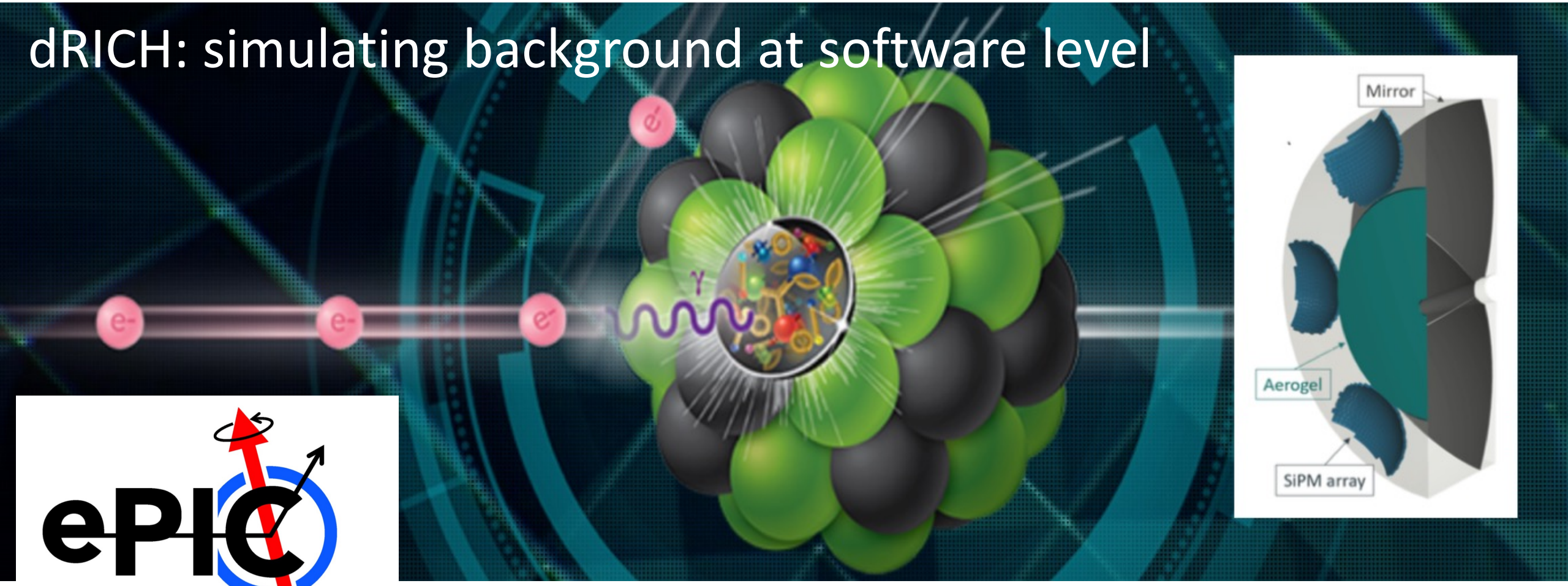
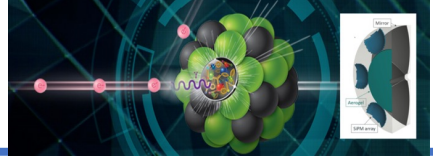
dRICH: simulating background at software level



P. Antonioli – INFN Bologna

Why it is important?

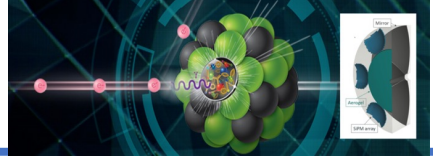


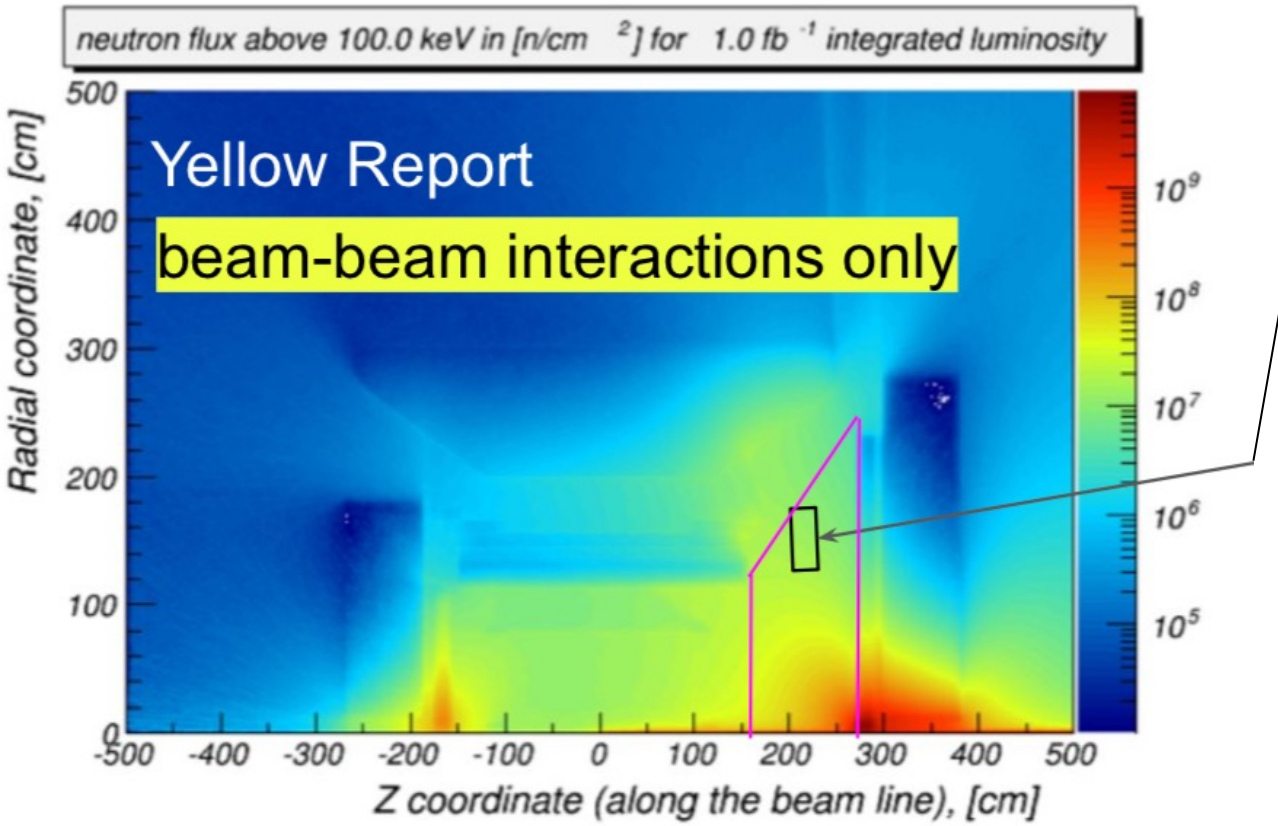
- dRICH with SiPM is expected having increasing background (DCR) with radiation load
- We now have a much clearer view of what could be the DCR level following radiation damage + annealing

→ however we need to have an indication of which would be the maximum DCR we can “tolerate” “by software” i.e. when we start to loose the possibility to identify rings and/or how much resolution worsens with increasing background

This presentation:
- Presented in December to dRICH software group
- Updated taking into account development in R&D + other info from ePIC

How much radiation? (the usual plot)





potential location of photosensors:
≈ **1-5 10^7 n/cm² every 1 fb^{-1}**

10^{11} n/cm² 1-MeV n_{eq} is a ”true maximum”

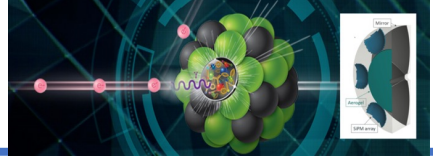
- 30 weeks @ 10^{34} cm^{-2} s^{-1}= 100 fb^{-1} → 1-5 10^9 n/cm²
- 10^{11} n/cm² would be reached in O(10+) years at full $\mathcal{L}$!

A moderately hostile environment:

10^9 1-MeV n_{eq}/cm² → most of the key physics topics
10^{10} 1-MeV n_{eq}/cm² → GPD and more statistically eager topics
10^{11} 1-MeV n_{eq}/cm² → may be we will never go here…

Can we use SiPM for a Cherenkov detector up to 10^{11} 1-MeV n_{eq} /cm² fluence?

Radiation is finally computed in ePIC



Finally with ePIC geometry

Best thing we had in the past (ATHENA)

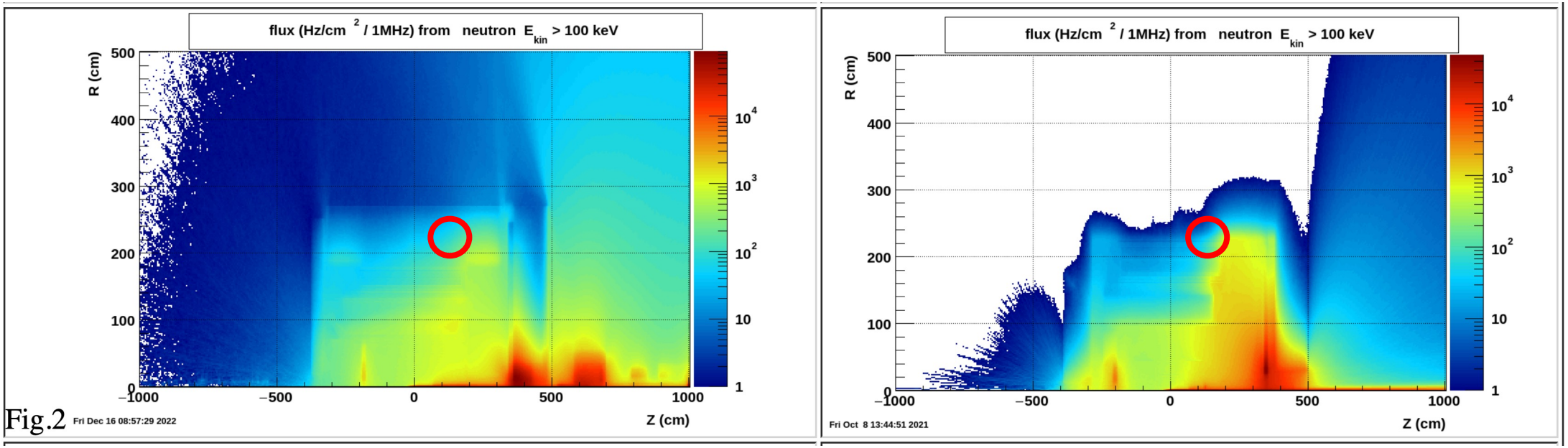
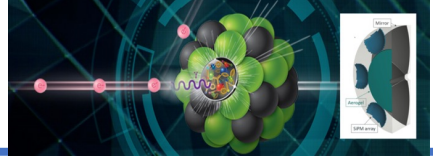


Fig.2

Results from (new) background task force

Current position of sensors: z = 100 cm R ~ 235 cm (higher than in my usual estimate…)



drich_geometry.txt

```
[RichGeo]     cellMask = 0X7FFF00
[RichGeo]     aerogelZpos = 1971.000000 mm
[RichGeo]     filterZpos  = 1991.160000 mm
[RichGeo]     aerogel thickness = 40.000000 mm
[RichGeo]     filter thickness  = 0.300000 mm
[RichGeo]
[RichGeo]       SECTOR 0 MIRROR:
[RichGeo]         mirror x = 1138.883110 mm
[RichGeo]         mirror y = 0.000000 mm
[RichGeo]         mirror z = 943.646010 mm
[RichGeo]         mirror R = 2185.353990 mm
[RichGeo]       SECTOR 0 SENSOR SPHERE:
[RichGeo]         sphere x = 1800.000000 mm
[RichGeo]         sphere y = 0.000000 mm
[RichGeo]         sphere z = 1450.000000 mm
[RichGeo]         sphere R = 1000.000000 mm
[RichGeo]     sensor: id=0X000000 pos=(1790.90, 178.73, 2433.86) normX=( 1.00,  0.00,  0.01) normY=(-0.00,  0.98, -0.18)
[RichGeo]     sensor: id=0X000800 pos=(1790.90, 153.19, 2438.16) normX=( 1.00,  0.00,  0.01) normY=(-0.00,  0.99, -0.15)
[RichGeo]     sensor: id=0X005000 pos=(1790.90, -79.22, 2446.82) normX=( 1.00, -0.00,  0.01) normY=(-0.00,  1.00,  0.08)
[RichGeo]     sensor: id=0X032000 pos=(1713.31, 58.51, 2444.52) normX=( 1.00,  0.01,  0.09) normY=(-0.00,  1.00, -0.06)
[RichGeo]     sensor: id=0X032800 pos=(1713.31, 32.64, 2445.70) normX=( 1.00,  0.00,  0.09) normY=(-0.00,  1.00, -0.03)
[RichGeo]     sensor: id=0X033000 pos=(1713.31,  6.75, 2446.21) normX=( 1.00,  0.00,  0.09) normY=(-0.00,  1.00, -0.01)
[RichGeo]     sensor: id=0X033800 pos=(1713.31, -19.15, 2446.05) normX=( 1.00, -0.00,  0.09) normY=(-0.00,  1.00,  0.02)
[RichGeo]     sensor: id=0X034000 pos=(1713.31, -45.04, 2445.22) normX=( 1.00, -0.00,  0.09) normY=(-0.00,  1.00,  0.05)
[RichGeo]     sensor: id=0X034800 pos=(1713.31, -70.89, 2443.71) normX=( 1.00, -0.01,  0.09) normY=(-0.00,  1.00,  0.07)
[RichGeo]     sensor: id=0X035000 pos=(1713.31, -96.70, 2441.53) normX=( 1.00, -0.01,  0.09) normY=(-0.00,  1.00,  0.10)
[RichGeo]     sensor: id=0X035800 pos=(1713.31, -122.44, 2438.68) normX=( 1.00, -0.01,  0.09) normY=(-0.00,  0.99,  0.12)
[RichGeo]     sensor: id=0X036000 pos=(1713.31, -148.10, 2435.16) normX=( 1.00, -0.01,  0.09) normY=(-0.00,  0.99,  0.15)
[RichGeo]     sensor: id=0X036800 pos=(1713.31, -173.66, 2430.98) normX=( 1.00, -0.02,  0.09) normY=(-0.00,  0.98,  0.17)
[RichGeo]     sensor: id=0X005800 pos=(1790.90, -105.01, 2444.43) normX=( 1.00, -0.00,  0.01) normY=(-0.00,  0.99,  0.11)
[RichGeo]     sensor: id=0X037000 pos=(1713.31, -199.10, 2426.14) normX=( 1.00, -0.02,  0.08) normY=(-0.00,  0.98,  0.20)
[RichGeo]     sensor: id=0X037800 pos=(1713.31, -224.41, 2420.63) normX=( 1.00, -0.02,  0.08) normY=(-0.00,  0.97,  0.23)
[RichGeo]     sensor: id=0X038000 pos=(1713.31, -249.57, 2414.47) normX=( 1.00, -0.02,  0.08) normY=(-0.00,  0.97,  0.25)
[RichGeo]     sensor: id=0X038800 pos=(1713.31, -274.55, 2407.66) normX=( 1.00, -0.02,  0.08) normY=(-0.00,  0.96,  0.28)
[RichGeo]     sensor: id=0X039000 pos=(1713.31, -299.36, 2400.20) normX=( 1.00, -0.03,  0.08) normY=(-0.00,  0.95,  0.30)
[RichGeo]     sensor: id=0X039800 pos=(1713.31, -323.95, 2392.09) normX=( 1.00, -0.03,  0.08) normY=(-0.00,  0.95,  0.33)
[RichGeo]     sensor: id=0X03A000 pos=(1713.31, -348.33, 2383.35) normX=( 1.00, -0.03,  0.08) normY=(-0.00,  0.94,  0.35)
[RichGeo]     sensor: id=0X03A800 pos=(1713.31, -372.48, 2373.98) normX=( 1.00, -0.03,  0.08) normY=(-0.00,  0.93,  0.37)
[RichGeo]     sensor: id=0X03B000 pos=(1713.31, -396.37, 2363.99) normX=( 1.00, -0.03,  0.08) normY=(-0.00,  0.92,  0.40)
[RichGeo]     sensor: id=0X03B800 pos=(1713.31, -420.00, 2353.37) normX=( 1.00, -0.04,  0.08) normY=(-0.00,  0.91,  0.42)
[RichGeo]     sensor: id=0X006000 pos=(1790.90, -130.73, 2441.38) normX=( 1.00, -0.00,  0.01) normY=(-0.00,  0.99,  0.13)
[RichGeo]     sensor: id=0X03C000 pos=(1713.31, -443.34, 2342.15) normX=( 1.00, -0.04,  0.08) normY=(-0.00,  0.90,  0.45)
[RichGeo]     sensor: id=0X03C800 pos=(1713.31, -466.38, 2330.33) normX=( 1.00, -0.04,  0.08) normY=(-0.00,  0.88,  0.47)
[RichGeo]     sensor: id=0X03D000 pos=(1713.31, -489.11, 2317.90) normX=( 1.00, -0.04,  0.08) normY=(-0.00,  0.87,  0.49)
[RichGeo]     sensor: id=0X03D800 pos=(1713.31, -511.50, 2304.90) normX=( 1.00, -0.04,  0.07) normY=(-0.00,  0.86,  0.51)
[RichGeo]     sensor: id=0X03E000 pos=(1713.31, -533.55, 2291.31) normX=( 1.00, -0.05,  0.07) normY=(-0.00,  0.84,  0.54)
[RichGeo]     sensor: id=0X03E800 pos=(1687.53, 534.53, 2287.63) normX=( 0.99,  0.06,  0.09) normY=(-0.00,  0.84, -0.54)
[RichGeo]     sensor: id=0X03F000 pos=(1687.53, 512.52, 2301.28) normX=( 0.99,  0.06,  0.10) normY=(-0.00,  0.86, -0.52)
[RichGeo]     sensor: id=0X03F800 pos=(1687.53, 490.16, 2314.35) normX=( 0.99,  0.06,  0.10) normY=(-0.00,  0.87, -0.49)
[RichGeo]     sensor: id=0X040000 pos=(1687.53, 467.46, 2326.83) normX=( 0.99,  0.05,  0.10) normY=(-0.00,  0.88, -0.47)
[RichGeo]     sensor: id=0X040800 pos=(1687.53, 444.45, 2338.71) normX=( 0.99,  0.05,  0.10) normY=(-0.00,  0.89, -0.45)
[RichGeo]     sensor: id=0X006800 pos=(1790.90, -156.36, 2437.66) normX=( 1.00, -0.00,  0.01) normY=(-0.00,  0.99,  0.16)
[RichGeo]     sensor: id=0X041000 pos=(1687.53, 421.14, 2350.00) normX=( 0.99,  0.05,  0.10) normY=(-0.00,  0.91, -0.42)
[RichGeo]     sensor: id=0X041800 pos=(1687.53, 397.54, 2360.67) normX=( 0.99,  0.04,  0.10) normY=(-0.00,  0.92, -0.40)
[RichGeo]     sensor: id=0X042000 pos=(1687.53, 373.67, 2370.72) normX=( 0.99,  0.04,  0.10) normY=(-0.00,  0.93, -0.38)
-:---  drich_geometry.txt   Top L10    (Text)
```

Geometry got from Chris

Electrically induced annealing techniques

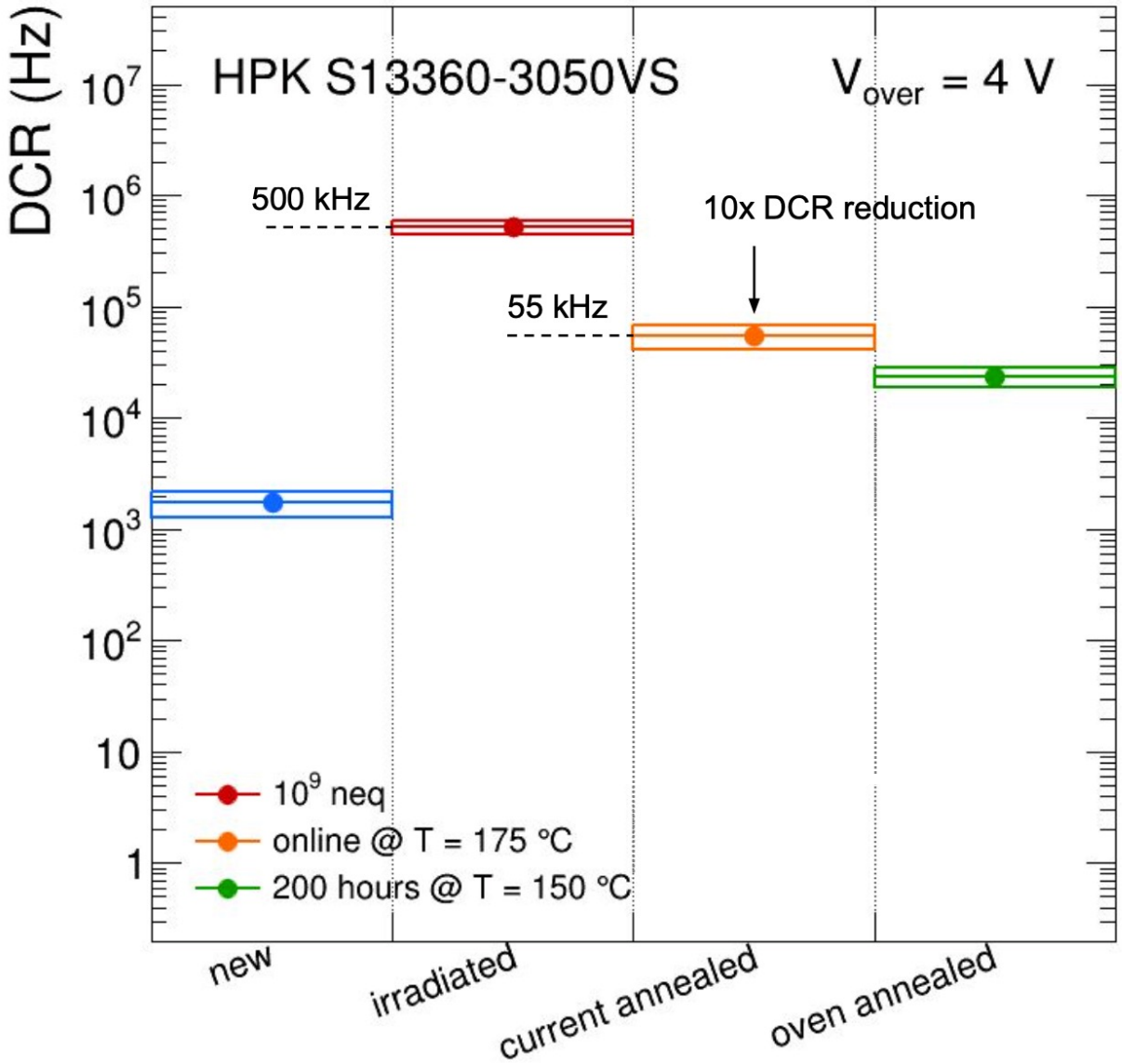
The sensors current-annealed found at 55 kHz

Residual DCR not good as in oven (15 kHz) but:

- 100 times faster!! (2.5 hours vs 200 hours!)
- can be done in-situ
- can be done more frequently

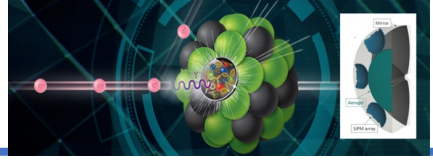
It looks very promising!

Specific R&D planned for 2023 on this item



See slides at CPAD https://indico.bnl.gov/event/17072/contributions/70455/

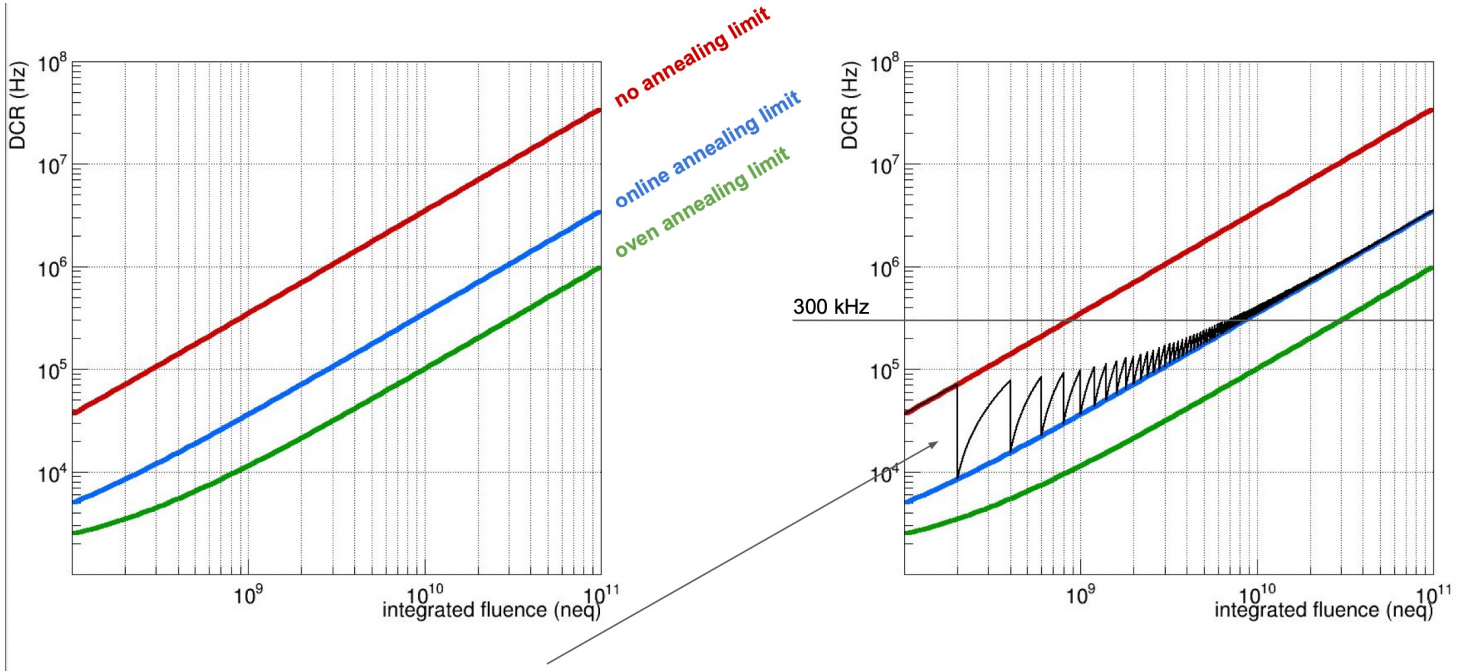
Radiation damage & annealing



Radiation damage model (HPK S13360-3050 @ Vover = 3 V)

- **reasonable assumptions**
  - radiation damage is additive
  - does not know and care of the past damage
  - annealing heals up to a certain fraction of damage, not more than that
- **numbers**
  - DCR when new = 1.5 kHz
  - DCR increase with radiation damage = 350 kHz / 10^9 neq
  - DCR increase with online annealing = 35 kHz / 10^9 neq
  - DCR residual after oven annealing = 3%
- **how it works?**
  - start with DCR as new → NEW
  - add DCR with increasing radiation → NEW + NIEL1
  - heal with annealing → NEW + x NIEL1
  - add DCR with increasing radiation → NEW + x NIEL1 + NIEL2
  - heal with annealing → NEW + x (NIEL1 + NIEL2)

Message:
Max “tolerable” rate per channel determines frequency of annealing



online annealing every 2 10^8 neq (500 times)

dRICH throughput estimates

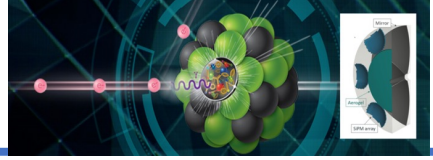


Table 2.5: Maximum data volume by detector.

from ATHENA proposal

Detector	Channels	DAQ Input (Gbps)	DAQ Output (Gbps)
B0 Si	400M	<1	<1
B0 AC-LGAD	500k	<1	<1
RP+OMD+ZDC	700k	<1	<1
FB Cal	4k	80	1
ECal	34k	5	5
HCal	39k	5.5	5.5
Imaging bECal	619M	4	4
Si Tracking	60B	5	5
Micromegas Tracking	66k	2.6	.6
GEM Tracking	28k	2.4	.5
pRWELL Tracking	50k	2.4	.5
dRICH	300k	1830	14
pfRICH	225k	1380	12
DIRC	100k	11	11
TOF	332k	3	.8
Total		3334	62.9

ASSUMPTIONS in these estimates

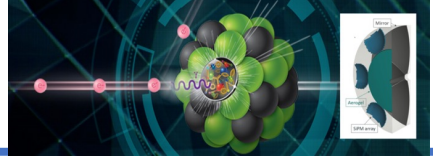
- throughput @ average 300 kHz DCR per pixel MAX before moving to annealing cycles given limitations on ALCOR and DAQ bandwidth
- factor 3 reduction due to timing selection
- throughput assumed 64 bit per hit (TOT)

Future developments and outlook

- timing reduction could be factor 10 (shutter on ALCOR)
- cooling at T= 40 ^{o}C would help another factor 2
- TOT might not be necessary?
- frequent electrically induced annealing
- ....

Note: 1.8 Tbps (300 kHz/pixel) is after > 6 10^8 n_{eq} (and no annealing and under above assumptions) but we will start @ 7.3 Gbps (2 kHz/pixel)

Some back of the envelope estimates



- DCR is easy to simulated: just white noise at a DCR given rate
- Simulate RICH “images” and have as external parameter fDCR = DCR rate / pixel
- Assume “shutter” (time cut) at 3 ns or 1 ns
- Assume 310k channels → 3x10^5

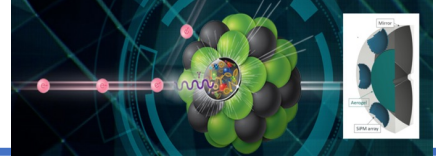
+ 20 hits from rings

sensor rate (3x3) [Hz]	Tot Hit (noise) /dRIch	Tot Hit (noise) / secto	dRICH channels	3,15E+05
3,00E+03	2,84E+00	4,73E-01	shutter 3 ns	3,00E-09
2,70E+05	2,55E+02	4,25E+01		
5,00E+06	4,73E+03	7,88E+02		
5,50E+04	5,20E+01	8,66E+00		
3,00E+03	9,45E-01	1,58E-01	shutter 1 ns	1,00E-09
2,70E+05	8,51E+01	1,42E+01		
5,00E+06	1,58E+03	2,63E+02		
5,50E+04	1,73E+01	2,89E+00		

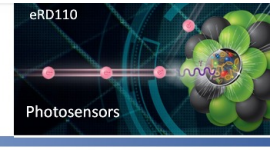
Random sample hits (from background) 1 ns or 3 ns window…
Worst case: 5 MHz input rate even if not totally realistic…
55 kHz seems at reach…

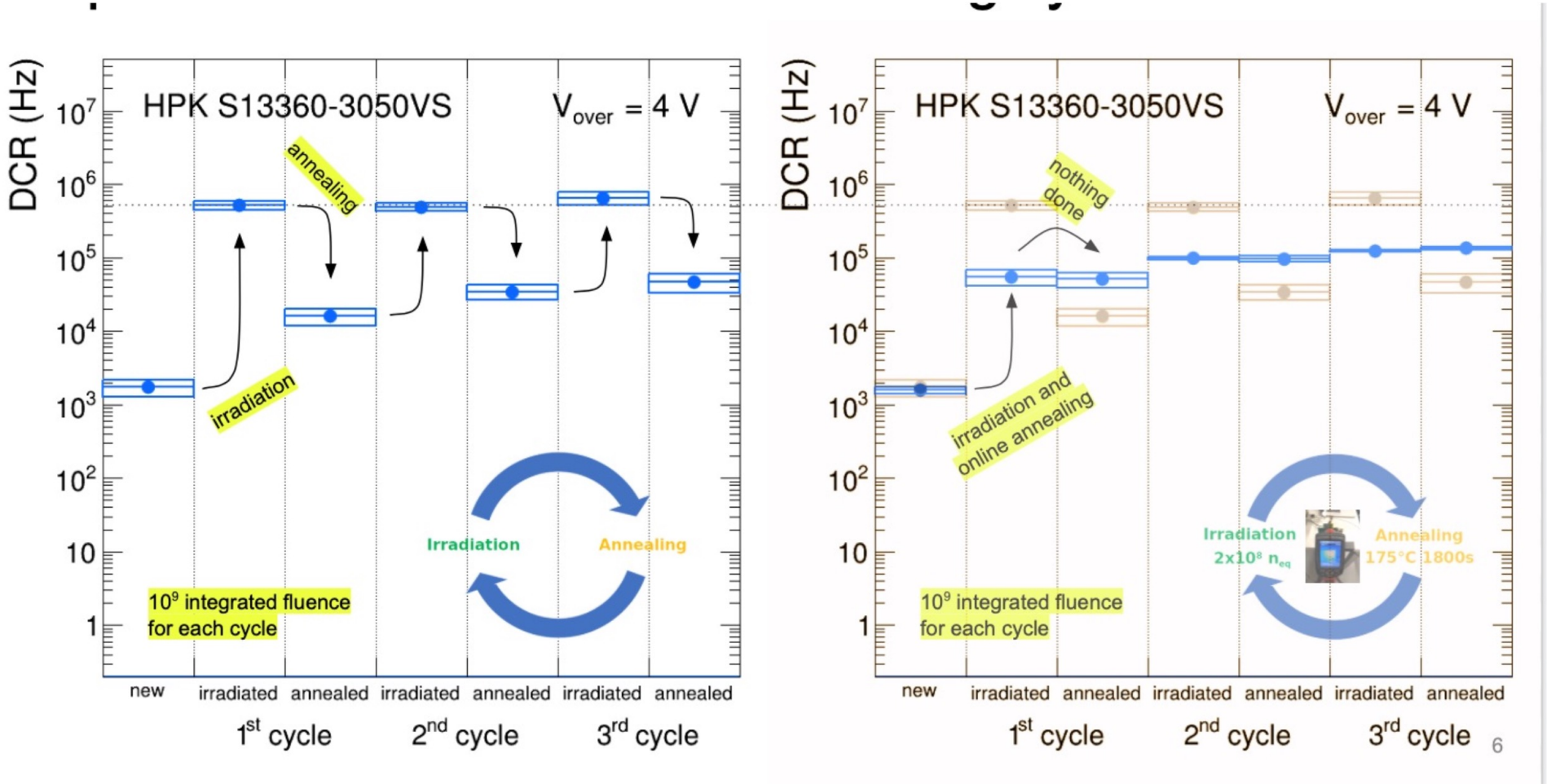
The **dRICH noise rule of thumb**:
“Every 20 kHz rate/sensor we have in 1 ns 1 noise hit / sector”

But 300 kHz is now too much…

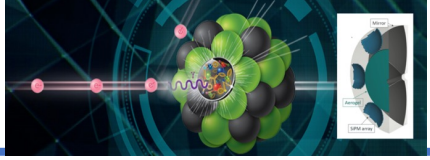


online annealing keeps DCR lower

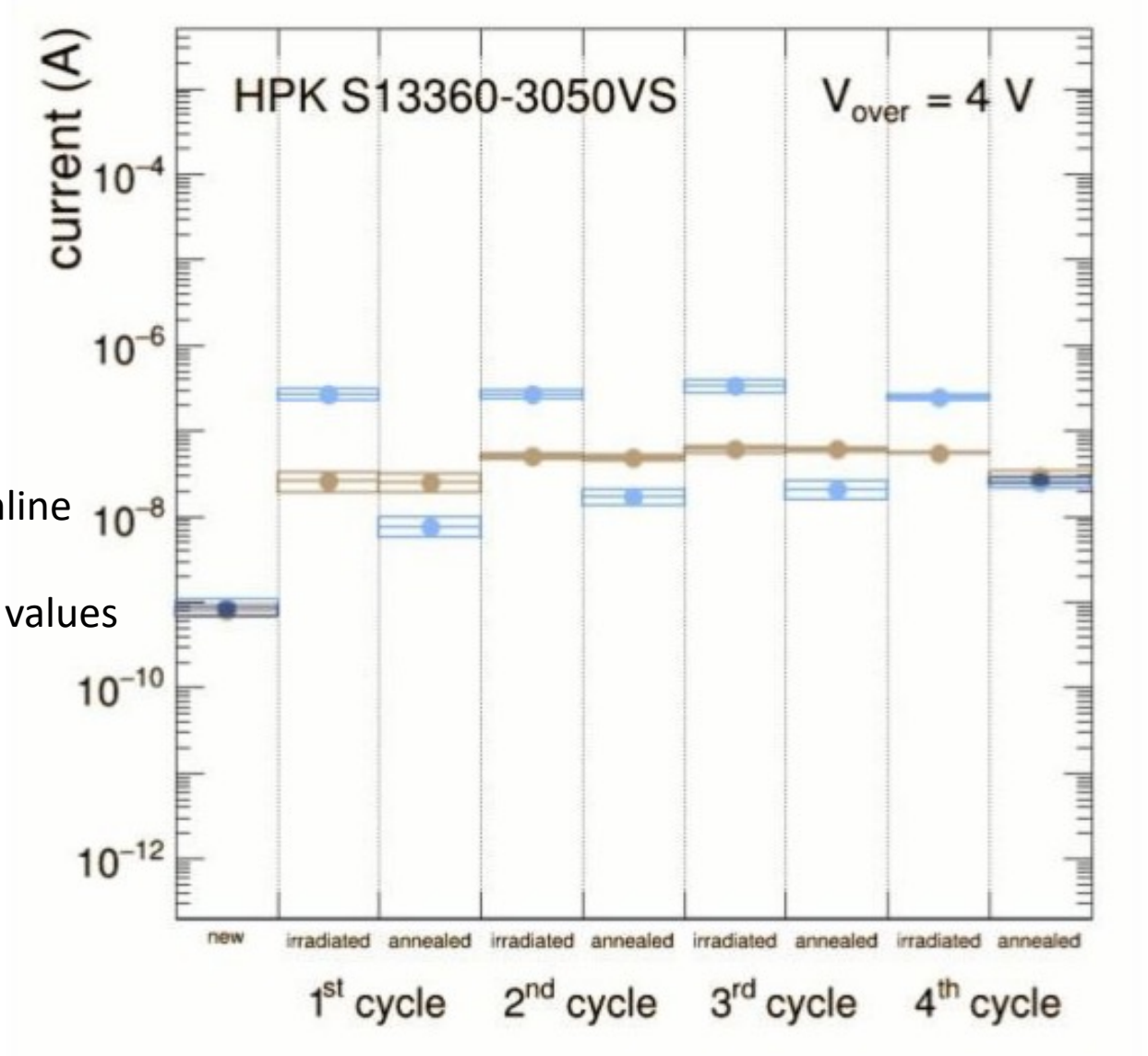




New



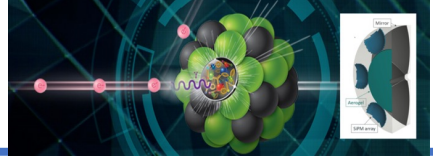
We curb noise rate with online Annealing
We go back to DCR “oven” values at the end

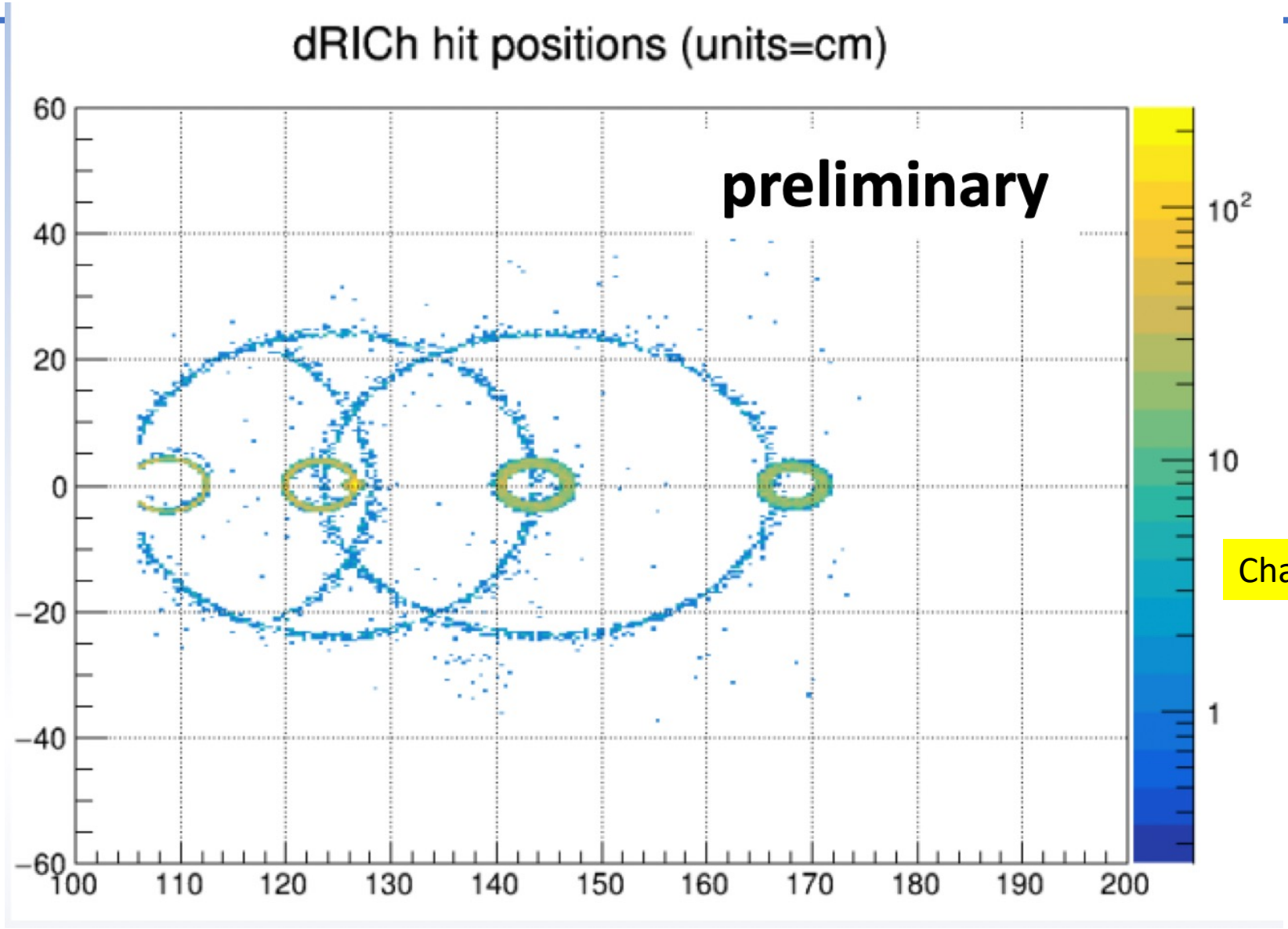


Plot from Roberto

Not shown at ePIC meeting,
Literally “cooked” during the meeting by Luigi and Nicola @BO

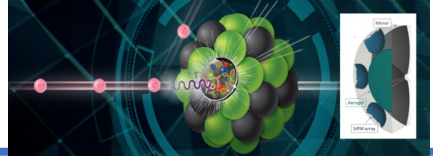
We need to add the DCR and check!





Chandra

Requests, Outlook and ToDO



Ask:

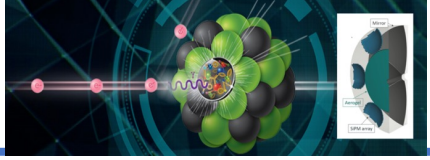
Produce images + background at increasing rate find the limit! [and: we might end up at **20 (signal) + 3 (noise) in the sector**]
“simple file format”
INFN groups with AI algorithm starting in February very much useful “sector matrix” (+ time)

@Luigi/Chandra: let’s do it….

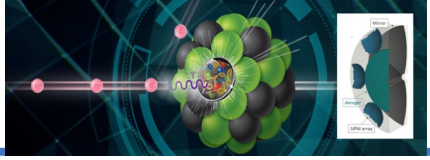
Comments
(+ news about Ejiit)
(+ comment about GSiPM)

My plan
+ Pietro TODO
- Advertise in DAQ group + ePIC at large (move from 1.8 Tbps detector to 200 Gbps to detector to start with…)
- Retro feedback on DAQ design + ALCOR
- Make serious estimates of radiation damage (working with background group)

Backup



Throughput (I)

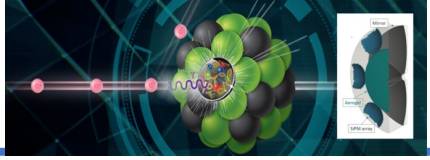


- ALCOR clock 320 MHz ma dati serializzati a frequenza DDR a gruppi di 8 canali → le parole di 32 bit sono encoded a 40 bit
- Questo porta a un limite massimo di 640 Mb/s che corrisponde a un nassimo rate su 8 canali di 16 MHz → quindi siamo ora limitati a 2 MHz su singolo canale (averaged su 8)

Starting to play with numbers and known limitations:
- Below no TOT
- Note that 10 Gbps limitation might be overcome (20 Gbps seems reachable even if rad. Tol. might be problem) to be investigated
- Exploit timing reduction

Singolo canale	serializer 8 canali ALCOR column				
5 MHz	**16 MHz**	8 ch	→ ALCOR-64	FPGA (16 ALCOR-64).	Timing reduction Opt Link
	2 MHz	64 MB/s.	→ 512 MB/s	8 GB/s → 64 Gbps	1 10 Gbps
300 kHz	300 kHz	9,6 MB/s.	→ 76,8 MB/s	1,2 GB/s → 9,8 Gbps	1 10 Gbps
300 kHz	300 kHz	9,6 MB/s.	→ 76,8 MB/s	1,2 GB/s → 9,8 Gbps	3 **3,3 Gbps**

Throughput (II)



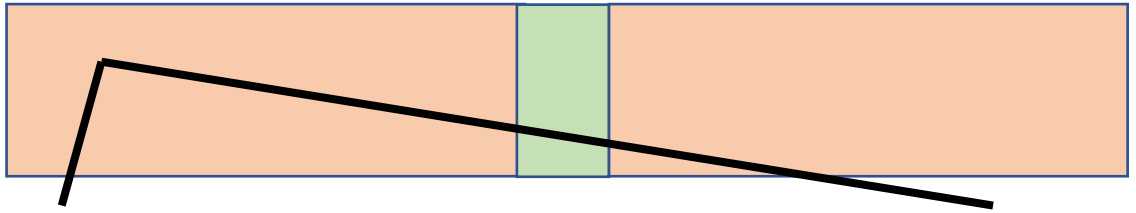
ALCOR test pulse (in inverse polarity) can act as “inhibit” of the digitalization. This could help greatly to reduce data throughput
Note EIC beam bunch timing presentation by Todd (Sep. 2022)

Short summary:

EIC Orbit	**12.78 usec**
Bunch spacing (Nb 290)	40.599 ns
Bunch spacing (Nb 1160)	10.150 ns
Gap length	1.01 usec
Collision spread (bunch length)	23-30 ps (ESR) 250-200 (ps) HSR

Notes:

- we will need to implement disable during gap region which is sizeable (8% data reduction ‘for free”)
- Bunch crossing every 10 ns! With a bunch length of 250 ps if we could select just 1 ns data reduction by a factor 10 before serializing stage in ALCOR



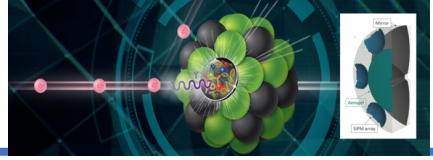
Critical measurement to be done in Turin:

- How react ALCOR to such “short” shutter cycles?
- What happens to the TOT measurement?
- What happens if trailing edge is ON and leading edge was OFF

Note LHCb is thinking something very similar with FastRich

If it works then requirement on precise clock alignment / phase shift inside FPGA sending shutter to ALCORs

Throughput (III)



Singolo canale	serializer 8 canali ALCOR column	8 ch → ALCOR-64	FPGA (16 ALCOR-64). Timing reduction	Opt Link
5 MHz	**16 MHz** → **2 MHz**	64 MB/s. → 512 MB/s	8 GB/s → 64 Gbps 1	10 Gbps
300 kHz	300 kHz	9,6 MB/s. → 76,8 MB/s	1,2 GB/s → 9,8 Gbps 1	10 Gbps
300 kHz	300 kHz	9,6 MB/s. → 76,8 MB/s	1,2 GB/s → 9,8 Gbps 3	**3,3 Gbps**
5 MHz	500 kHz	16 MB/s. → 64 MB/s	1,0 GB/s → 8 Gbps 1/0.92	**7,4 Gbps**

Hardware shutter reduces by factor 10

Orbit gap

The implementation of the shutter might reduce annealing cycles by a factor 10
Question for ASIC experts: will it really work this way?
Question for ALL: we will might have in 1 ns a 5 MHz DCR but… we will then still see the rings?
→ simulation with flat noise is a must!!