$\tau \to \mu\gamma$ at Super tau-charm

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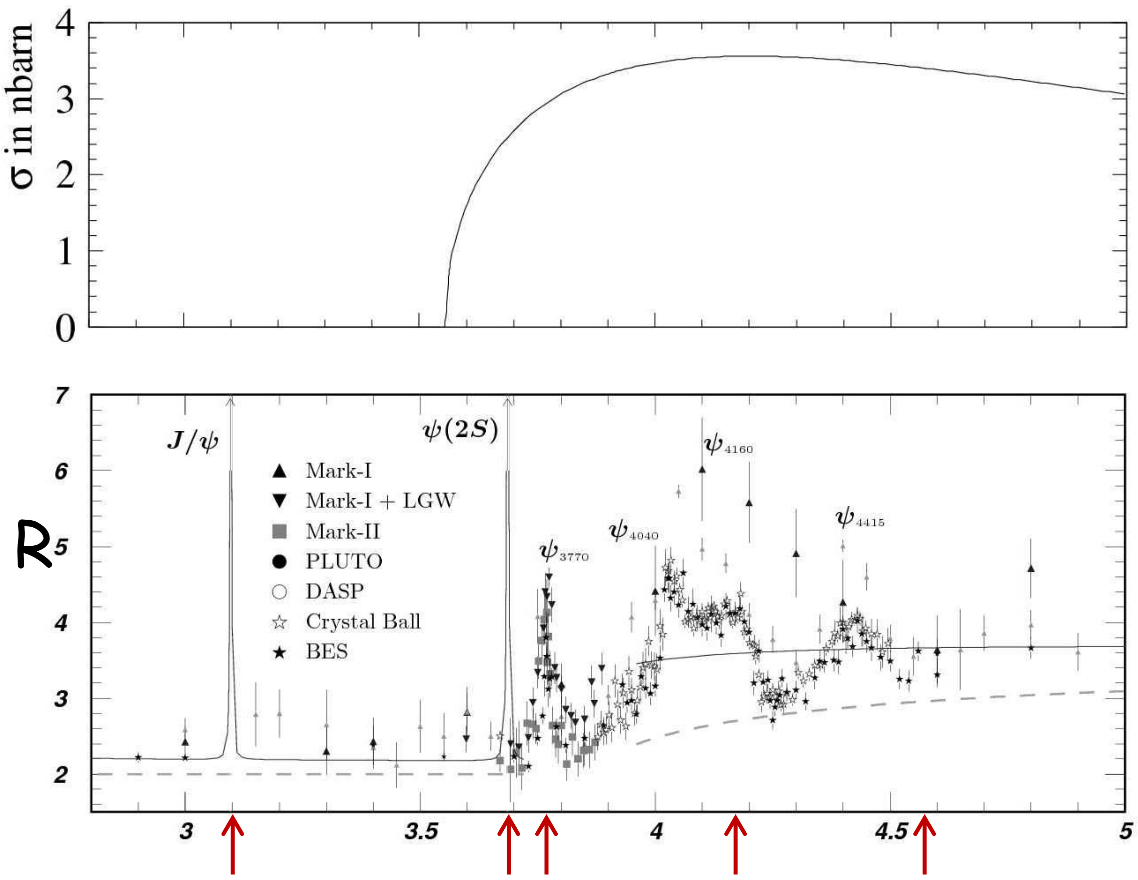
BINP, Novosibirsk

Workshop on Tau Charm at High Luminosity
26-31 May 2013, La Biodola, Italy

Statistics



Data (10 ab^{-1}) will be collected mainly in the energy points:

- J/ψ - 3.1 GeV
- $\psi(2S)$ – 3.69 GeV
- D – 3.77 GeV
- D_s – 4.17 GeV
- Λ_c – 4.65 GeV

The expected number of produced τ pairs is about 3×10^{10}.

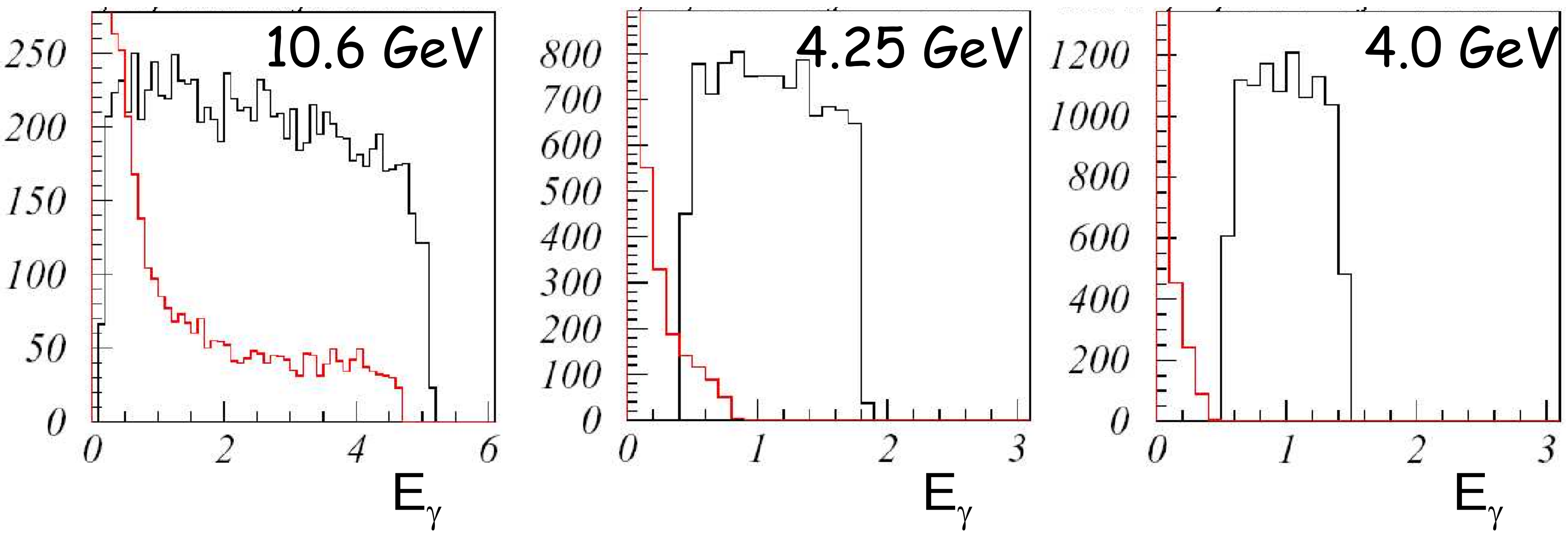
B factories: $\sigma(e+e- \to \tau+\tau-) \approx 0.9$ nb $\Rightarrow 10^9$ τ pairs
Super B factory: 7×10^{10} τ pairs

LFV decay $\tau \to \mu\gamma$

- Current best limit:
  4.4×10^{-8} by BaBar with 5×10^{8} τ pairs
- Super-B: 7×10^{10} τ-pairs $\to (2 \div 4) \times 10^{-9}$
  - ISR background from $e^+e^- \to \tau^+\tau^-\gamma$
  - Upper Limit $\propto 1/\sqrt{L}$
- tau-charm factory with 3×10^{10} τ pairs may has similar or better sensitivity

$\tau \to \mu\gamma$: background sources

The process $e^+e^- \to \tau^+\tau^-\gamma$, dominant background source at $\Upsilon(4S)$, does not contribute below $2E \approx 4m_\tau/\sqrt{3} \approx 4.1$ GeV.



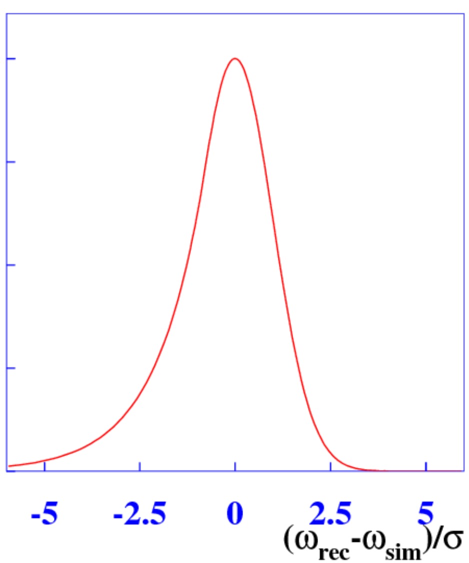
$\tau \to \mu\gamma$: background sources

- τ decays, direct ($\tau^+ \to \pi^+\pi^0\nu_\tau$) and combinatorial
- QED processes: $e^+e^- \to \mu^+\mu^-\gamma\gamma$, $e^+e^- \to e^+e^- \mu^+\mu^-\gamma$
- Continuum hadron production $e^+e^- \to qq$
- $\psi(2S)$ decays
- D-meson decays

Background from τ decays is studied in A.V.Bobrov and A.E.Bondar, arXiv:1206.1909, will be published in "Vestnik NGU".

MC simulation

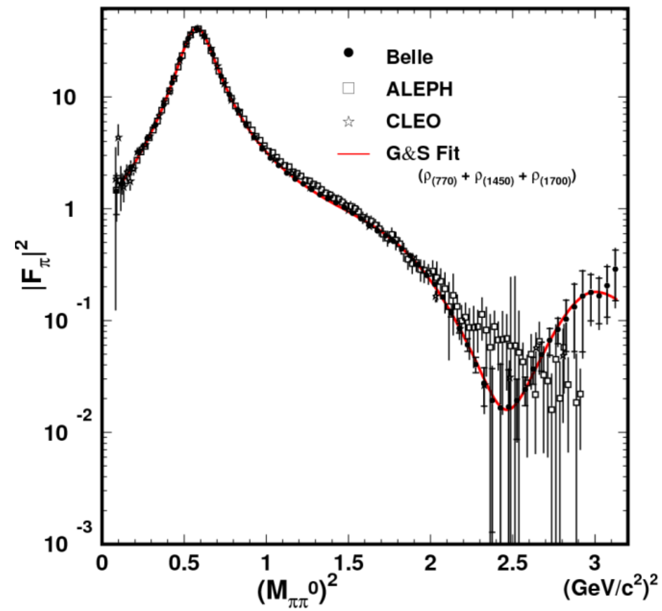
- Smeared generator level MC (TAUOLA)
- Acceptance: $20° < \theta < 160°$
- Charged tracks: $\Delta p_T/p_T = 0.5\%$ at 1 GeV/c
- Photons



  - Threshold – 20 MeV
  - Shower separation - 7°
  - Energy resolution: 1.5% or 2.5% at 1 GeV

MC simulation

- For most important background decay mode $\tau^+ \to \pi^+\pi^0\nu_\tau$, the form factor in TAUOLA was modified according recent Belle measurement.
- The signal decay $\tau \to \mu\gamma$ is simulated with the angular distribution $1+\alpha(\mathbf{nP})$, where **n** is the muon direction, and **P** is the τ polarization vector.



Selection criteria

- Signal side

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

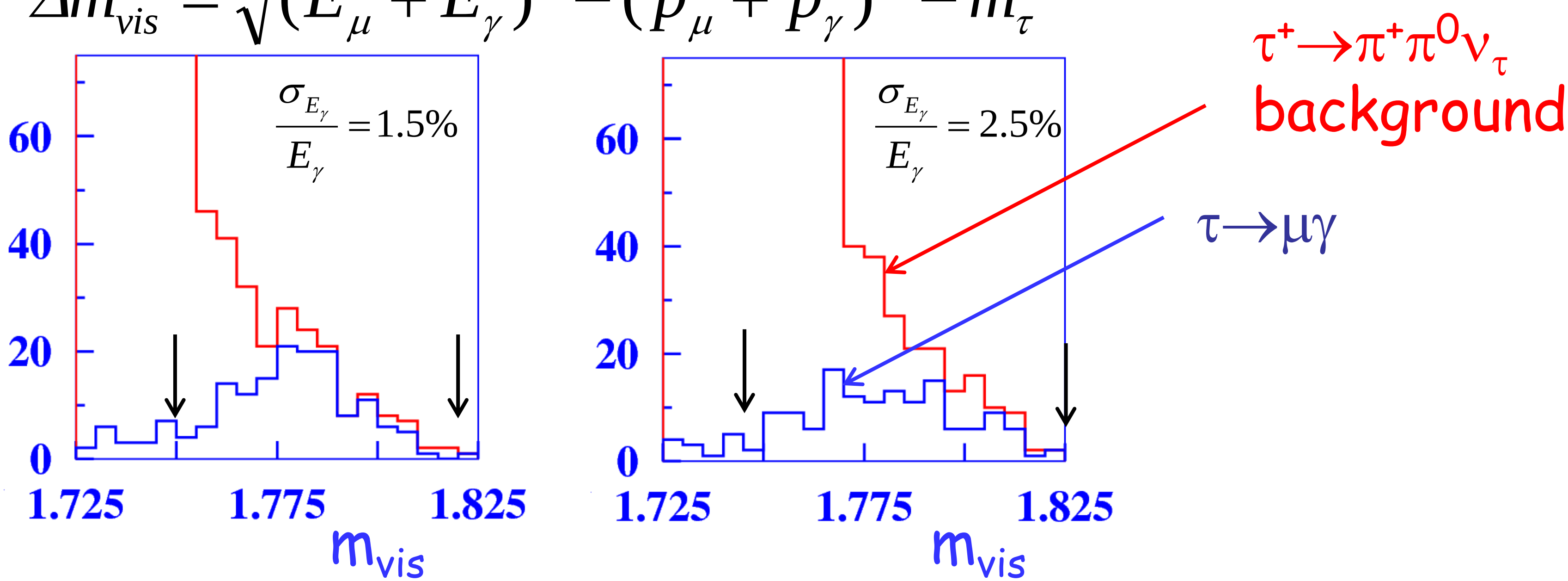
$$\Delta m_{bc} = \sqrt{E_{beam}^2 - (\vec{p}_{\mu} + \vec{p}_{\gamma})^2} - m_{\tau}$$

$$\Delta m_{vis} = \sqrt{(E_{\mu} + E_{\gamma})^2 - (\vec{p}_{\mu} + \vec{p}_{\gamma})^2} - m_{\tau}$$

+ π^0 veto

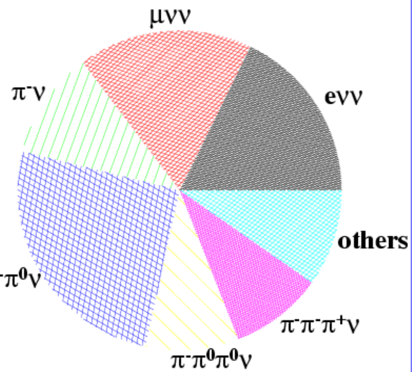
-Threshold – 20 MeV

-Shower separation - 7°



Selection criteria

- Tag side



Leptonic modes:

$$E_{mis} = 2E_{beam} - E_{\mu} - E_{\gamma} - E_{l}^{tag}$$

$$m_{\mu\nu\nu}^{2} = (2E_{beam} - E_{l}^{tag} + E_{\gamma})^{2} - (\vec{p}_{l}^{\,tag} + \vec{p}_{\gamma})^{2}$$

Semileptonic modes:

$$m_{mis}^{2} = (2E_{beam} - E_{h}^{tag} - E_{\mu} - E_{\gamma})^{2} - (\vec{p}_{h}^{\,tag} + \vec{p}_{\mu} + \vec{p}_{\gamma})^{2}$$

$$E_{mis} = 2E_{beam} - E_{\mu} - E_{\gamma} - E_{h}^{tag}$$

$$m_{\mu\nu}^{2} = (2E_{beam} - E_{h}^{tag} + E_{\gamma})^{2} - (\vec{p}_{h}^{\,tag} + \vec{p}_{\gamma})^{2}$$

...

Direct background

- $\tau^+ \to \mu^+ \gamma \nu_\mu \nu_\tau$, no events selected
- $\tau^+ \to \pi^+ \pi^0 \nu_\tau$

Signal: $B(\tau \to \mu\gamma) = 10^{-9}$, $N_{\tau\tau} = 3.2 \times 10^{10}$

E, GeV	σ_E/E=1.5%	σ_E/E=2.5%
3.686	25	22
3.77	24	21
4.17	16*	14*

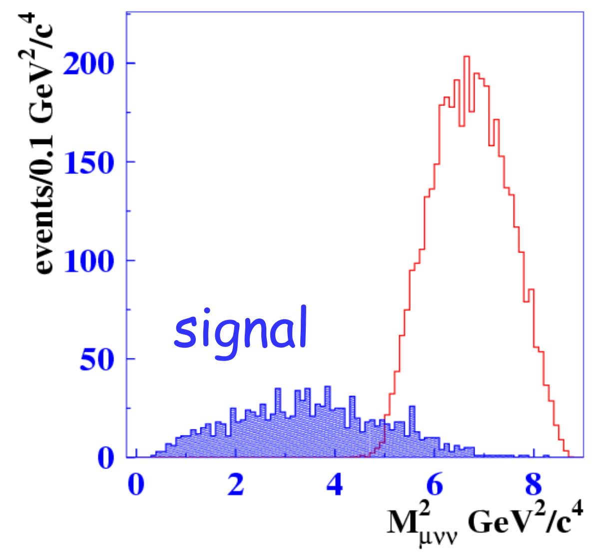
$N_{\tau\tau} = 3.2 \times 10^{10}$

σ_E/E=1.5%	e^-	μ^-	π^-	$\pi^-\pi^0$	$\pi^-\pi^+\pi^-$	$\pi^-\pi^0\pi^0$
3.686 ГэВ	3.5	5.1	8.2	18.2	3.7	3.2
3.77 ГэВ	5.9	6.3	8.3	18.7	4.6	3.2
4.17 ГэВ	10.7	12.8	12.0	24.2	5.0	4.0
σ_E/E=2.5%						
3.686 ГэВ	18.5	16.0	34.7	72.0	15.4	11.4
3.77 ГэВ	26.6	29.3	48.0	96.8	21.3	15.8
4.17 ГэВ	43.4	45.9	55.7	106.3	21.6	15.6

Combinatorial background

$$M^2_{\mu\nu\nu} = (2E_{beam} - E_l^{tag} + E_\gamma)^2 - (\vec{p}_l^{\,tag} + \vec{p}_\gamma)^2$$

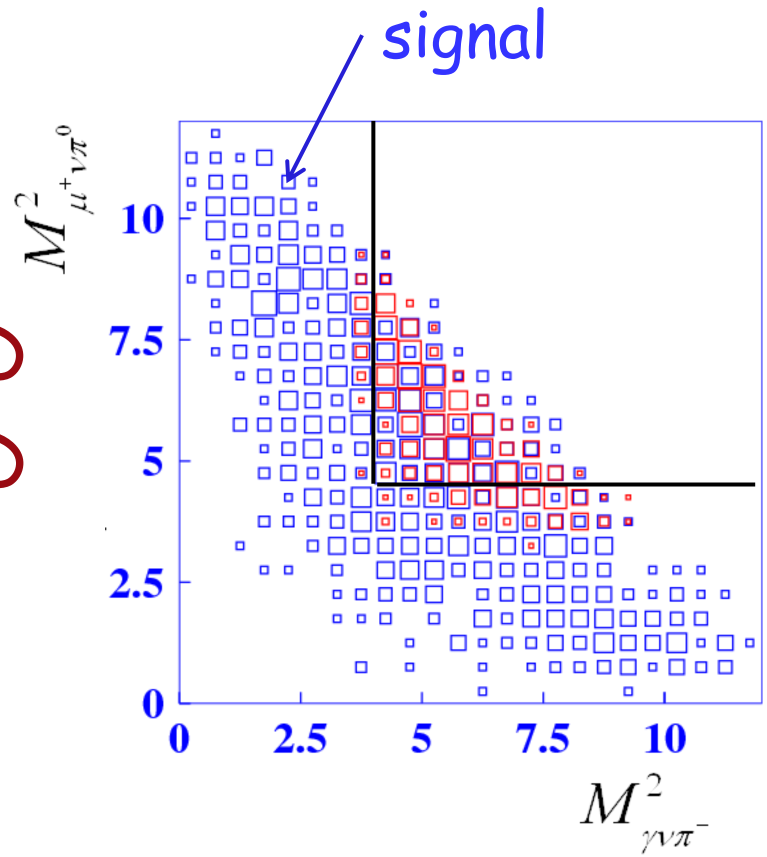
- $\tau^- \to e^- \nu_e \nu_\tau$ tag
  - $\tau^+ \tau^- \to \mu^+ \nu_\mu \nu_\tau + e^- \gamma \nu_e \nu_\tau$
  - $\tau^+ \tau^- \to \pi^+ \nu_\mu \nu_\tau + e^- \gamma \nu_e \nu_\tau$ misID
- $\tau^- \to \mu^- \nu_\mu \nu_\tau$ tag
  - $\tau^+ \tau^- \to \mu^+ \nu_\mu \nu_\tau + \mu^- \gamma \nu_\mu \nu_\tau$
  - $\tau^+ \tau^- \to \pi^+ \nu_\mu \nu_\tau + \mu^- \gamma \nu_\mu \nu_\tau$ misID
  - $\tau^+ \tau^- \to \mu^+ \nu_\mu \nu_\tau + \pi^- \pi^0 \nu_\tau$ misID
  - $\tau^+ \tau^- \to \pi^+ \nu_\tau + \pi^- \pi^0 \nu_\tau$ double misID



Combinatorial background

- $\tau^- \to \pi^- \nu_\tau$ tag
  - $\tau^+ \tau^- \to \mu^+ \nu_\mu \nu_\tau + \pi^- \pi^0 \nu_\tau$
  - $\tau^+ \tau^- \to \pi^+ \nu_\tau + \pi^- \pi^0 \nu_\tau$ misID
- $\tau^- \to \pi^- \pi^0 \nu_\tau$ tag
  - $\tau^+ \tau^- \to \mu^+ \nu_\mu \nu_\tau + \pi^- \pi^0 \pi^0 \nu_\tau$
  - $\tau^+ \tau^- \to \pi^+ \nu_\tau + \pi^- \pi^0 \pi^0 \nu_\tau$ misID
  - $\tau^+ \tau^- \to \pi^+ \pi^0 \nu_\tau + \pi^- \pi^0 \nu_\tau$ misID

Important parameters:
$|M^2_{mis}| < 0.1$ GeV^2,
$0.5 < E_{mis} < 1.0$ GeV



Combinatorial background

- $\tau^- \to \pi^-\pi^-\pi^+\nu_\tau$ tag
  - $\tau^+\tau^- \to \pi^+\pi^0\nu_\tau + \pi^-\pi^-\pi^+\nu_\tau$
- $\tau^- \to \pi^-\pi^0\pi^0\nu_\tau$ tag
  - $\tau^+\tau^- \to \pi^+\pi^0\nu_\tau + \pi^-\pi^0\pi^0\nu_\tau$

Important parameters:

- $|M^2_{mis}| < 0.1\ GeV^2$,
- $0.5 < E_{mis} < 1.0\ GeV$
- Different invariant masses

$N_{\tau\tau} = 3.2 \times 10^{10}$

	σ_E/E=1.5%	σ_E/E=2.5%
3.686 GeV	5.2	10.8
3.77 GeV	12.0	65.8
4.17 GeV	234.0	644.0

The $\tau^- \to \pi^-\pi^0\pi^0\nu_\tau$ tag mode is not used at 4.17 GeV.

Results

Signal: $B(\tau \to \mu\gamma) = 10^{-9}$, $N_{\tau\tau} = 3.2 \times 10^{10}$

	σ_E/E=1.5%	σ_E/E=2.5%
3.686 GeV	25	22
3.77 GeV	24	21
4.17 GeV	16*	14*

Muon background: $N_{\tau\tau} = 3.2 \times 10^{10}$

	σ_E/E=1.5%	σ_E/E=2.5%
3.686 GeV	7	10
3.77 GeV	9	14
4.17 GeV	12	18

Pion (direct from $\tau^+ \to \pi^+ \pi^0 \nu_\tau$) background: $N_{\tau\tau} = 3.2 \times 10^{10}$

	σ_E/E=1.5%	σ_E/E=2.5%
3.686 GeV	60 (42)	214 (168)
3.77 GeV	126 (47)	454 (238)
4.17 GeV	130 (65)*	338 (273)*

Results

E (GeV)	σ(nb)	L (ab^{-1})	$N_{\tau\tau}$ (10^{10})
3.686	5.0	1.5	0.75
3.77	2.9	3.5	1.03
4.17	3.6	2.0	0.71
Total		7.0	2.49

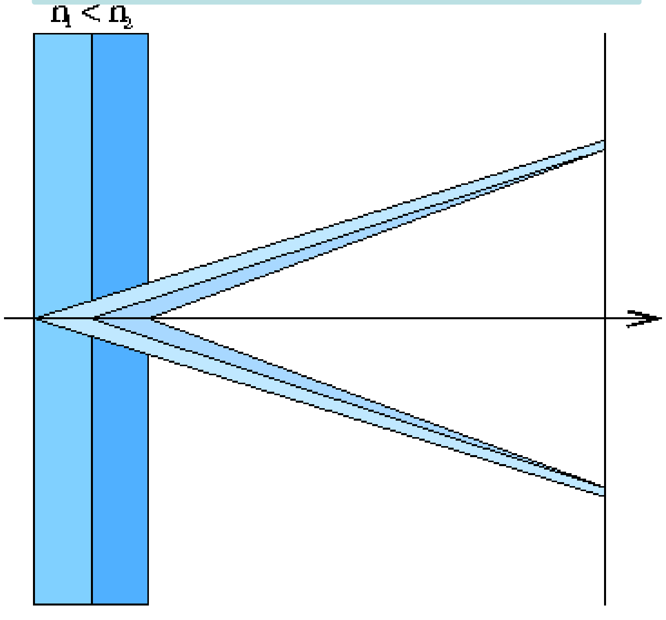
	σ_E/E=1.5%	σ_E/E=2.5%
Signal (Br=10^{-9})	17	15
Muon background	7	11
Pion background	83	271
Expected 90% CL upper limit for Br	1.1×10^{-9}	3.0×10^{-9}
Expected 90% CL upper limit for Br with pion suppression by a factor of 30	3.3×10^{-10}	5.1×10^{-10}

FARICH concept

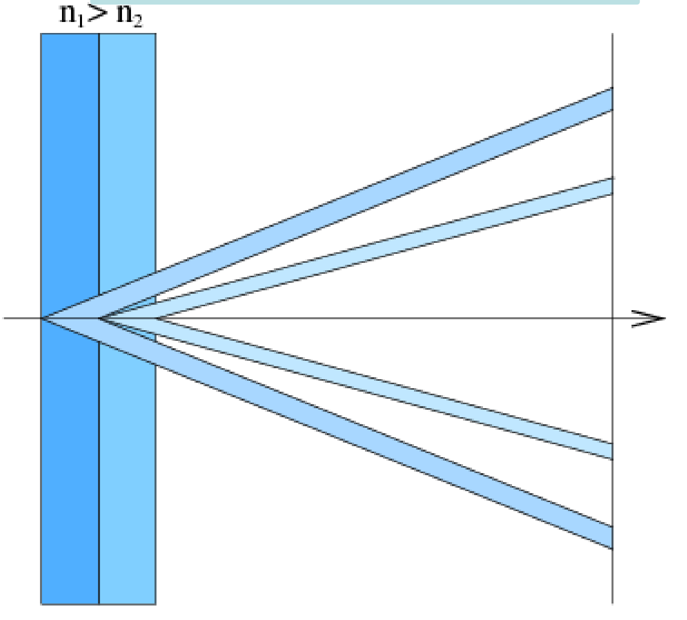
Focusing Aerogel RICH - FARICH

Employs aerogel with non uniform refractive index to minimize the contribution of the finite radiator thickness to Cherenkov angle measurement

Single ring option

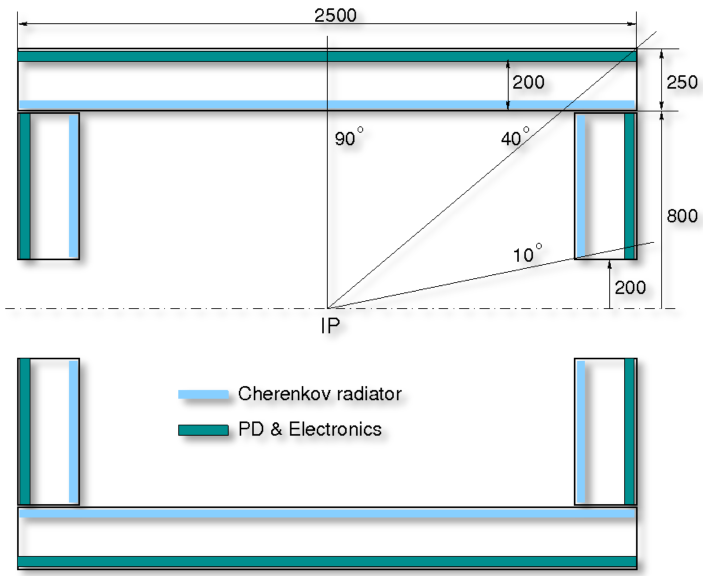


Multi-ring option

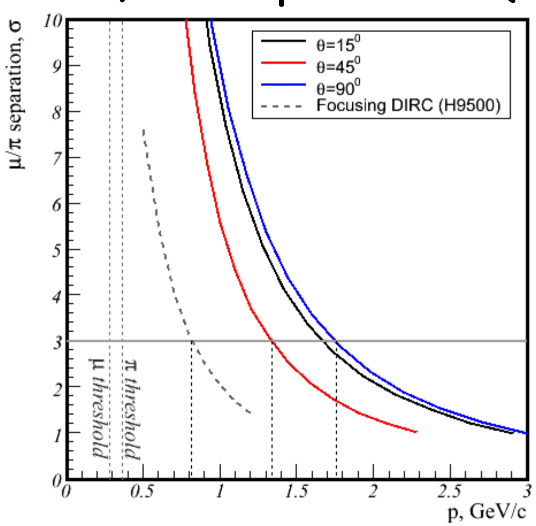


T.Iijima et al., NIM A548 (2005) 383
A.Yu.Barnyakov et al., NIM A553 (2005) 70

FARICH system



MC: μ/π separation (σ)



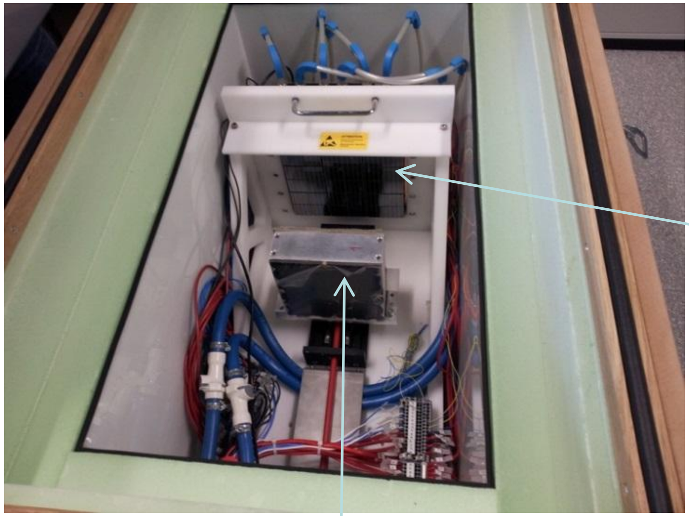
- μ/π/K/p separation in the momentum range not covered by DC (dE/dx) and muon system
- Radiator:
  - 4-layer aerogel with n_{max}=1.07
  - Total area: 17 m^2
- Photon detector:
  - SiPM (MPPC, DPC, …)
  - Total area: 21 m^2
  - ~10^6 pixels with 4mm pitch
  - Cooling to reduce dark current
- Readout:
  - FPGA-based TDC

  or

  - Digital Photon Counter (Philips)

FARICH prototype beam test

CERN PS/T10 beam channel, June 2012



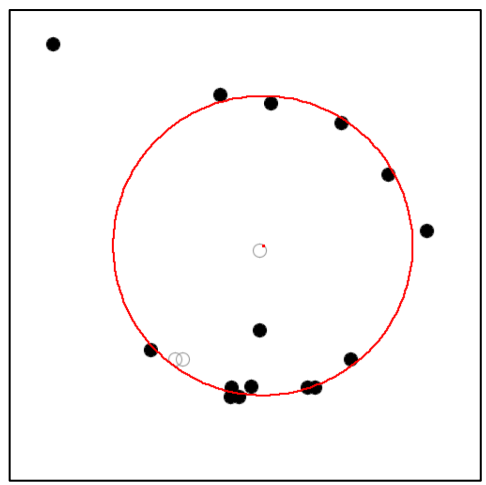
Philips DPC array 20x20 cm²

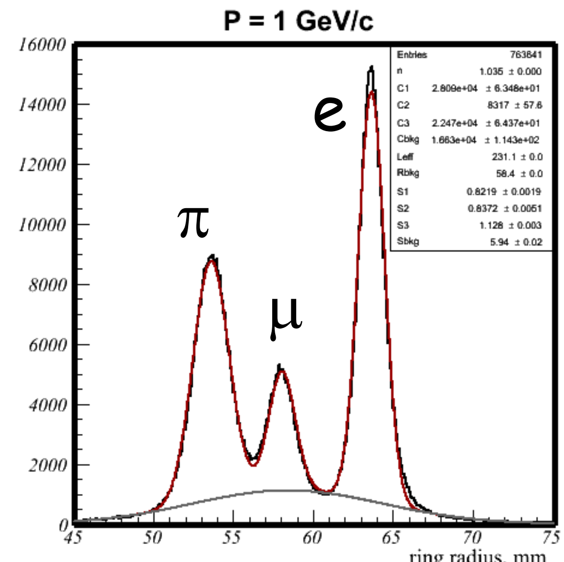
- Sensors: DPC3200-22-44
- 48x48 pixels 3.2x3.9 mm² (amplitude channels)
- 576 timing channels: 4 pixels per on-chip TDC
- 4 levels of FPGA readout
- Operated at -40°C

4-layer aerogel radiator

- n_{max} = 1.046
- Thickness 37.5 mm
- Calculated focal distance 200 mm
- Hermetic container with acrylic window to avoid moisture condensation on aerogel

Ring image





S.Kononov's talk at VCI'13

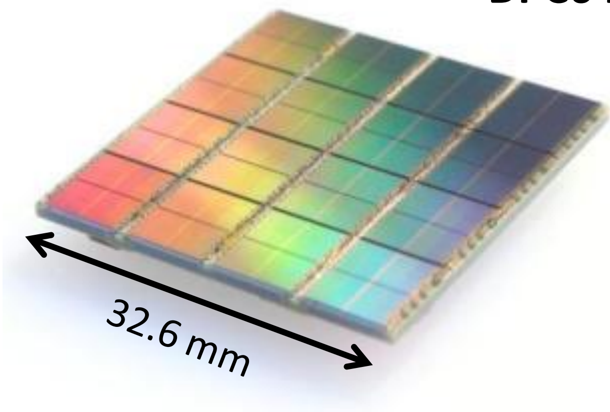
μ/π: 5.3σ @ 1 GeV/c

Conclusion

- Background for the LFV decay $\tau \to \mu\gamma$ from other τ decays has been studied using fast MC simulation
- The upper limit 3×10^{-9} can be reached without π/μ separation and 5×10^{-10} with pion suppression by a factor of 30
- Such separation in the momentum range 0.5-1.5 GeV/c may be obtained with FARICH technique
- Work on analysis of other background sources is in progress.

DPC is an Integrated "Intelligent" Sensor by Philips Digital Photon Counting

DPC3200-22-44 – 3200 cells/pixel
DPC6400-22-44 – 6396 cells/pixel



FPGA
- Clock distribution
- Data collection/concentration
- TDC linearization
- Saturation correction
- Skew correction

Flash
- FPGA firmware
- Configuration
- Inhibit memory maps