The τ/charm Factory Detector

An Opinionated Summary

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Orsay
Tau/CharmWorkshop
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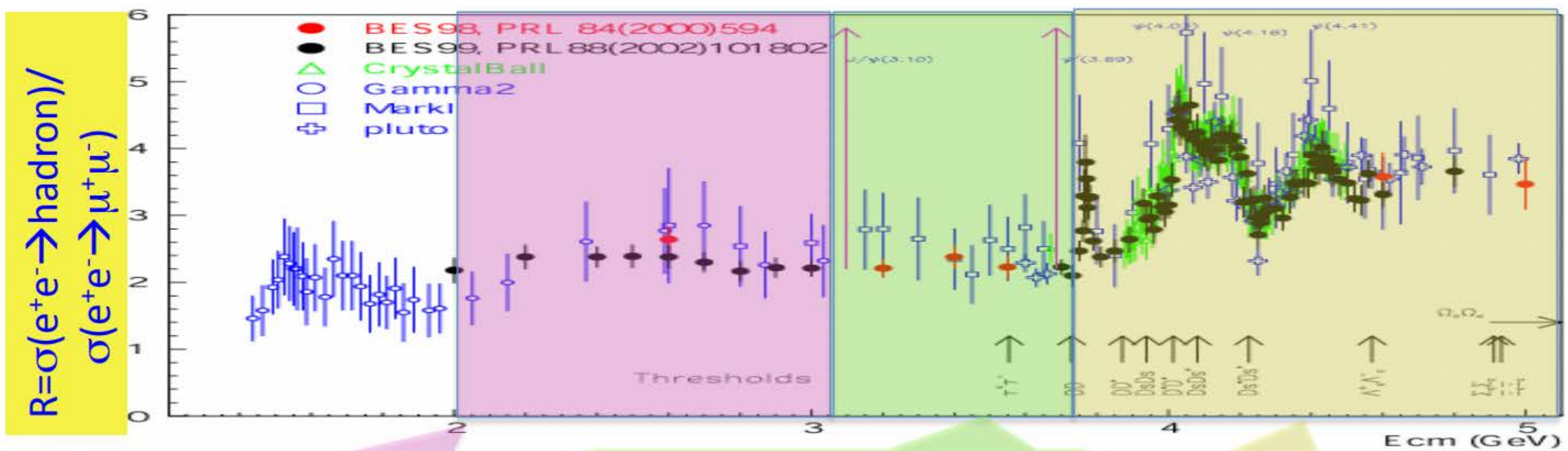
Summary of options for a τ/charm detector

- Summarizing Thursday's many interesting presentations, especially in the light of the Musée Orsay visit, was a daunting assignment
  - I want to thank all those contributors who provided me with drafts of their talks in advance to help turn the making of this summary into a tractable problem
    - I apologize to those whose work I was not able to fit into the talk
  - I will not provide a step-by-step condensation of everything that was presented
  - I will attempt to use "SCTF" for the BINP and "STCF" for the Hefei detectors
  - Rather, I will present the various viable options for each of the tasks that an appropriate τ/ charm factory detector must have
  - Other considerations that go into constructing a coherent detector design that matches the desires, technical capabilities, funding sources and political realities of the collaboration are left as an exercise
  - I will sprinkle here and there some comments and questions

Physics opportunities in the τ/c region



- Hadron form factors
- Y(2175) resonance
- Mutltiquark states with s quark, Zs
- MLLA/LPHD and QCD sum rule predictions

- Light hadron spectroscopy
- Gluonic and exotic states
- Process of LFV and CPV
- Rare and forbidden decays
- Physics with τ lepton

- XYZ particles
- D mesons
- f_D and f_{Ds}
- D_0-$\bar{D}_0$ mixing
- Charm baryons

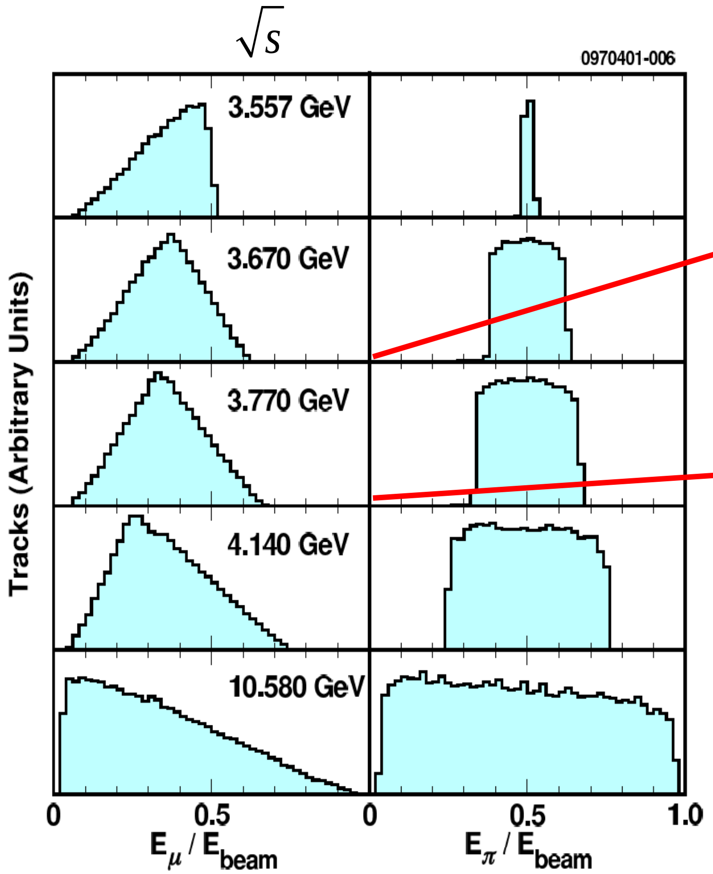
S.Olsen HIEPA 2015 Workshop

The demands on detector performance differ somewhat in different $\sqrt{s}$ regions

Event characteristics

- Topics of interest (general)
  - Charmonium states (J/ψ, $\psi(2S)$, ……
  - Charm production and decay ($\psi(3770)$, 4.03, 4.16, (Λ_c ,,,)
  - τ production and decay (for some modes below charm threshold, at the best e^- polarization (if it is part of the design)
- The operational situation is different from that at the B factories, where the large majority of running time was spent at the $\Upsilon(4S)$, with much less time at the other Υ resonances
  - At a τ/c factory, different physics $\Rightarrow$ different CM energies $\Rightarrow$ prioritization
  - This is closely connected with optimization of the collider
    - How much luminosity is needed at each CM energy to do the physics?
- Detector requirements must be matched to event characteristics, with emphasis on what is required to attack the most important physics objectives (see above) (τ LFV, *CP*V in *D* decay, …….)
  - Efficient exclusive state reconstruction (+ tagging efficiency and purity) and background discrimination
    - Best possible solid angle coverage and resolution for
      - Charged particle momentum measurement . 05 < p < 1.6 GeV/c
      - Particle identification (dE/dx, TOF, Cherenkov, range) .05 < p < 1.6 GeV/c
      - Photon reconstruction (efficiency, energy and position resolution) .02 < p < 1.6 GeV/c

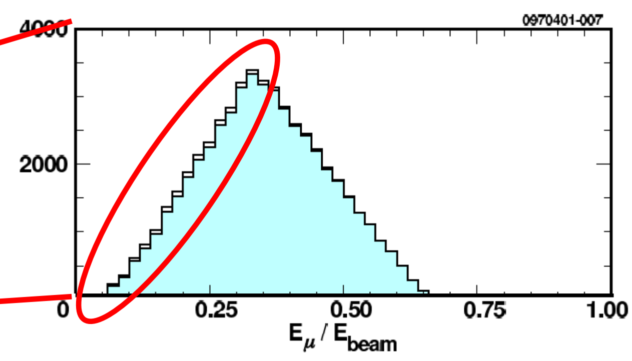
τ decay two and three body momentum spectra



$\tau^- \to \mu^- \bar{\nu}_\mu \nu_\tau$

$\tau^- \to \pi^- \nu_\tau$

Michel parameter η

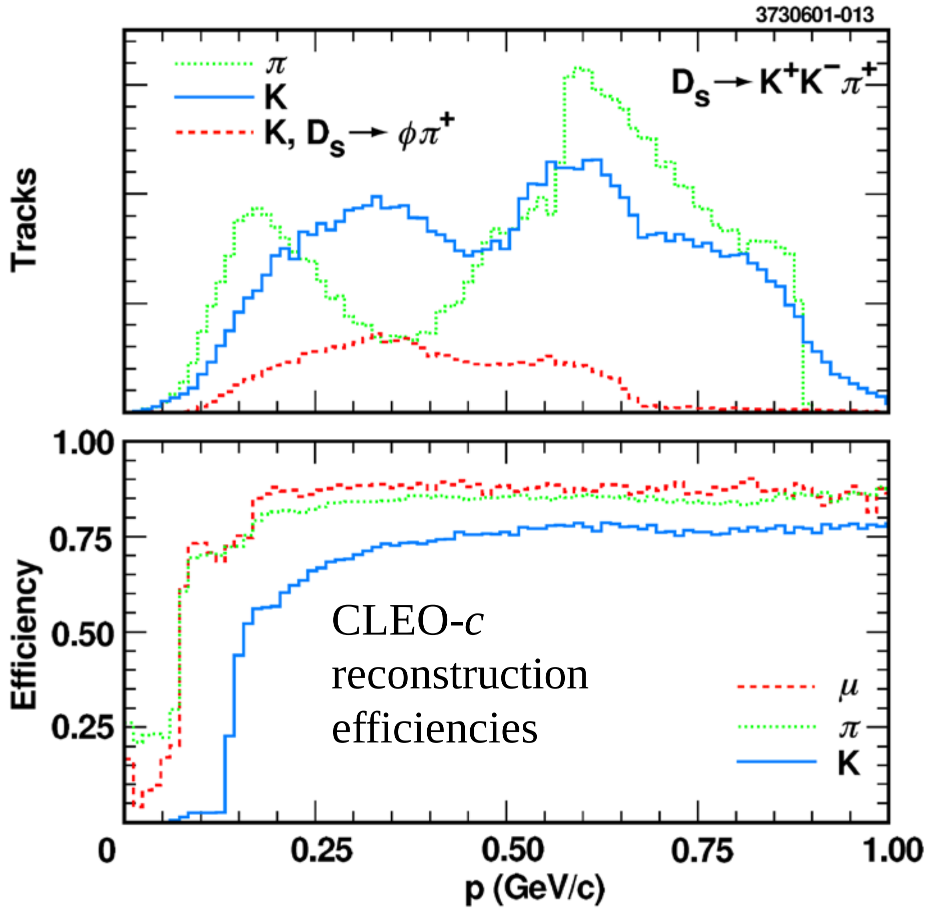


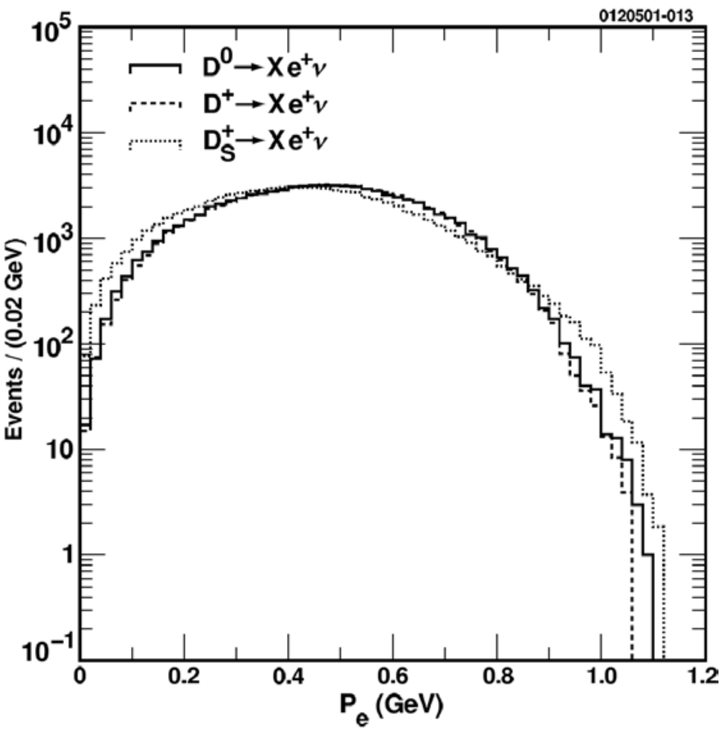
$\eta = 0$

$\eta = 0.2$

$\sqrt{s} = 3.77$

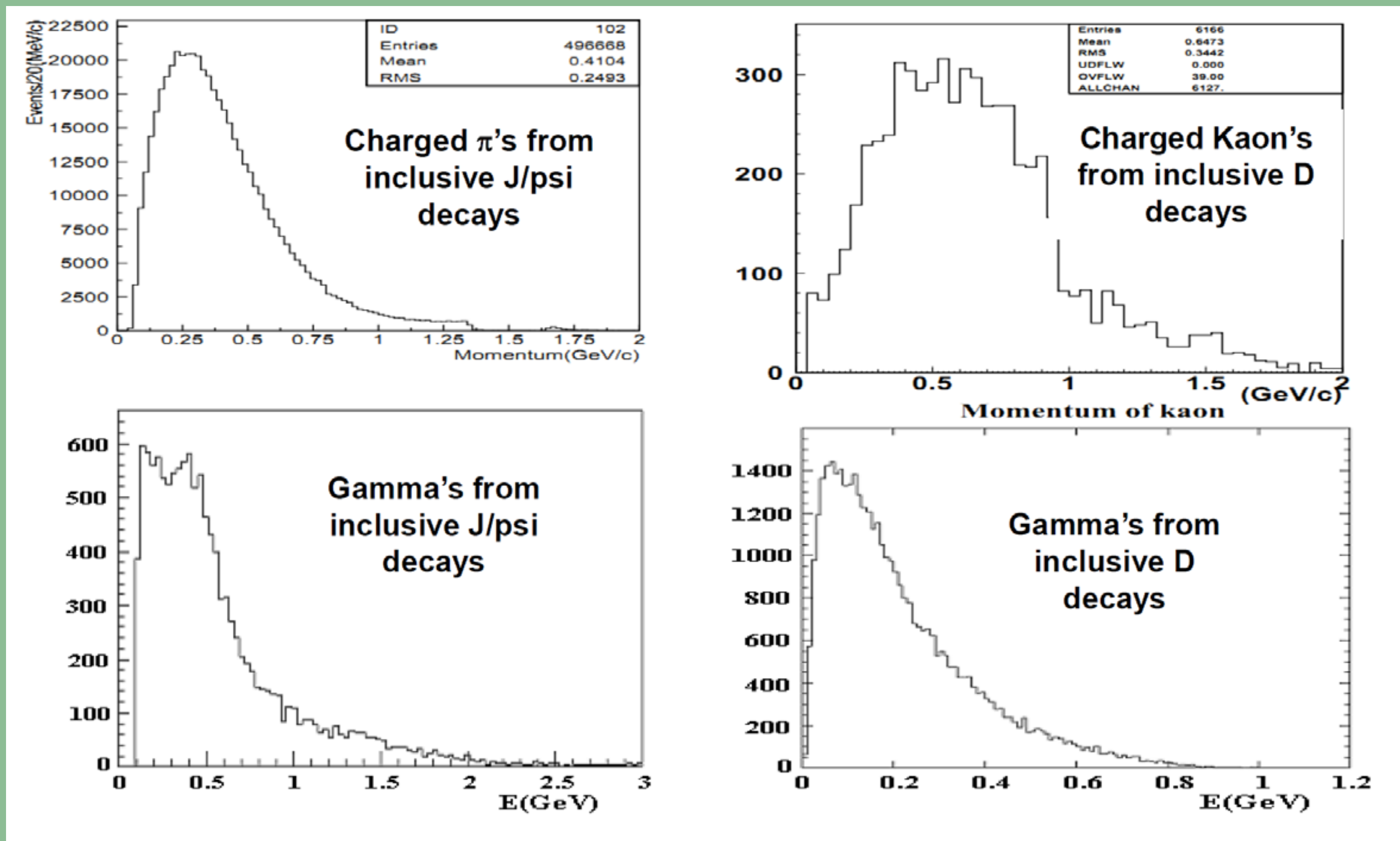
D_s^+ decays – typical momentum spectra





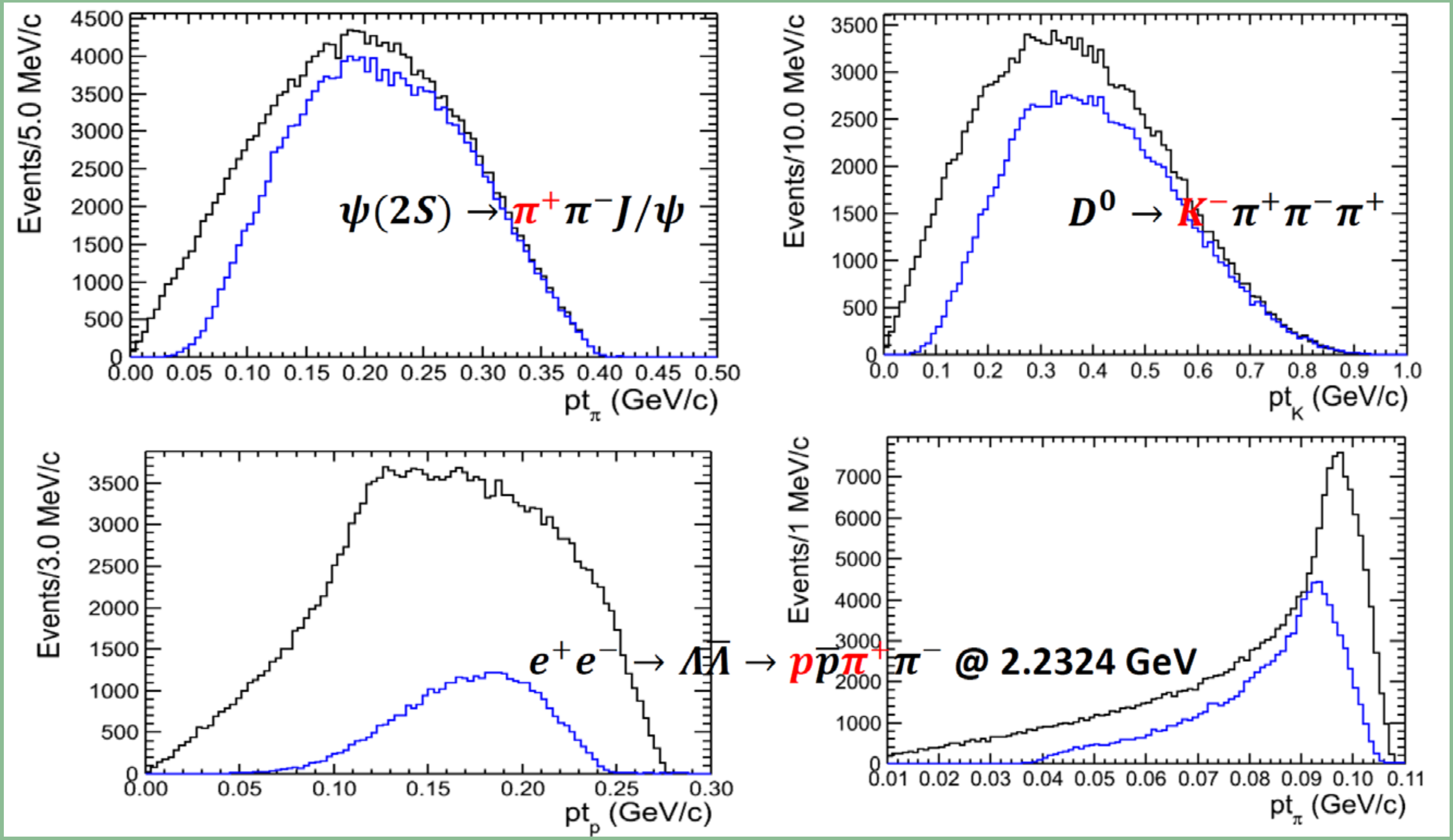
semileptonic D decay:
electron momentum spectra

Inclusive spectra



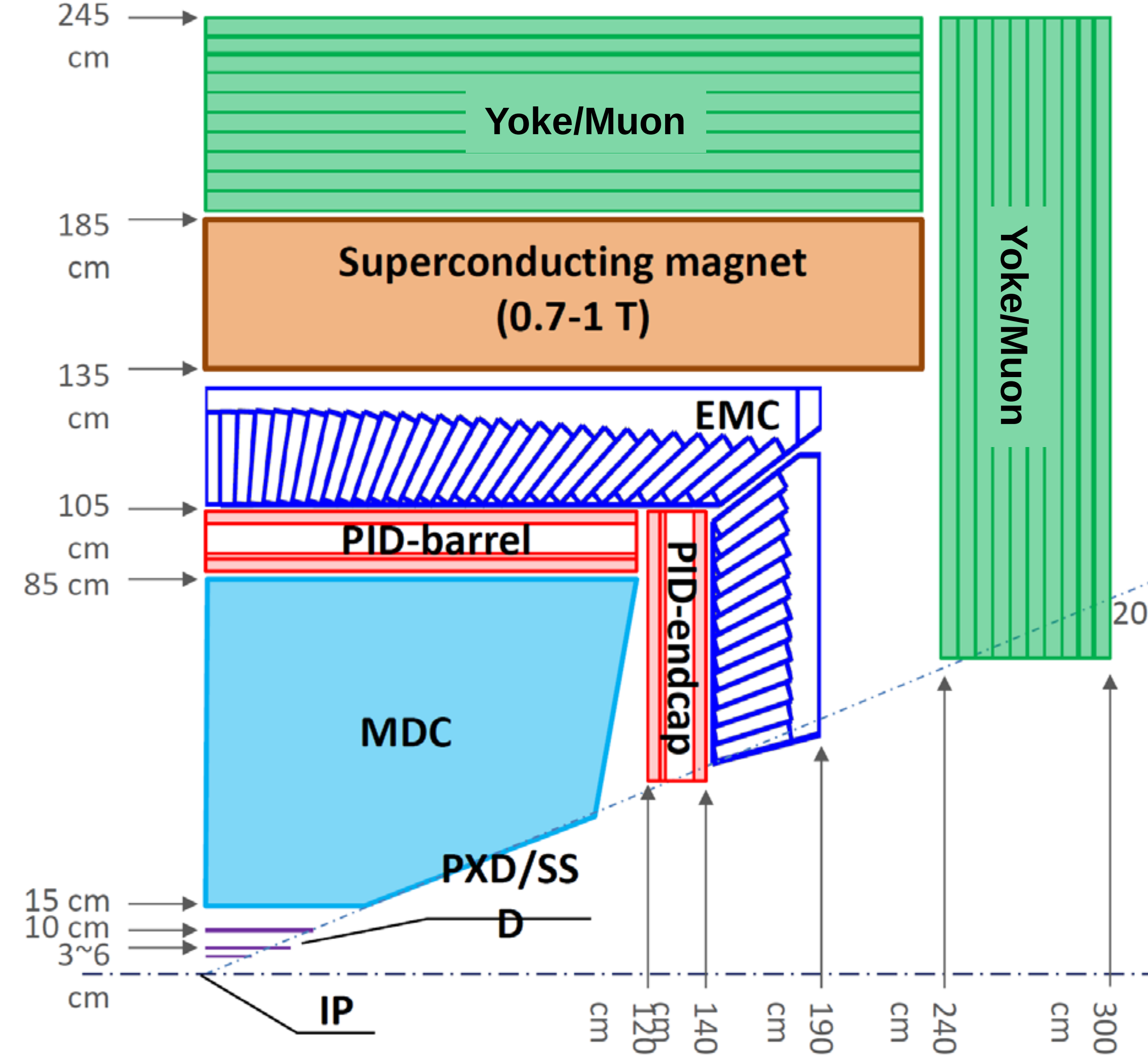
Low momenta matter

- Low momentum tracking efficiency and momentum are important



Should the particle ID system be able to tell a p from a K or π?

STCF concept - Hefei



MUD
- μ/π suppression power >10/30

EMC
- Energy range: 0.02-2.5 GeV
- At 1 GeV σ_E (%)
  - Barrel(Cs(I): 2
  - Endcap (Cs): 4

PID
- π/K (and K/p) 3-4σ separation up to 2GeV/c

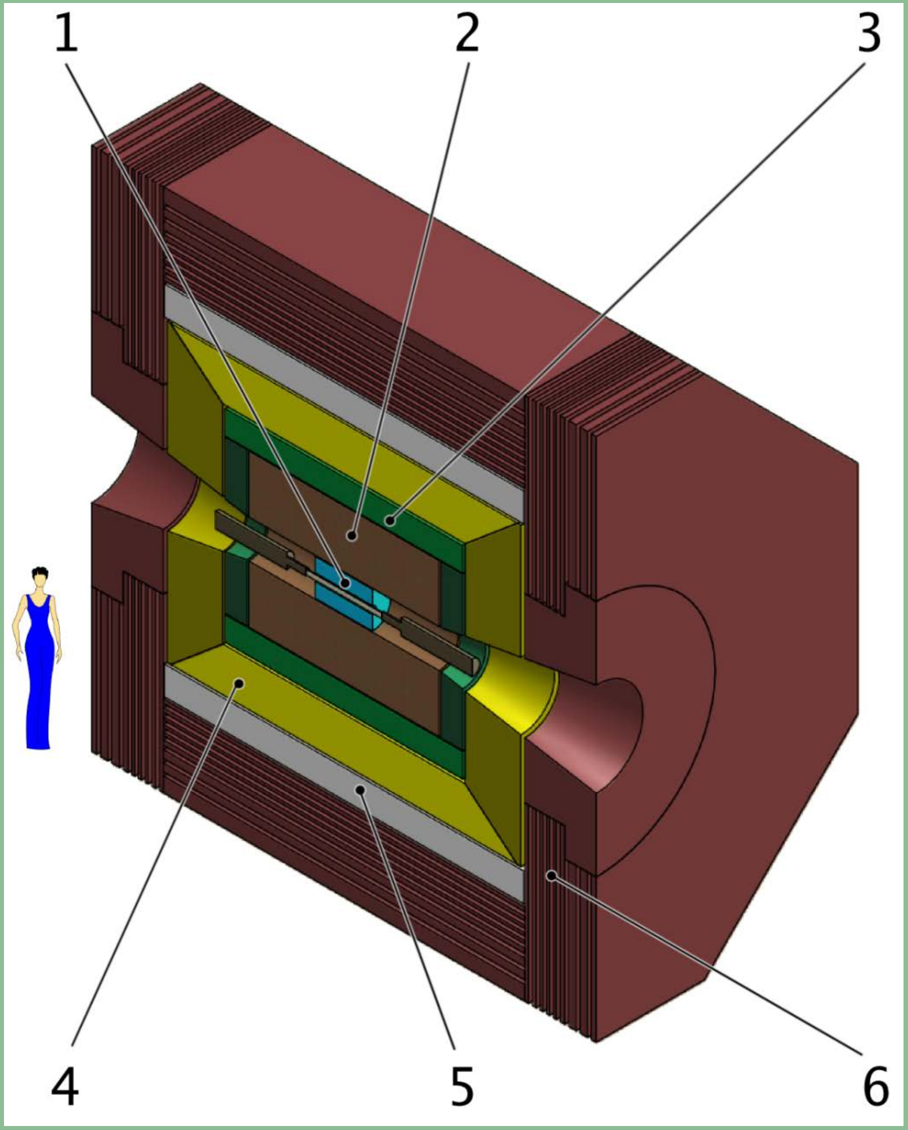
MDC (Low mass)
- σ_{xy}=130 mm
- dE/dx<7%, σ_p/p =0.5% at 1 GeV

PXD
- Material budget ~0.15%X_0/layer
- σ_{xy}=50 mm

SCTF detector - BINP

Standard set of subsystems

1 – Inner Tracker
2 – Drift Chamber
3 – PID => FARICH
4 – EMC
5 – Superconducting Solenoid
6 – IFR



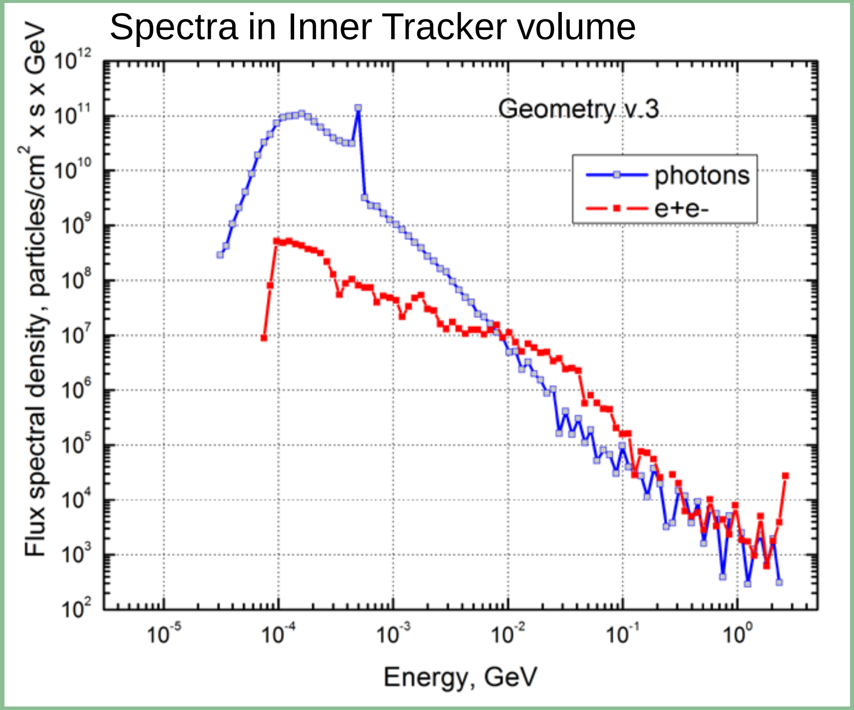
c-τ backgrounds

Main physical background sources:
Two-photon processes $e^+e^- \to \gamma^*\gamma^* \to e^+e^-e^+e^-$ 6 mb (at 3.5 GeV per beam)

Radiative Bhabha ($\theta > 5$mrad, $E\gamma > 3$ MeV) 1.7 mb (at 3.5 GeV per beam)

With 10^{35} cm^{-2}s^{-1} there are ~8×10^8 background events per second

If frequency of bunch crossings is 2×10^8 there are ~4 events per crossing, ~8 background particles with $\theta > 5$mrad
Charge particles rate in the region of Inner Tracker 10^5 – 10^3 cm^{-2}s^{-1}
Occupancies are too high for straw tubes or for a compact drift chamber
Occupancies for other options of IT are acceptable
1 MeV n-equivalent flux for Si is below 10^{11} n/cm^{2}y
Absorbed dose is below 100 Gy/y
Rad-tolerant are electronics required



Shekhtman

SCTF inner tracker options

- A low mass, large solid angle detector that can reconstruct tracks down to a p_T of ~55-60 MeV/c would be a desirable component, provided that it did not damage momentum resolution of other tracks too much
  - Detect secondary vertices from decays of K^0_S or Λ
  - Complement the drift chamber in measuring momenta
  - Soft $\pi^{\pm}$ meson registration (with momenta < 100 MeV/c)

***n.b.* pions below 50 Mev/c do not get out of the beam pipe**

- Maltsev, *et al*. have simulated three options with these properties
  - Sits between vacuum chamber and main tracker
  - Up to 98% solid angle coverage
  - Cylindrical: L 60 cm, ID 3 cm. OD 40 cm
- IT mist handle particle flux associated with luminosity of 10^{35} cm^{-2} s^{-1}

option/subsystem	Materials	Thickness (X0)
Vacuum Pipe	3 mm Be + 0.5 mm paraffin	1%
TPC	2x(1mm glass fiber (G10) + 0.1 mm teflon +15 μm copper)	1%
CGEM	4x(0.25 mm kapton + 40 μm copper)	1.2%
Si-strips	4x(0.32 mm Si + 0.4 mm carbon fiber)	2.4%

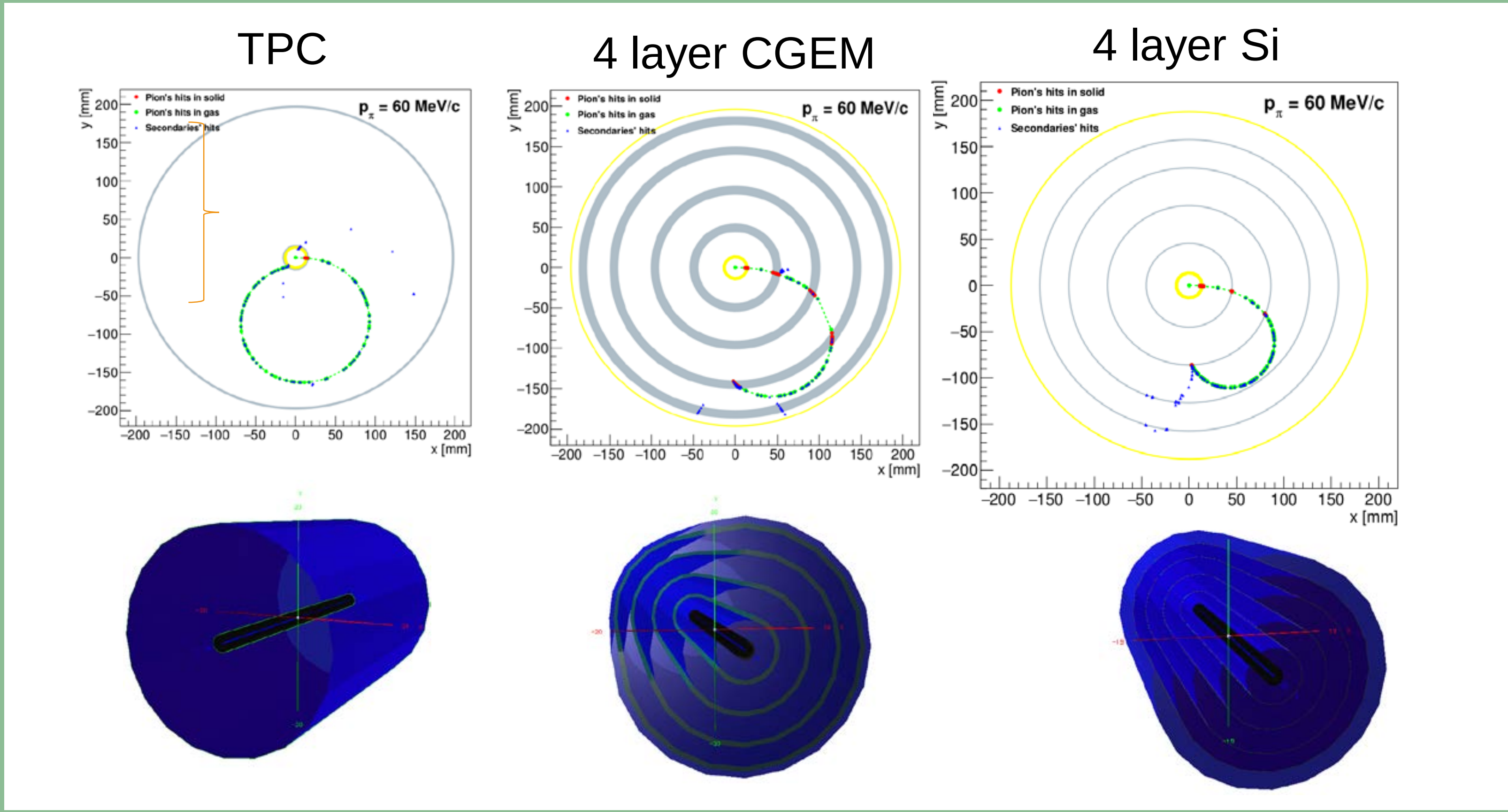
Occupancies are too high for straw tubes and for a compact drift chamber

Maltsev

Inner tracker simulation

- For three options a detailed simulation of track generation has been done – next step is reconstruction with backgrounds

Are three or four hits sufficient to efficiently reconstruct these very low momentum tracks in the presence of background, or is it necessary to have the more complete information from a TPC or μRWELL in TPC mode?



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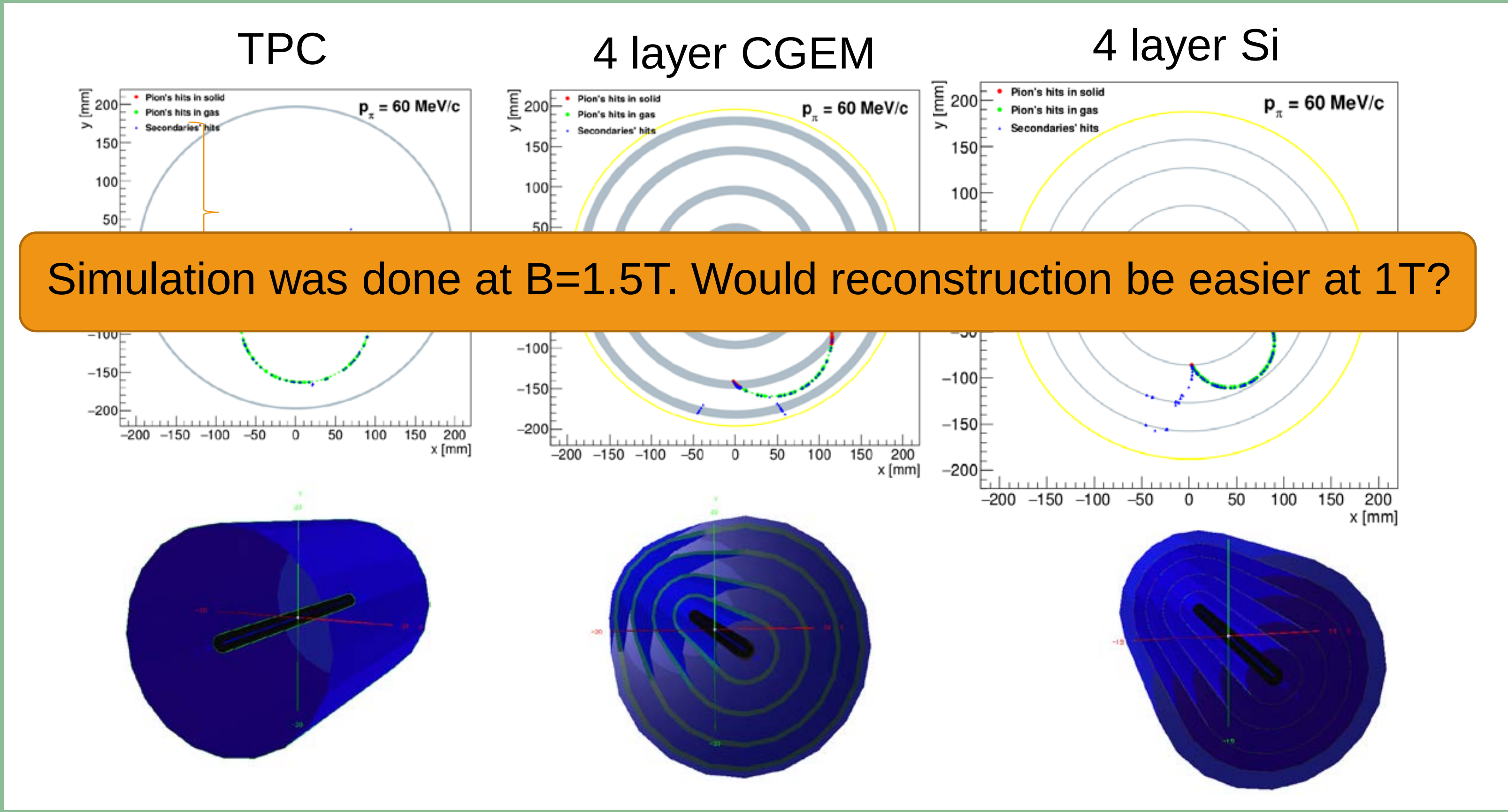
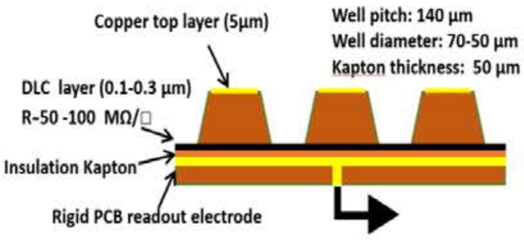


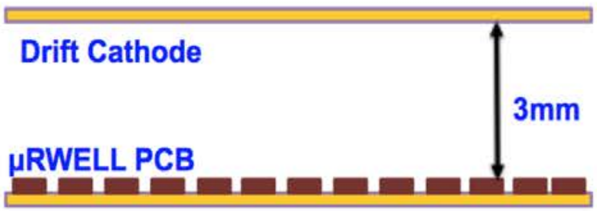
Simulation was done at B=1.5T. Would reconstruction be easier at 1T?

Maltsev

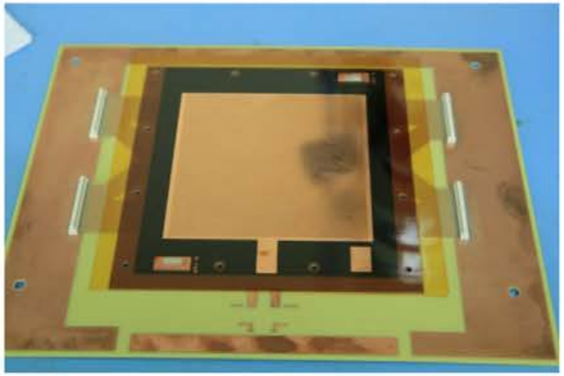
STCF inner tracker μRWELL

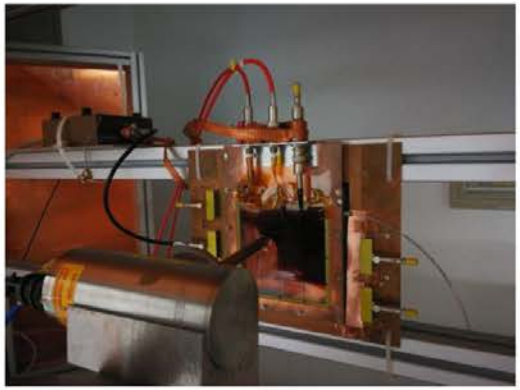
Very compact, spark protected, simple to assemble, flexible in shapes (rather easy to make a cylindrical detector)

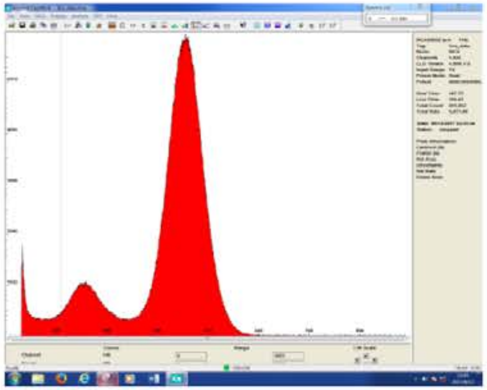




A possible solution to be inner tracking, R&D underway at USTC.

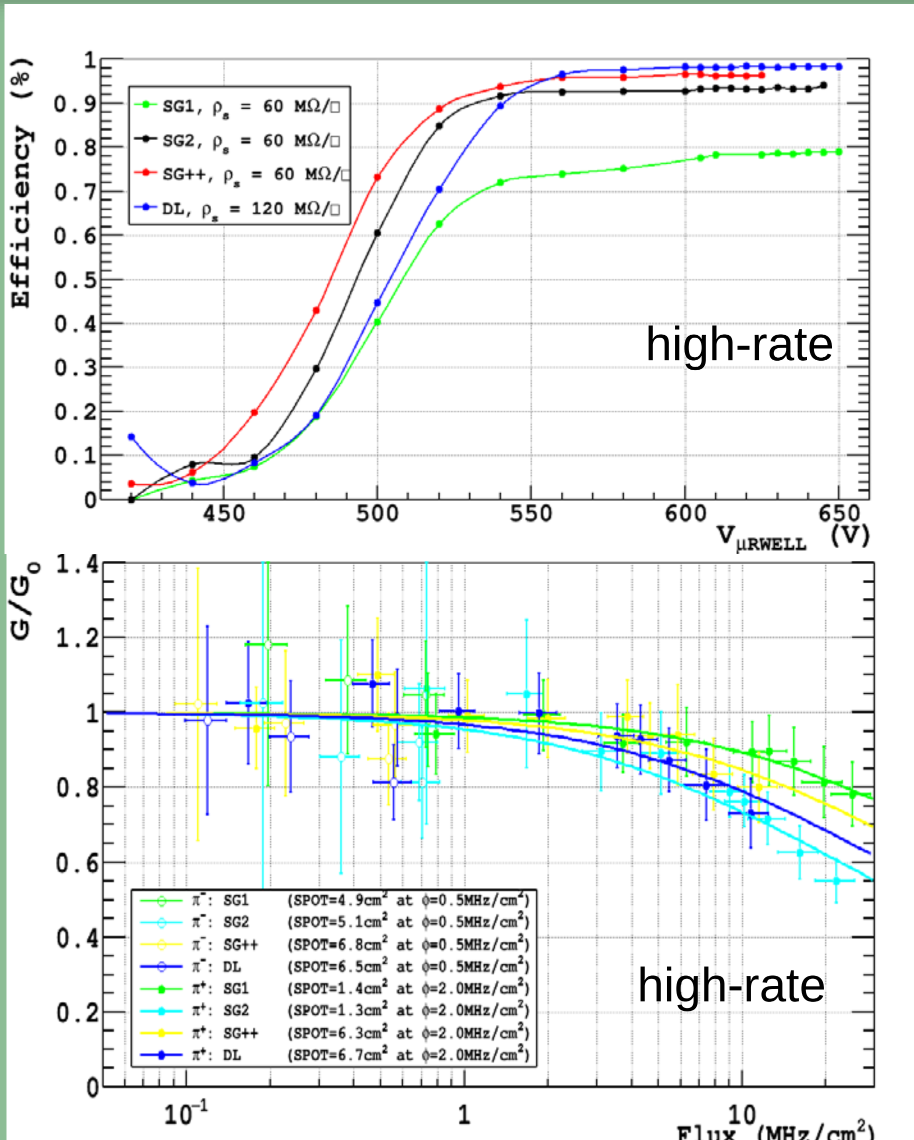






Bencivenni, Huang

STCF inner tracker μ-RWELL



- μ-RWELL has low and high-rate versions
- Would need high-rate version in TPC configuration
- Can reach full efficiency
- Gain drop due to ohmic effect on the resistive layer

Bencivenni

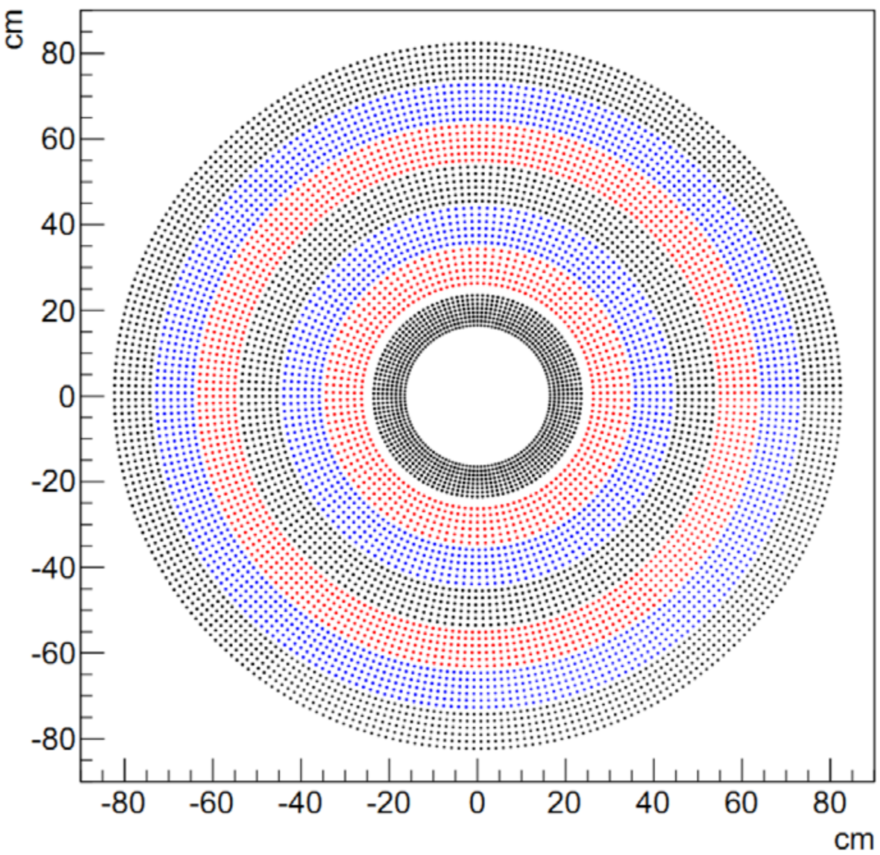
Main tracker – drift chambers

- Goal is efficient reconstruction of charged particle tracks over largest possible polar angle in the presence of backgrounds
- Common requirements
  - Low mass wires and gas
  - Low mass inner wall and end plates are generally carbon fiber

Is an inner RF shield required to avoid pickup in the drift chamber (or the inner tracker) from the ampere level circulating beam image charge on the outside of the beam pipe?
At *BABAR* we had such a shield. Was it necessary?

    - Inner radius 15-20cm to stay clear of beam-related activity
  - Spatial resolution 100-150 μm
  - Remain efficient with large collected wire charge
  - z as well as r,ϕ determination – small angle stereo
  - dE/dx capability for particle ID

STCF main tracker



- Rin = 15 cm, Rout = 85 cm, L = 2.4 m
- B = 1 T
- He/C_2H_6 (60/40)
- Cell size =1.0cm(inner),1.6cm(outer)
- Sense wire: 20 um W
- Field wire: 110 um Al
- # of layers = 44
- Layer configuration: 8A-6U-6V-6A-6U-6V-6A
- Carbon fiber for both inner and outer walls
- Expected spatial resolution: <130μm
- Expected dE/dx resolution: <7%

Huang

STCF main tracker – 1T field

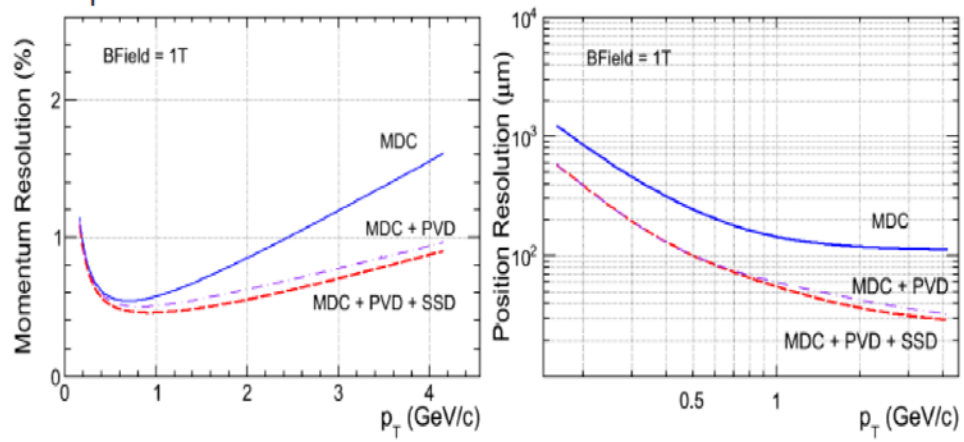
Option I: MDC + STAR HFT (geometry is not optimized)

Detector	radius (cm)	material (%X_0)	resolution (μm)
MDC Outer 9-48	23.5-82	0.0045 /layer	130
MDC Inner 1-8	15-22	0.0051 /layer	130
SSD	10	1.5	250
PXD 2 layers	3/6	0.37 /layer	30
Beam pipe	2	0.15	–

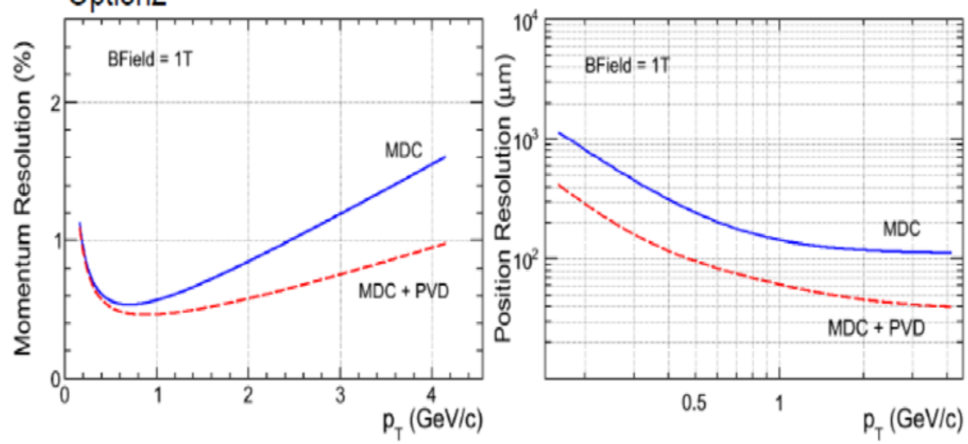
Option II: MDC + Belle-II PXD (geometry is not optimized)

Detector	radius (cm)	material (%X_0)	resolution (μm)
MDC Outer 9-48	23.5-82	0.0045 /layer	130
MDC Inner 1-8	15-22	0.0051 /layer	130
PXD 3rd layer	10	0.15	50
PXD 2 layers	3/6	0.15 /layer	50
Beam pipe	2	0.15	–

Option1



Option2

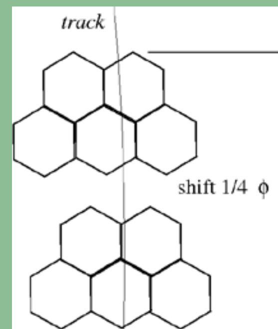


$$\frac{\sigma_{P_t}}{P_t} pos. = \frac{3.3\times 100\times \sigma_x}{BL^2} P_t \sqrt{\frac{720}{N+5}} \qquad \left.\frac{\sigma_{P_t}}{P_t}\right|_{MS} = \frac{5.7}{BL}\times\frac{1}{\beta}\times\sqrt{\frac{LP}{X_0 P_t}}$$

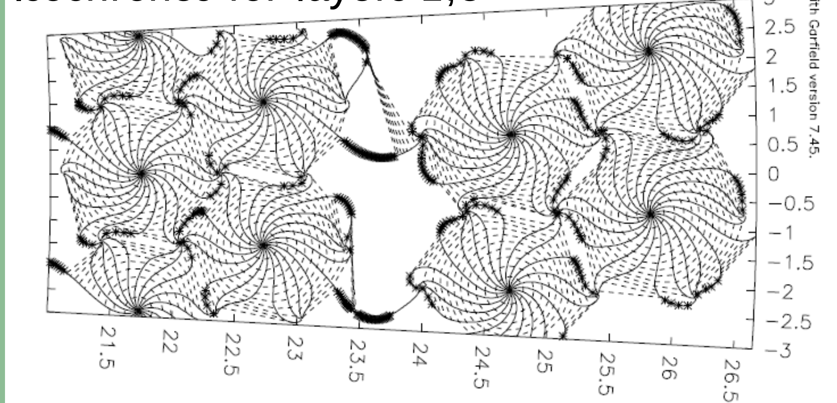
Huang

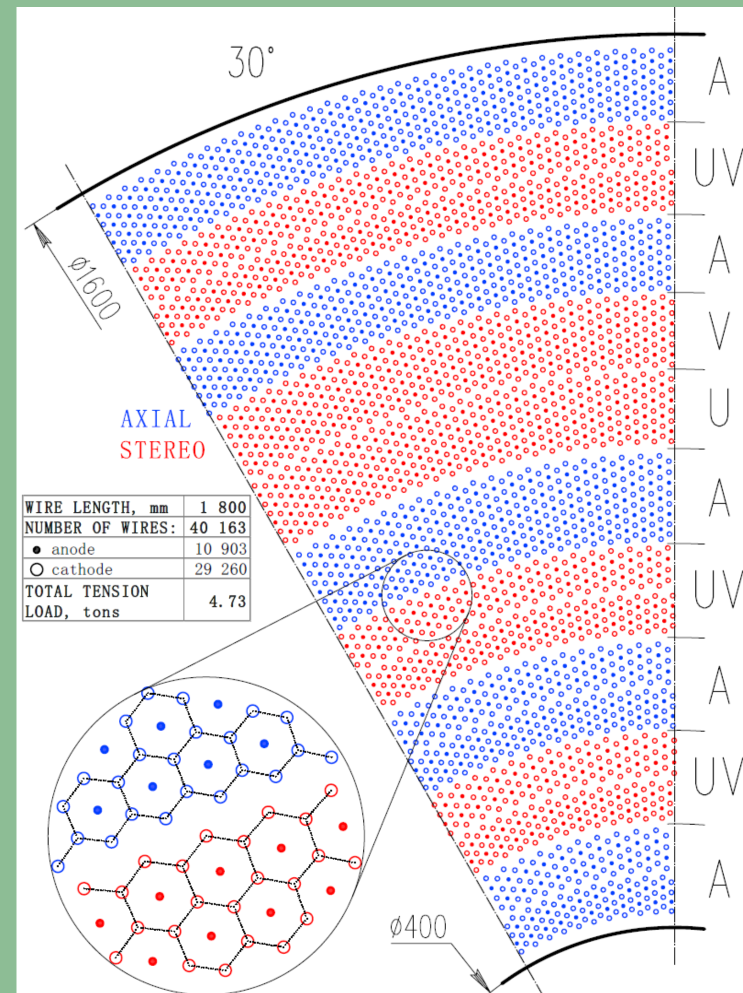
SCTF drift chamber – 1.5 T field

- Hexagonal cell configuration (~7mm radius) – 41 layers in 10 superlayers
- Odd number of cells for each layer to reduce systematic for $e^+e^- \to \mu^+\mu^-, \pi^+\pi^-$ events
- Inner superlayers have a shifted 2+2 structure for more homogeneous spatial resolution
- Gas mixture 60% helium, 40% propane



Isochrones for layers 1,3





WIRE LENGTH, mm	1 800
NUMBER OF WIRES:	40 163
● anode	10 903
○ cathode	29 260
TOTAL TENSION LOAD, tons	4. 73

Todyshev, Basok

Comparison with other experiments

Detector	CLEO III	BaBar	BES III	Belle	Belle II	SCTF
B,T	1.5	1.5	1.0	1.5	1.5	1.5
R_{in}/R_{out}, mm	125/820	236/809	59/810	77/880	160/1130	200/800
L_{in}/L_{out}, mm	1245(?)/2490	2764/2764	774/2582	747/2204	900/2417	1800/1800 (1100)
Construction inner tube						
Material h, mm	Composite 2.02	Be(near IP) 1	CF 1	CFPR 0.4	CFPR (Al) 0.52 (0.1)	CF (Al) 0.9 (.05)
X/X0,%	0.12	0.28	0.45	0.17	0.33	0.46
Endplate	**Conical**	**Flat**	**Conical**	**Spherical**	**Conical+**	**Flat**
N_{cells}	9796	7104	6796	8400	14336	10903
Shape	**Square**	**Hexagon**	**Square**	**Square**	**Square**	**Hexagon**
SW $d, \mu m$	W(Au) 20	W(Au) 20	W(Au) 25	W(Au) 30	W(Au) 30	W-Rh (Au) 25
FW $d, \mu m$	Al(Au) 110	Al(Au) 120	Al(Au) 110	Al 126	Al 126	Al(Au) 100,125
Size, mm × mm	**14 × 14**	**18 × 12**	**12 × 12, 16 × 16**	**17 × 16**	**7 × 7, 10 × 10**	**6.3 x 7.5**
$N_{layers}(\bar{h}, mm)$	**47(14.8)**	**40(14.3)**	**43(17.5)**	**50(16.1)**	**56(17.3)**	**41**
Gas mix	He/C_3H_8 60/40	He/iC_4H_{10} 80/20	He/C_3H_8 60/40	He/C_2H_6 50/50	He/C_2H_6 50/50	He/C_3H_8 60/40
Voltage,V	1900	1930	2200	2300	2300	2100-2200
T/D, ns/mm	$\sim 300/7$	$\sim 500/9$	$\sim 350/8$	$\sim 350/8$	$\sim 350/8$	~330/7
$\sigma, \mu m$	110	120	120	130	~ 130	<90
$\sigma_{\frac{dE}{dX}}$,%	5.7	7.5	6.0	6.9	–	~7.0
$\frac{\sigma_p}{p}$,% (1 GeV)	0.32	0.48	0.5	0.35	–	0.55

Todyshev, Basok

Low mass drift chamber with cluster counting (TraPID)

- Design based on previous chambers/proposals
  - KLOE chamber at Daϕne
  - CluCou Chamber proposed for the 4^{th}-Concept at ILC
  - I-tracker chamber proposed for the Mu2e
  - DCH for the MEG upgrade at PSI (under commissioning)
  - IDEA drift chamber proposal for FCC-ee and CEPC (2016)
- This experience leads to a concept for the the τ / charm factory that combines tracking and PID more effectively than a conventional chamber
  - **Cluster timing** for improved spatial resolution
  - **Cluster counting** for particle identification
  - No **feed-through** wiring
  - A **large number** of **thinner** (and **lighter** wires)
  - Separate **gas containment** from **wire support** functions
  - New concepts for **wire tension compensation**

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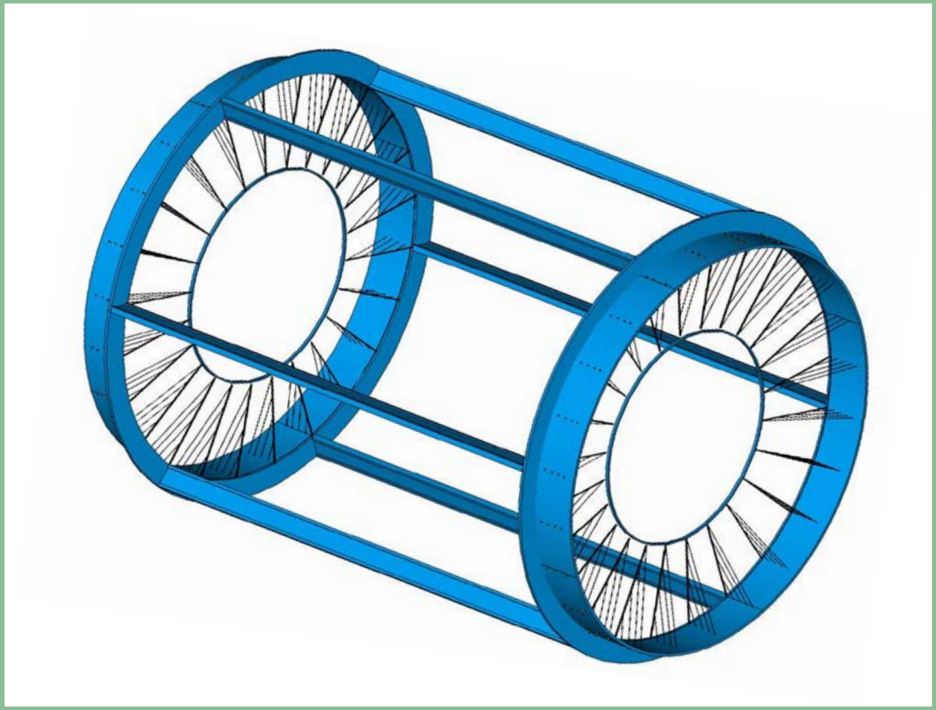
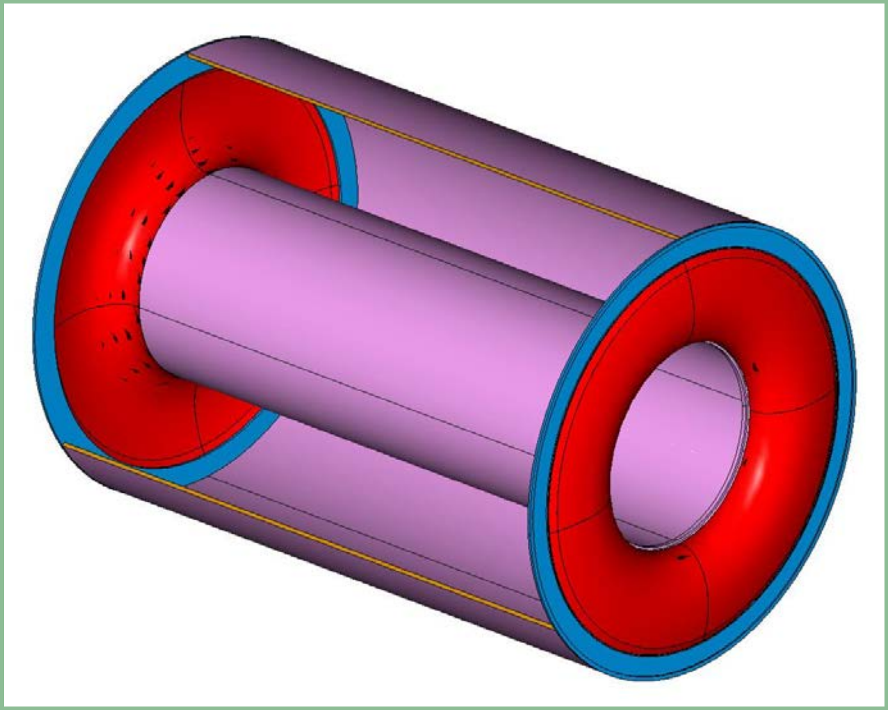
TraPID Wire Cage and Gas Envelope

Design separates the functions of wire tension support and gas enclosure





Wire support:

Wire cage structure is not subject to differential Pressure: can be light and feed-through-less.

Gas containment:

Gas envelope can freely deform without affecting the internal wire position and tension.

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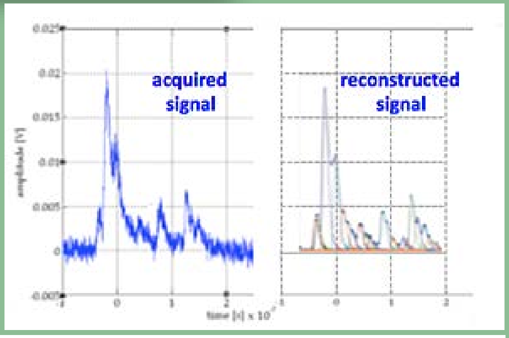
TraPID parmeters

$R_{in} – R_{out}$ [mm]		200 – 800
active L – service area [mm]		1800 – 200
inner cylindrical wall		
C-fiber/C-foam sandwich	2×80 μm / 5 mm	0.036 g/cm^2 – 8×10^{-4} X/X_0
outer cylindrical wall		
C-fiber/C-foam sandwich	2×5 mm / 10 mm	0.512 g/cm^2 – 1.2×10^{-2} X/X_0
end plate		
gas envelope	160 μm C-fiber	0.021 g/cm^2 – 6×10^{-4} X/X_0
instrumented wire cage	wire PCB, spacers, HV distr. and cables, limiting R, decoupling C and signal cables	0.833 g/cm^2 – 3.0×10^{-2} X/X_0

cell	
shape	square
size [mm]	7.265 – 9.135
layer	
8 super-layers	8 layer each
64 layer total	
stereo angles	66 – 220 mrad
n. sense wires [20μm W]	23,040
n. field wires [40/50μm Al]	116,640
n. total (incl. guard)	141,120
gas + wires [600 mm]	
90%He – 10%iC_4H_{10}	4.6×10^{-4}
wires (W=53%, Al=47%)	**13.1×10^{-4}**

Cluster timing and counting

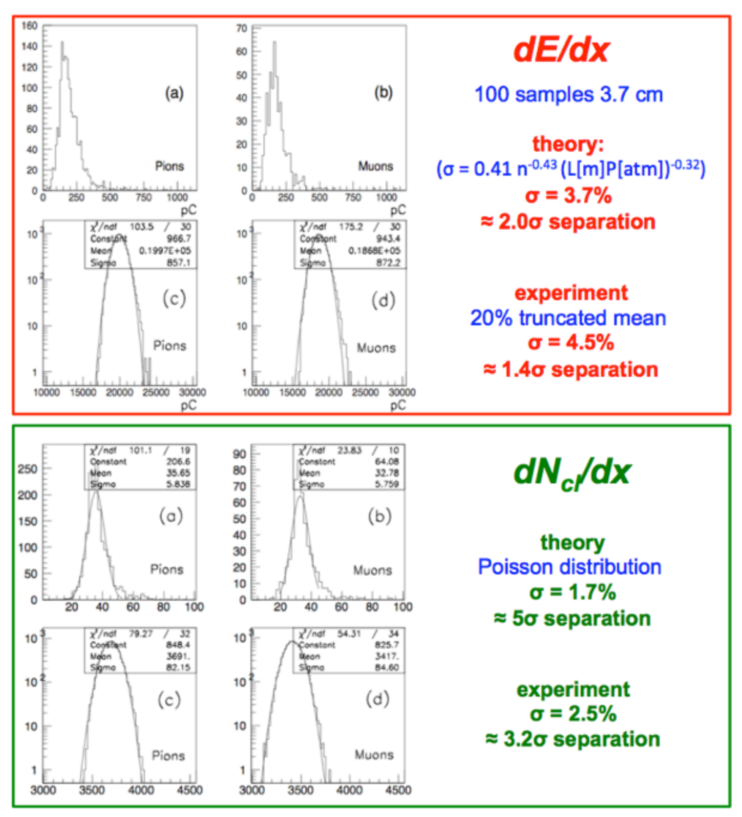
- Cluster timing
  - Reconstruct the most probable ordered sequence of electron arrival times, thereby reducing bias and improving drift distance resolution



- Cluster counting
  - Resolution in $dN_{cluster}/dx$ is improved over that in dE/dx
  - Example: μ and π 200 MeV/c
- Electronics is more complex than a conventional chamber
- PID 3.6% with cluster counting, allowing for π/K separation ≥ 3σ over a wide range of momenta

$$L_{track} = 0.6 \text{ m}$$
$$\delta_{cl} = 12.5/\text{cm}$$

- Could perhaps be improved to 2.8%



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Conventional/TraPID comparison

	$\frac{\Delta p_t}{p_t} \times 10^3$	at $p_t = 1GeV$	$\frac{dE}{dx} / \frac{dN}{dx}$	
KLOE	$0.5 p_t \oplus 2.6$	2.6×10^{-3}	5%	
BaBar	$1.3 p_t \oplus 4.5$	4.7×10^{-3}	7.5%	
Belle	$2.8 p_t \oplus 3.5$	4.5×10^{-3}	6.9%	
BelleII	$1.9 p_t \oplus 2.9$	3.5×10^{-3}	6.4%	
BESIII	$2.7 p_t \oplus 4.7$	5.1×10^{-3}	$6-7\%$	
Cleo3	$1.0 p_t \oplus 9.0$	9.1×10^{-3}	5%	
SCTF (Todyshev)	$2.6 p_t \oplus 5.1$	5.7×10^{-3}	7%	
TraPId (this proposal)	$0.78 p_t \oplus 1.8$	2.0×10^{-3}	3.6%	with cluster counting (dE/dx = 8.1%)
TraPId (this proposal)	$0.66 p_t \oplus 1.4$	1.6×10^{-3}	2.8%	with cluster timing and Ti + C wires 1 m track length - (dE/dx = 6.9%)

While the two “baseline” drift chambers are sufficiently conventional to not require prototyping, a TraPID chamber would likely need such a prototype

Particle identification

- Physics requirement π, K, p, e. μ separation up to ~1.6-2 GeV/*c*
- A difficult problem has spawned many potential solutions
  - TOF
  - DIRC(-like), RICH, FARICH - ring
  - ASHIPH – threshold
  - Conventional drift chambers – dE/dx
  - TraPID – dN/dx
- Capabilities of current detectors (π/K)
  - TOF: BES ~3.6 σ @ 0.9 GeV/c
  - ACC (Belle) ~2.6 σ @ 1.5 GeV/c
  - RICH (CLEO-c) ~3σ up to 2.5 GeV/c
  - DIRC (*BABAR*) ~4σ up to 2.5 GeV/c
  - AHSIPH (KEDR) ~4σ up to 1.5 GeV/c
- μ/π separation for p>1 GeV/c:
  Belle ~2.5 to 2.8 σ

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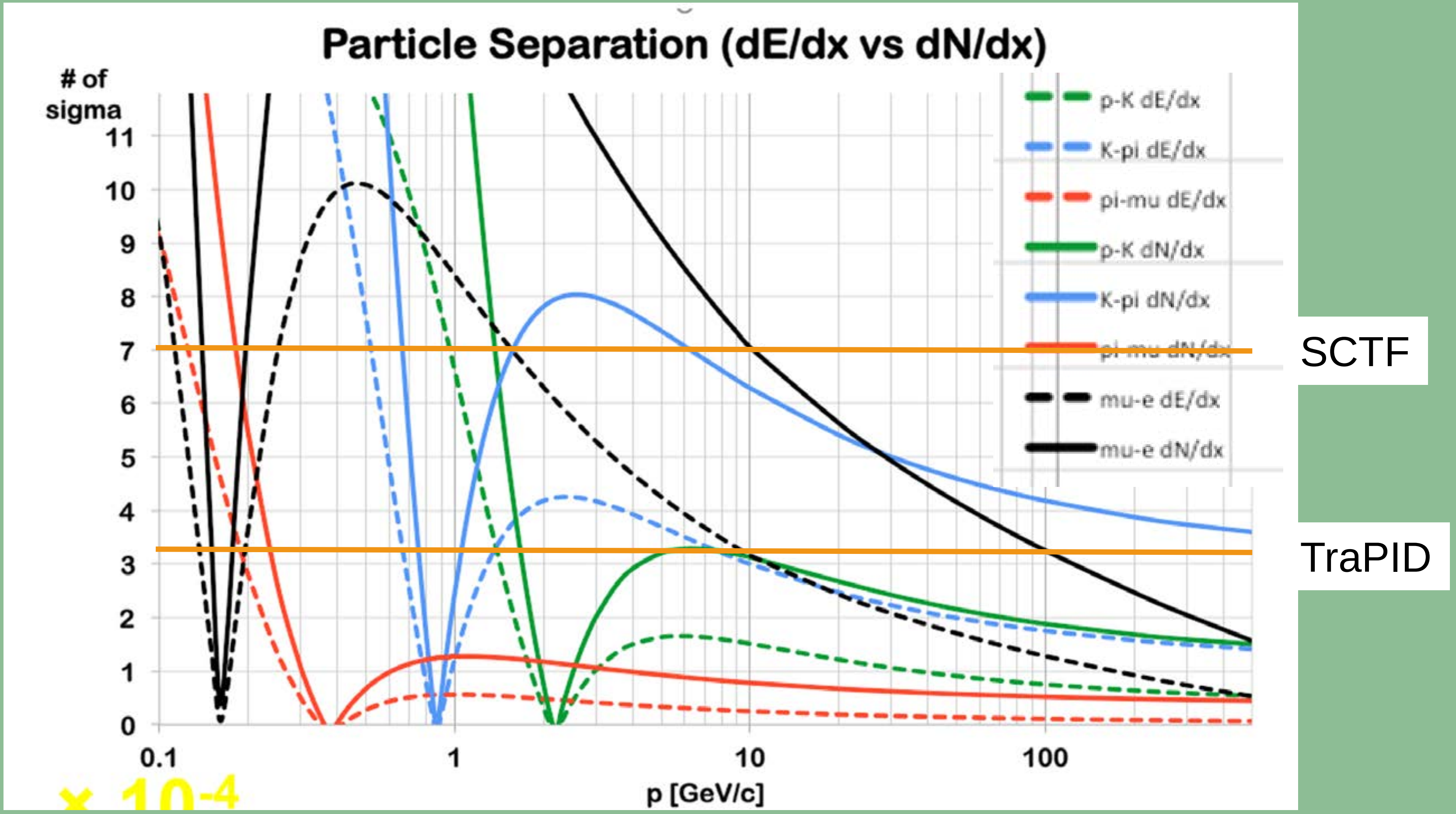
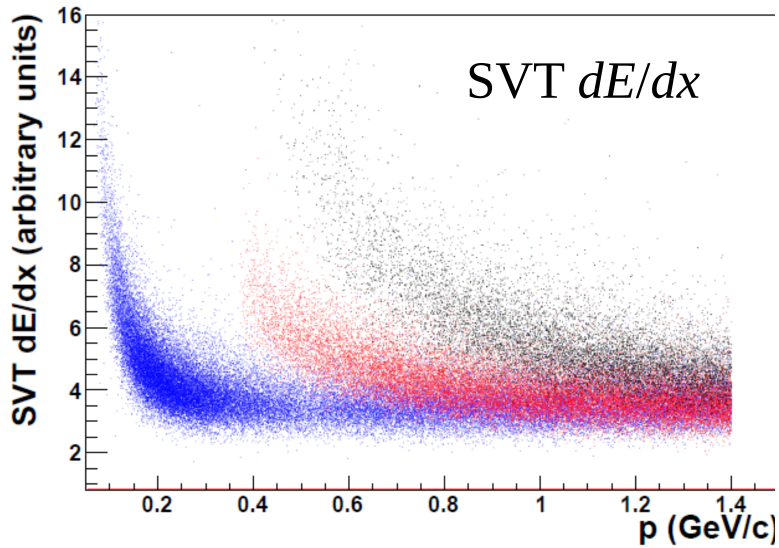
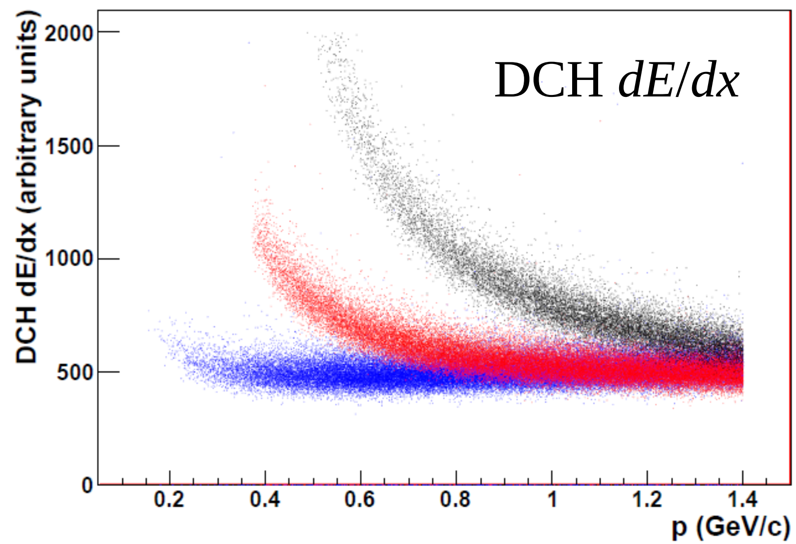
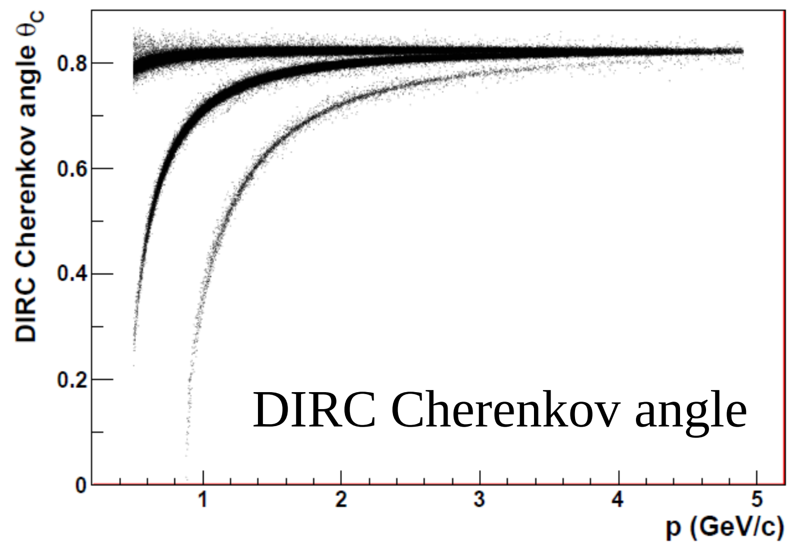
PID via *dE/dx* and *dN/dX*



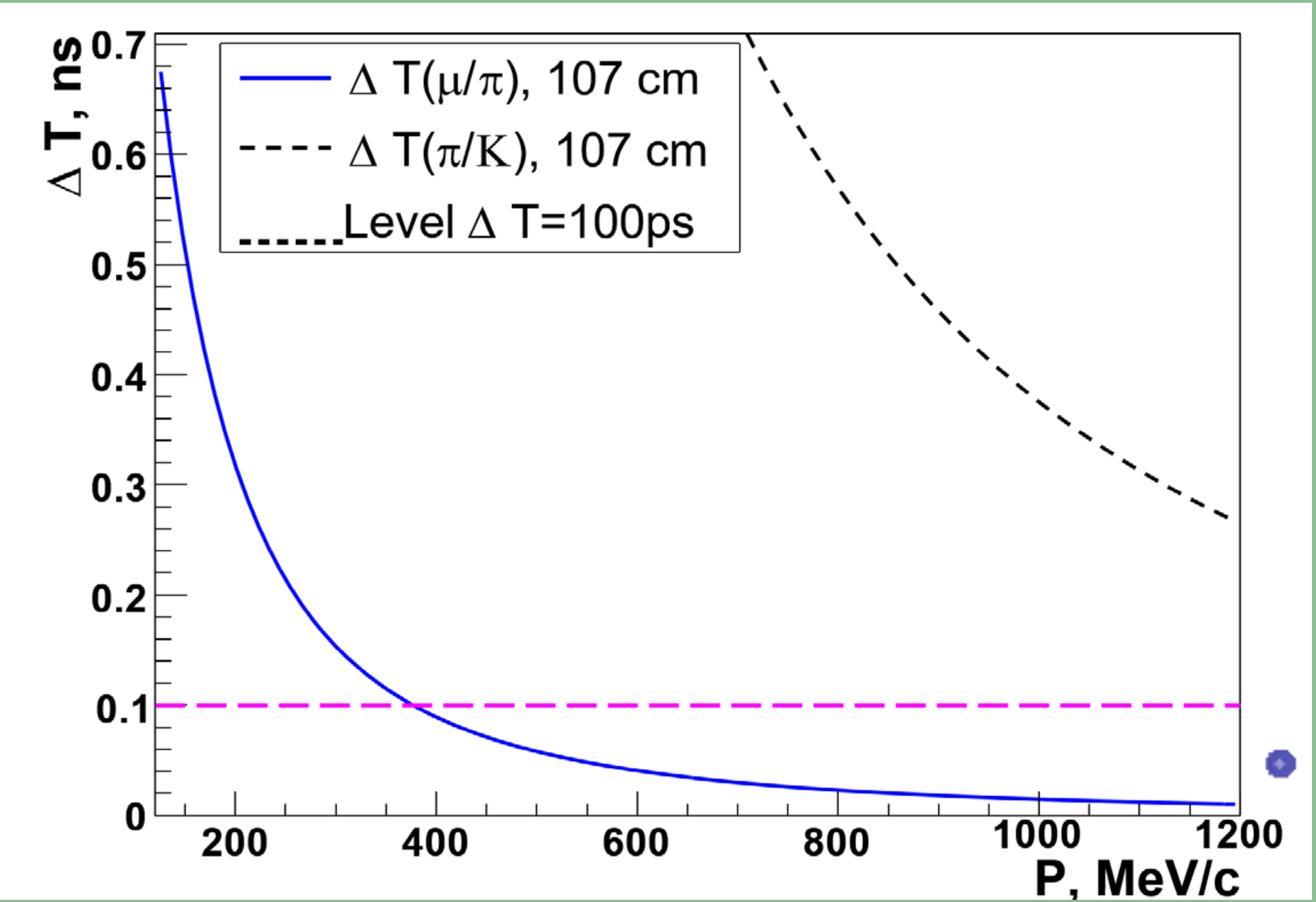
Benchmark -*BABAR* $\pi/K/p$ identification







TOF technique



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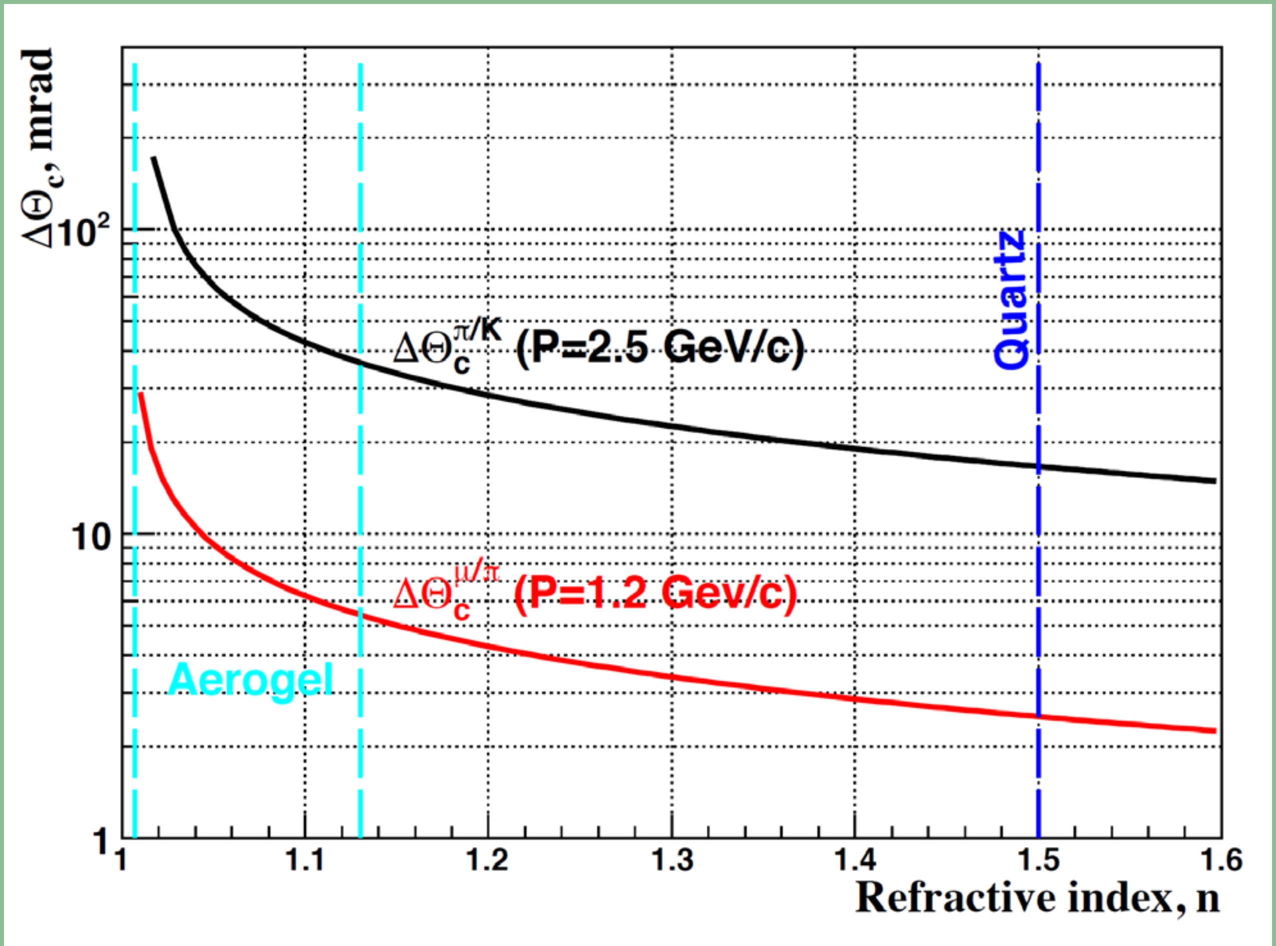
Aerogel (FARICH)



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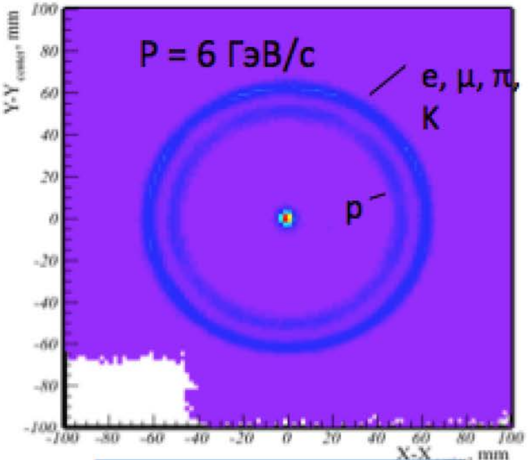
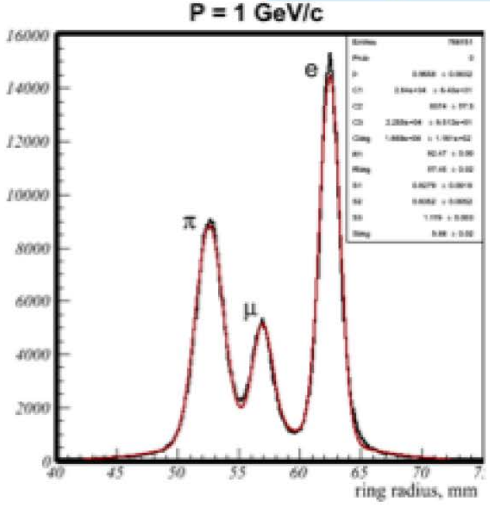
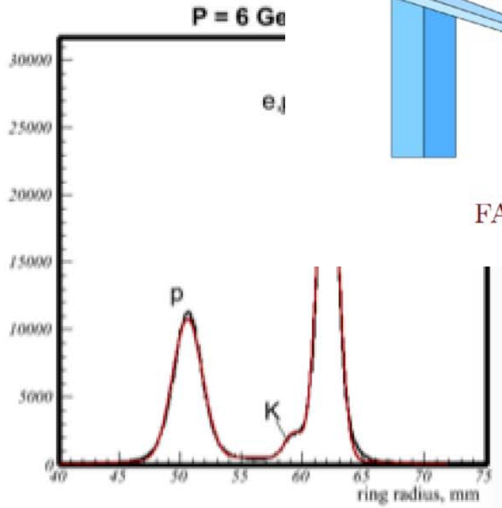
FARICH beam test results

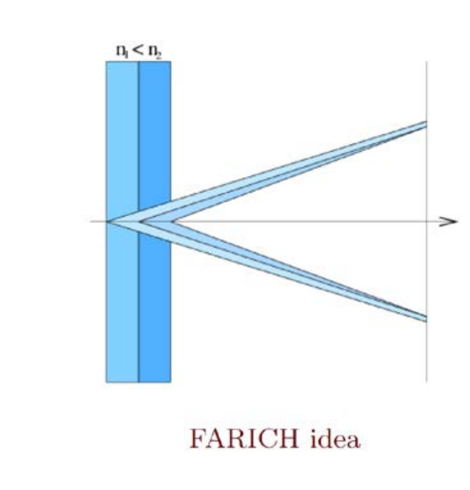
Hit positions



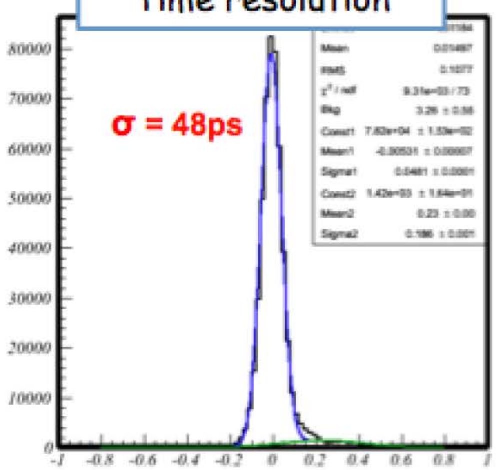
Ring radius distributions







Time resolution

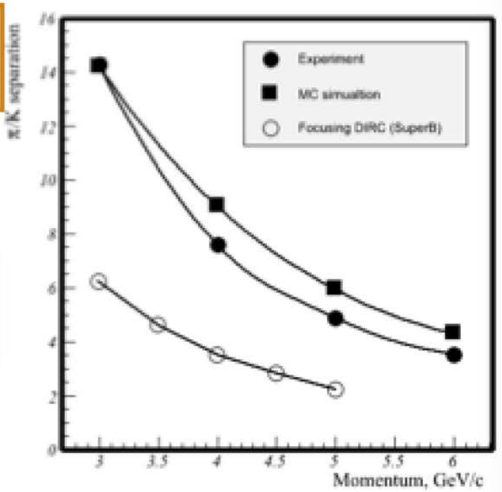


4-layer monolithic aerogel; thickness 30 mm; n_{max}= 1.046

$$S(\pi/K)= \frac{R_\pi - R_K}{\sigma_\pi}$$

π /K : 7.6σ @ 4 GeV/c
μ /π : 5.3σ @ 1 GeV/c

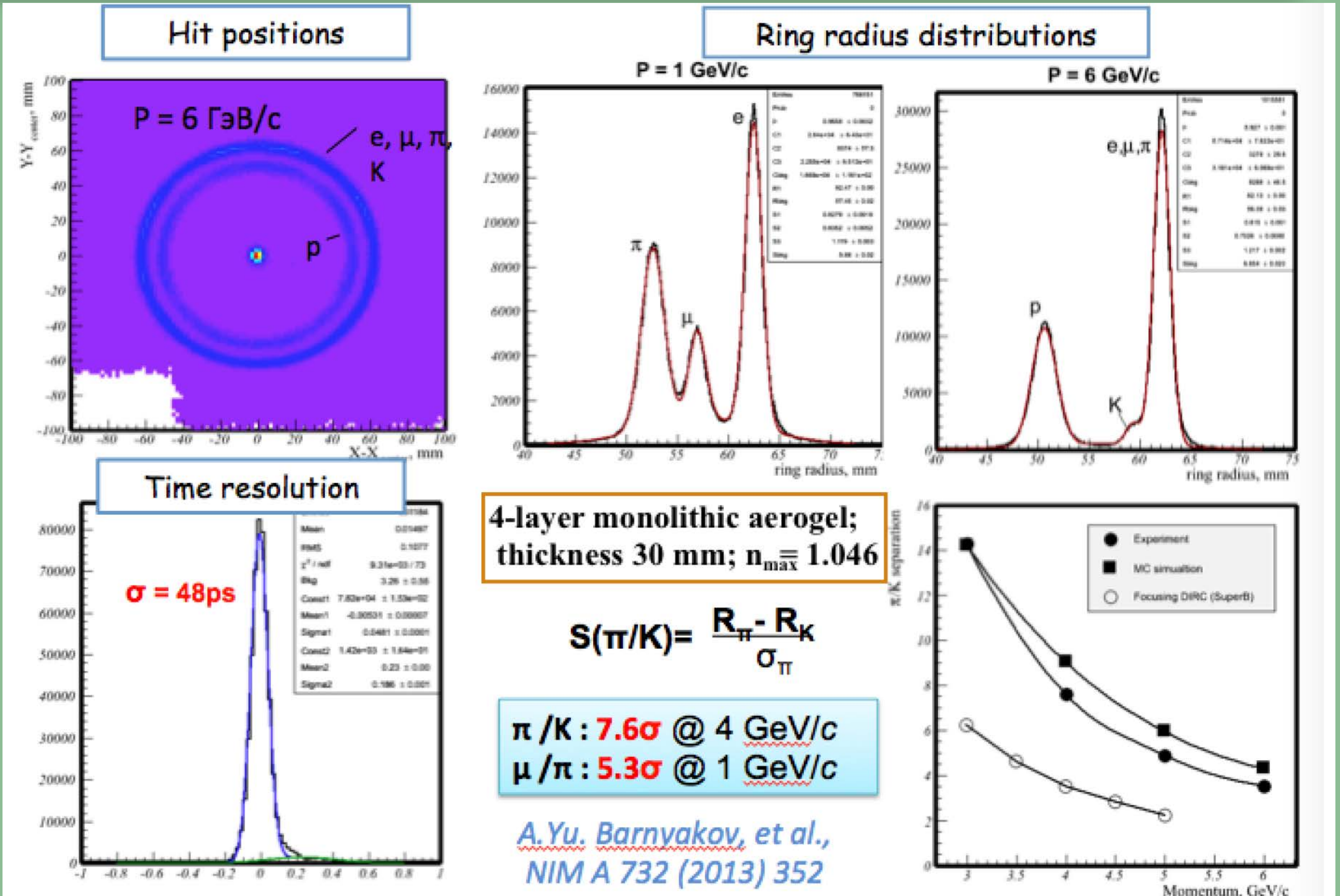
A.Yu. Barnyakov, et al., NIM A 732 (2013) 352



CERN beam test 2012

Barnyakov

FARICH beam test results



4-layer monolithic aerogel; thickness 30 mm; n_{max}= 1.046

$$S(\pi/K) = \frac{R_\pi - R_K}{\sigma_\pi}$$

π /K : 7.6σ @ 4 GeV/c
μ /π : 5.3σ @ 1 GeV/c

A.Yu. Barnyakov, et al., NIM A 732 (2013) 352

CERN beam test 2012

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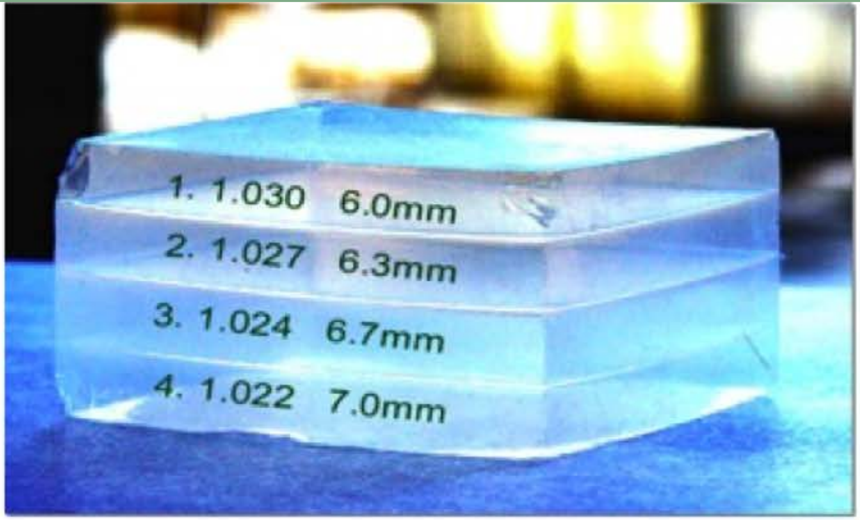
FARICH system for Super CTF

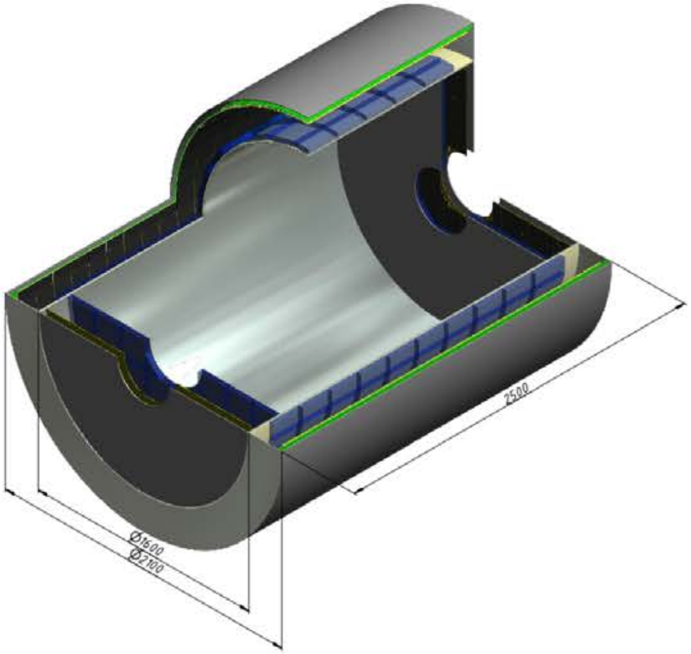


Main parameters:

- Focusing aerogel, $n_{max}=1.07$, 4 layers
- Area of the radiator: 17 m^2

- Photon detectors (3×3 mm^2):

  Barrel – SiPMs (16 m^2)
  Endcap – SiPMs or MCP PMTs (5 m^2)
- $1\div1.8\cdot10^6$ channel of electronics
- Operational rate $0.5\div1.0$ MHz/channel
- Power consumption ~40 kW
- Cooling system (-30°C or 77°K?!)
- Amount of material $\sim13\div30\%X_0$



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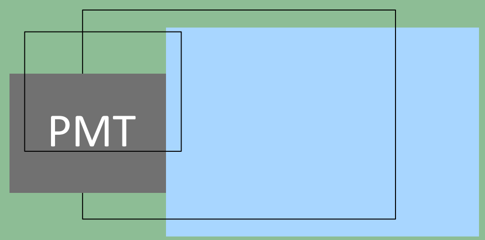
Aerogel threshold Cherenkov counters

Direct light collection



Pros: Simplicity
Cons: Counter size limited
Large PMT number & area
High total cost

ASHIPH – Aerogel-SHIfer-PHotomuliplier

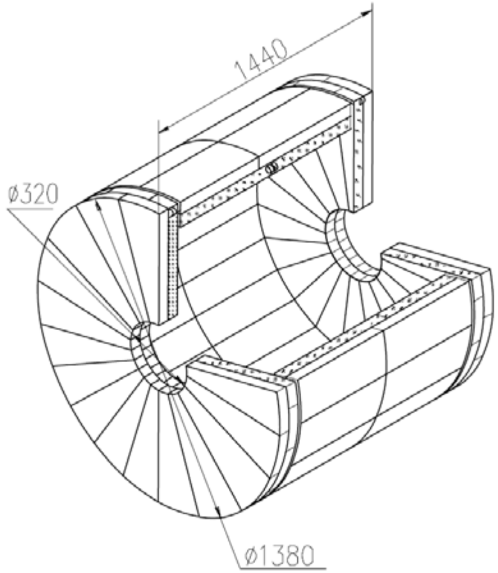
Suggested by A.Onuchin *et al.* for PID of the KEDR detector [NIM A315 (1992) 517]

Pros: Large light collection area
Reduces number of photosensors
Smaller total photosensor area
Lower cost
Cons: Loss of acceptance due to WLS

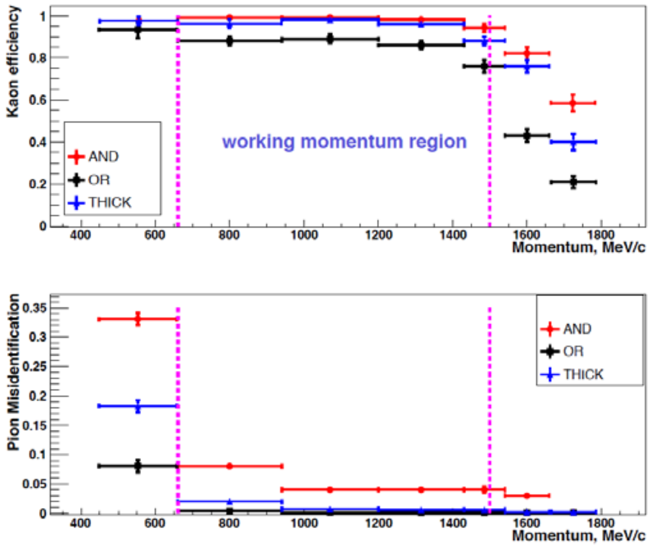
Barnyakov

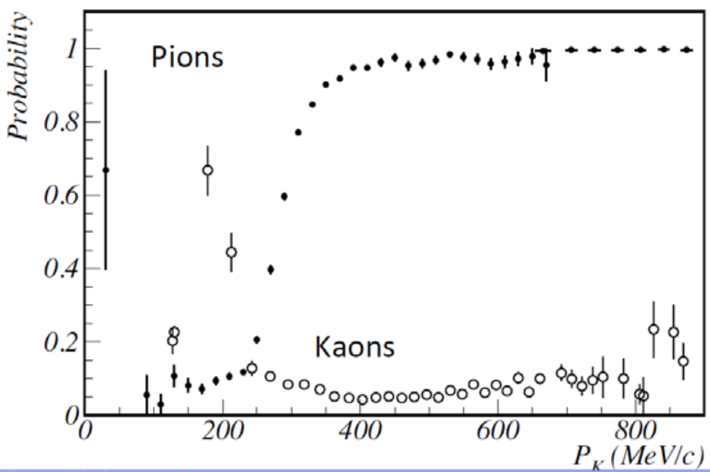
ASHIPH systems in operation

Aerogel Cherenkov ASHIPH counters

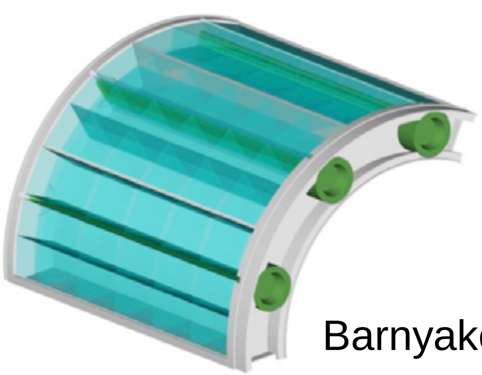


KEDR:
- 160 counters (2 layers)
- n=1.05 (1000l)
- WLS (BBQ)
- MCP PMT øPC=18 mm
- 0.97x4π
- 24% X_0





SND:
- 9 counters (1 layer)
- n=1.13 (9l)
- WLS (BBQ)
- Thickness ~ 30 mm
- MCP PMT øPC=18 mm
- 0.6x4π



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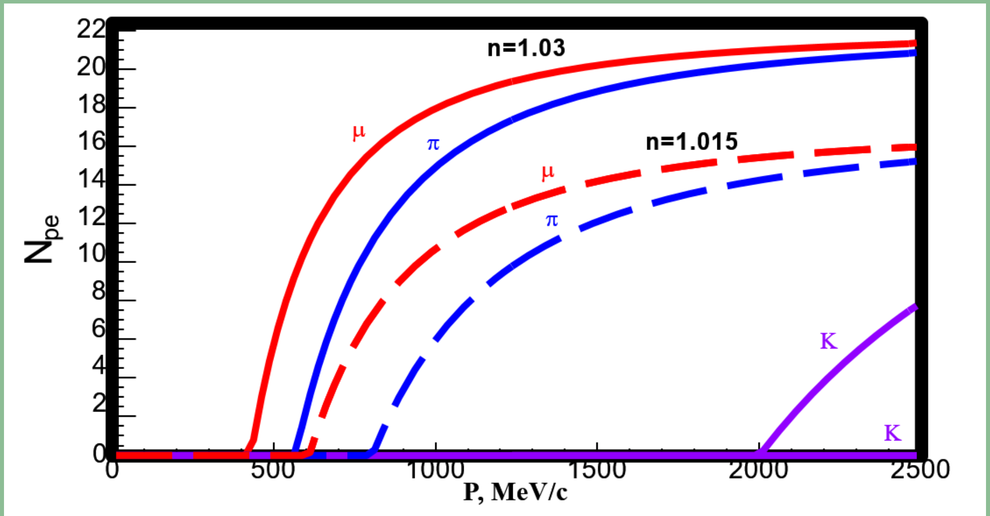
Upgrade of KEDR ASHIPH to SiPMs

π/K-separation from 500 to 2000 MeV/c

μ/π-separation from 400 to 900 MeV/c

Preliminary design:

- 6000 l of aerogel in three layers: n=1.03 (8 cm) and n=1.015 (8+8 cm)
- 1400 counter with sizes ~18×30×8 cm
- Amount of material ~ 15%X_0
- Light collection – WLS(BBQ) and 28000 SiPMs 3×3 mm^2
- Radition hardness of SiPMs to be investigated



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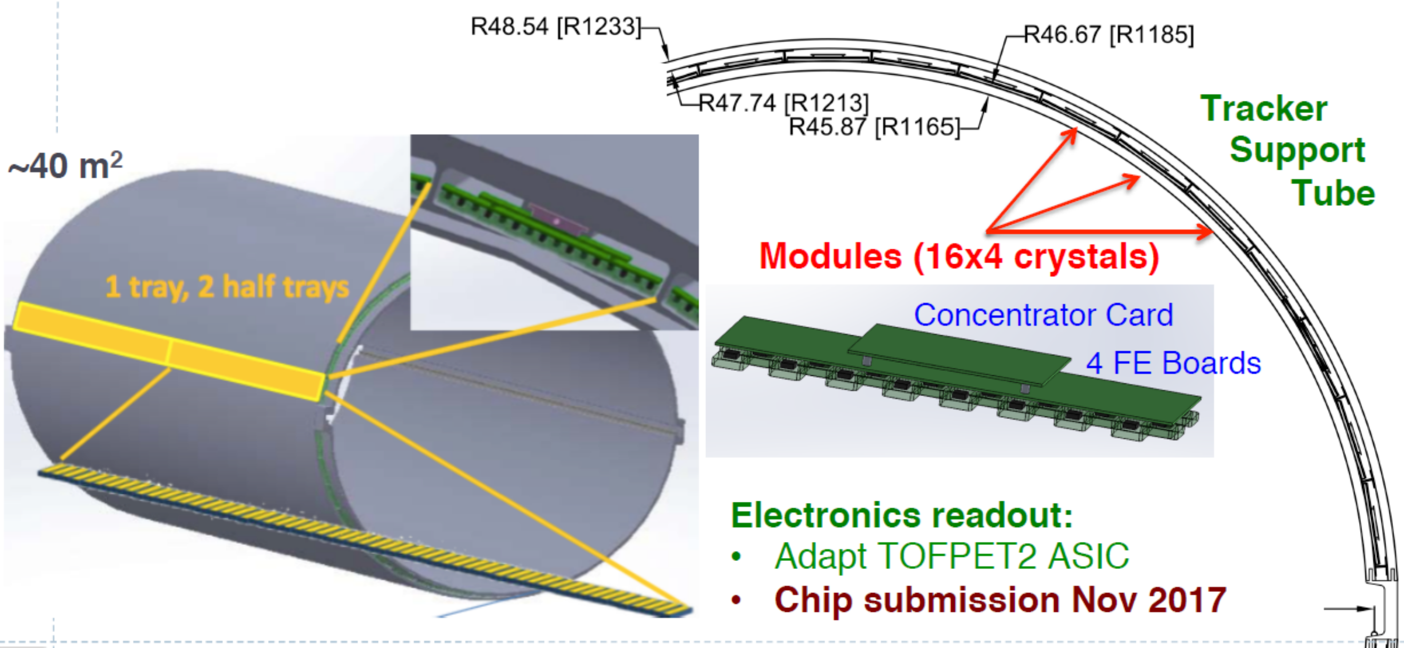
TOF technique

TOF with $\sigma_t \approx 30$ ps and L≈1m – 3σ for P<400 MeV/c

Barrel MIP timing detector

- **LYSO crystals + SiPM embedded in the Tracker tube**
  - Ready before TK integration (mid 2022)
  - Maintain performance at radiation level **2×10^{14} n_{eq}/cm^2**



2

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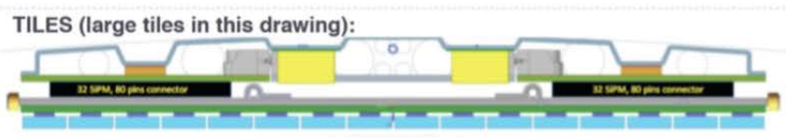
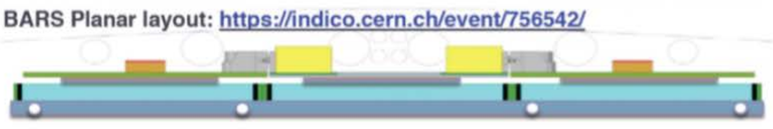
Beam test results

There are two system geometry options:



Tiles option



Bars option

- Tile: 11.5×11.5×3.75 mm
- 500k SiPMs 3×3 mm^2 and 500k LYSO tiles
- Light Output per SiPM ∼ 6500 ph.
- Beam test results obtained with NINO2 and DRS4 based digitizer:
  - $\sigma_t \sim 32 \pm 2$ ps & PDE=40%
- Position correction required: impact from position ∼ 30 ps

- Bar: 56×3.75×3.75 mm
- 400k SiPMs 3×3 mm^2 and 200k LYSO bars
- Light Output per SiPM ∼ 7200 ph.
- Beam test results obtained with NINO2 and DRS4 based digitizer:
  - $\sigma_t \sim 27 \pm 2$ ps & PDE=40%
- Does not required position measurements
- Geometry efficiency is reduced by ∼5%

- Radiation tolerance of time resolution?!
- Clock distribution with accuracy better than 30 ps and time alignment procedure have to be developed

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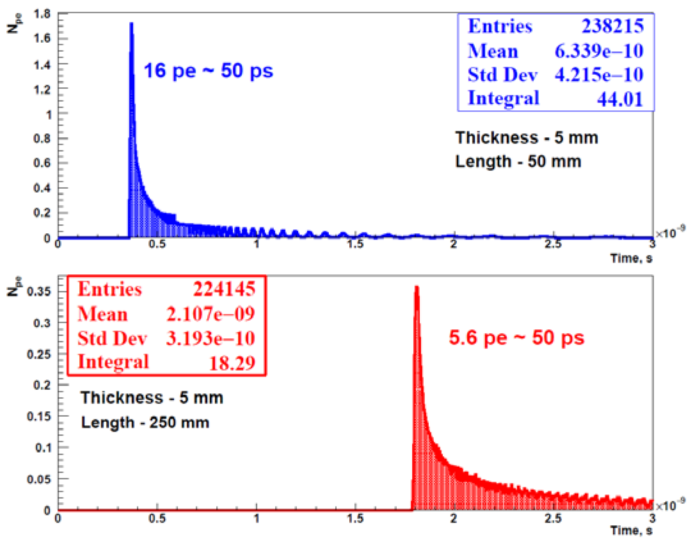
TOF + TOP

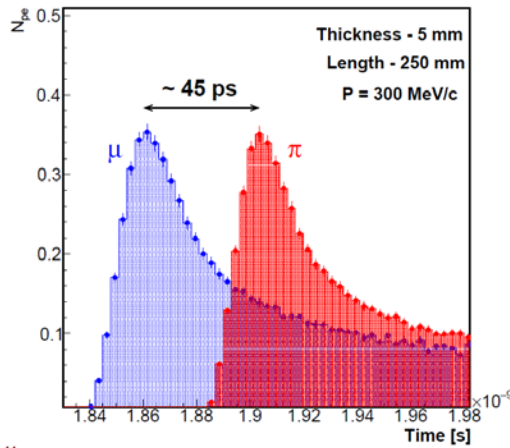
Time Of Propagation (TOP) can improve the Time Of Flight (TOF).

Time resolution mainly is determined by:

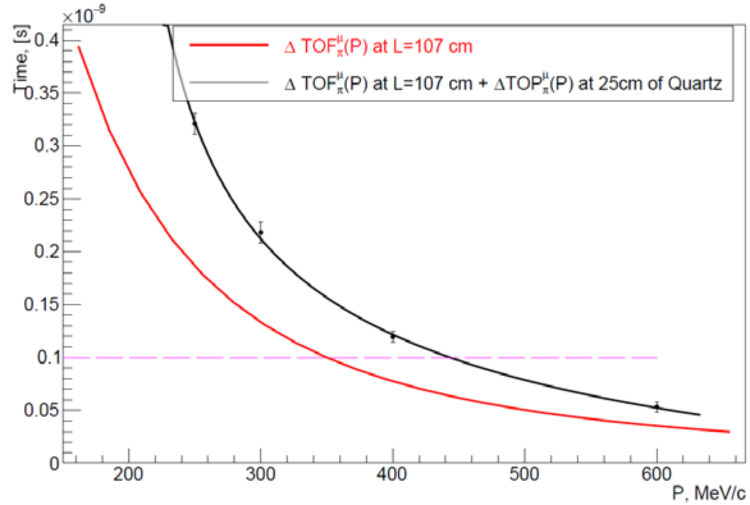
- refractive index dispersion
- time of light collection
- photon detector & electronics jitter



Time distribution of photoelectrons produced by Cherenkov photons emitted in Sapphire at different distances from SBialkali PC



ΔTOP^{μ}_{π}(P=300MeV/c) in Sapphire at 25 cm.



TOF with $\sigma_t \approx 30$ ps and L≈1 m – 3σ for P<400 MeV/c

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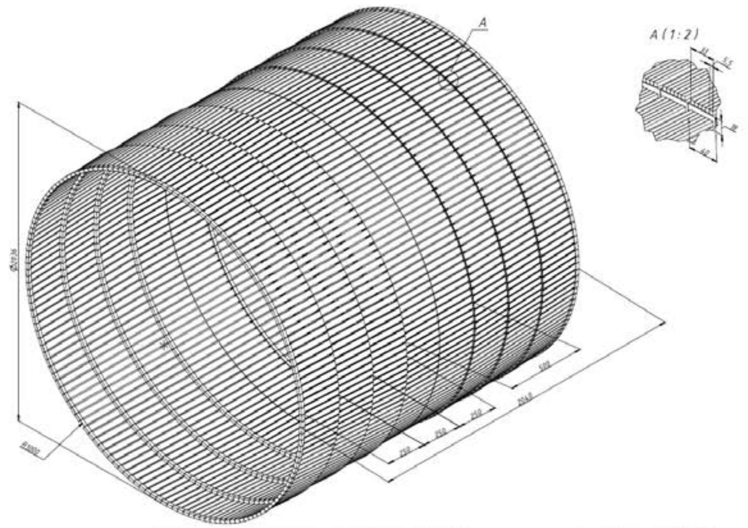
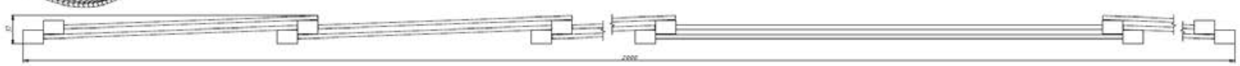
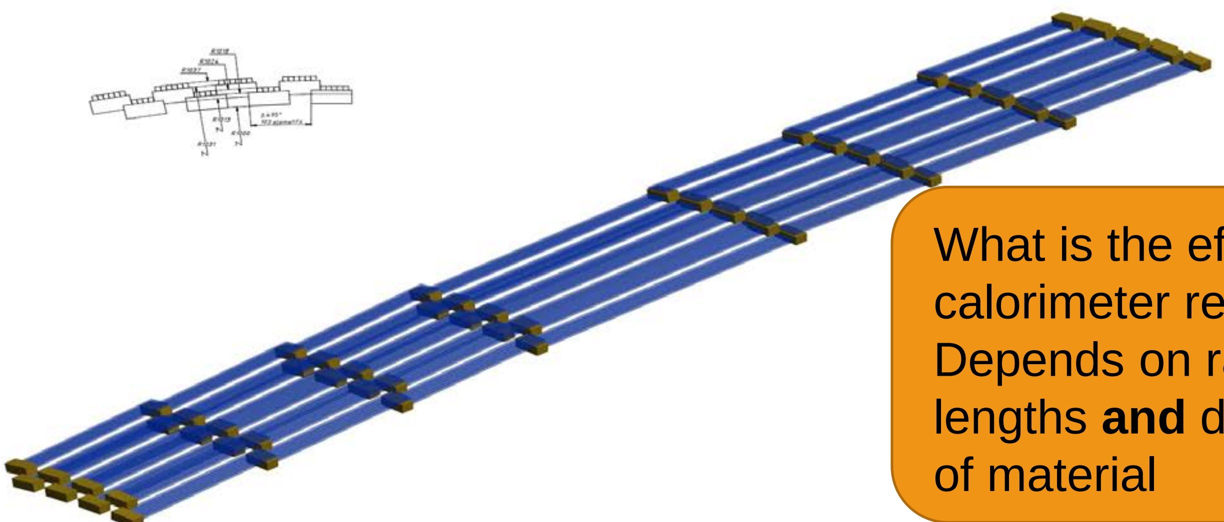
TOF system for SCTF barrel



Main parameters

- π/K-separation from up to 2500 MeV/c
- μ/π-separation from 250 to 500 MeV/c
- Preliminary design:
  - Quartz bars $5\times5\times250\div500$ mm – 10000 pcs
  - 1648 – MCP PMTs $\sim40\times20$ mm with 12 anodes
  - Amount of material $\sim 7\% X_0$





What is the effect on calorimeter resolution? Depends on radiation lengths **and** distribution of material

Barnyakov

STCF DIRC-like TOF for endcap

The 3σ separation of TOF :

- For K/p at p=2 GeV/c, σ_T ~ 0.27ns*X(m) = 270 ps at X~1m
  3 σ K/p separation for overall TOF time resolution is 90 ps

$$\sigma_t < \frac{1}{3}\frac{x}{c}\frac{1}{2p^2}[m_K^2 - m_\pi^2]$$

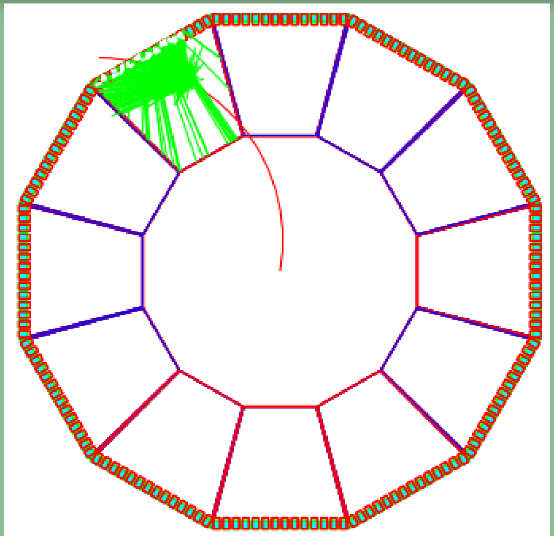
- For π/K at p=2 GeV/c, σ_T ~ 0.1ns*X(m) = 100ps at X~1m
  3 σ π/K separation for overall TOF time resolution is ~30 ps

Very challenge for TOF technology

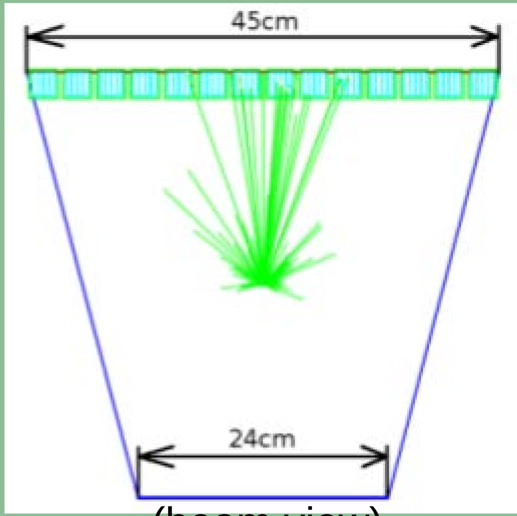
- Fast Timing TOF(<30 ps) based on new pico-second timing technology (TOF combined with DIRC method) is an endcap PID option for STCF
- DIRC-Like forward TOF detector (FTOF: quartz + MCP-PMT) was developed at LAL in Orsay for the SuperB project.

Huang

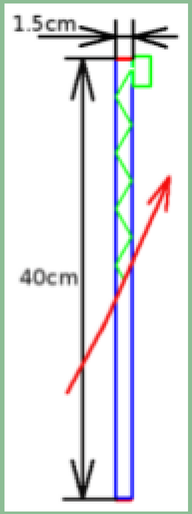
FTOF – TOF with Cherenkov light



Trapeze sector with 14 MCP PMT

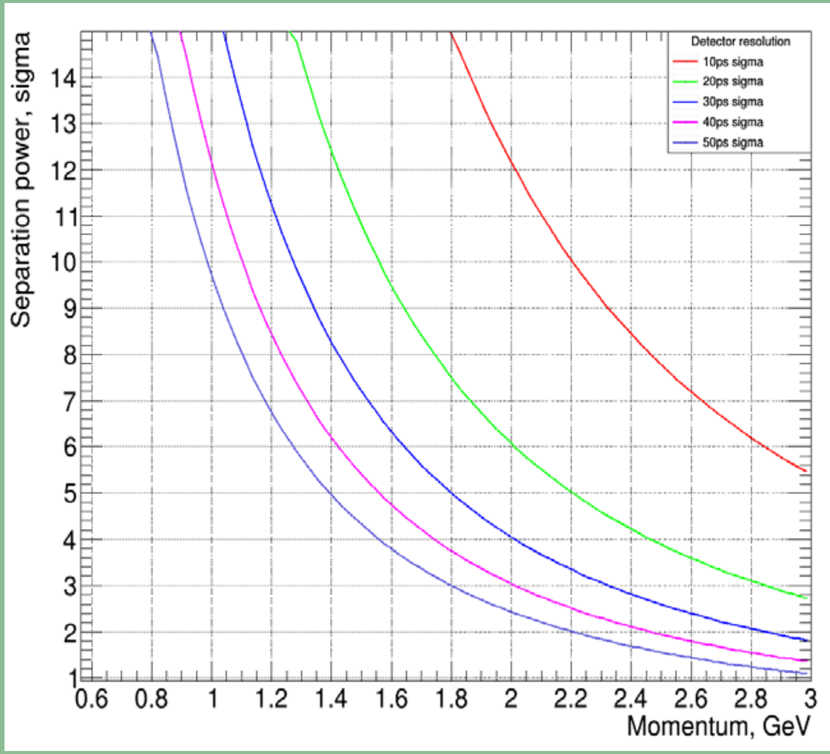


(beam view)



(side view)

$$separation\ power = \frac{|\Delta t|}{\sigma}$$



Studying SiPM readout (70ps) as well as other radiators

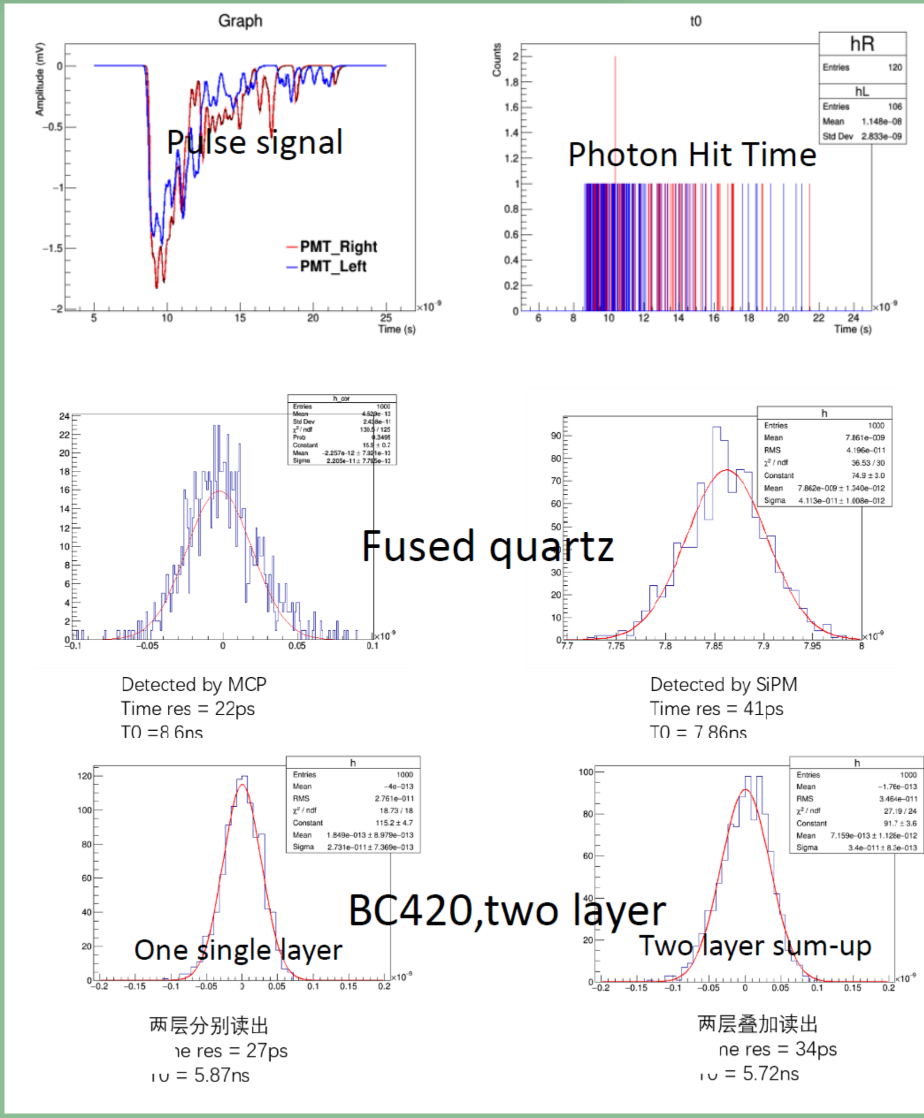
Barsuk

STCF DIRC-like TOF simulation

- Fused quartz + MCP-MPT readout
- Scintillator (BC420, double layer) with SiPM (or MCP) readout
- Threshold: 1 pe

Pulse signal Photon Hit Time
Fused quartz
BC420,two layer
Two layer sum-up One single layer

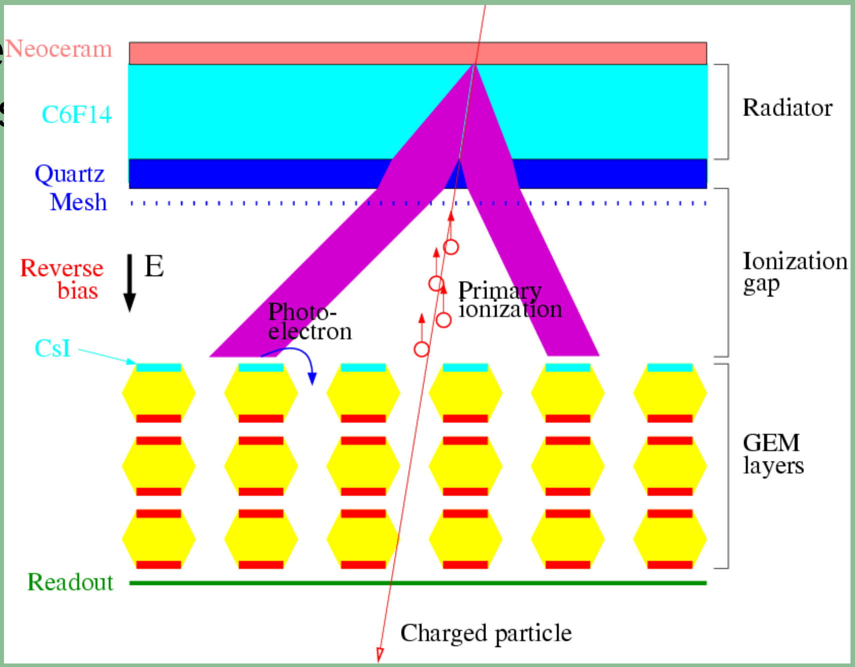
Intrinsic time resolution can reach ~30 ps (preliminary)



Huang

STCF RICH

Proximity focusing RICH, similar to ALICE, but with DLC photocathode replacing fragile CsI
Photon detector is Double-Mesh Microme
Provides high gain and high 2D spatial res



- Photo-cathode
  - Quantum Efficiency (QE)
  - Aging - Ion Back-Flow (IBF)
- Electron Amplification
  - Gain 3×10^6
  - Uniformity
  - Stability – charging-up
    - Suppress ion feedback
  - Coating with DLC overcomes surface charging
- Readout
  - High-density electronics

Shao

STCF RICH

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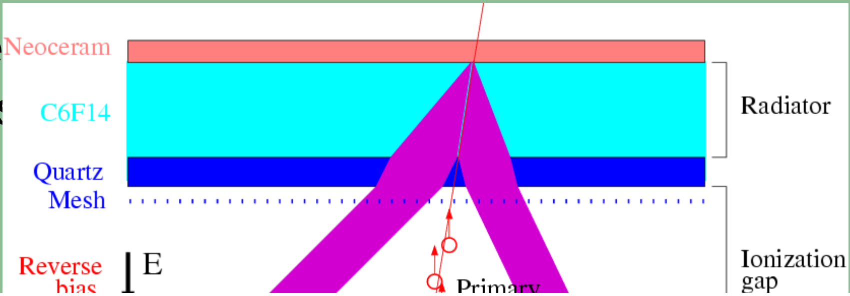

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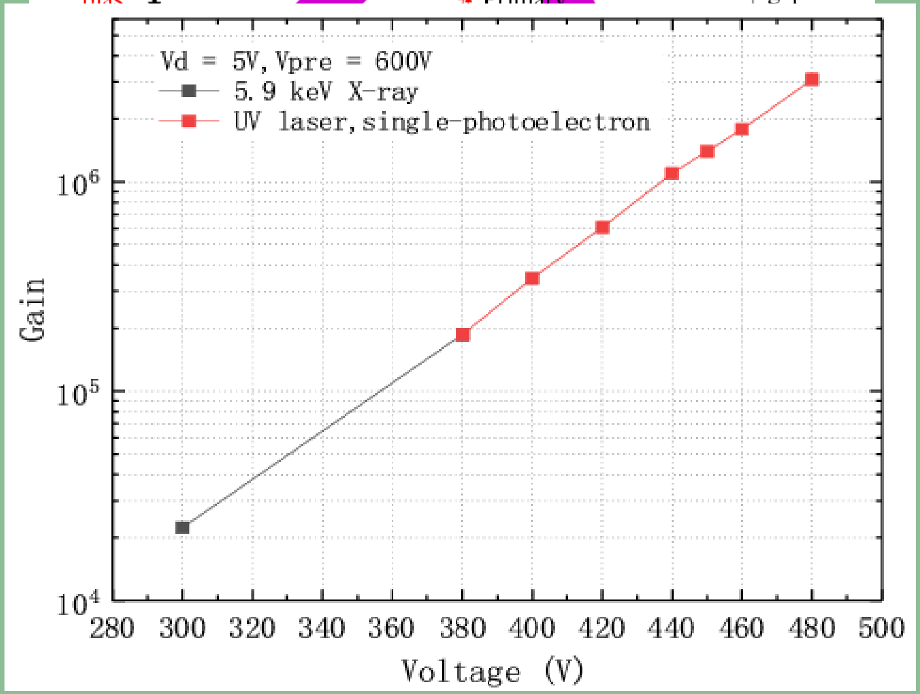

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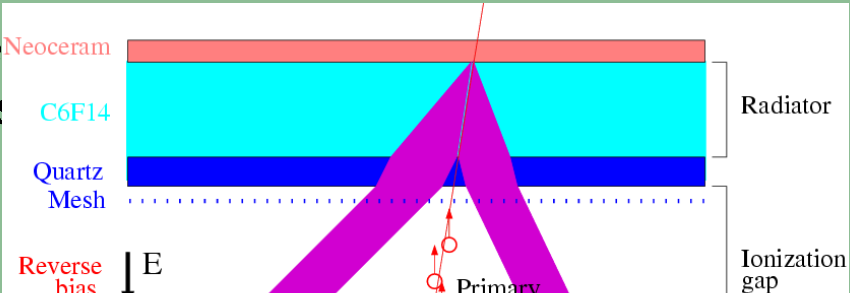

- Photo-cathode
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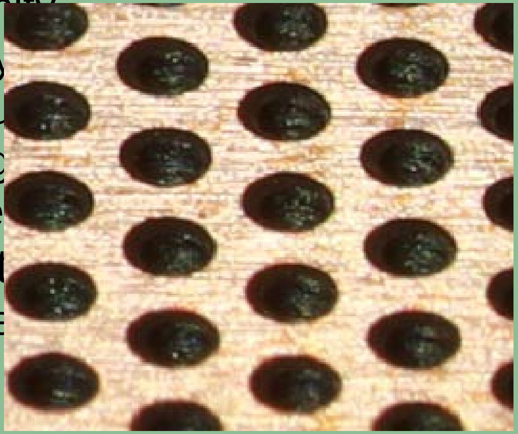
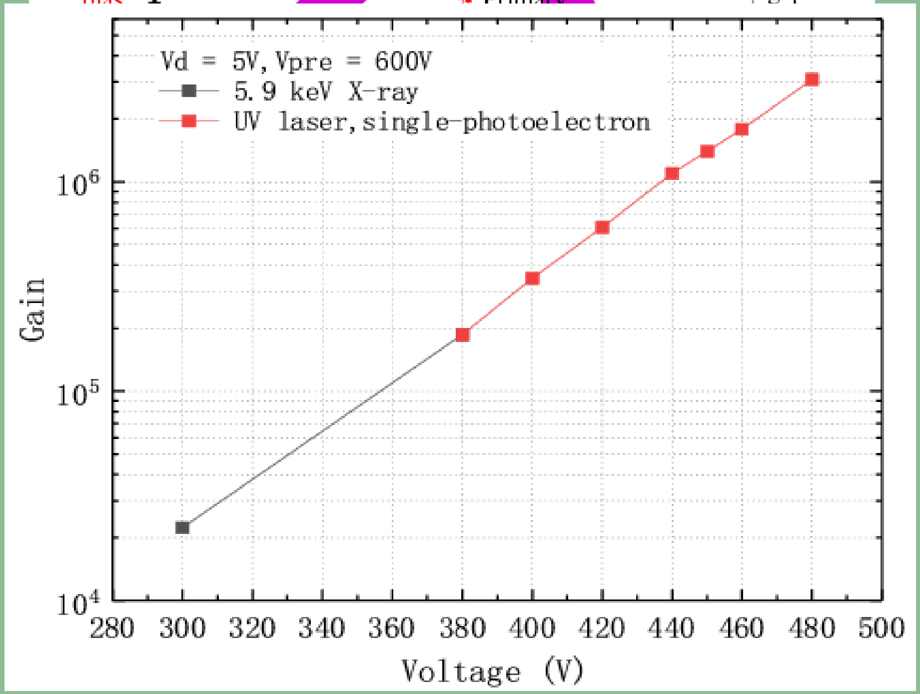
  - Aging - Ion Back-Flow (IBF)
- Electron Amplification
  - Gain 3x10^6
  - Uniformity
  - Stability
    - Su
  - Coating
    surface
- Readout
  - High-de





Shao

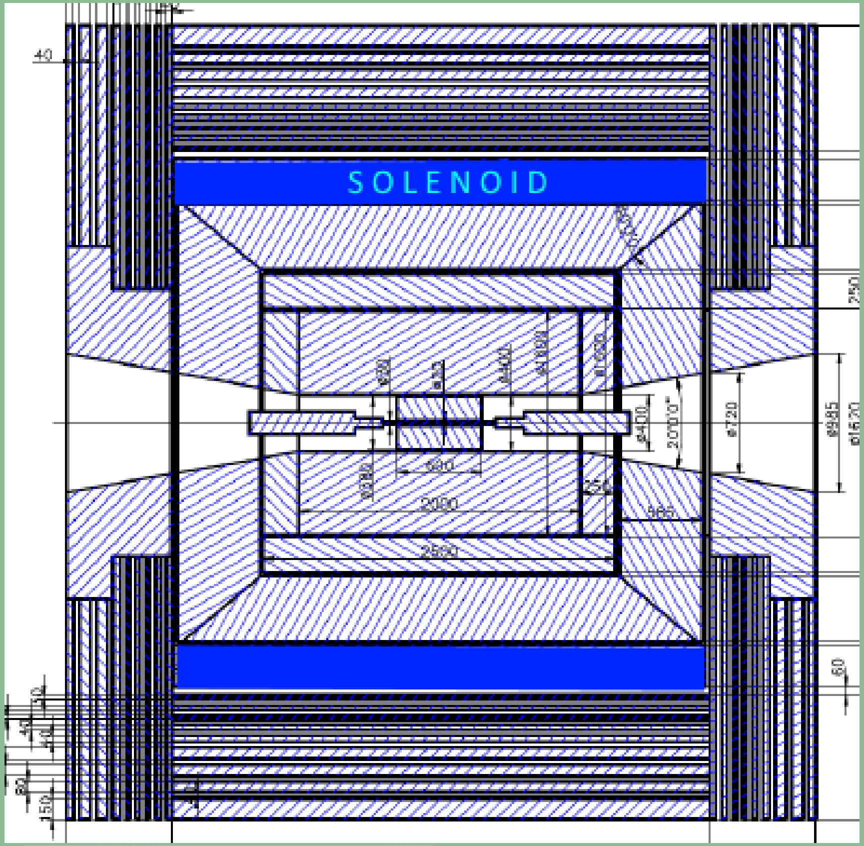
Solenoid field and placement

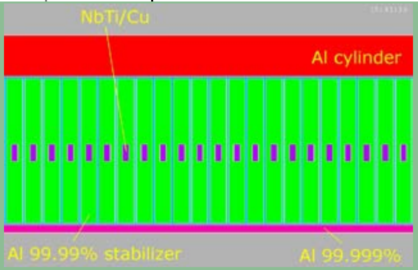
- Solenoidal magnetic field value
  - The choice of magnetic field is a compromise between momentum resolution and tracking efficiency at low p_T
  - Since $\sigma(p_T) \sim BL^2$ at high p_T, one must balance the feasible tracking length, and a field low enough to allow low p_T tracks to traverse a sufficient number of planes to be efficiently reconstructed
  - Volume of calorimeter crystals $\sim L^2$
  - Multiple Coulomb scattering dominates at low p_T
  - The values considered are 1~ (STCF) to 1.5 Tesla (SCTF)
- Preserving the intrinsic resolution of the electromagnetic calorimeter and the PID performance motivates placement of the PID and calorimeter inside the solenoid, in which case the thickness of the solenoid in radiation lengths is a less important criterion than power consumption and robustness
- If, however, a sufficiently thin solenoid could be made, it could perhaps be placed directly after the tracker, with the calorimeter and PID placed outside

A conventional outer solenoid

Many successful examples (latest is PANDA)

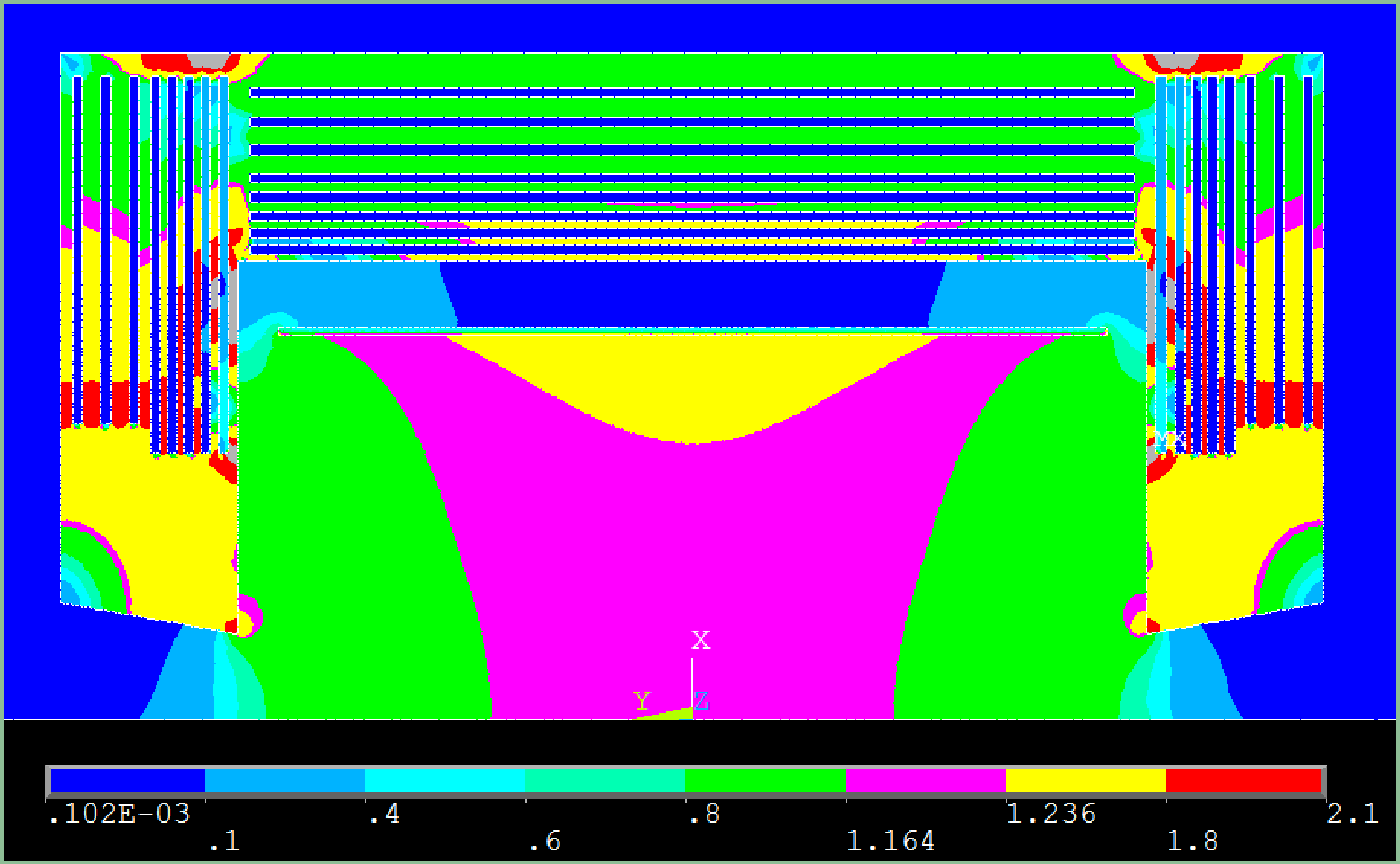
Length, m	3.8
Inner diameter, m	3.2
Number of layers (considered to be)	1 (2)
Number of turns	940
Current at 1.2 T, A	4300
Inductance $2E/I^2$, H	2.3
Ratio Iop/Icr, %	≤ 30
Cold mass, tons	5.1
Ratio E/M, kJ/kg	3.6
Magnetic field in the center, T	1.2
Stored energy, MJ	18.4
Cost, $0.56[E(MJ)]^{0.69}$, M$	4.2
Ramping rate, h	< 4





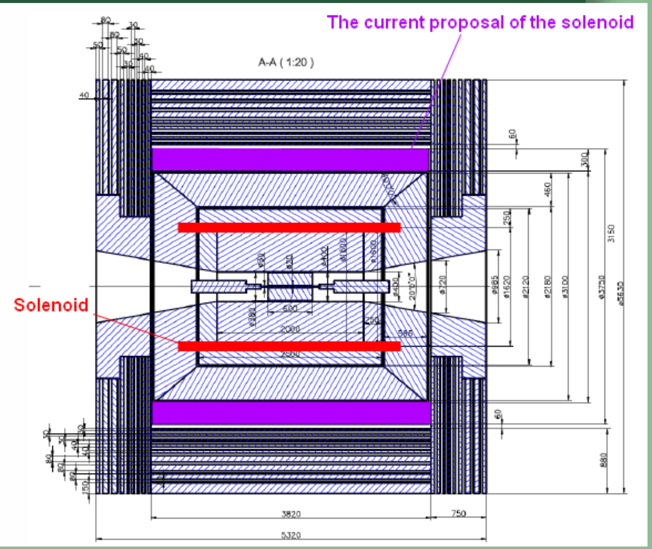
Bragin, Pyata

Outer solenoid – magnetic field in the detector



Bragin, Pyata

A thin solenoid



Parameters	Values
Length, m	~ 3
Inner diameter, m	~ 1.66
Radial thickness, mm	~ 80
Number of turns	1500
Number of layers	1
Current, kA	1.8
Diameter of the NbTi/Cu wire, mm	1.2
Icr at 5 T and 4.2 K, kA	1.7
I_{op}/Icr ratio, %	< 50
Cold mass, kg	173
Magnetic field, T	~ 1
Stored energy, MJ	3.0
Powering time, h	< 4

- The thin superconducting solenoid is placed in front of the identification system
- Minimal radiation length of the solenoid materials is ~ 0.1 X_0.
- The magnetic field is ~ 1 T (up to 1.5 T may be possible).
- Would require a redesign of the flux return

Bragin, Pyata

Design of the ultra thin solenoid for CTF detector

Carbon fiber composite for the solenoid support cylinder

Aluminum vacuum vessel

Same design approach as for solenoid for the CMD-2 and KEDR detectors.

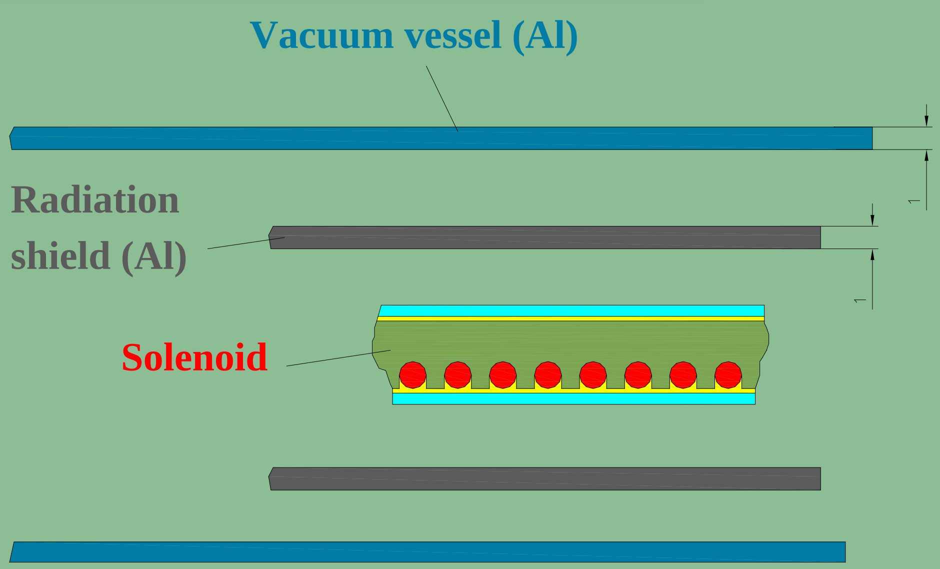
Aluminum strips, insulated from coil for temperature stabilization at ~ 4.2 K

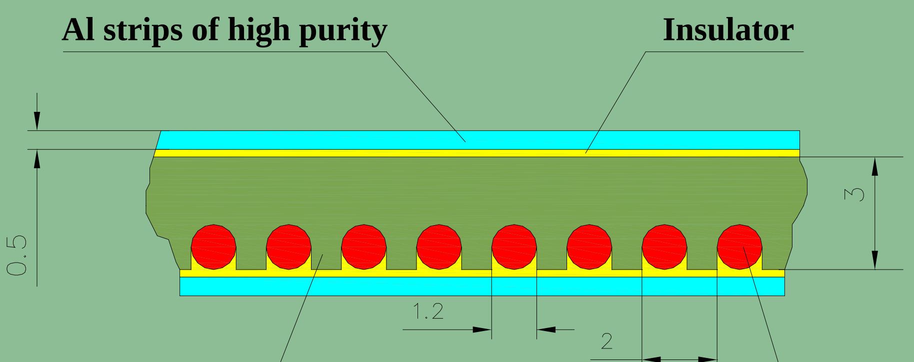
SC wire is not insulated

The carbon fibre should be chosen with specific electrical resistivity in the range $10^{-5} \div 10^{5}$ Ω*m

Stainless steel has 5.1×10^{-7} Ω*m

About 10%X_0 in total, not compactly distributed





Bragin, Pyata

Magnetic system design with thin solenoid

Possible magnetic system design with the thin solenoid.

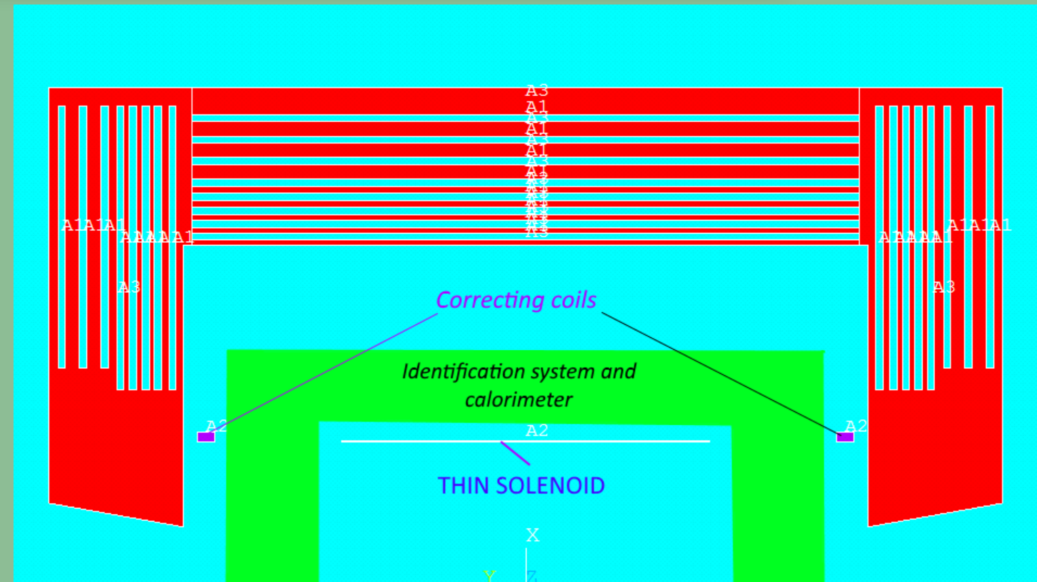
Correcting coils are used to improve uniformity of the magnetic field.

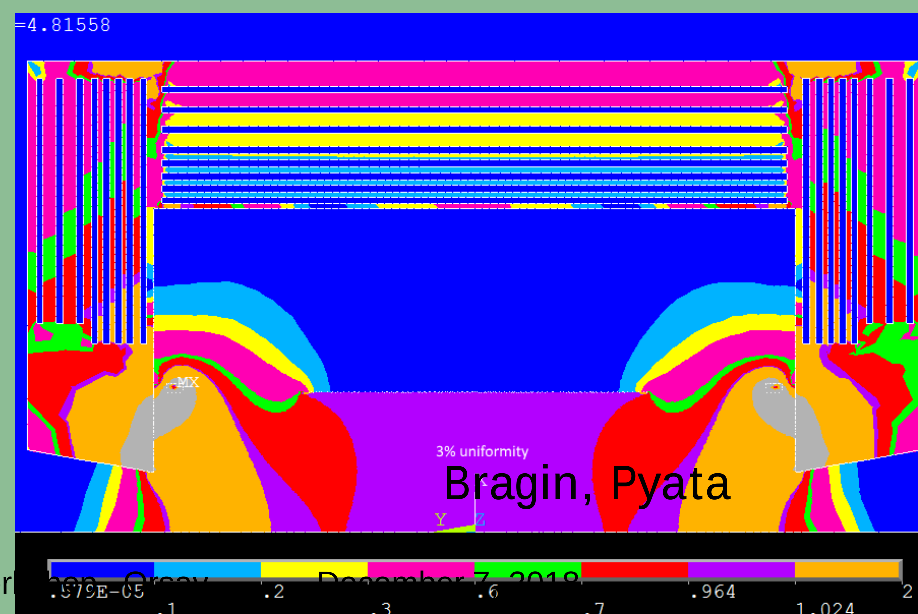
The identification system and the calorimeter may be placed almost around all space of the solenoid

Magnetic field uniformity is 3% at the center of the detector.

Effect on calorimeter performance?

How does furnishing of cryogenic, vacuum, power and instrumentation effect the projective crystal calorimeter and the PID system?





Advantages/disadvantages of the thin solenoid

- New technology of thin superconducting solenoid based on carbon fiber composite allows design of a “transparent” solenoid
- Quench behavior of the system should be analyzed taking into account carbon plastic properties at low temperatures. If the carbon plastic has too high electrical resistivity at T < 30 K it would be the best design because the quench propagation could be realized as in the CMD-3 design
- Eddy currents on neighbor structural elements should be estimated. They would absorb the significant part of the stored energy.
- Supports should be strong enough, as the current in the solenoid will be not uniform.
- The thickness of the radiation shields may be decreased by ~ a factor of 2 if they are cooled to lower temperatures and if pure aluminum would be used.
- Corrugated outer cylinder of the vacuum vessel should be made.

Bragin, Pyata

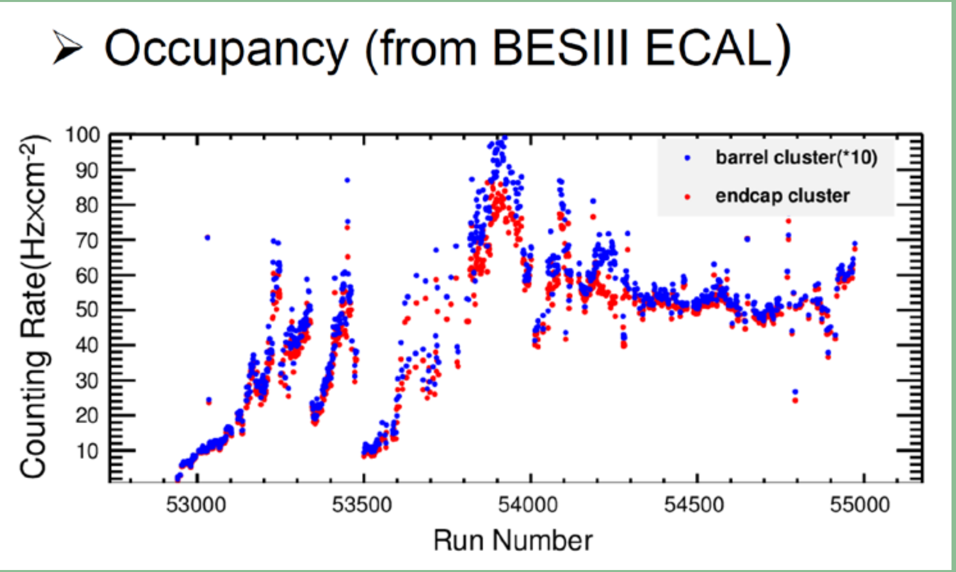
Electromagnetic calorimeter: choice of crystal

- Rates, backgrounds and radiation environment at a 10^{35} tau/charm factory require a change of crystal from the commonly used CsI(Tl)
- Motivates a new optimization of the calorimeter system for
    - Total crystal depth – energy resolution at high energy
    - Transverse crystal size – overlaps and position resolution
    - Energy resolution
    - Dynamic range – choice of sensor, digitizer
    - Time resolution
    - Rate capability
    - Radiation hardness
- Candidates studied include pure CsI, BGO, LYSO

Zhang

Choice of crystal

- Rates, backgrounds and radiation environment at a 10^{35} tau/charm factory



Occupancy

	BESIII	STCF	τ of crystal decay time (ns)
Barrel	4000	400,000	<1000 (2500/e)
Endcap	30000	3,000,000	<120 (333/e)

Radiation dose

	BESIII (rad/y)	STCF (rad/y)	STCF 10 years
Barrel	100	10,000	100,000
Endcap	200	20,000	200,000

Zhang

Scintillating crystal properties

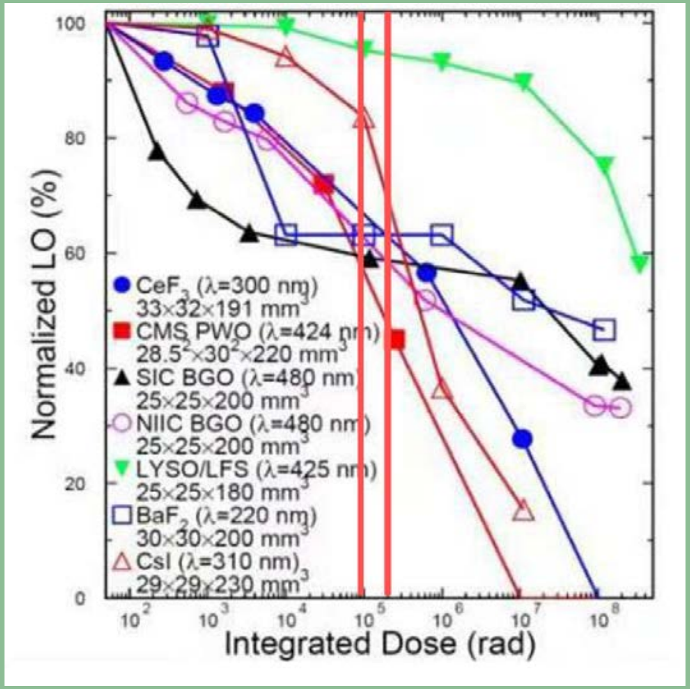
Crystal	Pure CsI	LYSO	GSO	YAP	PWO	BGO	CsI (Tl)
Density (g/cm^3)	4.51	7.40	6.71	5.37	8.30	7.13	4.51
Melting Point (°C)	621	2050	1950	1872	1123	1050	621
Radiation Length (cm)	1.86	1.14	1.38	2.7	0.89	1.12	1.86
Moliere Radius (cm)	3.57	2.07	2.23	4.50	2.00	2.23	3.57
Refractive index	1.95	1.82	1.85	1.95	2.20	1.82	1.95
Hygroscopicity	Slight	No	No	No	No	No	Slight
Luminescence (nm)	310	402	430	370	425 420	480	550
Decay time (ns)	30 6	40	60	30	30 10	300	1220
Light yield (%)	3.6 1.1	85	20	65	0.3 0.1	20	165
Dose rate dependent	No	No	TBA	TBA	Yes	Yes	No
d(LY)/dT (%/°C)	-1.4	-0.2	-0.4	TBA	-2.5	-1.0	0.4
Experiment	KTeV Mu2e				CMS ALICE PANDA	L3	BESIII BELLE(II) BaBar

Zhang`

Radiation hardness

- Csi will have light output loss under irradiation

Tests in Mu2e show variation of radiation hardness with CsI salt purity, crystal growth method and thus manufacturer
There are also correlation of purity with fast/slow light ratio



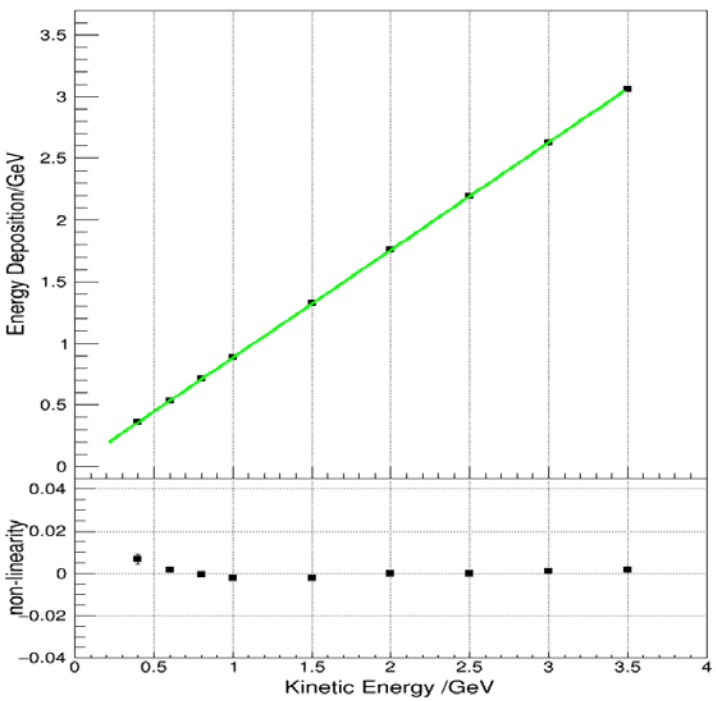
Evaluation of required photosensor readout noise should be done with light loss in mind.
Will contribution to energy resolution still be acceptable after irradiation?

Zhang

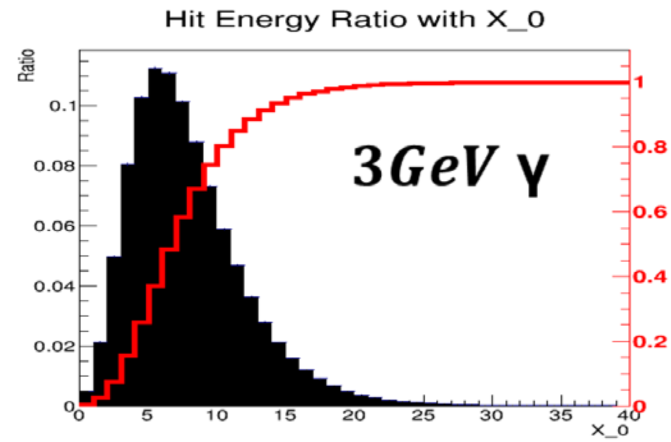
Shower containment

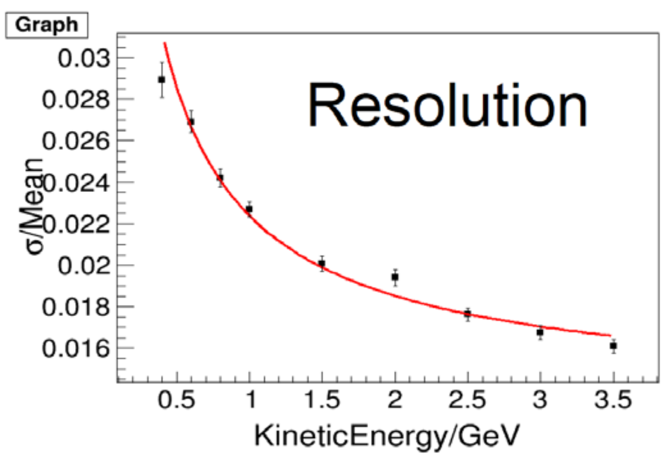
- Total thickness: $25X_0$

Thickness	$10\ X_0$	$15\ X_0$	$25\ X_0$
Ratio (%)	80%	95%	99%



Energy linearity



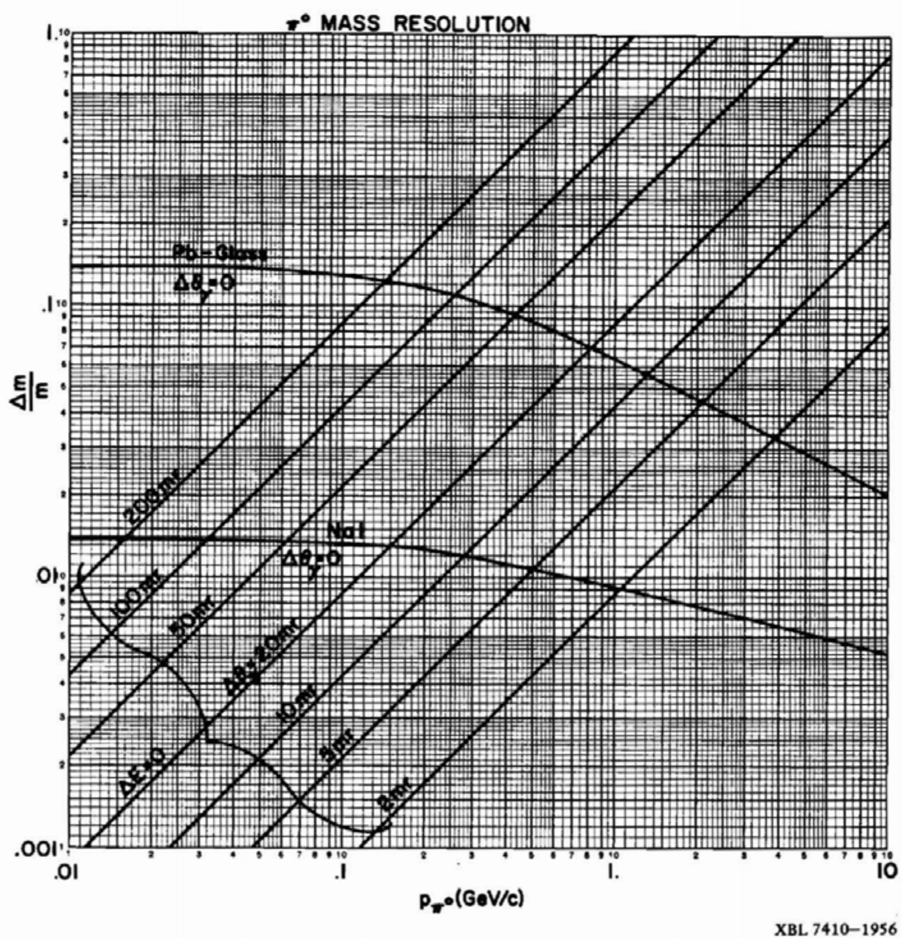


Zhang

An ancient nomgram

- Time resolution better 150 ps for γ/n separation
- Angular resolution determines π^0 mass resolution for high momentum π^0
    - e.g. for BES-III 4x4 cm^2 3.9 mm, 2x2 cm^2 2.7 mm

PEP-153-20

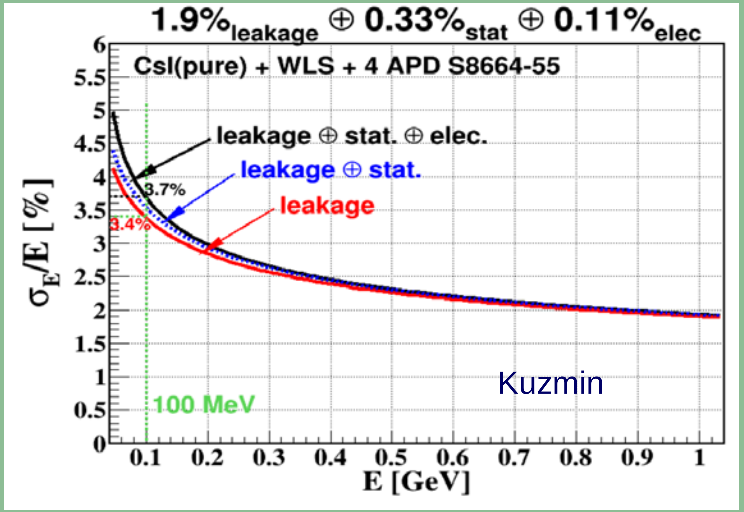


T. Mast
J. Nelson
PEP-II Summer Study

Fig. 14.

Calorimeter readout STCF

- Dynamic range will likely require a high/low gain system
- Sampling rate of ~250 MSPS needed for time resolution
- Rate is more than 100kHz in barrel and higher in the endcaps
- Requirement >150 pe/MeV ENE <0.4 MeV σ/E = 3.7% at 100 MeV



The main option is CsI(pure)+photopentode. Beam tests of the prototype showed good energy and spatial resolutions, as well as essential suppression of the pileup noise

The second option: CsI(pure)+WLS+4APDs is under development. The problems of the low LO and high ENE have been solved.

Zhang

Light yield comparison

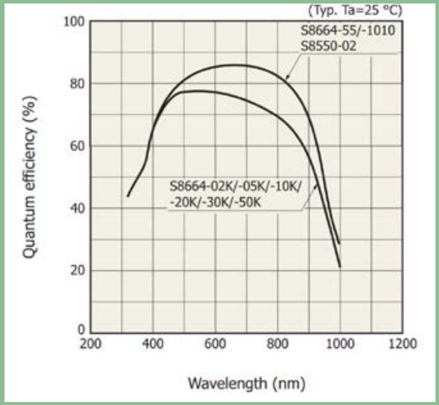
- BGO light output is rate-dependent
    - Achieving good energy resolutrion requires an elaborate calibration system (c.f. PWO_4 for CMS)
  - LYSO has become very expensive
  - Pure CsI light output is quite small
- BGO light output is rate-dependent
    - Achieving good energy resolutrion requires an elaborate calibration system (c.f. PWO_4 for CMS)

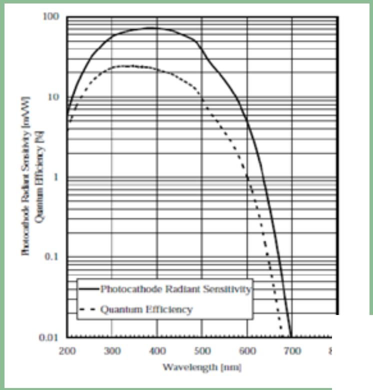
	Single p.e	signal	L.Y with PMT(pe/MeV)	L.Y with APD(pe/MeV)
~~BGO-1~~	~~24.2~~	~~513.4~~	~~358.4~~	~~159.3~~
~~BGO-2~~	~~23.5~~	~~633.2~~	~~456.5~~	~~202.9~~
LYSO-1	2.4(*)	2018.7	1343.3	597.0
LYSO-2	2.4	2586.4	1721.0	764.9
CSI-1	39	1647.5	63.8	28.4
CSI-2	39	1475.8	57.2	25.4

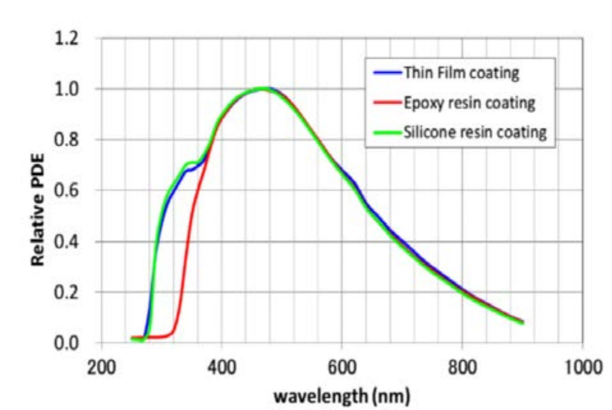
Zhang

CsI readout choices

- Limited choices for readout in a magnetic field
- Vacuum photopentode, APD, SiPM
- Photopentode works in 1-1.5 T magnetic field, but gain is reduced by ~3
    - Area provides reasonable coverage of crystal face
    - Photocathode QE at 310 nm ~25%
- APD large or small area
    - QE at 310 is limiting
    - Use a wavelength shifter
- Large area extended UV SIPM
    - Series/parallel connection (Mu2e)



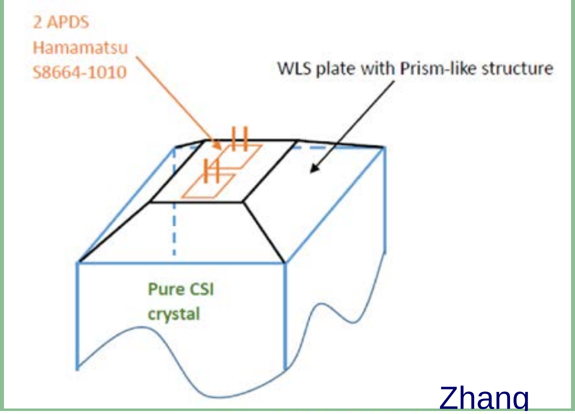




Zhang

Wavelength shifting

- The low QE of APDs at 310 nm, coupled with the difficulty in matching the crystal face area to a large area solid state photosensor, with the attendant large capacitance and poor time performance, has motivated studies of using a wavelength shifter and smaller photosensors
- the noisefigure achieved is ~330 to 400 keV



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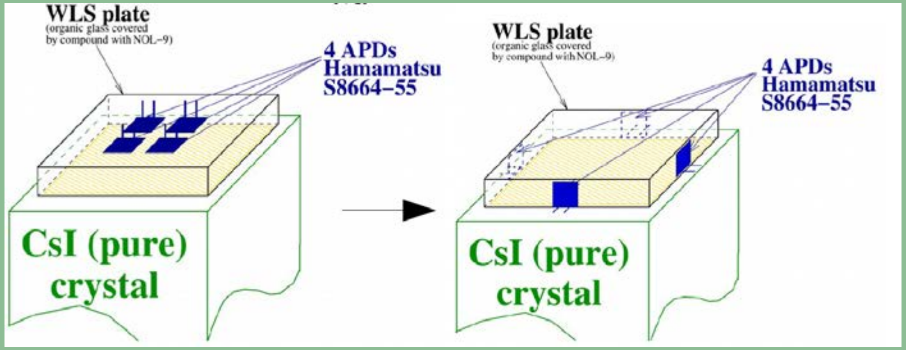
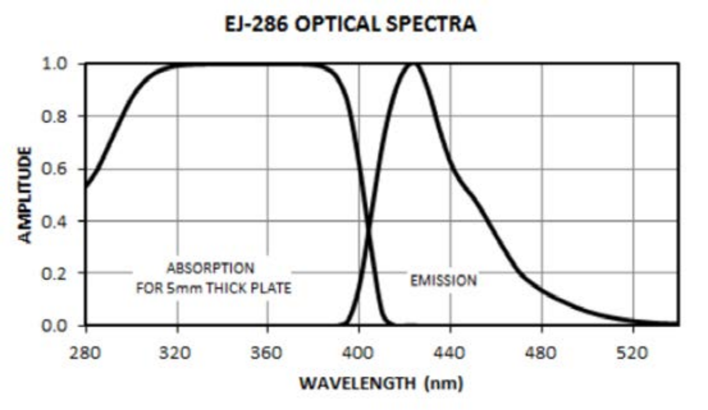
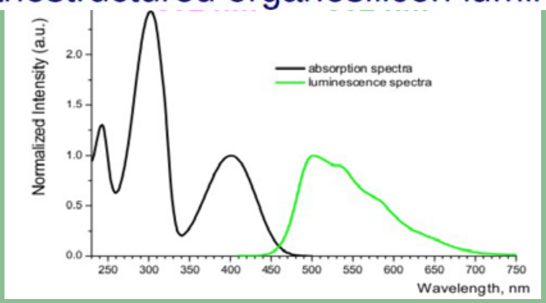


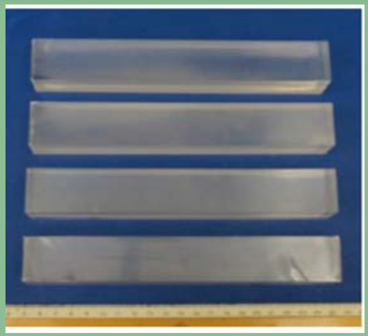
Kuzmin,Epifanov



nanostructured organosilicon luminophores

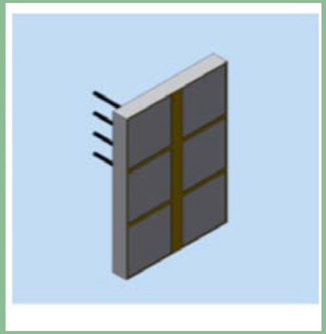


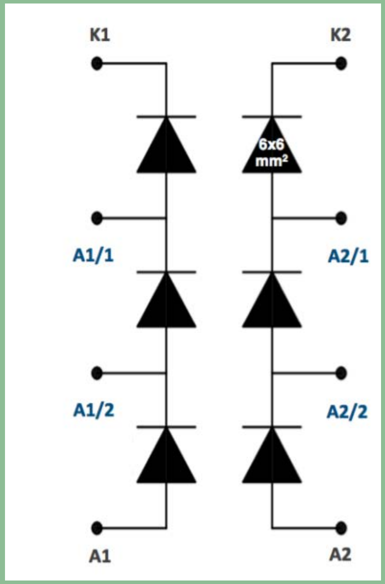
Mu2e pure Csi calorimeter large area SiPMs



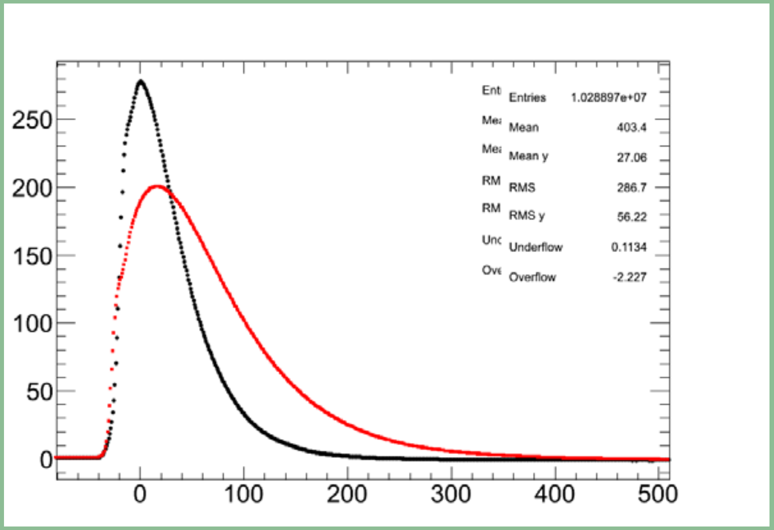
Channel	B1-C1	B1-C0	B0-C1	B0-C0
MIP (PC)	500	600	1000	1200
Sped (PC)	1	1.3	2.5	3.1
Noise(MeV) = 20 MeV x Sped/Mip	40 keV	43 keV	50 keV	51 keV

Results are for a single channel





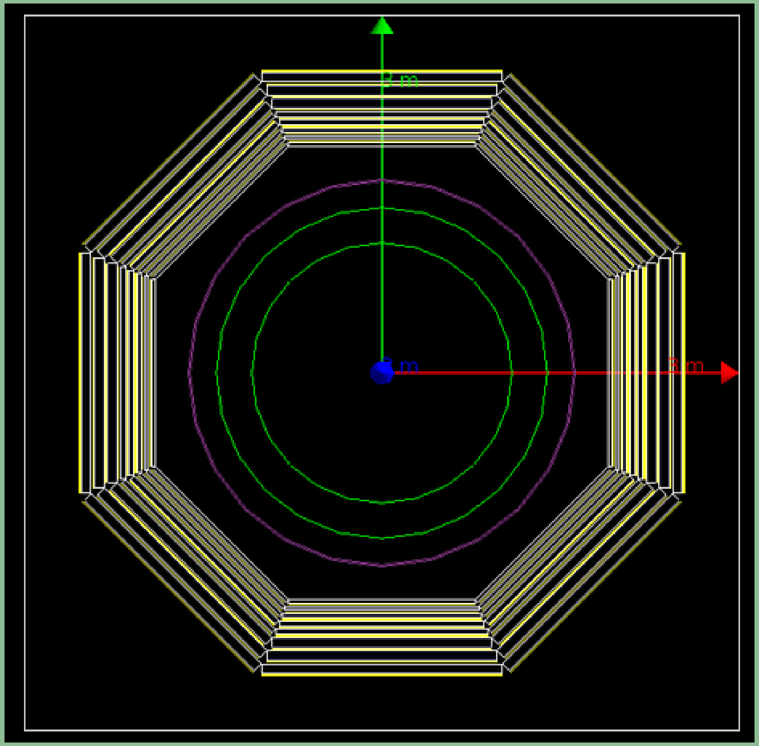
There is a gap between the crystal and SiPMs
We accept this light loss to allow SiPM cooling in th event of radiation damage



One channel = 6 @ 6x6 mm SiPM
w 50 μm pixels – there aretwo channels/crystal

Muon identification

- Muon ID duties may be shared between tracker, PID system and instrumented flux return
- Typically the flux return will have of the order of 10 steel plates (30 to 80 mm thickness, corresponding to 2 to 5 interaction lengths)
- Typically the SC coil after the calorimeter, will be first absorber
- Sensitive layers may be TPCs, streamer tubes, extruded scintillator
  - Scintillator typically has the highest rate capability
  - Used in MINOS, MU2e CRV, Belle II
- In Belle II, barrel retains Belle RPC system, except in first two layers, which, with the end caps, use scintillator



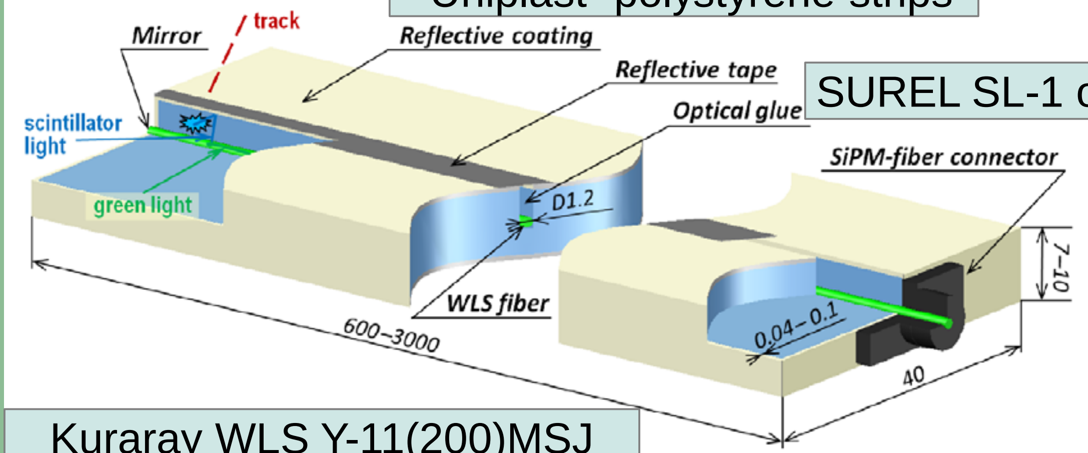
Uglov

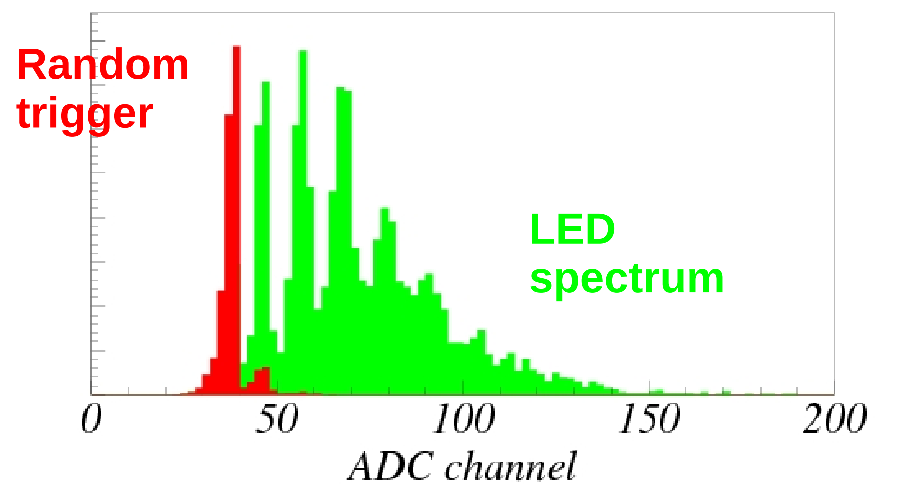
Muon identification – scintillator/WLS/SiPM

“Uniplast” polystyrene strips

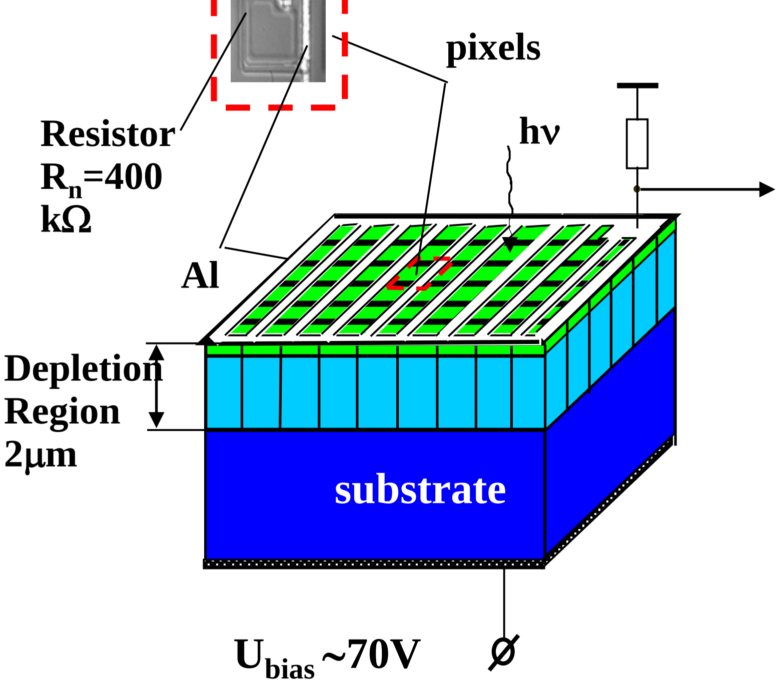
SUREL SL-1 optical glue

Kuraray WLS Y-11(200)MSJ

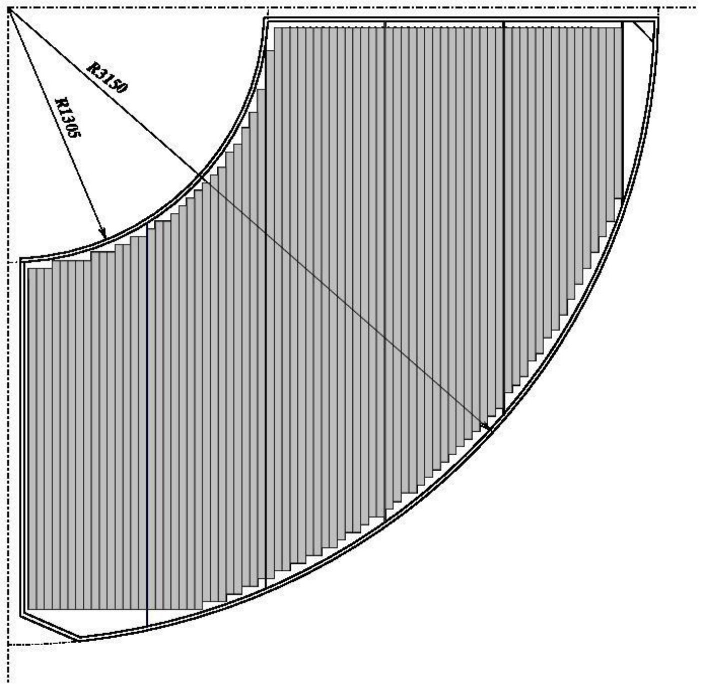


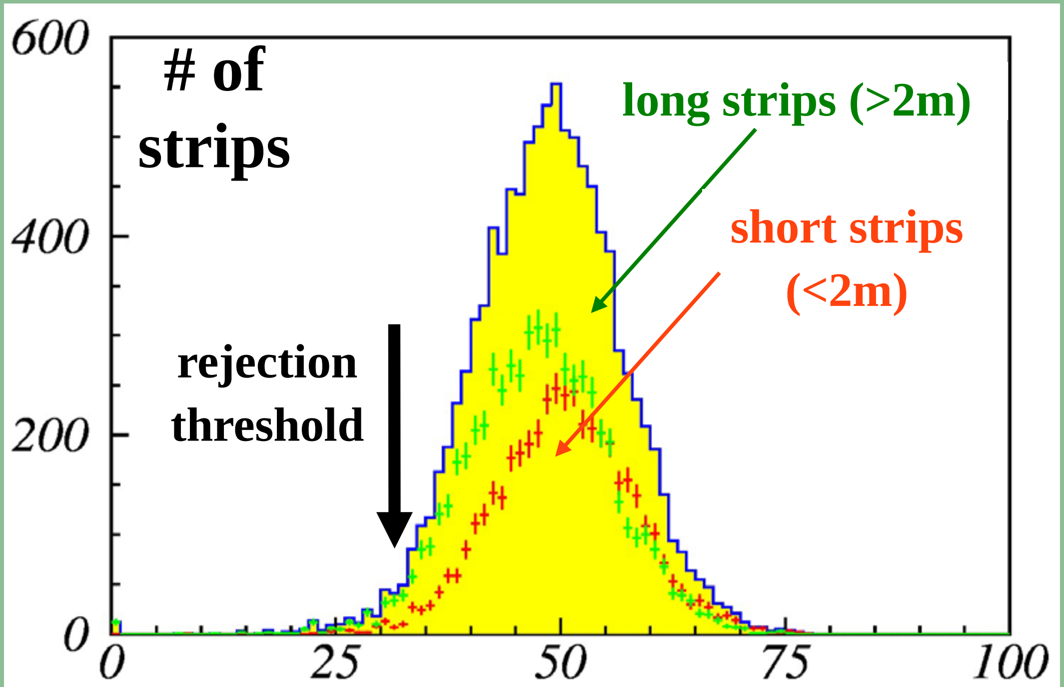


Hamamtsu MPPC S10362-13-050



Muon identification – scintillator/WLS/SiPM





~2% of strips rejected

Light yield in p.e.

75 strips (4 cm width)/sector

16800 strips for F&B Endcap KLM

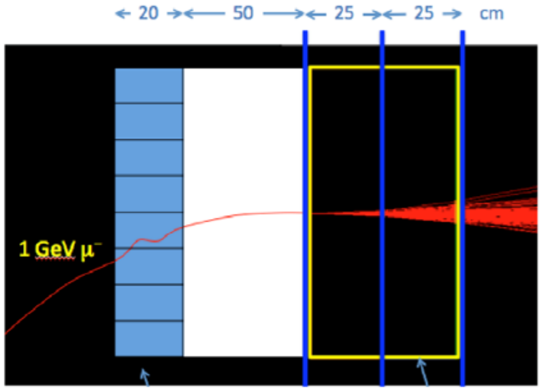
Longest strip 2.8 m; the shortest 0.6 m

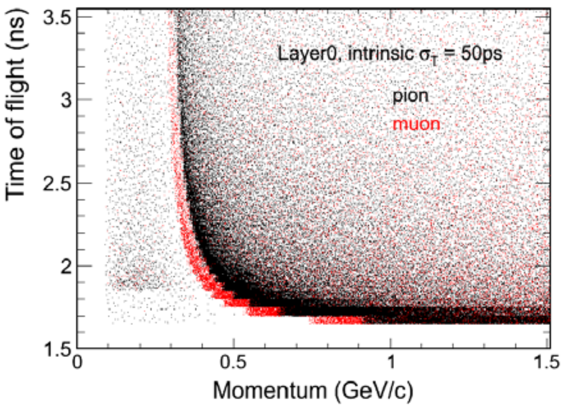
- WLS fiber in each strip
- SiPM at one fiber end
- mirrored far fiber end

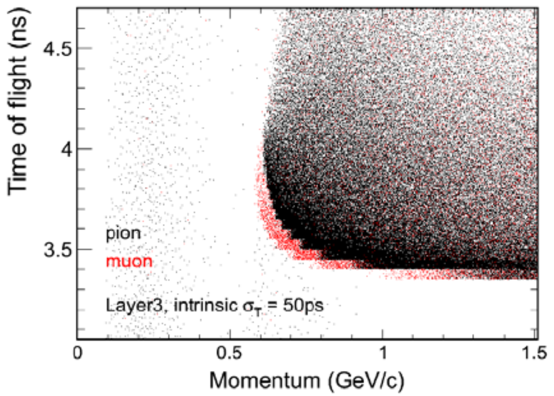
Uglov

Muon identification – STCF

- Low **momentum** threshold (p~0.4 GeV)
- high μ efficiency and **μ/π suppression** power>10 (30）
- Idea to lower muon detection threshold:
  - measuring TOF at entrance to iron yoke — a timing muon detector.
  - Can be realized with MRPC technology



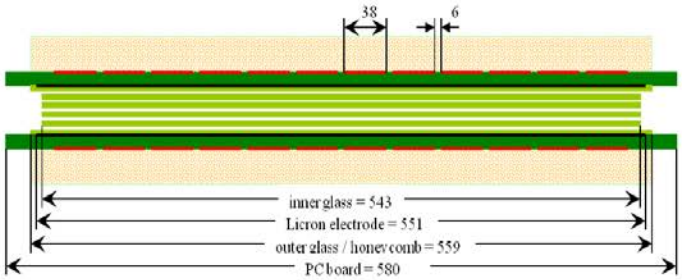




- Below 400 MeV, μ and π can be well separated
- Below 300 MeV, μ can't reach iron yoke

How much does capturing this narrow range of momentum improve physics performance in a particular example?

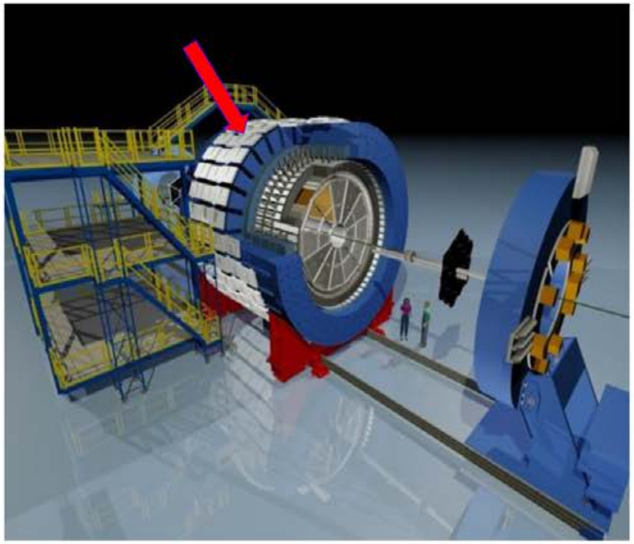
Muon identification by TOF – STCF



Long-Strip MRPC Module at STAR

- Active area: 87 x 52 cm^2
- Read out strip: 87 cm x 3.8 cm
- Gas gaps: 0.25 mm x 5

MTD at STAR



Performance:

- Efficiency: > 98%
- Time resolution: < 80 ps
- Spatial resolution: 0.6 cm

Conclusions

- The SCTF and STCF detector concepts embody many interesting ideas, some tried and true, some innovative, some very innovative

  It is appropriate at the current time to "let a thousand flowers bloom"
- However, as the project(s) move toward reality, it will become important to work through the various (incommensurate) options to arrive at a detector design that meets the physics requirements, can be built on a practical schedule and meets cost constraints
  - Having been through this several times, I know that this can be a difficult process. At the appropriate time this must be done, and it should be done in a manifestly fair, but expeditious manner
    - Use of internal and external review committees can prove very useful
    - The process of arriving at final detector components in a single project, or two separate projects, is not easy.
    - The merging of two project concepts is even more difficult

Conclusions - II

- Physics criteria
  - It would be useful to choose several benchmark physics topics, and then to optimize the individual systems and the overall design against the performance on these topics
  - Examples
    - $\tau \to \mu\gamma$, eee BR (efficiency and background rejection)
    - Mass resolution on XYZ particles
    - $D^0\bar{D}^0$ entanglement studies
    - ………
  - How does a given system or parameter choice change the performance against the benchmark?
  - In some cases, the physics performance will be affected, in some cases the result will be insensitive, in which case the other criteria, such as cost, readiness for construction, affect on other components, etc., come into play
- I look forward to seeing SCTF and STCF move forward towards CDR and TDR-ready designs

Conclusions - III

- The approval process differs markedly in different regions