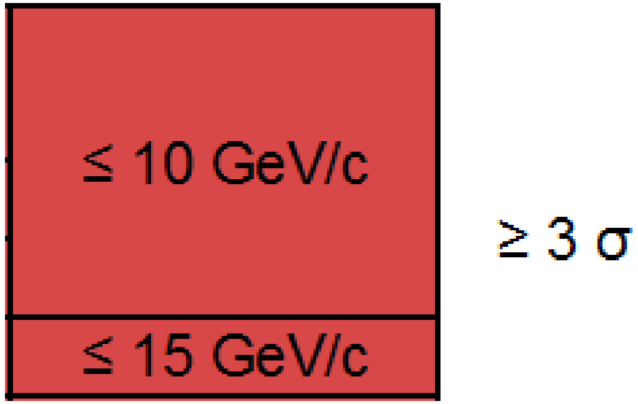


Goal: Investigate the feasibility of a Barrel RICH detector for pi/k separation beyond 10 GeV/c, as well as eID up to 4 GeV/c.

EIC Barrel RICH

Henry Klest and Tom Hemmick

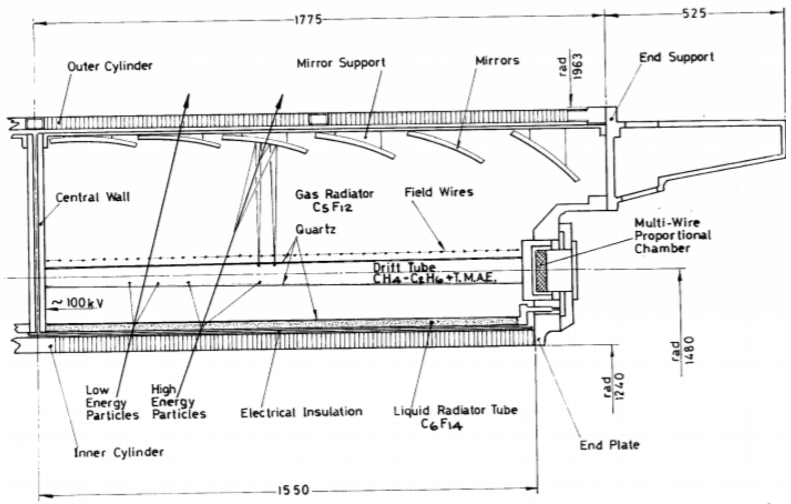
DISCLAIMER: Many things in this talk are speculative and depend on further R&D.

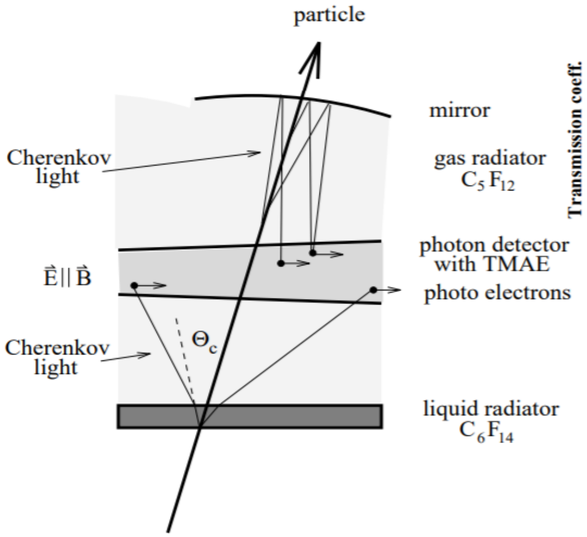
Stony Brook University

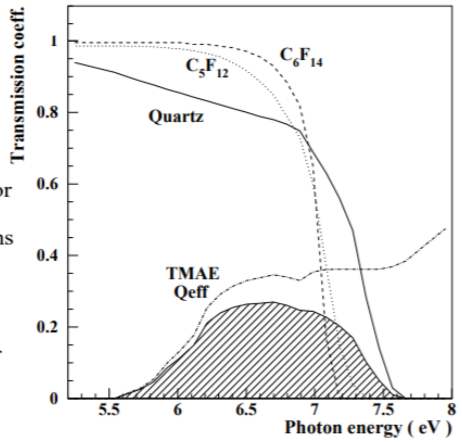
DELPHI Barrel RICH

- DELPHI had a dual-radiator RICH w/ C6F14 liquid and C5F12 gas in a 1.2T solenoid and it provided a modest level of probabilistic pi/k separation up to ~12 GeV/c or so. Gas radiator used focusing, liquid did not.
- Designed in the early ‘80s before many modern detector technologies. Their RICH was readout by a 4.2 cm thick TPC laced with TMAE gas. Gas radiator was 42 cm.
- It was a very complicated design and had many engineering issues that impacted the performance.

This detector had: 3 separate fluid control systems, heating elements to keep C5F12 at 40 degrees C, two field cages, a MWPC with blinders, a 150 kV cathode, nine quartz windows, and TMAE mixed in the TPC drift gas.



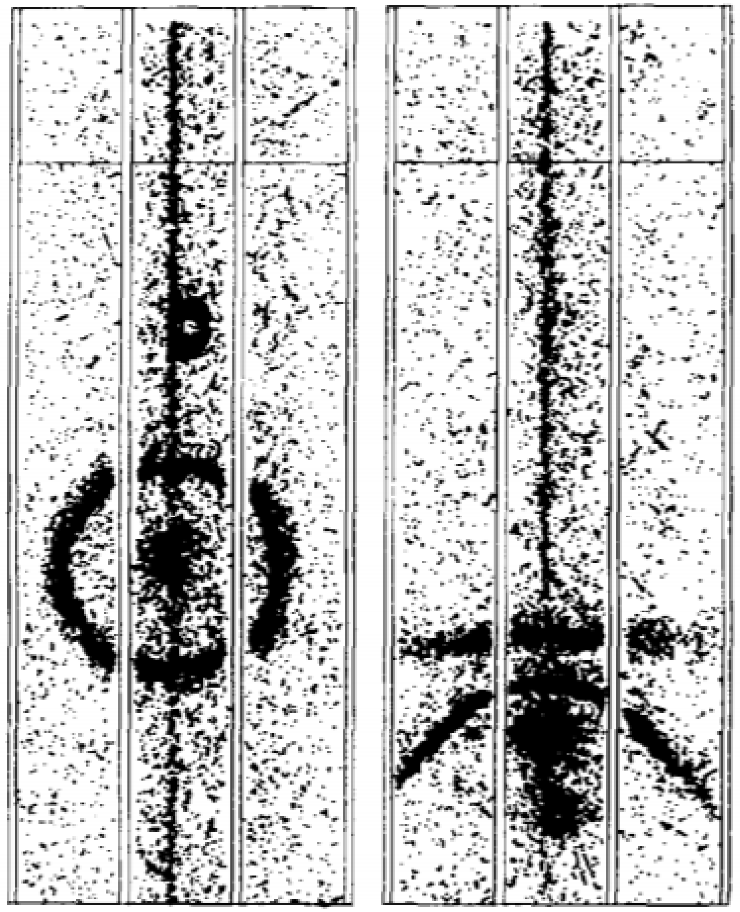




DELPHI serves only as a proof of principle that a Barrel RICH can be a feasible detector, nothing from this design other than geometry would be wanted at EIC

DELPHI Barrel RICH

- TPC readout introduced a lot of issues.
  - Hard to reconstruct Z-position precisely due to large time binning w.r.t drift velocity.
    - Lost electrons and resolution at large drift distance to field non-uniformities and diffusion.
  - Conversion point of photon arbitrary in R.
  - Only phi coordinate of a photon could be measured precisely, but rings smeared in phi due to bending in B-field.
  - Ionization trail, delta rays, electronic noise, crosstalk, after-pulses, photon feedback, all easily confused with ring photons signal/background ratio only .34
- Photodetection and pattern recognition have improved significantly since LEP.

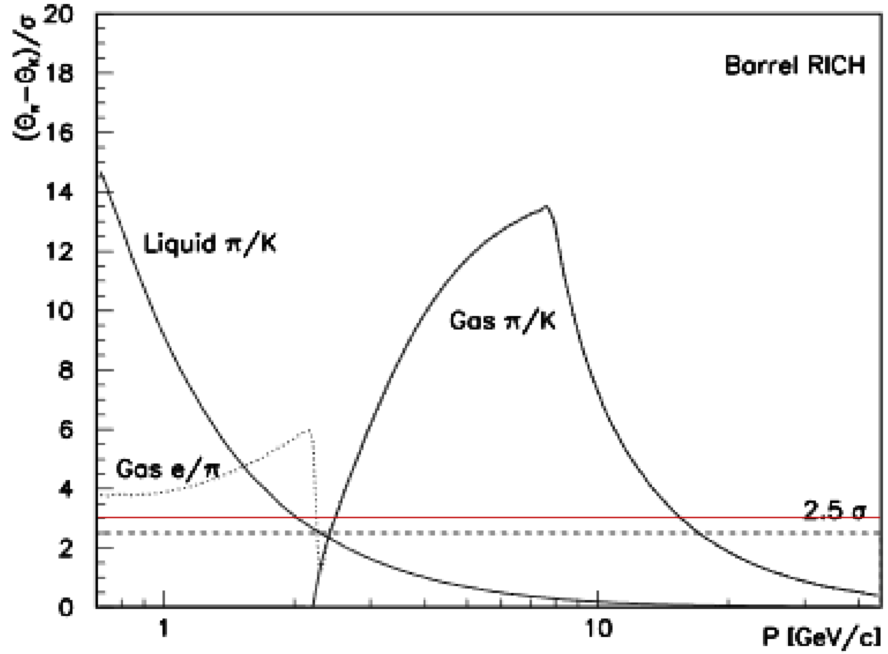


(a) (b)

Fig. 13. Scatter plots (x, t) over the full length of the drift volumes, obtained in the ungated mode by 200 superimposed images of 10 GeV/c pions, for (a) normal beam incidence $\theta_b = 0°$, $z_d = 85.8$ cm, (b) $\theta_b = 24°7$, $z_d = 35$ cm. A net parasitic background line is visible at the x position of the beam spots, essentially composed of single asynchronous electrons.

Note the dotted line is at 2.5σ, but we want 3.

Would prefer to make something simpler to analyze, if possible. Impetus for a barrel RICH is high Q^2 events, which require high statistics. The sooner the detector is understood and ready for physics the better.



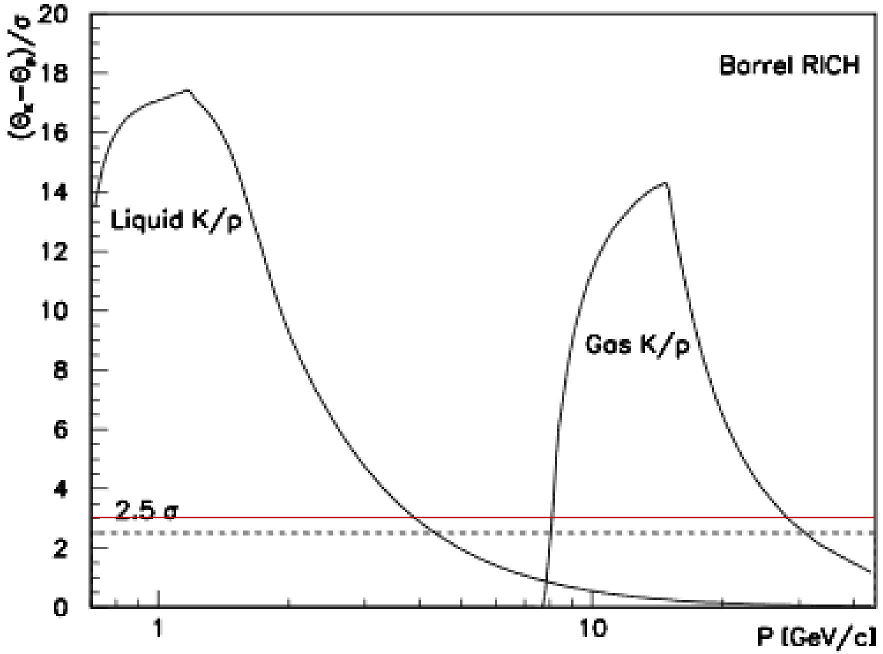
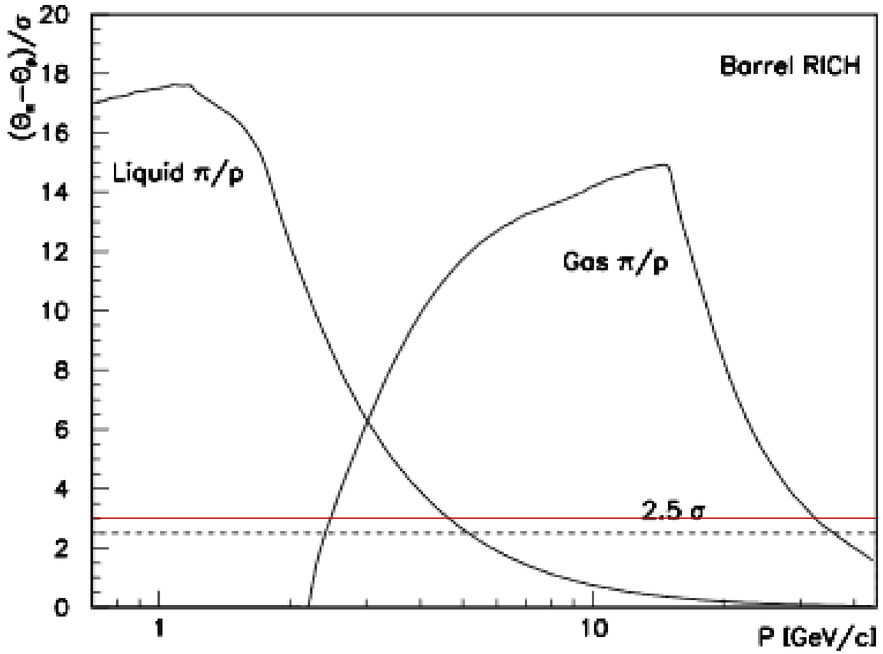
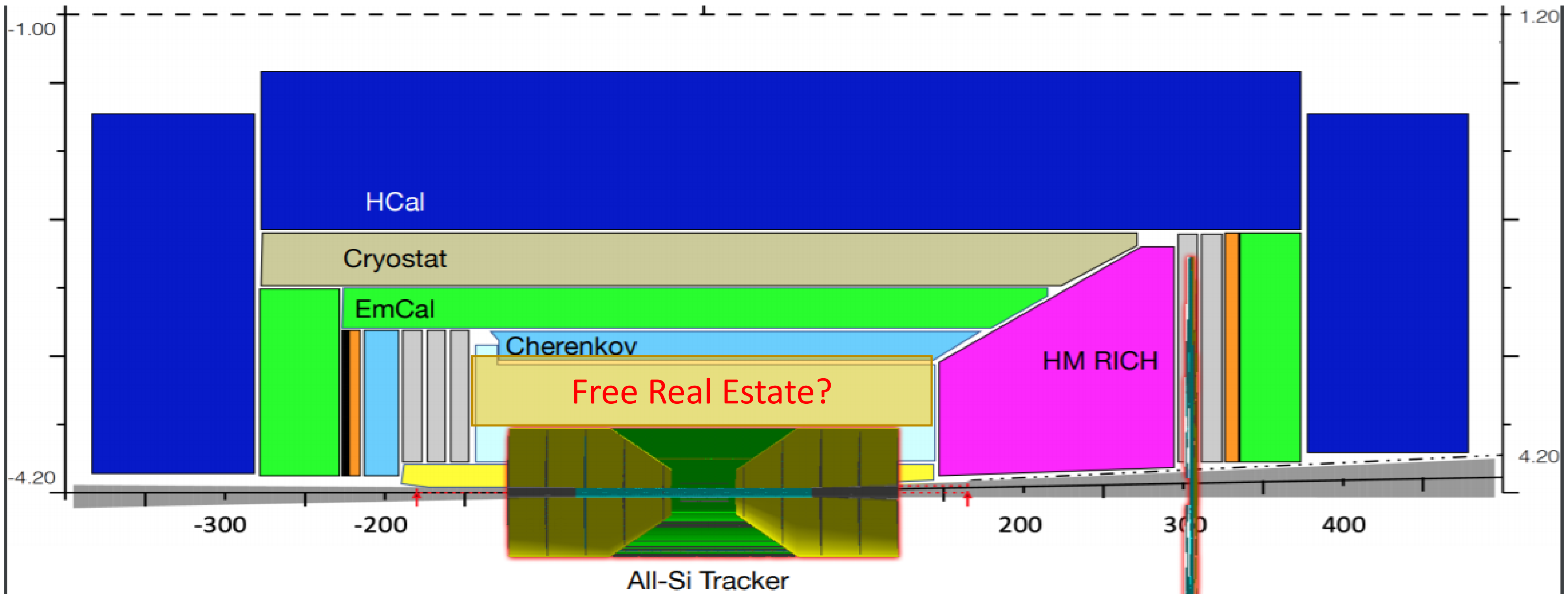


Figure 6.22: The $\pi^\pm/K^\pm$, $K^\pm/p\bar{p}$ and $\pi^\pm/p\bar{p}$ separation for reconstructed rings in the BRICH liquid and gas radiator. The dashed lines indicate the 2.5 standard deviations limit. The dotted line in the top-left plot shows the $e^\pm/\pi^\pm$ separation for momenta below the theoretical pion threshold in the gas radiator.



"PID with the DELPHI RICH" Dissertation, Emile Schyns

Detector cartoon from Rey Cruz-Torres (LBNL)



The compact all-silicon design has enough space for a RICH in the barrel. The question is what kind of a design can accomplish > 15 GeV/c pi/k separation with the tracks bending in the magnetic field.

In principle, a short O(40 cm) RICH could also be shoehorned into sPHENIX-like design if inner HCal is removed and EMCal is backed up to magnet.

Ingredients/Considerations for a Barrel RICH*

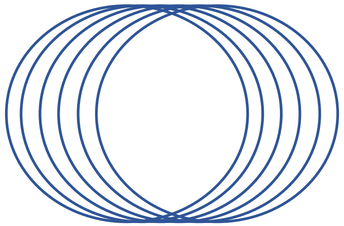
Ingredient	DELPHI	EIC, as considered in this presentation
1. Magnetic Field	1.2T	1.5T or 3T
2. Space	42 cm (gas)	~40-50 cm
3. Photodetector	TMAE TPC + MWPC	CsI MPGD or SiPM
4. Dark Rate/Background	Ionization trail from particle tracks in TPC	SiPM dark rate
5. Radiator	C5F12 @ 40°C	C4F10 or C3F8, pressurized and/or cooled.

*Not an exhaustive list. These represent only the considerations currently implemented in our fast simulation.

Limitations

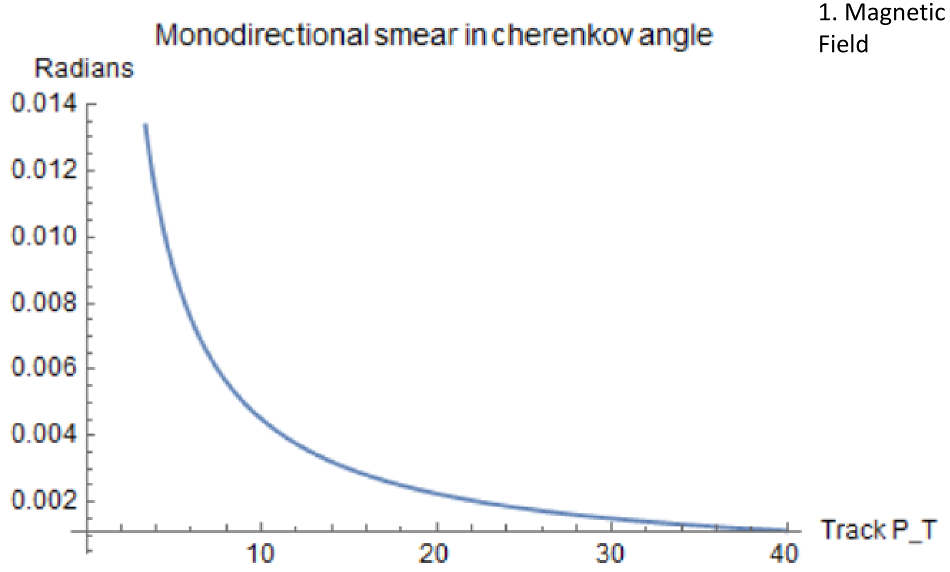
Ingredient	Known limitations	Possible solution
1. Magnetic Field	Larger bending of tracks in larger field means greater smearing of a ring. Strongly affects many photodetectors.	Decrease length of radiator
2. Space	Short radiator will produce fewer photons	Pressurize gas
3. Photodetector	B-field tolerance, SiPM Dark rate, crosstalk, and rad hardness	Change temperature/voltage, Needs further R&D
4. Radiator	Needs to have high momentum reach and produce enough photons	Heavy gas, pressurized
5. Dark Rate/Background	SiPM dark rate is large, scintillation spectra in the visible unknown	Needs further R&D
6. Low momentum	Needs to be supplemented by low momentum PID	DIRC, dE/dx, ToF? DIRC preferable to minimize gaps in positive pi/k separation

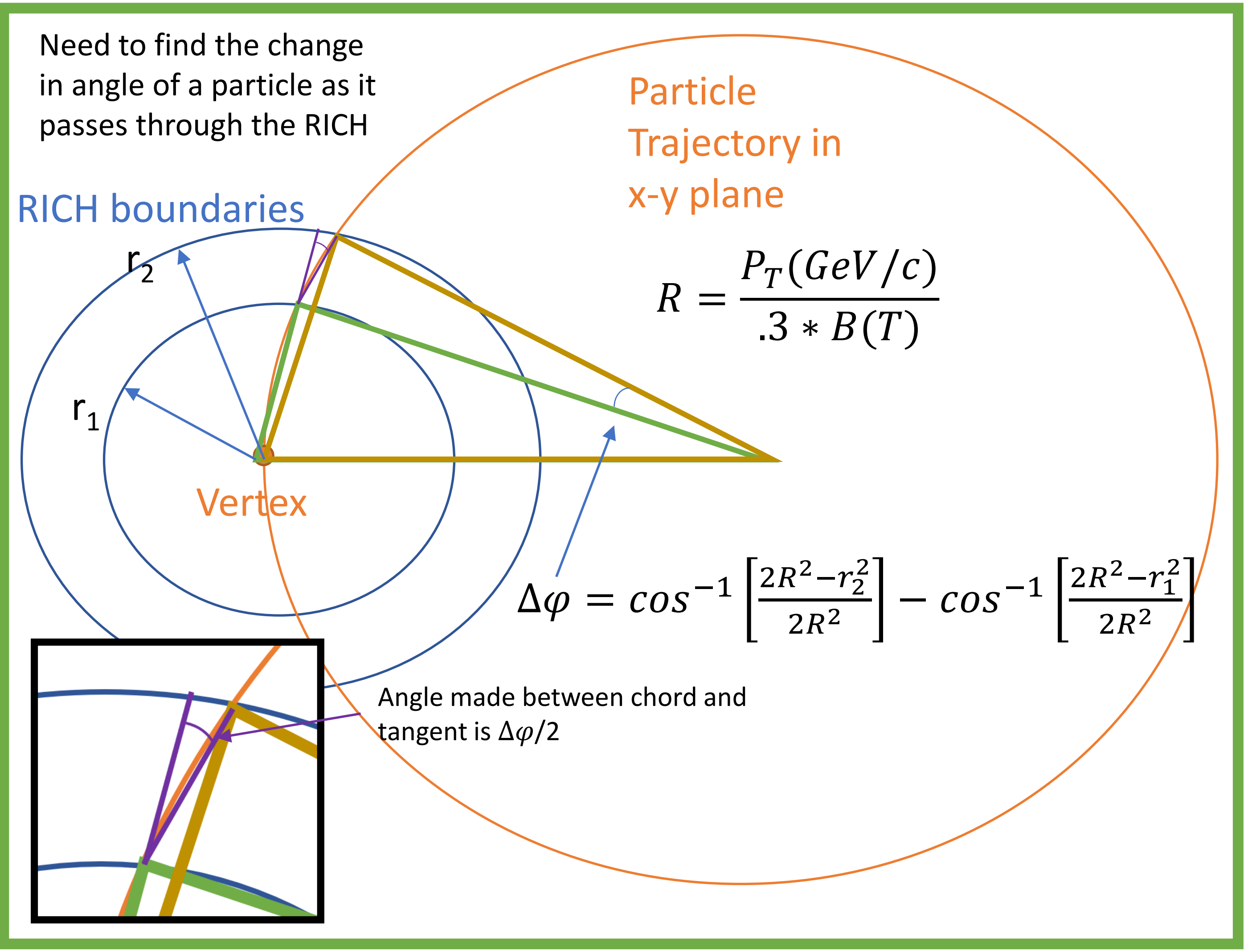
Bending Geometry



Toy model of how Cherenkov rings will look on the detector plane. Approximated in MC as a uniform distribution ranging from 0 to $\Delta\varphi/2$, multiplied by $\cos(\theta_c)$

1. Magnetic Field

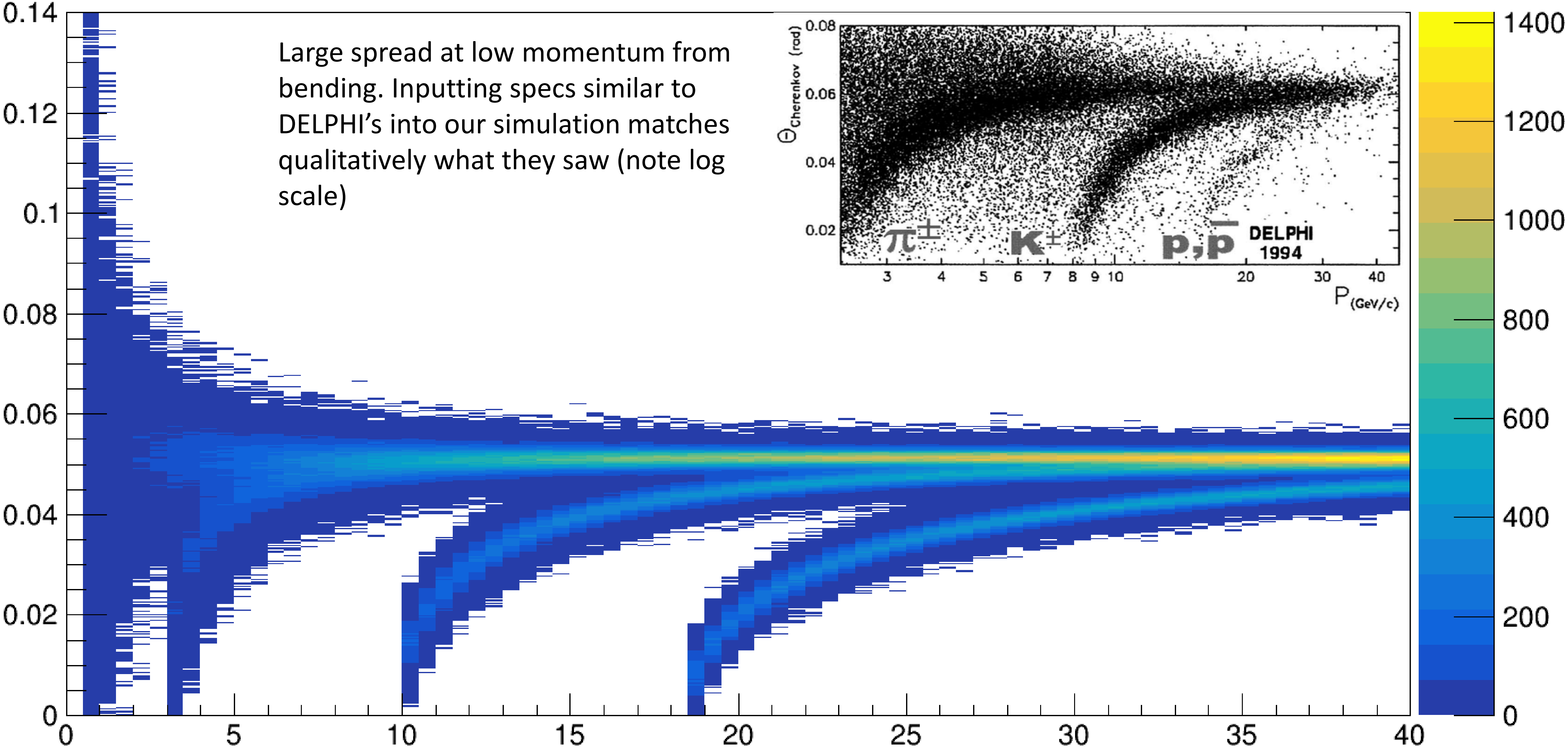




Momentum (GeV)	Smear over 20 cm radiator length in 1.5 T (mrad)
1.5	30
3	15
5	9
7	6.4
10	4.5
15	3
20	2.25
25	1.8

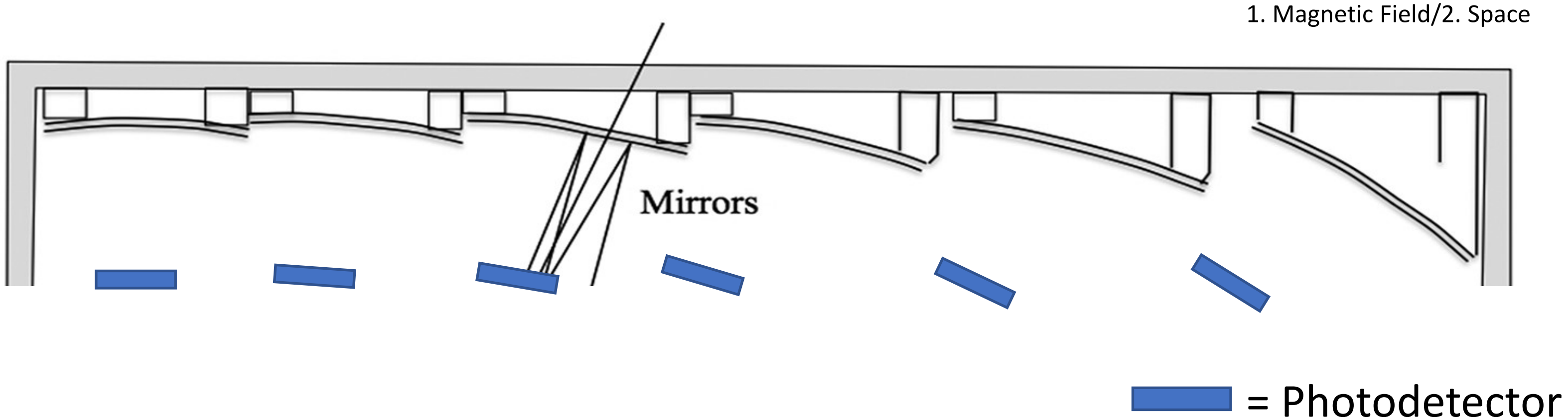
Note that this smear is applied only to one axis of the ring. Simulation assumes $P_T = P$.
θ_c at saturation in 3 Bar C3F8 is 80 mrad.

ThetaC vs. P



Large spread at low momentum from bending. Inputting specs similar to DELPHI's into our simulation matches qualitatively what they saw (note log scale)

Nominal design in Simulation



- Need to make best possible use of radial space, need to know how compact this can be and still get enough photons.
  - Greater length means greater bending of a track.
    - Thus the “Normal” RICH strategy of increasing radiator length is less efficient
  - Pressurizing a heavy gas is a good option
    - Note that this is necessary both to get enough photons, as well as getting the kaon threshold close to the DIRC 3-sigma k/pi separation momentum of ~6 GeV/c to provide consistent positive PID at all momenta up to 15 GeV/c
  - Also note that radiator length increases slightly with increasing |η|, all lengths quoted for η = 0.
- Silicon tracker gives excellent pointing resolution into RICH
- Lower B-field and length is better, decreased $\int B \cdot dl$
  - This brings about a radical idea from Tom

Two of them!

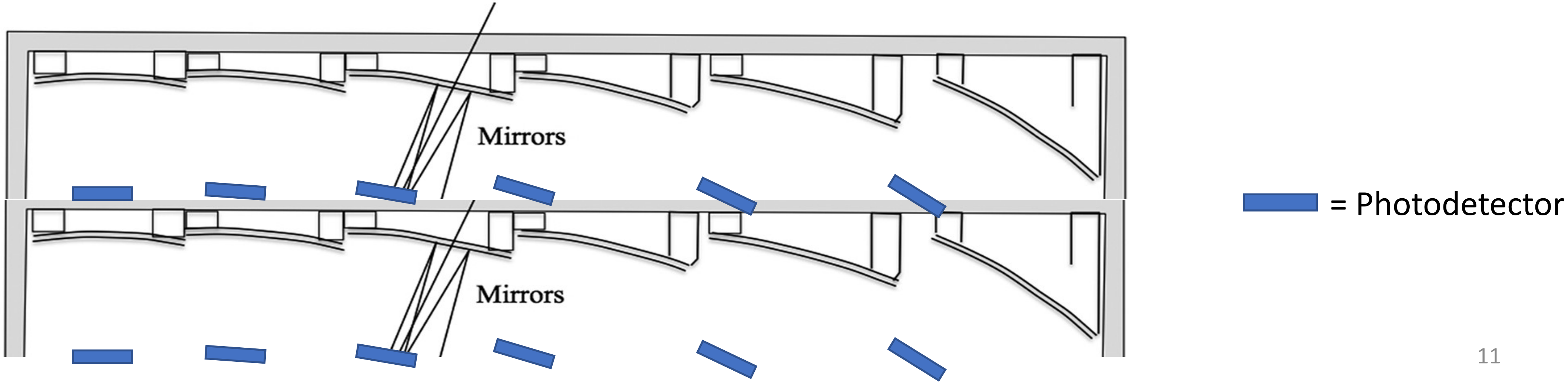
Cutting length in half improves bending resolution contribution by a factor of 2.

Can share a gas volume, provide 2 independent measurements of radius if you can get enough photons.

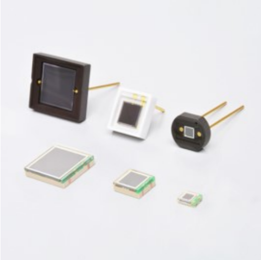
With pressurized gas, could get enough photons in ~20 cm.

Downside: more mirrors and more photodetectors = more $$$

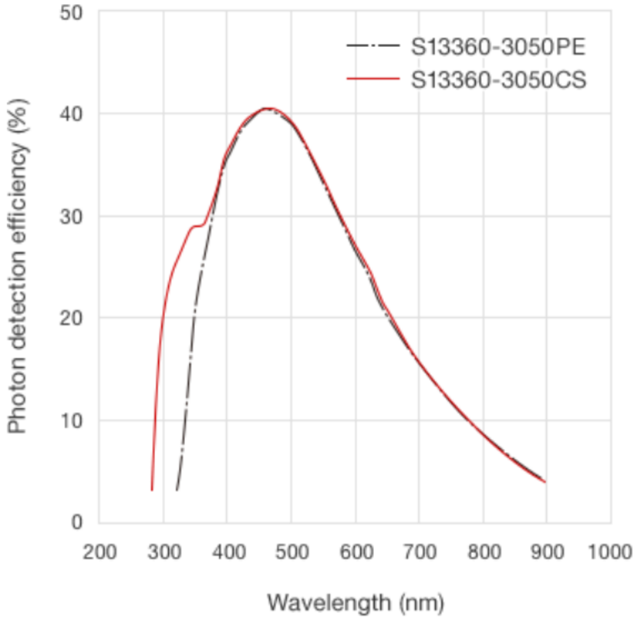
Impact of having 2 layers not in simulation, all results shown are for a single layer only.



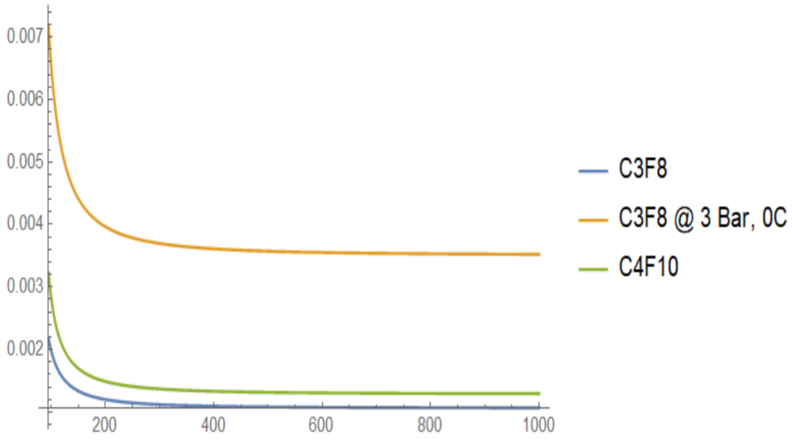
Photodetectors



- Only B-resistant technologies will operate in an optimal geometry (spherical mirrors w/ sensors pointed outwards) in the barrel.
  - SiPMs are the primary choice considered here, but photocathode-coated MPGDs are a possible alternative if SiPMs are deemed infeasible.
- SiPMs benefit hugely from operating in the visible range, all gases are transparent and have negligible chromatic dispersion, less perfluorocarbon scintillation.
- Beating down dark counts in SiPMs will be a formidable task.
  - Temperature, time resolution
- UV photocathode coated MPGDs are also possible, but aren't considered yet because of lack of accessible data on C3F8 gas.
  - In C4F10, transparency of gas in UV is too low. Needs to be measured for C3F8.
  - Low total photon yield, will need to reject track ionization as much as possible.
  - Pressurizing heavy gases exacerbates chromaticity, likely to be leading resolution term.

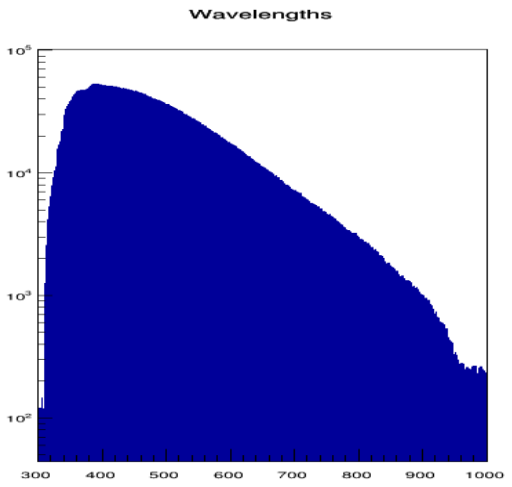


Sample SiPM Photon detection efficiency

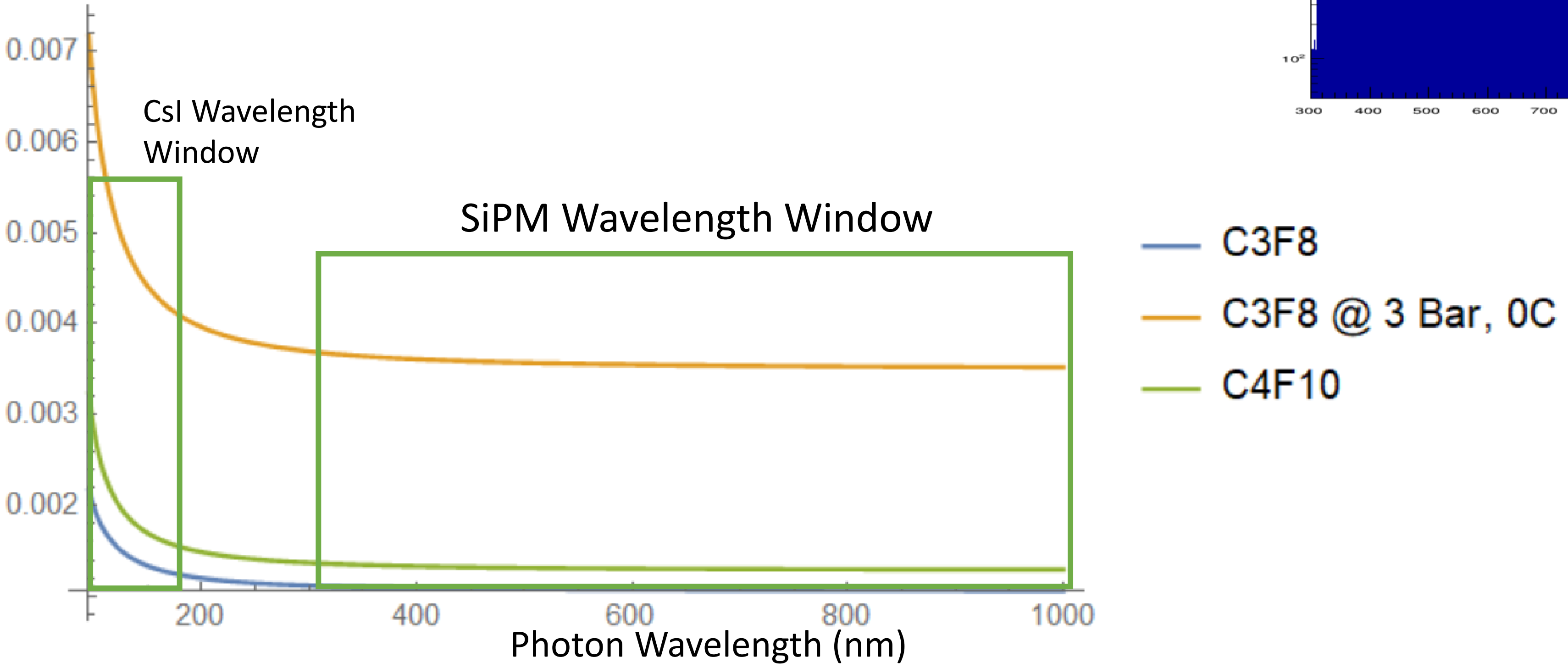


Perflourocarbon gas parameters from “VUV Absorbing Vapours in n-Perfluorocarbons.” publication, https://cds.cern.ch/record/600182/files/ep-2002-099.pdf

SiPM detected photon wavelength (note log scale)



Index of Refraction, n-1

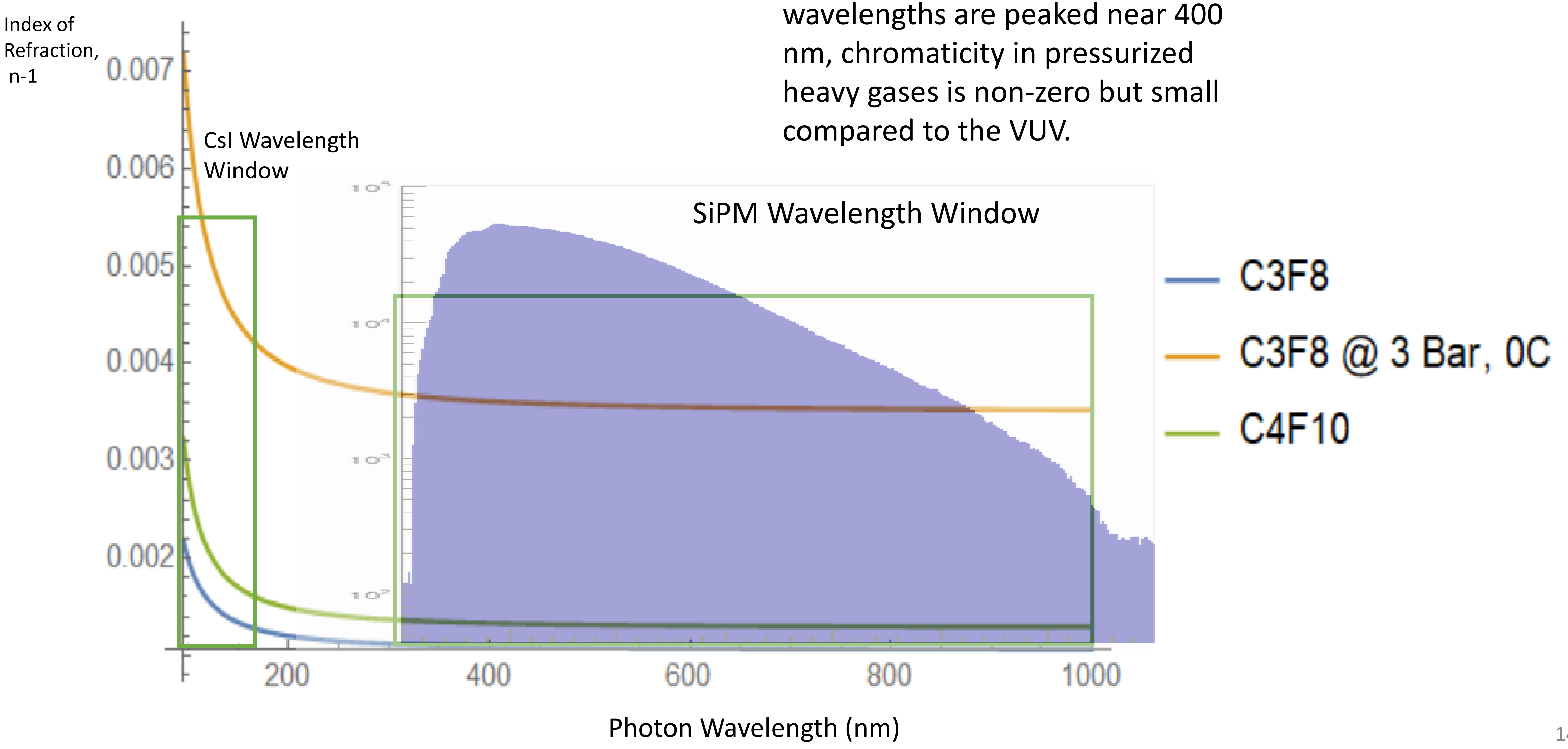


Chromatic dispersion increases with pressure, mainly affecting the UV. Pressurizing to increase N_{pe} in the VUV region therefore degrades resolution, especially in heavy gases.

C4F10 becomes opaque around 150 nm, CsI has QE out beyond 150, but not enough photons in this region in 50 cm or less of radiator. If pressurized C3F8 has transparency out to 130 nm or so, could be viable.

Perflourocarbon gas parameters from “VUV Absorbing Vapours in n-Perfluorocarbons.” publication, https://cds.cern.ch/record/600182/files/ep-2002-099.pdf

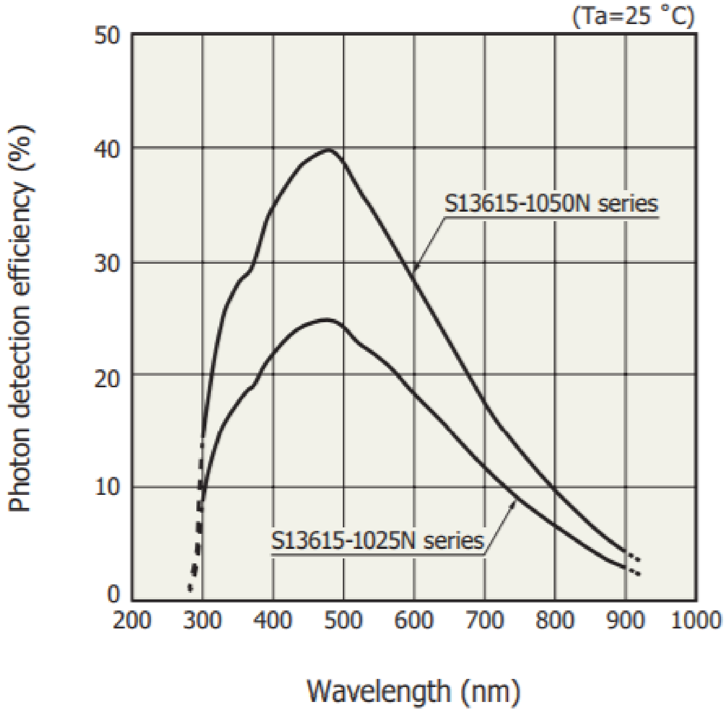
Note that SiPM detected wavelengths are peaked near 400 nm, chromaticity in pressurized heavy gases is non-zero but small compared to the VUV.



Hamamatsu SiPM Info

- Latest and greatest is the new TSV (Through-Silicon Via) S13615 series.
  - 1x1 mm channels with a high fill factor and PDE, also a dark rate that's very low compared to predecessors at STP.
  - High packing efficiency is also possible.
- PDE of this model assumed in simulation.

3. Photodetectors

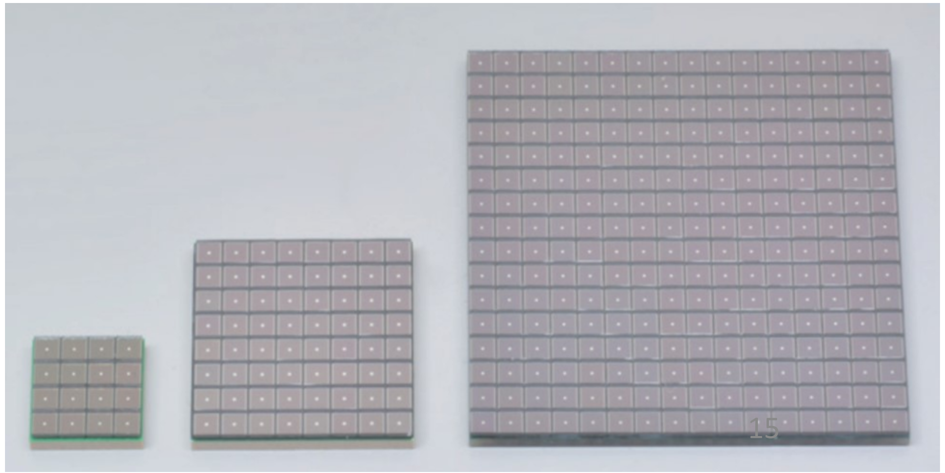


Structure

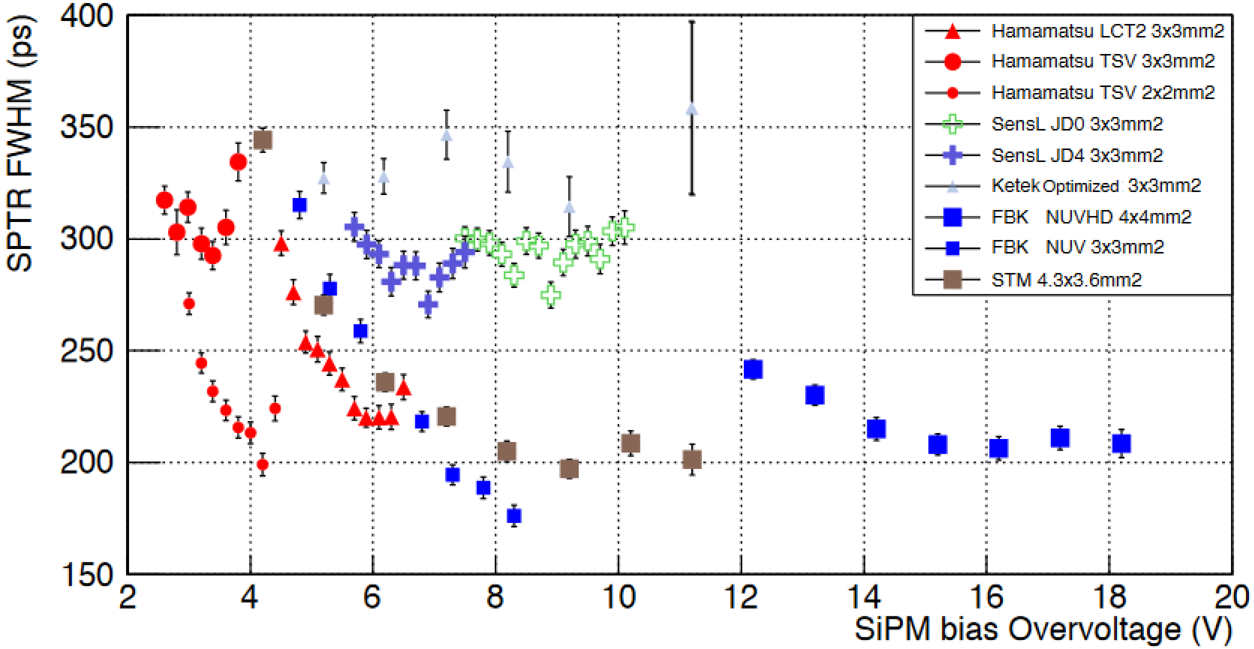
Type no.	Number of channels	Effective photosensitive area/ch (mm)	Pixel pitch (μm)	Number of pixels/ch	Fill factor (%)	Package	Window material	Refractive index of window material
S13615-1025N-04	4 × 4	1.0 × 1.0	25	1584	47	Surface mount type	Glass	1.51
S13615-1025N-08	8 × 8							
S13615-1025N-16	16 × 16							
S13615-1050N-04	4 × 4		50	396	74			
S13615-1050N-08	8 × 8							
S13615-1050N-16	16 × 16							

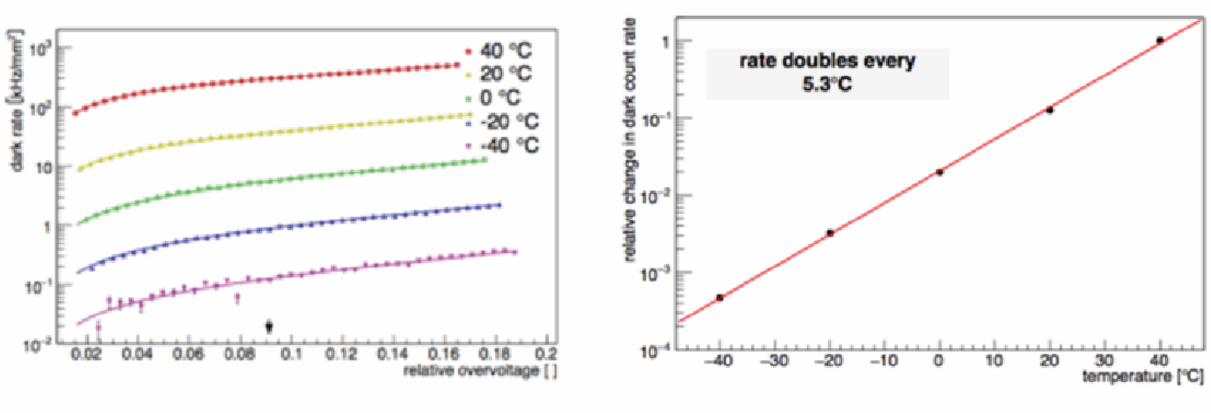
Electrical and optical characteristics (Typ. Ta=25 °C, unless otherwise noted)

Type no.	Spectral response range λ (nm)	Spectral response range λp (nm)	Photon detection efficiency PDE λ=λp (%)	Dark count (kcps) Typ.	Dark count (kcps) Max.	Crosstalk probability (%)	Terminal capacitance Ct (pF)	Gain M	Breakdown voltage VBR (V)	Recommended operating voltage Vop (V)	Operating voltage fluctuation between channels (V) Typ.	Operating voltage fluctuation between channels (V) Max.	Recommended operating voltage temperature coefficient ΔTVop (mV/°C)
S13615-1025N series	300 to 900	450	25	90	270	3	40	7.0×10^5	53 ± 5	VBR + 5	±0.05	±0.15	54
S13615-1050N series			40			10		1.7×10^6		VBR + 3			



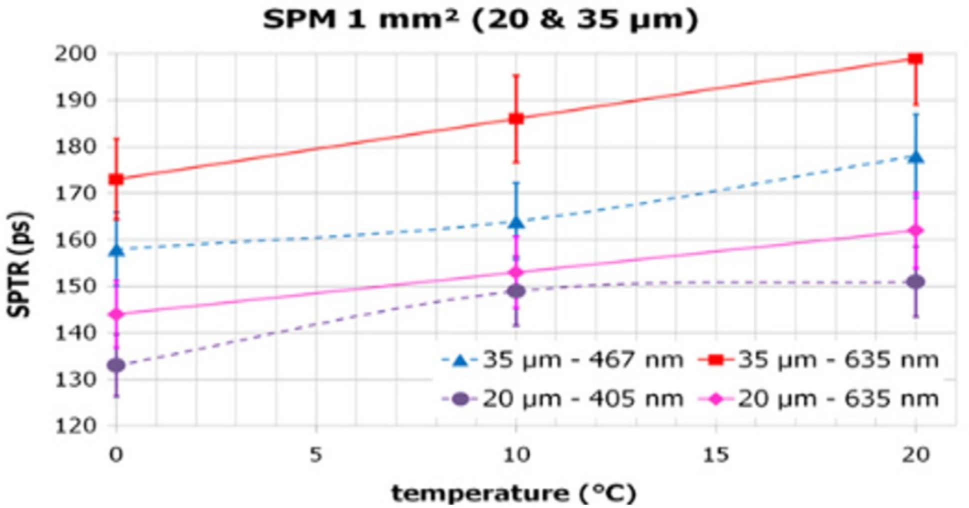
Timing





Dark rate decreases and time resolution improves at lower temperatures, so having the ability to cool the SiPMs is a must. At 0° C, DCR of S13615 could be as low as 6 kHz when new. 100 kHz is assumed in baseline simulation.

Fast, time-digitizing electronics are a must to beat DCR. By shrinking the time window during which hits are accepted, one can reject most dark hits.



In literature, time resolution of 80 ps has been achieved, Hamamatsu TSV has been tested and shown 100 ps performance

Radiation Damage

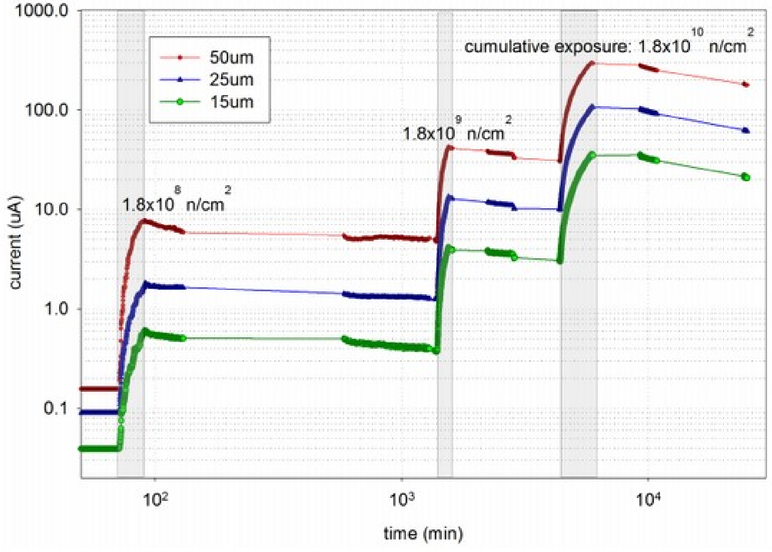


Fig. 6. Sequence of irradiations for Hamamatsu 15-, 25-, and 50-pixel devices up to 1.8×10^{10} n/cm^2 at the BNL SSGRIF at a flux of 10^5 n/cm^2/s. Currents were measured at the manufacturers' recommended operating voltage for each device listed in Table I.

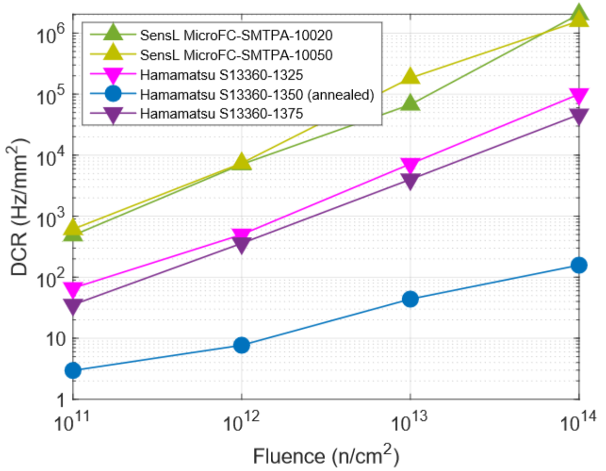
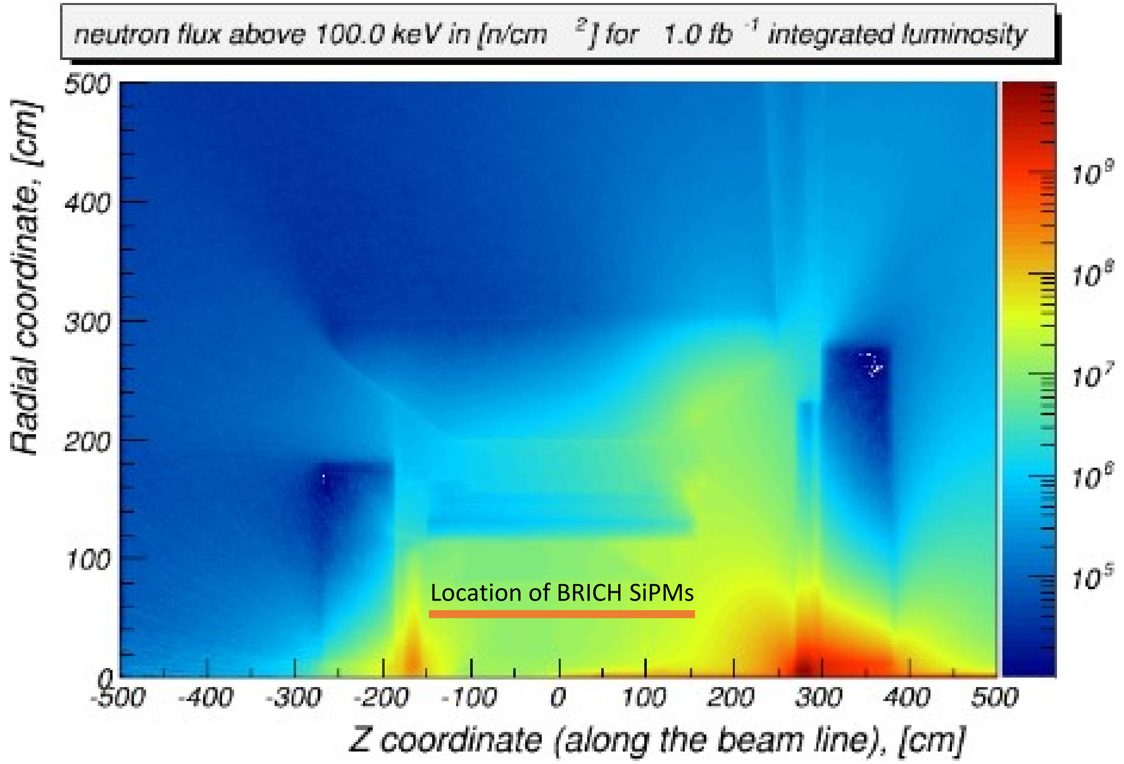


Figure 12: DCR at 77 K versus neutron fluence for all irradiated devices.



Irradiation with neutrons and protons introduces defects in the silicon that can produce energy levels in the band gap.

Dark current increases roughly proportional to neutron dose.

At possible location of SiPMs, ~3 to ~5x10^7 n/cm^2 per fb^{-1} according to preliminary studies.

Annealing has shown promise in reducing DCR, changing temperature and voltage reactively can also help combat increases in DCR due to irradiation. A large R&D effort from the world community is underway.

Dark Rate in Simulation

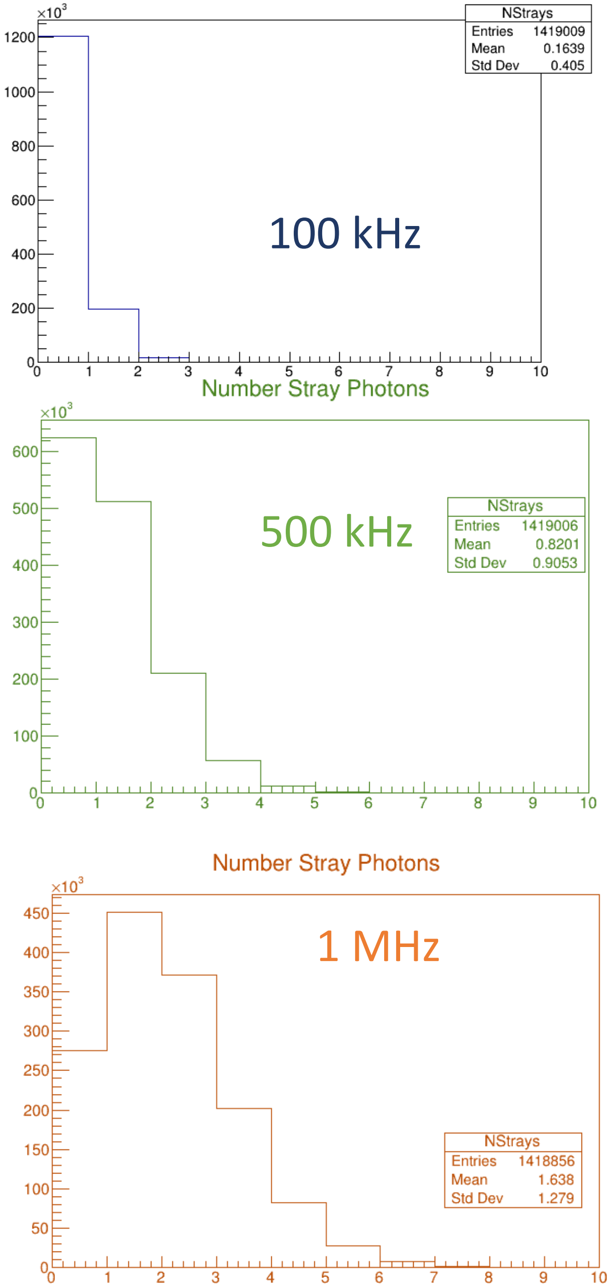
- Assuming a time cut on any hit pixel of $\pm 2\sigma_t$ The amount of dark hits in the active area on average is

$$DCR(Hz/mm^2) * Active\ Area\ (mm^2) * 4 * Time\ Resolution(s)$$

which follows a Poisson distribution.

  - Factor of 4 comes from a 2-sigma cut in incidence time, 2 sigma above and 2 sigma below the truth time.

- Dark hits with $\theta_{C\ Noise\ Hit} < 1.2*\theta_{C\ max}$ are taken to be confused with true hits as a quick approximation of some pattern recognition.
  - Prevents dark hits far away from the true ring having large pull and ruining results
  - This should be taken as a "worst case", better fitting techniques will improve the noise rejection.

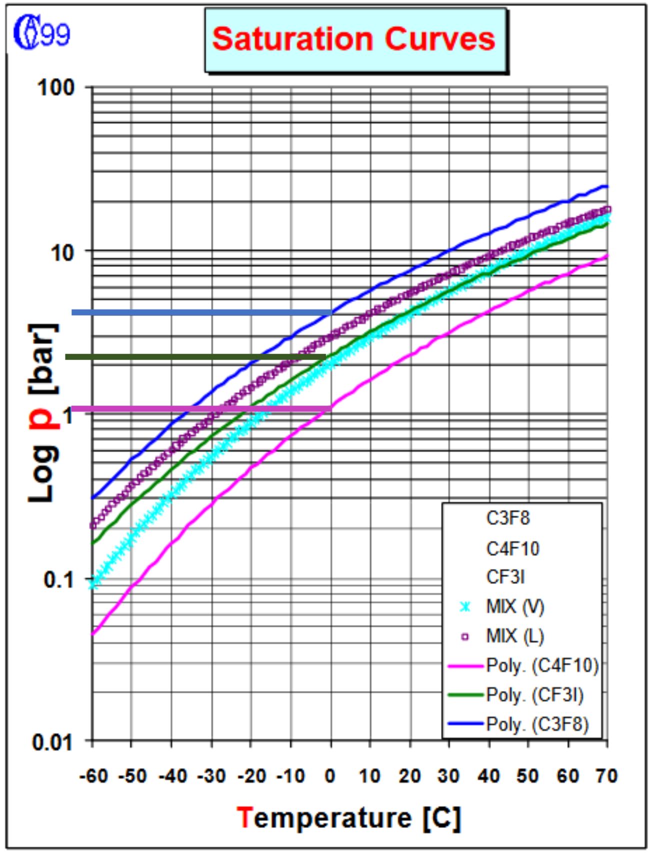


Number of dark counts inside of active area within a $\pm 2\sigma_t$ time window for σ_t = 100 ps

Gas Radiator Choice

https://tel.archives-ouvertes.fr/tel-00592091/file/Greg_memoire-version-for-final-printing-April-2011.pdf

Great resource on refrigerants.



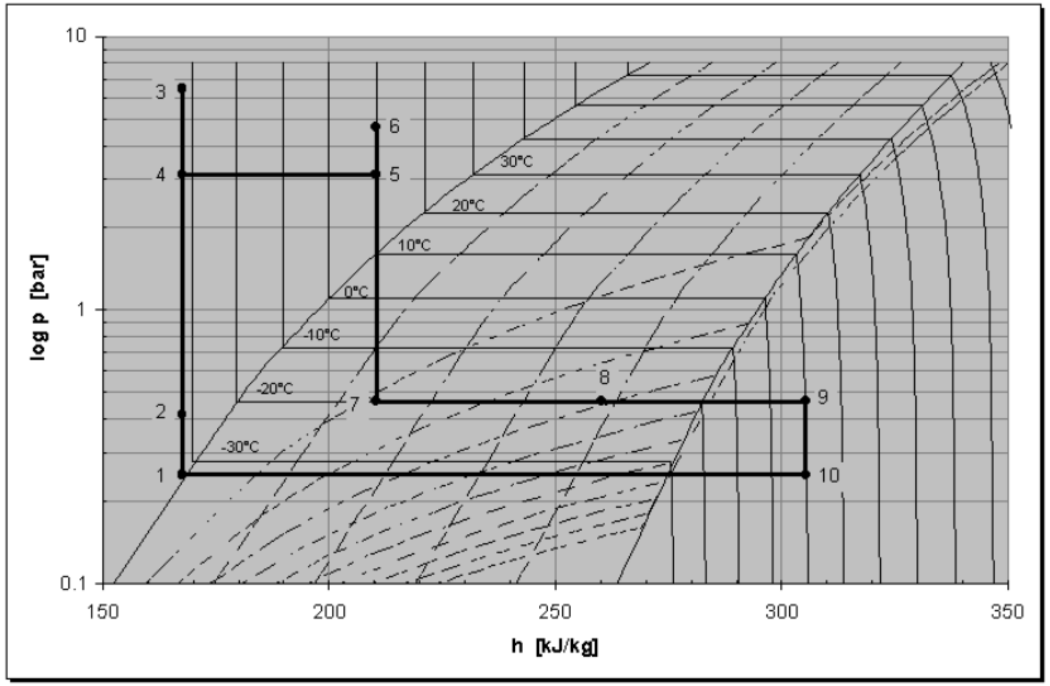


fig. 6: C4F10 lg p, h – diagram, operating conditions according to fig. 5

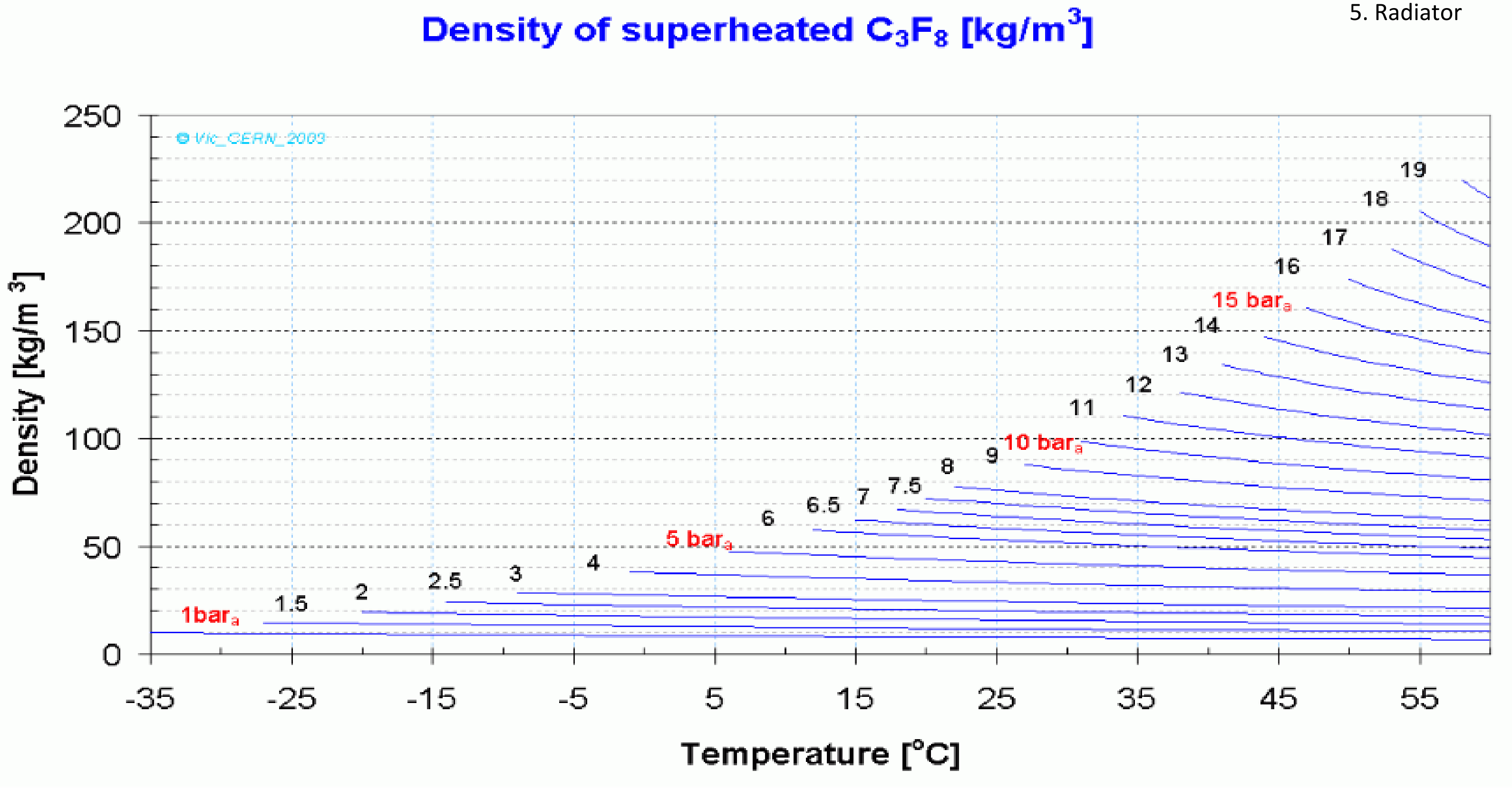
- Need relatively high index to get an appreciable amount of photons.
- However, heavy fluorocarbons are good refrigerants for a reason.
  - At room temperature, C4F10 cannot reach 3 bar without condensing.
    - Acquisition of C4F10 is also an issue
- C3F8 can be gaseous at 4 bar and 0° C, still widely produced for medical procedures.

Gas Radiator Choice

https://tel.archives-ouvertes.fr/tel-00592091/file/Greg_memoire-version-for-final-printing-April-2011.pdf

https://detector-cooling.web.cern.ch/fluidmaterial.html

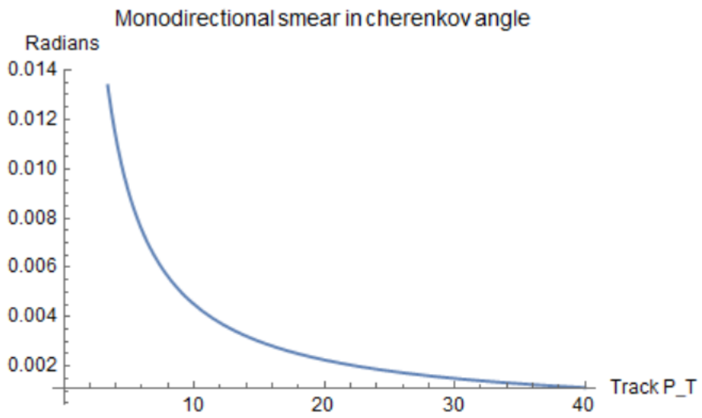
Great resources on refrigerants.



- Index of 1.004 can provide ~15 photons in 20 cm at β=1. DELPHI gas had n = 1.00172
- How does index depend on temperature near the condensation point? Scales as density, not pressure.
  - Can gain a bit of index by cooling. Not beyond 20-30% though at reasonable pressures and temp. differences.
- If PFCs are banned, Xenon or a greener refrigerant may be an option.
- Gas characterization is part of the R&D that a detector like this would require.
  - Large phase space of similar heavy gases such as C4F8, C3F8O. Optical and thermodynamic properties need to be studied and optimized.

Is 3 bar possible with low material budget?

- Maybe, with a honeycomb/carbon-fiber gas volume.
  - Such a structure has been proposed for use in car bodies to increase strength and decrease weight compared to aluminum.
- Excellent thermally insulating properties compared to metals.
- Cylinders are inherently strong, although the seams may be an issue.
  - The volume from 50 cm to 90 cm in radius would be ~ 5m^3 of gas
- Need to find out what the maximum pressure the SiPM windows can hold.



Smearing in simulation

Current status is $\sigma^2 = \sigma^2_{Pixel} + \sigma^2_{Chrom.} + "\sigma"^2_{Bend} + \sigma^2_{Extra}$

σ^2_{Pixel} is $\frac{Pixel\ size\ in\ mm}{L*\sqrt{12}}$ where L is radiator length, pixels assumed square

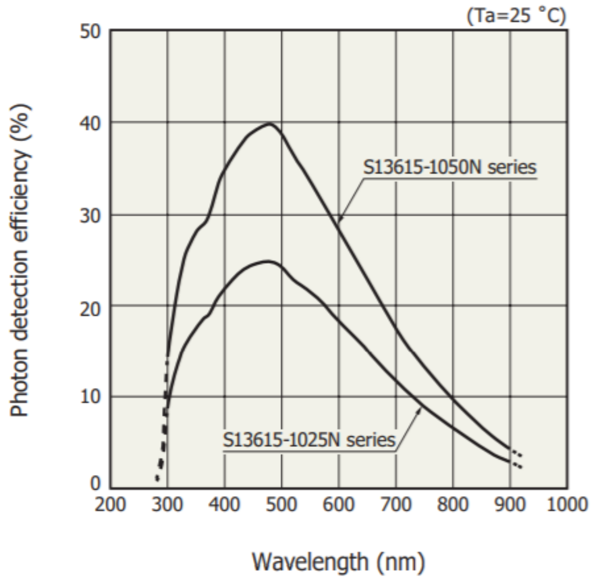
$"\sigma"^2_{Bend}$ is applied as a uniform distribution along one ring axis as described earlier.

σ^2_{Extra} is a 3 mrad smear to compensate for inevitable tracking and emission point errors. Tracking error will be small in Si-tracker design. Emission point? Shorter radiator but more mirrors. Can a track that goes between mirrors be reconstructed? Depends on N_{pe}.

$\sigma^2_{Chrom.}$ is inherent in the MC, photons are generated at wavelengths according to the efficiencies and that photons $\theta_{C\ obs.}$ is determined accordingly. Due to operating in the VIS, this term is subleading.

Efficiencies in Simulation

Efficiency	% of photons surviving (approx.)
SiPM PDE (25° C)	~40% at peak (475 nm)
Timing cuts	90%
Mirror reflectivity	92%
Glass window transparency	89%
PDE loss to a possible temperature/voltage operating point (0° C)	80%
Total @ PDE peak	~25%



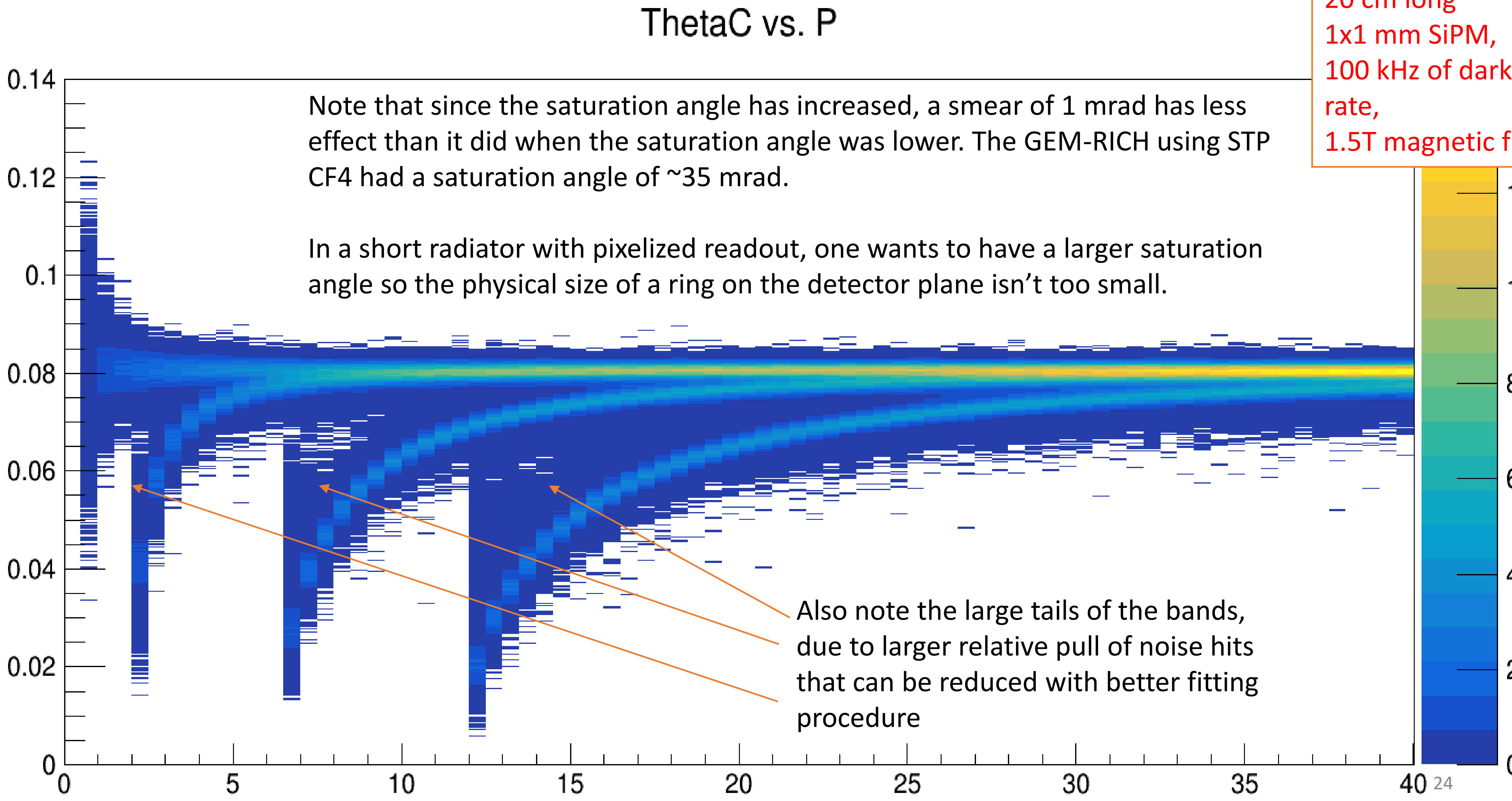
Baseline Detector Design in the following plots, parameters unless otherwise mentioned are:

C3F8 gas at 3 bar with n = 1.0033
1x1 mm SiPM,
100 kHz of dark rate,
20 cm length,
1.5T magnetic field

Species	Threshold P @ n = 1.0033 (GeV)
e	.06
pi	1.7
ka	6.1
p	11.6

For baseline configuration

C3F8 gas at 3 bar,
20 cm long
1x1 mm SiPM,
100 kHz of dark rate,
1.5T magnetic field



Note that since the saturation angle has increased, a smear of 1 mrad has less effect than it did when the saturation angle was lower. The GEM-RICH using STP CF4 had a saturation angle of ~35 mrad.

In a short radiator with pixelized readout, one wants to have a larger saturation angle so the physical size of a ring on the detector plane isn't too small.

Also note the large tails of the bands, due to larger relative pull of noise hits that can be reduced with better fitting procedure

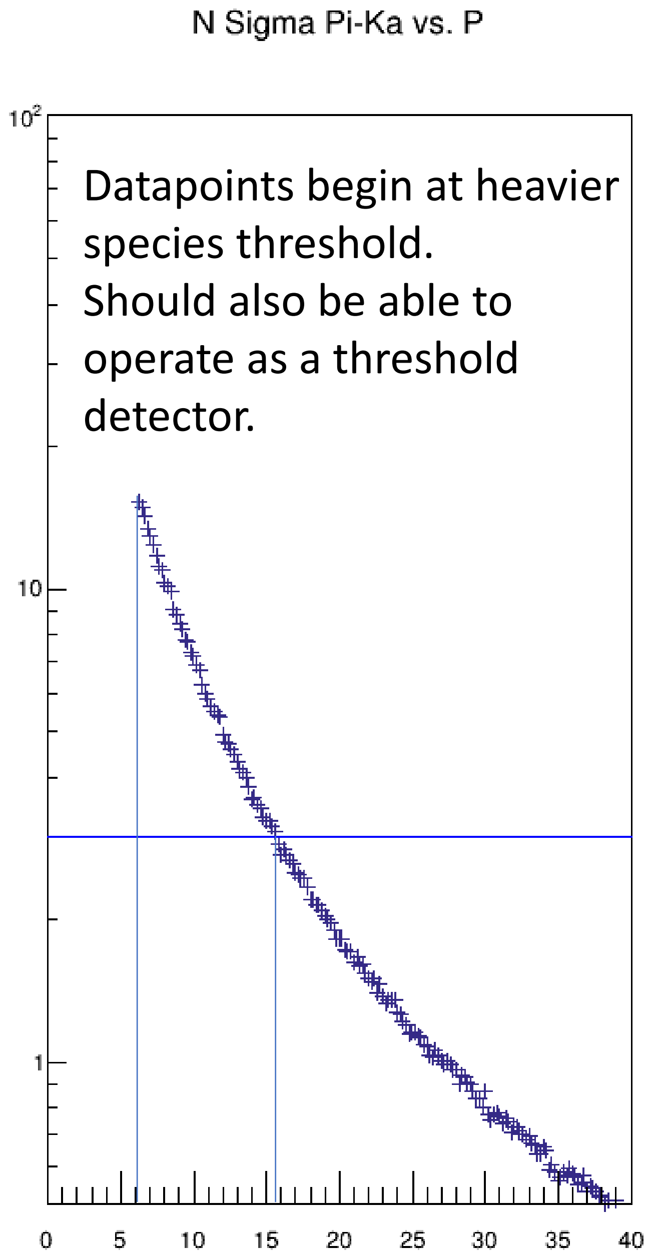
Preliminary Results

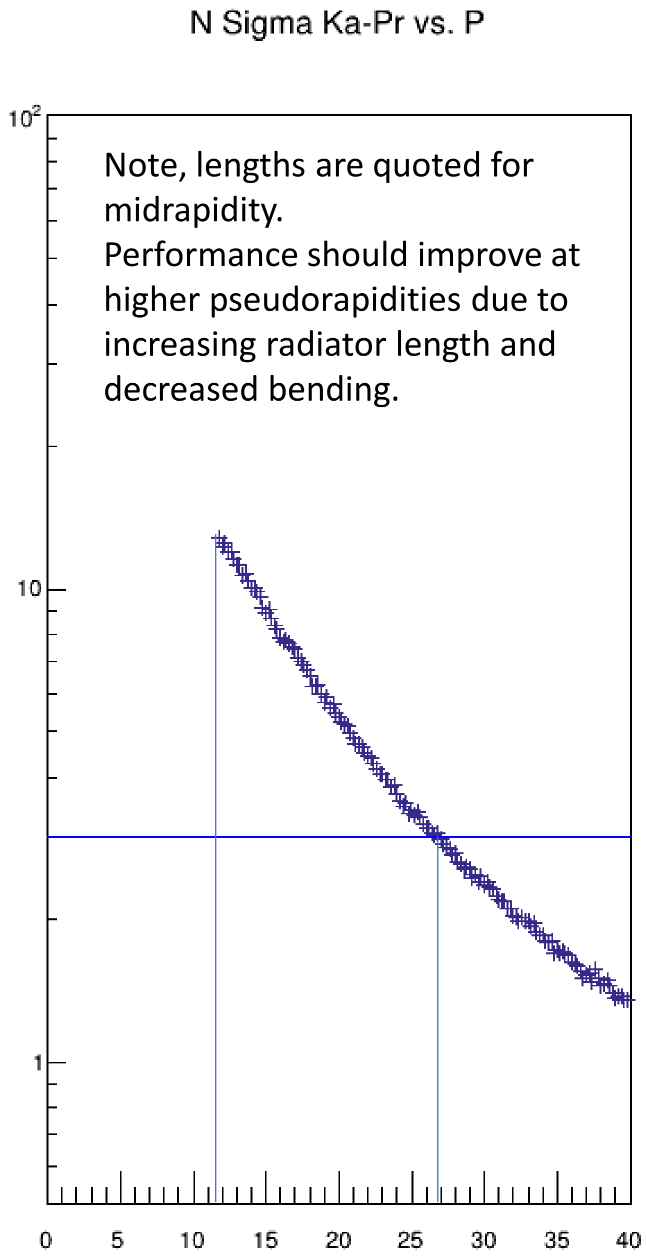
All the following results are still a work in progress and are subject to change.

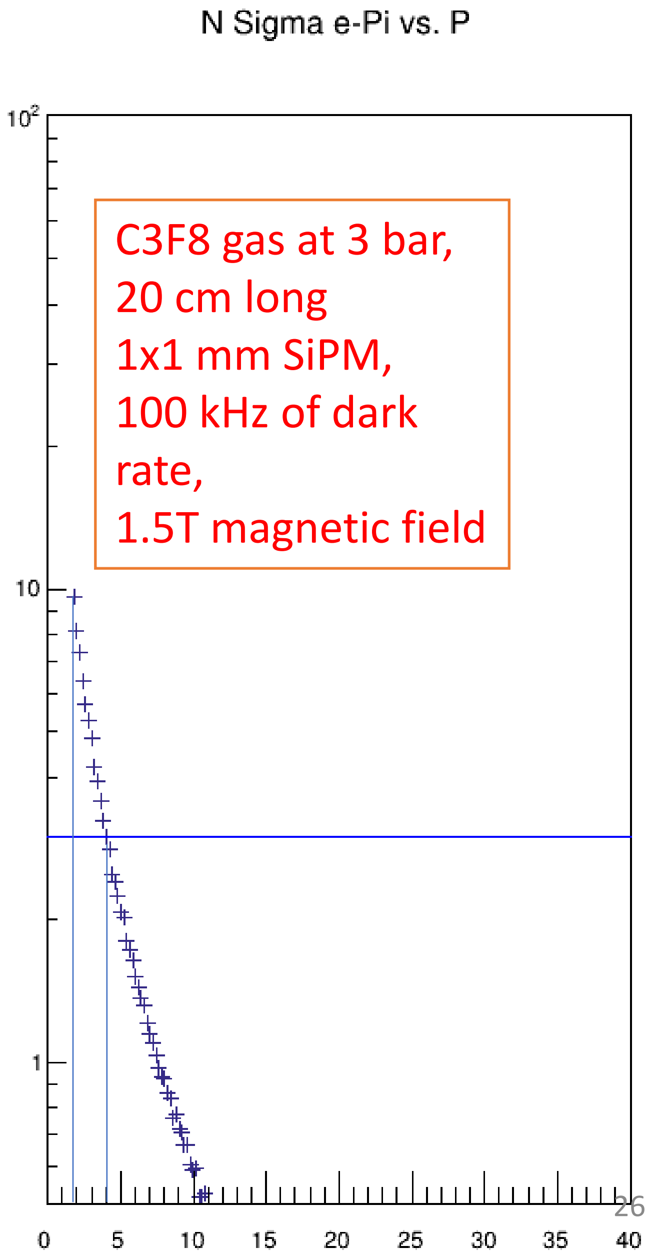
Also note that N_{sigma} in the following plots is calculated using average of the two peaks, not the wider peak as is sometimes done.

The fast simulation assumes track incidence on a spherical mirror with no aberrations, a more detailed study on possible mirror geometries will be necessary eventually.

For baseline configuration







Gas Options Comparison

Gold = C_3F_8 4 Bar abs. (16.1 N_{pe}) n = 1.0043

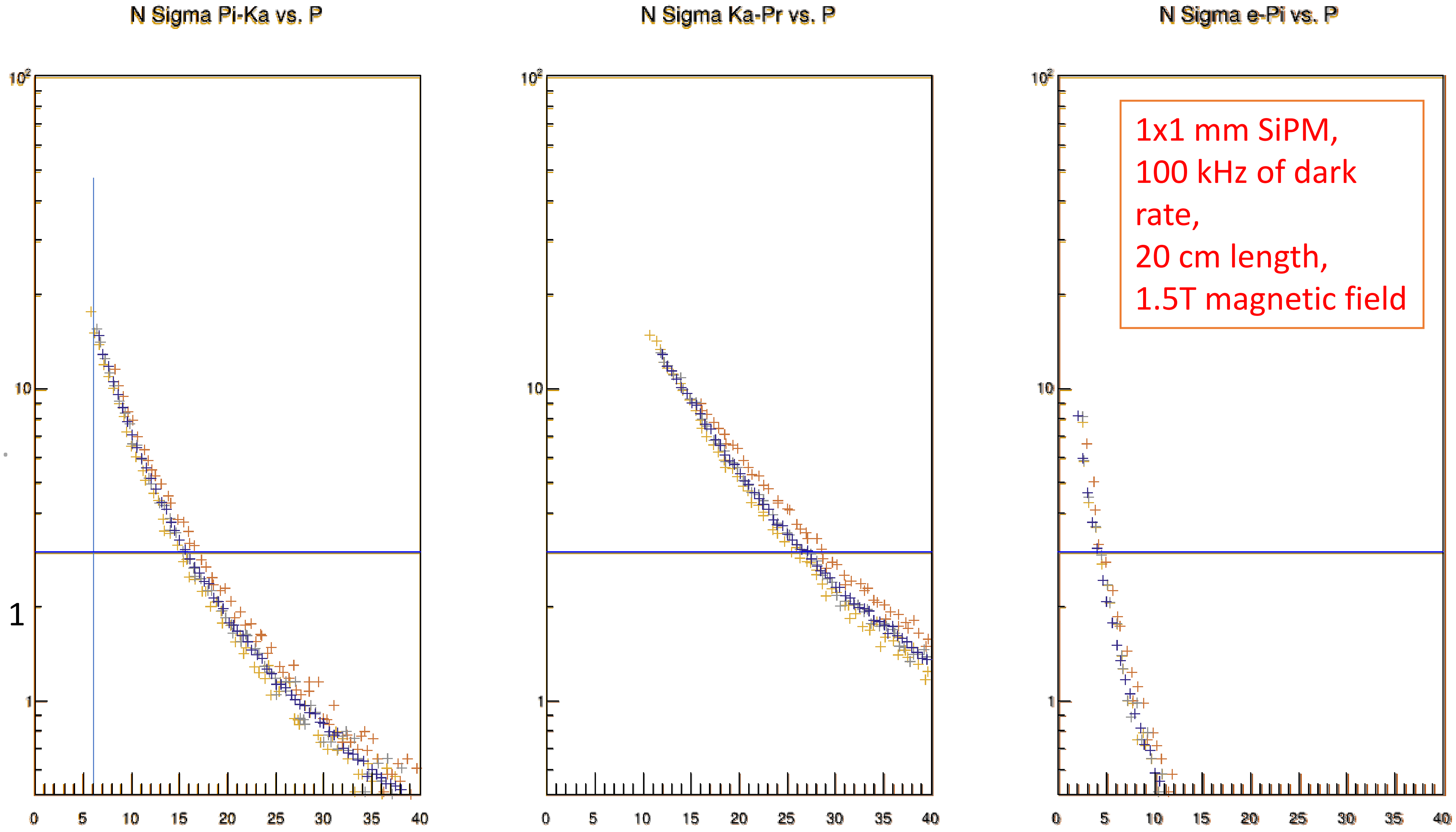
Blue = C_3F_8 3 Bar abs. (12.1 N_{pe}) n = 1.00328

Orange = C_4F_{10} 1.5 Bar abs. (7.4 N_{pe}) n = 1.002

Grey = C_4F_{10} 2.7 Bar Abs. (13.3 N_{pe}) n = 1.0036

Npe values quoted at β = 1

Higher pressure = higher index, roughly equal 3-sigma threshold, $N_{pe} \propto$ pressure



Main tradeoff is engineering difficulty (holding high pressure) and tunability of temperature vs. N_{pe} and kaon threshold

Length Comparison

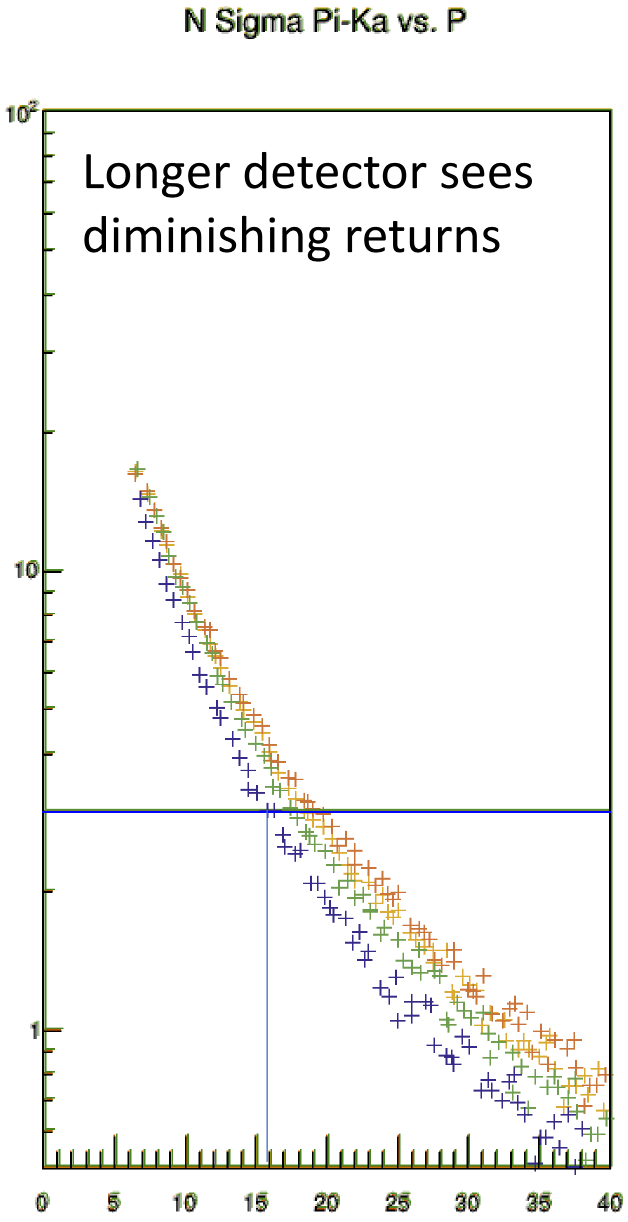
Blue = 20 cm (12.1 Npe)

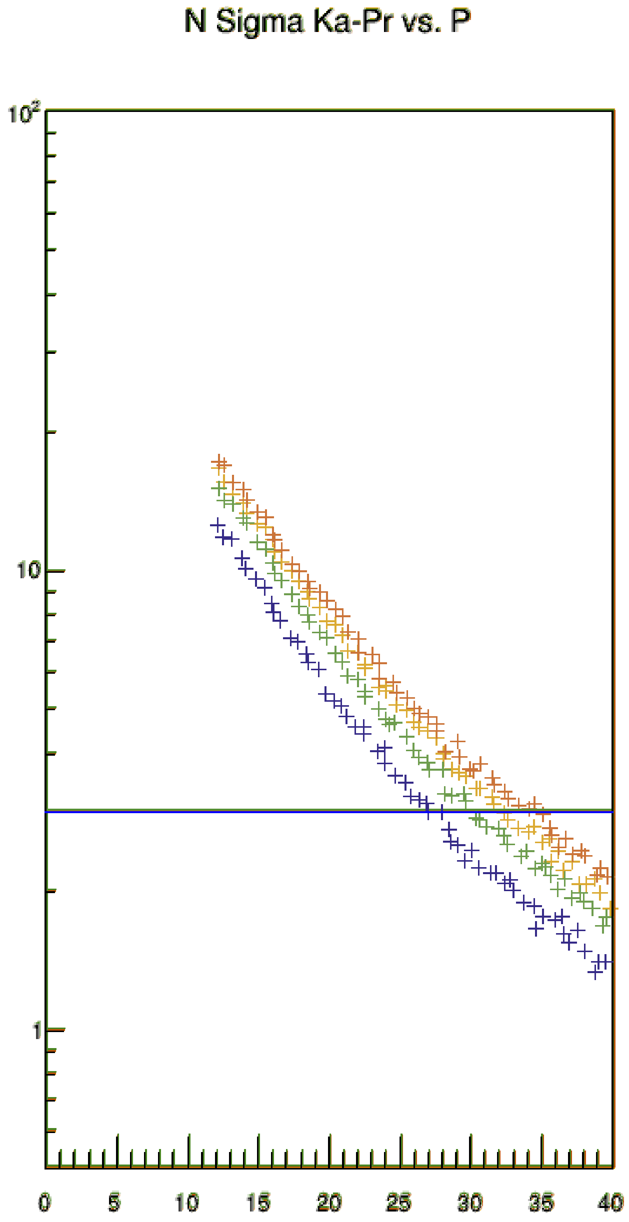
Green = 30 cm (18.2 Npe)

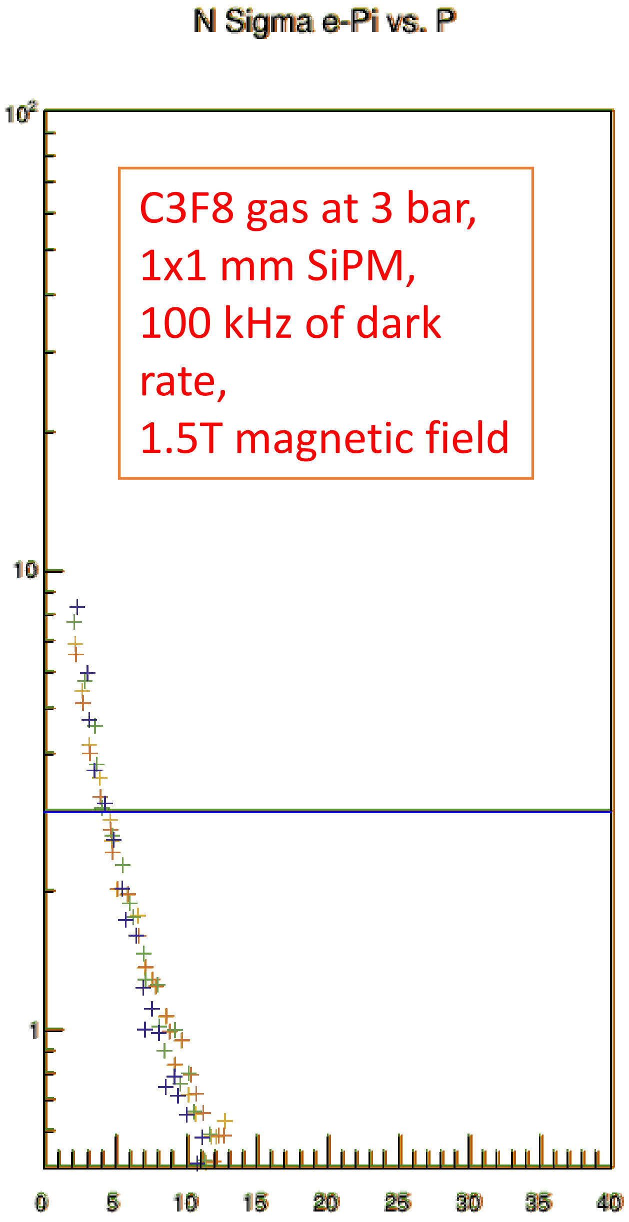
Gold = 40 cm (24.2 Npe)

Orange = 50 cm (30.3 Npe)

Momentum dependent smear along one axis of the ring due to bending





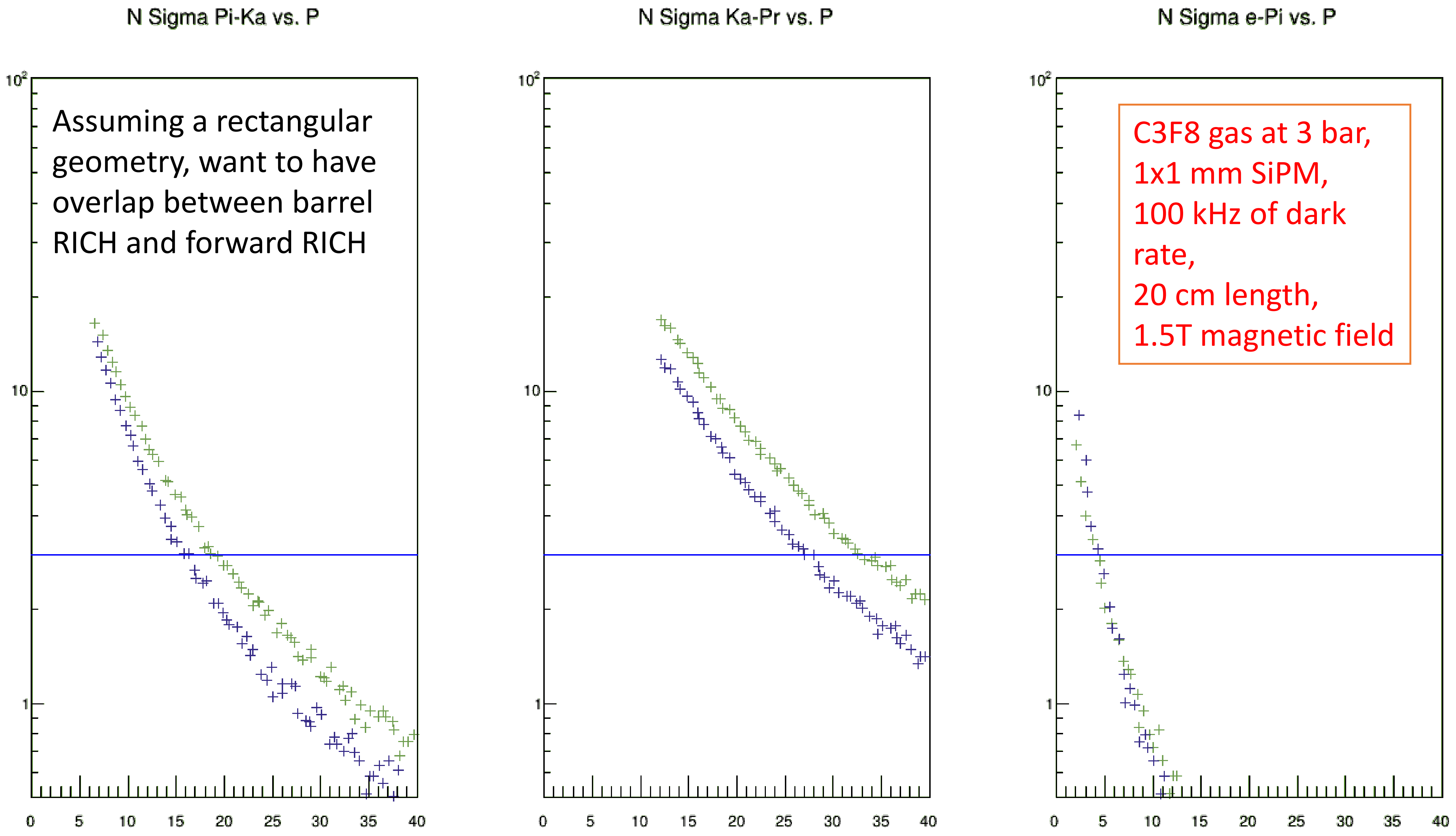


Rapidity Comparison

Blue = Midrapidity ($12.1\ N_{pe}$)

Green = Max. Path Length through detector @ η ≅ .7 47 cm ($28\ N_{pe}$)

Bending slightly overestimated at non-zero rapidity in simulation



Pixel Size Comparison

Blue = 1x1 mm

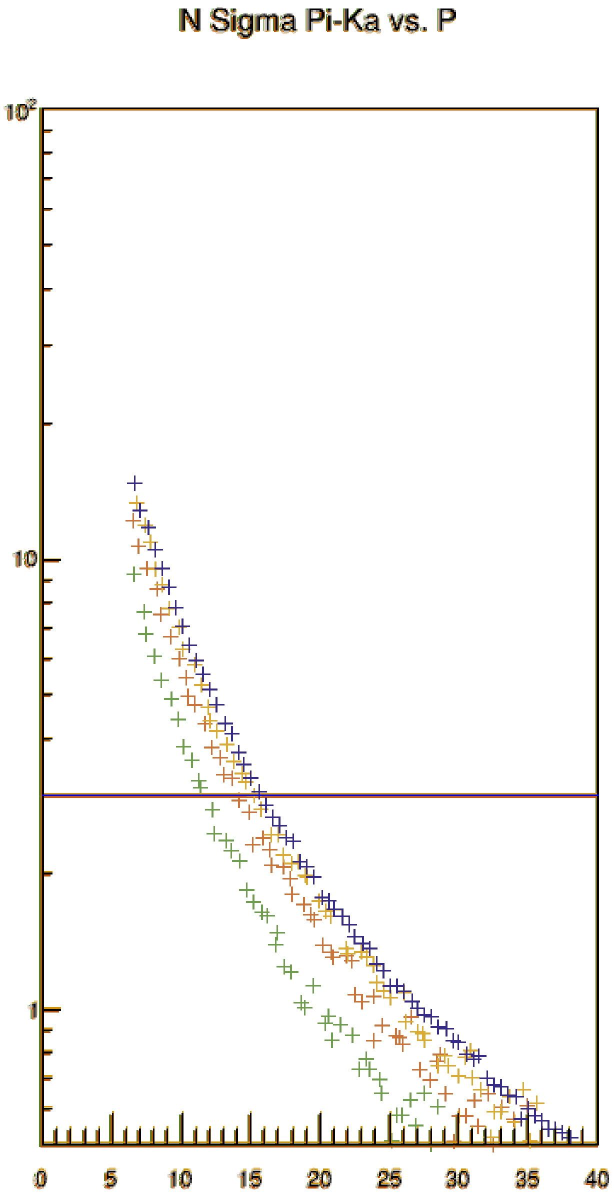
Gold = 2x2 mm

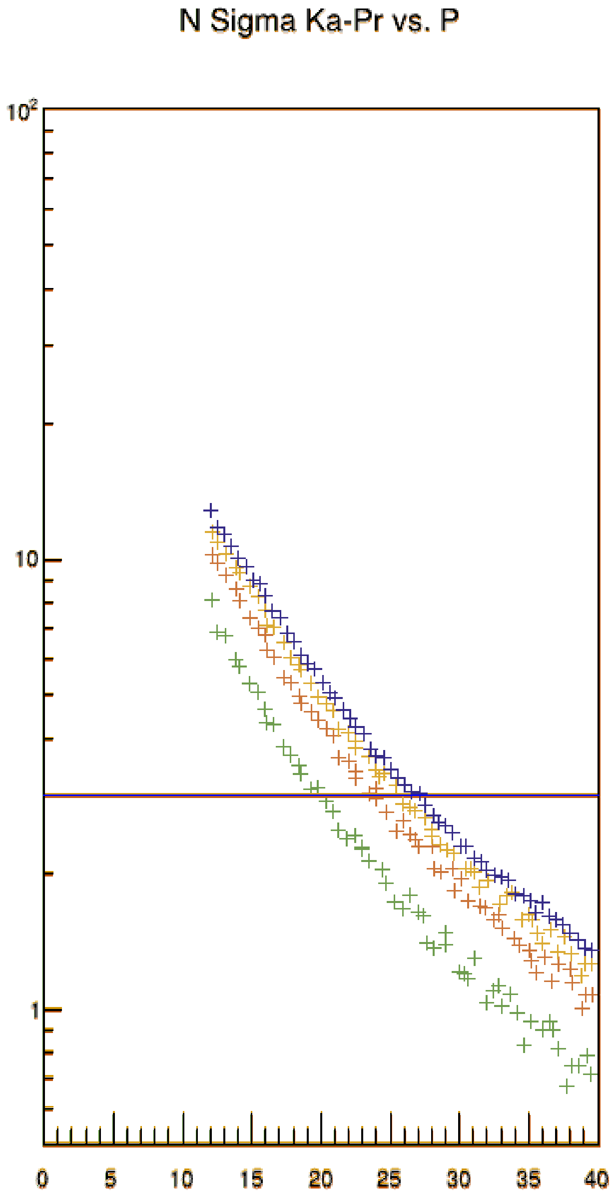
Orange = 3 x 3 mm

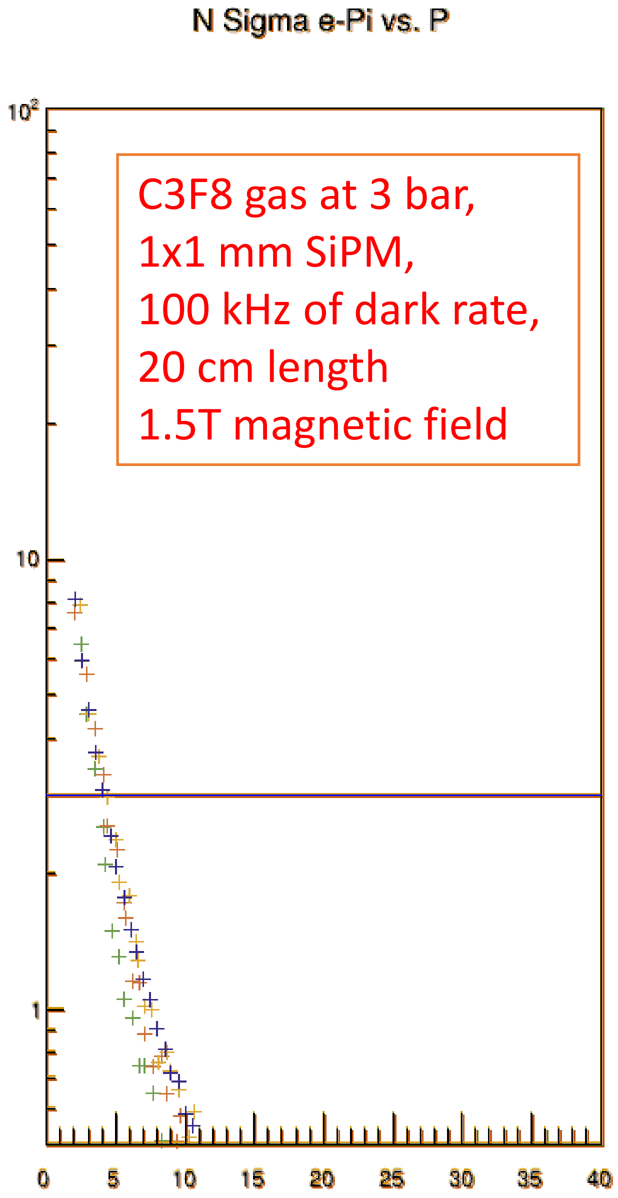
Green = 6x6mm

Pixel size is a substantial factor in resolution in a short radiator.

Smallest channel size available is typically 1x1 mm.







Pressure Comparison

Green = 1 Bar abs. (4.1 N_{pe}) n = 1.00109

Orange = 2 Bar abs. (8.2 Npe) n = 1.00218

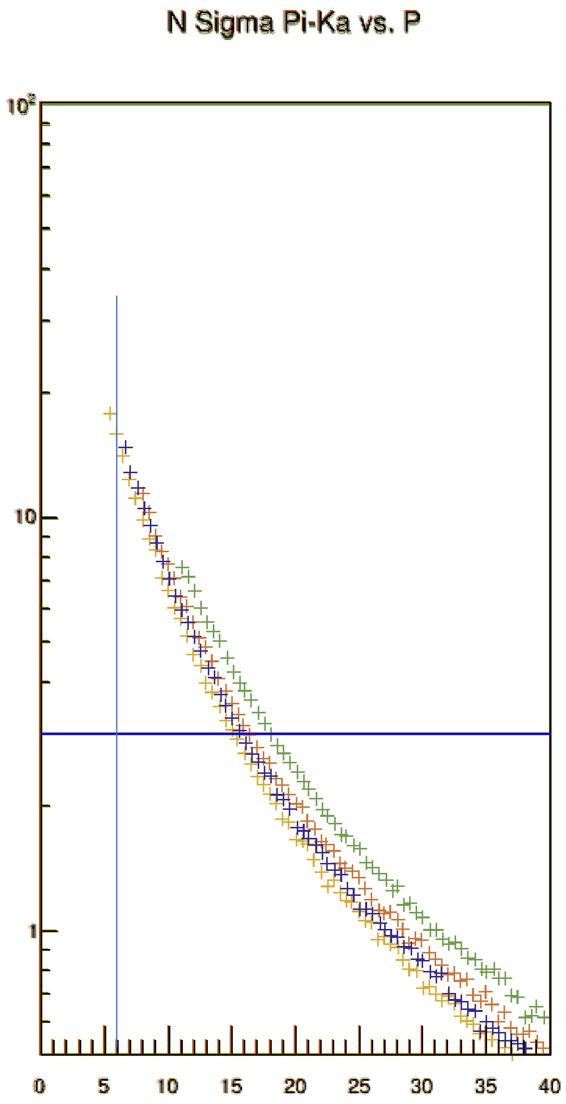
Blue = 3 Bar abs. (12.3 N_{pe}) n = 1.00327

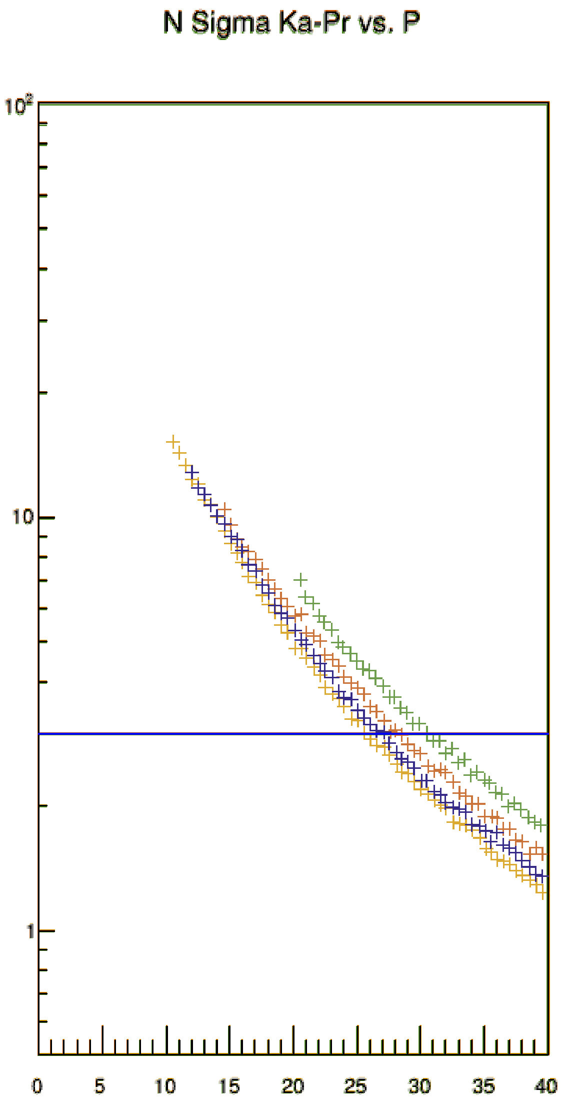
Gold = 4 Bar abs. (16.4 N_{pe}) n = 1.00436

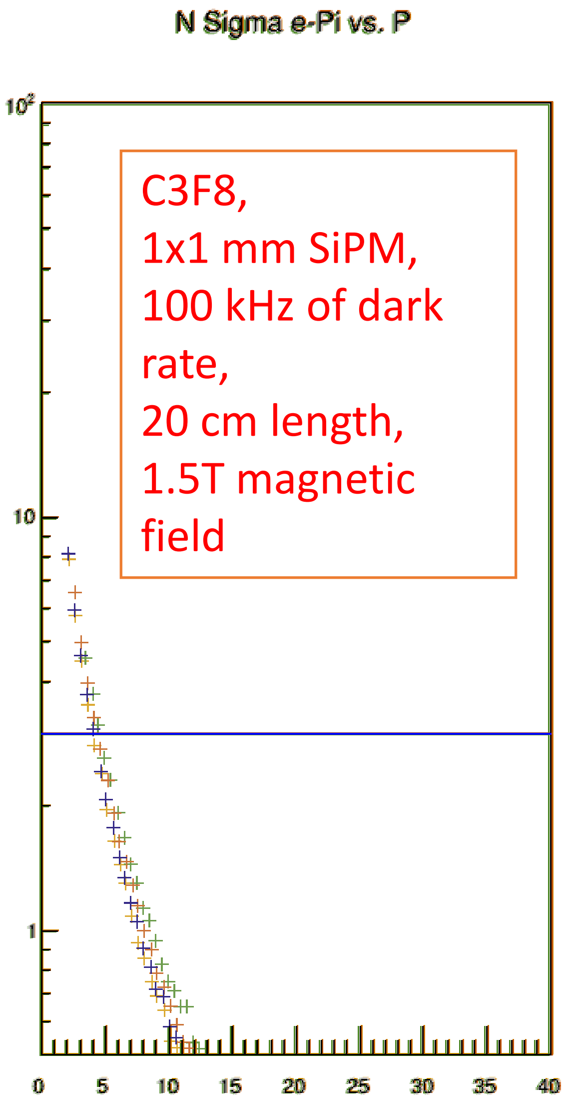
Npe values quoted at β = 1

Higher pressure = higher index & higher chromaticity

Roughly equal 3-sigma thresholds,
$N_{pe} \propto$ pressure







Note, DIRC 3-σ pi/k threshold at ~6 GeV. 3 Bar looks ok. In situ control of pressure and temperature would be nice.

B-Field Comparison

Blue = 1.5T, 20 cm

Green = 3T, 20 cm

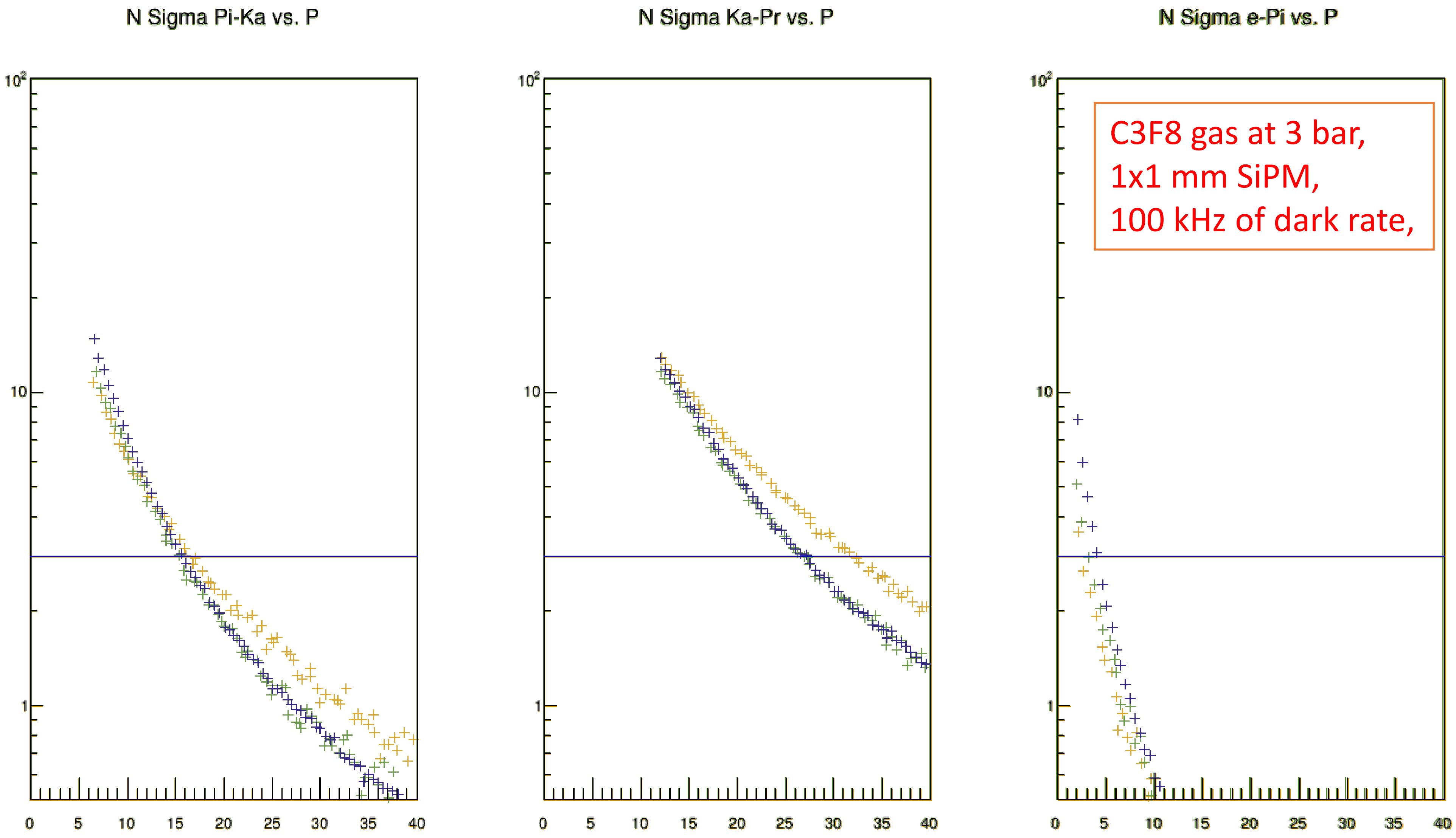
All ~12 N_{pe}

Gold = 3T, 50 cm

~30 N_{pe}

Angular resolution scales ~linearly in B and L since bending is $\int B \cdot dl$

Higher field and longer radiator hurts e/pi separation the most.



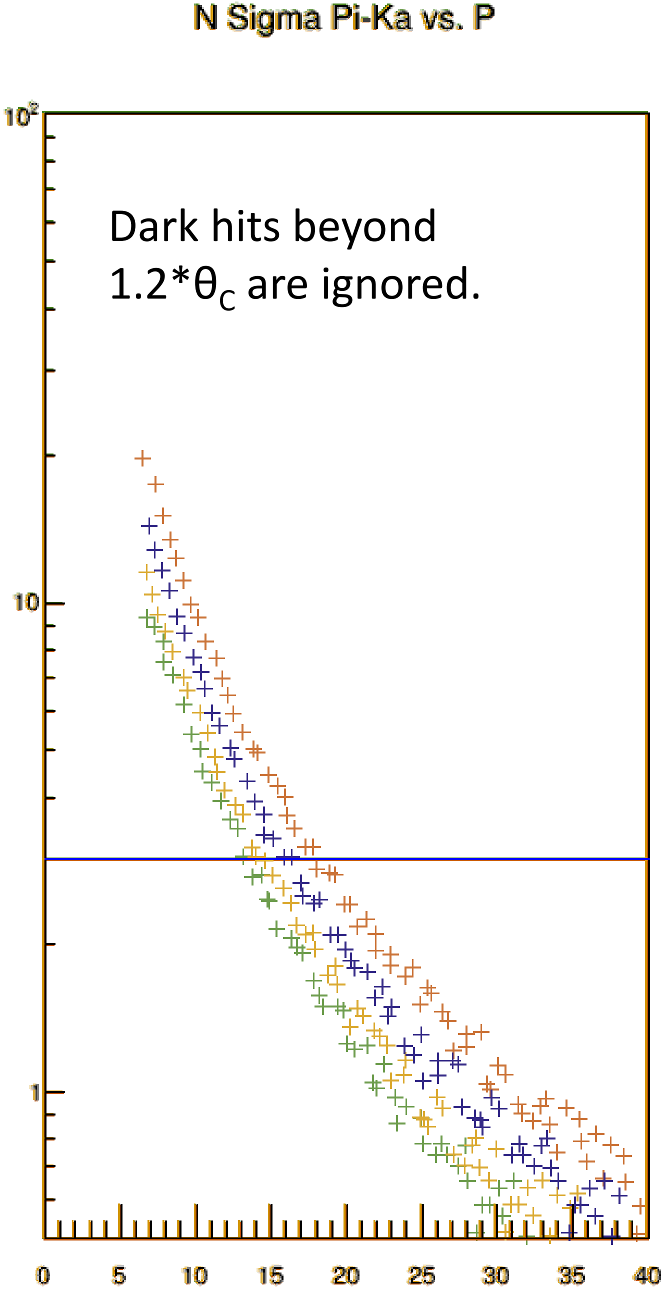
SiPM Time Res. Comparison @ 100 kHz Dark Rate

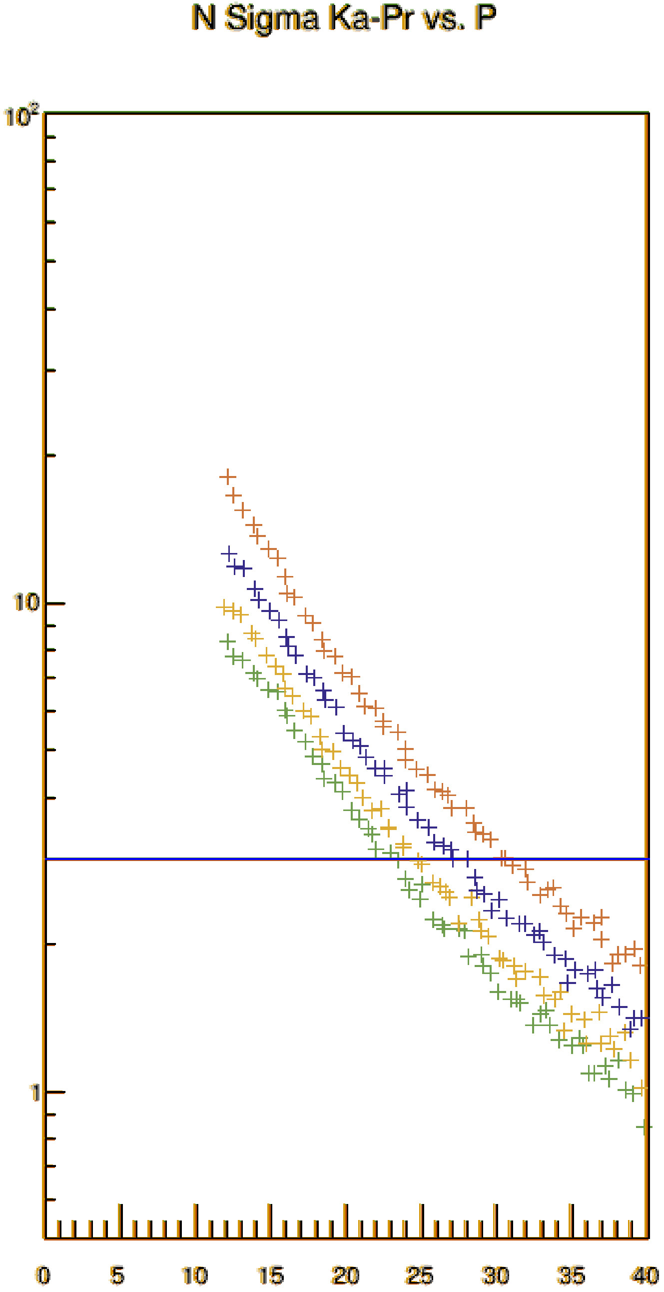
Blue: 100 ps

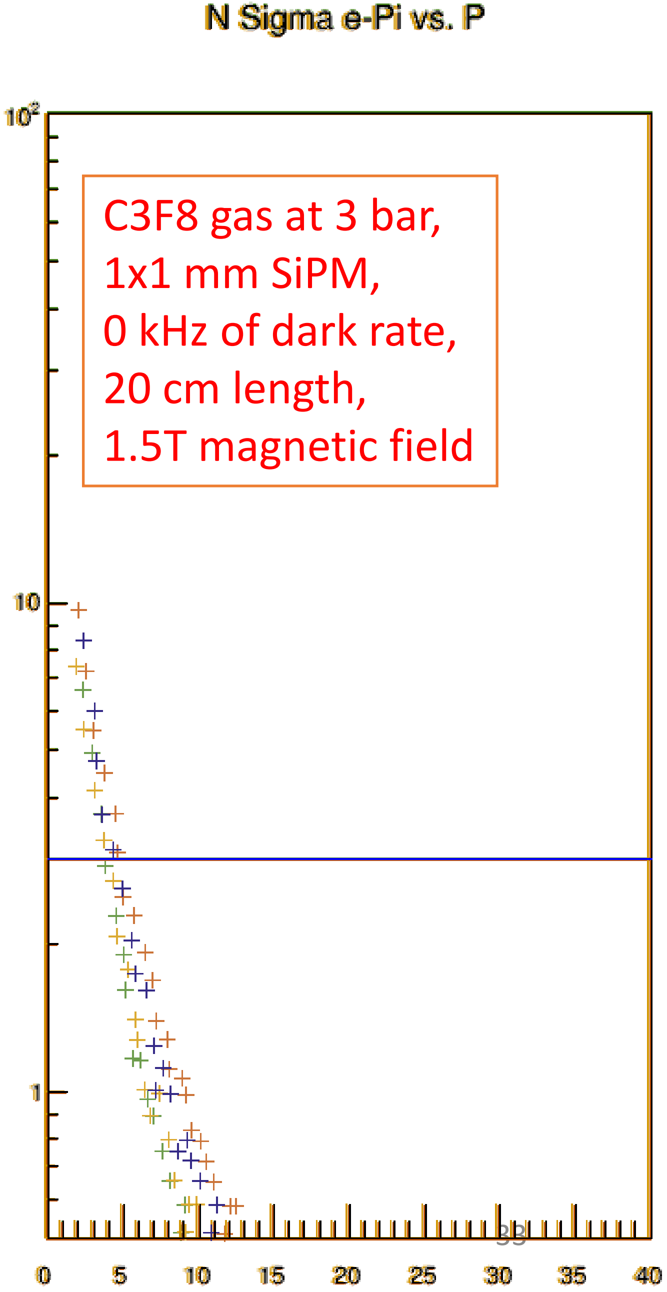
Orange: 50ps

Gold: 150 ps

Green: 200 ps







Dark Rate Comparison @ 100 ps Time Resolution

Orange: 0 Hz

Blue: 100 kHz

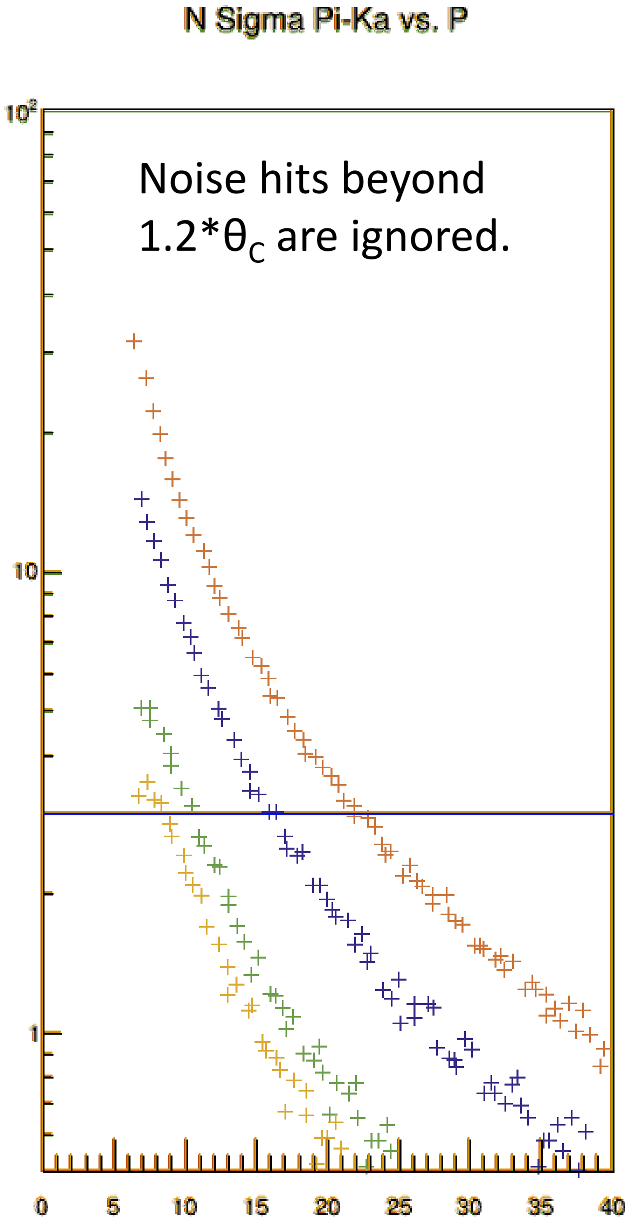
Green: 500 kHz

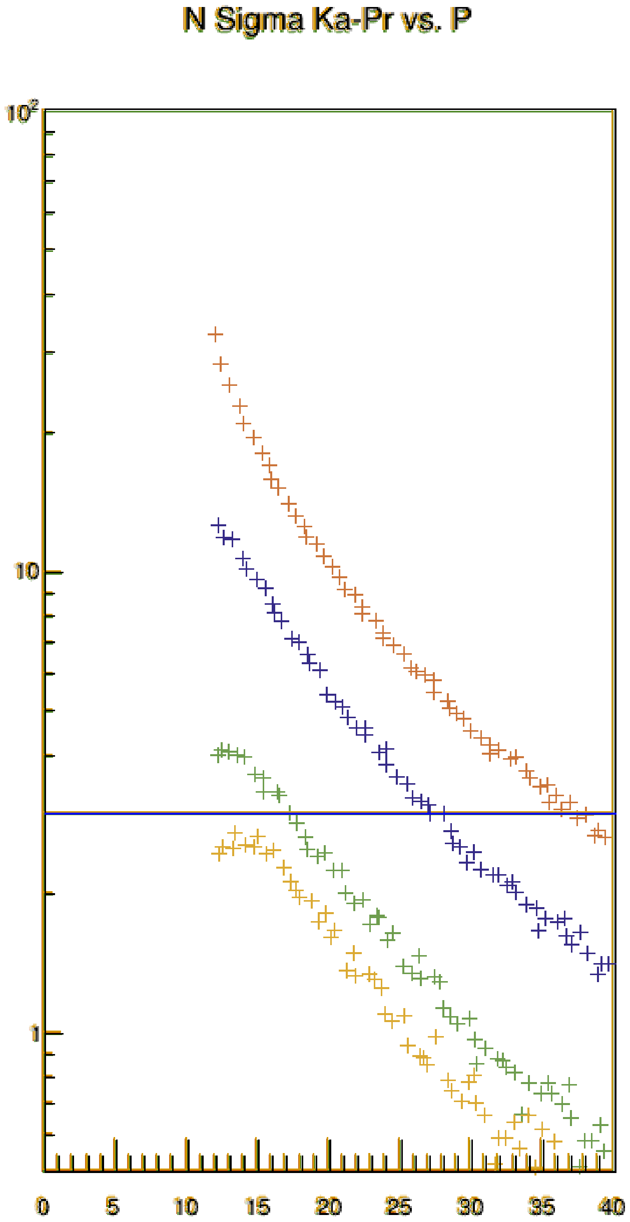
Gold: 1 MHz

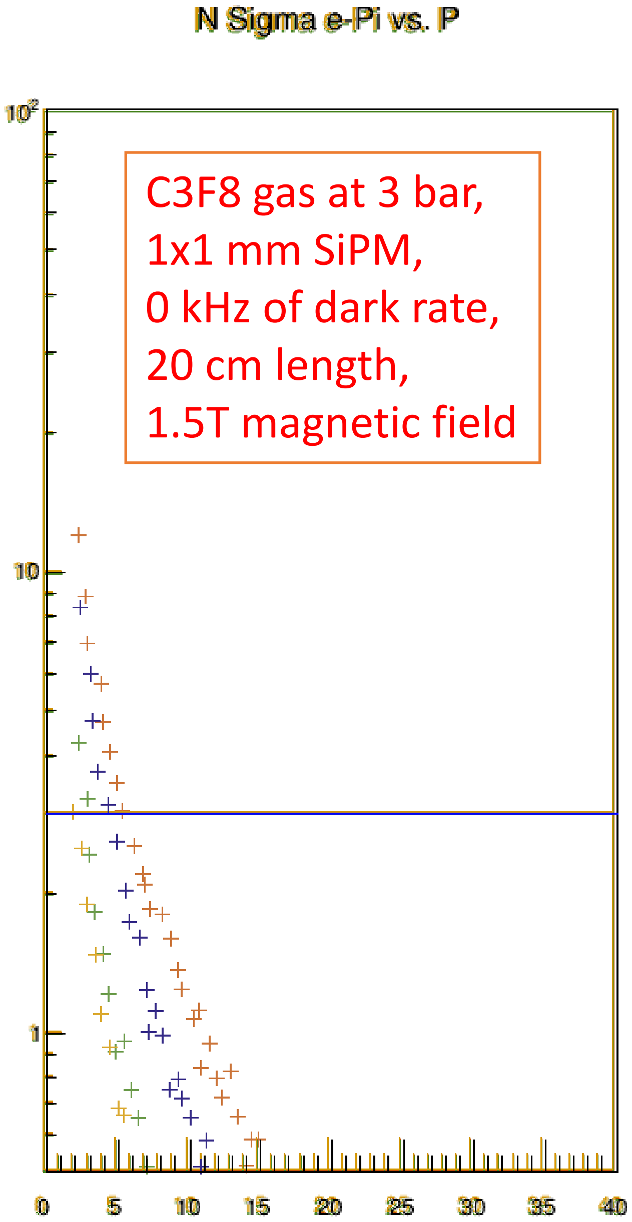
Nothing too unexpected here, 100 kHz is tolerable, but lower is preferred.

500 kHz+ is problematic.

Note that a proper fitting algorithm will improve these results







Impacts

Factor	Relative Impact on 3-Sigma thresholds	Relative Impact on N_{pe}
Length	Large but saturates	Large, Linear
Pressure	Small	Large, Linear
Gas	Small	Large
Pixel Size	Large for short length	Small, Packing efficiency can vary based on pixel size
Dark Rate (SiPM)	Very large	10% N_{pe} loss to timing cut may be able to be relaxed if dark rate is low
Timing Resolution (SiPM)	Very Large	10% N_{pe} loss to timing cut may be able to be relaxed if timing resolution is good
Magnetic Field	Large for long radiator, small for short radiator	None

In Summary

- Obviously SiPM R&D is a huge undertaking, if it succeeds and the dark counts can be controlled through the life of the experiment, then a detector design like this appears viable.
- N_{pe} needs to be high in a short radiator.
    - If one wants to reconstruct rings on top of SiPM dark counts, or rings split between two mirrors.
- Photocathode-coated MPGDs also need investigation as a back-up option in case the SiPMs cannot be made radiation hard or improved through annealing.

*Preliminarily, a pi/k separation of 3 sigma up to ~15 GeV/c or more seems realistic **IF** background can be tamed. This complemented with low momentum PID could provide consistent positive PID up through 15 GeV/c.*

e/pi separation may supplement the low momentum eID. But no definitive statement can be made until these results are double and triple-checked.

In Conclusion

- To-Do
  - Further background investigation and implementation into the MC is ongoing.
  - Material budget also needs consideration.
  - Need to think about possible mirror configurations.
  - Study gas characteristics.
    - Need more info about alternative gases
    - Need to see if MPGDs are viable in C3F8

- Please suggest ways to improve the design and realism of the simulation! We're all ears.
  - As we all know, the devil is in the details.

Backups

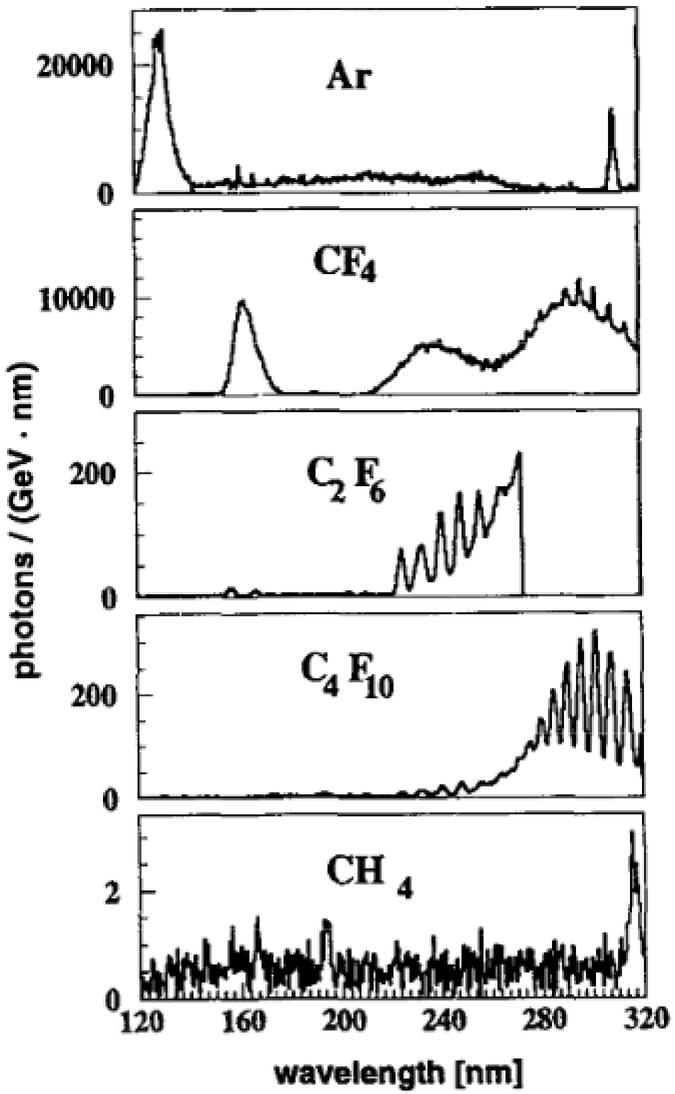
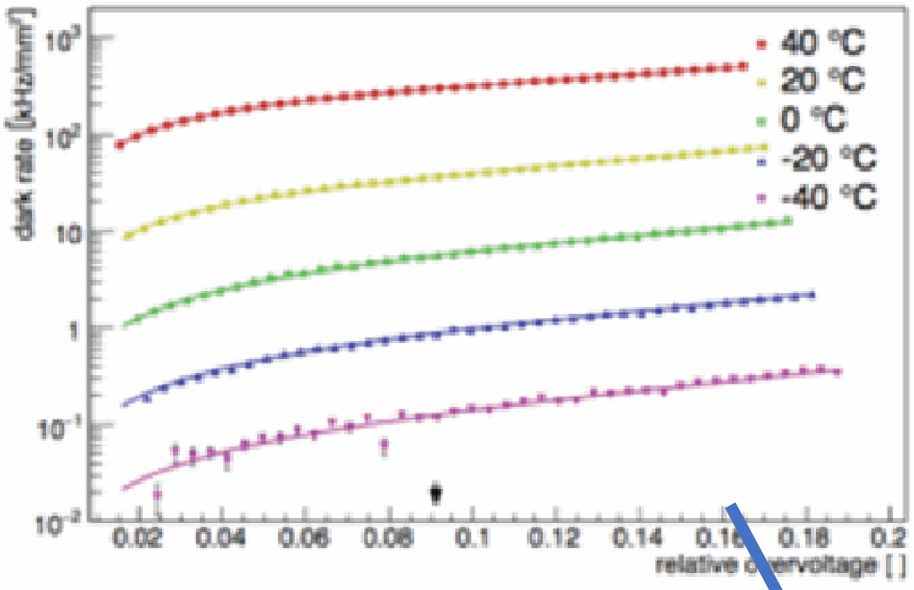


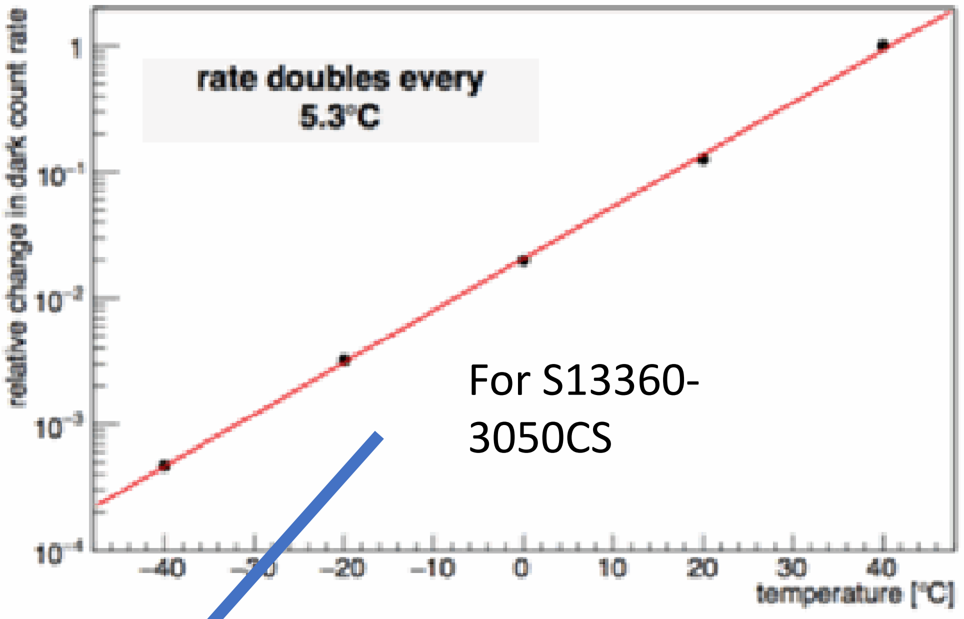
Fig. 2. Photon yield for various scintillating gases excited by ^{16}O ions of E_{kin} = 80 MeV. Intensities are normalized with respect to constant energy loss. A systematic error of about 50% has to be attributed to the absolute yield.

Dark Rates

20C of cooling gives factor of ~16 reduction in dark count, ~5.6 kHz typical, ~16.9 kHz max for S13615

How well can we control the overvoltage, what is the effect on PDE?





For S13360-3050CS

Type no.	Measurement conditions	Spectral response range λ (nm)	Peak sensitivity wavelength λp (nm)	Photon detection efficiency PDE*4 λ=λp (%)	Dark count*5 Typ. (kcps)	Dark count*5 Max. (kcps)	Terminal capacitance Ct (pF)	Gain M	Breakdown voltage VBR (V)	Crosstalk probability (%)	Recommended operating voltage Vop (V)	Temperature coefficient at recommended operating voltage ΔTVop (mV/°C)
S13360-3050CS	Vover =3 V	270 to 900	450	40	500	1500	320	1.7×10^6	53 ± 5	3	VBR + 3	54
S13360-3050PE		320 to 900										

Would want to see if this is a generic scaling or is dependent on the model number

Electrical and optical characteristics (Typ. Ta=25 °C, unless otherwise noted)

Type no.	Spectral response range λ (nm)	Spectral response range λp (nm)	Photon detection efficiency PDE λ=λp (%)	Dark count (kcps) Typ.	Dark count (kcps) Max.	Crosstalk probability (%)	Terminal capacitance Ct (pF)	Gain M	Breakdown voltage VBR (V)	Recommended operating voltage Vop (V)	Operating voltage fluctuation between channels (V) Typ.	Operating voltage fluctuation between channels (V) Max.	Recommended operating voltage temperature coefficient ΔTVop (mV/°C)
S13615-1025N series	300 to 900	450	25	90	270	3	40	7.0×10^5	53 ± 5	VBR + 5	±0.05	±0.15	54
S13615-1050N series			40			10		1.7×10^6		VBR + 3			