Detector Challenges at a Super B Factory

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Outline

- Experimental conditions at a Super B Factory(ies)
- Detector requirements at a Super B Factory
- Summarize findings of BABAR Roadmap Committee:
  - Up to what Luminosity will the current detector sub-systems survive?
  - What effects limit the detector lifetime?
  - What upgrade options are possible?
  - What is the amount of time required for R&D, Engineering, Procurement, Fabrication and Installation?
- Method
  - Extrapolate what we know from current PEP-II and BABAR performance, making reasonable assumption about what can be improved
  - Concrete approach moving from existing detector technologies

Links

- Roadmap home page: www.slac.stanford.edu/BFROOT/www/Organization/Roadmap/
- Belle workshops belle.kek.jp/workshops
- Babar workshops www.slac.stanford.edu/BFROOT/www/Organization/1036_Study_Group
- Hawaii joint workshop www.phys.hawaii.edu/~superb04

Experimental Conditions

- **Machine background is the name of the game**
  - Extrapolate from current conditions
  - Parameterized by LER, HER current and Luminosity terms

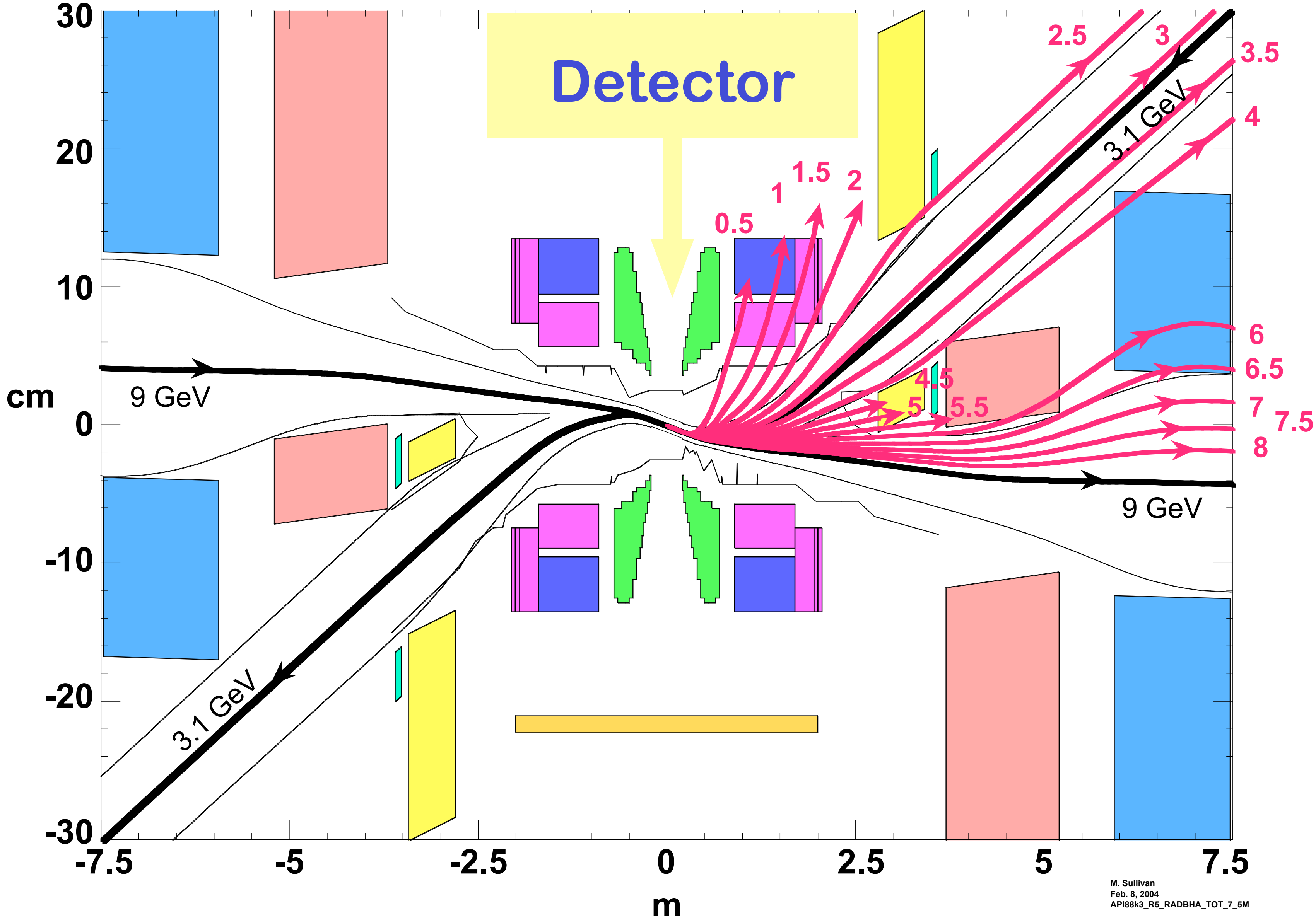
$$bkgd = a + b \cdot I_{HER} + c \cdot I_{LER} + d \cdot Luminosity$$

  - Luminosity term dominates the extrapolations!
    - In contrast Belle has no luminosity term
  - The large Luminosity term is due to radiative Bhabhas and might be a feature of head-on collisions.
- **Look at detector survival based on extrapolations with 20% and 100% of the measured Luminosity terms.**
- **There may be significant gains from improved shielding against backgrounds.**
- **Much depends on the details of the interaction region**

Conf.	I_{LER}	I_{HER}	$\mathcal{L}(10^{33})$
0	2.2A	1.4A	8
1	11A	4.8A	200
2	15.5A	6.8A	700
3	23A	10.1A	1000

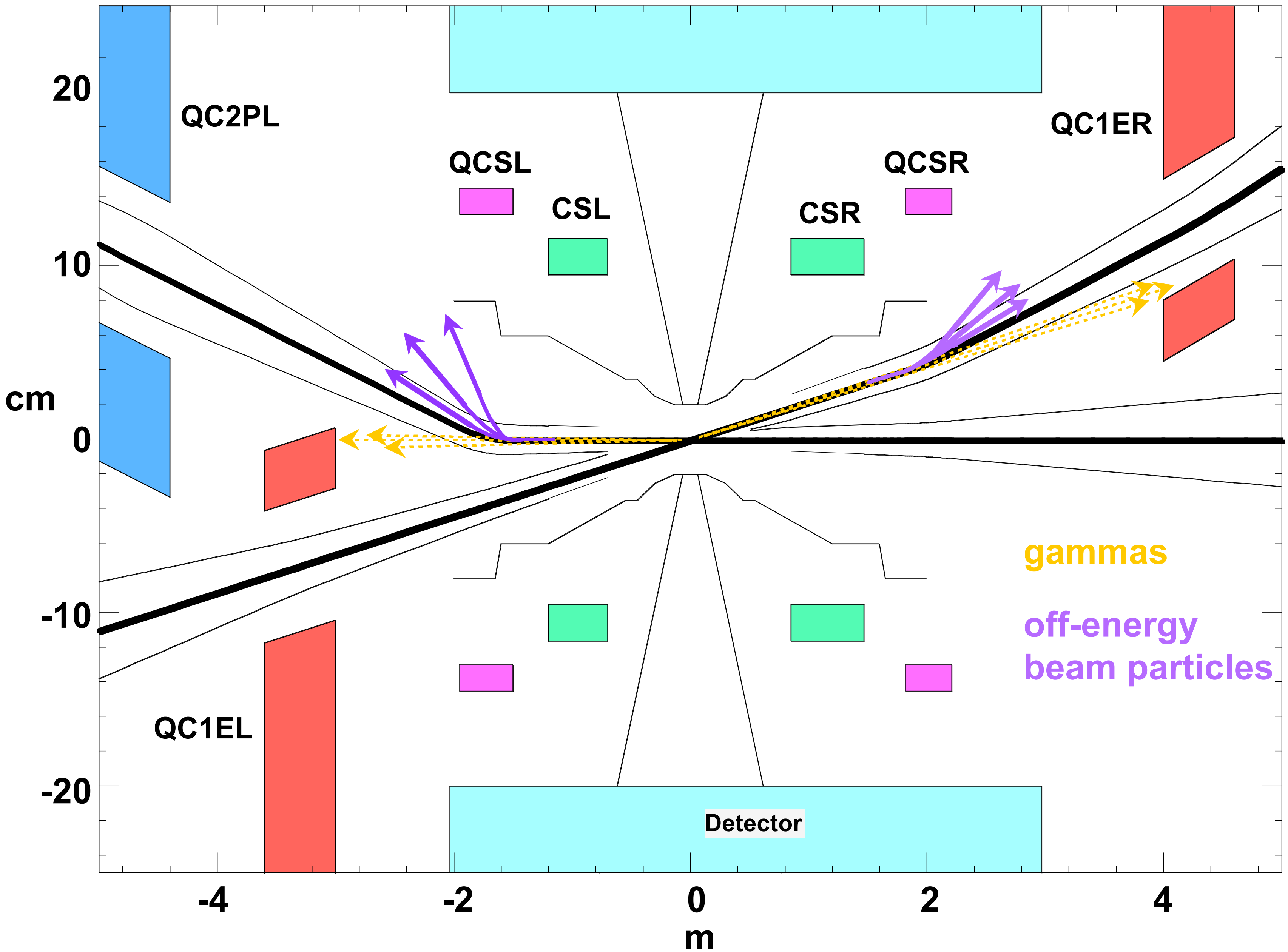
BABAR Interaction Region

HER Radiative Bhabhas



Radiative Bhabhas

KEK Interaction Region



Detector Requirements

- **Physics at Super B Factory covers the entire range of current B Factory physics**
  - Requirements for current detectors are all retained
    - Hermeticity. As large as possible angular coverage
    - High efficiency and precision charged particle tracking and vertexing
    - Good particle identification (π, K, e, μ) for event selection and tagging
    - Good energy and angle resolution in the reconstruction of gamma and π^0.
- **But at Super B Factories something more is needed**
  - Harsh environment
    - Rate capability
    - Radiation hardness
  - More physics
    - Very rare channels
    - Physics on the recoil B
    - Channels with large missing energy
  - → more requirements
    - Even more angular coverage.
    - Better vertexing to increased the background rejection capability

Backgrounds to fight

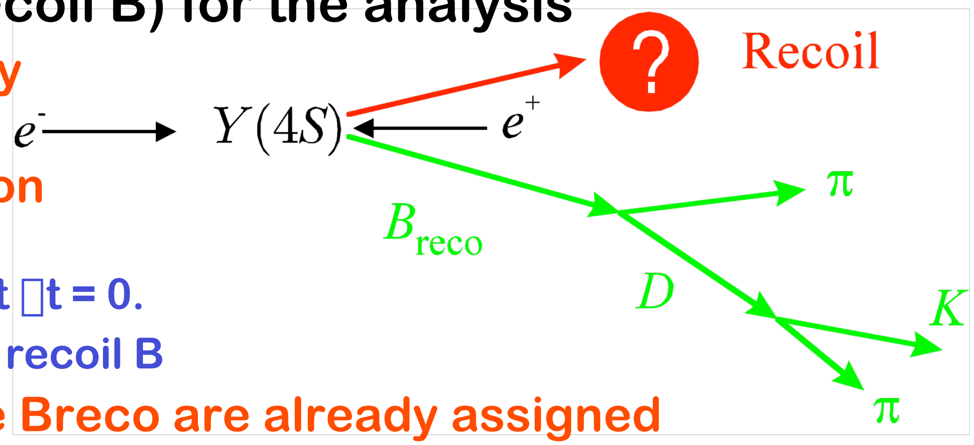
- Machine background → affects basic detector performance
  - Reduce tracking efficiency
  - Increase number of fake tracks
  - Increase number of fake calorimetric clusters
  - Deteriorates calorimeter energy resolution
  - Deteriorates PID performance
- Physics background – main categories
  - Continuum (udsc) events with same topology as channel under study
    - Eg: B→ □□, b→s□, b→d□
  - BB events with missed or misreconstructed particles
    - Eg: B→□□, B→K□□, many rare decays
  - BB events with same topology as channel under study
    - Many high multiplicity channels (Eg. B→DK)

Experimental tools

- Masses: m(D), m(D*)-m(D), m_{ES}, ΔE
  - Effectiveness depends critically on momentum resolution
- Event shape variables
  - Fox-Wolfram moments, Thrust, Sphericity, etc.
- Angular distributions
  - known angular momentum relations to select events or in the fits.
- Particle ID
  - Different usage pattern depending on how delicate the analysis and on how well the PID is understood:
    - Use directly to select events with a given particle
    - Use information in Maximum Likelihood fit
- Vertexing
  - Crucial for time-dependent asymmetries
    - But don't need more resolution than we have for this
  - Can use B-B separation along z for event selection
    - Effective to reject udsc bkgnd if one B is reconstructed (semi)-exclusively
  - Using the charm vertex separation would enormously improve event selection and tagging capabilities, but requires significantly better vertex resolution.
    - Can only be achieved with very thin and small beam pipe: out of reach ?

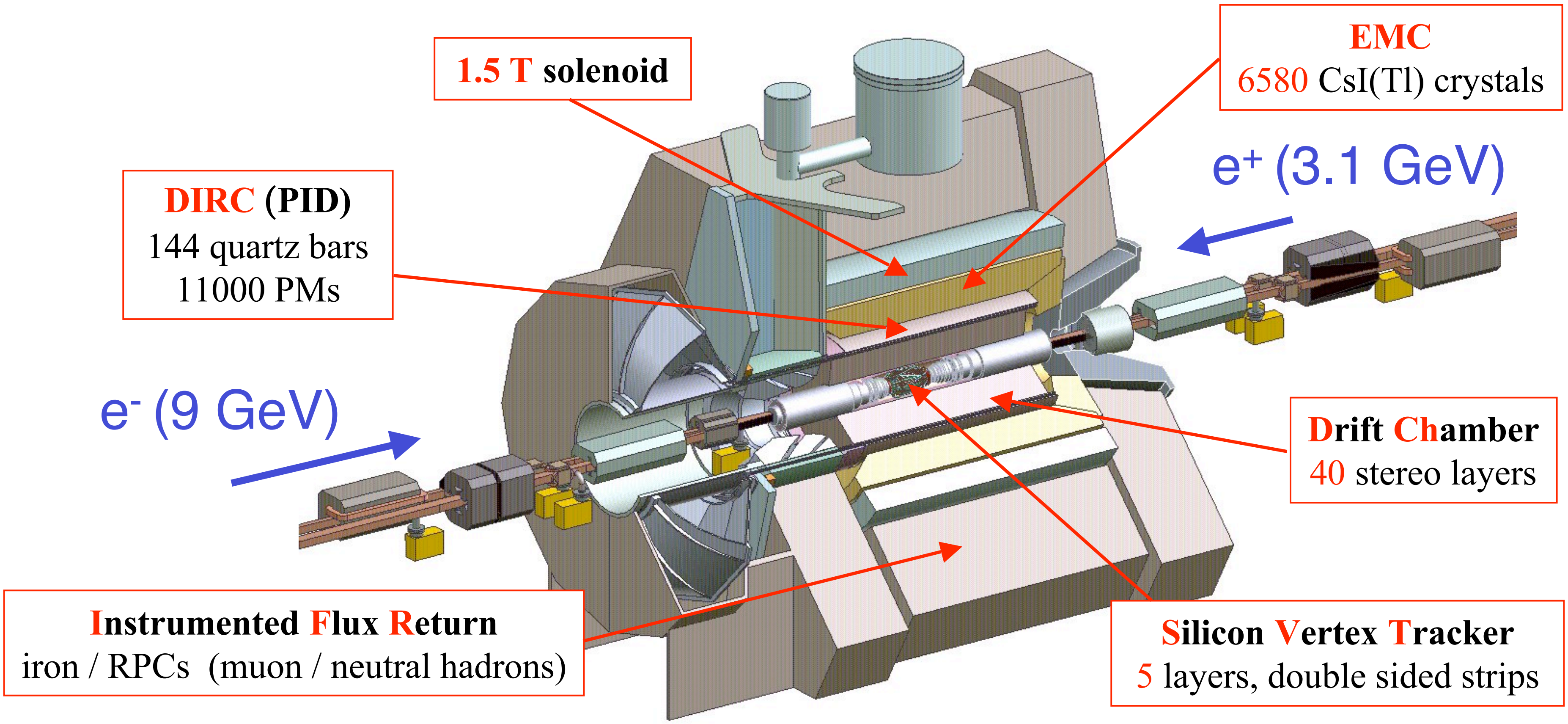
B-Beam technique

- Exclusively reconstruct one B in many hadronic modes and use the other tracks (recoil B) for the analysis
  - Eliminate almost completely continuum background
  - The exclusive reconstruction of one B fully determines
    - The flavor of the recoil B at $\Delta t = 0$.
    - The four momentum of the recoil B
  - The tracks belonging to the Breco are already assigned
    - Great reduction in combinatorial background



- Selection efficiency is of the order of 4×10^{-3}
  - With $10ab^{-1}$ → 40 million Breco → access 10^{-6} BR
  - Sacrifice statistics in exchange of
    - Improved kinematics → reduce model dependence in $|V_{ub}|$ and $|V_{cb}|$ studies
    - Reduces background for rare decays, especially those involving photons and neutrinos

The BABAR Detector



SVT: 97% efficiency, 15 μm z hit resolution (inner layers, perp. tracks)

SVT+DCH: $\sigma(p_T)/p_T = 0.13\ \% \times p_T + 0.45\ \%$, $\sigma(z_0) = 65$ @ 1 GeV/c

DIRC: K-π separation 4.2 σ @ 3.0 GeV/c → 2.5 σ @ 4.0 GeV/c

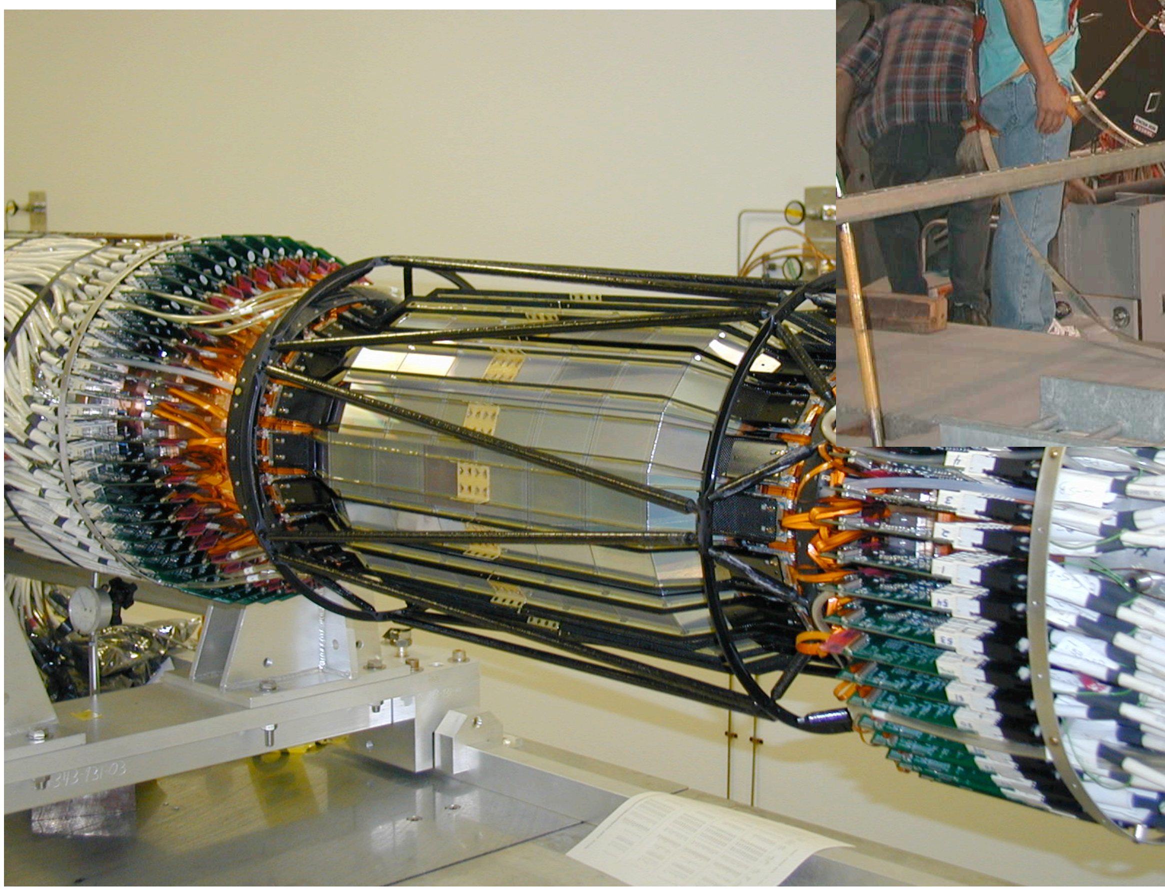
EMC: $\sigma_E/E = 2.3\ \% \cdot E^{-1/4} \oplus 1.9\ \%$

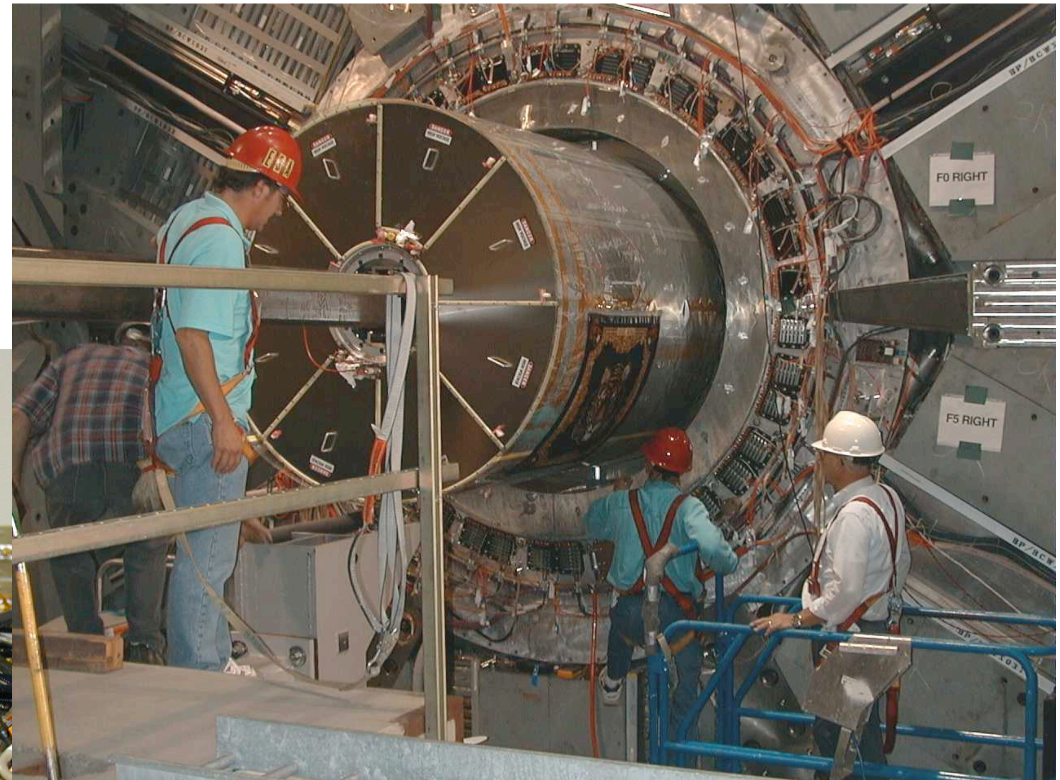
Detector Upgrades / New Detectors

- Current detectors (Babar, Belle) will not work at a high luminosity machine.
- Detector complexity undergoes a "phase transition" around few x 10^{35}
  - Requires significant R&D to go beyond
- Belle approach is to stay below the phase transition
- Babar is trying to define an "upgradeable platform" where the detector can be upgraded in due time up to 10^{36}.
  - This may require an almost new detector.

Vertexing and Tracking

SVT



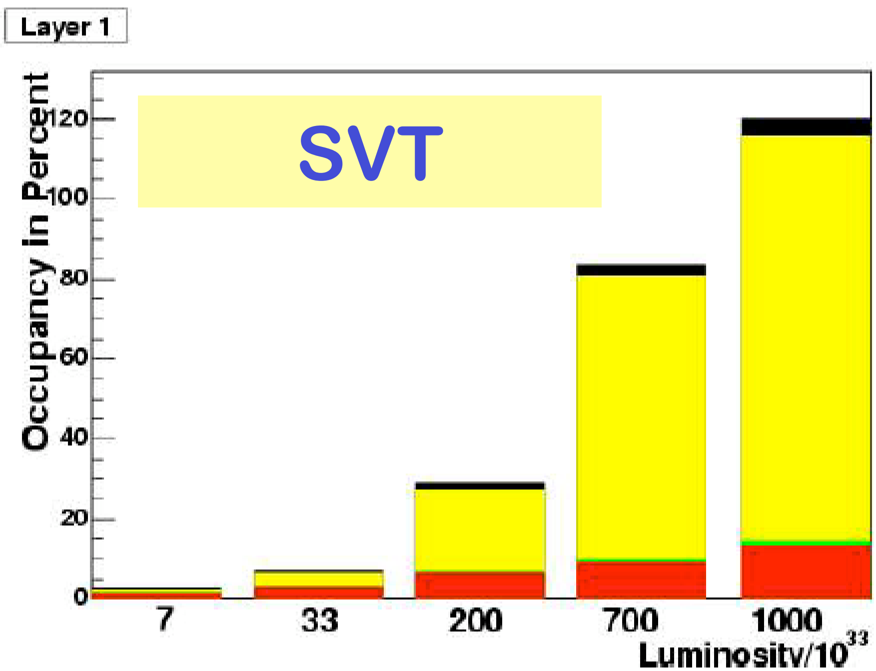


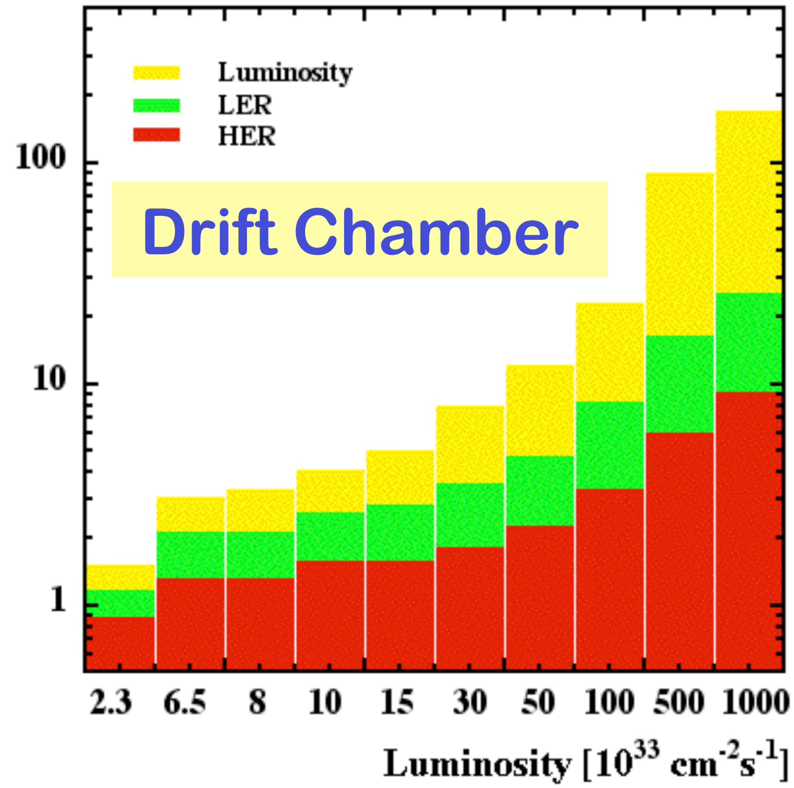
Drift Chamber

BABAR

Occupancy extrapolations

- Both SVT and DCH are unusable at very high lumi



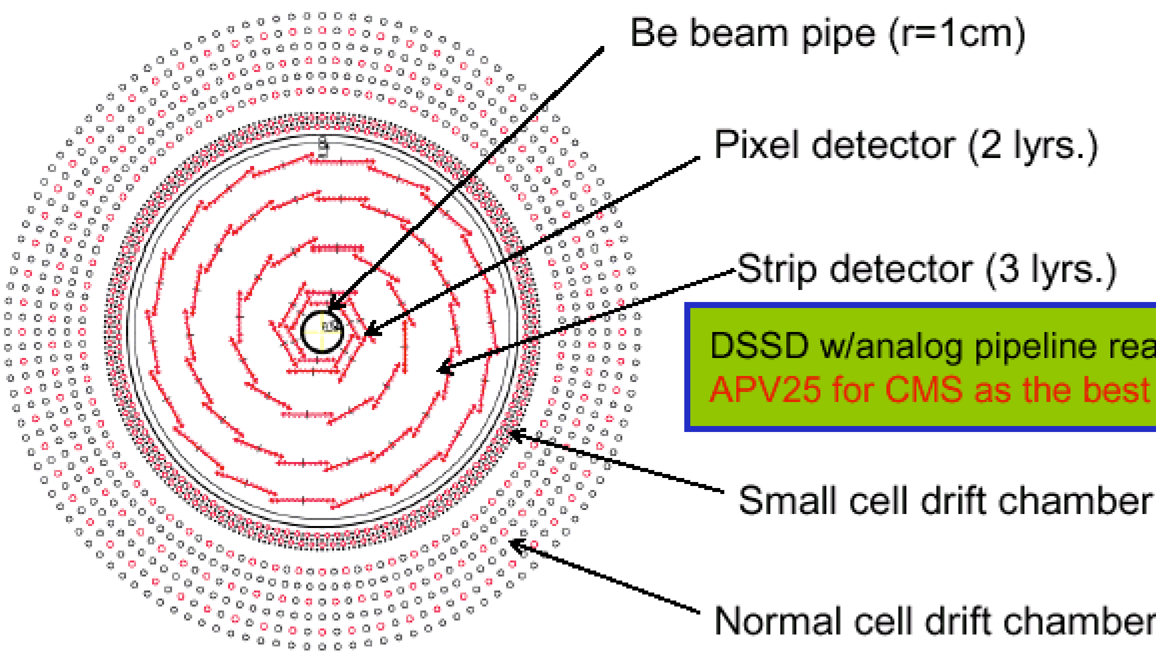


Vertexing and Tracking at 10^{36}

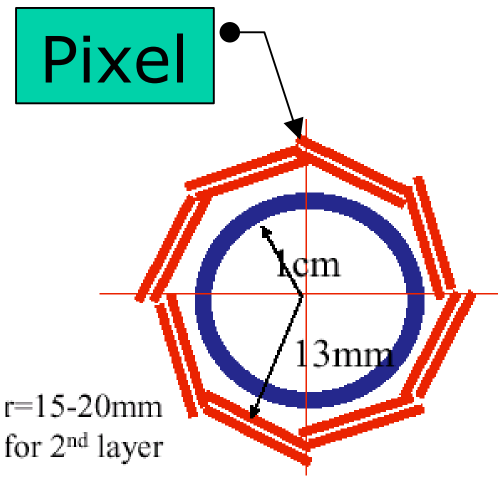
- The tracking system could be made of
  - One or two layers of pixel detectors near beam pipe
    - Pixel required mainly because of high occupancy
    - Beam pipe radius is a big issue, depends on machine details:
      - KEK-B plans on 1cm → more performing
      - PEP-II plans on 1.5-2 cm → safer
  - A few layers of silicon strip detectors at intermediate radii
    - Vertexing, impact parameter resolution, low P tracking
  - For the main tracker two possible solutions:
    - Small cell/fast gas drift chamber, combined with normal DCH
    - All silicon tracker
- Main issues
  - Radiation hardness: possible using LHC technology
  - Material budget: current hybrid pixel layers are thick; the all silicon solution can get pretty heavy
  - Rate capability: effects on silicon segmentation and drift chamber cell size

Belle approach to tracking

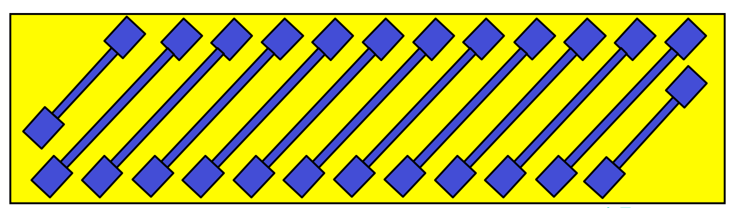
Possible central detector config.



DSSD w/analog pipeline readout
APV25 for CMS as the best candidate.



Silicon striplets



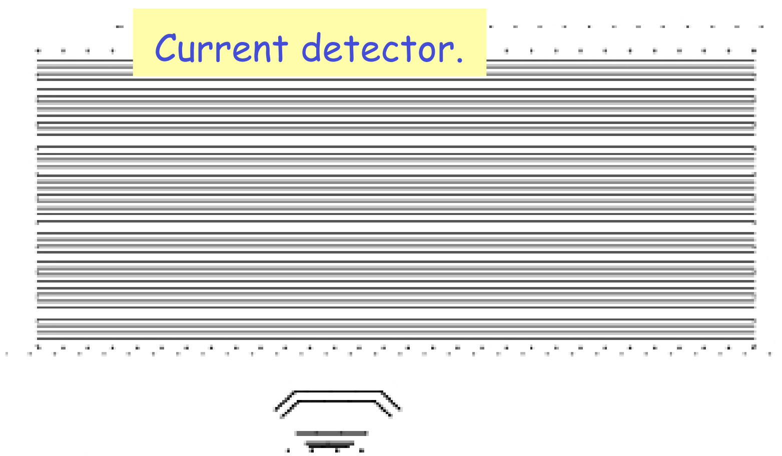
Babar approach to tracking

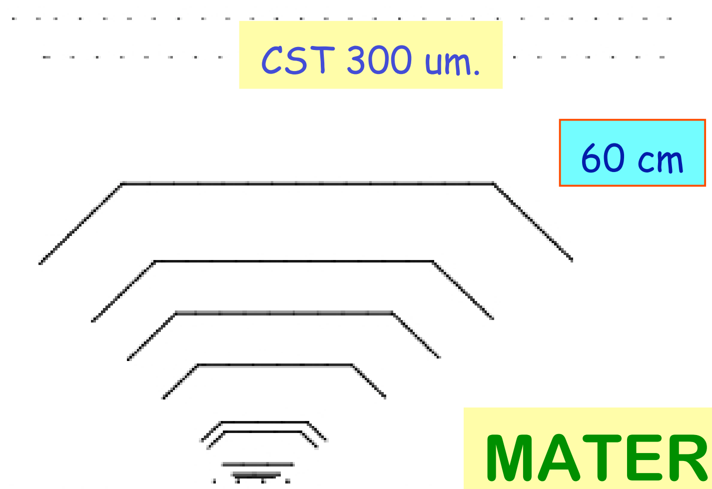
Babar ™ and © L. de Brunhoff

BABAR

- All silicon tracker
  - Two inner layers of pixel detectors (or striplets for initial luminosity)
  - Three intermediate layers of strips as with current SVT
  - Replace DCH with 4-layer silicon tracker with lampshade modules. Remove support tube
  - Radii of pixel modules: 3.3, 4.0
  - Radii of barrel part of SVT modules : 5.9, 12.2, 14.0 cm
  - Radii of barrel part of CST modules: 25,35,45,60 cm

Electronics & cooling outside of the tracking volume.





MATERIAL !

Pixels

- **Hybrid pixels**

  In hybrid pixel systems the readout chip is connected to the sensor through solder or Indium bumps

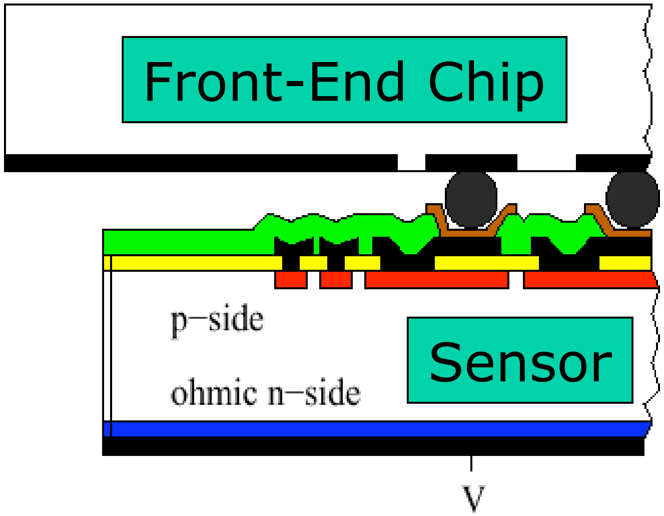
  \+ Separate development of readout electronics and sensors

  \+ Use best available technology for each component

  \- Complexity and reliability issues in assembly

  \- Material budget is high due to overlap of Sensor and readout chip + services.

    - At least 1-2% X_0 per layer (current Babar Si is around 0.4% X_0)

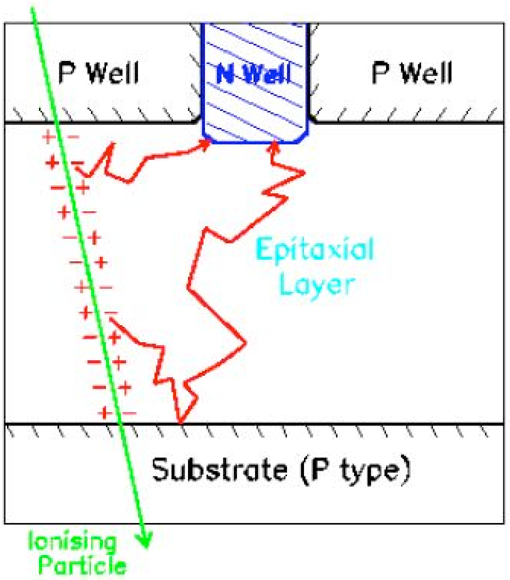


Monolithic Active Pixels

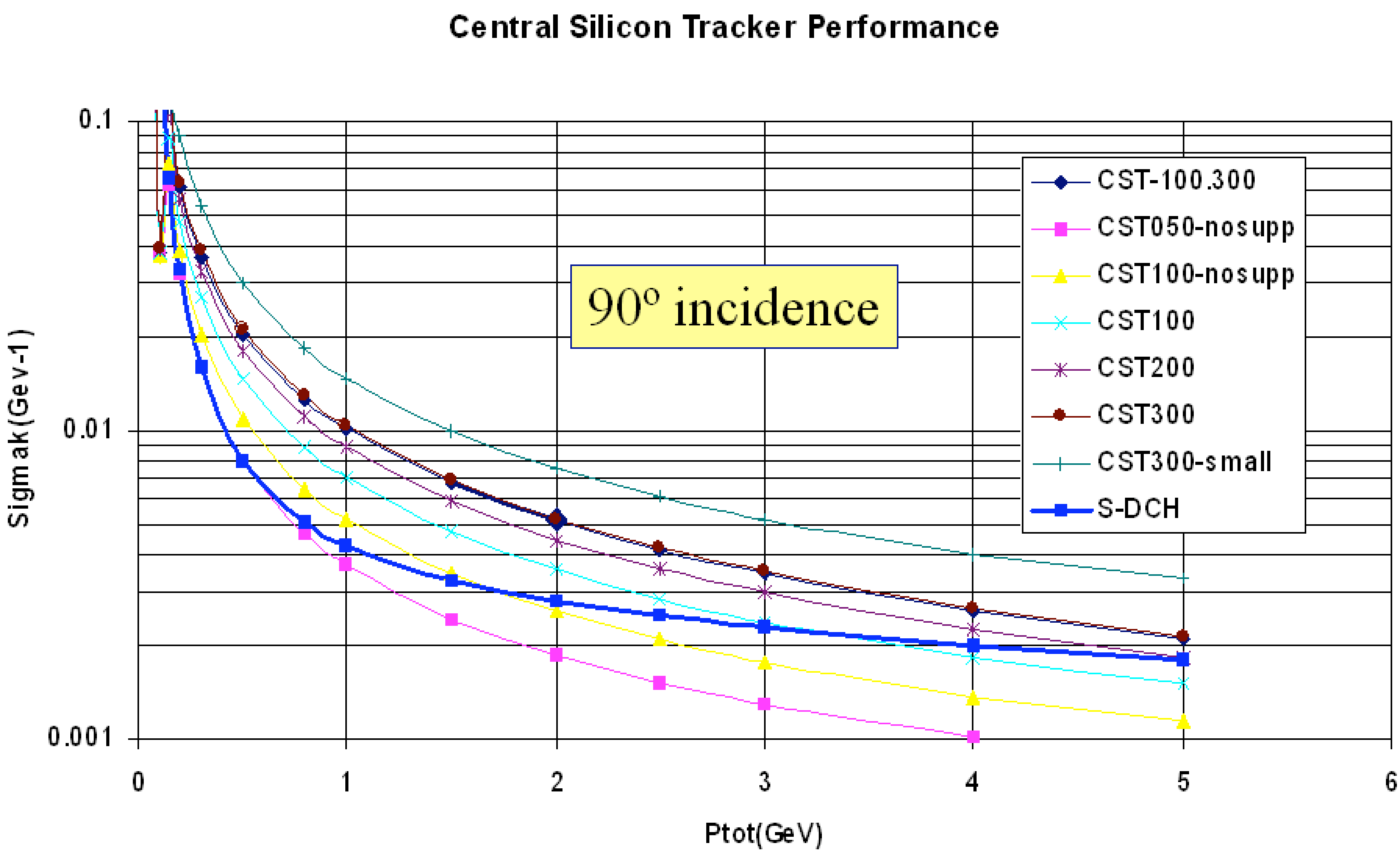
- **MAPS = Monolithic Active Pixels = sensor and electronics on the same substrate.**
- **R&D on monolithic pixels has started in several places.**
- **Possible approaches:**
  - Integrate electronics on the high resistivity substrate usually employed for sensors
    - Active components are not of the best quality
    - The fabrication process is highly non-standard with large feature size (>1-2μm)
    - Signal is high quality, and large
  - Use the low resistivity substrate of standard CMOS process as sensor
    - Can use standard sub-micron process with state-of-the-art electronics
    - Proven by the success of CMOS video cameras, replacing CCDs.
    - Signal is louzy, and very small

Pixel R&D

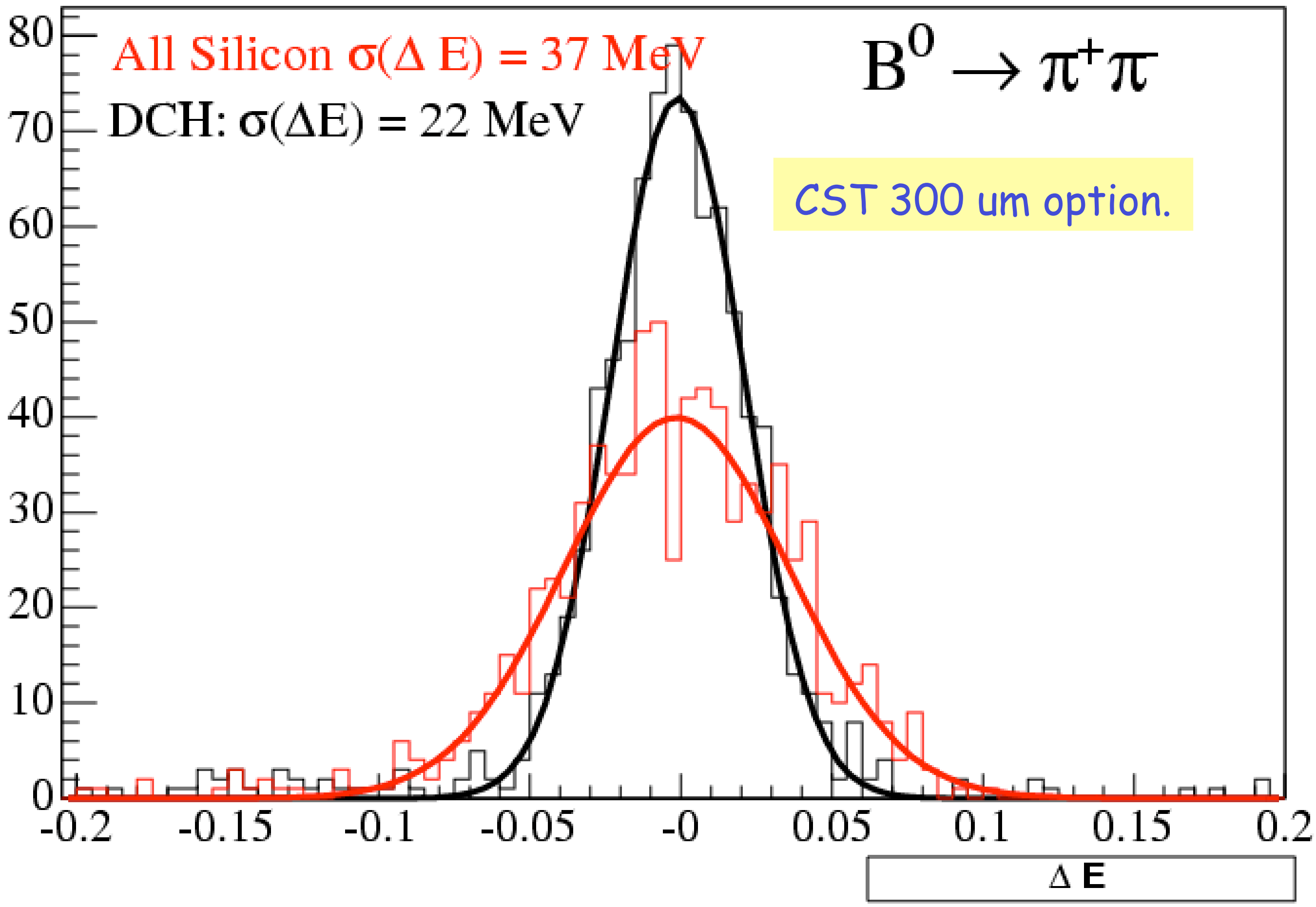
- Two possible R&D directions
- Reduce thickness of conventional hybrid pixels
  - It doesn't seem possible to go too far
- Develop large area MAPS
  - Development on-going in several places:
    - LEPSI, LBNL, Japan, Perugia
  - Proposal by Pisa-Pavia-Bergamo-Trento-Trieste-Modena approved by the Italian Ministry for Education and Scientific Research
    - Main goal is to develop a submicron CMOS MAPS that can be used on large area systems
    - Time frame is 2-3 years (at least)



Momentum resolution



Delta E impact



Central Silicon Tracker

- The Central Silicon Tracker seems to be the only solution for high luminosity, but:
  - Need to evaluate consequence of degraded momentum resolution on Physics
  - It is quite a bit of silicon: 13m^2
  - Requires significant engineering
    - Mechanics, support and service distribution
    - Electronics to readout very long modules
    - Trigger
  - Cost: in the range of 12 M$ M&S
    - The CDF Run2B upgrade project has about 8M$ M&S for 8m^2 of silicon.
- The inner layers are crucial
  - Silicon striplets are viable only up to few x 10^{35}.
  - To go beyond significant R&D on thin pixels is required

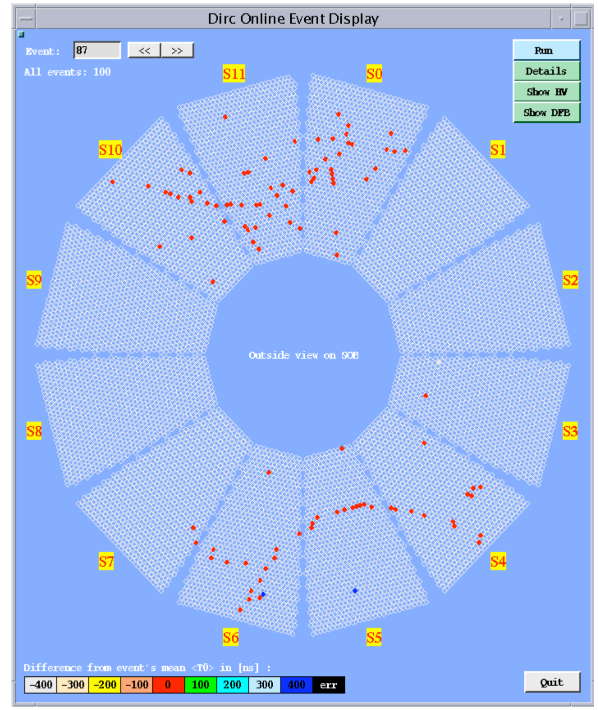
Layer	Area (cm2)
1	311
2	460
3	993
4	2382
5	3155
6	9975
7	19723
8	32487
9	57606
Total	**127092**

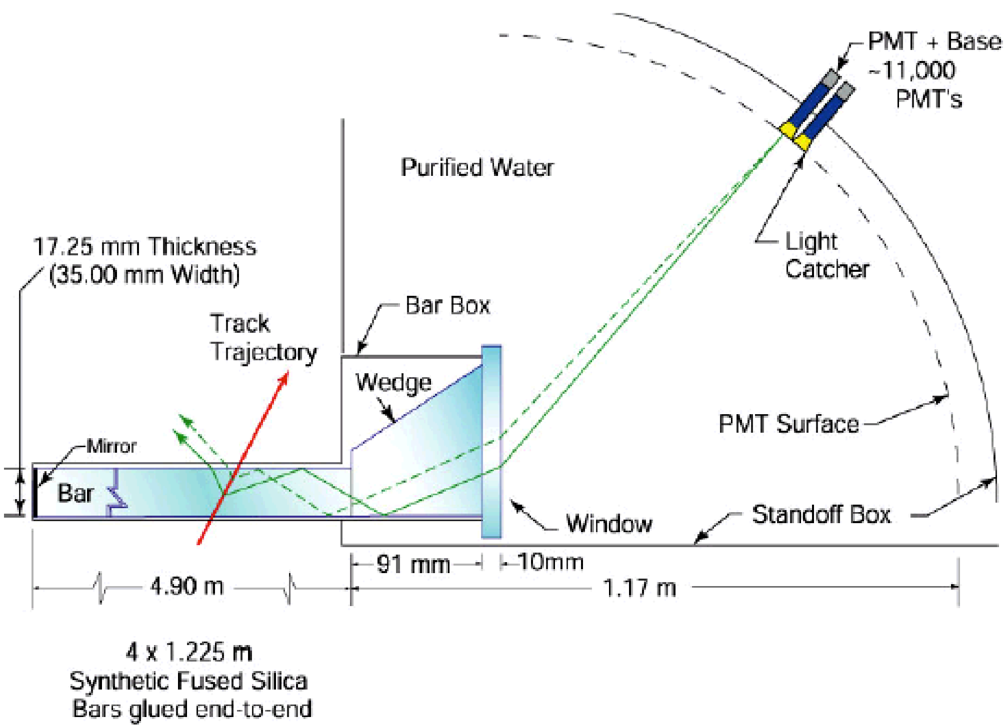
Particle Identification

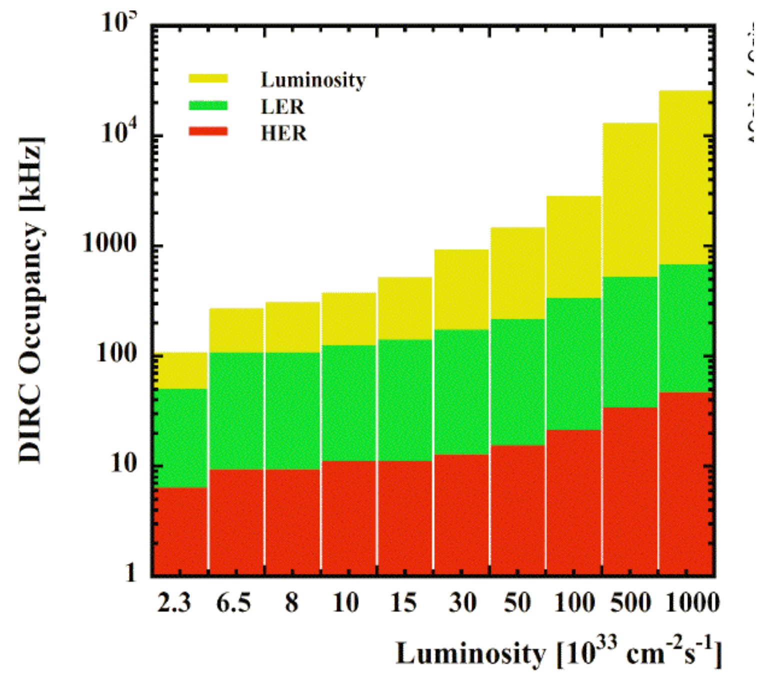
- **Complicated business. Current solution:**
  - K identification
    - low p: dE/dx (both Babar and Belle) + TOF (Belle only)
    - high p: dedicated Cherenkov detector
      - DIRC (Babar) – ring imaging cherenkov counter
      - ACC(Belle) – aerogel threshold cherenkov counter
  - e identification
    - Mainly E(Calorimeter)/p(tracking)=1 for electrons
  - μ identification
    - Absorption length in iron yoke. Effective only at high momentum.
- **Current PID detectors will not survive the 10^{36} environment.**

Babar PID: DIRC

- Light transmitted through length of radiator bar preserving angle information
- Rings projected in water-filled stand-off box to PM tubes
- Fused silica bars are OK, but backgrounds too high in Stand off box

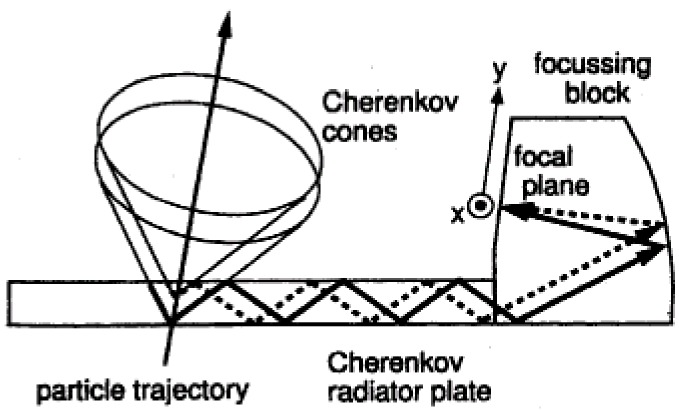






Babar approach: A different kind of DIRC

- **Barrel**
  - New non-SOB focussing DIRC is under development in SLAC Group B
    - Quartz is sufficiently radiation hard
    - Need pixellated readout that works inside the magnetic field
      - APDs, HPDs, MAPMTs, → Need R&D



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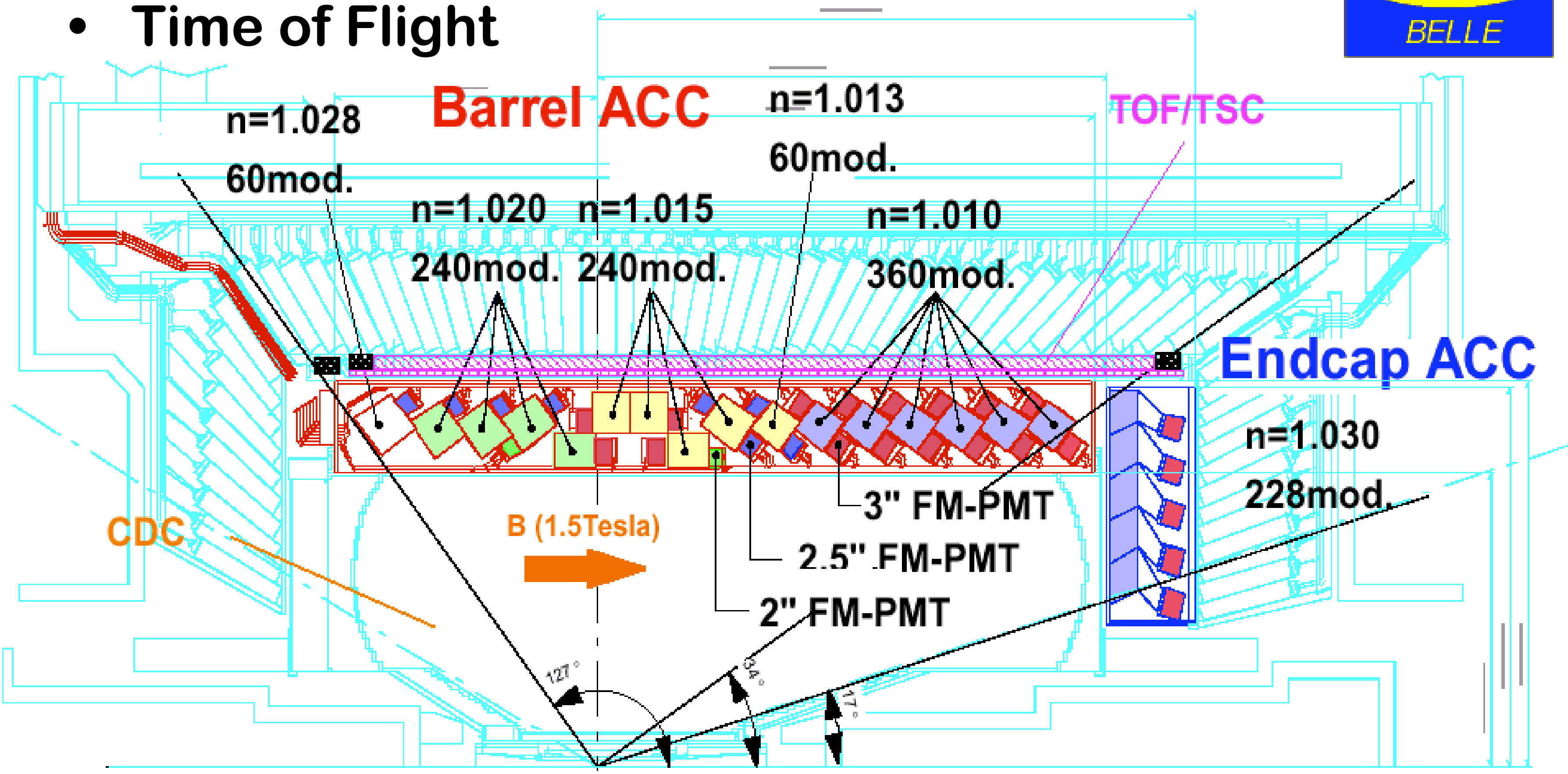
- **Endcap**
  - Requires single photoelectron readout in a magnetic field
  - An aerogel threshold counter would work, as would a RICH with an aerogel radiator

Belle PID

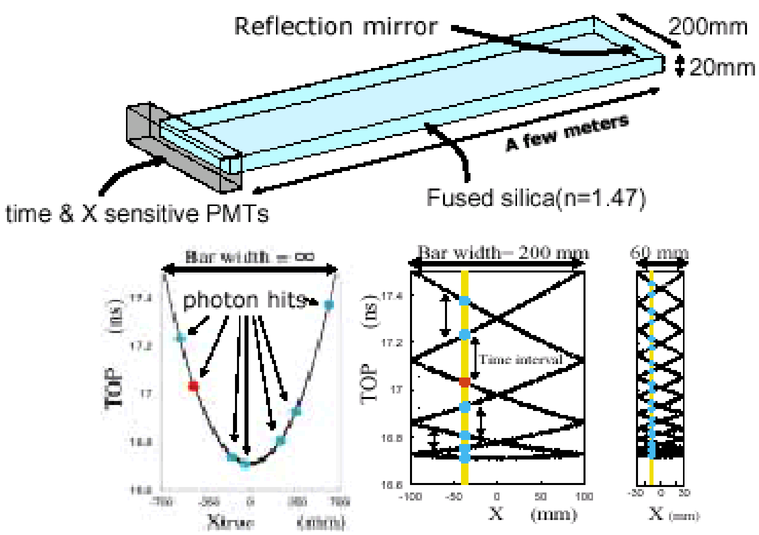
- Aerogel Cherenkov Counters
- Time of Flight



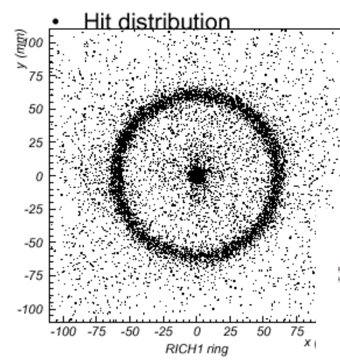
Belle approach: TOP + A-RICH

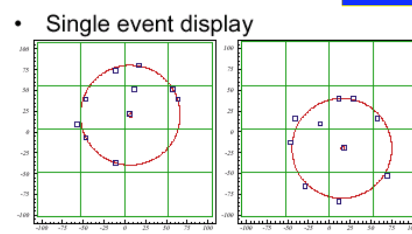
- **Time of propagation counter**
  - Use internally reflected light, but measure time instead of the y coordinate. Needs < 100ps time resolution

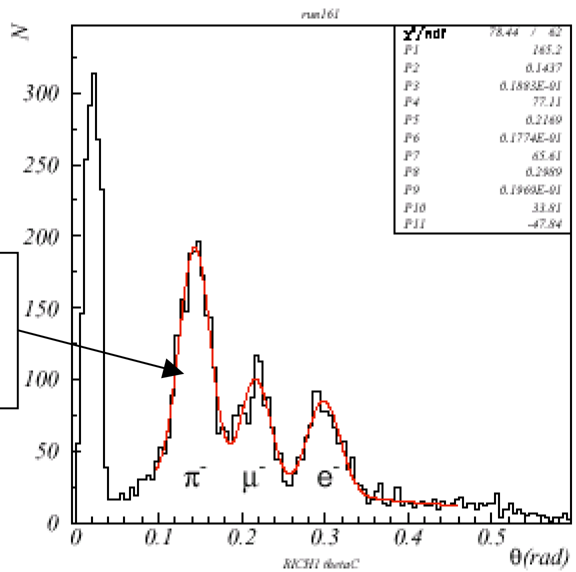
Time of propagation (TOP) counter



Aerogel RICH for endcap





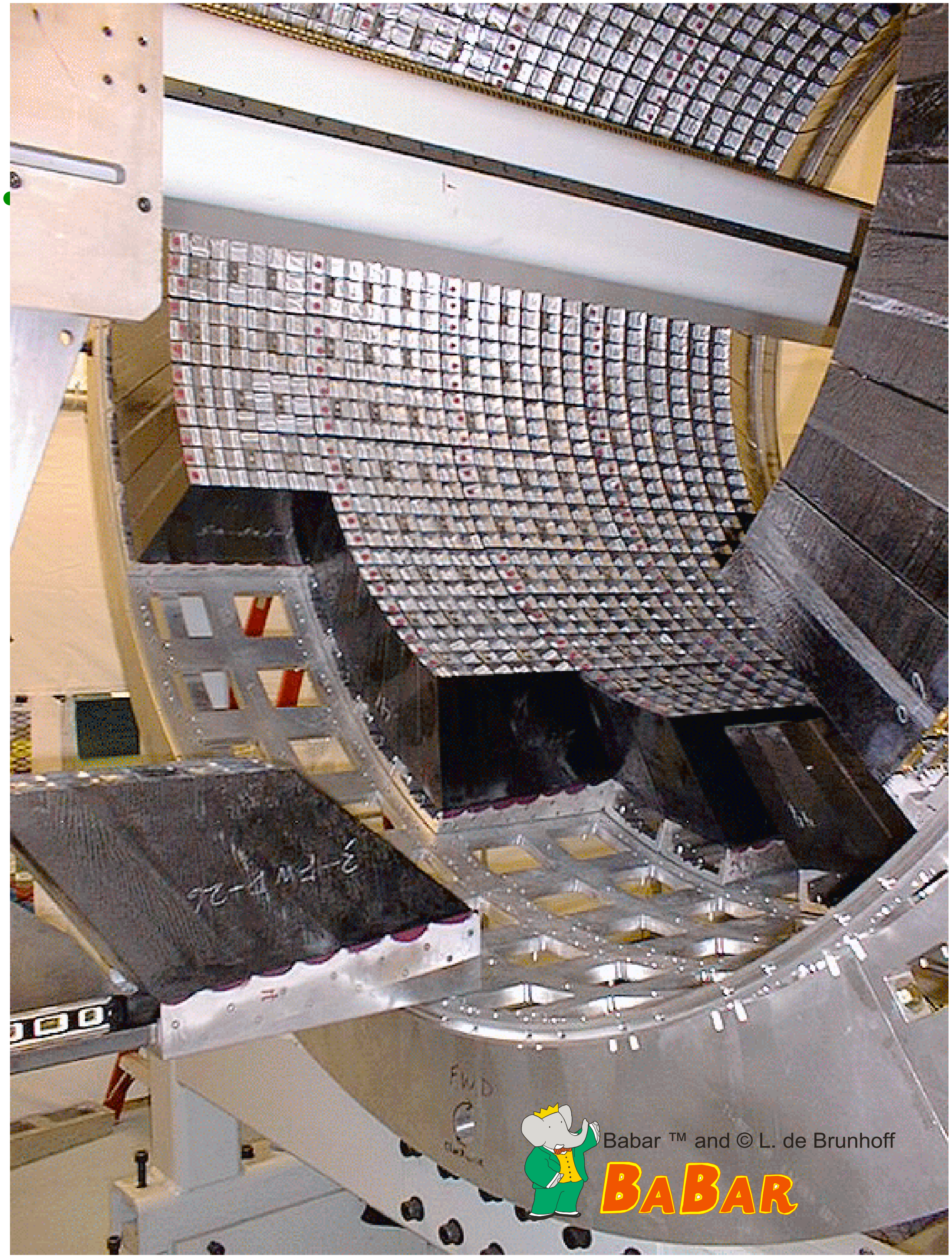


Cherenkov angle distrbution for 0.55 GeV/c beam

Achieves some □/□ separation at low p

Calorimetry

- Requirements
  - Speed
  - Good energy resolution
  - Radiation hardness
  - Excellent energy and position resolution
  - Large dynamic range
  - Uniformity and stability
- Desirable attributes
  - Longitudinal segmentation for best possible □/e separation
  - Minimal interruption in barrel/endcap region
- Options
  - CsI with no doping – light yield is small
  - New crystals – LSO, GSO, …, which are expensive
  - Scintillating liquid Xe concept



Calorimetry limitations

- **Just on the base of occupancy, the calorimeters are not usuable at 10^{36}.**

Number of clusters >10 Mev

Occupancy for >1MeV deposits

- **Radiation damage is also important**

Radiation Dose

Integral Lumi	Endcap	Barrel
250 fb-1	1.0 kRad	0.6 kRad
500 fb-1	1.5-3 kRad	0.8-2 kRad
1 ab-1	2-8 kRad	1-5 kRad
3 ab-1	3-24 kRad	2-15 kRad
10 ab-1	7-50 kRad	5-35 kRad
20 ab-1	10-80 kRad	6-50 kRad
50 ab-1	25-200 kRad	15-120kRad
100 ab-1	50-400 kRad	30-250kRad

Lowest Scenario = 20% Lumi term
Highest Scenario = 100% Lumi term

ENDCAP needs Upgrade (at 3 ab-1)

BARREL needs Upgrade (at 20 ab-1)

Need 10x more radiation hardness than CsI(Tl) (at 100 ab-1)

Light output drops by ~0.7 after 10-20 kRad

Crystal options

- **Finding the right compromise between speed, light yield and cost is not straightforward.**
- **Belle is proposing to keep the CsI(Tl) in the barrel EMC and replacing the encaps with pure CsI → R&D on readout.**

Crystal	CsI(Tl)	CsI	BGO	BaF_2	$PbWO_4$	CeF_3	YAP	GSO	LSO
τ decay(ns)	680, 3340	16	300	.6, 620	5, 15	10-30	27	56, 600	47
χ_0(cm)	1.86	1.86	1.12	2.03	0.89	1.66	2.63	1.39	1.14
R_{moliere} (cm)	3.8	3.8	2.3	3.4	2.2	2.6	2.8	2.4	2.3
λ_{nuclear} (cm)	37	37	22	30	22	26			
LY (γ/MeV)	56000, 64:36%	2500	8200	1400f, 9950s	100	3500	16200	12500, 1250	27000
λpeak (nm)	550	315	480	220f 310s	420-500	310-340	390	440	420
Rad Hard (Mrad)	.01	.01-.1	.1-1	1	100	1	10	100	100
ρ (g/cm3)	4.51	4.51	7.13	4.89	8.28	6.16	5.35	6.70	7.40
n_0	1.79	1.95	2.15	1.56	2.20	1.68	1.94	1.85	1.82
Cost ($ /cc)	3.2	4	4	5	8	3	?	> 15	> 7

Pure CsI crystals

- Fast component has decay time 28ns which is x30 faster than CsI(Tl). Solves occupancy problem.
- Light yield is lower than CsI(Tl) by x20 (and shifted from 565nm to 320nm)
  - Readout has been demonstrated using APDs
  - Resolution could be comparable to CsI(Tl)
- We think there is a gain of at least x2 in radiation hardness *(based on one set of measurements and vague claims from manufacturers!)*
- No change to geometry of calorimeter
- Cost is ~$4/cc which is x2 more than CsI(Tl)

Ok for Luminosity of 2x10^{35}. *Need to measure radiation damage to see if ok at higher luminosities*

LSO (or LYSO) Crystals

Lutetium (+Yttrium) OxyOrthosilicate

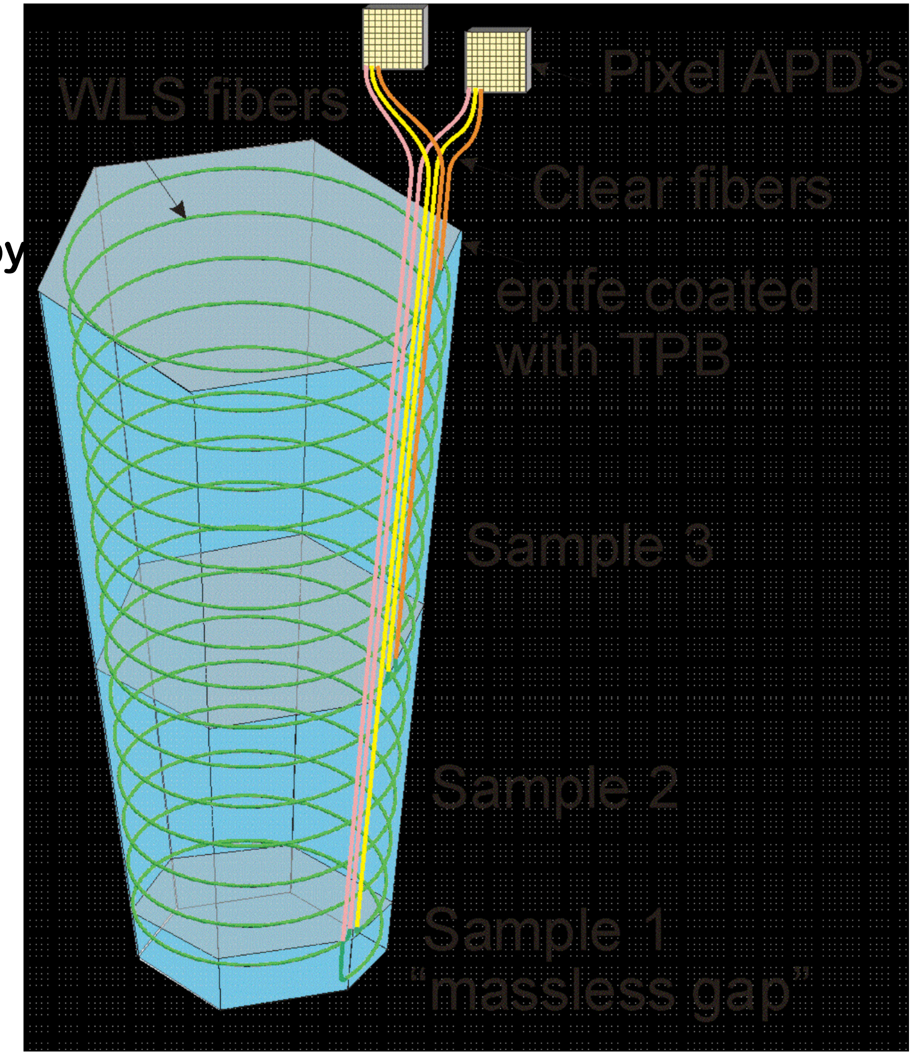
- Fast light output in 40ns. Solves occupancy problem.
- Smaller radiation length 1.15cm (CsI 1.86cm) and Moliere radius 2.3 cm (CsI 3.8cm)
- Believed to be radiation hard to 100MRad!
- Light output is 50% (60%) of CsI(Tl), but shifted to 420nm from 550nm.
- Again use APDs to read them out.
- LYSO has slightly more light output than LSO, and may be easier to obtain commercially (3-4 suppliers instead of only one)
- Currently the cost is ~$50/cc!!

Is an L(Y)SO calorimeter affordable?

	CsI Barrel	L(Y)SO Barrel	CsI Endcap	L(Y)SO Endcap
Radius	905-1300mm	705-1000mm	500-900mm	400-700mm
Z position	Rear -1178mm Front 1801mm	Rear -900mm Front 1400mm	Inner 1968mm Outer 1801mm	Inner 1530mm Outer 1400mm
Crystal Size	4.8cm x 4.8cm x 30/32cm	3.0cm x 3.0cm x 18.5/20cm	4.0cm x 4.7cm x 32cm	3.0cm x 3.0cm x 20cm
# in □/□	48/120	60/150	8/80-120	8/90-150
Total # Xtal	5760	9000	820	990
Volume	4.5 m^3	1.6 m^3	0.5 m^3	0.2 m^3
Cost/cc	~$4	~$50	~$4	~$50
Total Cost	$18M	$80M	$2M	$10M

The LXe Calorimeter concept

- Hexagonal cells of ~ 1 Molière radius in transverse dimension are formed from thin quadraphenyl butadiene (TPB)-coated eptfe sheets
  - Cells are not load-bearing, thus thin
- Longitudinal segmentation is provided by TPB-coated optical separators, with WLS fibers sensitive only in a particular segment
  - Three segments is probably optimal
    1. Massless gap – ascertain whether there was an interaction in material in front of the EMC
    2. Two larger segments, with division near shower max
- Fibers are read out by a pixelized APD, located in the LXe volume
  - Clear fibers between coil segment and APD
  - Redundant readout is simple and inexpensive
  - All readout at rear, minimizing nuclear counter effect



Xenon calorimeter

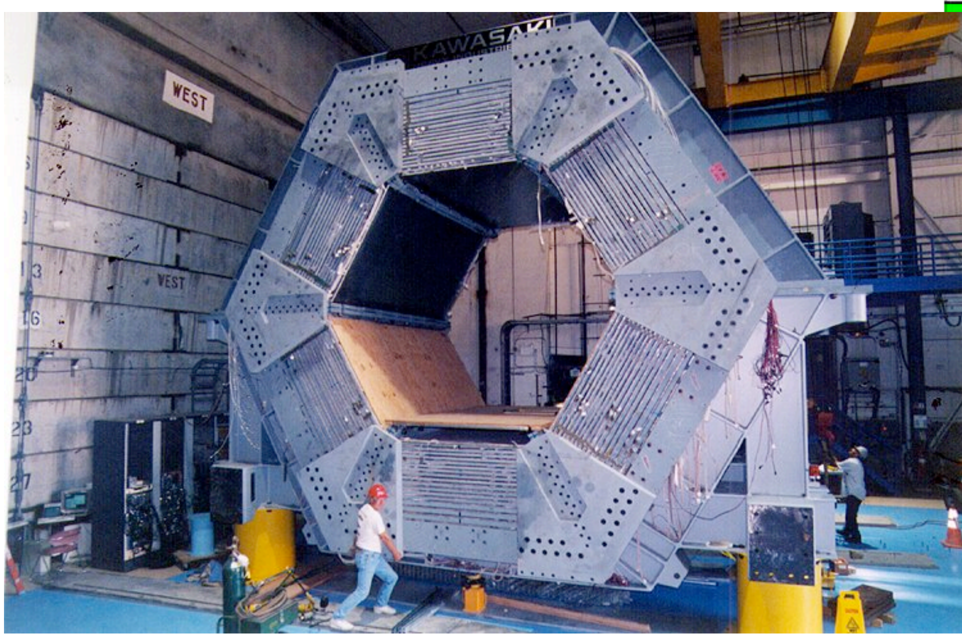
- Light output is within ~20ns.
- Radiation length is 2.9cm
  - Need all of radial space between 700 and 1350mm for cryostat, Liquid Xe and readout.
- Moliere radius 5.7cm.
  - *Need sampling along shower depth to separate overlaps.*
- Light yield is similar to CsI(Tl) but at 175nm.
  - Use wavelength shifters and readout by APDs
- Radiation hardness is not an issue
- Cost of Liquid Xe is $2.5/cc
  - Total cost $20M + readout and mechanics?

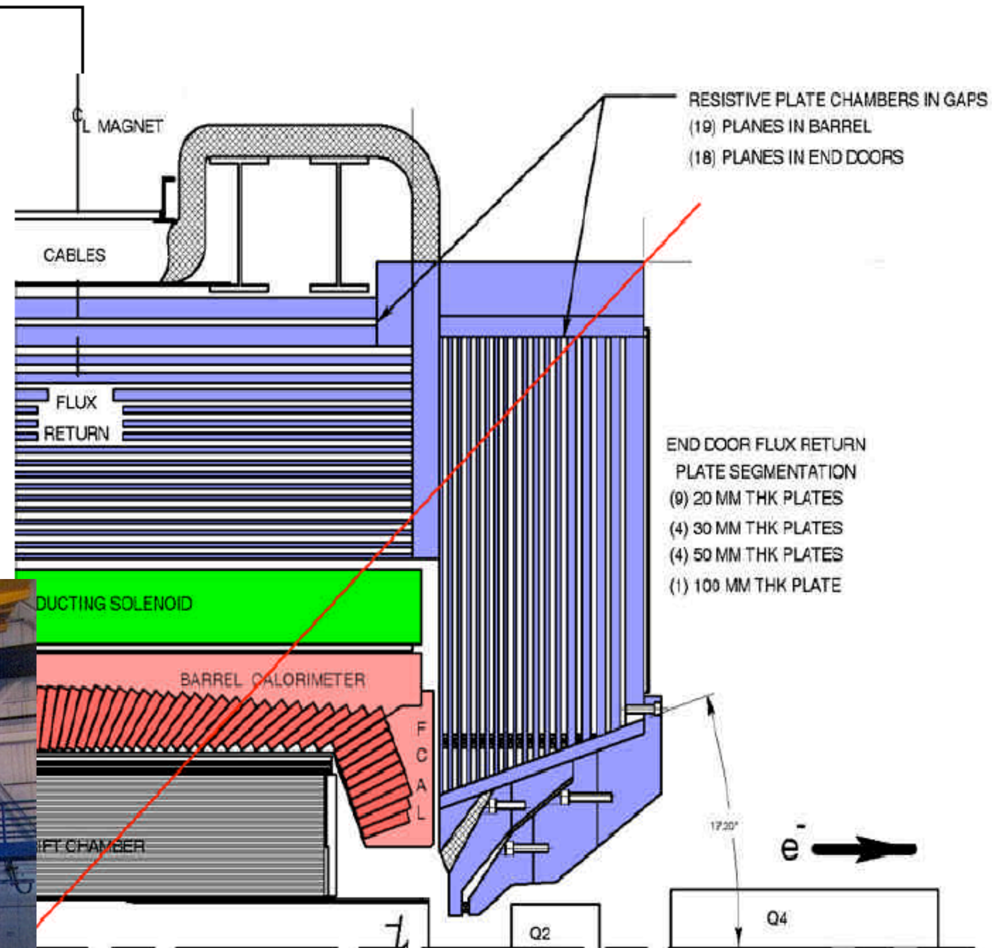
Calorimeter R&D

- CsI(Tl) and pure CsI radiation damage tests at SLAC by Schindler/Hry'nova
- LYSO crystal has been acquired by CalTech (Ren Yuan Zhu)
  - Will test readout with 1-4 APDs (from CMS)
- Liquid Xe design studies are ongoing
  - Cryostat available at CalTech
  - Possible Liquid Xe beam test in 2005

Instrumented Flux Return

- Babar: RPCs+LSTs
- Belle: RPCs





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BABAR

IFR upgrades

- Forward endcap RPCs will not survive $2x10^{35}$
  - Outer layers see large LER background (part of which will be shielded after summer 2004)
  - Inner layers see large Lumi background at small radii
- In principle one could replace the forward endcap with LSTs (in avalanche mode)
  - Scintillator also possible, although not really studied.
- Barrel LSTs should be ok for all scenarios
- Not clear if there is interest in replacing backward endcap RPCs
- Does not seem to be a critical issue.

Trigger, DAQ, Computing

- The 10^{36} environment will be quite challenging for trigger, DAQ and Computing
  - 10-100kHz Trigger rate
  - Assume 50 kB event size → roughly 5GB/s dataflow
  - Data logging at about 330MB/s (6kHz x 55kB/ev)
- It seems to be a solvable problem, through:
  - Moore's law
  - Draw extensively on LHC experiments experience
    - This applies to front end electronics as well
- Needs to be revisited when detector technology choices are clearer.

R&D

- Several detector elements require significant R&D activity before a complete design can be formulated
  - Thin silicon pixel and strip detectors (including mounting and cooling)
  - Small cell drift chamber under high radiation
  - Focussed DIRC, TOP detector
  - Crystals for EMC, Liquid Xe calorimeter, pure CsI readout
  - Technology for muon ID.
- Try to draw as much as possible from LHC developments and experience
  - Low energy environment is somewhat different
- The time frame for this R&D is

NOW

and the next 3 years

The international scene

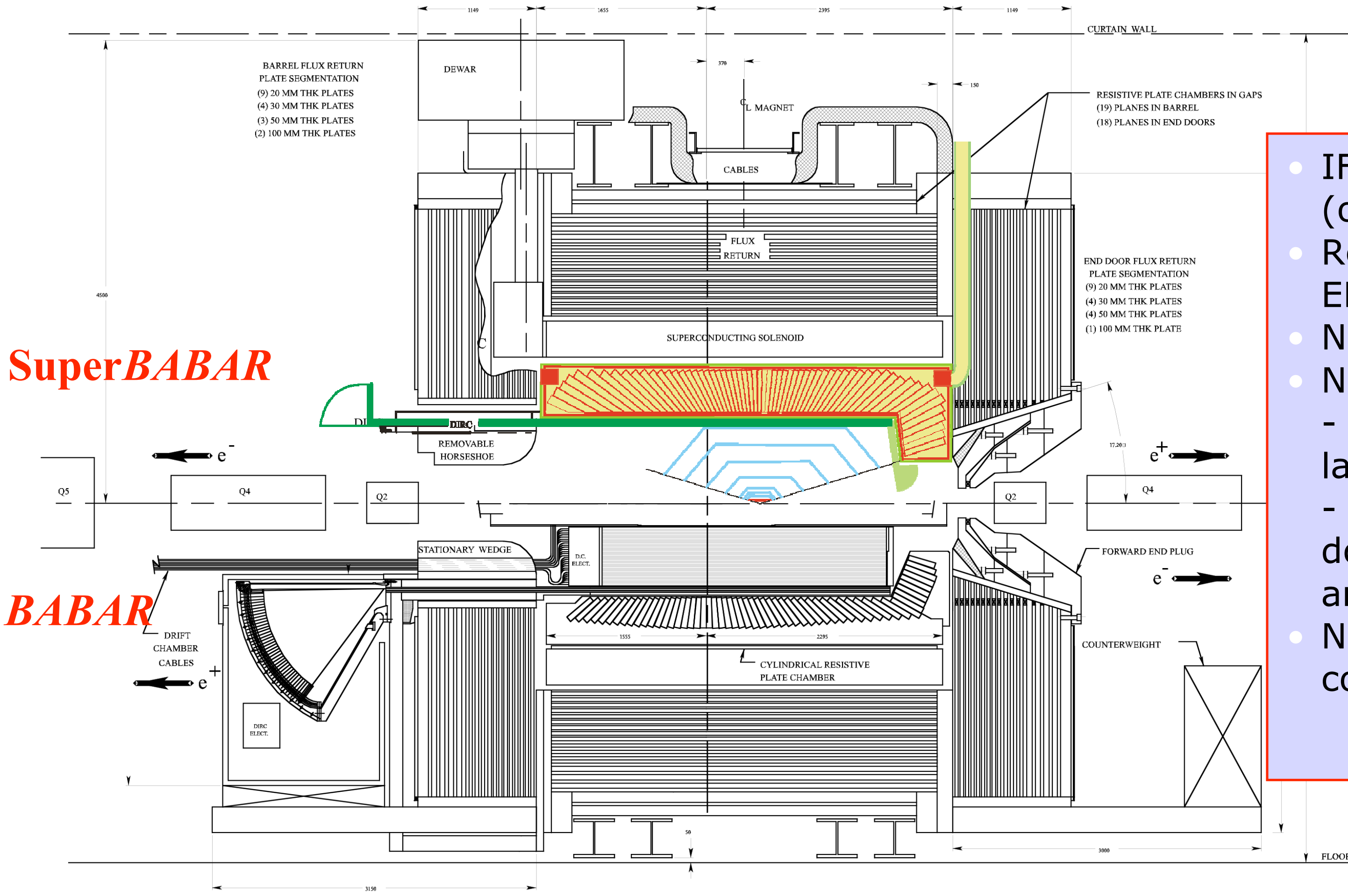
- KEK-B/Belle: A letter of intent has been put forward in February 2004 for a Super KEK-B machine and a Super Belle detector.
  - Luminosity ranges from 1×10^{35} to 5×10^{35}
  - Detector upgrades include:
    - •Silicon striplets
    - •Small cell drift chamber
    - •Pure CsI calorimeter endcap
- PEP-II/Babar: A "Roadmap committee" has prepared a report summarizing discussions and studies done over the past couple of years.
  - Current direction is to propose a "upgradable platform":
    - Start with $2\text{-}5\times10^{35}$ machine and detector, but already include an upgrade path to $7\text{-}8\times10^{35}$ for the $10ab^{-1}$/year goal.
  - Detector upgrades include
    - •Silicon striplets → thin pixels
    - •Small cell drift chamber → all silicon tracker
    - •Pure CsI calorimeter endcap → Liquid Xenon or LSO xtals
  - Base detector possible with current technology, while full upgrade will require significant R&D

Conclusions and outlook

- A detector for a Super B Factory may be possible
  - It will be challenging and not cheap
  - Relatively small parts of the existing detectors will be reusable
    - Magnets and iron, quartz bars, LSTs, little more.
  - R&D required to reach full luminosity (to start now)
- The OSBF Principle
  - a.k.a. “One Super B Factory”
  - It is unlikely that the HEP community has enough resources to build more than one Super B Factory
  - Encourage collaboration between Babar, Belle and other communities to join efforts
    - Joint workshop in Jan 2004 (Hawaii), second of a series, more to come
    - Already a concrete collaboration is active on backgrounds
- Approval process lengthy
  - Connected to global funding political decisions:
    - ITER, ILC, …
  - Unlikely to have serious funds before 2008
  - Successful only if there is overall community agreement and support
- Why not in Europe ?

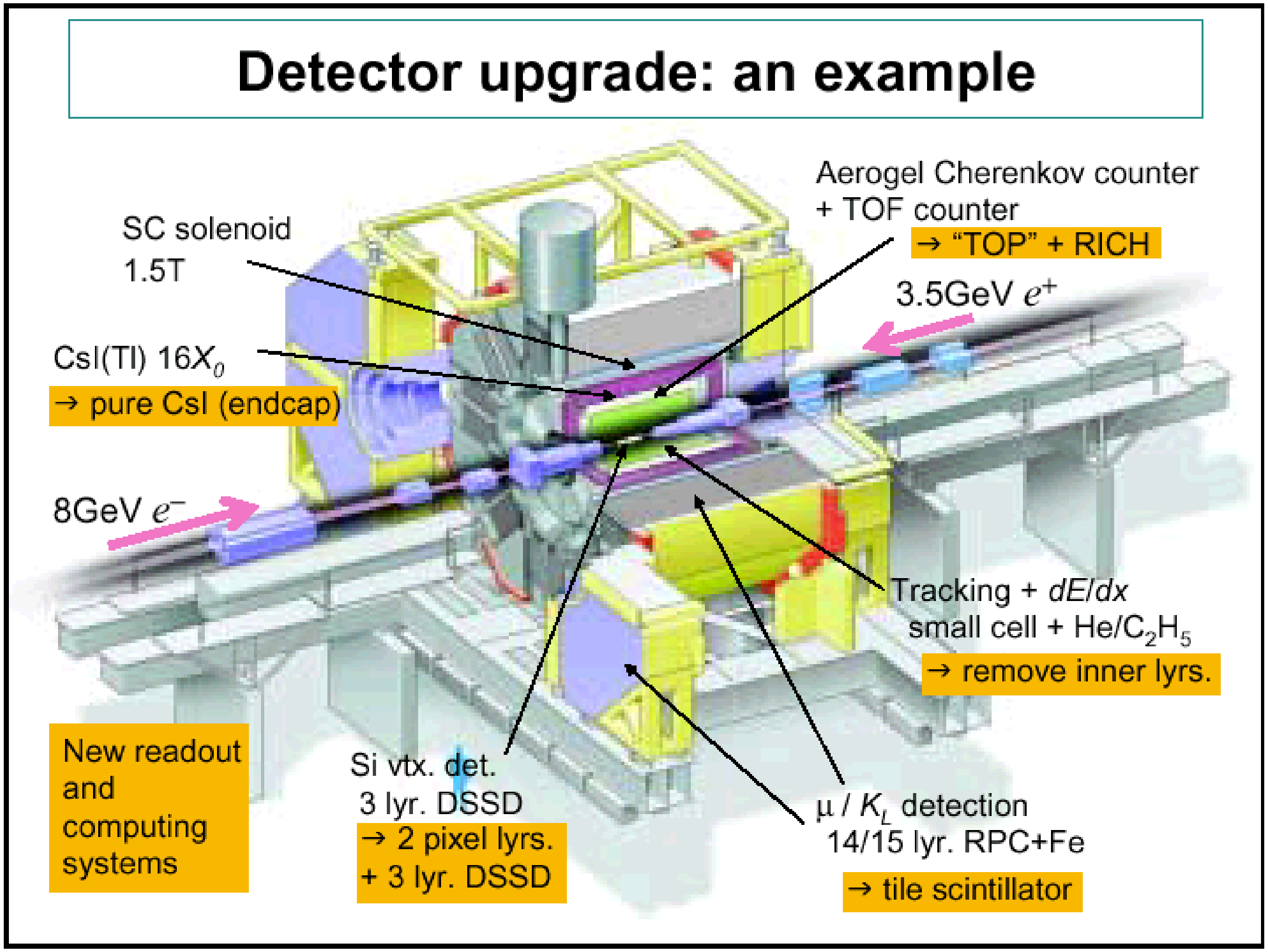
-------BACKUP SLIDES------

Babar upgrade path



- IFR upgraded (ongoing)
- Remove SVT,DCH, EMC, DIRC
- New EMC – liquid Xe
- New tracker
  - Two inner pixel layers
  - Seven(?) thin double-sided Si-strip arch layers
- New DIRC(s) with compact readout

Belle upgrade path

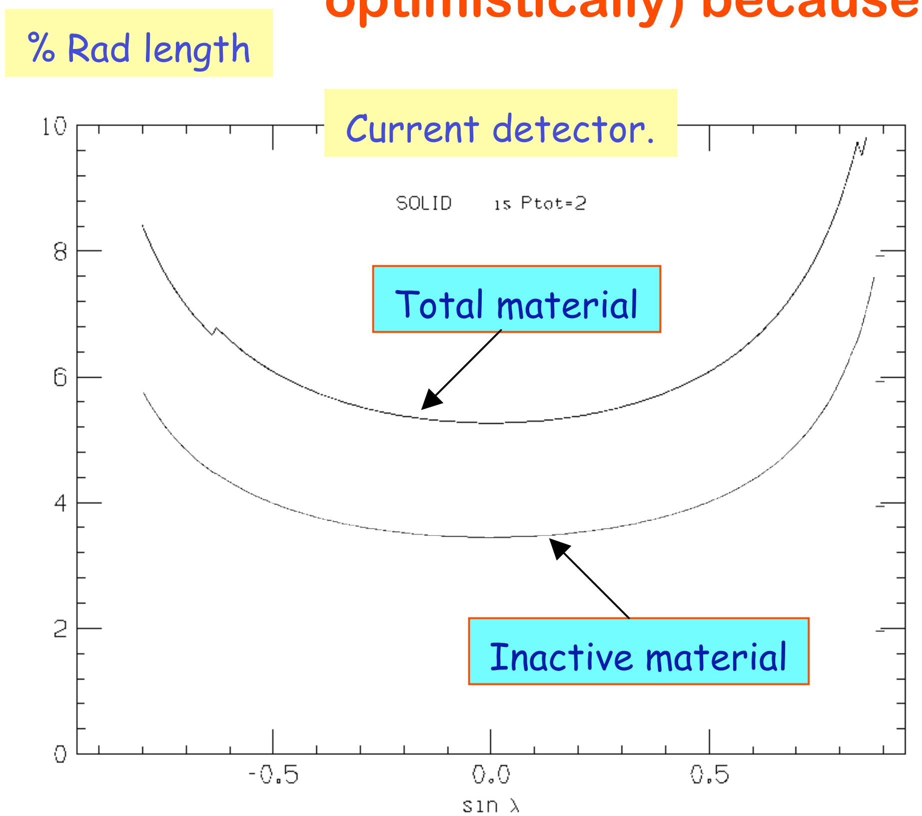


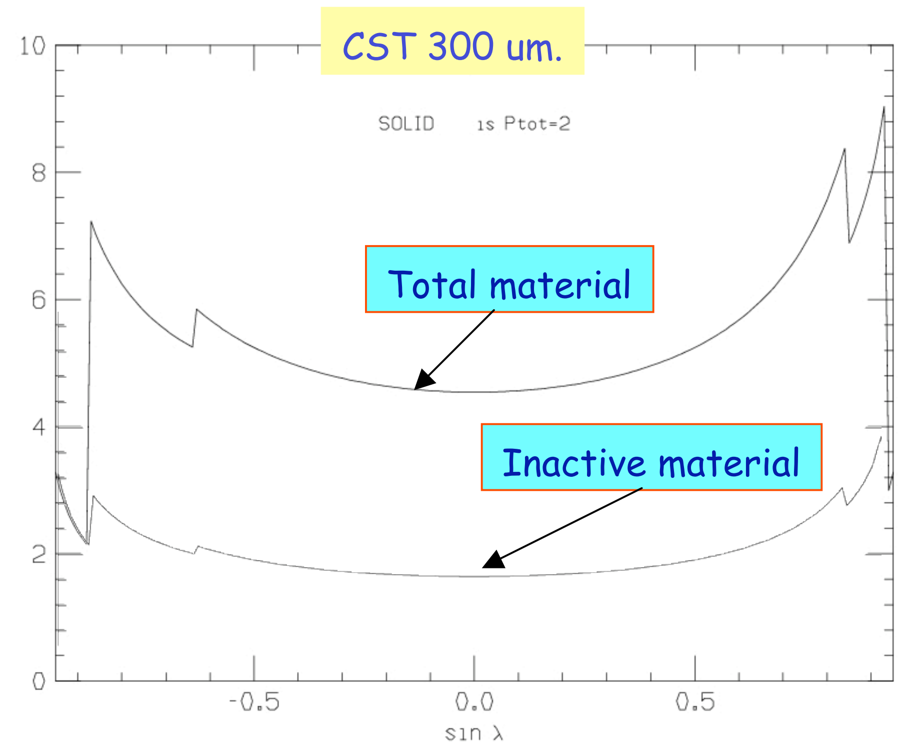
Timescale for BABAR upgrade

- Research & Development
  - SVT Pixels: 3 years, Si tracker: 2 years?, DRC: 2 years, EMC Barrel: 2-3 years, IFR Endcap: 1 year?
  - EMC R&D is longer for LSO, and LXe options
  - *This phase overlaps funding approval (3-4 years?)*
- Engineering, Procurement and Assembly
  - SVT Pixels: 2.5 years, Si tracker: 3.5 years, DRC:2 years, EMC Barrel: 2.5-3.5 years, IFR Endcap: 2 years
  - Longest item is Si tracker readout electronics
  - EMC procurement CsI: 2 years, LSO: 3 years, LXe: 2 years
- Installation in 2011/2 if all goes well

Material

- **Material comparison**
  - Silicon tracker has less total material (well, optimistically) because of removal of Support Tube

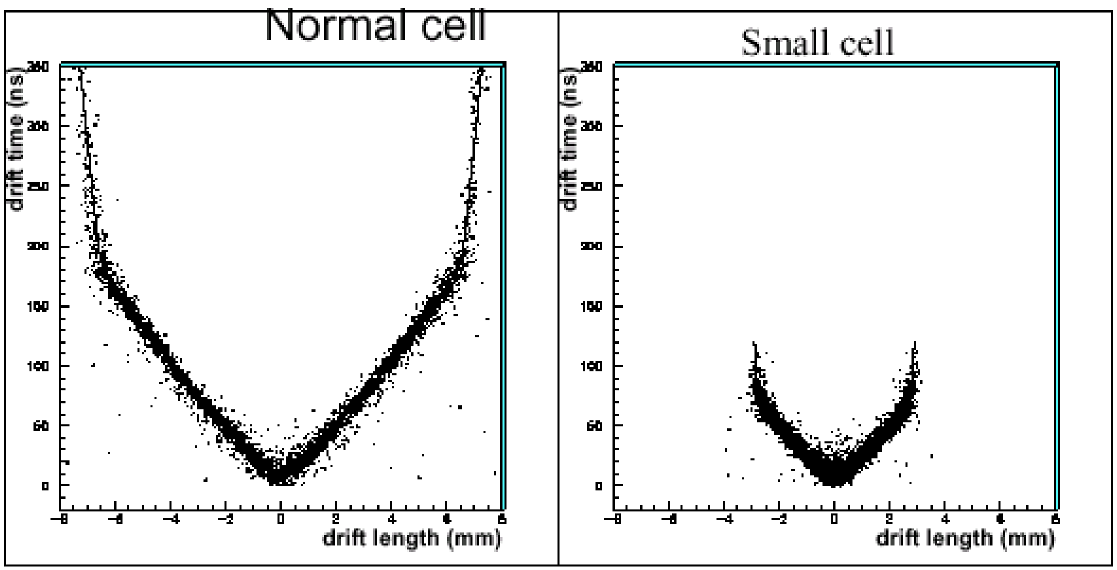


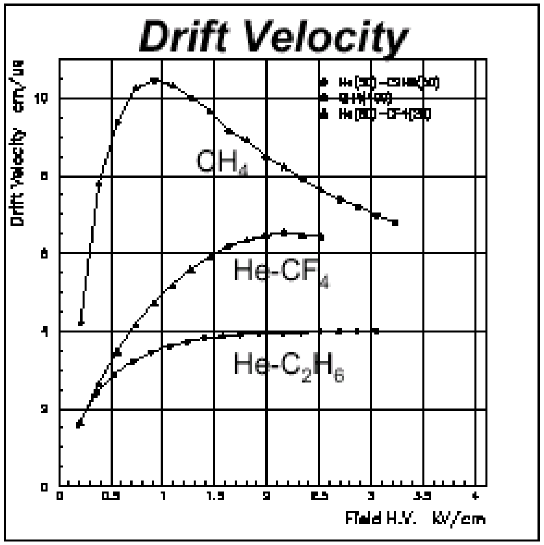


Small cell drift chamber

- To reduce occupancy
  - Smaller cell drift chamber
  - New gas with faster drift velocity → CH_4

XT curve for small cell





Crystals or Lxe ?

	CsI(Tl)	LSO	LXe
Atomic number Z	54 effective	65 effective	54
Atomic weight A			131
Density (g/cc)	4.53	7.40	2.953
Radiation length (cm)	1.85	1.14	2.87
Molière radius (cm)	3.8	2.3	5.71
□ scint (nm)	550	420	175
□scint (ns)	680, 3340	47	4.2, 22, 45
Light yield (photons/MeV)	56,000 (64:36)	27,000	75,000
Refractive index	1.8	1.82	1.57
Liquid/gas density ratio			519
Boiling point at 1 atmosphere (°K)			165
Radiation hardness (Mrad)	0.01	100	-
Cost/cc	3.2	>7 (50 ???)	2.5