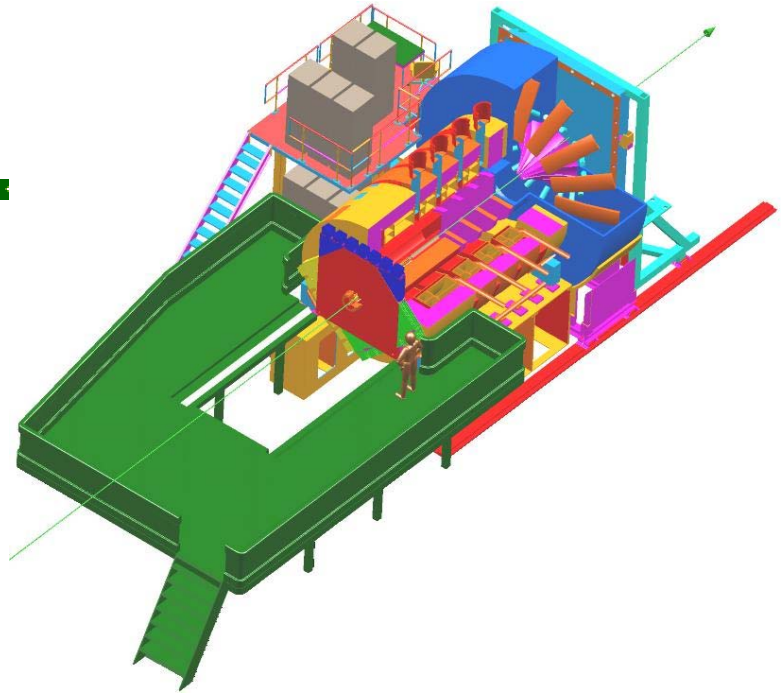
The Electromagnetic Barrel Calorimeter for the GlueX Experiment

Mauricio Barbi

University of Regina

Outline

- GlueX – The Physics Motivation
- The Planned GlueX Experiment
- The GlueX Barrel Calorimeter
  - Geometry
  - Technology
  - Simulation
  - Readout
- Summary and Perspectives



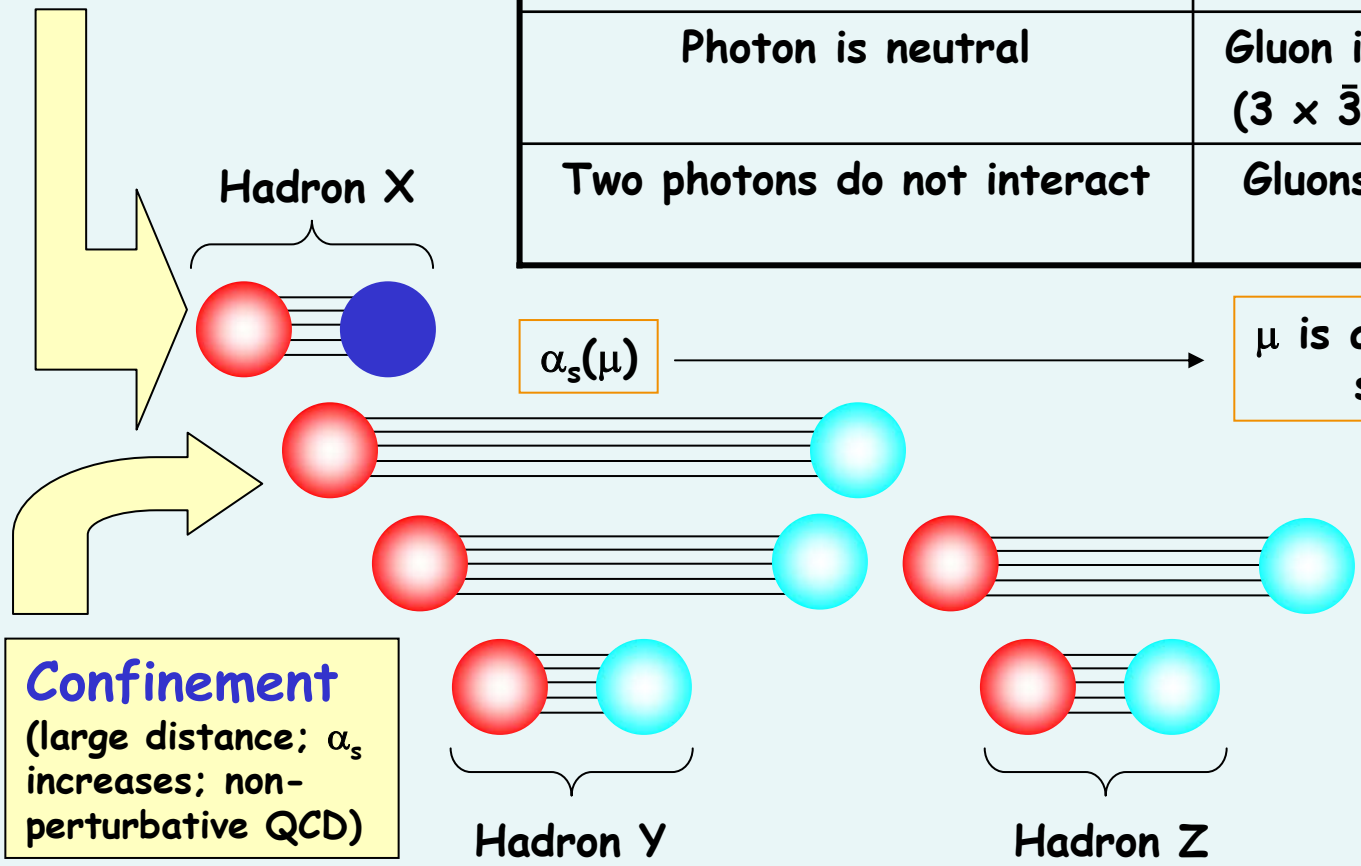
CALOR 2006
Chicago, June 5-9 2006

GlueX - The Physics Motivation

Confinement Mechanism

Asymptotic freedom
(short distance; α_s small; perturbative QCD)

QED	QCD
Two electric charges +1 , -1	6 color charges R B G $\bar{R}$ $\bar{B}$ $\bar{G}$
Photon is neutral	Gluon is colored (R$\bar{B}$, R$\bar{G}$,…) (3 x $\bar{3}$)-1 color combinations
Two photons do not interact	Gluons do interact for they carry net color



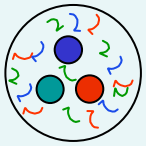
μ is an energy scale of the strong interaction

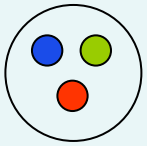
Hadron breaks if $\mu = \mu_0 \approx 1$ GeV

Confinement
(large distance; α_s increases; non-perturbative QCD)

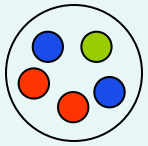
GlueX - The Physics Motivation

QCD is much richer than the Quark Model





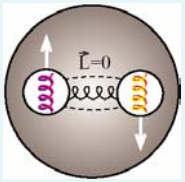
Allows bound states with more than 3 quarks!



Gluons carry color charge → they can interact → they can form bound states

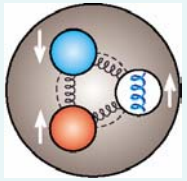
⇩

Glueballs



Light glueballs are difficult to observe as they mix with normal quark states

Bound states formed by gluons and quarks also possible → **Hybrids**

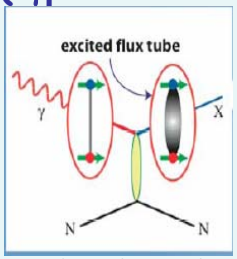


Hybrids can have quantum numbers J^{PC} not allowed in the Quark Model

- **Hybrid states:** gluons participate with additional degrees of freedom;
- **Objective:** Measure and fully establish the lightest hybrid mesons ⟶ gluon dynamics;
- **Gluon Dynamics:** shed new light onto the confinement mechanism.

The GlueX Detector (Hall-D, JLAB)

GlueX Experiment (γp reactions)



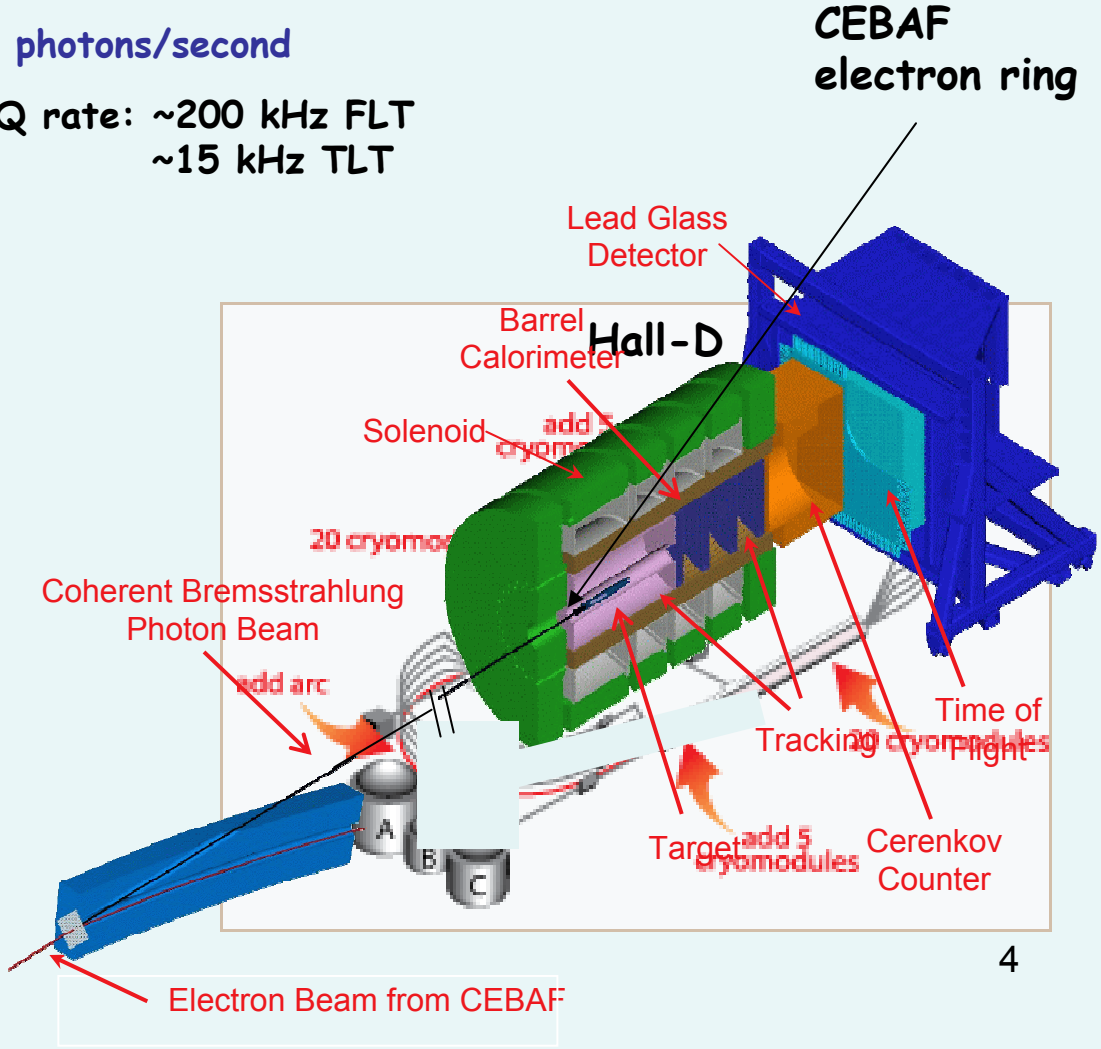
- Goal:
  - Search and map the low-lying hybrid meson spectrum

    Shed light onto the QCD confinement mechanism

- Physics analysis technique:
  - Partial Wave Analysis
- Need:
  - Excellent PID
  - High energy and time resolution
  - Large acceptance

- Acceptance:
  $1^\circ < \theta < 170^\circ$ (charged particle)
  $2^\circ < \theta < 120^\circ$ (photons)

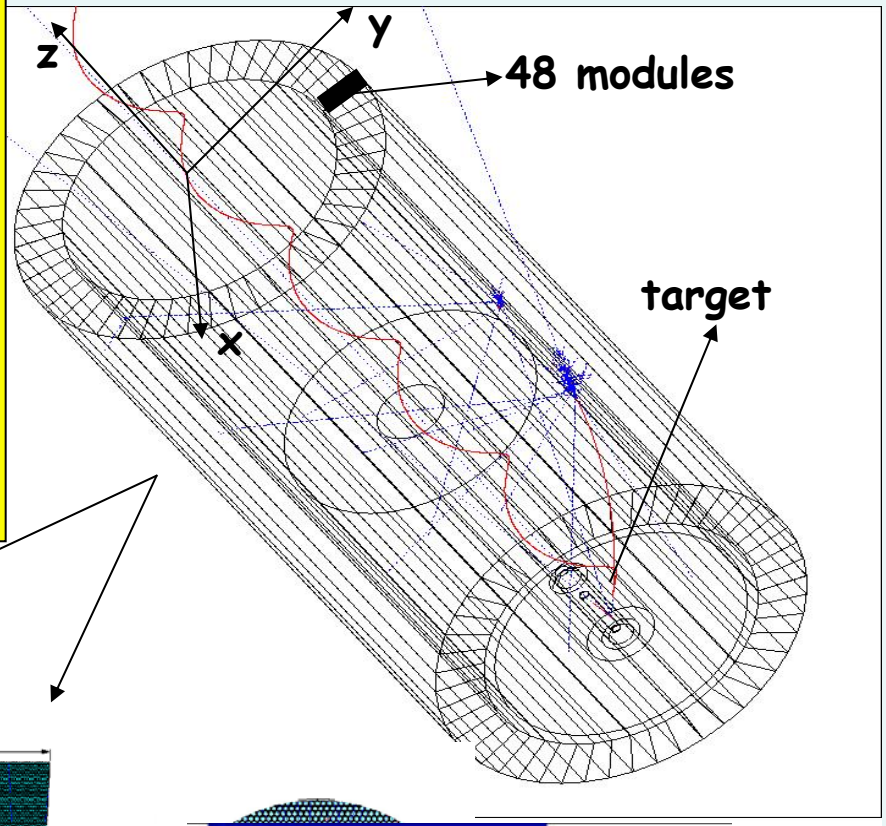
- 8 to 9 GeV linearly polarized photons : mesons masses up to 2.5 GeV/c^2 with $J^{PC} = (0^{+-}, 1^{-+}, 2^{+-})$
- 10^8 photons/second
- DAQ rate: ~200 kHz FLT
  ~15 kHz TLT

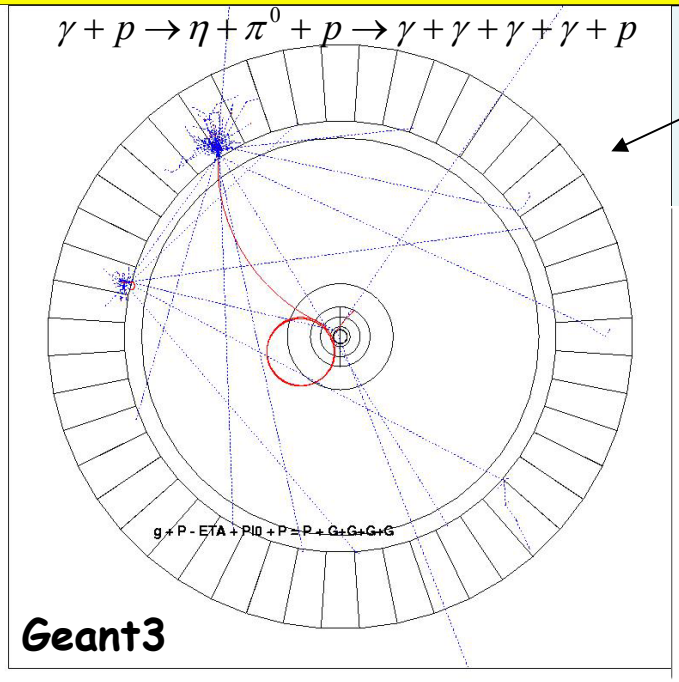


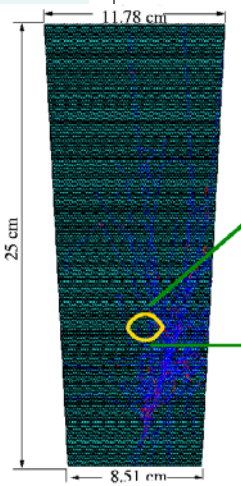
The GlueX EM BCAL (Geometry)

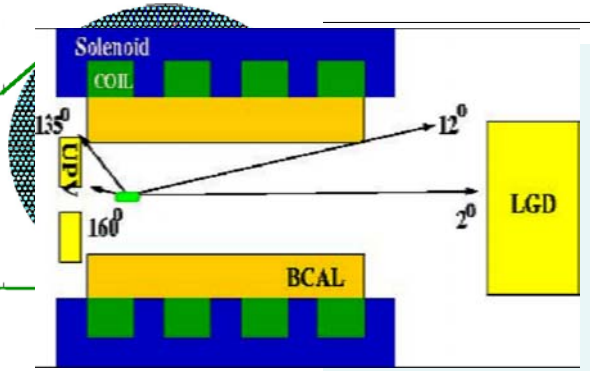
- High-resolution (non-compensating) sampling calorimeter;
  - 3.9 m long, 24 cm deep Pb-SciFi matrix
  - lead:fibers:glue = 37:49:14

  (Similar to KLOE EM calorimeter at DAFNE)
- Inner radius: 65 cm; outer radius: 95 cm constrained by the solenoid (including an aluminum backing plate) . Acceptance $12^o < \theta < 135^o$
- Goal is to detect photons from the decays of π^0's η's







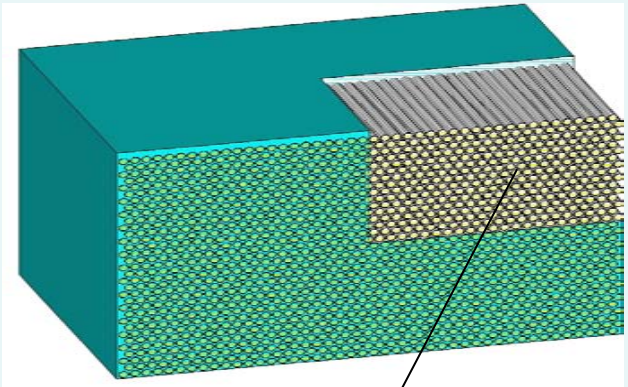


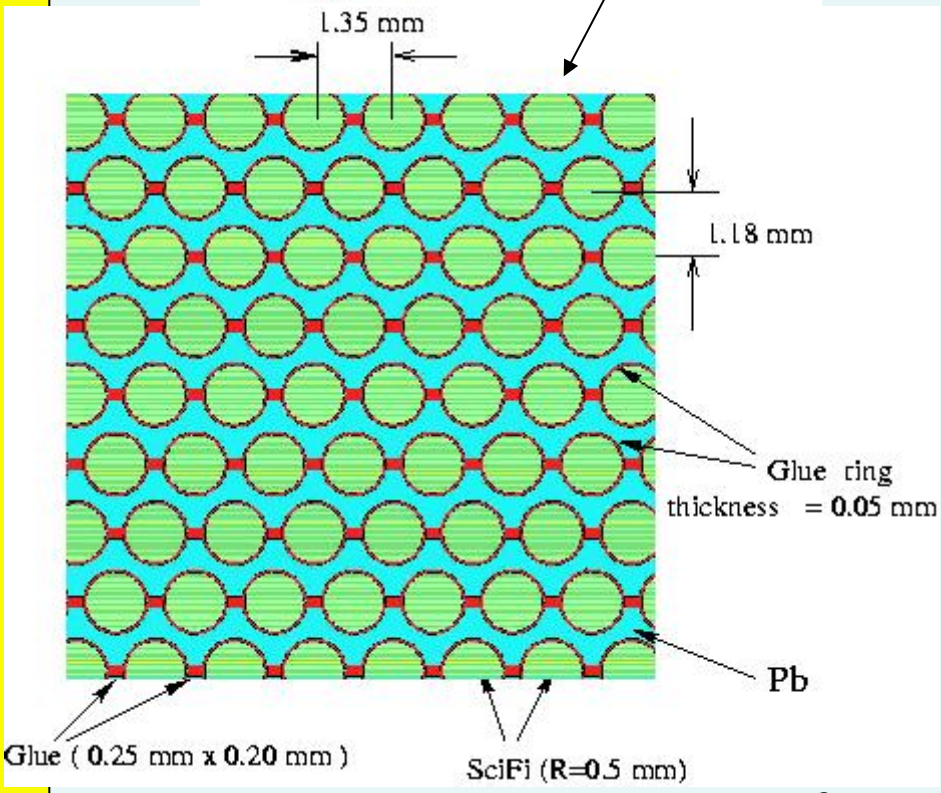
The GlueX EM BCAL (Structure)

- Double clad fast green SciFi (BCF-20)
  - Emission peak: 492 nm
    Attenuation length ~300 cm
    Decay time ~3 ns; ~8000 photons/MeV
  - ~18K fibers/module for a total of ~3500 Km of fibers/detector
    ~63 fibers/cm^2
- Radiation length: ~15.6 X_0 to contain EM showers up to 3 GeV incident particles.
- Longitudinal shower evolution (3 GeV photon):
  $t_{max} \approx 6.5$ cm; $t_{95\%} \approx 22.2$ cm
- Transverse shower profile:
  $R_{Molière} \approx 4.0$ cm
- Designed Resolution:

$$\frac{\delta(E)}{E} \approx \frac{5\%}{\sqrt{E}} \oplus 2\%$$
$$\delta(t) \approx 200 \text{ ps}$$
$$\delta(x) \approx 1 \text{ cm}$$

- Dynamic range: ~20 MeV to few GeV's
- Will operate in a ~2 T magnetic field

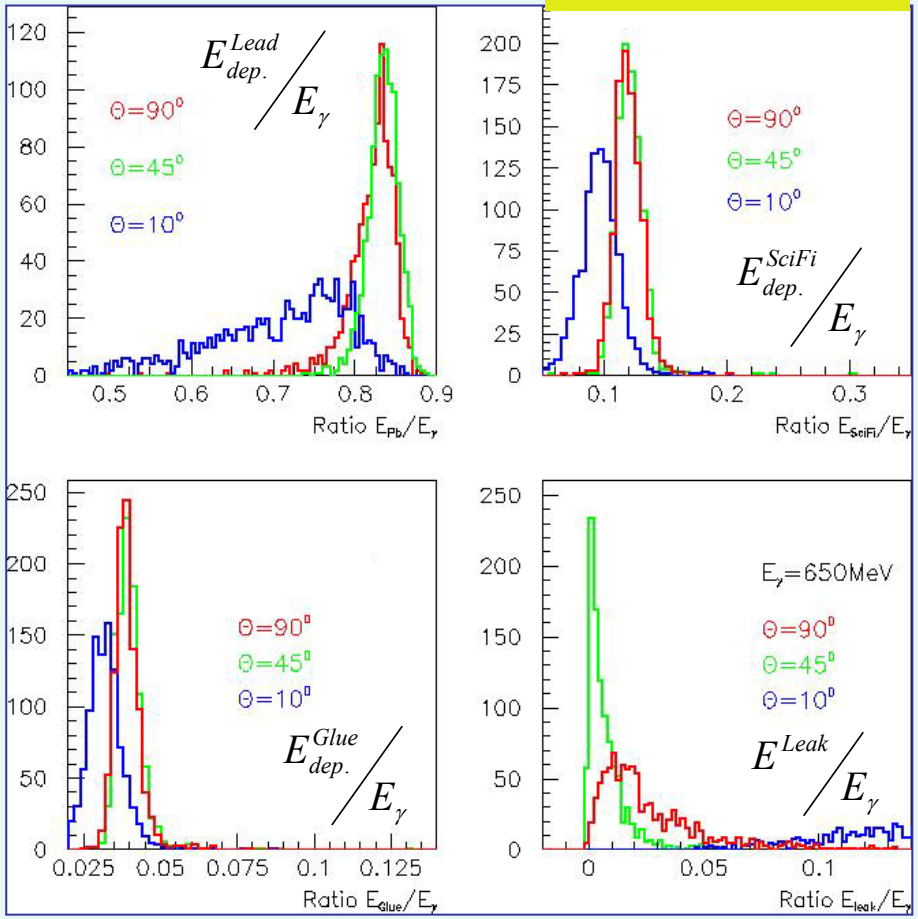




The GlueX EM BCAL (Simulation)

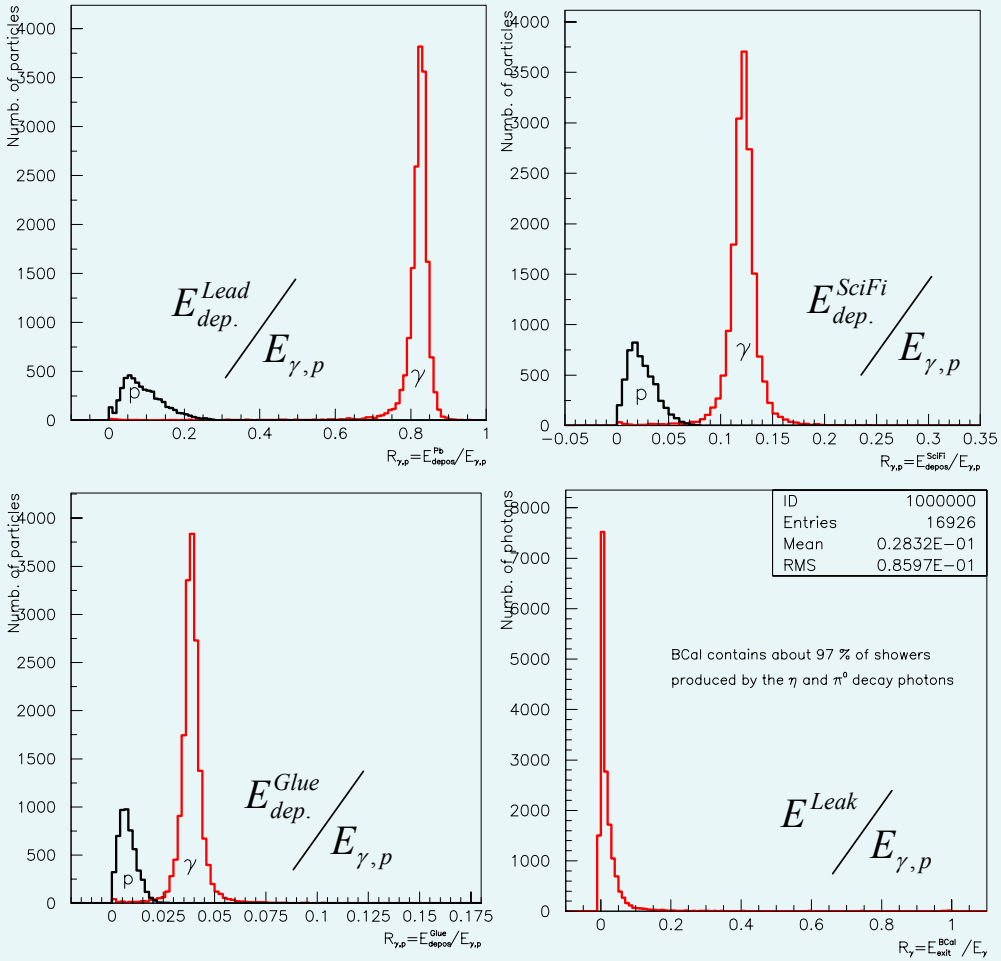
Photons entering the BCAL at angles larger than 20° leave about 81% of their energies in the lead, 12% in the SciFi's and 4% in the glue material.

Geant3 Simulation



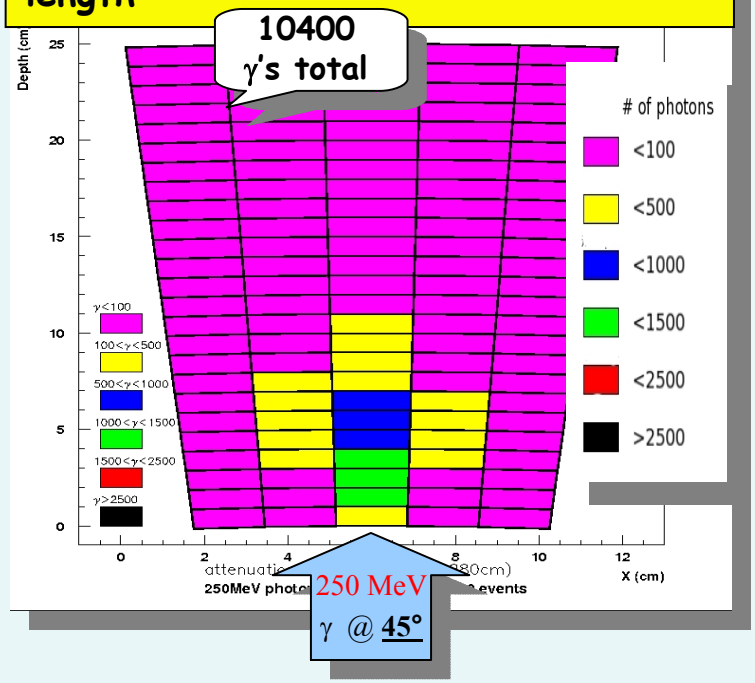
BCAL contains ~97% of the showers produced by photons from the decay of η and π^0 in

$$\gamma + p \rightarrow \eta + \pi^0 + p \rightarrow \gamma + \gamma + \gamma + \gamma + p$$



The GlueX EM BCAL (Segmentation)

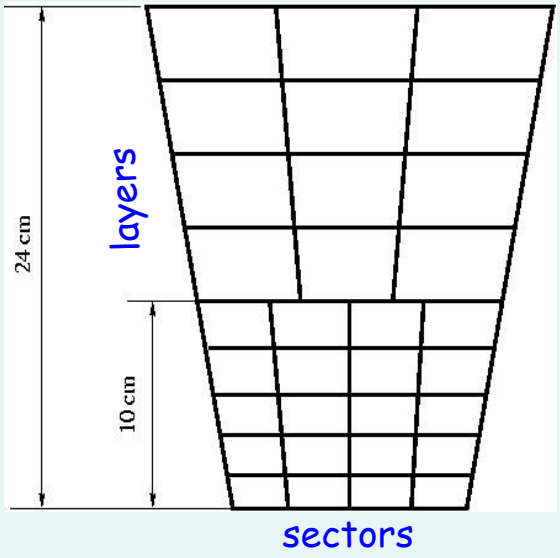
Light collection: SciFi with 9.3% capture ratio and 280 cm attenuation length



Most of the photon energy is left in the first 10 cm

Also true for different energies and incident angles

Geant3 Simulation



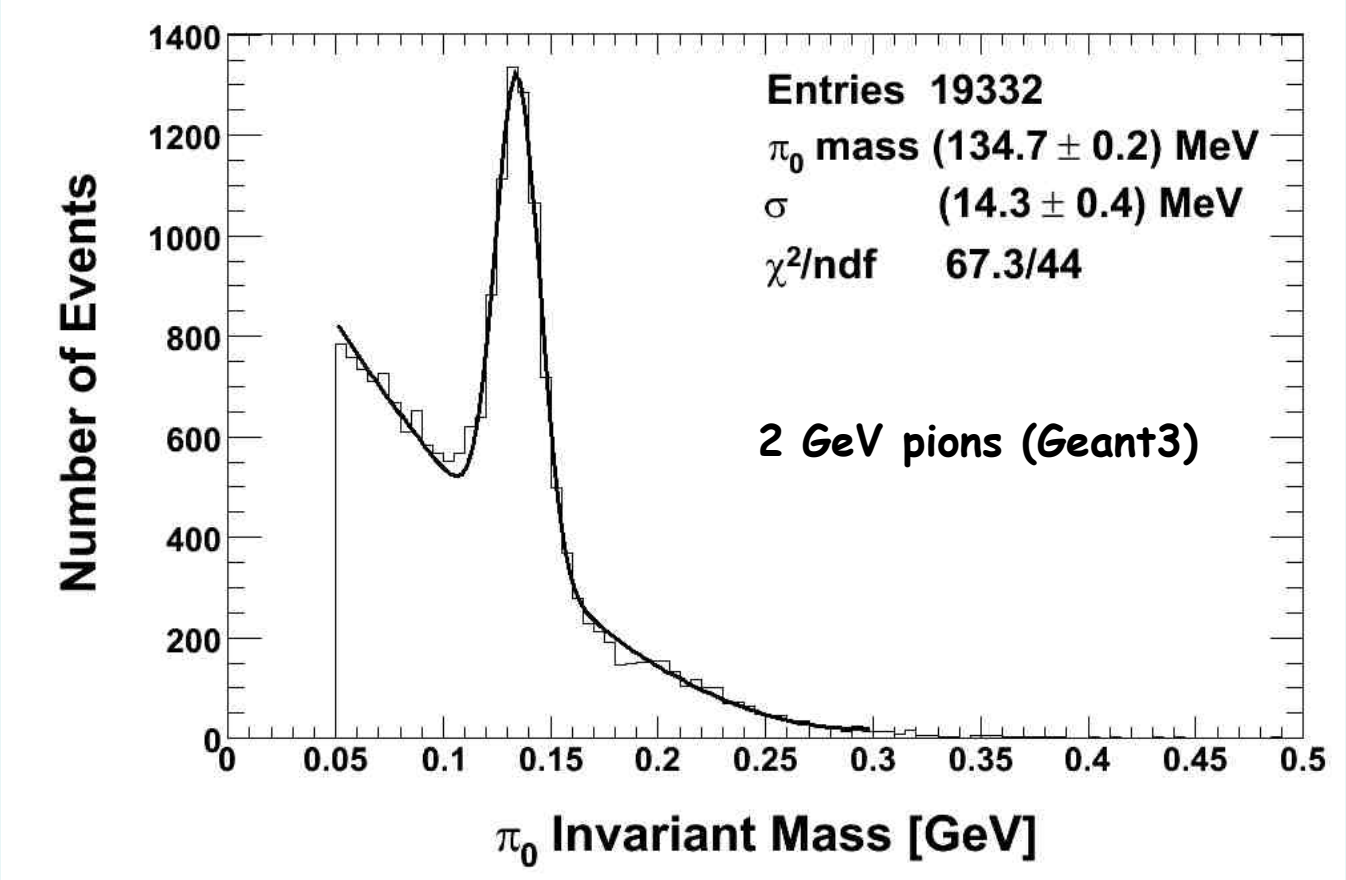
Readout:

- **Segmentation:**
  - ~2x2 cm² for inner layers (first ~10 cm)
  - ~3.5x4 cm² for outer layers (last ~14 cm)
- **Light collection at both BCAL ends**
- **Total of ~3072 readout channels divided into:**
  - ~1920 for the inner layers
  - ~1152 for the outer layers

The GlueX EM BCAL (Reconstruction)

π^0 invariant mass using a very preliminary reconstruction code and a variation of the BCAL simulation code with an effective radiation length (mixed material)

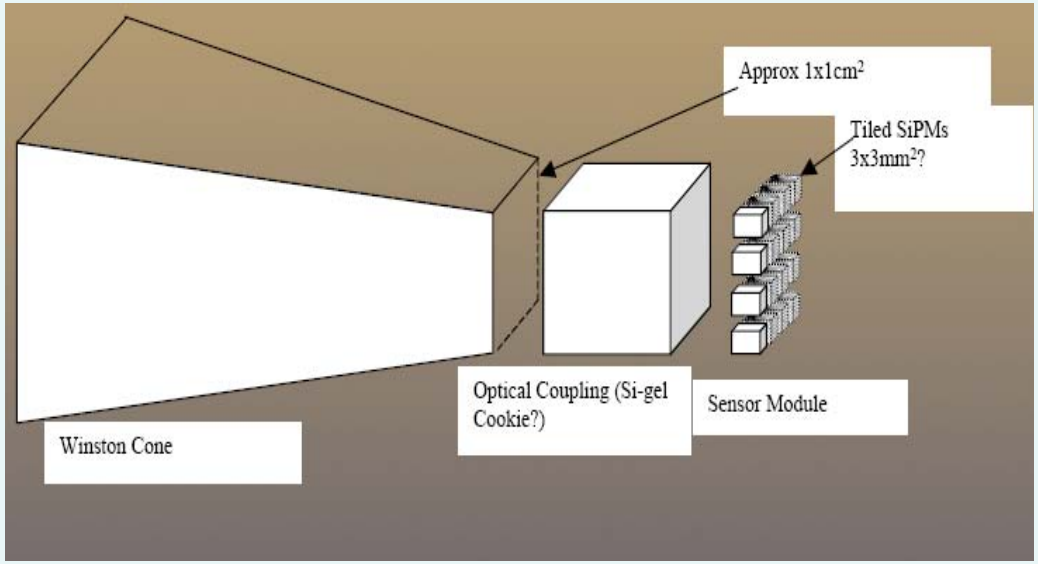
No electronics simulation has been included yet



The GlueX EM BCAL (Readout)

Readout:

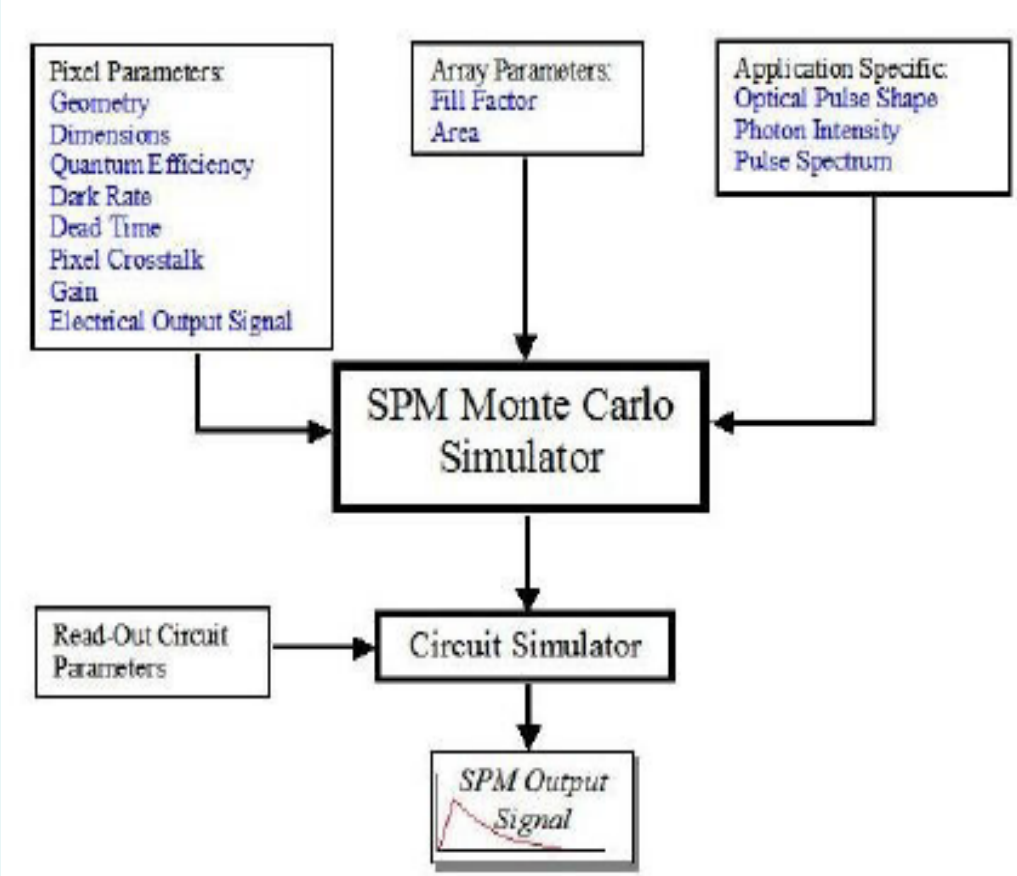
- **Photon sensors:**
  - **High magnetic field (~2 T) and cost limit photodetector options**
  - **Best candidate to date: Silicon Photomultipliers (SiPM) (SiPM has been covered by Hans-Guenther Moser)**
- **Possible readout solution**
  - **Winston cones with ~4x reduction factor**
  - **Inner layers seen by 1x1 cm^2 array of SiPM's coupled to Winston cones**



The GlueX EM BCAL (Readout R&D)

Photo-sensors: R&D by SensL Company – Cork Island, Ireland

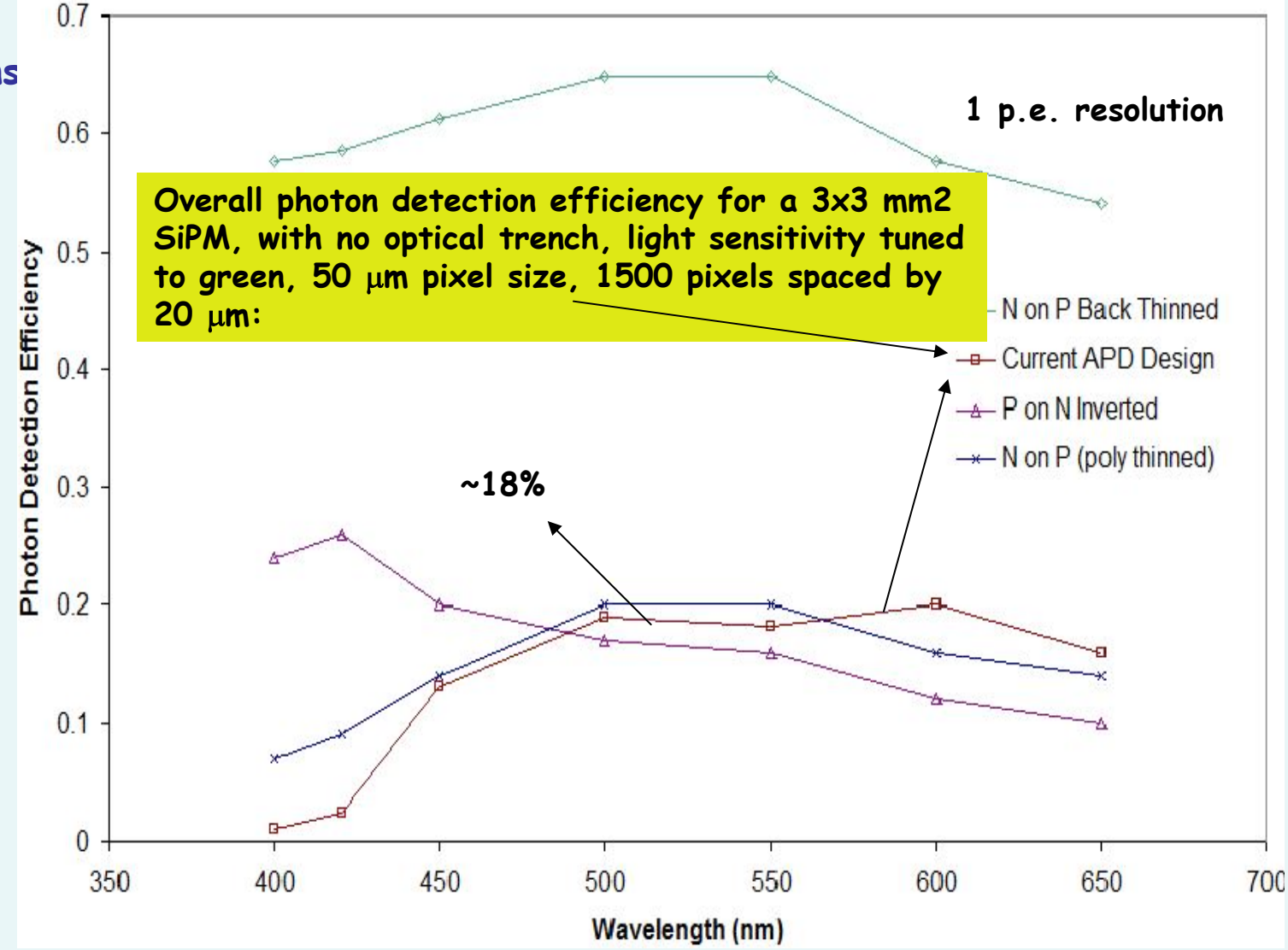
- A multi-phase project (3 phases)
- NxN Arrays of silicon photomultipliers (SiPM's) in the same silicon wafer, also called Sensor Modules (SM)
- Dark rate is an issue: want to measure as low as 20 MeV, or ~900 photons surviving to the end of the BCAL, which has to be folded with the Winston cone efficiency (>90%) and PDE (target is at least 15%)
- Linearity – over 50K photons can survive to the end of the BCAL per few GeV's particle
- Several ongoing simulations to optimize the SM design - R&D Phase 1



The GlueX EM BCAL (Readout R&D)

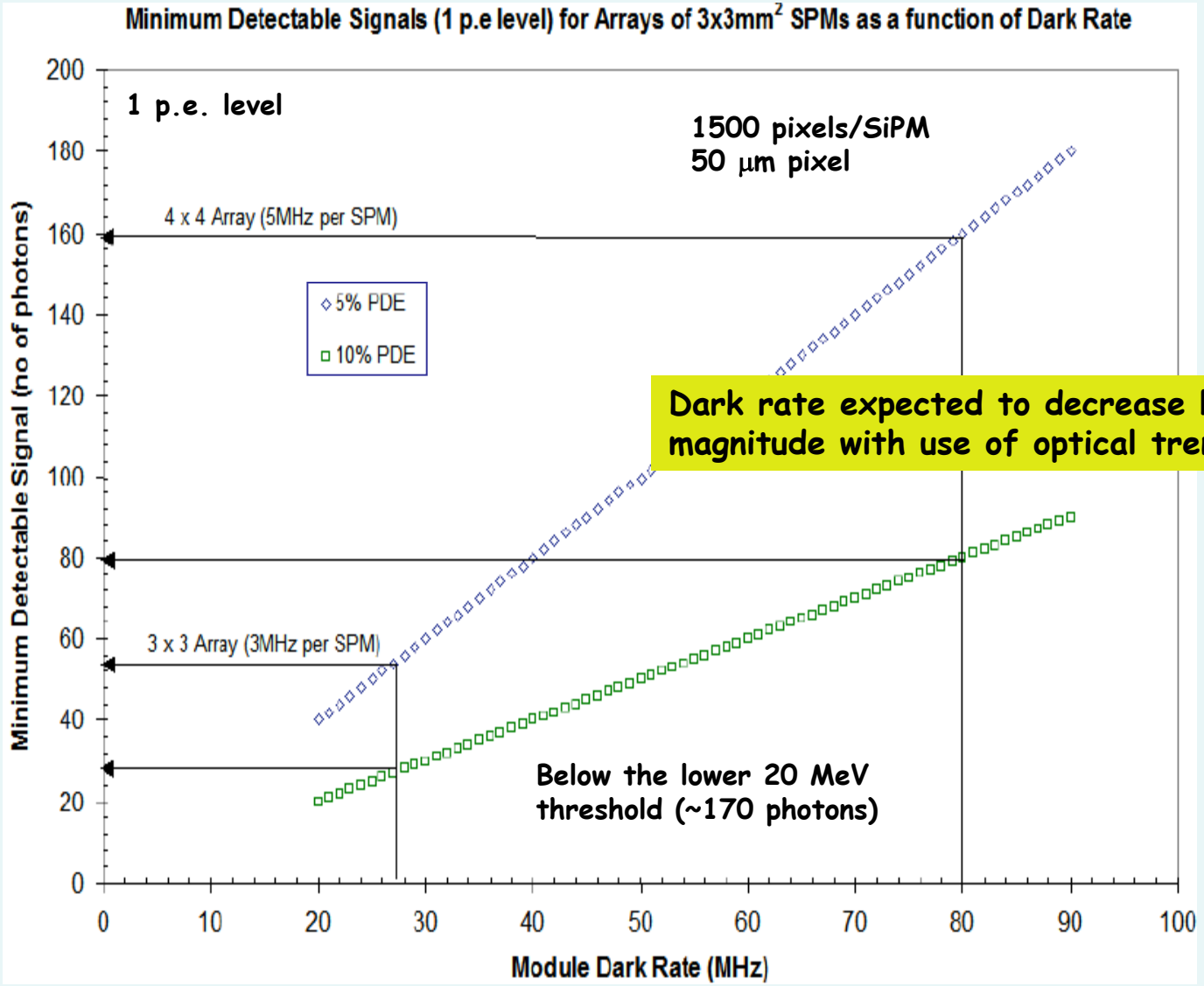
Expected gain > ~10^6

and rise time ~3 ns



The GlueX EM BCAL (Readout R&D)

Total Dark rate versus minimum number of photons



Dark rate expected to decrease by an order magnitude with use of optical trench

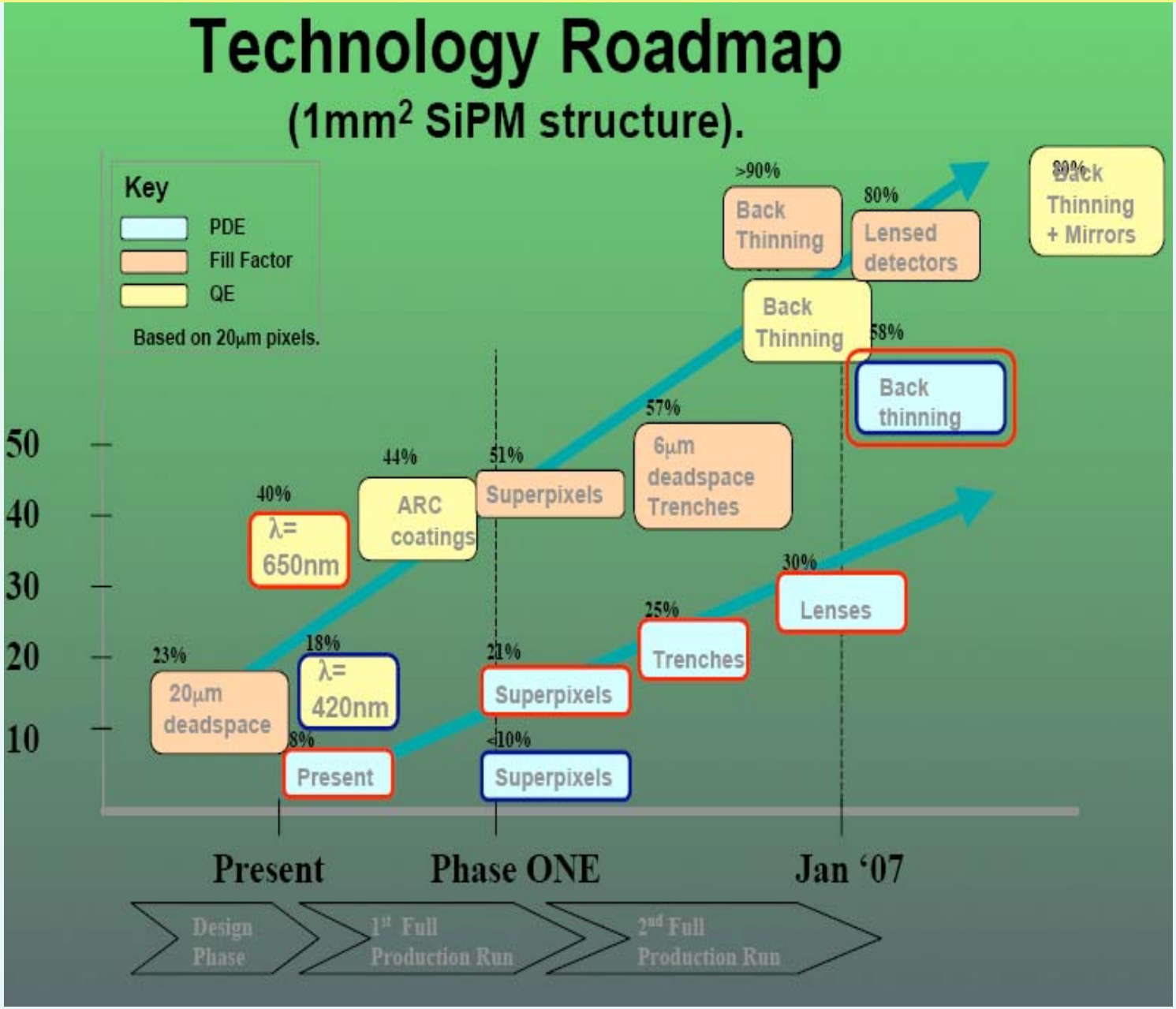
Below the lower 20 MeV threshold (~170 photons)

The GlueX EM BCAL (Readout R&D)

- Phase 1: (Proto-)Prototyping and first characterizations
  - Some 3x3 mm^2, blue-green sensitive, ~200 Hz dark rate/pixel (?) will be delivered for first tests by July. Pixel size will be ~30 μm (low PDE).
  - First arrays expected shorter thereafter:
    1 cm^2, for 1x1 mm^2 SiPM's,
    and/or 1.3 cm^2 for 3x3 mm^2 SiPM's.

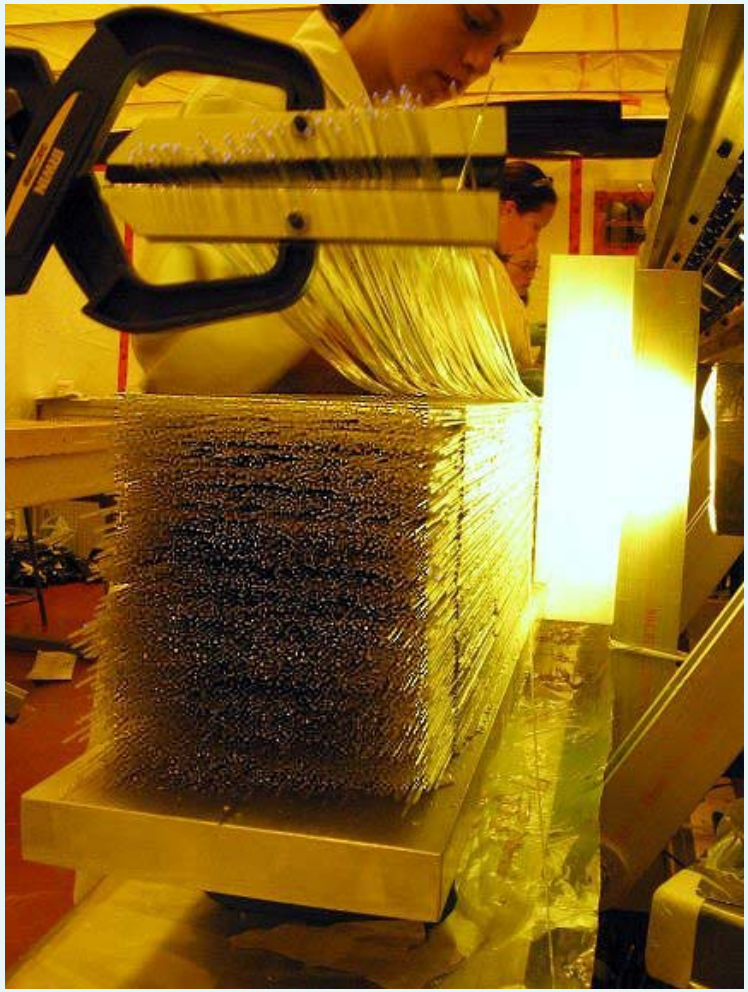
- Feedback from tests to be used for Phase 2 $\longrightarrow$ improve dark rate, fill factor, optical cross-talk, temperature dependence, overall PDE, etc.
- Other effects have to be studied: after pulsing, etc..
- Expect first "close-to-final" version by 2007.

The GlueX EM BCAL (Readout R&D)



The GlueX EM BCAL (Prototyping and Beam Test)

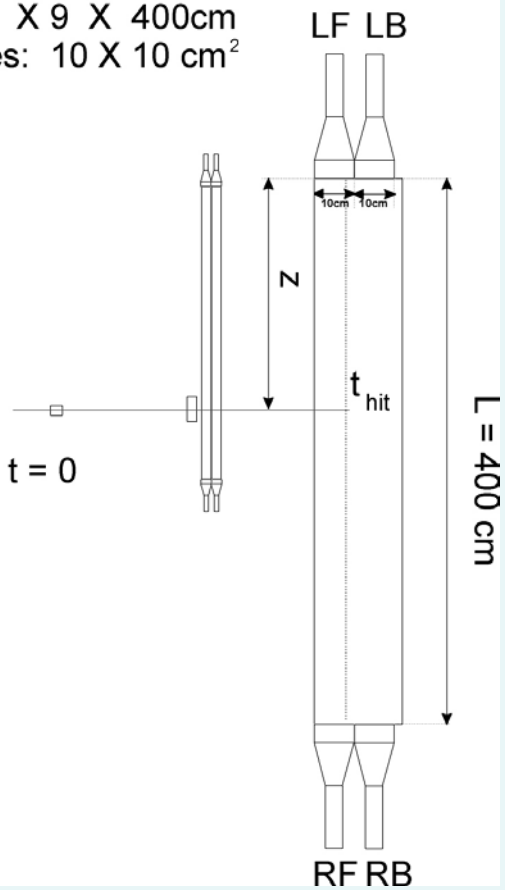
A Full 4-m long (rectangular shape), 14 cm wide and 24 cm thick prototype with double clad blue SciFi (PolHiTech).

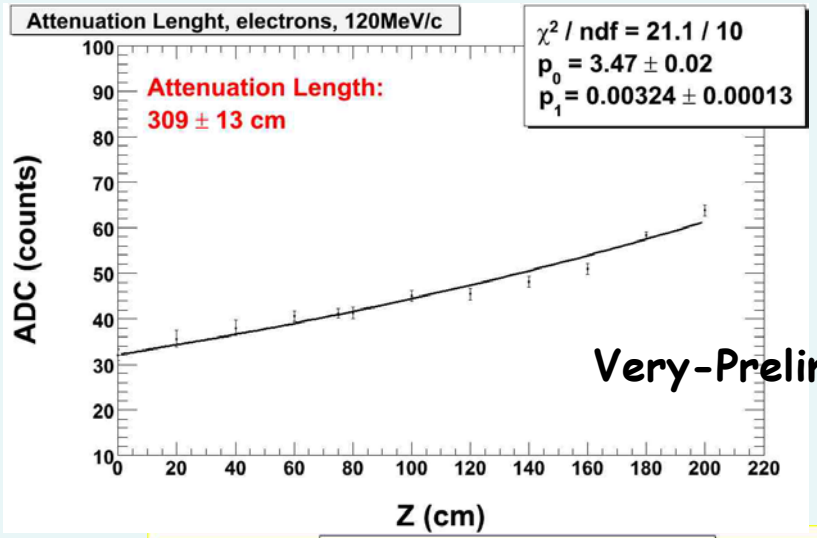


The GlueX EM BCAL (Prototyping and Beam Test)

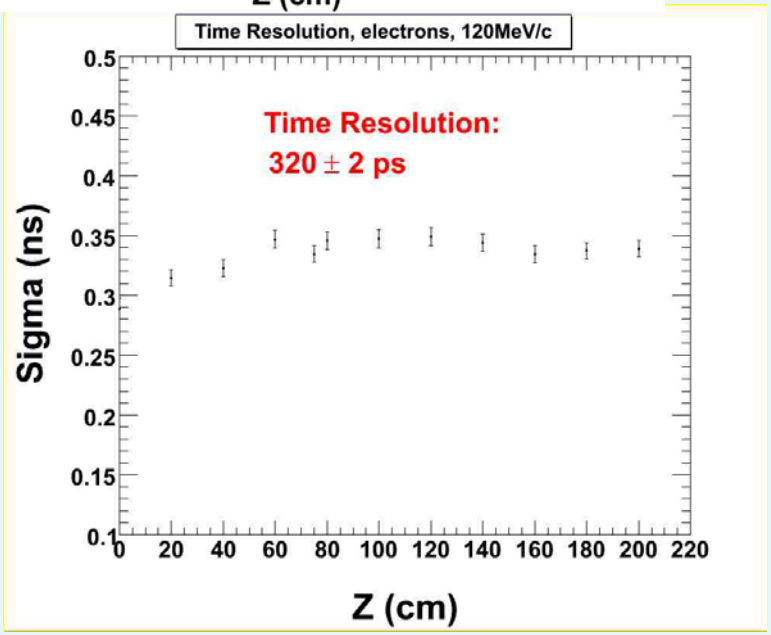
Prototype tested in beam conditions at TRIUMF (~120-300 MeV electrons-muons-pions)

PMT: BURLE 8575
LED: LeCroy 821Z
TDC: LeCroy 2228A (50ps least count)
ADC: LeCroy 2249A
Module: 23 X 9 X 400cm
Light Guides: 10 X 10 cm^2





Very-Preliminary



JLAB-CEBAF 12 GeV upgrade:

Has been granted CD0 and CD1;

CD2 expected next year, followed by CD3 and than CD2A, etc, etc..;

Many delays (approval) have affected the development of this project.

On the other hand, GlueX is one of the several experiments expected to operate under the CEBAF 12 GeV upgraded facility, and is generally considered as the flagship of the upgrade. The Collaboration was formed in 1998 with intention of having first data by 2009.

Now, beam commissioning expected by 2013.

First data for physics – 2014????

Summary and Perspectives

- GlueX is a proposed large acceptance experiment aiming at searching for exotic hybrid meson states with masses up to 2.5 GeV/c^2.
- The EM Barrel Calorimeter is one of the main components of GlueX, and based on an existing technique - KLOE.
- An intensive R&D effort is under way to meet the requirements for the operation of the BCAL.
- Monte Carlo simulations based on Geant3 are being developed, as well as the first version of a reconstruction code. Geant4 will be implemented soon, and the reconstruction code improved.
- MC studies indicates that the BCAL contains about 97% of the shower energy from photons up to few GeV's.
- Study on the optimal segmentation based on the reconstructed meson invariant mass and EM shower separation is being carried out. Cost for the construction of the readout system has also been considered.
- Silicon Photomultipliers are being considered for the readout, though other alternatives are under investigation (field resistant PMT's, hybrid PMT, etc).
- Dedicated tests will take place this Fall at JLAB using 140-650 MeV photon beams. Goal is to measure time and energy resolution, and validate the MC simulations.
- First physics analysis by 2014????

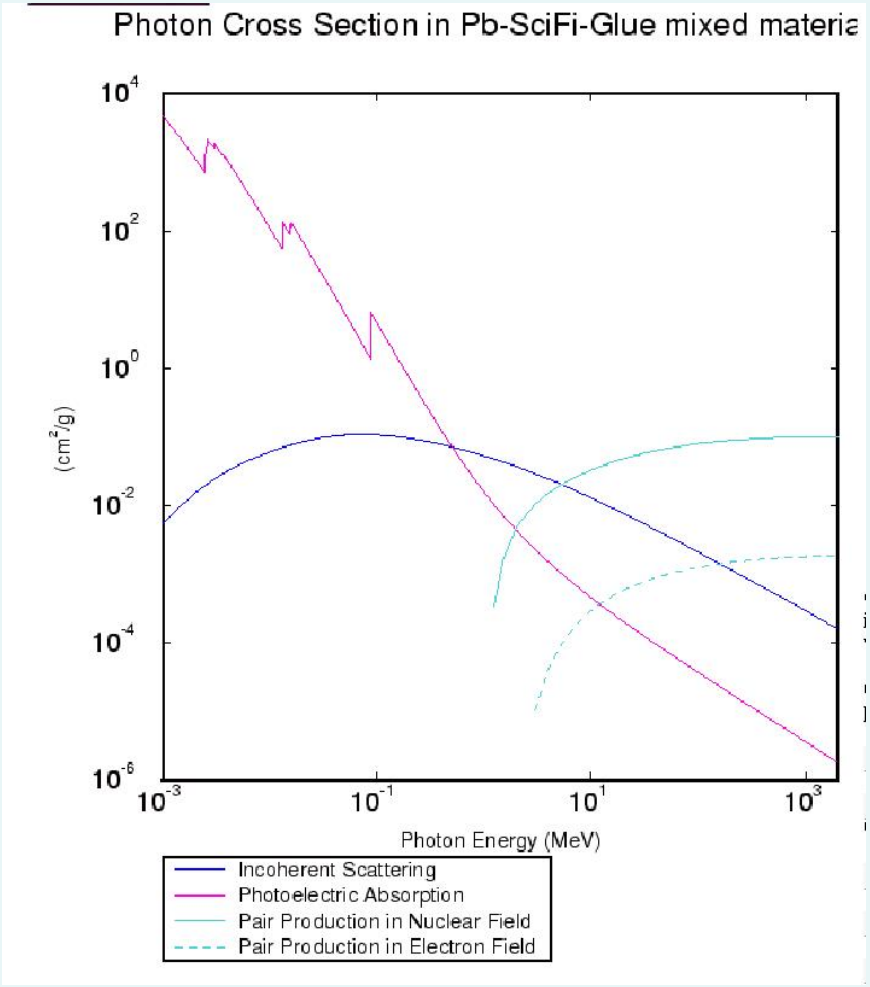
EXTRA SLIDES

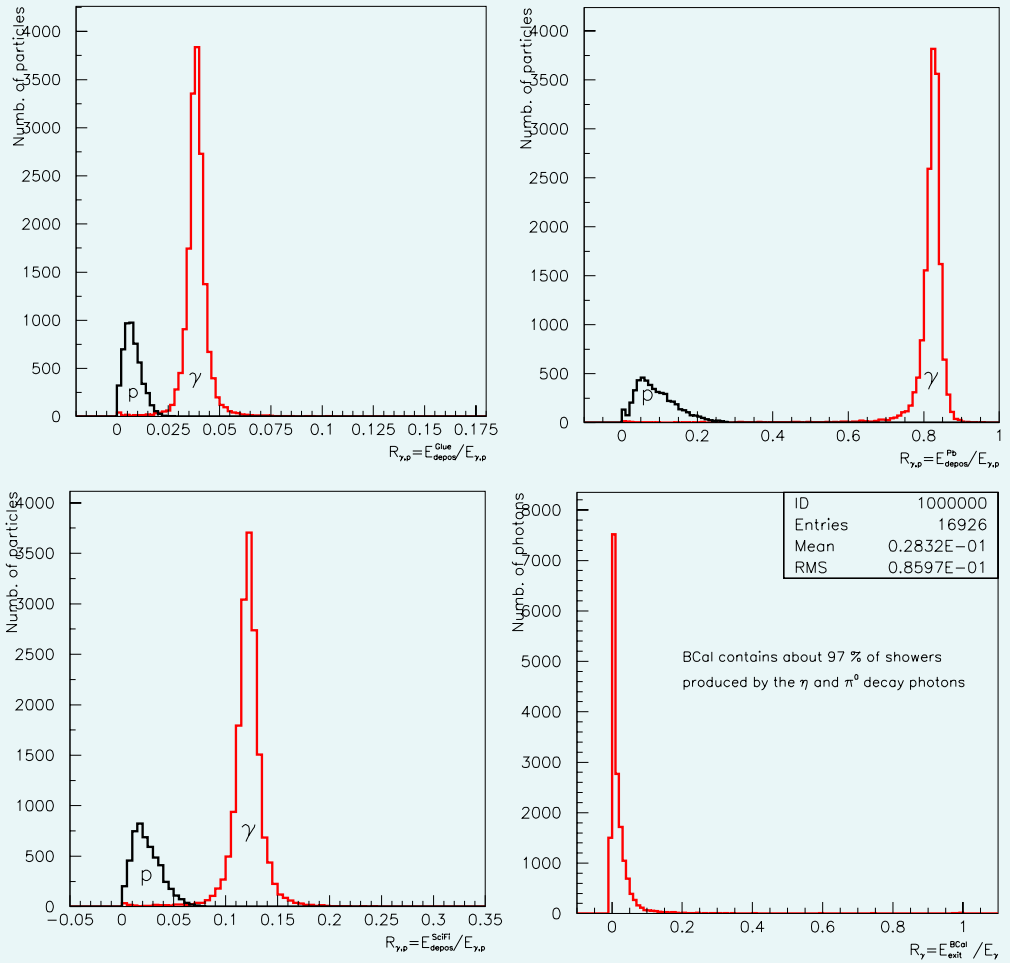
Reaction	E_γ *GeV*	σ (μb)	*Events*	*Ref.*
$\gamma p \to p\pi^+\pi^-$	9.3		3500	[Ba73]
$\gamma p \to p\pi^+\pi^-$	19.3		20908	[Ab94]
$\gamma p \to p\pi^+\pi^-\pi^\circ$	2.8		2159	[Ba73]
$\gamma p \to p\pi^+\pi^-\pi^\circ$	4.7		1606	[Ba73]
$\gamma p \to p\pi^+\pi^-\pi^\circ$	9.3		1195	[Ba73]
$\gamma p \to p\pi^+\pi^-\pi^\circ$	4.7–5.8	$13.5 \pm 1.5\,\mu b$	3001	[Ei72]
$\gamma p \to p\pi^+\pi^-\pi^\circ$	6.8–8.2	$11.8 \pm 1.2\,\mu b$	7297	[Ei72]
$\gamma p \to n\pi^+\pi^+\pi^-$	4.7–5.8	$4.6 \pm 1.4\,\mu b$	1723	[Ei72]
$\gamma p \to n\pi^+\pi^+\pi^-$	6.8–8.2	$4.0 \pm 1.2\,\mu b$	4401	[Ei72]
$\gamma p \to n\pi^+\pi^+\pi^-$	16.5–20		3781	[Co93]
$\gamma p \to p\pi^+\pi^-\pi^\circ$	20–70		14236	[At84]
$\gamma p \to p\pi^+\pi^-\pi^+\pi^-$	4–6	$4.0 \pm 0.5\,\mu b$	~ 330	[Da73]
$\gamma p \to p\pi^+\pi^-\pi^+\pi^-$	6–8	$4.8 \pm 0.5\,\mu b$	~ 470	[Da73]
$\gamma p \to p\pi^+\pi^-\pi^+\pi^-$	8–12	$4.5 \pm 0.6\,\mu b$	~ 470	[Da73]
$\gamma p \to p\pi^+\pi^-\pi^+\pi^-$	12–18	$4.4 \pm 0.6\,\mu b$	~ 380	[Da73]
$\gamma p \to p\pi^+\pi^-\pi^+\pi^-$	15–20		6468	[Ab85]
$\gamma p \to p\pi^+\pi^-\pi^\circ\pi^\circ$	20–70		8100	[At84a]
$\gamma p \to p\pi^+\pi^+\pi^-\pi^-\pi^\circ$	19.5		2553	[Bl97]
$\gamma p \to \Delta^{++}\pi^-\pi^+\pi^-$	4–6	$1.65 \pm 0.2\,\mu b$	~ 200	[Da73]
$\gamma p \to \Delta^{++}\pi^-\pi^+\pi^-$	6–8	$1.8 \pm 0.2\,\mu b$	~ 200	[Da73]
$\gamma p \to \Delta^{++}\pi^-\pi^+\pi^-$	8–12	$1.1 \pm 0.2\,\mu b$	~ 200	[Da73]
$\gamma p \to \Delta^{++}\pi^-\pi^+\pi^-$	12–18	$1.15 \pm 0.2\,\mu b$	~ 200	[Da73]
$\gamma p \to p\omega$	4.7–5.8	$2.3 \pm 0.4\,\mu b$	< 1600	[Ei72]
$\gamma p \to p\omega$	6.8–8.2	$2.0 \pm 0.3\,\mu b$	< 1200	[Ei72]
$\gamma p \to p\omega$	4.7	$3.0 \pm 0.3\,\mu b$	1354	[Ba73]
$\gamma p \to p\omega$	9.3	$1.9 \pm 0.3\,\mu b$	1377	[Ba73]
$\gamma p \to p\phi$	4.7	$0.41 \pm 0.09\,\mu b$	136	[Ba73]
$\gamma p \to p\phi$	9.3	$0.55 \pm 0.07\,\mu b$	224	[Ba73]
$\gamma p \to n a_2^+$	4.7–5.8	$1.7 \pm 0.9\,\mu b$		[Ei72]
$\gamma p \to n a_2^+$	6.8–8.2	$0.9 \pm 0.9\,\mu b$		[Ei72]
$\gamma p \to n a_2^+$	19.5	$0.29 \pm 0.06\,\mu b$	~ 100	[Co93]

The GlueX EM BCAL

BCAL contains ~97% of the showers produced by photons from the decay of η and π^0 in

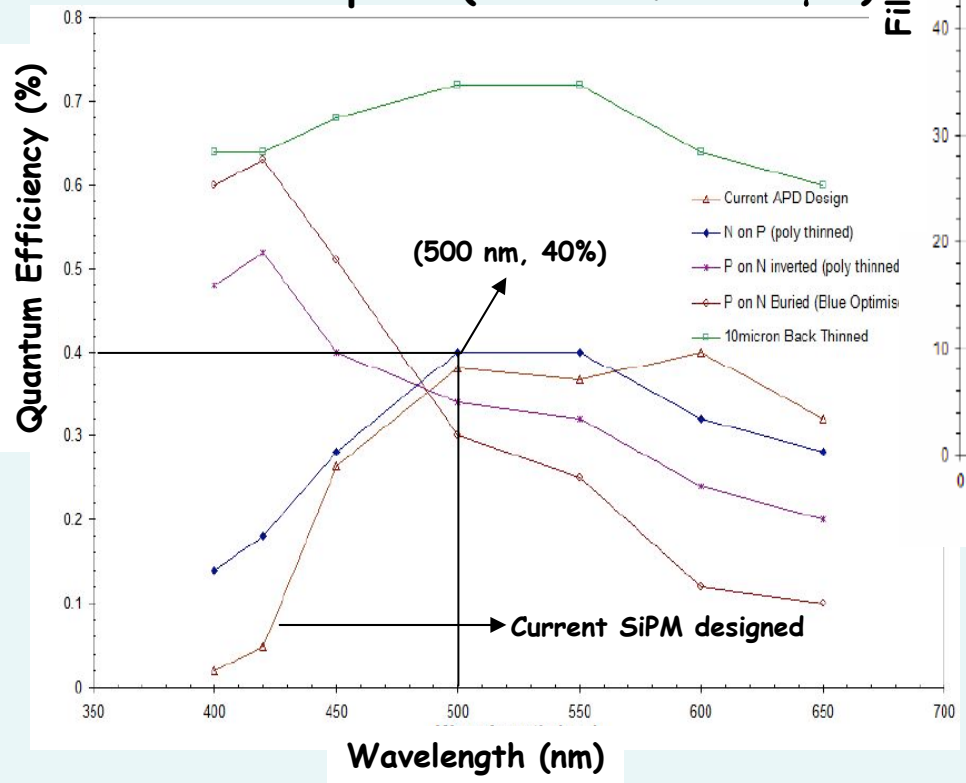
$$\gamma + p \rightarrow \eta + \pi^0 + p \rightarrow \gamma + \gamma + \gamma + \gamma + p$$

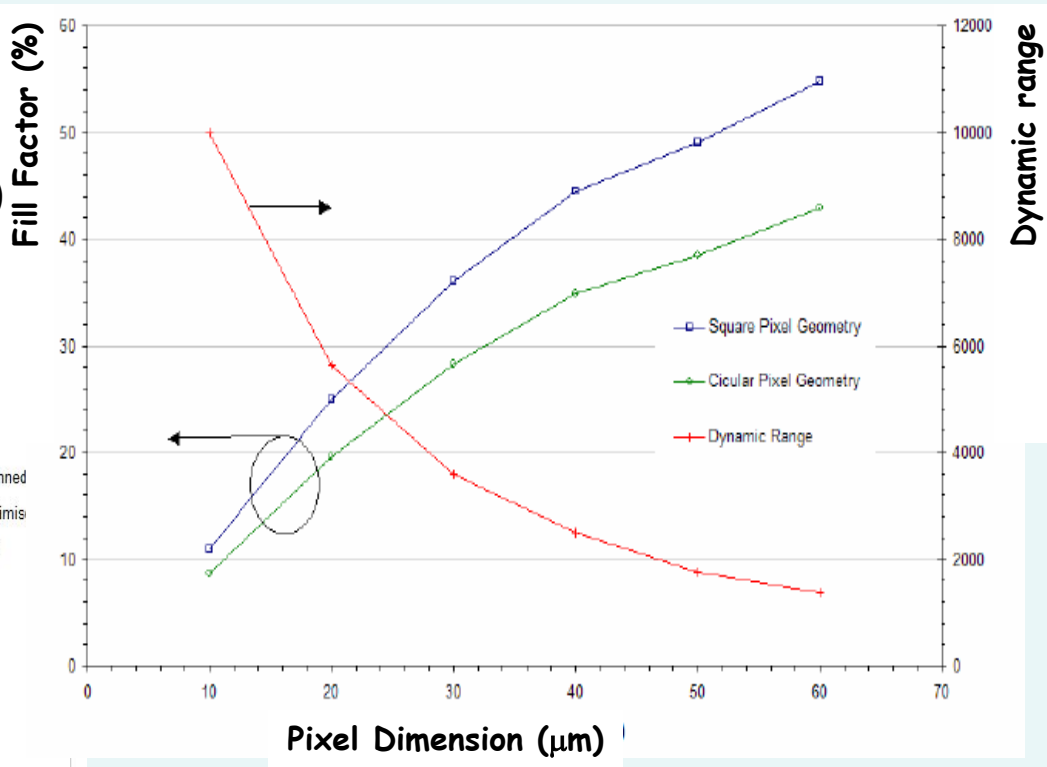




Ongoing SiPM Development for the GlueX EM BCAL (Phase 1)

- For a 3x3 mm^2 SiPM, with no optical trench, light sensitivity tuned to blue-green (can be further tuned to lower wavelength), and spacing between pixels of 20 μm (can also be improved):
- Gain is ~10^6, rise time ~3 ns
- 1500 (50 μm) pixels; dark rate ~2 kHz/pixel (200 Hz for 20 μm)





QE = Avalanche probability × Photon absorption probability

- 1 P.E. corresponds to ~ 13 KeV energy deposition in a 2 cm x 2 cm read-out cell with SM.

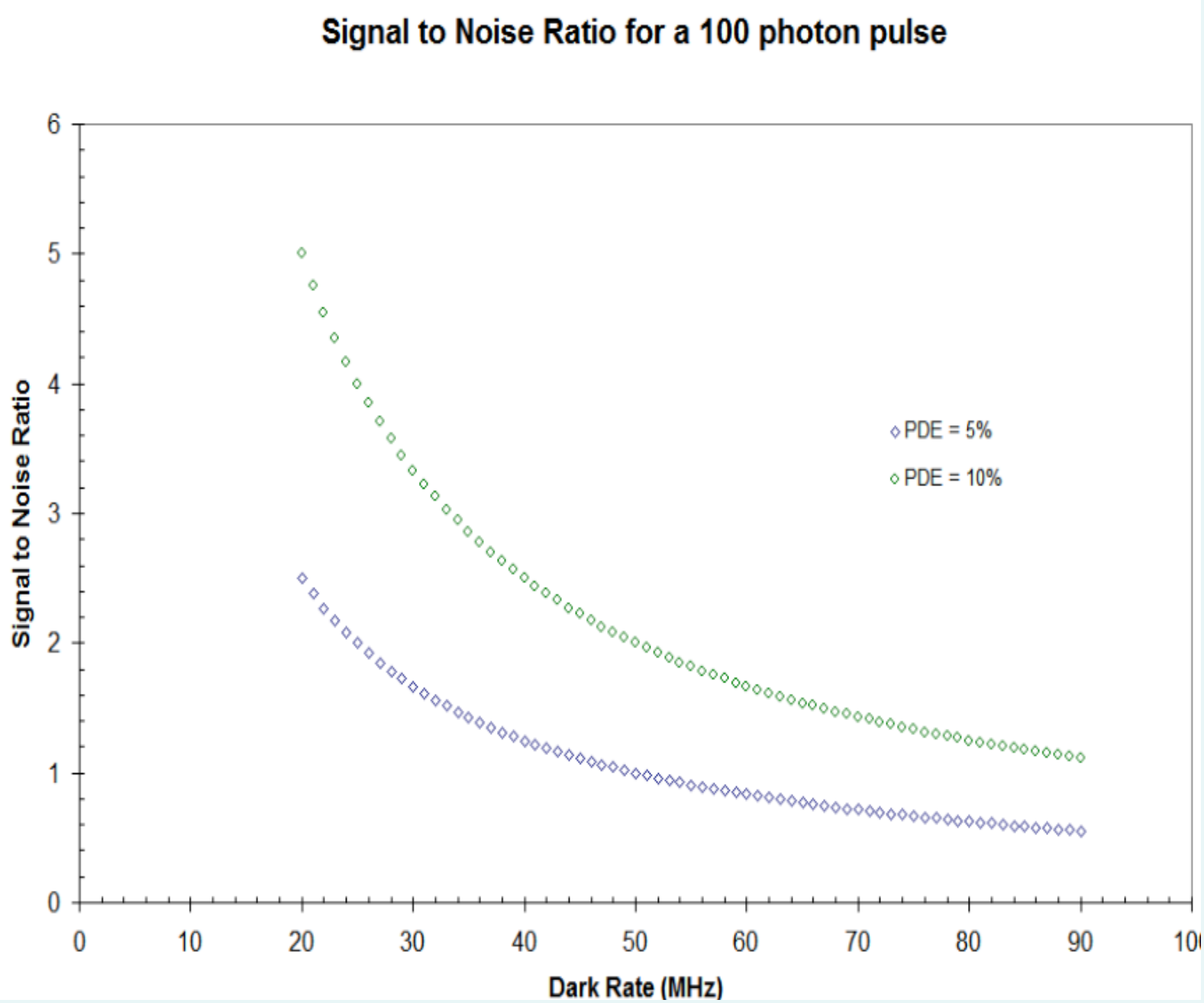
- For a 250 MeV γ, we get ~ 11,000 photons x .2 PDE = ~ 2,200 P.E.'s/side.

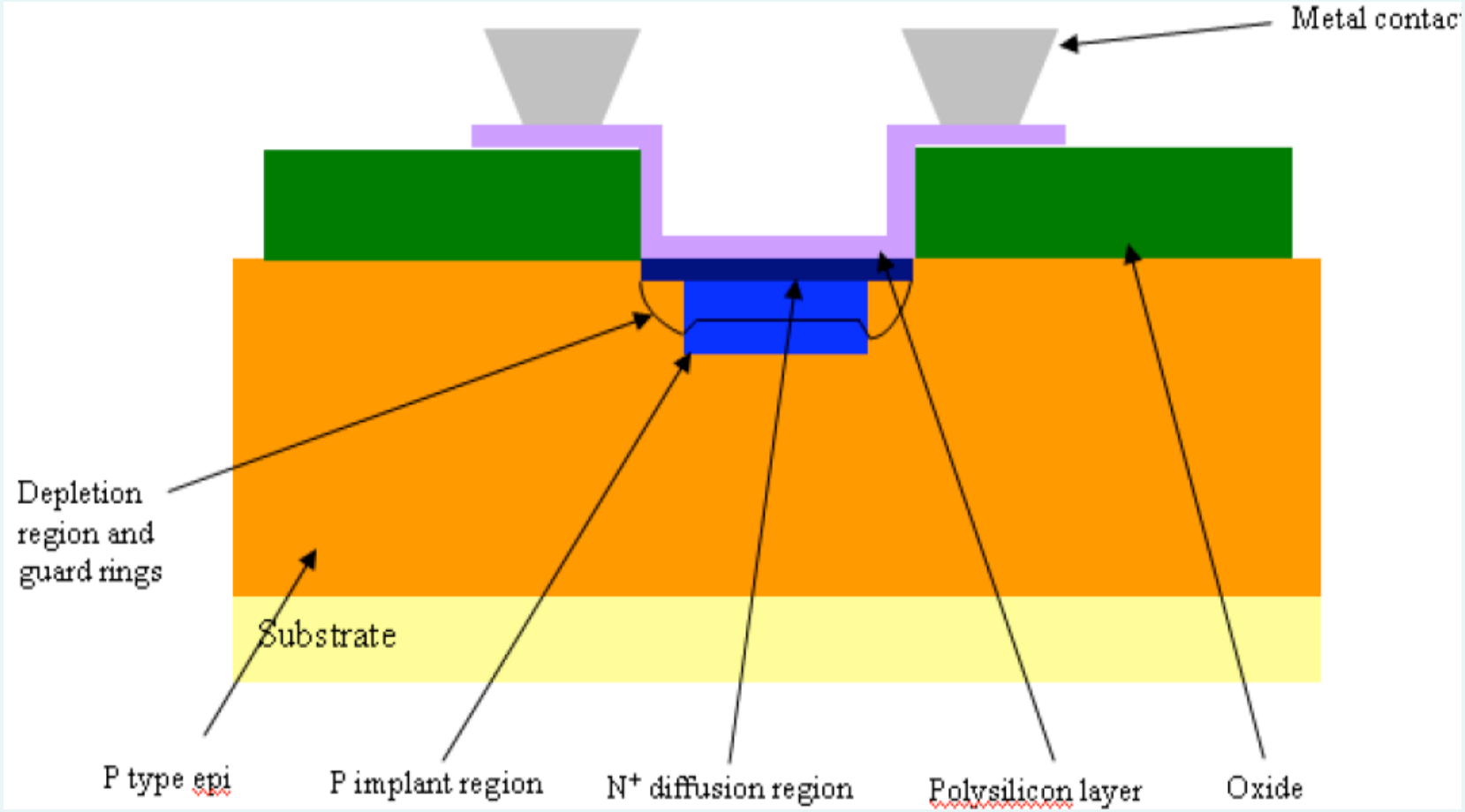
- With 5 MHz dark rate at the 1 P.E. level, by assuming that 30 SM's exceed the threshold and a 100 ns coincidence gate, we expect 15 P.E.'s added due to dark counts.

- This adds a noise contribution of ~ 200 keV to a deposited energy of 30 MeV in the SciFi's at 250 MeV incident photon energy. Hardly a problem.

The Phase 1 specifications for the SPM sensor modules based on correspondence with GlueX are as follows:

- 32 Sensor Modules/Winston Cones per SciFi Module per side
- 48 SciFi Modules in Complete System
- Peak wavelength = 490nm
- Rise time [4-5ns]
- Dark Rates – 200Hz per pixel - cooling maybe required.
- Dynamic Range ~1000 (few MeV to a few GeV)
- Decay times [10-20ns]
- Linearity defined by the number of pixels; <1000 pixels.
- High Gain $>10^5$
- Summing Amp board with variable gain 1, 10, 25.
- Resolution: A 1pe resolution seen as ideal but not strictly necessary
- Array area > $0.7cm^2$ and <$1.5cm^2$
- Protective windows: we do not need quartz; glob-top with antireflective coating
- Preamps: external for Phase 1 with computer control via a slow bus (USB 2.0); SensL will provide a GUI and a DLL for control via Windows laptop
- Summing amplifier - no pulse shaper/discriminator.
- Gain: three settings for Phase 1: 1x, 10x and 25x via a jumper.
- Electronics compatibility (Phase 1): analog signal from -0.5 to -1.0V, with a Lemo connector for the signal and simple wires for connection to the Bias supply and RF-shielded solder


Signal to Noise Ratio for a 100 photon pulse
Signal to Noise Ratio
Dark Rate (MHz)
PDE = 5%
PDE = 10%
0
1
2
3
4
5
6
0
10
20
30
40
50
60
70
80
90


Metal contac
Depletion
region and
guard rings
Substrate
P type epi
P implant region
N+ diffusion region
Polysilicon layer
Oxide