Tau and Charm physics at a Super c/τ factory

Bondar A.

Budker INP, Novosibirsk

Physics at τ-charm factory

- Precision charm physics
  - Precision charm$\rightarrow$ precision CKM (strong phases, f_D, f_{Ds} …)
  - High sensitivity search for rare processes (rare D & Λ_c decays, CPV, mixing)
- Precision τ-physics with polarized beams
  - Lepton universality, Lorentz structure of τ-decay…
  - CPV
  - LFV decays
  - Second class currents
- High statistic spectroscopy and search for exotics
  - Charm and charmonium spectroscopy
  - Light hadron spectroscopy in charmonium decays ($N_{J/\psi}$~10^{12})

Facility key features and principles

- Two rings with a single interaction point
- Nano Beams + Crab waist collision
- SC wigglers to keep the same damping and emittance in the whole energy range (optimal luminosity ~10^{35})
- Polarized e- injector and spin control to get the longitudinally polarized electron beam at IP

Advantages of near threshold production

- Particle multiplicity at 3.77 GeV is about two times lower than at 10.6 GeV
- Two body production $e^+e^-\to D\bar{D}$. This allows to use double tag method:
    - fully reconstruct one D
    - then either fully reconstruct the other D (absolute branching ratios)
    - or look for events with one missing particle (leptonic, semileptonic decays)
- Coherent production of D pairs allows to use quantum correlations for D-meson mixing and CP violation studies

Polarization

If even one beam polarized, τ almost 100% longitudinally polarized near the threshold

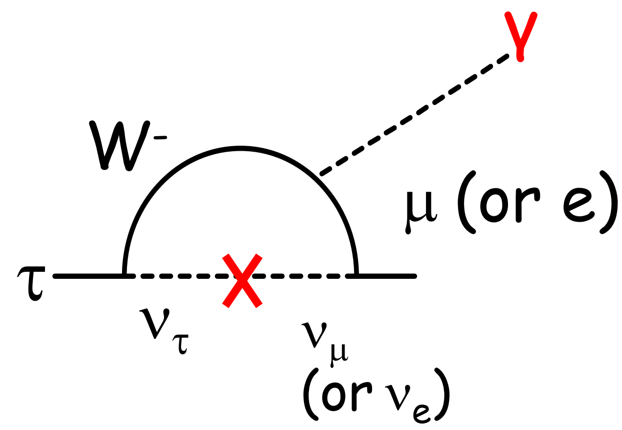
- Michel parameters
- CP-violation in τ-decays and/or Λ_C

- CP-violation $\rightarrow$ new physics, charged Higgs
- Two amplitudes with different weak and strong phases
- Observables
  - Rate asymmetry: $\Gamma(\tau^+ \rightarrow f^+) - \Gamma(\tau^- \rightarrow f^-) \sim \sin\delta \, \sin\phi$
  - Triple product asymmetry (T-odd) $\sigma \cdot (p_1 \times p_2)$ $T_+ - T_- \sim \cos\delta \, \sin\phi$
- For complete description of matrix element , polarization and direction of τ should be known
  - Polarization may increase sensitivity by several times

Lepton flavor violation (LFV) in charged lepton

⇒negligibly small probability in the Standard Model (SM) even including neutrino oscillation

- Br($\tau \to \ell\gamma$) < O(10^{-54})



Why SM + m_ν prediction is so small ?

$$Br(\tau \to \mu\gamma) = \frac{3\alpha}{32\pi}\left|\sum_{i=1,2} U^*_{\tau i} U_{\mu i} \frac{\Delta m^2_{li}}{m^2_W}\right|^2 < 10^{-54}$$

U : PMNS neutrino mixing matrix

⇨ $\Delta m^2_{ij} = m^2_{\nu i} - m^2_{\nu j}$:Neutrino mass square difference

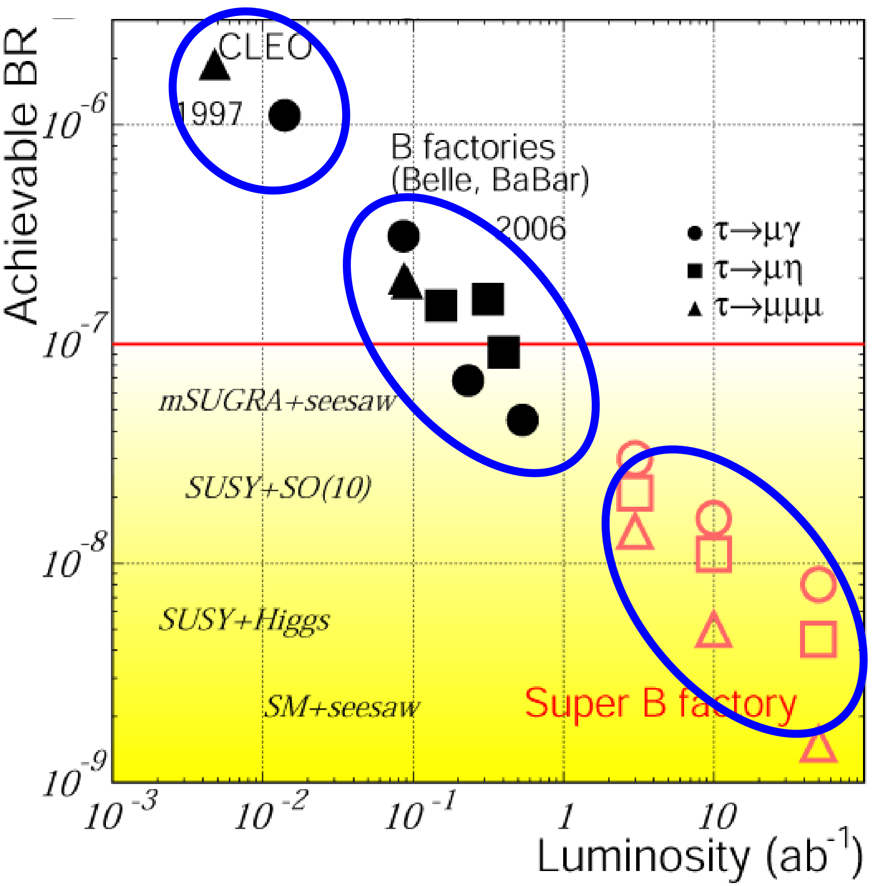
-Lepton Flavor is conserved accidentally.

-If O(1TeV) particles exit, Br is enhanced significantly, Theory needs some suppression mechanism.

-Almost all Beyond Standard Model predict LFV

LFV decays

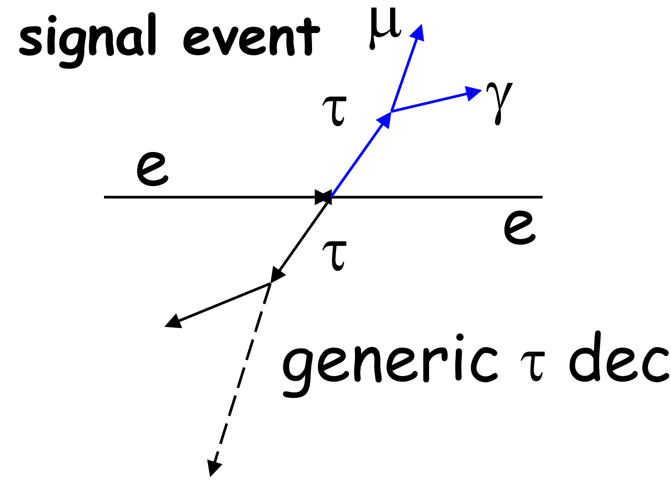
Super-B, 75 ab^{-1}
7×10^{10} τ-pairs



- $\tau\to\mu\gamma$ decay
- Current limit: ~ 3×10^{-8} by Belle with 7×10^{8} $\tau\tau$
- At Υ(4S):
  - ISR background $e^+e^-\to\tau^+\tau^-\gamma$
  - Upper Limit $\propto 1/\sqrt{L}$
- tau-charm factory with 10^{10} $\tau\tau$ may have better sensitivity

Some details of $\tau \to \mu + \gamma$ search

- $e^+e^- \to \tau^+\tau^-$
  - → 1 prong + missing (tag side)
  - → $\mu+\gamma$ (signal side)



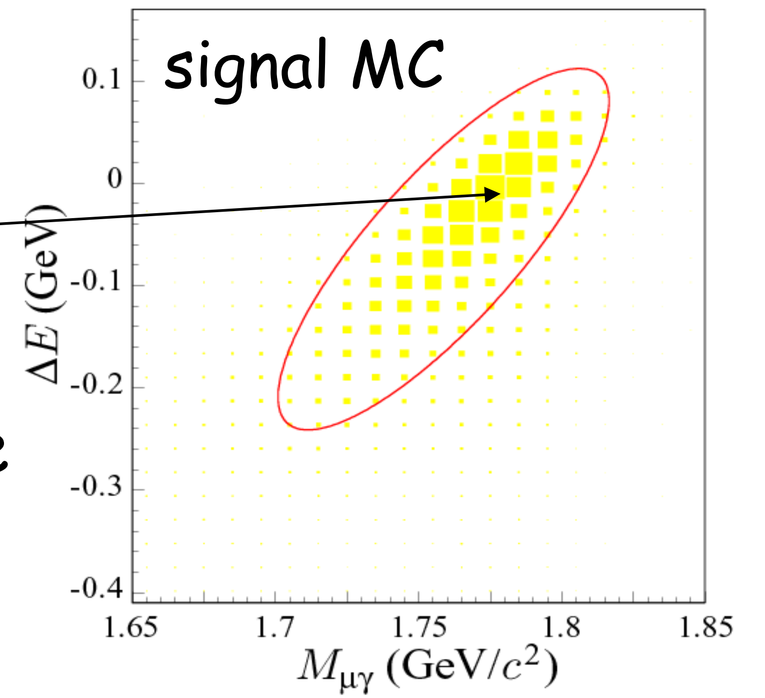
-Tag side is not muon.

$$M_{\mu\gamma} = \sqrt{(E_{\mu\gamma}^2 - p_{\mu\gamma}^2)}$$

$$\Delta E = E_{\mu\gamma}^{CM} - E_{beam}^{CM}$$

for signal event

$$M_{\mu\gamma} \sim m_\tau, \Delta E \sim 0$$



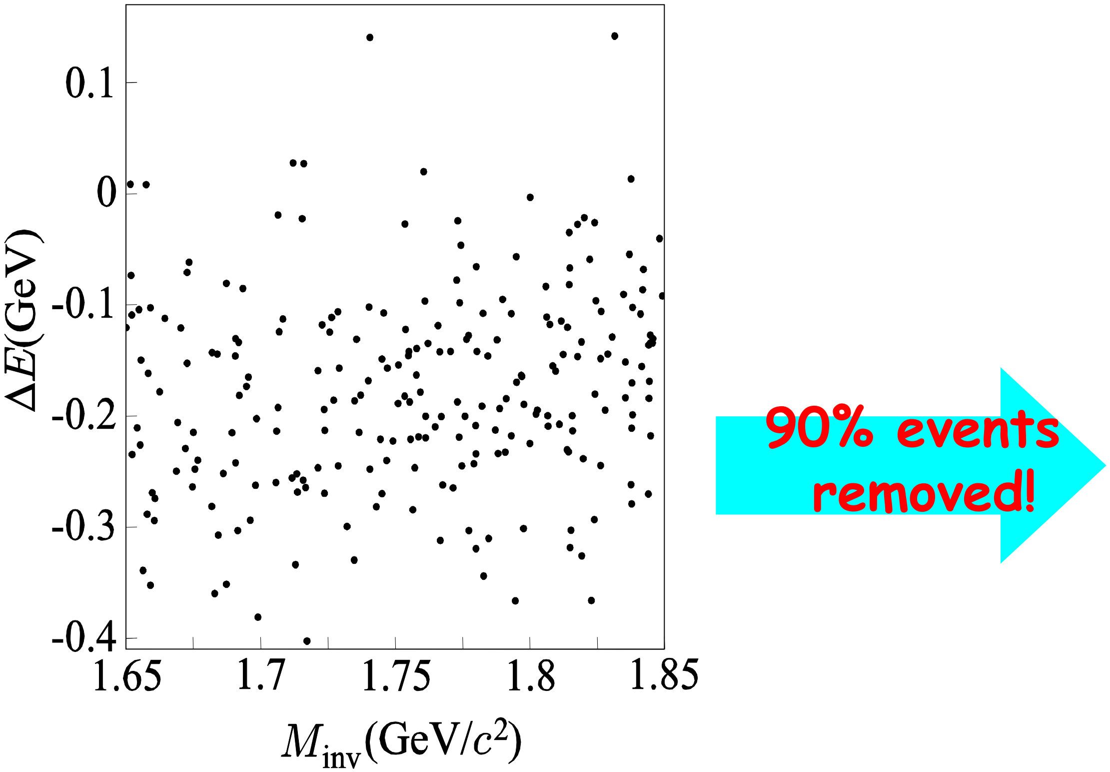
signal extraction: $M_{\mu\gamma}$–ΔE plane

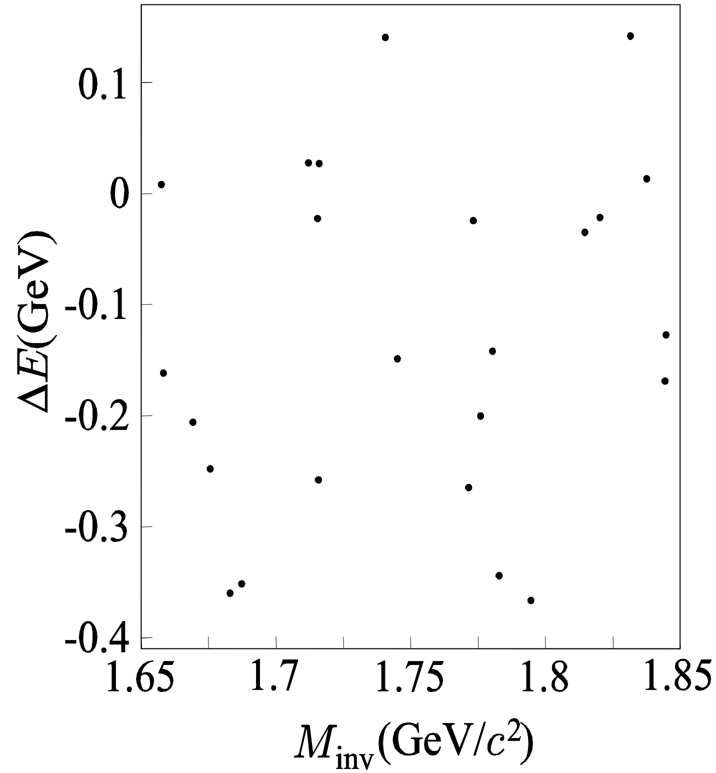
- blind analysis

$\tau\tau\gamma$ BG events in $\tau \to \mu\gamma$ analysis

If we can remove BG events caused by ISR completely…

1.5 ab^{-1} generic $\tau\tau$ MC sample removed by MC generator info.





When we run an accelerator with lower energy than Υ(4s), Can we reduce these ISR BG events?

H.Hayahii 2008

ISR Spectrum

At near threshold

- $E\gamma$ for $ee \to \tau\tau\gamma$ background cannot be as high as $E\gamma$ for $\tau \to \mu\gamma$.
- Background from $ee \to \mu\mu\gamma$ will become more important.

  → good MUID is essential.

$E\gamma$ (CMS) from $\tau \to \mu\gamma$ and ISR($\tau\tau\gamma$)

$\Upsilon(4s)$

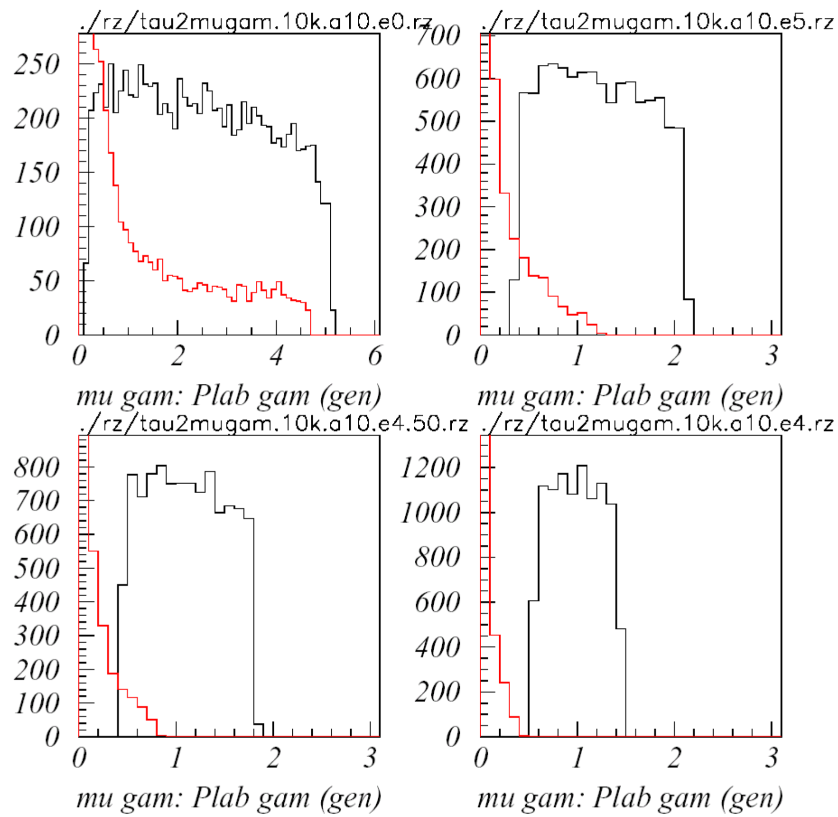
$\sqrt{s} = 10.58GeV$

$\sqrt{s} = 5.0GeV$

maximum σ

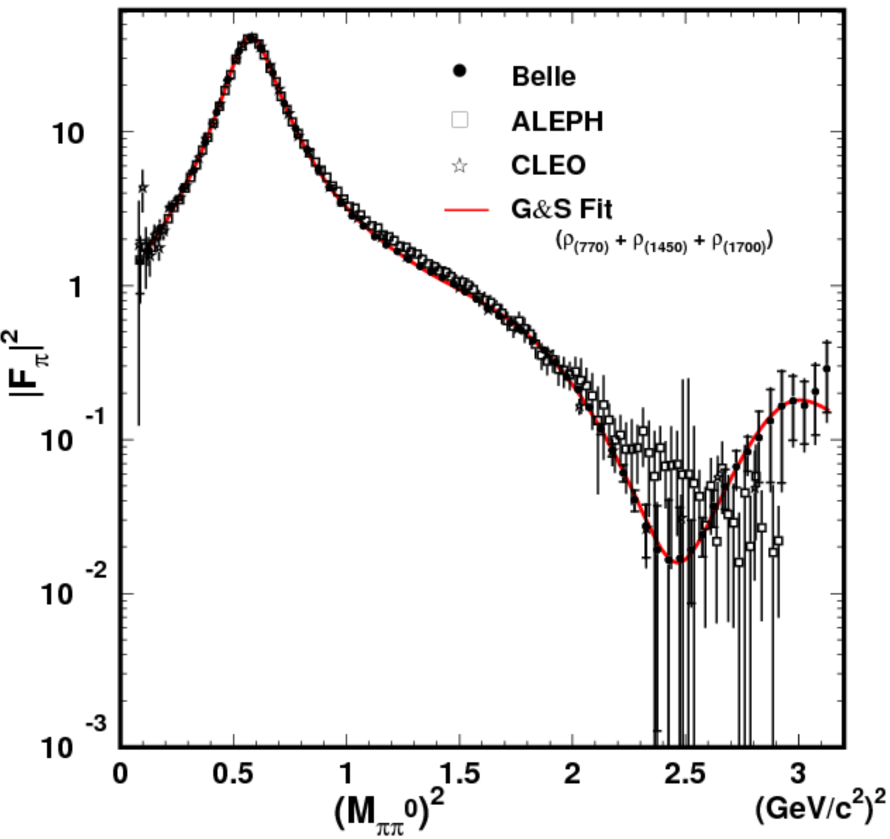
$\sqrt{s} = 4.25GeV$

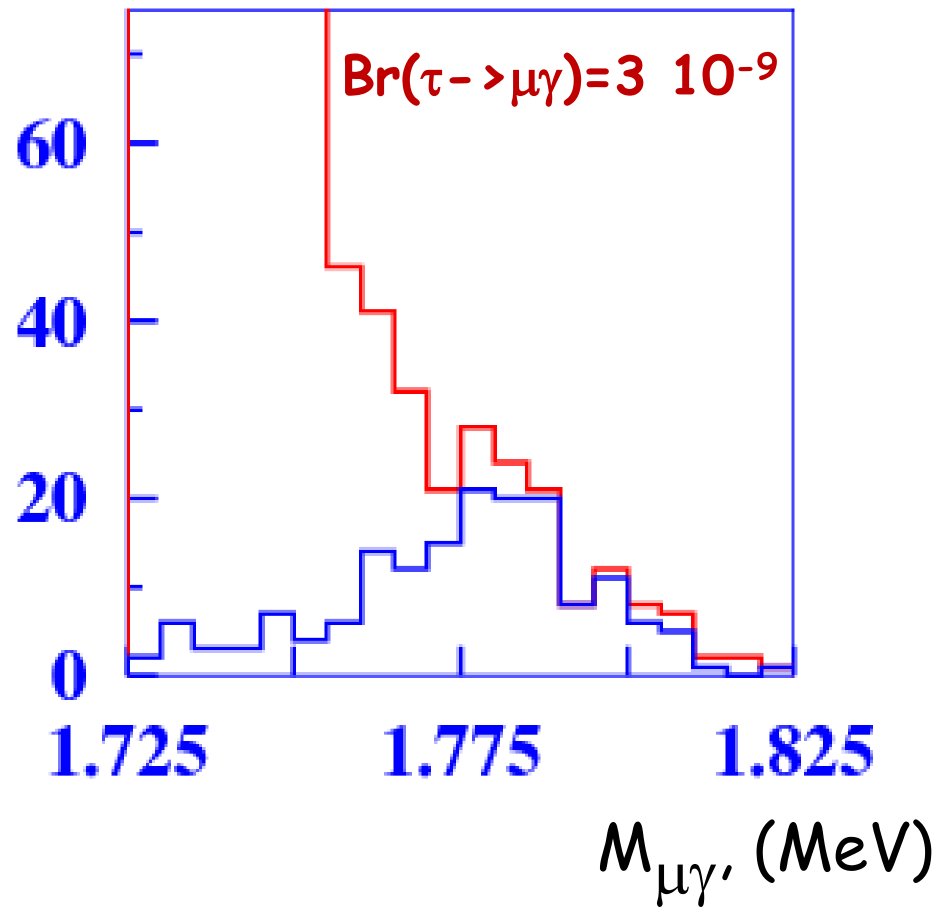
$\sqrt{s} = 4.0GeV$



H.Hayahii 2008

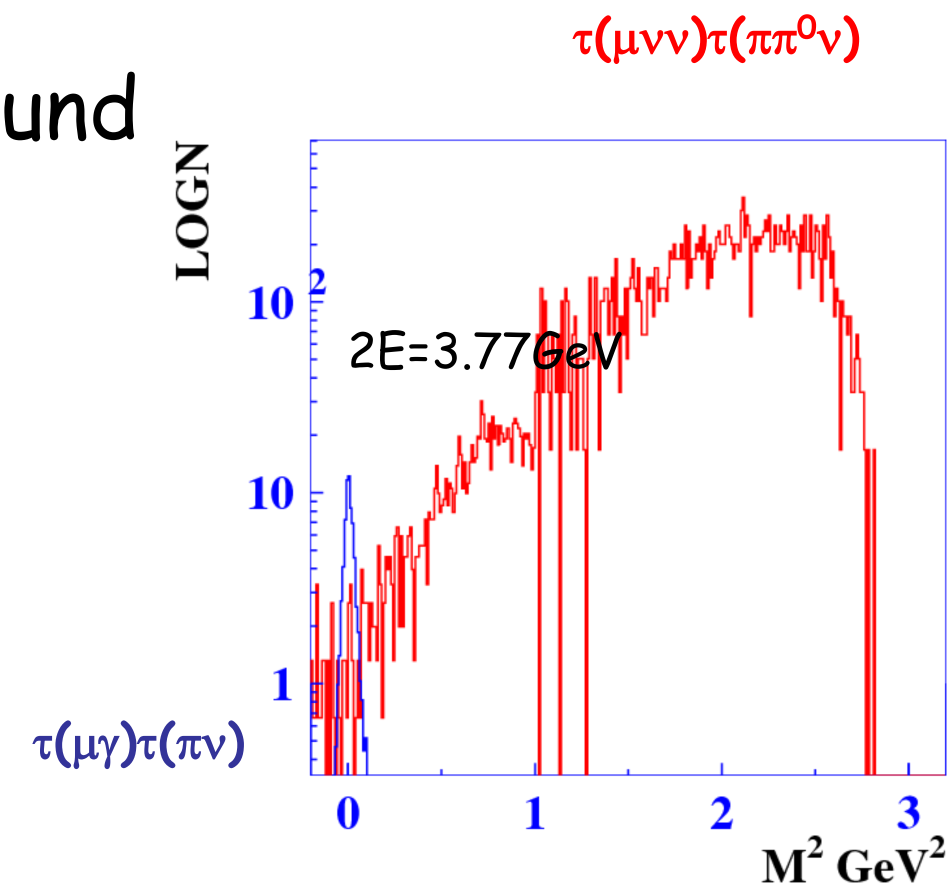
BG from $\tau \to \pi\pi^0\nu_\tau$





More Backgrounds

- Combinatorial background from $\tau^+\tau^-$ events
- QED processes
- Continuum background
- Charm
- Anything else?



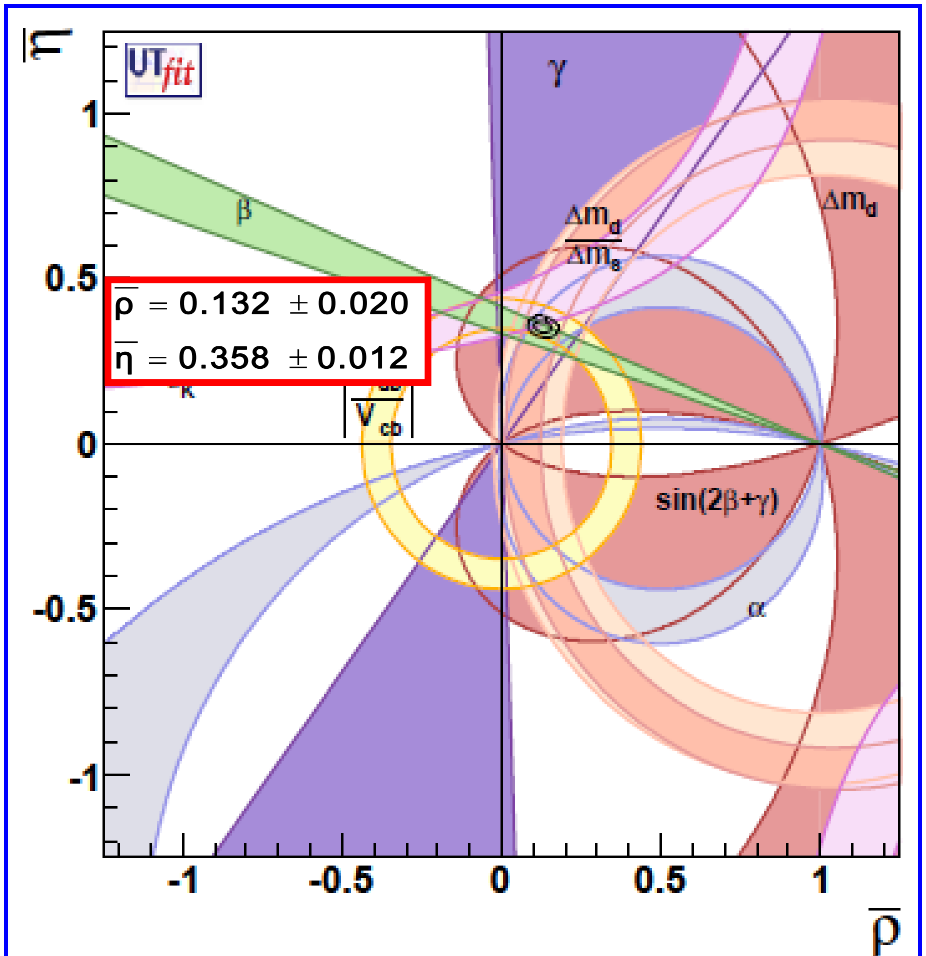
Level of the sensitivity to $Br(\tau \to \mu\gamma) < 10^{-9}$

The UT within the Standard Model

The experimental constraints:

$$\varepsilon_K, \Delta m_d, \left|\frac{\Delta m_s}{\Delta m_d}\right|, \left|\frac{V_{ub}}{V_{cb}}\right|$$ → relying on theoretical calculations of hadronic matrix elements

$$\sin 2\beta, \cos 2\beta, \alpha, \gamma, (2\beta+\gamma)$$ → independent from theoretical calculations of hadronic parameters

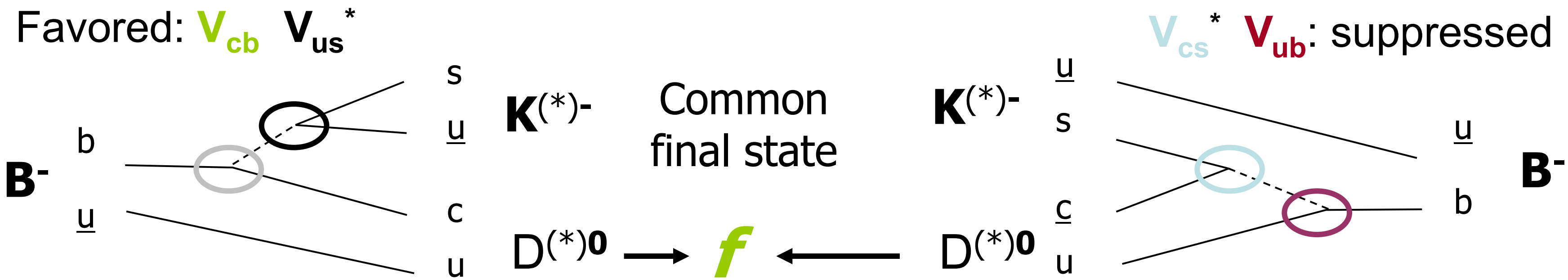


overconstrain the CKM parameters consistently

UTfit, ICHEP10

The weak phase γ (φ_3)

Interference between tree-level decays; theoretically clean



$$\frac{A\left(B^- \to \overline{D}^0 K^-\right)}{A\left(B^- \to D^0 K^-\right)} = r_B e^{i\delta} e^{-i\phi_3}$$

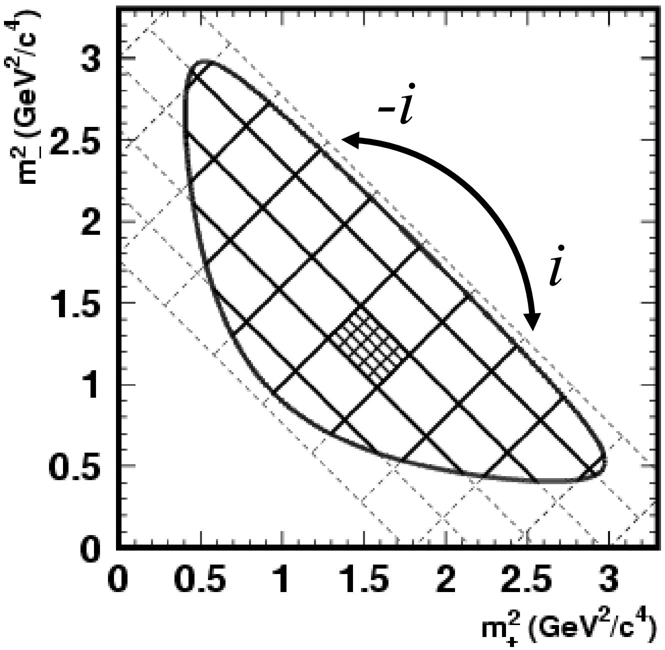
Parameters: ϕ_3, (r_B, δ) per mode

Three methods for exploiting interference (choice of D^0 decay modes):

- Gronau, London, Wyler (GLW): Use CP eigenstates of $D^{(*)0}$ decay, e.g. $D^0 \to K_s\pi^0$, $D^0 \to \pi^+\pi^-$
- Atwood, Dunietz, Soni (ADS): Use doubly Cabibbo-suppressed decays, e.g. $D^0 \to K^+\pi^-$
- Giri, Grossman, Soffer, Zupan (GGSZ) / Belle: Use Dalitz plot analysis of 3-body D^0 decays, e.g. $K_s\pi^+\pi^-$

Model-Independent ϕ_3 measurement

Number of events in flavor tagged D^0-plot: K_i



Number of events in B-plot

$$M_i = K_i + r_B^2 K_{-i} + 2\sqrt{K_i K_{-i}}(xc_i + ys_i)$$

Where x and y:

$$x = r_B \cos(\delta_B + \phi_3); \; y = r_B \sin(\delta_B + \phi_3)$$

$$c_i = < \cos\Delta\delta(\mathcal{D}) >_{\mathcal{D}\,i} \qquad s_i = < \sin\Delta\delta(\mathcal{D}) >_{\mathcal{D}\,i}$$

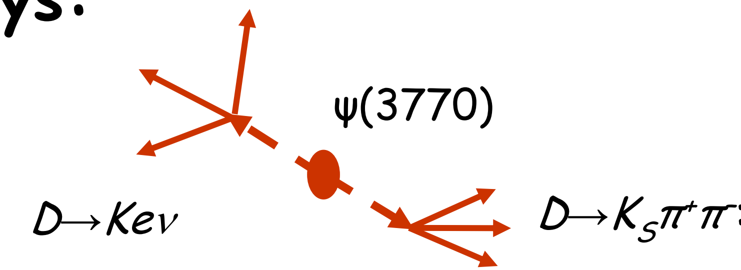
$$c_i = c_{-i}, s_i = -s_{-i} \; and \qquad s_i^2 + c_i^2 \le 1$$

- c_i, s_i can be obtained from B data (M_i) only $\Rightarrow$ Very poor sensitivity
- c_i from D_{CP}, s_i from B data $\Rightarrow$ Poor sensitivity for y

Quantum correlated DD decays for strong phase measurements

In case of flavor tagged D decays:

$$< N >_i = h K_i$$



2 correlated Dalitz plots, 4 dimensions:

$$< N >_{ij} = h [K_i K_{-j} + K_j K_{-i} + \sqrt{K_i K_{-i} K_j K_{-j}} (c_i c_j + s_i s_j)]$$

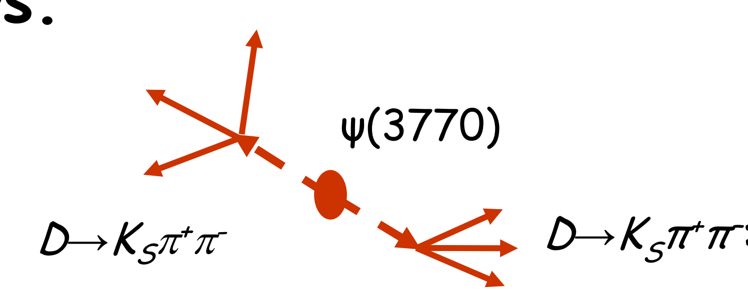
Can use maximum likelihood technique:

$$-2 \log \mathcal{L} = -2 \sum \log p_{Poisson} (N_{ij}, < N >_{ij}) \rightarrow \min$$

with c_i and s_i as free parameters.

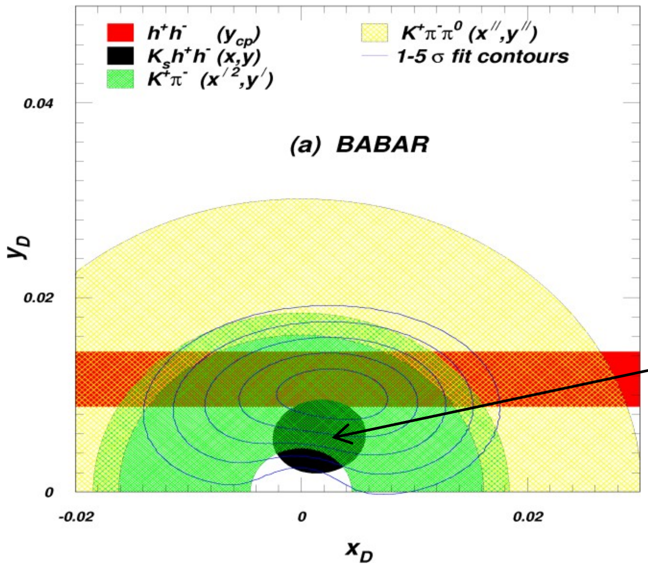
With Poisson PDF, it's OK to have N_{ij}<1.

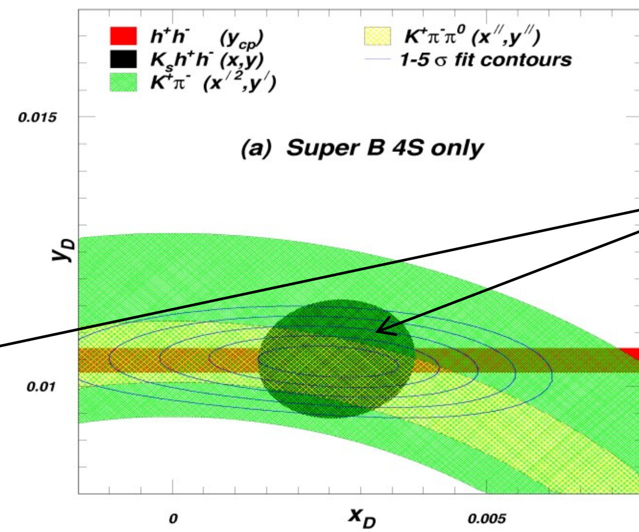
Can obtain both c_i and s_i.



Project to 75_{ab}^{-1}@Υ(4S):

480 fb^{-1} → 75 ab^{-1}





Golden channels

Min. χ^2 fits (blue contours)

$$x_D = (3.01^{+3.12}_{-3.38}) \times 10^{-3}$$
$$y_D = (10.10^{+1.69}_{-1.72}) \times 10^{-3}$$

Unofficial average !!

→

$$x_D = (xxx^{+0.72}_{-0.75}) \times 10^{-3}$$
$$y_D = (xxx \pm 0.19) \times 10^{-3}$$

Uncertainties shrink: but are limited by the IMU (biggest effect on x_D)

Strong phase measurement from ψ(3770) can greatly reduce this.

$$x_D \rightarrow xxx \pm 2.0 \times 10^{-4} \qquad y_D \rightarrow xxx \pm 1.2 \times 10^{-4}$$

How D mixing may impact on the quantum-correlated DD decays

Effect of D mixing depends on C-parity of DD state.

For ($K_S\pi^+\pi^-$ vs $K_S\pi^+\pi^-$) events.
C=-1:

$$N'^{(asym)}_{ij} = K_i K_{-j} + K_{-i} K_j - 2\sqrt{K_i K_{-i} K_j K_{-j}}(c_i c_j + s_i s_j) + O(x_D^2, y_D^2)$$

For C=+1:

$$\begin{aligned} N'^{(sym)}_{ij} = {} & K_i K_{-j} + K_{-i} K_j + 2\sqrt{K_i K_{-i} K_j K_{-j}}(c_i c_j + s_i s_j) + \\ & 2\sqrt{K_i K_{-i}} K_j (y_D c_i - x_D s_i) + 2\sqrt{K_i K_{-i}} K_{-j} (y_D c_i + x_D s_i) + \\ & 2\sqrt{K_j K_{-j}} K_i (y_D c_j - x_D s_j) + 2\sqrt{K_j K_{-j}} K_{-i} (y_D c_j + x_D s_j) + \\ & O(x_D^2, y_D^2) \end{aligned}$$

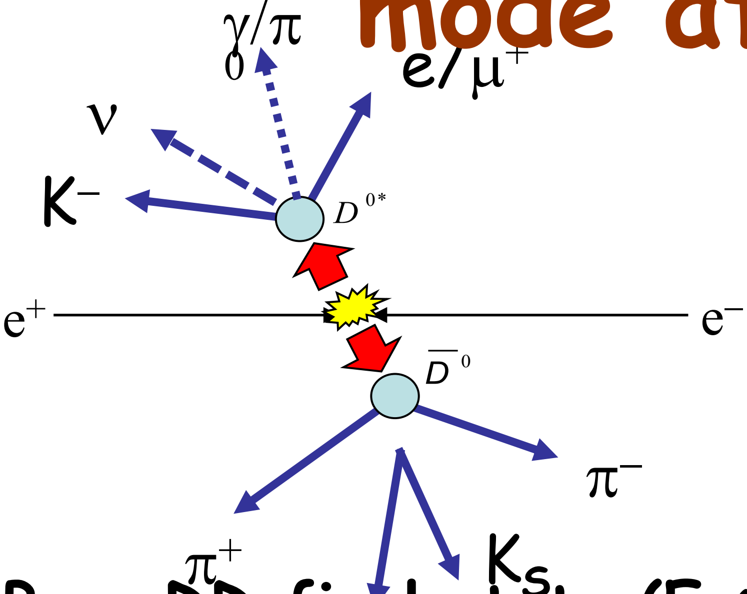
Quantum correlated DD state decay is a instrument for strong phase measurement in the hadronic D-meson decays

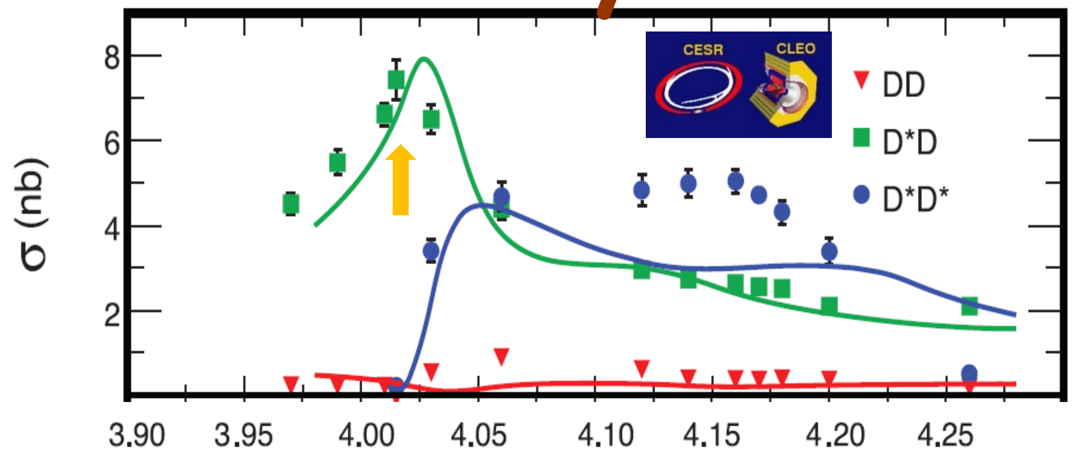
D mixing contribution to the $K_S\pi^+\pi^-$ Dalitz plot distributions for even and odd DD states is different. It can be used for CPV and Mixing parameters measurement in the time integrated mode !

(A.B. et al PRD82:034033,2010)

How create even and odd DD correlated states?

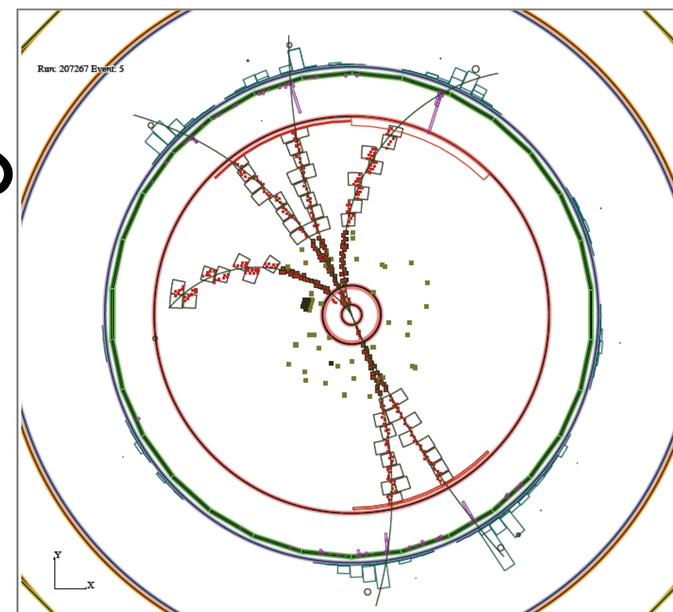
D mixing in time integrated mode at c/τ Factory





- Pure DD final state ($E_{D^{(*)}} = E_{beam}$)
- Equal to $\Psi(3770)$ cross-section of DD
- Low particle multiplicity ~6 charged part's/event
- Good coverage to reconstruct ν in semileptonic decays
- Pure $J^{PC} = 1^{--}$ initial state -

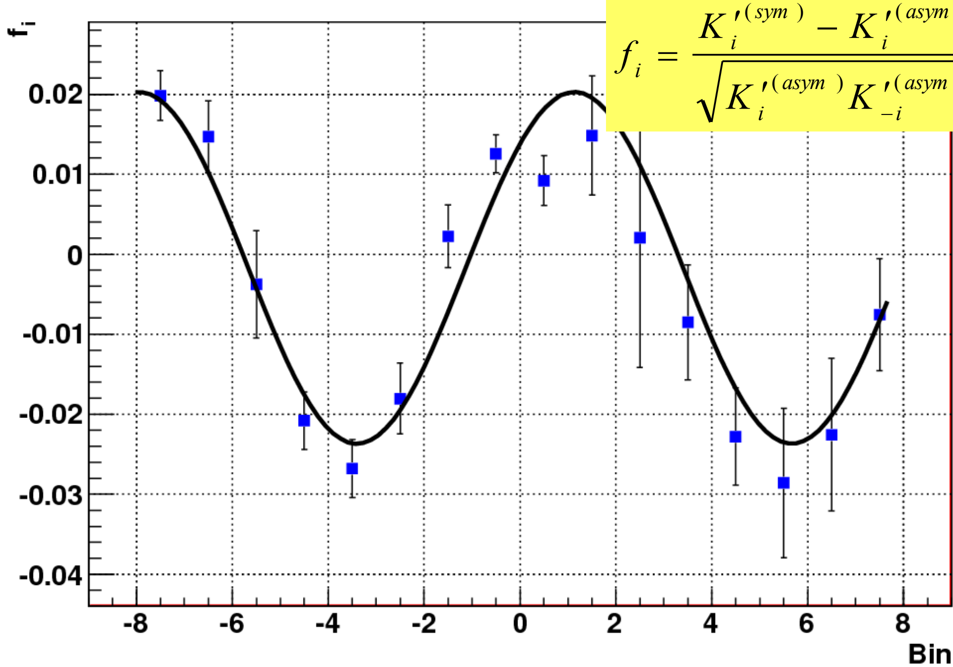
Flavor tags ($K^-\pi^+$, $K^-\pi^+\pi^0$, $K^-\pi^+\pi^-\pi^+$), Semileptonic ($Xe\nu$)

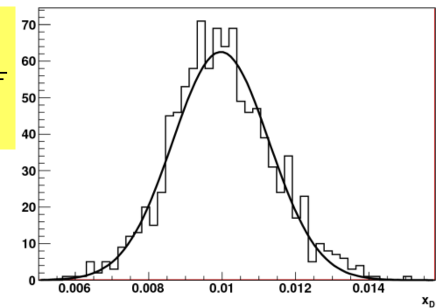


e^+e^- -> $K_S\pi^+\pi^-$ + $K^+\pi^-$ (CLEO-c)

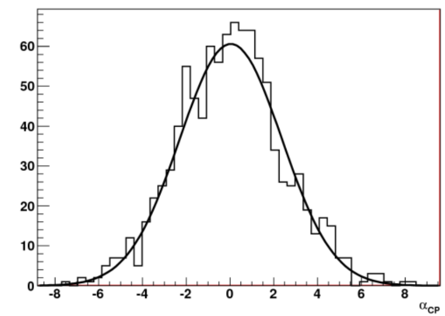
MC Sensitivity ($K_S\pi^+\pi^- + K^+l^-\nu$) 1ab^{-1}

$$f_i = \frac{K_i'^{(sym)} - K_i'^{(asym)}}{\sqrt{K_i'^{(asym)} K_{-i}'^{(asym)}}}$$

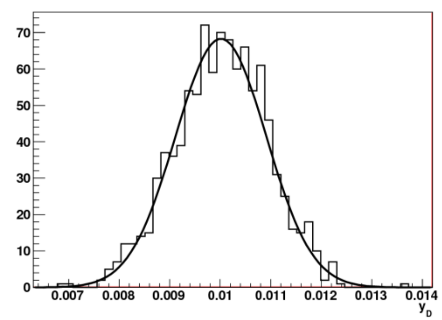




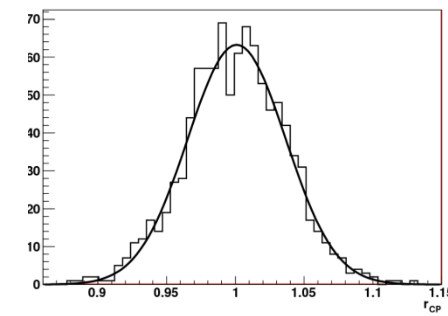
$\sigma(x_D)$=1.3 10^{-3}



$\sigma(\phi_{CP})$=2.3 °



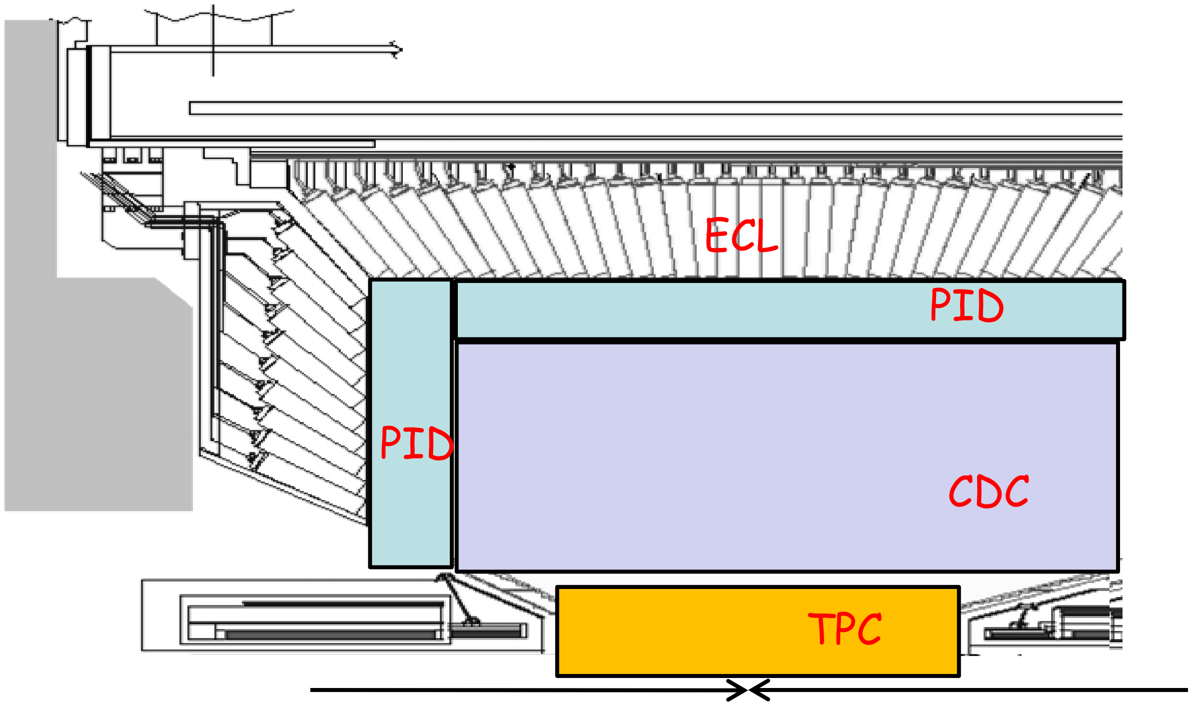
$\sigma(y_D)$=0.9 10^{-3}

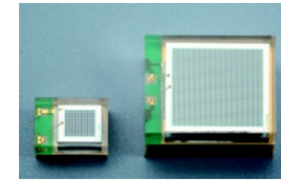


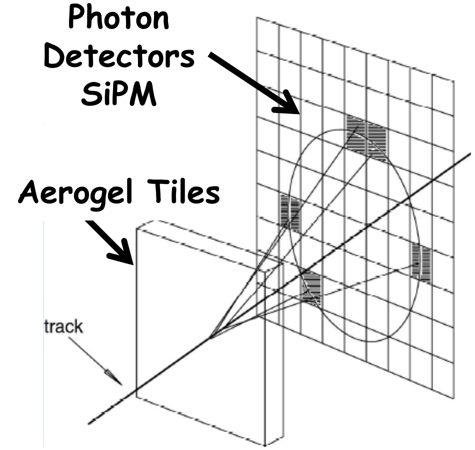
$\sigma(|q/p|)$=3.6 10^{-2}

If sensitivity of other states is comparable, the total statistical uncertainty should be 2-3 times better.

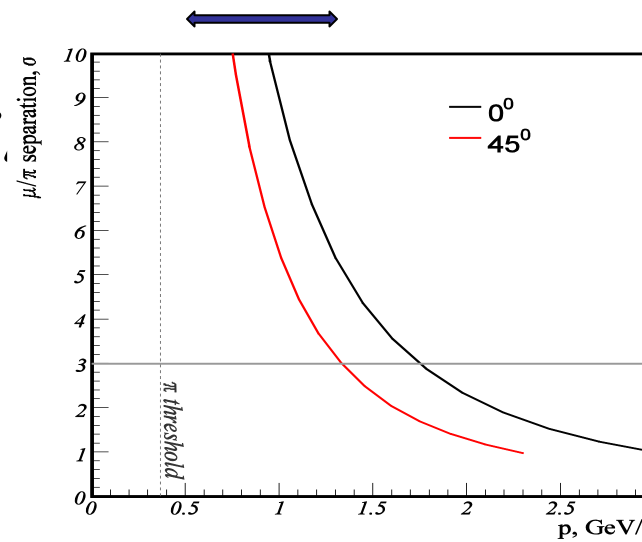
Detector





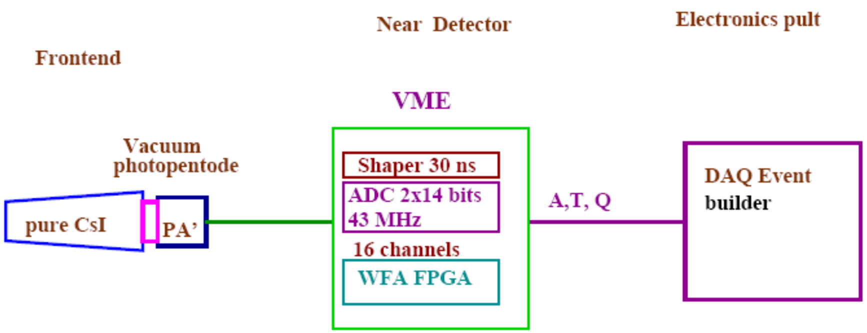


μ momentum range in τ->μγ



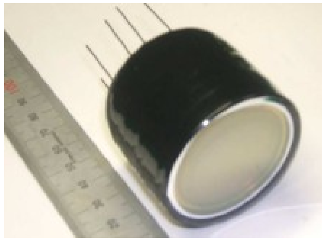
- Ultimate Hermeticity
- PID e/μ/π/K separation up to 2GeV
- Momentum resolution
- Low p_T track efficiency
- ECL energy resolution
- Low energy (~20MeV) photons efficiency

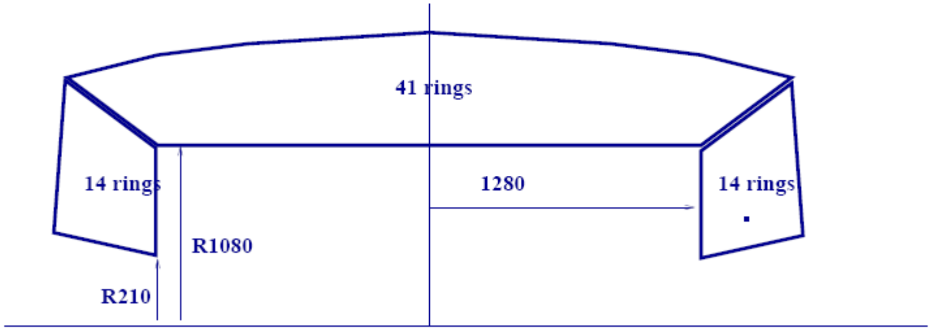
Electromagnetic calorimeter



- To detect photons and measure their energy and coordinates from 10 MeV upto 2 GeV
  - Thick enough active material to have good energy resolution in wide energy range
  - Fast scintilator to have small pile-up noise
  - Good time resolution to suppress beam background
  - As thin passive material in front of the calorimeter as possible
- e/hadron-separation

Pure CsI crystals
truncated pyramid with small size $\sim 5.5 \times 5.5\ cm^2$ and lenghth 35 cm ($18.8\ X_0$)
Readout 2" PP
In barrel: 41 rings(21 types) with 128 crystals in ring
total barrel:= 5248 weight $\sim 31t$.
Endcaps: 14 rings
total endcaps: $= 1120 \times 2$ weight $6\ t \times 2$
Total: 7488 counters, 43 t.
PP: 7488 pcs.
Electronics: 7488 channels.





Conclusions

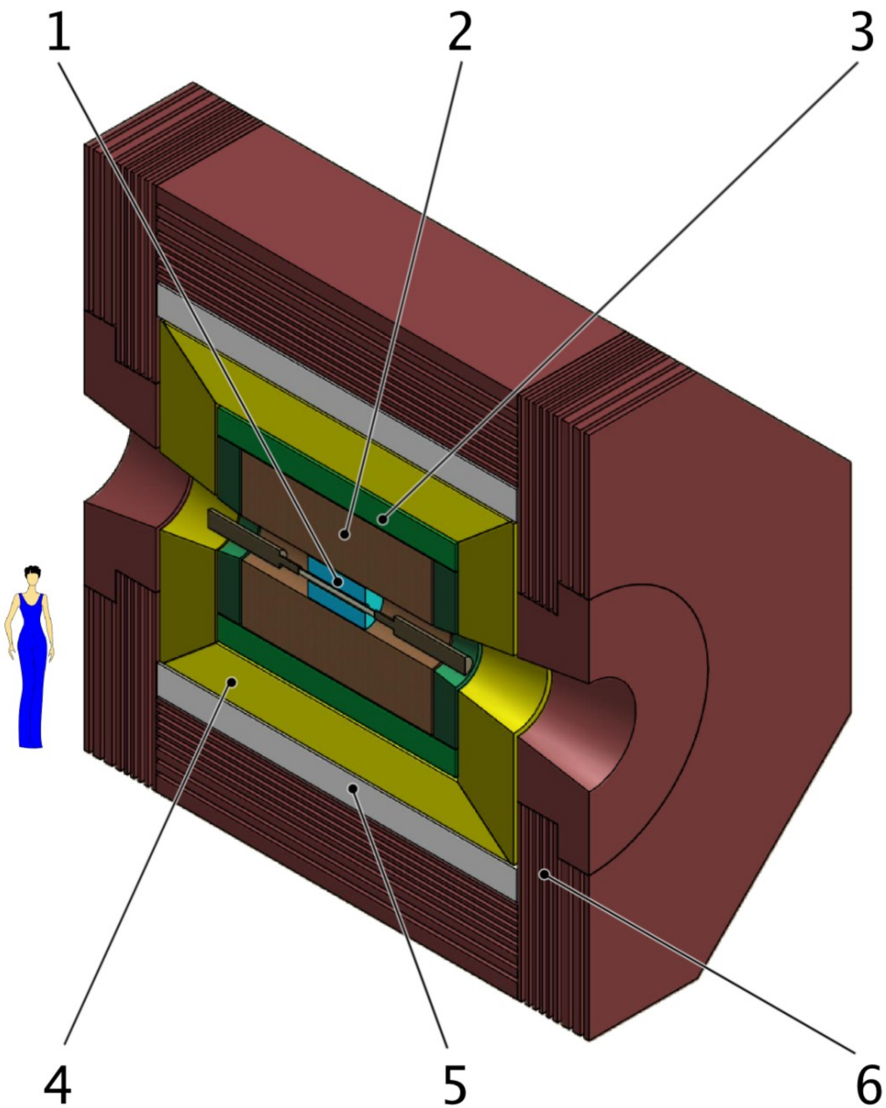
Flavor Physics remains to be very promising for search of New Physics and activity in this field will continue with Super B-factories

c/tau factory with high luminosity and longitudinal polarization could provide complementary opportunities for tests of the Standard Model

Novosibirsk group is working on development of such a project. We welcome international collaboration and hope for support from HEP community and funding agencies of Russia

Super Charm-Tau detector

- Standard set of subsystems (1-Vertex Detector, 2 - Drift Chamber, 3 - PID => FARICH, 4 - EMC, 5 - Superconducting Solenoid, 6 - IFR)



Physics motivation for PID system

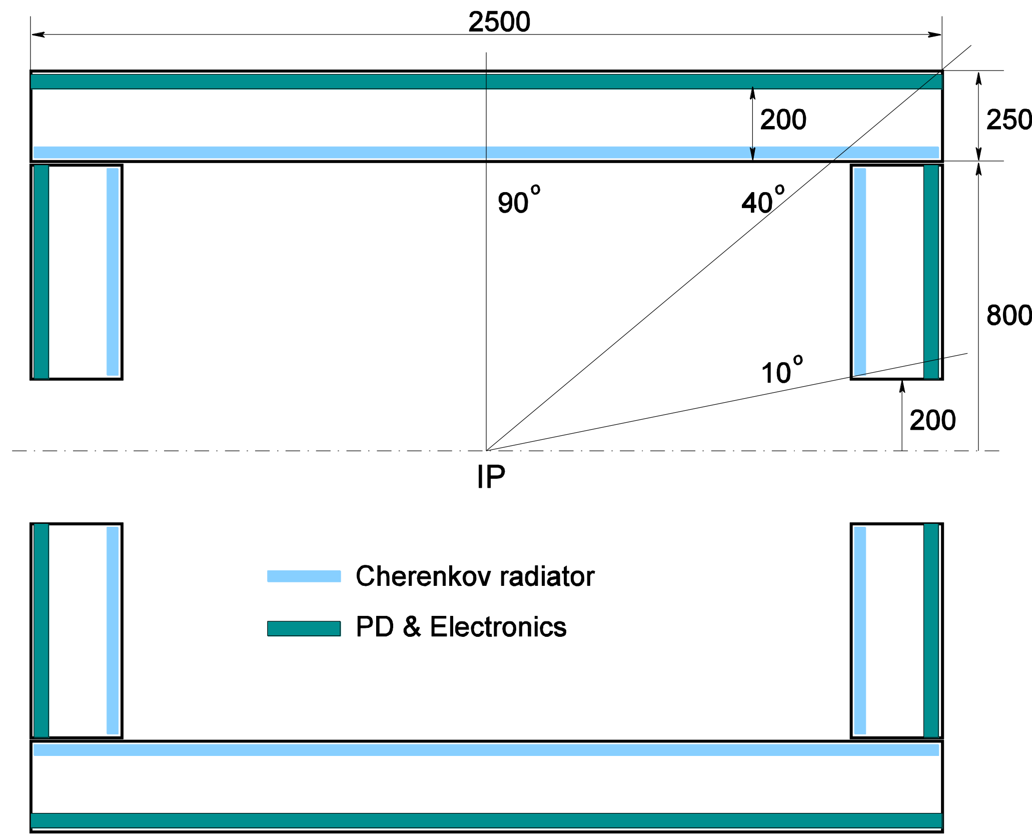
- "golden" process is the search for lepton flavor violation in τ decays: $\tau \rightarrow \mu\gamma$ (projected sensitivity Br $\leq 10^{-9}$)
  - main background is $\tau \rightarrow \pi\pi^0\nu$ (Br = 25%)
- muon tagging of τ decays doubles tagging efficiency

powerful μ/π separation is needed below 1 GeV/c (pion suppression at the level 100 or better, muon system can not provide this)

=>This task is accessible only with a FARICH

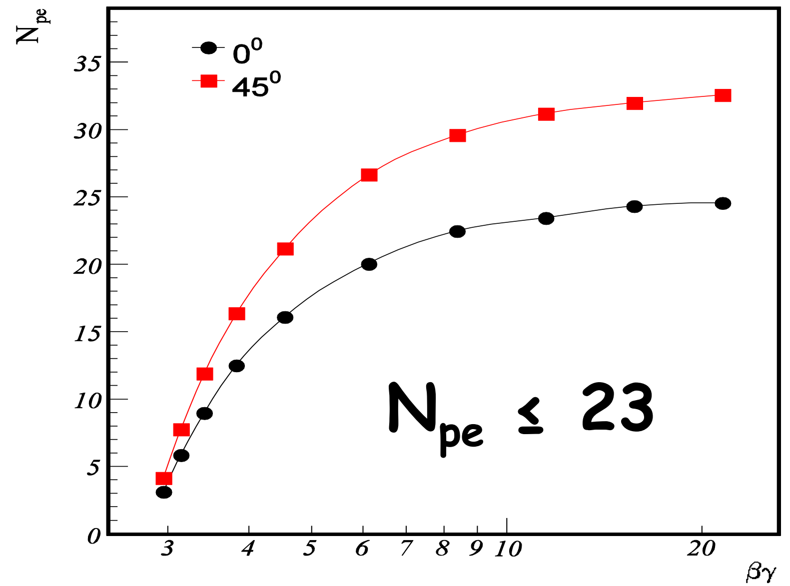
FARICH for Super Charm-Tau detector

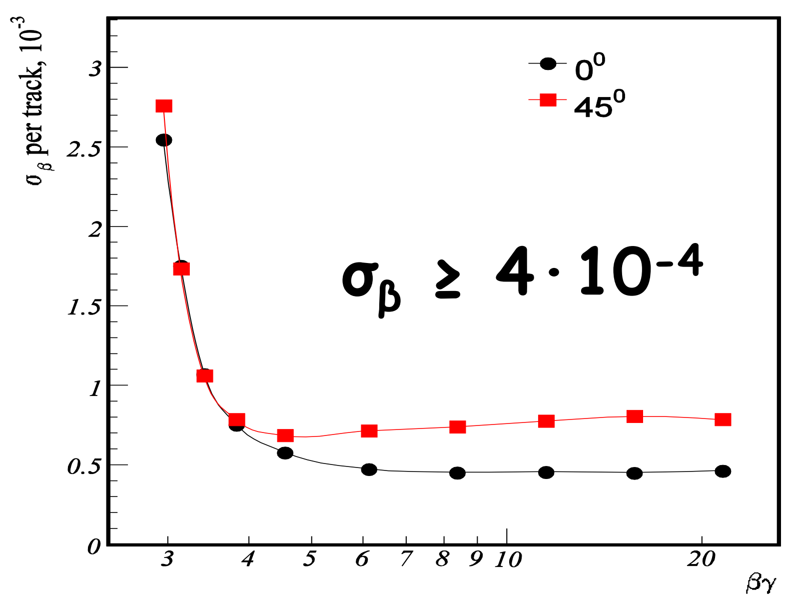
- 4π geometry
- 20 m^2 of radiator and photon detectors
- focusing aerogel
- 10^6 channels
- SiPMs are the main candidate for the photon detector (gas filled photo-detectors with bialkali photo-cathode could be a cheap alternative?)



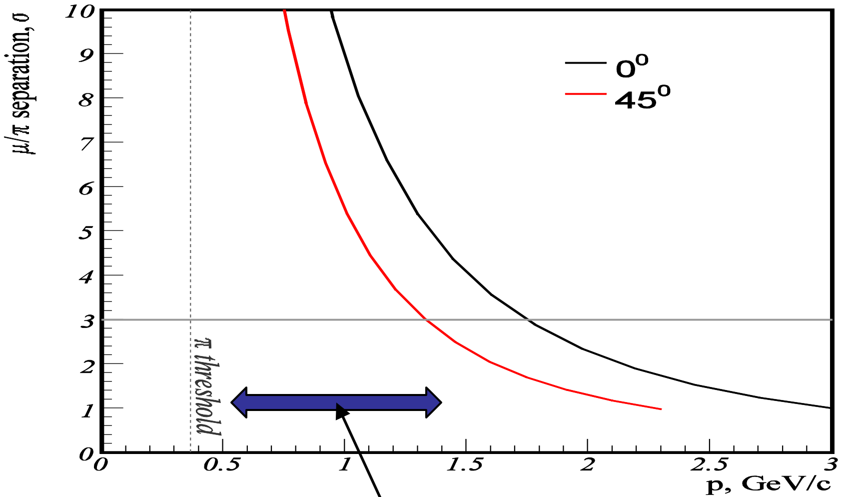
MC simulation

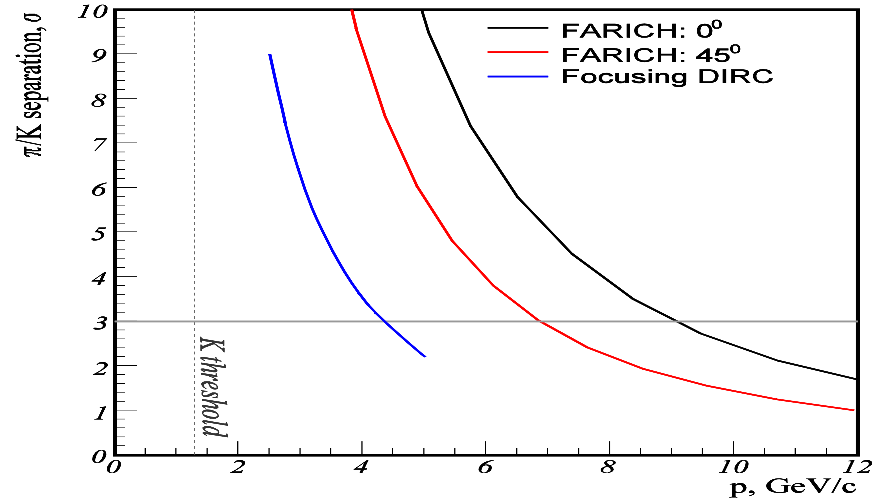
- Expansion gap 200 mm
- Photon detector: Hamamatsu MPPC 3x3 mm, pitch 4.1 mm (fill factor 53%)
- Radiator: 4-layer aerogel, (optimal focusing at P_{π}=1 GeV/c) , n_{max}=1.07, total thickness 35 mm





MC simulation

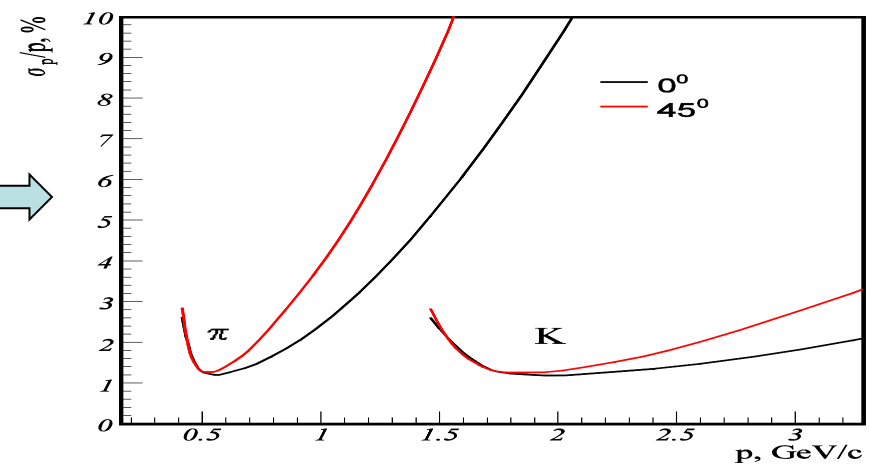




μ momentum range in τ->μγ

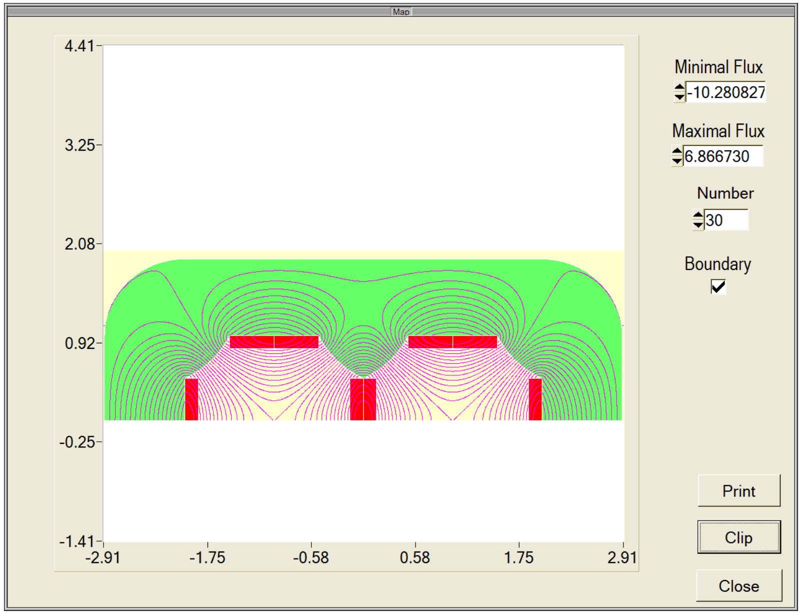
$\sigma_P/P=\gamma^2\cdot\sigma_\beta/\beta$

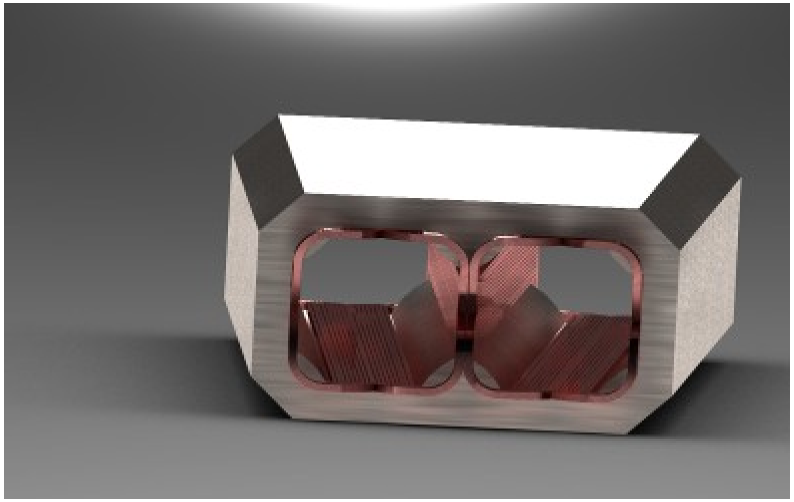
$\sigma_P/P \geq 1\%$

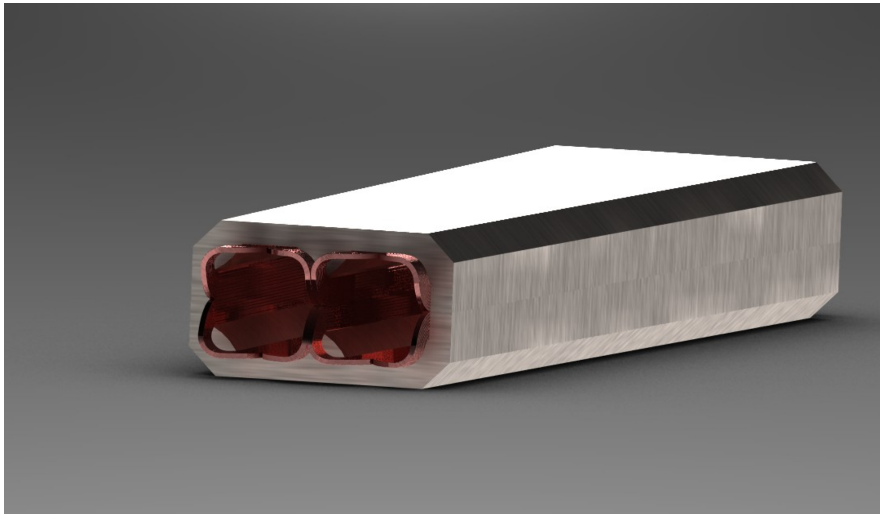


QD0

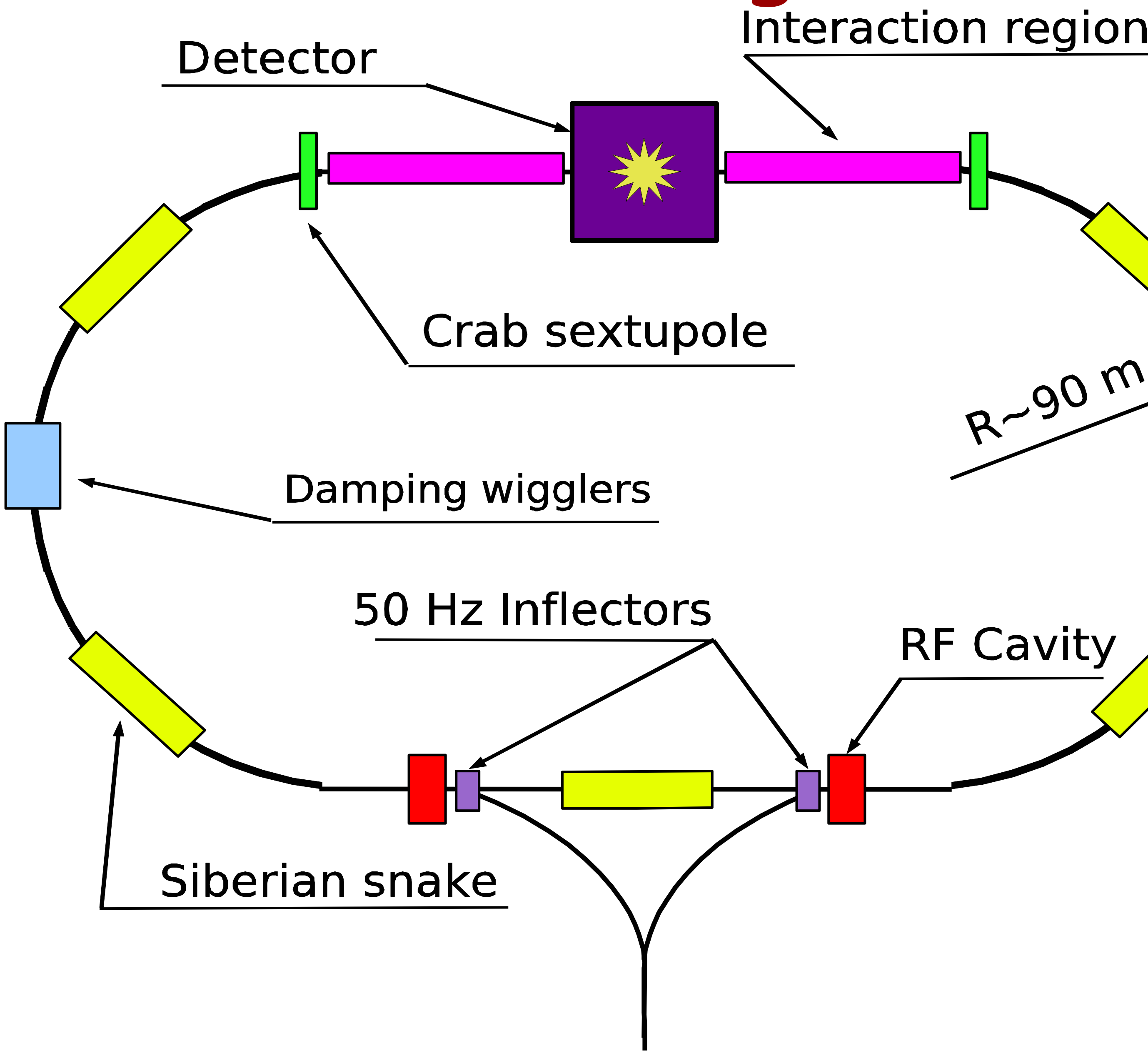
SC iron yoke twin aperture magnet
Excitation current 1150 A
Single aperture 2 cm
Gradient 150 T/m







Main ring

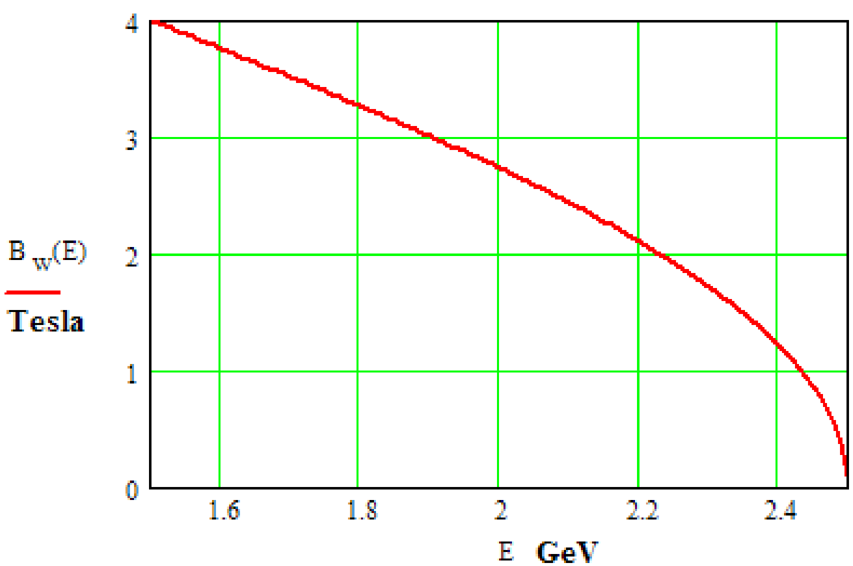


Interaction region
Detector
Crab sextupole
R~90 m
Damping wigglers
50 Hz Inflectors
RF Cavity
Siberian snake

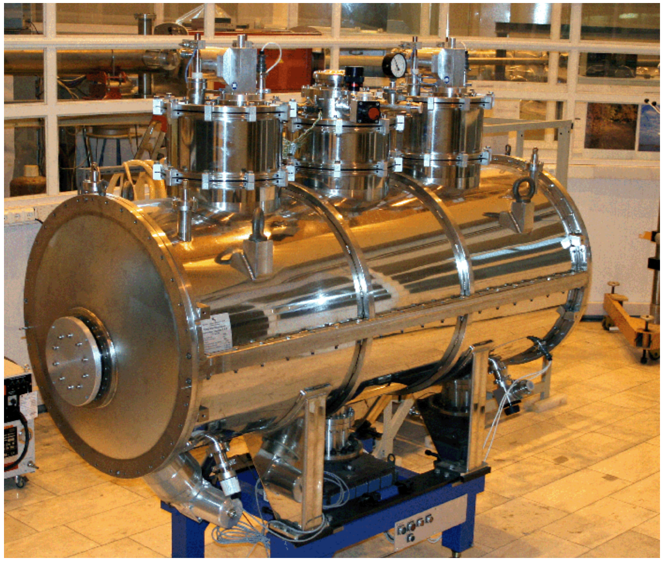
Damping wigglers

The damping wigglers keep the damping time τ_x =30 ms and the horizontal emittance (ε_x=10 nm) in the energy range 1.0 – 2.5 GeV

Field amplitude at 1.0 GeV	5.4 T
Period length	0.2 m
Total length	8 m
Damping integral i_2 at 1.0 GeV	12.4 m^{-1}
Excitation integral i_5 at 1.0 GeV	0.08 m^{-1}

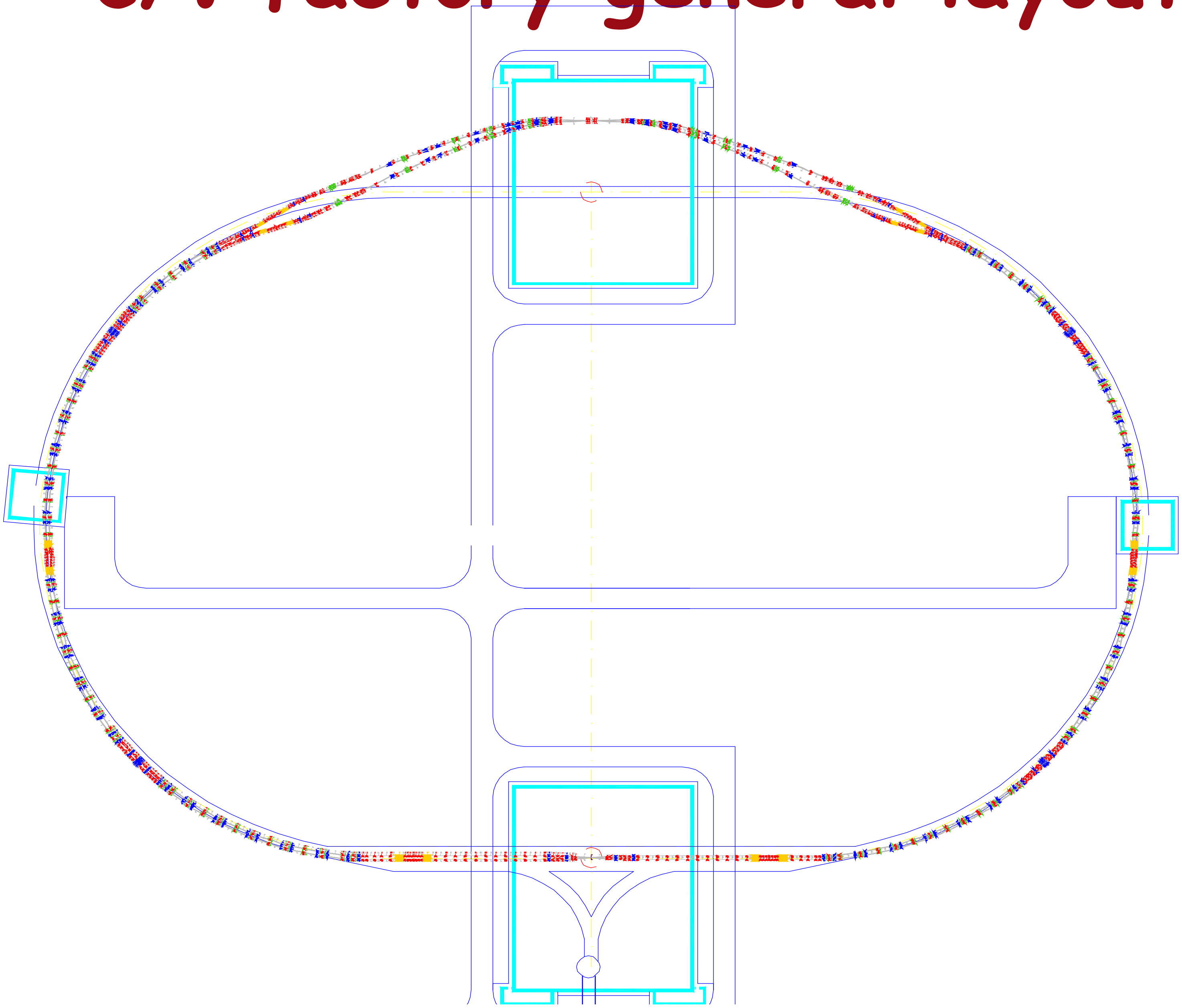


Wiggler field amplitude vs energy

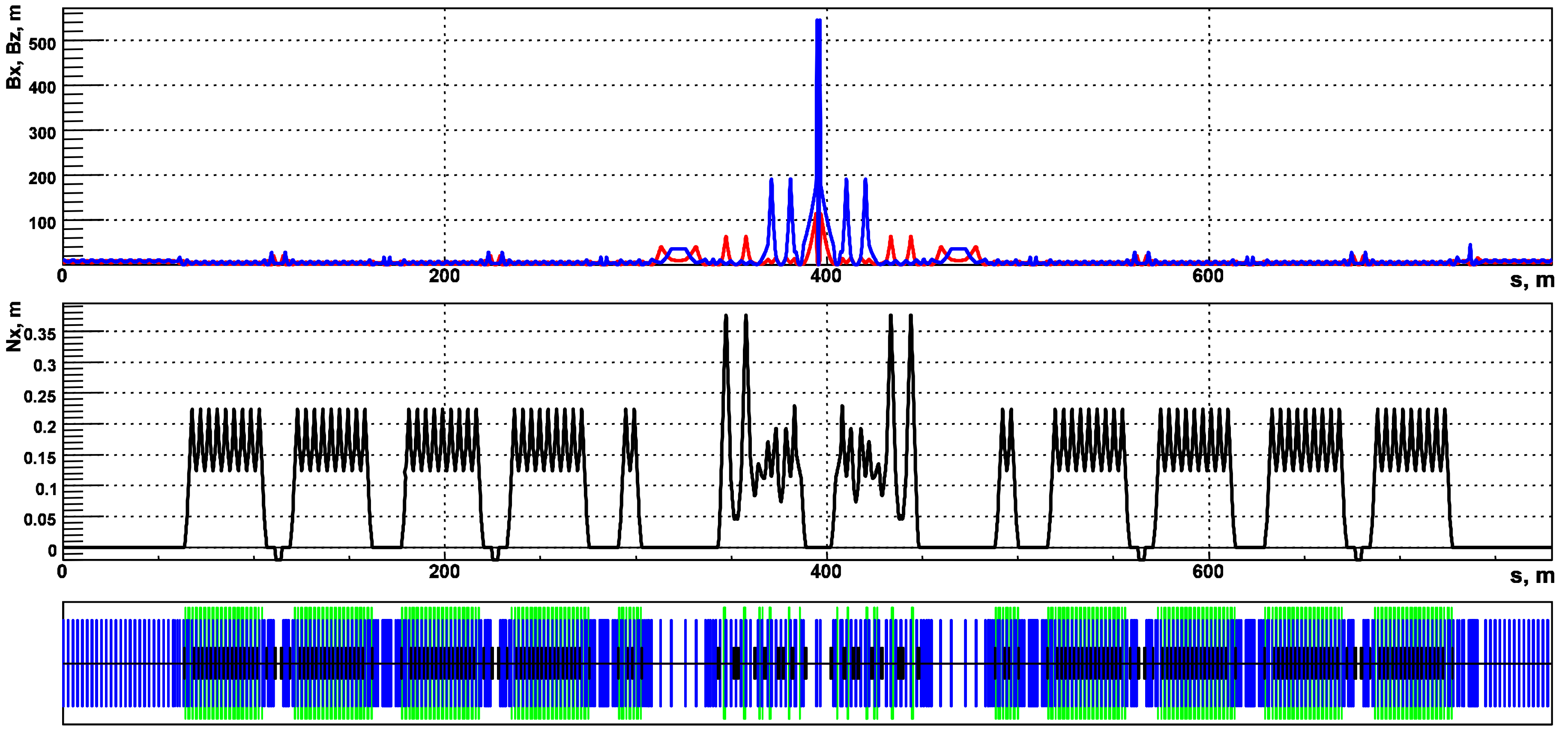


Wiggler with similar parameters produced by BINP

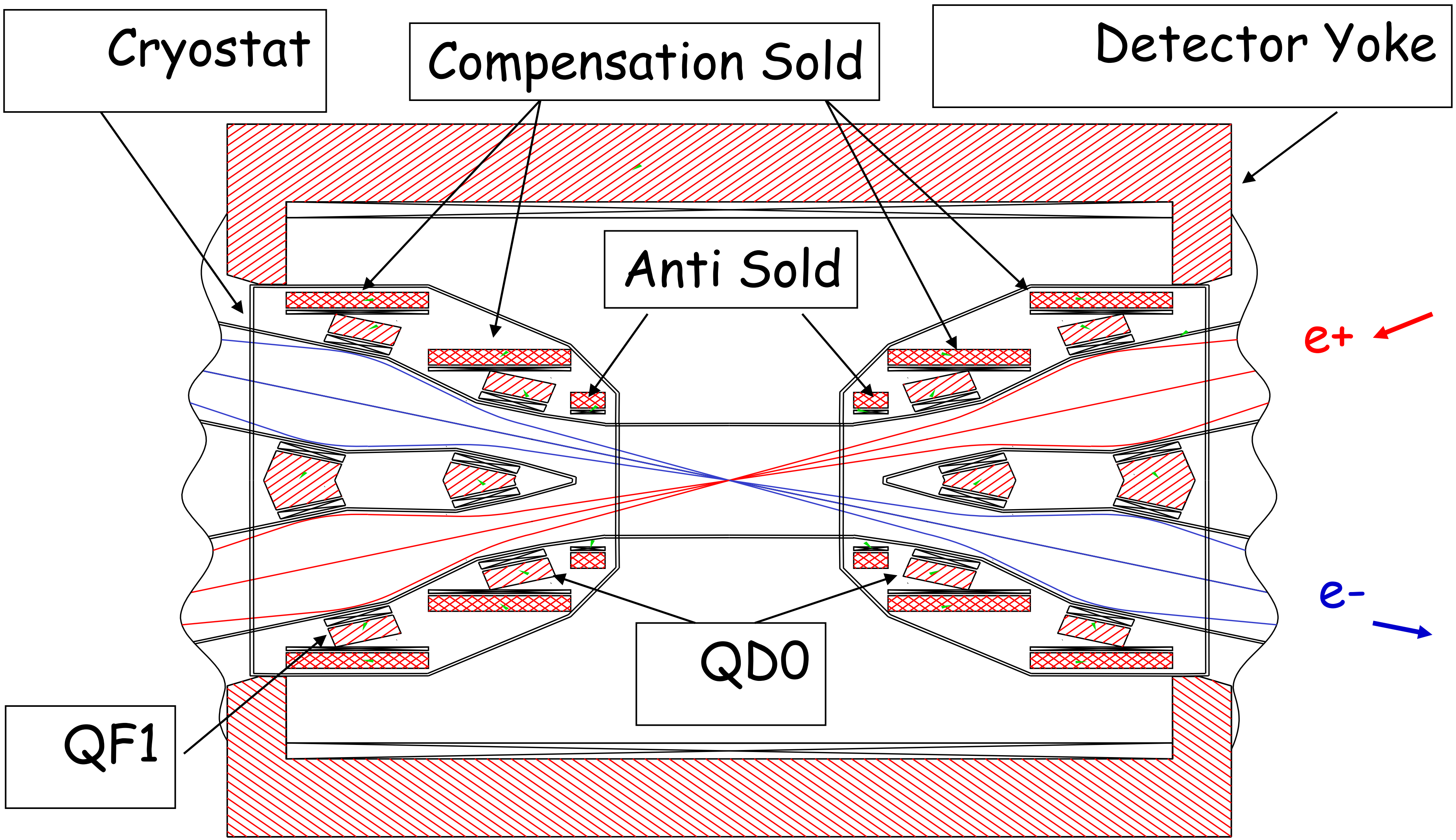
c/τ factory general layout



Optic functions



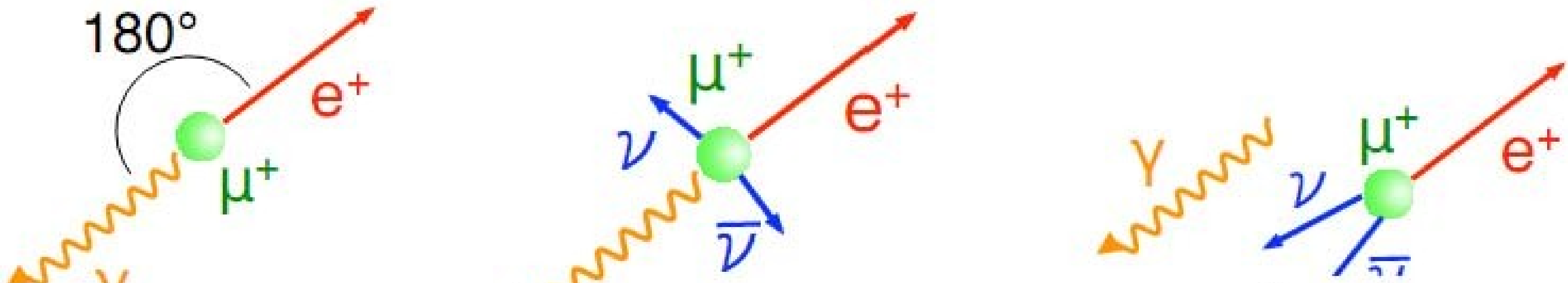
Final Focus System



$\mu \rightarrow e\,\gamma$ **At PSI**

Signal and Background

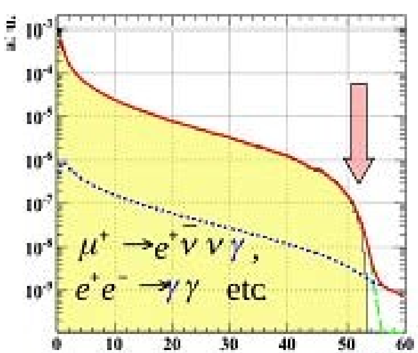
Signal | Prompt Background | Accidental Background



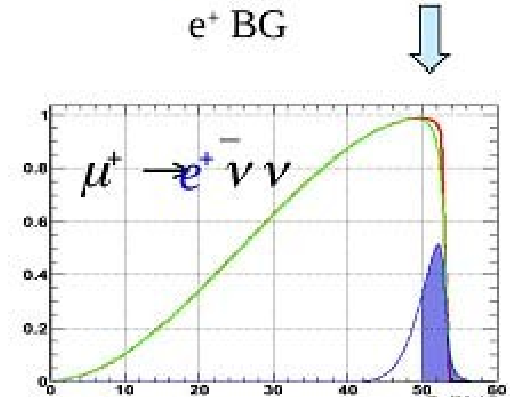
$$B_{acc} \propto \delta E_e \cdot (\delta E_\gamma)^2 \cdot (\delta\vartheta_{e\gamma})^2 \cdot \delta t_{e\gamma}$$

$e\,\gamma$		Signal	Radiative muon decay	Accidental pileup
	Angle	Back-to-Back	Any angle	Any angle
	Energy	52.8 MeV/c	< 52.8 MeV/c	< 52.8 MeV/c
	Time	Same time	Same time	Flat

γ BG



e^+ BG

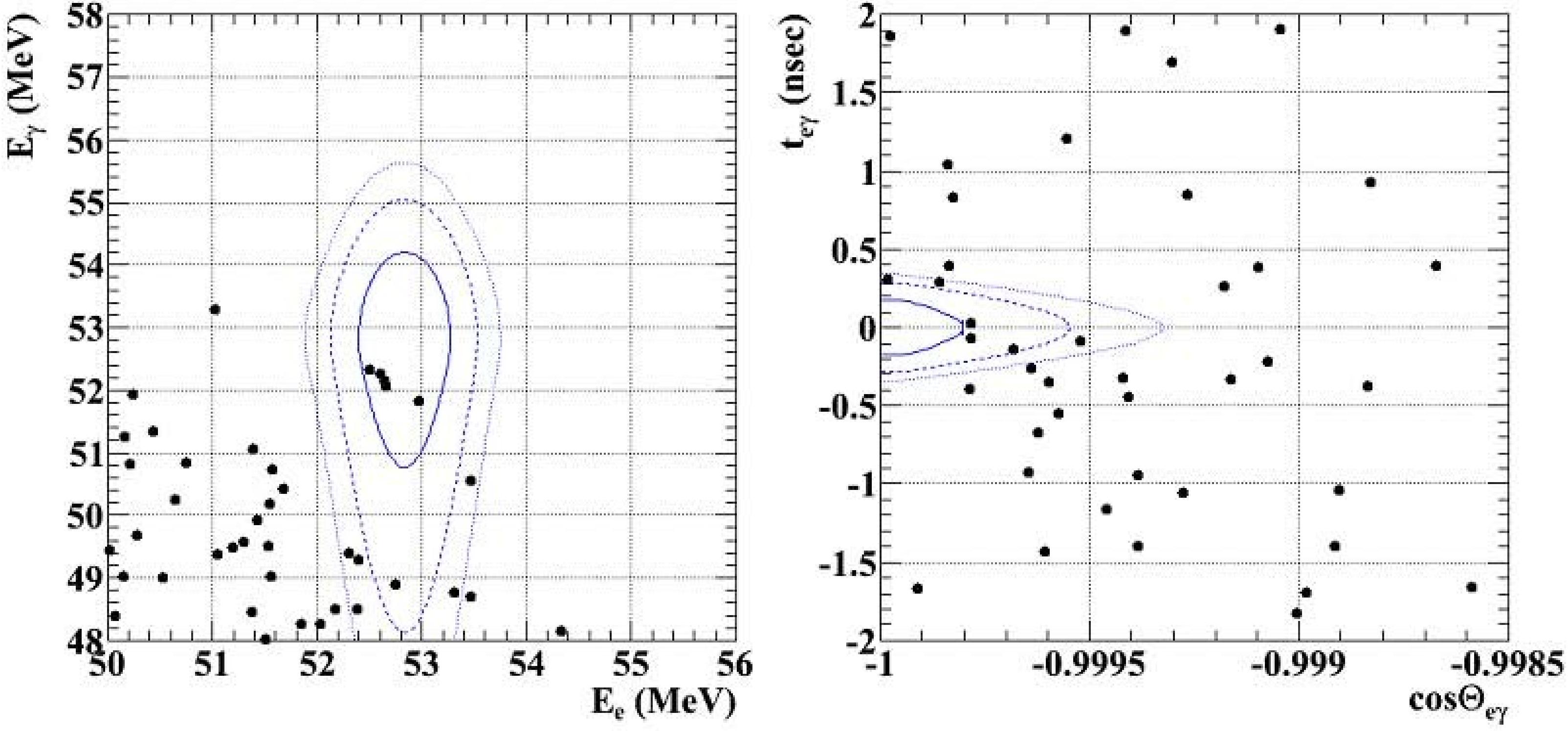


Dominant background is accidental.

Detector resolution is crucial.

MEG,ICHEP10

Event distribution after unblinding

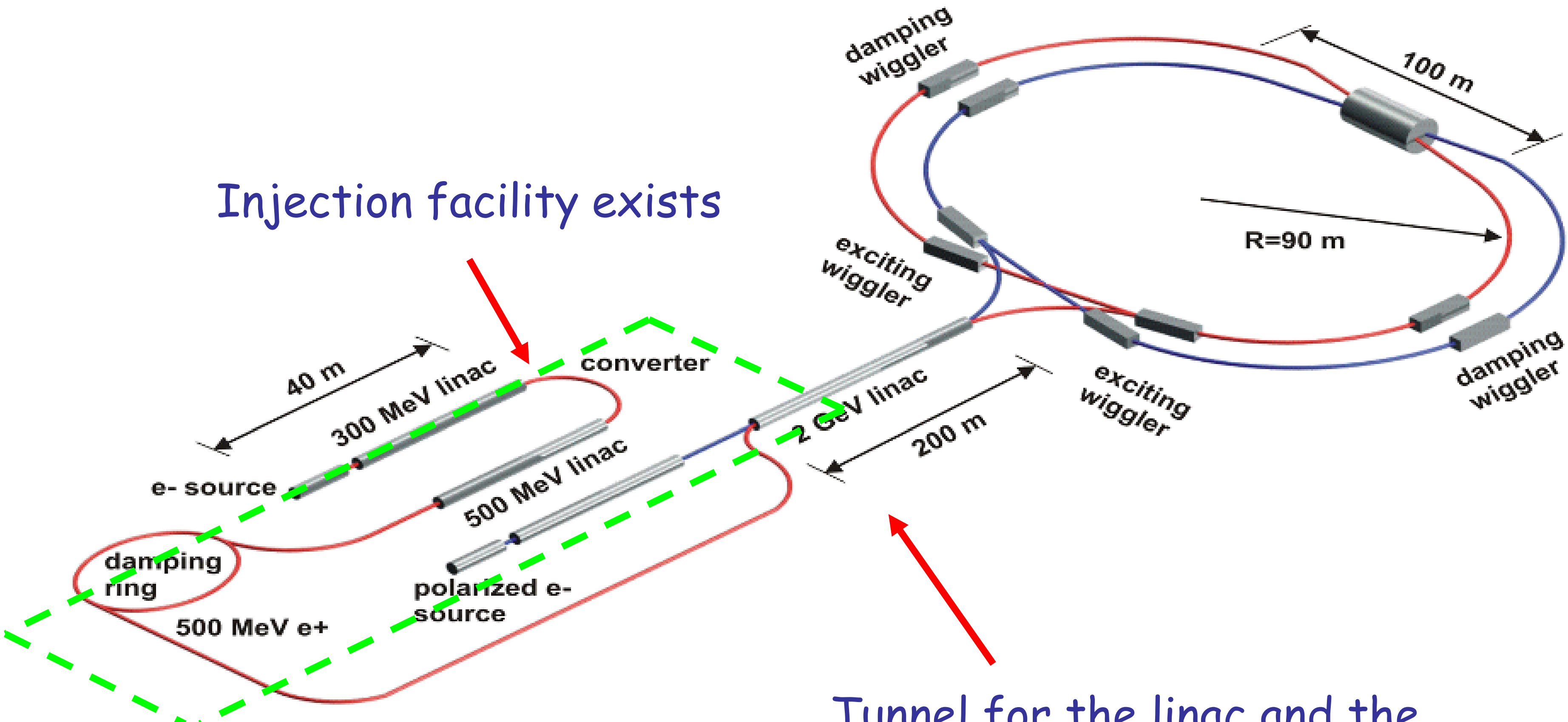


Blue lines are 1(39.3 % included inside the region w.r.t. analysis window), 1.64(74.2%) and 2(86.5%) sigma regions.
For each plot, cut on other variables for roughly 90% window is applied.

MEG,ICHEP10

General Layout of the Novosibirsk c/τ factory

Injection facility exists



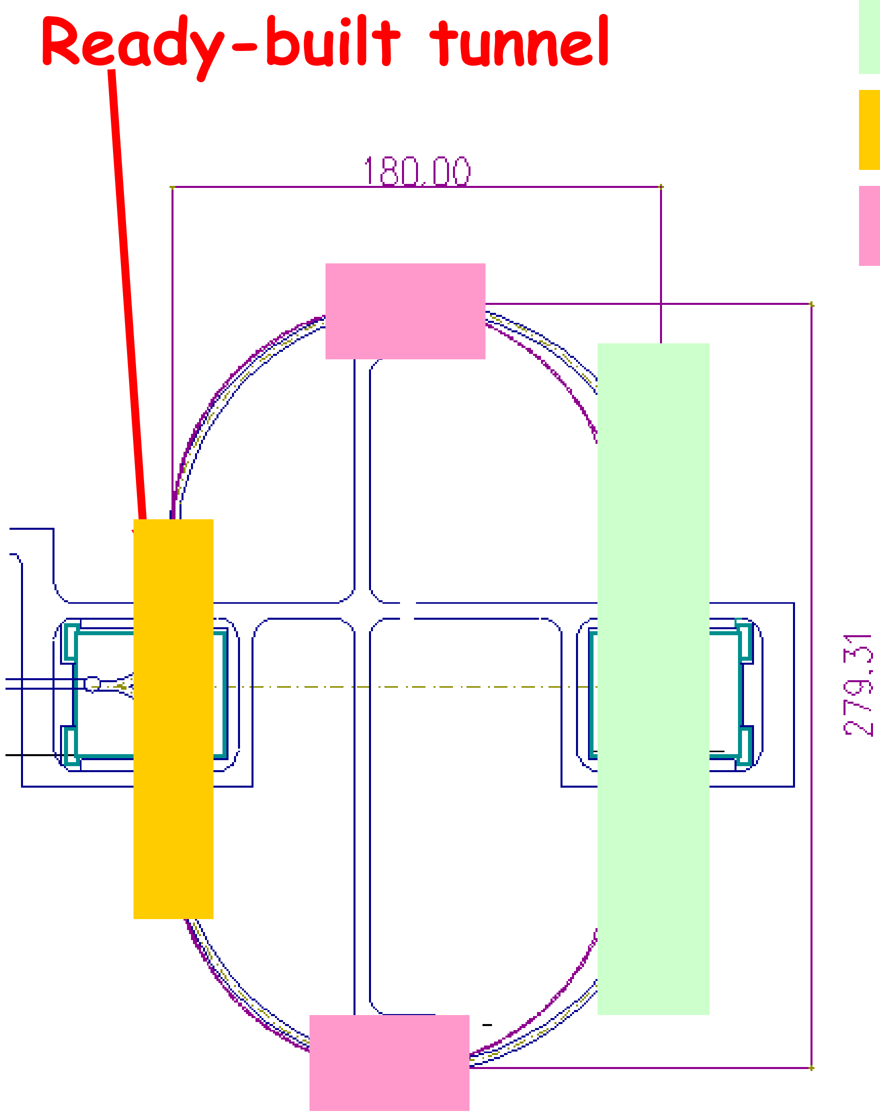
Tunnel for the linac and the technical straight section of the factory is ready

Main accelerator parameters

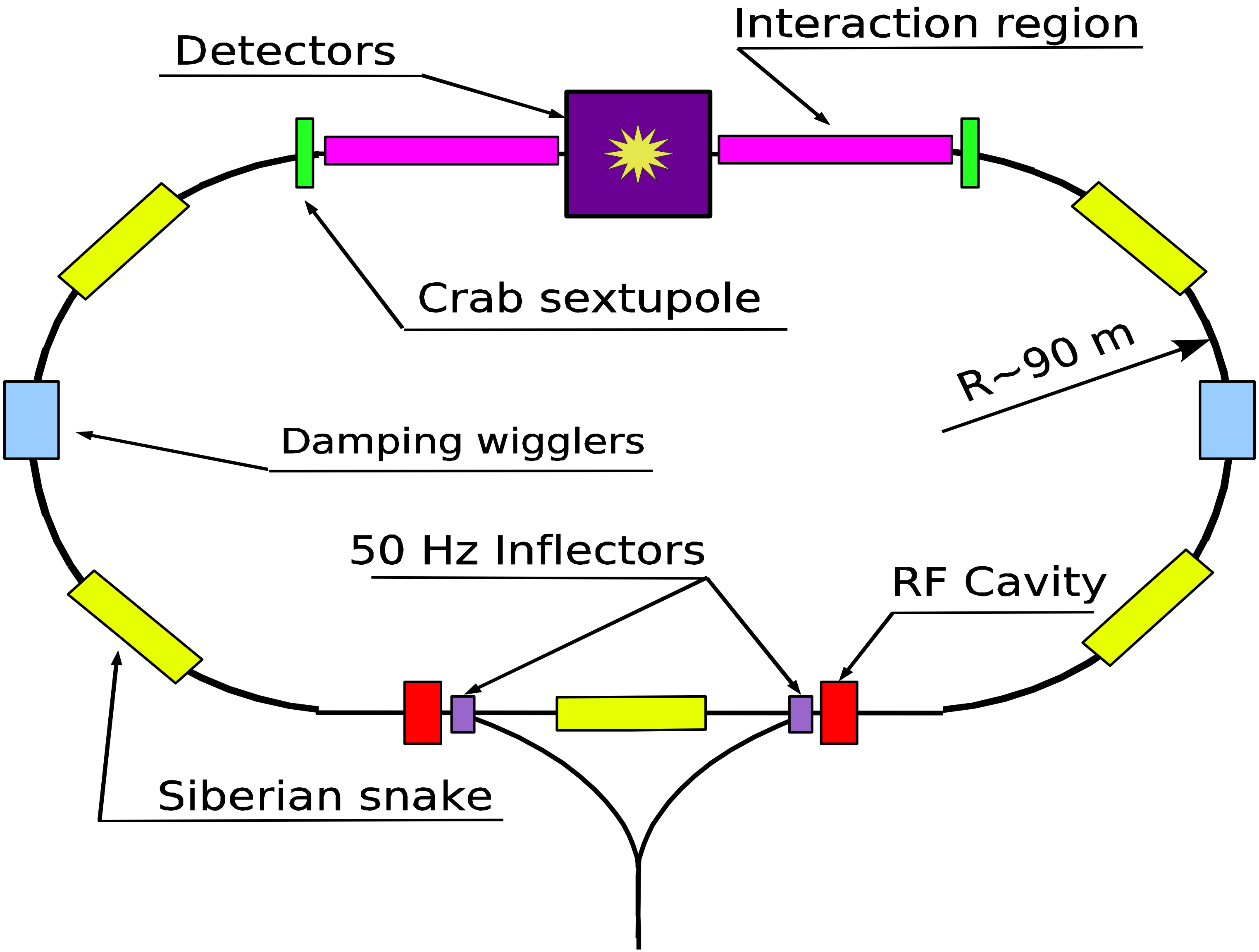
Energy	1.0 GeV	1.5 GeV	2.0 GeV	2.5 GeV
Circumference	766.6 m			
Emittance hor/ver	8 nm/0.04 nm @ 0.5% coupling			
Damping time hor/ver/long	30/30/15 ms			
Bunch length	16 mm	11 mm	10 mm	10 mm
Energy spread	$10.1 \cdot 10^{-4}$	$9.95 \cdot 10^{-4}$	$8.43 \cdot 10^{-4}$	$7.38 \cdot 10^{-4}$
Energy loss/turn	170 keV	256 keV	343 keV	434 keV
Momentum compaction	$0.89 \cdot 10^{-3}$	$0.90 \cdot 10^{-3}$	$0.91 \cdot 10^{-3}$	$0.91 \cdot 10^{-3}$
Synchrotron tune	0.013	0.014	0.012	0.010
Wiggler field	4.5 T	4.0 T	2.8 T	0
RF frequency	500 MHz			
Particles/bunch	$7 \cdot 10^{10}$			
Number of bunches	390			
Bunch current	4.4 mA			
Total beam current	1.7 A			
Beam-beam parameter	0.15	0.15	0.15	0.12
Luminosity	$0.63 \cdot 10^{35}$	$0.95 \cdot 10^{35}$	$1.08 \cdot 10^{35}$	$1.08 \cdot 10^{35}$

6 m of the SC wigglers with 20-cm-period are used to control the beam parameters at different energies

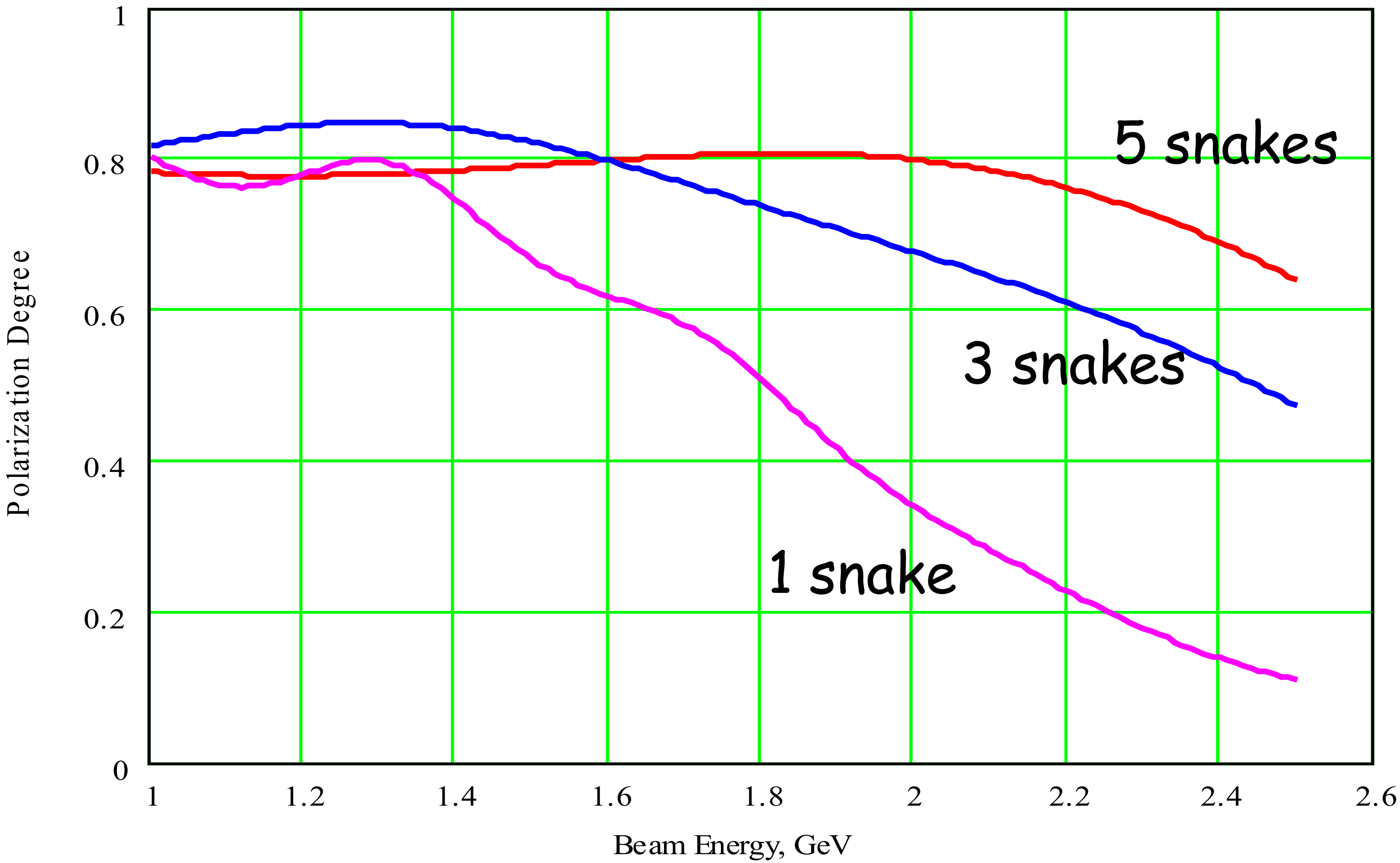
Main ring: tunnel



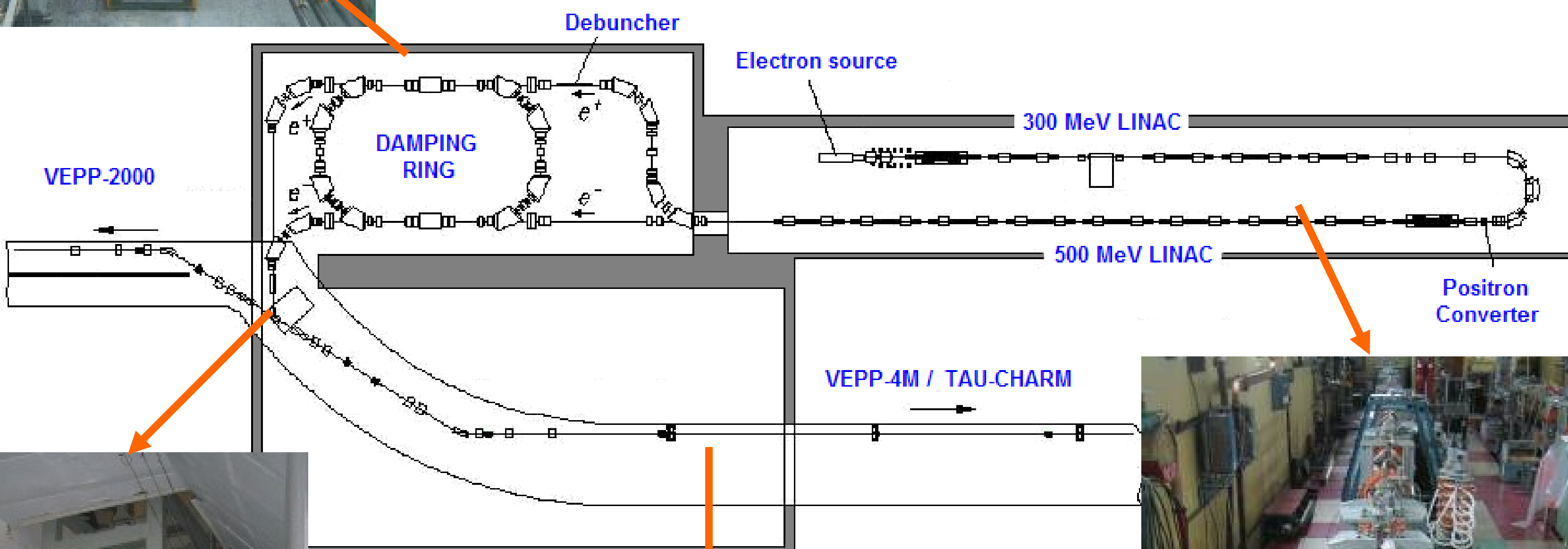
Polarization scheme



Polarization vs energy



Injection facility



- Crab Waist collision seems a very promising idea to enhance a circular colliders luminosity beyond the present value by factor of 10-100 without current increase.

- CW approach was successfully proved experimentally at DAFNE in the end of 2008

- Novosibirsk SuperCT project is under way. The key issues like IR design, DA optimization, polarization scheme, QD0 design, etc. seem solved successfully