High Energy Physics Acronym Dictionary

SCAN ME

A Large Ion Collider Experiment

Simulation studies for soft photon measurements with the Forward Conversion Tracker for ALICE 3

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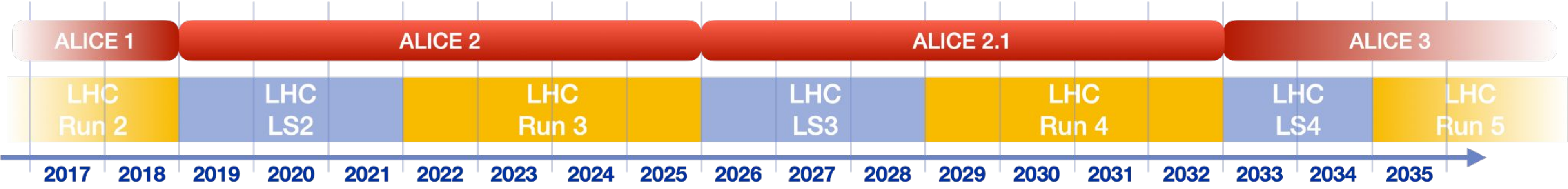
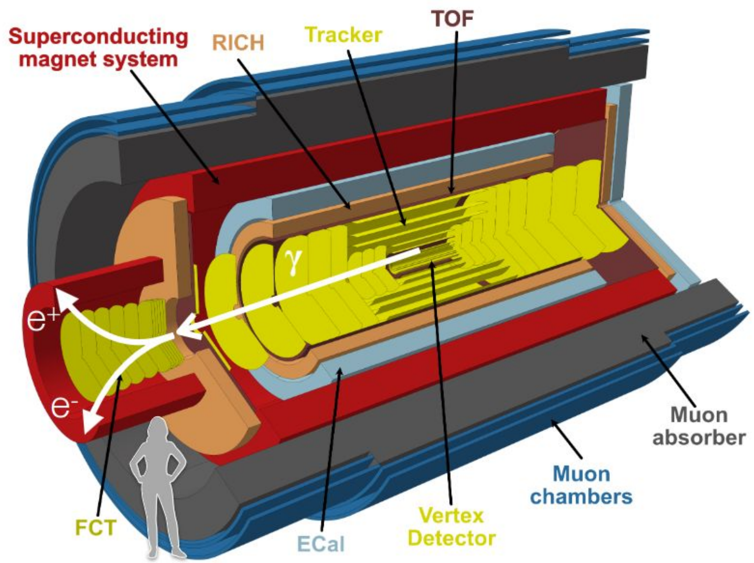
ALICE 3 - A Large Ion Collider Experiment 3





Scheduled for run 5 - 2035

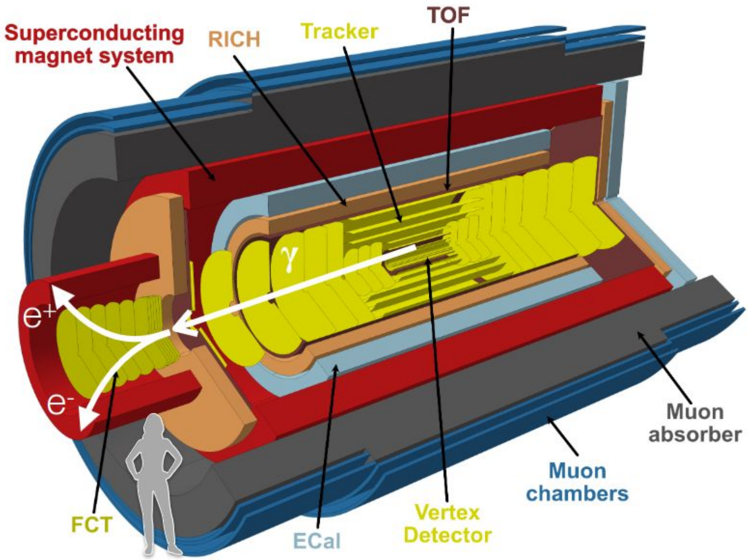
$$\sqrt{S_{NN}} = 14\text{TeV} \qquad L_{pp} = 3.0 \times 10^{32} (\text{cm}^{-2}\text{s}^{-1})$$

The luminosity will be 2 orders of magnitude lower than CMS and ATLAS, but this allows for the first layer to be 5 mm away from the interaction point.

More of ALICE 3 and its physics program:

LOI: https://arxiv.org/pdf/2211.02491.pdf

ALICE 3 - A Large Ion Collider Experiment 3



Vertex detector: First tracking layer 5 mm away from interaction point inside the beam pipe

TOF: Time of Flight - particle identification over the full acceptance of $|\eta| < 4$

$$\eta \equiv -\ln\left[\tan\left(\frac{\theta}{2}\right)\right]$$

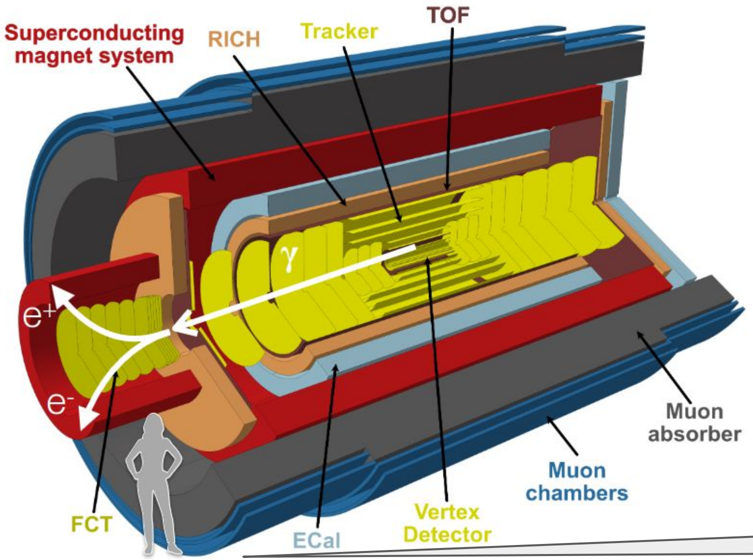
RICH: Ring-Imaging CHerenkov detector - extends the PID capabilities of the TOF

Tracker: All-silicon pixel trackers to track charged particles

ECal: Electromagnetic Calorimeter - detects photons (e.g. direct photons)

Muon chambers: Detects muons

ALICE 3 - The Forward Conversion Tracker



~9 consecutive silicon discs with pixel trackers

The FCT will measure soft photons in the forward direction via photon conversion

$$-3 > \eta > -5$$

Measure photon spectrum predicted by Low's theorem and shine light on the soft photon puzzle

p_T in the range of 1 to 10 MeV/c

The FCT will have a dipole magnet instead of a solenoid for better tracking

The forward region

ALICE

Low's theorem predicts the soft photon spectrum. What is a soft photon?

The transverse momentum of the photon must be small in comparison to the scales in the production process, but the photon must still have enough energy to convert into an electron and positron.

$$E_\gamma = p_T \cosh(\eta)$$

$E_\gamma = 100$ MeV:

η	3	4	5
p_T (MeV/c)	10	3.7	1.3

For photon conversions to be measurable, we estimate the energy of the photon must at least be 10 MeV, otherwise tracks in the detector are hardly visible and energy loss due to multiple scattering effects are too prominent.

And so the region for the Forward Conversion Tracker was chosen

$$-3 > \eta > -5$$

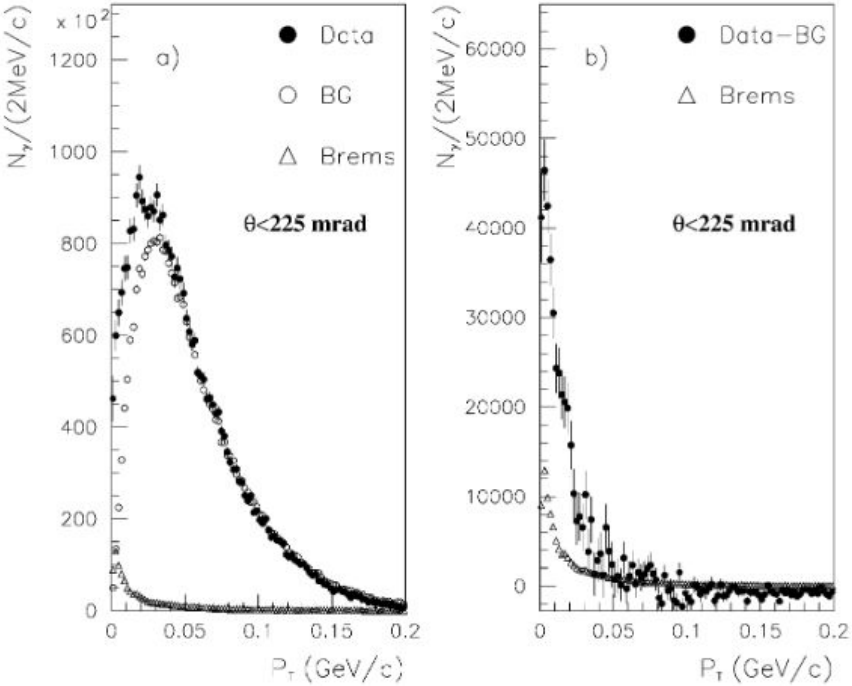
The FCT to solve the Soft photon puzzle

WA102 experiment in 2002

Excess of 4.1+-0.8 measured on top of what was predicted by Low's theorem

b) same as a), but with background subtracted

A. Belogianni et al. / Physics Letters B 548 (2002) 129–139



Most previous experiments show an excess of a factor of 4-8

Experiment	Year	Collision energy	Photon p_T	Photon / Brems Ratio	Detection method	Reference (click to go to paper)
π^+p	1979	10.5 GeV	p_T < 30 MeV/c	1.25 ± 0.25	bubble chamber	Goshaw et al., Phys. Rev. Lett. 43, 1065 (1979)
K^+p WA27, CERN	1984	70 GeV	p_T < 60 MeV/c	4.0 ± 0.8	bubble chamber (BEBC)	Chliapnikov et al., Phys. Lett. B 141, 276 (1984)
π^+p CERN, EHS, NA22	1991	250 GeV	p_T < 40 MeV/c	6.4 ± 1.6	bubble chamber (RCBC)	Botterweck et al., Z. Phys. C 51, 541 (1991)
K^+p CERN, EHS, NA22	1991	250 GeV	p_T < 40 MeV/c	6.9 ± 1.3	bubble chamber (RCBC)	Botterweck et al., Z. Phys. C 51, 541 (1991)
π^-p, CERN, WA83, OMEGA	1993	280 GeV	p_T < 10 MeV/c (0.2 < E_γ < 1 GeV)	7.9 ± 1.4	calorimeter	Banerjee et al., Phys. Lett. B 305, 182 (1993)
p-Be	1993	450 GeV	p_T < 20 MeV/c	< 2	pair conversion, calorimeter	Antos et al., Z. Phys. C 59, 547 (1993)
p-Be, p-W	1996	18 GeV	p_T < 50 MeV/c	< 2.65	calorimeter	Lissauer et al., Phys.Rev. C54 (1996) 1918
π^-p, CERN, WA91, OMEGA	1997	280 GeV	p_T < 20 MeV/c (0.2 < E_γ < 1 GeV)	7.8 ± 1.5	pair conversion	Belogianni et al., Phys. Lett. B 408, 487 (1997)
π^-p, CERN, WA91, OMEGA	2002	280 GeV	p_T < 20 MeV/c (0.2 < E_γ < 1 GeV)	5.3 ± 1.0	pair conversion	Belogianni et al., Phys. Lett. B 548, 122 (2002)
pp, CERN, WA102,	2002	450 GeV	p_T < 20 MeV/c (0.2 < E_γ < 1 GeV)	4.1 ± 0.8	pair conversion	Belogianni et al., Phys. Lett. B 548, 129 (2002)
$e^+e^- \rightarrow$ 2 jets CERN, DELPHI	2006	91 GeV (CM)	p_T < 80 MeV/c (0.2 < E_γ < 1 GeV)	4.0 ± 0.3 ± 1.0	pair conversion	DELPHI, Eur. Phys. J. C 47, 273 (2006)
$e^+e^- \rightarrow \mu^+\mu^-$ CERN, DELPHI	2008	91 GeV (CM)	p_T < 80 MeV/c (0.2 < E_γ < 1 GeV)	~ 1	pair conversion	DELPHI, Eur. Phys. J. C57, 499 (2008)

Overview made by Klaus Reygers

Low's theorem

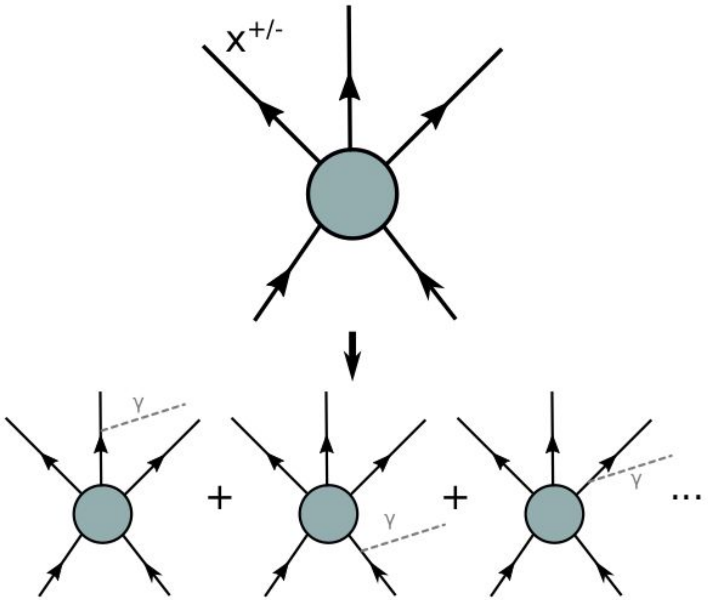
Low's theorem predicts the inner bremsstrahlung spectrum in a process independent way for m to n scattering processes

Condition: E_γ or p_T must be small in comparison to the scales in the process

$$\langle out|a_+^{out}(\vec{q})\mathcal{S}|in\rangle = e\Big[\sum_{k=1}^{m}\frac{Q_k^{out}p_k^{out}\cdot\varepsilon^+}{p_k^{out}\cdot q} - \sum_{k=1}^{m}\frac{Q_k^{in}p_k^{in}\cdot\varepsilon^+}{p_k^{in}\cdot q}\Big]\langle out|\mathcal{S}|in\rangle + \mathcal{O}(q^0)$$

Andrew Strominger, arXiv:1703.05448 eq 2.9.1. p 30

So by evaluating the scattering processes without photons, you can get the inner bremsstrahlung spectrum without having to calculate all the underlying processes



Low's theorem - for a single event

For a single event, Low's theorem predicts

$$\frac{d^3N}{dE_\gamma d\theta d\phi} = -\frac{\alpha}{2\pi^2}\cos(\theta/2)\sin(\theta/2)E_\gamma\sin(\theta)\left(\sum_i \eta_i q_i \frac{P_i}{P_i K}\right)^2 \sim \frac{1}{E_\gamma}$$

η: prefactor (+/-1)
q: charge
P: particle four momentum

K: photon four momentum
θ: Polar angle
ϕ: Azimuthal angle

Average number of photons per event when integrated over E, eta and phi

Low Photon Generator

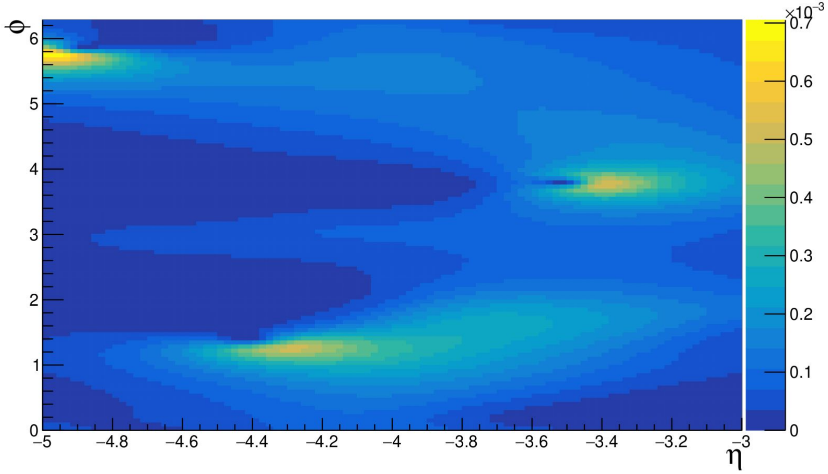
To generate collisions of particles, PYTHIA 8.3 is used

But PYTHIA does not generate the inner bremsstrahlungs spectrum, so we needed an additional generator

Narrow peaks + Dead cone effect + Interference effects produce structures on small scales
-> Emission at finite angle

It fills a 100 x 100 grid which tells you the amount of photons that are emitted in a certain pseudorapidity and azimuthal region.

It then samples from this distribution to generate photons with corresponding energy, pseudorapidity and azimuthal angle.



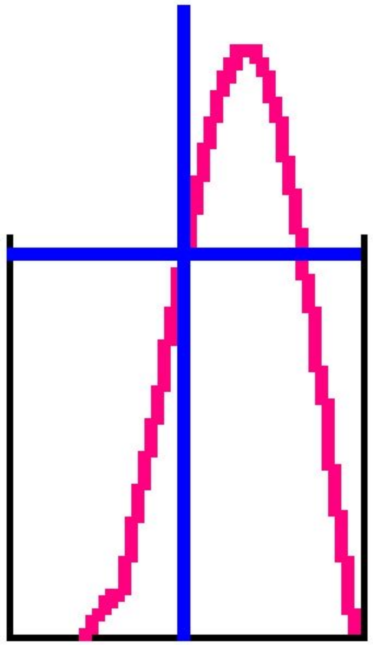
Random sampling

The function is very “peaked”, especially for electrons. To account for the shape of the function, the sampling follows the recipe:

1) Propose a bin based on the cumulative integral scaled to 1
2) Rejection sample in the area of the bin for phi and eta
    a) Accept -> Done
    b) Reject -> Select new bin and repeat

This then gives you sampling according to the analytical pdf.

Peaked bin example



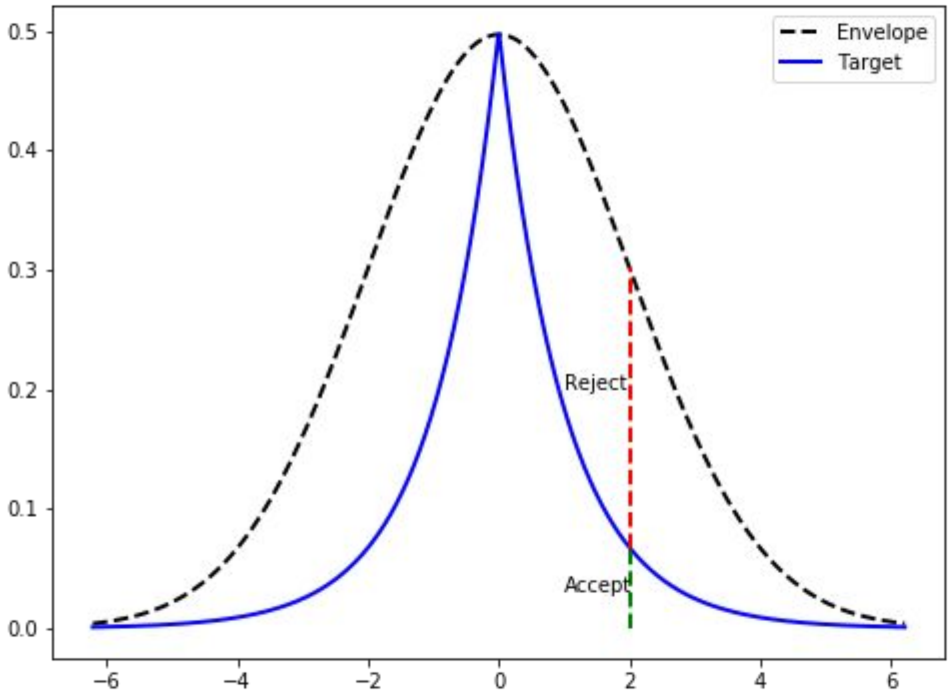
Rejection sampling

Rejection sampling
- Target Function
- Envelope function (proxy)

For the Low Photon Generator
- The envelope function is flat.
- The height of the envelope function is selected to be 3 times the value of the proposed bin.

The value of 3 is chosen because the peaks inside the region of the proposed bin all have values smaller than 3 times the center bin value.

This also gives you an accept ratio of ~0.33 which is computationally doable.



We have our signal (simulated)!

Now to find it...

What does a simulated event look like?

We have our collision, handled by PYTHIA and the Low Photon Generator

-

The generator

Then the final particles get propagated through the detector setup with GEANT4

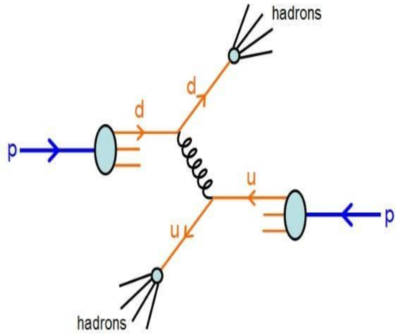
-

The engine

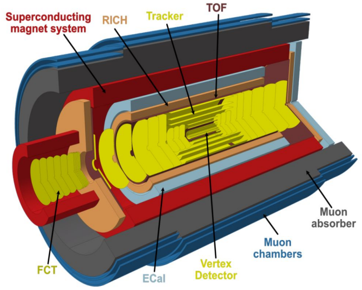
The detector readout is done according to the hits

-

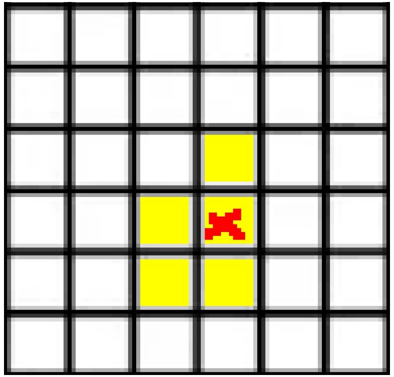
The digitizer



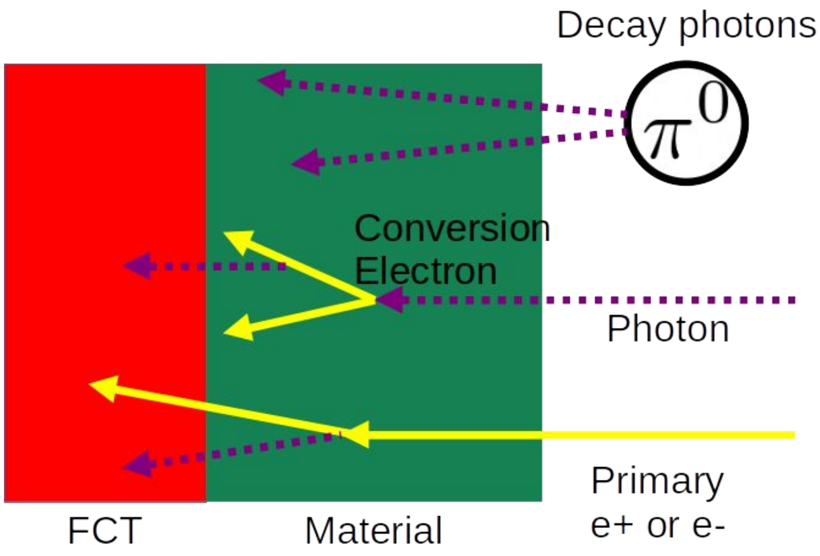
Particle stack



Hits



Background to arrive at the FCT



Background from material interactions will be very prominent

Reminder:

$$1 < p_T < 10\,\mathrm{MeV}/C$$

$$-3 > \eta > -5$$

$$E_\gamma > 10\,\mathrm{MeV}$$

Expected signal to arrive at the FCT

Low = 1 / 0.033 pT

Analytic Low signal, not actual simulation

Primary particle emission (PYTHIA):

$\pi^0 \rightarrow \gamma\gamma \quad \eta \rightarrow \gamma\gamma$

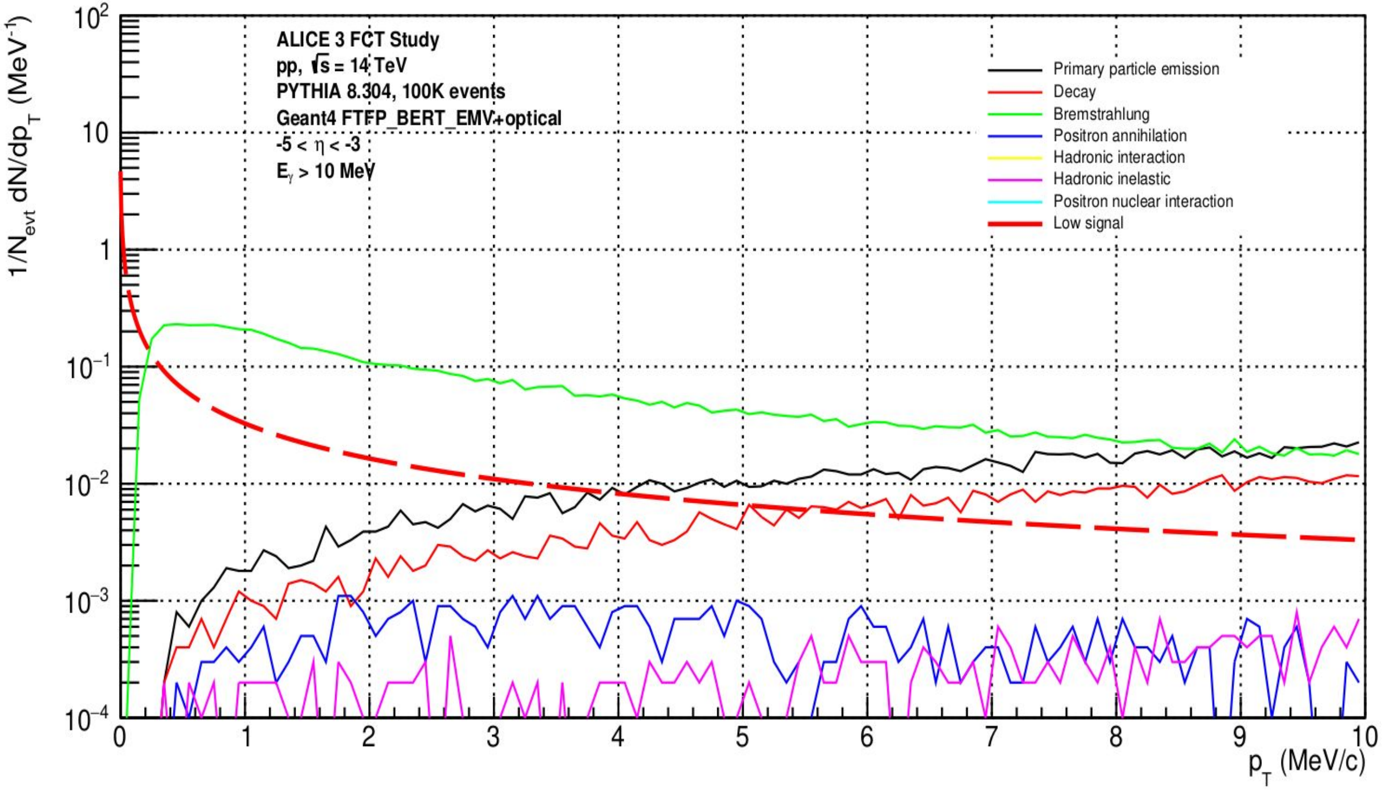
- Direct photons

Decay (GEANT4):

$k_s^0 \rightarrow \pi^0\pi^0 \rightarrow \gamma\gamma\gamma\gamma$

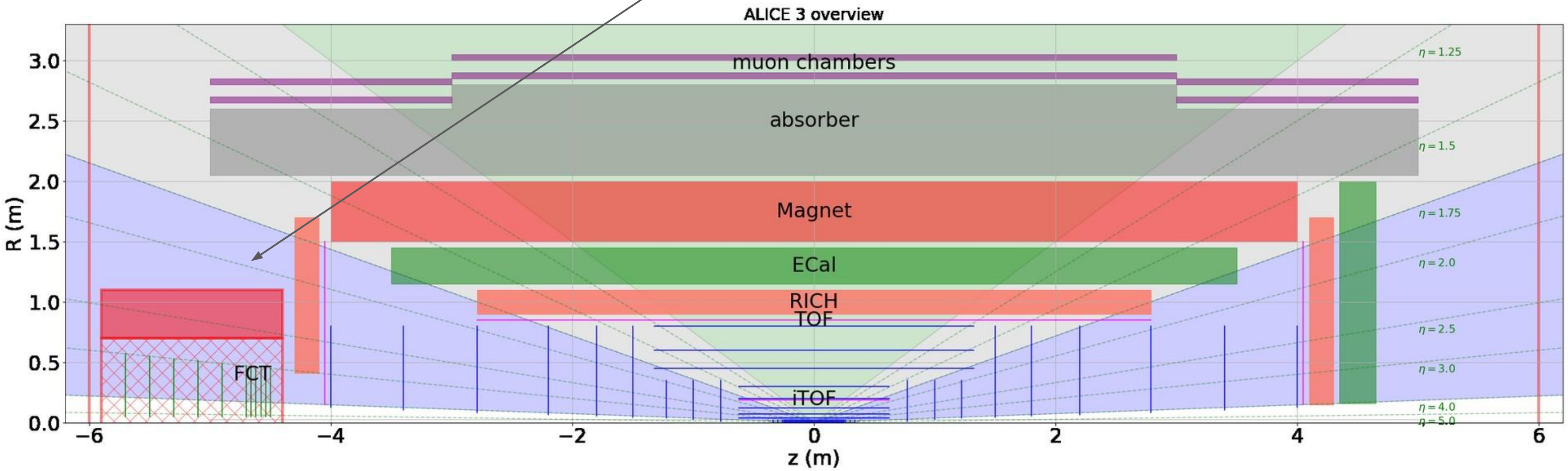
Bremsstrahlung:

- Material interactions



The Forward Conversion Tracker

The FCT with a
dipole magnet



The Forward Conversion Tracker - Material in front

O2 naming convention

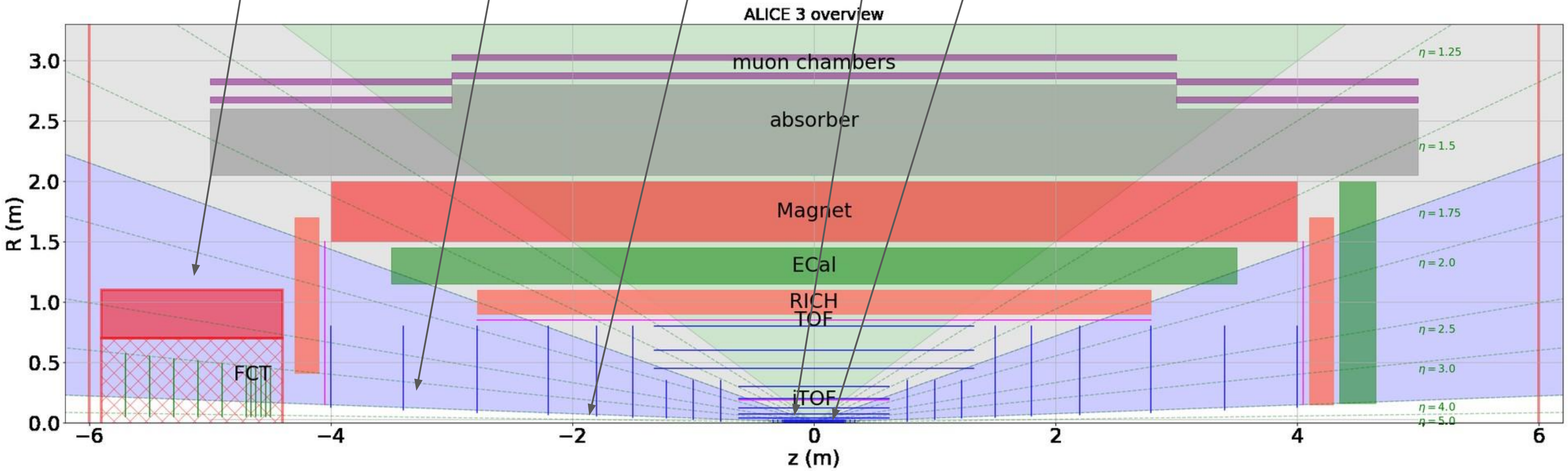
The FCT with a dipole magnet

FT3 - Forward discs

A3IP - Beam pipe

TRK - The barrel layers

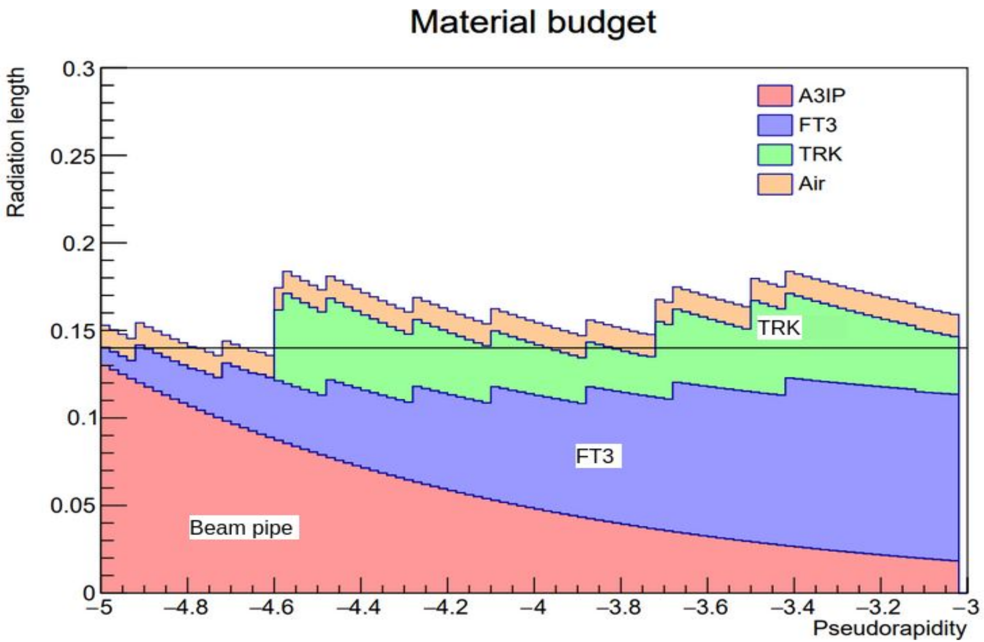
IRIS tracker - Inner tracker

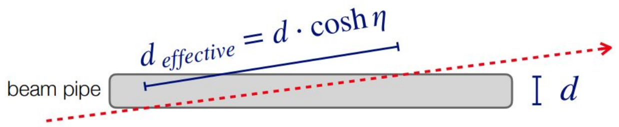


Material budget in front of the FCT - As per the LOI

LOI: https://arxiv.org/pdf/2211.02491.pdf

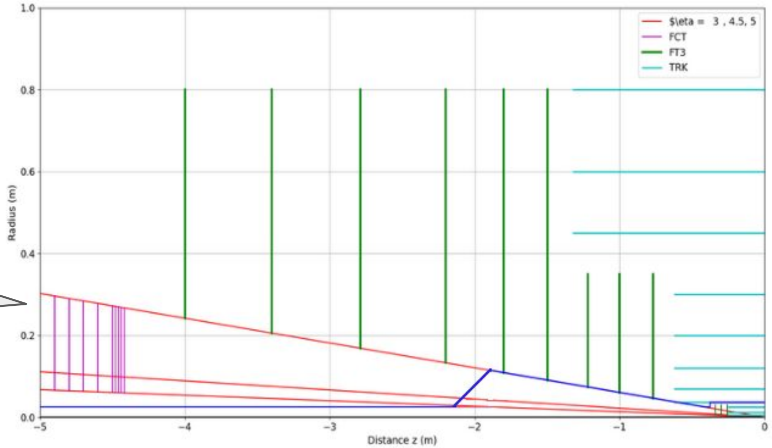
- Big contribution from the beam pipe (A3IP)
  - becomes larger at higher pseudorapidity
- The FT3 (disc layers) cover the FCT
- The barrel layers still cover some of the FCT
- Air could be replaced by helium balloons
- Services, like the vacuum vessel, are not in this plot yet

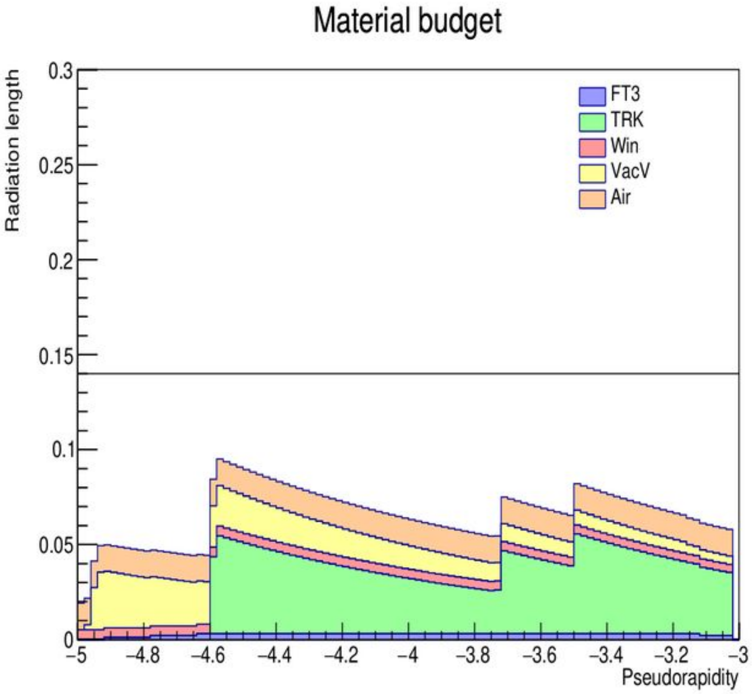




Material budget in front of the FCT - Ideal scenario

Artist impression





For this setup:

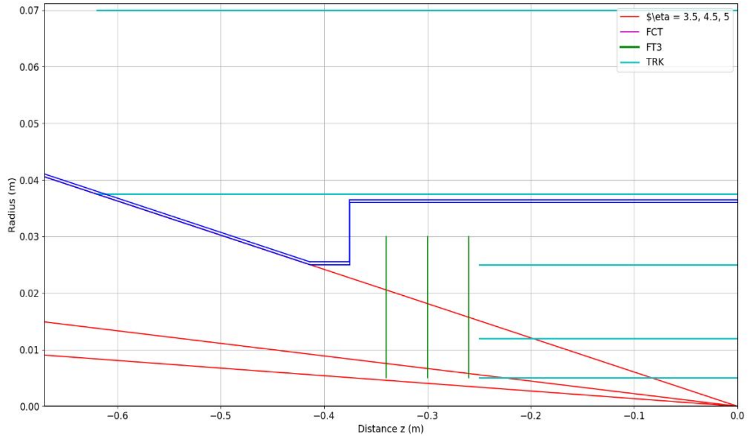
- The FT3 (disc layers) do not contribute
- There is a window in the beam pipe to allow for less effective material of the beam pipe
- The TRK (barrel layers) still contribute

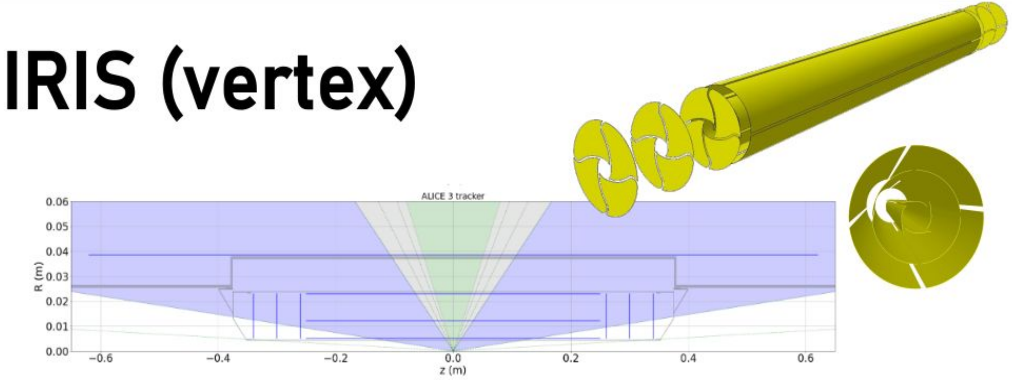
With these optimizations there will be room for the services to be added

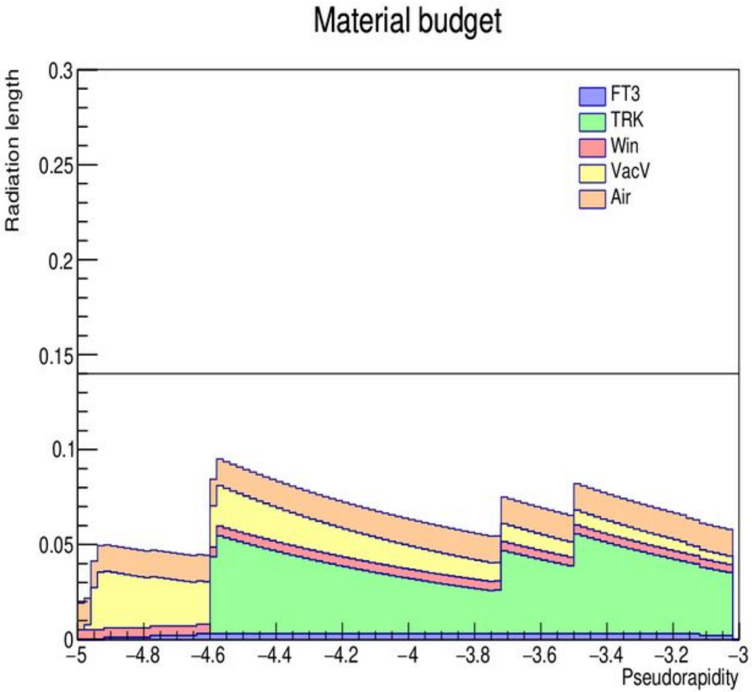
FCT in the pseudorapidity -3 to -5

Material budget in front of the FCT - Ideal scenario

Artist impression







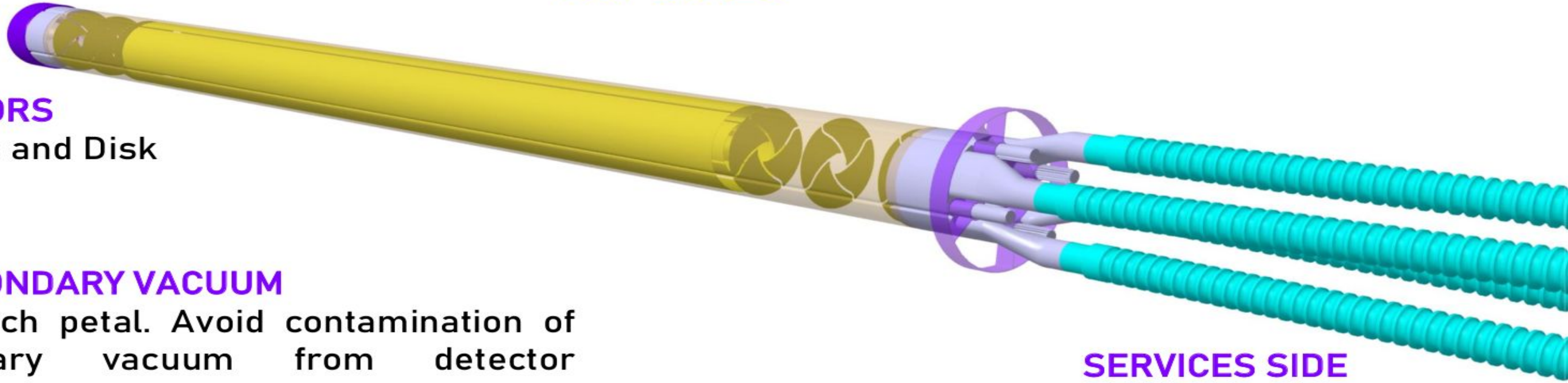
FCT in the pseudorapidity -3 to -5

IRIS TRacker - The petals

Iris tracker: Petals

IRIS is constituted by 4 petals; each petal consists in a vacuum case that contains sensors and are independently connected to services.

4 x PETALS



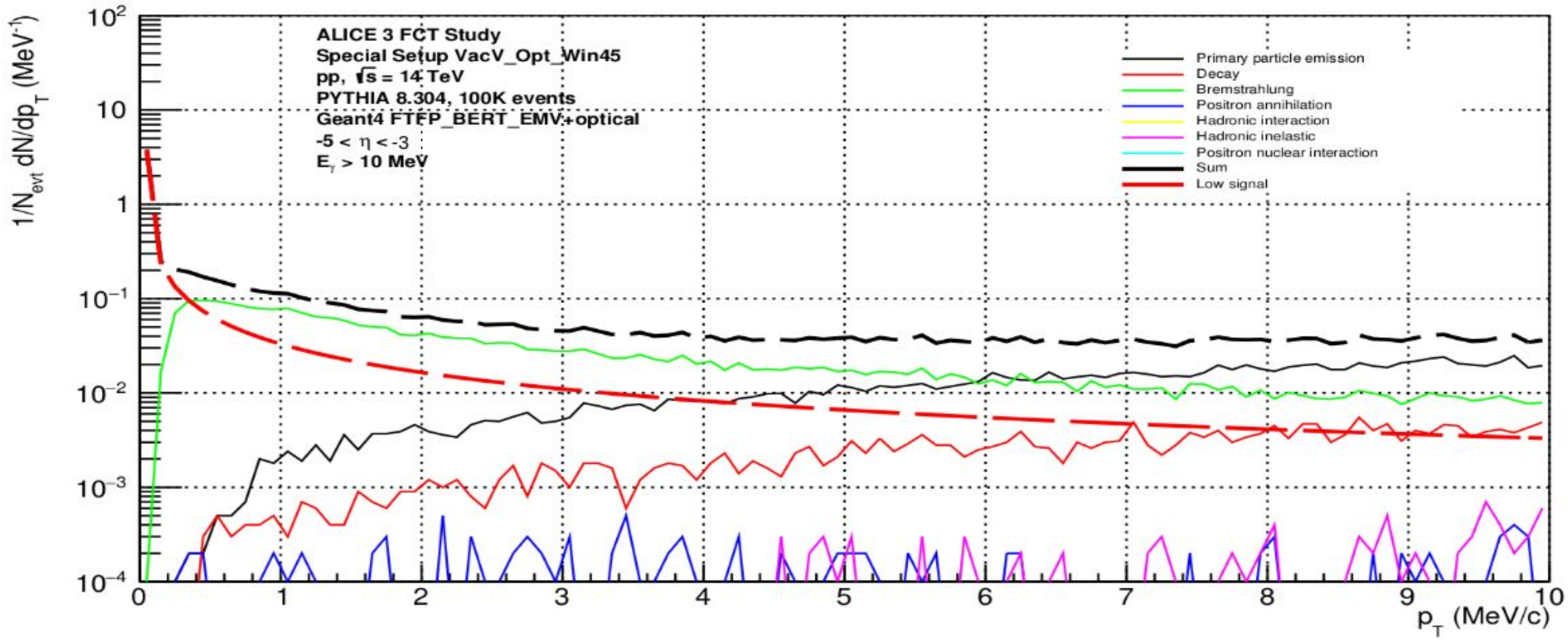
SENSORS
Layers and Disk

SECONDARY VACUUM
in each petal. Avoid contamination of primary vacuum from detector outgassing

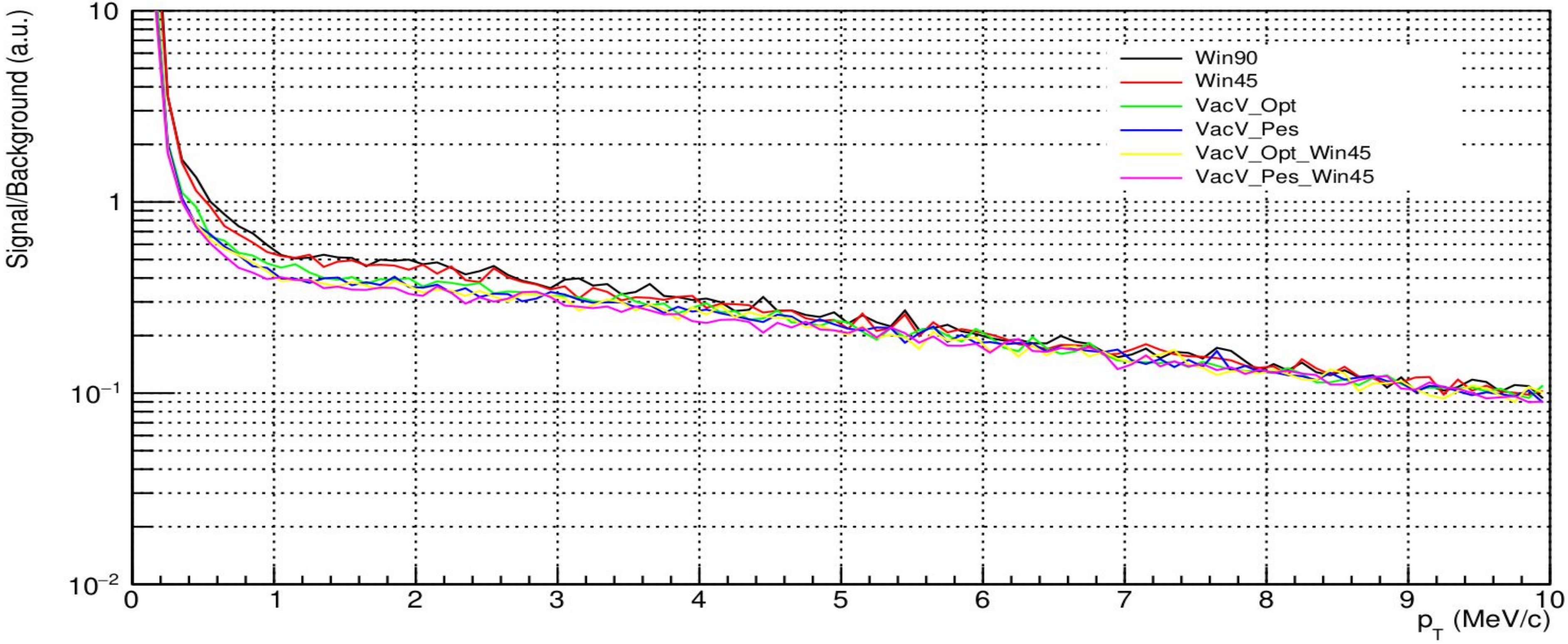
SERVICES SIDE
All services from one side
Power, Data, Cooling, Rotation

Normalized photon distribution to reach the FCT

Pseudorapidity -3 to -5, Vacuum Vessel Optimistic + Diagonal Window



Signal over background - pseudorapidity -3 to -5



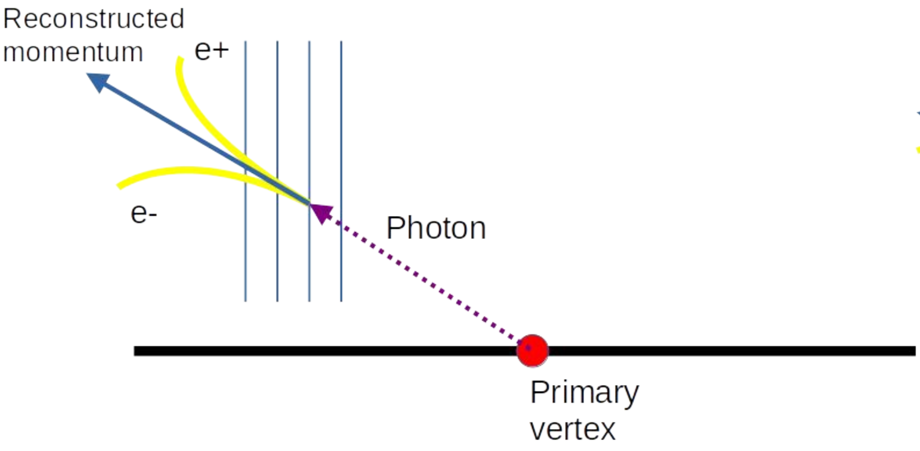
Even more background reduction - cuts on the data

- Cut on the pointing angle

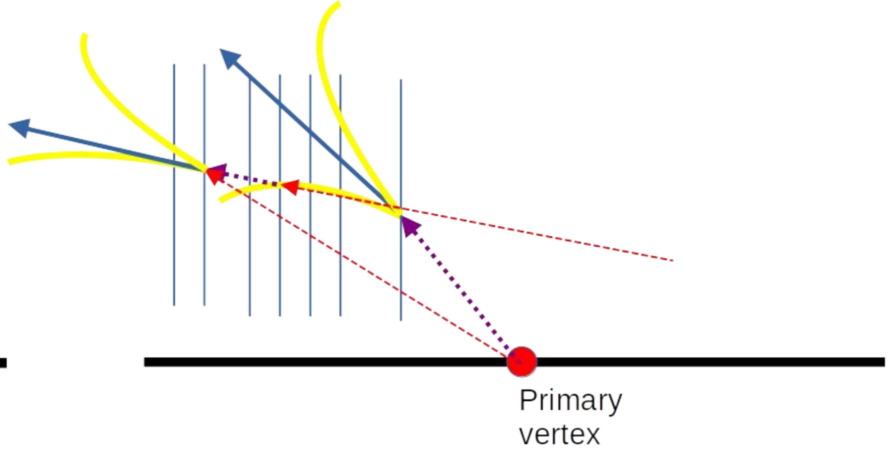
Pointing angle

The pointing angle is the angle between the emitted photon and its reconstructed momentum

Pointing angle zero



Pointing angle not zero
(of the second reconstructed momentum)



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  - Inner bremsstrahlungs photons have a pointing angle of 0
  - Requires a good position resolution

Even more background reduction - cuts on the data

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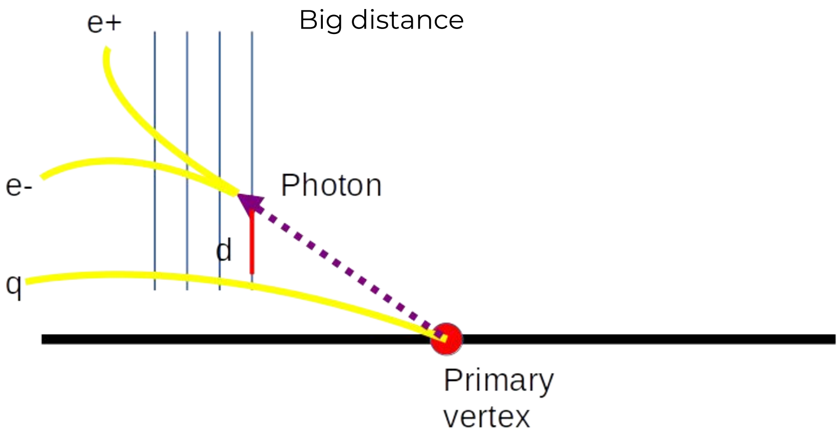
- Cut on the distance between photon and charged particle

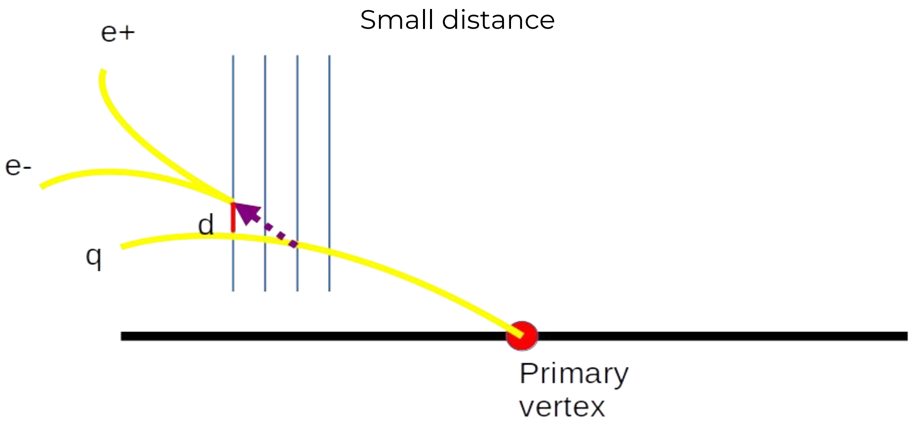
The distance between photons and charged particles

Cut on the distance between the charged particle and the photon

Inner bremsstrahlung photon



Material interaction bremsstrahlung



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  - Inner bremsstrahlungs photons will be emitted close to the charged particle initially, but the magnetic field will bend the charged particles away

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  - e+/e- make a lot of bremsstrahlung
  - Requires ePID, so an electromagnetic calorimeter

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- As discussed before, reduction of material in front of the FCT
  - Expensive
  - Reshaping of the beam pipe is difficult

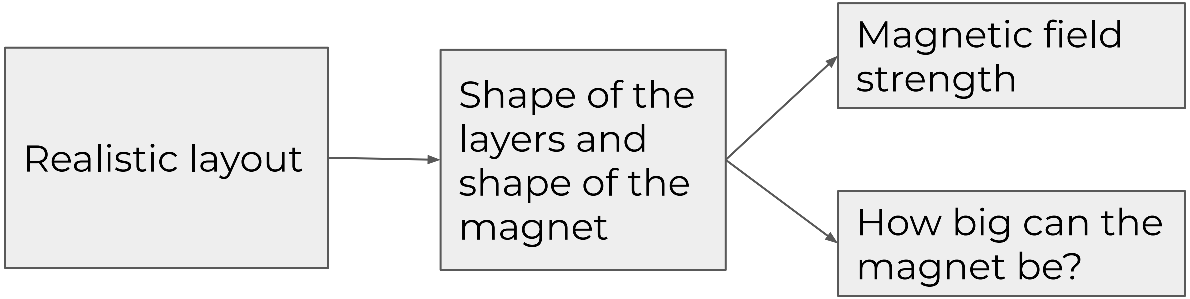
Investigation into background reduction is ongoing

But now possible via full event by event simulations

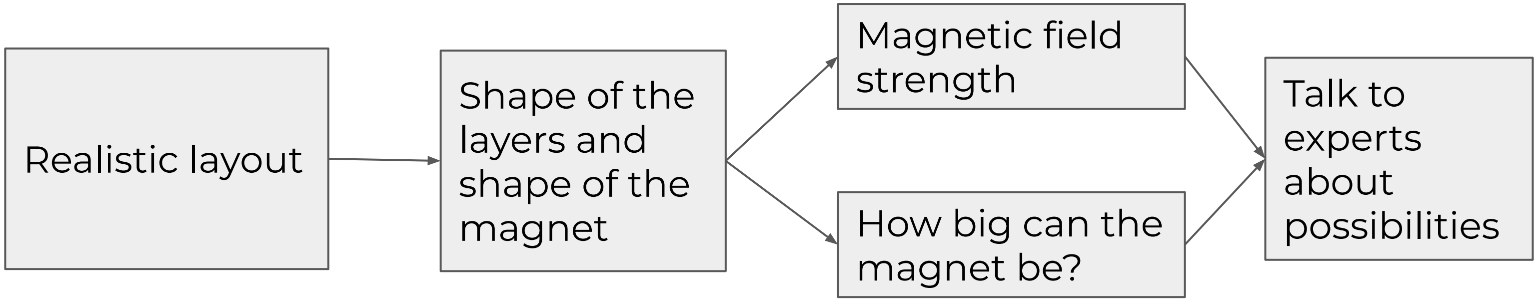
The Forward Conversion Tracker

Layout and magnetic field strength optimizations

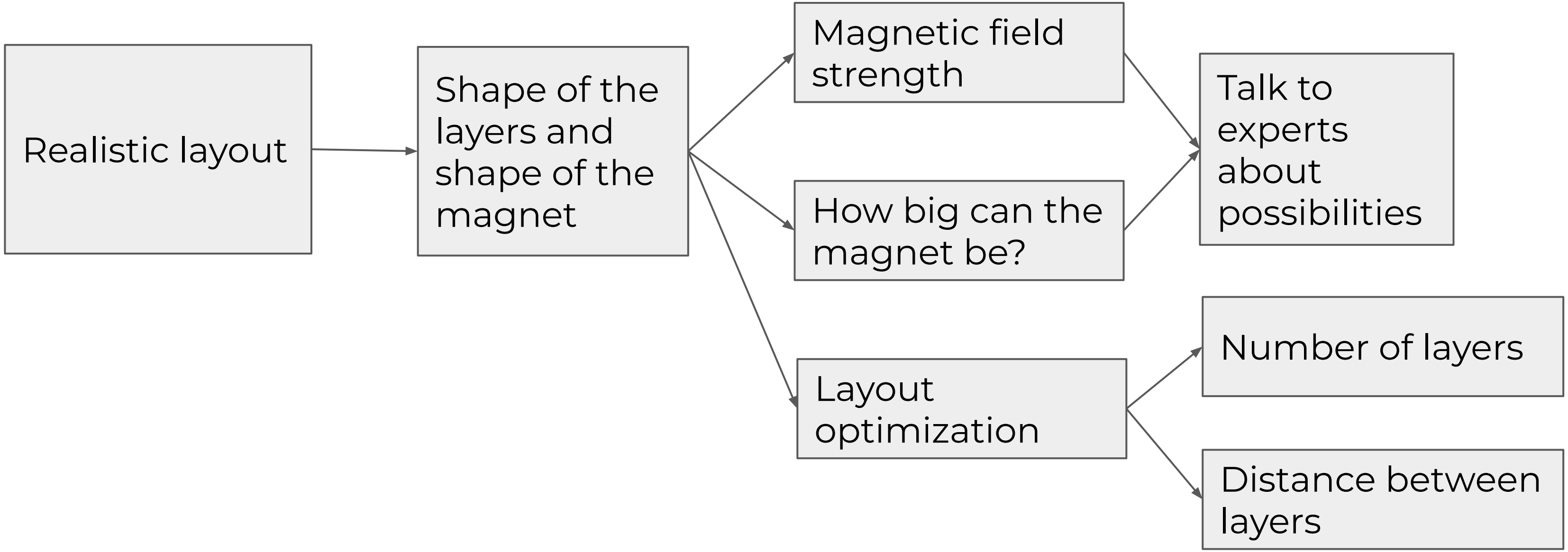
The Forward Conversion Detector - Design



The Forward Conversion Detector - Design



The Forward Conversion Detector - Design



Conclusion

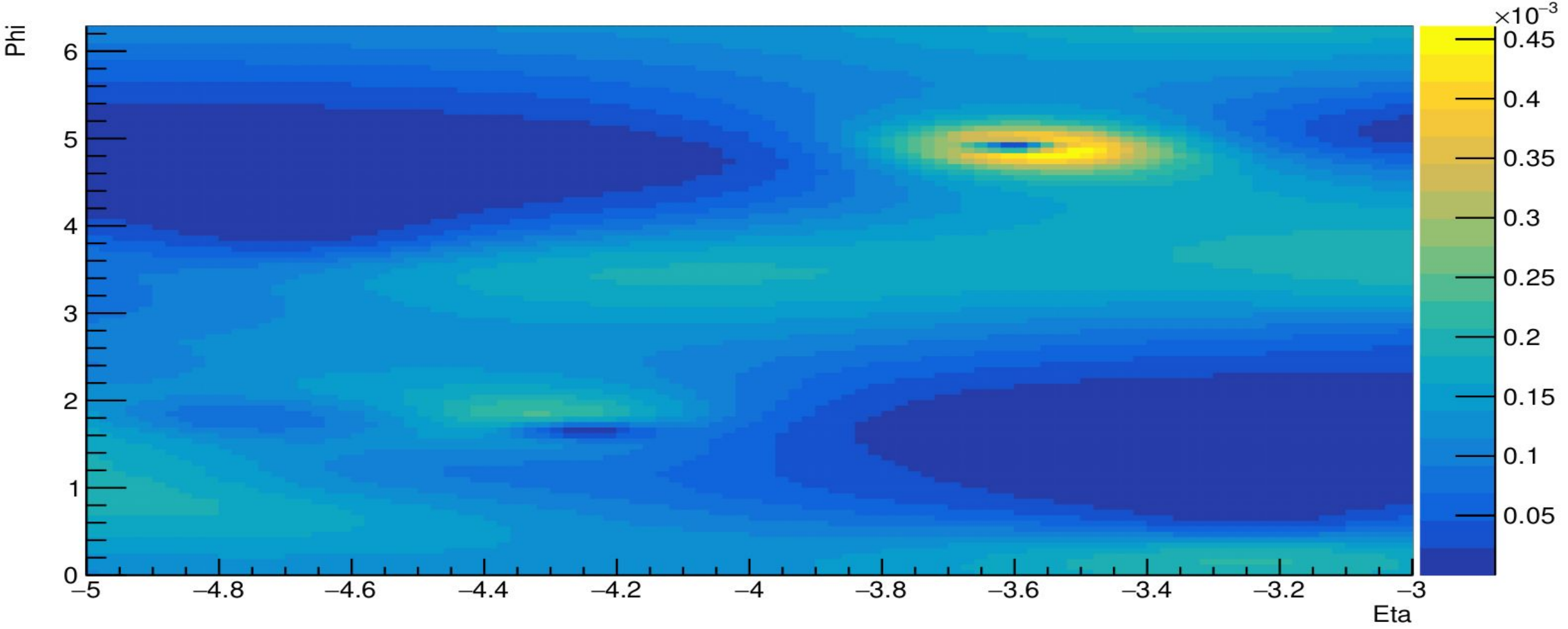
- The Low Photon Generator makes event by event studies possible

- Reduce the background by cutting on the data
    - Pointing angle
    - Distance charged particle and photon
    - Select events without primary e+/e-
    - Reduce material in front of the FCT to reduce material interactions

- Optimize the design of the FCT
    - Magnetic field
        - Strength
        - Size
    - Layers
        - Distance between the layers
        - Number of layers

Backup slides

More classical dead cone



Contribution from the vacuum vessel and services

Services not included

Window
0.5mm - Thickness
Beryllium - Material
45 / 90 - Angle (deg) wrt to bp
Same pseudorapidity coverage as FCT

Horizontal Vacuum Vessel Wall
0.15mm - Thickness
Beryllium - Material

Vertical Vacum Vessel Wall
0.15mm - Thickness (Optimistic)
0.5mm - Thickness (Pessimistic)
Beryllium - Material