Prospects for testing Low's theorem with ALICE 3

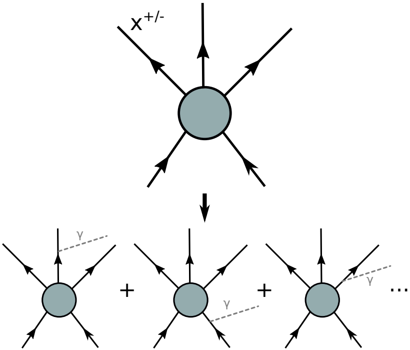
Martin Völkl

Universität Heidelberg

2022-04-08

Quark Matter 2022

- Consider production of photons from interactions of charged particles
- Limit of low photon energies: attach photon line to each external line of charged particles – no other contributions need to be considered
- Connects soft photon production to hadronic cross section even without calculating the process
- Names: Soft photon production/inner bremsstrahlung/hadronic bremsstrahlung



- Very fundamental for infrared behavior of quantum field theories
- E_γ small compared to scales in process; quantitative estimate not simple for general process

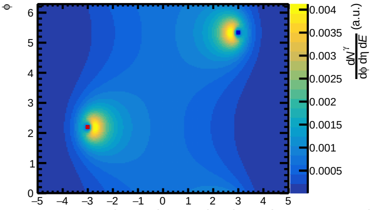
- Low's Theorem connects interaction of charged particles with 4-momenta $\mathbf{P_i}$ with expectation value for soft photon production (with 4-momentum $\mathbf{K}$):

$$\frac{\mathrm{d}N^{\gamma}}{\mathrm{d}^3 k} = \frac{\alpha}{(2\pi)^2} \frac{-1}{E_\gamma} \int (\mathrm{d}^3 p_1 \dots \mathrm{d}^3 p_N) \left(\sum_{\text{Particle } i} \frac{\eta_i e_i \mathbf{P_i}}{\mathbf{P_i K}} \right)^2 \frac{\mathrm{d}N^{\mathrm{H}}}{\mathrm{d}^3 p_1 \dots \mathrm{d}^3 p_N}$$

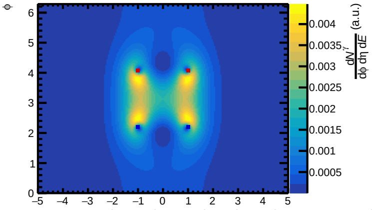
- Via the square, interference terms between the particles are created
- For a single event, this means

$$\frac{d^3 \mathrm{N}}{d|k| d\eta d\phi} = -\frac{\alpha}{(2\pi)^2} \cos(\vartheta/2) \sin(\vartheta/2) E_\gamma \sin\vartheta \left(\sum_{\text{Particle } i} \frac{\eta_i e_i \mathbf{P_i}}{\mathbf{P_i K}} \right)^2 \sim \frac{1}{E_\gamma}$$

- In particular direction, always $1/E_\gamma$ spectrum
- Signal typically between $+$ and $-$ particles, depletion very close to particle
- Signal estimate usually done with input from event generators

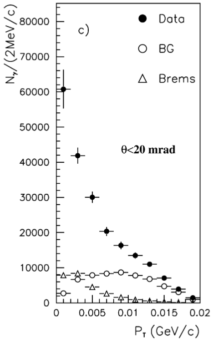


1 pos, 1 neg charged particle plus arbitrary neutral



2 pos, 2 neg charged particles plus arbitrary neutral

Previous measurements of excess production



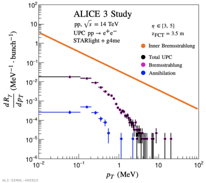
WA91

(from Klaus Reygers' talk at the ALICE 3 workshop)

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 ($0.2 < E_\gamma < 1$ 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 ($0.2 < E_\gamma < 1$ 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 ($0.2 < E_\gamma < 1$ GeV)	5.3 ± 1.0	pair conversion	Belogianni et al., Phys. Lett. B 548, 122 (2002)
pp, CERN, WA102, OMEGA	2002	450 GeV	$p_T < 20$ MeV/c ($0.2 < E_\gamma < 1$ 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 ($0.2 < E_\gamma < 1$ 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	~ 1	pair conversion	DELPHI, Eur. Phys. J. C57, 499 (2008)

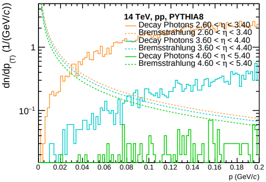
- Measurements with experiments using different setups; somewhat different analysis strategies
- Very simple signal prediction based on very fundamental principles ...
- ... but data exceeds prediction by a factor of ~ 5
- Good agreement for electroweak processes ($e^+e^- \rightarrow \mu^+\mu^-$)
- Aim for precise measurements at LHC energies; investigate and understand excess

Ultraperipheral collisions



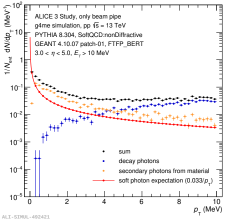
- Ultraperipheral collisions can produce e^+e^--pairs, which create bremsstrahlung
- Positrons can also annihilate with material
- Backgrounds small in pp collisions, but may be relevant in Pb–Pb

Decay Photons



- Background more boosted at forward η
- Less background for soft photons
- Measurement needs minimum photon energy; motivates detector at forward η

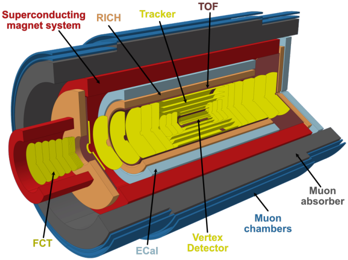
Bremsstrahlung in material



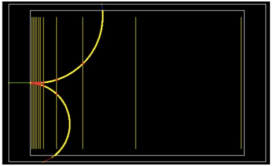
- Directly via electrons interacting with material
- Also from secondary electrons from photon conversion
- Strong dependence on material budget

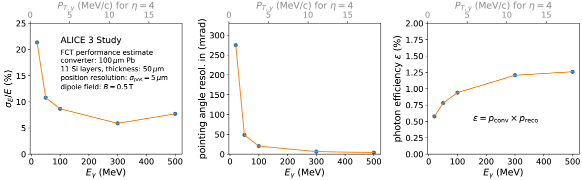
Forward Conversion Tracker

- Several layers of silicon tracker
- Measures photons via e^+e^--pairs from converter
- Energy from track bending in dipole field
- Tests with Geant4 suggest measurements for E_γ below a few 10 MeV possible
- Conclusion: The FCT can measure a possible excess; in conjunction with entire ALICE 3 setup it allows for many more differential studies of the nature of the signal



ALICE 3





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