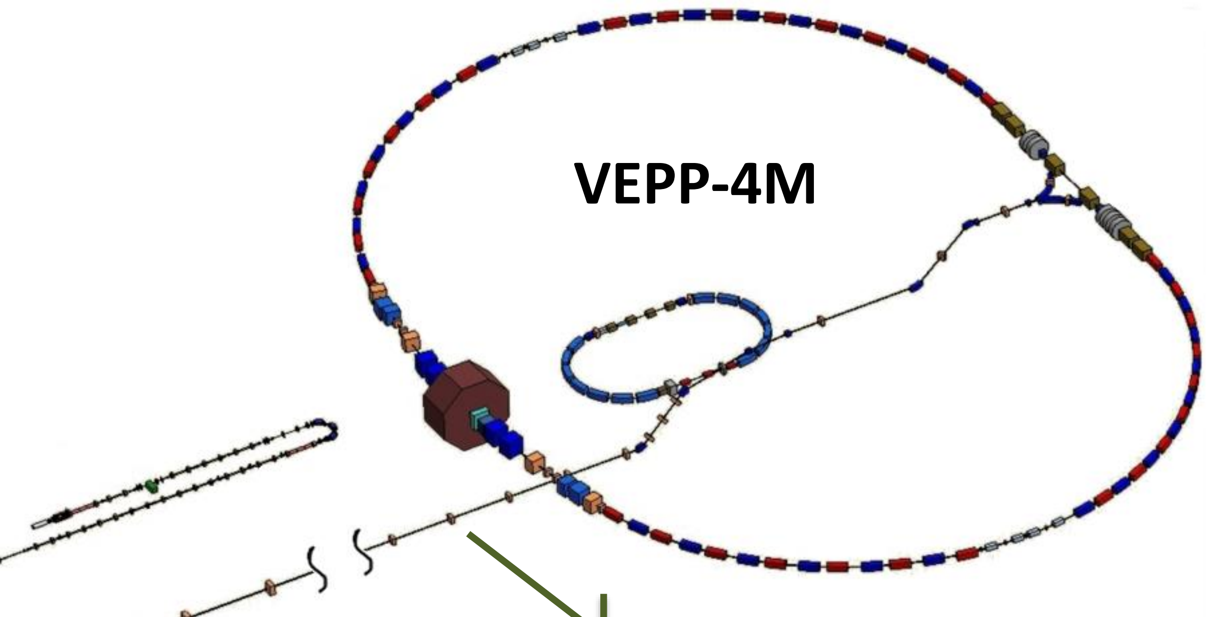
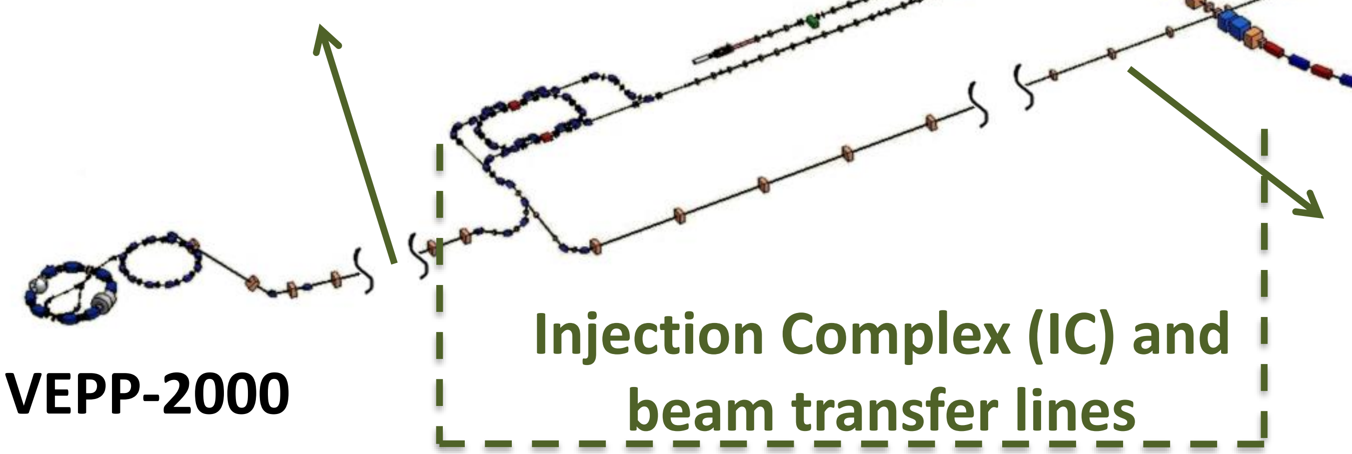
BINP electron-positron facilities

Timoshenko Maksim
on behalf of
IC, VEPP-4M, VEPP-2000 teams

Dec 16, 2019

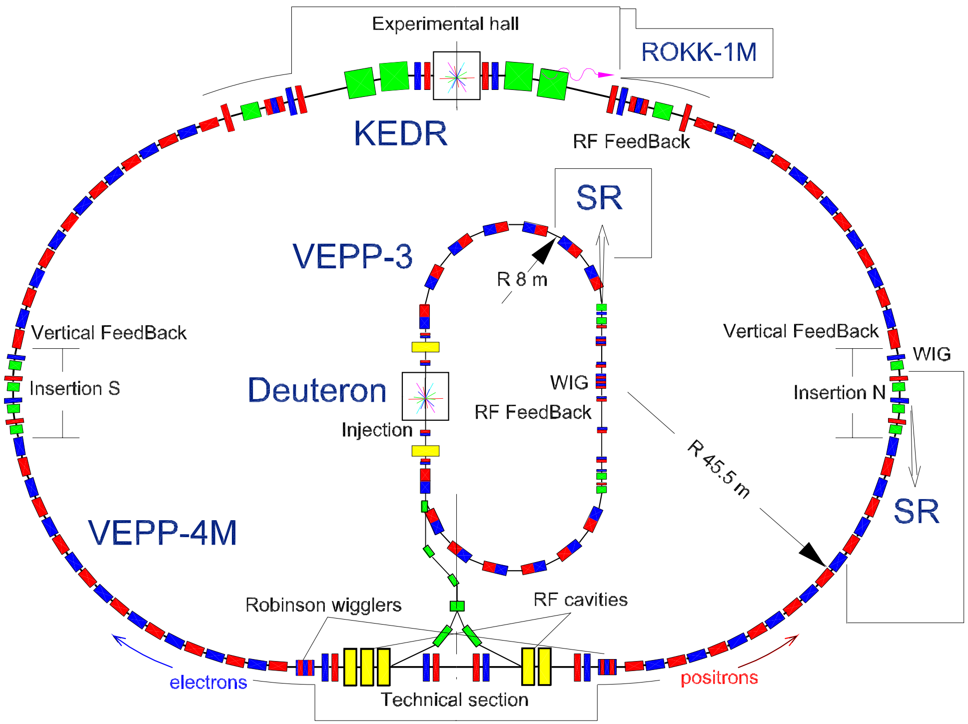
BINP - IHEP Seminar

BINP accelerator complex layout

IC Parameters (2016)	
Beam Energy:	**395 MeV**
Storage rate e^- @ 12.5 Hz:	**$4.0\cdot10^{10}$/s** (70 mA/s)
Storage rate e^+ @ 12.5 Hz:	**$4.0\cdot10^{9}$/s** (7 mA/s)

VEPP-4M complex



VEPP-4M collider parameters

Energy	0.925 ÷ 4.75 (5.3)				GeV
Circumference	366				m
N of bunches	$2e^+ \times 2e^-$ ($16e^-$)				
Harmonic number	222				
Betatron tunes, h/v	8.54/7.57				
Coupling	0.05%				
Bunch length	5				cm
Beam Energy	1.5	1.9	*4.7*	*5.2*	GeV
Emittance	16	25	*167*	*200*	nm·rad
Energy Spread	2.5	3.0	*7.8*	*8.5*	$\cdot 10^{-4}$
Bunch Current	1.6	3.5	*25*	*25*	mA
Luminosity	0.9	**3.3**	*44*	*25*	10^{30} cm$^{-2}\cdot$s^{-1}

Experimental program:

- e^+e^- HEP at VEPP-4M with KEDR detector
- SR at VEPP-3 (2 GeV)
- SR at VEPP-4M (2÷4 GeV)
- Nuclear physics at VEPP-3 with Deuteron facility
- Test Beam Facility at VEPP-4M
- Accelerator physics activity

★ Universal magnetic detector KEDR

★ Electron-positron tagging system

★ Wide energy range 0.9÷6 GeV

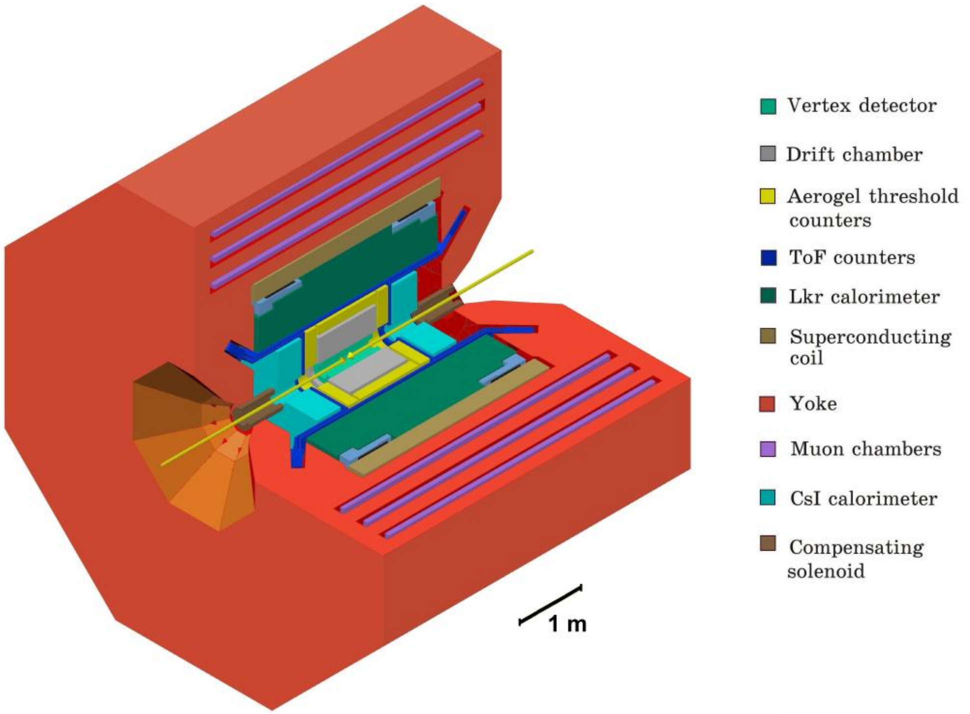
★ Energy spread control

★ Precision beam energy calibration by resonance depolarization (10^{-6} accuracy!)

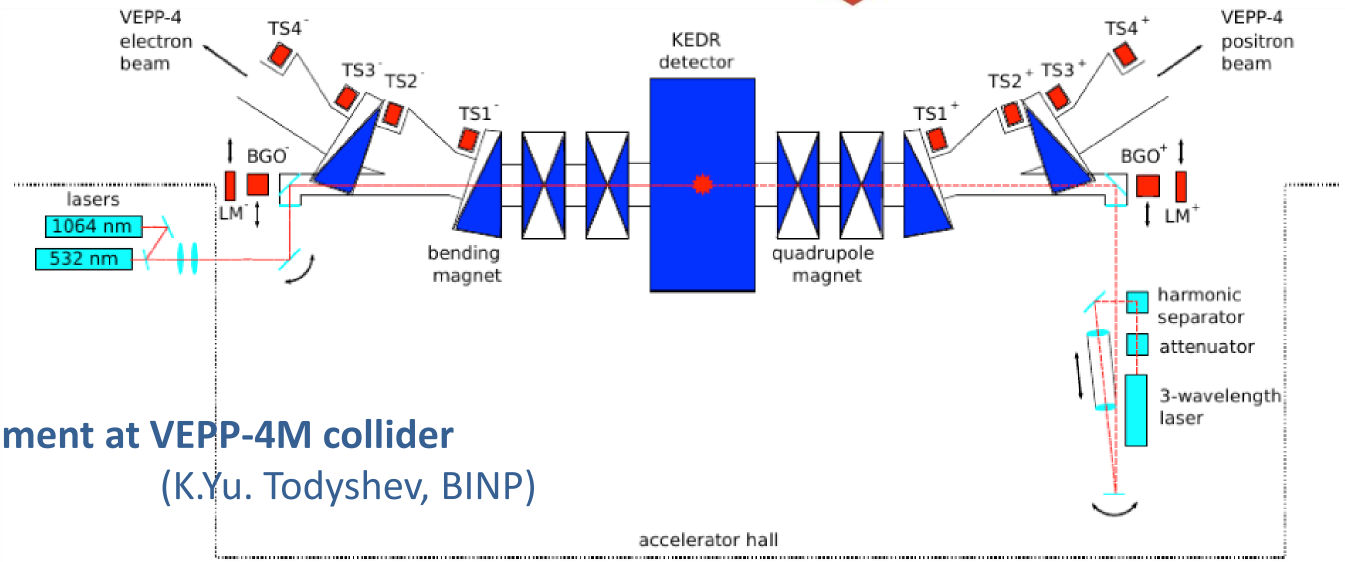
★ The first collider with beam energy monitoring by Compton backscattering

HEP VEPP-4M with KEDR

2001-2017 low energy luminosity run 2x(0.9÷1.9) GeV
- ✓ J/ψ, ψ' , ψ'', ψ(3770) meson masses
- ✓ τ lepton mass
- ✓ D^0 mesons masses
- ✓ $D^{\pm}$ mesons masses
- ✓ Search for narrow resonances 1.85÷3.1 GeV
- ✓ R-scan 1.85÷3.1 GeV
- ✓ R_{uds}- and R- scan 3.12÷3.72 GeV
- ✓ $J/\psi \to \gamma\eta_c$
- ✓ ψ-mesons, η_c, … parameters



High energy luminosity run 2x(1.9÷Max energy) GeV
- ✓ R scan 2x(2.3÷3.5) GeV (~ 10 bp^{-1})
- ✓ ϒ-mesons study (~ 50 pb^{-1})
- ✓ gamma-gamma physics (~ 200 pb^{-1})

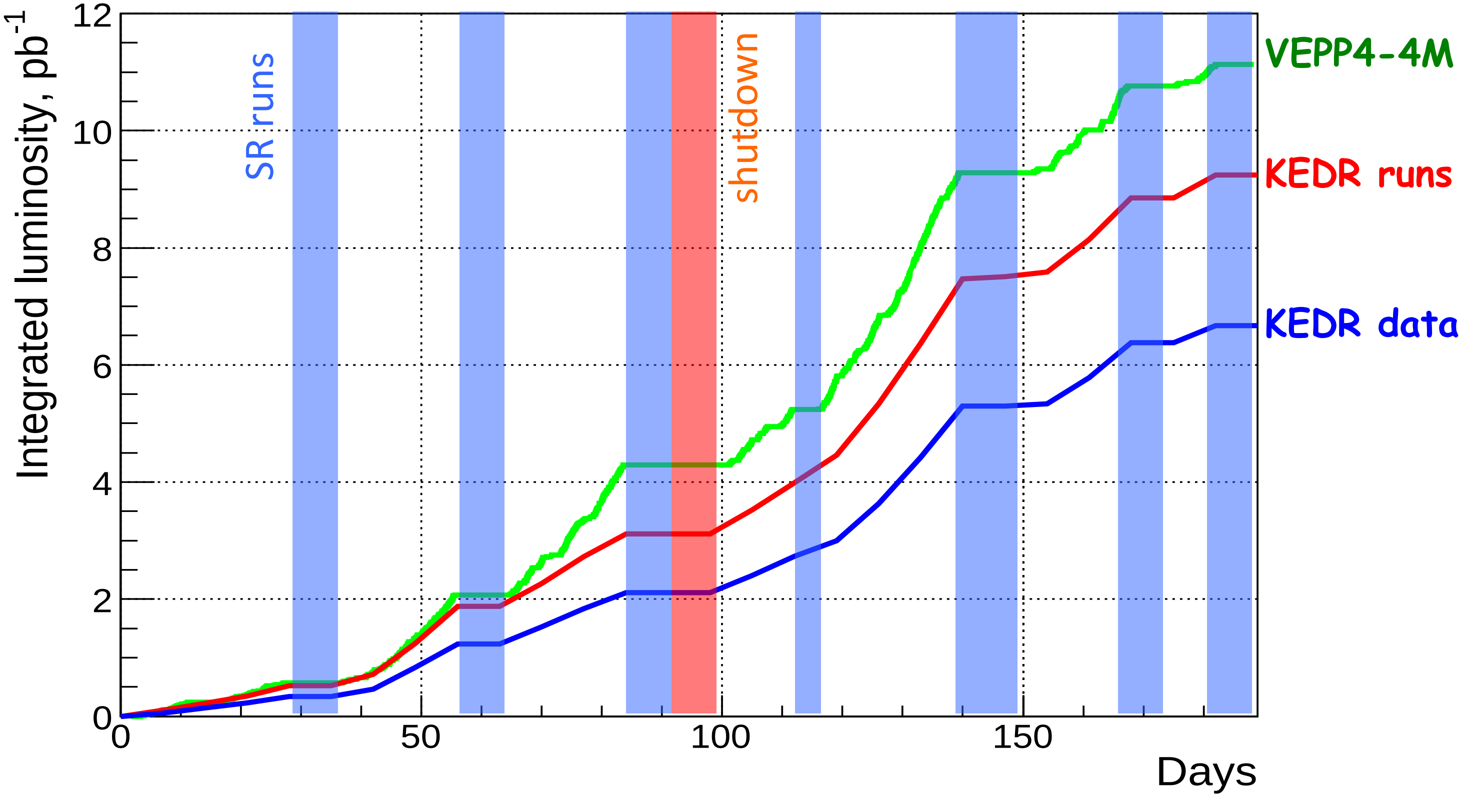


➢ **R measurement at VEPP-4M collider**

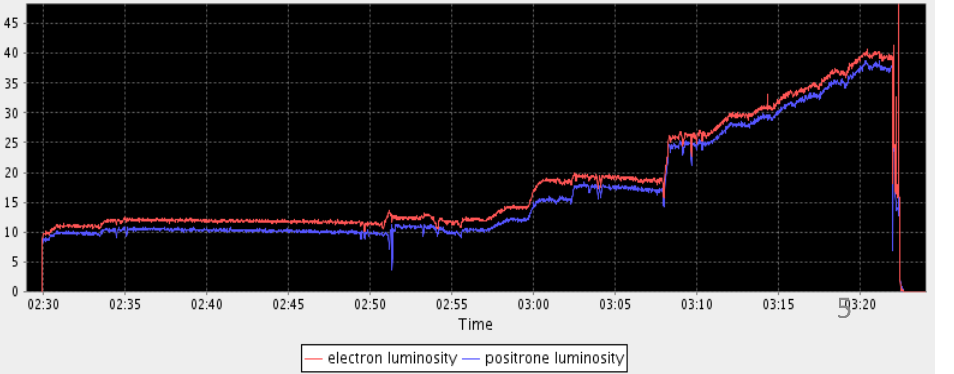
(K.Yu. Todyshev, BINP)

Run 2017/18 highlights

In 2017 hadron cross section measurement
from 2.3 to 3.5 GeV in two runs was started



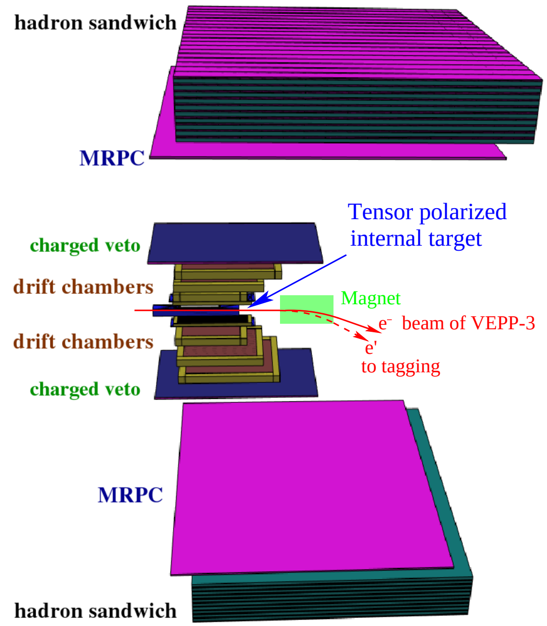
First luminosity
$\Upsilon(1S)$

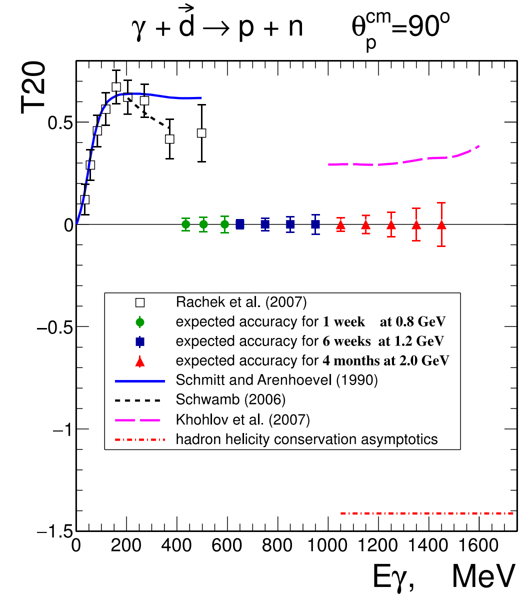


Deuteron VEPP-3

Tensor-polarized deuteron photodisintegration at the VEPP-3 storage ring

The two-body deuteron photodisintegration is one of the most studied process in nuclear physics. Tensor analyzing power T20 reaction will be measured in an unexplored region of the photon energy up to 1.5 GeV.





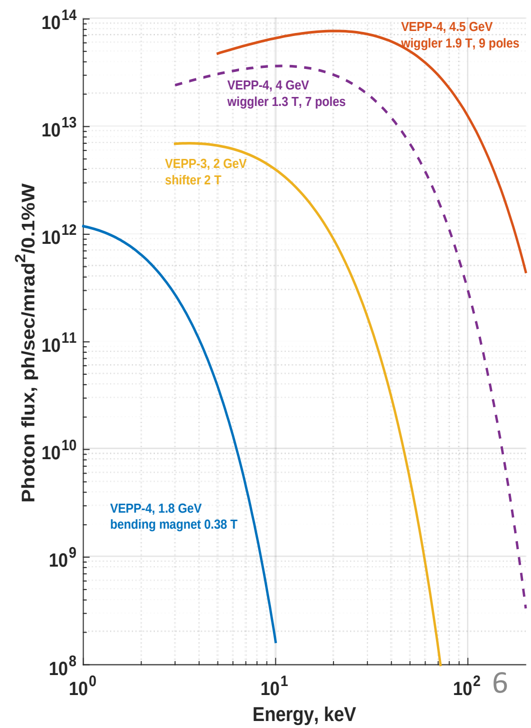
- ✓ SR @ VEPP-3 – 1.2 or 2.0 GeV with 2 T shifter
- ✓ SR @ VEPP-4M – 1.9 or 4.5 GeV with new 9-poles hybrid 2 T wiggler

VEPP-3

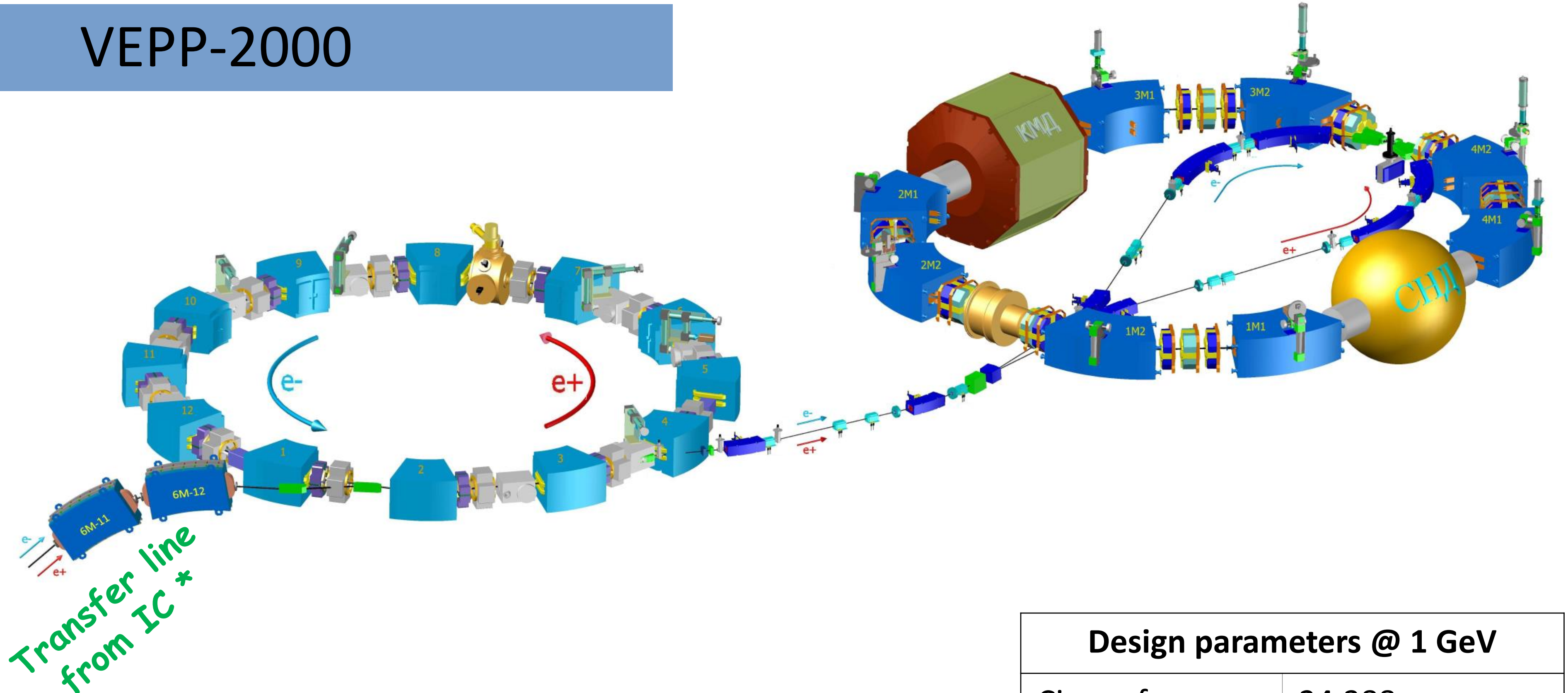
- LIGA-technology and X-ray lithography.
- Fast dynamic process.
- Precise diffraction and anomalous scattering.
- X-ray fluorescence analysis.
- High pressure diffraction.
- X-ray microscopy and micro-tomography.
- Time resolved diffraction.
- Time resolved luminescence.
- Precise diffraction.

VEPP-4M

- Metrology experiments.
- Phase contrast microscopy, micro-tomography and hard X ray fluorescence.
- Nanosecond spectroscopy of fast processes.
- Material study under extremal conditions
- Material study for thermonuclear applications



VEPP-2000



Design parameters @ 1 GeV	
Circumference	24.388 m
Beam energy	150 ÷ 1000 MeV
N of bunches	1×1
N of particles	1×10^{11}
Betatron tunes	4.14 / 2.14
Beta*	8.5 cm
Luminosity	1×10^{32} cm^{-2}s^{-1}

- **Round beams concept!**
- Single-ring head-on collisions
- 13 T superconducting solenoids for FF
- 2.4 T NC dipoles at 1 GeV
- CBS for energy control

* Operating with IC since 2016

VEPP-2000. Experimental program

- **Recent results from SND detector at VEPP-2000 collider.**
  Measurement of pion formfactor. (A.S. Kupich, BINP)
- **Study of electron-positron annihilation to hadrons with CMD-3 at VEPP-2000**

1. Precision measurement of $R = \sigma(e^+e^- \to hadrons)/\,\sigma(e^+e^- \to \mu^+\mu^-)$ exclusive approach, up to <1% for major modes
2. Study of hadronic final states:
$$e^+e^- \to 2h, 3h, 4h, \ldots \quad h = \pi, K, \eta$$
3. Study of vector mesons and theirs excitations:
$$\rho', \rho'', \omega', \varphi', \ldots$$
4. Comparison of cross-sections $e^+e^- \to hadrons\ (T = 1)$ with spectral functions of τ-decays
5. Study of nucleon electromagnetic formfactor at threshold
$$e^+e^- \to p\bar{p}, n\bar{n}$$
6. Measurement of the cross-sections using ISR
7. Study of higher order QED processes

Target luminosity integral is 1 fb^{-1} per detecor

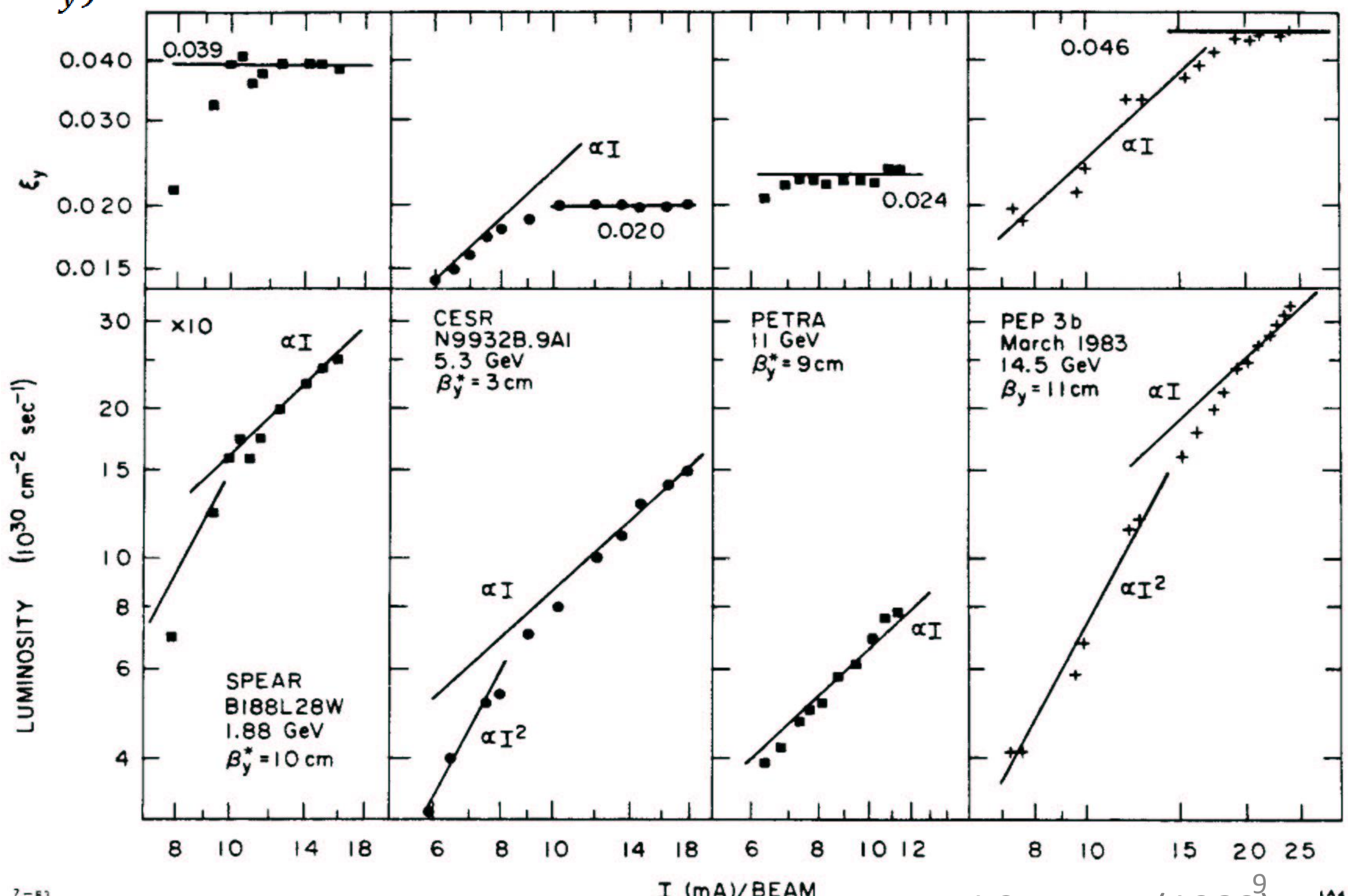
Beam-beam limit (for lepton collider)

$$L = \frac{N_1 N_2 n_b f_0}{4\pi\sigma_x\sigma_y} = \frac{\pi\gamma^2\xi_x\xi_y\varepsilon_x f_0}{{r_e}^2\beta_y^*}\left(1+\frac{\sigma_y}{\sigma_x}\right)^2$$

$$\xi_{x,y} = \frac{r_e\beta_{x,y}^*}{2\pi\gamma}\frac{N}{\sigma_{x,y}(\sigma_x+\sigma_y)}$$

Final limit:

1) emittance blowup,
2) lifetime reduction,
3) flip-flop effect



J.Seeman (1983)

Round Colliding Beams

stochastic particles motion

Final limit:
1) emittance blowup,
2) lifetime reduction,
3) flip-flop effect

Axial symmetry of counter beam force **RCB** + X-Y symmetry of transfer matrix IP2IP

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: $\beta_x = \beta_y$
- Equal beam emittances: $\varepsilon_x = \varepsilon_y$
- Equal fractional parts of betatron tunes: $\nu_x = \nu_y$

Round beam

$M_x = M_y$

Make motion "more integrable" and stable

Beam-beam limit at VEPP-2000

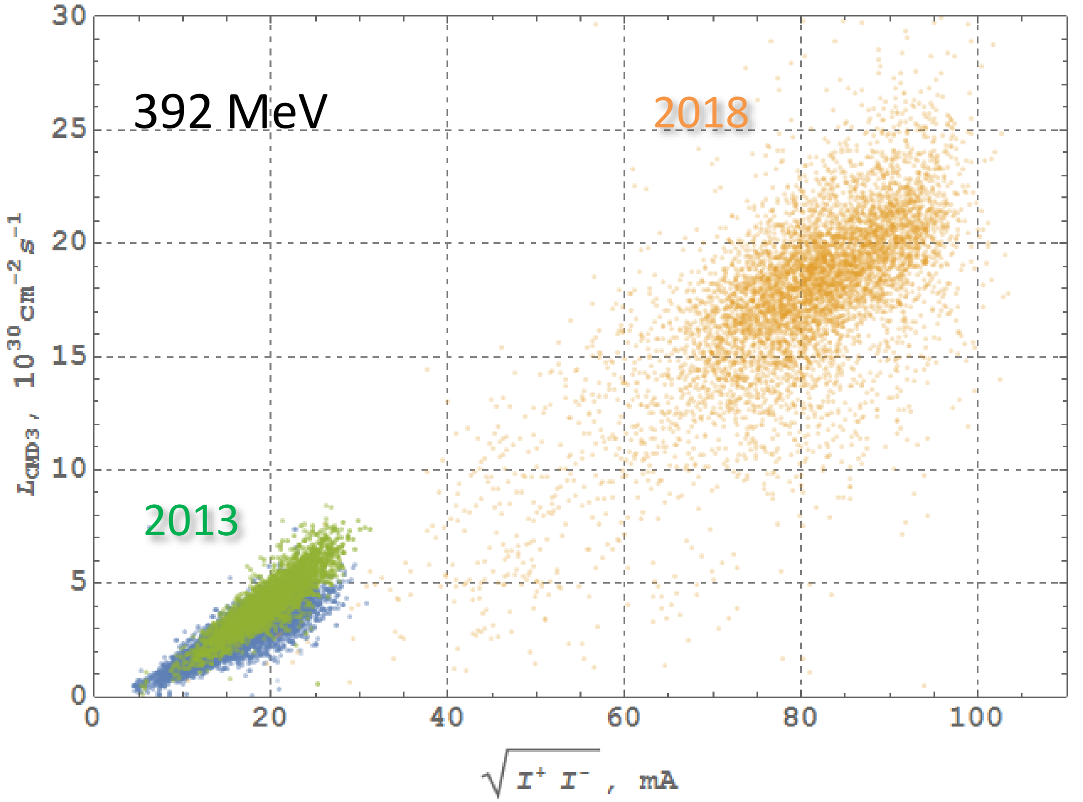
$$L = \frac{N_1 N_2 n_b f_0}{4\pi\sigma_x\sigma_y} = \frac{\pi\gamma^2\xi_x\xi_y\varepsilon_x f_0}{r_e^2\beta_y^*}\left(1+\frac{\sigma_y}{\sigma_x}\right)^2$$

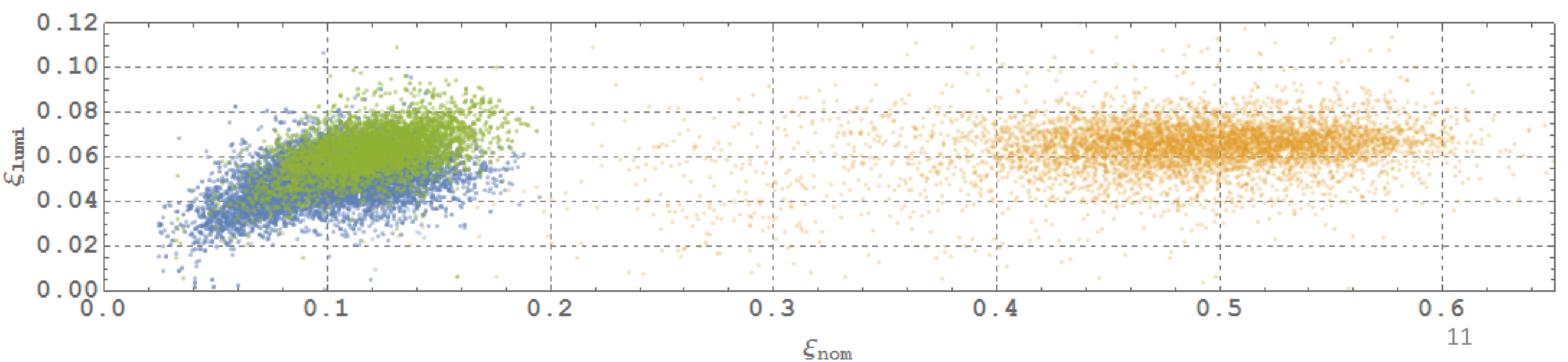
$$\xi_{x,y} = \frac{r_e\beta_{x,y}^*}{2\pi\gamma}\frac{N}{\sigma_{x,y}(\sigma_x+\sigma_y)}$$

$$\xi_{nom} = \frac{N^- r_e \beta_{nom}^*}{4\pi\gamma\sigma_{nom}^{*2}}$$ - normalized beam current

$$\xi_{lumi} = \frac{N^- r_e \beta_{nom}^*}{4\pi\gamma\sigma_{lumi}^{*2}}$$ - “beam-beam parameter”

$$L = \frac{N^+N^-}{4\pi\sigma^{*2}} f_0 = \frac{N f_0 \gamma}{r_e}\frac{\xi_{lumi}}{\beta_{nom}^*}$$





Flip-flop effect

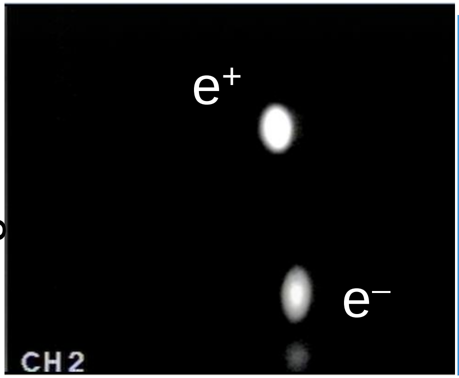
$$\xi \approx \Delta\nu = \nu_\pi - \nu_\sigma$$

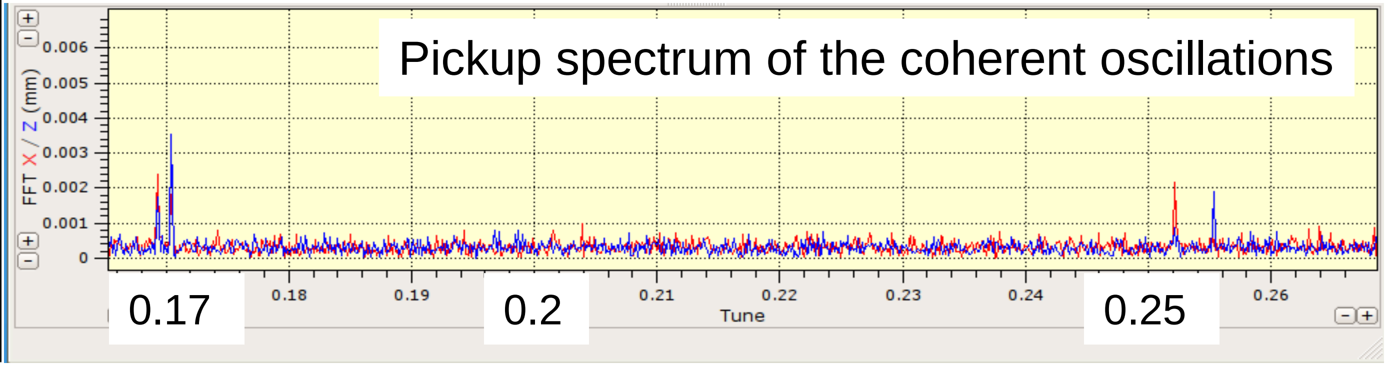
TV

σ

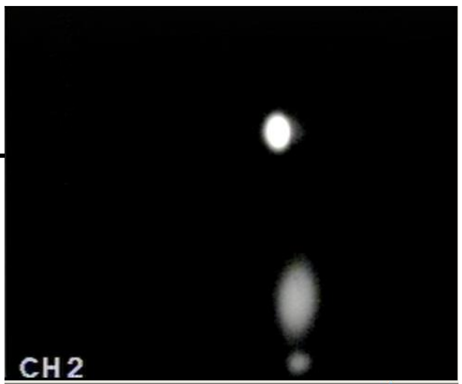
π

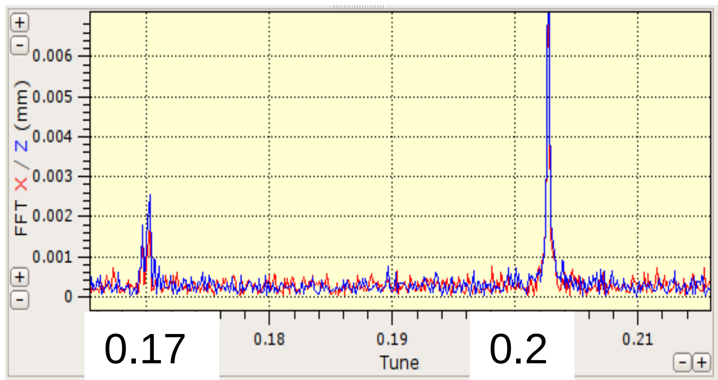
regular



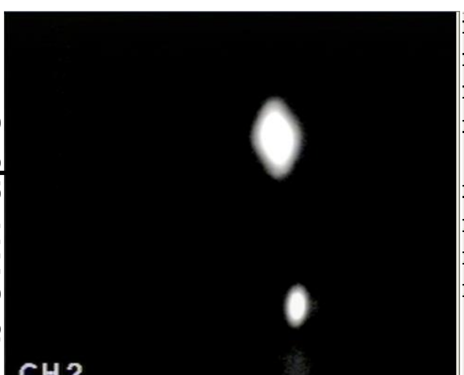


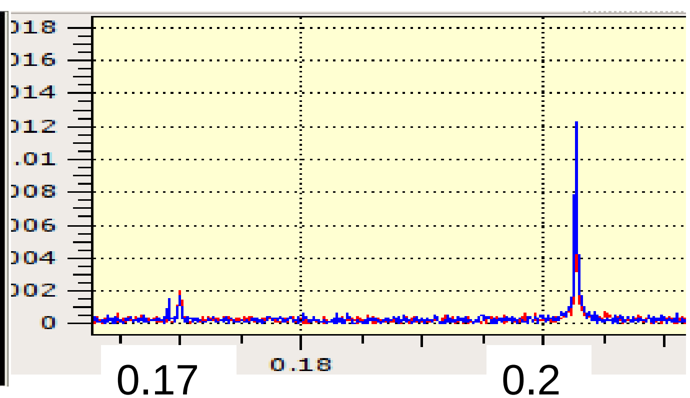
blown-up e–





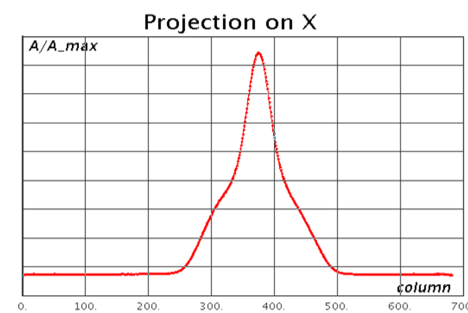
blown-up e+





E = 240 MeV,

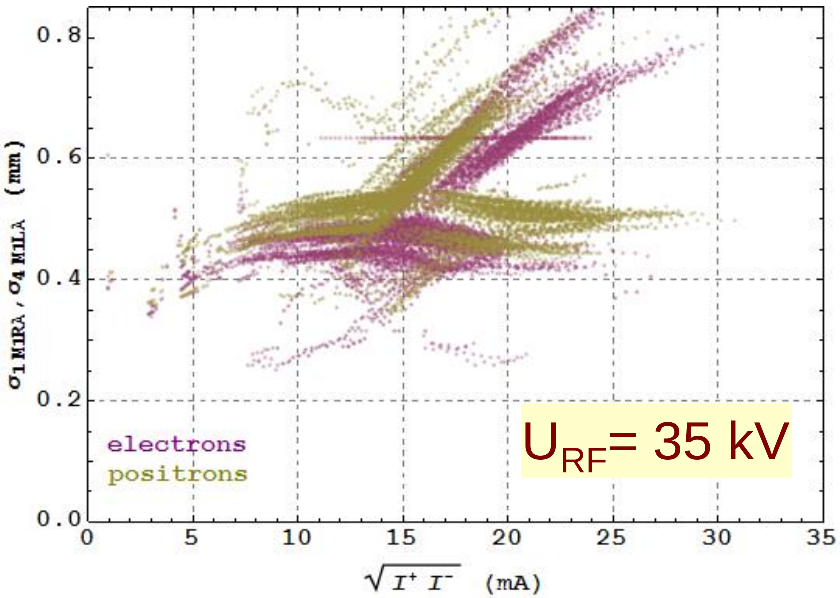
I_{beam} ~ 5×5 mA

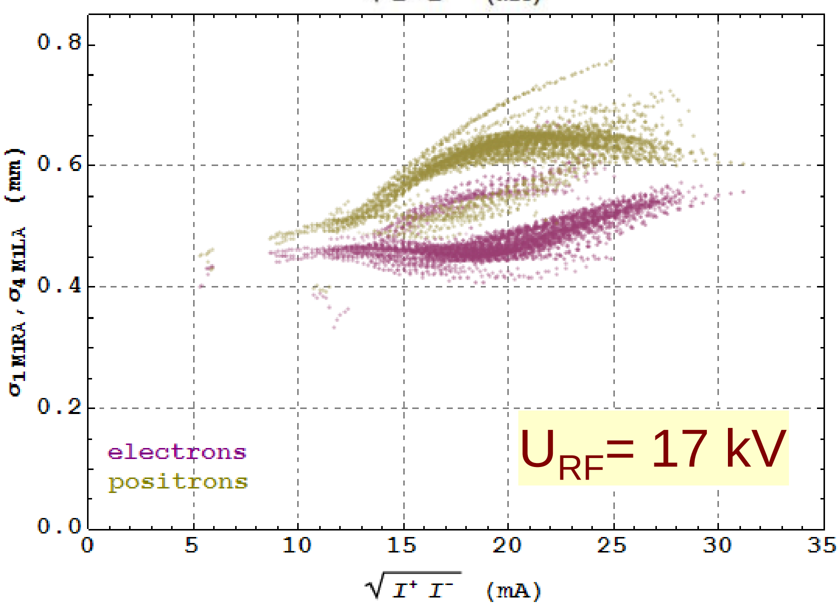


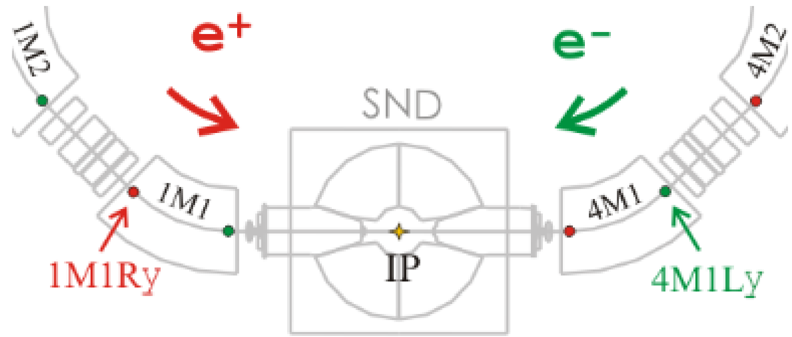
Coherent beam-beam π-mode interaction with machine nonlinear resonances

A: Flip-flop suppression with long bunch

E= 392.5 MэВ

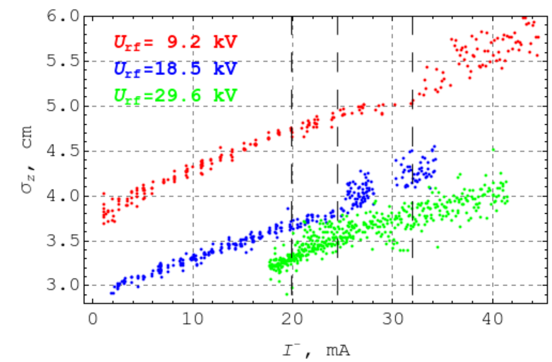




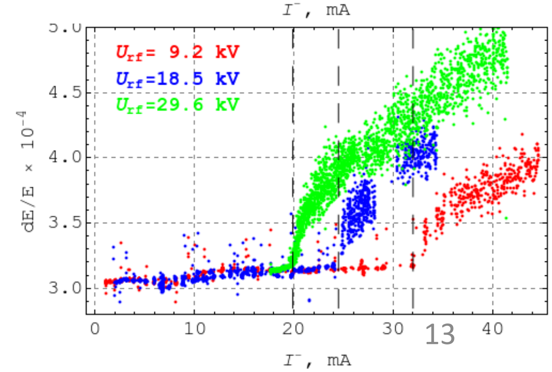


Bunch lengthening & mw instability

Single bunch length measurement with phi-dissector as a function of single beam current for different RF voltage @ 478 MeV.



Energy spread dependence, restored from beam transverse profile measurements.



B: Beam shaking *

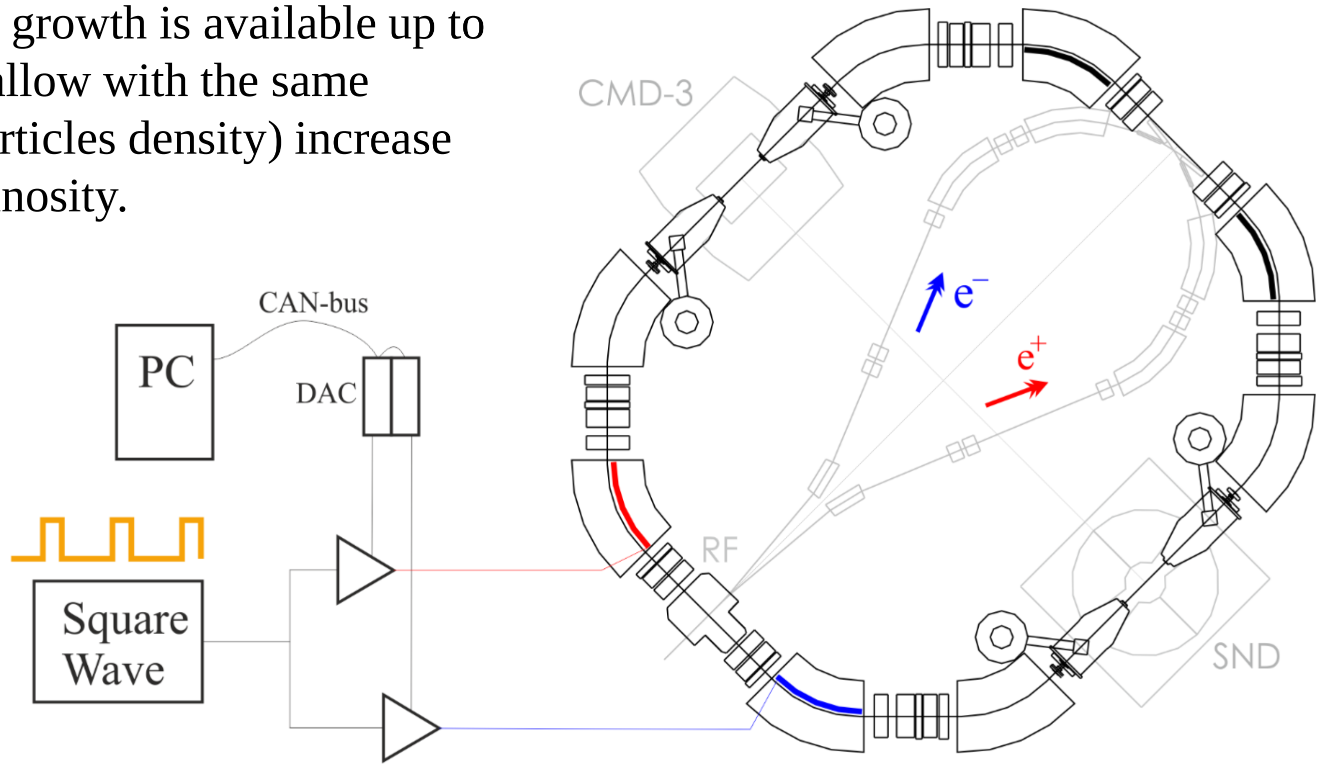
*only at energy < 500 MeV

<u>Idea (I.Koop)</u>: kicked bunch oscillations decoheres very fast in the presence of counter beam's strongly nonlinear field. Weak and frequent kicks should effectively increase the emittance, similarly to quantum excitation by wiggler.

At low energies emittance growth is available up to aperture restriction. That allow with the same beam-beam parameter (particles density) increase the beam current and luminosity.

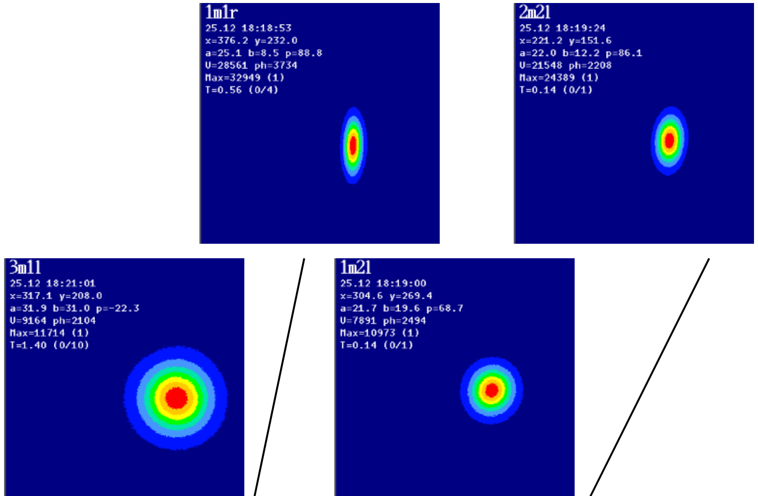
Typical values:
50-100 V, 300 ns, 50 μs

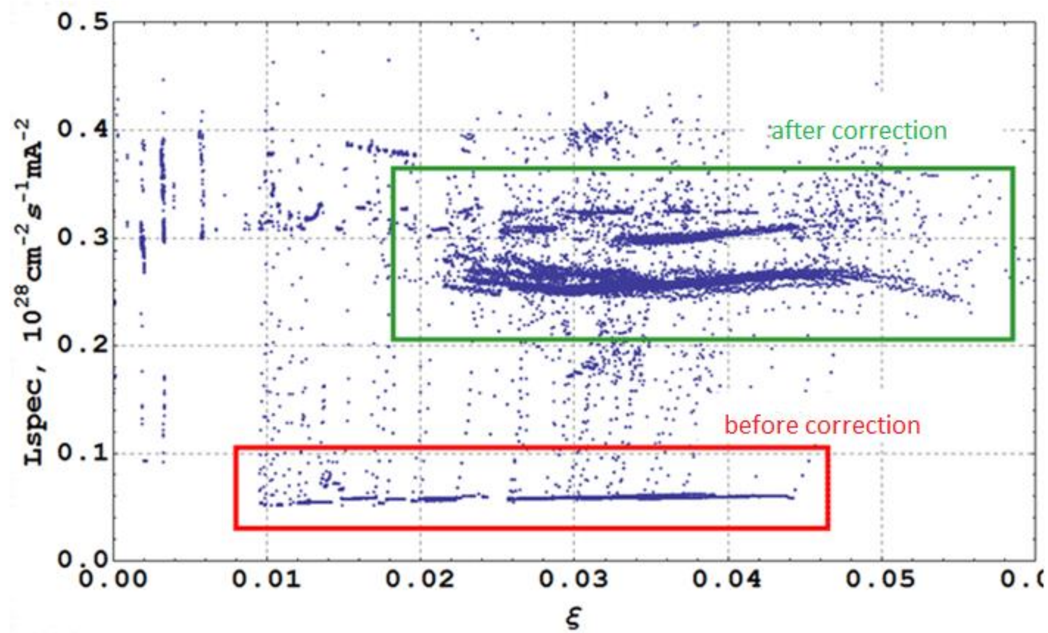
(T_{rev} = 81.4 ns)

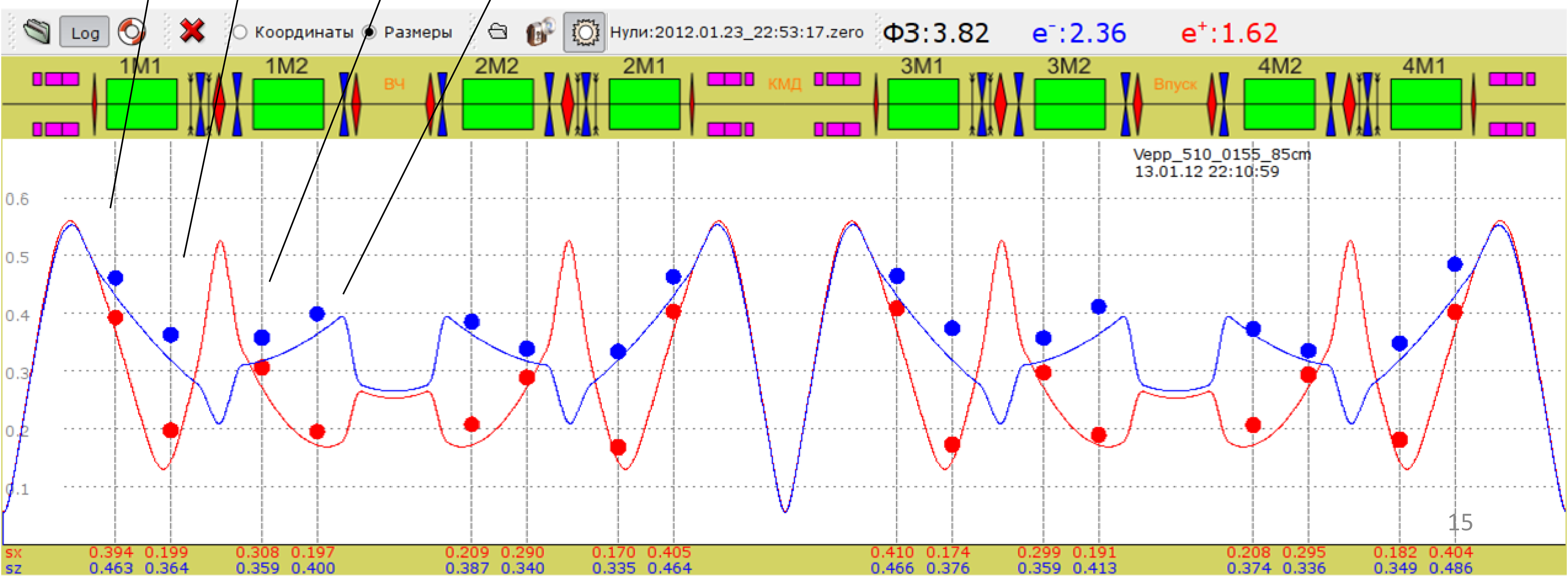


<u>Experimentally</u>: permanent excitation of "strong" beam size prevent it from shrinkage to natural value during injection cycle of "weak" beam, or whatsoever. Very effective suppression of flip-flop meta-stable states.
In addition large emittance results in a lifetime enhancement.

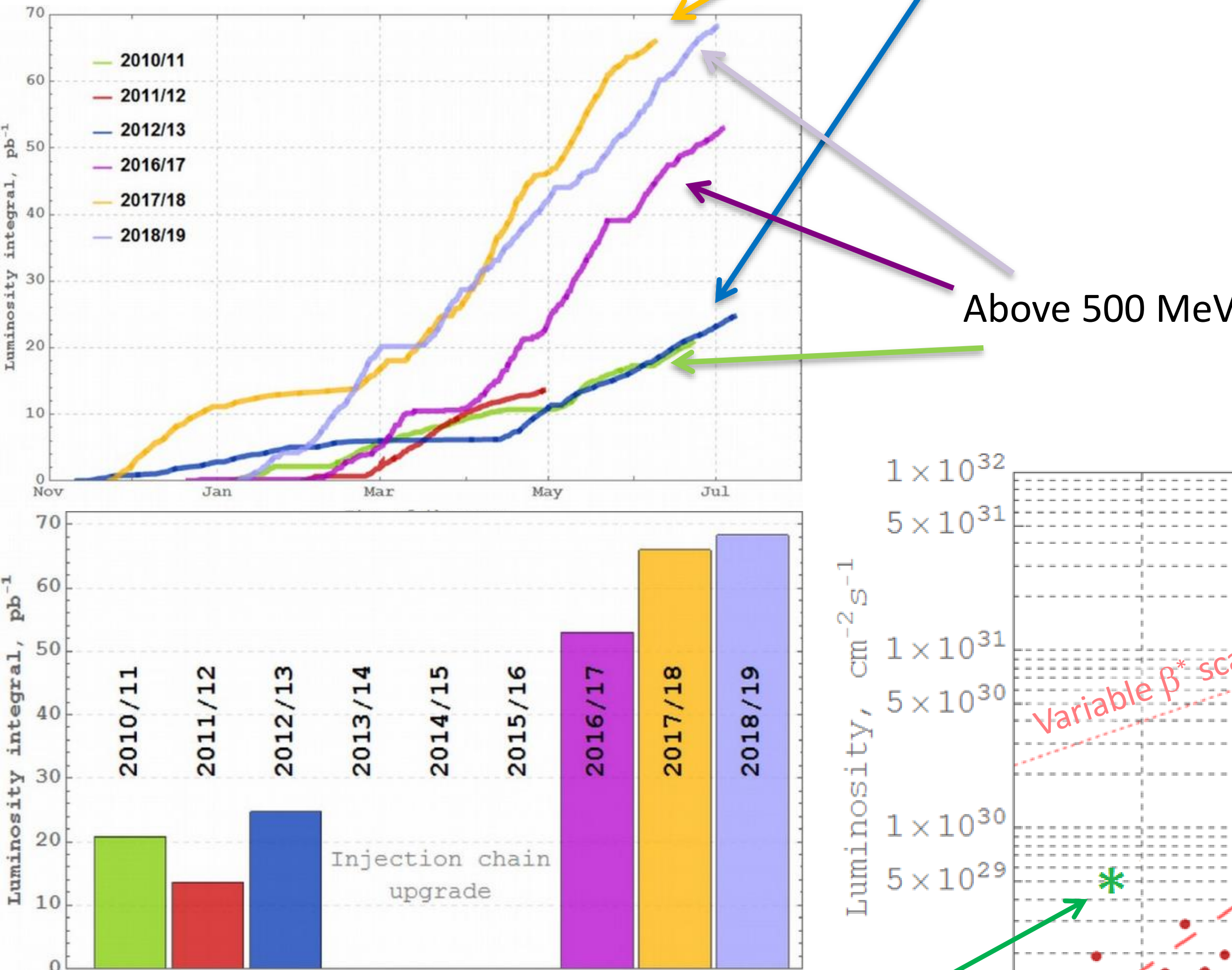
C: Machine tuning







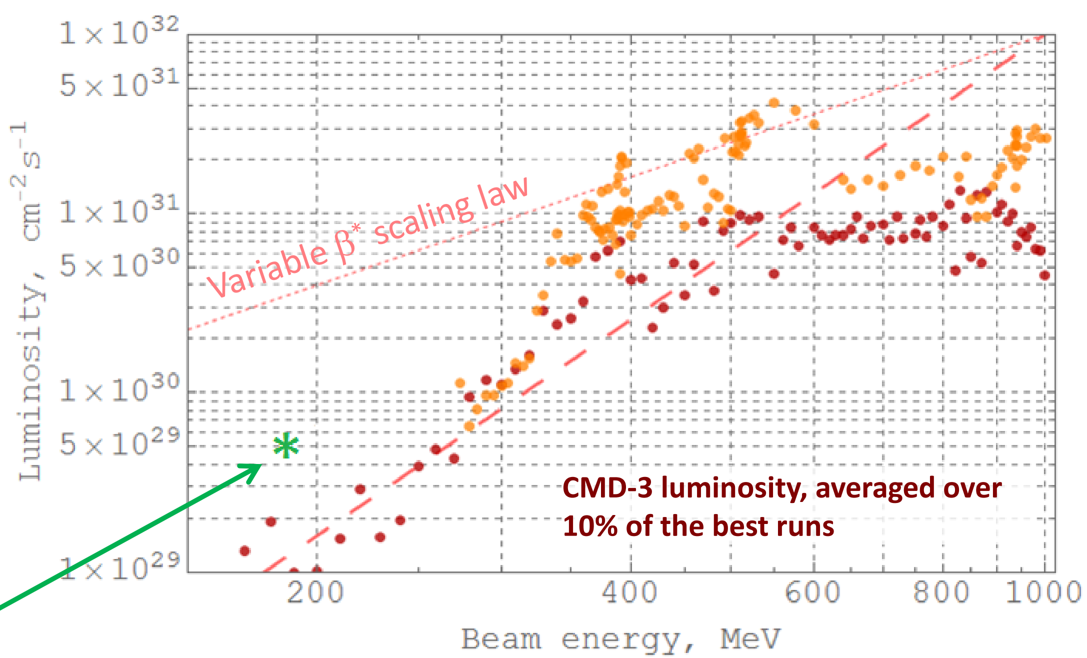
Data collection



Highest luminosity achieved

$L_{peak} = 5\times10^{31}$ cm^{-2}s^{-1}

at 550 MeV

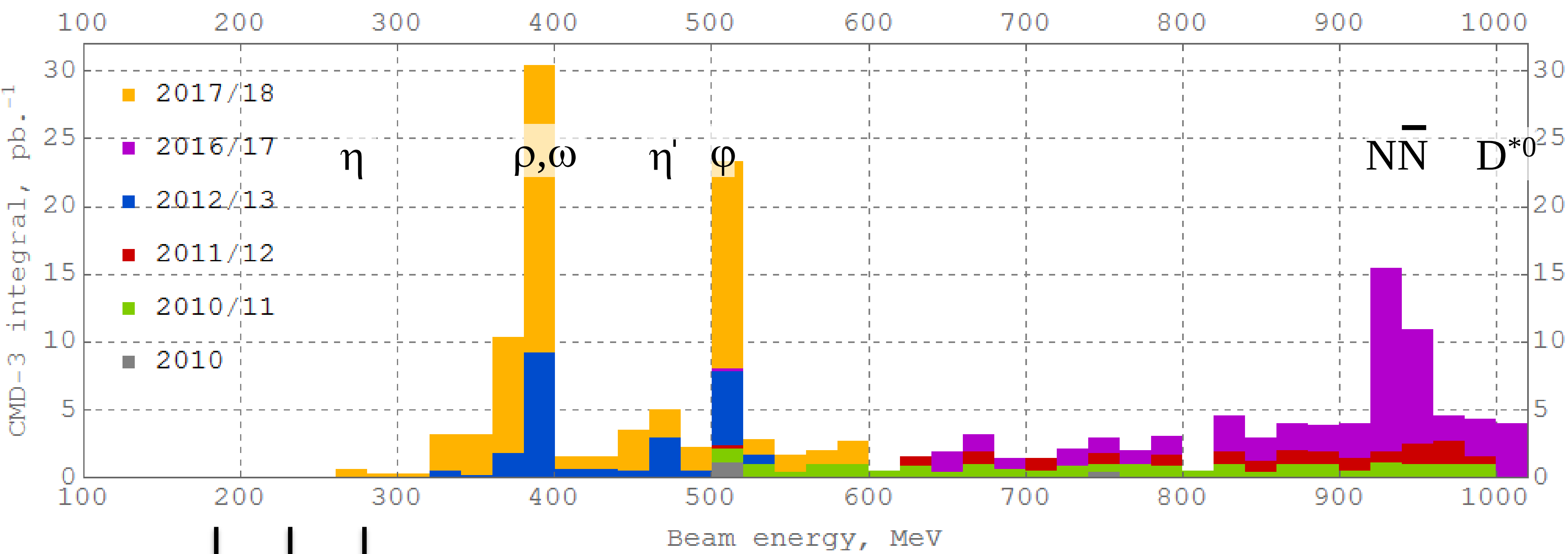


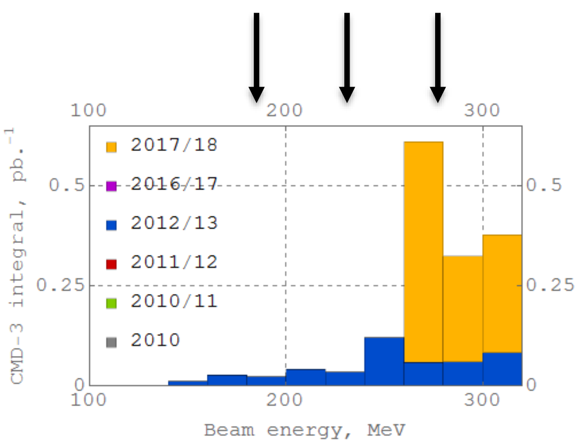
"yesterday"

2017-2018 data

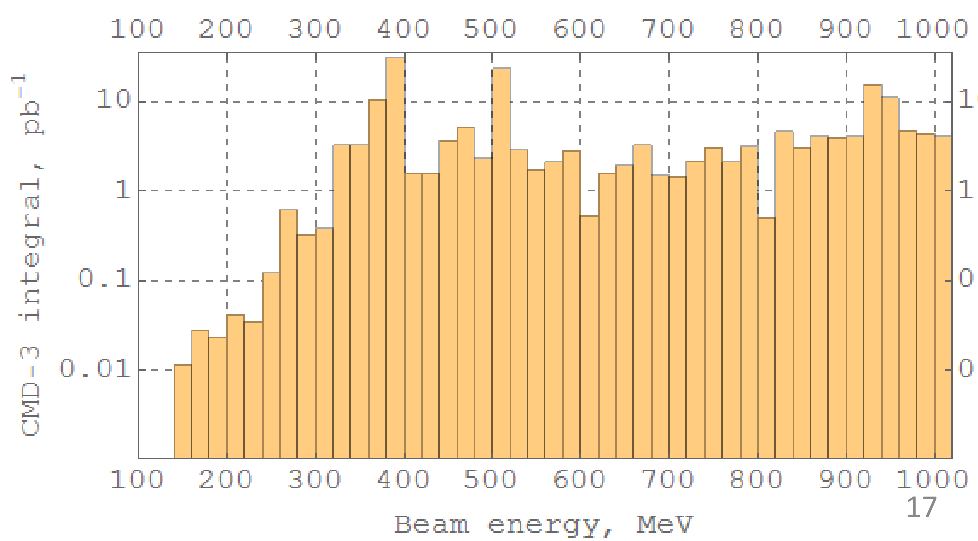
2010-2013 data

Total luminosity integral

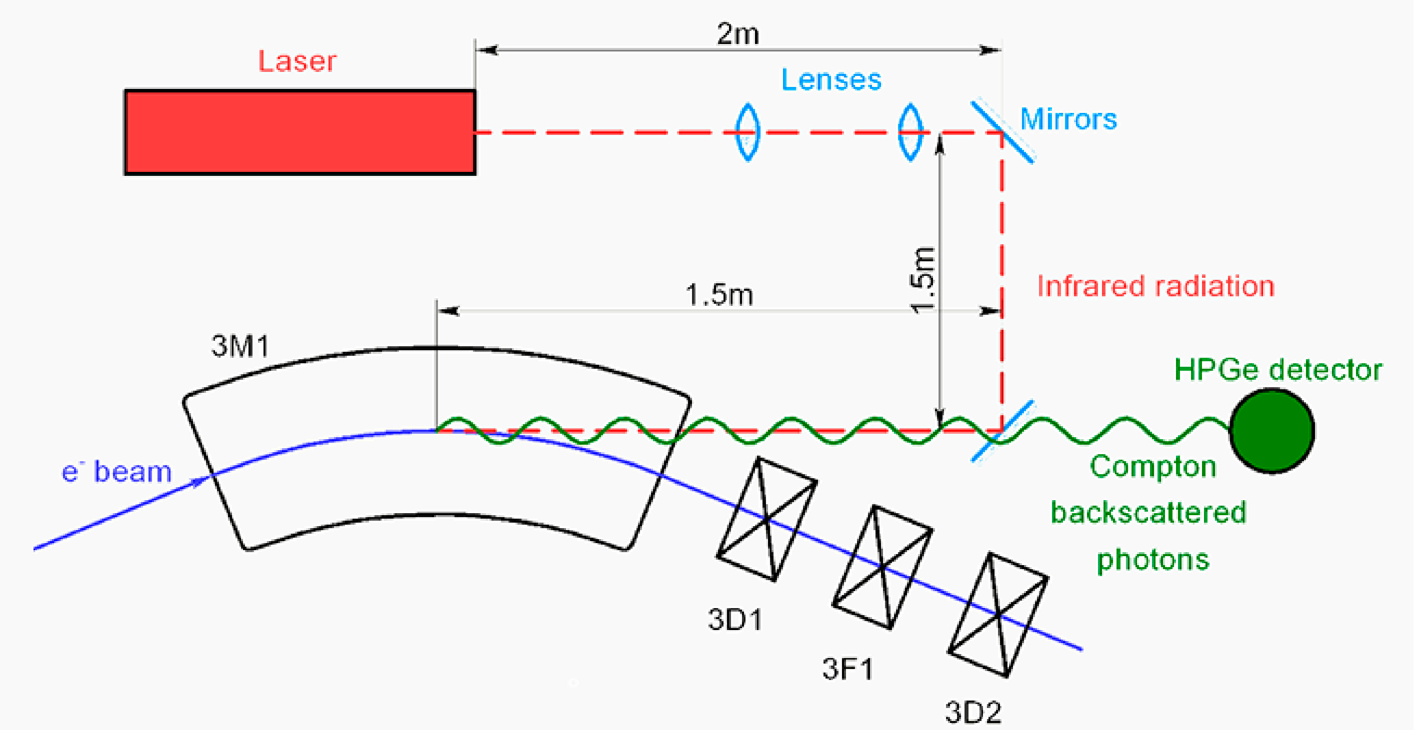




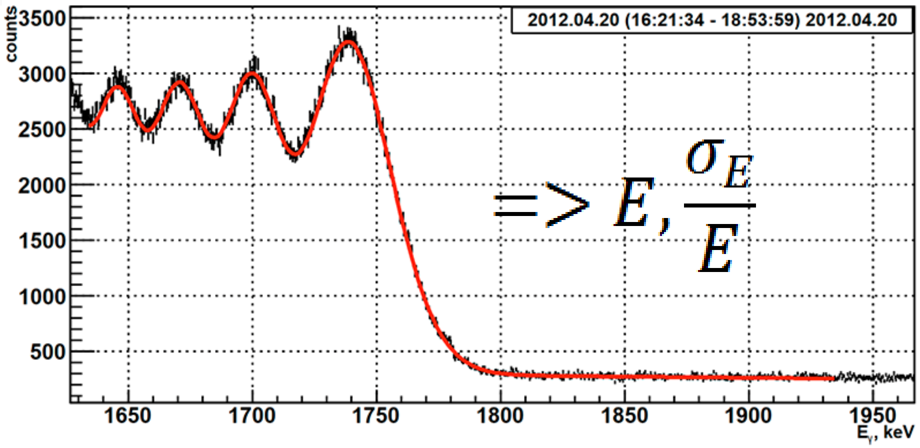
Lowest energy ever obtained in e^+e^- colliders



Beam energy measurements: CBS system



Backscattered photons spectrum edge:



➢ **Inverse Compton Scattering at Budker INP: experiments & prospects**

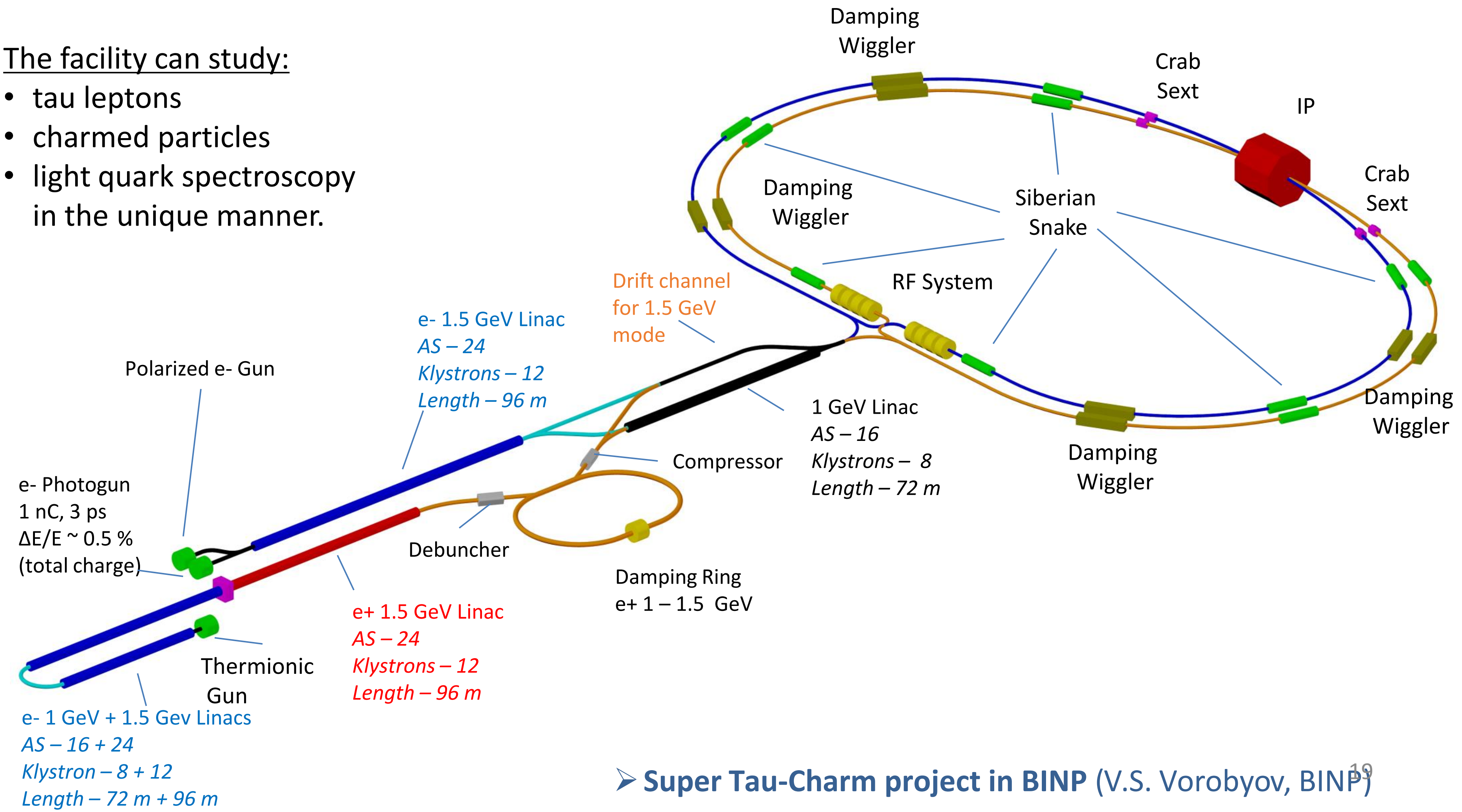
(N.Yu.Muchnoi, BINP)

Super-CT Project

- e+e- collider
- Beam energy range from 1 to 2.5 GeV
- Extremely high luminosity (~ 10^{35} $cm^{-2}\cdot s^{-1}$)
- Longitudinal polarization of electron beam at the IP.

The facility can study:

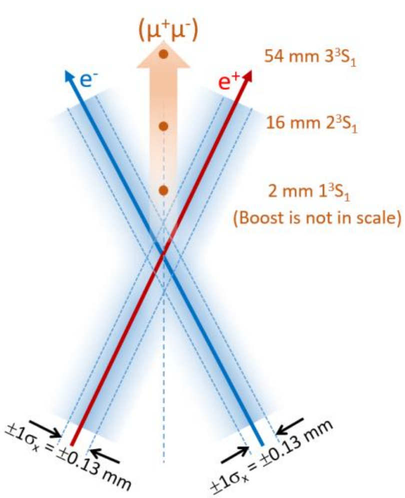
- tau leptons
- charmed particles
- light quark spectroscopy in the unique manner.

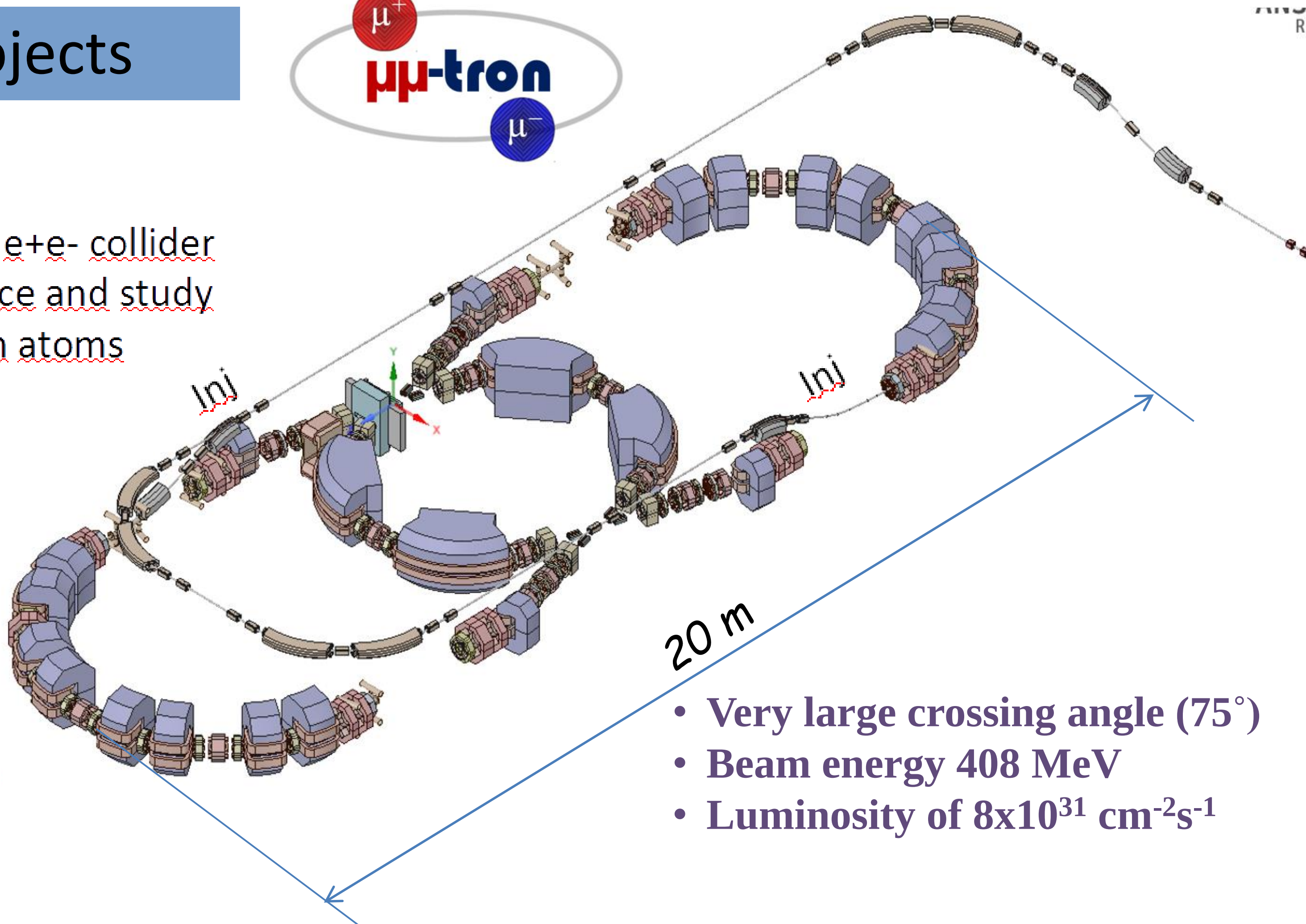


➢ **Super Tau-Charm project in BINP** (V.S. Vorobyov, BINP)

Future projects

New Budker INP e+e- collider project to produce and study dimuonioum atoms





- **Very large crossing angle (75°)**
- **Beam energy 408 MeV**
- **Luminosity of $8x10^{31}$ $cm^{-2}s^{-1}$**

- Dimuonium, bimuonium or true muonium is a lepton atom (μ+μ-).
- Dimuonium is pure QED system (no strong interaction, calculable).
- From 6 leptonic atoms (e^+e^-), (μ^+e^-), ($\mu^+\mu^-$), (τ^+e^-), ($\tau^+\mu$-), ($\tau^+\tau^-$) only two (e^+e^-), (μ^+e^-) were observed.
- Very compact (large m_μ), more sensitive to new physics than other exotic atoms.

Details are in: https://arxiv.org/abs/1708.05819

Thanks for your attention