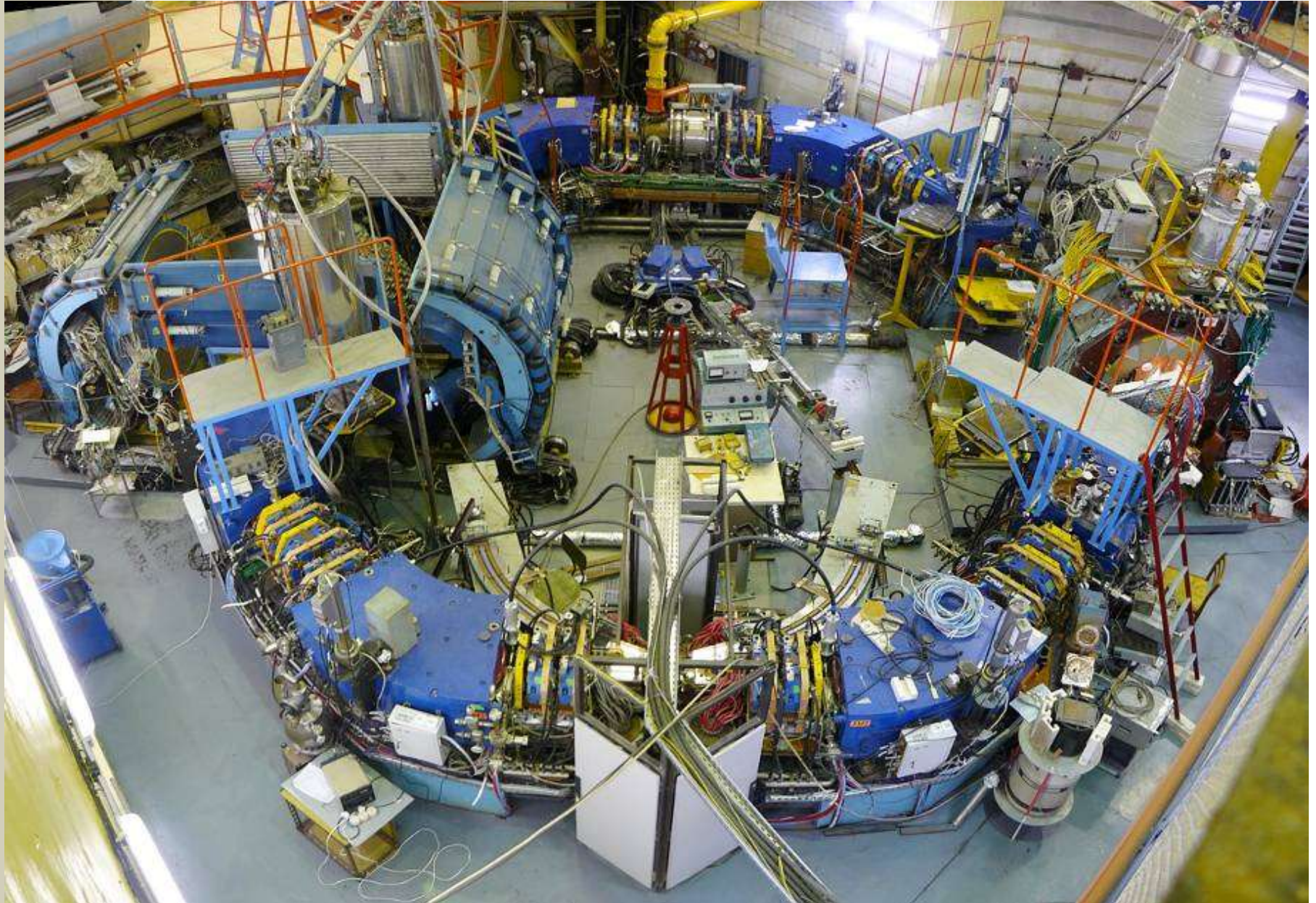


Upgrade parts 4: VEPP-2000 ring

- Detectors KMD/SND profilactics
- New vacuum chambers with additional inflector/deflector
- New synchrotron output copper mirrors



VEPP-2000 @ 01.09.2014



Summary

- Round beams give a serious luminosity enhancement.
- The achieved beam-beam parameter value at middle energies amounts to $\xi \sim 0.1\text{--}0.12$ during regular operation.
- “Long” bunch ($\sigma_l \sim \beta^*$) mitigates the beam-beam interaction restrictions, probably affecting on flip-flop effect.
- VEPP-2000 is taking data with two detectors across the wide energy range of 160–1000 MeV with a luminosity value two to five times higher than that achieved by its predecessor, VEPP-2M. Total luminosity integral collected by both detectors is about 110 pb^{-1} .
- To reach the target luminosity, injection chain upgrade was started.

Main control room of VEPP-2000



Thanks for your attention!

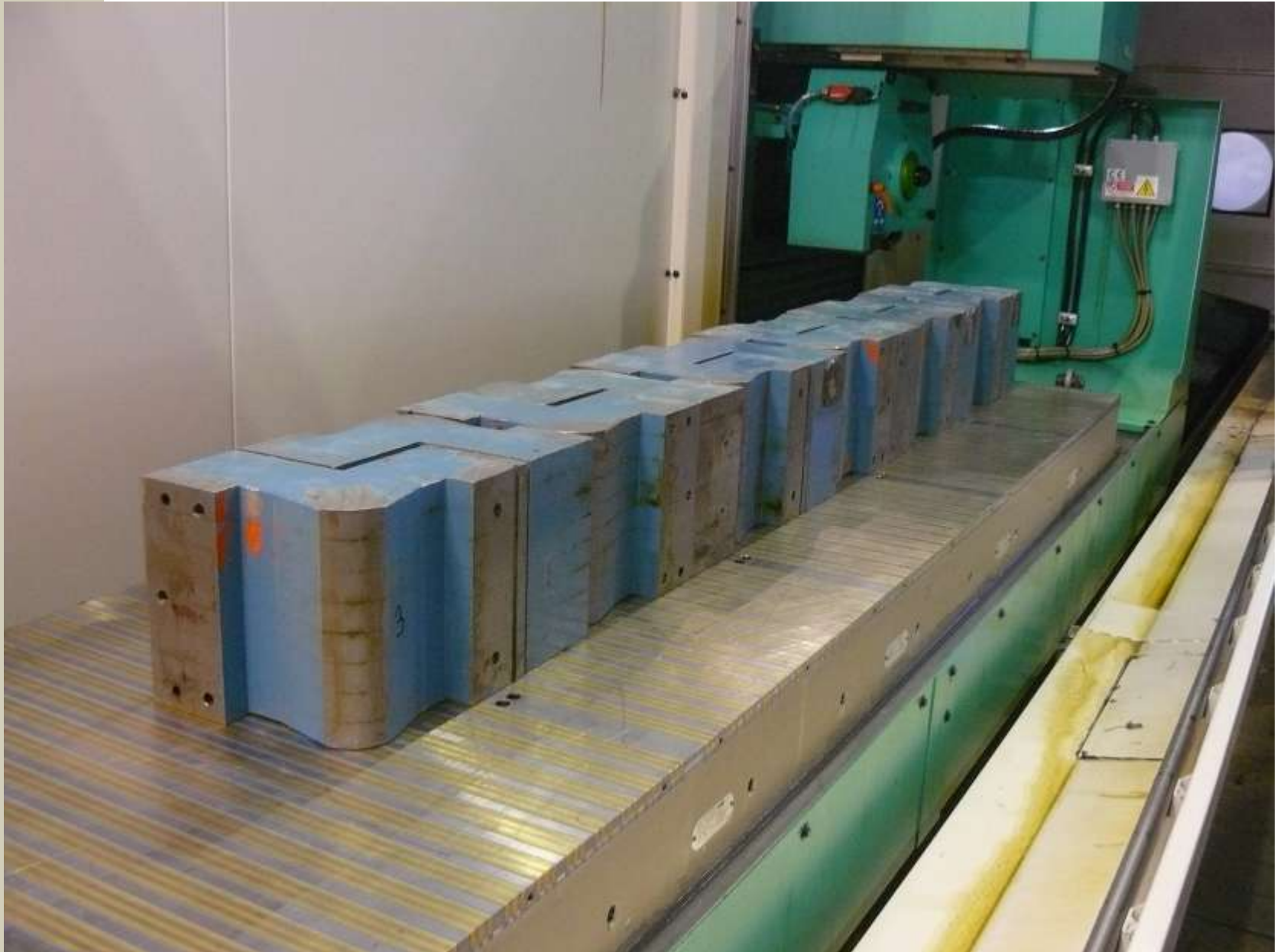
Yu. Rogovsky on behalf of VEPP-2000 team

Backup Slides

Backup Slides



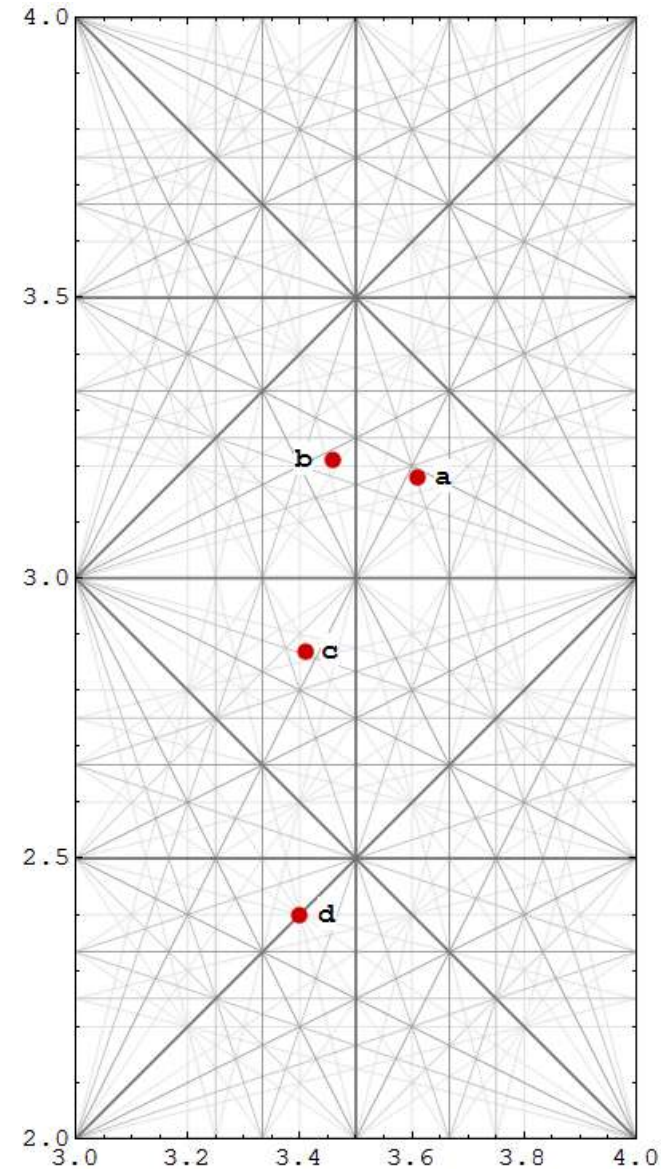
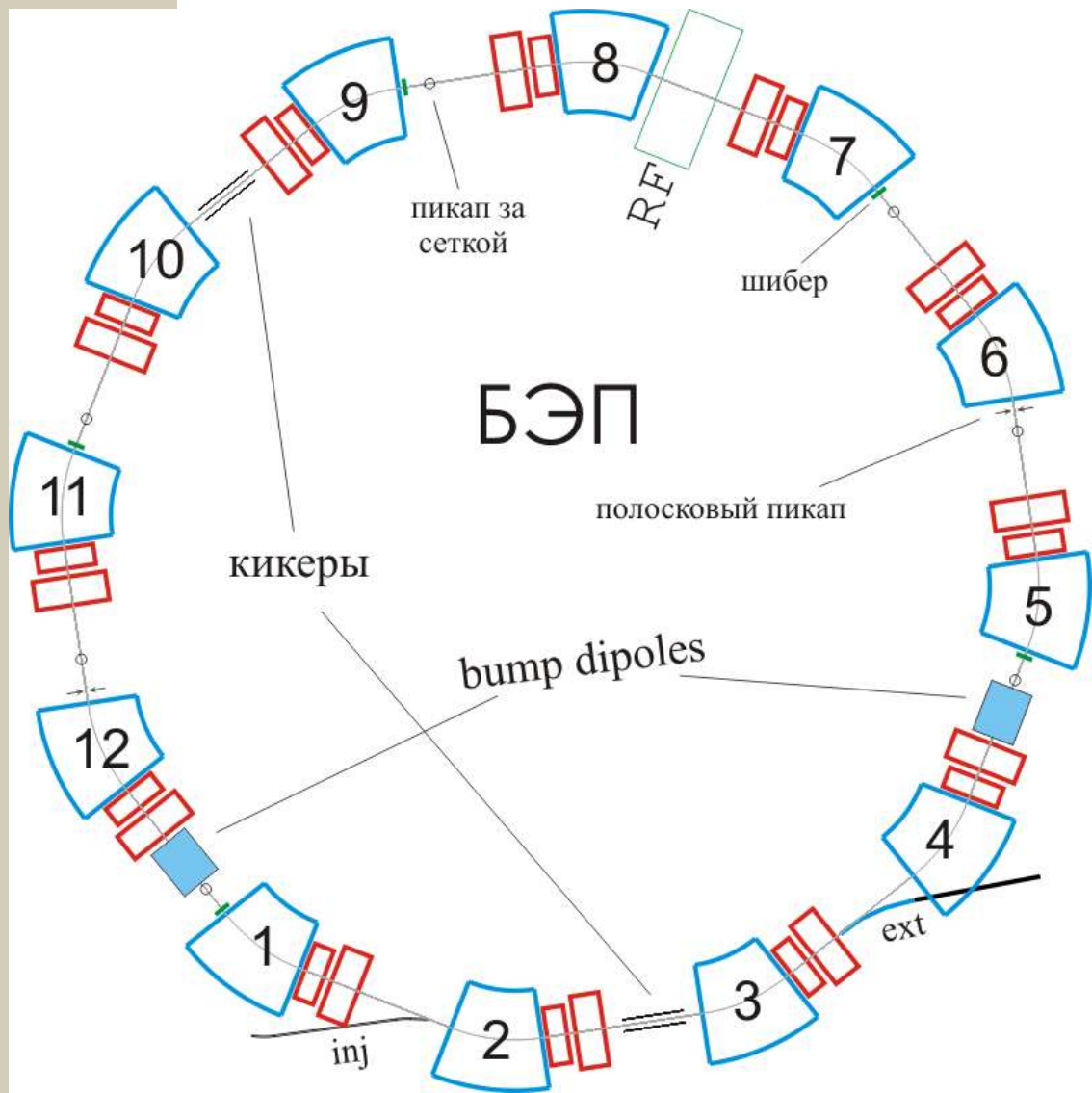
Backup Slides



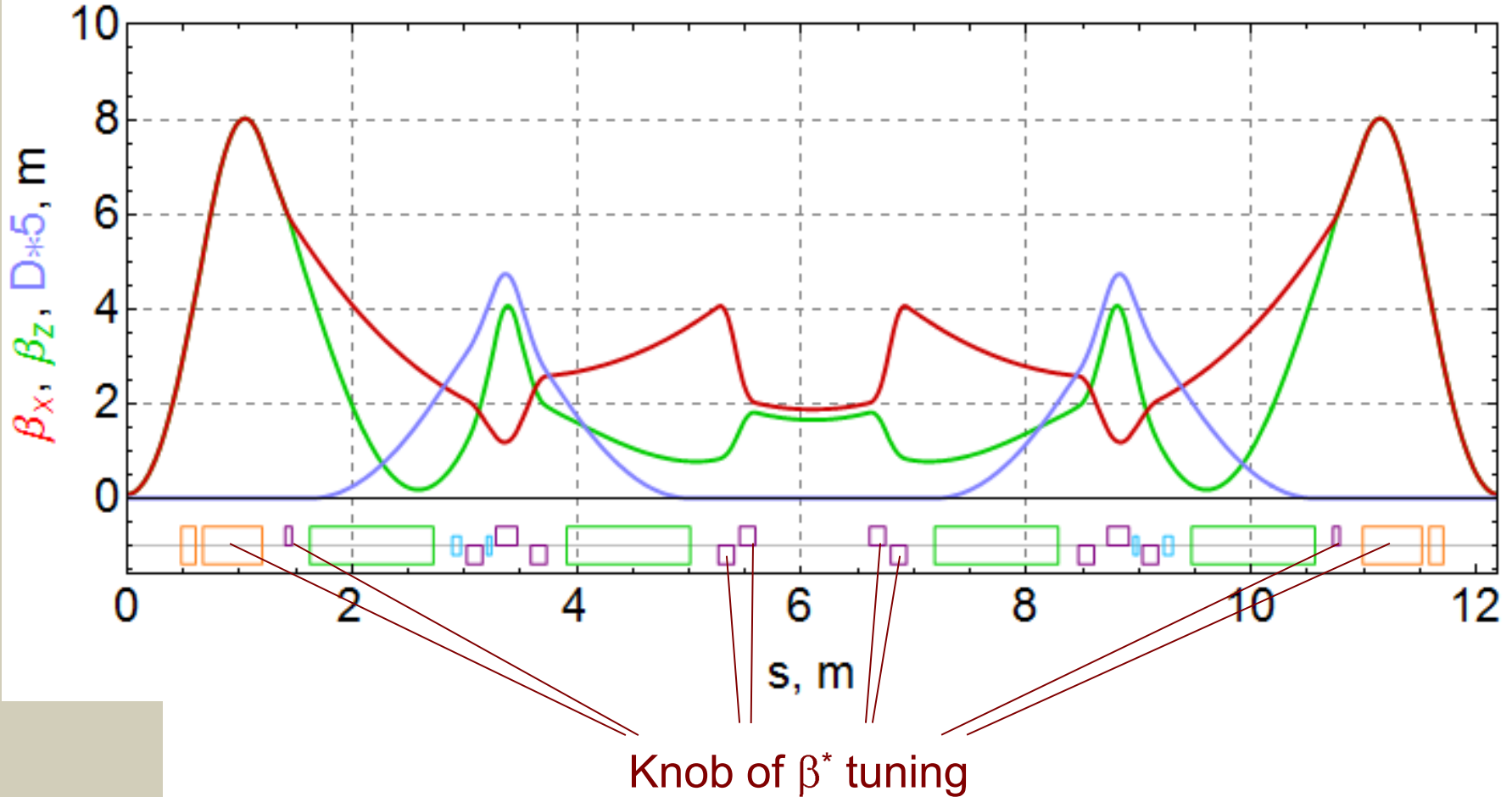
Backup Slides



БЭП layout



Lattice functions of half of the ring



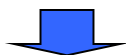
VEPP-2000 lattice special feature: β^* variation modifies radiative beam emittance in the way that $\beta^* \varepsilon = \sigma^{*2} = \text{inv}(\beta^*)$

VEPP-2000 latticefunction/orbit correction

Правка равновесной орбиты (РО)

- 1) Набор матрицы откликов РО в пикапах, вариация градиентов линз ($4 \otimes 32$).
- ↳ 2) SVD-анализ и вычисление искажений орбиты в линзах.
- ↳ 3) Расчёт токов коррекций для правки расчётных искажений.
- ↳ 4) 2–3 итерации (~10 мин на итерацию)
- ↳ 5) + процедура минимизации токов корректоров ΣI_{cor}

$$\Delta_x; \Delta_z \approx \pm 0.5 \text{ мм}$$



Правка оптики

- 1) Набор МО в пикапах и ПЗС-камерах, вариация дипольных корректоров ($20 \otimes 36$).
- ↳ 2) SVD-анализ и вычисление действующей модели.
- ↳ 3) Коррекция токов элементов (квадруполи + соленоиды).
- ↳ 4) 3–4 итерации (~10 мин на итерацию, 1 час в 2011 г.)

ровные размеры, проектная β^* ; нулевая дисперсия вне ахроматов



Компенсация связи

- 1–1.3 кГц × 1 м поле КМД + компенсирующие соленоиды S3
3 семейства скью-квадрупольных коррекций

$$\nu_1 - \nu_2 < 0.003$$

Хронология работы в 2012-2013 году (I)

Сентябрь 2012	–	Начало работ. Модернизация СУ ускорительного комплекса. Установка новой системы ПЗС-камер на ВЭПП-2000. Установка новой электроники пикапов
Октябрь – начало ноября 2012	–	Введение в эксплуатацию новой дистилляторной. Геодезическая выставка ВЭПП-2000. Начало работ с круглым пучком. Настройка ВЭПП-2000
8 октября 2012	–	Оба пучка в ВЭПП-2000
9 ноября – 4 декабря	–	Эксперимент PHI/OMEGA2012 . Калибровка энергии по фи/омега-мезону. Энергии 510 и 390 МэВ, 19 точек, 0.91 пб^{-1} (КМД)
4 декабря 2012 – 28 января 2013	–	Эксперимент RHO2013 . Диапазон 490 – 360 МэВ, 32 точки, 4.1 пб^{-1}
28 января – 1 февраля 2013	–	Измерение 13 магнита БЭП. Калибровка энергии методом резонансной деполяризации. «Тёплый» ВЭПП-2000.

Хронология работы в 2012-2013 году (II)

1 февраля – 8 апреля 2013	–	Поход на низкие энергетические эксперименты RHO2013 . Диапазон 360-160 МэВ, 21 точка.
12 апреля – 11 мая 2013	–	Продолжение эксперимента RHO2013 . Диапазон 440-530 МэВ, 18 точек, 7 пб ⁻¹ .
12 мая – 26 июня 2013	–	Окончание эксперимента RHO2013 . Диапазон 410-370 МэВ, 11 точек, 5 пб ⁻¹ .
26 июня – 9 июля 2013	–	Эксперимент ETAPRIME2013 , 1 точка E=478.89 MeV, 5 пб ⁻¹ (КМД)
10 июля – 17 июля 2013	–	Изучение возможности удлинения сгустка.
Август 2013	–	Работа по демонтажу канала БЗМ-БЭП, разборка узлов БЭП