LST and the BaBar barrel
Instrumented Flux Return upgrade

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Outlines

- Brief survey of the past and present large LST systems;
- Basic properties of the LST tube:

  Electrostatic properties;

  Anode and strip signal;

  Aging;

  Rate capability;

  Robustness and quality assurance;
- BaBar barrel IFR system upgrade project

  Double-gap LST tube;

  budgetary estimation.

Brief survey of the past and present large LST systems

	system	date	Function	size
1	UA1 (upgraded muon system)	1985	Muon system	0.9×0.9cm tubes covered 800m^2 area, first large LST system used in HEP accelerator experiment.
2	NUSEX(Mt. Blanc Lab)	1982 - 1986	Necleon decay	43,000 tubes (0.9×0.9cm×3.5m), 1,500m^2.
3	CHARM II (CERN SPS)	1986 - 1991	calorimeter	155,232 tubes (0.9×0.9cm×3.75m), 5,820m^2.
4	LVD (Gran Sasso Lab)	1992 -	Underground , tracking detector	160,000 tubes (0.9×0.9cm×6.3m), 7,560m^2. (constructed by SCARF, Houston-Northeastern)
5	ALEPH (LEP, CERN)	1989 -	Hadron calorimeter and muon	8000 8-cell profiles (0.9×0.9cm×7m) for barrel, ?? for end caps of hadron calorimeter.
6	DELPHI (LEP, CERN)	1989 -	Hadron cal.	20,000 tubes for hadron calorimeter.
7	OPAL (LEP, CERN)	1989 - 2000	Hadron calorimeter	3482 8-cell, 900 7-cell, 3 - 7.3m long for barrel. 2304 8-cell, 0.5-2.2m long for endcap. Total 52,588 tubes.

... Brief survey

8	SLD (SLAC)	1991-1998	Function	10,000 8-cell modules, length varying from 1.9 to 8.6m. Covered 4500m^2.
9	ZEUS barrel and rear muon detector (HERA)	1992-	Muon detector	3600 LST with length varying from 0.7m to 10.2m. Covered 2,000m^2. Noryl instead of PVC for better wire aging and less safety hazard in case of fire. **Two chambers were the world largest single-unit (10.5x4m^2) chambers ever built by 1993**.
10	MACRO	1989 -	Underground, tracking	2.9cm×2.7cm×12m big size tubes. 6 supermodules, 5856 tubes/supermodule.
11	COMPASS muon wall detector	1999	Muon detector	1200 LST tubes
12	SMC (Spin Muon experiment at CERN)	1992-1996	Muon detector	768 8-cell, 4m long chambers. Total 6144 tubes. Covered 245m^2. (Constructed by SCARF, Houston-Northeastern)
13	WA98 (SPS, CERN)	1996 -	Tracking	Charged Particle Veto Detector(CPV) and Streamer Tube Detector are made of LSTs. (earlier generation WA80,WA93 used LST too)
14	PHENIX muon identifier	1999 -	Muon detector	12,680 8-cell 0.9cm×0.9cm×(5.2 or 2.5)m LSTs.

... Brief survey

LST with same geometry but run at proportional mode:

CLEO II

D0

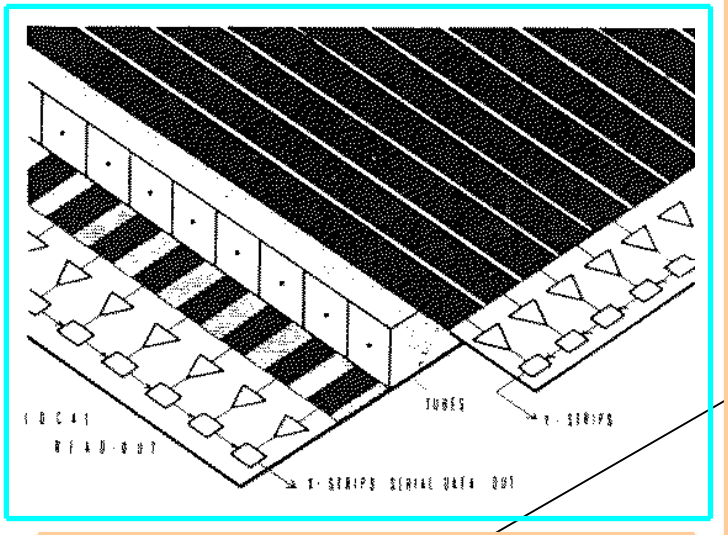
E802 (BNL)

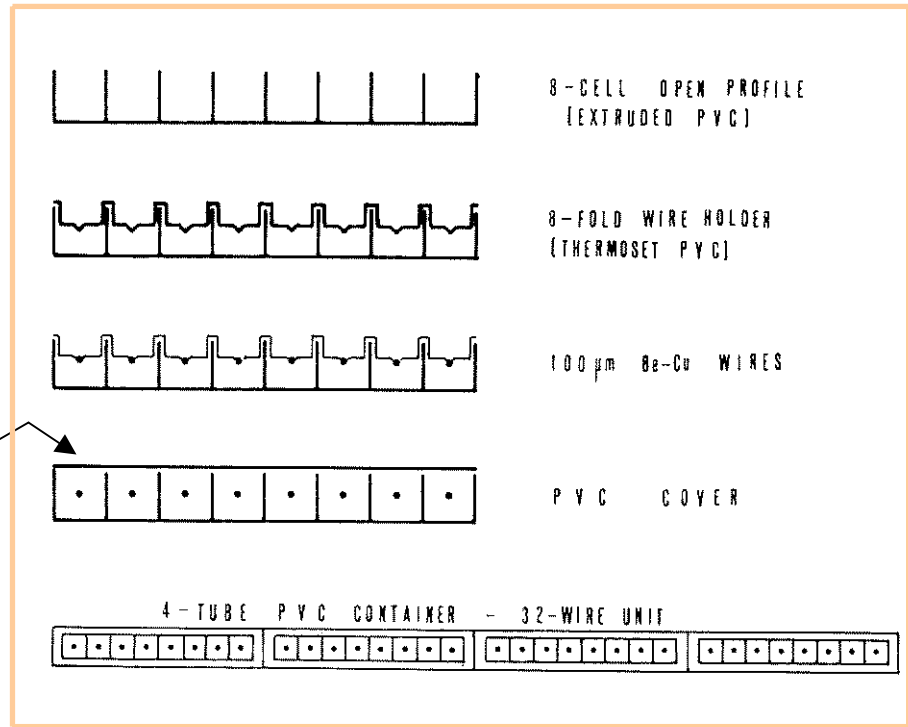
A detailed excel file for the survey can be found at:

http://feynman.princeton.edu/~lu/BaBar_RPC/iaroccitube.xls

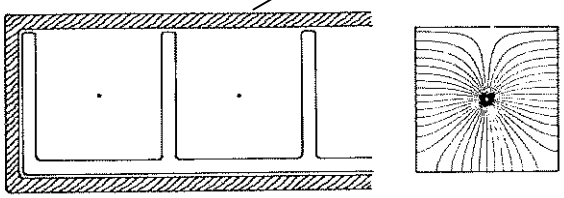
Basic properties of LST tube

The LST technology was first introduced to HEP community by E. Iarocci et al in 1978.





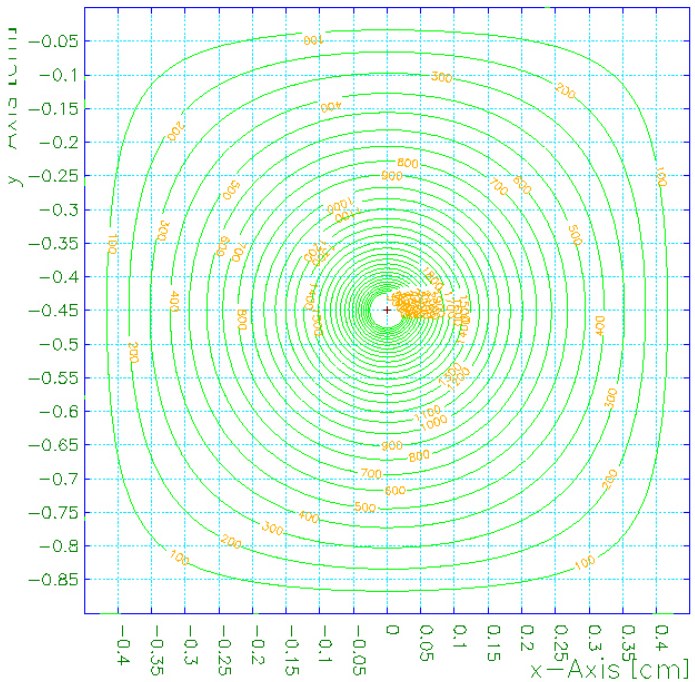
Coverless version doesn't have this PVC cover



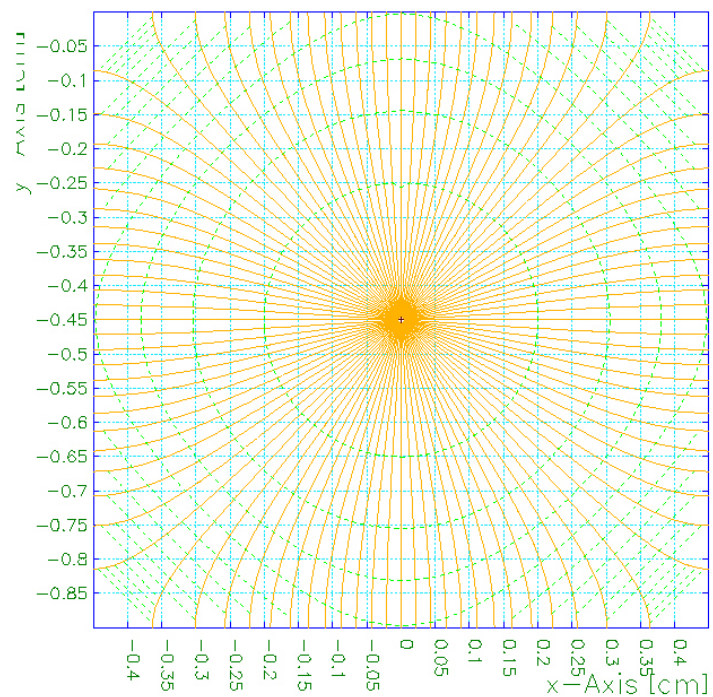
Coverless LST chamber

Electrostatic properties of LST tube

9 x 9 mm^2 cell with conductive cover

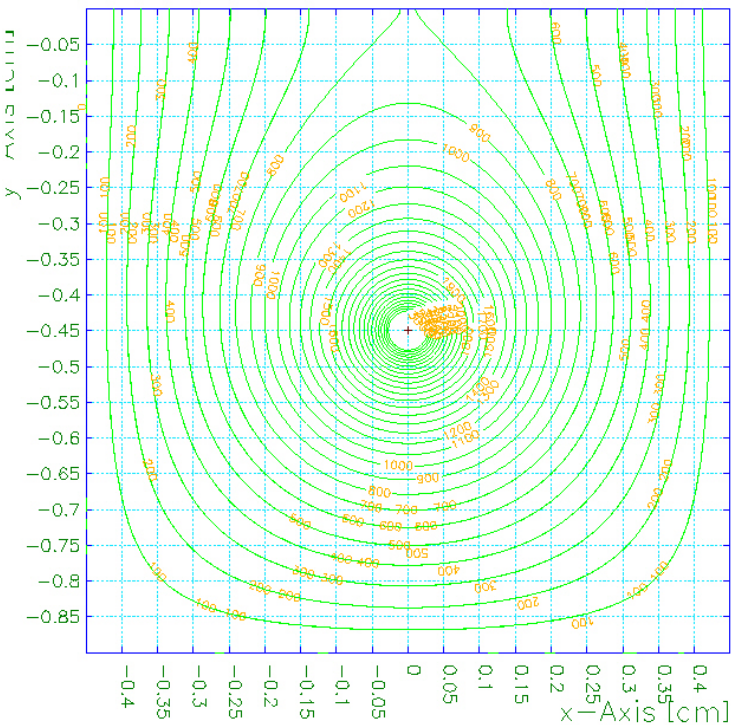


V contour plot

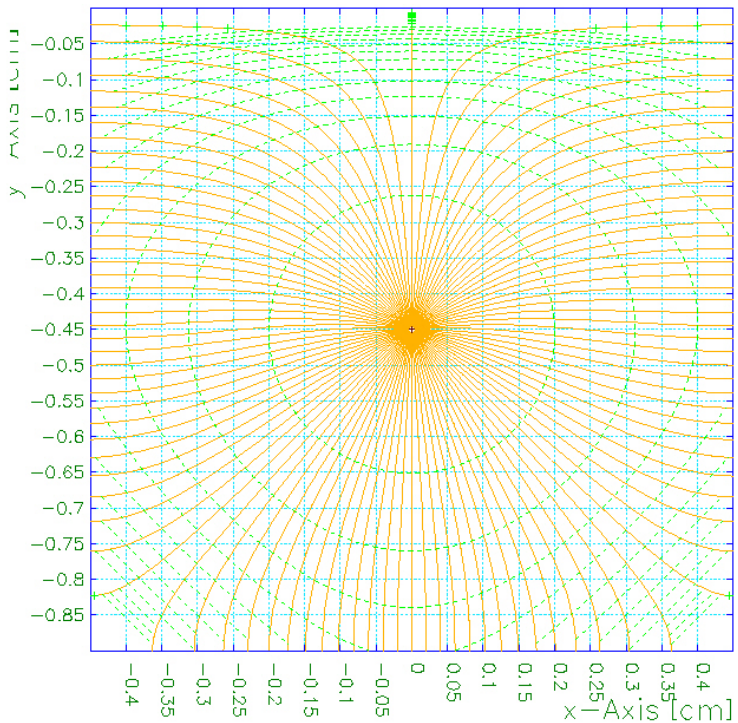


E-field lines

... Electrostatic properties of LST tube



V contour plot



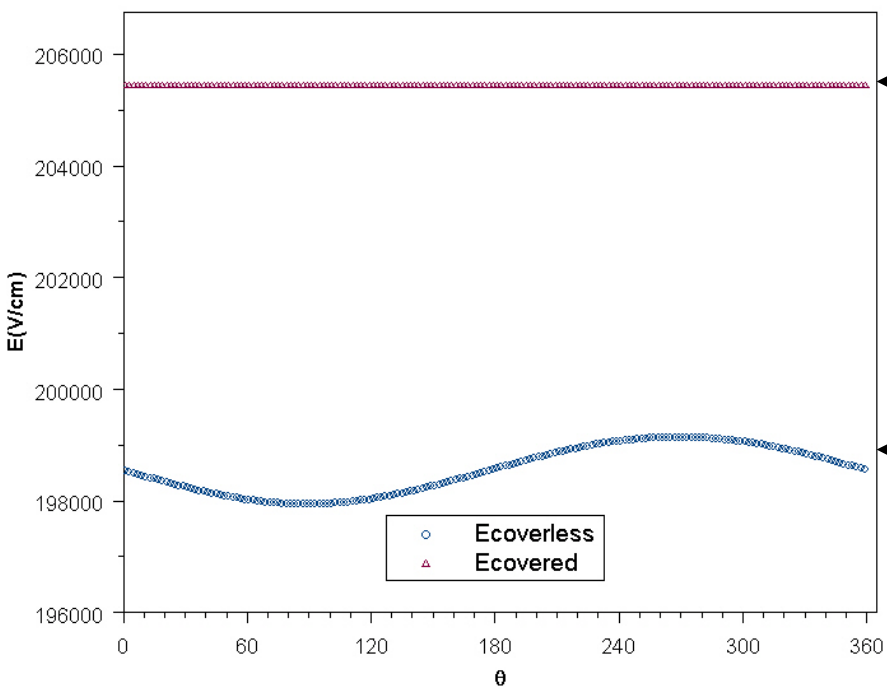
E-field lines

Analytical formulae for LST E-field distribution can be found in
http://puhep1.princeton.edu/~mcdonald/examples/iarocci.pdf

E-field distribution on the anode wire surface

Because of the coverless feature of LST cell, the E-field distributions on the anode wire surface and cathode wall are having some special features.

9 x 9 mm^2 cell size, 100μm anode wire, V_{anode} = 4700V

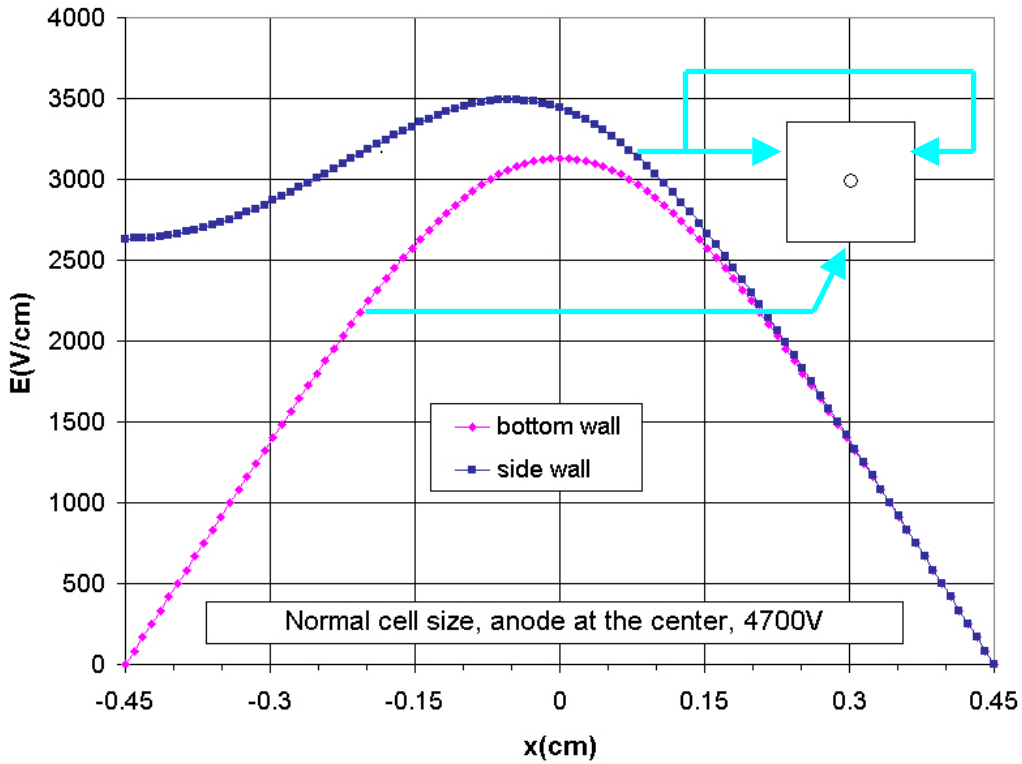


For all-covered cell E-field on the anode wire surface is constant.

For coverless cell E-field varies with θ.

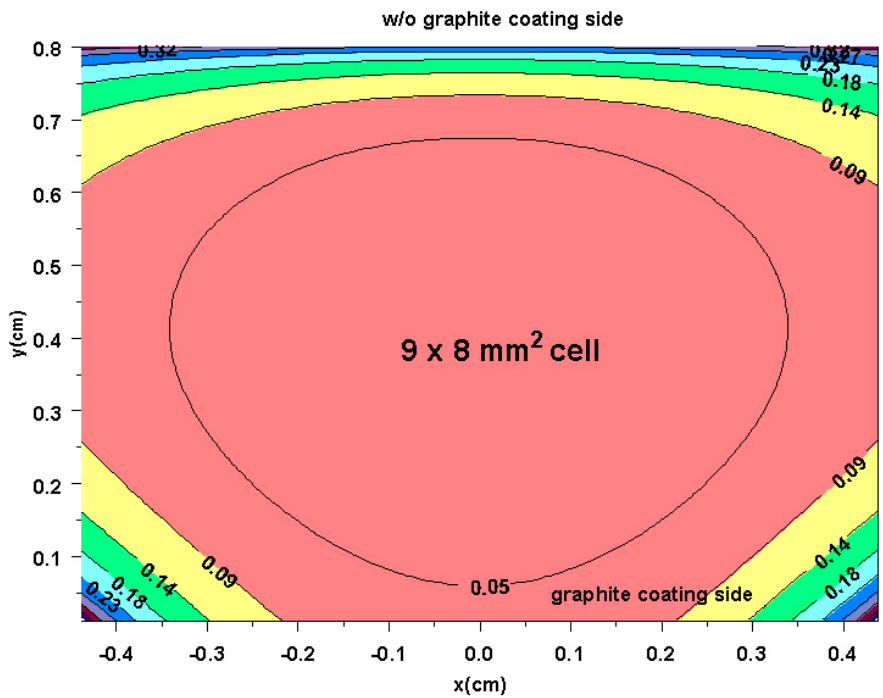
E-field distribution on the cathode wall surface

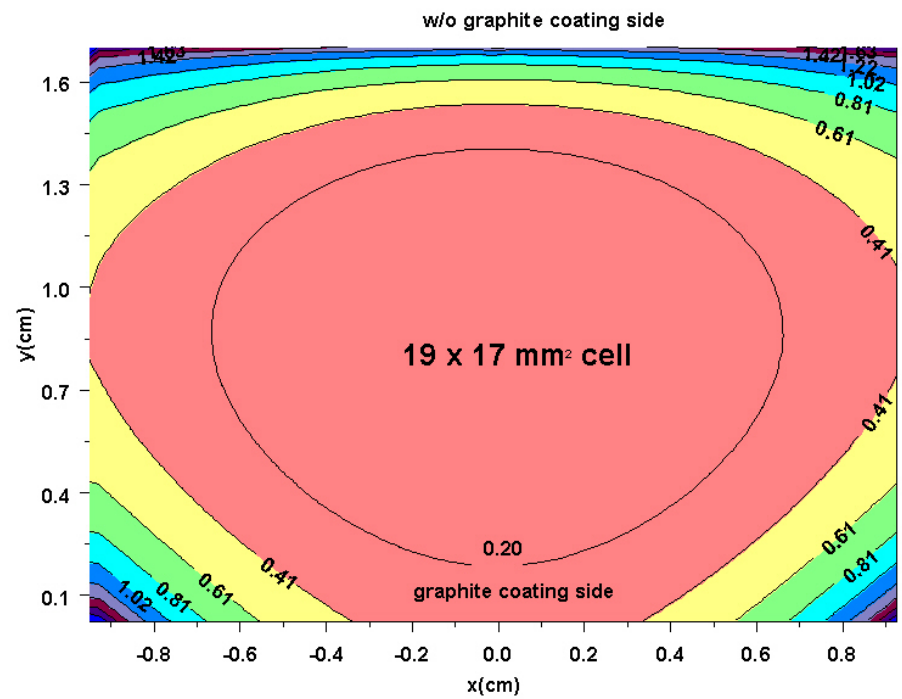
The electric field on the upper half of the side wall is high. Any defect on the upper corners may cause discharge.



Drift time distribution

Use CERN Garfield and Magboltz programs we can calculate the drift time in a LST cell with certain precision.

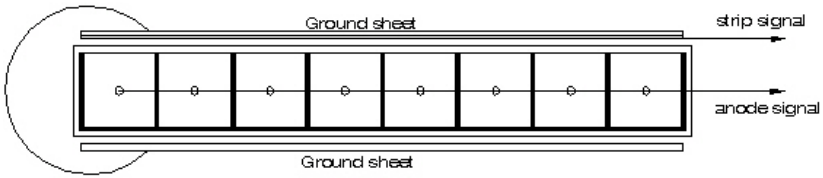




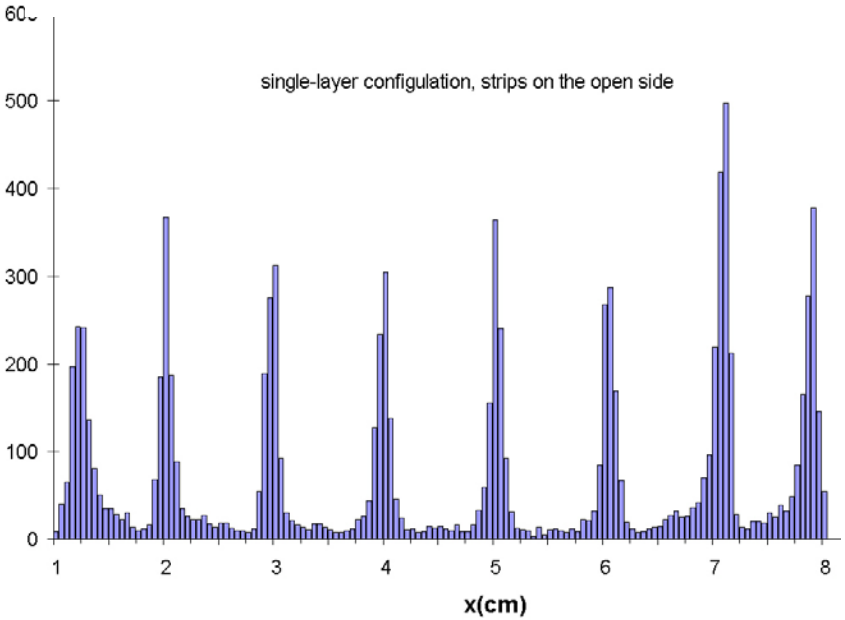
$Ar/C_4H_{10}/CO_2$ (3/8/89)

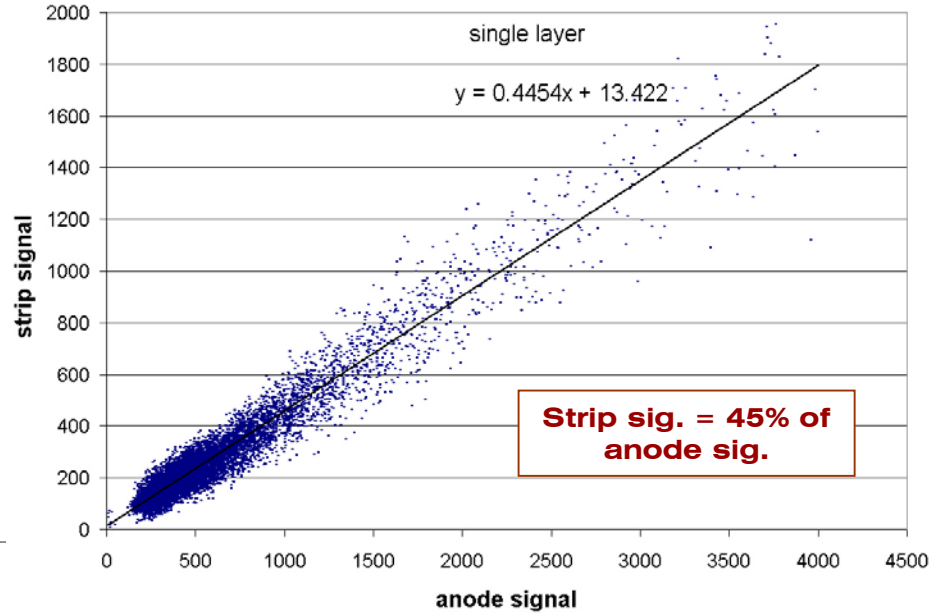
Anode and strip signal

Strips on open side of the LST tubes



Readout 8 strips individually, reconstruct the track position with center-of-mass method, we can clearly see the anode wire peaks. The resolution along x axis is 1cm/sqrt(12).

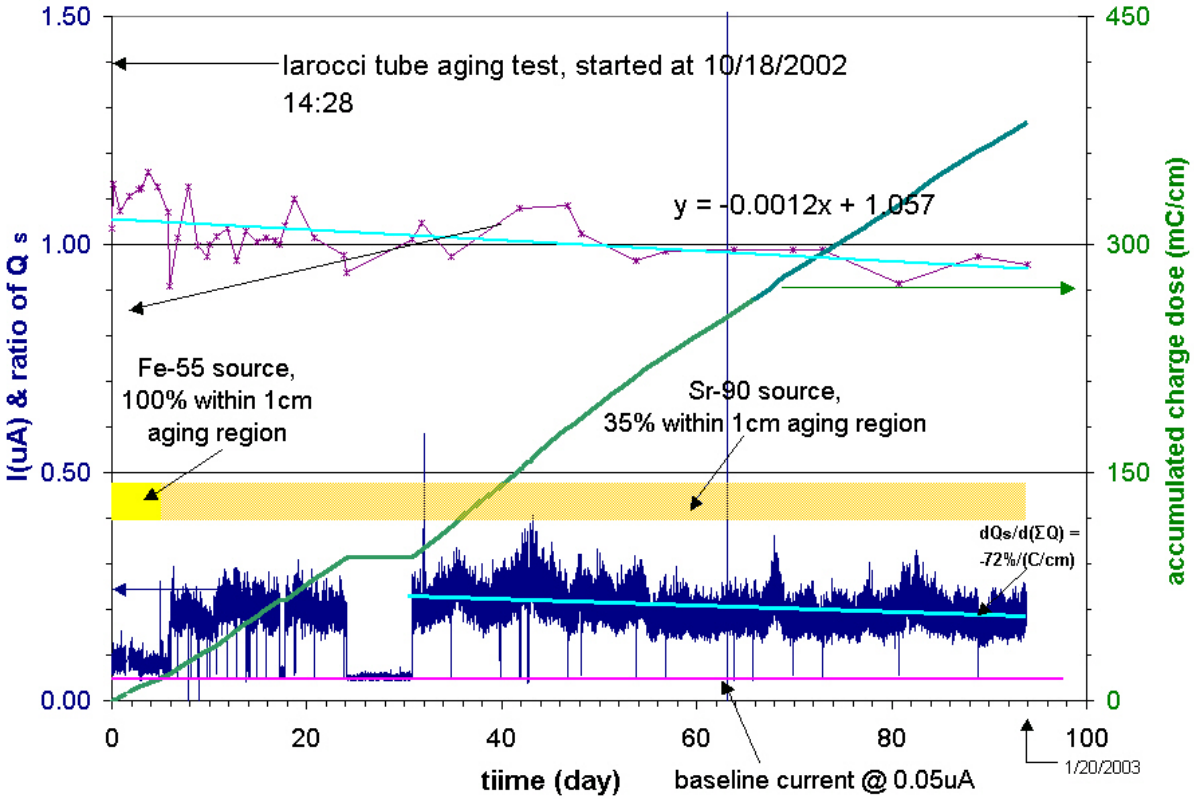




Easily obtain big signal from strip plane.

Aging performance

For an underground or ν experiment the aging should never post any trouble on LST system. In an accelerator experiment, such as BaBar, we are testing its longevity:



With $CO_2/Ar/C_4H_{10}$ (89/3/8) gas mixture, up to 380mC/cm charge dose, the LST still works smoothly, charge reduction rate is:

~ -72%/(C/cm)

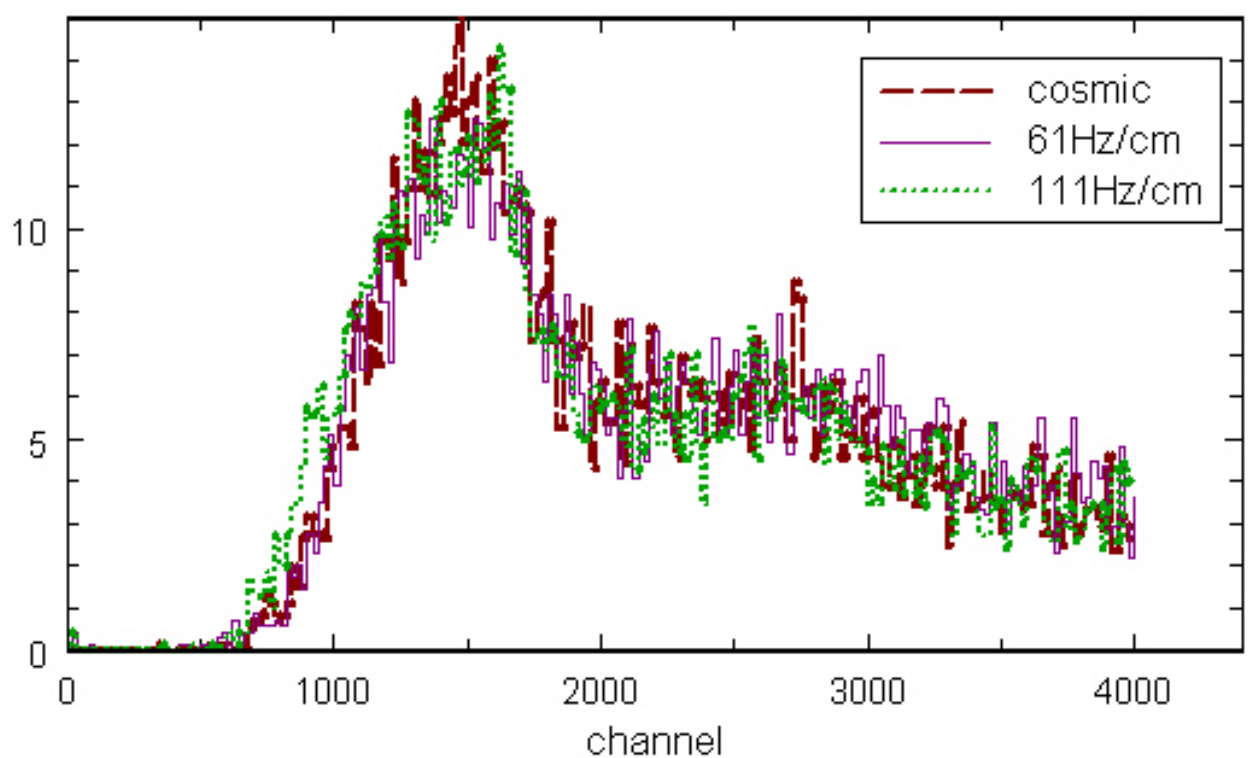
Within BaBar life span (0.1C/cm up to 2010) aging won't cause any trouble.

Rate capability

The rate capability of LST (highly resistive cathode, ~ 1MΩ/□) is around 100Hz/cm^2 (Iarocci, 1983). Our test results confirm this conclusion.

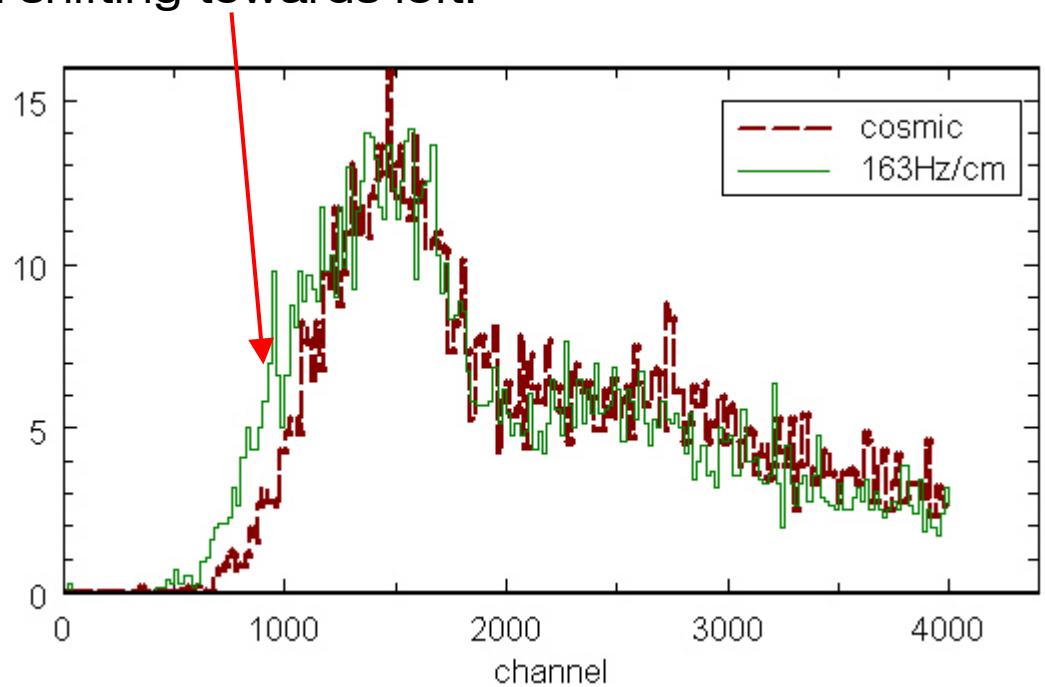
The spectra of 61Hz/cm and 111Hz/cm are generated by Sr-90 source with different absorbers.

Very similar to cosmic ray background.



... Rate capability

Further increase the source intensity we can see the charge spectrum shifting towards left:



Robustness and quality assurance

- Various groups to chose LST because of being cheap, robust, easy to operate, easy to setup an industrial mass production line, etc.
- The robust nature of LST can initially hide serious manufacturing flaws. The flaws can be as trivial as wires displaced by more than 2mm or pieces of metal left inside of the tube. If it were metal tube such flaw would have been revealed immediately after HV on! But in LST this kind of flaw could be hidden up to 10 days of operation!
- infant mortality varies: 4%(LVD) ~ 30%(SLD);
- long term failure rate: 1.3%/year(LVD) ~ 1.9%/year(SLD);
- Quality control for the mass production, especially the uniformity of the graphite paint coating, is the key to cut down the rejection rate;

BaBar barrel IFR upgrade project

The present barrel BaBar IFR RPC chamber efficiencies continue to deteriorate. Average chamber efficiencies extrapolate to below 50% well before 2005. Present μ id performance is already inadequate for many applications. There is a compelling physics case for requiring excellent μ detection efficiency with good π rejection over the greatest solid angle in BaBar. BaBar decided to upgrade the barrel RPC system and add additional absorber layers. Among several competing technologies the LST technology has been chosen for the upgrade. The time schedule is very tight:

- Pre-production double gap prototypes should be fabricated and thoroughly tested by May 1, 2003;
- First 1/3 of the barrel system should be installed during 2004 shut down period;
- The remaining 2/3 should be installed during 2005 shut down period.

Words from BaBar Review Committee on LST

1. LSTs are conceptually well understood and have been used in more than a dozen HEP experiments with generally good results. (A notable exception is SLD). More recently constructed experiments have had good operational experience…
2. The proposed system design is modular and robust with well-developed plans for QA.
3. Successful prototype tests have demonstrated robustness against the highest expected rates, and the integrated charge for the experimental lifetime…
4. The production path is clear. All chambers could be completed well before 2005…
5. …

(excerption from Outline of Executive Summary, BaBar barrel IFR upgrade review committee)

The BaBar LST team so far

M. Andreotti, D. Bettoni, R. Calabrese, V. Carassiti, A. Cotta Ramusino,G. Cibinetto, E. Luppi, M. Negrini, L. Piemontese
INFN Ferrara

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A. Rahimi, C. Rush, Q. Wong
Ohio State University

C. Fanin, M. Morandin, M. Posocco, M. Rotondo, R. Stroili, C. Voci
INFN Padova

L. Cavoto, R. Fernholz, C. Lu, J. Olsen, W. Sands, A.J.S. Smith
Princeton University

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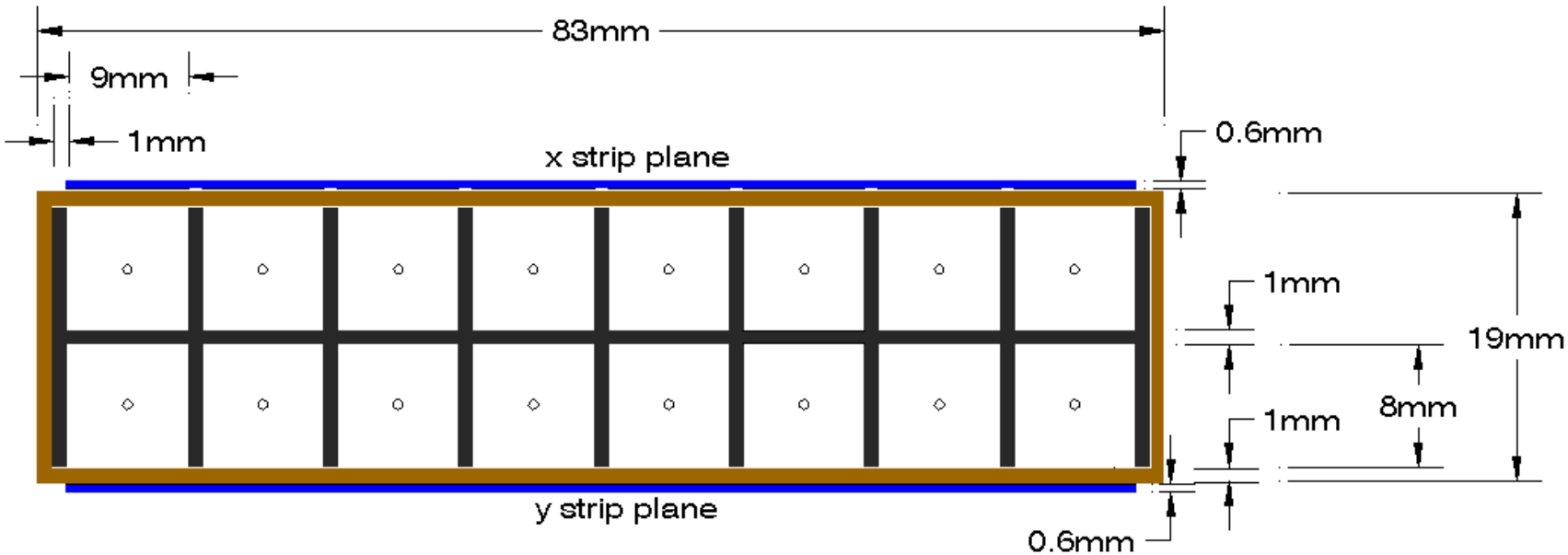
INFN Roma

(Engineers in Orange)

Plus technicians and graduate students

Double-gap LST configuration

Due to the geometrical limitation of LST tube, 10% of dead space for a LST tube is inevitable – profile fins and gas envelop walls. Under the severe 22 mm gap restriction, to gain higher efficiency and to provide assurance in the case of occurrence of dead tube, we proposed a double-gap LST configuration.

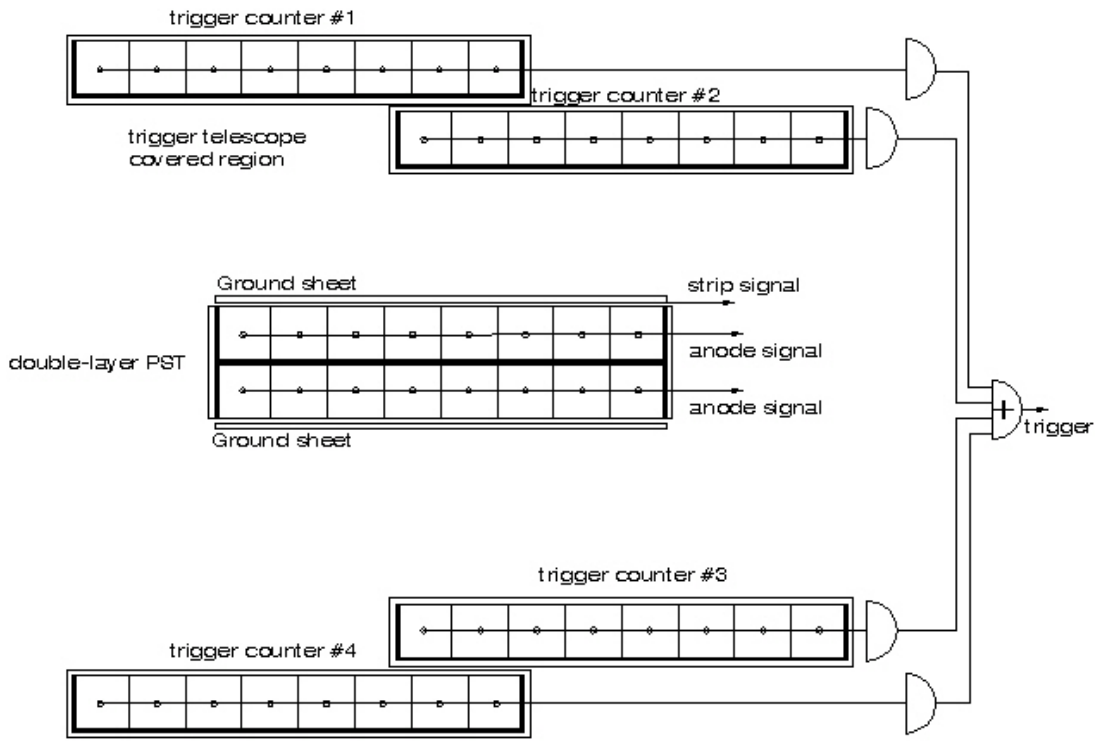


Test results of the double-gap LST

For a highly resistive coating LST tube, both layers can induce large enough signal on the strip plane, therefore this tube acts just like two separate layers of regular LST tubes.

- Efficiency of double-gap LST;
- Induced signal distribution on phi and Z-strips.

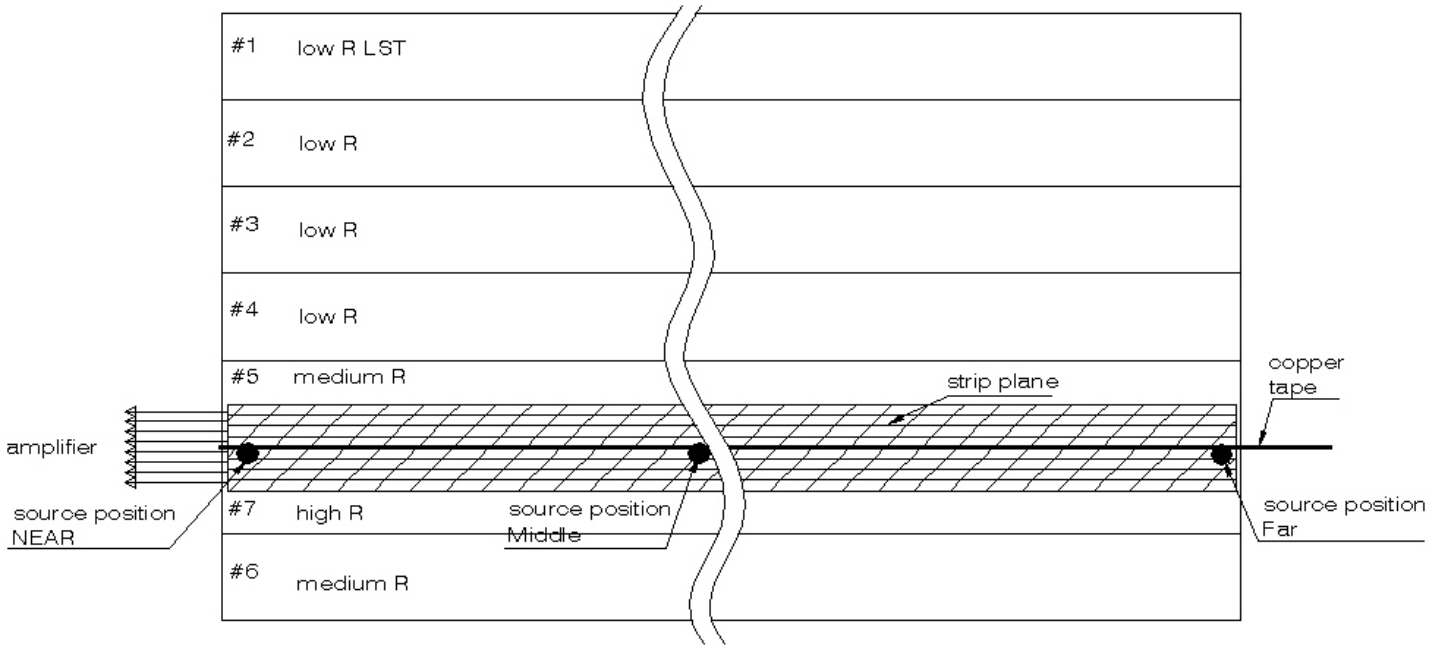
Efficiency



HV	Efficiency
Both layers	96.4%
Top layer	92.5%
Bottom layer	89.8%

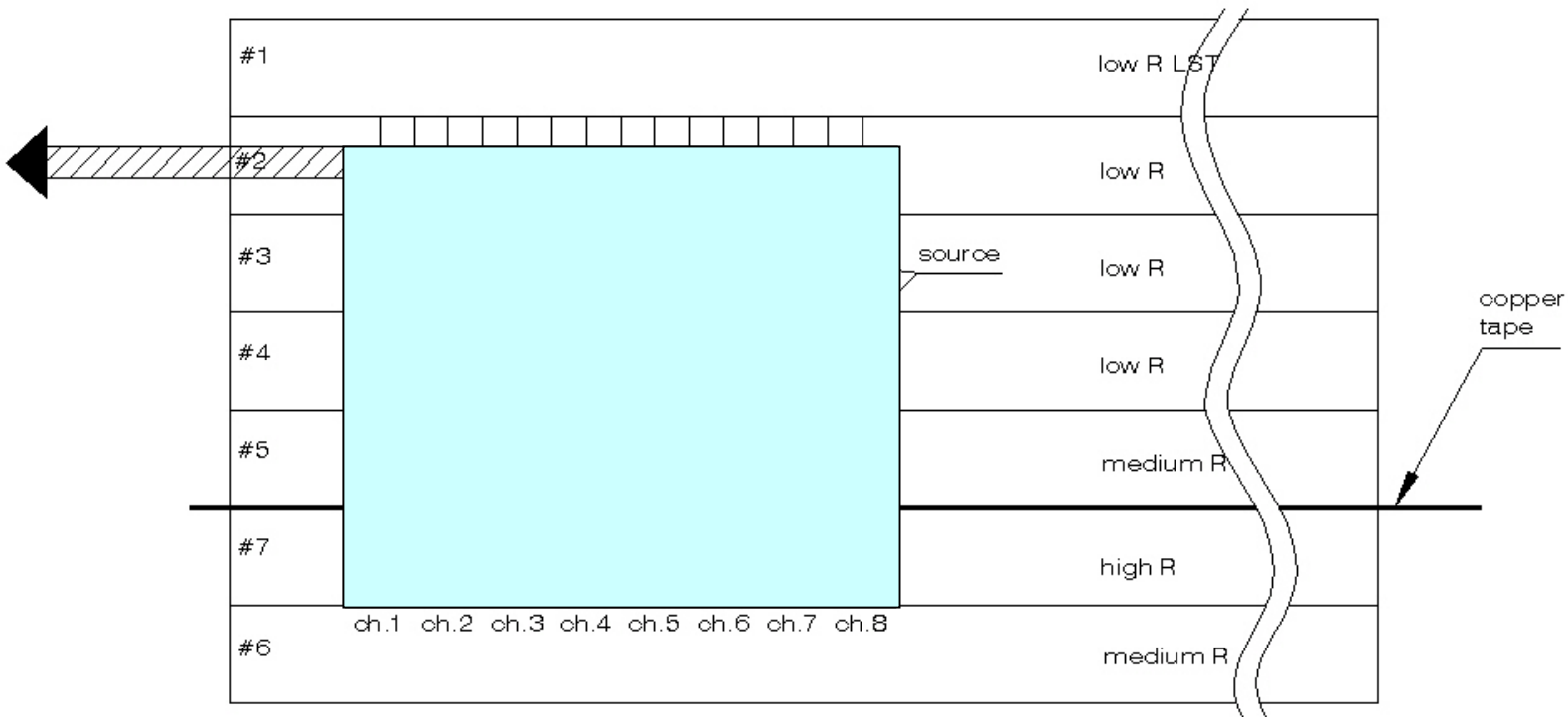
Induced signal spread on phi and z strips

Phi strip readout



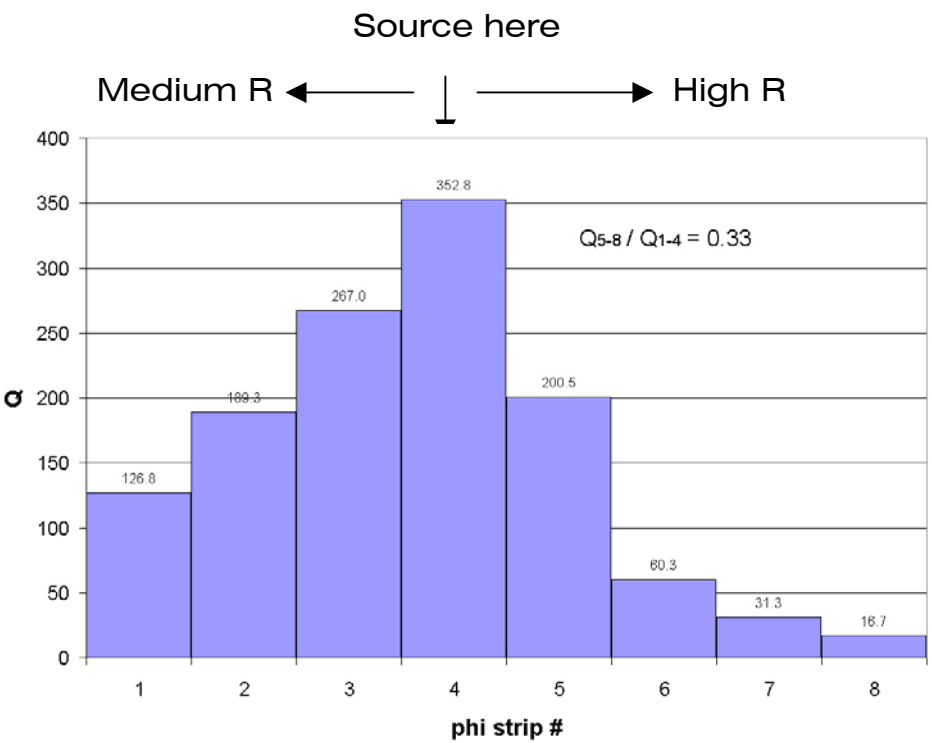
... Induced signal spread on phi and z strips

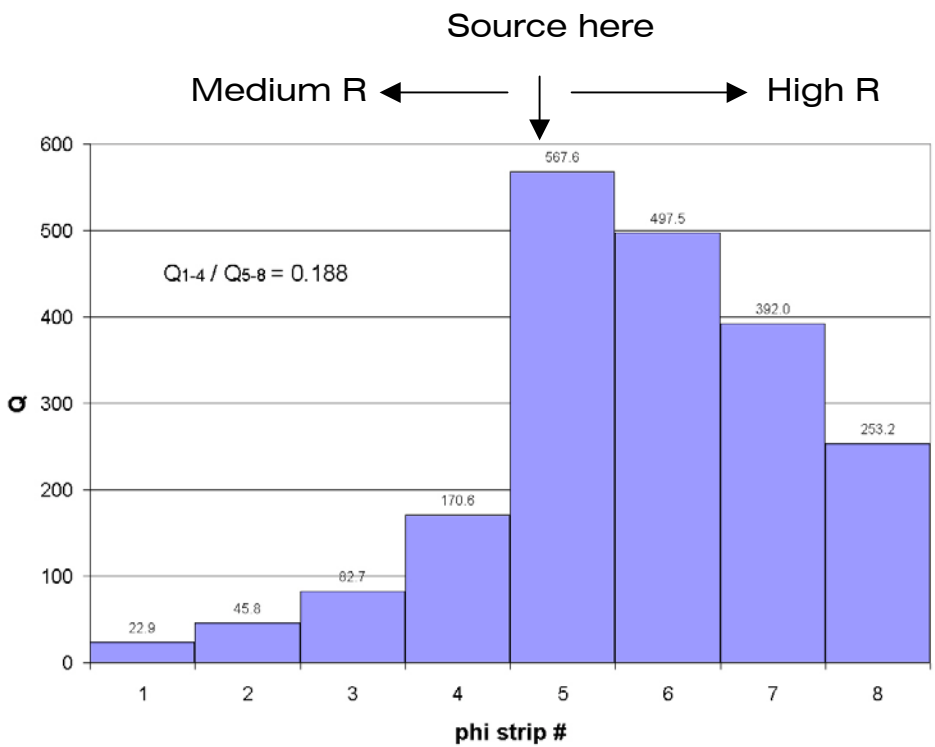
Z strip readout



Induced signal spread on phi strips

Bottom layer HV on only

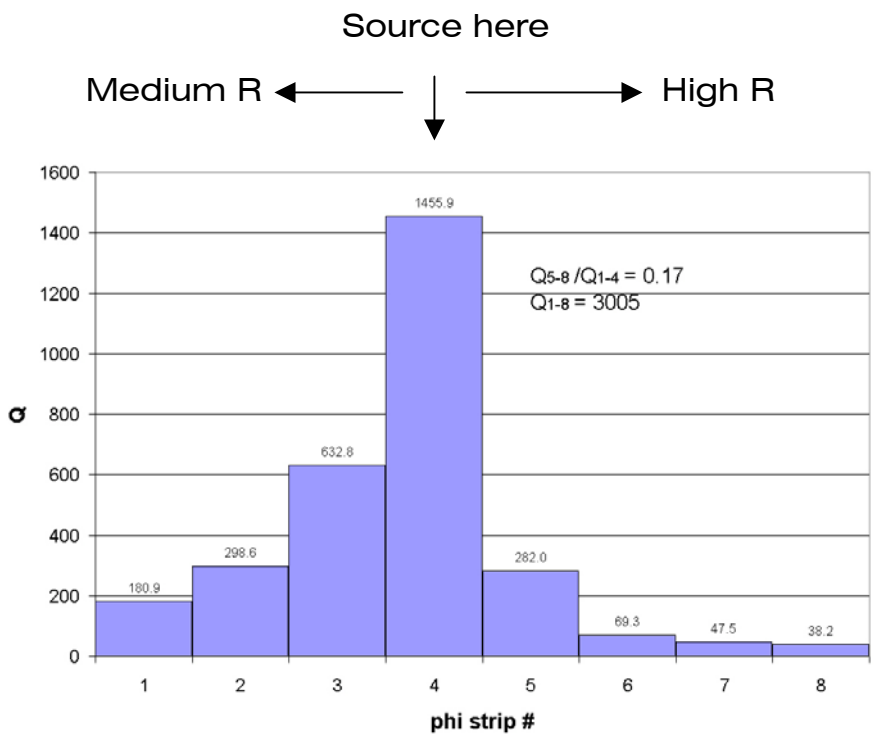


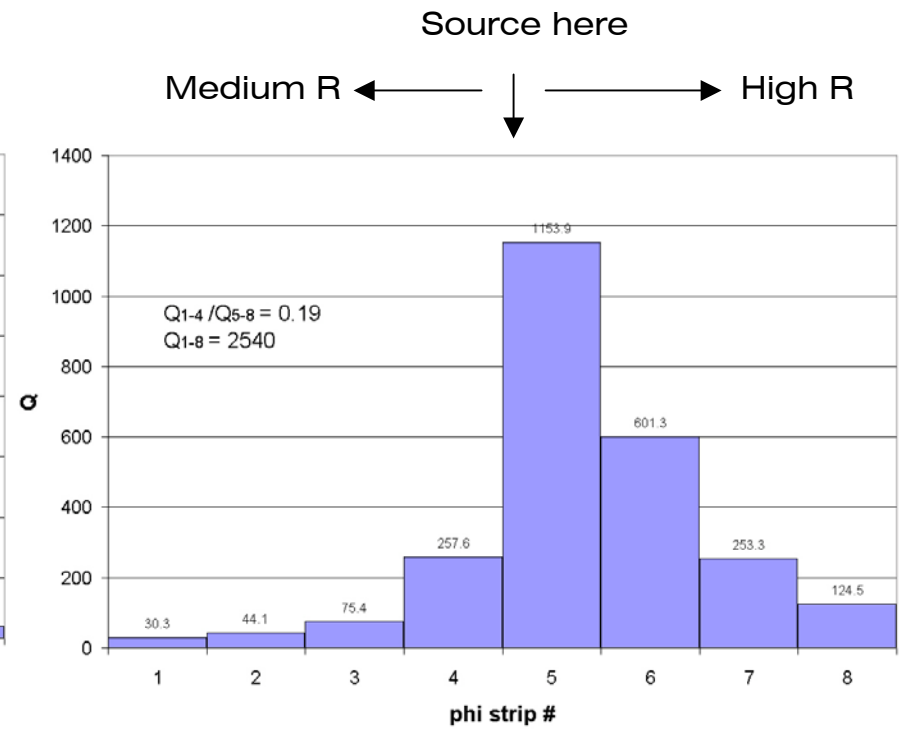


Phi strip pitch is 1cm.

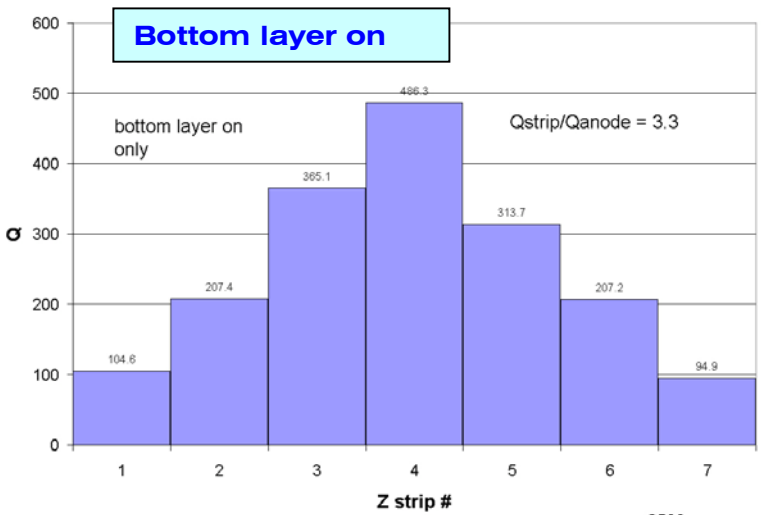
... Induced signal spread on phi strips

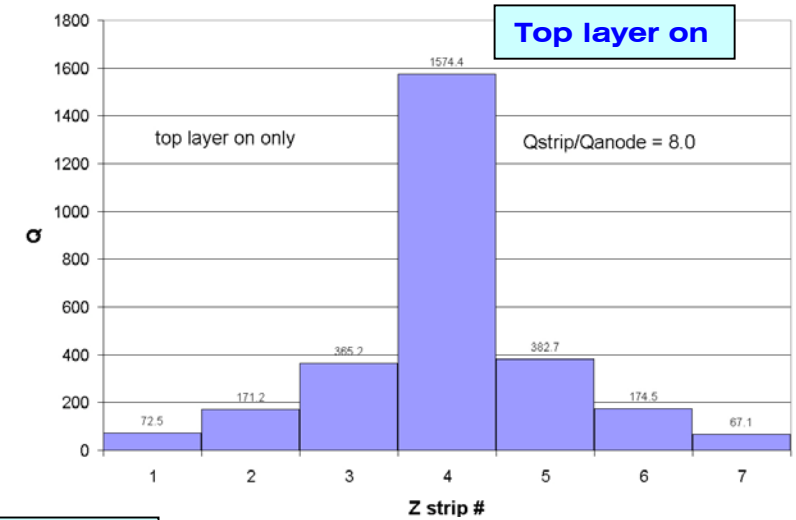
Top layer HV on only



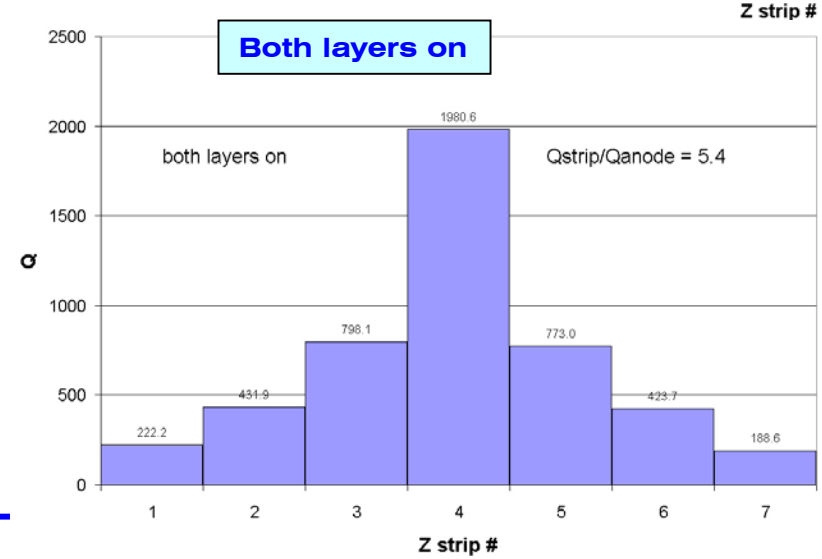


Induced signal spread on Z strips





Z strip width: 6cm



Performance summary of the double-gap LST

- Efficiency is better than 96%;
- Demonstrated the working principle: large enough induced signal from the far layer;
- The signal distribution among strips is sufficient to reconstruct the track position from either layers.

Budget estimation: overall scale

(The estimation is excerpt from Roberto Calabrese, http://www.slac.stanford.edu/~roby/gen_overview_LST_dec8.ppt)

Total number of 8-cell LSTs:	1866
Total number of 7-cell LSTs:	210
Total number of HV channels:	4152
Total number of Z strips :	6912
Total number of PHI strips :	4074
Total number of signals:	10986
Total number of microribbon flat cables:	786
Total number of FE CRATEs (16 NEW FE cards per CRATE):	12
Total number of NEW FE CARDS:	192 (12288 ch.)
Total area of Z /PHI strip plane [m^2]:	1290.3

Budget estimation: LST chamber

LST chamber

Tubes:

- 30 K$ (setup)
- 405 K$ (195 $/tube x 2076 double layer tubes)

Total cost (tubes) 435K$

(using single layer tube this cost would be about 300K$)

Strip readout planes

215 m^2/sextant x 6 sextant x 70 $/$m^2$ = 90 K$

Signal collection (PCB's) inside iron 18 K$

Total cost (readout planes) 108 K$

Grand total: chambers (tube + strip)

Double layers = 543K$;

Single layers = 408K$

Budget estimation: HV system, electronics, etc.

HV system
11 SY546 systems with 87 A548 12 ch Active boards
Total HV system : 168 K$

Electronics
Total cost = 122 K$

Gas system
Total cost = 50 K$

Signal cables
Total cost = 153 K$

HV cables
Total cost = 15 K$

LV cables
Total cost = 11 K$

Budget estimation: Grand total

Grand total = 955 K$ $\leftrightarrow$ 1090 K$

(LSTs cover $\sim$650m^2 area $\Rightarrow$ \$1470 $\sim$ \$1670/m^2)