Liquid noble gases option of the calorimeter for c-tau detector

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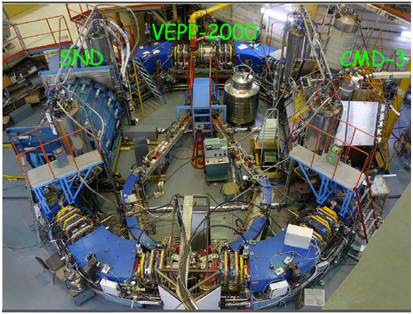
Introduction

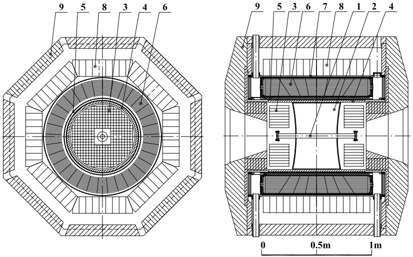
- Main option for C-Tau Factory Detector – calorimeter based on pure CsI crystals with photopenthode or APD light readout
- Other options shoud be dicussed also
- Calorimeters based on liquid nobel bases at BINP : CMD-3 and KEDR detectors
- Fine granularity gives high spatial resolution and dE/dx measurements for charged particles
- Liquid Xe – highest density and shortest radiation length

Liquid noble gases parameters

Parameter	**Xe**	**Kr**	**Ar**
Z	54	36	18i
A	131.29	83.8	39.95
ρ, g/cm^3	2.95	2.42	1.40
X_0, cm	2.87	4.7	14.0
R_M, cm	5.22	5.86	9.04
$(dE/dx)_{min}$ Mev/cm	3.71	3.28	2.11

VEPP-2000 and CMD3 @ BINP





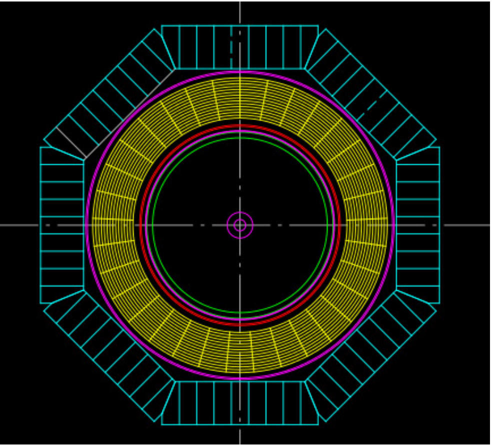
1 – Be beam pipe, 2 – drift chamber, 3 – BGO calorimeter, 4 – Z-chamber, 5 – superconducting solenoid, 6 – LXe calorimeter, 7 – TOF, 8 – CsI calorimeter, 9 – yoke

VEPP-2000

- $E_{c.m.s.} = 0.32 \div 2$ GeV
- round beams $\sigma_x = \sigma_y$
- $L_{exp.max} = 2 \cdot 10^{31} \mathrm{cm}^{-2}\mathrm{c}^{-1}$

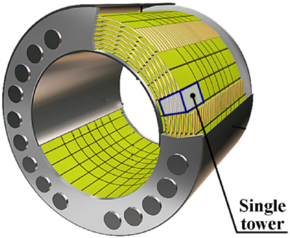
CMD-3

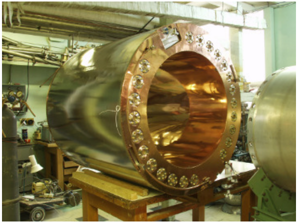
- Calorimetry is based on three subsystems: LXe and CsI barrel calorimeters and BGO endcap calorimeter



- Liquid Xenon calorimeter 5.4 X_0
- CsI(Tl) crystal calorimeter 8.1 X_0
- Full width $13.5X_0$, $\sigma_E/E = \frac{0.036}{\sqrt{E/GeV}} \oplus 0.027$
- Spacial resolution $\approx 2mm$
- Passive material between calorimeters $0.25X_0$
- Passive material in front of LXe $0.35X_0$

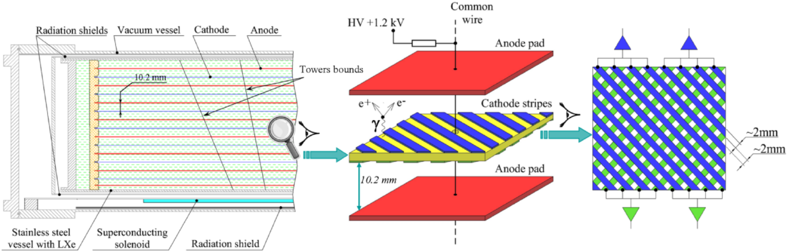
LXe calorimeter





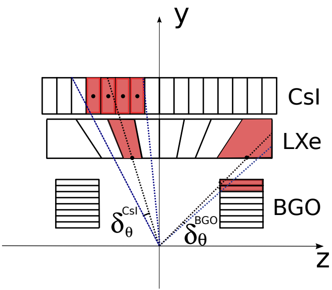
Solid angle coverage	$0.8 \times 4\pi$
Thickness	15 cm ($5.4X_0$)
Attenuation length of electrons	15–20 mm
Electric field in the gap	$E \sim 1.2$ kV/cm
Max. drift time of electrons in the gap	4.5 μs
Num. of electronics channels	2112 + 264
Anode channels sensitivity	~14 000 el/MeV
Anode channels noise	~3000 e (0.22 MeV)
Cathode channels average amplitude	~36 000 e
Cathode channels noise	~2000 e
LXe volume	400 l (1200 kg)
Start-up time (xenon filling)	~30 h
Draining time	~20 h
Liquid nitrogen consumption	~150 l/day
LXe temperature	~175 K
LXe pressure	~1.5 bar

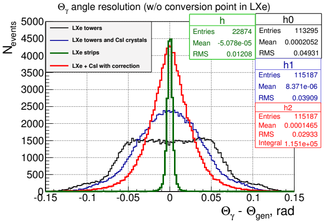
Electrodes structure

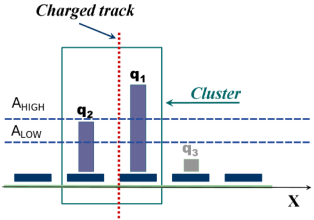


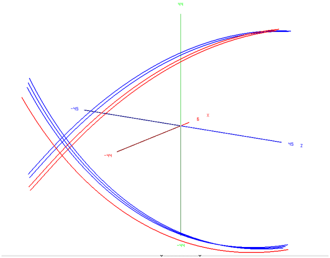
- 14 inonization chambers with 10.2 mm gap : 8 anode and 7 cathode cylinders
- Anodes are divided into ($\sim 8.5 \times 10\,\mathrm{mm}$) pads forms 264 "towes" to measure energy deposition :
  8 towers along Z-axis
  33 along ϕ angle
- Angular size of the tower is $\approx$0.2 rad
- Cathode cylinders are devided into 2112 semi-transperent strips for precise coordinate measurement
- Strip size is about 16 cm

Reconstruction







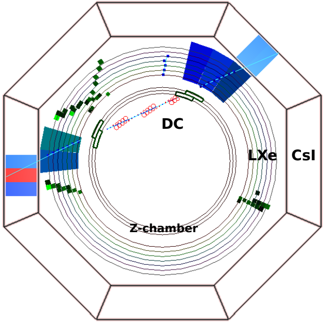


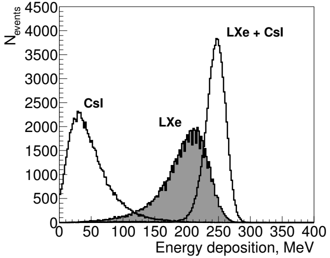
Cosmic

- Tracks reconstructed in LXe are used
- Specific energy losses in LXe and CsI
  $\epsilon = E/L$

Bhabha

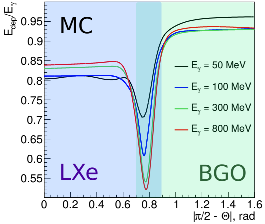
- Only LXe calorimeter
- $e^+e^- \to e^+e^-$ events
- $$\chi^2 = \sum_{n=1}^{N} \frac{(E^j_{mc}(\theta,\phi) - \sum E^n_i k_i - E^n_{CsI})^2}{\sigma^2(\theta)}$$
  $\chi^2 \to min \Rightarrow$
  System of the linear equations on k_i



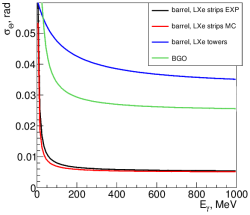


γ reconstrution

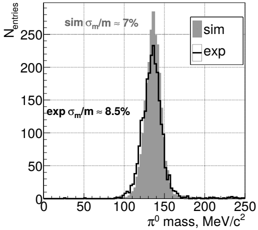
Shower leackage correction



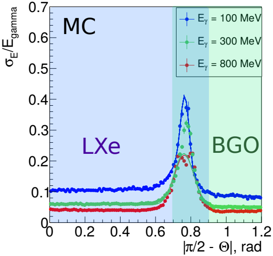
Θ resolution



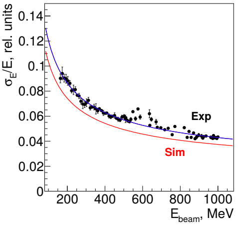
π^0 mass resolution



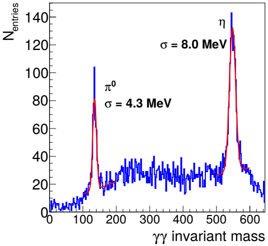
resolution vs Θ



Energy resolution

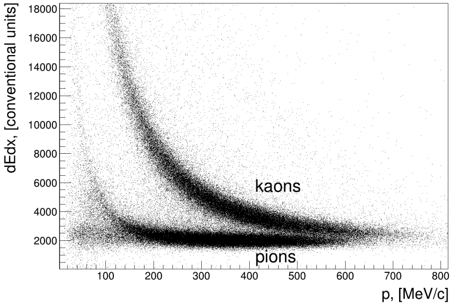


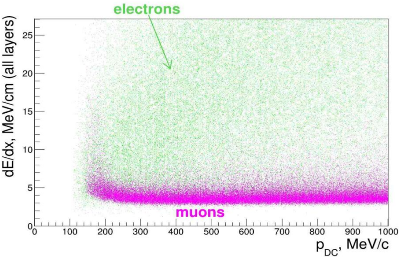
kinematic fit

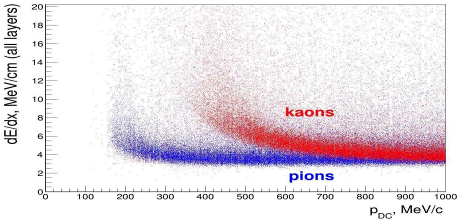


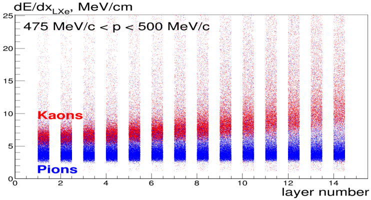
K/π separation (V.Ivanov)

- dE/dx measurements in LXe layers give additional information for particle identification

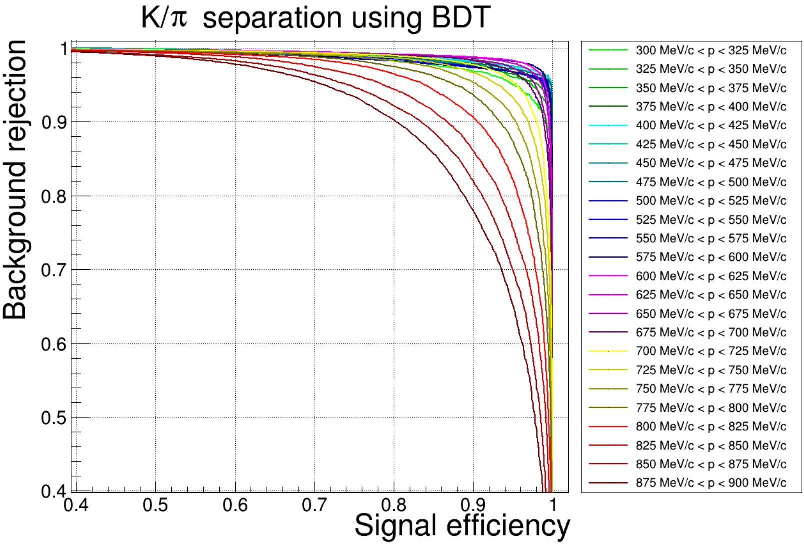




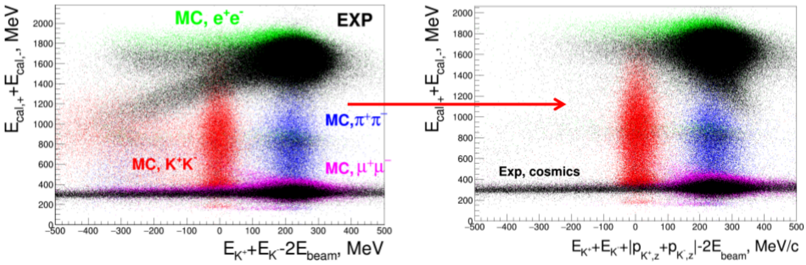




K/π separation

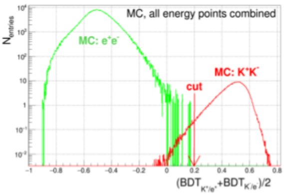


Example: selection of $e^+e^- \to K^+K^-(\gamma)$ at $\sqrt{s} > 1.8$ GeV

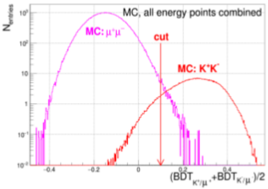


- Background suppression via cuts on BDT responses:

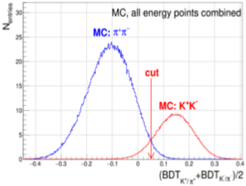
electrons



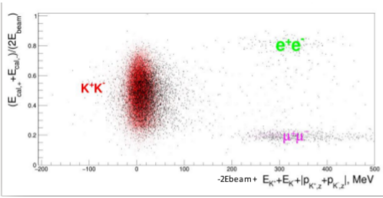
muons

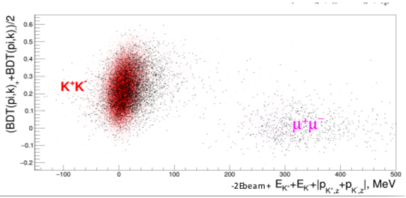


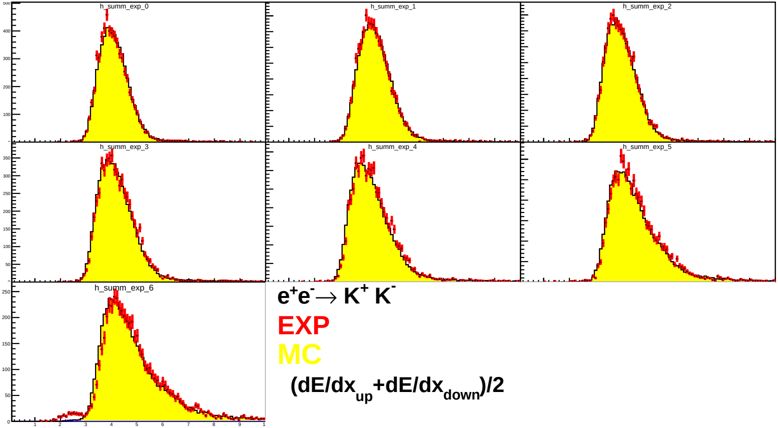
pions



K/π separation







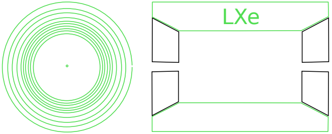
Main disadvantages

- The Xe vessel is made of stainless steel with wall width 3.7 mm and 3 mm
- Width of outer wall of vacuum vessel is 4 mm
- Significant ammount of passive material between LXe and CsI of about $0.25X_0$
- High angular size of towers of about $12^\circ \rightarrow$ significant drop of the reconstruction efficiency for high energy π^0

Possible improvements

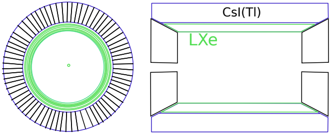
- Aluminium walls of the Xe vessel, optimize mechanical structure $\rightarrow$ reduce passive material between calorimeters to about $0.05X_0$
- Strip size 10 mm $\rightarrow$ 5 mm
- Reduce gap size to about 5mm
- Strips readout from both calorimeter endcaps $\rightarrow$ reduce strips area

Homegenious LXe calorimeter



- Width 46 cm (16 X_0)
- mass 26 ton
- Xe cost (2-5 \$/g): 52 – 130 M\$ depending on purity
- $\sim 50,000 - 100,000$ channels of electronics depending on segmentation

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 : $\sim$ 15M\$
- $\sim 20,000$ channels of electronics

- Excelent spacial resolution better than 1mm (0.06°)
- Reconstruction of the point of converstion γ-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:
  - Low energy γ rate $\sim 0.05 MHz/cm^2$
  - Strip area $\approx 75 cm^2$, pilup rate $\sim 0.2 MHz$ 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

Conclusion

- Liquid Xe option is interesting as additional to basiline option with pure CsI crystals
- We can start to study the parameters which can be acheived using existent simulation of the calorimeter of CMD-3 detector
- Amount of reserve Xe volume is enough for R&D and prototyping