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R. BÄR, A. BALANDA, J. BAUMANN, W. BERG, K. BETHGE, H. BOKEMEYER, H. FOLGER, O. FRÖHLICH, R. GANZ, O. HARTUNG, M. SAMEK, P. SALABURA, W. SCHÖN, D. SCHWALM, K. STIEBING, P. THEE, E. BERDERMANN, F. HEINE, S. HEINZ, O. JOERES, P. KIENLE, I. KOENIG, W. KOENIG, C. KOZHUHAROV, U. LEINBERGER, A. SCHRÖTER, H. TSERTOS

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Gesellschaft für Schwerionenforschung mbH
Postfach 11 05 52 · D-64220 Darmstadt · Germany

EXPERIMENTS ON e^+e^--LINE EMISSION IN HI COLLISIONS

R. Bär[2], A. Bałanda[4], J. Baumann[1], W. Berg[2], K. Bethge[2], H. Bokemeyer[1], H. Folger[1], O. Fröhlich[2], R. Ganz[3], O. Hartung[2], M. Samek[1], P. Salabura[4], W. Schön[2], D. Schwalm[3], K. Stiebing[2], P. Thee[2] (EPOS Collaboration)

E. Berdermann[1], F. Heine[5], S. Heinz[5], O. Joeres[5], P. Kienle[5], I. Koenig[1], W. Koenig[1], C. Kozhuharov[1], U. Leinberger[1], A. Schröter[1], H. Tsertos[6] (ORANGE Collaboration)

[1] Gesellschaft für Schwerionenforschung (GSI), D–64291 Darmstadt, Germany
[2] University of Frankfurt, D–60325 Frankfurt am Main, Germany
[3] University of Heidelberg, D–69120 Heidelberg, Germany
[4] Jagiellonian University, Cracow, Poland
[5] Technical University of Munich, D–85748 Garching, Germany
[6] University of Cyprus, Nicosia, Cyprus

We summarize the current status of e^+e^--coincidence experiments performed by the EPOS and ORANGE collaborations at GSI.

1 INTRODUCTION

Electron-positron coincidence measurements in heavy ion (HI) collisions at the Coulomb barrier, carried out at the GSI UNILAC accelerator independently by the ORANGE and EPOS collaborations, have revealed a series of narrow e^+e^--sum-energy lines with energies ranging from ~550 keV to ~820 keV [1, 2]. Missing a conventional explanation, the appearance of narrow lines was first set in the context of the decay of a new neutral particle [3], soon associated with the illusive axion. The two-body decay of such a particle, if produced at low velocity in the HI- center-of-mass system (CMS), can explain the surprising narrowness of the lines. Narrow lines are otherwise untypical for a lepton emission process in HI collisions. However, the identification of more than one line in subsequent experiments made this spectacular proposal very unprobable and, in particular, any elementary neutral particle was totally dismissed in related Bhabha-scattering and beam-dump experiments [4, 5].

To date, the lines together with their rather complex features observed still present a puzzle. The narrowness of the lines and their similar appearance in various heavy-collision systems may point towards a common origin, which seems to be closely connected with the particular situation of the heavy-ion collision environment [4]. The data are incomplete as far as a systematic dependence on the collision parameters and the lepton emission scenario is concerned, and partially suffer from poor statistical evidence. Apparently, such limited information is insufficient to identify the origin of the lines. This origin could be new, so far unknown physics but a complex combination of known processes still cannot be excluded. Arrived at this point, a major upgrade of both the ORANGE and EPOS experiments as well as of the accelerator injection system has been accomplished to considerably enlarge the experimental basis in a new round of experiments. This effort is joined by the APEX collaboration using a newly designed solenoidal pair spectrometer recently installed at the ATLAS heavy-ion beam facility [6]. This article describes the upgraded EPOS and ORANGE devices and reports on the status of the experimental knowledge on the sum-lines including results from the newly started investigations.

2 THE GSI e^+e^- SPECTROMETERS

Electron-positron spectroscopy in HI-collisions needs efficient and selective high-resolution spectrometers of high luminosity. This is achieved by combining either two large-acceptance dispersive magnetic spectrometers (ORANGE) or a solenoidal magnetic transport system (EPOS) with Si solid state detectors at the focal areas. The collision parameters are determined from the HI scattering products, detected in position-sensitive parallel plate avalanche counters (PPAC). Nuclear excitation is simultaneously controlled by NaI(Tl) and Ge(i) detectors. As already mentioned, both spectrometers have been considerably upgraded, leading to increased e^+e^--HI-coincidence efficiency, and better determination of the lepton opening angles.

2.1 The Double-Orange e^+e^- spectrometer

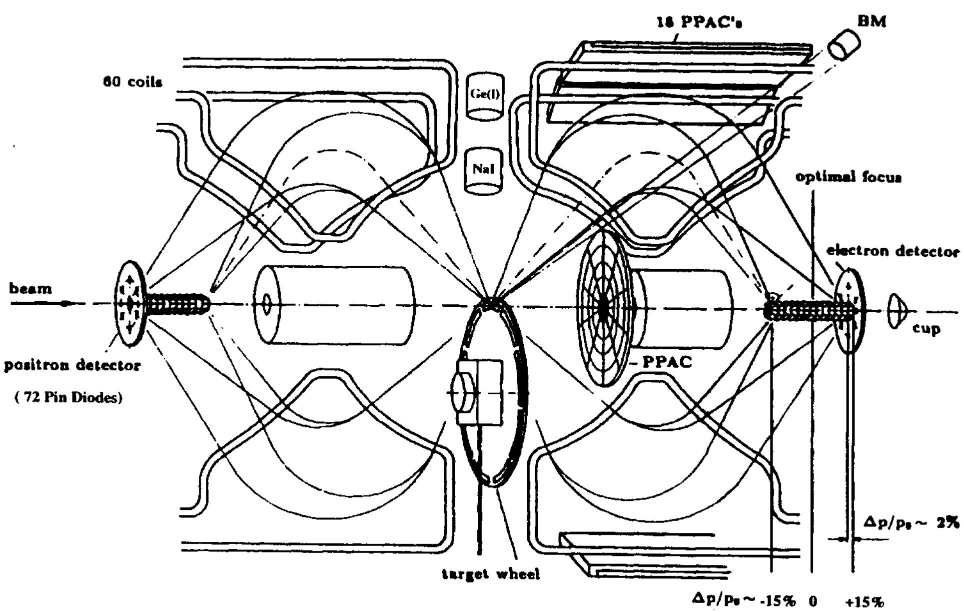


Figure 1: *Schematic view of the Double-Orange device. Also shown are the PAGODA lepton detectors, the HI detectors (PPAC's), the beam monitor, the rotating target wheel and NaI(Tl) and Ge(i) γ detector.*

The Double-Orange consists of two identical iron-free, orange-type β- spectrometers [2], facing each other with a common object point, at which a rotating target wheel is placed. e^+ emitted in the backward ($\vartheta_{e^+} = 110° - 142°$) and e^- emitted in the forward hemisphere ($\vartheta_{e^-} = 35° - 70°$) are focussed onto their corresponding focal cylinders, each covered by an array of high-resolution Si PIN detectors (PAGODA) (see Fig. 1). At a given field setting only a certain momentum interval of e^+ or e^- is focussed by totally rejecting the opposite charge. This is a major advantage because the high δ-electron background is therewith suppressed completely on the e^+-side, while the sharp low-energy cut-off on the e^--side enables operation at high luminosities. For the identification of the positrons an additional coincidence requirement with the 511 keV annihilation radiation is not necessary.

Both lepton detection systems consist of 72 Si PIN diodes (1 mm thick), mounted on a Pagoda-like structure of 12 roofs, each consisting of 6 detectors. Each of the 72 detectors has three active sectors, covering 20° of the total azimuthal range. The sum-energy resolution achieved in-beam amounts to ~15 keV (FWHM). Each PAGODA covers a momentum acceptance of $\Delta p/p$=30% (ΔE ~150 keV at 300 keV). Within this momentum interval, the full-energy peak efficiency is ~14% of 4π for e^- and e^+. With respect to the e^+e^--coincidence efficiency and the range of the e^+e^--energy-difference covered, this is an improvement by approx. a factor of two as compared to the previous set-up.

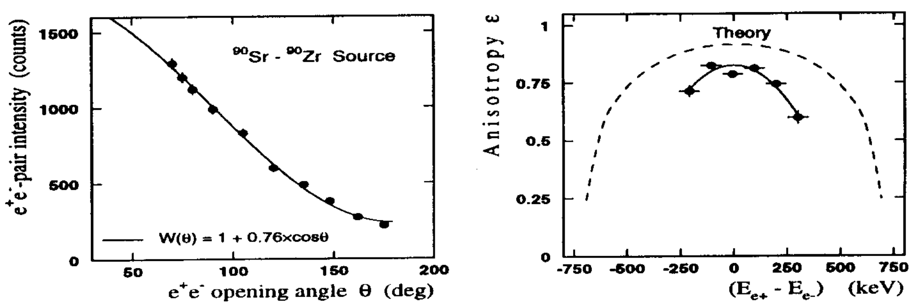


Figure 2: Left: $\vartheta_{e^+e^-}$ *distribution for the 739 keV e^+e^--sum-energy line of an E0 transition in ^{90}Zr measured with ORANGE. The solid line is a fit of W($\vartheta_{e^+e^-}$).* Right: *the extracted anisotropy coefficient ε (solid line to guide the eye) vs. the e^+e^--energy difference together with theory [7] (dashed line).*

The opening angle of the e^+e^--pair, $\vartheta_{e^+e^-}$, is measured directly within a range of 40° – 180° in the laboratory. Using the ϕ-separation of the PAGODA's, this range can be subdivided into ten angular bins with a typical width of ~ ±10° and centroids at $\vartheta_{e^+e^-}$ = 70°, 75°, 80°, 90°, 105°, 120°, 135°, 148°, 162°, and 175°. A set of PPAC's measures the polar angles of the scattered ions in the ranges $13° \leq \vartheta_{ion} \leq 35°$ and $40° \leq \vartheta_{ion} \leq 70°$ with an accuracy of 1° and 0.5°, respectively. The total azimuthal range is covered with a resolution in ϕ_{ion} of 20°. The Q-value and mass resolution achieved are 18 MeV and 5 amu, respectively.

The capability of the lepton detection systems has been studied extensively in source measurements. The results of the first measurement of the energy-dependent $\vartheta_{e^+e^-}$-distribution W($\vartheta_{e^+e^-}$,E_{e^+}-E_{e^-}) of the 739 keV e^+e^--sum-line of the E0 transition in ^{90}Zr using a rather thick ^{90}Sr source is shown in fig. 2 together with recent theoretical predictions [7]. Accordingly, W($\vartheta_{e^+e^-}$) should exhibit the relation $W(\vartheta_{e^+e^-}) \propto (1+\varepsilon\cos\vartheta_{e^+e^-})$, with the anisotropy factor ε depending on the energy difference of e^+ and e^- [7]. The measured ε is ~10% lower than predicted (fig. 2). Whether this discrepancy could be attributed to the effect of small-angle scattering of the leptons in the source is currently investigated by MC- calculations.

2.2 The EPOS solenoidal transport system

The main elements of the new set-up are shown in fig. 3. e^- and e^+ are transported simultaneously within the full energy range of interest onto planar Si(Li)-detector arrays by the solenoidal magnetic field of ~ 0.1 T perpendicular to the beam direction. Contrary to the old device, where e^- have only been detected on one, e^+ on the other side of the solenoid, the new set-up measures e^+ and e^- on both sides simultaneously, thus covering

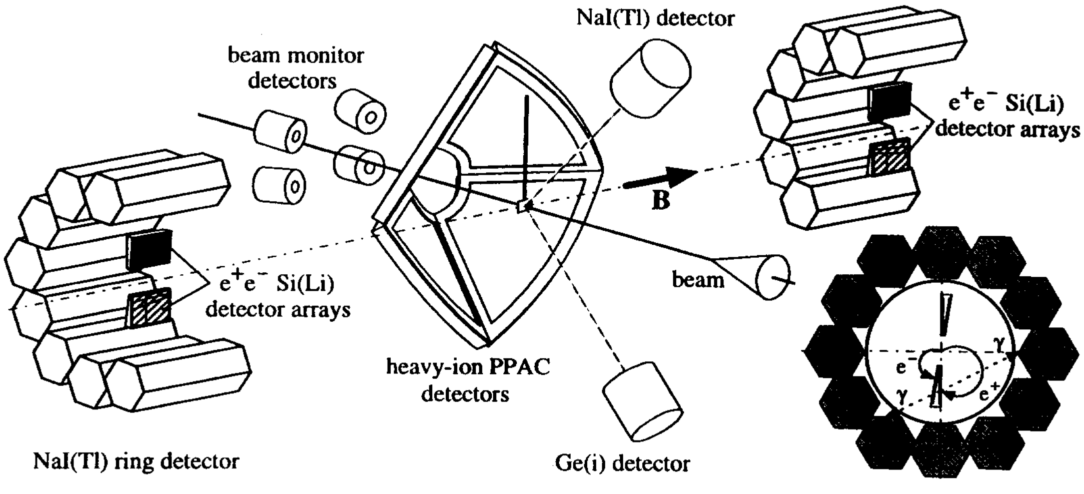


Figure 3: ***A perspective view of the new EPOS spectrometer with the main modules indicated. The Si(Li)-detector–target distance is 150 cm.*** Insert: ***cross section of the Si(Li) and NaI(Tl) detector arrays.***

the full solid angle irrespective of the lepton charge. Arrived at the detectors, e^- and e^+ are detected separately: the e^+ on one, the e^- on the other side of the Si(Li)–sandwich arrays mounted at each end of the solenoid. This technique utilizes the opposite sign of helical paths of e^- and e^+ in magnetic fields. e^+ are moreover identified by detecting at least one of its 511 keV annihilation γ-rays with a 54% efficiency in the surrounding NaI(Tl) detector arrays. The six-fold segmentation of each 2.5 mm thick Si(Li)–wafer copes with shape and intensity of the δ-electron background. The detection of the most intensive low-energy part ($E_{cut} < 150$ keV) is prevented by a radial displacement of each sandwich from the axis (~20mm). The new set-up avoids all mechanical baffles to safely exclude secondary e^+ production as used in the old EPOS. Leptons emitted backward or forward with respect to the beam direction are separately detected in the up and down detector modules. This feature is intrinsic to the detector geometry of the setup. The polar angle ϑ with respect to the solenoid axis can be derived from the time the lepton needs to reach the detector. The lepton transport and detection features are investigated using source measurements and MC-simulations with the GEANT-code. Results are summarized in fig.4. The full-energy peak pair detection efficiency of 5.4% (leptons emitted back to back) is larger by a factor of ~4 as compared to the old EPOS. Pair emission of less correlated leptons yields smaller efficiencies. The intrinsic angular separation allows a division of the $\vartheta_{e^+e^-}$-range into four intervals centered at $\vartheta_{e^+e^-} = 20°, 60°, 120°$, and $160°$. The old EPOS, being optimized for back-to-back lepton pair emission, covered only half of this range. The measurement of the 1.76 MeV E0 IPC transition of a ^{90}Sr source is well described by the simulation giving a peak-to-total ratio of ~ 40% and a FWHM of the sum-line of <18 keV. The PPAC's cover a range of ϑ_{ion}=20°-70° and 76% of the total ϕ_{ion}-range of the scattered HI. The ϑ_{ion} and ϕ_{ion} resolution amounts to 0.7° and 1.8°, respectively, including the effect of the ionic charge. The mass and Q-value resolution derived is 11 amu and 22 MeV.

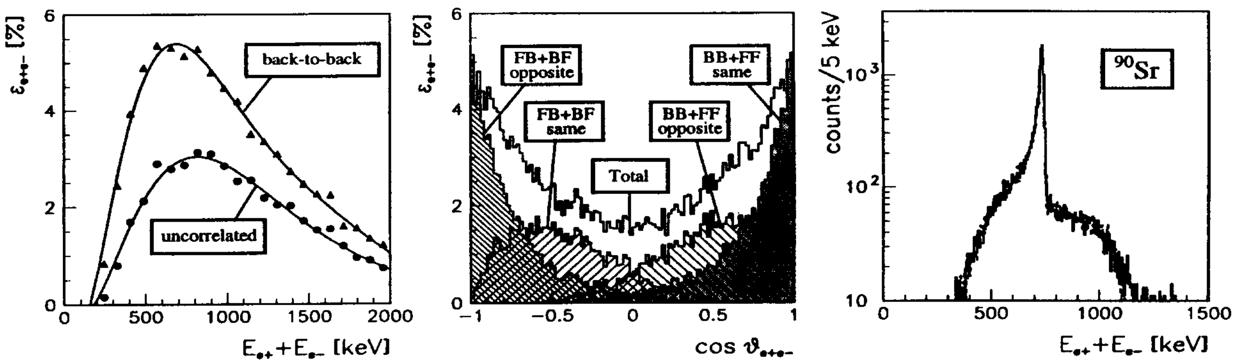


Figure 4: ***Full energy pair detection efficiencies for $E_{e^+}=E_{e^-}$*** Left: ***vs. e^+e^--sum-energy for back-to-back and uncorrelated emission ($E_{e^+}=300$ keV) and*** Center: ***vs. $\vartheta_{e^+e^-}$ for uncorrelated emission for the four intrinsic $\vartheta_{e^+e^-}$-bins given by forward/backward detector combinations on same and opposite side.*** Right: ***Sum-energy spectrum of the E0 IPC line of a ^{90}Sr-source and MC-calculation (dashed).***

3 EXPERIMENTAL RESULTS AND DISCUSSION

Narrow sum-energy lines have been identified in ^{238}U + ^{238}U , ^{238}U + ^{232}Th , ^{238}U + ^{208}Pb , ^{238}U + ^{206}Pb and ^{238}U + ^{181}Ta collisions in EPOS and ORANGE experiments. The sum energies of the lines depend on the collision system and kinematical parameters. The lines group around ~550, ~620, ~740 and ~810 keV if the assumption of a common origin can be made. The observed cross sections vary from $d\sigma_{e+e-}/d\Omega_{ion}^{CM} \simeq 0.1\mu/sr$ (815 keV, ^{238}U + ^{208}Pb) to 3.6 μb/sr (748 keV, ^{238}U + ^{181}Ta). The statistical significance of the lines reaches values of up to 6.5σ (634 keV, ^{238}U + ^{181}Ta) but in some cases is limited. The experimental knowledge on production and decay channels is poor. In the following we show dependences on the collision and lepton emission parameters by giving selected examples.

collision system	Orange	EPOS	Orange	EPOS	Orange	EPOS	Orange	EPOS
U+U	555±8		630±8				815±8	
U+Th				608±8		760±20		809±8
U+Pb	575±6				787±8	773±10		
U+Ta			634±5	625±8		748±8 740±10		

Table 1: *Sum energy lines observed in Orange and EPOS experiments. For Details see text.*

3.1 Dependence on the HI entrance and exit channel

Generally, the e^+e^--lines were found for various heavy collision systems at beam energies around the Coulomb barrier. This supports the assumption that a near contact of the colliding nuclei is necessary for the production of the lines. This conjecture has been studied in most detail for U+Ta collisions.

Selecting (quasi-)elastic ion-scattering events, EPOS (old) observed a 748 keV sum-energy line (fig. 5) within a beam energy bin of 5.93 MeV/u to 6.16 MeV/u but not at 5.3, 6.3 and 6.6 MeV/u. The production probability follows an exponential dependence on the distance of closest approach (R_{min}) according to $\exp(-2\alpha R_{min})$ with $2\alpha = 0.43 \pm 0.08$,

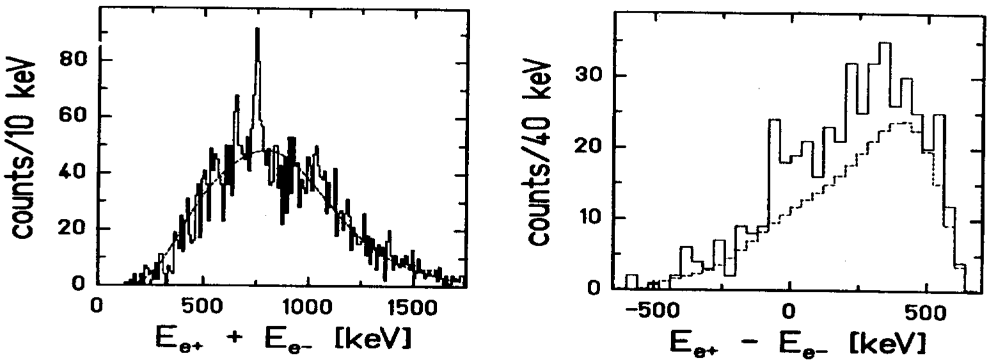


Figure 5: *e^+e^--sum-energy and energy-difference spectra for U+Ta collisions at 5.93 to 6.16 MeV/u, selected for delayed e^- emission, measured with the old EPOS [1].*

indicating a cut-off at $R_{min} \leq 17.5$ fm. The resonance-like beam-energy dependence is essentially consistent with the R_{min}-dependence.

With the new EPOS set-up two nominally equal $^{238}U + ^{181}Ta$ runs were performed within a beam energy bin of 5.98 to 6.07 MeV/u using metallic Ta-targets of $\leq 400\ \mu g/cm^2$ thickness. A sum-energy line around 740 keV is identified in the first run, with an energy uncertainty of $\sim$ 10 keV (fig.6). The line is poorly visible on the total spectrum of 45000 pair events which can be fully described otherwise by a MC-calculation based on quasi-atomic [8] and nuclear pair production, reproducing all global dependences established by the previous experiments. The 740 keV line shows a comparable R_{min}-dependence as the 748 keV line, although it is found to be most pronounced selecting $R_{min} > 18.6$ fm. This value is suggested by the apparent onset of Coulomb nuclear interference at smaller nuclear distances. This dependence is used to further reduce the background (fig.6): The

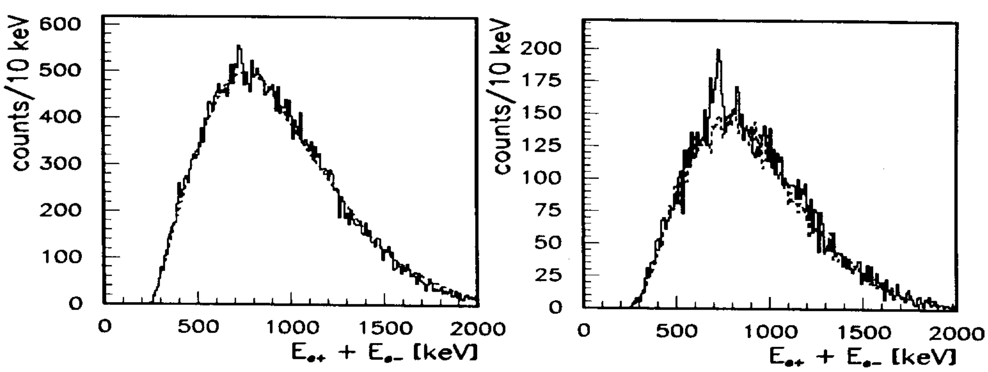


Figure 6: *e^+e^--sum-energy spectra for quasi-elastic U+Ta collisions at 5.98 and 6.07 MeV/u (new EPOS).* Left: *total spectrum (dahsed line see text).* Right: *selected for R_{min} >18.6 fm and $\langle E_{e^+} - E_{e^-} \rangle > 0$. The dashed line is calculated from combinatorial background.*

line of 300 events, superimposed on a total spectrum of 12000 pairs, represents a 5.5σ significance. The production probability amounts to $\sim 2.7 \times 10^{-6}$ ($\sim$3.2μb/sr) as compared to the $\sim 4.2 \times 10^{-6}$ for the previously measured 748 keV line. These values are derived assuming an isotropic e^+e^--emission. In the second run with $\sim$ 3 times more total pair events the existence of a comparable line is not evident. Changes in the experimental set-up are presently investigated to clarify if these could influence the observation of the line. Nevertheless, this apparent inability to properly set the experimental conditions again supports the assumption that important parameters for the source of the lines still remain unidentified.

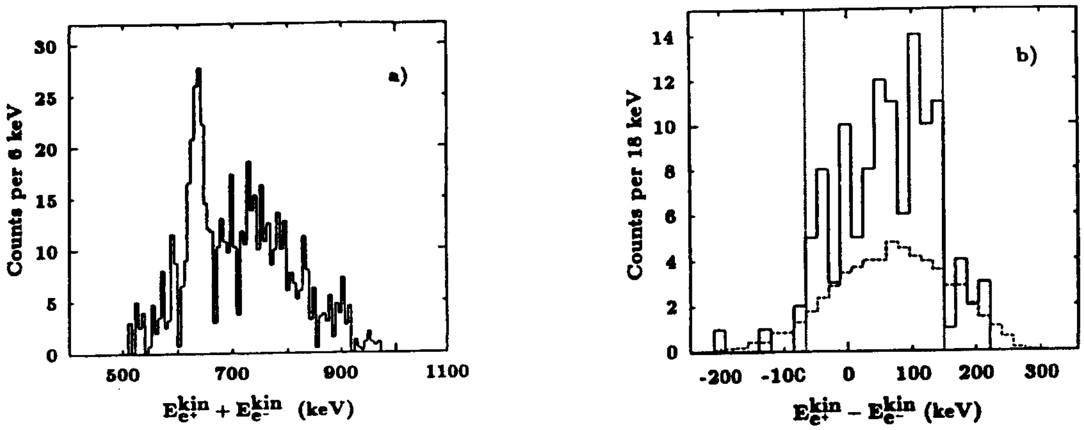


Figure 7: *634 keV line measured with the Double ORANGE in the system $^{238}U + ^{181}Ta$ at 6.3 MeV/u in coincidence with fission events (see text).* a: *Sum-energy spectrum* b: *Energy difference spectrum for the events in the line and on each side of the line (dashed). The indicated window was applied for* a)

The study of closer collisions where the nuclei start to overlap requires to increase the beam energy slightly above the Coulomb barrier. At a beam energy of 6.3 MeV/u triggering on quasi-elastic events a 624 keV line has been observed in previous EPOS experiments [1] with a cross section of ~5.8 μb/sr (for isotropic emission) exploiting a comparably steep R_{min} dependence as the 748 keV line. The previous ORANGE experiment [2] using 1 mg/cm^2 targets identifies a line at 634 keV at the same beam energy triggering on quasielastic non-central collisions of R_{min} >20 fm with a cross section of 1.4 μb/sr. Central collisions at this energy cover the typical range of few-nucleon transfer leading to an order of magnitude increase of the nuclear IPC background dominating these spectra. This may hinder the isolation of a clear line for closest collisions although its production probability still raises as conjectured from the EPOS data. The 634 keV line is observed in ORANGE as a pronounced line with by a factor of ~20 larger emission probability by triggering on U fission products in coincidence with Ta recoils around the grazing angle of $\sim 19° \pm 6°$ (fig.7). The total cross section is estimated to 2-4 μb, using a rough estimate for the acceptance of fission products [2]. It is anticipated that the fission trigger supports the selection of collisions with longer reaction times expected to occur for nuclear collisions at the Coulomb barrier. Experiments with the upgraded ORANGE to further investigate this exciting detection are underway. The improved pulse-structure of the new High Charge-state Injector (HLI) with ECR–ion-source (108 MHz vs. 36 MHz) allows four times higher luminosities in ORANGE at the same random rate. A first run using such intense beams of ~6 pnA shows that the peak/background-ratio can be optimized by triggering on fission products slightly out of plane ($\Delta\vartheta \sim 20°$) in order to suppress binary events completely. The data indicate that only a subset of the fission products contribute to the line. Here further experiments after upgrading the HI-detection system for the much higher count rates are eagerly expected.

3.2 e^+e^--emission properties

The emission characteristics of e^+ and e^- are directly related to the nature of the source. The speculation about an object decaying at low velocity in the CMS corresponds to a clear pattern of a narrow sum-energy line associated with a symmetrically broadened structure in the energy-difference emitted dominantly at large $\vartheta_{e^+e^-}$. Such behaviour is essentially found for the 809 keV sum line in ^{238}U + ^{232}Th (fig. 8) and the 787 keV sum line in ^{238}U + ^{208}Pb (fig. 8).

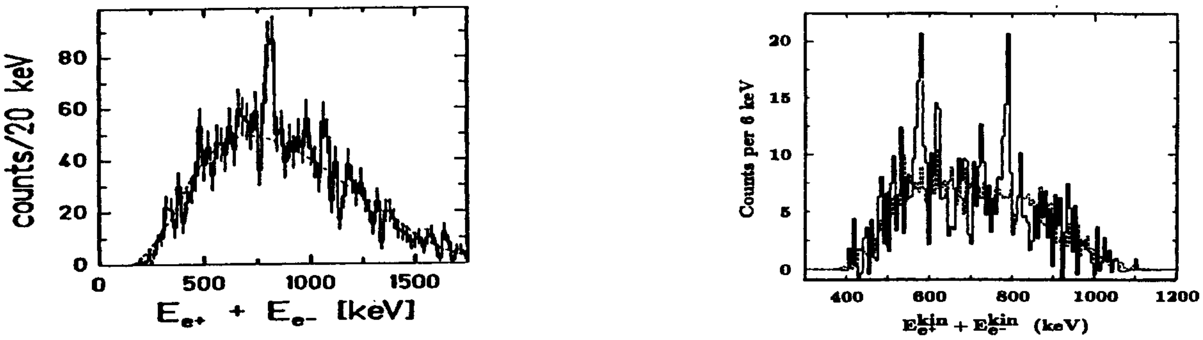


Figure 8: e^+e^--sum-energy spectra *Left:* for quasi-elastic ^{238}U + ^{232}Th -collisions (EPOS) with a line at 809 keV. Dashed: MC-simulated background [1] Right: ***for quasielastic*** $^{238}U + ^{208}Pb$ ***-collisons with b=2-16.5 fm (ORANGE). Full line: only 180°-bin. Dashed: all other*** $\vartheta_{e^+e^-}$***-bins (downscaled)*** [2].

The 809 keV line observed in the old EPOS with a linewidth of ~40 keV associated with a symmetric difference-energy distribution could be shown to be consistent with an approximate back-to-back $\vartheta_{e^+e^-}$-distribution by inspection of the lepton transport time; correspondingly it represents a cross section of ~4 μb/sr. The $\vartheta_{e^+e^-}$-dependence is directly observed with the ORANGE set-up: The 787 keV line in ^{238}U + ^{208}Pb collisions with a width of (15 ± 4) keV exclusively appears in the opening angular bin of $180° \pm 20°$, being most pronounced at close R_{min}-values of 17 to 26.5 fm. Assuming a two-body decay scenario, this line represents a cross section of ~ 0.11 μb/sr. In a recent investigation of ^{238}U + ^{206}Pb with the new EPOS a sum line was found at a comparable energy of 773 keV in a similar R_{min}-bin of 18–22 fm (fig. 10). The line of ~180 counts represents a ~ 4σ significance and gives a cross section of 1–2 μb/sr. The statistics is insufficient to derive further dependences. It is presently not clear, if the difference in the cross sections can be explained by the different acceptances of ORANGE and EPOS.

Other lines clearly deviate from the above pattern: The 748 keV as well as the 740 keV EPOS lines in ^{238}U + ^{181}Ta (fig. 5+6) show very broad and strongly asymmetric difference energy spectra with a mean $\langle E_{e^+} - E_{e^-}\rangle$ around 250 keV and essentially isotropic $\vartheta_{e^+e^-}$-distributions. This behaviour is similar for the 634 keV ORANGE line mostly associated with fission events in U +Ta collisions (fig. 7) being consistent with an isotropic $\vartheta_{e^+e^-}$-distribution and showing a broad difference energy spectrum shifted to higher e^+energies by about 100 keV. It appears reasonable to attribute the strong asymmetry to the Coulomb potential of the involved nuclei at the vertex point. A line at ~640 keV has also been detected in a recent EPOS ^{238}U + ^{181}Ta run at same beam energy (being uncertain by 10 to 20 keV) with a width of < 30 keV and a 3σ significance, selecting close quasielastic collisions. The narrow 608 keV line of ~25 keV width observed in the old EPOS for quasielastic collisions in ^{238}U + ^{232}Th is also inconsistent with the back-to-back scenario although the difference spectrum is essentially symmetric. The sharp 555 keV line in ^{238}U + ^{238}U (ORANGE) appears to be isotropically distributed in $\vartheta_{e^+e^-}$.

3.3 Velocity dependences

The kinematic shifts of the leptons provide access to the velocity of the emitting system thus identifying the source. Only few scenarios result in narrow lines in the laboratory system (LS). Except for the decay at rest in the LS, all scenarios require a reduction of phase space either by the kinematics of a two body decay or by preceding processes. The narrow line widths are then the result of mutual cancellations of kinematical shifts.

Since IPC is frequently discussed as the source of the lines, measurements to fully investigate this decay mode and the respective response of the spectrometers are presently carried out. The 739 keV E0 IPC in ^{90}Zr as an example for emission at rest in the LS is presented above. Other IPC candidates in high-Z nuclei following Coulomb excitation are found in ^{209}Bi and ^{206}Pb with the pairs emitted from scattered HI at high velocity.

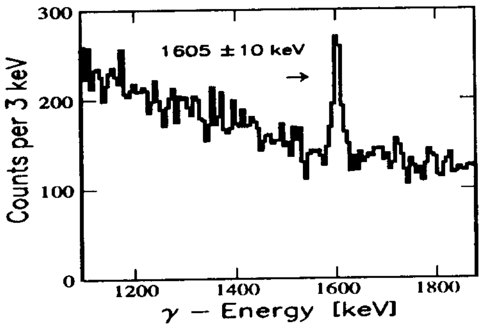
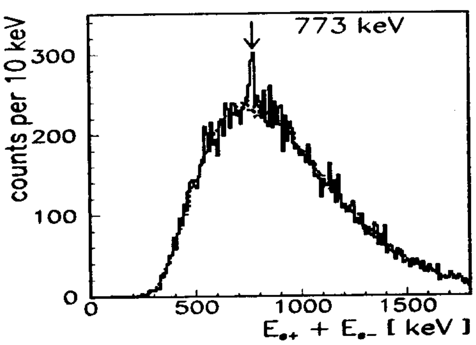


Figure 9: *Doppler shift corrected γ-ray spectrum obtained with ORANGE in (quasi-)elastic ^{209}Bi + ^{208}Pb collisions at 6.5 and 6.9 MeV/u The 1.61 MeV transition in ^{209}Bi is clearly visible.*

The system ^{209}Bi + ^{208}Pb was investigated in the new ORANGE at beam energies of 6.5 and 6.9 MeV/u using ^{208}Pb targets of 0.4 mg/cm^2 evaporated on C-backing. 38000 e^+e^-–coincidences have been collected at beam intensities of up to 6 pnA. Fig.9 shows the γ-ray spectrum Doppler corrected for Bi. The 1.6 MeV mixed E3/M2 γ-ray transition line can be clearly seen. For the estimation of the expected IPC–counts in the e^+e^-–sum-energy spectrum a shift of the emission point ($\sim$3 mm) due to the long life-time of $\sim$0.3 ns of the nuclear state has to be taken into account, leading to a reduction of the detectable prompt e^+e^-–HI-coincidences. Even a weak indication of a IPC line in the sum-energy spectrum is associated with a very prominent line in the γ-ray spectrum. At the correct position of 590 keV we find an indication of a line in the Doppler corrected e^+e^-–sum-energy spectrum as weak as expected from the γ-line intensity. A new analysis code taking the effects of the delayed emission on the lepton identification and the geometrical cutoffs given by the target frames is under development. It aims both at reduction of background and better identification of delayed leptons. Without Doppler correction neither the γ– nor the e^+e^-–line are visible. More detailed studies will be carried out in a new run with improved statistics. The system ^{209}Bi + ^{208}Pb has the same Z_u=Z_1+Z_2=165 as ^{238}U + ^{181}Ta . A similar quasiatomic behaviour of the two systems is thus expected, but the nuclear structures are quite different. Correspondingly, fission triggered events in ^{238}U + ^{181}Ta relate to deep inelastic scattering for ^{209}Bi + ^{208}Pb . The analysis of deep inelastic collisions in the latter case indicates an appearance of similar structures as in ^{238}U + ^{181}Ta in the sum-energy spectrum, if no Doppler shift correction is applied. These exciting prospects will be investigated at higher statistics taking advantage of the meanwhile improved accelerator capabilities.

The system ^{238}U + ^{206}Pb has recently been measured in EPOS at 5.8 MeV/u using C/^{206}Pb/C targets of 40 μg/cm^2/300 μg/cm^2/5 μg/cm^2. Fig.10 shows the pair spectrum Doppler corrected for ^{206}Pb recoils. The spectrum is restricted to R_{min}= 22.5–27 fm where the e^+e^-–line at 823 keV and the according γ-ray line of the 1.844 MeV pure E1 transition in ^{206}Pb appear most prominently. The e^+e^-–line intensity (79±26 counts) corresponds to the value obtained from the experimental γ-ray cross section of 48±2 mb/sr using a pair-conversion coefficient of β_{IPC}= 5.10^{-4} [7]. The presently achieved statistics is insufficient to compare the experimental $\vartheta_{e^+e^-}$-distribution with the theoretical prediction. The IPC



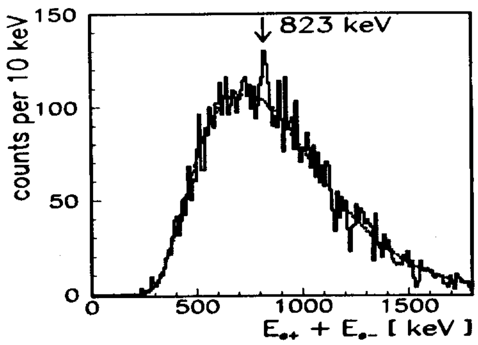


Figure 10: *Lines measured with new EPOS in the system $^{238}U + ^{206}Pb$ at 5.8 MeV/u.* Left: R_{min}*=18–22 fm, not Doppler-shift corrected. Dashed lines: combinatorial background.* Right: R_{min}*=22.5–27 fm, Doppler-shift corrected for the ^{206}Pb recoil.*

line is spread over a 120 keV bin if no kinematic correction is applied and remains broad if corrected for U or the CMS. The uncorrected spectrum shows the narrow 775 keV line discussed above as a member of the puzzling e^+e^-–line family. This line smears out when corrected for emission from Pb-ions, U-ions or the CMS.

4 CONCLUSION

The variant features underline that rather complex production mechanisms and decay scenarios must be involved in the observed phenomena. The lines grouped around 809 keV seem to consistently reflect the features of a back-to-back emission scenario. The variations in the lepton momentum correlation observed for other lines might be intrinsic to the unknown source or its particular environment. It will have to be investigated whether the Coulomb shifts observed could be a tool to distinguish different source configurations. None of the lines fit the typical signature investigated for an IPC scenario nor have γ-ray lines or electron conversion lines [9] of sufficient strength been found at the proper energies. With the improved abilities of the new spectrometers, nuclear IPC can now be measured simultaneously with the lines of unknown origin. Among the open questions remaining is the production of the lines including the problem of their reproduceability. Different reaction channels have to be probed. The inclusion of U-fission as a reaction trigger appears very promising and will be extensively investigated.

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