

CERN NA63

and accelerator + detector R&D

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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).
- 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)
- 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).

Strong field effects

Real and virtual photon interactions

Tertiary photons as fast luminosity monitor

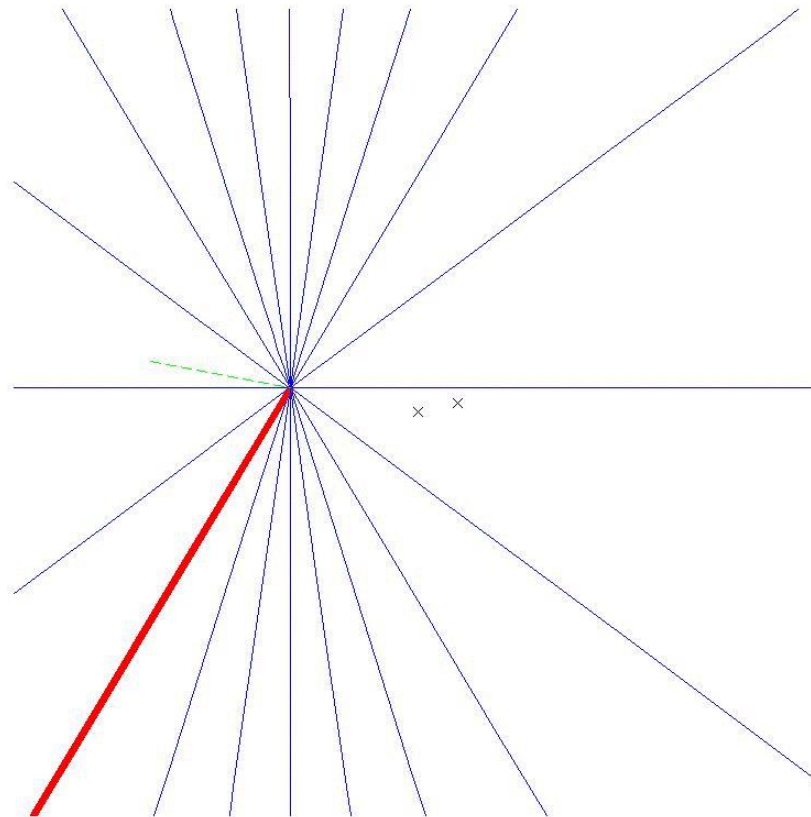
after the IP. Moreover, the beam-beam interaction leads to **depolarisation**. Simulations indicate that the depolarisation varies throughout the luminosity spectrum [16, 17], starting below 1% around the high energy peak at 3 TeV (i.e. for events with a lower degree of beam-beam losses) and reaching 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

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. Connell⁶

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Logarithmic t dependence

Transition between Bethe-Heitler and LPM regimes:

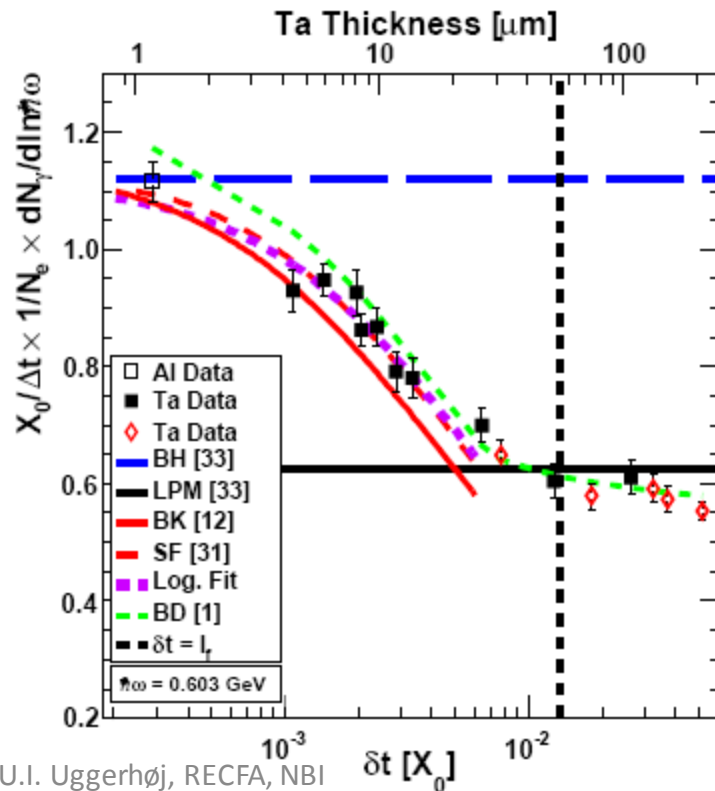
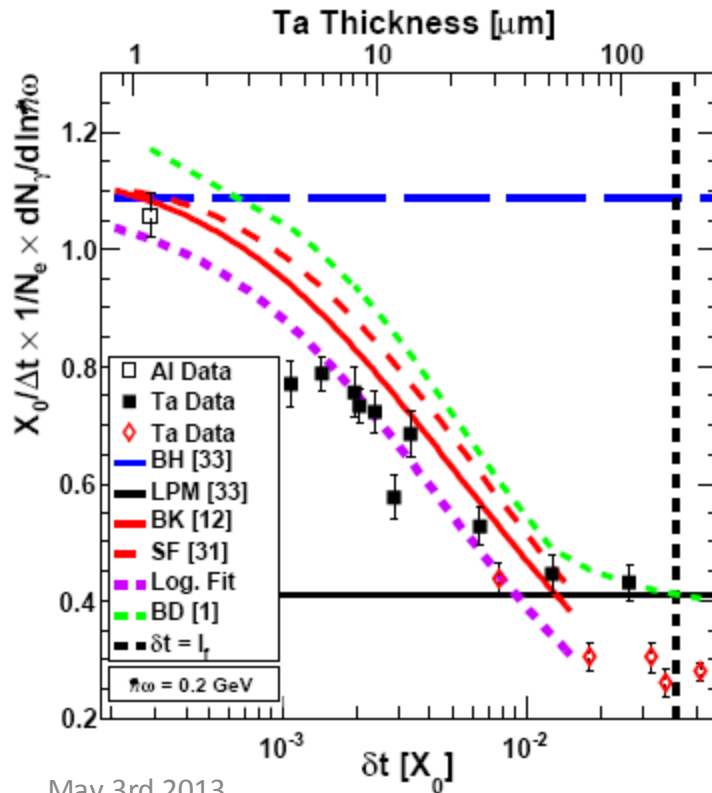
$$\frac{1}{N_e} \times \frac{dN_\gamma}{d \ln \hbar \omega}$$

$$\simeq a \times \frac{\ln(b \times \delta t + 1)}{b \times \delta t}$$

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

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

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



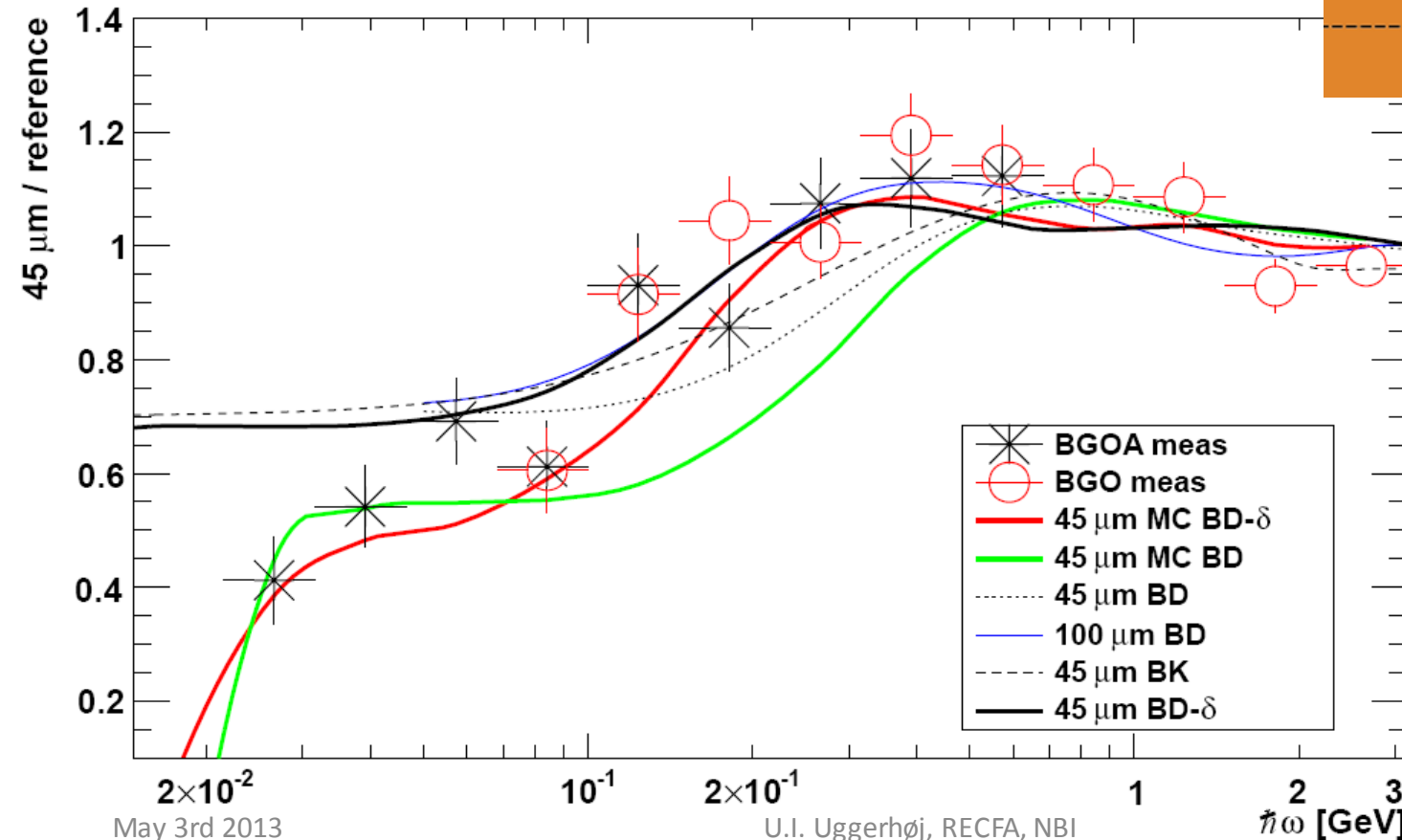
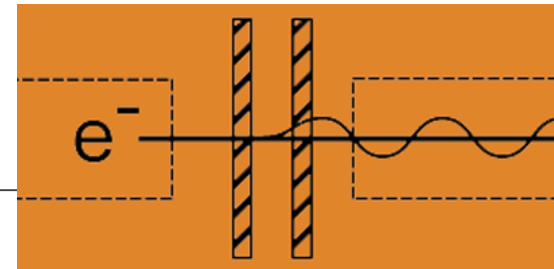
Direct Measurement of the Formation Length of Photons

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 Ballestrero⁵

(CERN NA63)

Synopsis: Going the Distance

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



Discrepancy reported at SPSC Oct 2011 was a theory problem!

Strong fields

Strong – compared to what?

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

- The critical field:

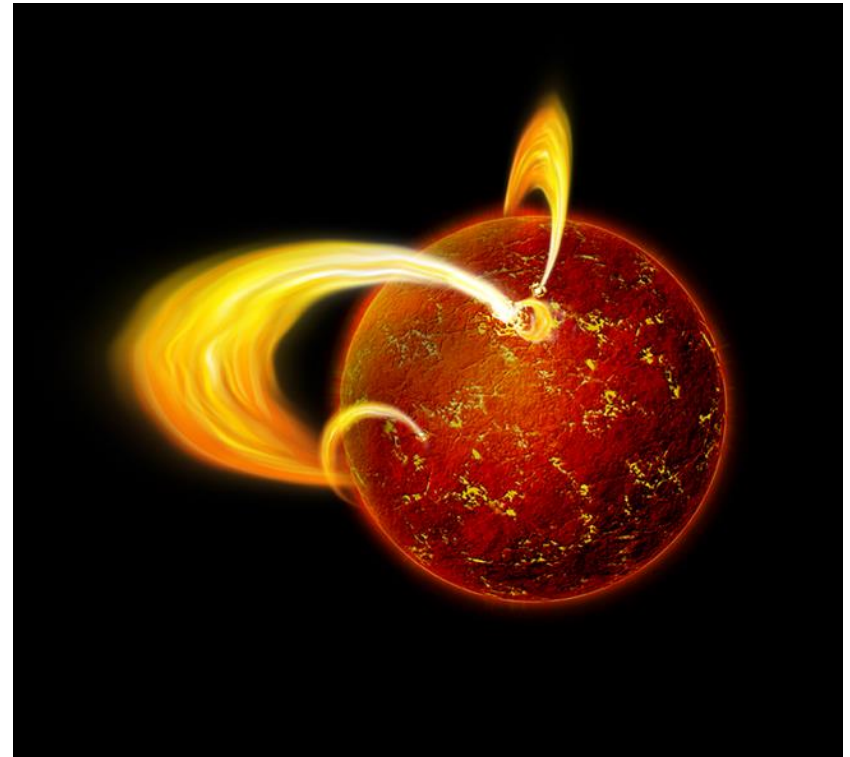
$$\begin{aligned}\mathcal{E}_0 &= m^2 c^3 / e \hbar \\ &= 1.32 \times 10^{16} \text{ V/cm}\end{aligned}$$

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

Exists at the surface of some neutron stars (magnetars)

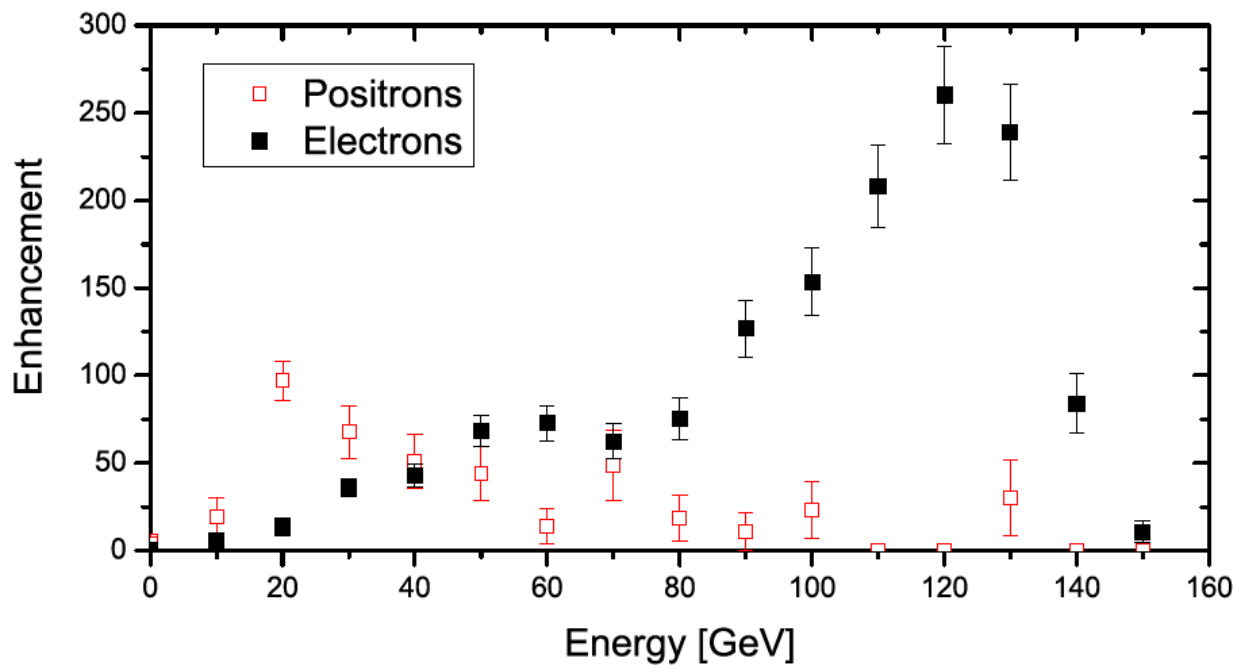
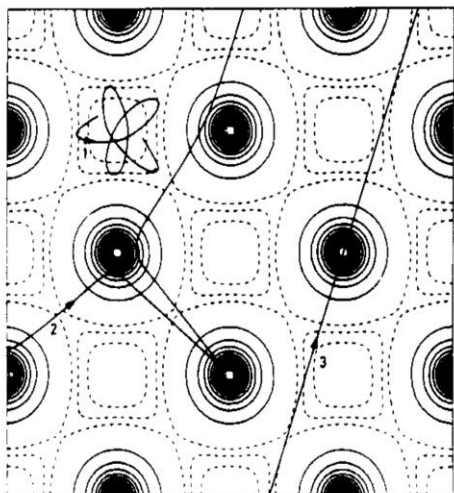
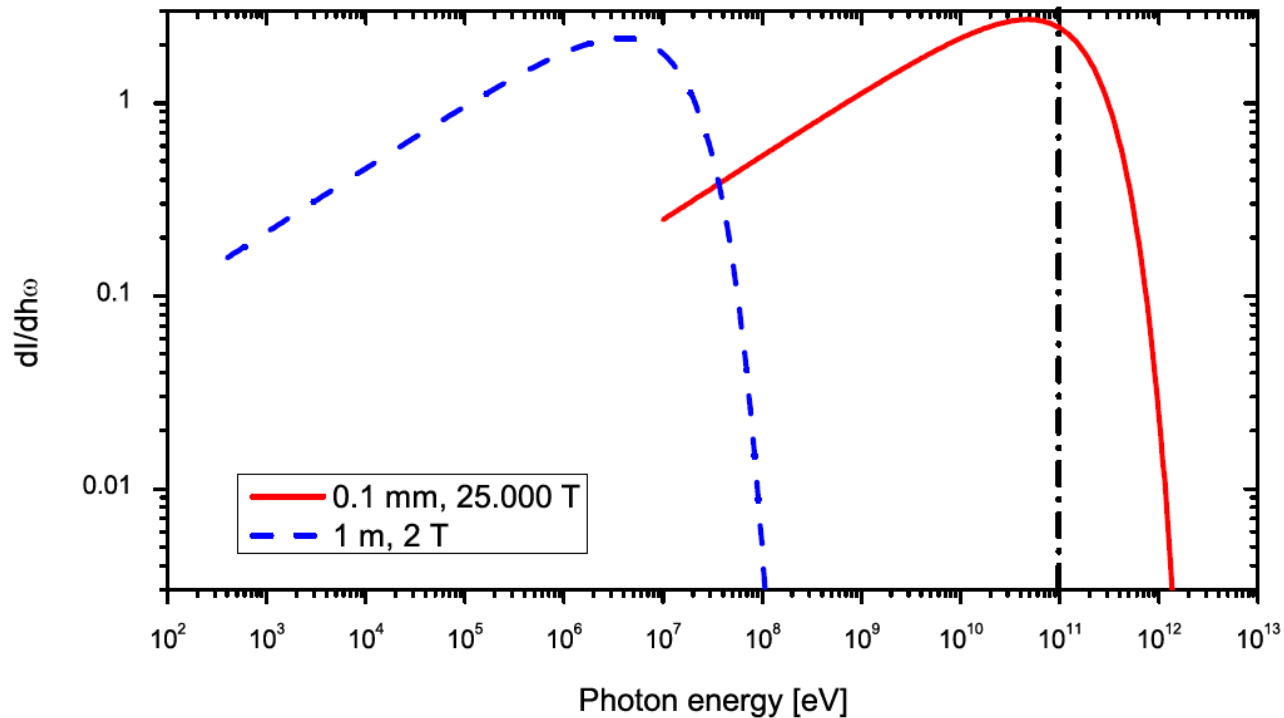
Relativistic invariant:

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



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

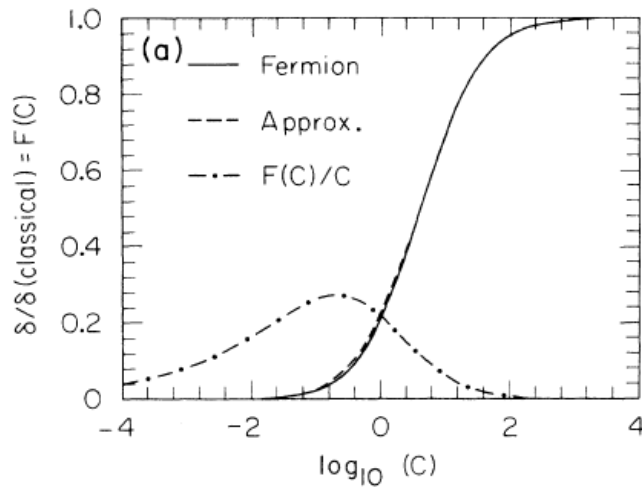
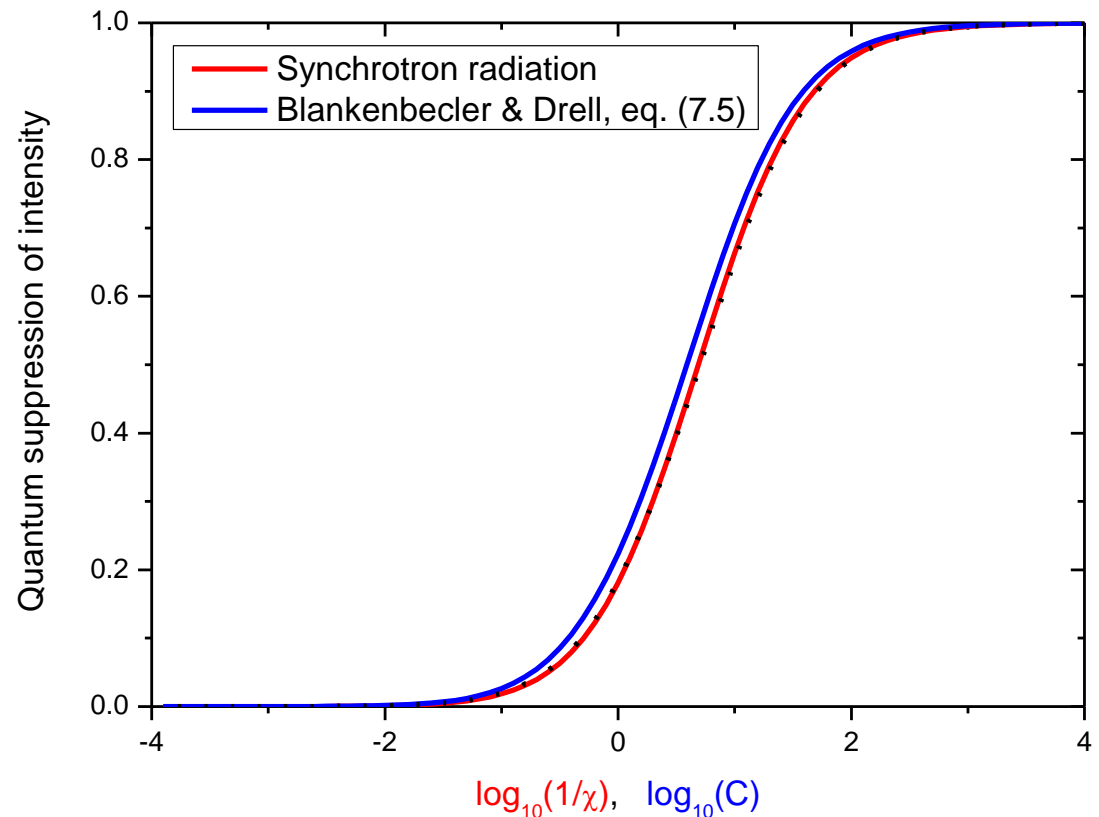


FIG. 1. (a) The form factor

$$C_b = \frac{m^2 c^3 R L}{4 N e^2 \gamma^2 \hbar}$$

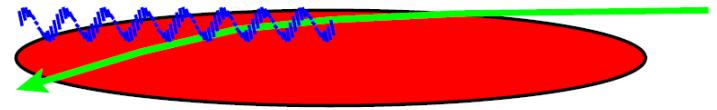
Classical: $\rightarrow 0 \Rightarrow C_b \rightarrow \text{infy}$

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



Quantum suppression

Beam-Beam Interaction



- beamstrahlung \Rightarrow luminosity spectrum

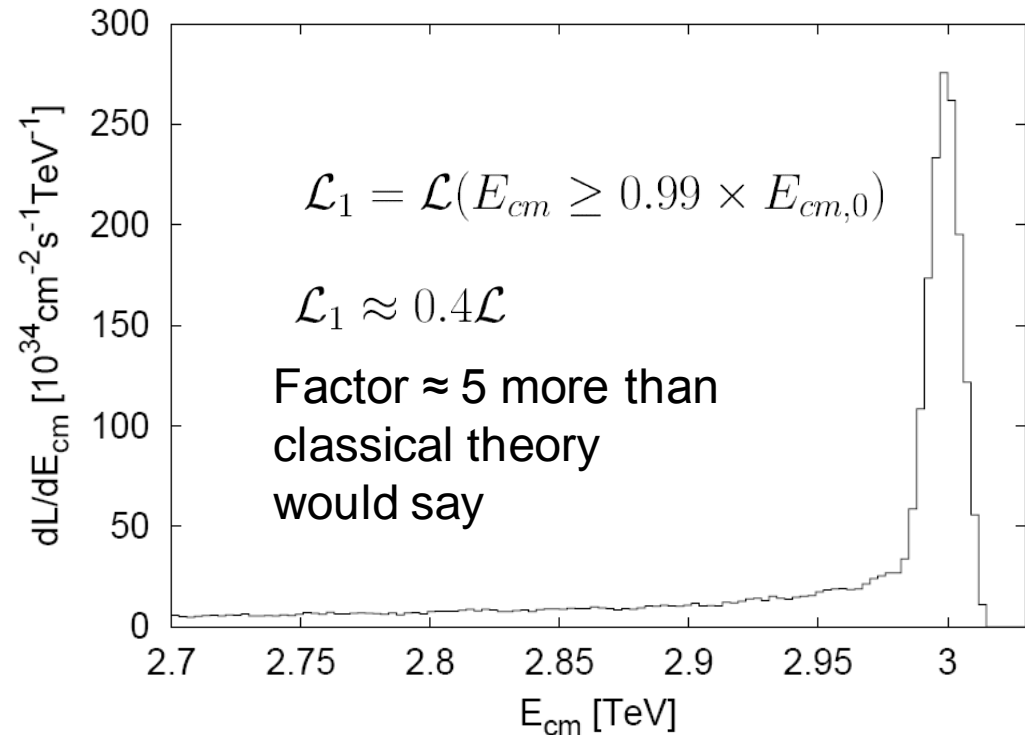
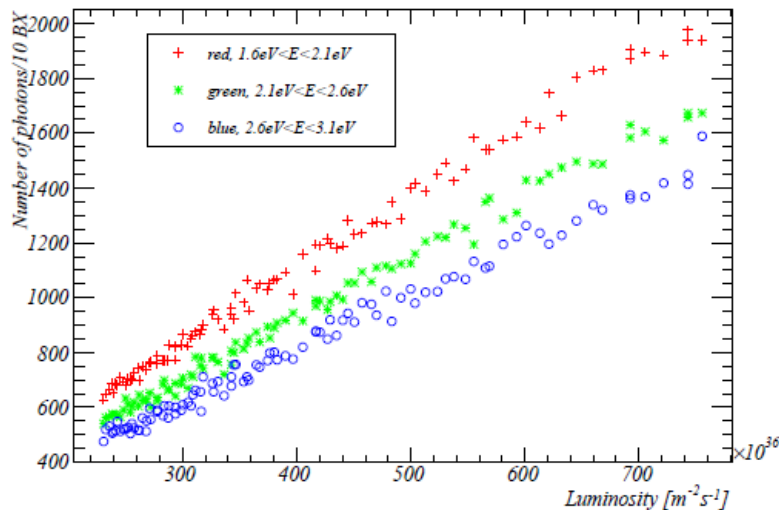
$$\mathcal{L}_0 = \frac{N^2}{4\pi\sigma_x\sigma_y} f_{rep} N_b$$

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

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

$\Upsilon \ll 1$: classical regime

$\Upsilon \gg 1$: quantum regime

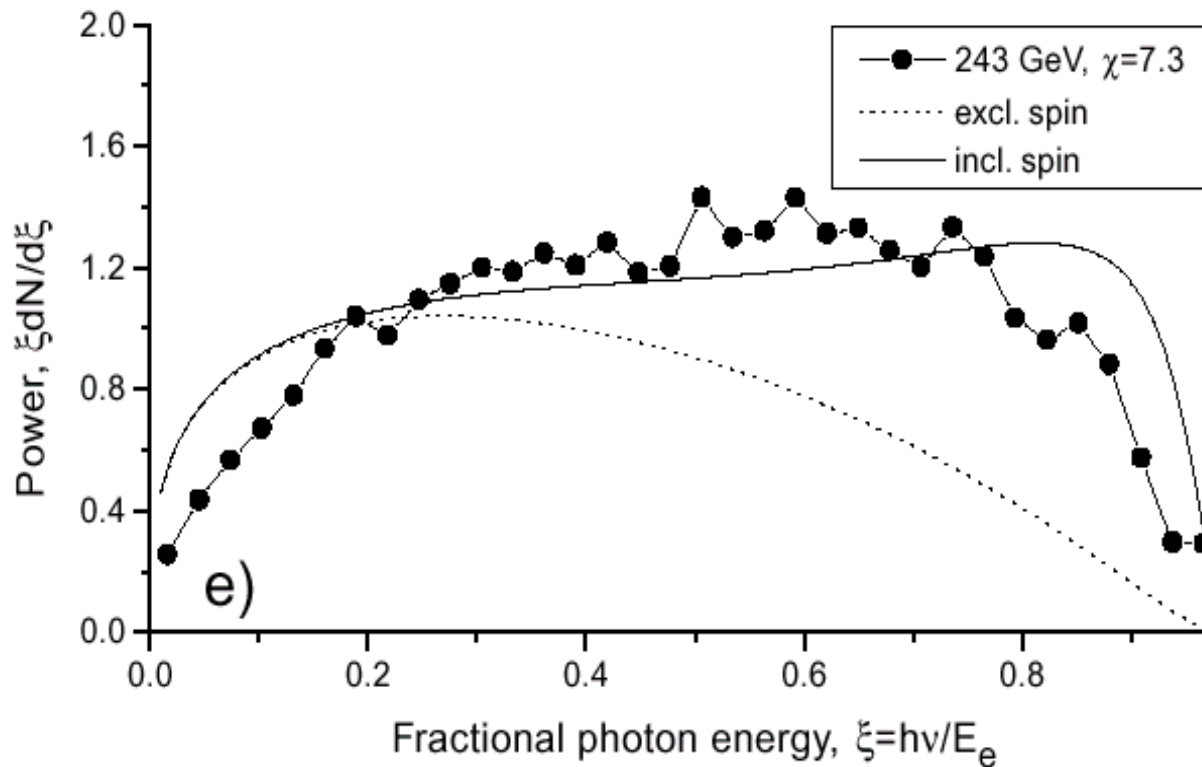


From: CLIC: Beam Dynamics and Limitations on Main Parameters

J. Esberg (NA63) – CTF3, GUINEA-PIG implementation
optical tertiary photons as a fast (ns) luminosity signal for CLIC

Spin-flip

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



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

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

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

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

100 GeV

$\chi=1$

$c\tau_{sf} = 10 \mu\text{m}$

$\tau_{sf} = 32 \text{ fs}$

1 GeV

$B=1 \text{ T}$

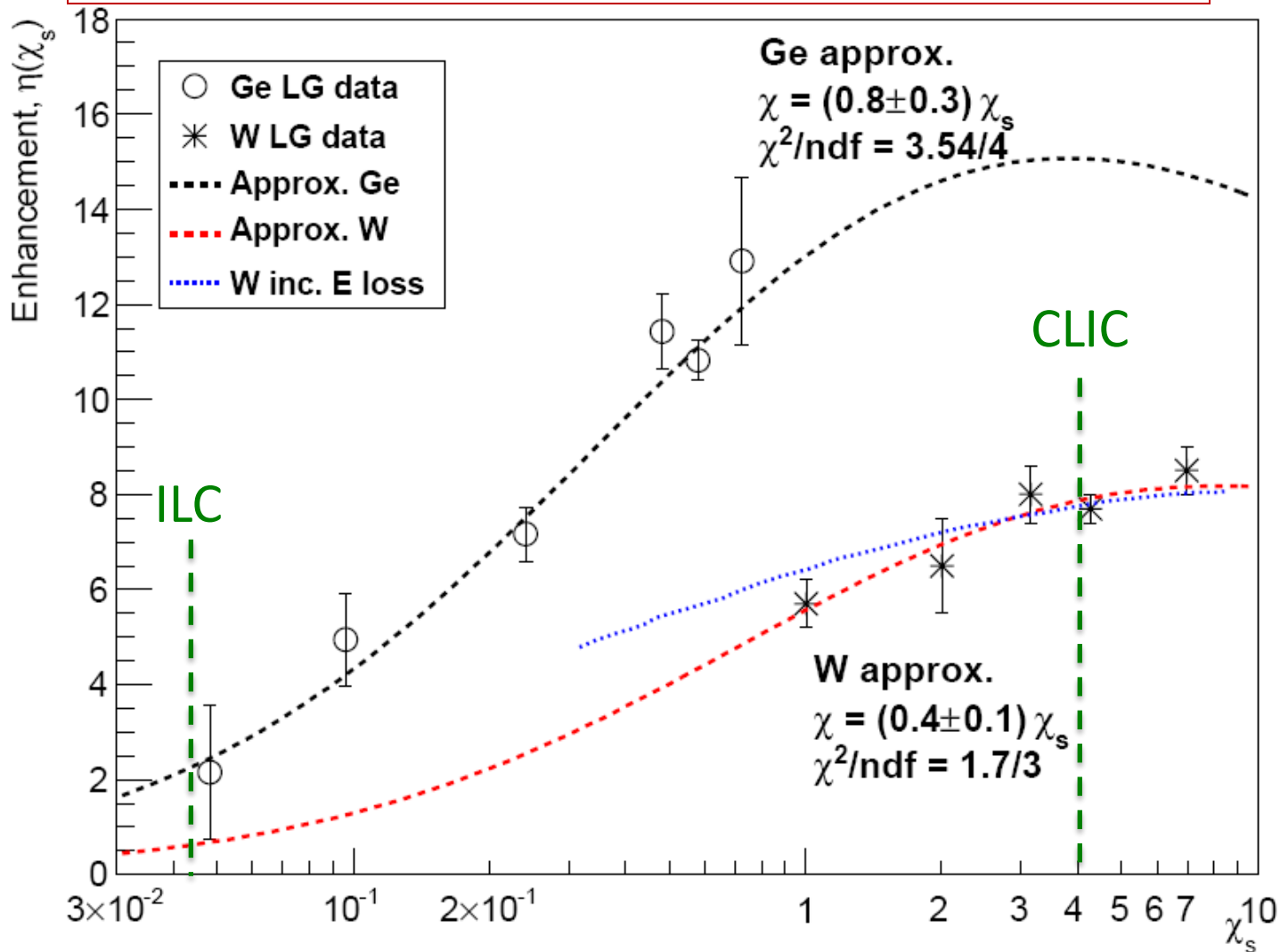
$c\tau_{sf} = 7.3 \text{ A.U.}$

$\tau_{sf} = 61 \text{ min.}$

'Polarization time/length'

Classical -> Quantum synchrotron

$$\frac{I_e}{I_{cl}} = (1 + 4.8(1 + \chi) \ln(1 + 1.7\chi) + 2.44\chi^2)^{-2/3}. \quad \text{Plotted as: } \cdots$$



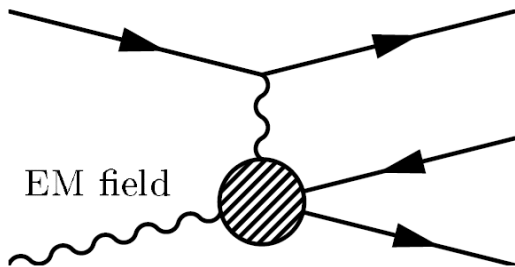
CERN NA63

K.K. Andersen *et al.*

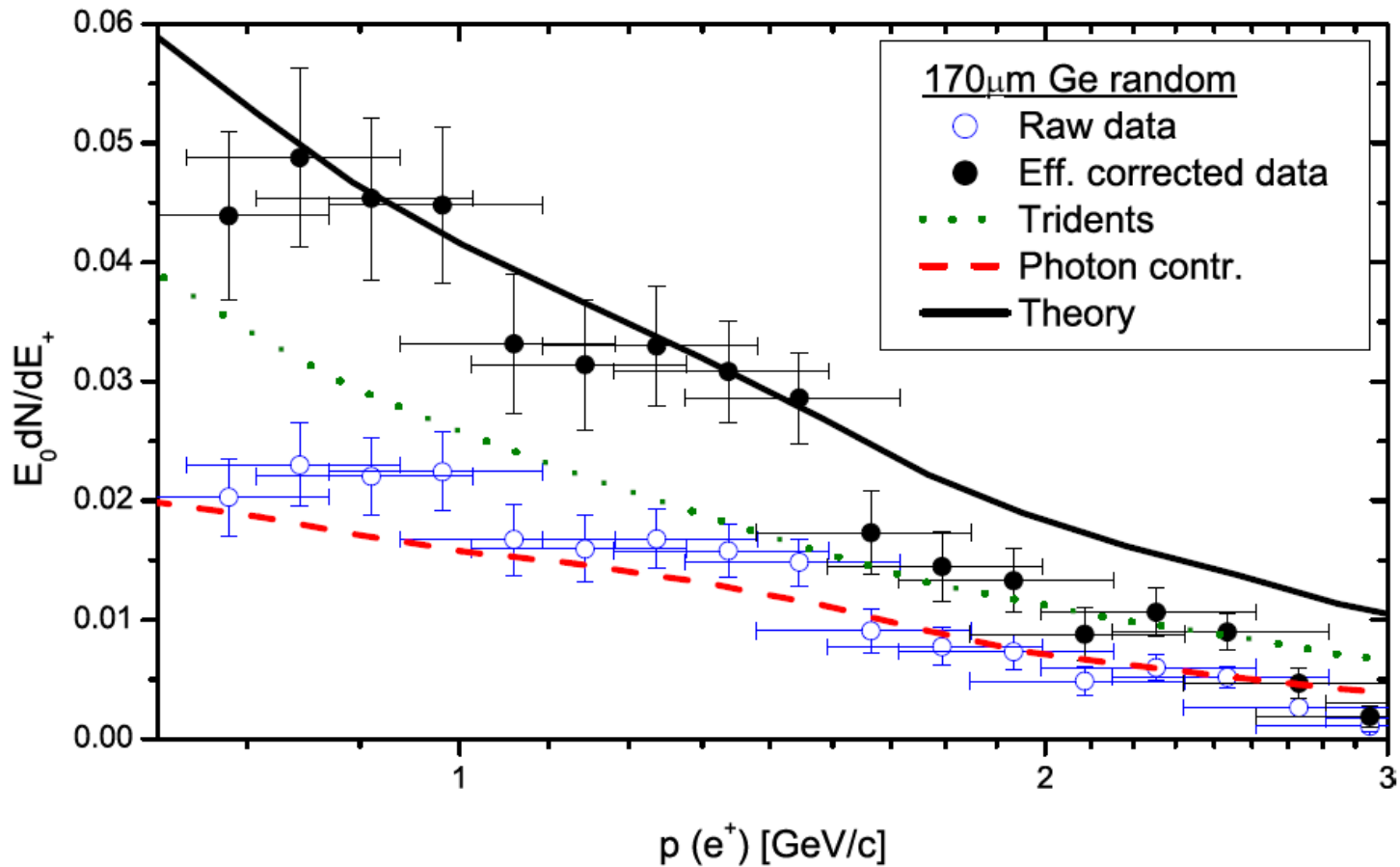
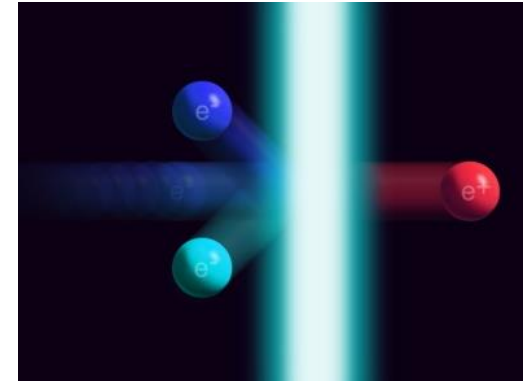
Phys.Rev. D **86**,
072001, 2012

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

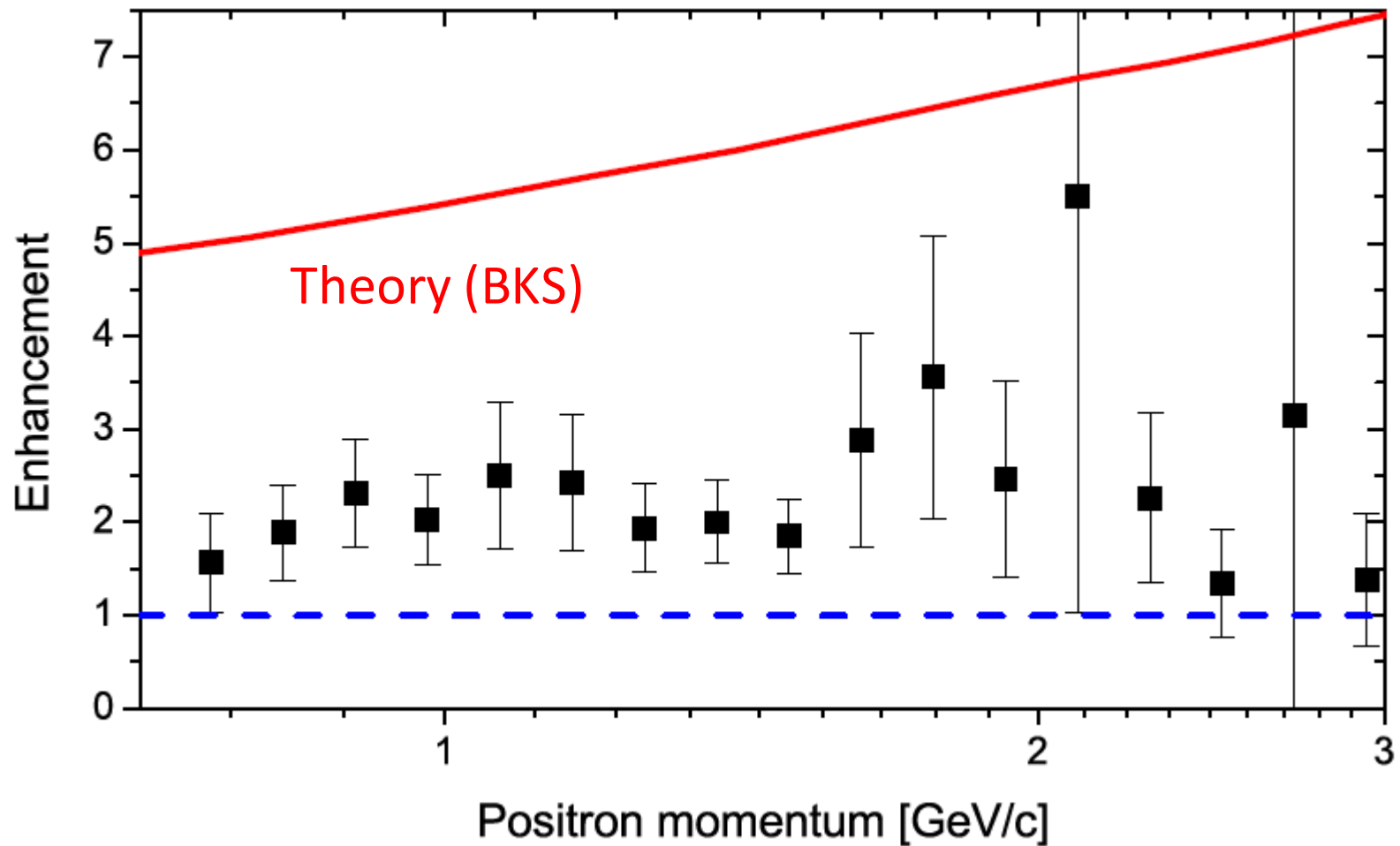
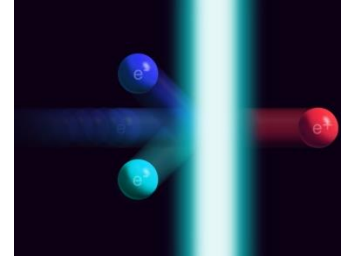
Trident production



$$e^- \rightarrow e^- e^+ e^-$$



Trident enhancement in strong field



Plasma wakefields

Transverse focusing forces:

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

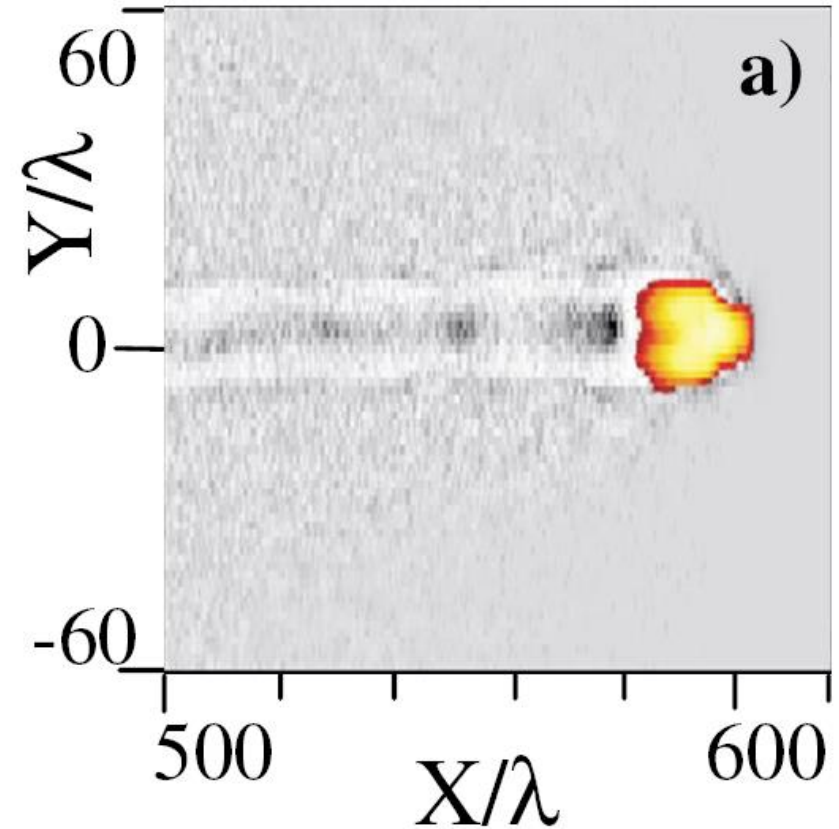
Lead to values

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

for realistic parameters:

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

cavitation or bubble regime



PHYSICAL REVIEW E 75, 057401 (2007)

AWAKE - Proton Driven Plasma Wakefield Facility at CERN
[SPSC-I-240](#)

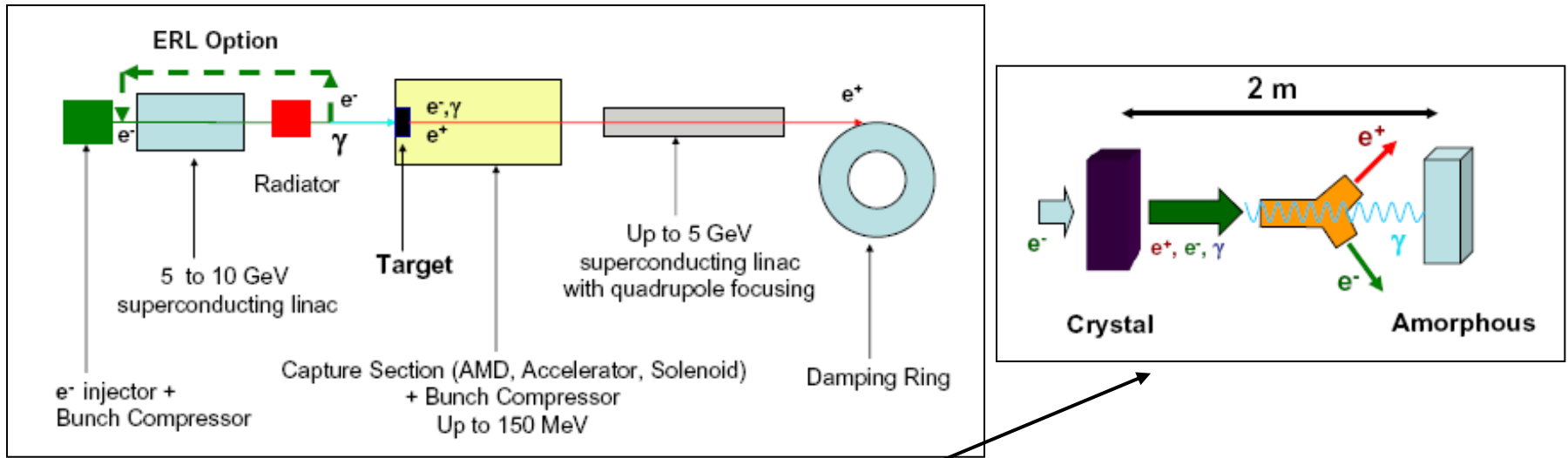
Positron production

...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

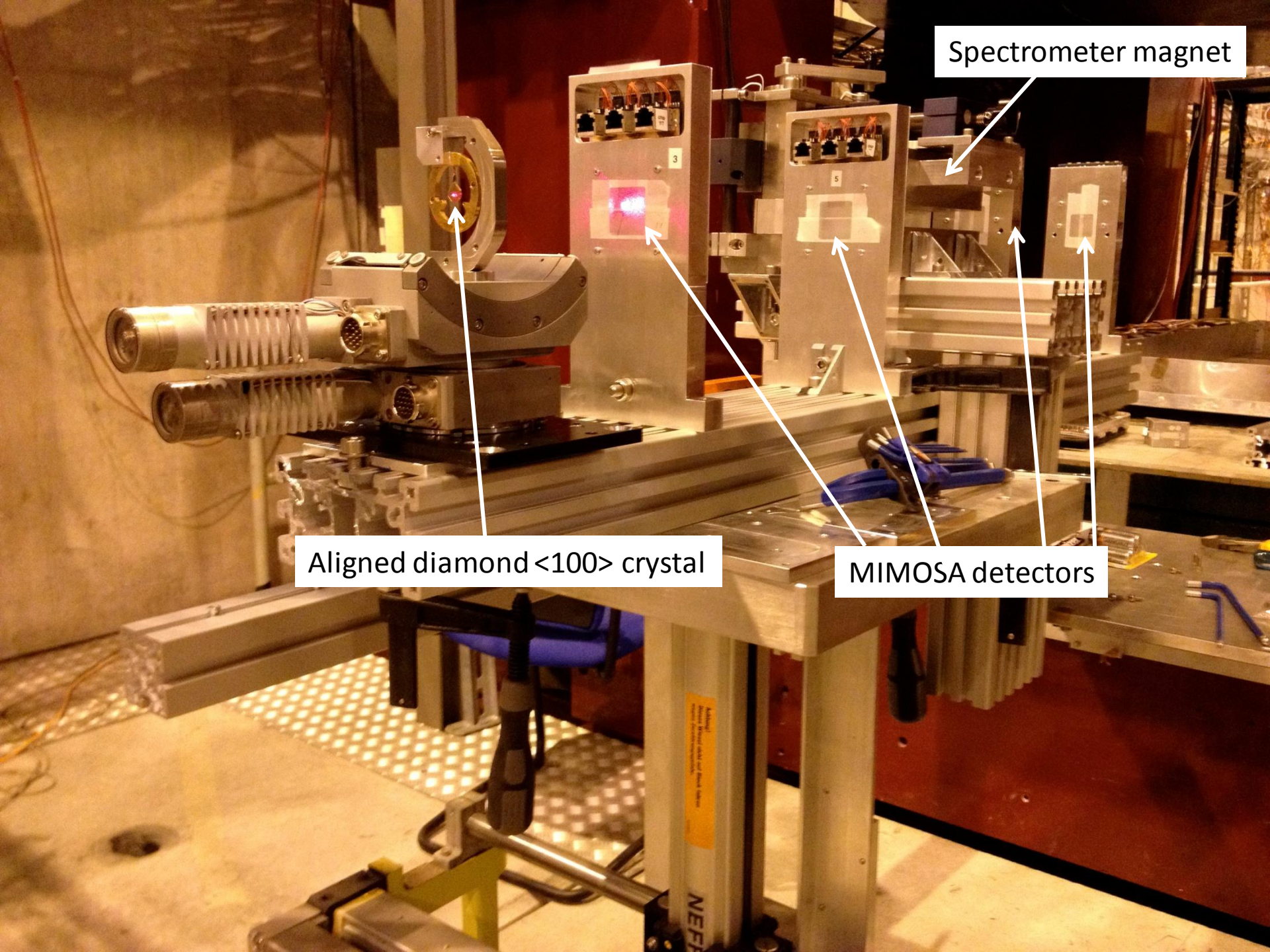


High multiplicity and 'low' energies (10 MeV e^+)

Spectrometer magnet

Aligned diamond $\langle 100 \rangle$ crystal

MIMOSA detectors



Positron production

MIMOSA detectors (M. Winter, Strasbourg)

- Vertex detectors for CLIC (?)

CMOS-based position sensitive detectors

1152 columns of

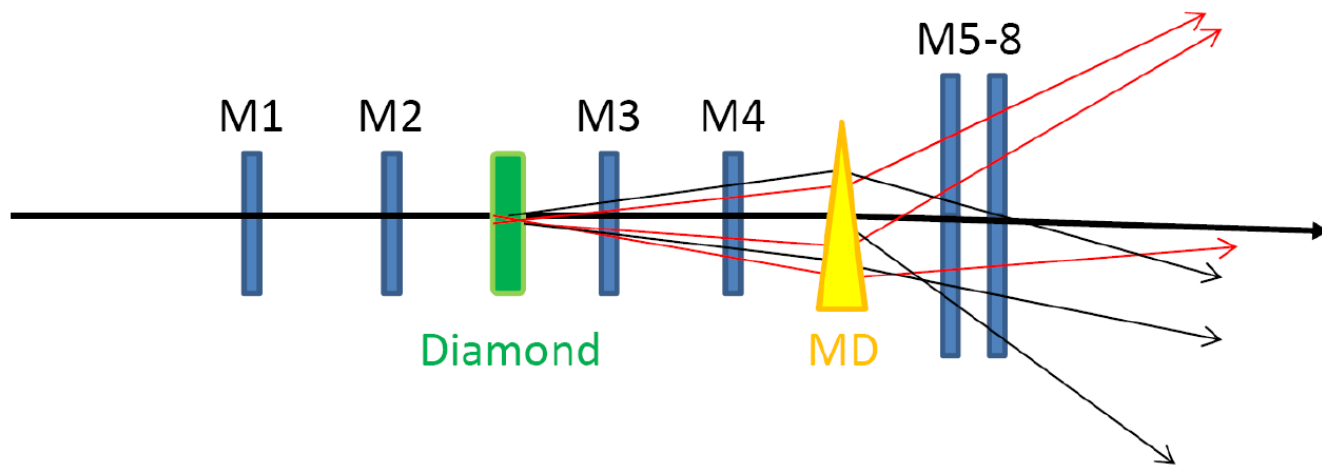
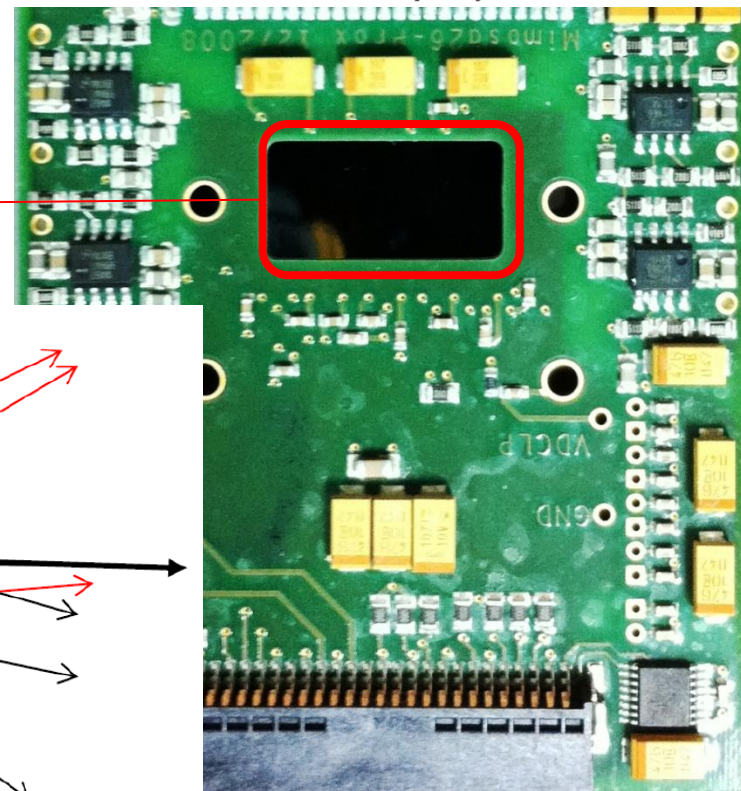
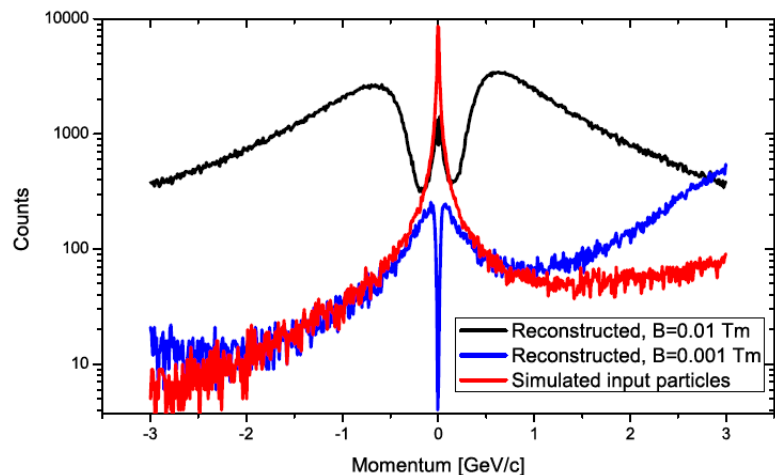
576 pixels, $\approx 18.4 \mu\text{m}$ pitch

readout in 110 ms, $\approx 3.5 \mu\text{m}$ resolution

true multi-hit capability

$1 \times 2 \text{ cm}^2$

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

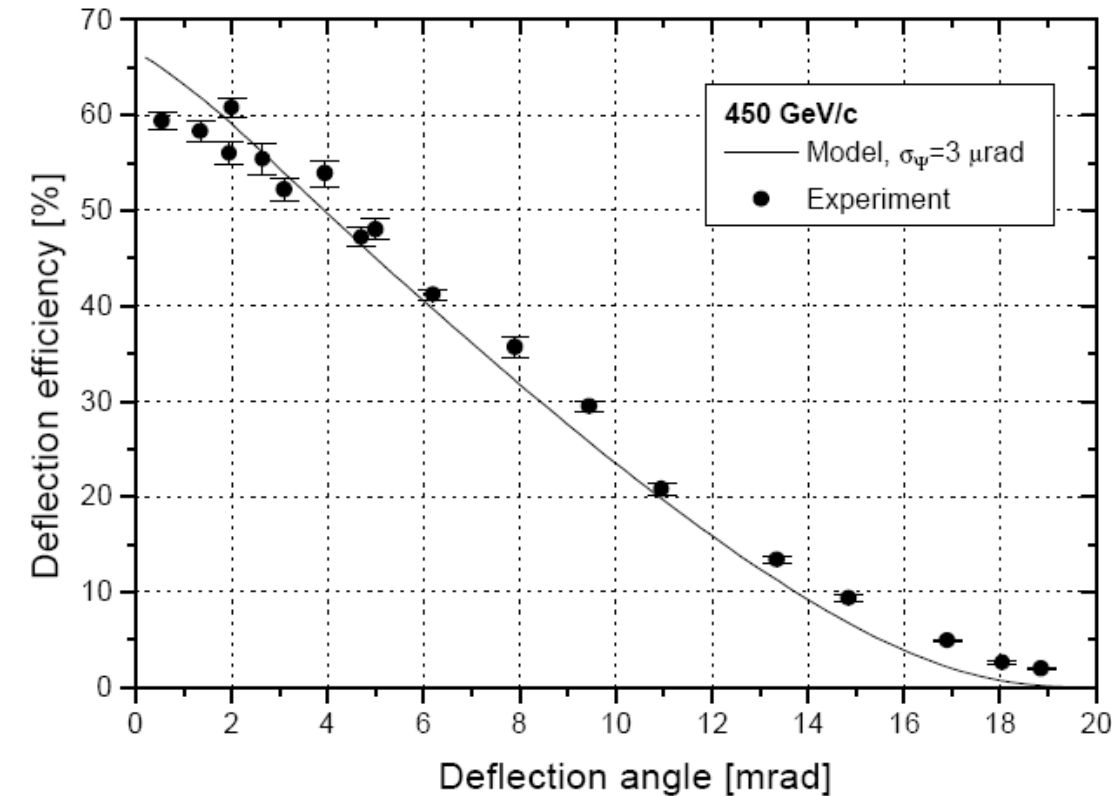
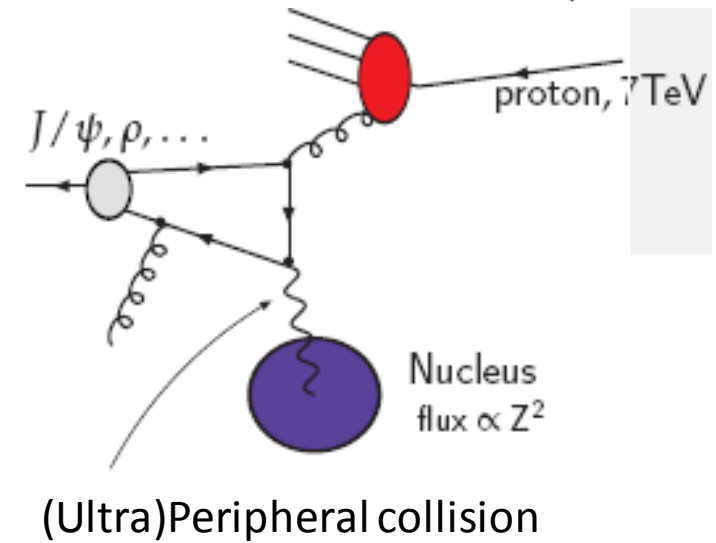
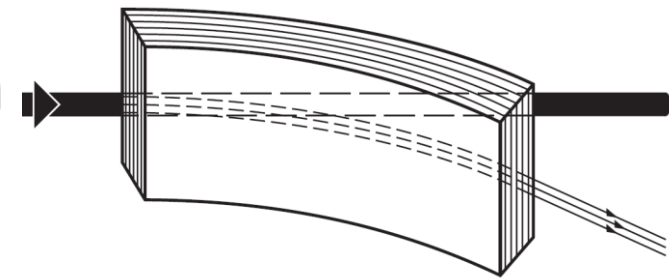


Detector R&D

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

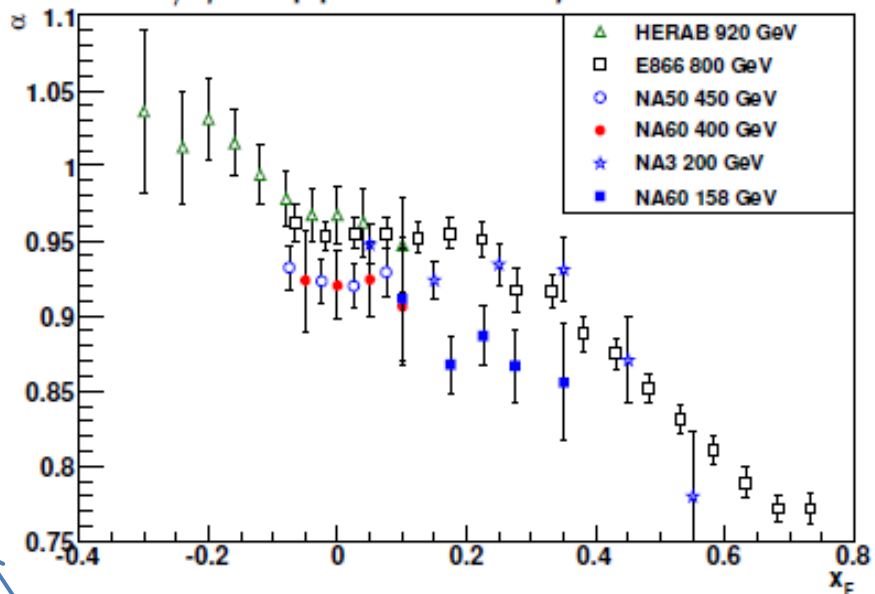
[J.P. Lansberg](#), [V. Chambert](#), [J.P. Didelez](#), [B. Genolini](#), [C. Hadjidakis](#), [P. Rosier](#),
[R. Arnaldi](#), [E. Scomparin](#), [S.J. Brodsky](#), [E.G. Ferreira](#), [F. Fleuret](#), [A. Rakotozafindrabe](#), [U.I. Uggerhøj](#)



Extraction of 7 TeV
LHC protons for
'fixed-target'
physics:

AFTER@LHC

J/ψ suppression in pA collisions

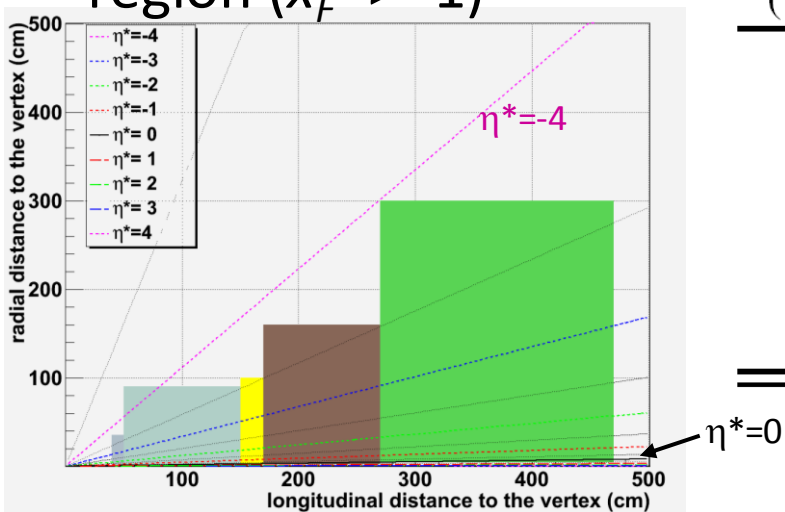


Extraction by a bent crystal



Luminosity at LHC

Access to target rapidity region ($x_F \rightarrow -1$)



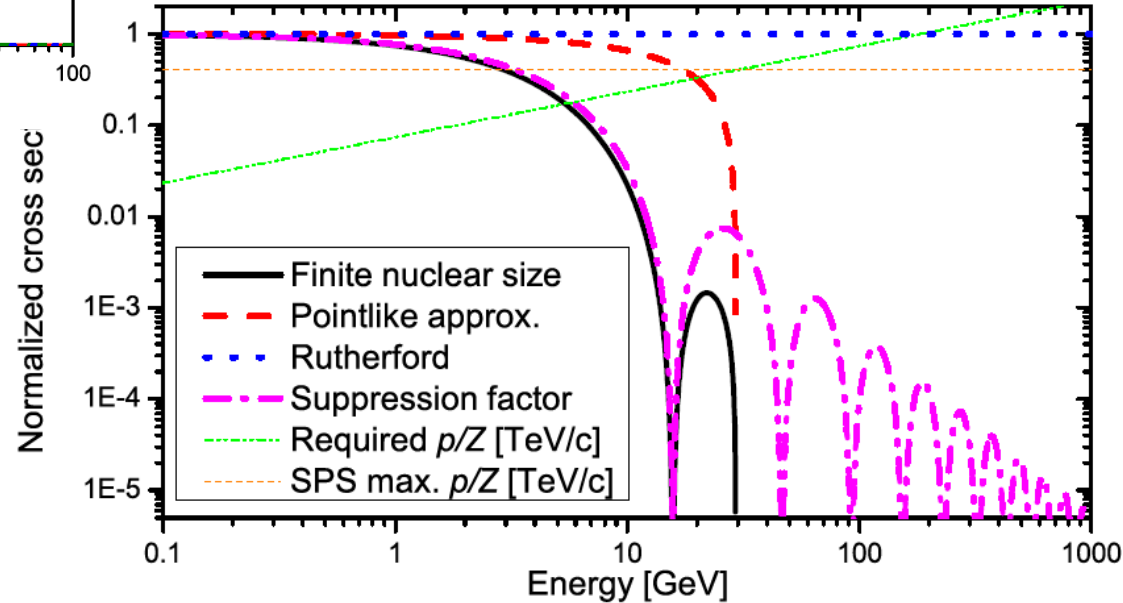
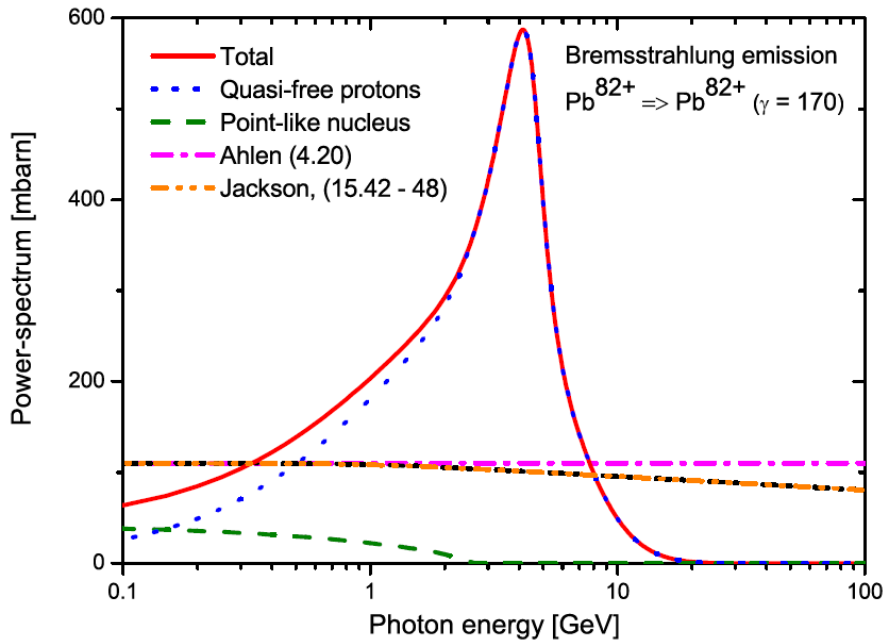
Target (1 cm thick)	ρ (g cm^{-3})	A	\mathcal{L} ($\mu\text{b}^{-1} \text{s}^{-1}$)	$\int \mathcal{L}$ ($\text{pb}^{-1} \text{yr}^{-1}$)
solid H	0.088	1	26	260
liquid H	0.068	1	20	200
liquid D	0.16	2	24	240
Be	1.85	9	62	620
Cu	8.96	64	42	420
W	19.1	185	31	310
Pb	11.35	207	16	160

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

S.J. Brodsky¹, F. Fleuret², C. Hadjidakis³, J.P. Lansberg³

Heavy ion bremsstrahlung

Delta-electron emission



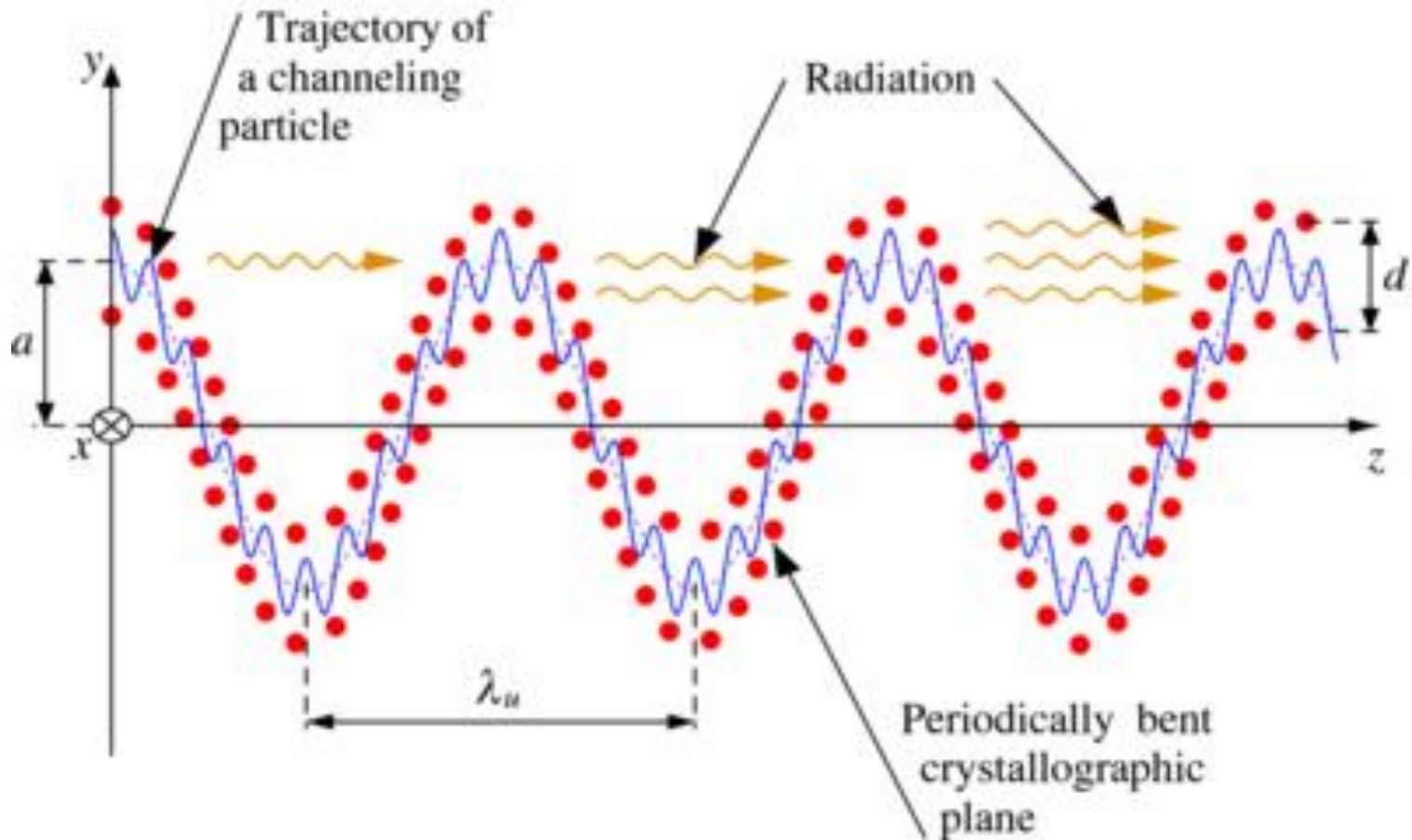
Finite nuclear size

Photon emission

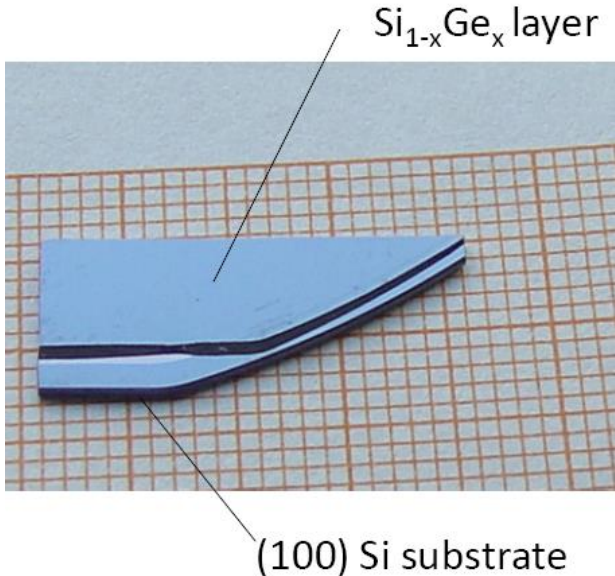
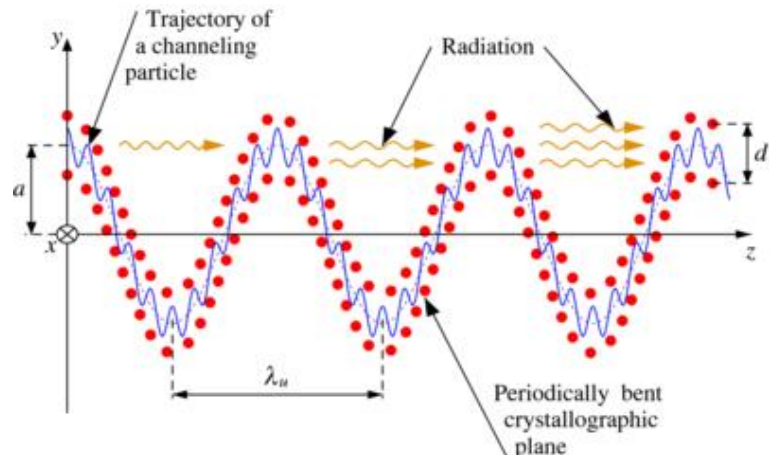
Nuclear charge distribution for
short-lived species
(Aarhus-CERN-Berkeley collab.)

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

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



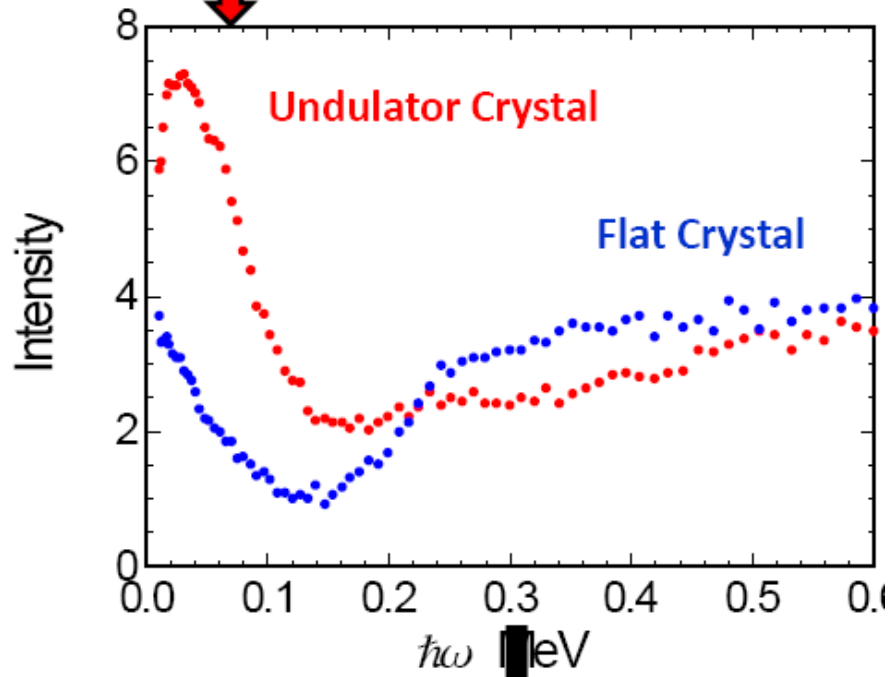
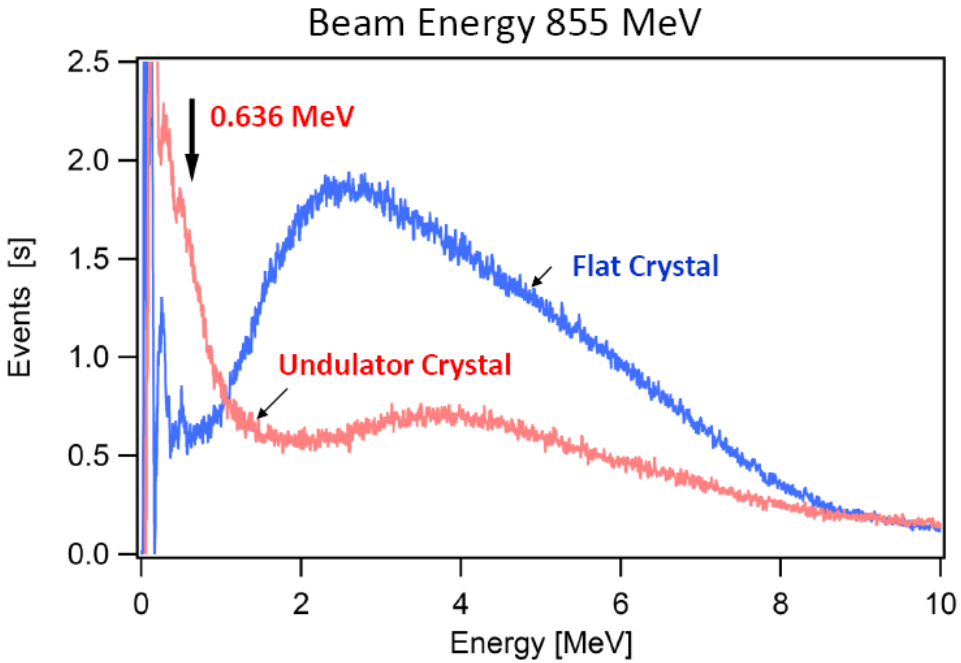
Crystalline undulator radiation



Electrons

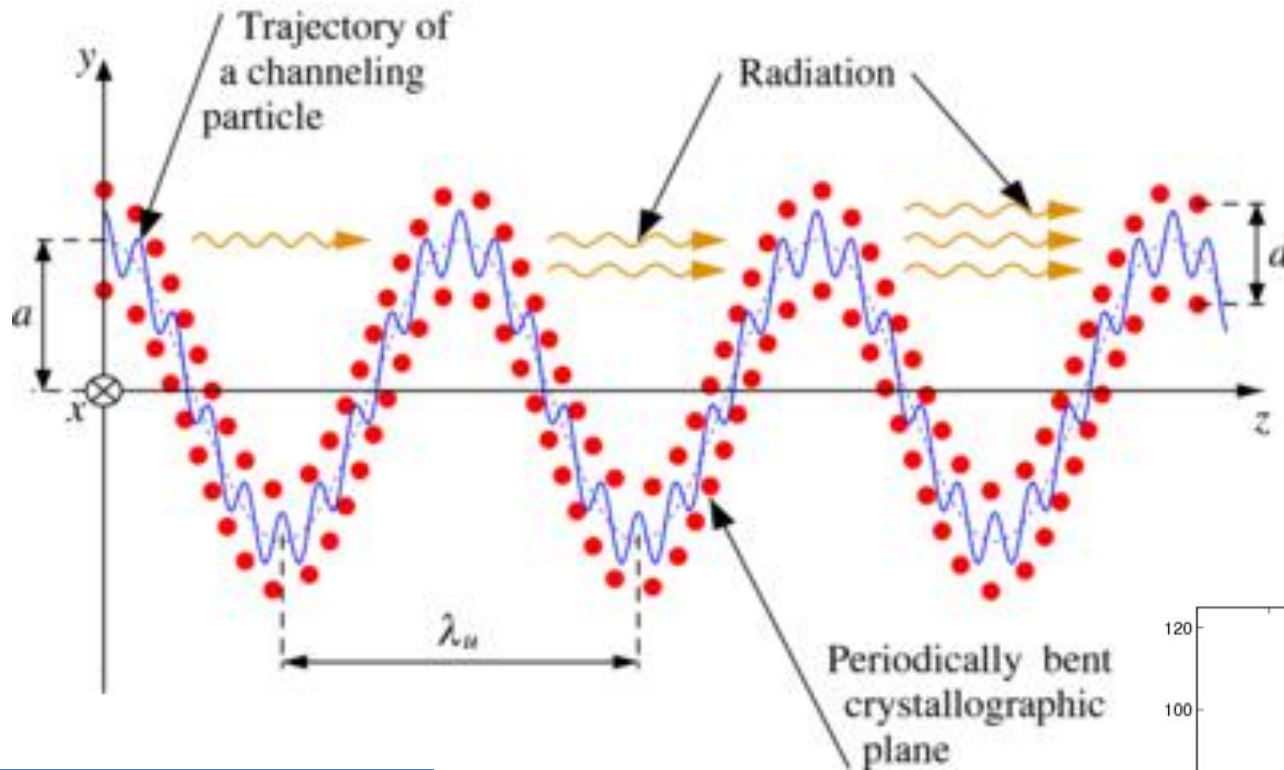
270 MeV

69.2 keV



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

SLAC E-212

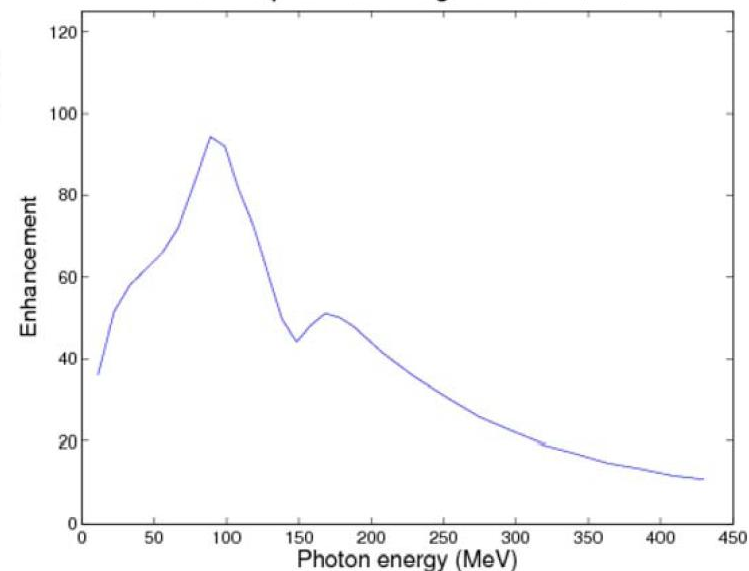


Stimulated
emission in
(nearly)
harmonic
potential



Facility for Advanced Accelerator Experimental Tests

10 GeV positrons along diamond (110)



A possible route to a gamma-ray laser?

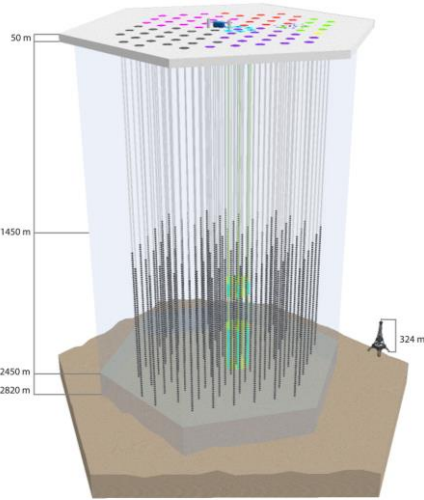
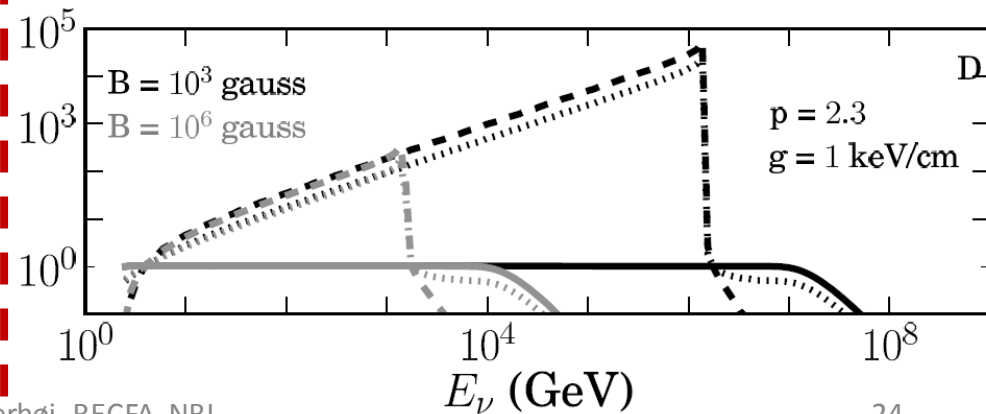
IceCube (-related)

MUON ACCELERATION IN COSMIC-RAY SOURCES

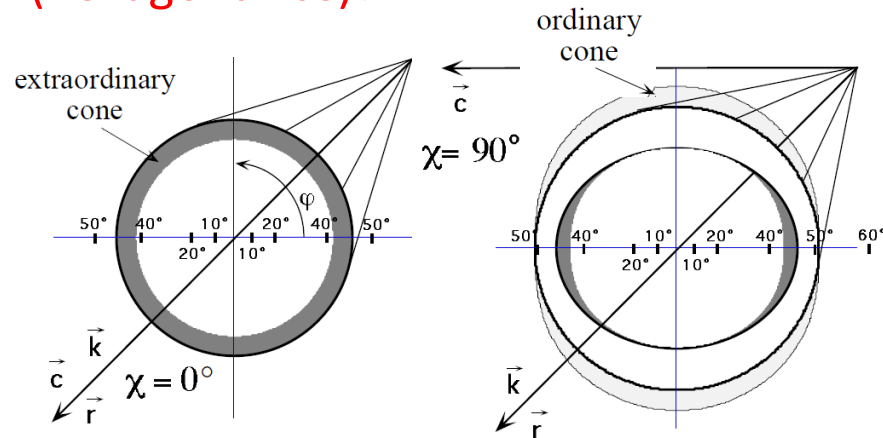
SPENCER R. KLEIN^{1,2}, RUNE E. MIKKELSEN^{1,3}, AND JULIA BECKER TJUS⁴

Subm. ApJ Lett.

“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.”



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

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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