Project of the Charm-Tau factory in Novosibirsk

- *B.Shwartz,*
- *Budker Institute of Nuclear physics,*
- *Novosibirsk State University, Novosibirsk*

We (BINP) are here

The Budker Institute of Nuclear Physics,
history and main activities

BINP was founded in 1958.

First director - G.I.Budker

Total number of emploee - about 2800

Researchers - 450

The main activities:

1. **Accelerators for high energy physics**
2. **Experiments on high energy physics.**
3. **Theoretical studies in high energy physics.**
4. **Studies on plasma physics (as a way to obtain the controlled thermonuclear reactor).**
5. **Application of the accelerators in the industry and other fields of researches.**
6. **Collaborations (on particle physics): Belle, BaBar, ATLAS, LHCB, MEG, …**

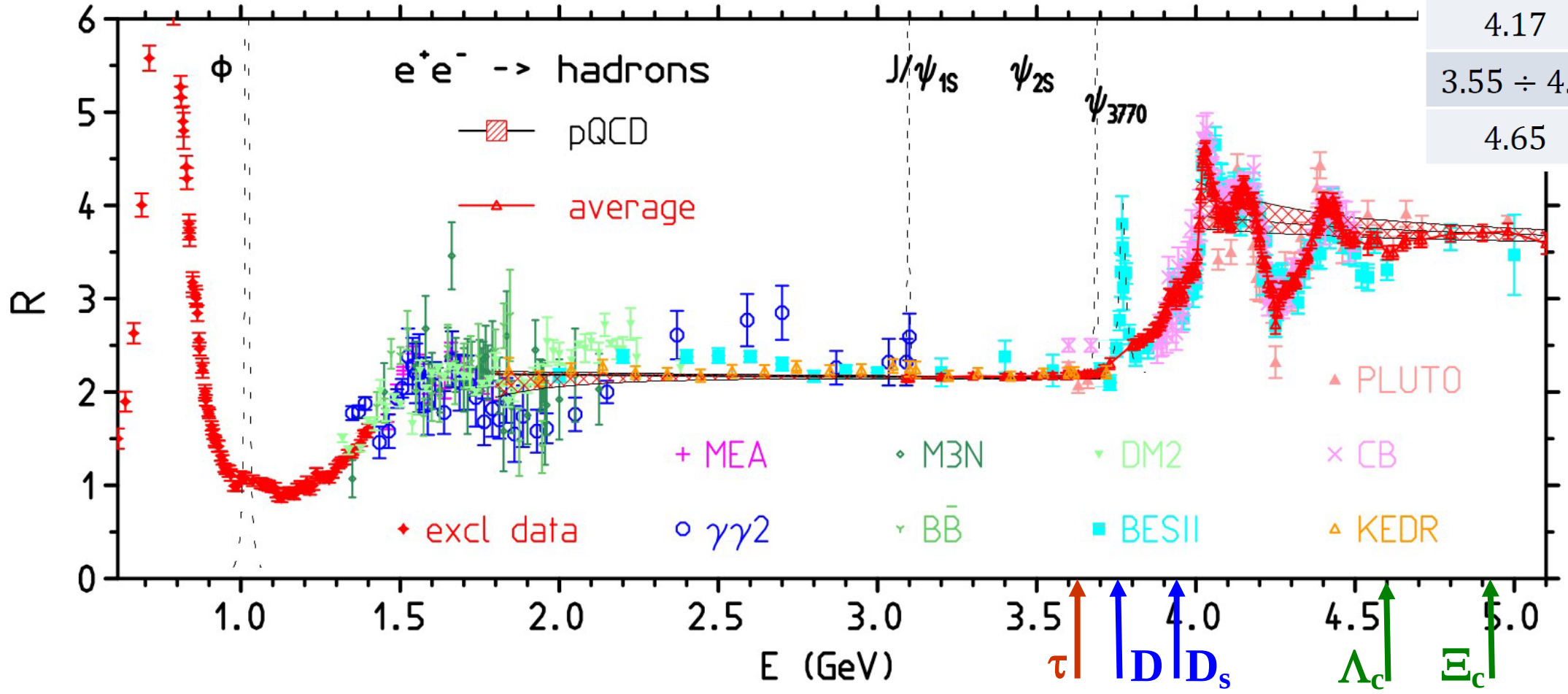
BINP e^+e^- colliders

- VEP-1, VEPP-2 – first e^-e^- and e^+e^- colliders – sixties;
- **VEPP-4 – E_{CM}= 2 – 12 GeV: under operation,** detectors: OLYA, MD1, KEDR (now).
- VEPP2M - E_{CM}= 0.3 – 1.4 GeV: 1974 – 2000, detectors: OLYA, CMD, ND, CMD-2, SND.
- **VEPP 2000 – E_{CM} = 0.3 – 2 GeV: in operation from 2010; detectors: CMD-3, SND-M**

- **Beam energy from 1.0 to 2.5 GeV (3 GeV)**
- **Peak luminosity is 10^{35} cm^{-2}s^{-1} at 2 GeV**

Annual yields

$2E$, GeV	Yield
3.1	$10^{12}\, J/\psi$
3.69	$10^{11}\, \psi(2S)$
3.77	$10^{9}\, D\bar{D}$
4.17	$10^{8}\, D_s\bar{D}_s$
3.55 ÷ 4.3	$10^{10}\, \tau\,\tau$
4.65	$10^{8}\, \Lambda_c^+\Lambda_c^-$



BINP Super c/τ factory project

- **Beam energy from 1.0 to 2.5 GeV (3 GeV)**
- **Peak luminosity is 10^{35} $cm^{-2}s^{-1}$ at 2 GeV**
- **Electrons can be polarized longitudinally at IP**
- **On-line energy monitoring (~$5 \div 10 \cdot 10^{-5}$)**

Charmonia

Spectroscopy, BR`s of J/ψ decays to light mesons, detail study of higher cc and XYZ states;

Weak decays of J/ψ, the total branching ratio of c → s transition is (2–4)×10^{-8}

Charm mesons and Charm baryons

Spectroscopy, BR's, cross sections, Mixing, Search for $\mathcal{CP}$ violation

τ lepton

Michel parameters, Spectral functions, search for $\mathcal{CP}$ violation,
Lepton flavour violation, Lepton universality

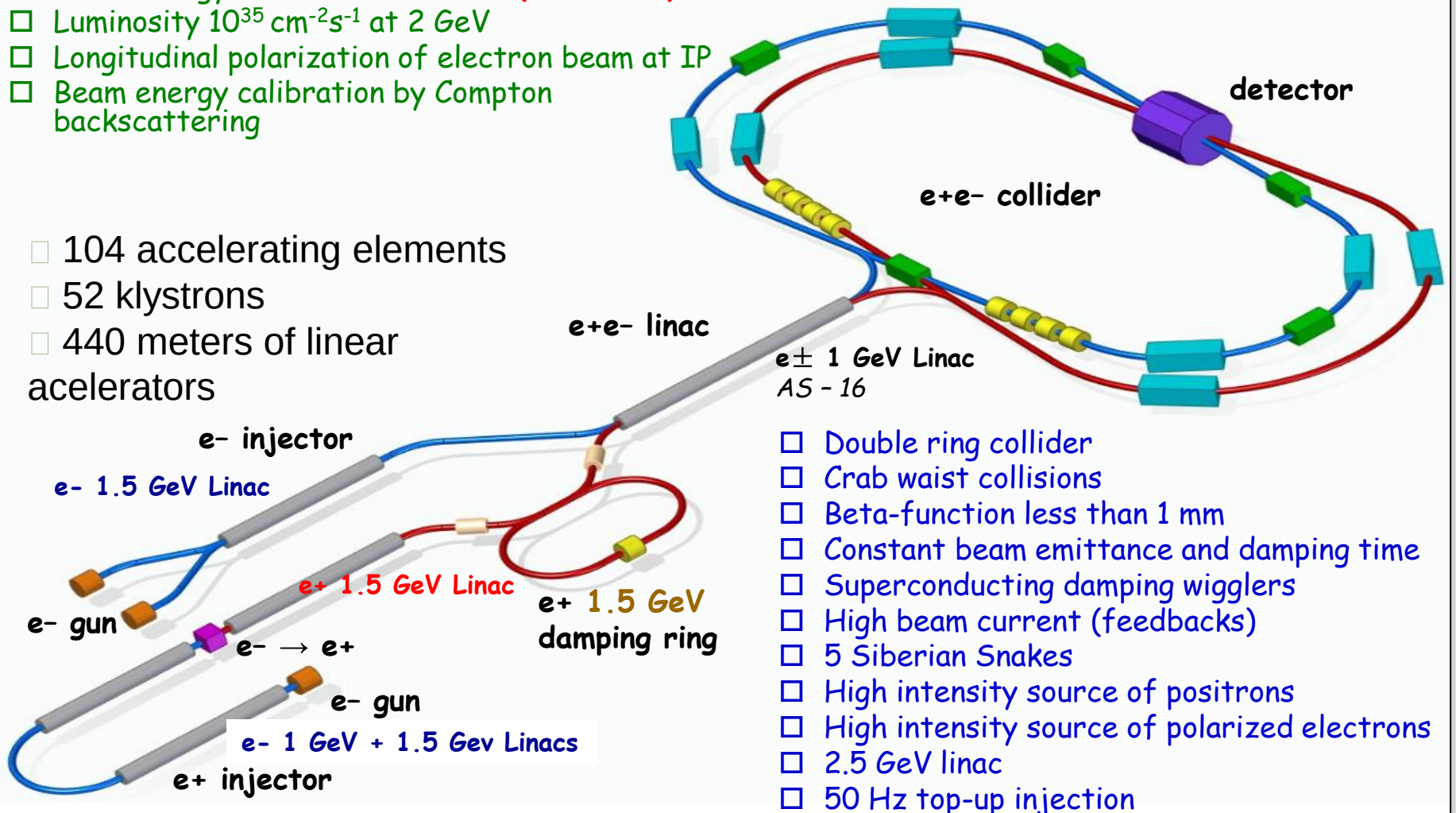
Two-photon processes

Search and study of the normal and exotic C-even states,
measurement of the σ(γγ→ hadrons), TFF measurements

e+e- -> hadrons: total cross section by scan and ISR

Layout & Solutions

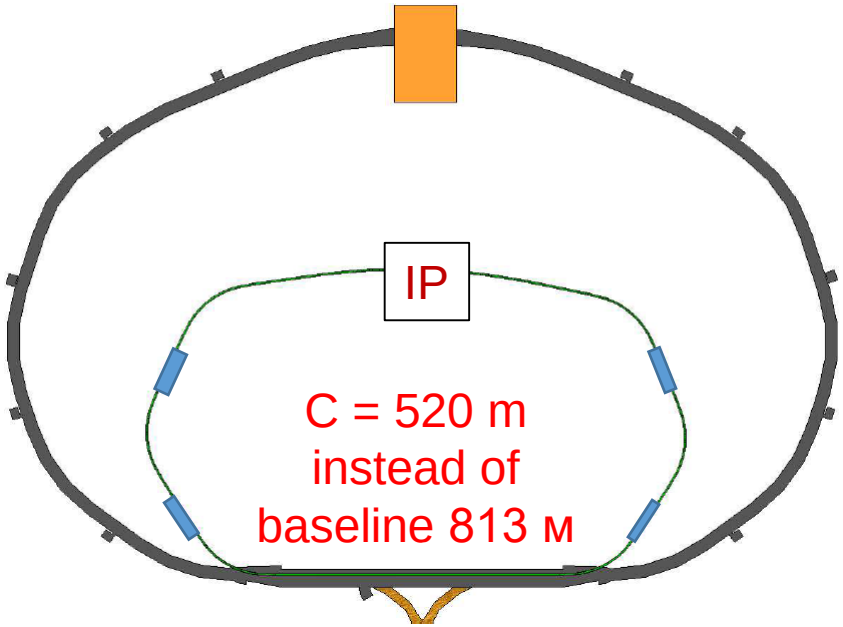
- Beam energy from 1.0 to 2.5 GeV (3.0 GeV !?)
- Luminosity 10^{35} $cm^{-2}s^{-1}$ at 2 GeV
- Longitudinal polarization of electron beam at IP
- Beam energy calibration by Compton backscattering



- 104 accelerating elements
- 52 klystrons
- 440 meters of linear acelerators

- Double ring collider
- Crab waist collisions
- Beta-function less than 1 mm
- Constant beam emittance and damping time
- Superconducting damping wigglers
- High beam current (feedbacks)
- 5 Siberian Snakes
- High intensity source of positrons
- High intensity source of polarized electrons
- 2.5 GeV linac
- 50 Hz top-up injection

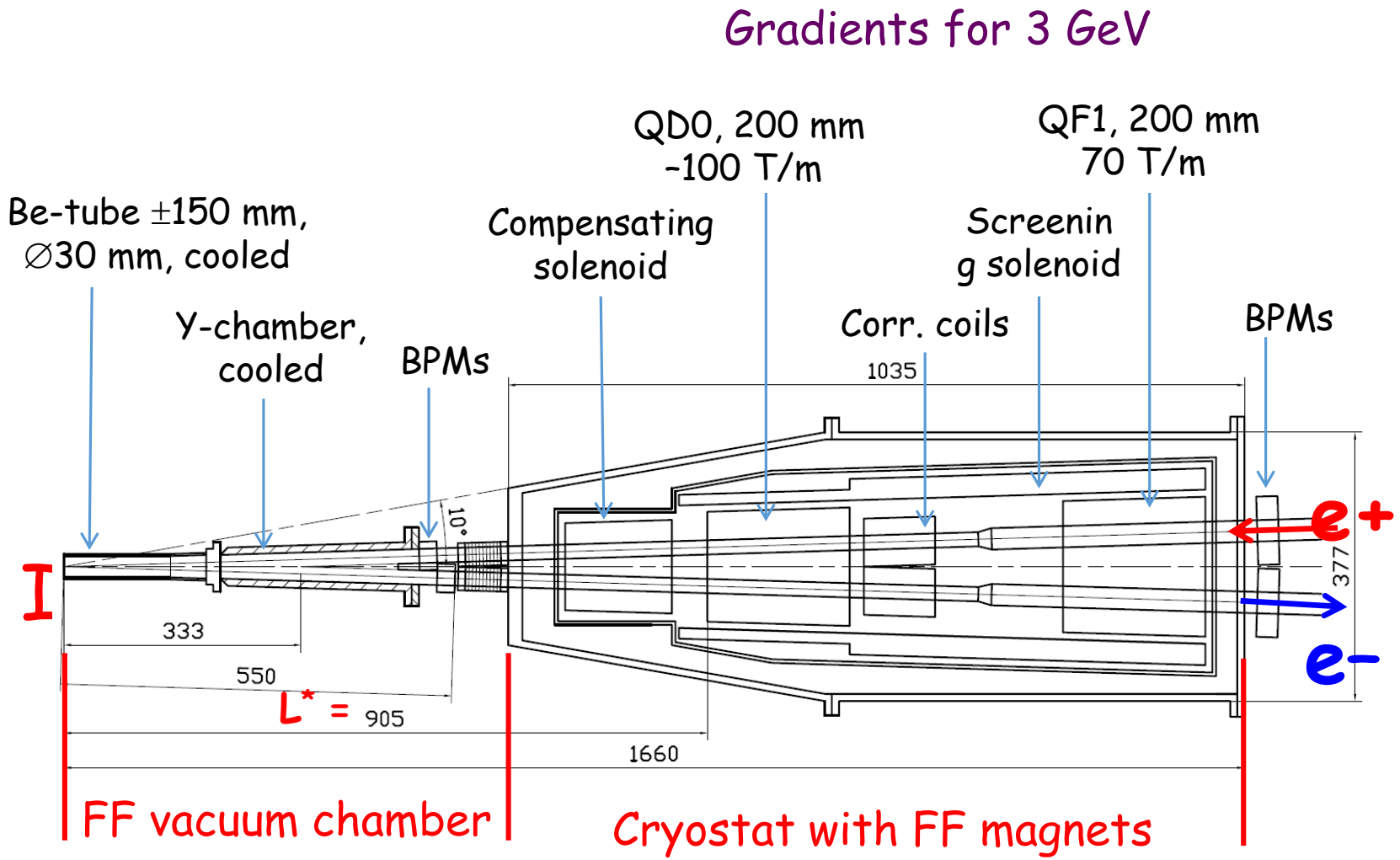
General design and characteristics



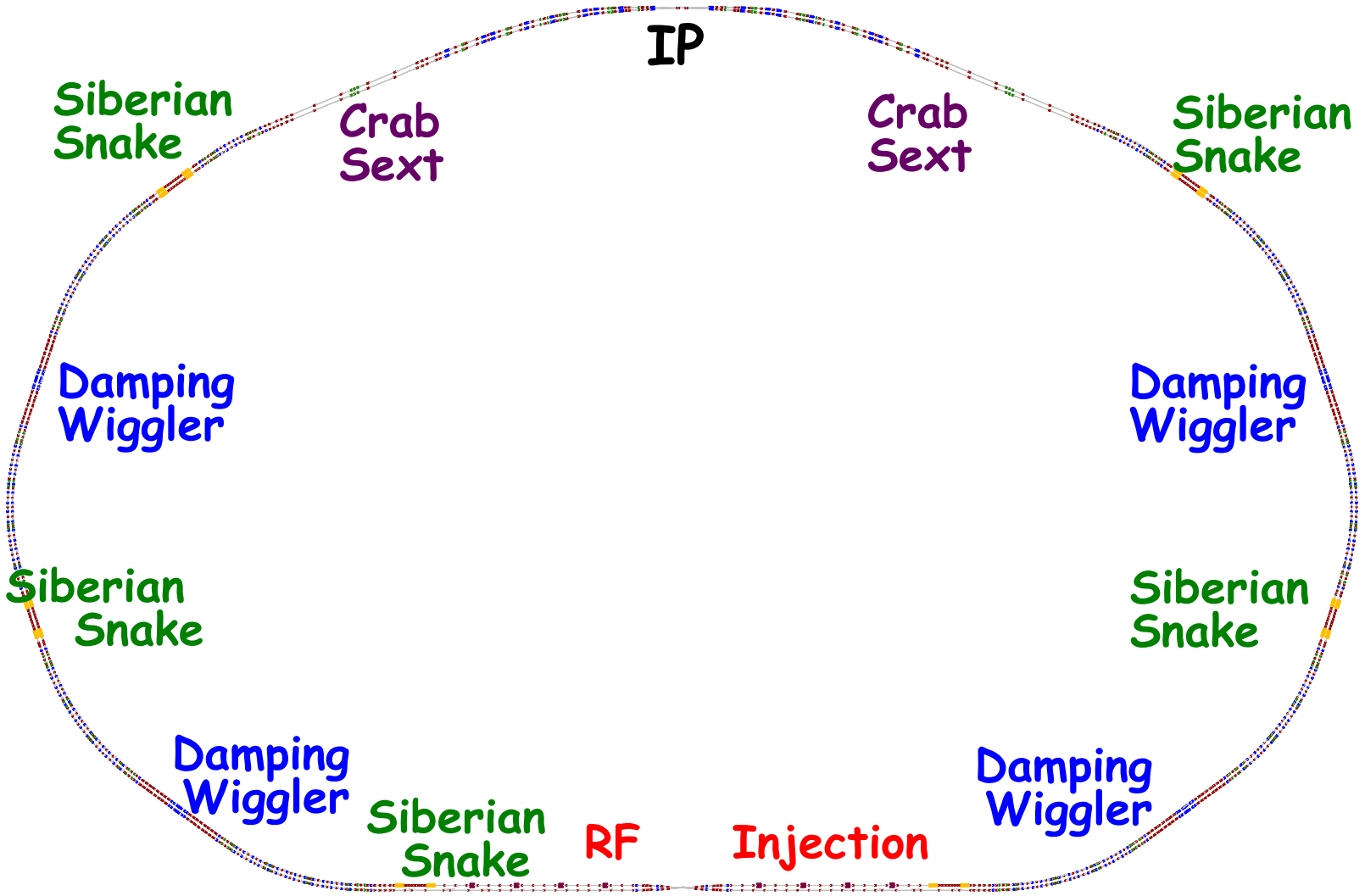
E (MeV)	1000*)	1000	2000	3000
Π (m)	522.665			
F_{RF} (MHz)	351.034			
q	612			
θ (mrad)	±30			
κ (%)	0.5			
β_x^* (cm)	5			
β_y^* (mm)	0.5			
I (A)	2.2	2.3	2.2	2.2
$N_{e/bunch}\times10^{10}$	5.5	7	6.7	9
N_b	440	360	360	270
U_0 (keV)	11	11	176	894
V_{RF} (kV)	700	700	700	1600
$\nu_s\times10^{-3}$	6.1	6.1	4.3	4.9
δ_{RF} (%)	3.5	3.5	2	1.7
$\sigma_E\times10^{-3}$	0.3/2	0.3/1.8	0.6/0.93	0.93/0.96
σ_s (mm)	3.2/13	3.2/11	6.7/10	8.8/9.1
ε_x (nm)	0.5/10	0.5/15	2.1/4.3	4.8/5/0
$L_{HG}\times10^{35}$ ($cm^{-2}s^{-1}$)	0.9	0.7	2	2.8
HG (%)	78	73	86	85
$\xi_x\times10^{-3}$	5.8	4.3	4.2	4.6
ξ_y	0.12	0.1	0.12	0.11
ϕ	15	15	20	17
τ_L (s)	1900	2600	830	620

*) Two SC wigglers with 3.5 T field amplitude and 1.5 m length in the dispersion free section reduce the horizontal damping time from 300 ms to 100 ms.

Machine-detector interface (MDI)

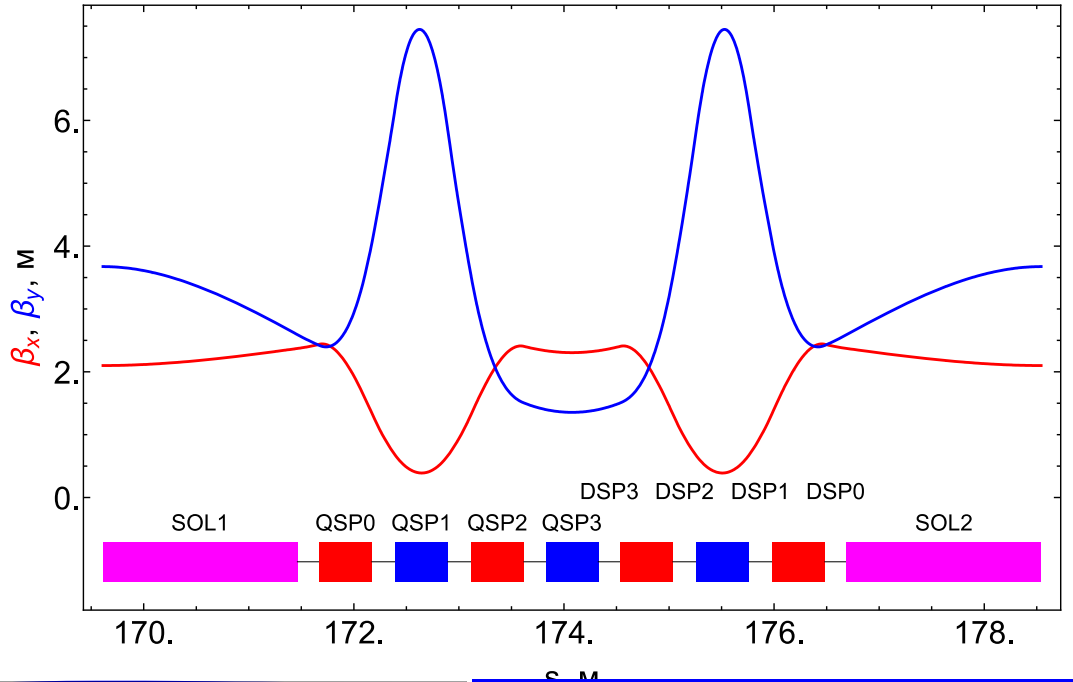


Collider

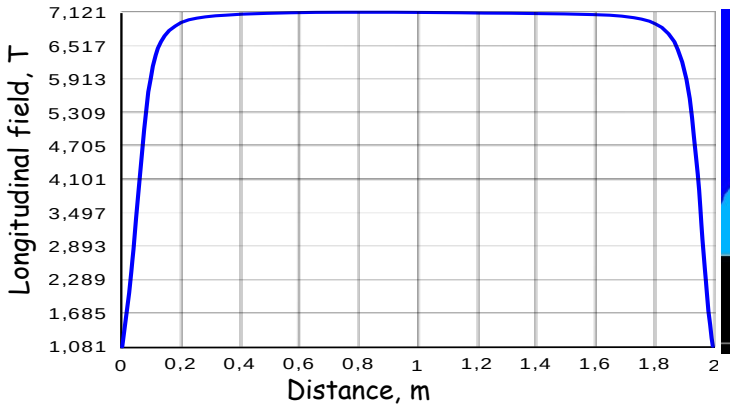

IP
Siberian Snake
Crab Sext
Crab Sext
Siberian Snake
Damping Wiggler
Damping Wiggler
Siberian Snake
Siberian Snake
Damping Wiggler
Damping Wiggler
Siberian Snake
RF
Injection

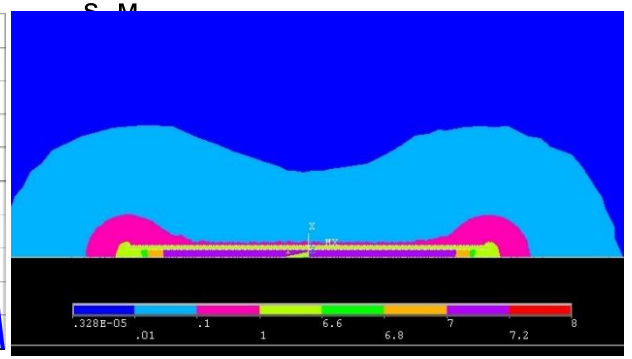
Siberian snake

7 quadrupoles
Gradient……2.6 kGs/cm
Length……50÷65 cm
Aperture……Ø76 mm

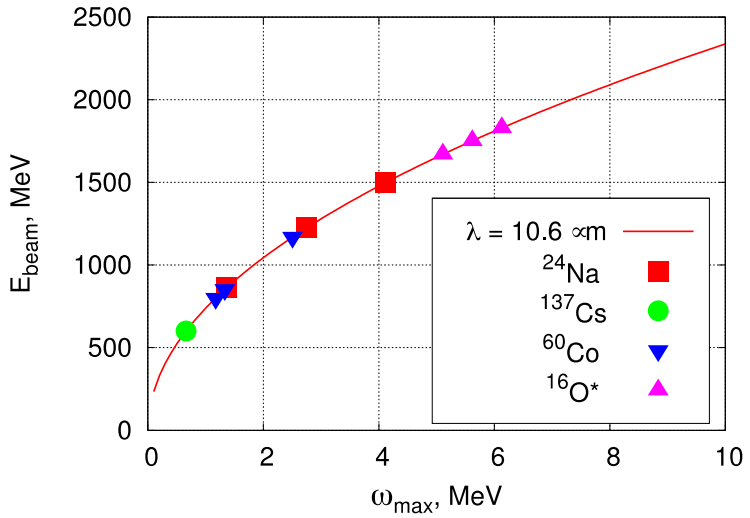


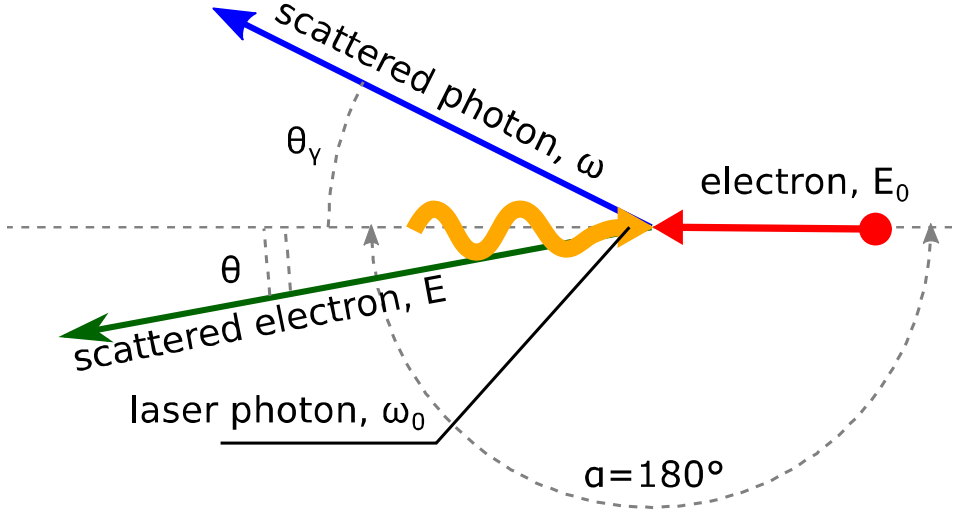
2 superconducting solenoids
Field……71 kGs
Length……1.85 m
Aperture…..Ø76 mm
Wire……220 A
Turns……50000
Wire……NbTi

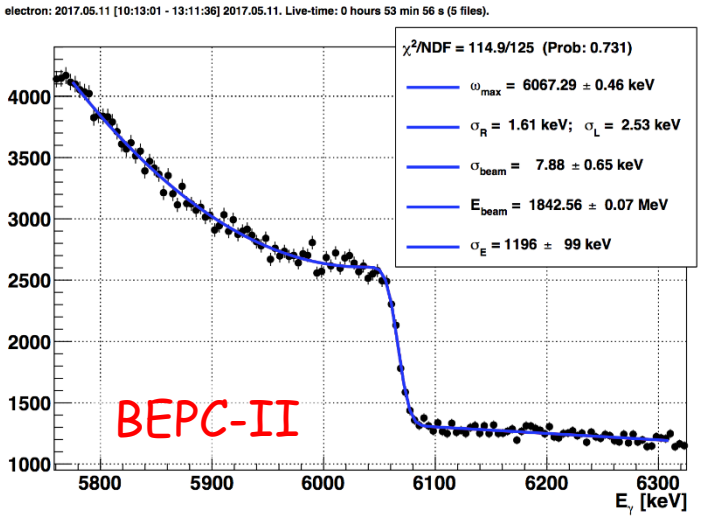


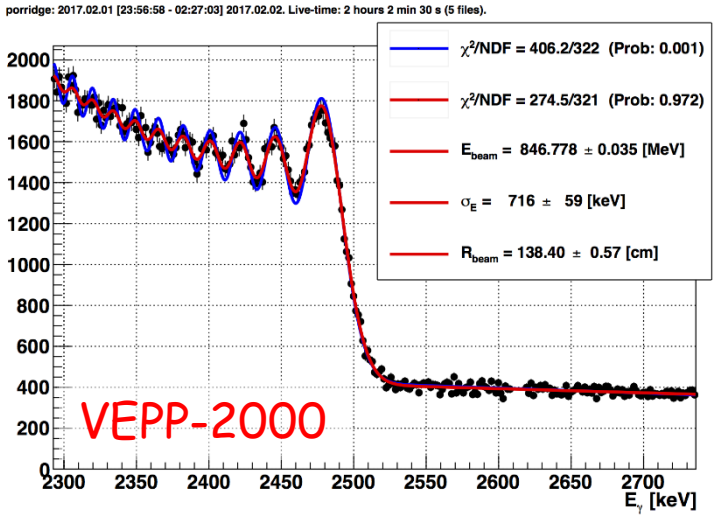


Beam Energy Measurement by Compton Backscattering

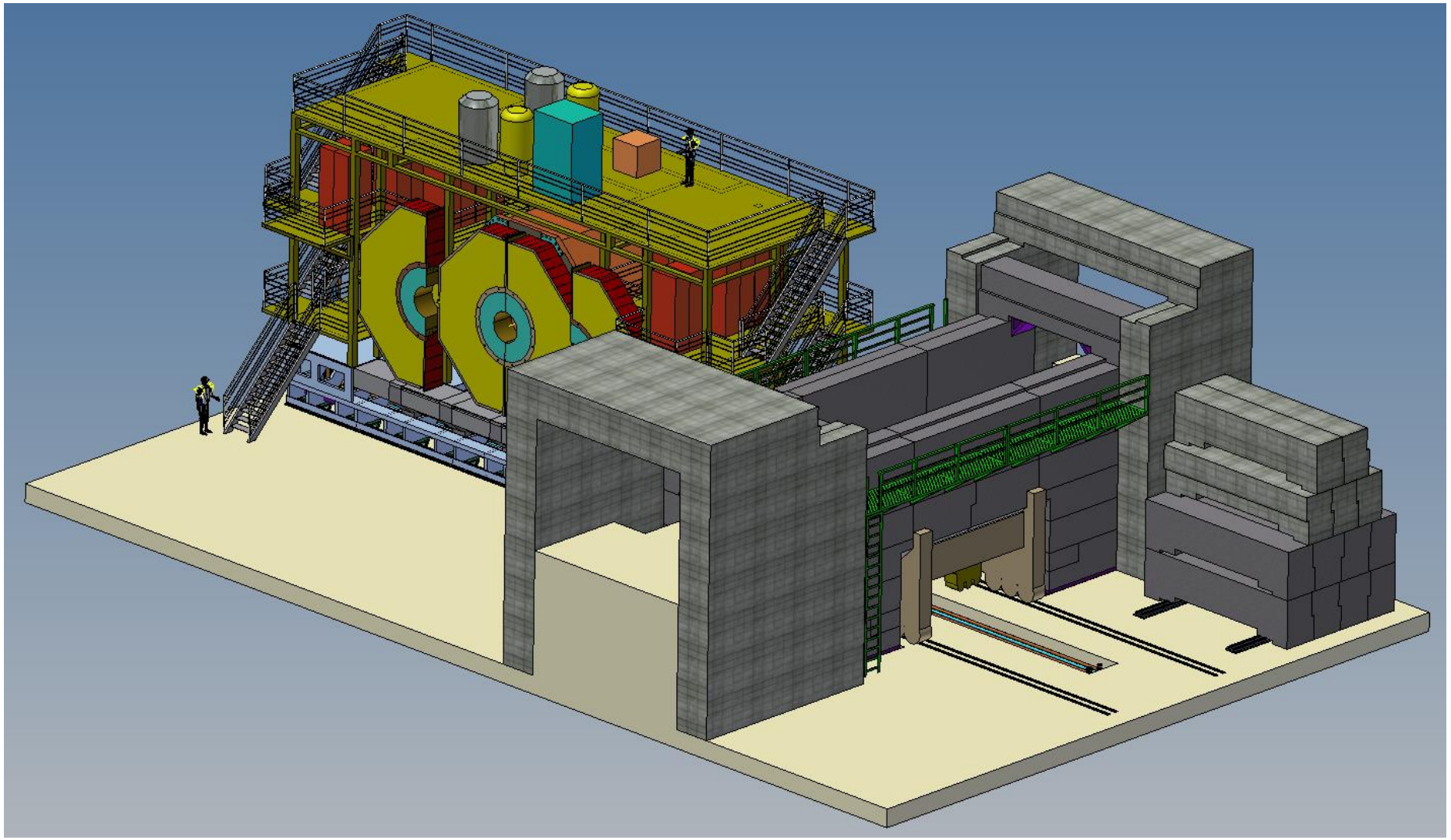








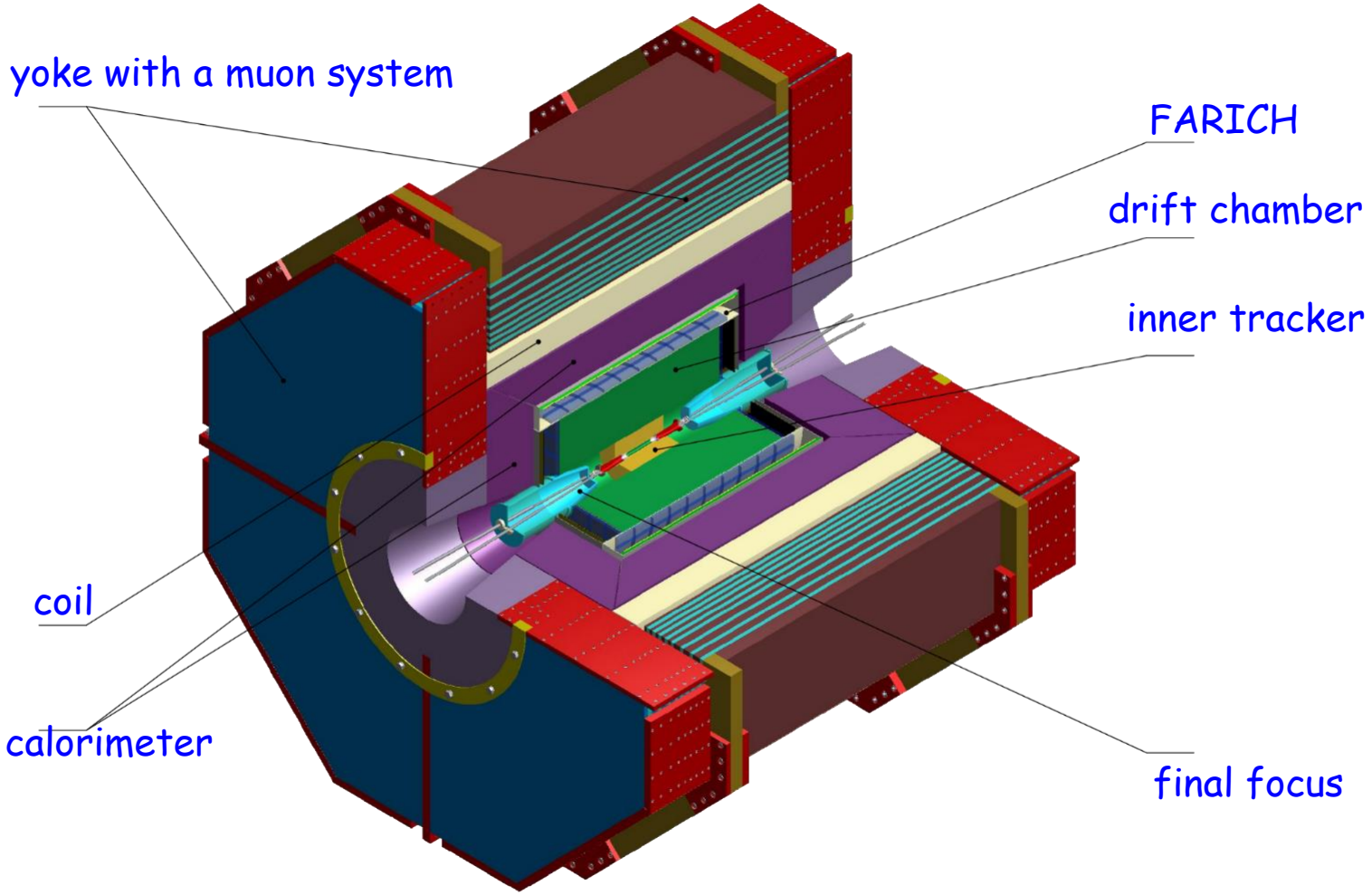
Detector



Detector

Requirements

- **Occupancy up to 300 kHz**
- **Good energy and momentum resolution**
- **High reconstruction efficiency to soft tracks**
- **Perfect π/K and π/μ separation**
- **Minimal *CP* detector asymmetry**



Inner tracker (options)

Requirements

- Reconstruction of K_S and hyperons
- Increase a solid angle of the detector up to 98 %
- Detection of particles with momentum from 50 MeV/c
- Dimensions: $R_{inner} \geq 2.5$ cm, $R_{external} \leq 20$ cm, $L \leq 60$ cm

TPC + GEM endcap redout

- 80% Ar , 20% $CO_2 \rightarrow$ 30 clusters / cm
- $\sigma_{XY} \sim 50–100$ μm
- $\sigma_Z \sim 300$ μm
- $\sigma_{dE/dx} \sim$ few %
- E = 300–400 V / cm → $V_{dr} \sim 5$cm / μs
- $P(p)_{min} \sim 55$ MeV/c

Cylindrical GEM

- Material budget ~ 1.5% X_0
- $\sigma_{XY} \leq 100$ μm / layer
- $\sigma_T \leq 7$ ns
- No $\sigma_{dE/dx}$ information
- $P(p)_{min} \sim 55$ MeV/c

Si-tracker

- 4 layers
- Material budget ~ 2.4% X_0
- $P(p)_{min} \sim 80$ MeV/c

Straw tubes

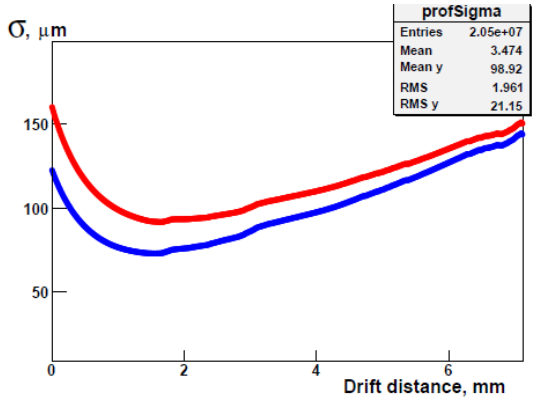
- $\sigma_{XY} \leq 100$ μm
- $P(p)_{min} \sim 55$ MeV/c
- Rate ~ 10^4-10^5 track / (cm^2/s)

Drift Chamber

Parameters

- Dimensions; $R_{in\,/\,ext}$ = 20 / 80 cm, L = 180 cm
- Small cell, drift distance < 8mm
- 10 903 cells, 29 260 field wires

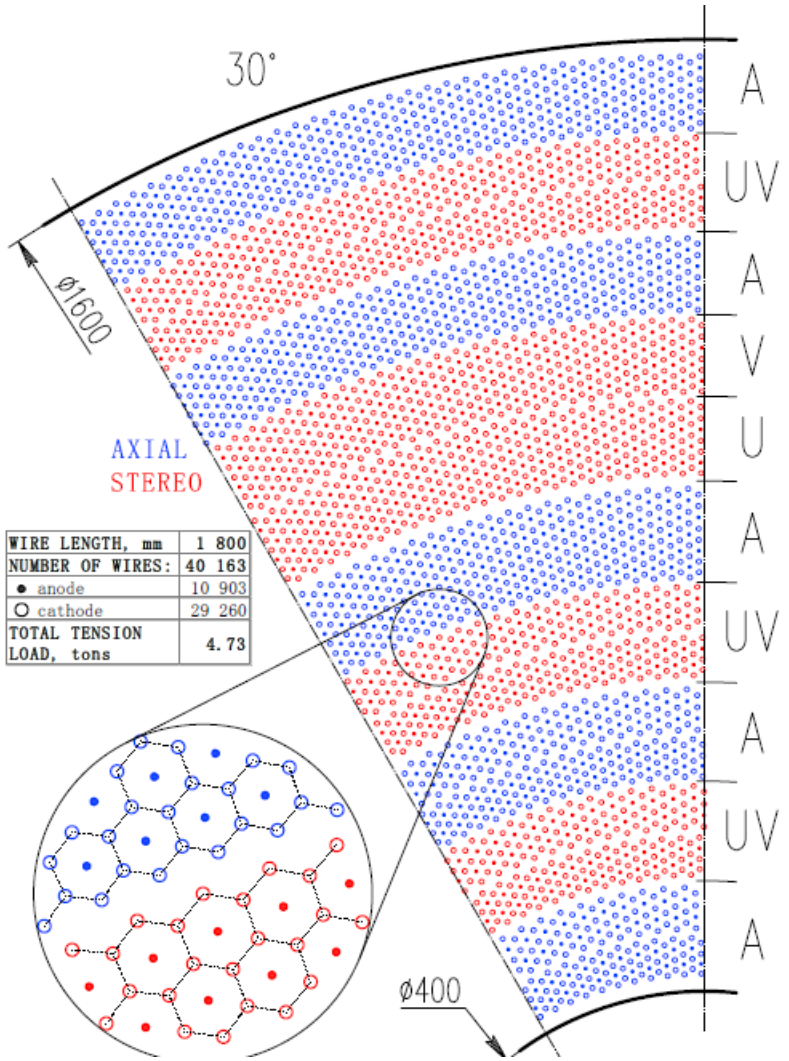
Gas mixture 60% helium, 40% propane (He/C_3H_8)
Drift time less than 350 ns (B = 1.5 T)
Designed to operate at 2100 ÷ 2200 V
expected gas gain ~ 3 · 10^4



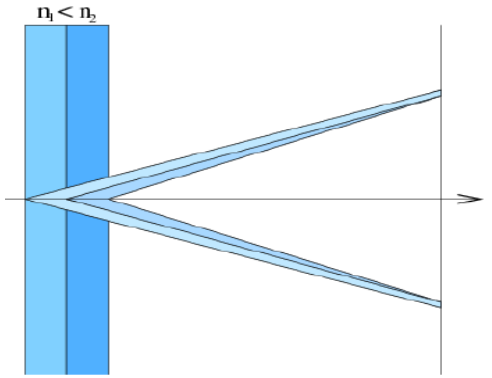
$$\frac{\sigma_{p_t}}{P_t} = \sqrt{a^2 p_t^2 + b^2}$$

a = 0.26%, at $\sigma \simeq 100\mu$m, $X/X_0 \sim 0.006$, b = 0.44%

Using inner tracker increase L, a = 0.26%→ 0.16%



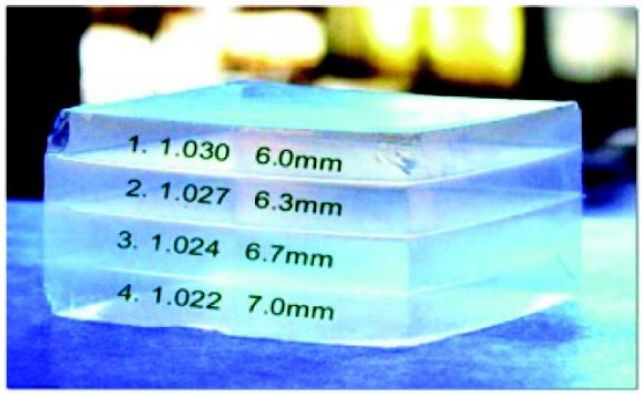
Particle Identification - Focusing Aerogel RICH or …



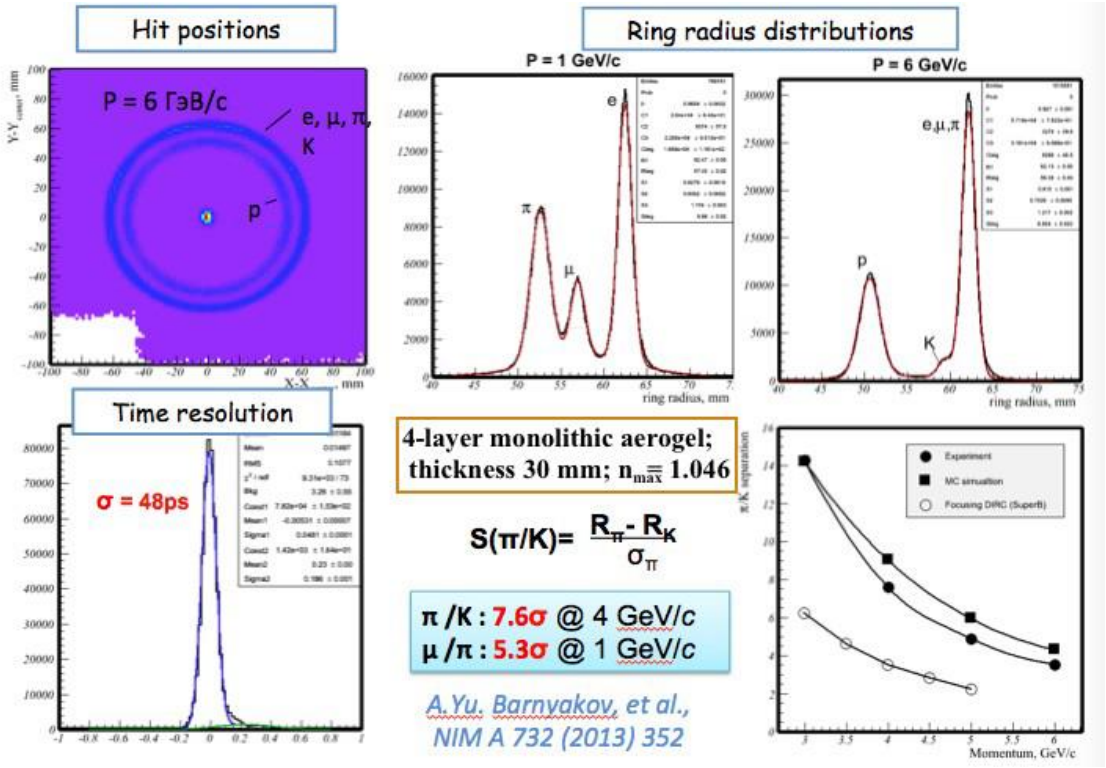
FARICH idea

Tasks

- π / K separation for P ≥ 0.6 GeV/c
- μ / π separation for P ≤ 1.2 GeV/c



- Photon detectors (3×3 mm^2):
  - Barrel – SiPMs (16 m^2)
  - Endcap – SiPM, MCP PMT?, HAPD? (5 m^2)
- 1÷2·10^6 channels (it depends on pitch)
- load 0.5÷1.0 MHz/channel
- Cooling system is needed



Calorimeter

Tasks

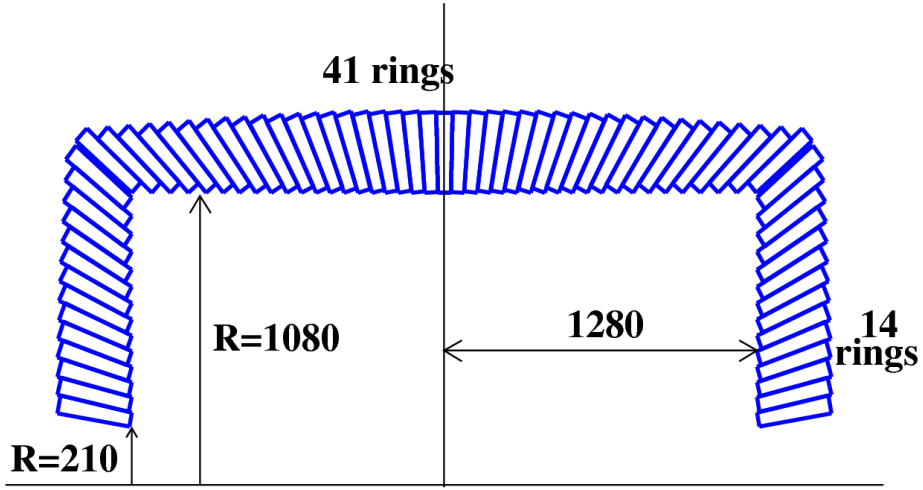
- Detection of γ from 1 MeV to 2 GeV
- Good energy and spatial resolution
- Separation of electrons and hadrons
- Trigger formation

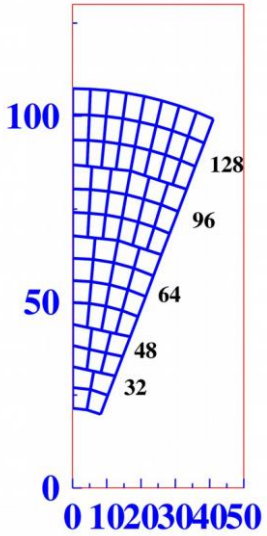
Expected parameters (pure CsI)

- σ_E/E =1.8% at 1 GeV
- σ_z ~ 6mm / $\sqrt{E(GeV)}$
- 16-18 $X_0 \rightarrow$ 30-34 cm
- τ ~ 30ns (1μs for CsI(Tl))
- 5248 crystals → 26-31 tones
- Photodetectors: Photopentodes, APD or SiPM (+ WLS)

	ρ, g/cm^3	X_0, cm	$\lambda_{em,}$ nm	n($\lambda_{em,}$)	N_{ph}/MeV	τ, ns
CsI(Tl)	4.51	1.85	550	1.8	52000	1000
Pure CsI	4.51	1.85	305		2000-5000	20/1000
BGO ($Bi_4Ge_3O_{12}$)	7.13	1.12	480	2.1	9000	300
$LaBr_3$(Ce)	5.1	1.95	380	1.9	63000	30
LSO (Lu2SiO5:Ce)	7.41	1.14	420	1.8	27000	40
LYSO ((Lu,Y)2SiO5:Ce)	7.1	1.20	400	1.8	33000	30
LuAP $LuAlO_3$(Ce)	8.34	1.08	365	1.9	20500	20
GSO (Gd2SiO5:Ce)	6.71	1.37	440		8000	40
GAGG (Gd3Al2Ga3O12(Ce))	6.63	1.59	520		46000	90

Super C-Tau calorimeter layout

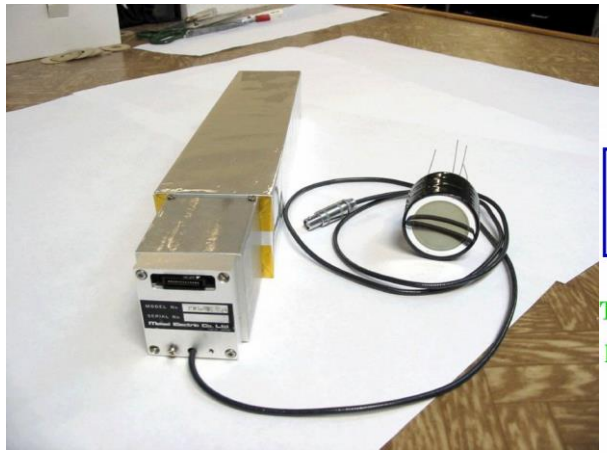


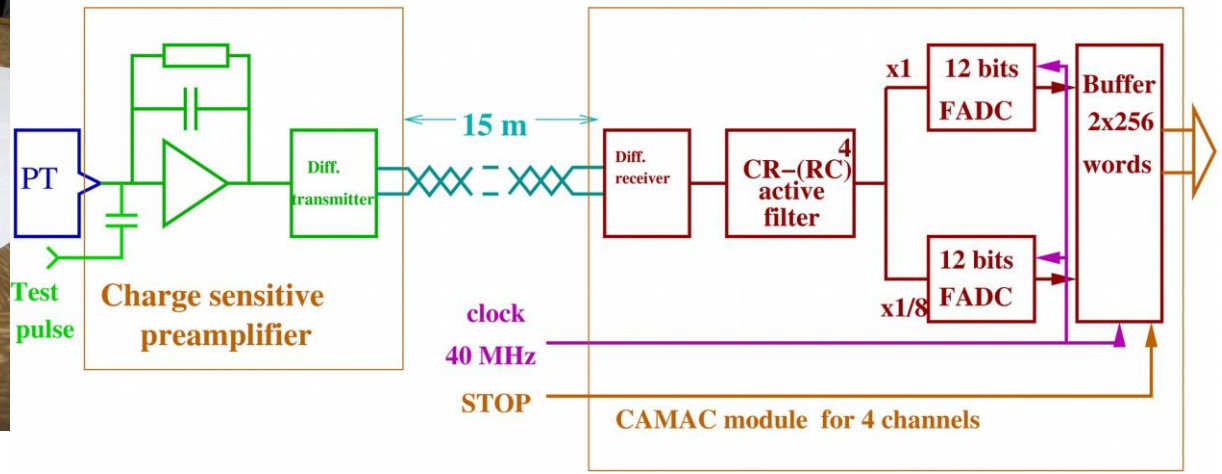


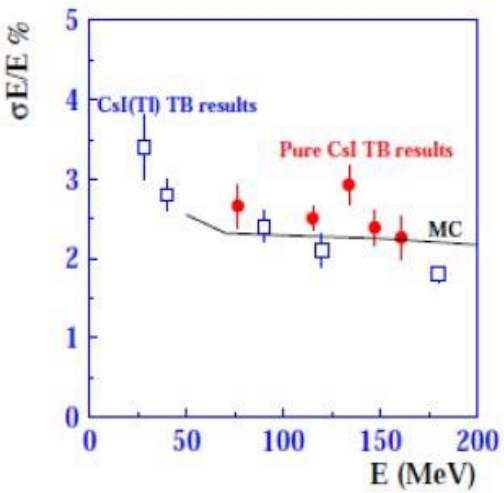
Crystal of truncated pyramidal form (small facet ~(5.5 x 5.5) cm2) with the length of 30/34 cm (16/18 X0)

- The barrel part includes 5248 counters = 41 θ-rings x 128 counters, total weight is 26/31 tons
- Two endcap parts: 2 x 16 sectors x 68 = 2 x 1088 = 2176 counters, total weight is 10/12 tons
- The whole calorimeter: 7424 counters with the total weight of 36/43 tons

CsI(pure)+PP option (I)

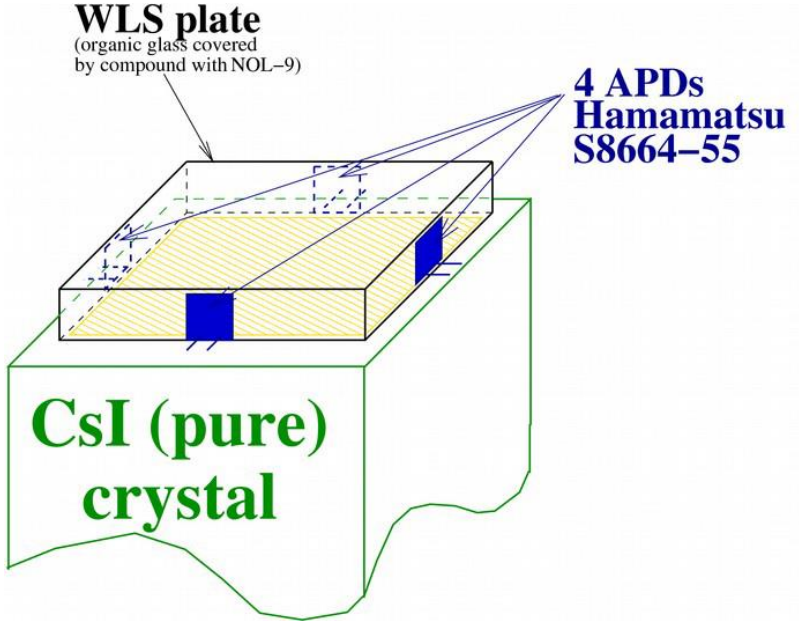


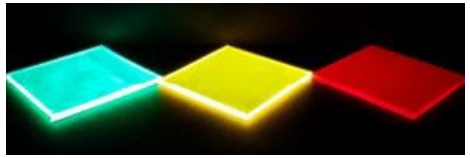


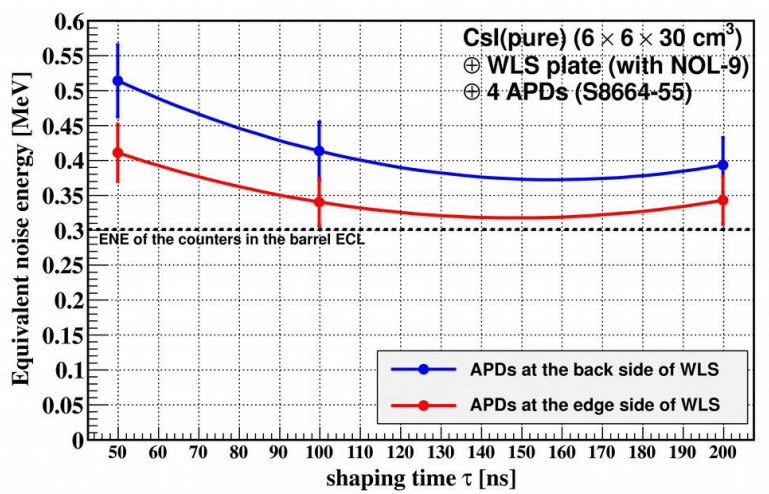


Due to the drop of the signal in magnetic field of 1.5 T by a factor of ~3, the ENE = 150 keV for B = 1.5 T

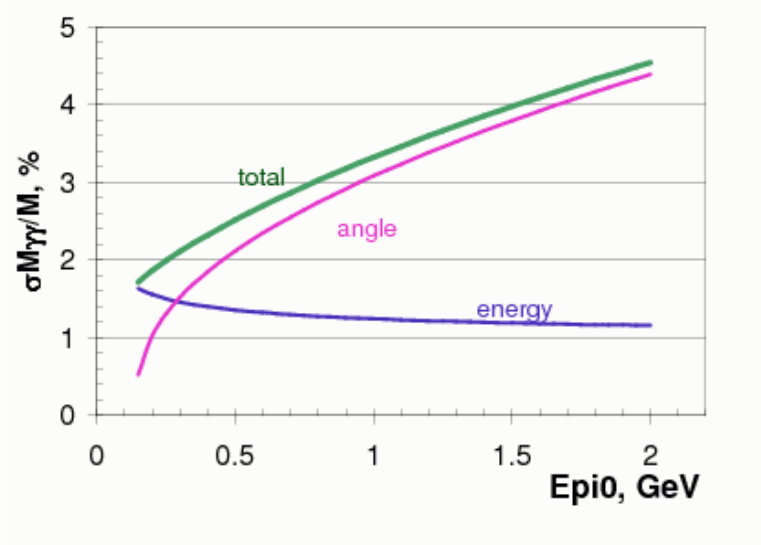
CsI(pure)+WLS+4APD option (I)





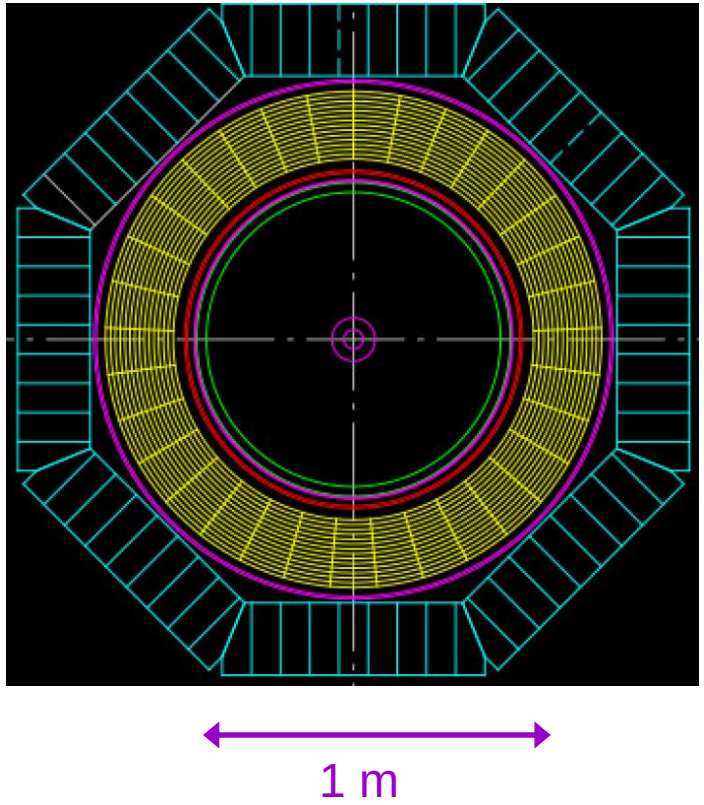


Combined liquid-crystal calorimeter?



Liquid Xenon calorimeter 5.4X_0
CsI(Tl) crystal calorimeter 8.1 X_0
Full width 13.5X_0,
sE/E = 3.6% at 1 GeV
Coordinate resolution 2*mm*
Passive material between calorimeters 0.25X_0
Passive material in front of LXe 0.35X_0

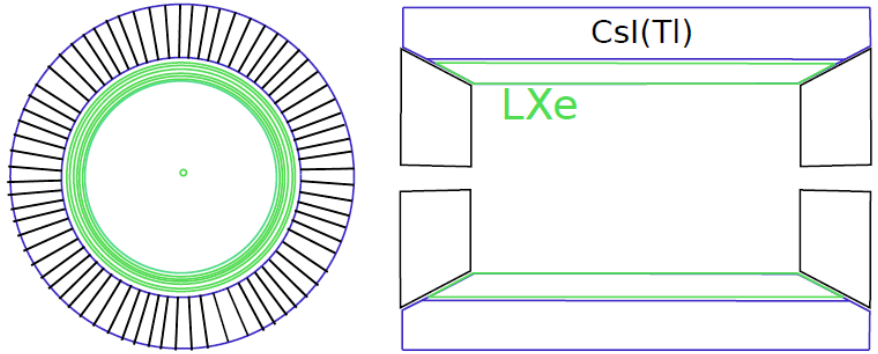
Barrel calorimeter of CMD-3 detector



LXe option for C-Tau factory

- **Excelent spatial resolution, better than 1mm (0.06)**
- **Reconstruction of the point of converstion -quanta to *e*+*e*− pair**
- **Electromagnetic shower profile reconstruction**
- **Time resolution of about 1 ns with towers**
- **Pileup noise suppression due to fine radial segmentation:**
- **Strip area 75*cm*2, pile-up rate 0.2 *MHz* per channel (2*MHz* for crystals option)**
- **Crystals with long scintillation time as CsI(Tl) may be used behind the LXe calorimeter**
- **Additional information of dE/dx per layer for particle identification**

Combined calorimeter



Width 11 – 15 cm (3 – 5 X_0) +
19 cm CsI
mass 5 – 7 ton
Xe cost (2-5 $/g): 10 – 25 M$
crystals cost : 15M$
20, 000 channels of electronics

Muon ID (μ /hadron-separation)

Parameters

- Barrel – 9 layers in the yoke (64% of 4π)
- Endcap – 8 layers in the yoke (30% of 4π)
- Stotal ~ 1000 m^2

Current detectors

- BaBar 64% efficiency, 2% p fake rate at 0.5 – 2 GeV/c
- BaBar 90% efficiency, 2% p fake rate for P > 1 GeV/c
- KEDR 95% efficeincy, 5% p fake rate for P > 1 GeV/c

Pion fake rate must be suppressed by factor 100. It is necessary to use an additional system, e.g. FARICH, TOF with σ_T < 30 ps.

Gas tubes

- Used by SND, KEDR, PANDA
- ageing? Rate capability?

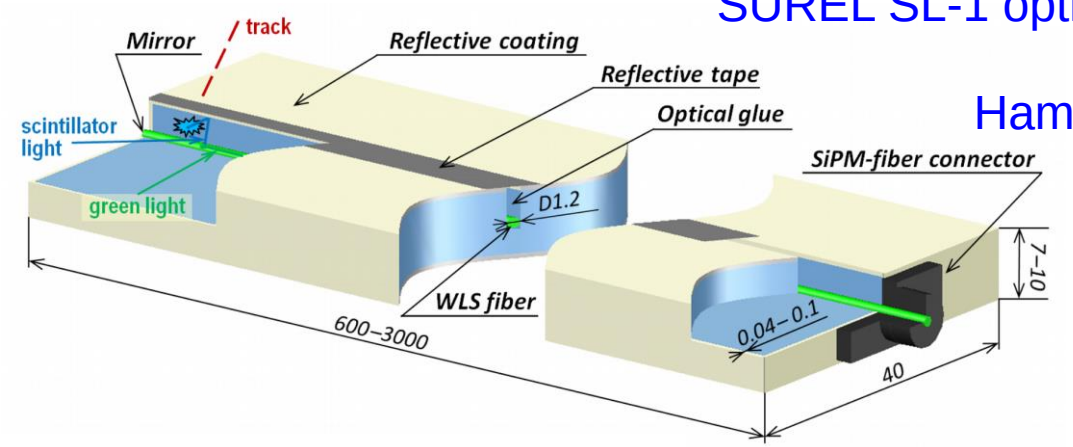
RPC

- Used by BaBar, Belle
- Ageing, complex electronic required

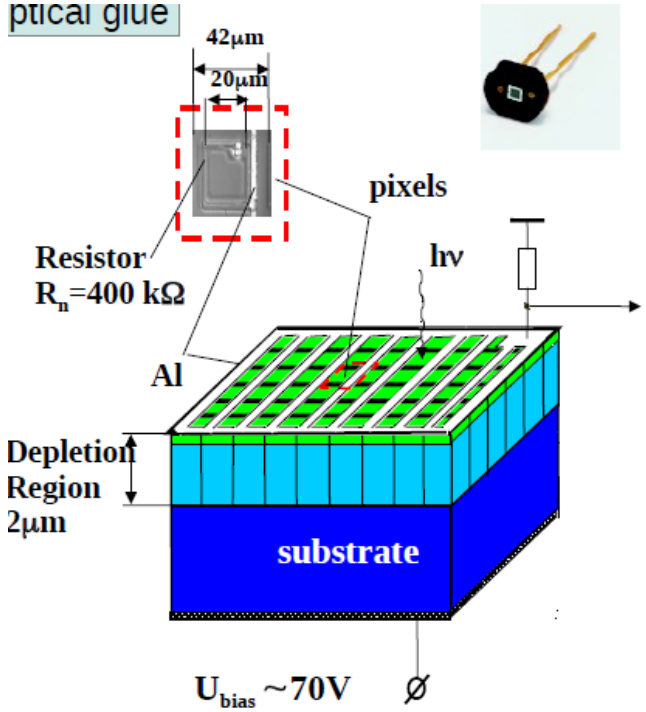
Scintillator - WLS - SiPM

"Uniplast" polystyrene strips

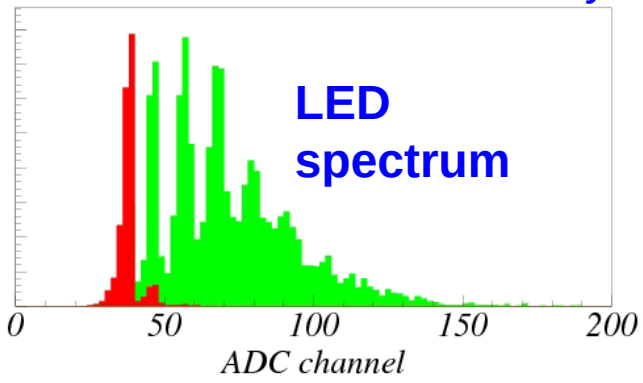
SUREL SL-1 optical glue



Hamamtsu MPPC S10362-13-050



Kuraray WLS Y-11(200)MSJ



Status of the project

- **Detailed physics program is developed.**
- **CDR was issued in 2011 and updated in 2017.**
- **R&D for accelerator and detector is in progress.**
- **Preliminary civil engineering and infrastructure design is completed.**
- **CERN, IHEP, INFN, KEK and other organizations expressed their interest in the project.**
- **By the end of 2019 we have to present the TDR (may be not final version)**
- **Now we have to form the international collaboration that is certainly required to apply for funding.**

Conclusion

- **A few generations of colliders and detectors successfully operated at Budker INP with world-wide recognized contributions to particle physics**
- **Experiment on Super c-τ factory has rich physics program which is complementary to Belle II and LHCb**
- **Physics program is developed.**
- **CDR was issued in 2011 and updated in 2017.**
- **Project is supported (not funded yet) by Russian government, R&D is ongoing**
- **Budker INP successfully collaborates in many outstanding experiments in other lab's and we hope our colleagues will join to SCTF project**