CERN NA63

and accelerator + detector R&D

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Aarhus University
Denmark

Physics and Detectors at CLIC

CERN–2012–003

14 February 2012

CLIC Conceptual Design Report

p.43 & 49

The experimental environment at CLIC differs from that at previous e^+e^- colliders such as LEP and also the proposed ILC. In particular, there are three main aspects of the CLIC machine that determine the physics environment and significantly impact the CLIC detector design:

– The high bunch charge density, related to the small beam size at the interaction point, means that the electrons and positrons radiate strongly in the electromagnetic field of the other beam, an effect known as beamstrahlung (similar to synchrotron radiation). Consequently the centre-of-mass energies of the e^+e^- collision have a long tail towards significantly lower values than the notional centre-of-mass energy (discussed in Section 2.1.1).

Strong field effects

– There are significant beam related backgrounds. The e^+e^- incoherent pair background has a major impact on the design of the inner region of the detector and the forward region. The pile-up of approximately 3.2 $\gamma\gamma \rightarrow$ hadrons "mini-jet" events per bunch crossing (BX) impacts the timing requirements placed on the individual detector elements and is an important consideration in all physics analyses (discussed in Section 2.1.2)

Real and virtual photon interactions

– The CLIC beam consists of bunch trains of 312 bunches with a train repetition rate of 50 Hz. Within a bunch train, the bunches are separated by 0.5 ns. The short time between bunches means that a detector will inevitably integrate over a number of bunch crossings. This combined with the significant $\gamma\gamma \rightarrow$ hadrons background implies fast readout of all detector elements and excellent time resolution (discussed in Section 2.5).

Tertiary photons as fast luminosity monitor

after the IP. Moreover, the beam-beam interaction leads to depolarisation. Simulations indicate that the depolarisation varies throughout the luminosity spectrum [16, 17], starting below 1% around the high energy peak at 3 TeV (i.e. for events with a lower degree of beam-beam losses) and reaching up to 4% at the lower energies (i.e. where the beam-beam effects are strongest). The systematic uncertainty on the absolute degree of beam polarisation is therefore left to future detailed studies

Spin-flip interactions

CLIC is part of 'délibérations' of: Update of the European Strategy for Particle Physics

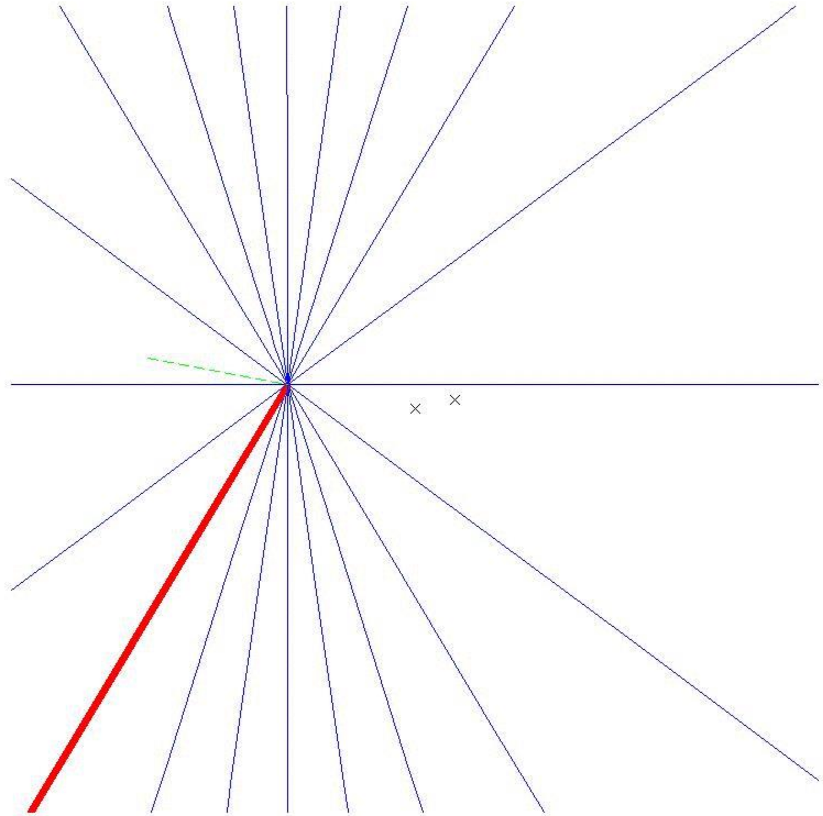
PHYSICAL REVIEW D **81**, 052003 (2010)

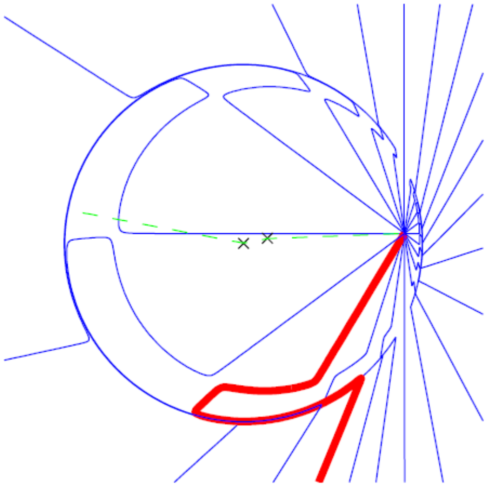
Distorted Coulomb field of the scattered electron

H. D. Thomsen,[1] J. Esberg,[1] K. K. Andersen,[1] M. D. Lund,[1] H. Knudsen,[1] U. I. Uggerhøj,[1] P. Sona,[2] A. Mangiarotti,[3] T. J. Ketel,[4] A. Dizdar,[5] S. Ballestrero,[6] and S. H. Connell[6]

(CERN NA63)

CERN
NA63





Logarithmic *t* dependence

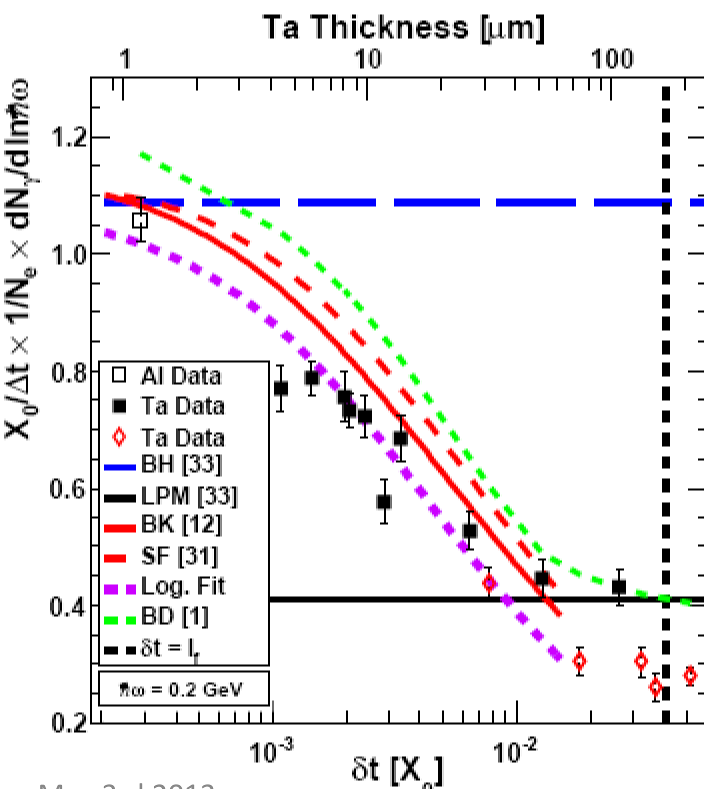
Transition between Bethe-Heitler and LPM regimes:

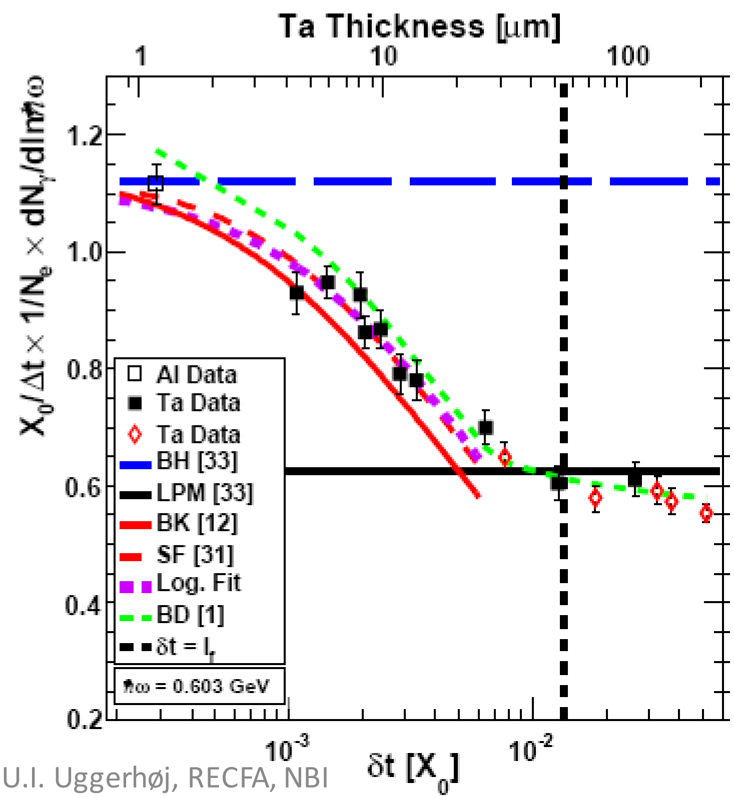
$$1/N_e \times \frac{dN_\gamma}{d\ln\hbar\omega} \simeq a \times \frac{\ln(b\times\delta t+1)}{b\times\delta t}$$

$$\ln(b\times\delta t+1)$$

$$b = 2\pi/3\alpha X_0 \simeq 287/X_0$$

'Radiation per interaction as a function of number of scatterings'





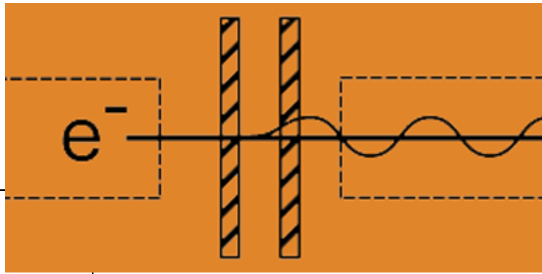
PRL 108, 071802 (2012) PHYSICAL REVIEW LETTERS week ending 17 FEBRUARY 2012

Direct Measurement of the Formation Length of Photons

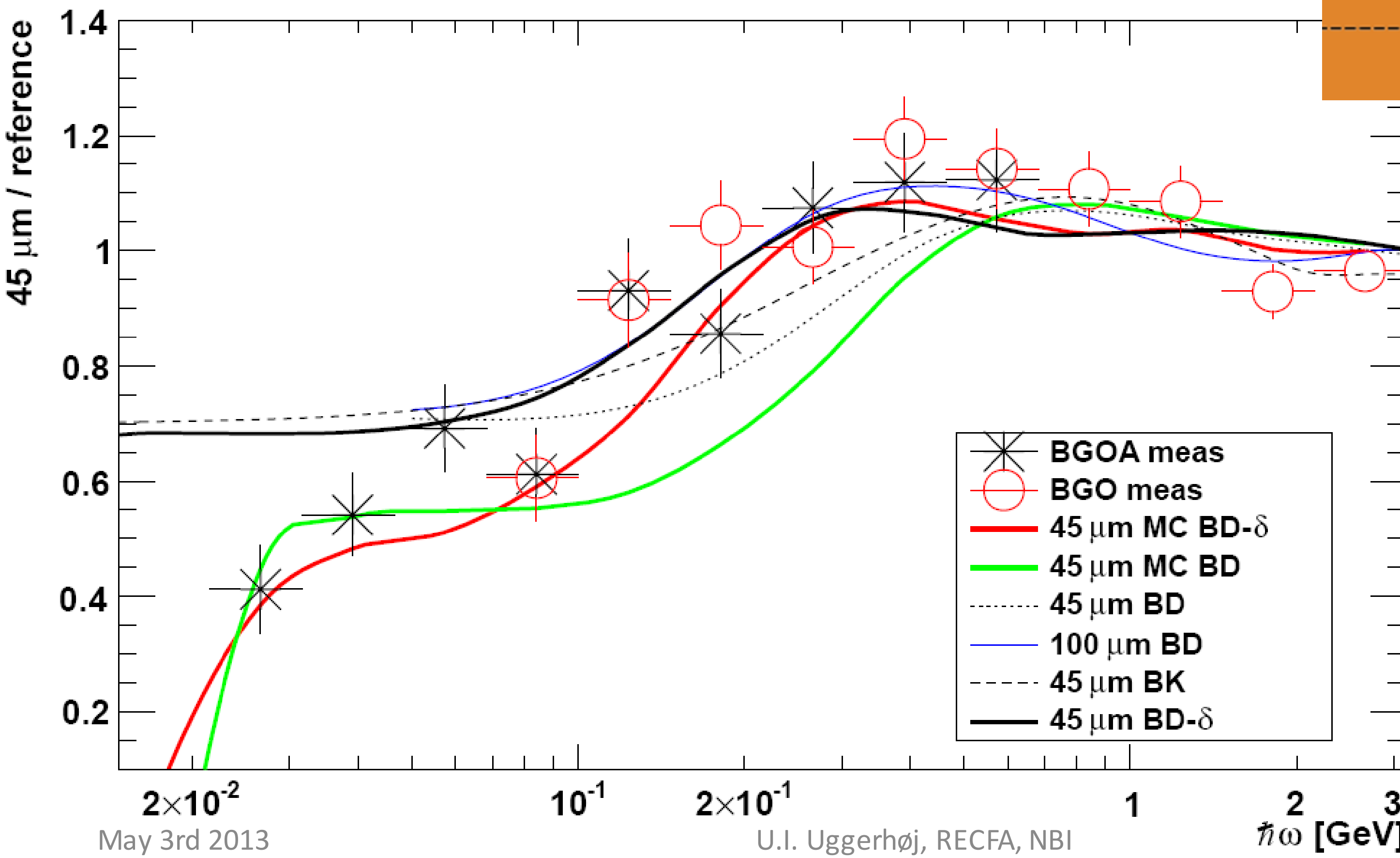
Kristoffer K. Andersen,[1,*] Søren L. Andersen,[1] Jakob Esberg,[1] Helge Knudsen,[1] Rune Mikkelsen,[1] Ulrik I. Uggerhøj,[1]
Pietro Sona,[2] Alessio Mangiarotti,[3] Tjeerd J. Ketel,[4] and Sergio Ballestrero[5]

(CERN NA63)

Synopsis: Going the Distance



Measuring the formation length with a micrometer screw....



Discrepancy reported at SPSC Oct 2011 was a <u>theory</u> <u>problem</u>!

Strong fields

Strong – compared to what?

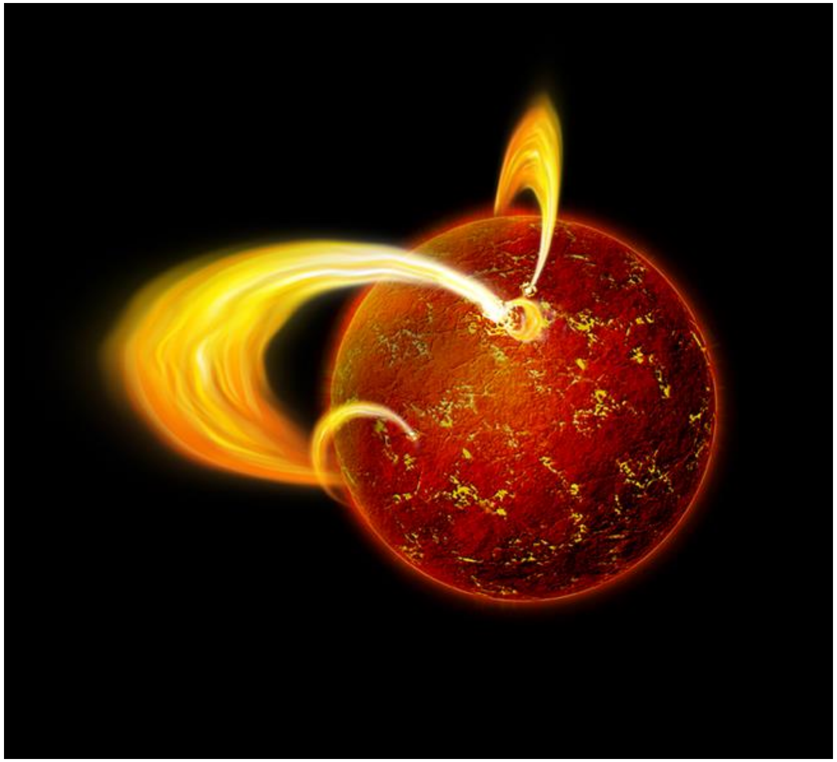
relativistic (c) quantum ($\hbar$) field for electrons (m, e)

- The critical field:

$$\mathcal{E}_0 = m^2c^3/e\hbar$$
$$= 1.32 \times 10^{16} \text{ V/cm}$$

$$B_0 = 4.41 \times 10^9 \text{ T}$$

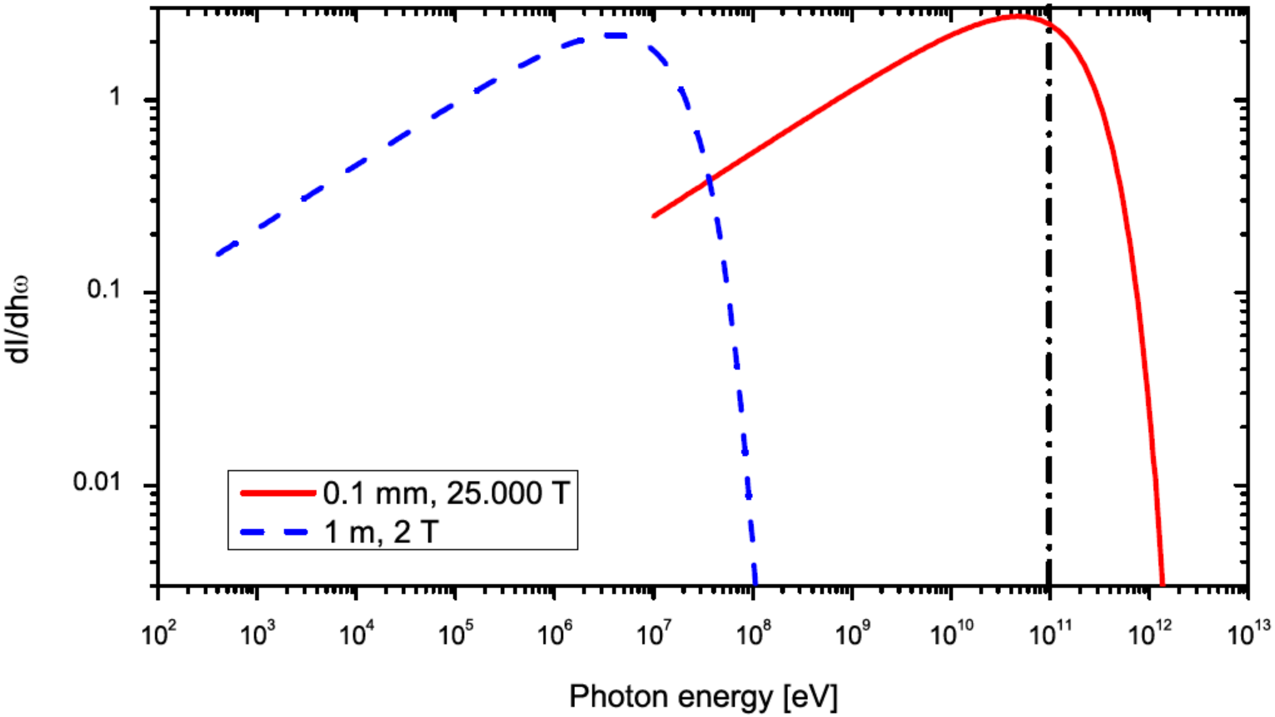
Exists at the surface of some neutron stars (magnetars)



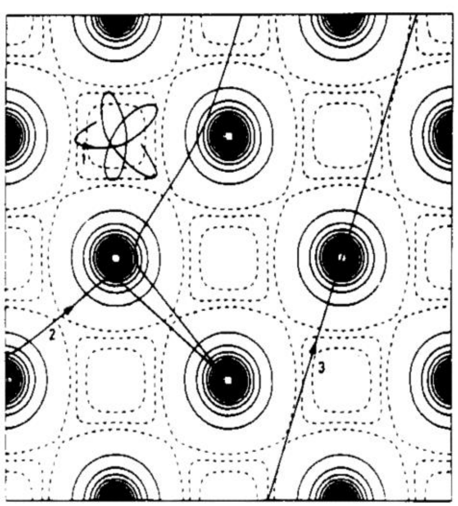
Relativistic invariant:

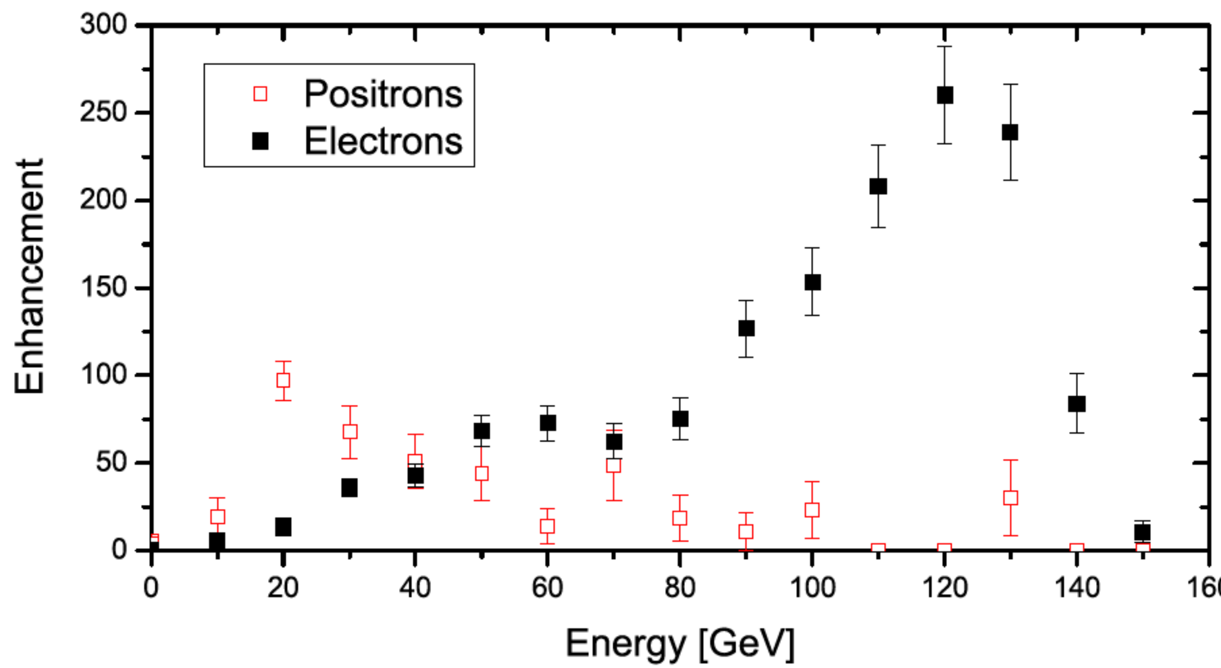
$$\chi = \gamma\mathcal{E}/\mathcal{E}_0$$

Radiation emission



$$\chi = \gamma \mathcal{E} / \mathcal{E}_0$$





Beamstrahlung – synchr.rad.

PHYSICAL REVIEW D VOLUME 36, NUMBER 1 1 JULY 1987

Quantum treatment of beamstrahlung

Richard Blankenbecler and Sidney D. Drell

$$\frac{I_e}{I_{\rm cl}} = (1 + 4.8(1+\chi)\ln(1+1.7\chi) + 2.44\chi^2)^{-2/3}.$$

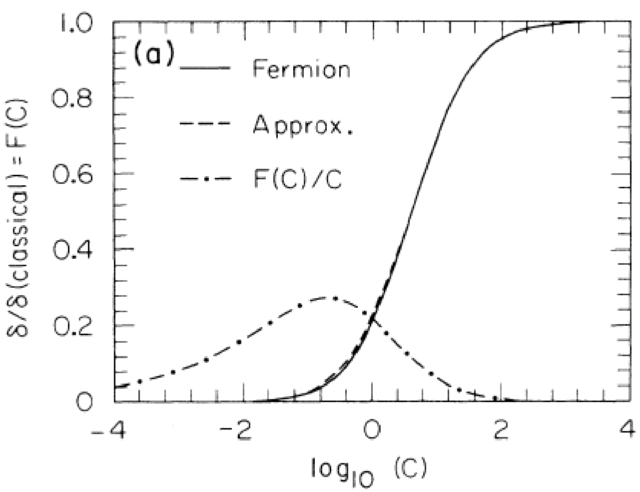
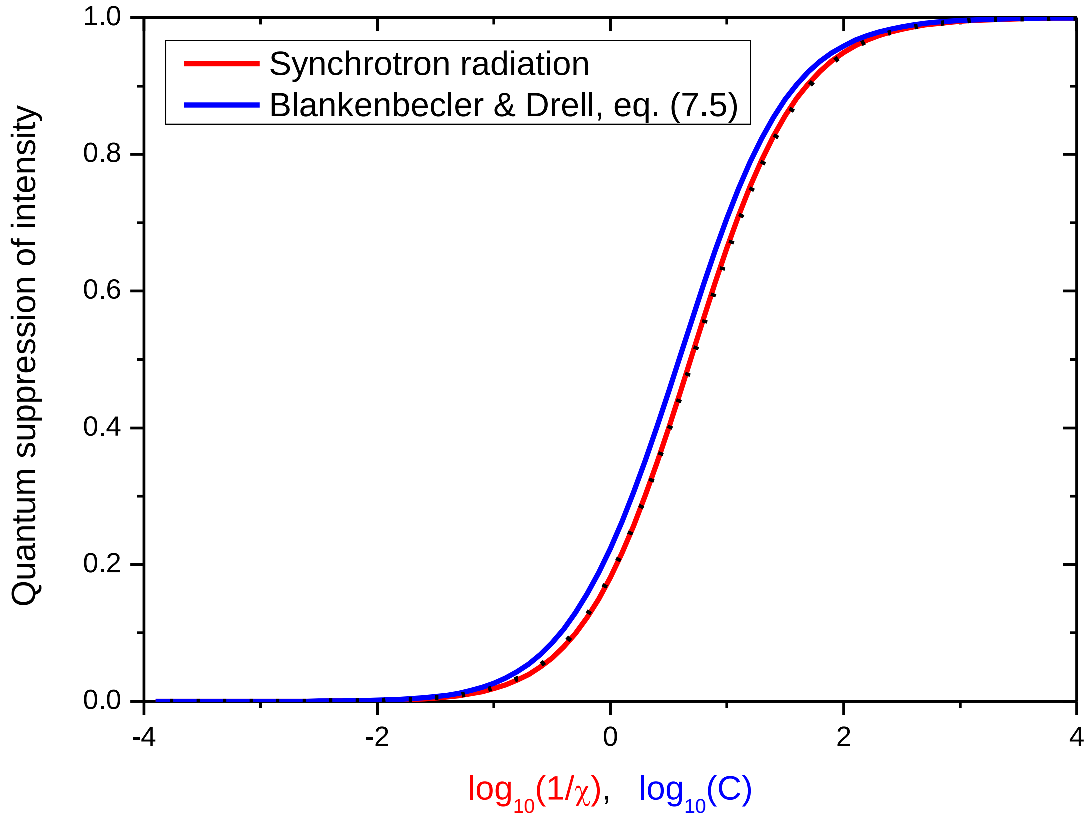


FIG. 1. (a) The form factor

$$C_b = \frac{m^2c^3RL}{4Ne^2\gamma^2\hbar}$$

Classical: -> 0 => C_b -> infty



Quantum suppression

$$\mathcal{L}_0 = \frac{N^2}{4\pi\sigma_x\sigma_y} f_{rep} N_b$$

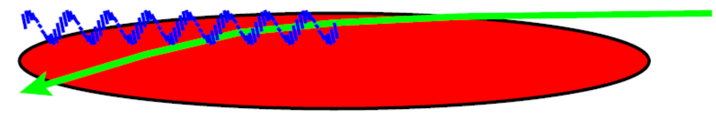
$$\langle \Upsilon \rangle = \frac{5}{6}\frac{\gamma N r_e^2}{\alpha\sigma_z(\sigma_x+\sigma_y)},$$

$$\Upsilon = \frac{2}{3}\frac{\hbar\omega_c}{E_0}$$

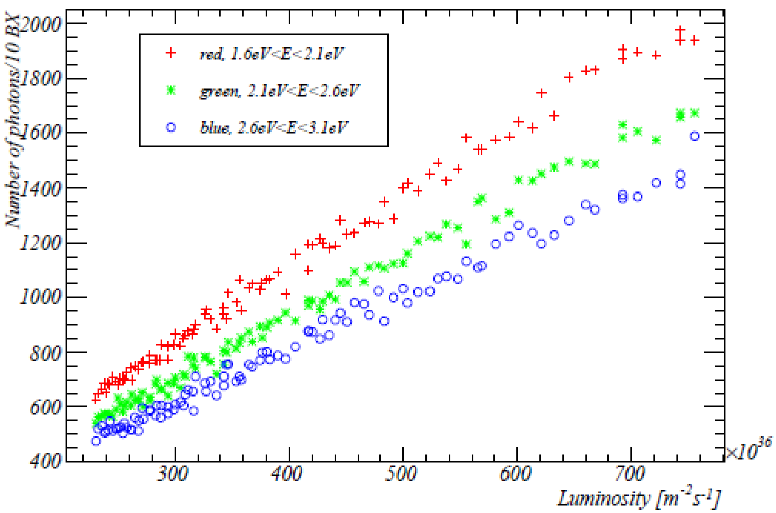
$\Upsilon \ll 1$: classical regime

$\Upsilon \gg 1$: quantum regime

Beam-Beam Interaction

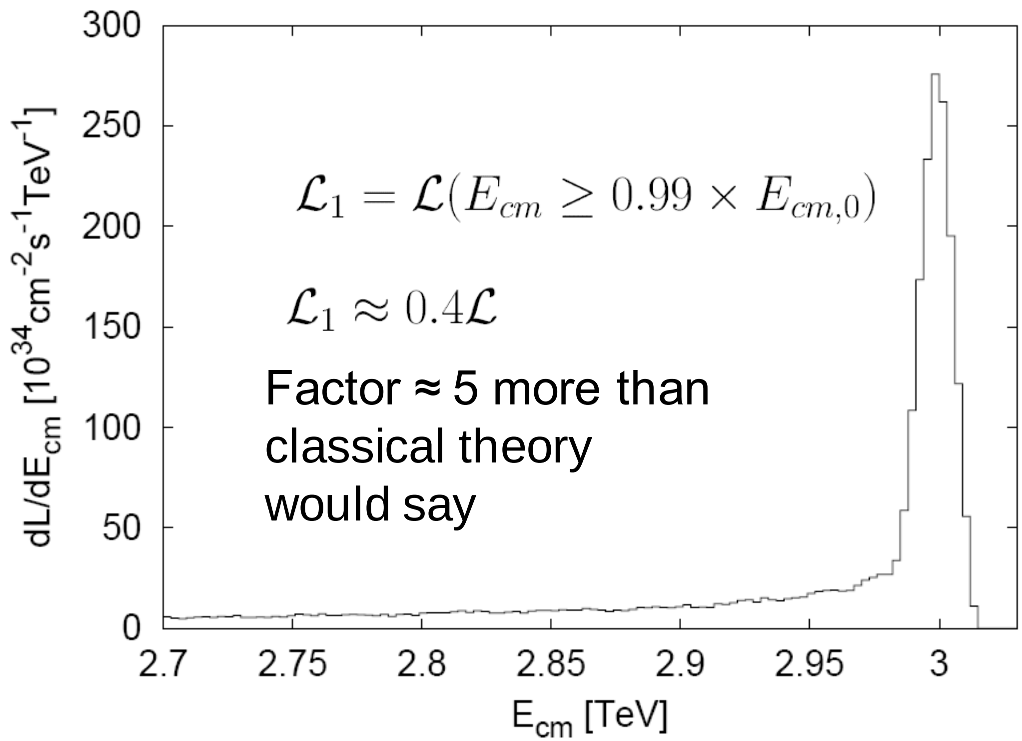


- beamstrahlung $\Rightarrow$ luminosity spectrum



J. Esberg (NA63) – CTF3, GUINEA-PIG implementation

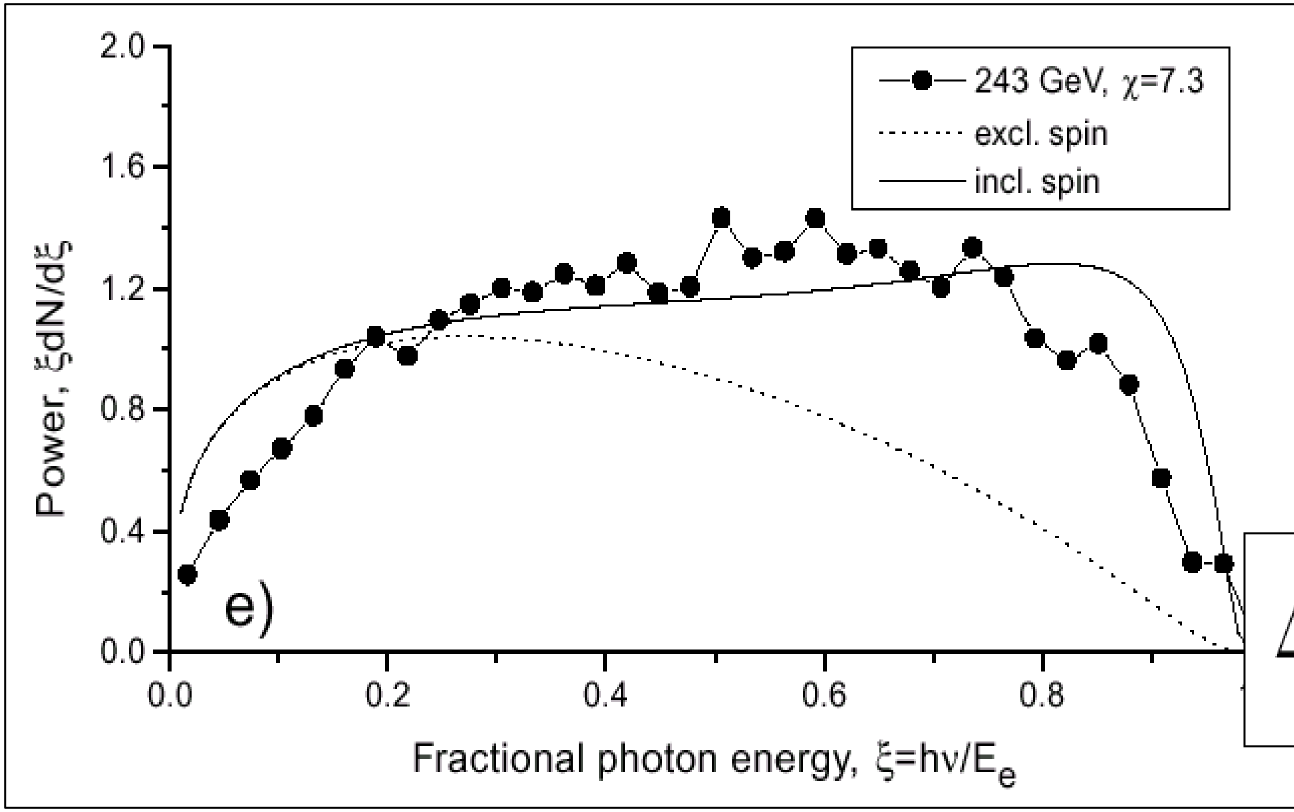
optical tertiary photons as a fast (ns) luminosity signal for CLIC



From: CLIC: Beam Dynamics and Limitations on Main Parameters

Daniel Schulte

Spin-flip



$$\chi = \gamma \mathcal{E} / \mathcal{E}_0$$

$$\Delta W = \gamma^2 \beta \frac{\mathcal{E}}{\mathcal{E}_0} mc^2$$

$$c\tau_{\rm sf} = \varepsilon_{\rm sf} \gamma a_0 / \chi^3$$

$$\tau = \frac{8\hbar}{5\sqrt{3}\,\alpha m} \left(\frac{B_0}{B}\right)^3 \frac{1}{\gamma^2} = \frac{8\hbar}{5\sqrt{3}\,\alpha m} \frac{\gamma}{\chi^3}$$

$$\varepsilon_{\rm sf} = 8/5\sqrt{3} \simeq 92.4\%$$

100 GeV
$\chi=1$
$c\tau_{sf}$ = 10 µm
τ_{sf} = 32 fs

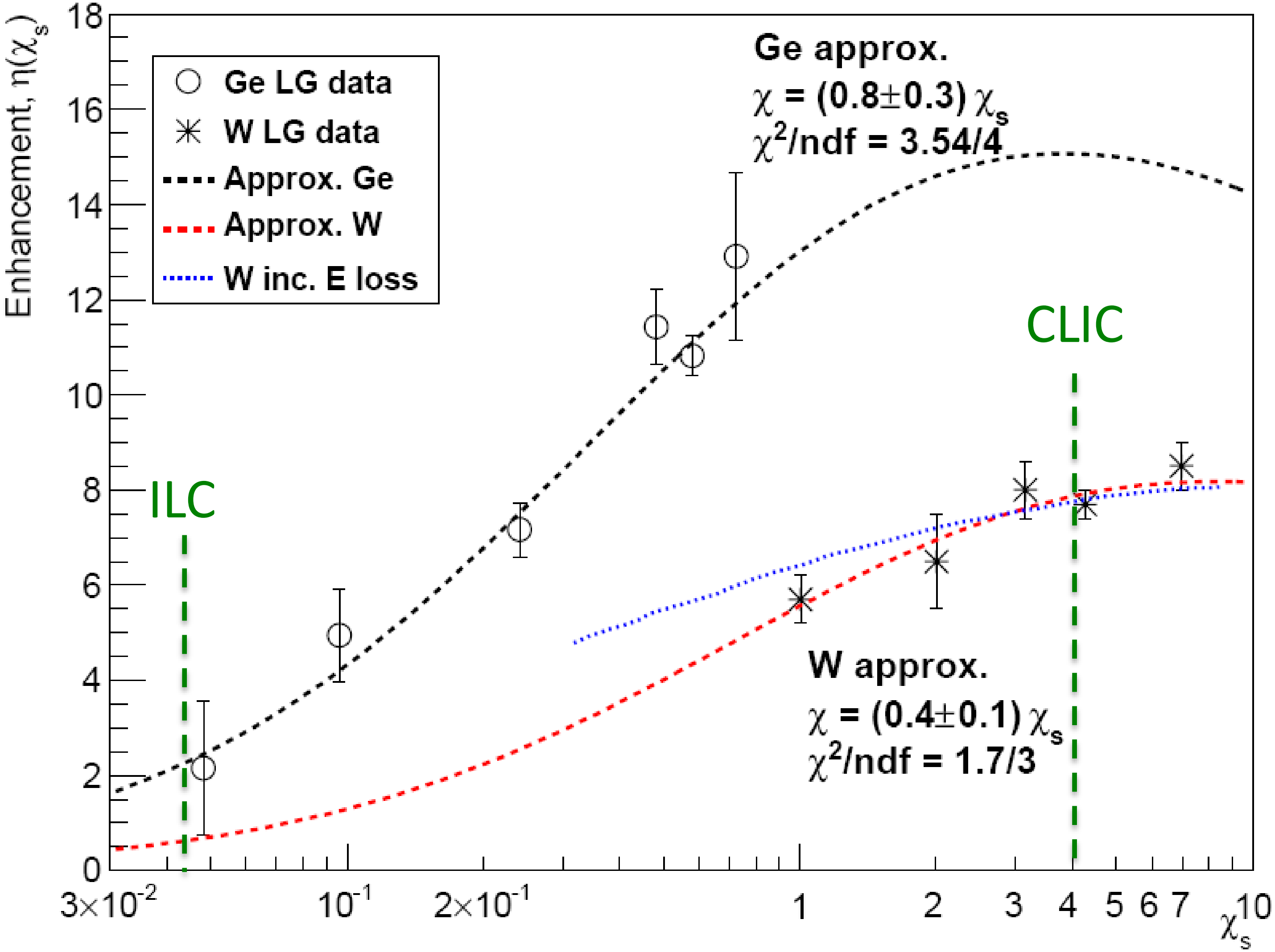
1 GeV
B=1 T
$c\tau_{sf}$= 7.3 A.U.
τ_{sf} = 61 min.

’Polarization time/length’

Classical -> Quantum synchrotron

$$\frac{I_e}{I_{\rm cl}} = \left(1 + 4.8(1+\chi)\ln(1+1.7\chi) + 2.44\chi^2\right)^{-2/3}.$$

Plotted as:



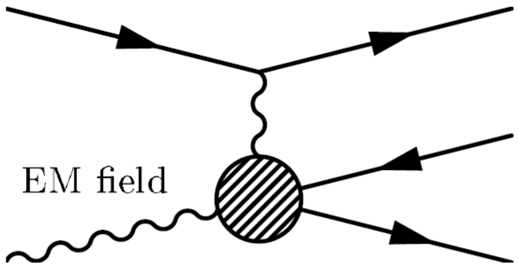
CERN NA63

K.K. Andersen *et al.*

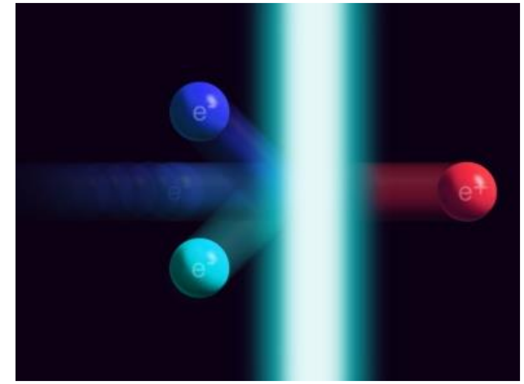
Phys.Rev. D **86**, 072001, 2012

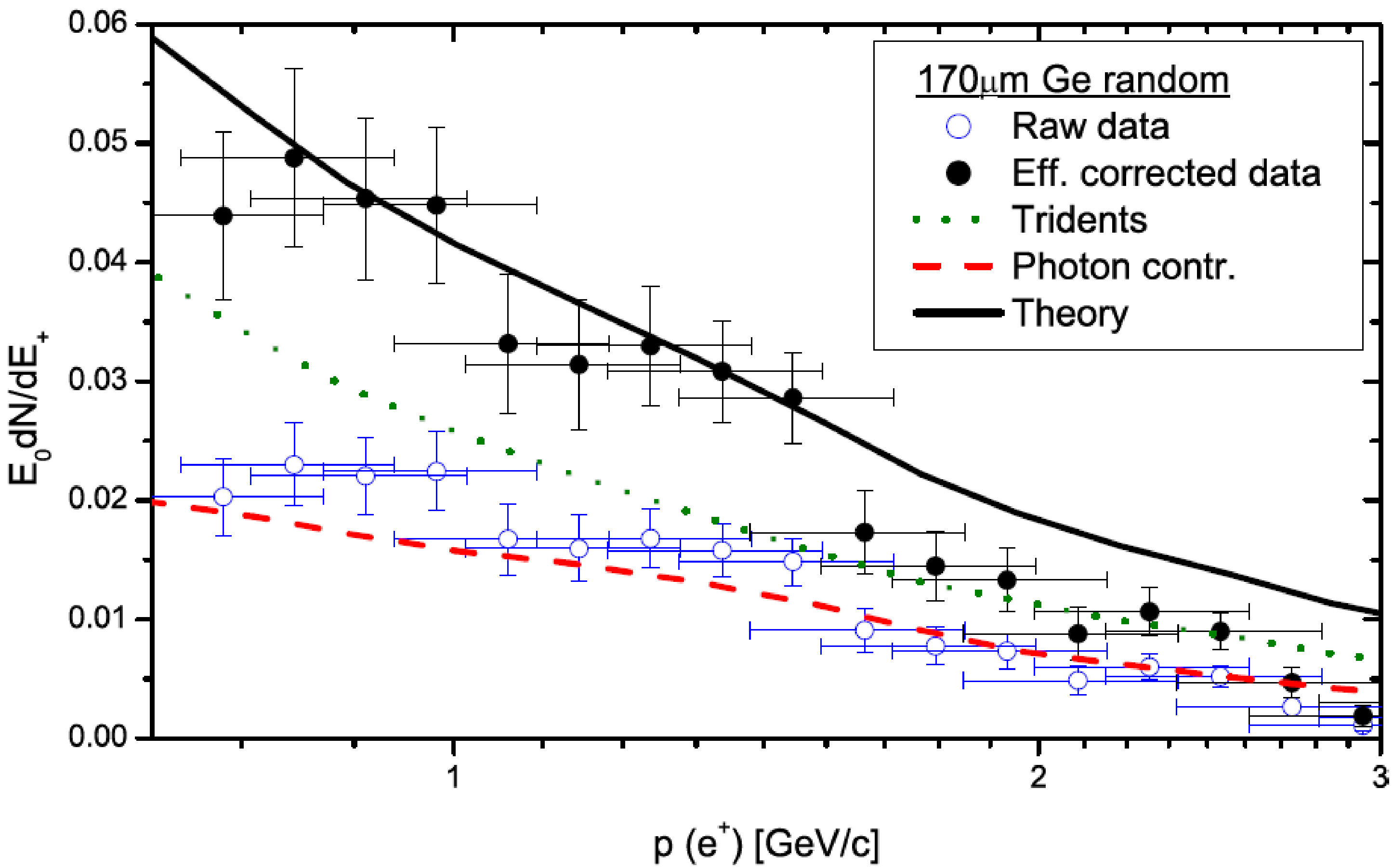
GUINEA-PIG (D. Schulte, CERN) simulations of beamstrahlung are now 'experimentally verified'

Trident production

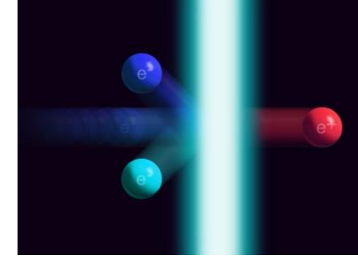


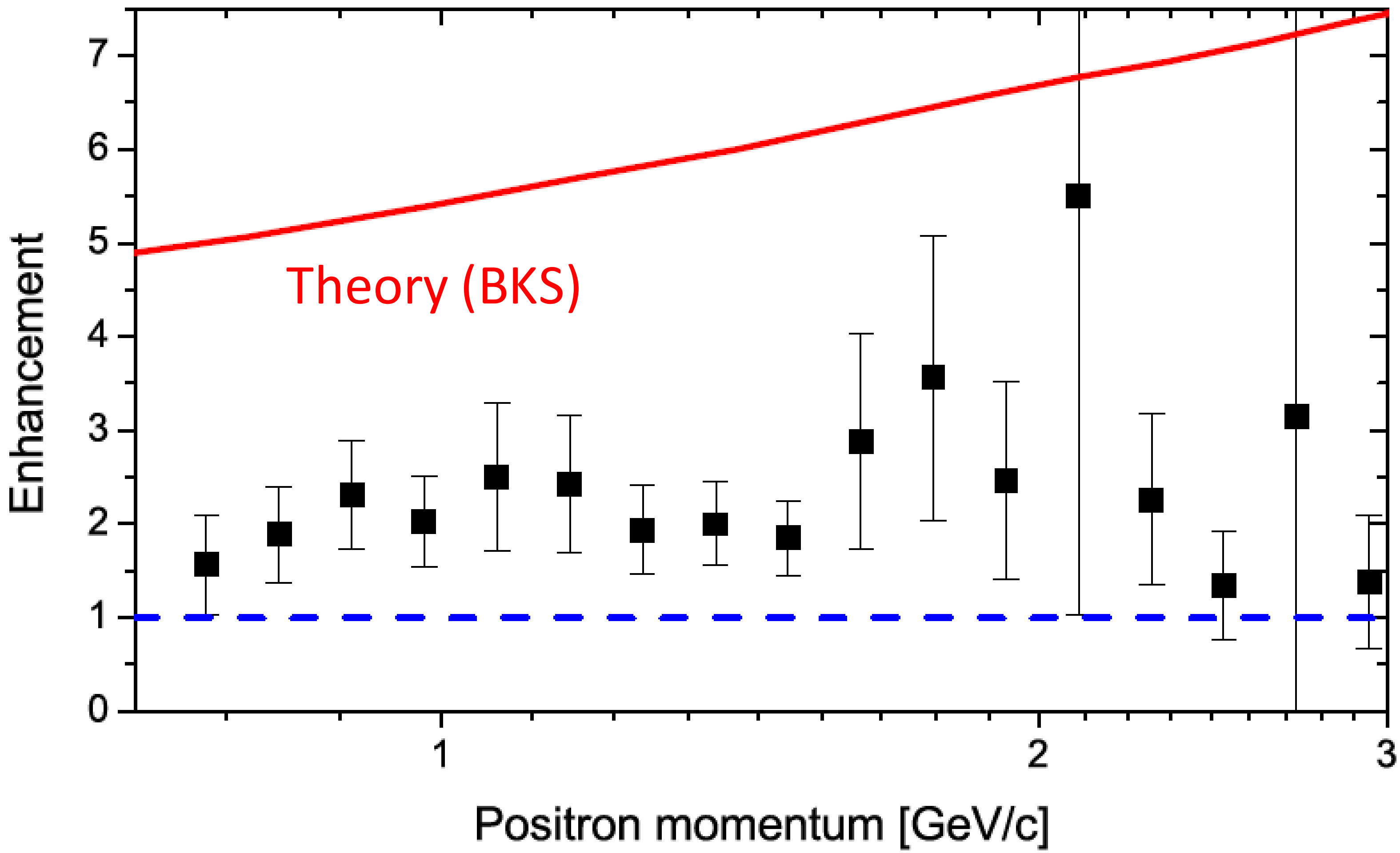
$$e^- \to e^- e^+ e^-$$





Trident enhancement in strong field





GeV electron beams from a centimetre-scale accelerator

nature physics | VOL 2 | OCTOBER 2006 |

Plasma wakefields

Transverse focusing forces:

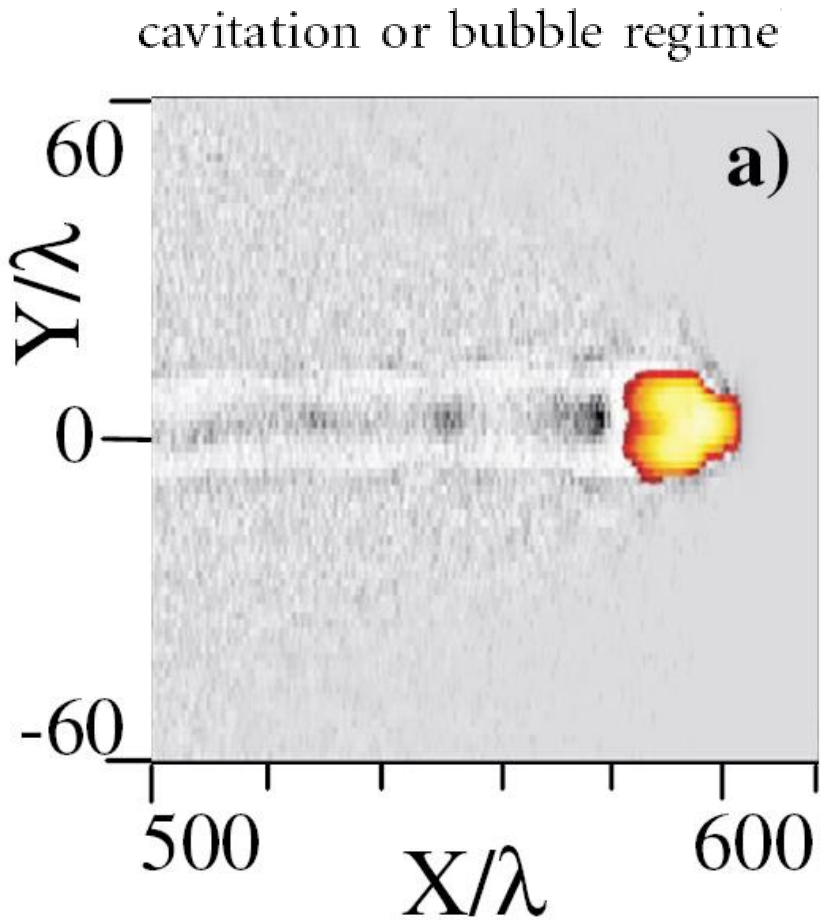
$$F_{\perp} \approx m\omega_p^2 r/2$$

Lead to values

$$\chi \approx \gamma(F_{\perp}/eE_{cr}) \approx 10^{-6}\gamma$$

for realistic parameters:

$$n_0 \approx 10^{19}\ \mathrm{cm}^{-3} \ \text{ and } \ r = 15\ \mu\mathrm{m}$$



PHYSICAL REVIEW E **75**, 057401 (2007)

AWAKE - Proton Driven Plasma Wakefield Facility at CERN

[SPSC-I-240]

Positron production

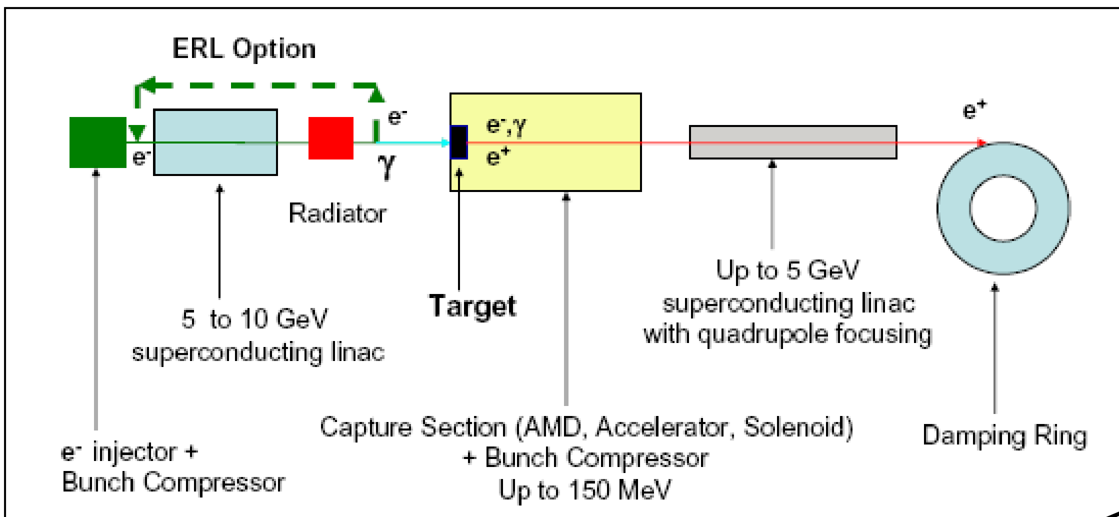
…studies with aligned crystals – to be used for e.g. CLIC, LHeC

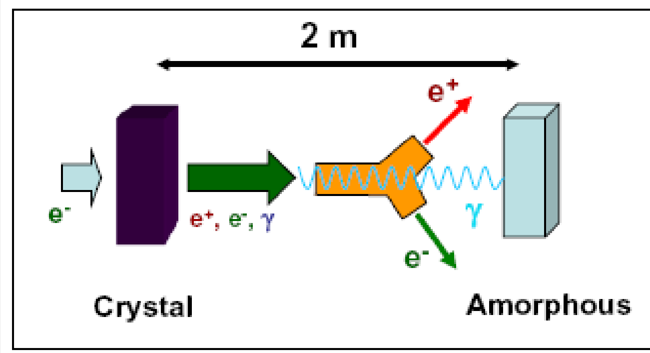
previous studies with tungsten

Nuclear Instruments and Methods in Physics Research B 266 (2008) 3868–3875

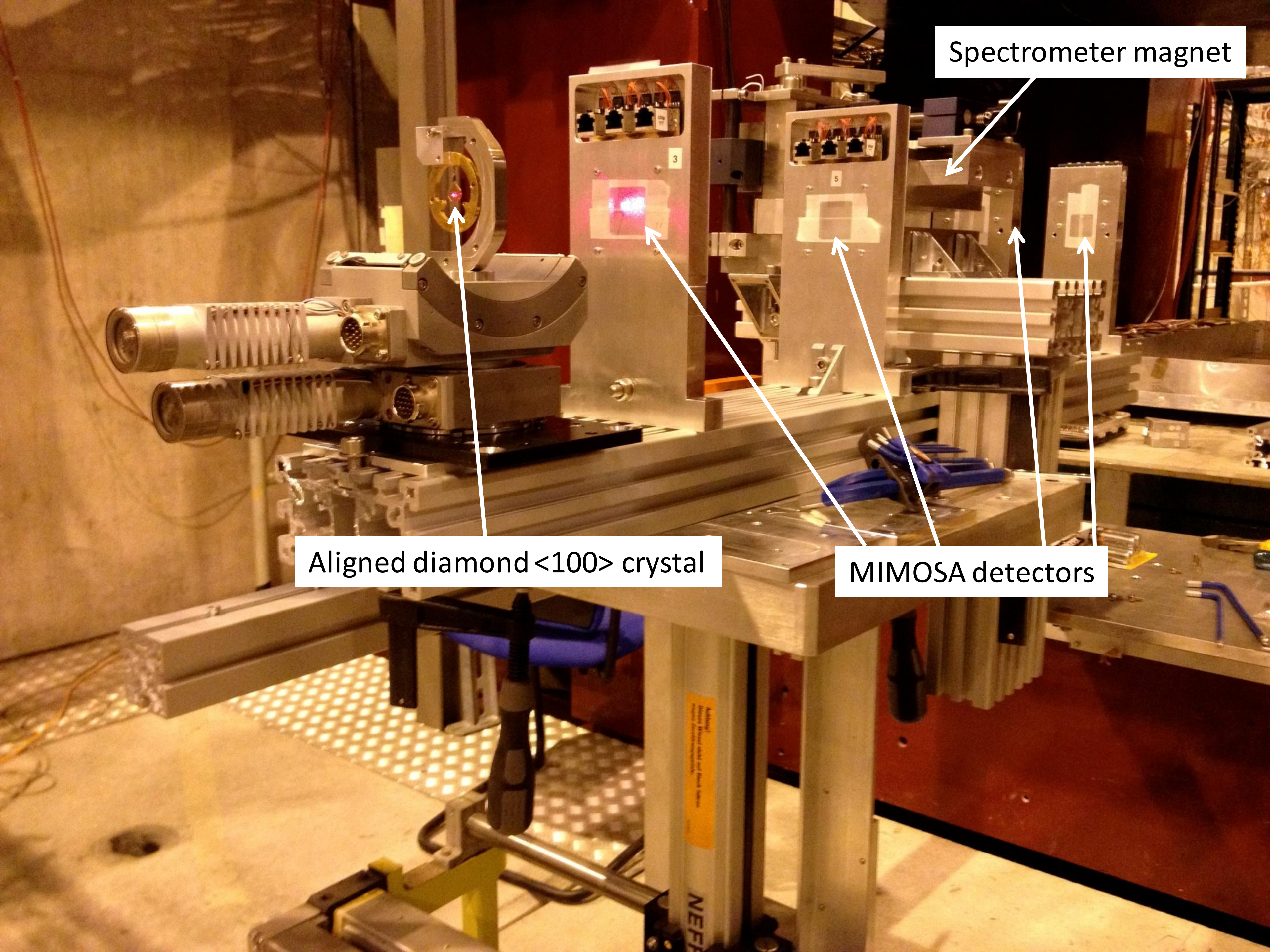
Polarized and unpolarized positron sources for electron–positron colliders

X. Artru[a], R. Chehab[a,*], M. Chevallier[a], V.M. Strakhovenko[b], A. Variola[c], A. Vivoli[c]





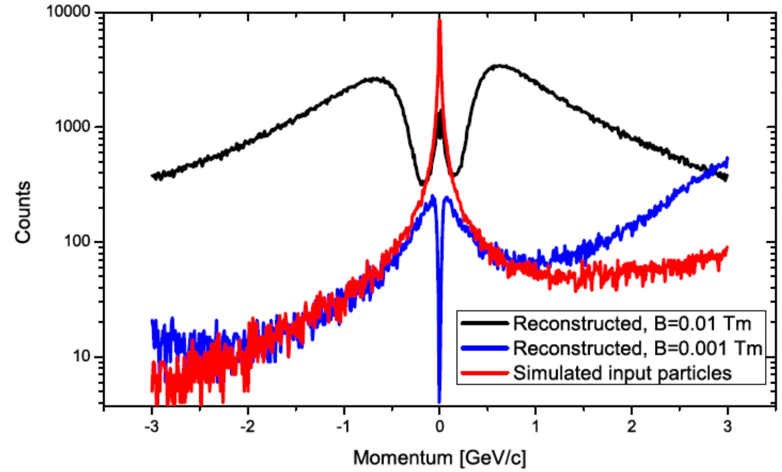
High multiplicity and ’low’ energies (10 MeV e^+)


Spectrometer magnet
Aligned diamond <100> crystal
MIMOSA detectors

Positron production

MIMOSA detectors (M. Winter, Strasbourg)

- Vertex detectors for CLIC (?)



CMOS-based position sensitive detectors

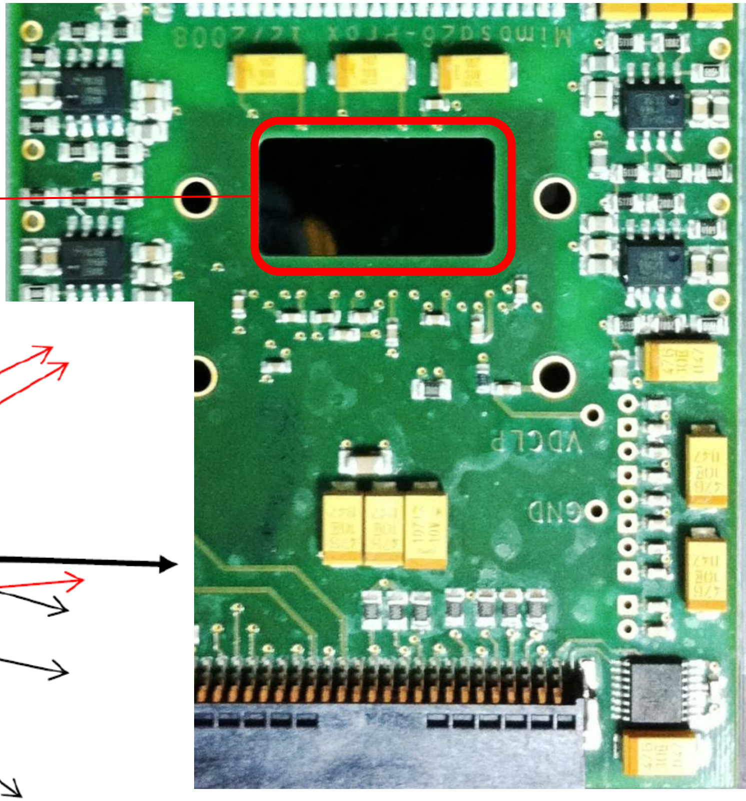
1152 columns of 576 pixels, $\simeq$ 18.4 μm pitch

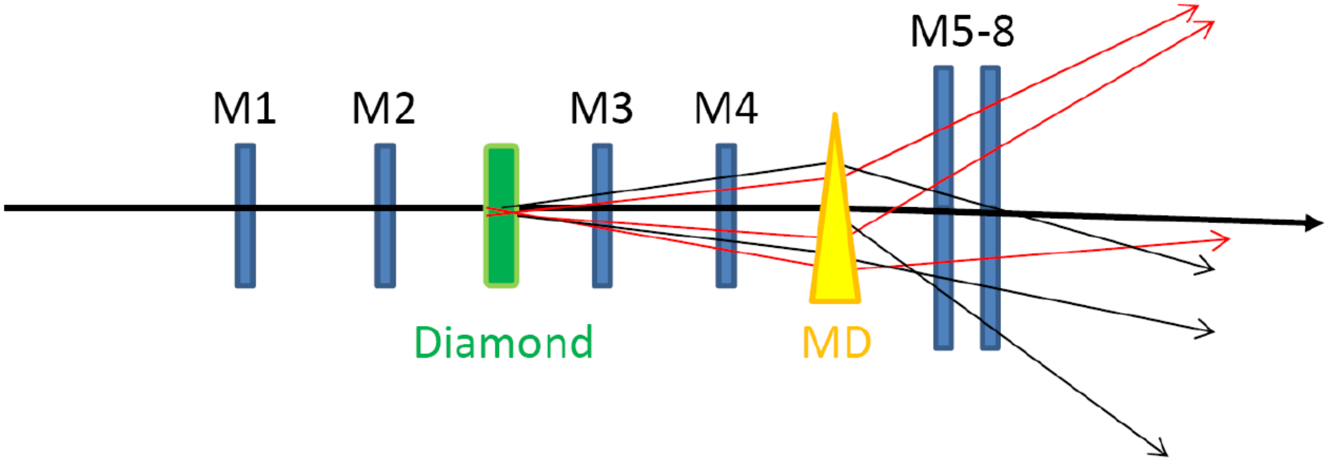
readout in 110 ms, $\simeq$ 3.5 μm resolution

true multi-hit capability

1×2 cm^2

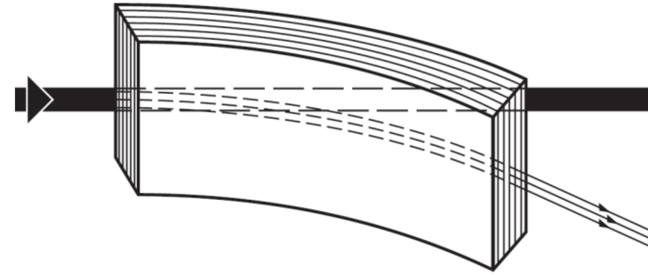
$\Delta t / X_0 \simeq 0.05\%$





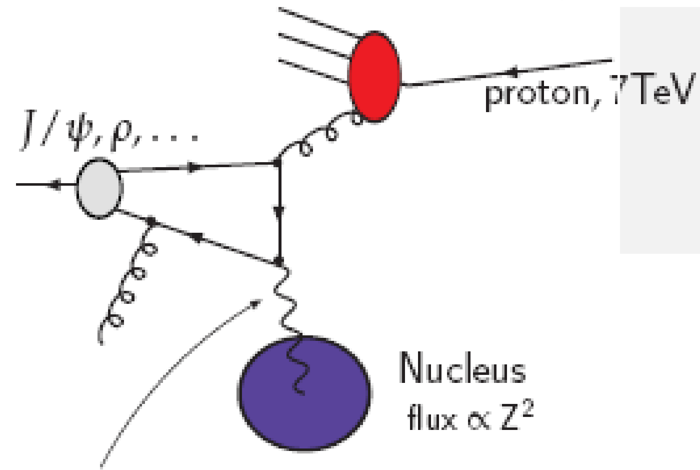
Detector R&D

A Fixed-Target ExpeRiment at the LHC (AFTER@LHC) : luminosities, target polarisation and a selection of physics studies

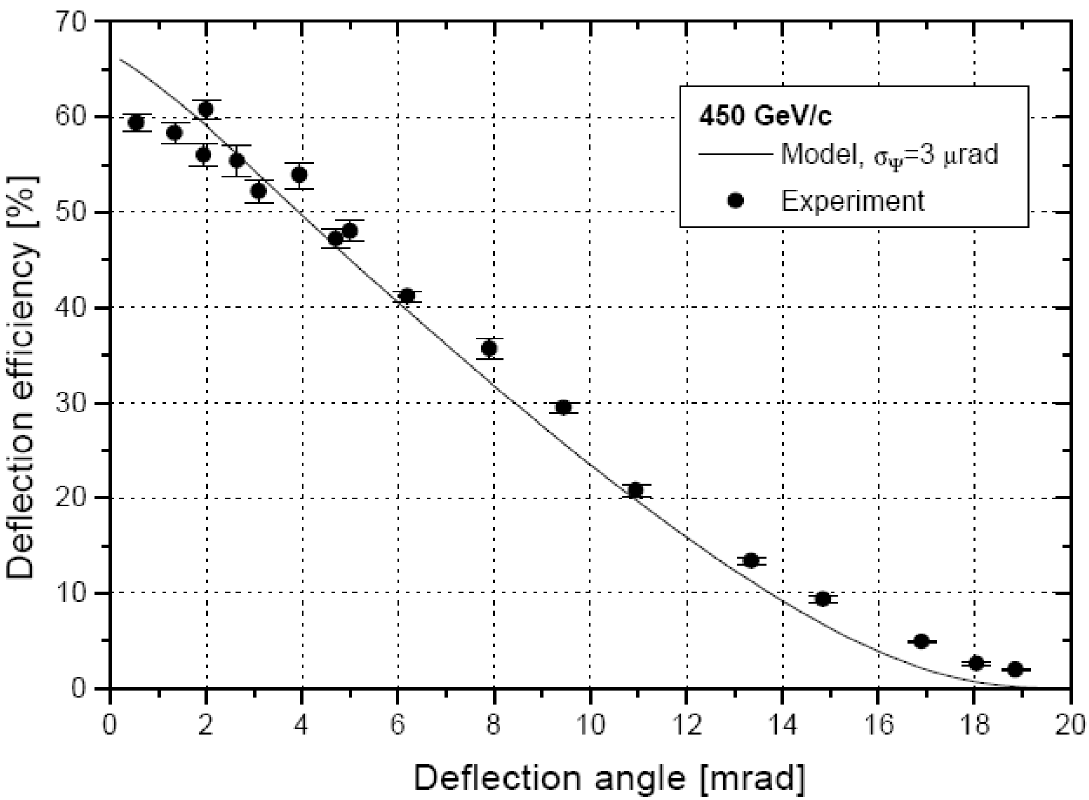


arXiv:1207.3507v1 [hep-ex] 15 Jul 2012

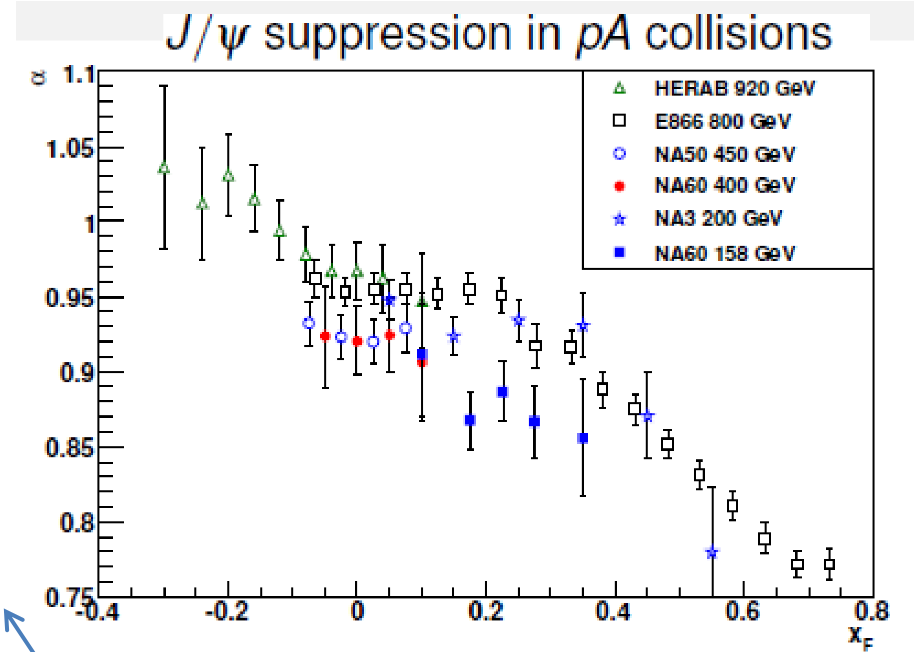
J.P. Lansberg, V. Chambert, J.P. Didelez, B. Genolini, C. Hadjidakis, P. Rosier, R. Arnaldi, E. Scomparin, S.J. Brodsky, E.G. Ferreiro, F. Fleuret, A. Rakotozafindrabe, U.I. Uggerhøj



(Ultra)Peripheral collision



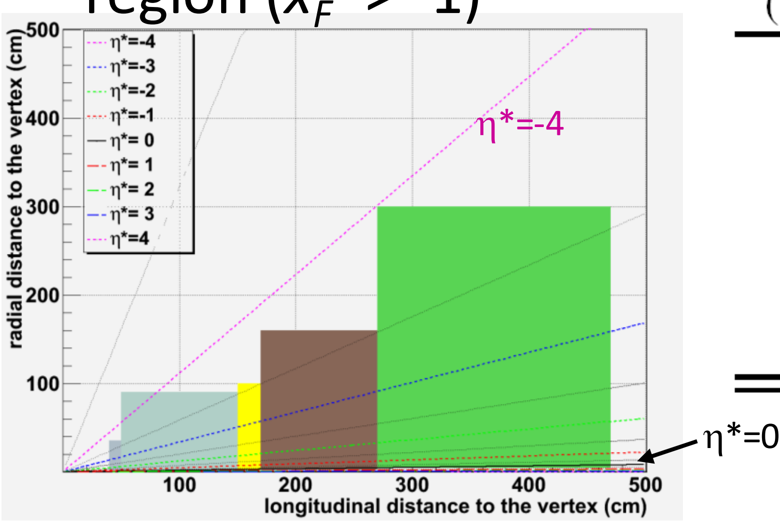
Extraction of 7 TeV LHC protons for ‘fixed-target’ physics: AFTER@LHC



Extraction by a bent crystal

Luminosity at LHC

Access to target rapidity region (x_F -> -1)



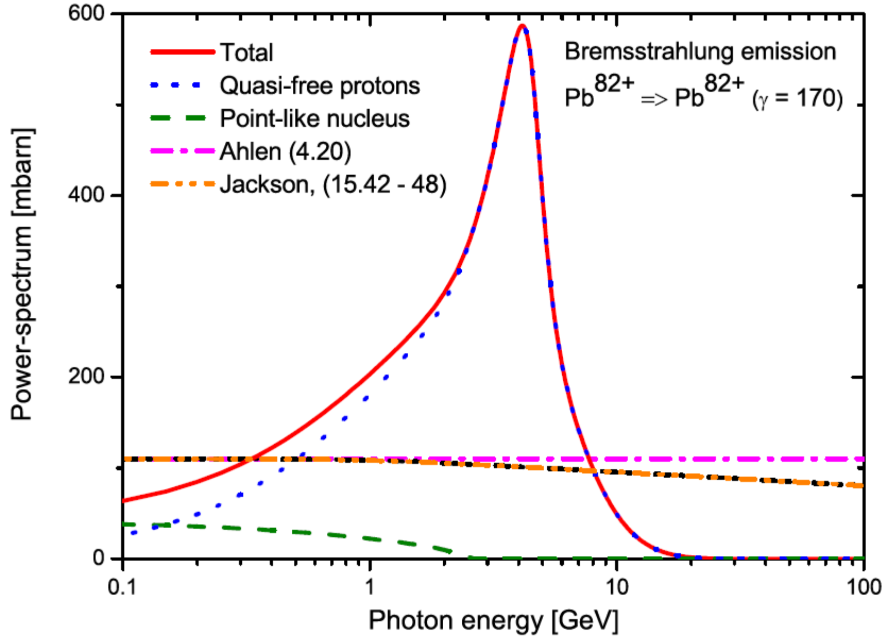
Target (1 cm thick)	ρ ($\mathrm{g\,cm^{-3}}$)	A	$\mathcal{L}$ ($\mu\mathrm{b}^{-1}\,\mathrm{s}^{-1}$)	$\int\mathcal{L}$ ($\mathrm{pb}^{-1}\,\mathrm{yr}^{-1}$)
solid H	0.088	1	26	260
liquid H	0.068	1	20	200
liquid D	0.16	2	24	240
Be	1.85	9	62	620
Cu	8.96	64	42	420
W	19.1	185	31	310
Pb	11.35	207	16	160

Reach few fb^{-1} with 10cm liq H/D target

arXiv:1202.6585v1 [hep-ph] 29 Feb 2012

S.J. Brodsky[1], F. Fleuret[2], C. Hadjidakis[3], J.P. Lansberg[3]

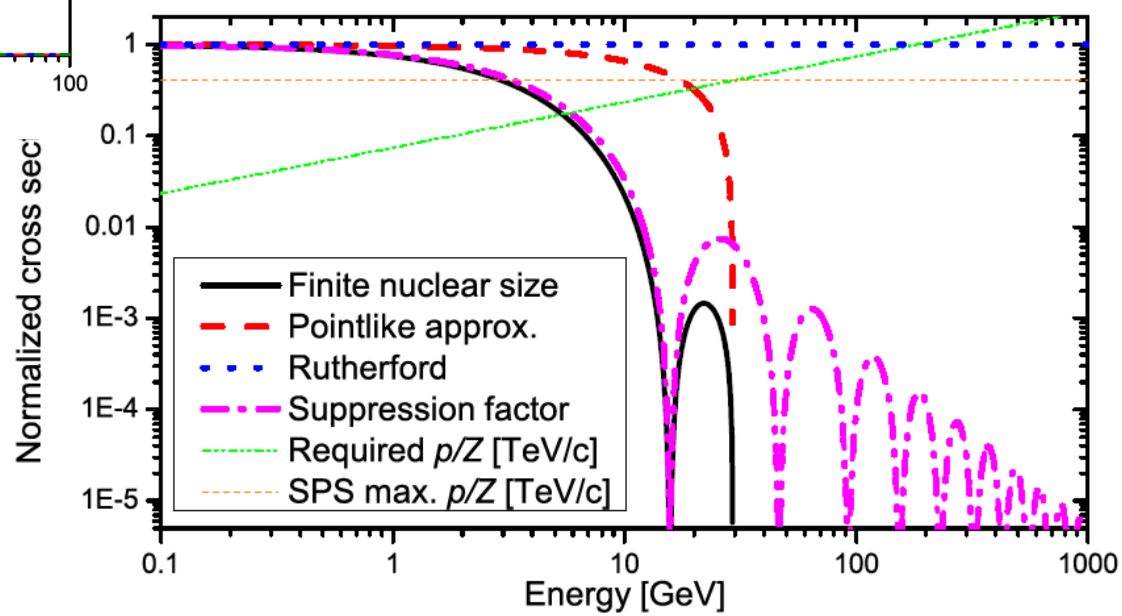
Heavy ion bremsstrahlung



Finite nuclear size

Photon emission

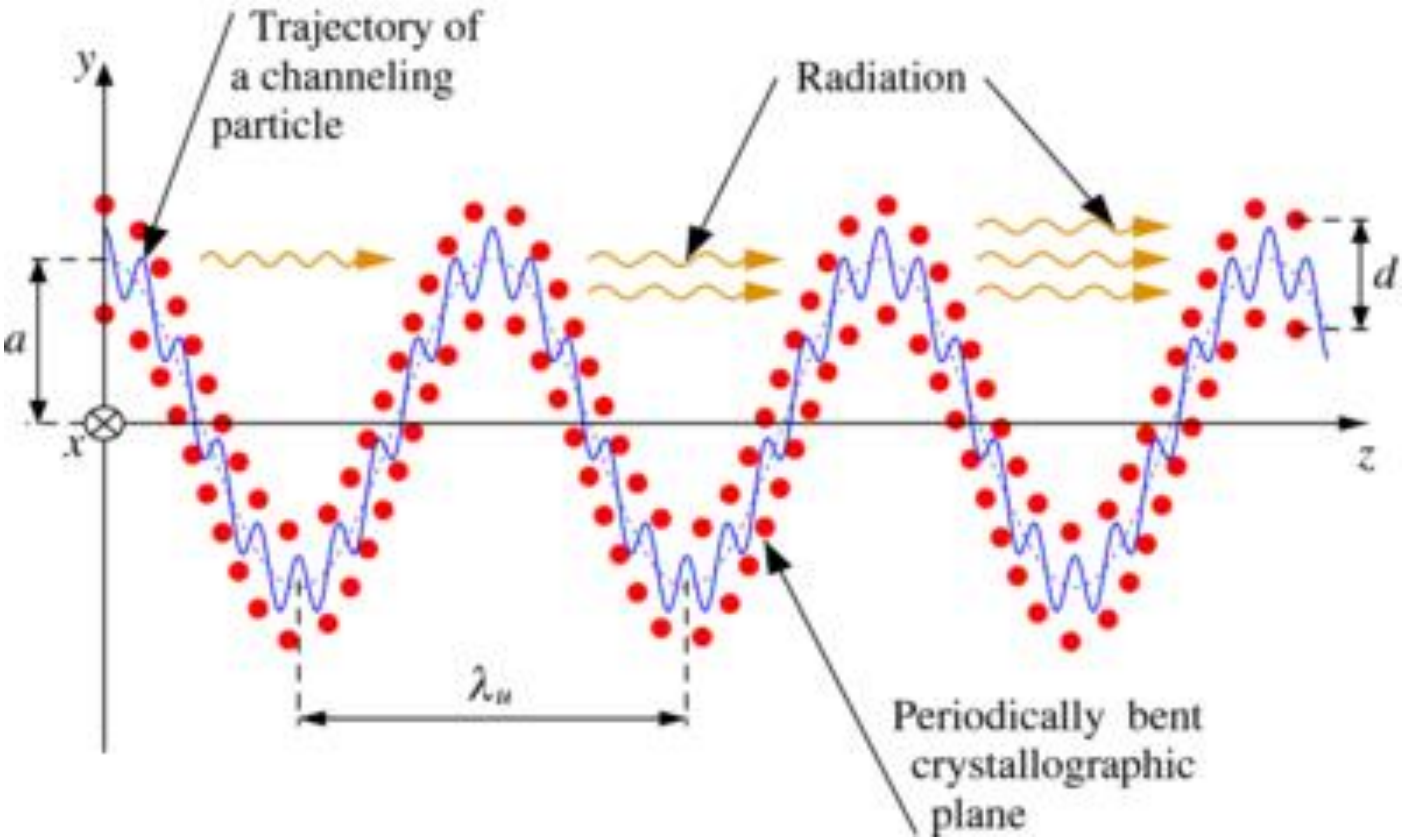
Delta-electron emission



Nuclear charge distribution for short-lived species (Aarhus-CERN-Berkeley collab.)

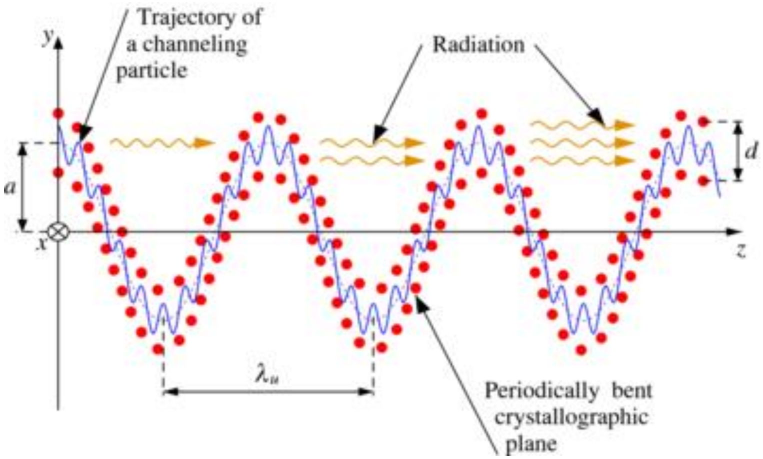
Undulator Radiation
from **Positron** Channeling in a Single Crystal

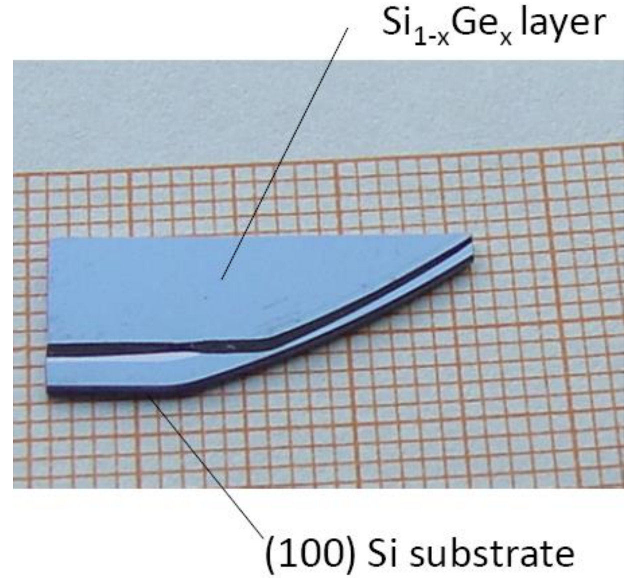
A. Solov'yov, A. Korol, W. Greiner *et al.*



MAMI, Mainz

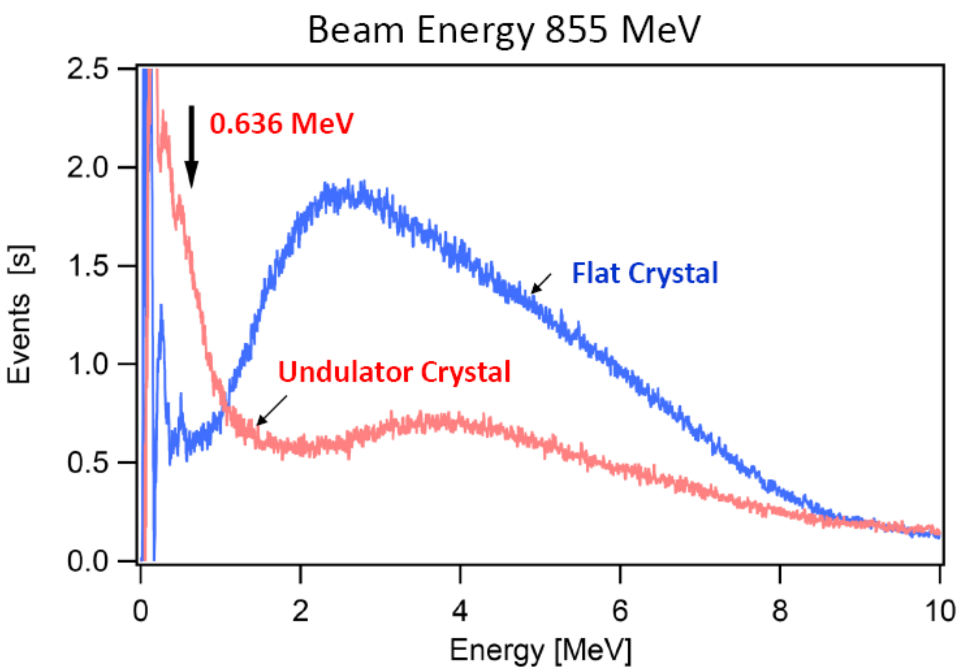
Crystalline undulator radiation

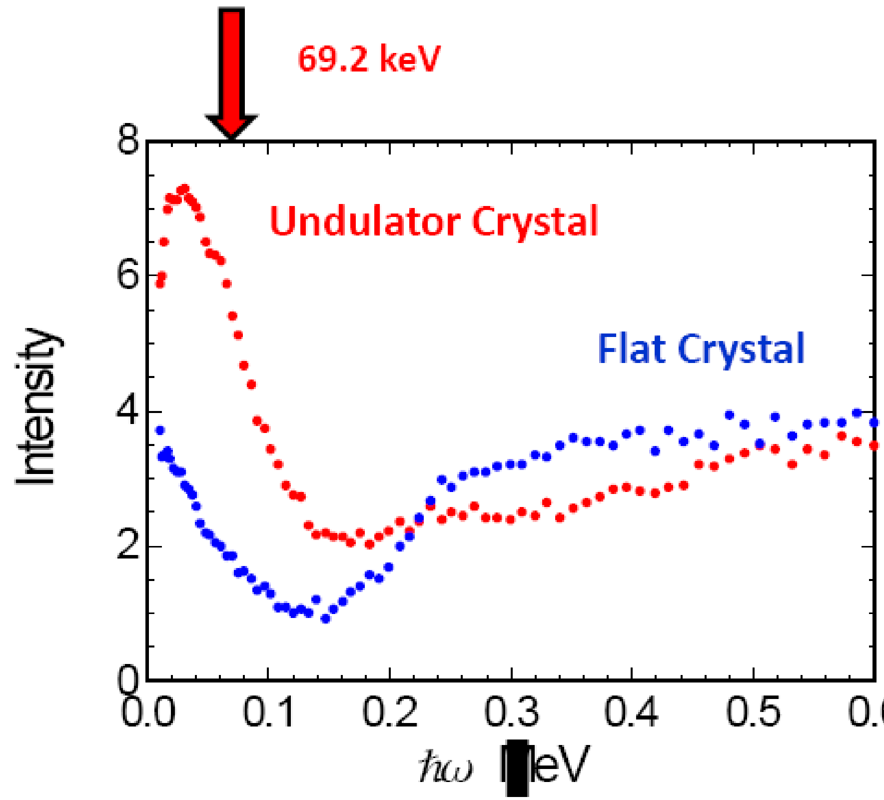




270 MeV

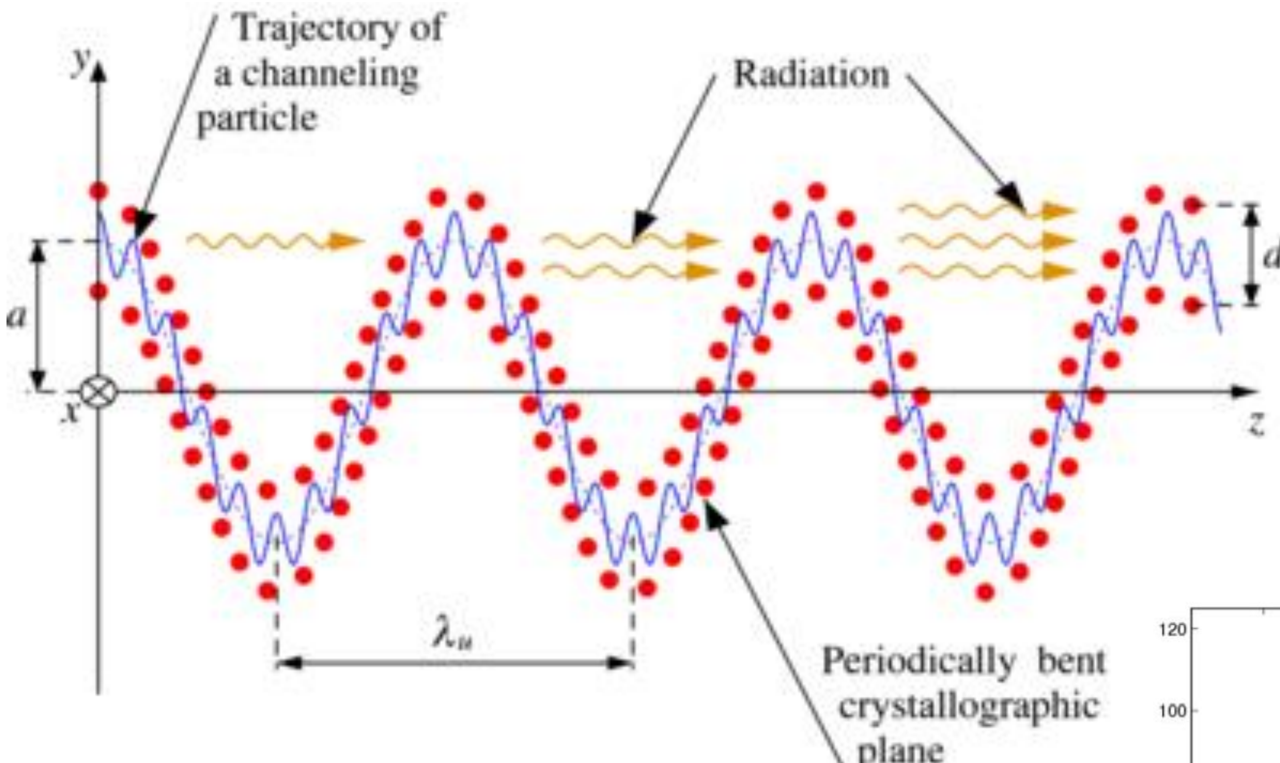
Electrons





Undulator Radiation
from **Positron** Channeling in a Single Crystal

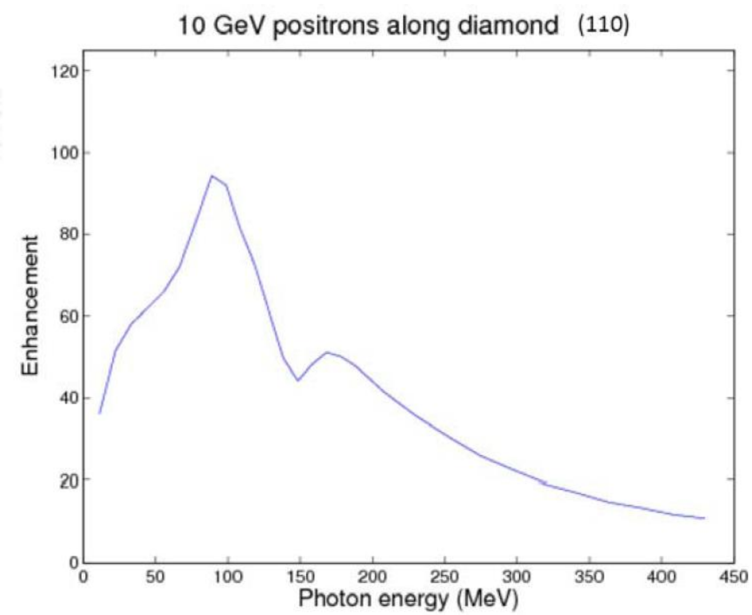
SLAC E-212



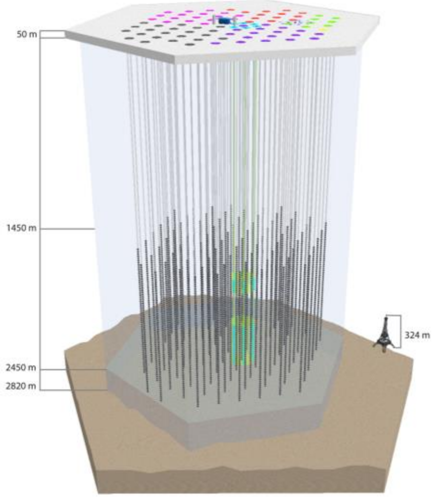
Stimulated emission in (nearly) harmonic potential

FACET

Facility for Advanced Accelerator Experimental Tests



A possible route to a gamma-ray laser?



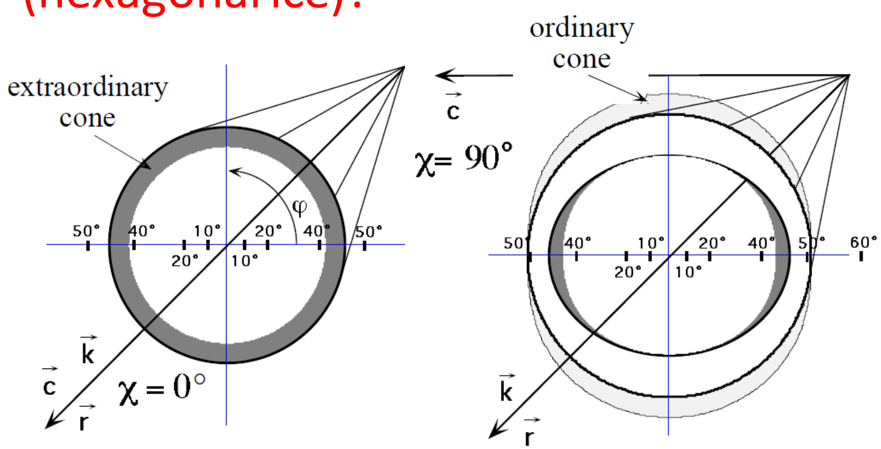
IceCube (-related)

MUON ACCELERATION IN COSMIC-RAY SOURCES

SPENCER R. KLEIN [1,2], RUNE E. MIKKELSEN [1,3], AND JULIA BECKER TJUS [4]

Subm. ApJ Lett.

Does Čerenkov emission depend on direction in a birefringent crystal (hexagonal ice)?

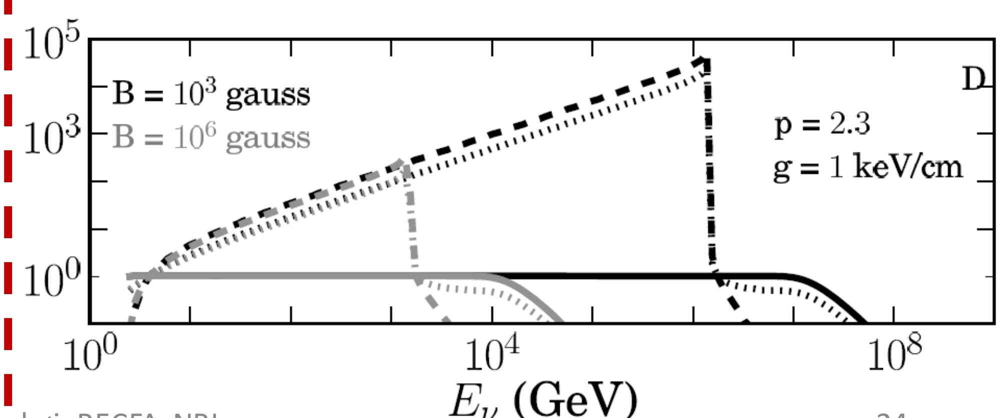


Experiment underway (week 20)

Eur. Phys. J. D 1, 109-116 (1998)

… and S. Klein, X. Artru

"Using the IceCube high energy diffuse neutrino flux limits, we […] put strong constraints on different models of particle acceleration, particularly those based on plasma wakefield acceleration, and limit models for sources like Gamma-Ray Bursts and magnetars."



Summary

- Incoherent bremsstrahlung (formation time)
- Strong fields
  - Radiation, quantum suppression
  - Spin-flip
  - Plasma wake-fields
  - Positron production
  - Tridents
  - Beamstrahlung, luminosity measurement
- AFTER@LHC – extract 7 TeV for FT QCD
- Heavy ion bremsstrahlung
- Crystalline undulator, E-212 (stimulated emission?)
- IceCube-related studies

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